

**KEK Theory Center Cosmophysics Group Workshop  
on High Energy Astrophysics 2009  
HEAP09**

# **PAMELA experiment status and updates**

**M. Casolino**

***INFN & University of Roma Tor Vergata***

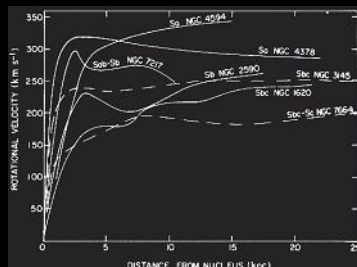
**on behalf of the PAMELA collaboration**



# Dark Matter Searches

## •Cosmology

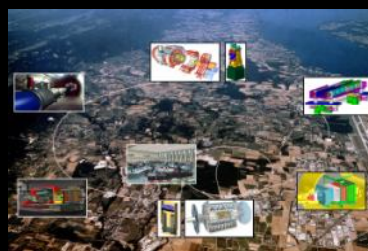
*Detection, not identification*



1E 0657-56 - Bullet Cluster

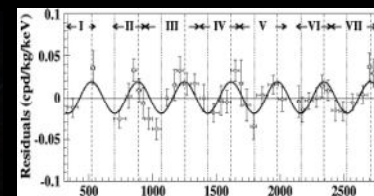
## •LHC Search

*Supersymmetry, not necessarily DM*



## •Direct Detection

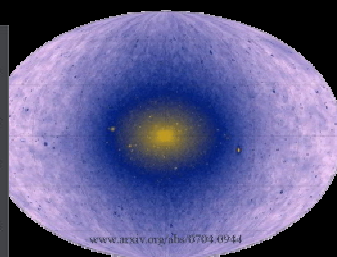
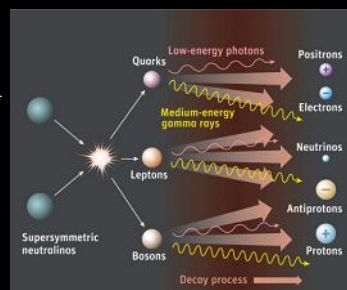
*Local structure and nature*



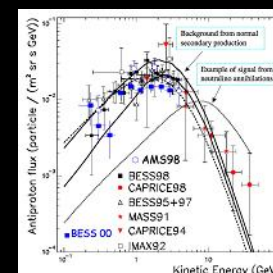
DAMA

## •Indirect Detection

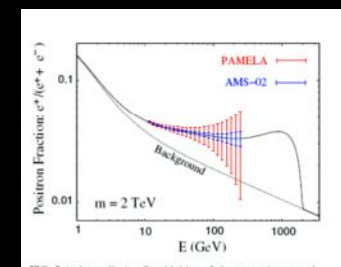
*Various galactic scales*



$\gamma$ : Galactic centre



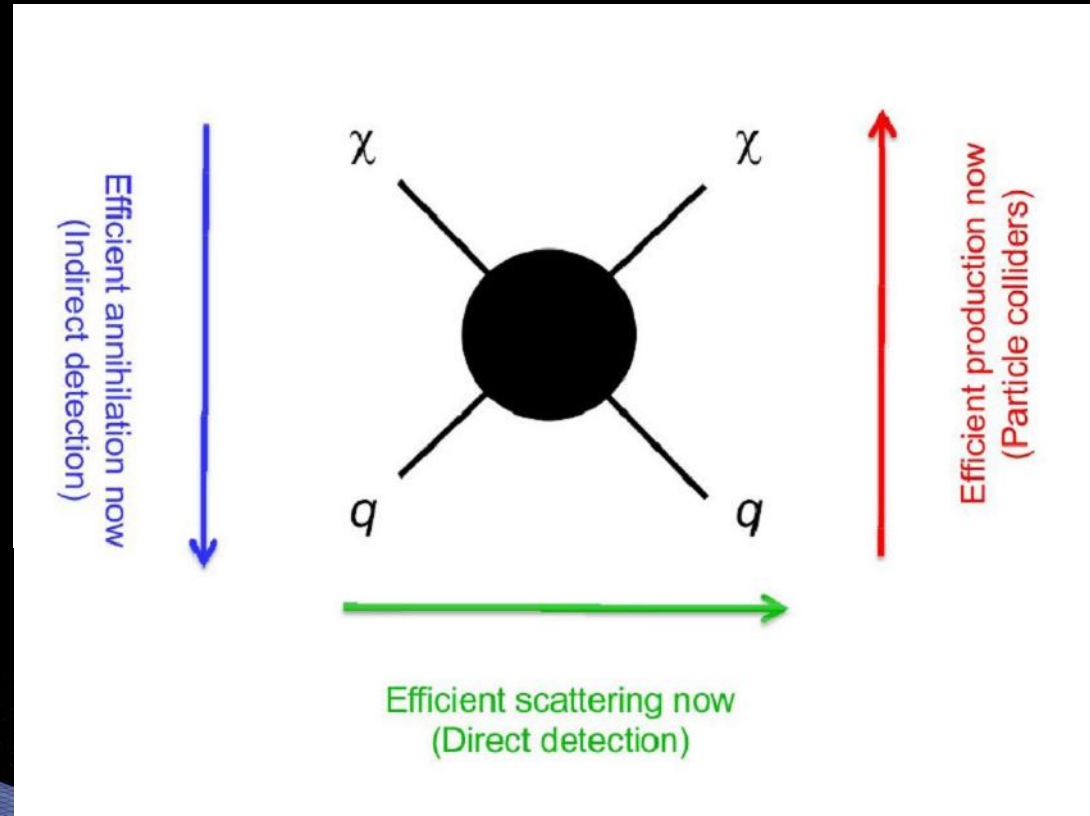
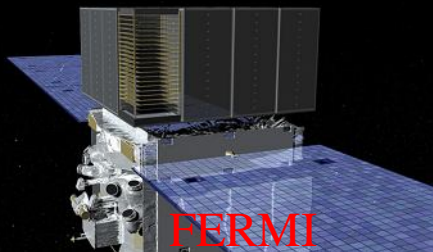
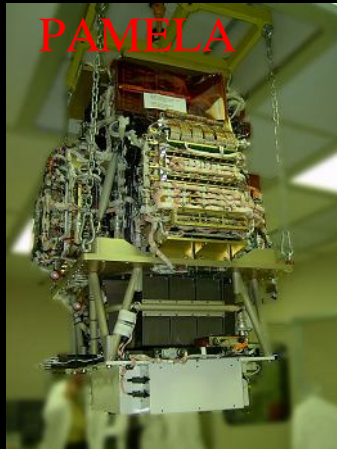
**Antiprotons:**  
*Galactic average*



**positrons:**  
*Local galactic 1kpc*



# 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”

Russian: Андрей Дмитриевич Сахаров) (May 21, 1921 – December 14, 1989)

# Matter – Antimatter domain separation?

- $\gamma$ -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?

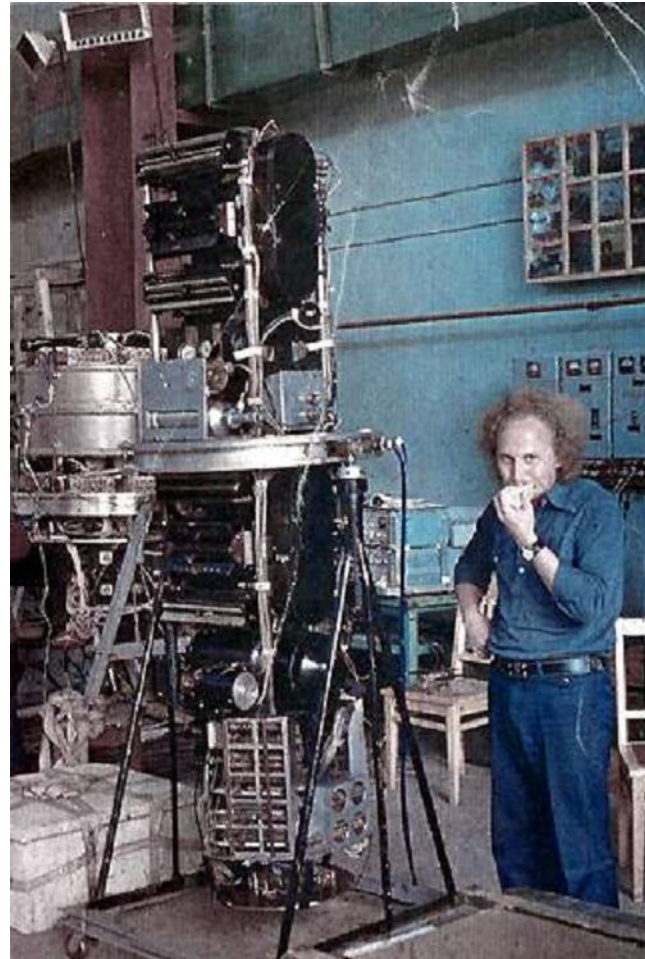
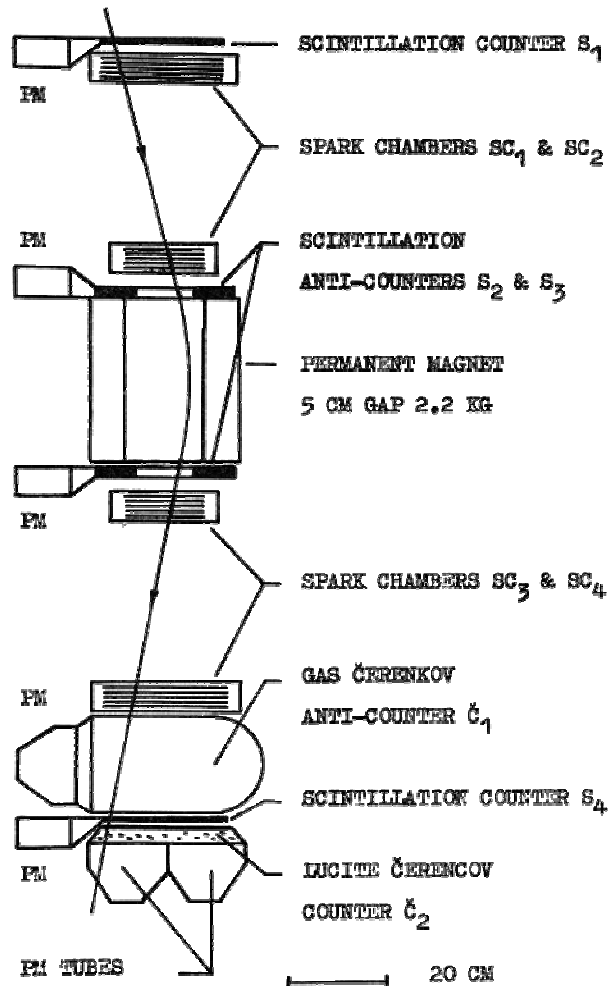
Ahlen, S.P. et al. 1982, ApJ, 260, 20,  
“Can we detect antimatter from other galaxies?”



M33



# Discovery of antiprotons in cr, 1979



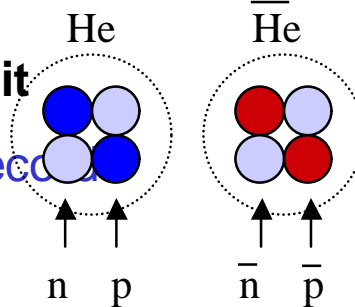
—  
p/p ratio  
 $6 \times 10^{-4}$   
2-5 GeV

From  
Robert E. Streitmatter

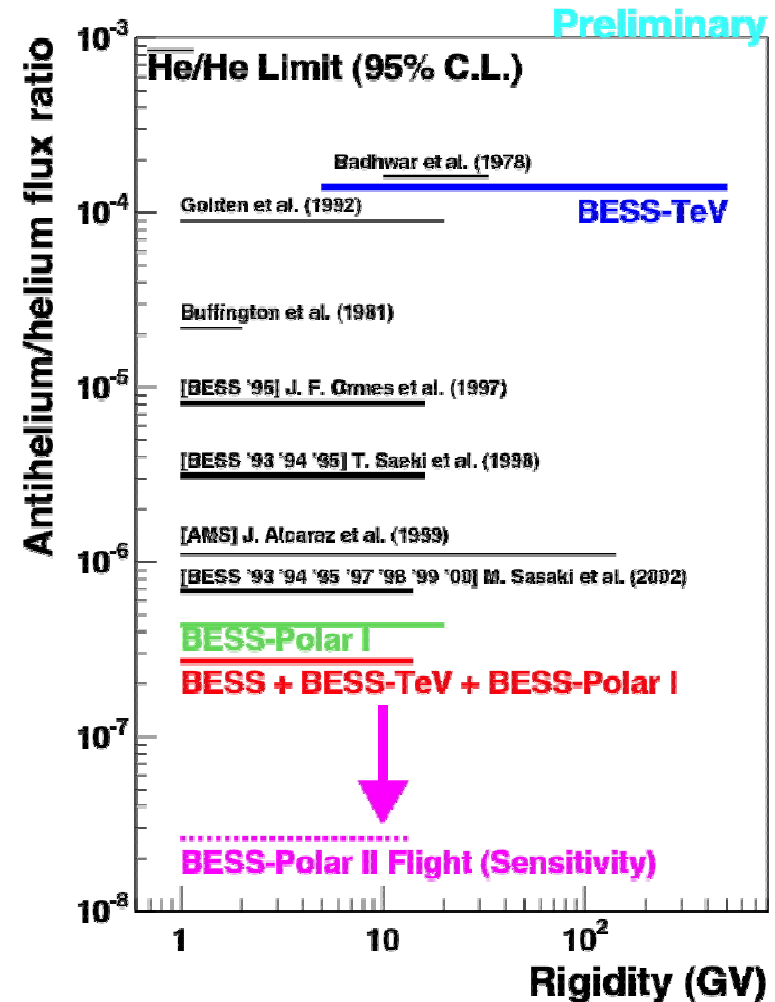
Bogomolov, E.A. et al. 1979, Proc. 16th ICRC, Kyoto, 1, 330,  
“A Stratospheric Magnetic Spectrometer Investigation of the Singly Charged Component  
Spectra and Composition of the Primary and Secondary Cosmic Radiation”

# 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**



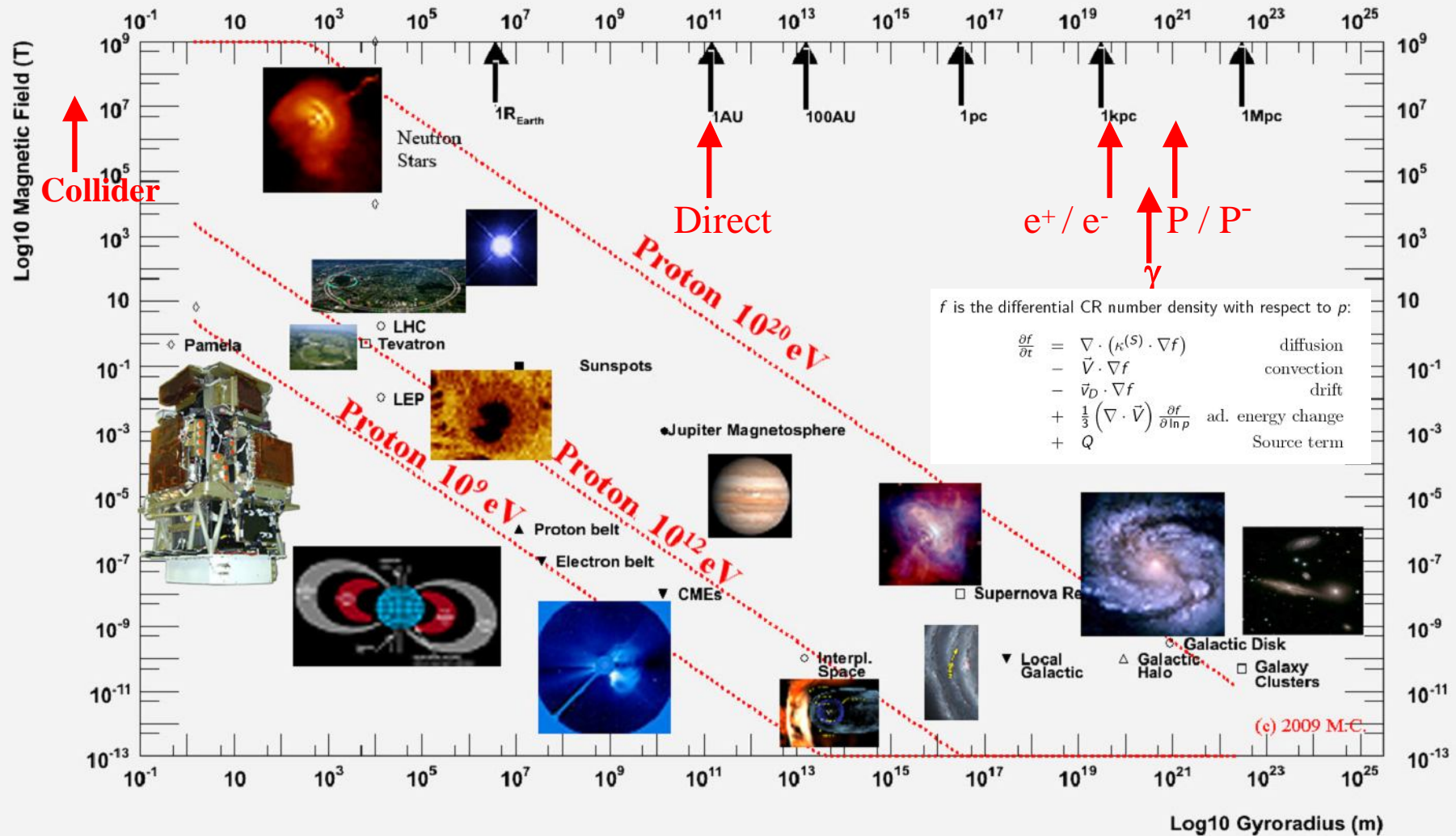
M. Casolino, INFN & University Roma Tor Vergata



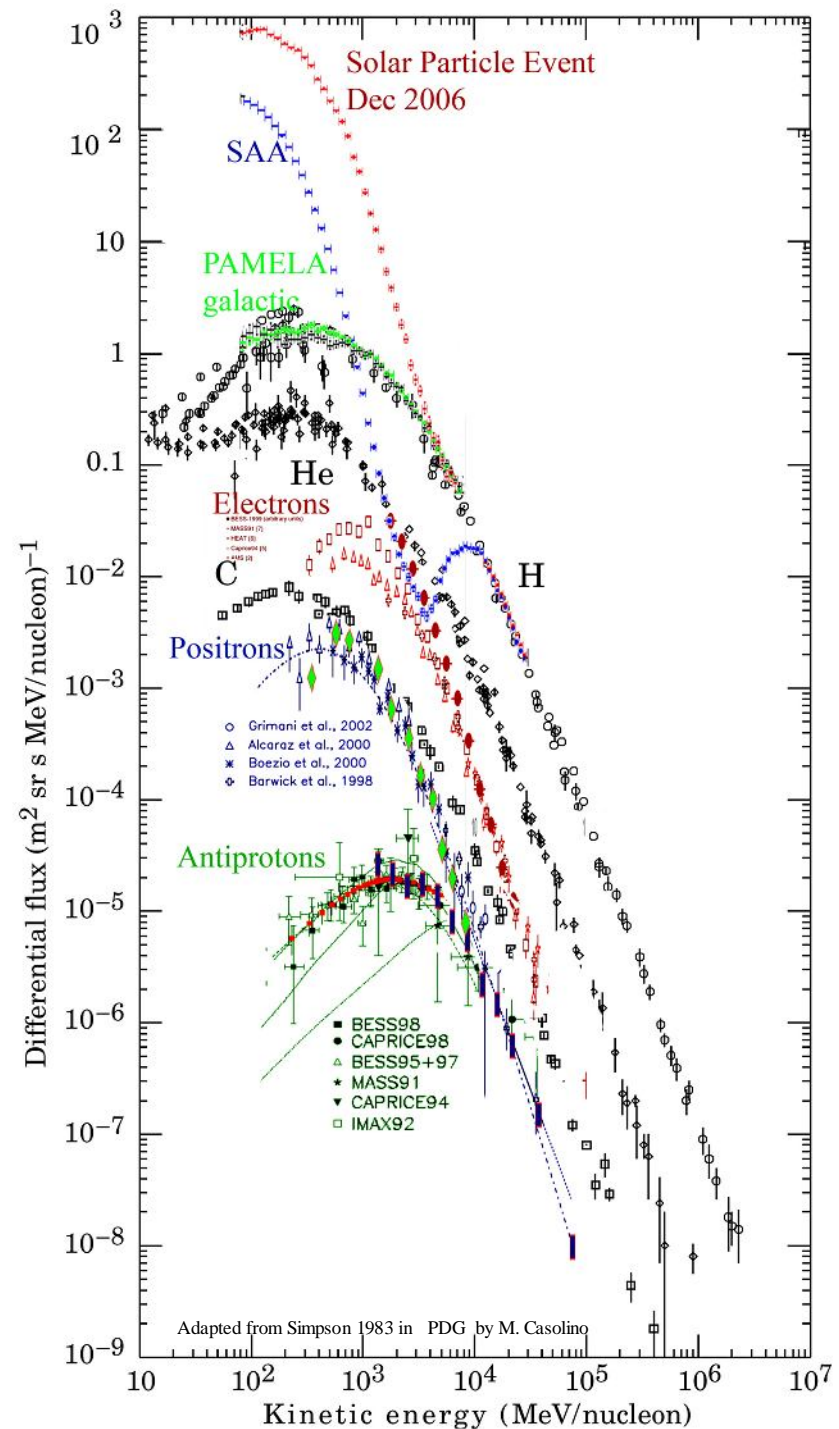
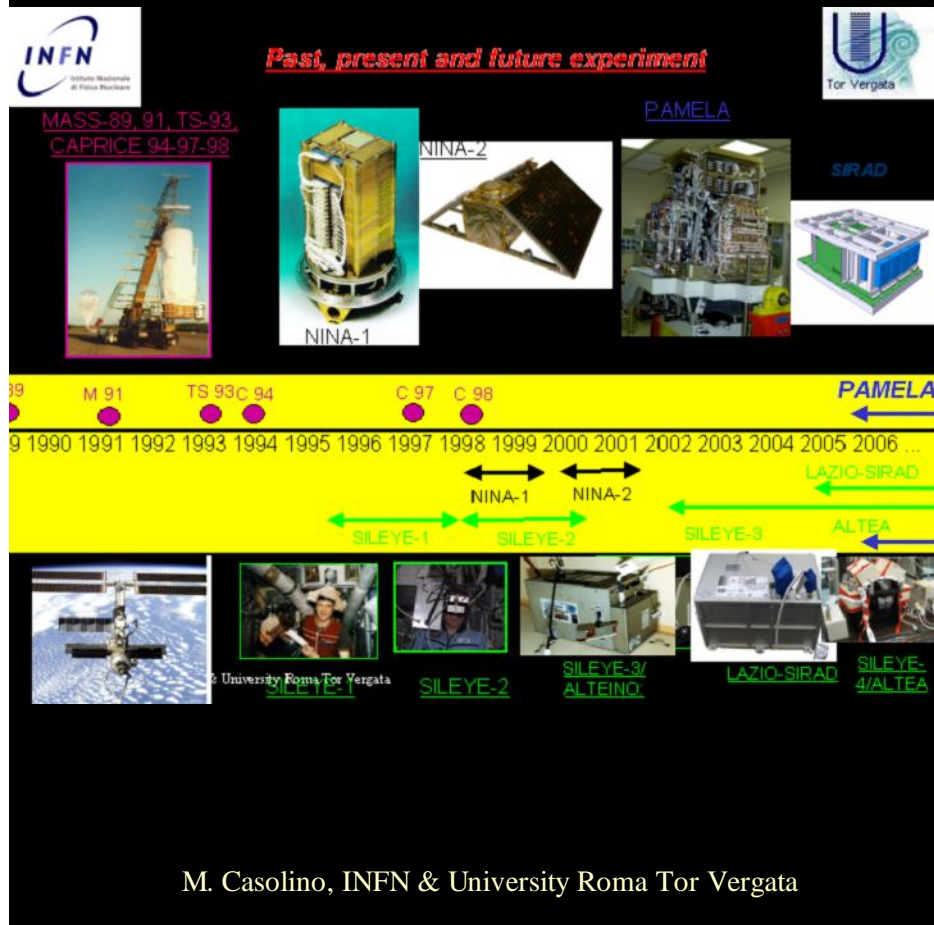
Ref.: M. Sasaki et al. at COSPAR-2006



# Pamela Physics objectives in the Hillas Plot



# High precision charged cosmic ray measurement in Low Earth Orbit





RESURS DK1 SATELLITE

**Time  
of Flight**

(three scintillators,  
6 planes, 48 phototubes)

**Magnetic (0.46T)  
Spectrometer  
Microstrip  
detector**

(6 double sided  
microstrip planes)

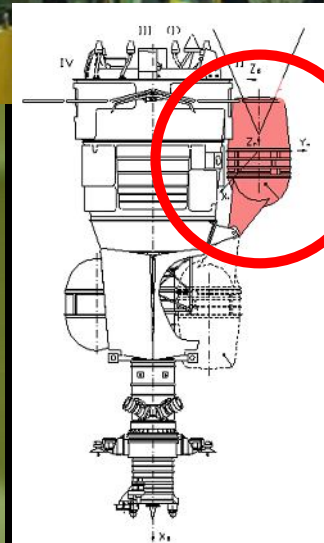
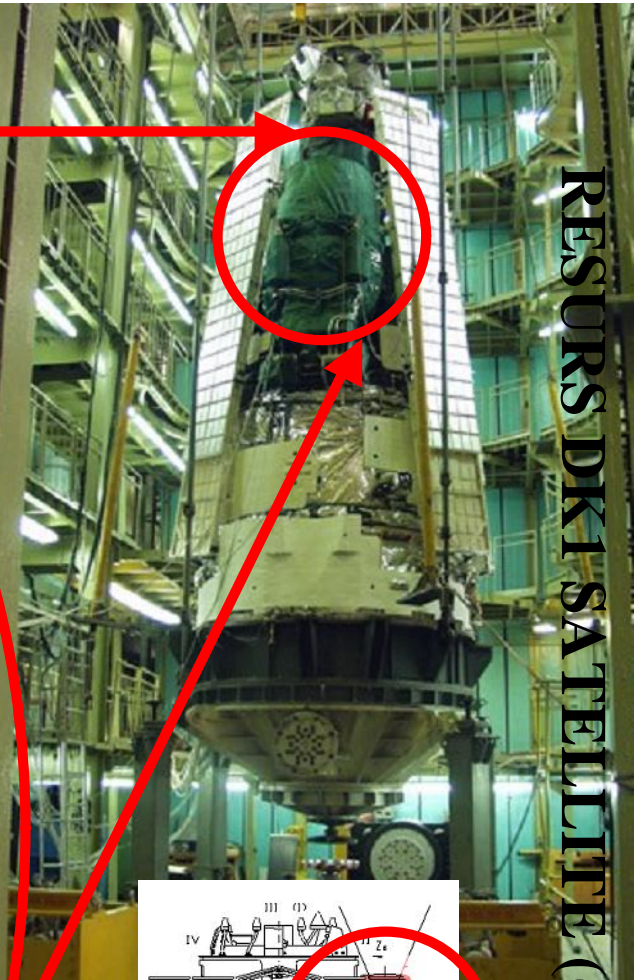
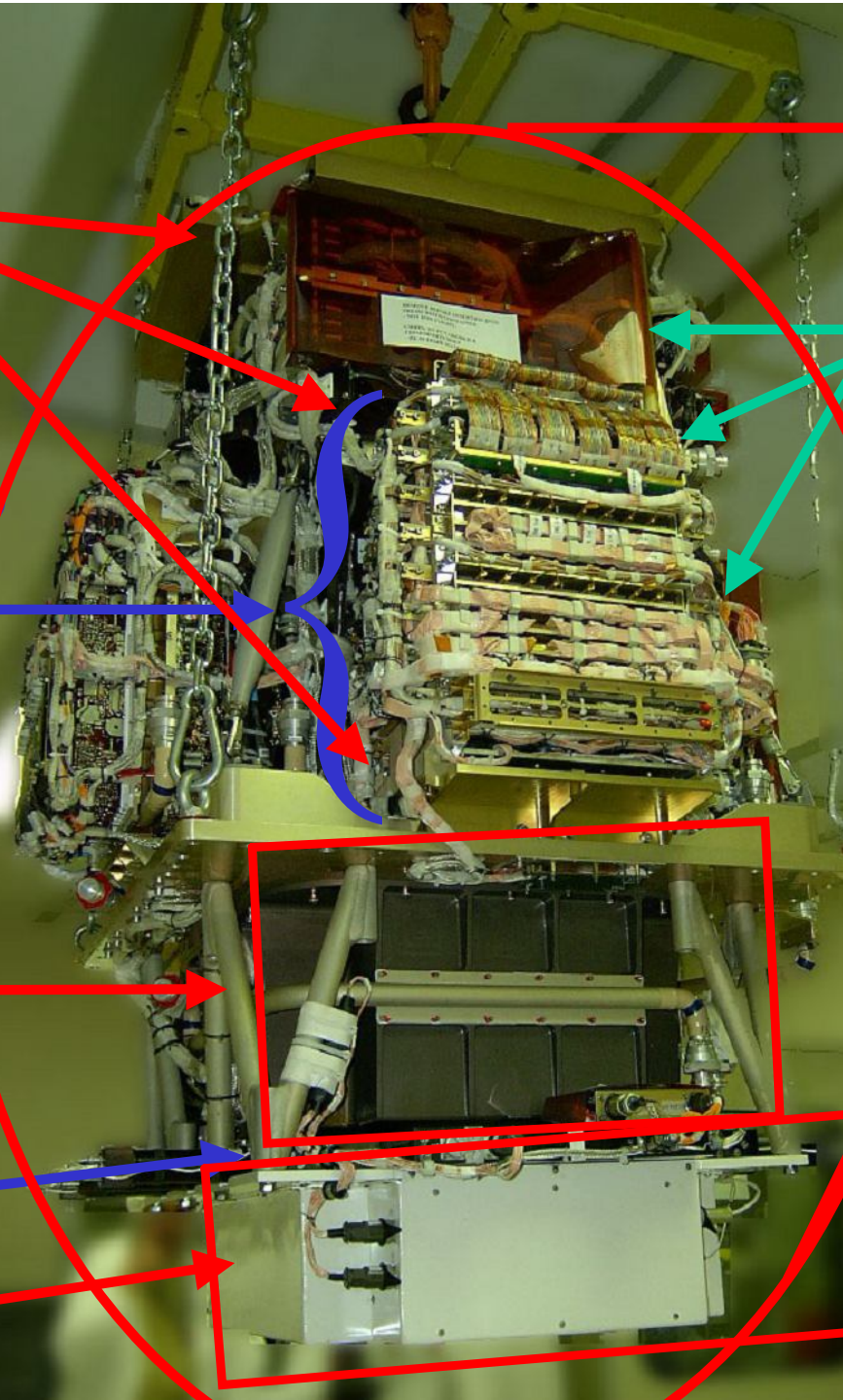
**Silicon  
Tungsten  
Tracking  
Calorimeter**

(44 planes of 96 strip)

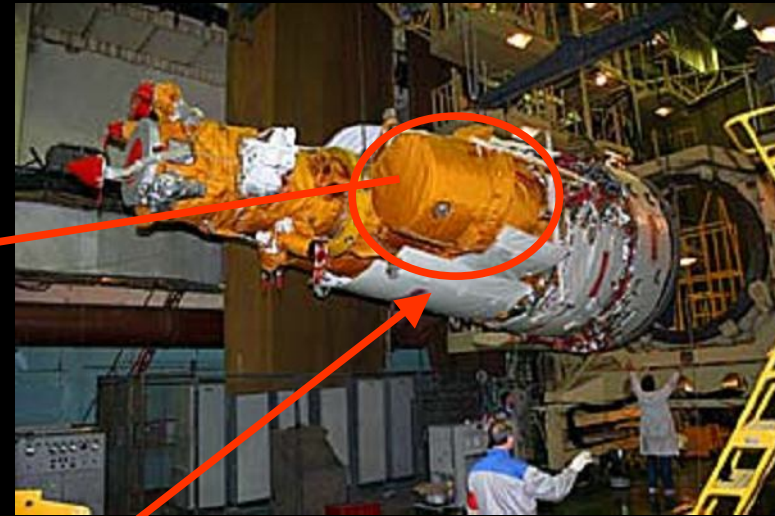
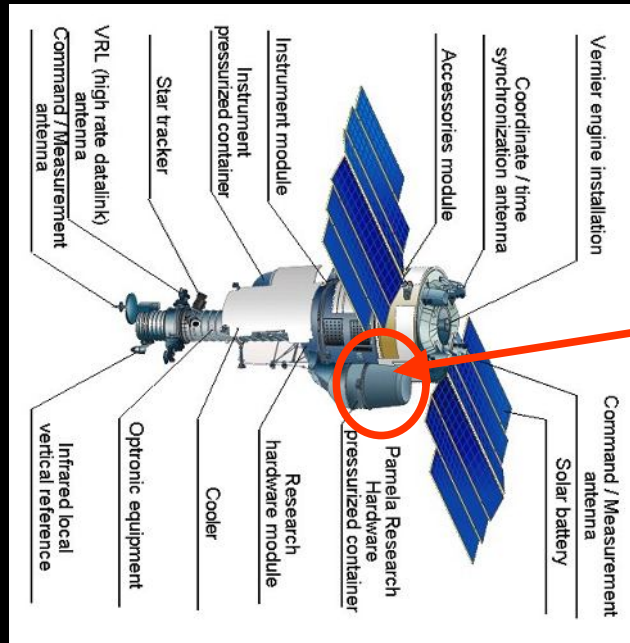
**Shower  
Catcher  
Scintillator**

**Neutron  
Detector**

M. Casoli





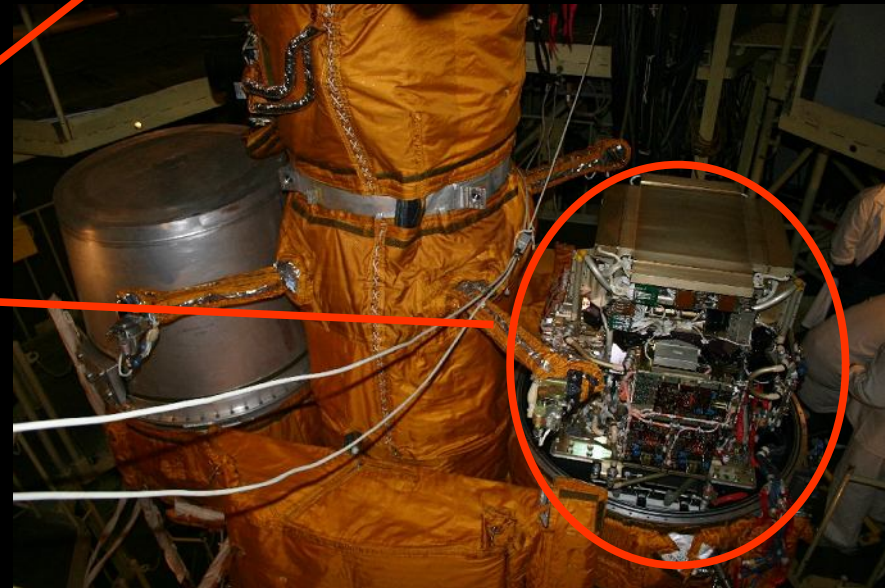


**Coupling to Soyuz**



M. Cao

**Resurs DK integrated**



*Pamela during integration in Baikonur*



# Baikonur Cosmodrome

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

85 km NS  
125 km EW

Baikonur Cosmodrome, Kazakhstan  
aka Tyuratam - 5-GIK MO - 5-NIIP  
Mercator Projection  
© 2000 Mark Wade

