ICRR

24-03-2009

Recent results and perspectives on cosmic ray matter and antimatter from Pamela experiment

M. Casolino

INFN & University of Roma Tor Vergata

on behalf of the PAMELA collaboration

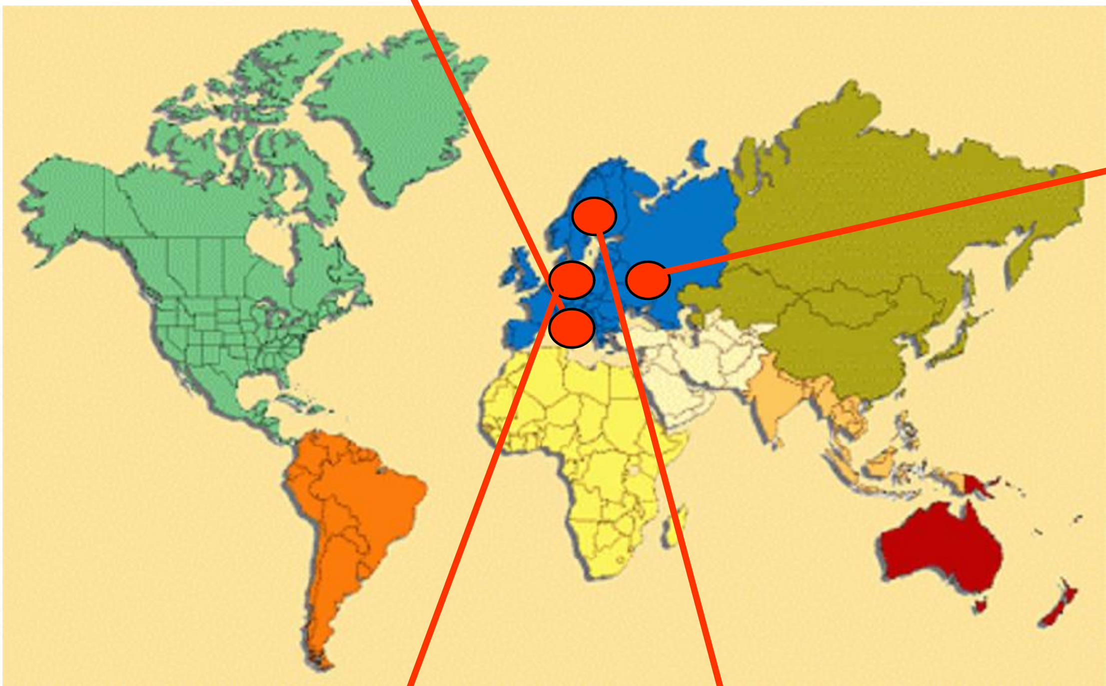
PAMELA Collaboration

Italy:

Bari Florence Frascati Naples Rome Trieste CNR, Florence

Russia:

Moscow
St. Petersburg



Germany:

Siegen

Sweden:

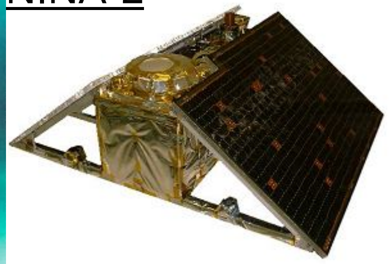
KTH, Stockholm

Past, present and future experiment

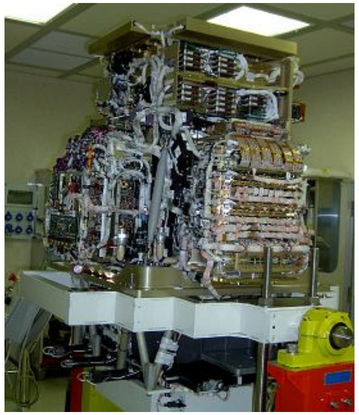
MASS-89, 91, TS-93, CAPRICE 94-97-98

NINA-1

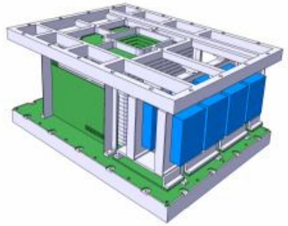
NINA-2

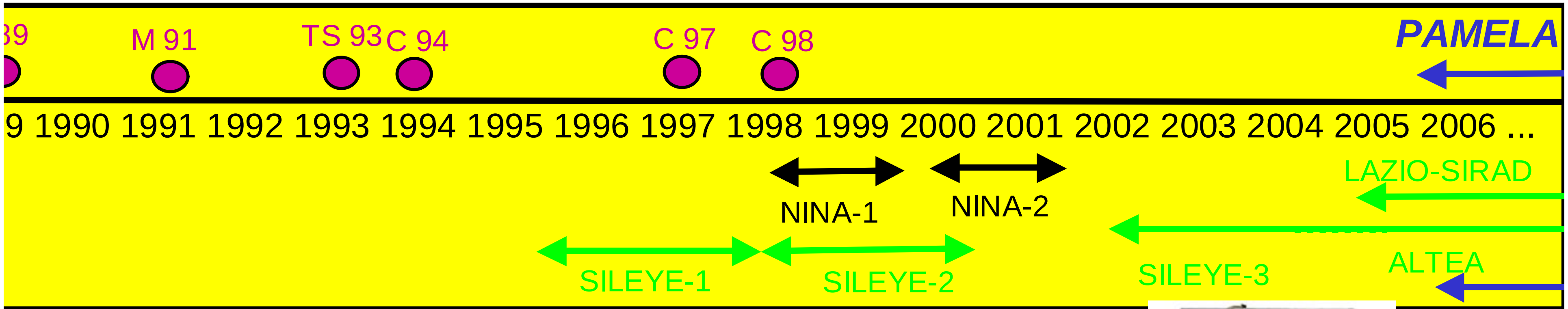


PAMELA



SIRAD





SILEYE-1

SILEYE-2

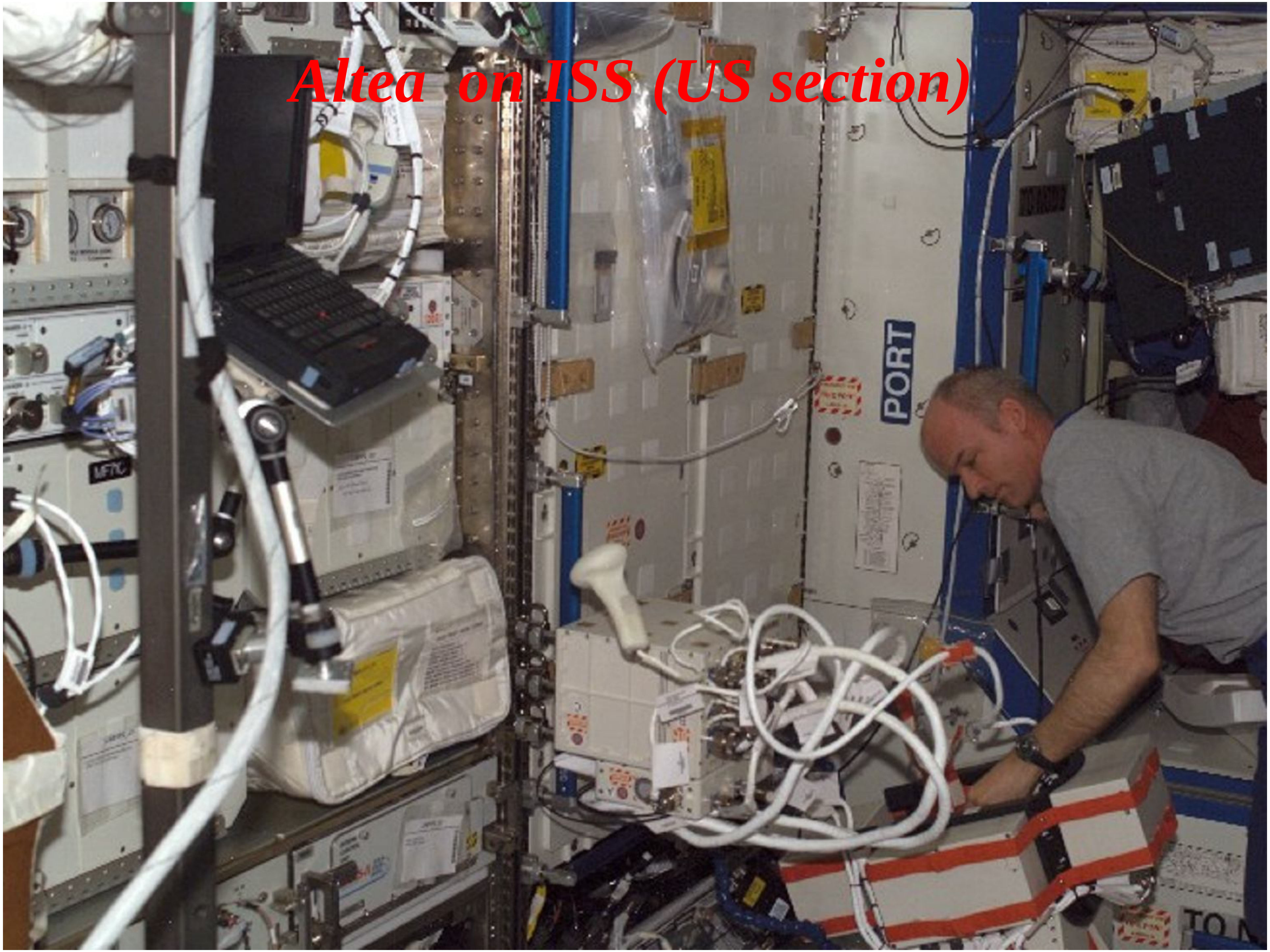
SILEYE-3/ ALTEINO:

LAZIO-SIRAD

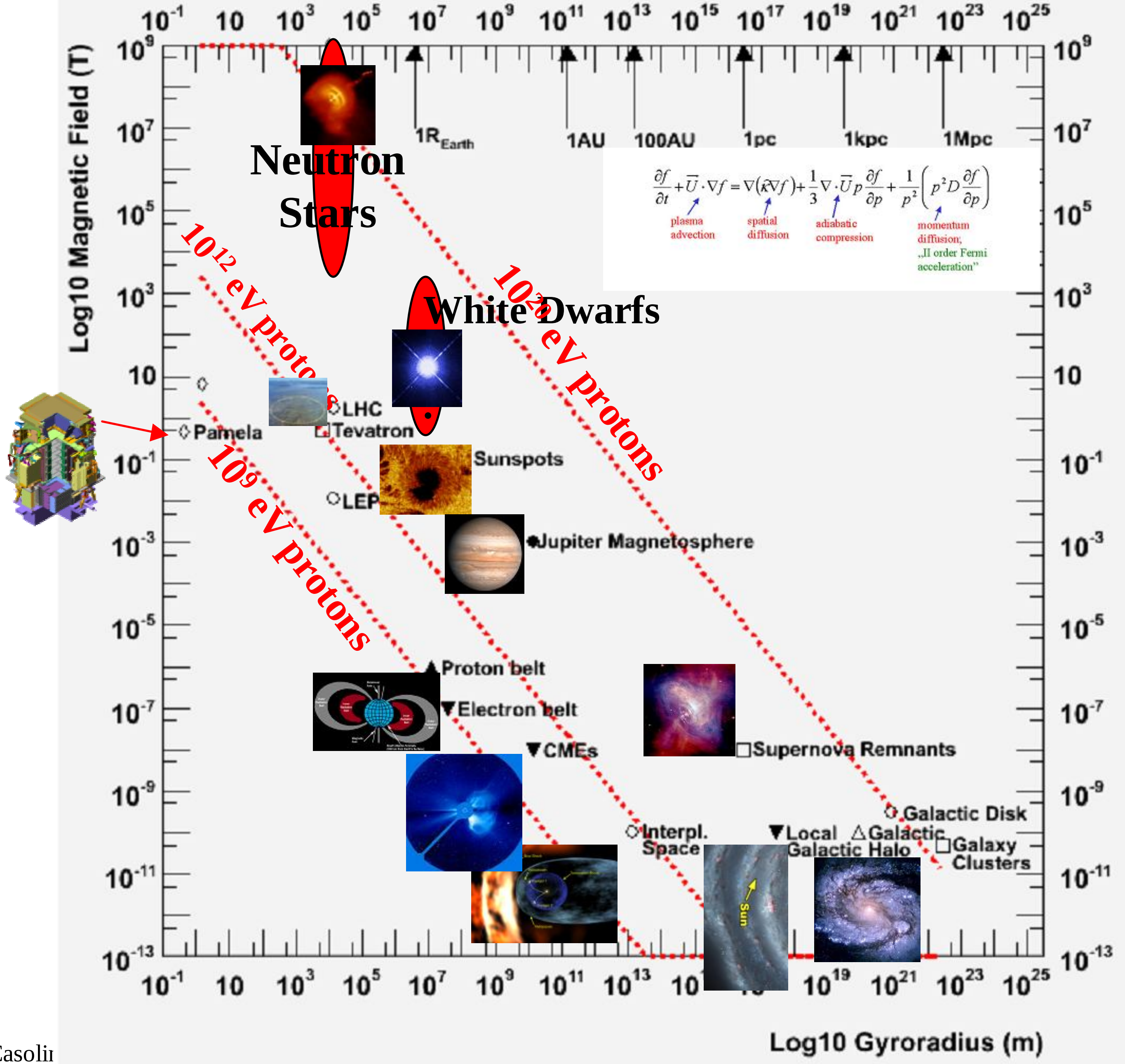
SILEYE-4/ALTEA

Sileye-3/Alteino on ISS (Russian)

Altea on ISS (US section)

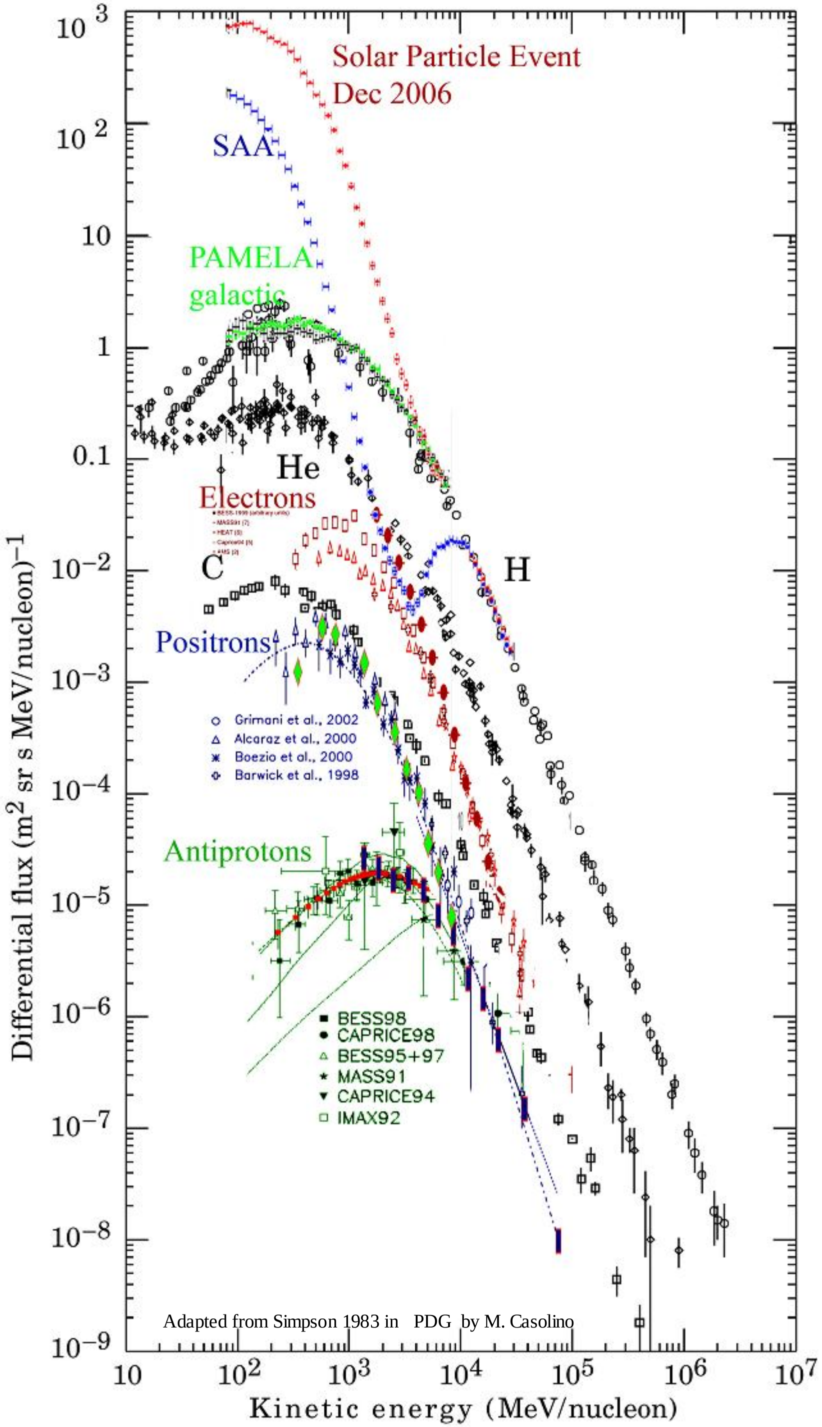


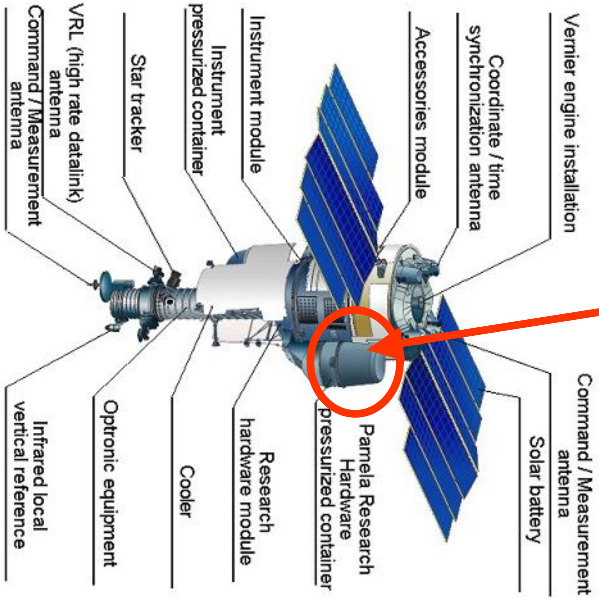
Pamela in the Hillas plot

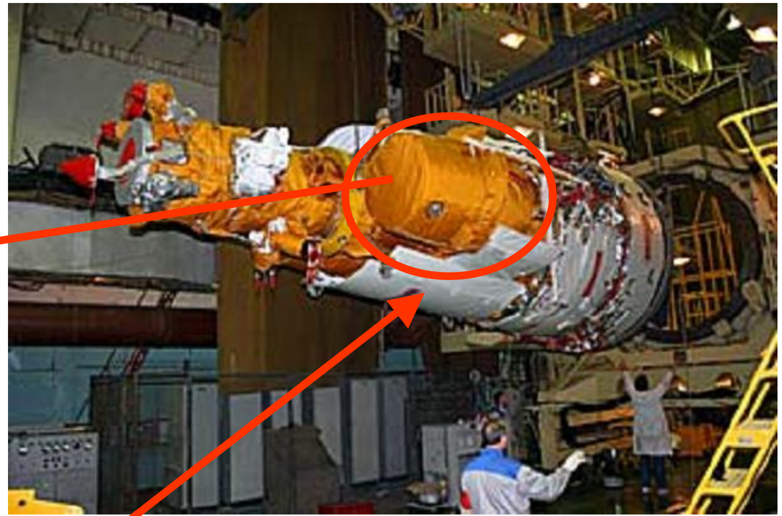


M. Casoli

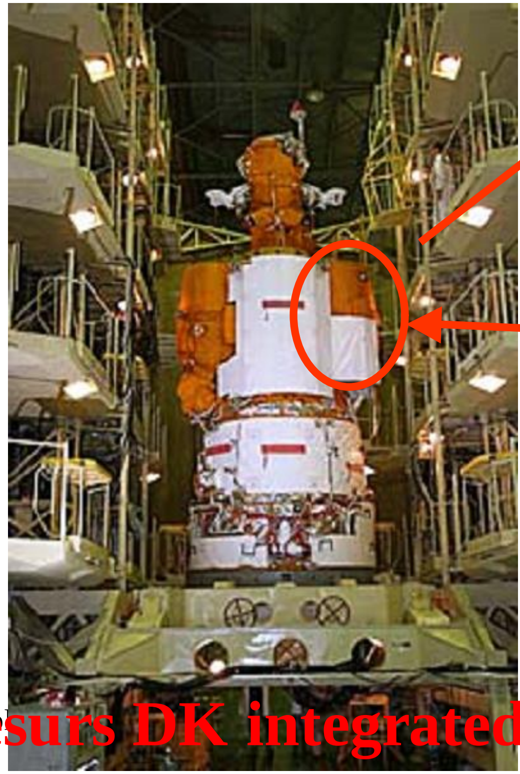
High precision charged cosmic ray measurement in Low Earth Orbit



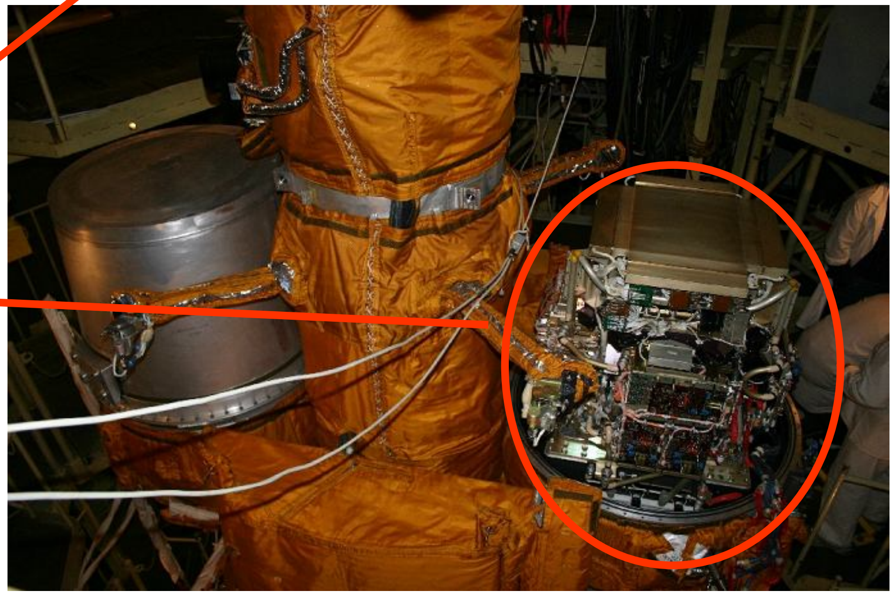




Coupling to Soyuz



Resurs DK integrated



Pamela during integration in Baikonur

Gagarinsky Start

Launch on June 15th 2006 Soyuz-U rocket

Time of Flight

(three scintillators, 6 planes, 48 phototubes)

Magnetic (0.46T) Spectrometer

Microstrip detector

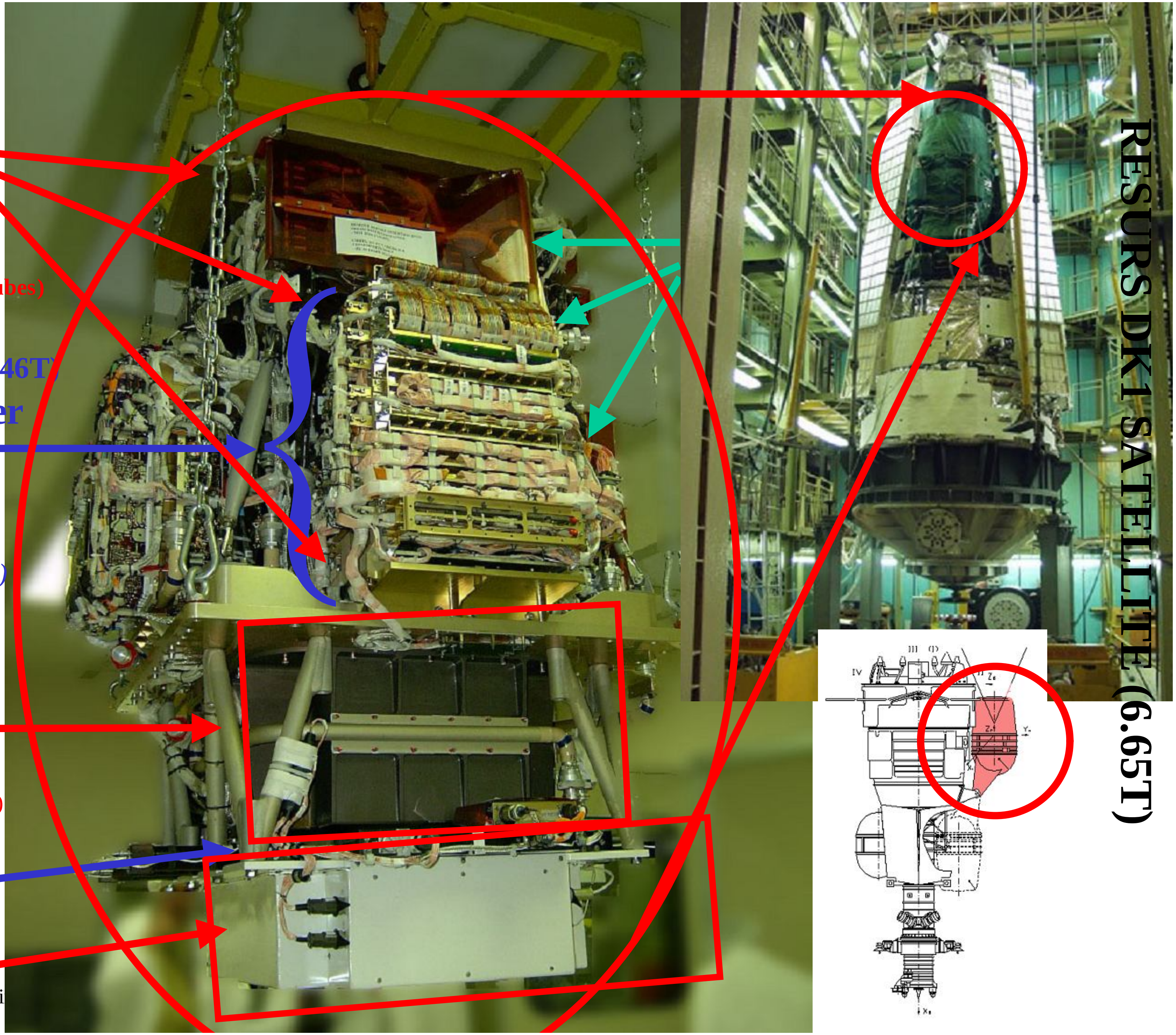
(6 double sided microstrip planes)

Silicon Tungsten Tracking Calorimeter

(44 planes of 96 strip)

Shower Catcher Scintillator

Neutron Detector

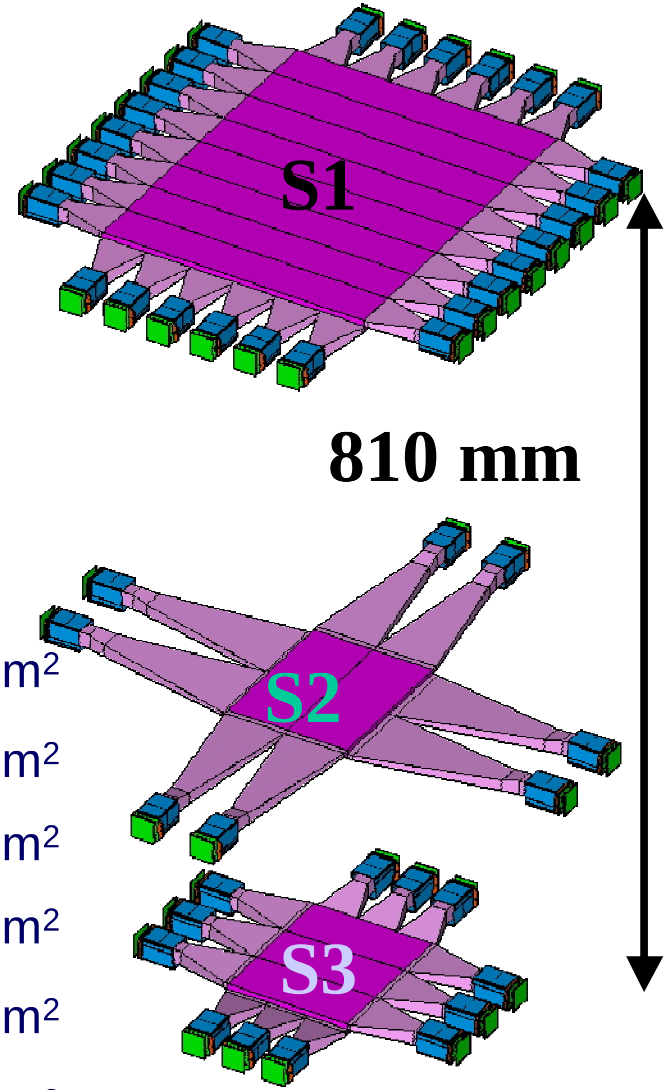


Time of Flight / Scintillator

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

3 double-layer scintillator paddles

- Timing resolution:
  - σ(paddle) ≈ 110 ps
  - σ(ToF) ≈ 330 ps (MIPs)



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

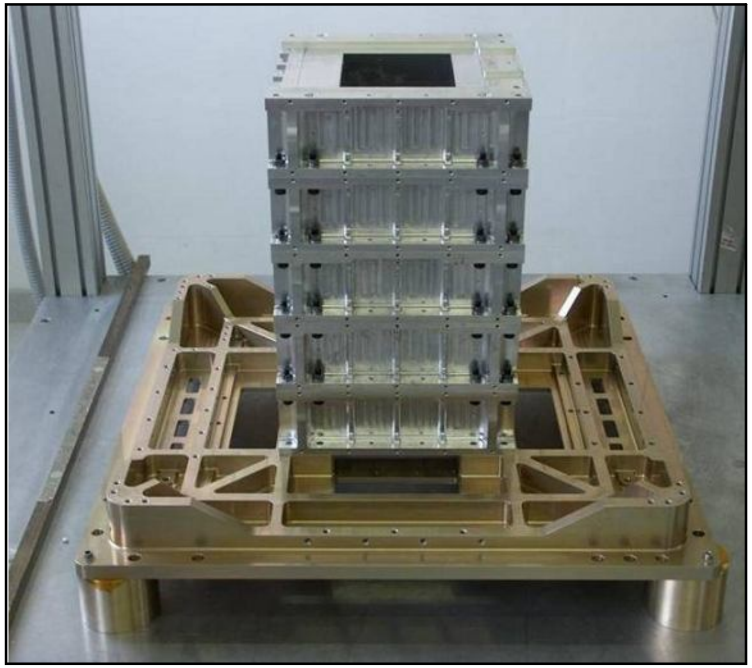
Adapted from W. Menn

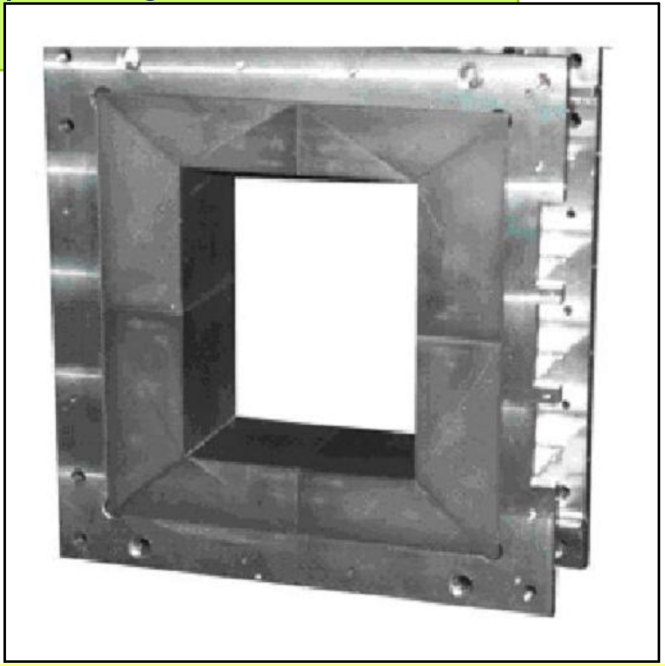
The permanent magnet

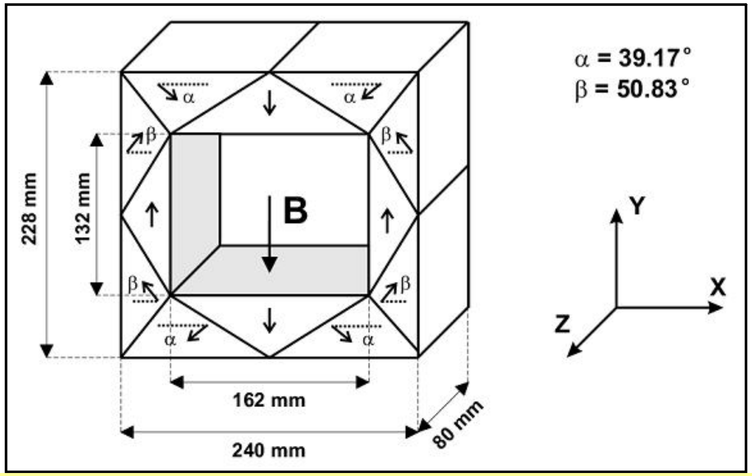
- 5 magnetic modules
- Permanent magnet (Nd-Fe-B alloy) assembled in an aluminum mechanics
- Magnetic cavity sizes (132 x 162) mm^2 x 445 mm
- Field inside the cavity 0.48 T at the center
- Average field along the central axis of the magnetic cavity : **0.43 T**

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

- Black IR absorbing painting
- Magnetic shields





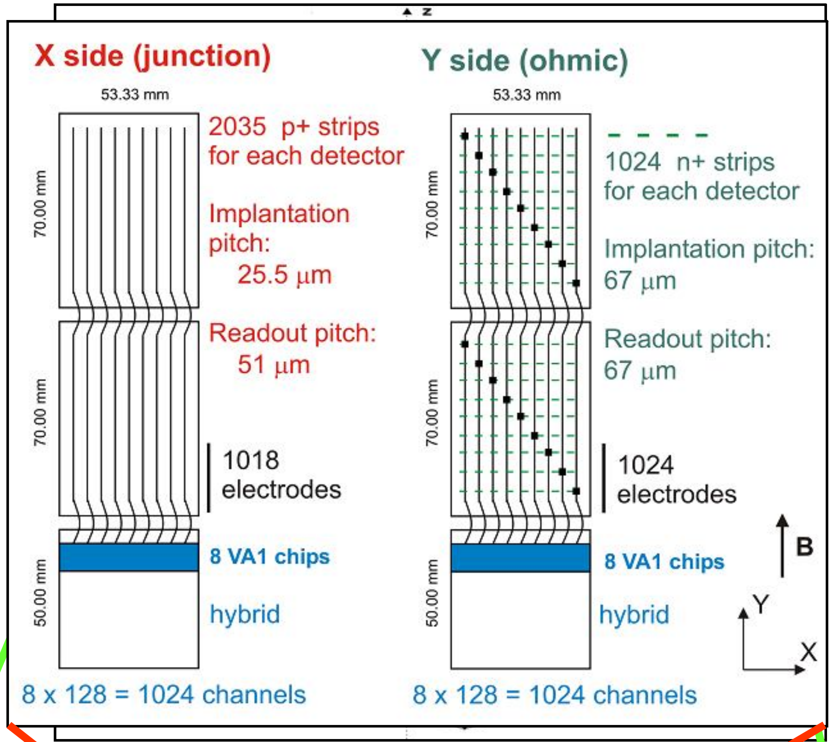


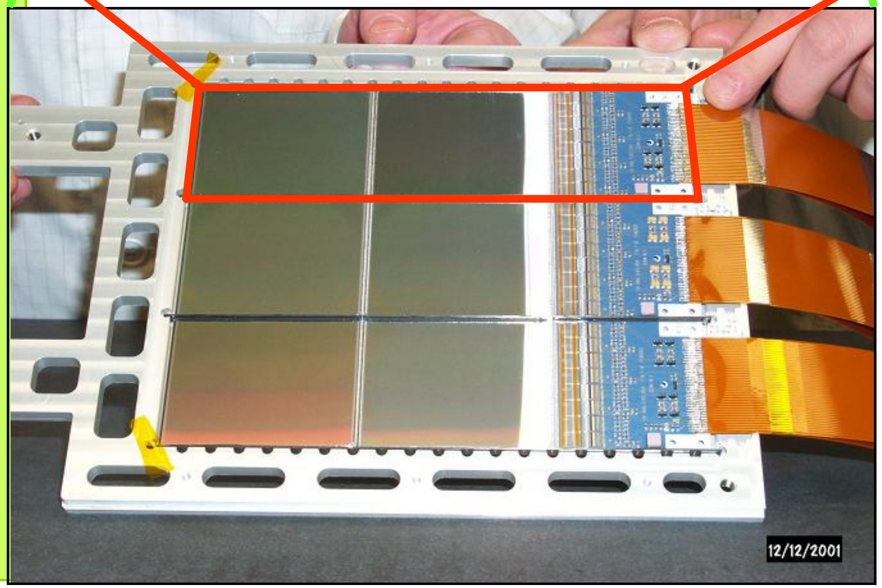
Adapted from E.Vannuccini .... ICRC2005 – Pune (India)

