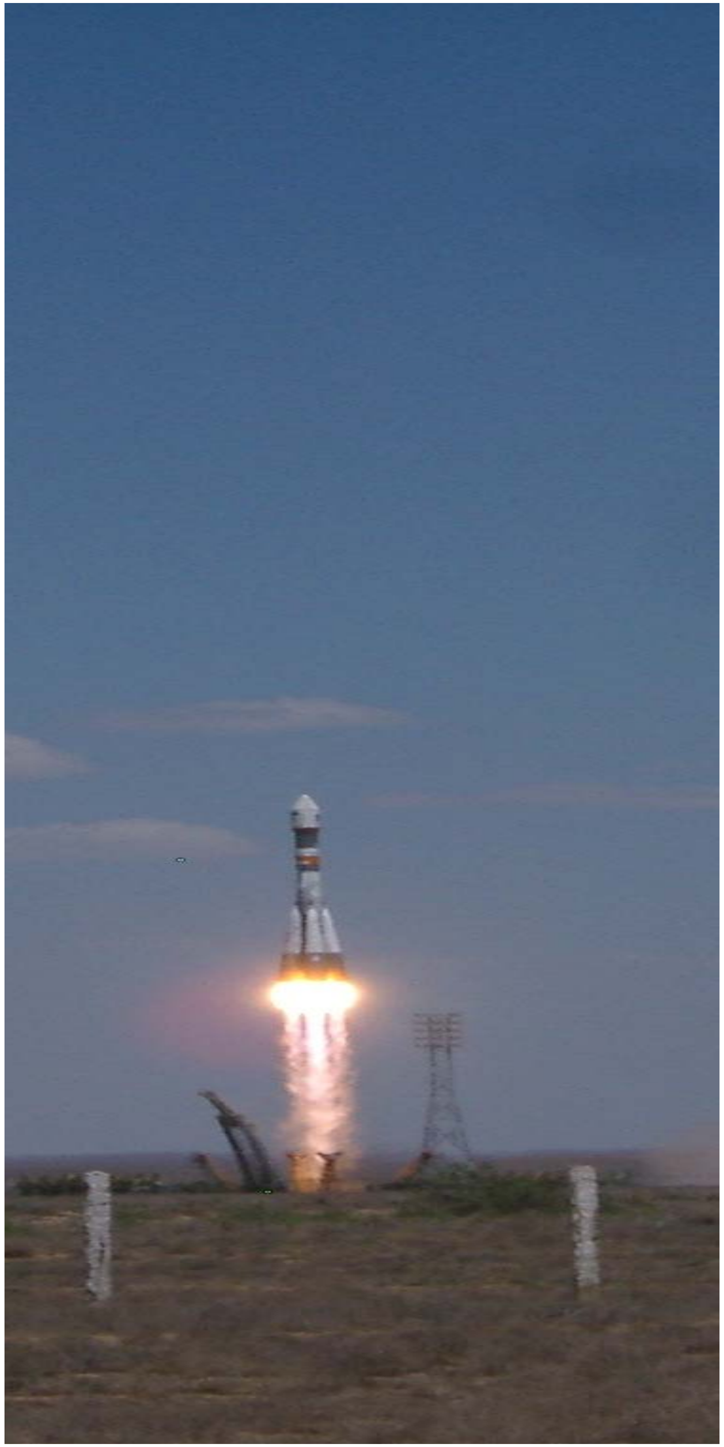


# The Science and First Results of the PAMELA Space Mission


**Mirko Boezio**
*INFN Trieste, Italy*


On behalf of the PAMELA collaboration

CERN

*October 28th 2008*

# PAMELA

**Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics**

# PAMELA Collaboration

Bari | Florence | Frascati | Naples | Rome | Trieste | CNR, Florence

Russia:

Ioffe Physico-Technical Institute

Moscow
St. Petersburg

Germany: Universität Gesamthochschule Siegen

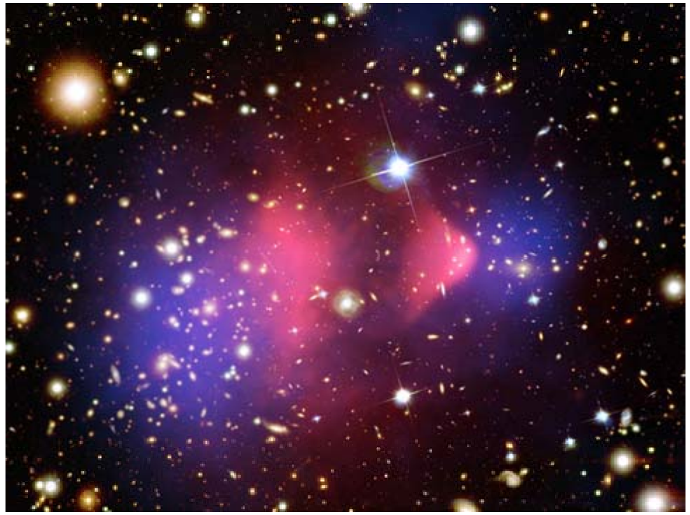
Siegen

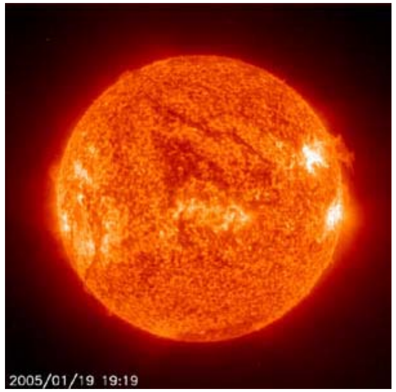
Sweden: Kungl Tekniska Högskolan

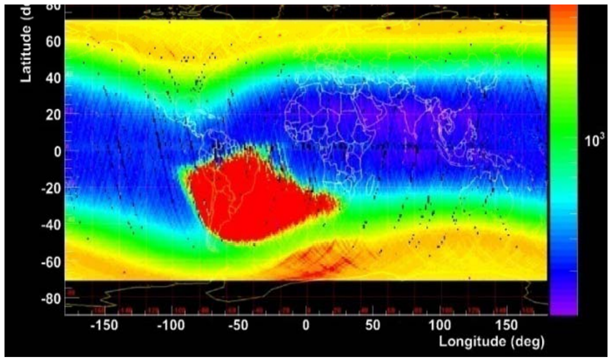
KTH, Stockholm

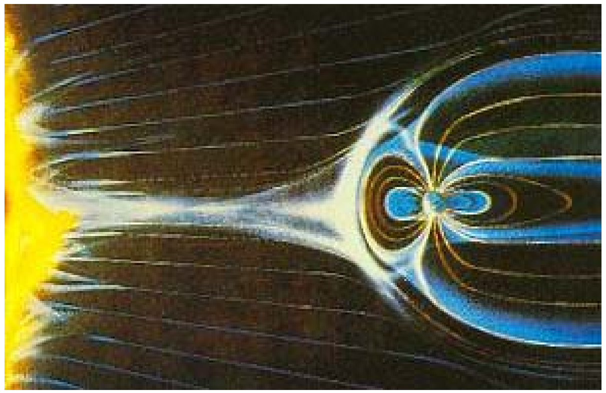
# PAMELA as a Space Observatory at 1 AU

- **Search for dark matter annihilation**
- **Search for antihelium (primordial antimatter)**
- **Search for new Matter in the Universe (Strangelets?)**
- **Study of cosmic-ray propagation**
- **Study of solar physics and solar modulation**
- **Study of terrestrial magnetosphere**
- **Study of high energy electron spectrum (local sources?)**

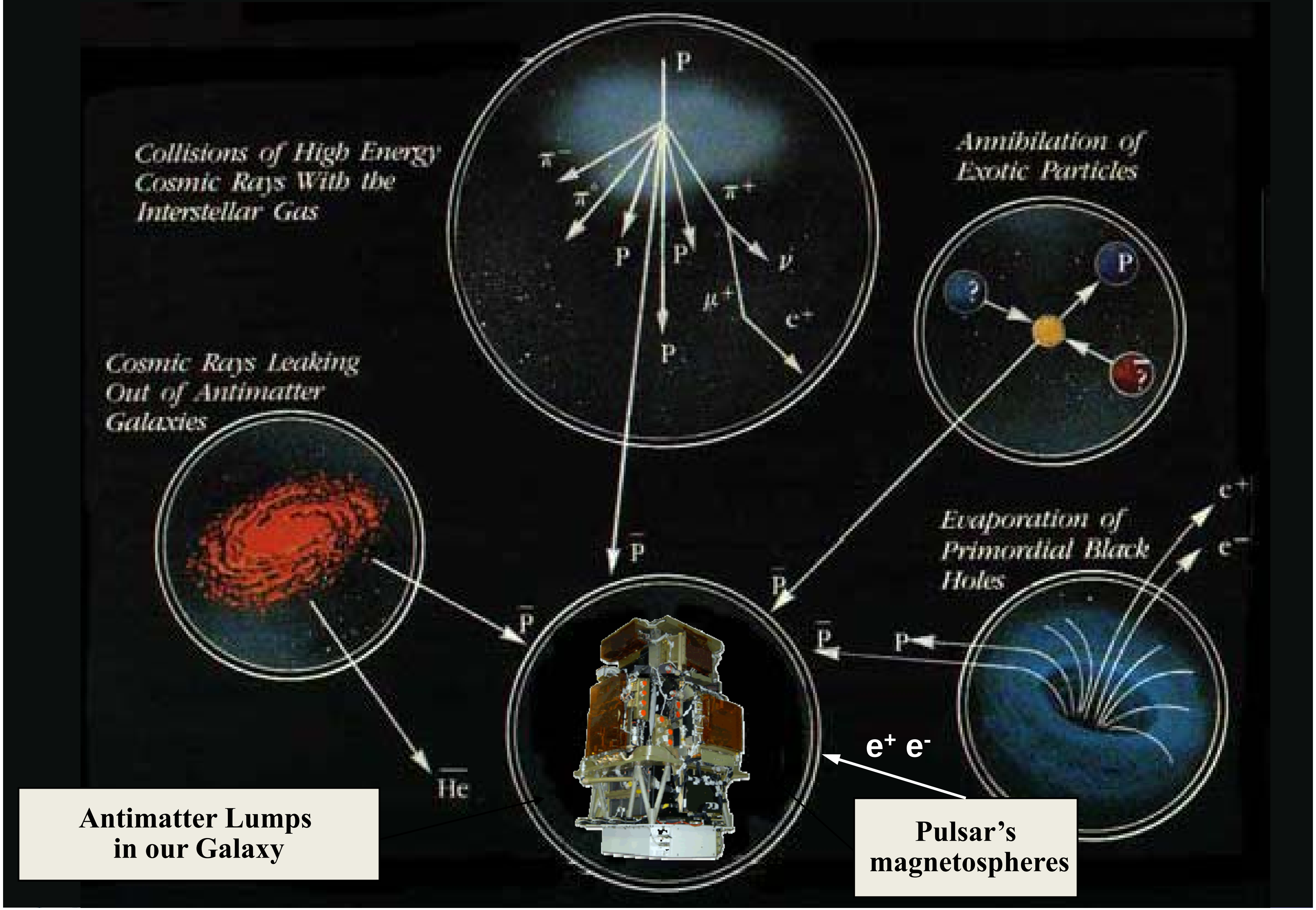




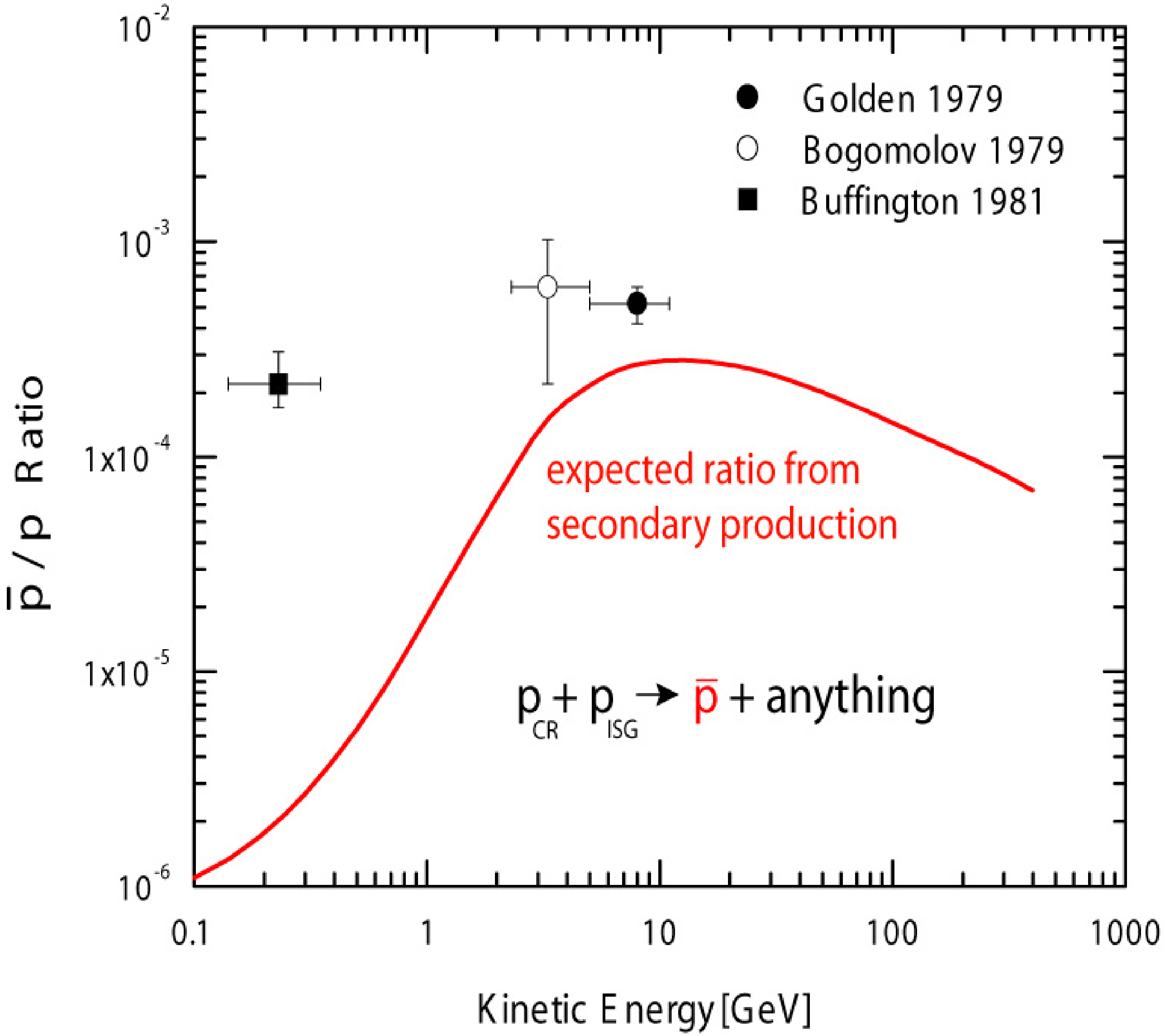



# ANTIMATTER

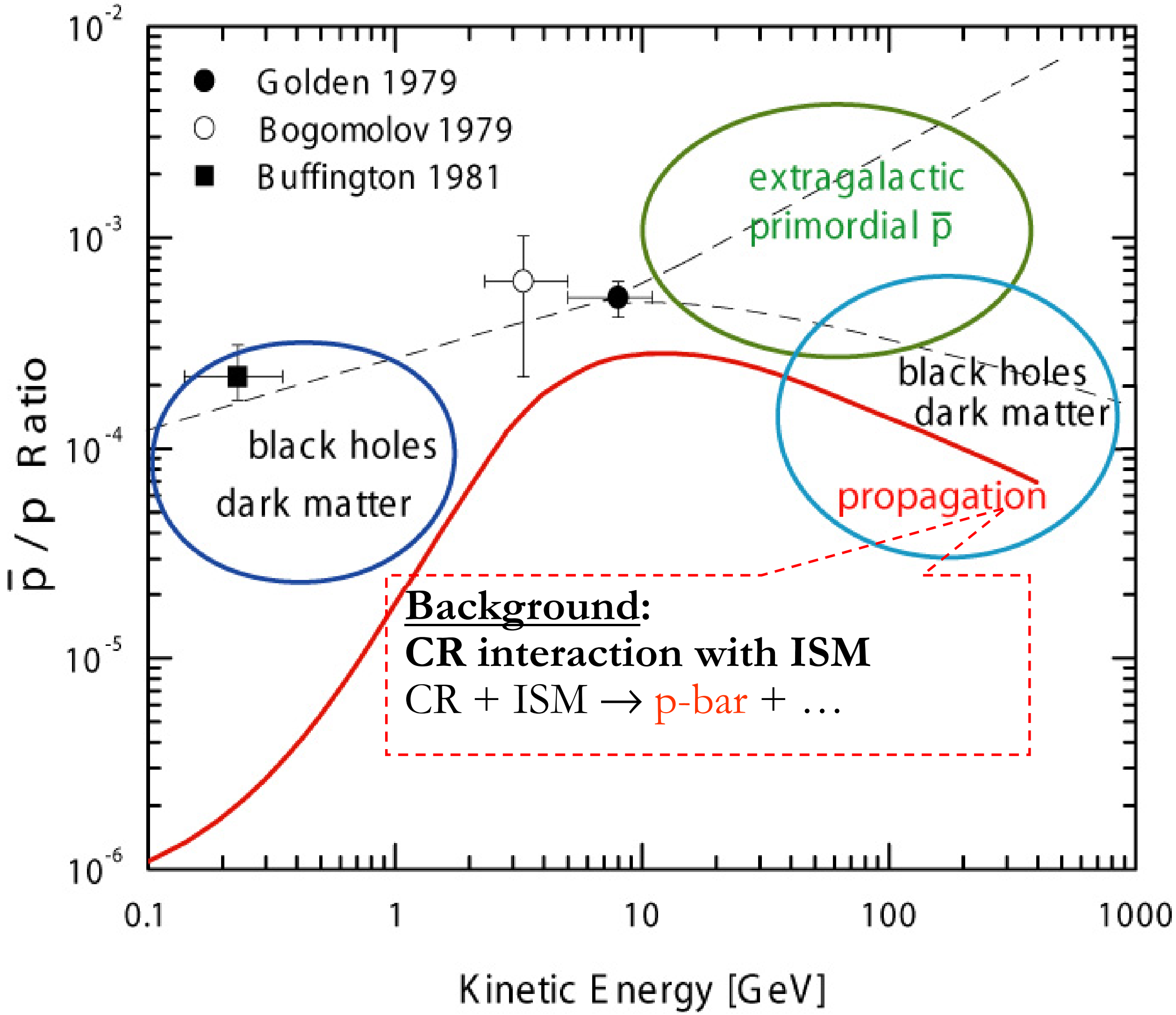


Collisions of High Energy Cosmic Rays With the Interstellar Gas
Annihilation of Exotic Particles
Cosmic Rays Leaking Out of Antimatter Galaxies
Evaporation of Primordial Black Holes
e+ e-
Antimatter Lumps in our Galaxy
Pulsar's magnetospheres

# The first historical measurements on galactic antiprotons



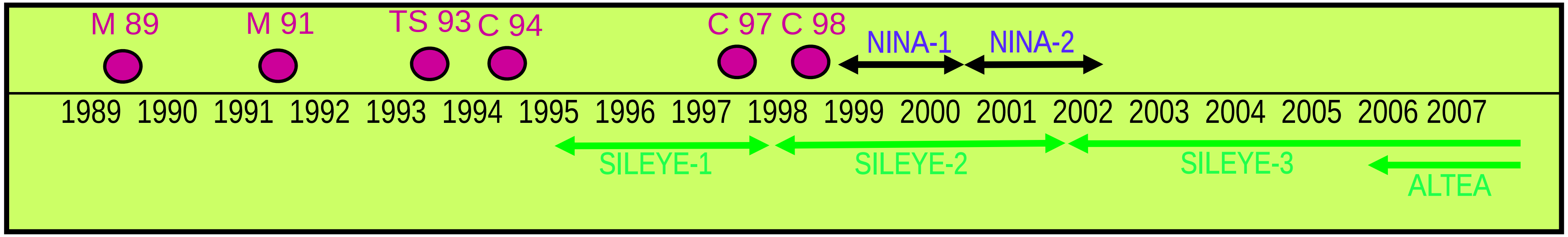
## The first historical measurements of the $\bar{p}/p$ - ratio and various Ideas of theoretical Interpretations



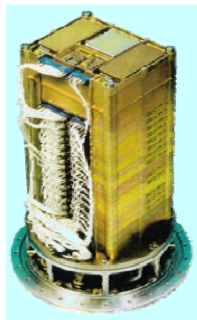
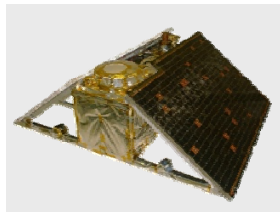
# PAMELA prehistory

- Balloon-borne experiments MASS-89,91 TS-93 CAPRICE-94,97,98
- Space experiments*: NINA-1,2 SILEYE-1,2,3 ALTEA

  (*study of low energy nuclei and space radiation environment)





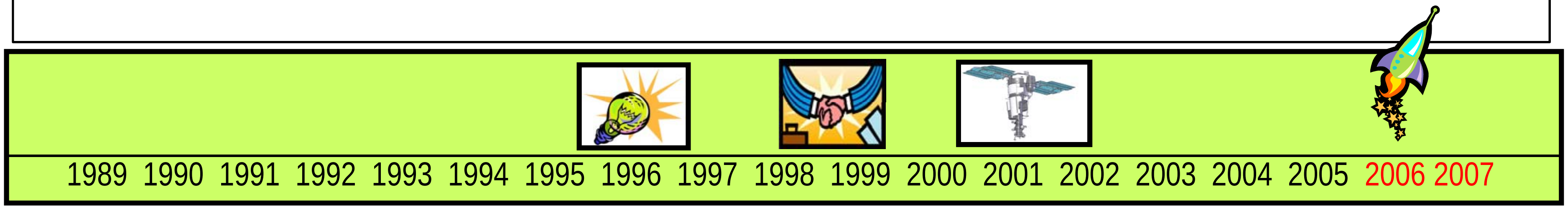




# PAMELA history

- 1996: PAMELA proposal
- 22.12.1998: agreement between RSA (Russian Space Agency) and INFN to build and launch PAMELA.

  Three models required by the RSA:
  - Mass-Dimensional and Thermal Model (MDTM)
  - Technological Model (TM)
  - Flight Model (FM)

  → ***Starts PAMELA construction***
- 2001: change of the satellite → ***complete redefinition of mechanics***
- 2006: flight!!!



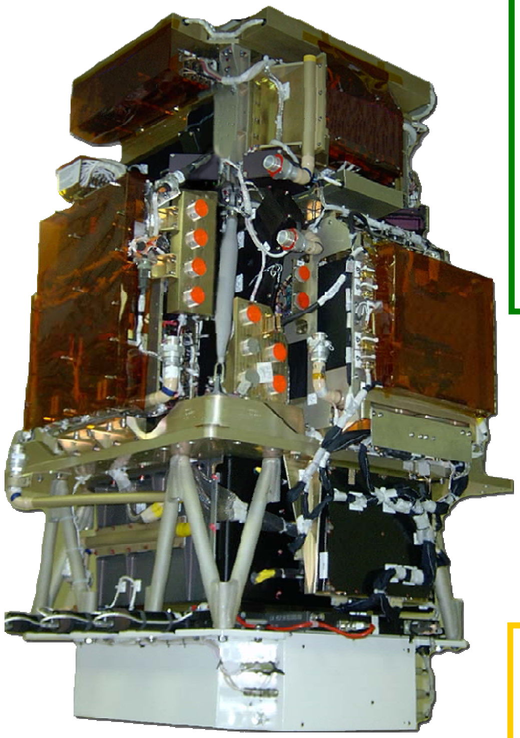
# Design Performance

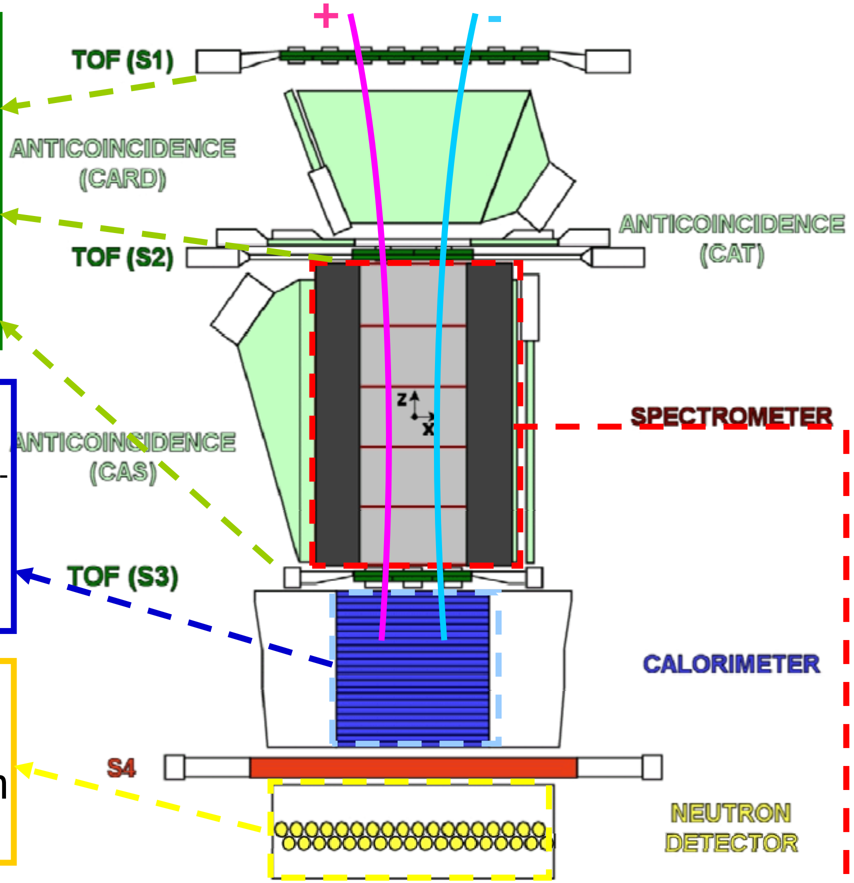
| | energy range |
|---|---|
| • Antiprotons | 80 MeV - 150 GeV |
| • Positrons | 50 MeV – 270 GeV |
| • Electrons | up to 400 GeV |
| • Protons | up to 700 GeV |
| • Electrons+positrons | up to 2 TeV (from calorimeter) |
| • Light Nuclei (He/Be/C) | up to 200 GeV/n |
| • AntiNuclei search | sensitivity of $3 \times 10^{-8}$ in $\overline{He}$/He |

→ Simultaneous measurement of many cosmic-ray species
→ New energy range
→ Unprecedented statistics

# PAMELA detectors

**Main requirements → high-sensitivity antiparticle identification and precise momentum measure**






**Time-Of-Flight**
**plastic scintillators + PMT:**
- **Trigger**
- **Albedo rejection;**
- **Mass identification up to 1 GeV;**
- **Charge identification from dE/dX.**

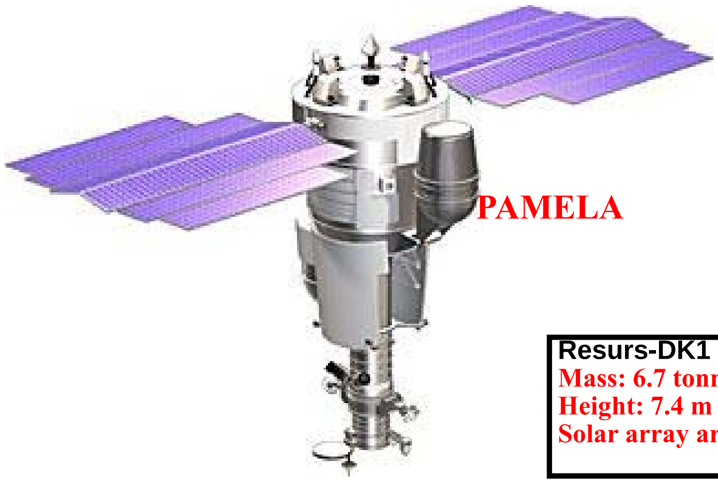
**Electromagnetic calorimeter**
**W/Si sampling (16.3 $X_0$, 0.6 $\lambda I$)**
- **Discrimination e+ / p, anti-p / $e^-$ (shower topology)**
- **Direct E measurement for $e^-$**

Neutron detector
plastic scintillators + PMT:
- High-energy e/h discrimination

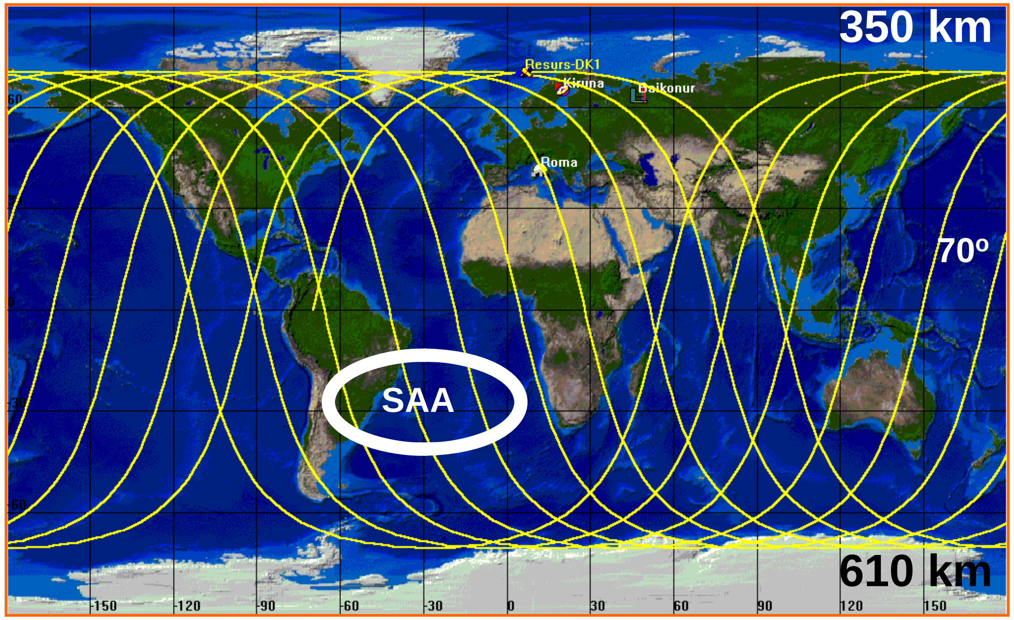
**GF: 21.5 cm² sr**
**Mass: 470 kg**
**Size: 130x70x70 cm³**
**Power Budget: 360W**

**Spectrometer**
**microstrip silicon tracking system + permanent magnet**
**It provides:**
- ***Magnetic rigidity* → R = pc/Ze**
- ***Charge sign***
- ***Charge value from dE/dx***

# Resurs-DK1 satellite + orbit

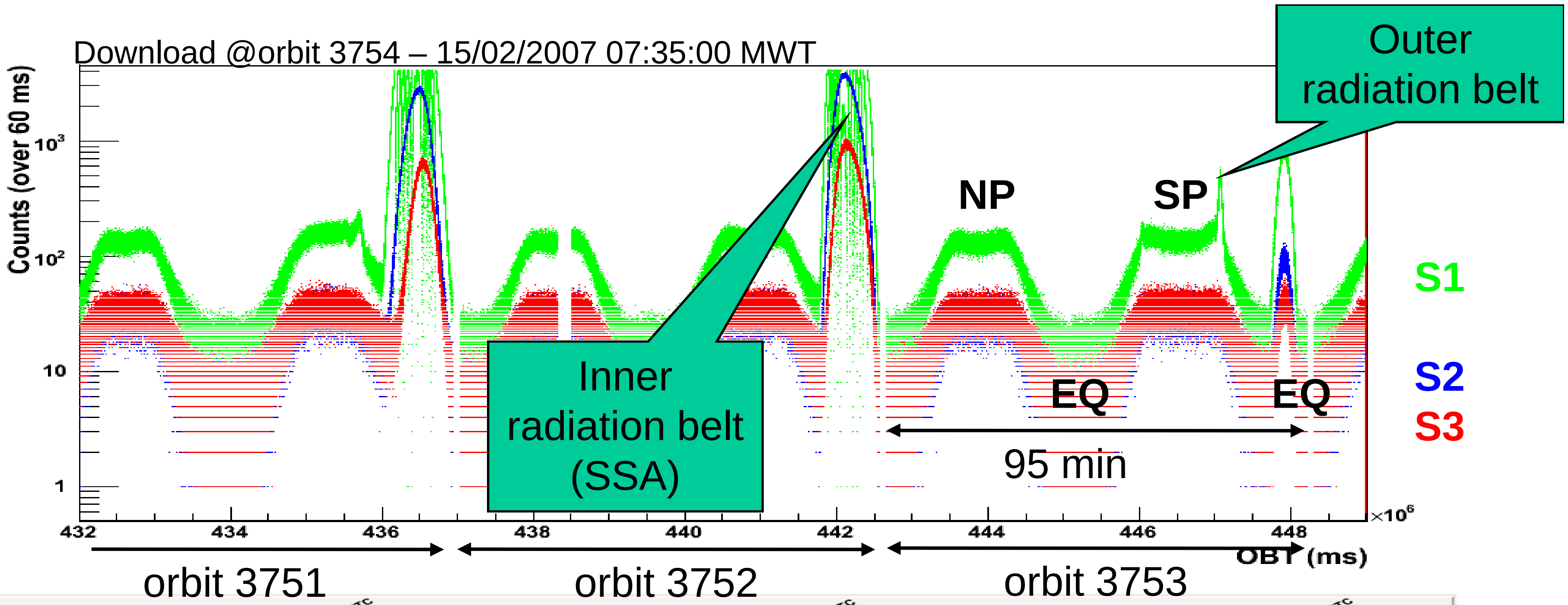


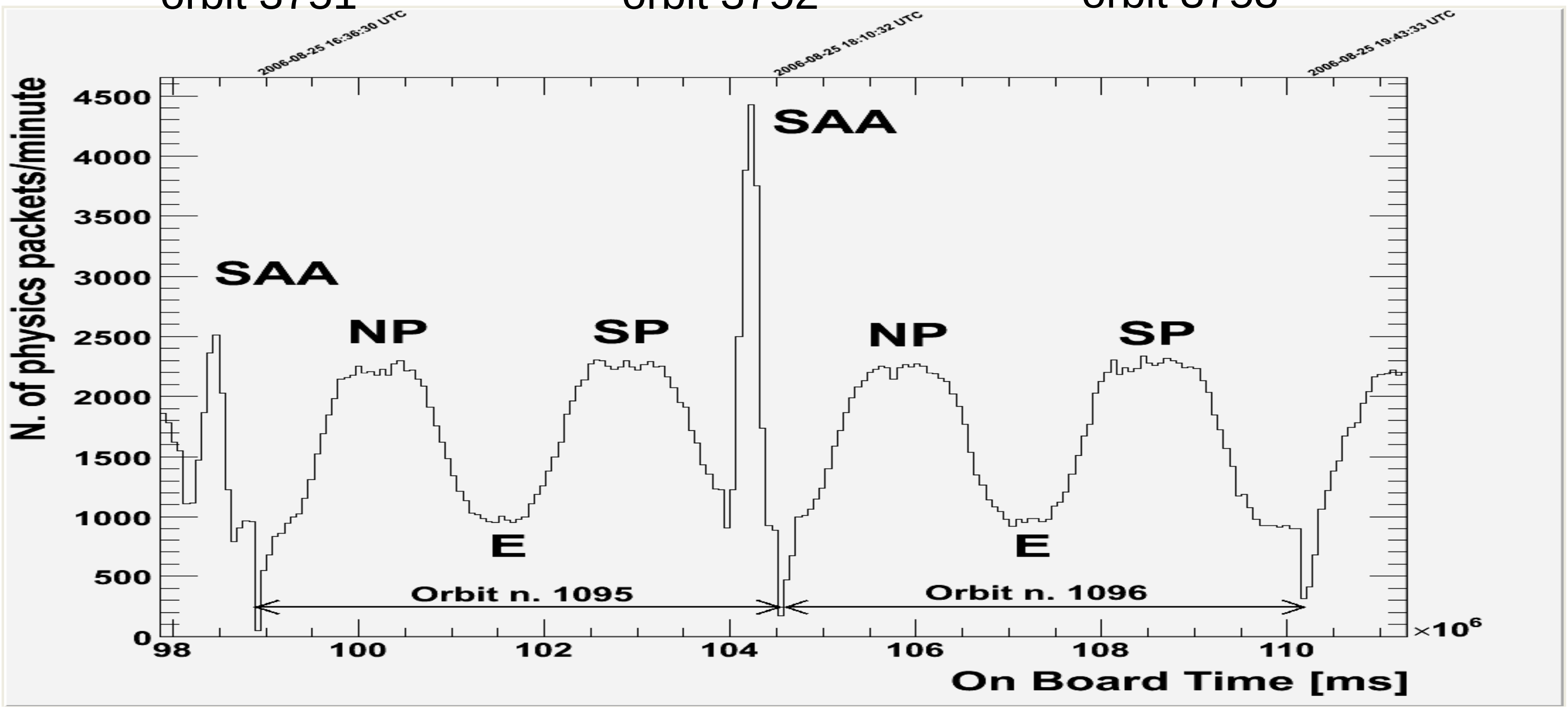

**Resurs-DK1**
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 $m^2$




~90 mins

- Resurs-DK1: multi-spectral imaging of earth's surface
- PAMELA mounted inside a pressurized container
- Lifetime >3 years (assisted)
- Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day
- Quasi-polar and elliptical orbit (70.0°, 350 km - 600 km)
- Traverses the South Atlantic Anomaly
- Crosses the outer (electron) Van Allen belt at south pole


Download @orbit 3754 – 15/02/2007 07:35:00 MWT
Outer radiation belt
Inner radiation belt (SSA)
NP
SP
EQ
EQ
95 min
S1
S2
S3
Counts (over 60 ms)
OBT (ms)
orbit 3751
orbit 3752
orbit 3753


2006-08-25 16:36:30 UTC
2006-08-25 18:10:32 UTC
2006-08-25 19:43:33 UTC
SAA
SAA
NP
SP
NP
SP
E
E
Orbit n. 1095
Orbit n. 1096
N. of physics packets/minute
On Board Time [ms]

# PAMELA milestones

- **Launch from Baikonur: June 15th 2006, 0800 UTC.**
- **'First light': June 21st 2006, 0300 UTC.**
- **Detectors operated as expected after launch**
- **PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006**
- **As of ~now:**
  - **~650 days of data taking (~73% live-time)**
  - **~11 TByte of raw data downlinked**
  - **>$10^9$ triggers recorded and under analysis**

# Matter in the Universe

Microwave Anisotropy
**WMAP - NASA - Explorer Mission** →

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

(Universe is flat)

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

$$\Omega_{total} = \underbrace{\Omega_{total,baryon.}}_{\text{baryonic matter}} + \underbrace{\Omega_{dyn.}}_{\text{dark matter}} + \underbrace{\Omega_{required}}_{\text{dark energy}}$$

| baryonic matter | dark matter | dark energy |
|---|---|---|
| **5%** | **23%** | **72%** |
| | ?? | ??? |
| stars, galaxies | candidates: | quintessence |

Dark matter candidates:

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

# Cosmic-ray Antimatter from Dark Matter annihilation

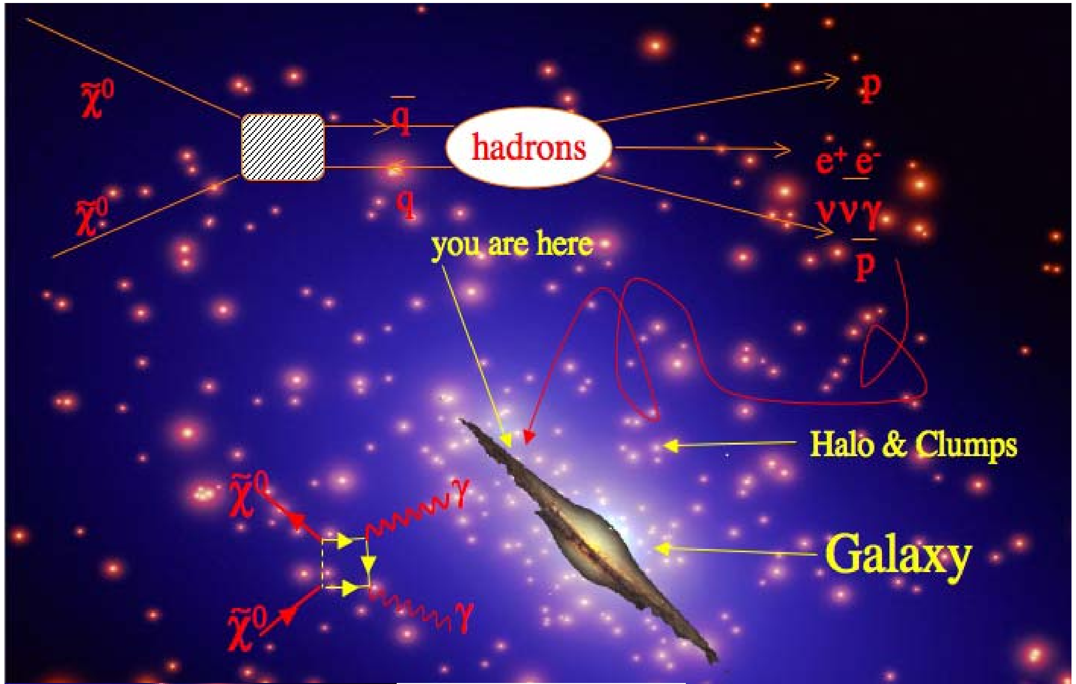
**A plausible dark matter candidate is neutralino (χ), the lightest SUSY particle.**

**Annihilation of relic χ gravitationally confined in the galactic halo**

**→ Distortion of antiproton and positron spectra from purely secondary production**

**Most likely processes:**

- $\chi\chi \rightarrow qq \rightarrow$ hadrons $\rightarrow$ anti-p, $e^+$,…
- $\chi\chi \rightarrow W^+W^-, Z^0Z^0, \ldots \rightarrow e^+, \ldots$
  direct decay ⇒ positron peak Ee+~Mc/2
  other processes ⇒ positron continuum Ee+~Mχ/20




$$\chi + \bar{\chi} \rightarrow X + \gamma$$ (GLAST)

$$+ \nu$$ (AMANDA / IceCube)

$$+ \bar{p}$$

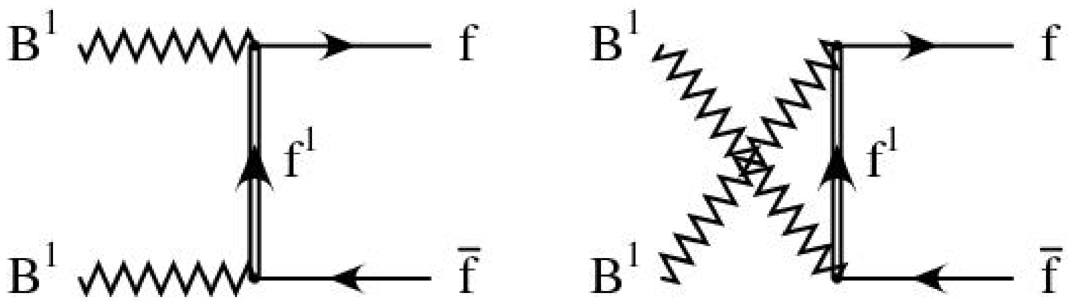
$$+ e^+$$

$$+ \bar{D}$$

} PAMELA (and Bess, HEAT, AMS etc.)