Legend:  
— Railroad  
— Road  
— Power Lines

## Manned and unmanned launches to International Space Station

**125 km EW**



# Leninsk / Baikonur





# Integration in Baikonur cosmodrome, Spring 2006





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









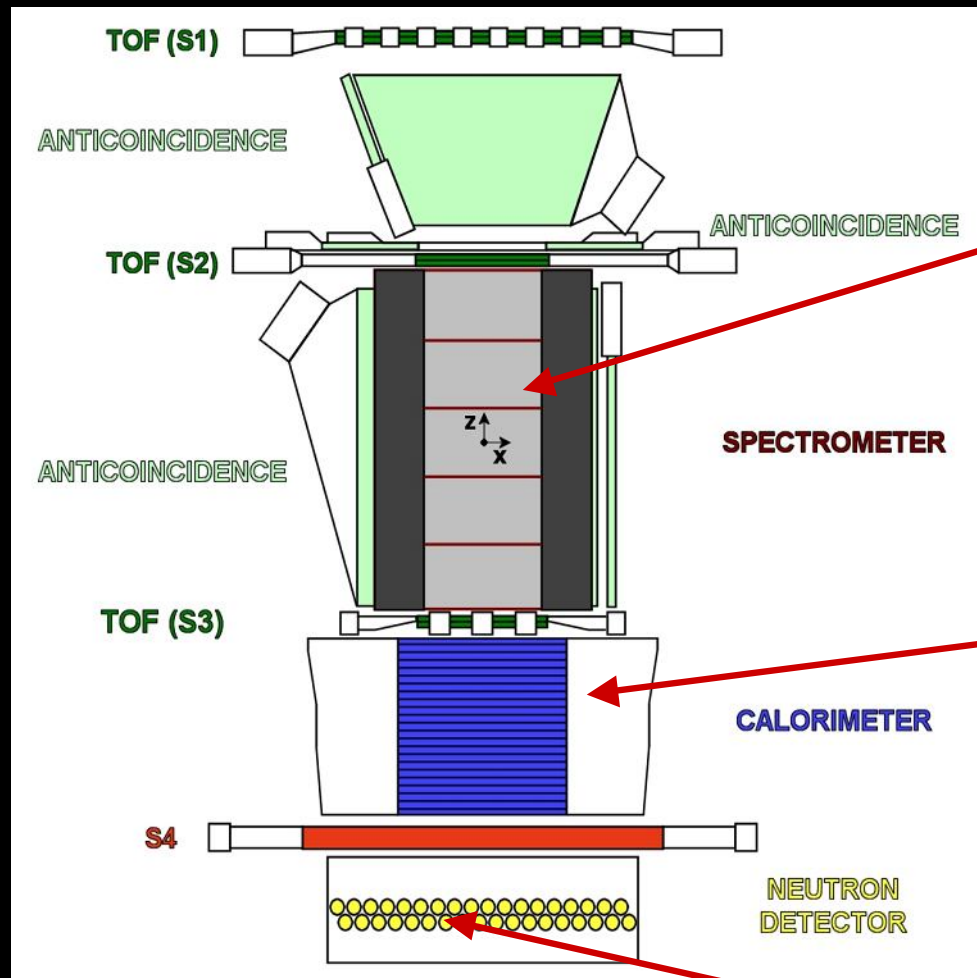
# Gagarinsky Start





Launch on June 15<sup>th</sup> 2006 Soyuz-U rocket





### Spatial Resolution

- $\cong 2.8 \mu\text{m}$  bending view
- $\cong 13.1 \mu\text{m}$  non-bending view

MDR from test beam data  $\cong 1 \text{ TV}$

### Calorimeter Performances:

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

ND  $p/e$  separation capabilities  $> 10$   
above  $10 \text{ GeV}/c$ , increasing with energy

GF  $\sim 20.5 \text{ cm}^2\text{sr}$

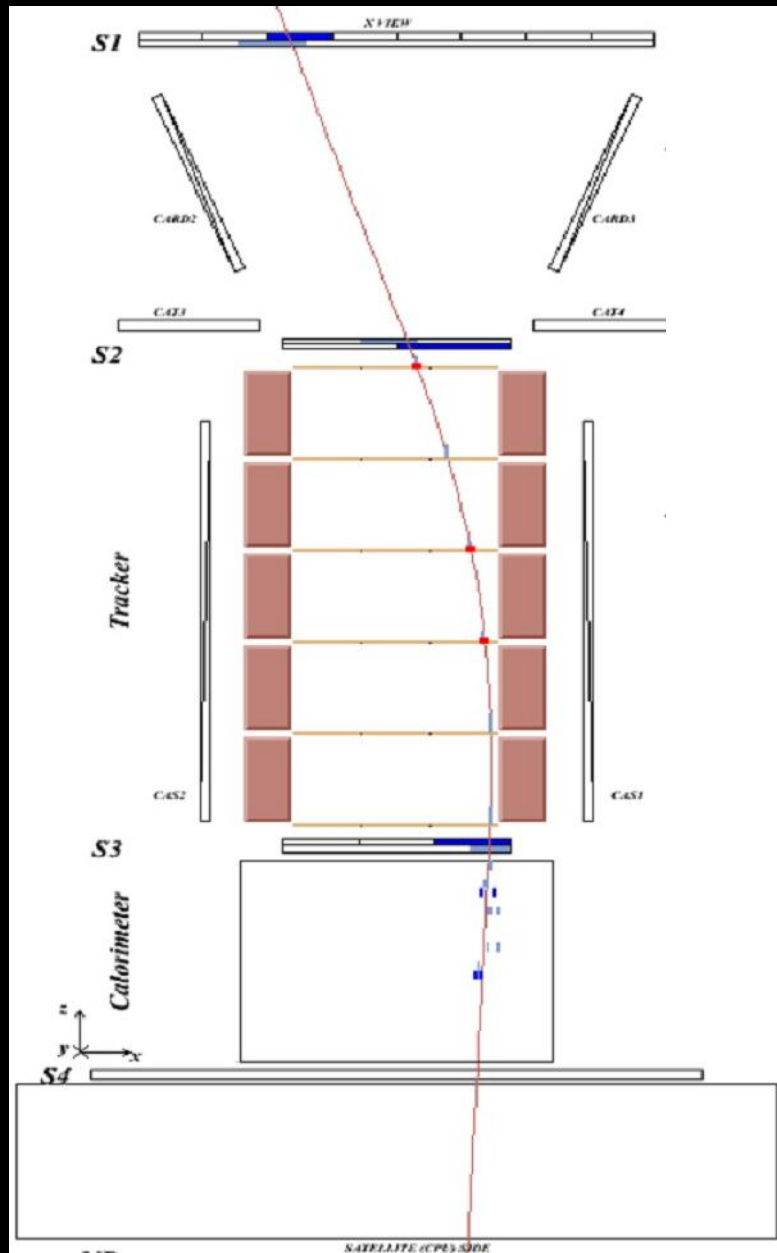
Mass:  $470 \text{ kg}$

Size:  $120 \times 40 \times 45 \text{ cm}^3$

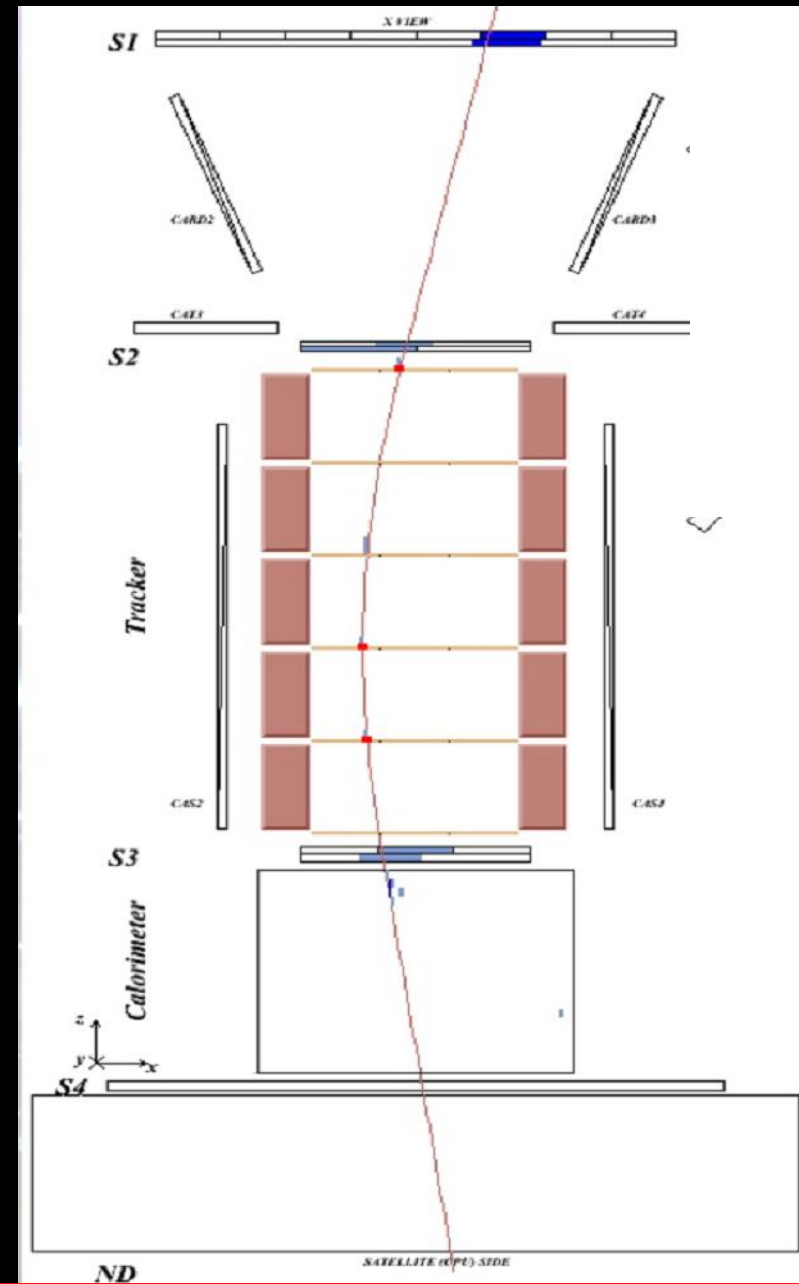
Power Budget:  $360 \text{ W}$

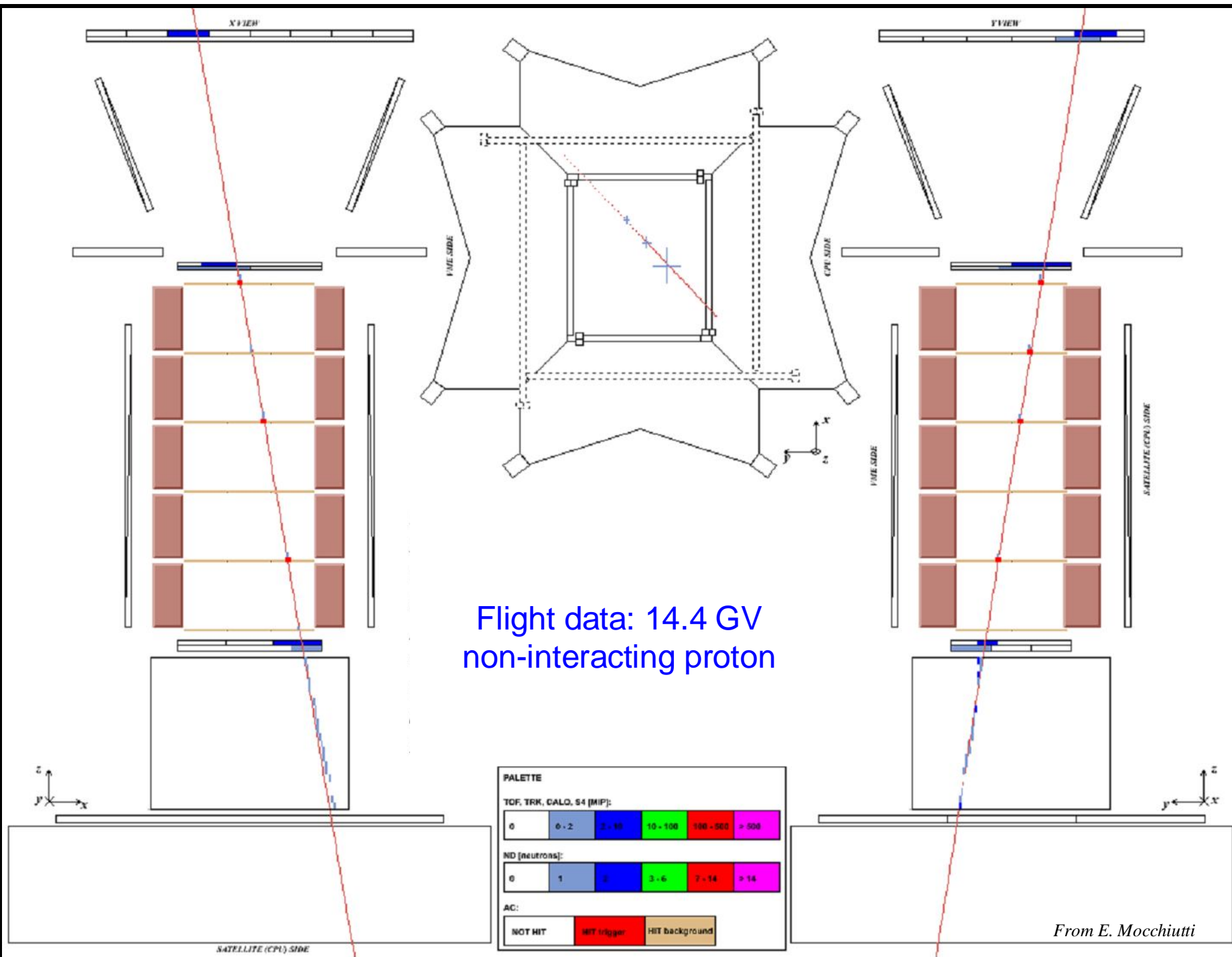


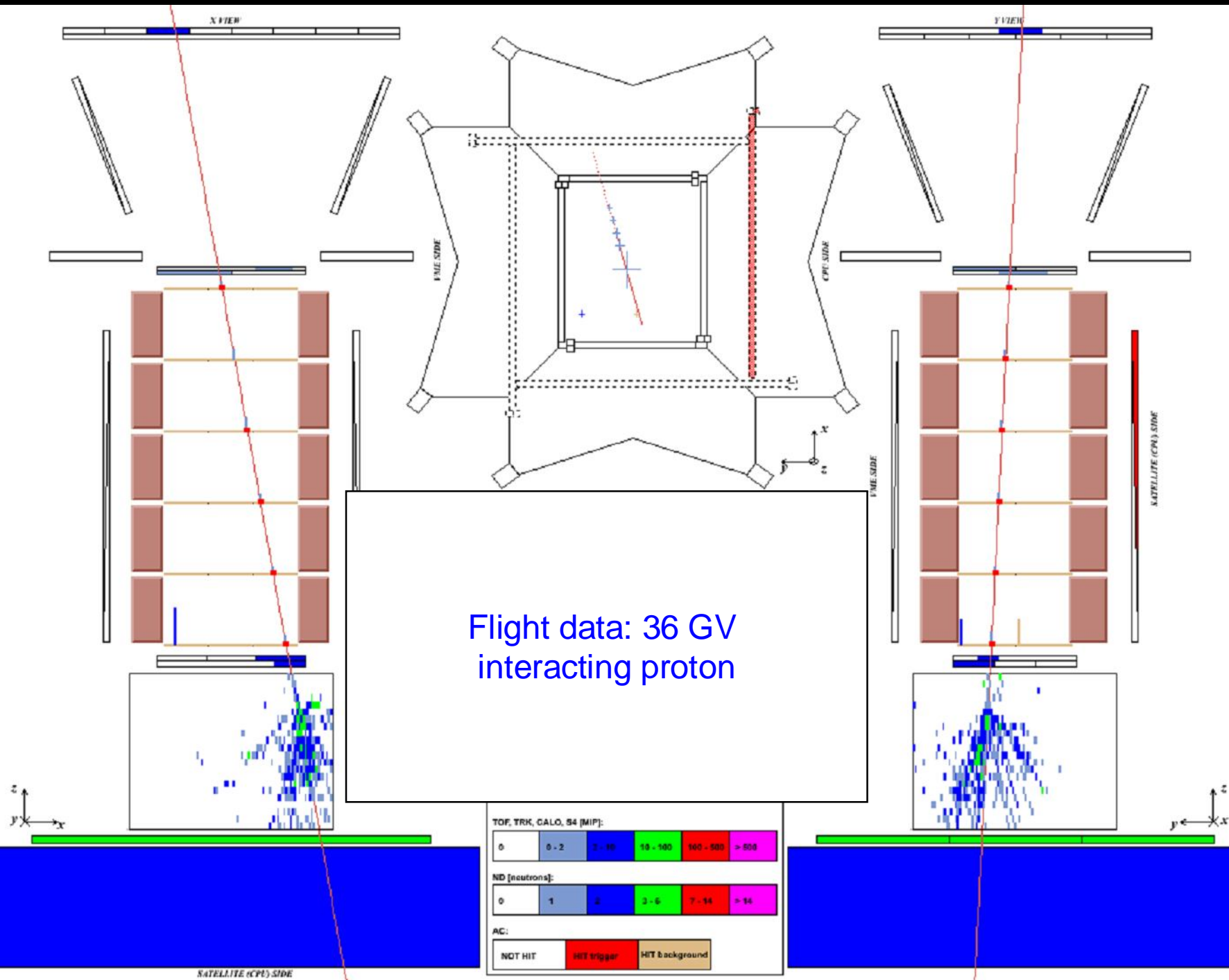
$e^+ 0.171$  GV Bending view

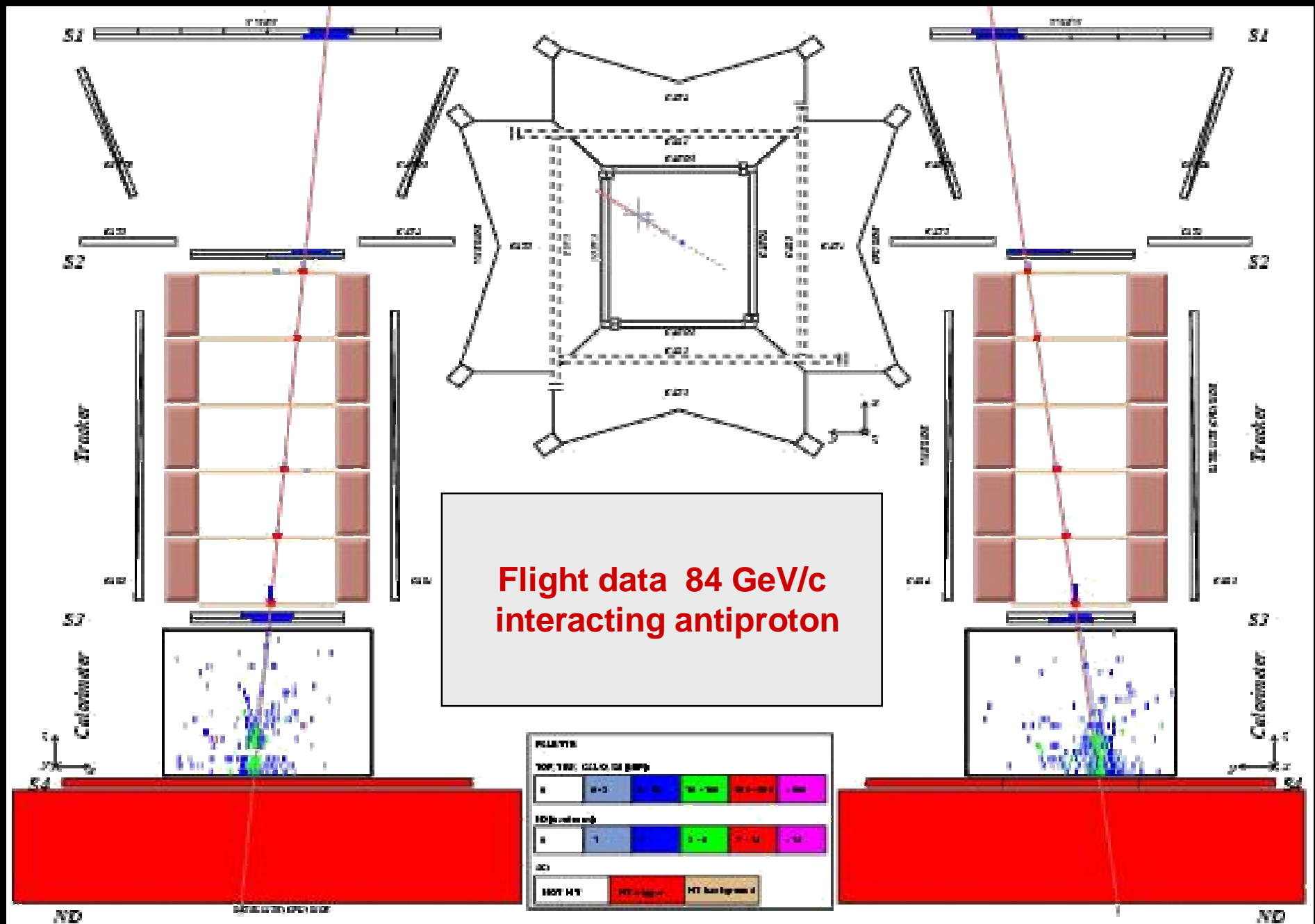


$e^- 0.169$  GV Bending view

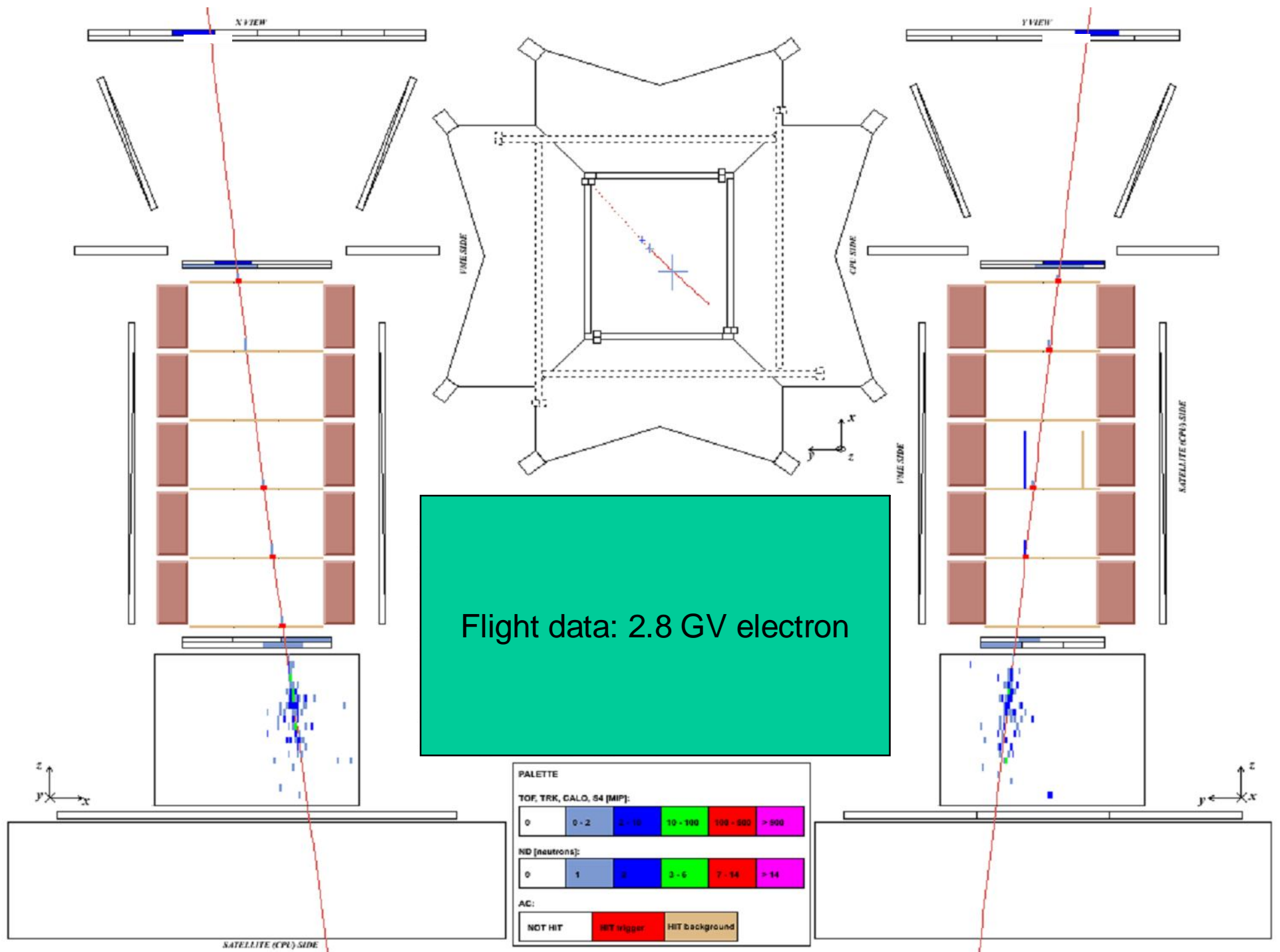


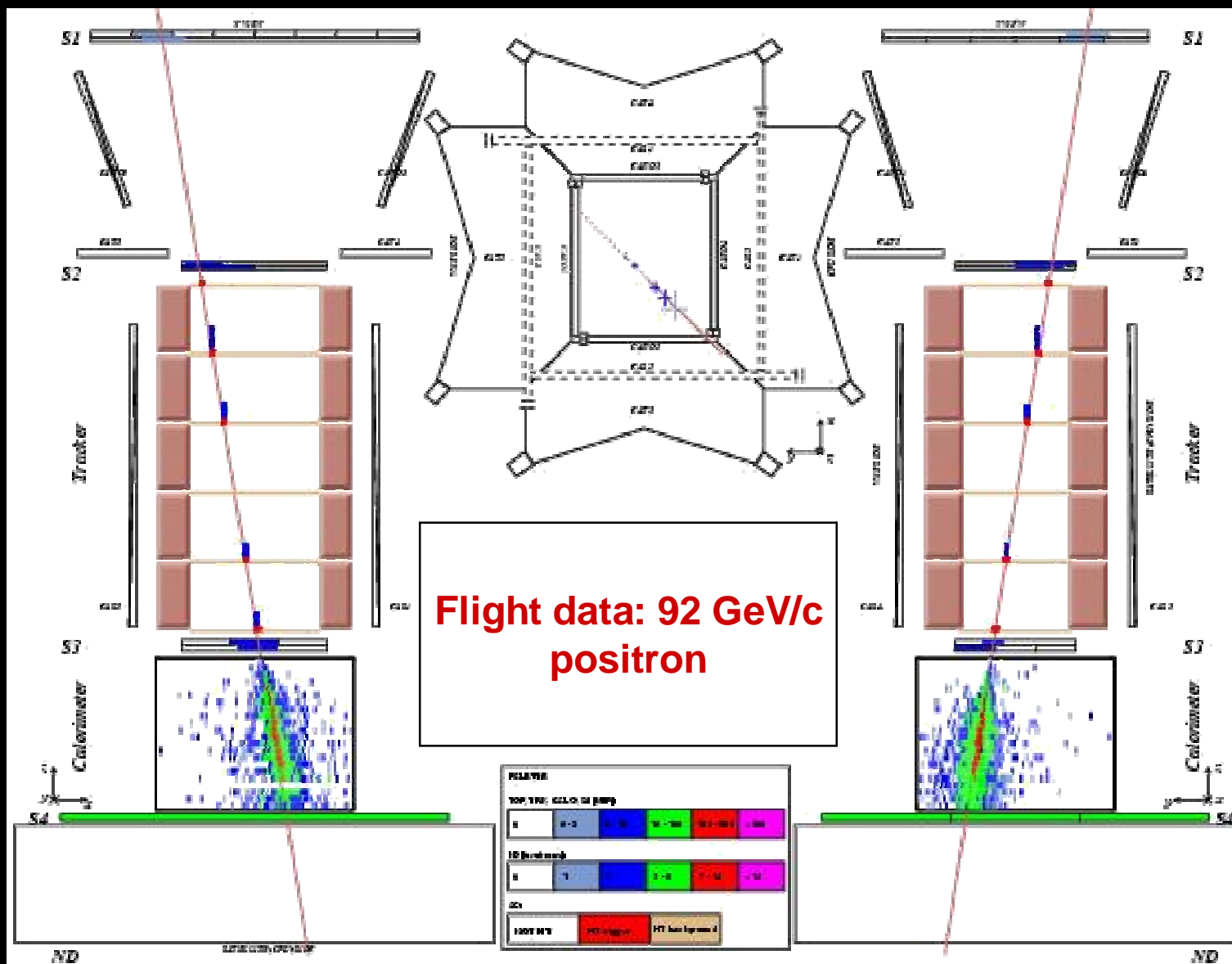






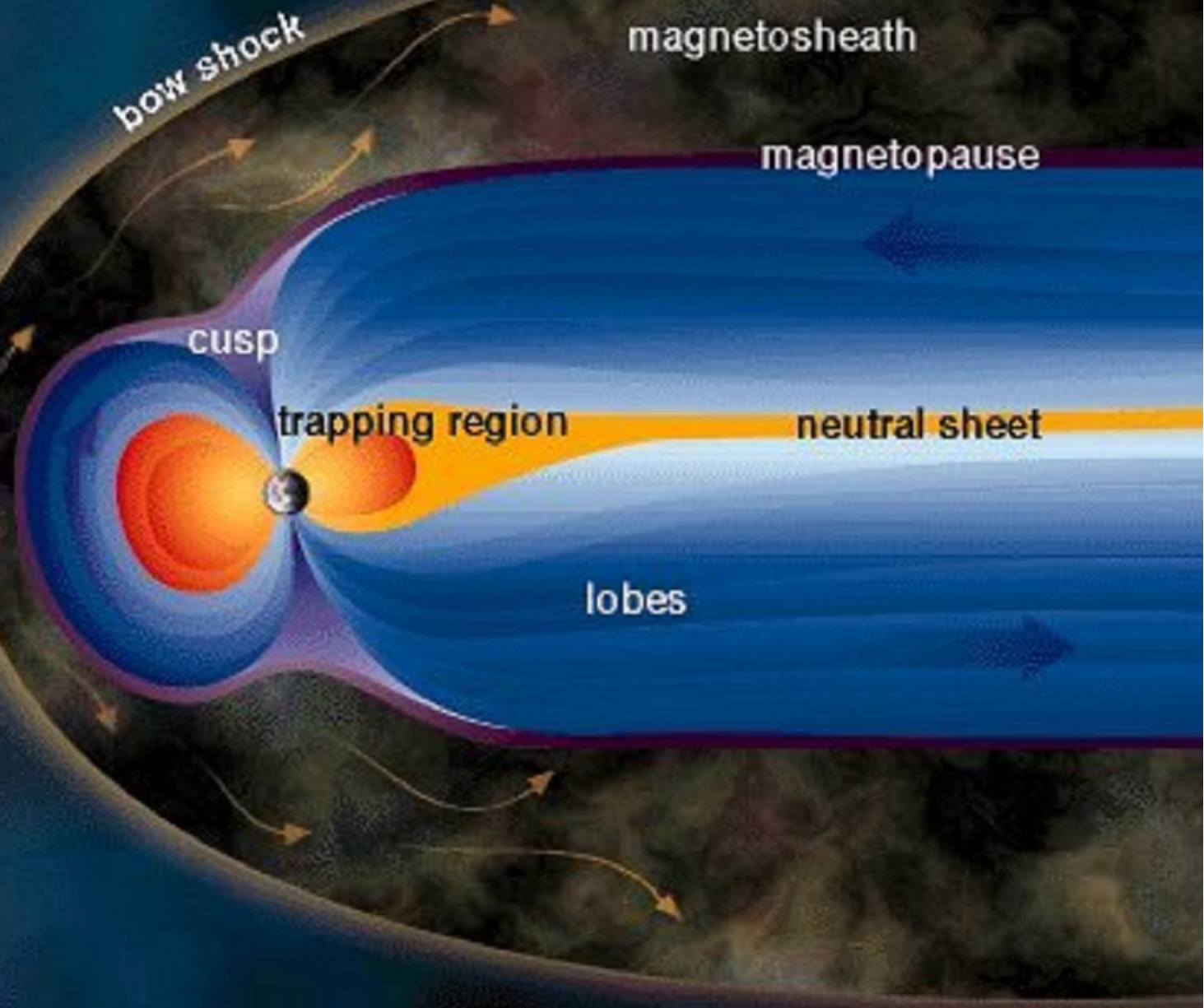






# Earth's magnetosphere

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





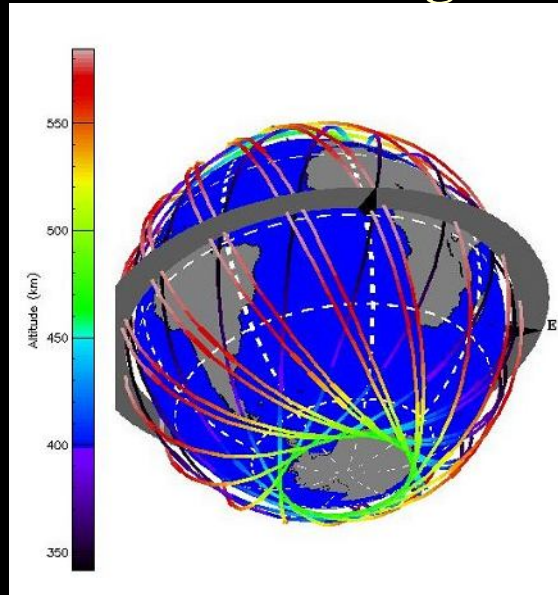


# *Pamela Measurement of the radiation belts*

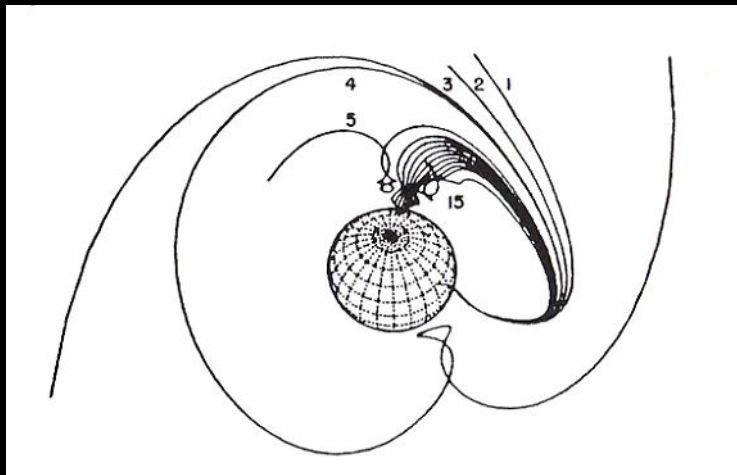
<http://www.youtube.com/watch?v=OaoiPw5Pqbg>

*2008 M. Casolino*

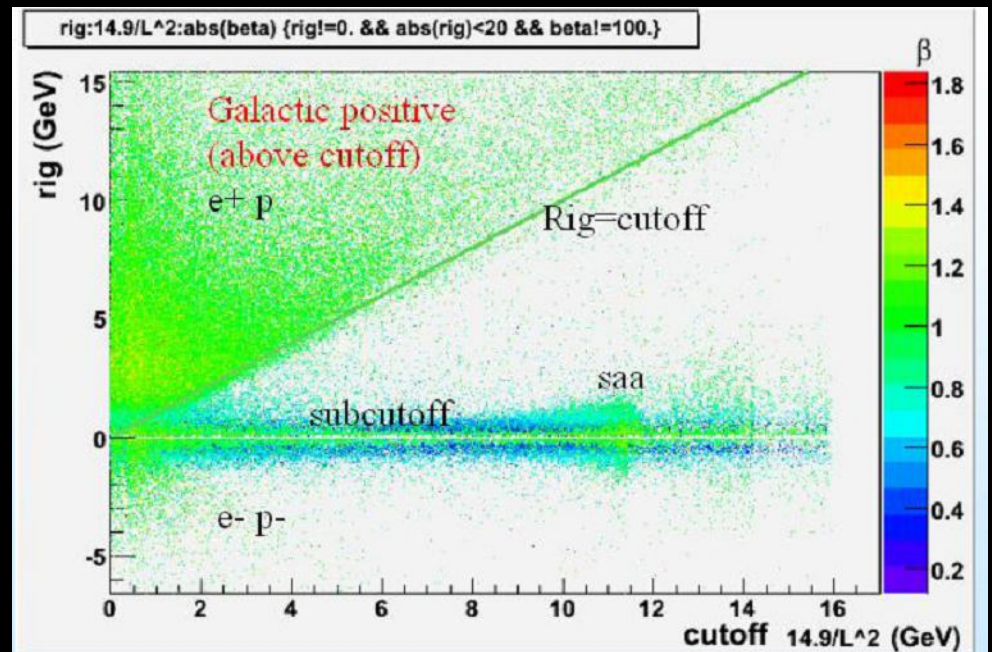
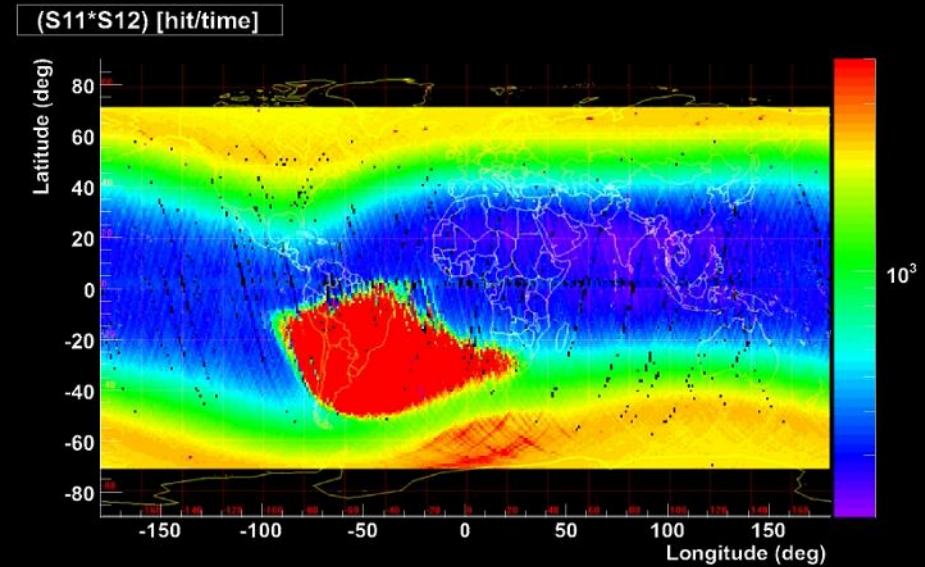
# Selection of galactic component according to geomagnetic cutoff



$$R_{\text{cutoff}} = 14.9 \text{ GV} / L^2$$



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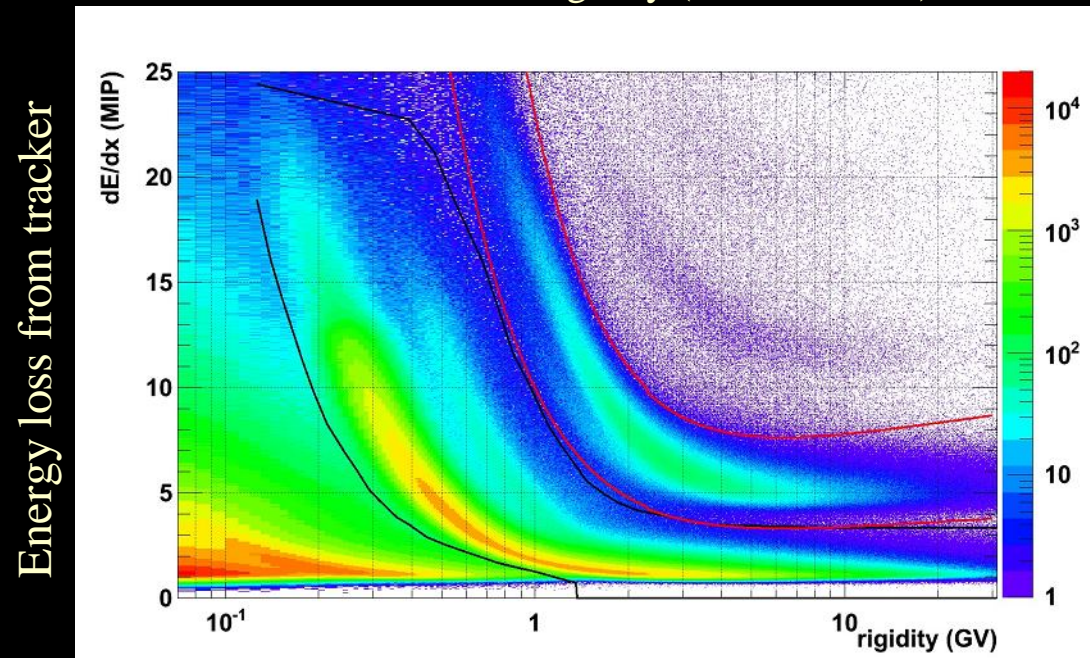
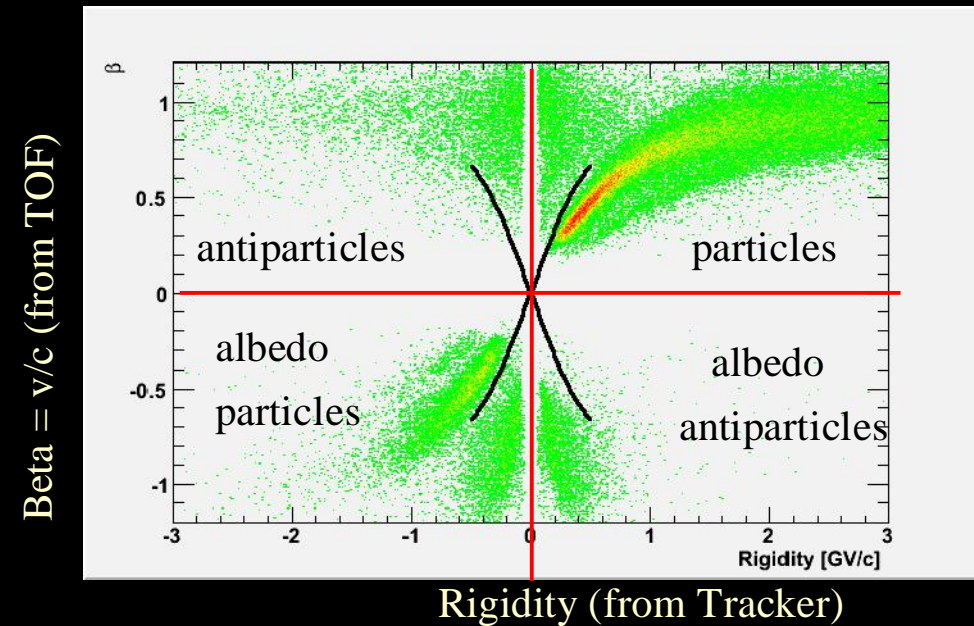


# Proton and Helium Absolute flux

- Montecarlo efficiency 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.