The tracking system

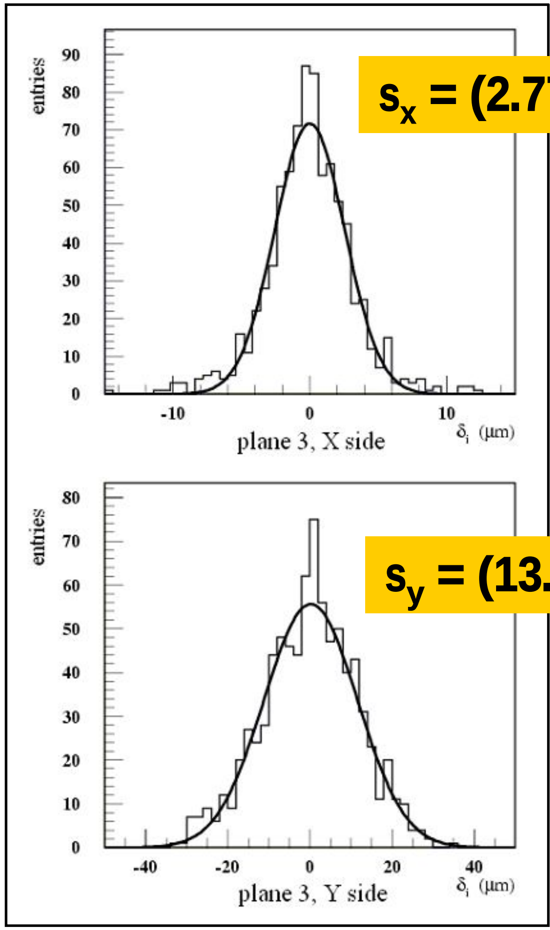
6 detector planes composed by 3 “ladders”

- 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

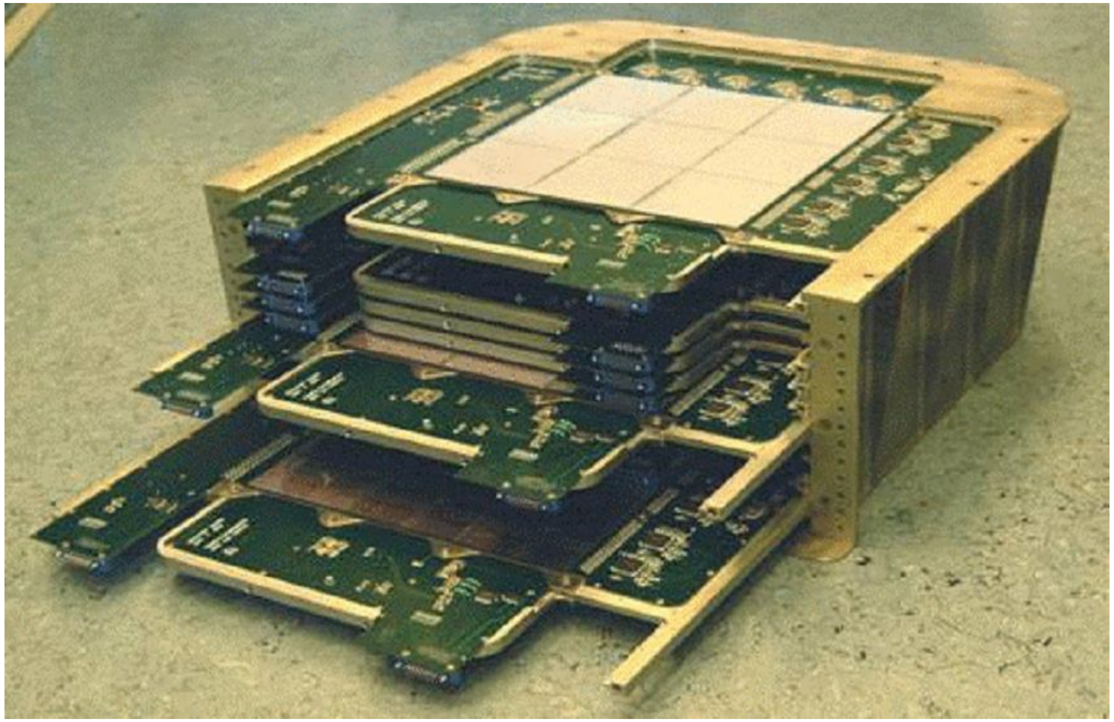


$s_x = (2.77 \pm 0.04)\ \mu m$

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

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

Imaging Calorimeter



- **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:**
- **p,e^+ selection efficiency ~ 90%**
- **p rejection factor ~ 10^5**
- **e rejection factor > 10^4**
- **Energy resolution ~ 5% @ 200 GeV**

Adapted from V. Bonvicini

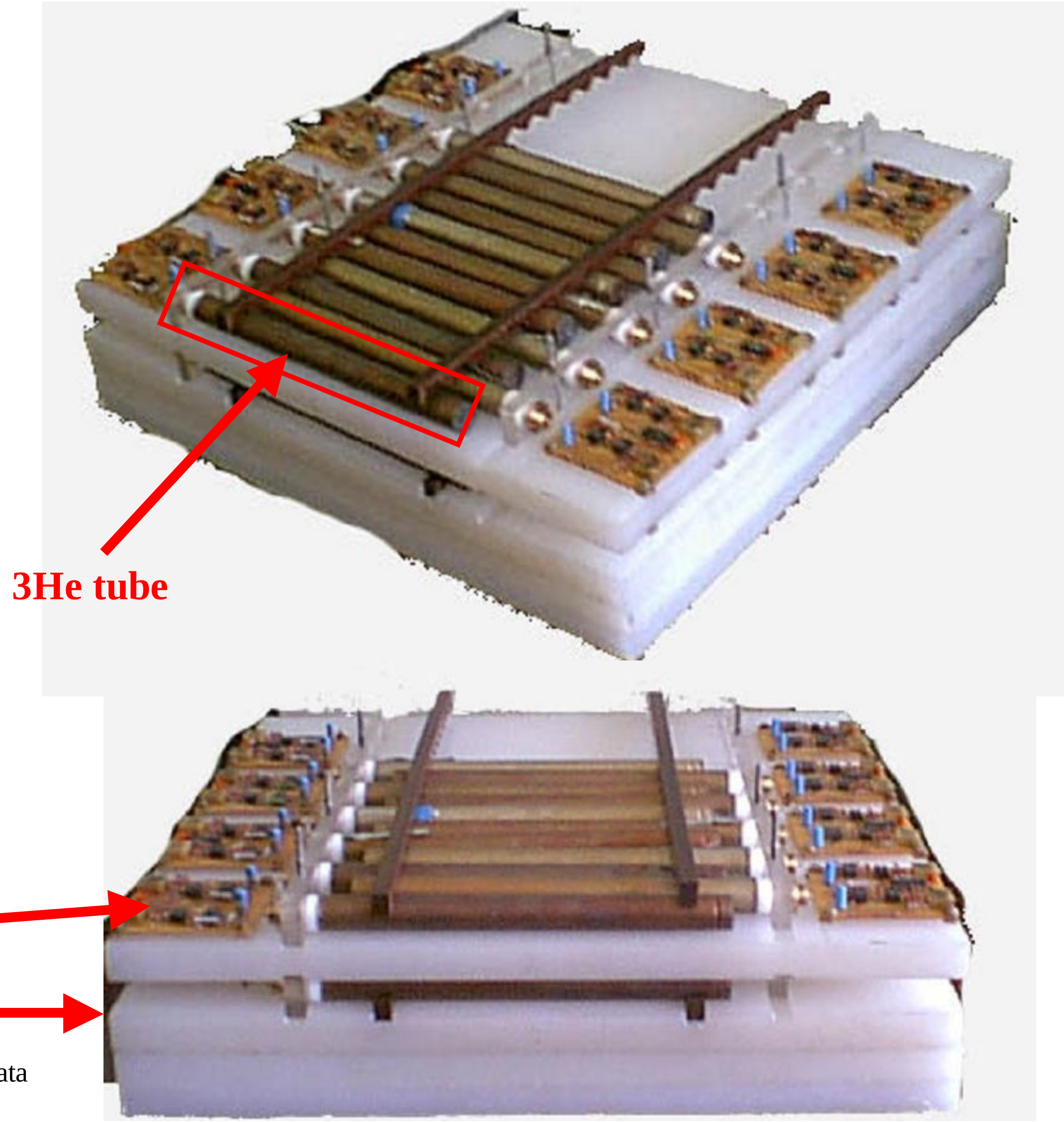
;ata

Neutron Detector

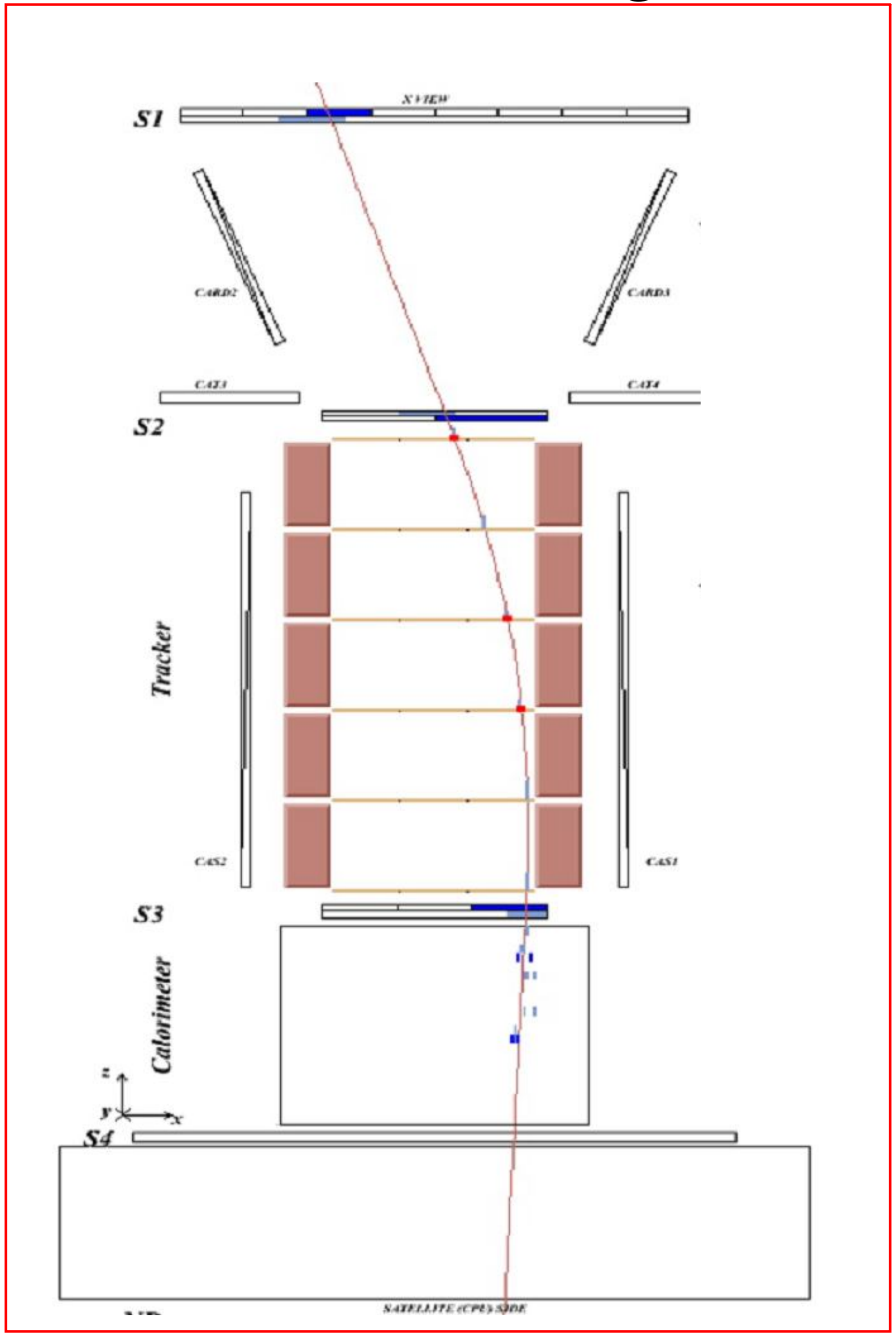
Lebedev Physical Institute Academy of Science, Russia

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

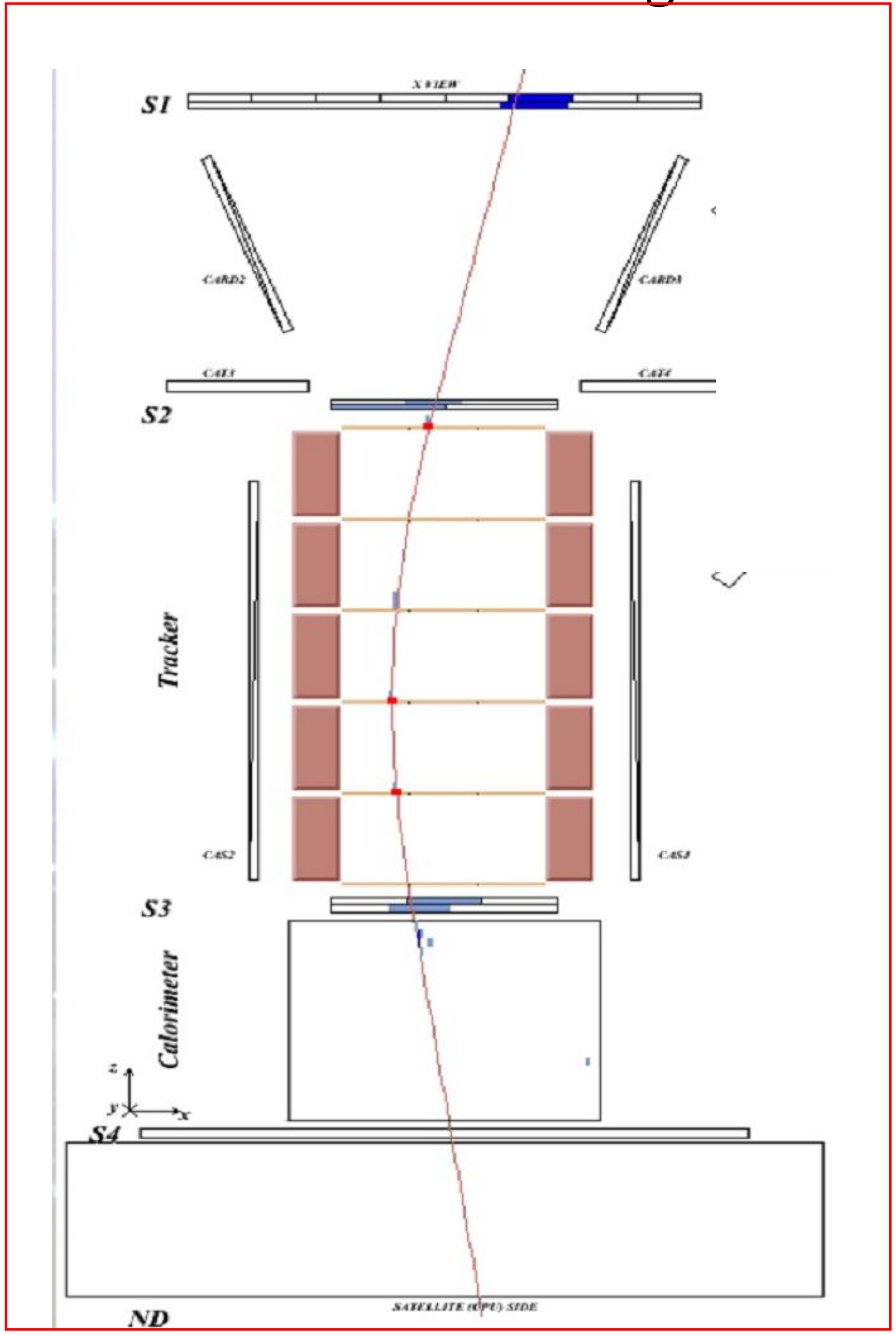
- **(10% eff for E<1MeV n)**
- Triggered counts
- Background counting

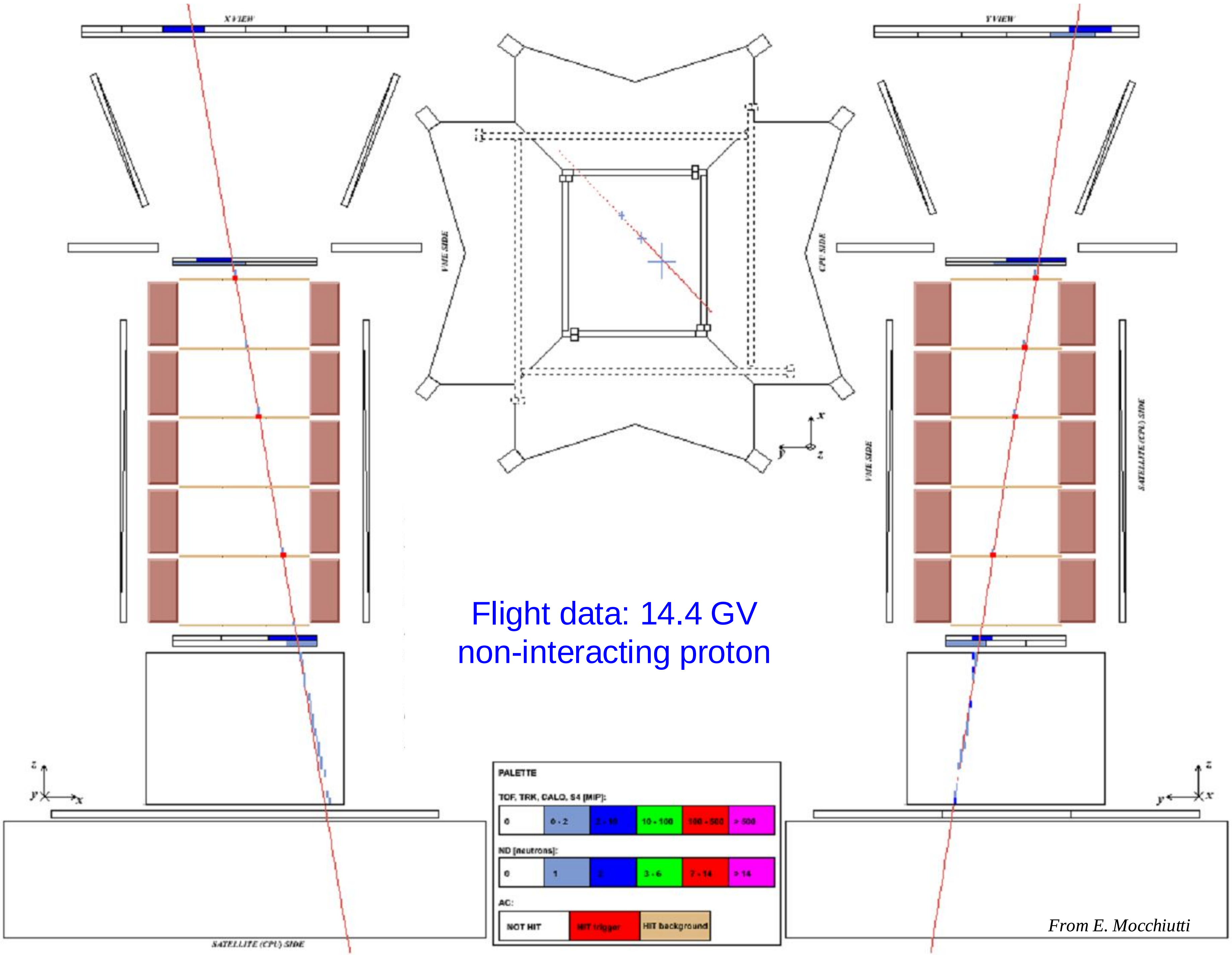


e+ 0.171 GV Bending view



e- 0.169 GV Bending view

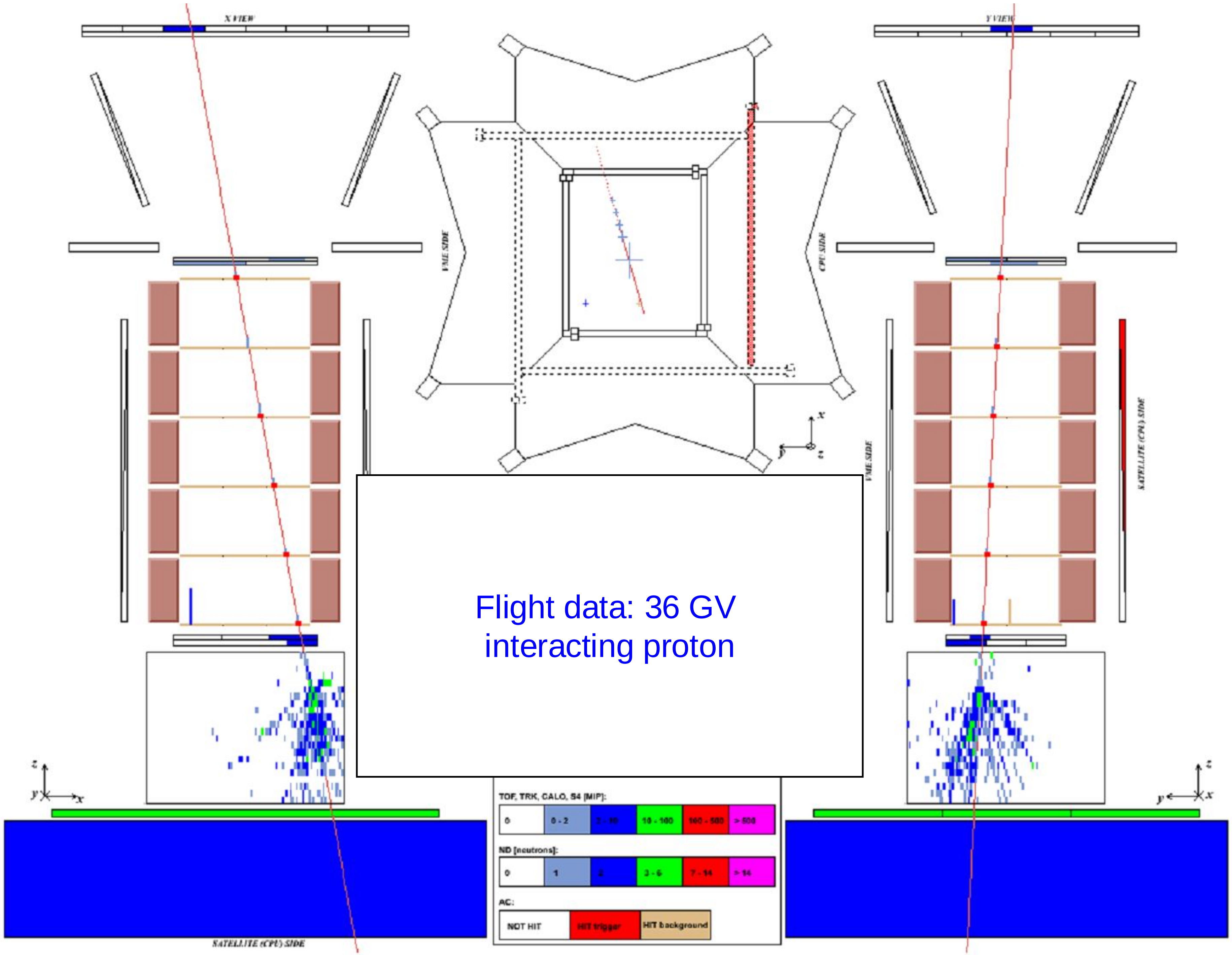


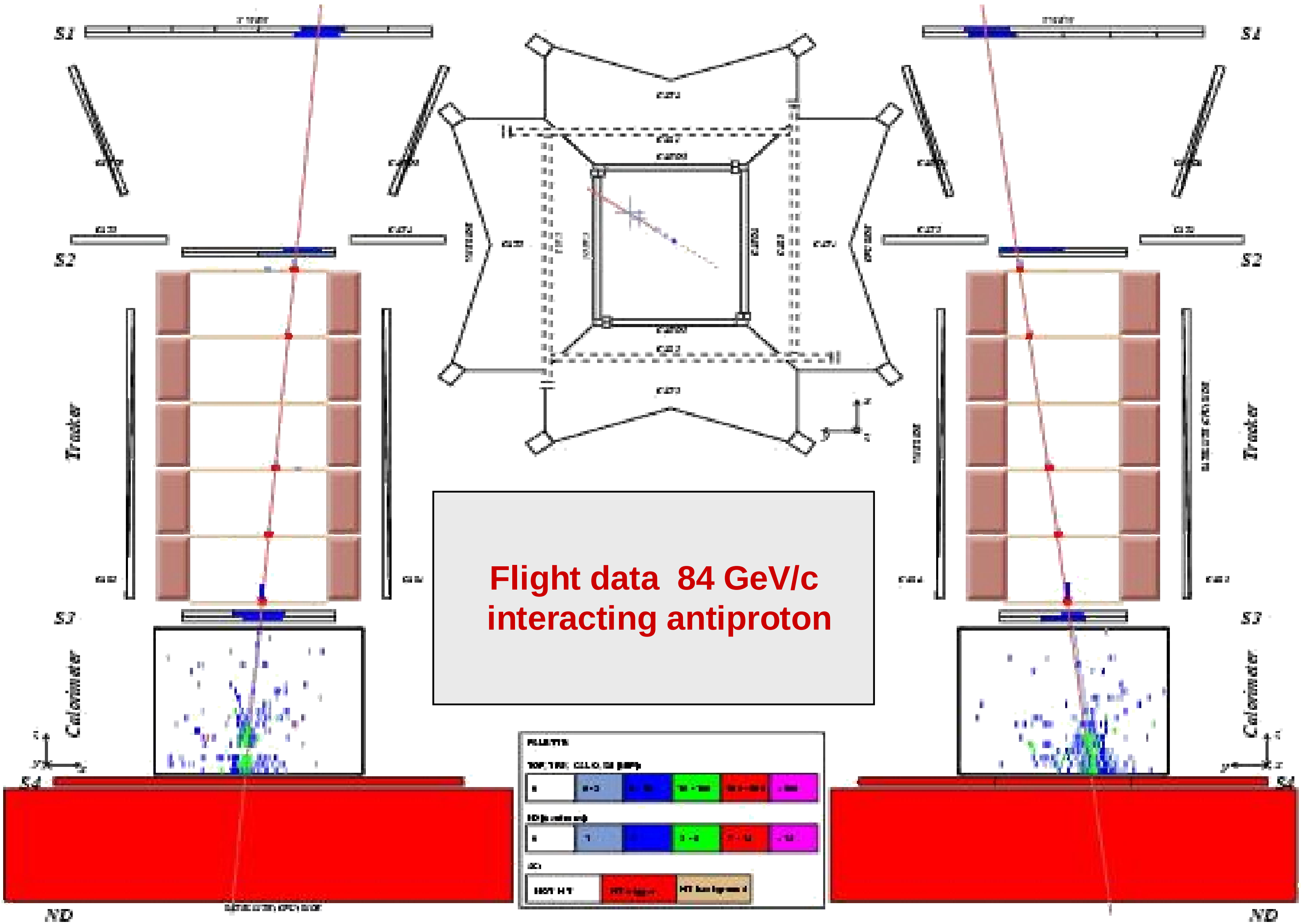


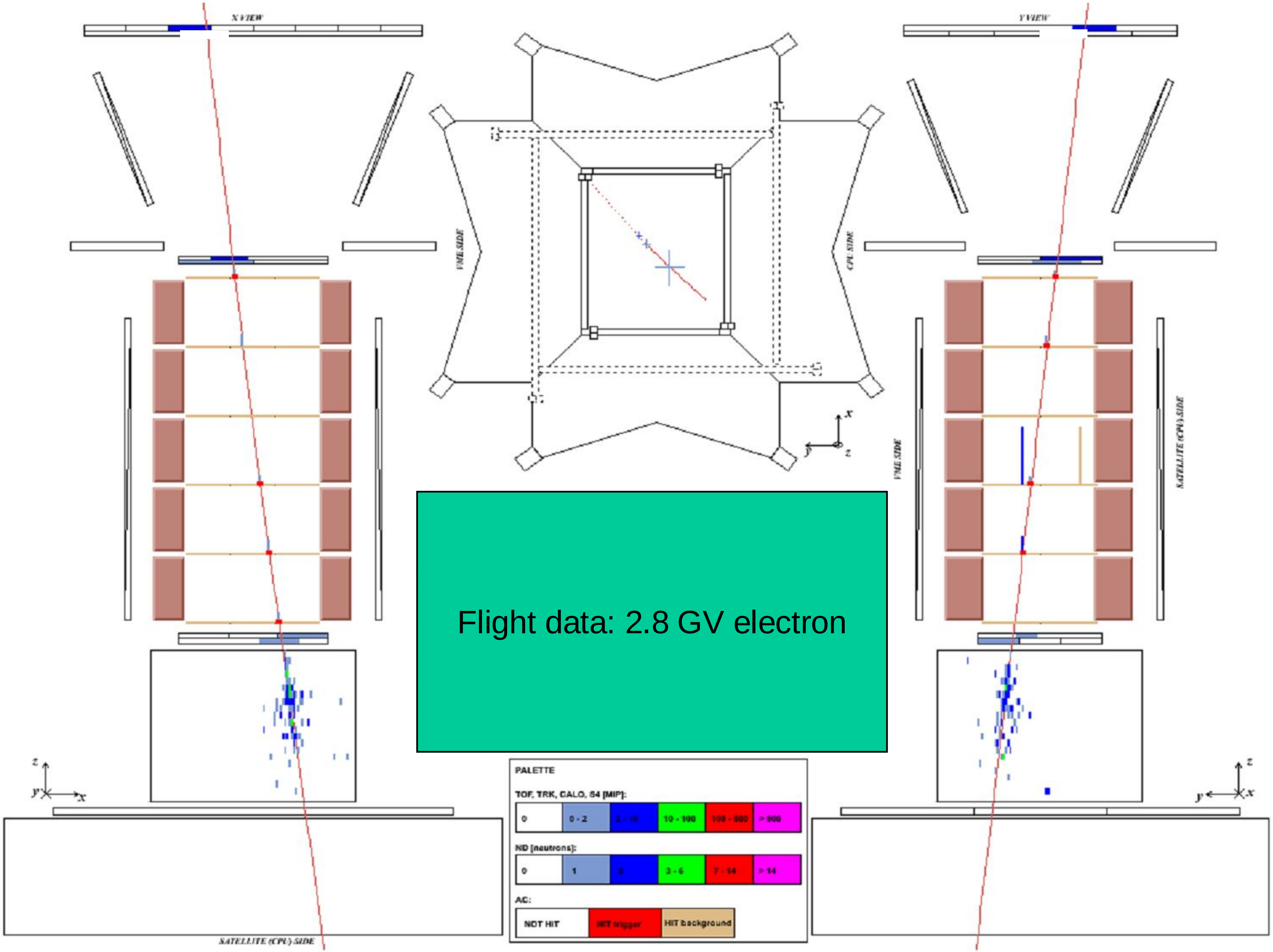
Flight data: 14.4 GV
non-interacting proton

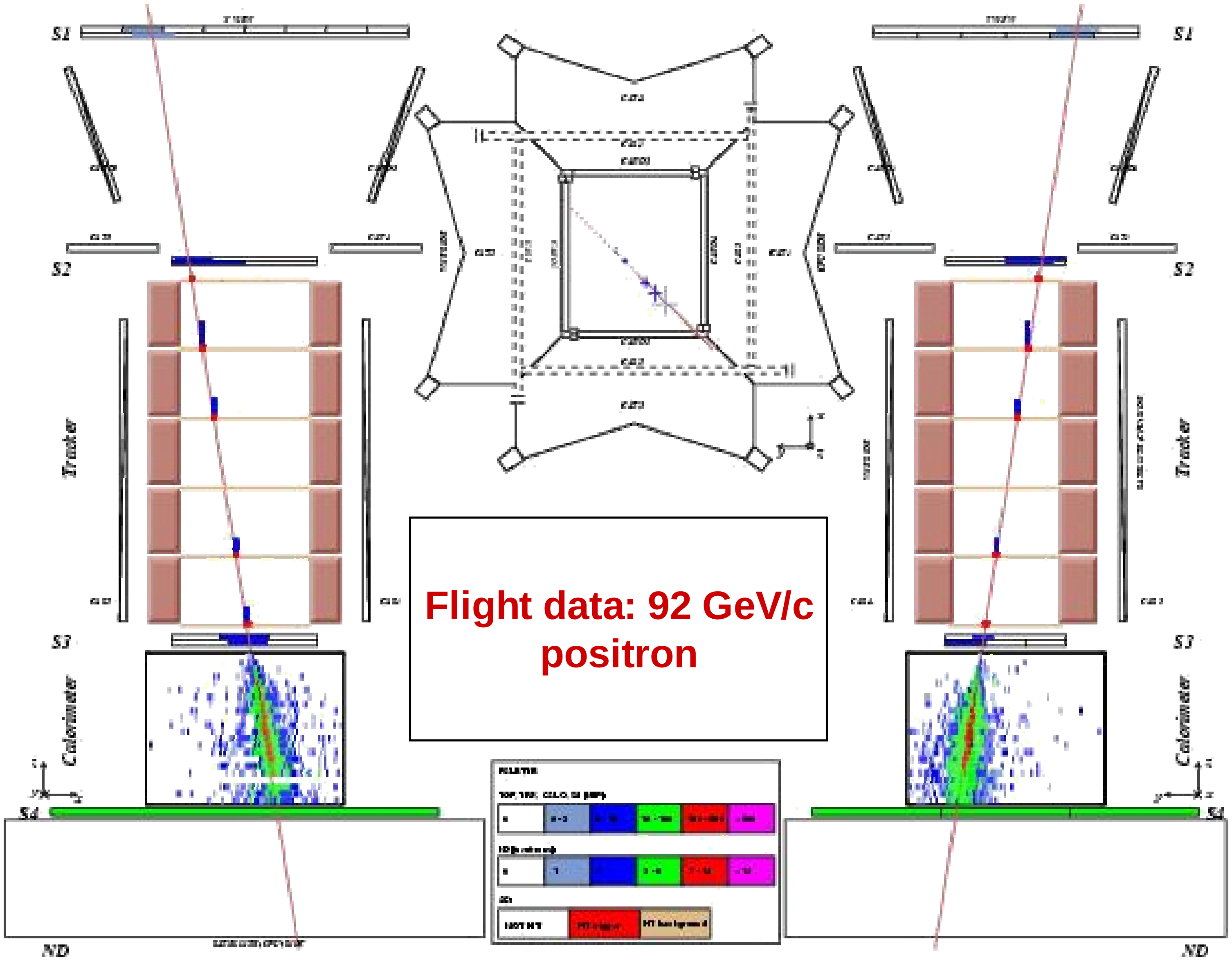
From E. Mocchiutti

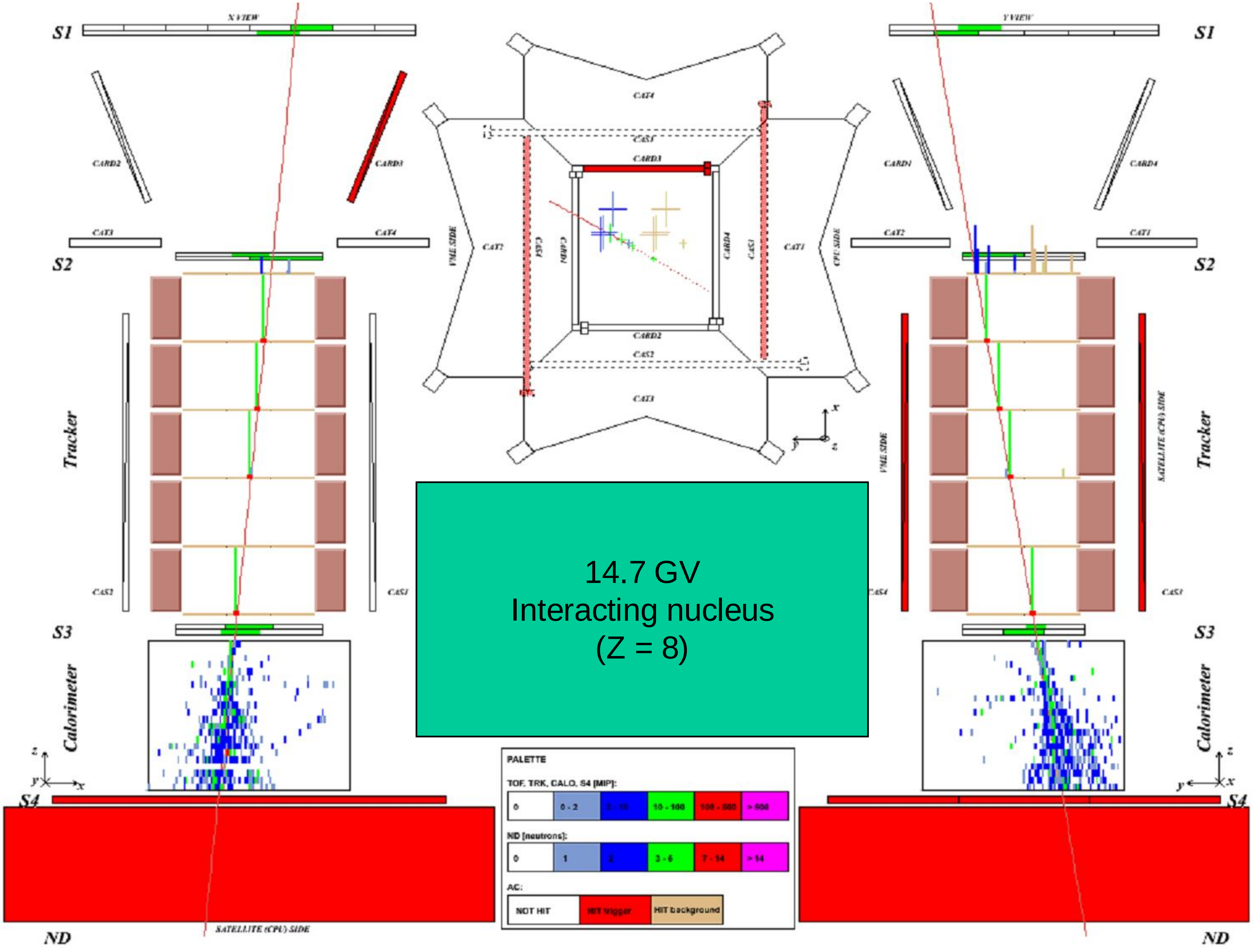
Flight data: 36 GV
interacting proton




S1
S2
Tracker
S3
Calorimeter
S4
ND
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


