

14 marzo 1879 - 14 Marzo 2019



Buon Compleanno Mr. Einstein!

La fisica delle astroparticelle e l'esperimento AMS-02 sulla ISS

**CERN Teacher Programme
14 Marzo 2019**

Sonia Natale

1912 - 2012: 100 anni di scoperte



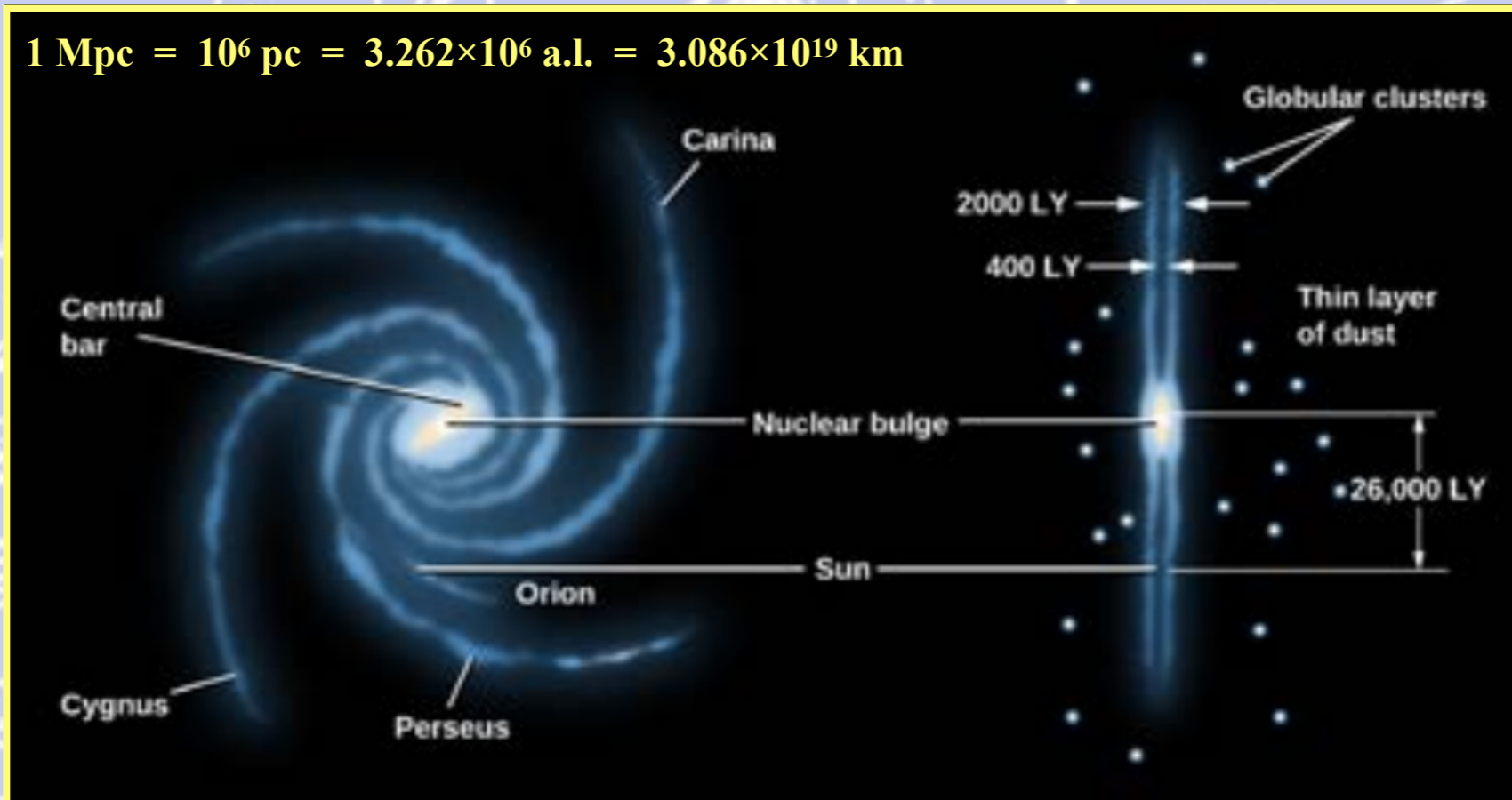
La rivelazione della radiazione cosmica può essere considerata la scoperta del secolo e ha modificato la nostra visione del cosmo.

A ragione può essere considerata una pietra miliare degli inizi della fisica delle particelle

Prima dello sviluppo della fisica degli acceleratori, la ricerca sui raggi cosmici ha portato alla scoperta di molte importanti particelle elementari come ad esempio l'anti-particella dell'elettrone, il positrone, così come il muone ed il pione.

L'universo intorno a noi (1)

La **Via Lattea** è una galassia a spirale larga circa 100.000 anni luce (a.l.) e spessore di 1000 a 2000 a.l.;

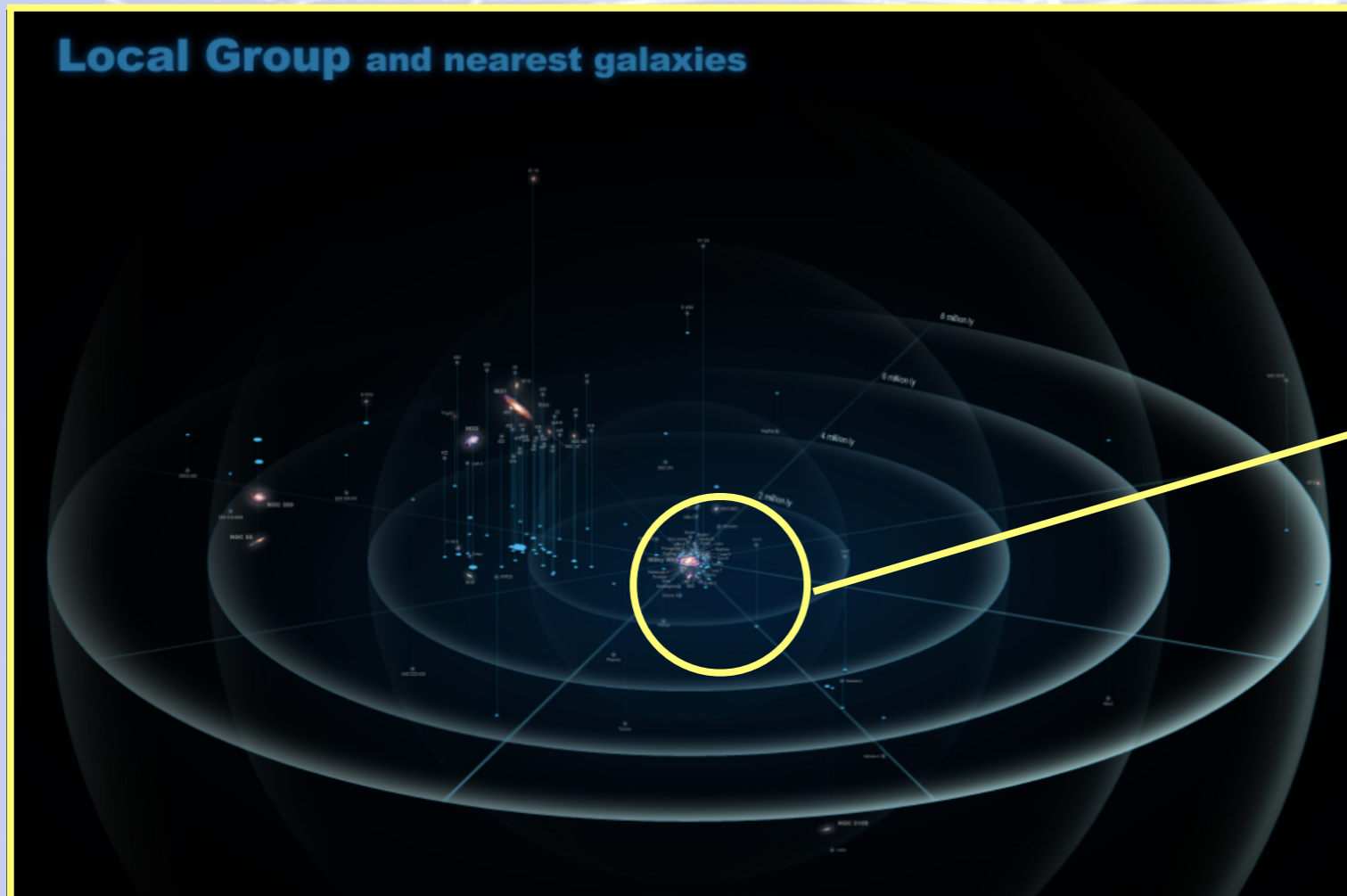


Il **Sistema Solare**, situato nel braccio di Orione, si trova all'interno del disco, a circa 30 000 a.l. di distanza dalla Centro Galattico (G.C.);

- Le stelle presenti nei 10 000 a.l. interni formano un rigonfiamento.
- Il G.C. ospita il buco nero superassimo BH SgrA * di circa 4 milioni di masse solari (come determinato studiando le orbite delle stelle vicine).
- Il mezzo interstellare (ISM) è riempito da gas parzialmente ionizzati, polvere e raggi cosmici e rappresenta il 15% circa della massa totale del disco galattico;
- Un campo magnetico di pochi Gauss interagisce con l'ISM.

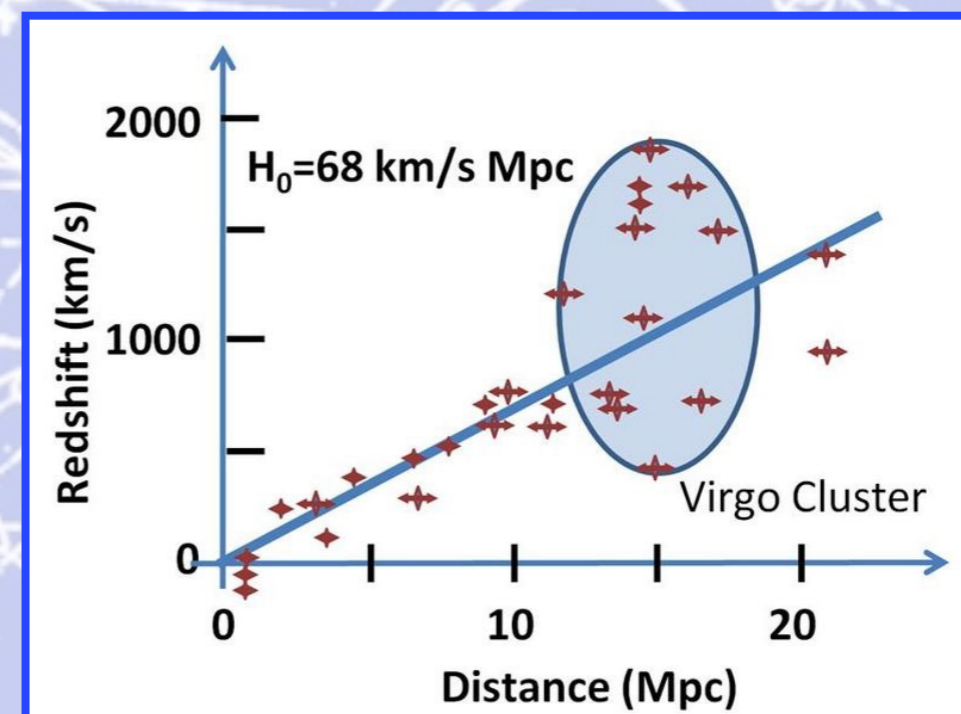
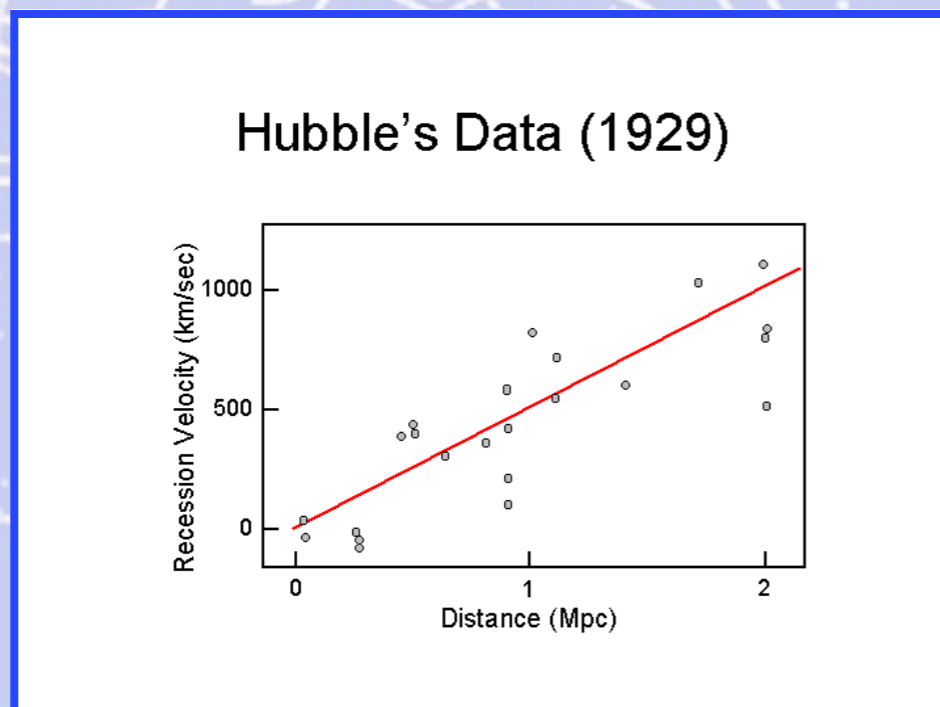
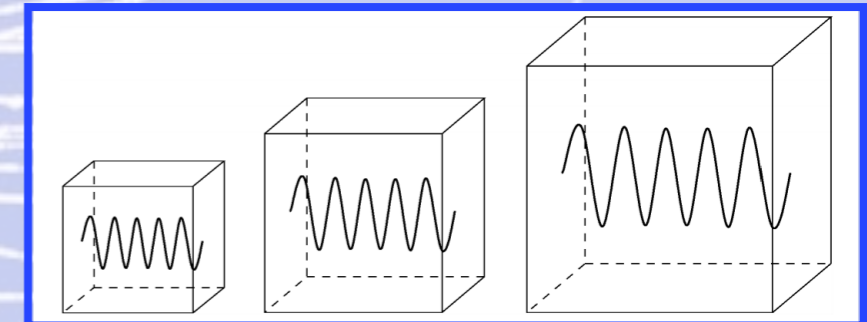
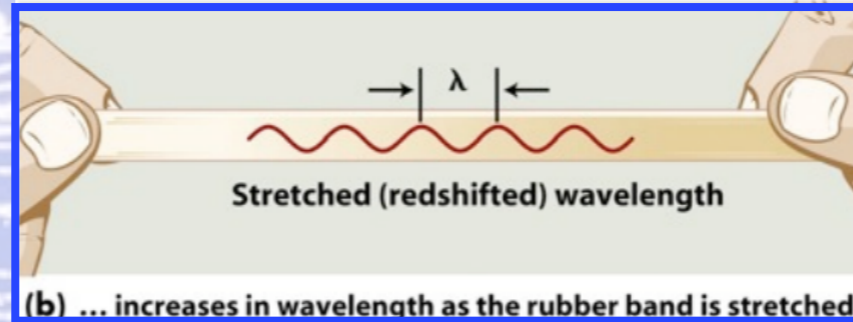
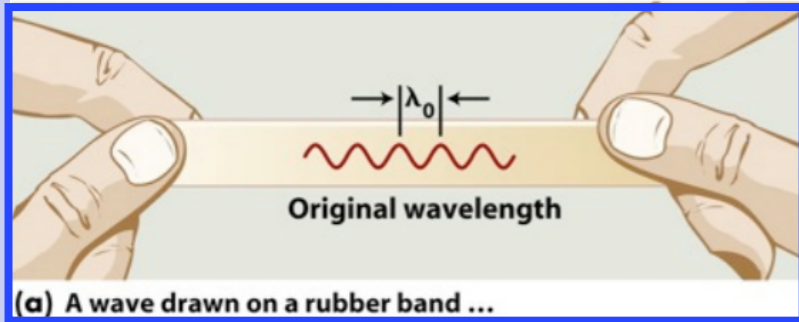
L'universo intorno a noi (2)

- Con le sue 10^{11} stelle, la Via Lattea è una struttura relativamente grande.
- Insieme alla Galassia di Andromeda (di simili dimensioni), essa intrappola gravitazionalmente molte galassie più piccole costituendo il cosiddetto **Gruppo Locale** che include:
 - più di 50 galassie, ed anche numerose galassie nane - alcune sono agglomerati sferici di centinaia di stelle chiamati ammassi globulari;
 - Il gruppo locale copre un diametro di 10 Ma.l. (cioè 3,1 Mpc); ha una massa totale di circa 10^{12} masse solari;
 - I supergruppi (supercluster) possono estendersi fino a ~ 50 Ma.l.)



L'universo in espansione (1)

- Emissione di radiazioni da galassie (Hubble, 1929): velocità v (calcolata dallo spostamento Doppler delle linee di emissione) vs a distanza D : $v = H_0 D$, ($H_0 \sim 68 \text{ km / s / Mpc}$) ;
- Osservazione: le galassie si allontanano a velocità in proporzione più elevate per distanze maggiori e la a costante di Hubble H_0 descrive il tasso di incremento delle velocità di recessione all'aumentare della distanza;
- Il **redshift Doppler** $z = \Delta\lambda / \lambda$ può quindi essere utilizzato anche come metrica della distanza degli oggetti.



L'universo in espansione (2)

Principio cosmologico:

l'universo è omogeneo (la sua struttura a grande scala è uguale in tutte le direzioni) ed isotropo (le sue proprietà fisiche generali sono le stesse in ogni punto).

Interpretazione legge di Hubble:

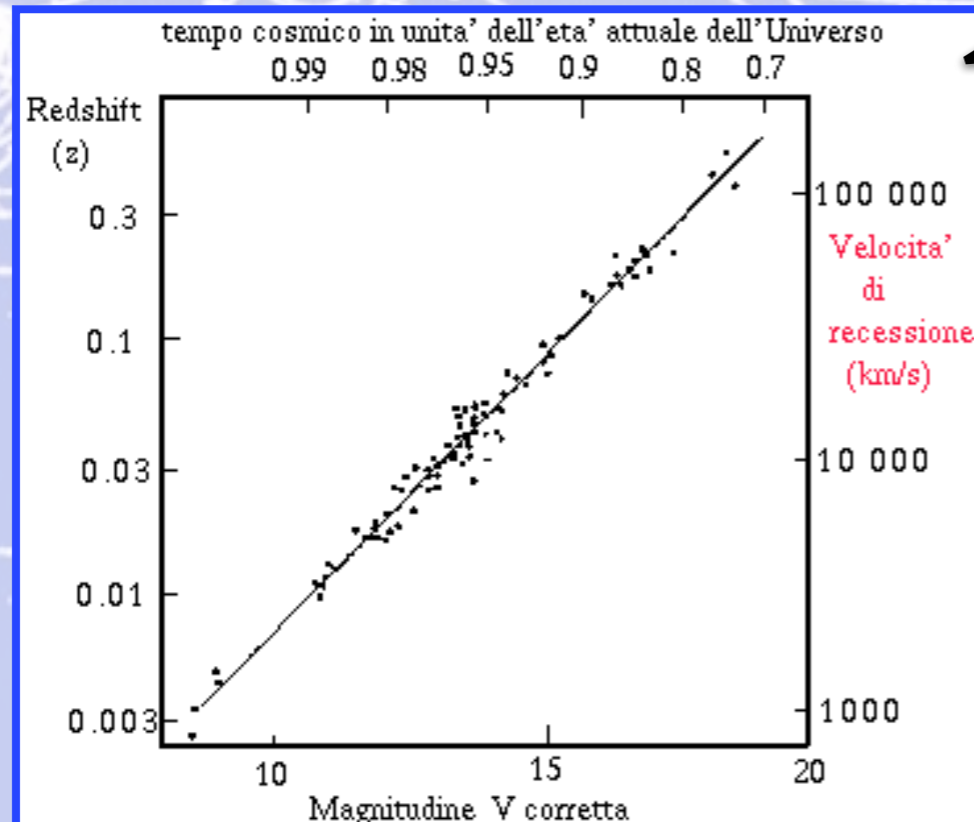
- l'universo si sta espandendo a tasso costante;
- estrapolazione indietro nel tempo: inizio;
- singolarità cosmica: tutta la materia e la radiazione ha avuto origine da un singolo punto con densità e temperatura infinita;
- questo punto di singolarità è l'INIZIO dello spazio e del tempo.

- le leggi della fisica non avevano valore PRIMA del tempo di Planck:

$$t_p = \sqrt{G h/c^5} = 1.35 \times 10^{-43} \text{ s}$$

con $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$
 $h = 6.626 \times 10^{-34} \text{ J/s}$
 $c = 2.99 \times 10^8 \text{ m/s}$

Big Bang

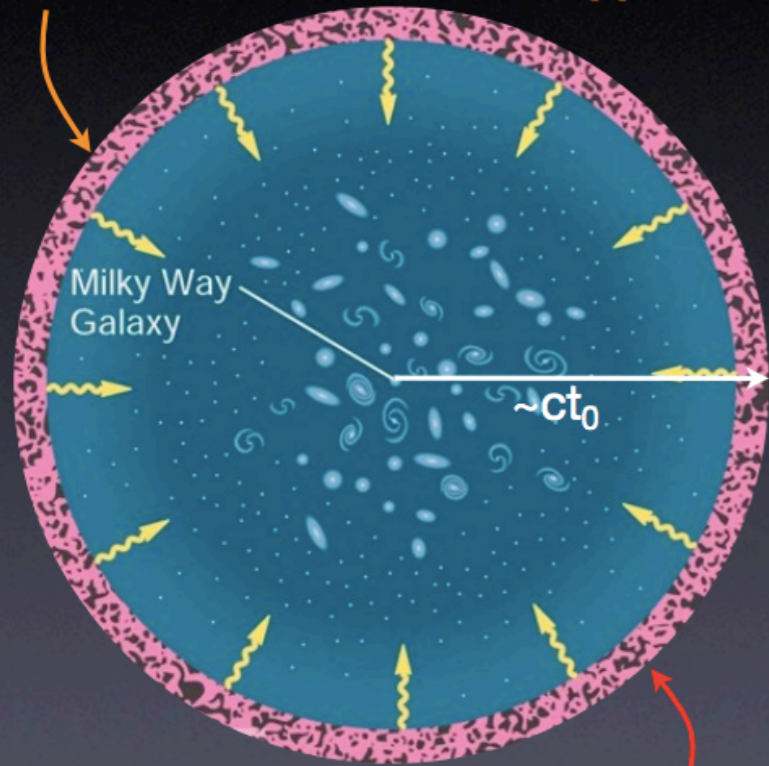


Quadro coerente:

- età dell'universo (~14 miliardi di anni) in accordo con le stime attuali all'interno delle teorie gravitazionali;
- solo leggermente più grande dell'età (13.7 miliardi di anni) delle stelle più vecchie (misurata dalla presenza di nuclei pesanti).

L'universo in espansione (3)

Regione di universo visibile dalla nostra Galassia: sfera di raggio $\sim ct_0$



Gas riscaldato dal Big Bang che emette radiazione termica

Segnali dal passato:

- L'universo primordiale deve essere stato molto caldo e denso.
- Un plasma caldo deve emettere radiazione termica (corpo nero).
- Deve allora essere possibile rivelare l'emissione dell'universo primordiale ad un « look-back time » sufficientemente grande;
- La radiazione deve avere un spettro di corpo nero ed un grosso redshift;
- Deve essere uniforme su tutto il cielo (l'universo si è espanso a partire dal Big Bang).

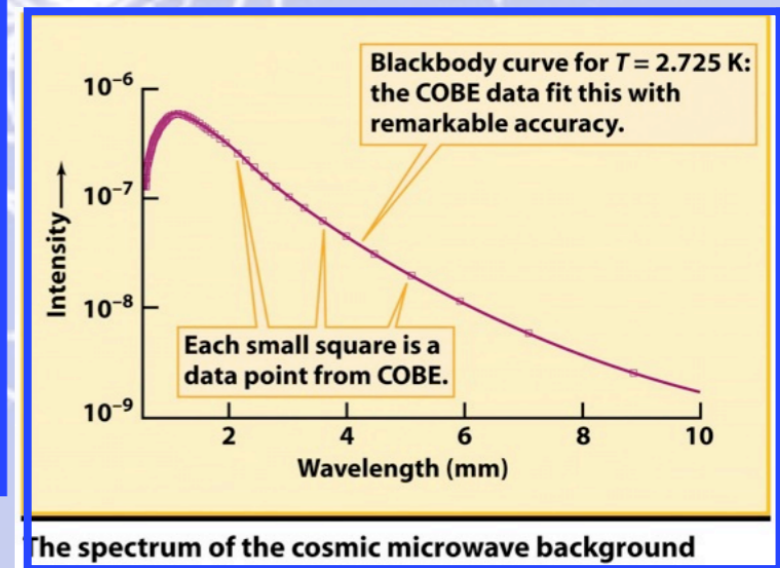
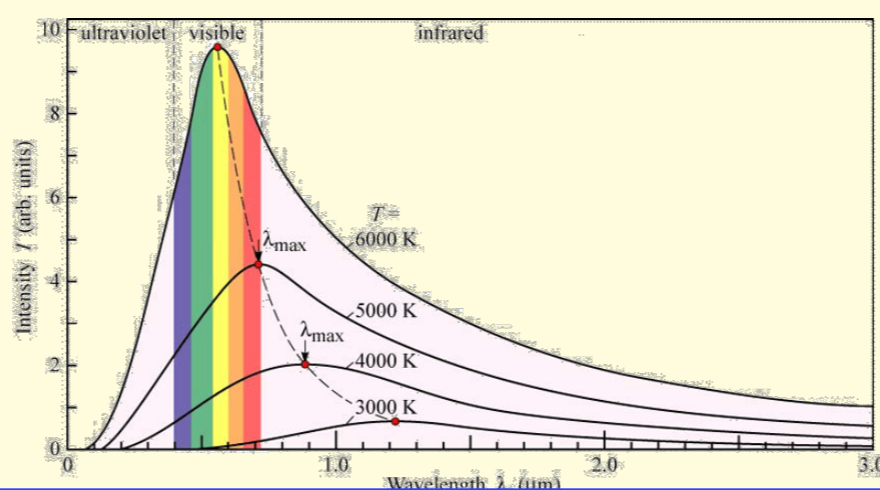
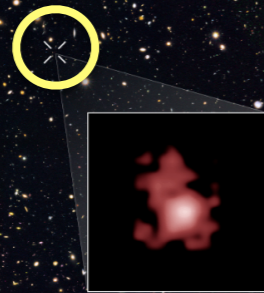
Pentias & Wilson (1965)

Radiazione cosmica di fondo:

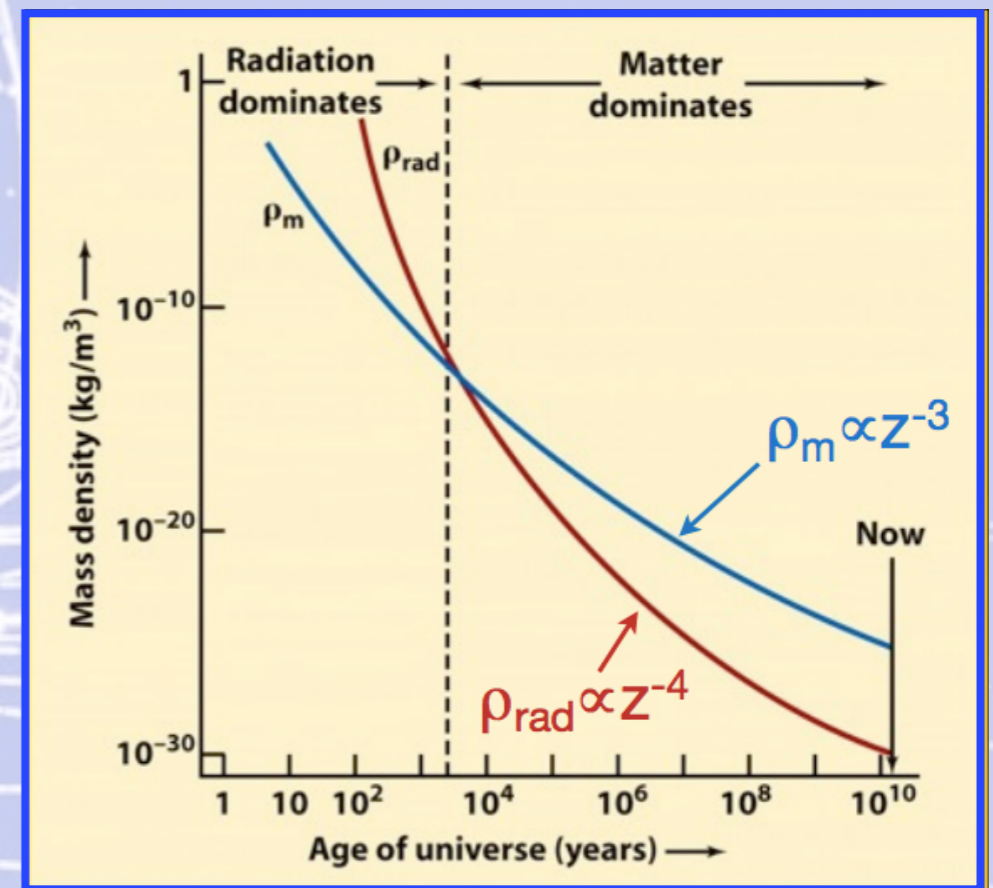
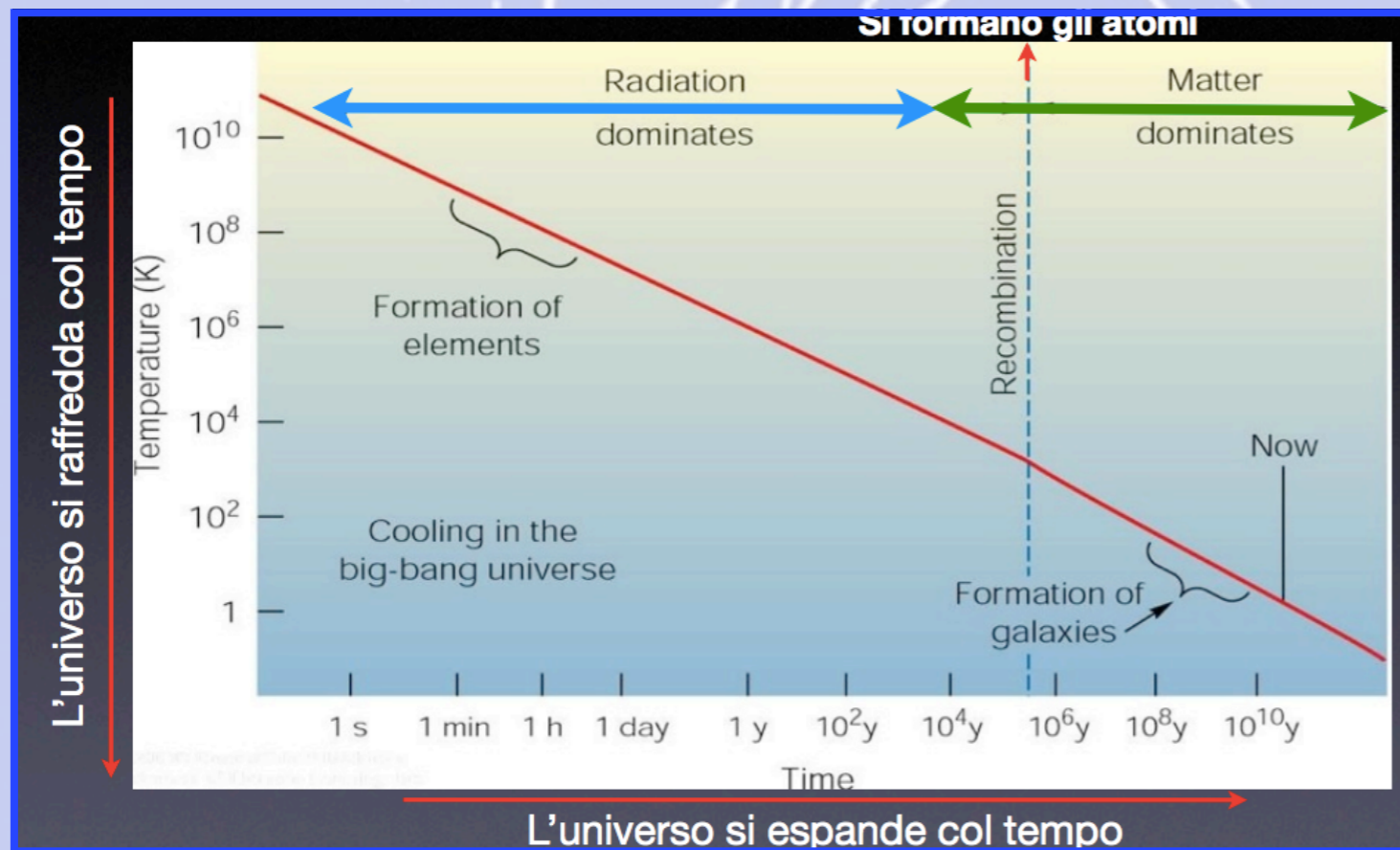
- altamente ISOTROPA ;
- intensità quasi perfettamente costante in tutte le direzioni;
- Radiazione termica di corpo nero emessa da plasma caldo a $T=2.725$ K .

2016: GN-z11 (Galaxy in Ursa Major)

redshift = 11.09
distanza = 32×10^{12} a.l.
età : 13.4×10^{12} anni



La storia dell'universo (1)

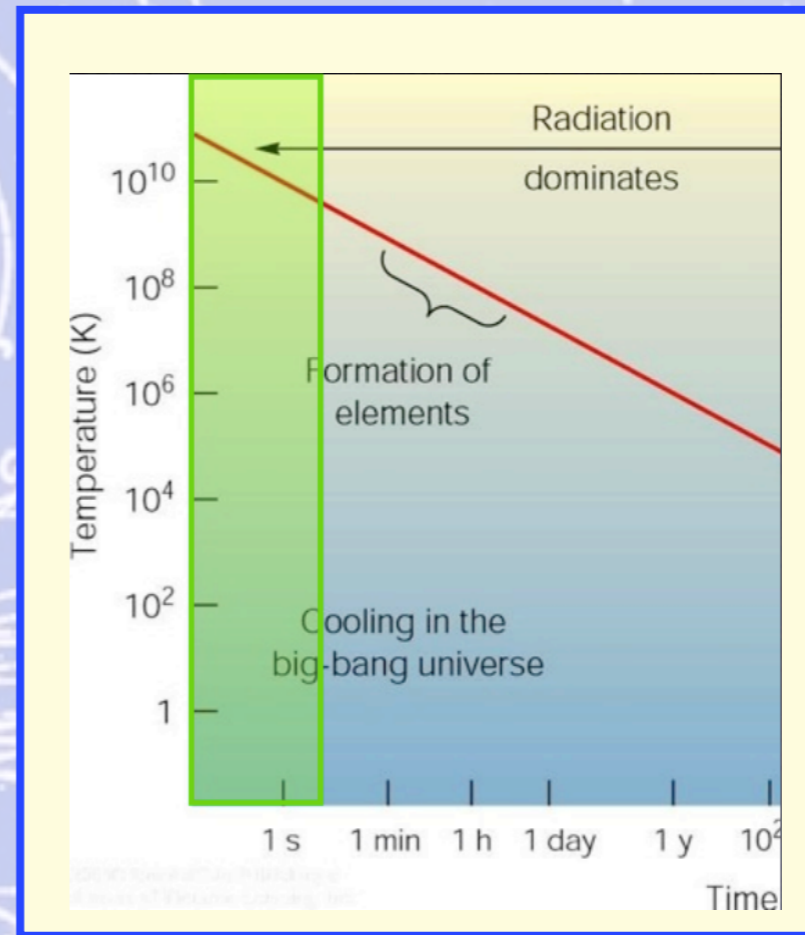
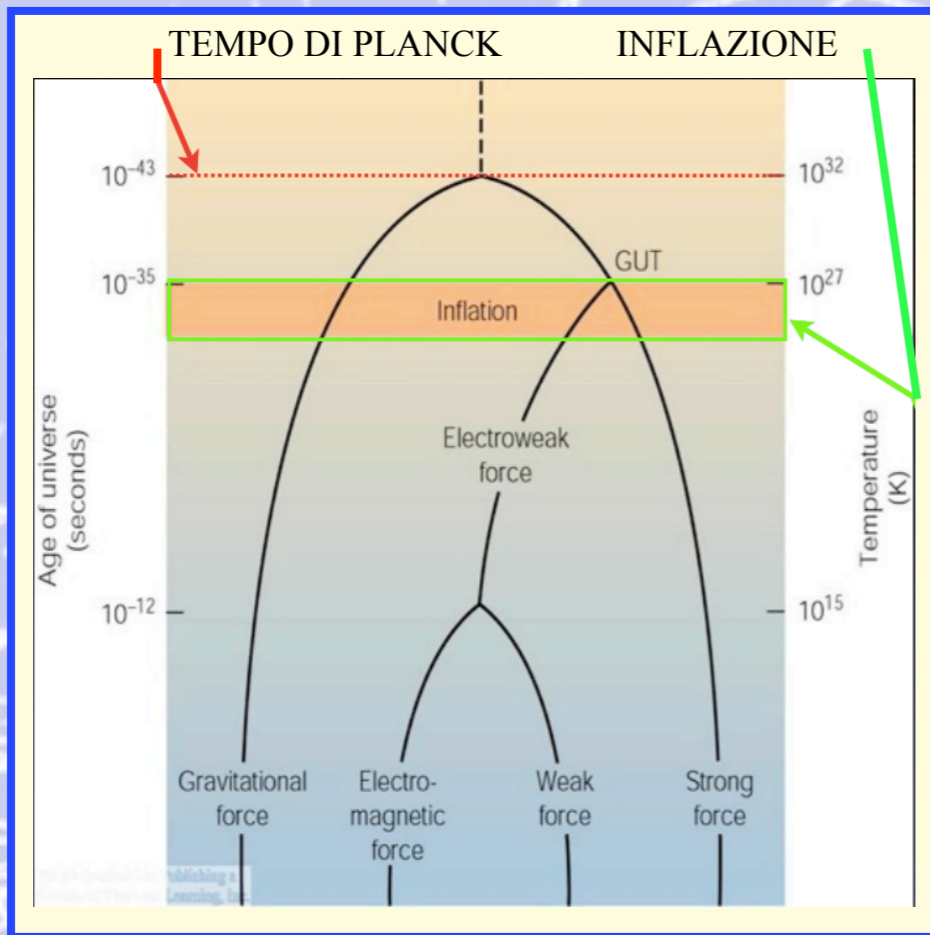


Materia e Radiazione:

- Equivalenza tra massa ed energia: $E = mc^2$;
- Densità di materia: $\rho_m \propto 1/s^3 \Rightarrow \rho_m \propto 1/z^3$;
- Densità di energia di radiazione: $\rho_{rad} \propto T^4 \Rightarrow \rho_{rad} \propto 1/z^4$ (Legge di Stefan, densità massa equivalente, Legge di Wien);

La densità di energia della radiazione aumenta più rapidamente con il redshift rispetto alla densità della materia:
 ρ_{rad} domina su ρ_m oltre un certo redshift.

La storia dell'universo (2)



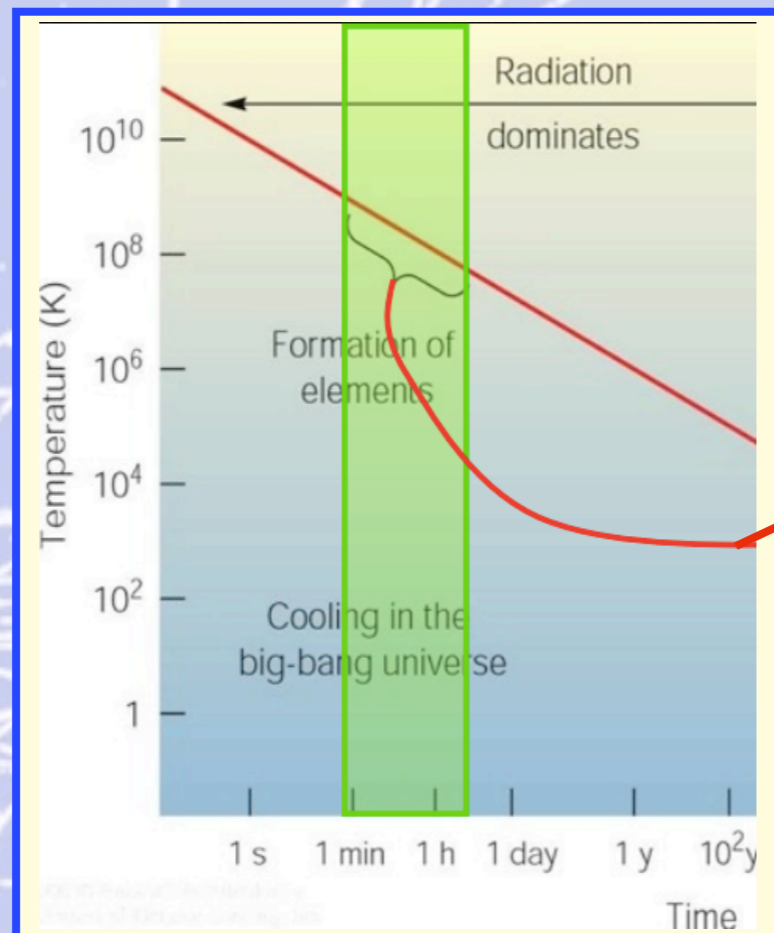
L'epoca dell'Inflazione:

- Big Bang: le 4 interazioni fondamentali sono indistinguibili;
- $t \sim 10^{-35}$ s : interazione elettrodebole e nucleare forte si disaccoppiano;
- Conseguenza: enorme rilascio di energia che provoca una rapida espansione (Inflazione);

I primi 4 secondi:

- Fotoni di alta energia creano particelle ed antiparticelle: $E_{\gamma\gamma} \geq E_{pp} = 2mc^2$ (m massa particella/antiparticella);
- Inizialmente equilibrio tra produzione ed annichilazione di coppie: coesistenza tra fotoni, particelle, antiparticelle;
- Al diminuire di z , λ aumenta, E_{γ} diminuisce ;
- quando $E_{\gamma} < E_{pp}$: stop creazione coppie particella-antiparticella, particelle e antiparticelle annichilano;
- piccolo residuo di particelle "normali": TUTTI i protoni e neutroni che ci sono ora nell'universo.

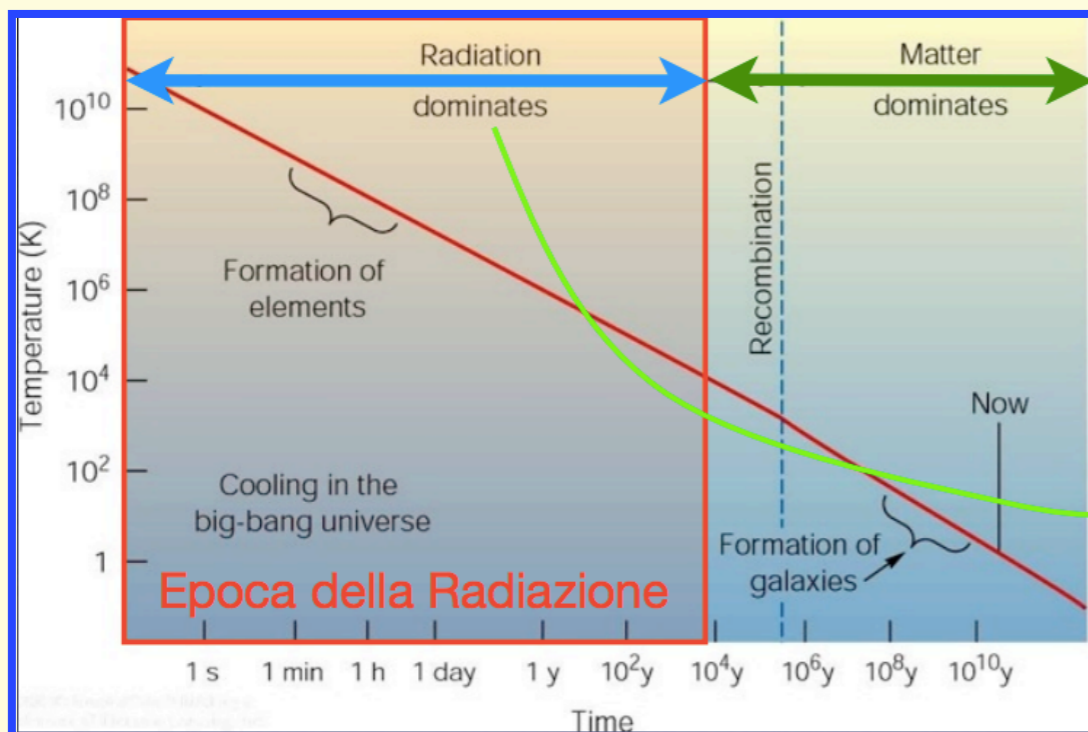
La storia dell'universo (3)



Dopo ~ 2 minuti: creazione dei nuclei atomici

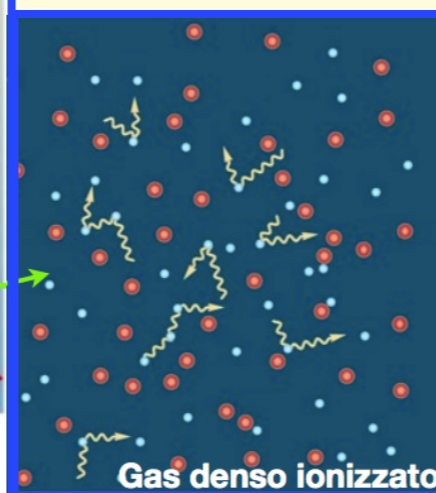
- energie dei fotoni sufficientemente basse da permettere la sopravvivenza dei nuclei atomici;
- gas sufficientemente caldo: possibile fusione di 2 protoni per formare deuterio (^2H) ed elio (He);
- composizione:
 - 25 % della massa totale è elio con tracce di deuterio e litio;
 - 75 % sono protoni;
- Ci sono dei « buchi » nella scala dei pesi atomici: rara la produzione di elementi più pesanti dell'He.

La storia dell'universo (4)



Epoca della Radiazione:

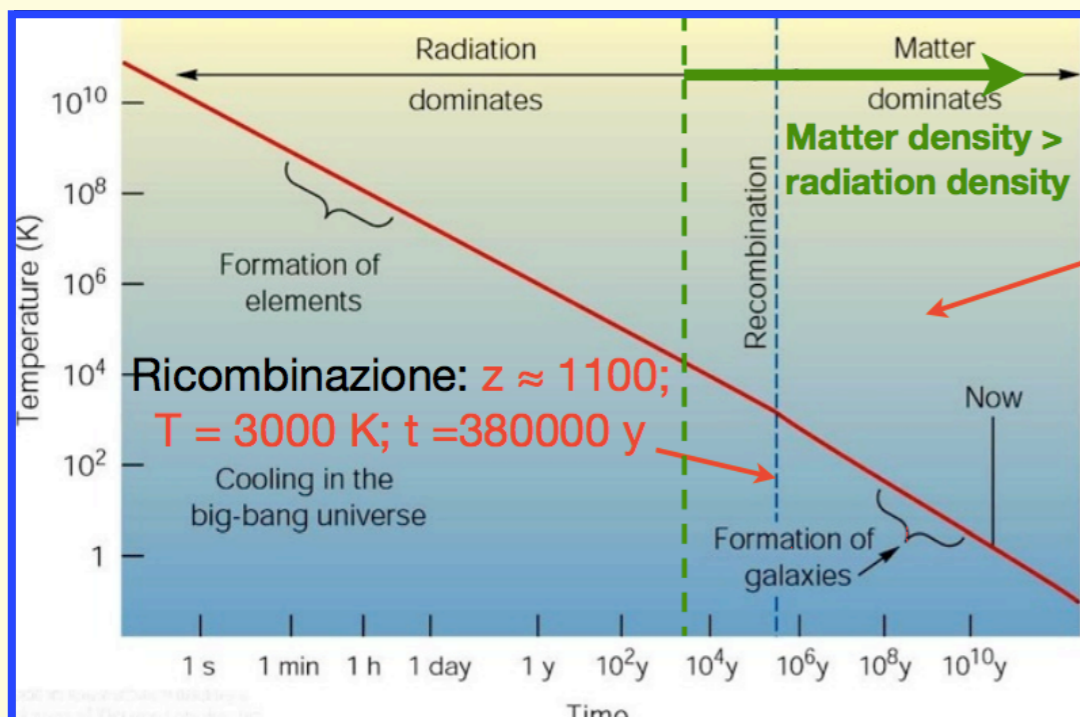
• $\rho_{\text{rad}} > \rho_{\text{m}}$: diffusione (interazione radiazione con elettroni) ;



• diffusione: interazione tra elettroni e radiazione;

• conseguenza: equilibrio termico tra radiazione e materia.

• fotoni hanno spettro di corpo nero alla stessa temperatura della materia.



Epoca della Ricombinazione:

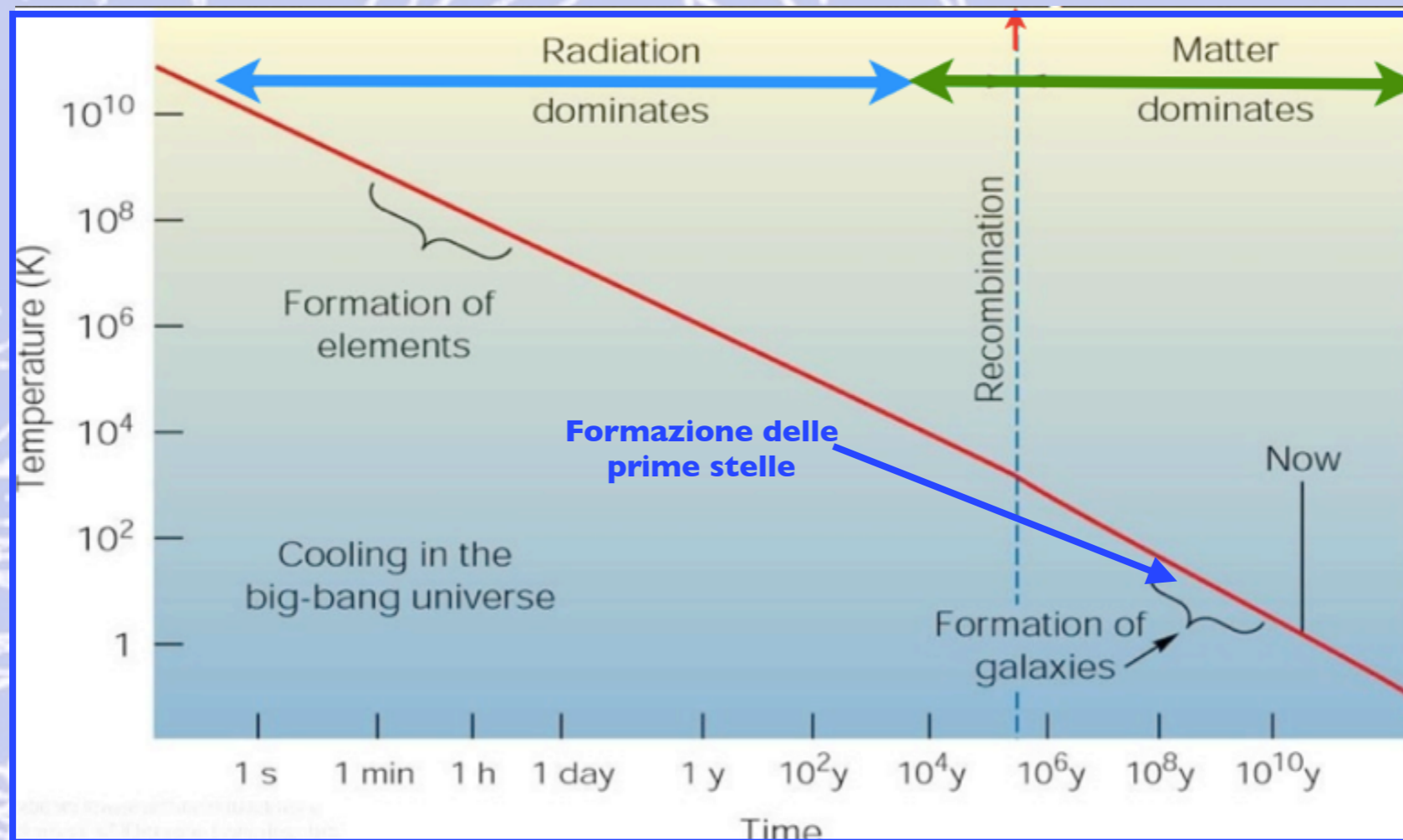
• $T < 3000\text{K}$: protoni ed elettroni si combinano a formare gli atomi ;



• universo diventa trasparente ai fotoni che sono osservati oggi come radiazione di fondo;

• i fotoni non hanno più sufficiente energia per ionizzare gli atomi di H.

La storia dell'universo (5)

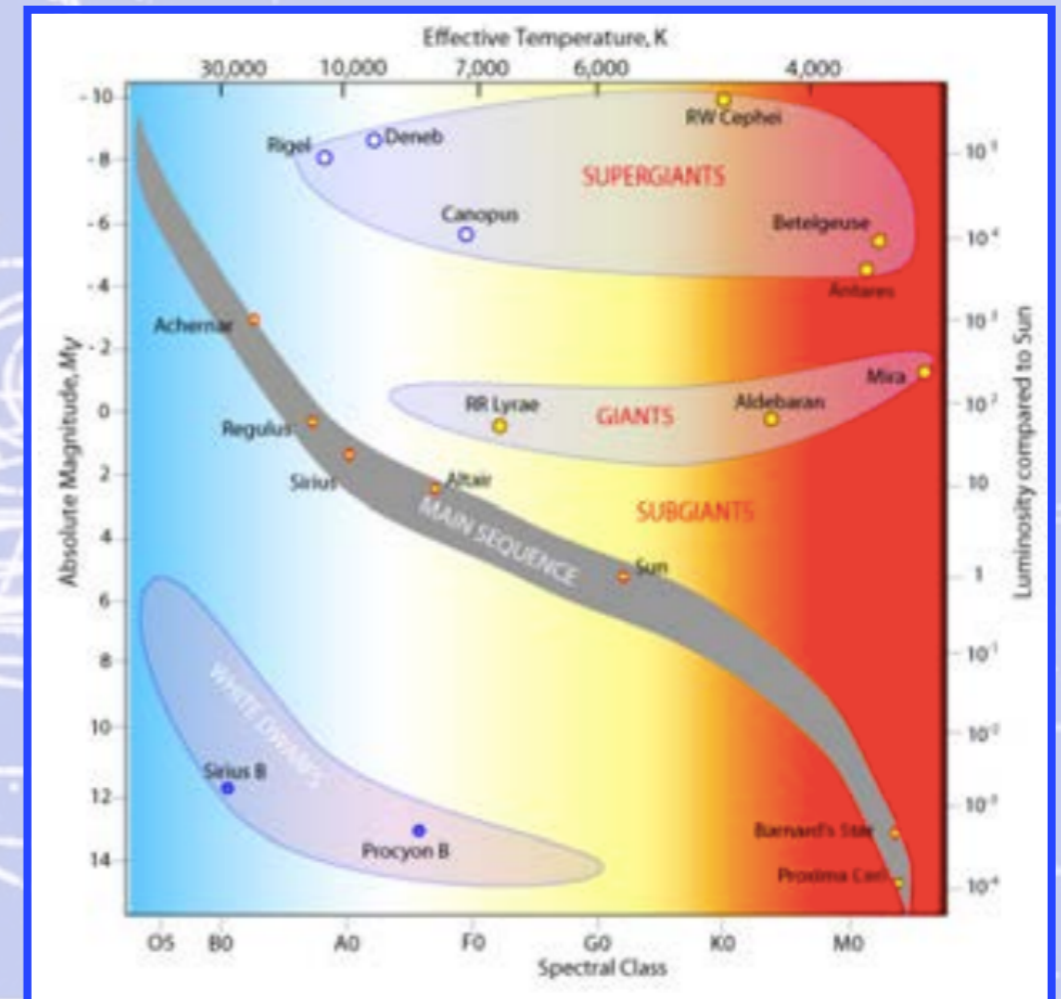


Epoca della Reionizzazione:

- $\sim 10^8$ anni: formazione della prima generazione di stelle (popolazione III);
- La radiazione UV emessa dalle prime stelle re-ionizza il gas nell'universo primordiale.

Le stelle (1)

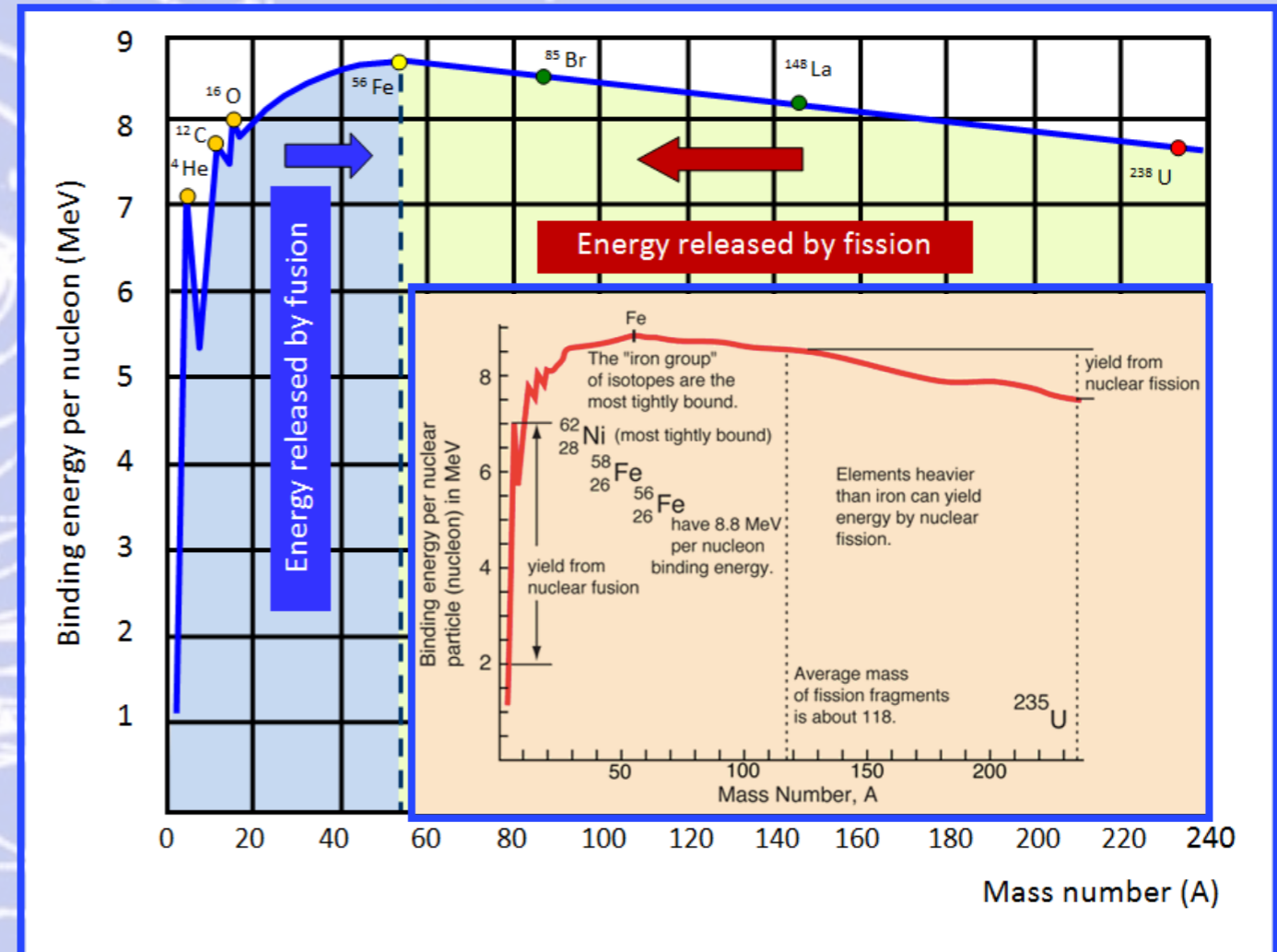
- Anche le stelle sono il prodotto di instabilità gravitazionali: nuvole di gas formate dopo la nucleosintesi primordiale (principalmente H e He) collassano e, se la loro massa è sufficiente, alla fine formeranno stelle.
- Le masse stellari sono limitate da due condizioni: che le reazioni nucleari si possano attivare nel nucleo stellare (> 0.1 solare masse), e che l'emissione di radiazione della luminosità prodotta sul plasma non interferisca con la struttura della stella (< 100 masse solari).
- Per una stella come il Sole, la formazione richiede ~ 50 Myr; il totale corso della vita è ~ 11 Gyr prima di diventare una nana bianca (Sole ha già circa 4,5 miliardi di anni).



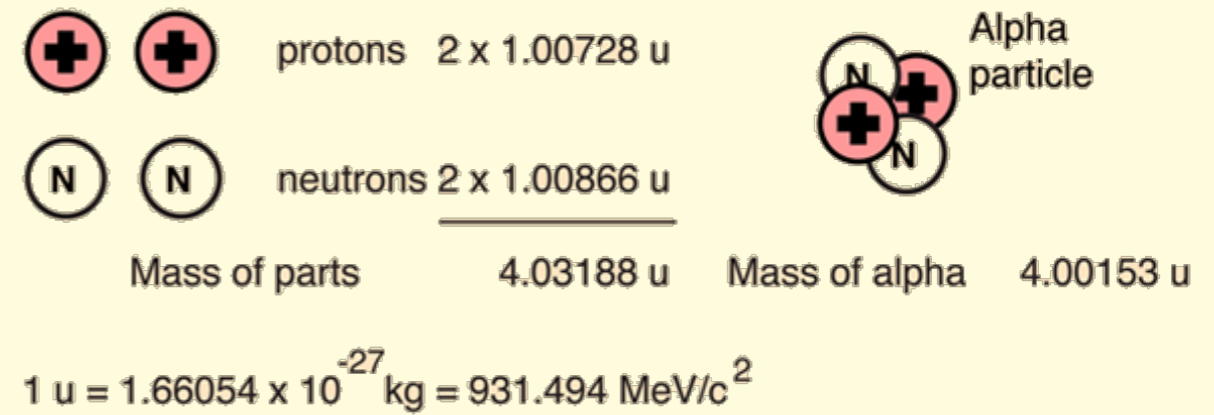
- Il destino di una stella dipende dalla sua massa: più pesante è la stella, più grande è la sua energia gravitazionale, e più efficaci sono i processi nucleari coinvolti.
- Gli strati esterni sono alimentati contro la gravità finché il nucleo stellare smette di produrre energia dalla fusione;
- Le stelle della sequenza principale con massa superiore ad 8 masse solari possono « morire » con un'esplosione molto violenta detta supernova (core-collapse o Tipo II);

Le stelle (2)

- **Supernova:** nucleo della stella, fatto di ferro (massimo difetto di massa per nucleone) collassa e l'energia gravitazionale rilasciata ($\sim 10^{46}$ J) va a riscaldare la massa sovrastante;
- Più è pesante la stella, più efficace è il processo di fusione, e più breve è la vita.

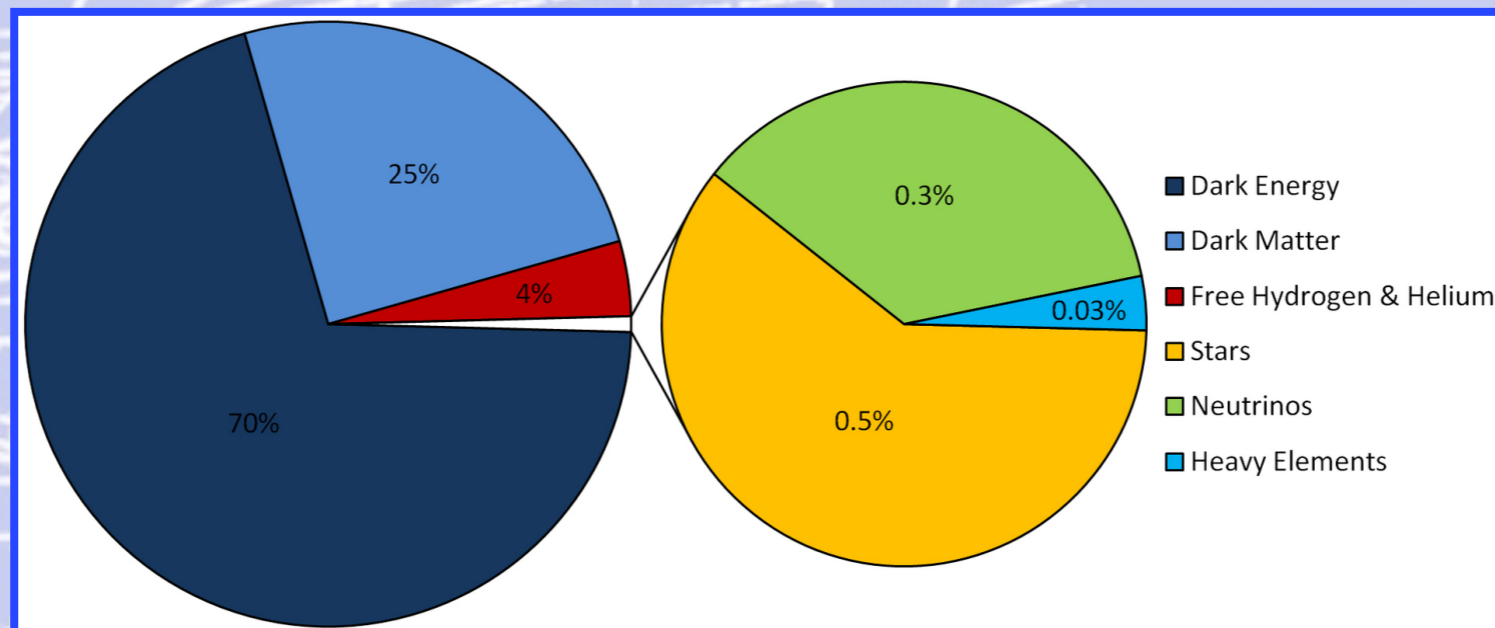


- **Energia di legame nucleare:** differenza tra la somma delle singole masse dei protoni e dei neutroni del nucleo e la massa del nucleo stesso (sempre inferiore).
- Misura dell'energia di legame nucleare che tiene insieme il nucleo e può essere calcolato dalla relazione di Einstein: Δmc^2
- Per la particella α si ha $\Delta m = 0,0304\text{u}$ che fornisce un'energia legante di 28,3 MeV :



La composizione dell'universo (1)

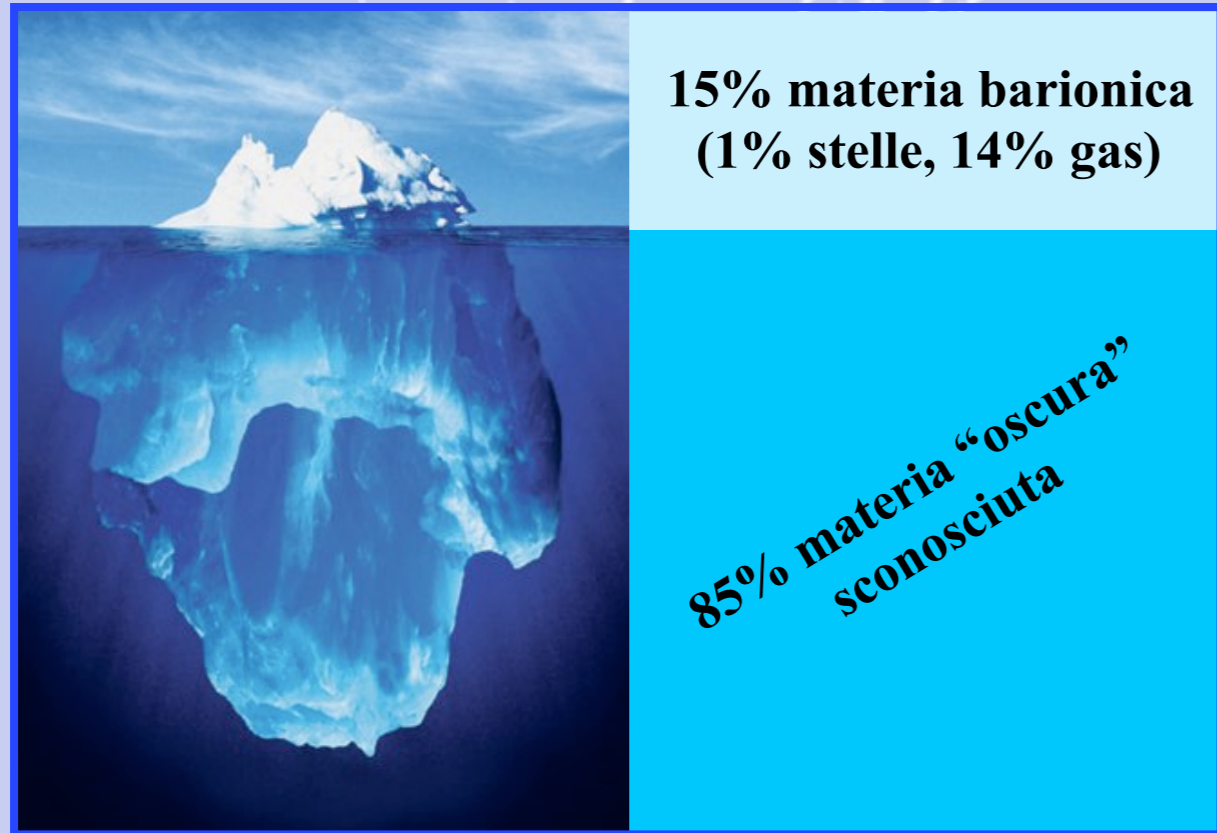
- Lo studio dei moti stellari nelle galassie indica la presenza di una grande quantità di massa invisibile nell'Universo. Questa massa sembra essere di un genere attualmente a noi sconosciuto: né emette né assorbe radiazione elettromagnetica (compresa la luce visibile) a qualsiasi livello significativo. E' chiamata **materia oscura**.
- La materia oscura rappresenta uno dei più grandi misteri attuali della fisica delle astroparticelle. La sua abbondanza equivale ad un ordine di grandezza in più rispetto alla materia convenzionale di cui siamo fatti.
- Esistono anche indicazioni di una ulteriore forma di energia, che noi chiamiamo **energia oscura**.



- Inoltre, ogni secondo, particelle ad alta energia (oltre 1 GeV) di passaggio origine extraterrestre attraverso ogni centimetro quadrato sulla la Terra, e sono messaggeri da regioni in cui avvengono fenomeni altamente energetici. Questi sono i **raggi cosmici**.

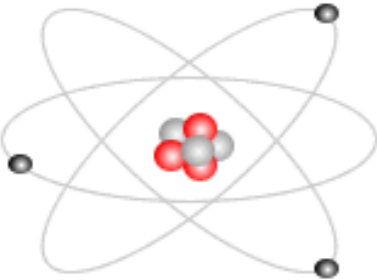
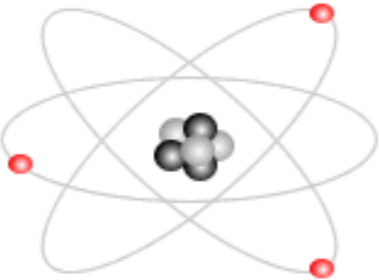
È naturale provare a usare questi **messaggeri per ottenere informazioni sugli eventi di più alto di energia che si verificano nell'Universo, e sulla sua composizione.**

Due dei problemi aperti per la fisica delle astroparticelle



Materia Oscura

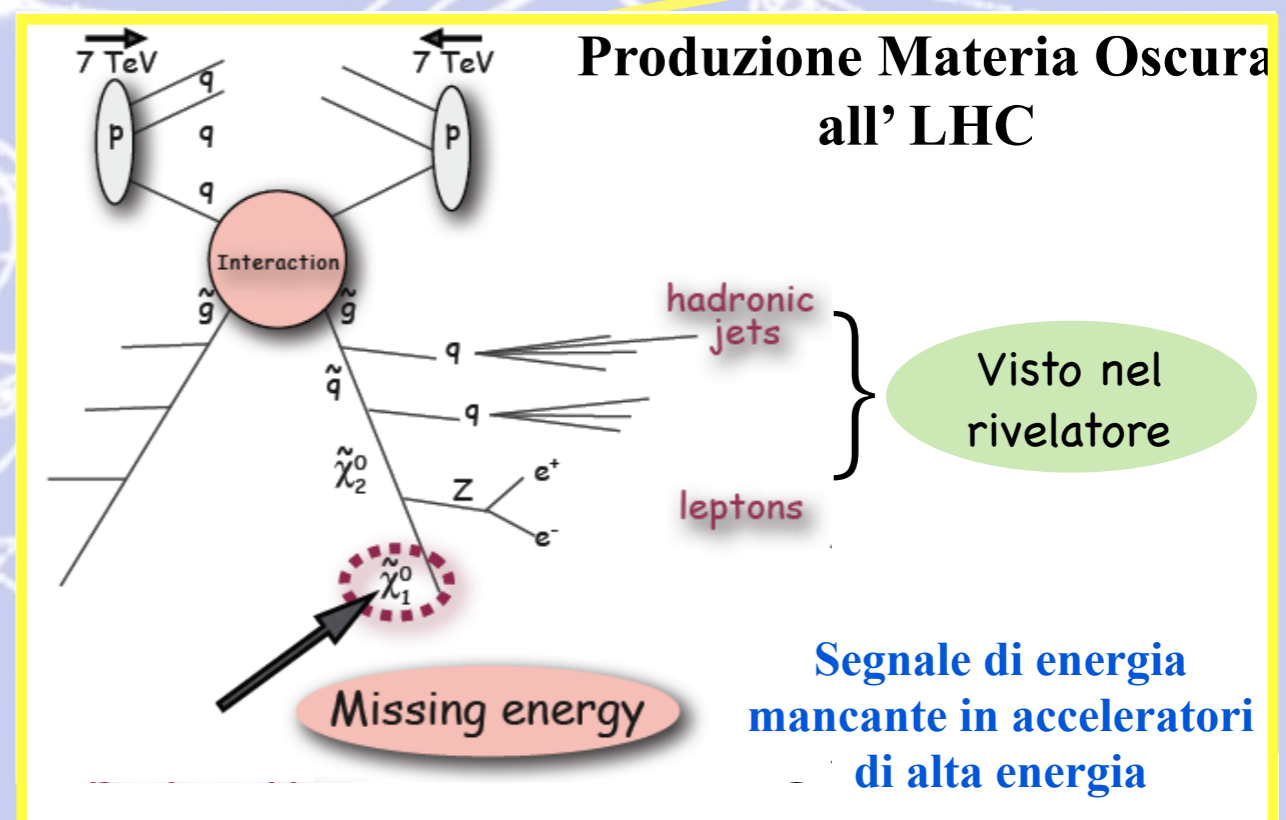
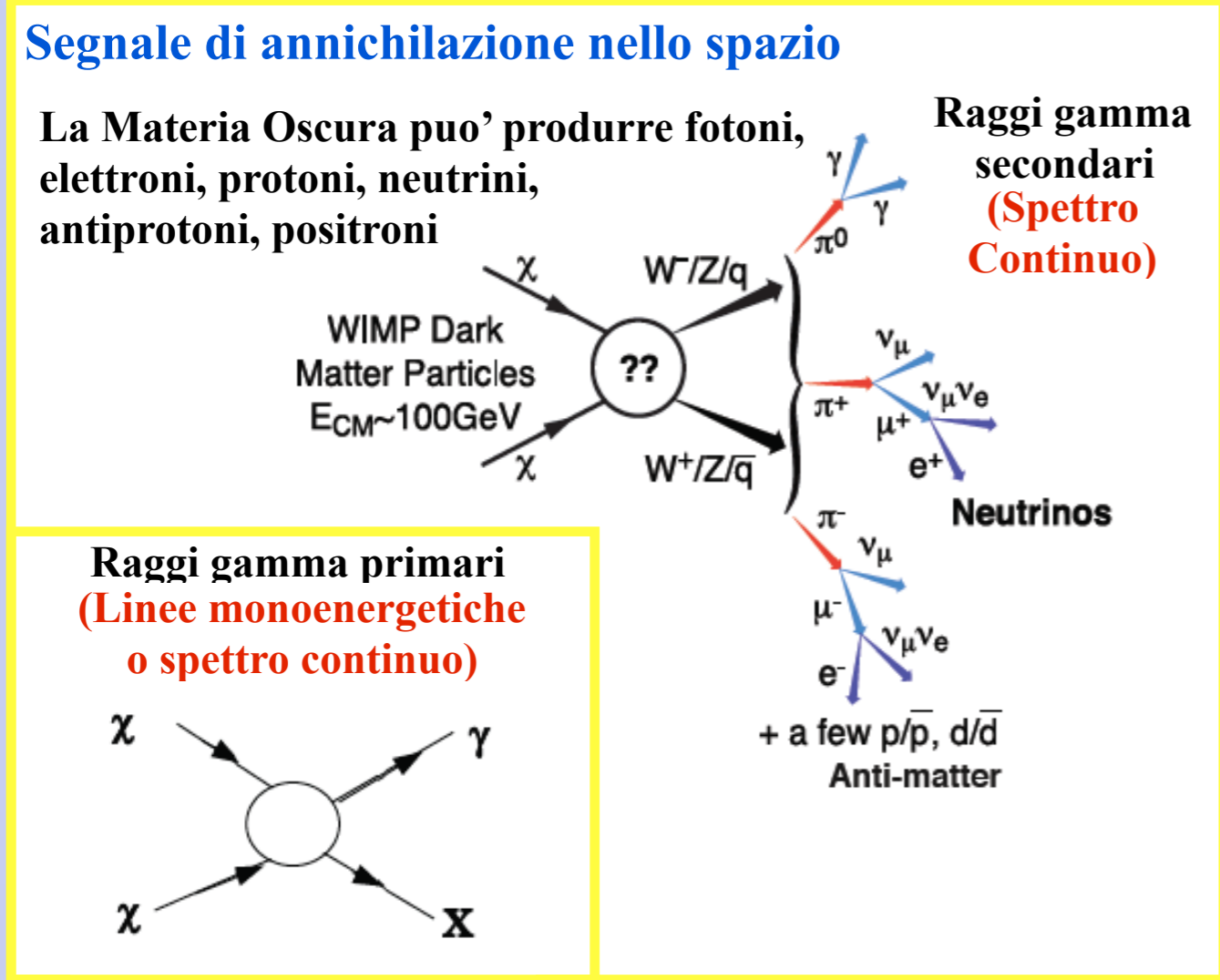
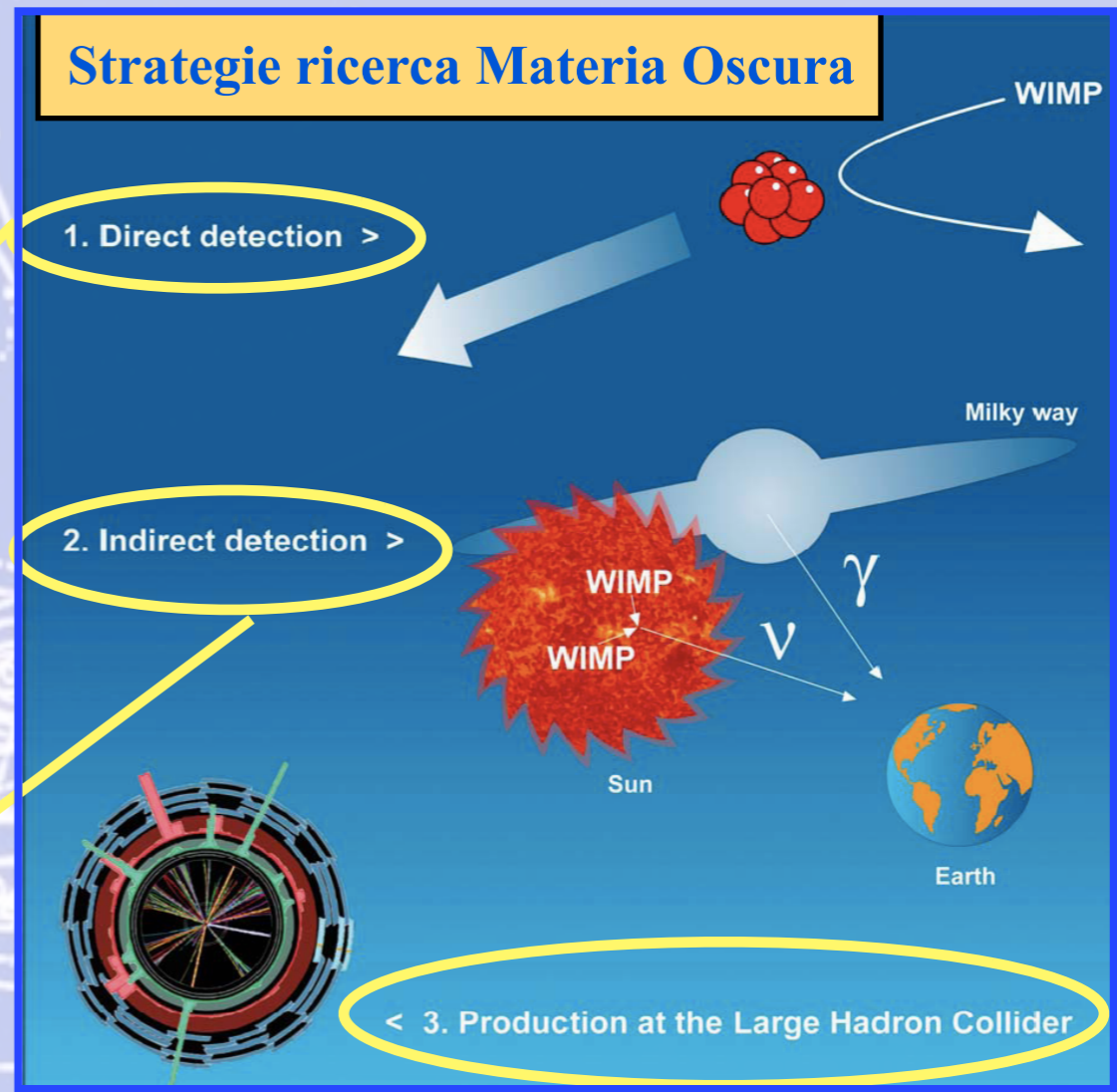
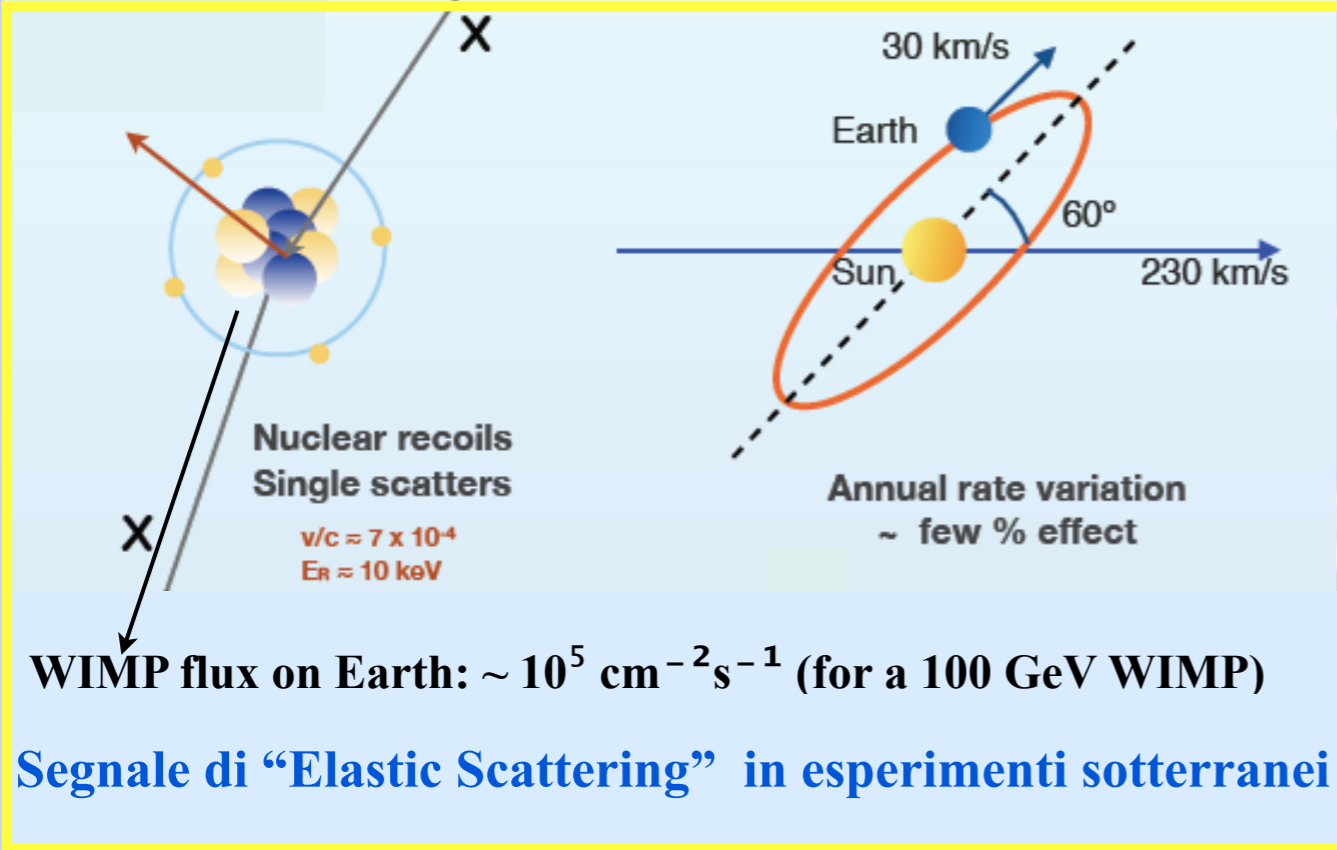
Un tipo di materia invisibile e trasparente
(non interagisce con i fotoni)
la cui presenza e' dedotta attraverso i suoi
effetti gravitazionali.

materia	antimateria
	
● PROTONE (+)	● ANTIPROTONE (-)
● NEUTRONE	● ANTINEUTRONE
● ELETTRONE (-)	● ANTIELETTRONE (+) (o positrone)

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(Quasi) assenza di antimateria

Asimmetria barionica:
$$\frac{n_B - \bar{n}_B}{n_B + \bar{n}_B} \sim 10^{-10}$$

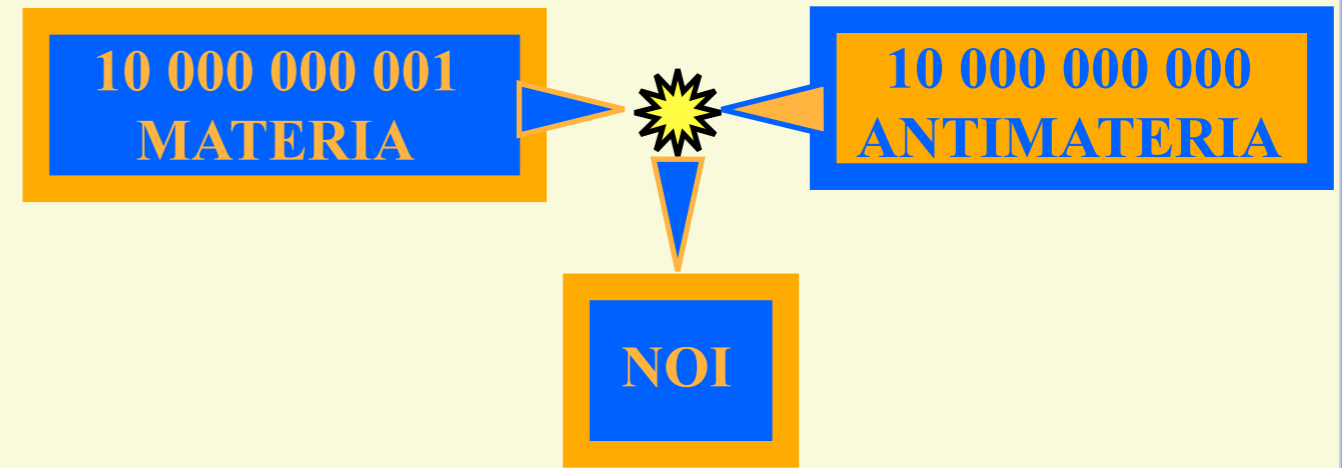


Antimateria: problemi e domande

La Teoria del Big Bang richiede una uguale abbondanza di materia e antimateria.

Dopo l'inizio dell' "era" delle particelle, non si è trovato alcun processo che possa cambiare il numero netto di particelle dell'universo.

A partire da un millisecondo dopo il Big Bang, il bilancio tra materia ed antimateria è stato fissato per sempre.



Esiste una qualche **ASIMMETRIA** nel modo in cui la natura tratta materia e antimateria?

Una linea di investigazione molto promettente è quella della **violazione della simmetria CP**

nei decadimenti di particelle via **interazione debole**.

Prima evidenza (3.5σ) a **LHCb** con **0.8%** di differenza nel tasso di decadimento del **mesone D** e della sua antiparticella (2011).

Esclusa presenza di antimateria entro il nostro gruppo di galassie :

il segnale di annichilazione è troppo piccolo.

...ma se una volta è esistita, dov'è ora ?

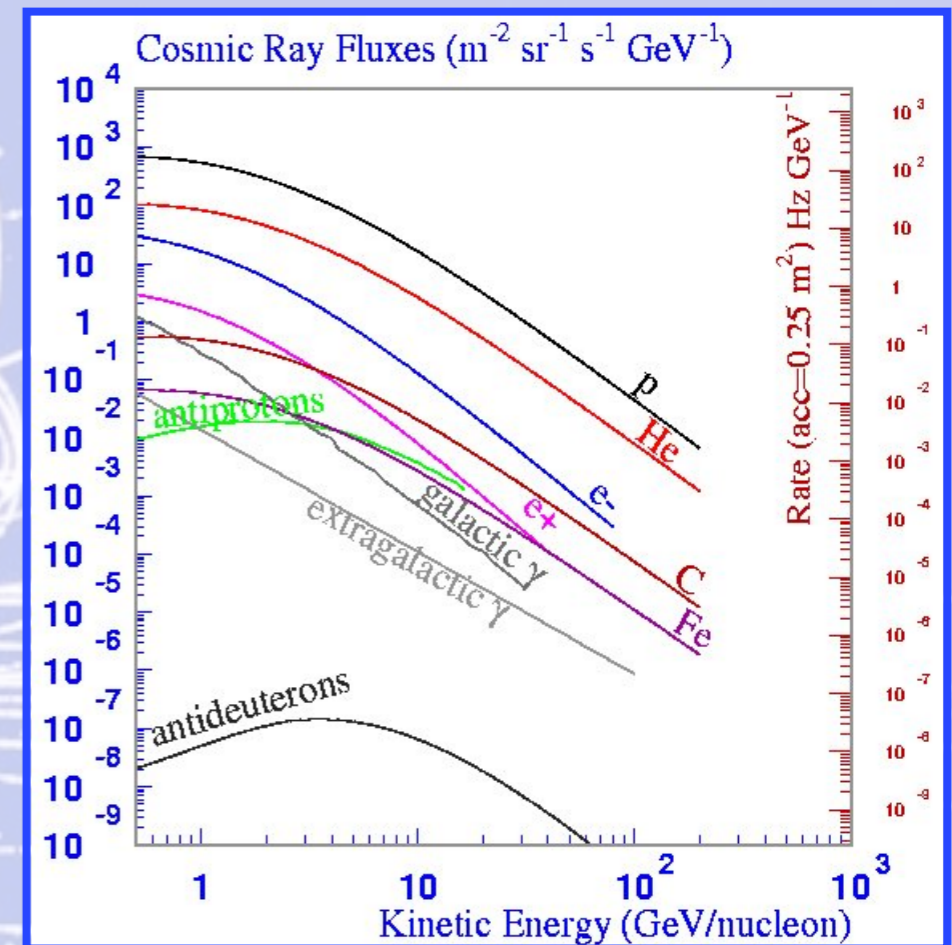
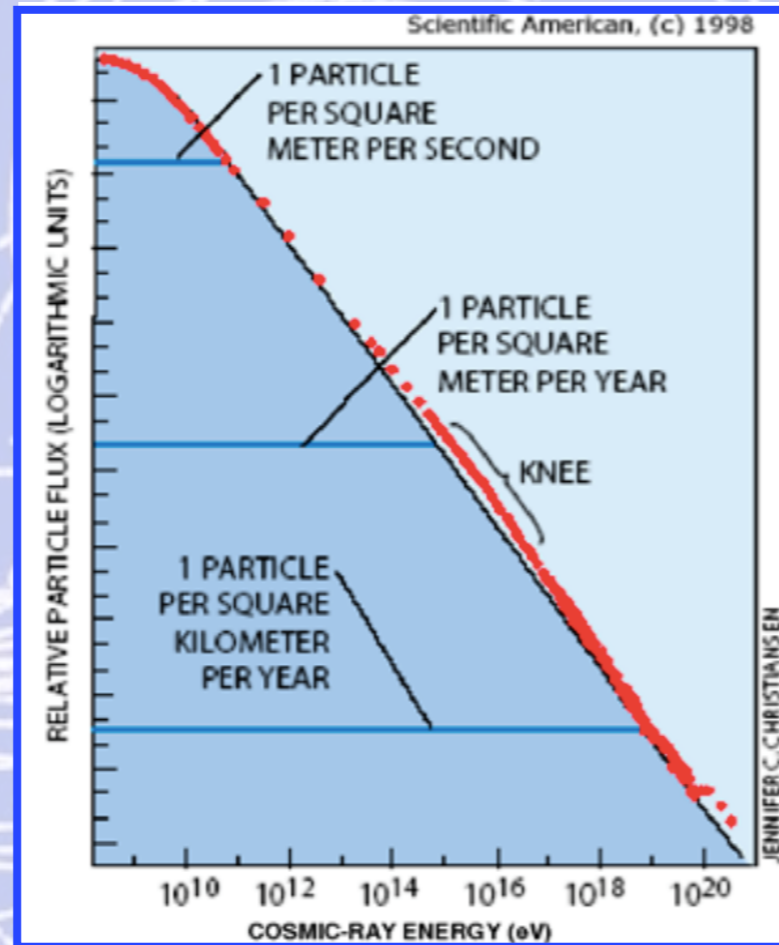
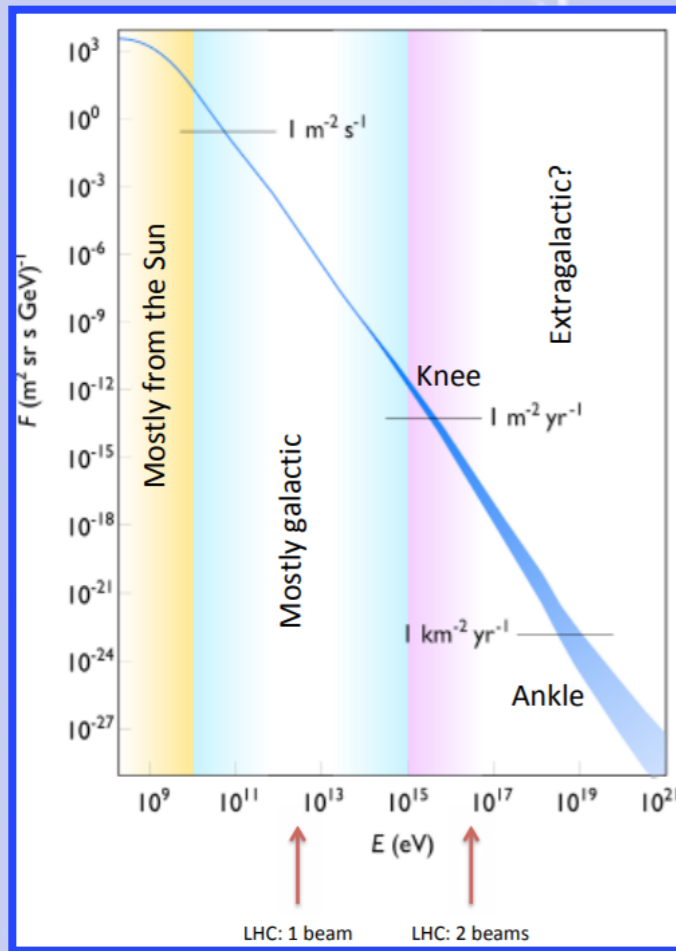
Lontano da noi ?

