Aspen 2010 Aspen Winter Conference
"The Revolution in Particle Physics is Here“
Aspen, 18-22 January 2010

New Results from PAMELA

M. Casolino
INFN & University of Roma Tor Vergata

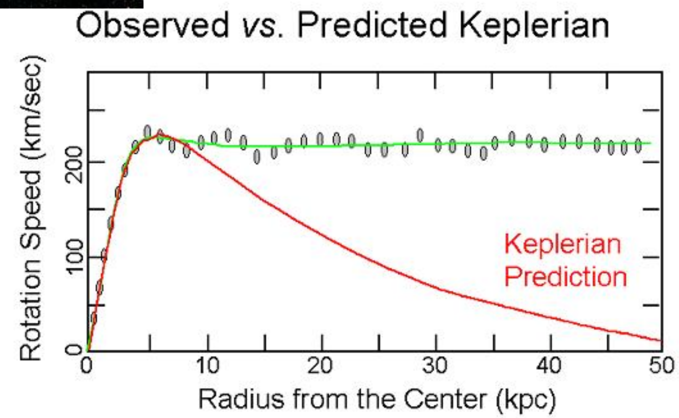
on behalf of the PAMELA collaboration

Dark Matter from gravitational interaction

1933: Cluster of galaxies
In movement of Coma cluster galaxies
$M_{dark}=160\ M_{visible}$
(Zwicky, not believed)

Blu – visible (Sloan Digital Sky Survey)
Red green – Infrared (NASA's Spitzer Space Telescope)

1959: Louise Volders studied rotation curve of M33 galaxy
Doppler shift 21 cm hyperfine line

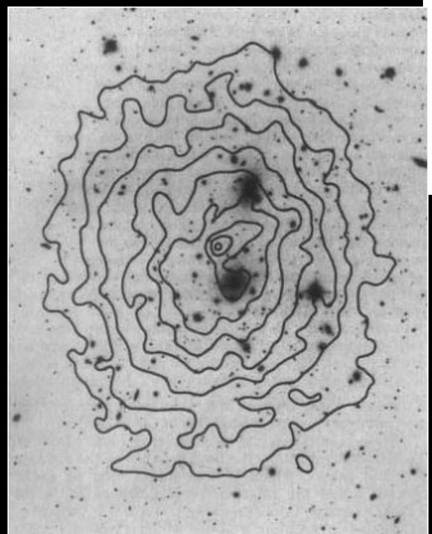


- X-ray emission from Hydrogen gas falling in the gravitational well of galaxy clusters
- Visible barion fraction: 0.56%

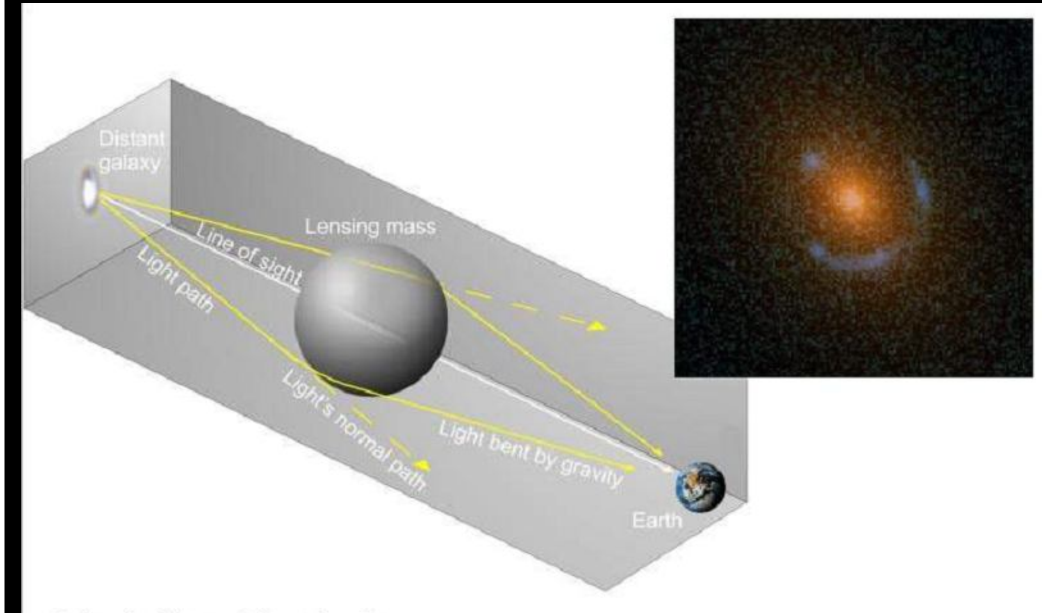
  $f_B h^{3/2}=0.056\pm0.014$
- Matter from Big Bang:

  38%

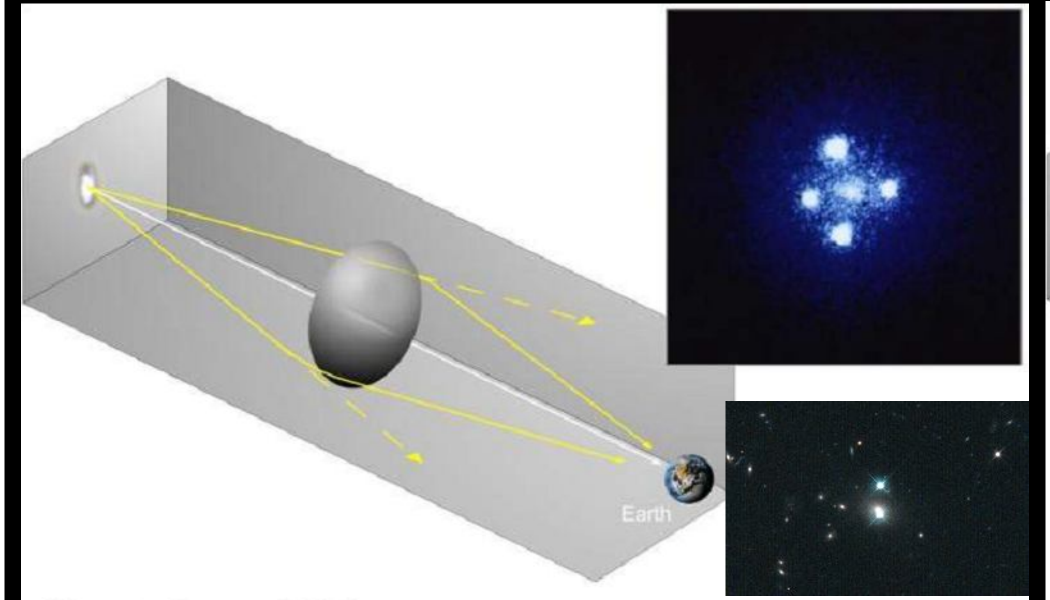
  $W_{matter} h^{1/2}=0.38\pm0.07$



Shape of gravitational lenses

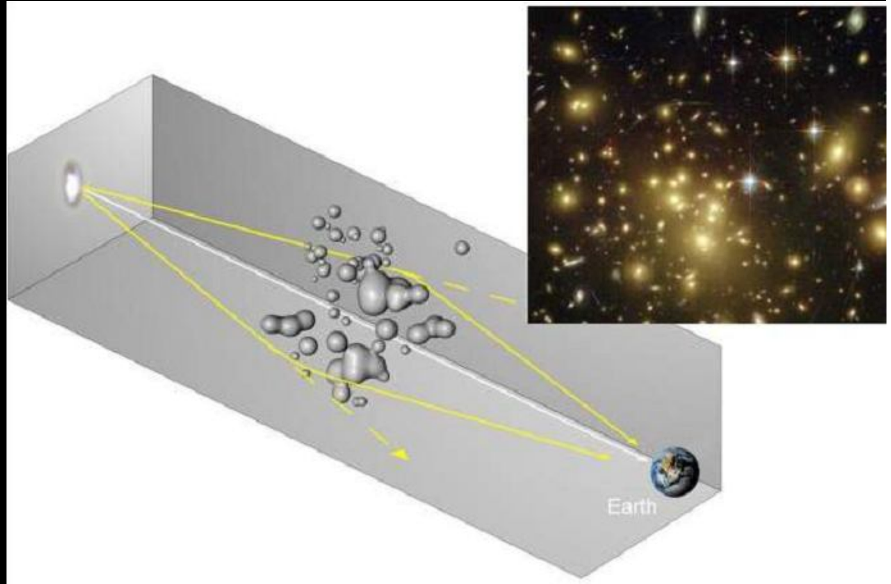


Spherical lens: Einstein ring



Elongated lens: multiple images

1937 Zwicky, 1979, Q0957+56

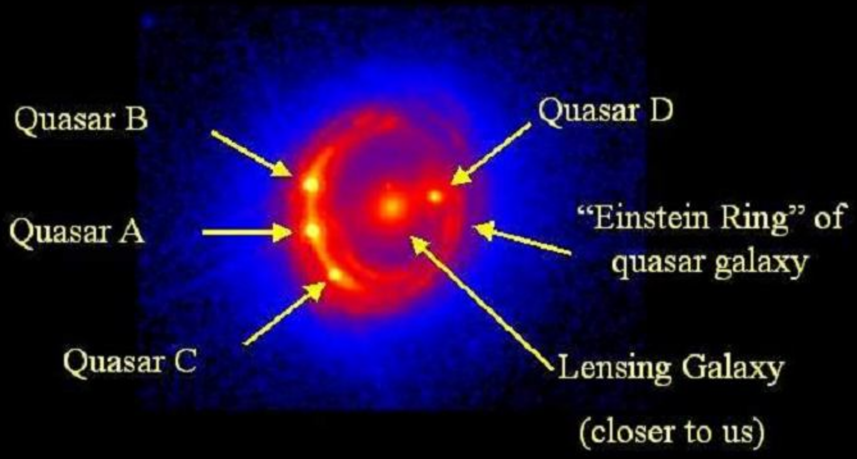


Non uniform lenses – multiple images, arcs

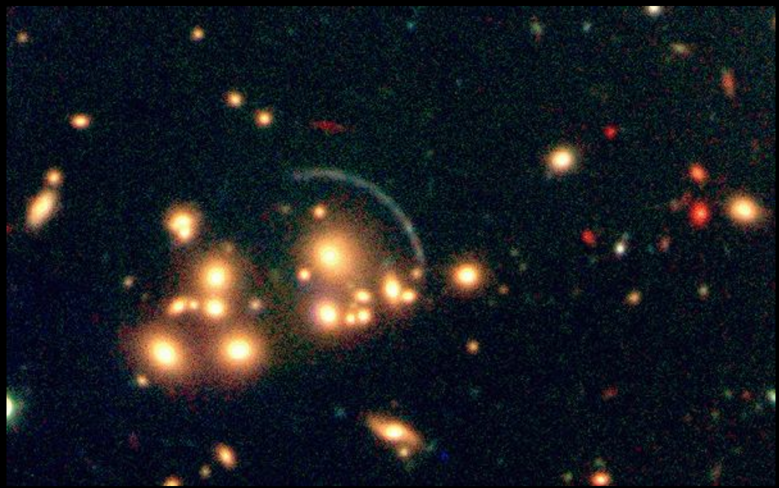
Gravitational lens:

Visible matter

RXJ1131-1231

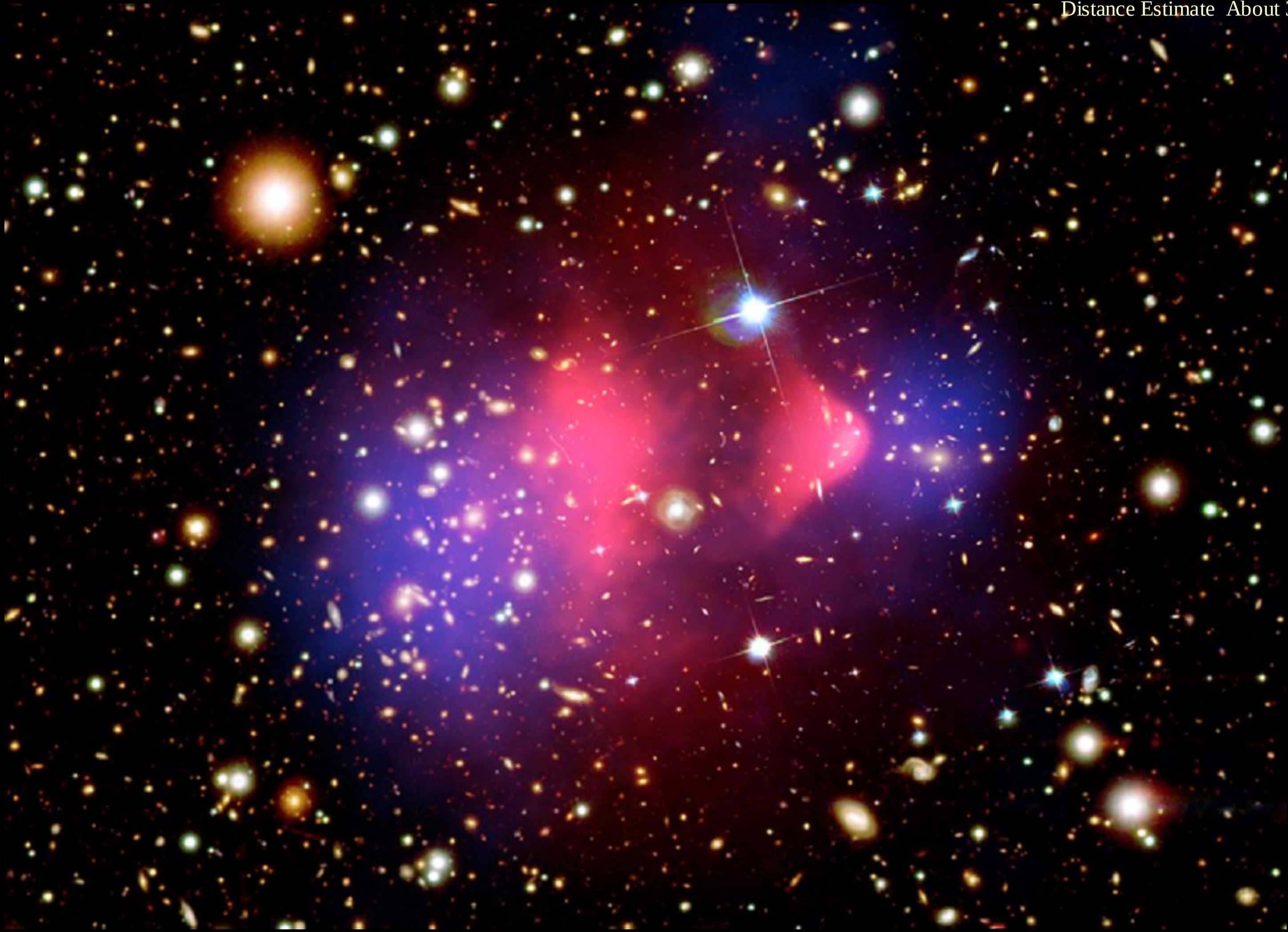


Gravitational lens:
invisible matter



1E 0657-56 - Bullet Cluster

Credit X-ray: Chandra
NASA/CXC/CfA/M.Markevitch et al.; Optical:
NASA/STScI; Magellan/U.Arizona/D.Clowe
Lensing Map: NASA/STScI; ESO WFI;
Magellan/U.Arizona/D.Clowe et al.
Scale Image is 7.5 x 5.4 arcmin
Distance Estimate About 3.8 billion light years

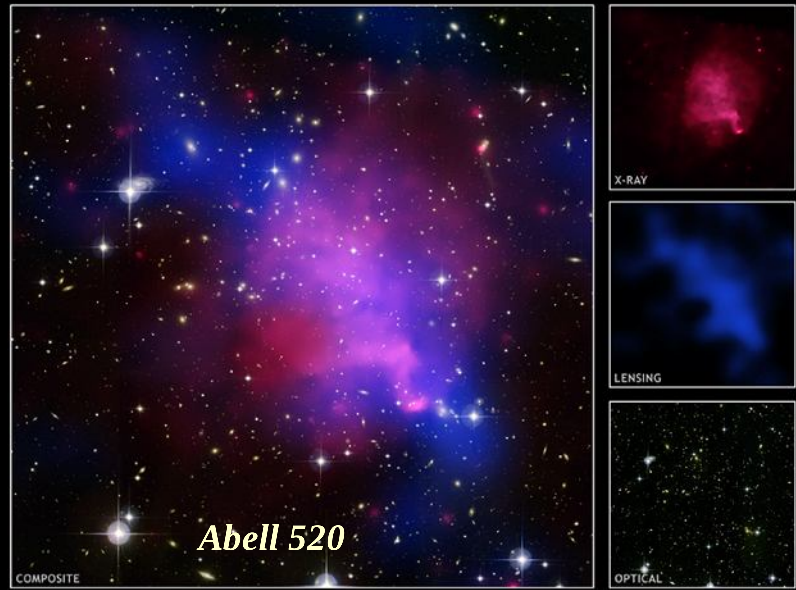


Red: Xray Blue: Gravitational lens → Non visible matter (DM) density

Set upper limit to DM annihilation
$\sigma/M \leq 3\ 10^3/GeV^3$

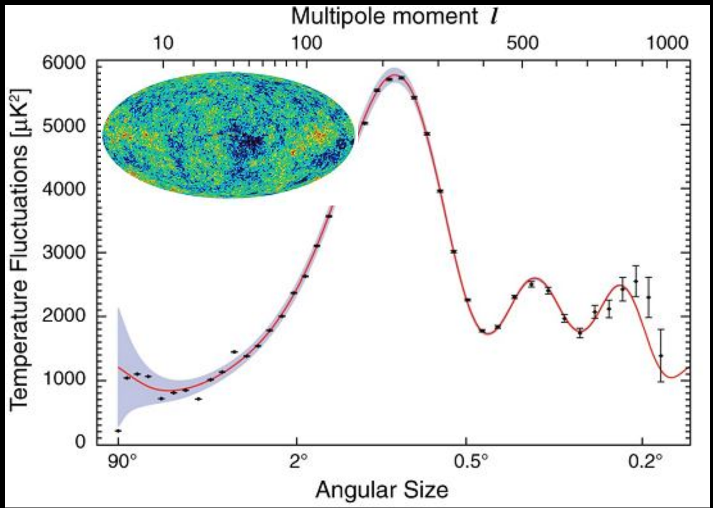
Exclude MOND *(modified Newtonian Dynamics)*

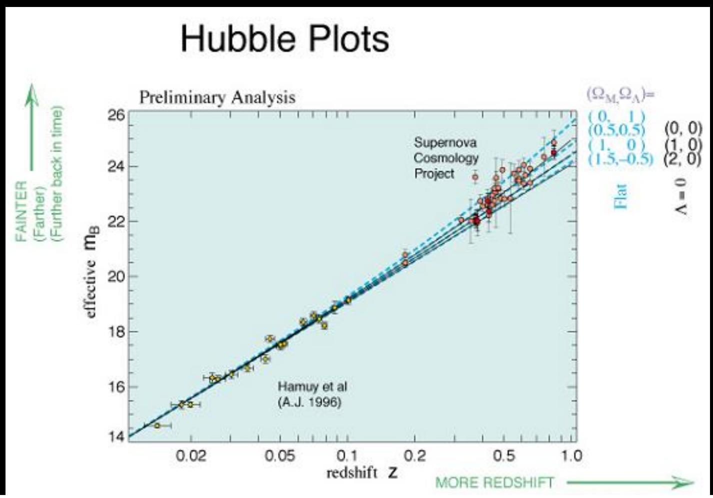
Dynamical Simulations

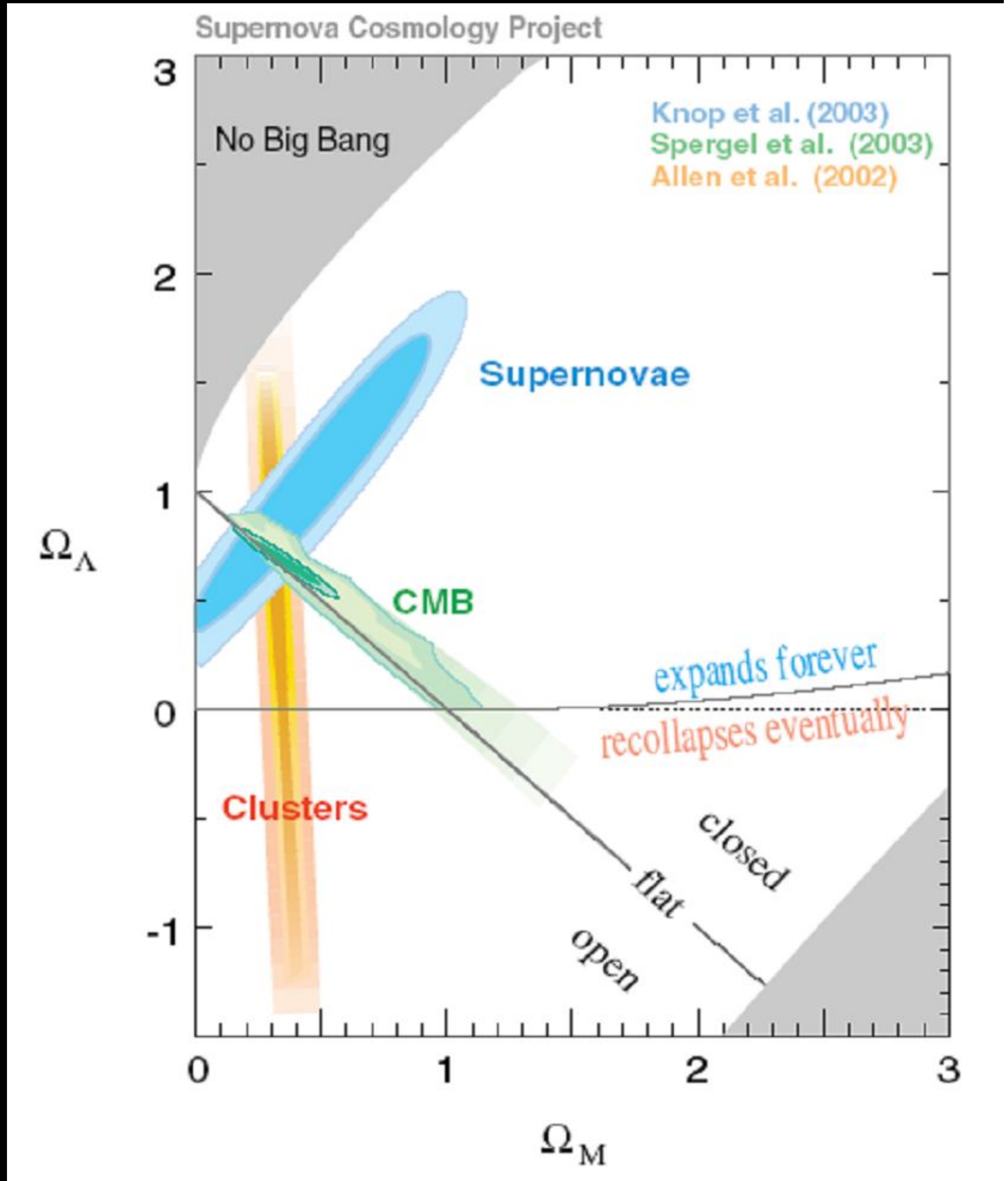


Abell 520

1E 0657-56 - Bullet Cluster a

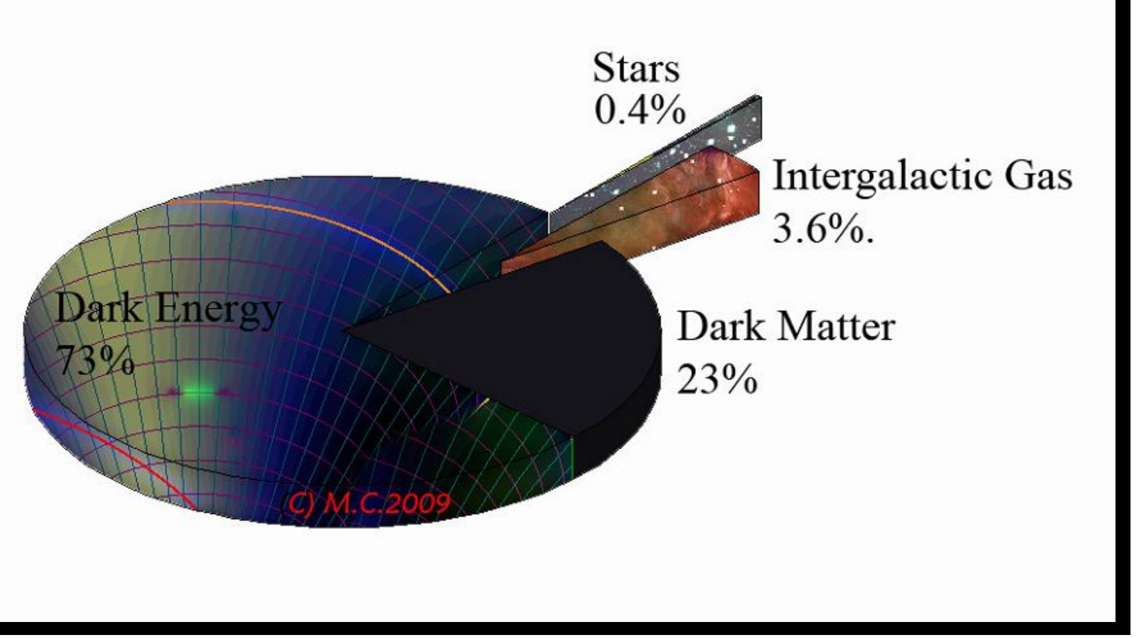

Multipole moment l
10
100
500
1000
6000
5000
4000
3000
2000
1000
0
Temperature Fluctuations [μK²]
90°
2°
0.5°
0.2°
Angular Size


Hubble Plots
Preliminary Analysis
FAINTER
(Farther)
(Further back in time)
effective m_B
26
24
22
20
18
16
14
Supernova
Cosmology
Project
Hamuy et al
(A.J. 1996)
(Ω_M,Ω_Λ)=
(0, 1)
(0.5,0.5)
(1, 0)
(1.5,-0.5)
Flat
(0, 0)
(1, 0)
(2, 0)
Λ = 0
0.02
0.05
0.1
0.2
0.5
1.0
redshift z
MORE REDSHIFT


Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
Ω_Λ
Ω_M
3
2
1
0
-1
0
1
2
3

Ω=1

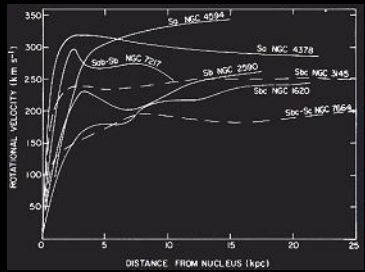
Visible luminous matter (stars): 0.2% - 0.6% Ω
Barions (H, He, n): 1.6% - 2.4% Ω
Neutrinos: ~ 0.3 –10% Ω
Rest of cosmic rays (photons, e^- …) ~5% Ω
Dark matter in Galactic Halo: ~10% Ω
Dark Matter in the galaxies: ~30% Ω

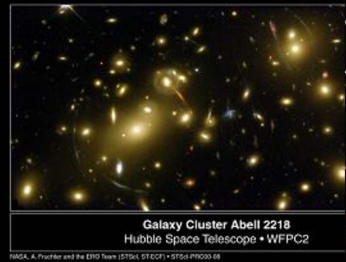


Dark Matter Searches

•Cosmology

Detection, not identification





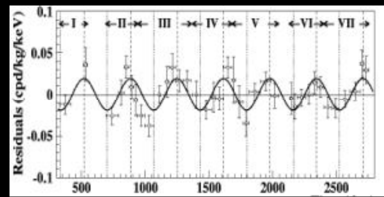
1E 0657-56 - Bullet Cluster

•LHC Search

Supersymmetry, not necessarily DM

•Direct Detection

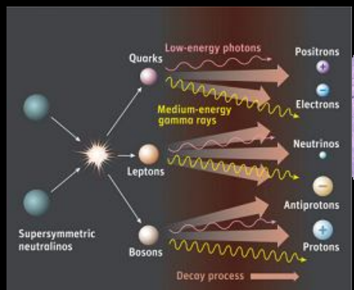
Local structure and nature

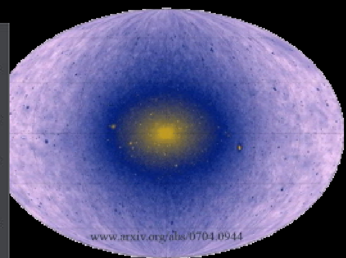


DAMA

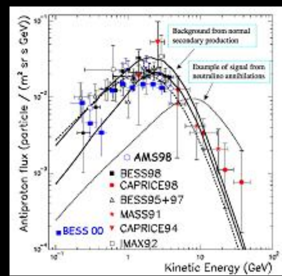
•Indirect Detection

Various galactic scales

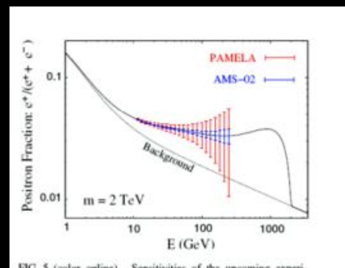




γ: Galactic centre



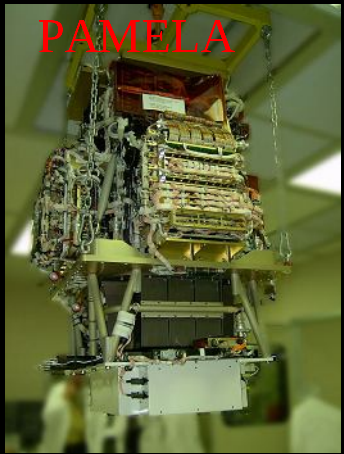
Antiprotons: Galactic average

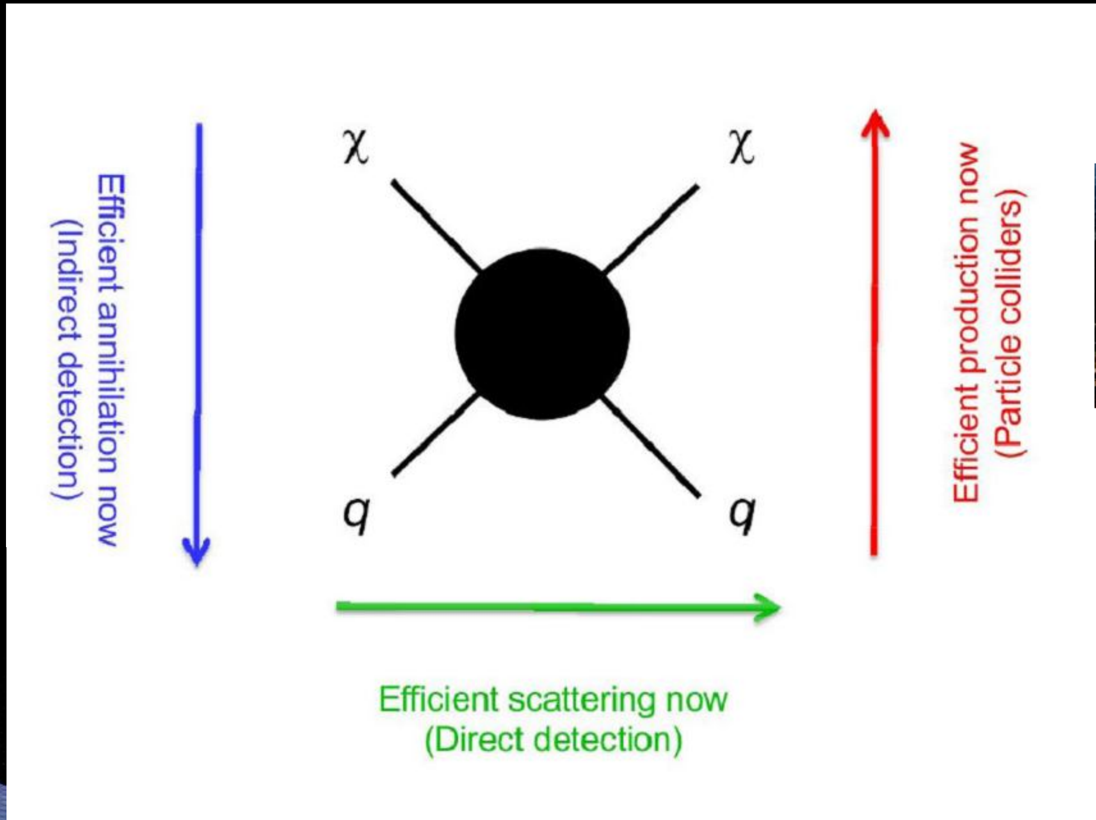


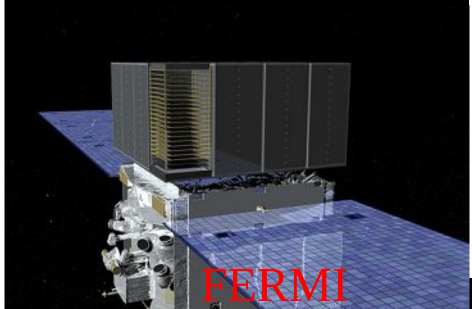
positrons: Local galactic 1kpc

M. Casolino, INFN & University Roma Tor Vergata

Different approaches to search for Dark Matter







Adapted from P. Lipari

Another problem:

Matter / Antimatter Asymmetry in the Universe

Sakharov conditions

1) Direct violation of barionic number

particle “X” decays breaking barion symmetry

2) CP violation

to avoid specular antiparticle decay

3) Non thermal equilibrium at a given time

To avoid barion compensation through inverse processes

Sakharov, A.D. 1967, J. of Exper. and Theo. Phys. Letters, 5, 24-28,
“Violation of CP Invariance, C Asymmetry, and Baryon Asymmetry of the Universe”

Matter – Antimatter domain separation?

- γ-ray $\approx$ 0.1 GeV from annihilation in boundary regions

- ***Current limit: separation above cluster of galaxy ($\geq$ 10 Mpc)***

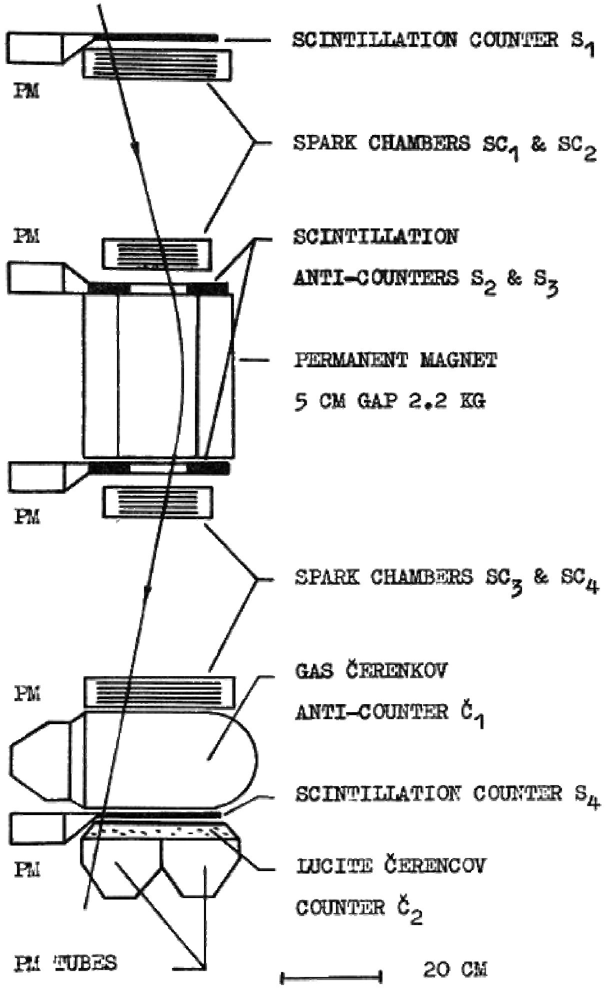
Steigman, G. 1976, Ann. Rev. Astron. Astrophys. 14, 339,
"Observational tests of antimatter cosmologies"

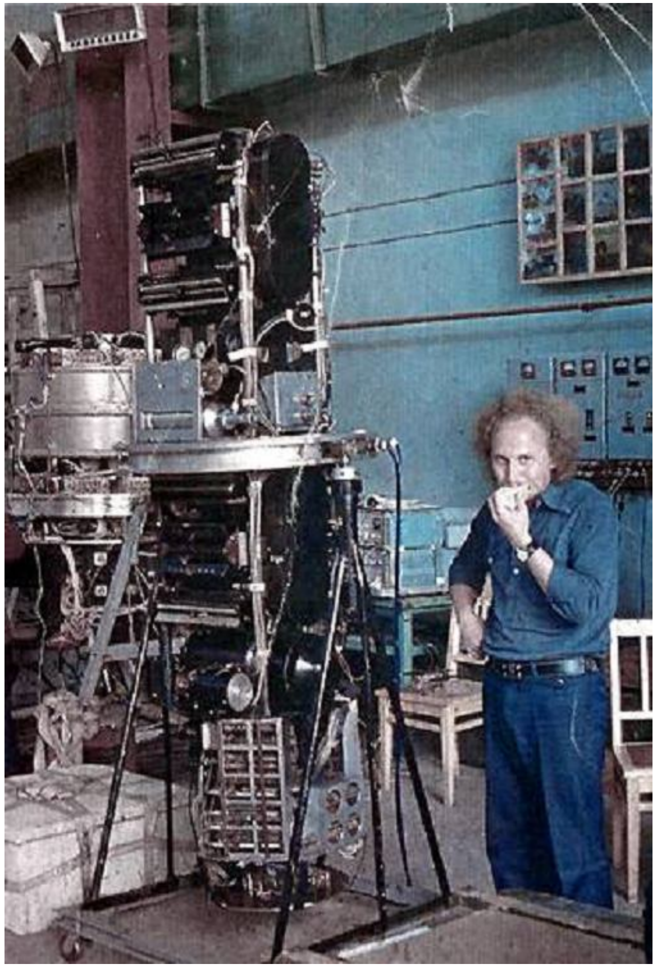
- Observable?
- Magnetic fields ?
- Survival probability?

Ahlen, S.P. et al. 1982, ApJ, 260, 20,
"Can we detect antimatter from other galaxies?"

M33

Discovery of antiprotons in cr, 1979





$\bar{p}/p$ ratio

6×10^{-4}

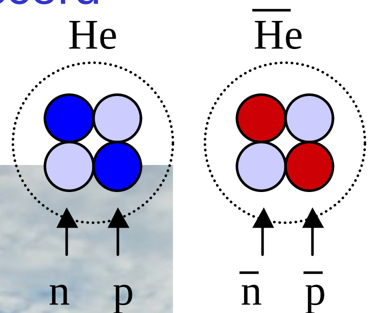
2-5 GeV

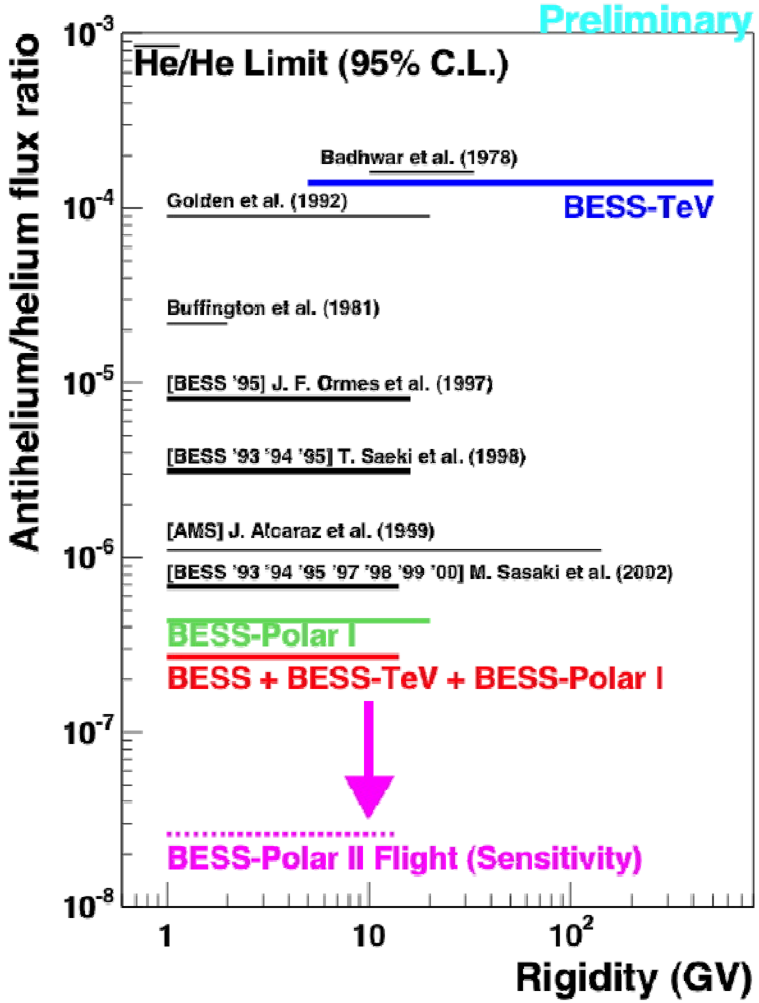
From
Robert E. Streitmatter

Bogomolov, E.A. et al. 1979, Proc. 16th ICRC, Kyoto, 1, 330,
"A Stratospheric Magnetic Spectrometer Investigation of the Singly Charged Component Spectra and Composition of the Primary and Secondary Cosmic Radiation"

Antihelium search

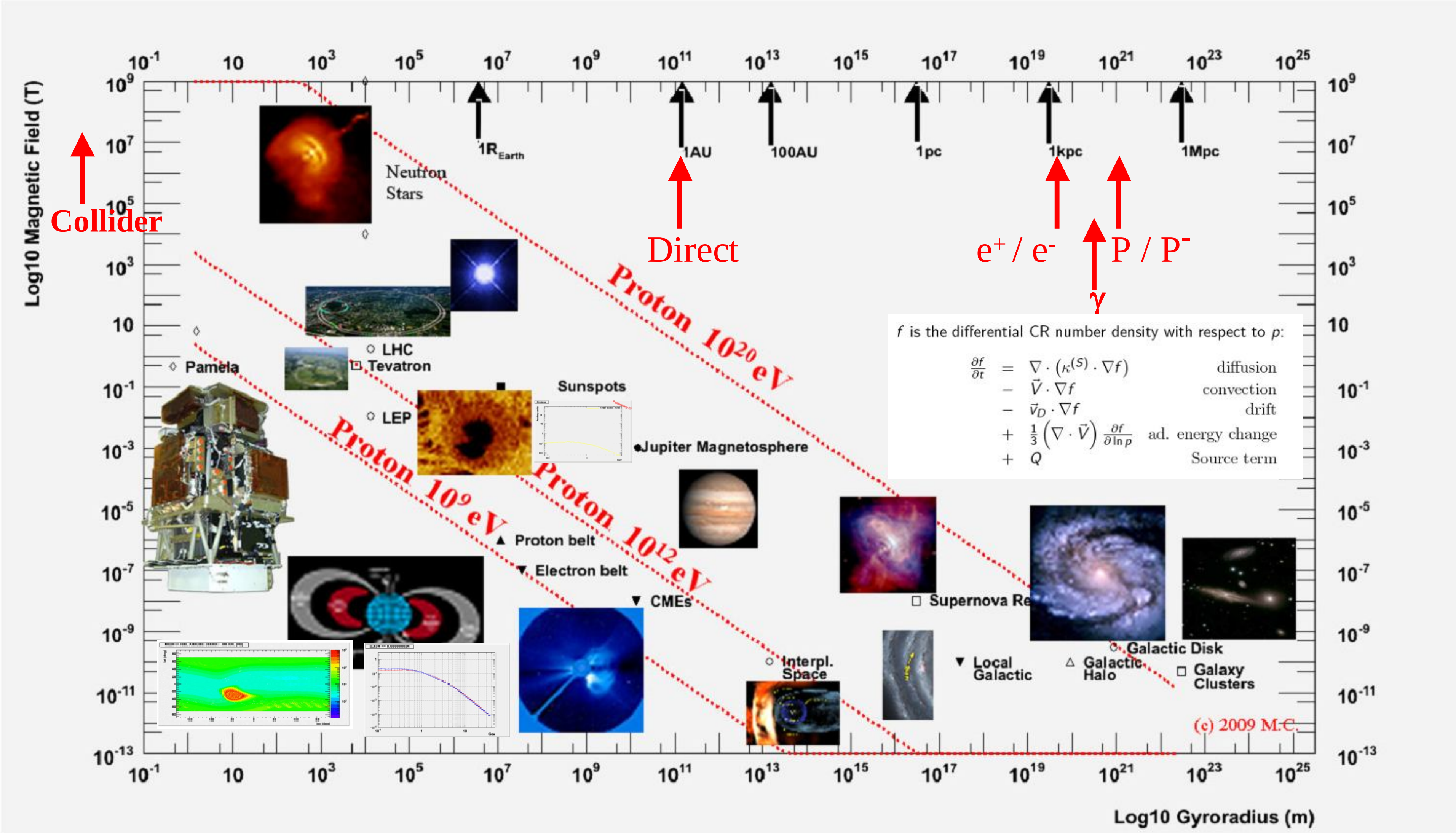
- Probability to produce antinuclei in cosmic rays is negligible. AntiHe could be produced in Big Bang.
- **Look in cosmic rays**
- **Up to now only upper limit**
- BESS has current world record





Ref.: M. Sasaki et al. at COSPAR-2006

Pamela Physics objectives in the Hillas Plot



Supersymmetry:

Standard Model particles and fields		Supersymmetric partners			
		Interaction eigenstates		Mass eigenstates	
Symbol	Name	Symbol	Name	Symbol	Name
$q = d, c, b, u, s, t$	quark	$\tilde{q}_L$, $\tilde{q}_R$	squark	$\tilde{q}_1$, $\tilde{q}_2$	squark
$l = e, \mu, \tau$	lepton	$\tilde{l}_L$, $\tilde{l}_R$	slepton	$\tilde{l}_1$, $\tilde{l}_2$	slepton
$\nu = \nu_e, \nu_\mu, \nu_\tau$	neutrino	$\tilde{\nu}$	sneutrino	$\tilde{\nu}$	sneutrino
g	gluon	$\tilde{g}$	gluino	$\tilde{g}$	gluino
$W^\pm$	W-boson	$\tilde{W}^\pm$	wino	$\tilde{\chi}^\pm_{1,2}$	chargino
H^-	Higgs boson	$\tilde{H}_1^-$	higgsino		
H^+	Higgs boson	$\tilde{H}_2^+$	higgsino		
B	B-field	$\tilde{B}$	bino	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
W^3	W^3-field	$\tilde{W}^3$	wino		
H_1^0	Higgs boson				
H_2^0	Higgs boson	$\tilde{H}_1^0$	higgsino		
H_3^0	Higgs boson	$\tilde{H}_2^0$	higgsino		

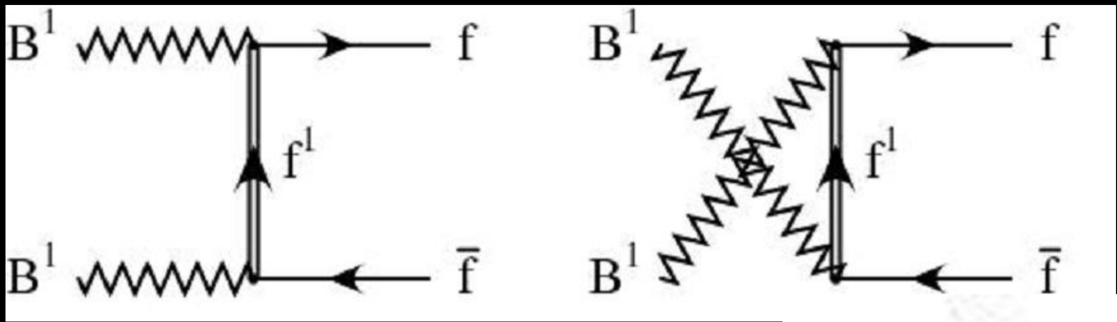
LSP – can not decay
But can annhilate

M.

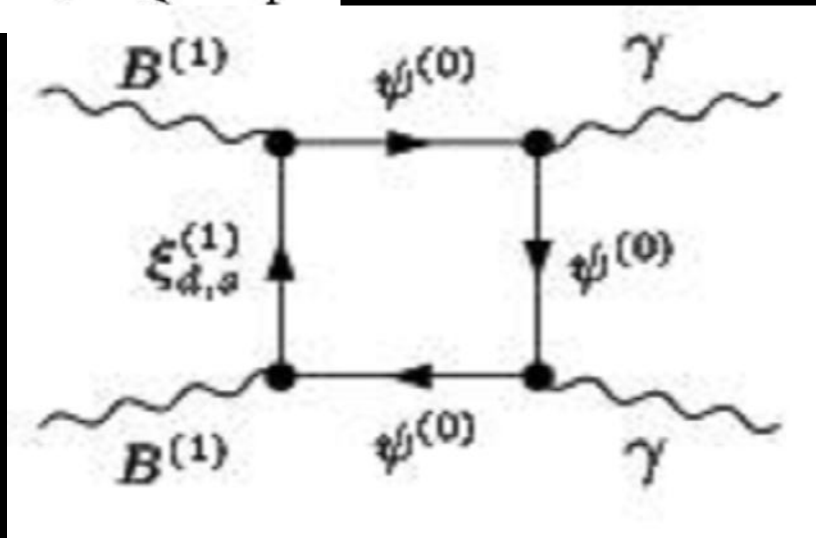
Another possible scenario:
KK Dark Matter

LKP

Bosonic Dark Matter



no longer helicity suppressed



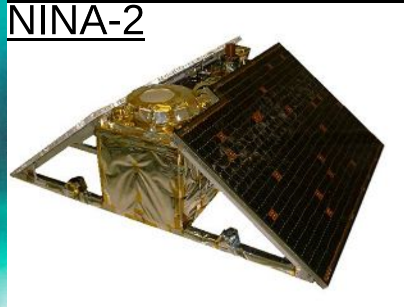
monoenergetic
γ γ in the final state

Past, present and future experiment

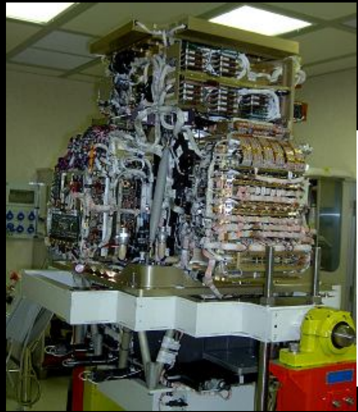
MASS-89, 91, TS-93, CAPRICE 94-97-98

NINA-1

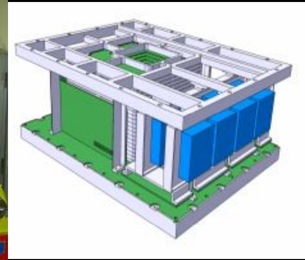
NINA-2



PAMELA



SIRAD



89 M 91 TS 93 C 94 C 97 C 98 *PAMELA*

9 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 ...

NINA-1 NINA-2 LAZIO-SIRAD

SILEYE-1 SILEYE-2 SILEYE-3 ALTEA

SILEYE-1

& University Roma Tor Vergata

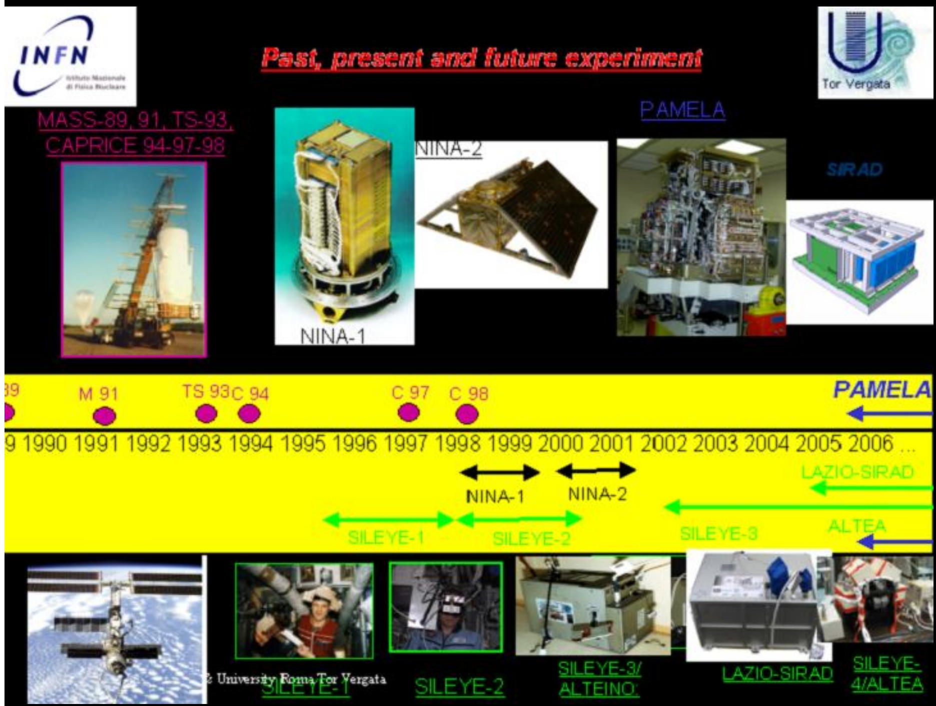
SILEYE-2

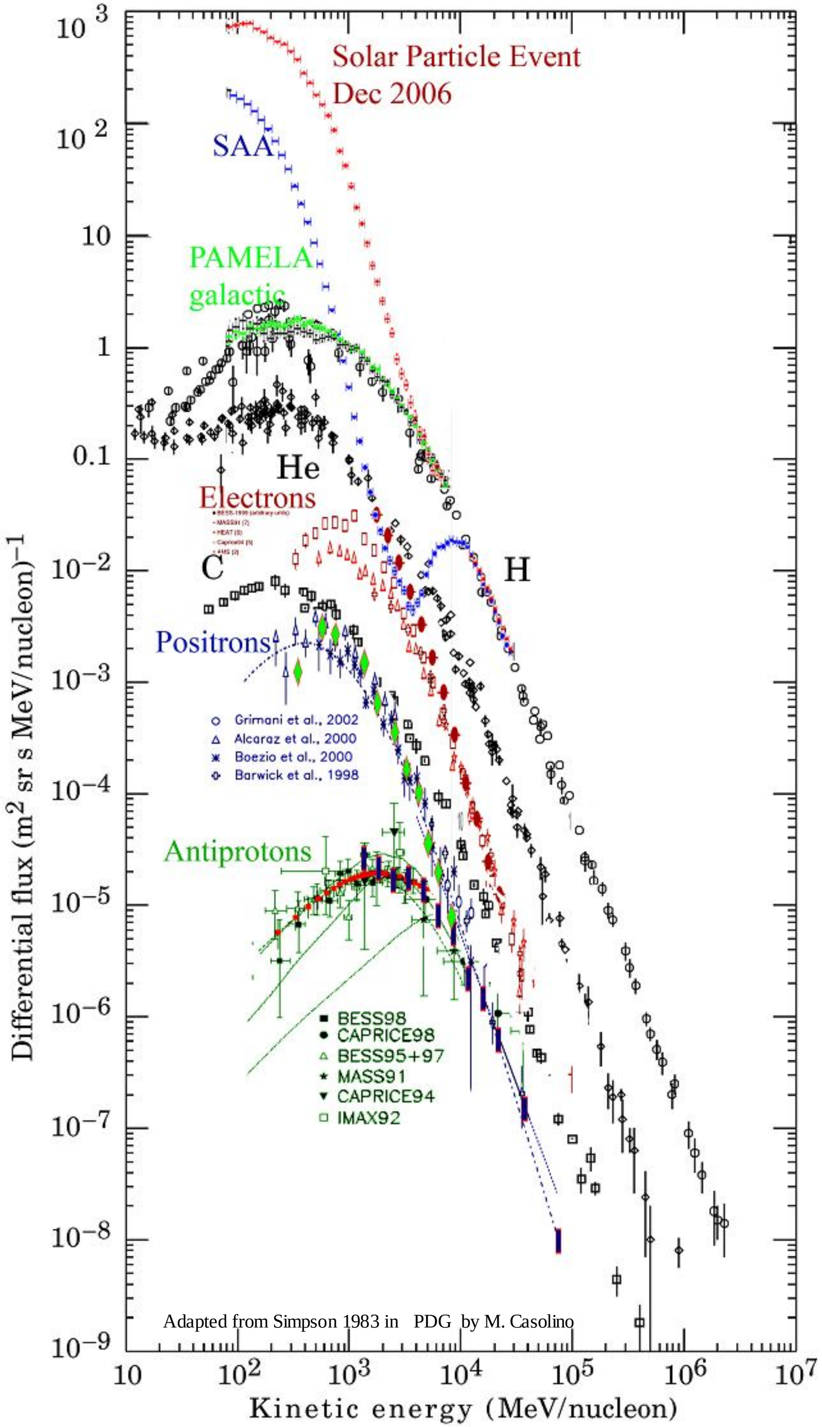
SILEYE-3/ ALTEINO:

LAZIO-SIRAD

SILEYE-4/ALTEA

High precision charged cosmic ray measurement in Low Earth Orbit





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Time of Flight
(three scintillators, 6 planes, 48 phototubes)

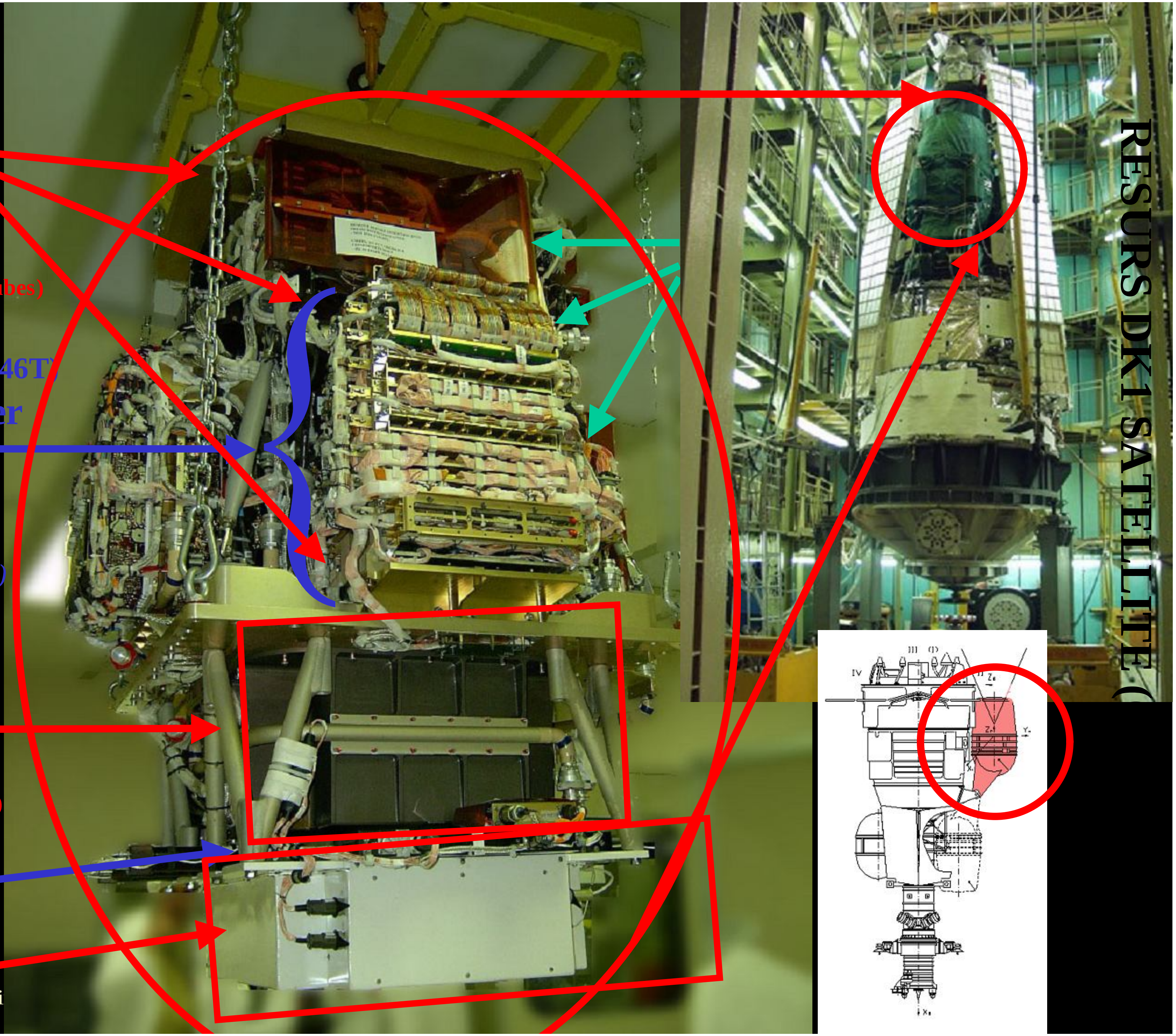
Magnetic (0.46T) Spectrometer Microstrip detector
(6 double sided microstrip planes)

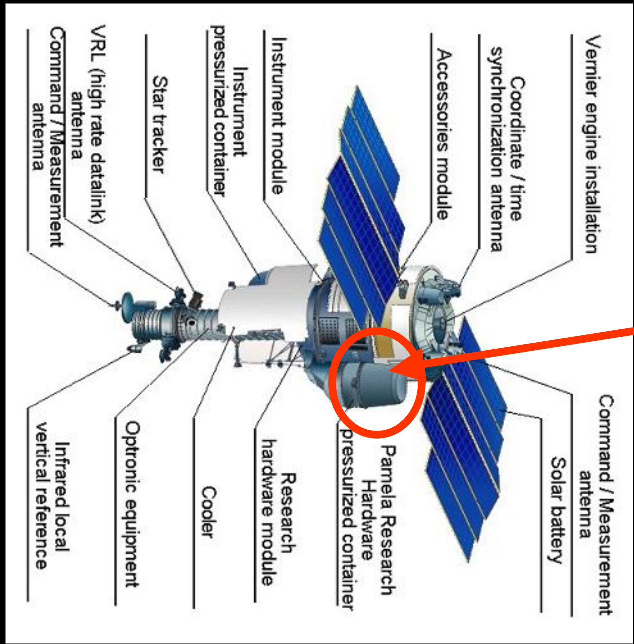
Silicon Tungsten Tracking Calorimeter
(44 planes of 96 strip)

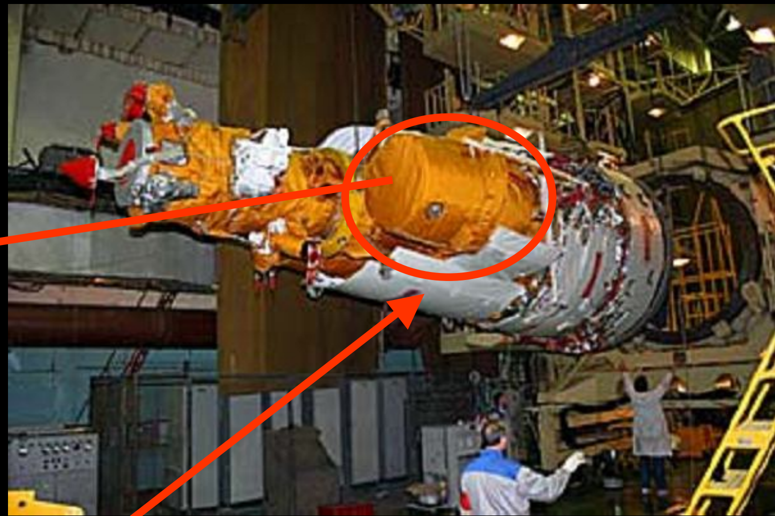
Shower Catcher Scintillator

Neutron Detector

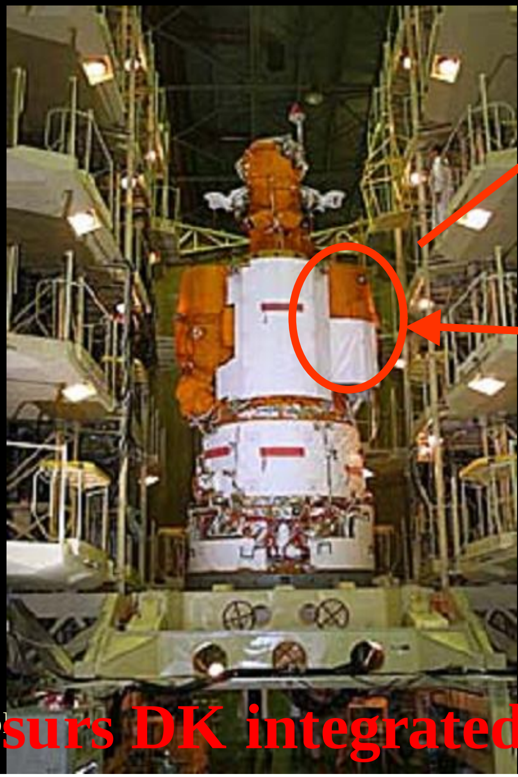
M. Casoli



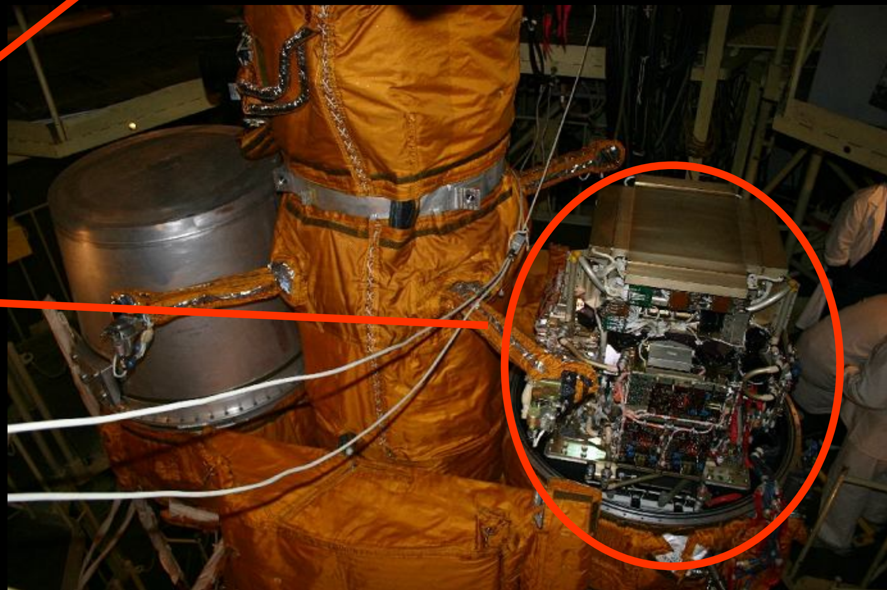




Coupling to Soyuz



Resurs DK integrated



Pamela during integration in Baikonur

Baikonur Cosmodrome

Two main Russian cosmodromes (Plesesk for polar launches)
Russian enclave in Kazakistan
Manned and unmanned launches to International Space Station