S1
S2
S3
S4
ND
Tracker
Calorimeter
Flight data: 92 GeV/c positron



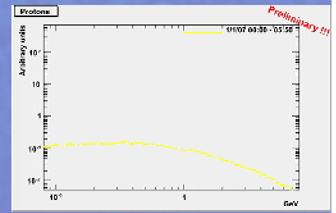
14.7 GV
Interacting nucleus
(Z = 8)

Pamela as a Space observatory at 1AU

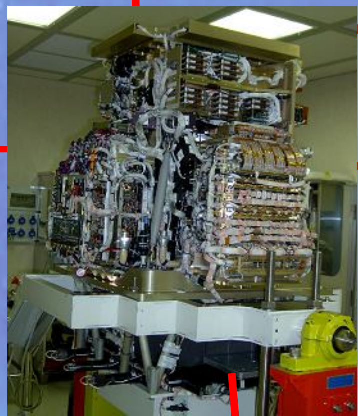
High Inclination Orbit 70.0°

Galactic cosmic ray
Matter / Antimatter
/ Dark Matter

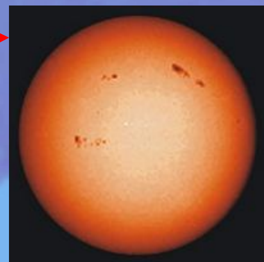
Solar Energetic particles

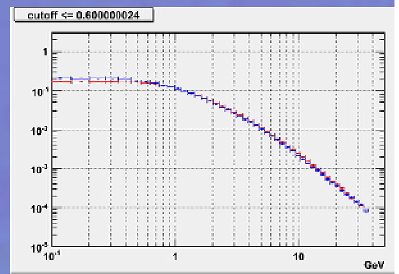


Jovian electrons

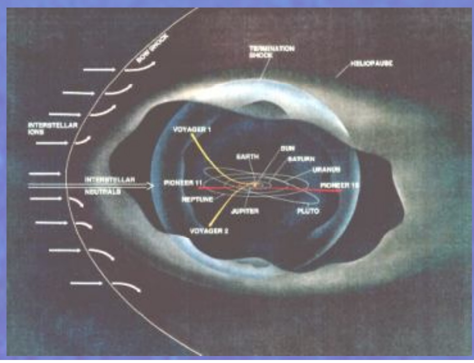


Solar Modulation

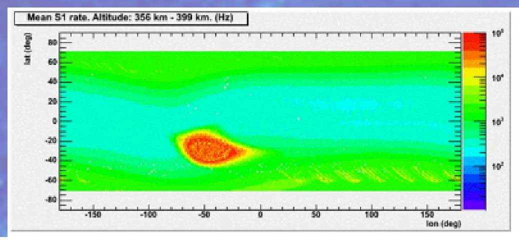




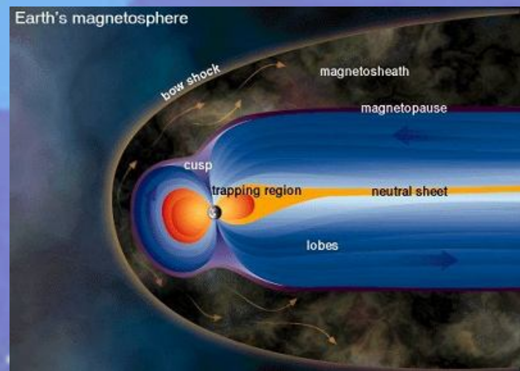
Interplanetary Physics,
Solar Wind Termination Shock



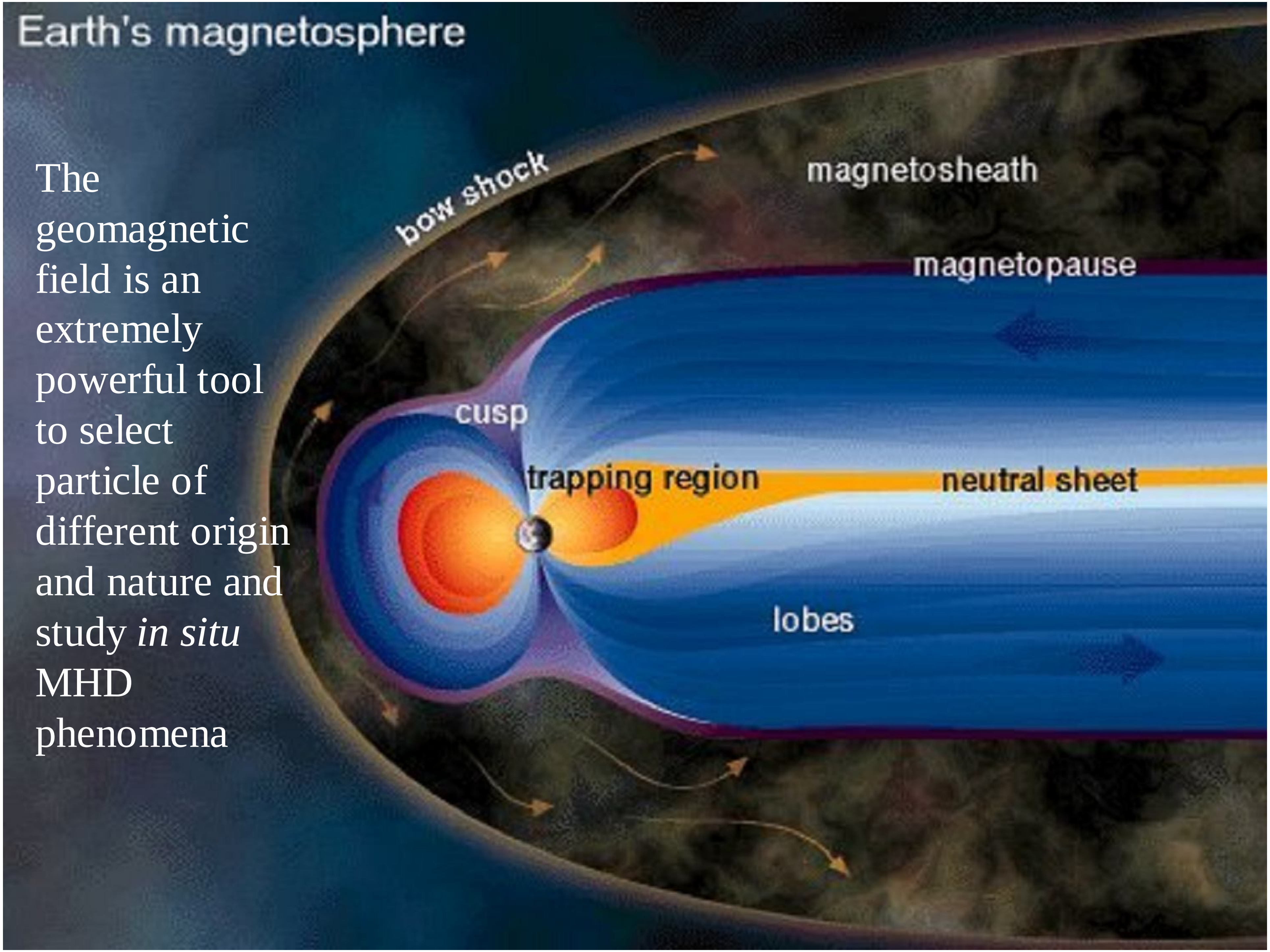
SAA, Albedo,
secondary particle



Magnetospheric physics

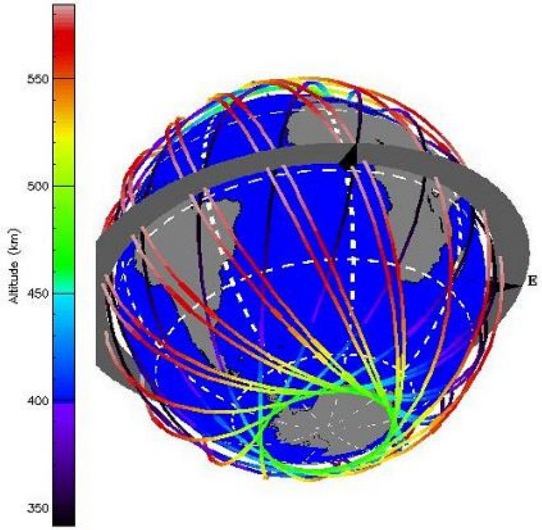


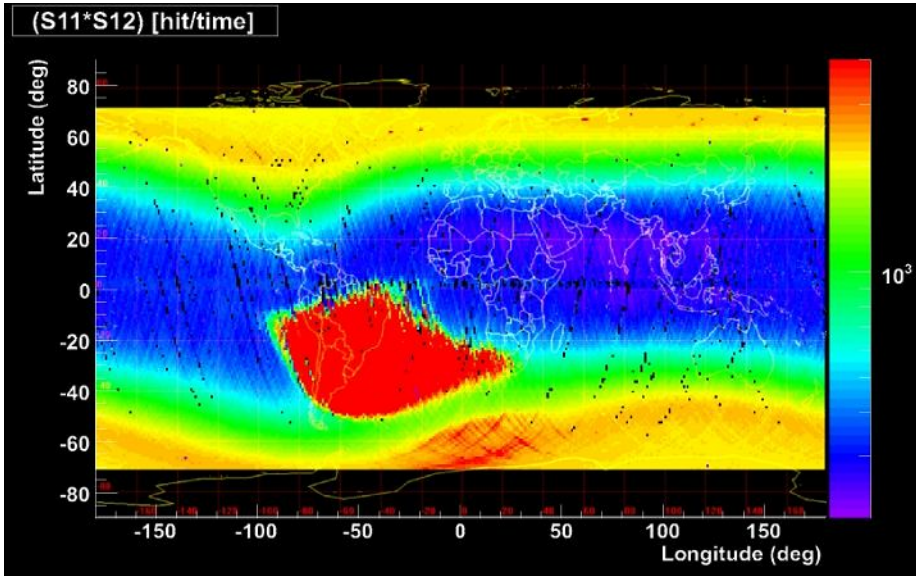
The geomagnetic field is an extremely powerful tool to select particle of different origin and nature and study *in situ* MHD phenomena



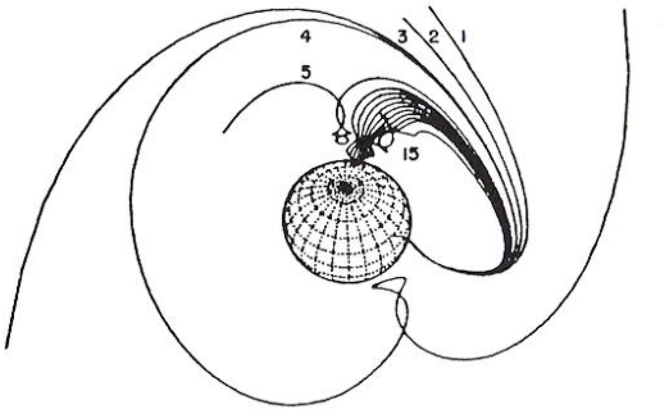

Pamela
Measurement of
the radiation belts
2008 M. Casolino
Google
Image NASA

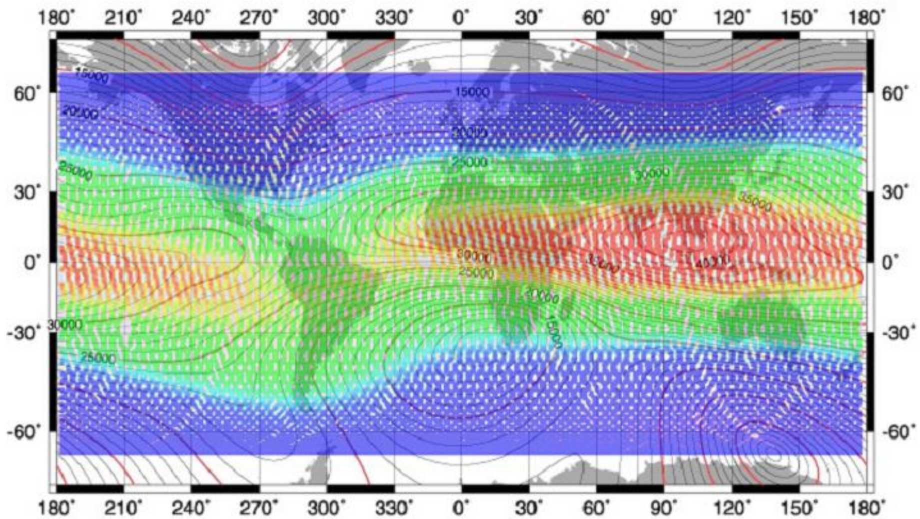
Selection of galactic component according to geomagnetic cutoff



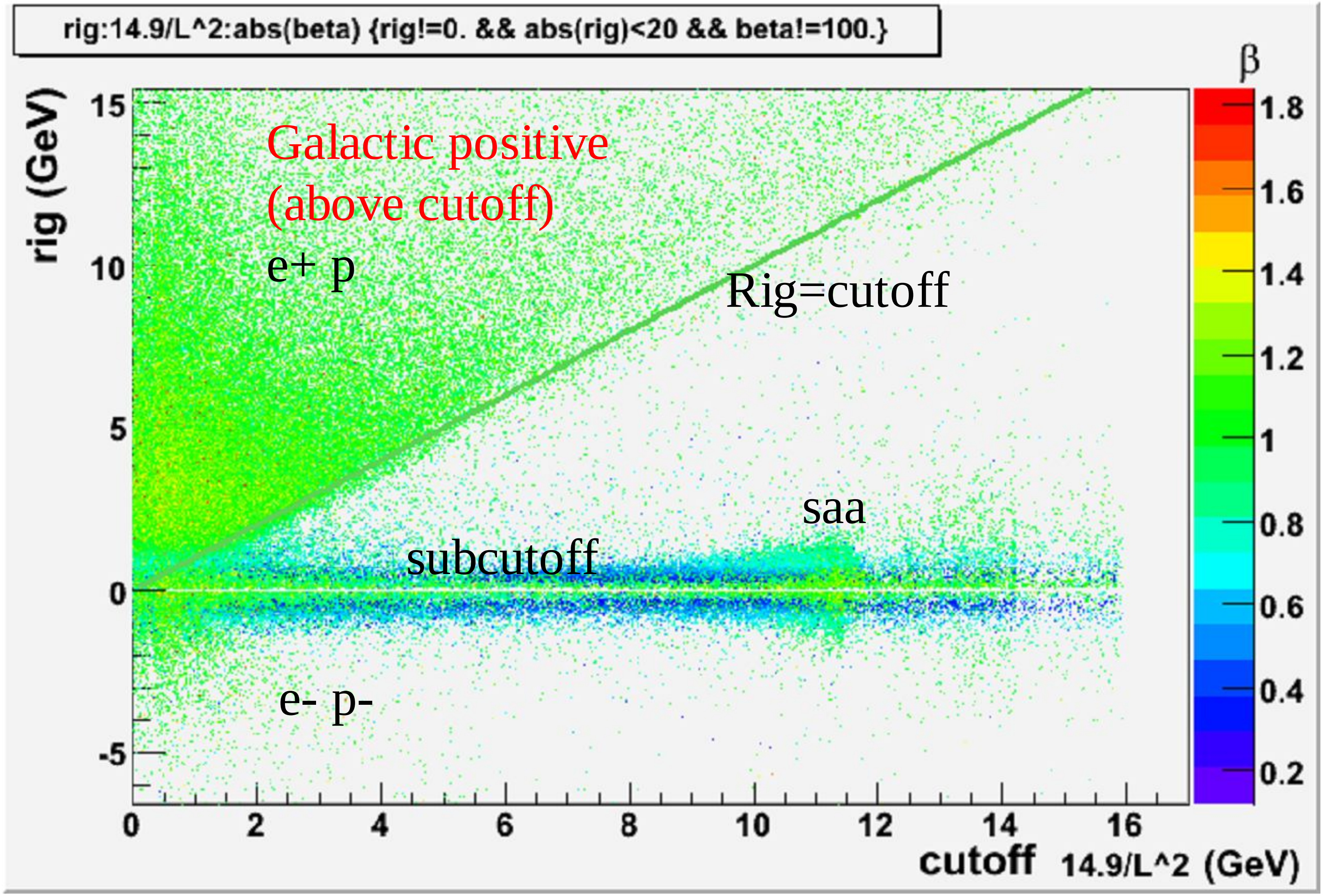


R_{cutoff}=14.9GV/L^2

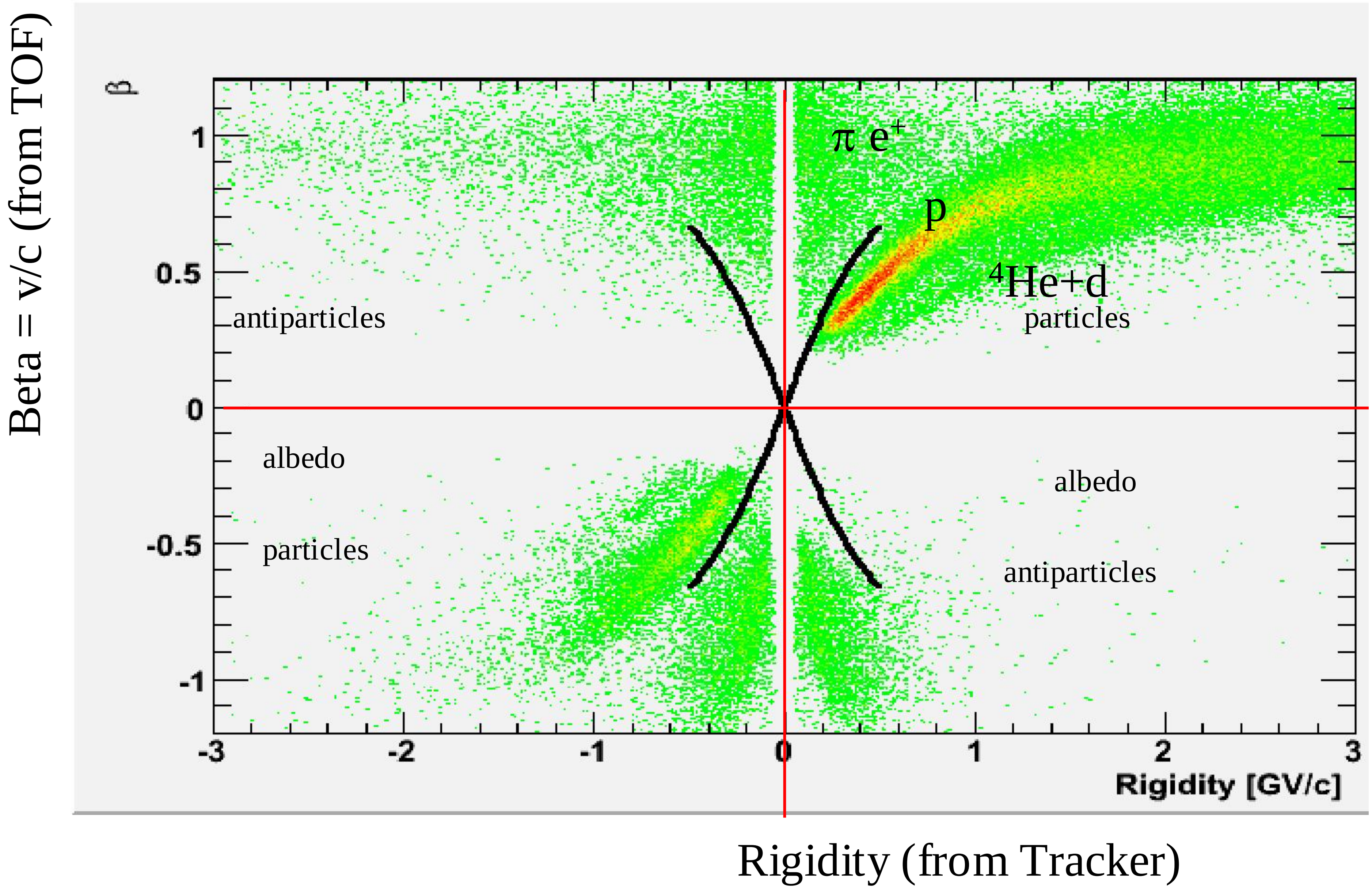




Particle rigidity vs Vertical Stormer Cutoff



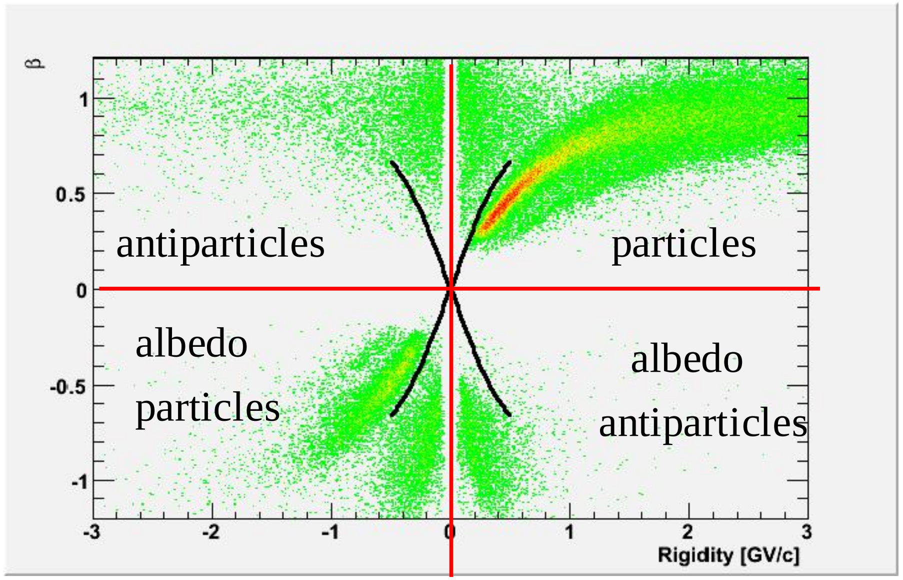
Particle identification: basic principle



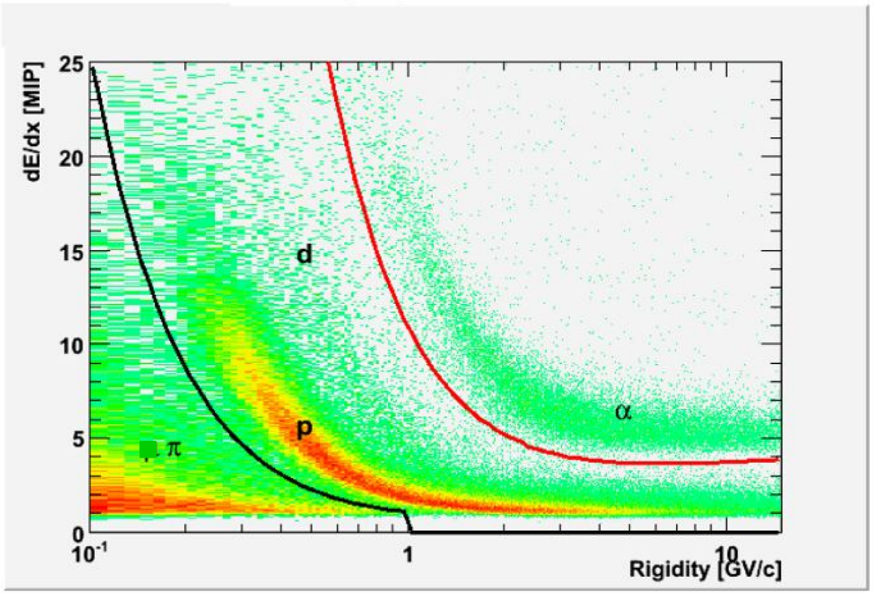
M. Casolino, INFN & University Roma Tor Vergata

Proton Absolute flux

•**Montecarlo efficency for cuts**
•**Trigger efficiency**
•**Tracking efficiency**
•**Multiple Scattering**
•**Back scattering…**
•**Systematics under close investigation, currently 10% uncertainty on abs flux.**
To be reduced to less than 5%



Energy loss from tracker



Selection criteria

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

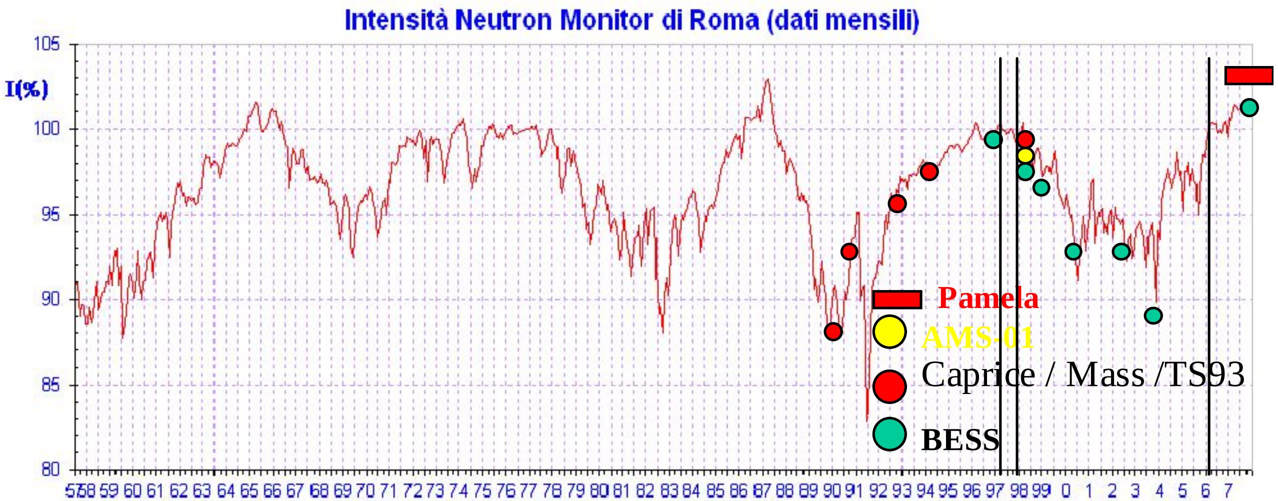
Solar Modulation of Galactic Cosmic Rays

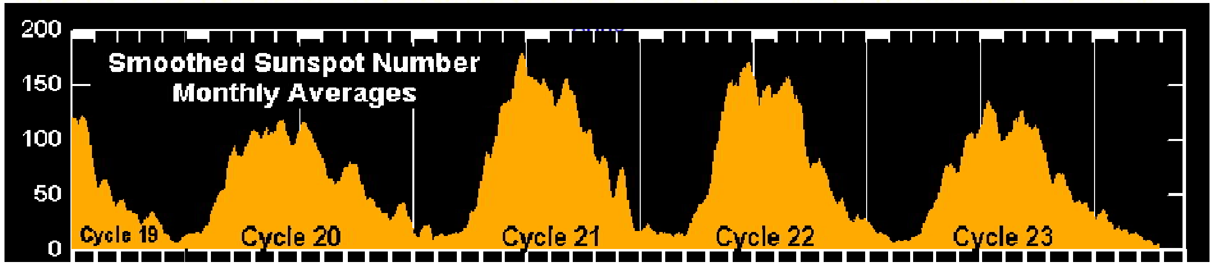
→Balloon: low frequency modulation
→Pamela: low and high frequency modulation

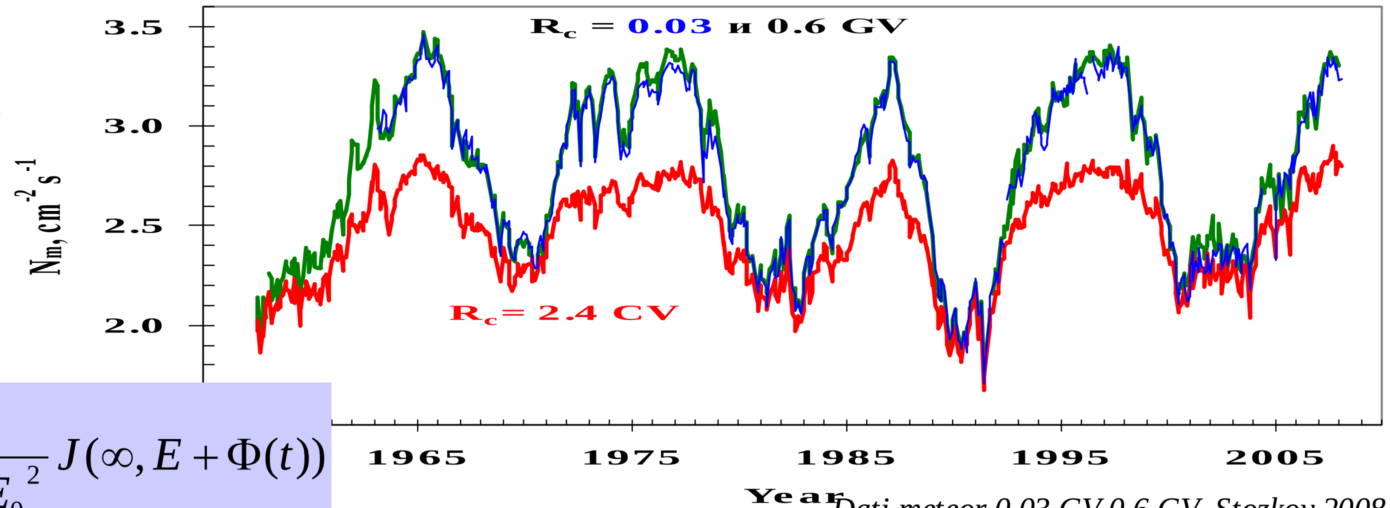
→Long solar minimum

→Variation in Galactic flux
- →Short Term (months)
- →Long term (years)

→Charge dependence
(e.g. Asaoka Y. et al. 2002, Phys. Rev. Lett. 88, 051101)







Dati meteor 0.03 GV 0.6 GV, Stozkov 2008

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

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

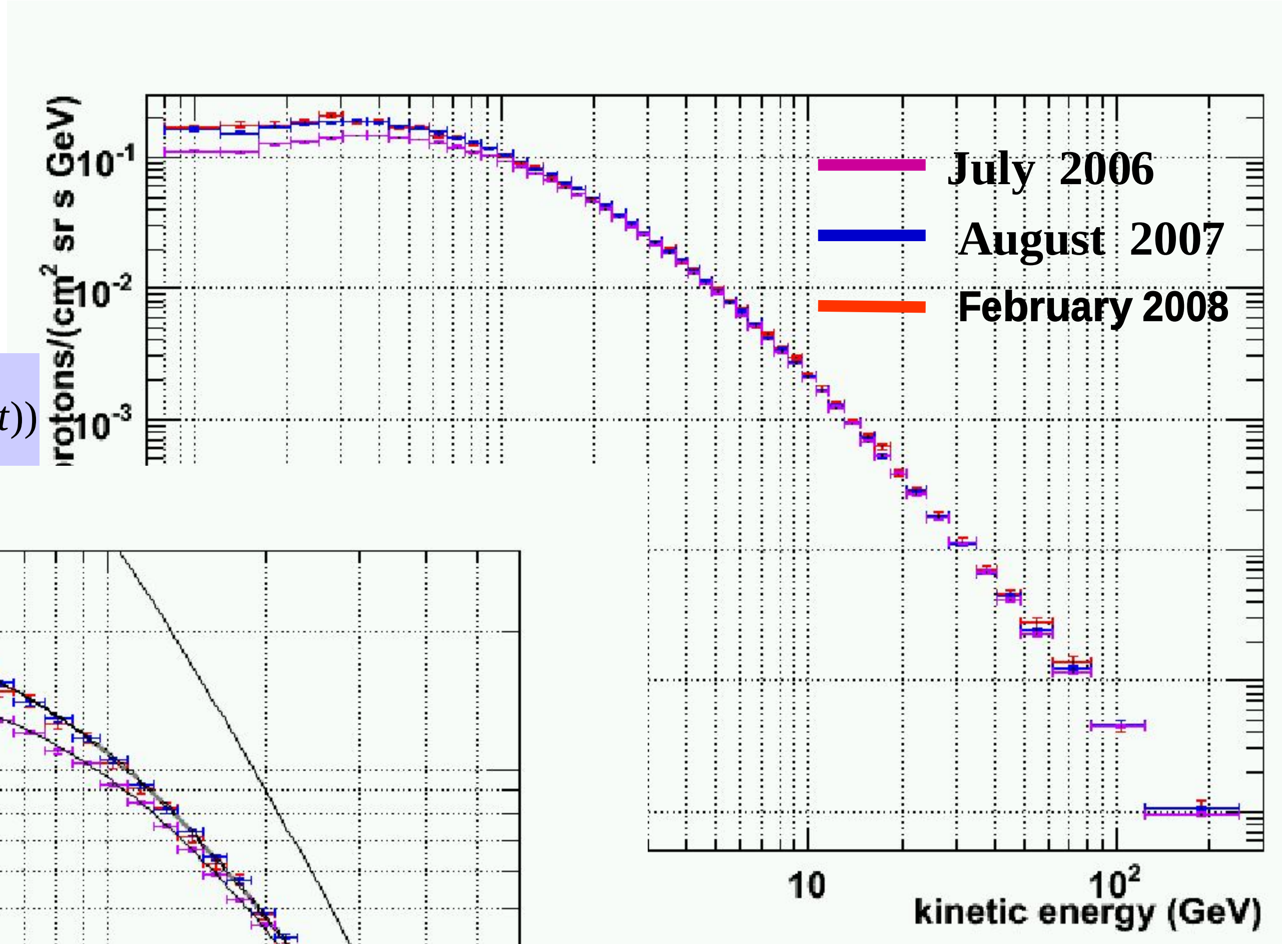
$F_{is} = 1.54\ \beta_{is}^{0.7}\ R_{is}^{-2.76}$

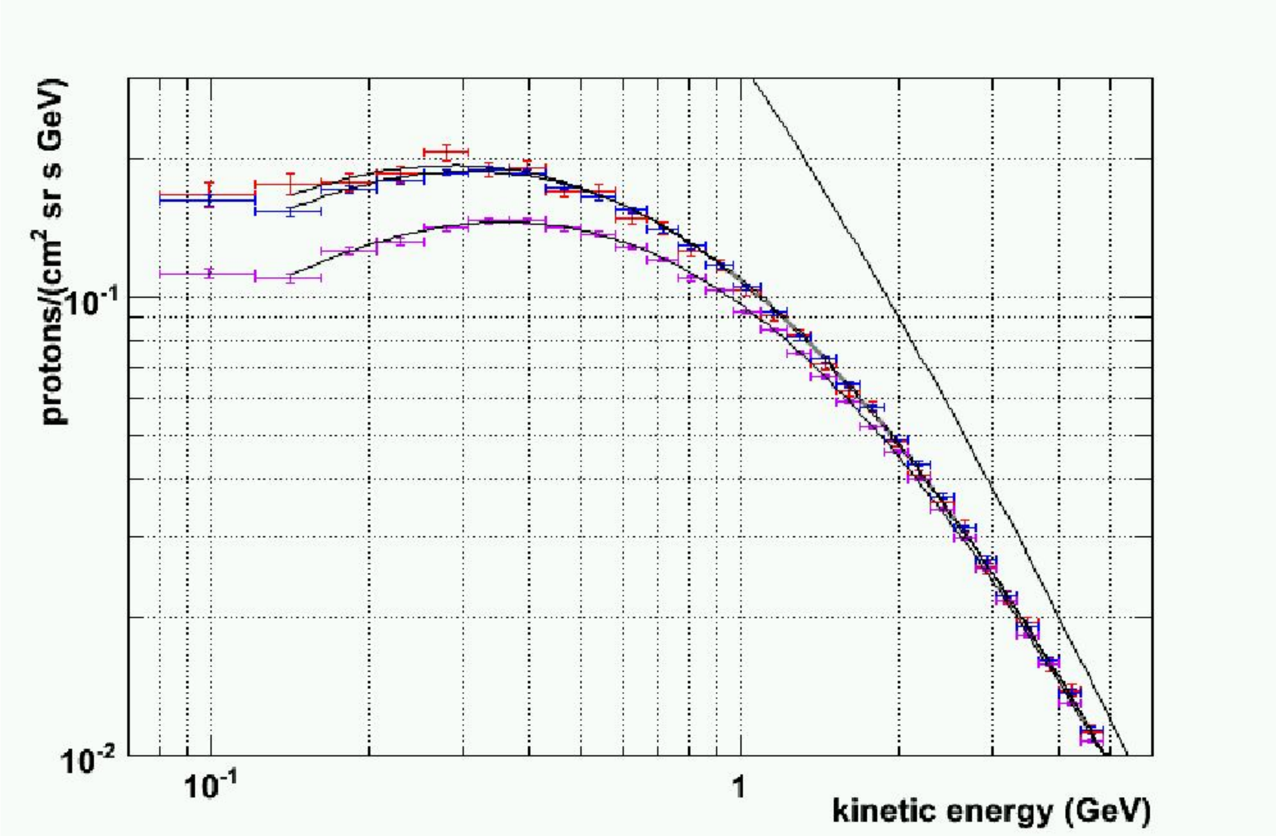
p/(cm² s sr GV)

