# The AMS Project

**Particle physics detector conceived for high precision study of CRs at TV energy**

## Physics goals

- ✓ **Antimatter search (|Z|>1 anti-nuclei)**
- ✓ **Dark Matter (light anti-matter & γ-rays)**
- ✓ **Exotic signals?**
- ✓ **GCR & γ-rays astrophysics**
- ✓ **Solar Physics (modulation & SEP)**
- ✓ **Magnetospheric physics**

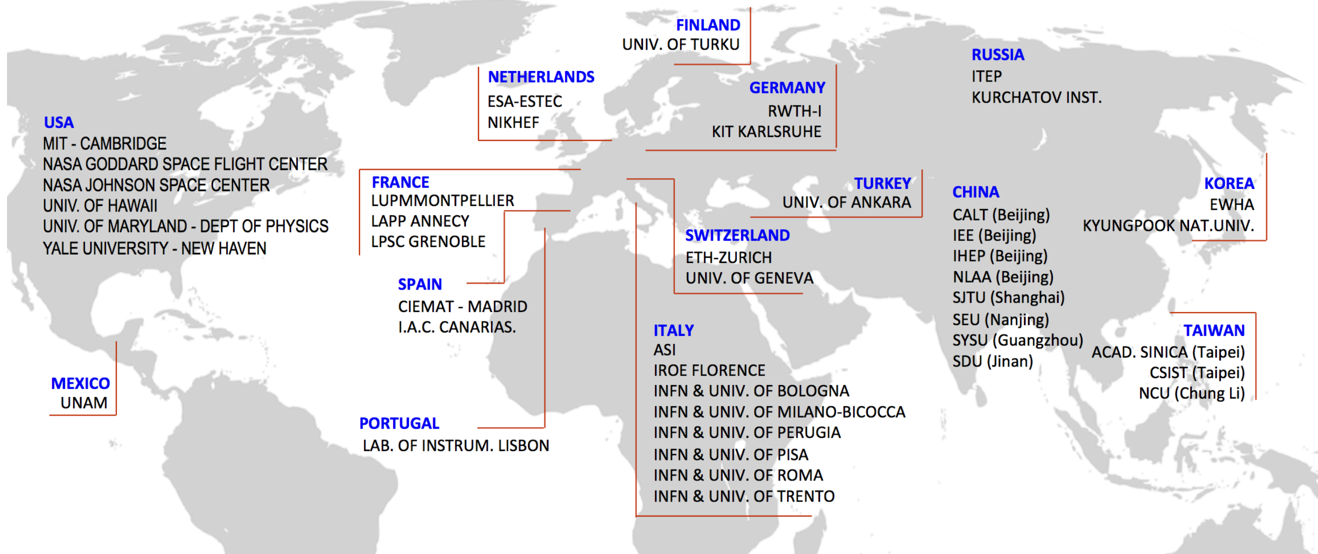

## How it will fulfill these goals?

- **Large collaboration: 16 Countries, 60 Institutes and ~500+ Physicists**
- **Same concept (precision & capability) as the large state-of-the-art HEP detectors [but: fitting into the space shuttle & no human intervention after installation]**
- **Operation in space, ISS, at 400km, no backgrounds from atmospheric interactions [extensive multi-step space qualification tests]**
- **Collection power: geometrical factor (≈ 0.5 m2sr) X exposure time ( = ISS lifetime) [extensive calibration campaigns on ground]**

# The AMS Project

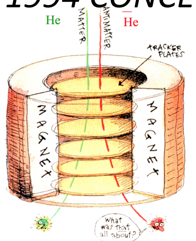
## AMS Collaboration

- *16 countries*
- *60 institutes*
- *500+ physicists*
- *20 years*



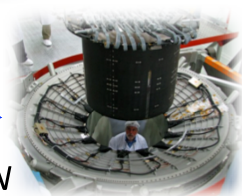

## Project timeline

*1994 CONCEPT*

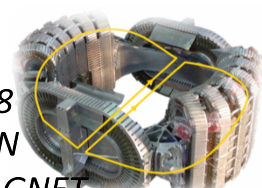



*1997 AMS-01 PROTOTYPE*

*1998: STS-91*



*2000 @CERN AMS-02 CONSTRUCTION*



*2008 @CERN SC MAGNET BEAM TEST*

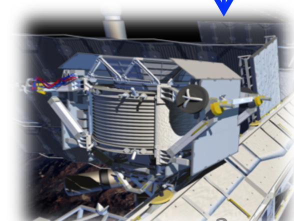
*2010 TVT @ ESA (NL)*

*2010 @CERN SC -> PM NEW BEAM TEST*


*2011 @KSC INTEGRATION & CR-μ RUN*

*MAY 2011 STS-134 FLIGHT*

*ON THE ISS*



**→ Steadily taking data on the ISS since May 19th 2011**

# May 16th 1011: launch!

# May 19th 2011: activation!

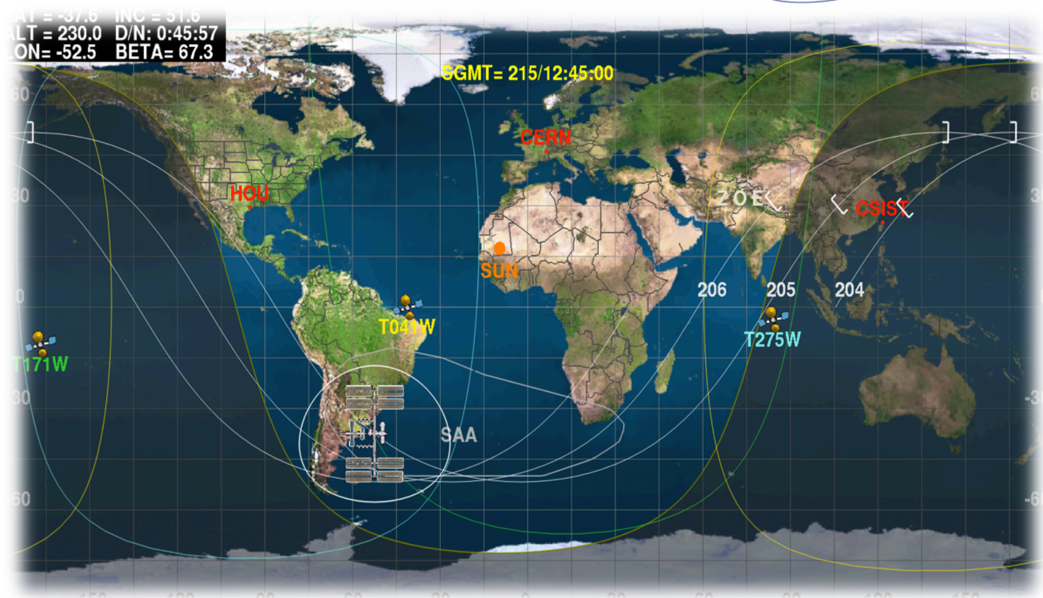
# Full time monitored

## The Payload Operation Control Center (POCC)

*Since the 27th June, 2011, 5:00 am GMT, AMS-02 is controlled 24/7 from the new POCC building at CERN, Prevessin site.*

*Shifts are organized to monitor the AMS-02 conditions, operations, and the continuous flow of data to ground.*

*Since July 2012, a second control room (the asia POCC) is running at the CSIST facility in Taiwan.*