85 km NS
125 km EW

Leninsk / Baikonur

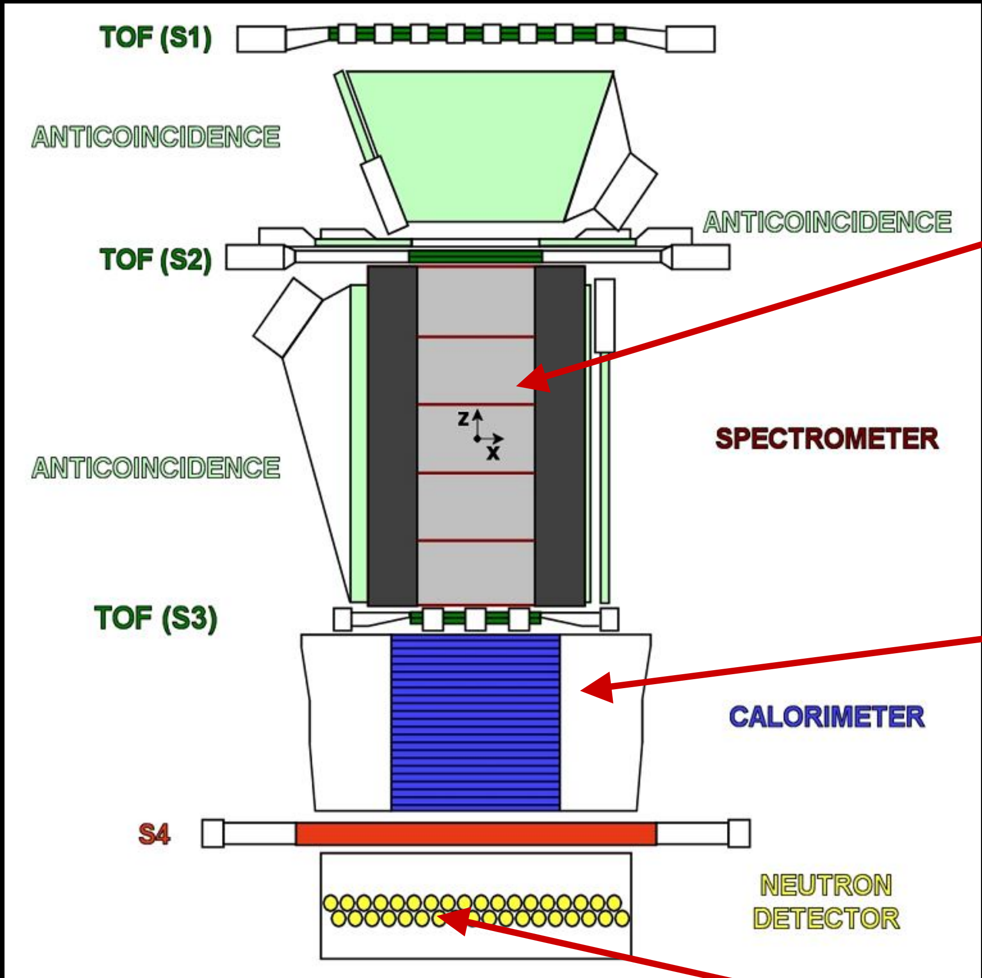
Integration in Baikonur cosmodrome, Spring 2006

photo M. Casolino

Pamela launch:
Transport from Progress building to Launch Pad, 13-6-2006


Gagarinsky Start

Launch on June 15th 2006 Soyuz-U rocket



Spatial Resolution
- ≅ 2.8 μm bending view
- ≅ 13.1 μm non-bending view

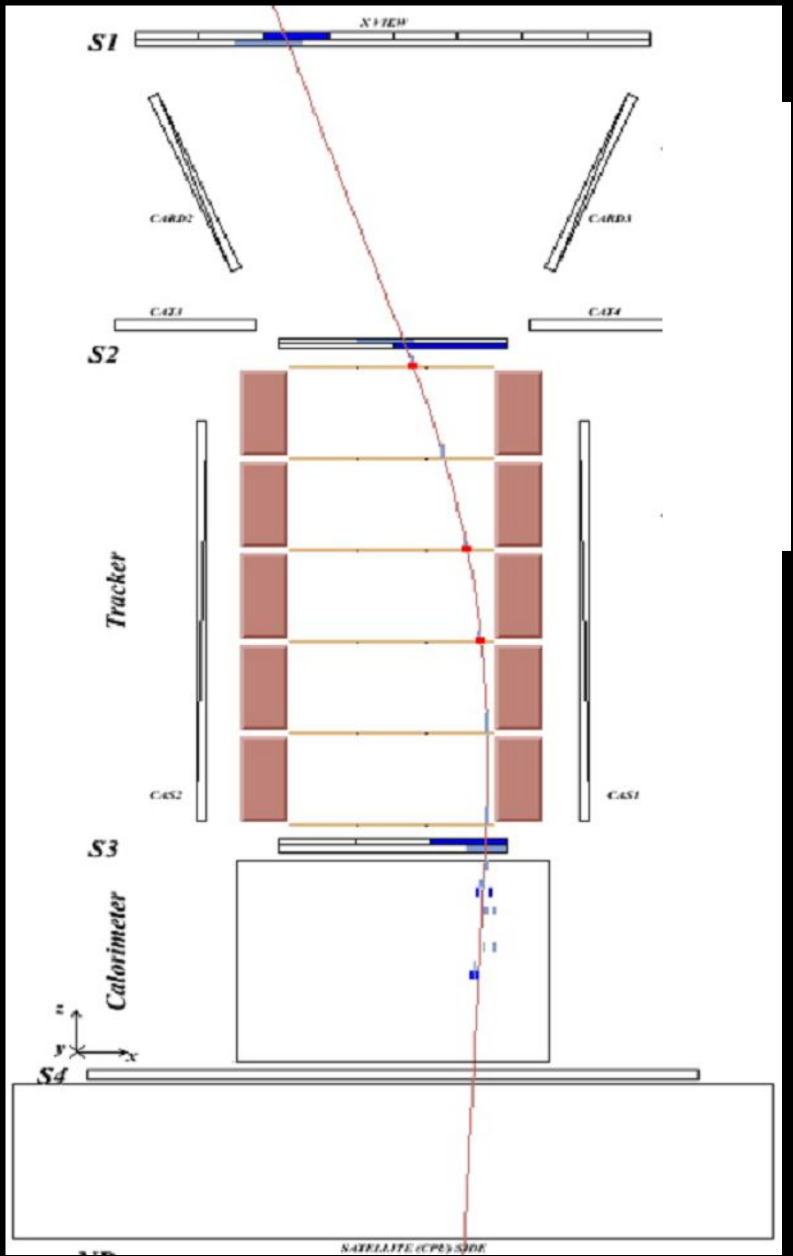
MDR from test beam data ≅ 1 TV

Calorimeter Performances:
- $\bar{p}/e^+$ selection eff. ~ 90%
- p rejection factor ~ 10^5
- e^- rejection factor > 10^4

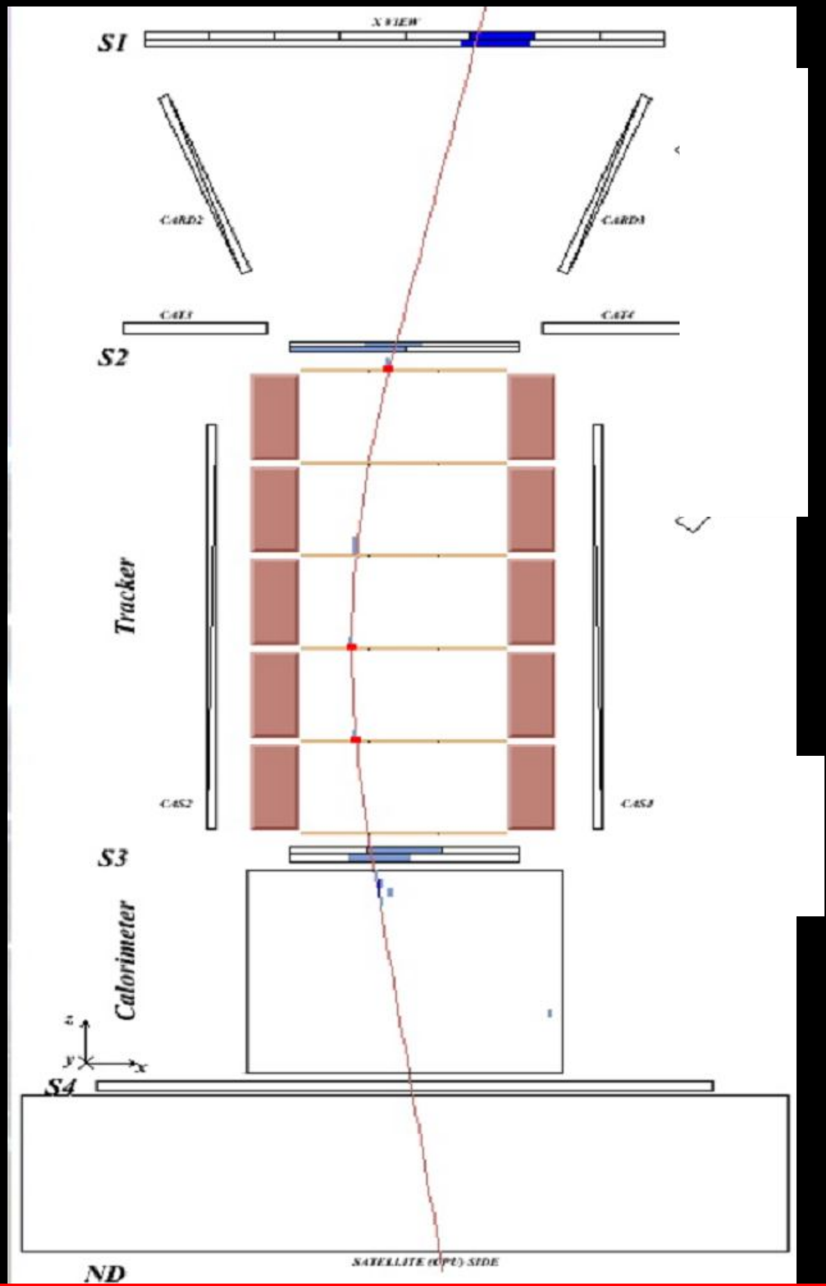
ND p/e separation capabilities >10
above 10 GeV/c, increasing with energy

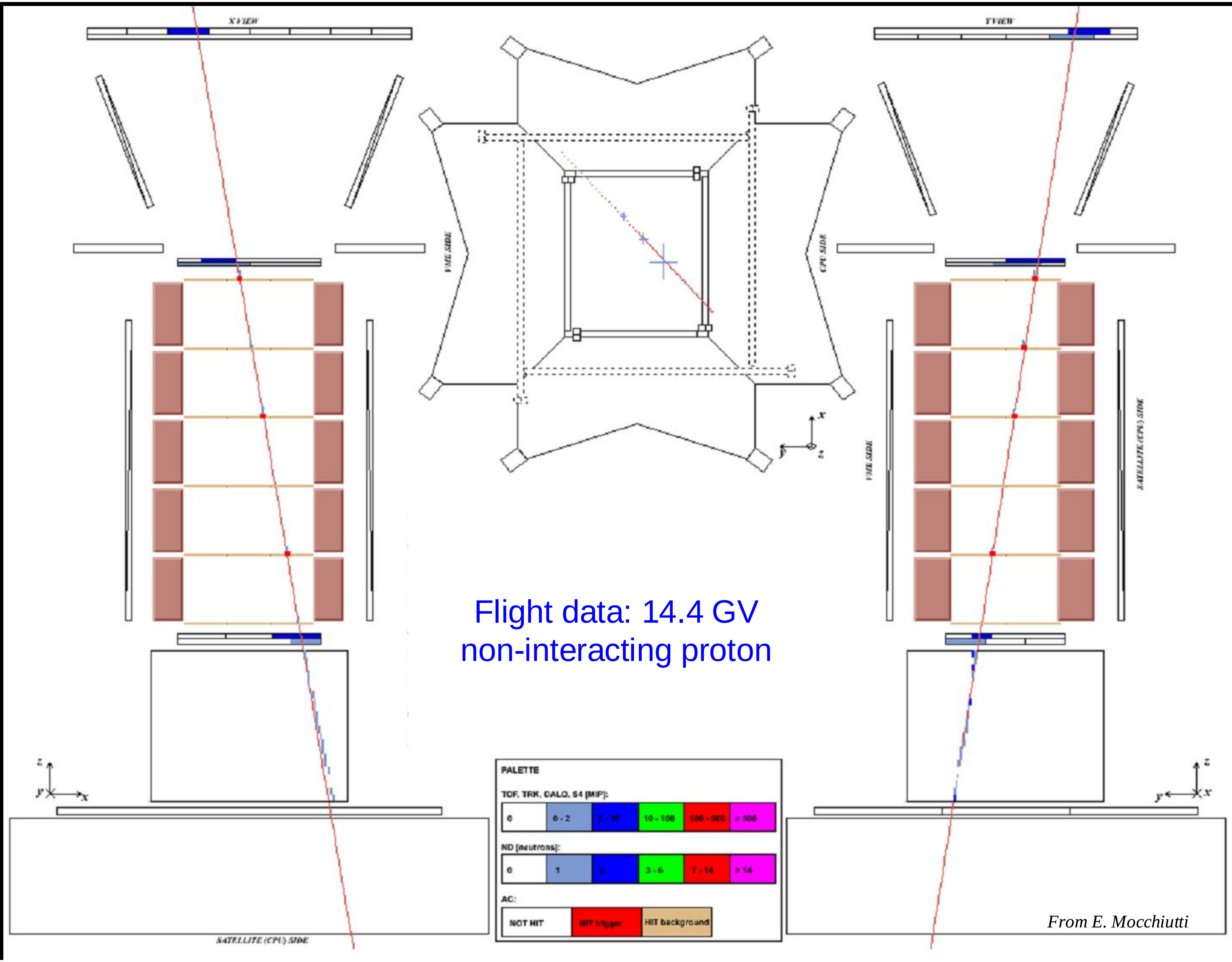
GF ~20.5 cm^2sr
Mass: 470 kg
Size: 120x40x45 cm^3
Power Budget: 360 W

e+ 0.171 GV Bending view



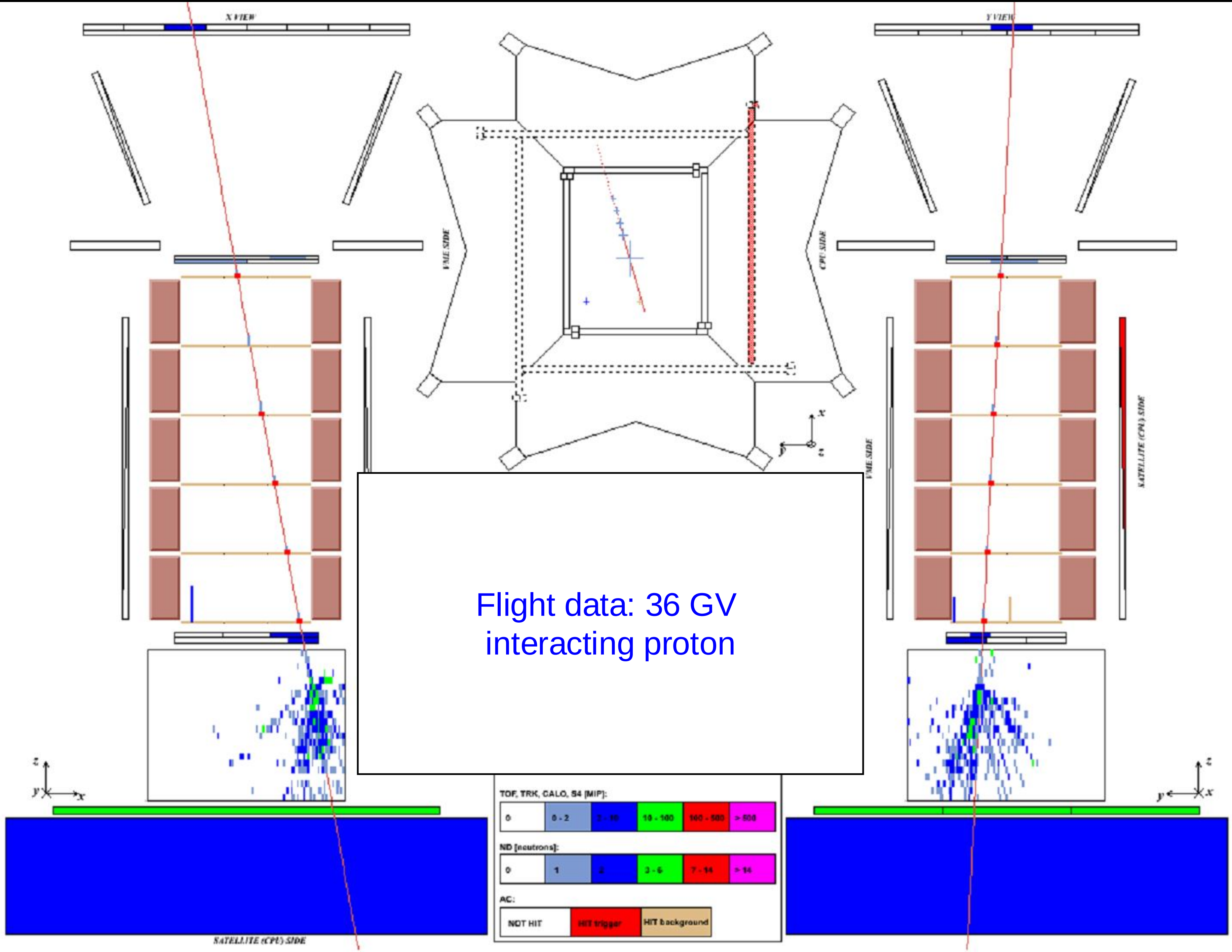
e- 0.169 GV Bending view



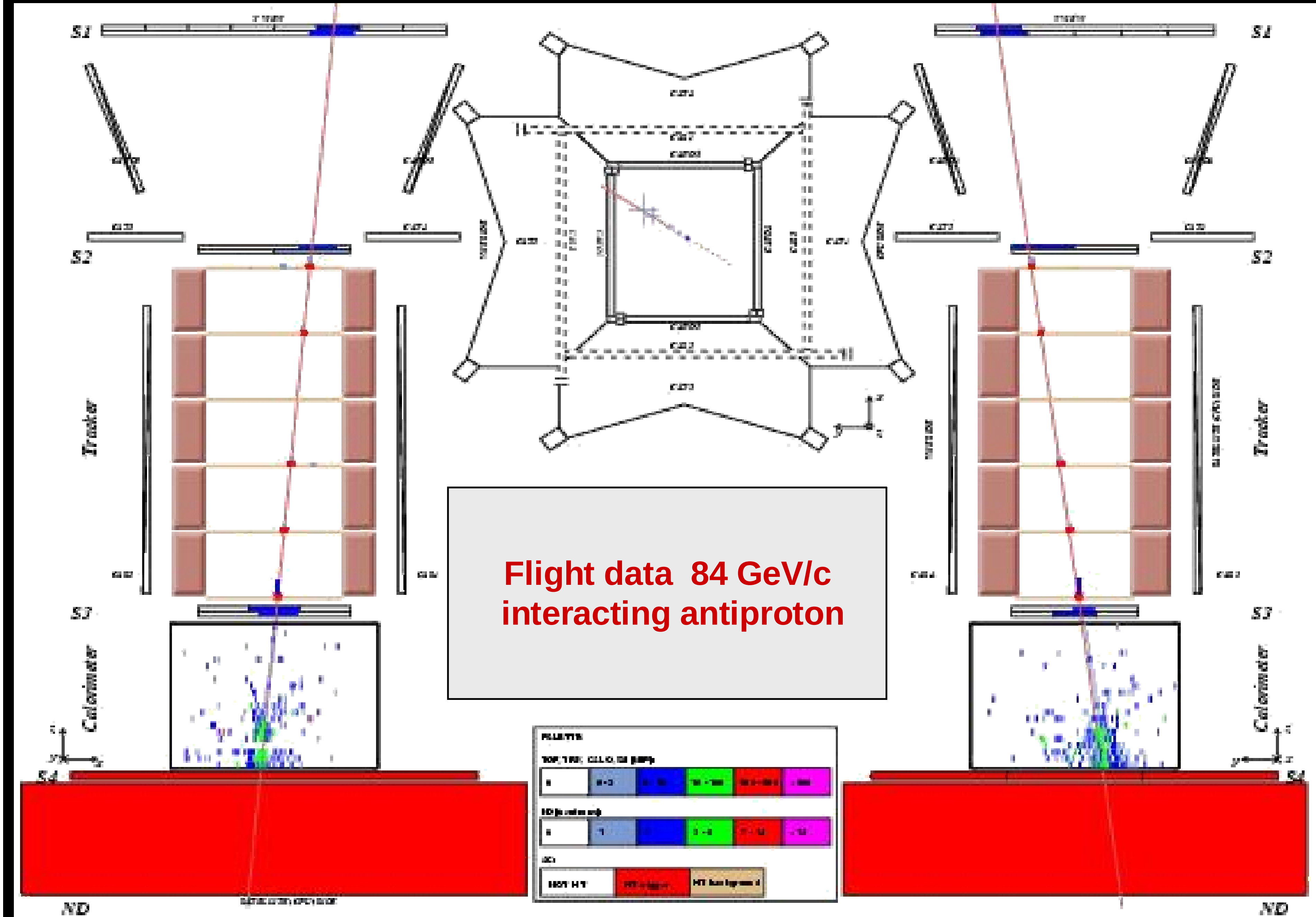


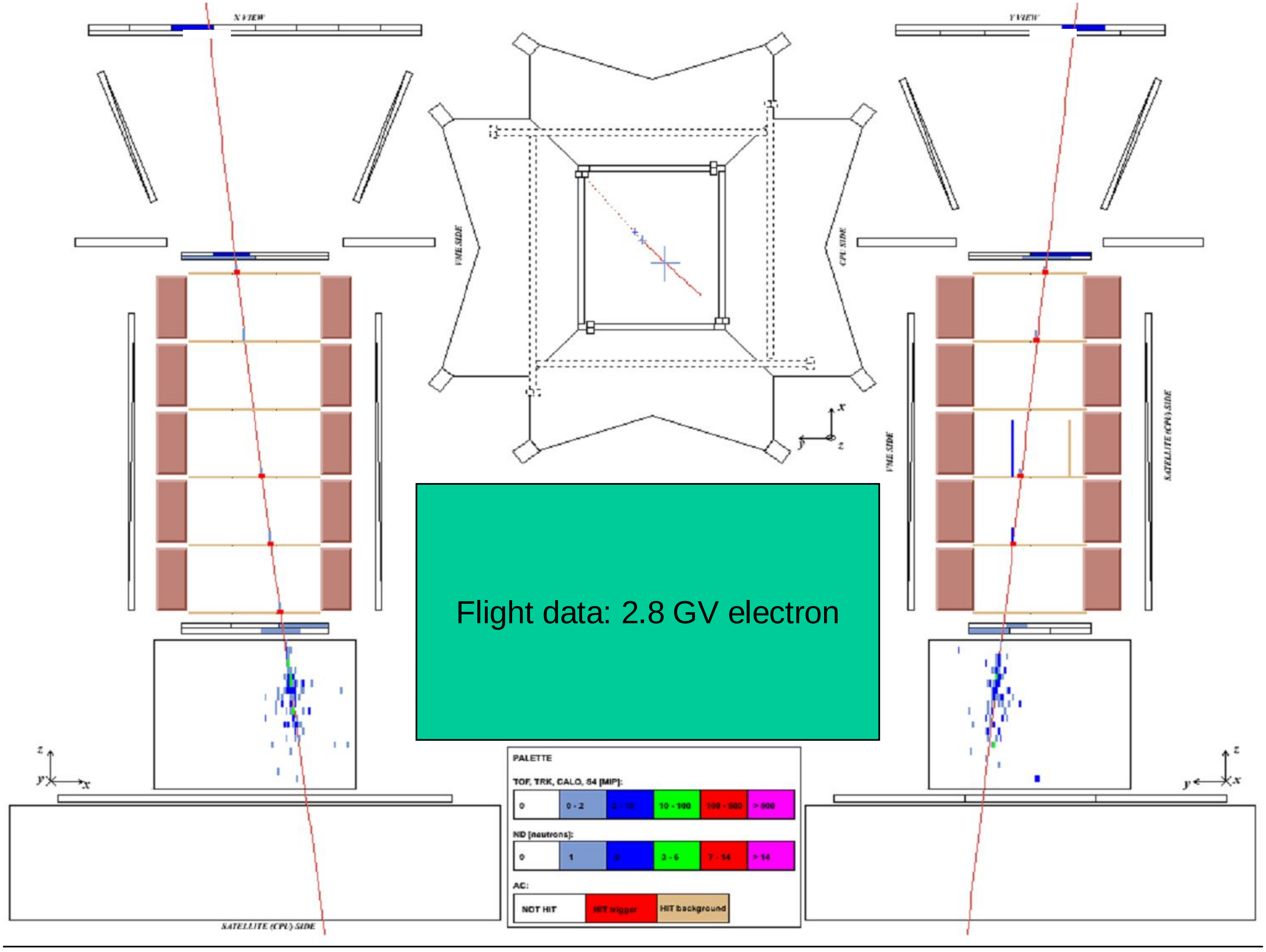
Flight data: 14.4 GV
non-interacting proton

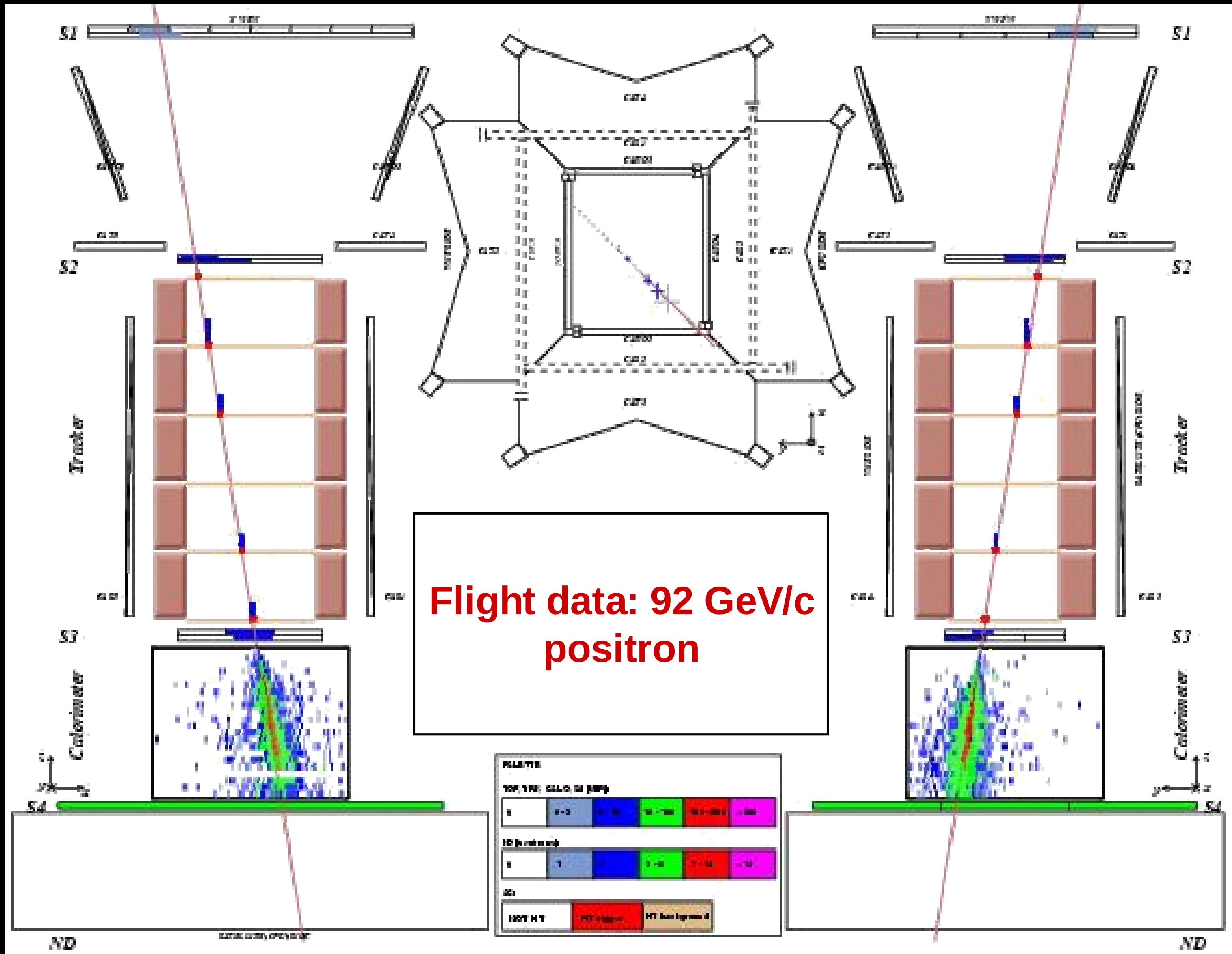
From E. Mocchiutti



Flight data: 36 GV
interacting proton


S1
S2
S3
S4
ND
Tracker
Calorimeter
Flight data 84 GeV/c
interacting antiproton


X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
Flight data: 2.8 GV electron
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background

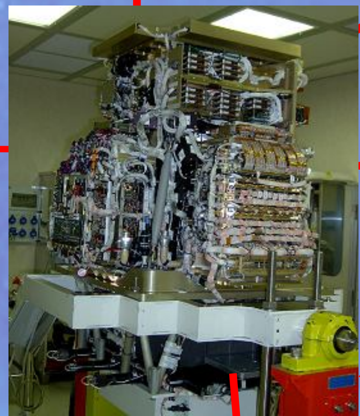


Flight data: 92 GeV/c positron

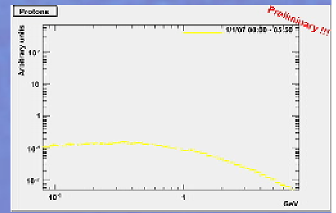
Pamela as a Space observatory at 1AU

High Inclination Orbit 70.0º

Galactic cosmic ray
Matter / Antimatter
/ Dark Matter

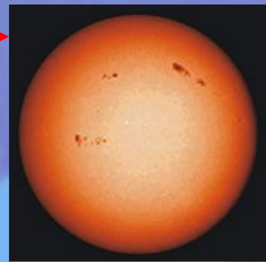


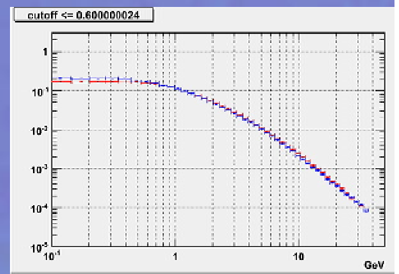
Solar Energetic particles



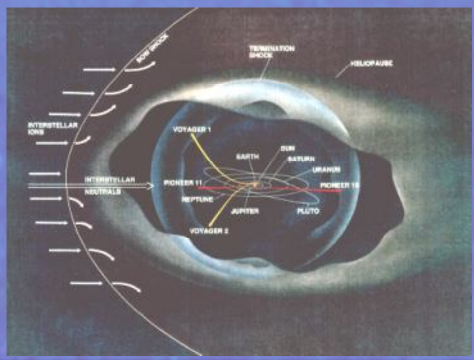
Jovian electrons

Solar Modulation

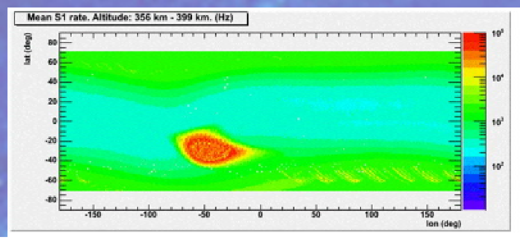




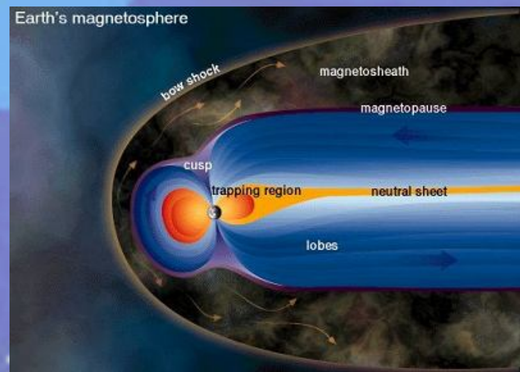
Interplanetary Physics,
Solar Wind Termination Shock



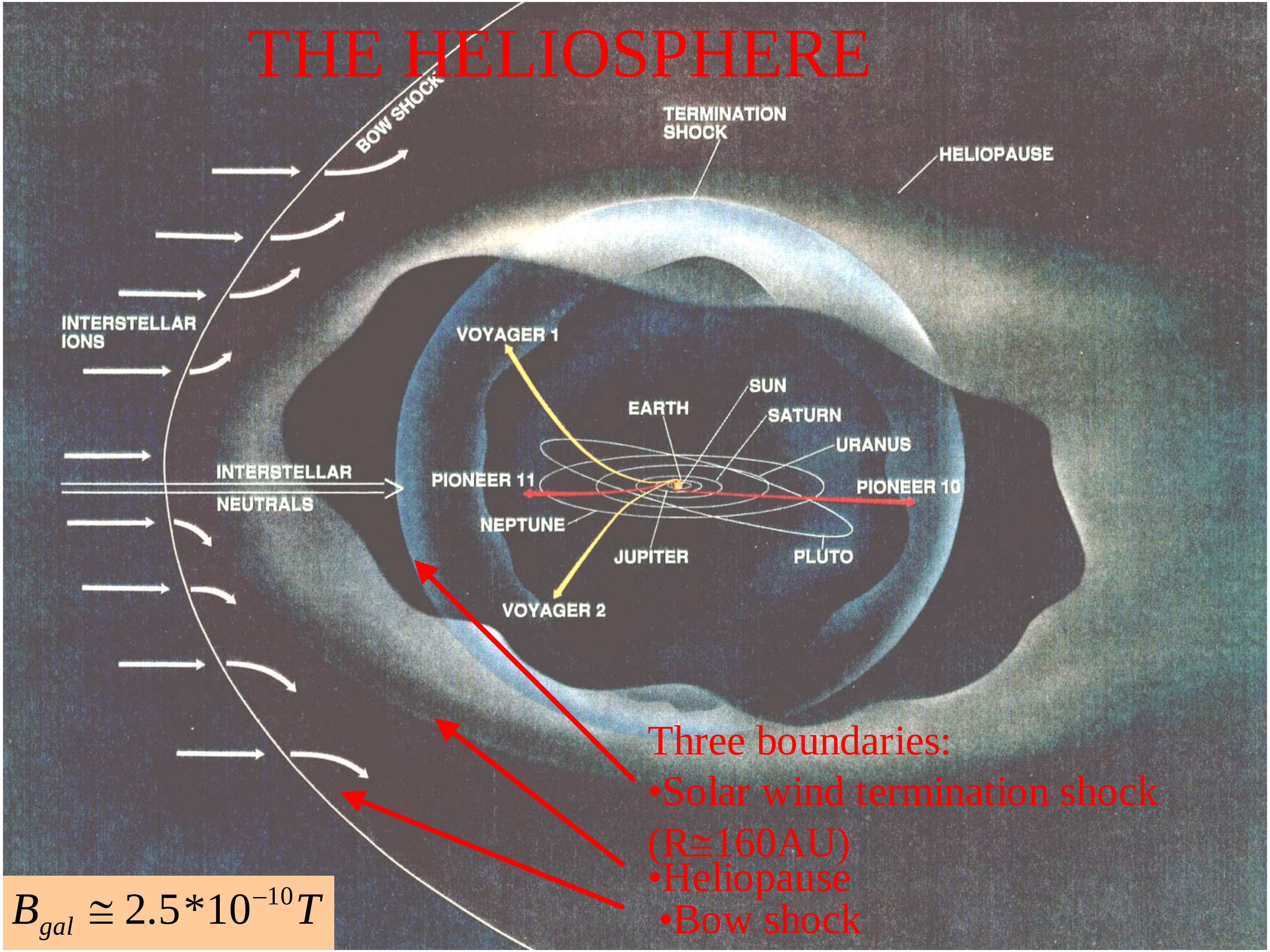
SAA, Albedo,
secondary particle



Magnetospheric physics



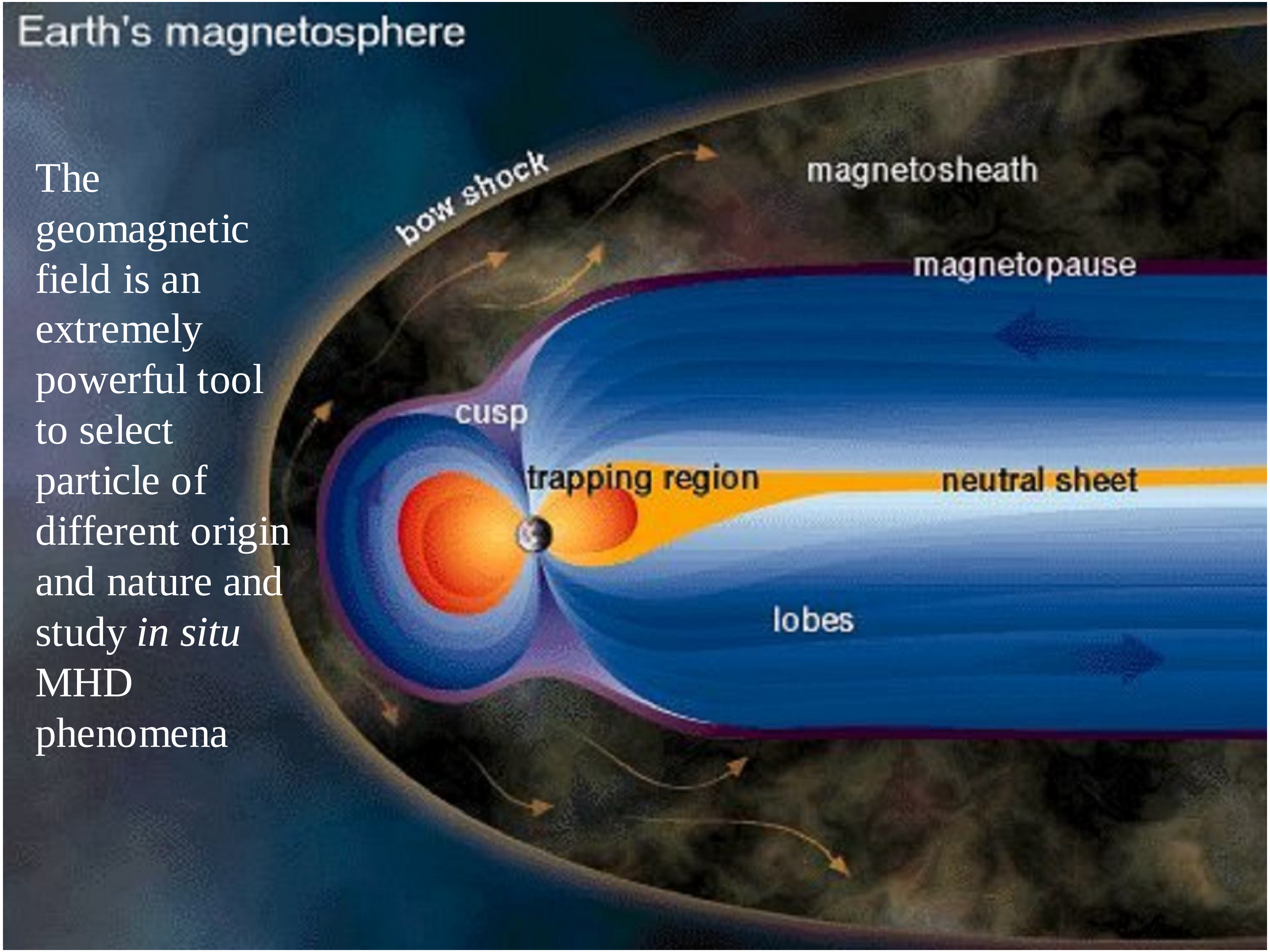
THE HELIOSPHERE



Three boundaries:

- Solar wind termination shock (R≅160AU)
- Heliopause
- Bow shock

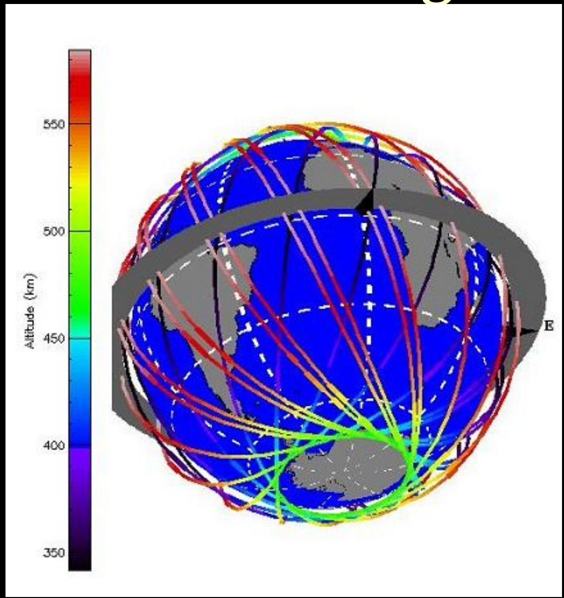
$B_{gal} \cong 2.5*10^{-10}T$

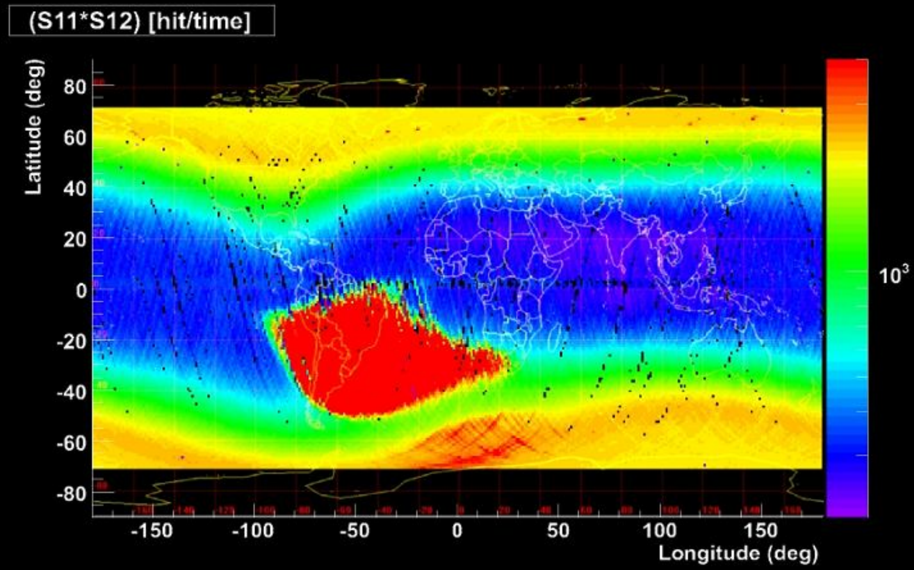


The geomagnetic field is an extremely powerful tool to select particle of different origin and nature and study *in situ* MHD phenomena

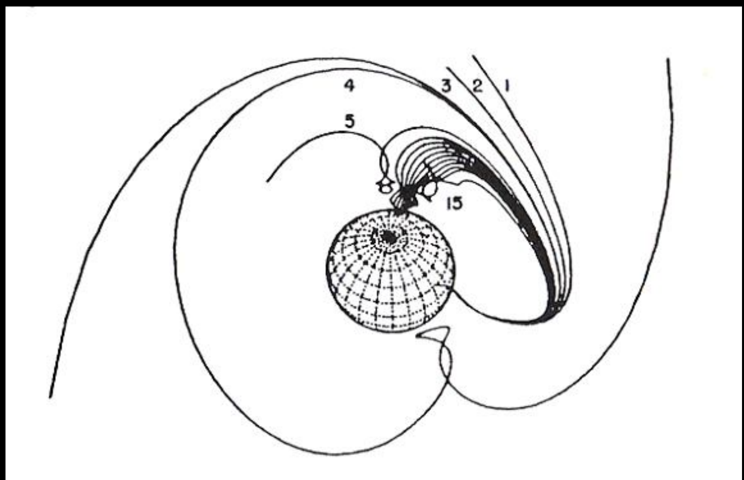
http://www.youtube.com/watch?v=OaoiPw5Pqbg

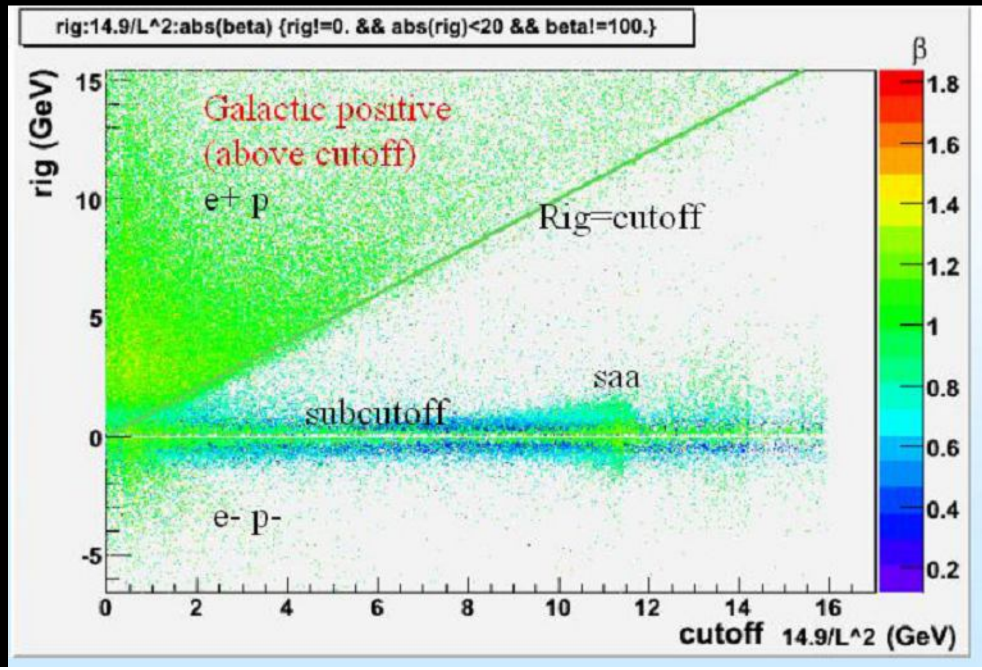
Selection of galactic component according to geomagnetic cutoff





R_{cutoff}=14.9GV/L^2





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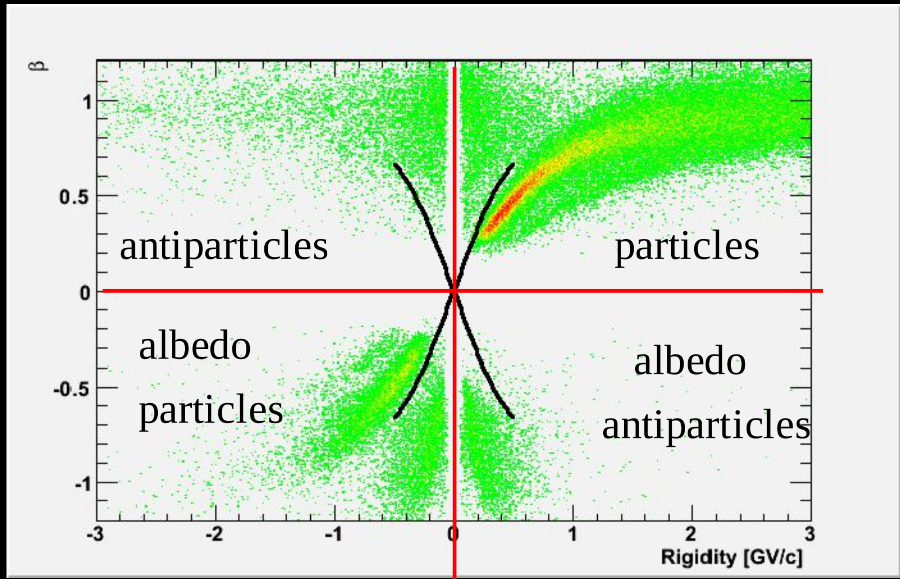
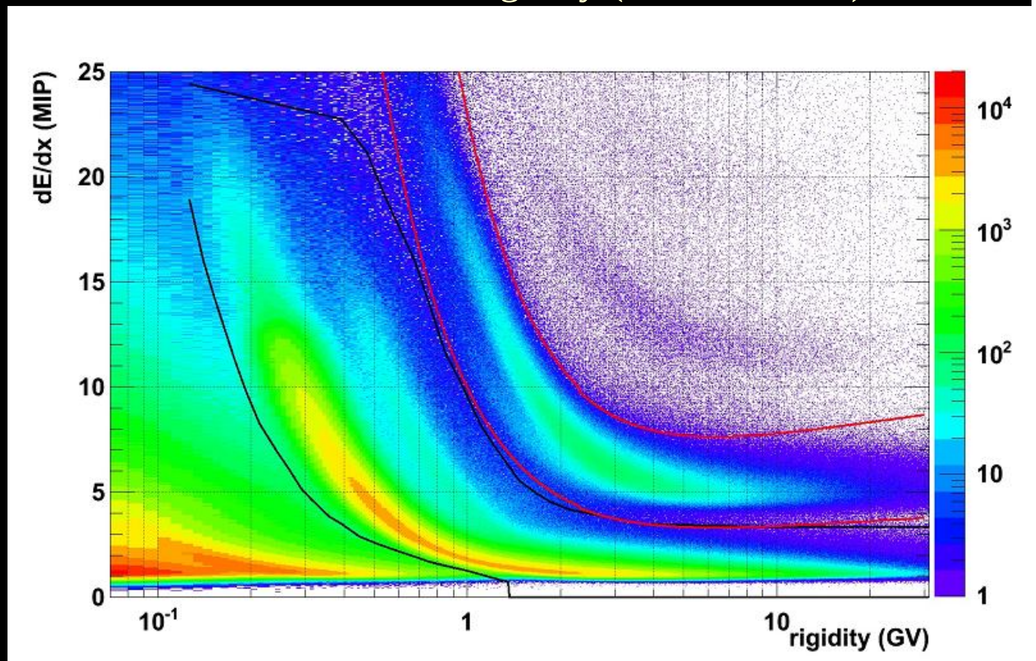
Proton and Helium Absolute flux

- **Montecarlo efficency for cuts**
- **Trigger efficiency**
- **Tracking efficiency**
- **Multiple Scattering**
- **Correction for energy loss in det**
- **Back scattering…**
- **Systematics under close investigation, currently about 1-2% uncertainty on abs flux.**

Selection criteria

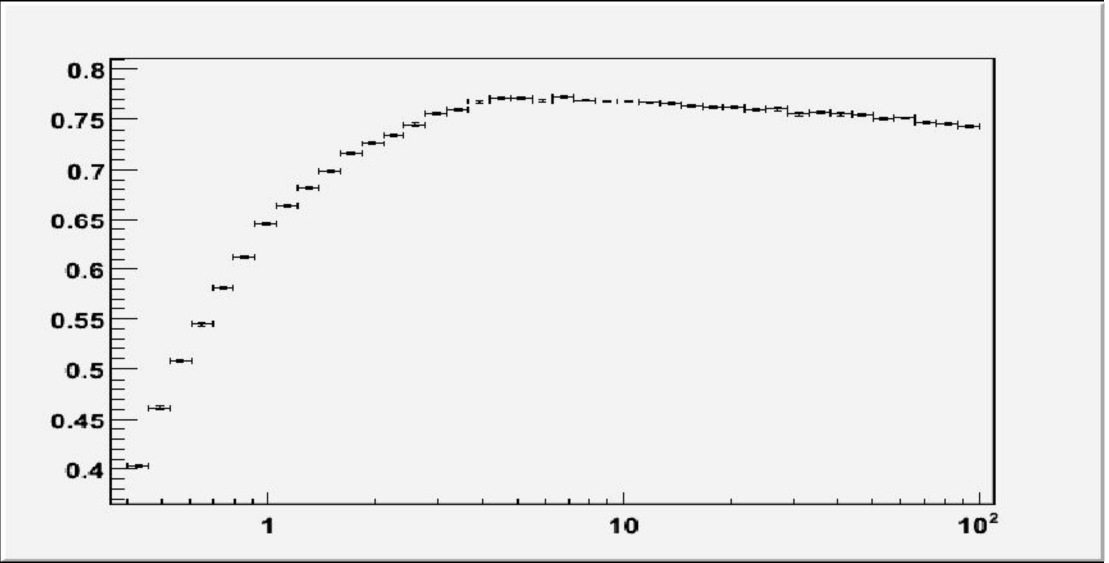
Fitted, single track
High lever arm, Nx
Rigidity R>0
Beta>.2
No anti



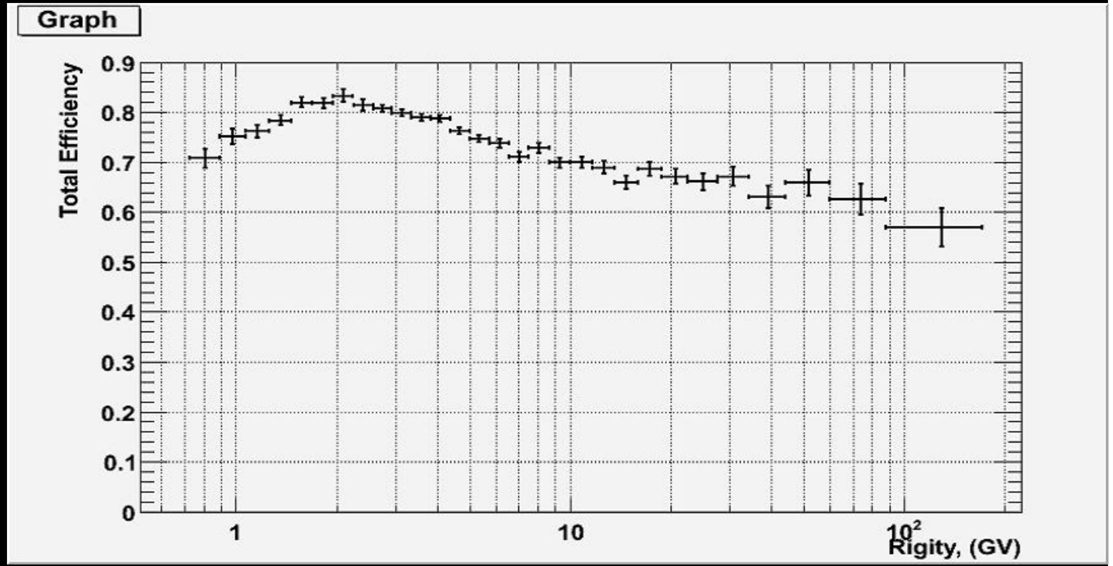


Efficiencies

P



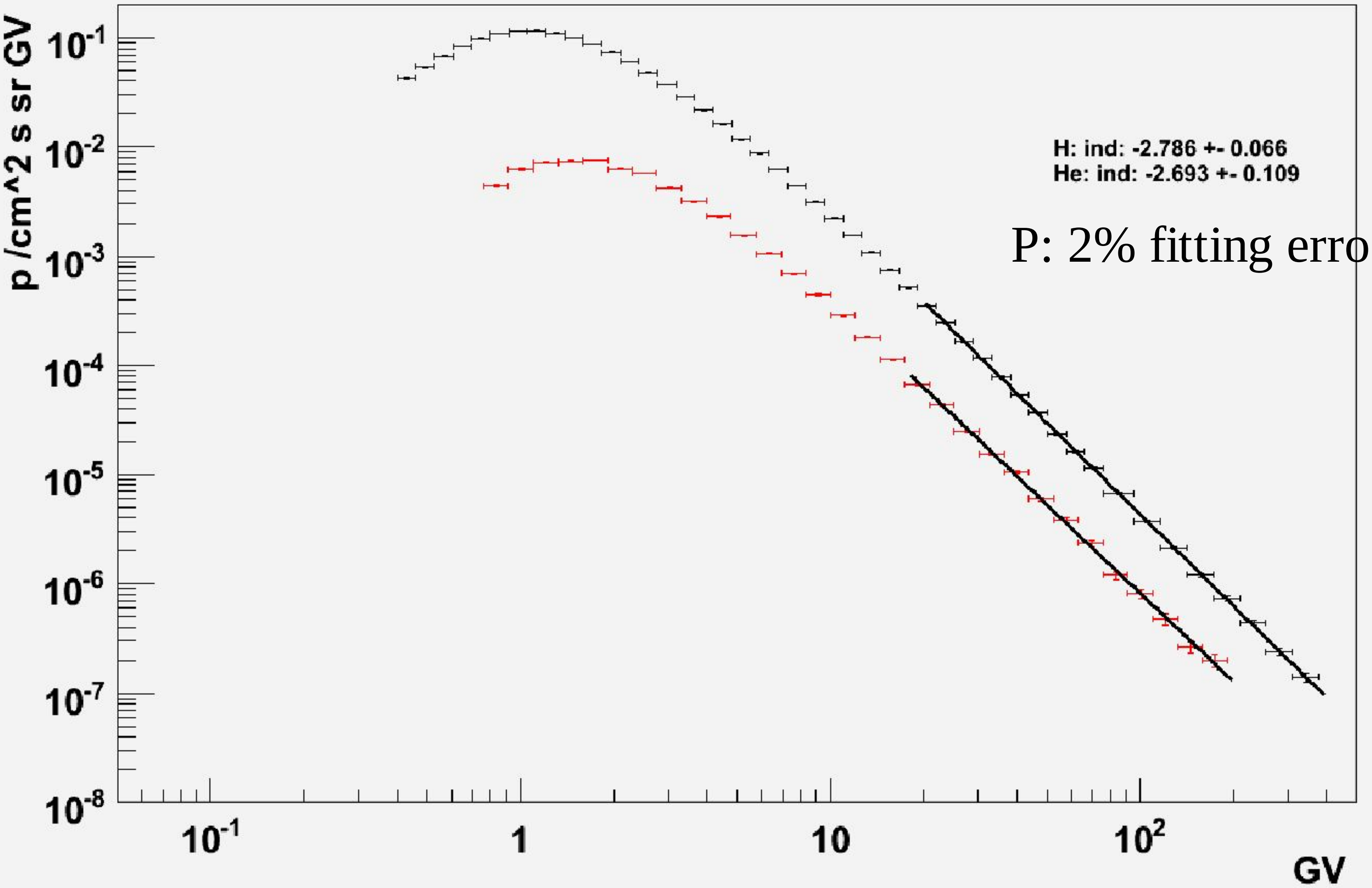
He



estimated with MC
experimental data

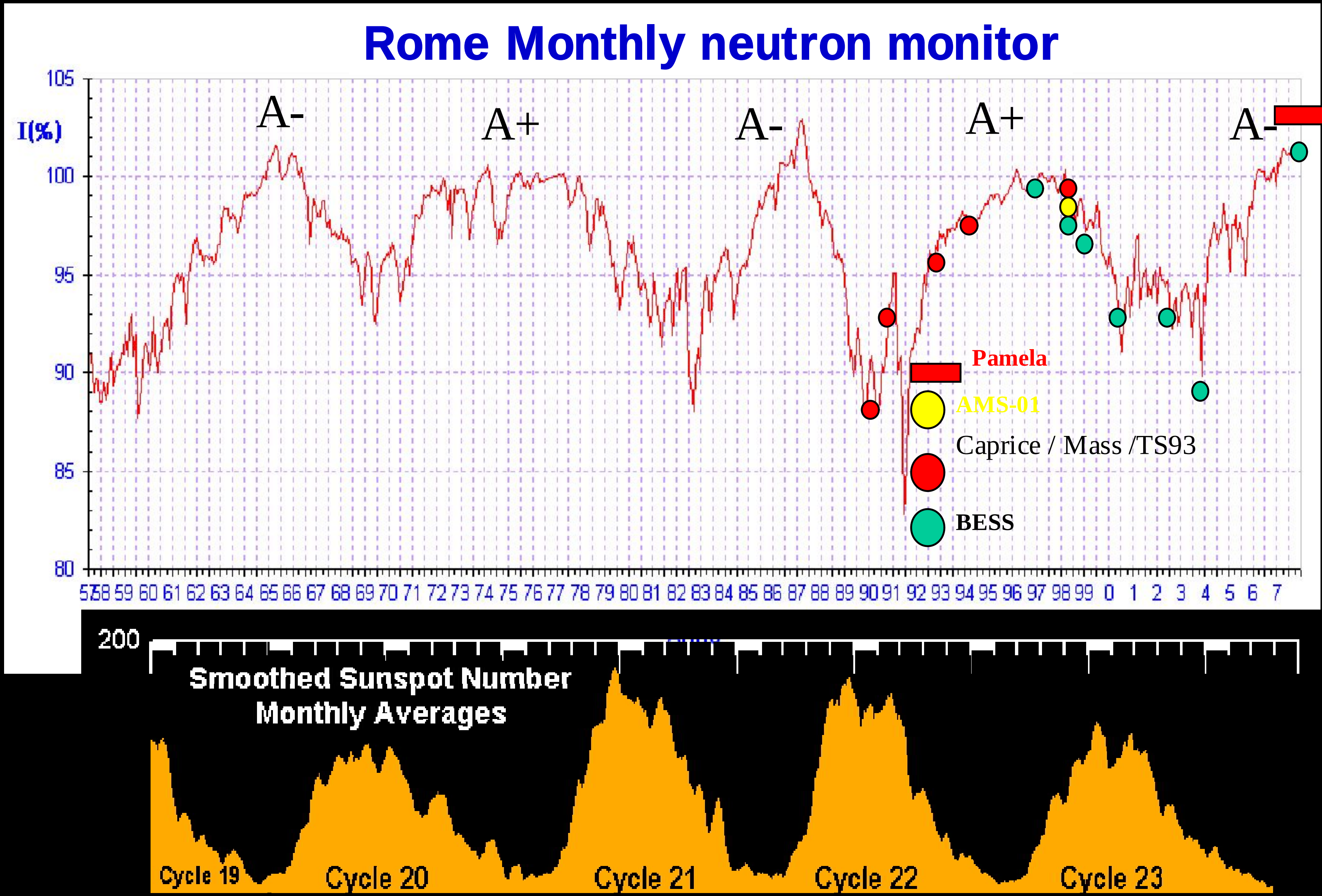
Proton and Helium spectra, rigidity Jul 2006