Spectral index

2.76 ±0.01

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

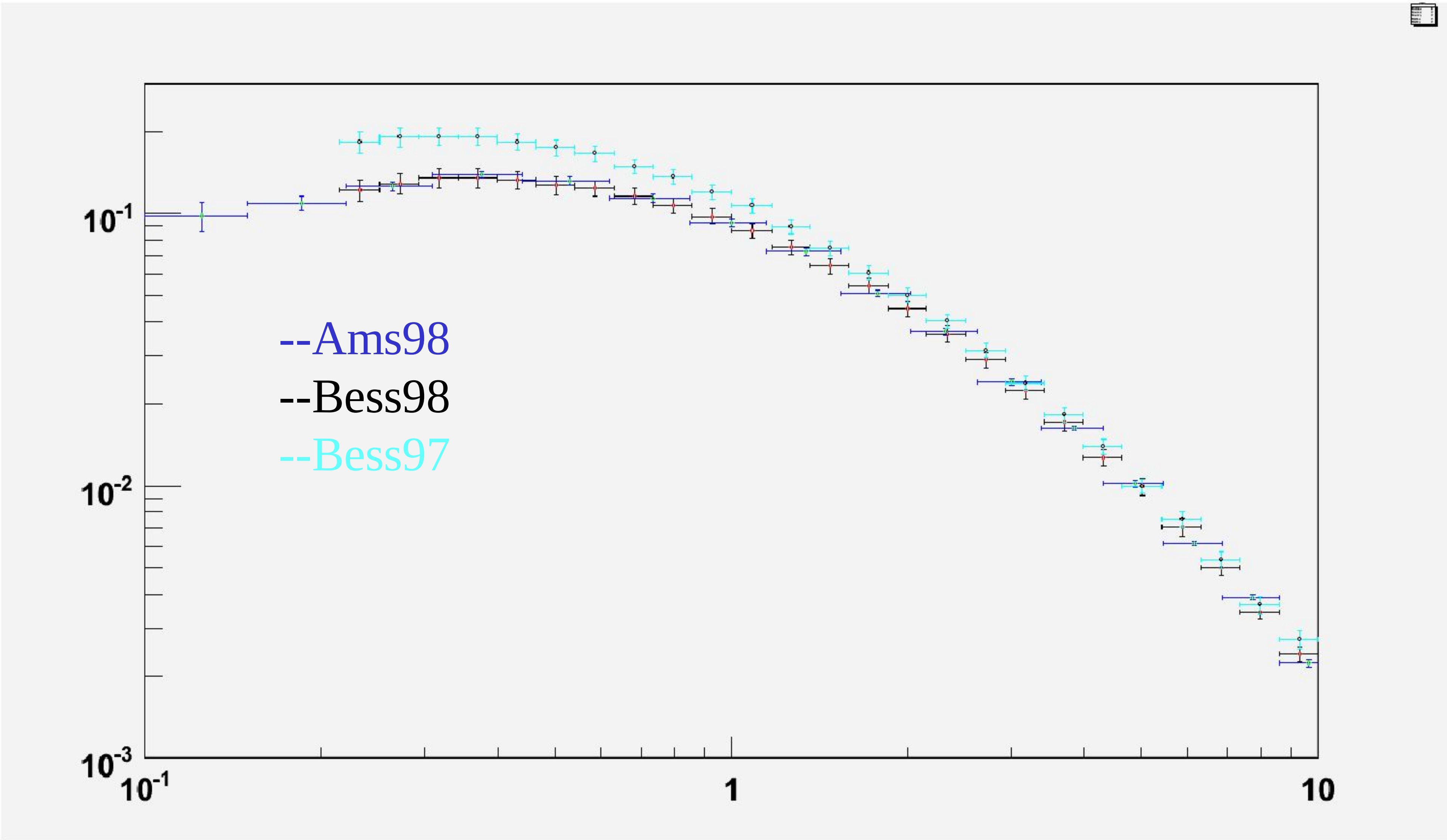




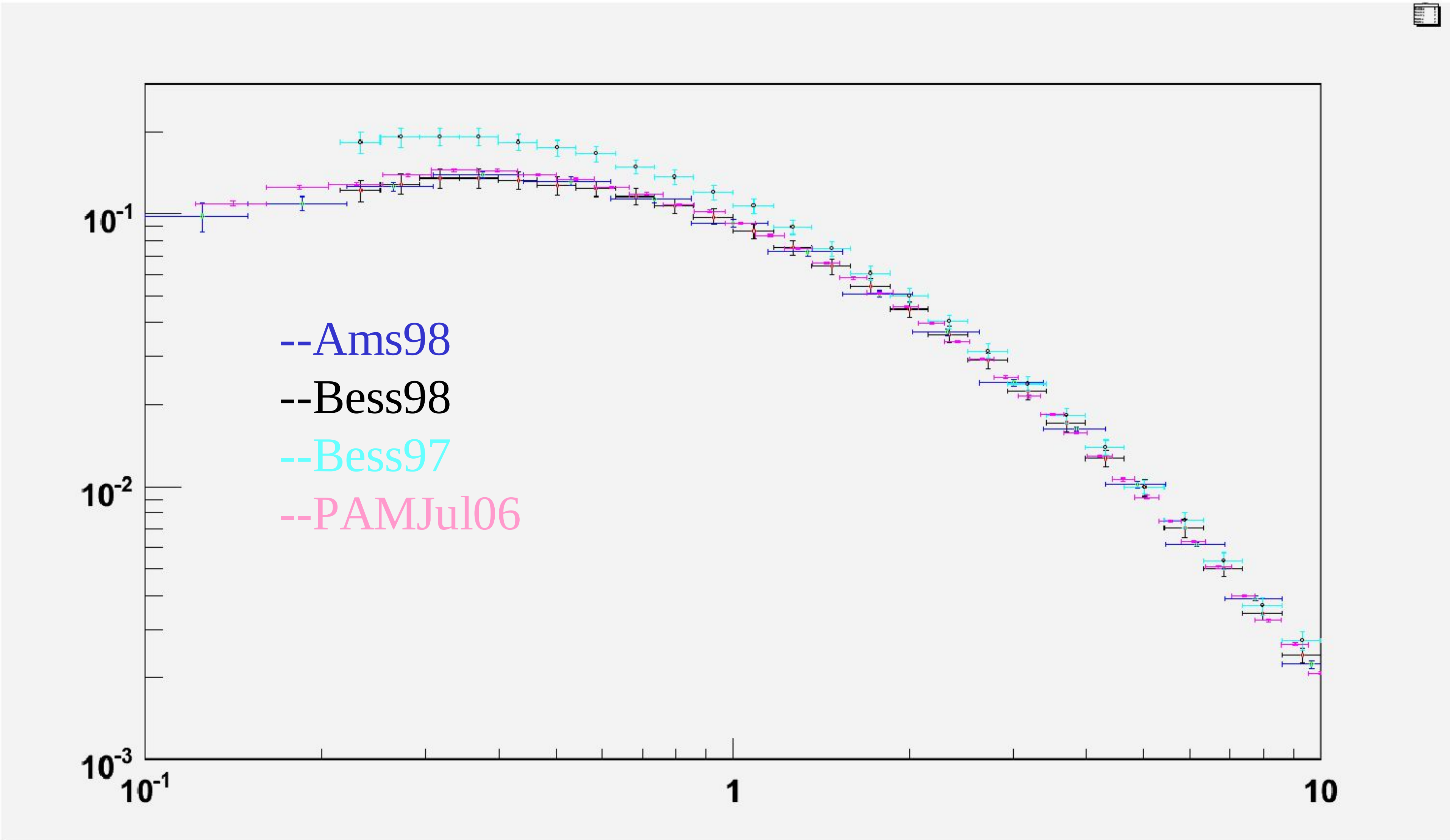
Solar modulation parameters

	ϕ(GV)	error
JUL06	5.01-01	± 2e-03
JAN07	4.16-01	± 2-03
AUG07	4.02-01	± 3-03

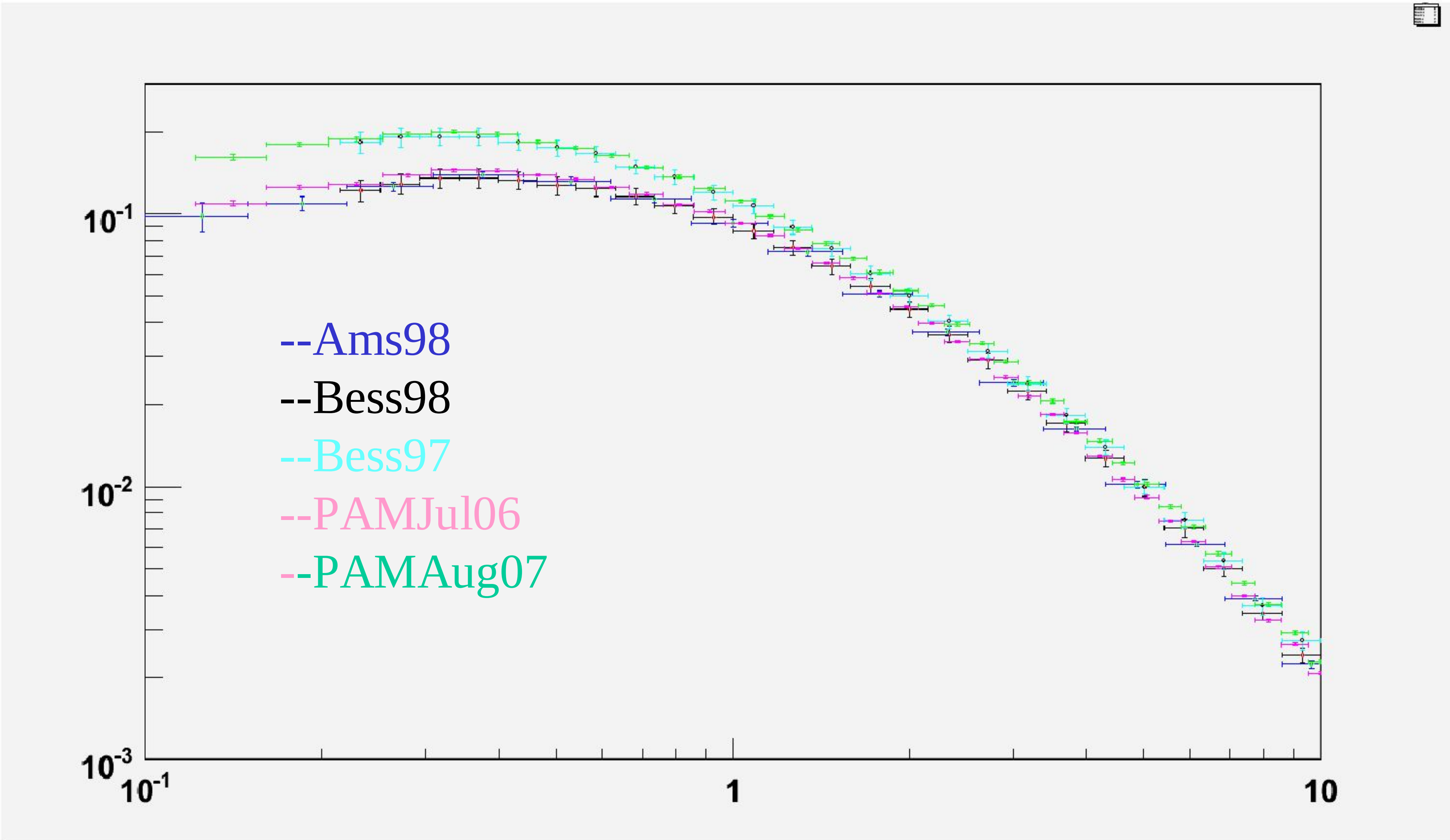
Comparison Pamela –AMS-Bess



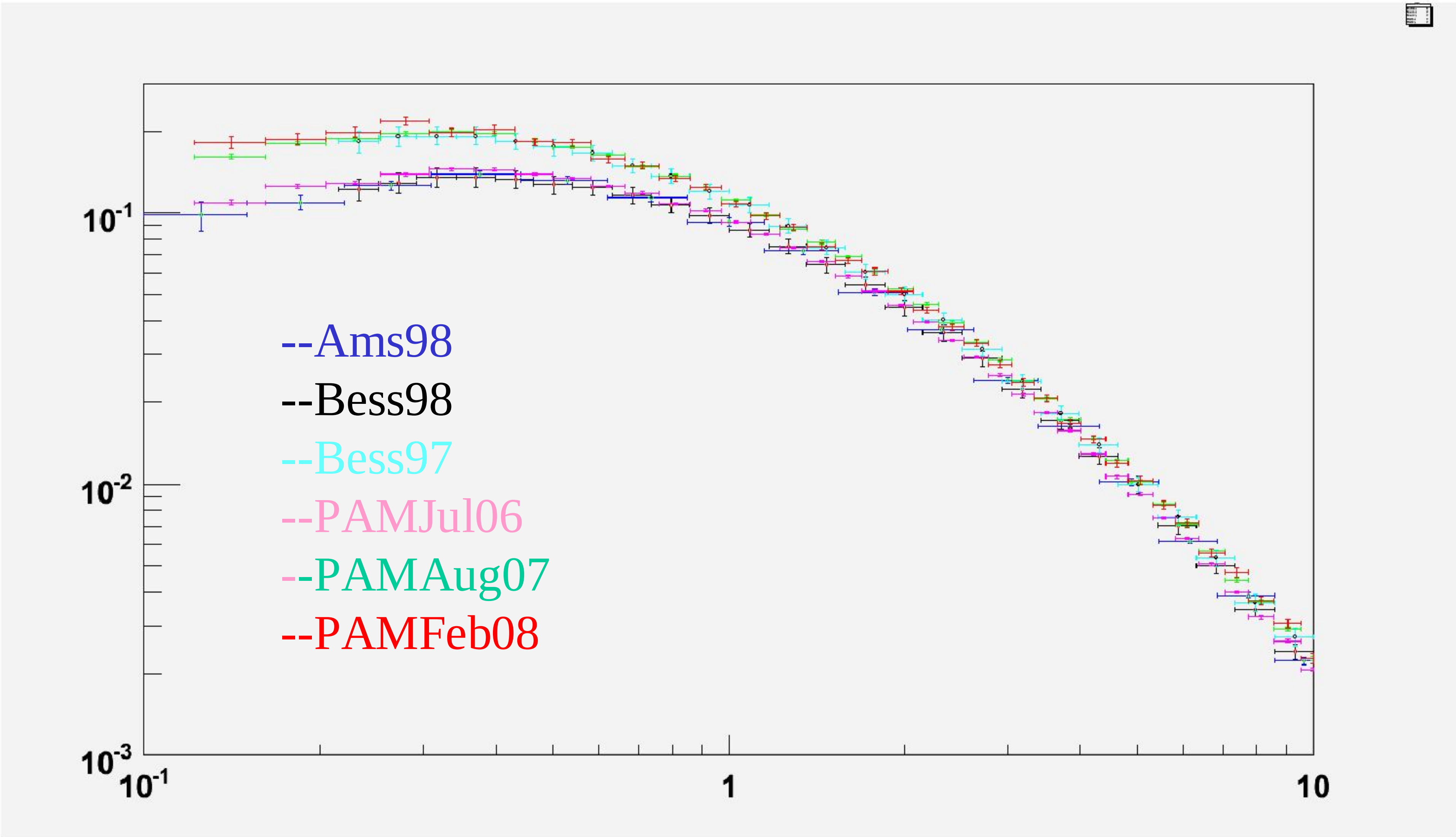
Comparison Pamela –AMS-Bess



Comparison Pamela –AMS-Bess



Comparison Pamela –AMS-Bess



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

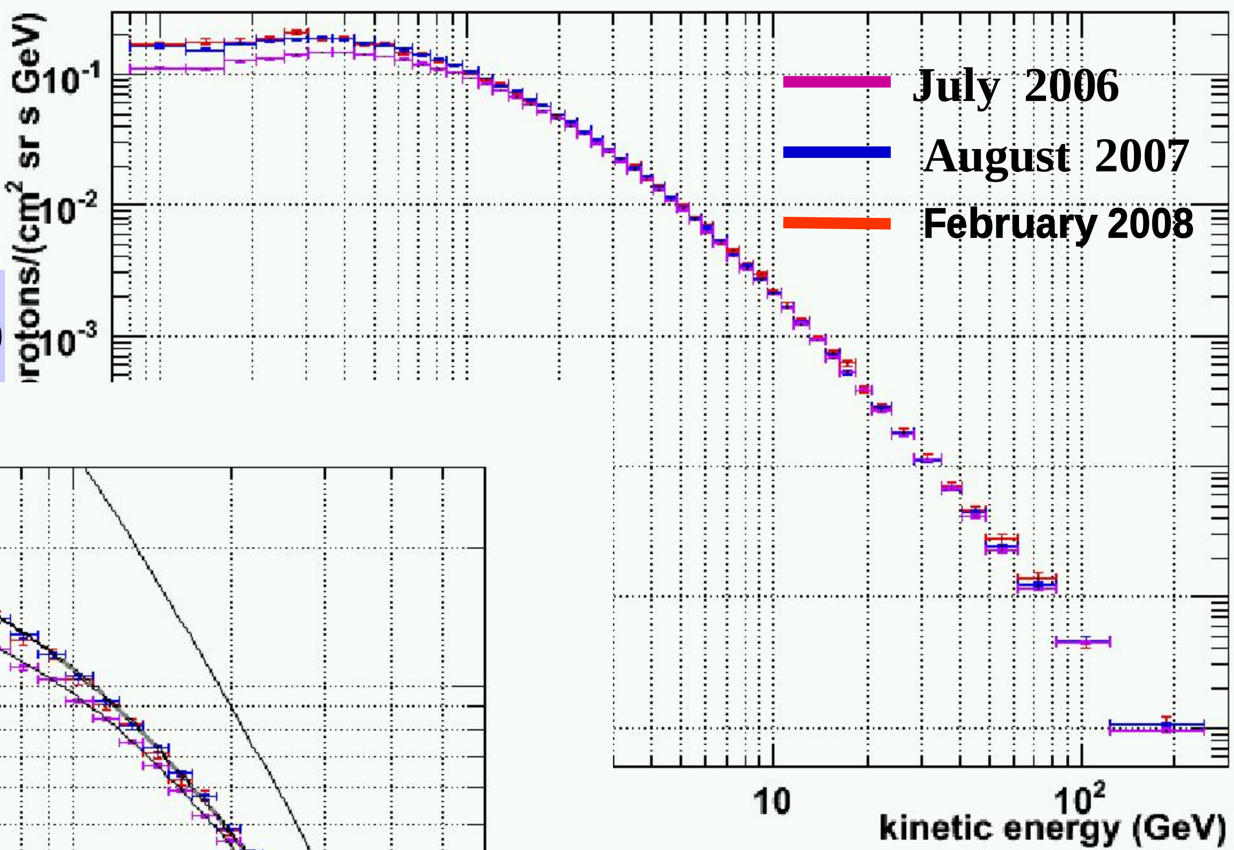
$F_{is} = 1.54\ \beta_{is}^{0.7}\ R_{is}^{-2.76}$

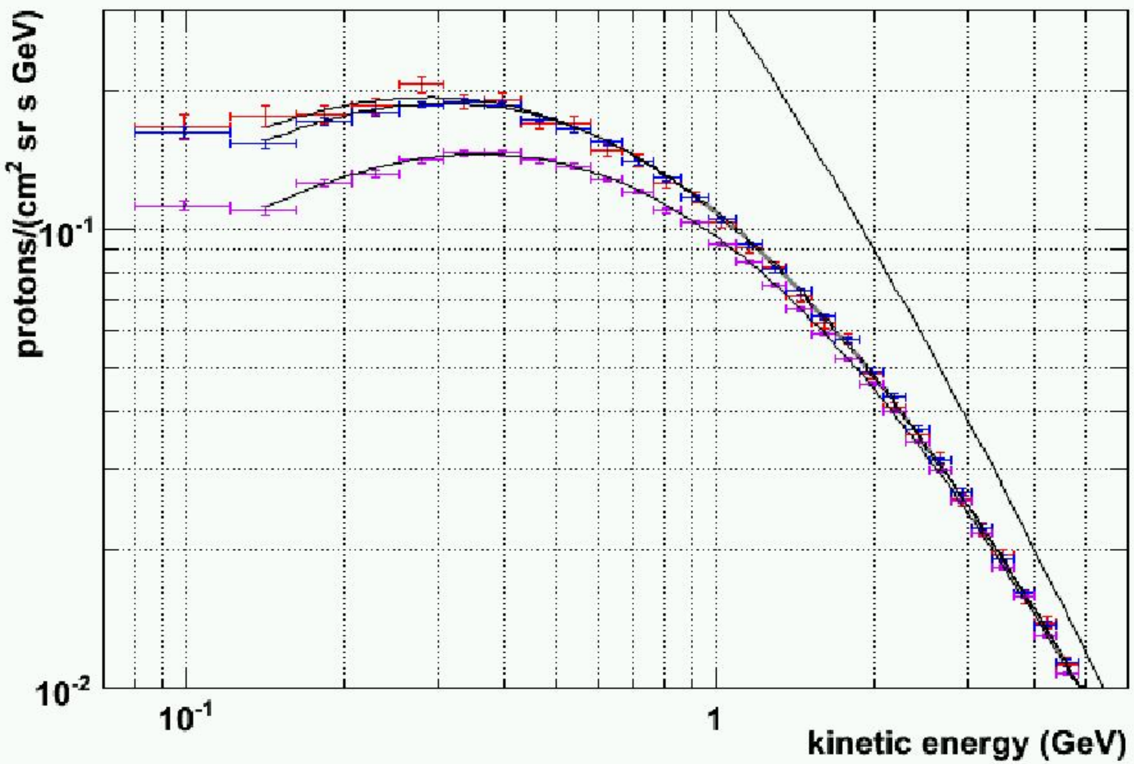
p/(cm² s sr GV)

Spectral index

2.76 ±0.01

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



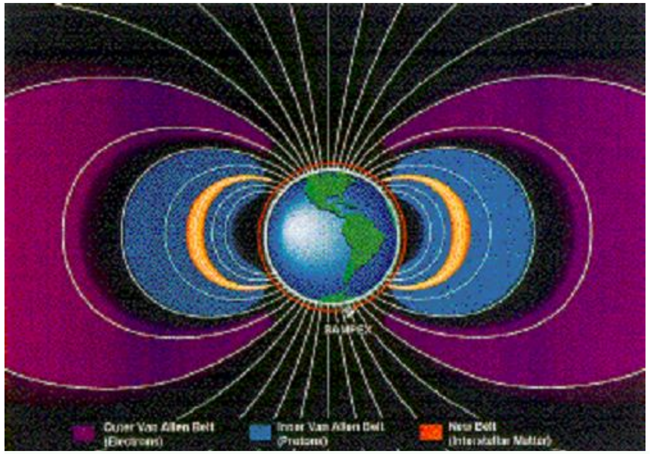


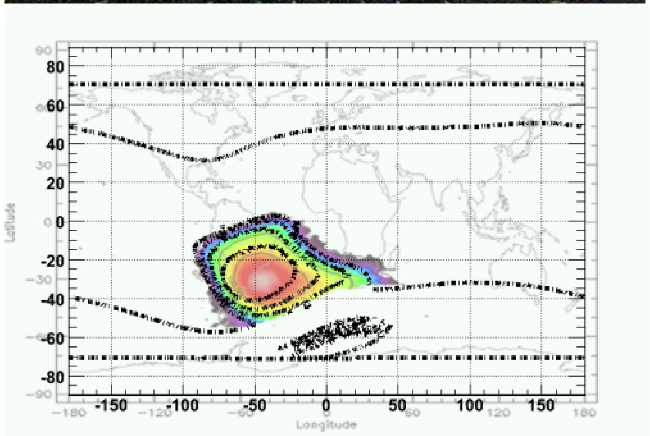
Solar modulation parameters

	φ(GV)	error
JUL06	5.01-01	± 2e-03
JAN07	4.16-01	± 2-03
AUG07	4.02-01	± 3-03

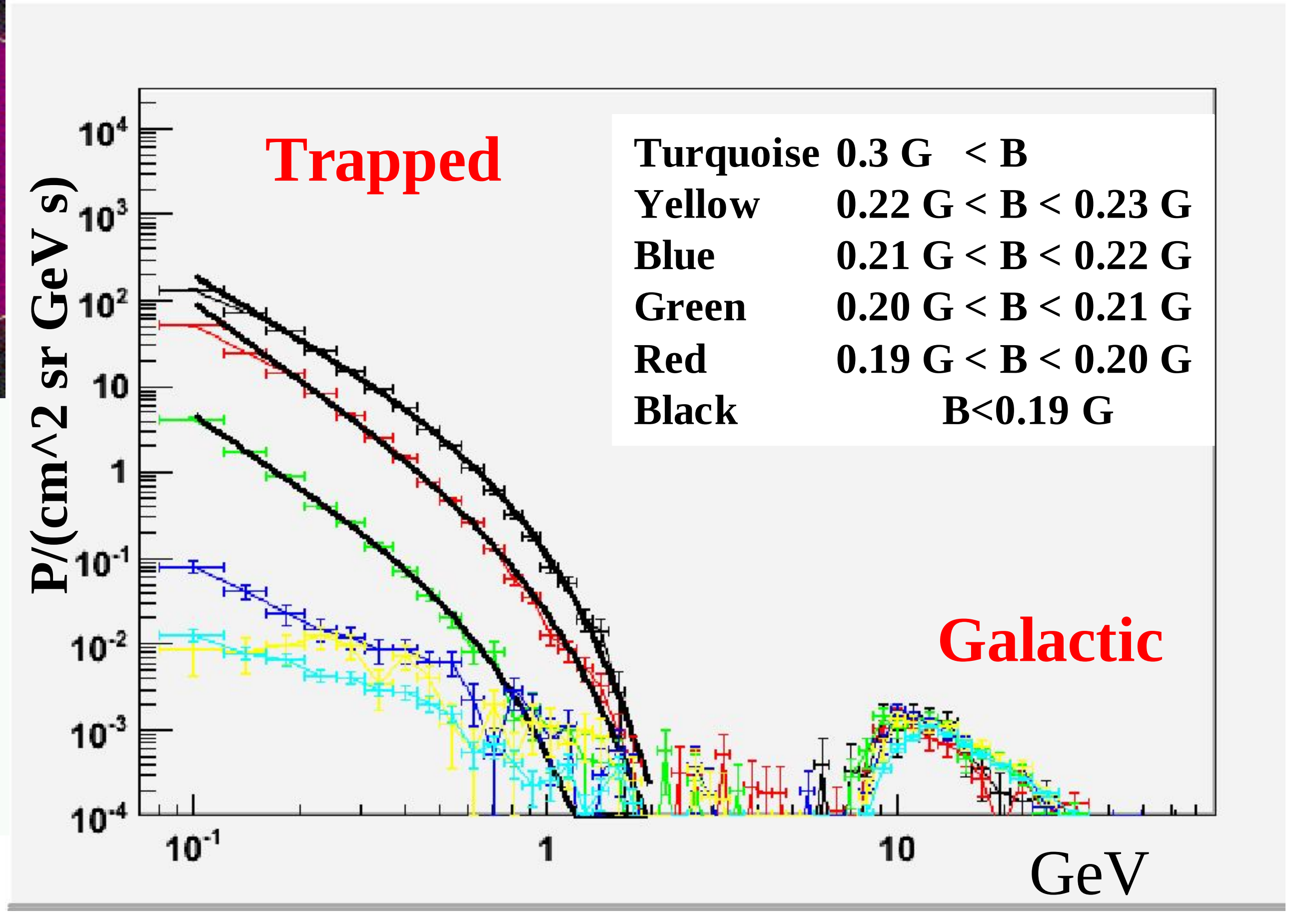
Trapped proton flux in the Van Allen belt (South Atlantic Anomaly)

Arxiv 0810.4980v1





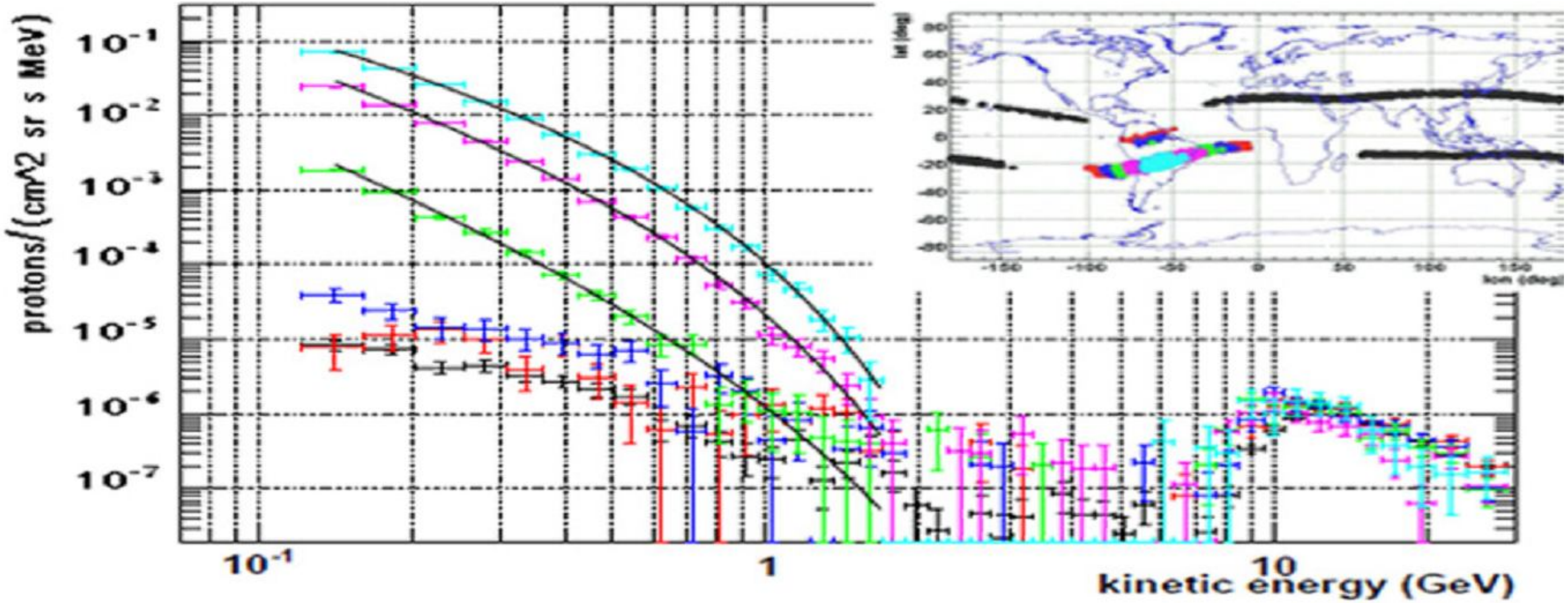
Integral Pamela flux
(E>35 MeV)
(PSB97 plot by SPENVIS project, model by BIRA-IASB)



$$\Phi = A\,E^{-(\gamma_0+\gamma_1 E)}$$

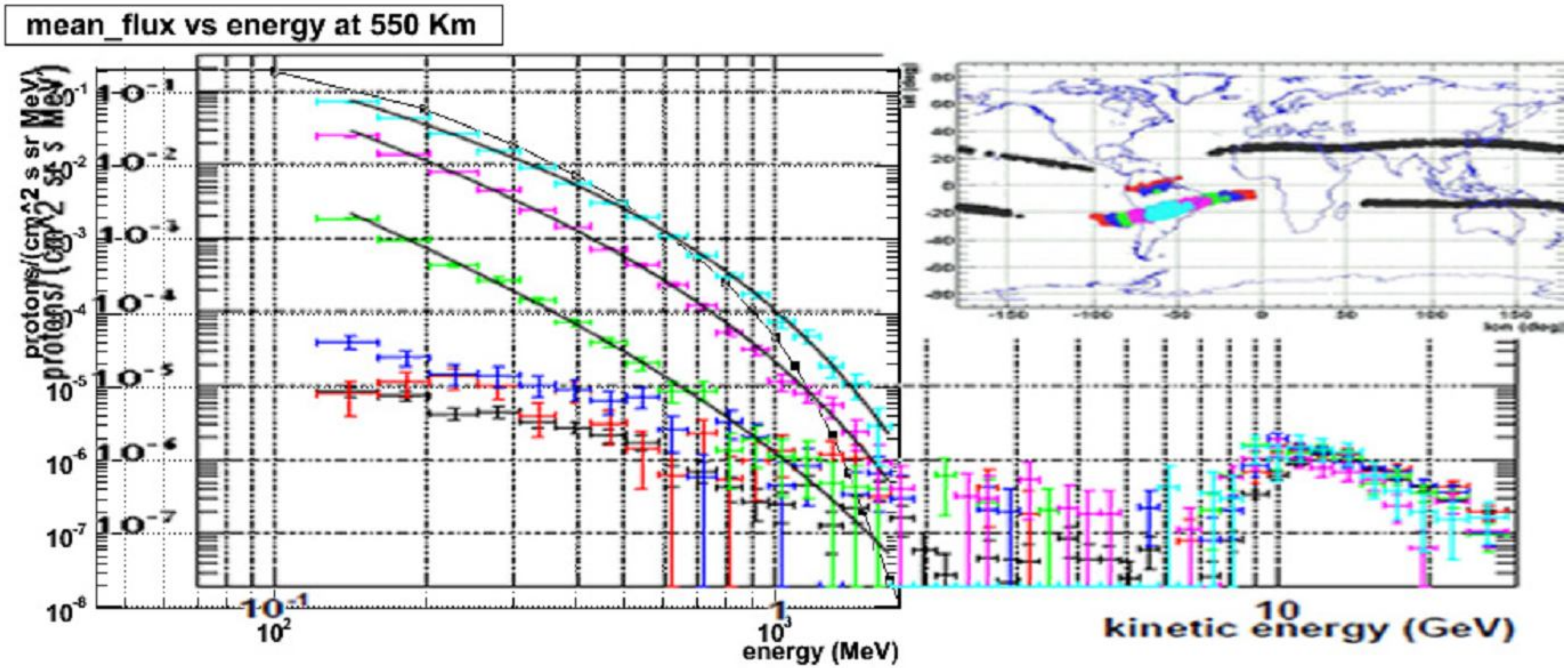
	A	γ_0	γ_1	χ^2/ndf
nero	0.11±0.01	6.0±0.4	3.1±0.5	7.1
rosso	(2.3±0.3) 10^{-2}	5.9±0.5	2.6±0.6	6.8
verde	(5±3) 10^{-4}	8.1±1.8	4.7±1.8	10.