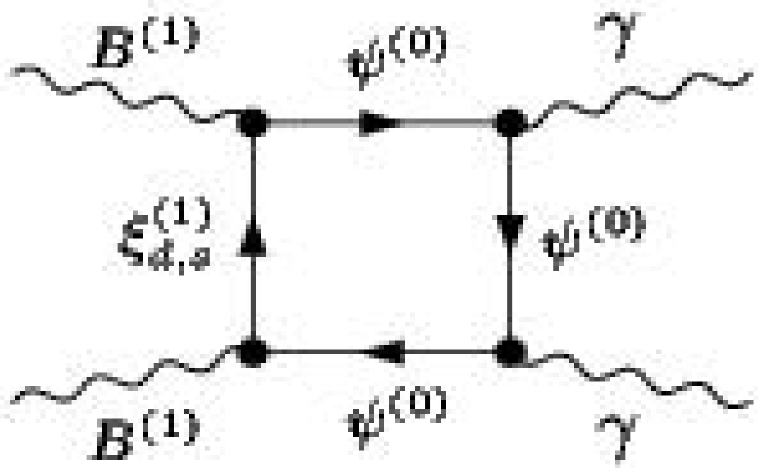
# Another possible scenario:
# KK Dark Matter

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




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

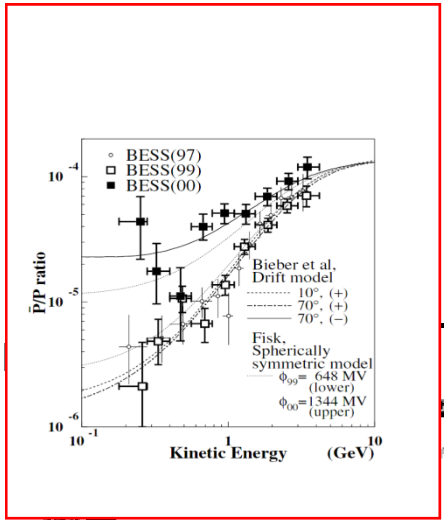
As in the neutralino case
there are 1-loop
processes that produces
monoenergetic
γ γ in the final state.

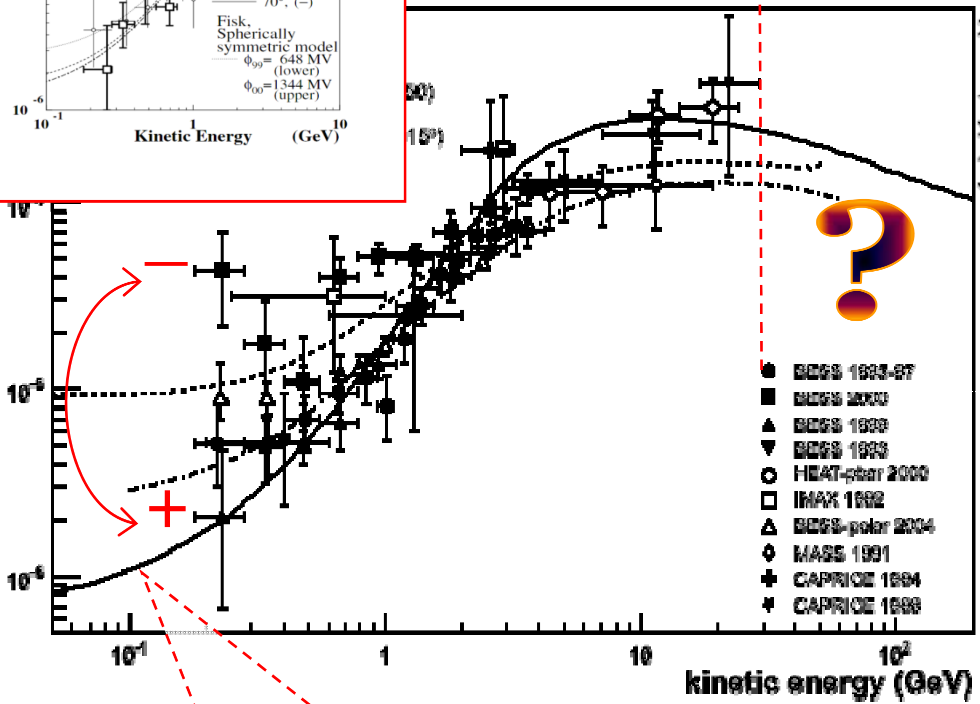


# CR antimatter

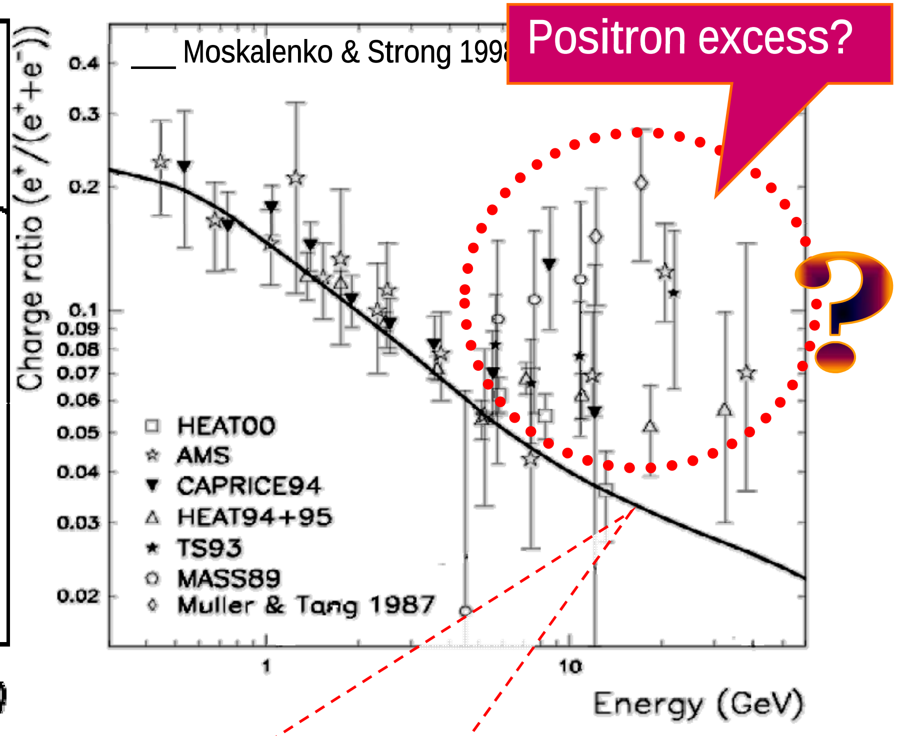
## Present status

### Antiprotons




### Positrons

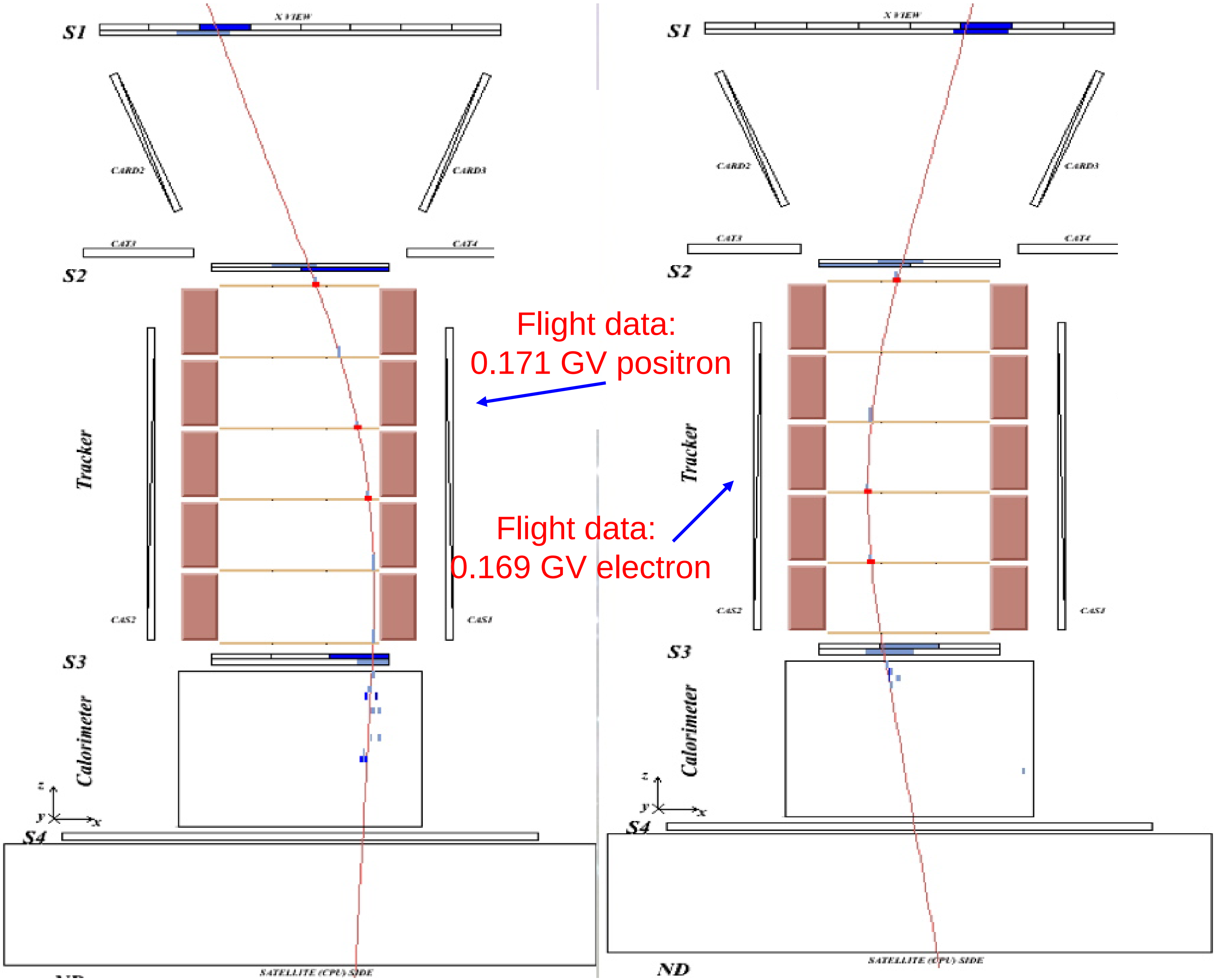



CR + ISM → **p-bar** + …
kinematic treshold:
5.6 GeV for the reaction

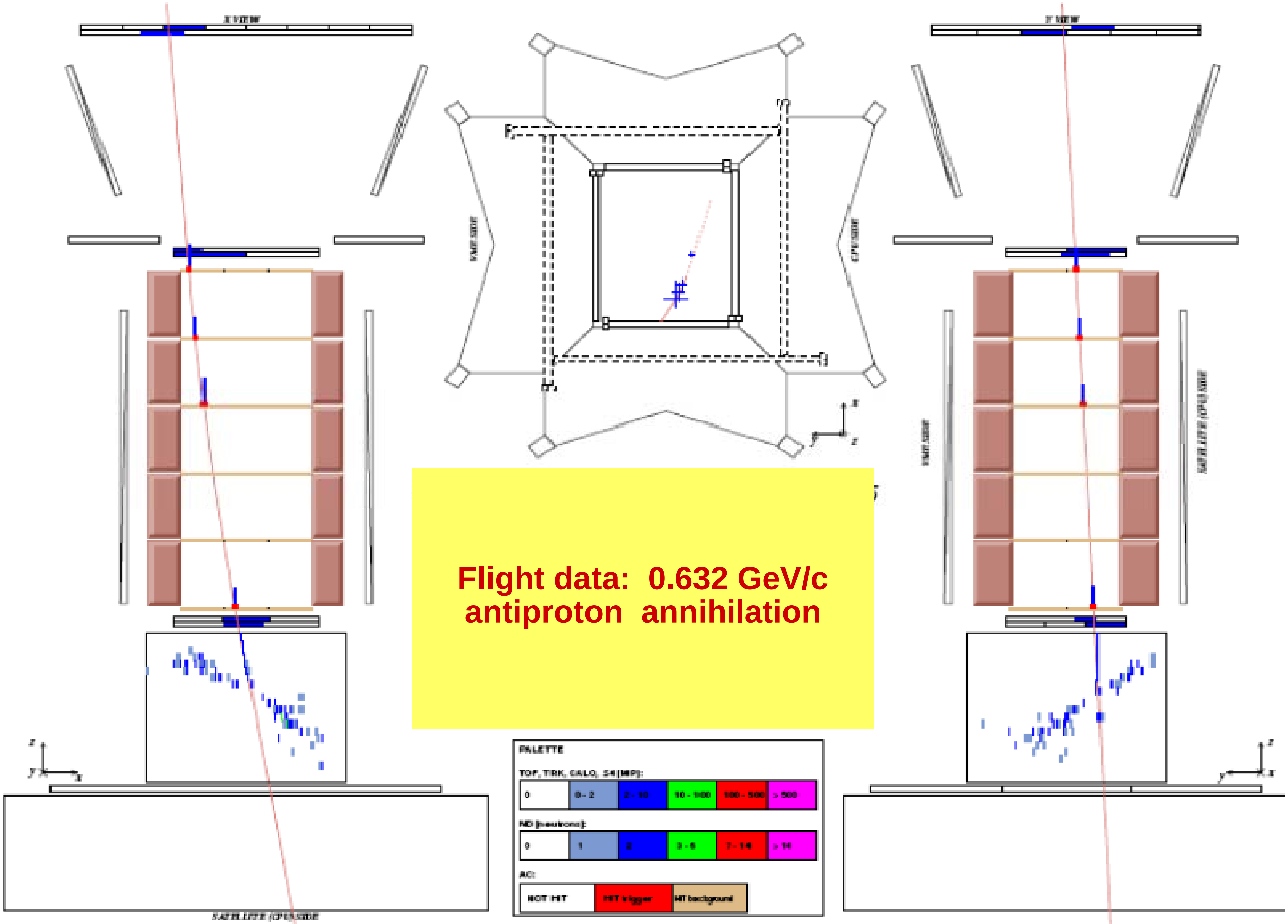
$pp \rightarrow \bar{p}ppp$

CR + ISM → $\pi^{\pm}$ + x → $\mu^{\pm}$ + x → **$e^{\pm}$** + x
CR + ISM → $\pi^0$ + x → $\gamma\gamma$ → **$e^{\pm}$**

Mirko Boezio, CERN, 2008/10/28

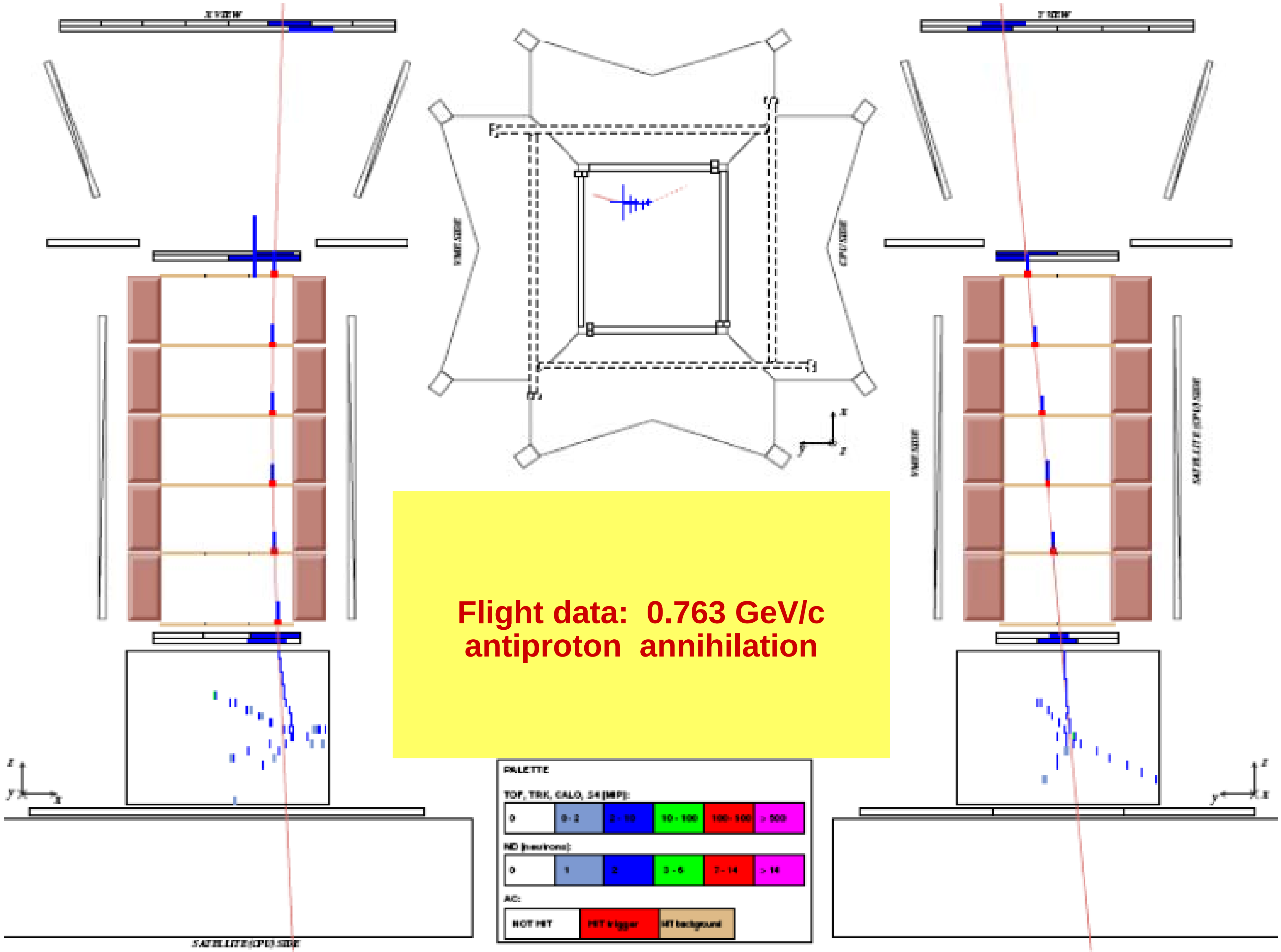


S1
X VIEW
CARD2
CARD3
CAT3
CAT4
S2
Tracker
CAS2
CAS1
S3
Calorimeter
S4
SATELLITE (CPU) SIDE
ND
Flight data:
0.171 GV positron
Flight data:
0.169 GV electron



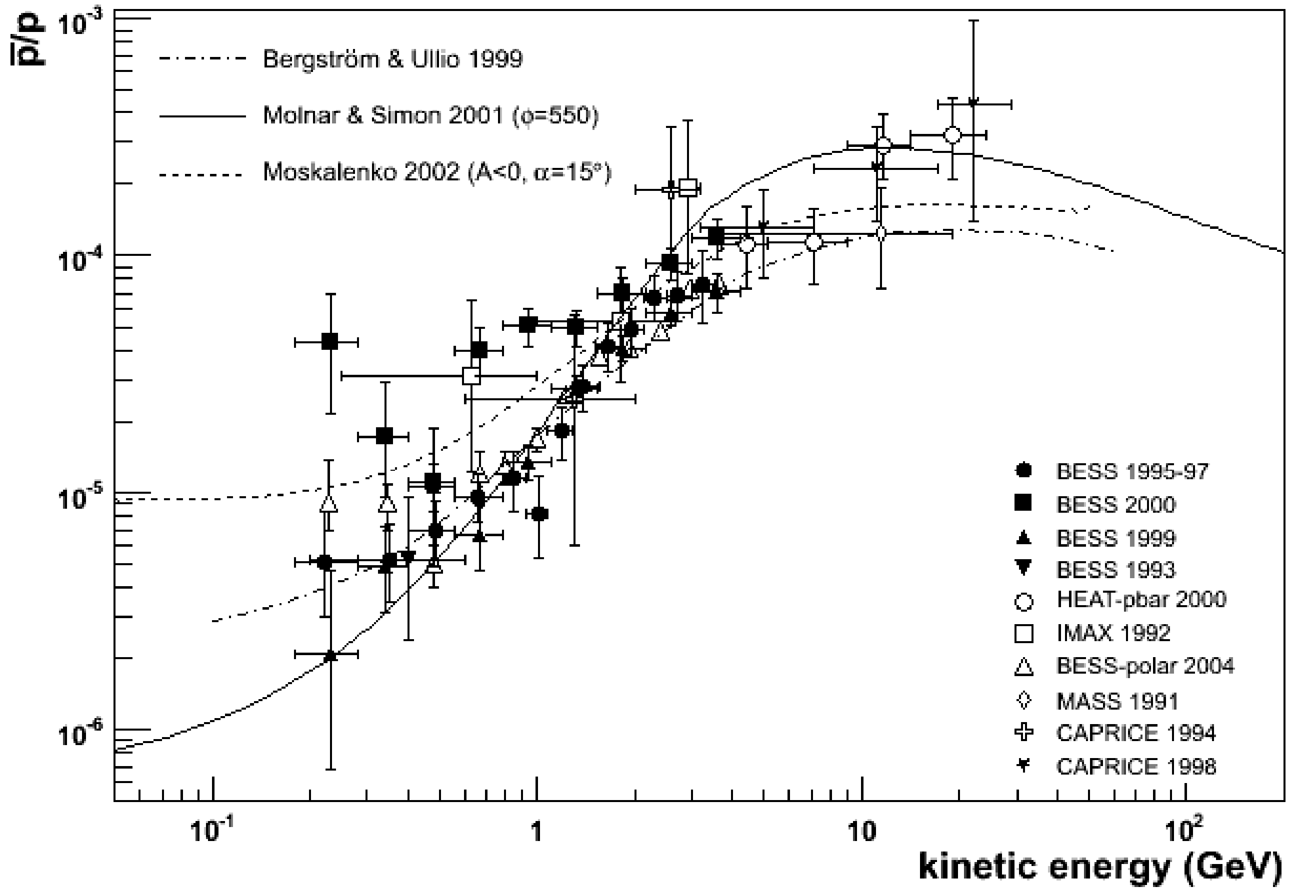

**Flight data: 0.632 GeV/c antiproton annihilation**

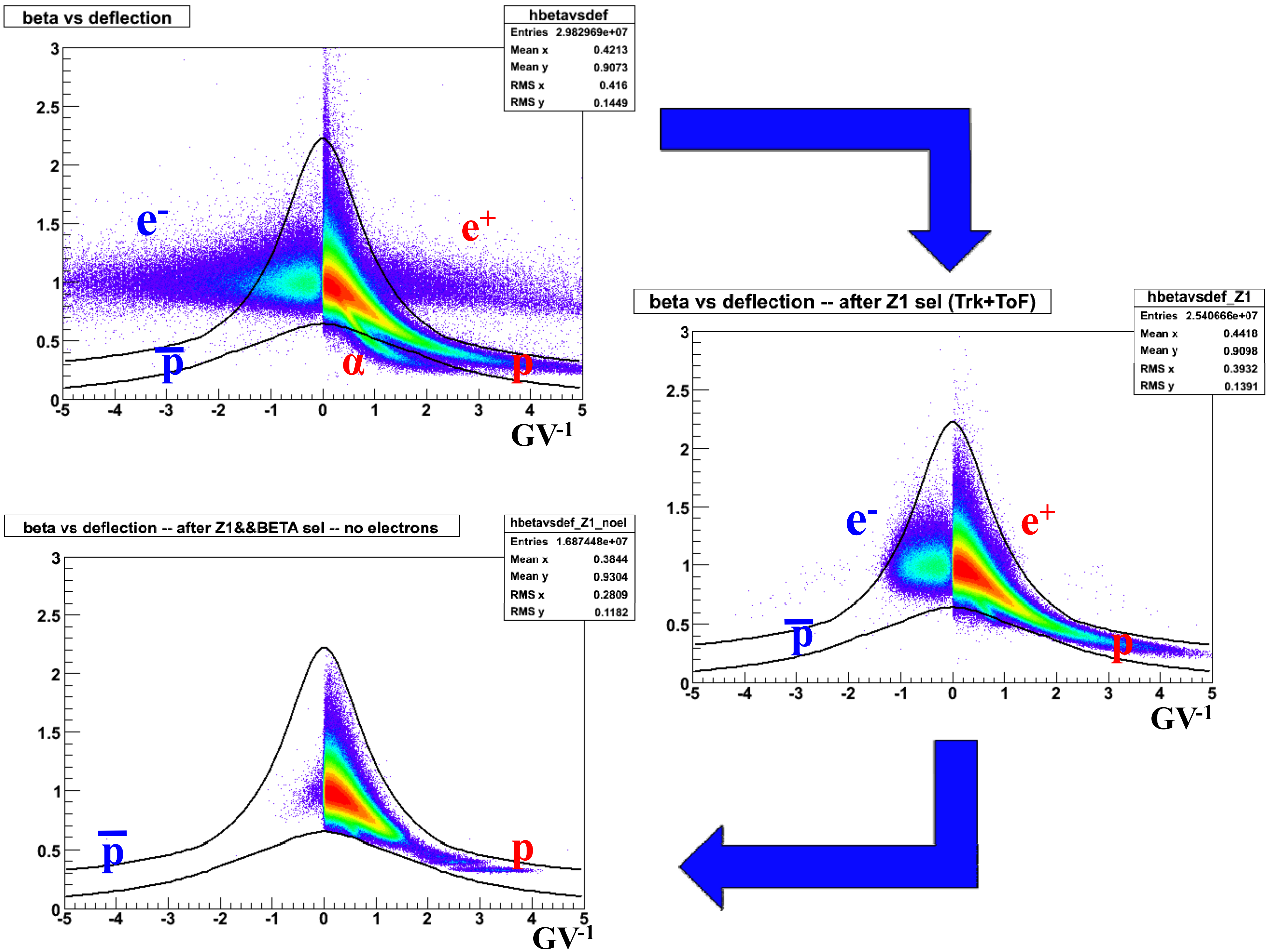
# Flight data: 0.763 GeV/c antiproton annihilation



# Antiprotons

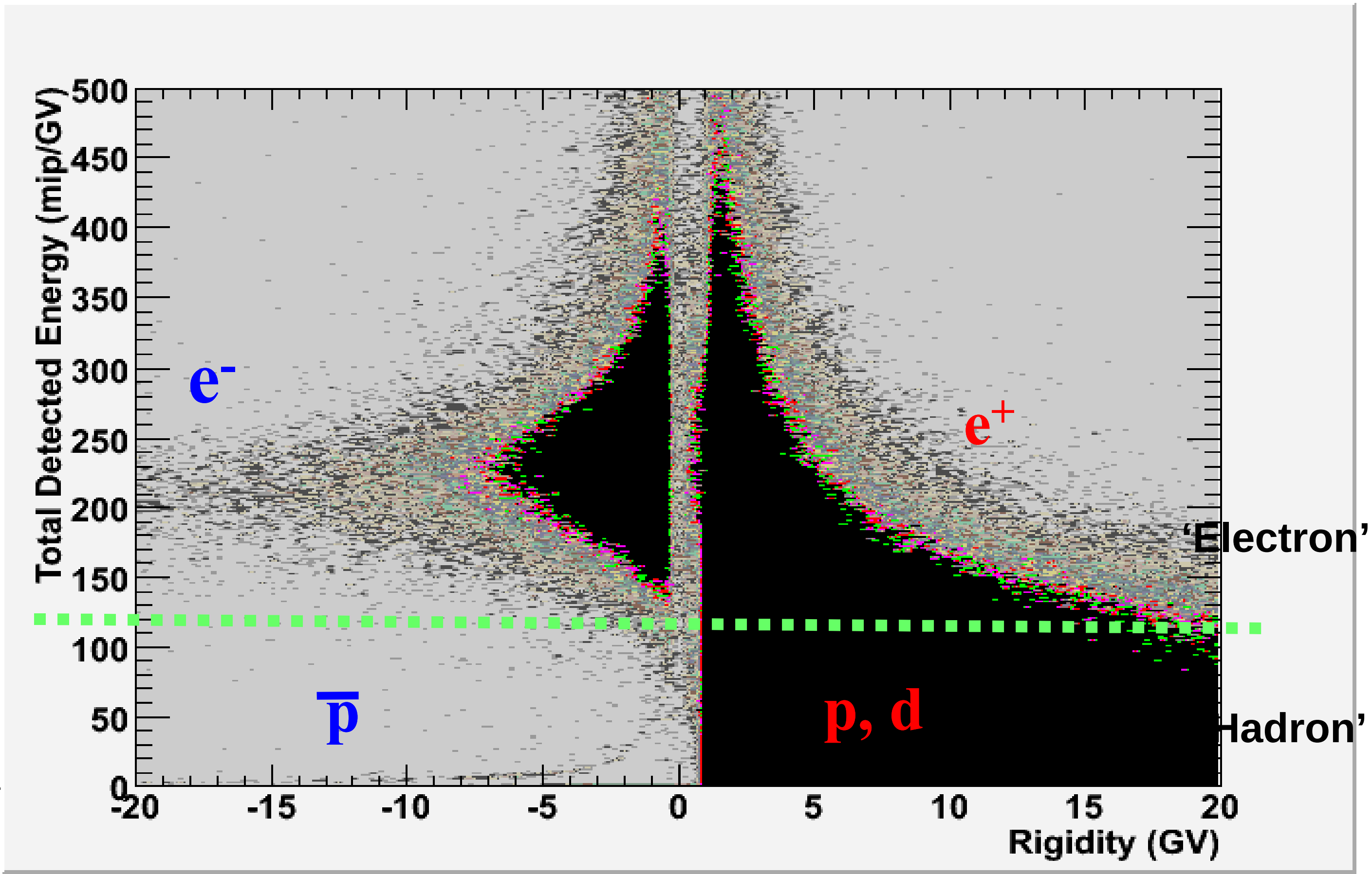
# Antiproton to proton ratio

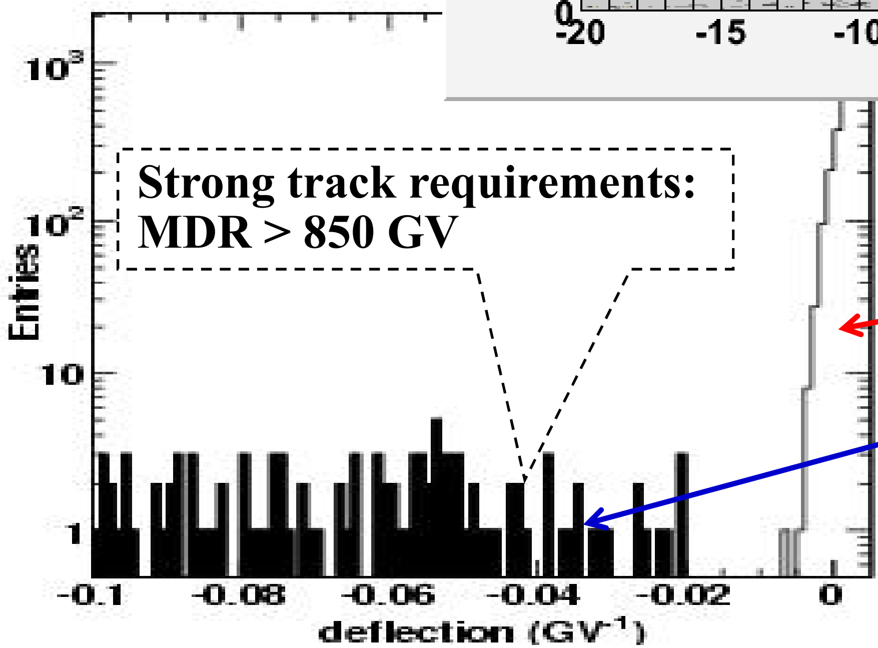




beta vs deflection
hbetavsdef
Entries 2.982969e+07
Mean x 0.4213
Mean y 0.9073
RMS x 0.416
RMS y 0.1449
e-
e+
p̄
α
p
GV-1
beta vs deflection -- after Z1 sel (Trk+ToF)
hbetavsdef_Z1
Entries 2.540666e+07
Mean x 0.4418
Mean y 0.9098
RMS x 0.3932
RMS y 0.1391
e-
e+
p̄
p
GV-1
beta vs deflection -- after Z1&&BETA sel -- no electrons
hbetavsdef_Z1_noel
Entries 1.687448e+07
Mean x 0.3844
Mean y 0.9304
RMS x 0.2809
RMS y 0.1182
p̄
p
GV-1