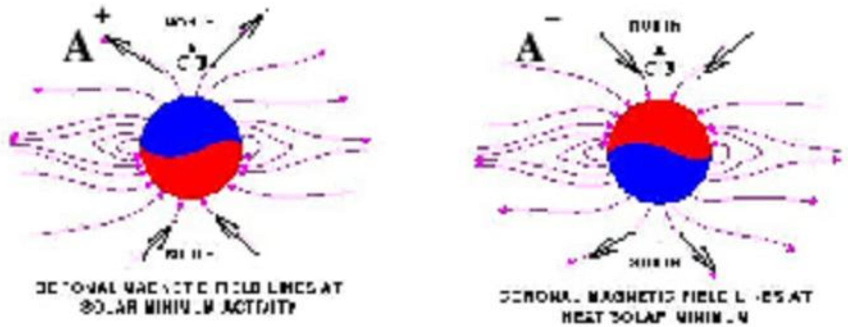
preliminary

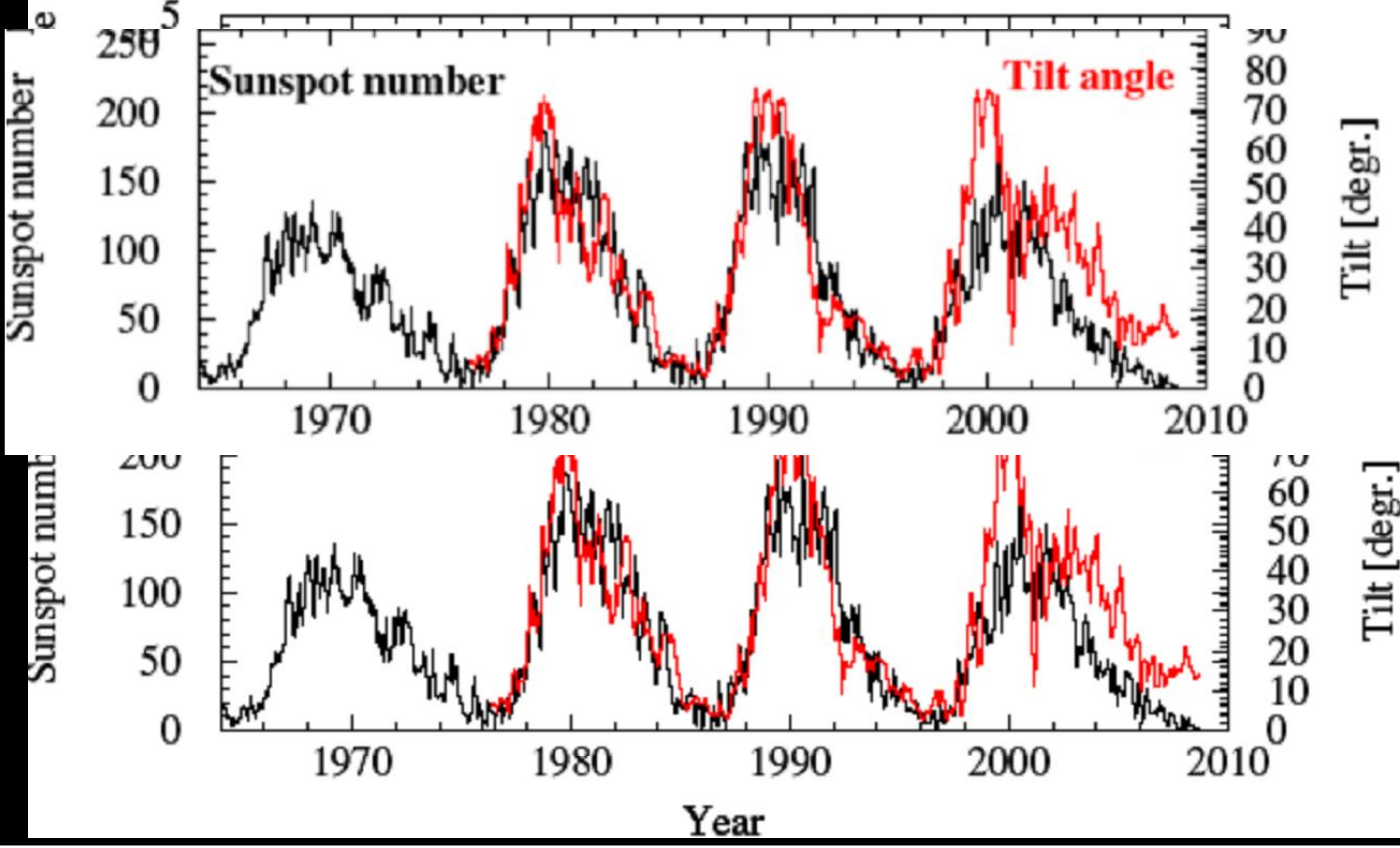


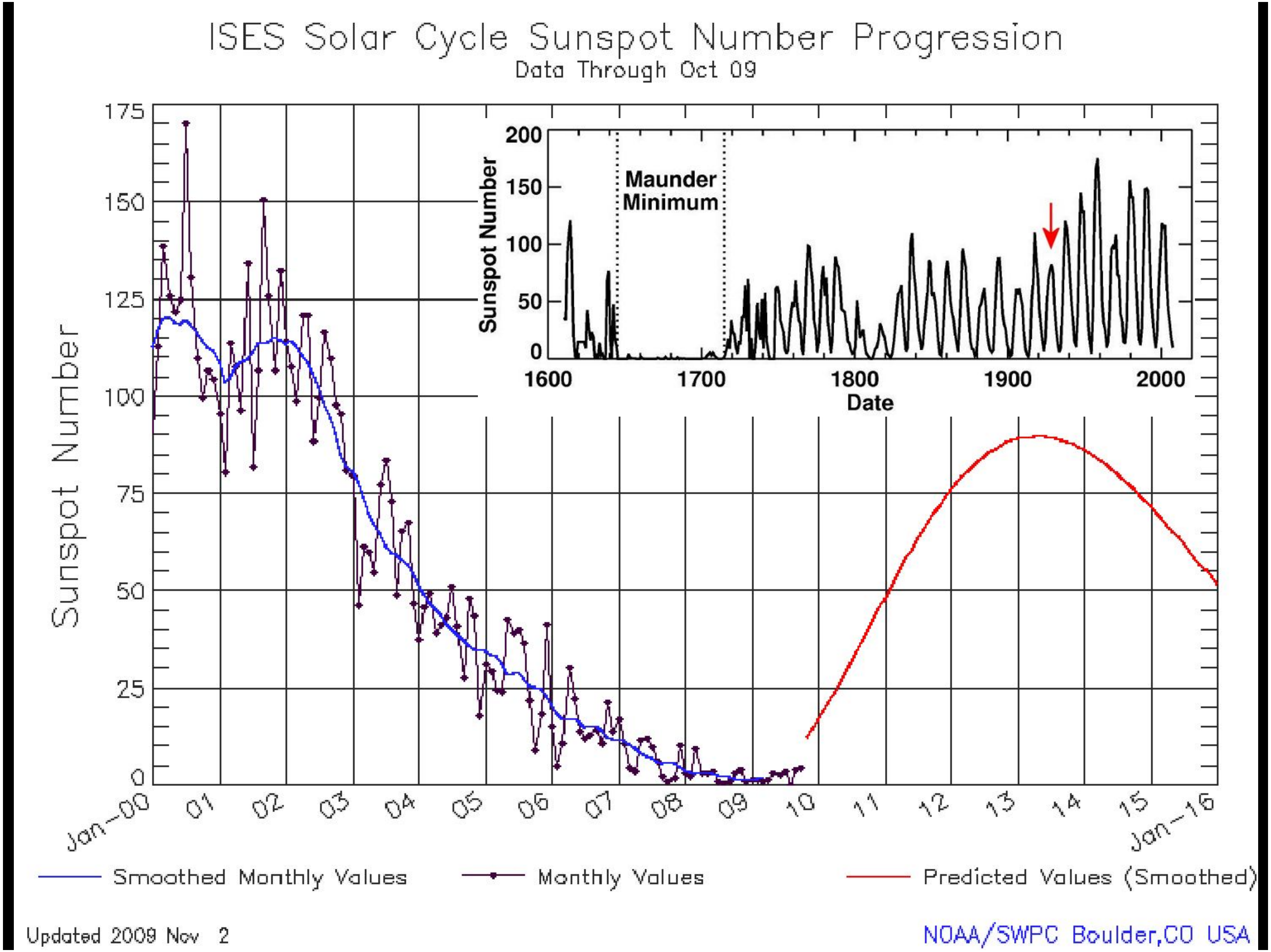
P: 2% fitting error

Solar modulation at minimum of solar cycle XXIII years 2006-2008



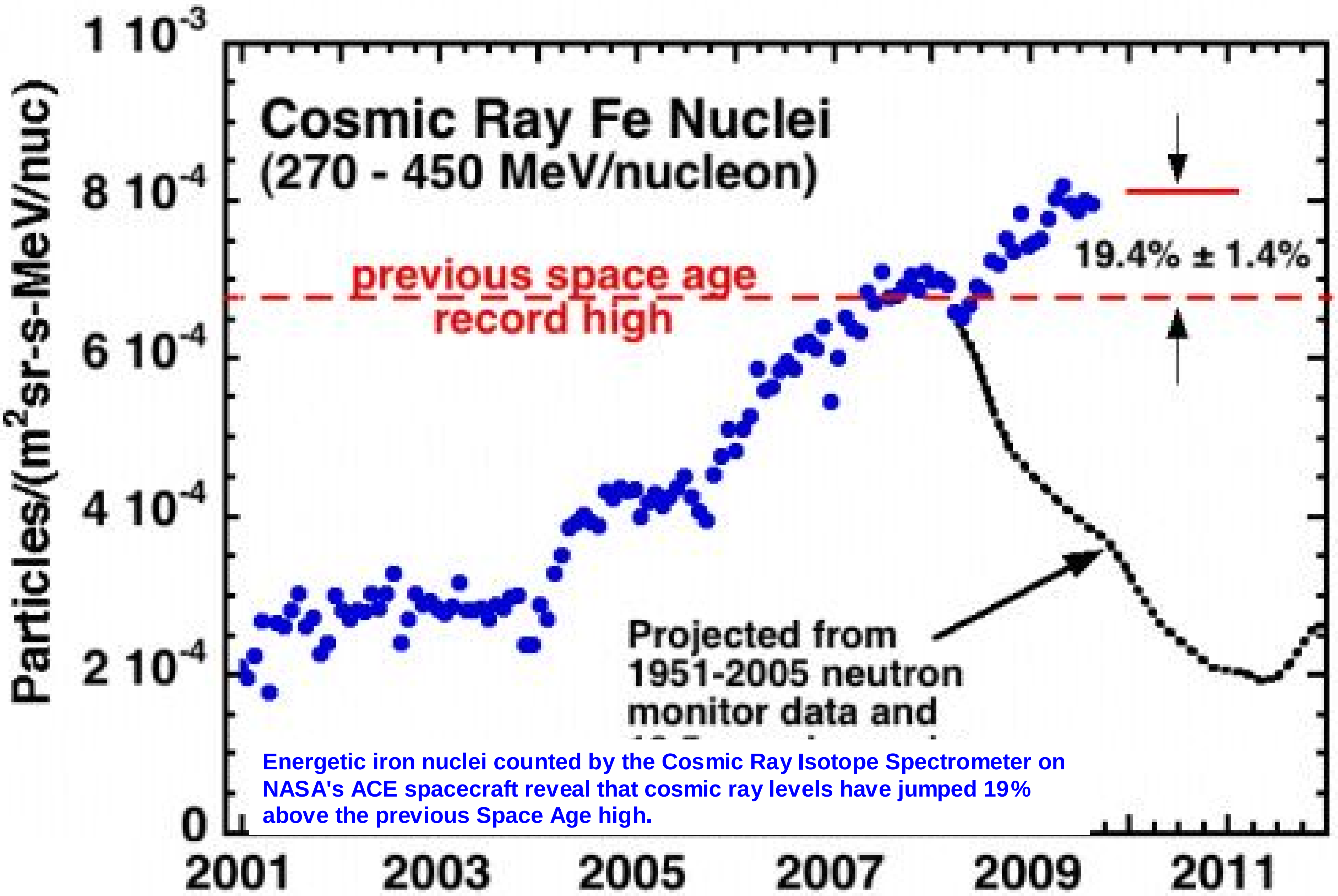

A+
A−


Sunspot number
Tilt angle
Sunspot number
Tilt [degr.]
Year

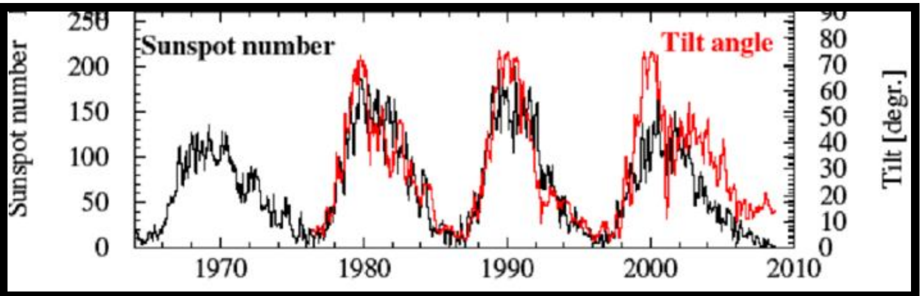


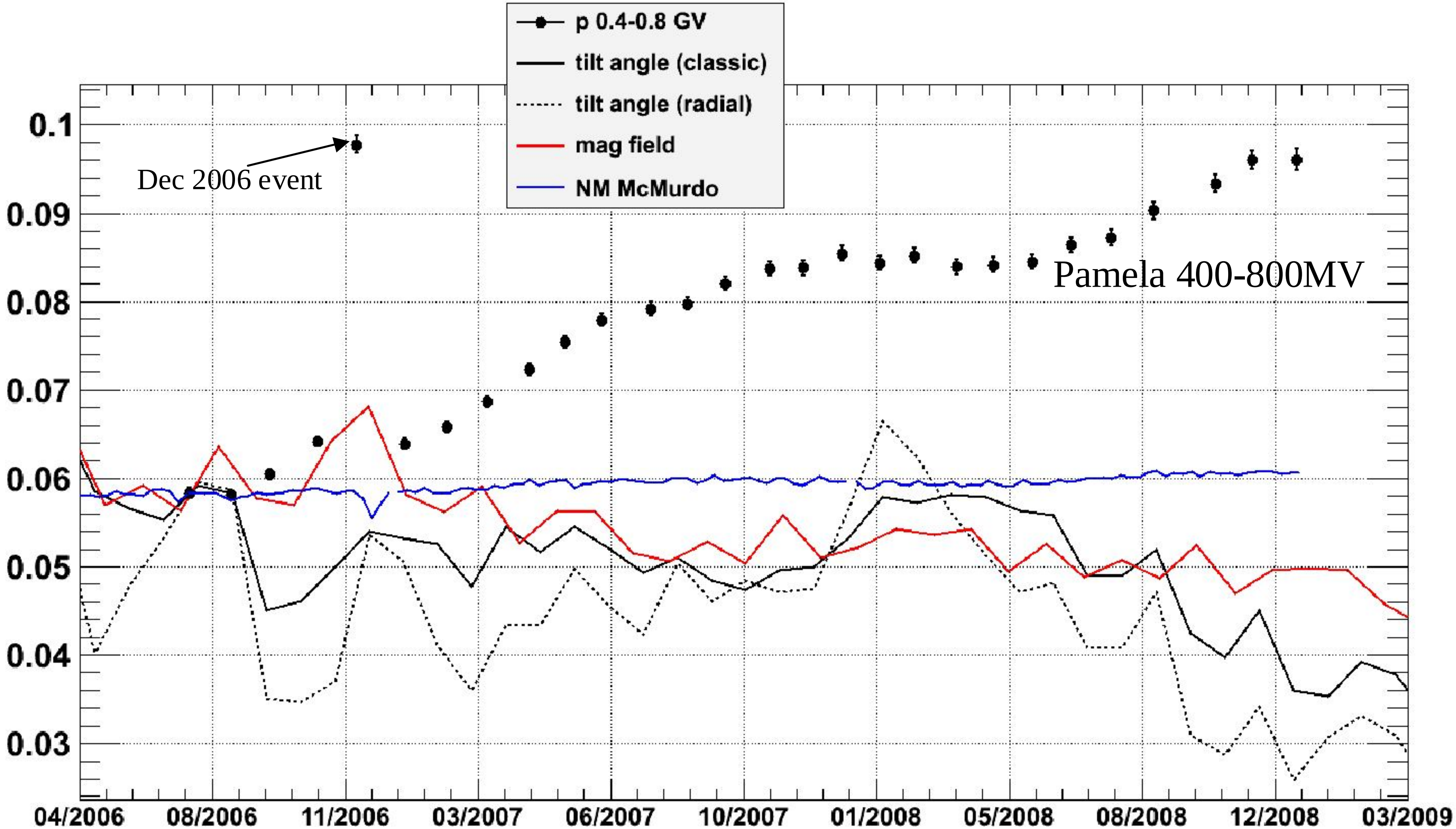
ISES Solar Cycle Sunspot Number Progression
Data Through Oct 09
Sunspot Number
175
150
125
100
75
50
25
0
Jan-00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
Jan-16
Sunspot Number
200
150
100
50
0
Maunder Minimum
1600
1700
1800
1900
2000
Date
Smoothed Monthly Values
Monthly Values
Predicted Values (Smoothed)
Updated 2009 Nov 2
NOAA/SWPC Boulder,CO USA

Low Solar Activity → high particle flux

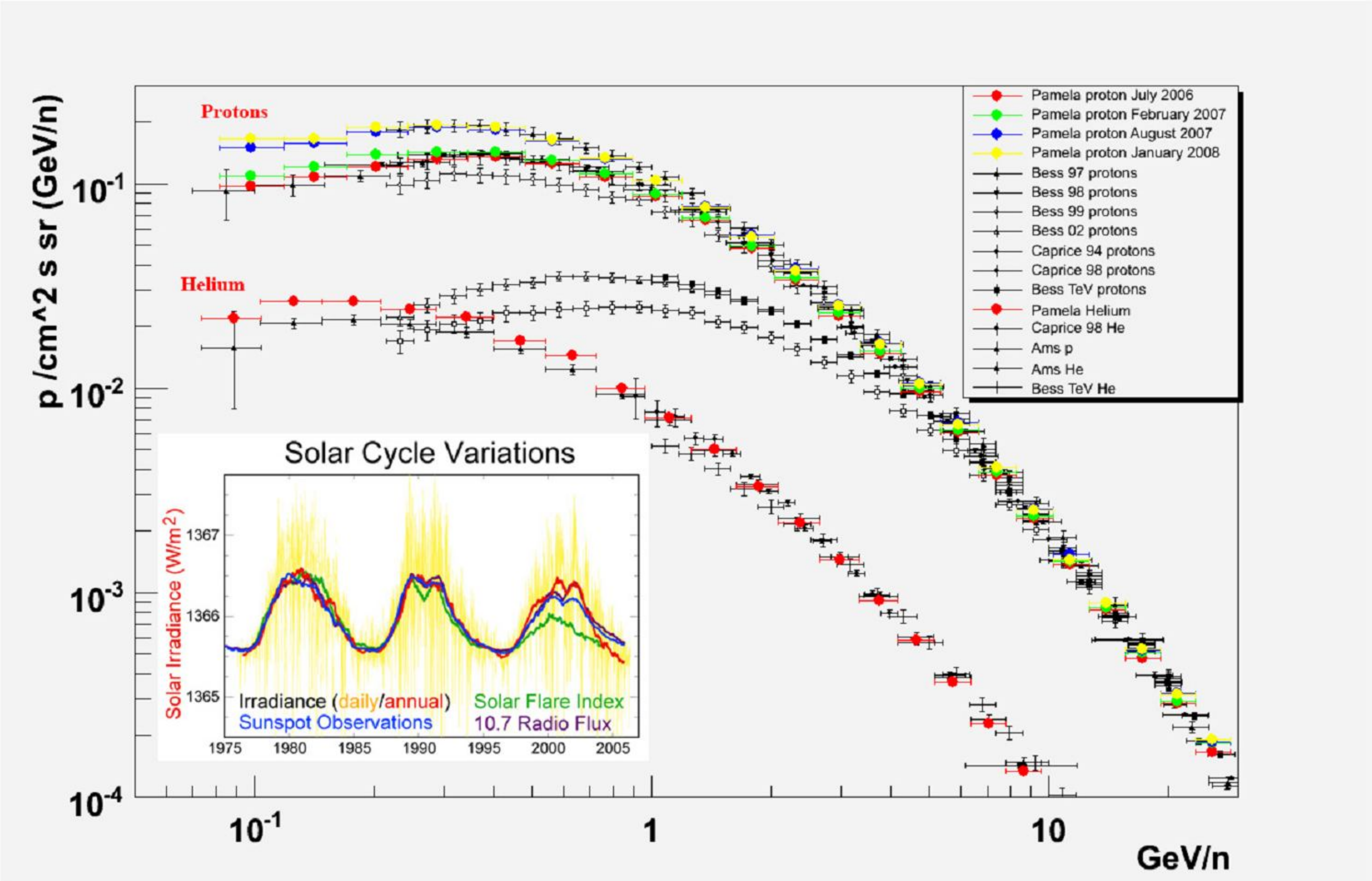


Time evolution of Pamela low energy proton flux





Solar modulation is effective below 10 GeV



Solar modulation at minimum of solar cycle XXIII years 2006-2008

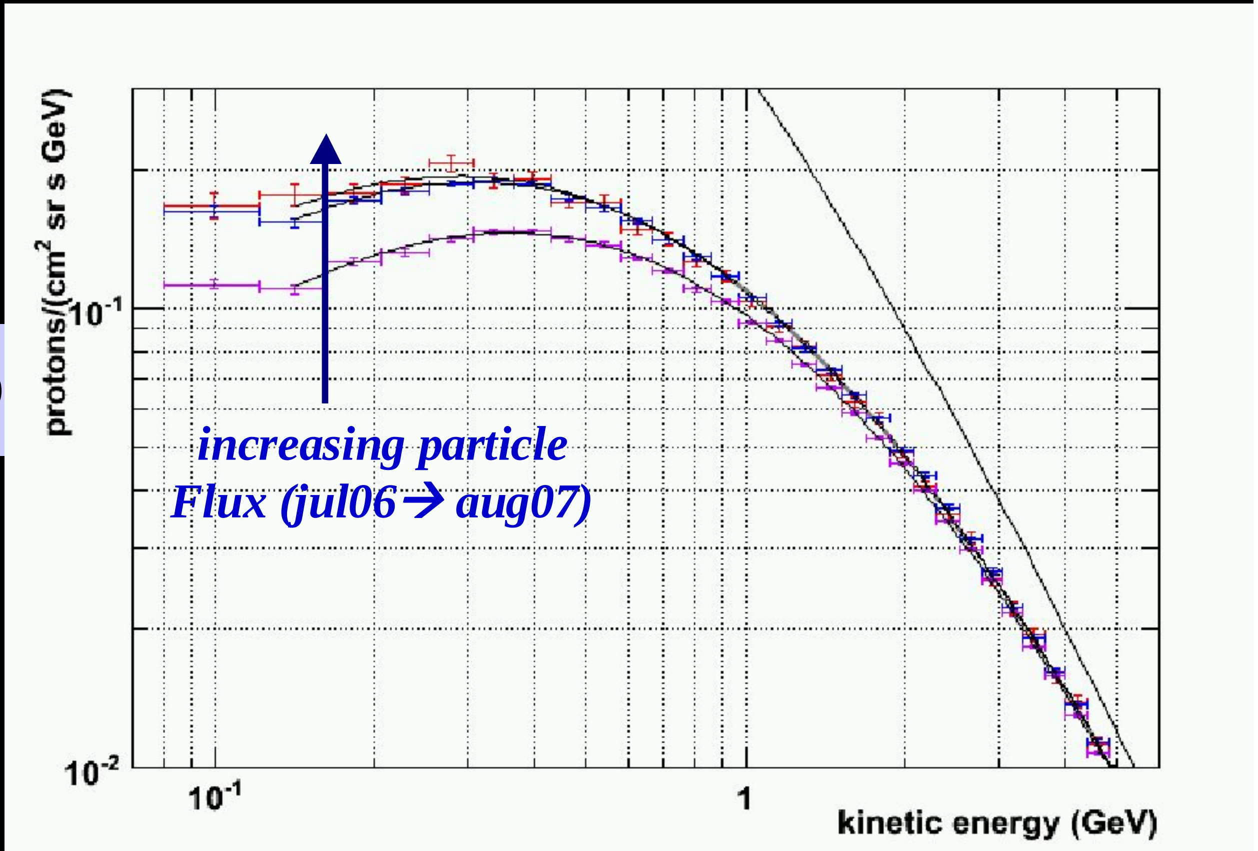
$F_{is} = 1.54\, \beta_{is}^{0.7}\, R_{is}^{-2.76}$

p/(cm² s sr GV)

Spectral index

2.76 ±0.01

$$J(r,E,t) = \frac{E^2 - E_0^2}{(E^2 + \Phi(t))^2 - E_0^2} J(\infty, E + \Phi(t))$$



Solar modulation parameter

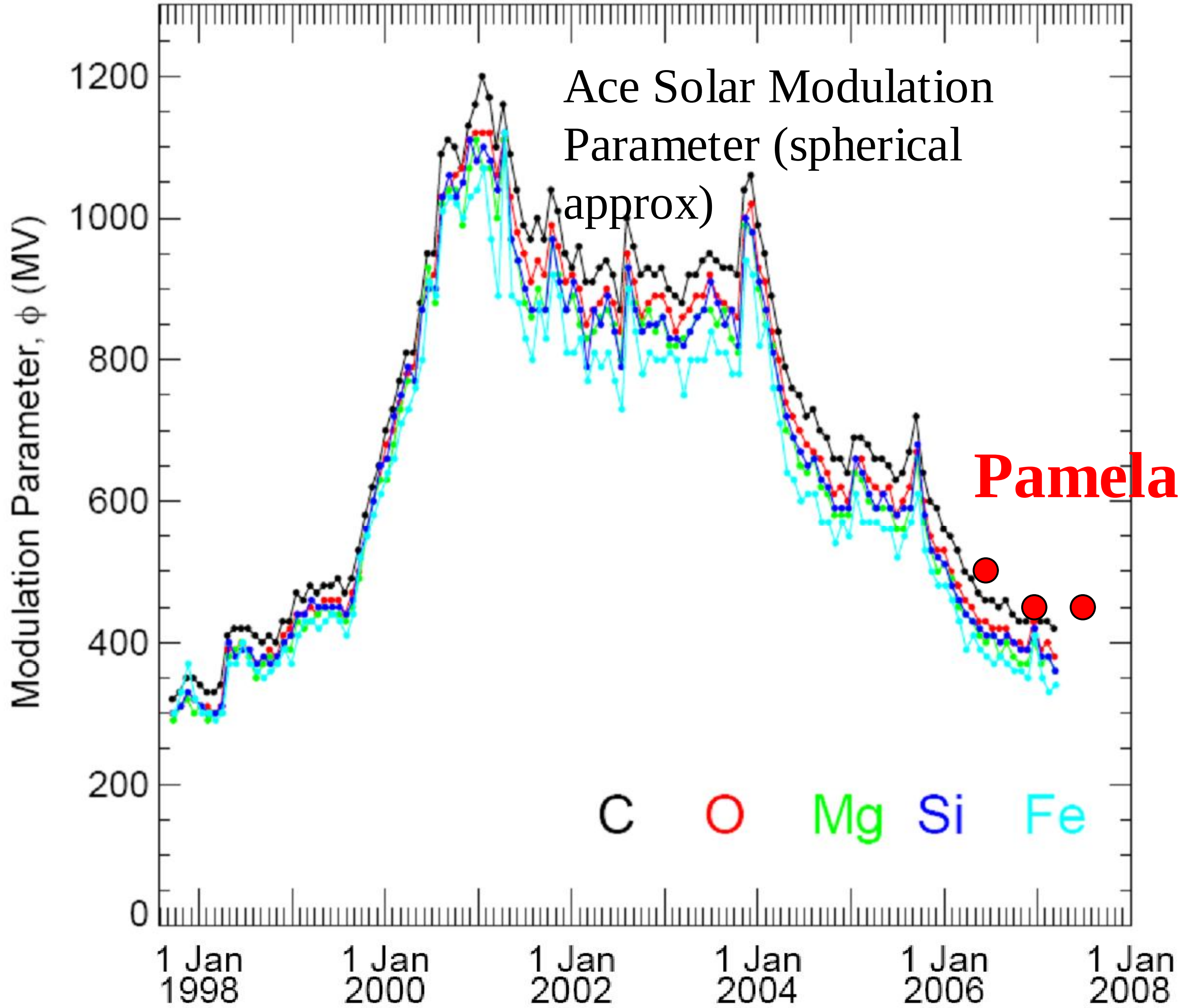
ϕ(GV)

JUL06 5.01-01 ± 2e-03

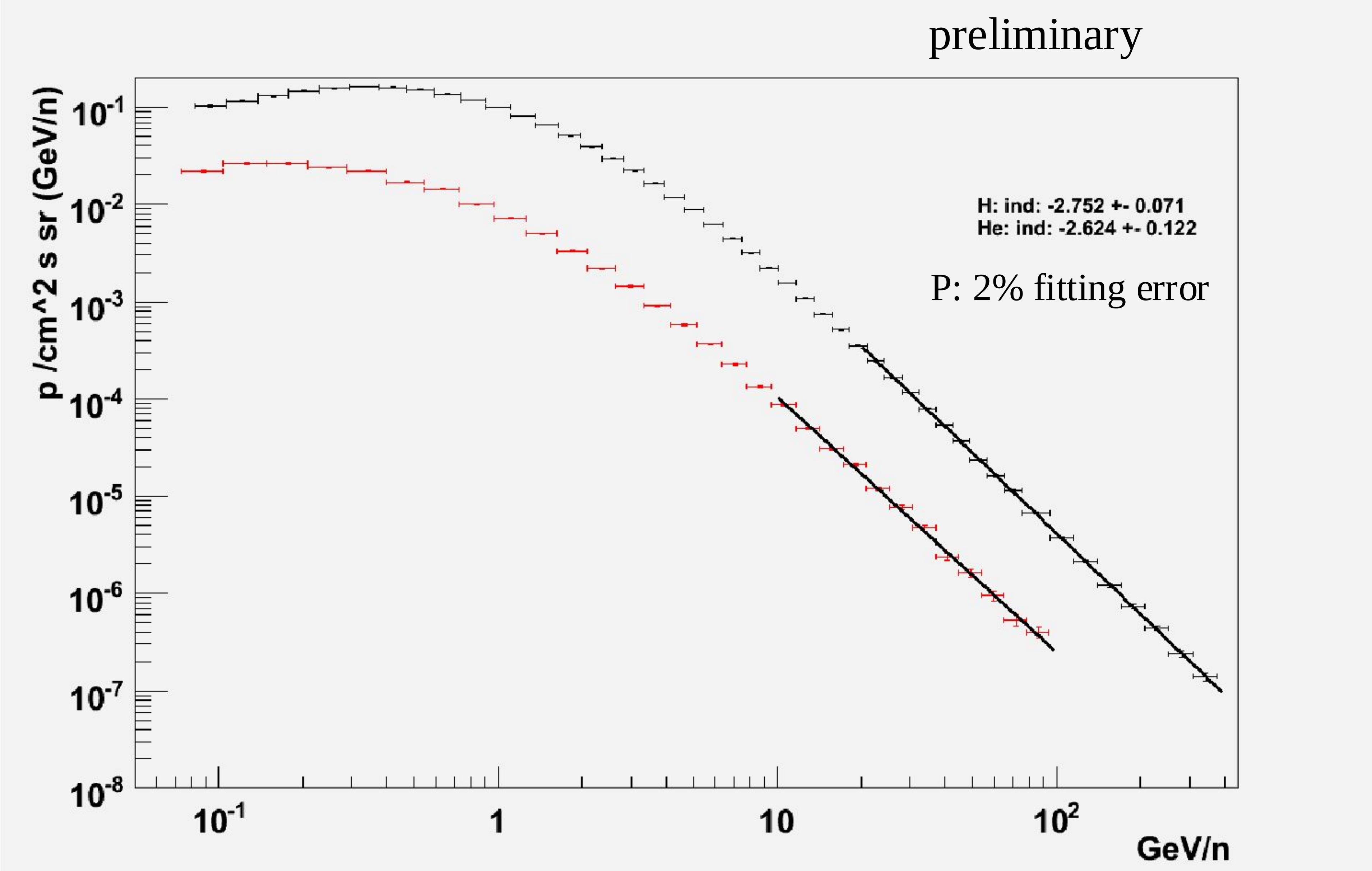
JAN07 4.16-01 ± 2-03

AUG07 4.02-01 ± 3-03

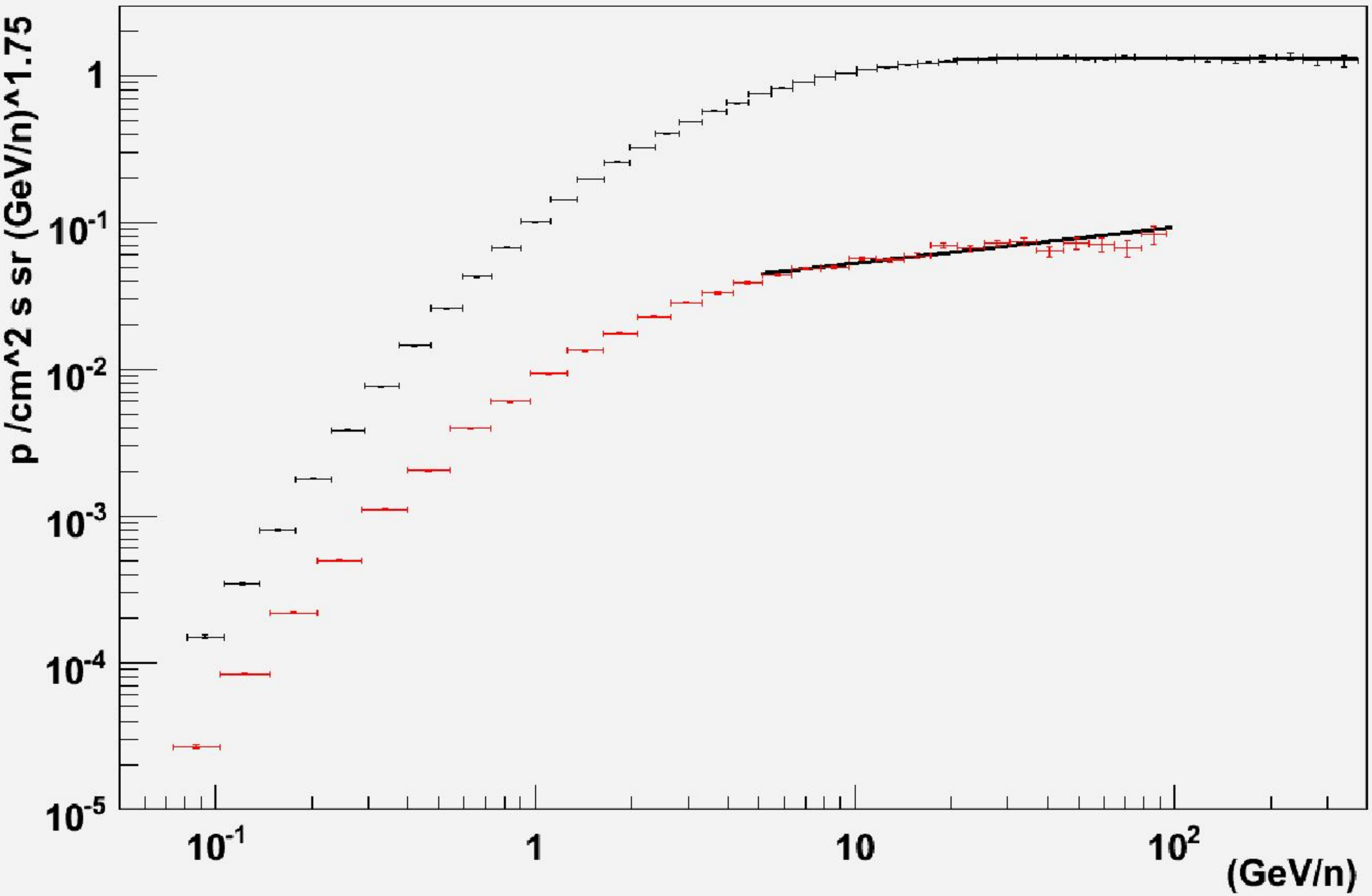
But Spherical approximation is not sufficient for charge dependent solar modulation


Ace Solar Modulation Parameter (spherical approx)
Pamela
Modulation Parameter, ϕ (MV)
1200
1000
800
600
400
200
0
C
O
Mg
Si
Fe
1 Jan 1998
1 Jan 2000
1 Jan 2002
1 Jan 2004
1 Jan 2006
1 Jan 2008

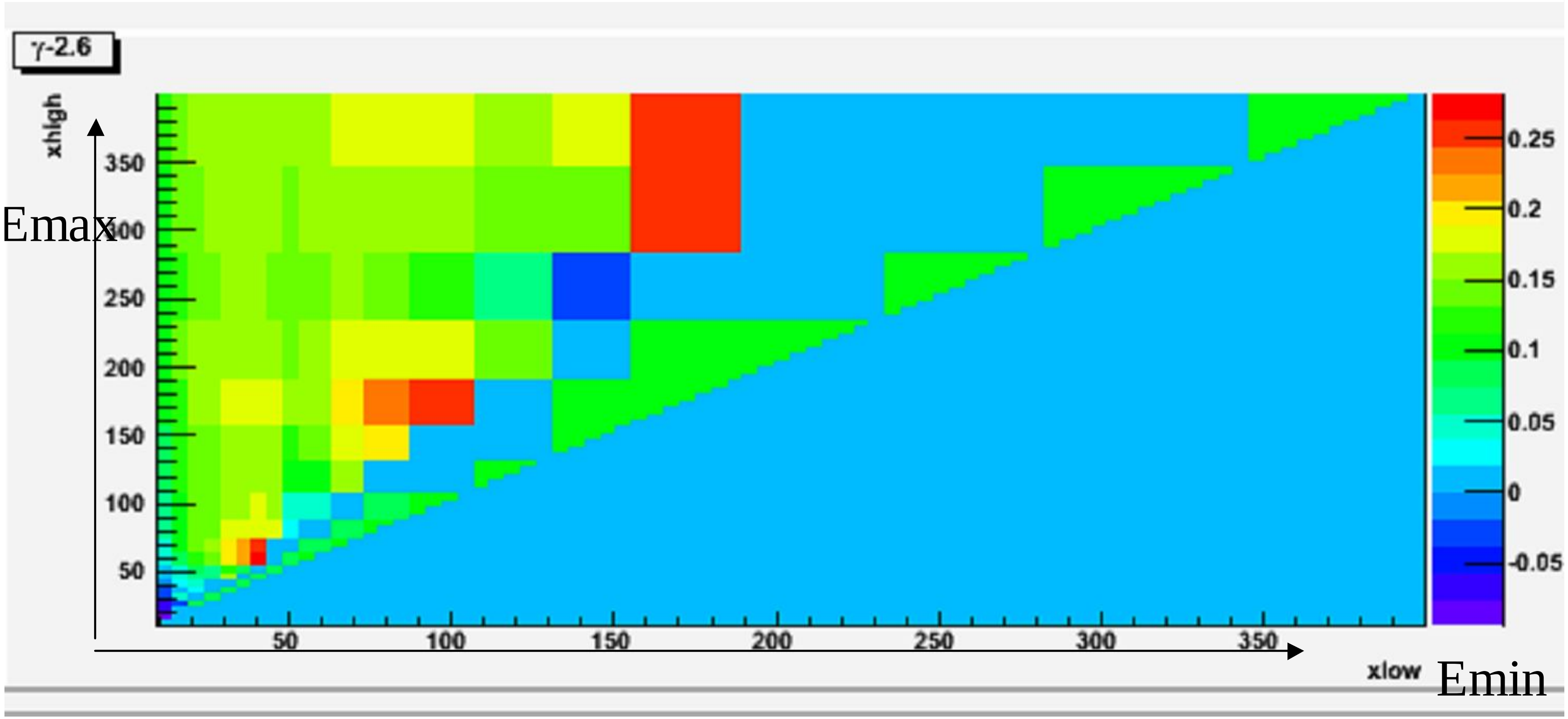
Proton and Helium spectra, kinetic energy, Jul 2006



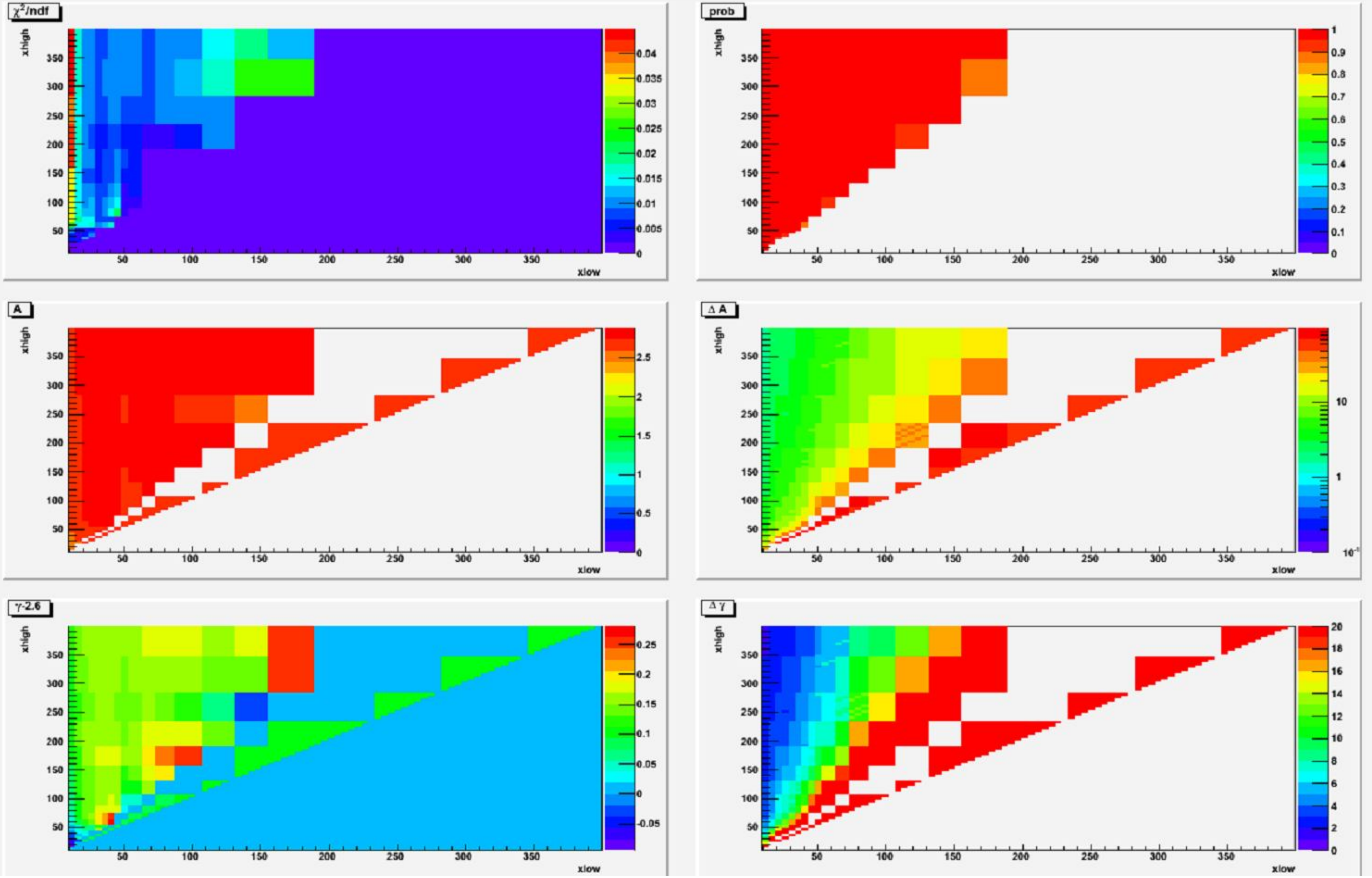
preliminary



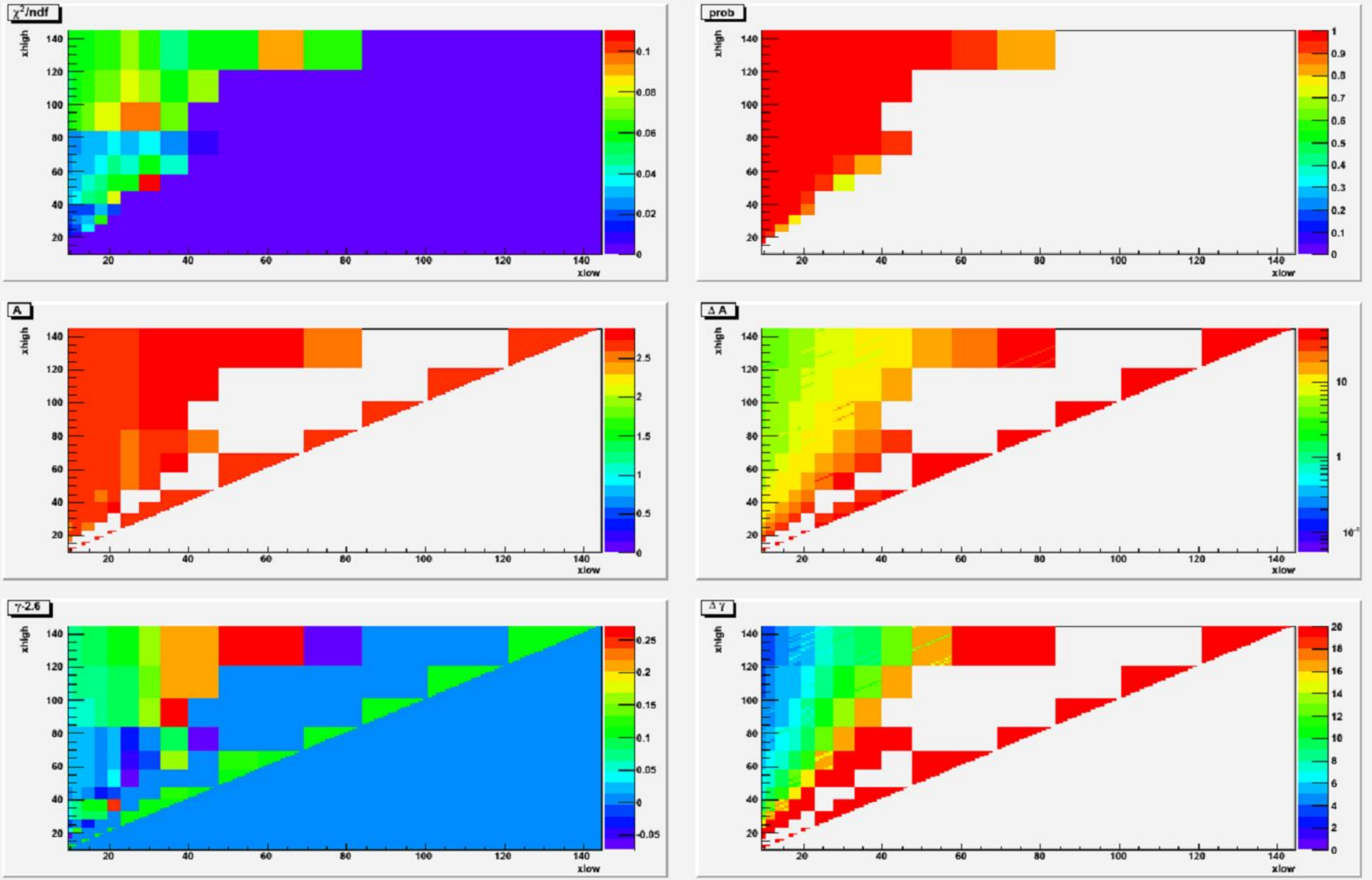
Proton flux fitting
vs starting and ending energy



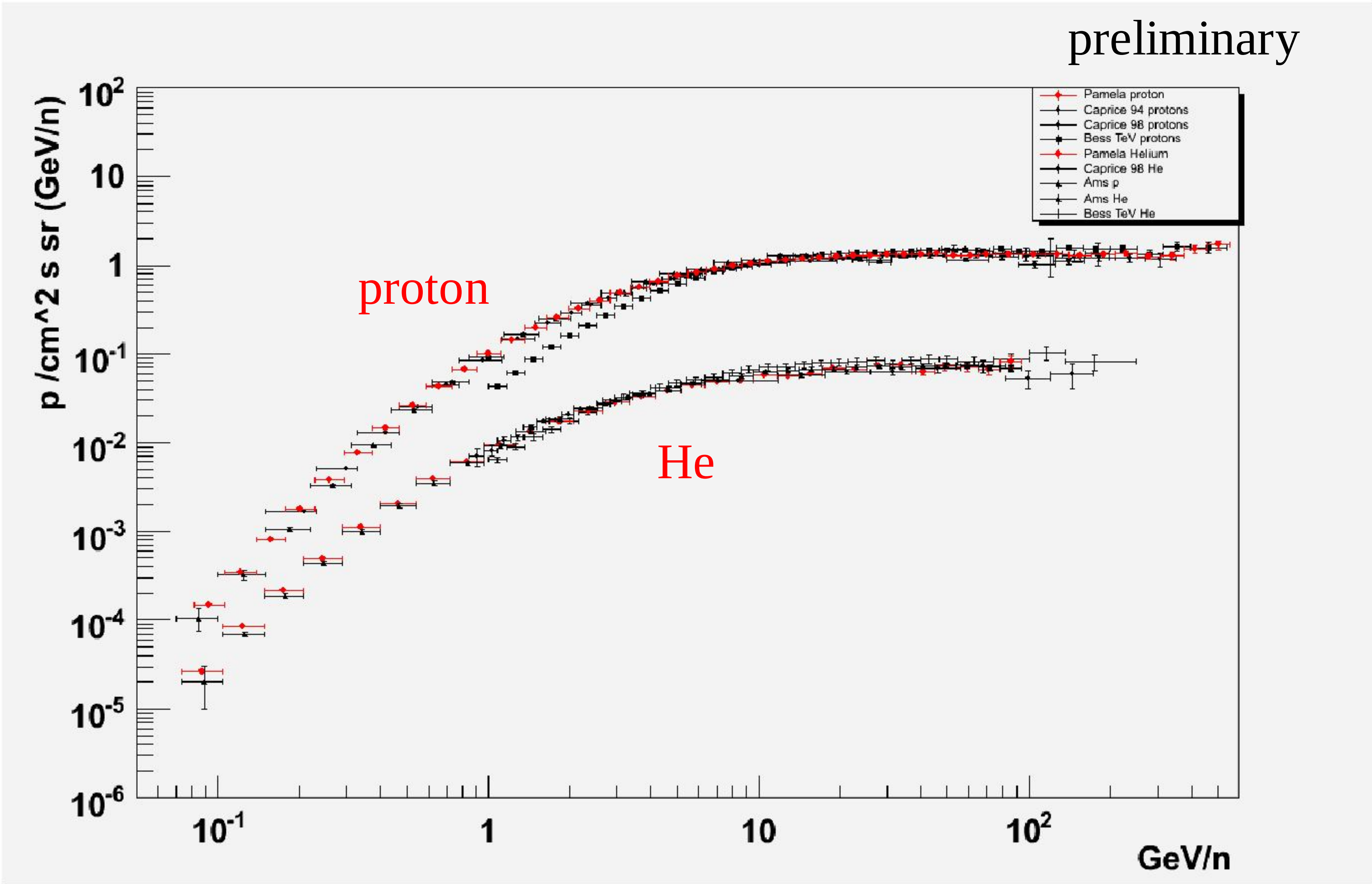
Proton fitting in various energy range



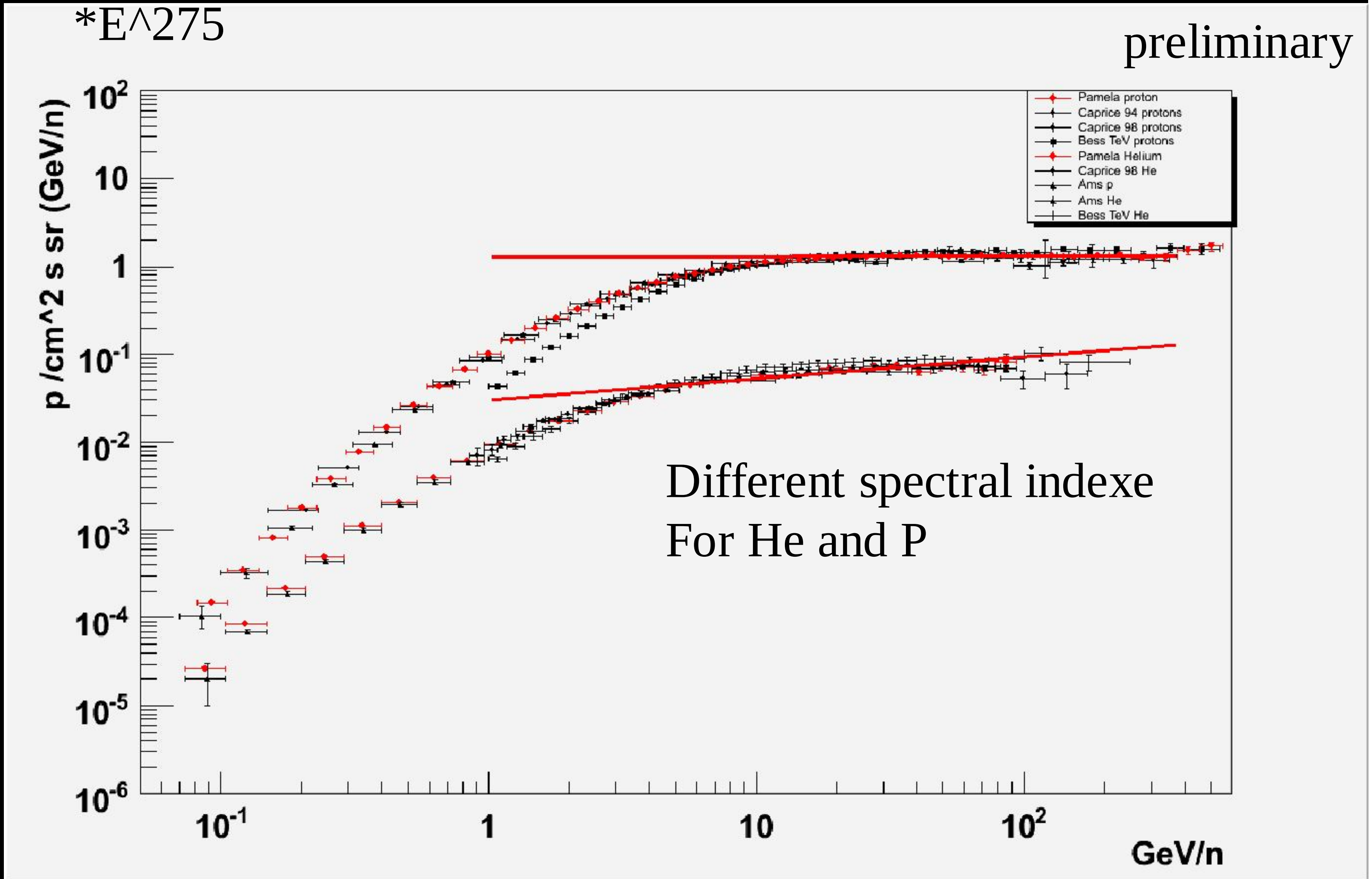
He fitting at various energy range

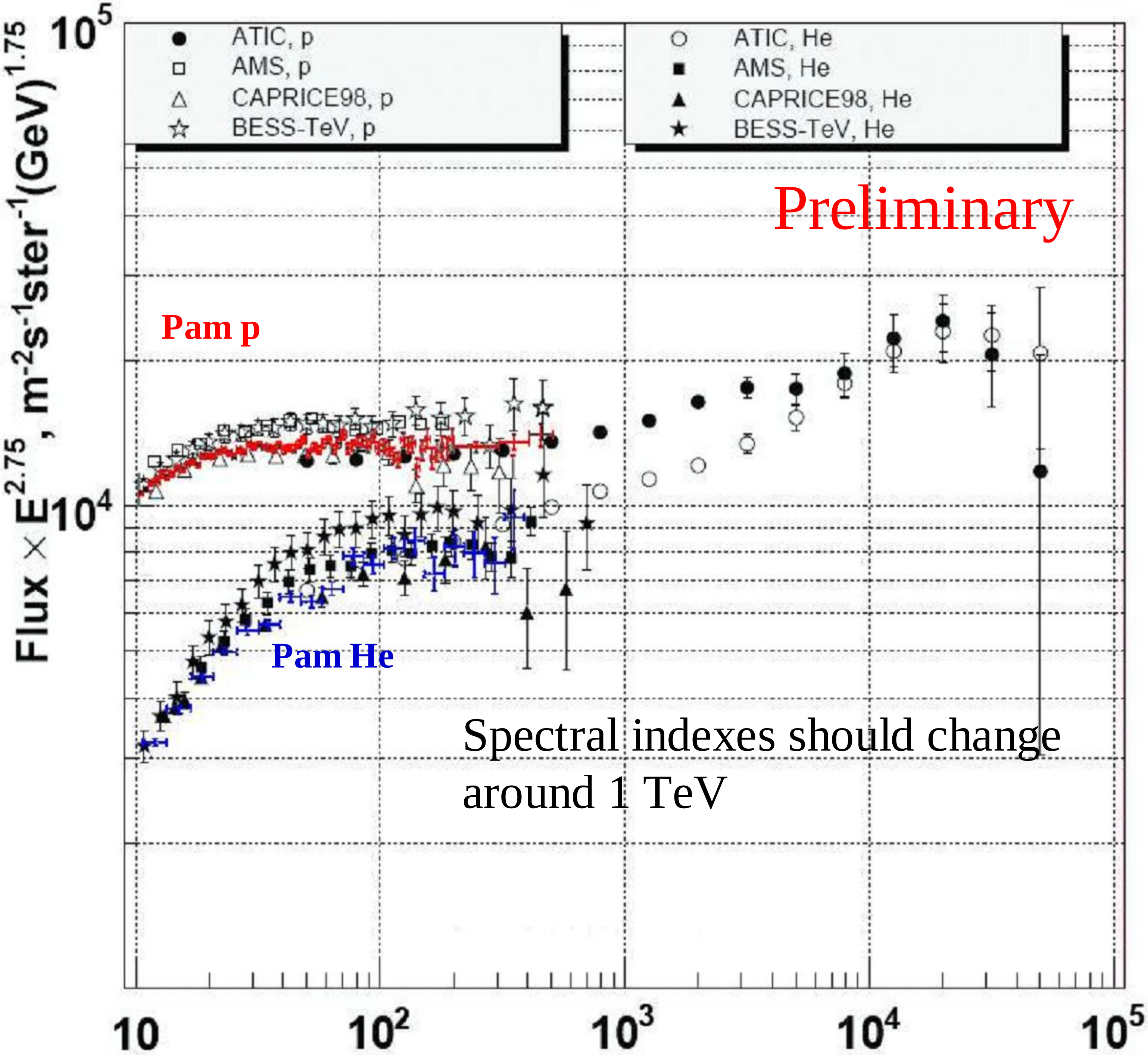


Comparison with other experiments



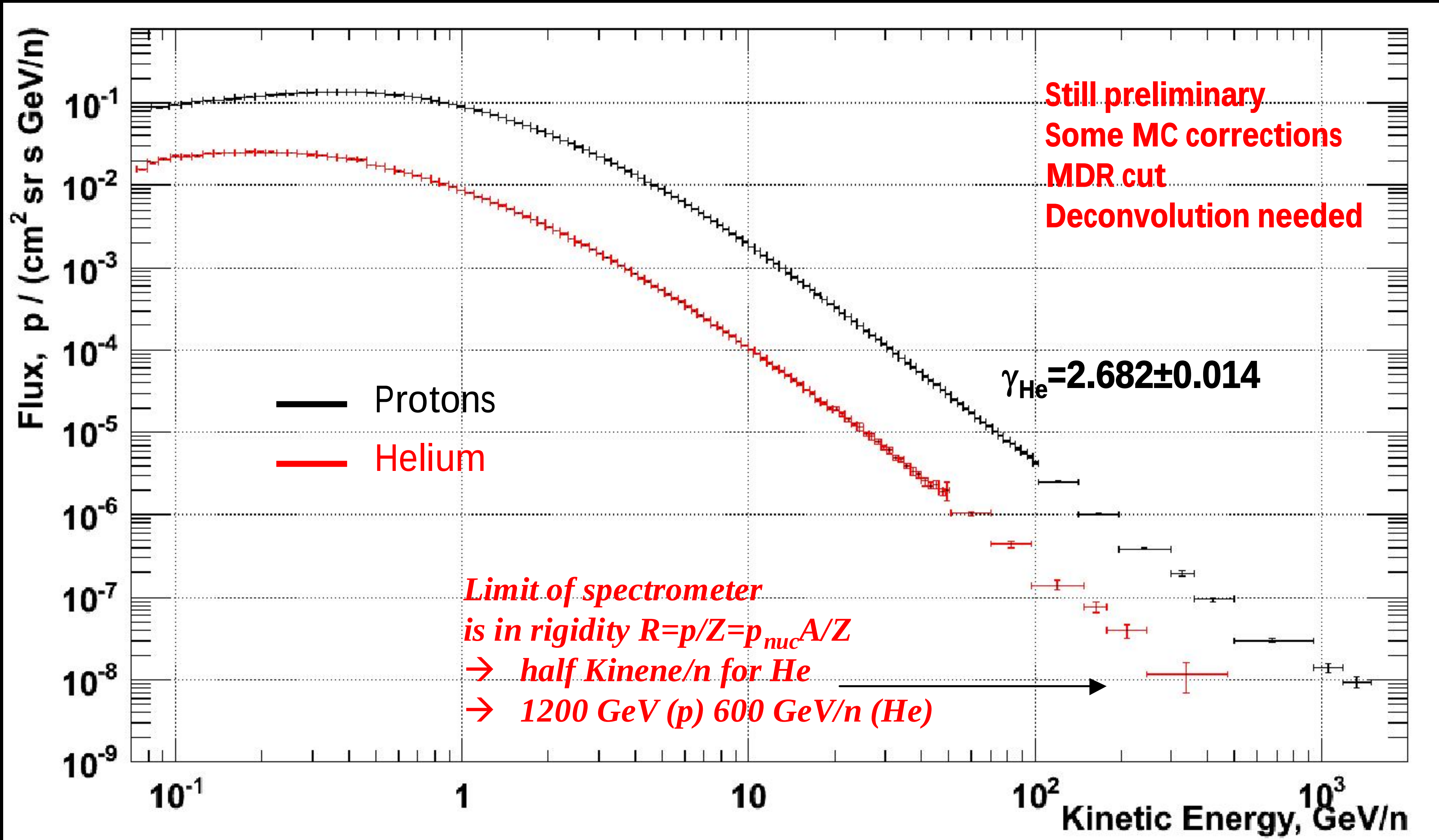
Comparison with other experiments



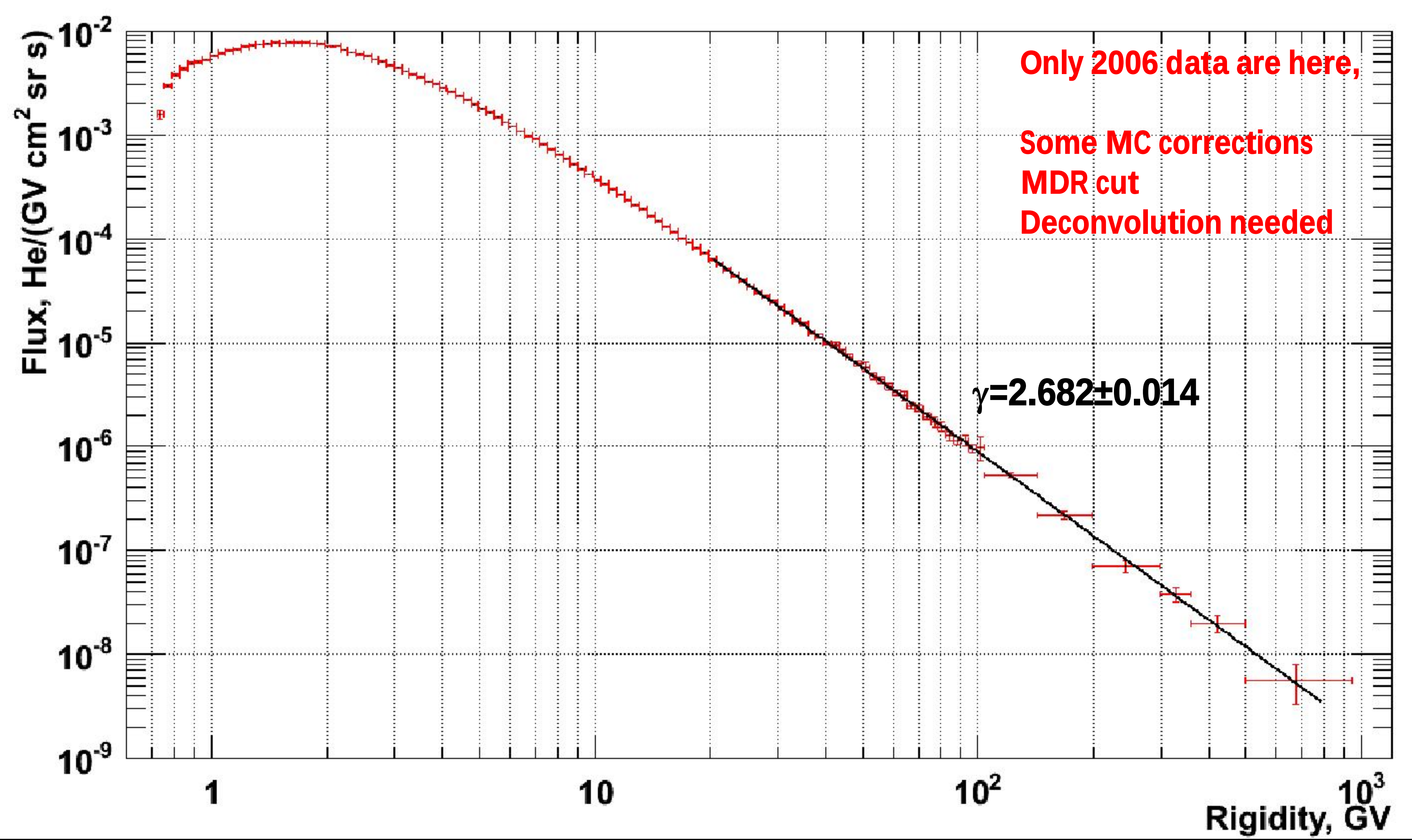


ATIC, p
AMS, p
CAPRICE98, p
BESS-TeV, p
ATIC, He
AMS, He
CAPRICE98, He
BESS-TeV, He
Preliminary
Pam p
Pam He
Spectral indexes should change around 1 TeV
Flux × E^2.75, m^-2s^-1ster^-1(GeV)^1.75
10^5
10^4
10
10^2
10^3
10^4
10^5

Preliminary results at high energy

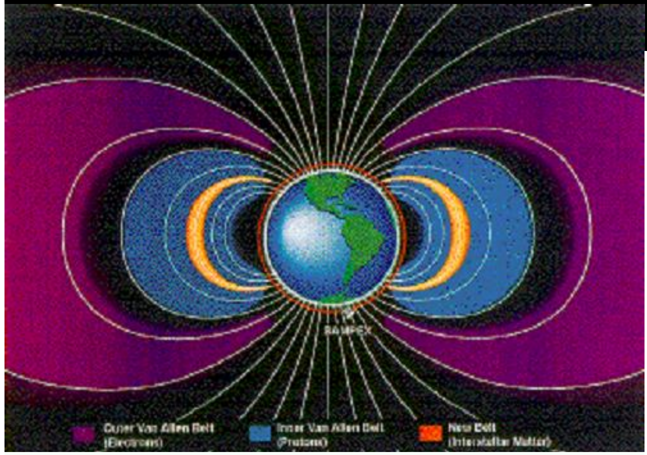


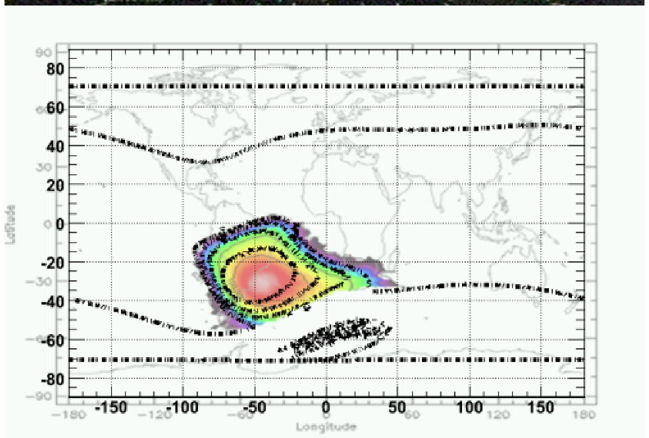
Preliminary results at high energy



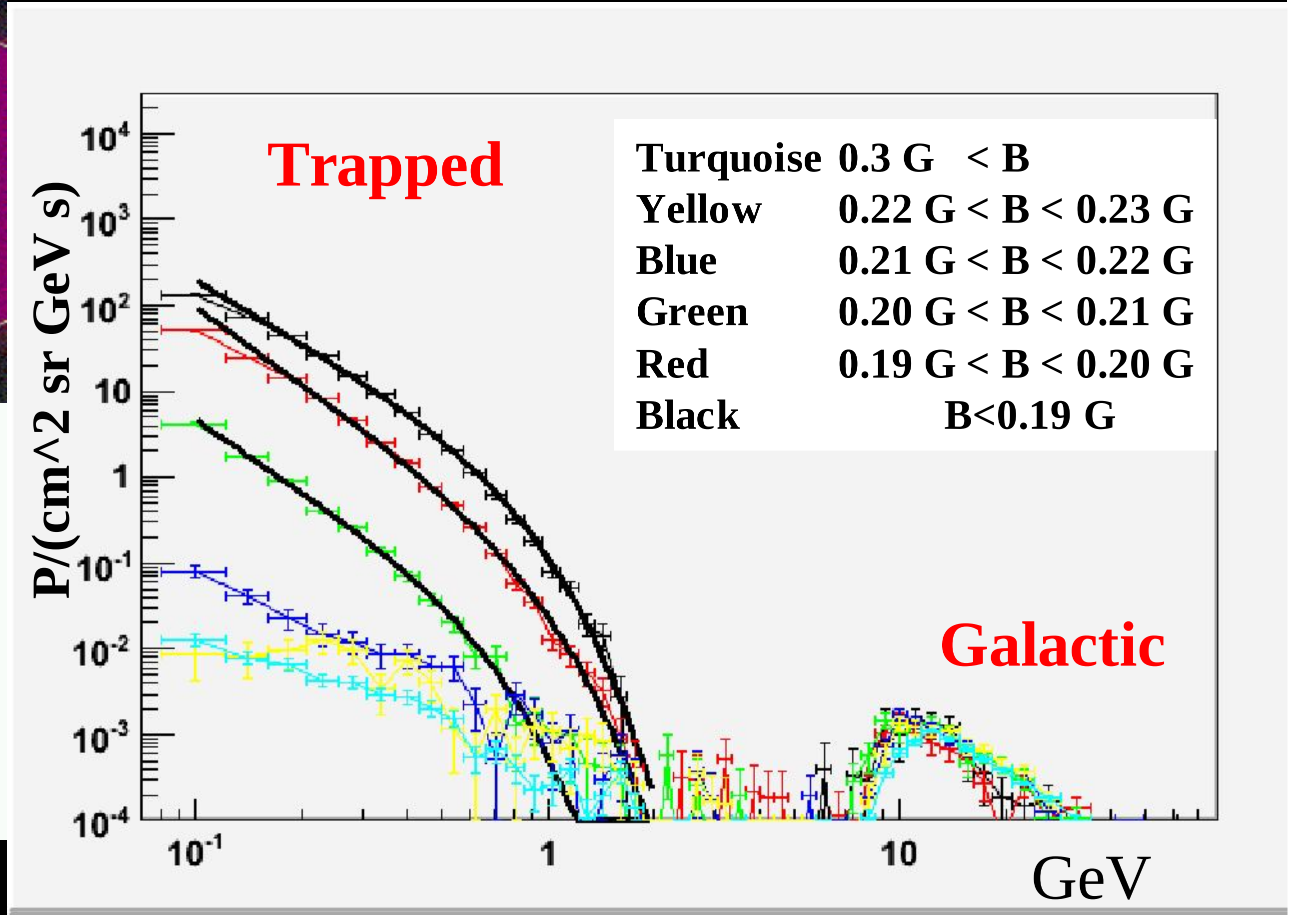
Trapped proton flux in the Van Allen belt (South Atlantic Anomaly)

Arxiv 0810.4980v1





Integral Pamela flux
(E>35 MeV)
(PSB97 plot by SPENVIS project, model by BIRA-IASB)



	A	γ_0	γ_1	χ^2/ndf
nero	0.11±0.01	6.0±0.4	3.1±0.5	7.1
rosso	(2.3±0.3) 10^{-2}	5.9±0.5	2.6±0.6	6.8
verde	(5±3) 10^{-4}	8.1±1.8	4.7±1.8	10.