Esiste un qualche resto di antimateria nell'Universo vicino?

Singolo nucleo di anti-He nei raggi cosmici:
Agglomerati di Antimateria

Singolo nucleo di anti-C nei raggi cosmici:
Stelle di Antimateria

Raggi Cosmici primari carichi



I raggi cosmici (CR) sono particelle subatomiche che raggiungono la Terra dallo spazio;

- Il flusso dipende fortemente sull'energia ;
- Le più alte energie registrate: fino a 10^{21} eV ;

- **p: componente dominante**
- **He: 5% del flusso p @ 10GeV**
- **D, Li, Be, B e C**
- **Anti-protoni: $\sim 10^{-4}$ del flusso p**

Protoni: un modo per misurare l'attività solare ;

Isotopi: informazioni sulla propagazione dei Raggi Cosmici nella Galassia ;

$^{10}\text{Be}/^9\text{Be}$ ratio (^{10}Be , $\tau_{1/2}=1.6 \times 10^6$ yrs):

- Tempo di confinamento dei Raggi Cosmici nella Galassia;
- Densità media del materiale interstellare attraversato.

Panoramica sui diversi rivelatori: raggi cosmici di alta energia (1)

I raggi **cosmici primari** sono prevalentemente protoni e nuclei atomici più pesanti:

- colpiscono le molecole dell'atmosfera a circa 15-20 km di altitudine formando « **sciami atmosferici** » di particelle secondarie;
- coprono un gigantesco **intervallo di energia** (da frazioni fino a migliaia di GeV);
- a bassa energia provengono dal Sole mentre quelli di alta energia sono un **mistero**;
- i raggi **cosmici primari** possono essere misurati o con esperimenti su pallone o nello spazio;
- a causa delle limitazioni di peso, tali rivelatori possono investigare solo uno spettro energetico inferiore al TeV.

Esperimenti come il satellite **Pamela** (2006) o il rivelatore **AMS-02** (2011) sulla ISS hanno misurato e misurano con estrema precisione :

- la composizione di massa dei raggi cosmici primari;
- gli spettri di energia di fotoni, elettroni, protoni ed elio e altri nuclei leggeri, così come le loro anti-particelle.

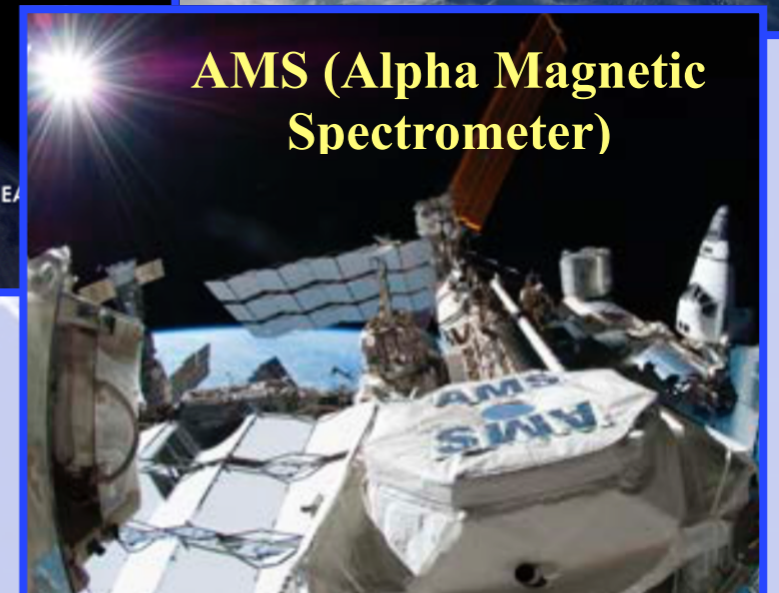
Caratteristiche interessanti osservate in alcuni di questi spettri hanno innescato dibattiti animati sulle possibili origini: potrebbero essere attribuiti al decadimento di nuove particelle, come la Materia Oscura, o altre cause astrofisica sconosciute.



Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

PAMELA

AMS (Alpha Magnetic Spectrometer)



Panoramica sui diversi rivelatori: raggi cosmici di alta energia (2)

Gli sciami atmosferici prodotti da raggi cosmici di alta energia possono essere registrati usando un insieme di rivelatori a terra tra essi collegati (array) : in media 1 solo raggio cosmico di 10^9 GeV viene rivelato in un anno su 1 km^2 .

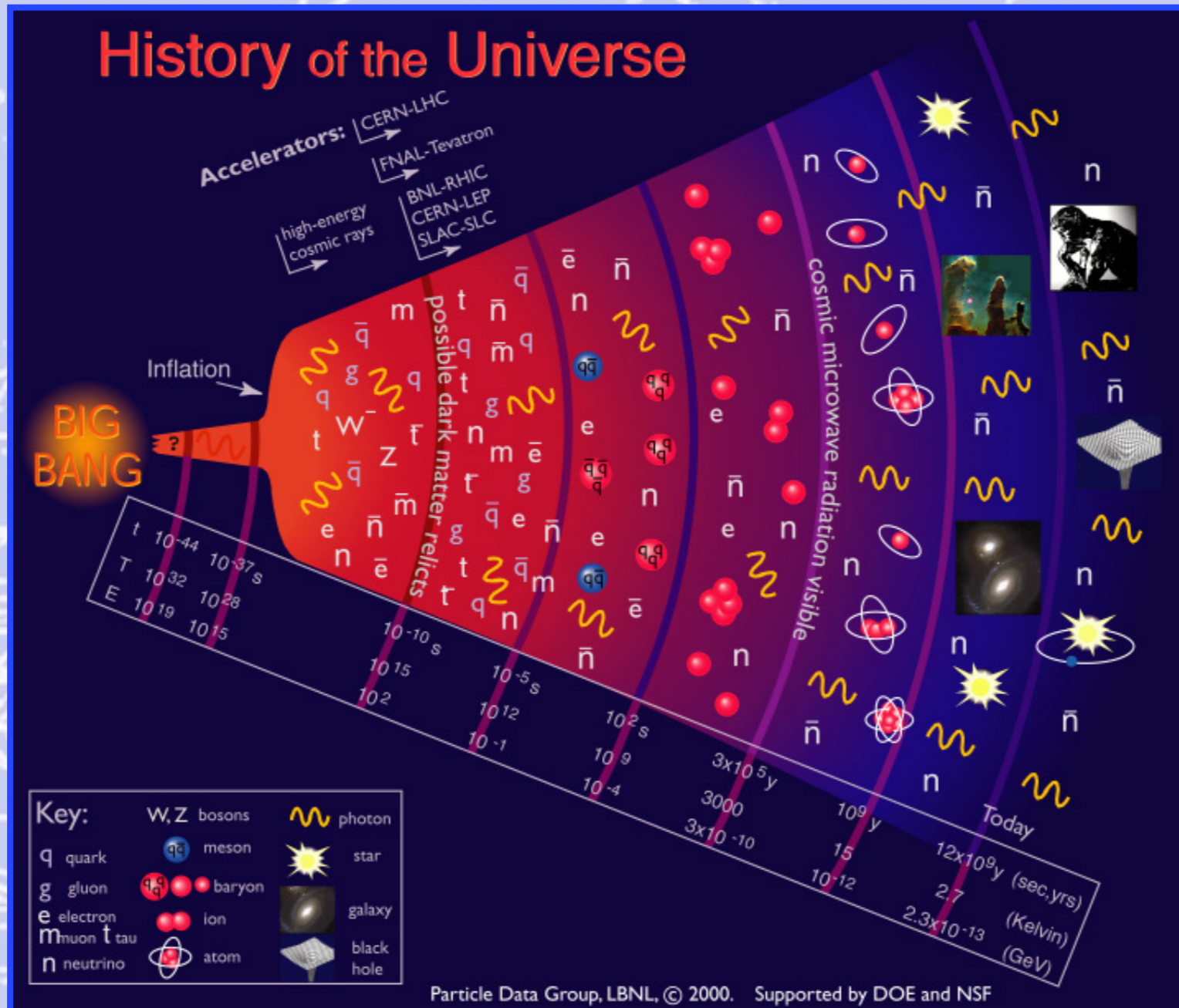
I raggi cosmici di più alta energia hanno probabilmente di origine extragalattica. Sono interessanti perché:

- solo questi possono essere realisticamente fatti risalire alle loro fonti;
- i protoni primari, dovrebbero esibire un cut-off di circa 50×10^9 GeV a causa della forte probabilità di interagire con i fotoni onnipresenti nella CMB (Cosmic Microwave Background).



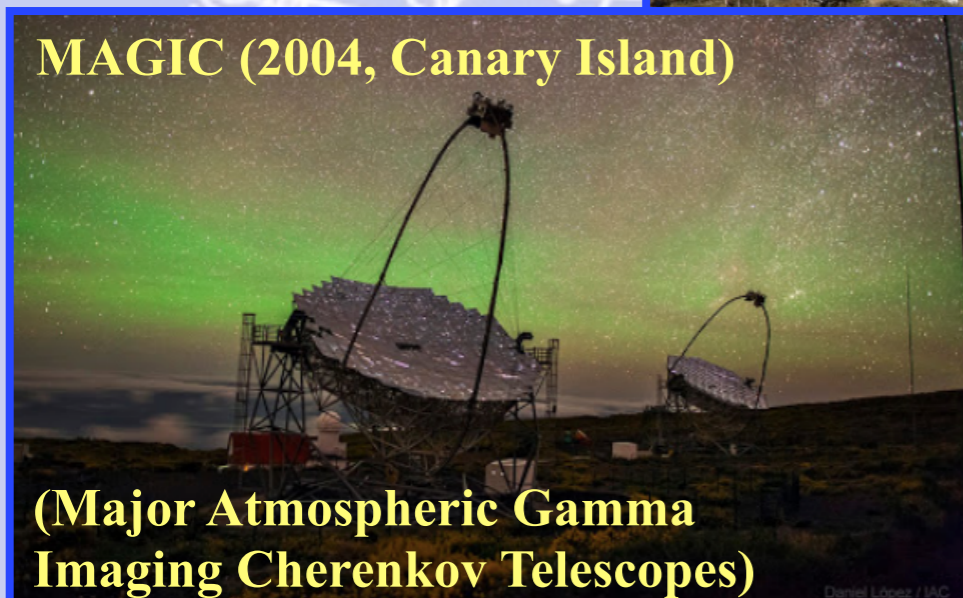
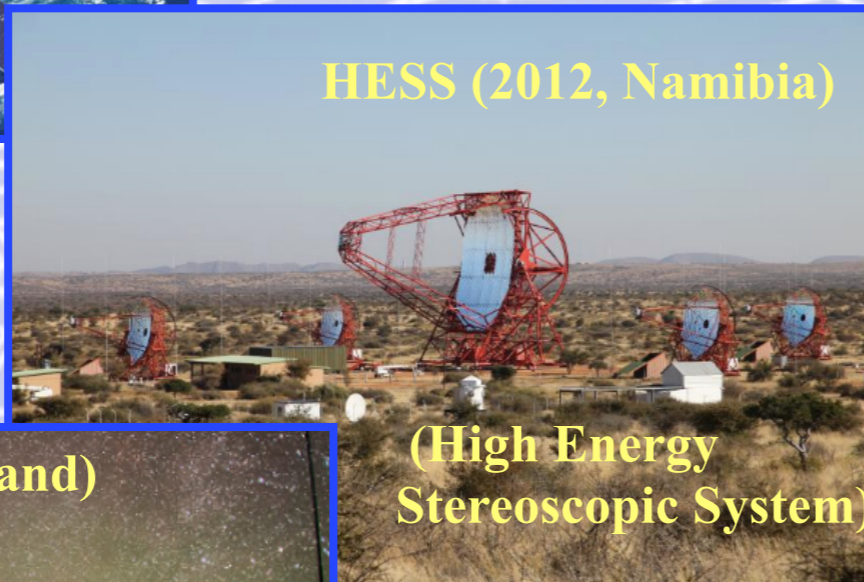
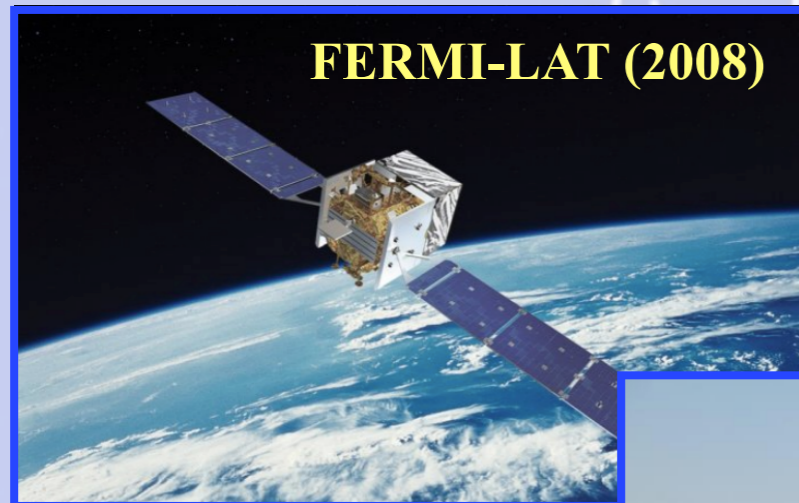
L'**Osservatorio Pierre Auger** (dal 2008),:

- il più grande e sensibile rilevatore di sciami atmosferici esistente;
- 3000 km^2 di prateria (circa dieci volte Parigi);
- 1600 serbatoi di acqua per registrare le particelle come elettroni e muoni che colpiscono il suolo;
- l'array è accoppiato a 5 telescopi che registrano, durante l'oscurità, la debole luce fluorescente causata sciami nell'atmosfera;
- la combinazione di queste due misurazioni permette di determinare la direzione e l'energia del raggio cosmico originario in entrata e riduce significativamente le incertezze.
- Alle energie più elevate, Auger registra tipicamente decine di eventi all'anno.



Altri messaggeri sono raggi gamma di alta energia ed i neutrini

Panoramica sui diversi rivelatori: raggi gamma di alta energia



I telescopi come **HESS** e **MAGIC** e le missioni satellitari come **Fermi-LAT** (GLAST), hanno permesso uno studio approfondito dei raggi gamma ad alta energia:

- i fotoni sono i messaggeri ideali per consentire l'esplorazione dell'Universo estremo;
- grande numero di sorgenti di raggi gamma scoperte negli ultimi anni.

Il progetto globale di prossima generazione a guida europea, previsto per il 2023, sarà il Cherenkov Telescope Array (**CTA**), che ha un eccellente potenziale di scoperta che spazia dall'astrofisica alla fisica fondamentale.

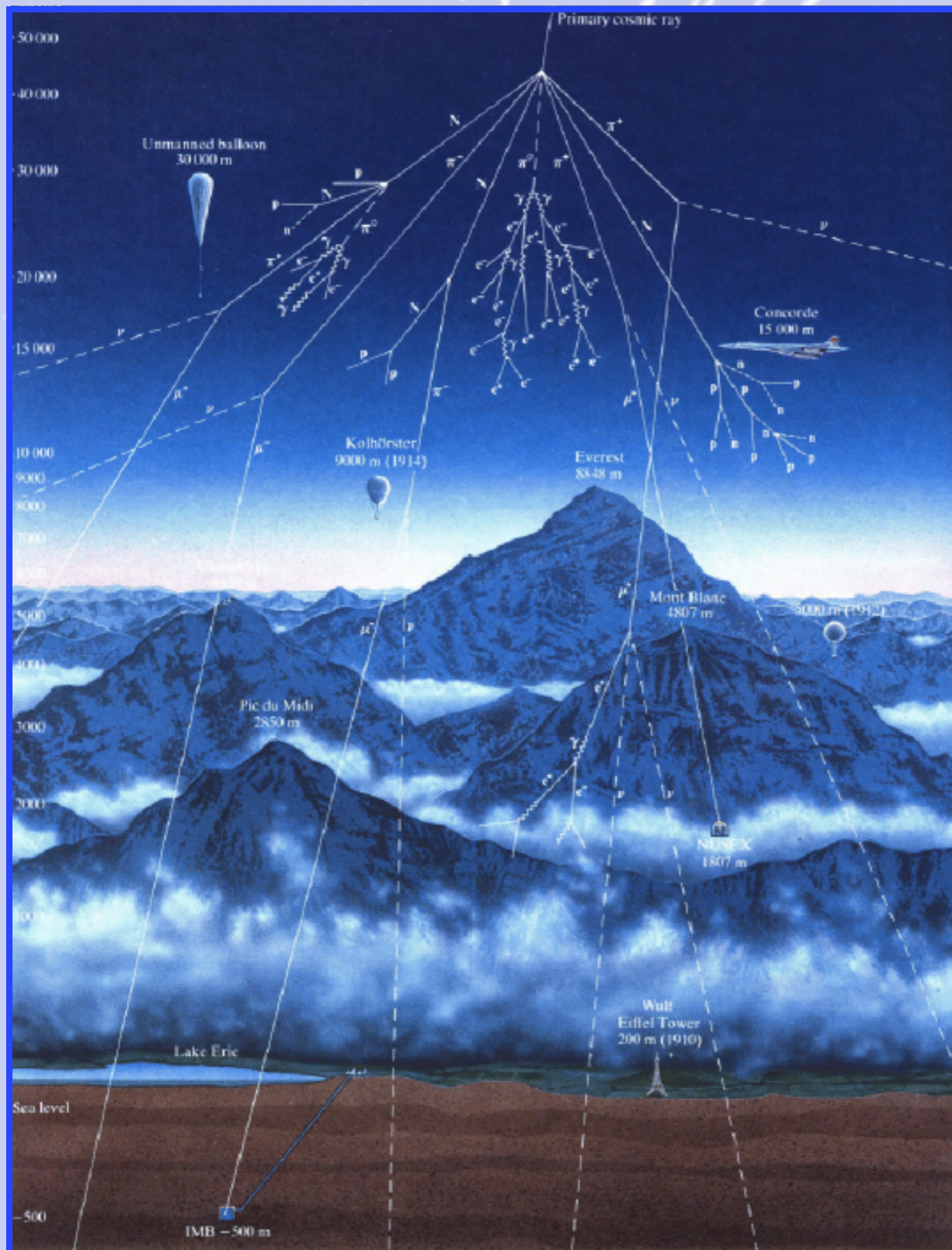
Ovviamente il panorama è molto più complesso e variegato!



Sofferamoci allora sulla fisica delle particelle nello spazio



Perché investigare nello spazio?



L'atmosfera non è trasparente alle particelle cariche o ai raggi X e gamma: le interazioni degradano l'informazione della particella iniziale.

Il suo spessore in termini di massa ($1\text{kg}/\text{cm}^2$) è equivalente ad uno schermo di 4 m di cemento.

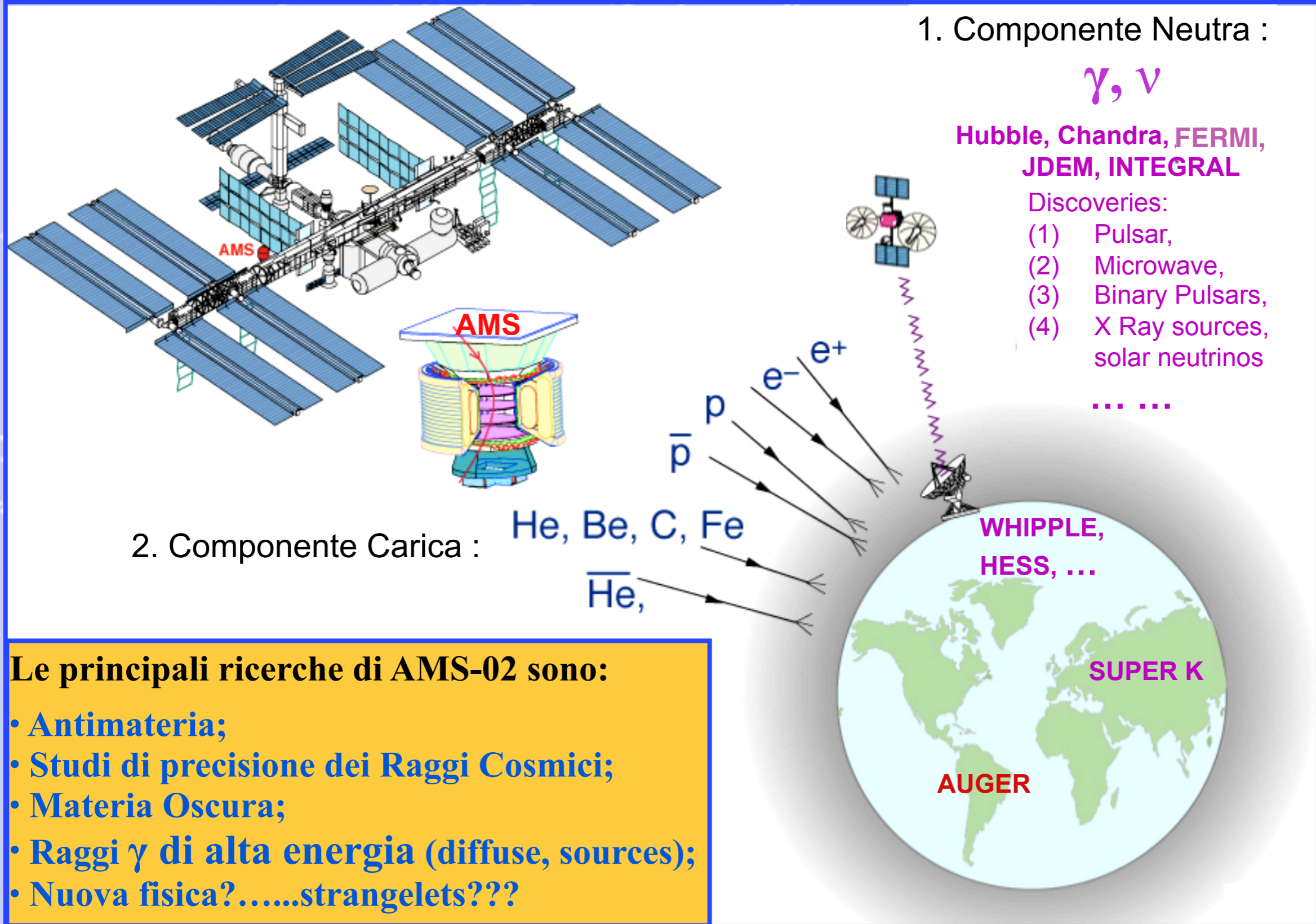
Palloncini aerostatici a 35 km ($5\text{g}/\text{cm}^2$) ma il tempo di esposizione è limitato a ~ 20 giorni.

I rivelatori su satellite hanno un tempo di esposizione più lungo dell'ordine di qualche anno ($3 \rightarrow 15$).

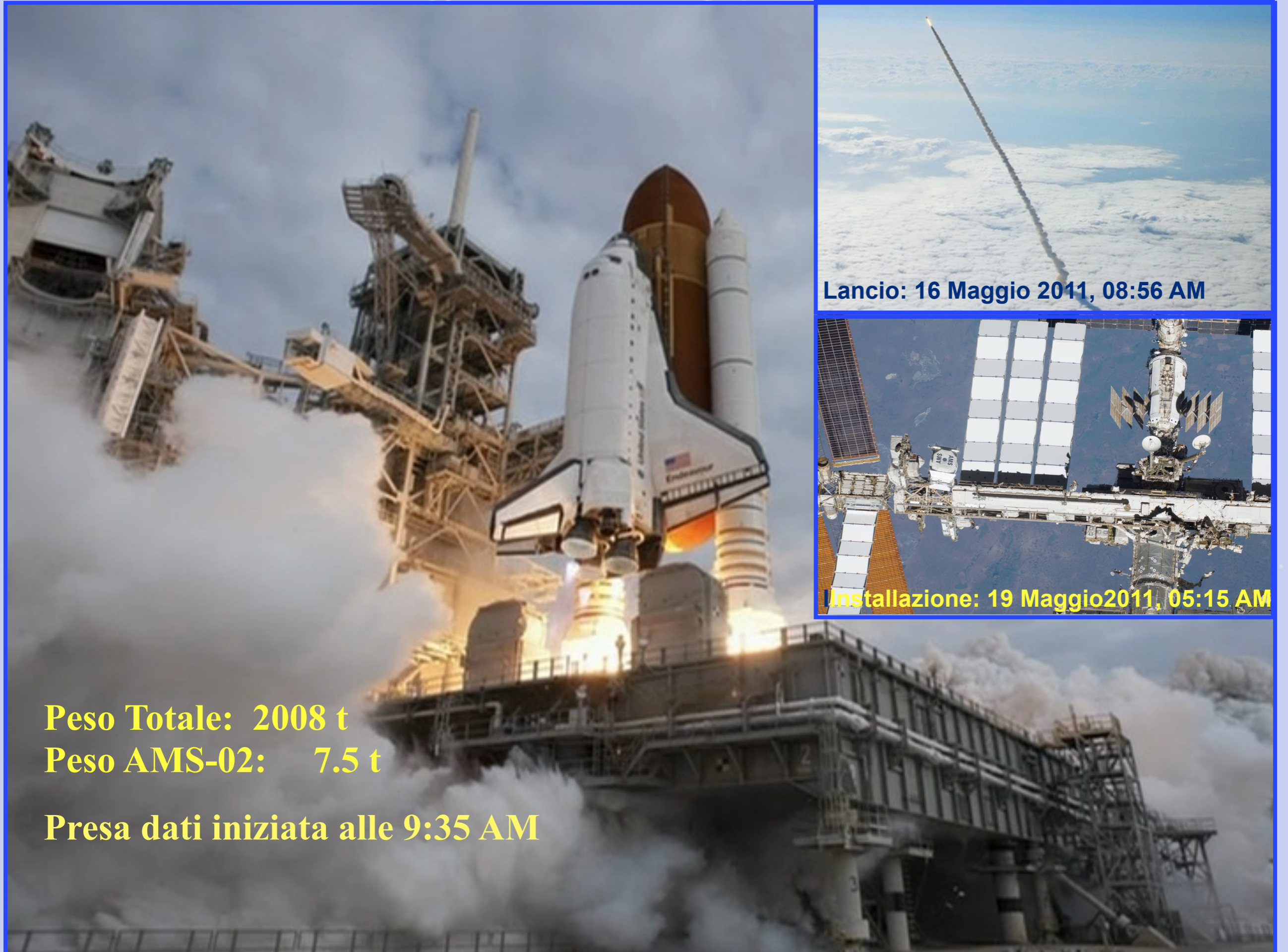
L' esperimento AMS-02 sulla ISS



AMS-02: un esperimento “multipurpose” di fisica delle particelle operante nello spazio



- Le principali ricerche di AMS-02 sono:**
- Antimateria;
 - Studi di precisione dei Raggi Cosmici;
 - Materia Oscura;
 - Raggi γ di alta energia (diffuse, sources);
 - Nuova fisica?.....strangelets???



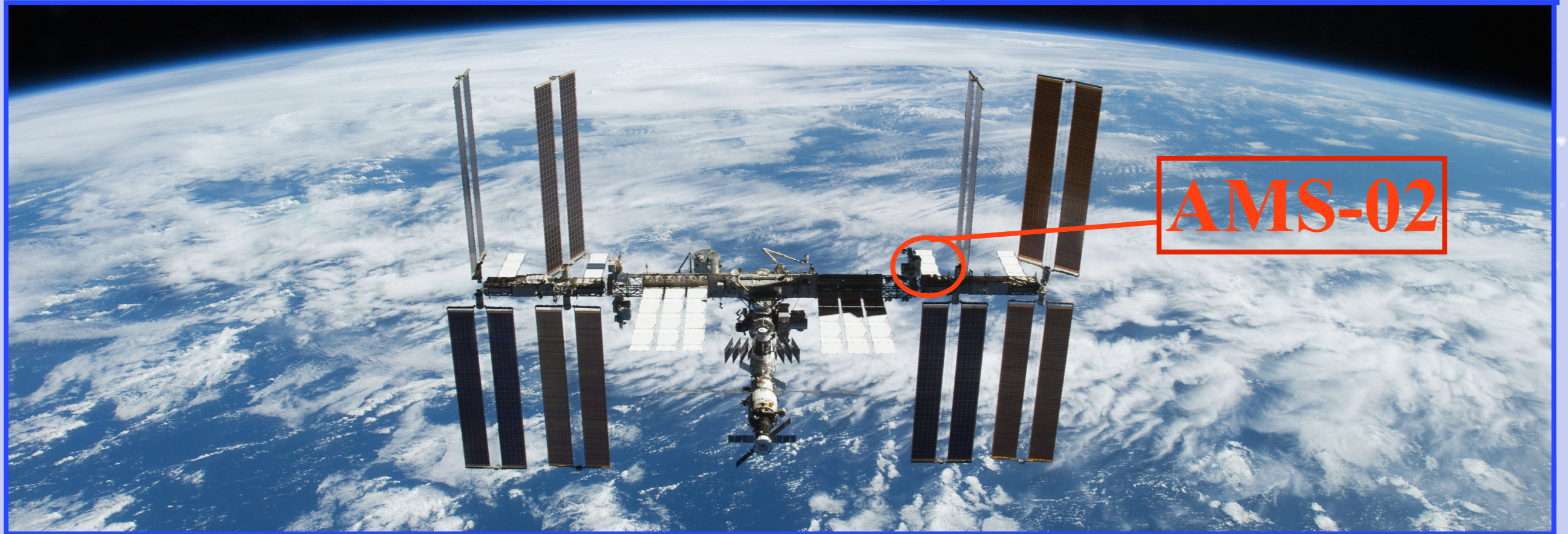
Lancio: 16 Maggio 2011, 08:56 AM

Installazione: 19 Maggio 2011, 05:15 AM

Peso Totale: 2008 t

Peso AMS-02: 7.5 t

Presenza dati iniziata alle 9:35 AM



AMS-02

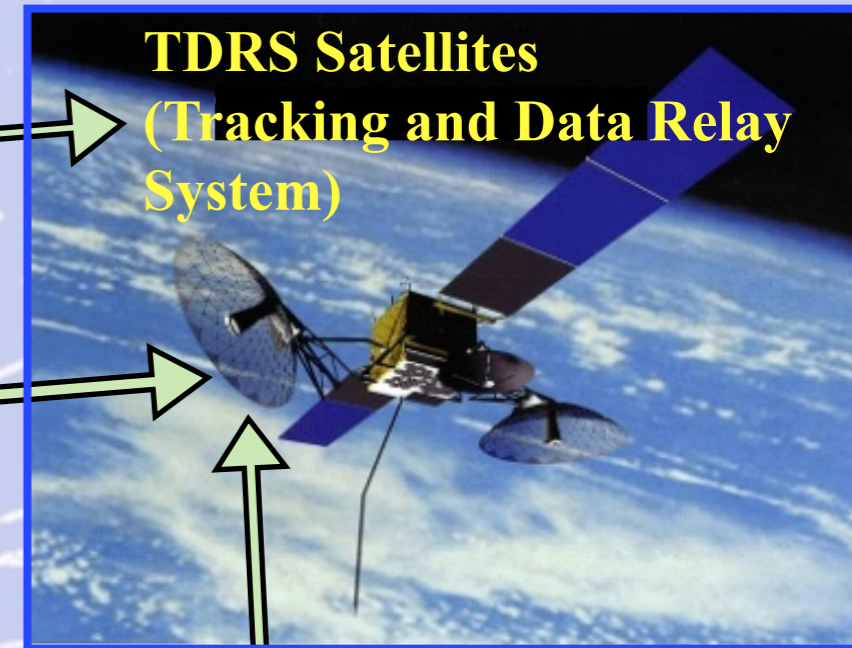
Come opera AMS-02 in volo e a terra



AMS



Astronauta usa il "laptop" di AMS presente sulla ISS



TDRS Satellites (Tracking and Data Relay System)

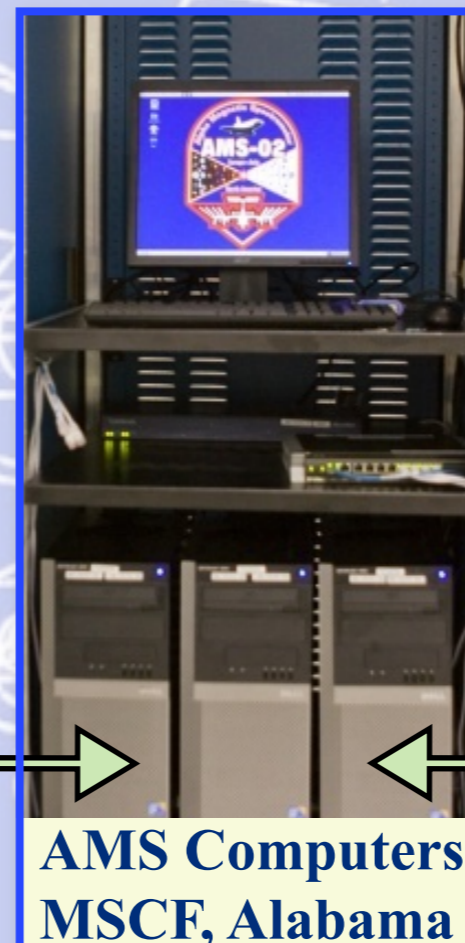
**Ku-Band High Rate (down):
Events <10Mbit/s>**

**Flight Operations
Ground Operations**

**S-Band Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s**



AMS Payload Operation Control and Science Operation Centers (POCC,SOC) at CERN



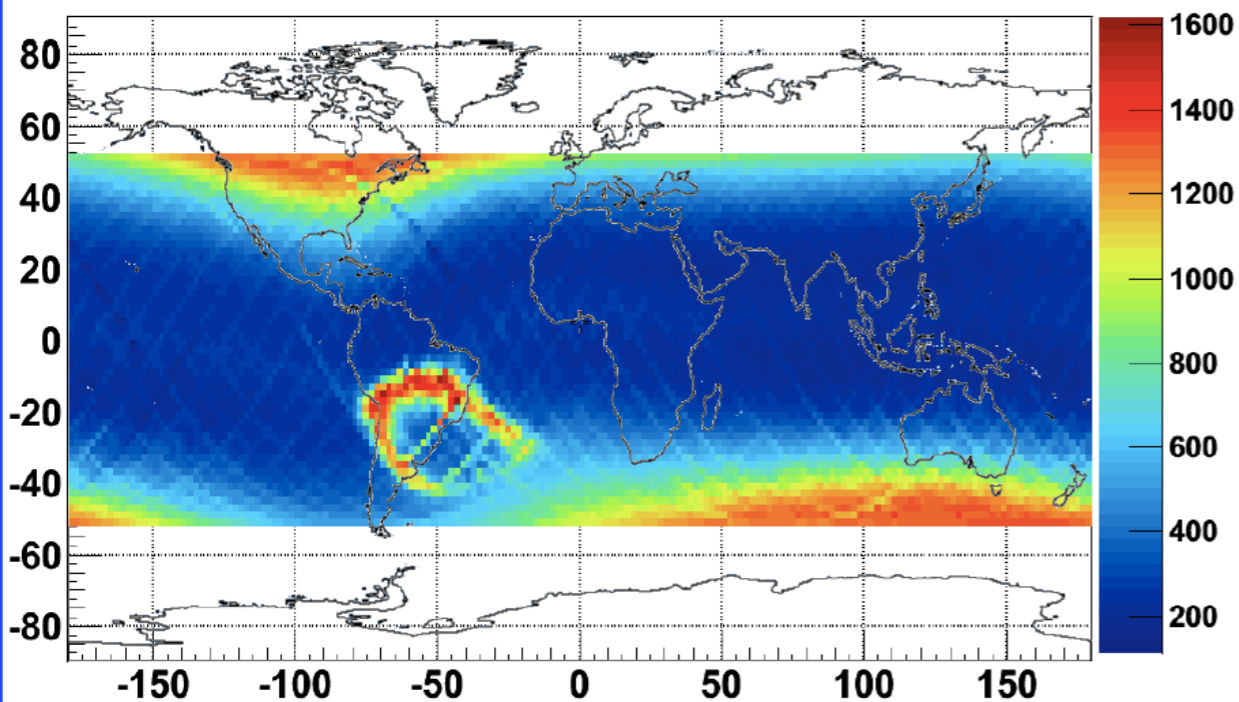
AMS Computers MSCF, Alabama



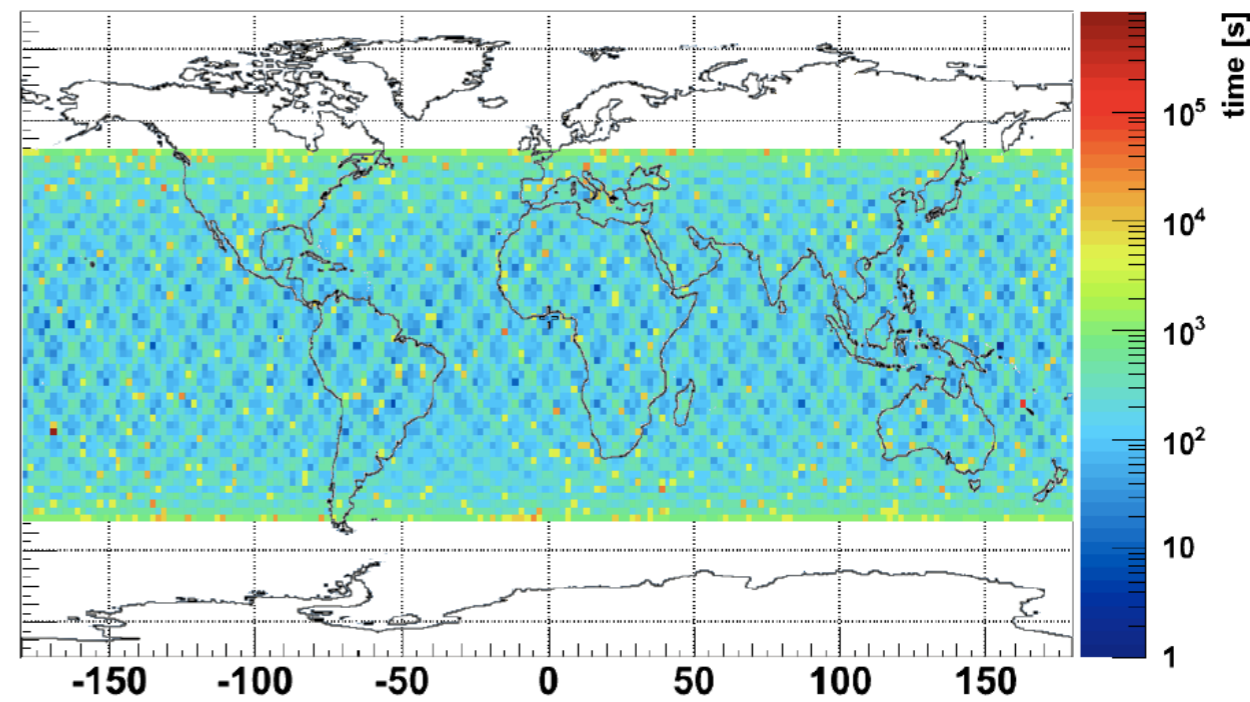
White Sands Ground terminal, NewMexico

Parametri orbitali del DAQ di AMS-02

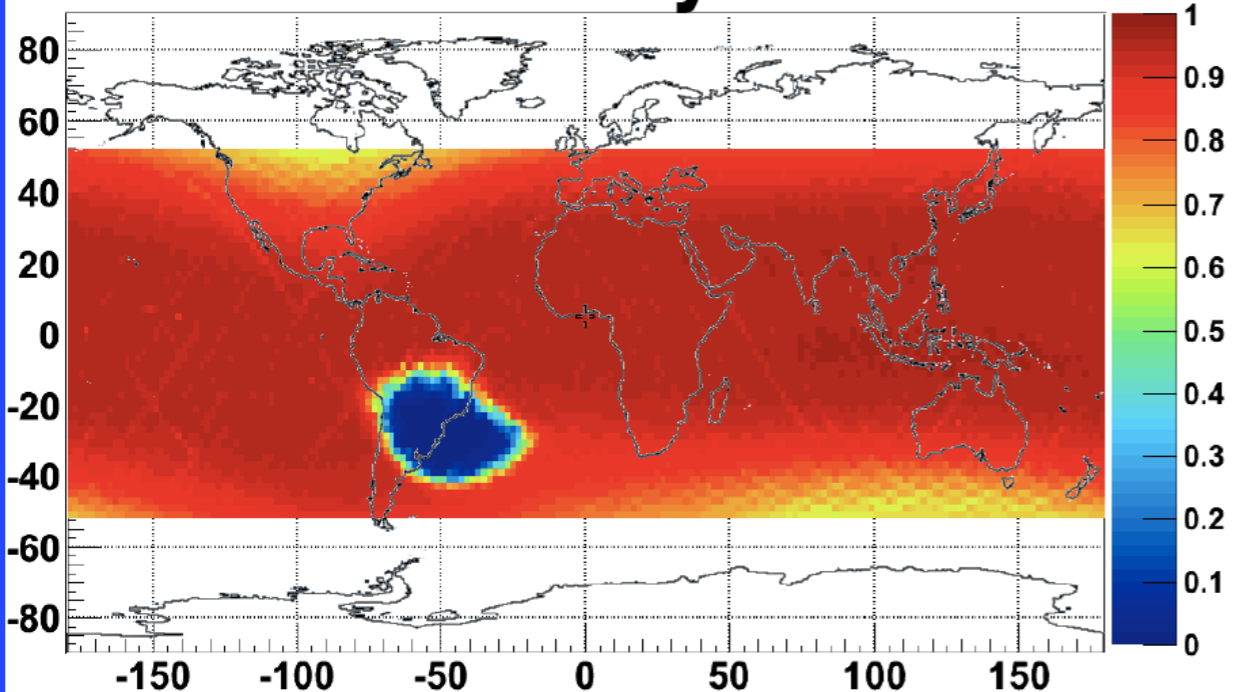
Acquisition rate [Hz]



Time at location [s]



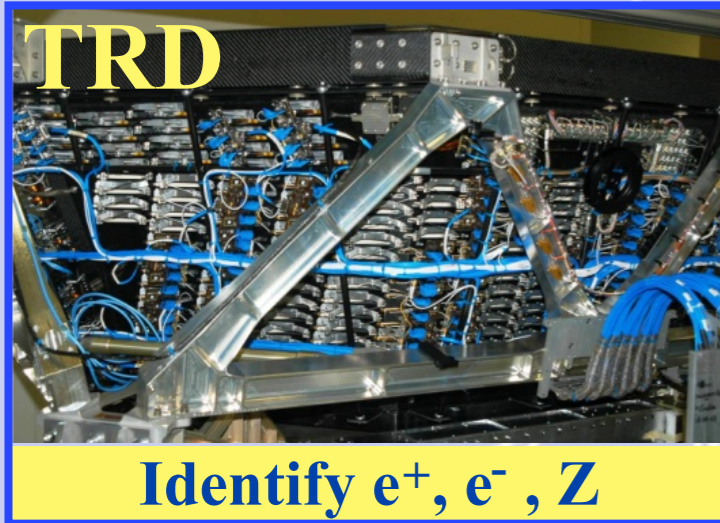
DAQ efficiency



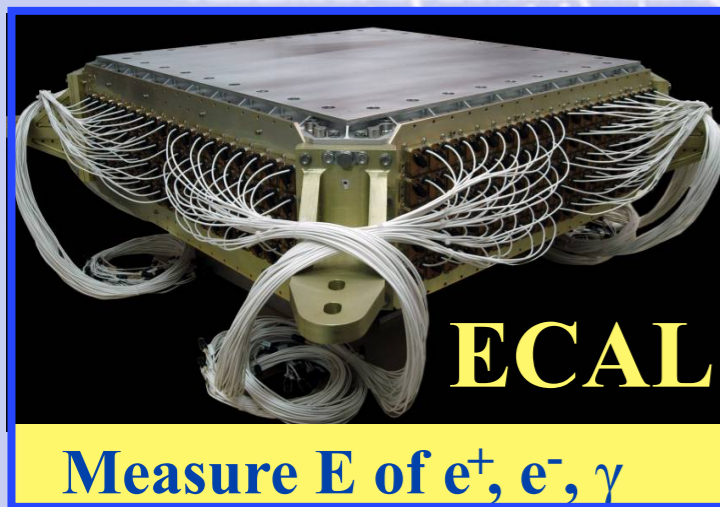
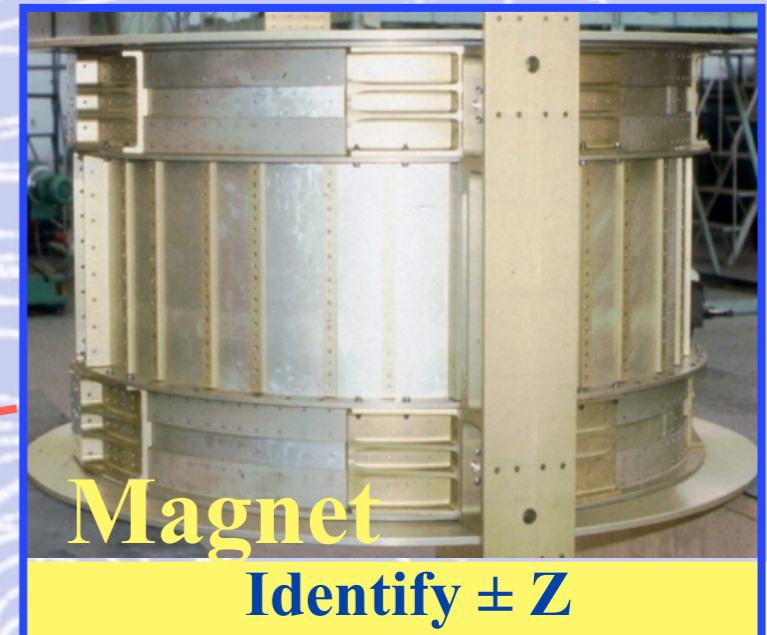
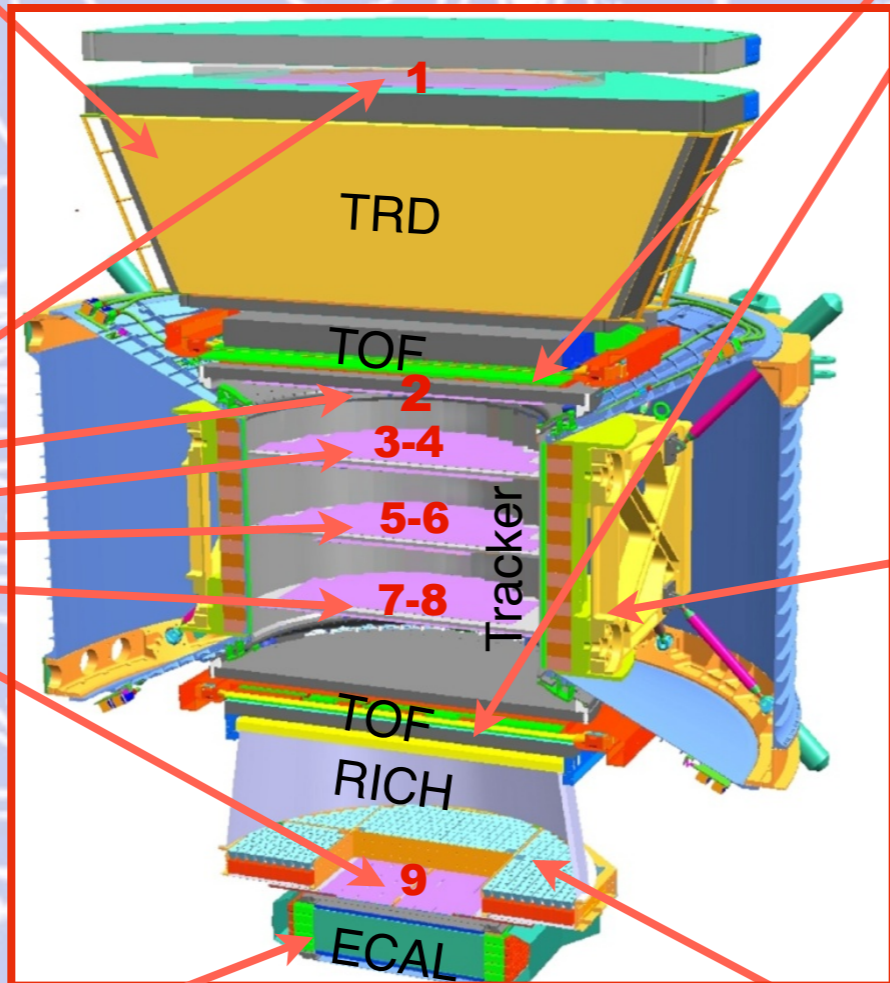
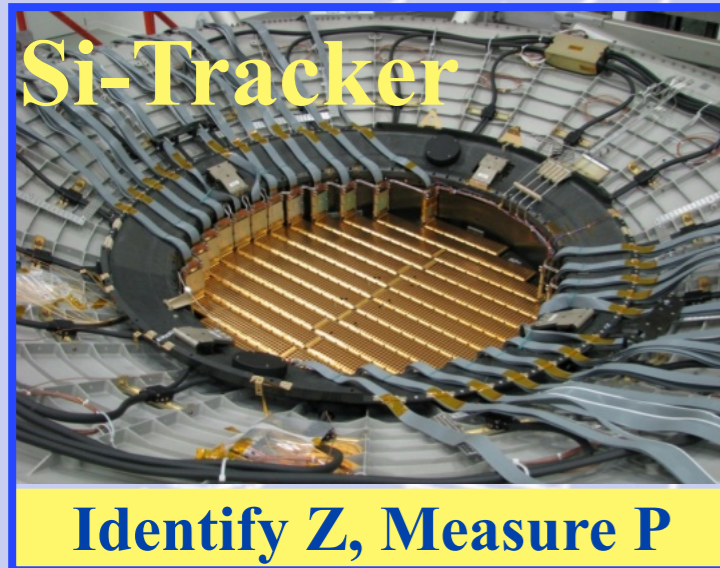
“Particles rate” varia da 200 to 2000 Hz per orbita

**In media:
DAQ efficiency 85%
DAQ rate ~700Hz**

AMS-02: uno spettrometro di precisione per energie GeV/TeV



Le particelle ed i nuclei sono definiti dalla loro carica (Z) e dall'energia ($E \sim P$)



Z , P sono misurati indipendentemente dal Tracker, RICH, TOF e ECAL



Potenziale di fisica di AMS-02

Ricerca dell'antimateria primordiale:

- anti-nuclei: $\overline{\text{He}}$, ... ;

Ricerca della Materia Oscura:

- e^+ , e^\pm , \overline{p} , γ , ... ;
- osservazione simultanea di diversi canali di segnale ;

Ricerca di nuove forme di materia :

- strangelets, ... ;

Misura degli spettri dei CR - “fine tuning” del modello di propagazione:

- D, He, Li, Be, B, C.....Fe....Ni;

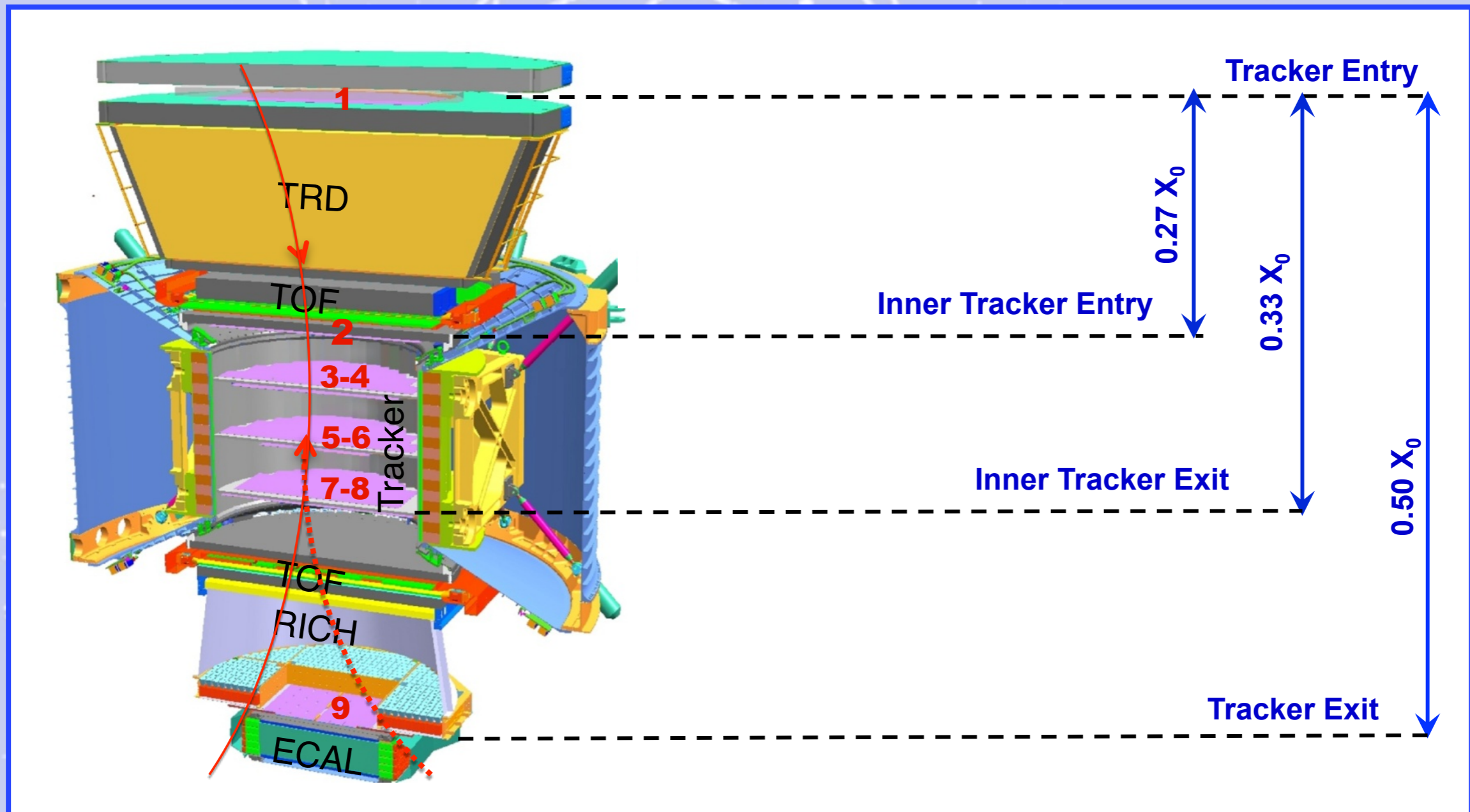
Studi di sorgenti locali (astrofisica dei raggi γ):

- SuperNovae Remnants, Pulsars, Primordial Black Holes,

Studio degli effetti della modulazione solare sugli spettri dei CR lungo tutto il ciclo solare (11 anni) ;

.....

Sensitivita' della ricerca dell'Antimateria: $\text{He}/\bar{\text{He}} > 10^{10}$



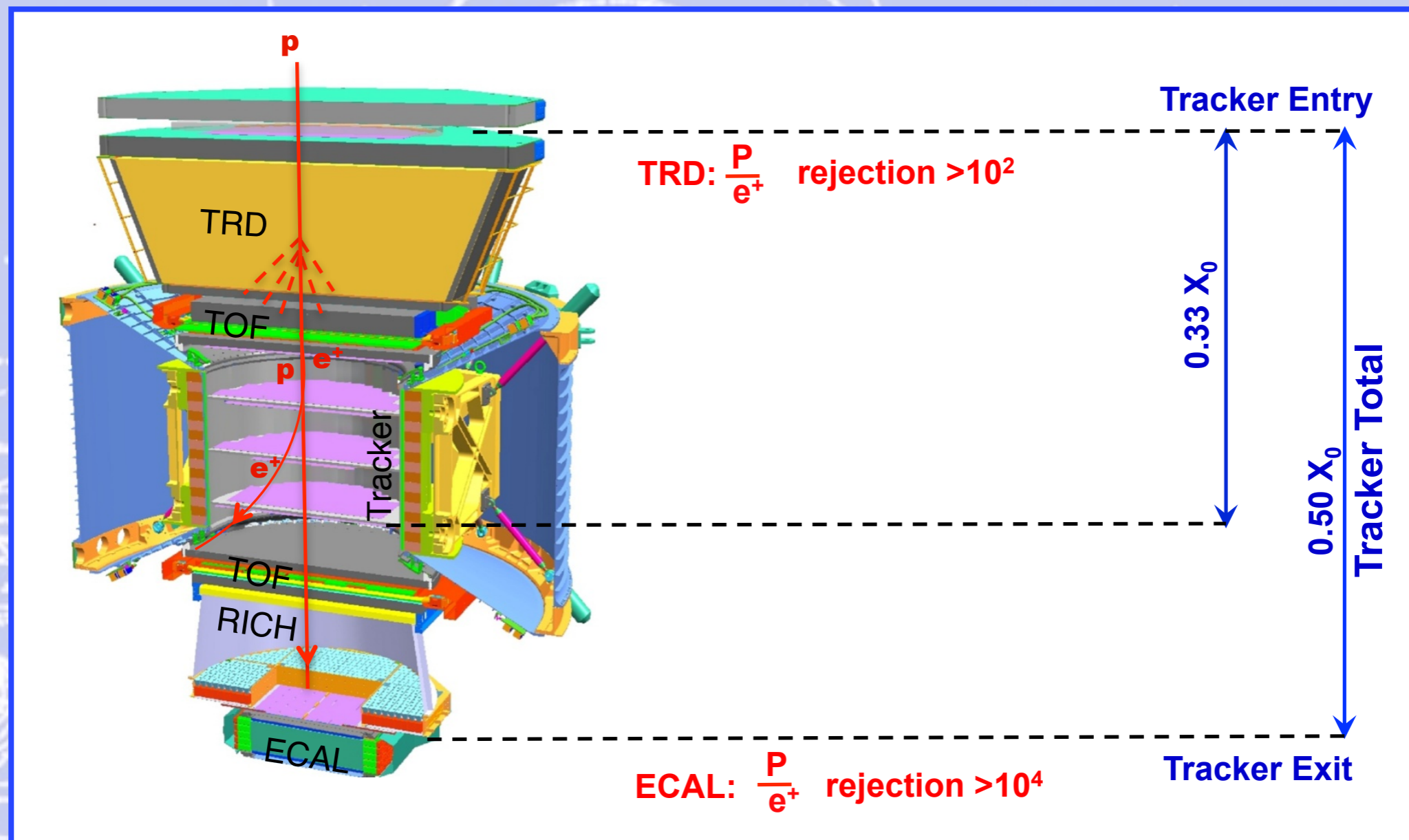
a) **Minimo materiale nel rivelatore:**

quindi il rivelatore **NON** diventa una sorgente di “large angle scattering”;

b) **Misure ripetute dell'impulso:**

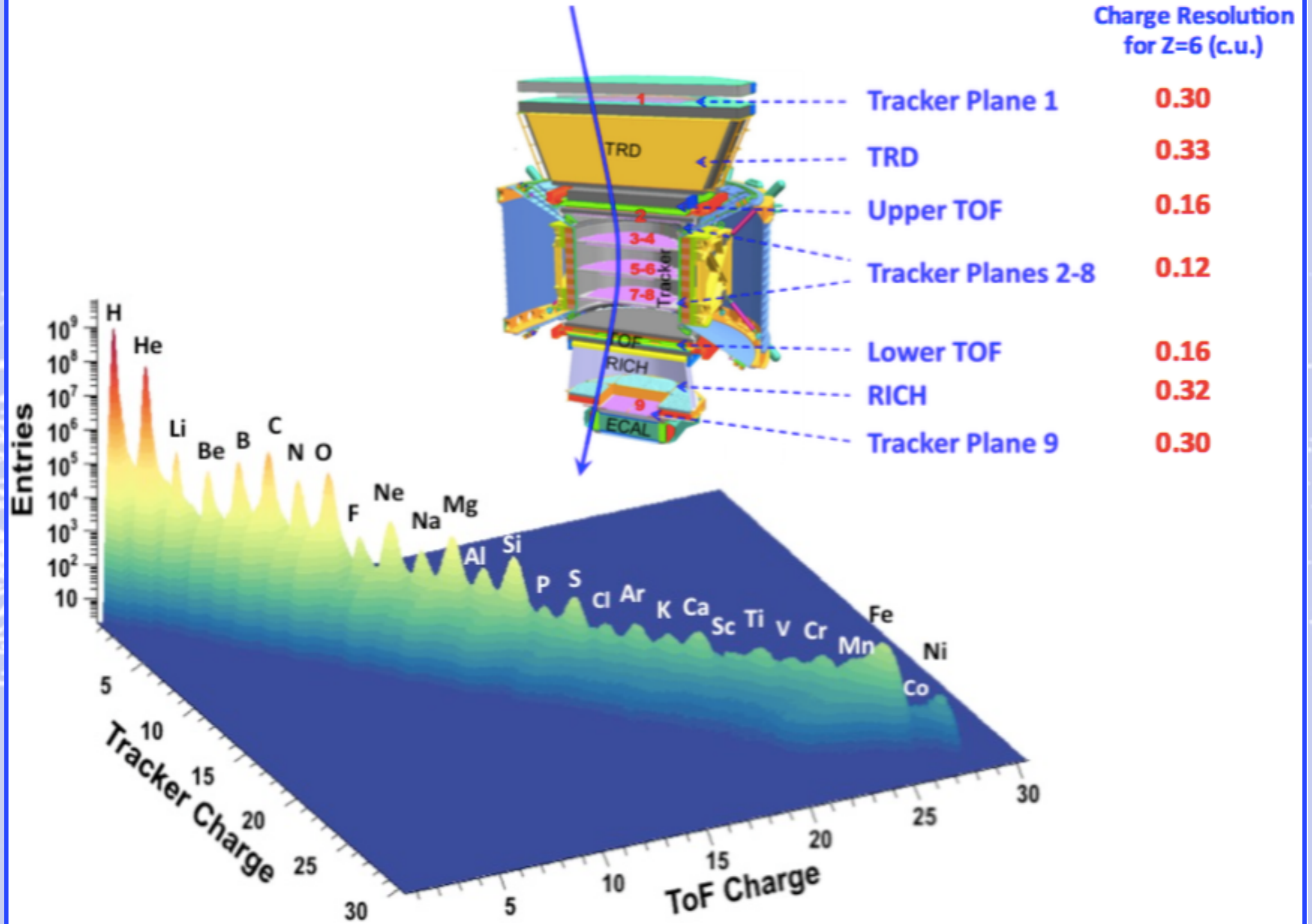
per assicurare che le particelle con “large angle scattering” non siano confuse con il segnale.

Sensitivita' della ricerca dell'origine della materia Oscura: $p/e^+ > 10^6$



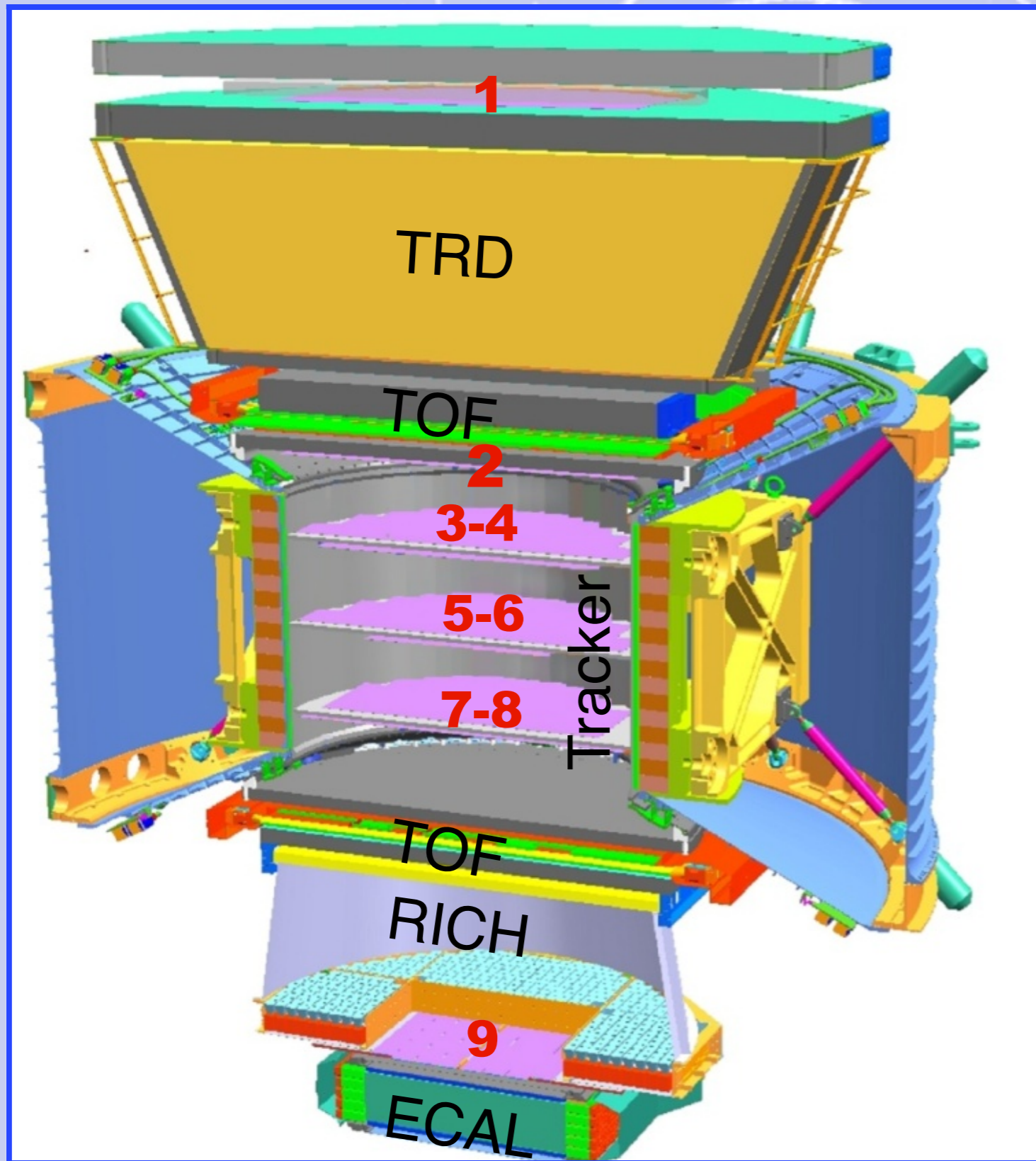
- Minimo materiale nel TRD e nel TOF:
quindi il rivelatore NON diventa una sorgente di e^+ ;
- Il magnete separa il TRD e ECAL cosi' gli e^+ prodotti nel TRD sono deviati e non entrano nell'ECAL:
in tal modo il "rejection power" del TRD e dell' ECAL sono indipendenti;
- "Matching" dell'impulso dai 9 piani del Tracker con le misure di energia dell' ECAL.

Multiple Measurements of Charge



La precisa identificazione delle particelle si ha combinando le risposte dei diversi sotto rivelatori (ridondanza ...utile anche per eventi rari)

→TeV	e^-	P	He, Li, Be, ... Fe	γ	e^+	\bar{P}, \bar{D}	\bar{He}, \bar{C}
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics Strangelets				Dark matter		Antimatter



**Ulteriori dettagli sui
rivelatori di
AMS-02**


**saranno/sono stati
forniti durante la
visita
(vedi appendice)**

Performance del rivelatore AMS-02 sulla ISS

**L'esperimento AMS-02 sta operando senza particolari problemi.
In circa 2750 giorni di attività ha raccolto più di 125 miliardi di particelle.**

**Ogni anno si raccolgono circa 16×10^9 eventi
che in 10-20 anni saranno $160-320 \times 10^9$.**

**Questa capacità AMS-02 fornisce una sensibilità
senza precedenti per la ricerca di nuova fisica.**

The background of the slide is a light blue color with a complex pattern of white lines and dots. These lines represent particle tracks, some straight and some spiraling, set against a field of small white dots that resemble a starry sky or a detector's internal structure. The overall aesthetic is scientific and technical.

**Risultati dell'esperimento AMS-02
e “physics expectations”
dal maggio 2011 a settembre 2016**

(Vedi appendice 13)

The background of the slide is a light blue color with a complex pattern of white lines and dots. These lines represent particle tracks, some straight and some spiraling, set against a field of small white dots that resemble a detector or a particle interaction region. The overall aesthetic is scientific and technical.

**Risultati dell'esperimento AMS-02
e "physics expectations"
aggiornati a Settembre 2017**

Produzione di CR

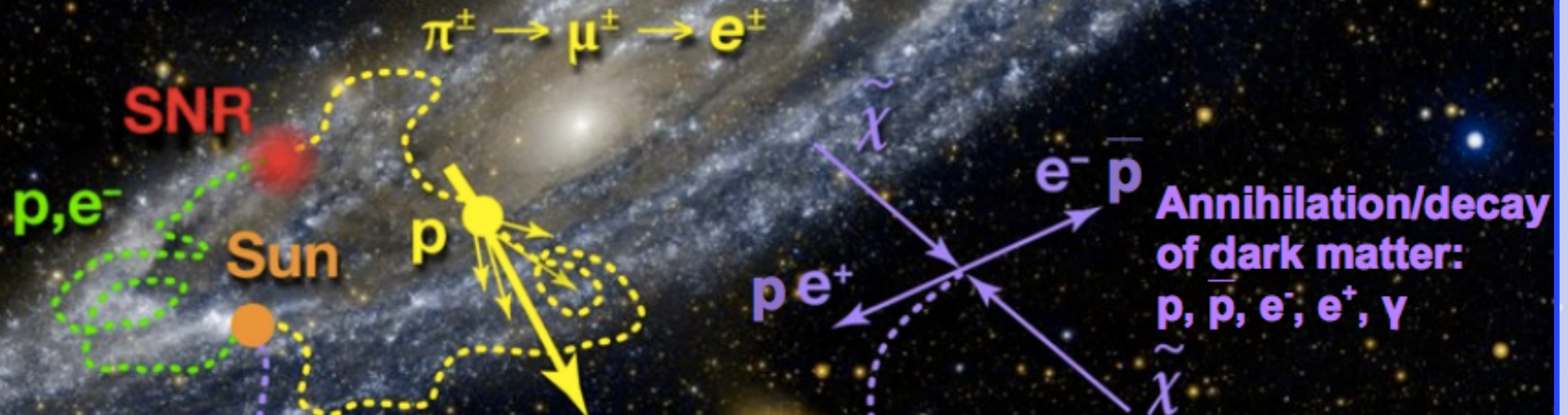
Acceleration of p, e⁻, nuclei in SNRs

Diffusion (scattering off magnetic turbulence)

Production of secondary particles

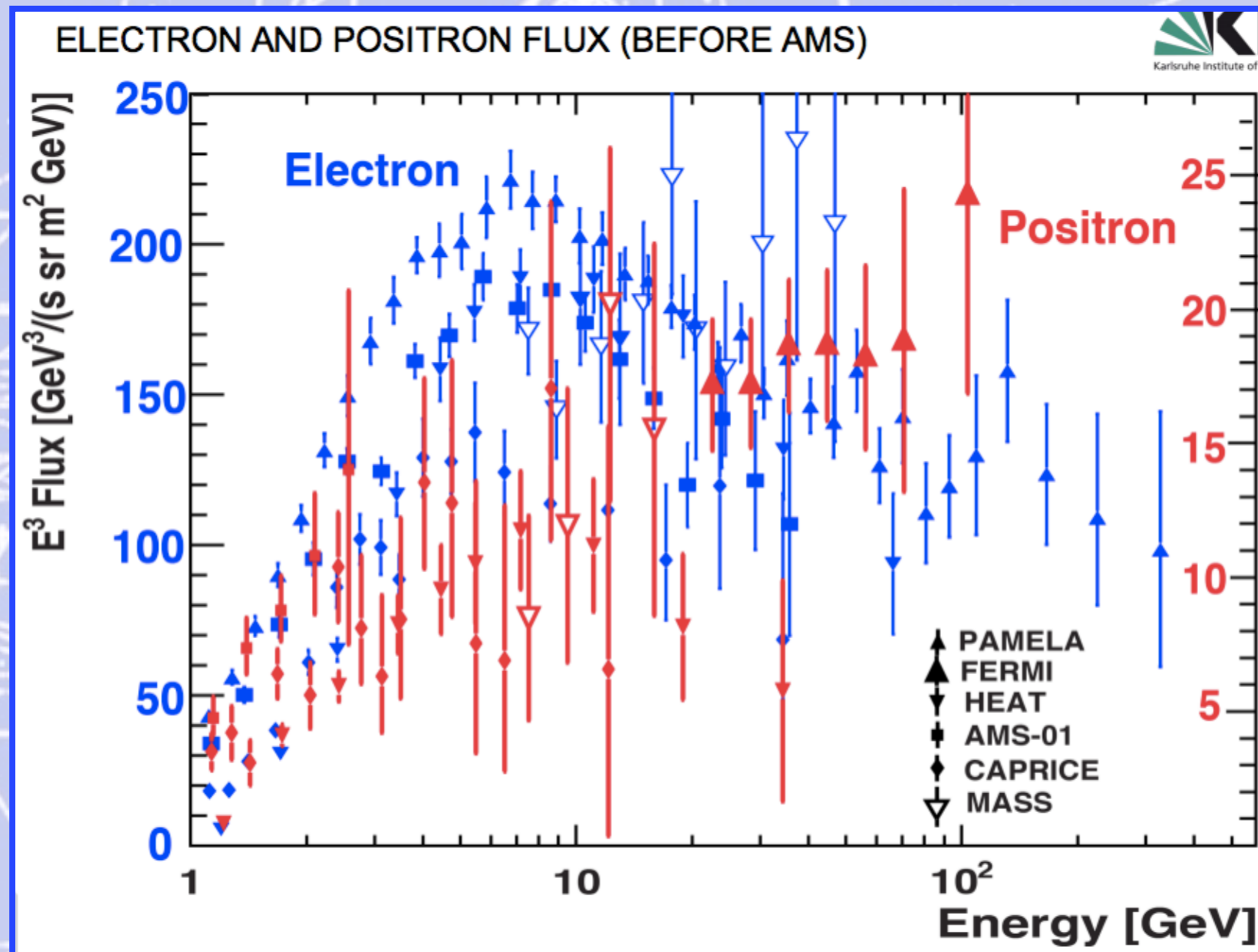
Energy losses + gains

Secondary particles:
positrons, electrons,
protons, **antiprotons**, nuclei
photons

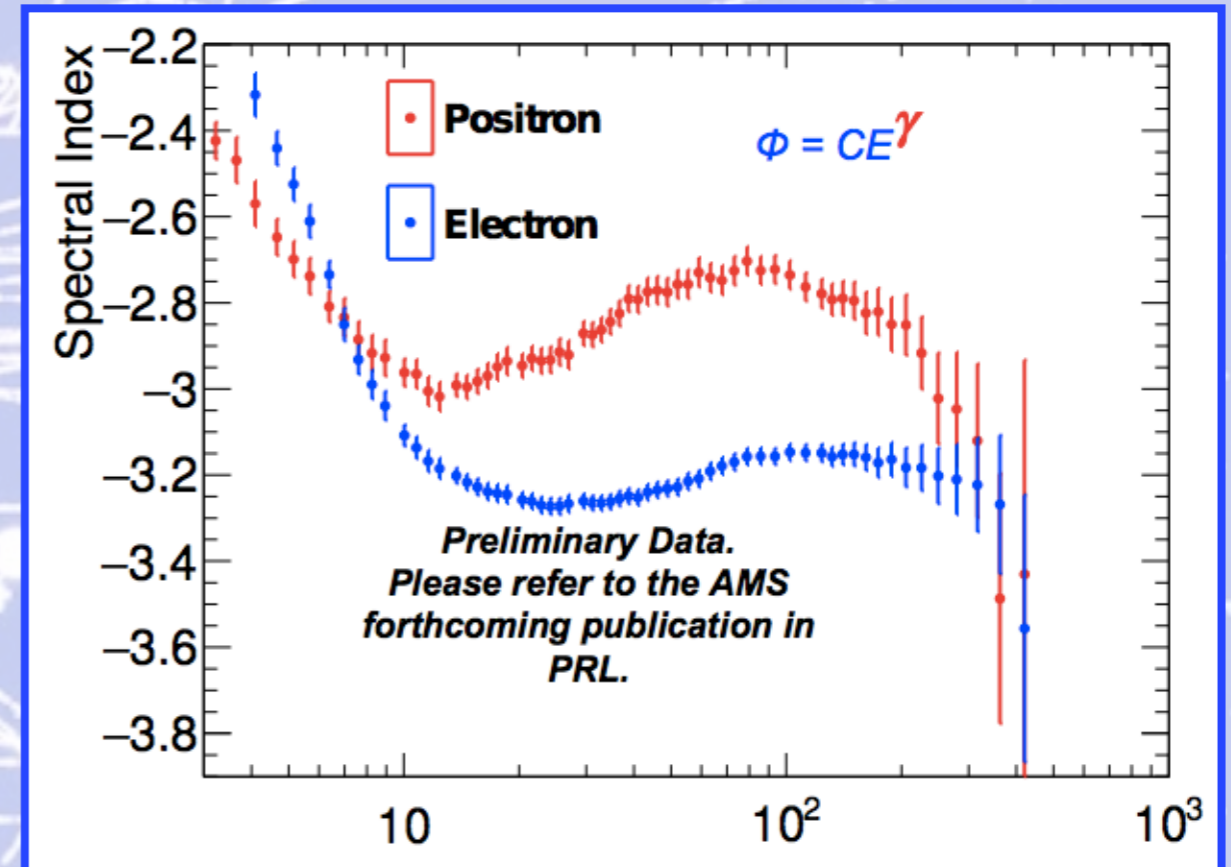
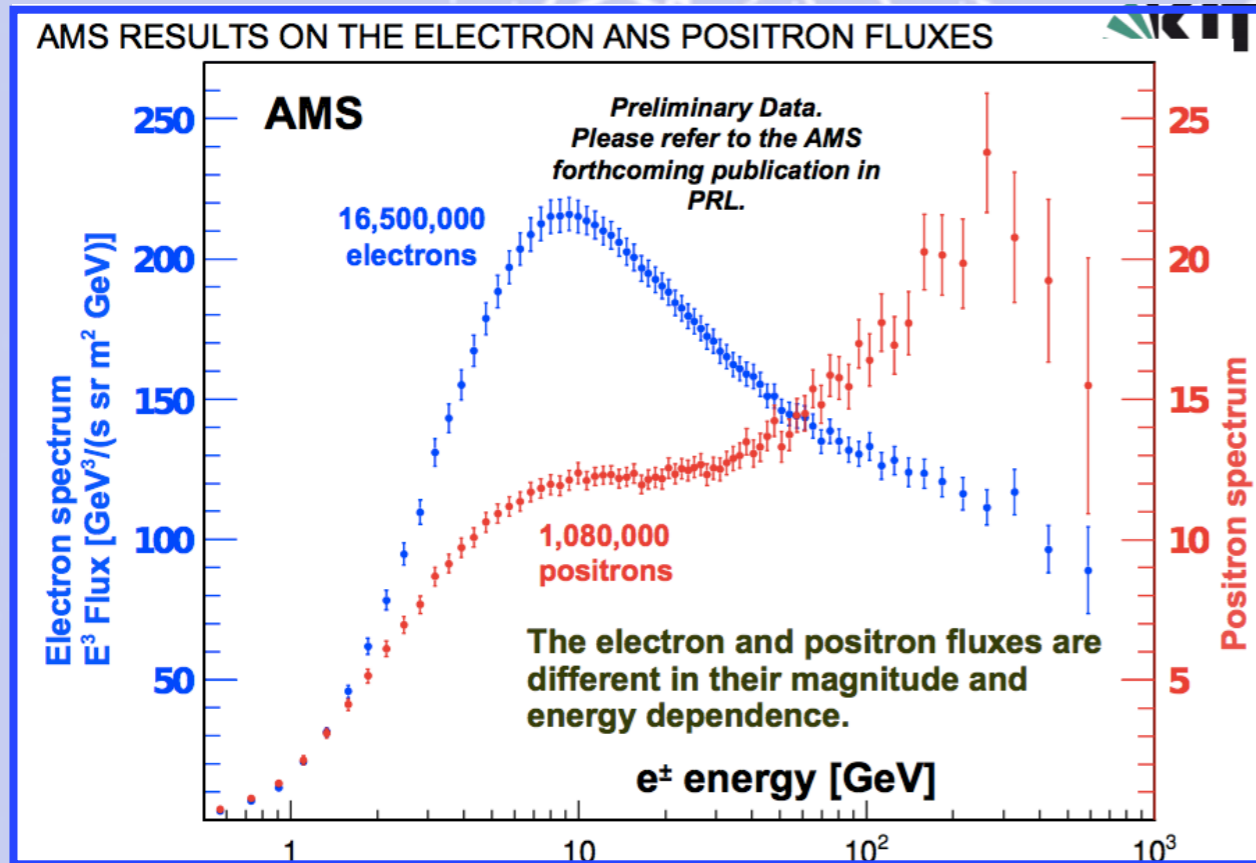


Such an excess of e⁺, \bar{p} from Dark Matter annihilation can be measured by magnetic spectrometers like AMS

Flusso di e^- ed e^+ prima di AMS



Flusso di e- ed e+ con AMS



$$\Phi_{e^\pm}(E) = \frac{E^2}{\hat{E}^2} \left[C_{e^\pm} \hat{E}^{\gamma_{e^\pm}} + C_S \hat{E}^{\gamma_S} \exp(-\hat{E}/E_S) \right]$$

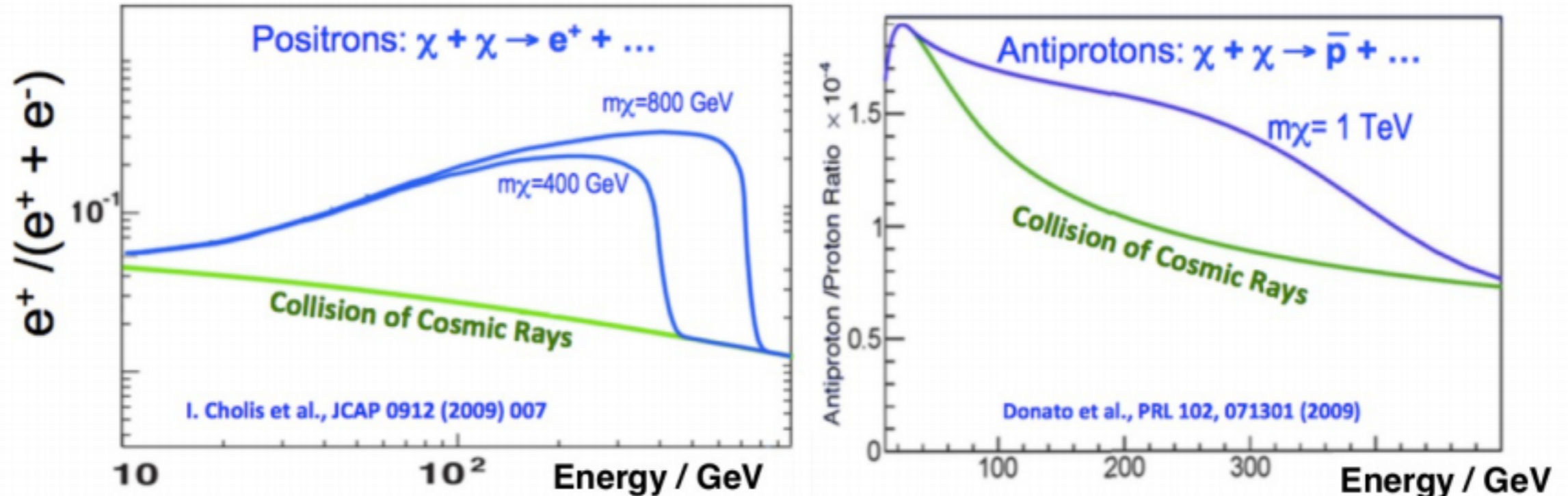
with $E_S = 530$ GeV from the $e^+/(e^+ + e^-)$ fit and $\hat{E} = E + \Psi$ as the energy scale of the LIS

The spectral index of the diffuse term has to become energy dependent:

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2} \left[C_e \hat{E}^{\gamma_e(\hat{E})} + C_S \hat{E}^{\gamma_S} \exp(-\hat{E}/E_S) \right]$$

The source term parameters are constrained from the positron flux fit.

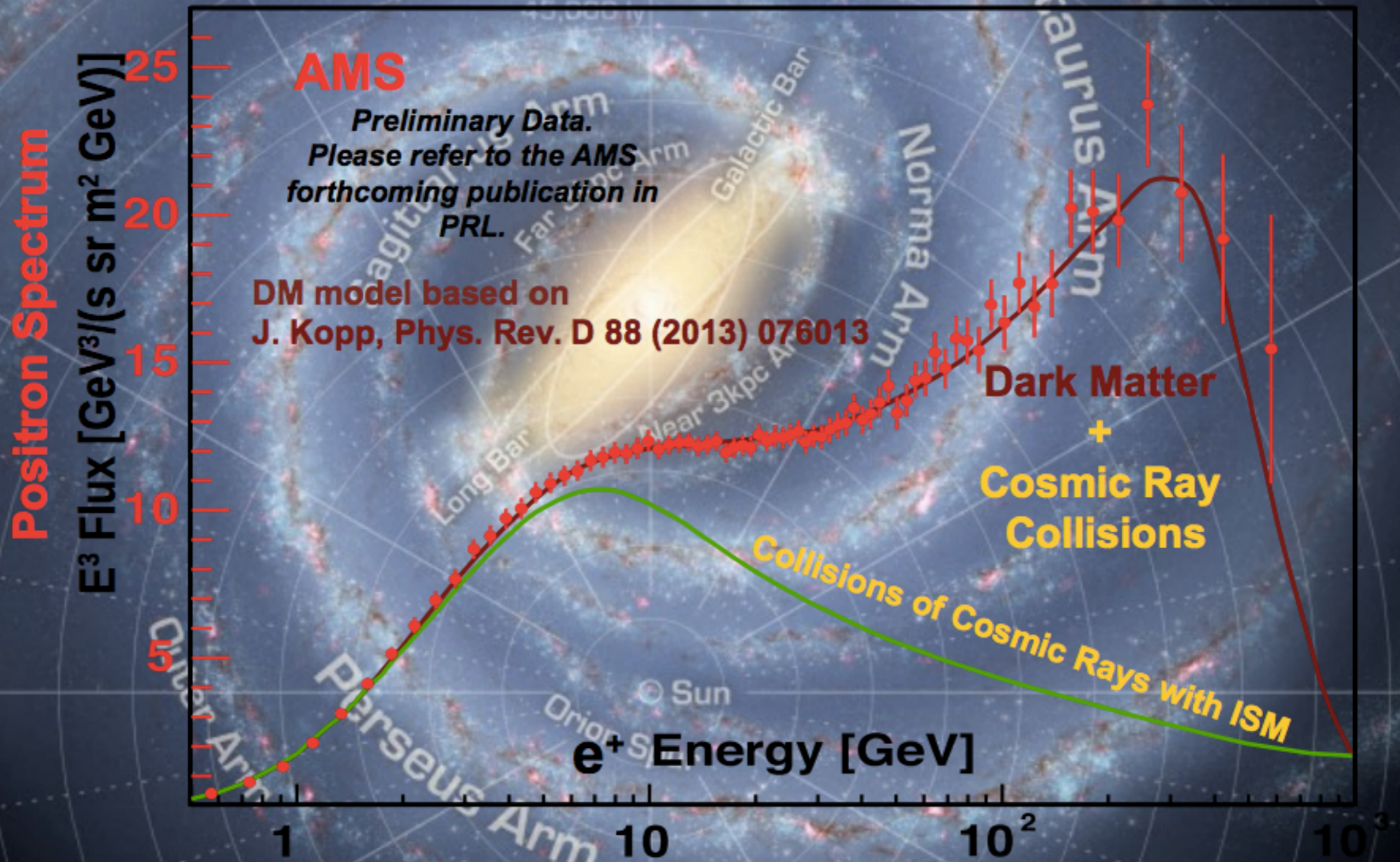
Ricerca di Materia oscura



e^+/\bar{p} are sensitive probes for dark matter....

...BUT: "collision of cosmic rays" needs to be understood.