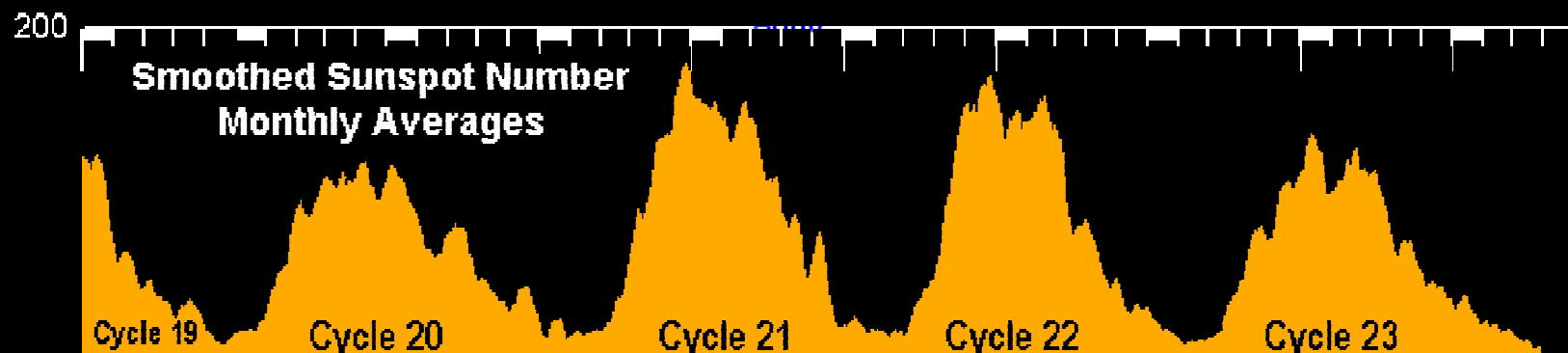
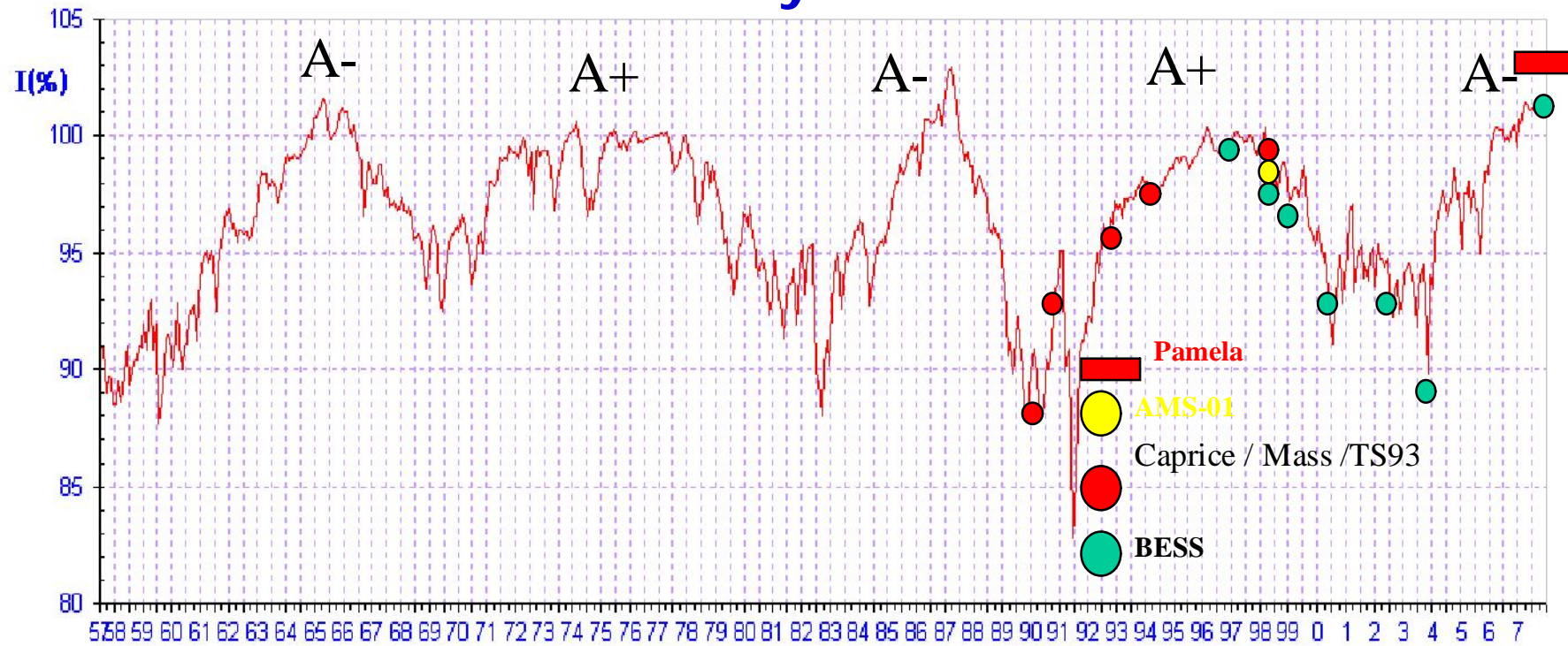
## Selection criteria

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



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

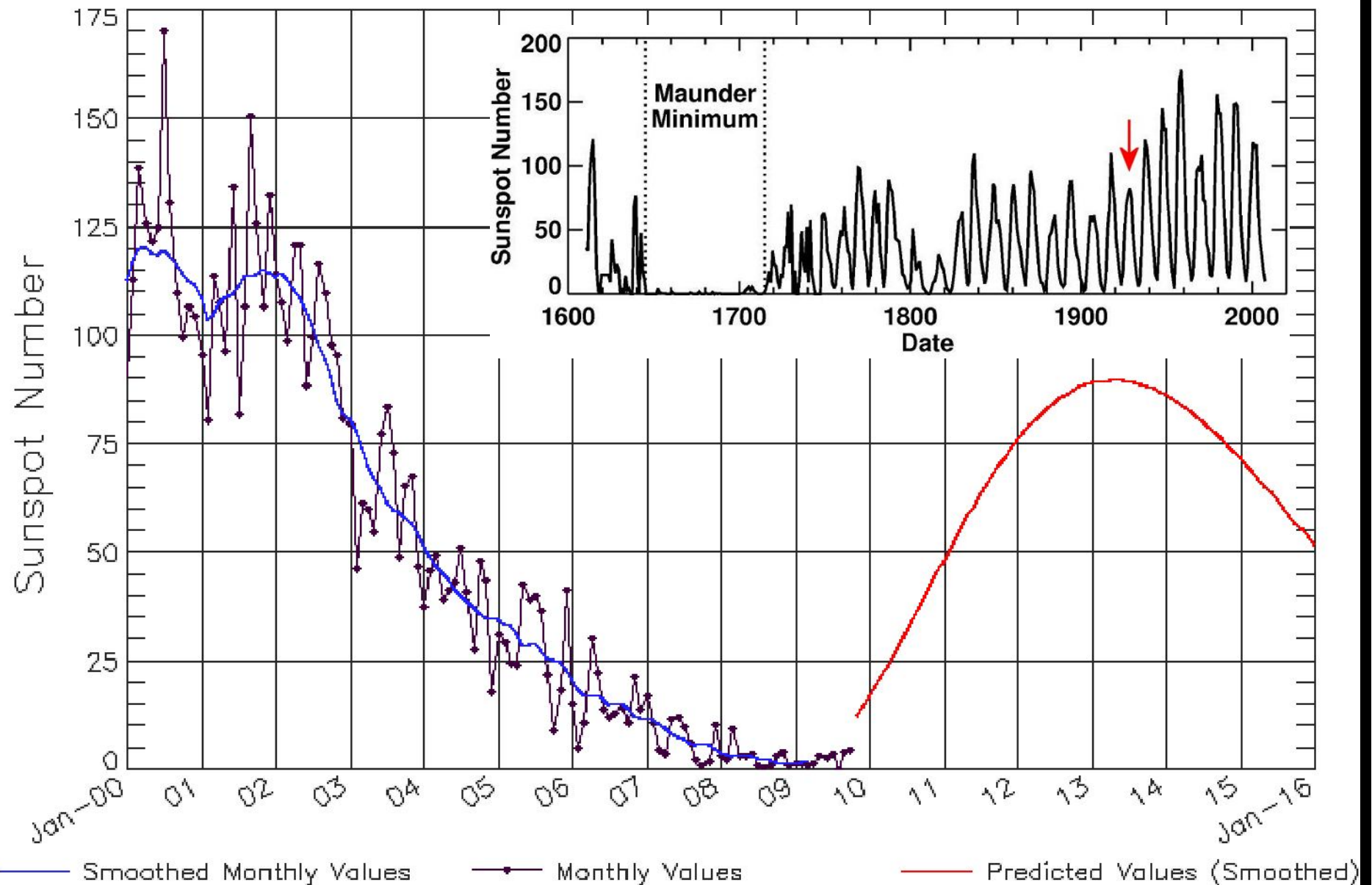
## Rome Monthly neutron monitor



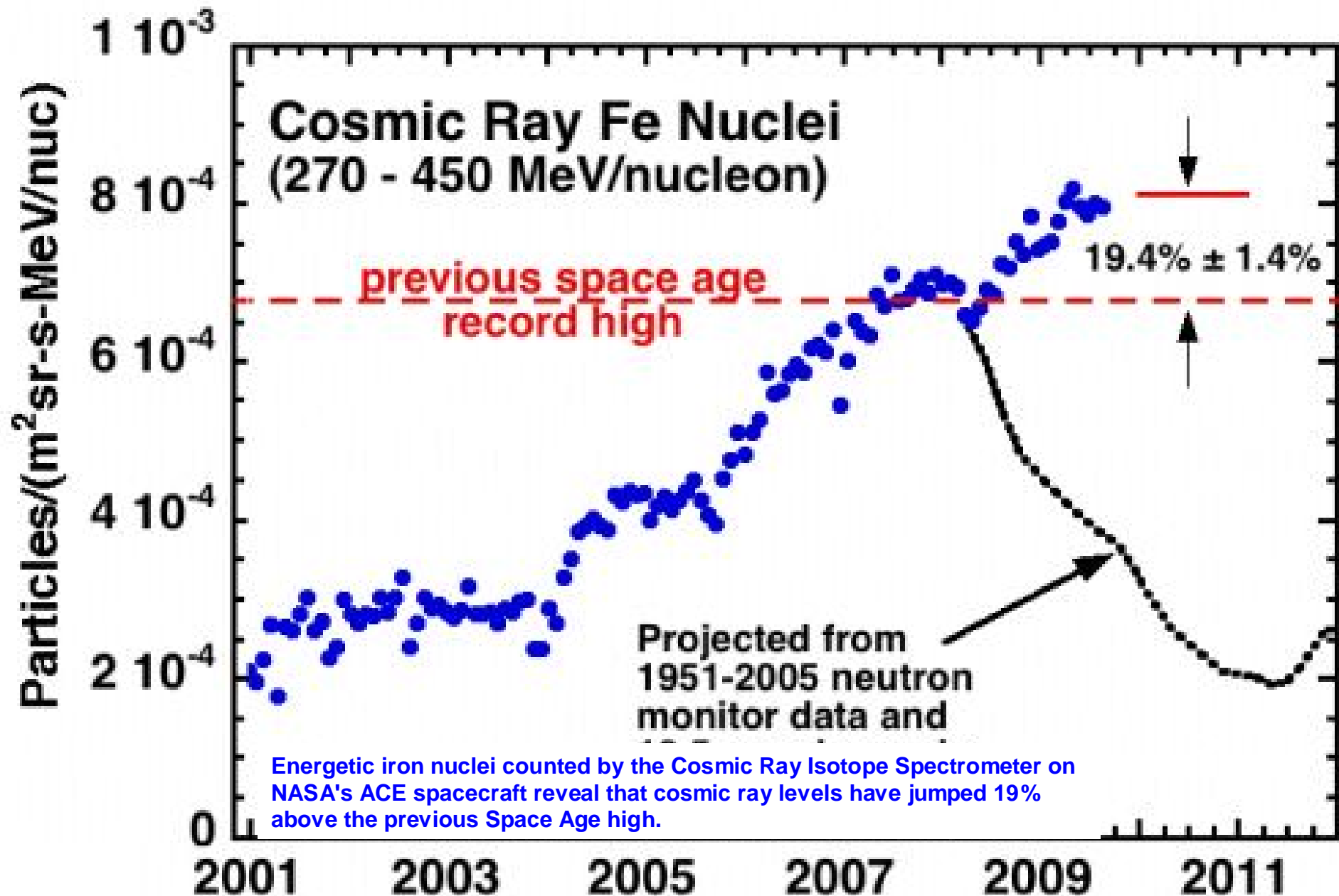


# ISES Solar Cycle Sunspot Number Progression

Data Through Oct 09

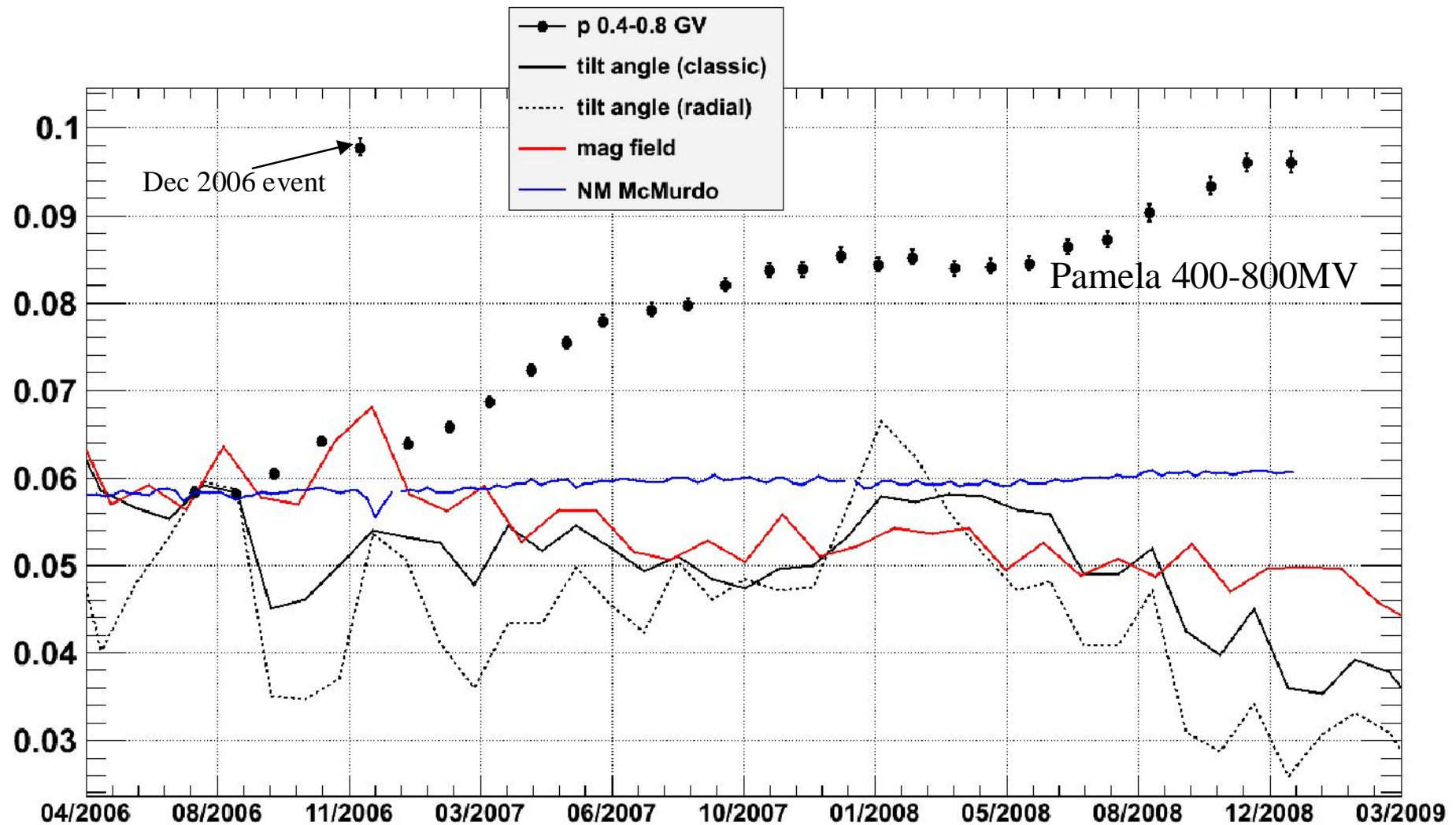
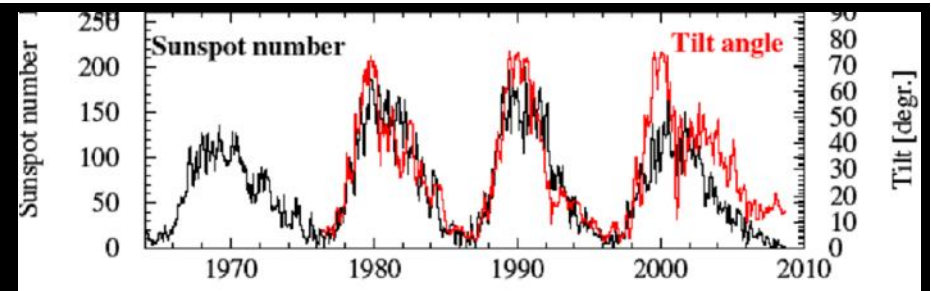


Low Solar Activity → high particle flux

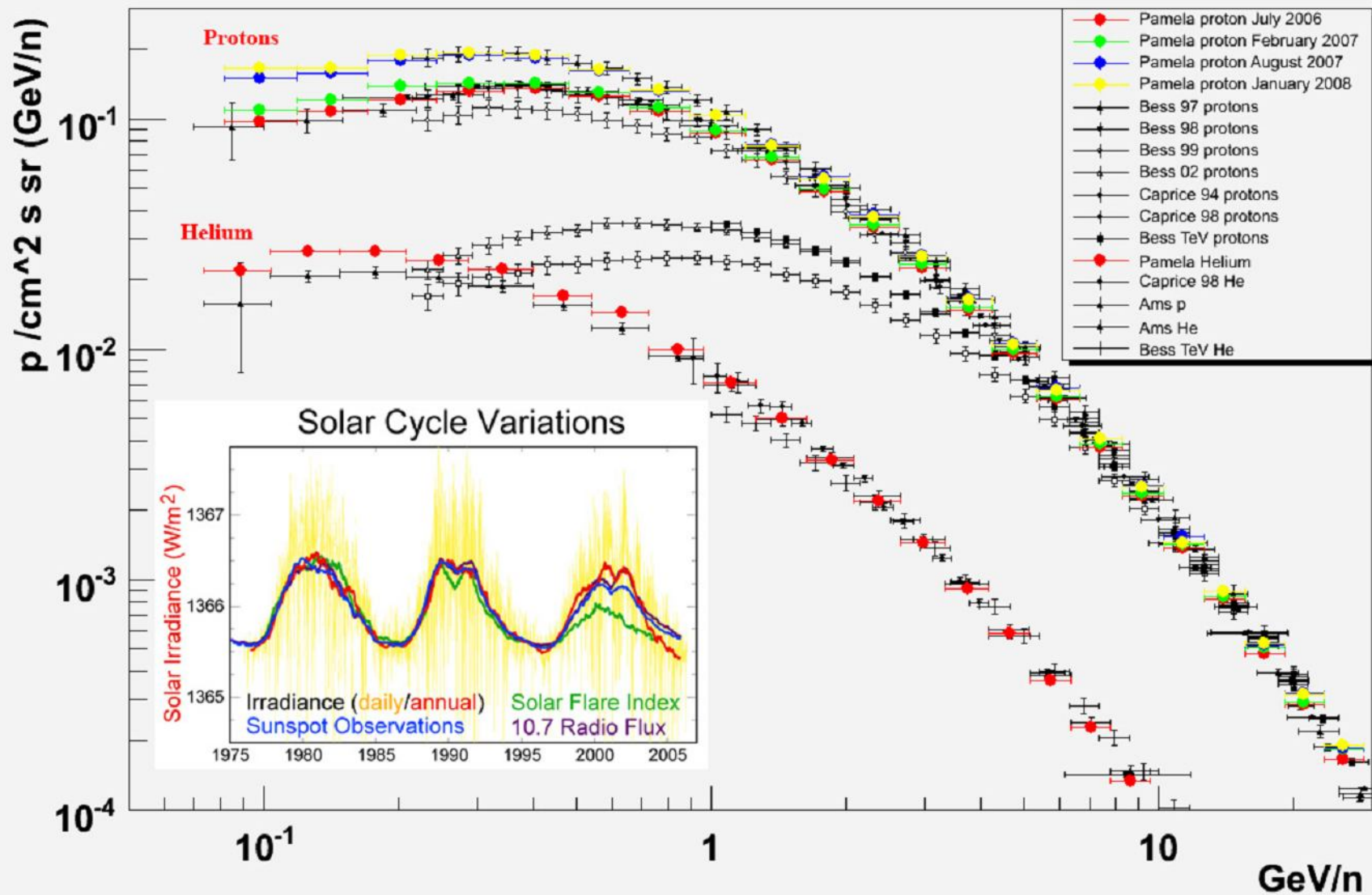




# Time evolution of Pamela low energy proton flux



# Solar modulation is effective below 10 GeV



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

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

$p/(cm^2 s sr GV)$

Spectral index

**$2.76 \pm 0.01$**

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

Solar modulation parameter

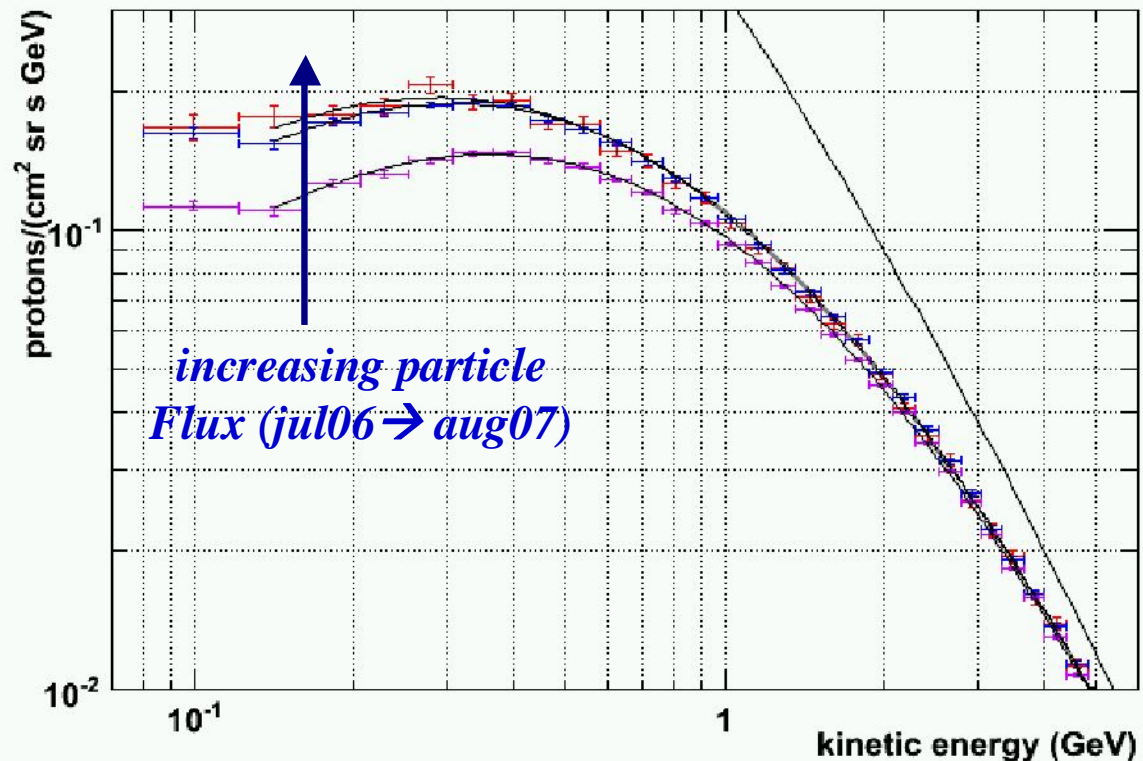
$\phi(GV)$

JUL06  $5.01-01 \pm 2e-03$

JAN07  $4.16-01 \pm 2-03$

AUG07  $4.02-01 \pm 3-03$

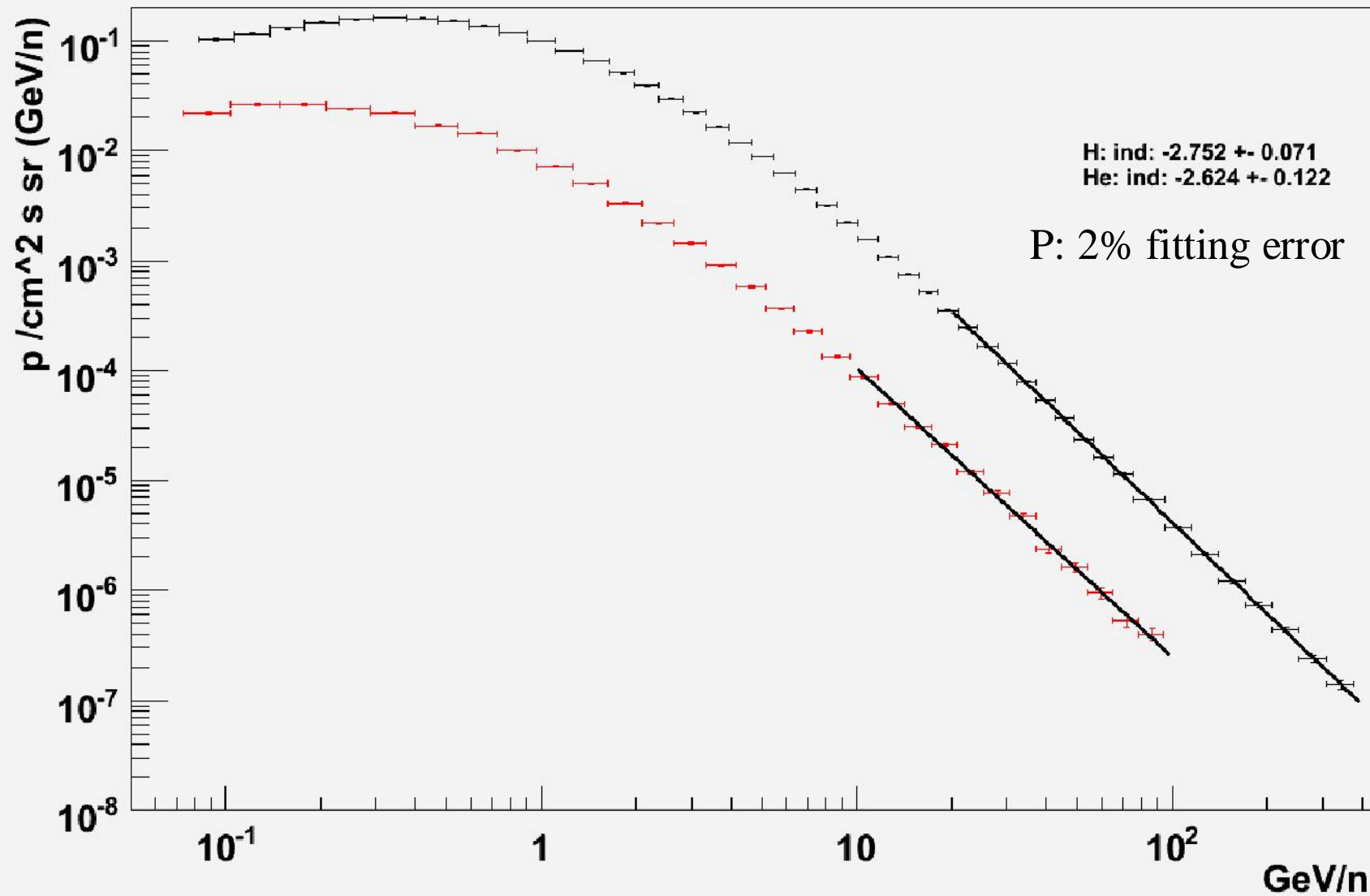
But Spherical approximation is not sufficient for charge dependent solar modulation