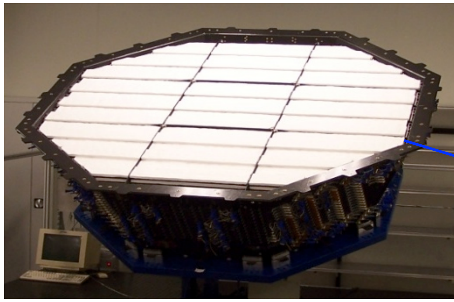




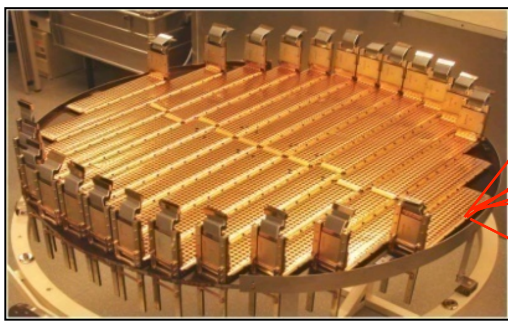
*Inside the POCC*

# The AMS-02 instrument

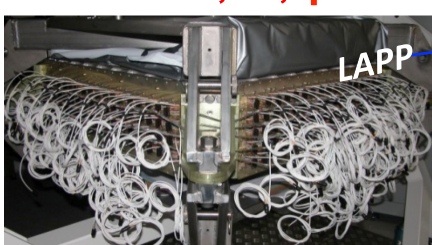
**TRD**
**Identify e+, e-**



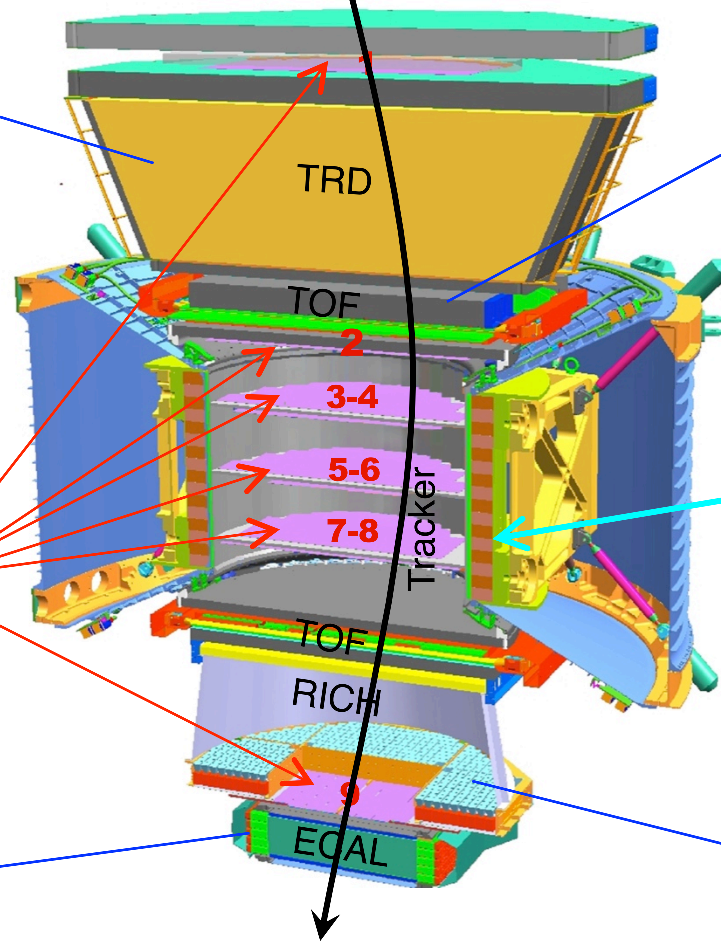
**Silicon Tracker**
**Z, P**



**ECAL**
**E of e+, e-, γ**

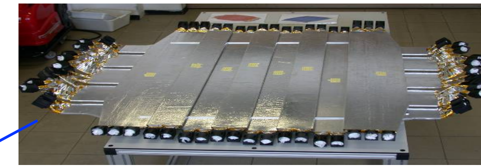



**Particles and nuclei are defined by their charge (Z) and energy (E ~ P)**

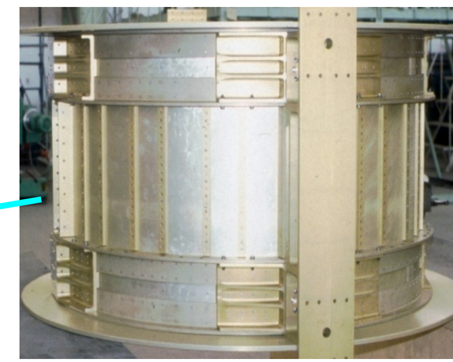



***Z, P are measured independently from Tracker, RICH, TOF and ECAL***

**TOF**
**Z, E**

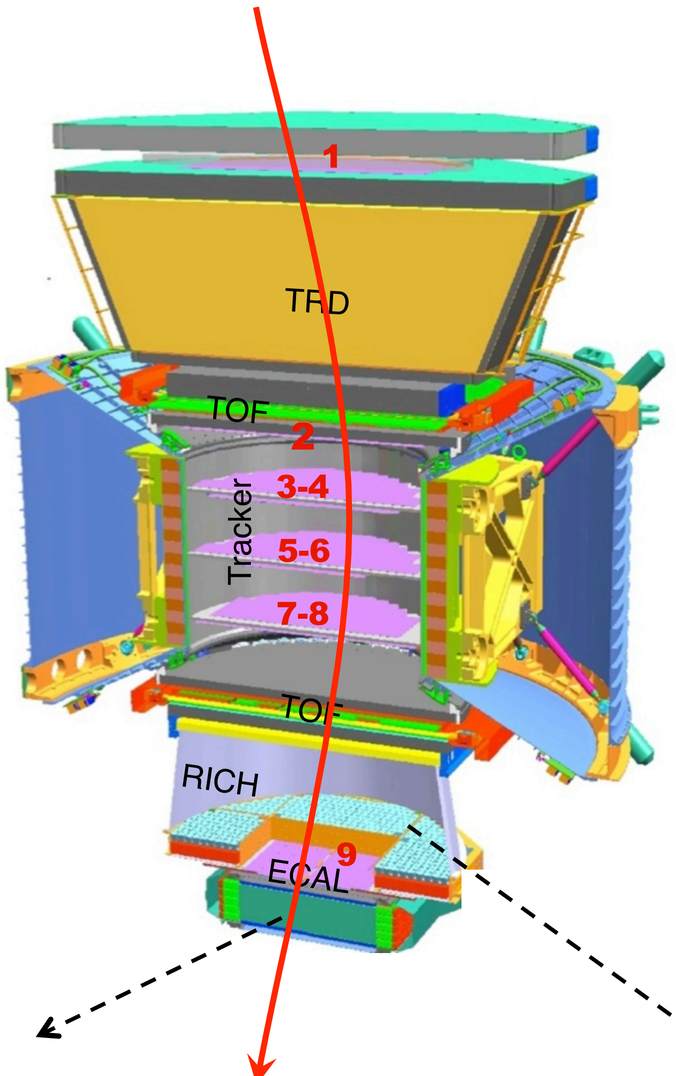