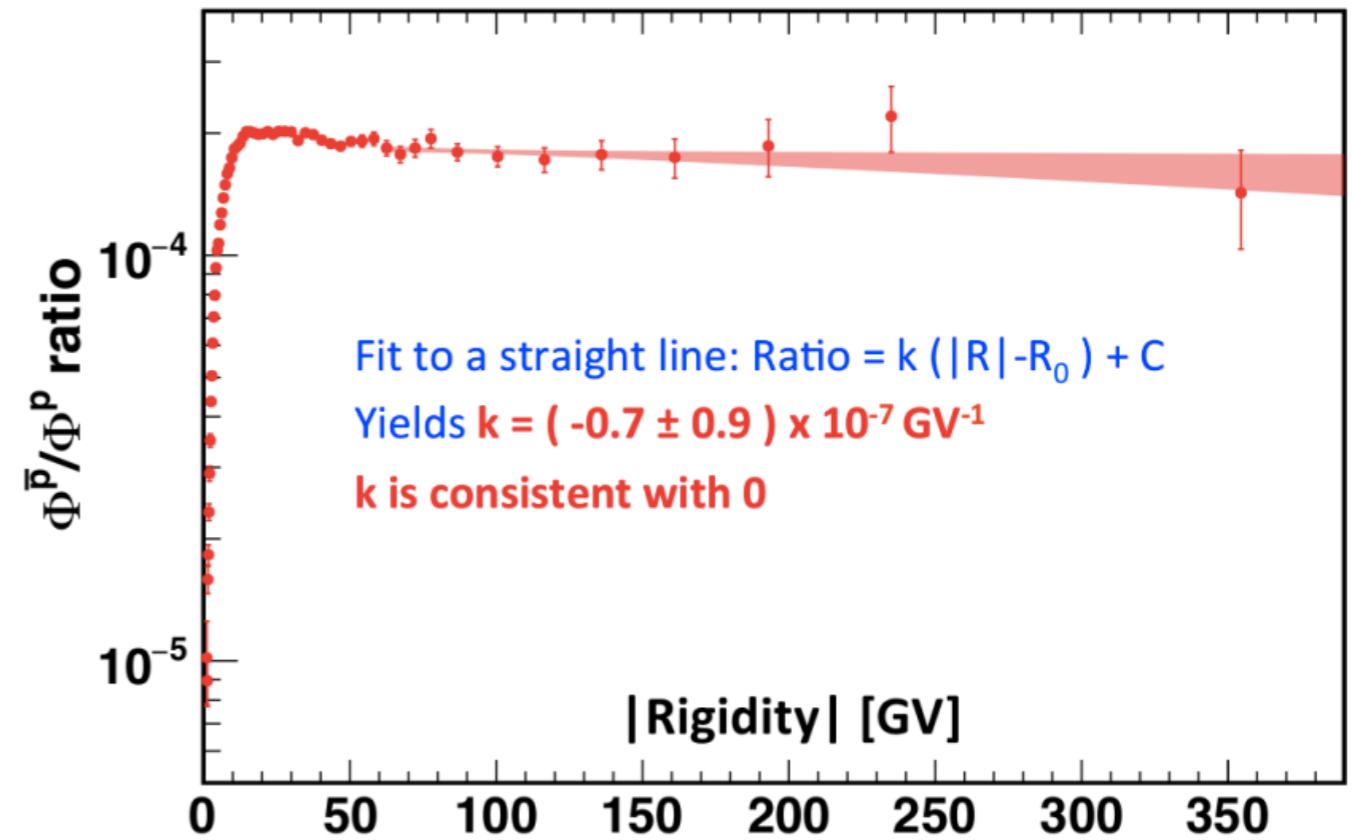
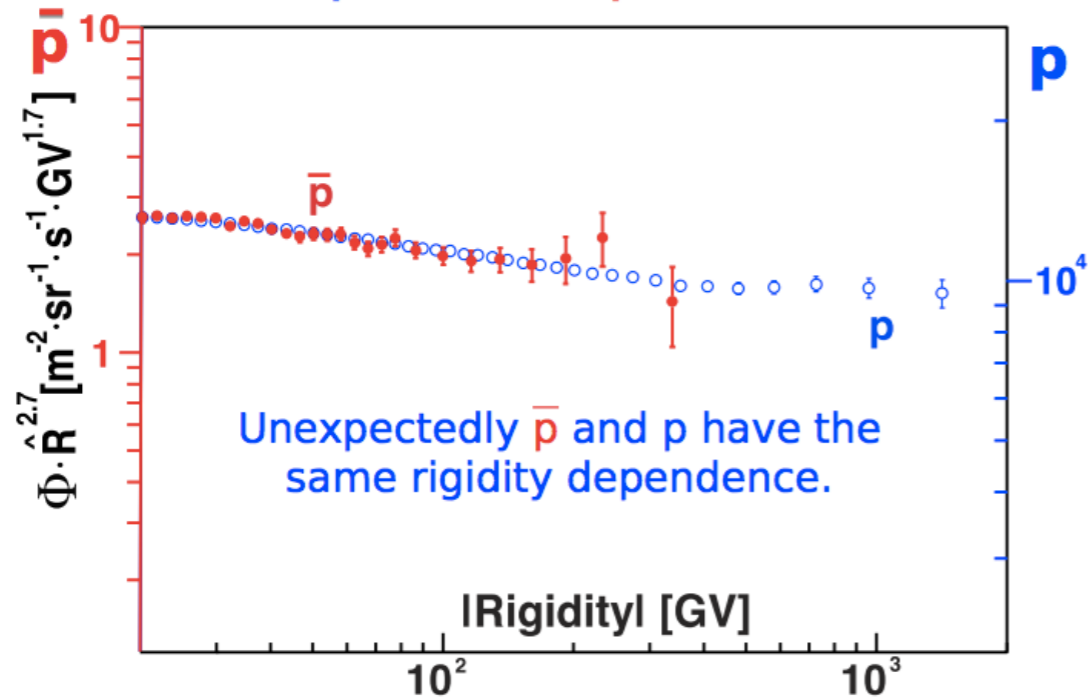
The AMS results are in excellent agreement with a Dark Matter Model



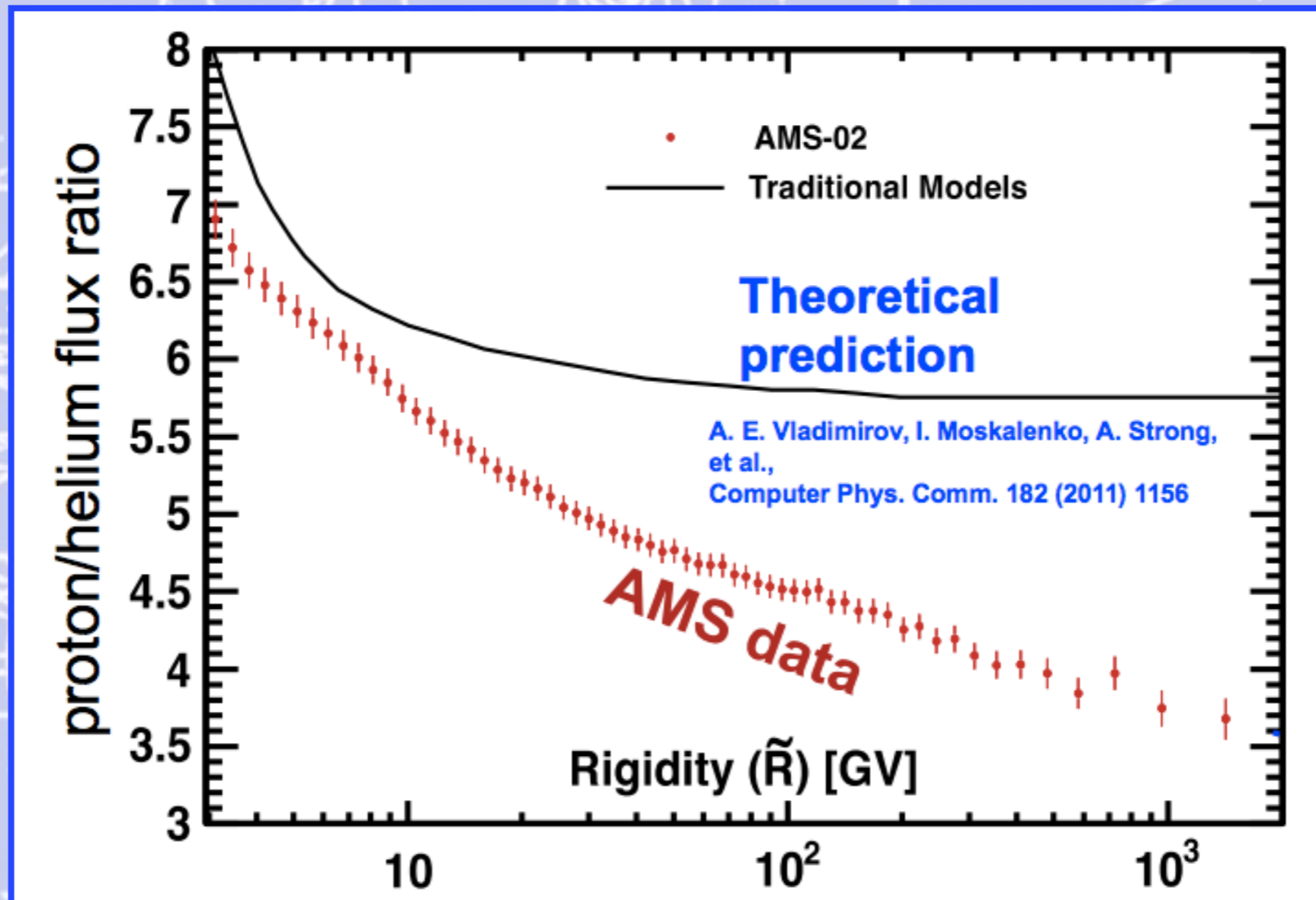
Flusso antiprotone/protone

If \bar{p} are secondaries, their rigidity dependence should be different from p :

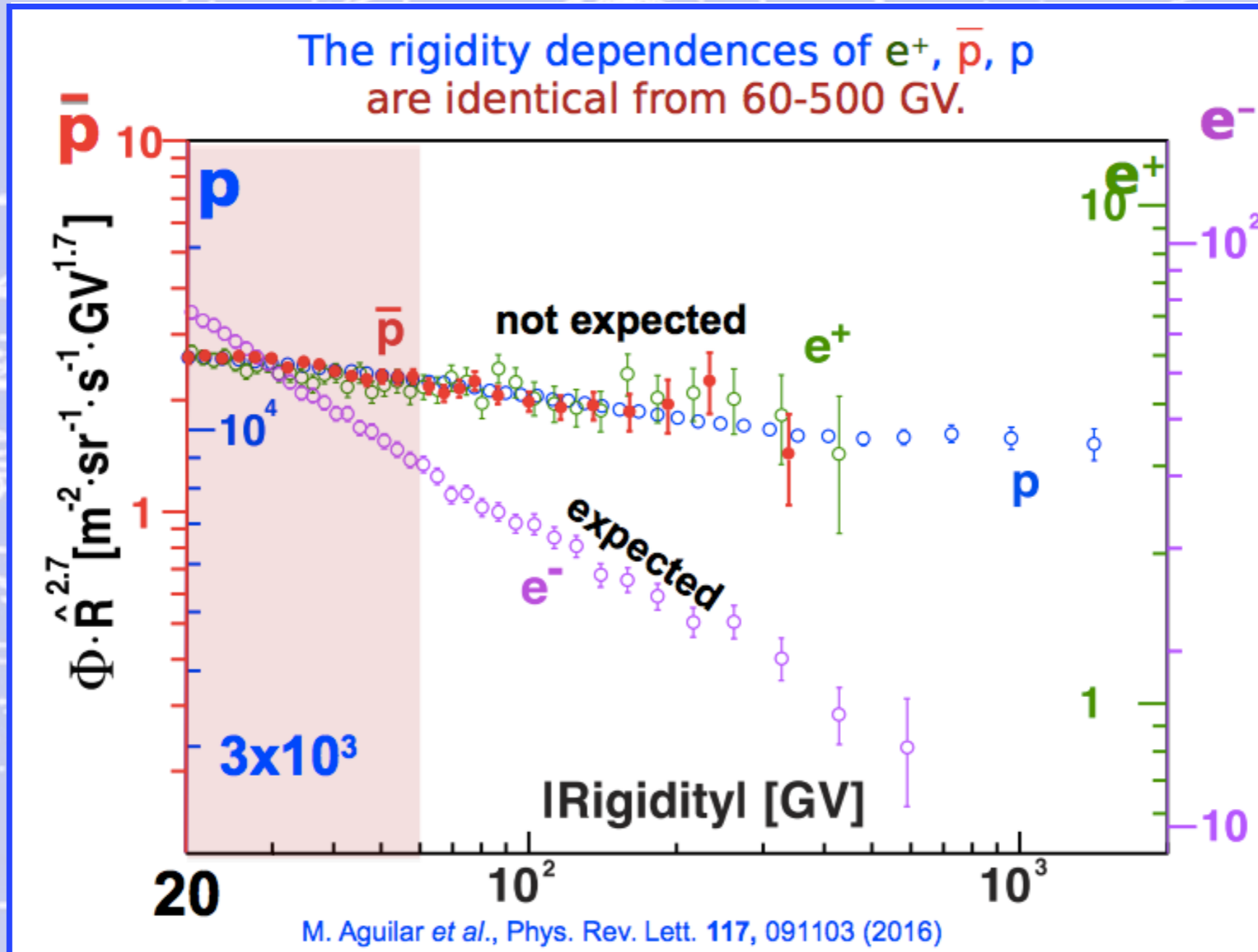
$$p + \text{ISM} = \bar{p} + \dots$$



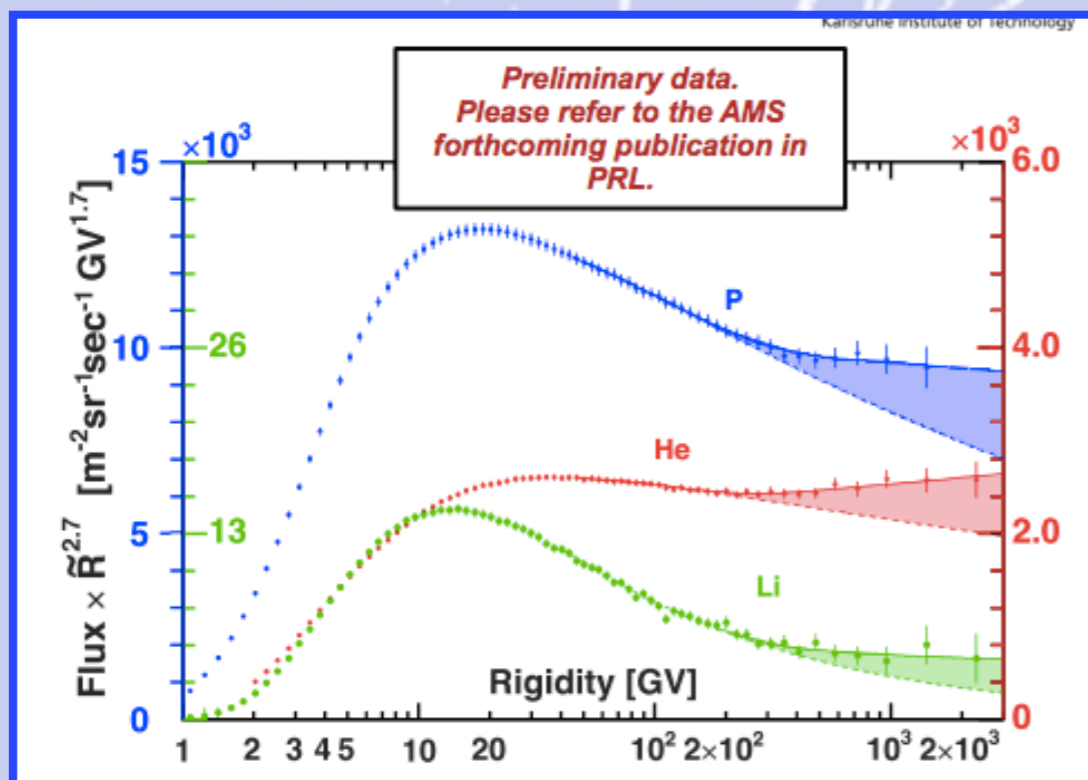
Flusso protone/elio



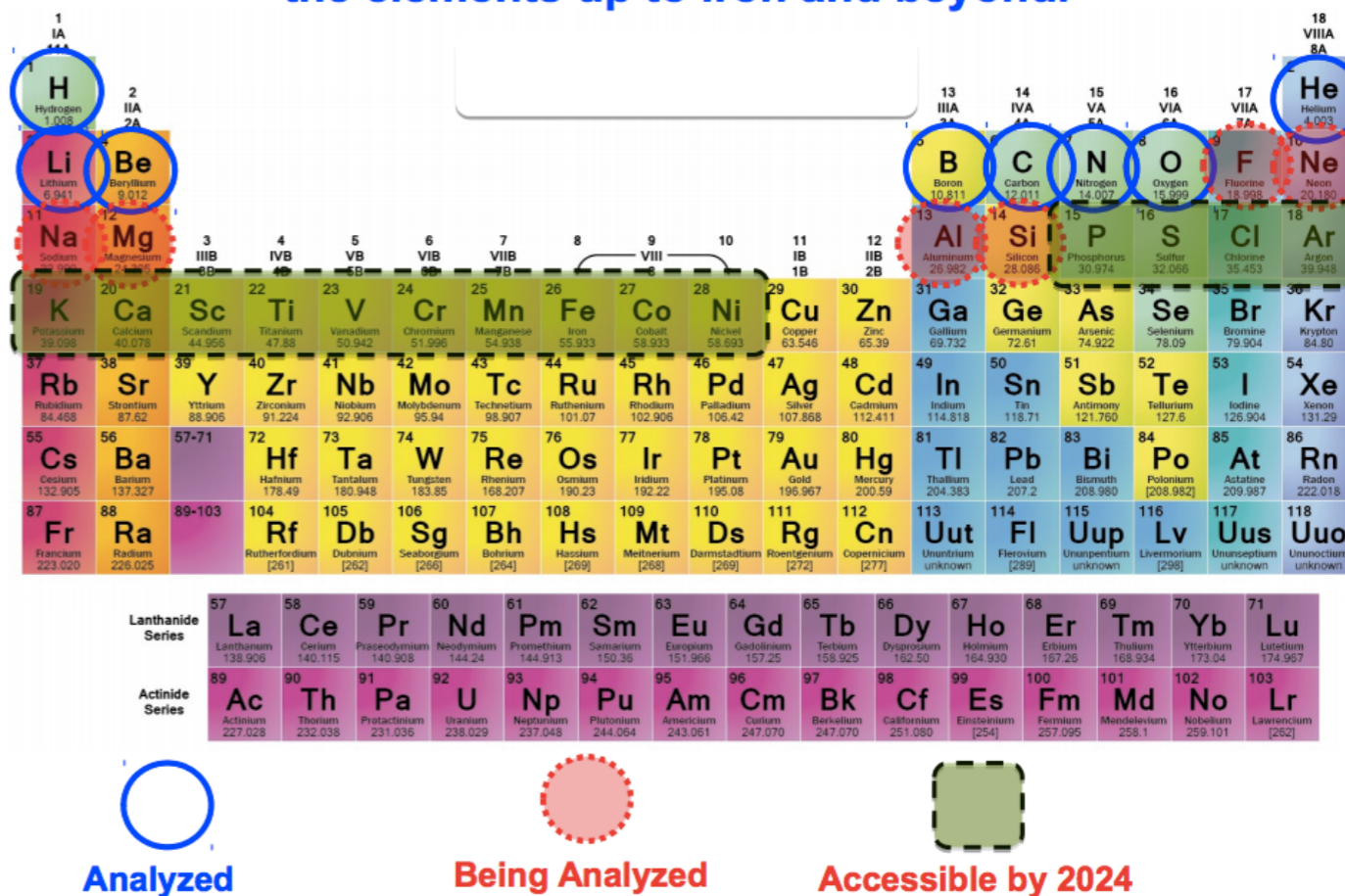
Quindi in generale.....



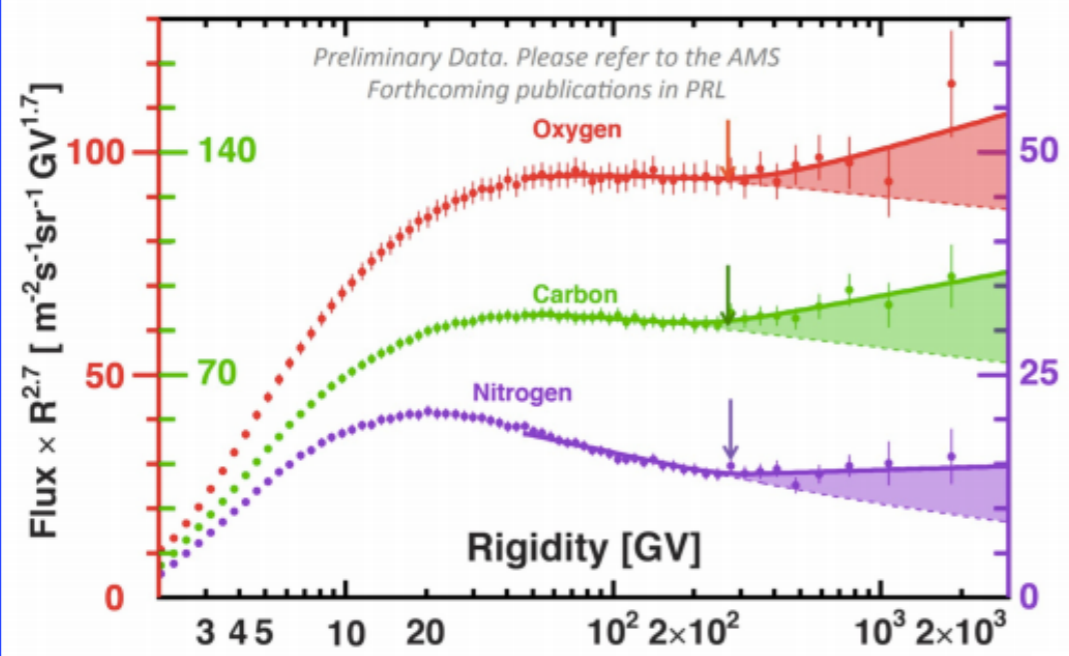
Inoltre il flusso di H, He, Li, O, C, N



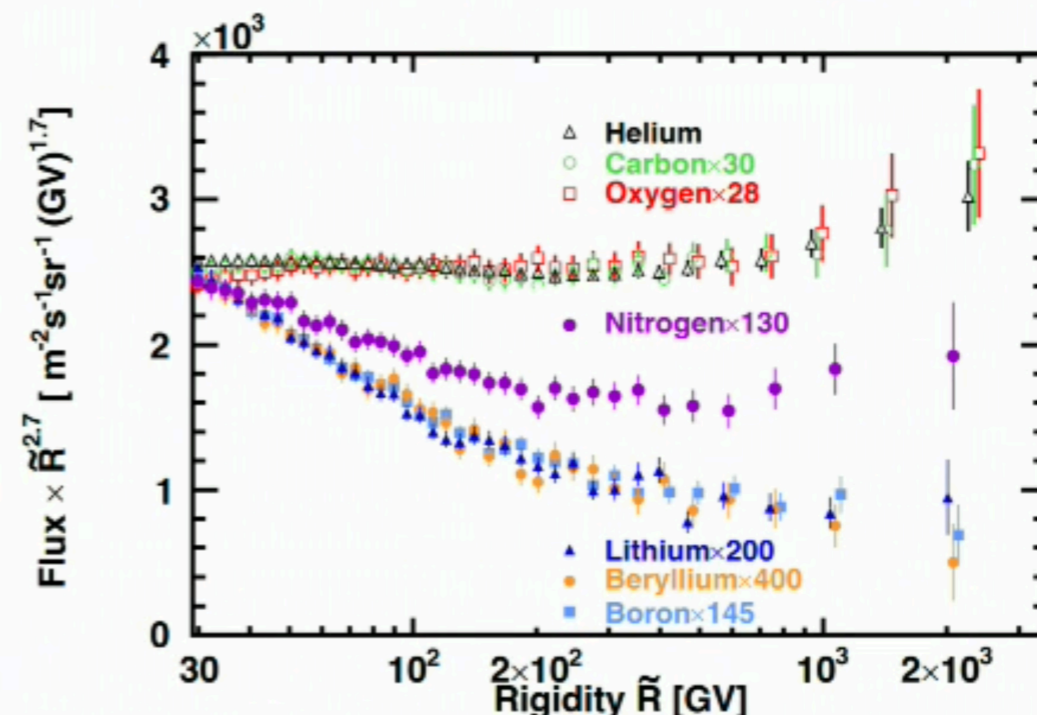
With increasing statistics through 2024, we will measure the elements up to iron and beyond.



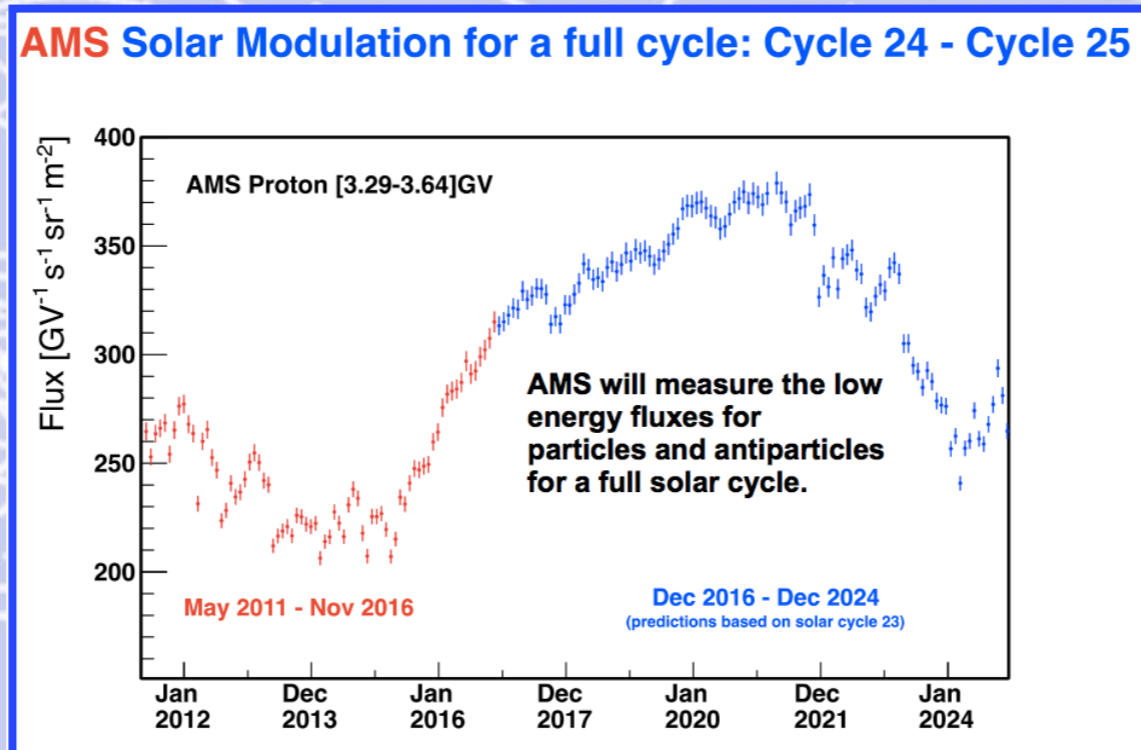
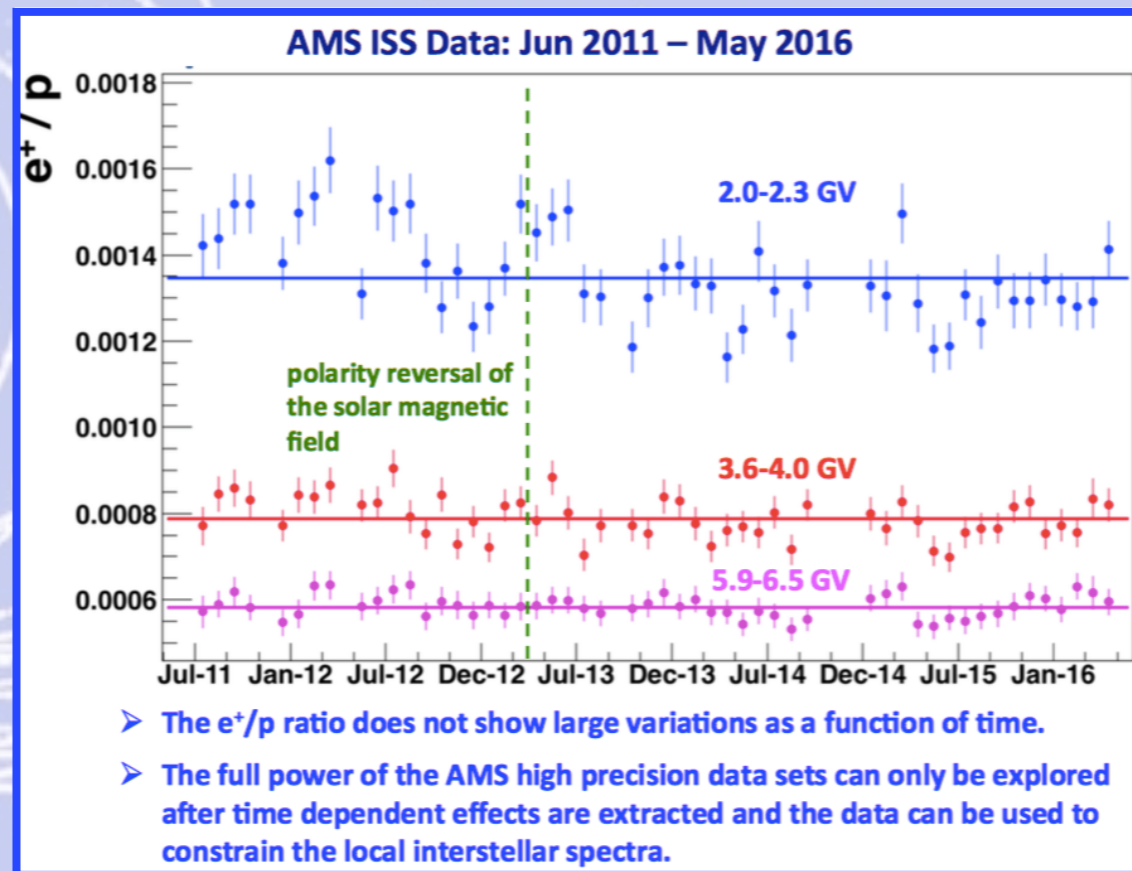
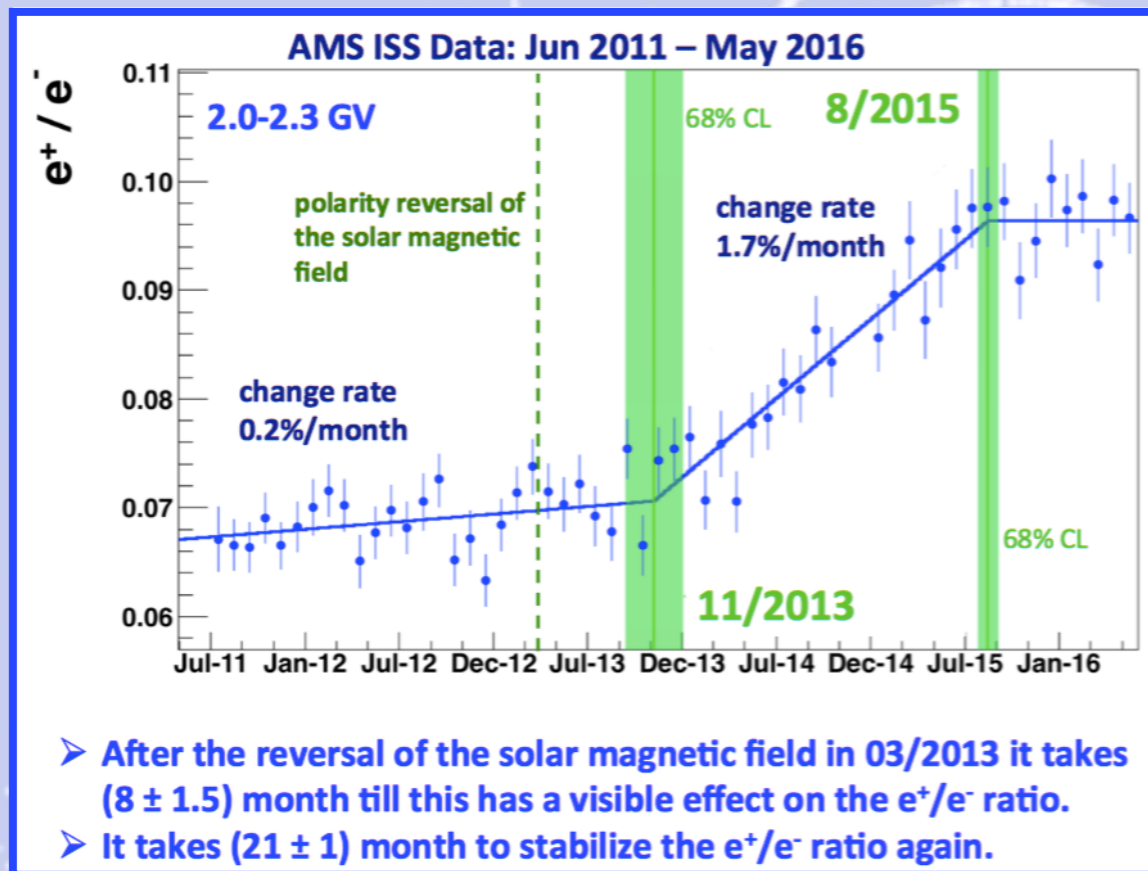
The spectra of oxygen, carbon and nitrogen do not follow the traditional single power law.



The AMS measurements of the primary cosmic ray fluxes and the secondary cosmic rays fluxes with the nitrogen flux.



Ciclo solare: inversione del campo magnetico solare +...

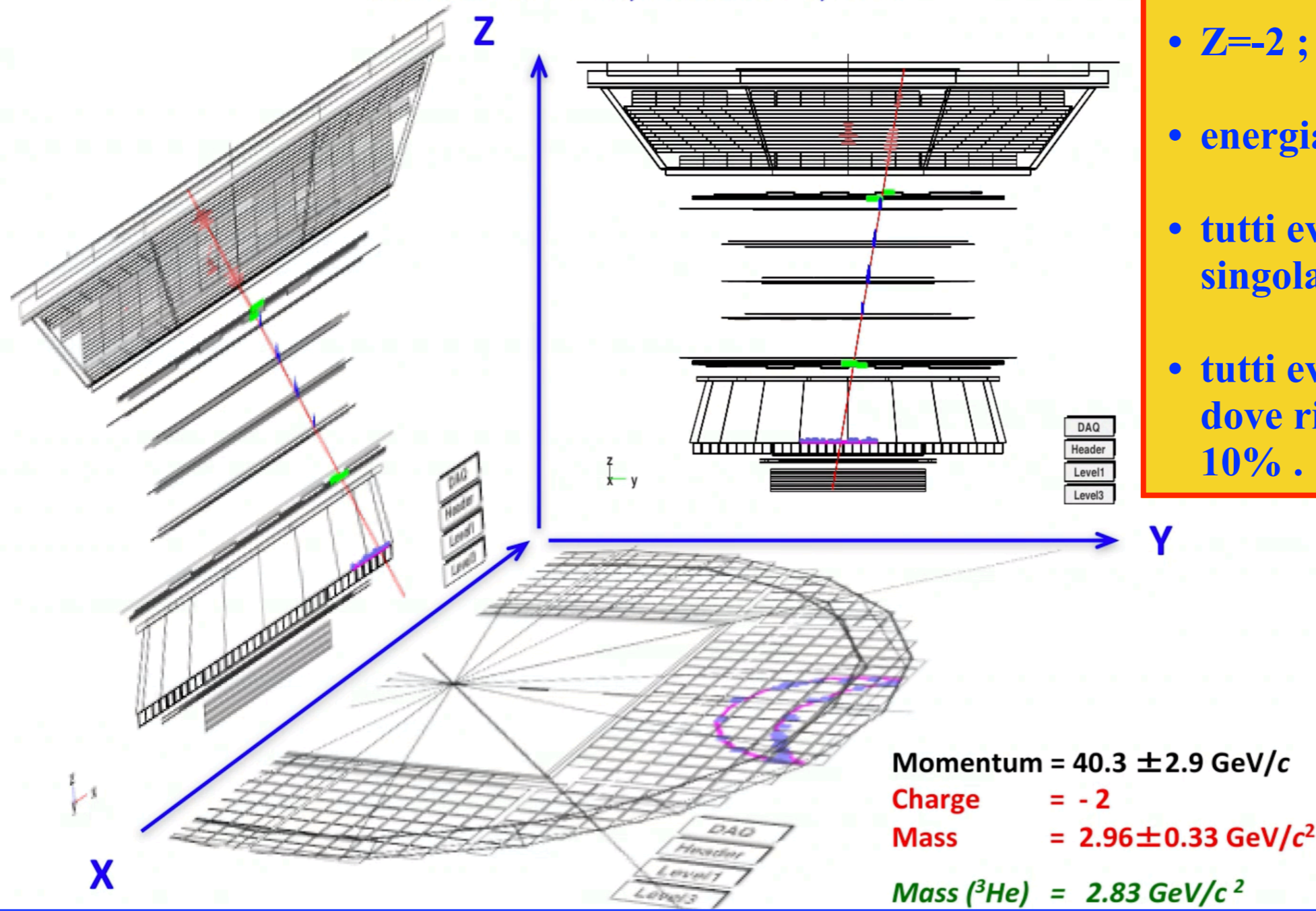


AMS ed il monitoraggio continuo intorno alla Terra

.....segnali di antimateria cosmica?

An anti-Helium candidate:

Presented at CERN, December 8, 2016



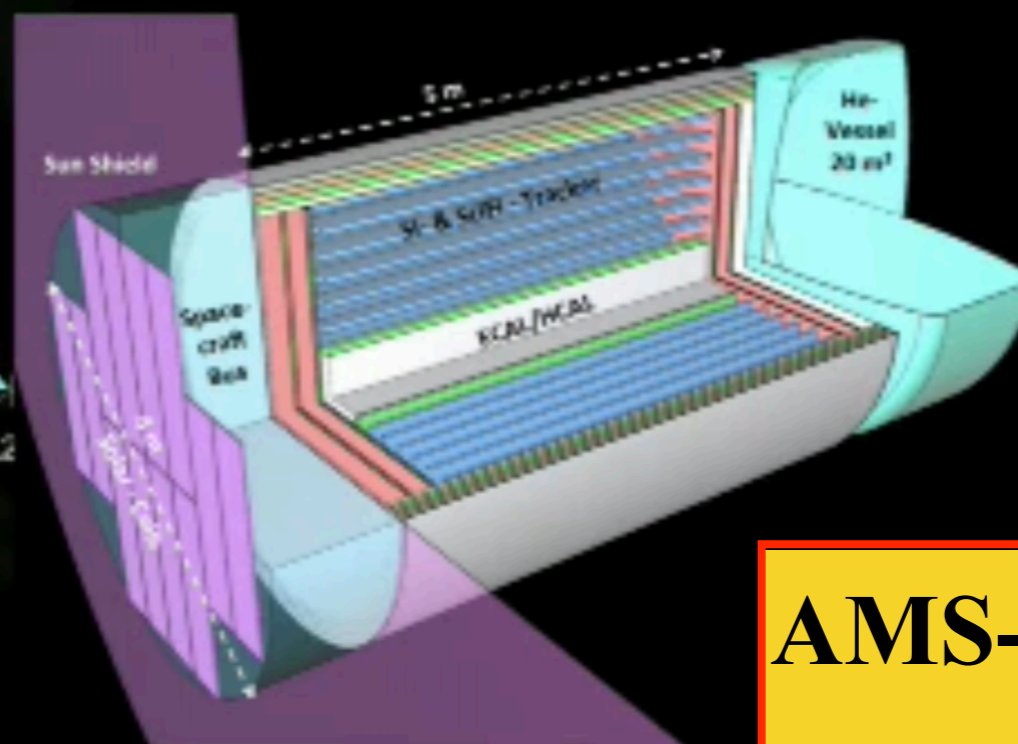
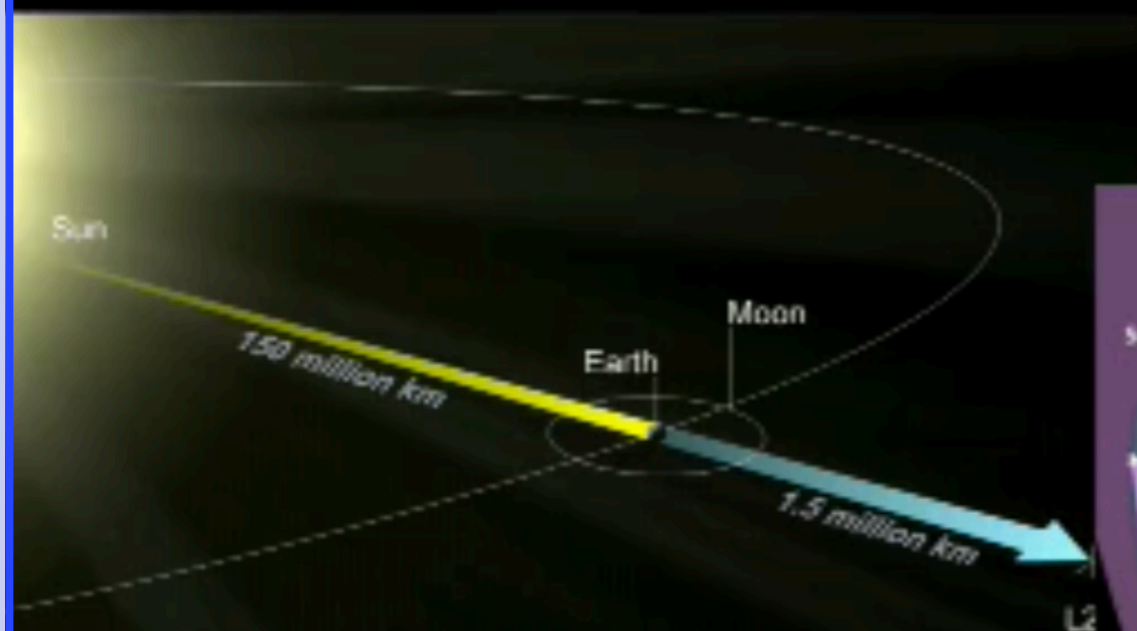
8 eventi osservati (2011-2018)

- $Z=-2$;
- energia tra 0 e 10 GeV;
- tutti eventi a traccia singola, no hits;
- tutti eventi $p < 100$ GeV/c dove risoluzione migliore 10% .

..... un nuovo AMS.....

AMS-100: Next Generation Cosmic Ray Experiment

Due to earth magnetic field a cryogenic solenoid magnet can only be operated at L2.



Thin coil Solenoid (like ATLAS), field 1 T
Silicon and Scintillating Fiber tracker (like LHCb)
Calorimeter – $86 X_0$, 3λ

Acceptance $100\text{m}^2 \text{sr}$
MDR 100 TV, near the "knee"

AMS-100

- lancio per il 2030 ;
- 40 t (nuovi razzi NASA);
- magnete superconduttore;

L'Universo è il vero laboratorio !

I raggi cosmici sono accelerati ad energie enormemente maggiori di quelle raggiungibili da un qualsiasi dispositivo umano.

L'obiettivo principale di AMS è di investigare l'ignoto, ricercare fenomeni naturali che non abbiamo ancora immaginato o per i quali non abbiamo ancora sviluppato i mezzi per riprodurli e capirli.

Link utili:

Generalita':

<http://math.ucr.edu/home/baez/physics/>
<http://home.web.cern.ch/topics>
<https://cds.cern.ch/collection/Videos> (*cercare poi l'argomento specifico in "search"*)
<http://www.windows2universe.org/>
<http://www.cernland.net/>

Astroparticelle:

<http://www.astroparticelle.it/>
<http://www.aspera-eu.org/>

Raggi Cosmici:

<http://scienzagiovane.unibo.it/100RC.html>
<http://scienzagiovane.unibo.it/100RC/2/AlbumFoto-IIIF.html>
<http://scienzagiovane.unibo.it/100RC/3/AlbumFoto-IIIIF.html>
<http://www.palazzosomeda.it/Osservatorio/Raggicosmicieattivitsolare.htm>

Materia Oscura:

http://www.ge.infn.it/~pesce/research/dm_tesina.pdf
<http://ned.ipac.caltech.edu/level5/Bosma2/frames.html>

Antimateria:

http://www.nationalgeographic.it/scienza/spazio/2012/02/16/news/nell_antimateria_il_segreto_dell_energia_oscura_-855266/
http://planet.racine.ra.it/testi/mat_osc.htm
http://scienzapertutti.Inf.infn.it/index.php?option=com_content&view=article&id=7:materia-e-antimateria&catid=5&Itemid=79
<http://home.web.cern.ch/topics/antimatter/matter-antimatter-asymmetry-problem>

AMS e NASA:

<http://www.ams02.org/> (*in "Multimedia" ci sono filmati interessanti*)
<http://ams.nasa.gov/>
<http://www.ustream.tv/NASAHDV> (*in "Videos" sono disponibili diversi filmati*)

Lavori didattici:

http://try.iprase.tn.it/old/in05net/upload/doc/libri/U1011t3n729_Raggi_cosmici.pdf
http://www.liceogioberti.it/didattica/prog_EEE_articoloCeresole.pdf
http://eee.centrofermi.it/component/k2/item/download/1_80cbadb159b503626a30e04b169f2372
http://appunti.studentville.it/appunti/tesine-6/tesina_antimateria_realta_o_fantasia-3391.htm (*scaricare il file*)

**Questa, perciò, non è la fine della storia!
Siamo solo all'inizio dei
“*Tempi Moderni*”**

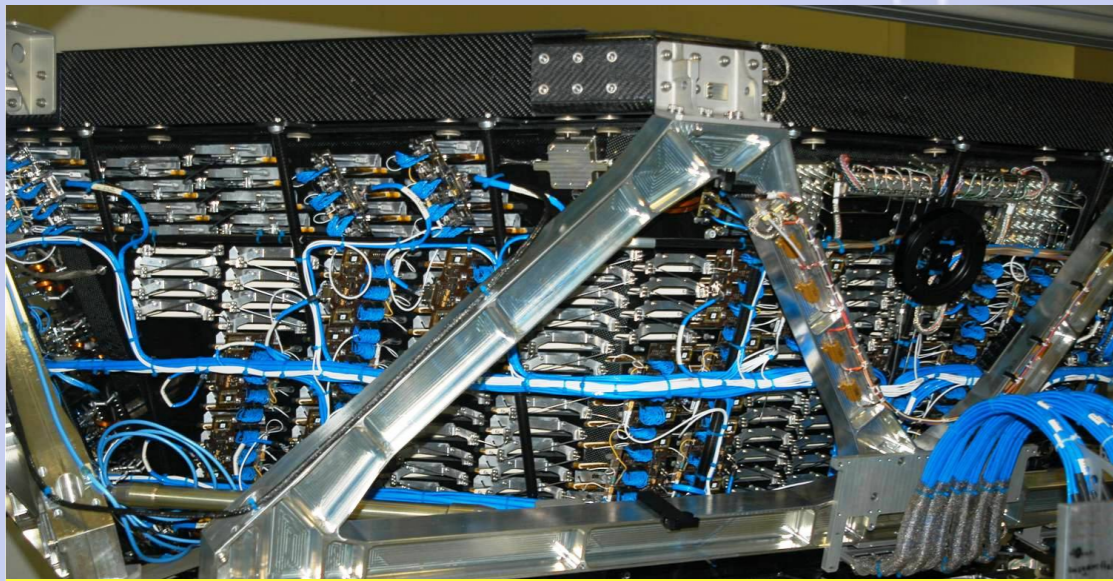
Grazie!

Ringraziamenti;
I. Gebauer, A. Kounine,
II. V. Kudryavtsev,
D. Rapin, P. Salati,
S. Schael, G. Servant

Appendice 1

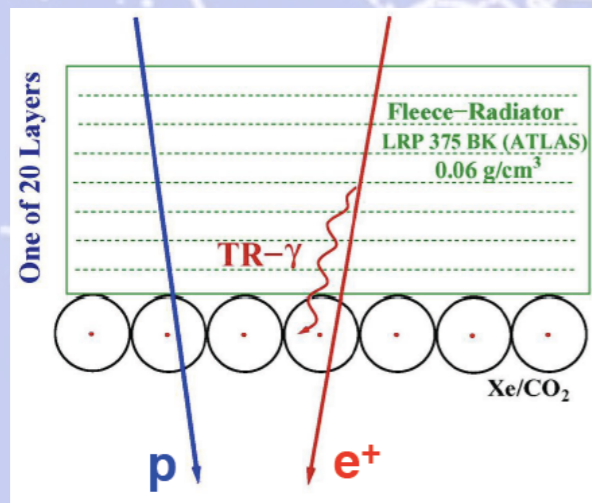
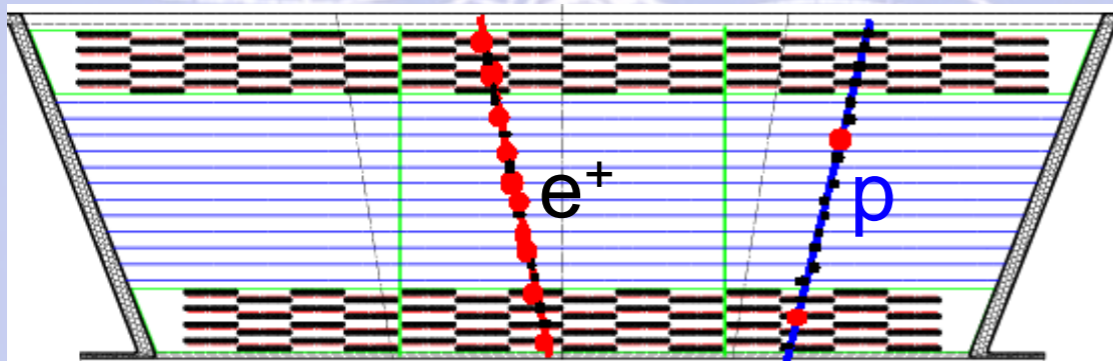
(I rivelatori di AMS-02)

Transition Radiation Detector (TRD)

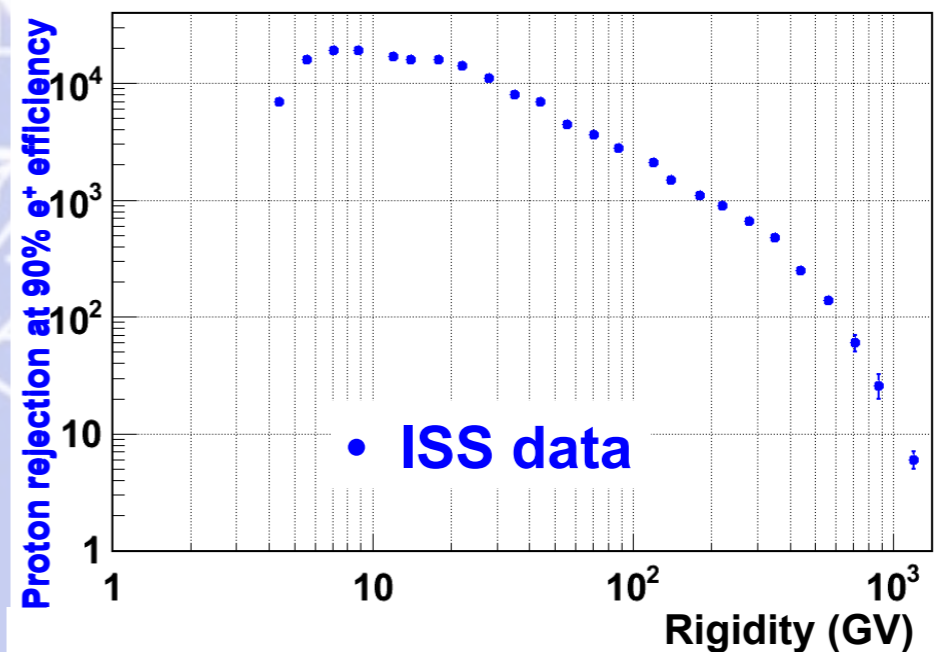
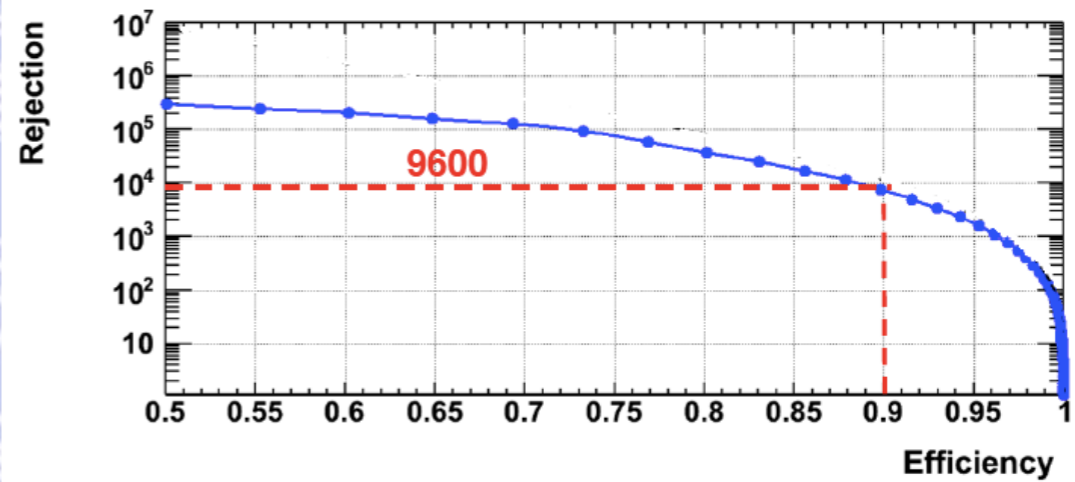
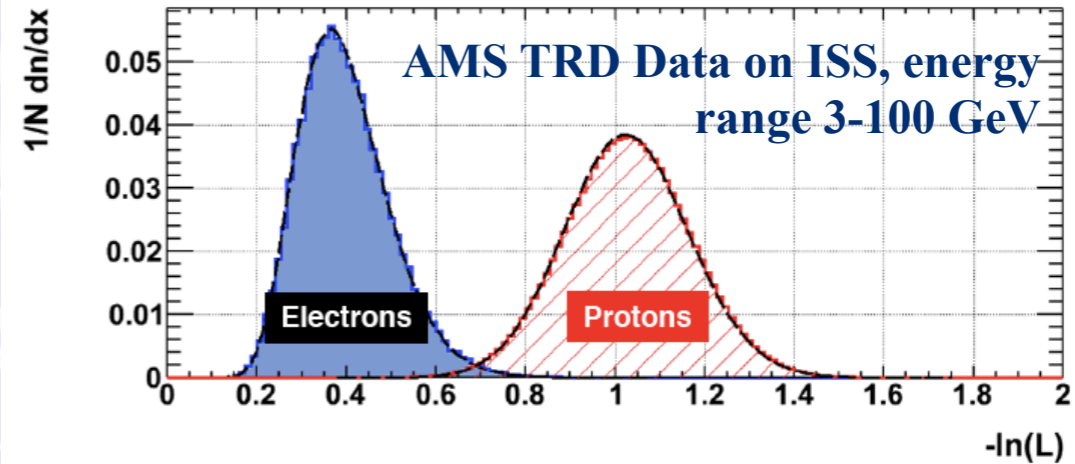


20 layers assembled in octagonal structure;
328 modules of fleece and straw tubes;
Gas mixture: 80% Xe – 20% CO₂;

Leakrate of 5 μg/s, caused by CO₂ diffusion,
corresponds to a lifetime ~20 years in Space

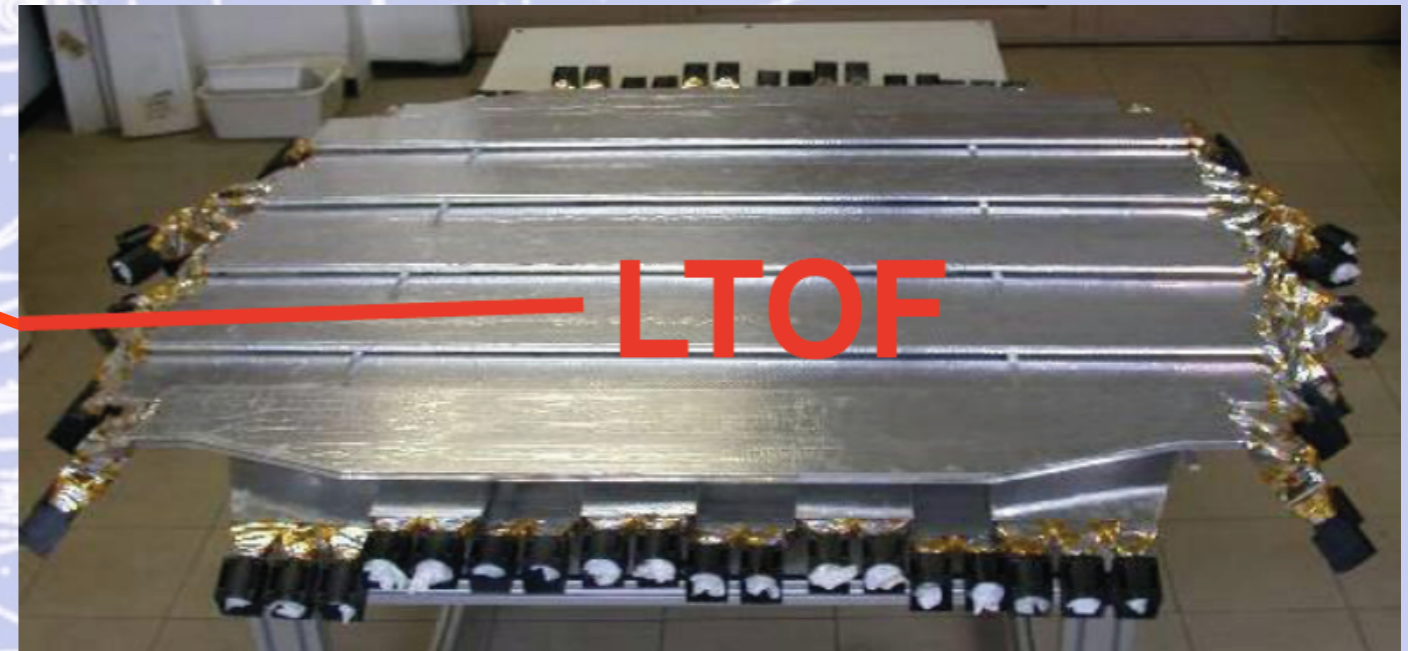
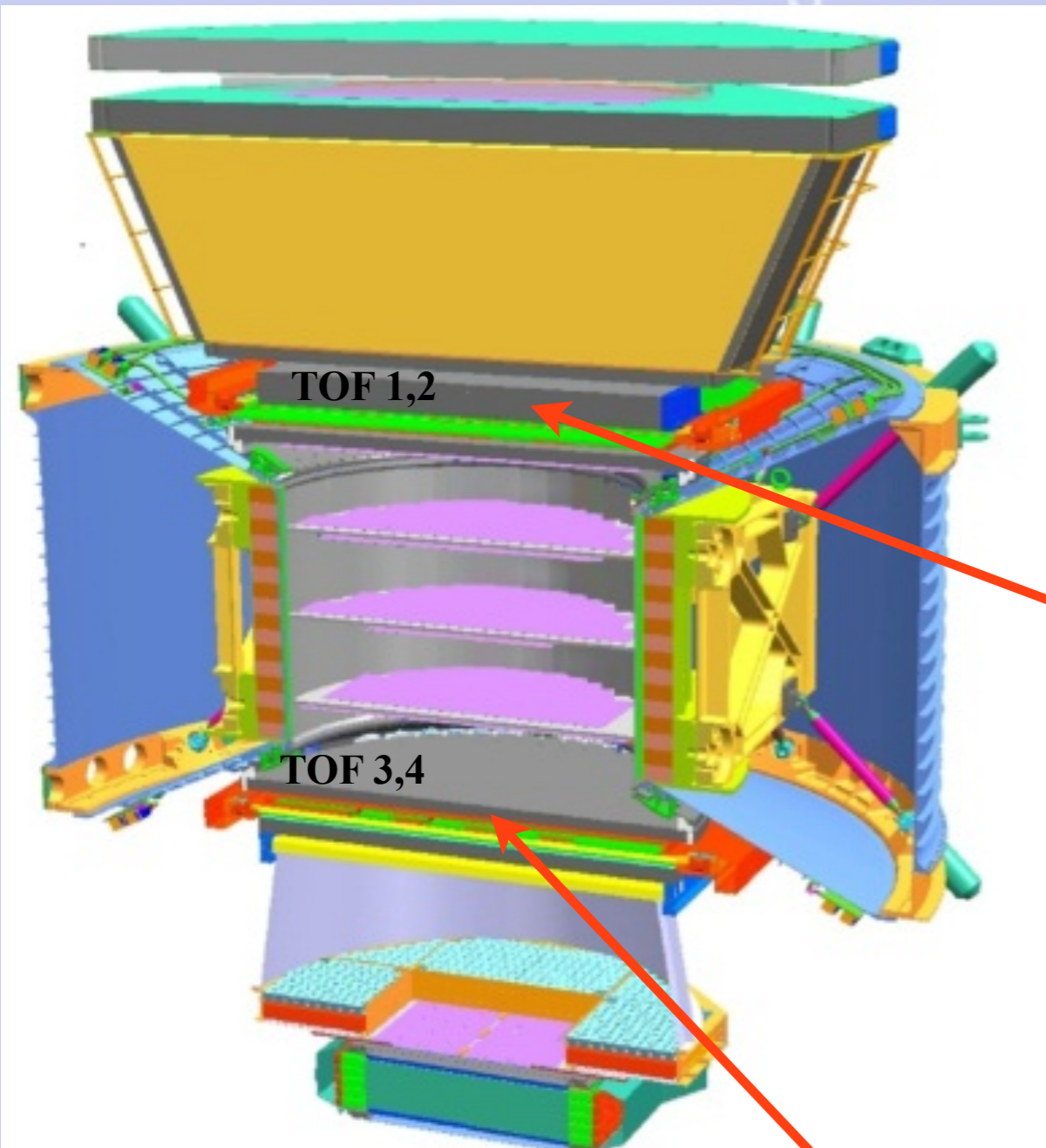


identifies e^\pm by transition radiation
and Nuclei by dE/dX



Time of Flight (TOF)

Measures Velocity and Charge of particles



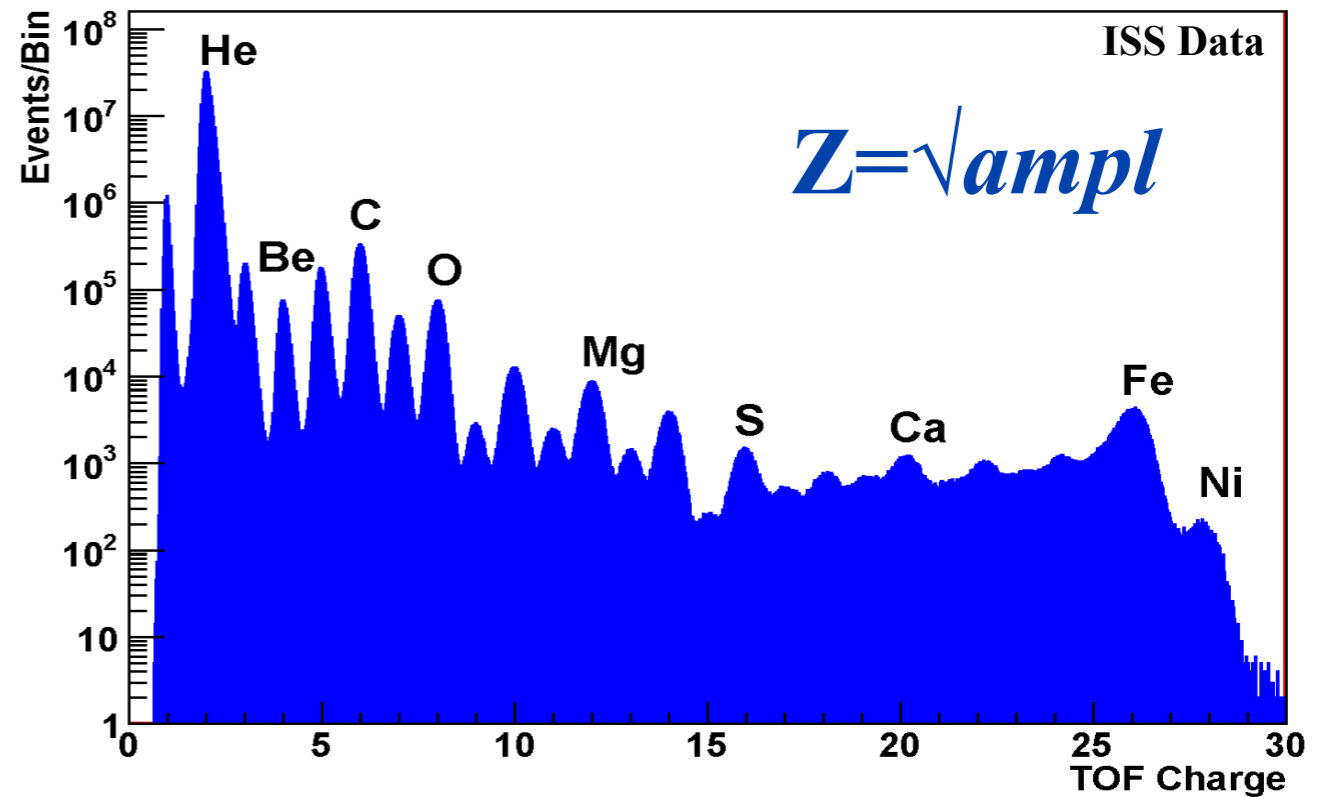
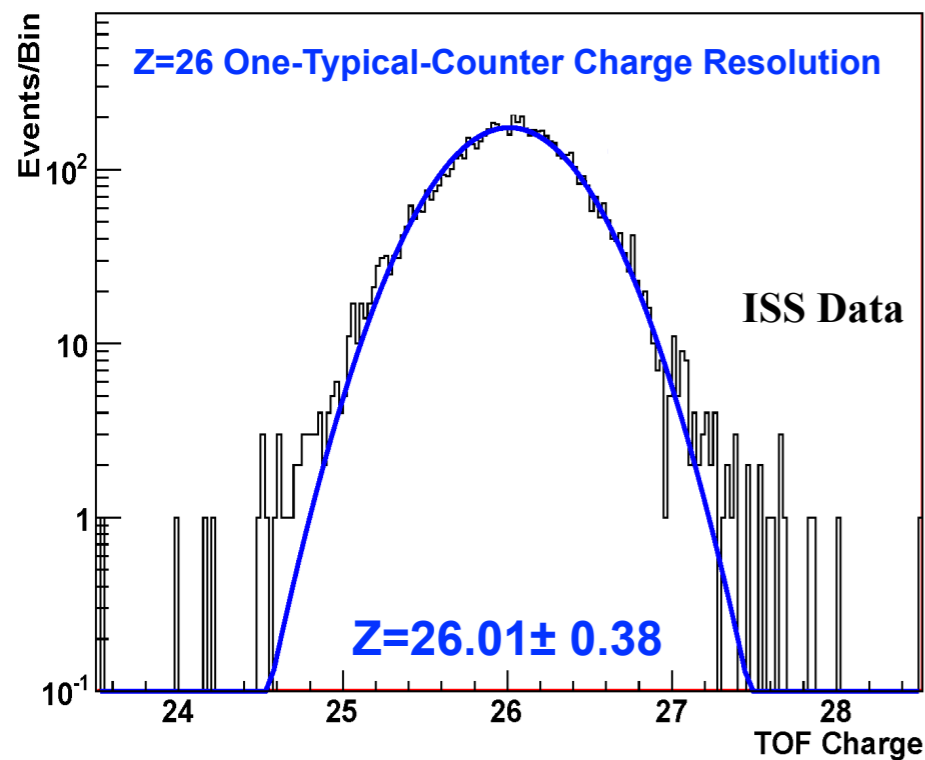
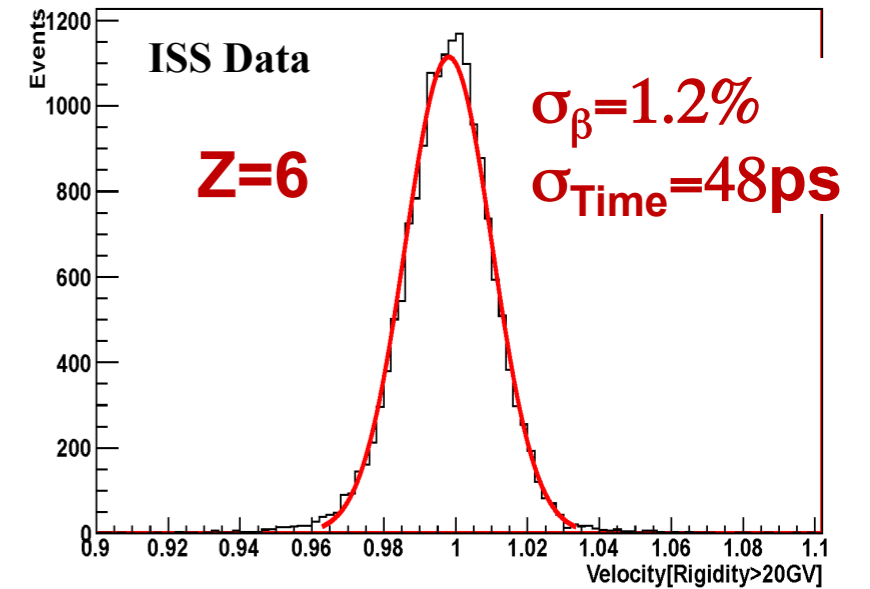
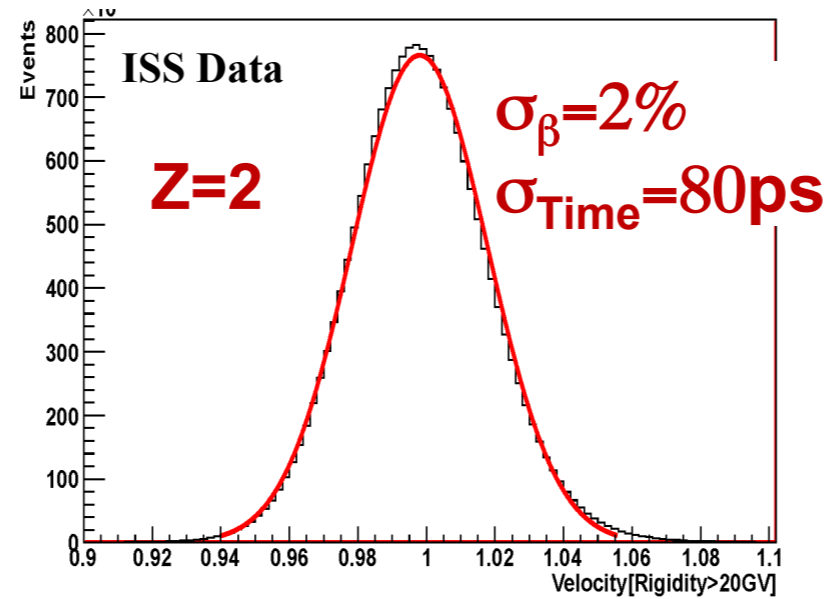
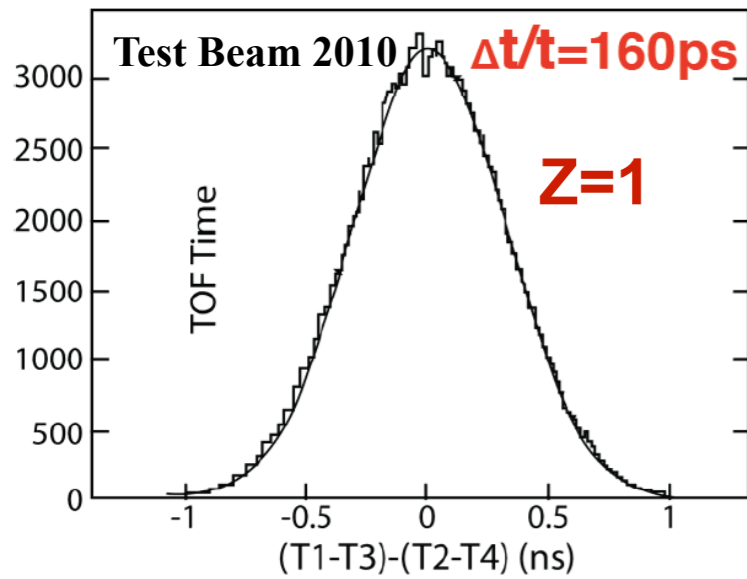
2x2 planes + total of 34 scintillator paddles
(seen by 2 (or 3) PMTs on each side);



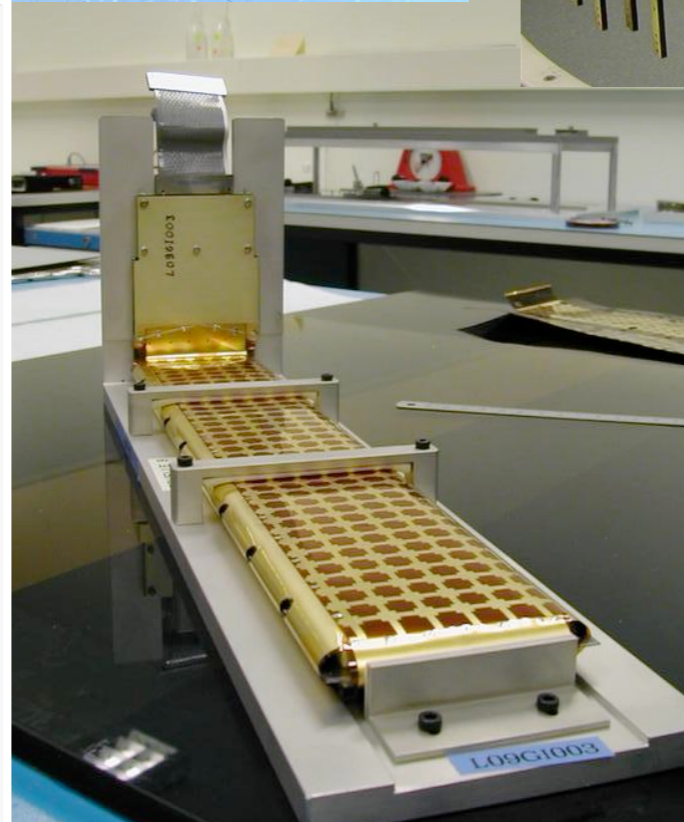
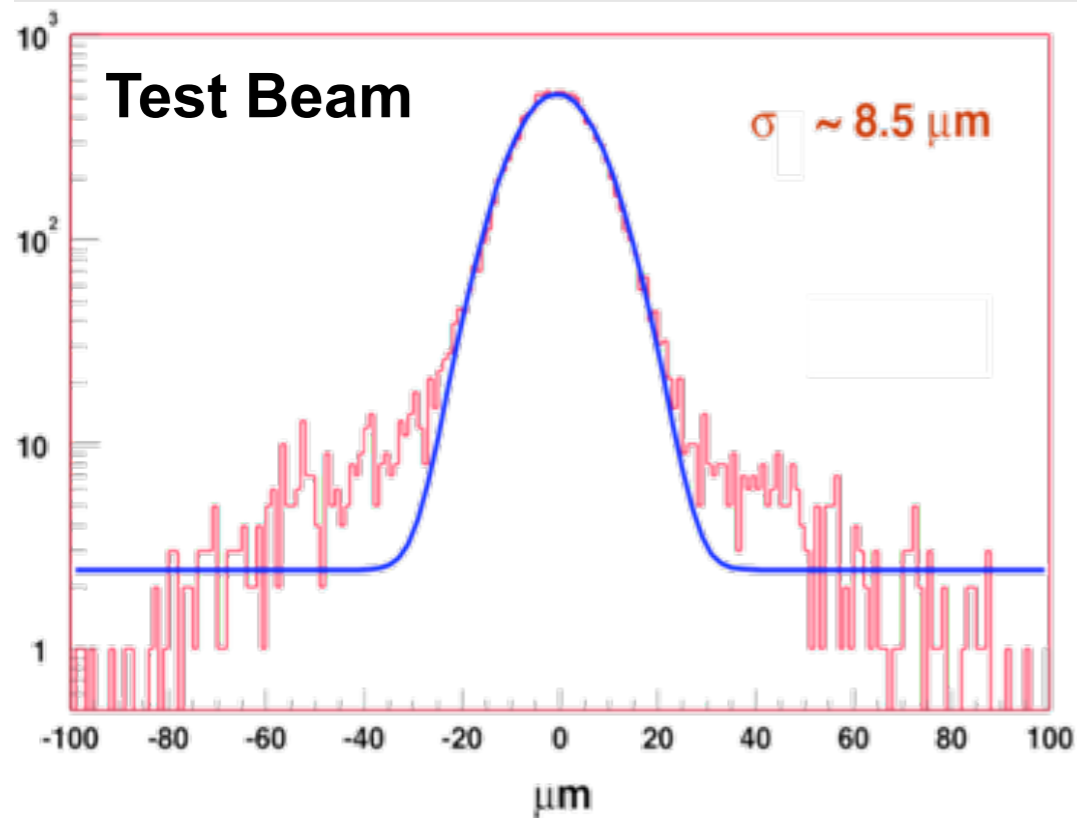
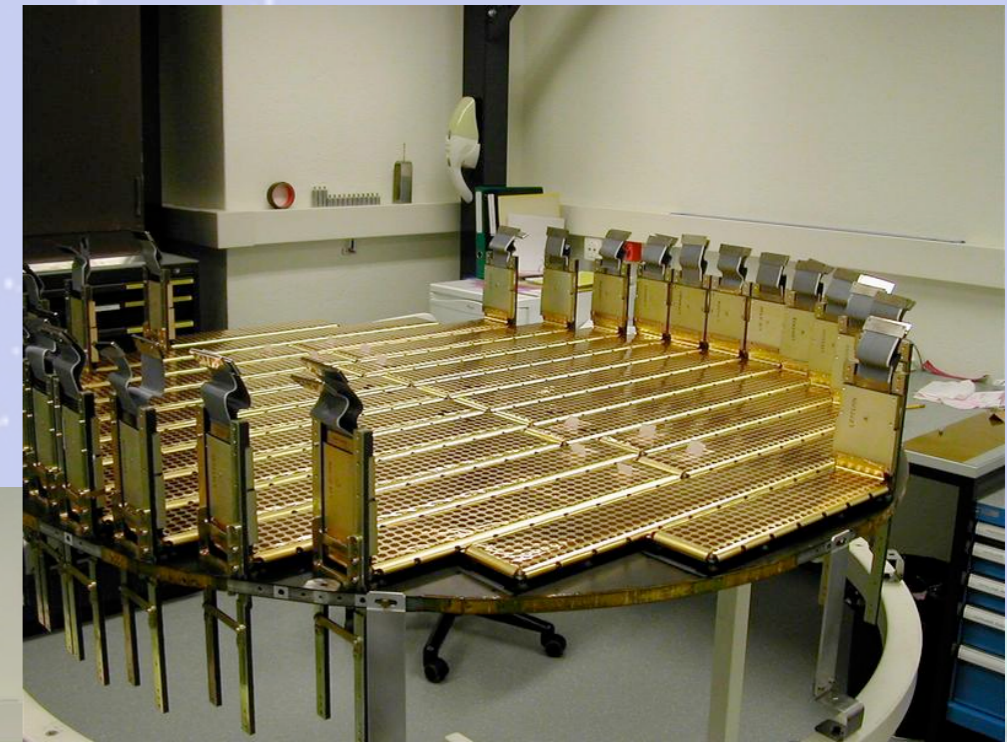
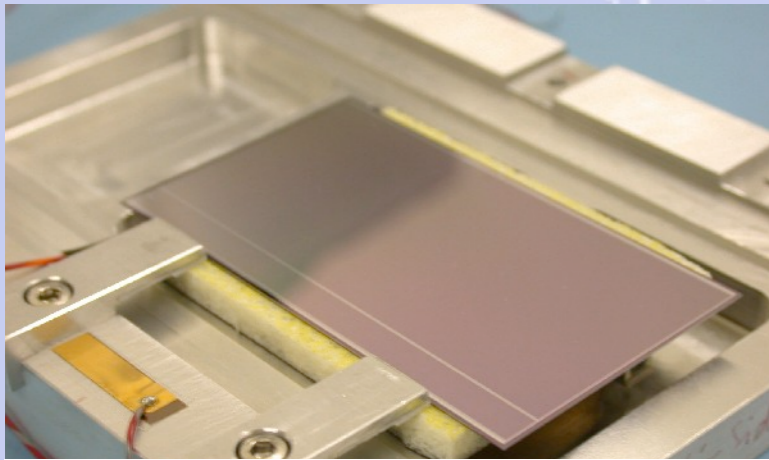
Measures the time of relativistic protons to 160 picoseconds
Provides trigger for charged particles
Trigger time is synchronized to UTC time to $1\mu\text{s}$

Time of Flight (TOF):

Measures Velocity and Charge of particles



Tracker



**9 layers of double sided silicon sensors (detector material $\sim 0.04 X_0$)
6.6m² \rightarrow 192 Ladders \rightarrow 196k channels \rightarrow 192 Watts dissipated**

Spatial resolution:

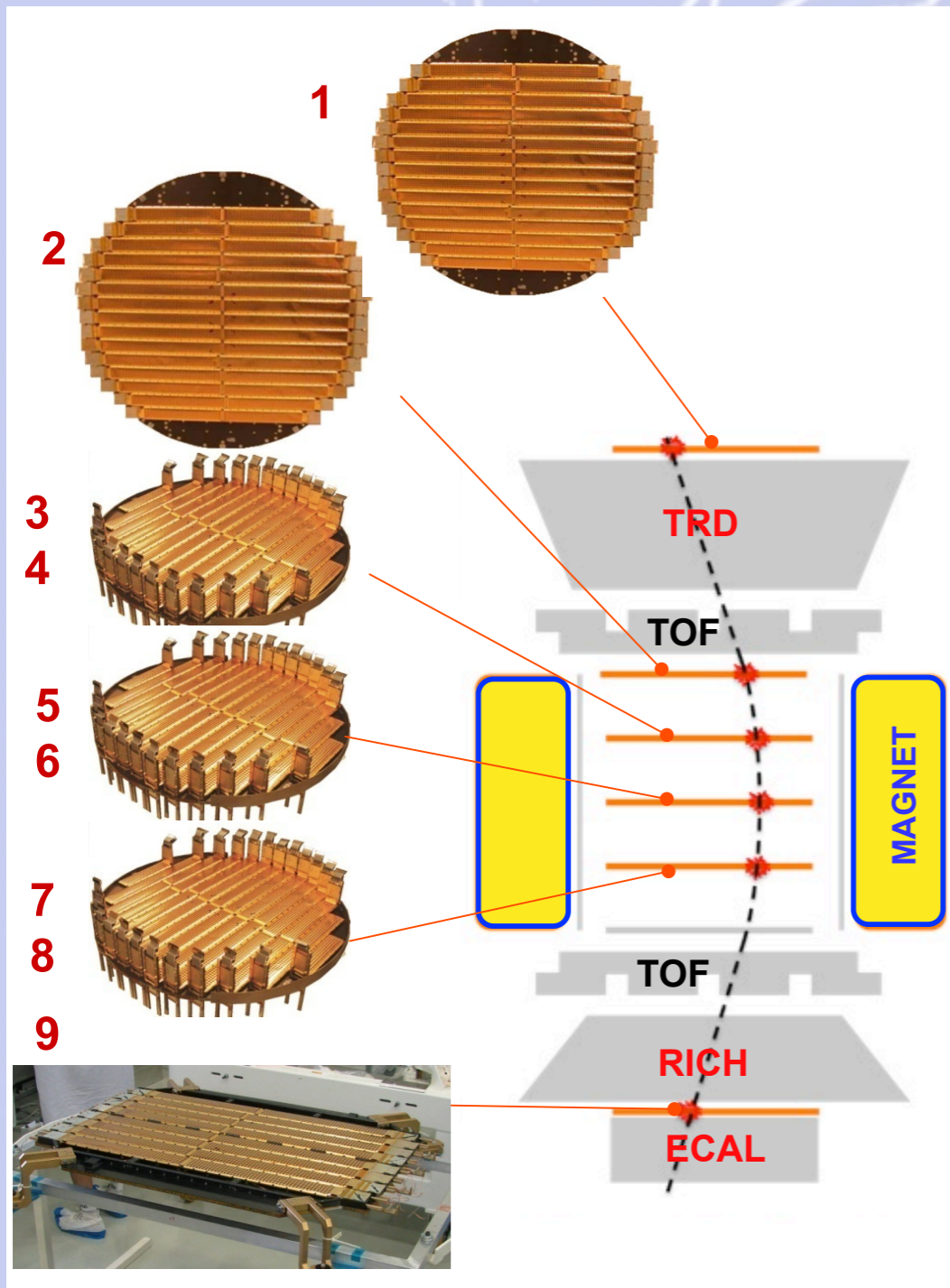
- (σ) $\sim 8\mu\text{m}$ (bending plane)
- (σ) $\sim 30\mu\text{m}$ (non bending plane)

Momentum resolution $\sim 10\%$ at 10 GV

**Wide temperature range
(-20/+40 survival, -10/+25 oper.)**

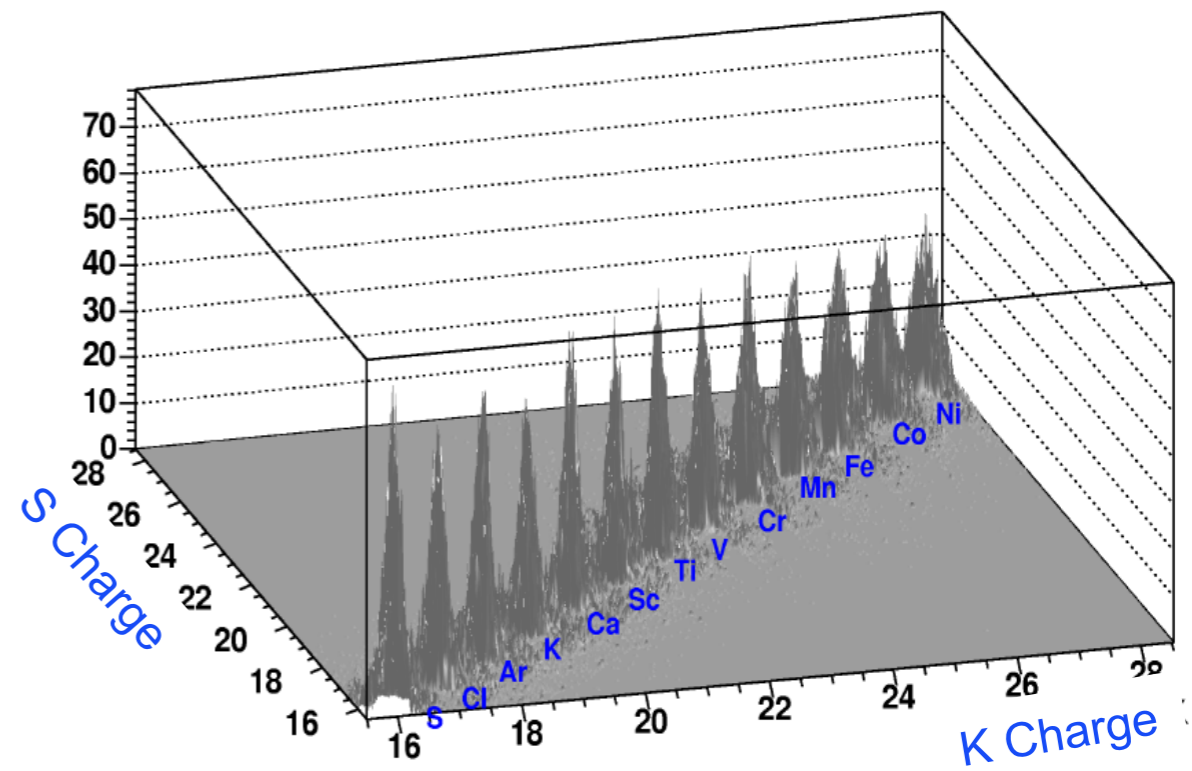
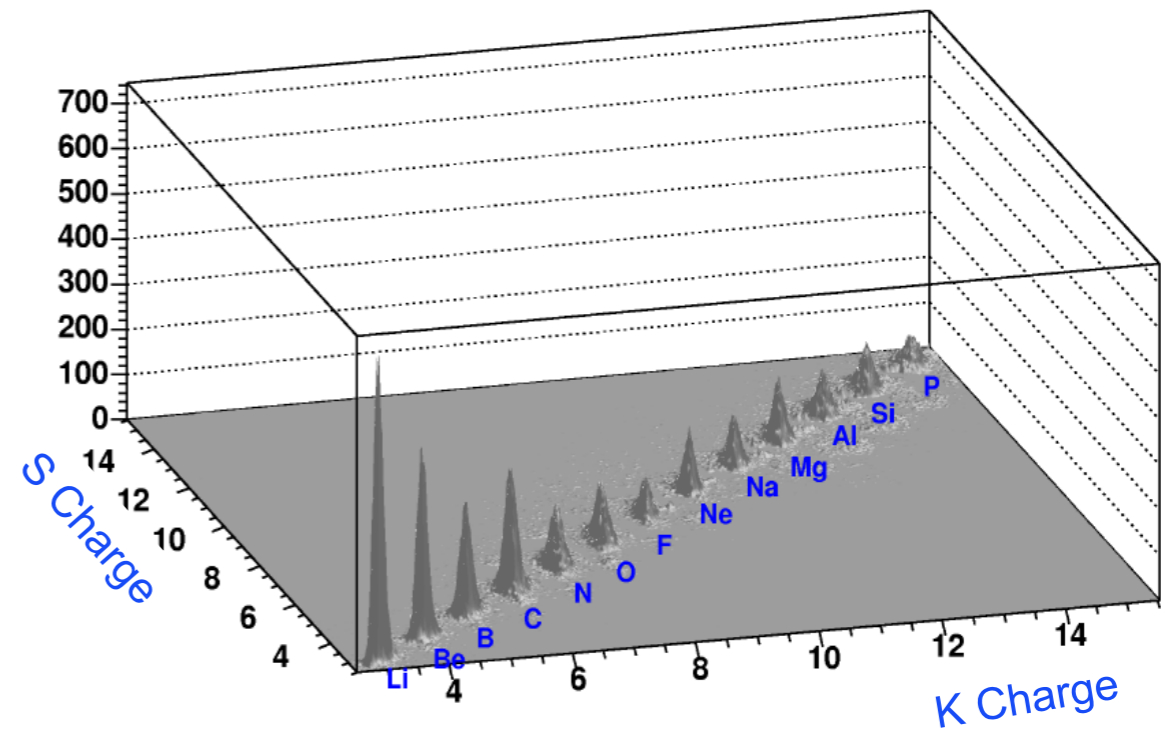
**High dynamic range front end for
charge measurement**

Tracker



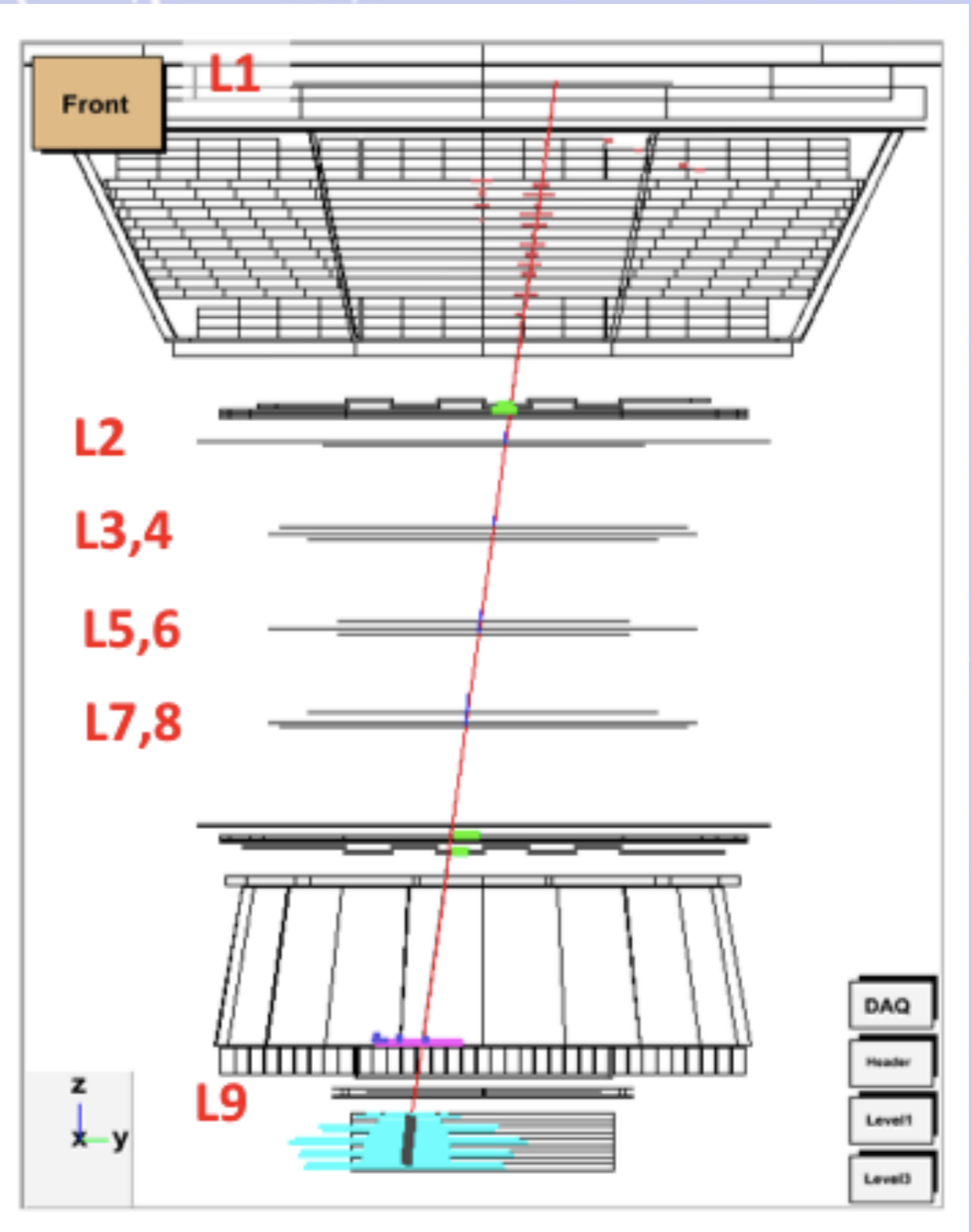
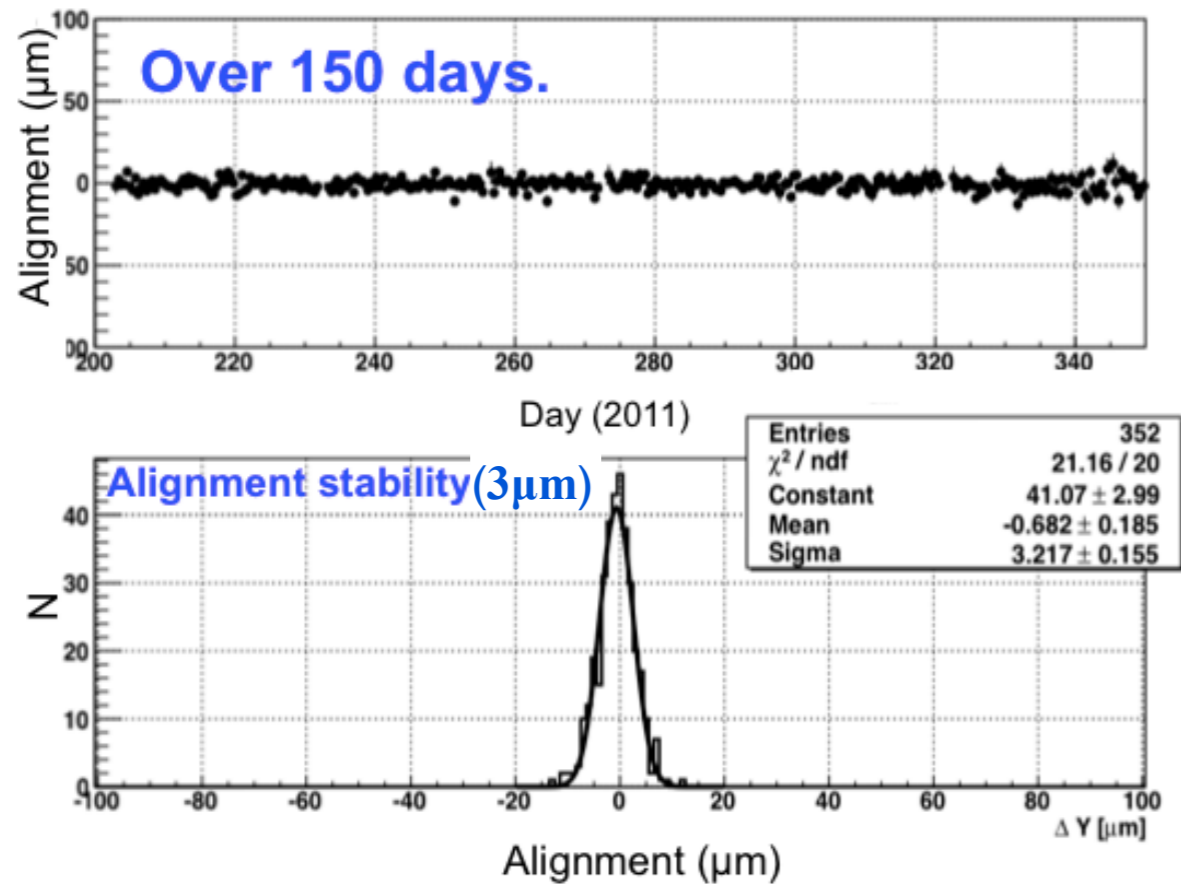
The particle trajectory is measured on several points (9) by its intersection with silicon microstrips detector layers.