Comparison with theoretical model of inner rad belt



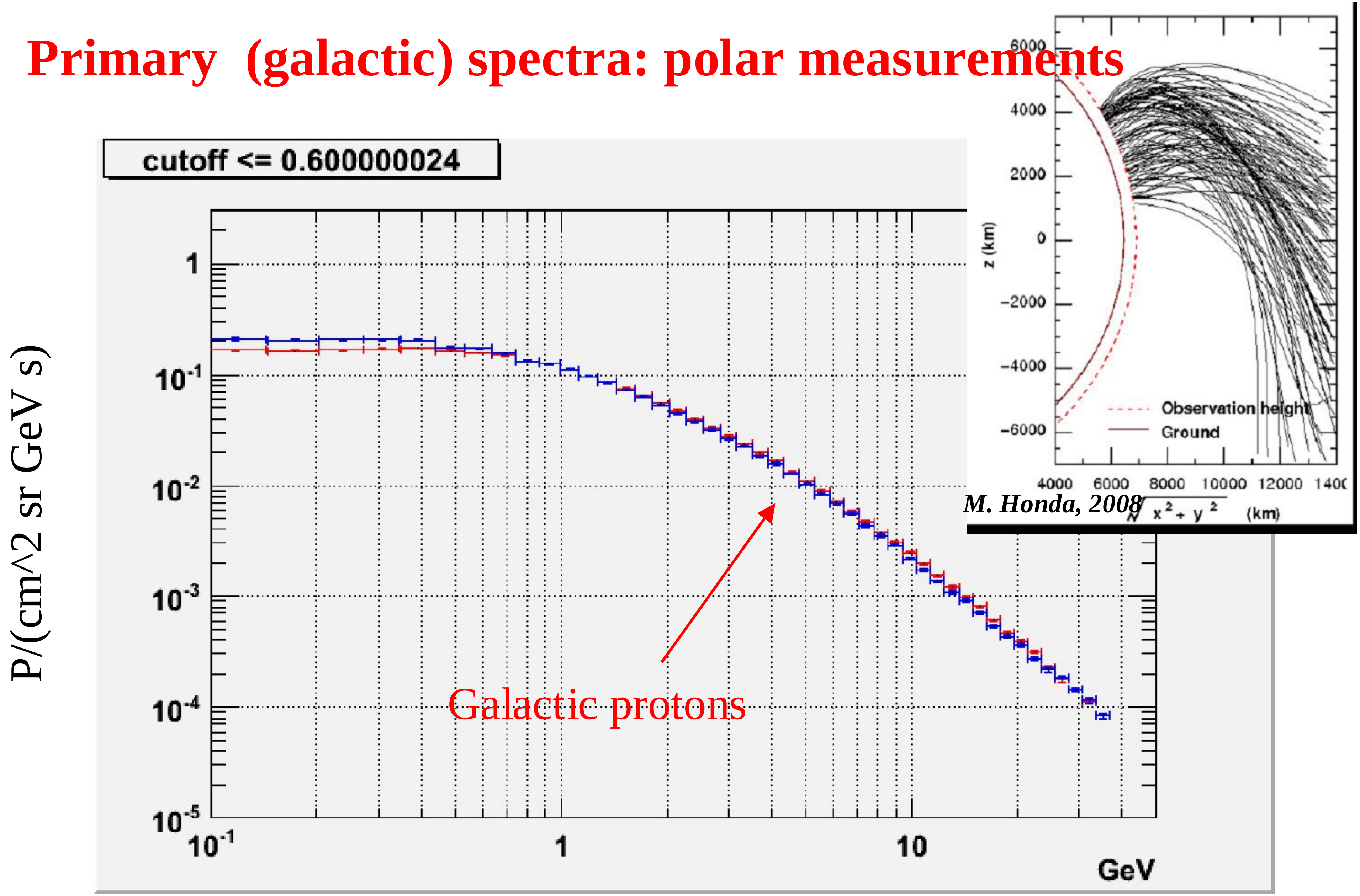
R. S. Selesnick,1 M. D. Looper,1 and R. A. Mewaldt2
SPACE WEATHER, VOL. 5, S04003, doi:10.1029/2006SW000275, 2007

Comparison with theoretical model of inner rad belt



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

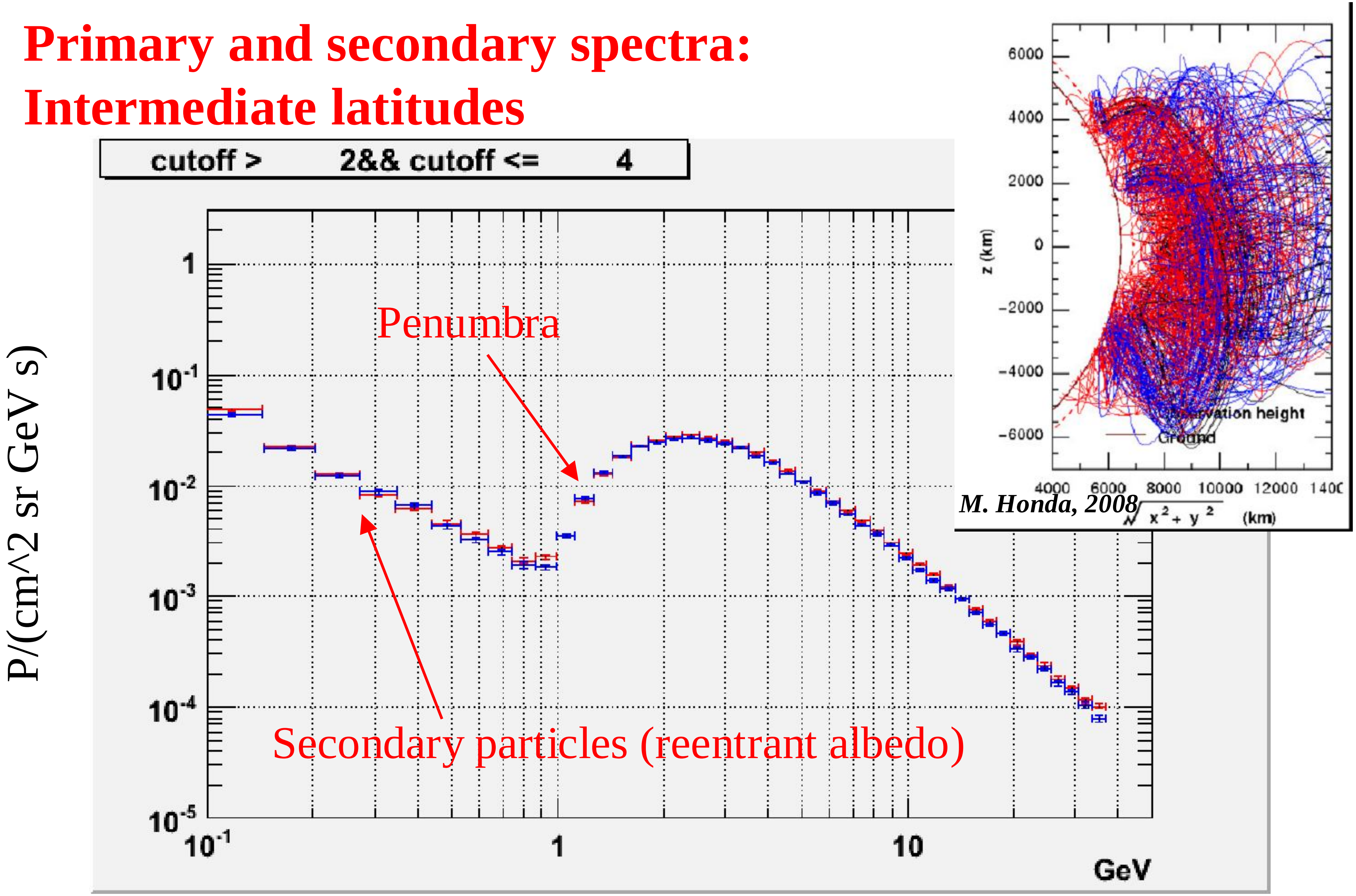


M. Honda, 2008

RED: JULY 2006

BLUE: AUGUST 2007

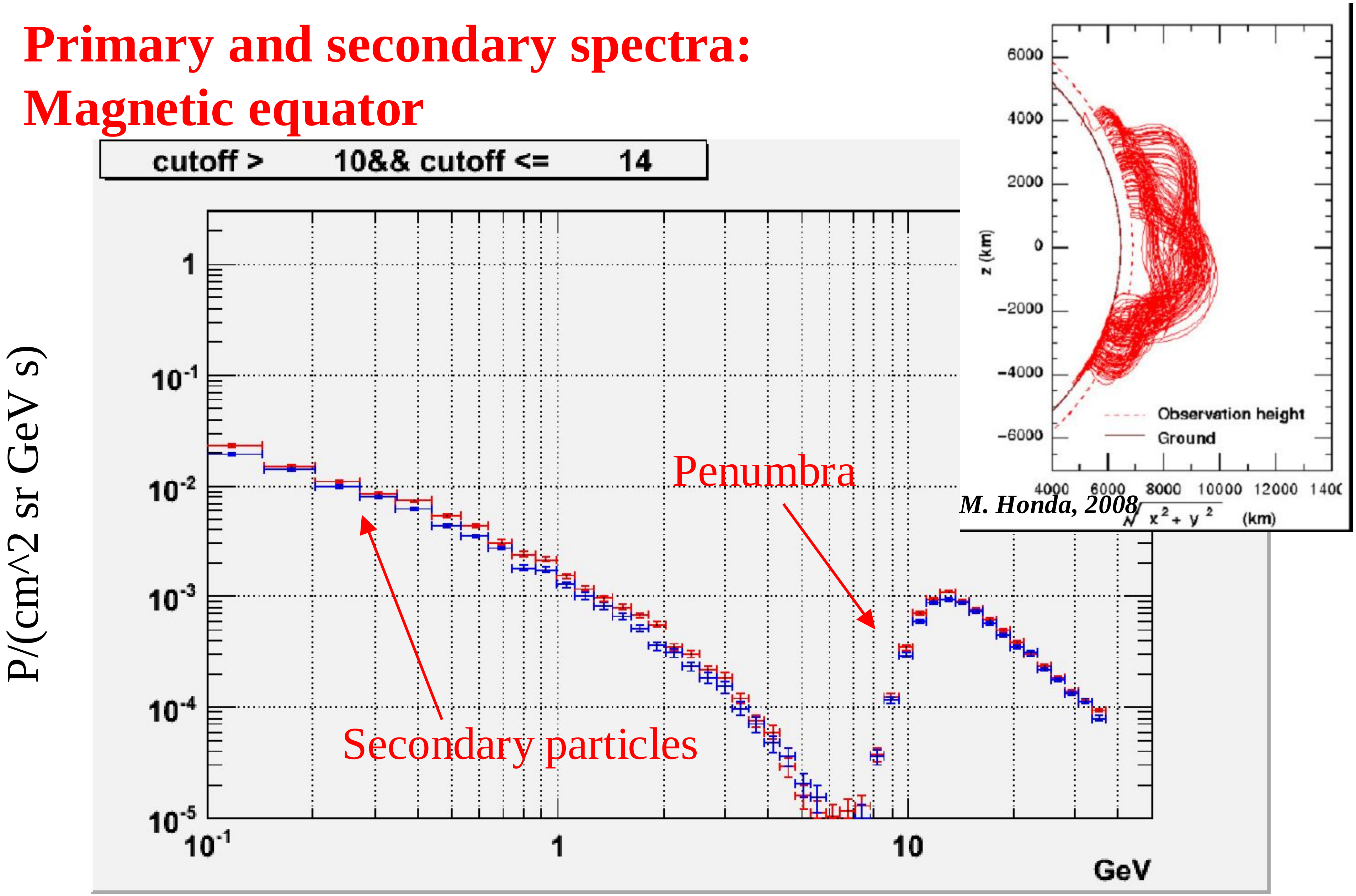
Primary and secondary spectra: Intermediate latitudes



RED: JULY 2006

BLUE: AUGUST 2007

Primary and secondary spectra: Magnetic equator

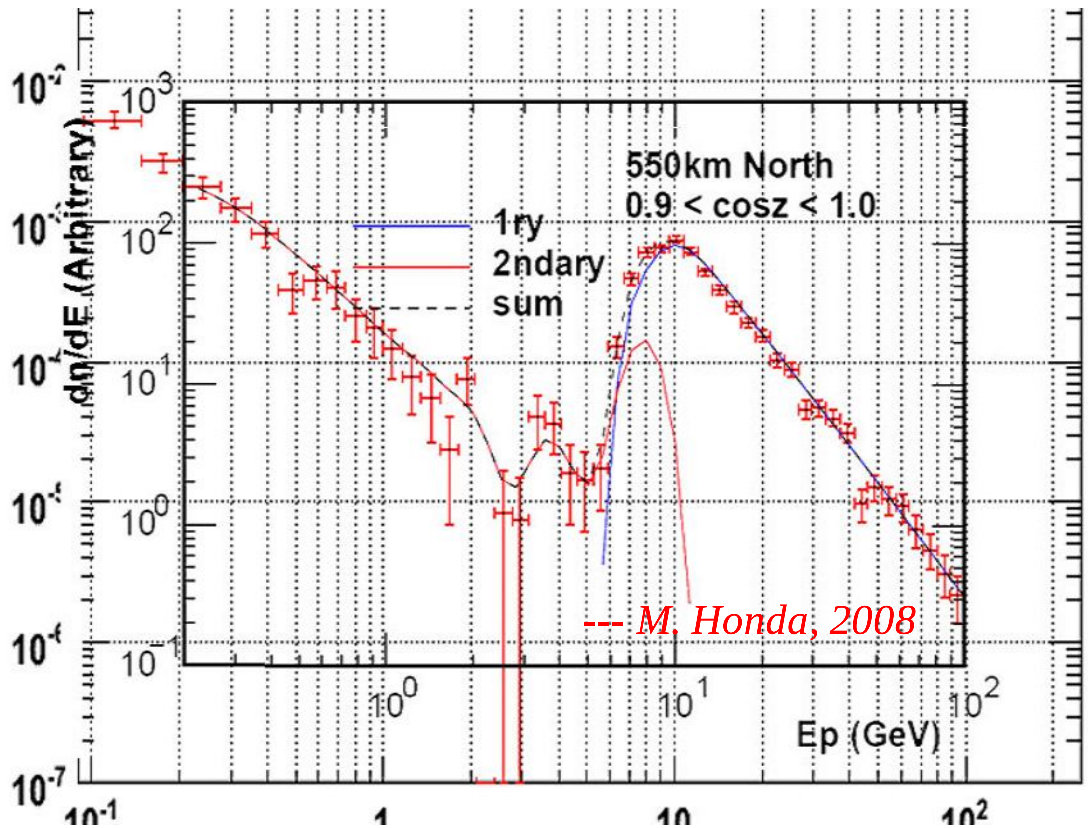


RED: JULY 2006

BLUE: AUGUST 2007

Proton flux at various cutoffs

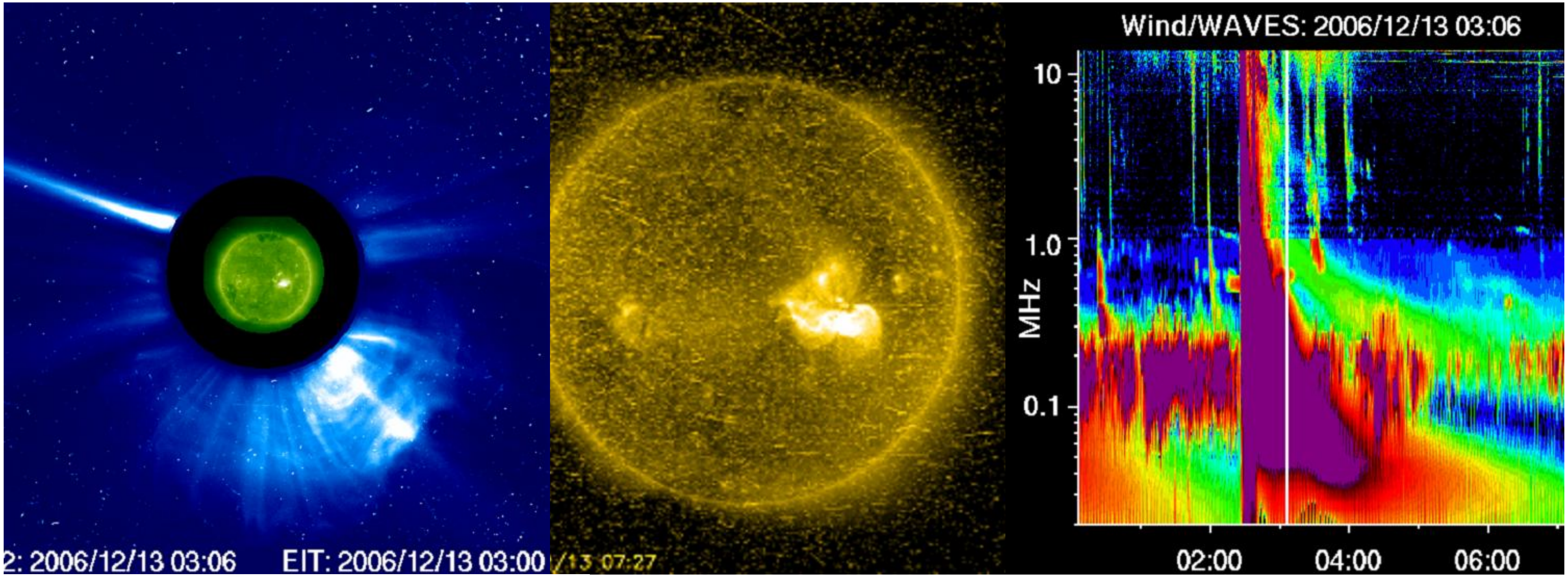
→Atmospheric neutrino contribution
→Astronaut dose on board International Space Station
→Indirect measurement of cross section in the atmosphere
→ Agile e Glast background estimation

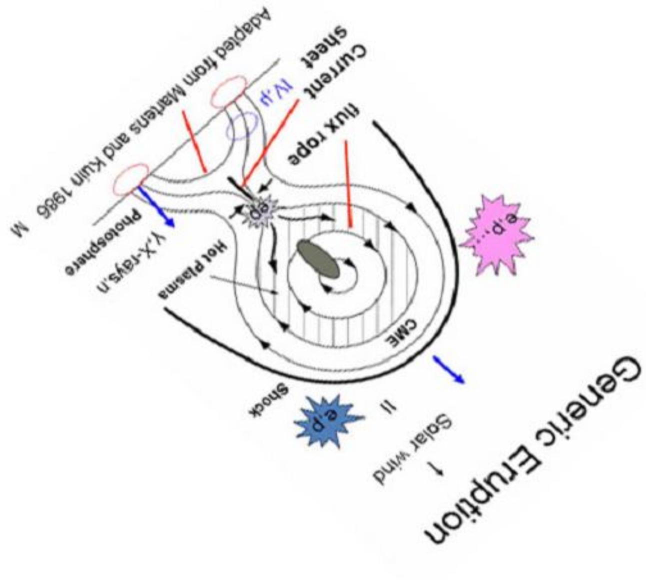


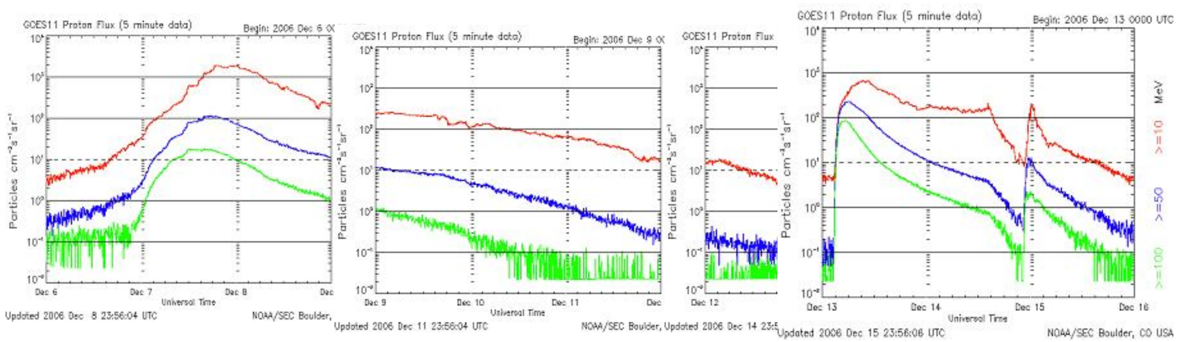
•*Grigorov, Sov. Phys. Dokl.* ***22***, *305 1977*
•*NINA ApJ Supp.132 365, 2001*
•*AMS Phys. Lett. B 472 2000.215,*
Phys. Lett. B 484 2000.10–22
•*Lipari, Astrop. Ph. 14, 171, 2000*
•*Huang et al, Pys Rev. D* ***68***, *053008 2003*
•*Sanuki et al, Phys Rev D75 043005 2007*
•*Honda et al, Phys Rev D75 043006 2007*

Arxiv 0810.4980v1

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

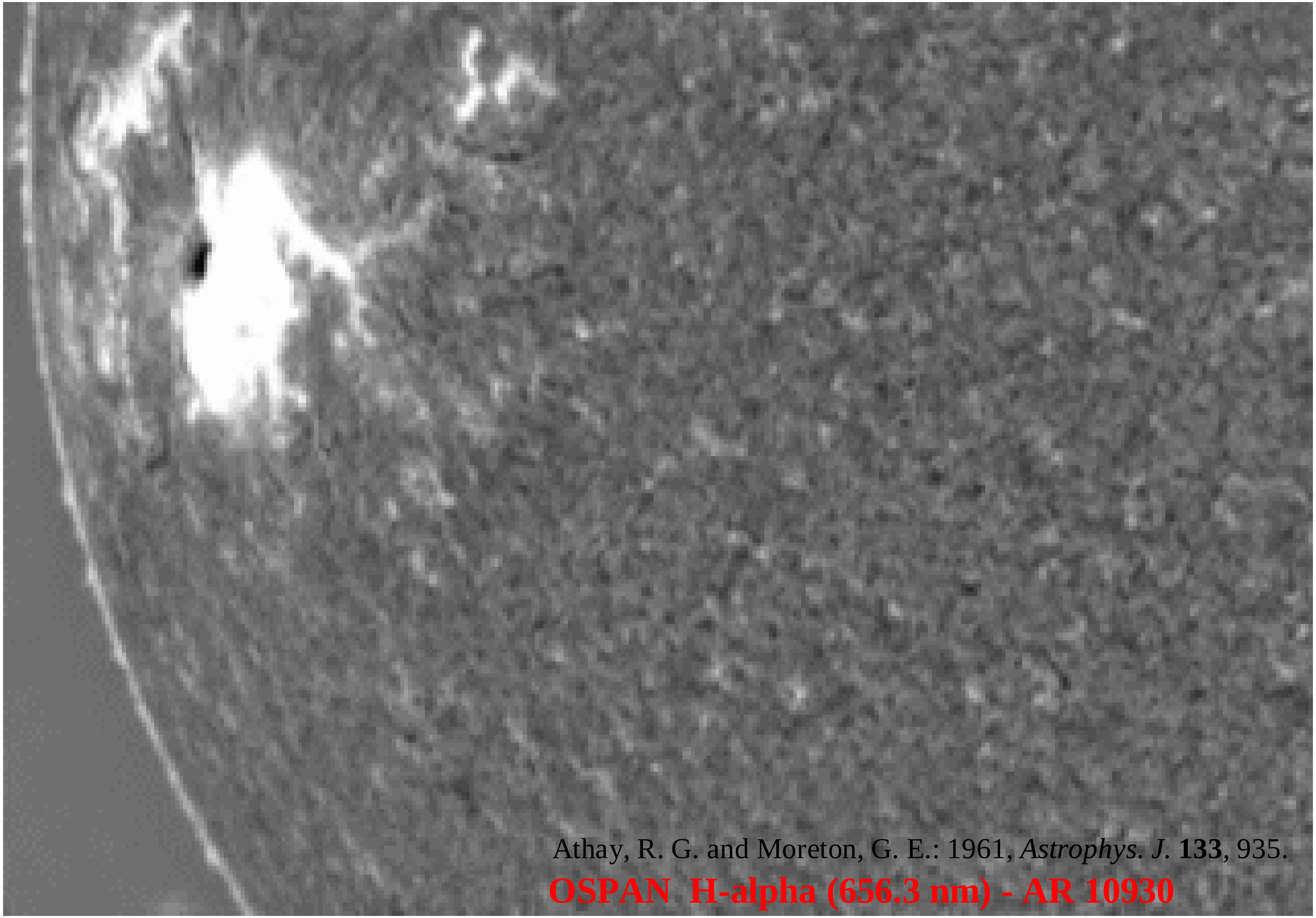


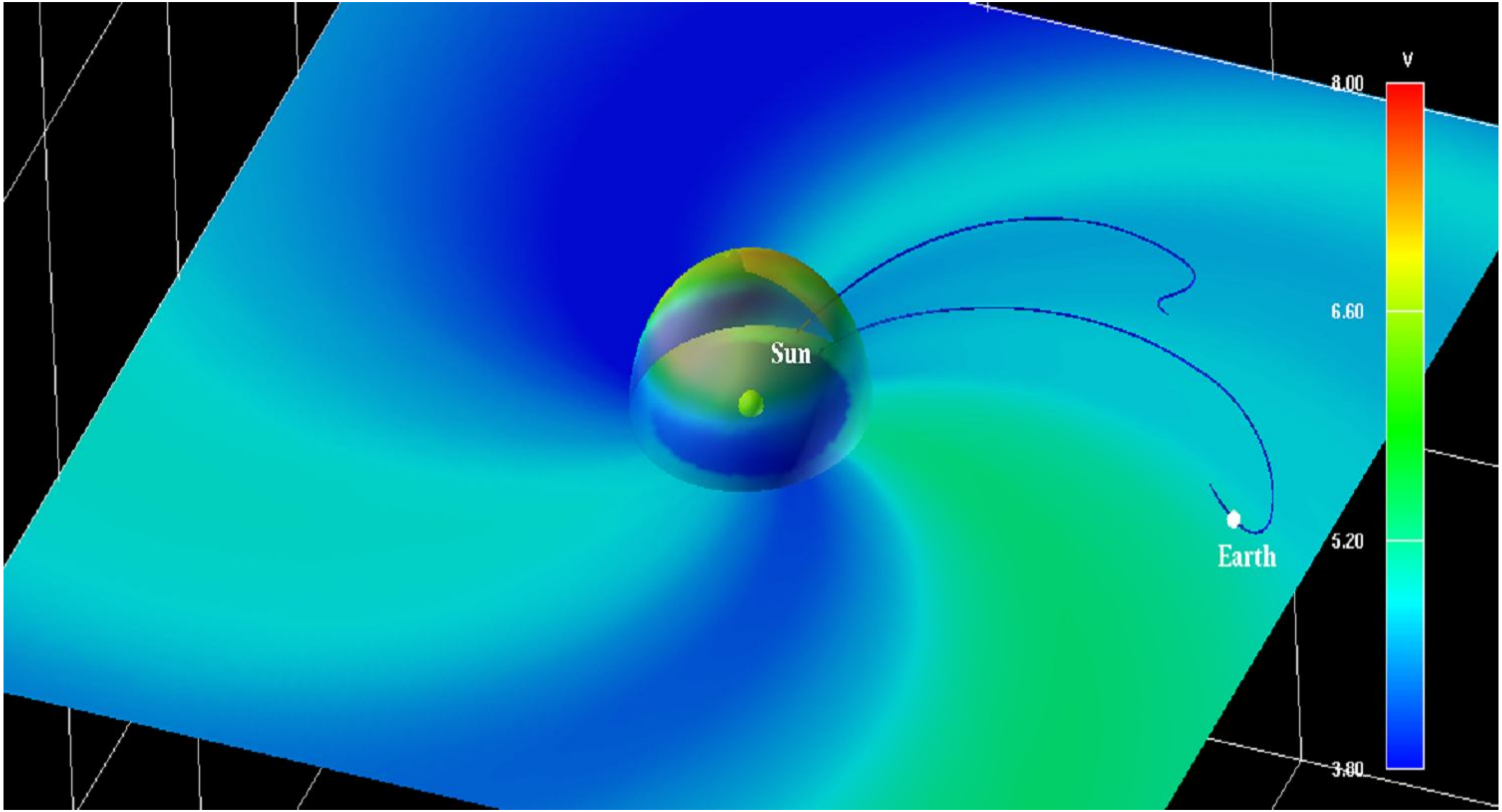




ergata

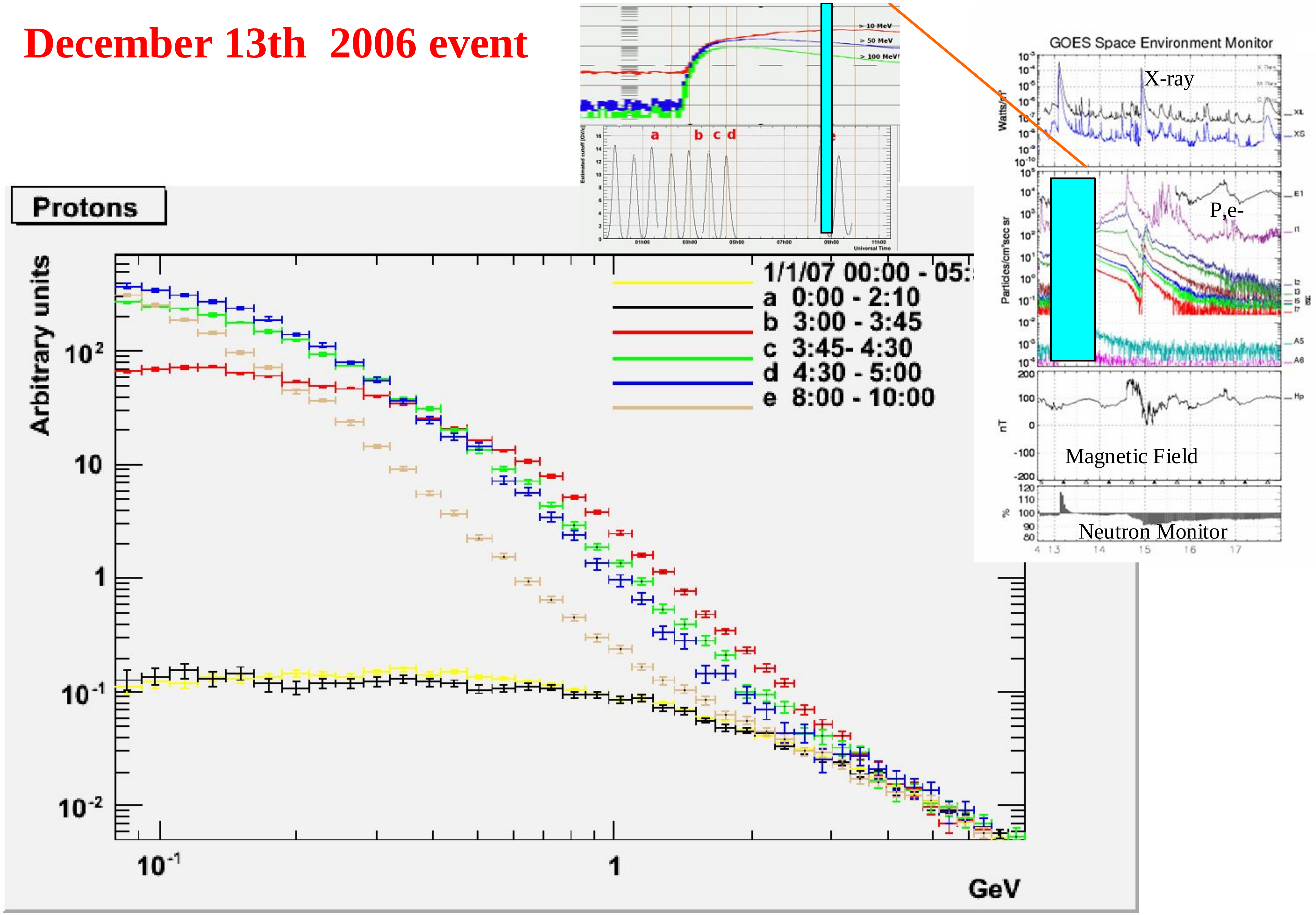
Moreton Wave, Dec 6th 2006 (from Ed Cliver)





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

December 13th 2006 event



M. Casolino, INFN & University Roma Tor Vergata

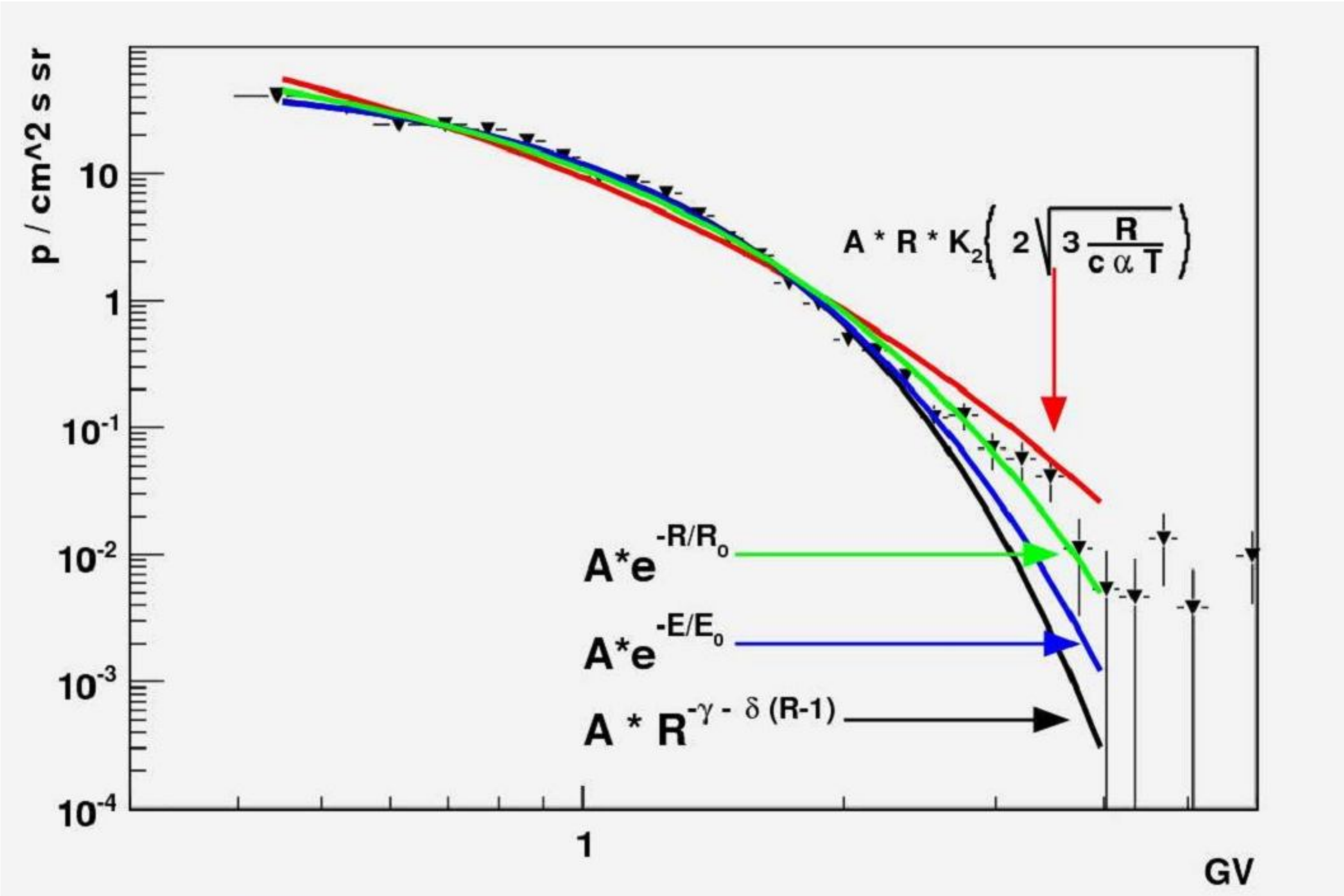
Preliminary!

Discrimination between acceleration processes

•Shock accel.
$E^{-a} \exp(E/E_o)$

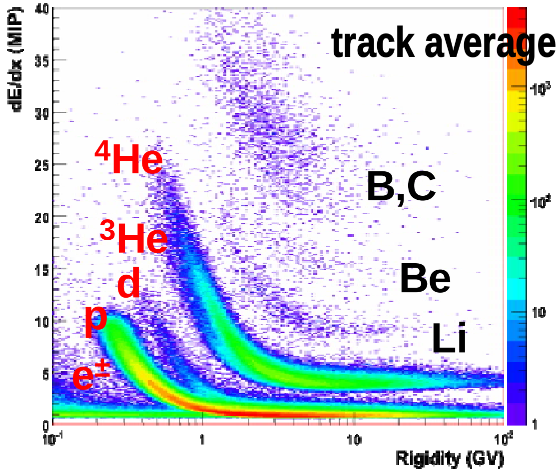
•Stochastic Fermi accel.
Impulsive events
Exp in Rigid/Kinene
Bessel function,

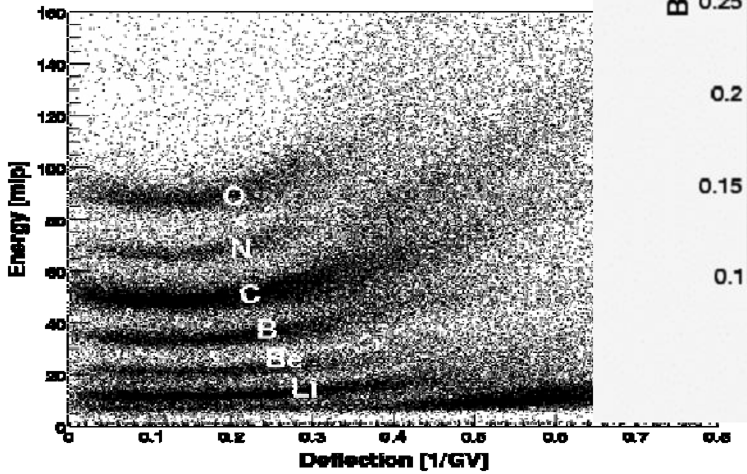
•Direct Acceleration in magnetic reconnection

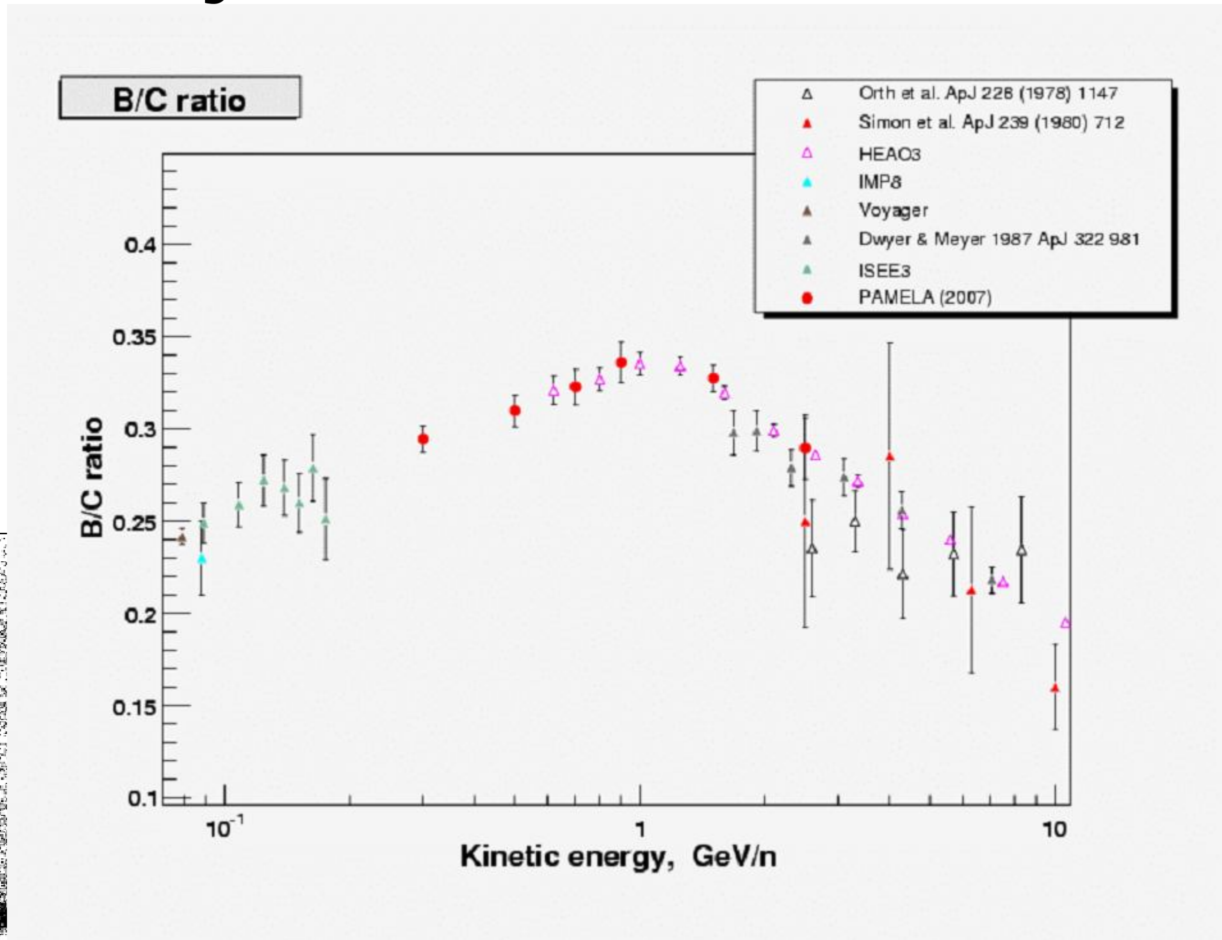


Arxiv 0810.4980v1

Preliminary Results B/C







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

Matter in the Universe

Microwave Anisotropy
WMAP - NASA - Explorer Mission →

$$\Omega_{total} = \frac{\rho_{total}}{\rho_{crit.}} = 1$$

(Universe is flat)

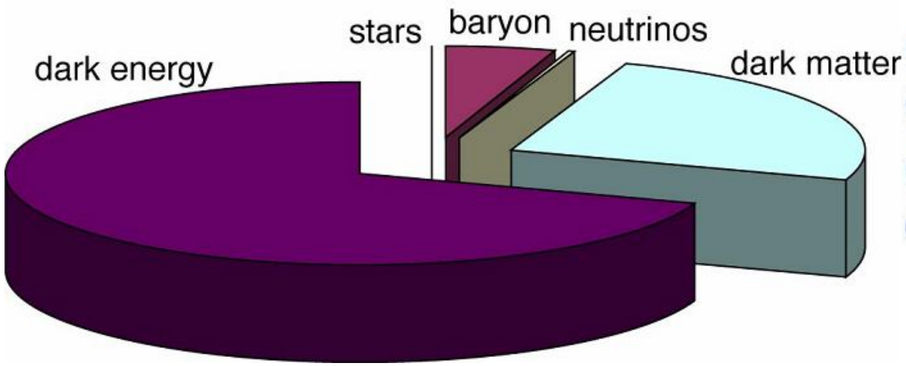
$$\rho_{crit.} = \frac{3H^2(t)}{8\pi G}$$

$$\Omega_{total} = \Omega_{total,baryon.} + \Omega_{dyn.} + \Omega_{required}$$

baryonic matter	dark matter	dark energy
4%	23%	73%
stars, galaxies	??	???
	candidates:	quintessence

candidates:

- WIMPs
- Q-balls
- axions
- Kaluza-Klein-part.