**Calorimeter selection**

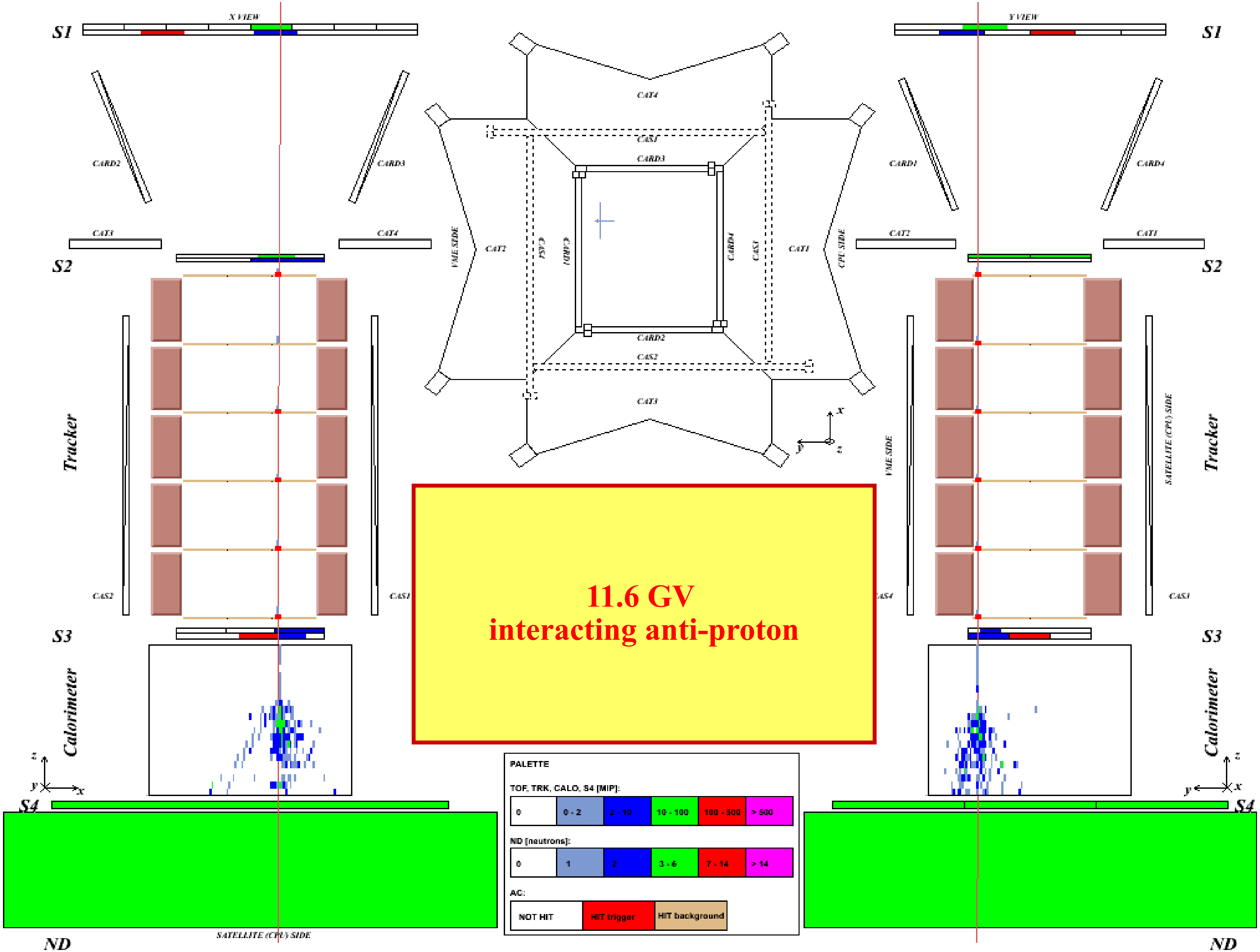



**Tracker Identification**

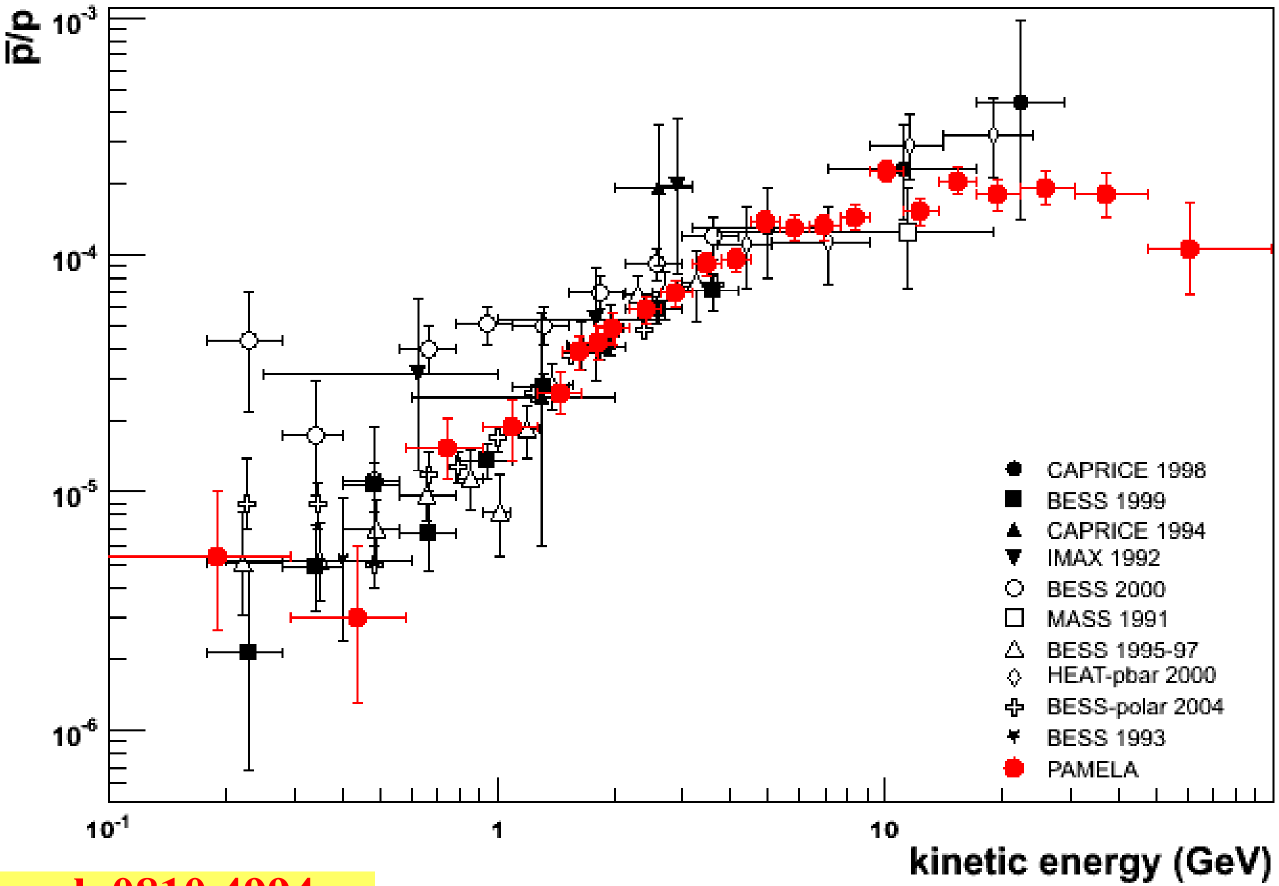
**Protons (& spillover)**

**Antiprotons**



X VIEW
Y VIEW
S1
S2
S3
S4
ND
Tracker
Calorimeter
CARD1
CARD2
CARD3
CARD4
CAT1
CAT2
CAT3
CAT4
CAS1
CAS2
CAS3
CAS4
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
11.6 GV
interacting anti-proton
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

# Antiproton to proton ratio

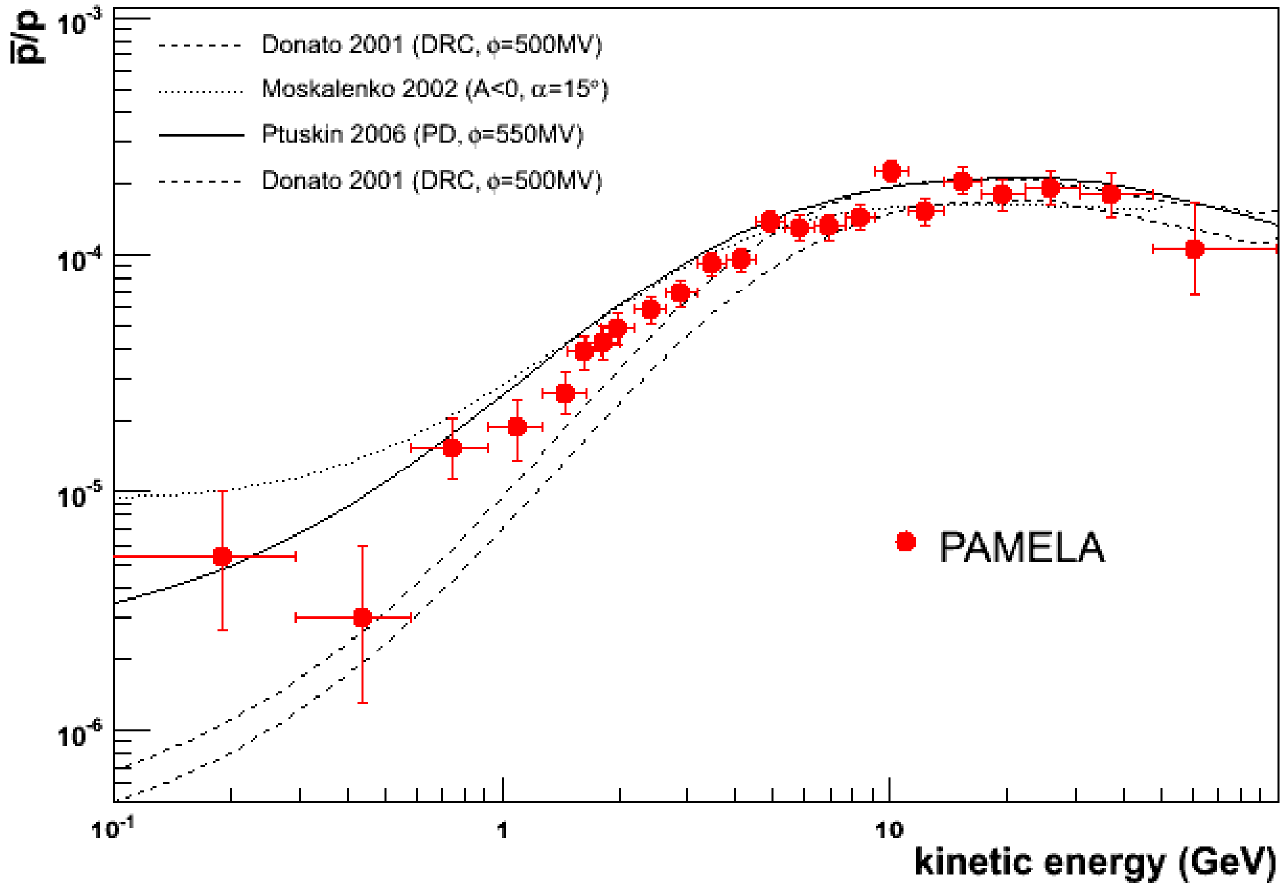



Astro-ph 0810.4994

Mirko Boezio, CERN, 2008/10/28

# Antiproton to proton ratio

**Seconday Production Models**

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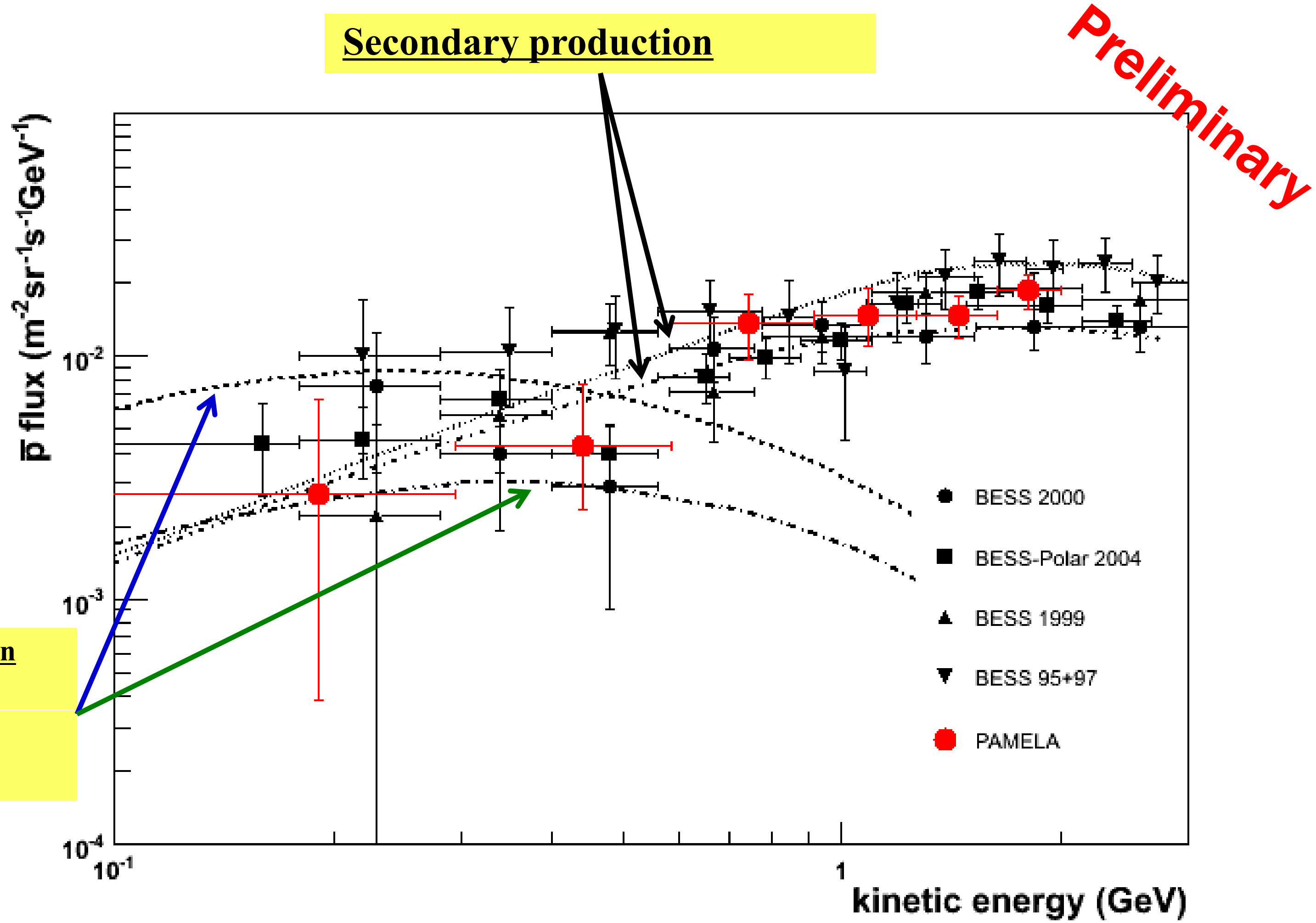
# Antiproton Flux

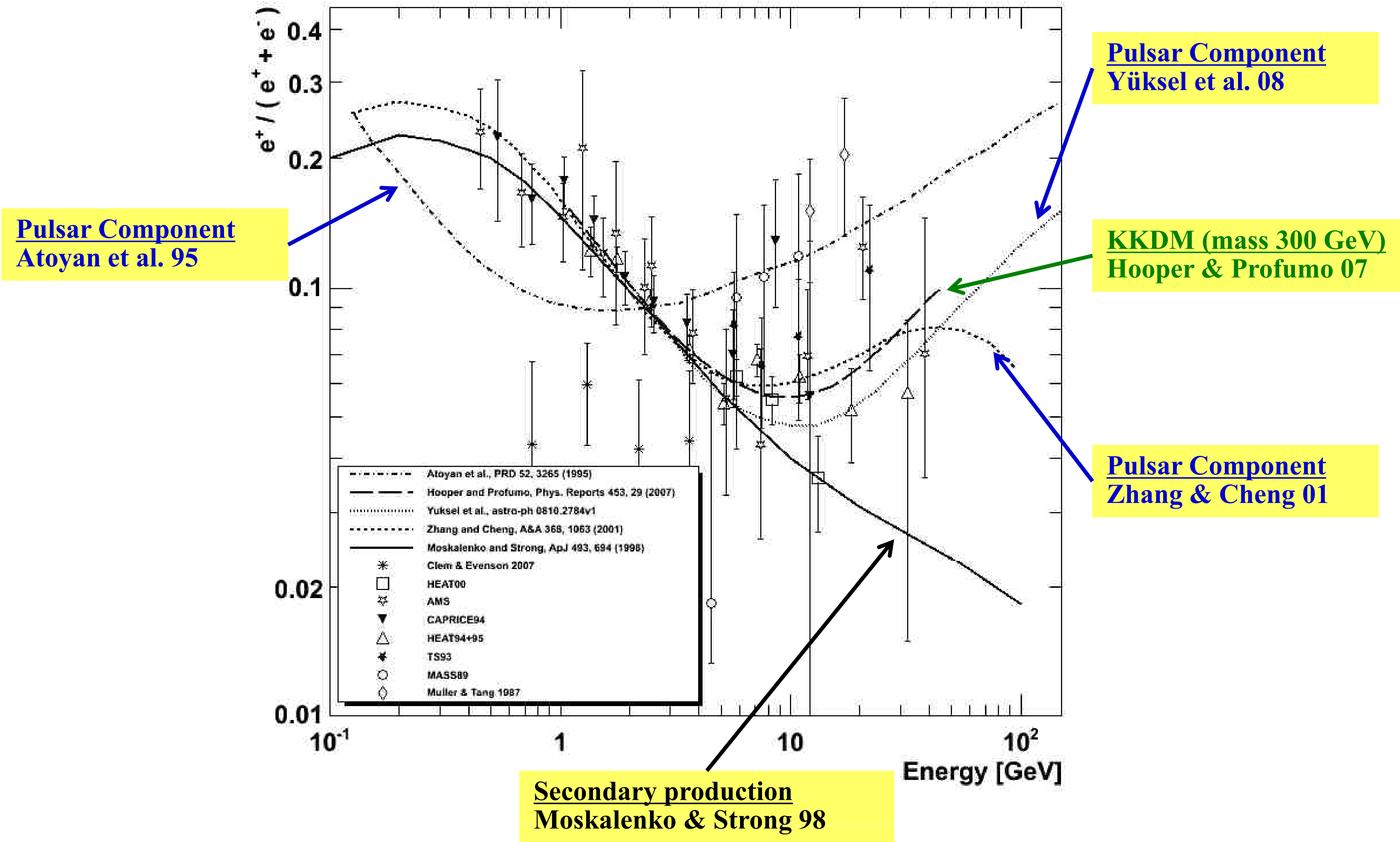
**Secondary production**



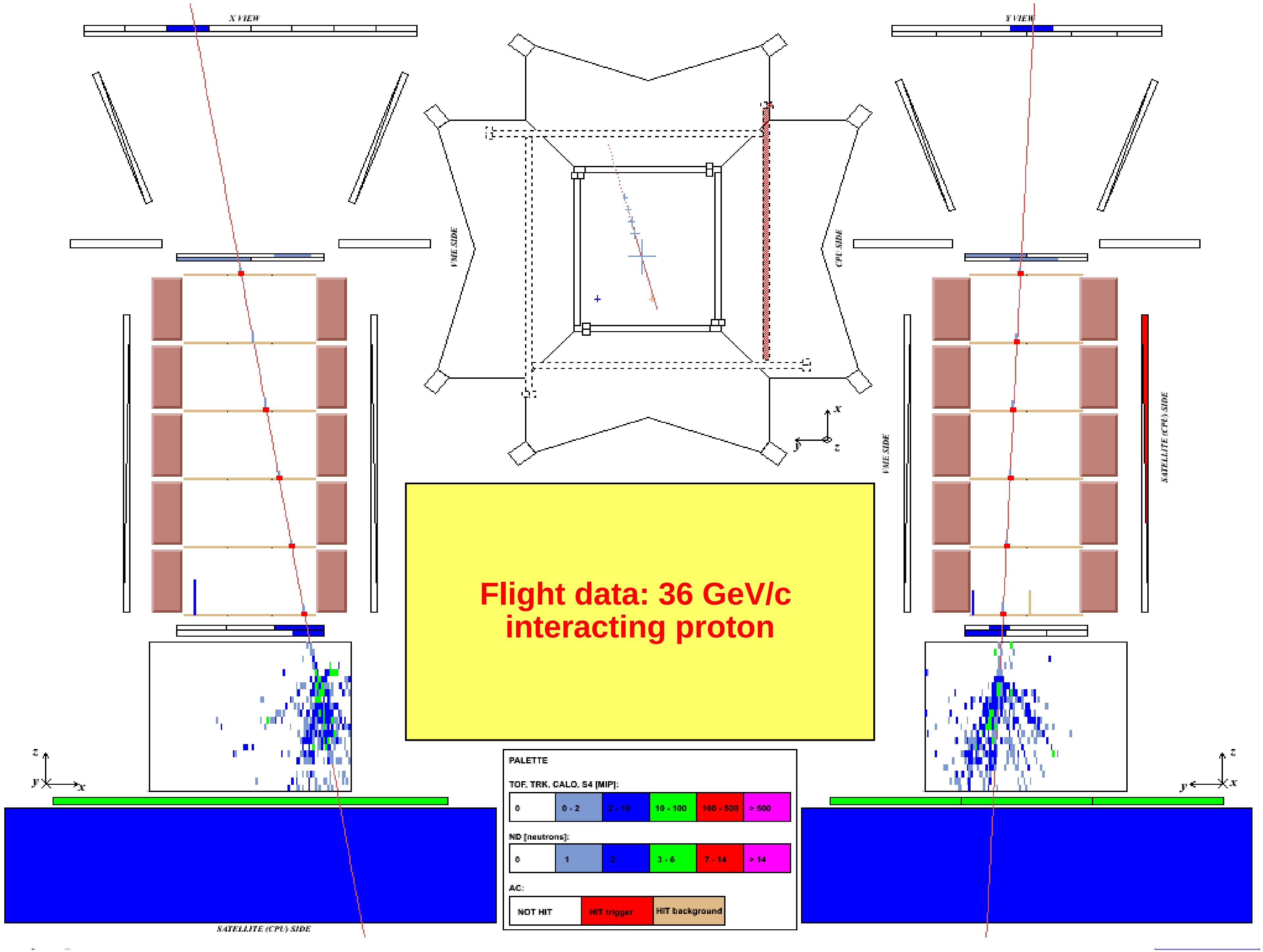

**Primary production Evaporation Mini Black Holes:**
Yoshimura et al.
Maki et al.

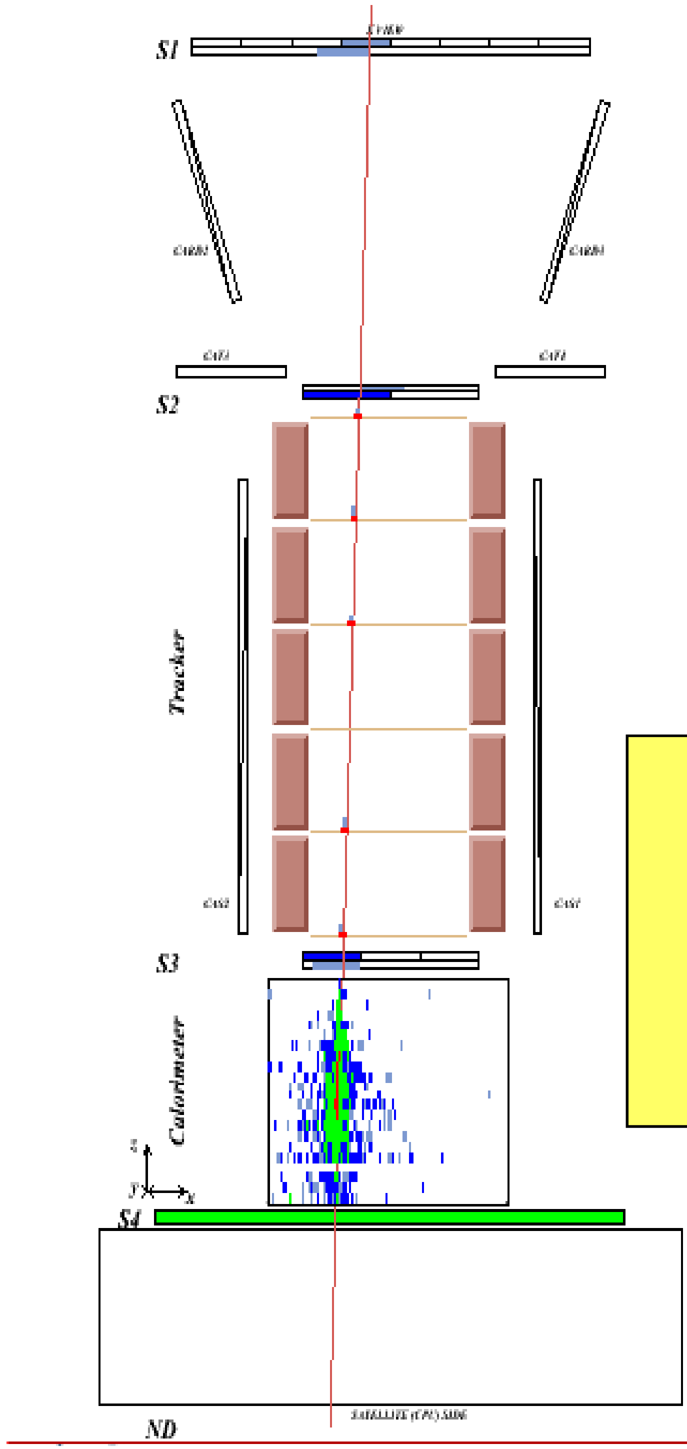
**From Petter Hofverberg's PhD Thesis**

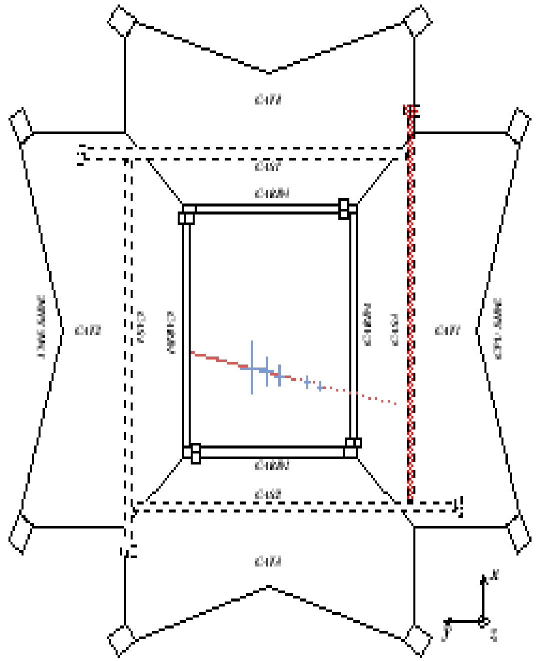
# Positrons

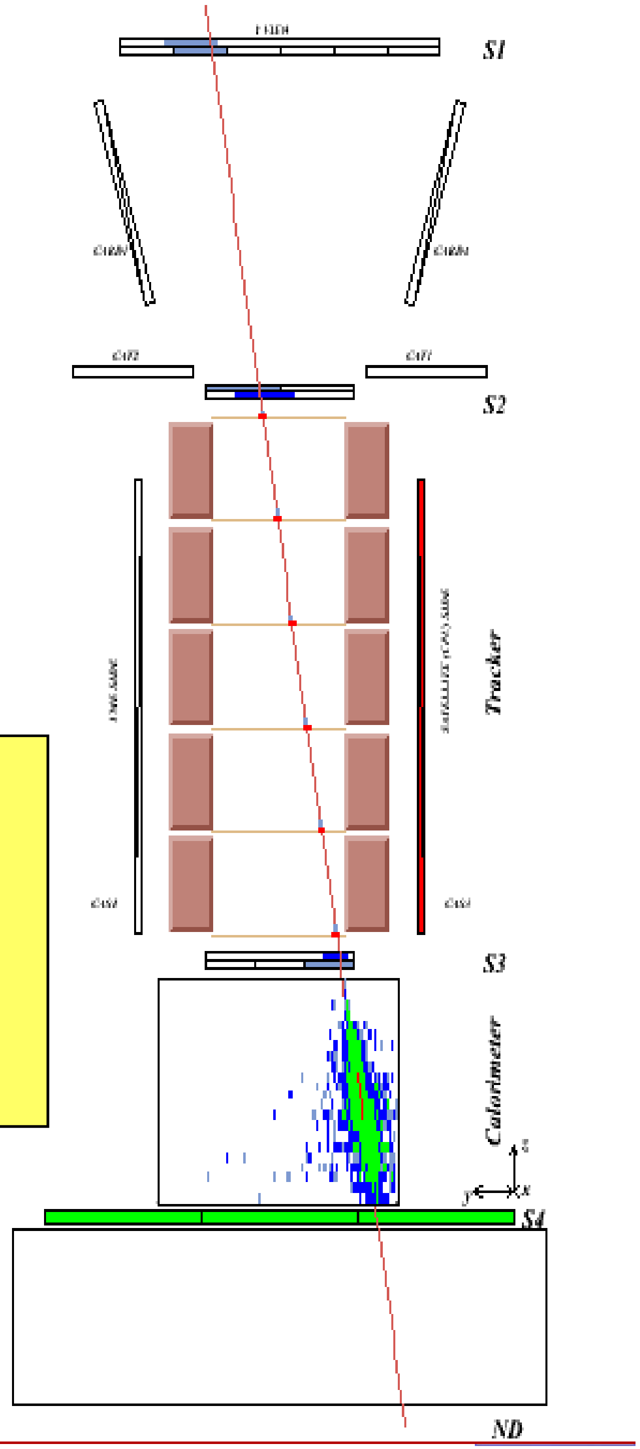


e+ / (e+ + e-)
0.4
0.3
0.2
0.1
0.02
0.01
10-1
1
10
10^2
Energy [GeV]
Atoyan et al., PRD 52, 3265 (1995)
Hooper and Profumo, Phys. Reports 453, 29 (2007)
Yuksel et al., astro-ph 0810.2784v1
Zhang and Cheng, A&A 368, 1063 (2001)
Moskalenko and Strong, ApJ 493, 694 (1998)
Clem & Evenson 2007
HEAT00
AMS
CAPRICE94
HEAT94+95
TS93
MASS89
Muller & Tang 1987
Pulsar Component
Atoyan et al. 95
Pulsar Component
Yüksel et al. 08
KKDM (mass 300 GeV)
Hooper & Profumo 07
Pulsar Component
Zhang & Cheng 01
Secondary production
Moskalenko & Strong 98

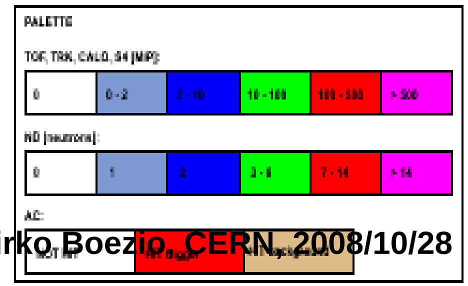

X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
Flight data: 36 GeV/c interacting proton
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background