Nuclei identification

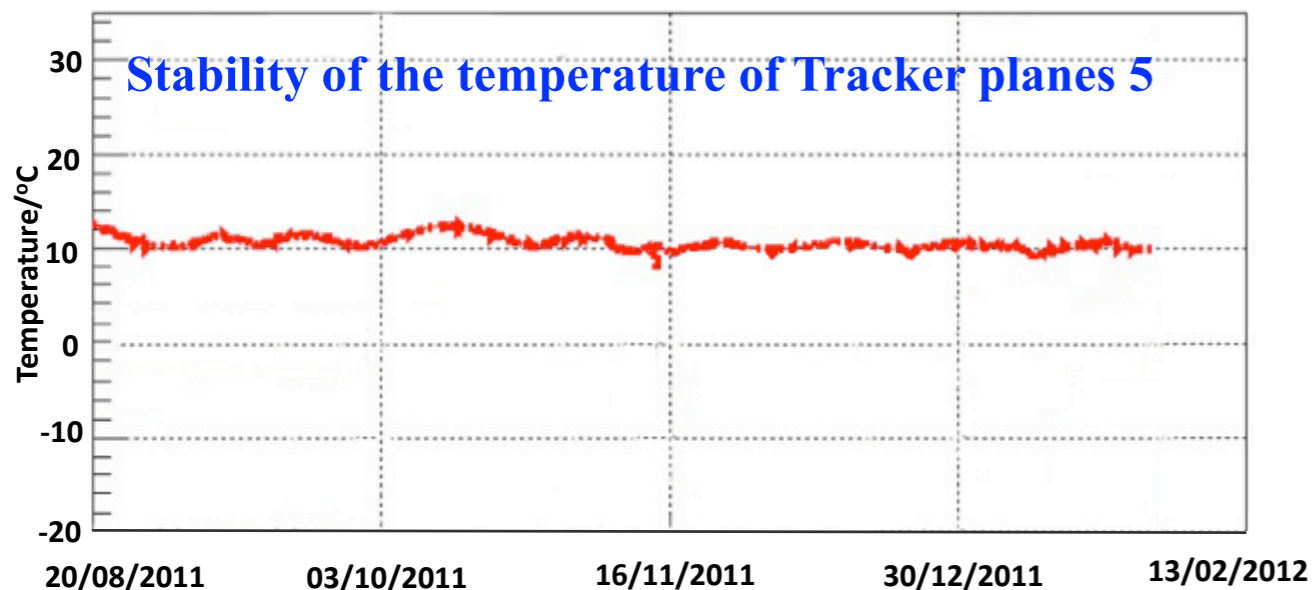


Tracker Performance on ISS

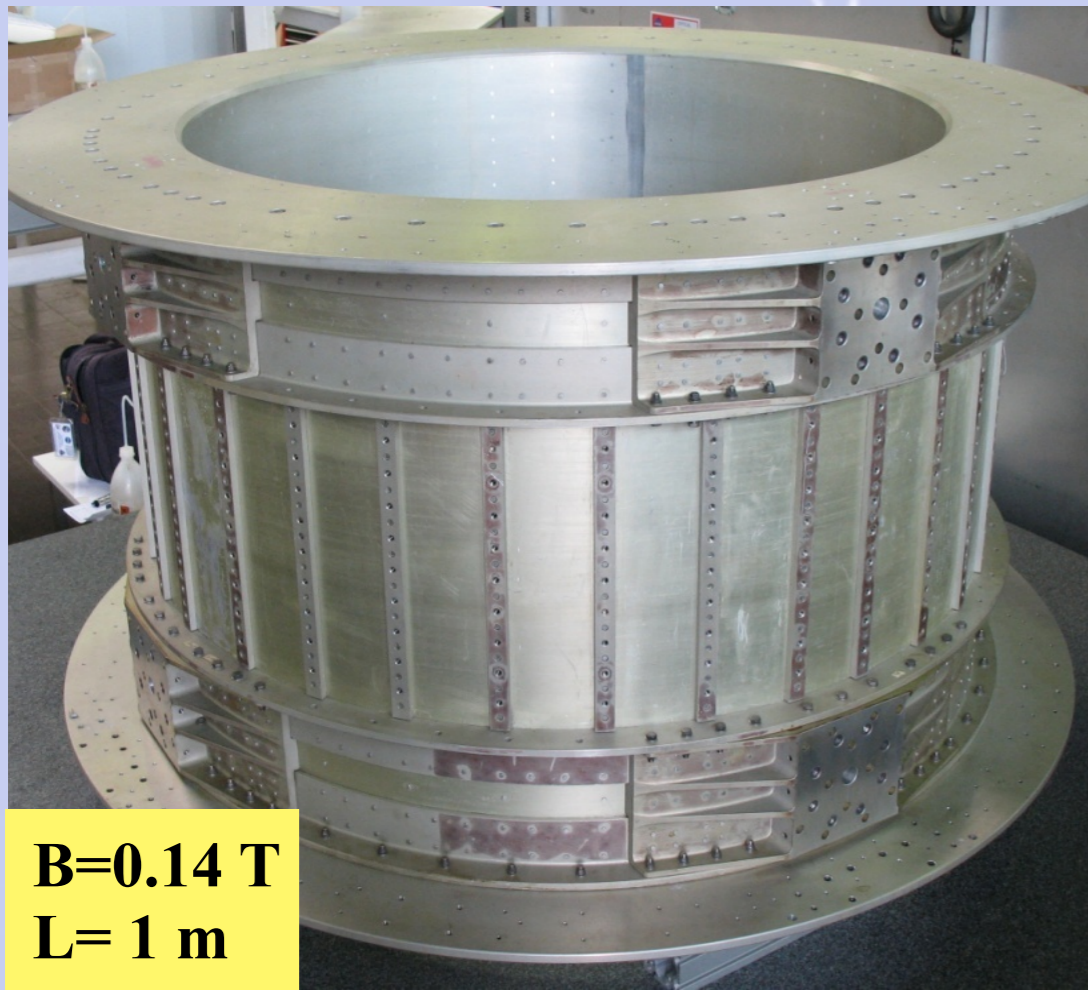
The alignment stability ($3\mu\text{m}$) of the uppermost Tracker plane (L1)



Stability of the temperature of Tracker planes 5

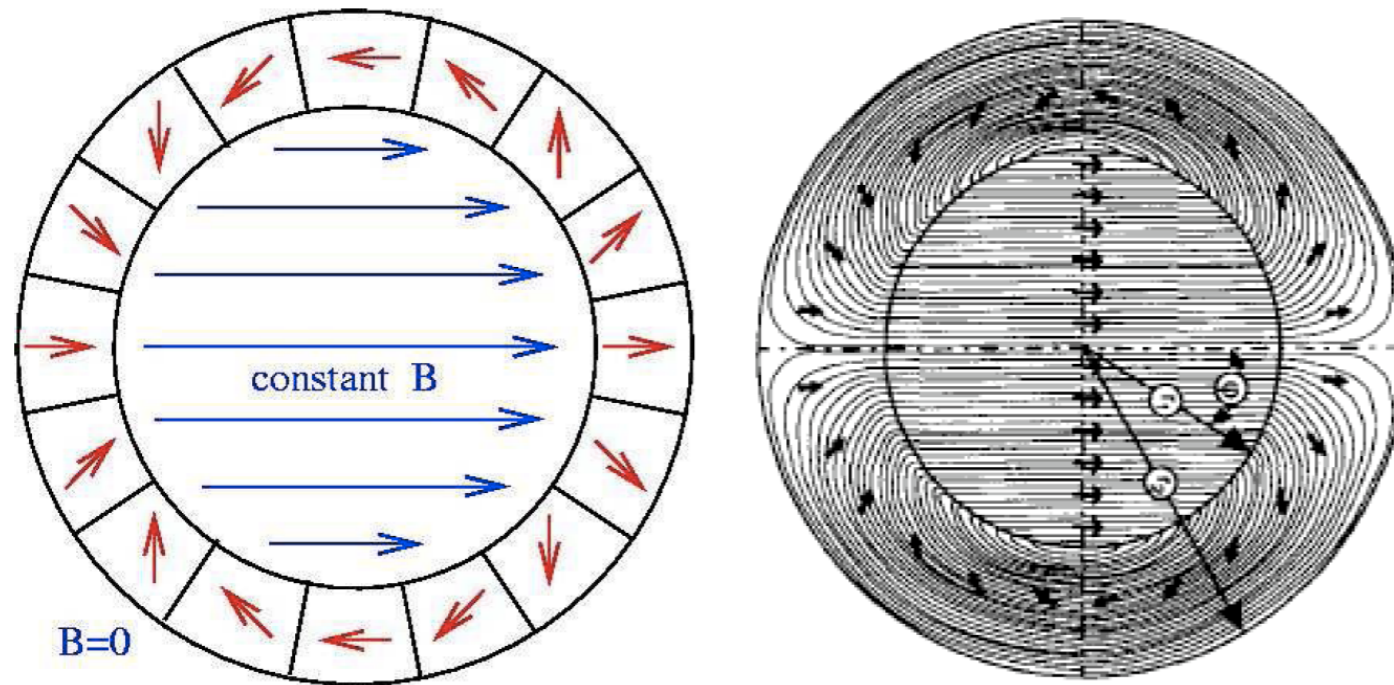


The AMS-02 permanent Magnet



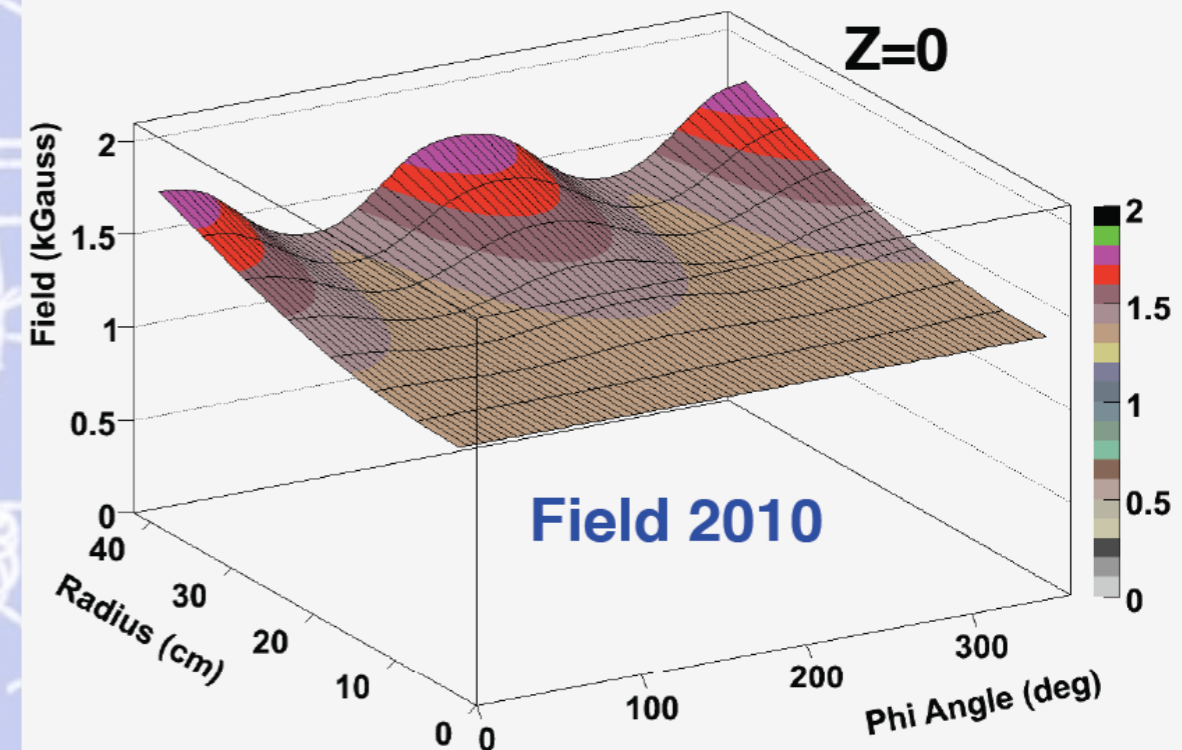
B=0.14 T
L= 1 m

Torques are forbidden in space so the total magnetic torque of the AMS-02 magnet must be zero!



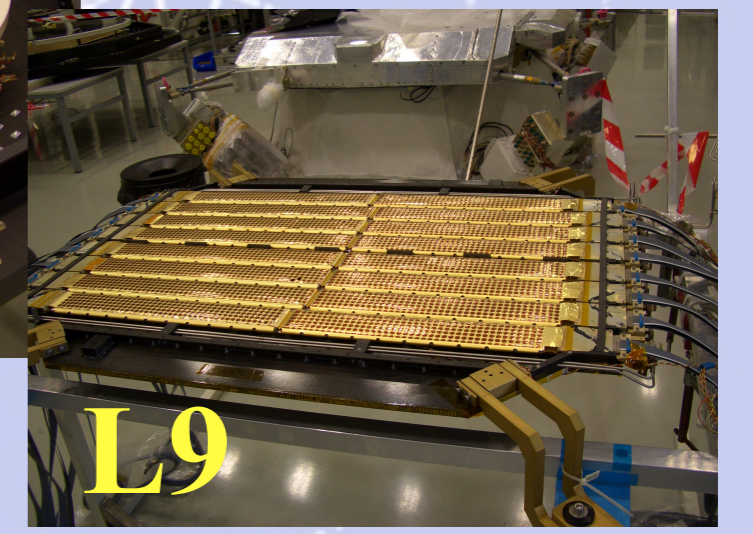
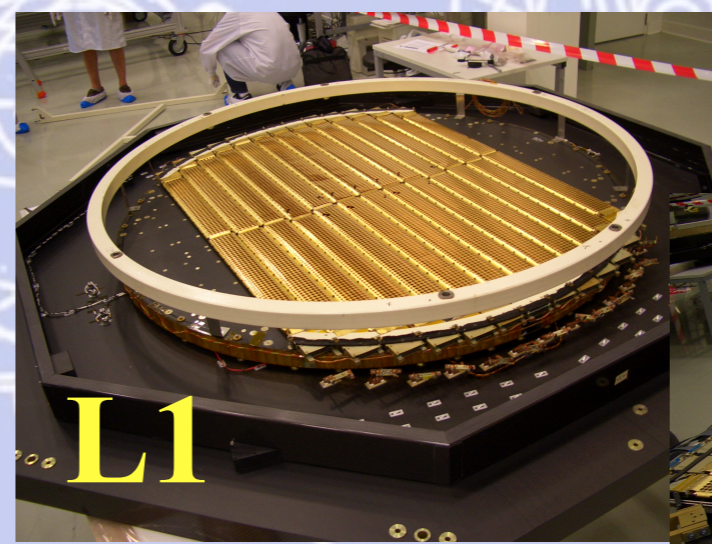
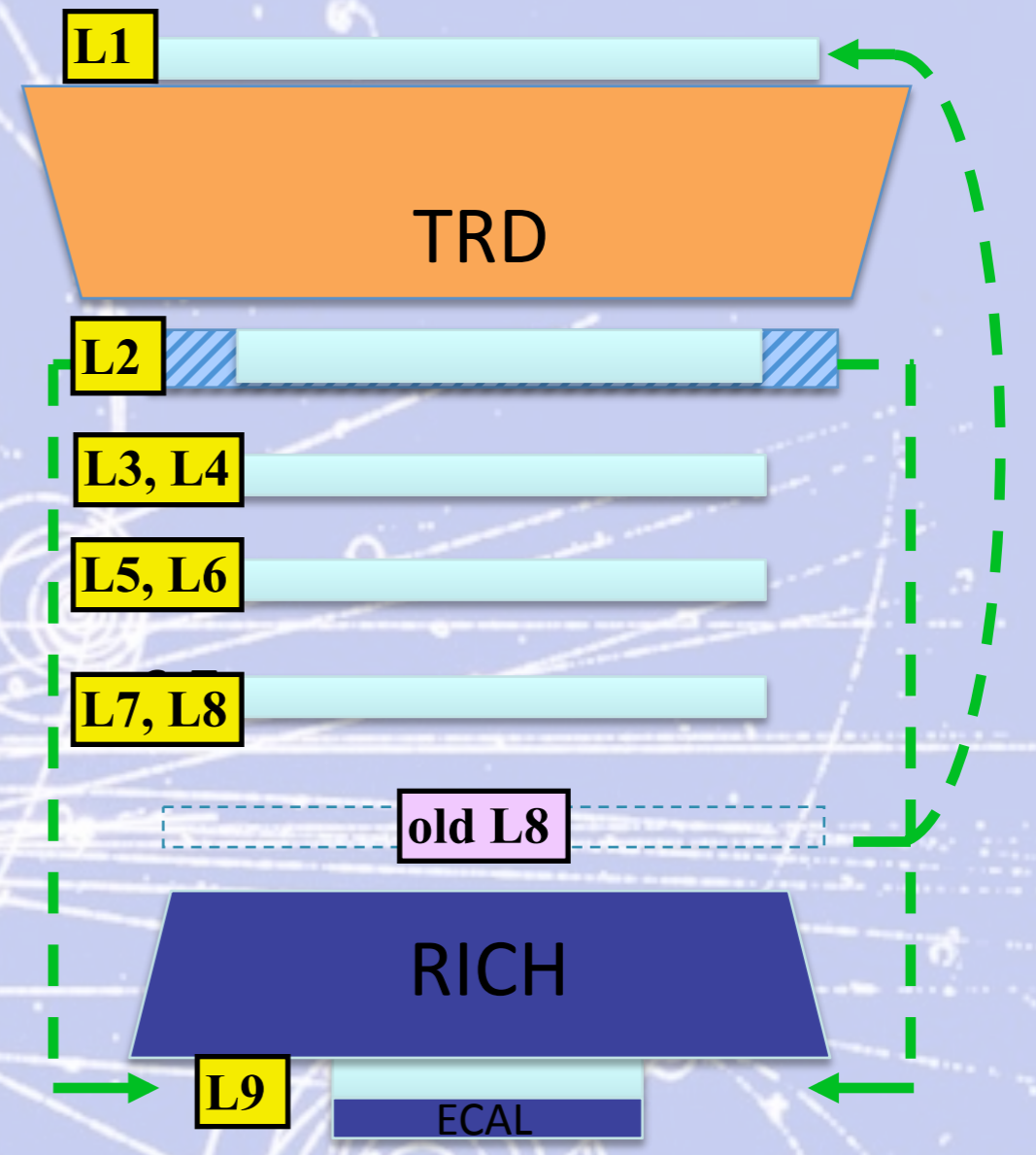
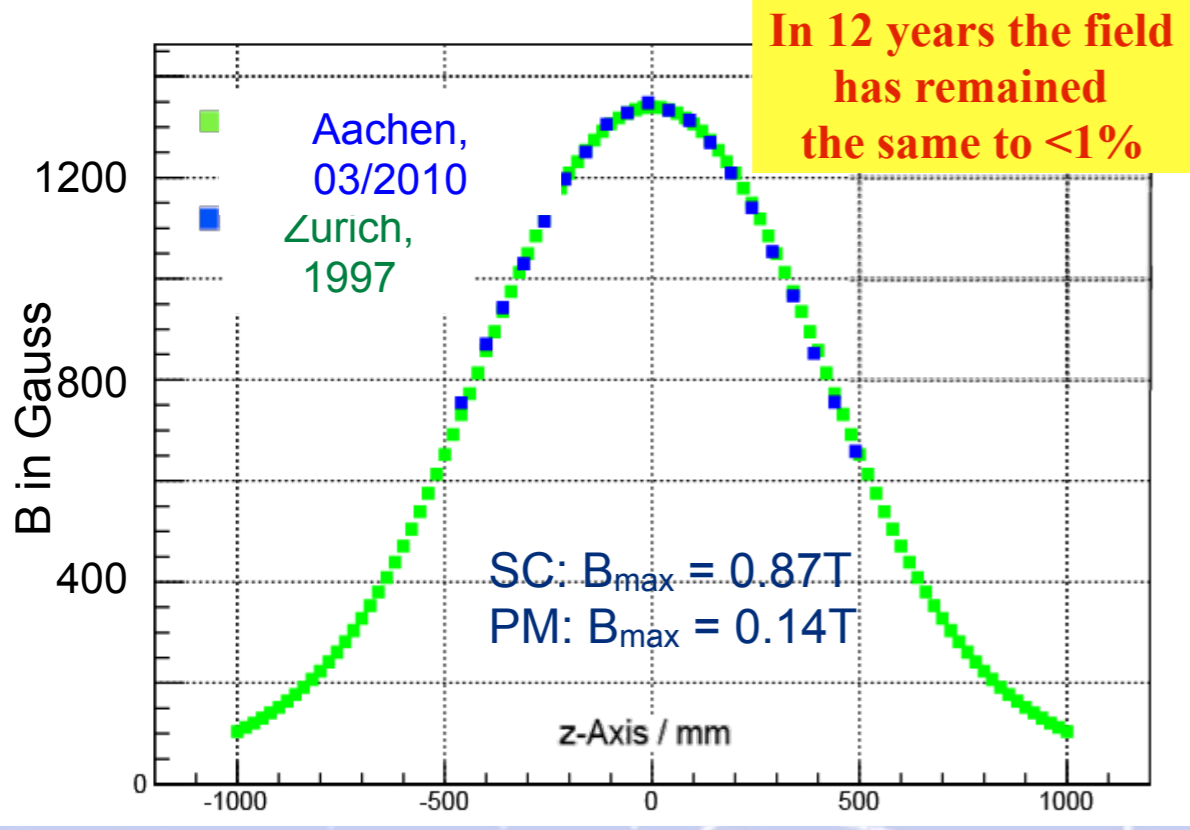
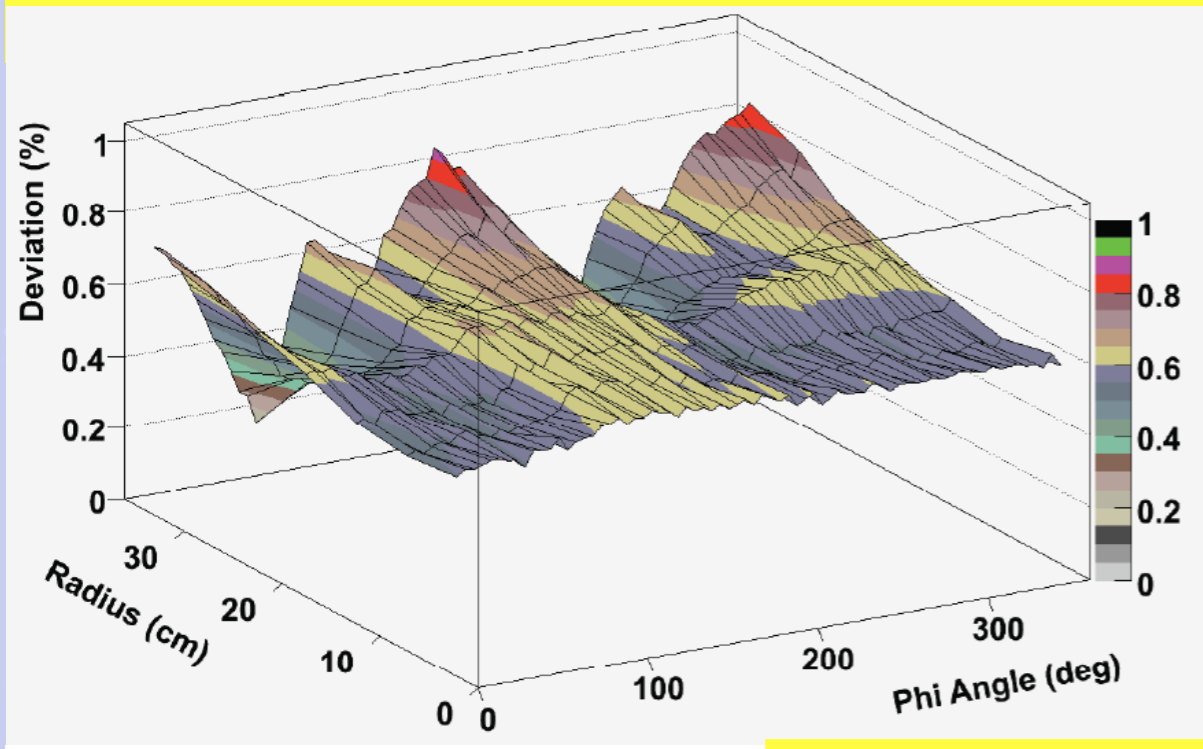
Magnetic field distribution at a cross-section of the centre of the magnet

The detailed 3D field map (120k locations)

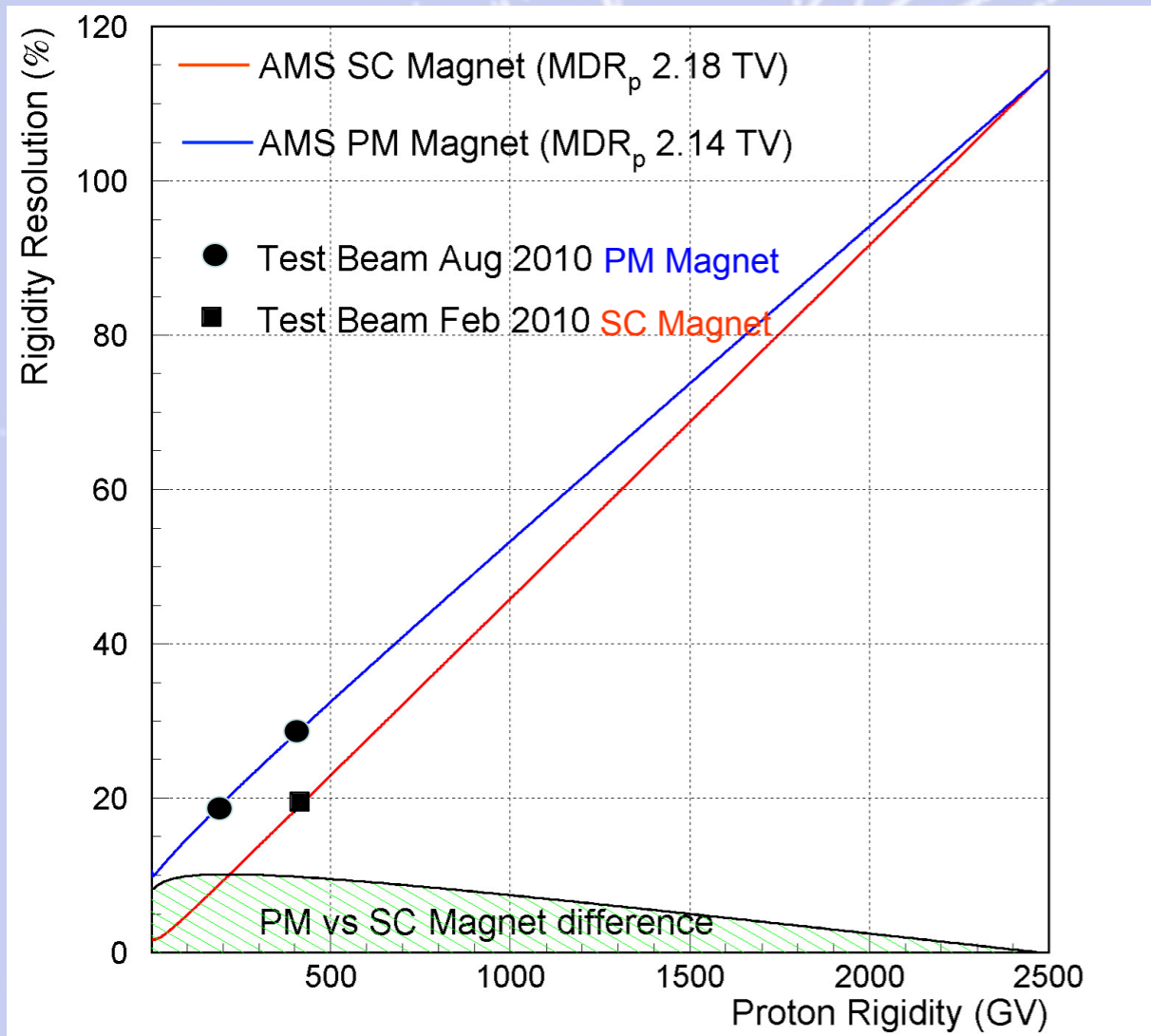


The AMS-02 Spectrometer modifications

Deviation from 1997 measurements



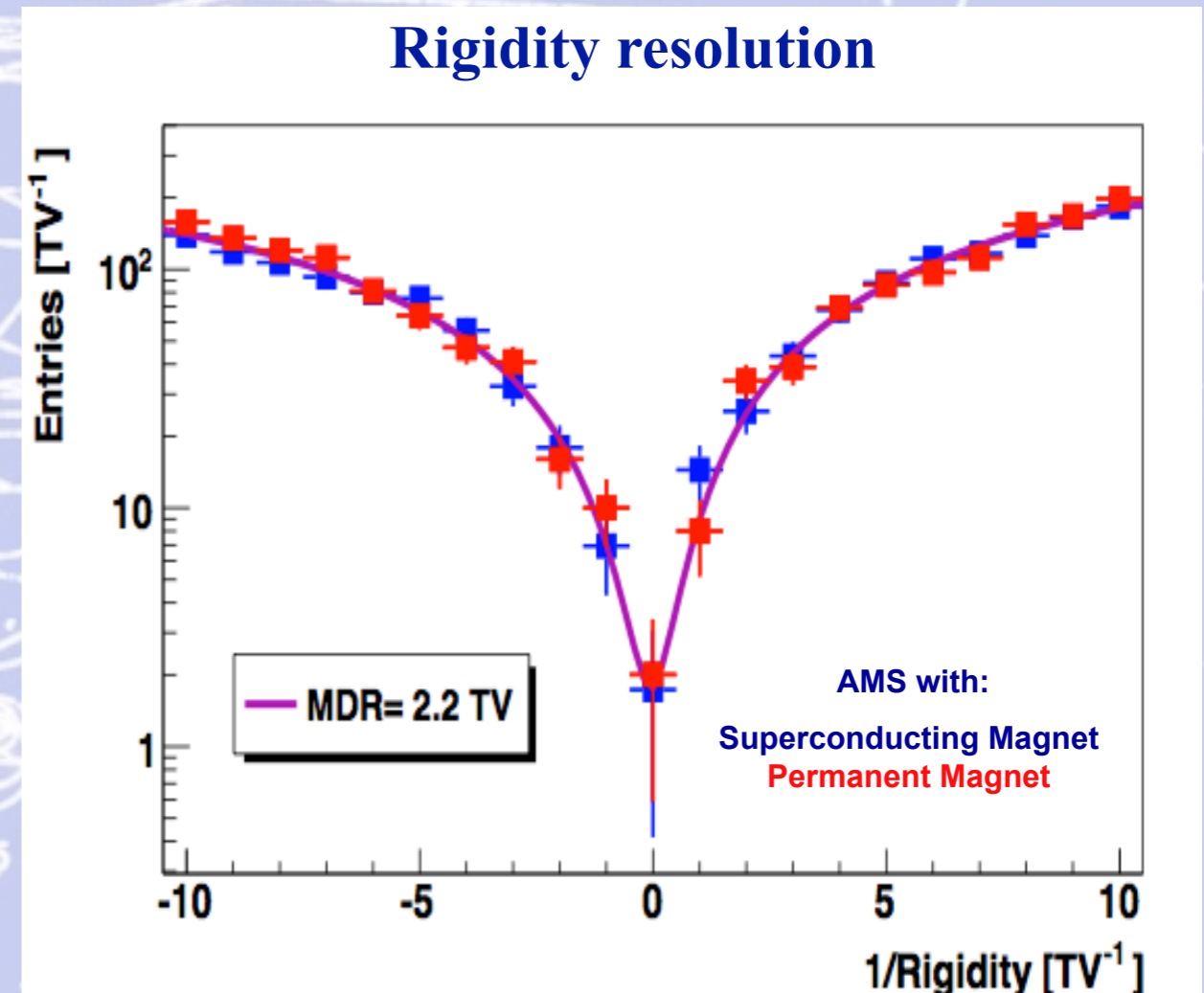
The AMS-02 Spectrometer performance



- For helium nuclei, the $MDR^{(*)}$ for the permanent magnet is 3.75 TV.
- Alignment will be done with 10'000 CR tracks per minute in orbit.

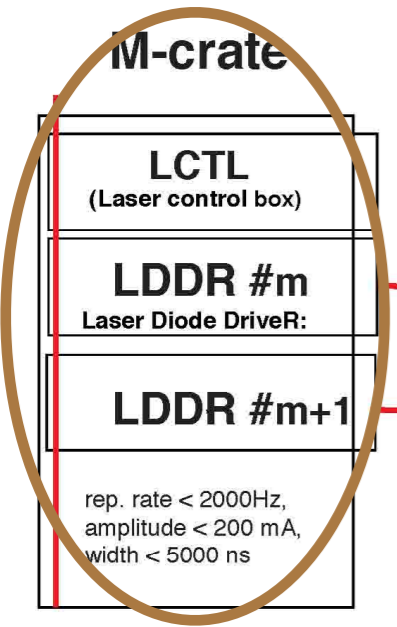
(*) Max detectable rigidity ($R=pc/Ze$)

With 9 tracker planes in the new configuration, the rigidity resolution of AMS with the permanent magnet is equal (within 10%) to that of the superconducting magnet.

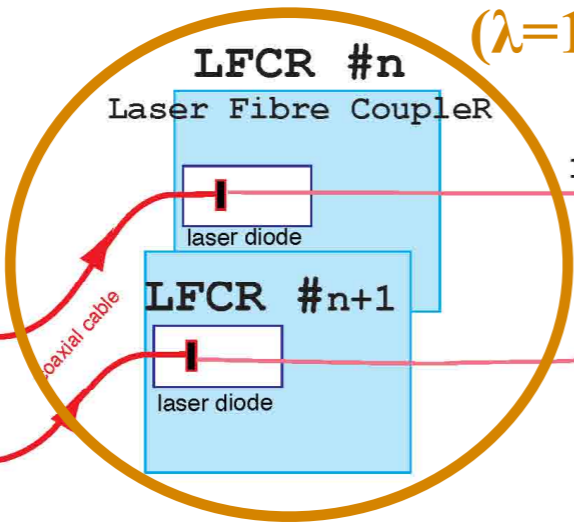


The AMS-02 Tracker Alignment System Layout

Front-End Electronics

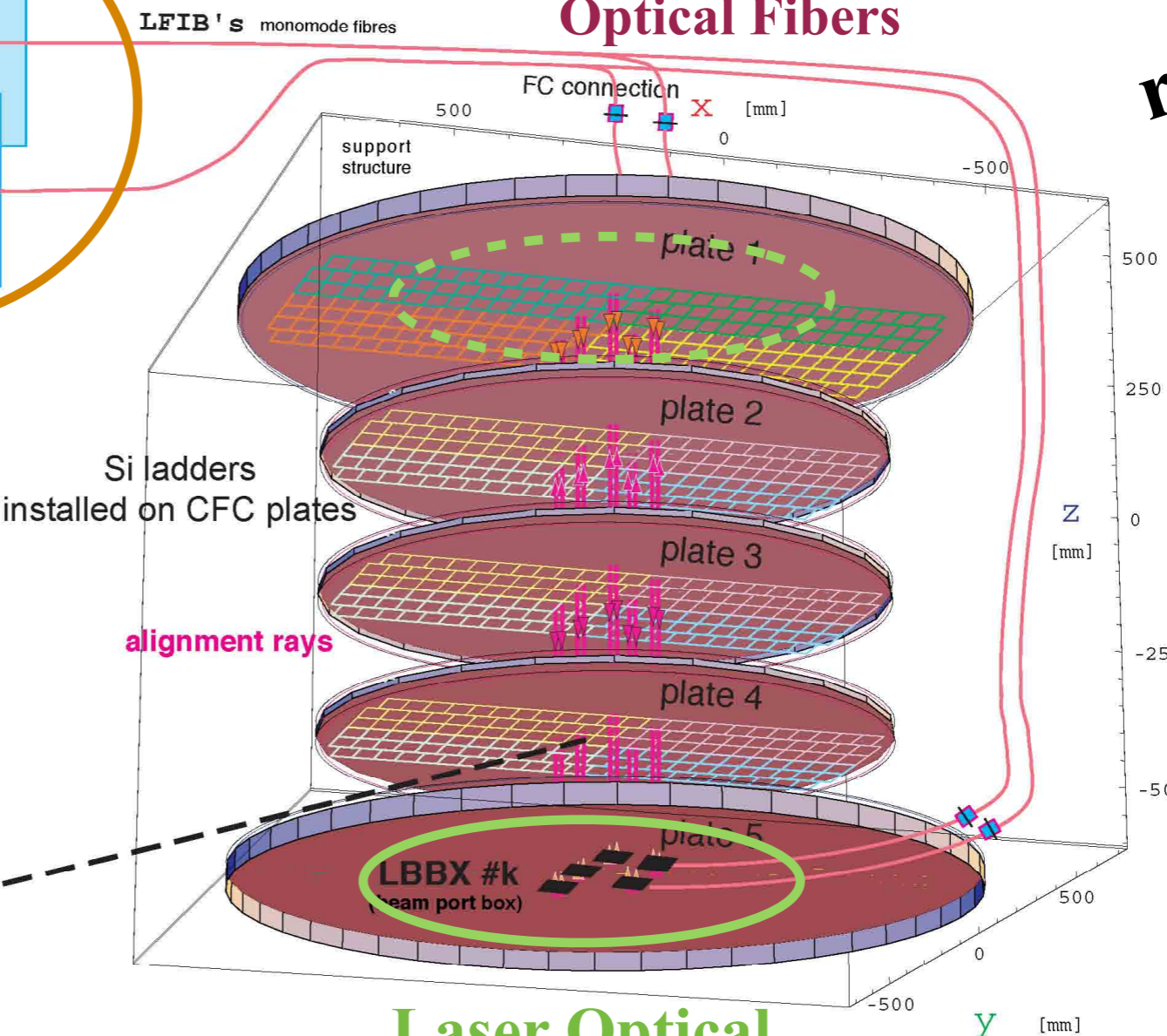


Laser Diodes ($\lambda=1082$ nm)

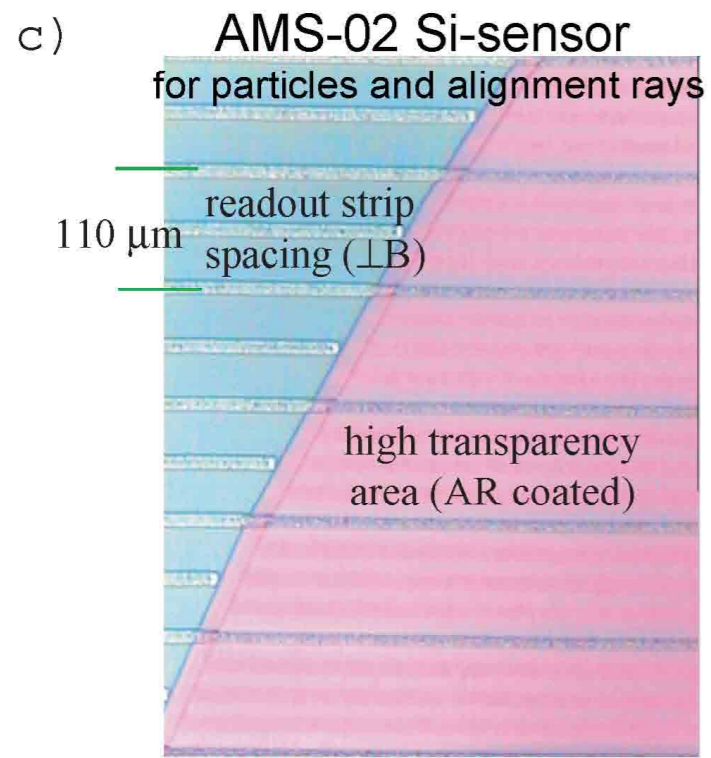


- 20 laser beams top-to-bottom
- ~~20 laser beams bottom-to-top~~

Optical Fibers



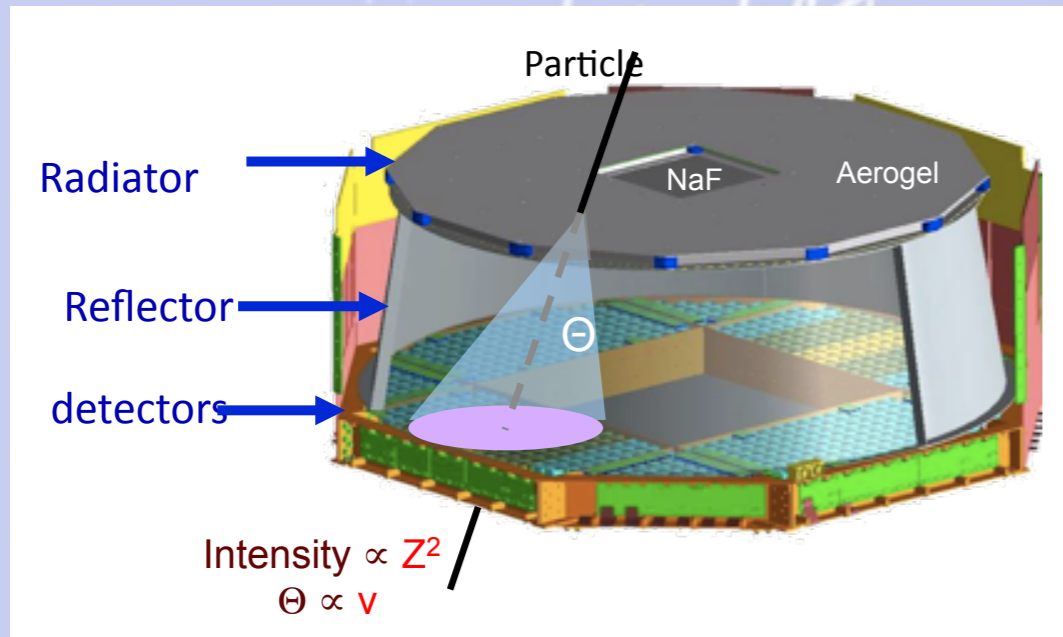
removed!



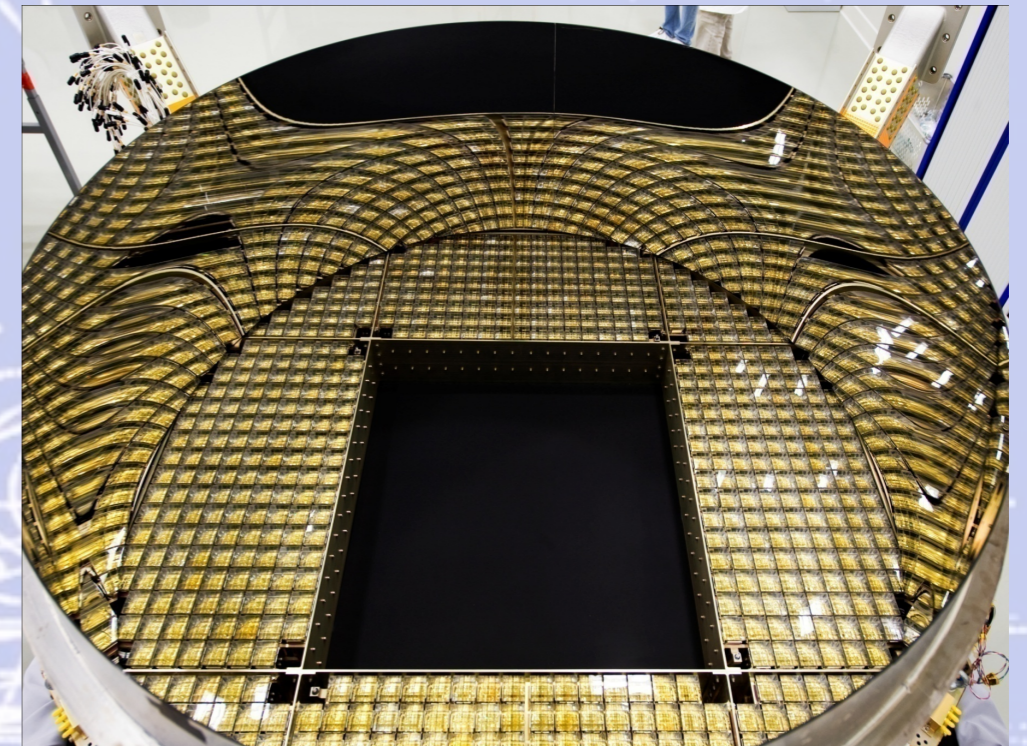
Laser Optical Beam Port Boxes

Ring Imaging Cherenkov (RICH)

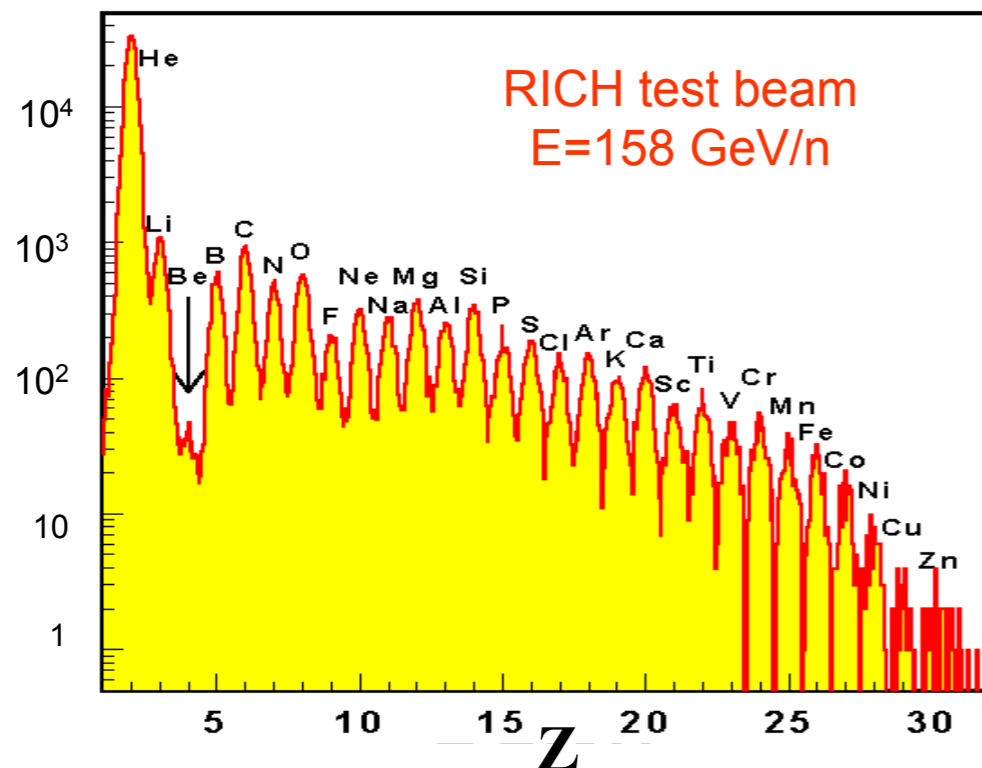
identify nuclei and their energy



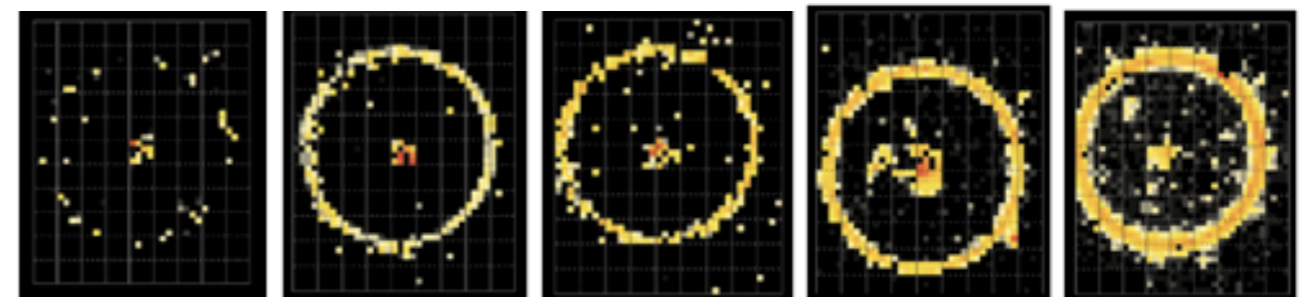
3cm silica Aerogel($n=1.05$) +NaF ($n=1.33$) radiator;



10,880 photosensors
21,760 Signal Pulses

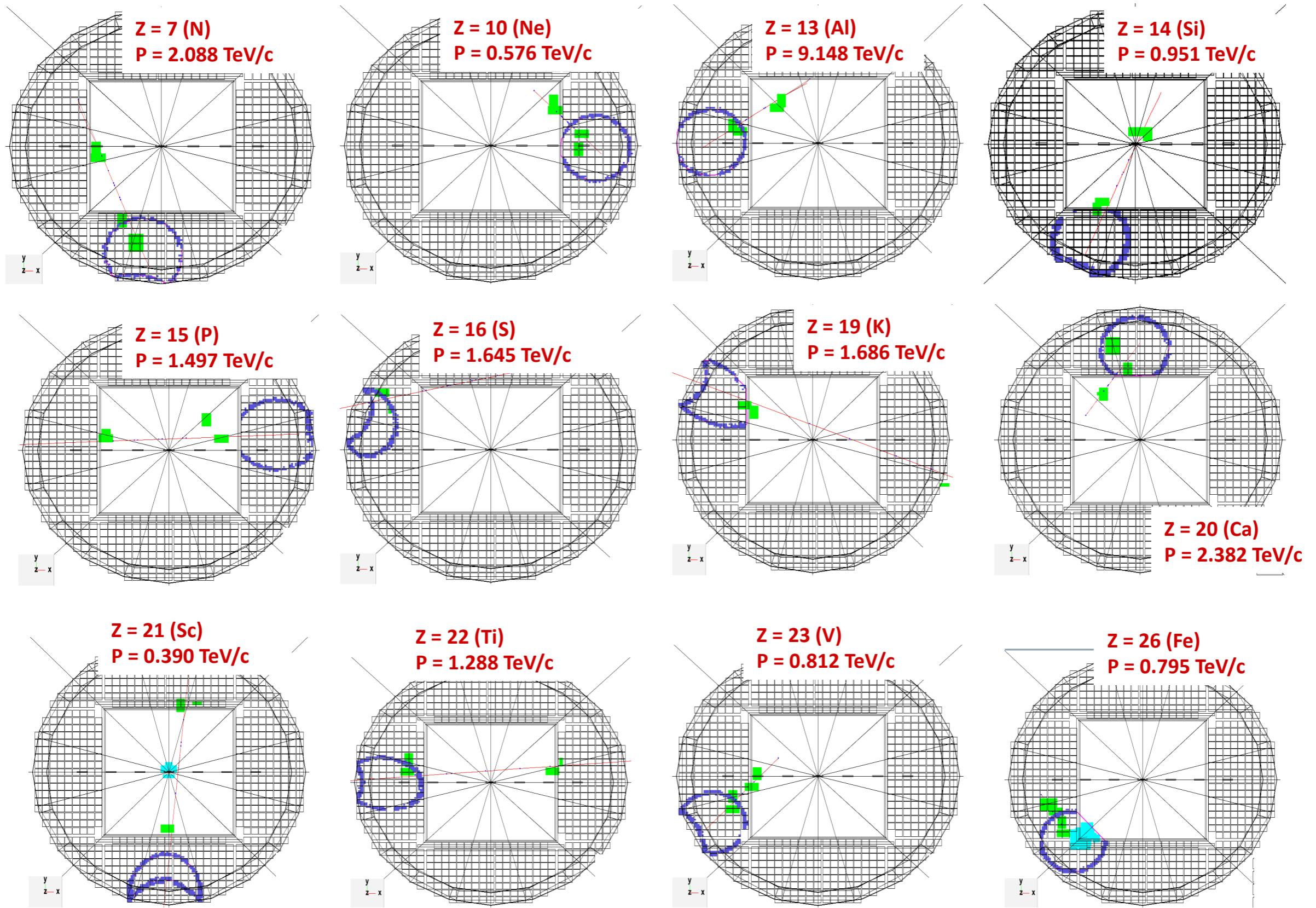


Single Event Displays from
RICH test beam $E=158 \text{ GeV/n}$



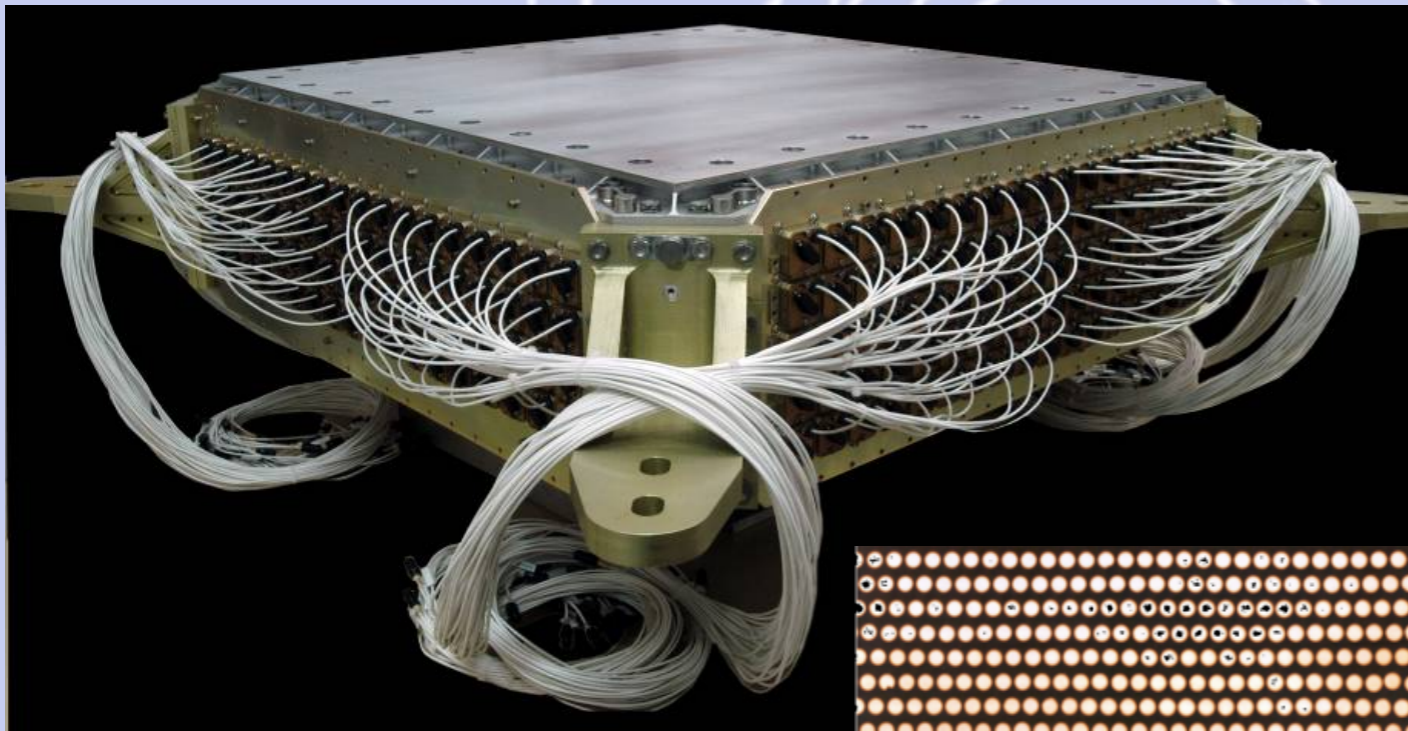
$\sigma(\beta)/\beta=0.1\% @ \beta=1$ (protons)
 $\Delta Z \sim 0.2$ up to Fe

Data from ISS: Nuclei identification from RICH

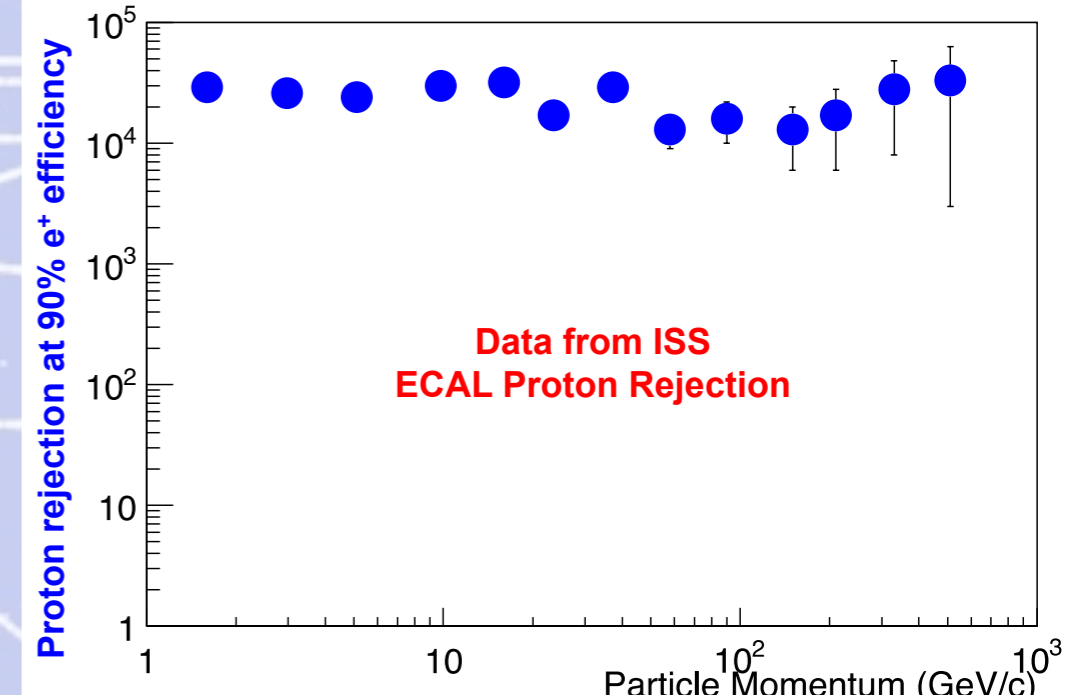
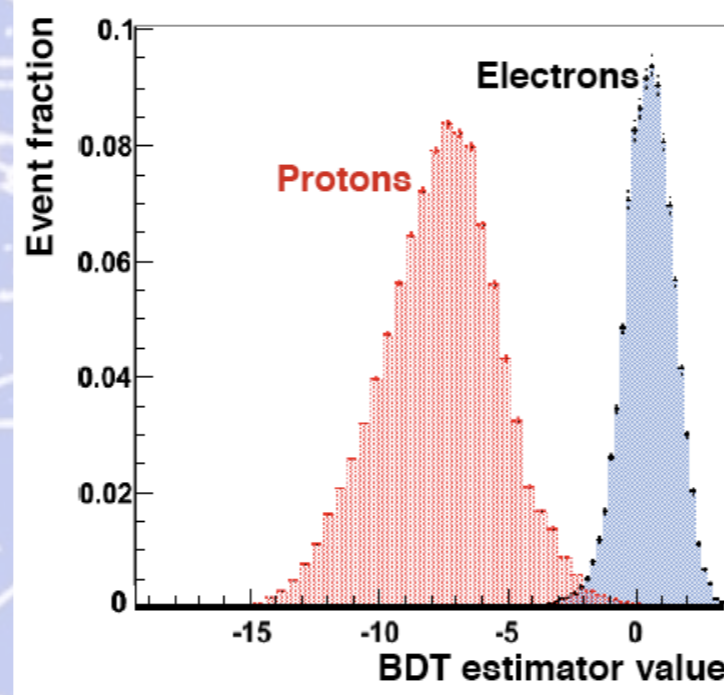
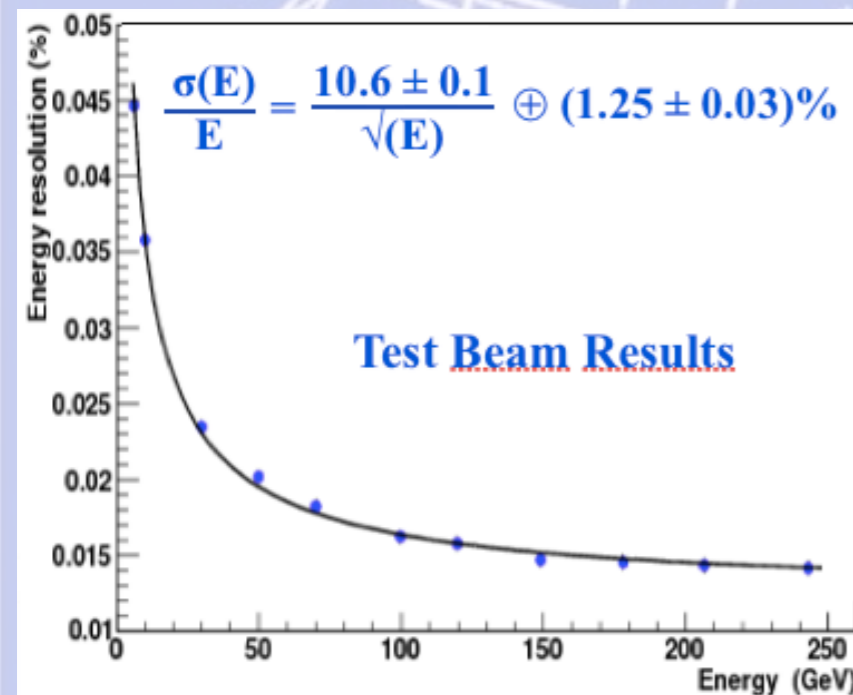
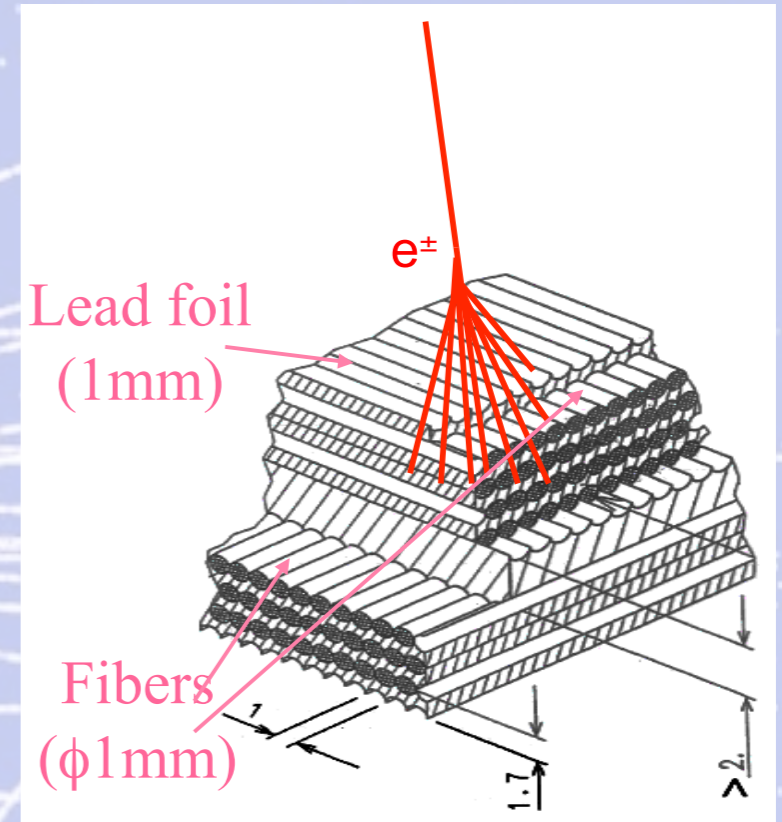


Calorimeter (ECAL)

A precision, $17 X_0$, TeV,
3-dimensional measurement of the
directions and energies of light rays
and electrons



10 000 fibers, $\phi = 1$ mm distributed uniformly
inside 1,200 lb of lead



AMS electronics

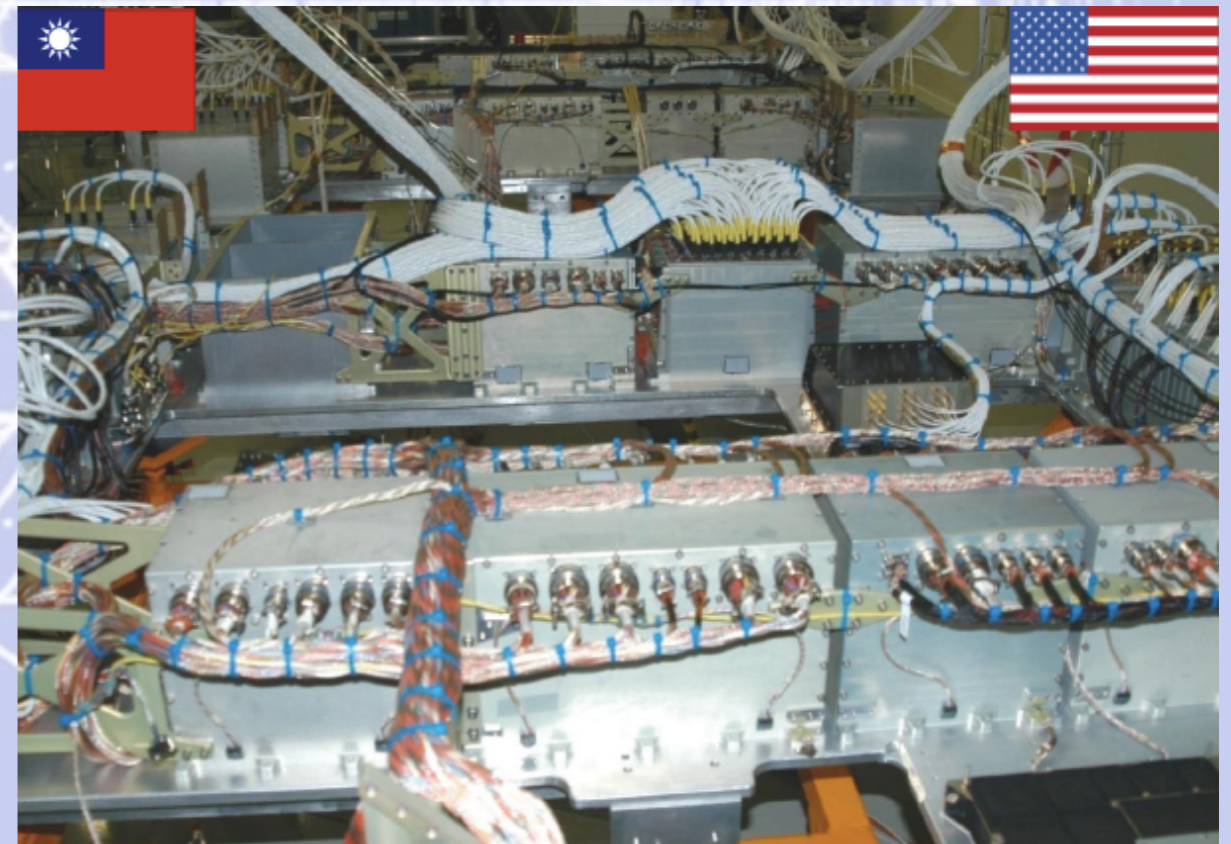
650 processors,
300,000 channels.
up to **400%** redundancy

Reduce data volume
7 Gbit/s to 10 Mbit/s

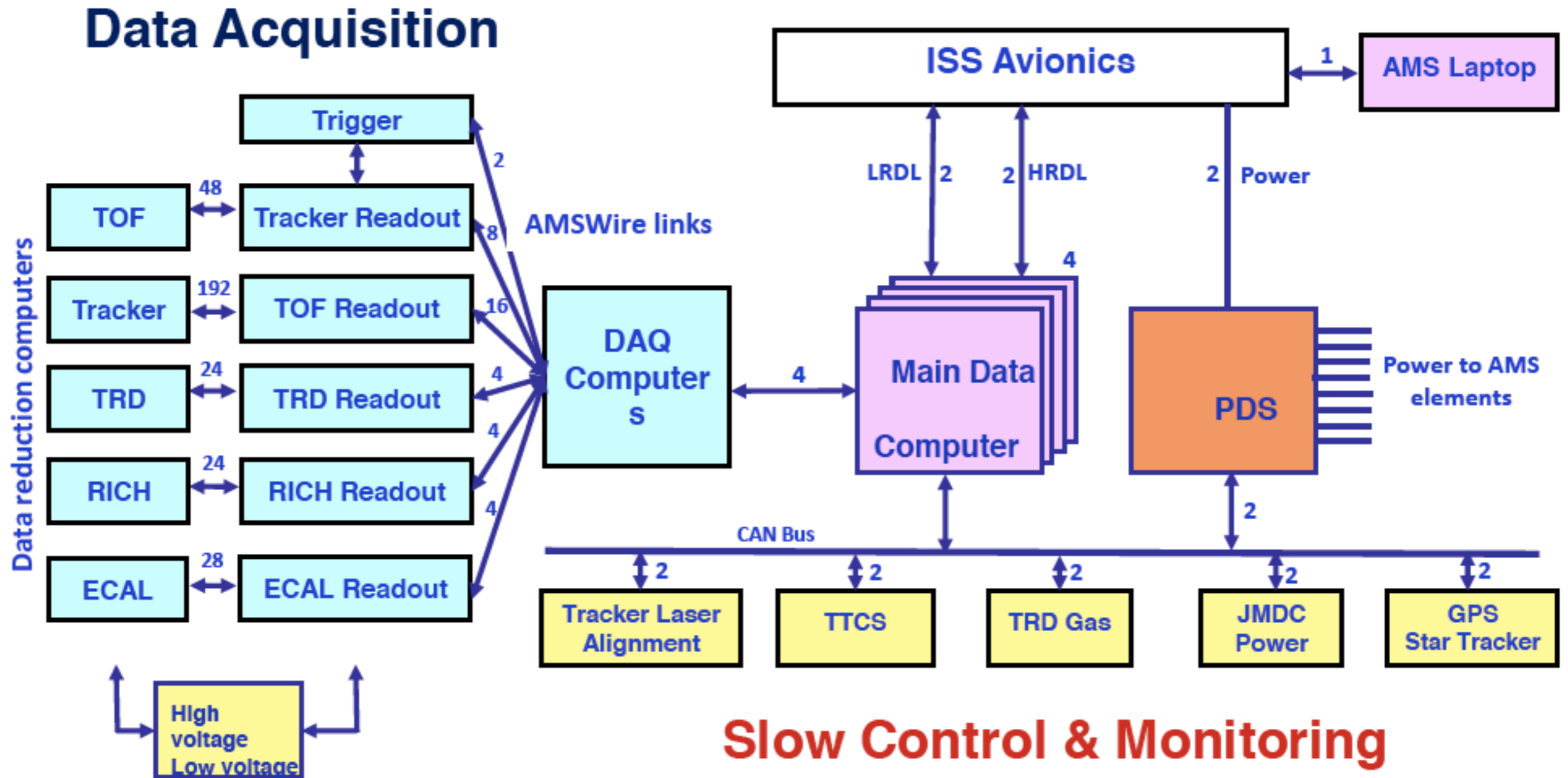
To read out 300,000 channels at up to 2 KHz, a large set of **computers (650)** which are **programmable from the POCC** have been developed.

All the different detectors are readout with up to 400% redundancy.

Hundreds of these computers are interconnected in a tree like structure with an 100 MBit/s serial link.



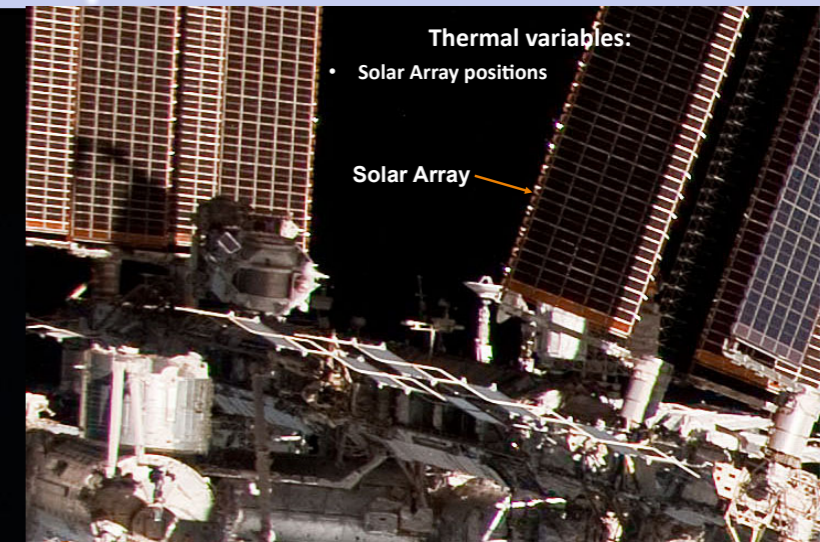
AMS electronics



Thermal Control is the most challenging task in the operation of AMS

The thermal environment on ISS is constantly changing due to:

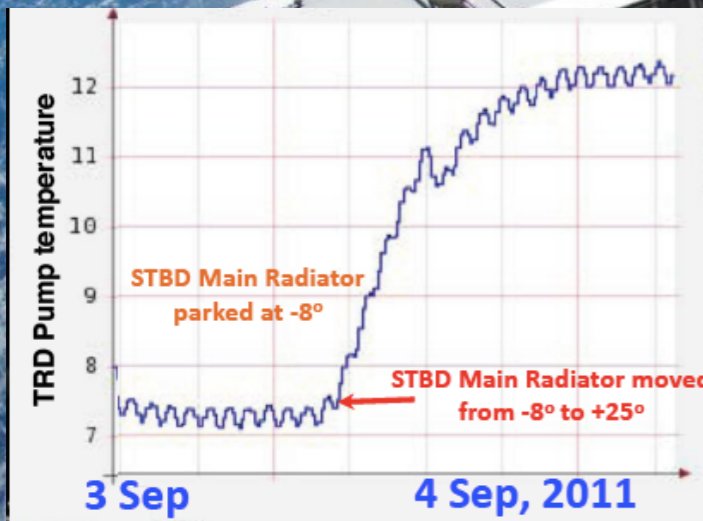
- Solar Beta Angle (β)
- Position of the ISS Radiators and Solar Arrays
- ISS Attitude



Thermal variables:

- ISS Radiator positions
- ISS attitude changes (primarily for visiting vehicles)

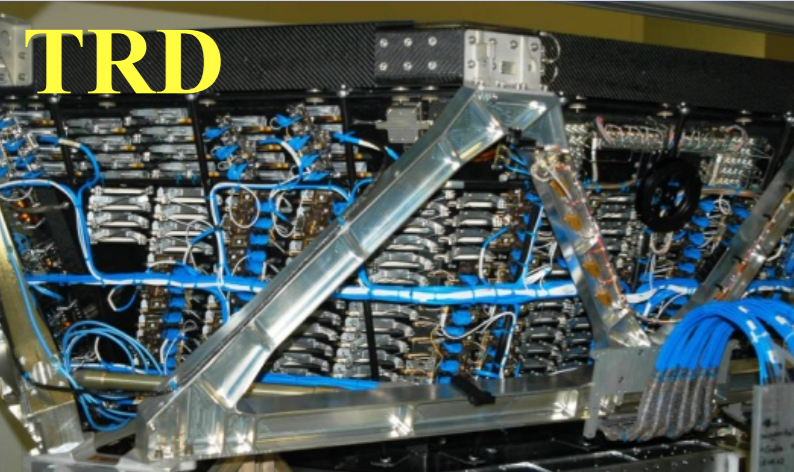
Visiting Vehicles
(Soyuz or Progress)



STBD Main Radiator

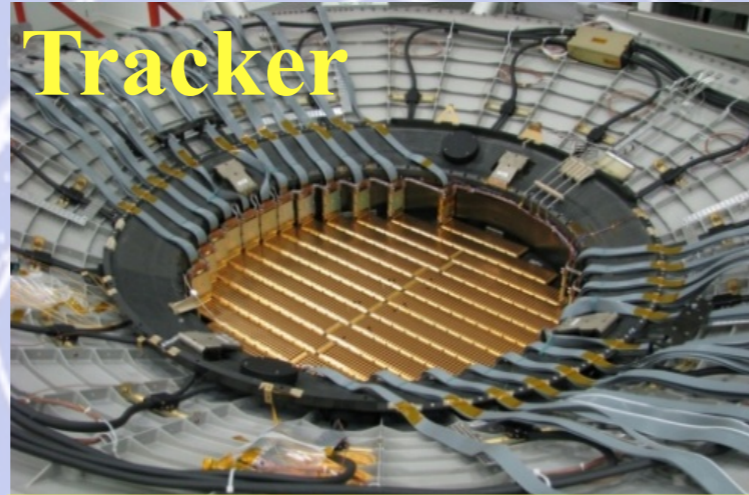
AMS Flight Electronics for Thermal Control

TRD



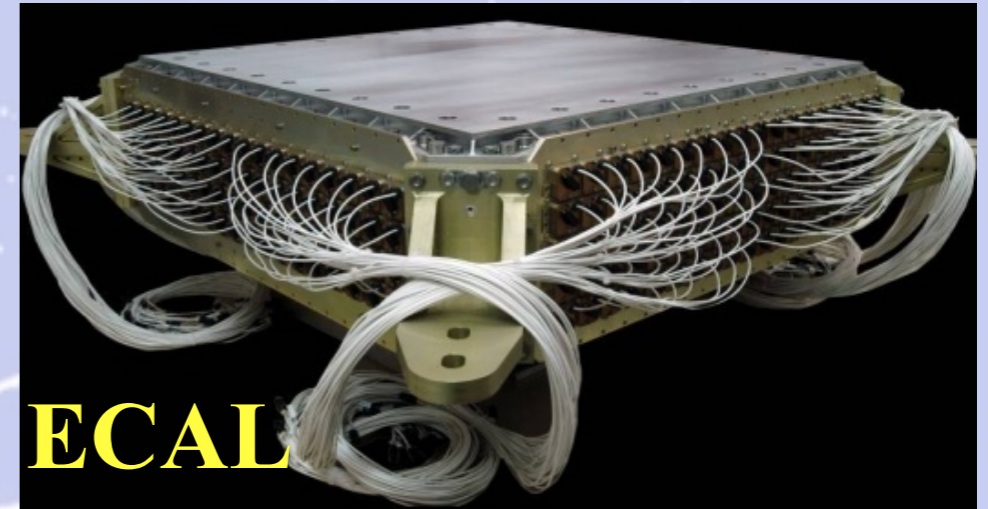
24 Heaters, 8 Pressure Sensors
482 Temperature Sensors

Tracker



4 -Pressure Sensors, 32 Heaters
142 Temperature Sensors

ECAL



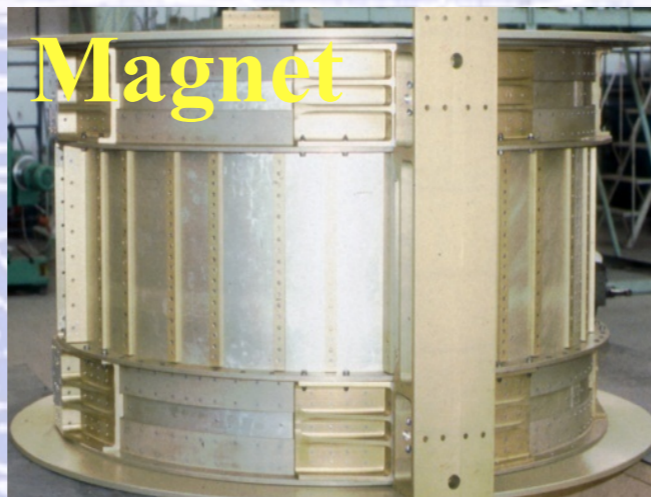
80 Temperature Sensors

TOF & ACC

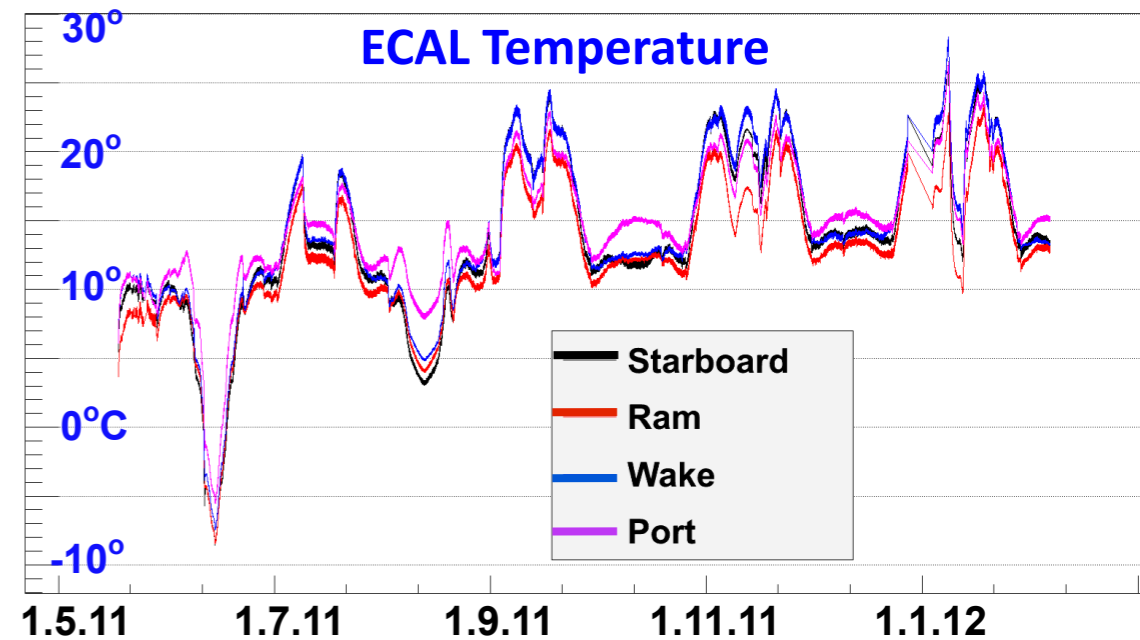


64 Temperature Sensors

Magnet



68 Temperature Sensors



RICH



96 Temperature Sensors

Over **1,100** temperature sensors and **298** heaters are monitored around the clock in the AMS POCC to assure components stay within thermal limits and avoid permanent damage.



Appendice 2

(Un po' di teoria)

Particle Physics Timeline

For over two thousands years people have thought about fundamental particles from which all matter is made.

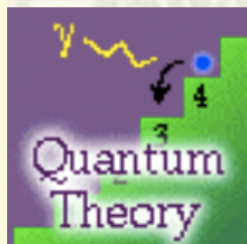
Starting with the gradual development of atomic theory, followed by a deeper understanding of the quantized atom, leading to the recent theory of the Standard Model.



Earliest times - 1550 AD: The Ancients



1550 - 1900 : The Scientific Revolution and Classical Mechanics



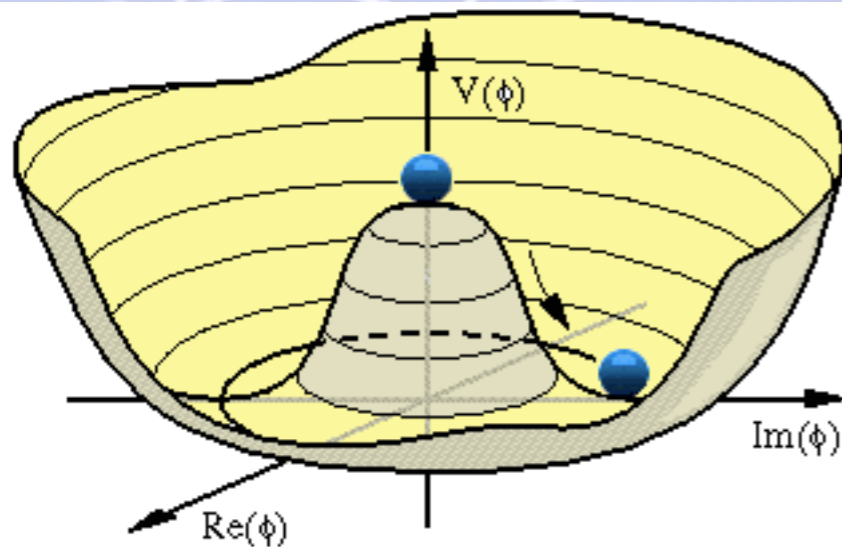
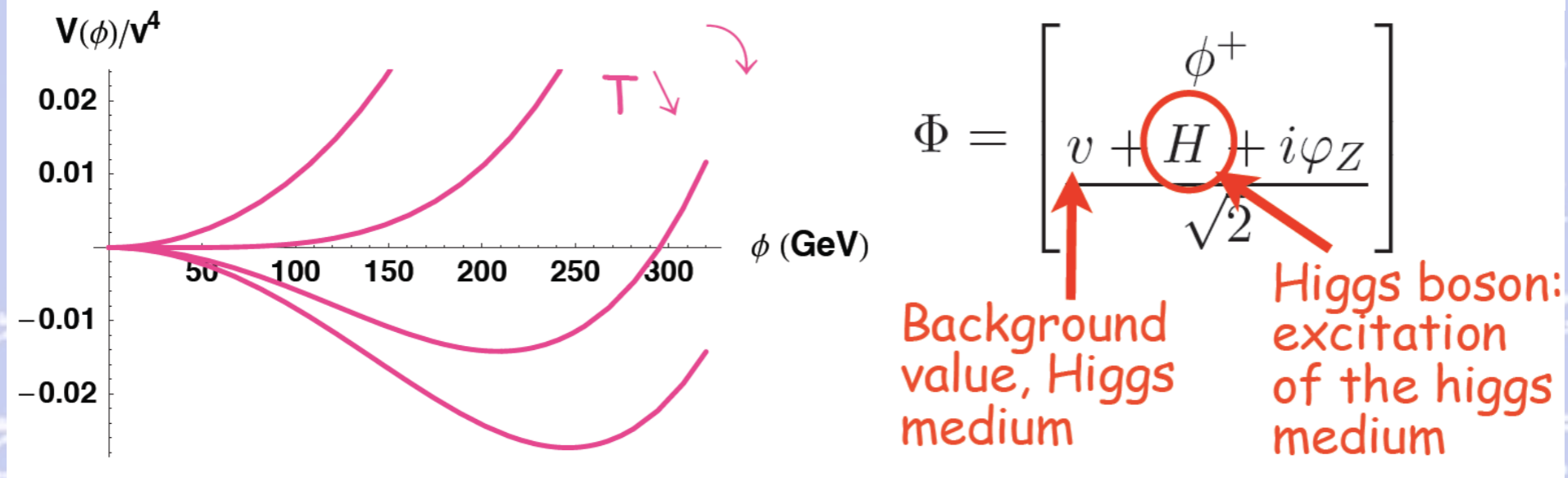
1900 - 1964 : Quantum Theory



1964 - Present: The Modern View (the Standard Model)

The (ad hoc) Higgs Mechanism (a model without dynamics)

EW symmetry breaking is described by the condensation of a scalar field



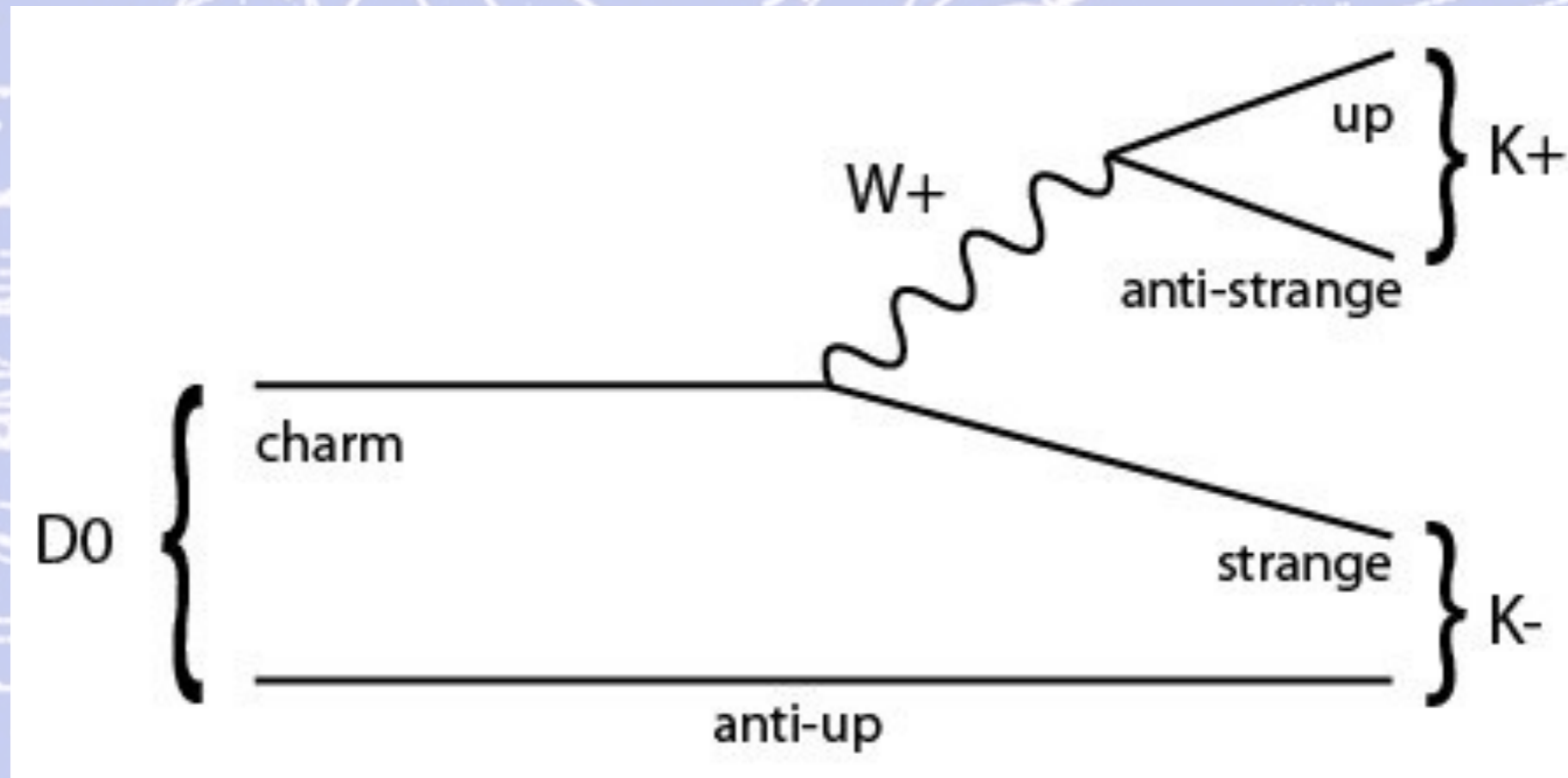
$$V(\Phi) = \frac{\mu^2}{2} \Phi^\dagger \Phi + \frac{\lambda}{4} \Phi^\dagger \Phi^2 \quad \text{Why is } \mu^2 \text{ negative?}$$

The Higgs selects a vacuum state by developing a non zero background value.

When it does so, it gives mass to SM particles it couples to.