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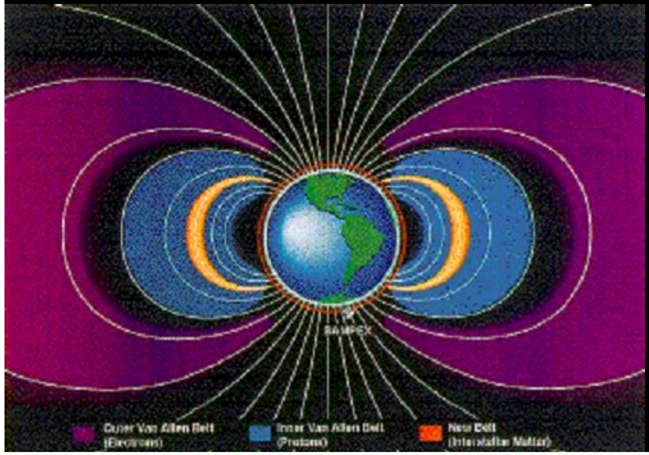
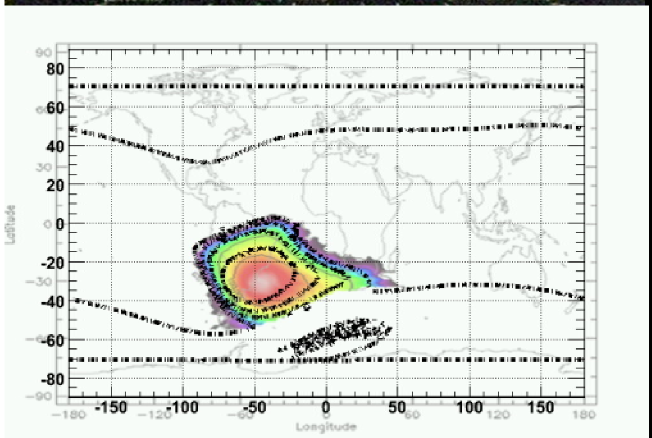
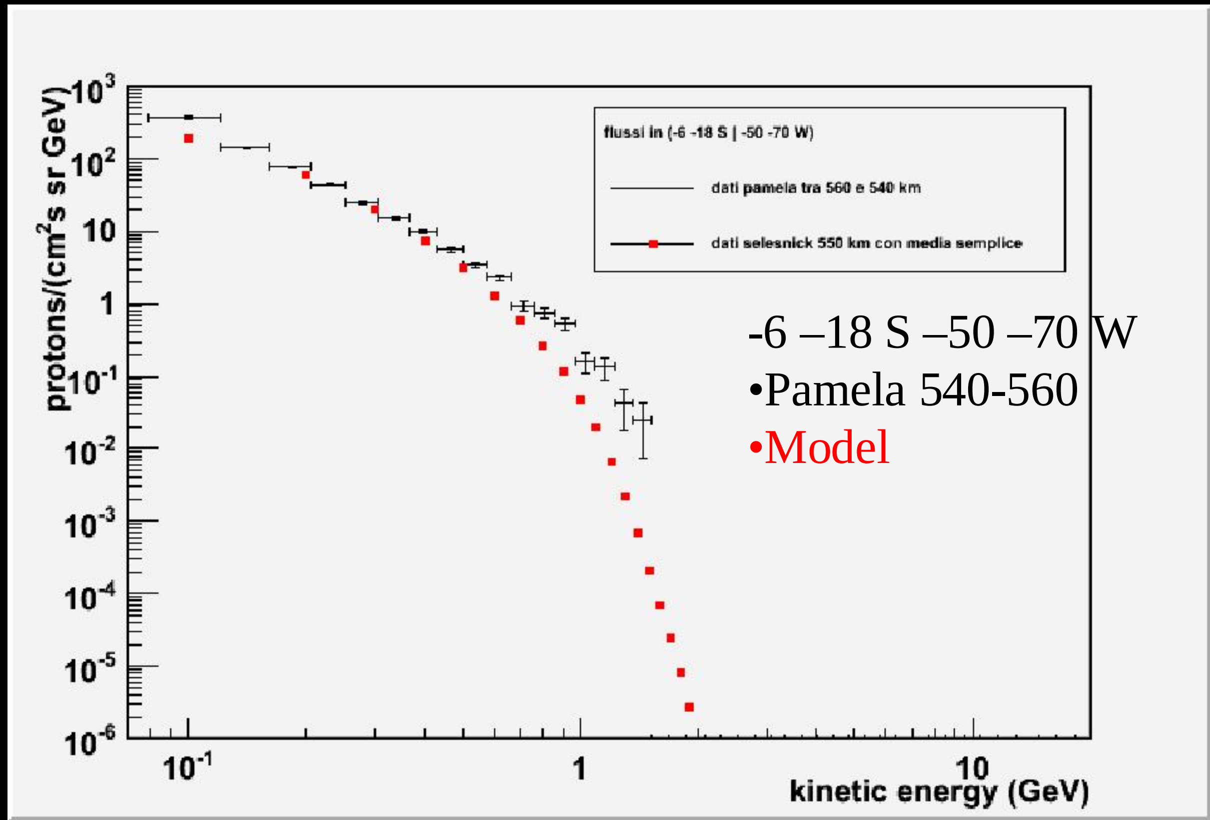
Trapped proton flux in the Van Allen belt
Comparison with models



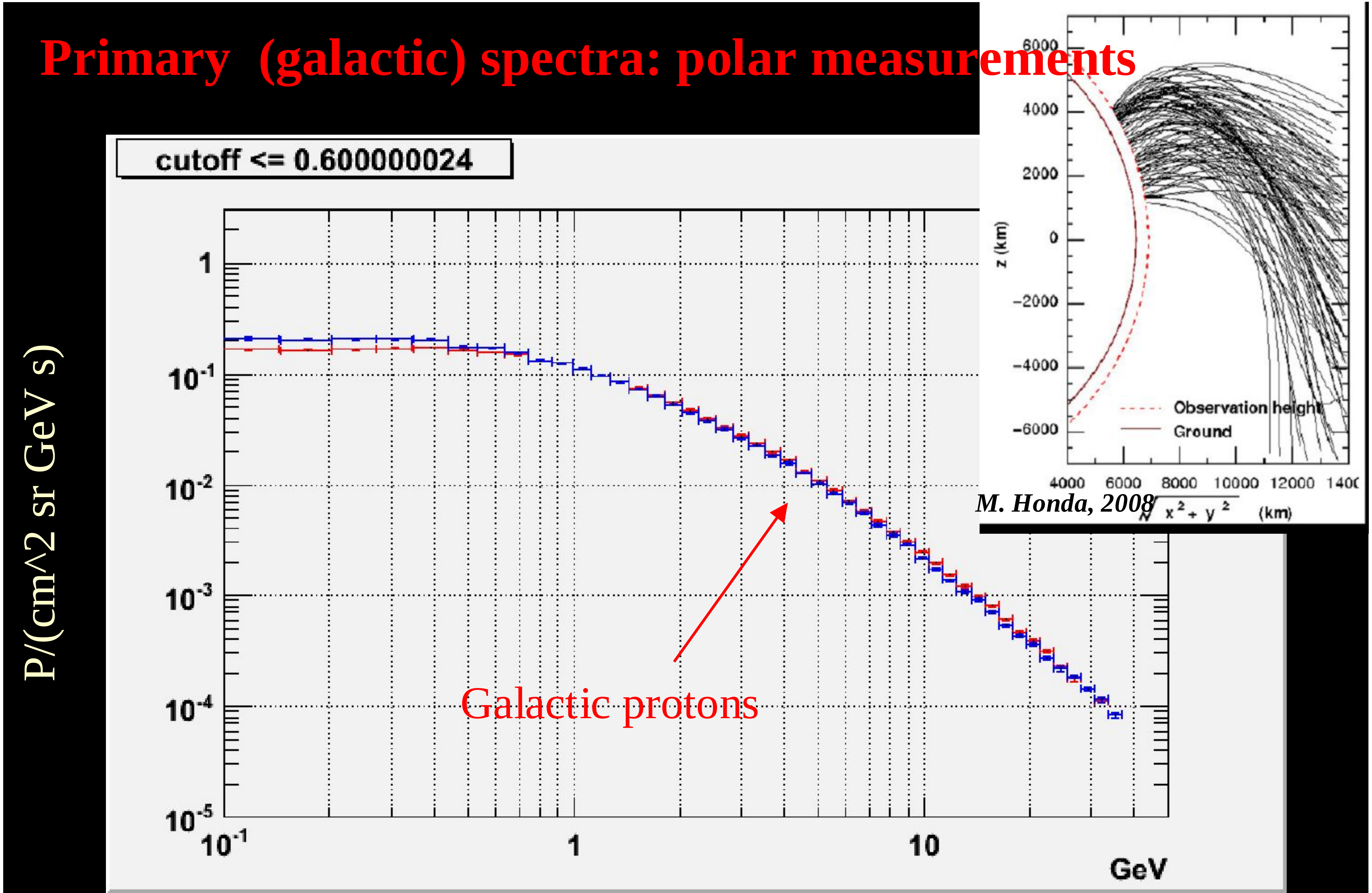




-6 –18 S –50 –70 W
- Pamela 540-560
- Model

R. S. Selesnick,1 M. D. Looper,1 and R. A. Mewaldt2
SPACE WEATHER, VOL. 5, S04003, doi:10.1029/2006SW000275, 2007

Primary (galactic) spectra: polar measurements

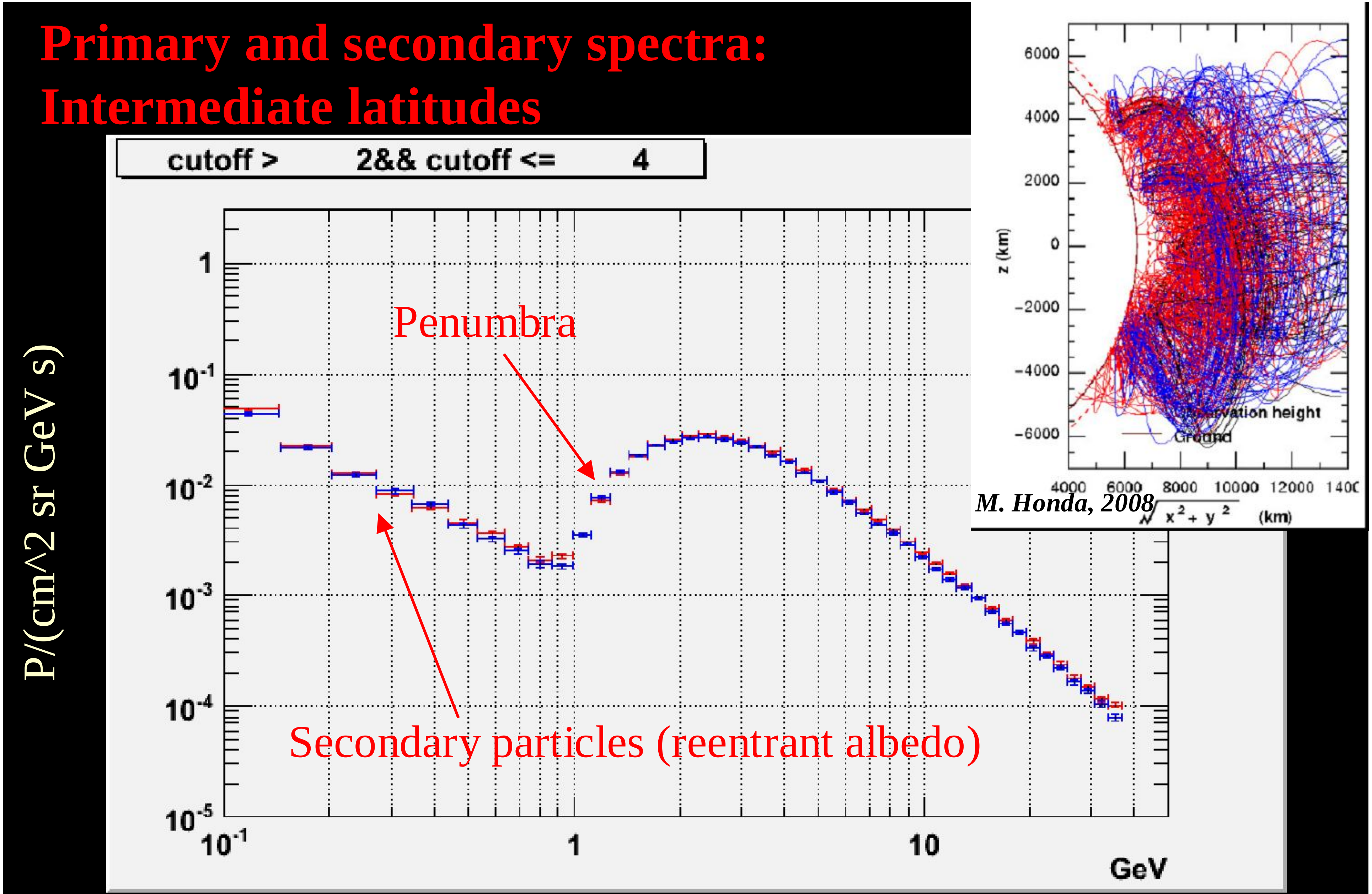


M. Honda, 2008

RED: JULY 2006

BLUE: AUGUST 2007

Primary and secondary spectra: Intermediate latitudes

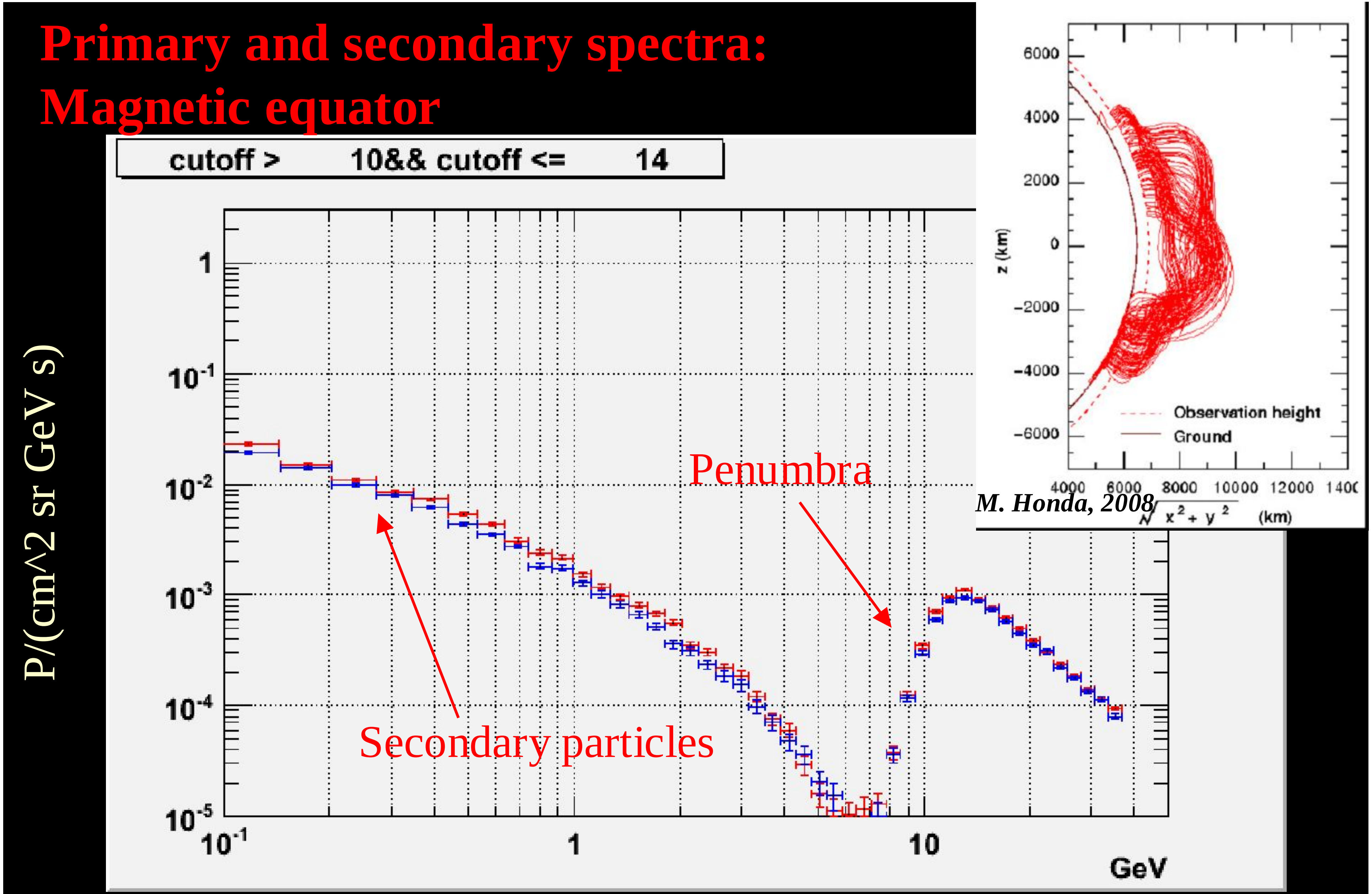


RED: JULY 2006

BLUE: AUGUST 2007

M. Casolino, INFN & University Roma Tor Vergata

Primary and secondary spectra: Magnetic equator



M. Honda, 2008

RED: JULY 2006

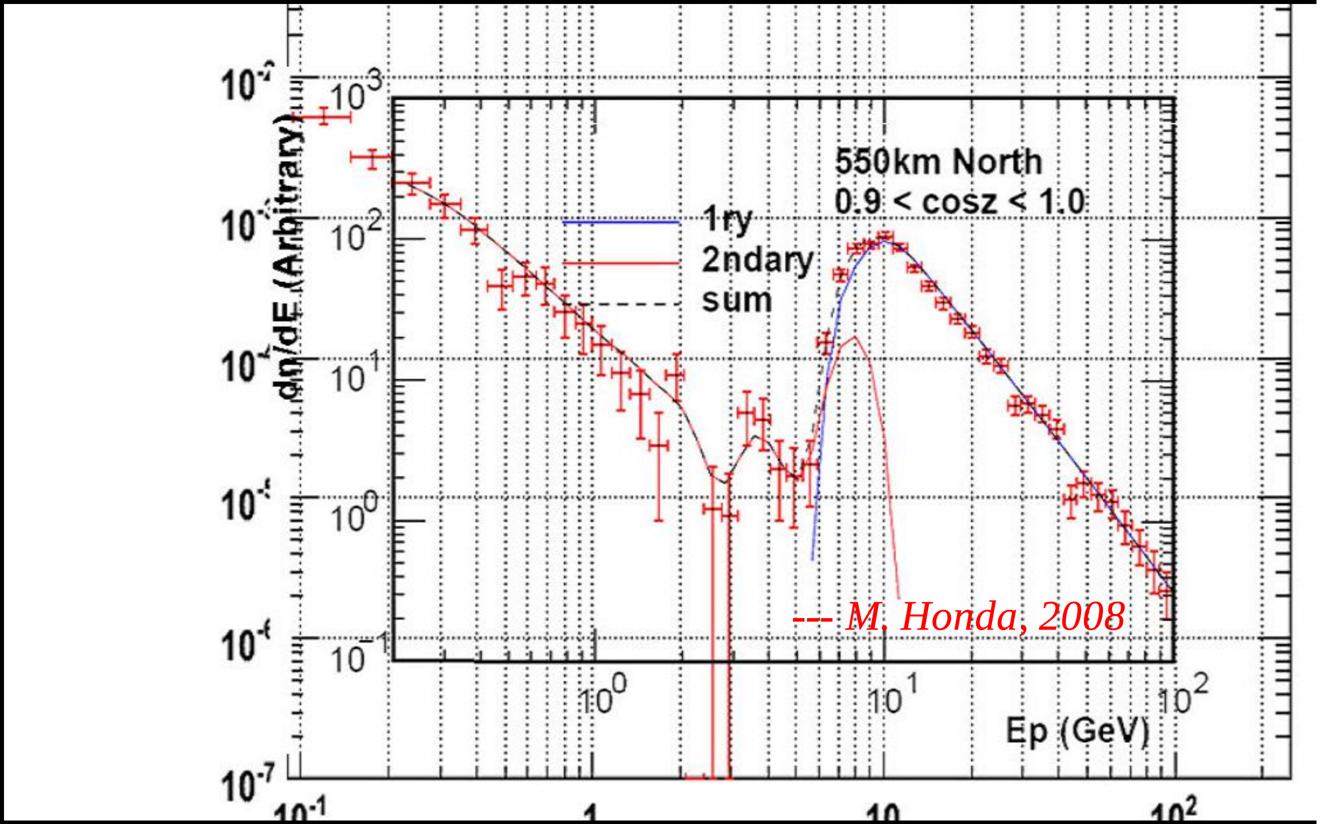
BLUE: AUGUST 2007

Secondary (reentrant albedo) proton flux at various cutoffs

→**Atmospheric neutrino contribution**

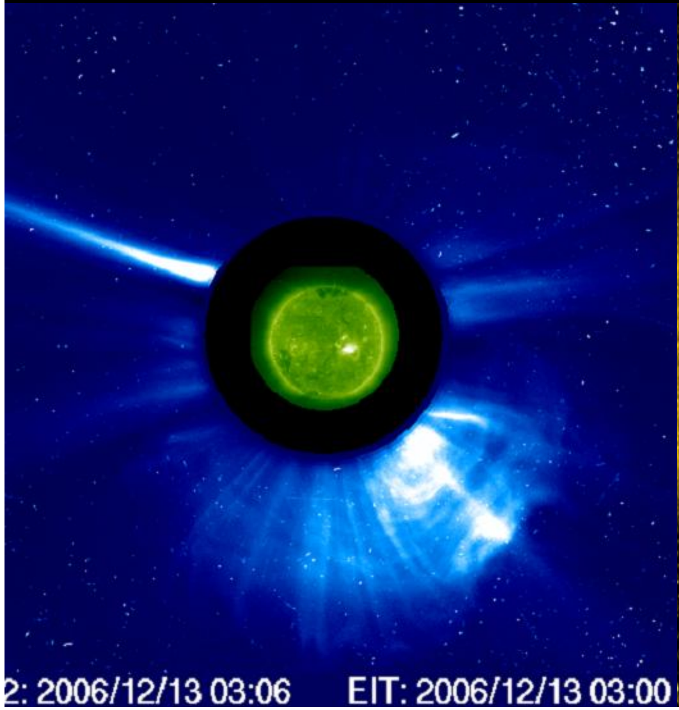
→**Astronaut dose on board International Space Station**

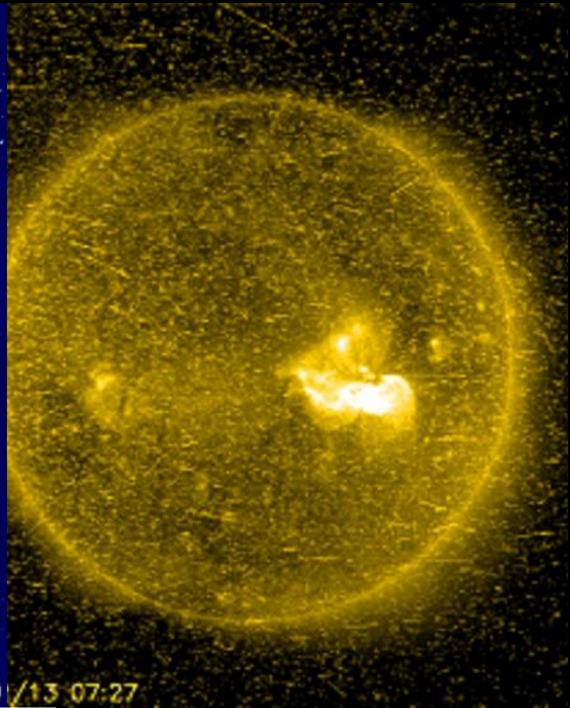
→**Indirect measurement of cross section in the atmosphere**

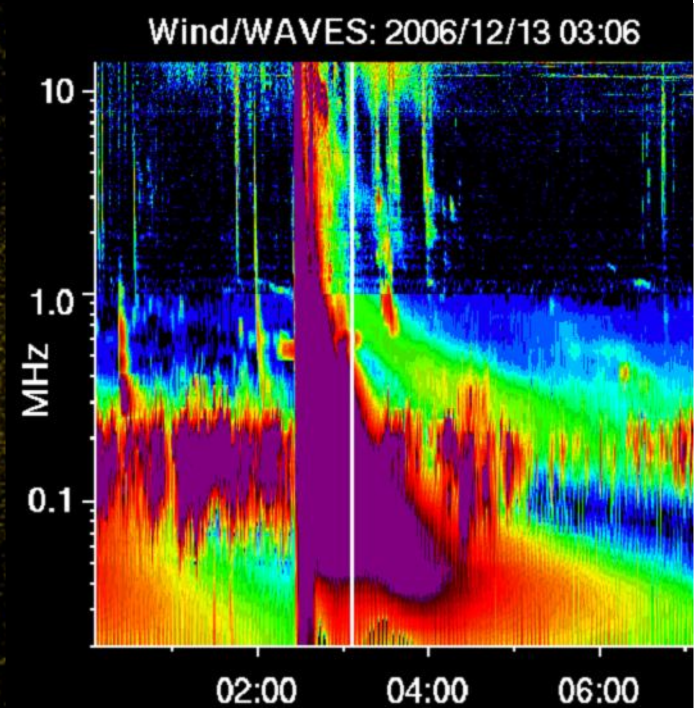


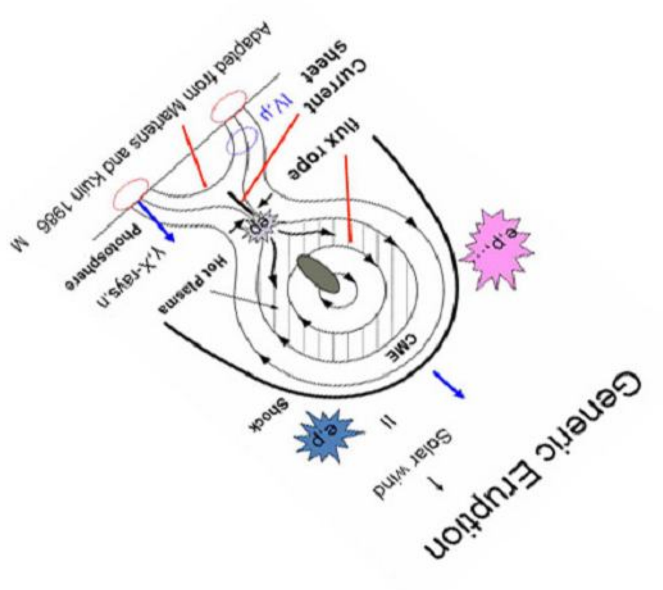
Arxiv 0810.4980v1

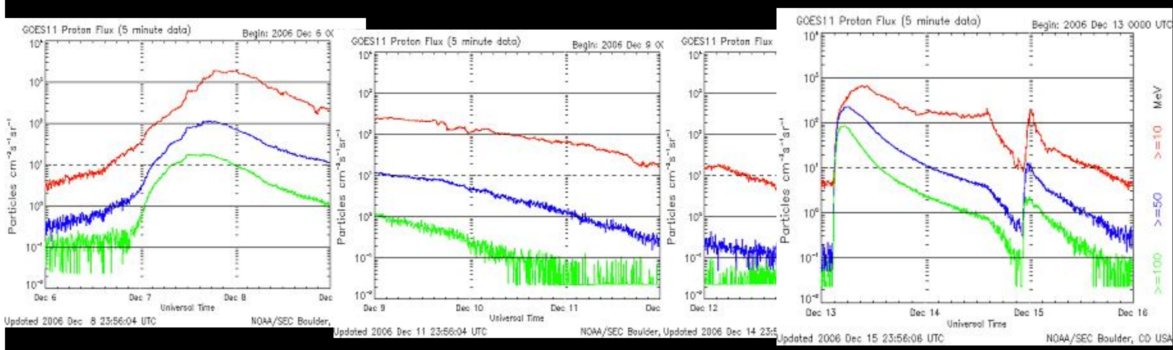
Solar Particle events 13-14/12/06 – GLE 70





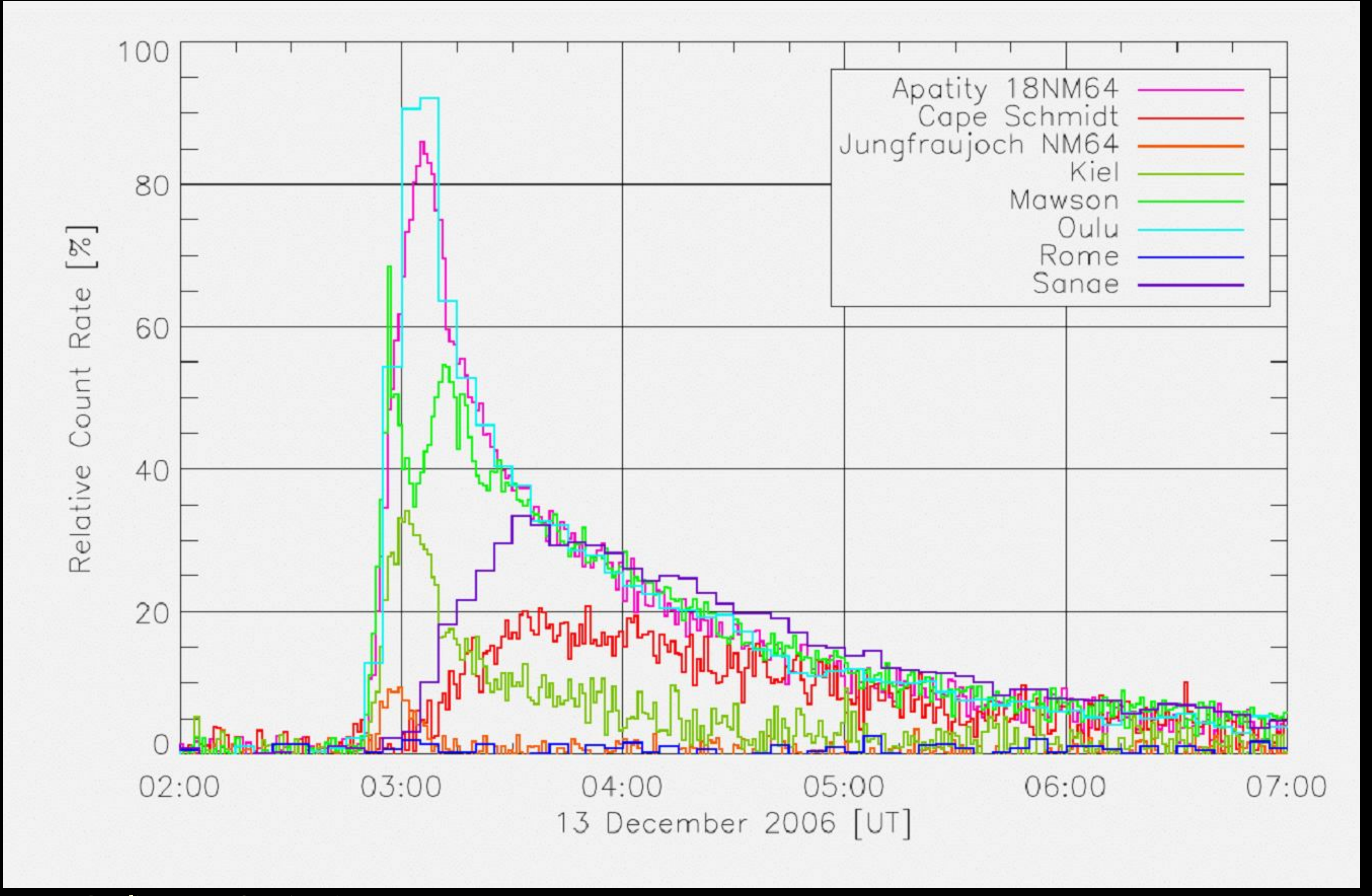






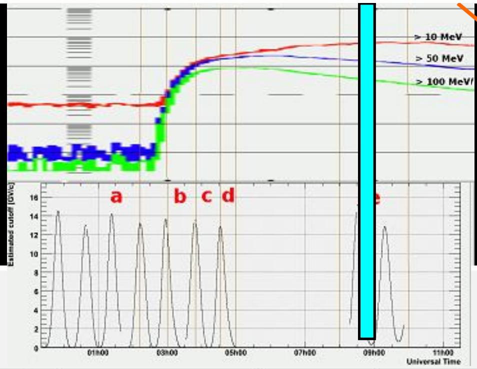
ergata

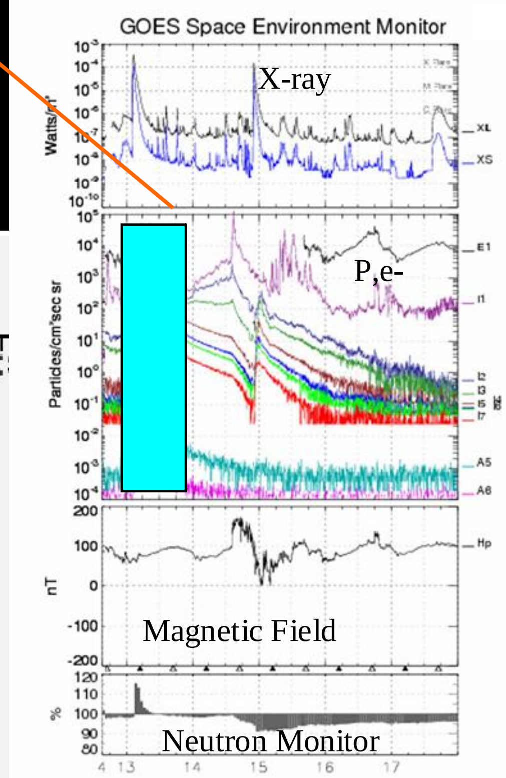
13 December 2006 Solar Particle Event
Neutron Monitor Observations (GLE70)

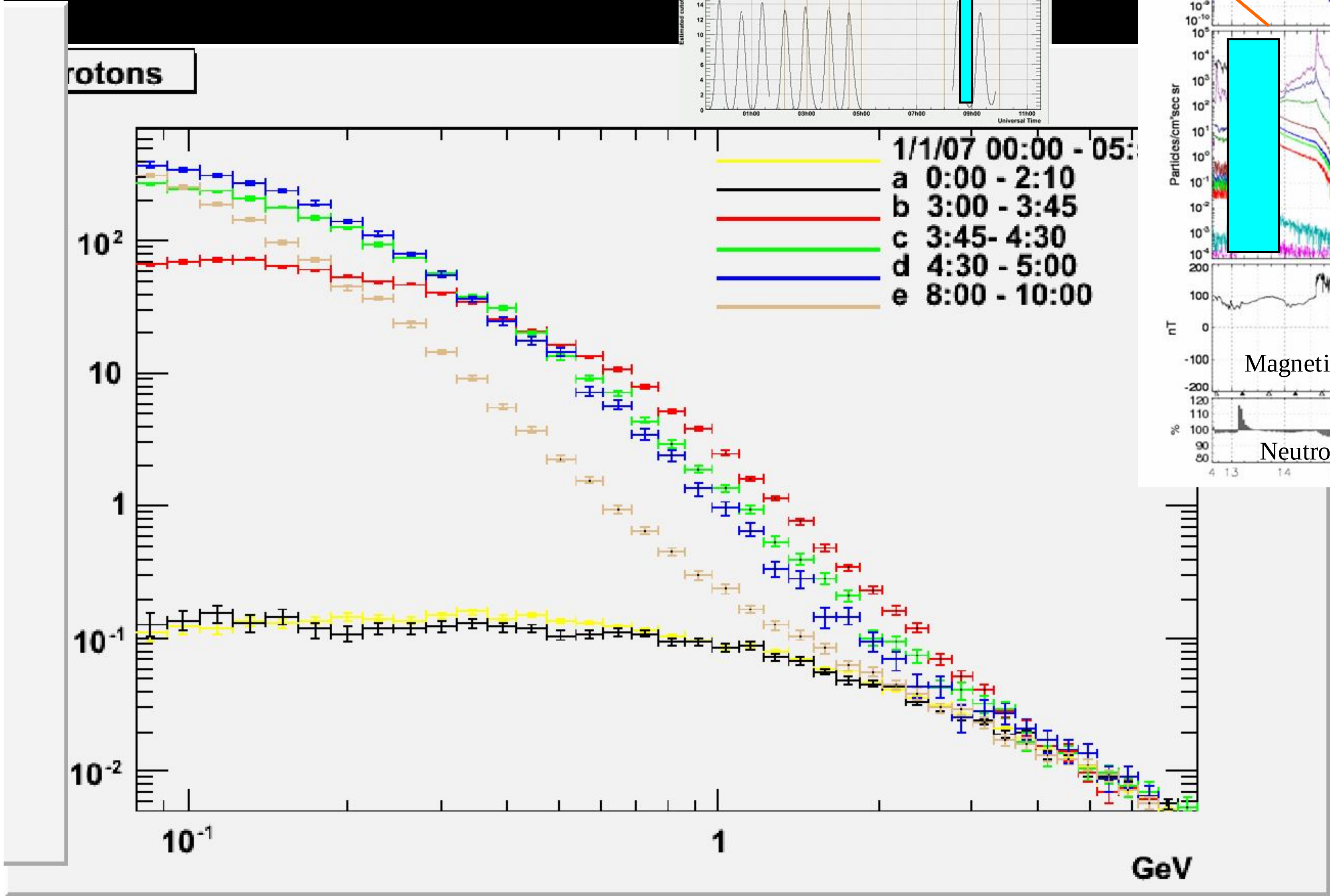


Erwin O. Flückiger

December 13th 2006 event





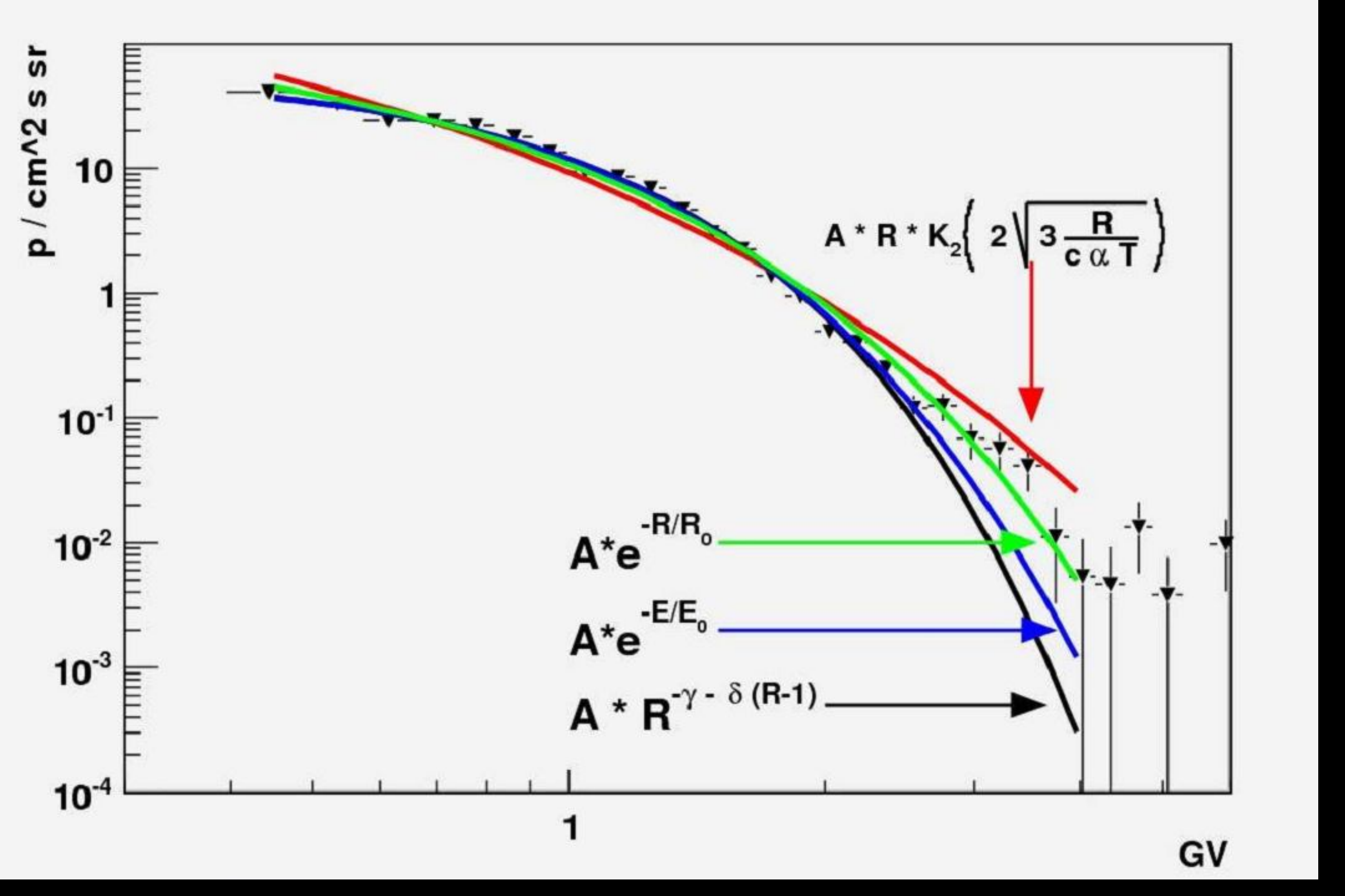


Discrimination between acceleration processes

•Shock accel.
$E^{-a} \exp(E/E_o)$

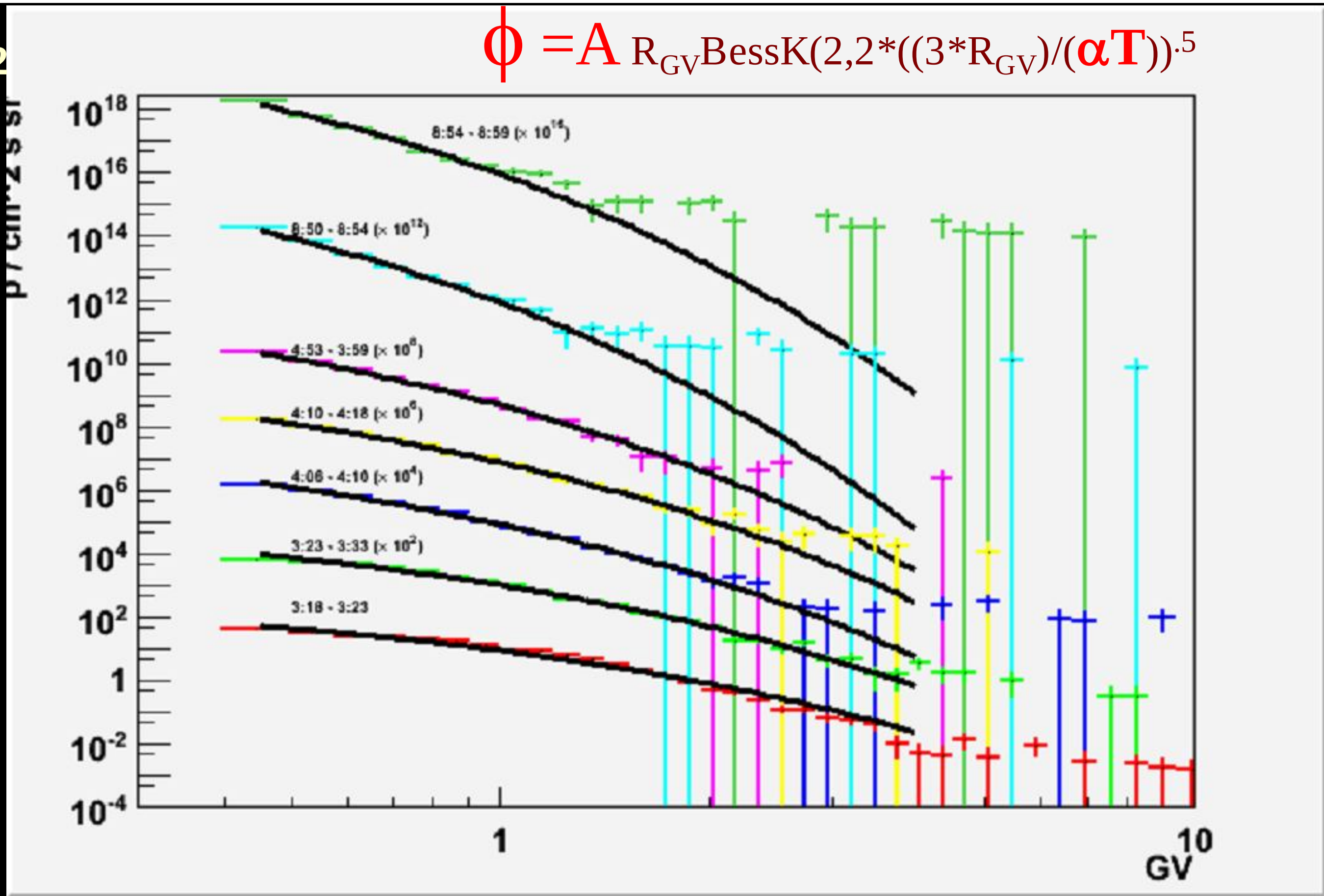
•Stochastic Fermi accel.
Impulsive events
Exp in Rigid/Kinene
  Bessel function,

•Direct Acceleration in magnetic reconnection



Arxiv 0810.4980v1

Bessel Modified Function K2



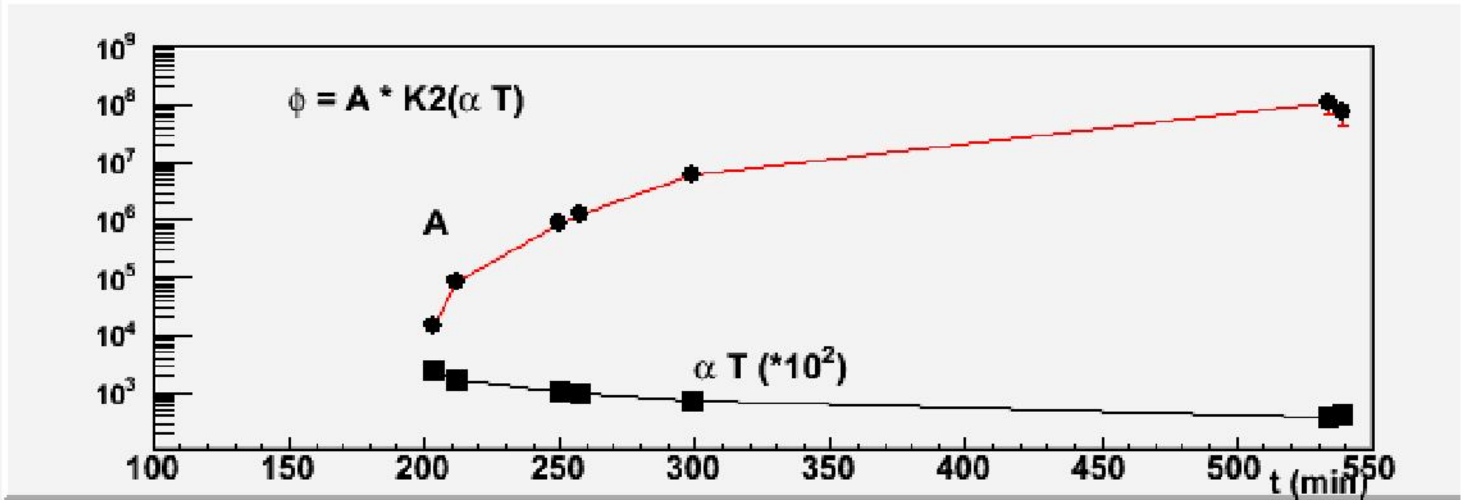
High energy tail

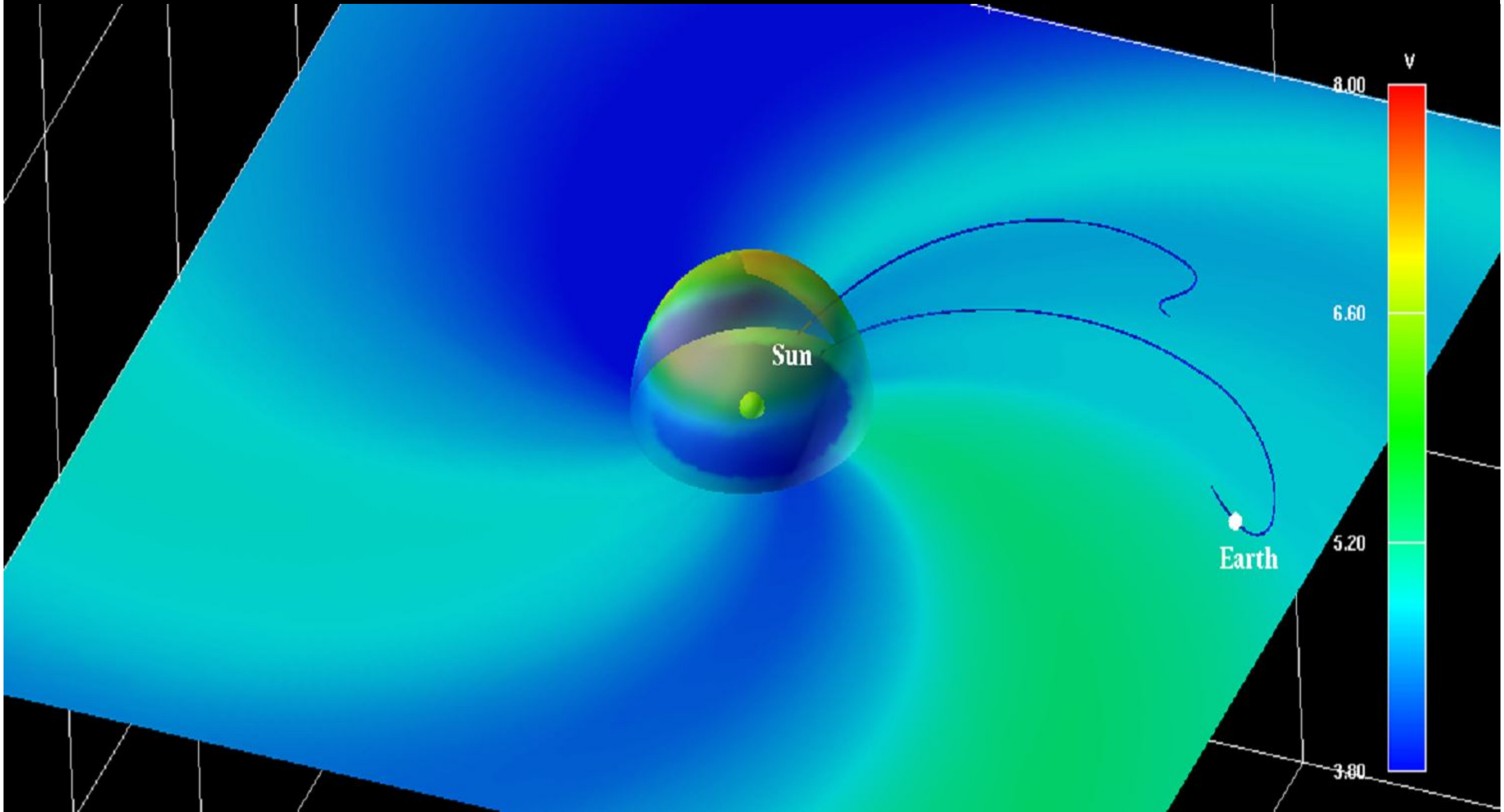
- Helps in discriminating between

- Shock accel.
- Exp in Rigid

- Stochastic accel.
  Bessel function, Rig dependent, etc..