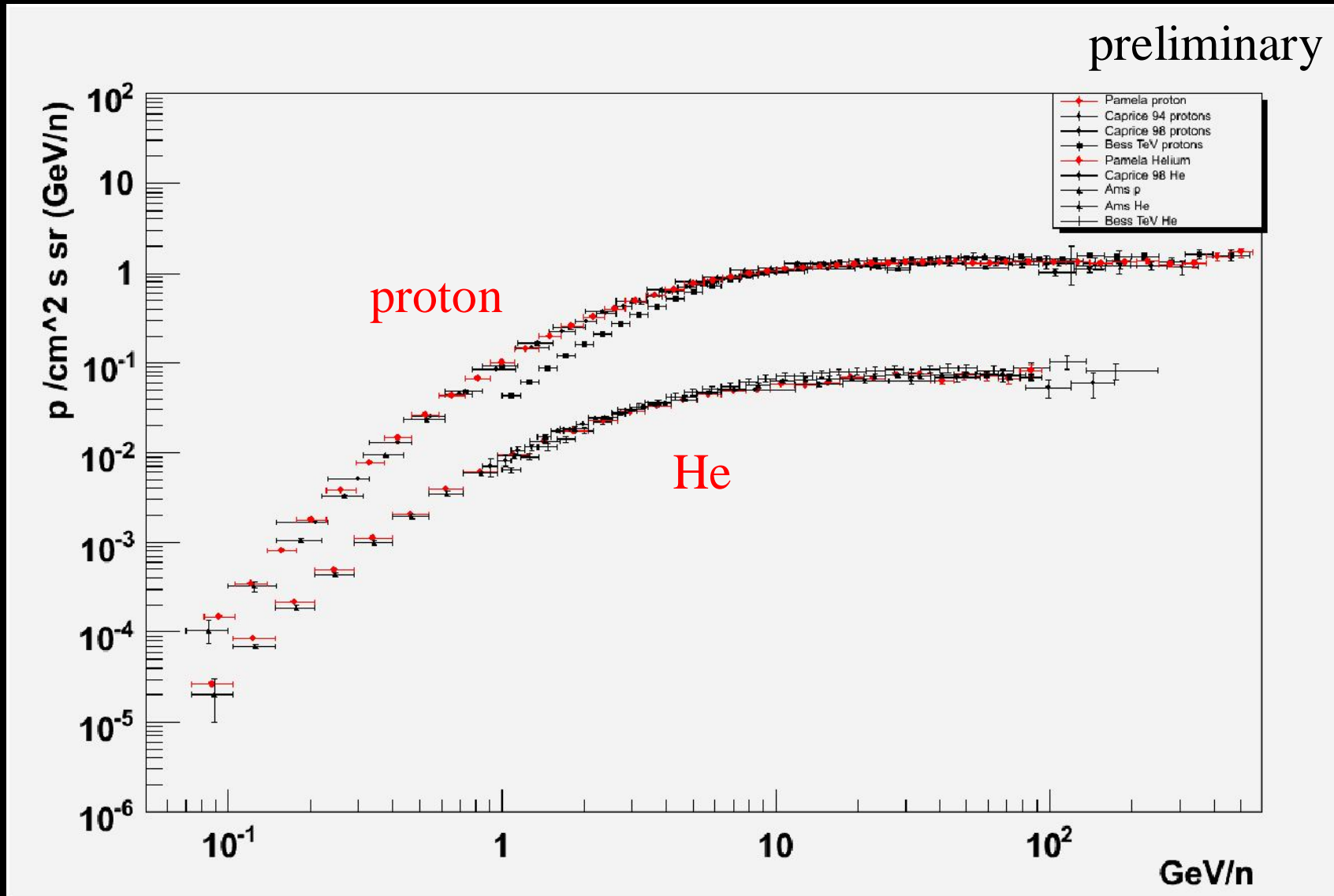


# Proton and Helium spectra, kinetic energy, Jul 2006

preliminary

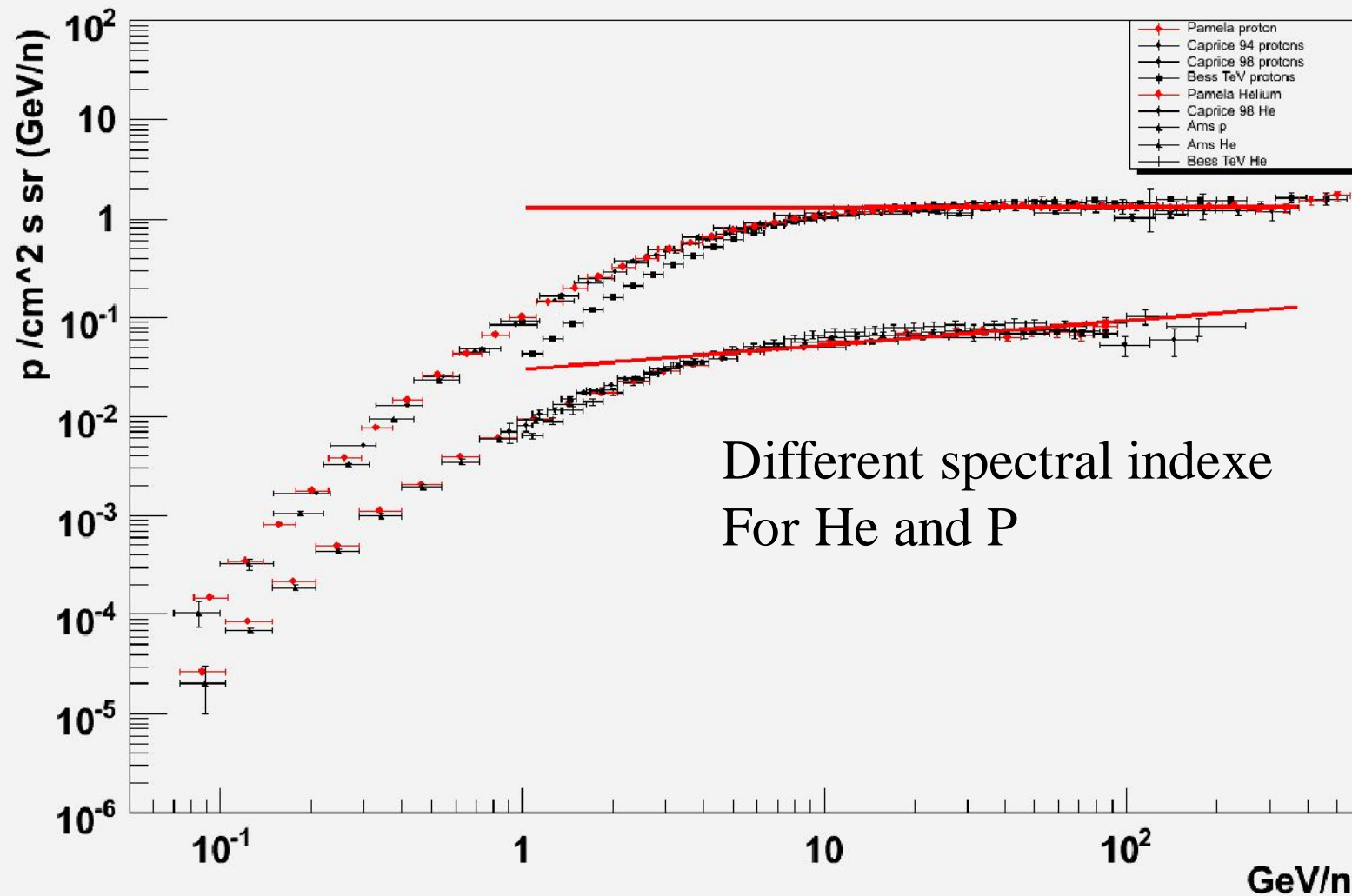


## Comparison with other experiments

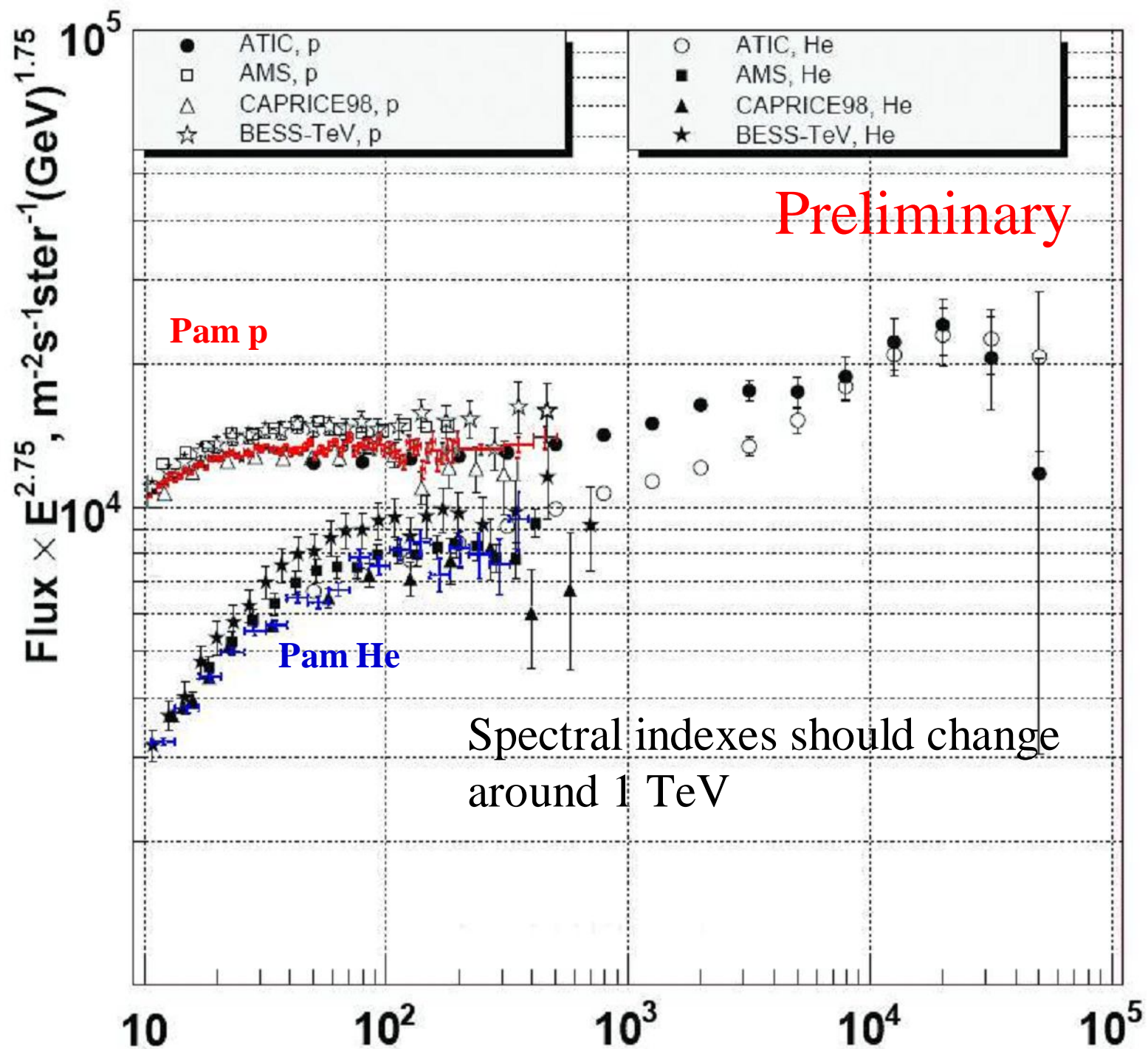


## Comparison with other experiments

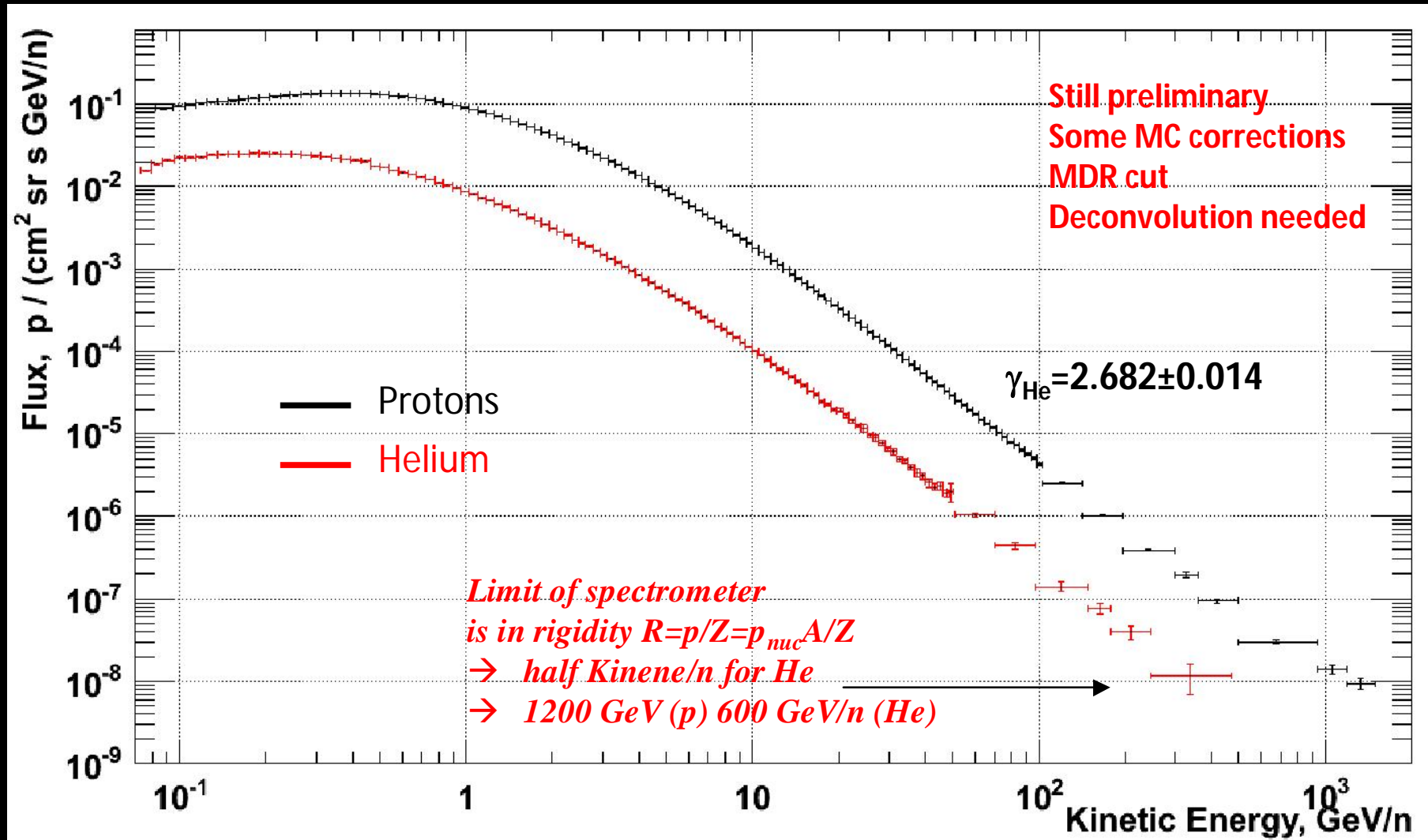
preliminary



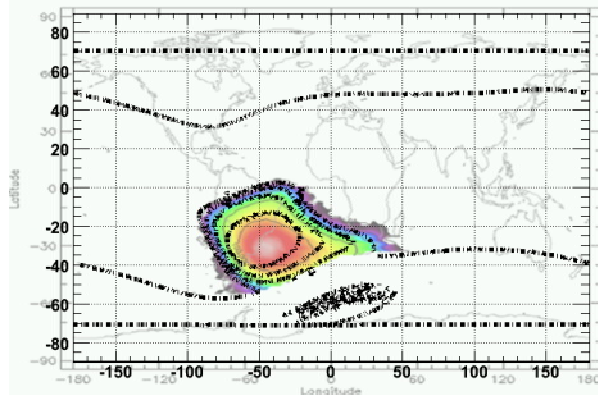
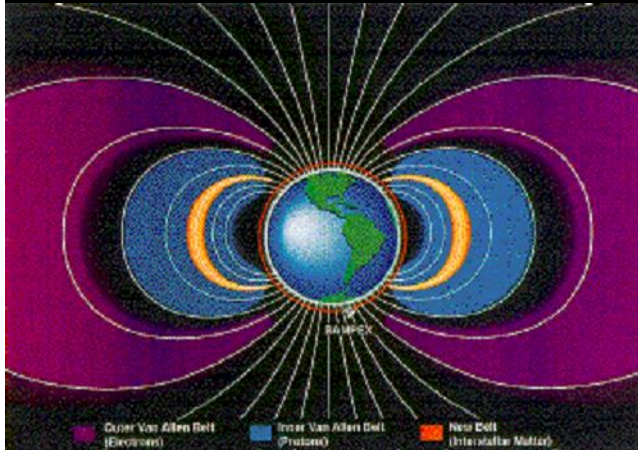




# Preliminary results at high energy

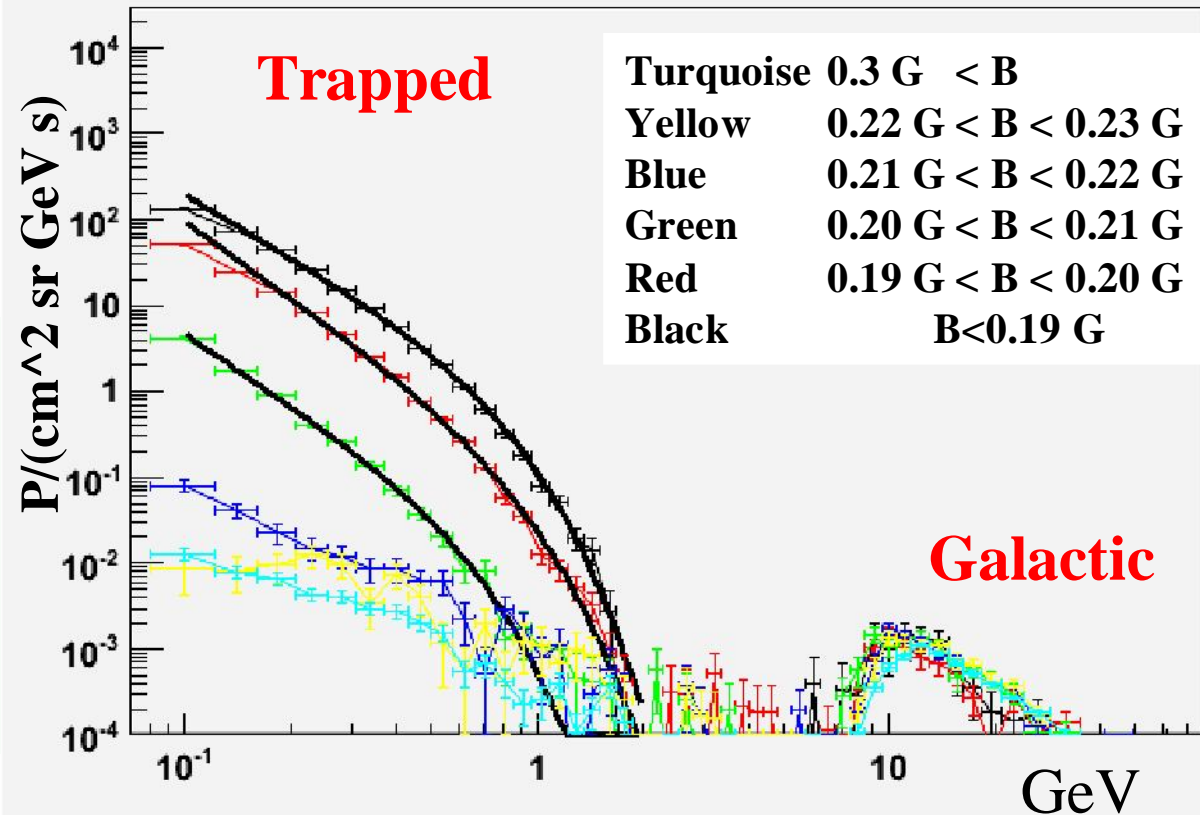


# Trapped proton flux in the Van Allen belt (South Atlantic Anomaly) Arxiv 0810.4980v1



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

M. Casolino, INFN & University Roma Tor Vergata

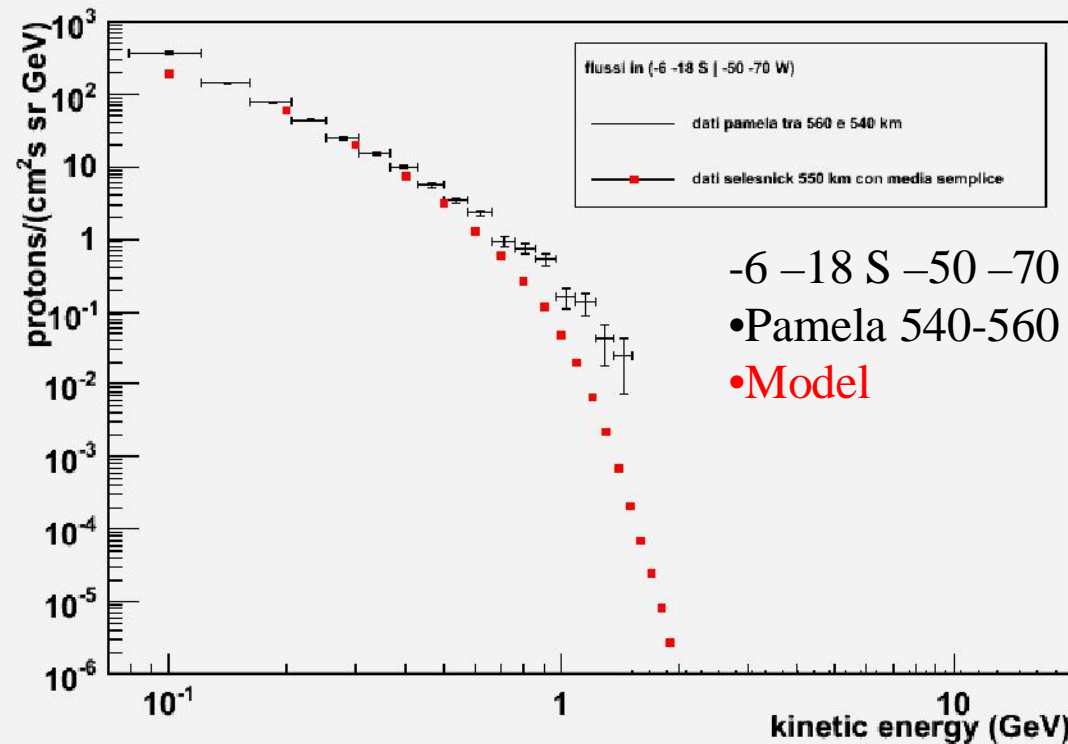
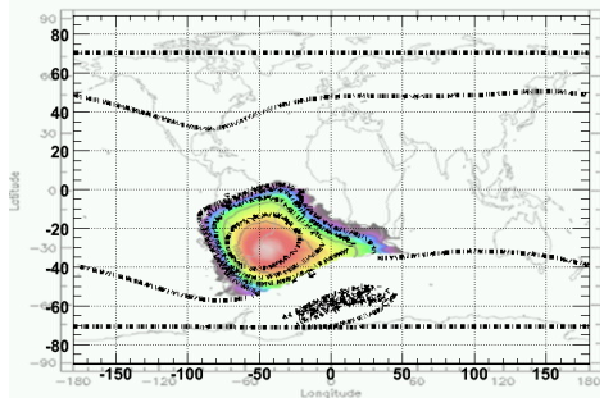
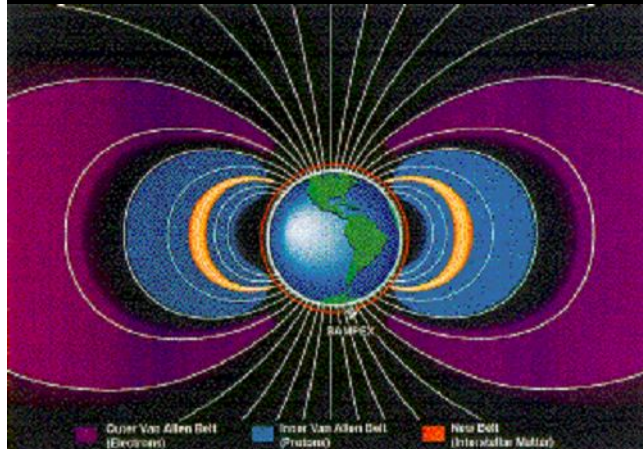


	A	$\gamma_0$	$\gamma_1$	$\chi^2/\text{ndf}$
nero	$0.11 \pm 0.01$	$6.0 \pm 0.4$	$3.1 \pm 0.5$	7.1
rosso	$(2.3 \pm 0.3) 10^{-2}$	$5.9 \pm 0.5$	$2.6 \pm 0.6$	6.8
verde	$(5 \pm 3) 10^{-4}$	$8.1 \pm 1.8$	$4.7 \pm 1.8$	10.



# Trapped proton flux in the Van Allen belt

## Comparison with models



-6 -18 S -50 -70 W

• Pamela 540-560

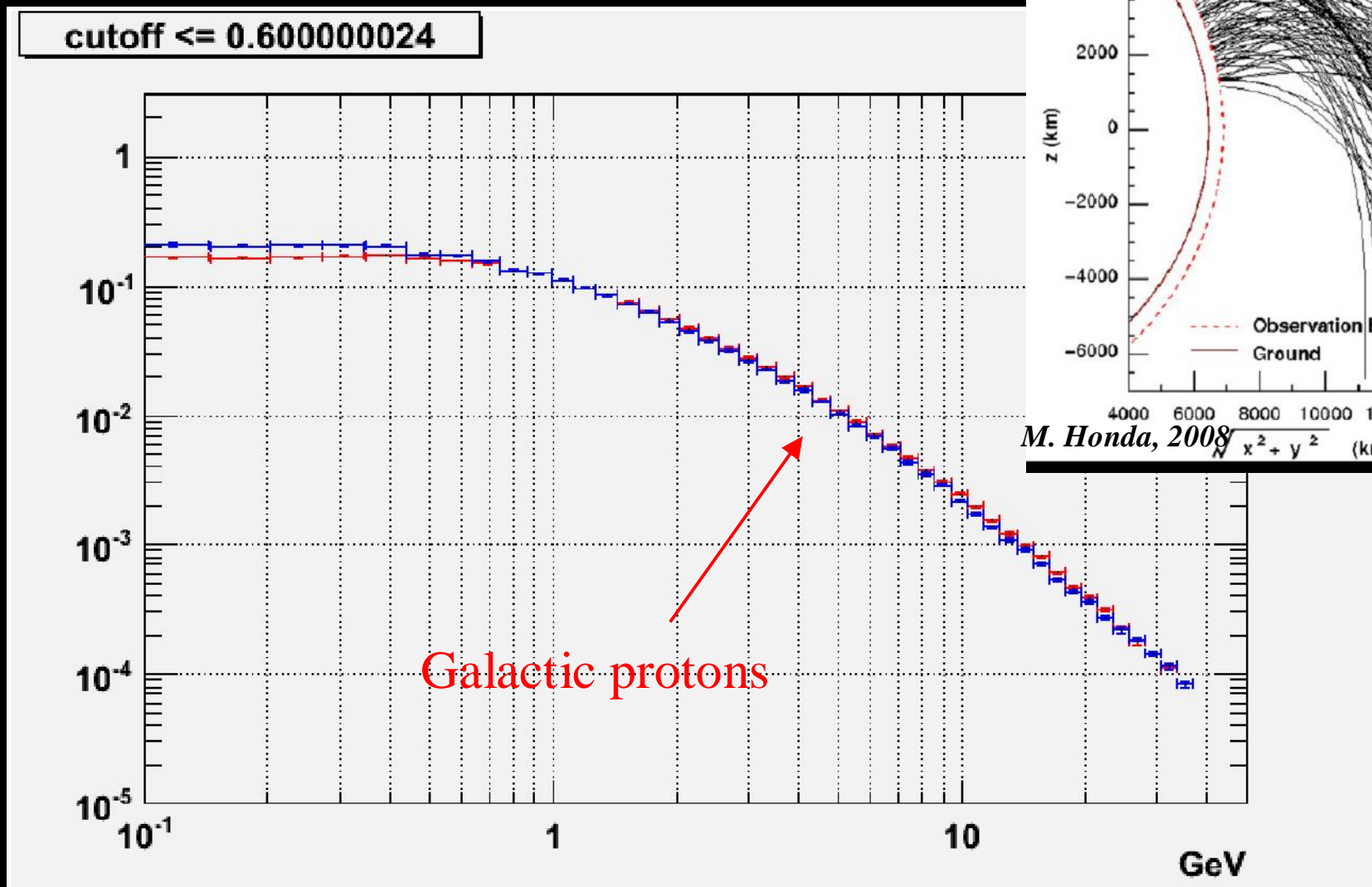
• Model

R. S. Selesnick,<sup>1</sup> M. D. Looper,<sup>1</sup> and R. A. Mewaldt<sup>2</sup>

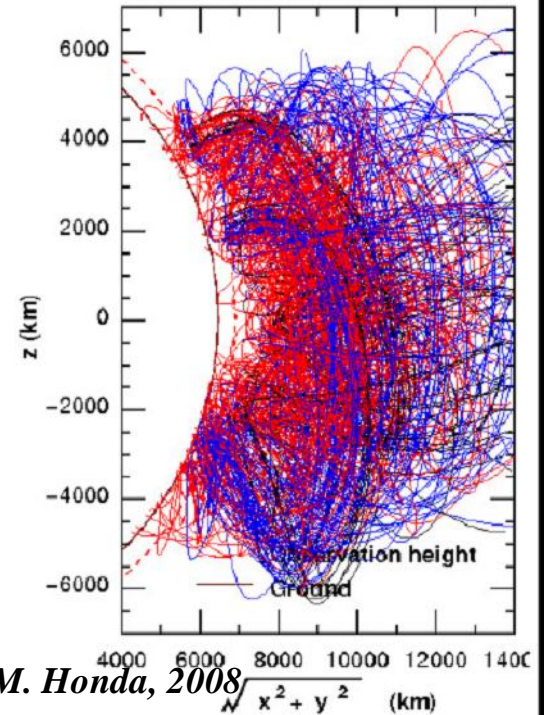
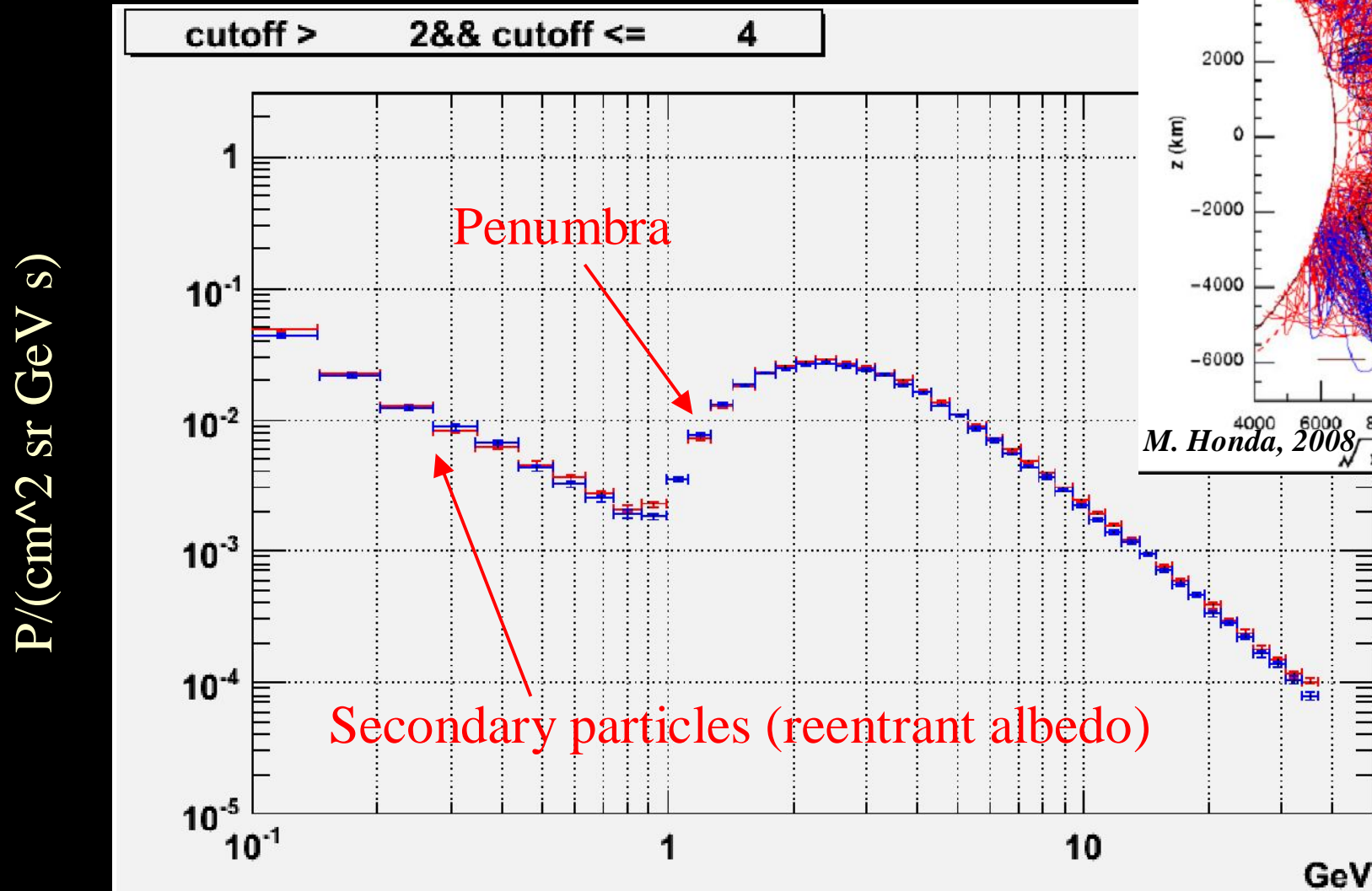
SPACE WEATHER, VOL. 5, S04003, doi:10.1029/2006SW000275, 2007

# Primary (galactic) spectra: polar measurements

$P/(\text{cm}^2 \text{ sr GeV s})$



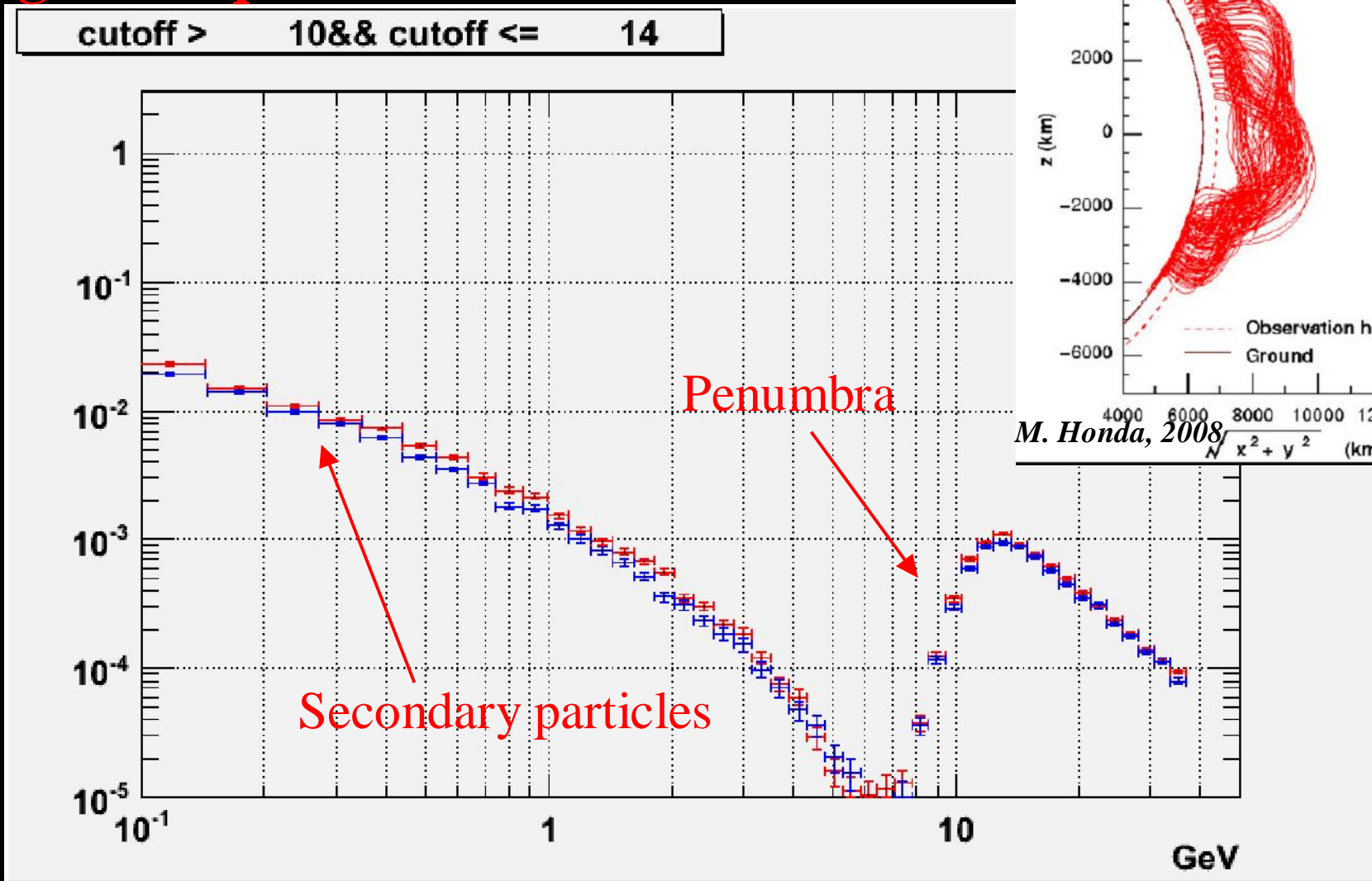
# Primary and secondary spectra: Intermediate latitudes