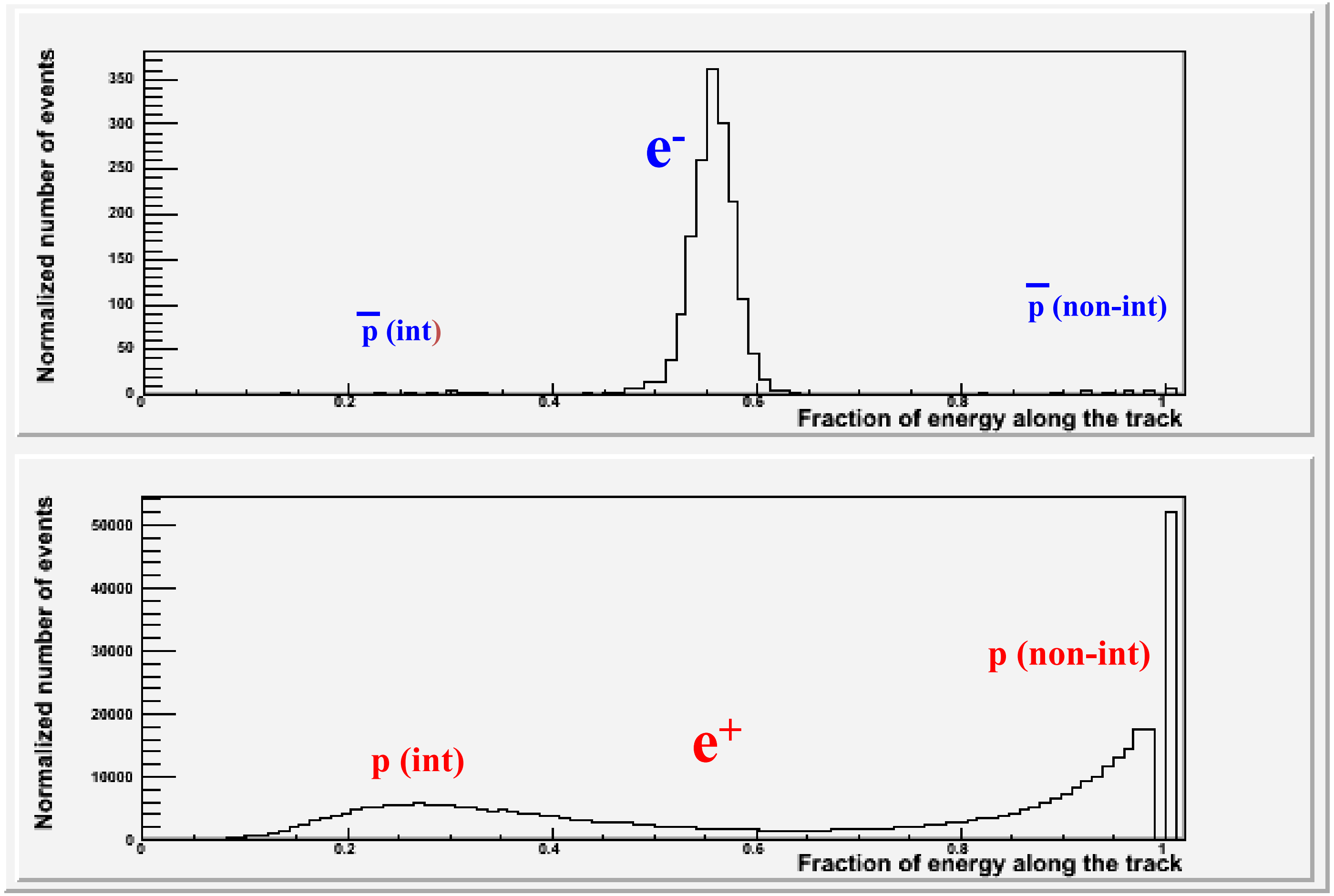



# Flight data: 42 GeV/c electron

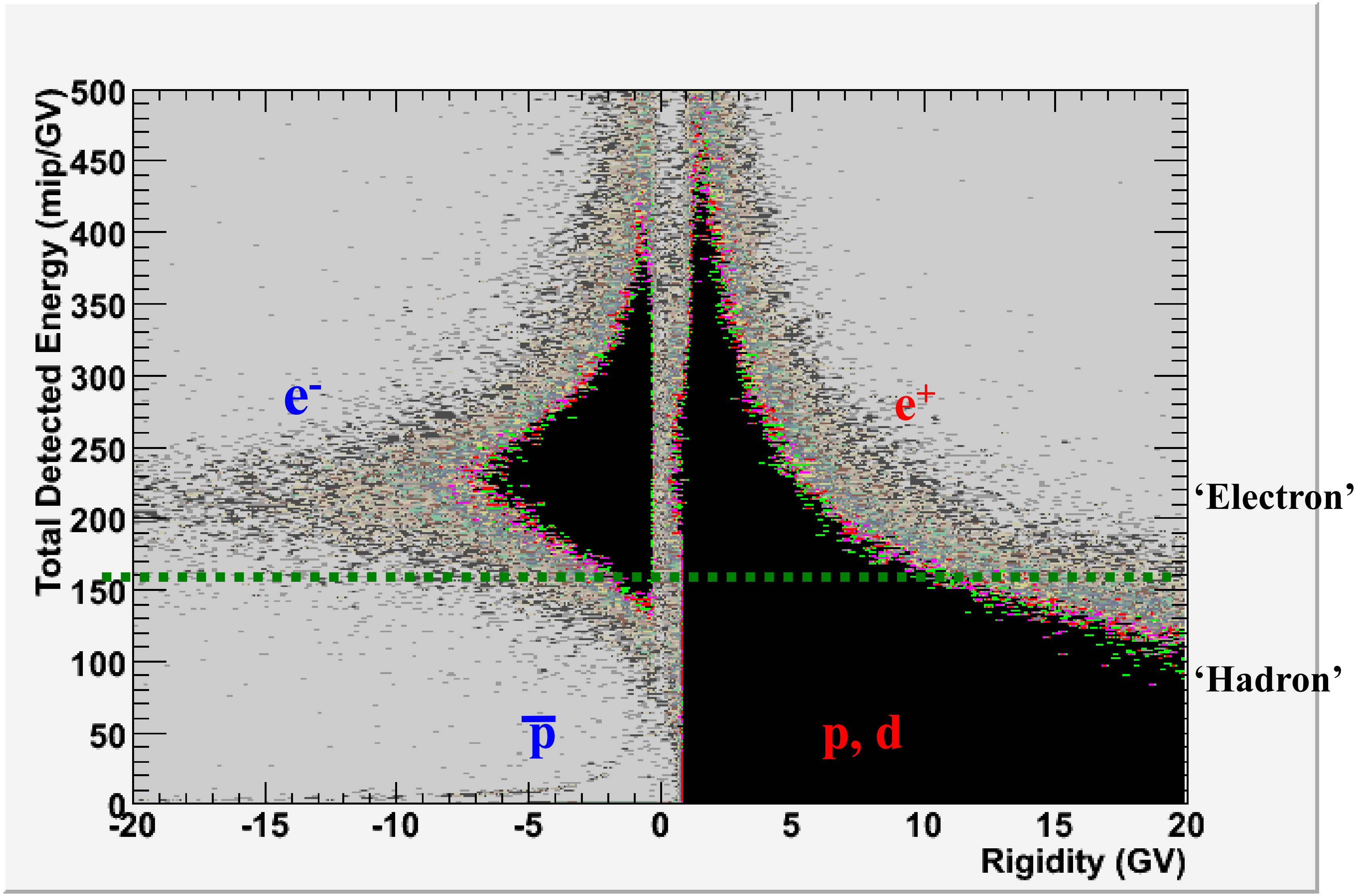


# Positron selection with calorimeter

Rigidity: 20-30 GV

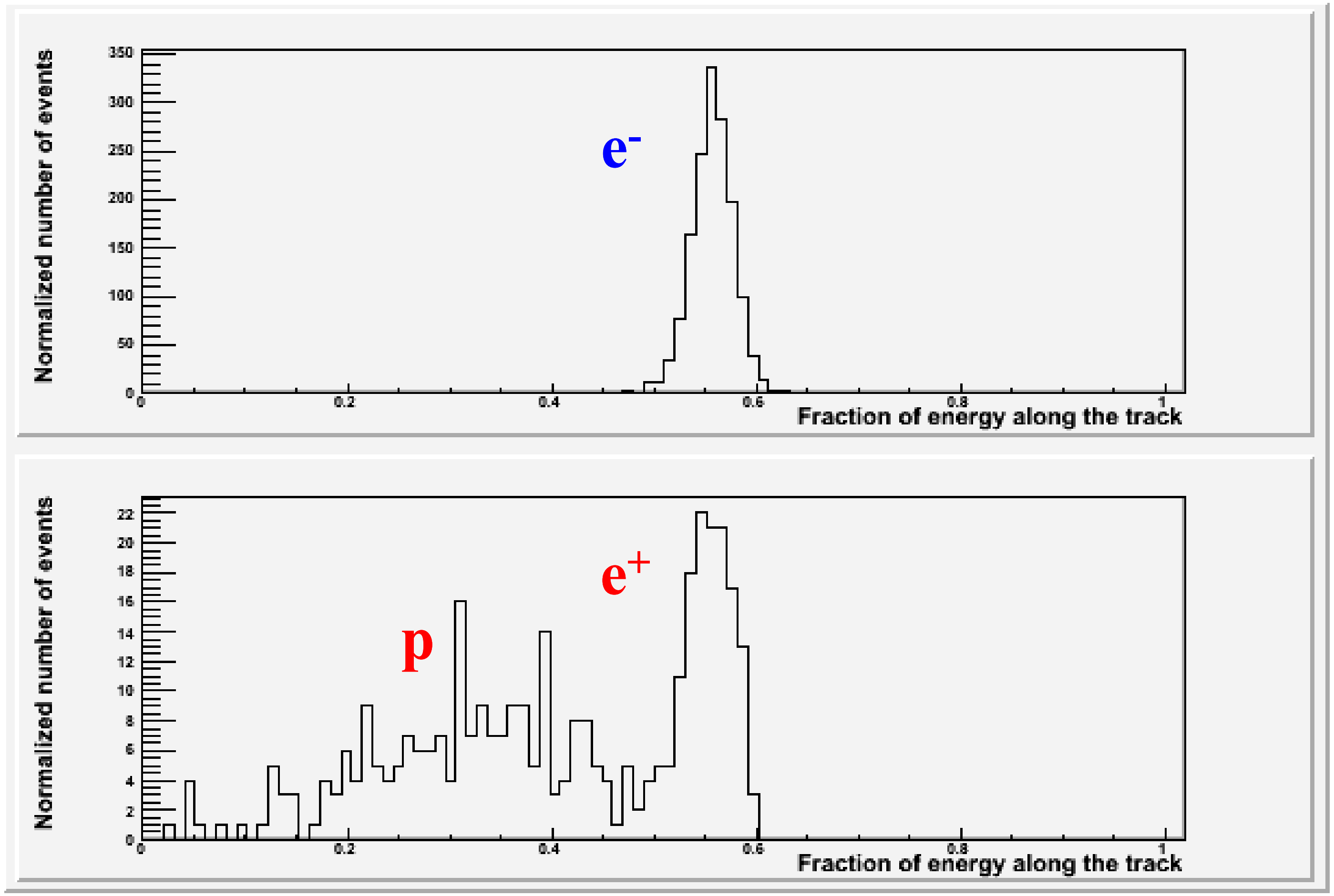


# Antiparticle selection



# Positron selection with calorimeter

**Rigidity: 20-30 GV**

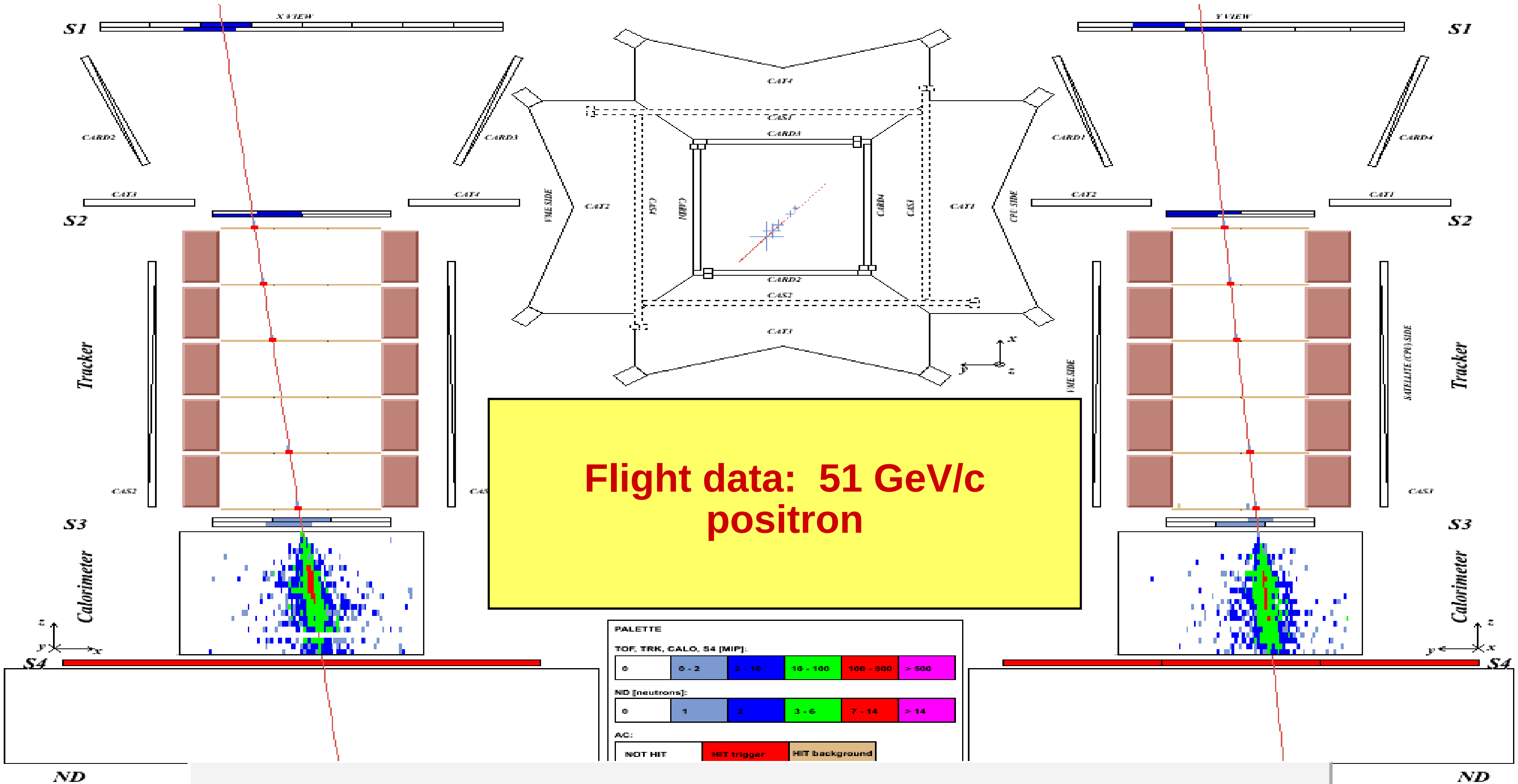


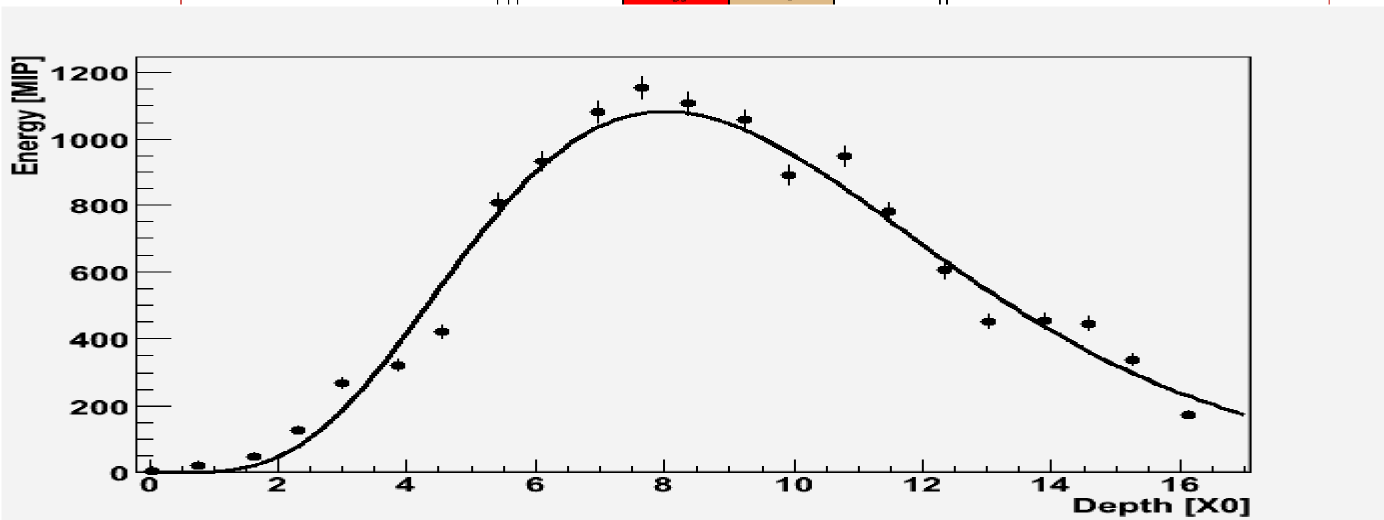

**Fraction of charge released along the calorimeter track (left, hit, right)**

**+**

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

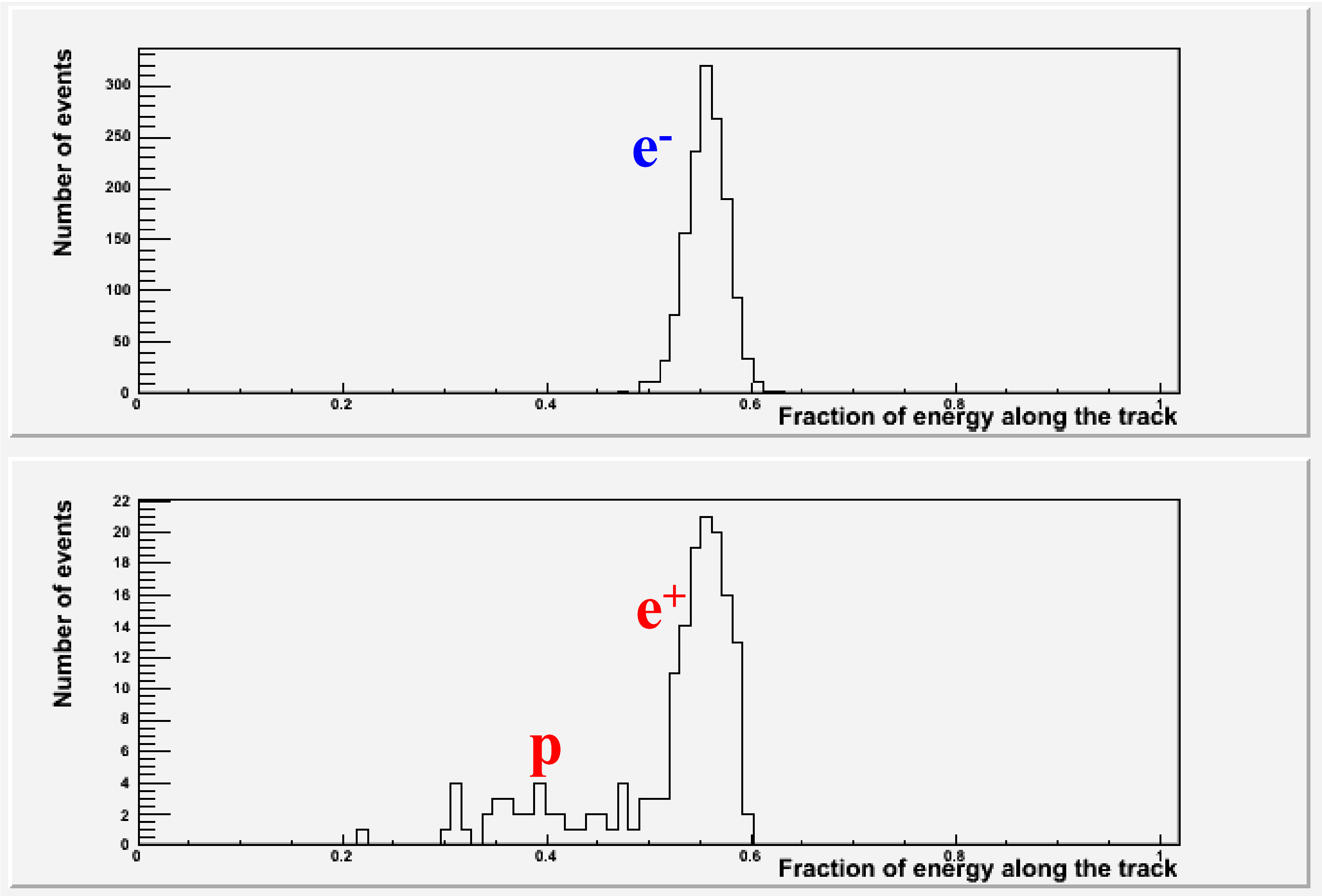
# Flight data: 51 GeV/c positron



# Positron selection with calorimeter

**Rigidity: 20-30 GV**

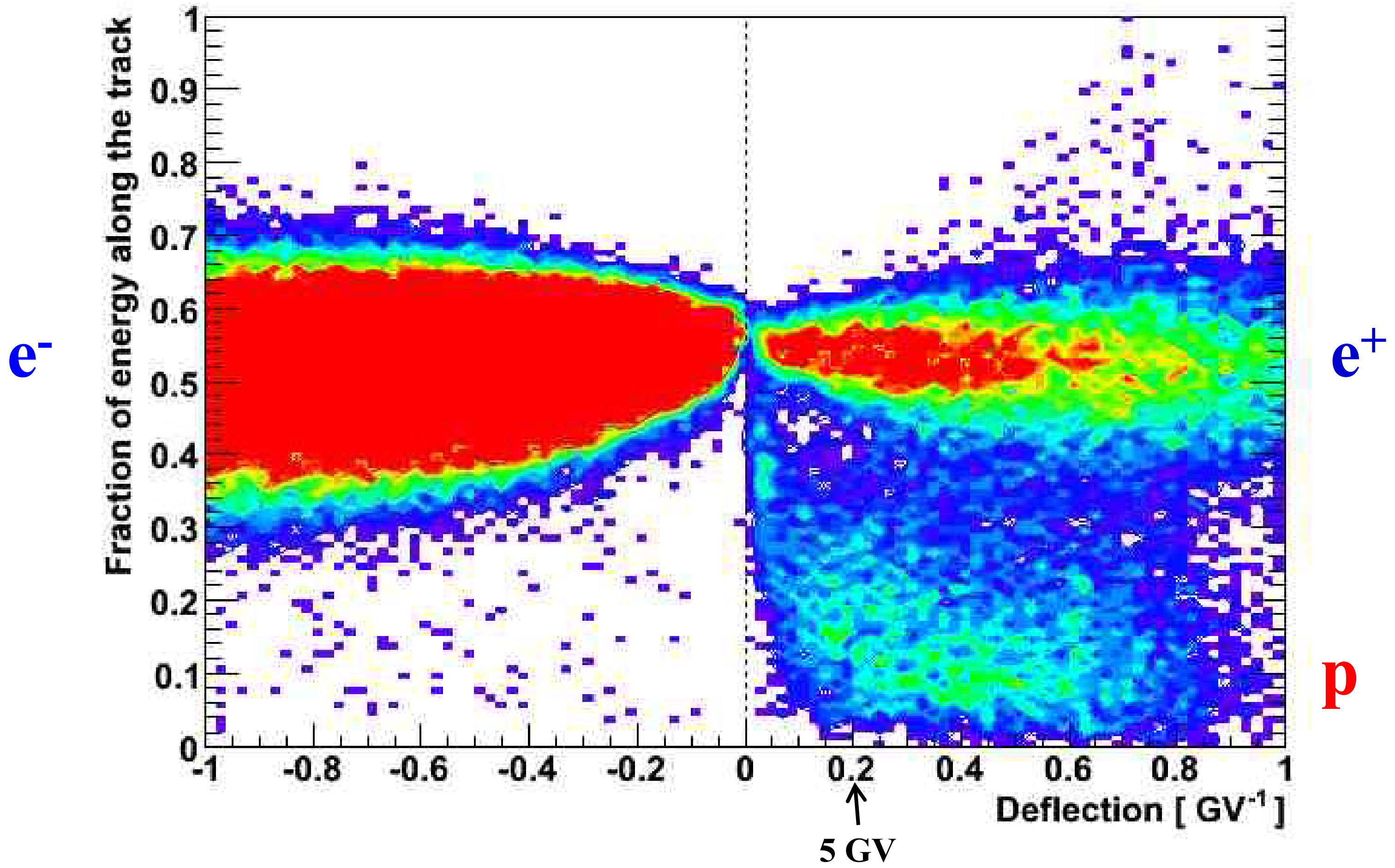



Fraction of charge released along the calorimeter track (left, hit, right)

+

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

# Positron selection with calorimeter




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

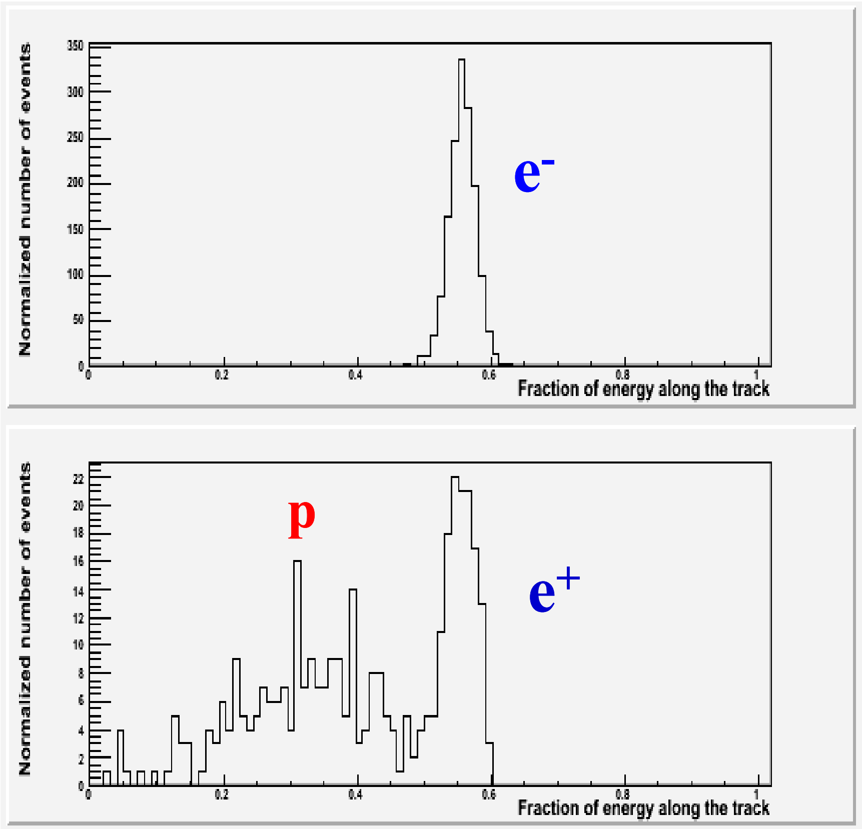
+

- Energy-momentum match
- Starting point of shower

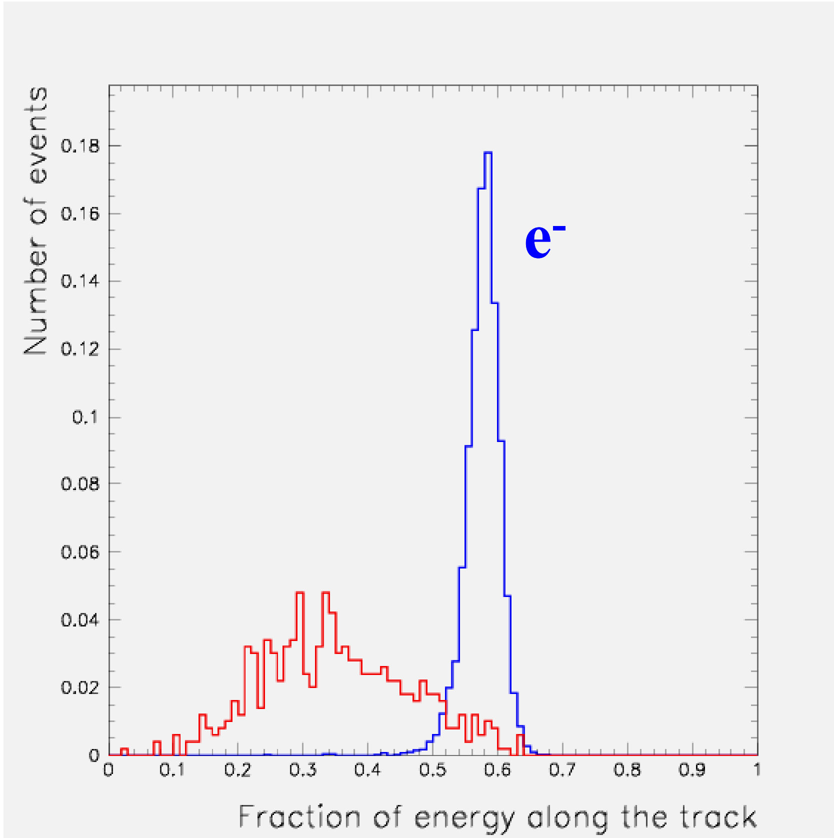
# Positron  selection with calorimeter

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

**Flight data:**
**rigidity: 20-30 GV**




**Test beam data**
**Momentum: 50GeV/c**

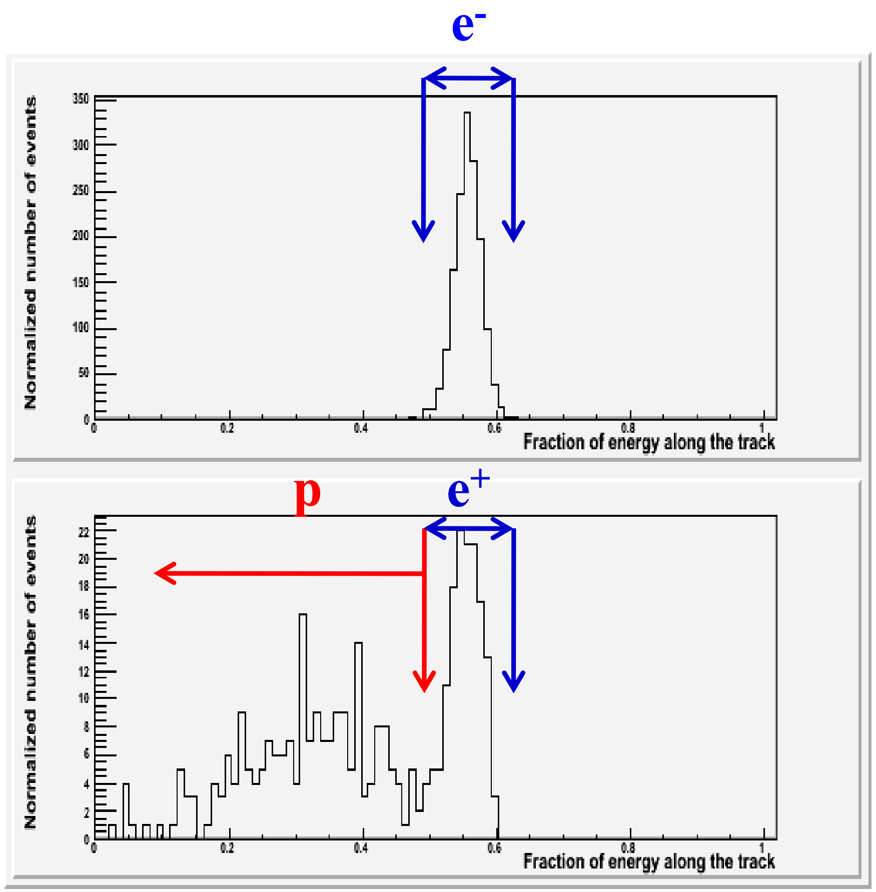



- **Energy-momentum match**
- **Starting point of shower**

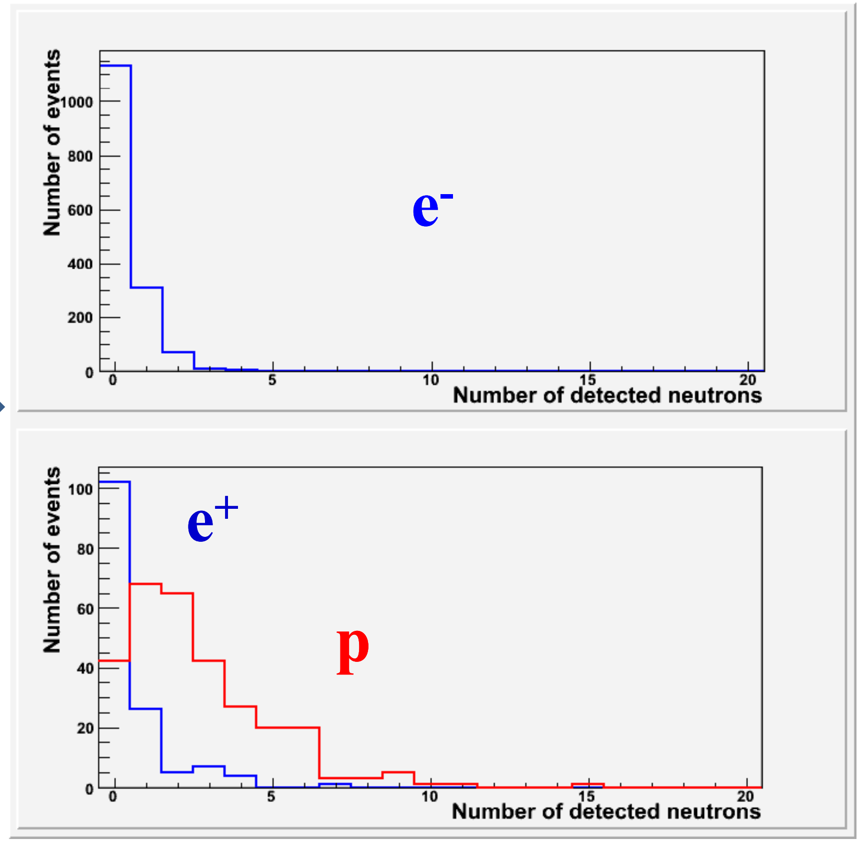
# Positron selection

**Rigidity: 20-30 GV**

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




**Neutrons detected by ND**

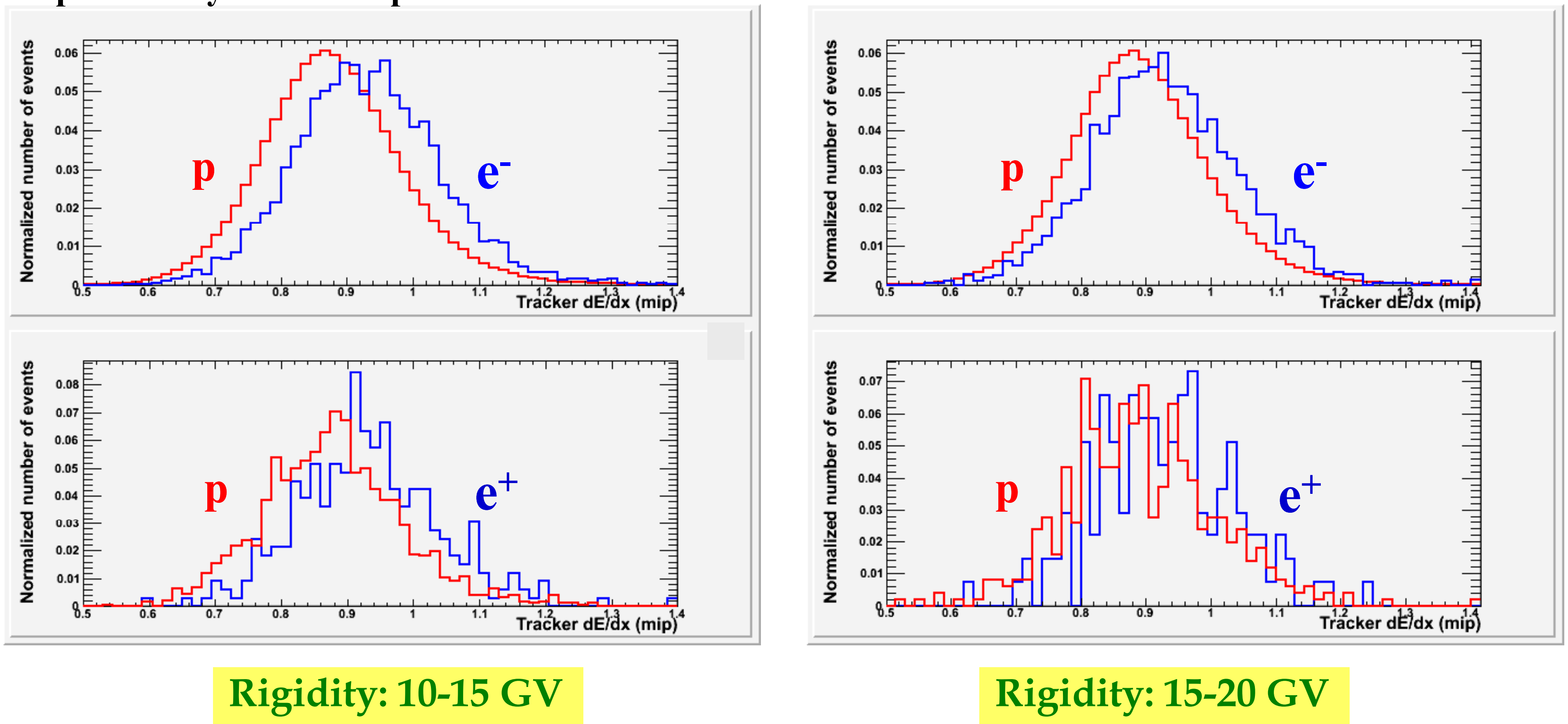



- **Energy-momentum match**
- **Starting point of shower**

# Positron selection

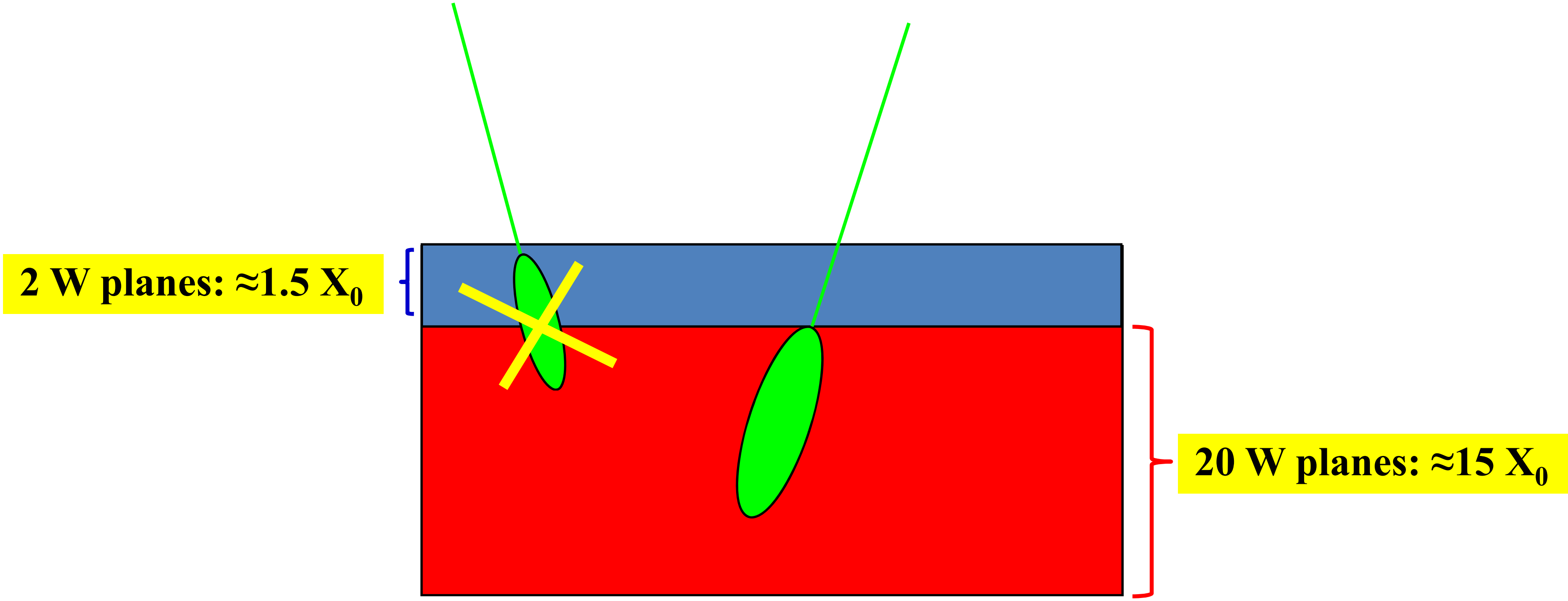
**Energy loss in silicon tracker detectors:**
**• Top: positive (mostly p) and negative events (mostly e⁻)**
**• Bottom: positive events identified as p and e⁺ by trasversal profile method**

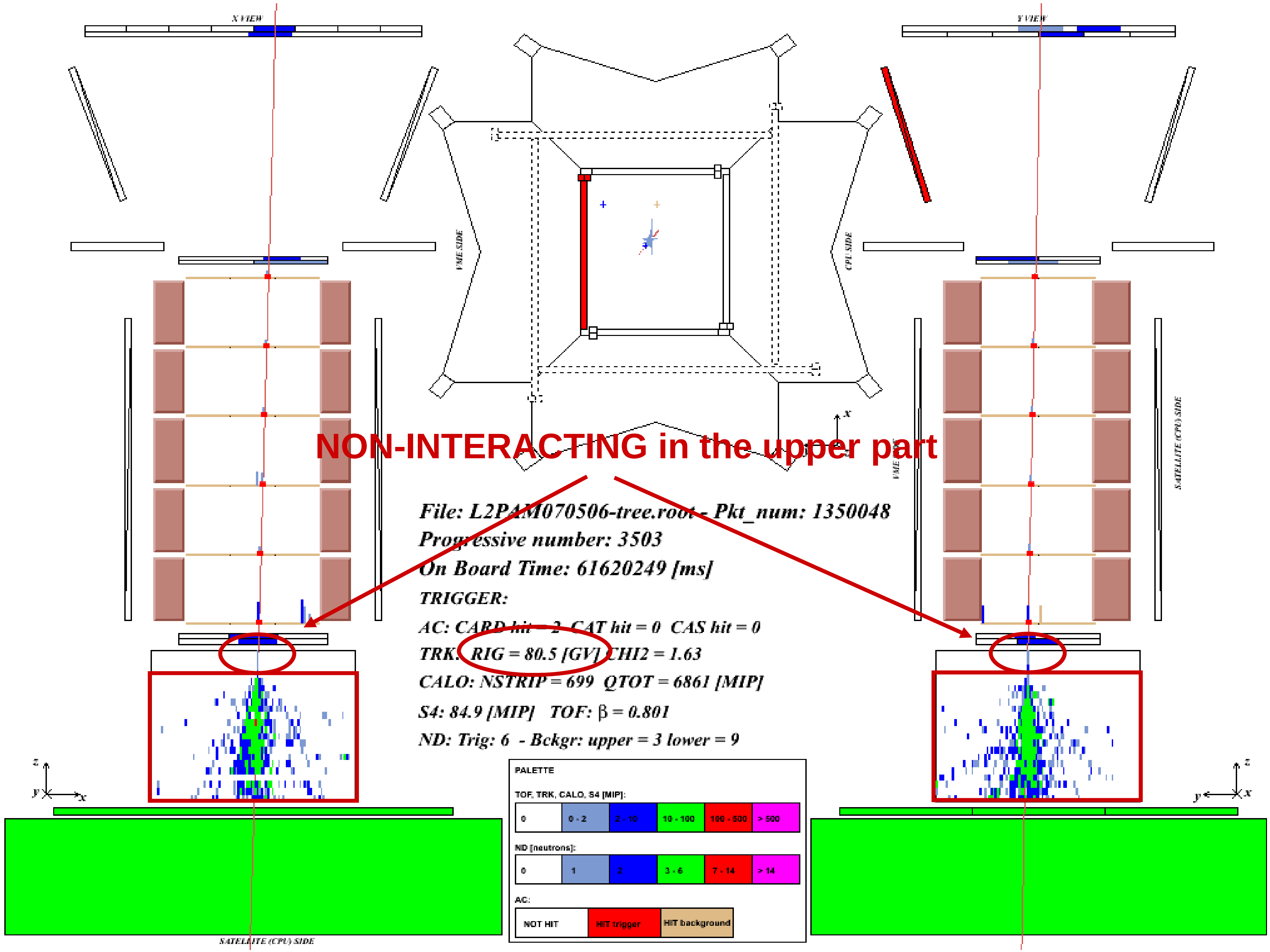
$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