- Direct Acceleration



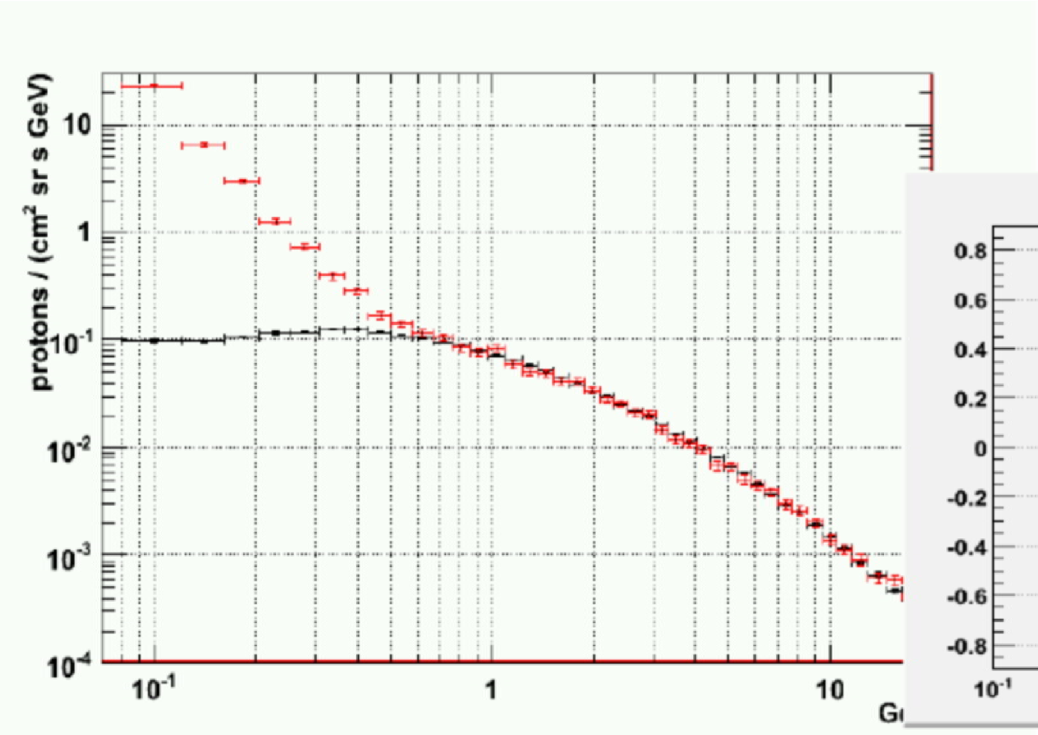


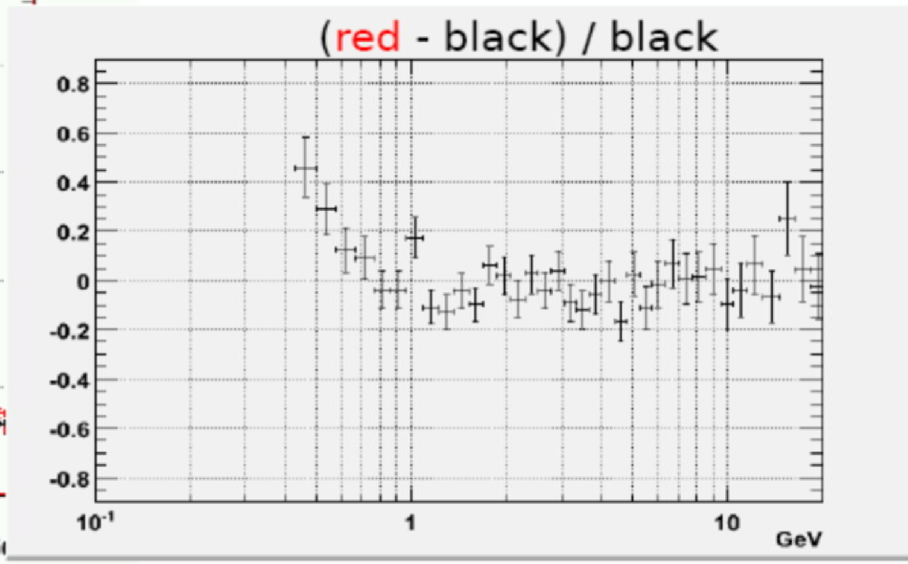
Kataoka, 2008 *hbksw1.stelab.nagoya-u.ac.jp/ryuho.html*

The 14th December 2006 Forbush Decrease

from 2006-12-1 to 2006-12-4

from 2006-12-14 08:58:42 to 2006-12-14 11:59:57

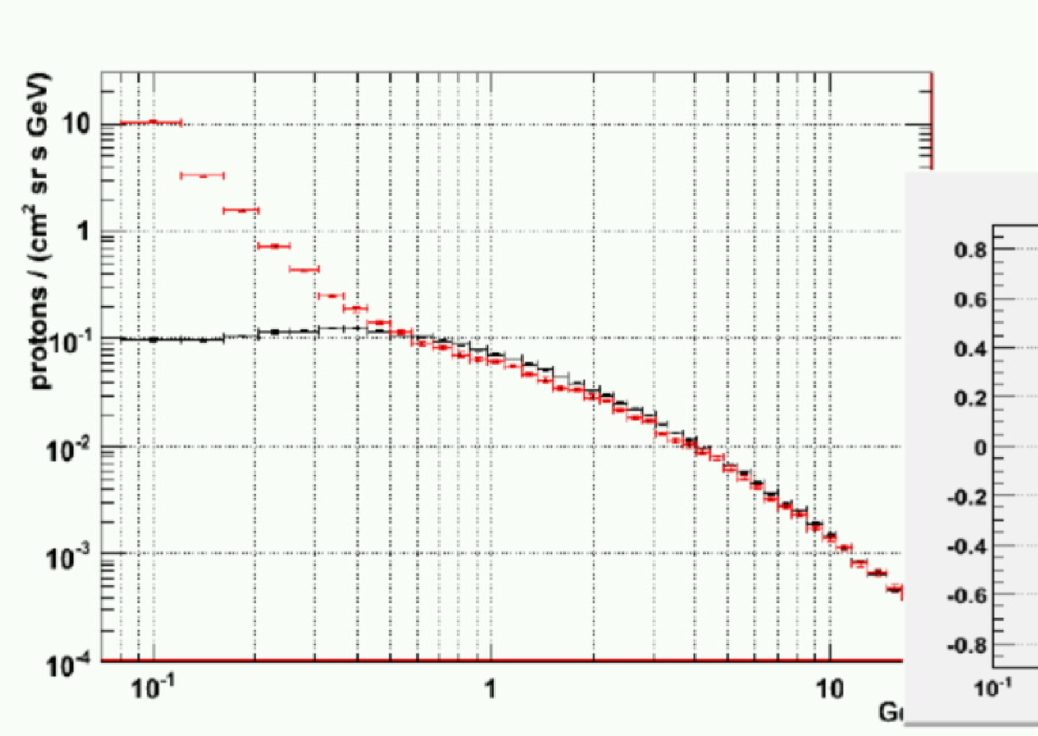


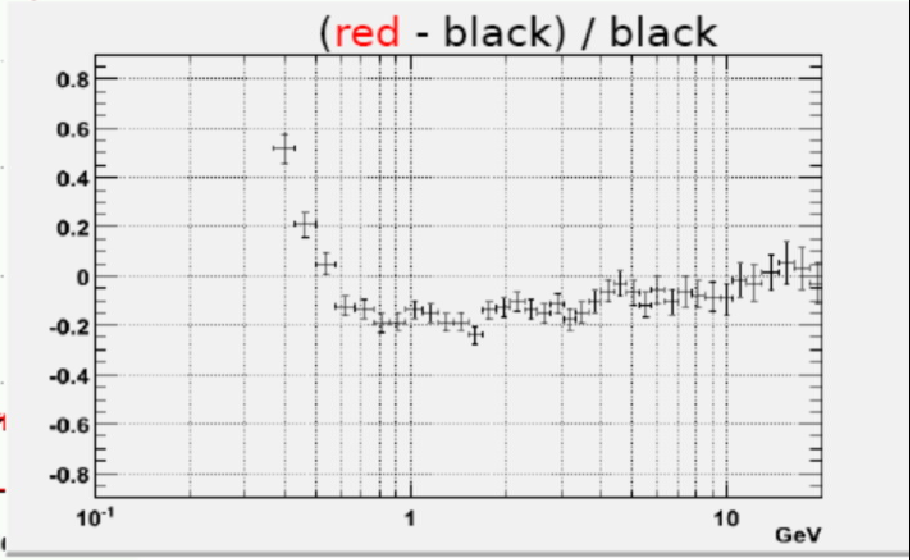


The 14th December 2006 Forbush Decrease

from 2006-12-1 to 2006-12-4

from 2006-12-14 12:00:01 to 2006-12-14 23:59:59

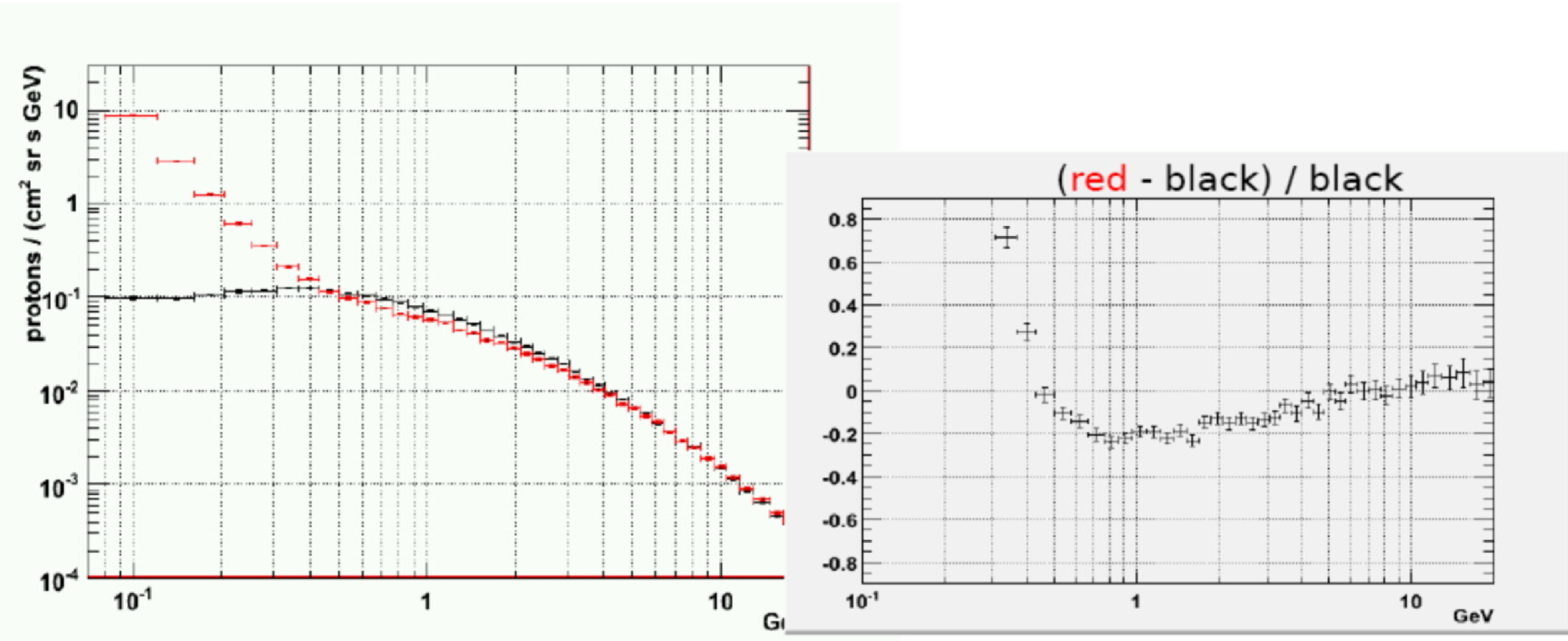




The 14th December 2006 Forbush Decrease

from 2006-12-1 to 2006-12-4

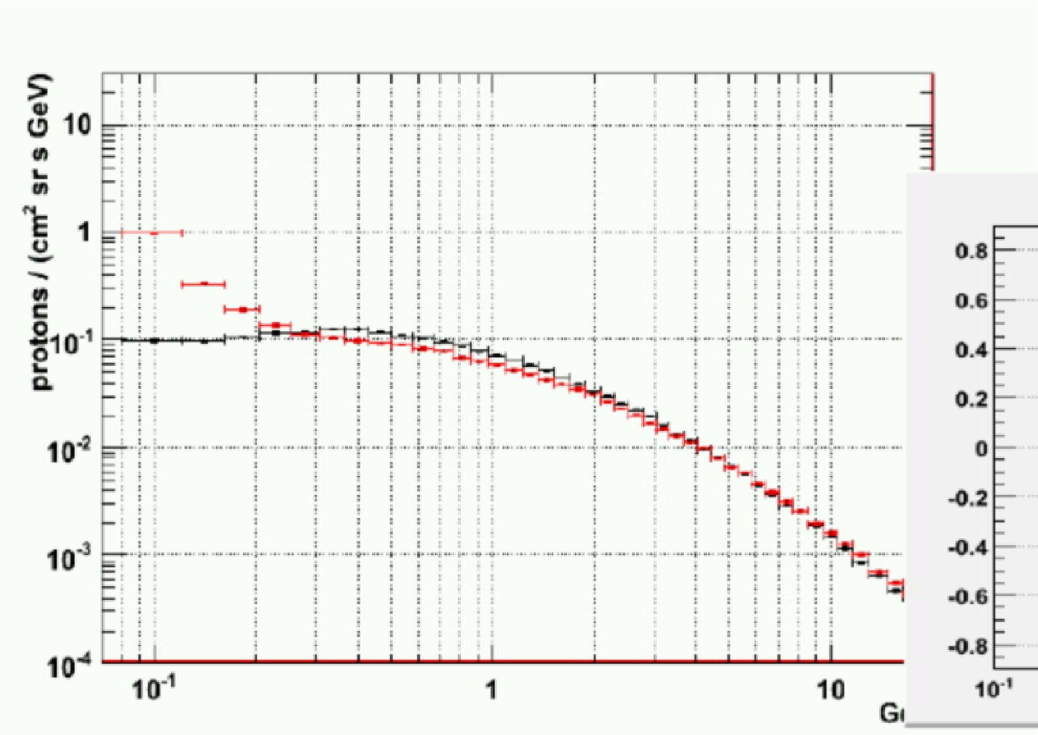
from 2006-12-15 00:00:01 a 2006-12-15 23:59:54

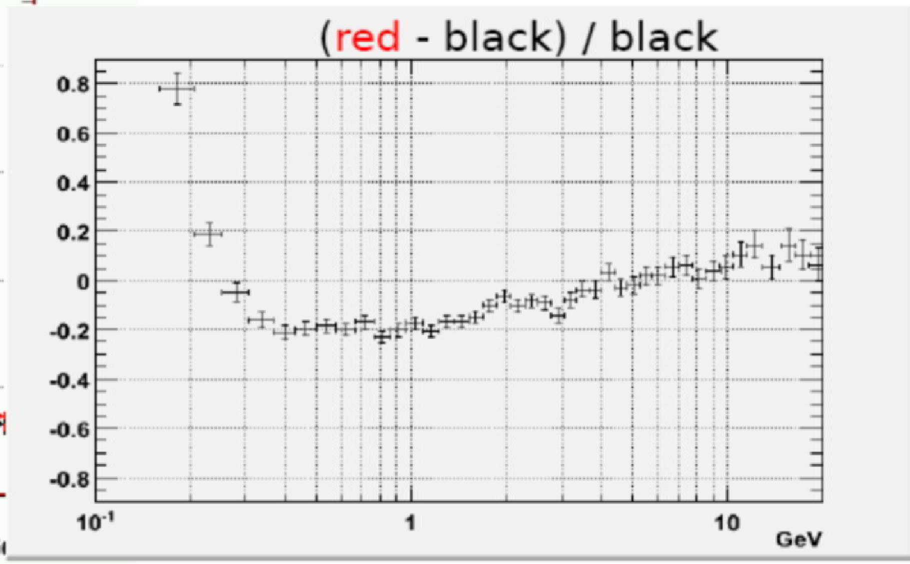


The 14th December 2006 Forbush Decrease

from 2006-12-1 to 2006-12-4

from 2006-12-16 00:00:04 a 2006-12-16 23:59:59

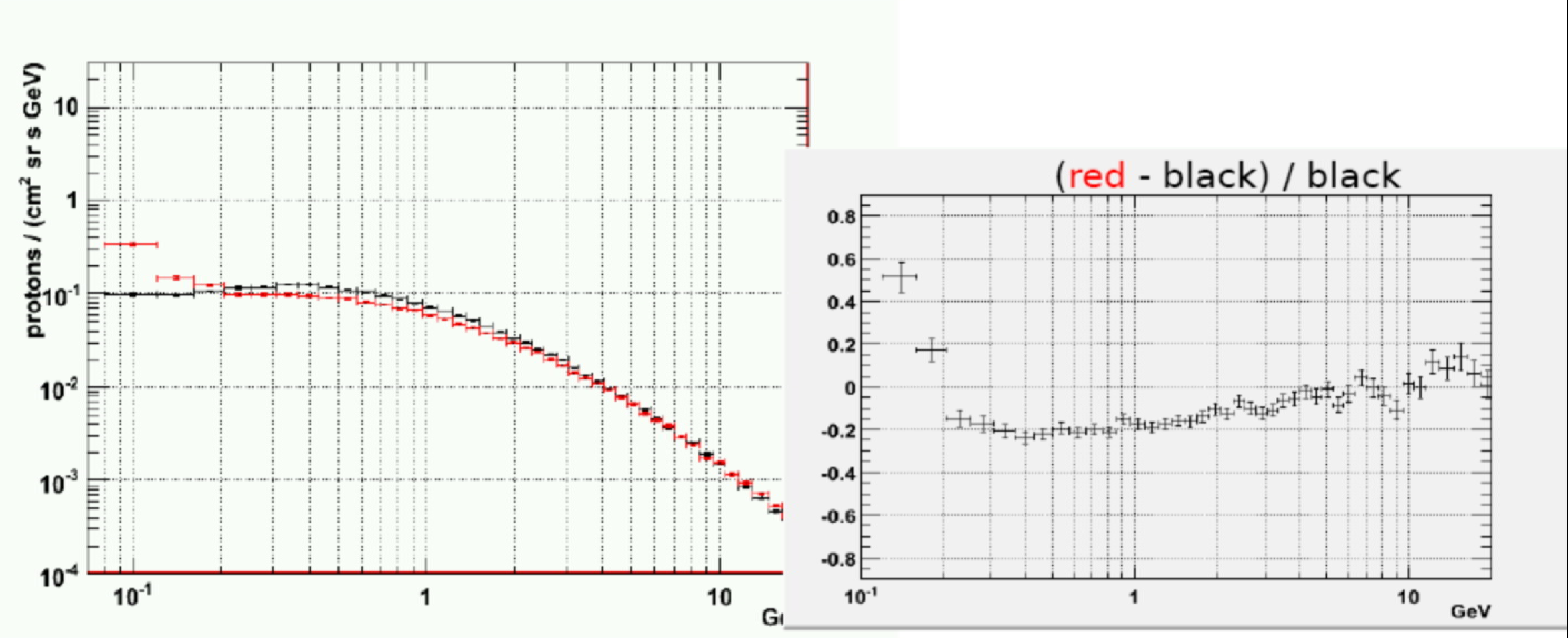




The 14th December 2006 Forbush Decrease

from 2006-12-1 to 2006-12-4

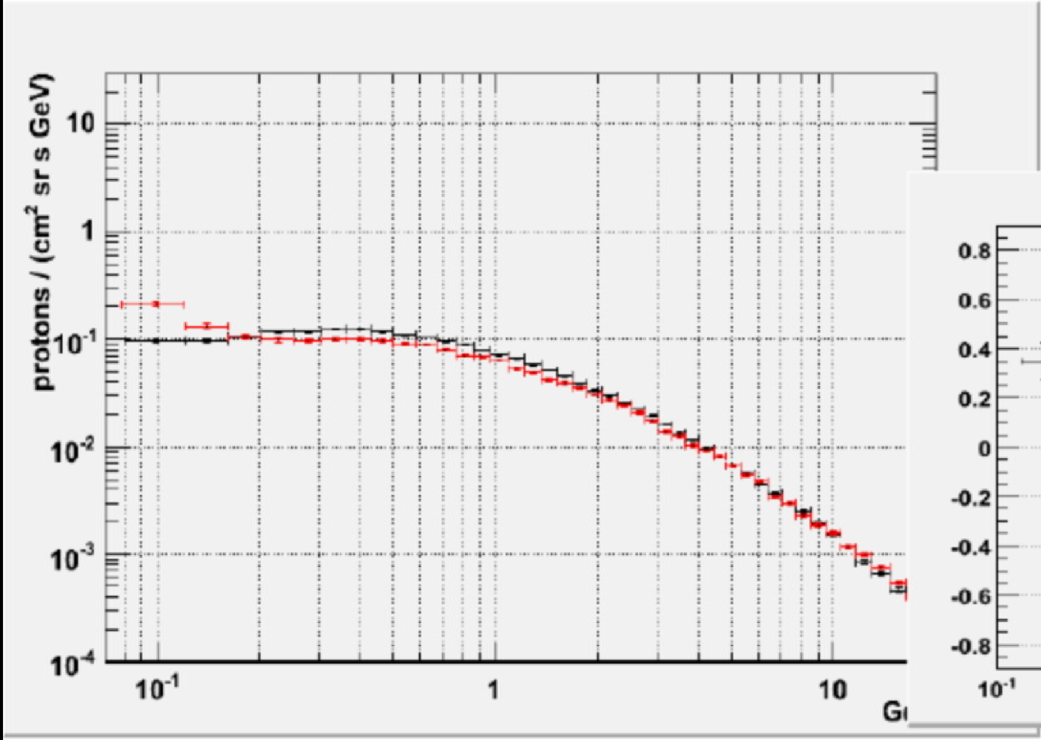
from 2006-12-17 00:00:04 a 2006-12-17 23:59:59

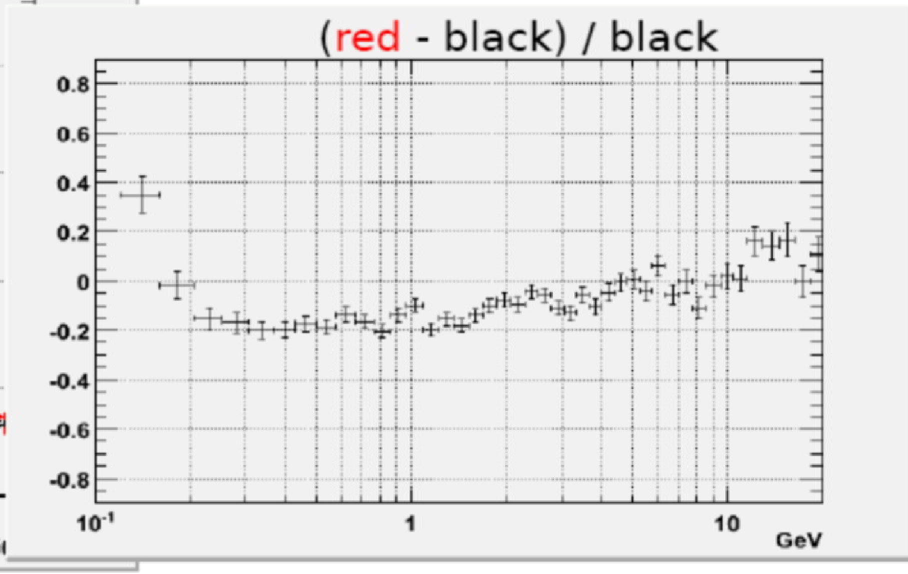


The 14th December 2006 Forbush Decrease

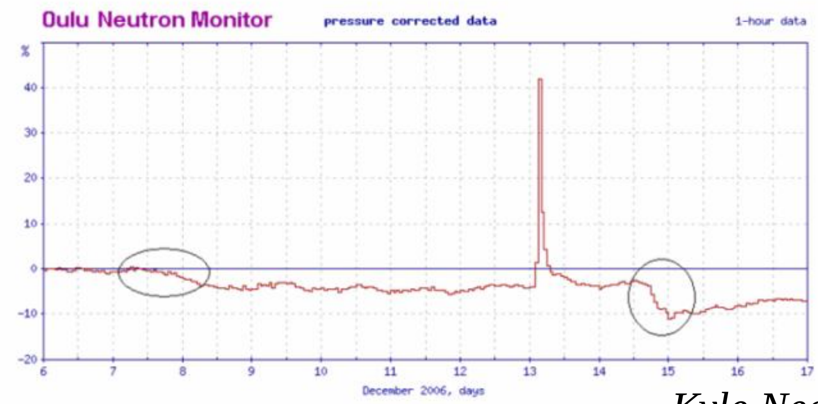
from 2006-12-1 to 2006-12-4

from 2006-12-17 00:00:04 a 2006-12-17 23:59:59



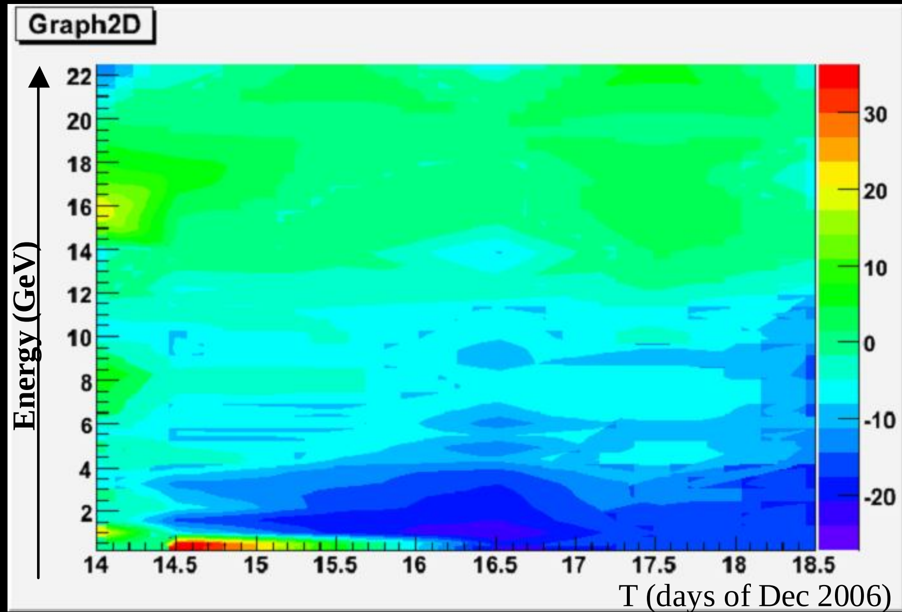


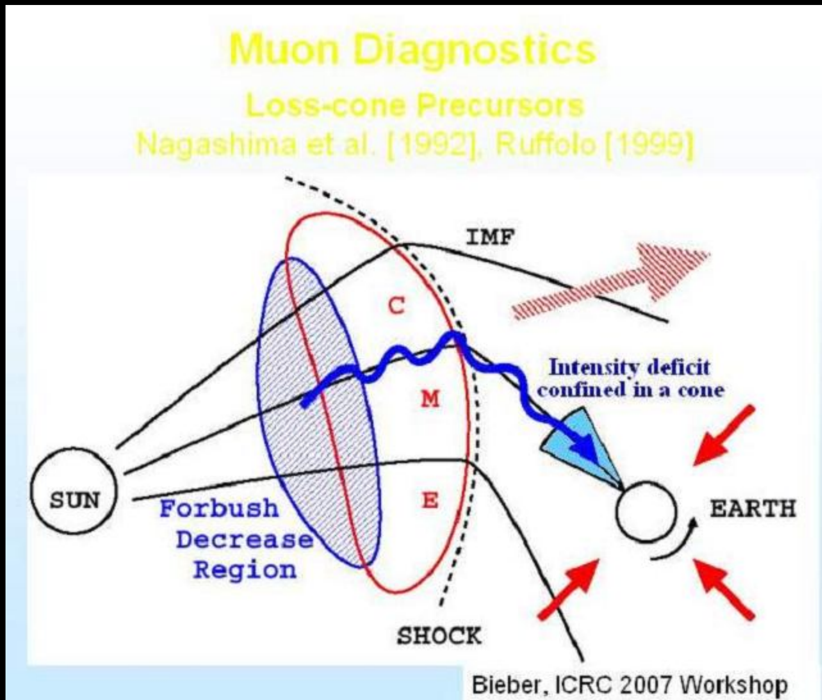
Forbush Decrease from space

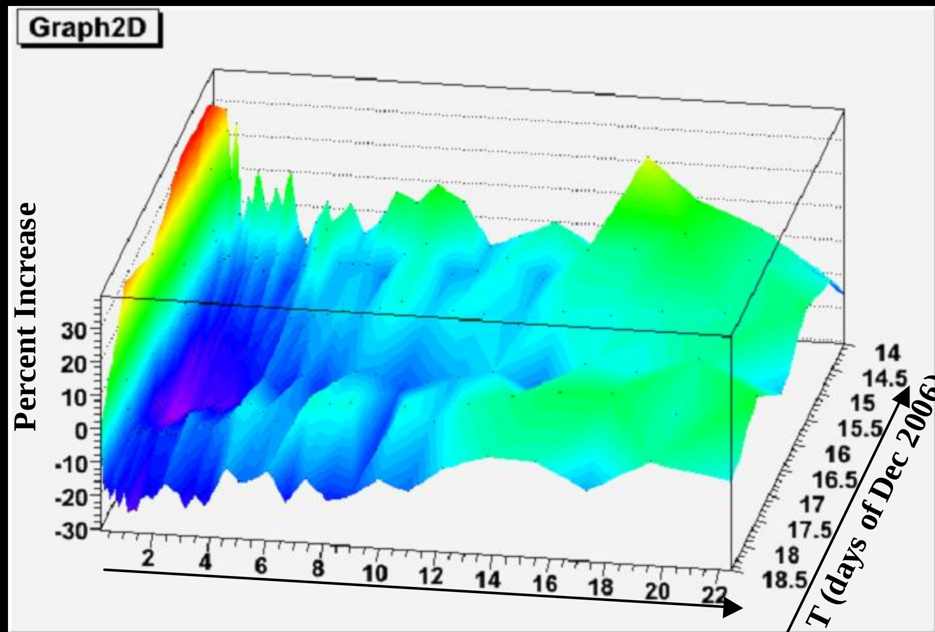


Kyle Neary

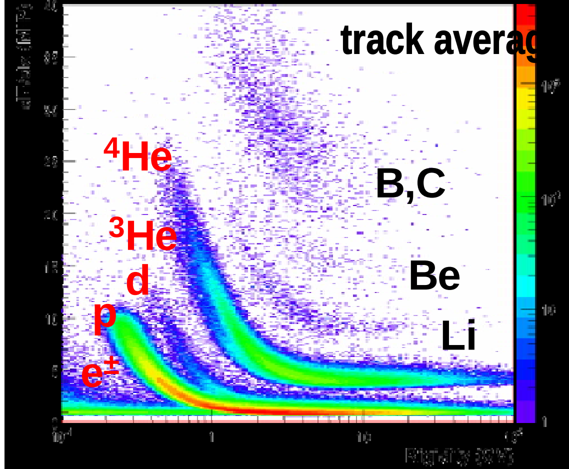
Figure 2: Circled are the Forbush decreases that occurred directly before and after the GLE. [2]

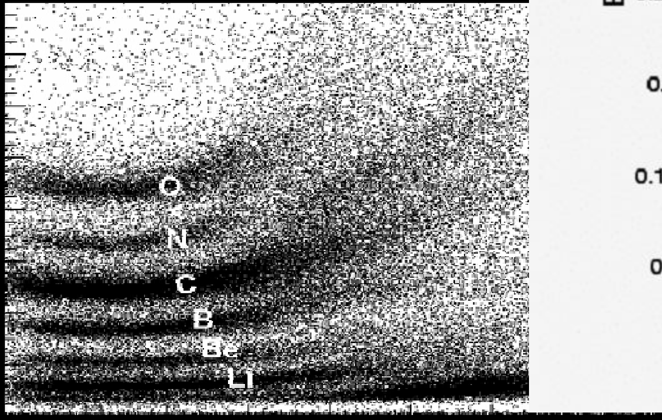


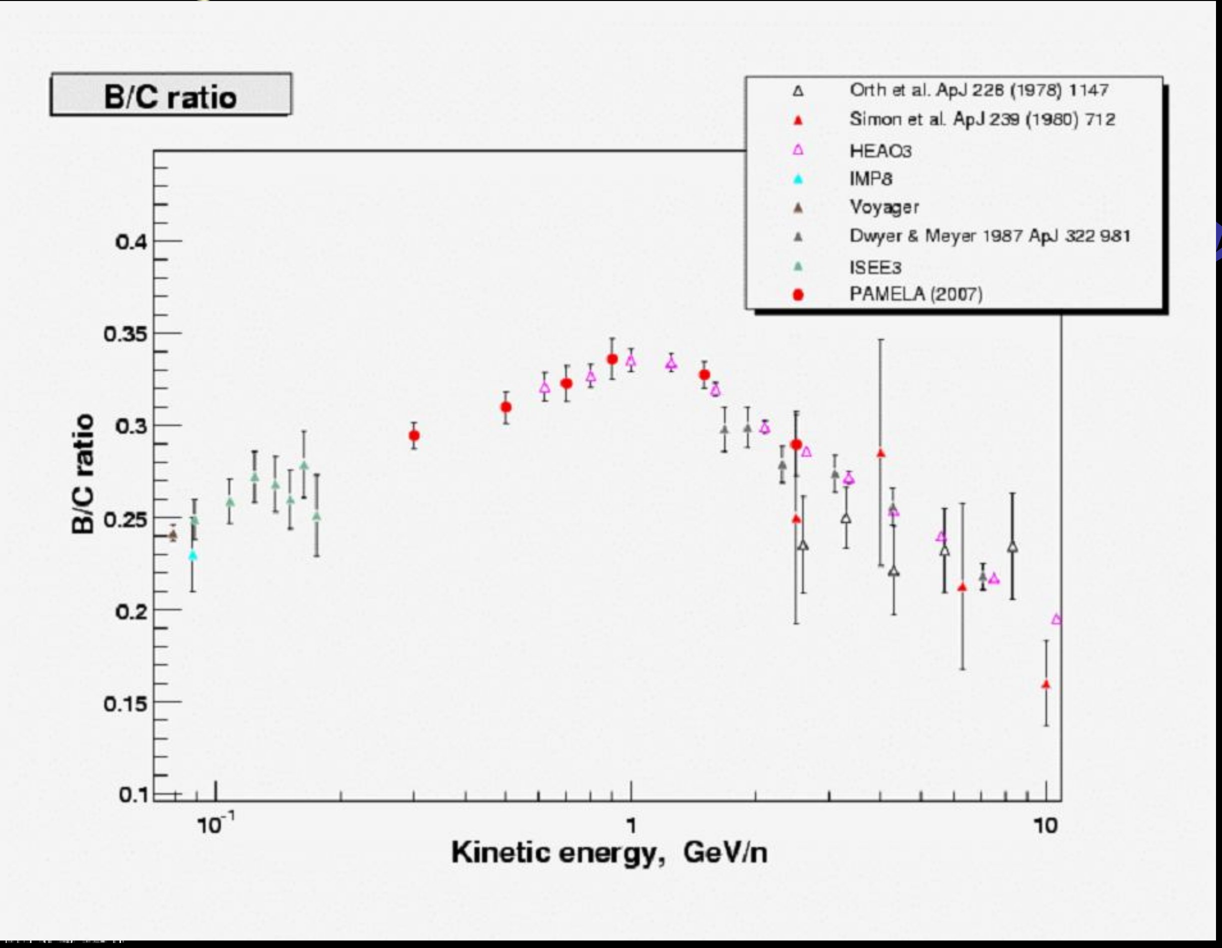




Preliminary Results B/C

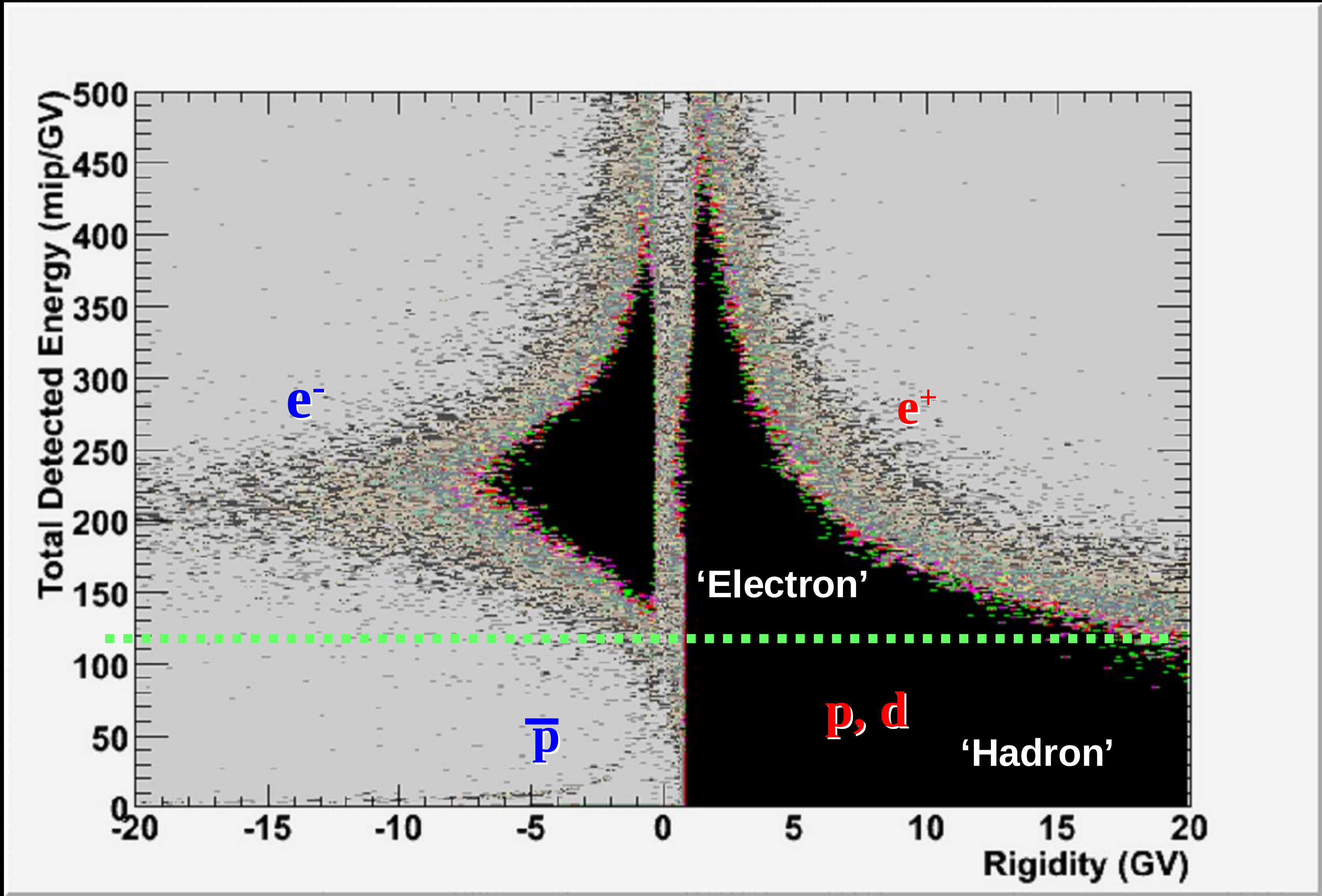






Boron is a secondary particle.
Its abundance is relevant for propagation in the Galaxy

Calorimeter Selection Criteria for Antiprotons

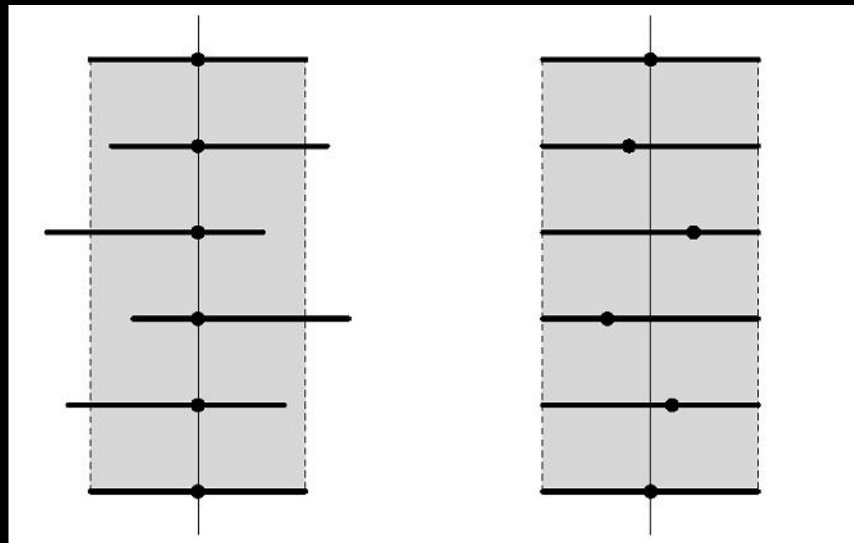


From M. Boezio

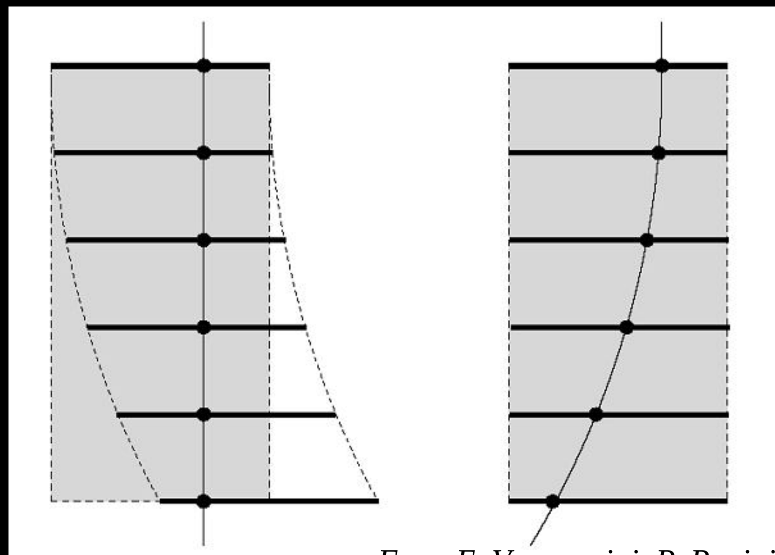
Alignment

Critical Issue: an antiparticle
Can be faked if alignment of the
detector is wrongly considered

Incoherent misalignment
Correction with protons
2 steps: column alignment +
inter-column alignment



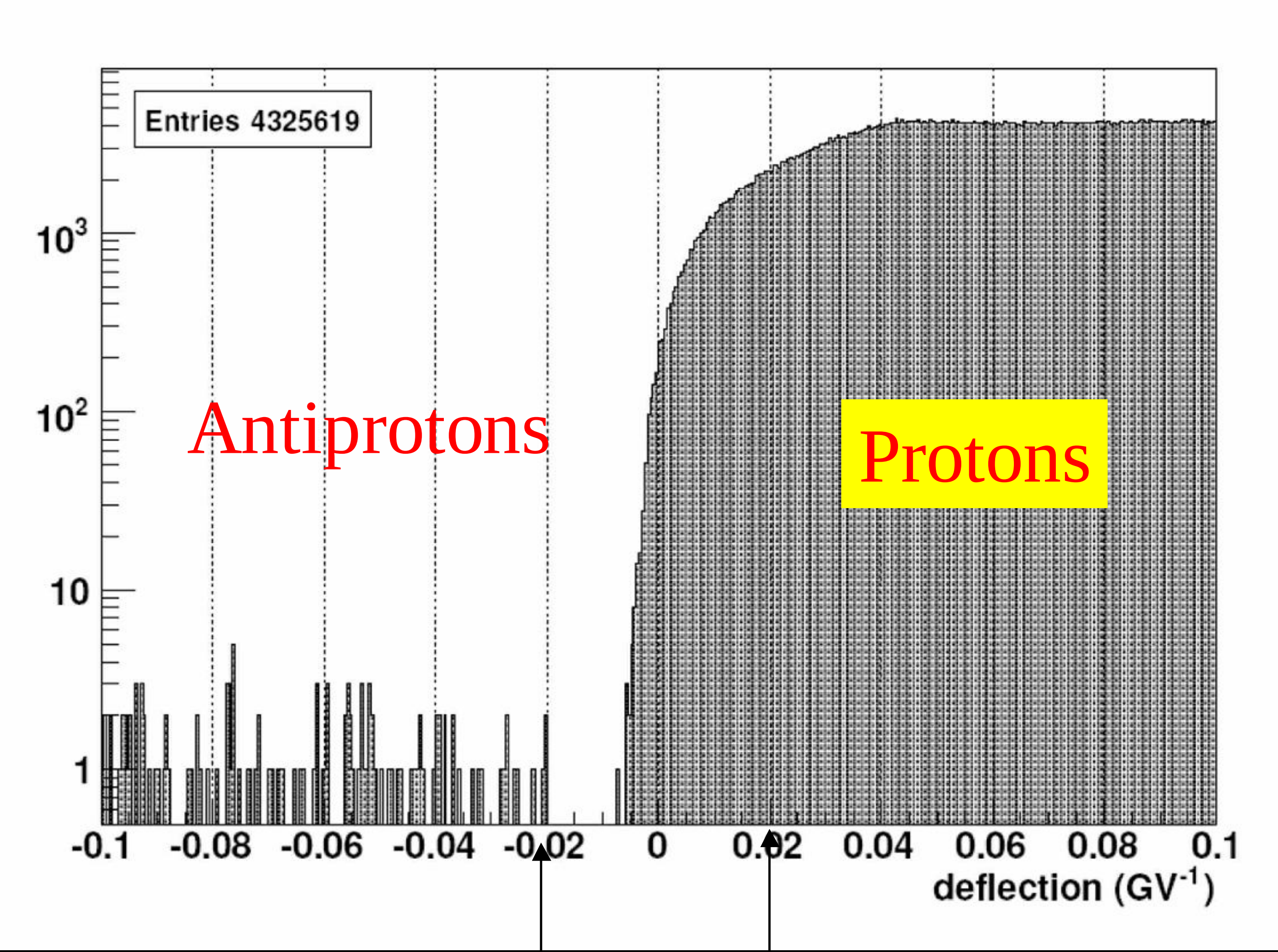
Coherent misalignment
Correction with electrons
(or electrons + positrons)
and comparison with
simulation



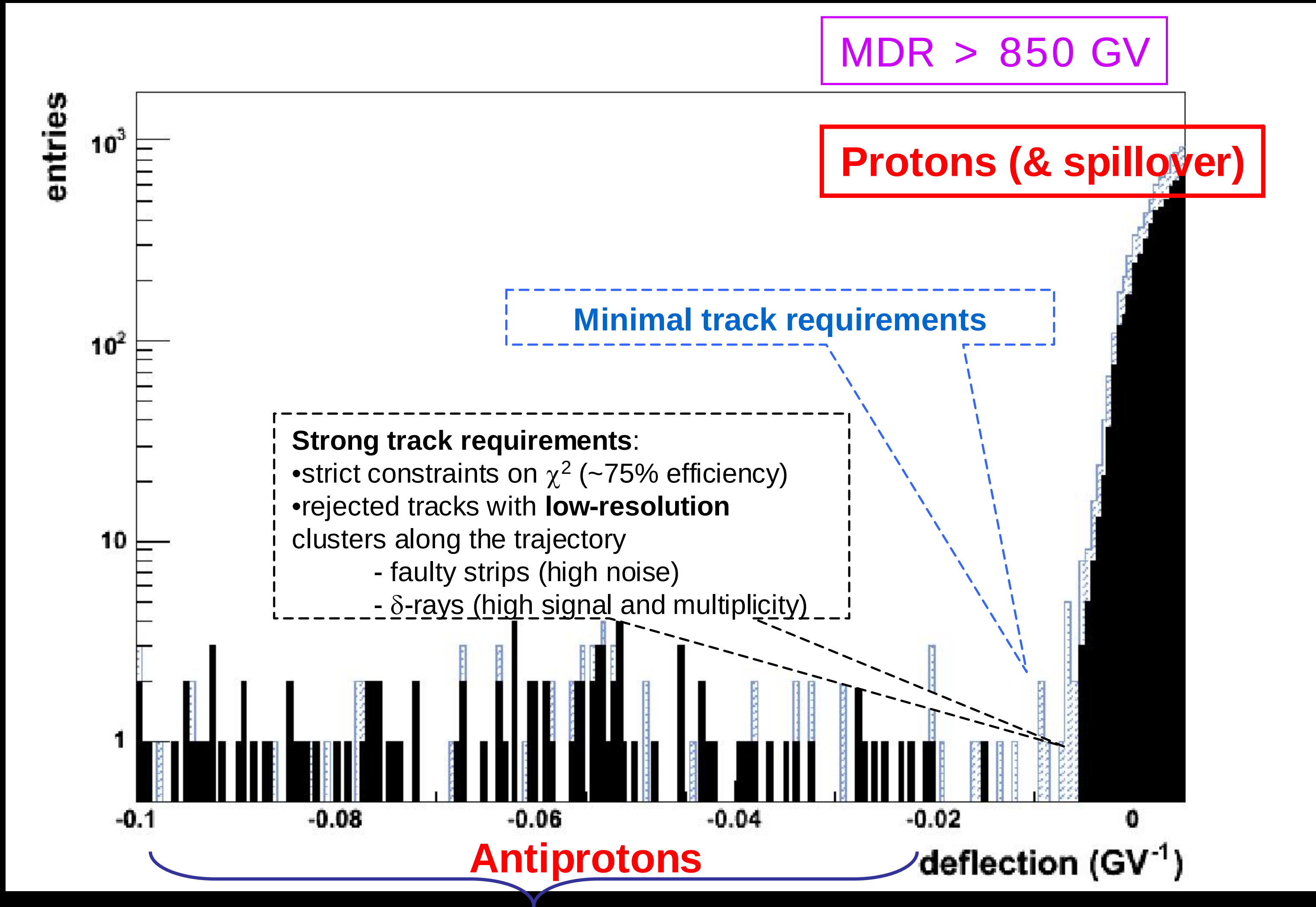
Deflection

D=1/R

Very sharp and conservative cuts Maximum lever (top and bottom planes of the spectrometer must be hit) arm in magnet to keep spillover under control Then release this criterium

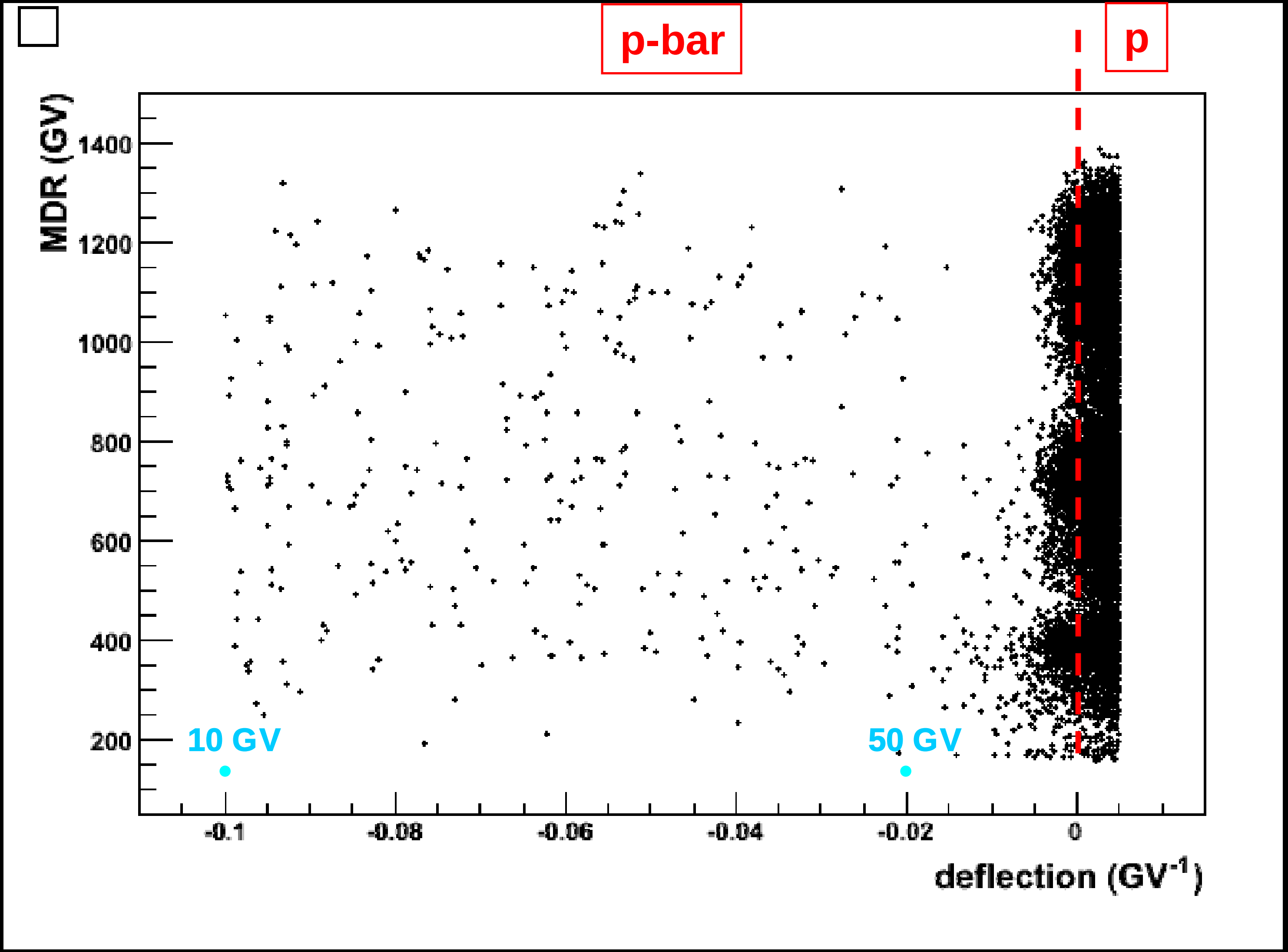


Proton spillover background



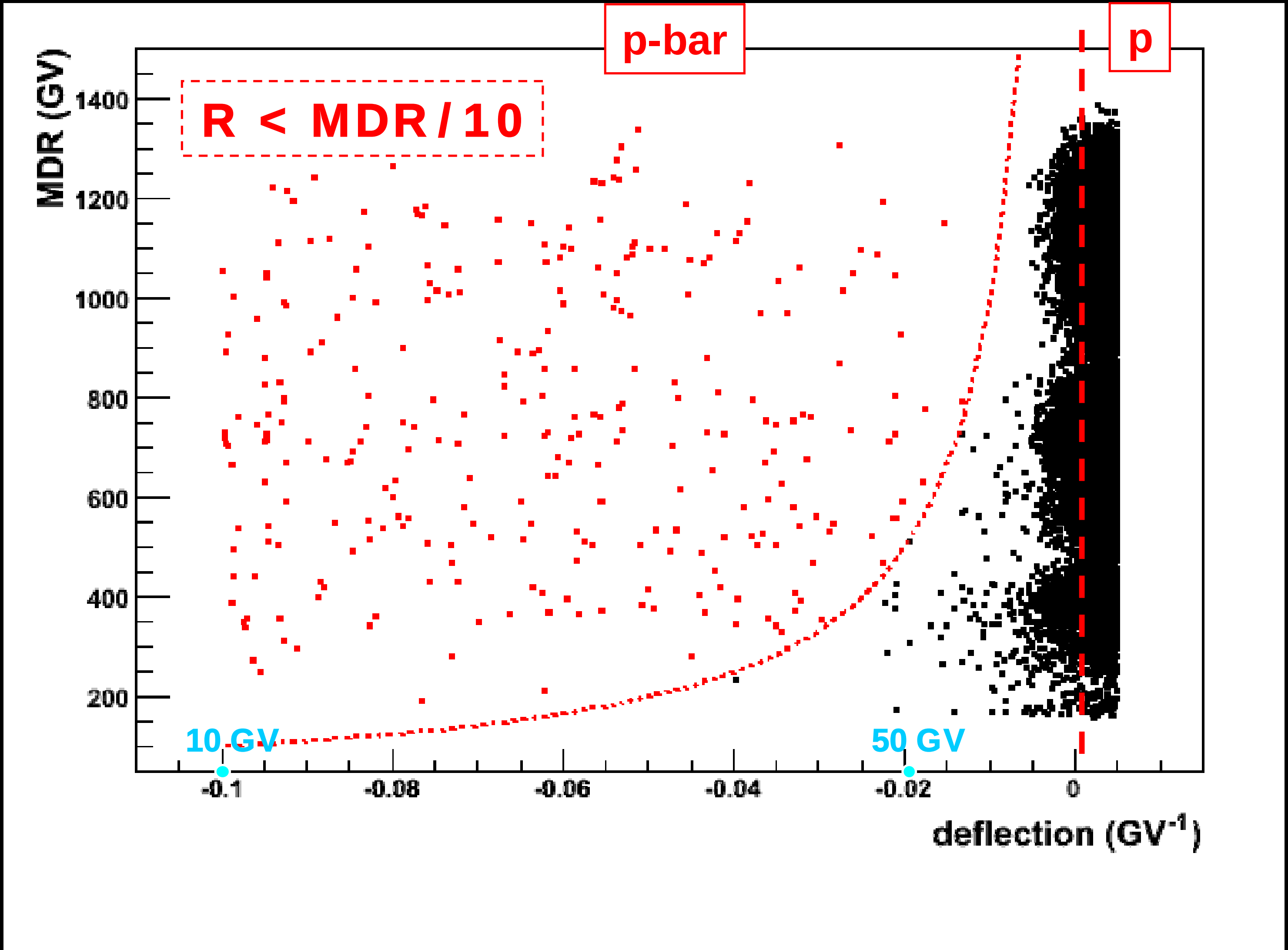
From O. Adriani ata

High-energy antiproton selection



From O. Adriani

High-energy antiproton selection



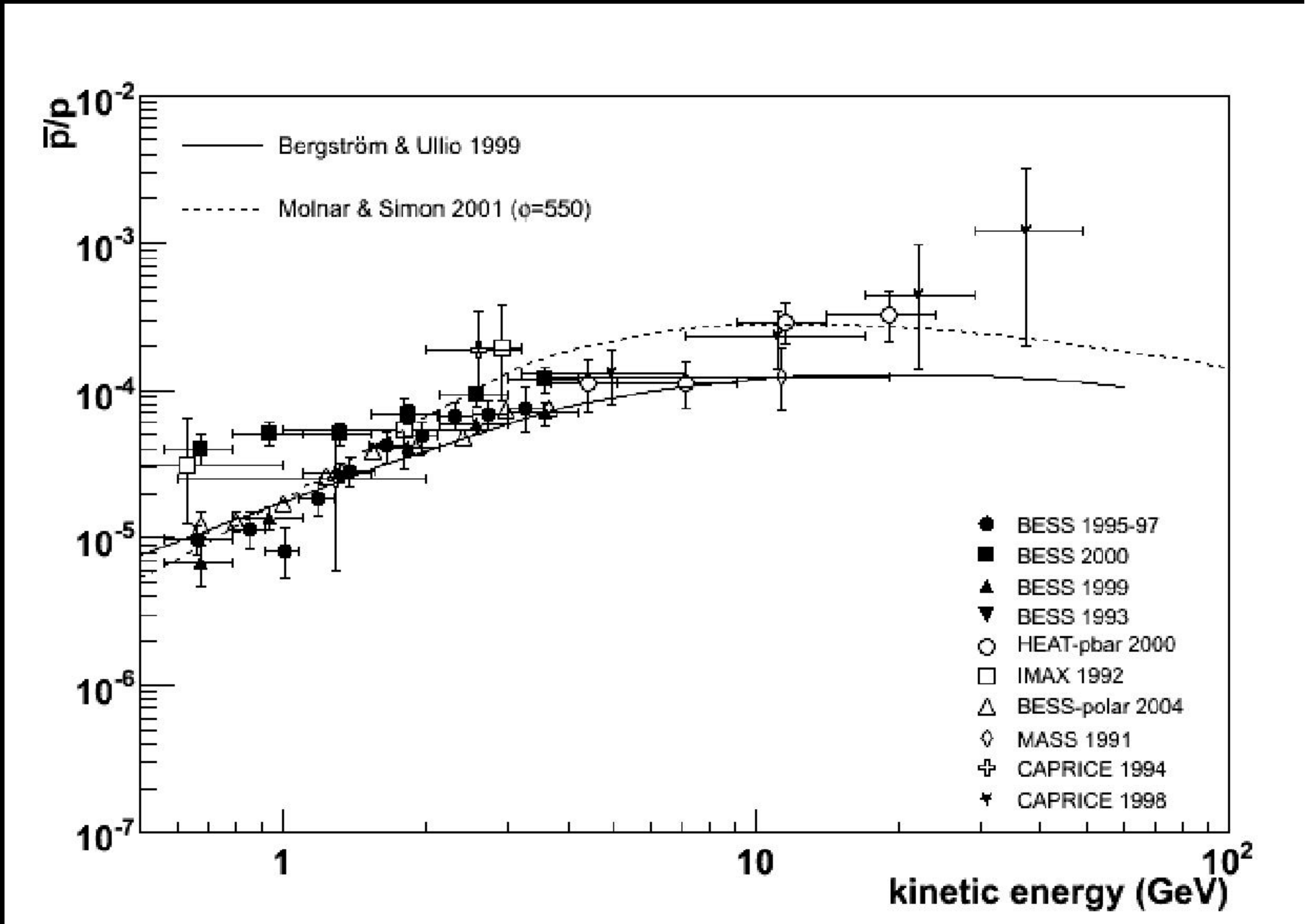
From O. Adriani

Antiproton-Proton Ratio

Why Ratios?