**We do not know what makes the Higgs condensate.
We ARRANGE the Higgs potential so that the Higgs condensates but this is just a parametrization that we are unable to explain dynamically.**

D^0 meson decay at LHCb

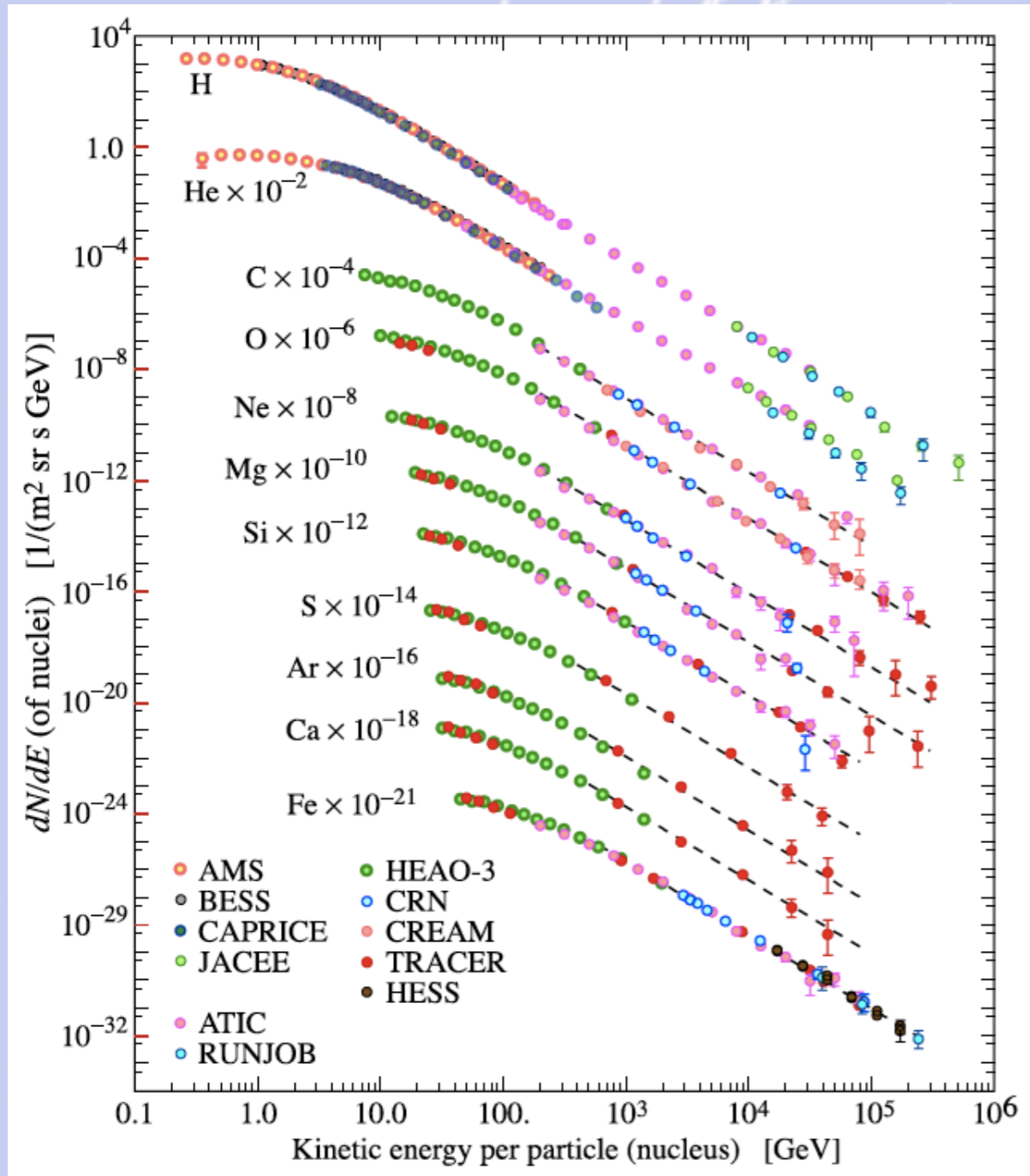




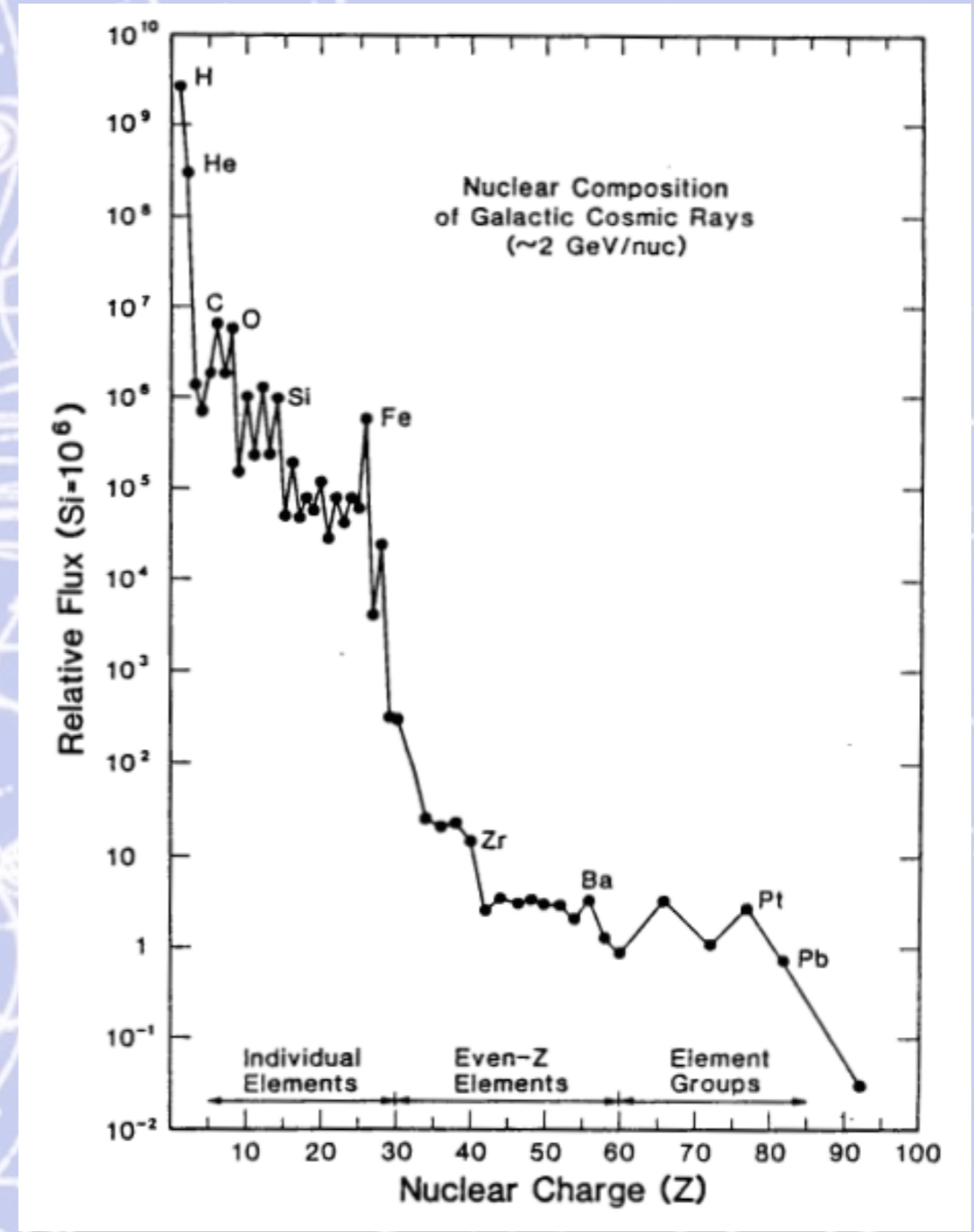
Appendice 3

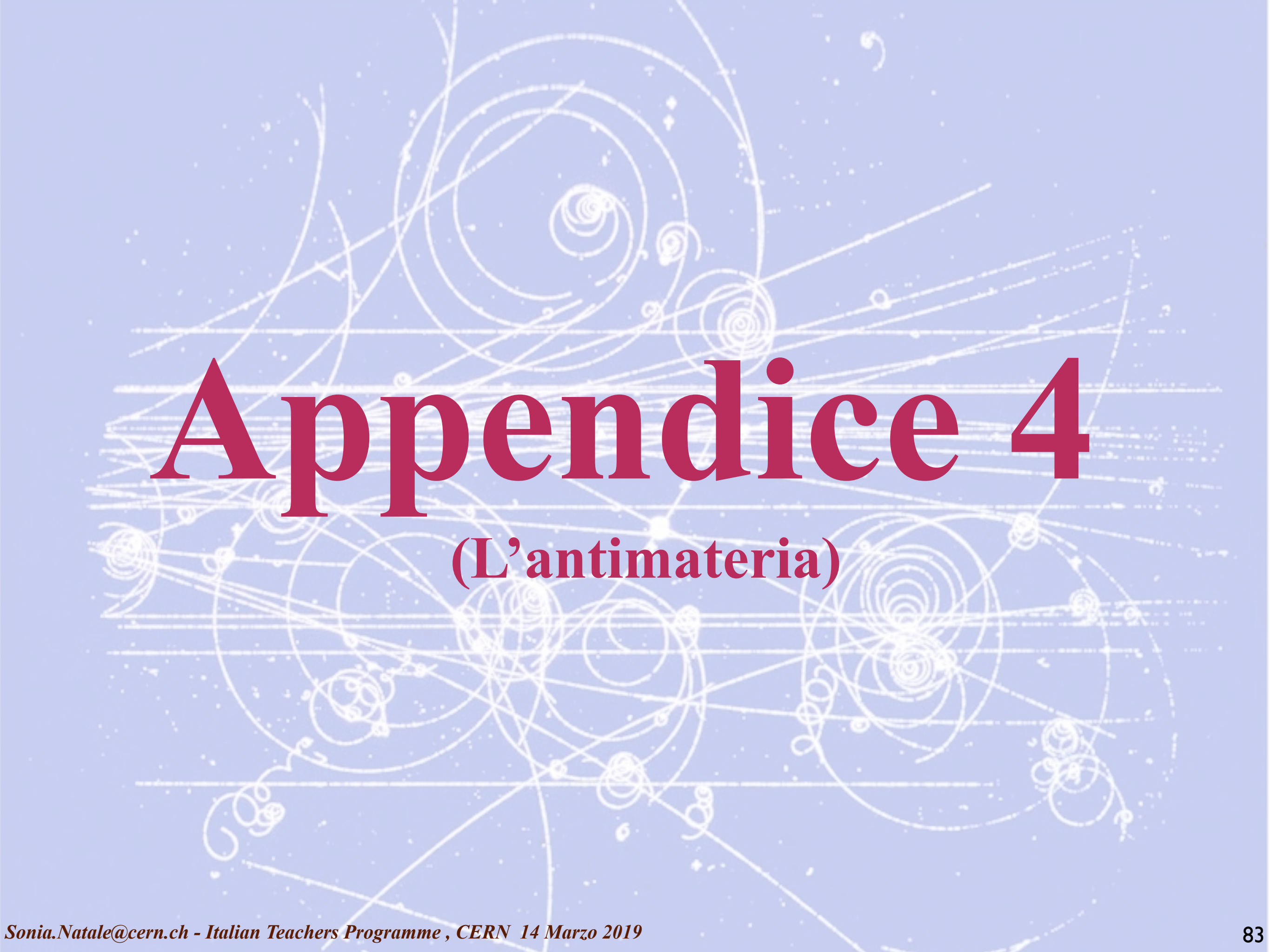
(I raggi cosmici)

Abundance of different particles (\rightarrow *identification*)



Abundance of different nuclei (elements)



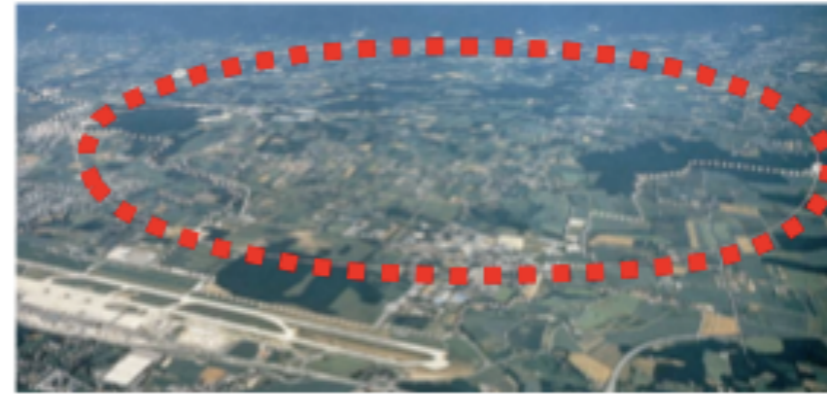


Appendice 4

(L'antimateria)

Physics of AMS: Search for Antimatter

in space



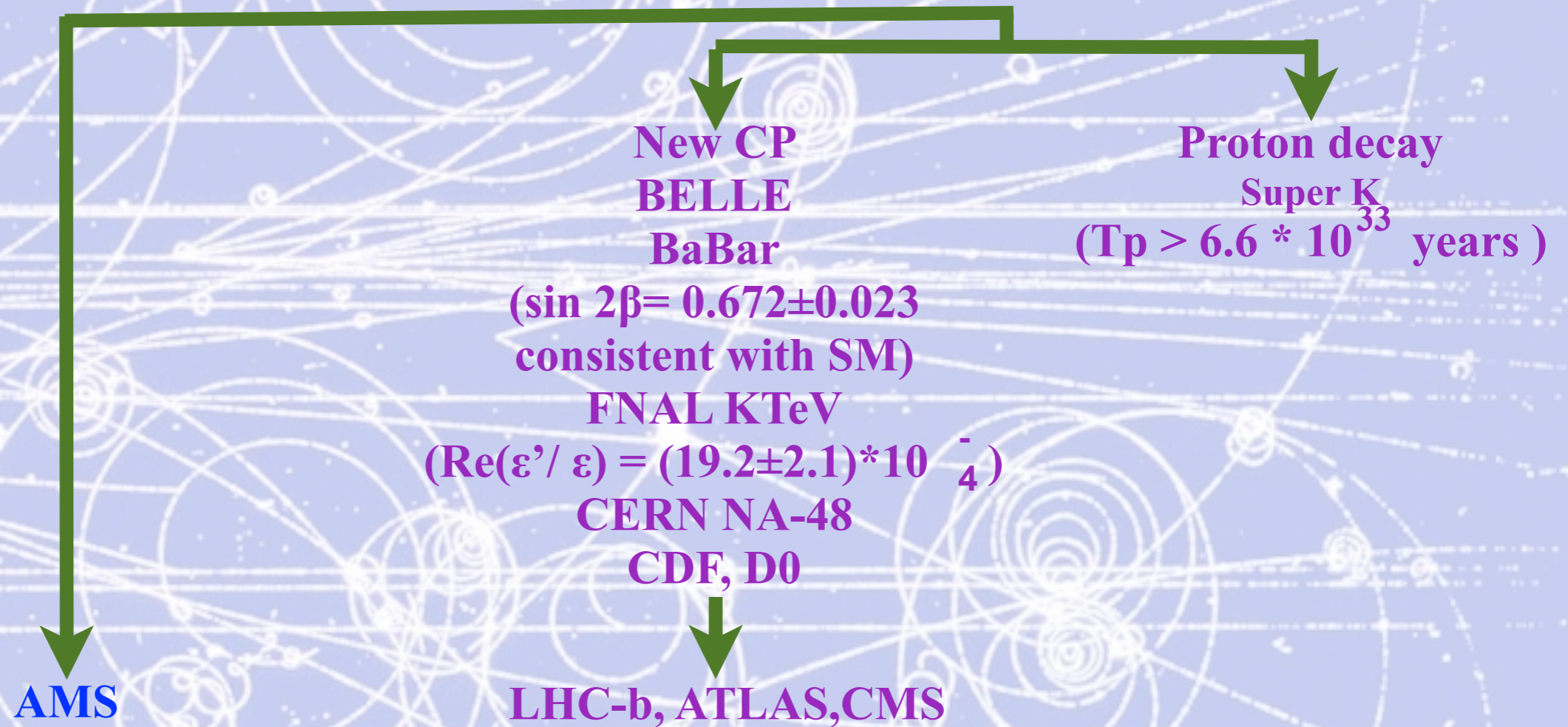
The Big Bang origin of the Universe requires Matter and Antimatter to be equally abundant at the very beginning

Physics of AMS: Search for Antimatter Universe

Experimental work on Antimatter in the Universe

Direct
search

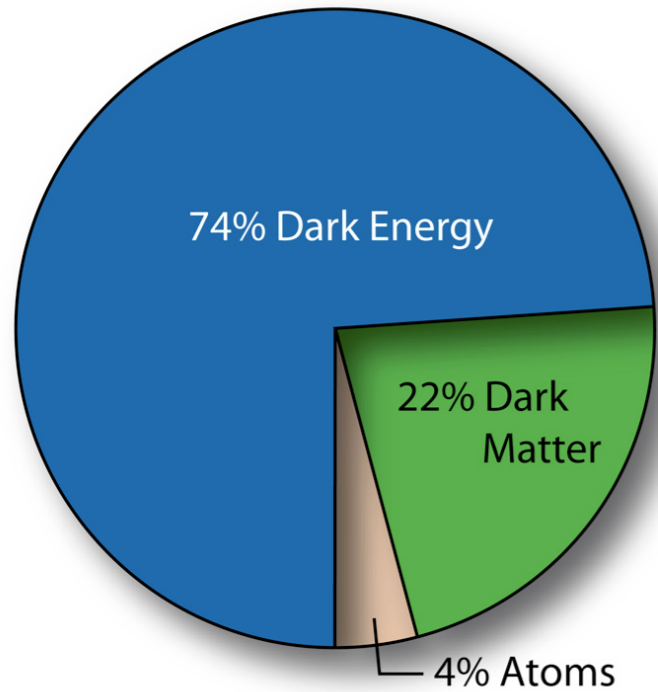
Search for
Baryogenesis



Increase in sensitivity: $\times 10^3 - 10^6$
Increase in energy to $\sim \text{TeV}$

No explanation found for the absence
of antimatter (no reason why
antimatter should not exist)

Are Dark Matter and baryon abundances related ?



Sakharov's conditions for baryogenesis (1967)

- 1) **Baryon number violation**
(we need a process which can turn antimatter into matter)
- 2) **C (charge conjugation) and CP (charge conjugation × Parity) violation.**
(we need to prefer matter over antimatter)
- 3) **Loss of thermal equilibrium**
(we need an irreversible process since in thermal equilibrium, the particle density depends only on the mass of the particle and on temperature, particles & antiparticles have the same mass , so no asymmetry can develop)

Baryonic asymmetry characterized in terms of the baryon to photon ratio

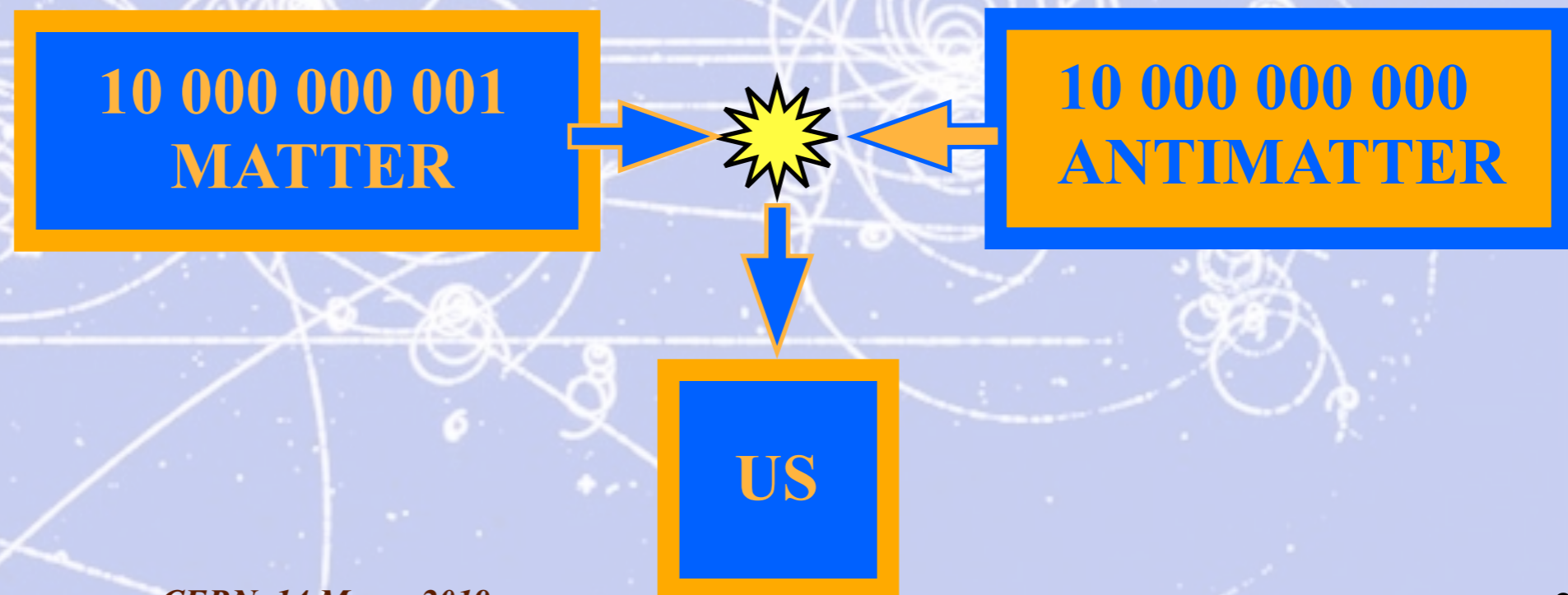
$$\frac{n_B - \bar{n}_B}{n_\gamma} \sim 6 \times 10^{-10}$$

$$\Omega_{DM} \approx 5-6 \Omega_{baryons}$$

if $n_{DM} - \bar{n}_{DM} \sim n_B - \bar{n}_B$

$$\frac{\Omega_{DM}}{\Omega_{baryons}} \sim C \frac{m_{DM}}{m_{baryons}}$$

Does this indicate a common dynamics?



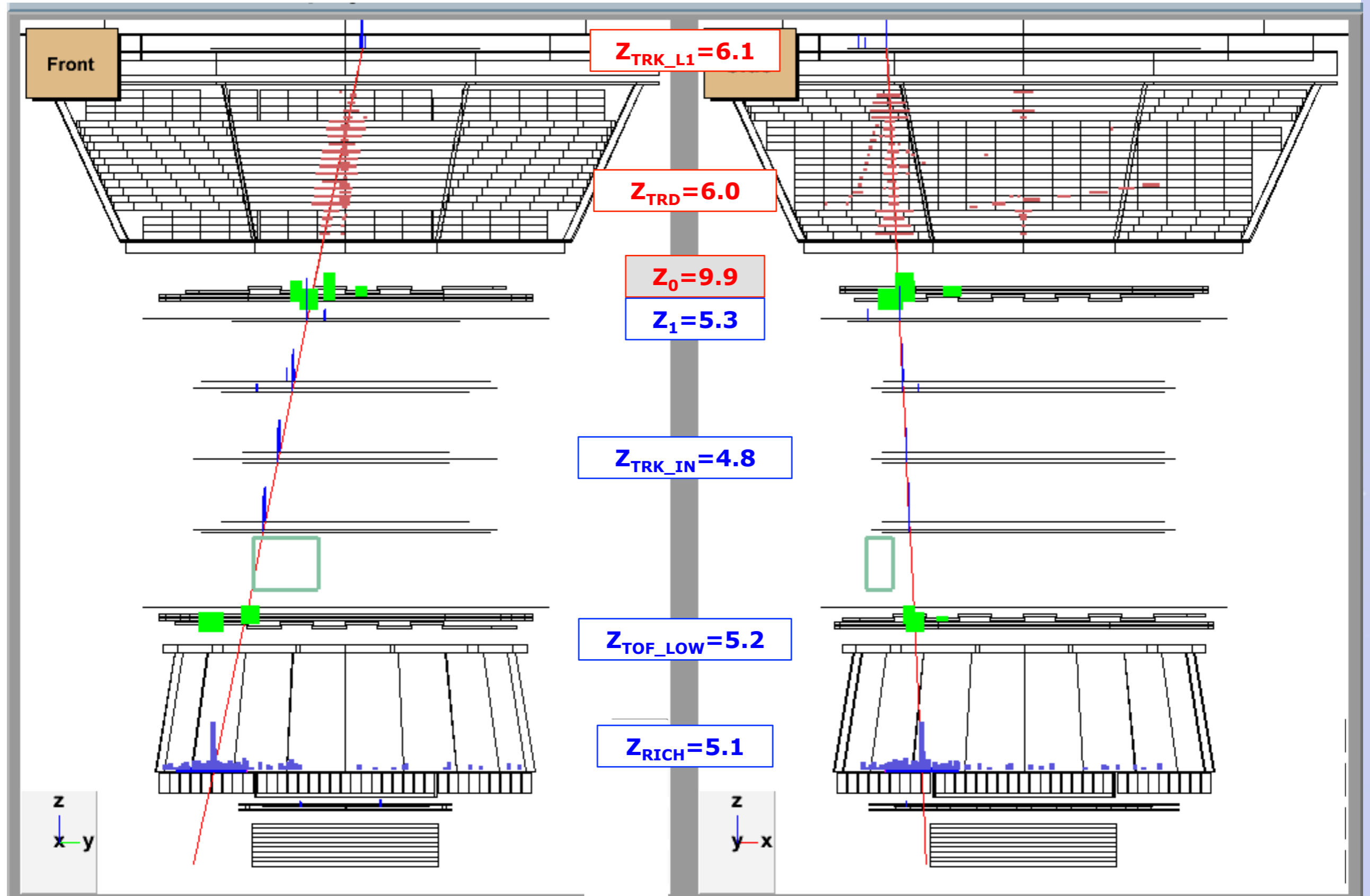
The background of the slide is a light blue color with a complex pattern of white lines. These lines represent particle tracks, consisting of many overlapping circles, spirals, and straight lines, some of which are dashed. The overall effect is that of a particle detector's output, such as a bubble chamber or a silicon detector.


Appendice 5

(Rapporto Boro/Carbonio)

Carbon Fragmentation to Boron in Upper TOF

Rigidity 10.6 GV

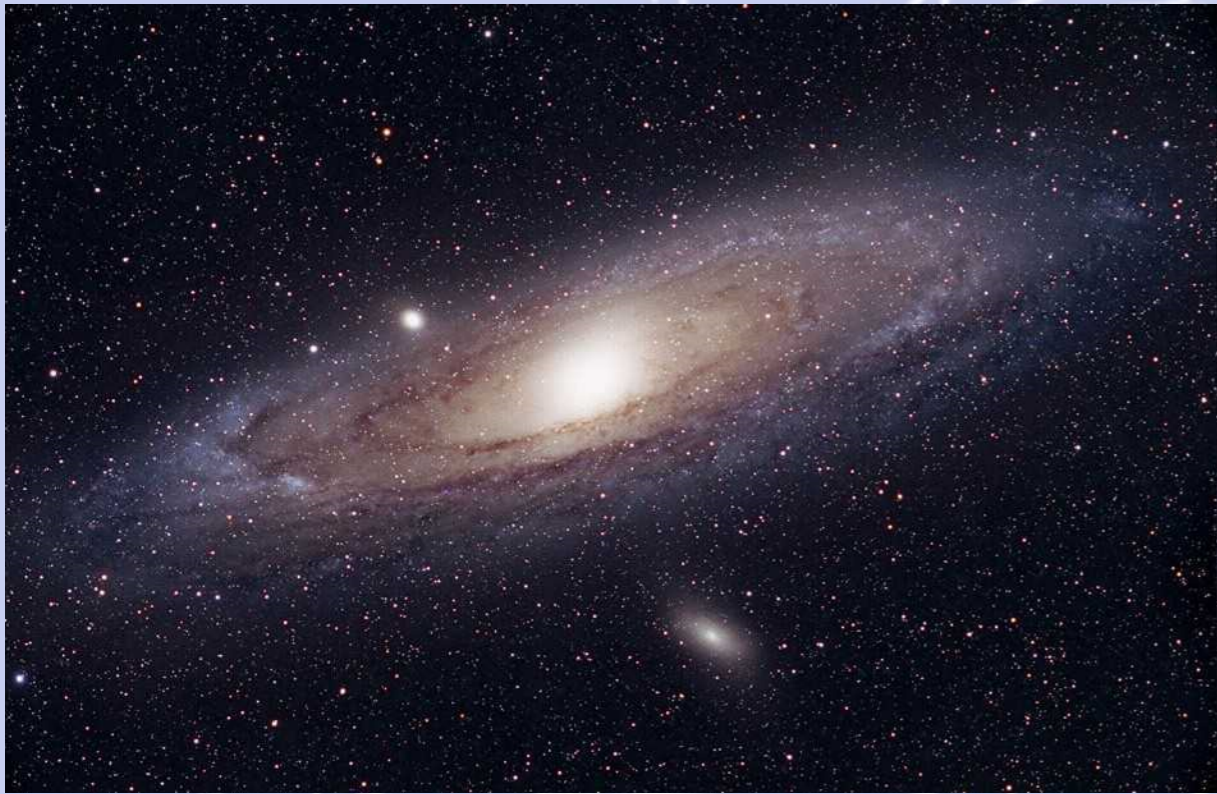


The background of the slide is a light blue color with a complex pattern of white lines and dots. These lines form various shapes, including spirals, circles, and straight paths, resembling star trails or the structure of galaxies. The dots are scattered throughout, representing stars or distant galaxies. The overall effect is a cosmic or astronomical theme.

Appendice 6

(La materia Oscura)

Dark Matter

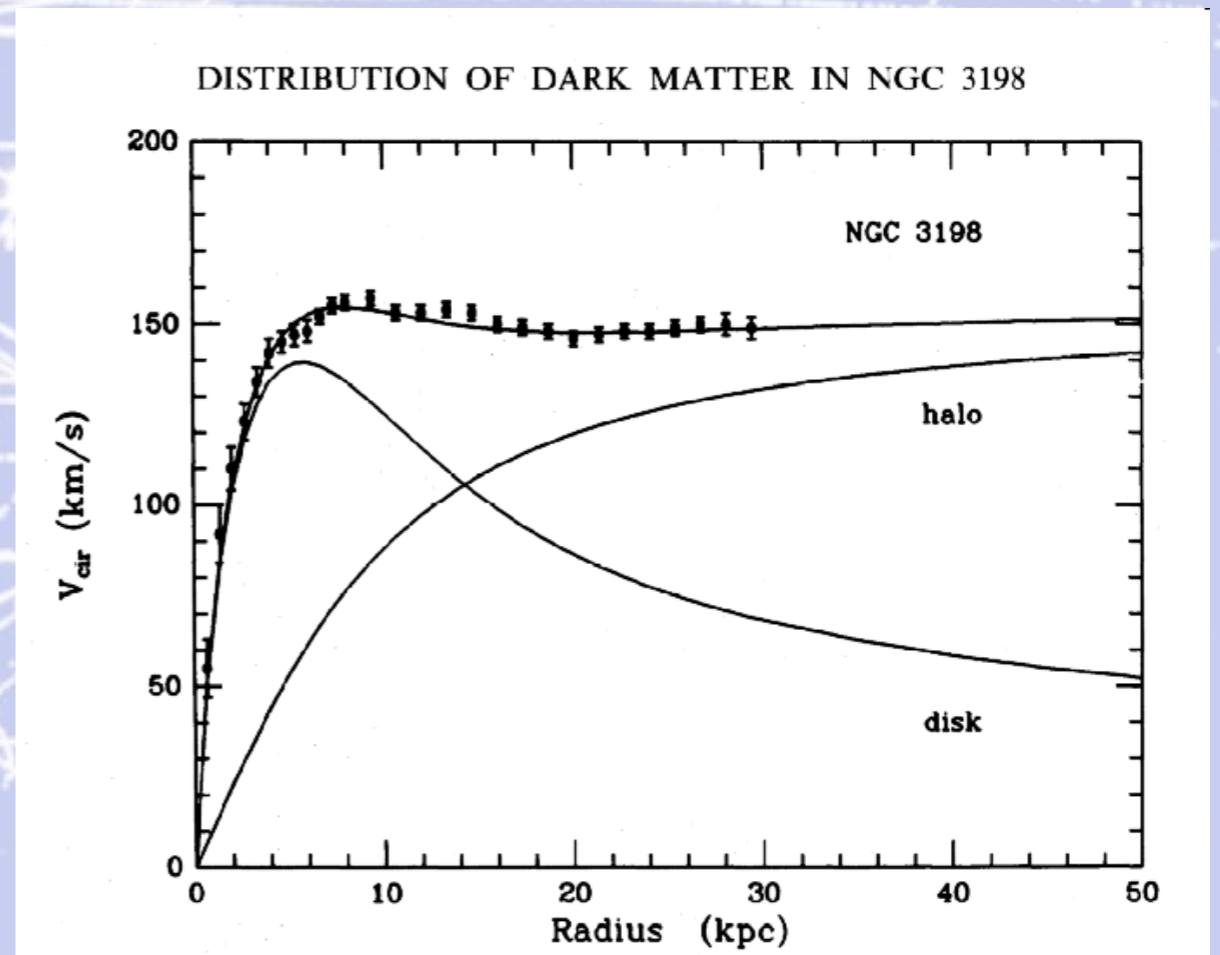


The velocity of stars lying at galaxies periphery indicate that there is much more matter in the galaxy than what we measure from visible stars.

We don't know the nature of this new kind of matter we can only detect from its gravitational effects.

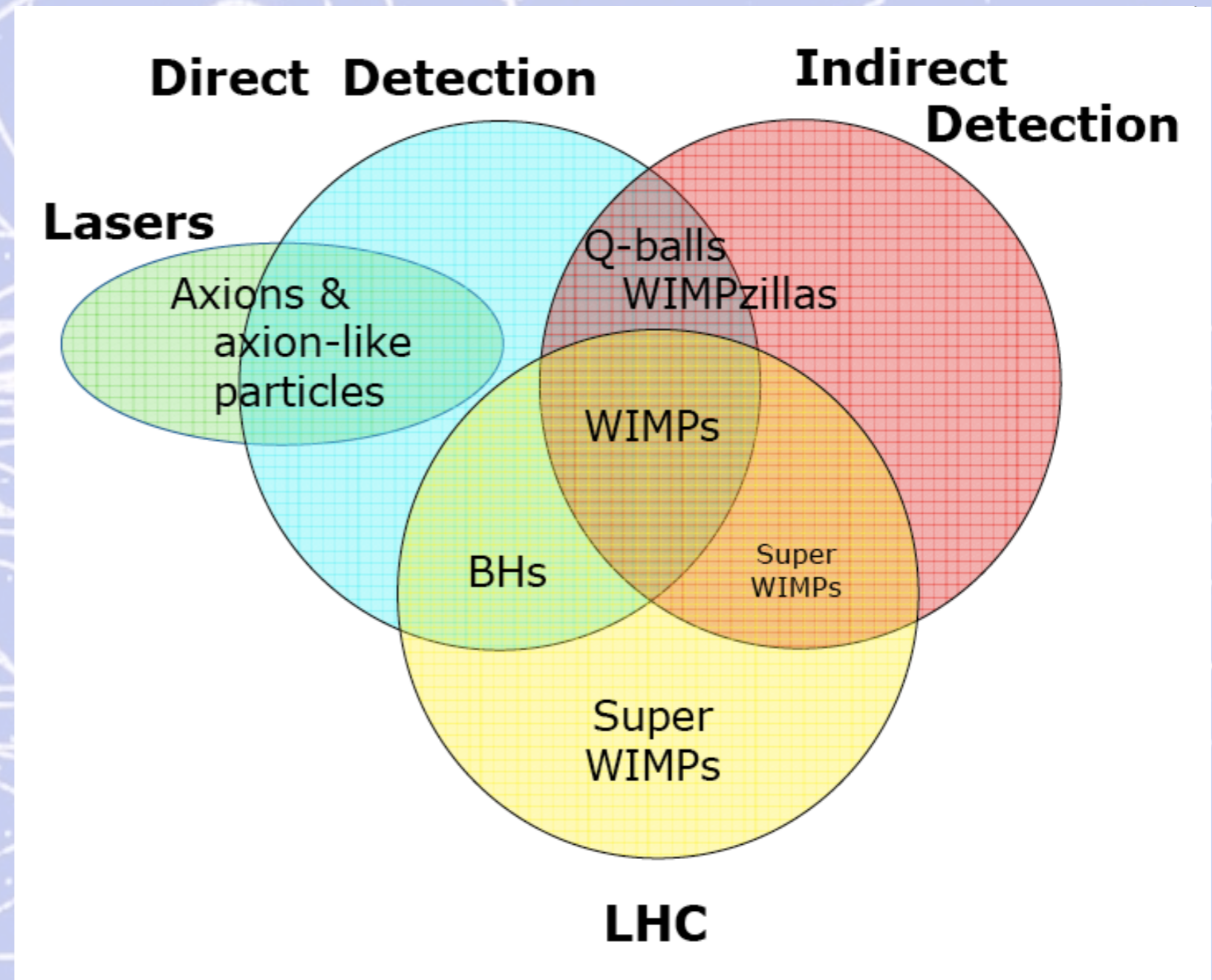
Several hypothesis exist to explain it.

One of them tells that Dark Matter should be composed by supersymmetric particles not yet detected nowadays.

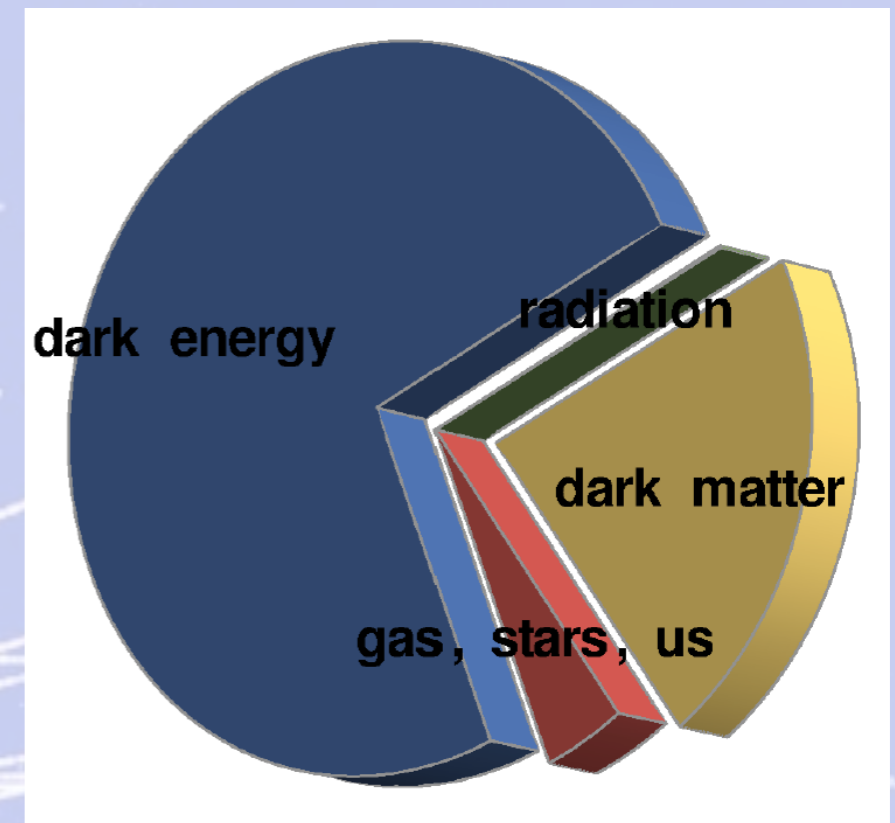
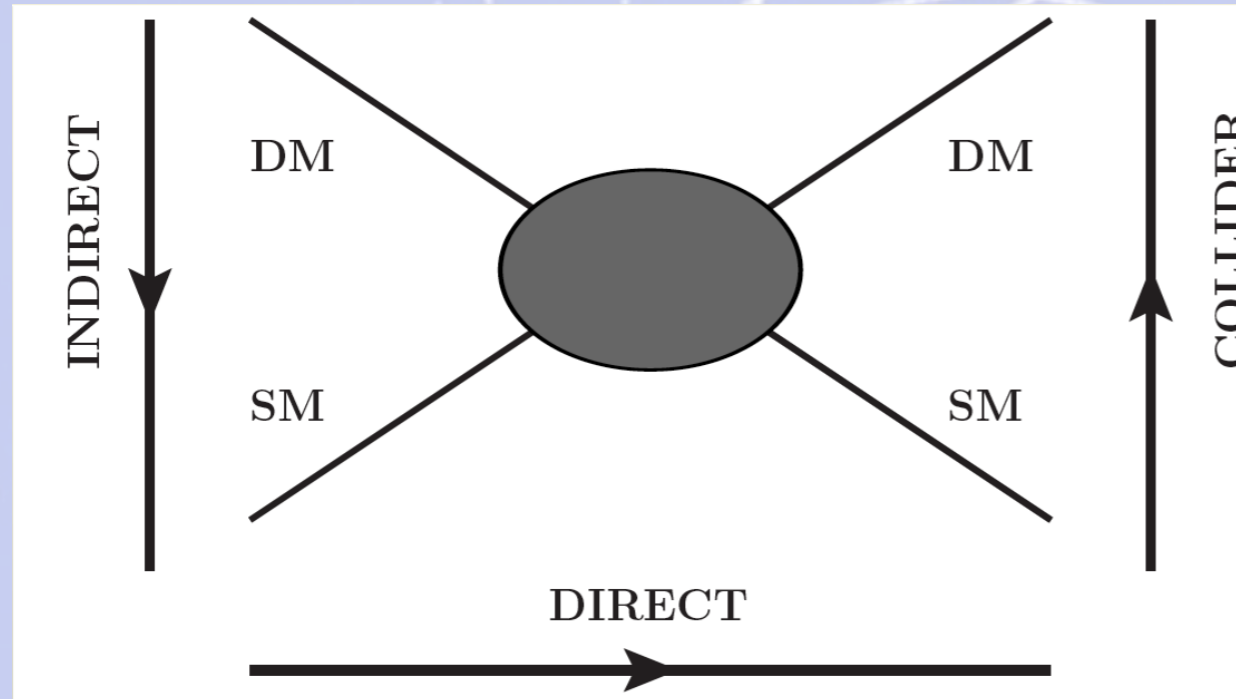


Dark Matter detection

- **WIMPs**
 - **Neutralinos**
 - **Kaluza-Klein particles**
 -
- **Axinos**
- **Super-WIMPs**
- **Axions**
- **Axion-like light bosons**
- **Sterile neutrinos**
- **Q-balls**
- **WIMPzillas**
- **Elementary BHs**



Ways of detecting dark matter



1 Direct detection.

2 Indirect detection: searching for products of annihilation.

High energy photons

- Space telescopes: COMPTEL, Fermi-LAT, AMS

- ACTs: HESS, Veritas, Magic.

Electrons/positrons: PAMELA, ATIC, Fermi-LAT, AMS, HESS, MAGIC.

Antiprotons: PAMELA, AMS.

Neutrinos: ANTARES, IceCube.

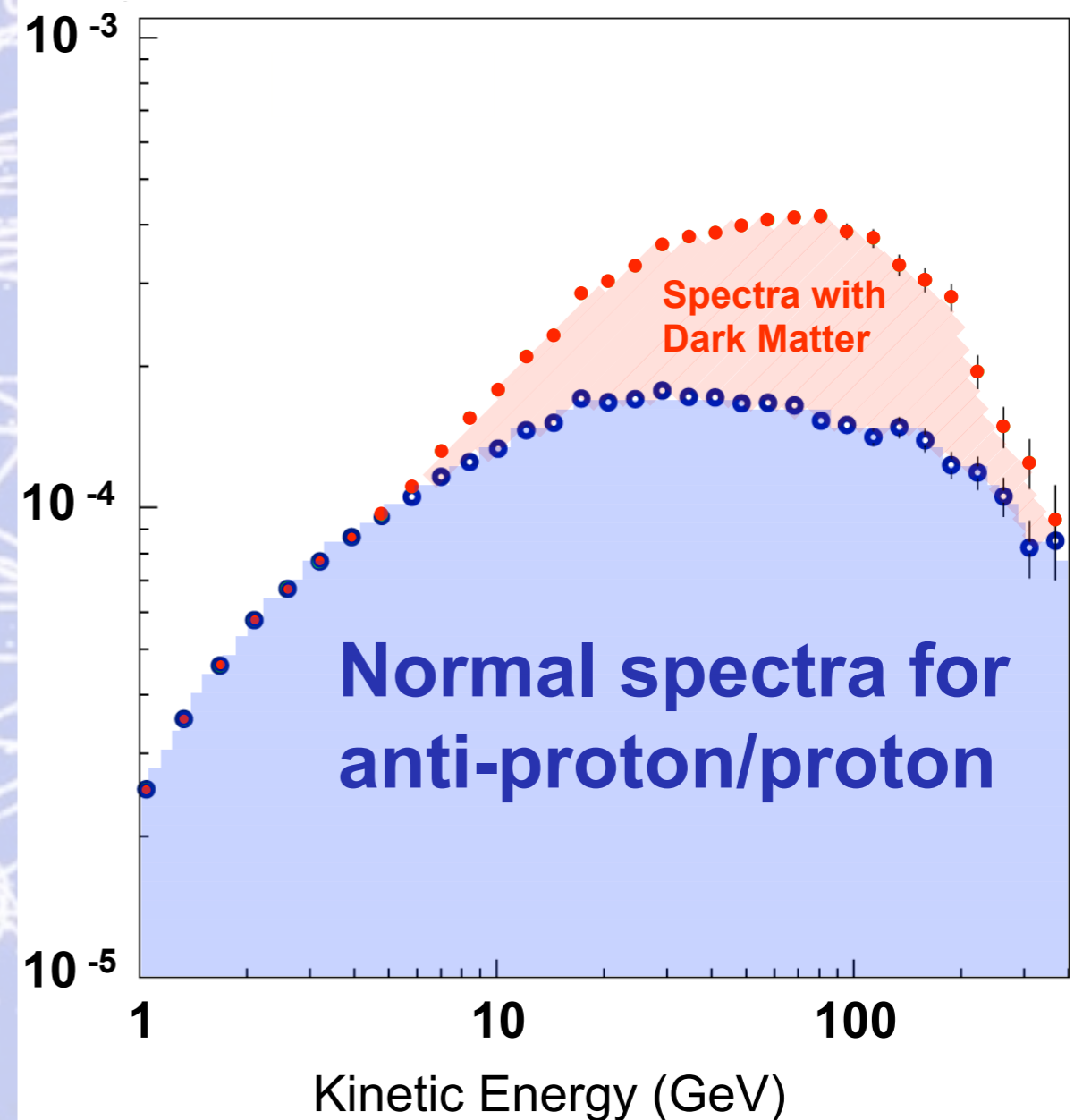
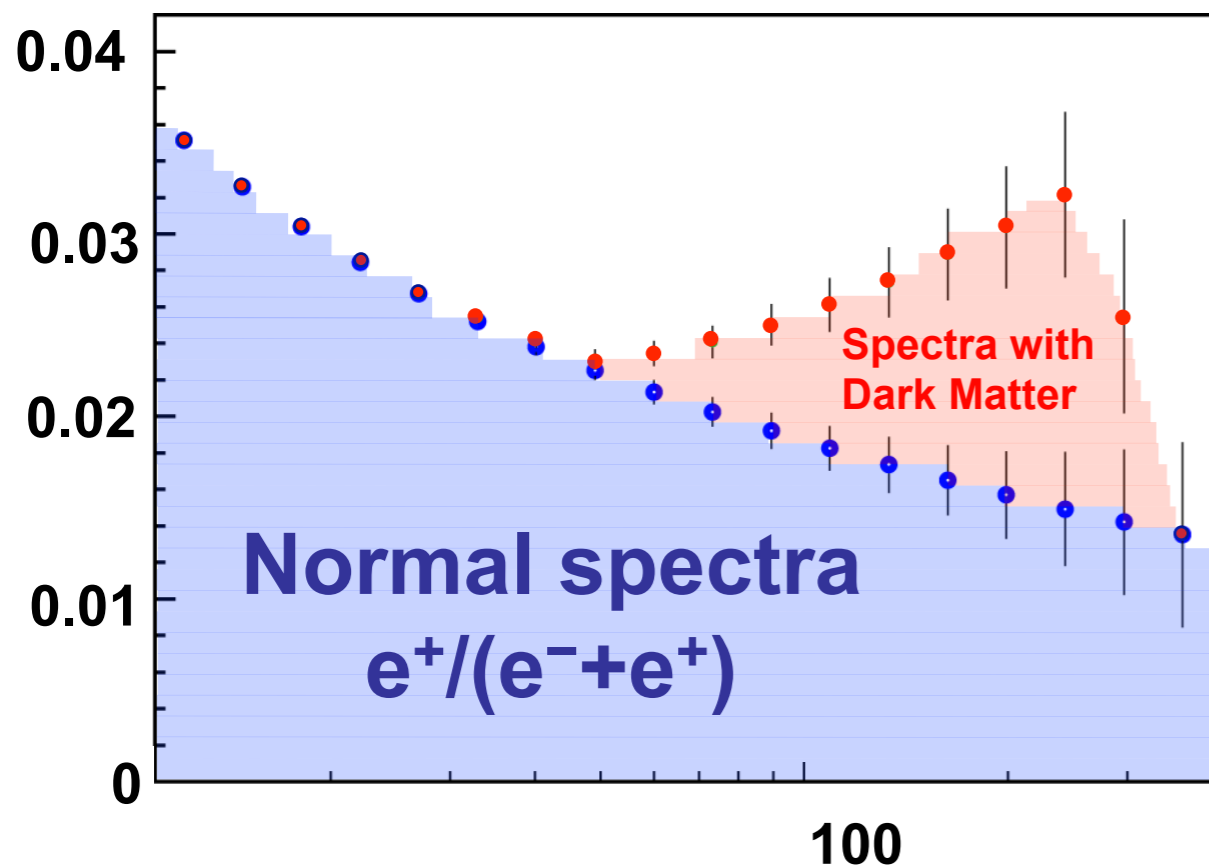
3 Collider searches: LHC.

4 Indirect2: CMB optical depth and anisotropies, IGM temperature and 21 cm - recombination and reionization observables, BBN.

Dark Matter: neutralino annihilation

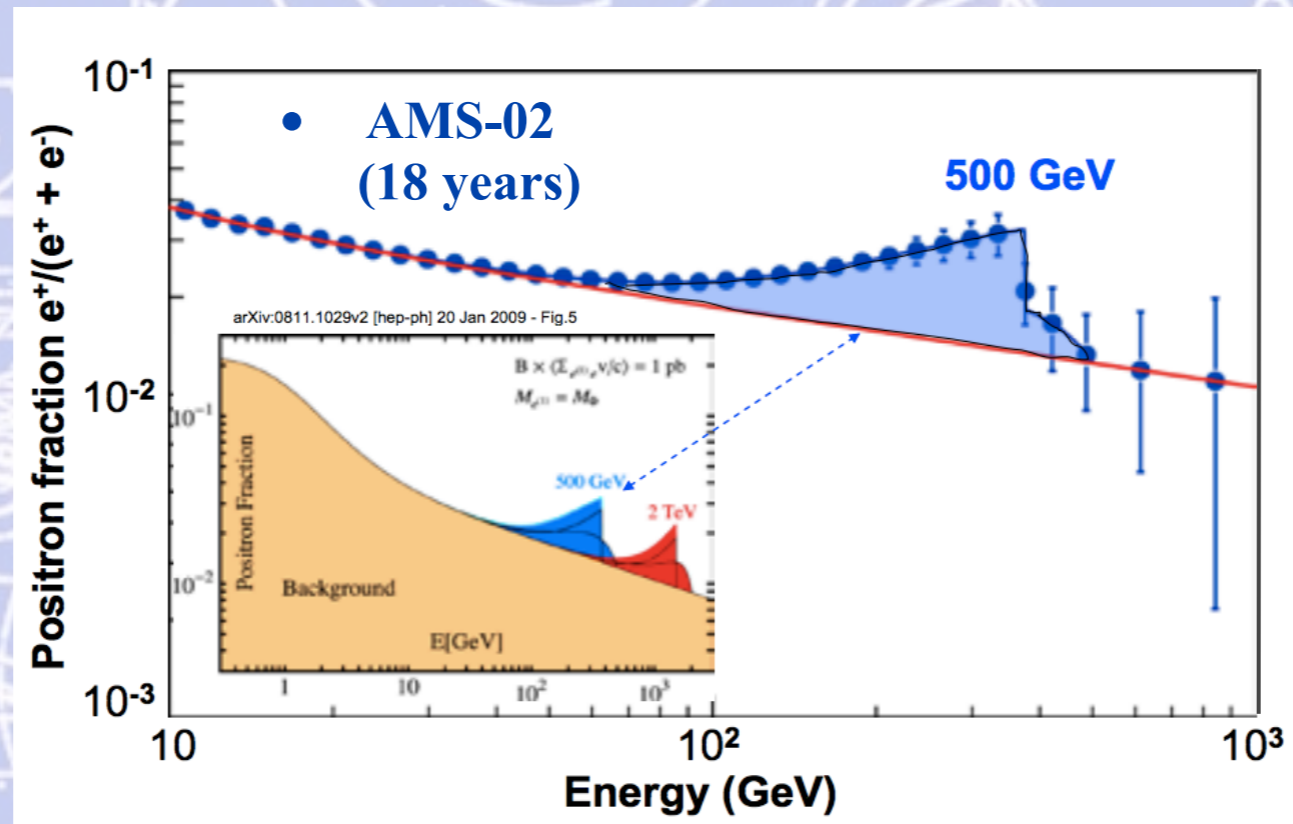
Lets suppose the existence of massive particles (χ) which are their own anti-particles.
If they meet they annihilate producing other particles and anti-particles
thanks to the available energy.

As a consequence, the cosmic rays
spectrum will be modified.
These anomalies can be searched in
positrons or anti-protons spectra.



Physics of AMS: Search for Dark Matter

The lightest Kaluza-Klein state is an excellent dark matter candidate if standard model particles propagate in extra dimensions (universal extra dimensions)



Expected spectrum from collisions of 500 GeV Kaluza-Klein bosons based on Pontón and Randall model

E.Pontón and L.Randall, preprint
arXiv:0811.1029v2 (2009)

Un esempio di modello (1)

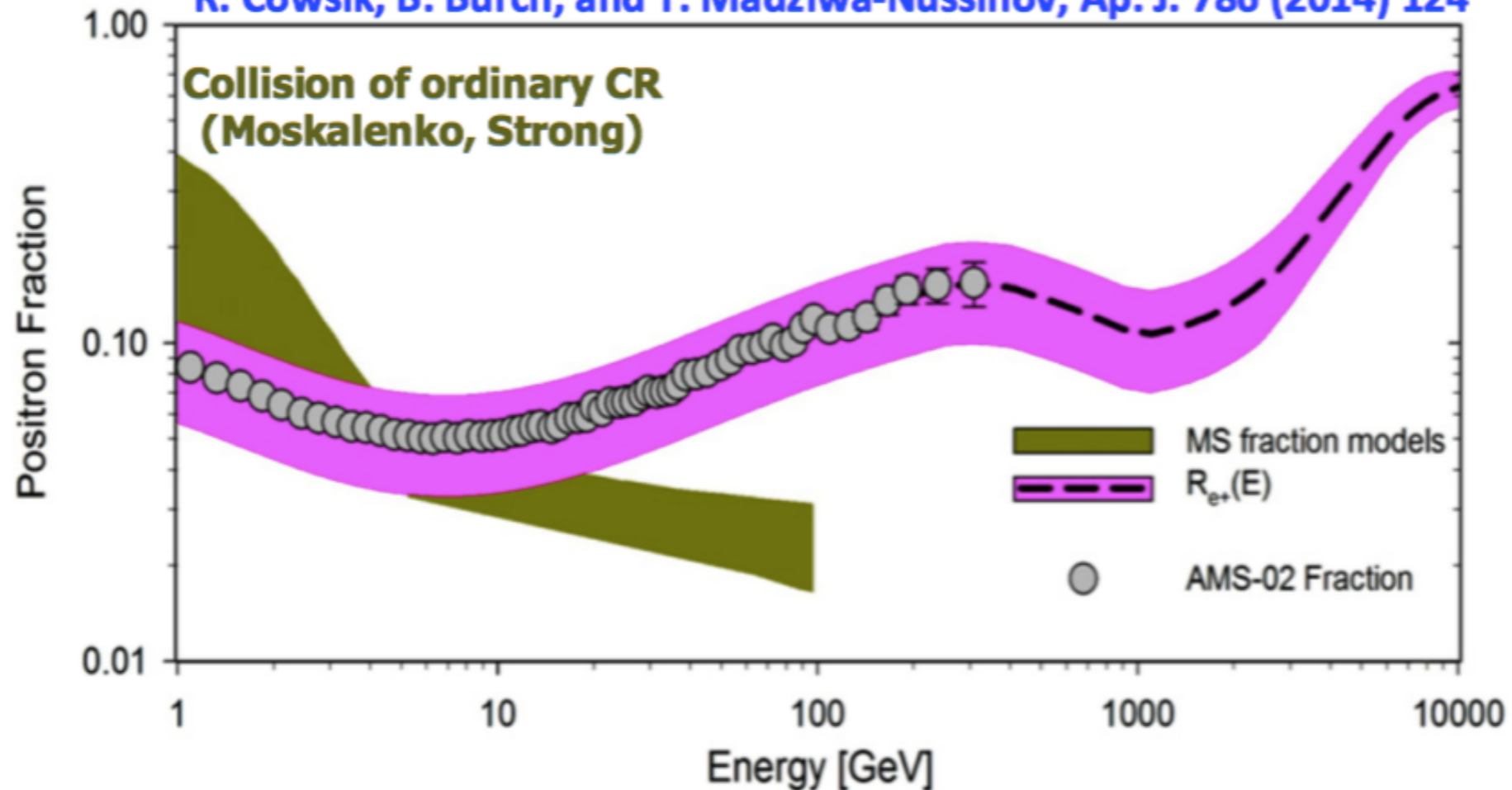
Theoretical models to explain the AMS positron fraction.

Among the 100's of models there are three classes:

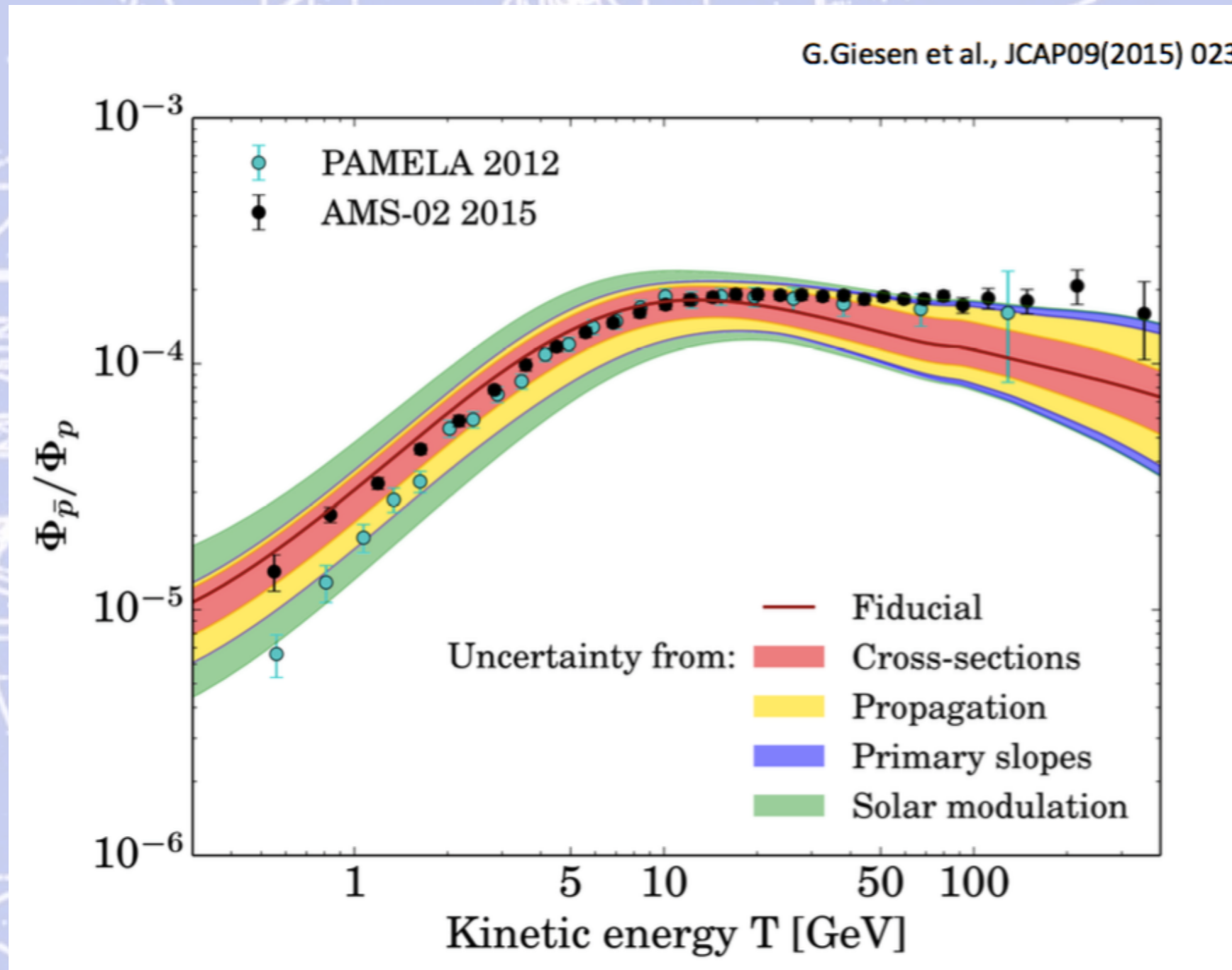
- a) dark matter
- b) new forms of propagation
- c) pulsars.

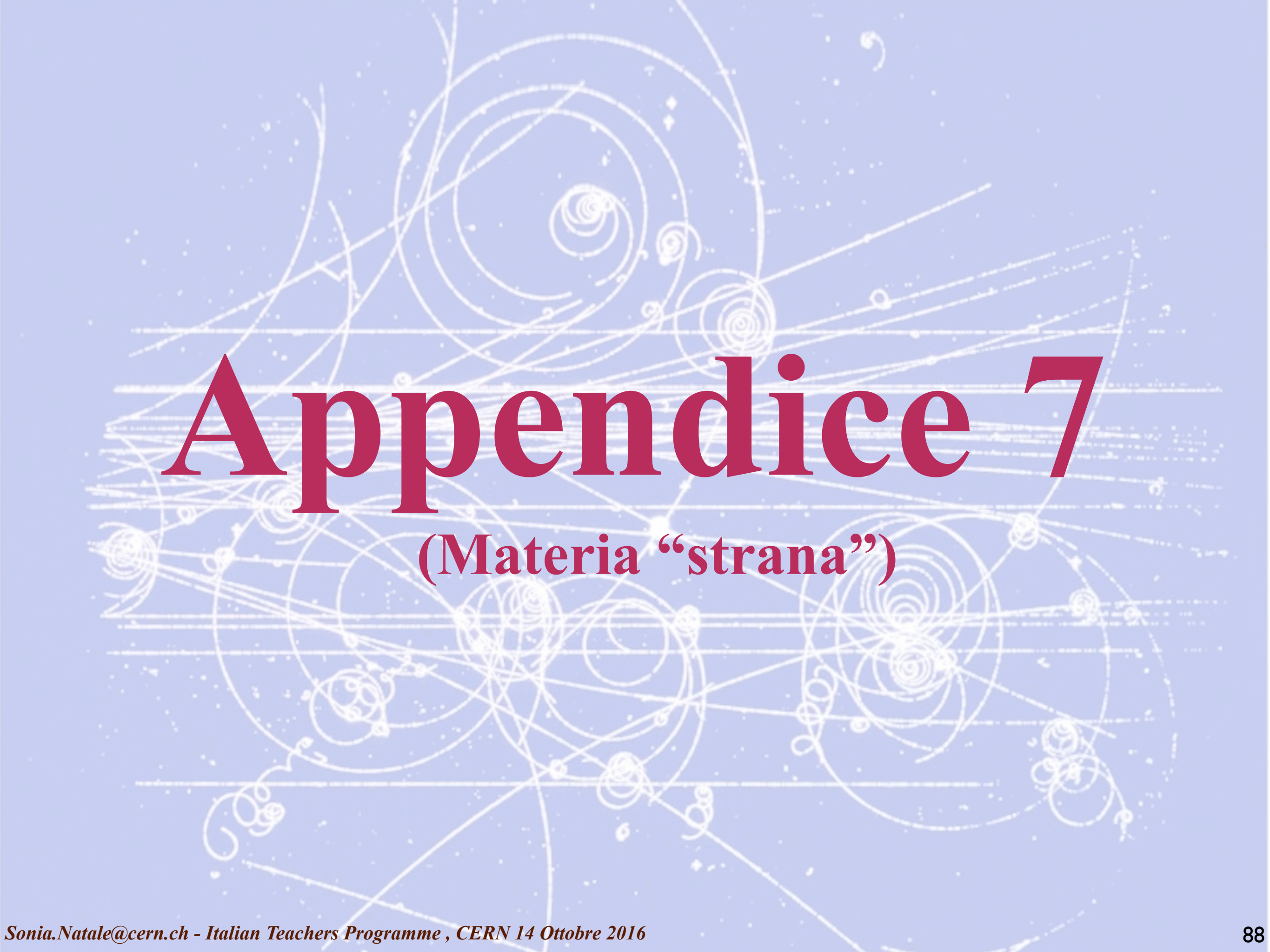
b) An example of new propagation:

R. Cowsik, B. Burch, and T. Madziwa-Nussinov, *Ap. J.* 786 (2014) 124



Un esempio di modello (2)



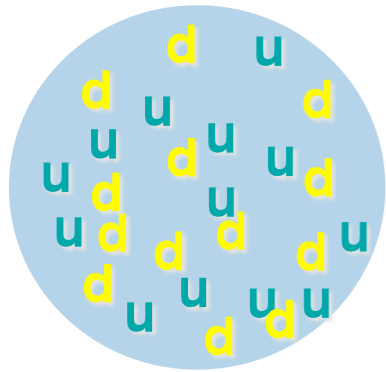


Appendice 7

(Materia “strana”)

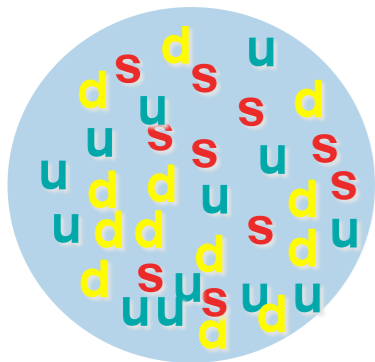
Search for Strangelets

All the known material on Earth is made out of u and d quarks



Diamond ($Z/A \sim 0.5$)

Is there material in the universe made up of u, d, & s quarks?

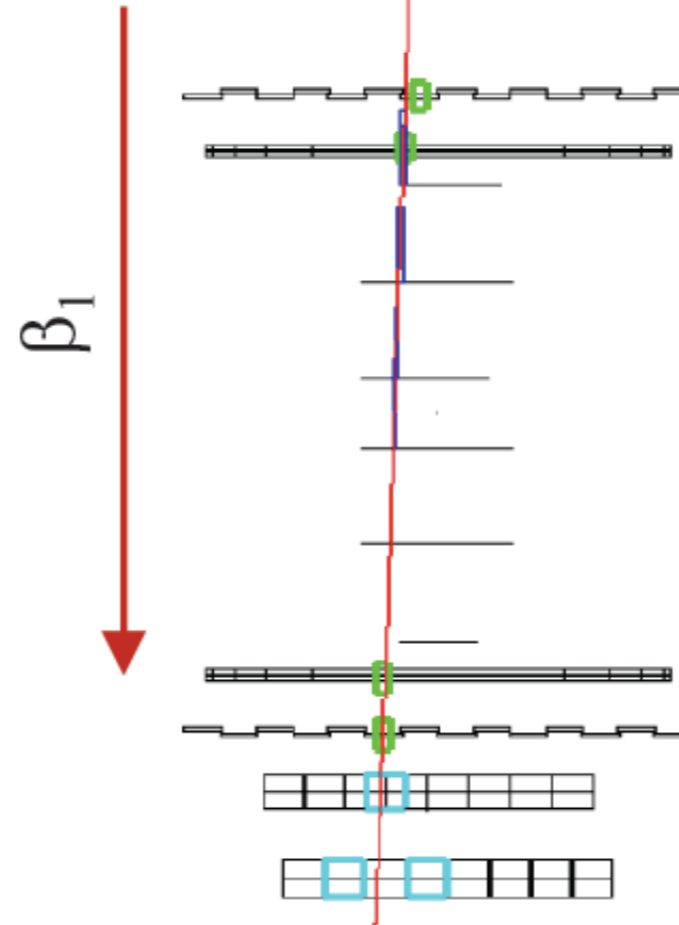


Strangelet ($Z/A < 0.1$)

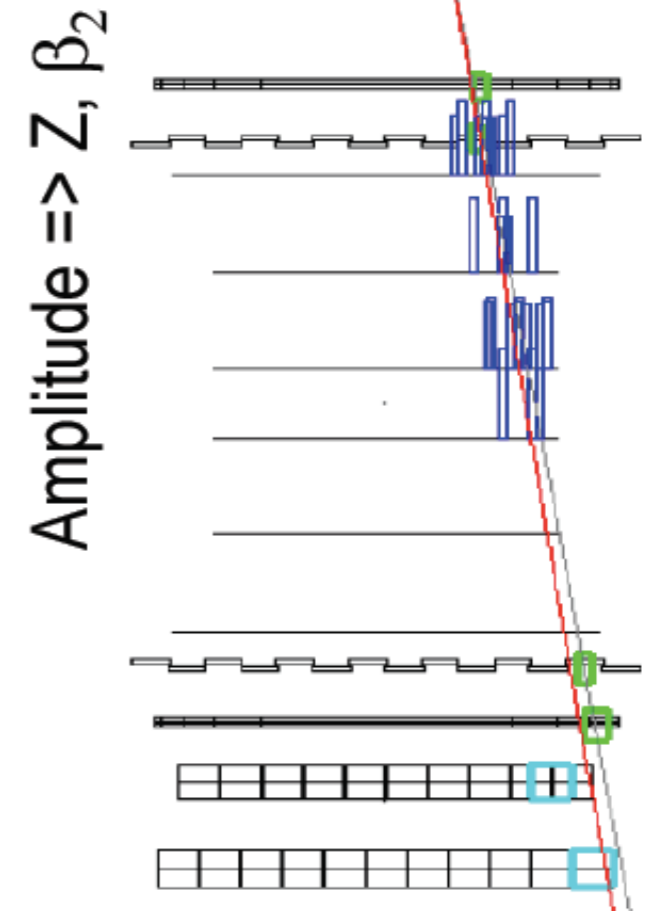
This can be answered definitively by AMS.

Candidate observed with AMS-01
5 June 1998 11:13:16 UTC

Front view



Side view



Rigidity = 4.31 ± 0.38 GV

Charge $Z = 2$

$\beta_1 = \beta_2 = 0.462 \pm 0.005$

Mass = 16.45 ± 0.15 GeV/c²

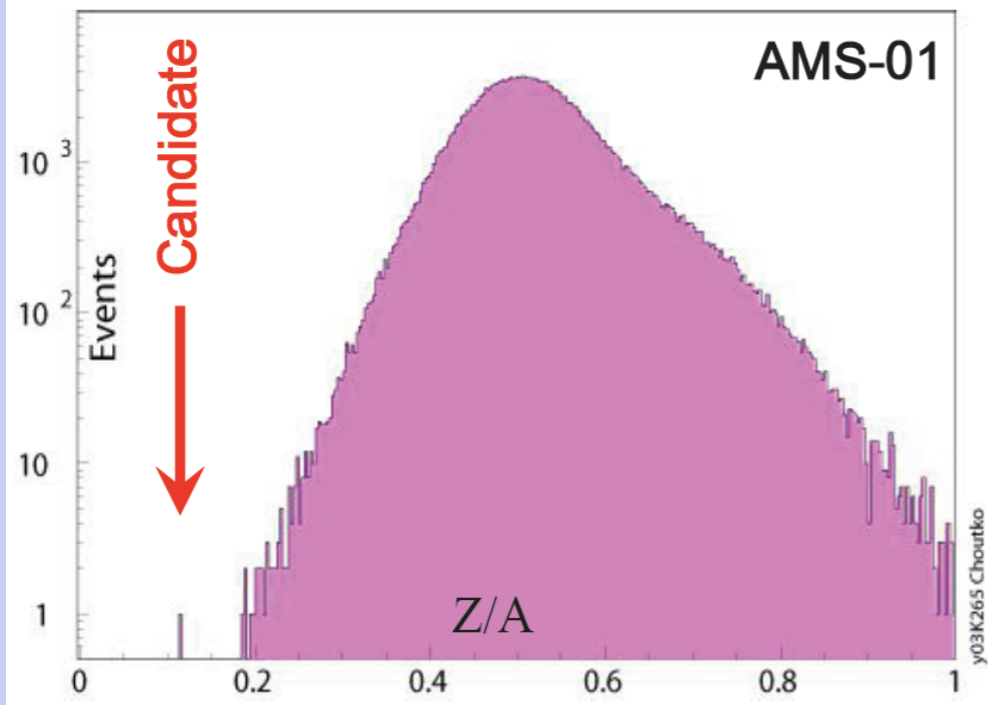
$Z/A = 0.114 \pm 0.01$

Flux ($1.5 < E_K < 10$ GeV) = 5×10^{-5} (m²sr sec)⁻¹

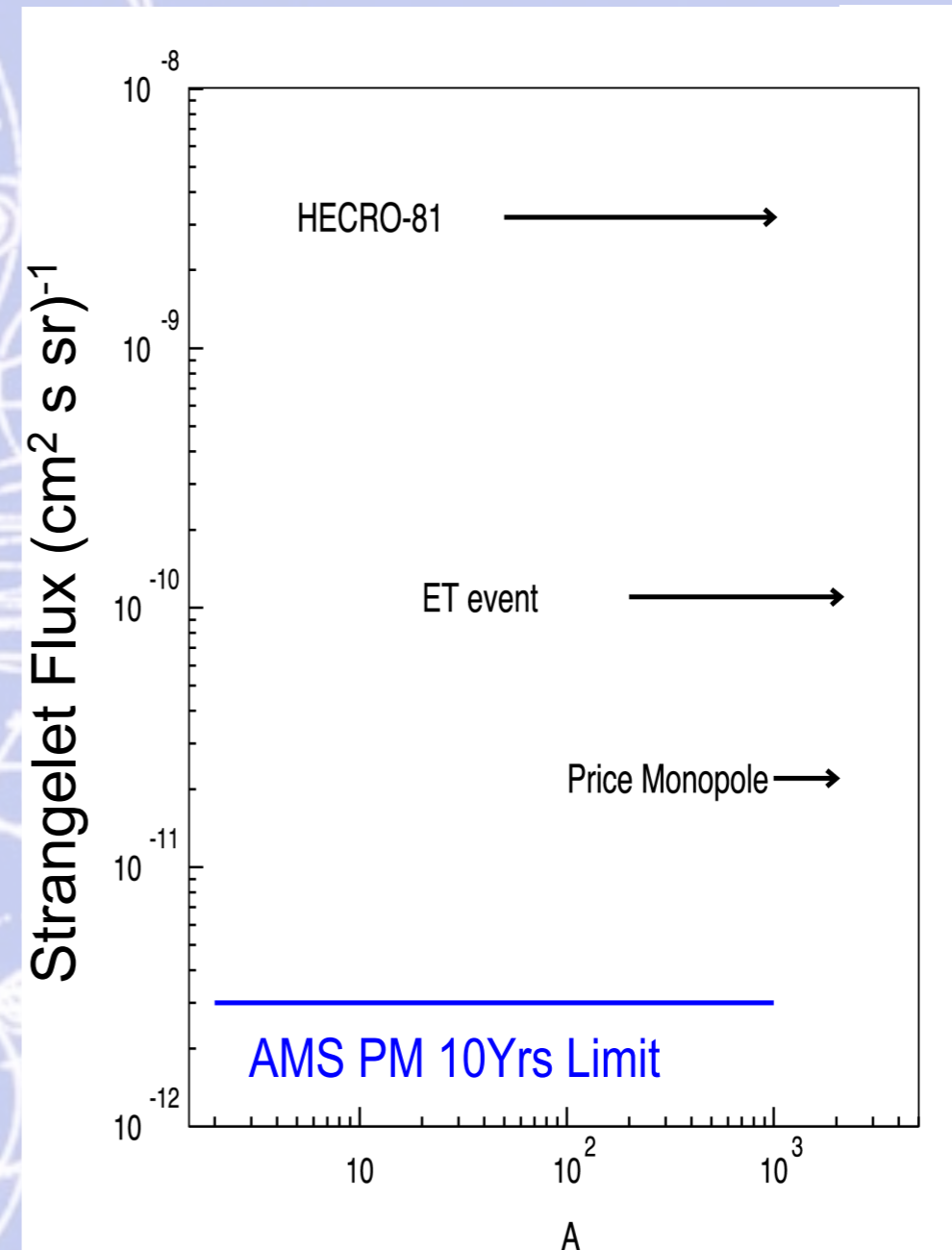
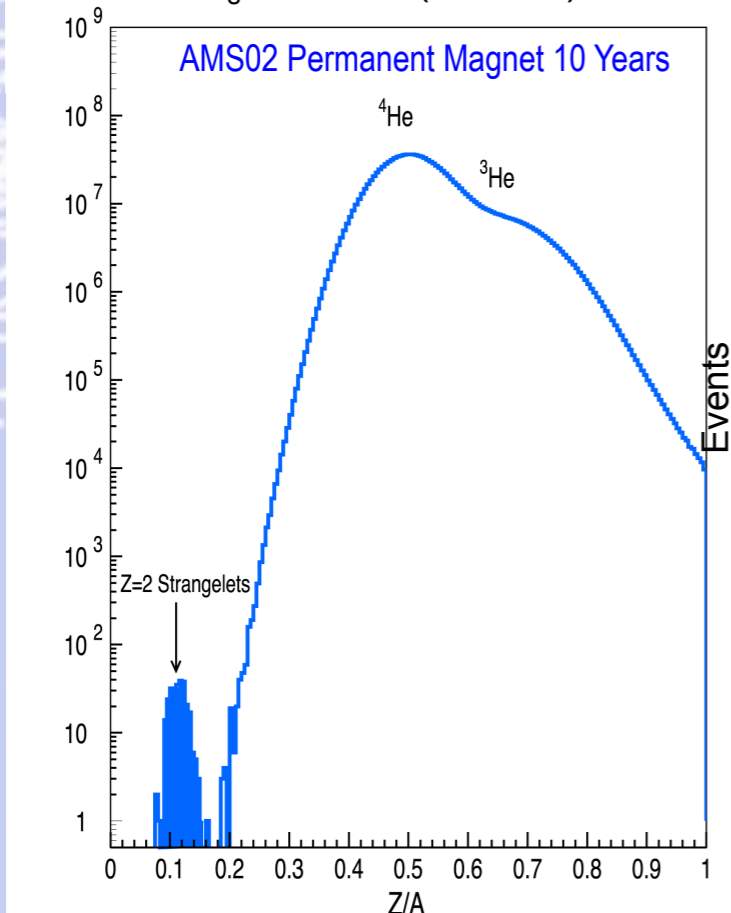
Search for Strangelets

E. Witten, Phys. Rev. D, 272-285 (1984)

Candidate observed with AMS-01
5 June 1998 11:13:16 UTC



$$\Phi_s = 5 \times 10^{-10} (\text{cm}^2 \text{s sr})^{-1}$$



Background probability $< 10^{-3}$

$\Phi_{\text{strangelets}} = 5 \times 10^{-10} (\text{cm}^2 \text{s sr})^{-1}$
or ~30 in 1st year for AMS-02

The background of the slide is a light blue field filled with numerous white, intricate particle tracks. These tracks consist of various geometric shapes, including circles, spirals, and intersecting lines, representing the paths of particles in a detector. The tracks are scattered across the entire page, creating a complex, scientific pattern.

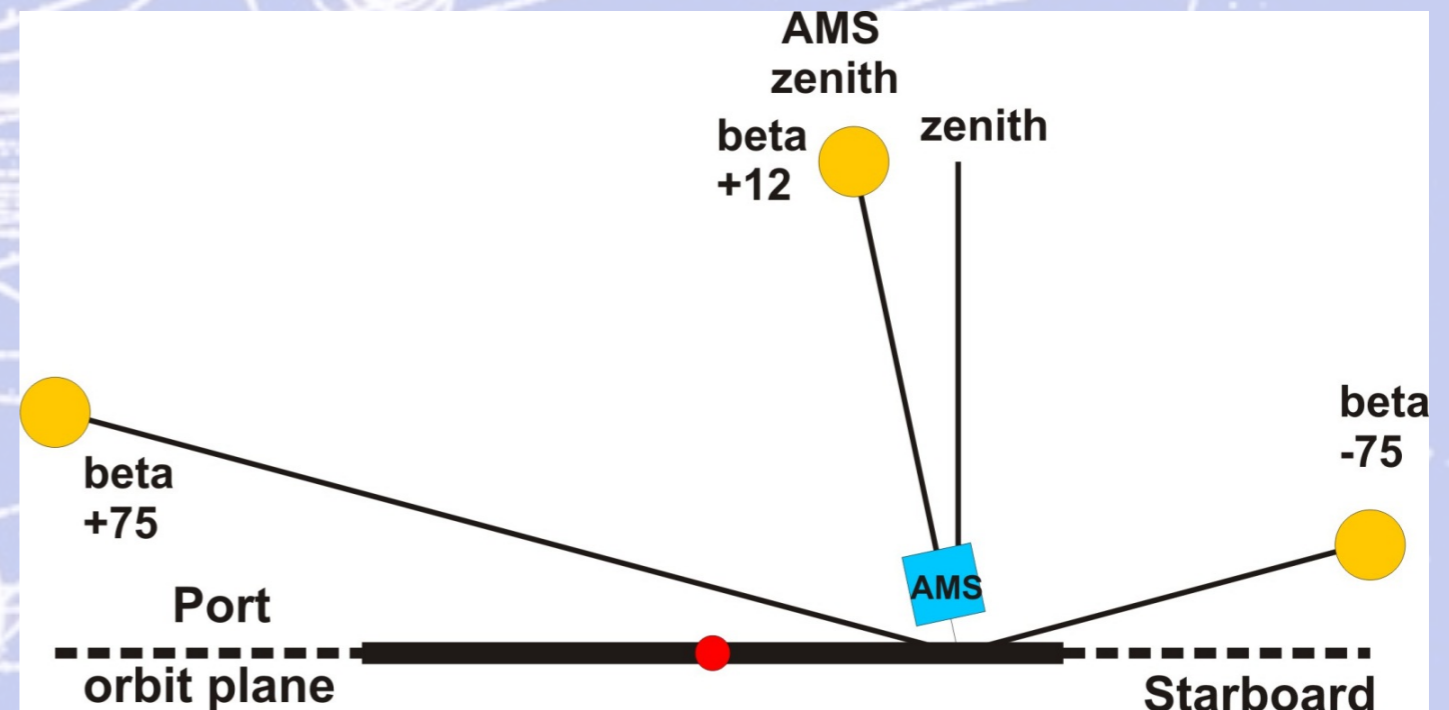
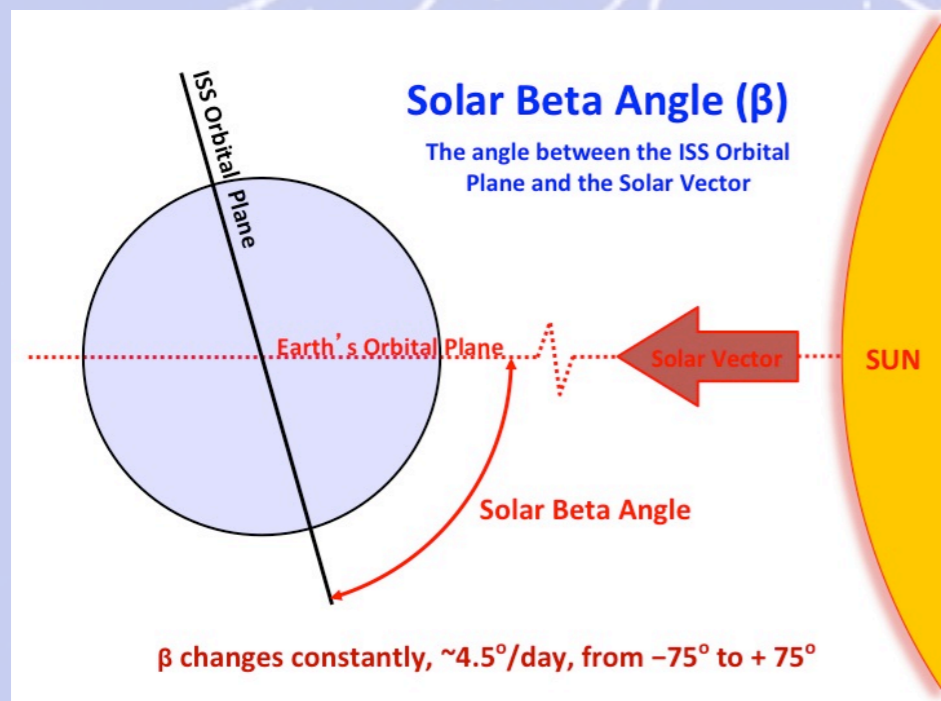
Appendice 8

(Condizioni termiche di AMS-02: angolo beta)

Thermal Control is the most challenging task in the operation of AMS

The thermal environment on ISS is constantly changing due to:

- Solar Beta Angle (β)
- Position of the ISS Radiators and Solar Arrays
- ISS Attitude



Over **1,100** temperature sensors and **298** heaters are monitored around the clock in the AMS POCC to assure components stay within thermal limits and avoid permanent damage.

The background of the slide is a light blue color. It features a complex pattern of white lines and dots. Some lines are straight, while others are curved or spiral. The dots are scattered across the background, some appearing as small clusters. The overall effect is reminiscent of particle tracks in a detector or a star map.

Appendice 9

(Il tracciatore di AMS-02)

The momentum resolution ($\Delta p/p$) is the sum of two contributions:

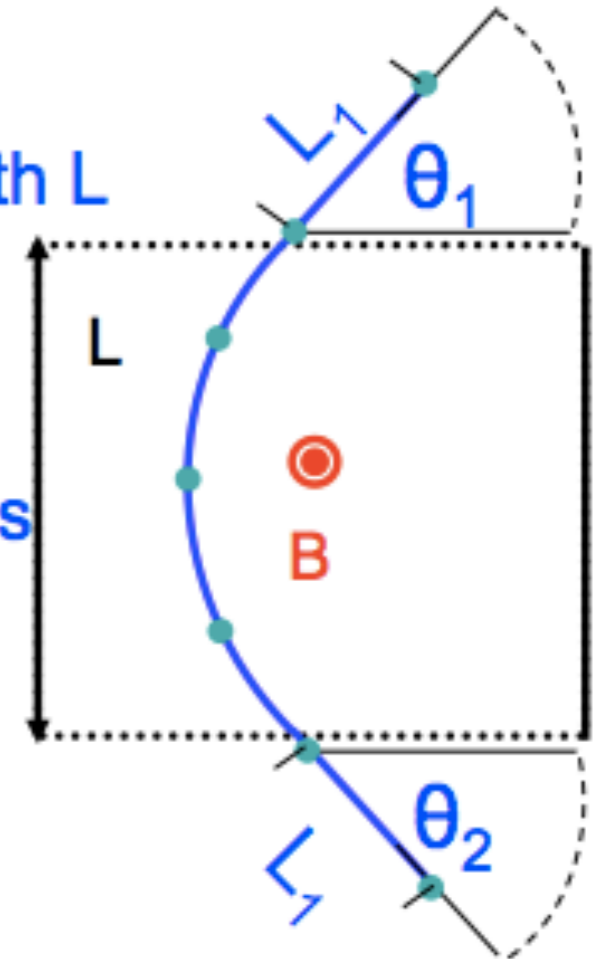
1. Measurement inside the magnet with an effective length L

$$(Q/p) \cdot (\Delta p/p) \propto 1/BL^2$$

2. Measurement of the incident (θ_1) and exit (θ_2) angles

which depend on the length L_1

$$(Q/p) \cdot (\Delta p/p) \propto 1/BL L_1$$



For both magnets, $L \sim 80$ cm,

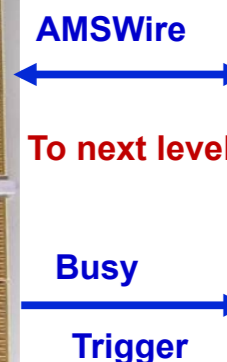
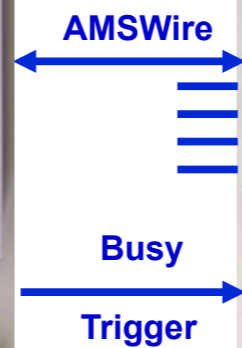
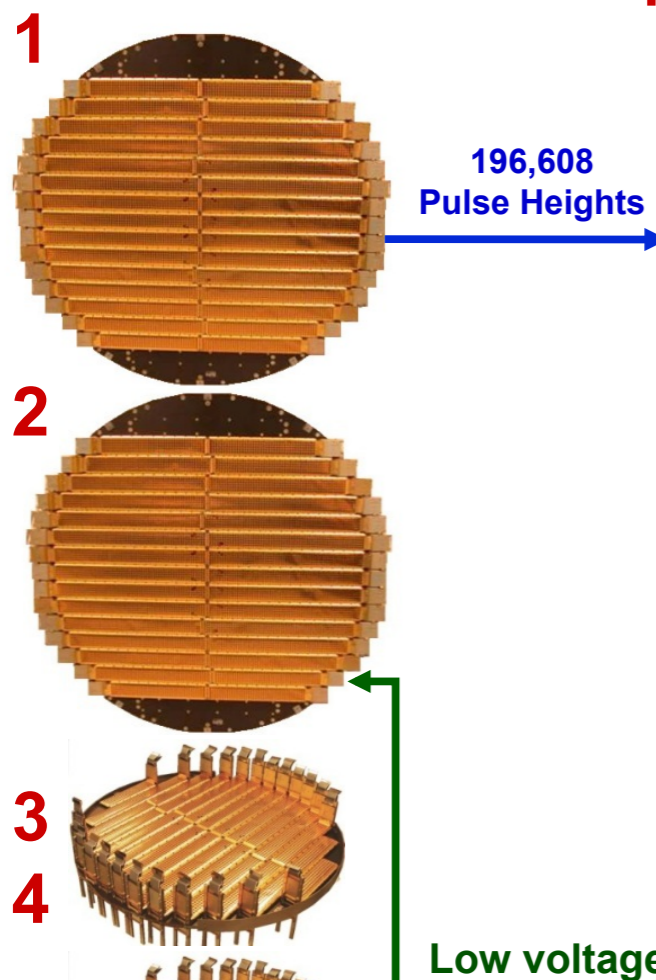
but in the permanent magnet B is 5 times smaller

to maintain the same $\Delta p/p$ we increase L_1 from ~ 15 cm
(Superconducting Magnet) to ~ 125 cm (permanent magnet)

196,608 Pulse Heights,
216 Low Voltages,

192 Tracker Data Reduction (TDR)

16 Readout Computers (JINF-T)



- Analog to digital conversion
coordinate resolution of 10 μm
- Data reduction:
Pedestal subtraction
Noise suppression
Cluster finding
- Format, send to next level

- Collect data from TDR (*)
- Format, send to next level
- Control Low Voltages
- Combine Busy signals
- Distribute Trigger
- Distribute command to TDR

(*) Tracker Data Reduction

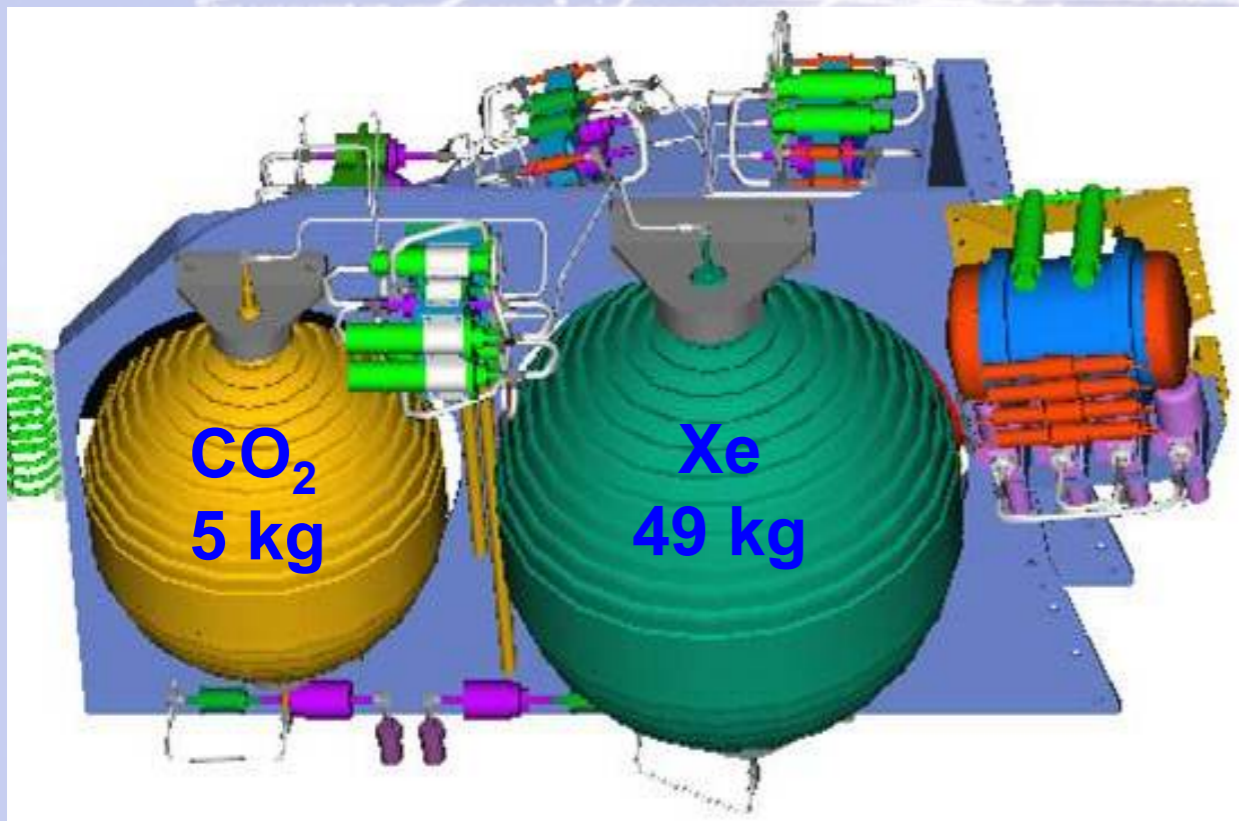
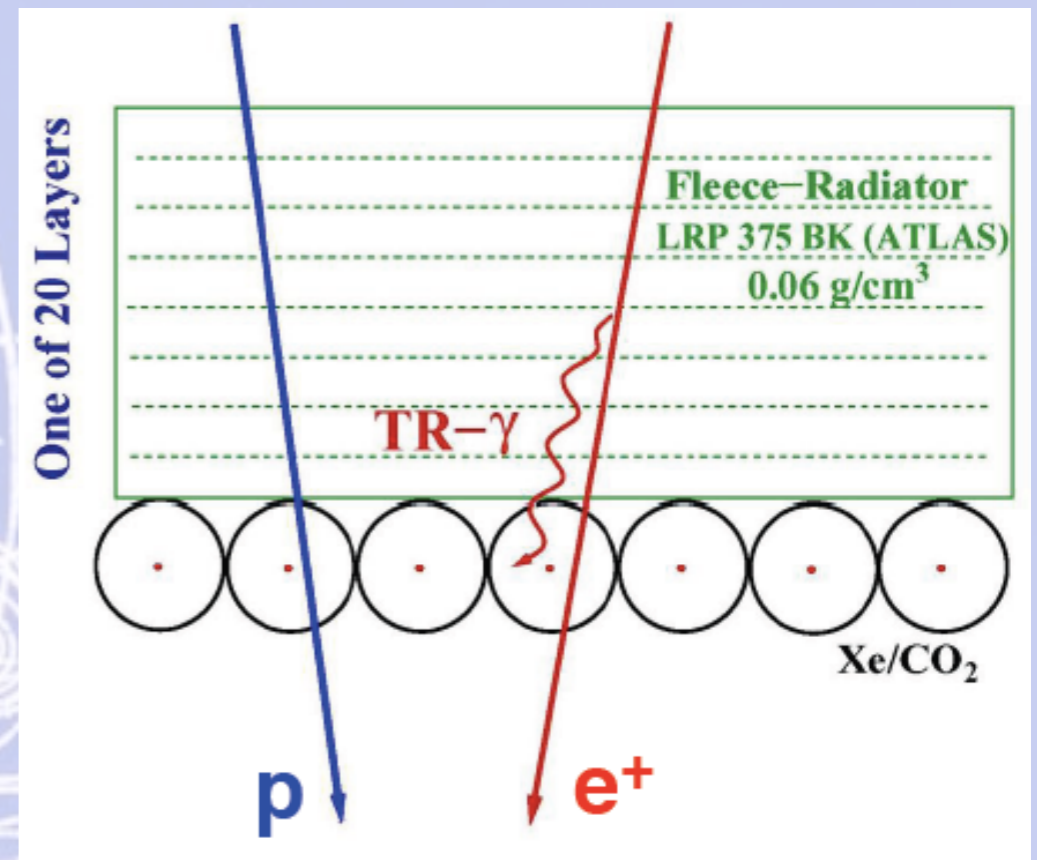
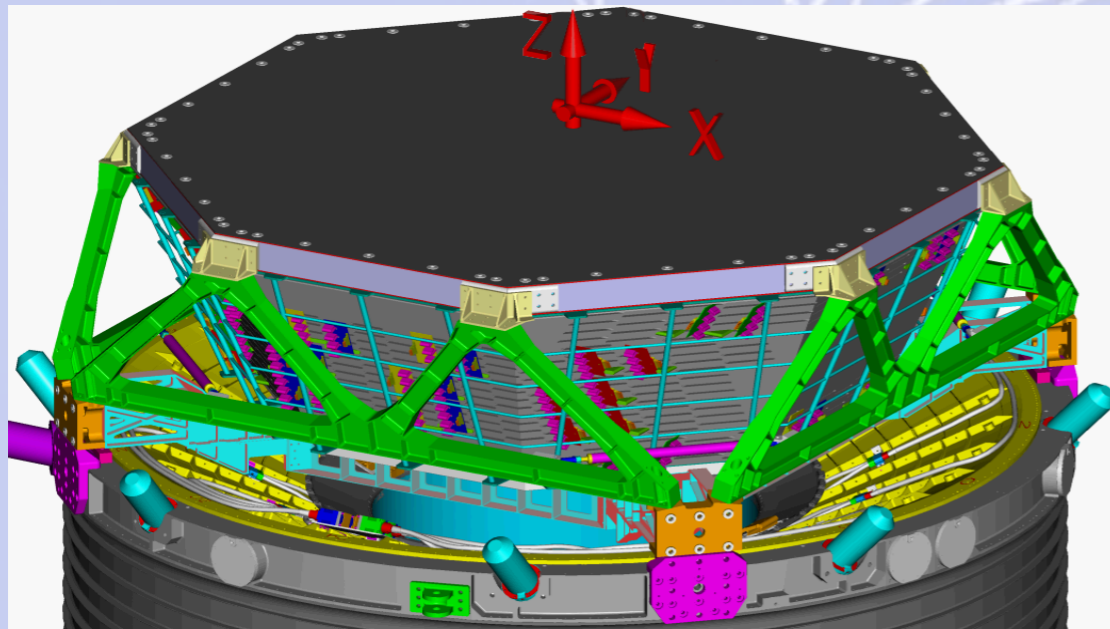




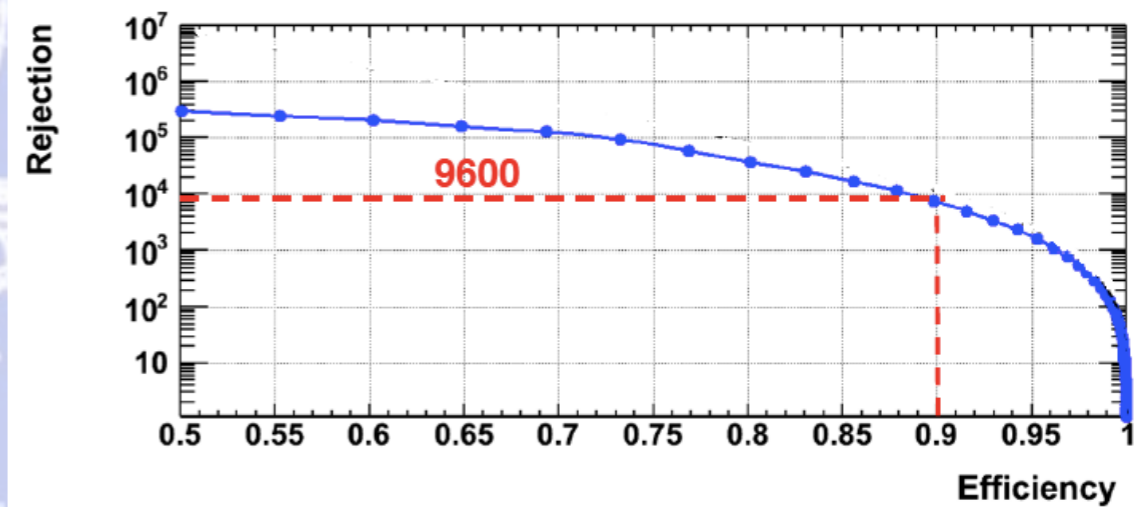
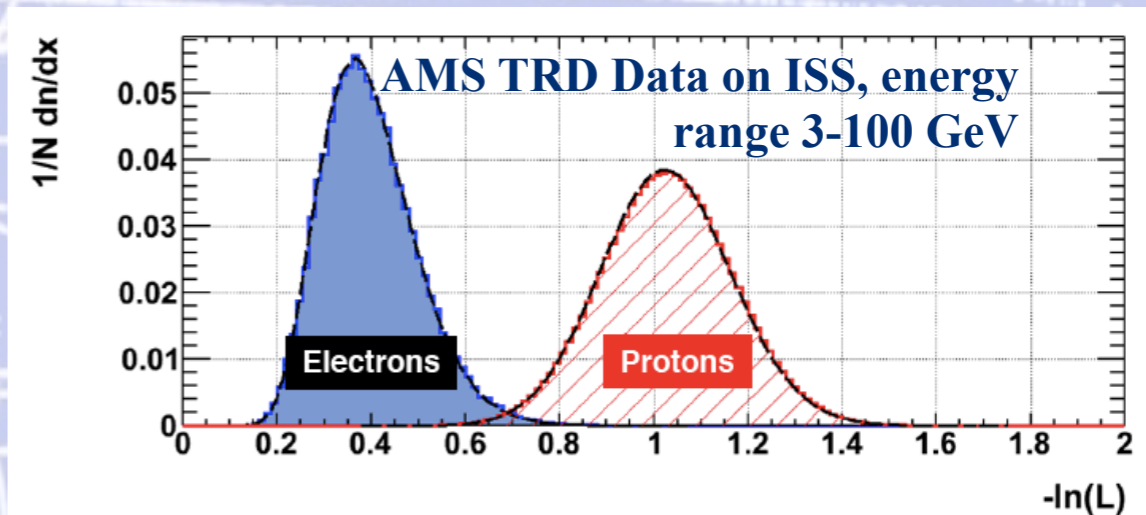
Appendice 10

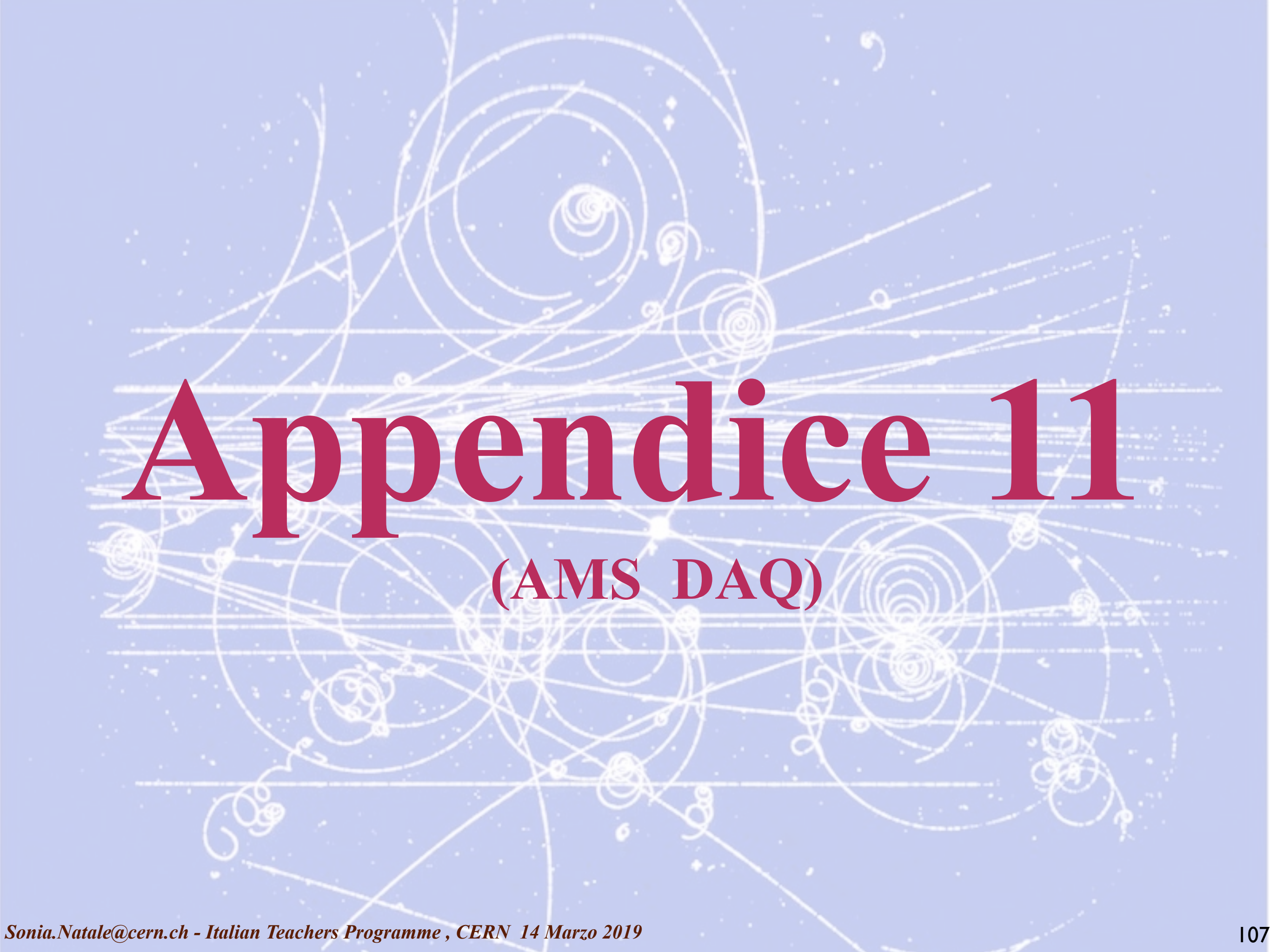
(II TRD: Gas System)

Transition Radiation Detector (TRD)



Leakrate of $5 \mu\text{g/s}$, caused by CO_2 diffusion, corresponds to a lifetime ~ 20 years in Space



The background of the slide is a light blue color. It features a complex pattern of white lines that resemble particle tracks or data paths, with some circular and spiral shapes. Scattered throughout the background are small white dots, similar to stars in a constellation chart.