**Magnet**
**±Z**



**RICH**
**Z, E**

# Multiple measurements of energy




***Tracker, R = p/Z***
*MDR ≈ 2TV*

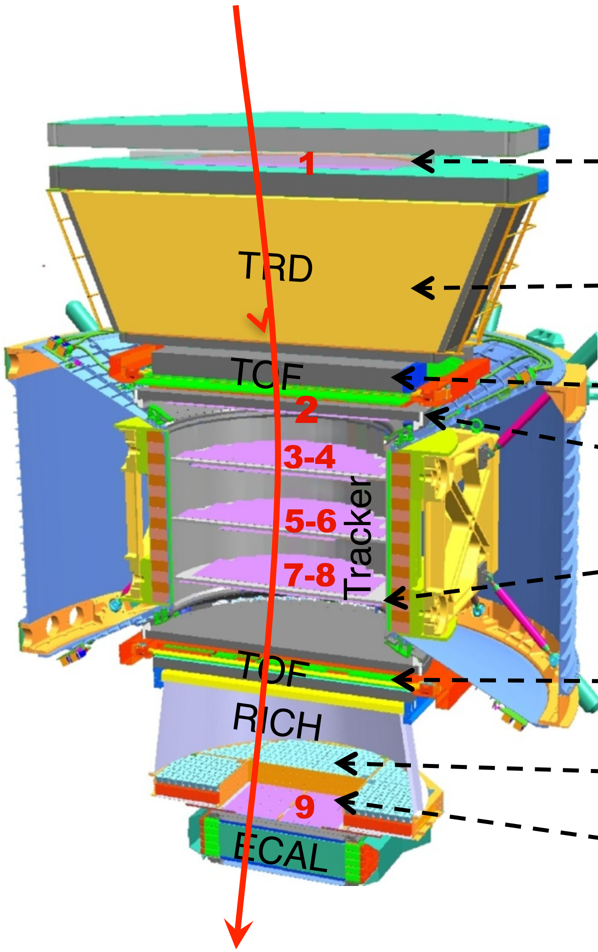
***TOF**, β*
*Δβ/β ≈ 1%*

***ECAL, E***
*ΔE/E (TeV e±) ~ 2 %*
*ΔE/E (TeV p) ~ 50 %*

***RICH**, β*
*Δβ/β ≈ 0.05%*

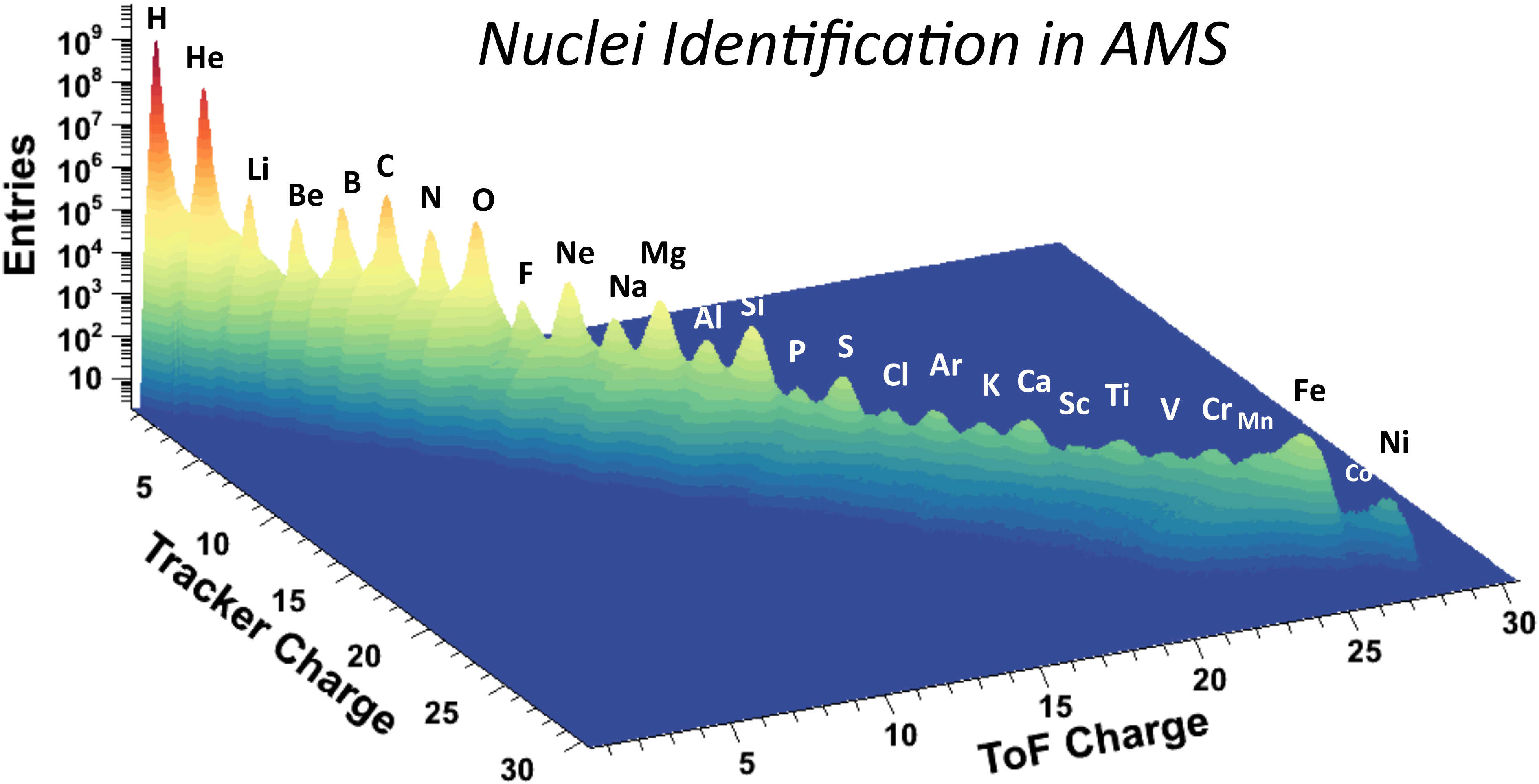
***Geomagnetic cutoff***
*ΔR/R ≈ 10% up ~25 GV*

# Multiple measurements of charge



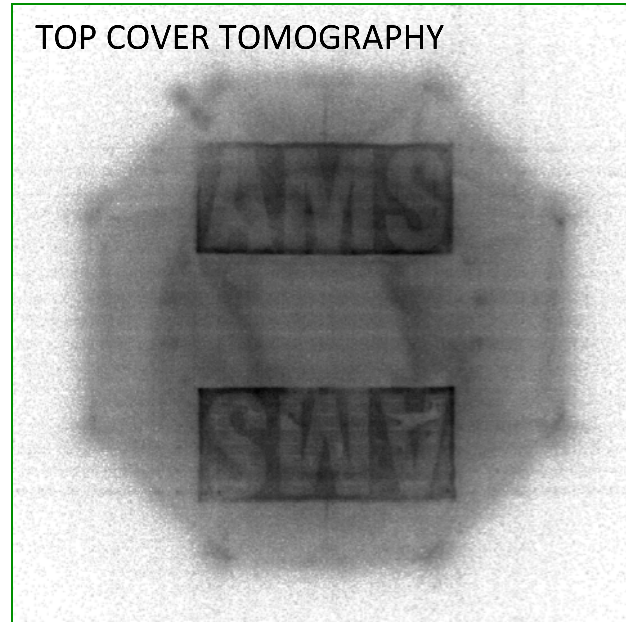

| | ΔZ (carbon) |
|---|---|
| *Tracker Plane 1 (L1)* | *0.30* |
| *TRD* | *0.33* |
| *Upper TOF (1 counter)* | *0.16* |
| *Inner Tracker (L2-L8)* | *0.12* |
| *Lower TOF (1 counter)* | *0.16* |
| *RICH* | *0.32* |
| *Tracker Plane 9 (L9)* | *0.30* |