# Primary and secondary spectra: Magnetic equator

$P/(\text{cm}^2 \text{ sr GeV s})$

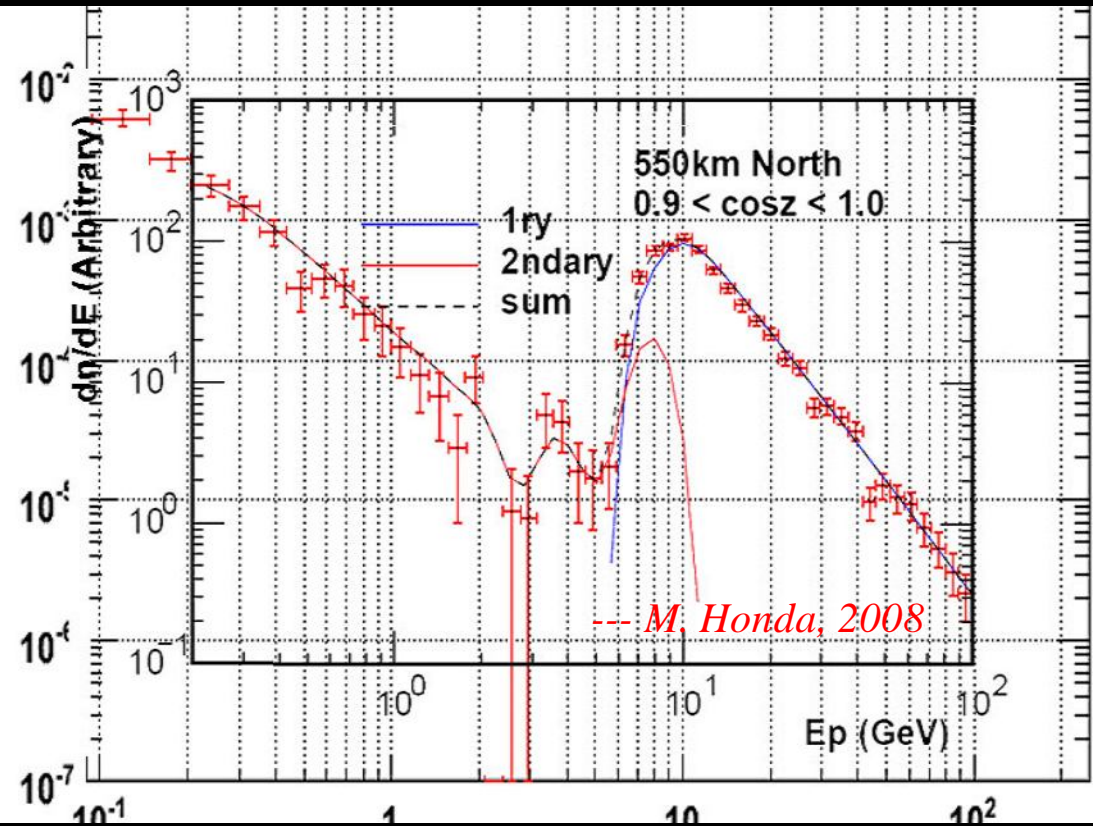


# Secondary (reentrant albedo) proton flux at various cutoffs

→ Atmospheric neutrino contribution

→ Astronaut dose on board International Space Station

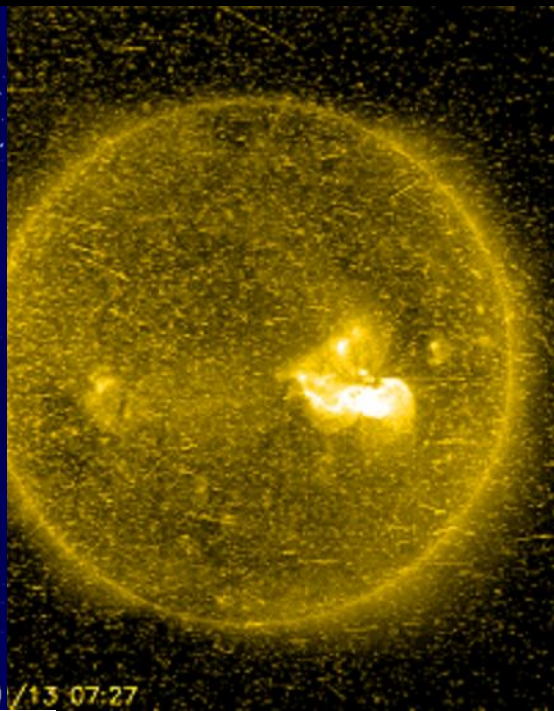
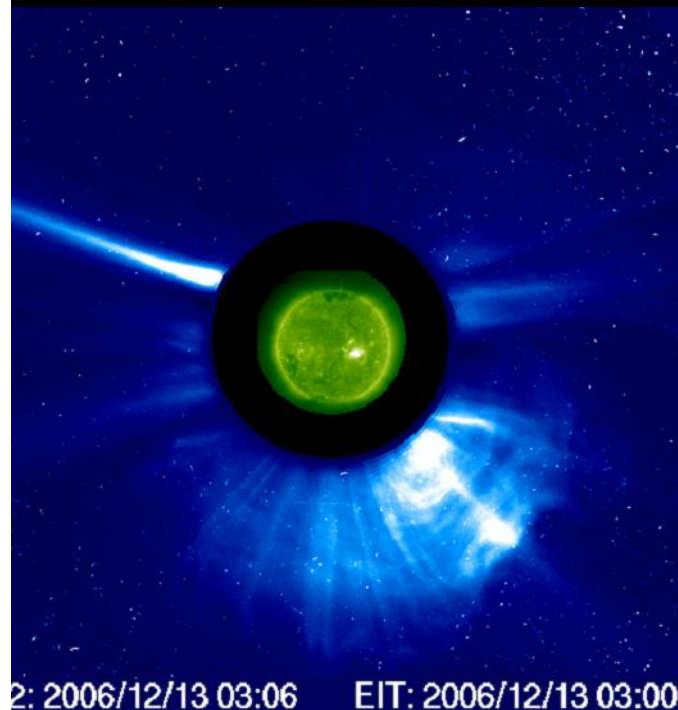
→ Indirect measurement of cross section in the atmosphere



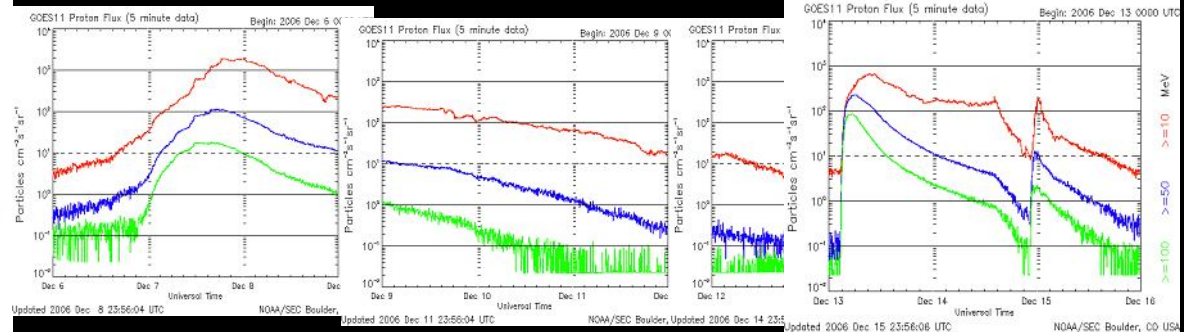
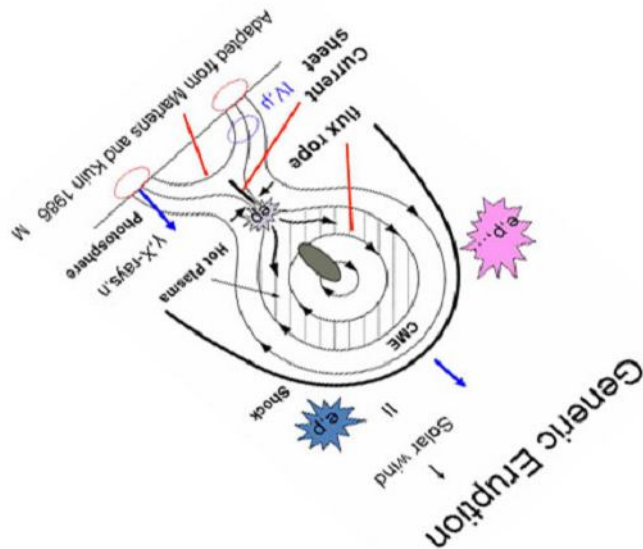
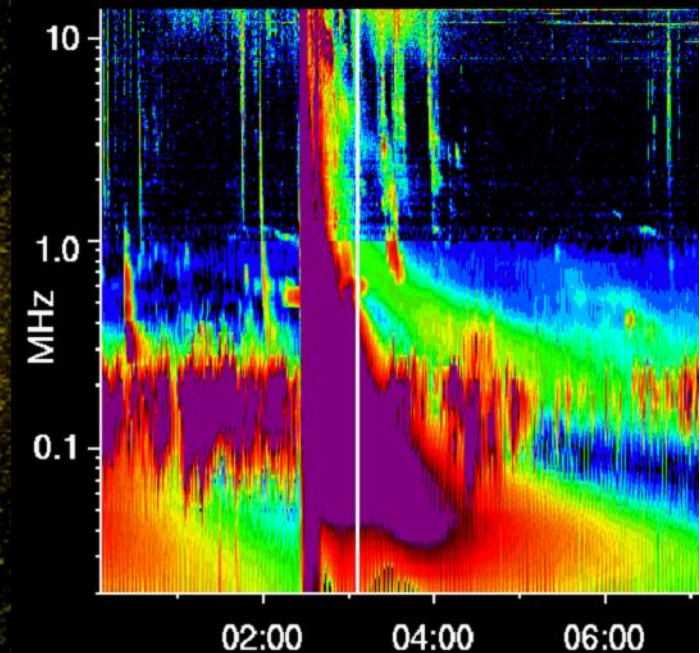
Arxiv 0810.4980v1



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



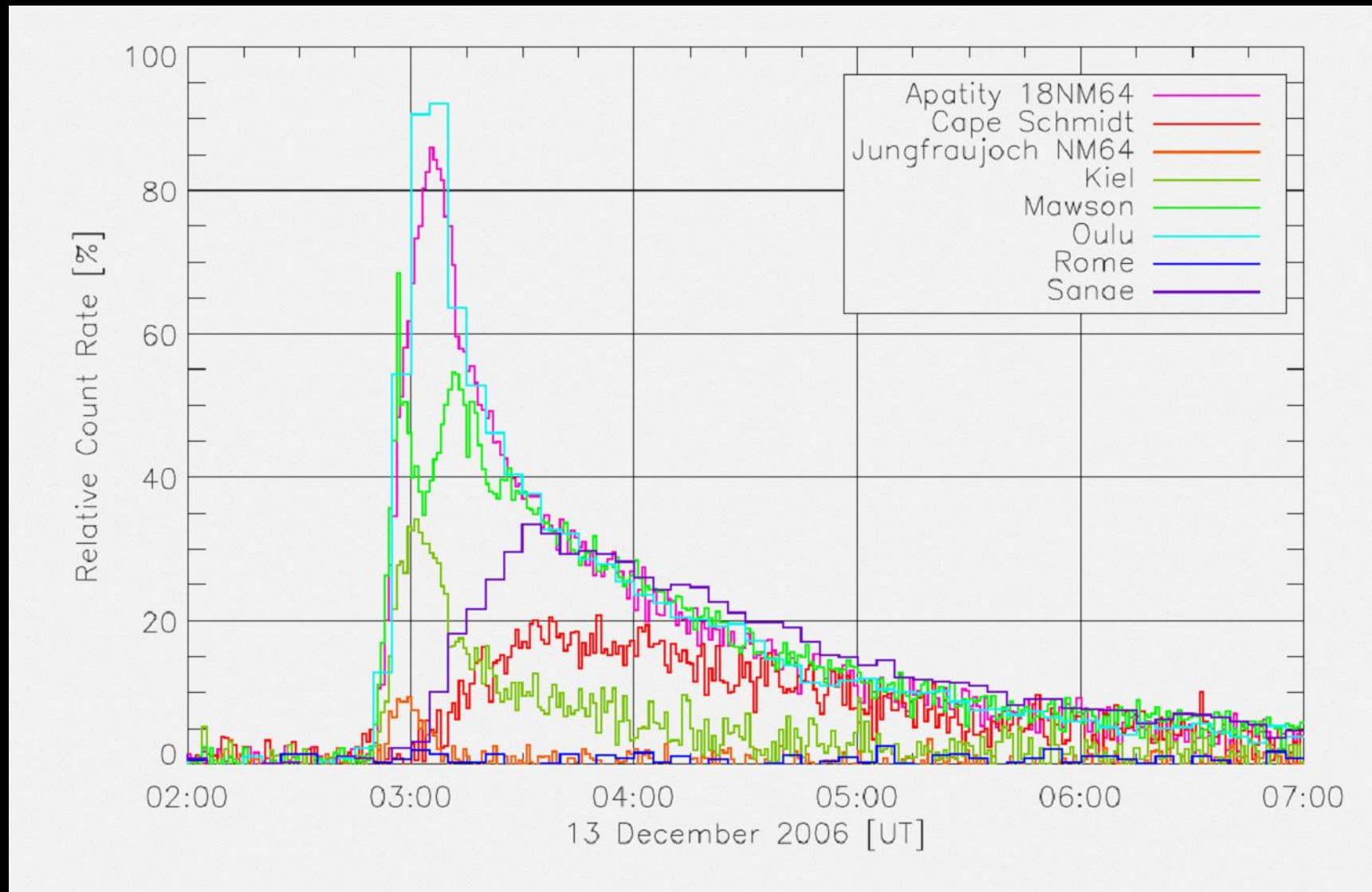
Wind/WAVES: 2006/12/13 03:06



ergata

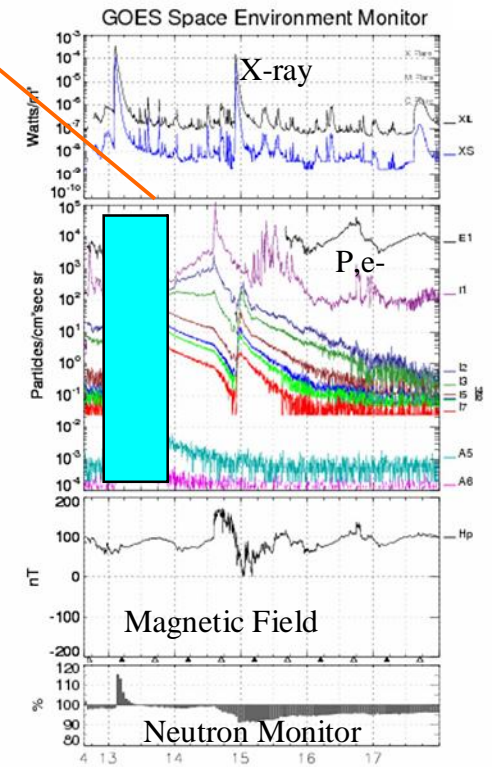
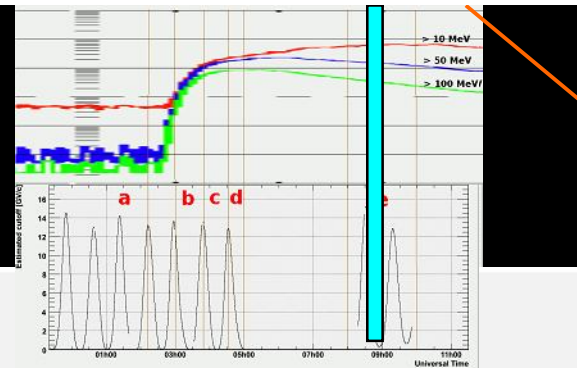
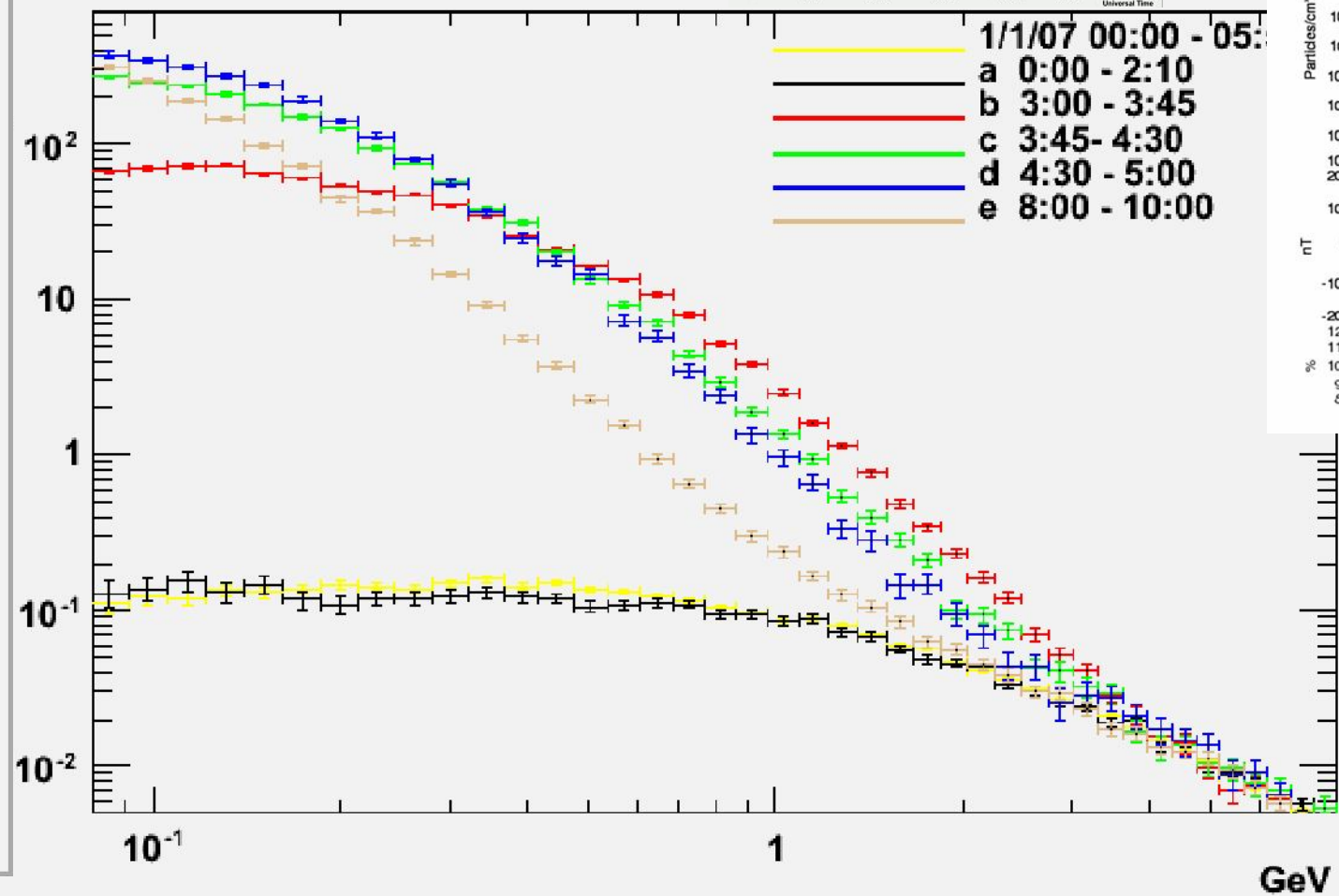


# 13 December 2006 Solar Particle Event Neutron Monitor Observations (GLE70)



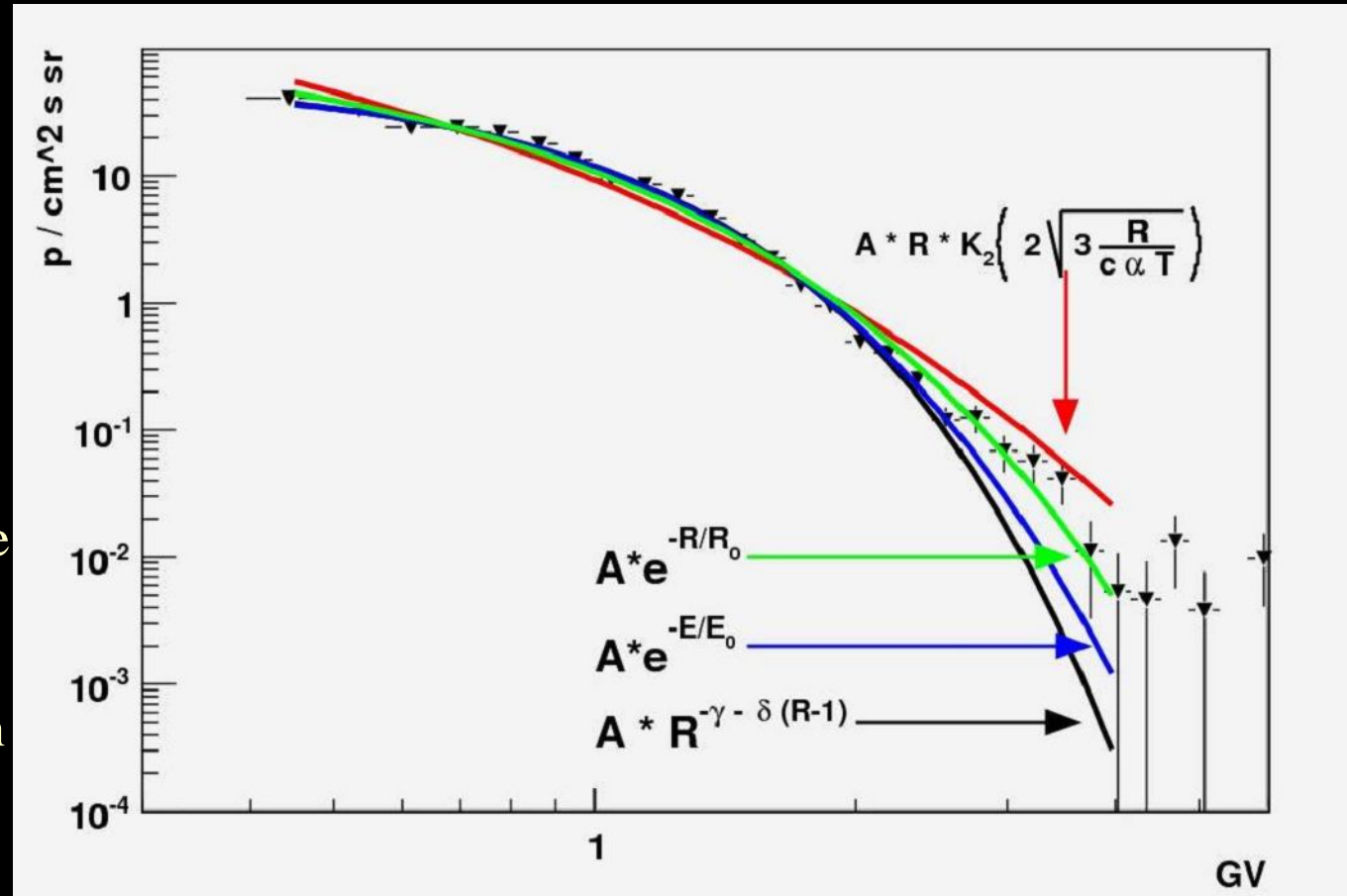
# December 13th 2006 event

Protons



## Discrimination between acceleration processes

- Shock accel.  
 $E^{-\alpha} \exp(E/E_0)$
- Stochastic Fermi  
accel.  
*Impulsive events*  
Exp in Rigid/Kinene  
Bessel function,
- Direct Acceleration  
in magnetic  
reconnection



Arxiv 0810.4980v1

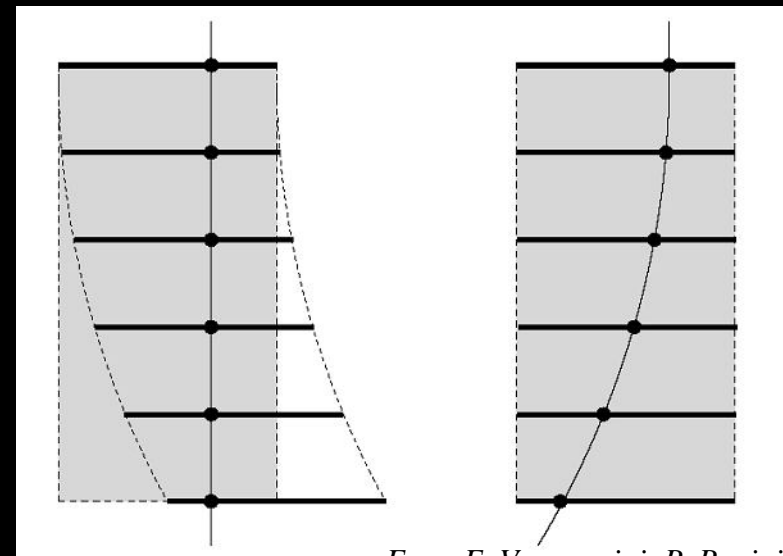
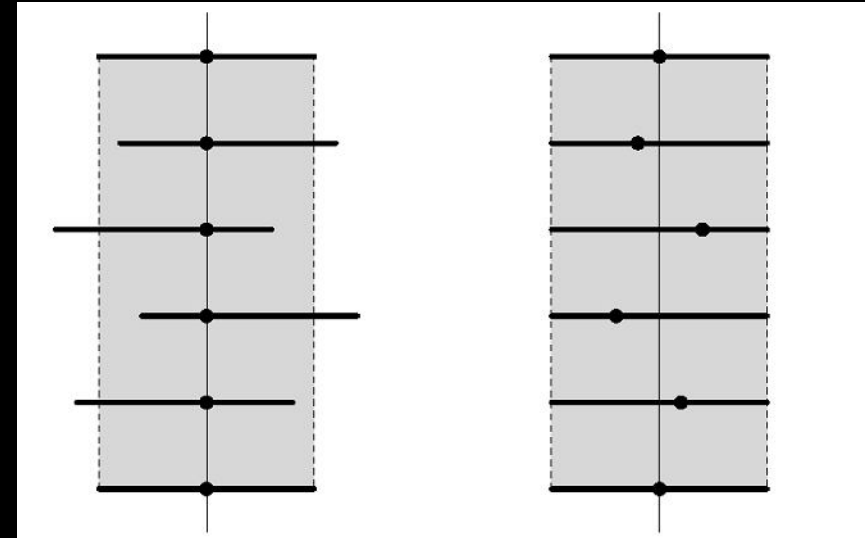


# Alignment

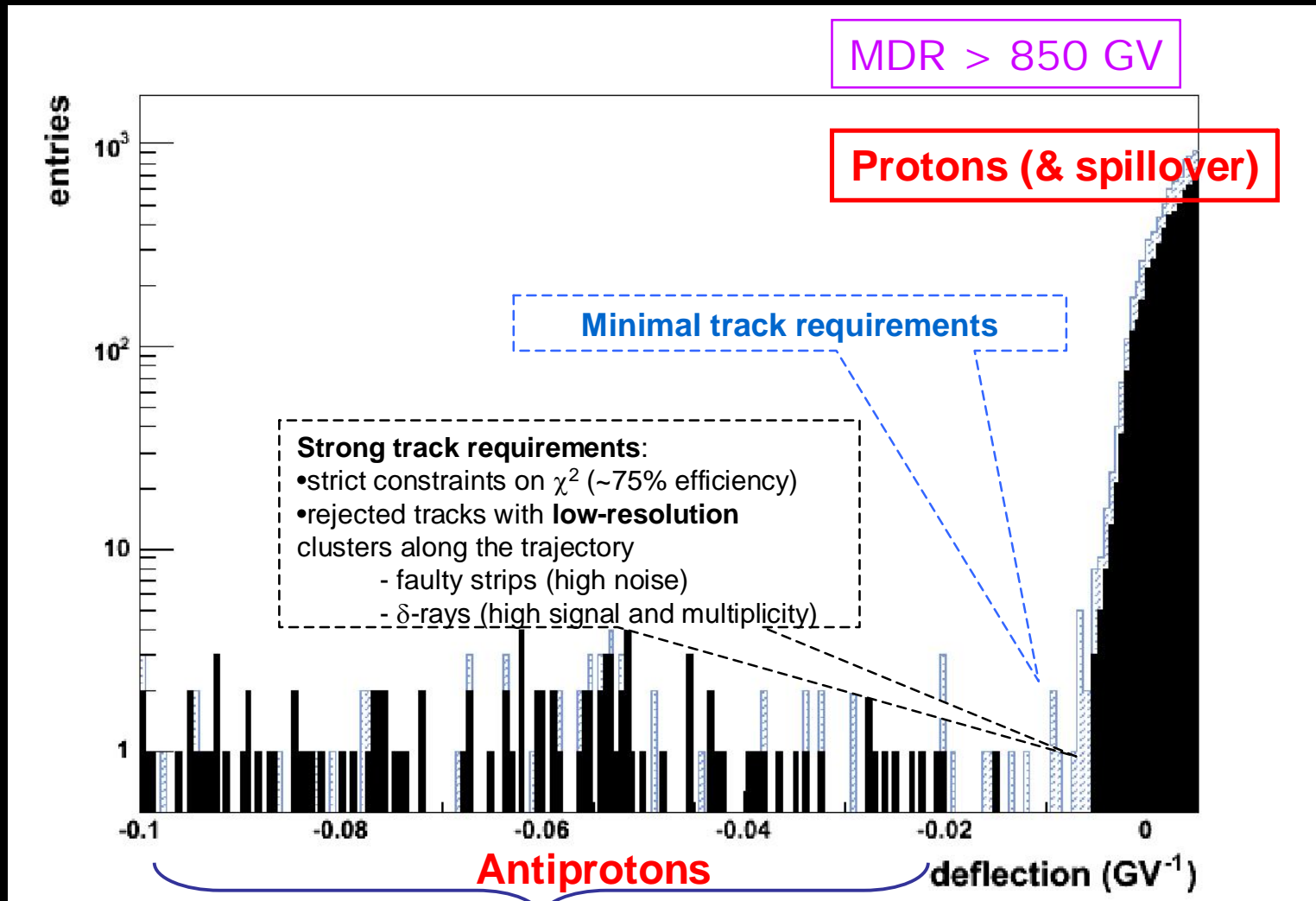
Critical Issue: an antiparticle  
Can be faked if alignment of the  
detector is wrongly considered

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

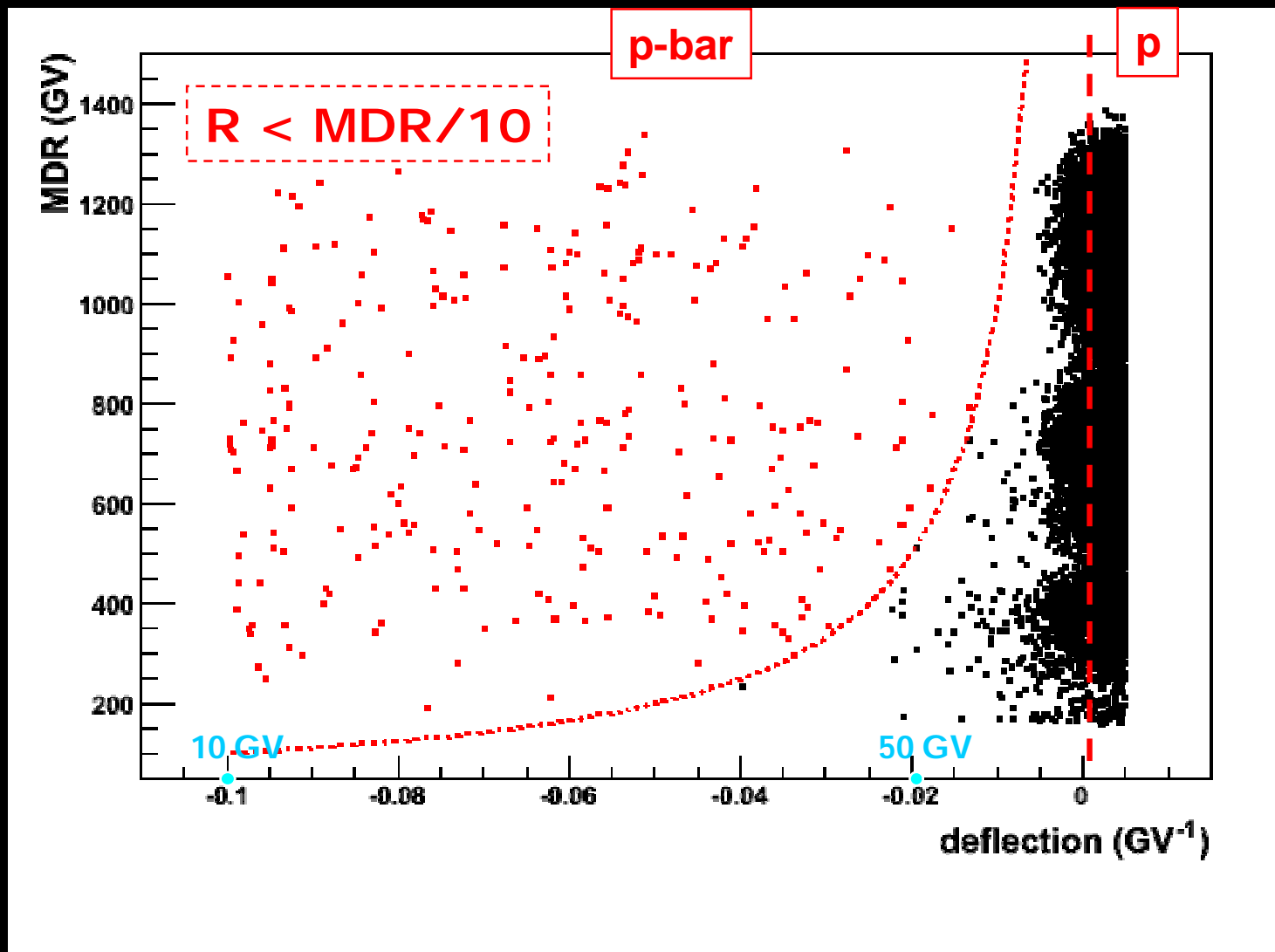
Coherent misalignment  
Correction with electrons  
(or electrons + positrons)  
and comparison with  
simulation



# Proton spillover background



# High-energy antiproton selection



From O. Adriani



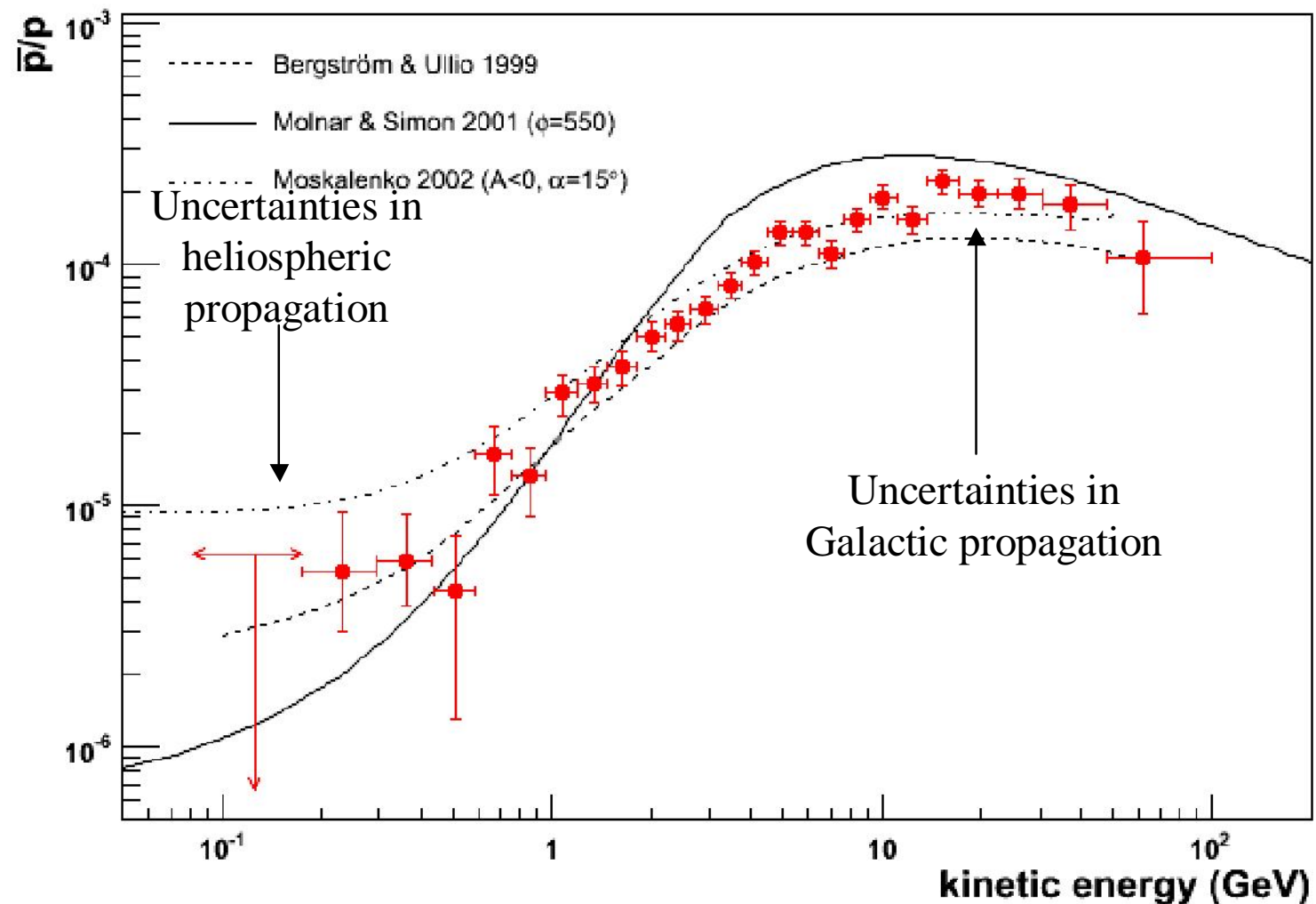
# Antiproton ratio measured with Pamela: Comparison with theoretical models