Reduce systematic error
All (most) efficiencies cancel out

Subsequently absolute fluxes



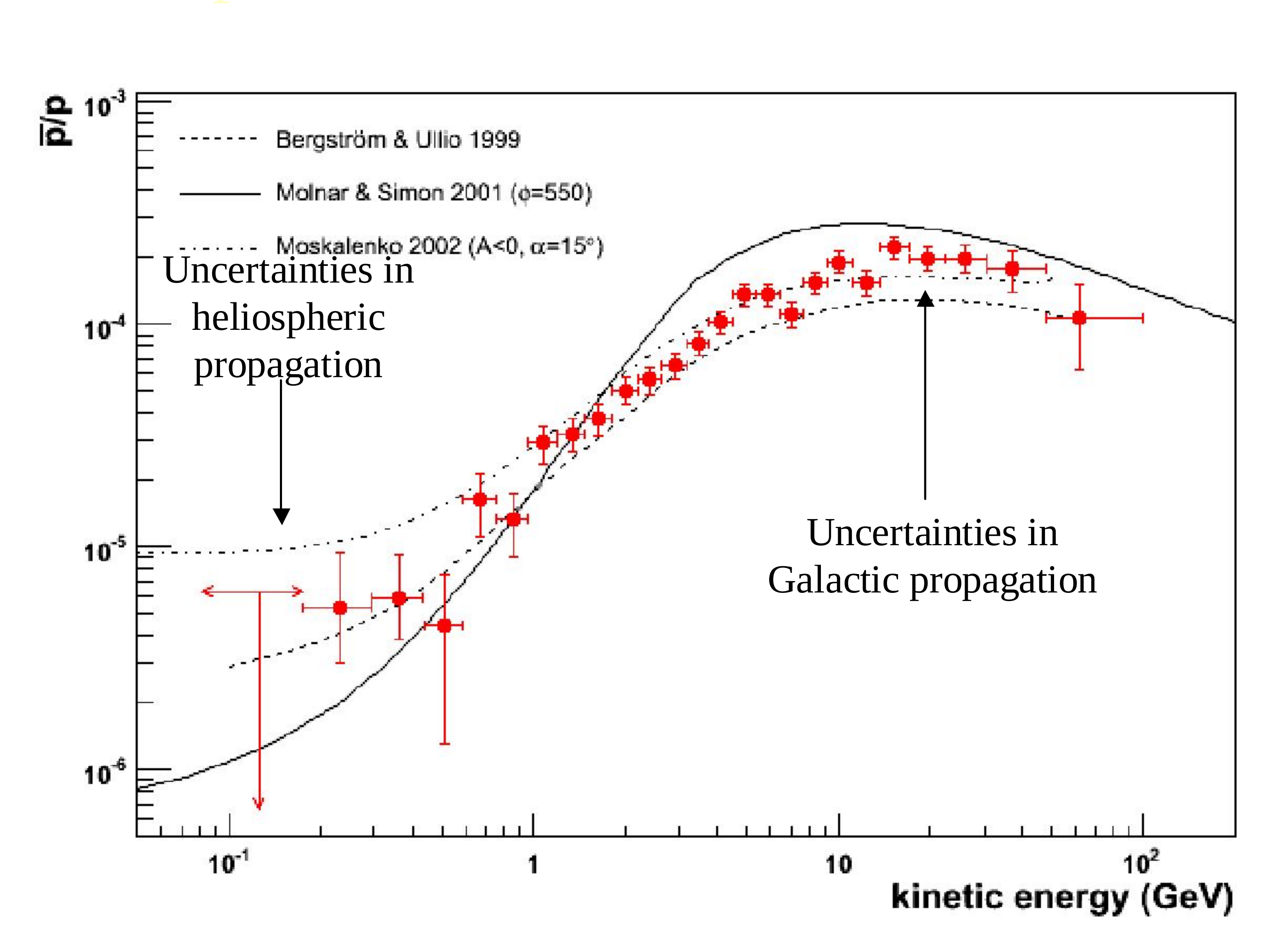
Antiproton ratio measured with Pamela: Comparison with theoretical models

Released data
1-100 GeV

Currently roughly 10 TB of data

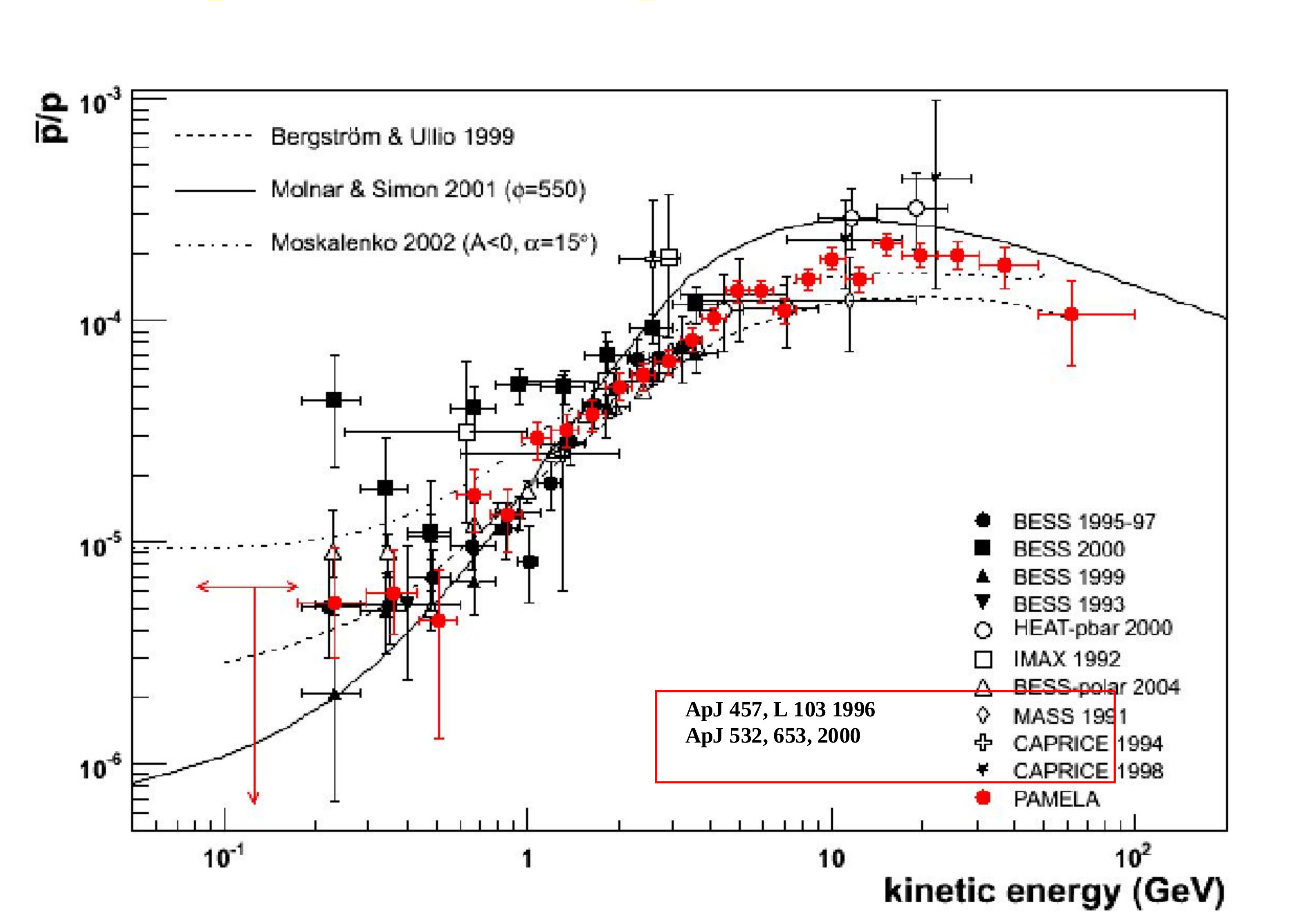
As of March '08
Out of 8.8 TB

- 10^7 p
- 800 p^-



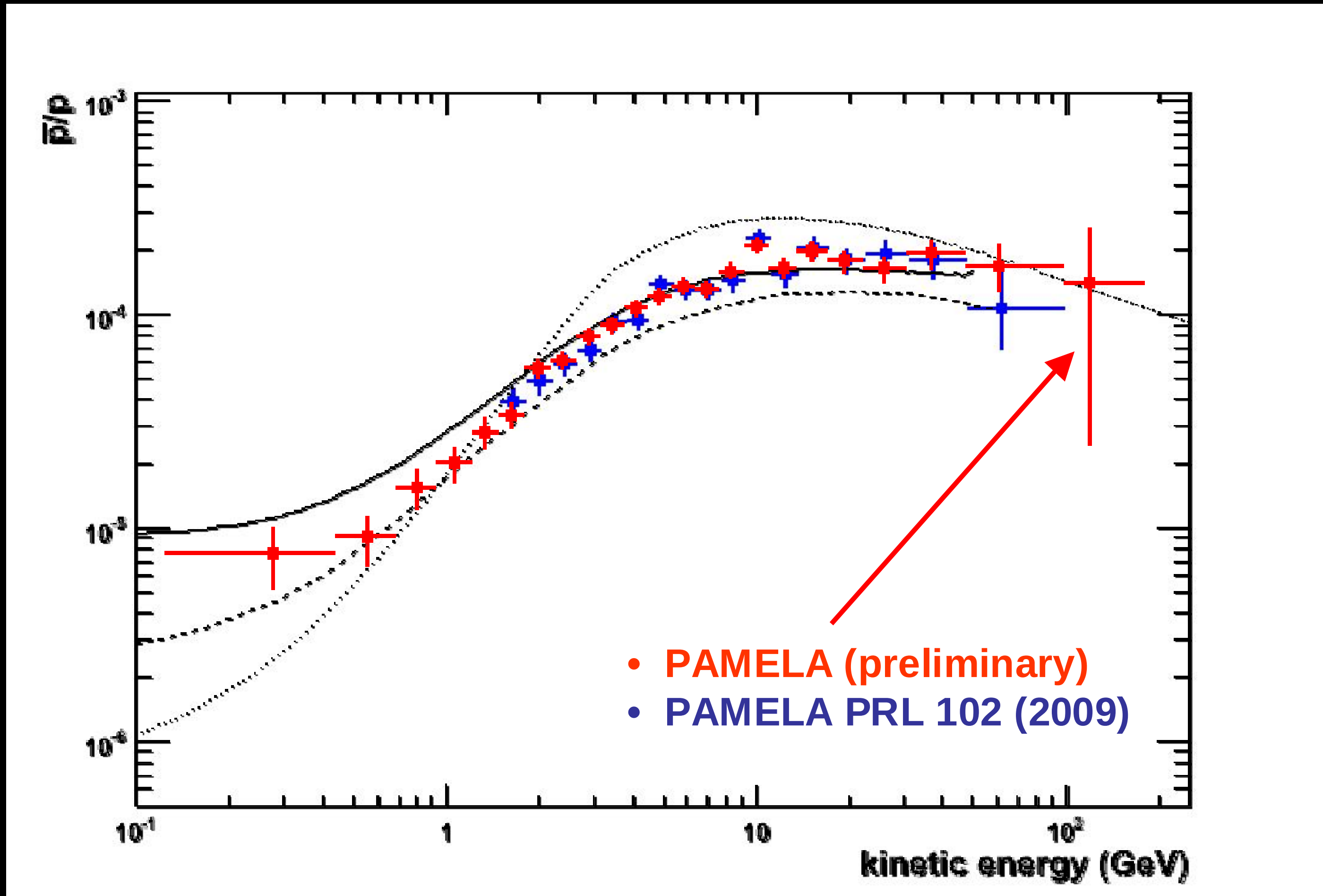
Antiproton ratio measured with Pamela: Comparison with experimental data

- •Highest energy up to now
- •Coherent with secondary production
- •Uncertainties of Galactic Propagation
- •Would favour Moskalenko 2002 (except highest energy)



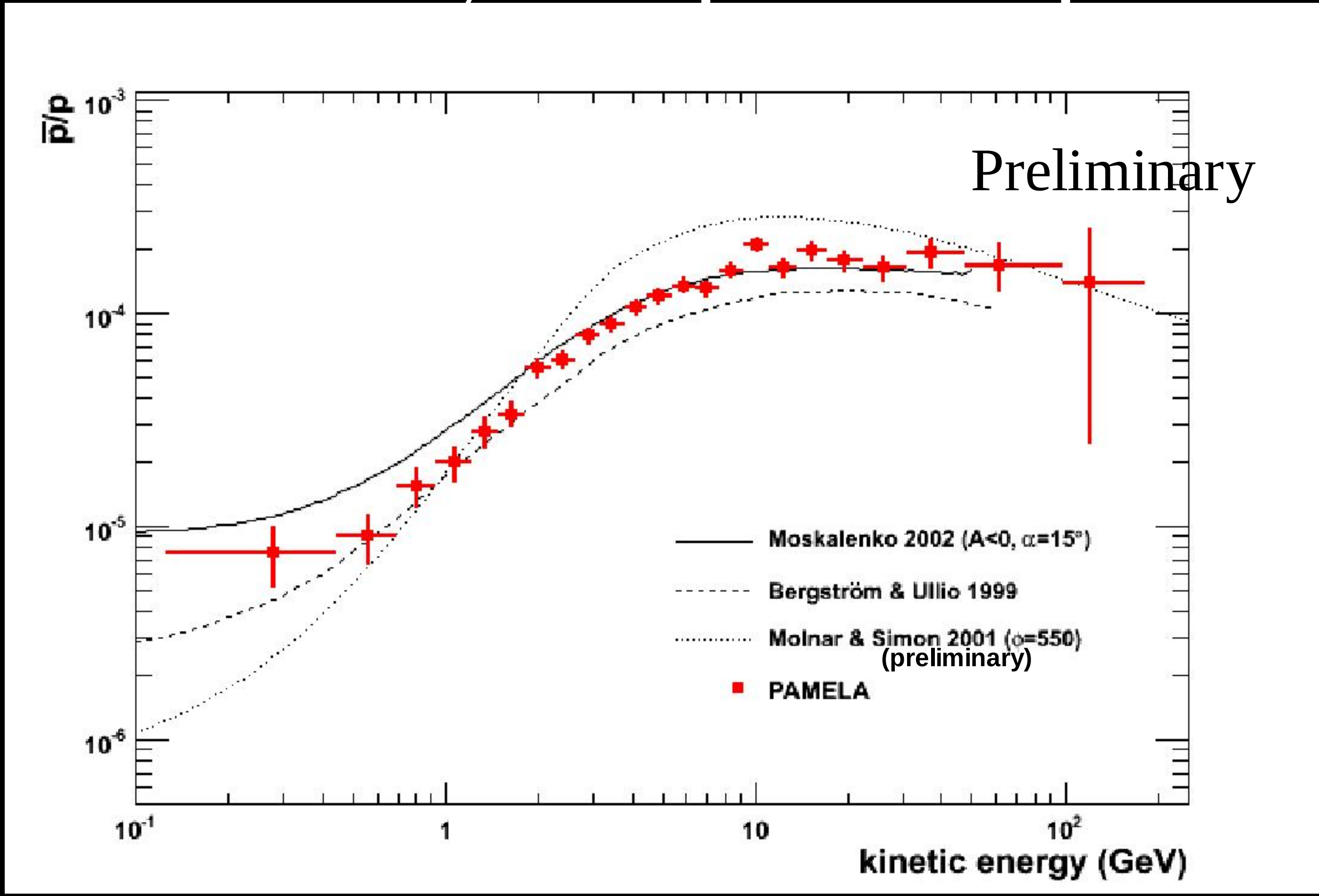
arXiv:0810.4994v1 [astro-ph] 28 Oct 2008 PRL

Antiproton ratio



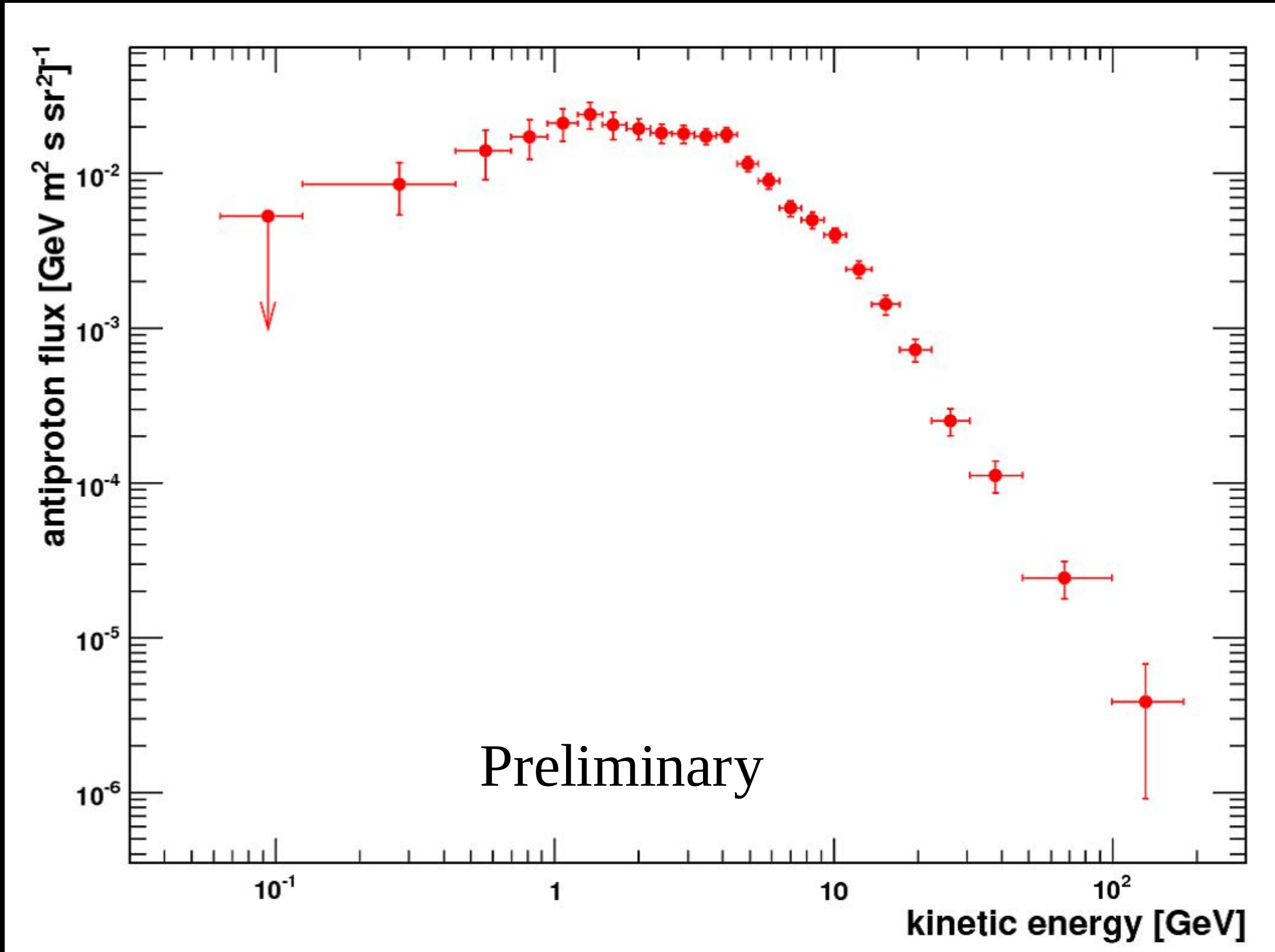
- New points consistent with old ones.

Preliminary antiproton spectrum



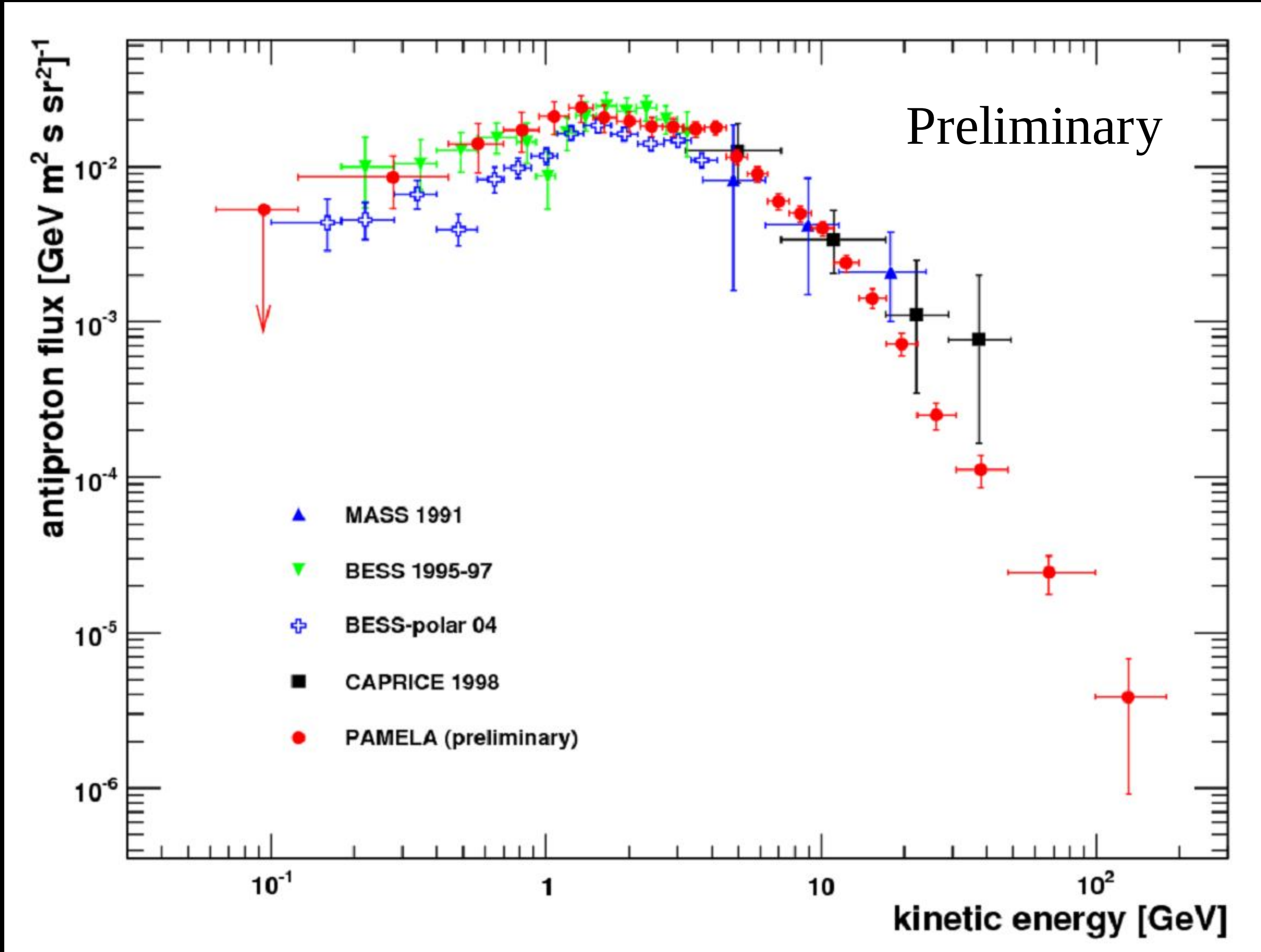
- highest bin: MDR > 6 · |R| is used to increase statistics..

Preliminary antiproton spectrum

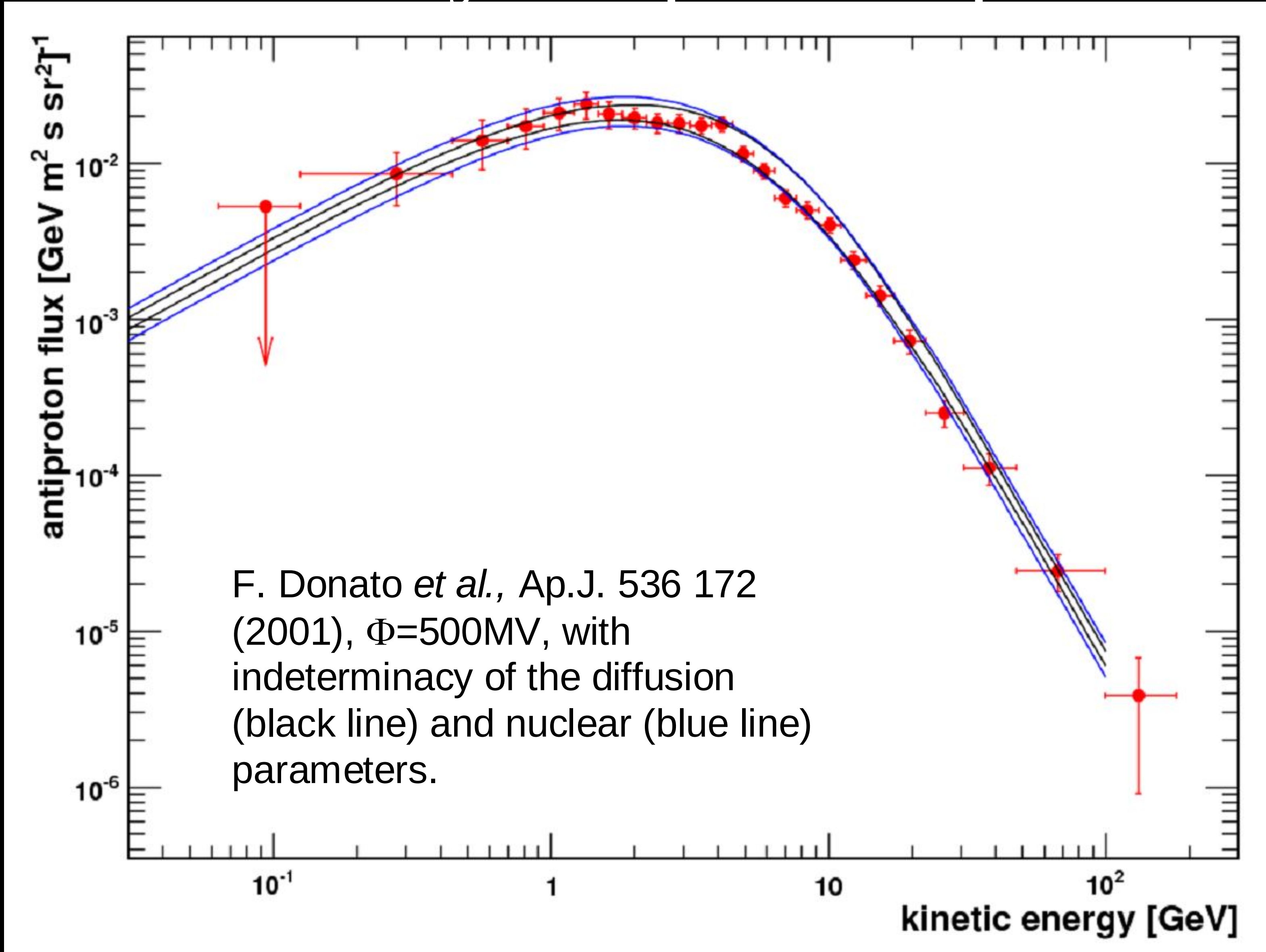


– Preliminary - Evaluation of systematics is under way.

Preliminary antiproton spectrum

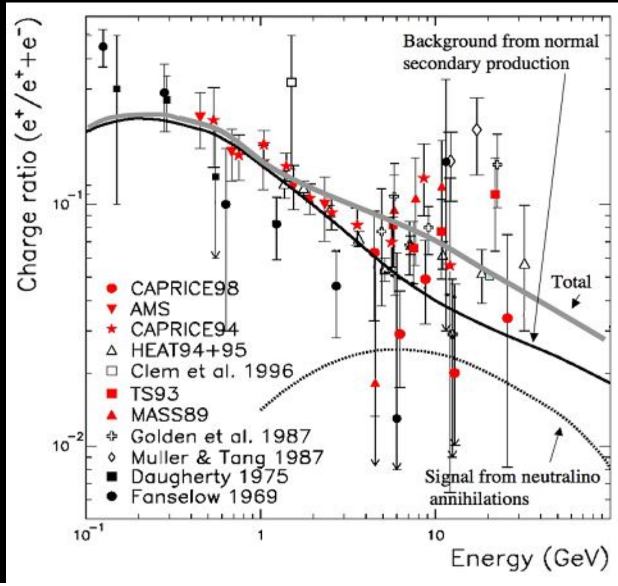


Preliminary antiproton spectrum



Positrons results

- Till August 30th about 20000 positrons from 200 MeV up to 200 GeV have been analyzed
- More than 15000 positrons over 1 GeV
- Other eight months data to be analyzed
- Selection criteria based on calorimeter
- Tuned and tested with
  - Montecarlo
  - Test Beam
  - In flight data
  - Cross-checked with Neutron Detector



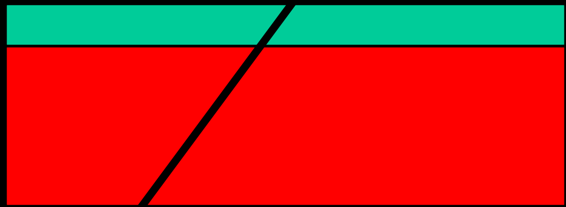
M. Casolino, INFN & University Roma Tor Vergata

Preshower Technique to reduce systematics of proton contamination:

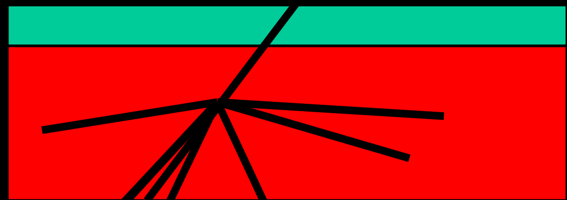
Optimize electromagnetic/hadronic shower discrimination, reduce systematics

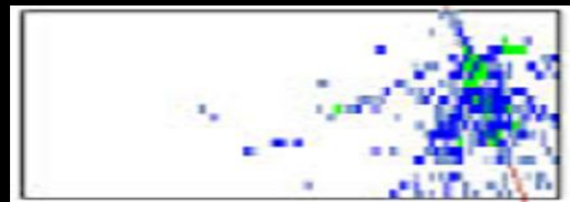
Protons:

- Non Interacting



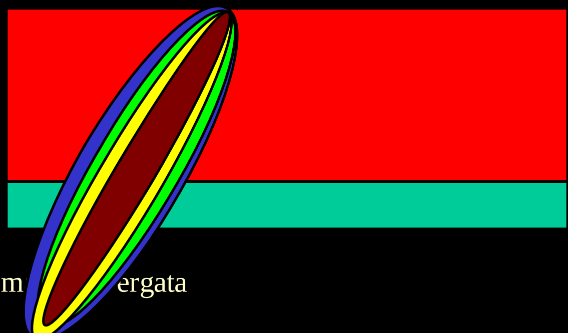
- Interacting

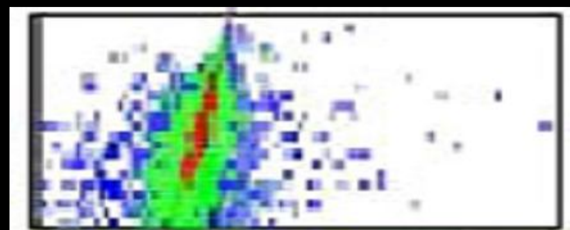




Electrons / Positrons

- Interacting (e.m.)

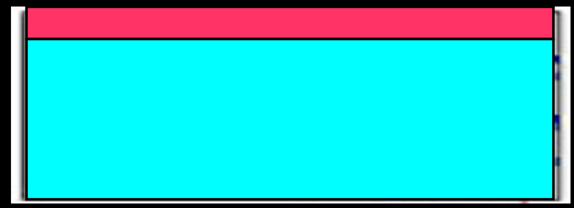




Recipe: M. Boezio, E. Mocchiutti

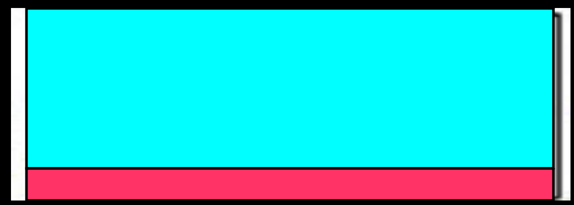
Preshower Technique to reduce systematics of proton contamination:

1. Take straight track in SmallTop → Select Protons
   Take interacting protons in BigBottom
   (known sample of hadronic shower. No leptons)



P hadronic shower

2. Define cuts (energy/topology) on 40 layers
   Using "BigTop" for e.m. showers (electrons)
   "BigBottom" for hadronic showers (protons)



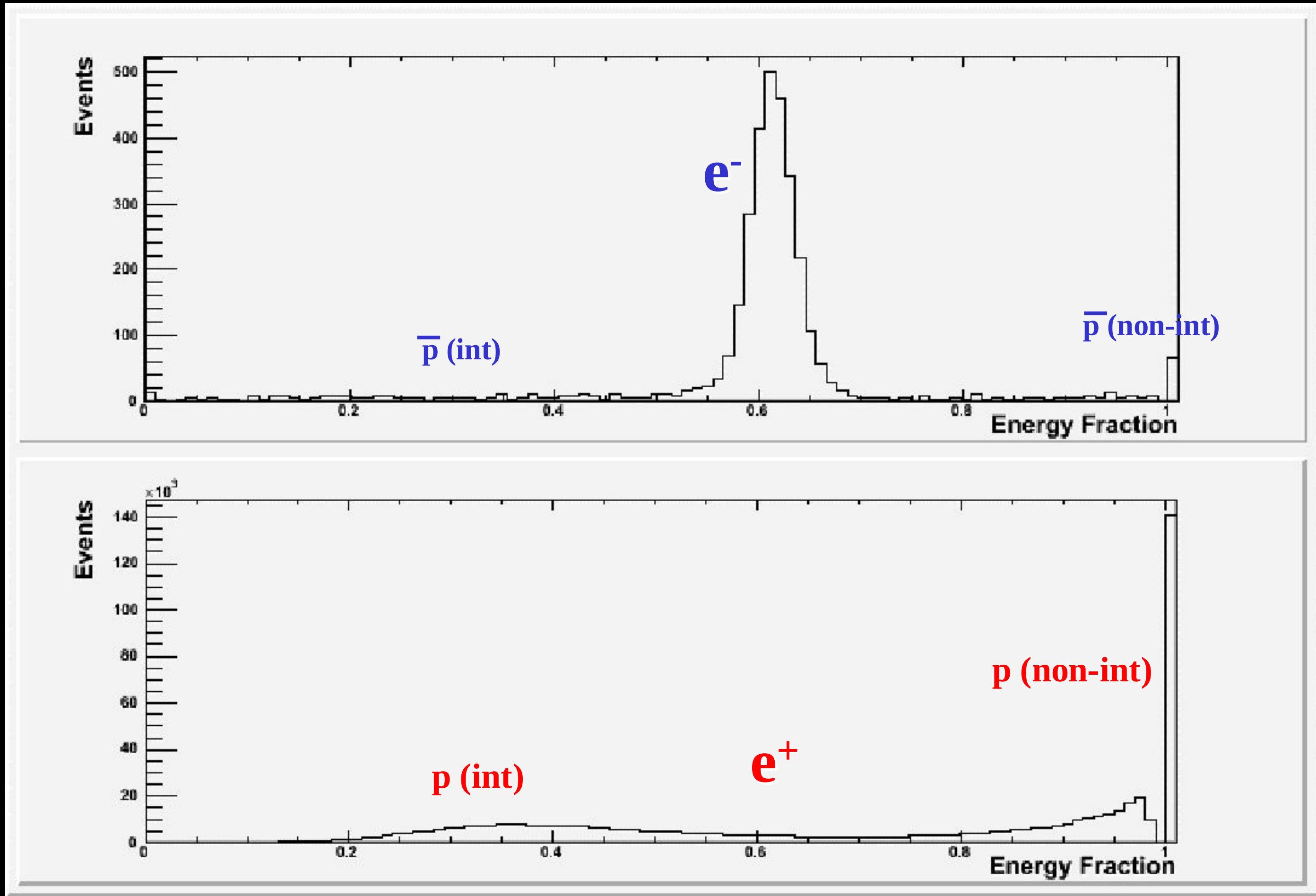
$e^{+/-}$ e.m. shower

3. Apply cuts to the positron sample

4. Apply cuts to electron sample to estimate efficiency

Positron selection with calorimeter (1)

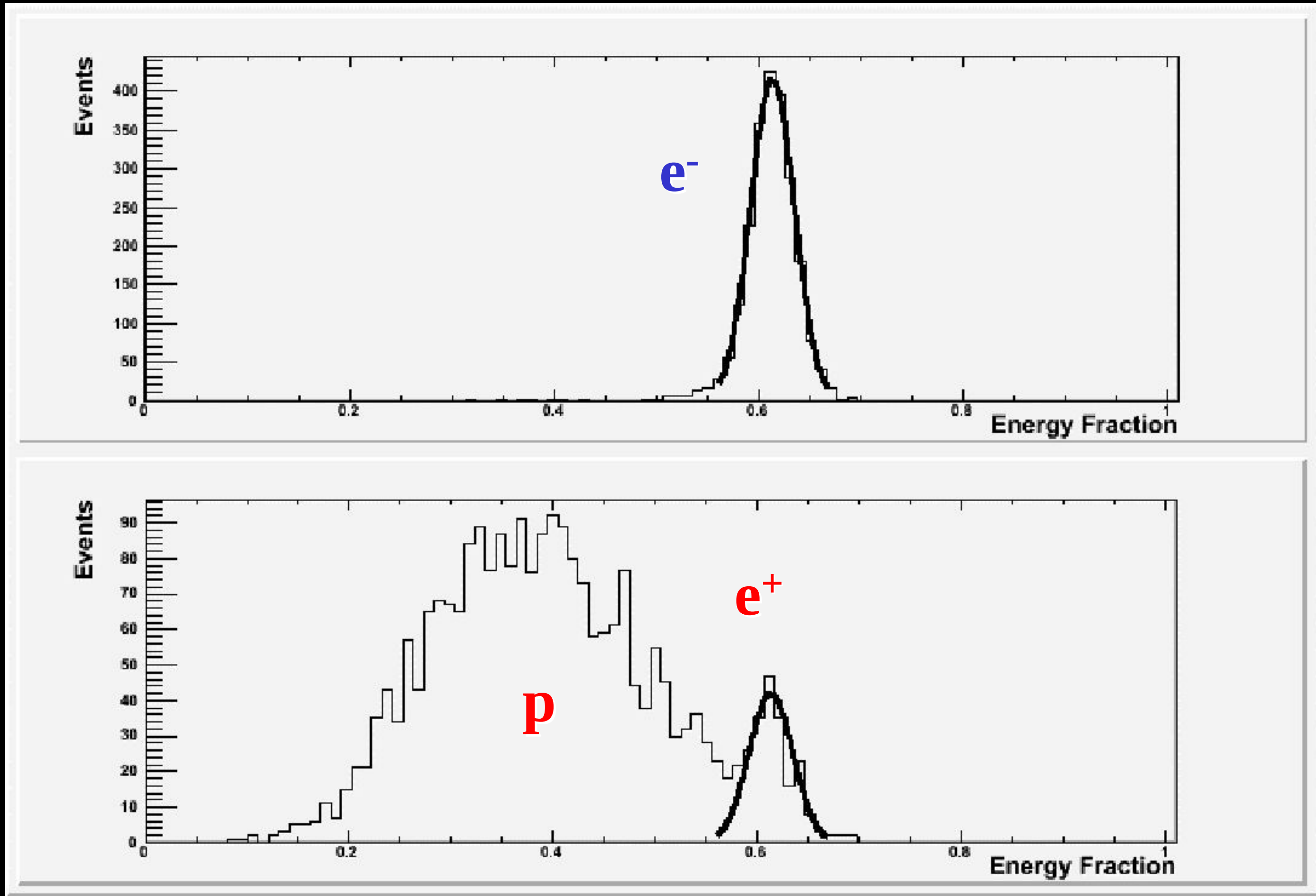
Rigidity: 20-30 GV



Fraction of charge released along the calorimeter track (left, hit, right)

Positron selection with calorimeter (2)

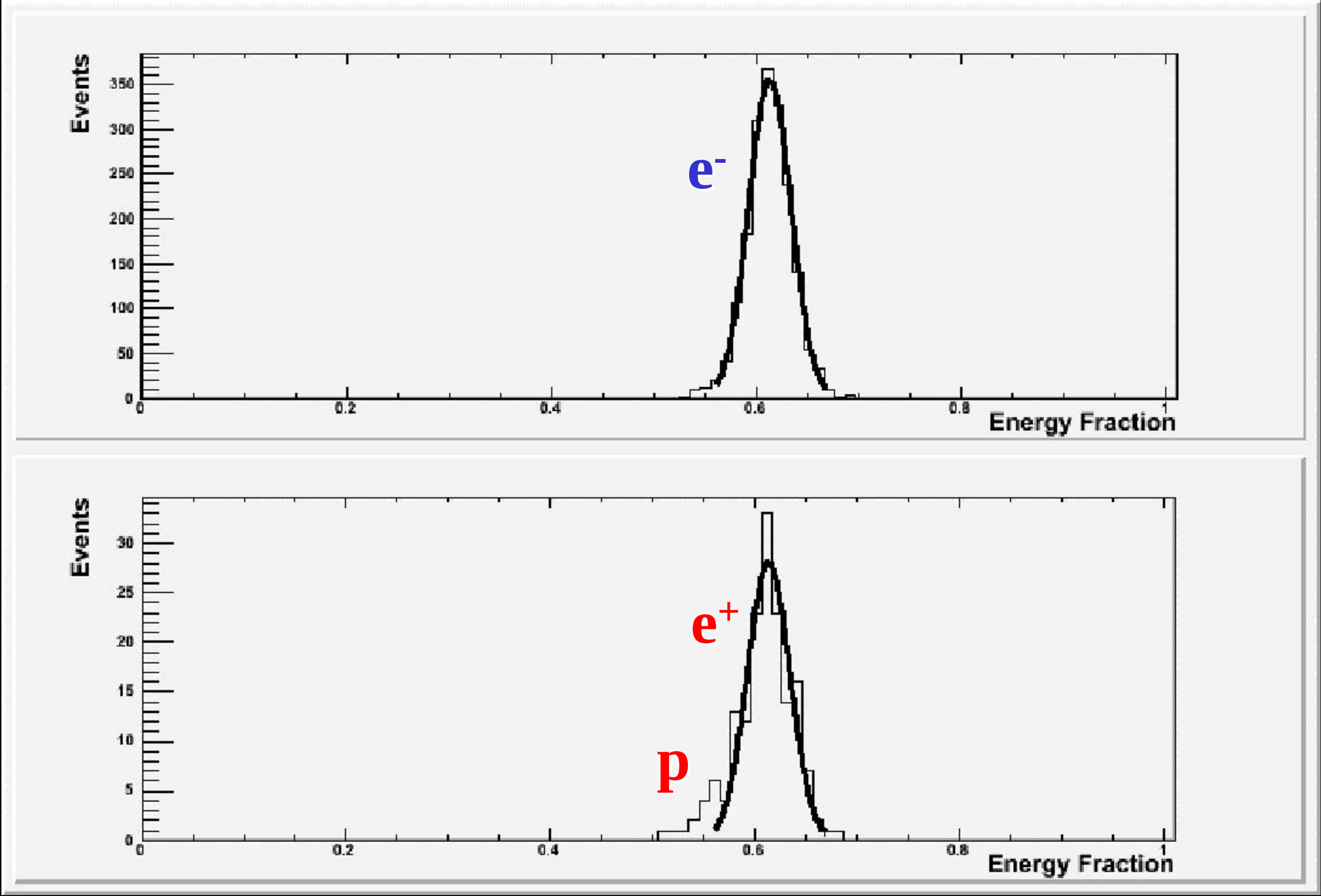
Rigidity: 20-30 GV



Fraction of charge released along the calorimeter track (left, hit, right) **+** **Energy-momentum match**

Positron selection with calorimeter (3)

Rigidity: 20-30 GV



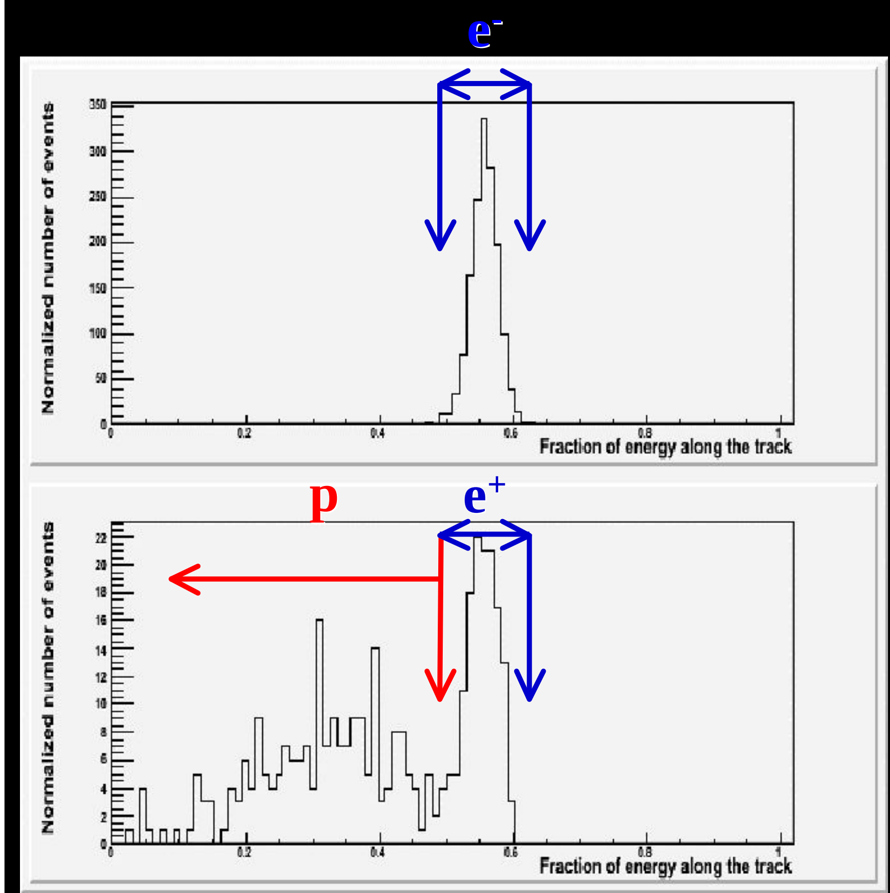
Fraction of charge released along the calorimeter track (left, hit, right) **+** **Energy-momentum match** **+**

- **Starting point of shower**
  Longitudinal profile

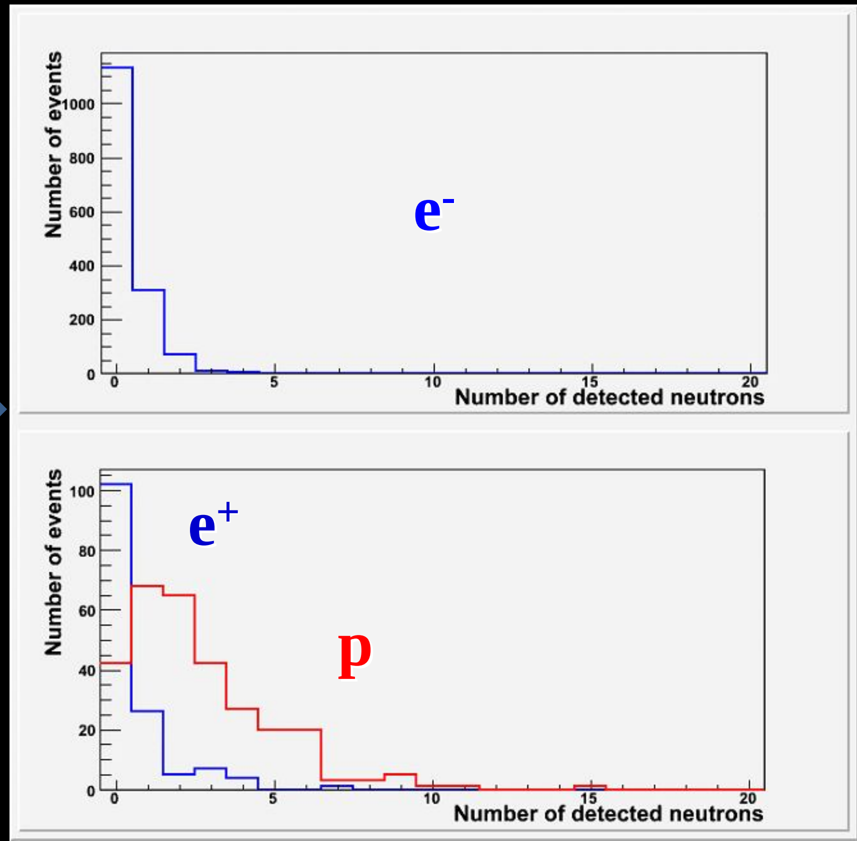
Positron selection (4)
Indipendent selection/check with ND

Rigidity: 20-30 GV

Fraction of charge released along the calorimeter track (left, hit, right)



Neutrons detected by ND

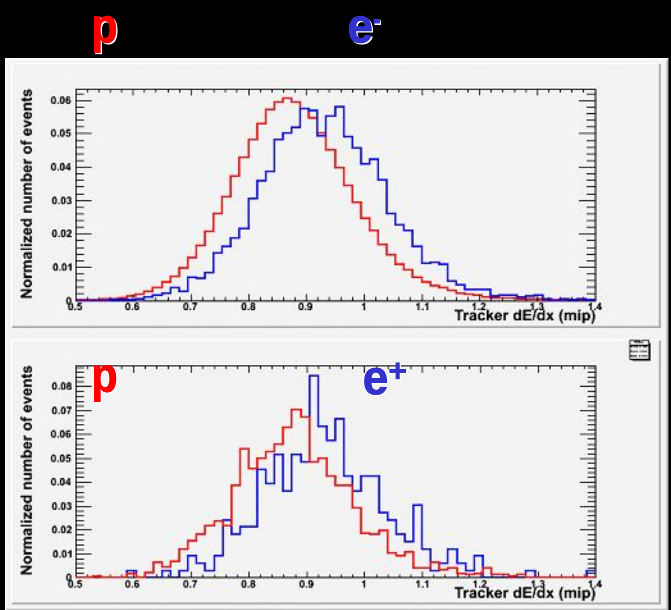


Energy-momentum match
Starting point of shower

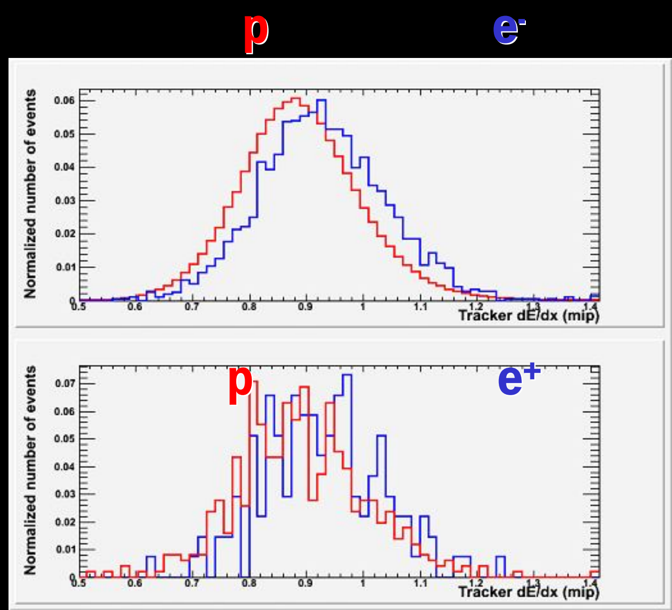
$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\rm max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

Top: proton and electron samples, identified with TRK only (charge sign).

Rigidity: 10-15 GV

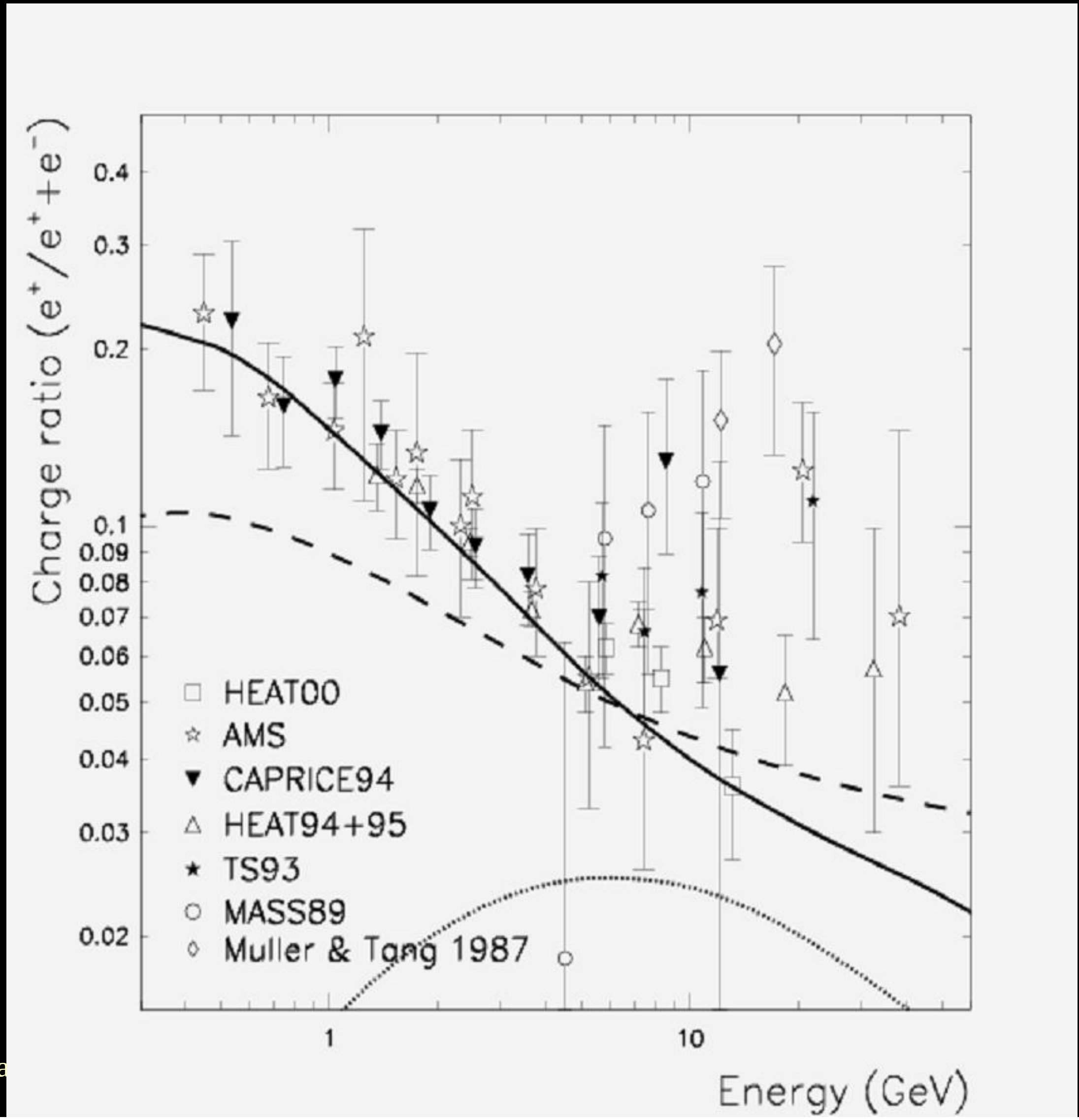


Rigidity: 15-20 GV



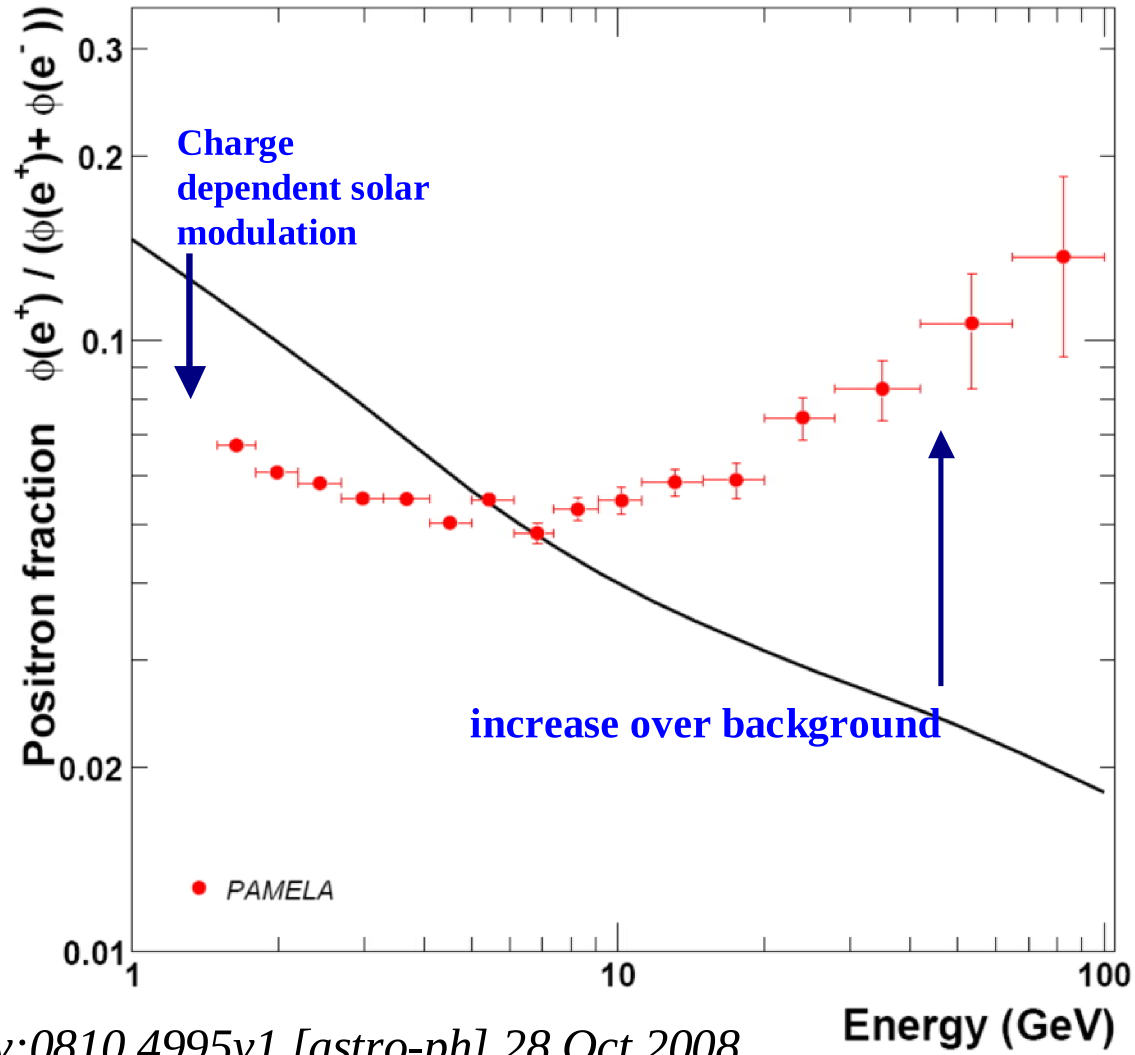
- Bottom: proton and positron (+ residual p background) samples, identified with present CALO requirements.

Status of Positron - Electron ratio



Pamela positron fraction

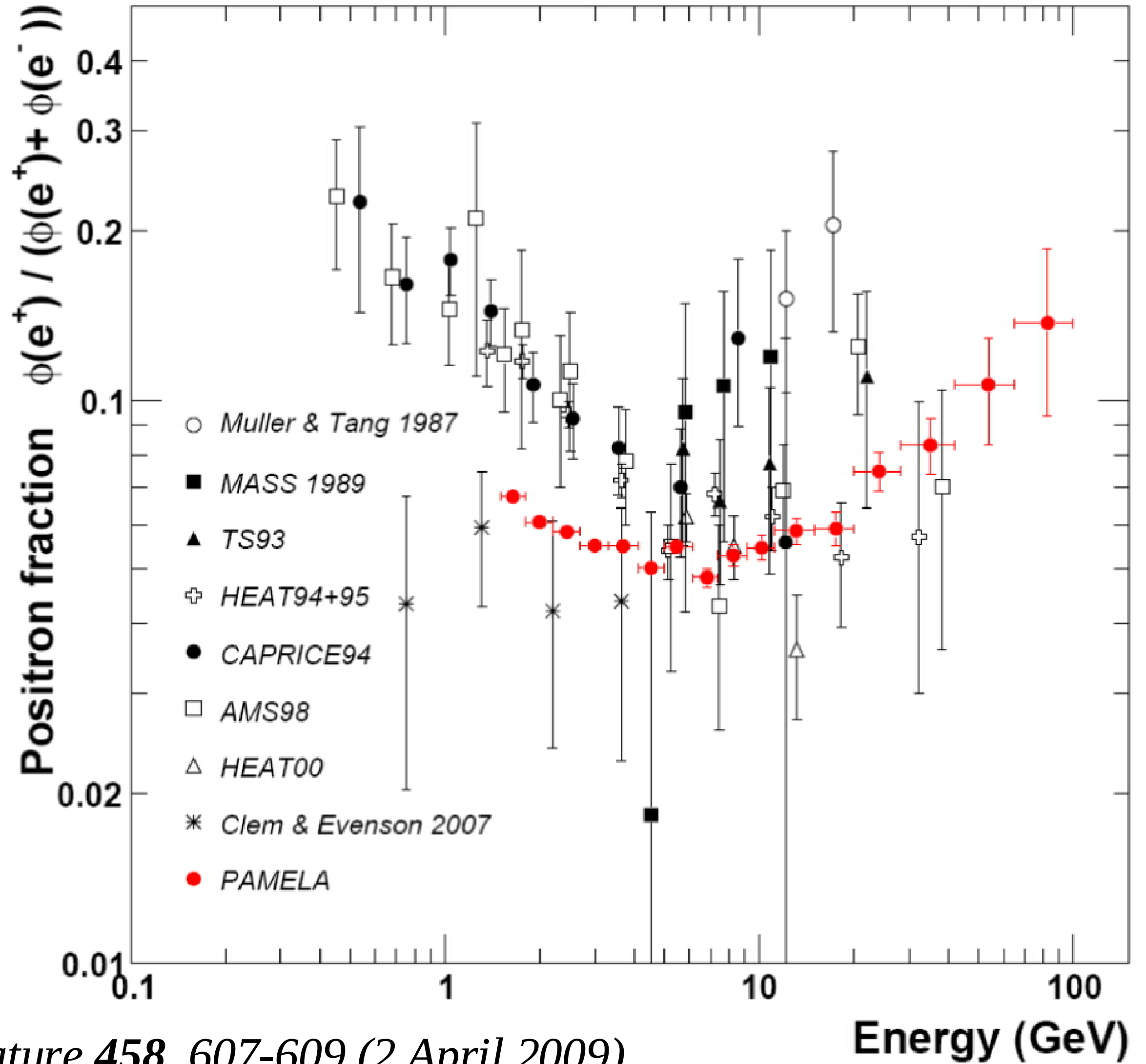
- July 2006 – February 2008 (~500 days)
- Collected triggers ~10^8
- Identified ~ 150 10^3 electrons and ~ 9 10^3 positrons between 1.5 and 100 GeV (180 positrons above 20 GeV



arXiv:0810.4995v1 [astro-ph] 28 Oct 2008

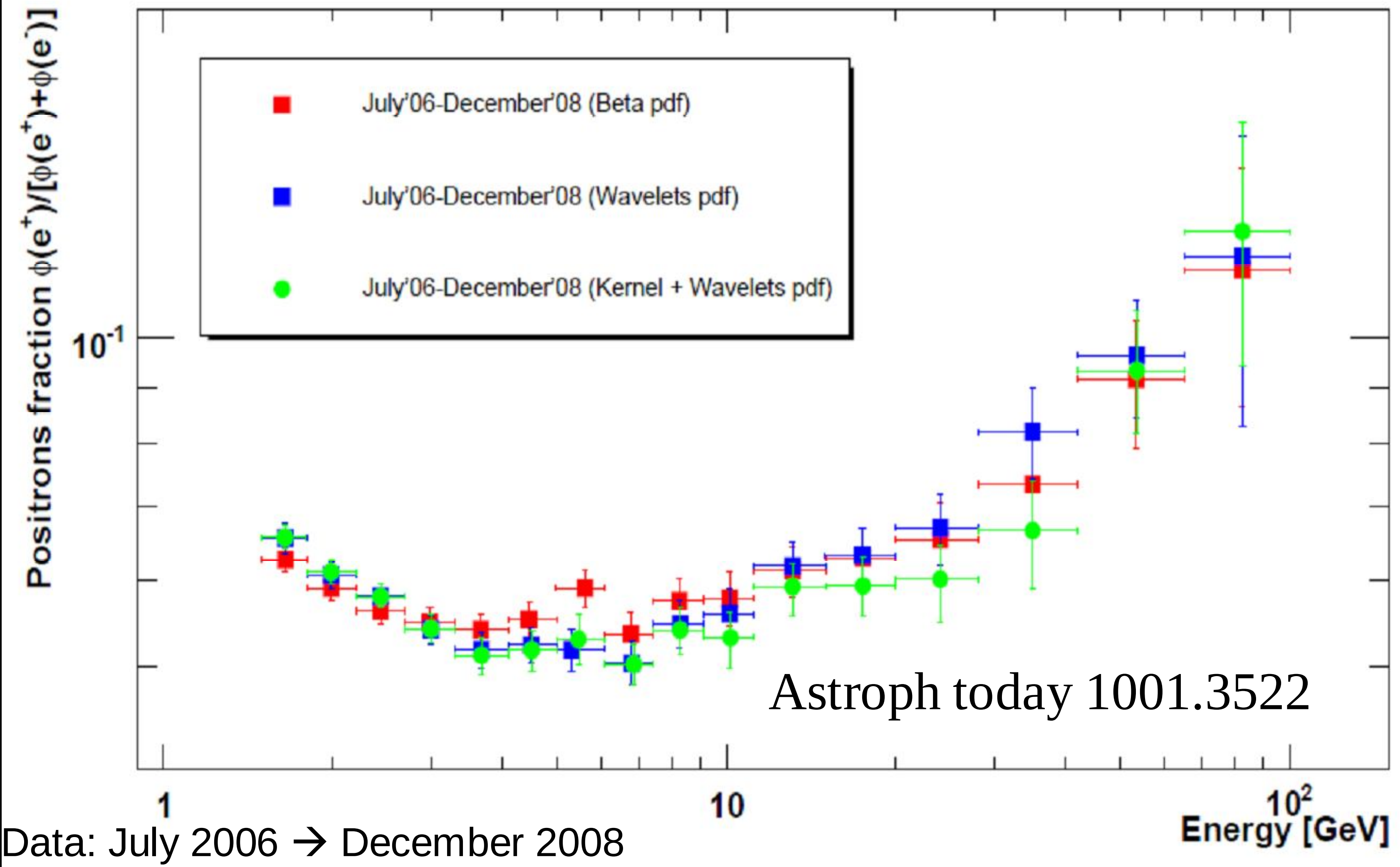
*Nature **458**, 607-609 (2 April 2009)*

Pamela positron fraction: comparison with other data



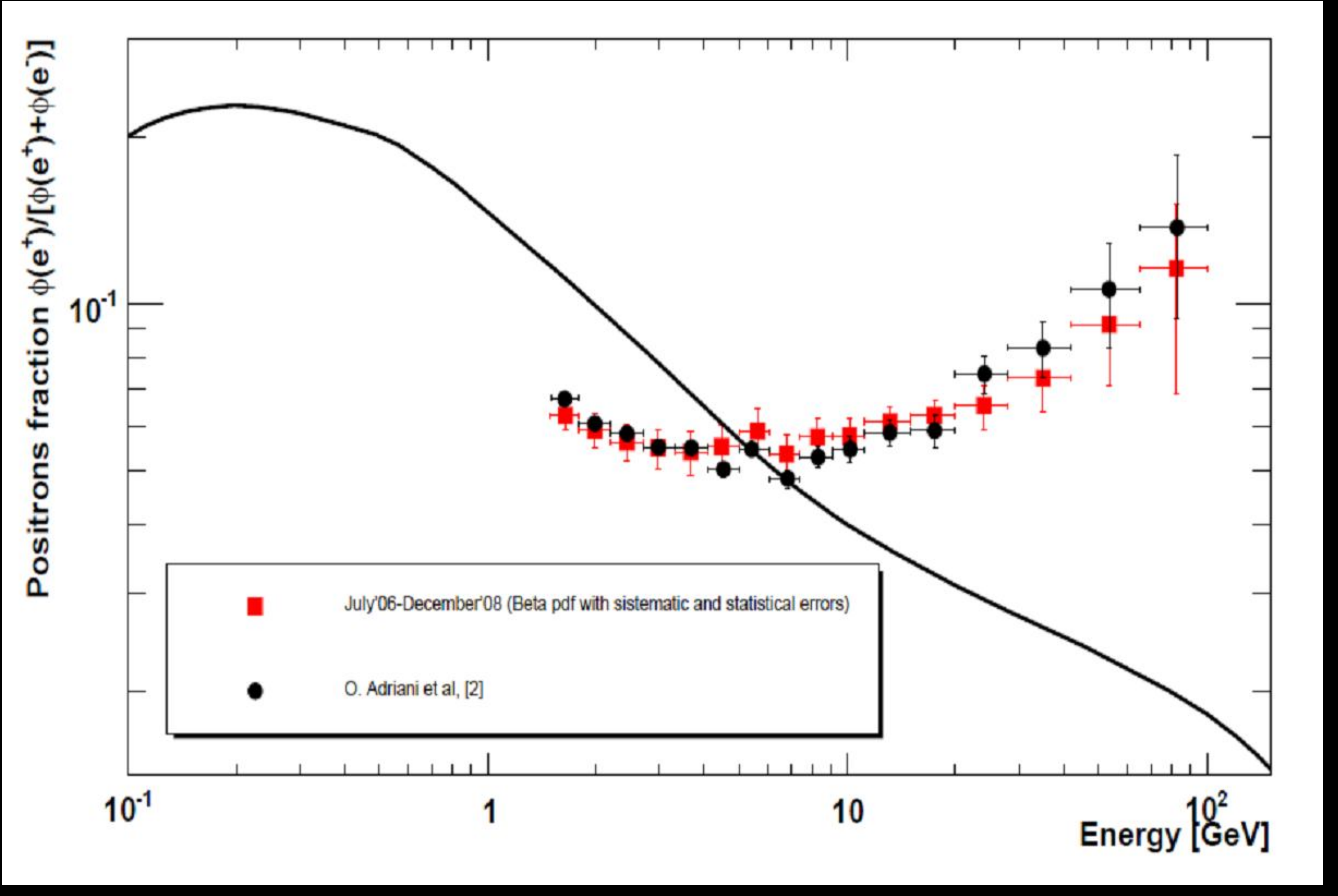
Nature ***458****, 607-609 (2 April 2009)*

Various approach to background subtraction

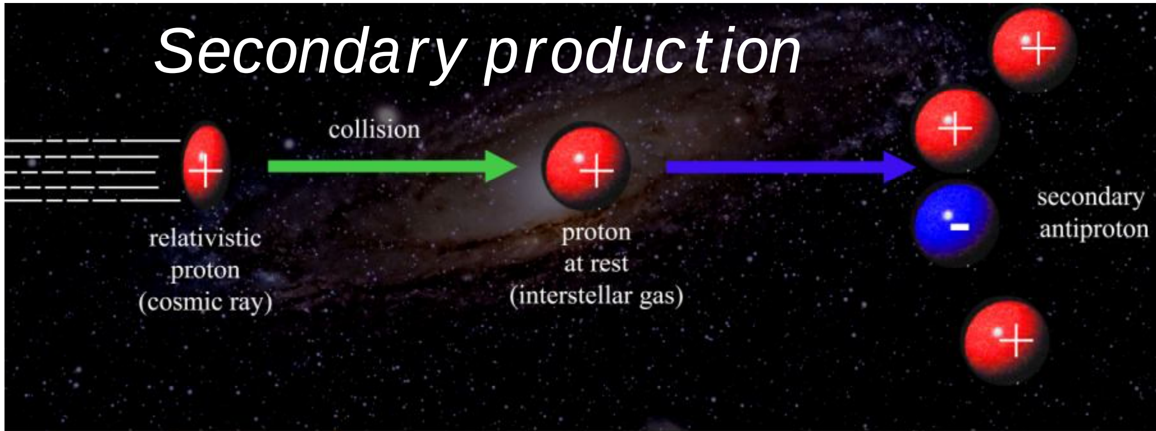


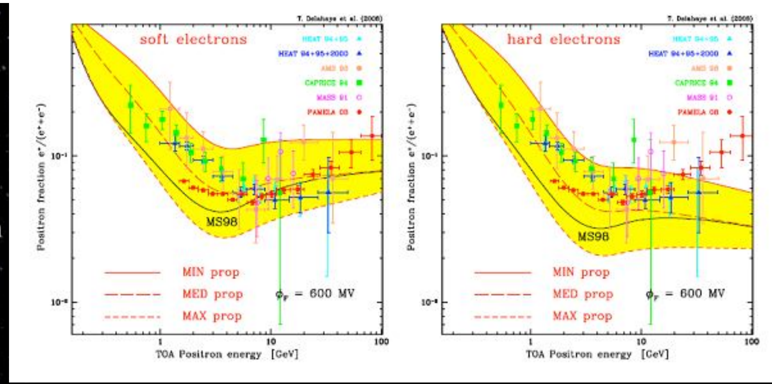
Data: July 2006 → December 2008

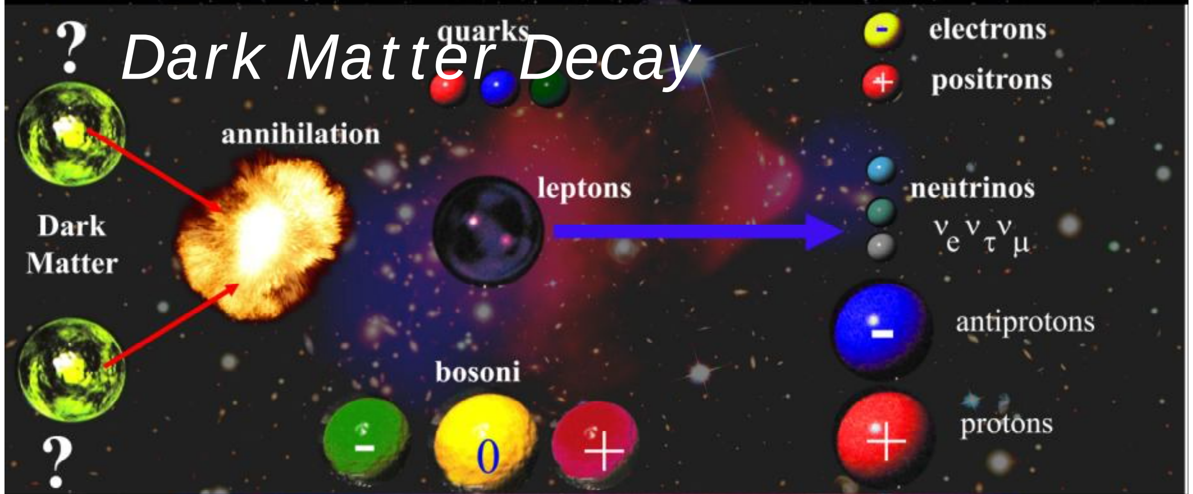
More positrons… data up to December 2008



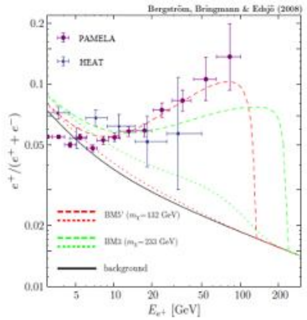
July 2006 → December 2008

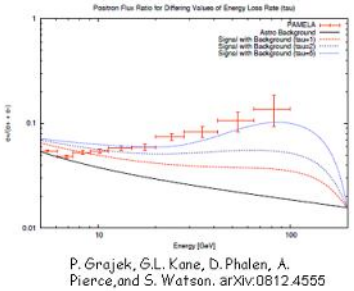






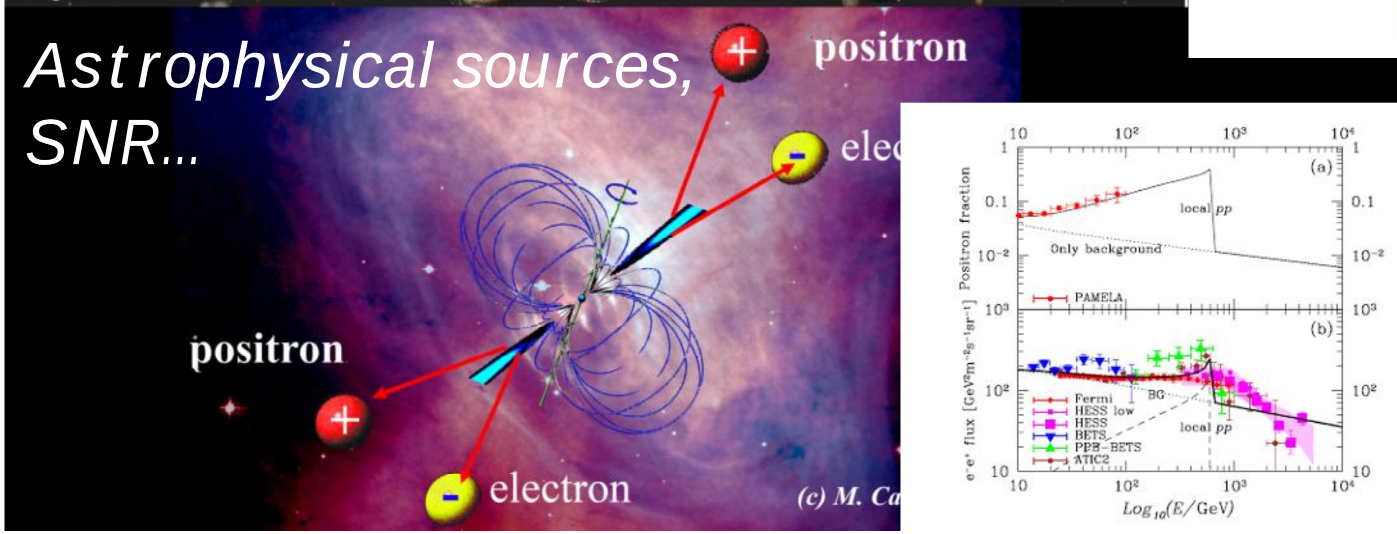
2. Example of DM solution: SUSY with internal bremsstrahlung and large boost factors, or Winos with unusual propagation parameters can give the right spectrum:

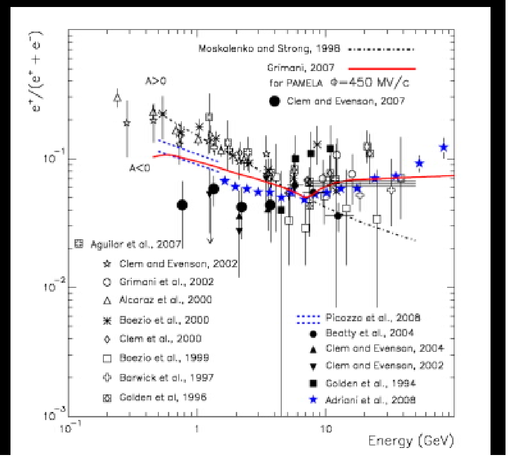




P. Grajek, G.L. Kane, D. Phalen, A. Pierce, and S. Watson. arXiv:0812.4555

However, does not explain new electron plus positron data (see later)





EDSJO 2009

Pulsars	New SNRs mechanisms	Dark matter	?
Uncertainties			
• Acceleration model (polar cap, outer gap, ...) • Injection spectrum $E^{-\alpha}$? • Release into the ISM (when, how much?) • Source locations, ages, ...	• Environmental parameters at SNR (production mechanism) • Distance to closest source • Cut-off energies	• Particle physics model • Particle physics enhancement (Sommerfeld) • Substructure enhancement (halo model)	?
Tests			
• Anisotropy of flux • Fluctuations in spectrum • consistency checks (gamma, X-ray, ...)	• Antiproton fluxes • Secondary nuclei	• FSR & IC photons from galactic centre • Continuing positron rise • CMBR distortions	?