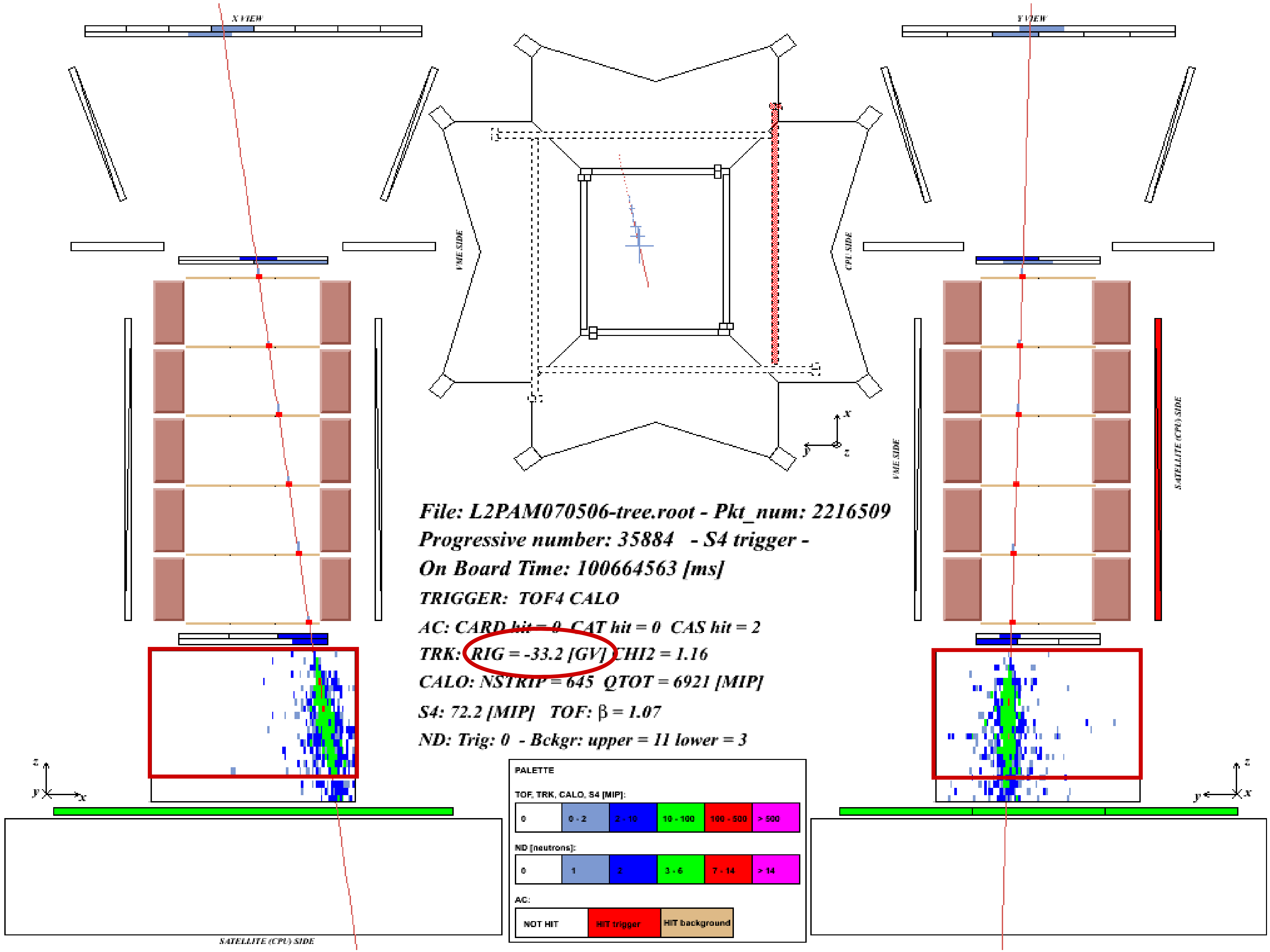


# The "pre-sampler" method

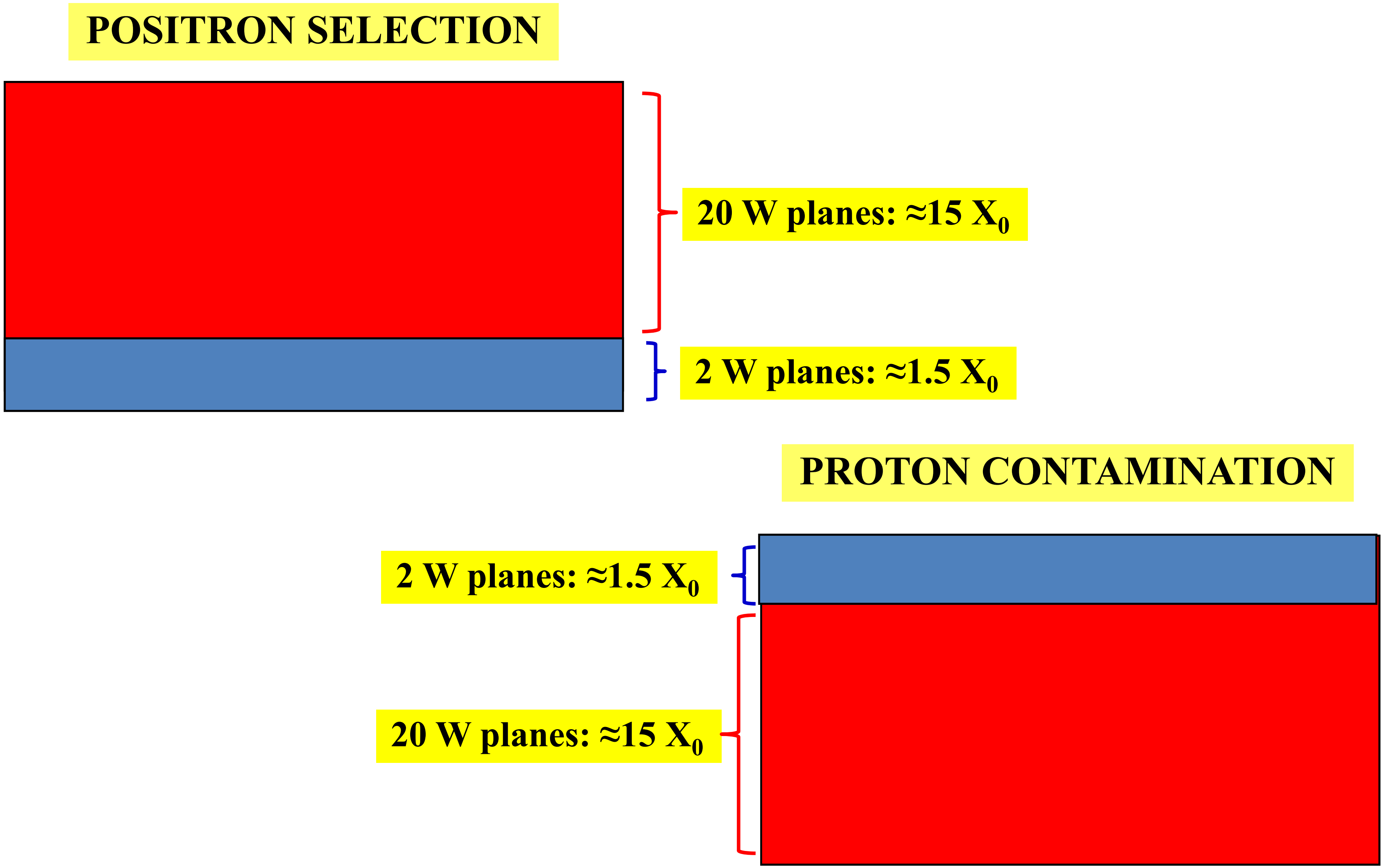
**CALORIMETER: 22 W planes: 16.3 $X_0$**




NON-INTERACTING in the upper part
X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
File: L2PAM070506-tree.root - Pkt_num: 1350048
Progressive number: 3503
On Board Time: 61620249 [ms]
TRIGGER:
AC: CARD hit = 2 CAT hit = 0 CAS hit = 0
TRK: RIG = 80.5 [GV] CHI2 = 1.63
CALO: NSTRIP = 699 QTOT = 6861 [MIP]
S4: 84.9 [MIP] TOF: β = 0.801
ND: Trig: 6 - Bckgr: upper = 3 lower = 9
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

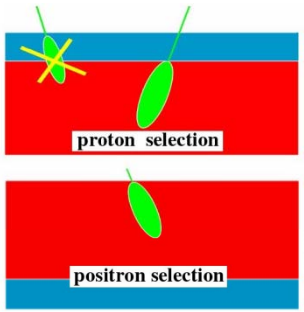

X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
File: L2PAM070506-tree.root - Pkt_num: 2216509
Progressive number: 35884 - S4 trigger -
On Board Time: 100664563 [ms]
TRIGGER: TOF4 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 2
TRK: RIG = -33.2 [GV] CHI2 = 1.16
CALO: NSTRIP = 645 QTOT = 6921 [MIP]
S4: 72.2 [MIP] TOF: β = 1.07
ND: Trig: 0 - Bckgr: upper = 11 lower = 3
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

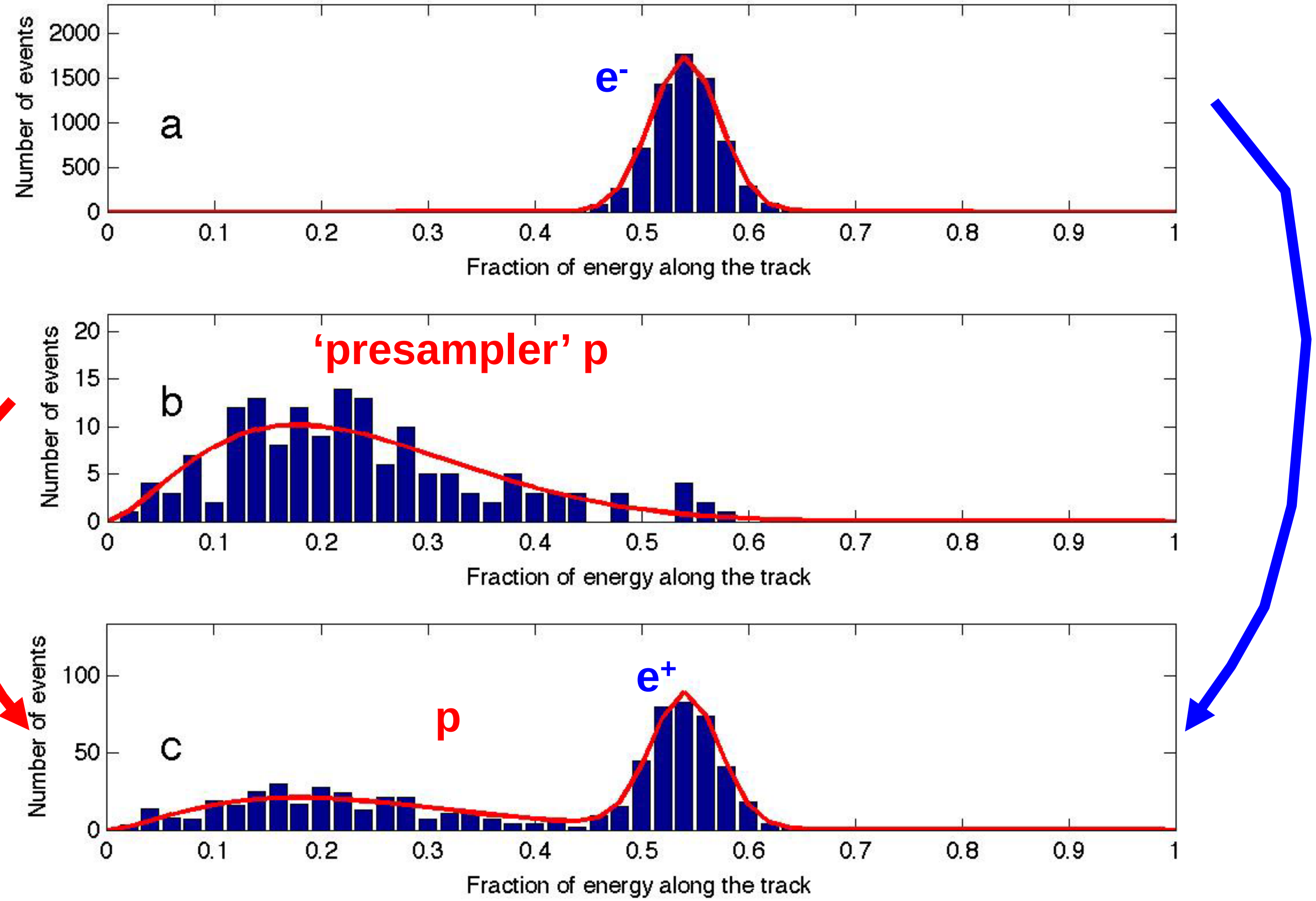
# The “pre-sampler” method



# e⁺ background estimation from data

**Rigidity: 20-28 GV**

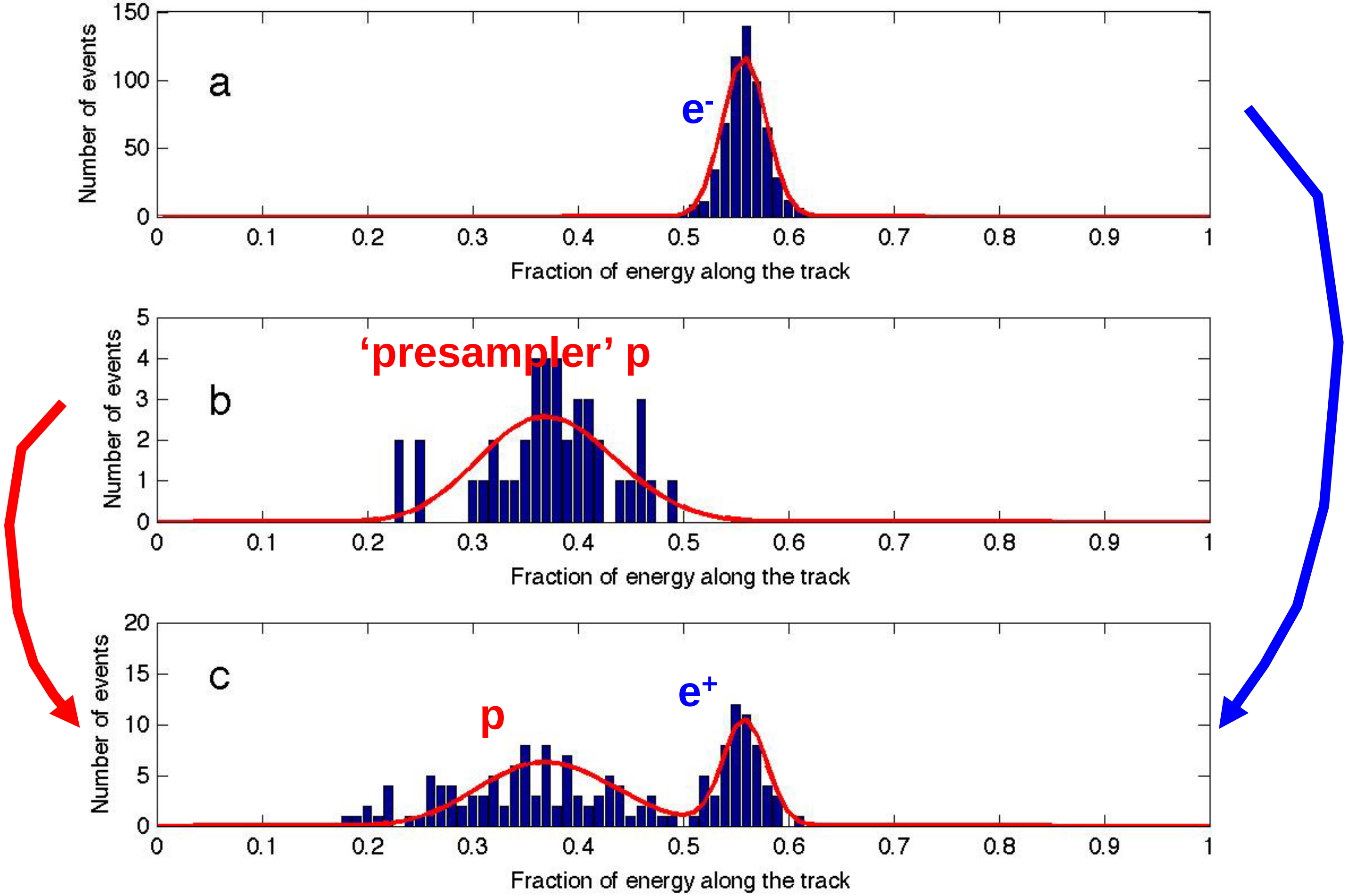


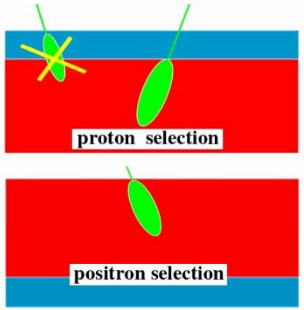




+
- **Energy-momentum match**
- **Starting point of shower**

# $e^+$ background estimation from data

**Rigidity: 28-42 GV**

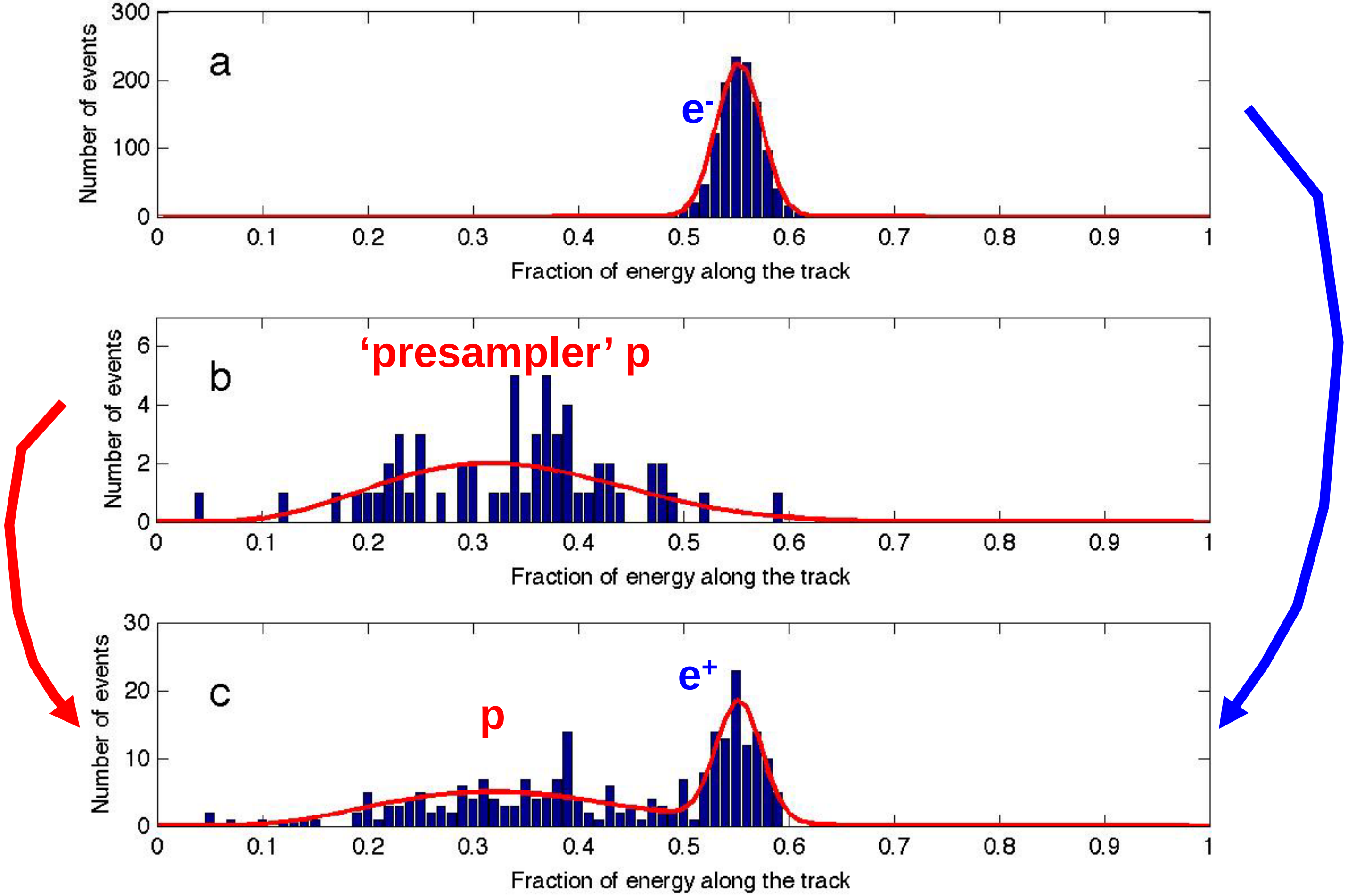


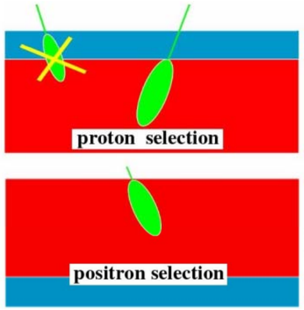




+
- **Energy-momentum match**
- **Starting point of shower**

# e⁺ background estimation from data

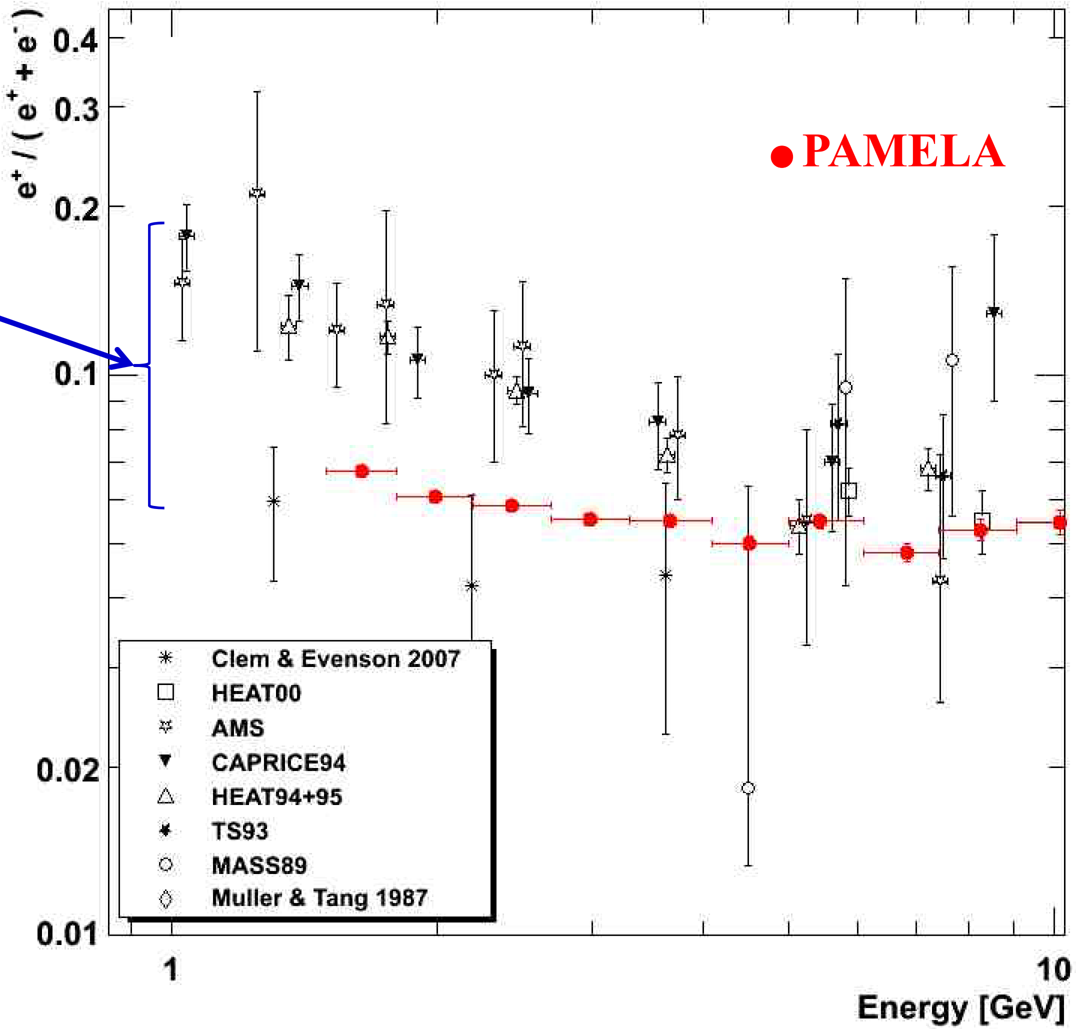
**Rigidity: 6.1-7.4 GV**




+ • Energy-momentum match
• Starting point of shower

# Positron to Electron Fraction




Charge sign dependent solar modulation

End 2007:
~10 000 $e^+$ > 1.5 GeV

# Solar Modulation of galactic cosmic rays

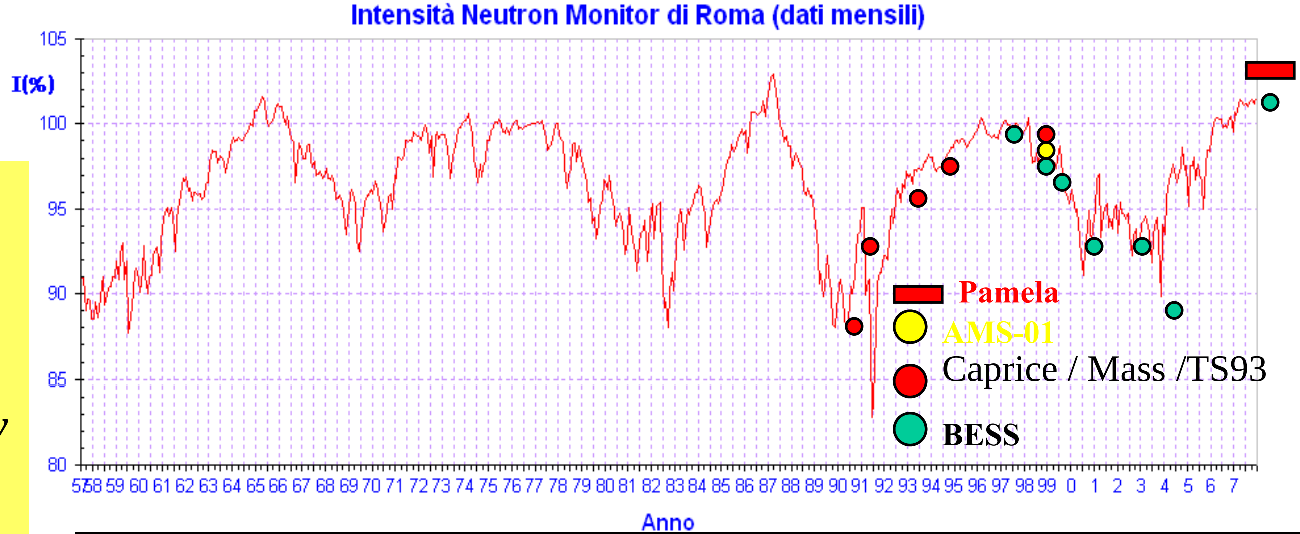
- **Study of charge sign dependent effects**

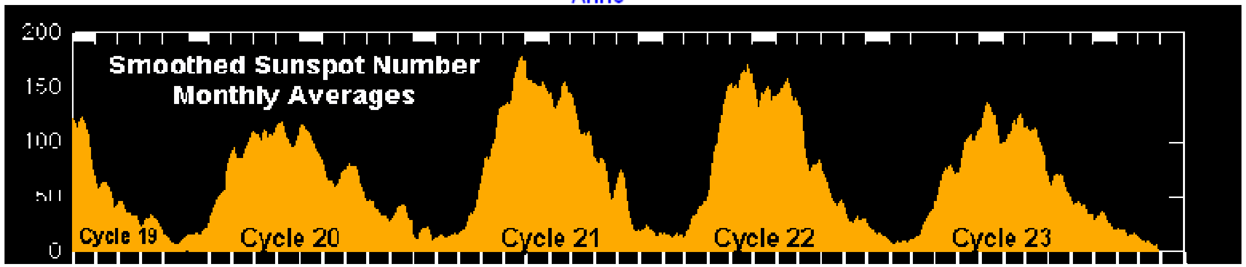
*Asaoka Y. et al. 2002, Phys. Rev. Lett. 88, 051101),*

*Bieber, J.W., et al. Physi-cal Review Letters, 84, 674, 1999.*

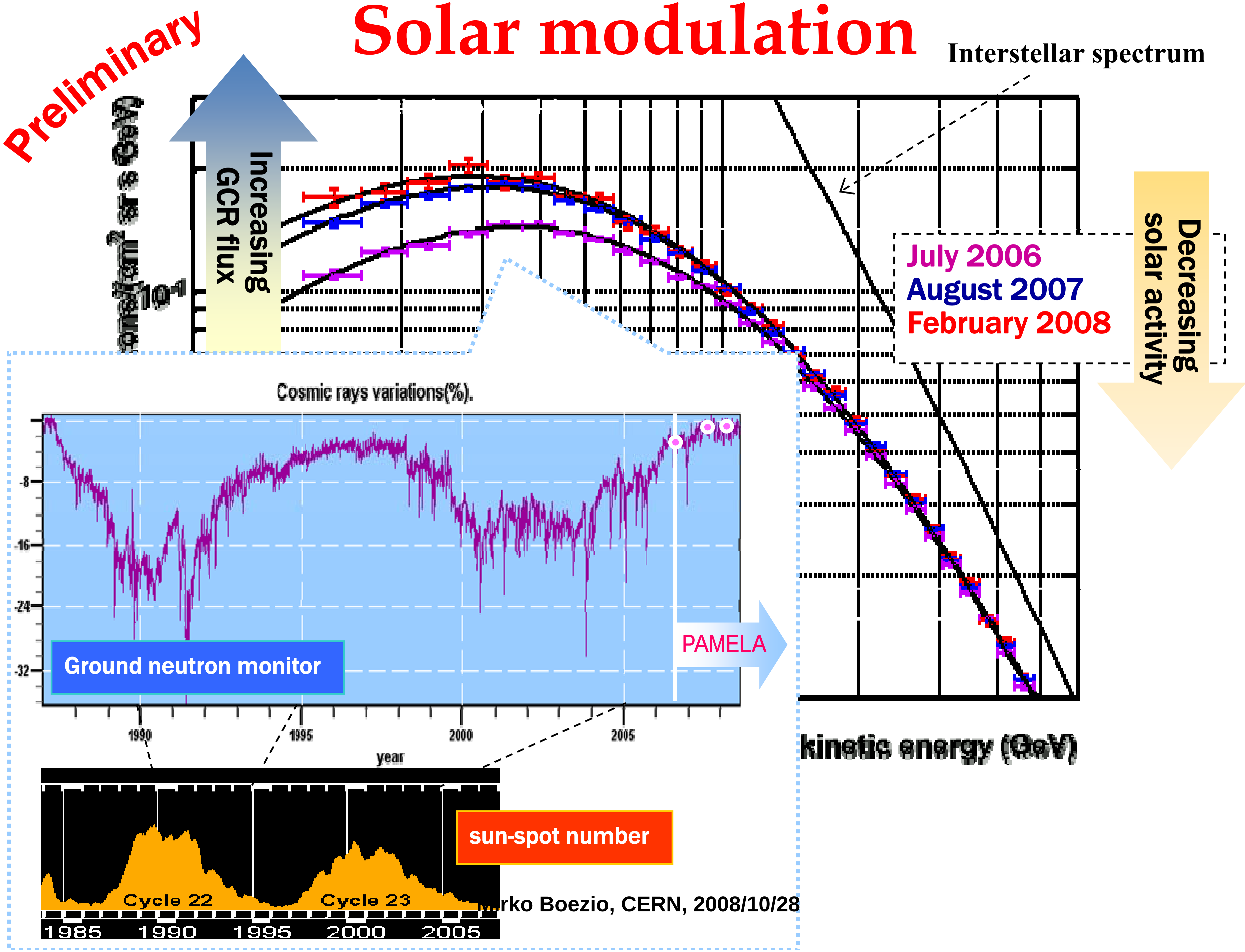
*J. Clem et al. 30th ICRC 2007*

*U.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)*



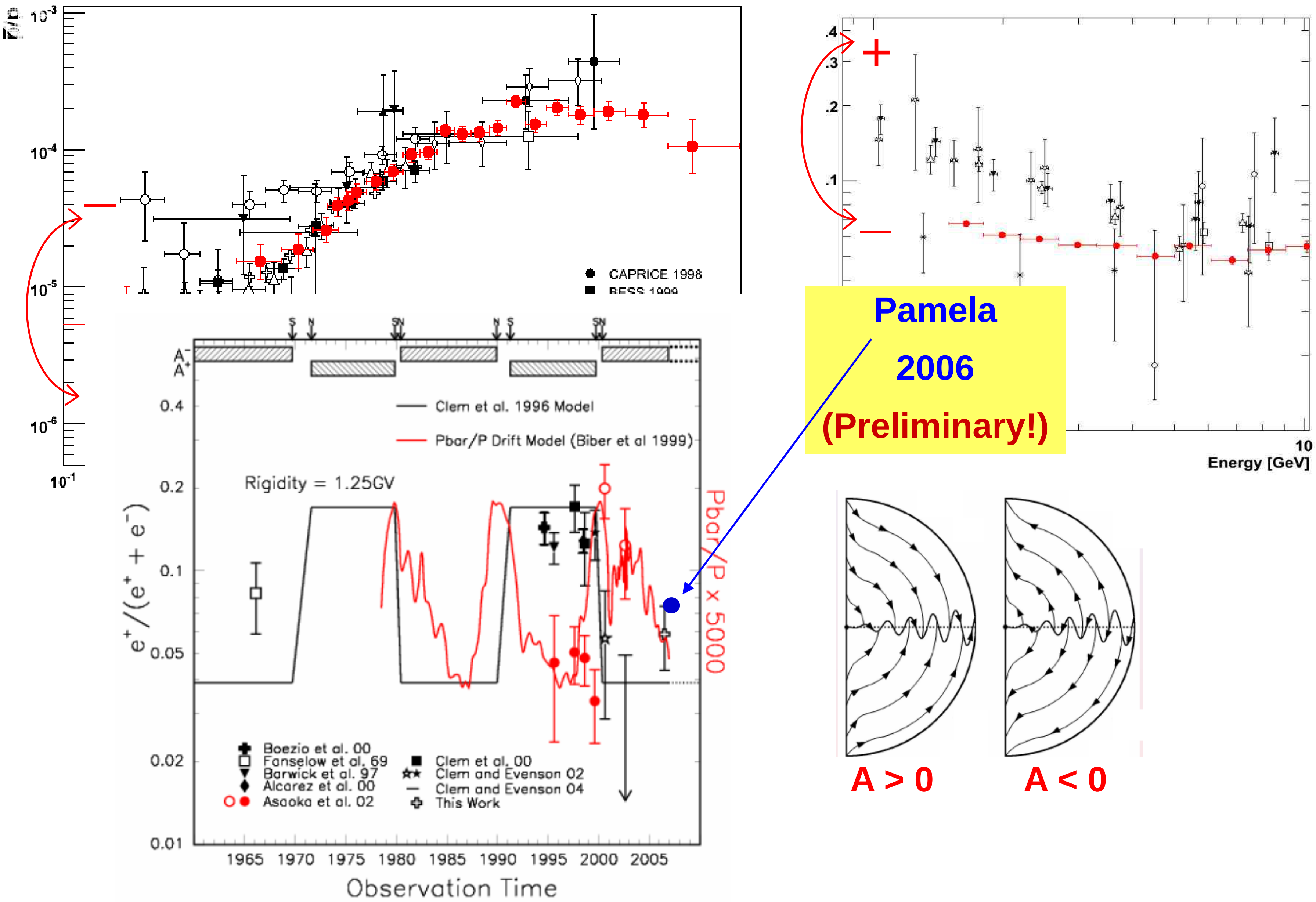



# Solar modulation

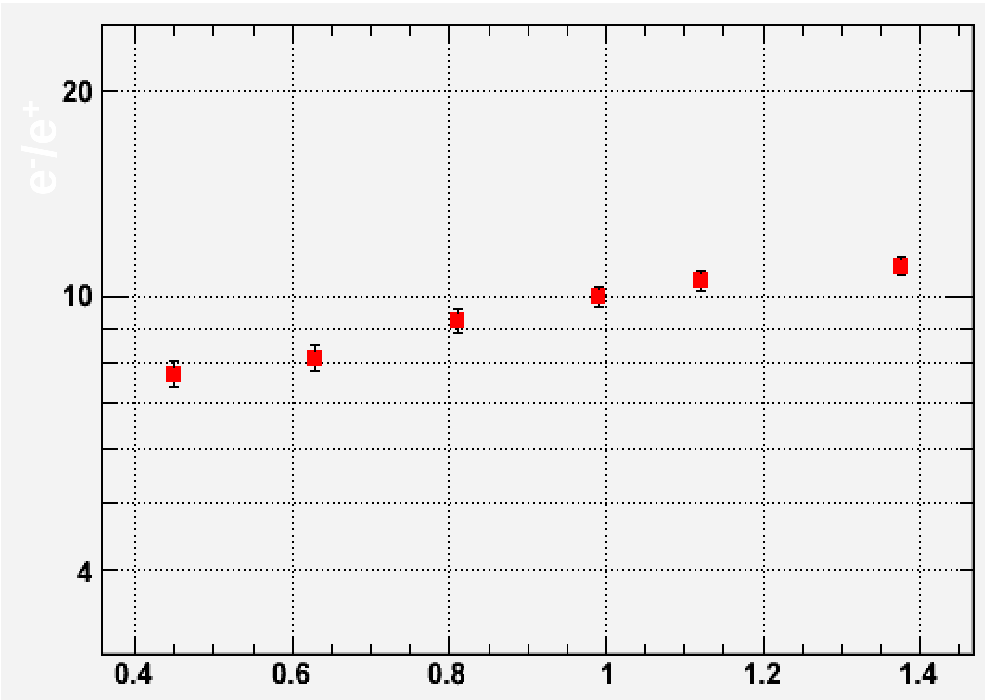



Mirko Boezio, CERN, 2008/10/28

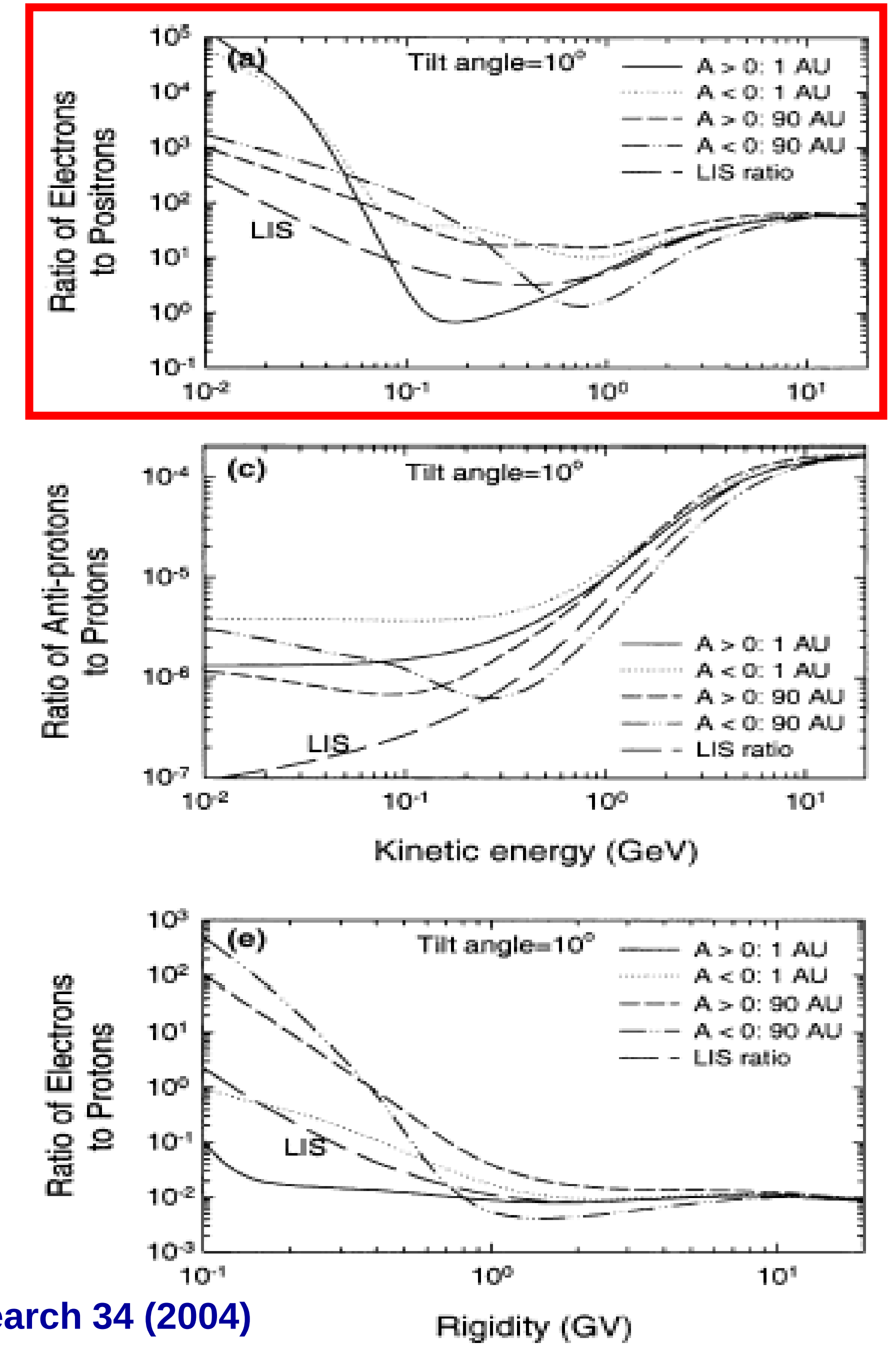
# Charge dependent solar modulation



# Electron to positron ratio

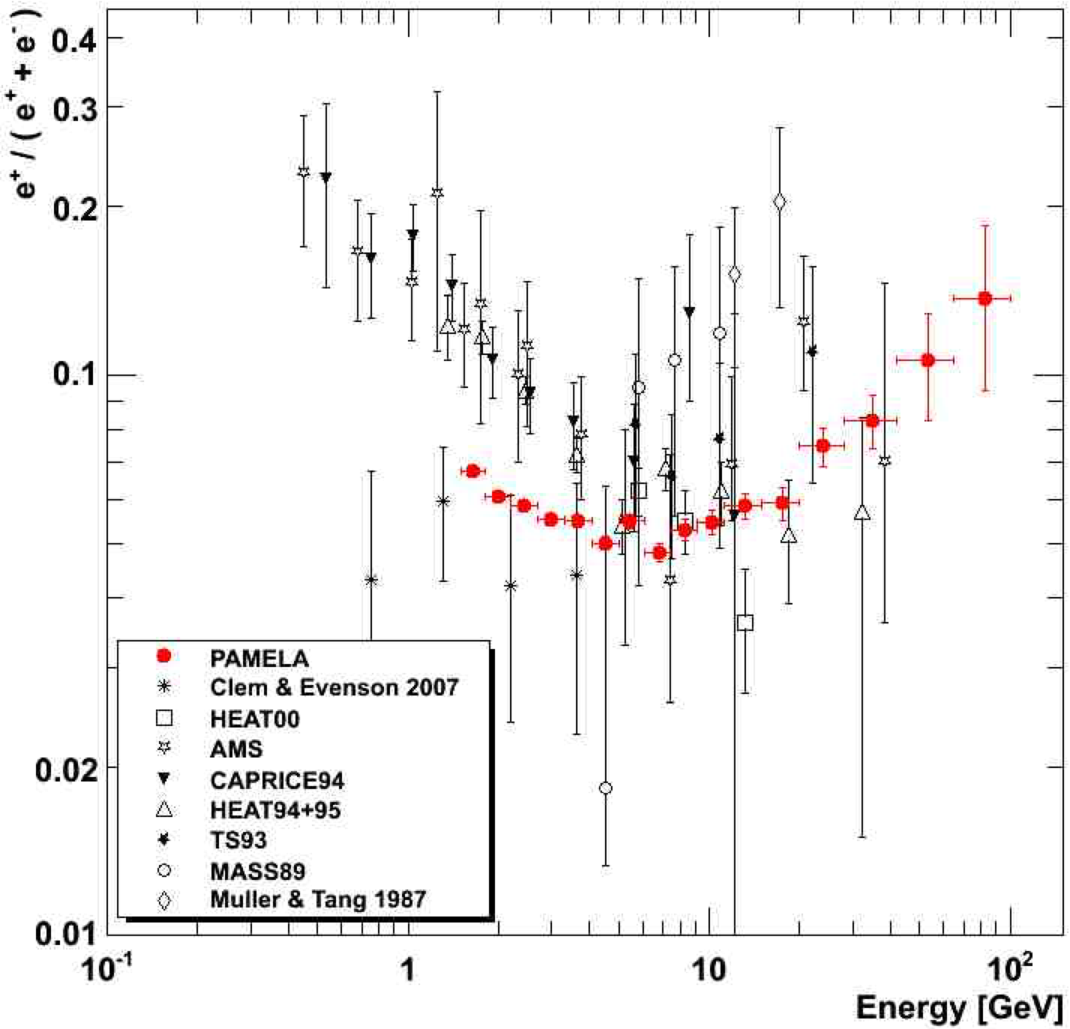



Preliminary PAMELA results




U.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)