Released data  
1-100 GeV

Currently  
roughly 10 TB  
of data

As of March  
'08  
Out of 8.8 TB

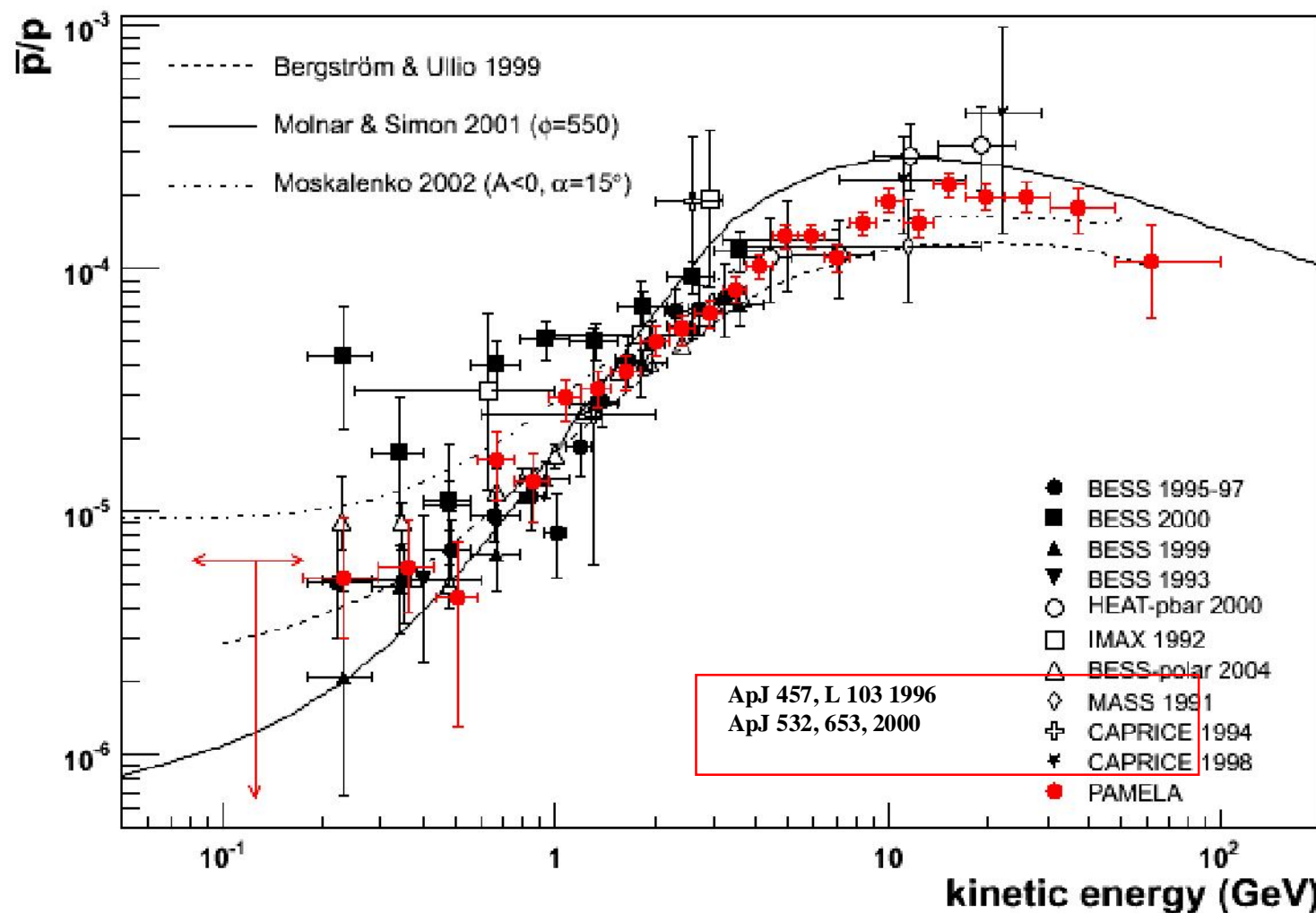
- $10^7$  p
- $800$   $p^-$



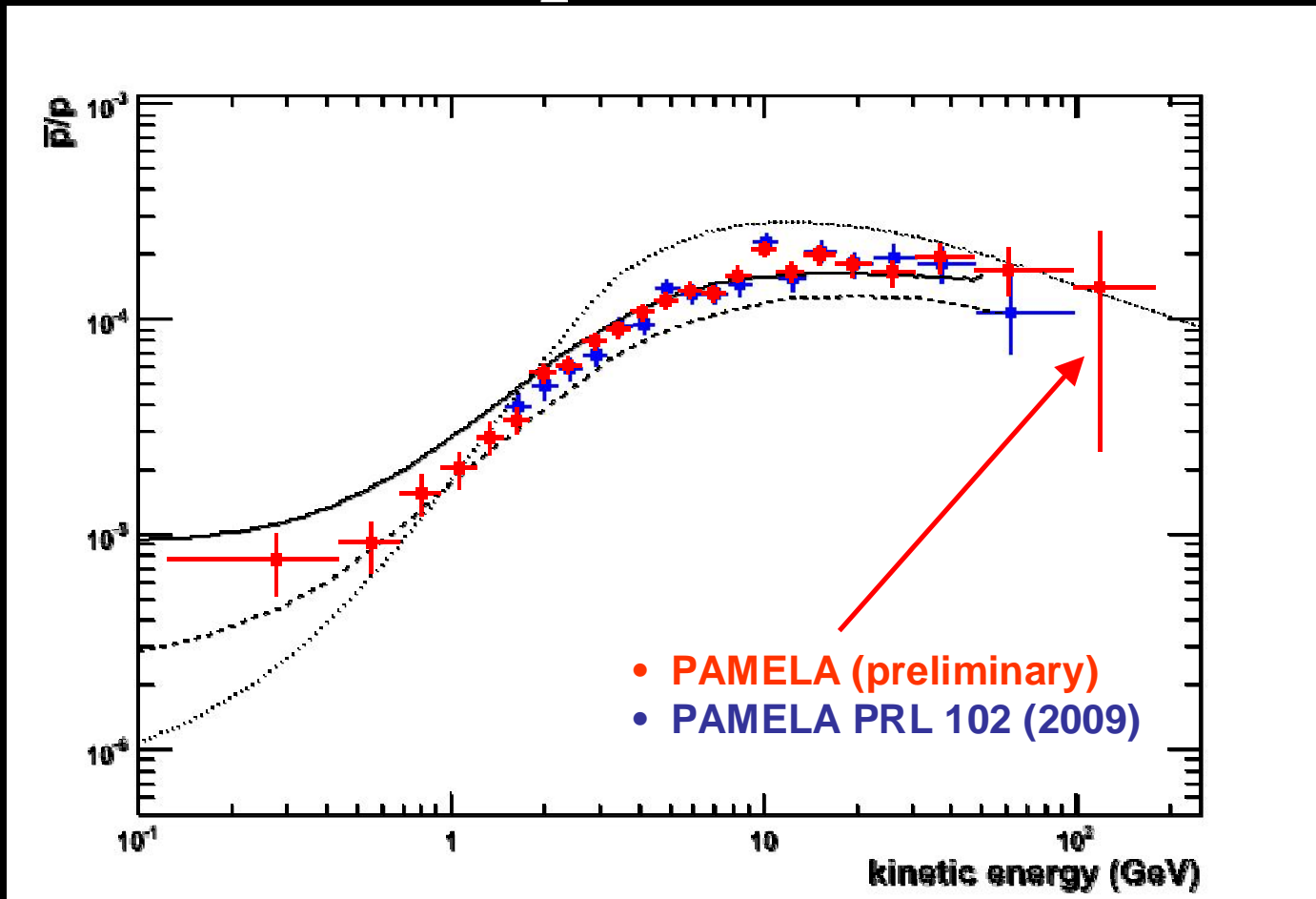
# Antiproton ratio measured with Pamela:

## Comparison with experimental data

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



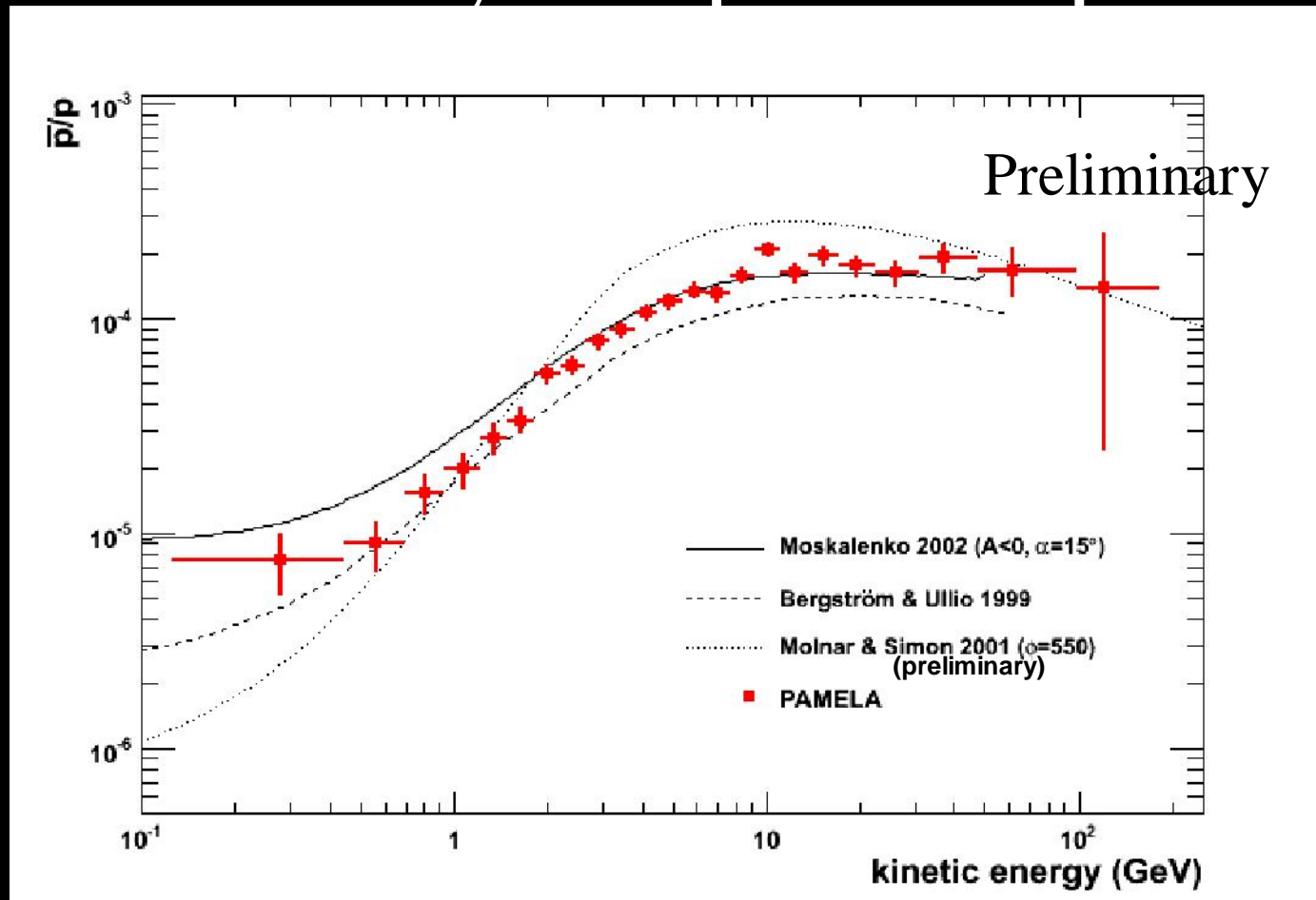
# Antiproton ratio



- New points consistent with old ones.

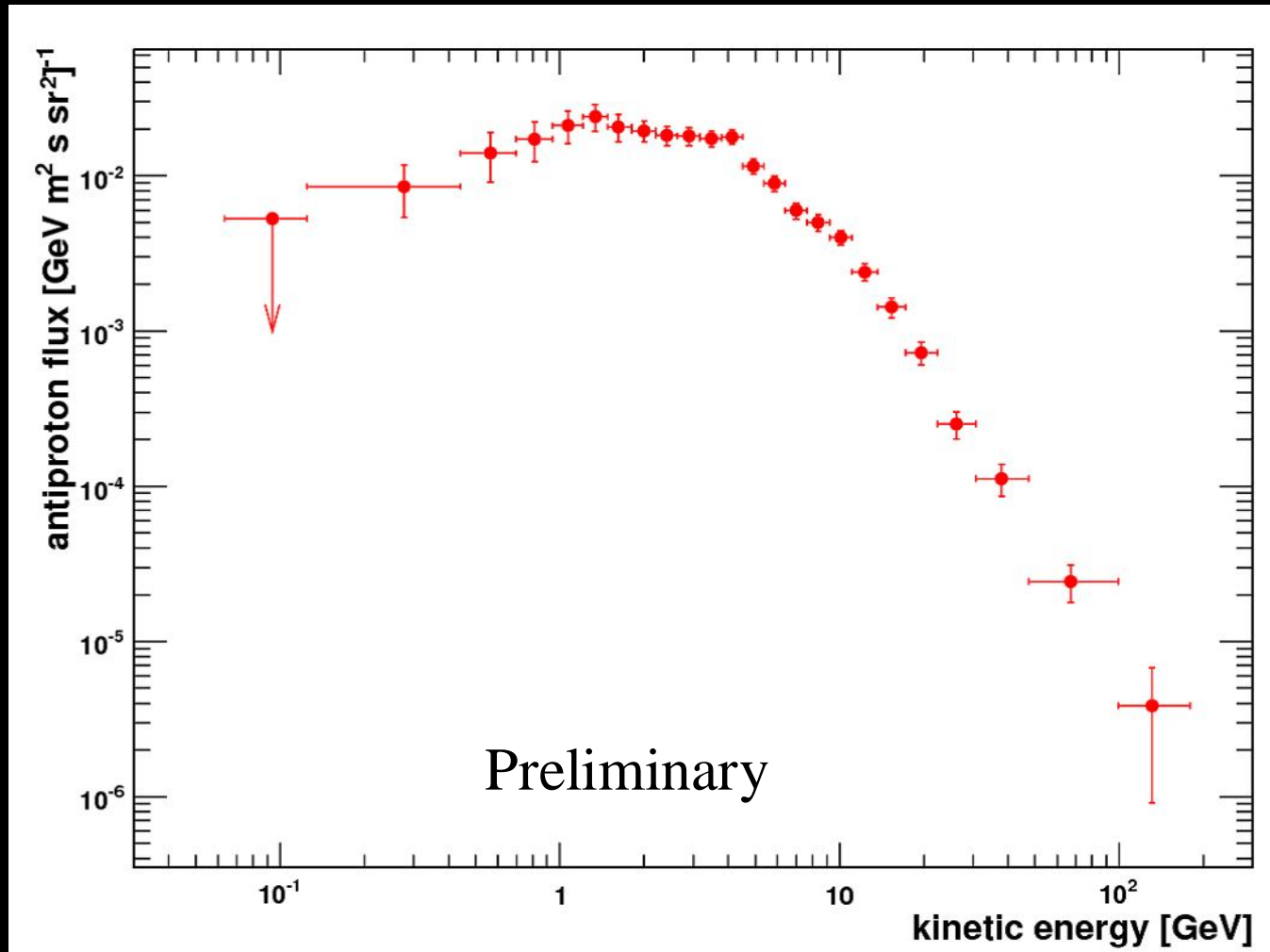


# Preliminary antiproton spectrum



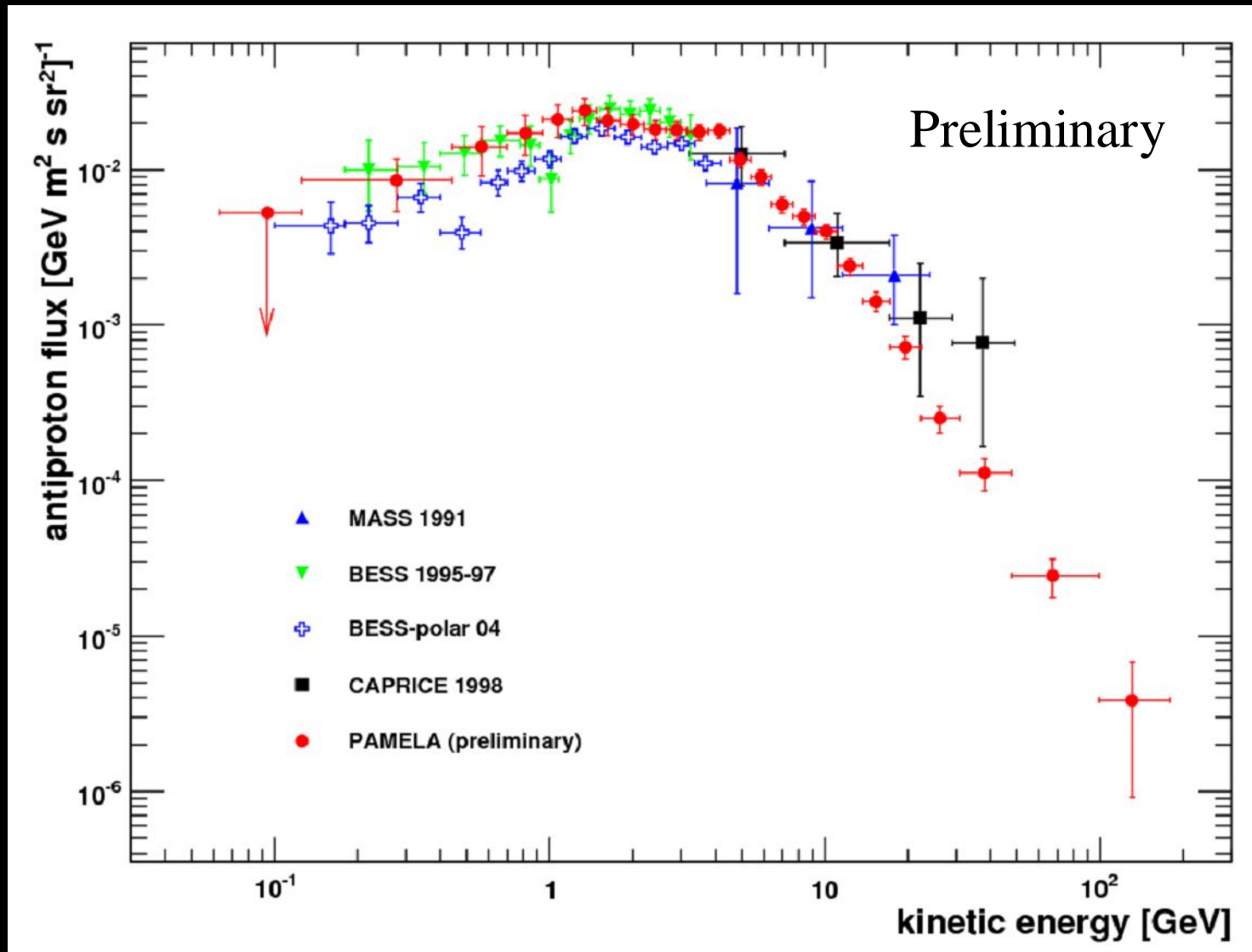
- highest bin:  $\text{MDR} > 6 \cdot |R|$  is used to increase statistics..

# Preliminary antiproton spectrum



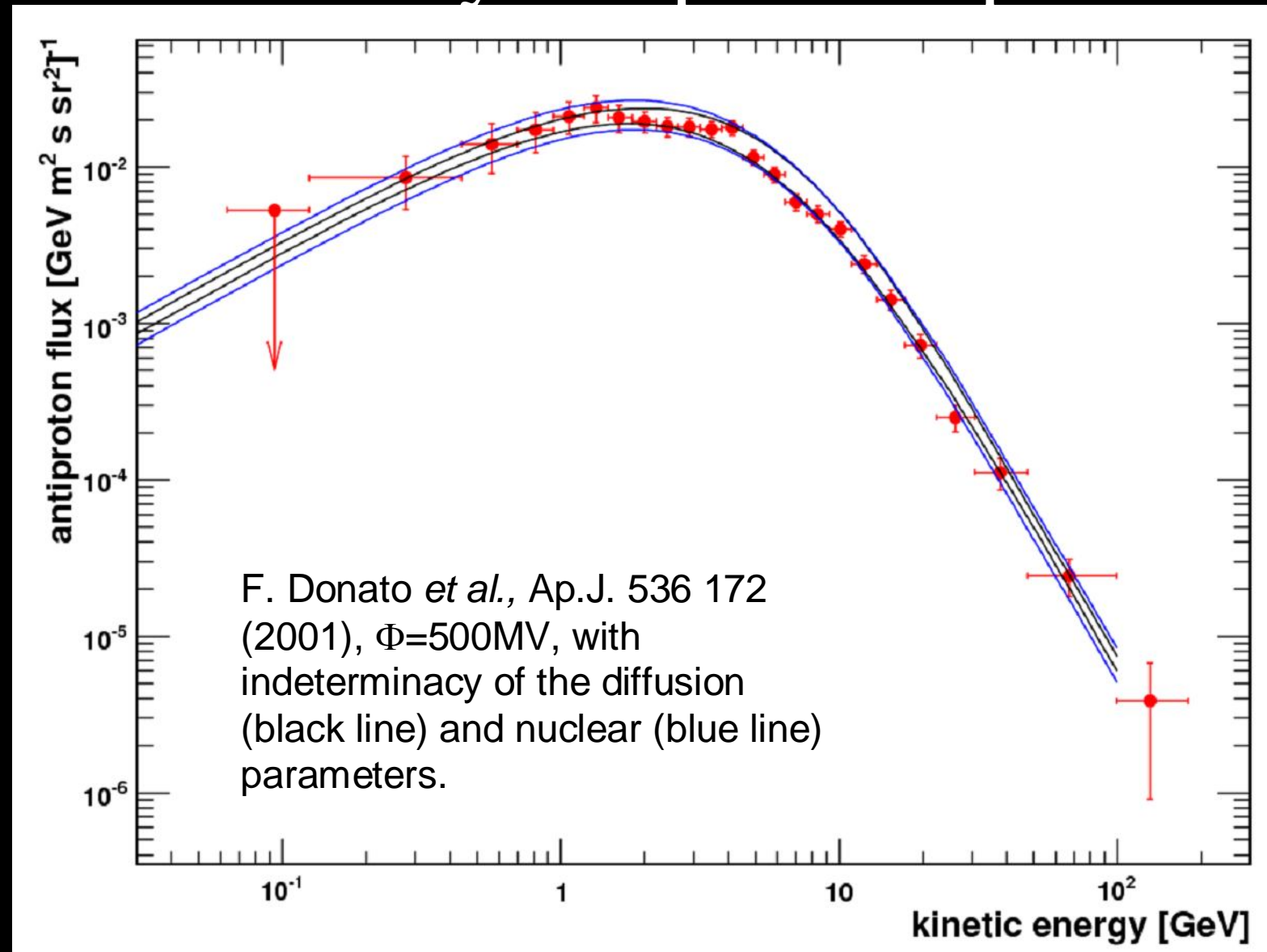
- Preliminary - Evaluation of systematics is under way.

# Preliminary antiproton spectrum



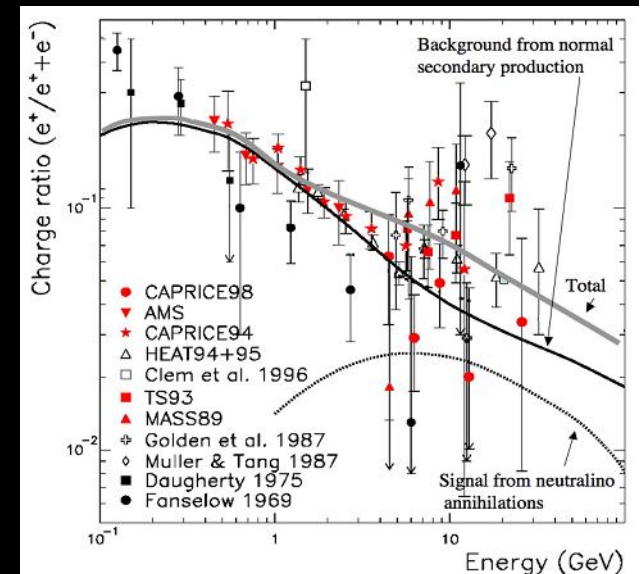


# Preliminary antiproton spectrum



# Positrons results

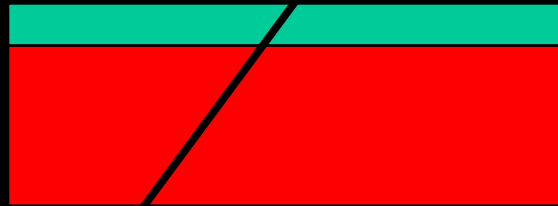
- Till August 30<sup>th</sup> about 20000 positrons from 200 MeV up to 200 GeV have been analyzed
- More than 15000 positrons over 1 GeV
- Other eight months data to be analyzed
- Selection criteria based on calorimeter
- Tuned and tested with
  - Montecarlo
  - Test Beam
  - In flight data
  - Cross-checked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



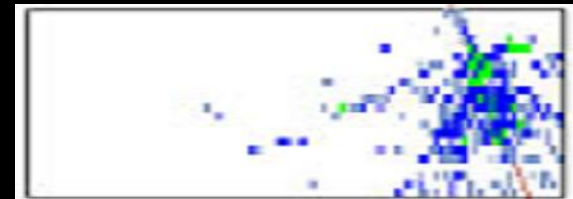
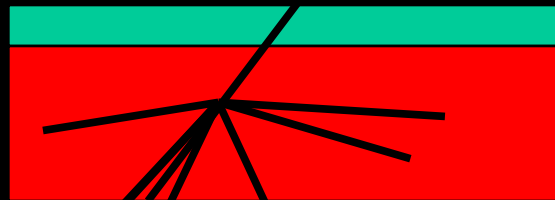
*Preshower Technique to reduce systematics of proton contamination:  
Optimize electromagnetic/hadronic shower discrimination,  
reduce systematics*

Protons:

- Non Interacting

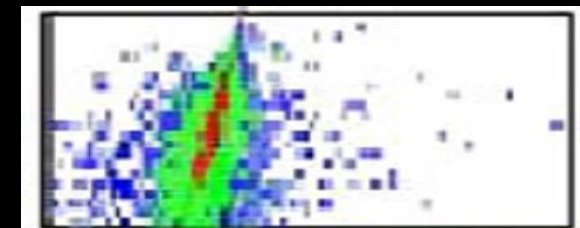
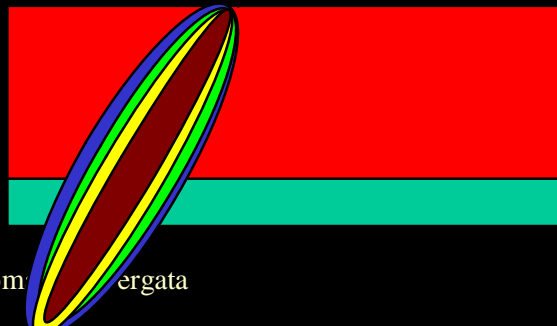


- Interacting



Electrons / Positrons

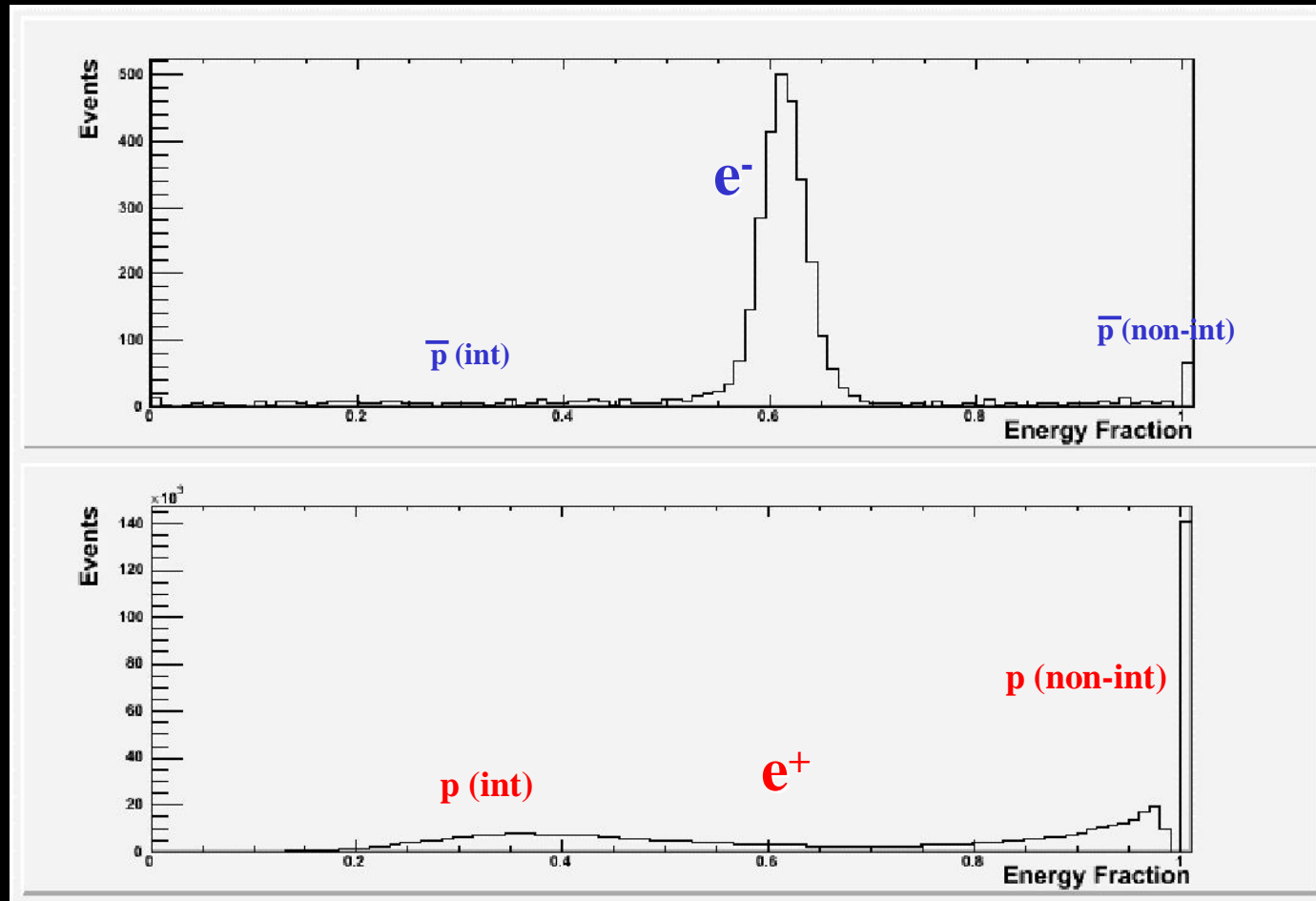
- Interacting (e.m.)





# Positron selection with calorimeter (1)

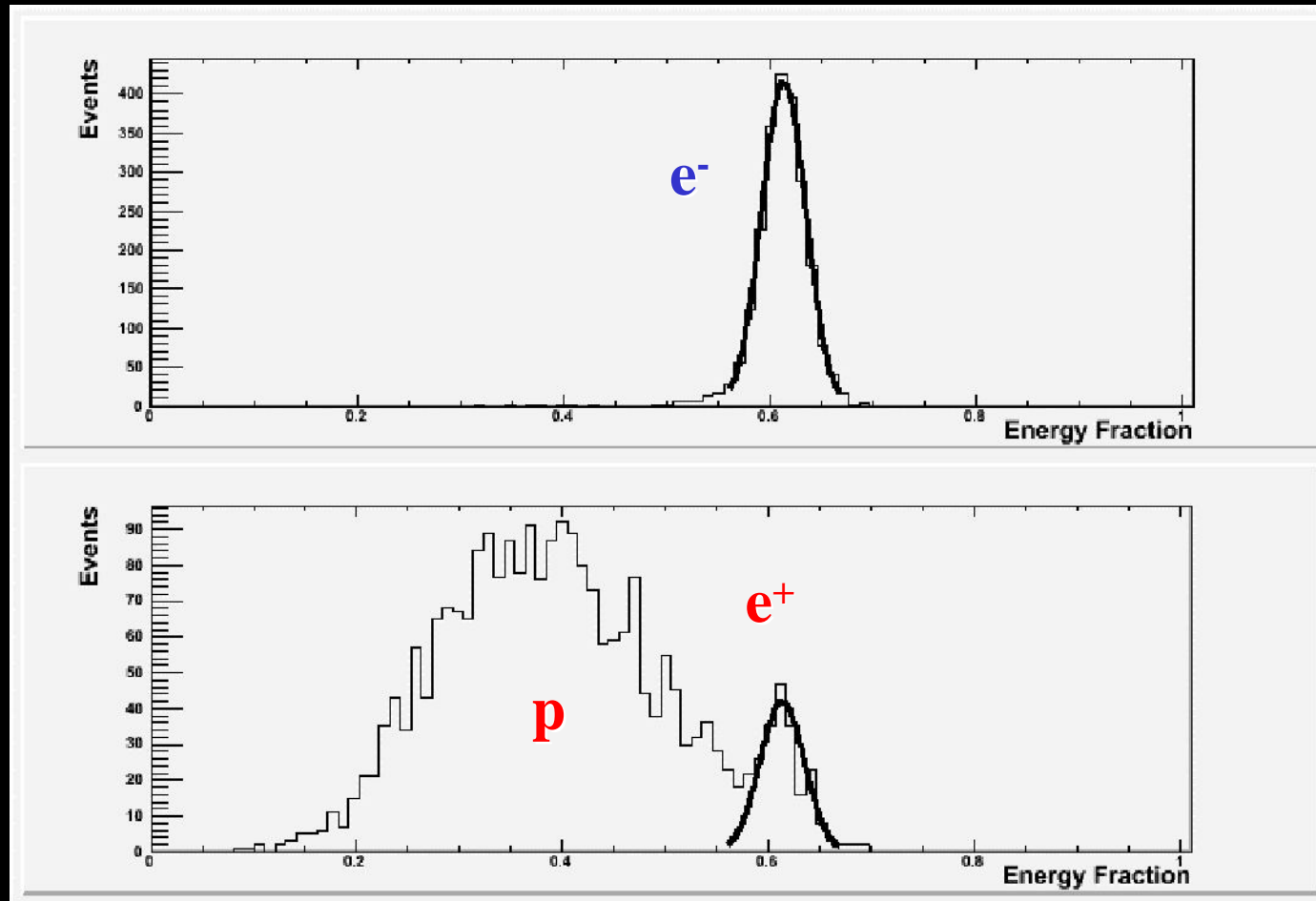
Rigidity: 20-30 GV



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

# Positron selection with calorimeter (2)

Rigidity: 20-30 GV



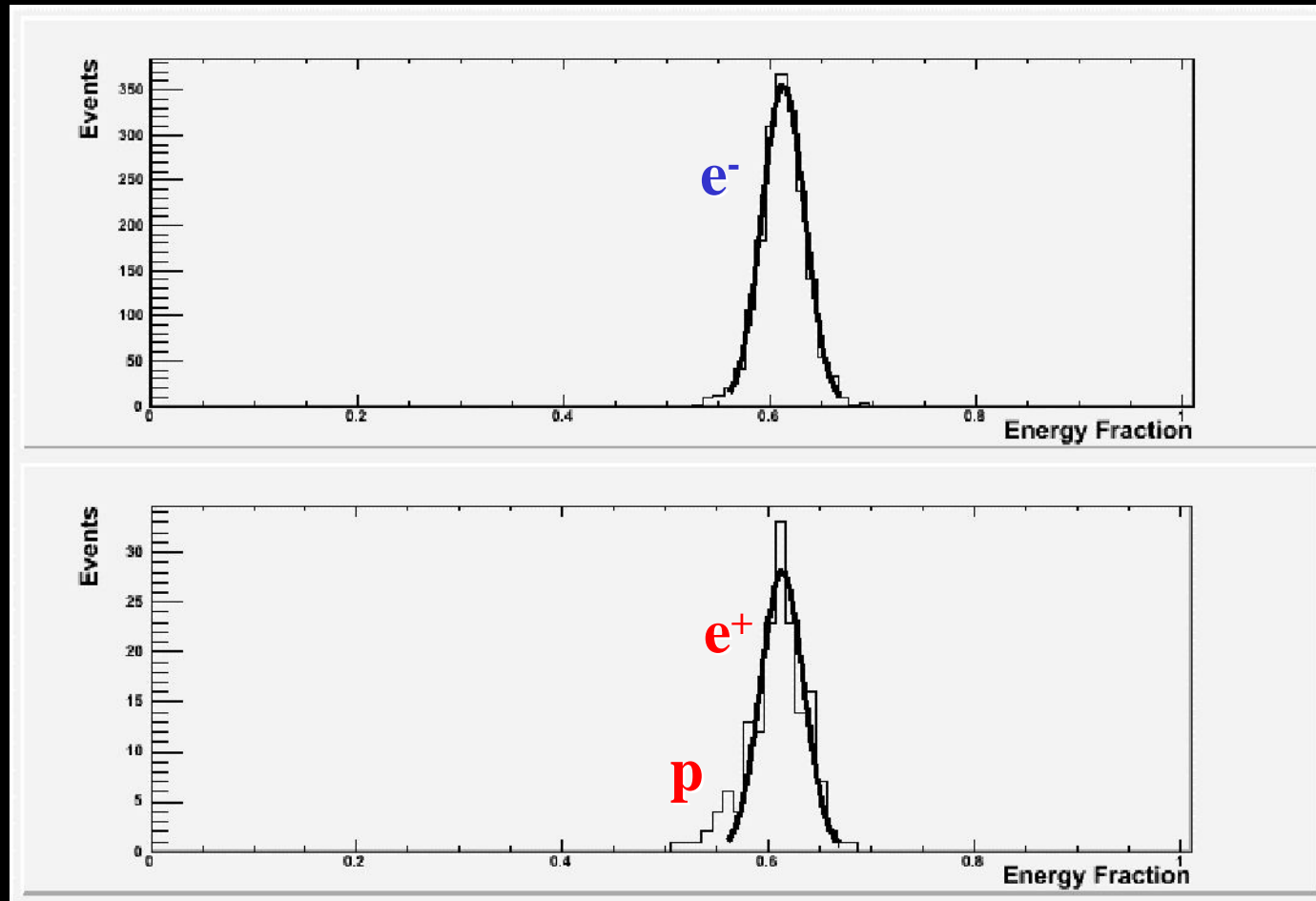
Fraction of charge released along  
the calorimeter track (left, hit, right)