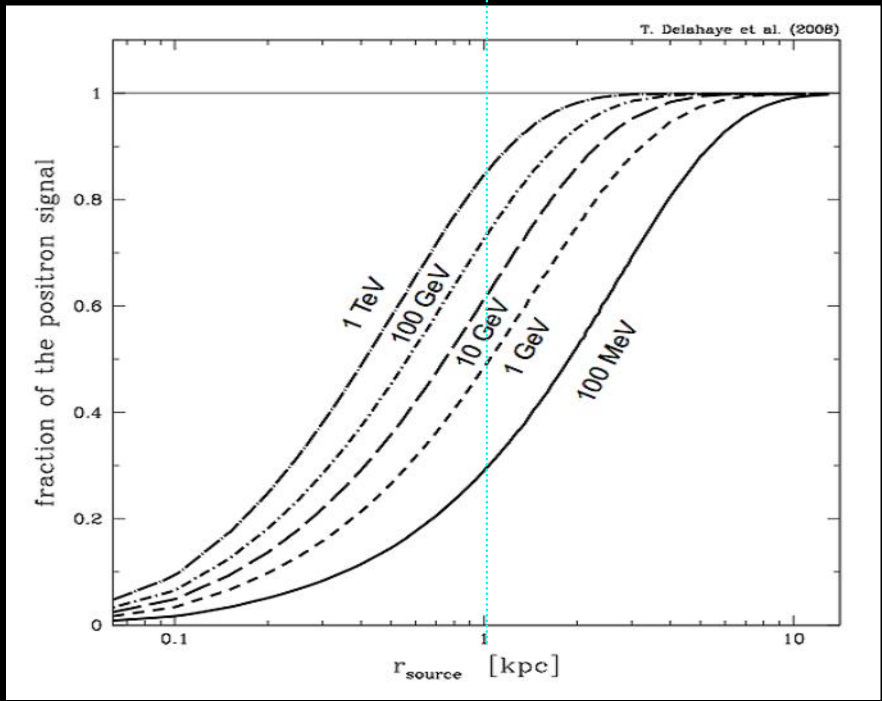
Positron origin

Where do positrons and electrons come from?

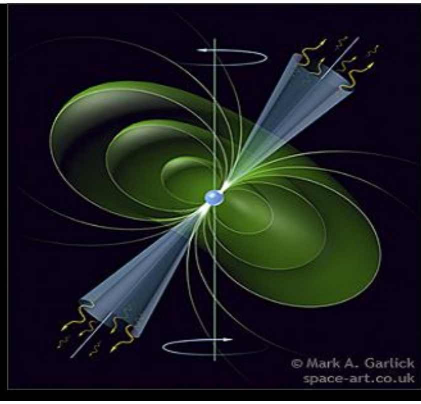
Mostly locally within 1 Kpc, due to the energy losses by Synchrotron Radiation and Inverse Compton
They sample the neighborhood of the galaxy
Protons and antiptotons the whole galaxy

Typical lifetime

$$\tau \simeq 5 \cdot 10^5 \mathrm{yr} \left(\frac{1\,\mathrm{TeV}}{E} \right)$$



Astrophysical Origin



Pulsars

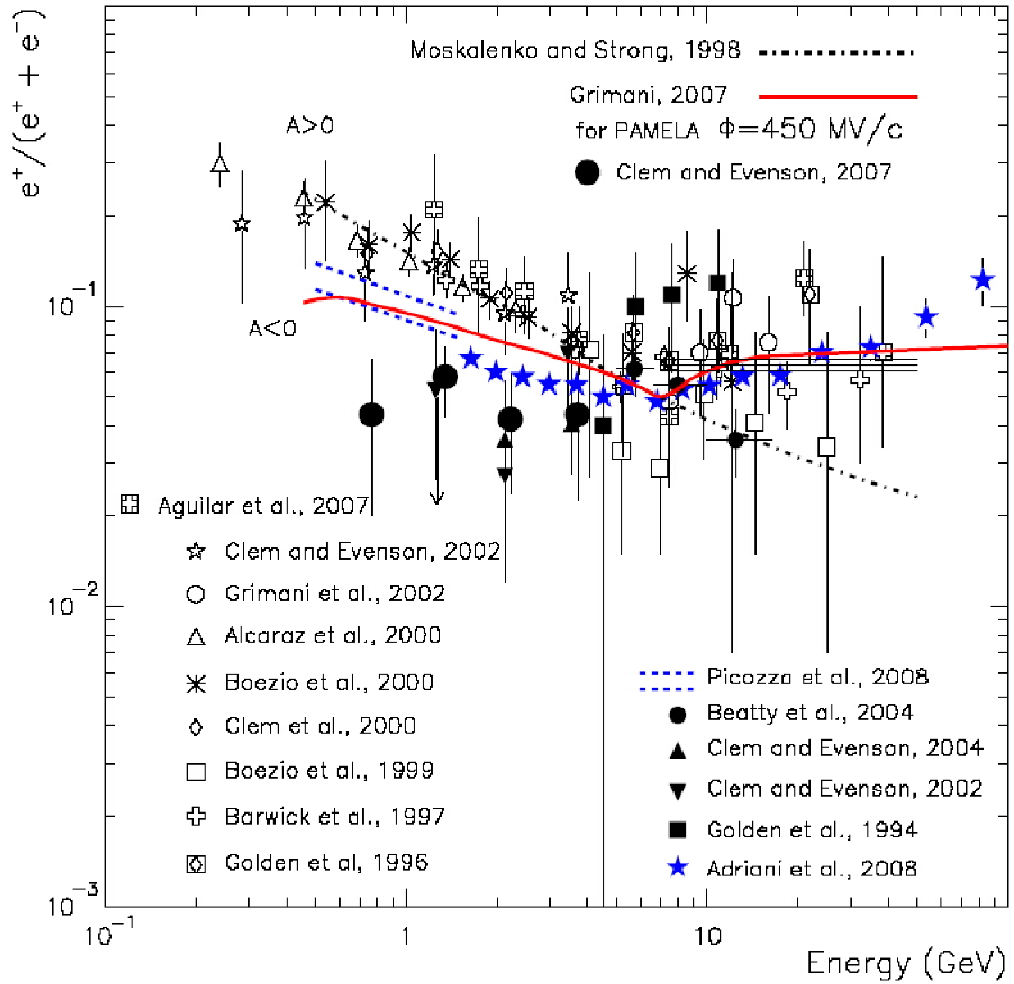
Must be young (T<10^5 yr) and nearby (<1 kpc). If not: too much diffusion, low energy, too low flux.

Injection flux:

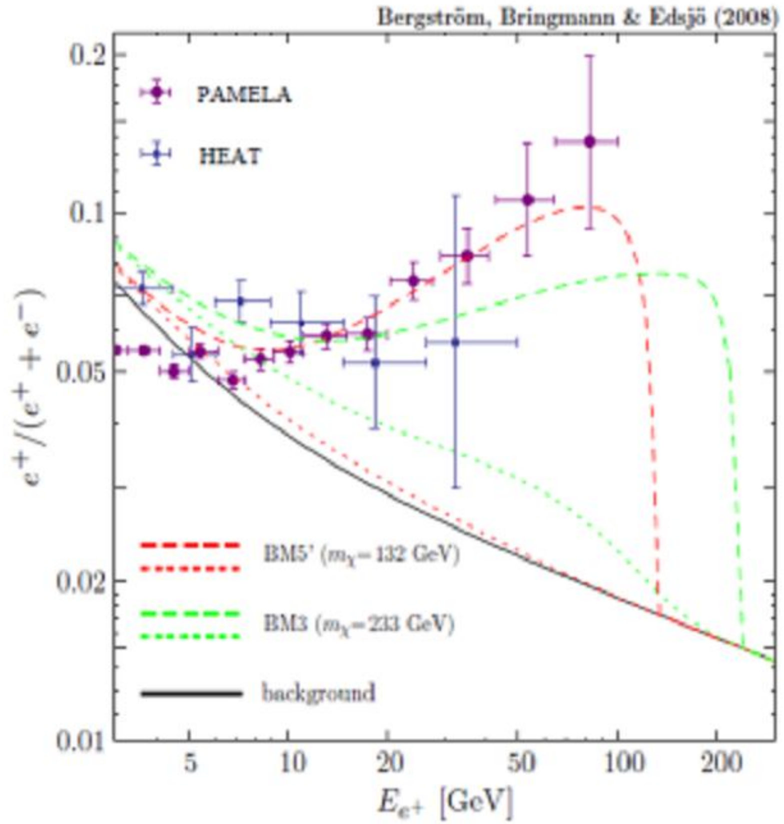
$$\Phi_{e^\pm} \simeq E^{-p} \exp(E/E_c)$$

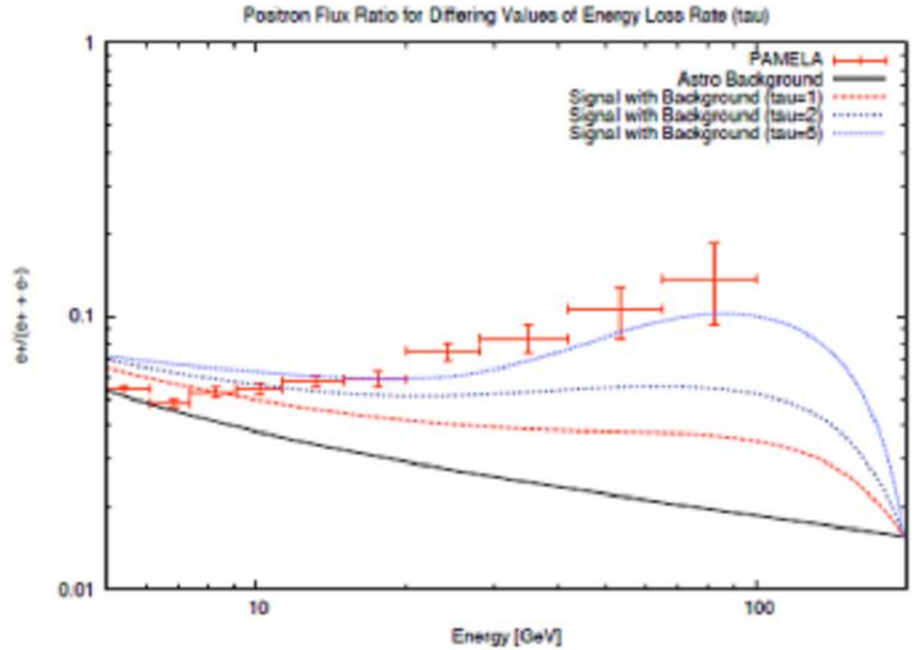
$$p \simeq 2$$

$$E_c \simeq 10 - 10^2 \,\mathrm{TeV}$$



2. Example of DM solution: SUSY with internal bremsstrahlung and large boost factors, or Winos with unusual propagation parameters can give the right spectrum:





P. Grajek, G.L. Kane, D. Phalen, A. Pierce,and S. Watson. arXiv:0812.4555

Bergstrom 2009

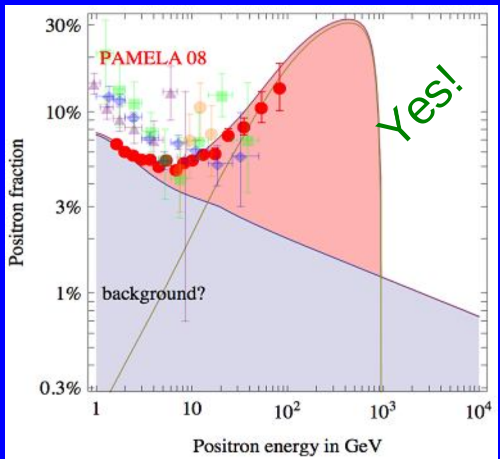
However, does not explain new electron plus positron data (see later)

Data fitting

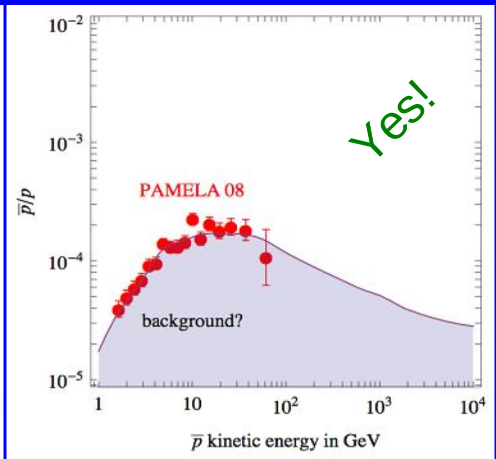
What if we consider ATIC and PPB-BETS data?

DM with $m_\chi \simeq 1\,\mathrm{TeV}$ and $\mu^+\mu^-$ dominant annihilation channel

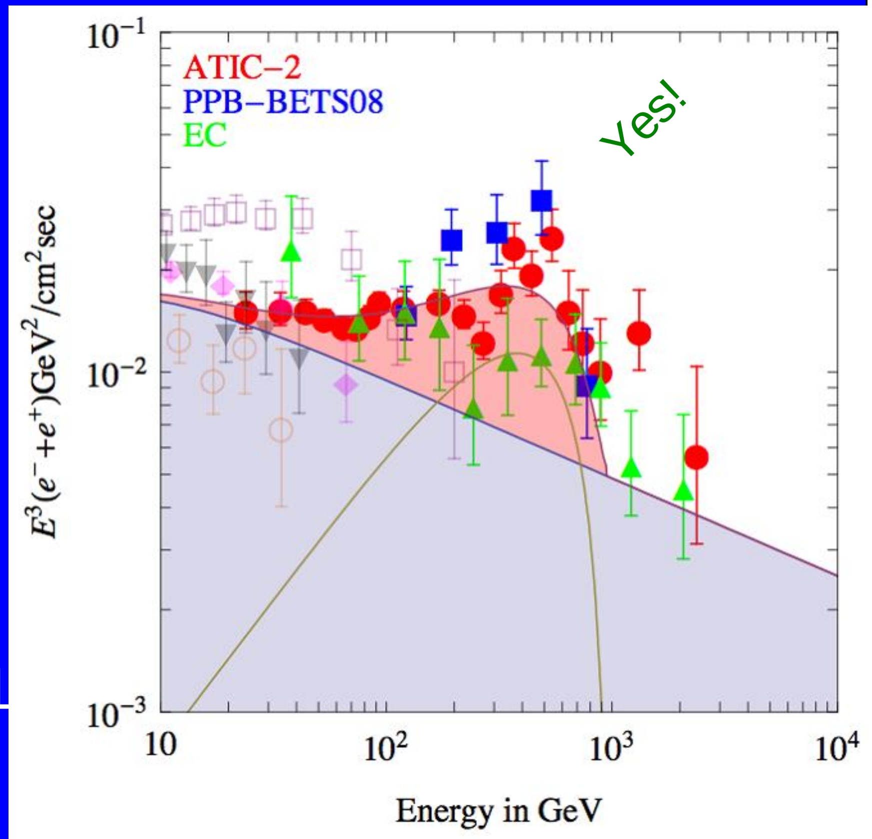
positrons



antiprotons



electron+positrons

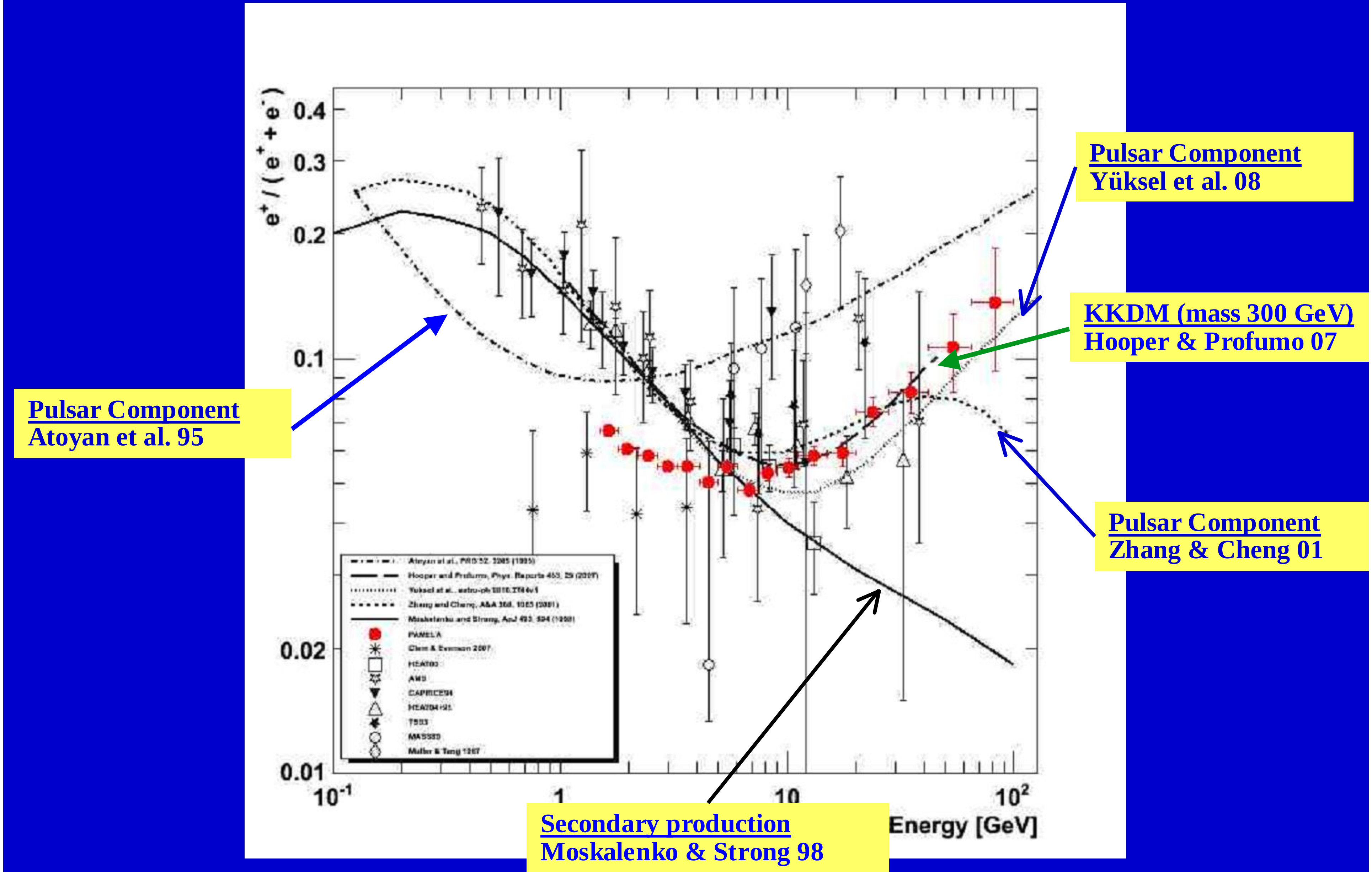


DM identification for the first time!?!?

Yes: Arkani-Hamed et al. arXiv:0810.071
+tons of other

From M. Cirelli, P. Picozza

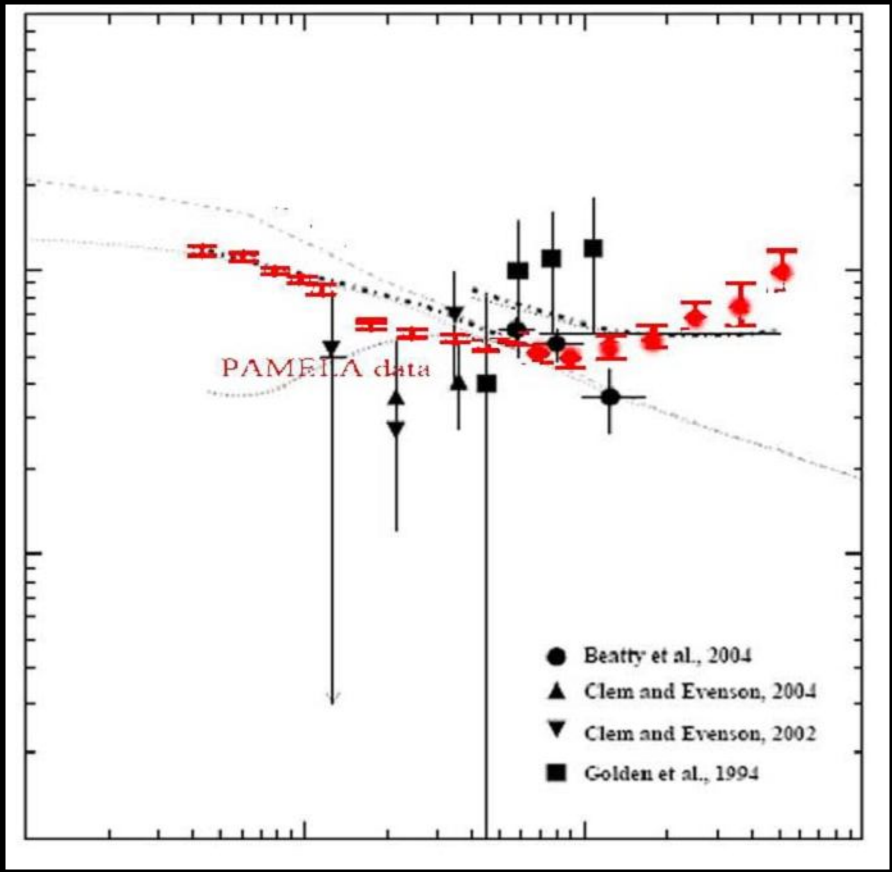
Positron fraction: comparison with models

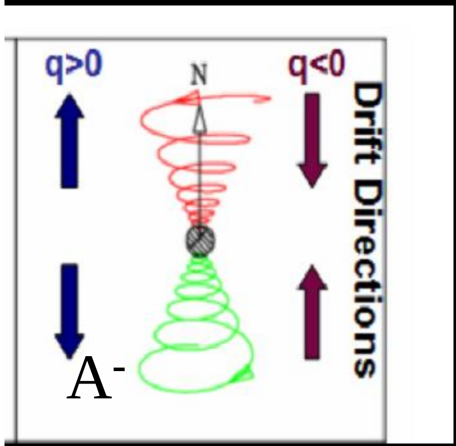


Comparison with solar cycle – low energy

qA<0 measurements (now or 22 years ago)

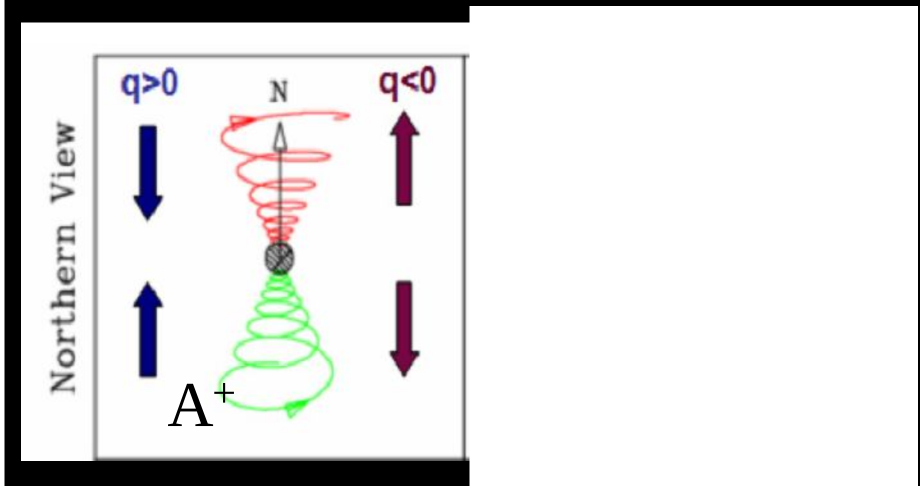
Solar modulation effects up to 10 GeV

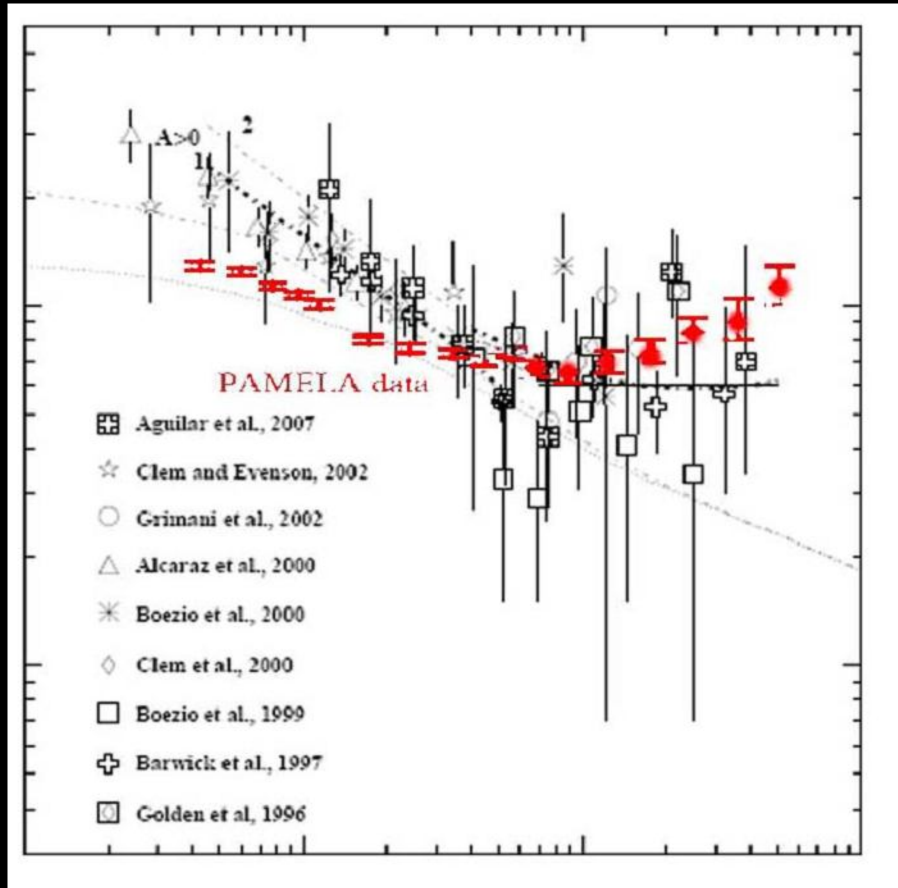




Comparison with solar cycle

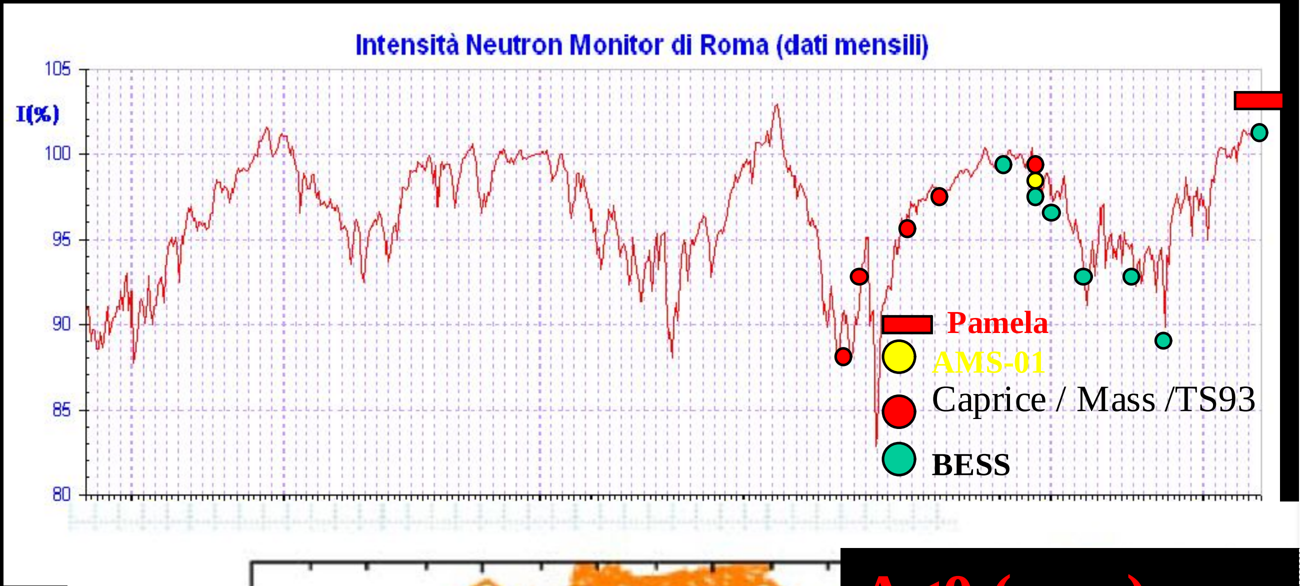
qA>0 measurements
(most data 11 years ago)

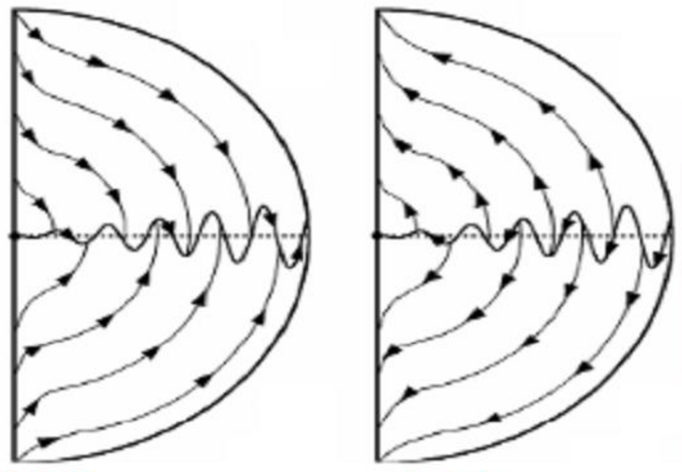


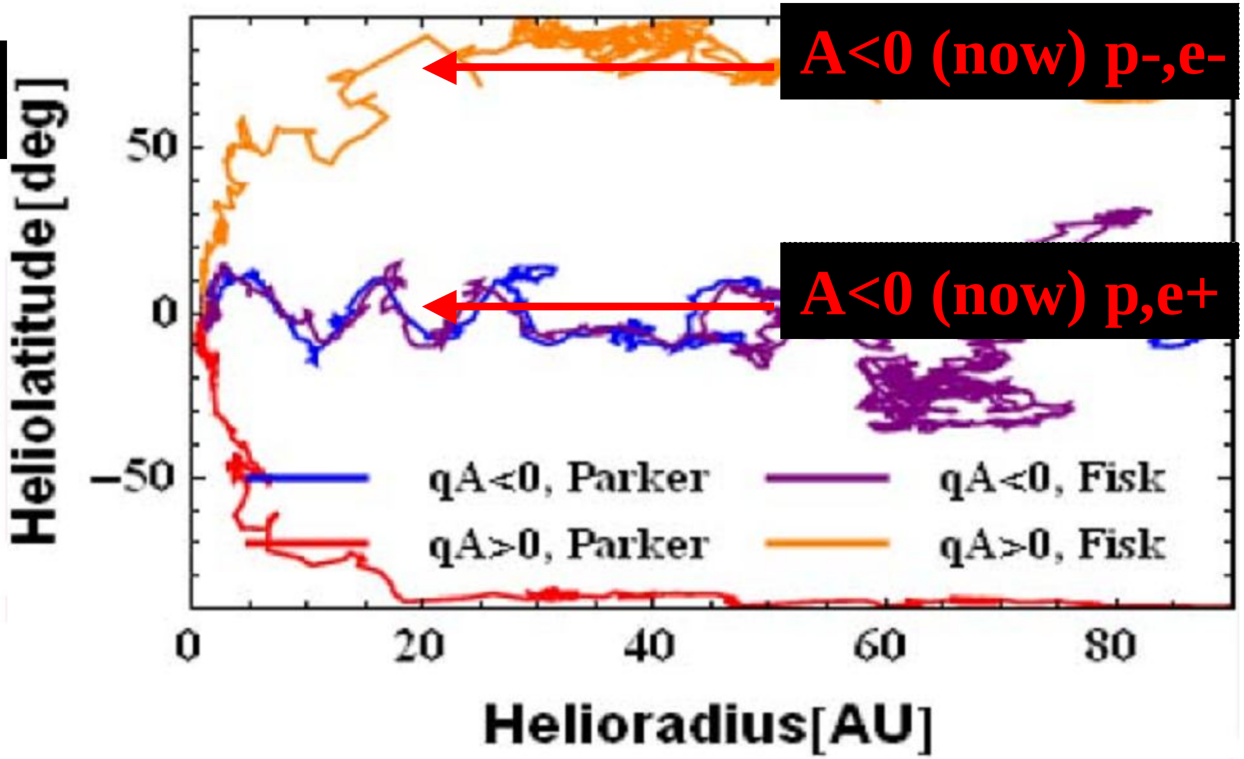


Charge dependent solar modulation of low energy positrons

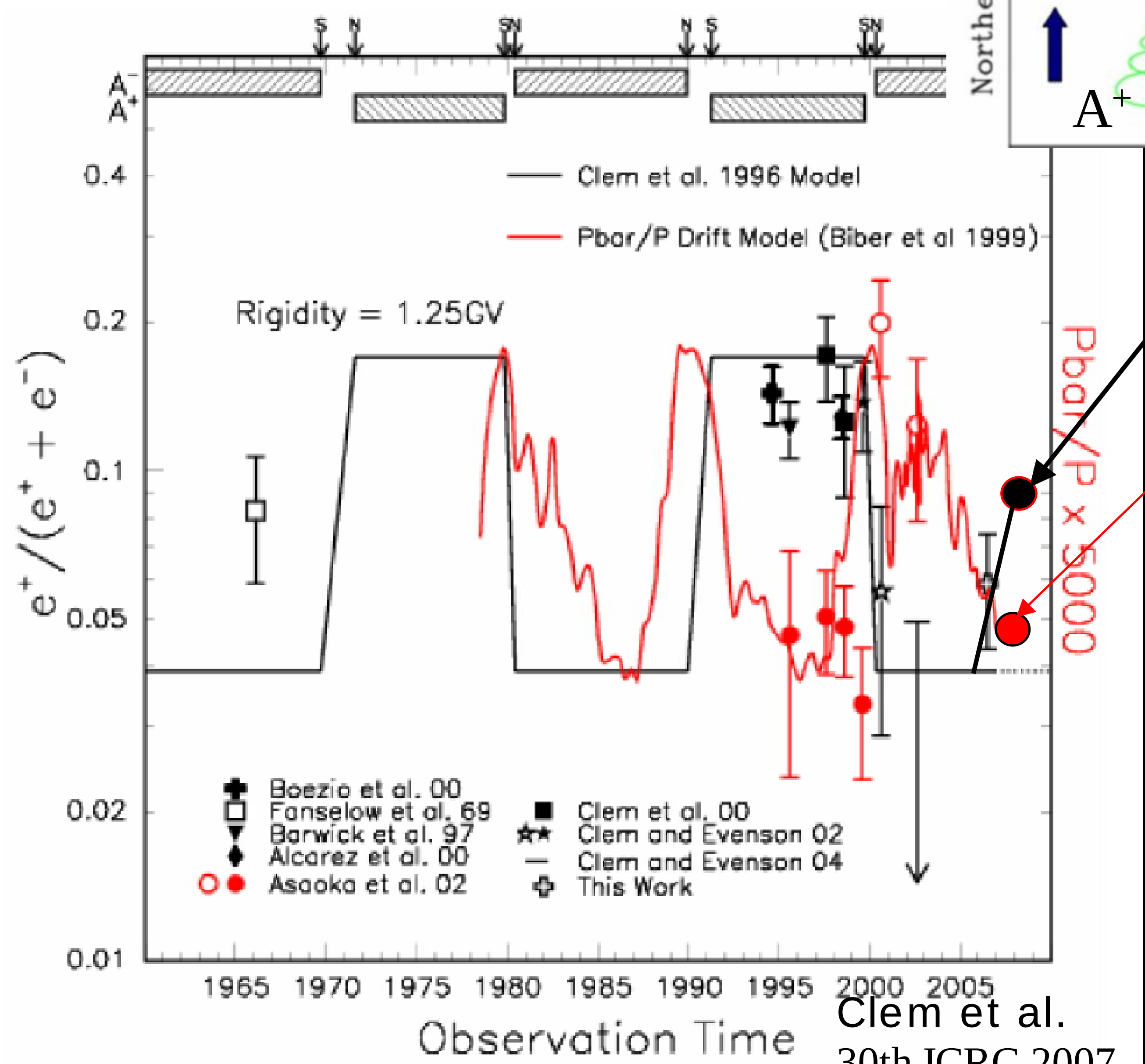
- •Charge dependent solar modulation
- •Separate qA>0 with qA<0 solar cycles
- •Evident in the proton flux
- •Observed in the antiproton channel by BESS
- •Full 3D solution of the Parker equation – drift term depends on sign of the charge

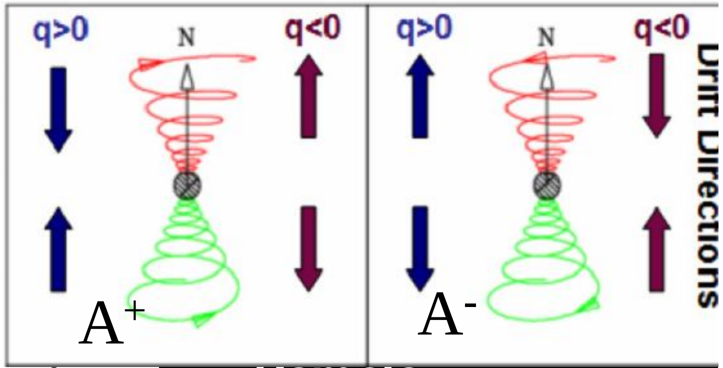






Charge dependent solar modulation

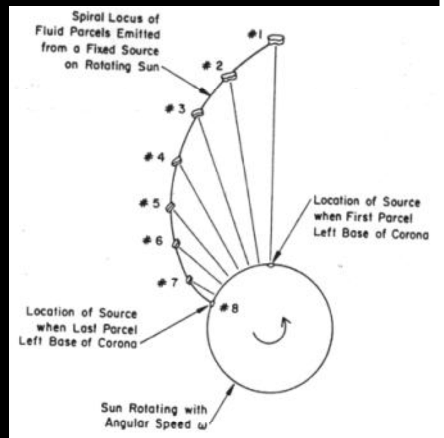




Pamela

Pamela e+

Pamela p-



Clem et al.
30th ICRC 2007

Fermi seems to exclude Egret excess

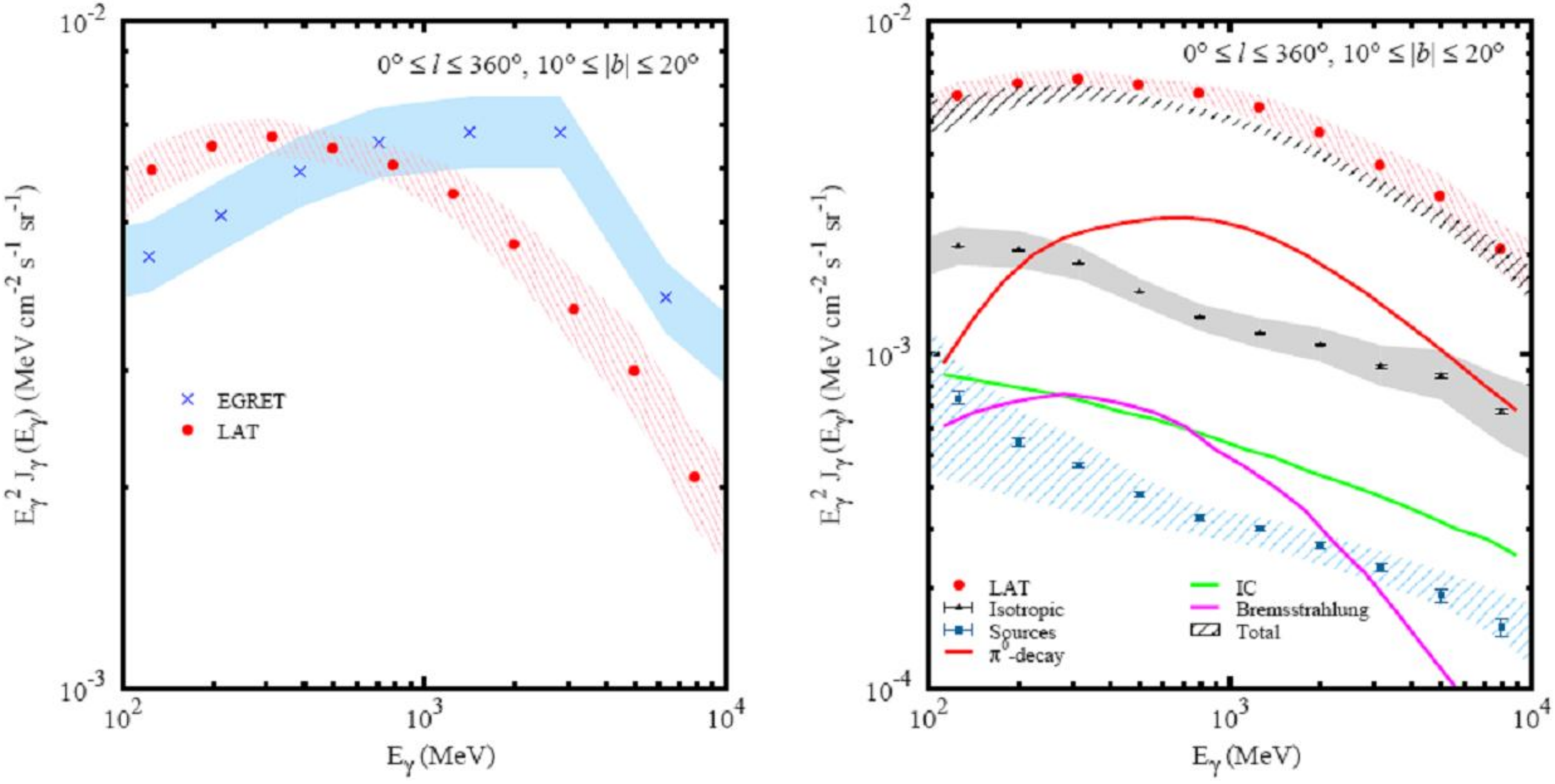


Fig. 1: *Left:* Preliminary diffuse emission intensity averaged over all Galactic longitudes for latitude range $10^\circ \leq |b| \leq 20^\circ$. Data points: LAT, red dots; EGRET, blue crosses. Systematic uncertainties: LAT, red; EGRET, blue. *Right:* Preliminary LAT data with model, source, and UIB components for same sky region. Model (lines): π^0-decay, red; Bremsstrahlung, magenta; IC, green. Shaded/hatched regions: isotropic, grey/solid; source, blue/hatched; total (model + UIB + source), black/hatched.

Porter, Icrc 2009

Fermi Haze
as IC counterpart of WMAP

Wmap haze in synchroton rad
Toward glactic center

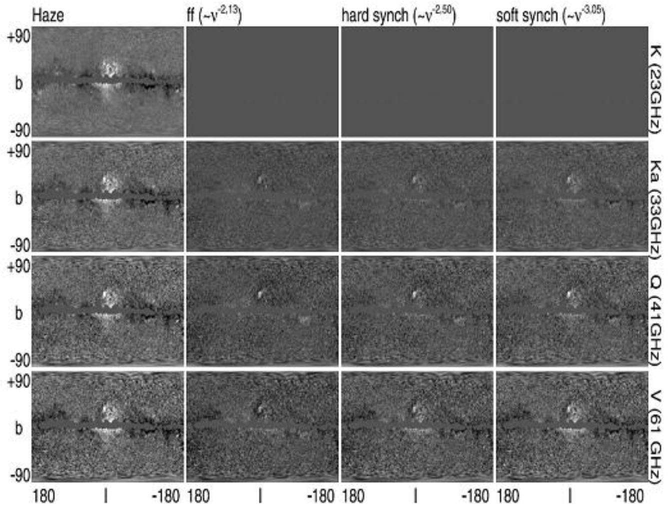


FIG. 5.—Haze is determined in 4 *WMAP* bands by subtracting CMB, soft synchrotron (Haslam et al. [1982] template), free-free (Hα template), and spinning dust. Using the K-band haze as a template, it is then subtracted from Ka, Q, and V bands assuming various power laws. A free-free spectrum fits most of the sky well, apart from the ζ Oph cloud $(l, b) = (5^\circ, 25^\circ)$. See § 3.3.

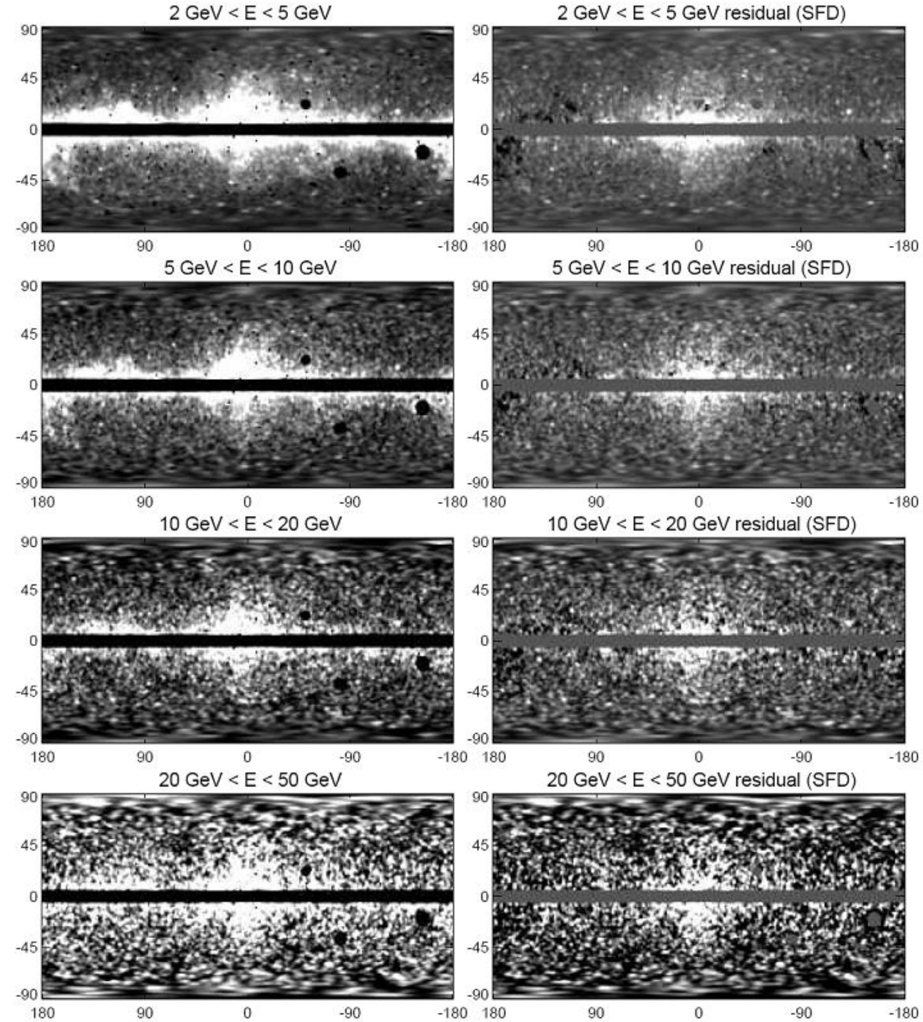


FIG. 3.— Residual maps after cross-correlating *Fermi* maps at various energies with the SFD dust map. The mask is described in §3.2. Cross-correlations are done over unmasked pixels and for $75 \leq \ell \leq 285$. Although the template removes much of the emission, there is a clear excess towards the Galactic center. This excess also includes a disky component which is likely due to ICS and bremsstrahlung from softer electrons (see Figure 5).

ApJ, 614:186–193,
2004 October 10

arXiv:0910.4583v1

Electrons and positrons are fashionable

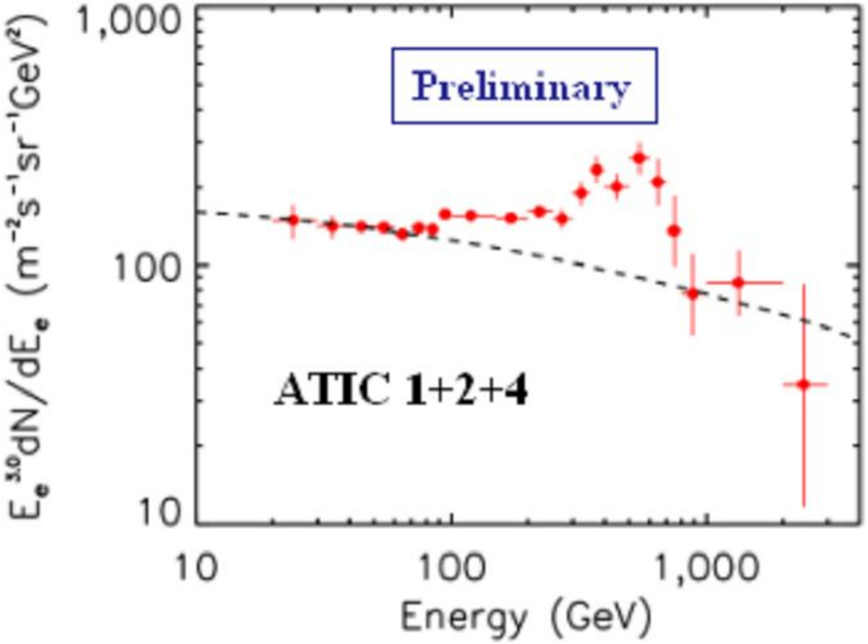
But there is disagreement on the $e^{+}+e^{-}$ spectrum

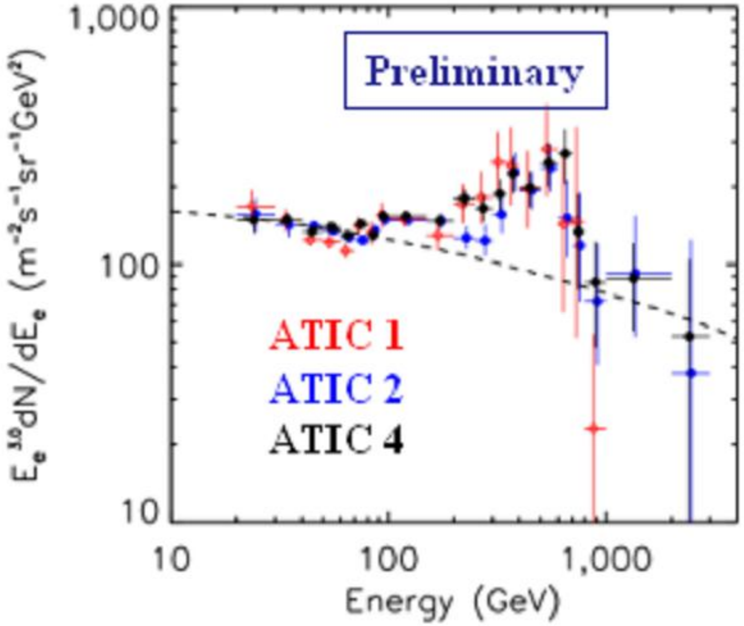
Atic: Balloon but deep detector

BGO calorimeter,
ATIC 1+2, 18.4 rl,
in 4 XY, planes,
ATIC 4, 22.9 rl,
in 5 XY planes,

Fermi: Large statistics (400 events in last bin) but shallow: **12.5 X_0**

All three ATIC flights are consistent



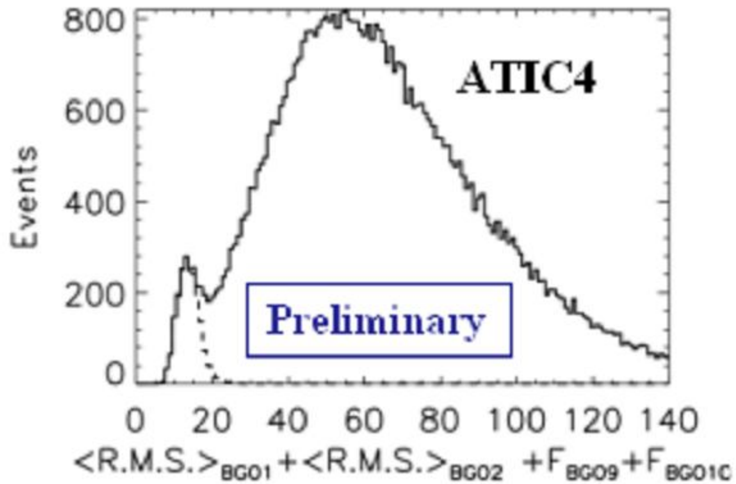


"Source on/source off" significance of bump for ATIC1+2 is about 3.8 sigma

ATIC-4 with 10 BGO layers has improved e , p separation. **(~4x lower background)**

"Bump" is seen in all three flights.

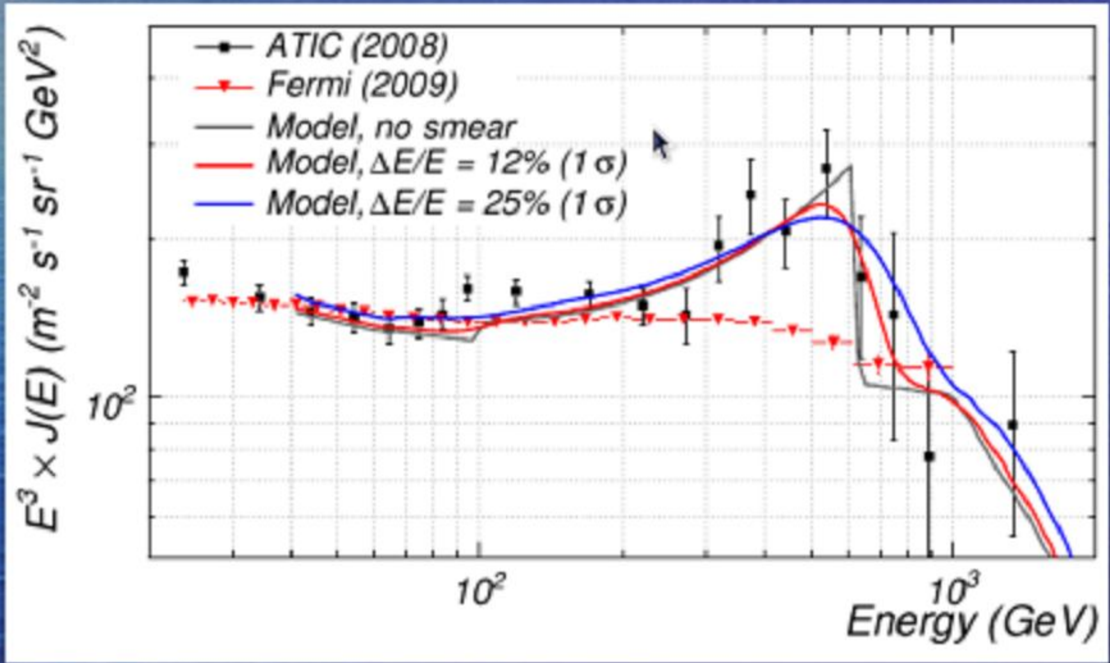
Significance for ATIC1+2+4 is 5.1 sigma



And finally we want to check - could we miss "ATIC-like" spectral feature?