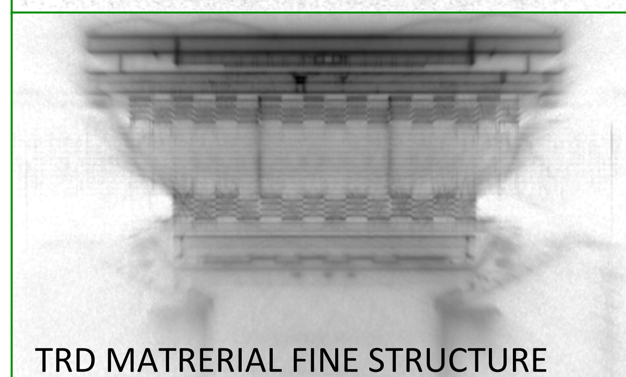
# Multiple measurements of charge



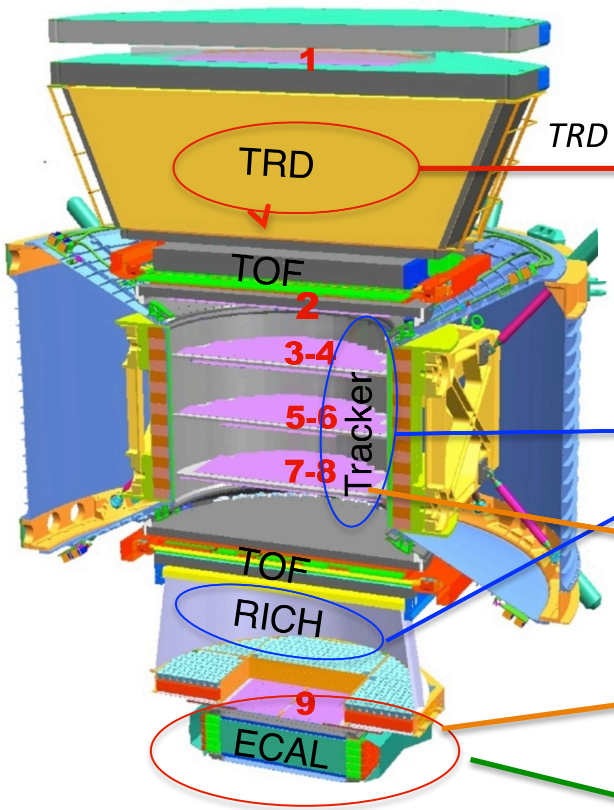
# Multiple measurement of interactions

**MATERIAL RECONTRUCTION USING INTERACTION VERTICES RECONSTRUCTED BY TRD**

# Multiple lepton/hadron separation

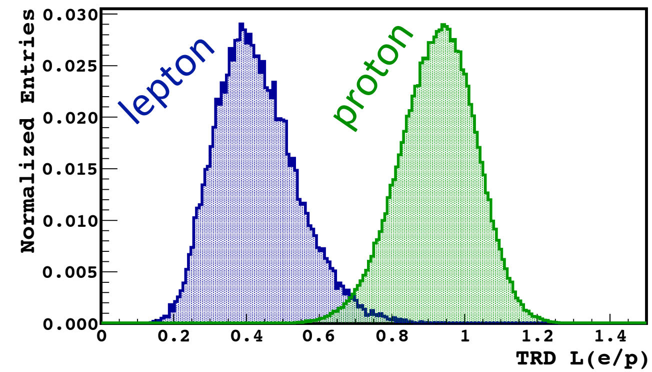



$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

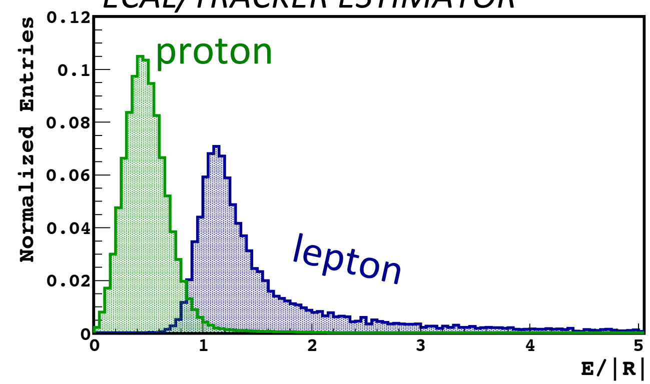
*TRD emission In 22 layers*

*Rigidity + β + Z = particle's mass*

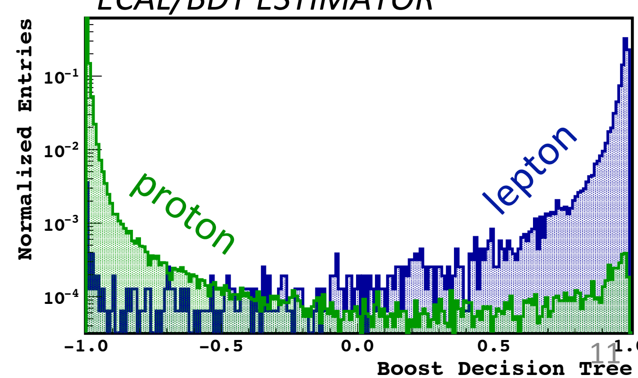
*TRD ESTIMATOR*



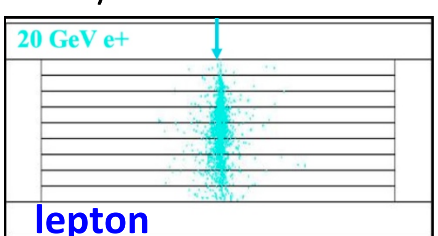

*ECAL/TRACKER ESTIMATOR*

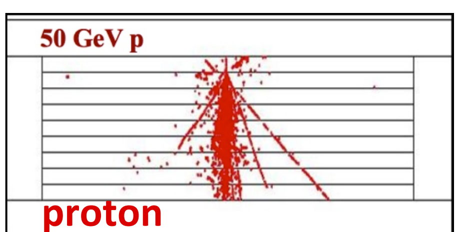



*ECAL/BDT ESTIMATOR*




ECAL/BDT DISCRIMINATION ON SHOWER TOPOLOGY

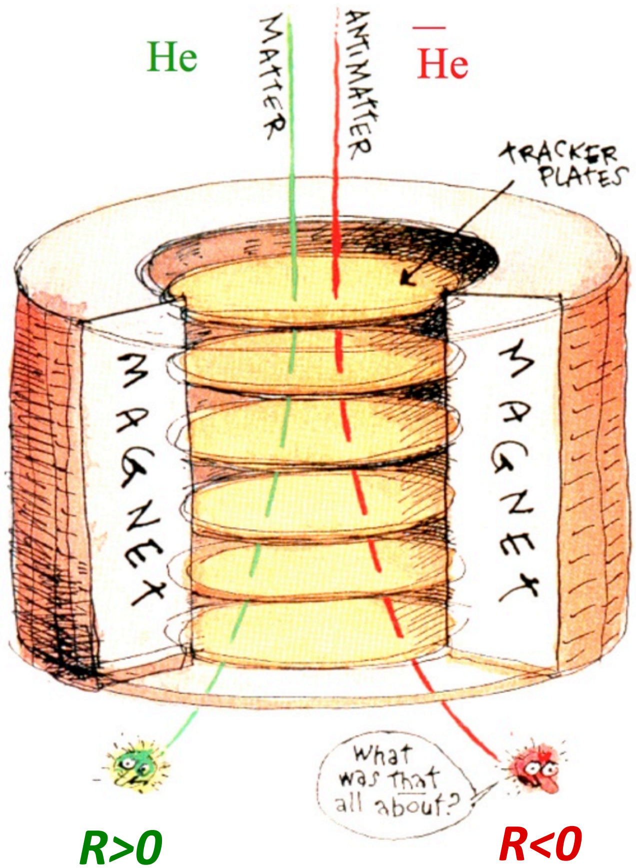


# No redundancy for particle sign

**Matter-antimatter distinction: only from the track curvature**

***Charge confusion*: probabilty to get the wrong particle sign**




*Sources of charge confusion:*

- Interactions & sec production
- Track mis-reconstruction
- Finite momentum resolution

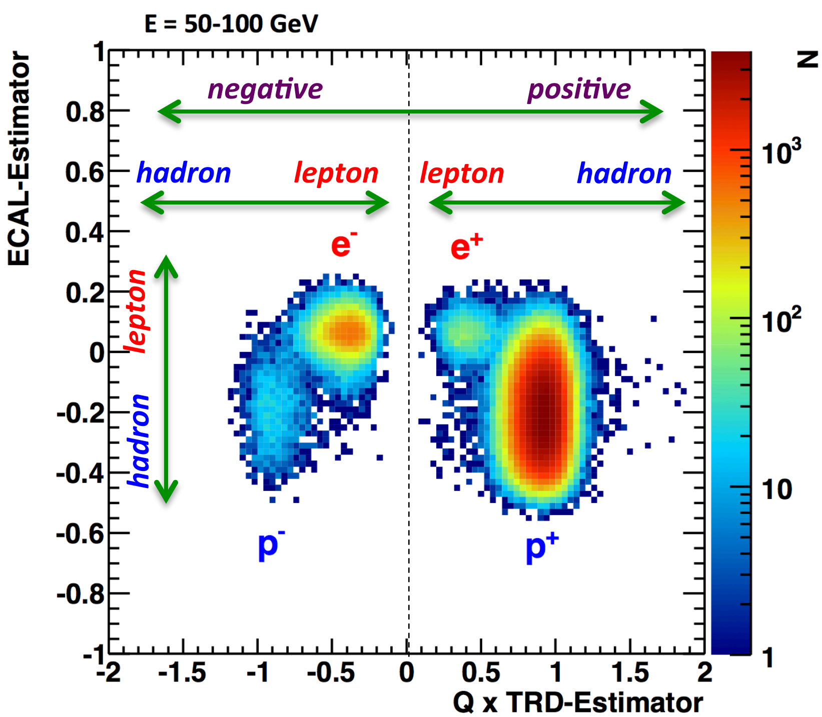
*Charge confusion probability estimators have been developed for leptons and hadrons, with the help of beam test data and MC simulation*