# Positron to Electron Fraction

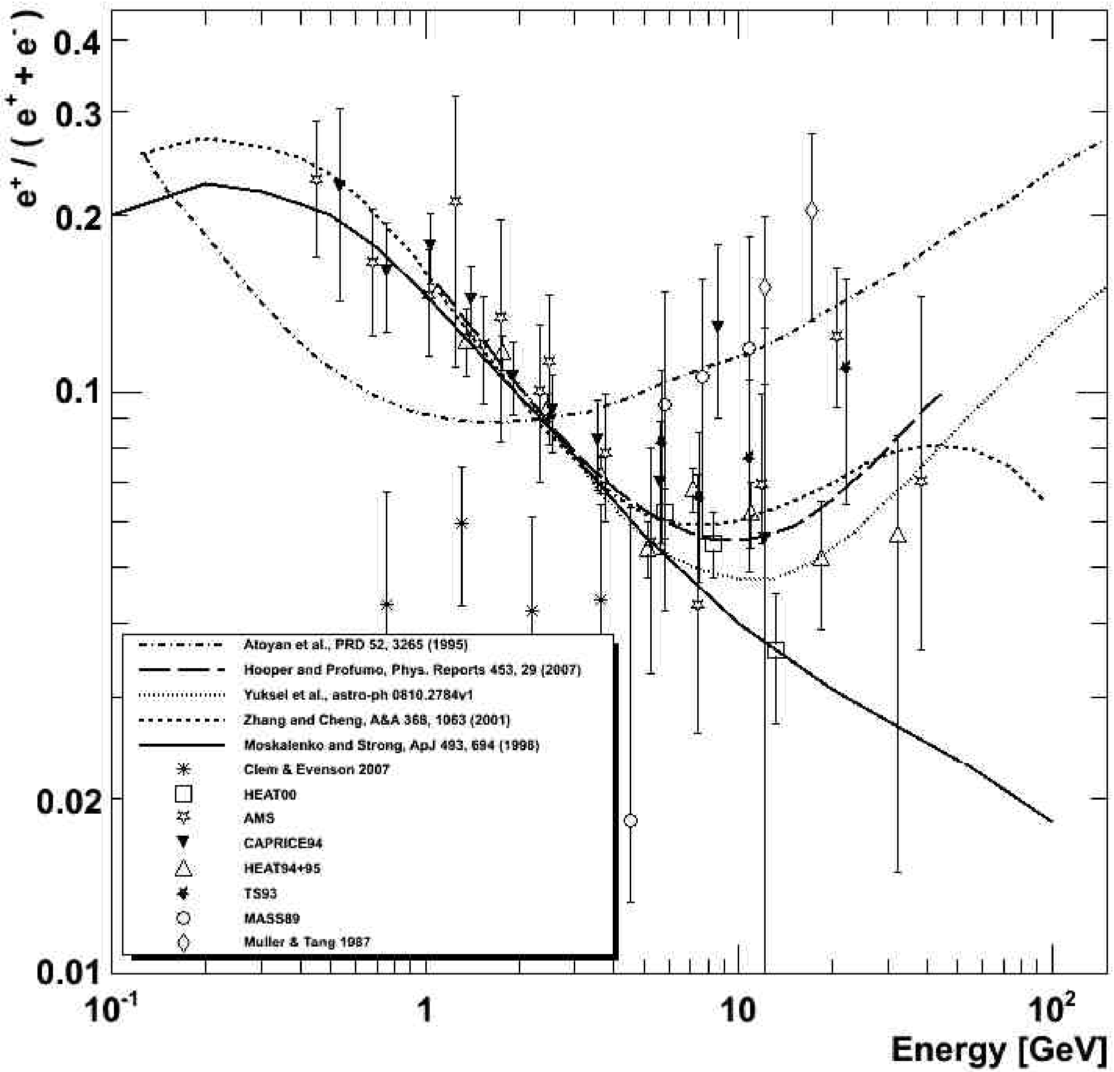


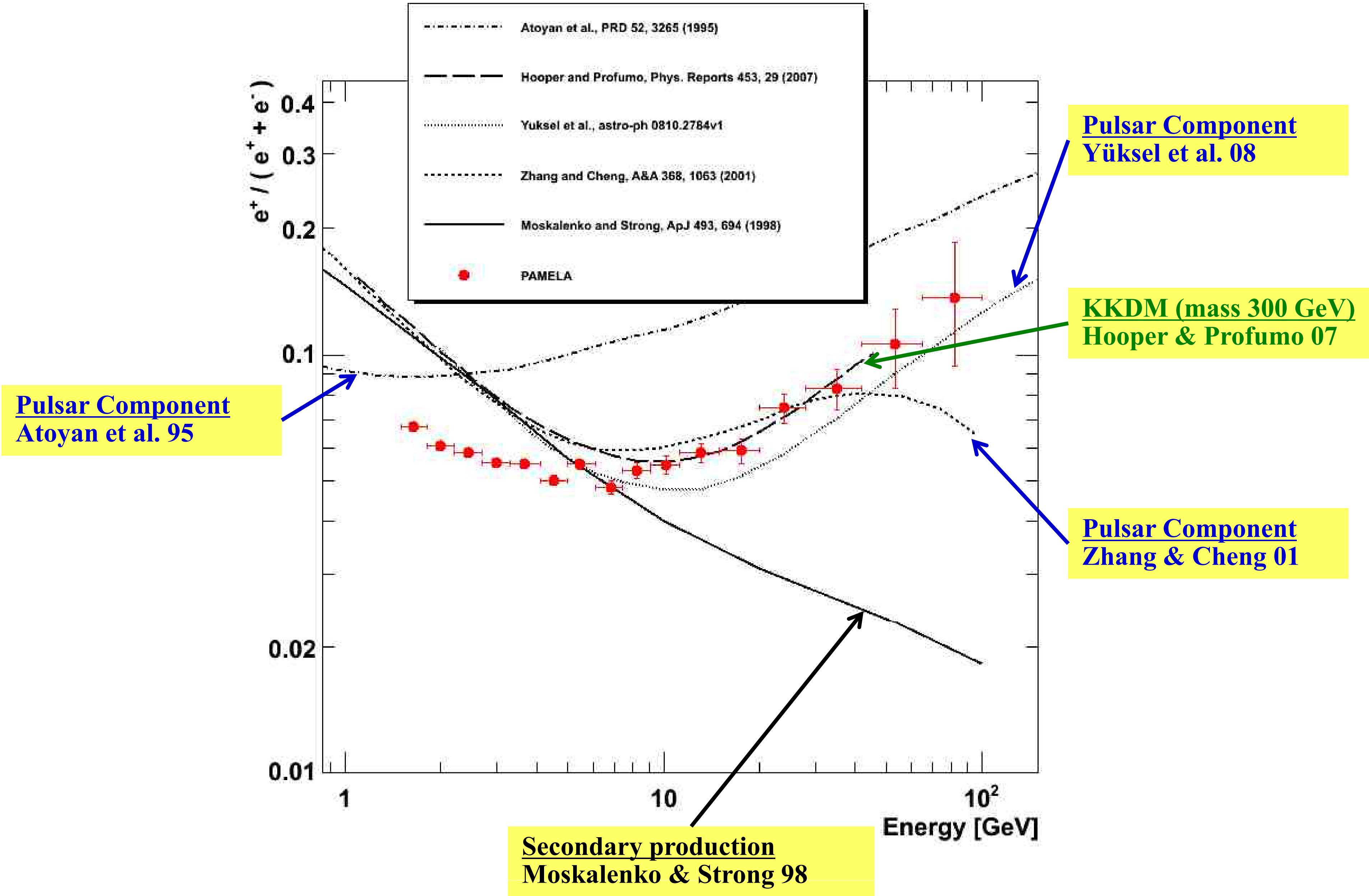

**End 2007:**
**~10 000 $e^+$ > 1.5 GeV**

**~2000 > 5 GeV**

**Astro-ph 0810.4995**

Mirko Boezio, CERN, 2008/10/28

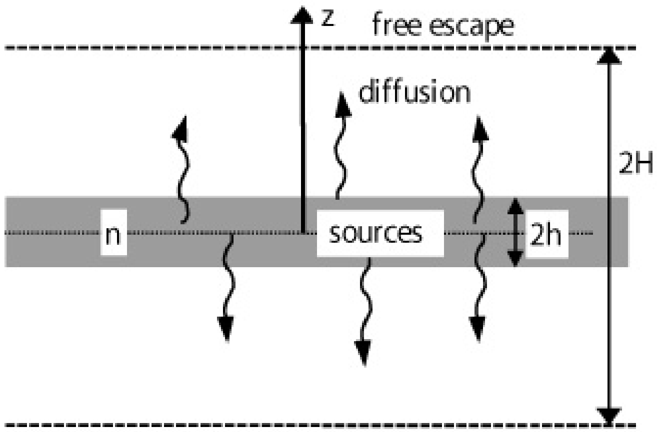

e+ / ( e+ + e- )
0.4
0.3
0.2
0.1
0.02
0.01
10-1
1
10
102
Energy [GeV]
Atoyan et al., PRD 52, 3265 (1995)
Hooper and Profumo, Phys. Reports 453, 29 (2007)
Yuksel et al., astro-ph 0810.2784v1
Zhang and Cheng, A&A 368, 1063 (2001)
Moskalenko and Strong, ApJ 493, 694 (1998)
Clem & Evenson 2007
HEAT00
AMS
CAPRICE94
HEAT94+95
TS93
MASS89
Muller & Tang 1987



Atoyan et al., PRD 52, 3265 (1995)
Hooper and Profumo, Phys. Reports 453, 29 (2007)
Yuksel et al., astro-ph 0810.2784v1
Zhang and Cheng, A&A 368, 1063 (2001)
Moskalenko and Strong, ApJ 493, 694 (1998)
PAMELA
e+ / ( e+ + e- )
0.4
0.3
0.2
0.1
0.02
0.01
1
10
10^2
Energy [GeV]
Pulsar Component
Yüksel et al. 08
KKDM (mass 300 GeV)
Hooper & Profumo 07
Pulsar Component
Atoyan et al. 95
Pulsar Component
Zhang & Cheng 01
Secondary production
Moskalenko & Strong 98

# Cosmic-Ray Propagation

# Diffusion Halo Model

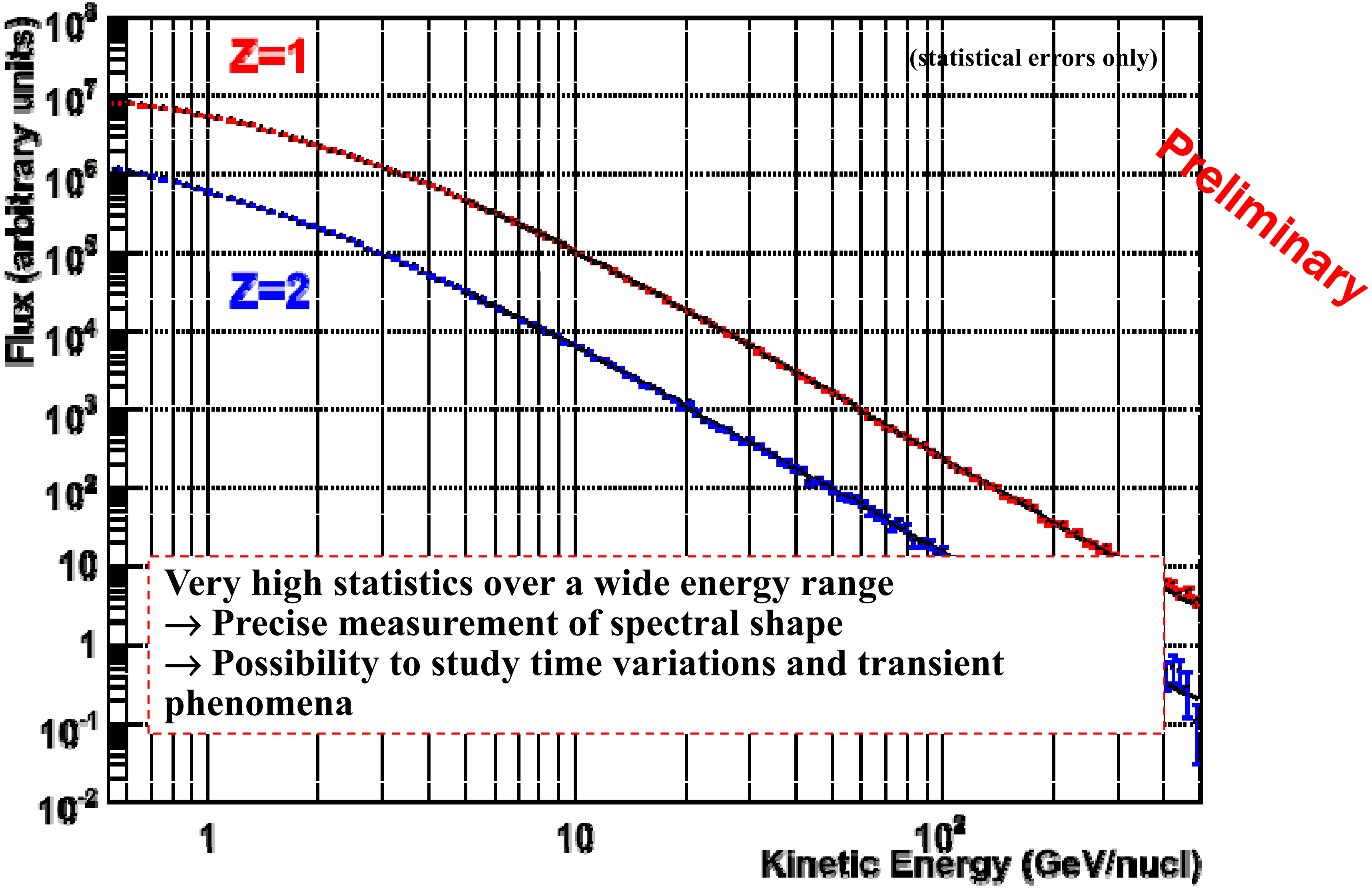



$$\frac{\partial N_i(E,z,t)}{\partial t} = \underbrace{D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t)}_{\text{diffusion}} - \underbrace{N_i(E,z,t)\left\{\frac{1}{\tau_i^{\text{int}}(E,z)}+\frac{1}{\gamma(E)\tau_i^{dec}}\right\}}_{\text{interaction and decay}}$$

$$+ \underbrace{\sum_{k>i}\frac{N_k(E,z,t)}{\tau_{\text{int}}^{k\to i}(E,z)}}_{\text{secondary production}} + \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

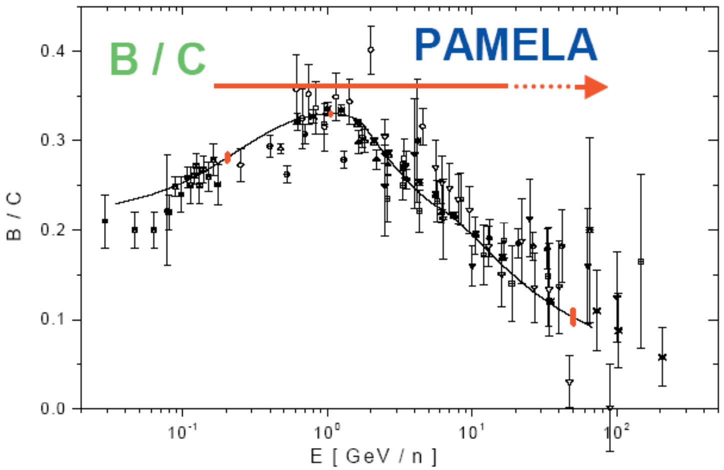
$$\underbrace{-\frac{\partial}{\partial E}\left\{\left\langle\frac{\partial E}{\partial t}\right\rangle\cdot N_i(E,z,t)\right\}+\frac{1}{2}\frac{\partial^2}{\partial E^2}\left\{\left\langle\frac{\Delta E^2}{\Delta t}\right\rangle\cdot N_i(E,z,t)\right\}}_{\text{energy changing processes (ionisation, reacceleration)}}$$

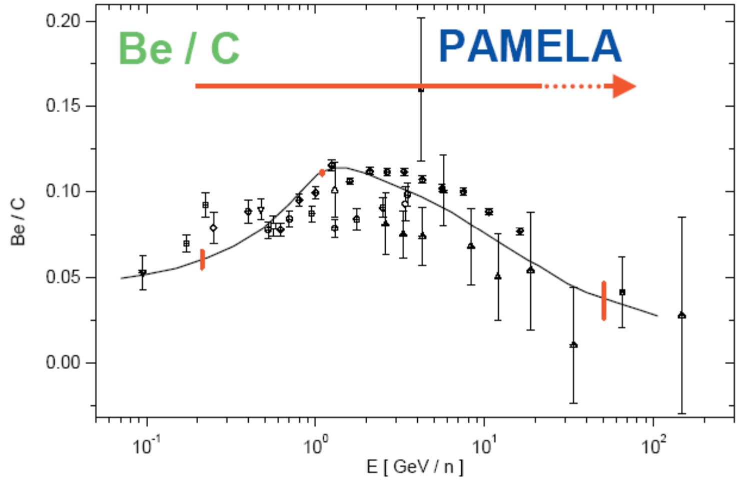
# Galactic H and He spectra

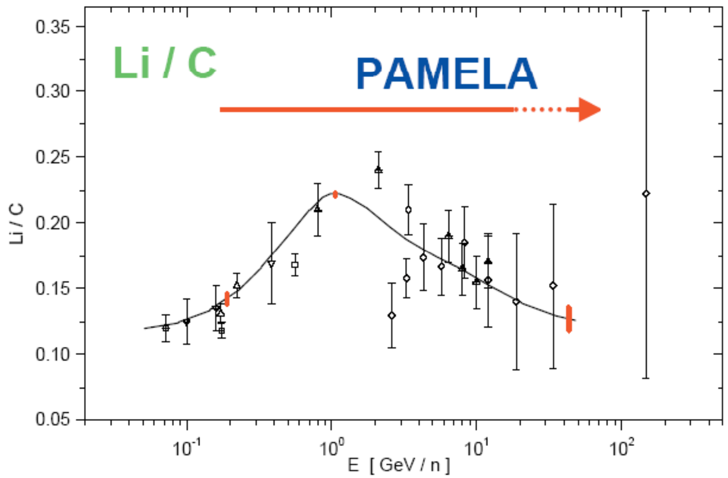



Very high statistics over a wide energy range
→ Precise measurement of spectral shape
→ Possibility to study time variations and transient phenomena

# Secondary to Primary ratios

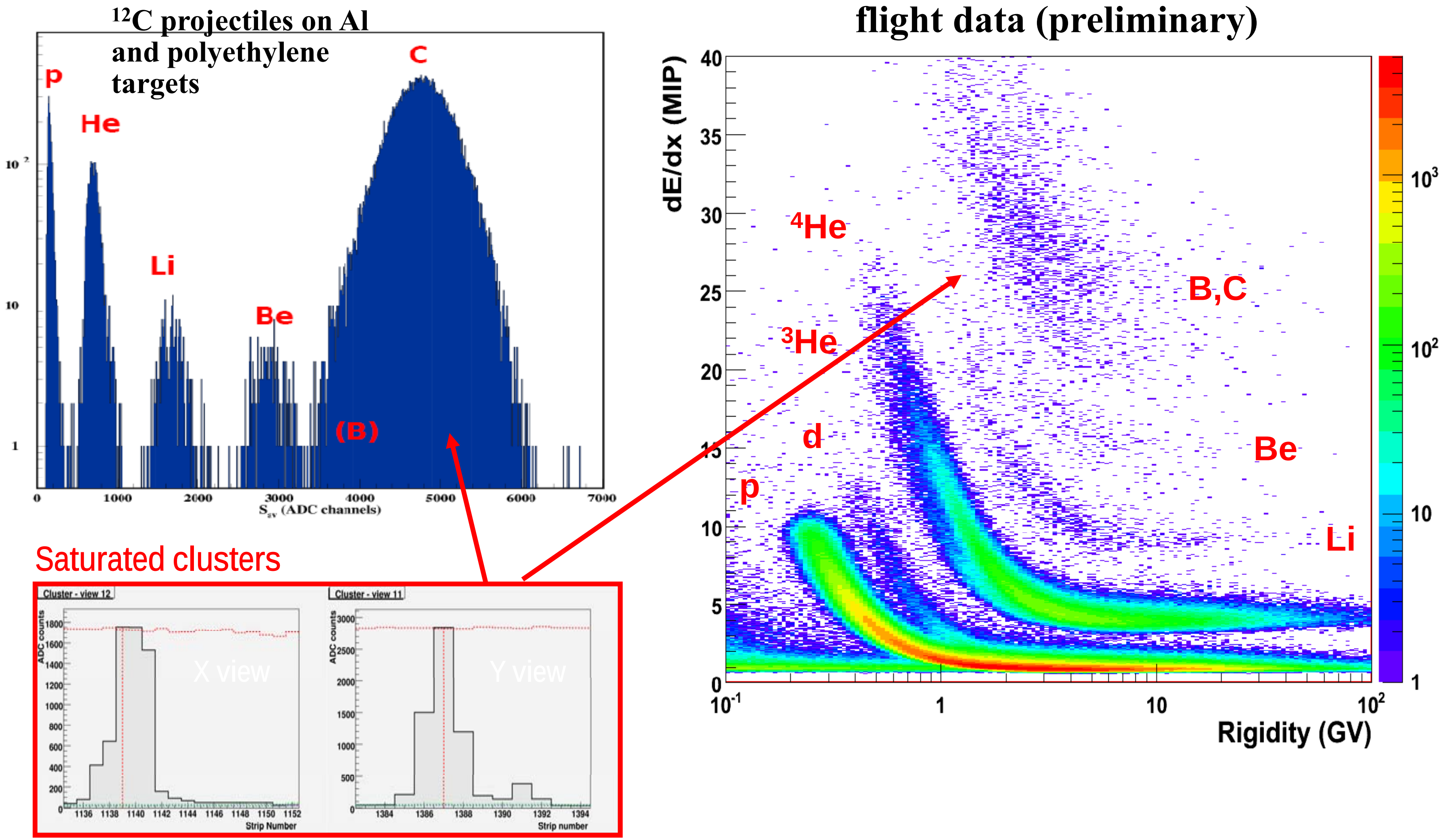


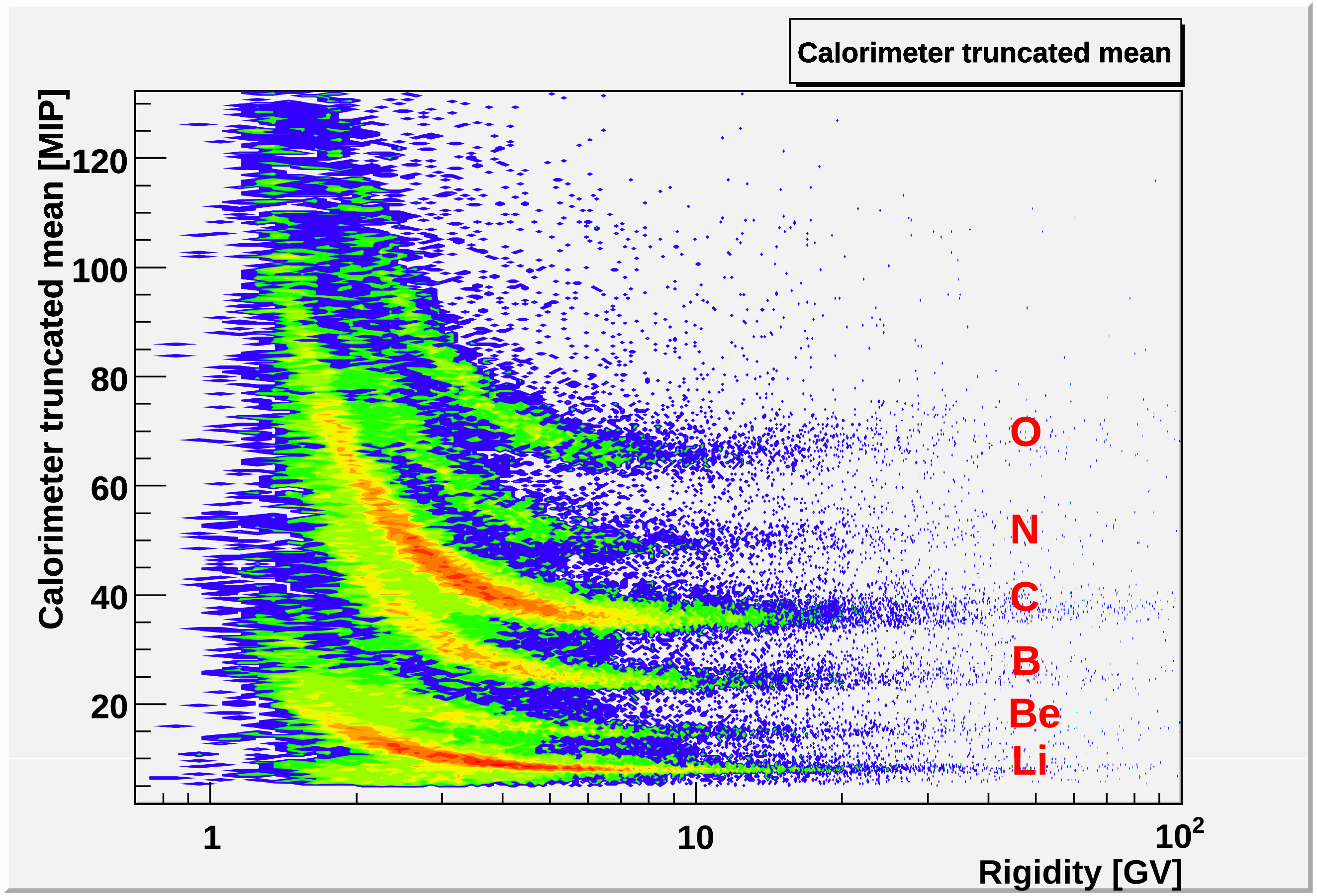

**Mirko Boezio, CERN, 2008/10/28**

# Charge identification capabilities (tracker)



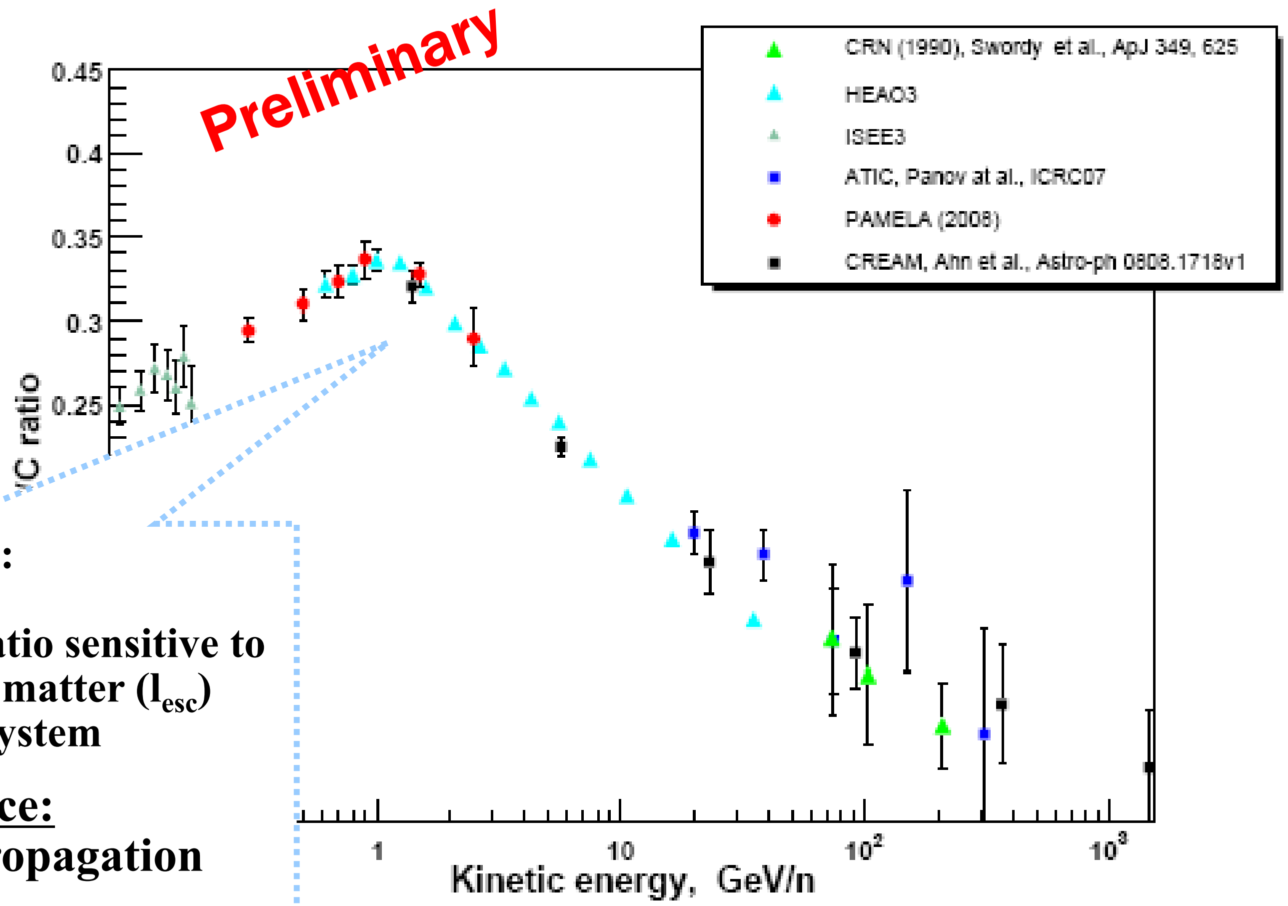

- Good charge discrimination of H and He
- Single-channel saturation at ~10MIP affects B/C discrimination

# Charge identification capabilities (calorimeter)




**Truncated mean of multiple dE/dx measurements in different silicon planes**

# Secondary nuclei




$$\frac{N_S}{N_P} \propto \lambda_{esc} \cdot \sigma_{P \to S}$$

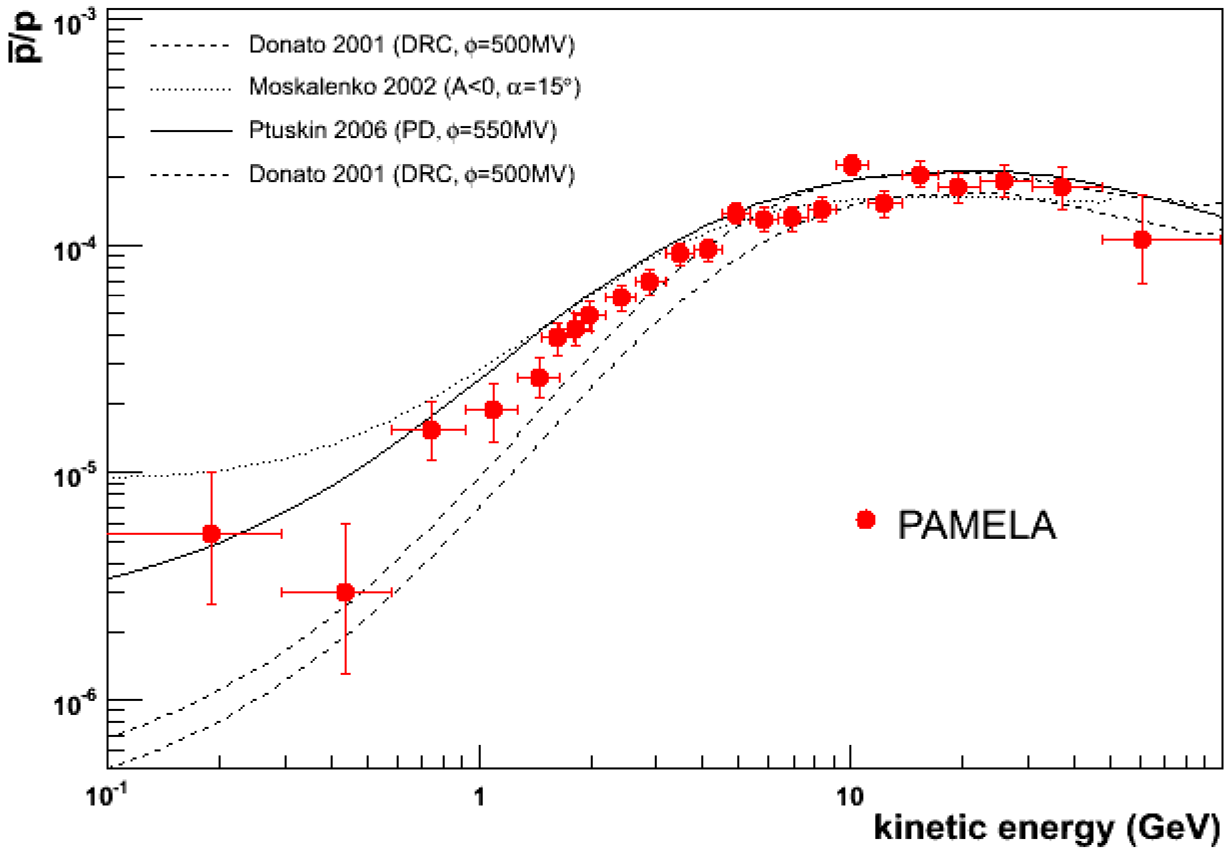
- **B nuclei of secondary origin:**
  **CNO + ISM → B + …**
- **Local secondary/primary ratio sensitive to average amount of traversed matter ($l_{esc}$) from the source to the solar system**