+

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



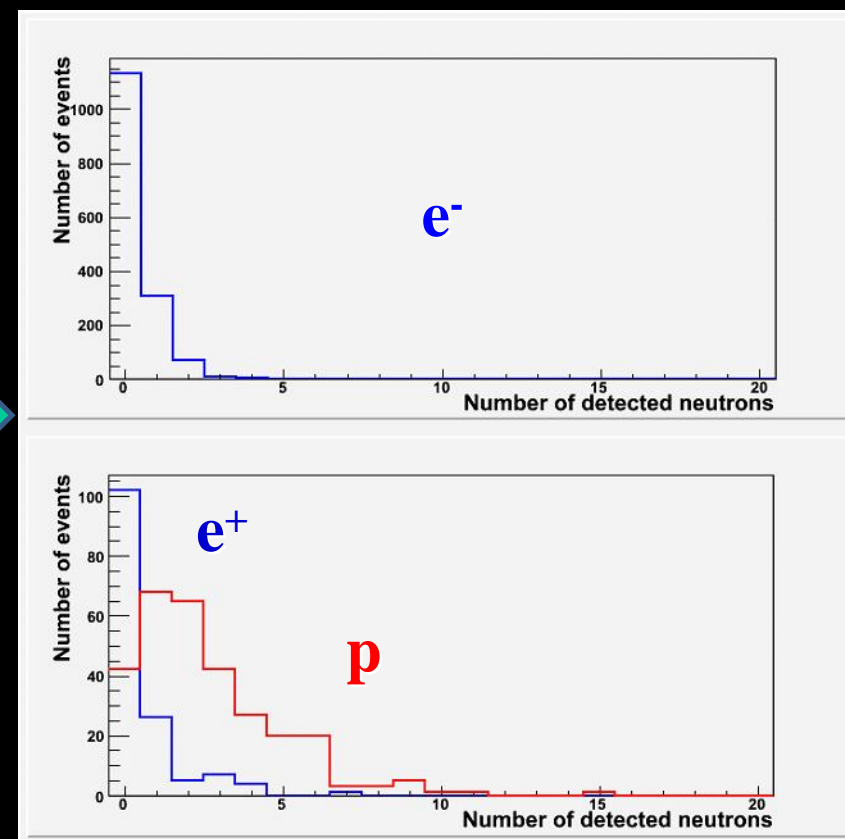
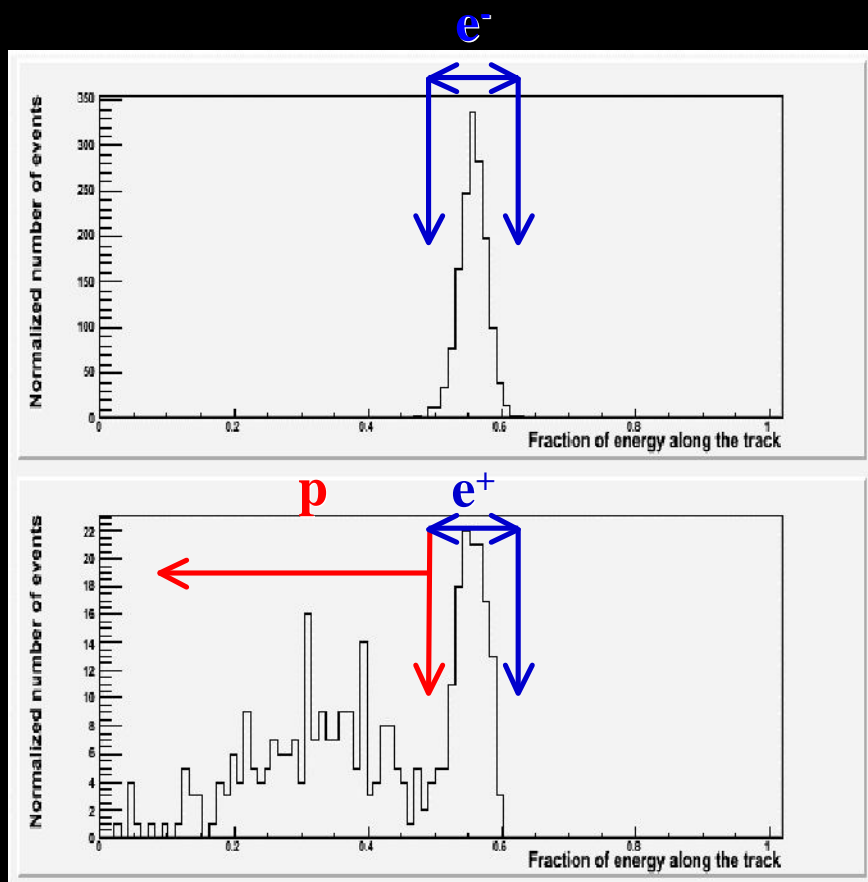
# Positron selection (4)

## Indipendent selection/check with ND

Rigidity: 20-30 GV

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

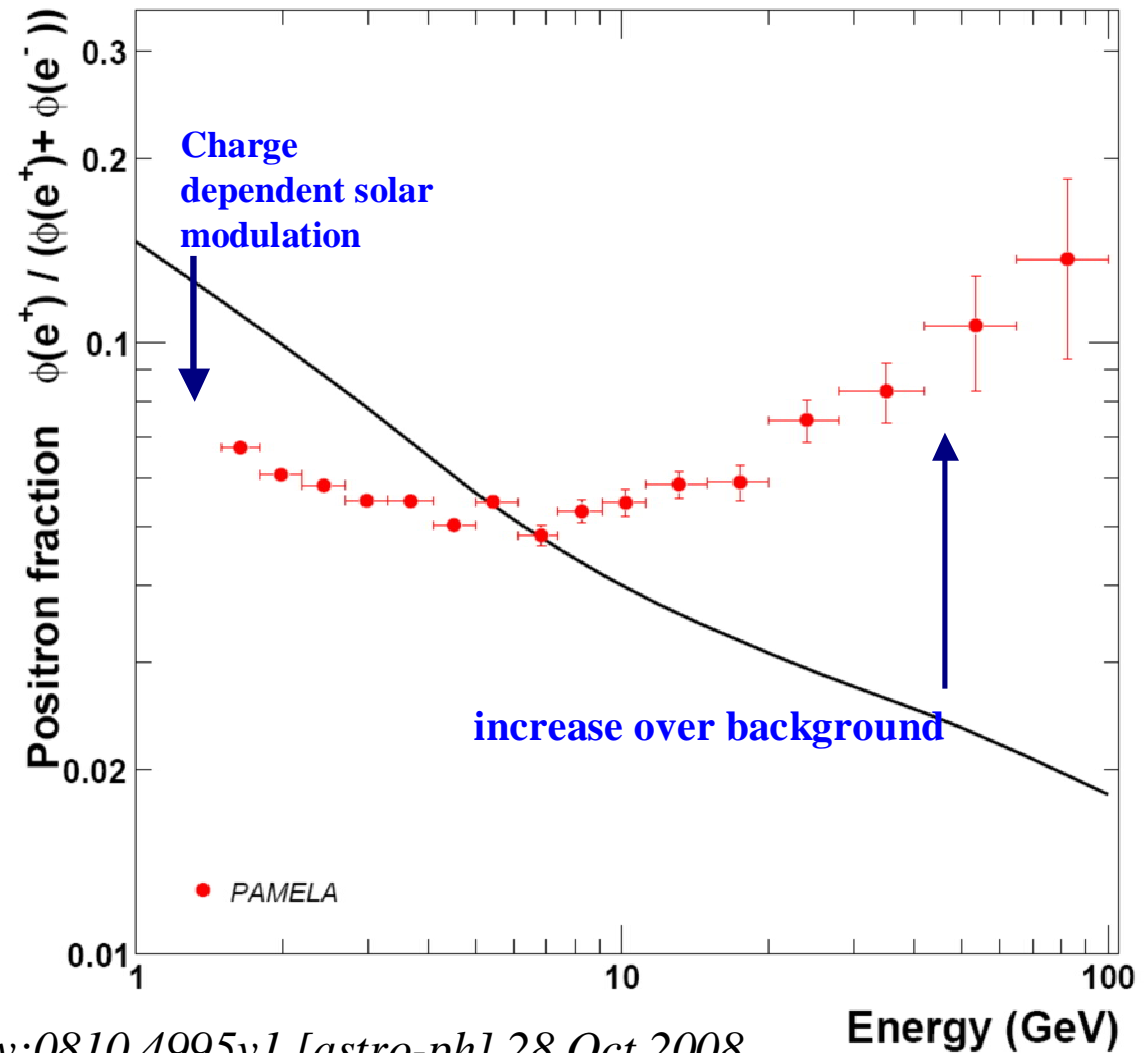
Neutrons detected by ND



Energy-momentum match  
Starting point of shower

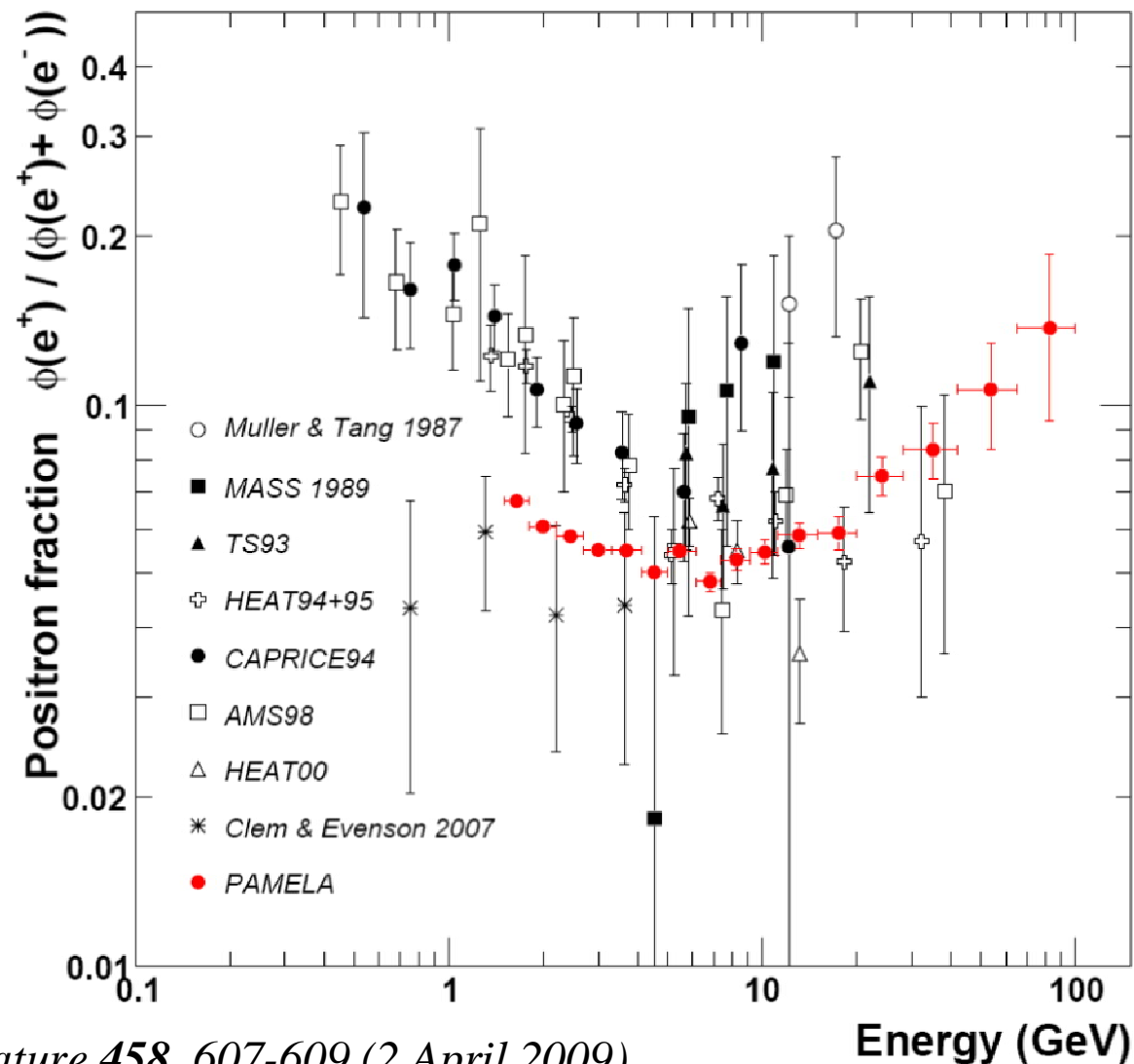
# Pamela positron fraction

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

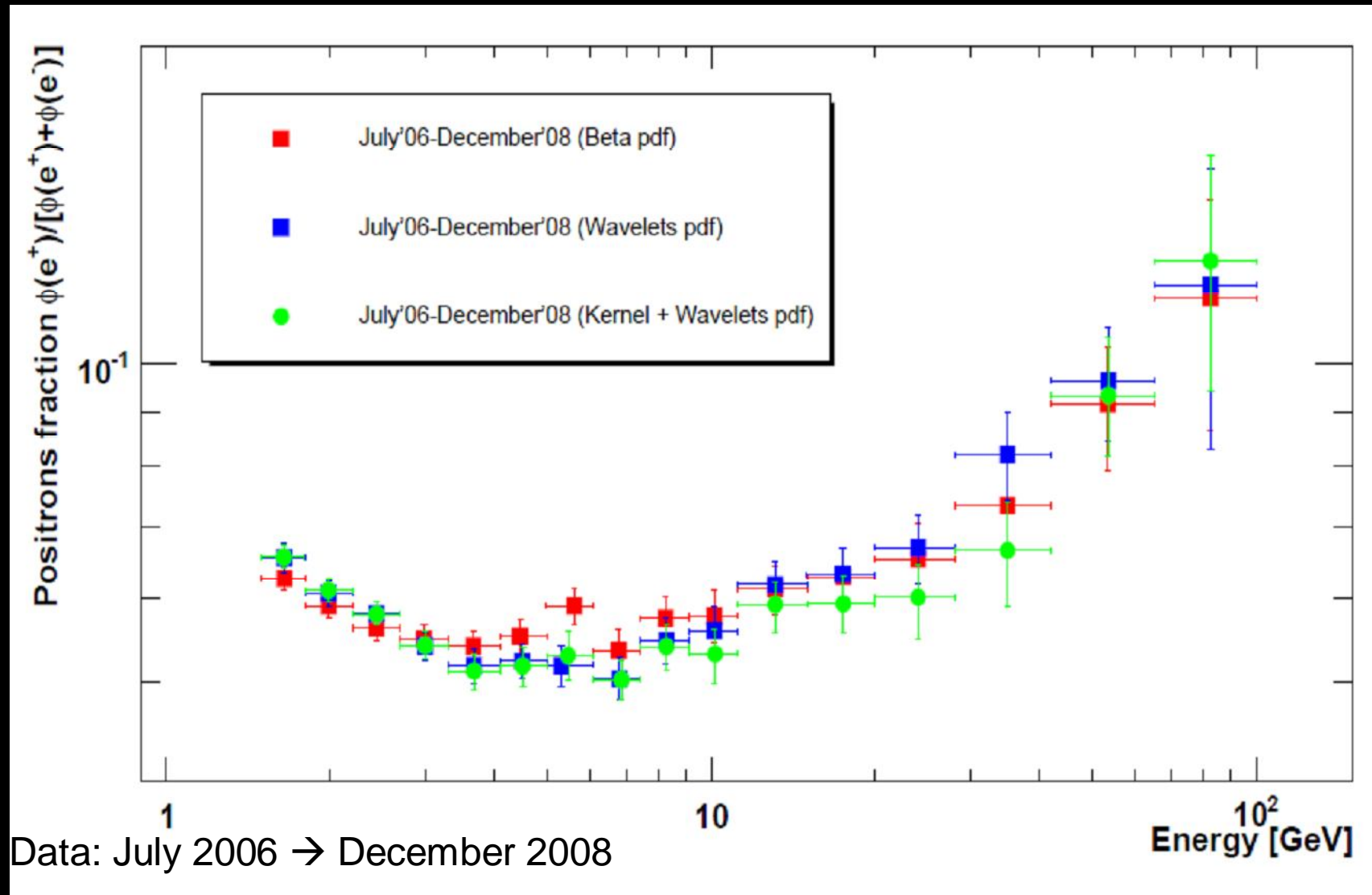


arXiv:0810.4995v1 [astro-ph] 28 Oct 2008

# Pamela positron fraction: comparison with other data

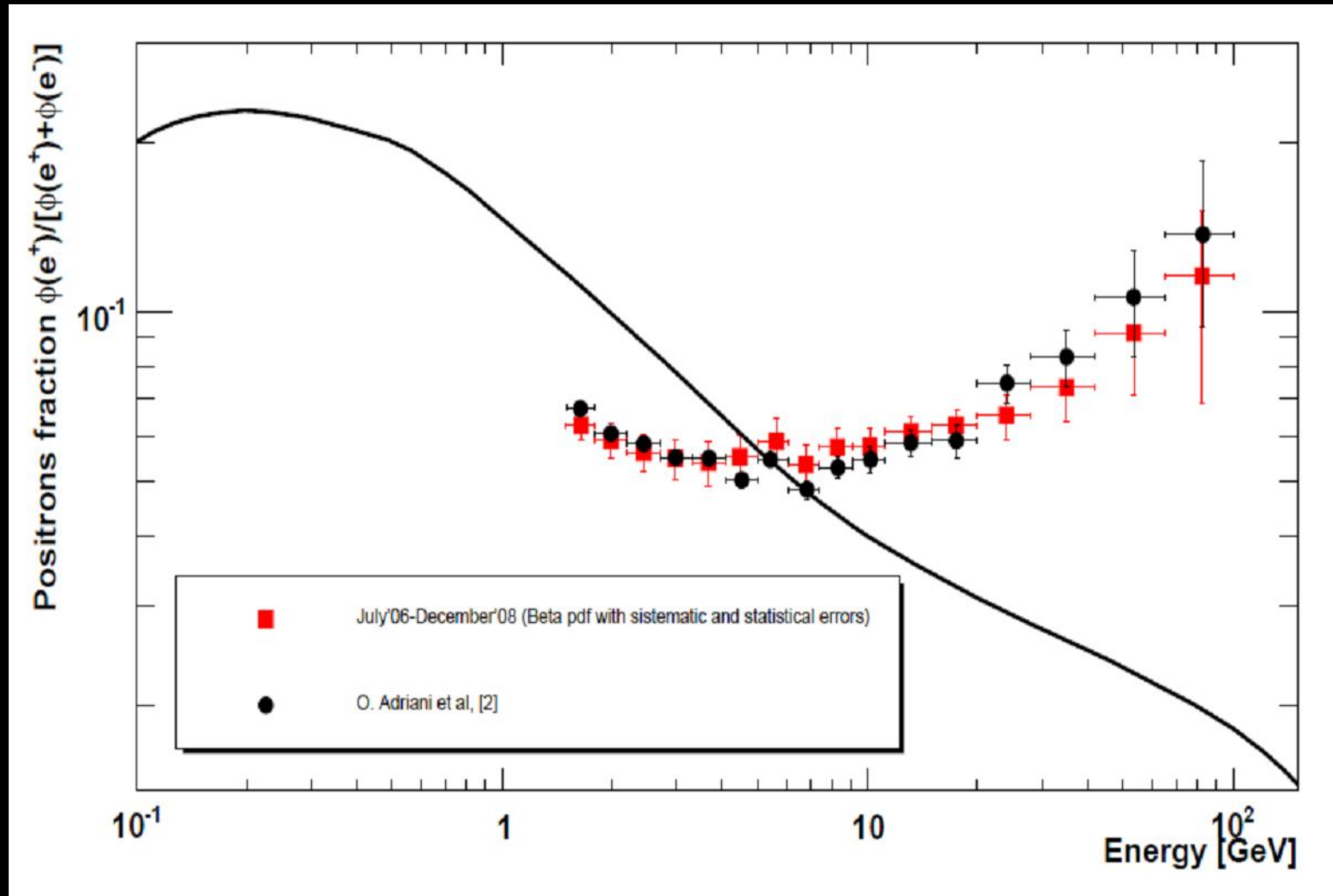


# Various approach to background subtraction



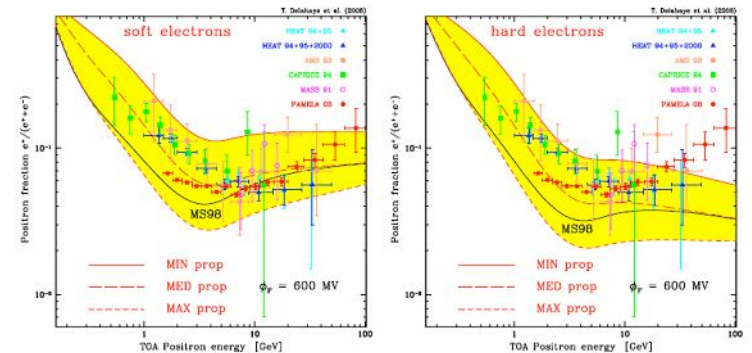
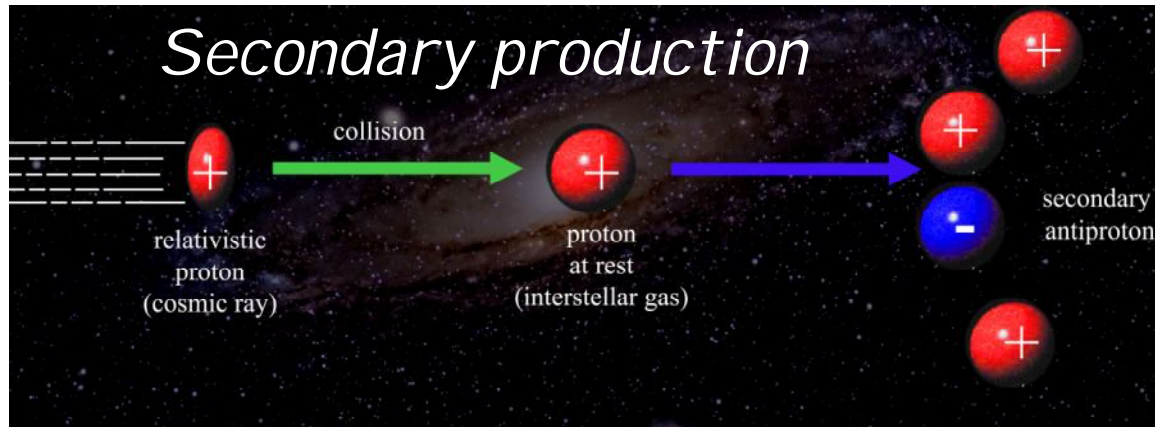


# More positrons... data up to December 2008



July 2006 → December 2008

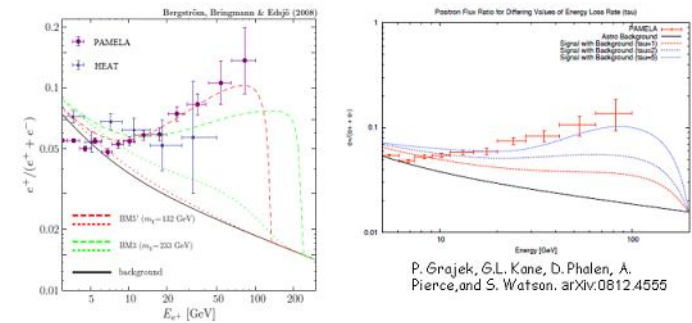
# Secondary production



## ? Dark Matter Decay



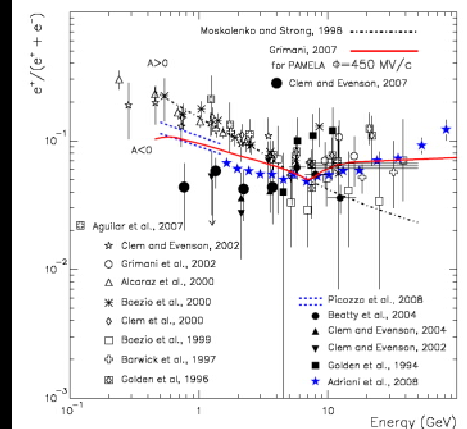
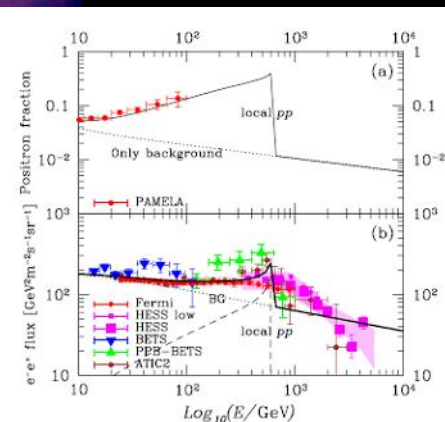
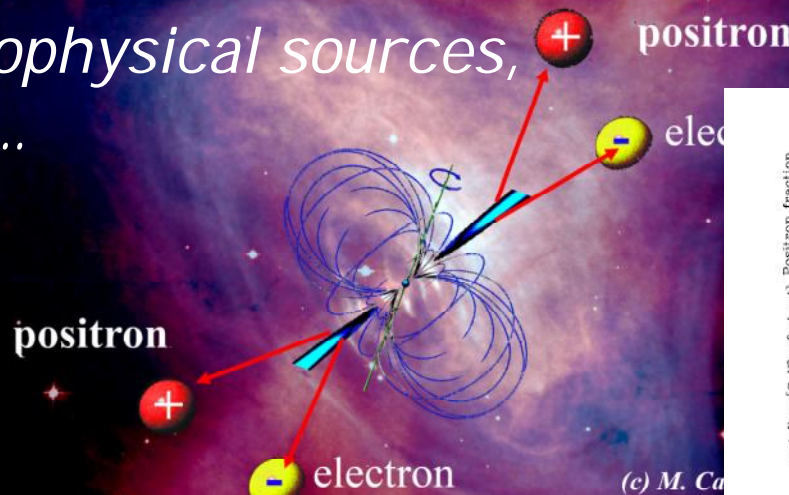
2. Example of DM solution: SUSY with internal bremsstrahlung and large boost factors, or Winos with unusual propagation parameters can give the right spectrum:



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

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

## Astrophysical sources, SNR...



**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

**?**

# Astrophysical Origin

## Pulsars

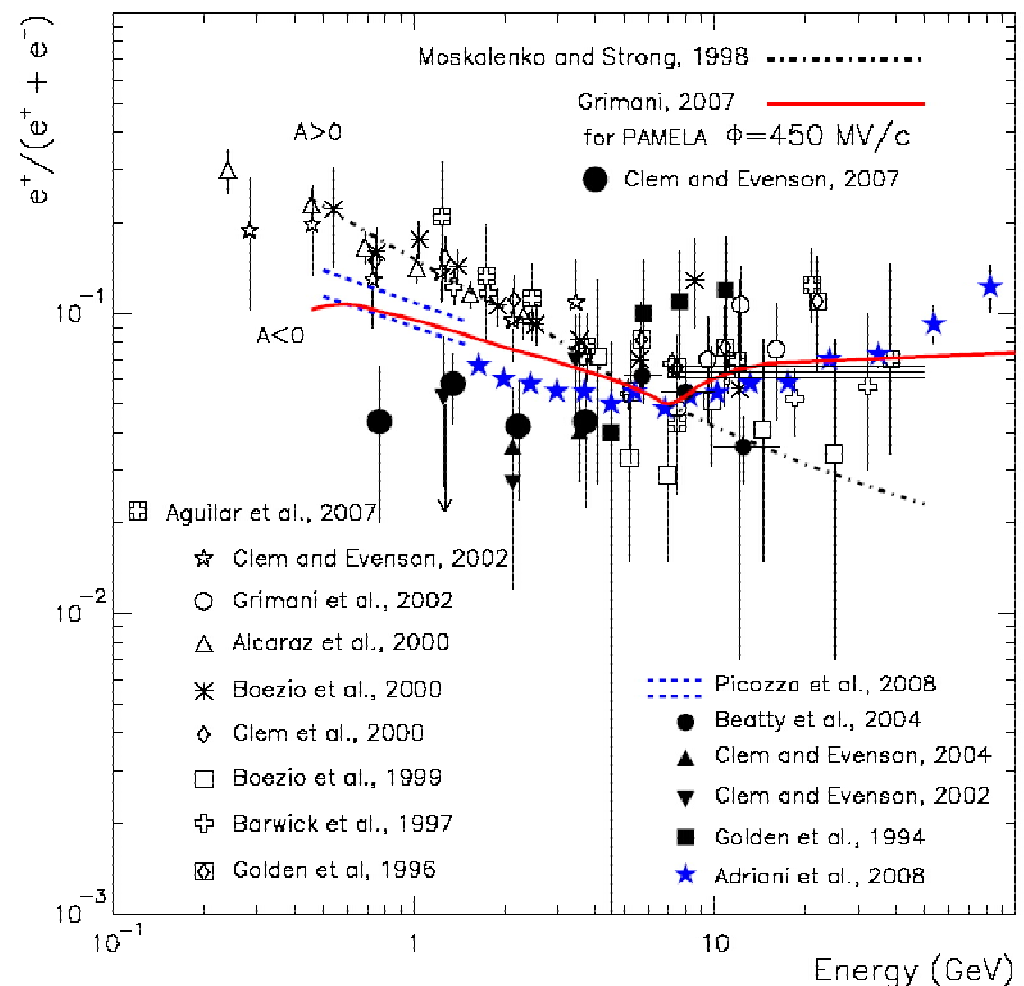
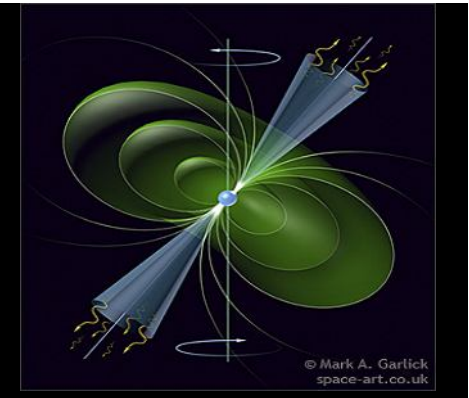
Must be young ( $T < 10^5$  yr) and nearby ( $< 1$  kpc). If not: too much diffusion, low energy, too low flux.