Appendice 11

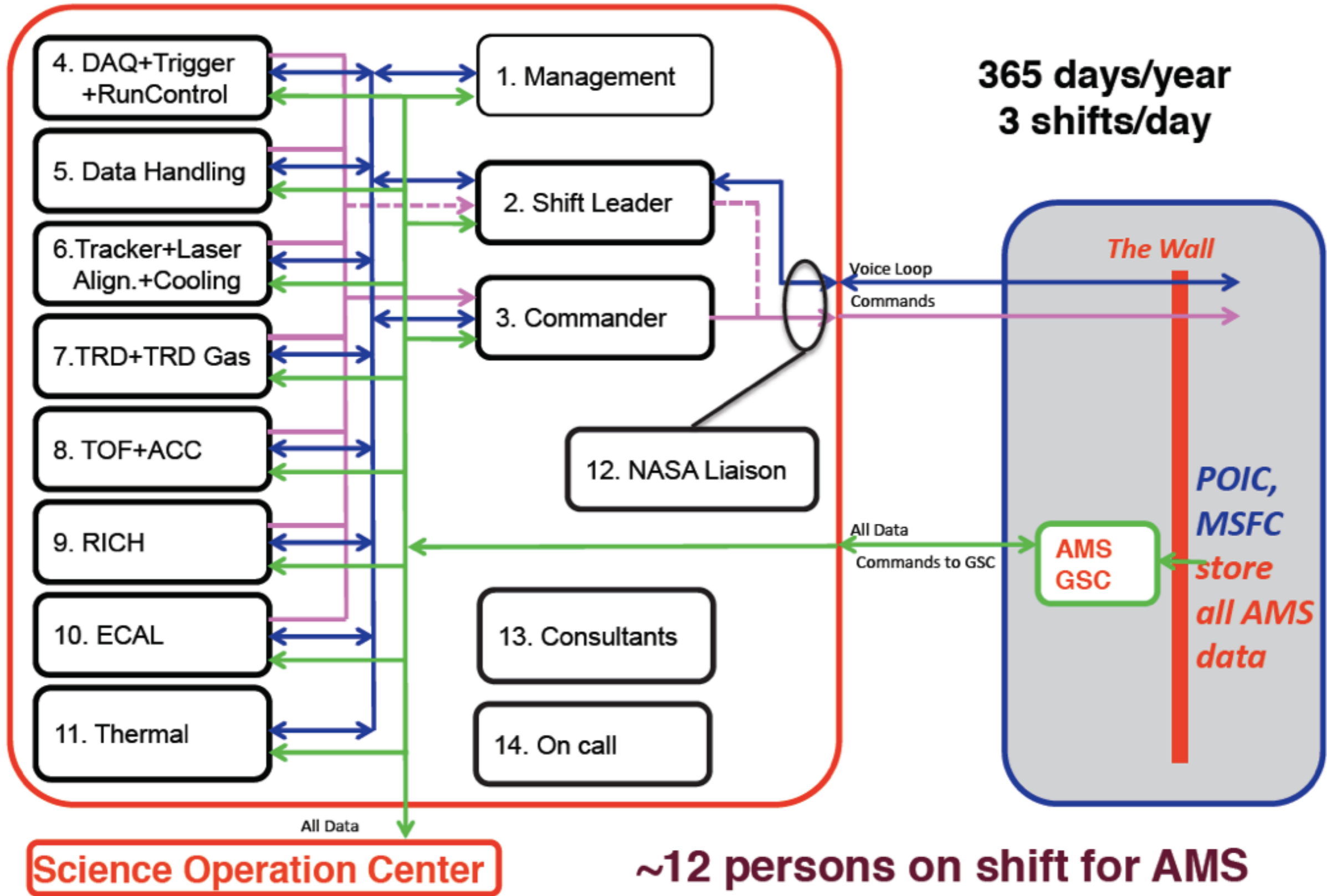
(AMS DAQ)

AMS Data Acquisition System



To read out 300,000 channels at up to 2 KHz, we developed a large set of **computers (650)** which **are programmable from the POCC** and which readout all the different detectors with up to 400% redundancy. Hundreds of these computers are interconnected in a tree like structure with an **100 MBit/s serial link.**

AMS Payload Operation and Control Center for ISS

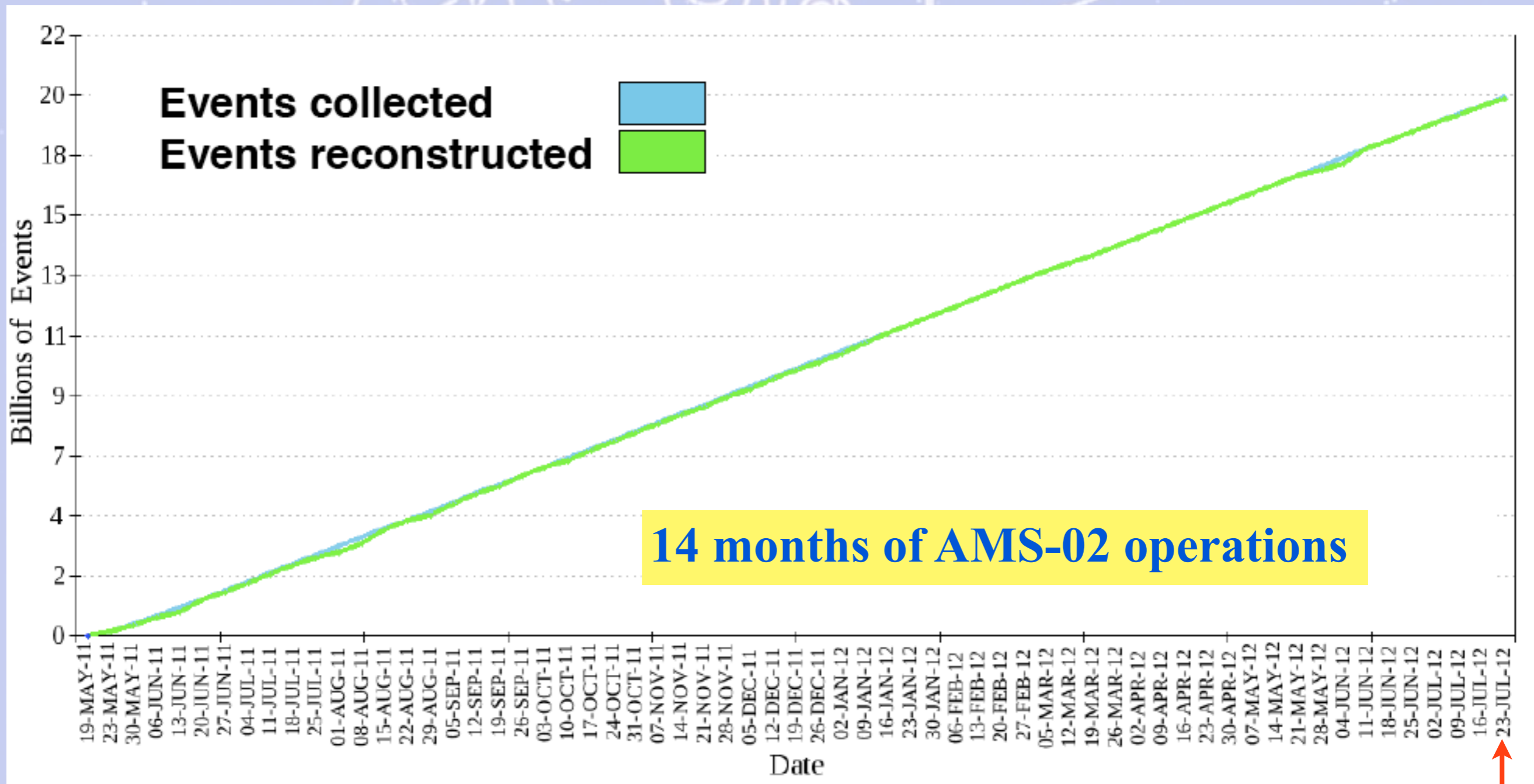


The background of the slide is a light blue color with a complex pattern of white lines. These lines represent particle tracks, consisting of many overlapping circles, spirals, and straight lines, some of which are dotted. The overall effect is that of a particle detector's output or a scientific visualization of particle interactions.

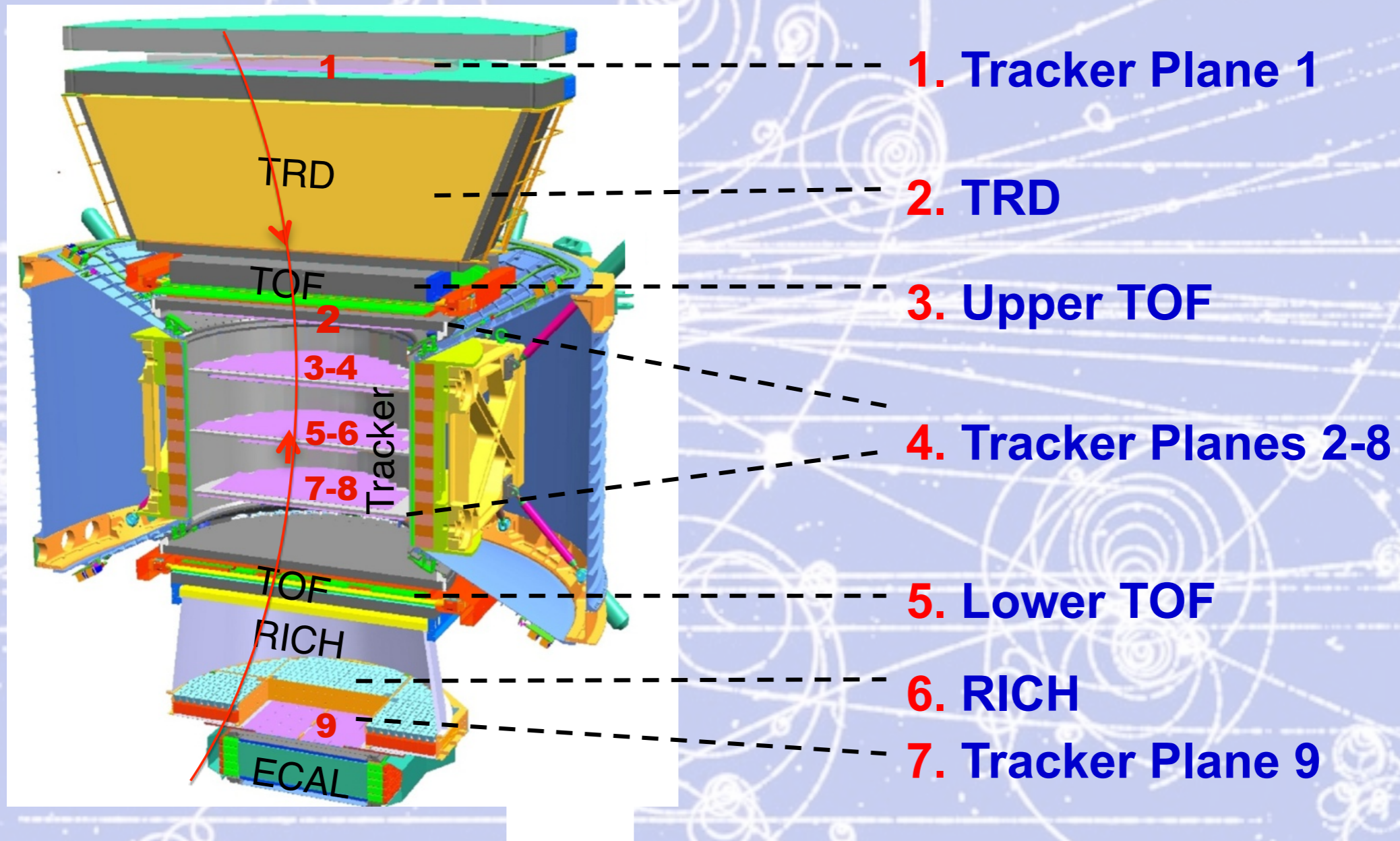
Appendice 12

(AMS-02 performance)

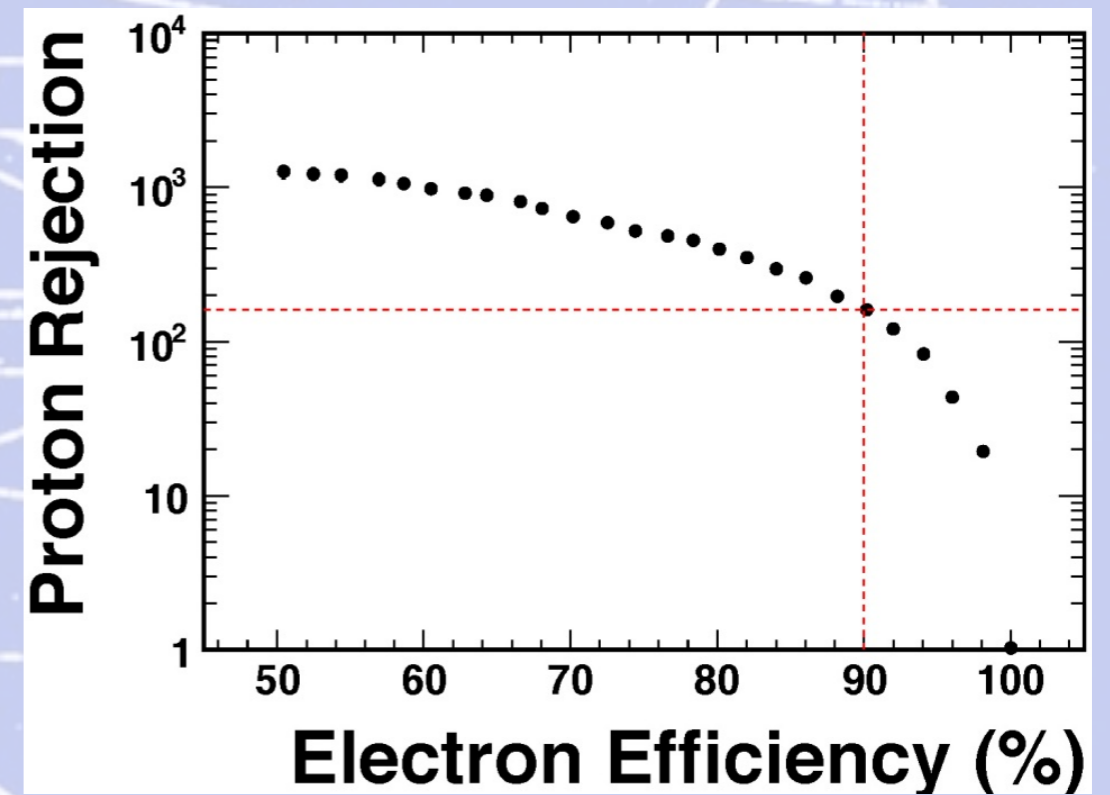
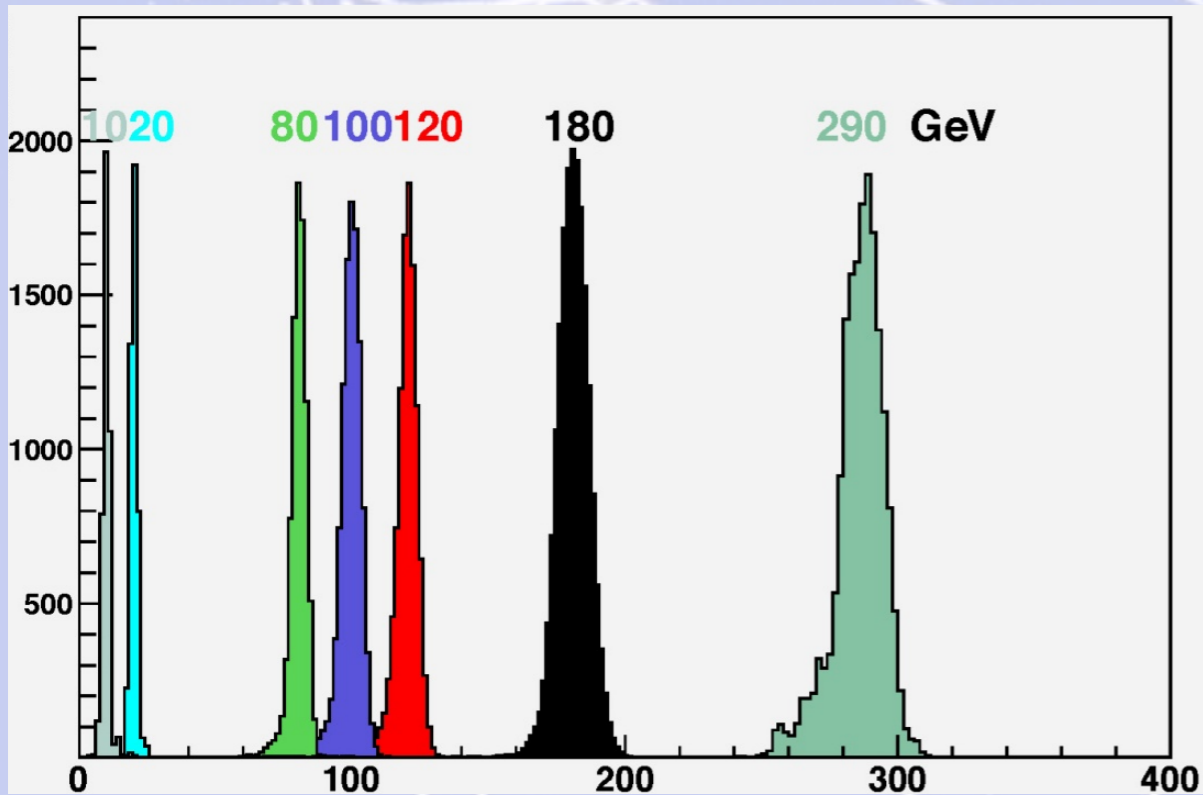
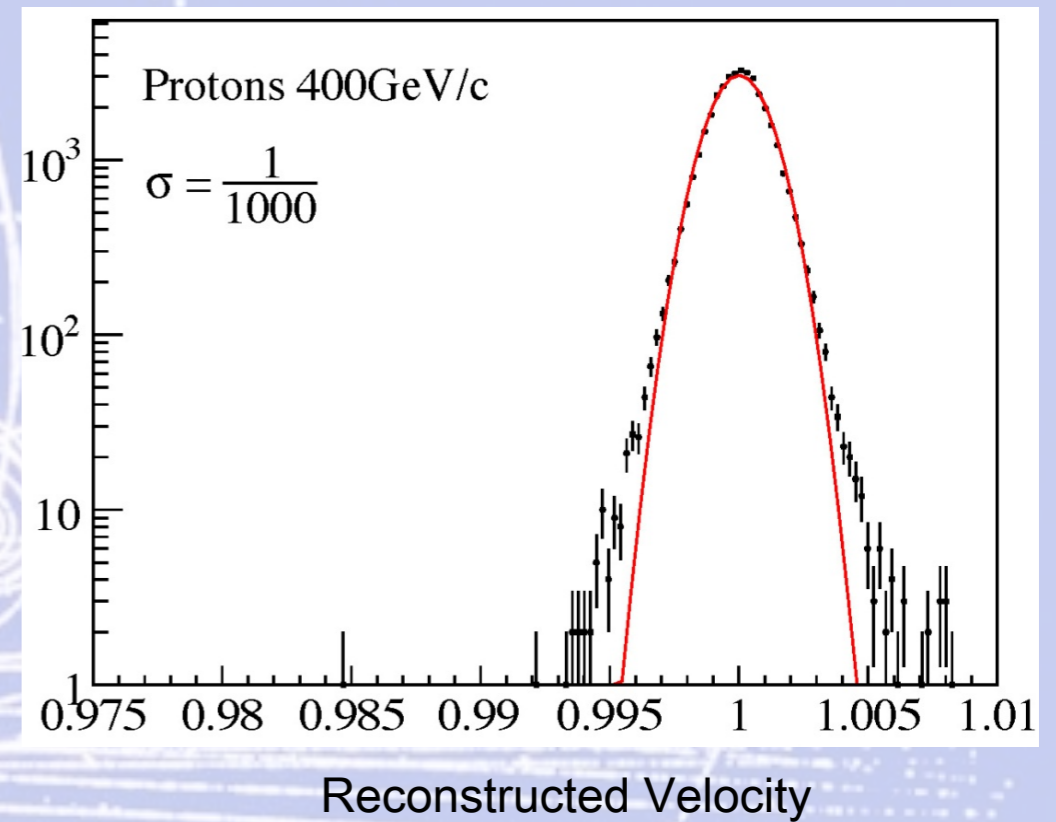
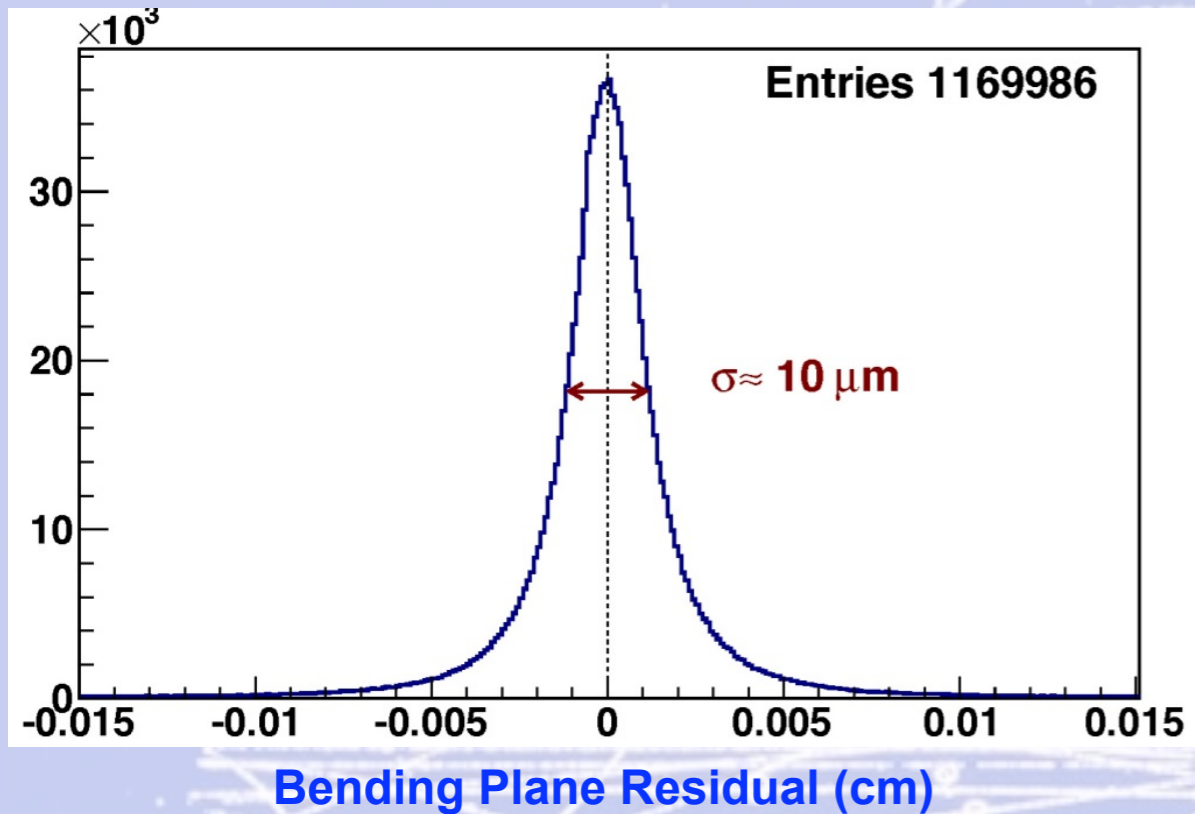
AMS-02 collected over 20 billion events in 14 months operation on ISS



Multiple independent Measurements of the Charge ($|Z|$)

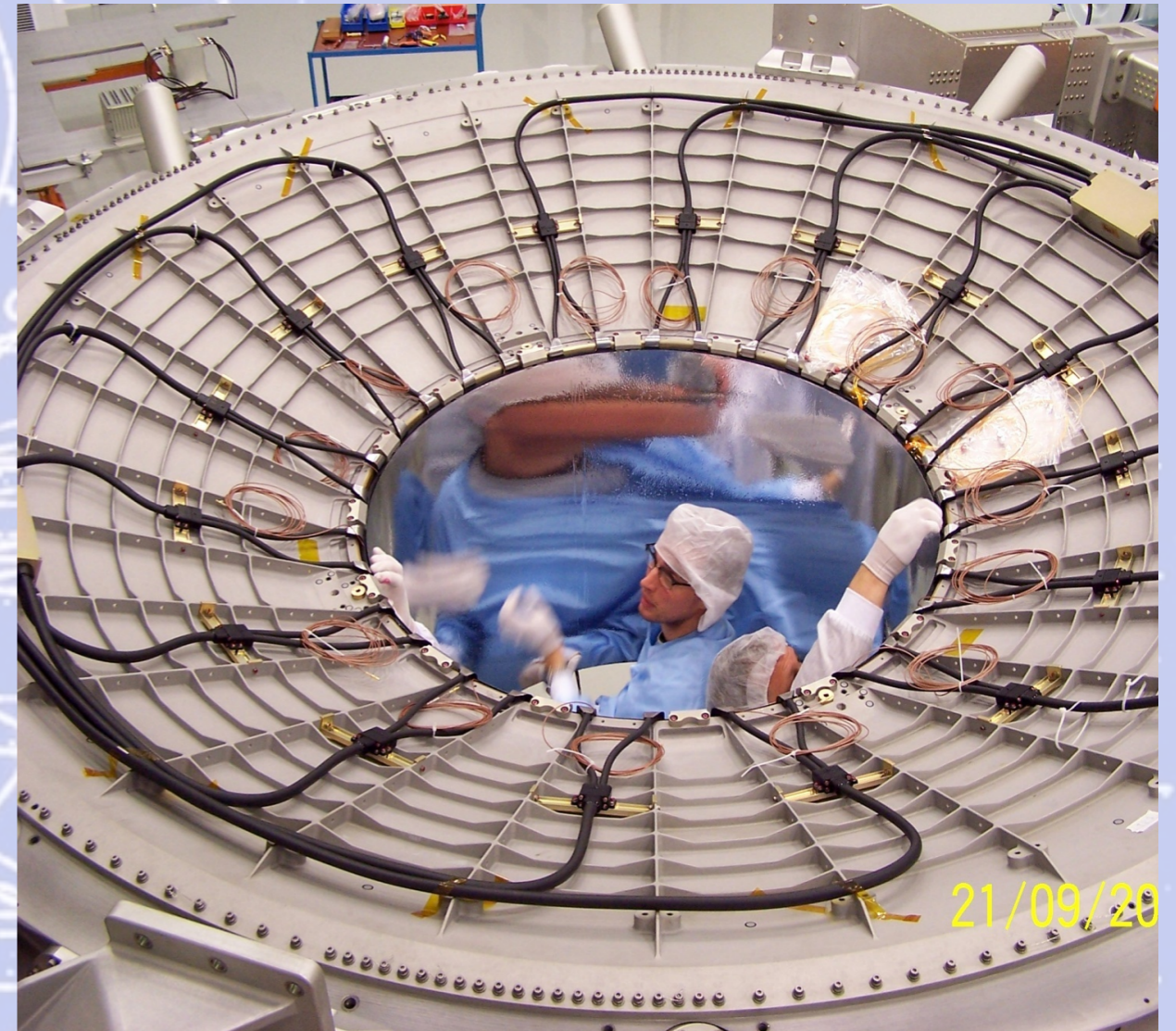
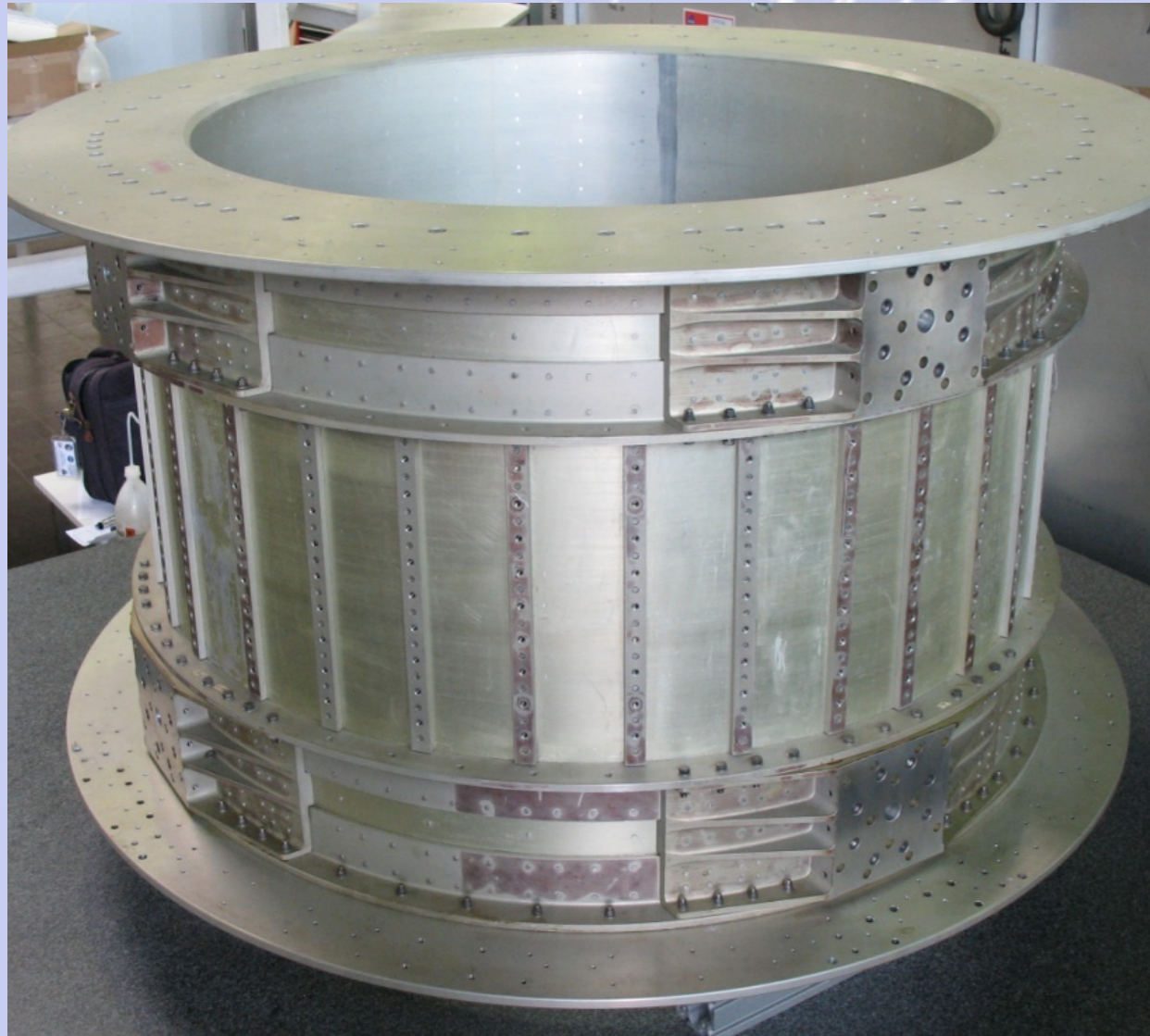


Test Beam Results at CERN 2010 (8-20 Aug)



Measured combined rejection power at 400 GeV: $e^+/p = 10^{-6}$

The Magnet and the VETO System reject random Cosmic Rays



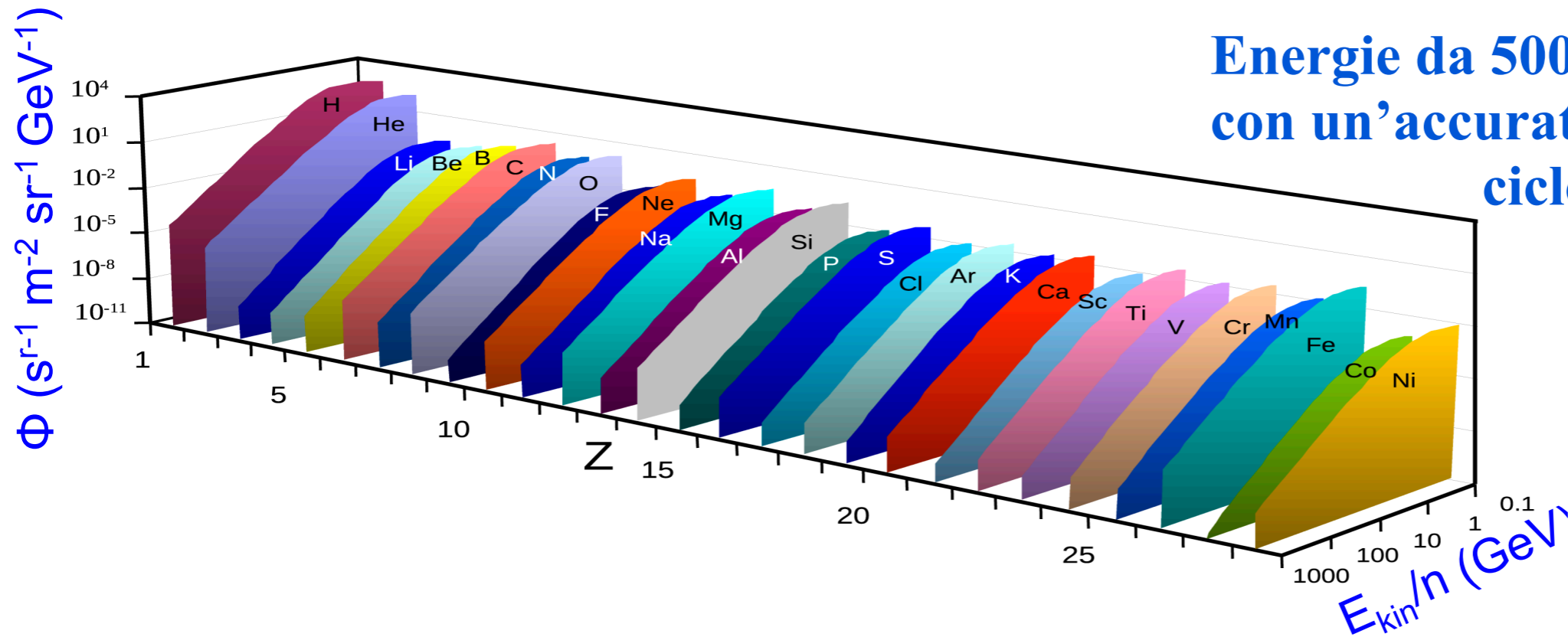
In 12 years the field has remained the same to $< 1\%$ (from 1997 to 2010)

Measured VETO (ACC) efficiency better than 0.99999

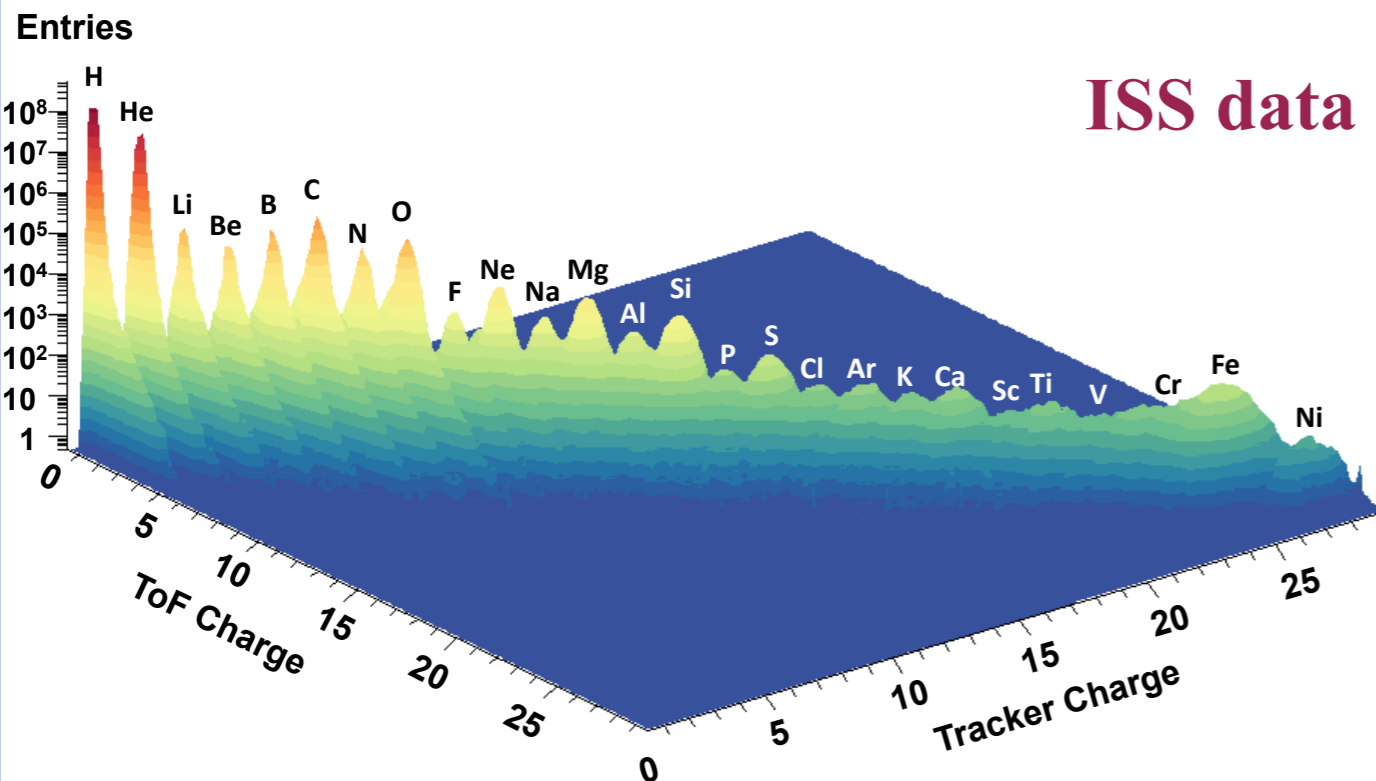
Appendice 13

(Risultati AMS-02 da maggio 2011 a settembre 2014
+
aggiornamento a settembre 2016)

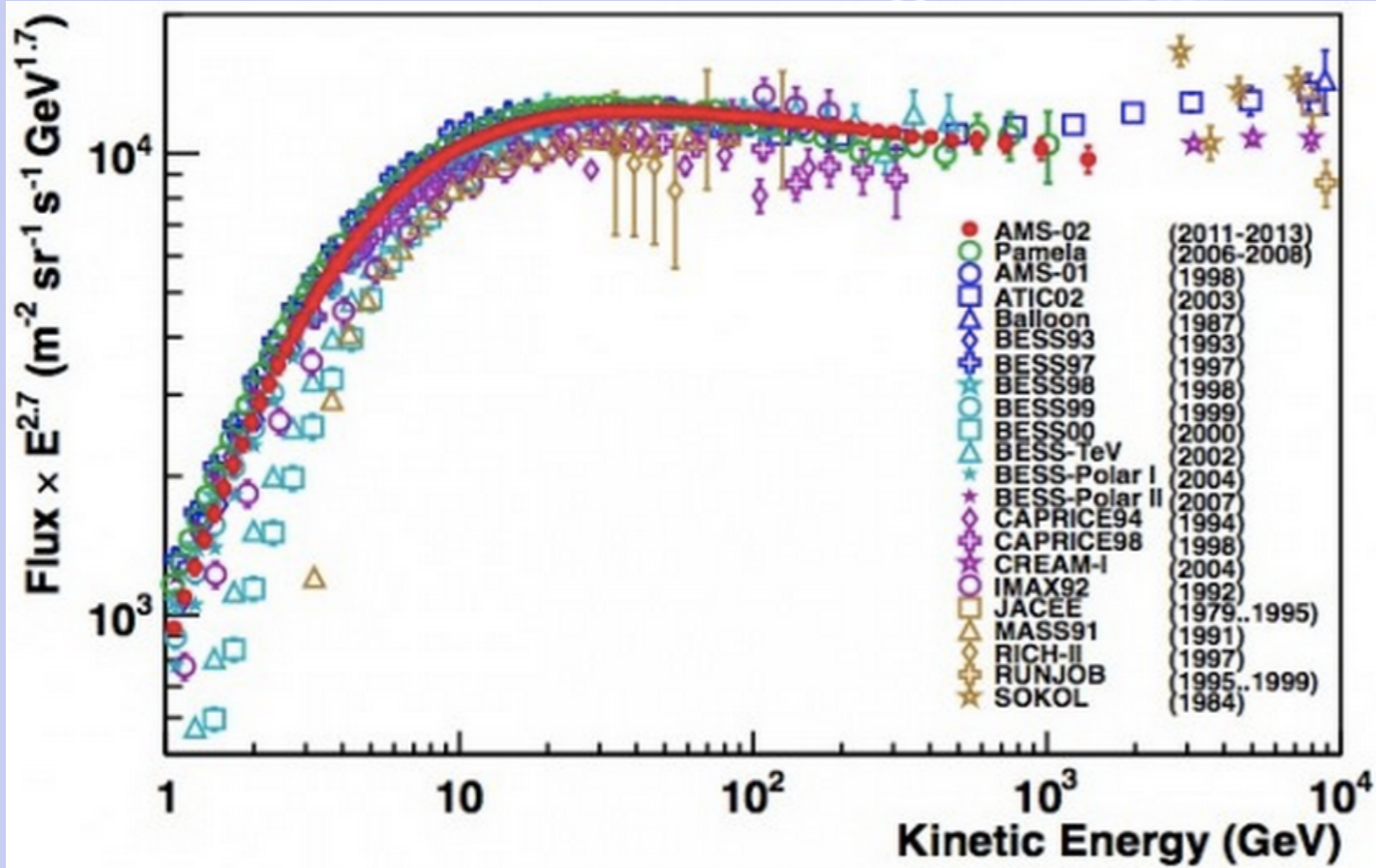
La fisica di AMS-02: misure di abbondanza nucleare



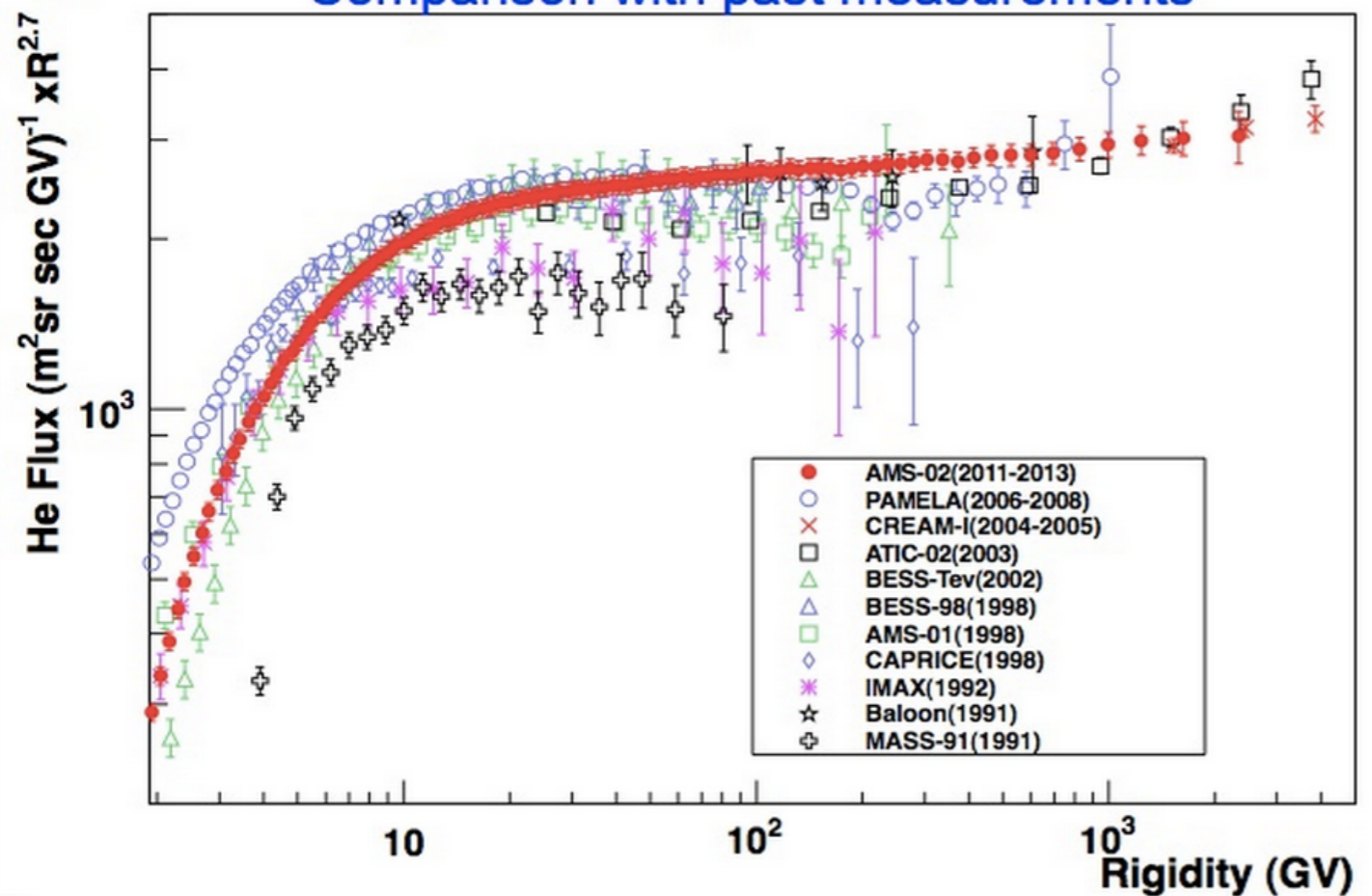
Energie da 500 MeV a 2 TeV
con un'accuratezza dell'1% sul
ciclo solare (11 anni).



Questi spettri forniscono
dati sperimentali necessari
per calcolare il
“background” nella ricerca
della Materia Oscura,
i.e., $p + C \rightarrow e^+, p, \dots$



Flusso di protoni (ICRC 2013)



Flusso dell'elio (ICRC 2013)

La fisica di AMS-02: rapporto Boro/Carbonio

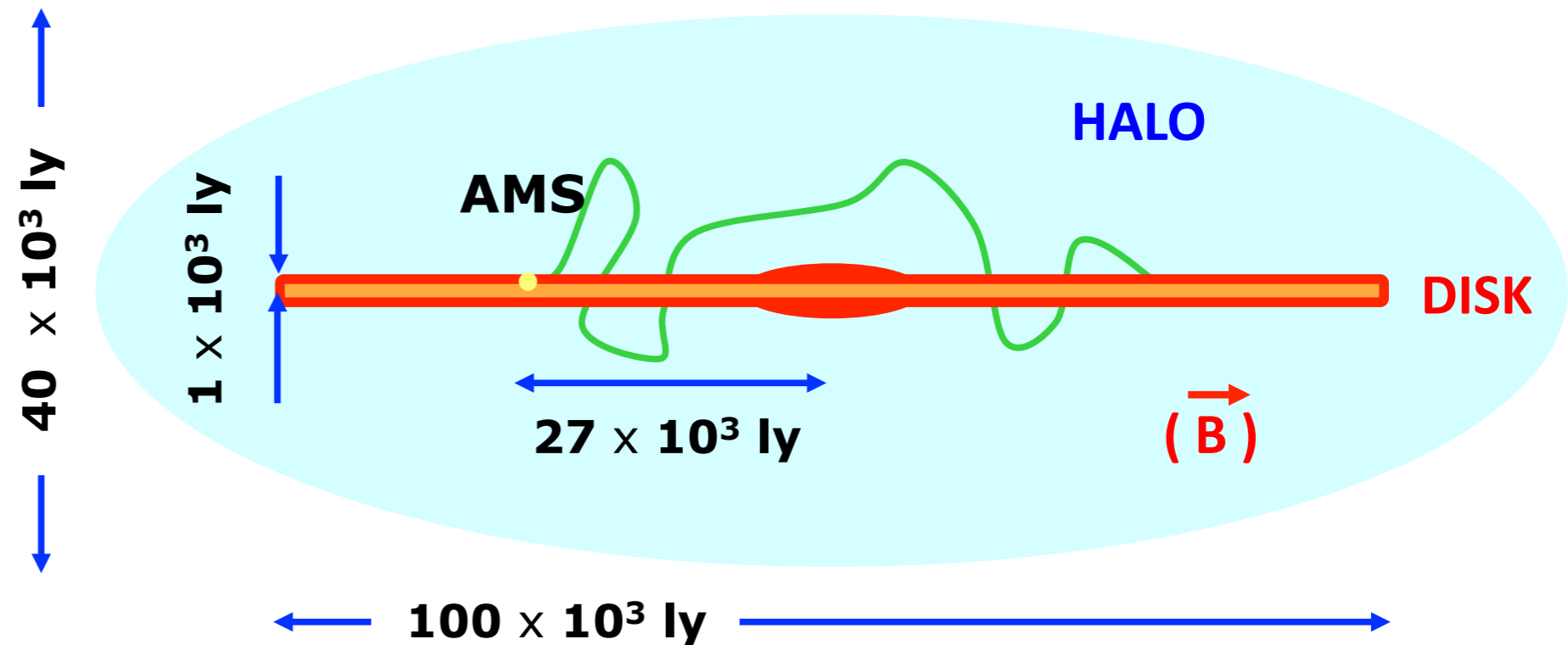
Misure precise degli spettri di energia del B/C forniscono informazioni sulle interazioni e la propagazione dei CR

Interazioni con il Mezzo Interstellare:
 $C + (p, He) \rightarrow B + \dots$

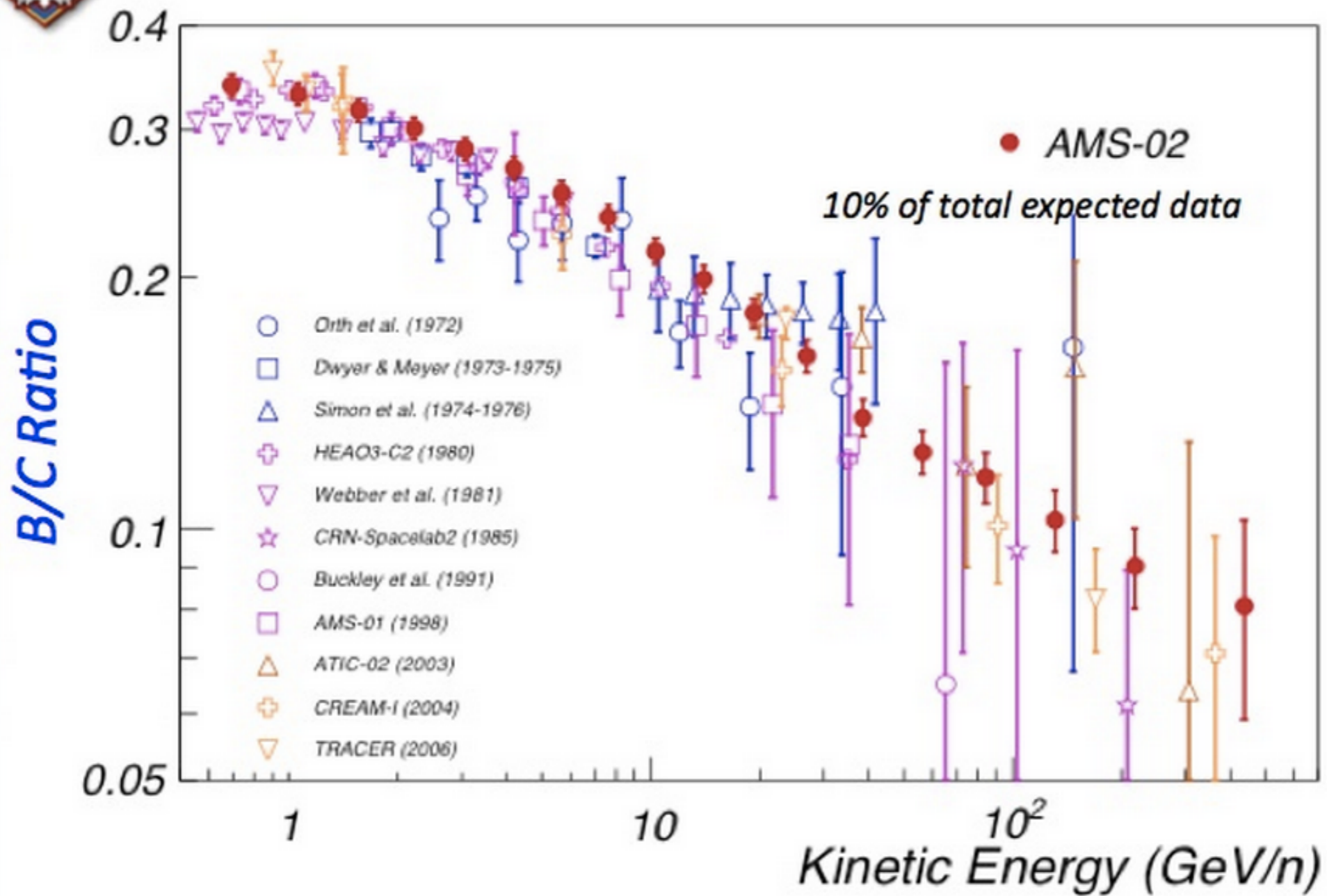
Diffusione
Convezione
Ri-accelerazione

Interazioni con il Mezzo Interstellare (ISM):

- Frammentazione
- Secondari
- Perdite energetiche

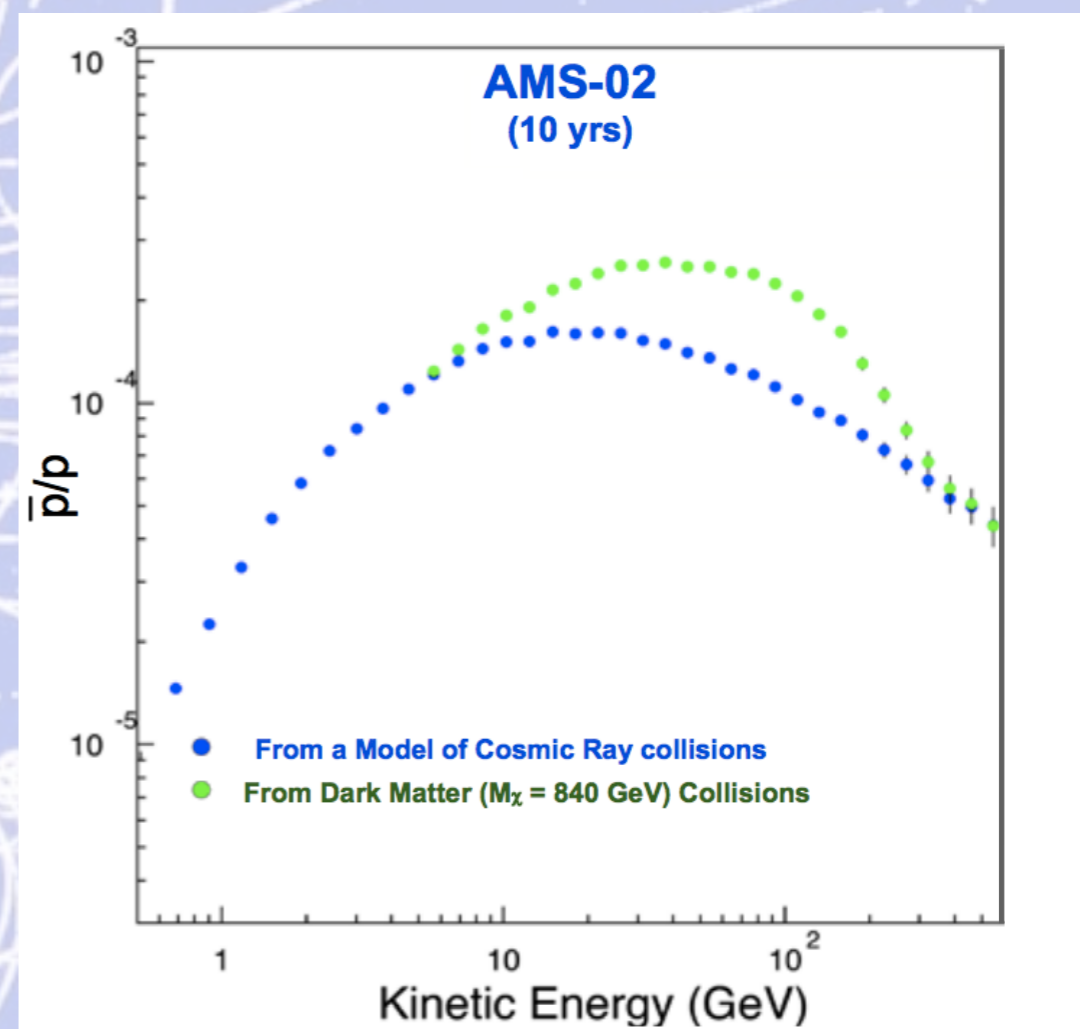
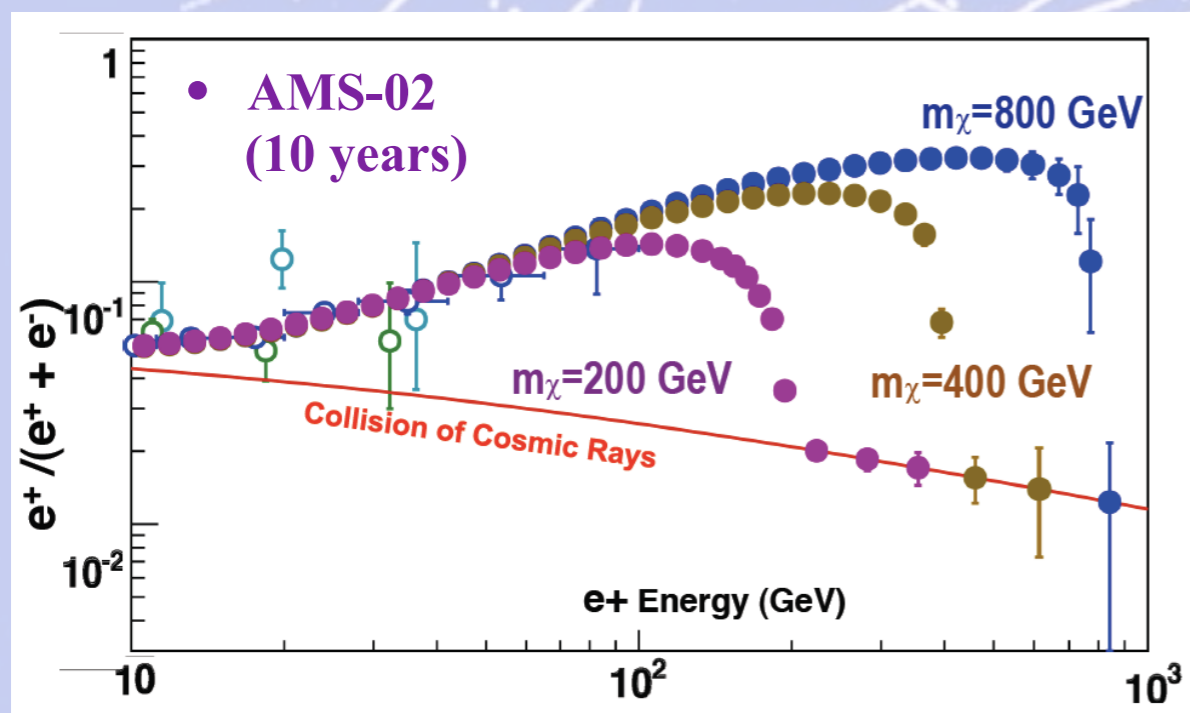


Rapporto Boro/Carbonio (ICRC 2013)



La fisica di AMS-02: ricerca indiretta della Materia Oscura

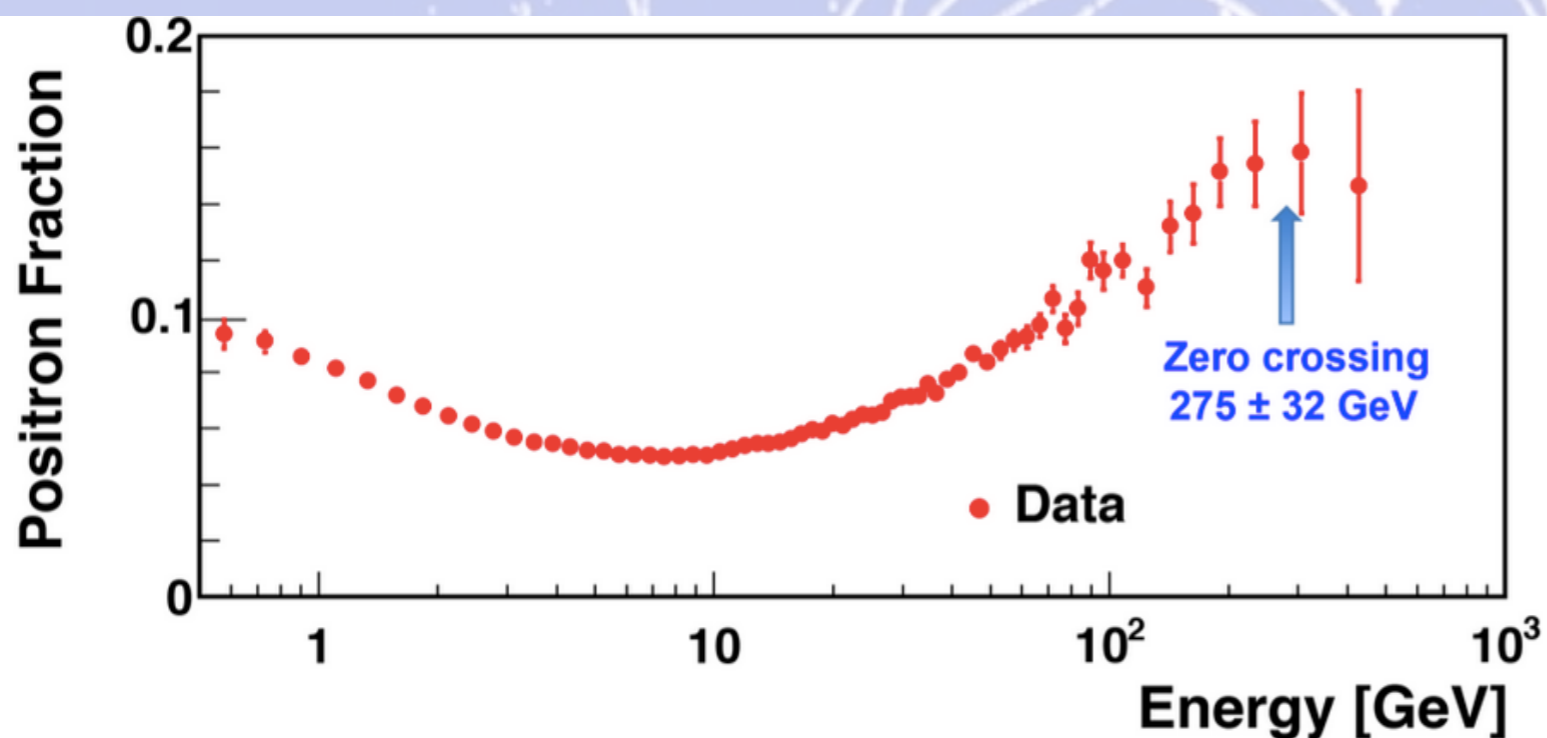
AMS-02 ha la capacita' di studiare l'annichilazione del Neutralino (candidato della Materia Oscura) usando simultaneamente quattro diversi stati finali di particelle: **positroni, anti-protoni, anti-deuteroni and fotoni.**



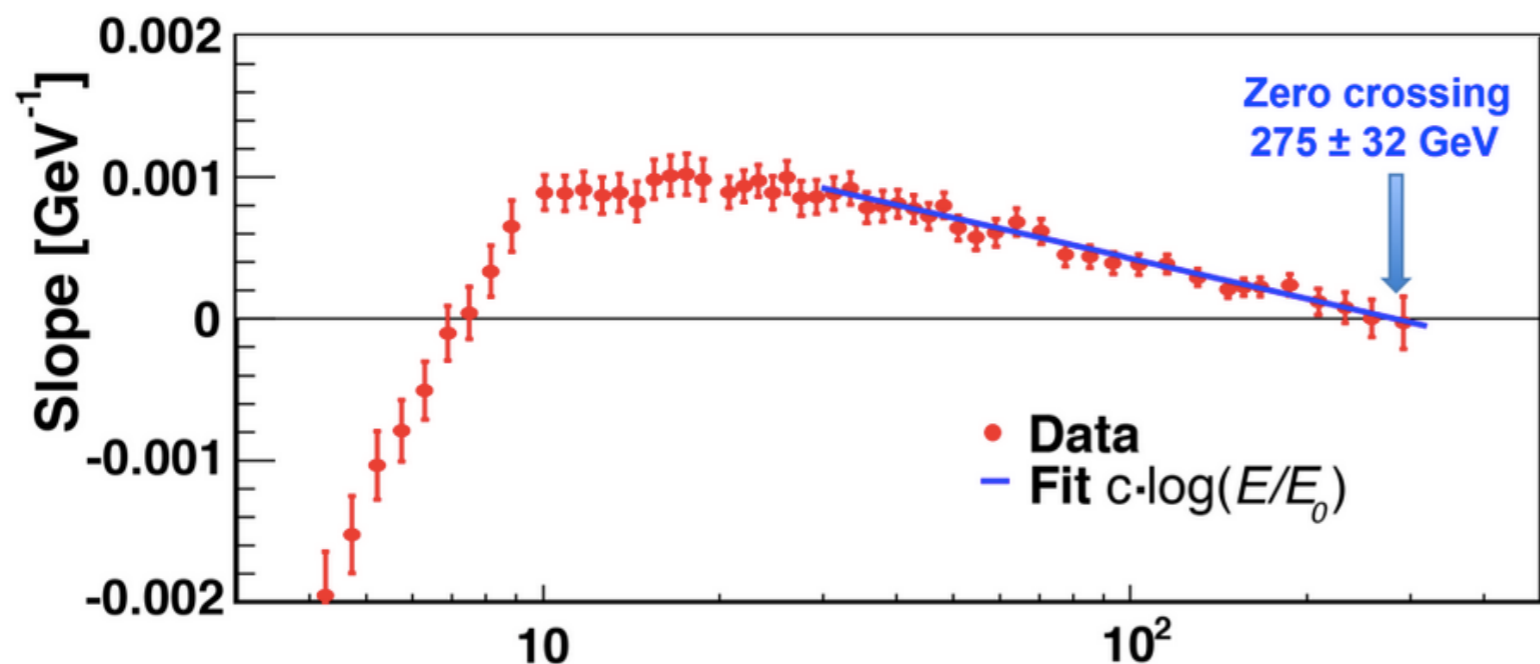
Segnale **aspettato** per la Materia Oscura da AMS-02 relativo alla misura della frazione del flusso di positroni e considerando diverse ipotesi della massa del Neutralino.

Segnale **aspettato** per la Materia Oscura da AMS-02 relativo alla misura della frazione del flusso di antiprotoni nell'ipotesi di massa del Neutralino $M_\chi = 840$ GeV .

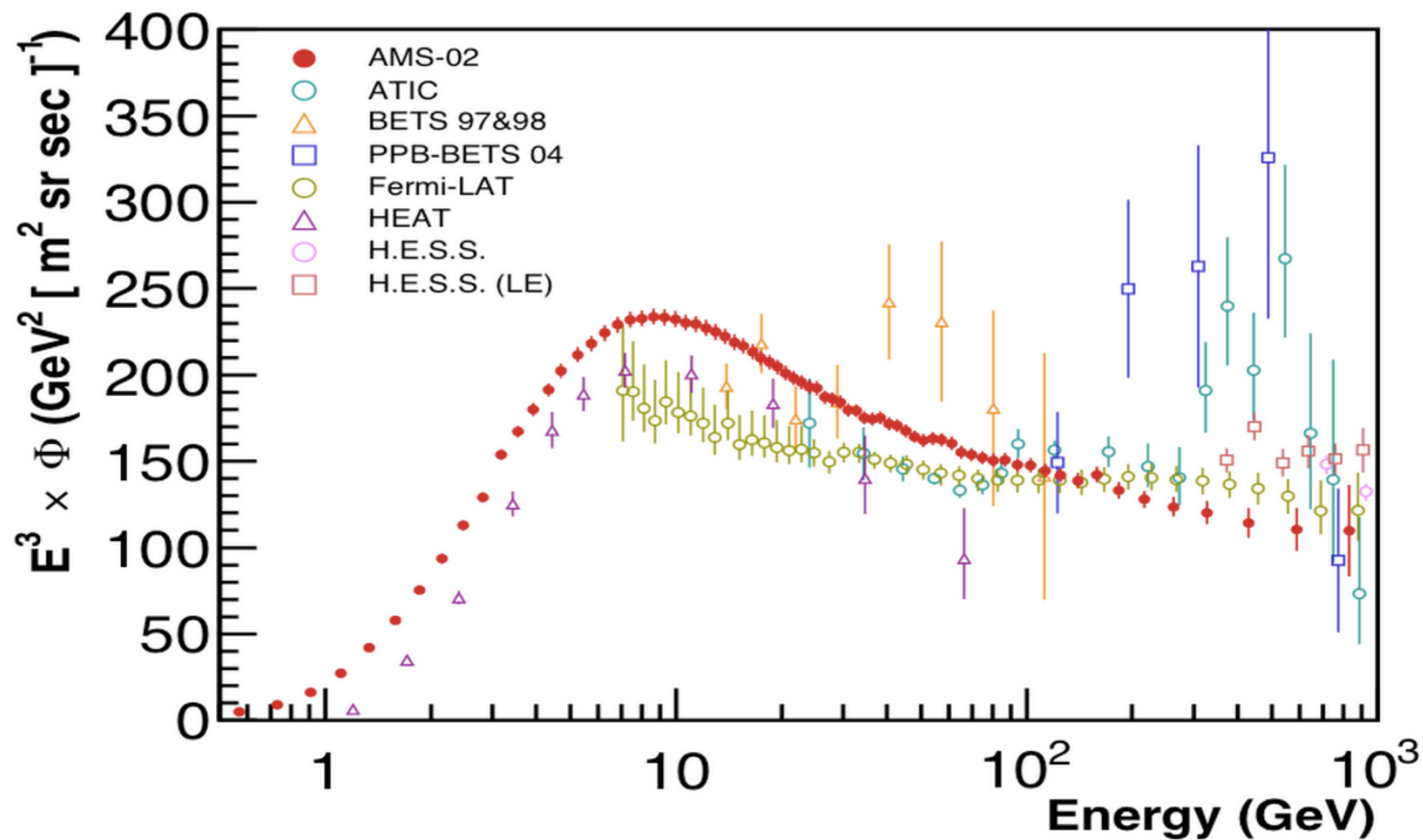
La fisica di AMS-02: ricerca indiretta della Materia Oscura

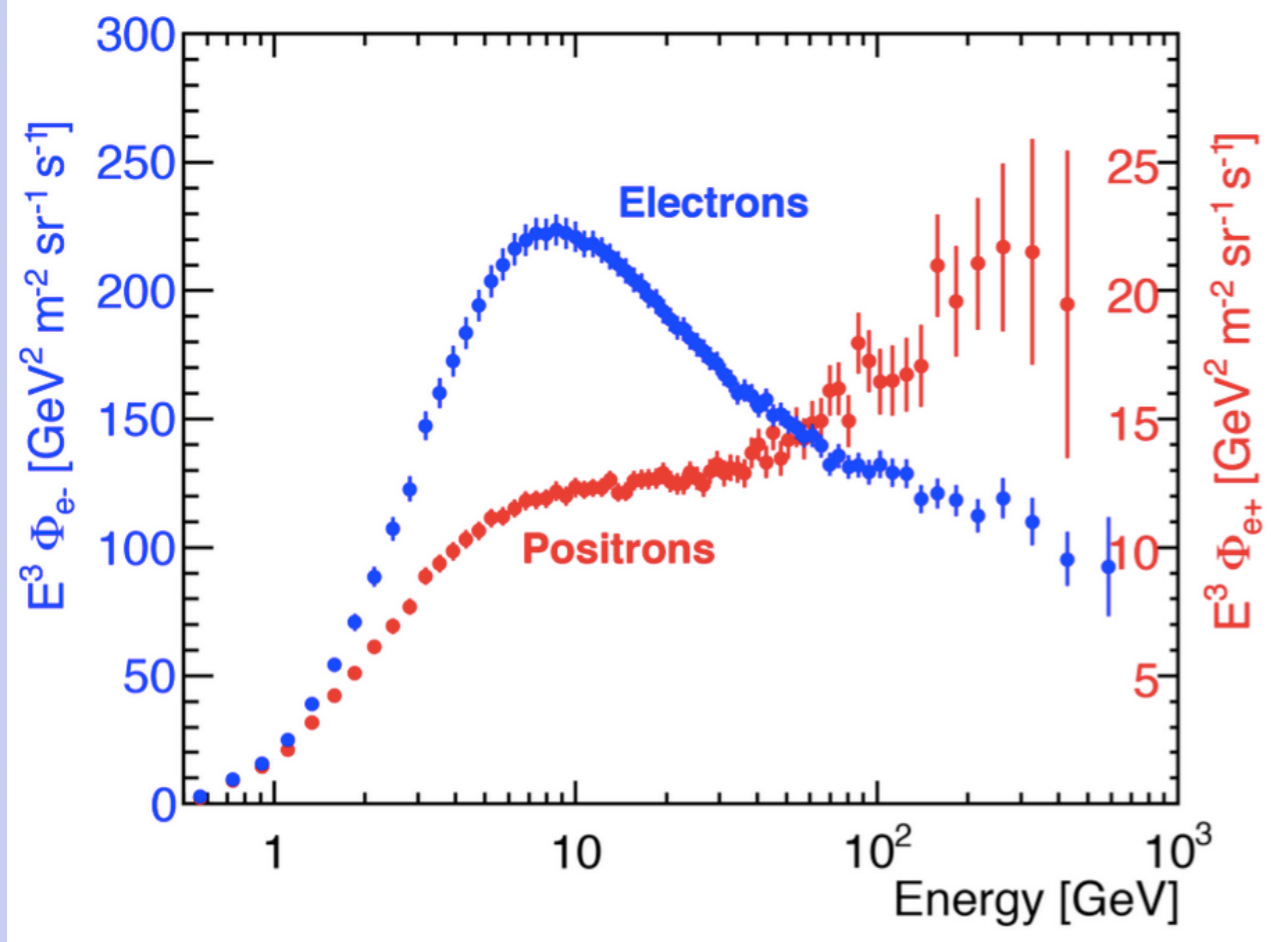


**Frazione di positroni
misurata da AMS-02
(Sett. 2014)**

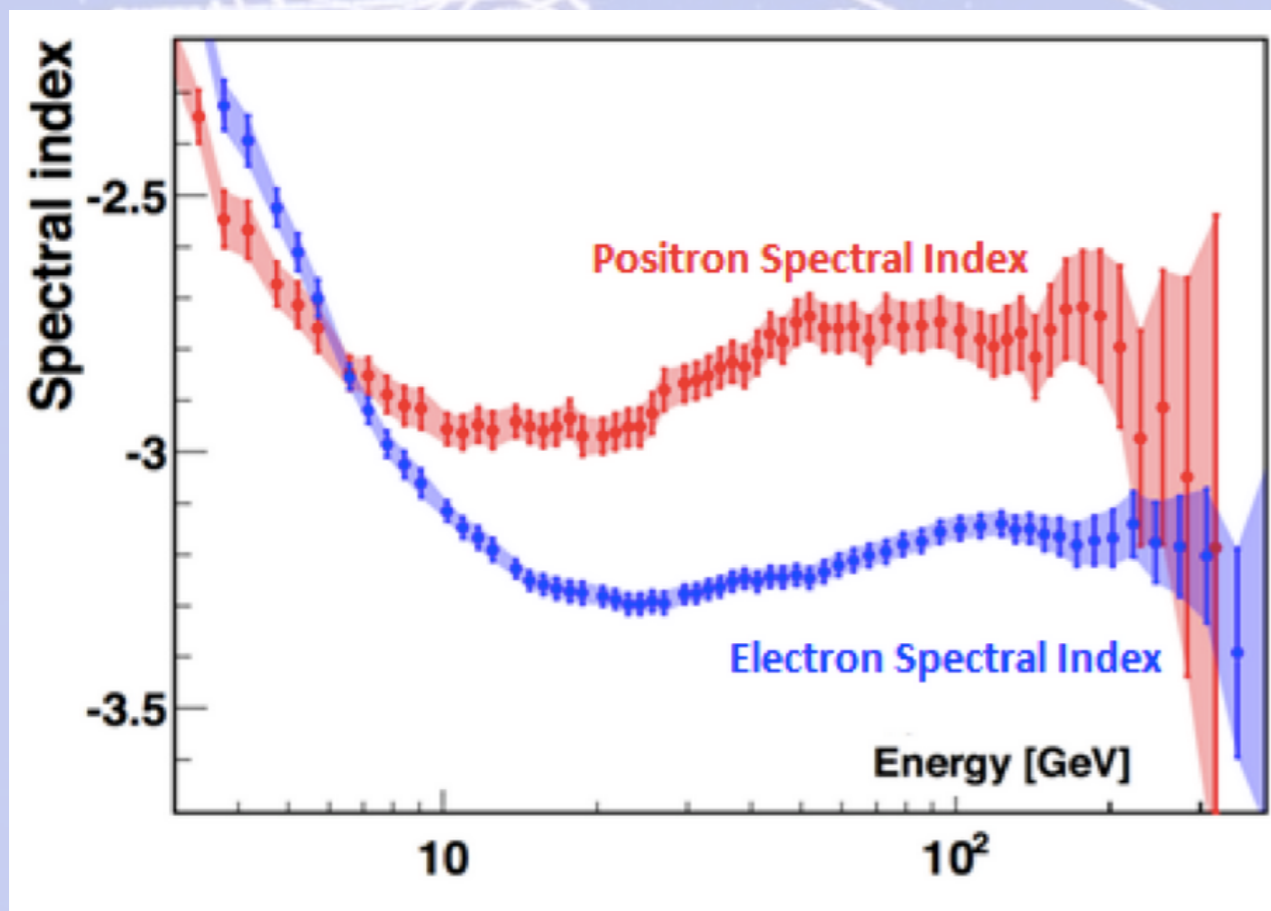


Flusso combinato $e^{\pm} \times E^3$ misurato da AMS (Sett. 2014)



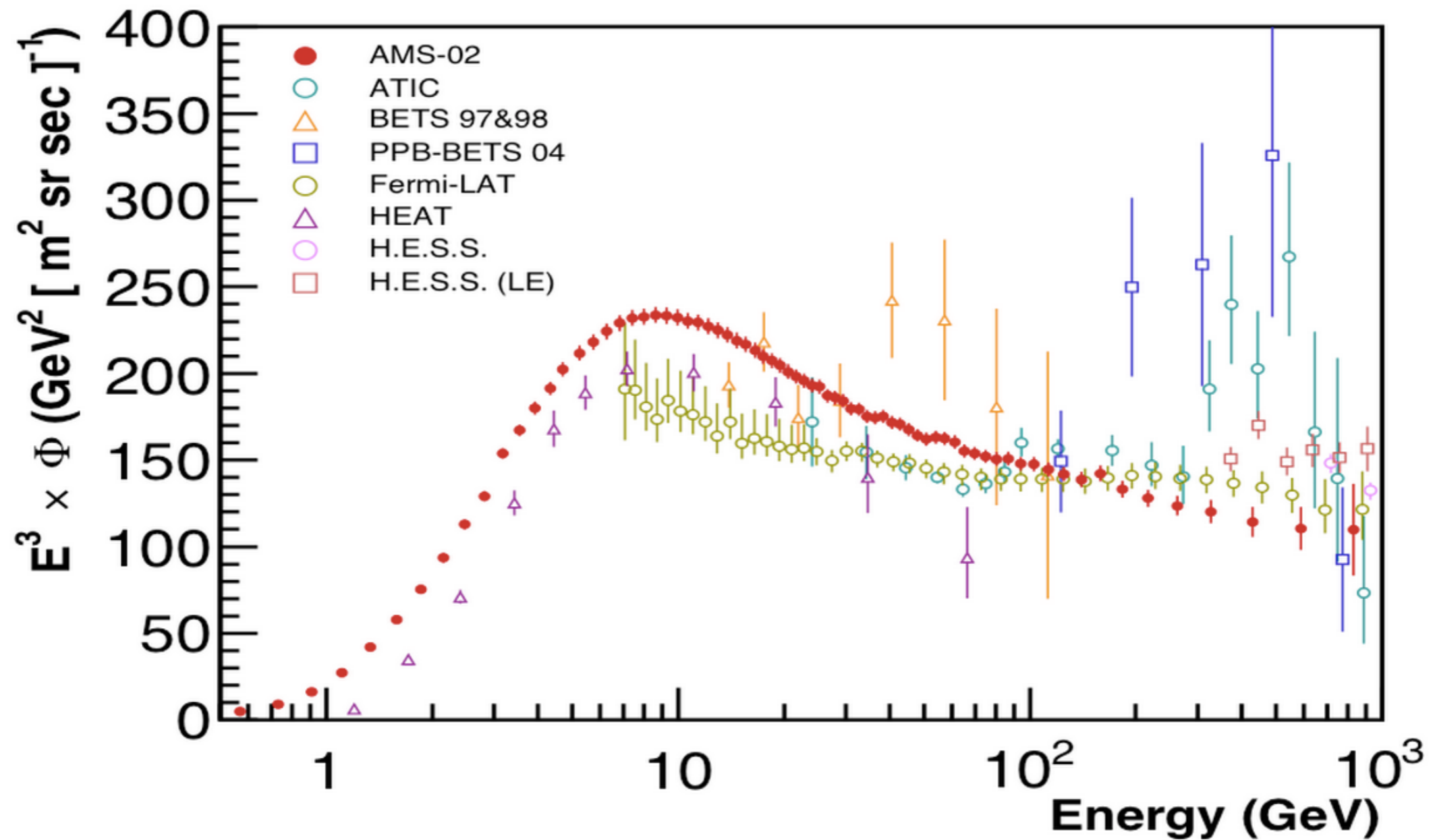


Flusso degli elettroni e dei positroni (Sett. 2014)

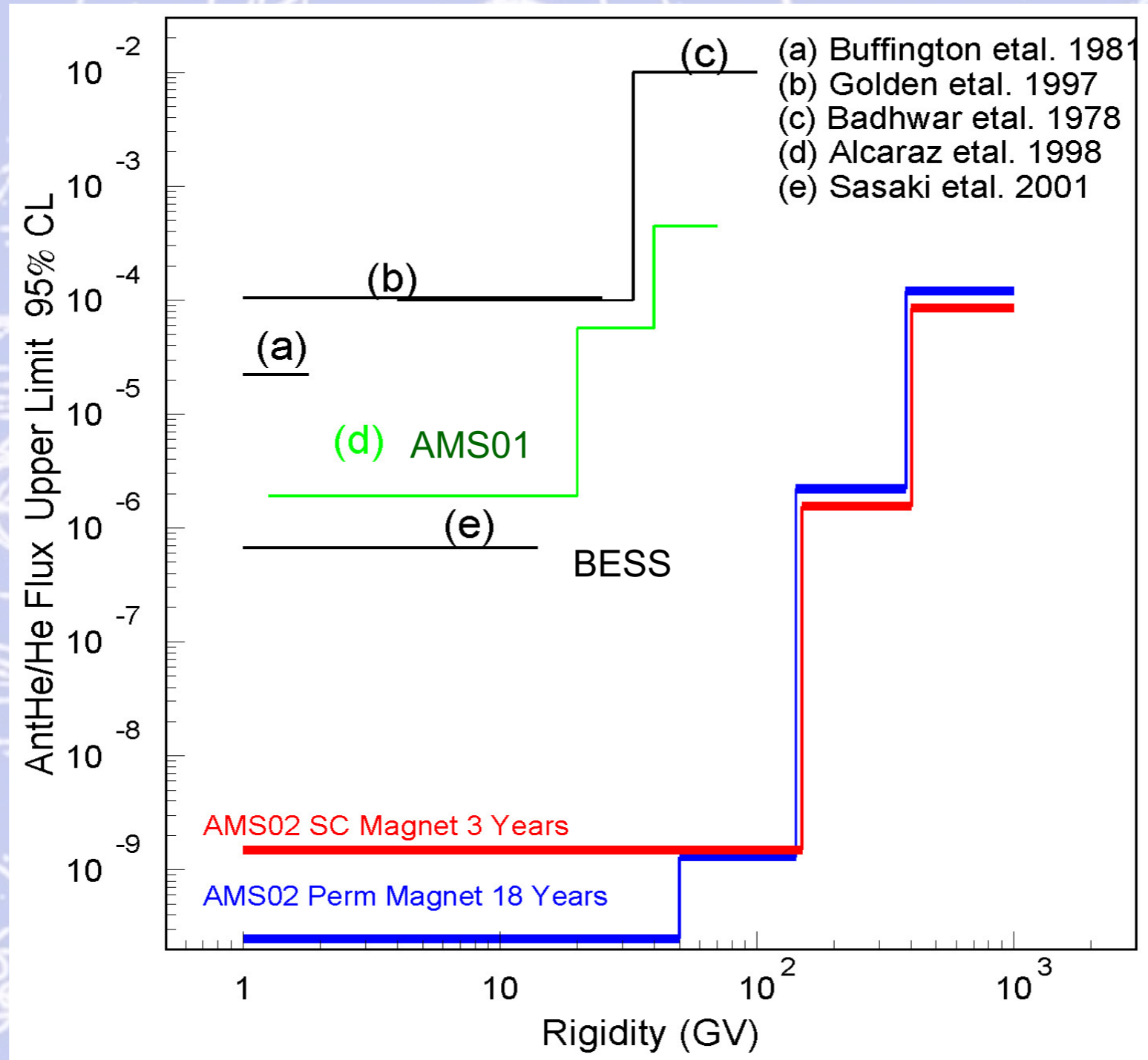


Indice spettrale degli elettroni e dei positroni (Sett. 2014)

Flusso combinato $e^\pm \times E^3$ misurato da AMS (Sett. 2014)



La fisica di AMS-02: ricerca di antimateria cosmica residua (limite sulla presenza di $\bar{\text{He}}$)



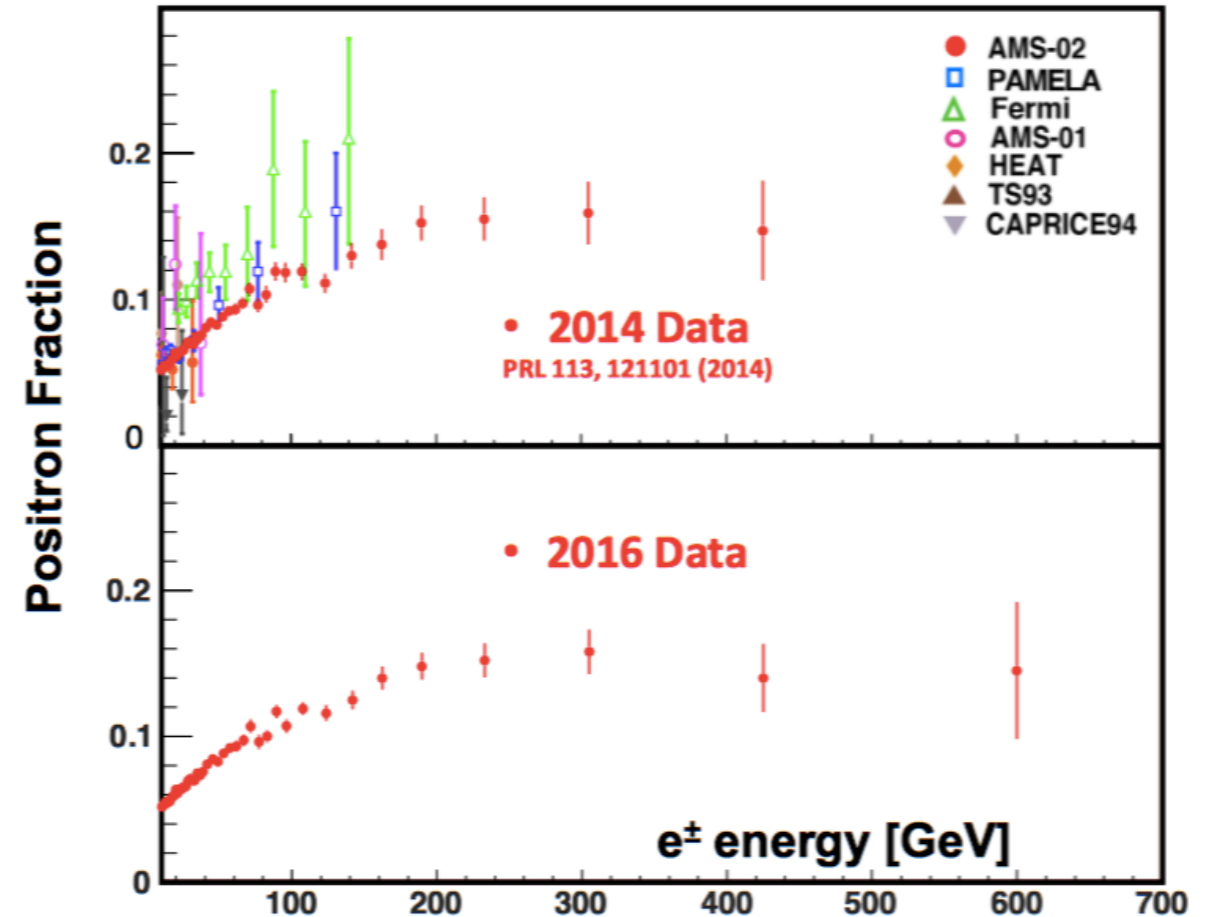
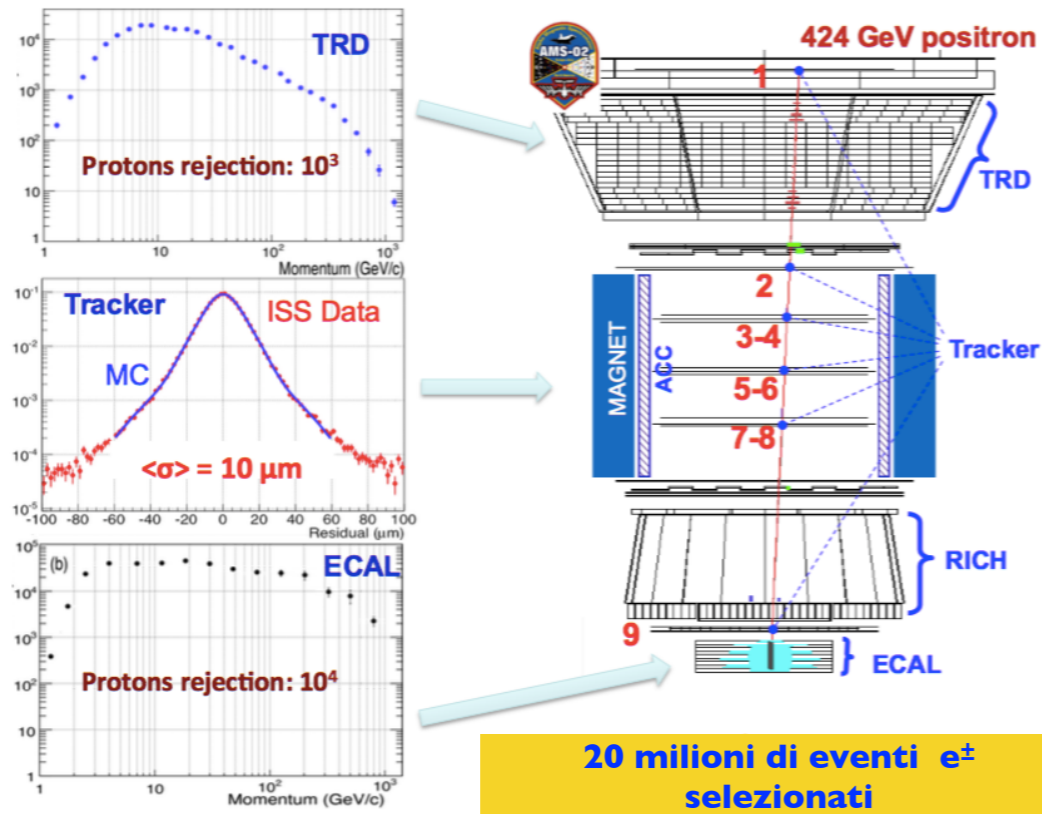