**<u>Local secondary abundance:</u>**
**⇒ study of galactic CR propagation**

**(B/C used for tuning of propagation models)**

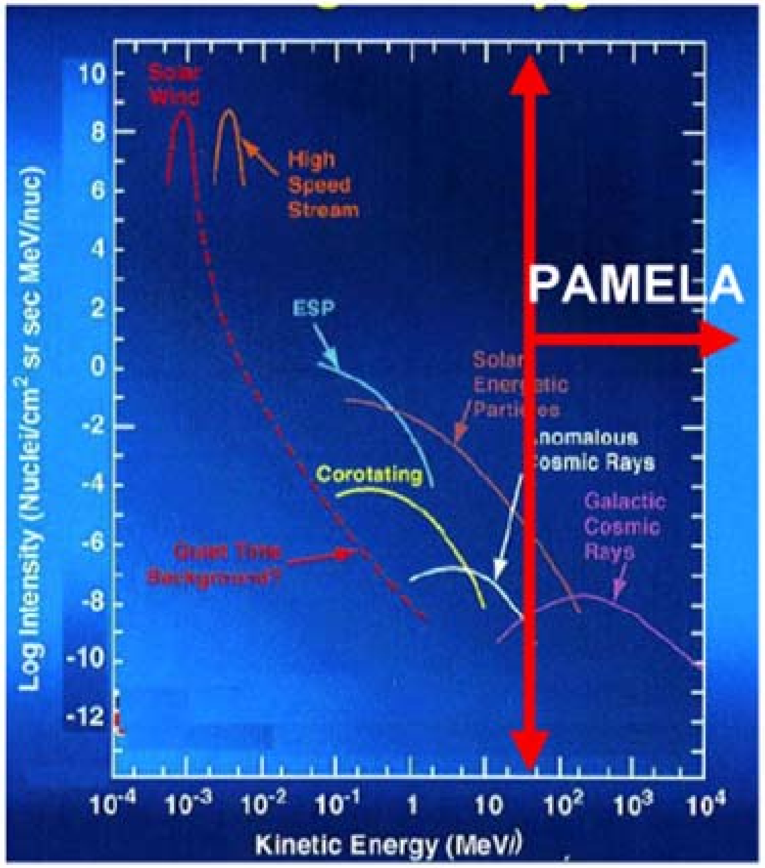
Mirko Boezio, CERN, 2008/10/28

# Antiproton to proton ratio



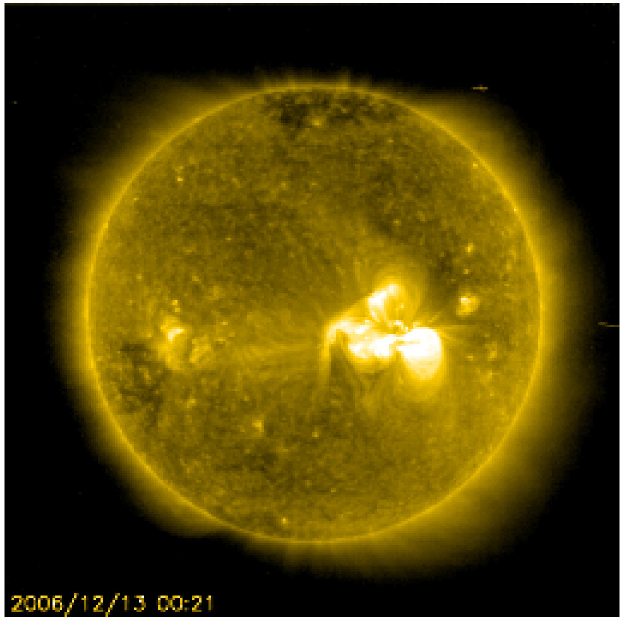
# Solar Physics

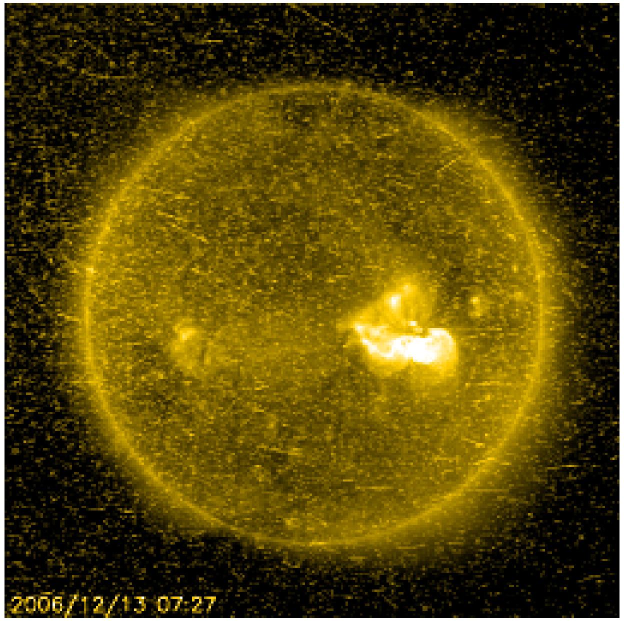
# Solar Physics with PAMELA

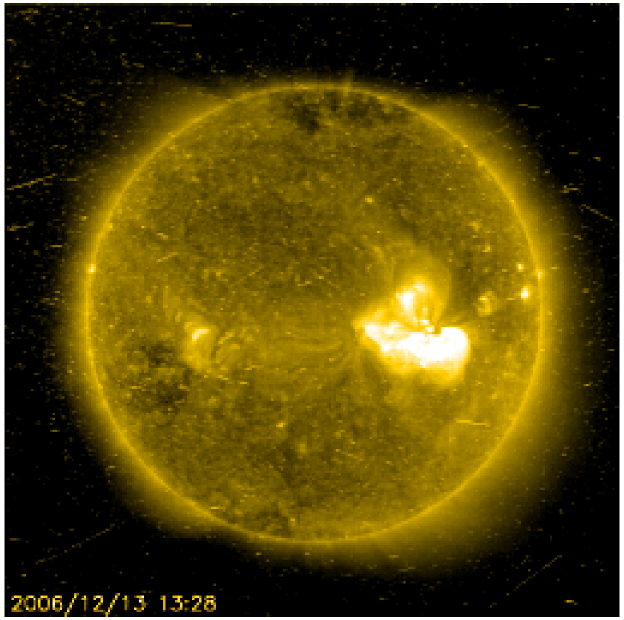



- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV)
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV)
- Nuclear composition of Gradual and Impulsive events
- $^3$He and $^4$He isotopic composition

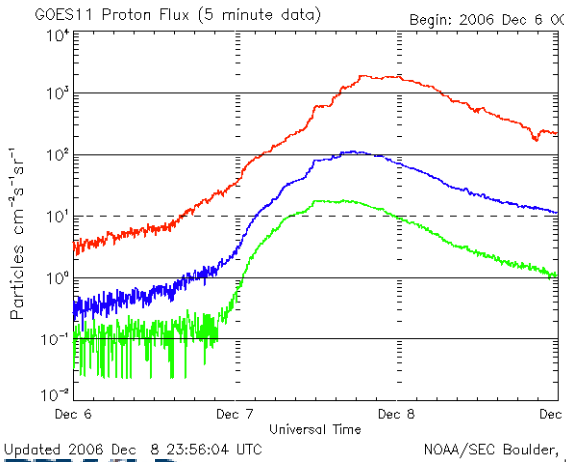
# December 2006 Solar particle events

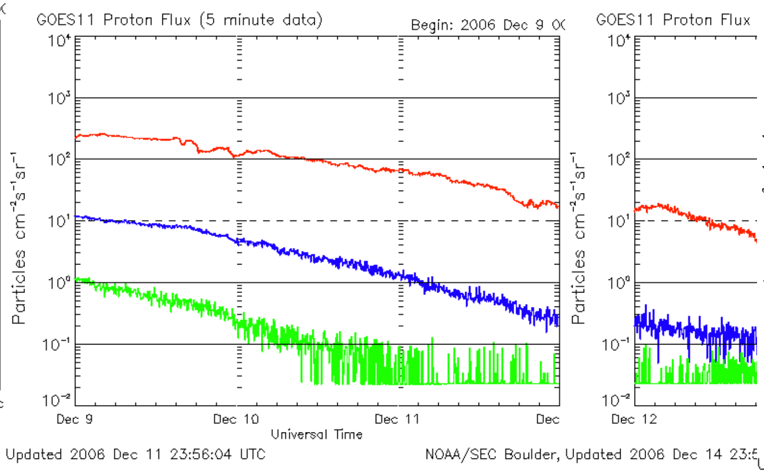


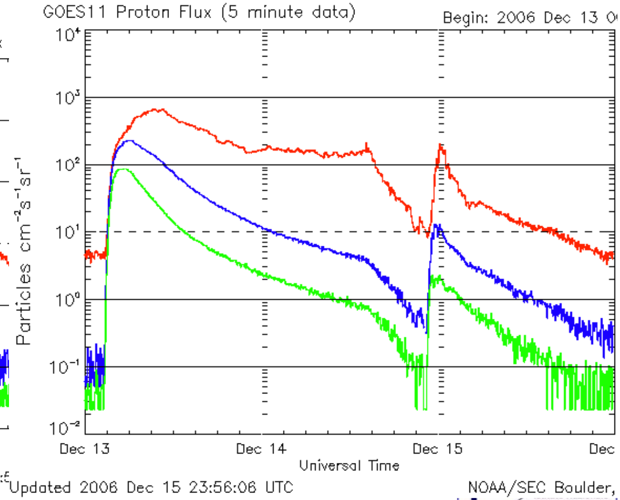




Dec 13th largest CME since 2003, anomalous at sol min X3.4 solar flare.



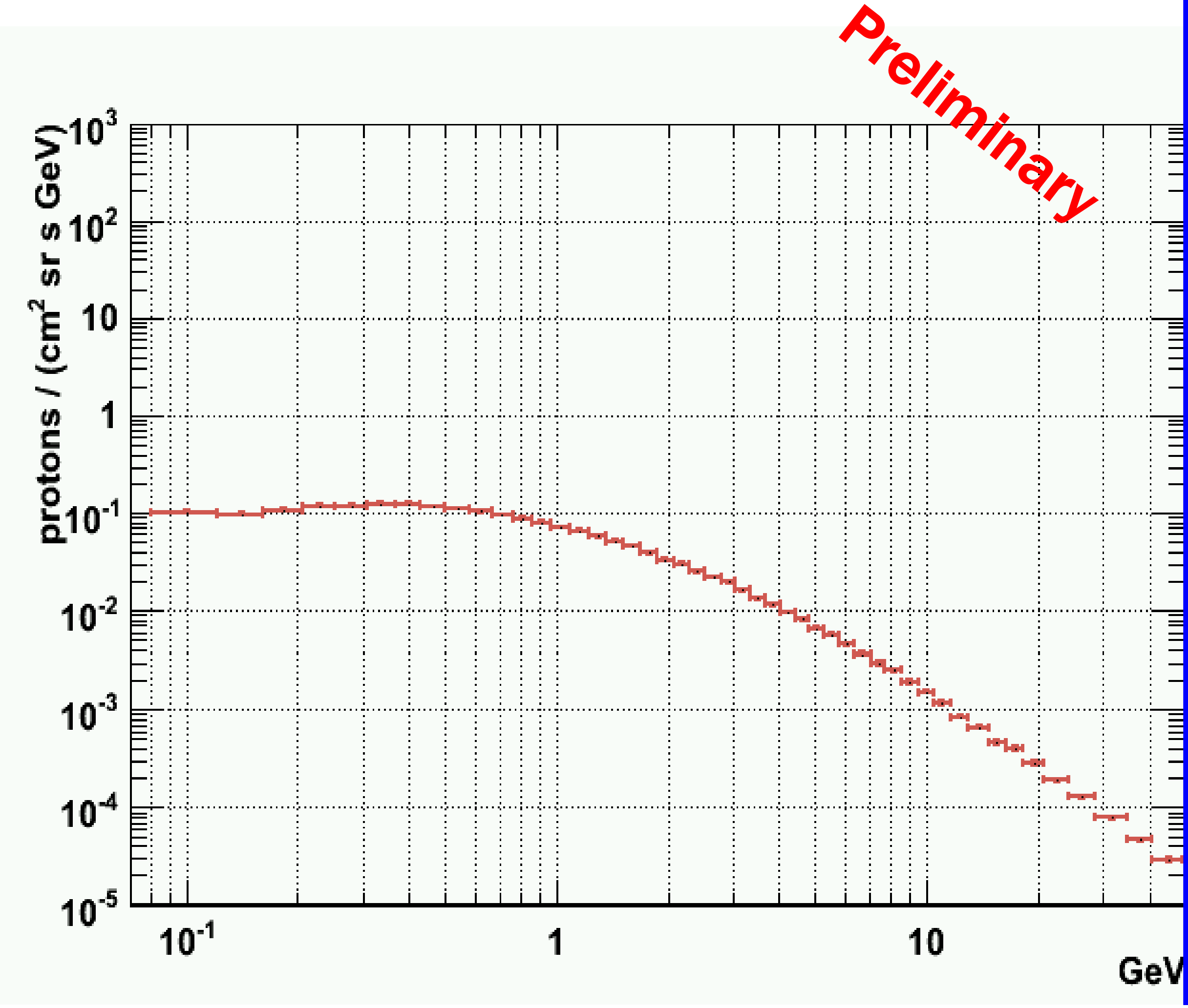



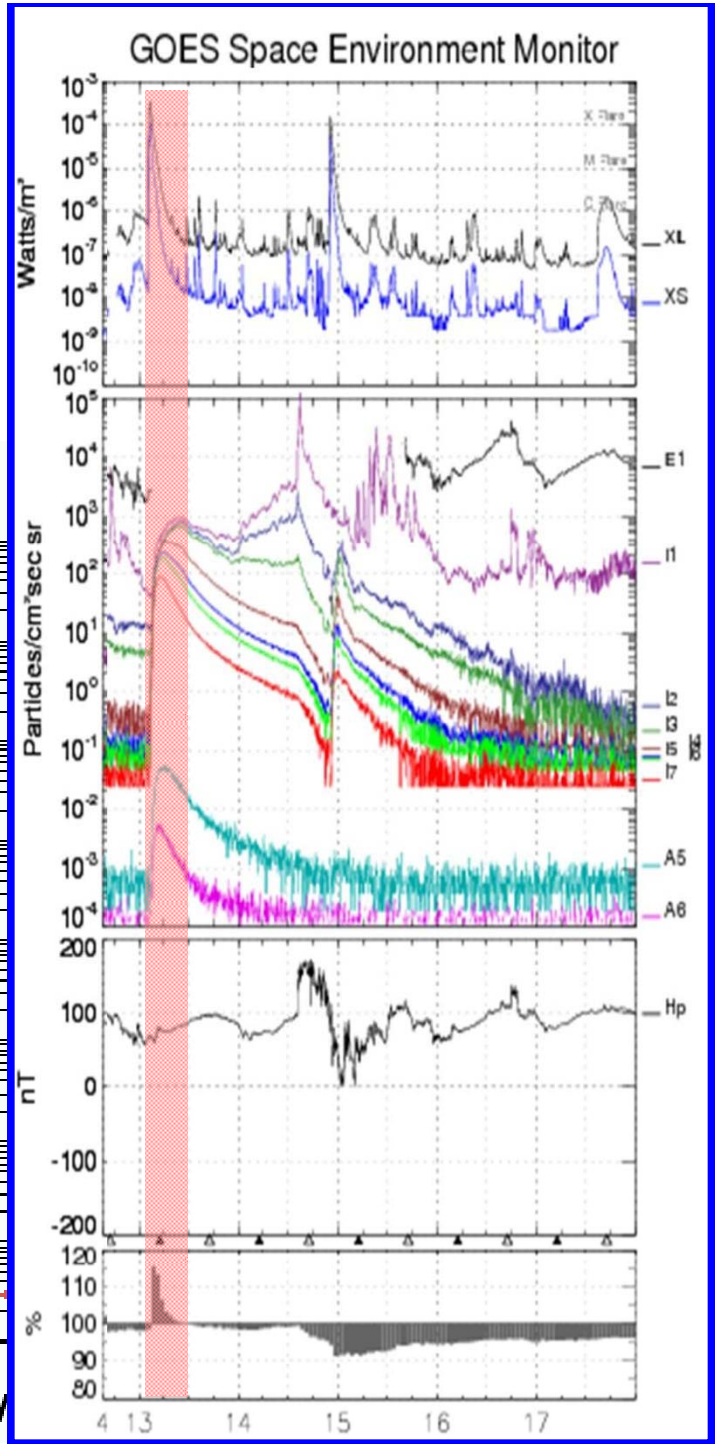




PaMeLa

# December 13th  2006 event

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

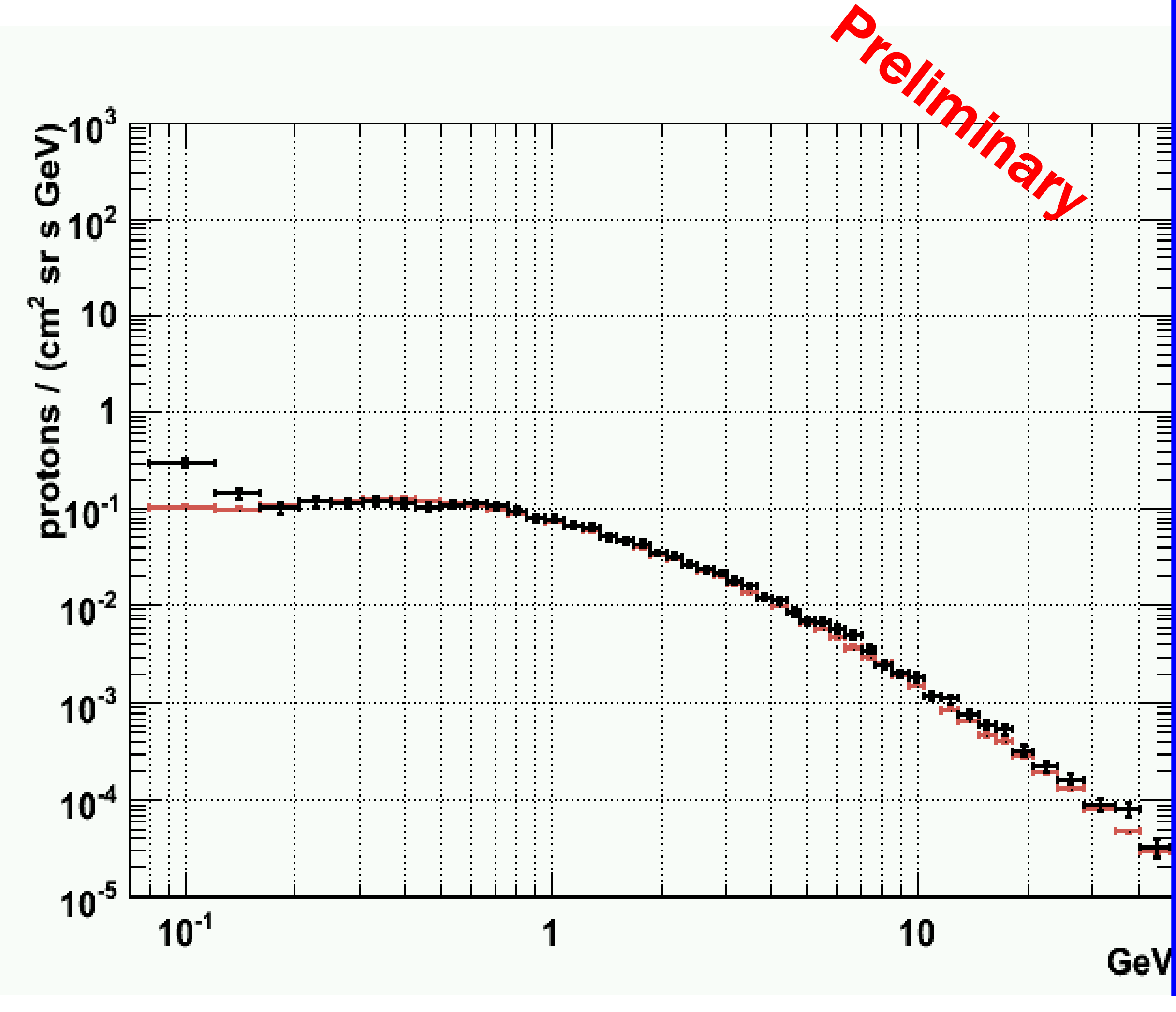


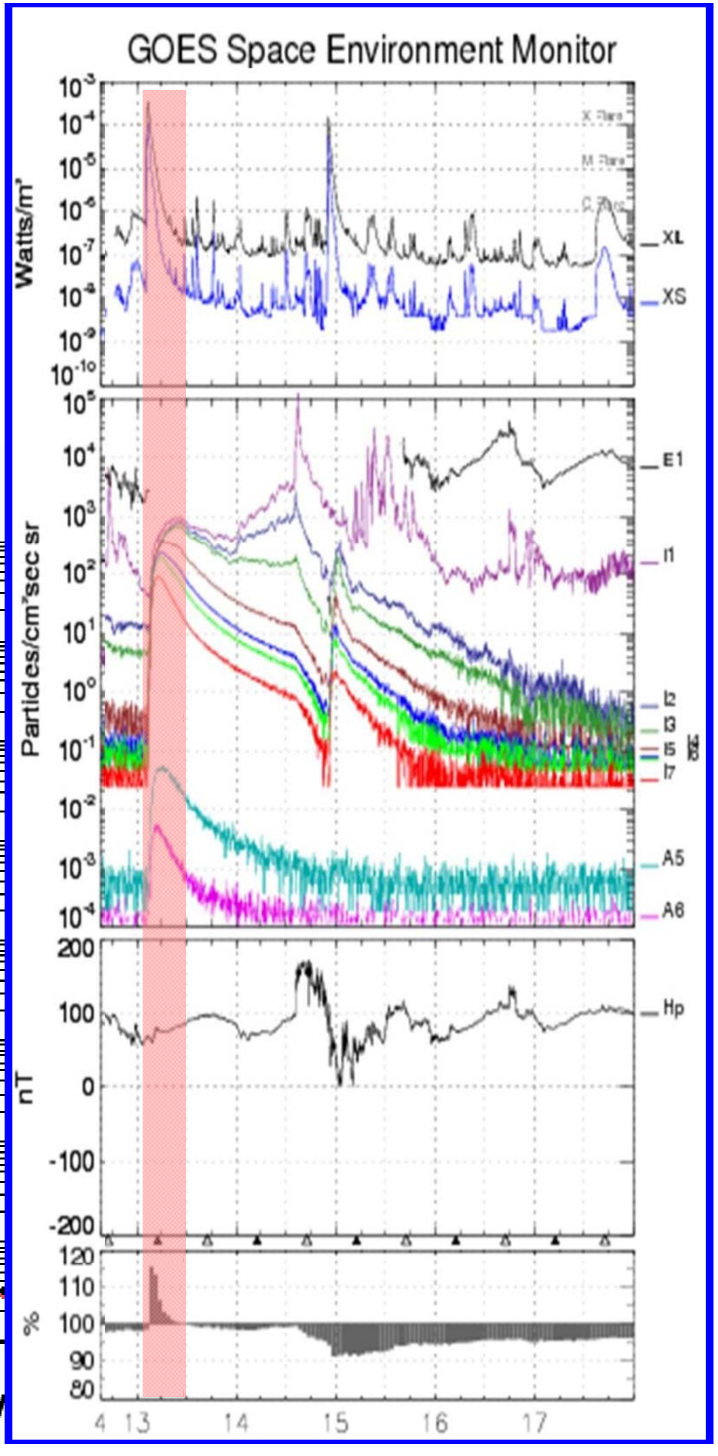



# December 13th  2006 event

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

from 2006-12-13 00:23:02 to 2006-12-13 02:57:46



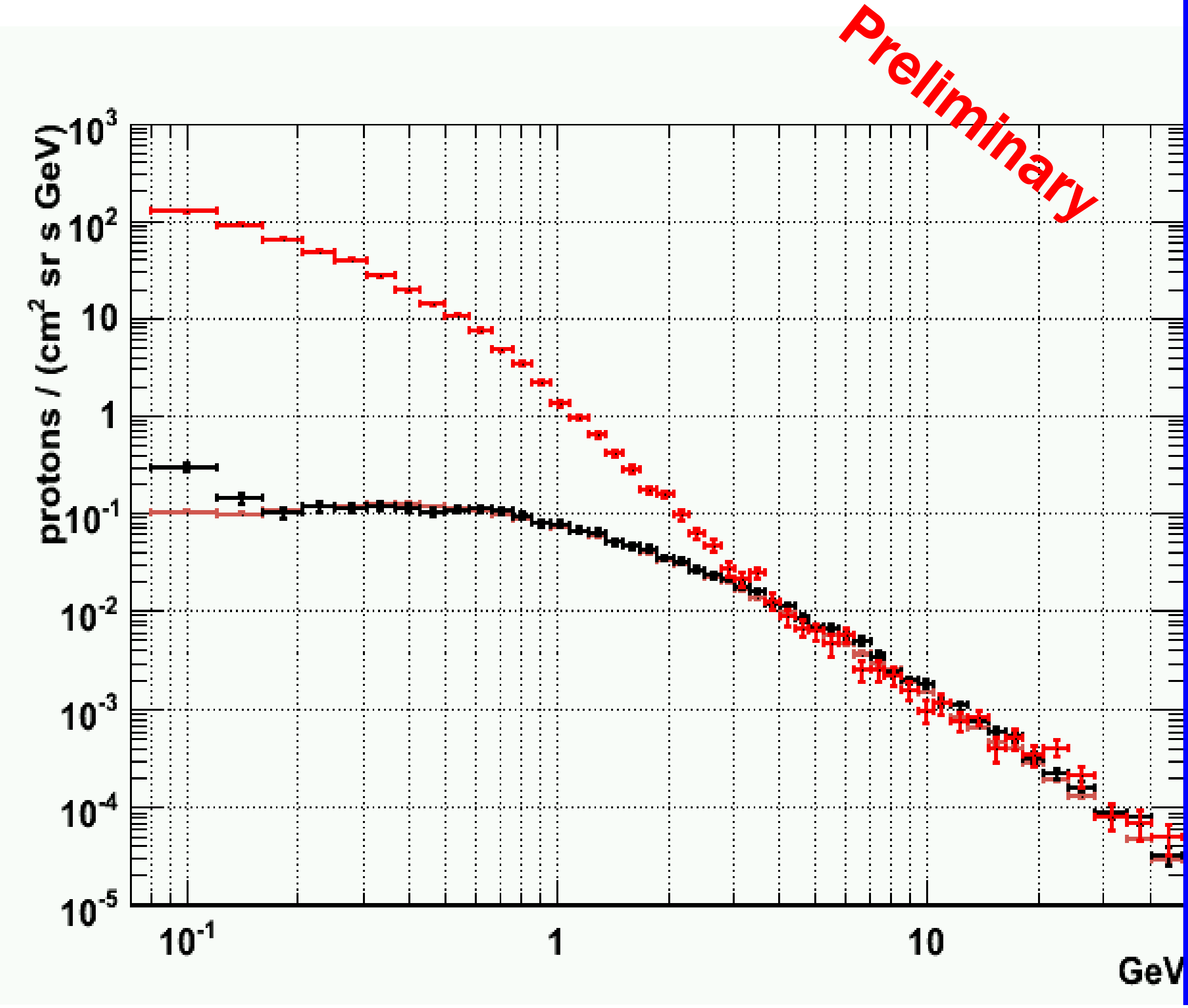



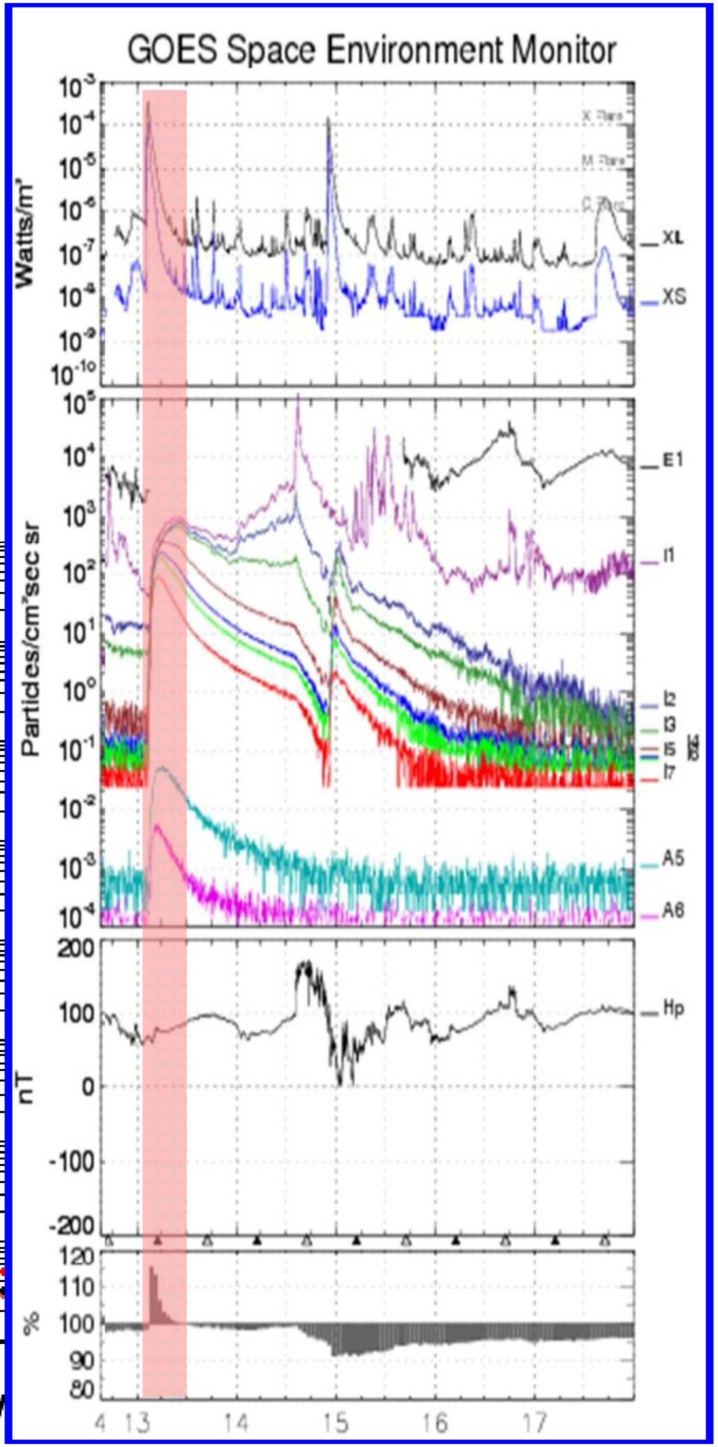
# December 13th 2006 event

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

from 2006-12-13 00:23:02 to 2006-12-13 02:57:46

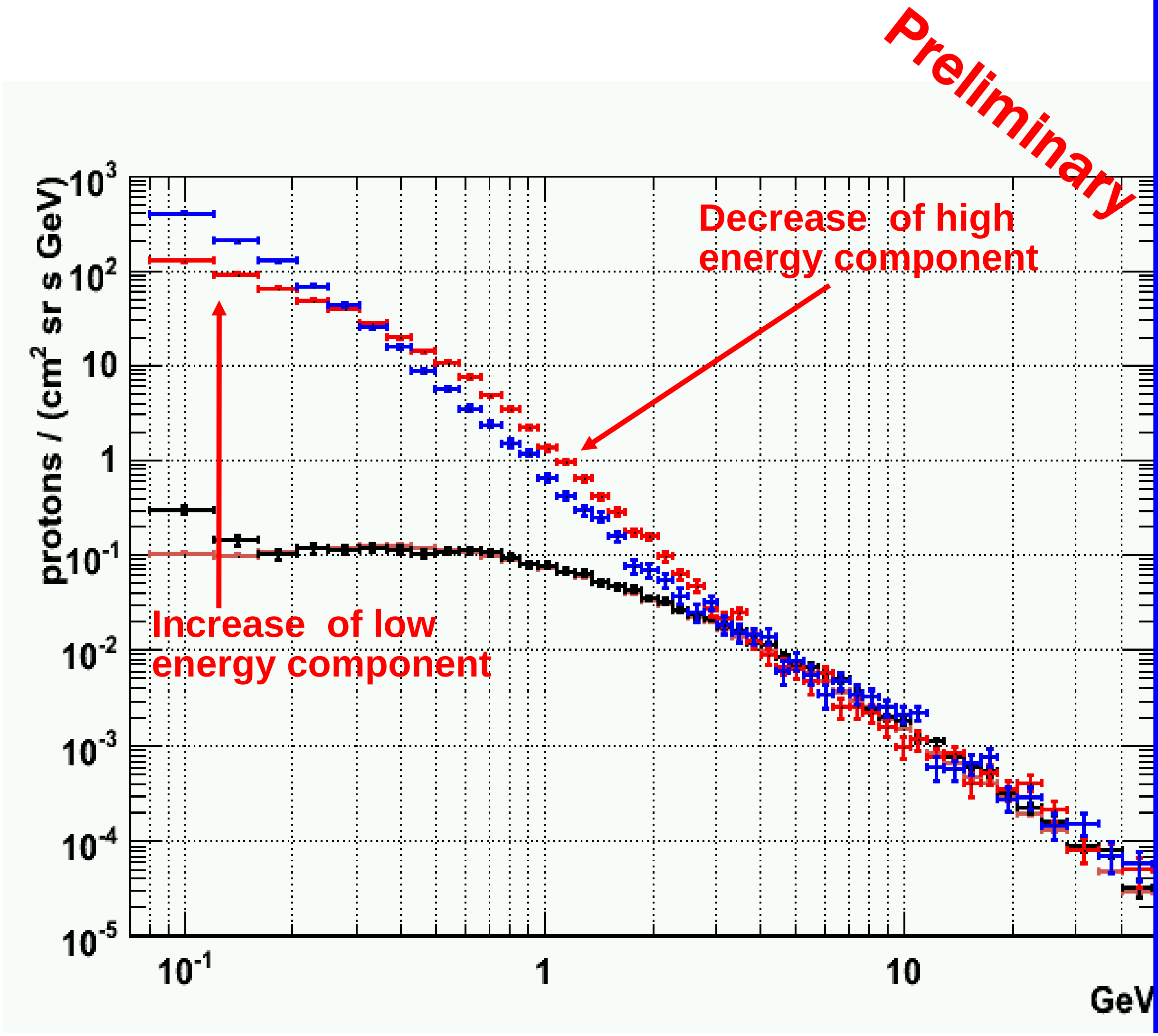
from 2006-12-13 02:57:46 to 2006-12-13 03:49:09

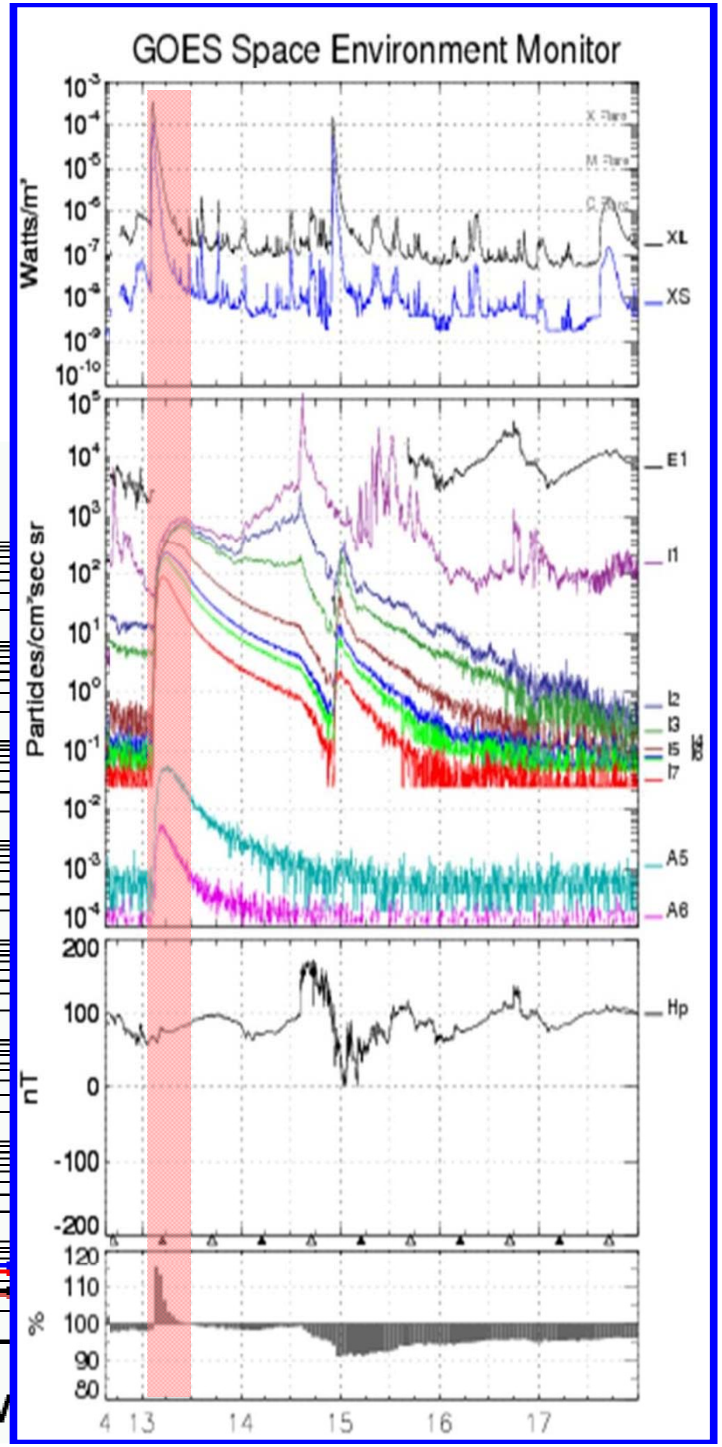


# December 13th  2006 event

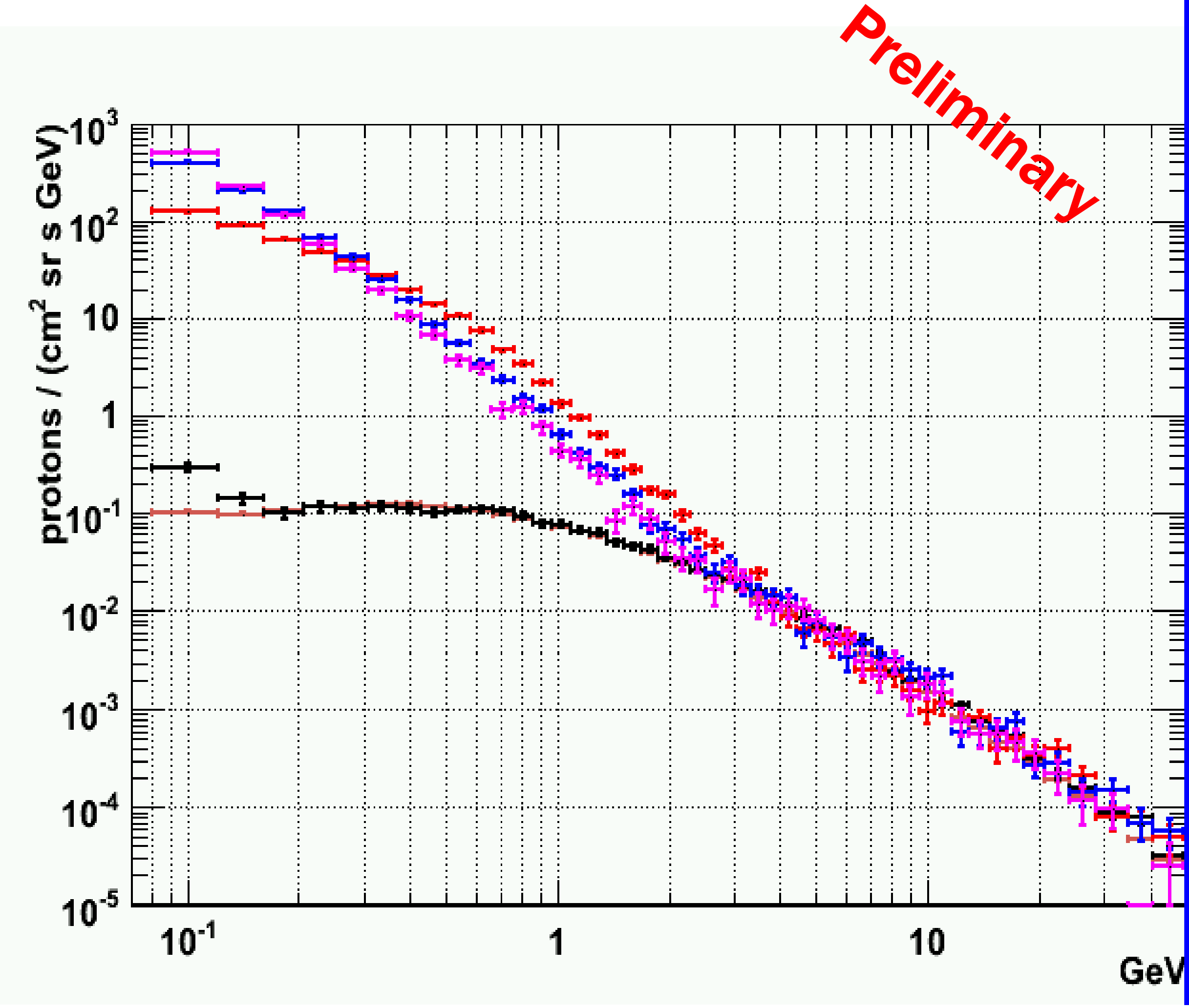
from 2006-12-1 to 2006-12-4
from 2006-12-13 00:23:02 to 2006-12-13 02:57:46
from 2006-12-13 02:57:46 to 2006-12-13 03:49:09
from 2006-12-13 03:49:09 to 2006-12-13 04:32:56