We validated the spectrum reconstruction by:

- *comparing the results for different path length subsets*
- *varying the electron selections*
- *simulating the LAT response to a spectrum with an "ATIC-like" feature:*

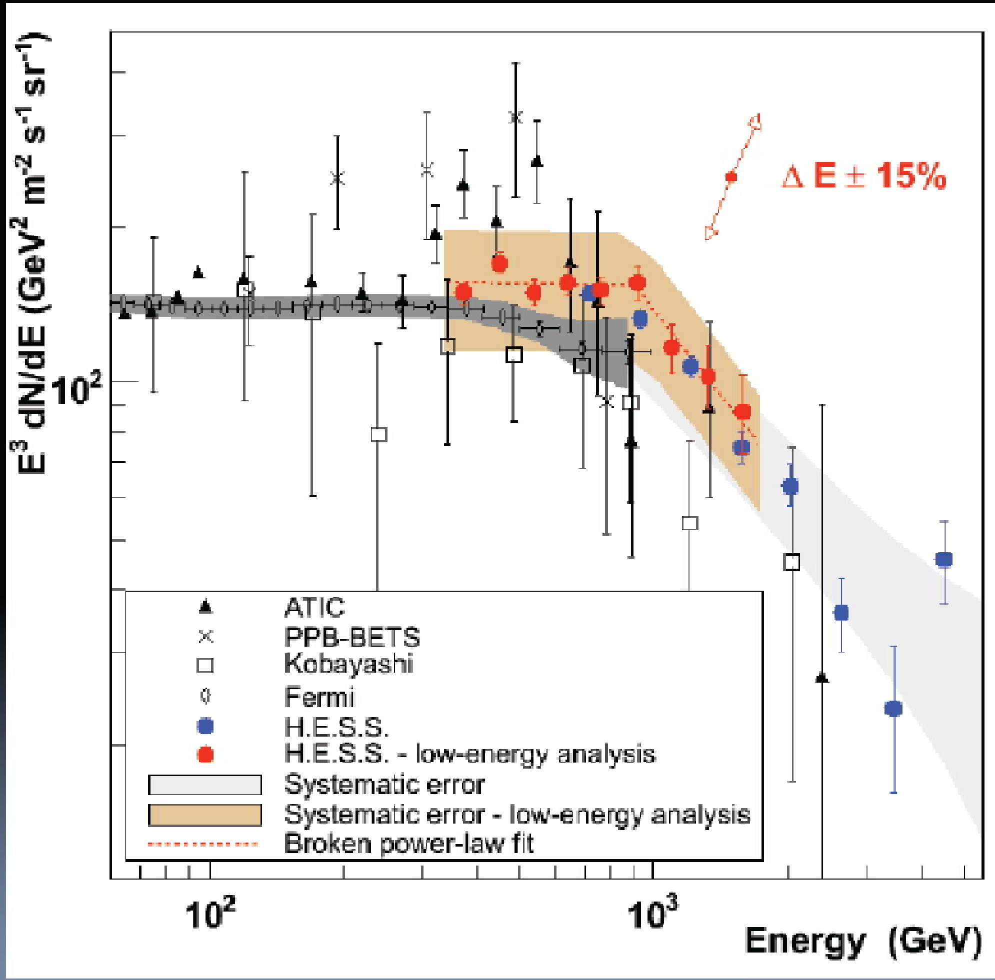


This demonstrates that the Fermi LAT would have been able to reveal "ATIC-like" spectral feature with high confidence if it were there. <u>Energy resolution is not an issue with such a wide feature</u>

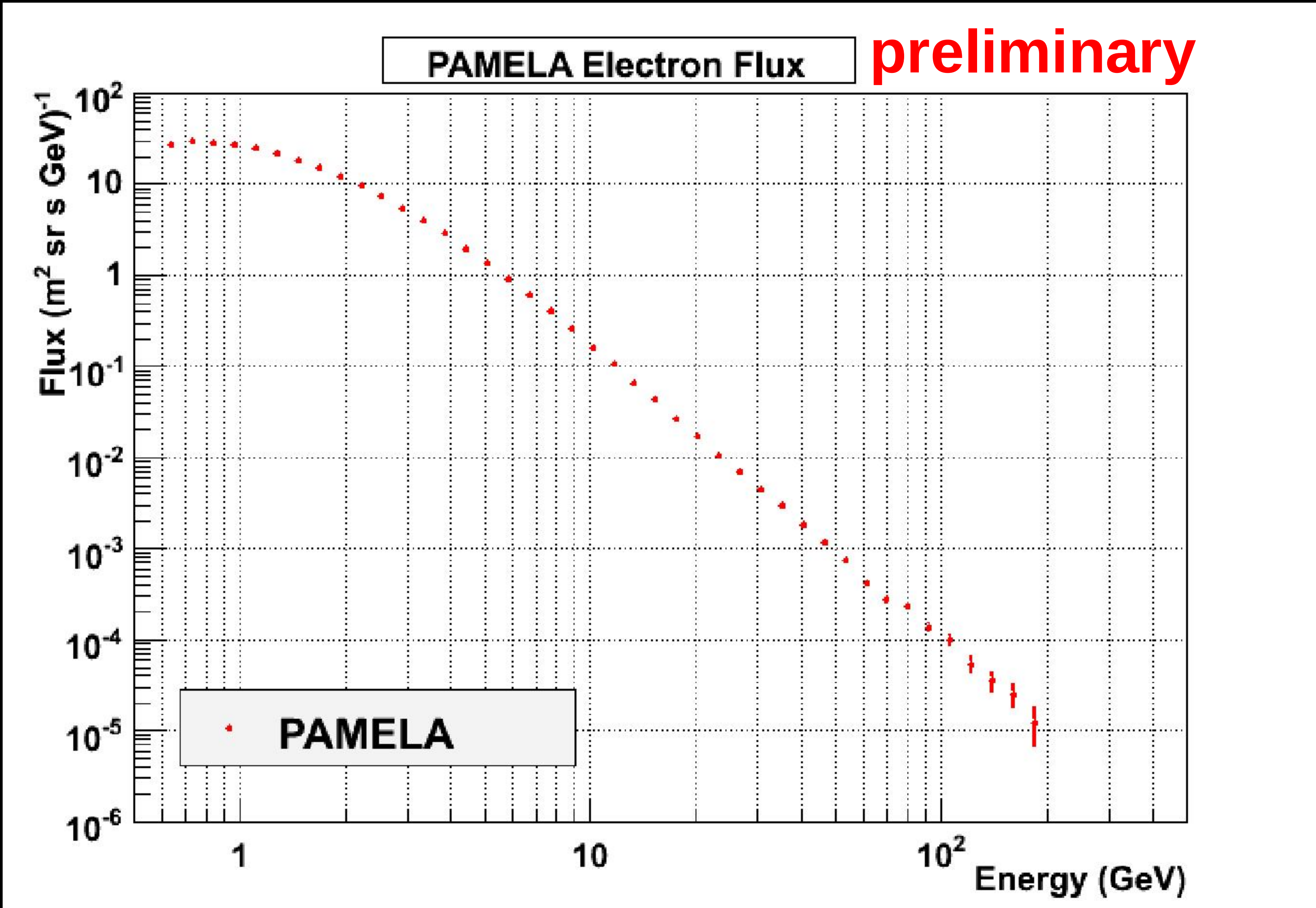
HESS electrons

Egberts, 2009

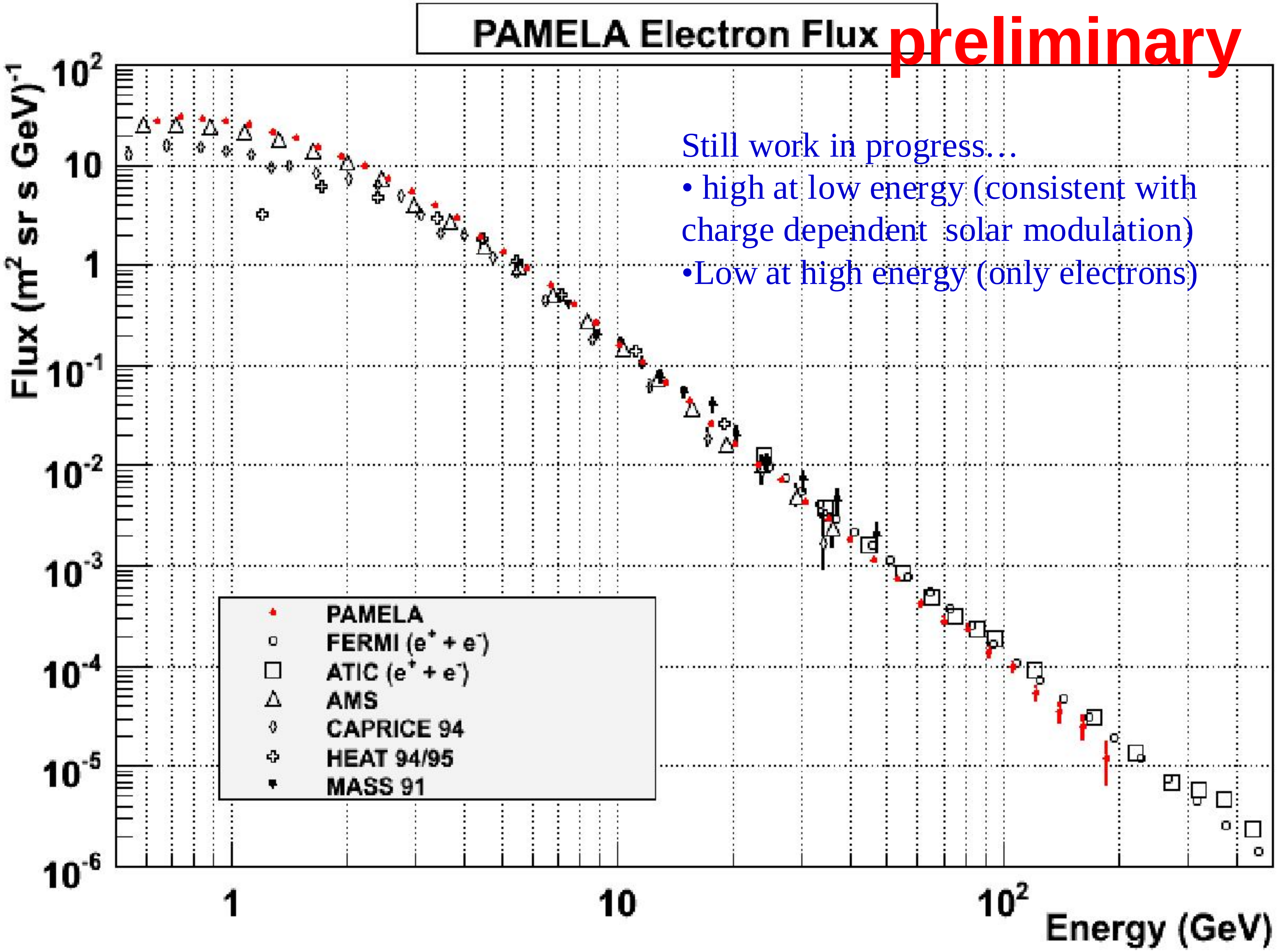
- Cuts:
  - impact distance < 100 m
  - image size in each camera > 80 photo electrons
  - Data set of 2004/2005
- Syst. uncertainty: atmospheric variations + model dependence of proton simulations (SIBYLL vs. QGSJET-II)
- Spectral index:
  Γ_1 = 3.0±0.1(stat)±0.3(syst.)
  Γ_2 = 3.9±0.1(stat)±0.3(syst.)

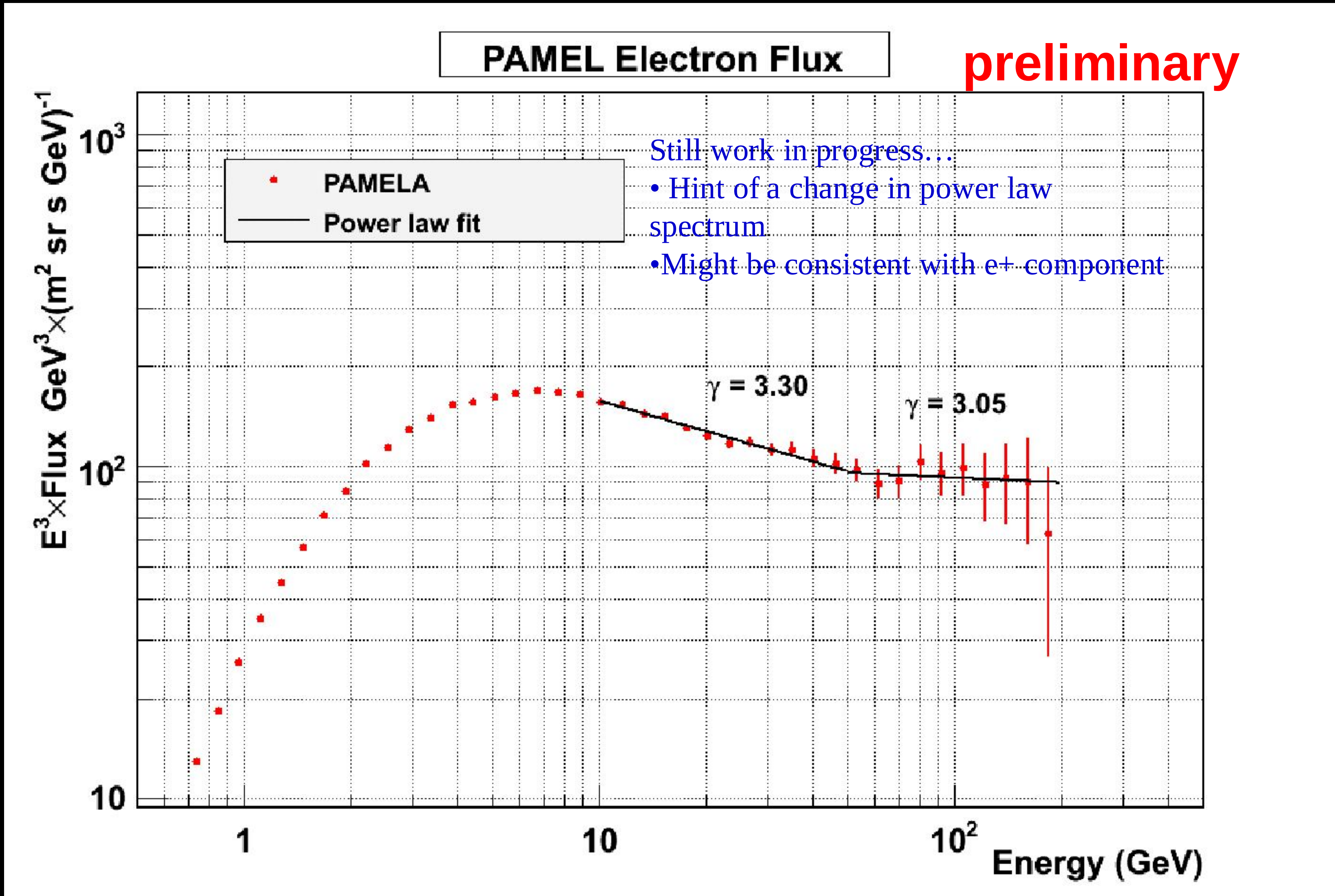


PAMELA electron flux



Comparison with other experiments

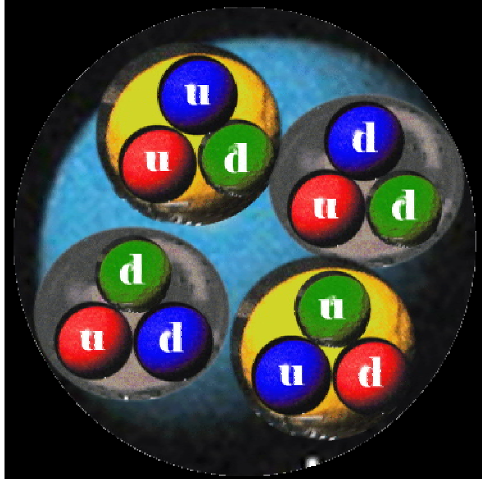



PAMEL Electron Flux
preliminary
Still work in progress…
• Hint of a change in power law spectrum
•Might be consistent with e+ component
PAMELA
Power law fit
γ = 3.30
γ = 3.05
E3×Flux GeV3×(m2 sr s GeV)-1
Energy (GeV)
10
10²
10³
1
10
10²

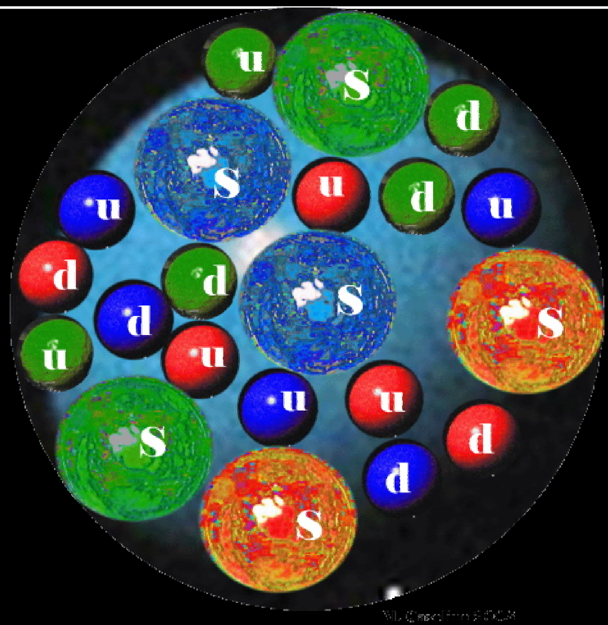
Search for exotic matter: Strangelets

(Lumps of Strange Quark Matter)

Roughly equal numbers of u,d,s quarks in a single ‘bag’ of cold hadronic matter.



Z=2 A=4 (He)
Z/A=0.5



Z=2 A=7
Z/A=0.286

u,d,s quark matter might be stable

Not limited in A

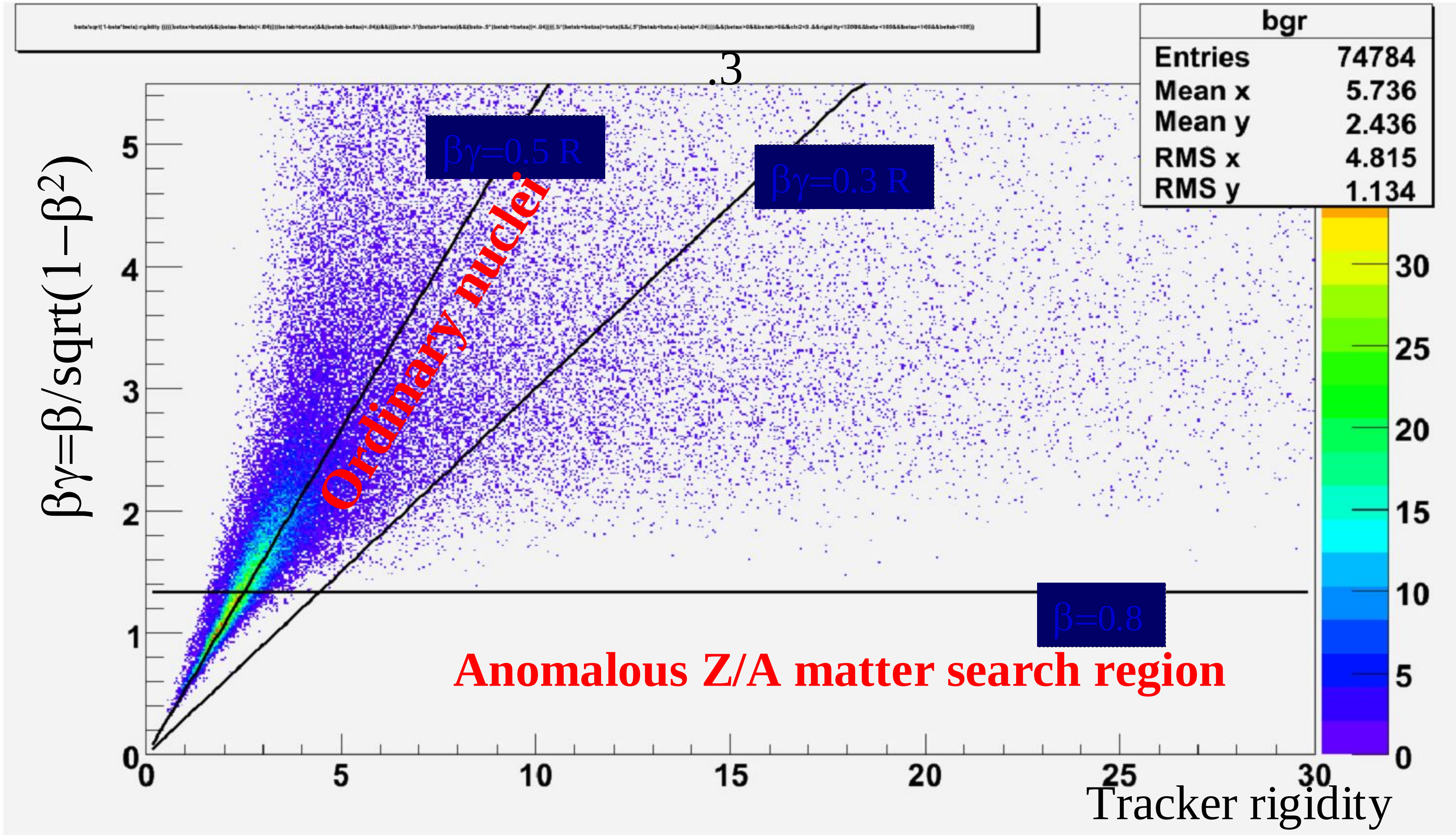
A=100, 1000….

Z is almost zero due to cancellation of quark charge

Could account for a (small) part of DM

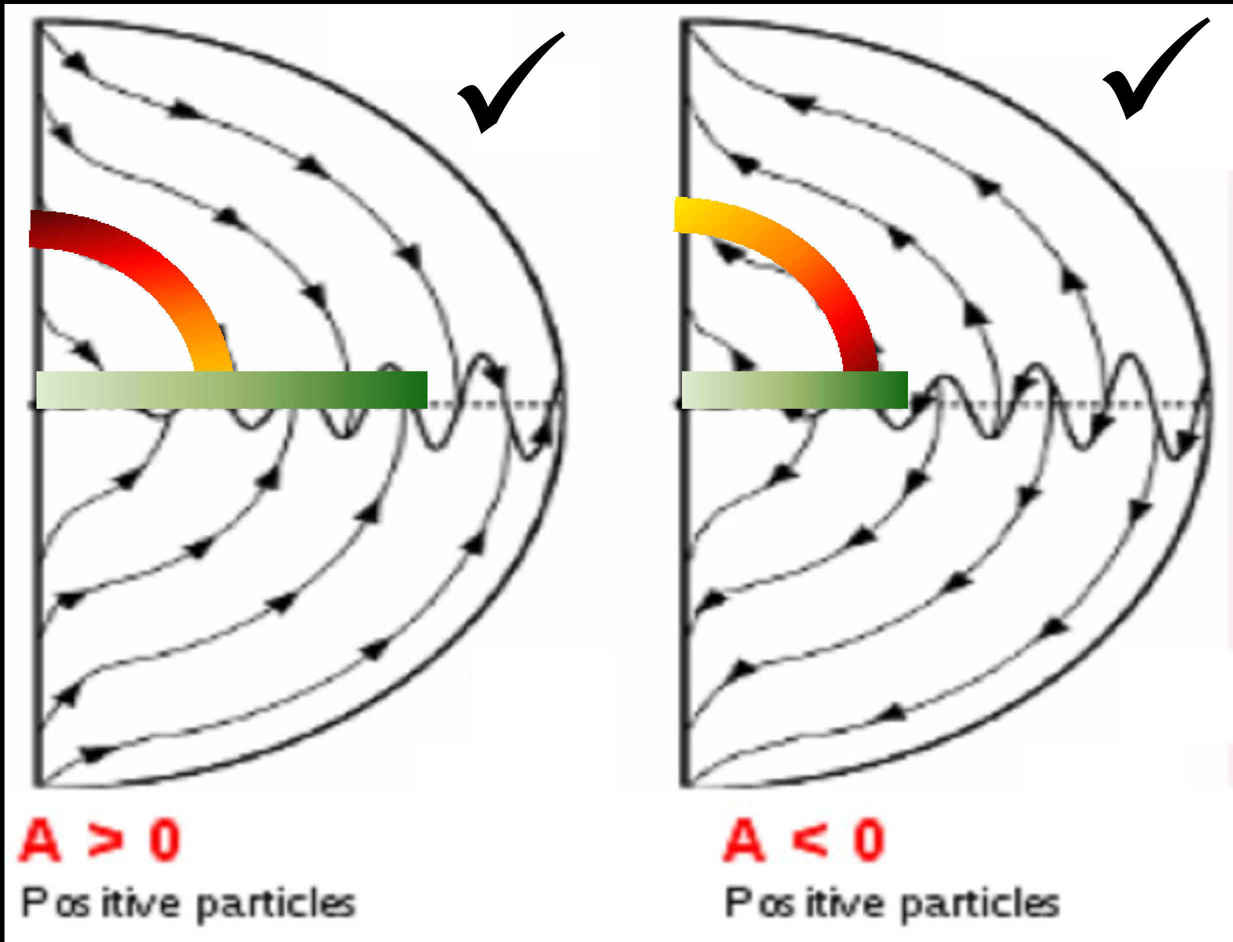
Also candidate of UHECR

Search for anomalous Z/A particles in cosmic radiation with PAMELA

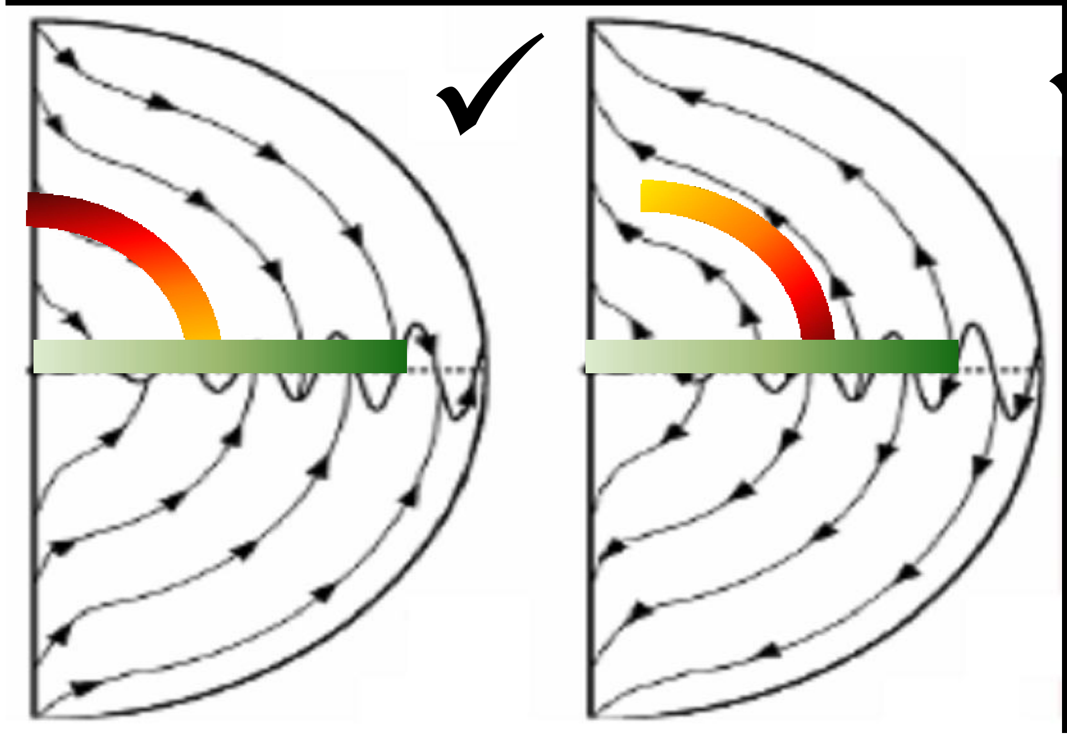



•Pamela is operating successfully in space
•Expected three years of operations – completed
Extended other 2 years
•Data received until now show good potential and fullfillment of scientific goals
http://pamela.roma2.infn.it
http://www.casolino.it

Expected intensity contours for the A>0 and A<0-magnetic epoch



Summary

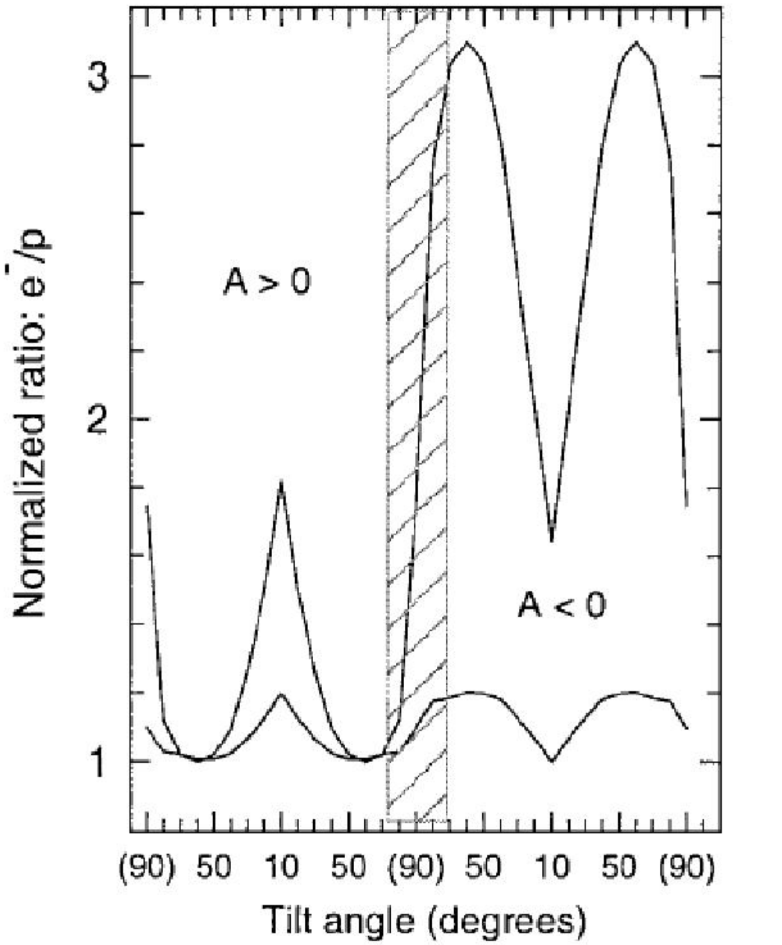


A < 0 **Negative particles**

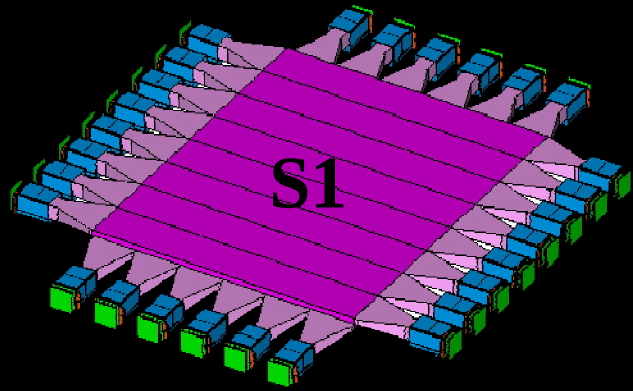
A < 0 **Positive particles**

- Radial and latitudinal gradients of protons achieved
- Latitudinal dependence of the e/p-ratio achieved.
- Pamela and Ulysses/KET show similar time profiles and support each other

Expected differences in the temporal variation due to drift effects: the $(e^+ + e^-)/p$-ratio

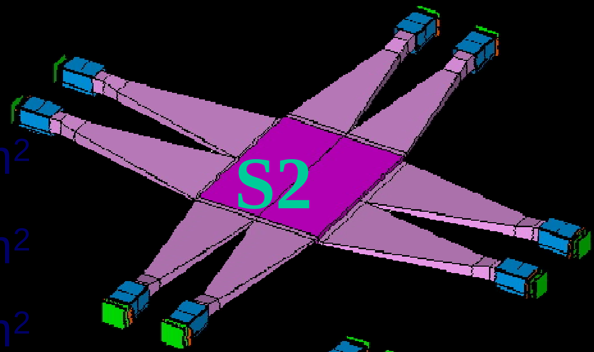


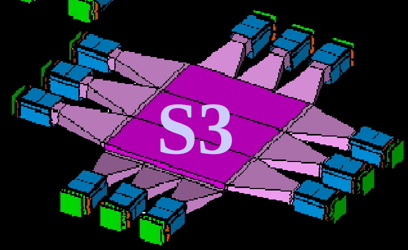
- 6 x-y layers arranged on 3 planes;
- 48 channels.
- Albedo rejection
- Part ident. Up to 1 GeV with 150ps resolution
- Nuclear identification up to Oxygen



DIMENSIONS

S11	8	330 x 51 mm^2	7 mm	357 mm^2
S12	6	408 x 55 mm^2	7 mm	385 mm^2
S21	2	180 x 75 mm^2	5 mm	375 mm^2
S22	2	150 x 90 mm^2	5 mm	450 mm^2
S31	3	150 x 60 mm^2	7 mm	420 mm^2
S32	3	180 x 50 mm^2	7 mm	350 mm^2





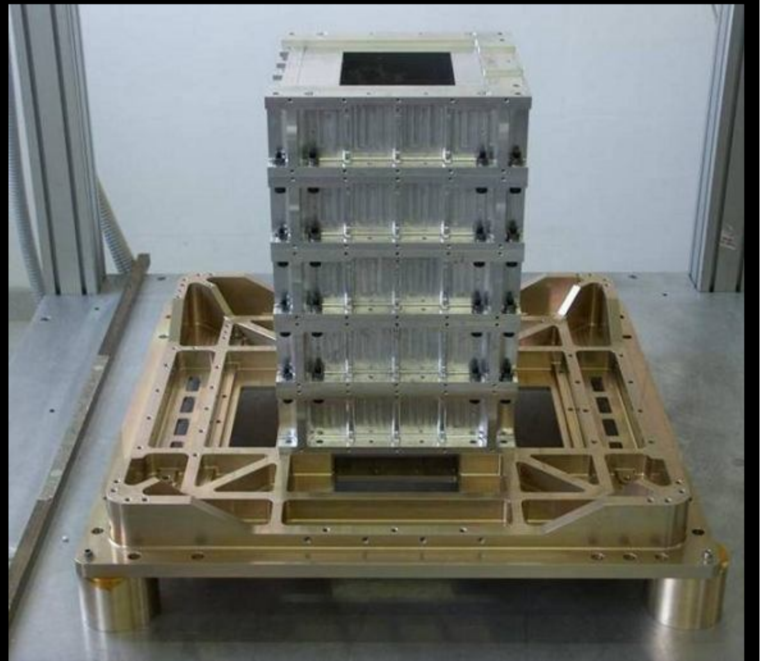
Adapted from W. Menn

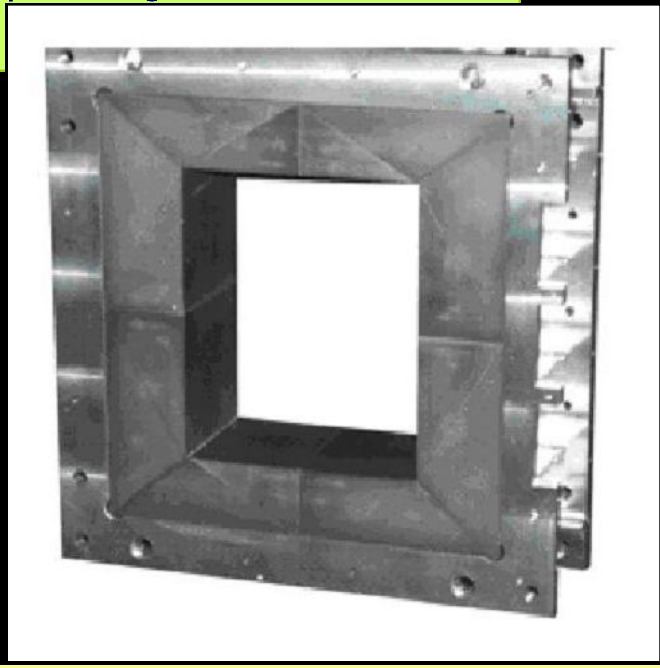
The permanent magnet

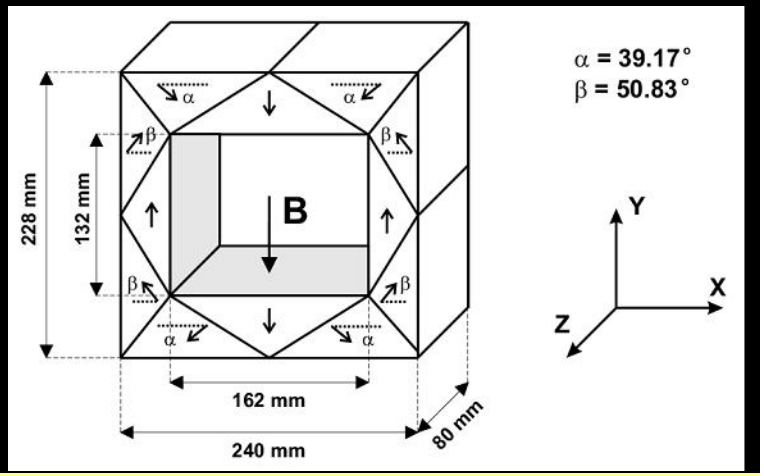
- 5 magnetic modules
- Permanent magnet (Nd-Fe-B alloy) assembled in an aluminum mechanics
- Magnetic cavity sizes (132 x 162) mm^2 x 445 mm
- Field inside the cavity 0.48 T at the center
- Average field along the central axis of the magnetic cavity : **0.43 T**

Geometric Factor: **20.5 cm^{2}sr**

- Black IR absorbing painting
- Magnetic shields







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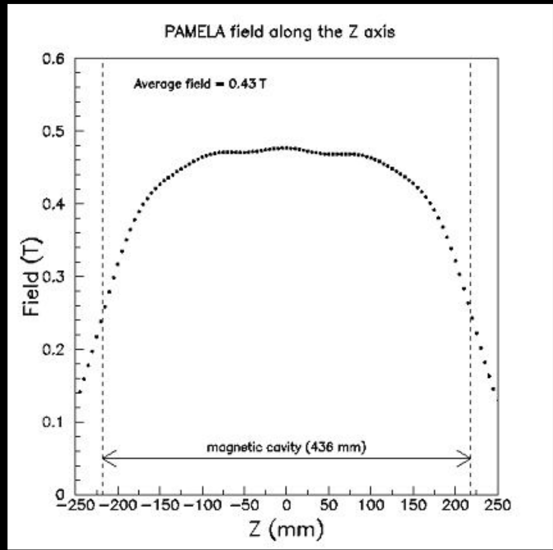
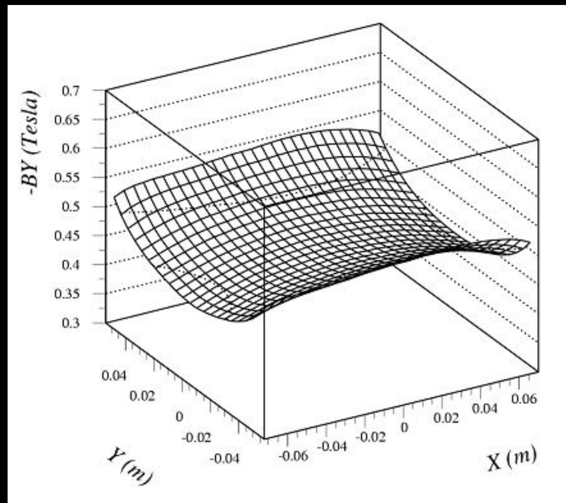


MAGNETIC FIELD MEASUREMENTS

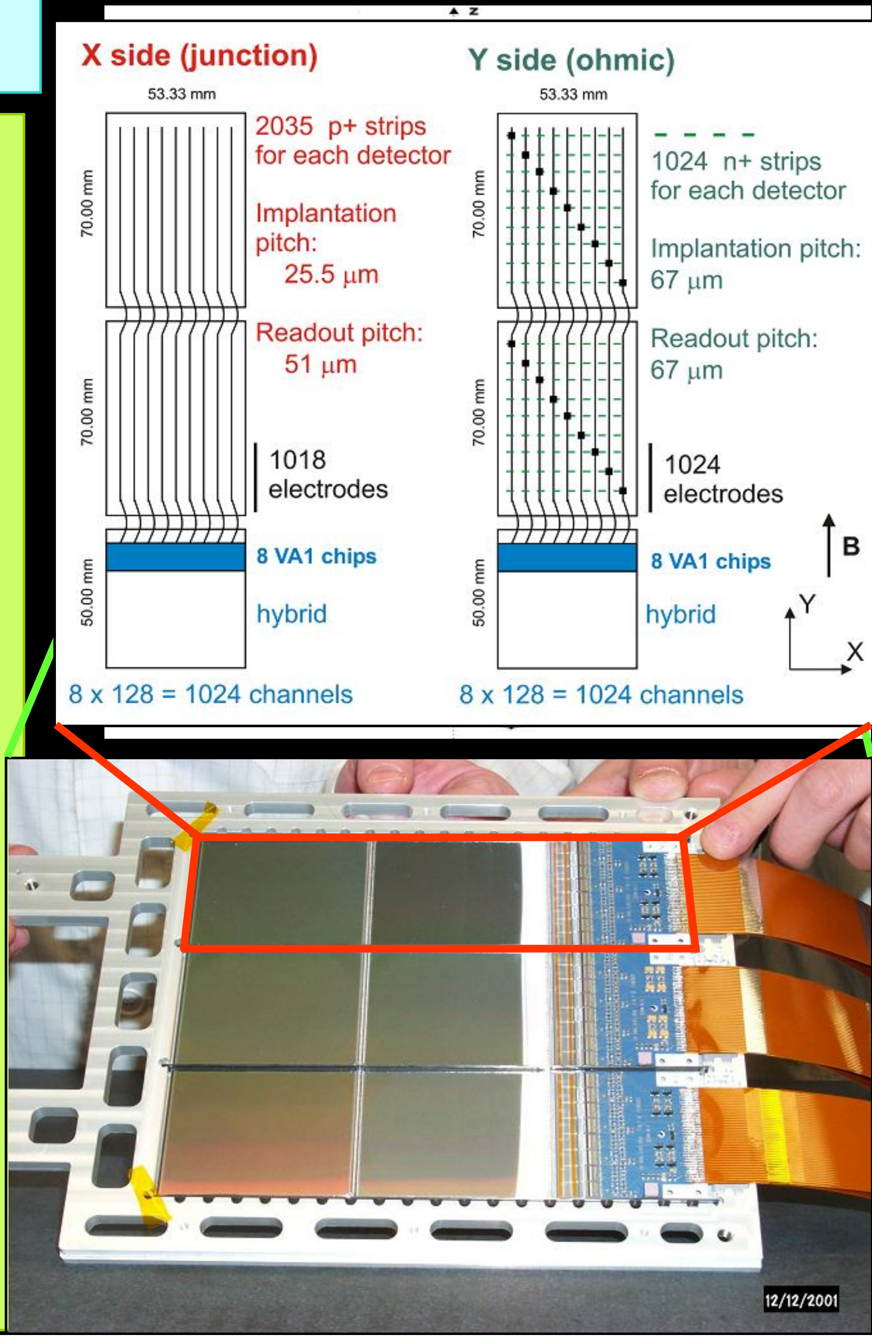
- Gaussmeter (F.W. Bell) equipped with 3-axis probe mounted on a motorized positioning device (0.1mm precision)
- Measurement of the three components in 67367 points 5mm apart from each other
- Field inside the cavity 0.48 T at the center
- Average field along the central axis of the magnetic cavity : **0.43 T**
- Good uniformity
- Measurement of external magnetic field – magnetic momentum < 90 Am^2



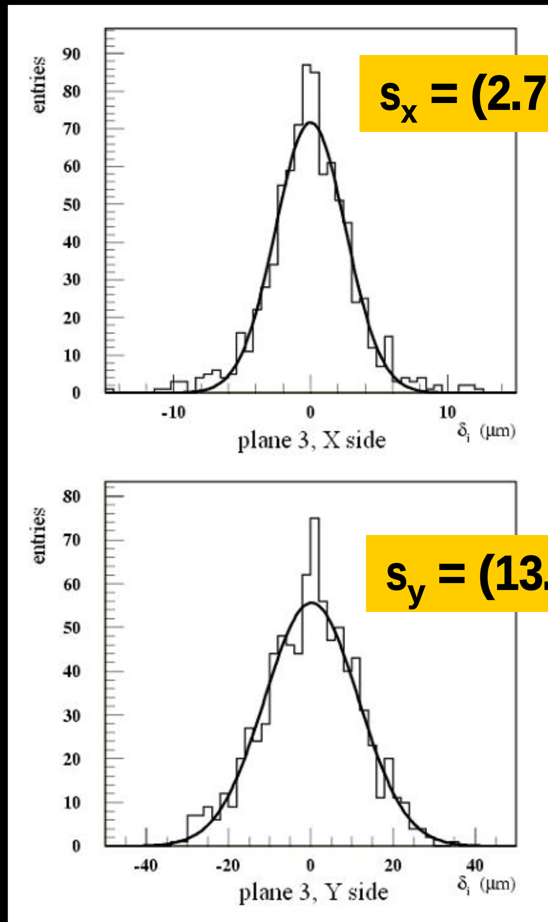
The tracking system

6 detector planes composed by 3 “ladders”

- Mechanical assembly
  - no material above / below the plane (1 plane = 0.3% X_0)
  - carbon fibers stiffeners glued laterally to the ladders
- ladder : - 2 microstrip silicon sensors
  - 1 “hybrid” with front-end electronics
- silicon sensors (Hamamatsu):
  - 300 mm, Double Sided - x & y view
  - Double Metal - No Kapton Fanout
  - AC Coupled - No external chips
- FE electronics: VA1 chip
  - Low noise charge preamplifier -
  - Operating point set for optimal compromise:
    - total FE dissipation: 37 W on 36864 channels
    - Dynamic range up to 10 MIP
- DAQ: 12 DSPs
  - data compression (>95%)
  - on-line calibration (PED,SIG,BAD)



Spatial resolution

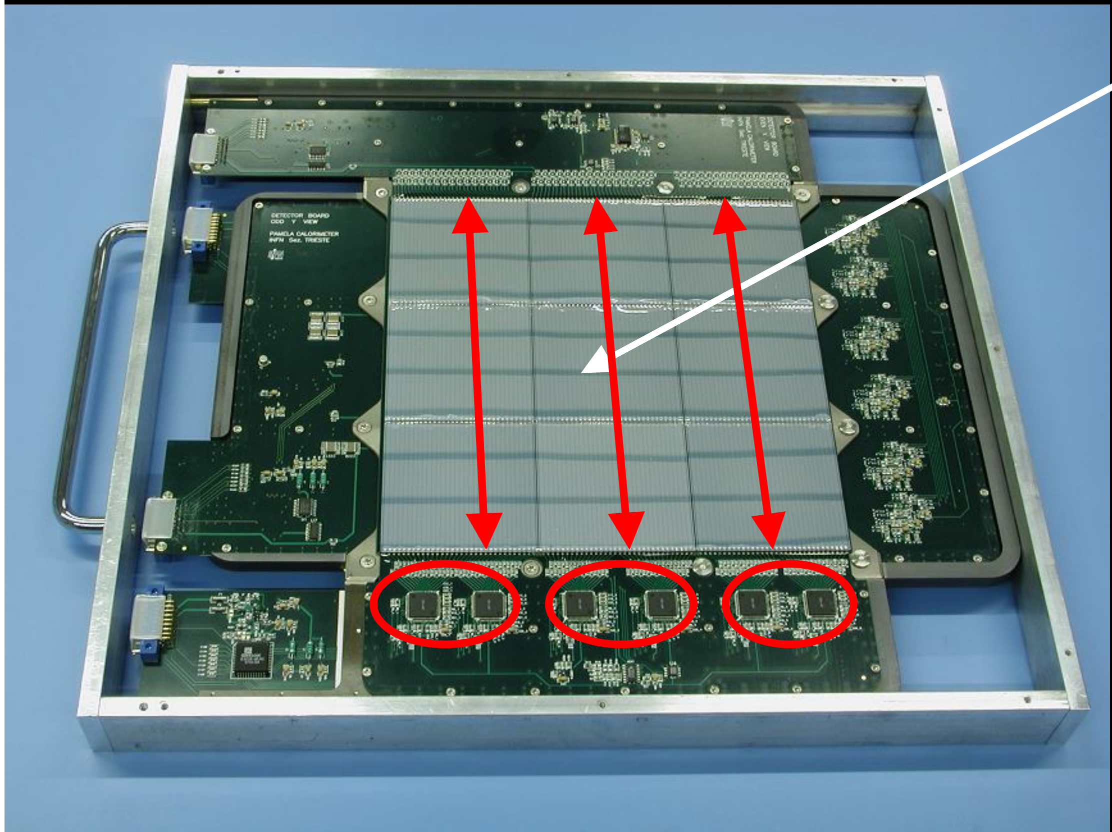


$s_x = (2.77 \pm 0.04)\ \mu m$

$s_y = (13.1 \pm 0.2)\ \mu m$

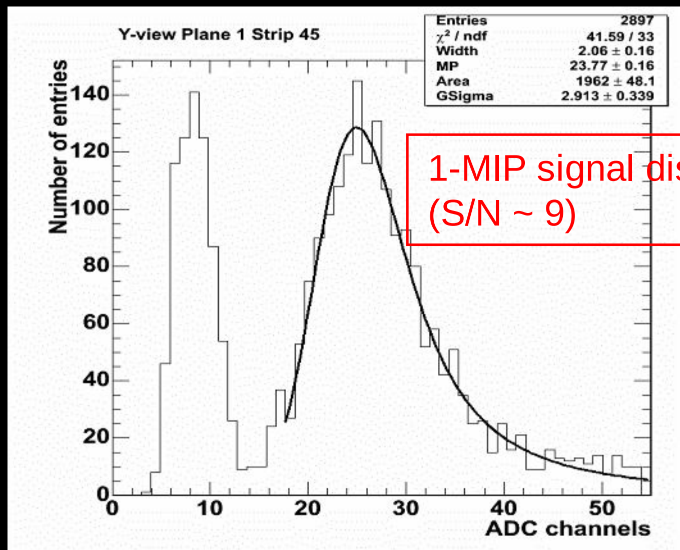
40-100 GeV pions (CERN-SPS 2000) beam-test of a small tracking-system prototype

Imaging Calorimeter



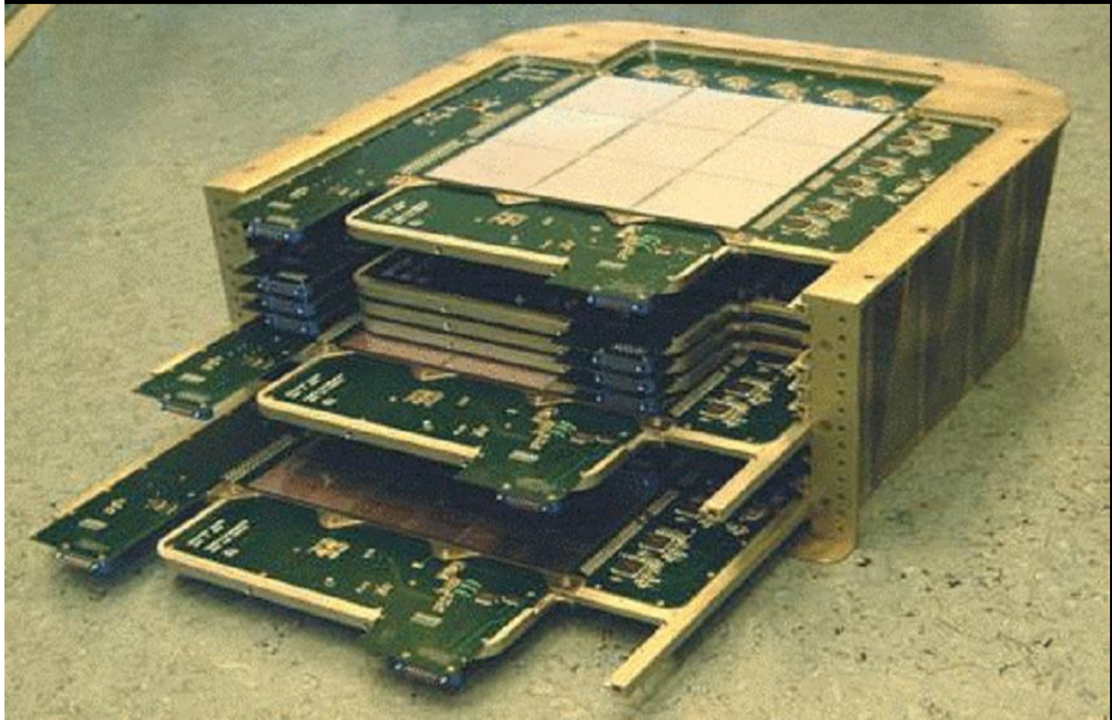
44 Si detector views (22X and 22Y)

- 8x8 cm^2 detectors arranged in a 3x3 matrix
- 32 strips/detector, 2.4 mm pitch
- Strips of detectors in the same row (column) are bonded together (ladder) ⇒ 24 cm long strips
- Each ladder (32 channels) is read out by 2 CR1.4P front-end chips ⇒ 6 front-end chips/view
- In total:
  - 396 silicon detectors
  - 264 CR1.4P chips
  - 4224 channels



From V. Bonvicini

Imaging Calorimeter



- **Main tasks:**
- lepton/hadron discrimination
- $e^{+/-}$ energy measurement

- **Characteristics:**
- 22 W plates (2.6 mm / 0.74 X_0)
- 44 Si layers (X-Y), 380 μm thick
- Total depth: 16.3 X_0 / 0.6 λ_I
- 4224 channels
- Self-triggering mode option (> 300 GeV; GF~600 cm^2 sr)
- Mass: 110 kg
- Power Consumption: 48 W

- **Design performance:**
- $\bar{p}$,e^+ selection efficiency ~ 90%
- p rejection factor ~ 10^5
- e rejection factor > 10^4
- Energy resolution ~ 5% @ 200 GeV

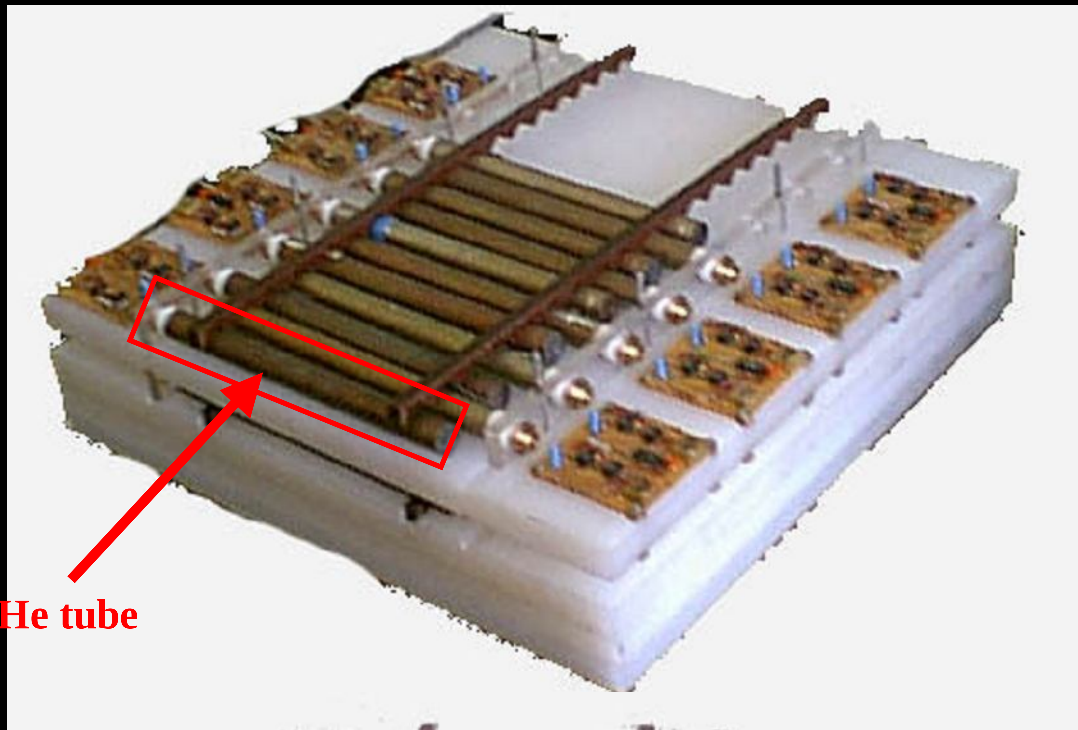
Adapted from V. Bonvicini

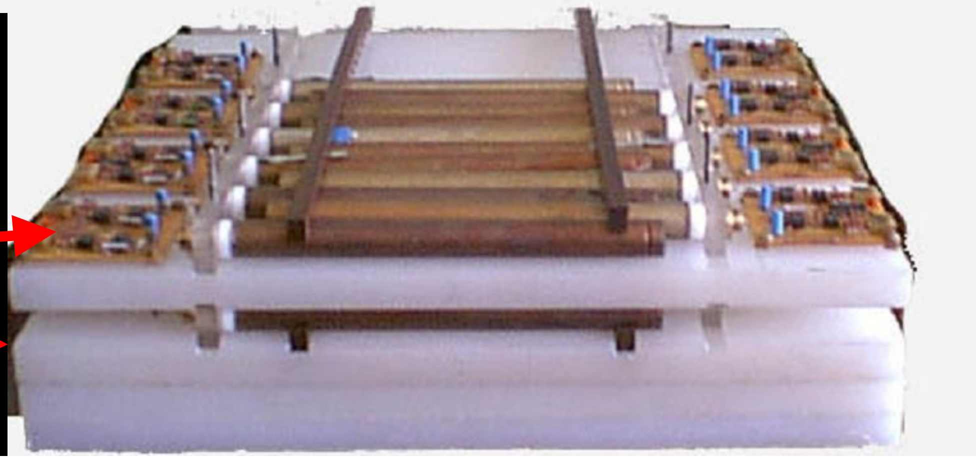
Neutron Detector

Lebedev Physical Institute Academy of Science, Russia

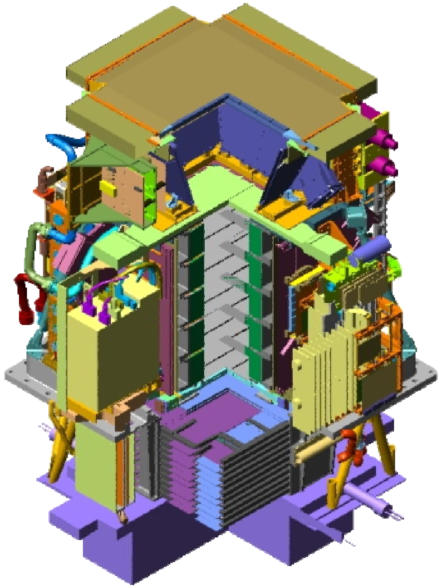
- 36 ^{3}He containers (2 planes)
- 9.5 cm polyethilene moderator enveloped in thin cadmium layer.
- 60x55x15 cm^3,   30 kg, 10 W

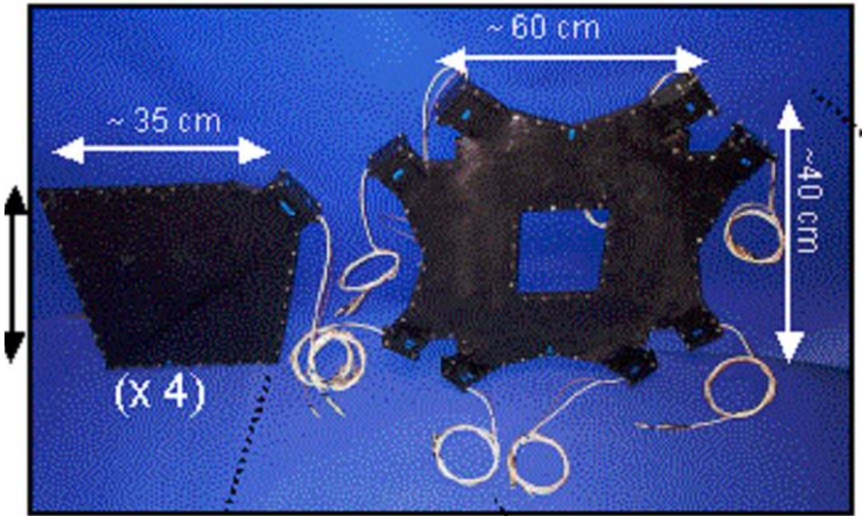
- **(10% eff for E<1MeV n)**
- Triggered counts
- Background counting



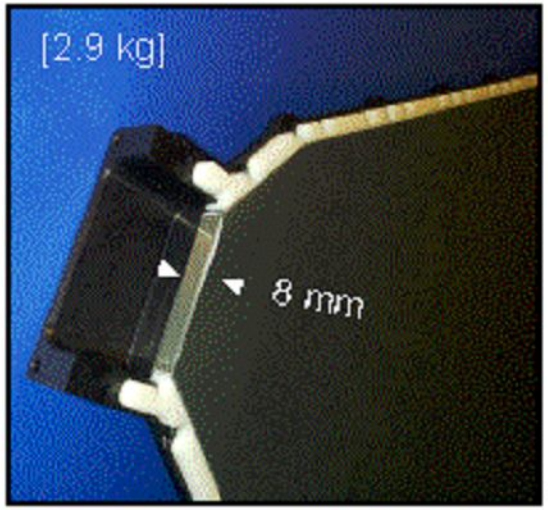


The Anticoincidence Systems



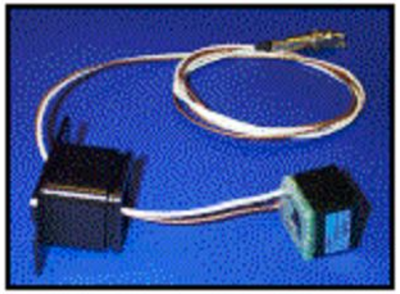


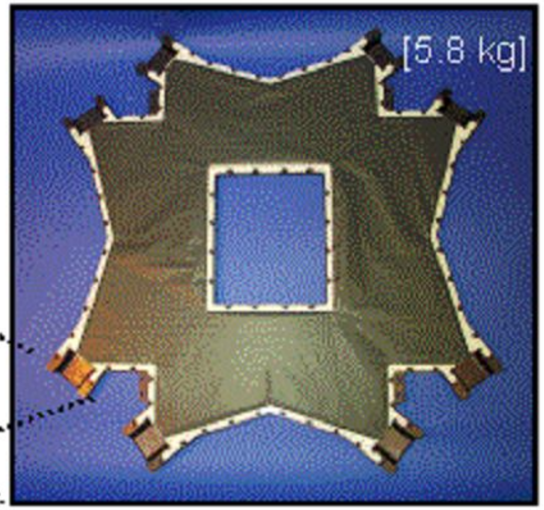
Anticoincidences are mounted on the sides, top and interscintillator area. They are used to reject false triggers coming from the satellite



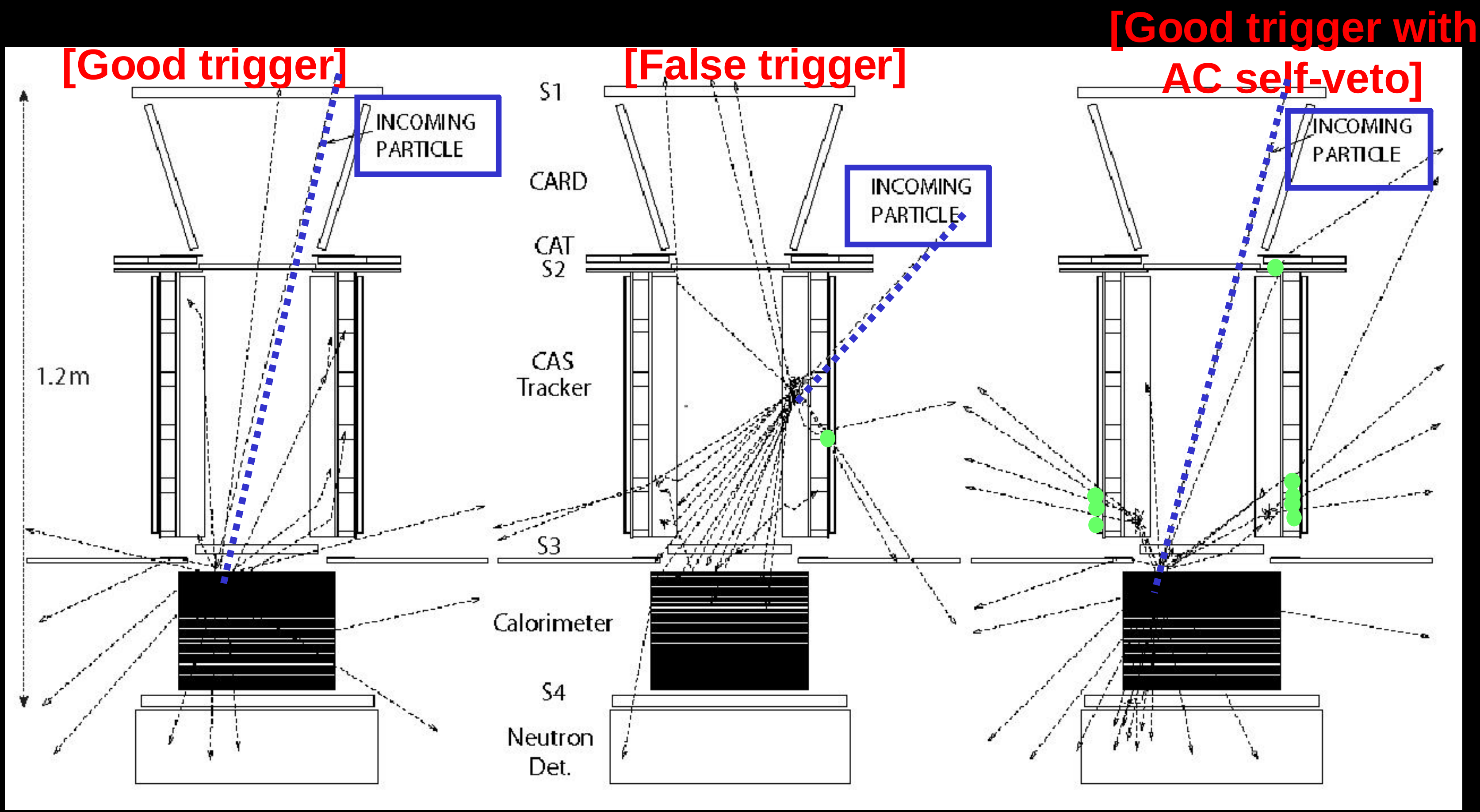
[Bicron BC-448M]

[Hamamatsu R5900U]





[3M Tedlar / Tyvek]



Main trigger = S1 AND S2 AND S3

Use AC offline or in L2 trigger to reduce false triggers

PAMELA Collaboration

Italy:

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IFAC

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