(aggiornamento a settembre 2016)

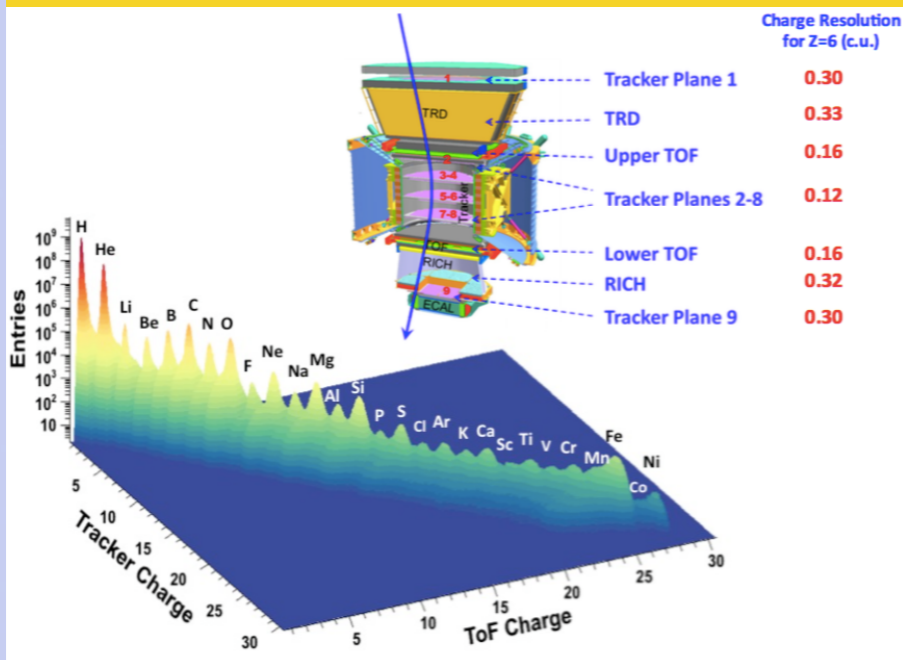
Positroni ed elettroni

Rispetto al 2014: - intervallo energetico e' esteso a 700 GeV
- statistica e' aumentata da 11 a 20 milioni di

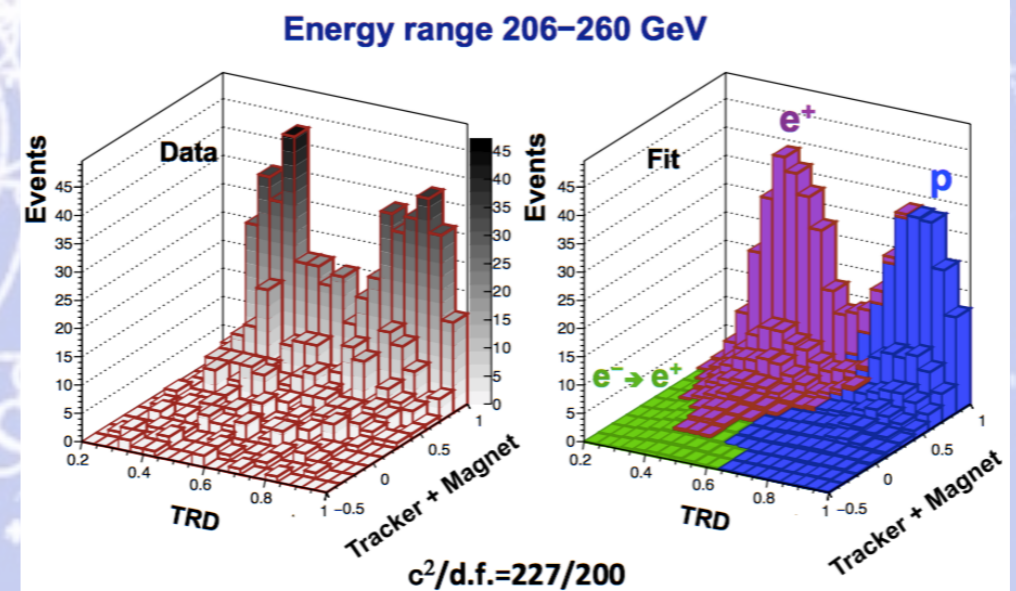
Positron fraction analysis: dopo 5 anni di presa dati ⇔



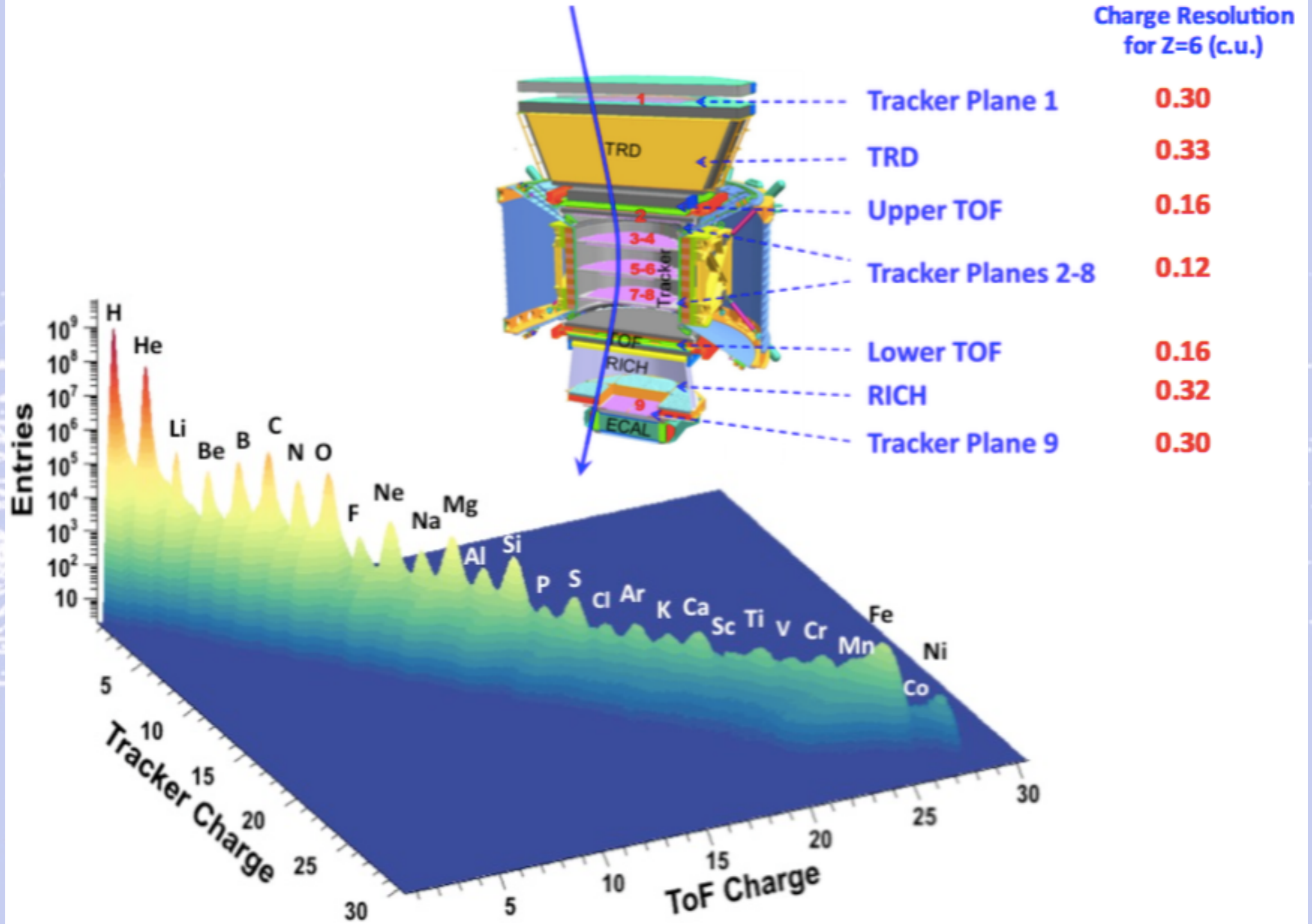
Misura della Carica: ridondanza



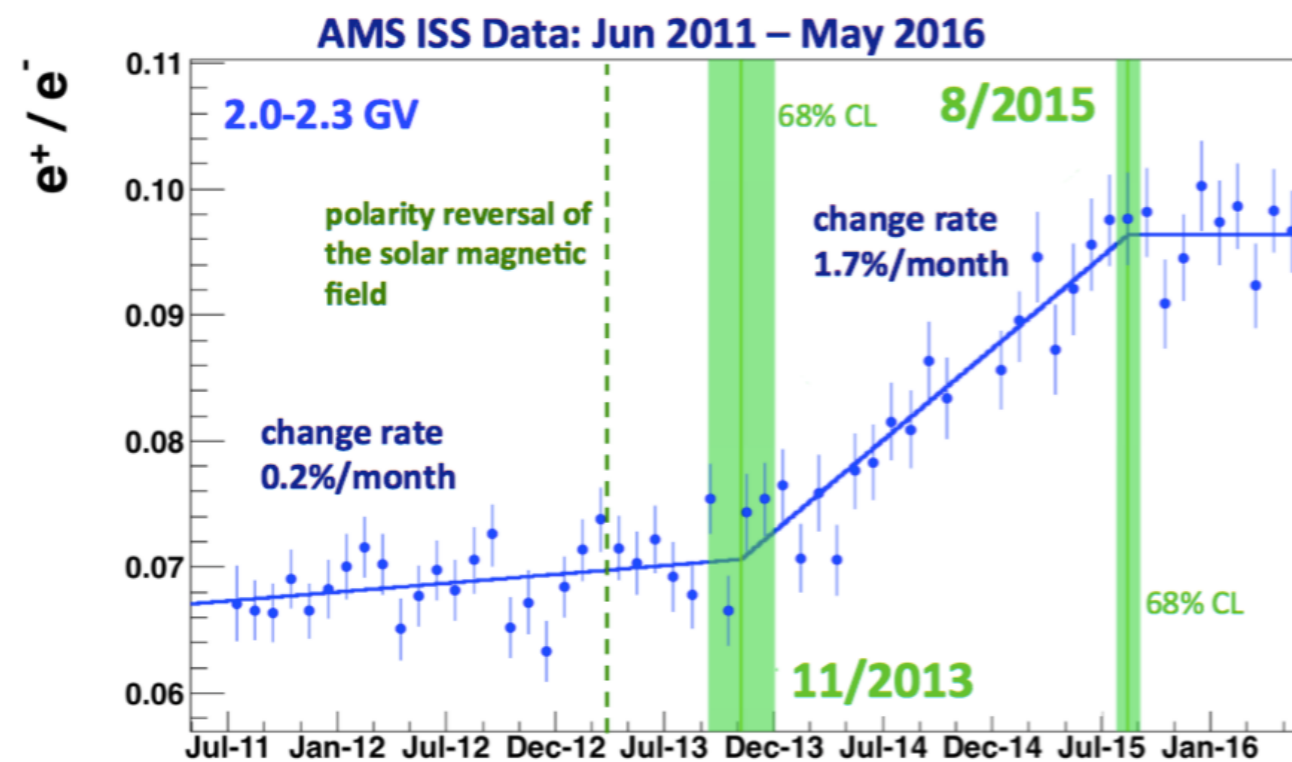
TRD Estimator: - chiara separazione tra positroni e



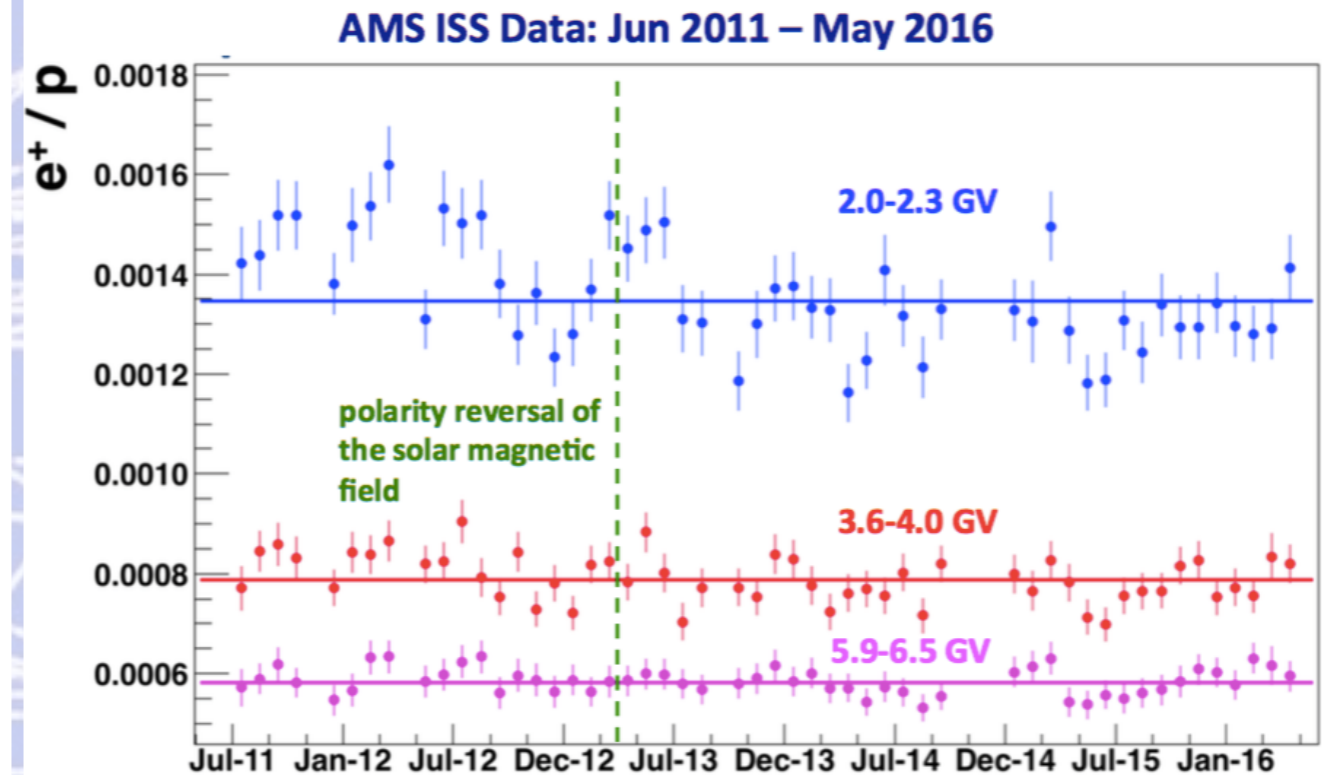
Multiple Measurements of Charge



Ciclo solare: inversione del campo magnetico solare



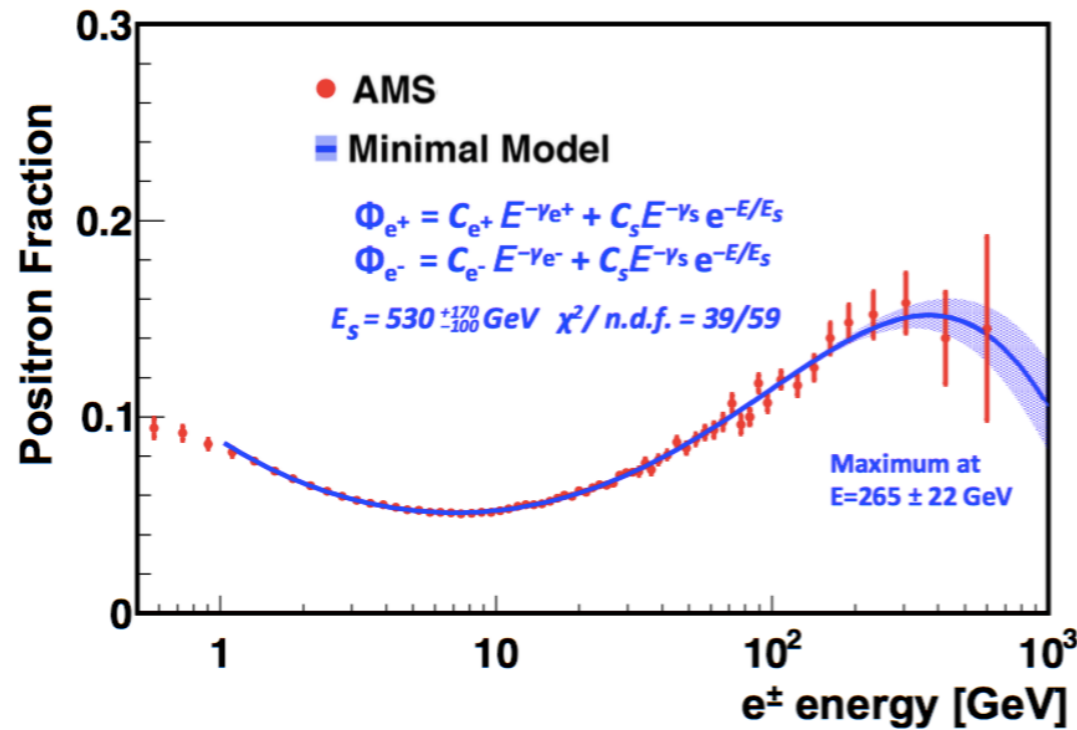
- After the reversal of the solar magnetic field in 03/2013 it takes (8 ± 1.5) month till this has a visible effect on the e^+/e^- ratio.
- It takes (21 ± 1) month to stabilize the e^+/e^- ratio again.



- The e^+/p ratio does not show large variations as a function of time.
- The full power of the AMS high precision data sets can only be explored after time dependent effects are extracted and the data can be used to constrain the local interstellar spectra.

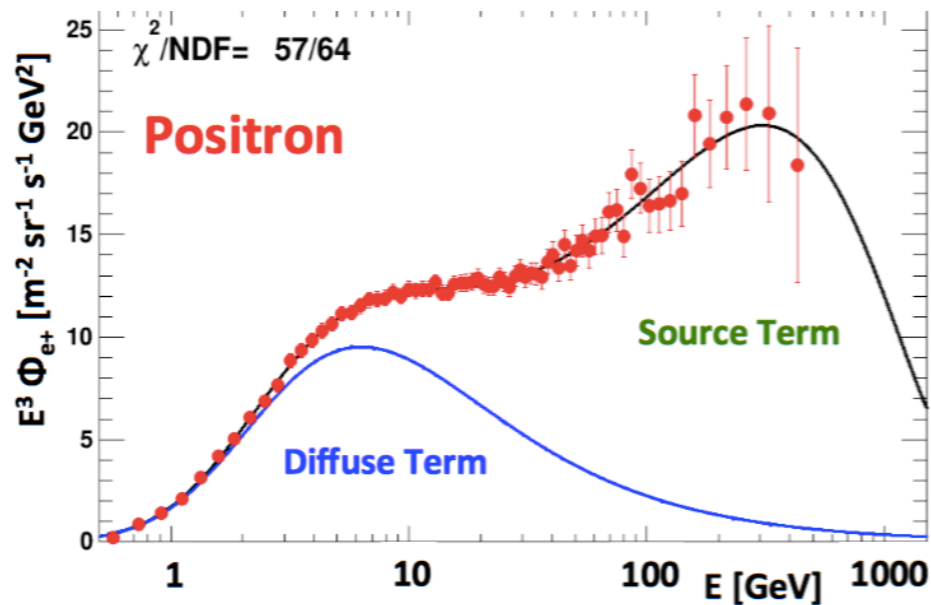
AMS ed il monitoraggio continuo intorno alla Terra

Additional source of positrons

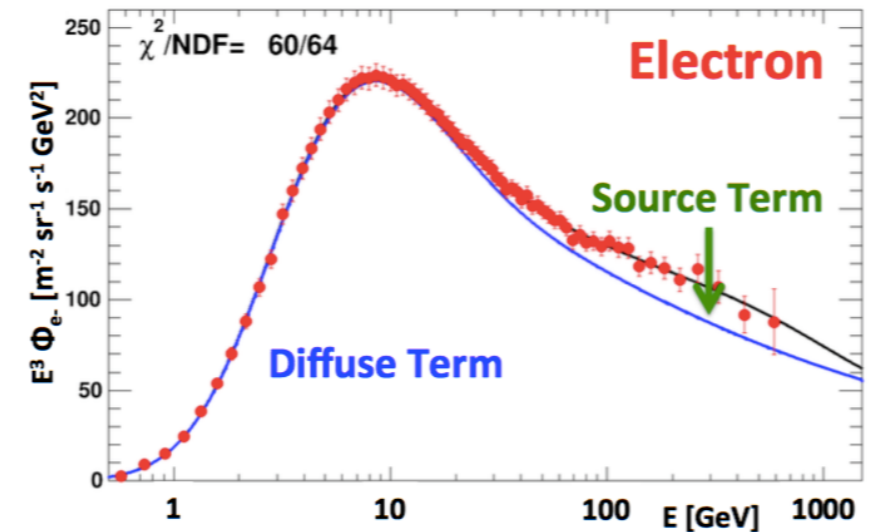


Positroni ed elettroni: lo spettro (1)

The Positron Flux has no sharp structures and is dominated at high energies by the source term.



The source term parameters are constrained from the positron flux fit.



The Electron Flux

- has no sharp structures and is dominated by the diffuse term.
- is consistent with a charge symmetric source term.

The spectral index of the diffuse term has to become energy dependent:

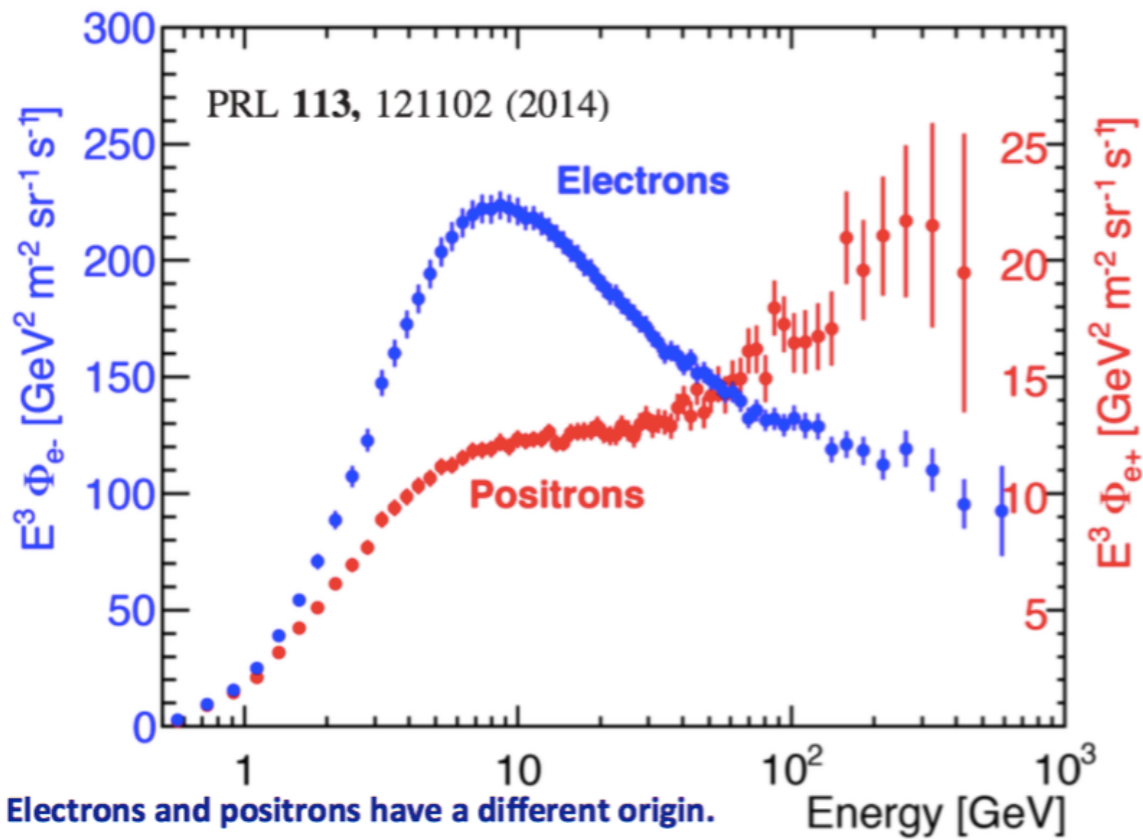
$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2} \left[C_{e^-} \hat{E}^{\gamma_{e^-}(\hat{E})} + C_s \hat{E}^{\gamma_s} \exp(-\hat{E}/E_s) \right]$$

The source term parameters are constrained from the positron flux fit.

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2} \left[C_{e^+} \hat{E}^{\gamma_{e^+}} + C_s \hat{E}^{\gamma_s} \exp(-\hat{E}/E_s) \right] \text{ with } E_s = 530 \text{ GeV from the } e^+/(e^+ + e^-) \text{ fit}$$

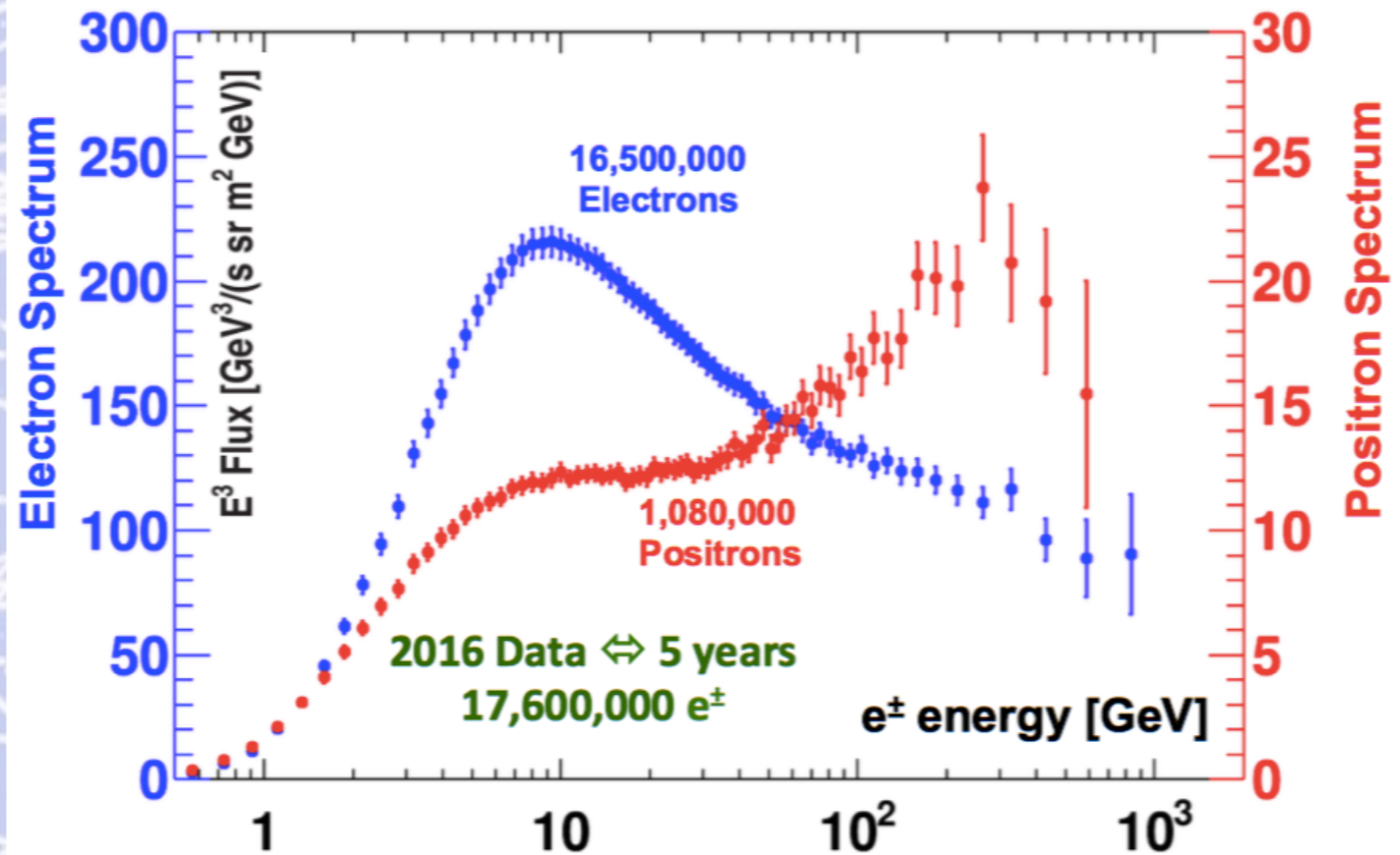
and $\hat{E} = E + \Psi$ as the energy scale of the LIS

Positroni ed elettroni: lo spettro (3)

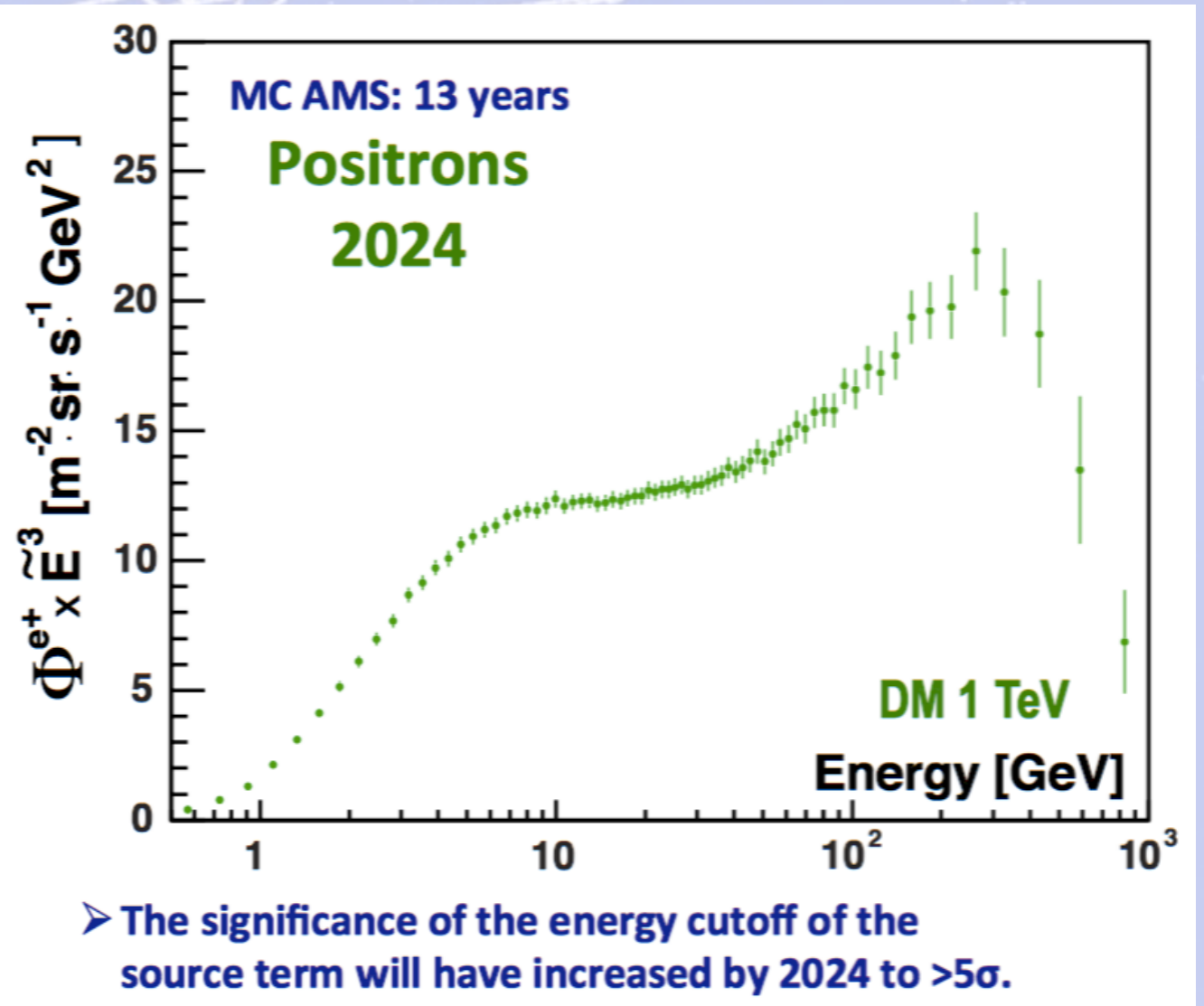
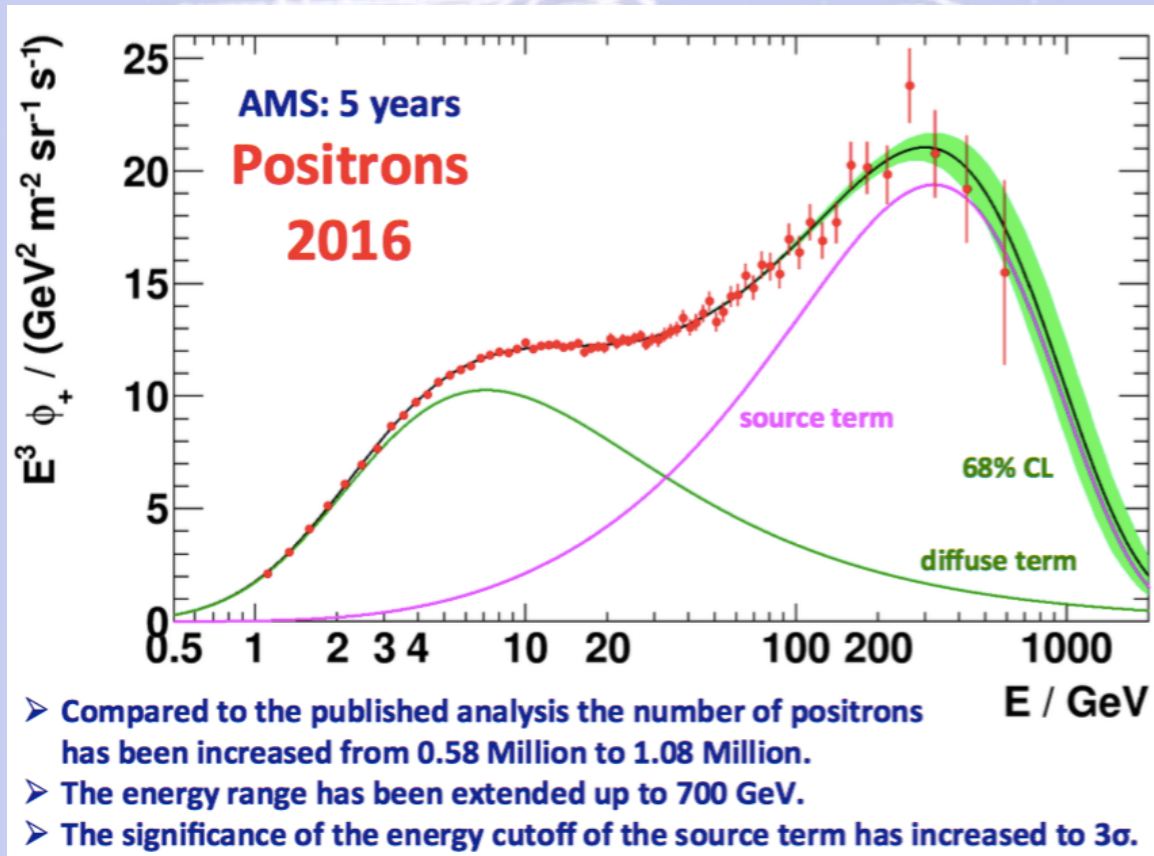
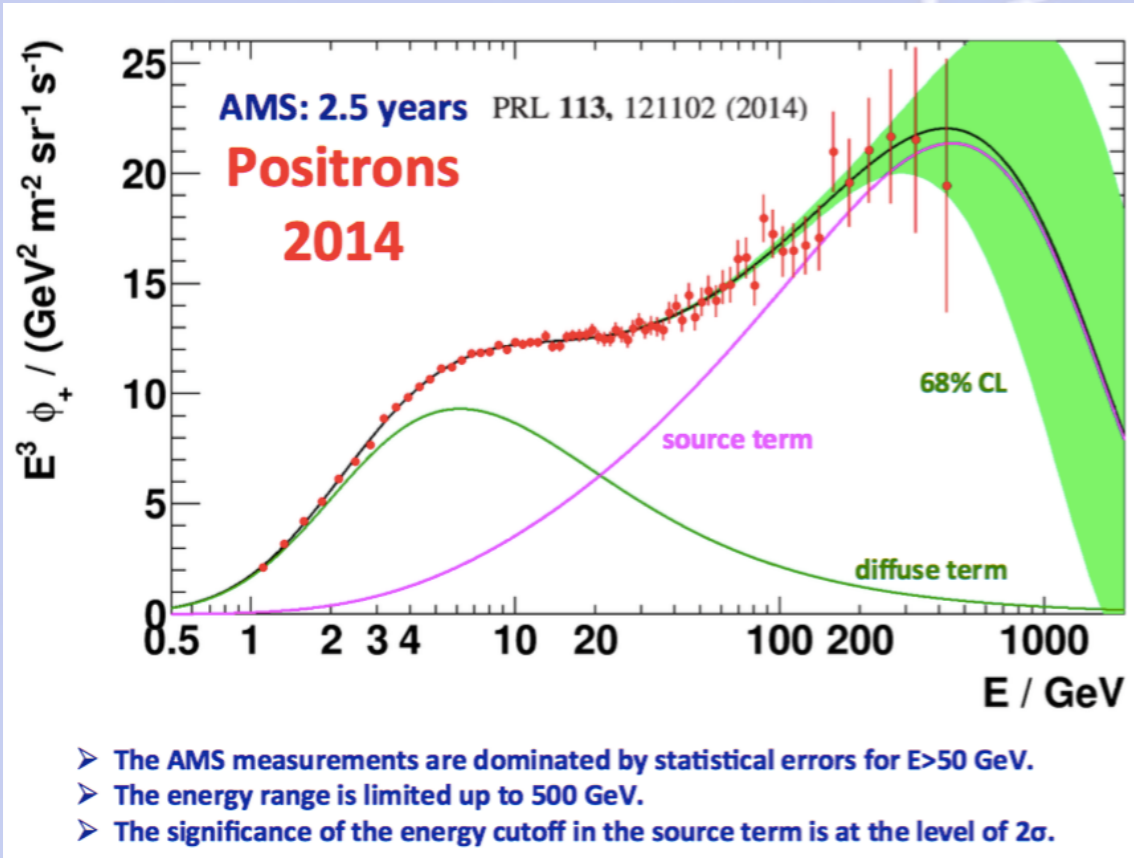


- Electrons and positrons have a different origin.
- A „Standard Model“ to describe all our data does not exist.
- Therefore we have to use simple phenomenological models.

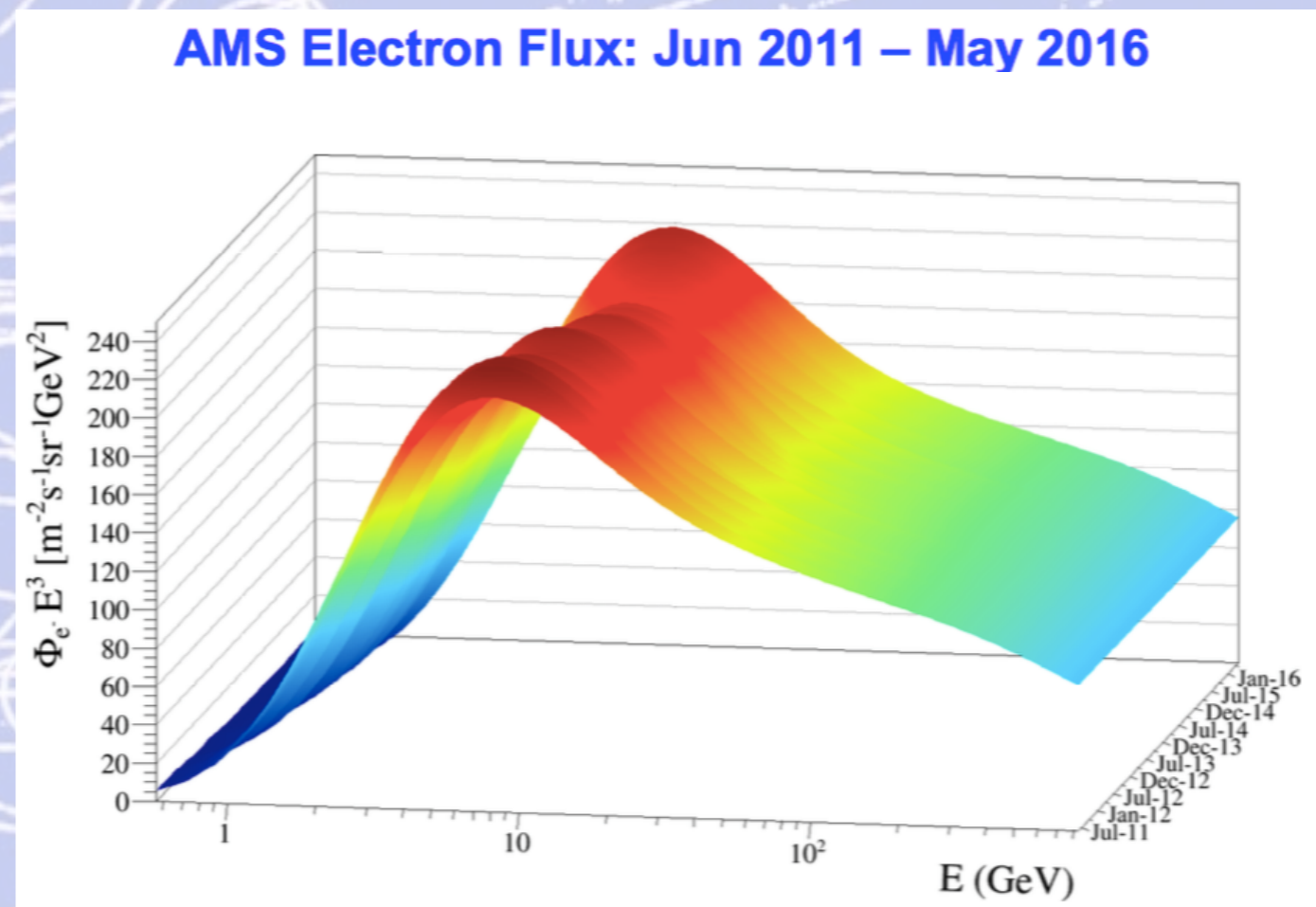
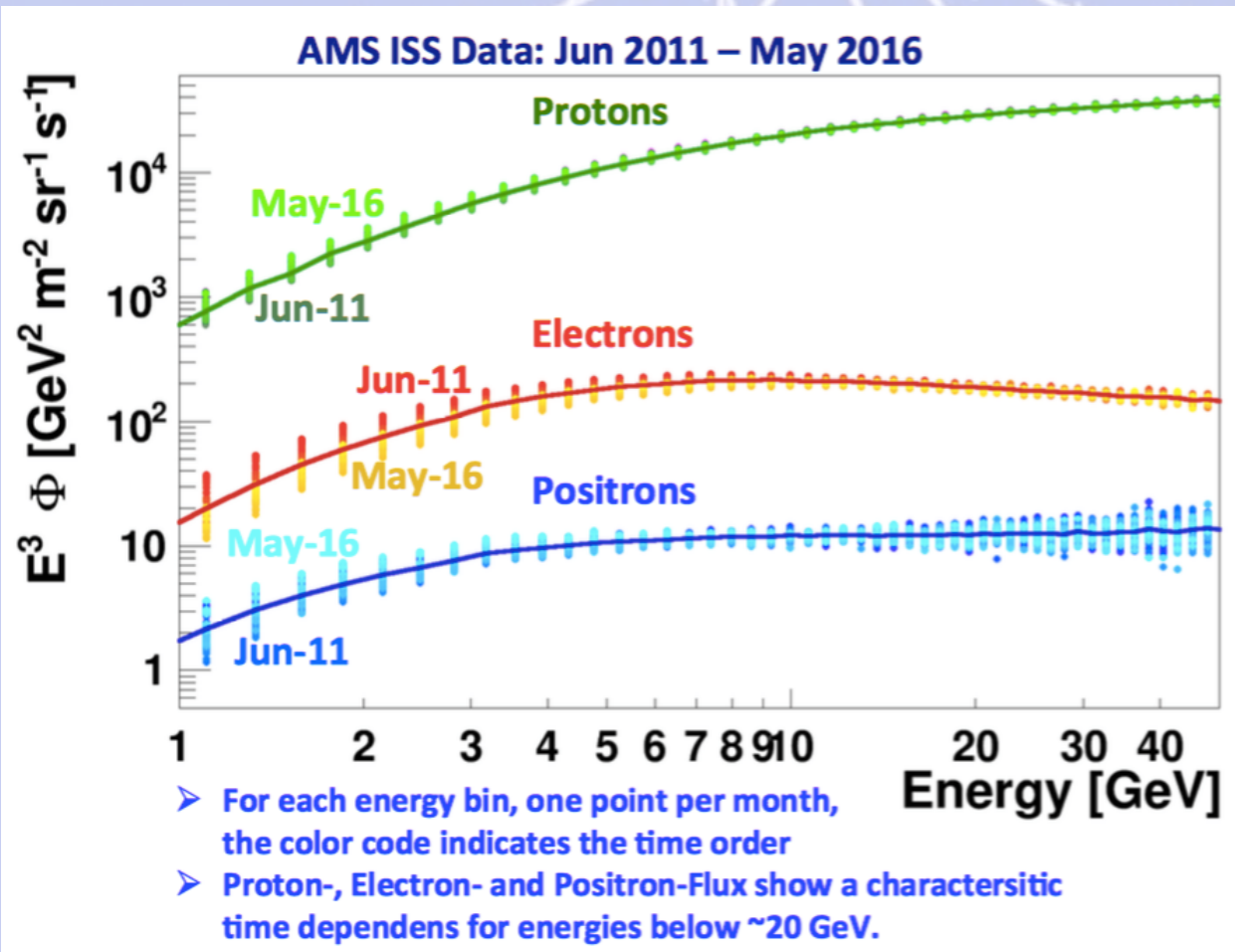
AMS measurements of the Electron and Positron spectra



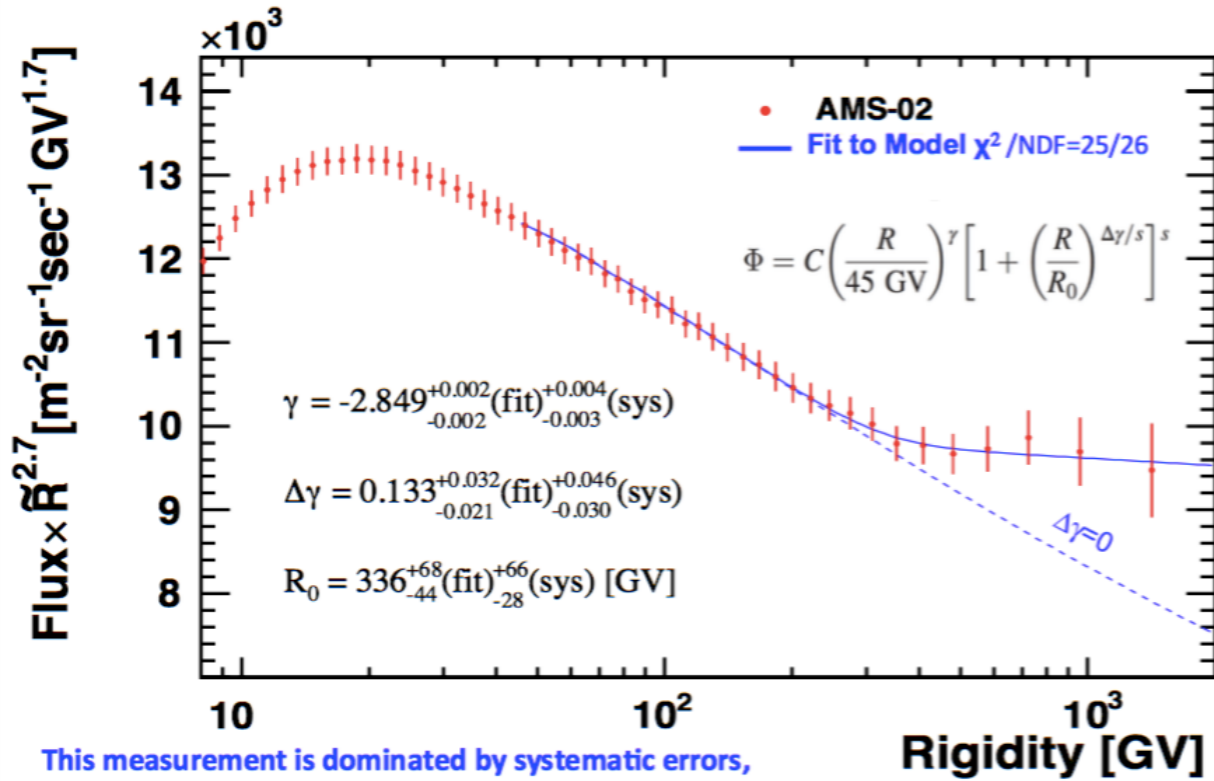
Positroni: dati e previsioni



Positroni, elettroni e protoni: segnale e fondo



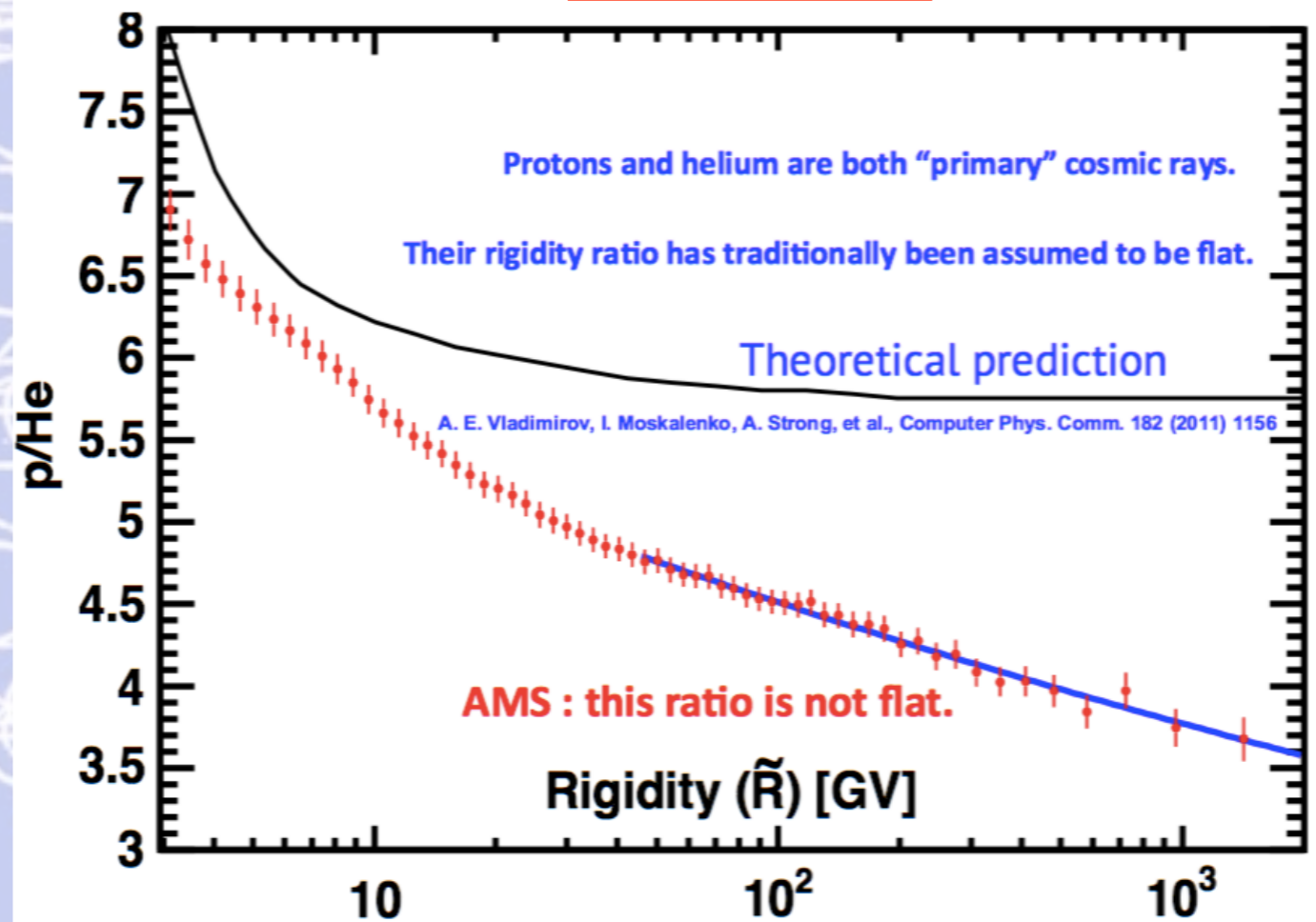
It was expected that the proton flux could be described with a single power law with spectral index $\gamma=-2.7$.



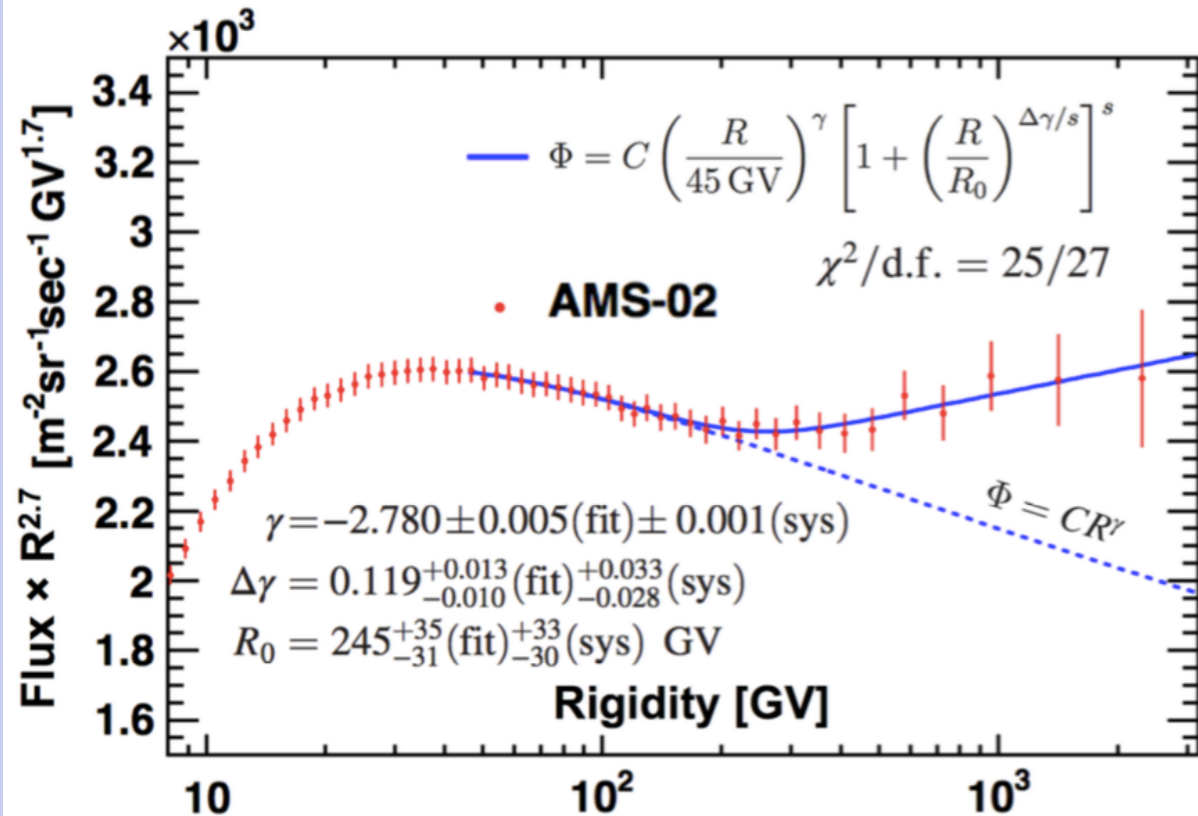
This measurement is dominated by systematic errors, we will therefore not be able to improve it.

Protoni ed elio: flusso

The AMS proton/helium flux ratio

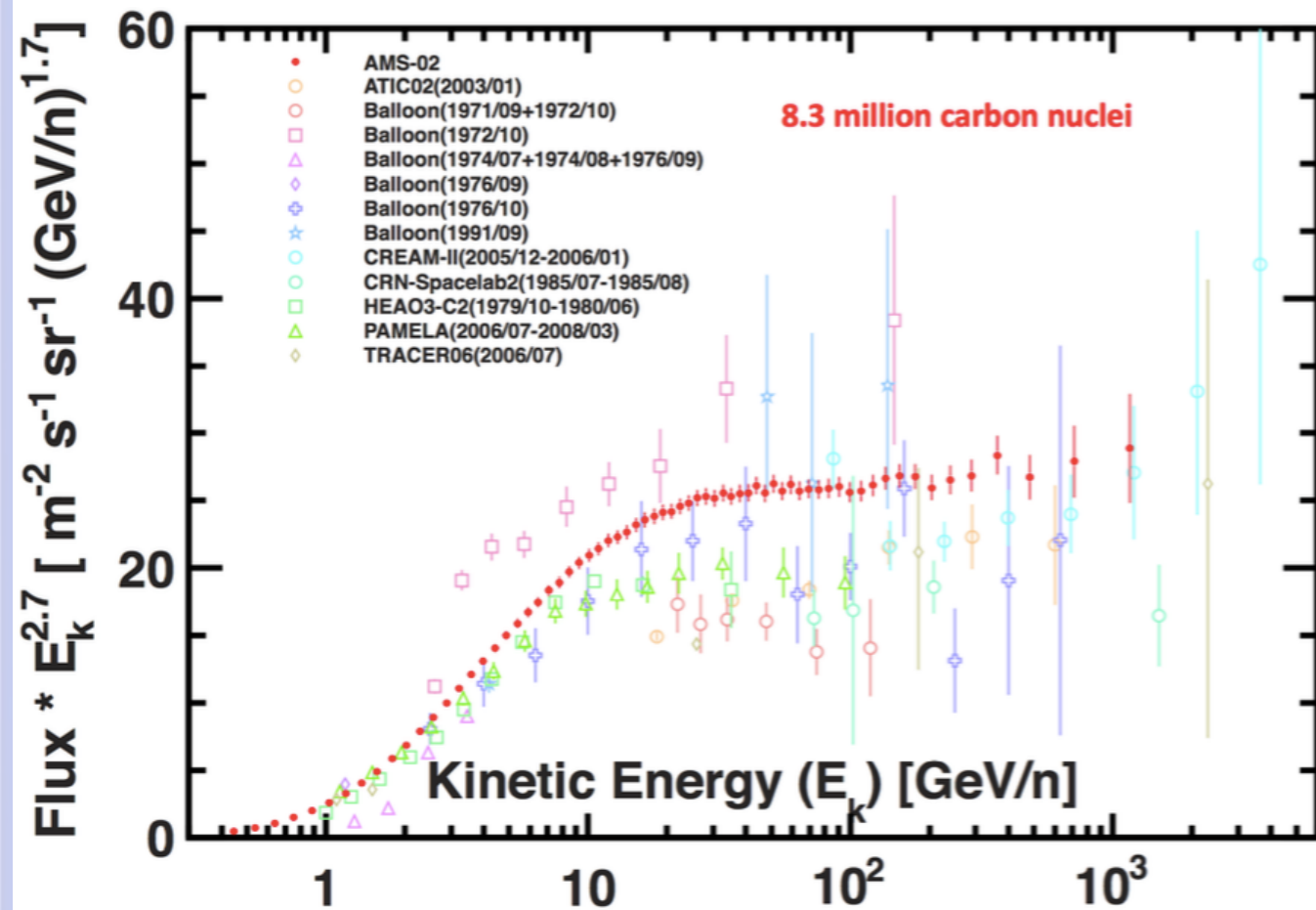


It was expected that the He flux could be described with a single power law with spectral index $\gamma=-2.7$.



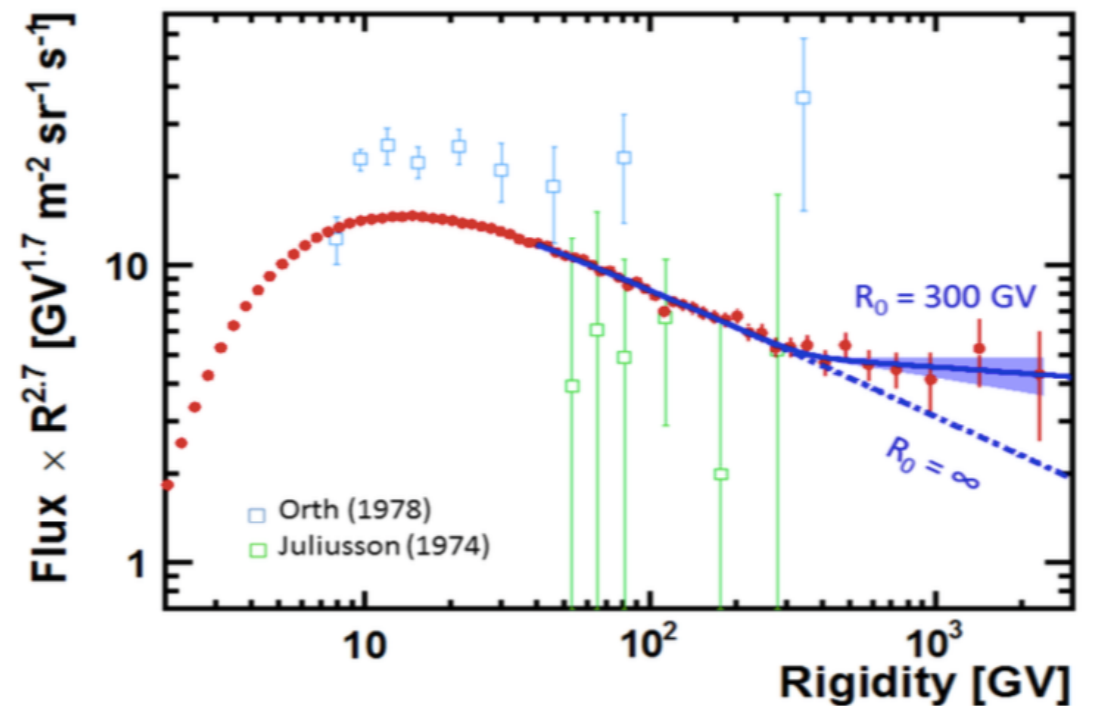
Carbonio e Litio: flusso

AMS Carbon flux



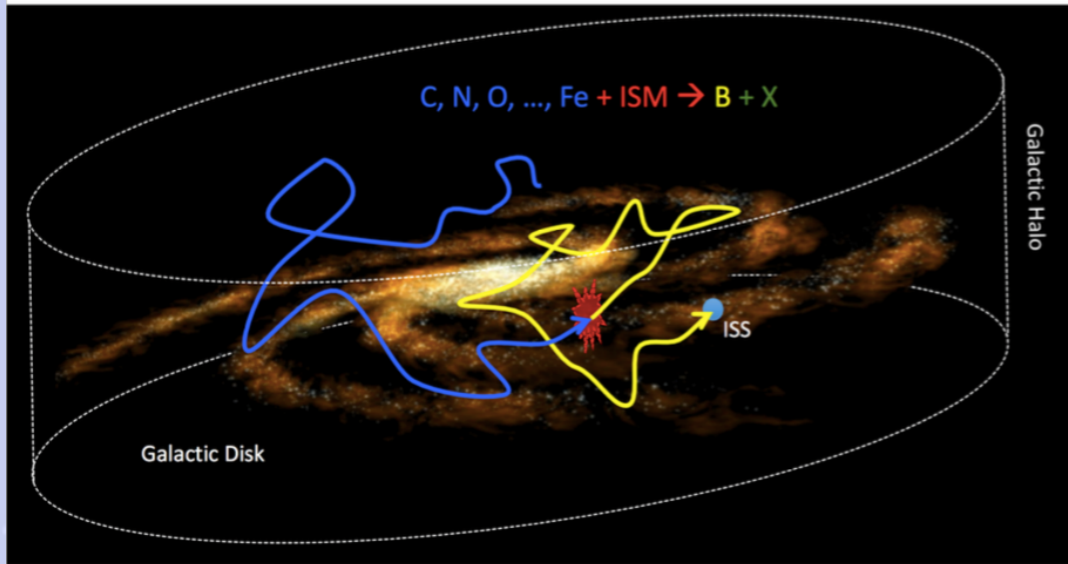
AMS Lithium flux

Up to now it was assumed that cosmic lithium is purely secondary in origin. The AMS data show that either cosmic lithium has also a primary origin or the diffusion coefficient that describes the propagation of cosmic rays is rigidity dependent.



The AMS lithium flux fitted with a double power law $\Phi=C \cdot (R/45\text{GV})^\nu \cdot (1+(R/R_0)^{\Delta\nu/s})^s$ (solid line, shaded region 1-sigma limits).

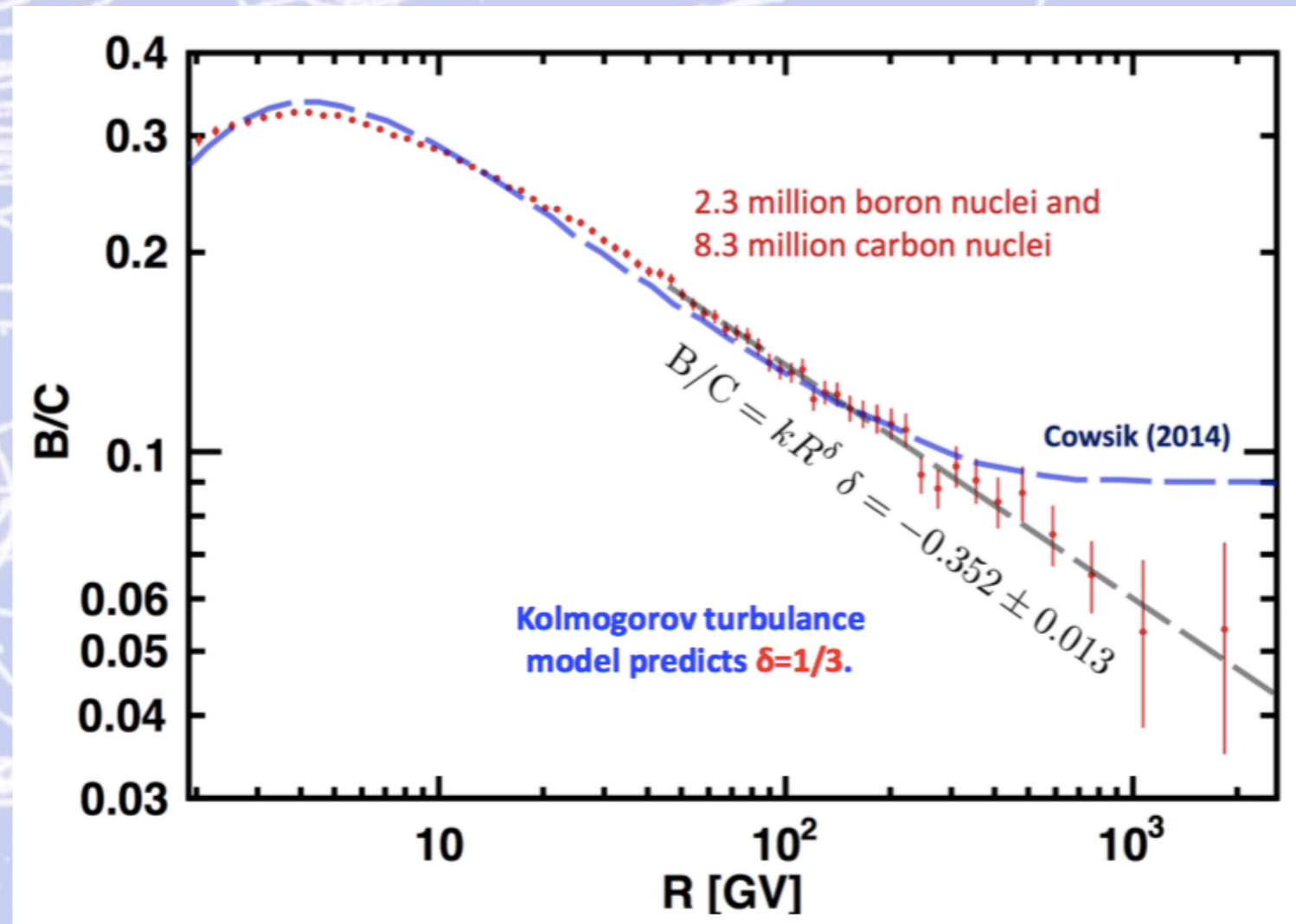
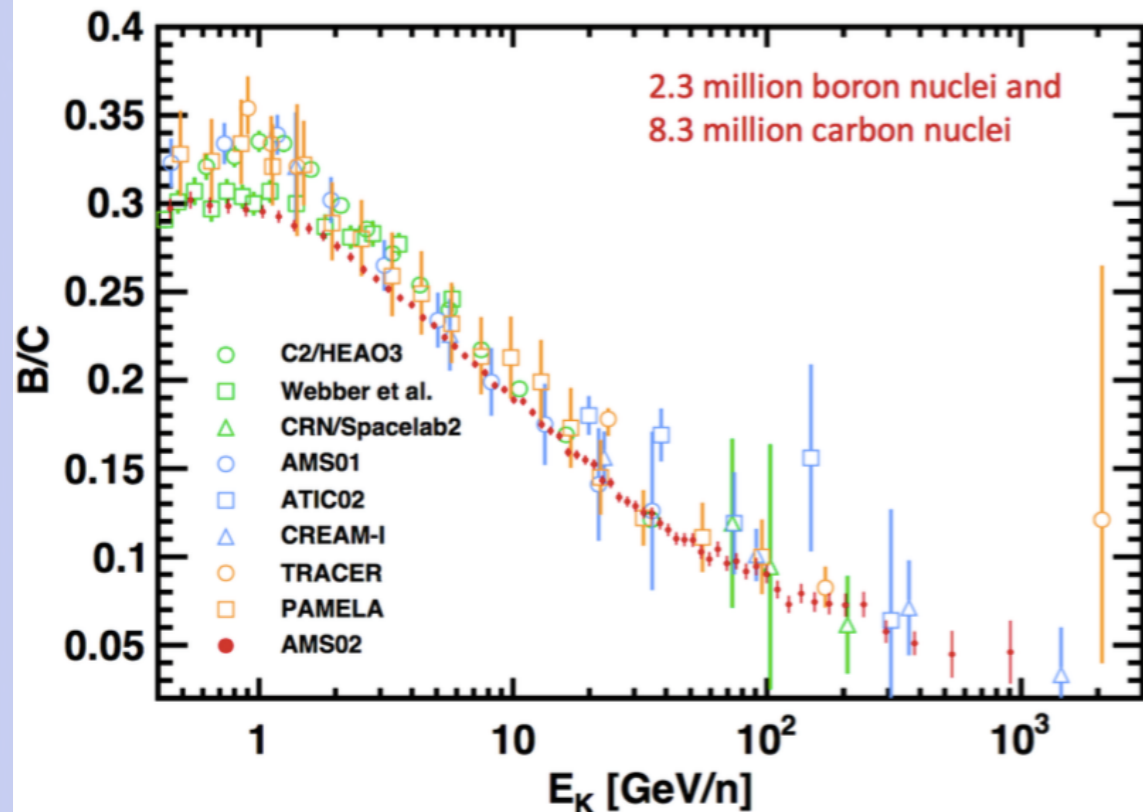
Flux Ratios: Boron/Carbon and cosmic ray propagation



The boron-to-carbon ratio (B/C) is important in the determination of cosmic ray propagation. Boron is assumed to be produced from the collision of primary cosmic rays, such as carbon (C), with the interstellar medium (ISM), hence the B/C ratio provides information on cosmic ray propagation.

Boro/Carbonio: dati e previsioni

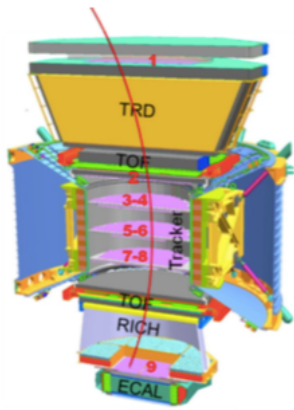
The AMS boron-to-carbon (B/C) flux ratio



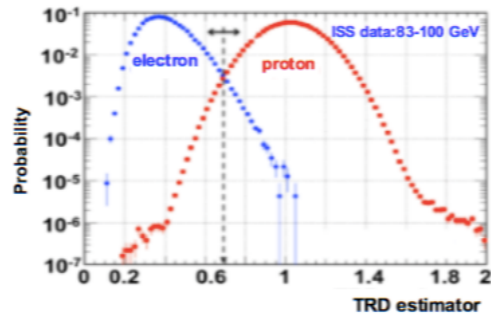
(Dettagli sui modelli teorici in appendice 6)

Antiproton analysis

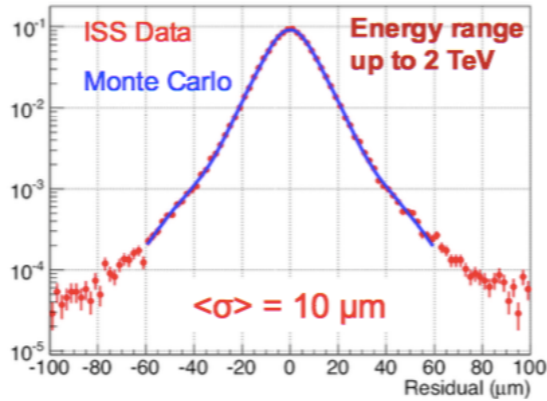
$6.5 \cdot 10^{10}$ cosmic rays
 $3.49 \cdot 10^5$ antiprotons
 $2.42 \cdot 10^9$ protons



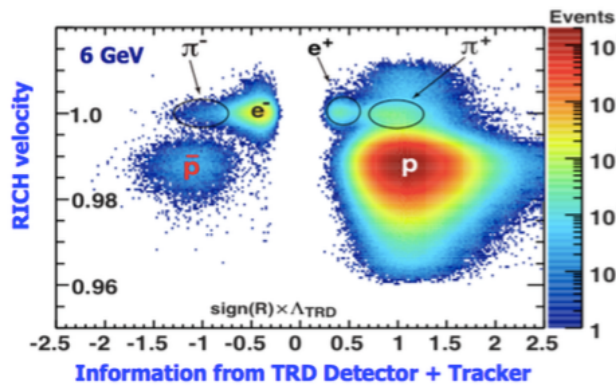
1. TRD (transition radiation) to separate e^\pm from p^\pm



2. Tracker measures momentum and separates $+$ from $-$

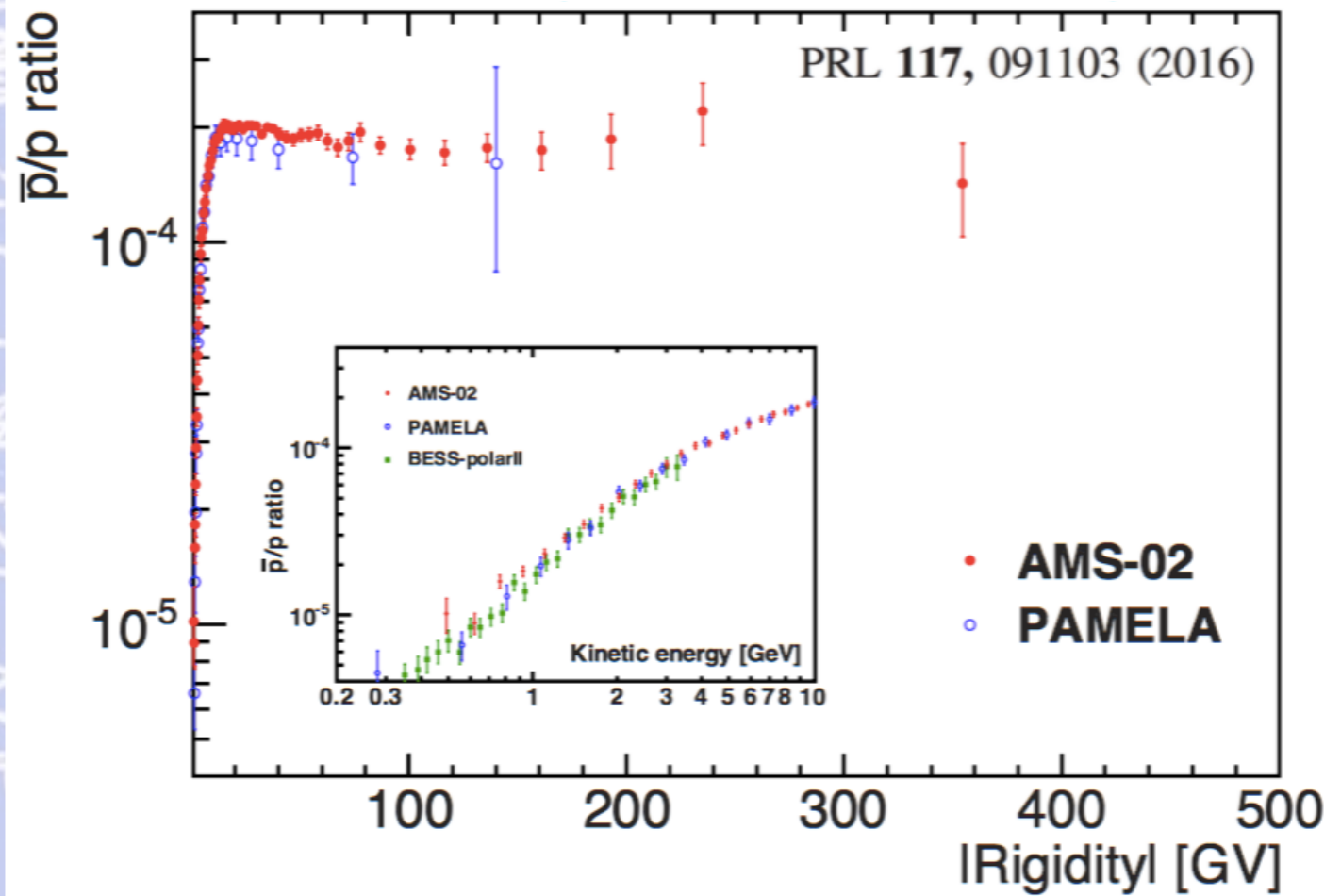


3. RICH measures velocity,

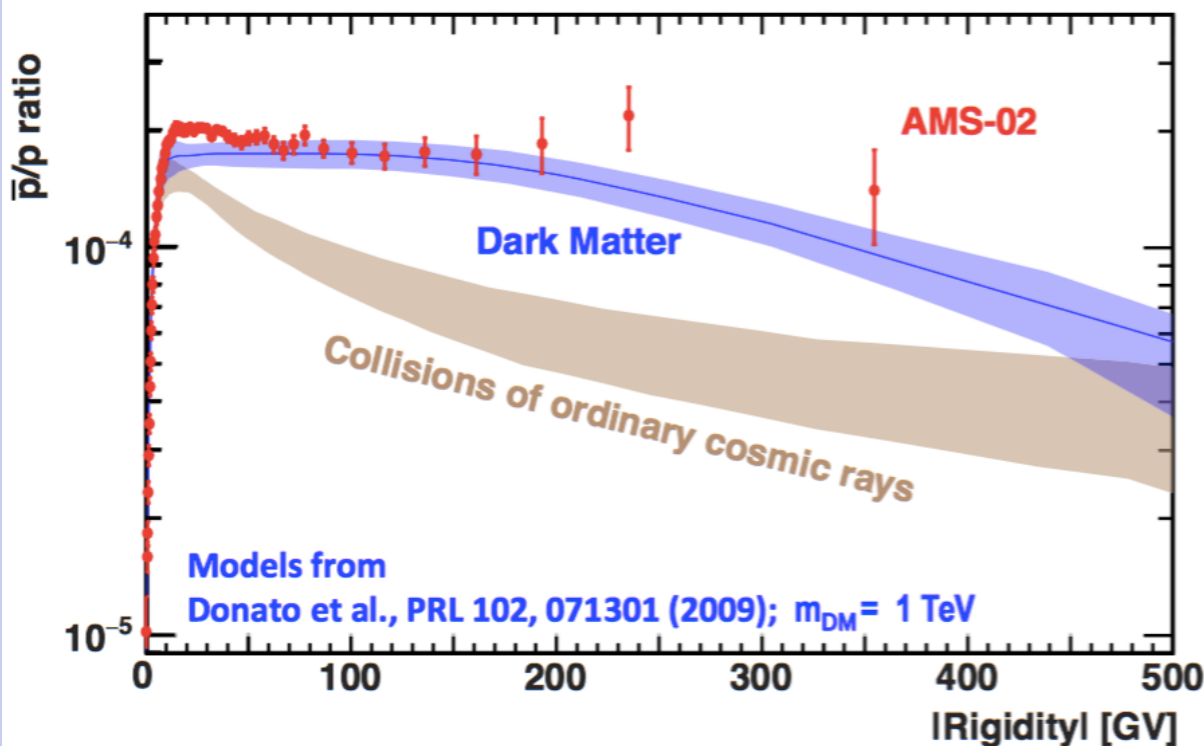


Protoni ed antiprotoni

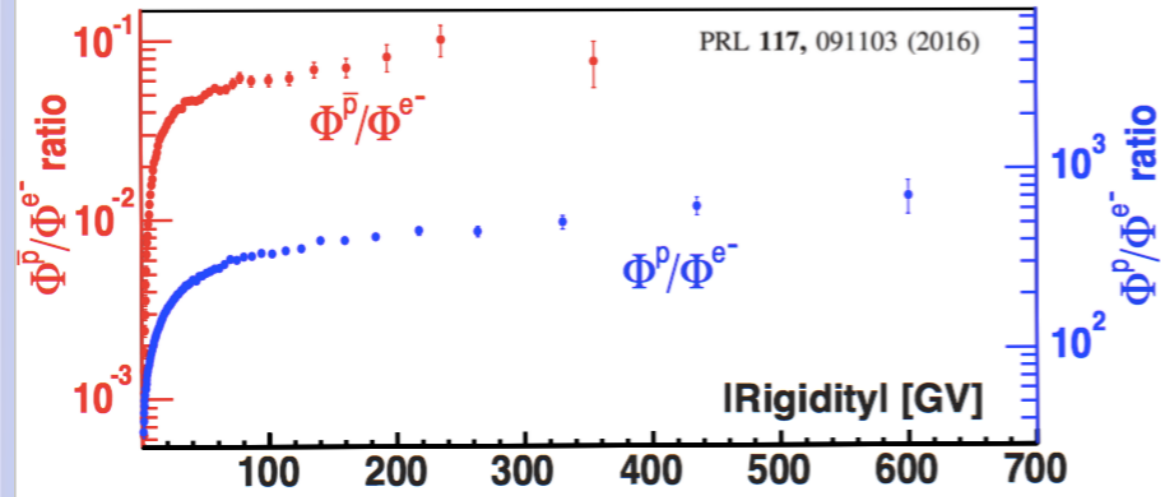
AMS results on the \bar{p}/p flux ratio



AMS \bar{p}/p results and modeling



Flux Ratios \bar{p}/e^- and p/e^- are **not** energy independent in the interval 60–450 GV



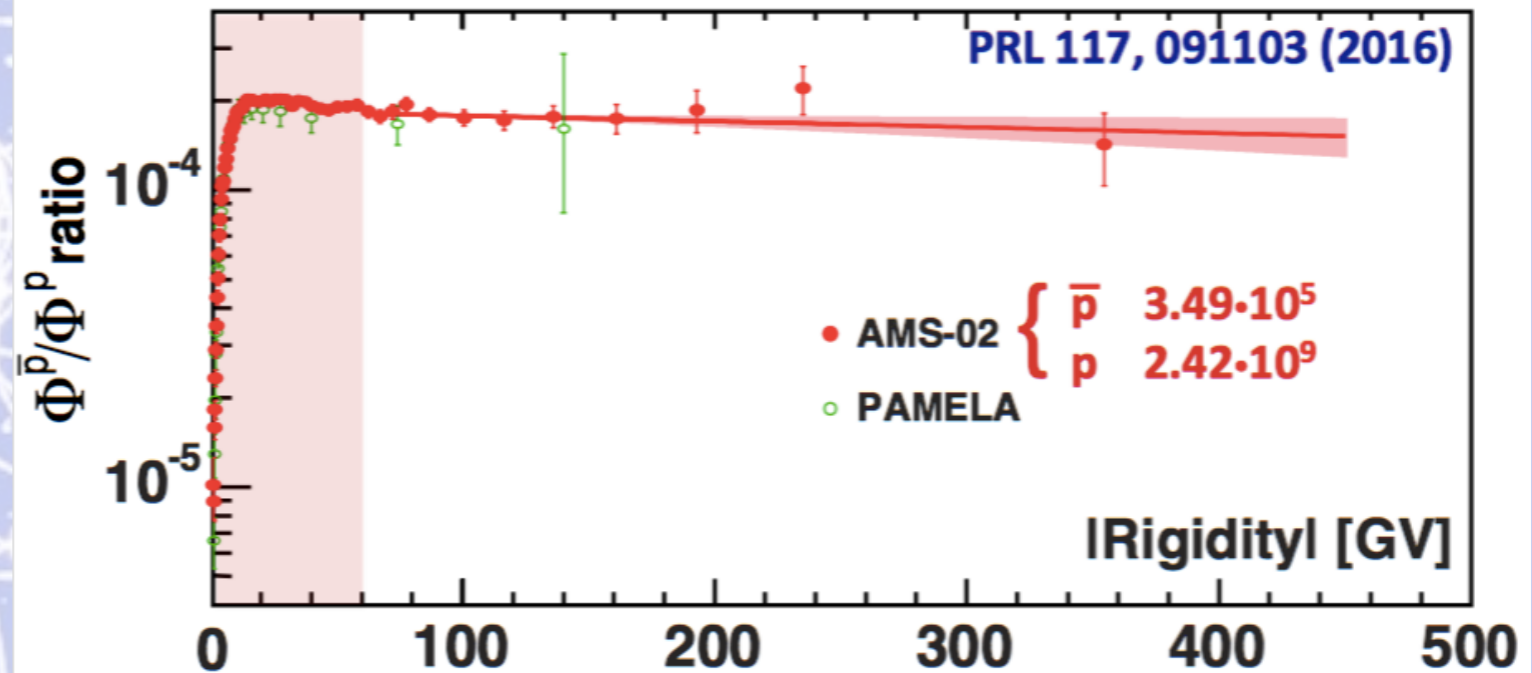
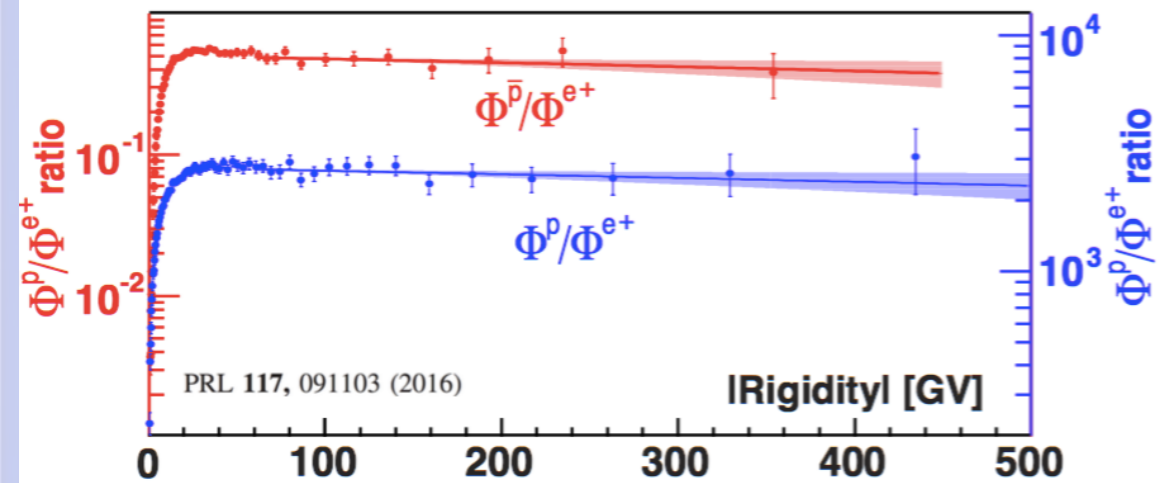
As expected: significant energy losses of e^- due to synchrotron radiation

Dipendenza energetica dei flussi

Unexpected Result

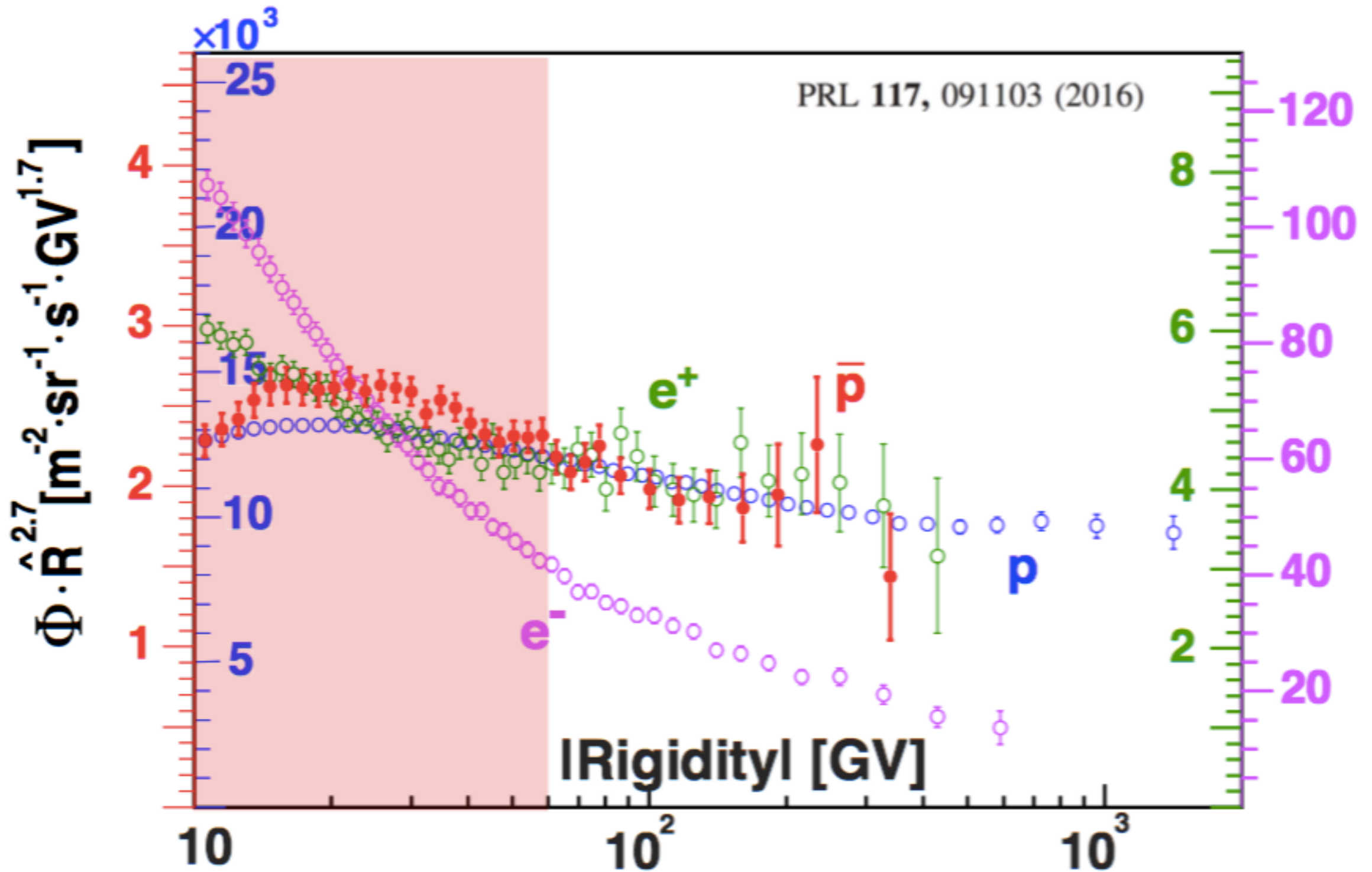
Flux Ratio of Elementary Particles \bar{p}/p is energy independent above 60 GeV

Flux Ratios \bar{p}/e^+ and p/e^+ are also energy independent in the interval 60–450 GV



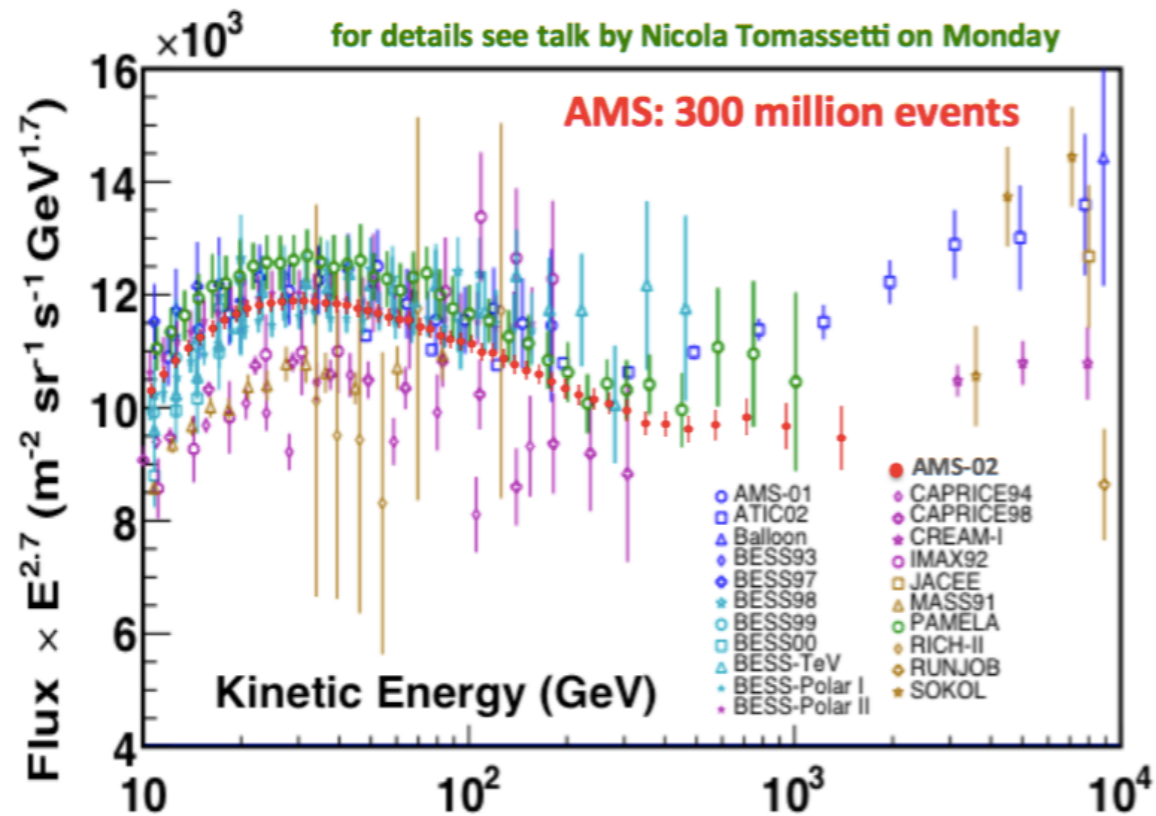
Summary

AMS results on the fluxes of elementary particles

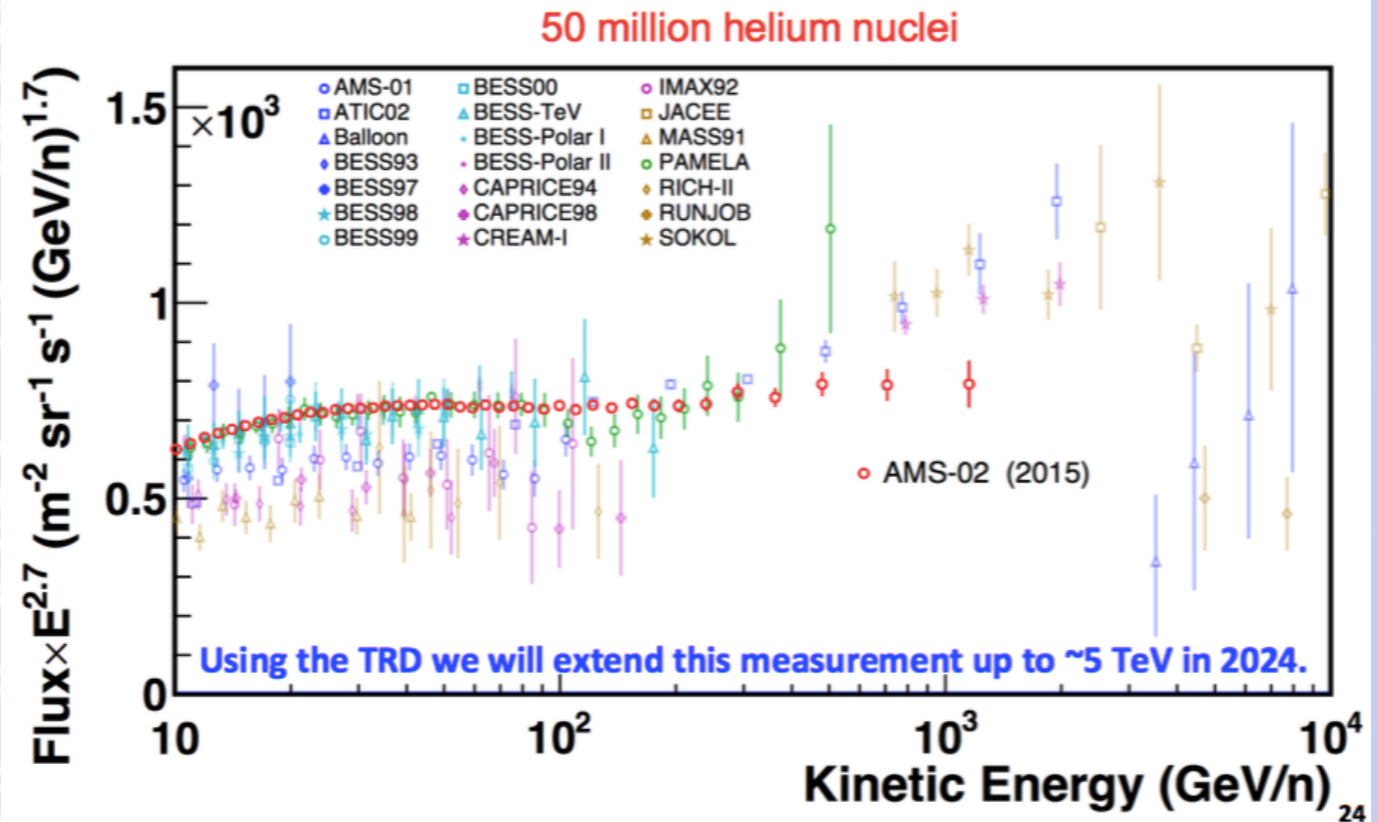


Alcune pubblicazioni: protoni ed elio (2015)

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station



Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station

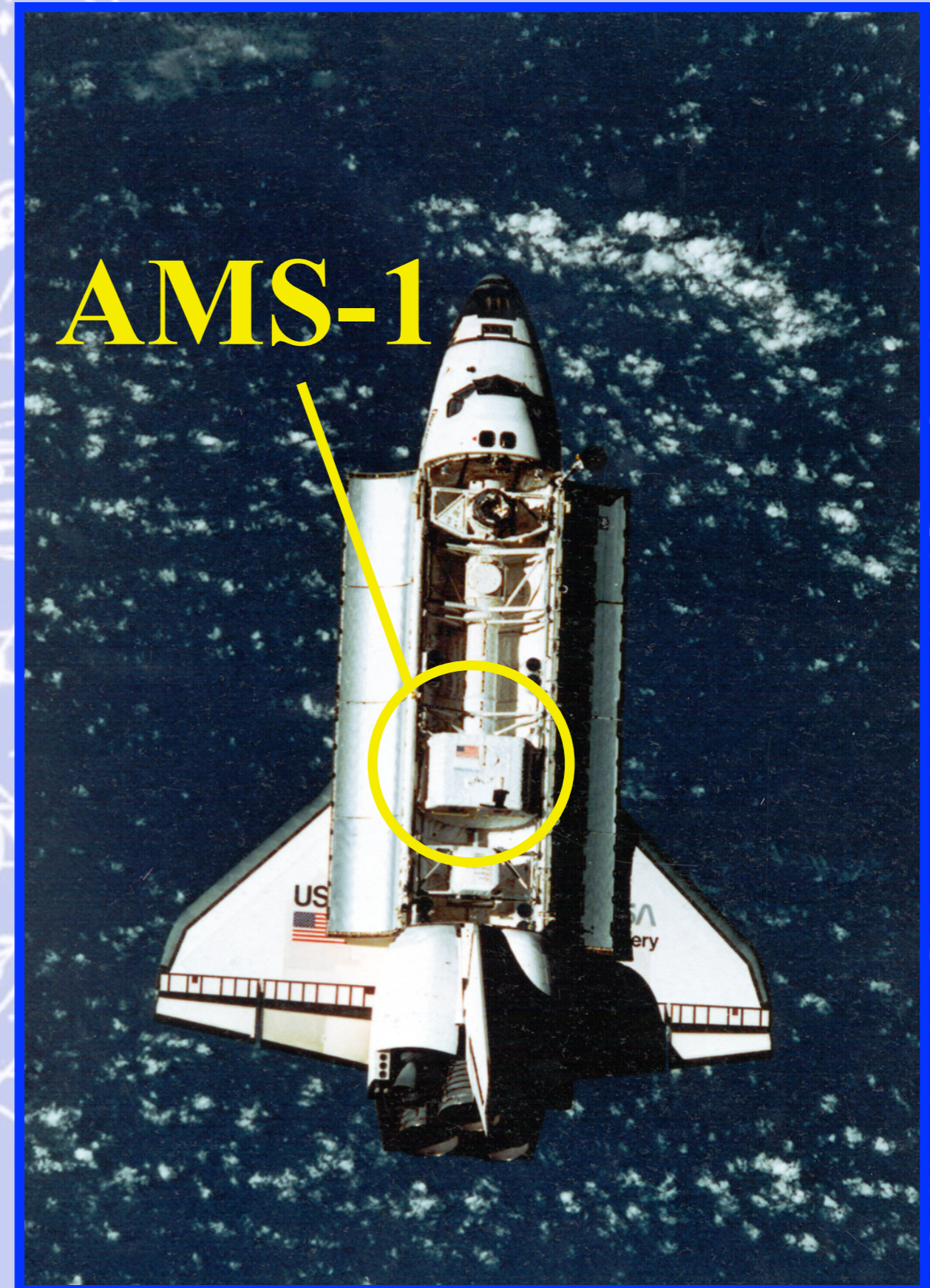
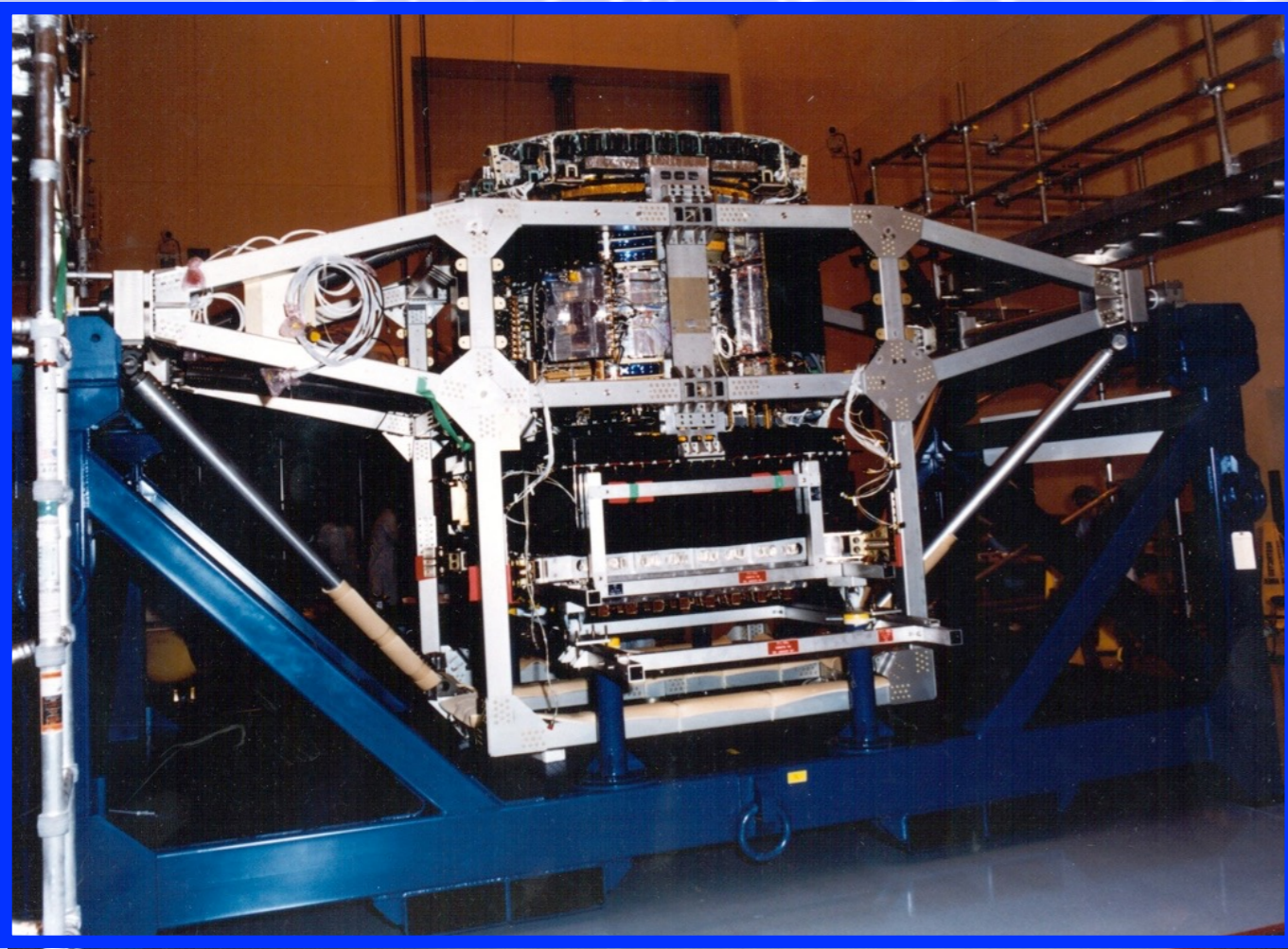


Appendice 14

(L' esperimento pilota AMS-01)

Experience from the AMS-1 flight (STS-91) 1998

- Data taking \approx 135 hours;
- Shuttle altitude \approx 370 km;
- 100 million events recorded.

