Results from the PAMELA space experiment

Tango in Paris
4th May 2009

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University of Rome "Tor Vergata" and INFN

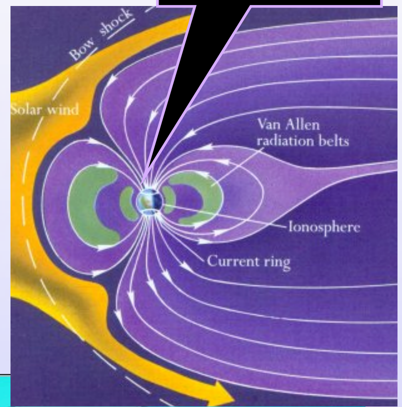
PAMELA science

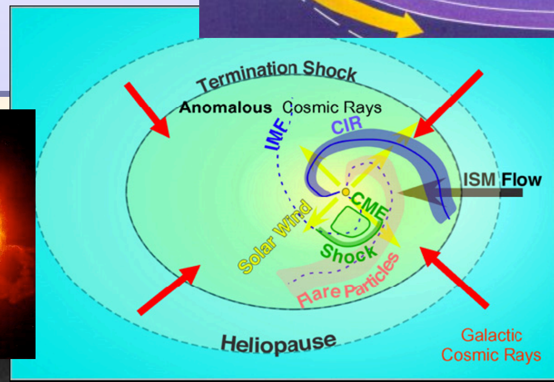
PAMELA is a Space Observatory @ 1AU

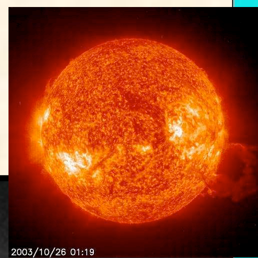
- Search for dark matter
- Search for primordial antimatter

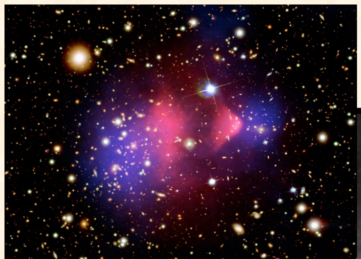
… but also:

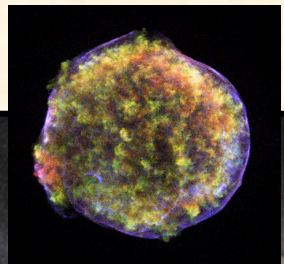
- Study of cosmic-ray origin and propagation
- Study of solar physics and solar modulation
- Study of terrestrial magnetosphere