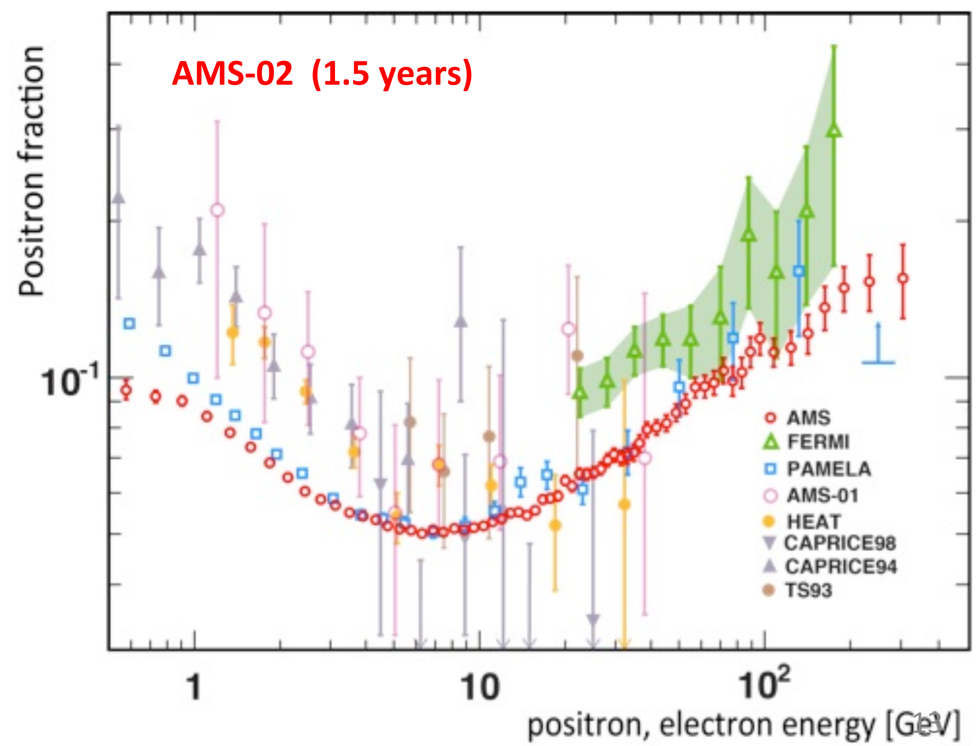
# Positron fraction results

Positron fraction measured between 0.5 to 350 GeV of energy

- ✓ *1.5 years of data. 74,000 events.*
- ✓ *72 events in the last energy bin*
- ✓ *No fine structure in the spectra.*
- ✓ *Persistent rise up ~ 200 GeV*

***The e+ secondary production is expected to decrease monotonically, while results indicate a persistent rise. The positron fraction increases steadily from 10 to 250 GeV.***



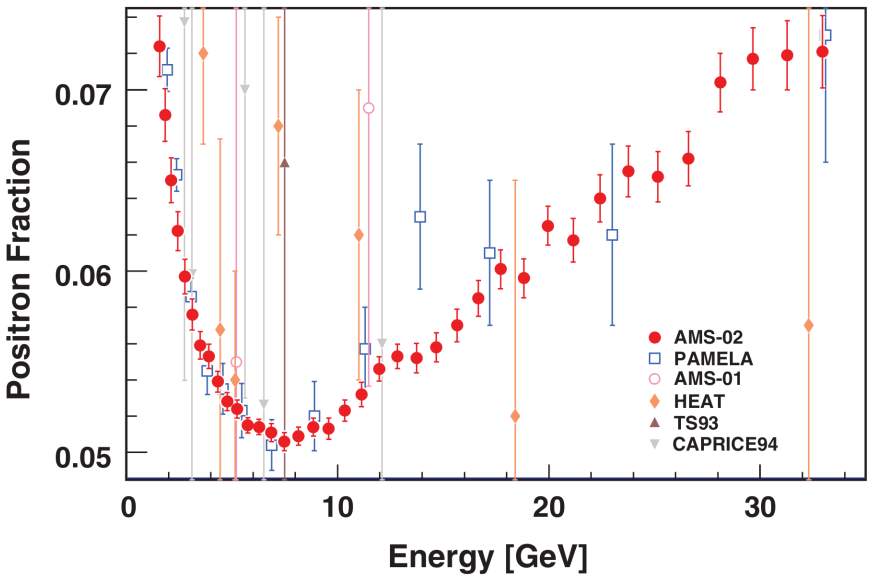



# Positron fraction at high energy

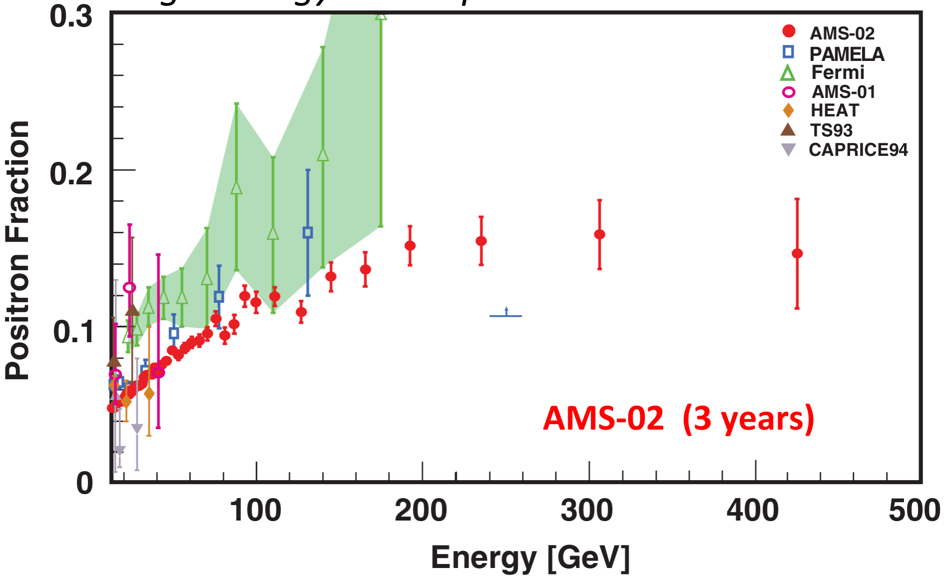
*October 2014 – New publication: positron fraction up ~500 GeV w/ 3yrs data*

- New high-energy data (3 yrs statistics) released. 0.5 GeV – 500 GeV
- The Positron fraction above ~200 GeV does not increase anymore

*low-energy close up*




*high-energy close up*



# Lepton fluxes: $e^+$, $e^-$, and "*all electron*"

***September 2014 – New publication: positron fraction in 0.5 - 500 GeV***

***October 2014 – New publication: electron and positron fluxes up to 700 GeV***

***November 2014 – New publication: electron + positron total flux up to 1 TeV***

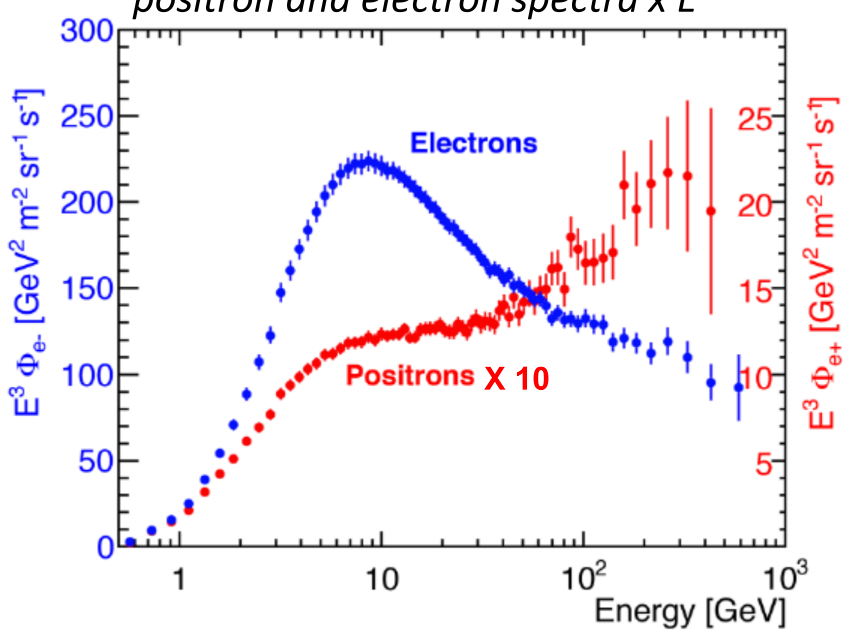
**Electron spectrum x $E^3$**

Above 10 GeV: smooth, slowly falling curve. Fairly good agreement with the PAMELA data. Different solar modulation at low energies.