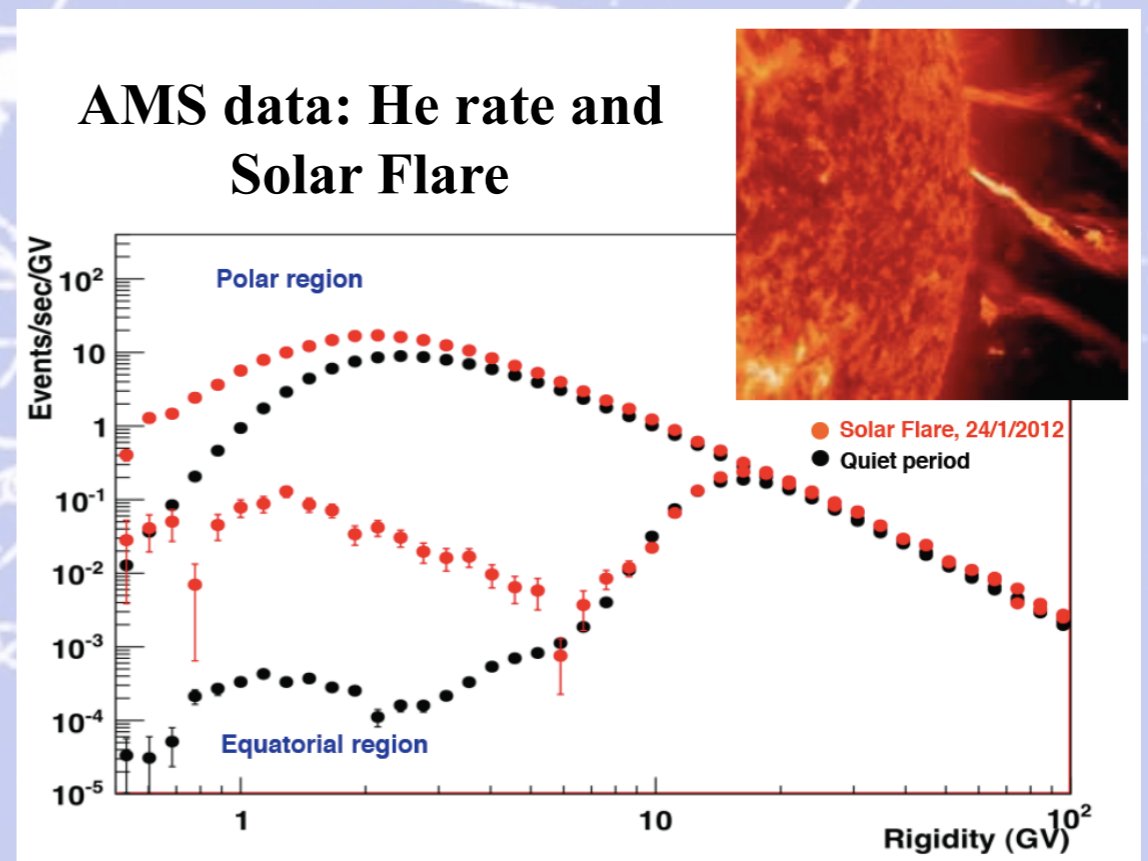
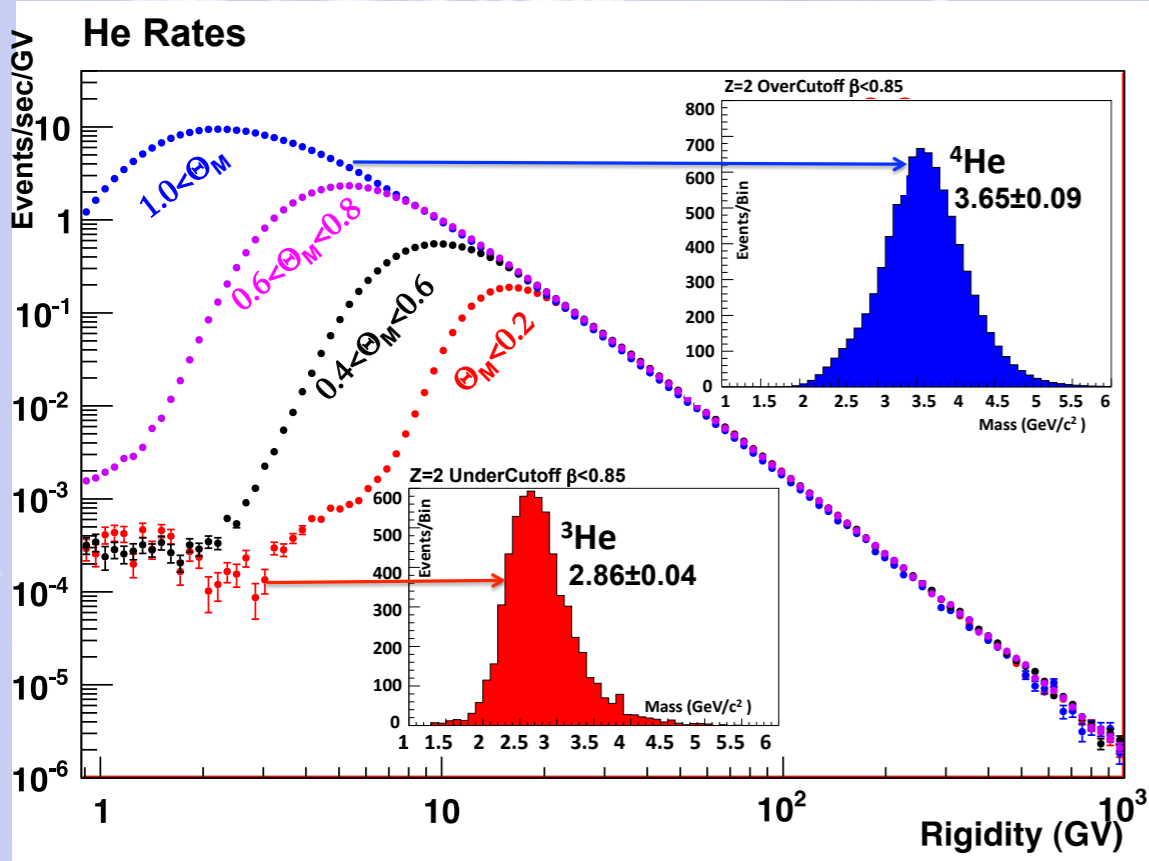
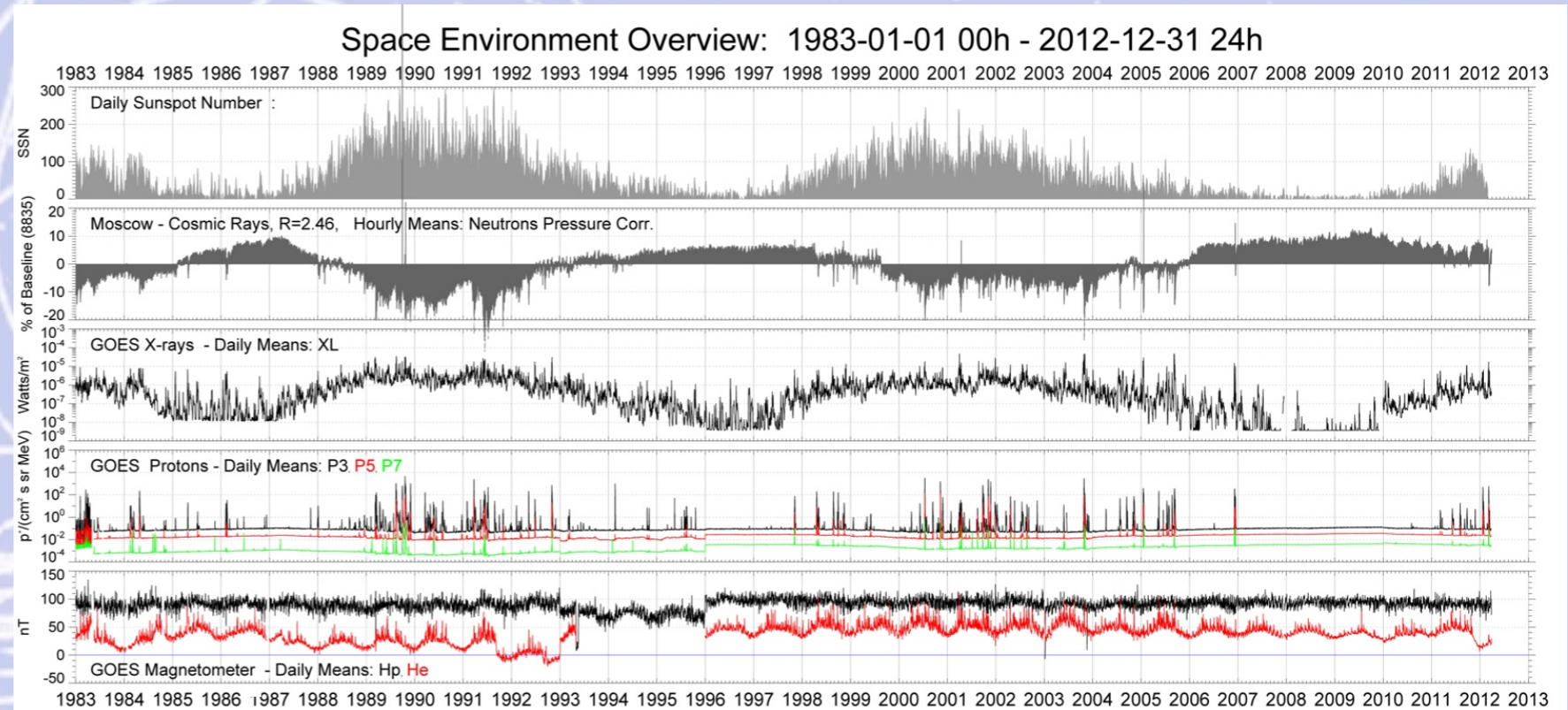
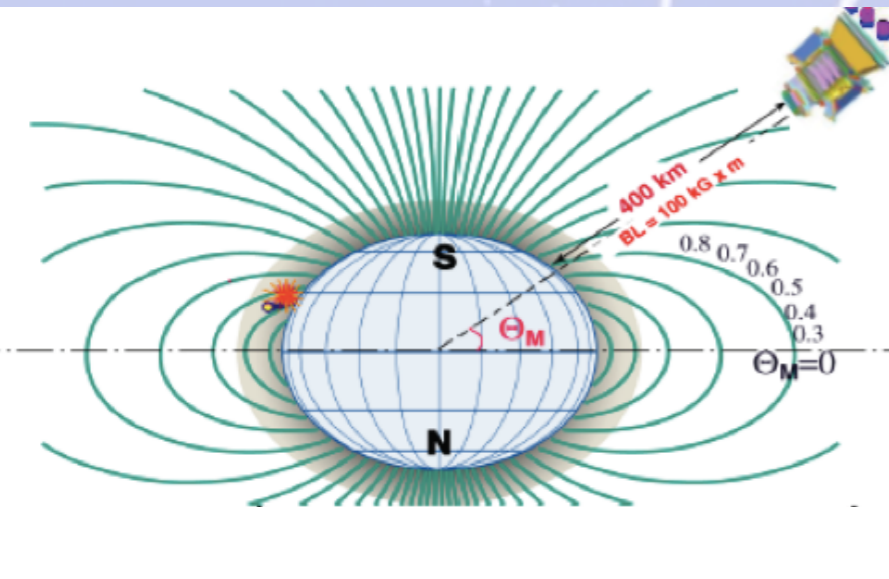


The background of the slide is a light blue color with a complex pattern of white lines. These lines represent particle tracks, consisting of various shapes such as spirals, circles, and straight lines, some of which intersect or overlap. The overall effect is that of a particle detector's output or a scientific visualization of particle interactions.

Appendice 15

(Varie ed eventuali AMS)

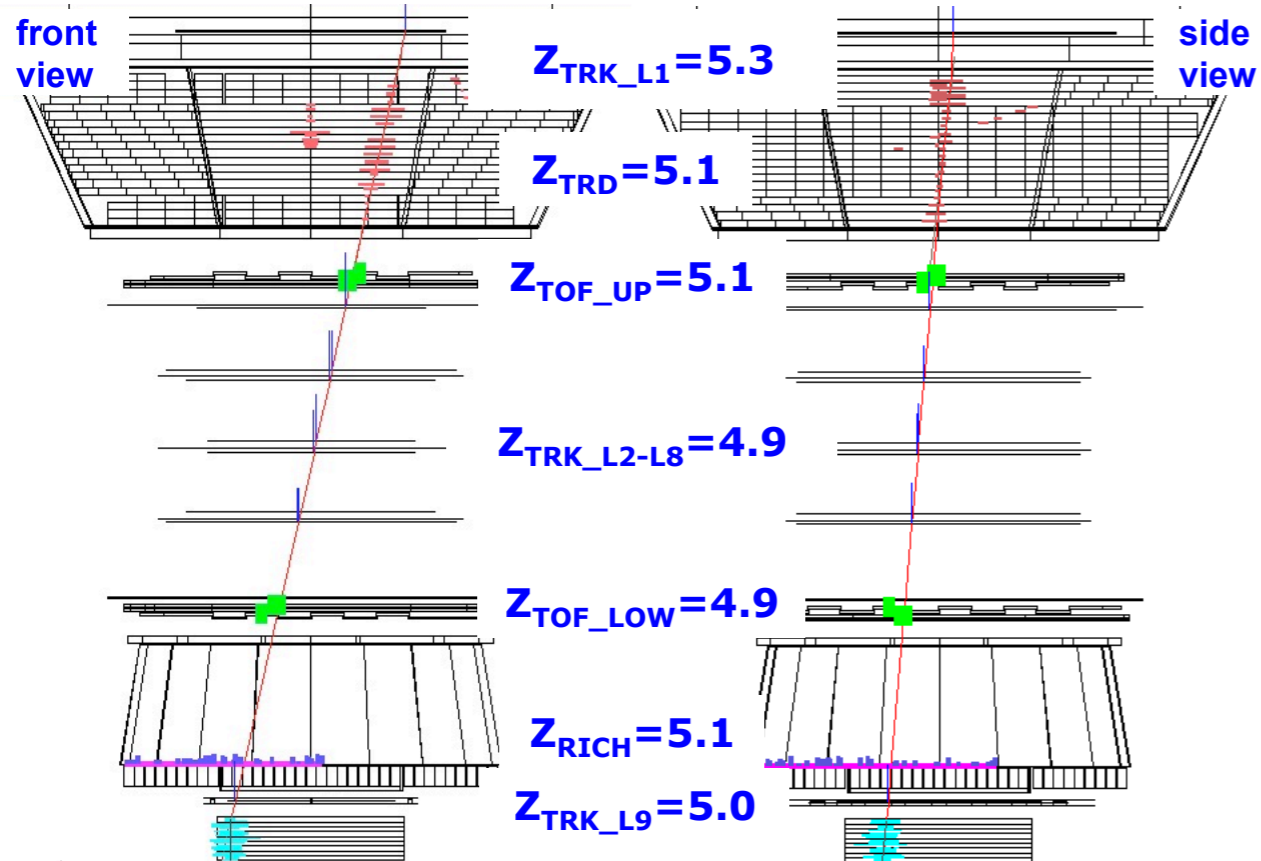
Data from AMS on ISS: He rate



Rigidity ~ 3 GV

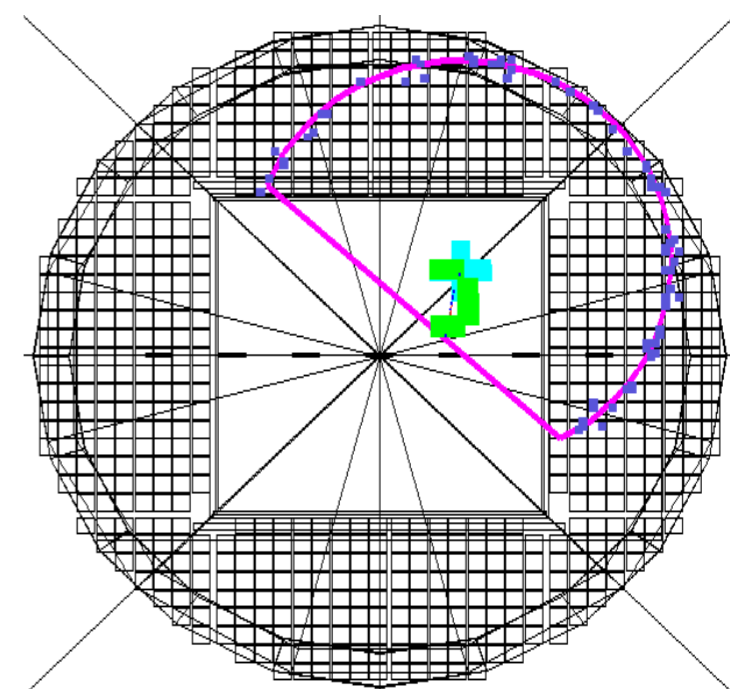
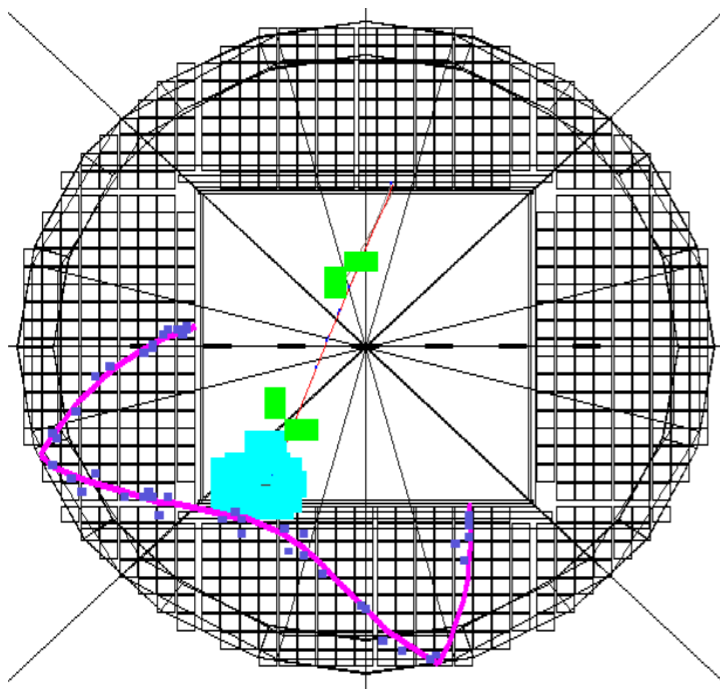
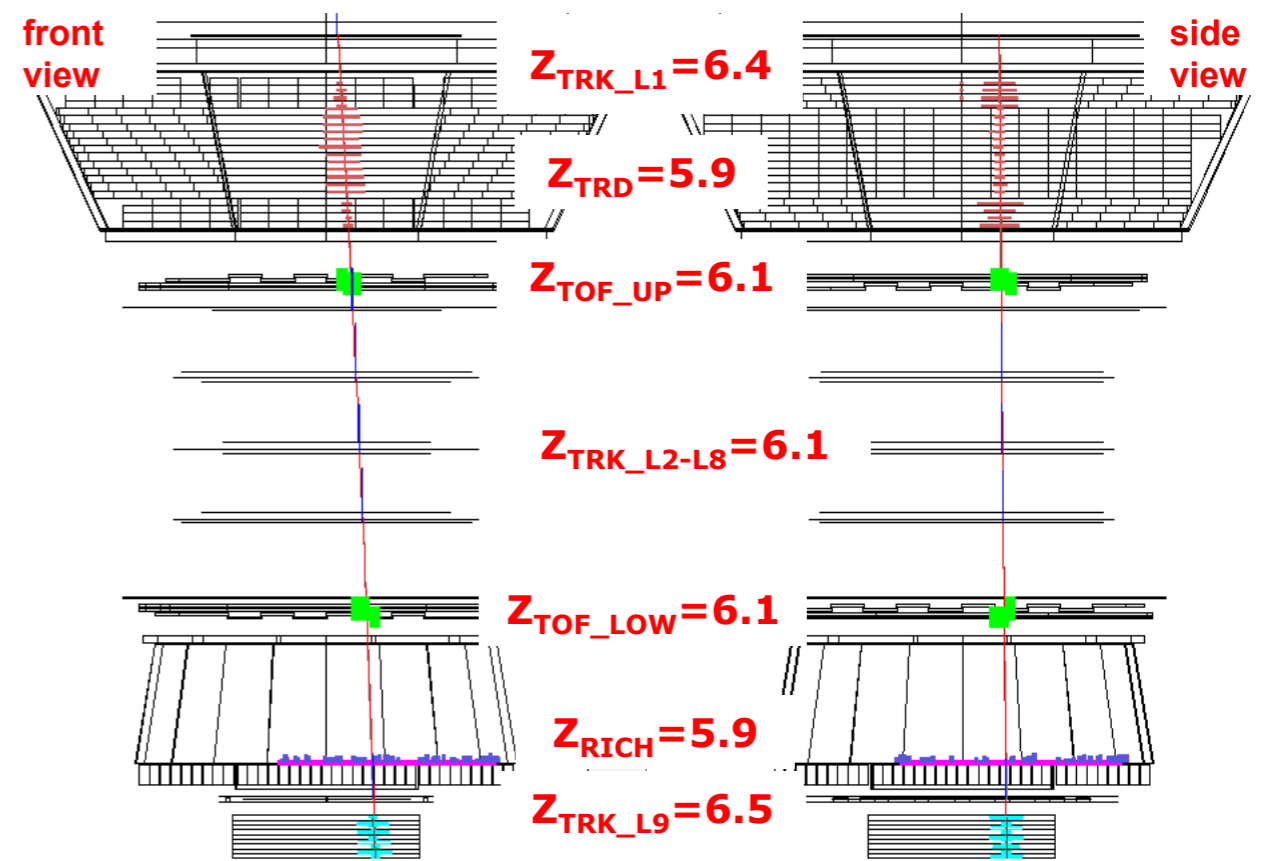
Boron Rigidity=3.7 GV

Run/Event 1333501084/ 42231



Carbon Rigidity=3.3 GV

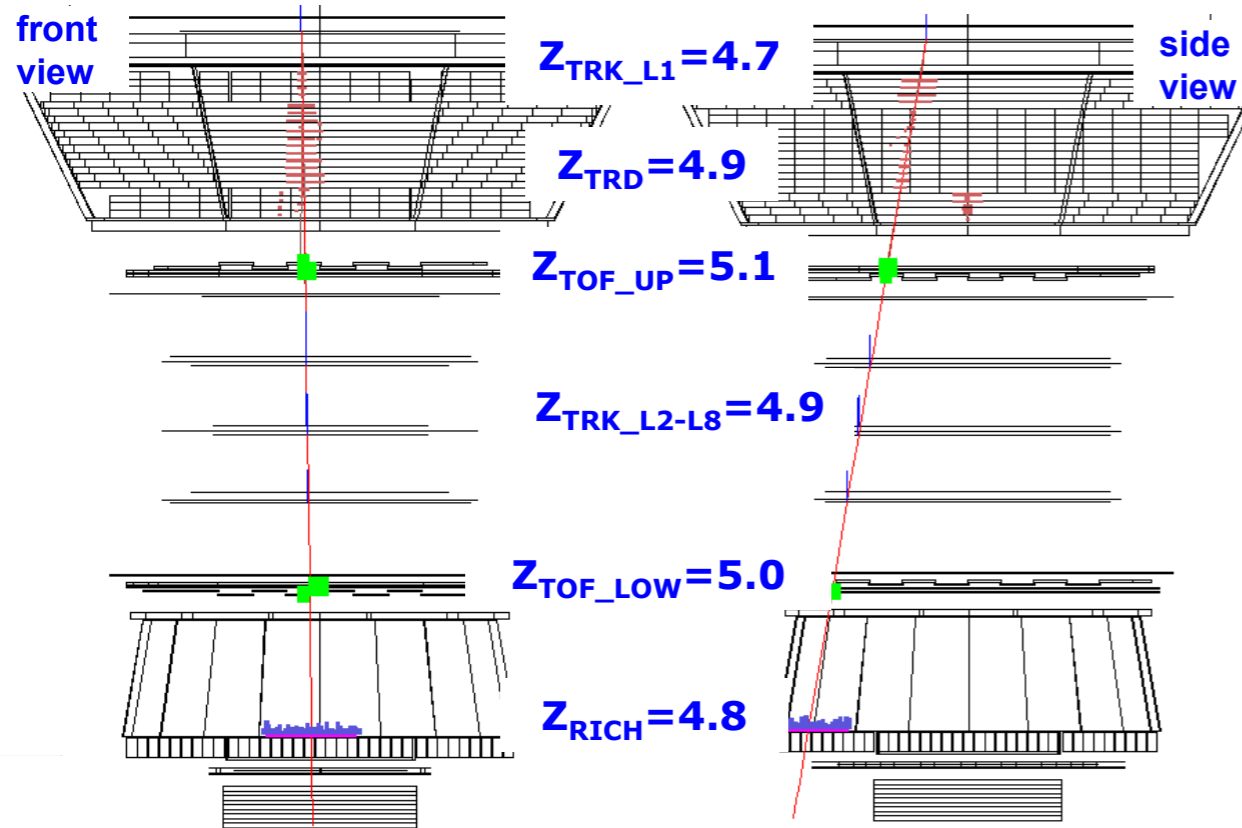
Run/Event 1327519853/ 487070



Rigidity ~ 20 GV

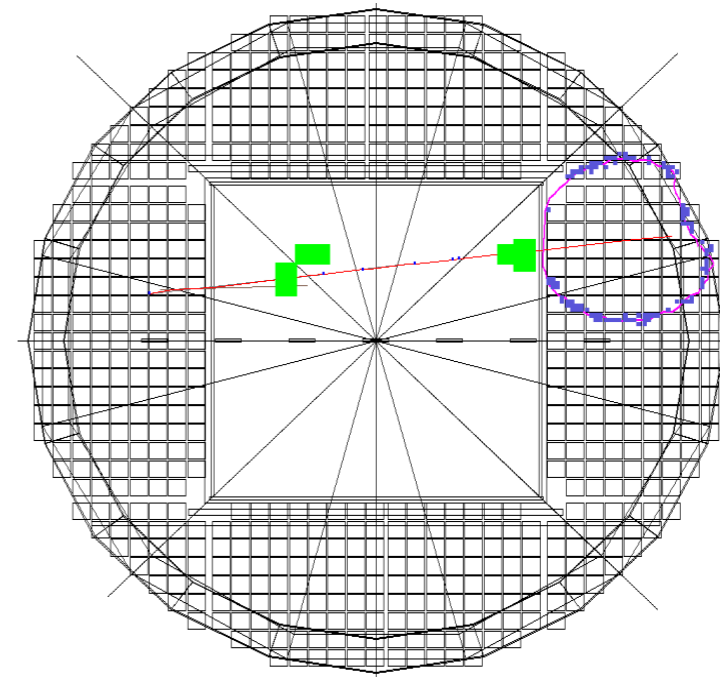
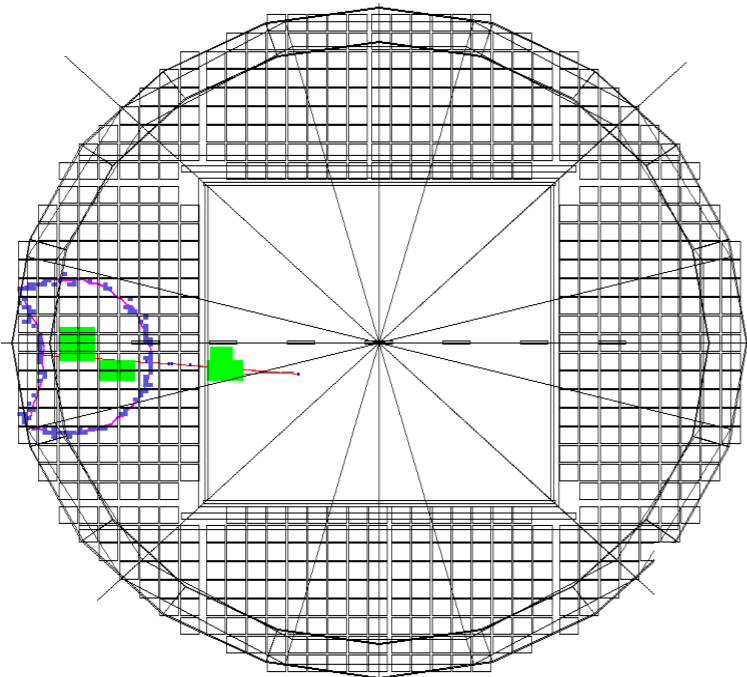
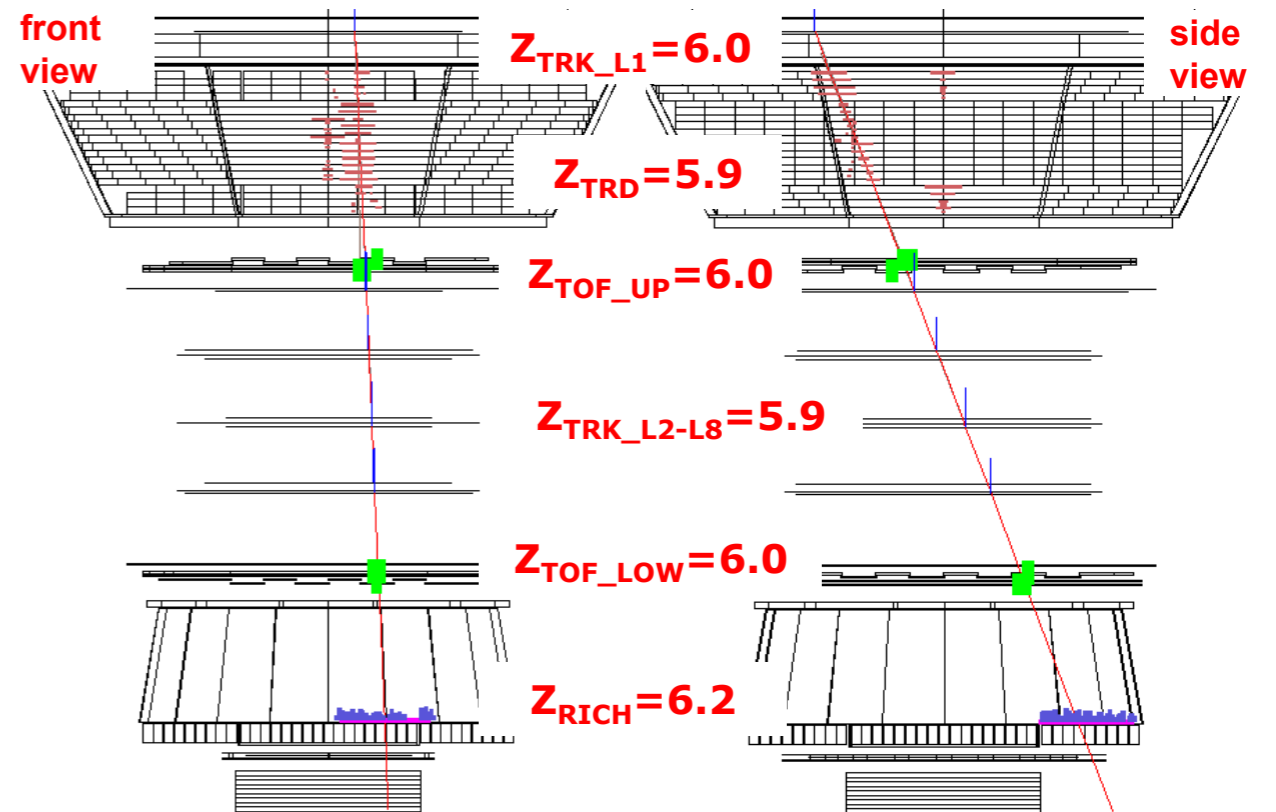
Boron Rigidity=24 GV

Run/Event 1326201809/ 798775



Carbon Rigidity=24 GV

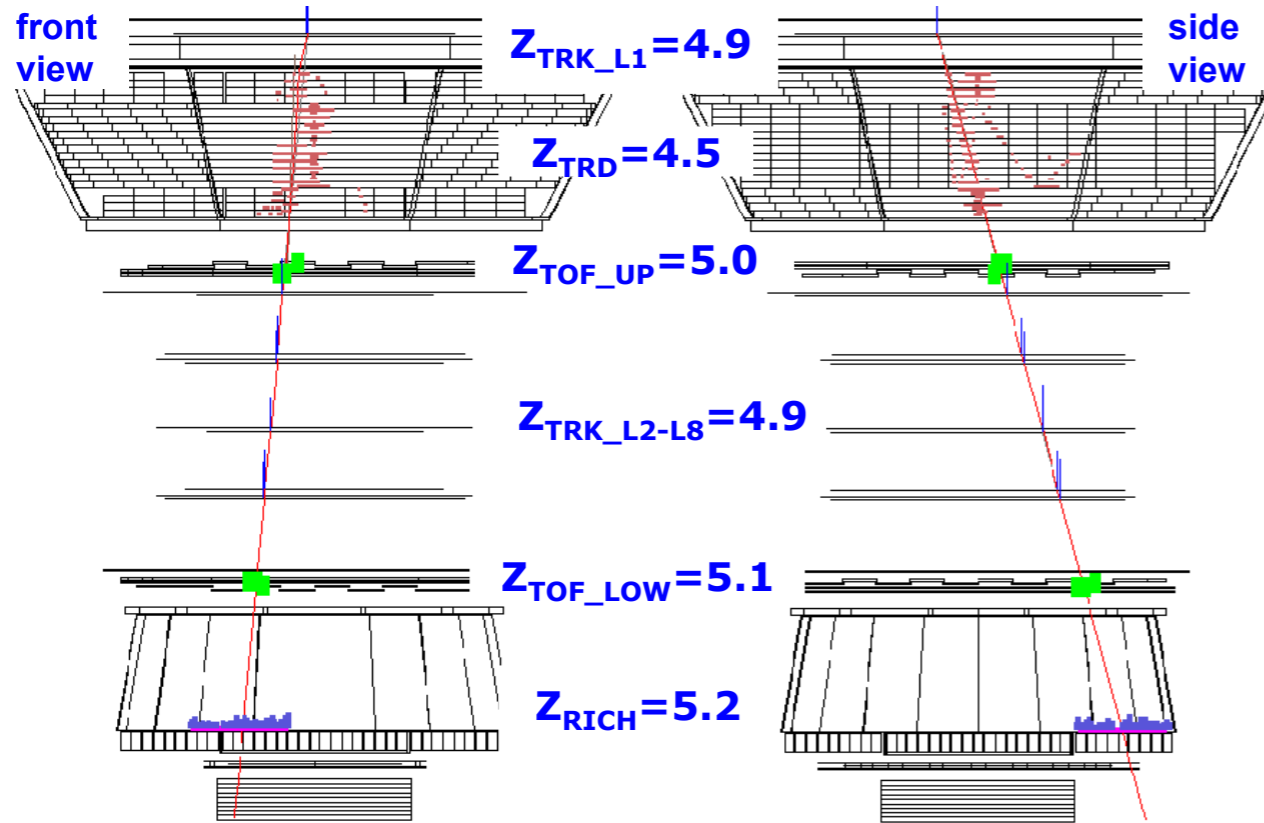
Run/Event 1329490720/ 473181



Rigidity ~ 200 GV

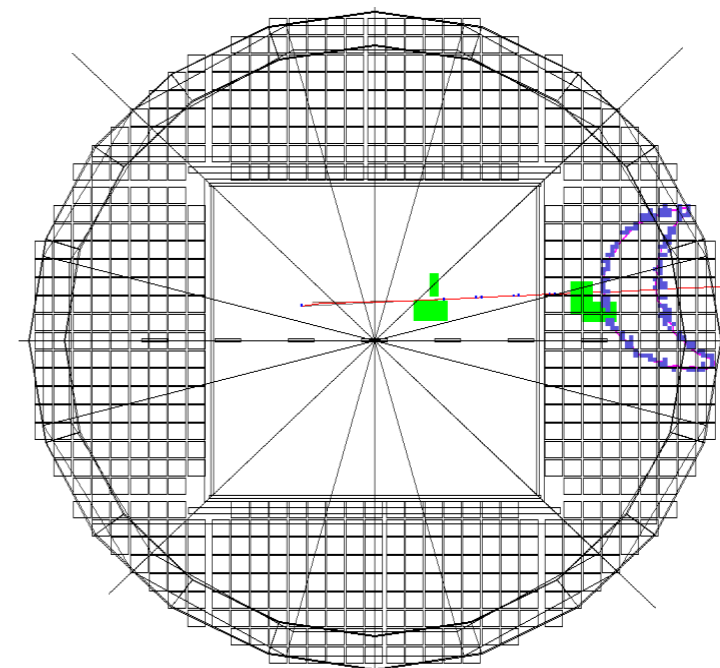
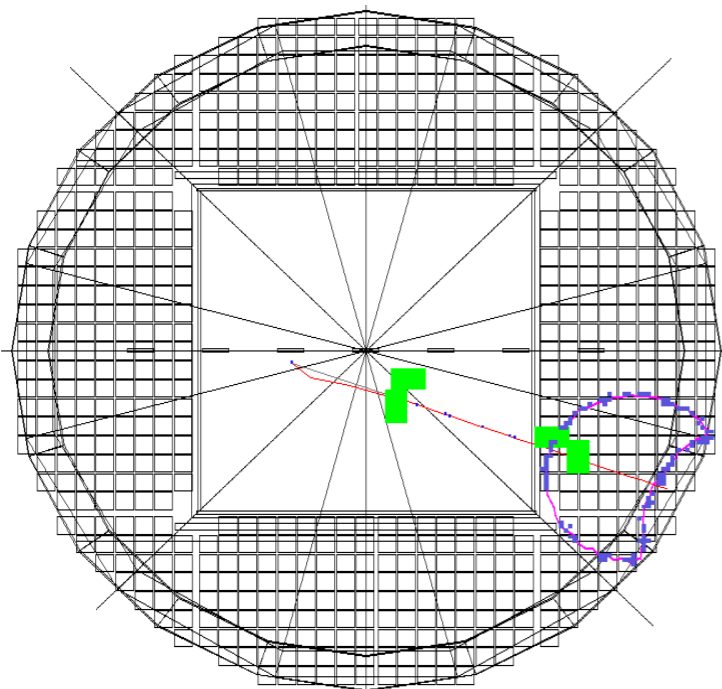
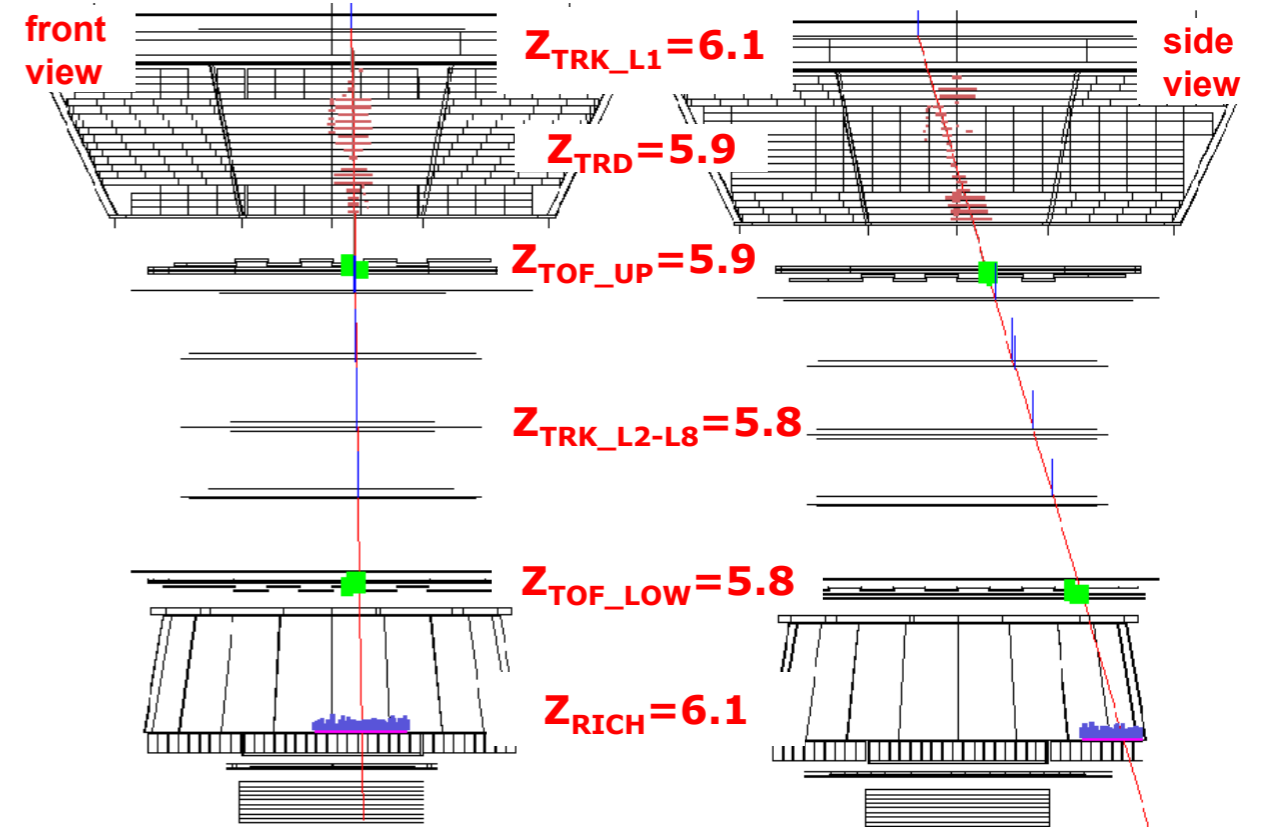
Boron
Rigidity=187 GV

Run/Event 1329086299/ 747549



Carbon
Rigidity=215 GV

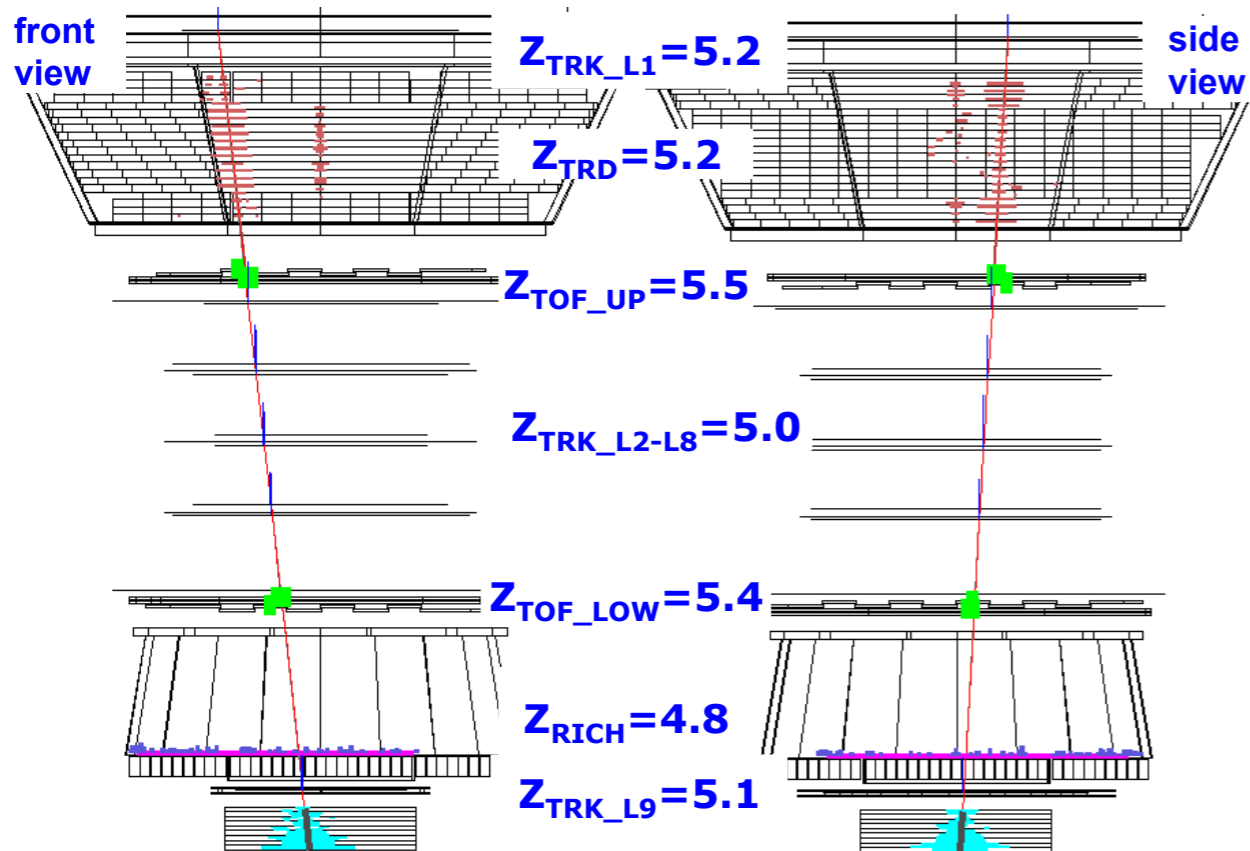
Run/Event 132643580/ 132197



Rigidity ~ 700 GV

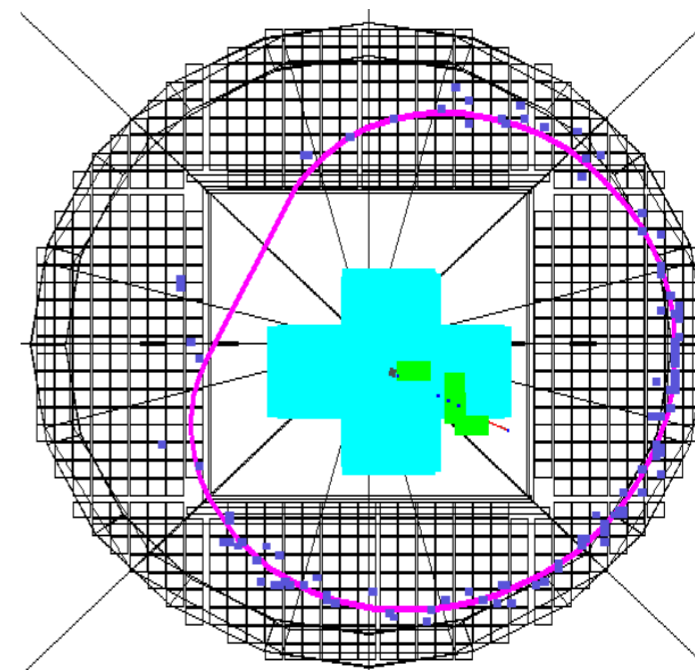
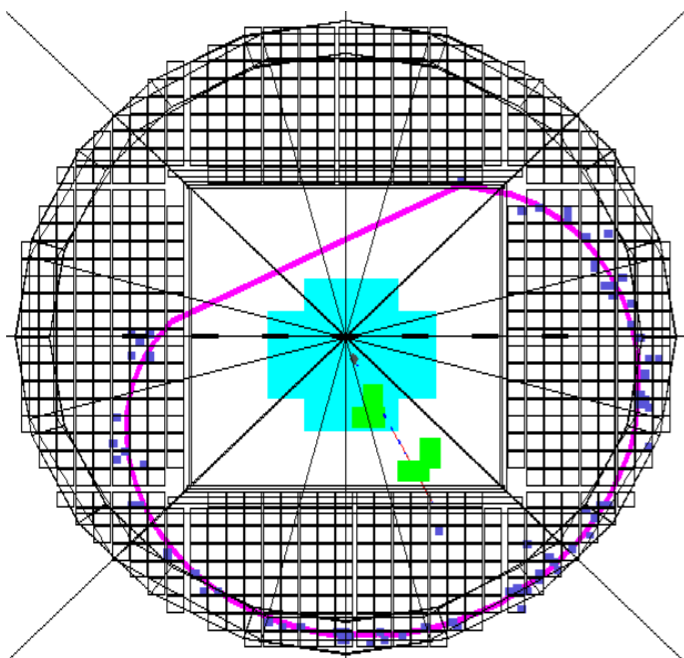
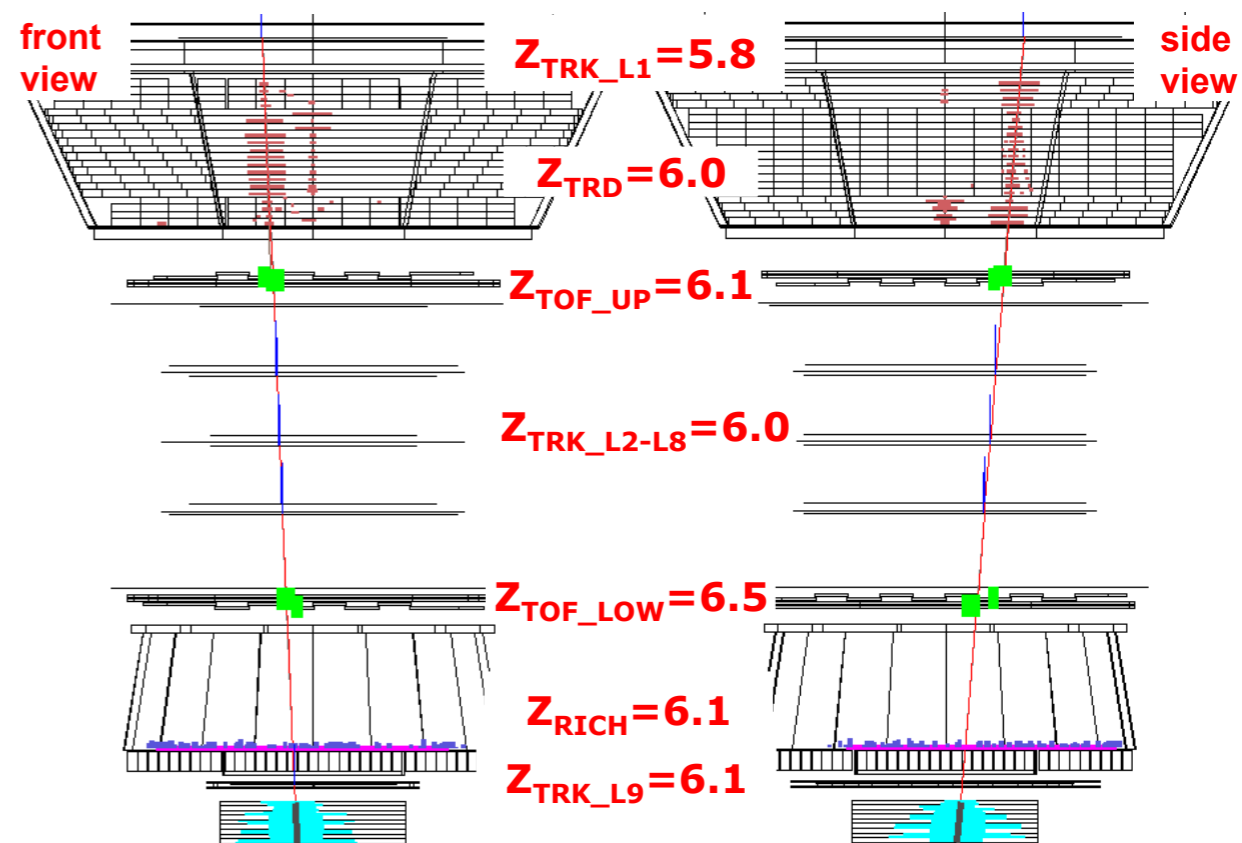
Boron
Rigidity=680 GV

Run/Event 1319990213/ 235892



Carbon
Rigidity=666 GV

Run/Event 1327184805/ 266043



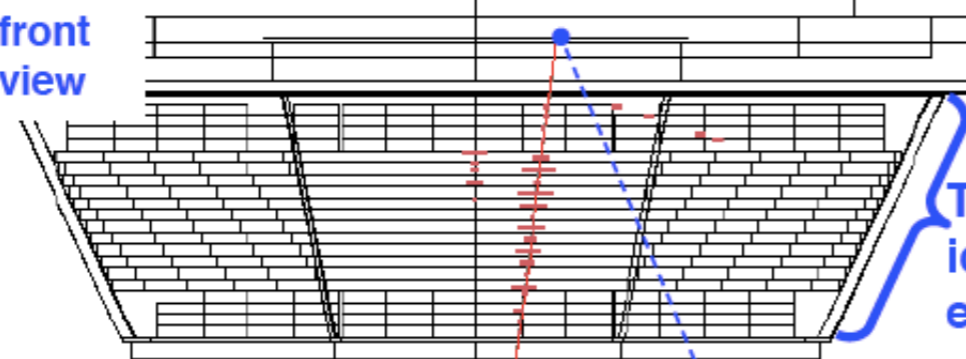
AMS ISS data: electrons

1.03 TeV electron

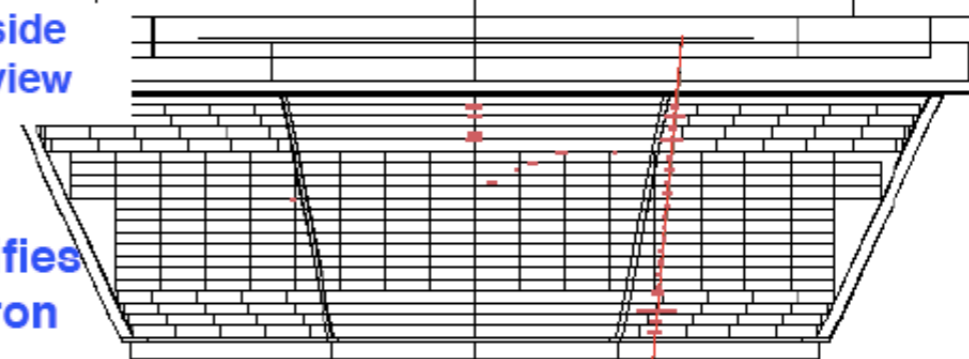
AMS Event Display

Run/Event 1315754945 / 173049 GMT Time 2011-254.15:31:15

front view



side view



TRD:
identifies
electron

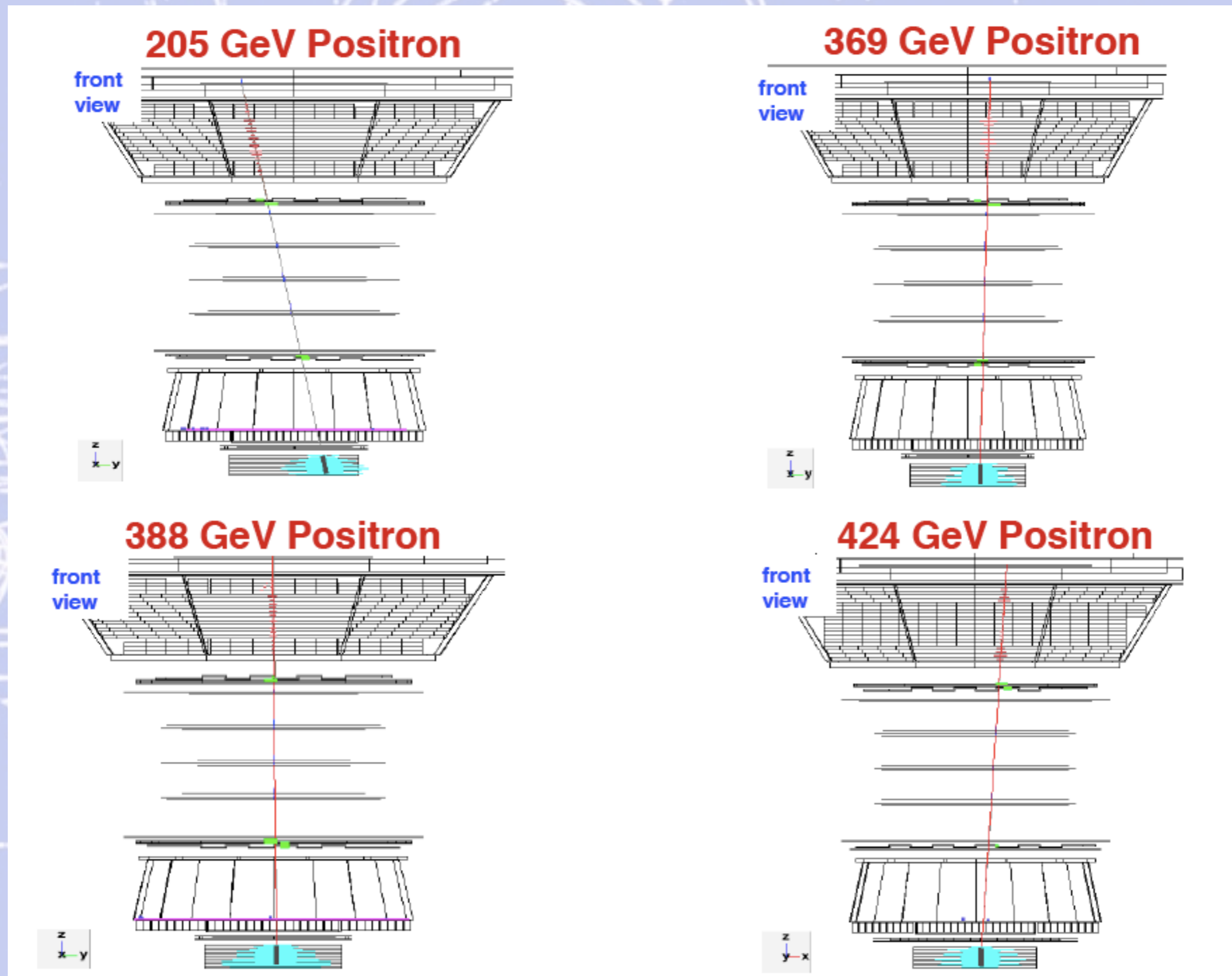
Tracker and Magnet:
measure momentum

RICH
charge of
electron

ECAL:
identifies electron and measures
its energy

35

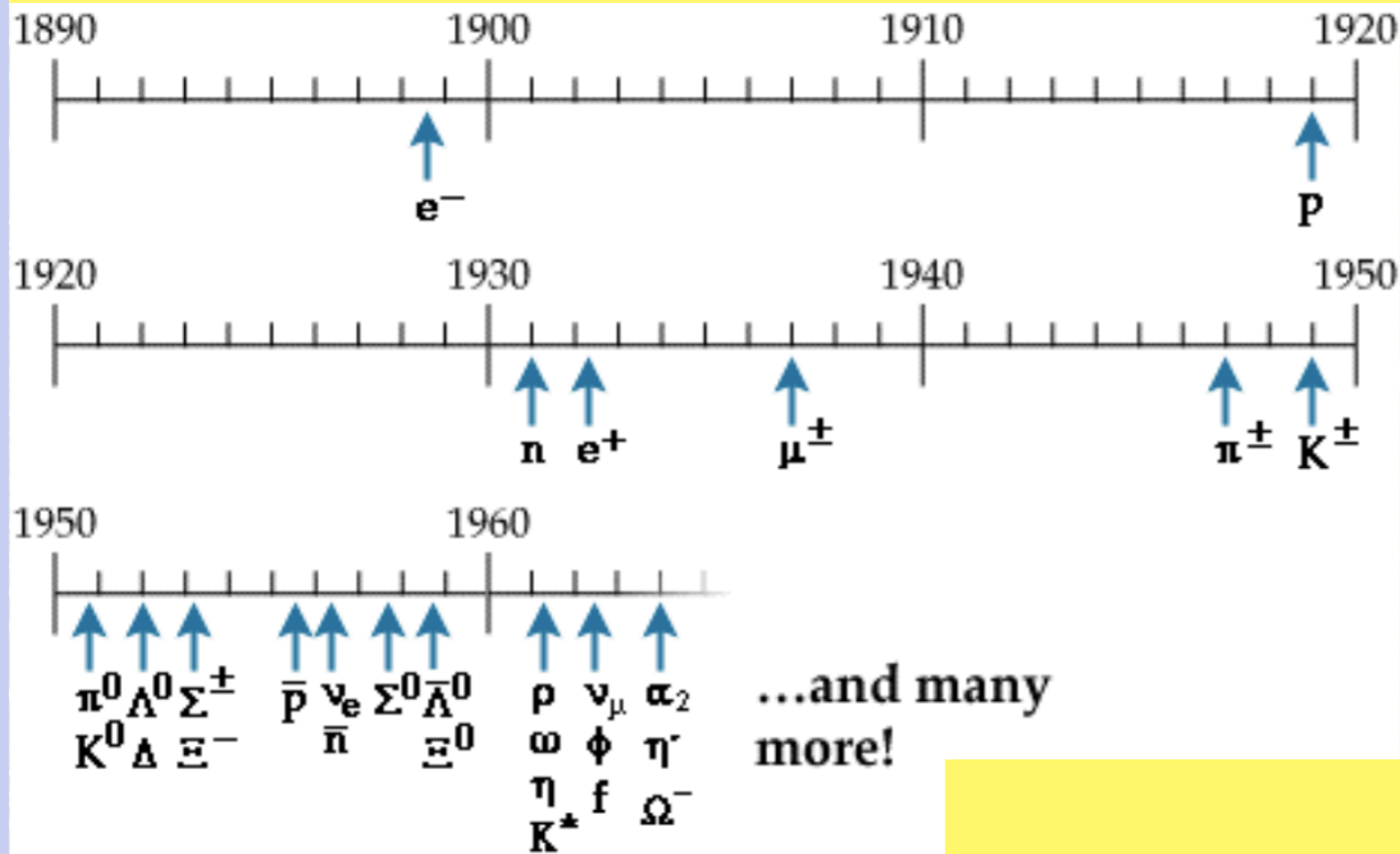
AMS ISS data: positrons



Appendice 16

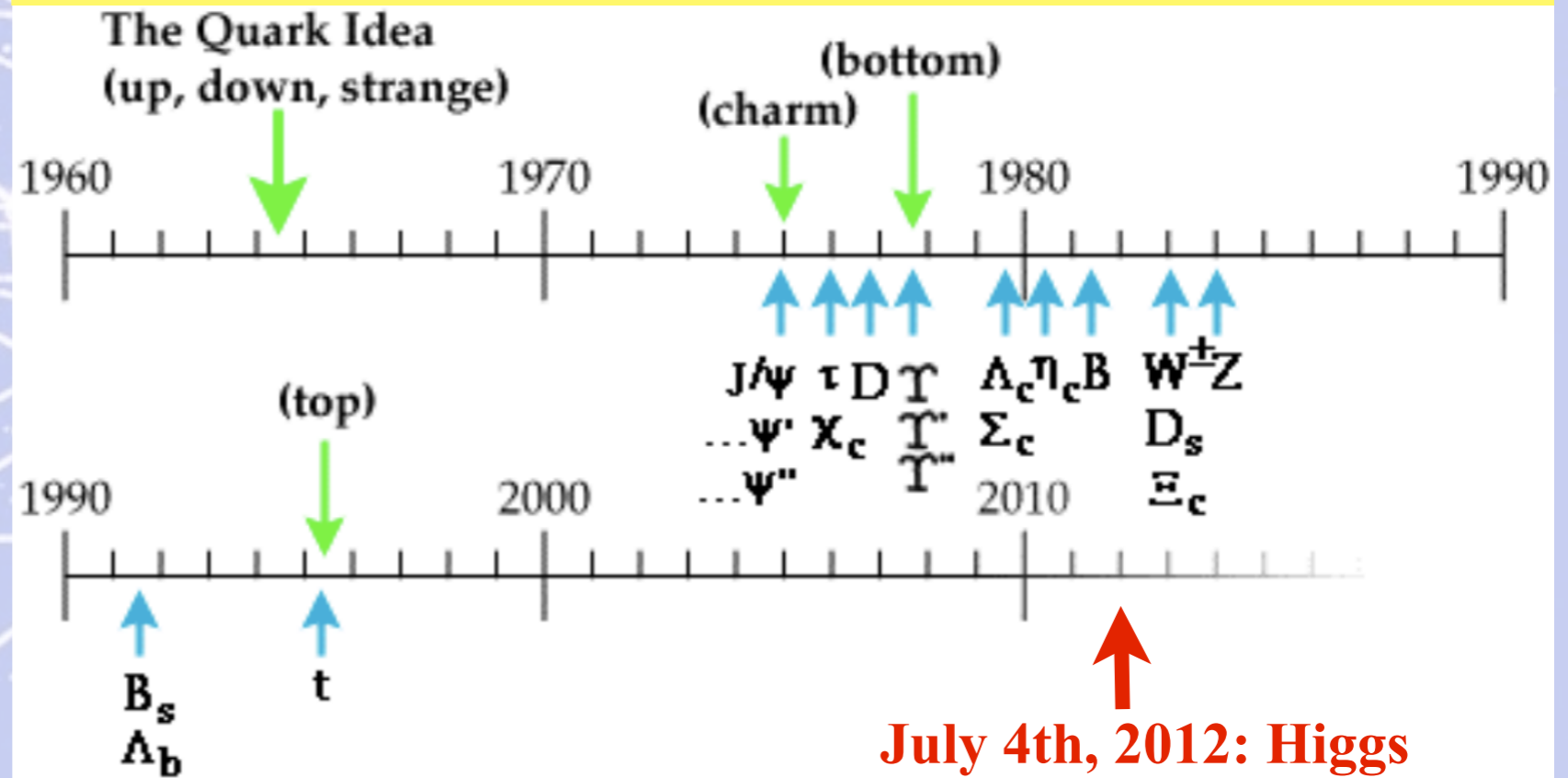
(Varie ed eventuali all)

Scoperte dal 1898 al 1964



Cronologia della scoperta delle particelle

Scoperte dal 1964



Cronologia delle Fisica delle Particelle

**Gli inizi:
sinergia tra l'infinitamente piccolo e
l'infinitamente grande**

1895 Scoperta dei raggi X (W. Roentgen)

1896 Scoperta della radioattività (H. Becquerel)

1897 Scoperta dell'elettrone (J.J. Thomson)

1898 Isolamento del radio (M. Curie and P. Curie)

1905 Teoria della relatività speciale (A. Einstein)

1909 La particella α è un nucleo di elio (Rutherford and Royds)

1911 Scoperta del nucleo dell'atomo (E. Rutherford)

1912 Scoperta della radiazione cosmica (Victor Hess)

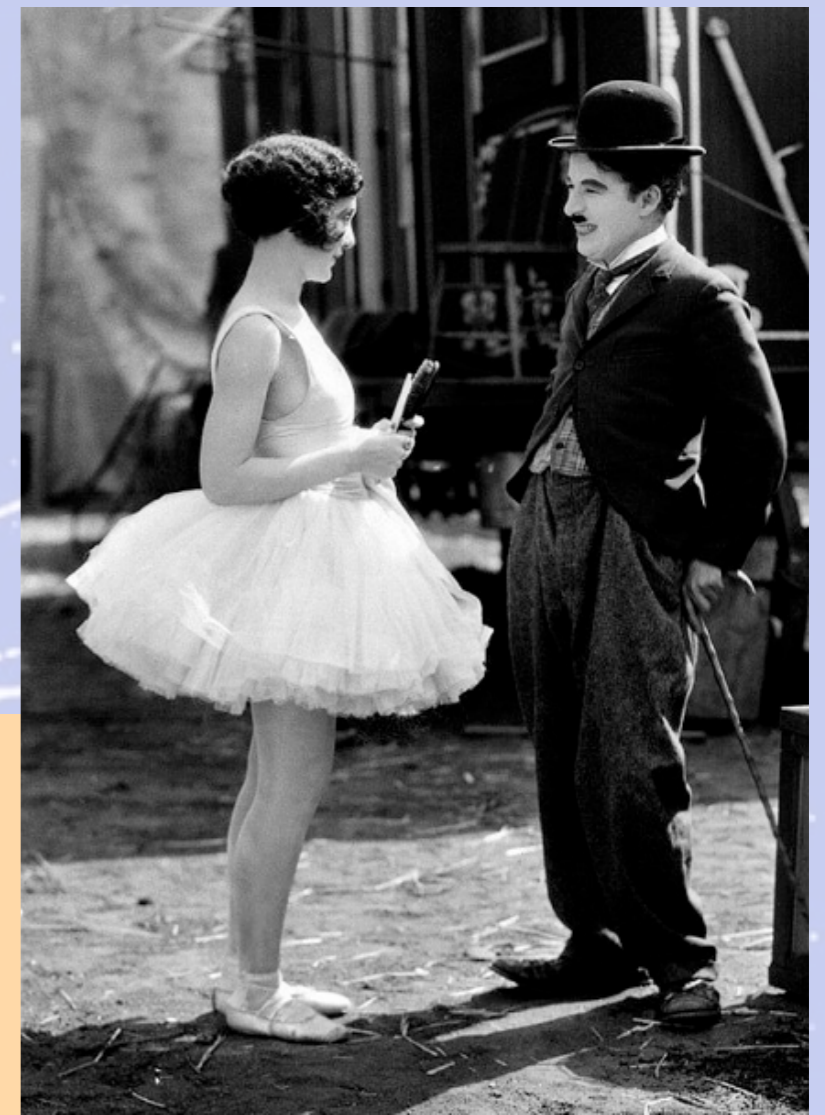
1913 Modello atomico planetario (N. Bohr)

1915 Teoria della relatività generale (forma finale) (A. Einstein)

1919 Eddington osserva deviazione della luce in una eclisse totale del Sole

1926 Meccanica quantistica (E. Schrodinger)

1927 Equazione di Dirac e predizione delle anti particelle (P. Dirac)



Cronologia delle Fisica delle Particelle

**Il periodo intermedio:
i tempi d'oro dell'infinitamente grande**



1928 Teoria della radioattività α (Gamow, Gurney, Condon)

1930 Hubble scopre L'espansione dell'universo

1930 Ipotesi esistenza neutrino (W. Pauli)

1930 Invenzione del ciclotrone (E.O. Lawrence)

1932 Scoperta del neutrone (Chadwick)

1933 Scoperta del positrone nei raggi cosmici (Anderson)

1934 Teoria della radioattività β (E. Fermi)

1935 Ipotesi dei mesoni (Yukawa)

1937 Scoperta del muone nei raggi cosmici (Neddermeyer, Anderson)

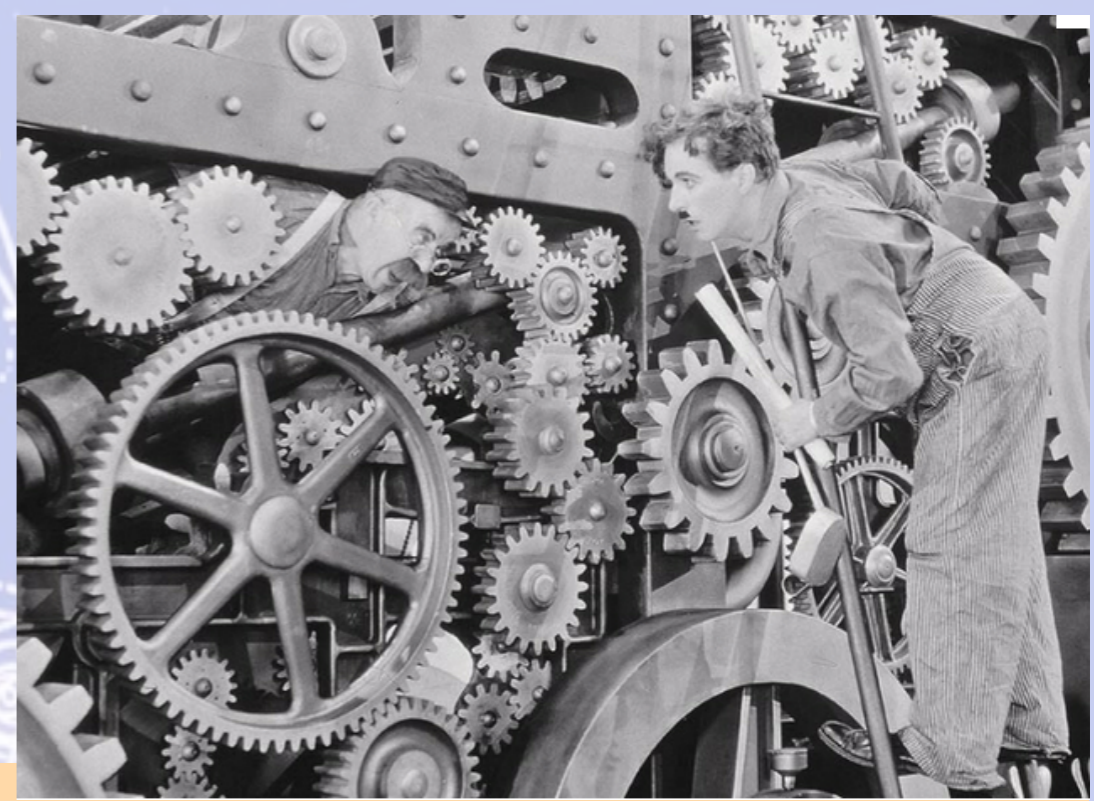
1947 Scoperta del pione nei raggi cosmici (Powell)

1947 Scoperta kaone e "particelle strane" nei raggi cosmici (Rochester & Butler)

1950 Scoperta del barione "strano" Λ (Hopper & Biswas)

Cronologia delle Fisica delle Particelle

**Tempi Moderni:
l'era d'oro dell'infinitamente piccolo**



1952 Altre particelle “strane” (Ξ , Σ) scoperte nei raggi cosmici.

1955 Scoperta dell'antiprotone al Bevatron (Chamberlain & Segre)

1956 Scoperta dell'antineutrone al Berkeley Bevatron

1956 Rivelazione sperimentale del neutrino (Reines, Cowan @ Los Alamos)

1974 Scoperta della risonanza J/ψ (quark Charm) (Richter & Ting)

1975 Scoperta del leptone τ (Perl SLAC-LBL)

1977 Scoperta del quark bottom (E288 Fermilab)

1983 Scoperta dei bosoni W e Z (Rubbia & Van der Meer)

1995 Scoperta del quark top (D0 e CDF)

2000 Scoperta del neutrino τ (DONUT)

1995- Scoperta delle oscillazioni e della massa del neutrino (neutrino solare ed atmosferico) (Homestake, GALLEX, SAGE, Super-K, SNO, ...)

2012 Scoperta del bosone di Higgs all' LHC (ATLAS, CMS)

Il Modello Standard della Fisica delle Particelle



100 anni per svilupparlo!

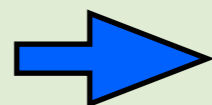
Verificato con incredibile precisione!

Tiene conto di tutti i dati raccolti della fisica delle particelle!

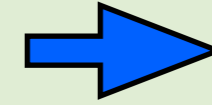
Il bosone di Higgs era il solo "pezzo del puzzle" rimasto inosservato e rappresenta un portale verso settori nascosti di nuova fisica

Candidati della Materia Oscura: due principali possibilita'

molto leggera & accoppiamento solo gravitazionale → stabile su scale cosmologiche



Long-lived
(stabile su scale cosmologiche)

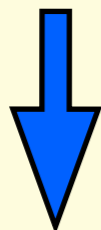


$\tau_{DM} > \tau_{universe} \sim 10^{18} \text{ s}$

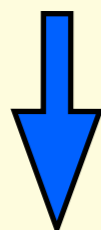
DM = Dark Matter

OR

interazione misurabile (ma non per via forte) con lo SM → simmetria necessaria per garantire a stabilita'



stabile rispetto ad una simmetria



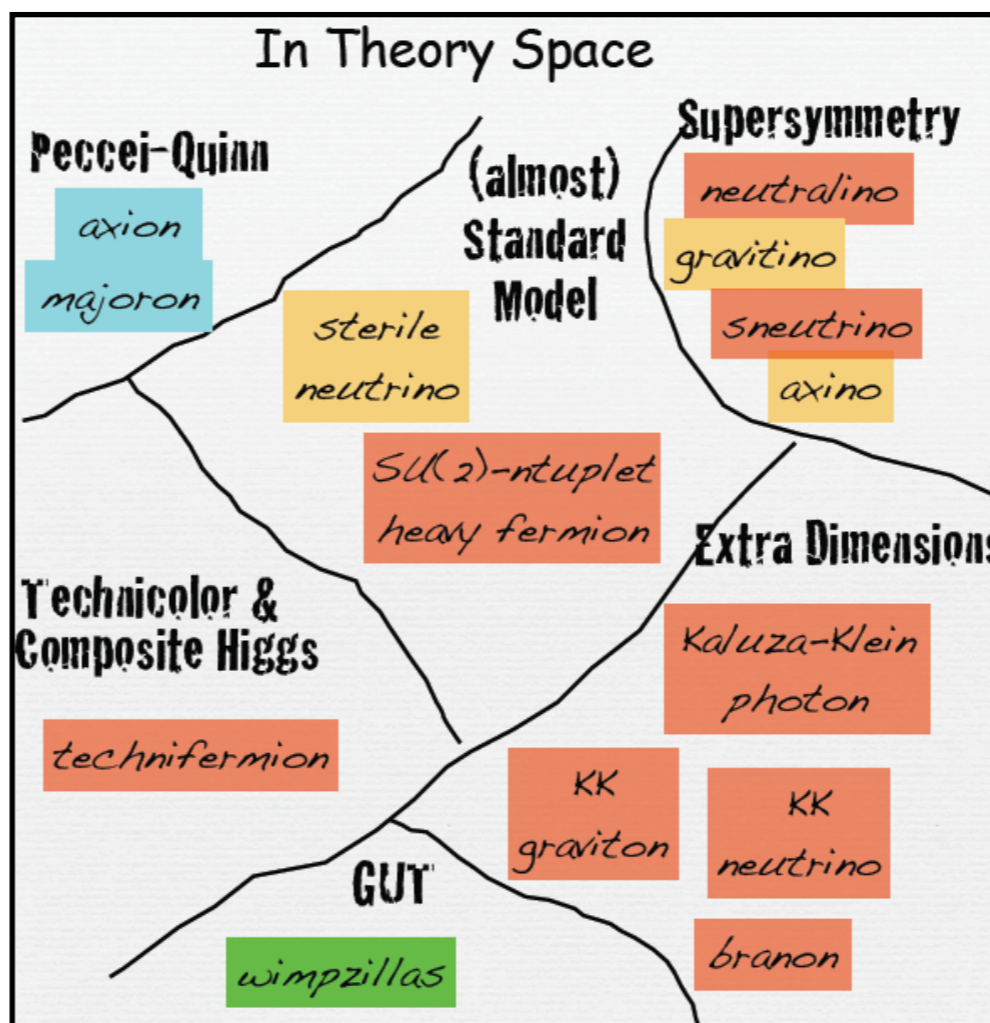
WIMP

WIMP = Weak Interactive Massive Particle

La restante abbondanza di un tipo di particella stabile segue dal generico meccanismo di "freeze-out" termico dell'espansione dell'universo.

Thermal relic: $\Omega_{DM} \propto 1/\sigma_{annih}$

$\sigma_{annih} \approx 1\text{pb}$ conduce alla corretta abbondanza di DM



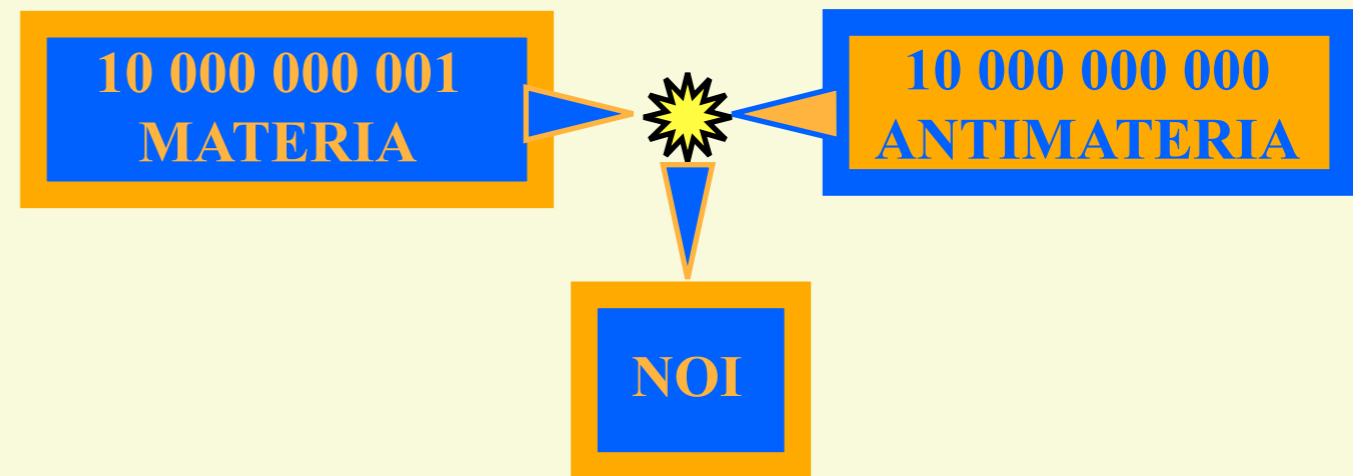
Candidati della Materia Oscura con $\Omega_{DM} \sim 1$

Antimateria: problemi e domande

La Teoria del Big Bang richiede una uguale abbondanza di materia e antimateria.

Dopo l'inizio dell' "era" delle particelle, non si è trovato alcun processo che possa cambiare il numero netto di particelle dell'universo.

A partire da un millisecondo dopo il Big Bang, il bilancio tra materia ed antimateria è stato fissato per sempre.



Esiste una qualche ASIMMETRIA nel modo in cui la natura tratta materia e antimateria?

Una linea di investigazione molto promettente è quella della violazione della simmetria CP nei decadimenti di particelle via interazione debole.

La principale evidenza sperimentale proviene dal decadimento del kaone neutro, che mostra una piccola violazione della simmetria CP. Nel decadimento dei kaoni in elettroni, abbiamo una netta distinzione tra materia e antimateria, e ciò potrebbe essere almeno una delle spiegazioni della predominanza di materia rispetto all'antimateria nell'universo.

Una prima evidenza (3.5σ) si è avuta a LHCb con 0.8% di differenza nel tasso di decadimento del mesone D e della sua antiparticella (2011).

Questo potrebbe essere un altro contributo alla soluzione del problema dell'antimateria.

Antimateria: problemi e domande

**La presenza di antimateria entro il nostro gruppo di galassie
e' esclusa:
il segnale di annichilazione e' troppo piccolo.**

...ma se una volta e' esistita, dov'e' ora ?

Lontano da noi ?

Esiste un qualche resto di antimateria nell'Universo vicino?

**Singolo nucleo di anti-He nei raggi cosmici:
Agglomerati di Antimateria**

**Singolo nucleo di anti-C nei raggi cosmici:
Stelle di Antimateria**