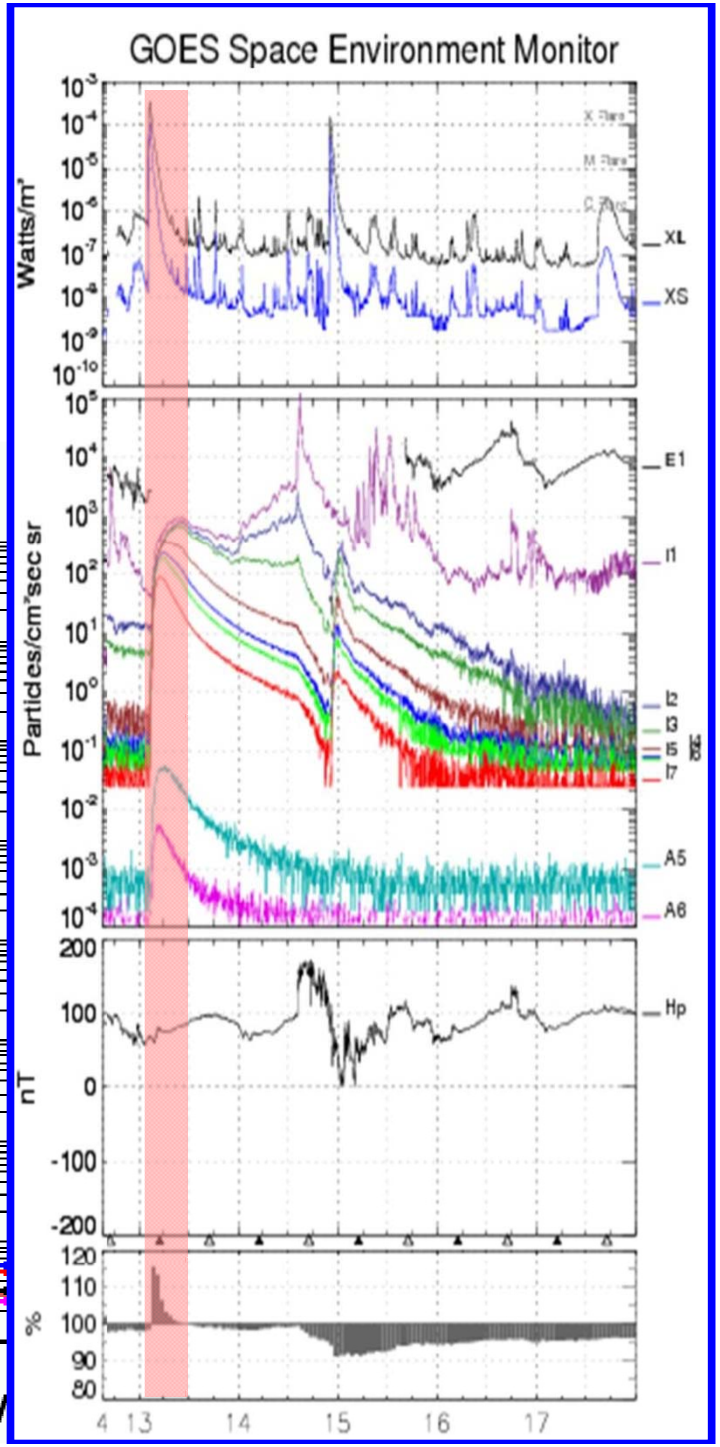


# December 13th  2006 event

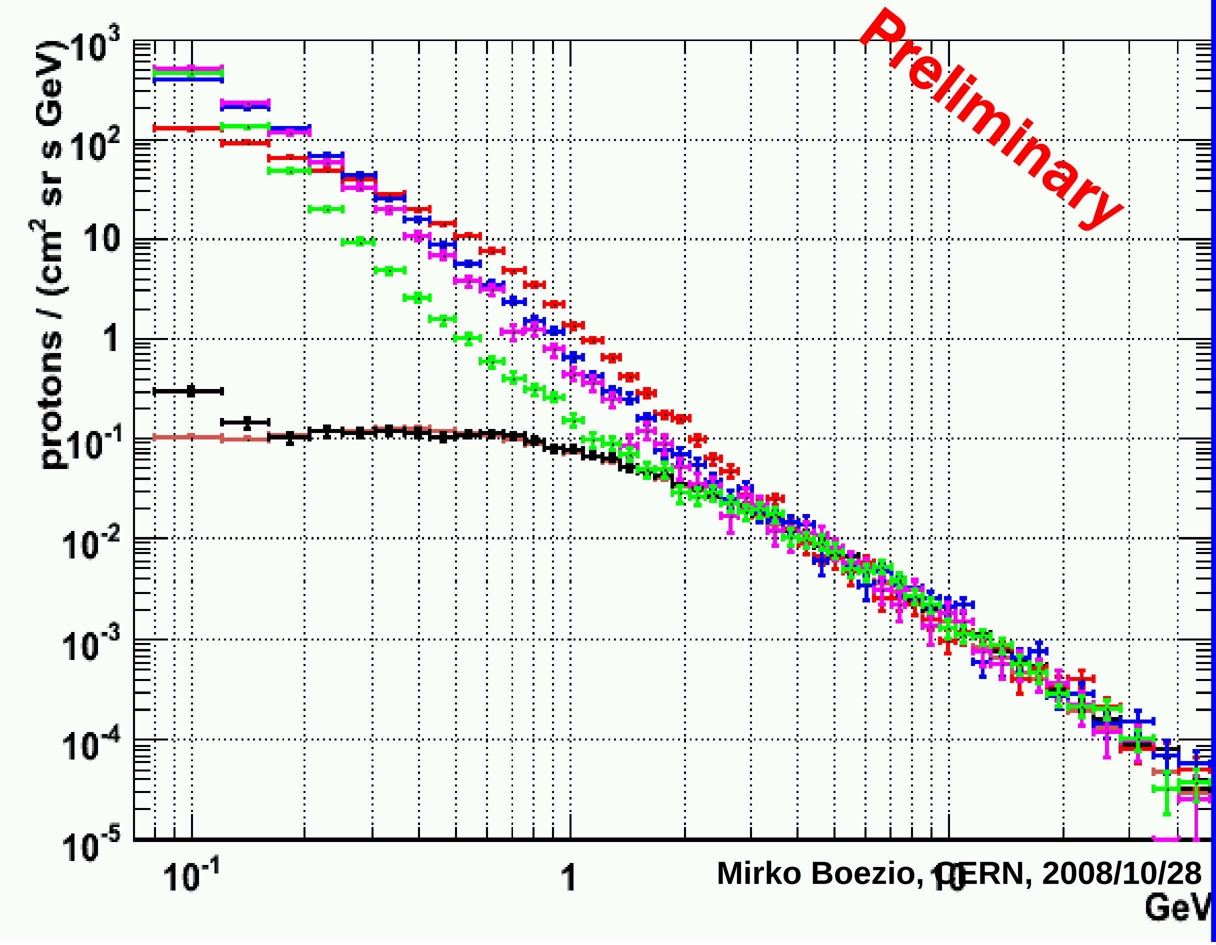
- from 2006-12-1 to 2006-12-4
- from 2006-12-13 00:23:02 to 2006-12-13 02:57:46
- from 2006-12-13 02:57:46 to 2006-12-13 03:49:09
- from 2006-12-13 03:49:09 to 2006-12-13 04:32:56
- from 2006-12-13 04:32:56 to 2006-12-13 04:59:16

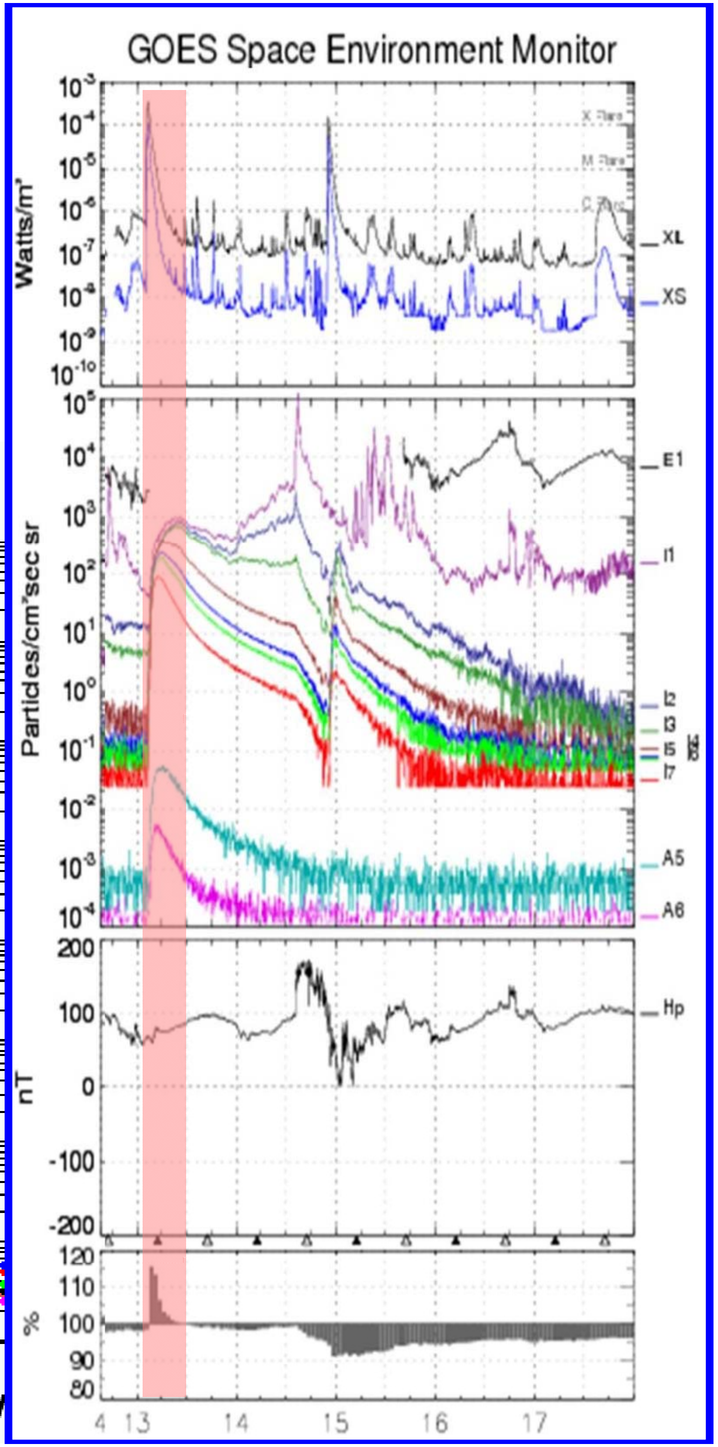


# December 13th 2006 event

from 2006-12-1 to 2006-12-4
from 2006-12-13 00:23:02 to 2006-12-13 02:57:46
from 2006-12-13 02:57:46 to 2006-12-13 03:49:09
from 2006-12-13 03:49:09 to 2006-12-13 04:32:56
from 2006-12-13 04:32:56 to 2006-12-13 04:59:16
from 2006-12-13 08:17:54 to 2006-12-13 09:17:34



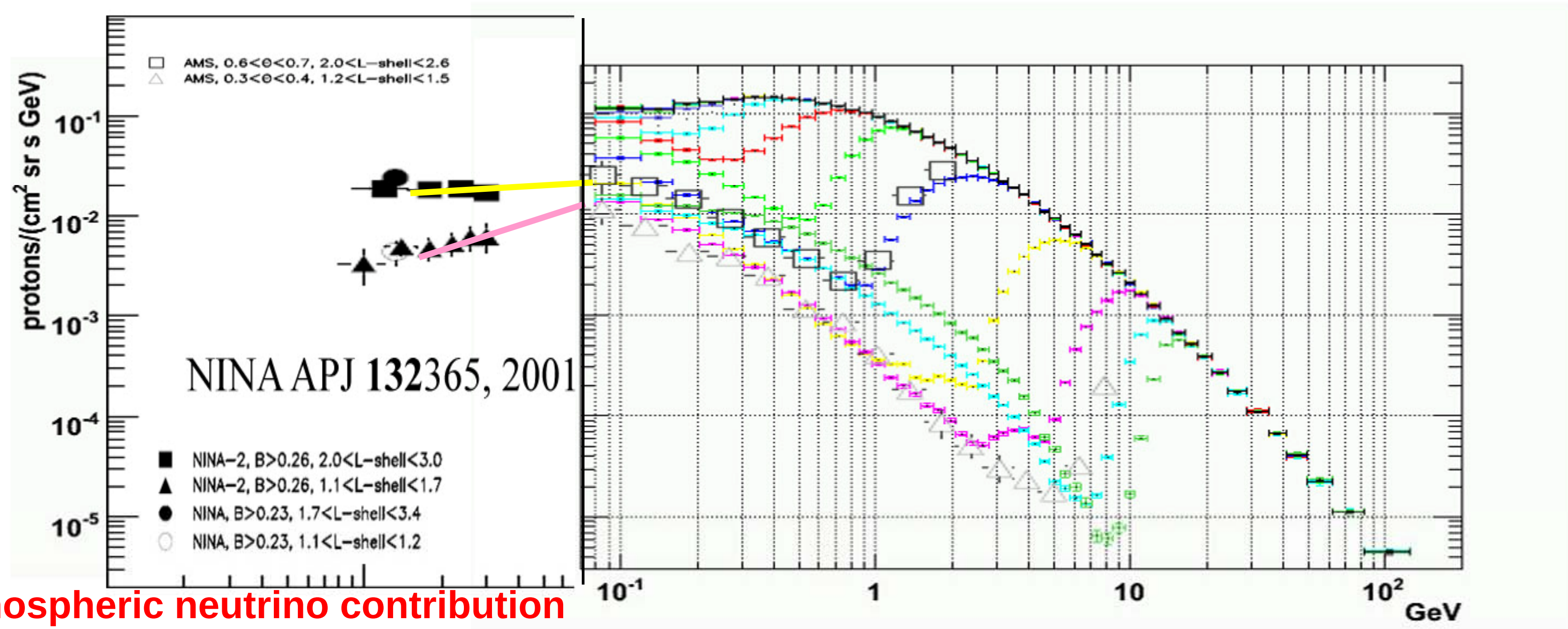



# Radiation Belts

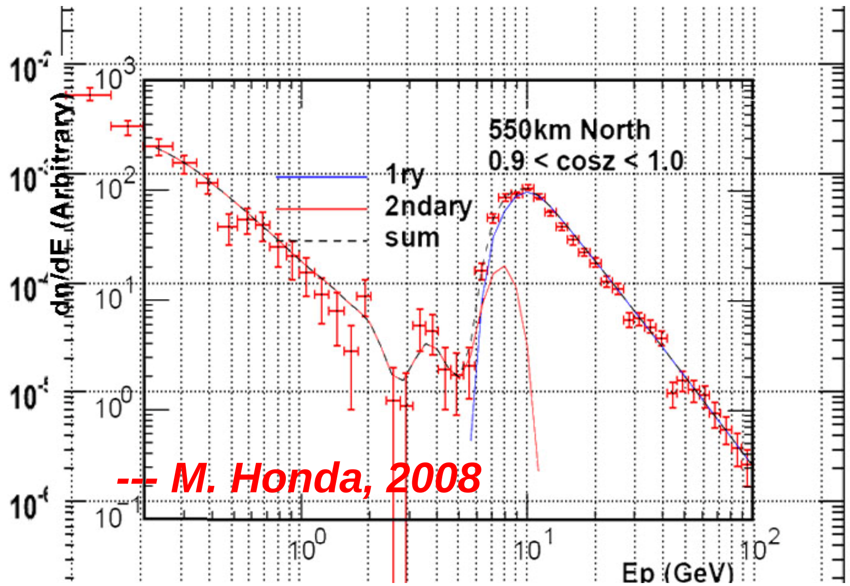
# South Atlantic Anomaly

# Secondary production from CR interaction with atmosphere

# Proton flux at various cutoffs

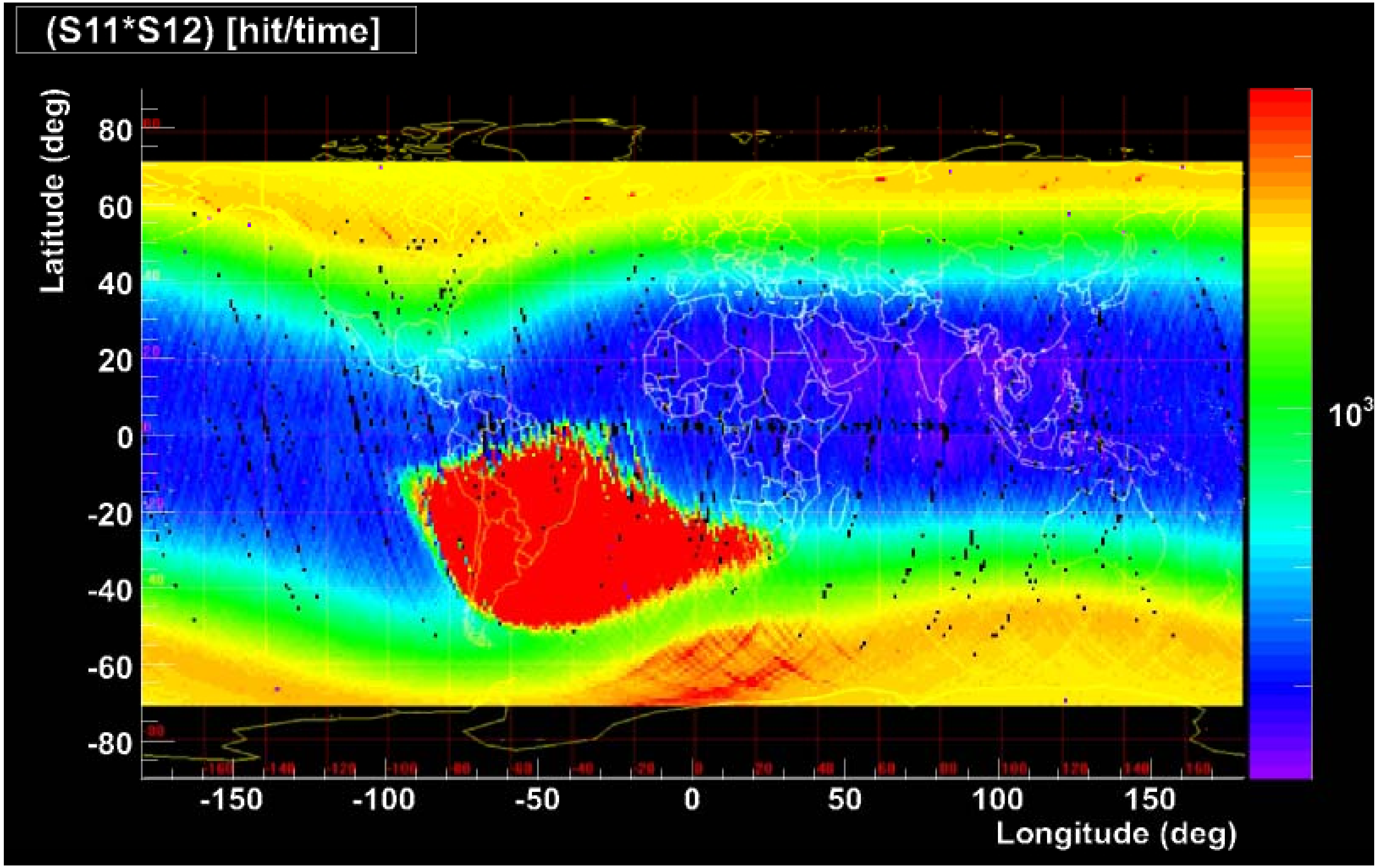



→Atmospheric neutrino contribution
→Astronaut dose on board International Space Station
→Indirect measurement of cross section in the atmosphere  nell'atmosfera
→ Agile e Glast background estimation




- *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*

# Pamela World Maps: 350 – 650 km alt

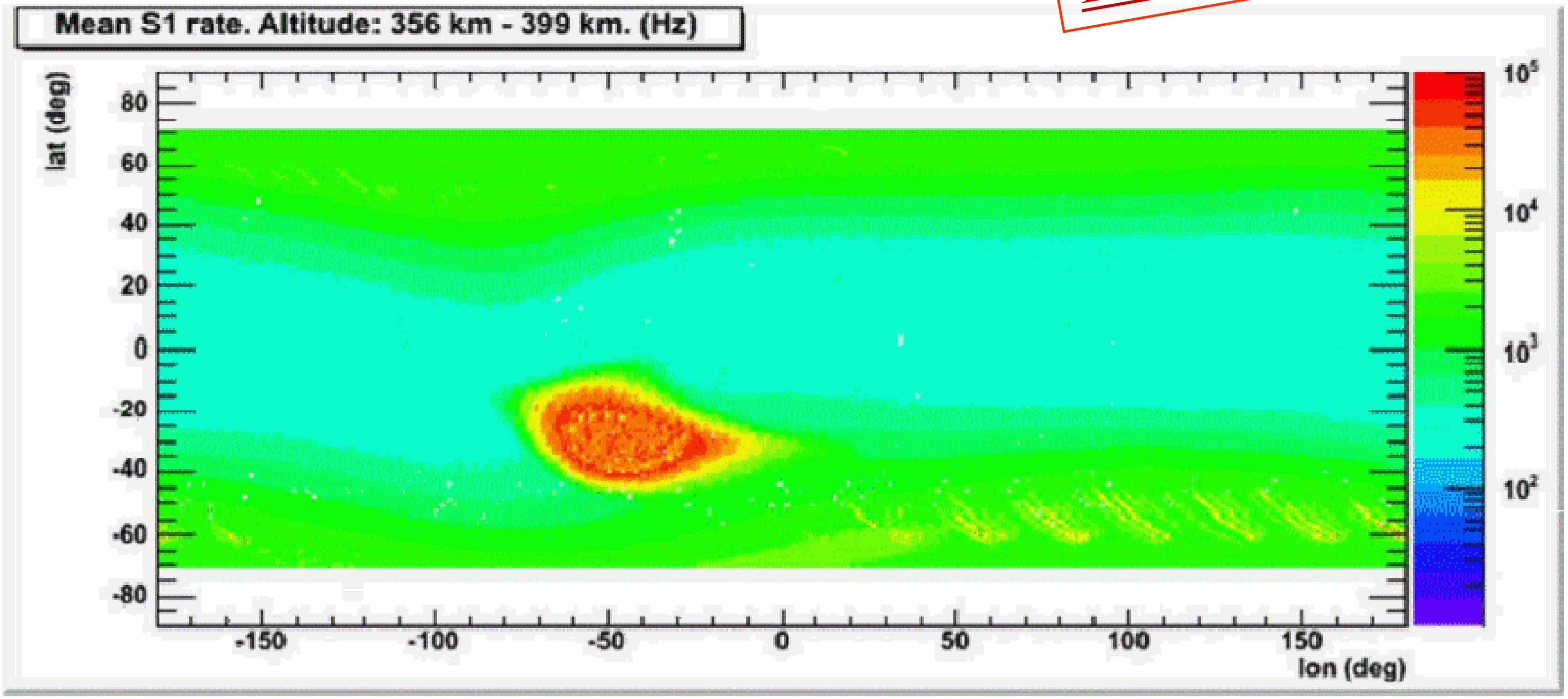



**36 MeV p, 3.5 MeV e⁻**

Mirko Boezio, CERN, 2008/10/28

# Pamela maps at various altitudes

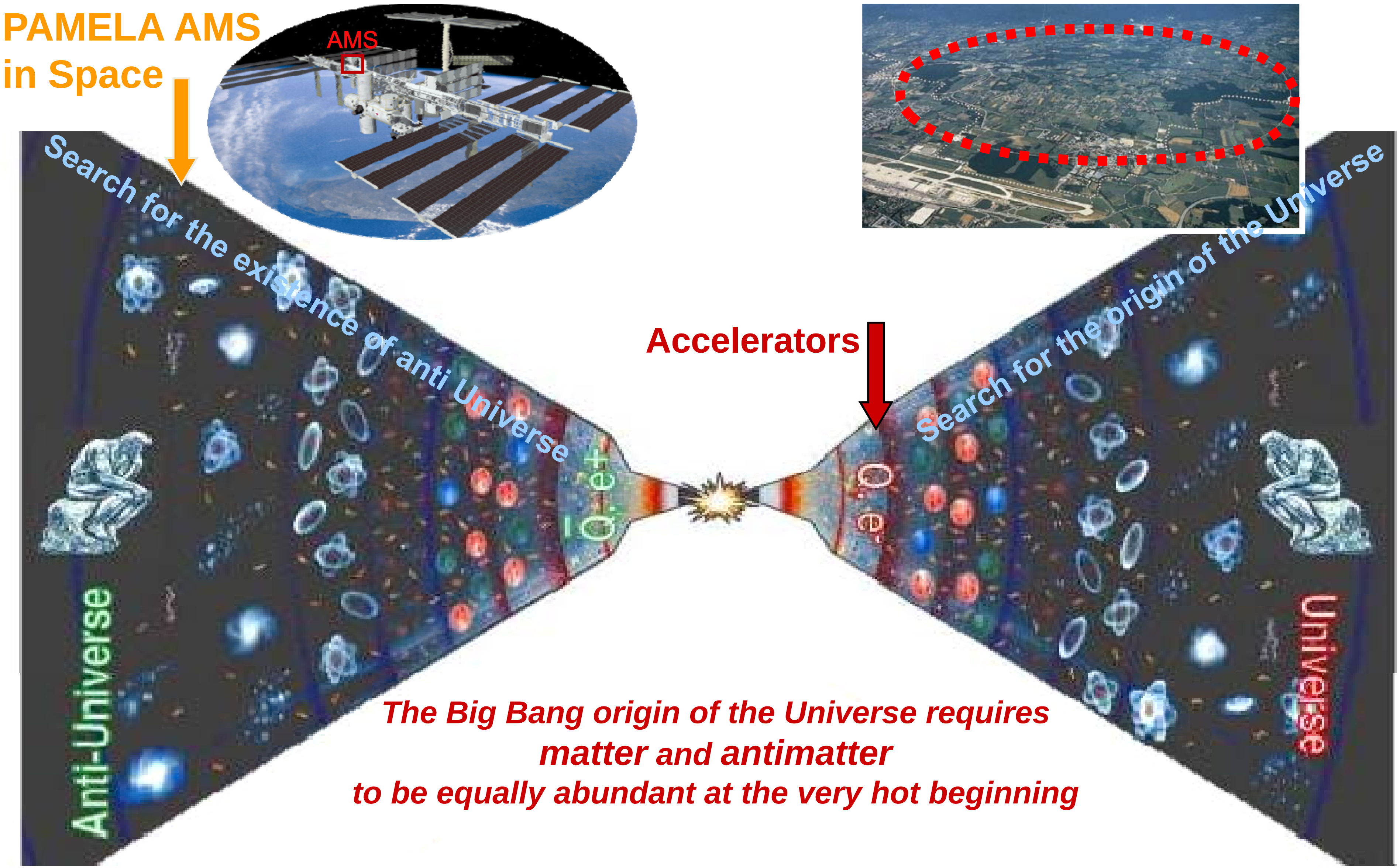
PRELIMINARY !!!!




Altitude scanning

# Other Objectives

# Search for the existence of Antimatter in the Universe




*The Big Bang origin of the Universe requires*
***matter** and **antimatter***
*to be equally abundant at the very hot beginning*

# What about heavy antinuclei?

- **The discovery of one nucleus of antimatter ($Z \geq 2$) in the cosmic rays would have profound implications for both particle physics and astrophysics.**

  - **For a Baryon Symmetric Universe Gamma rays limits put any domain of antimatter more than 100 Mpc away**

    ***(Steigman (1976) Ann Rev. Astr. Astrophys., 14, 339; Dudarerwicz and Wolfendale (1994) M.N.R.A. 268, 609, A.G. Cohen, A. De Rujula and S.L. Glashow, Astrophys. J. 495, 539, 1998)***

# Antimatter Direct research

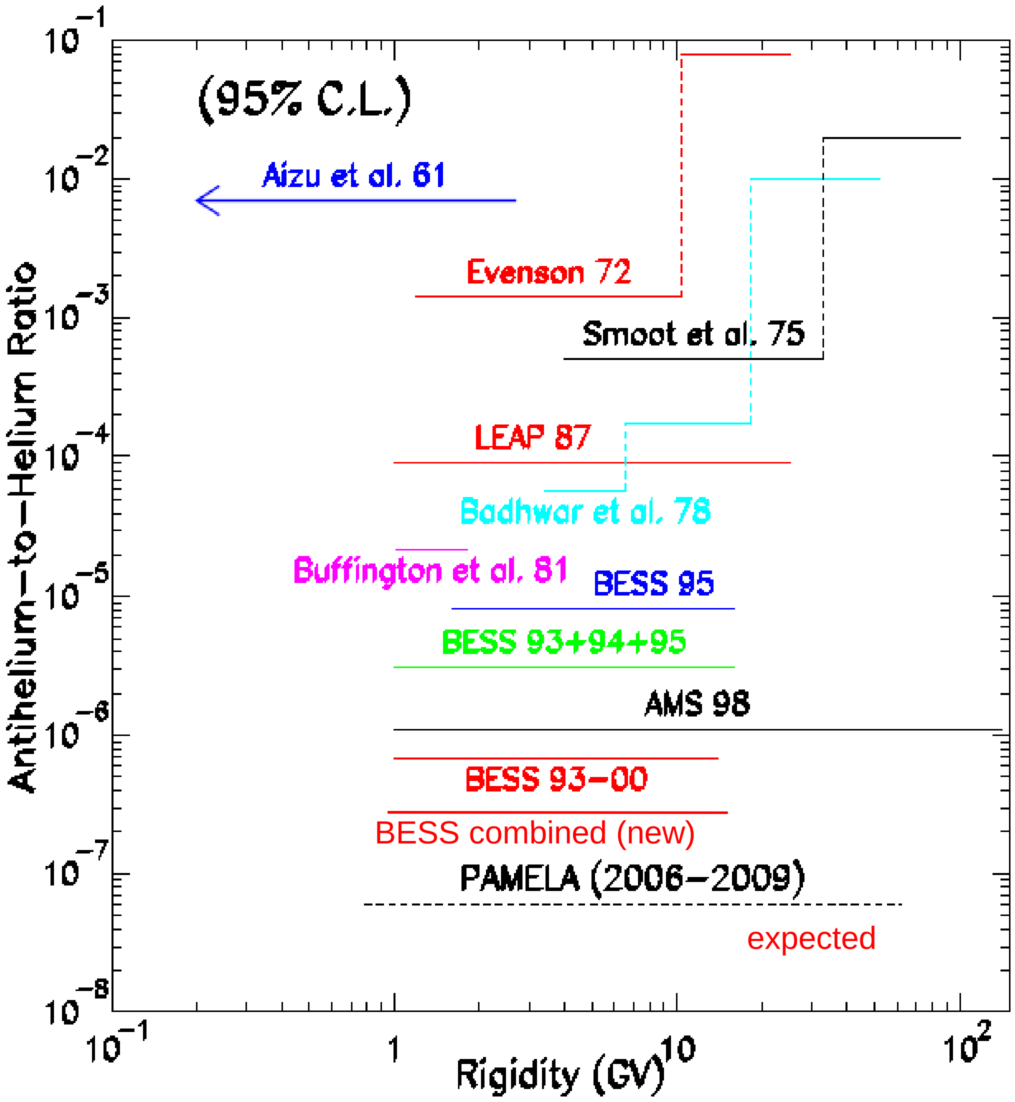
- **Antimatter which has escaped as a cosmic ray from a distant antigalaxy**

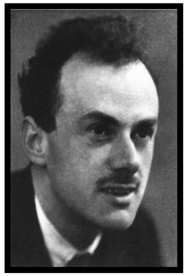
  ***Streitmatter, R. E., Nuovo Cimento, 19, 835 (1996)***

- **Antimatter from globular clusters of antistars in our Galaxy as antistellar wind or anti-supernovae explosion**

  ***K. M. Belotsky et al., Phys. Atom. Nucl. 63, 233 (2000), astro-ph/9807027***

# Cosmic-ray antimatter search



"We must regard it rather an accident that the Earth and presumably the whole Solar System contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about"

*P. Dirac, Nobel lecture (1933)*

PAMELA

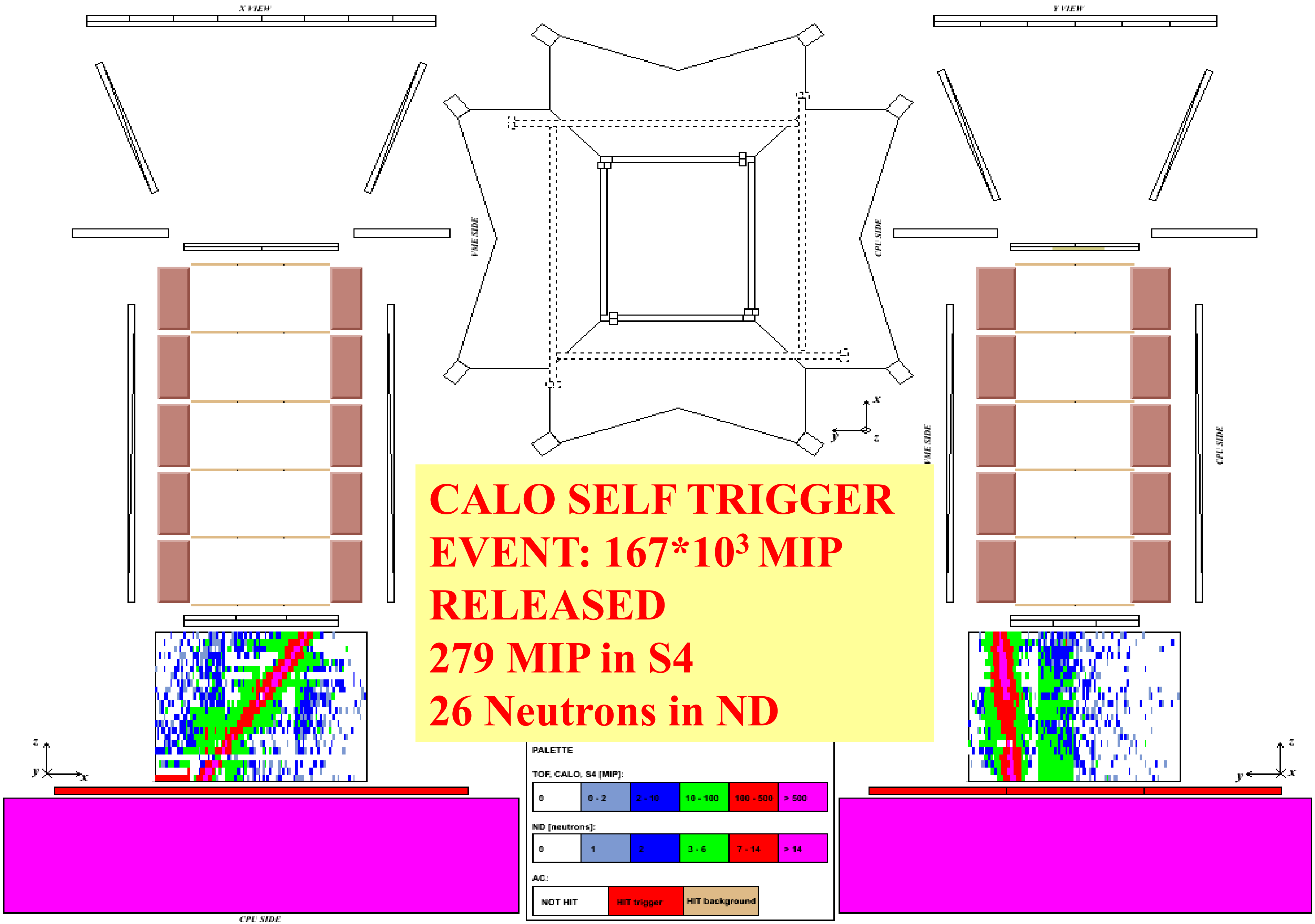
INFN Istituto Nazionale di Fisica Nucleare

# High Energy electrons

- **The study of primary electrons is especially important because they give information on the nearest sources of cosmic rays**

- **Electrons with energy above 100 MeV rapidly loss their energy due to synchrotron radiation and inverse Compton processes**

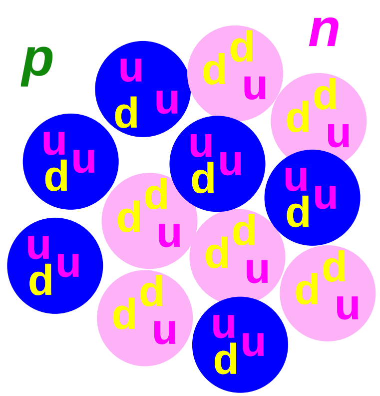
- **The discovery of primary electrons with energy above $10^{12}$ eV will evidence the existence of cosmic ray sources in the nearby interstellar space ($r \lesssim 300$ pc)**


CALO SELF TRIGGER
EVENT: 167*10^3 MIP
RELEASED
279 MIP in S4
26 Neutrons in ND
X VIEW
Y VIEW
VME SIDE
CPU SIDE
PALETTE
TOF, 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
CPU SIDE

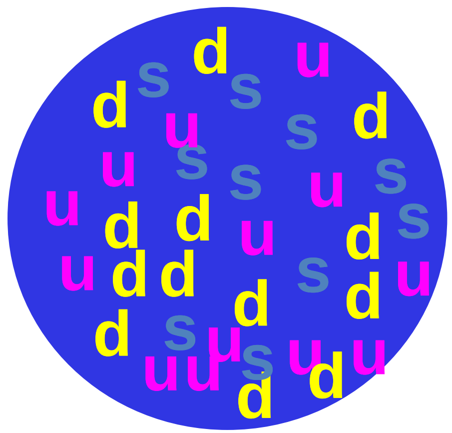
*An example is the search for “strangelets”.*

*There are six types of Quarks found in accelerators.*
*All matter on Earth is made out of only two types of quarks. “Strangelets” are new types of matter composed of three types of quarks which should exist in the cosmos.*

**Carbon Nucleus**




**Strangelet**



i. A stable, single “super nucleon” with three types of quarks

ii. “Neutron” stars may be one big strangelet

***AMS courtesy***

# Conclusion

- **PAMELA is the first space experiment which is measuring the antiproton and positron energy spectra to the high energies (>100GeV) with an unprecedented statistical precision**
- **PAMELA is looking for Dark Matter candidates and "direct"measurement of particle acceleration in astrophysical sources**
- **Furthermore:**
  - **PAMELA is providing measurements on elemental spectra and low mass isotopes with an unprecedented statistical precision and is helping to improve the understanding of particle propagation in the interstellar medium**
  - **PAMELA is able to measure the high energy tail of solar particles.**
  - **PAMELA is setting a new lower limit for finding Antihelium**

# THANKS

**http:// pamela.roma2.infn.it**