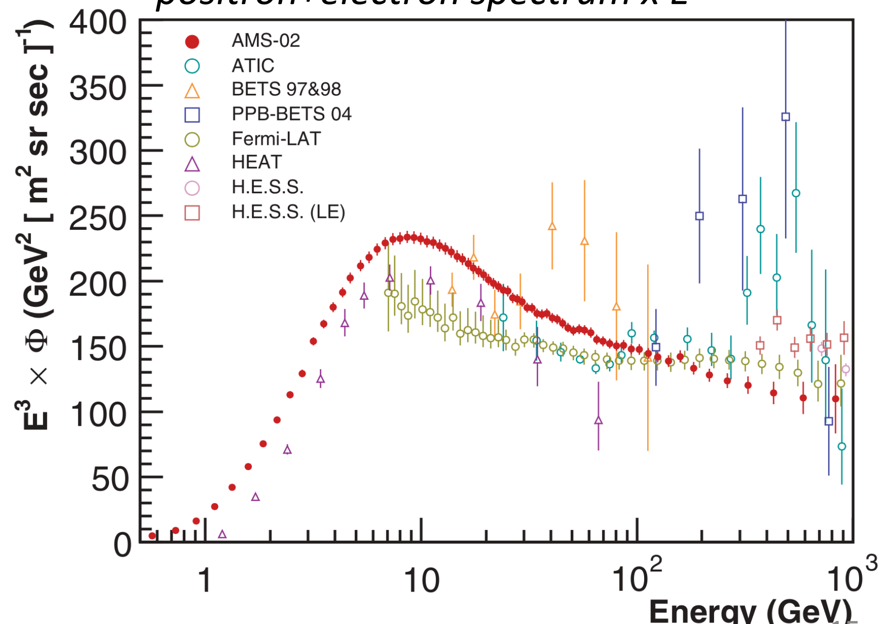
**Positron spectrum x $E^3$**

Flat spectrum from ~10 to 30 GeV. Change of slope above 30 GeV, harder than E-3, completely different from the e- spectrum.

*positron and electron spectra x $E^3$*




*positron+electron spectrum x $E^3$*



# Search for dark matter

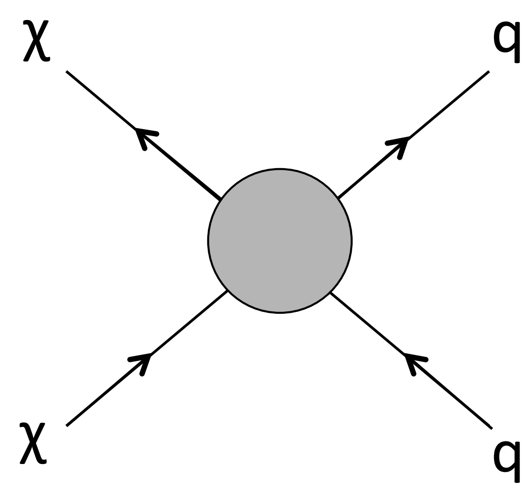
Annihilation **IN SPACE: AMS**

$\chi + \chi$ --> (...) --> e+, $\bar{p}$, $\bar{d}$, $\gamma$

Scattering

$\chi + N$ --> $\chi + N$

**UNDERGROUND: XENON, CDMS, LUX**

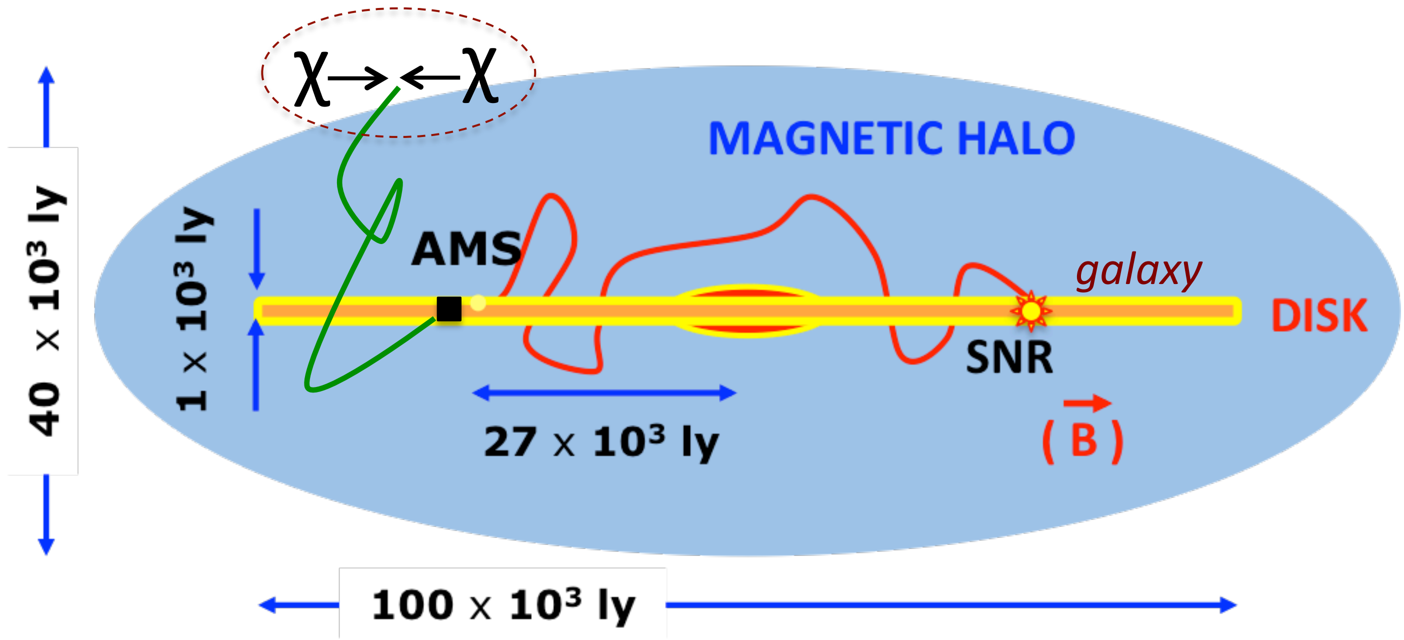



Production **IN ACCELERATORS: LHC**

p + p --> (...) --> $\chi + \chi$

# Dark matter and CR propagation physics

- ✓ *Background* from cosmic-ray sources (SNR) - No anti-matter expected
- ✓ *Background* from p+ISM collisions on disc: from propagation models
- ✓ *Signal* from DM annihilation $\chi + \chi$ --> (...) --> antimatter




*DISC*

- *Sources (SNRs)*
- *Intestellar matter (ISM)*

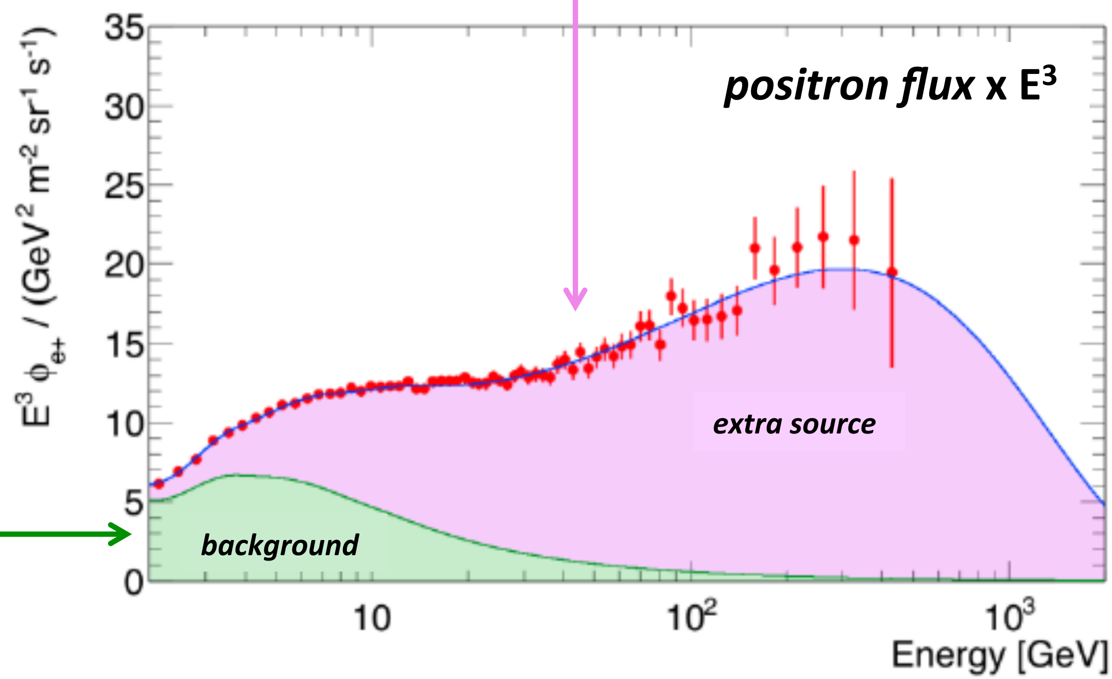
*MAGNETIC HALO*

- *Turbulent B-field. Zero matter.*
- *Energy dependent CR diffusion*

# Positron excess: sources of HE positrons

*Standard prediction: of e+ from p+ISM collisions*
*→Cannot account for the observed positron data*
*→Background for new physics/astrophysicssignals*