Adapted from M. Boezio, P. Picozza

Supersymmetry:

Neutralino as Dark Matter candidate

can not decay but can annhilate

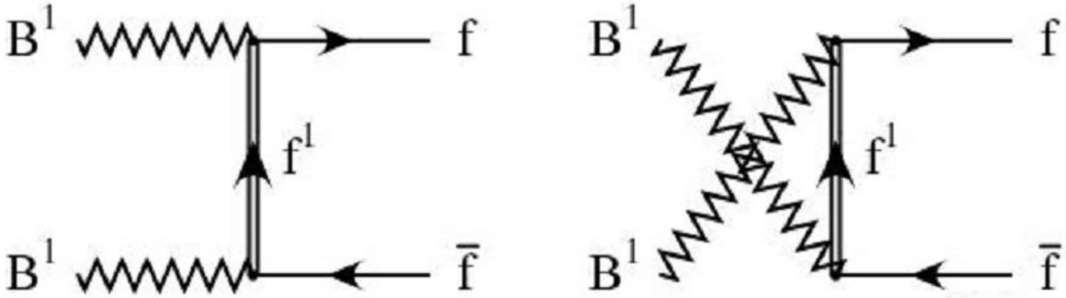
Standard Model particles and fields		Supersymmetric partners			
		Interaction eigenstates		Mass eigenstates	
Symbol	Name	Symbol	Name	Symbol	Name
$q = d, c, b, u, s, t$	quark	$\tilde{q}_L, \tilde{q}_R$	squark	$\tilde{q}_1, \tilde{q}_2$	squark
$l = e, \mu, \tau$	lepton	$\tilde{l}_L, \tilde{l}_R$	slepton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

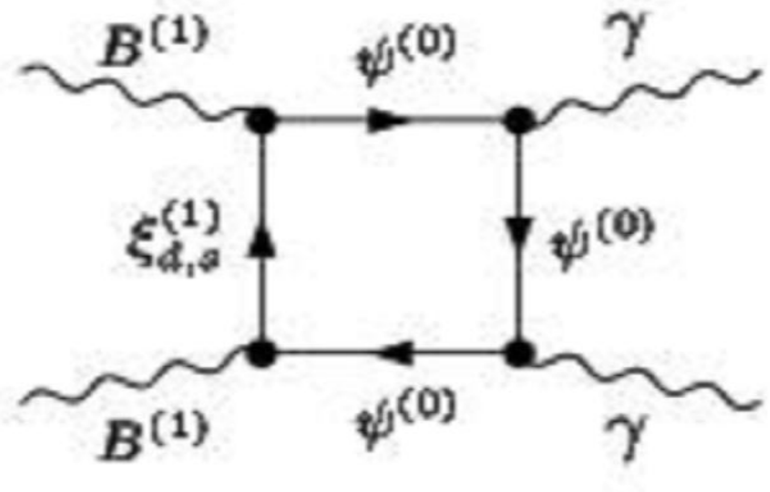
Another possible scenario:
KK Dark Matter

Lightest Kaluza-Klein Particle (LKP): $B^{(1)}$



Bosonic Dark Matter:
fermionic final states
no longer helicity
suppressed.
$e+e^-$ final states
directly produced.

As in the neutralino case there are 1-loop processes that produces monoenergetic $\gamma\ \gamma$ in the final state.

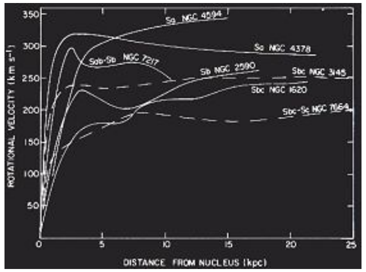


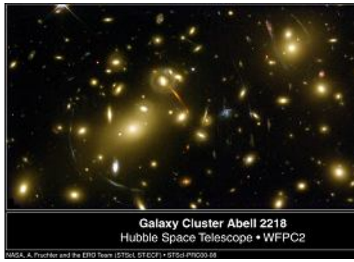
From P. Picozza

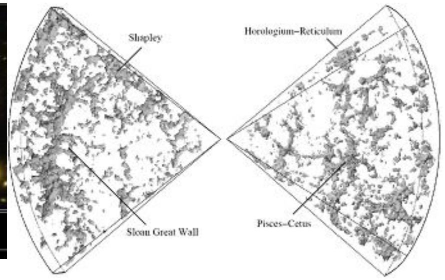
Dark Matter Searches

•Cosmology

Detection, not identification

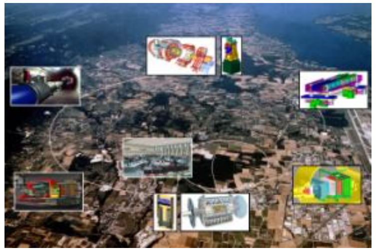






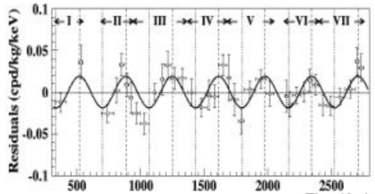
•LHC Search

Supersymmetry, not necessarily DM



•Direct Detection

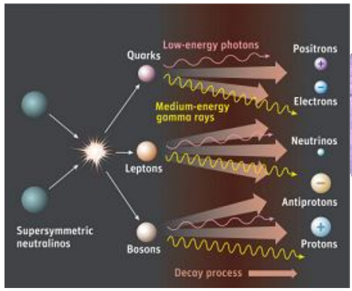
Local structure and nature

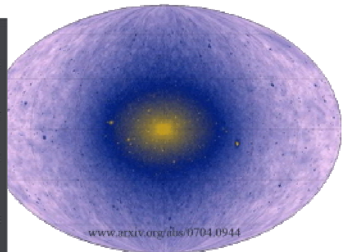


DAMA

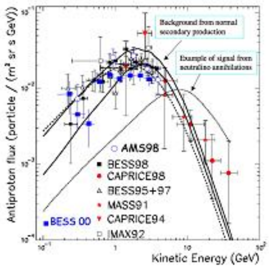
•Indirect Detection

Various galactic scales

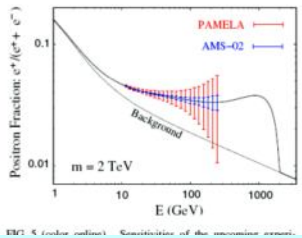




γ: Galactic centre



Antiprotons: Galactic average



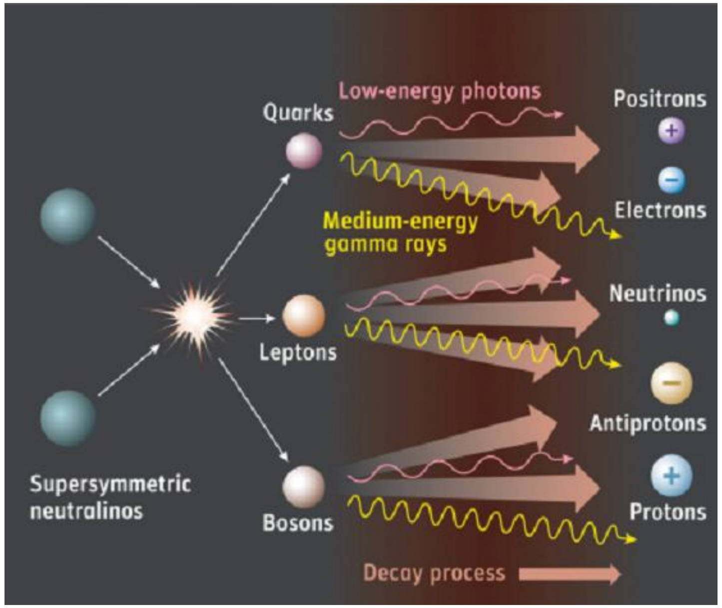
positrons: Local galactic 1kpc

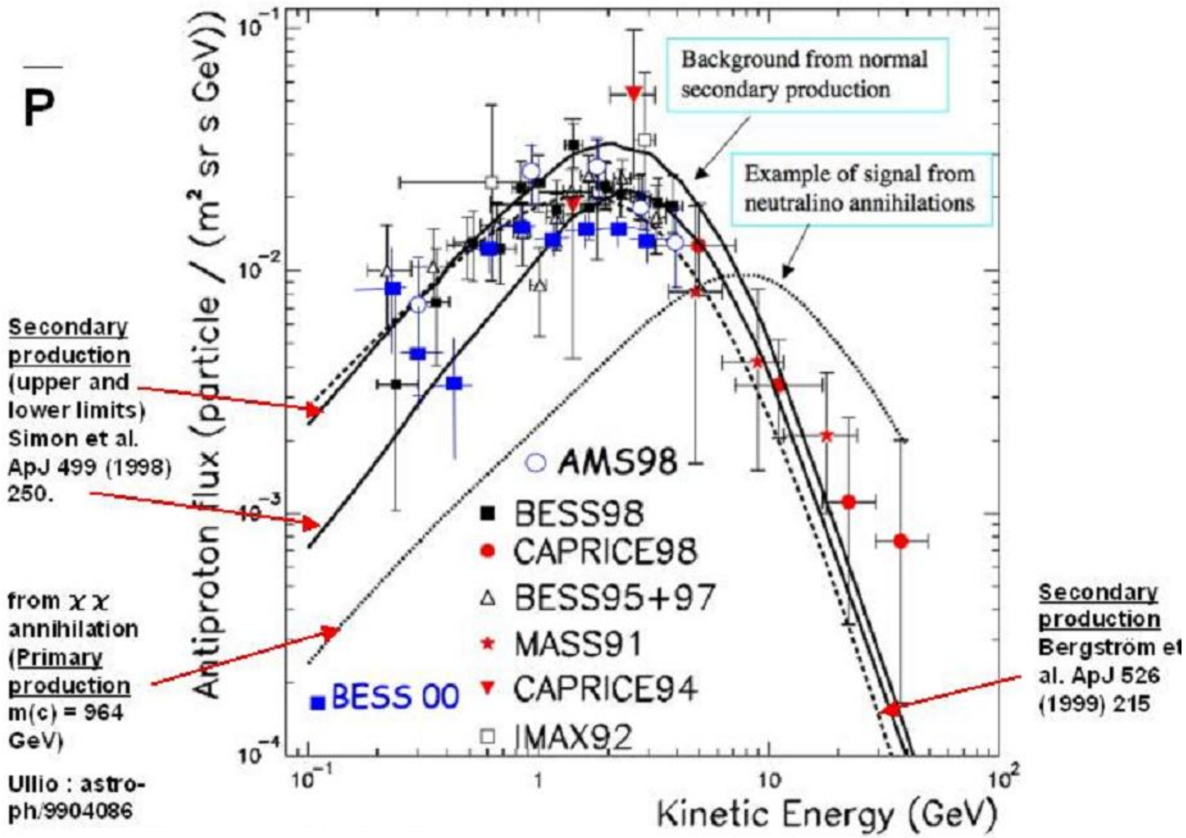
Dark matter search in cosmic ray antiparticles

Only secondary production in the galaxy e.g.: $p_{CR} + p_{ISM} \rightarrow \bar{p} + p + p + p$

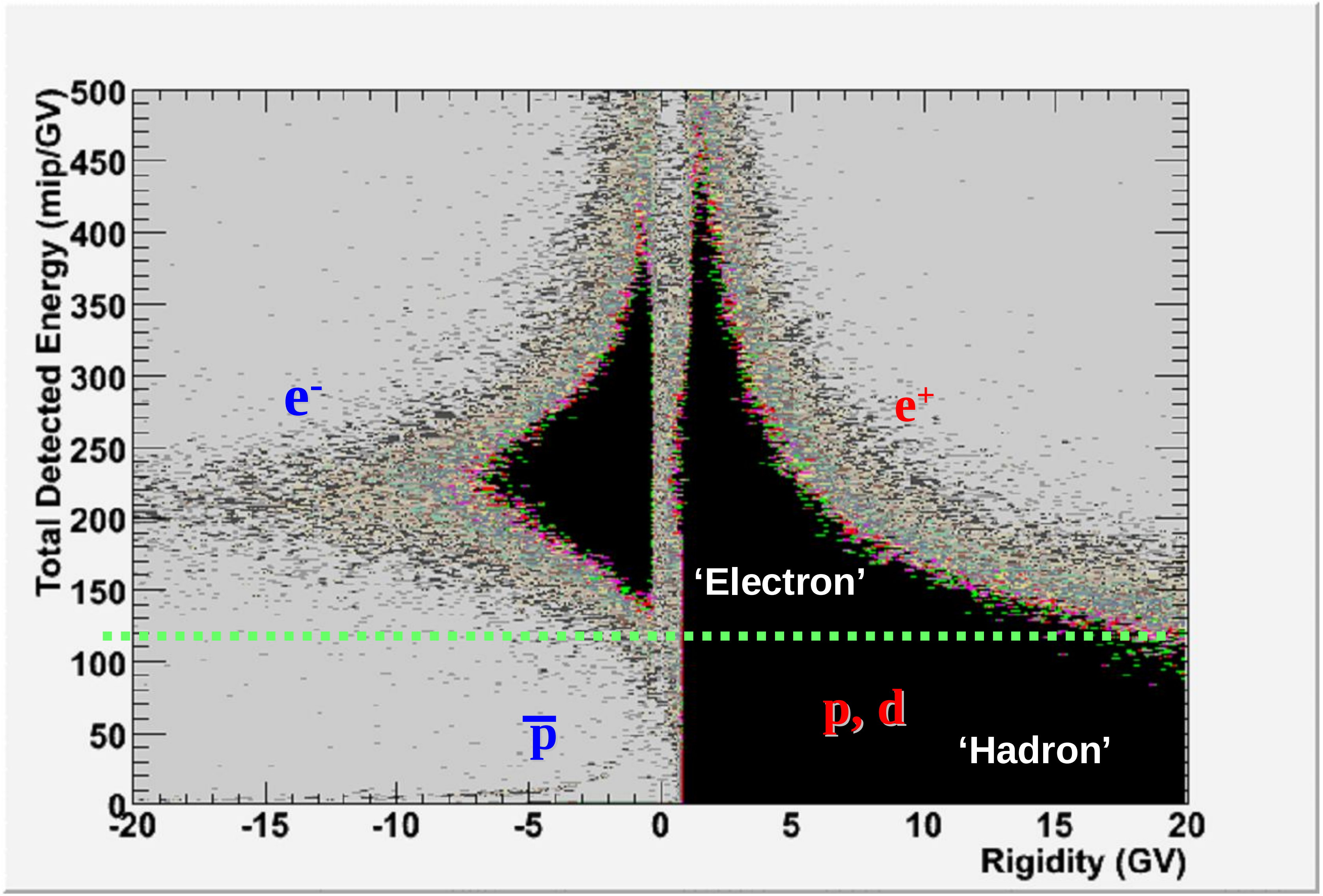
Depends on propagation in the galaxy

Background – free channel to study rare phenomena such as Dark matter decay





Calorimeter Selection Criteria for Antiprotons



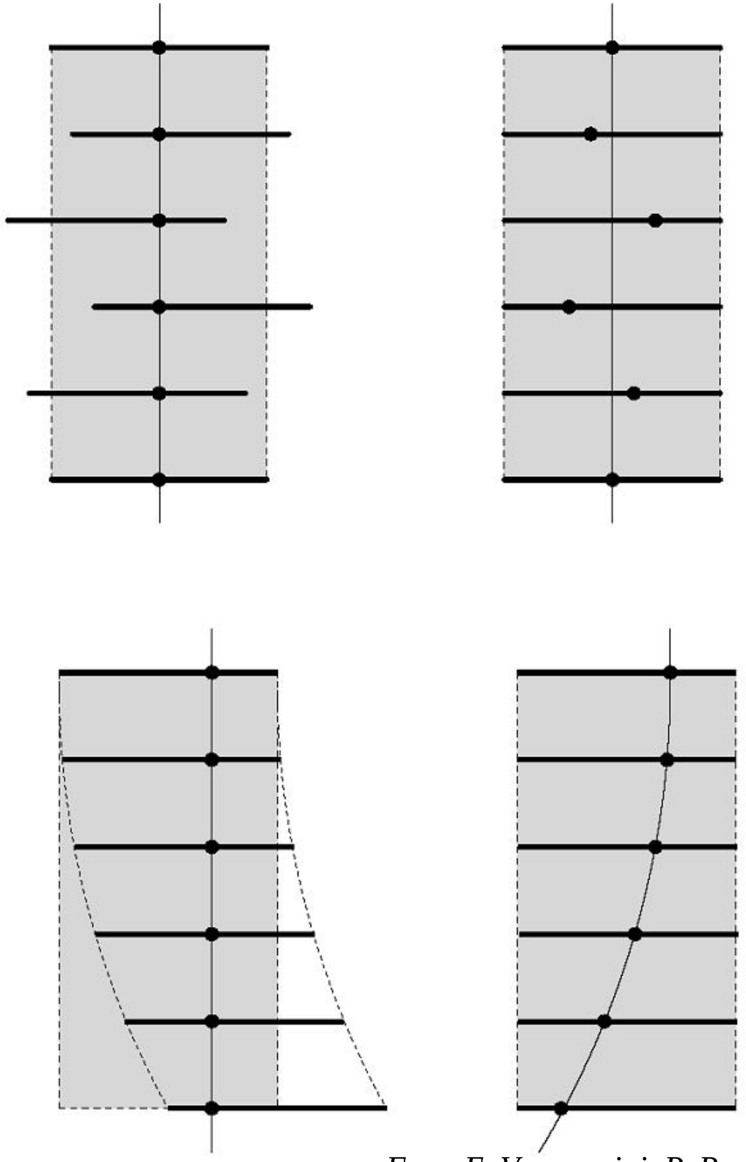
From M. Boezio

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

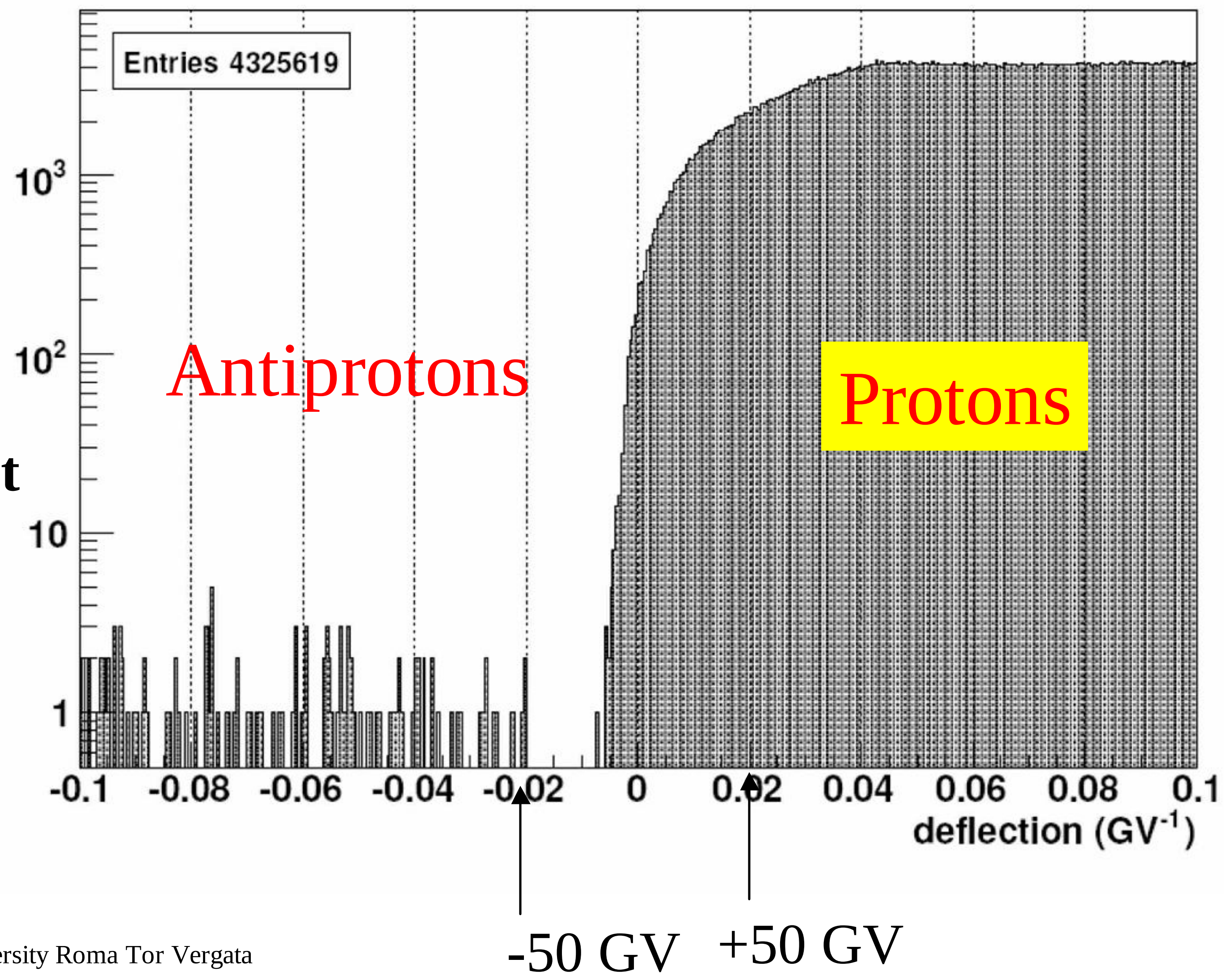


From E. Vannuccini, P. Papini

Deflection

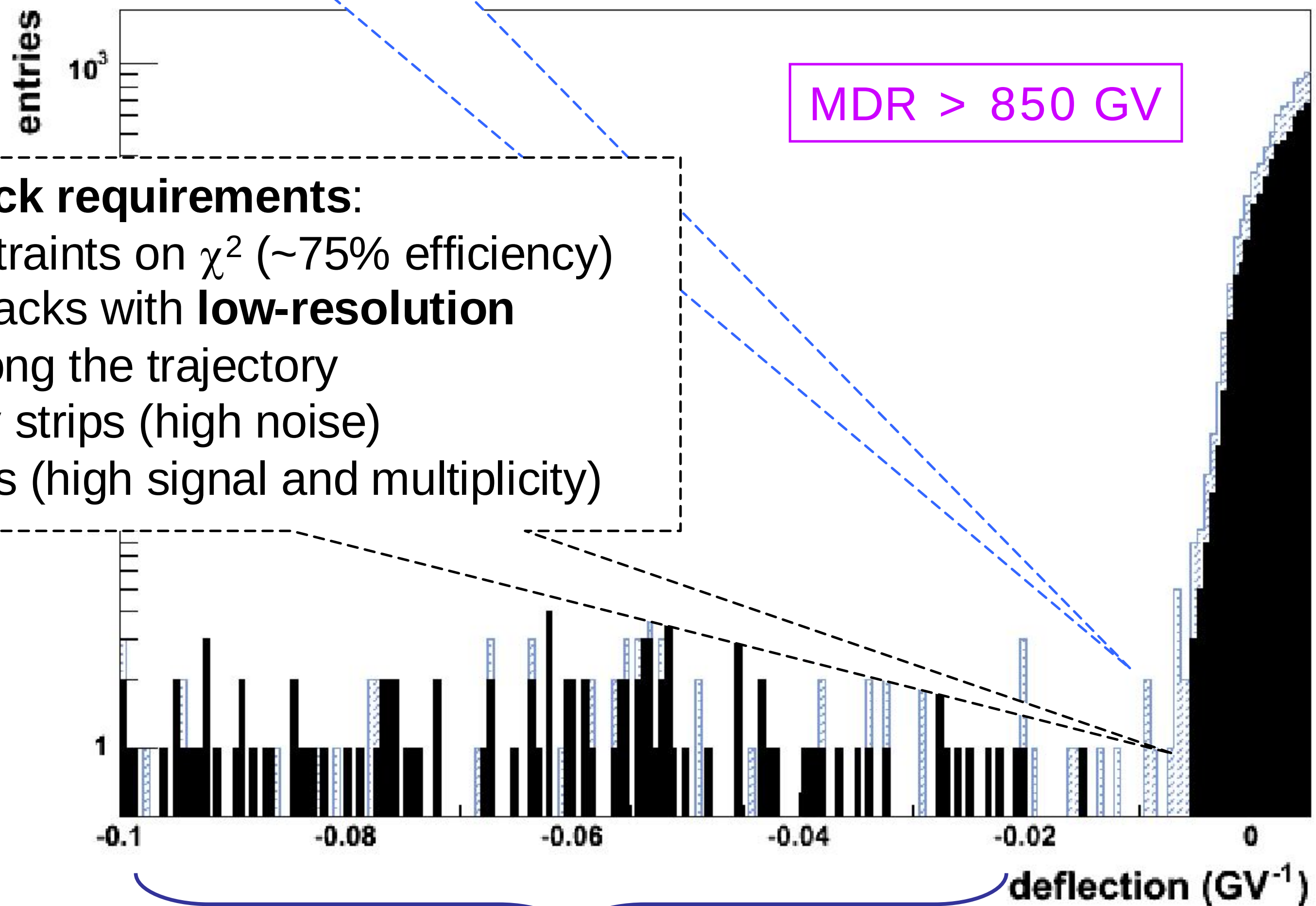
D=1/R

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

Minimal track requirements



MDR > 850 GV

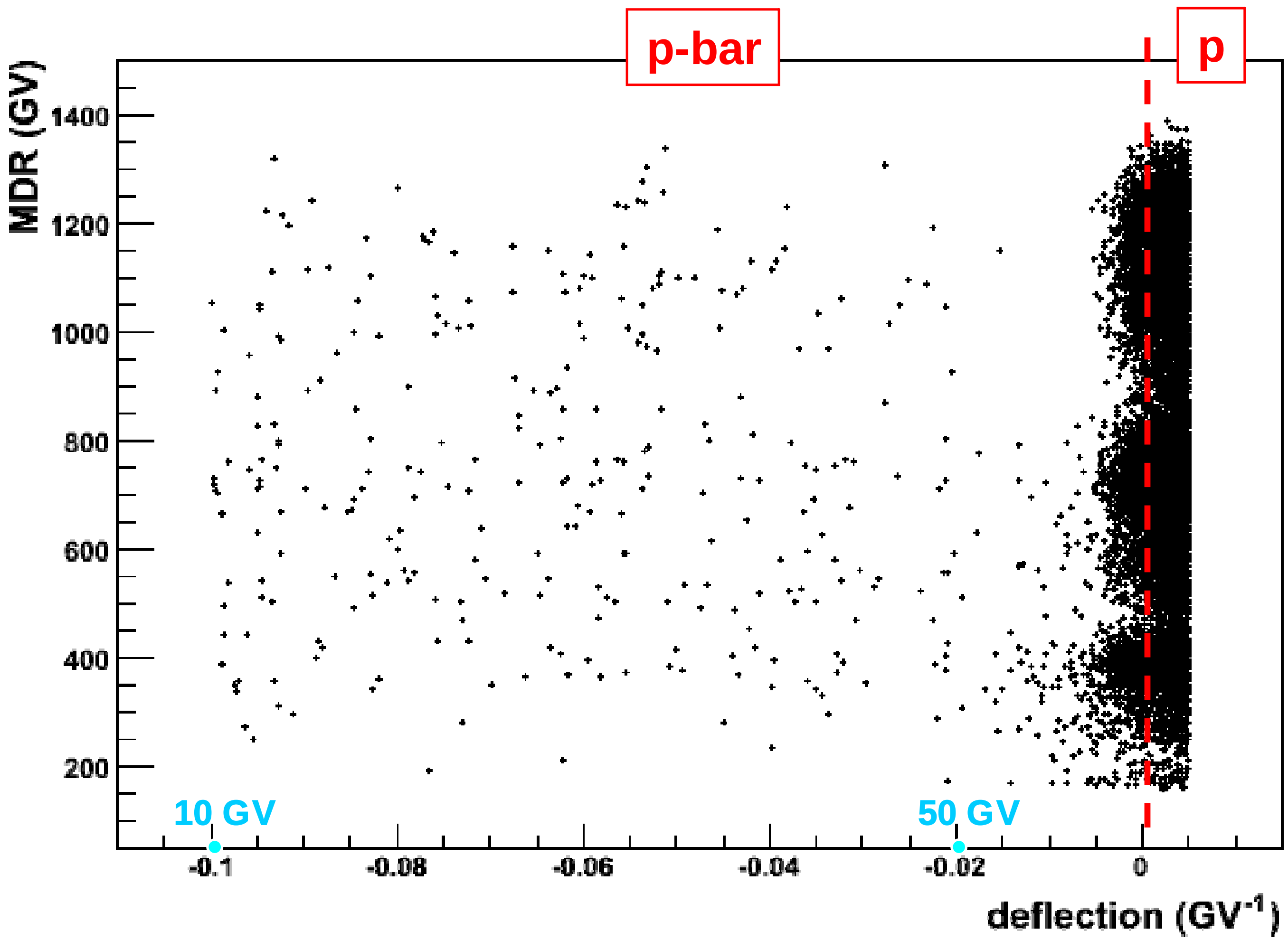
Strong track requirements:
•strict constraints on χ^2 (~75% efficiency)
•rejected tracks with **low-resolution** clusters along the trajectory
- faulty strips (high noise)
- δ-rays (high signal and multiplicity)

Antiprotons

Protons (& spillover)

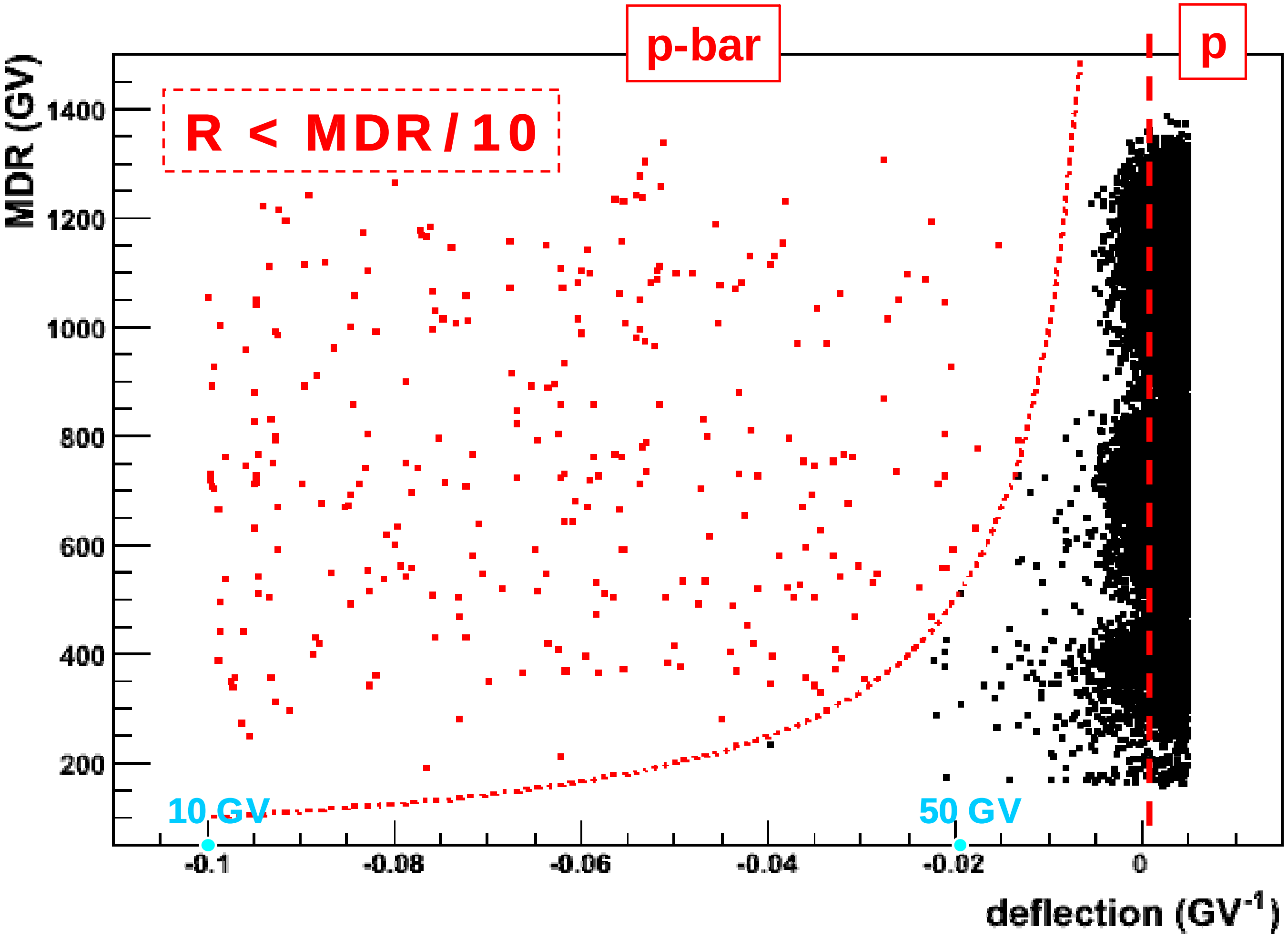
From O. Adriani

High-energy antiproton selection



From O. Adriani

High-energy antiproton selection



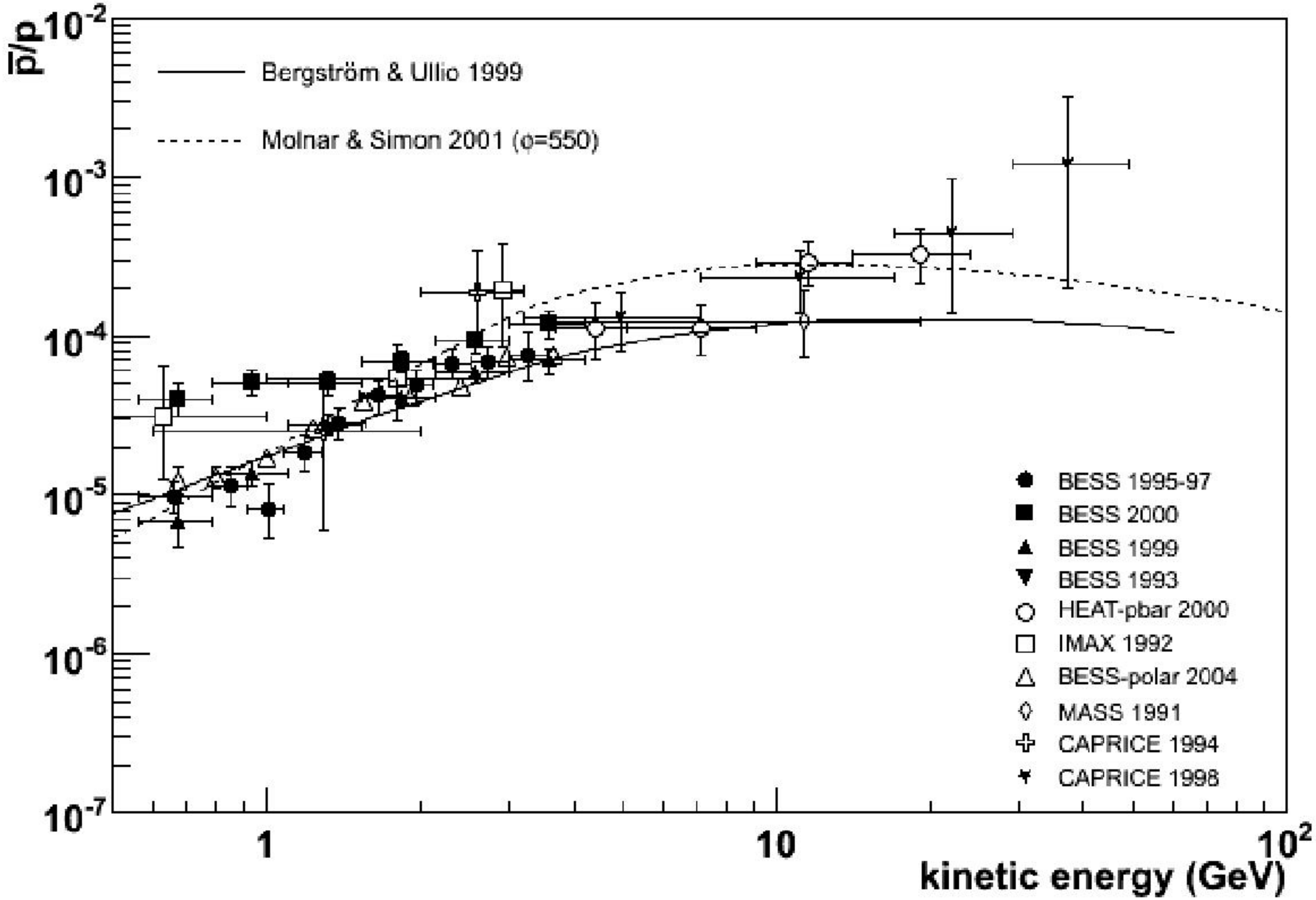
From O. Adriani

Antiproton-Proton Ratio

Why Ratios?