Injection flux:

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

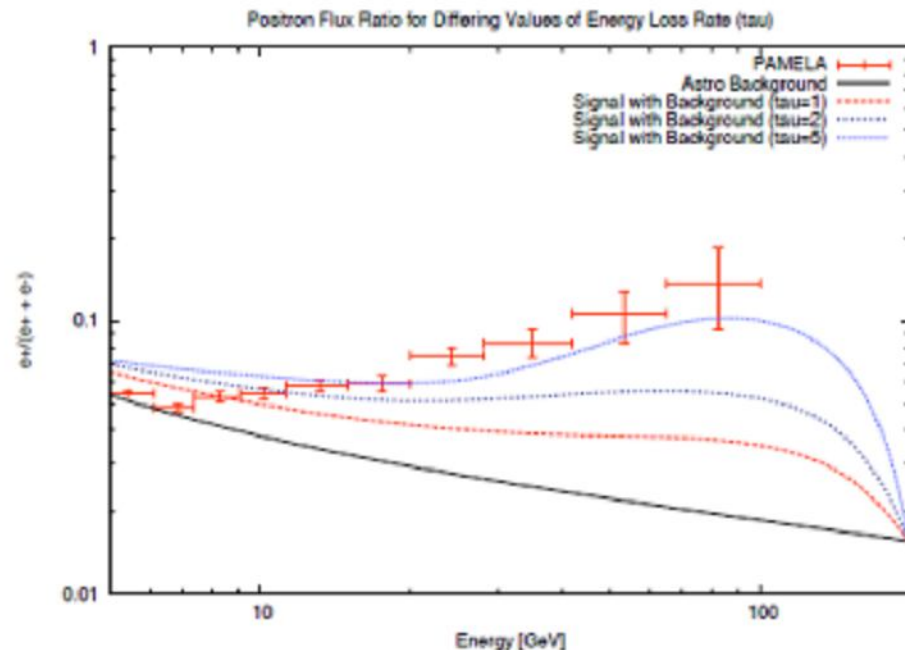
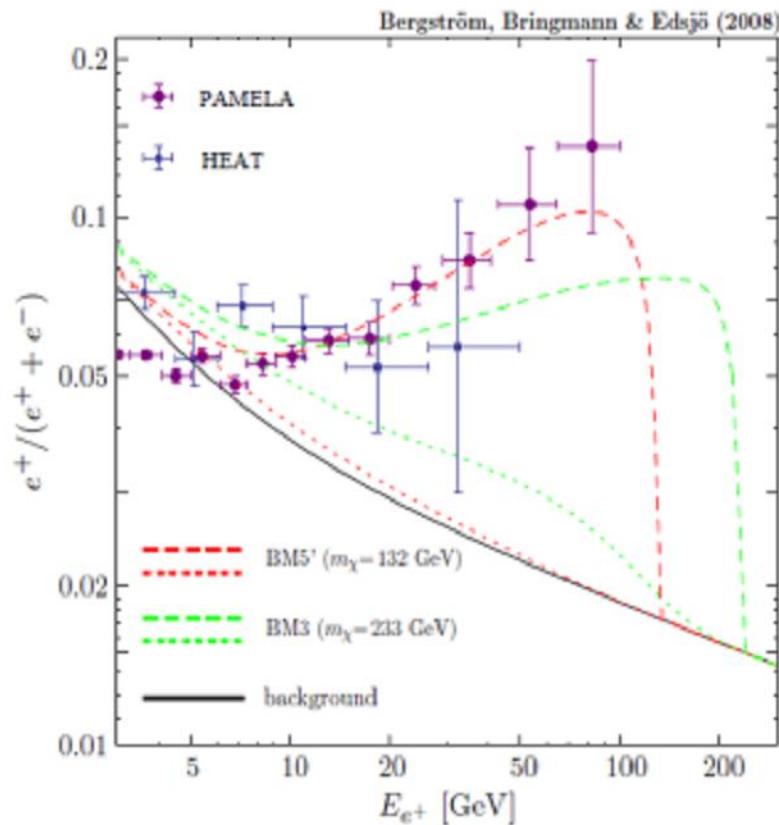
$$p \simeq 2$$

$$E_c \simeq 10 - 10^2 \text{ TeV}$$





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

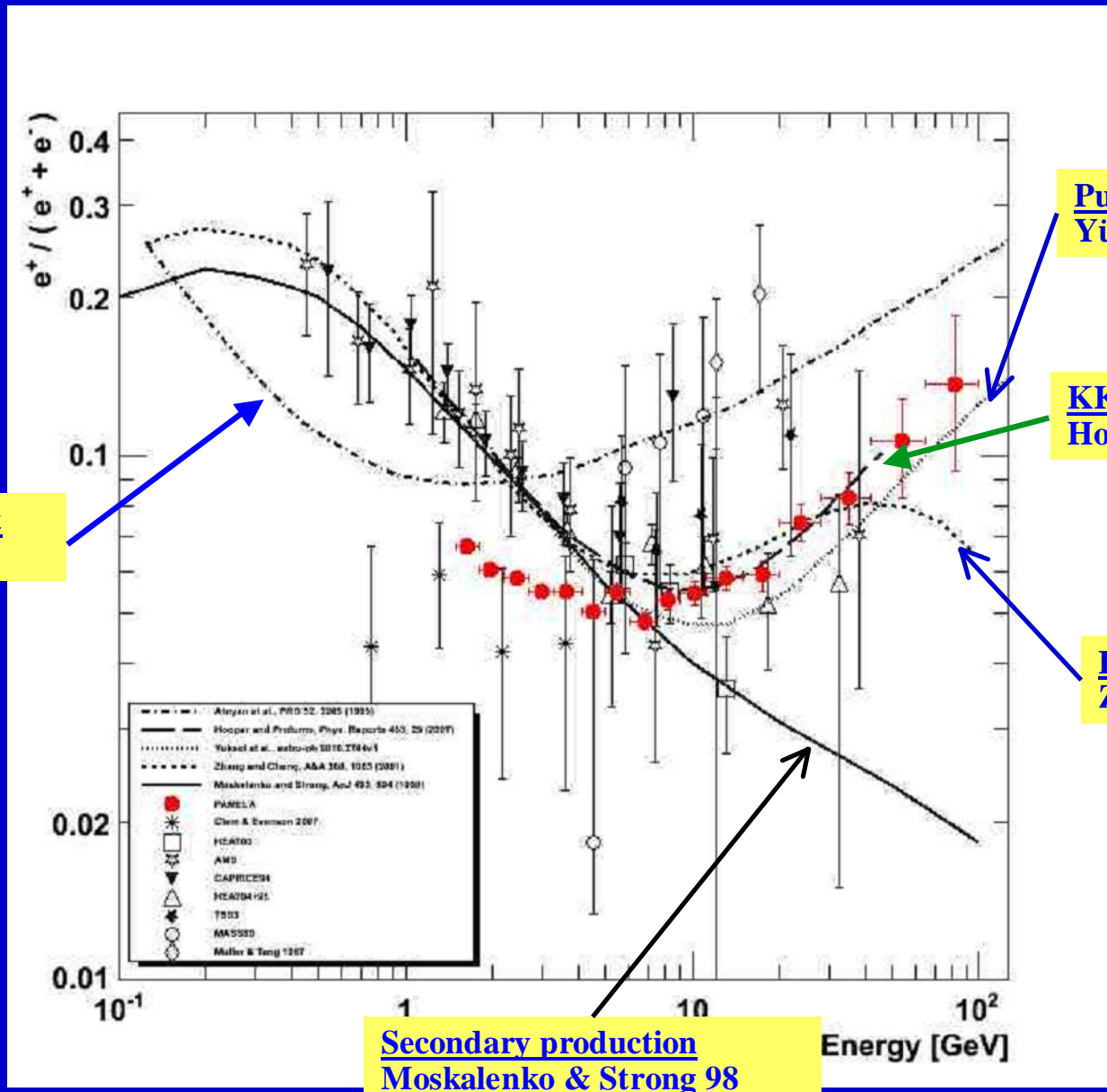


P. Grajek, G.L. Kane, D. Phalen, A. Pierce, and S. Watson. arXiv:0812.4555

Bergstrom 2009

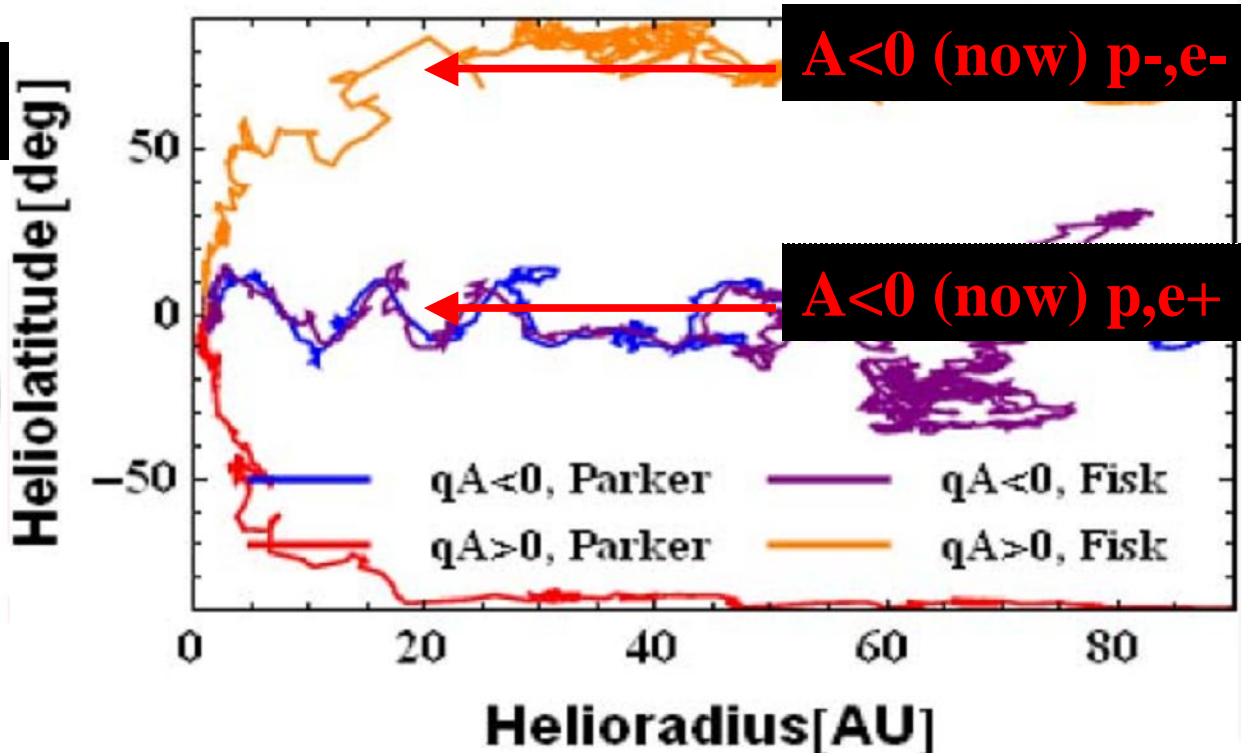
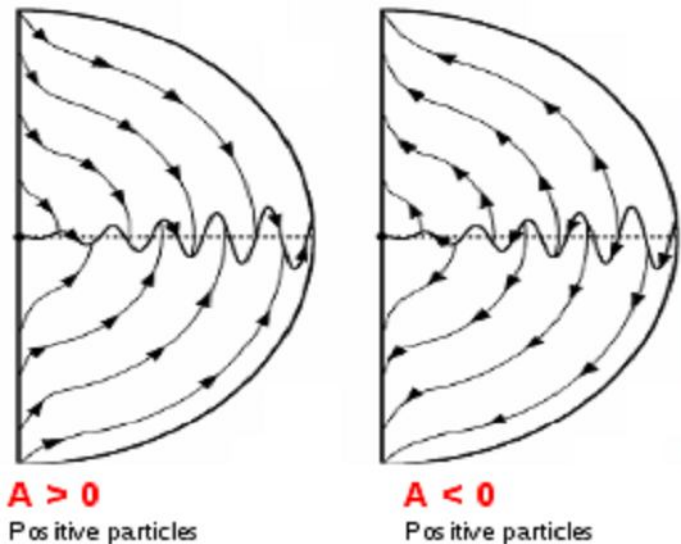
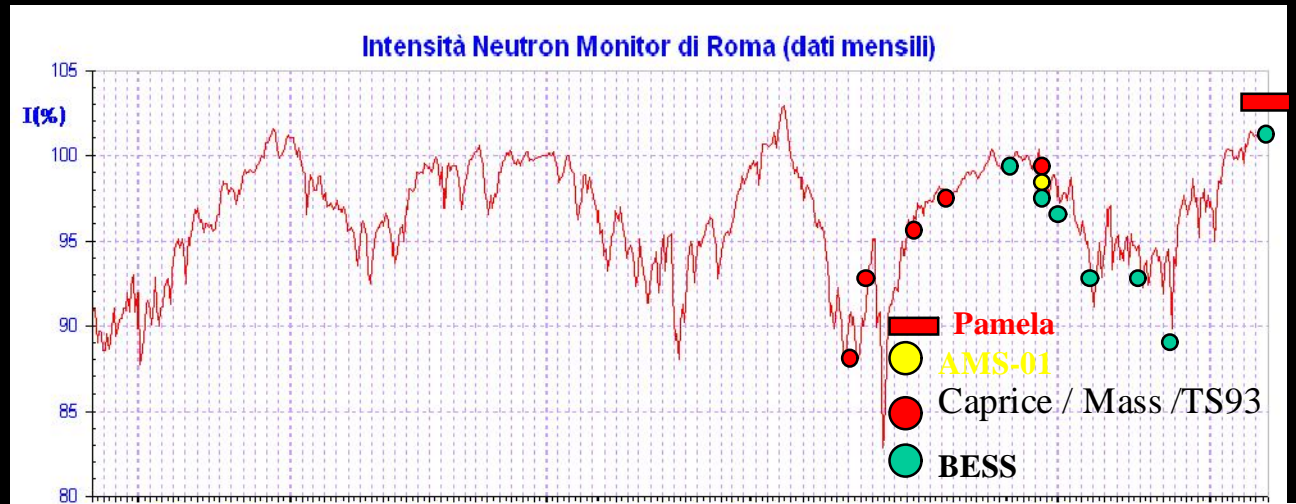
However, does not explain new electron plus positron data (see later)

# Positron fraction: comparison with models

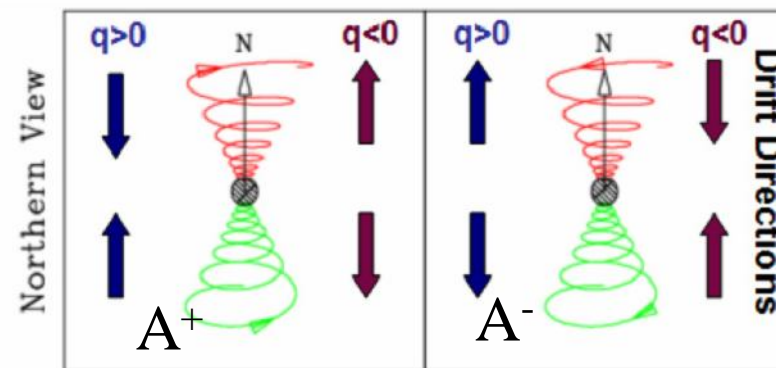
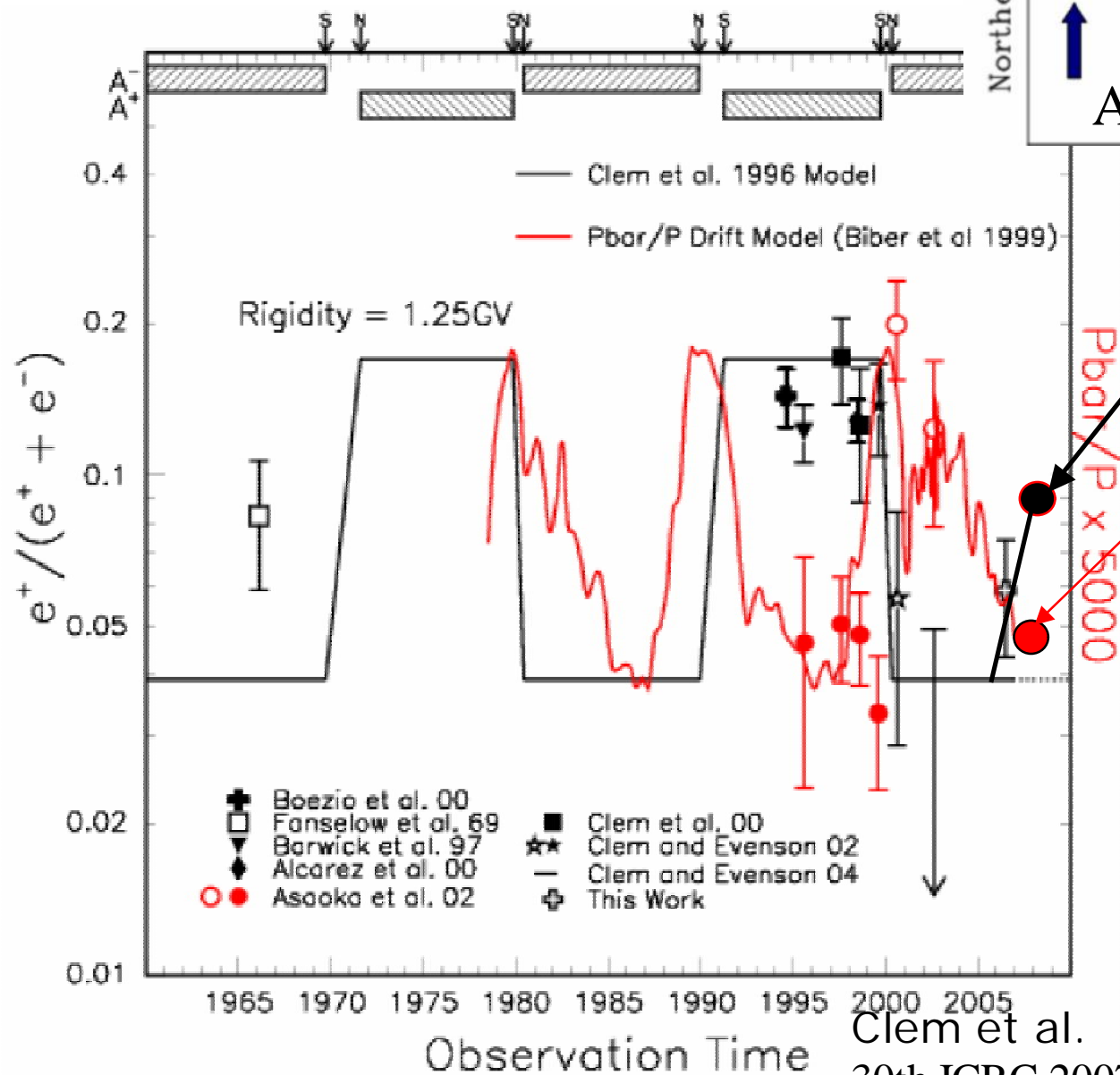


# Charge dependent solar modulation of low energy positrons

- 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

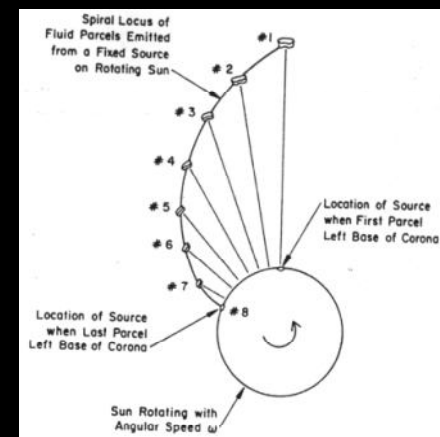


# Charge dependent solar modulation



Pamela

Pamela p-



Clem et al.  
30th ICRC 2007



# Electrons and positrons are fashionable

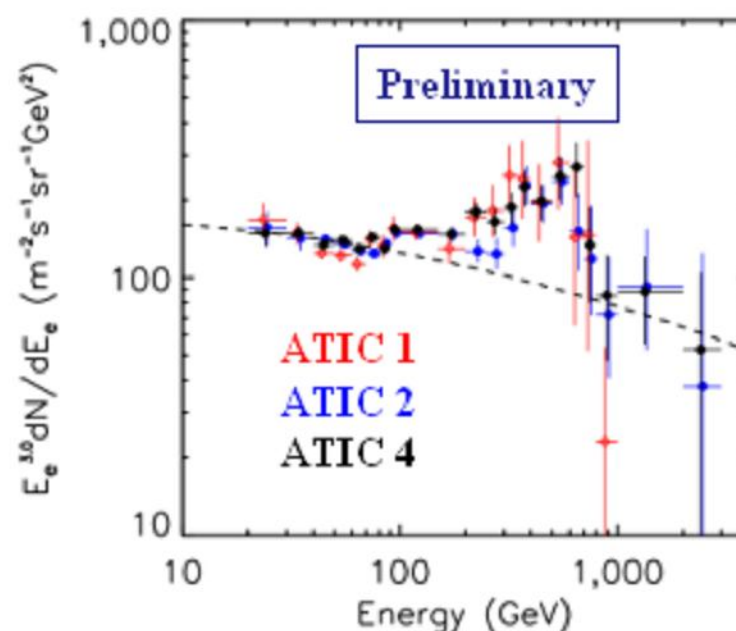
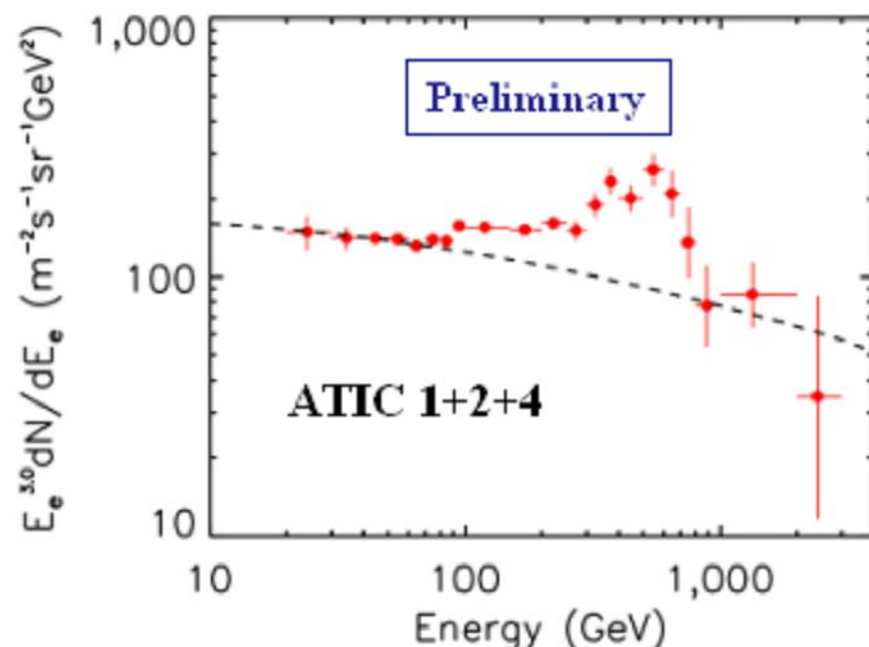
But there is disagreement on the  $e^+e^-$  spectrum

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

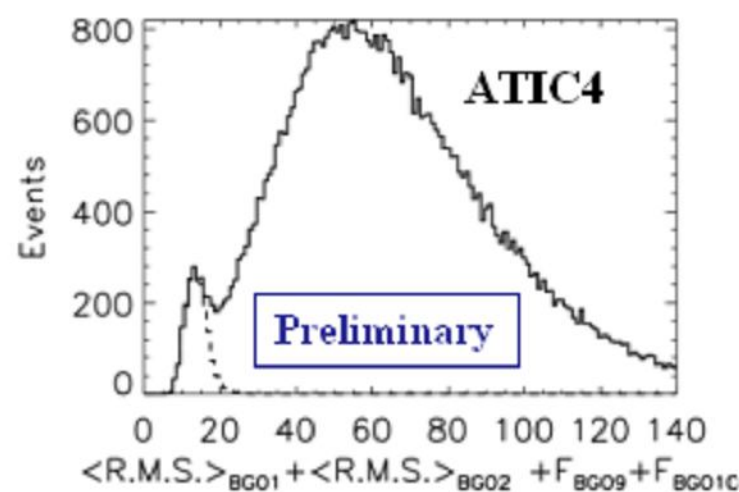


"Source on/source off" significance of bump for ATIC1+2 is about 3.8 sigma

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

"Bump" is seen in all three flights.

Significance for ATIC1+2+4 is 5.1 sigma

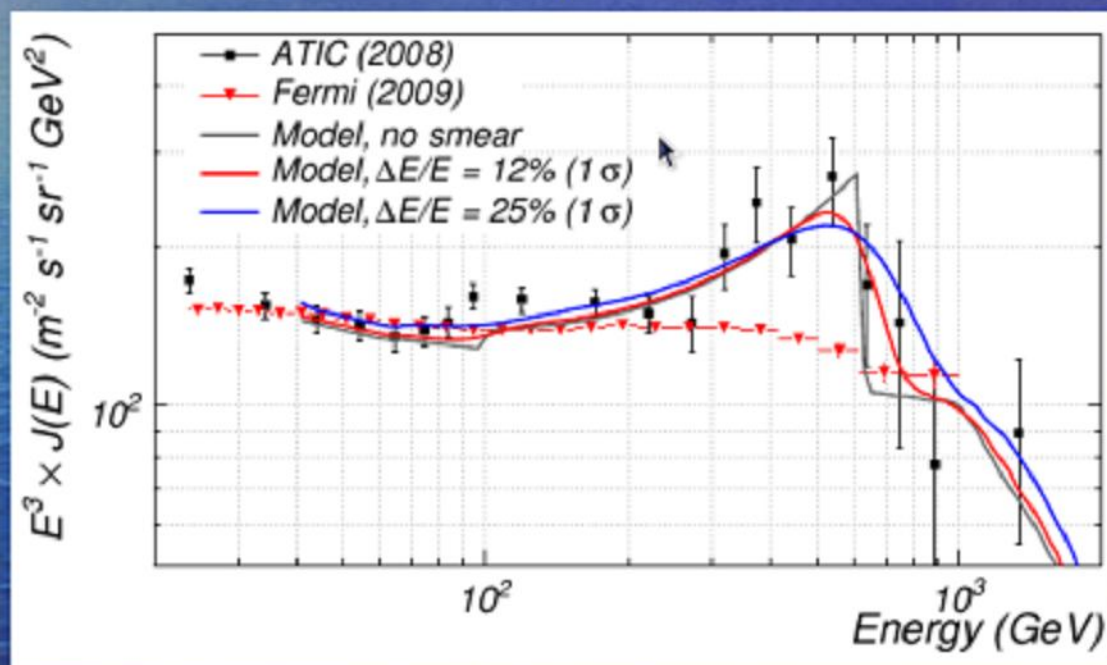




## And finally we want to check - could we miss “ATIC-like” spectral feature?

*We validated the spectrum reconstruction by:*

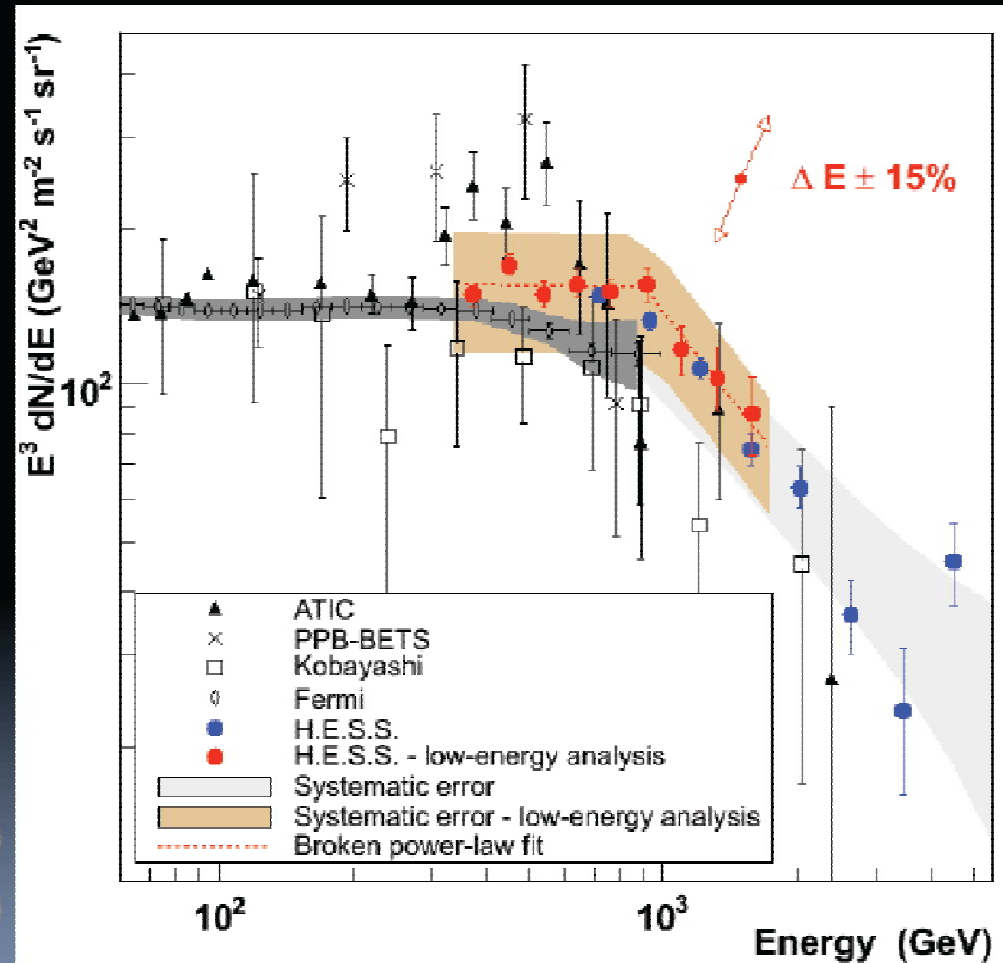
- *comparing the results for different path length subsets*
- *varying the electron selections*
- *simulating the LAT response to a spectrum with an “ATIC-like” feature:*



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

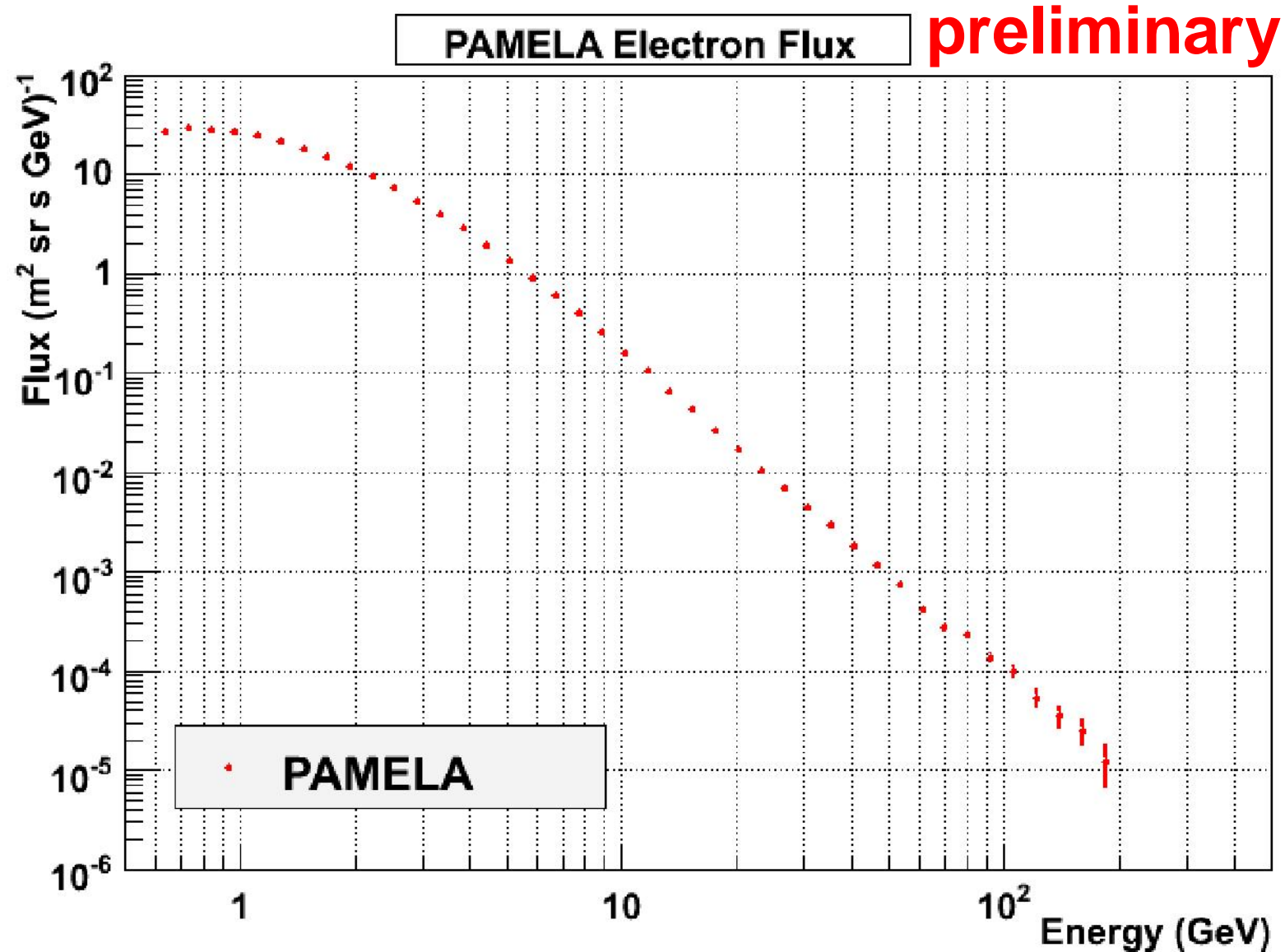
- Cuts:
  - ▢ impact distance < 100 m
  - ▢ image size in each camera > 80 photo electrons
  - ▢ Data set of 2004/2005
- Syst. uncertainty: atmospheric variations + model dependence of proton simulations (SIBYLL vs. QGSJET-II)
- Spectral index:
 
$$\Gamma_1 = 3.0 \pm 0.1(\text{stat}) \pm 0.3(\text{syst.})$$

$$\Gamma_2 = 3.9 \pm 0.1(\text{stat}) \pm 0.3(\text{syst.})$$

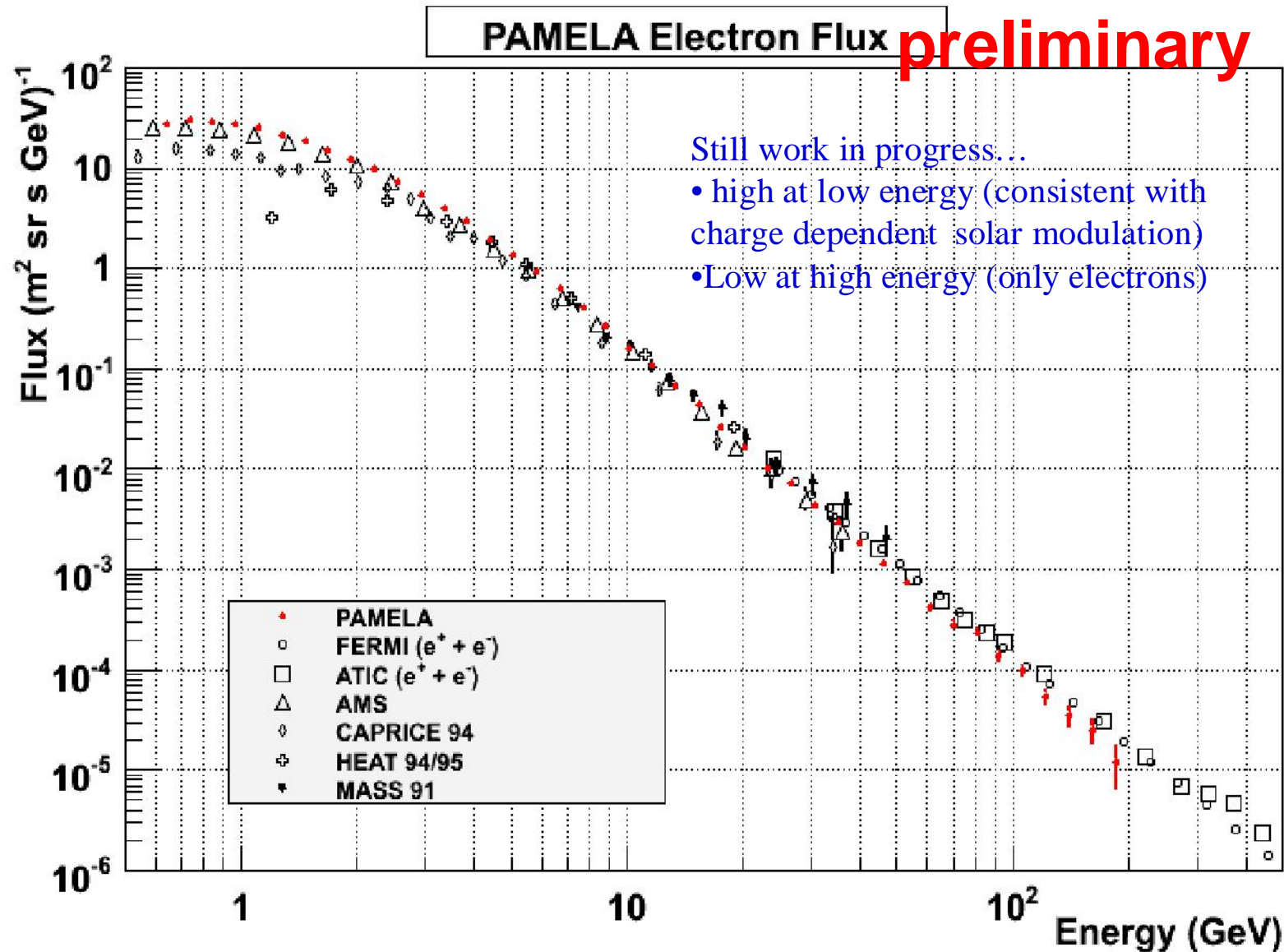




# PAMELA electron flux

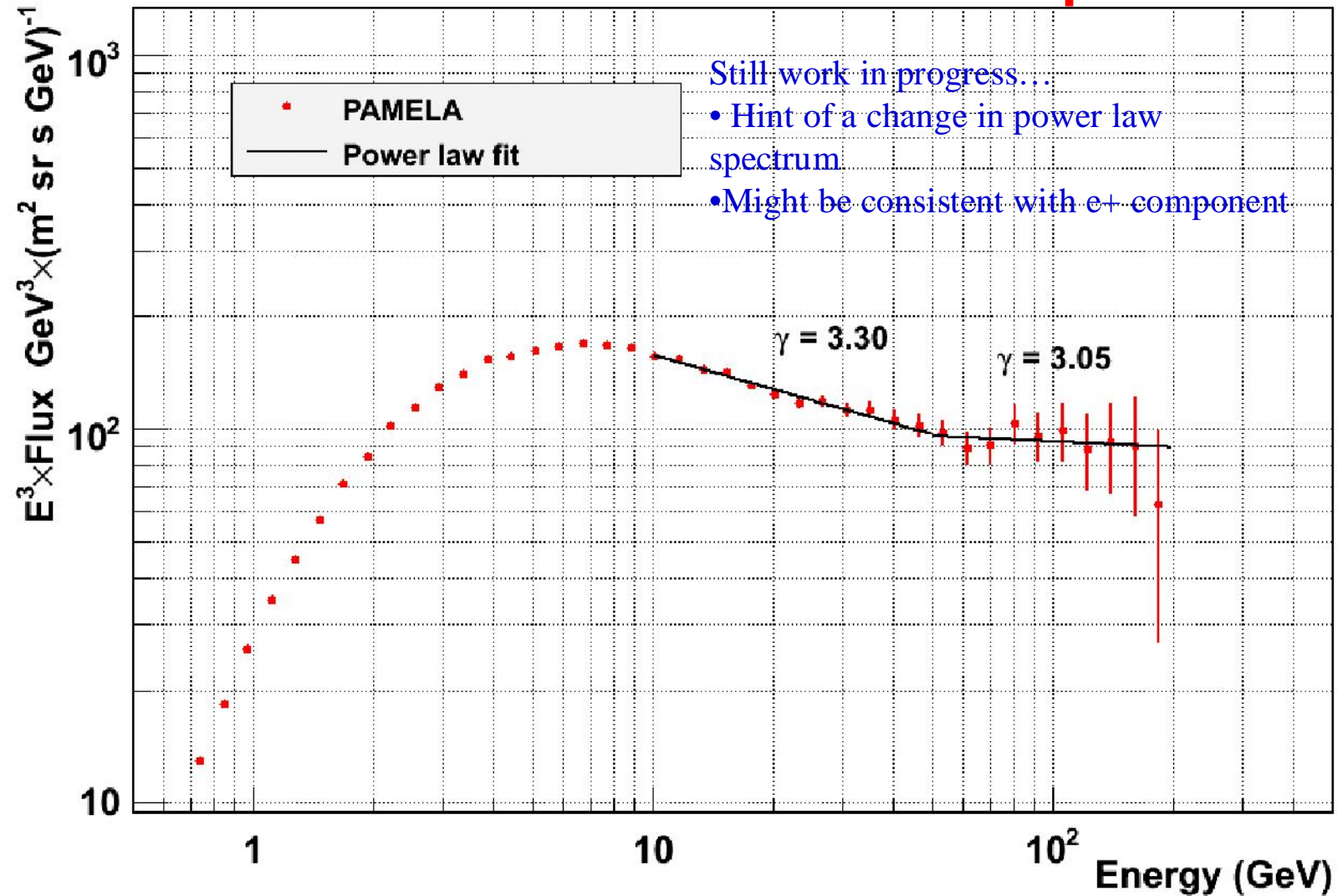


# Comparison with other experiments



## PAMEL Electron Flux

preliminary







- Pamela is operating successfully in space

- Expected three years of operations –  
completed

Extended other 2 years

- Data received until now show good potential and  
fulfillment of scientific goals

<http://pamela.roma2.infn.it>

<http://www.casolino.it>