- Dark Matter particles
- Astrophysical sources (SNR/PWN)
- ✓ CR collisions with ISM



# Pure Dark-Matter scenarios

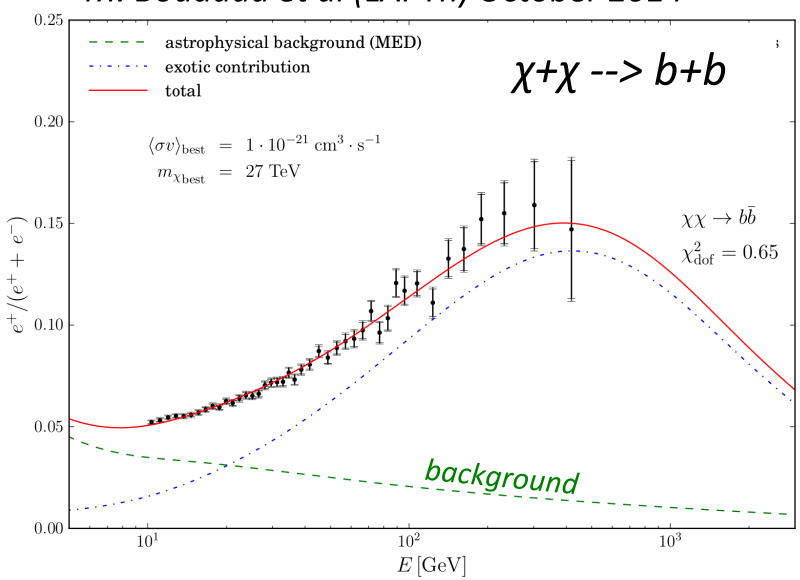
DM fits more challenging w/i precision of data. But many unknowns from DM particles

*Bosonic or hadronic channels (bb,WW): large masses (Mχ ~10 TeV). Large <σv> ~$10^{-21}$ $cm^3$/sec*
*Leptonic channels (e+e- … 2 x τ+τ-): ~ TeV mass, <σv>~ $10^{-23}$ $cm^3$/sec*

New data: hints of flattening above ~300 GeV
Pure DM scenario: TeV-scale DM, into leptonic states, with enhanced annihilation rates.

- ✓ **Search for signal in hadronic data: pbar/p ratio**
- ✓ **Uncertainty in background *and* signal propagation: CR nuclear data**

*M. Boudaud et al (LAPTh) October 2014*

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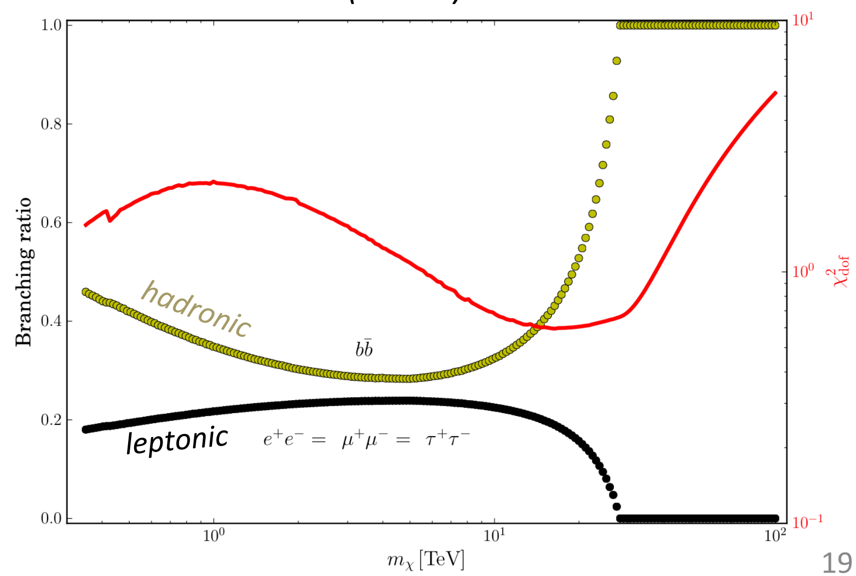


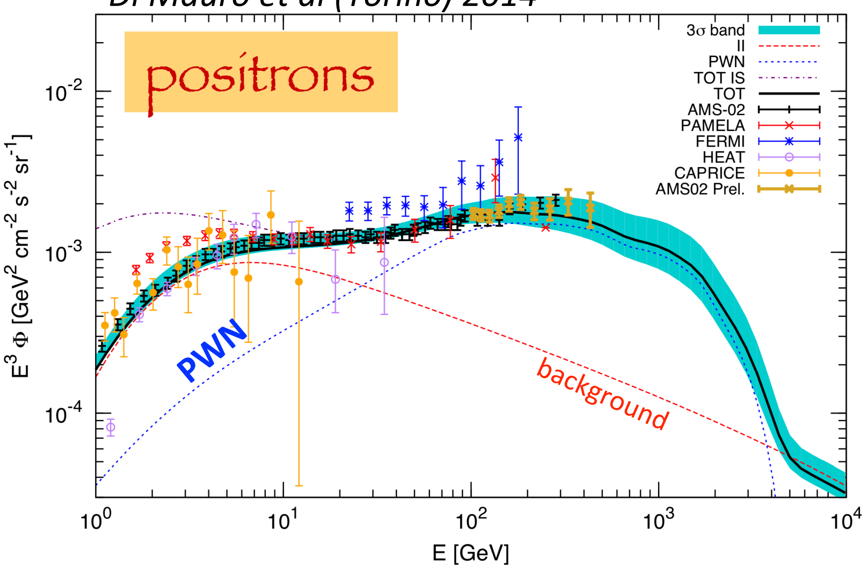
# Astrophysical Interpretations: nearby source

## *Nearby Pulsar scenario*

- ✓ **SNRs: electron, hadrons**
- ✓ **hadrons+ ISM collisions: secondary e+ and e-**
- ✓ **PWN: primary e+ and e-**

- *Additional contribution to SNRs*
- *Astrophysically plausible*
- *Many parameters unknown*
- *No signal in hadronic channels*

*Di Mauro et al (Torino) 2014*

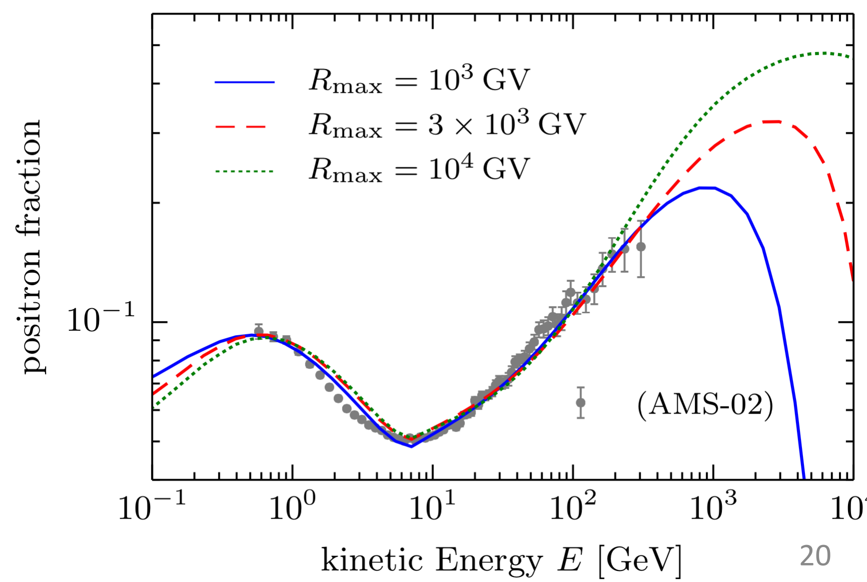



## *Old Supernova Remnant scenario*

- ✓ **SNRs: electron, hadrons, e+ from p-p collisions**
- ✓ **hadrons+ ISM collisions: secondary e+ and e-**

- *No additional source required*
- *Astrophysically plausible*
- *Atypical SNR properties. Model dependent.*
- *Signals in hadronic & nuclear channels*