Reduce systematic error
All (most) efficiencies cancel out

Subsequently absolute fluxes



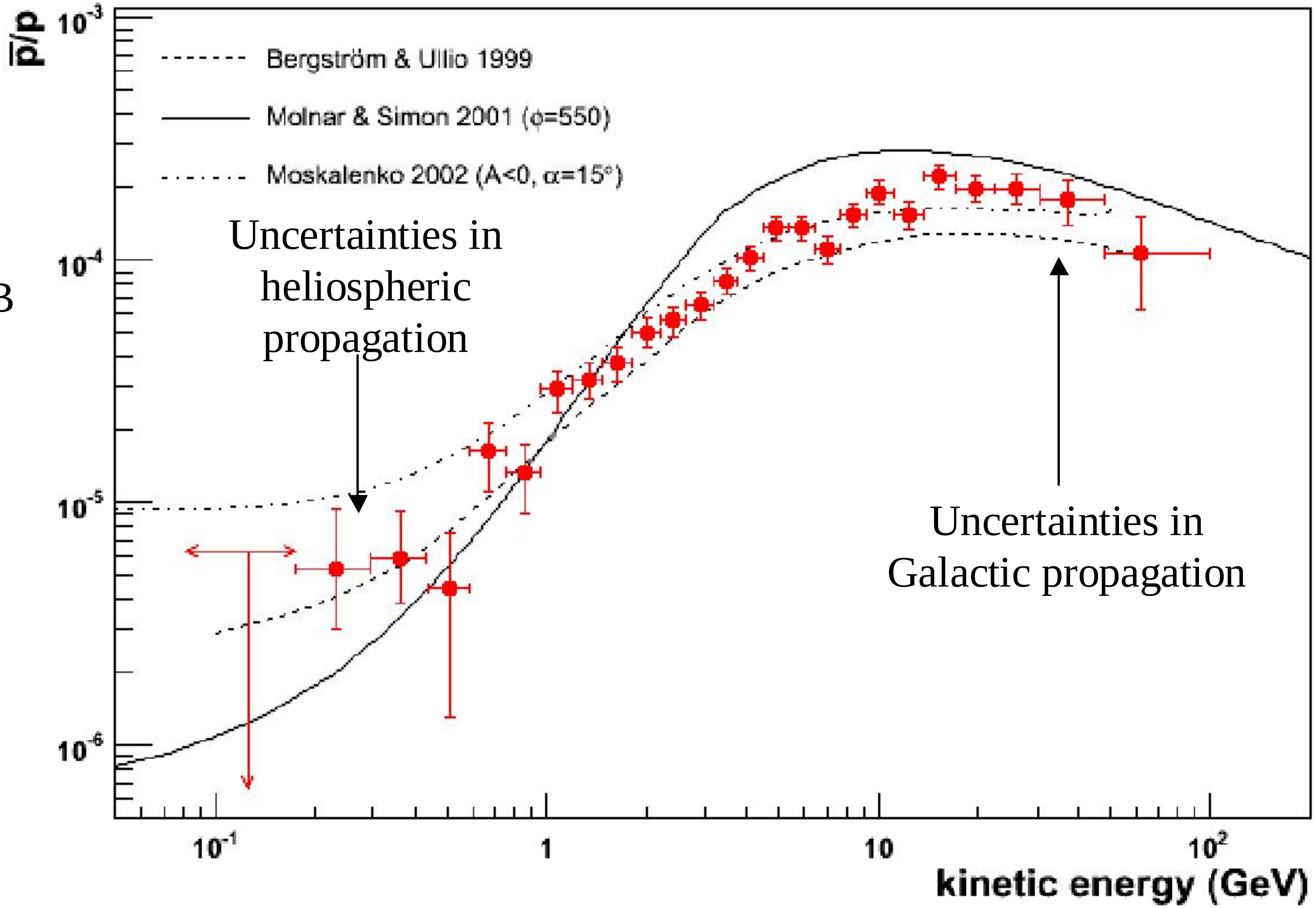
Antiproton ratio measured with Pamela: Comparison with theoretical models

Released data
1-100 GeV

Currently roughly 10 TB of data

As of March ’08
Out of 8.8 TB

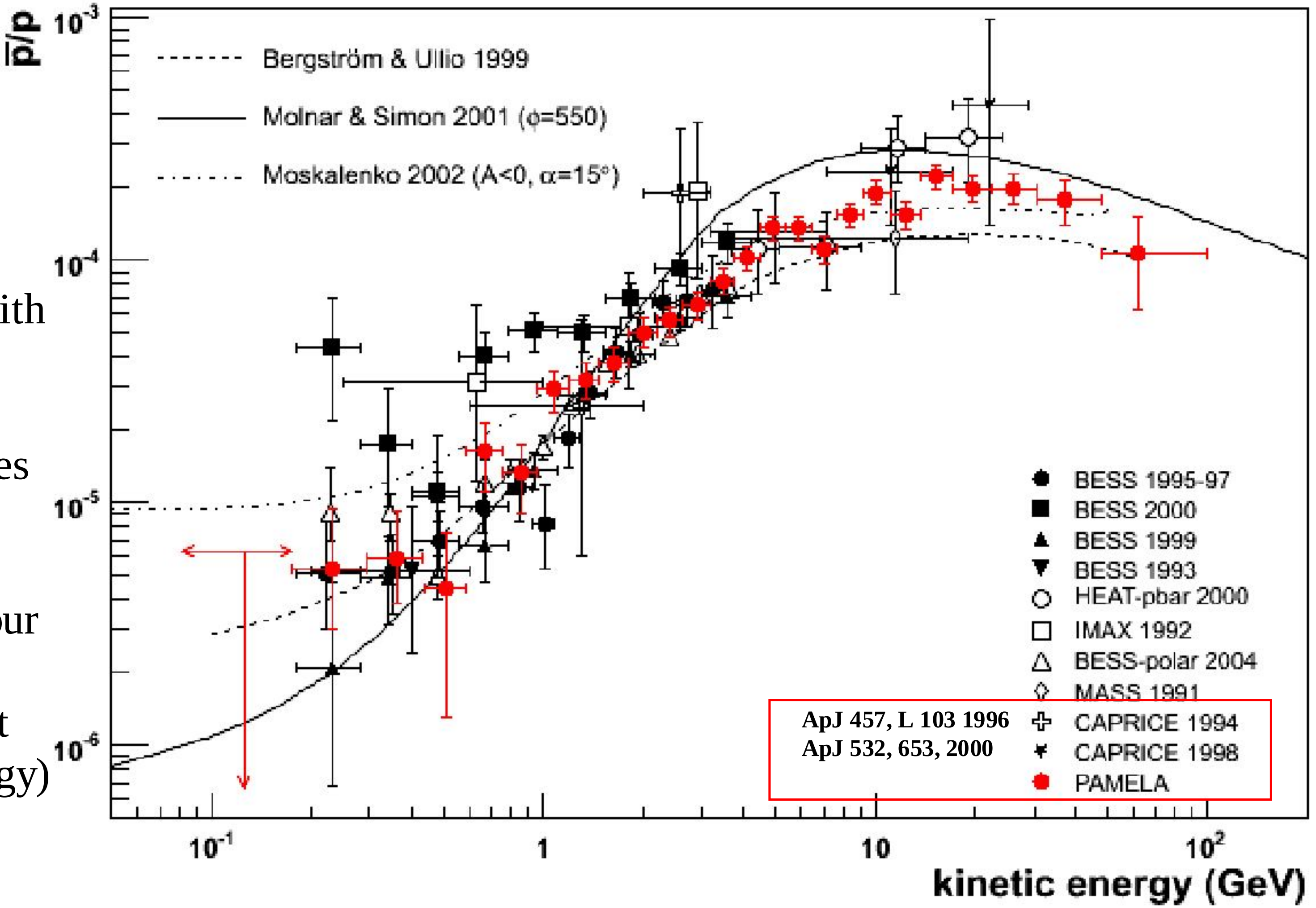
- 10^7 p
- 800 p^-



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

Antiproton ratio measured with Pamela: Comparison with experimental data

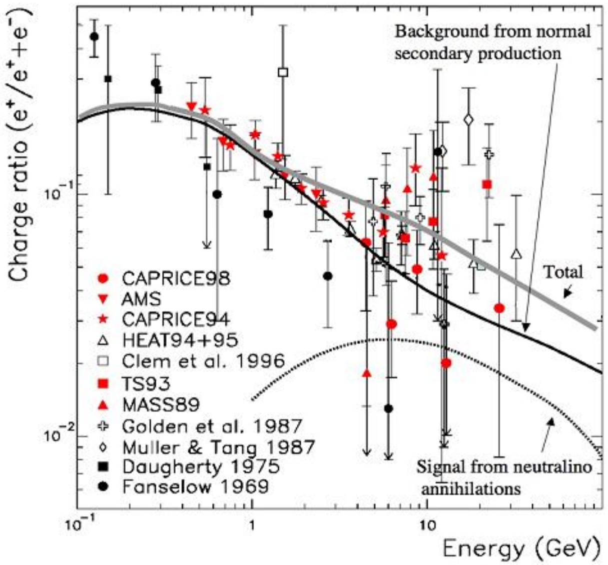
- Highest energy up to now
- Coherent with secondary production
- Uncertainties of Galactic Propagation
- Would favour Moskalenko 2002 (except highest energy)



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

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



Preshower Technique to reduce systematics of proton contamination:

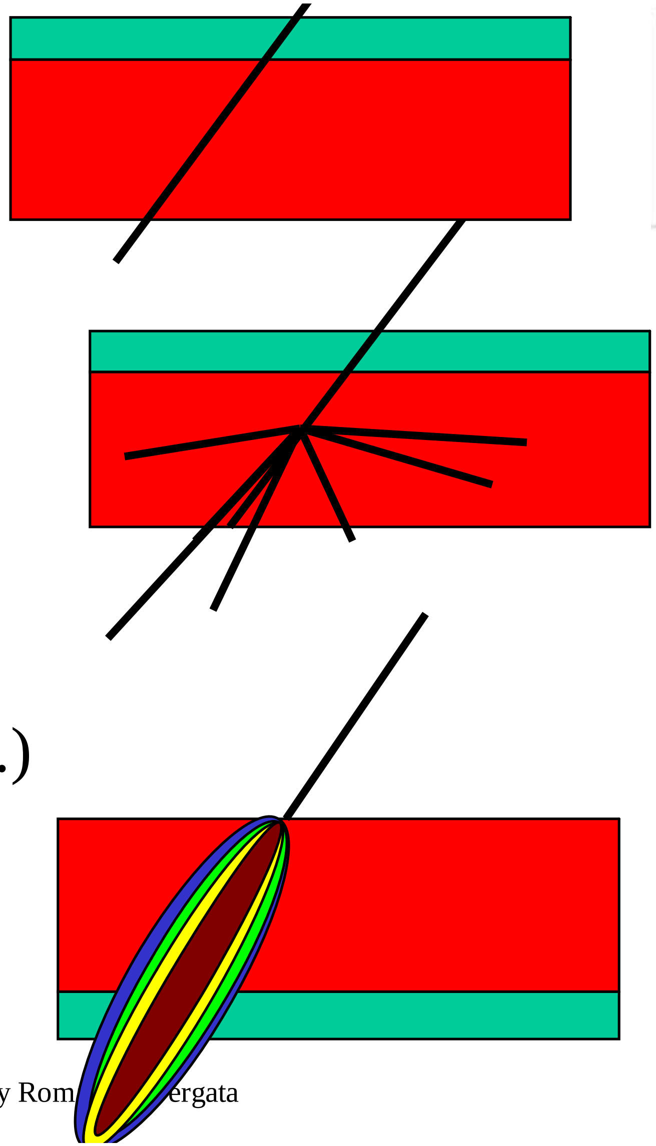
Optimize electromagnetic/hadronic shower discrimination, reduce systematics

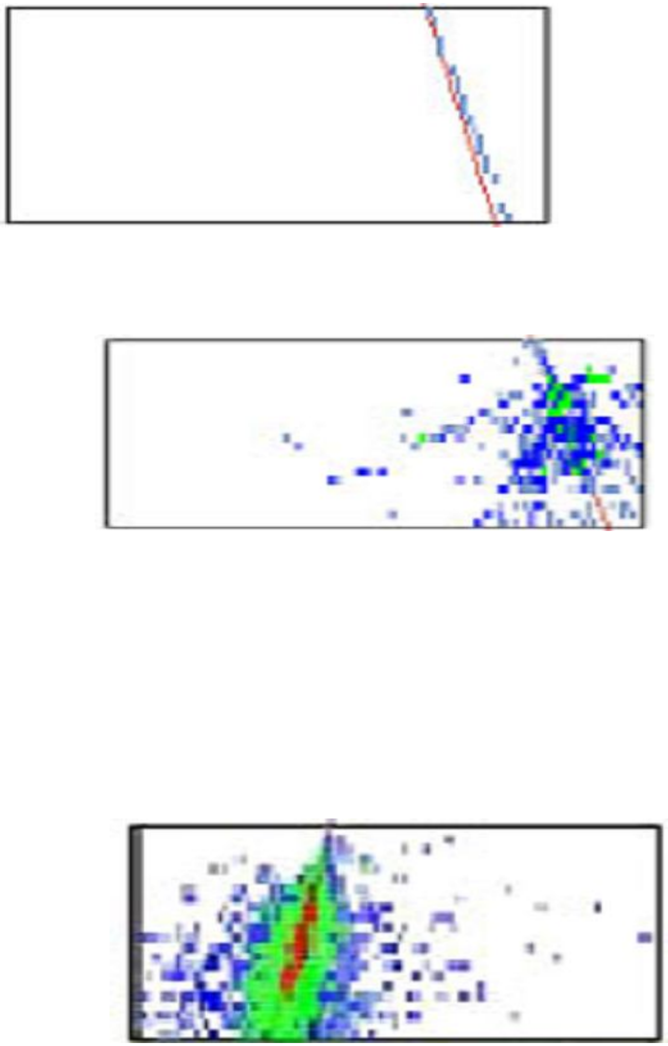
Protons:

- Non Interacting
- Interacting

Electrons / Positrons

- Interacting (e.m.)

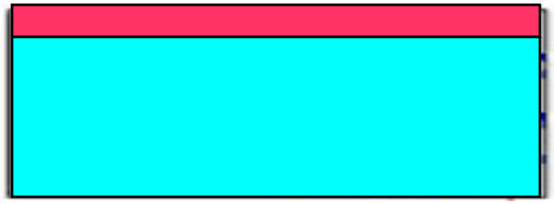




Recipe: M. Boezio, E. Mocchiutti

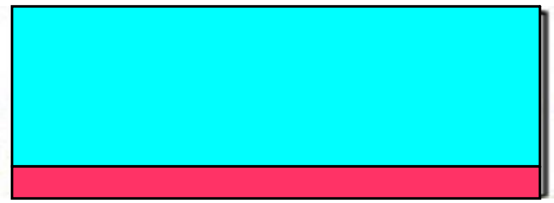
Preshower Technique to reduce systematics of proton contamination:

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)



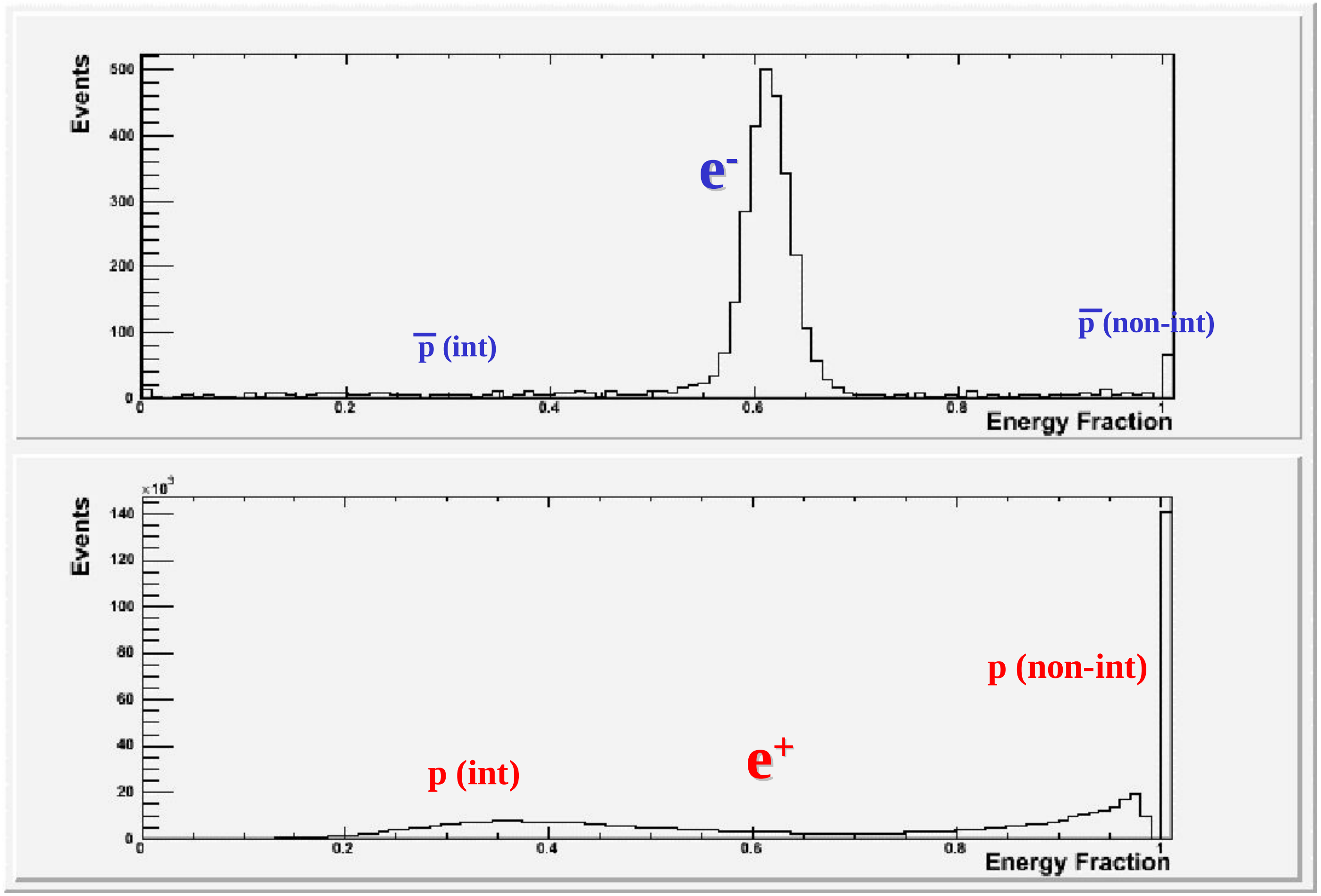
$e^{+/-}$ e.m. shower

3. Apply cuts to the positron sample

4. Apply cuts to electron sample to estimate efficiency

Positron selection with calorimeter

Rigidity: 20-30 GV

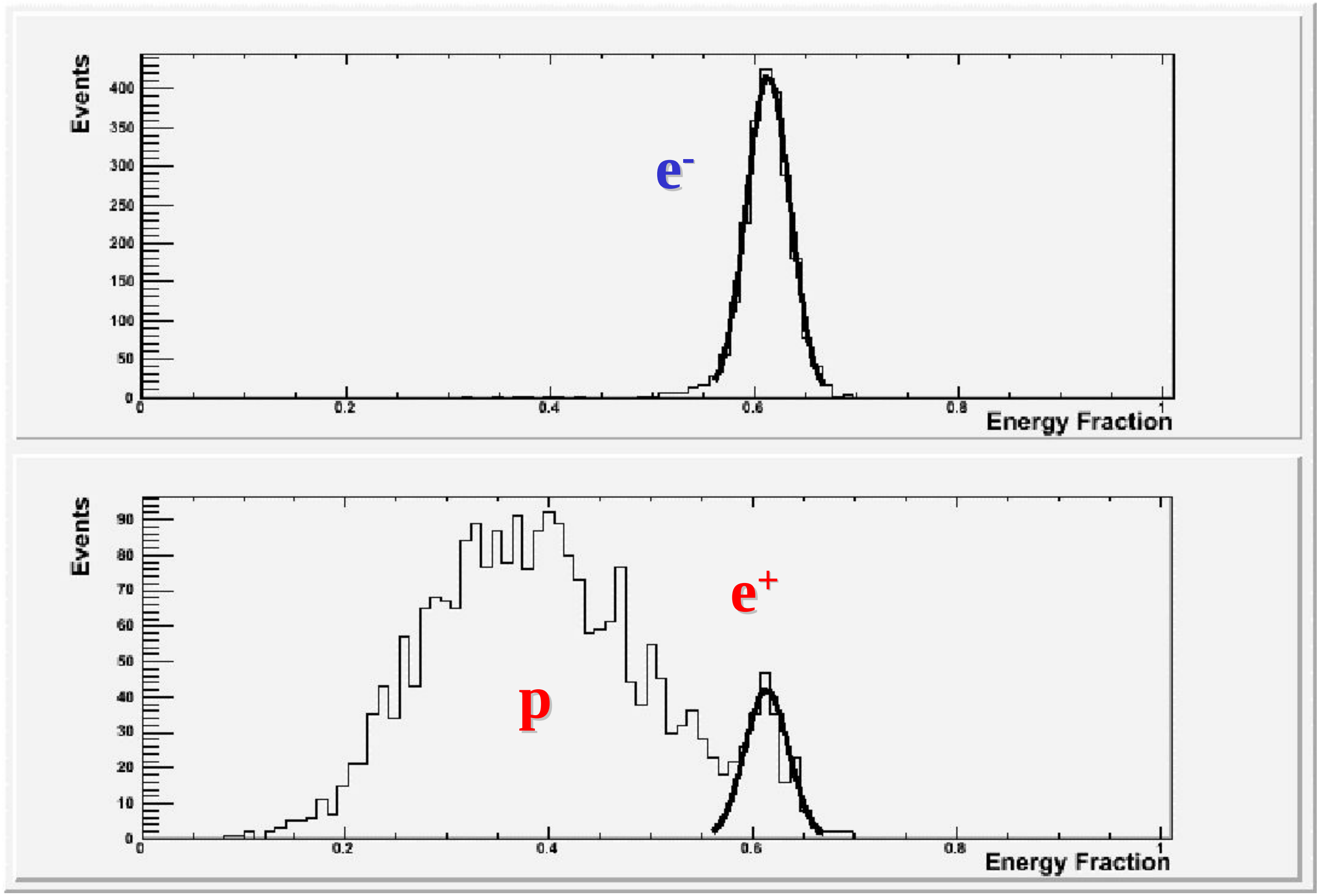


Fraction of charge released along the calorimeter track (left, hit, right)

From P. Picozza, M. Boezio, E. Vannuccini

Positron selection with calorimeter

Rigidity: 20-30 GV

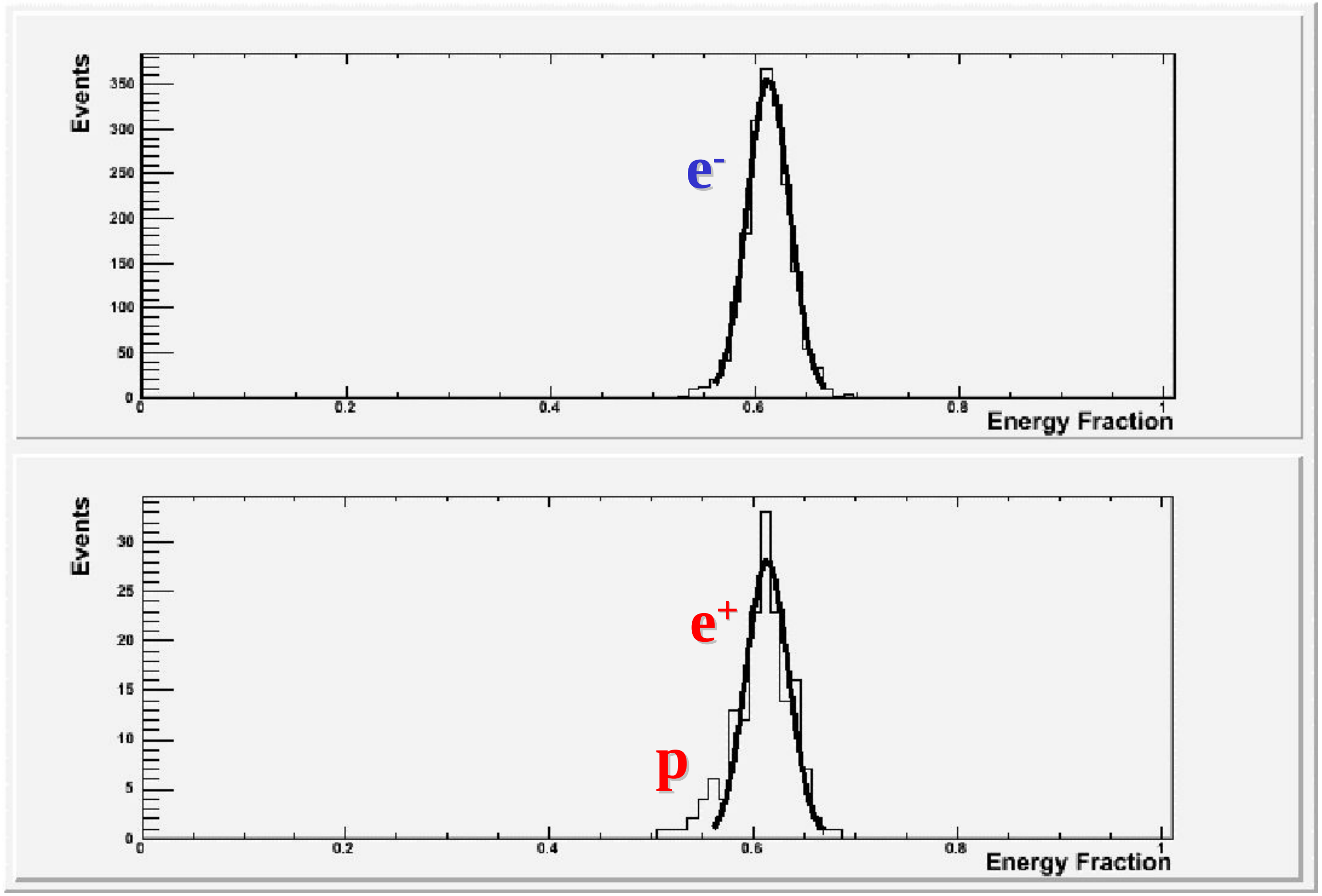


Fraction of charge released along the calorimeter track (left, hit, right) **+** **Energy-momentum match**

From P. Picozza, M. Boezio, E. Vannuccini

Positron selection with calorimeter

Rigidity: 20-30 GV



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

+

- **Energy-momentum match**
- **Starting point of shower**
- **Longitudinal profile**

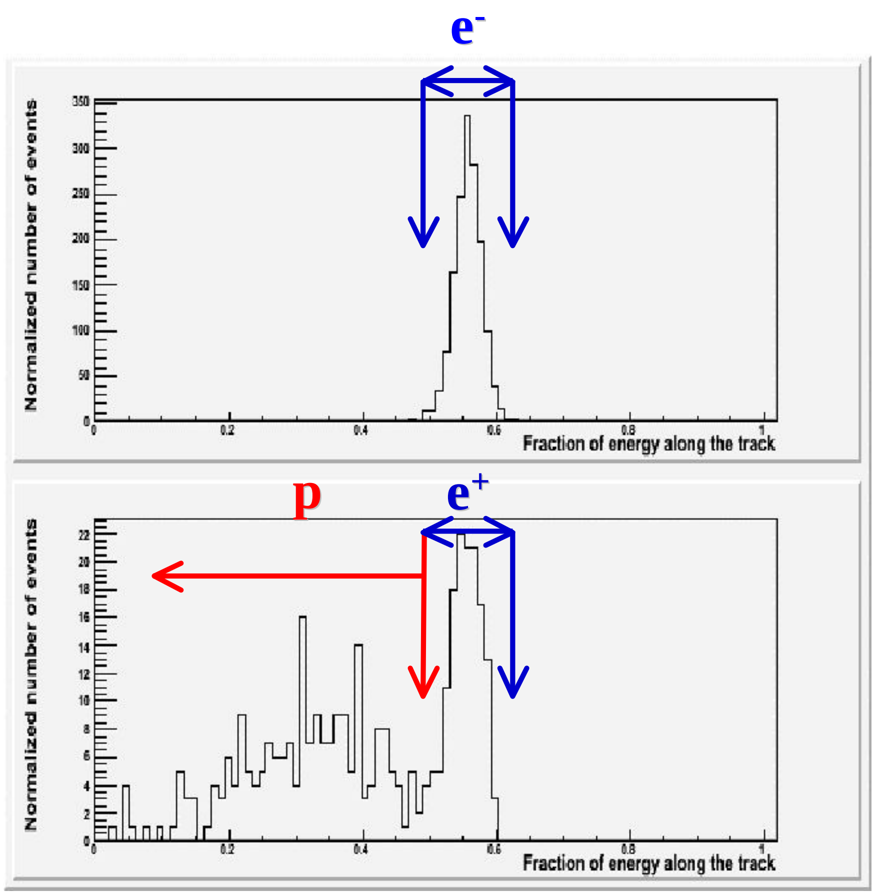
M. Casolino, INFN & University Roma Tor Vergata

From P. Picozza, M. Boezio, E. Vannuccini

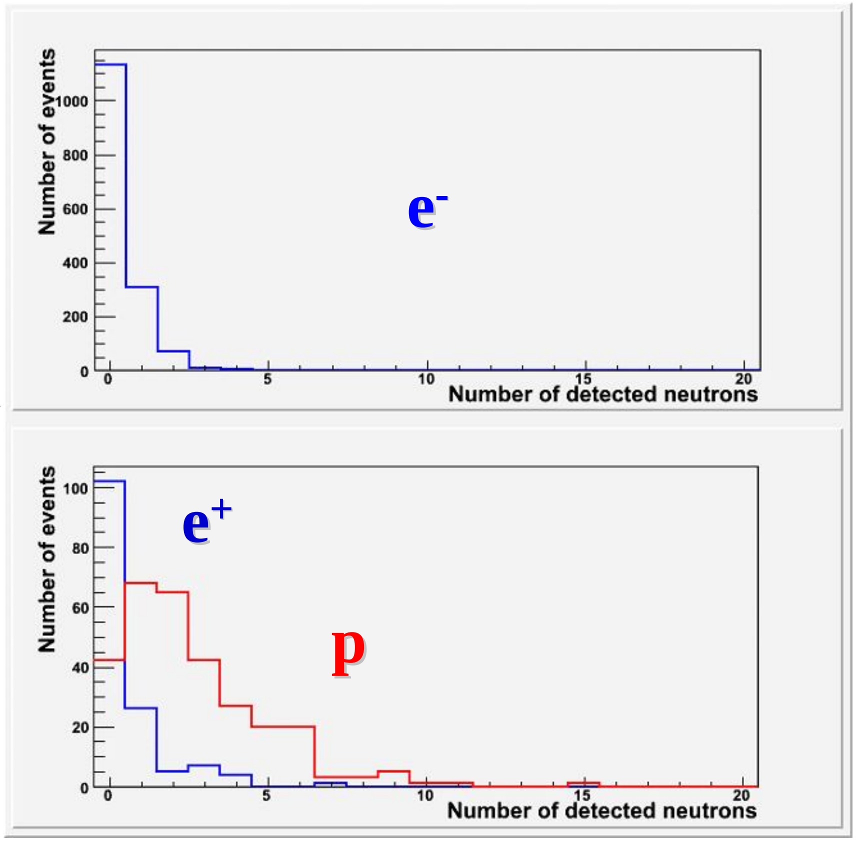
Positron selection – indipendent selection/check with ND