*Mertsch & Sarkar 2014*



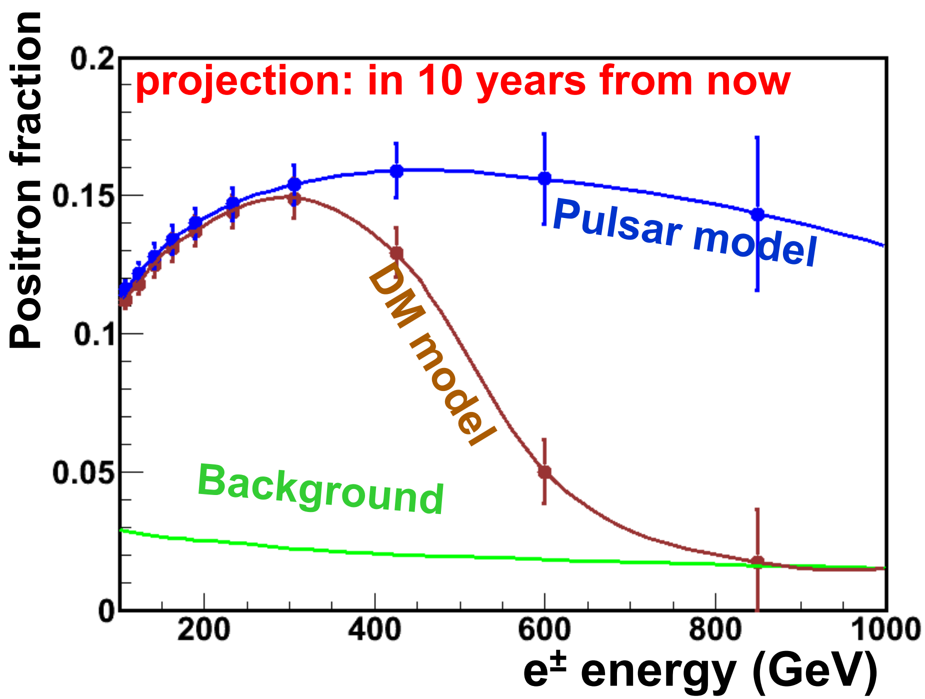
# Perspective for the DM search

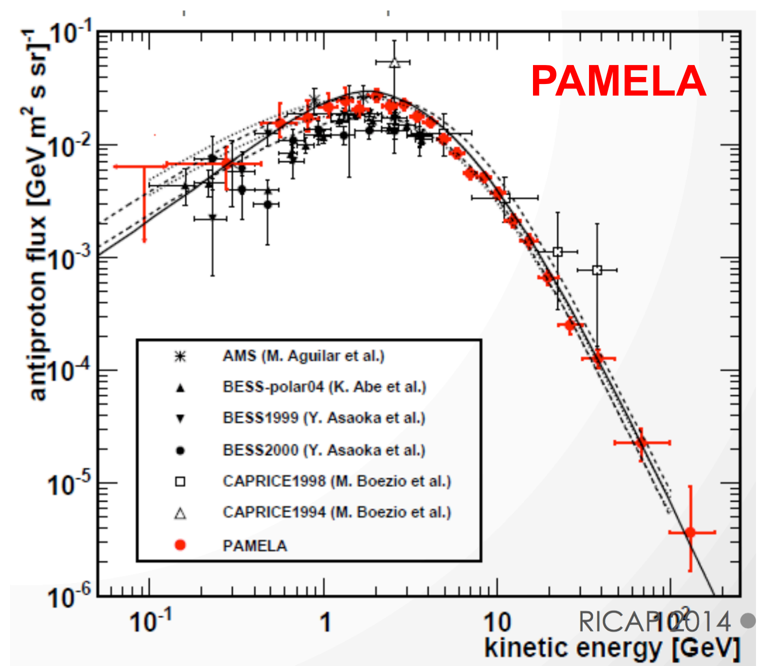
### *Lepton data at TeV energy*

- Discrimination DM/Astro scenarios
- Long observation time
- Model unknown, parameter degeneracy

### *Anti-proton/proton ratio above ~100 GeV*

- Expected signature from DM
- Present data consistent with background
- BG uncertainty (propagation &cross-sections)



# Conclusions

**AMS fundamental science experiment in the International Space Station**

**Dark Matter search is central to the AMS Physics Program**

- **Potential to shed a light on the nature of the Dark Matter**
- **Positron fraction up to 500 GeV with ~3 years of time exposure**
- **Search for anomalies in the anti-proton spectrum at high energy**
- **CR spectra measurements of proton and light nuclei**

**Data taking ongoing. Extensive data analysis ongoing.**

**~1300 days of mission. 60 Giga-particles collected**

***2014: lepton data released***

**Positron fraction at high energy**

**Electron & Positron spectra**

**All-electron energy spectrum**

***2015: hadrons and nuclei***

**Proton and Helium spectra at TeV**

**Nuclei: B/C ratio and C/O ratio**

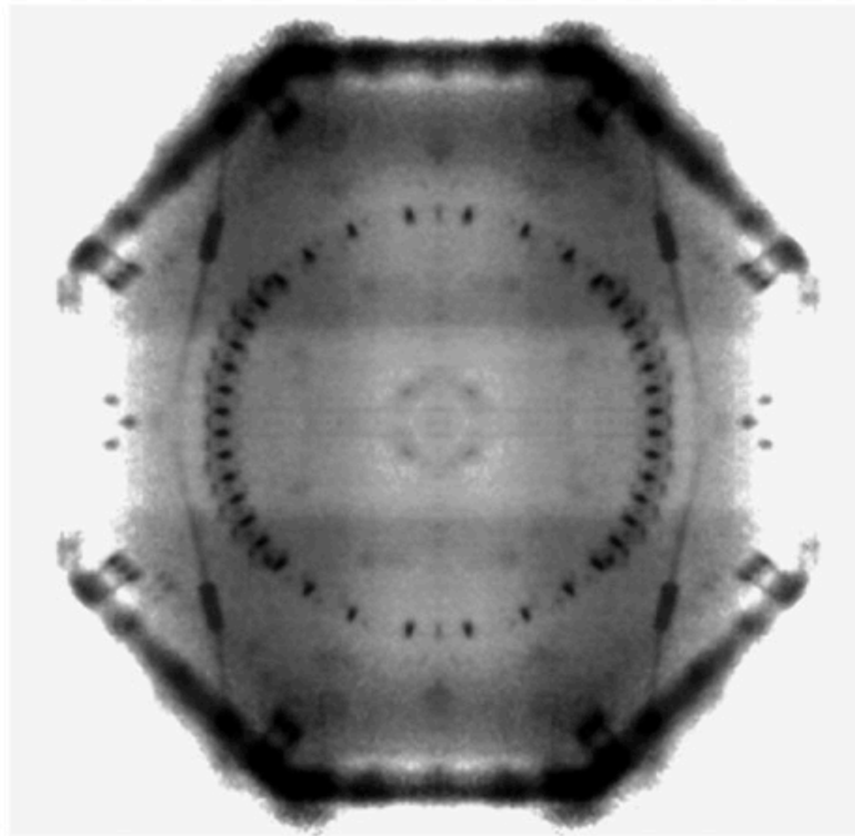
**Antimatter: antiproton/proton ratio**

# AMS-02 : Evidence of fragmentation    He absorption in TOI

## AMS Hadronic Tomography

### with the cosmic-ray p/He ratio

| | |
|---|---|
| Exposure Time: | May 20 2011 – May 20 2012 |
| Number of Protons: | 3,676,863,217 |
| Number of Helium nuclei: | 620,303,906 |
| Rigidity range: | 2 GV – 2000 GV |
| Tomographic plane: | Z = +165 cm |
| XY pixel area: | 1 $cm^2$ |



Operating in the International Space Station since May 2011, AMS is performing very accurate measurements of cosmic ray (e.g. Proton and Helium nuclei) with unprecedent sensitivity. This picture represents a “tomographic” reconstruction of the AMS top-of-instrument material obtained using the Proton-to-Helium flux ratio. Tiny changes of the interaction probabilities of these nuclei with different materials are used to trace the material inhomogenities. Detector elements such as screws, electronics boards, and mechanical interfaces are clearly recognizable.

# AMS-02 : Evidence of fragmentation Carbon → Boron

## Carbon → Boron in Upper TOF

**Optimized for high-Z measurements**
- -Large dinamical range: Z~ 1 - 30
- -Many layers of active material.
- -Many independent evaluations of Z.

**Dedicated Trigger for Z>1:**
- -4/4 TOF planes fired
- -Multiple TOF hits allowed
- -NACC <5

**Minimum bias trigger:**
- -1/100 prescaling!!
- -3/4 TOF fired
- -No conditions on NACC