Rigidity: 20-30 GV

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

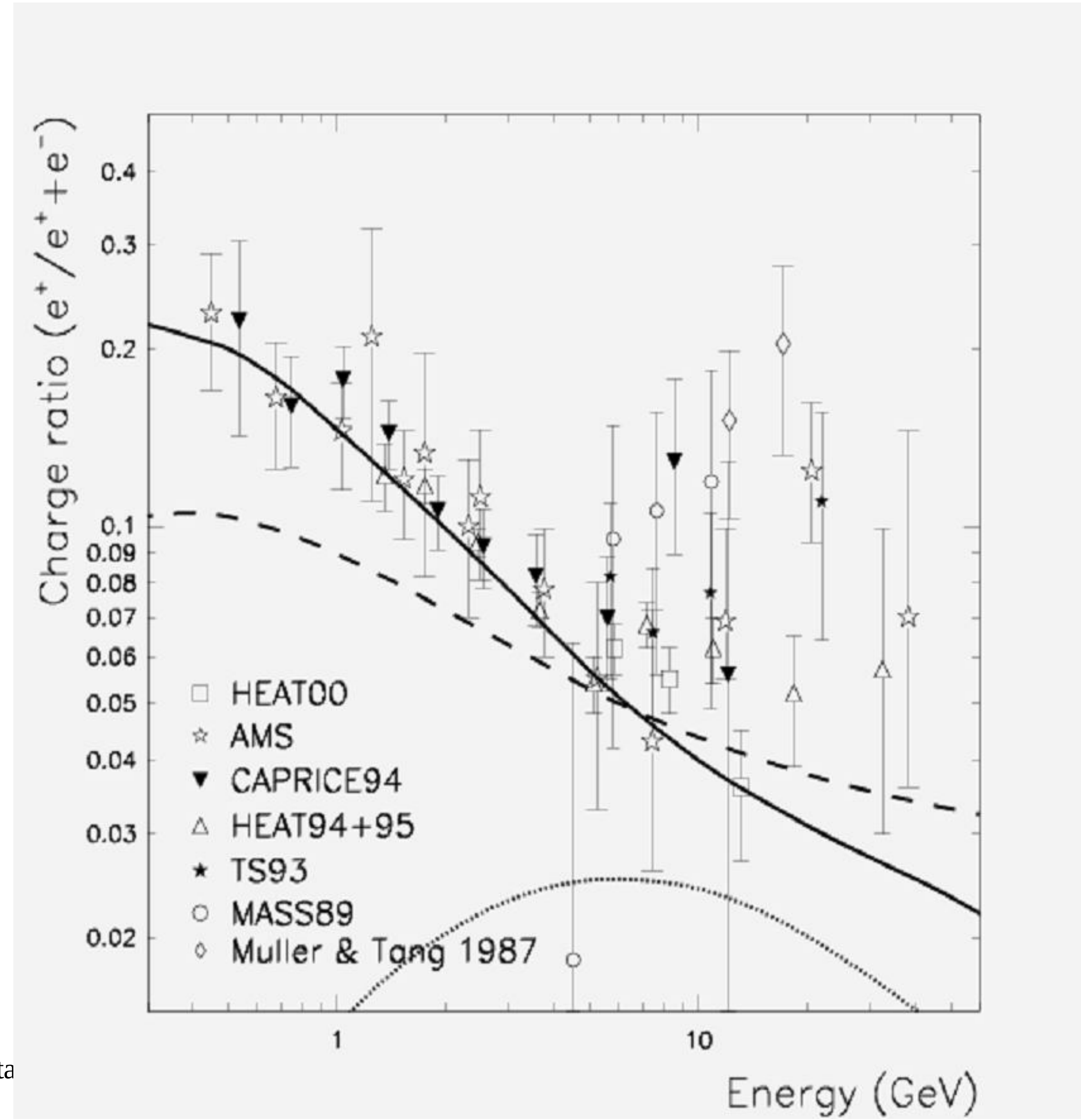


Neutrons detected by ND

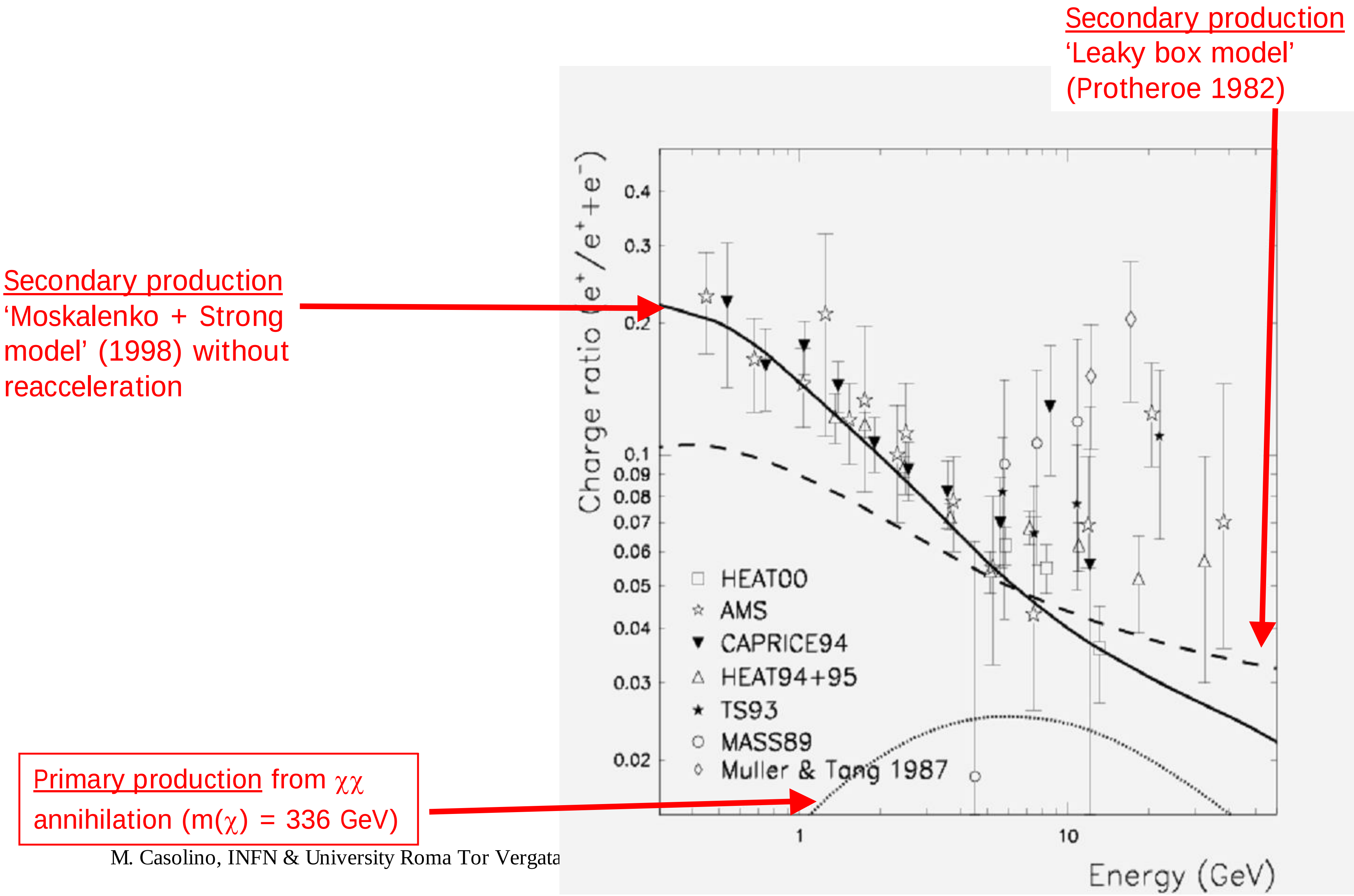


- **Energy-momentum match**
- **Starting point of shower**

Status of Positron - Electron ratio



Status of Positron - Electron ratio

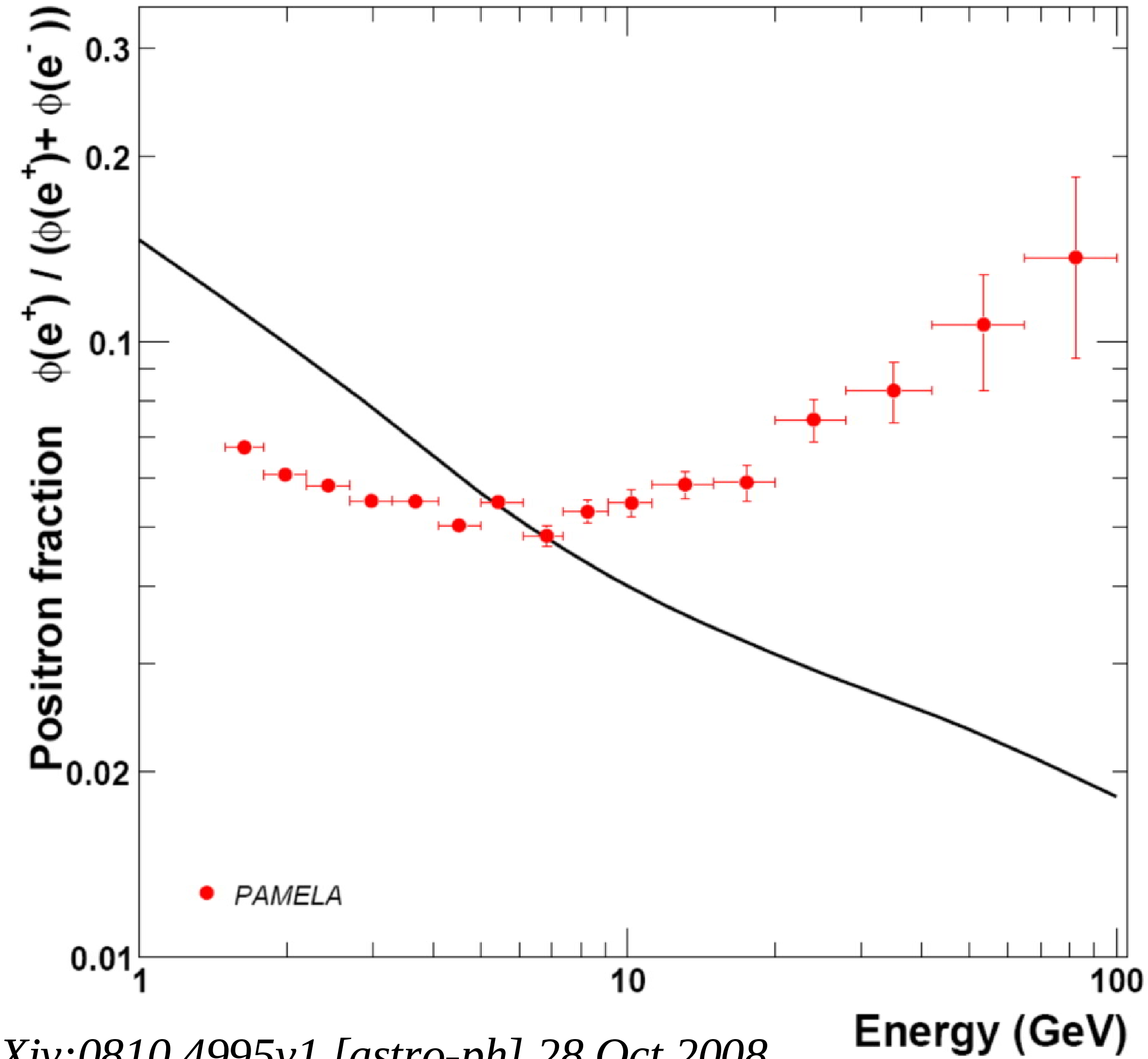


Pamela e+ results

- Till August 30th about 20000 positrons from 200 MeV up to 200 GeV have been analyzed

- More than 15000 positrons over 1 GeV

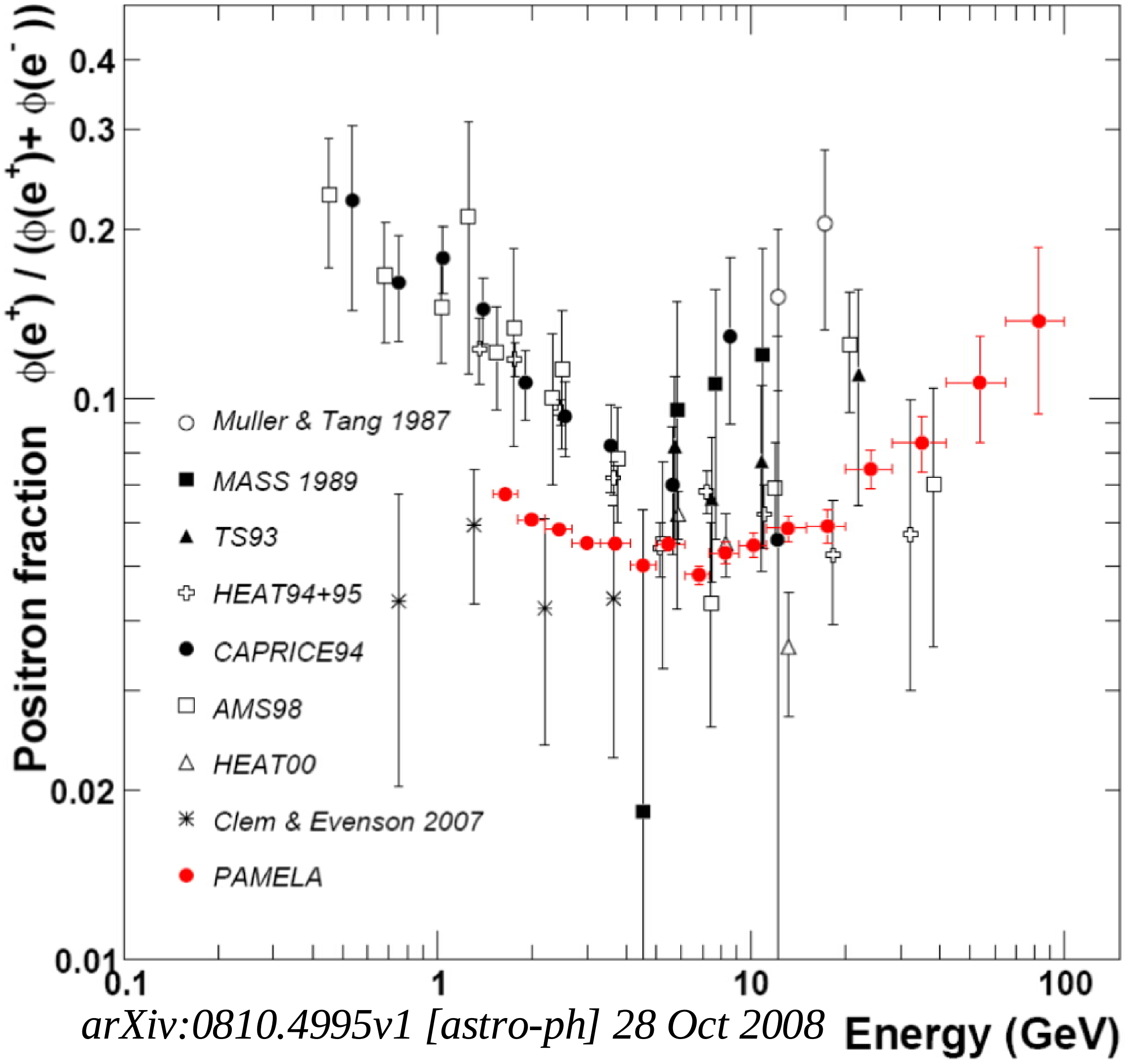
- Other eight months data to be analyzed



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

Accepted on Nature

Pamela e+ results



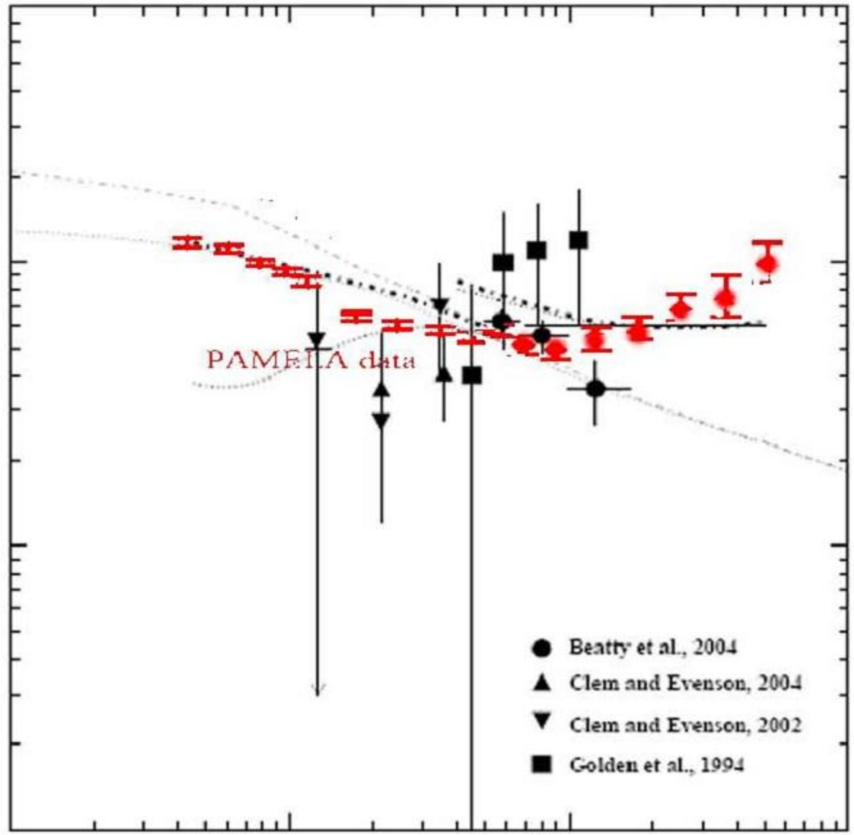
arXiv:0810.4995v1 [astro-ph] 28 Oct 2008

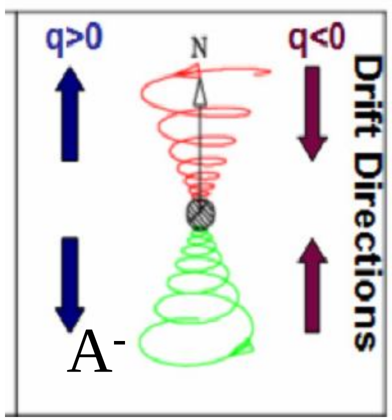
Accepted on Nature

Comparison with solar cycle – low energy

qA<0 measurements (now, 22 years ago)

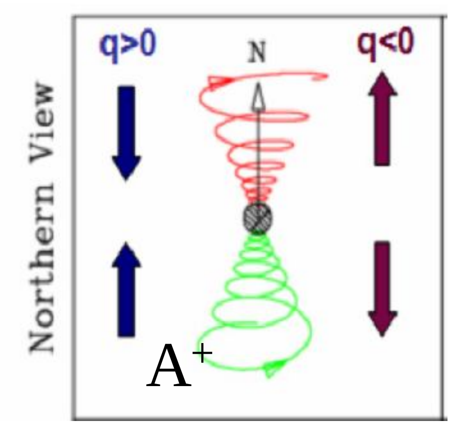
Solar modulation up to 10 GeV

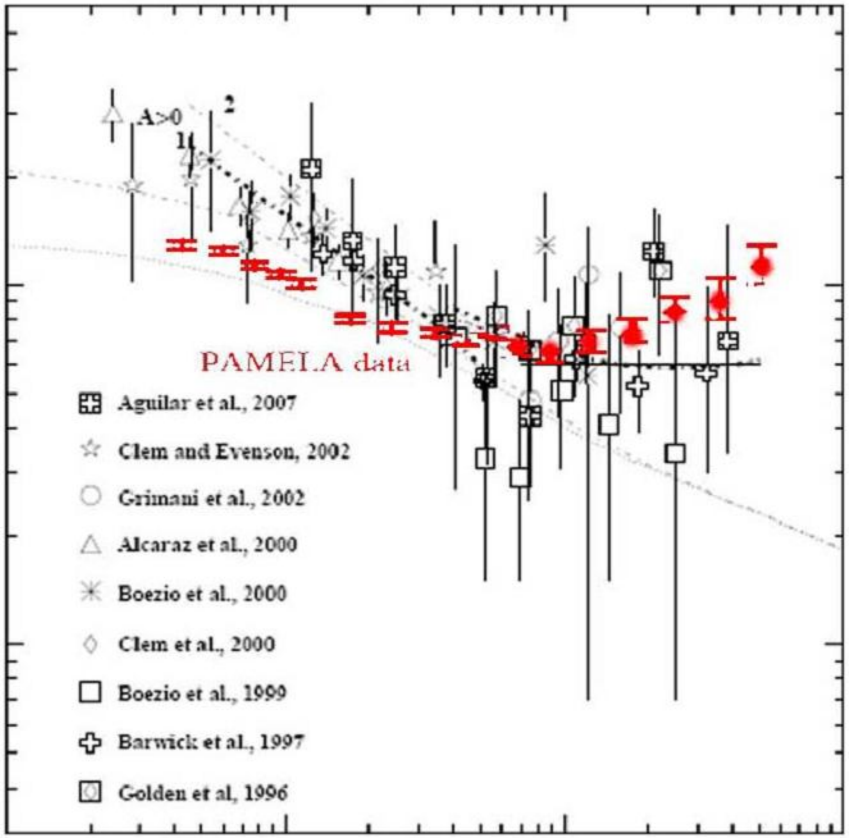




Comparison with solar cycle

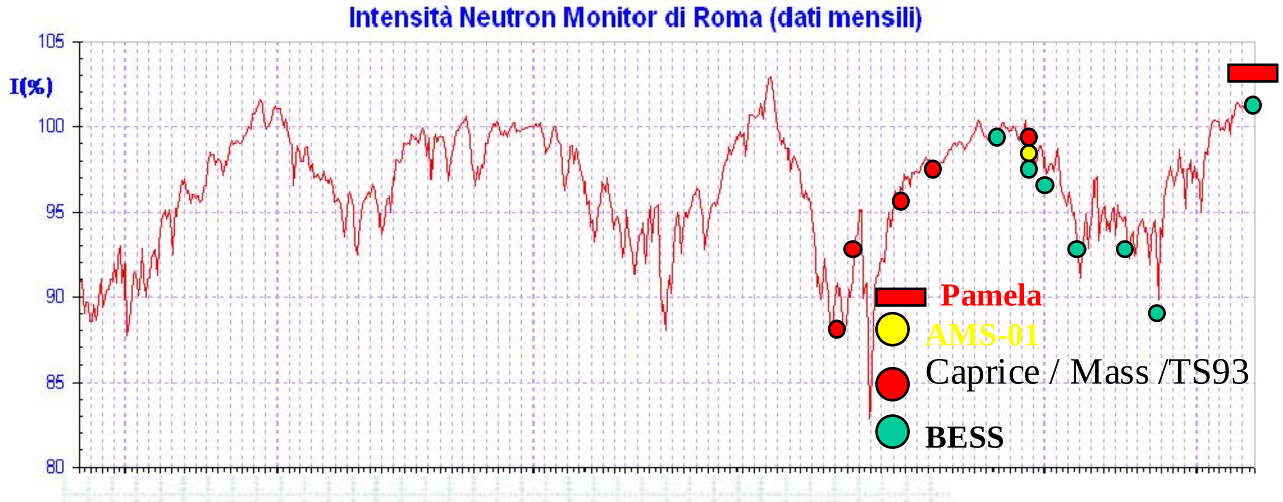
qA>0 measurements
(11 years ago)

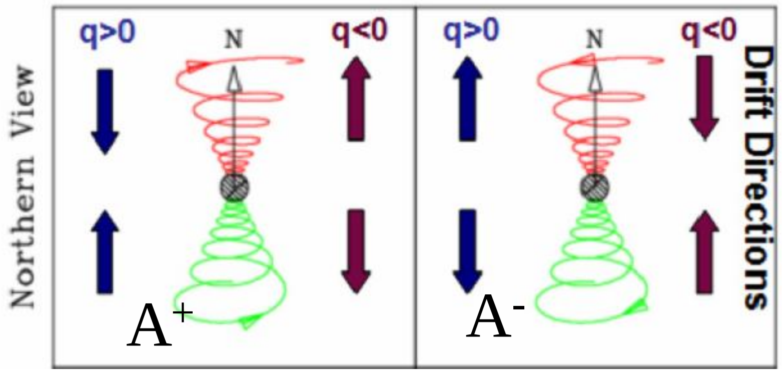


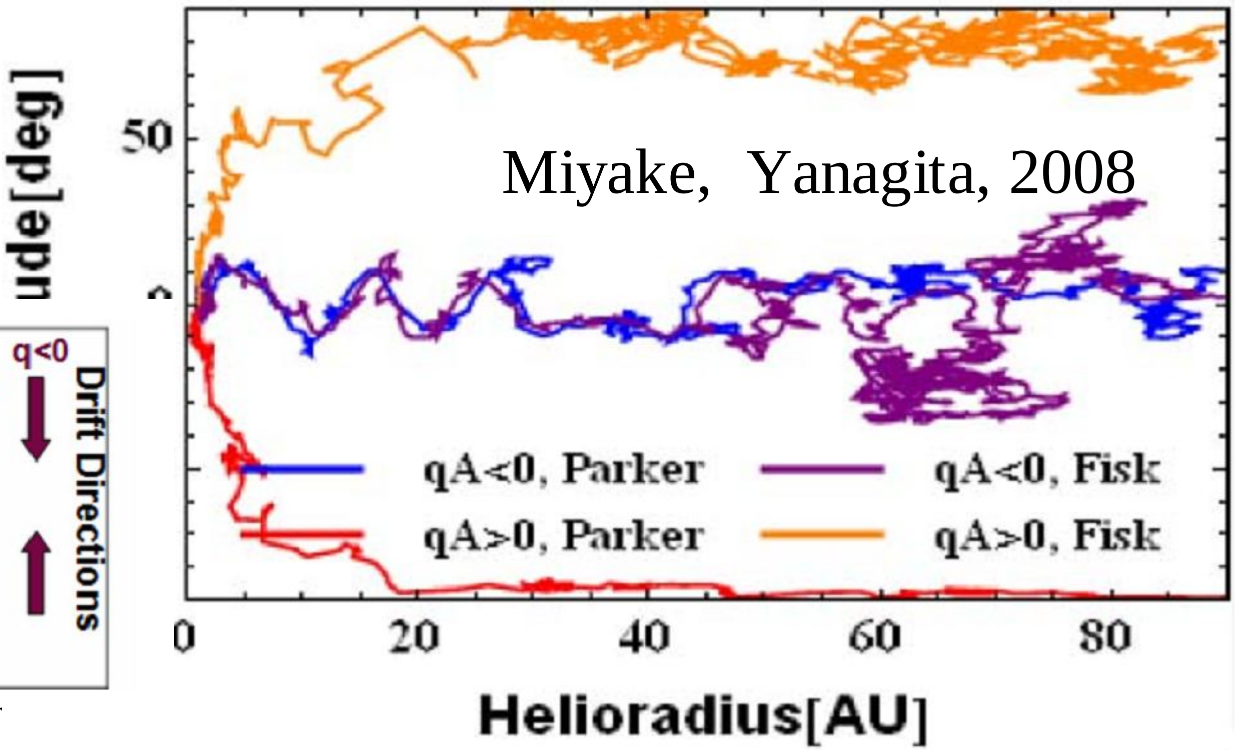


Low energy positrons

- •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

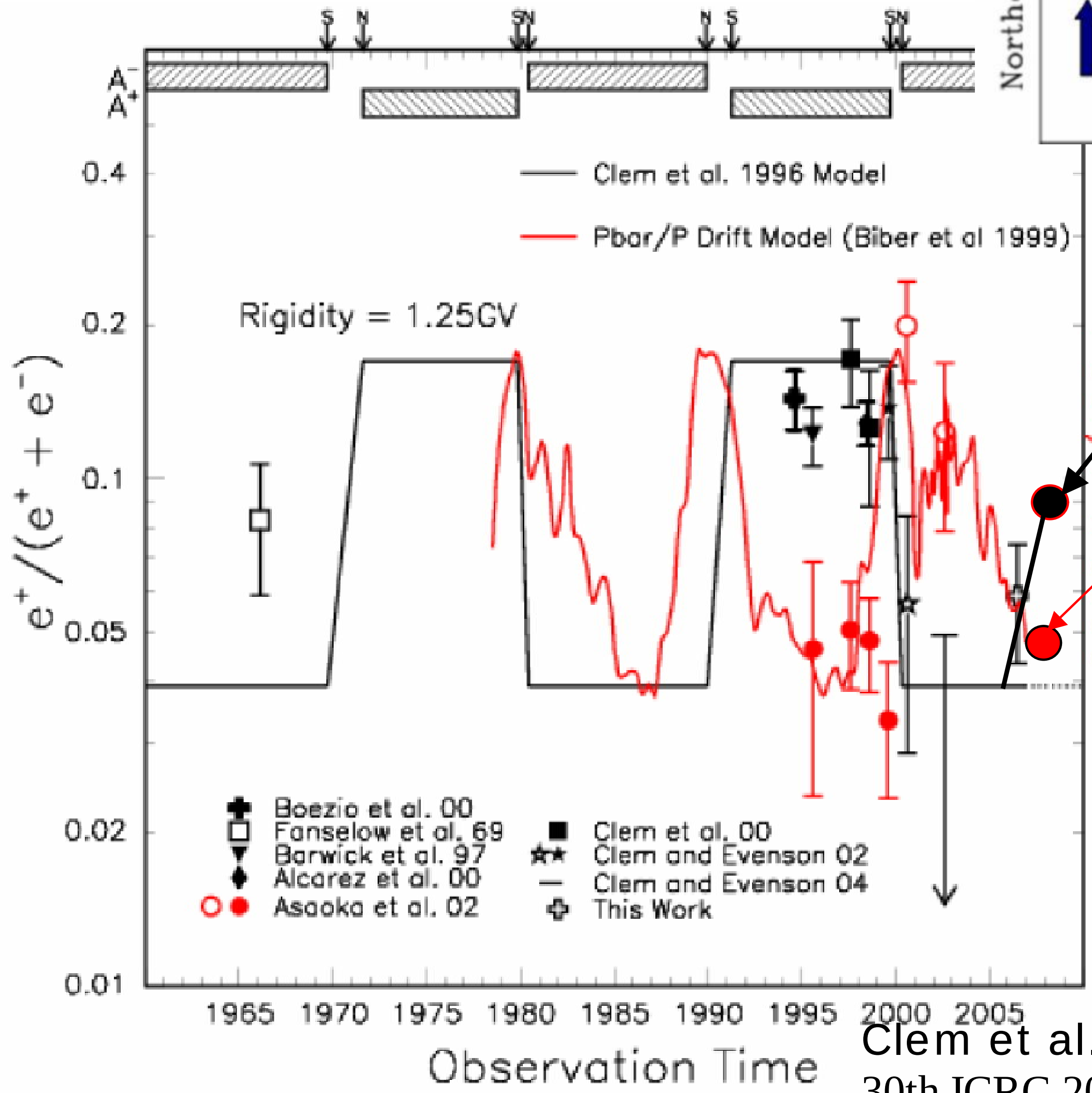


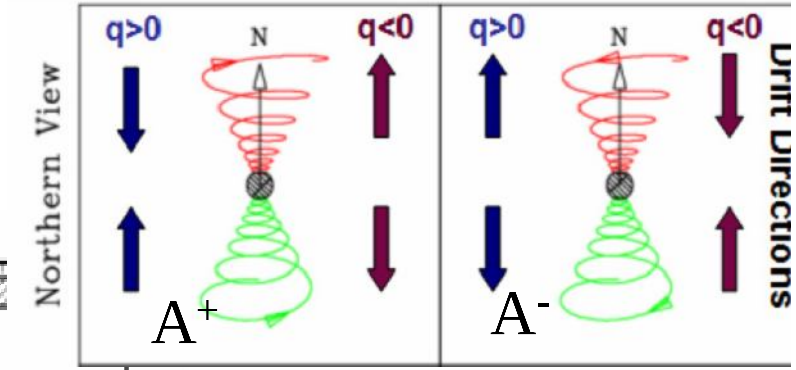




Miyake, Yanagita, 2008

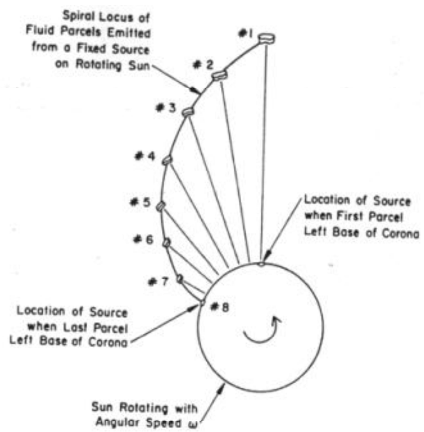
Charge dependent solar modulation





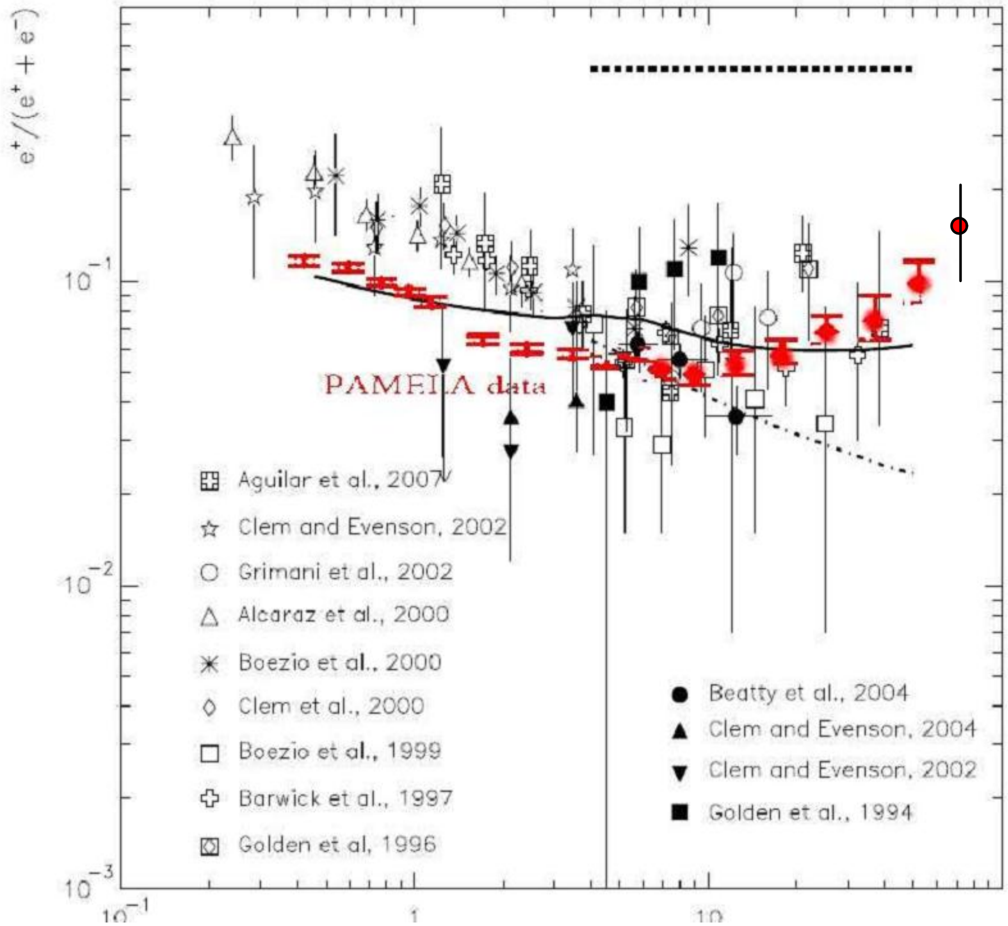
Pamela e+

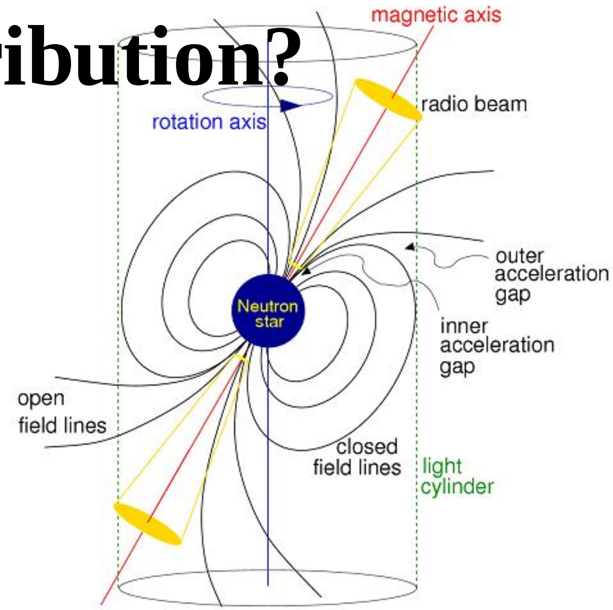
Pamela p-

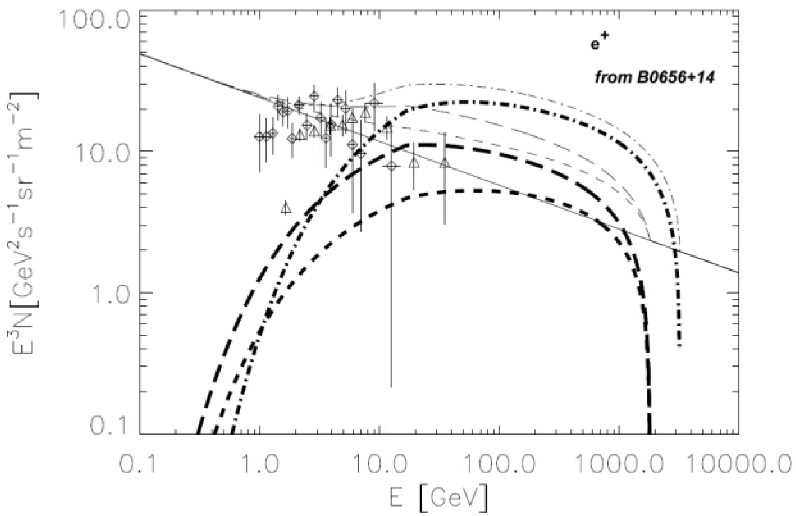


Clem et al.
30th ICRC 2007

High energy nearby Pulsar contribution?







C. Grimani A&A 474, 2, November I 2007, pp.339-343
Adv. Sp.Res. 39, Issue 2, 2007, p. 280-284.

Potgieter at al.
arXiv:0804.0220v1

Atic results on all electron flux at 300-500 GeV

- No separation between electrons and positrons

- Requires high boost factor

- Glast?

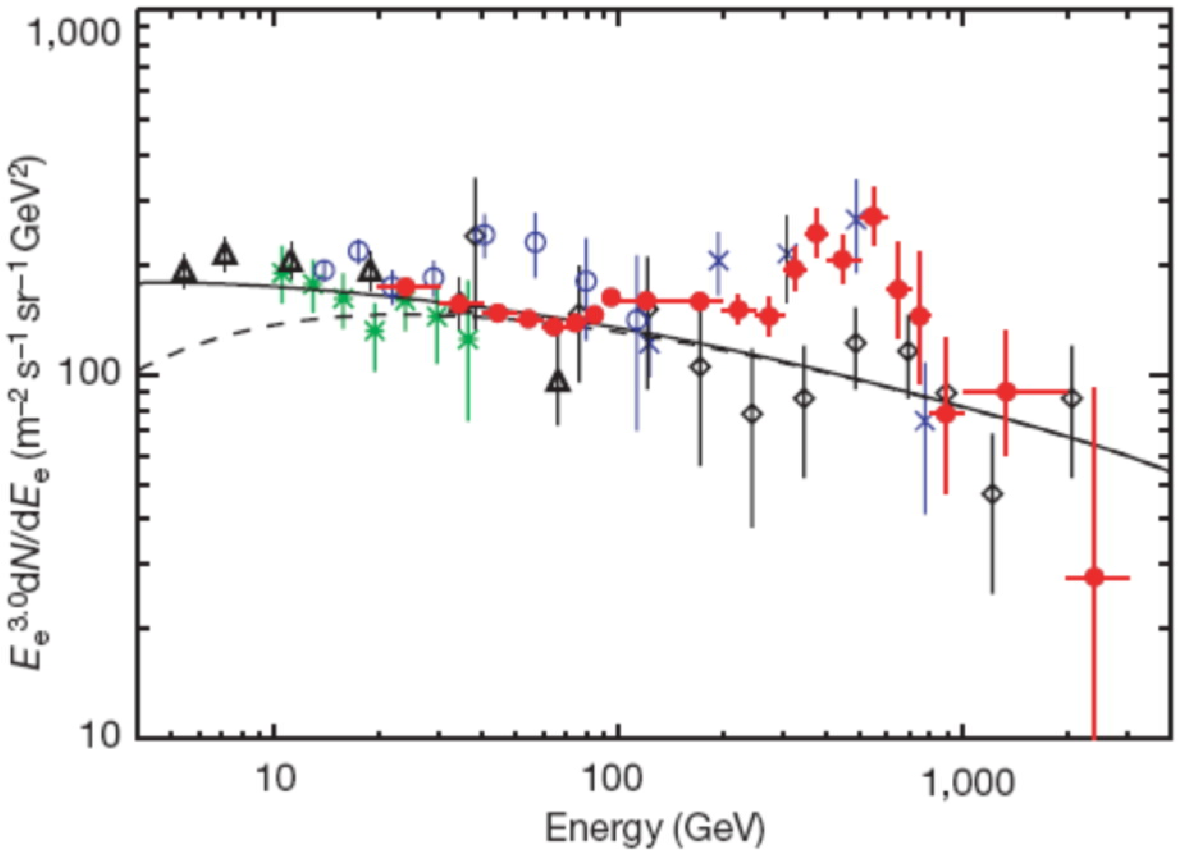


Figure 3 | ATIC results showing agreement with previous data at lower energy and with the imaging calorimeter PPB-BETS at higher energy. The electron differential energy spectrum measured by ATIC (scaled by E^3) at the top of the atmosphere (red filled circles) is compared with previous observations from the Alpha Magnetic Spectrometer AMS (green stars)[31], HEAT (open black triangles)[30], BETS (open blue circles)[32], PPB-BETS (blue crosses)[16] and emulsion chambers (black open diamonds)[4,8,9], with uncertainties of one standard deviation. The GALPROP code calculates a power law spectral index of −3.2 in the low energy region (solid curve)[14]

Nature, 456, 362

20 November 2008
doi:10.1038/nature07477


•Pamela is operating successfully in space
•Expected three years of operations – completed more than 1000 days
•Data received until now show good potential and fullfillment of scientific goals
http://pamela.roma2.infn.it
http://www.casolino.it