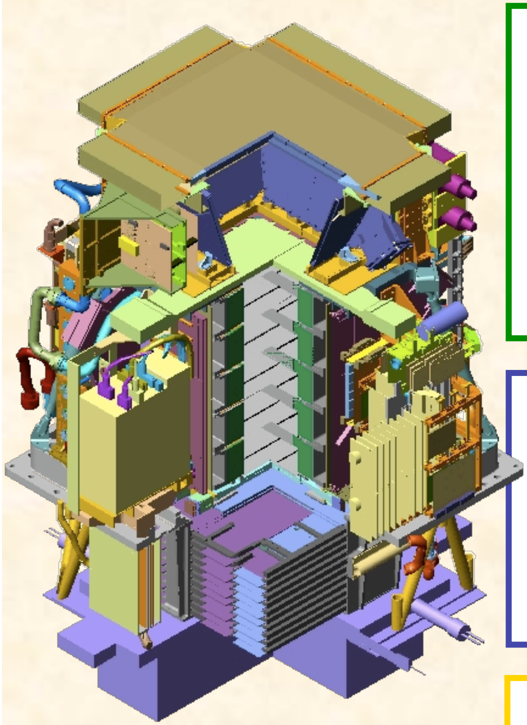






PAMELA detectors

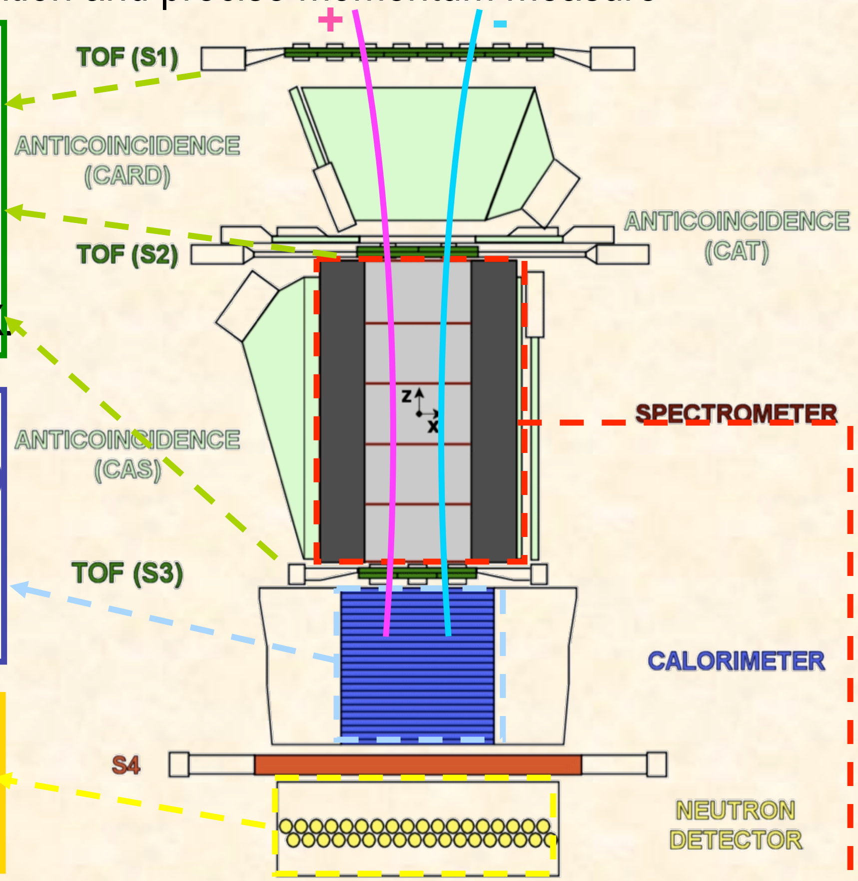
Main requirements → high-sensitivity antiparticle identification and precise momentum measure



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 Xo, 0.6 λ l)
- Discrimination e+ / p, anti-p / e^- (shower topology)
- Direct E measurement for e^-

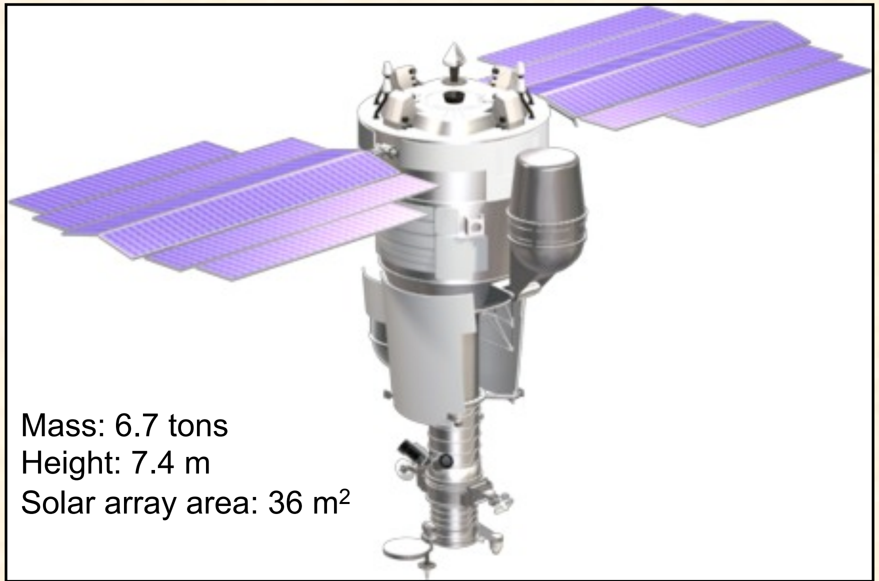
Neutron detector
plastic scintillators + PMT:
- High-energy e/h discrimination



GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360 W

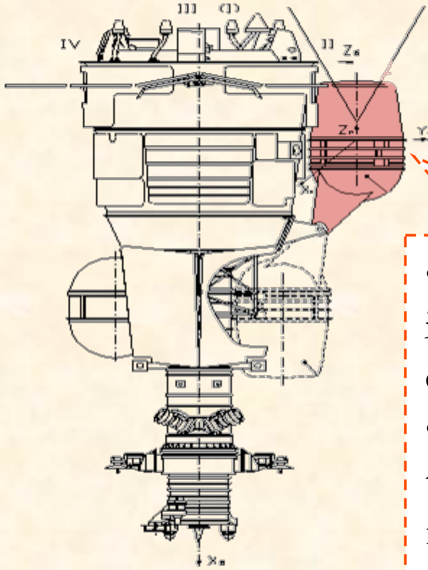
Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

The Resurs DK-1 spacecraft

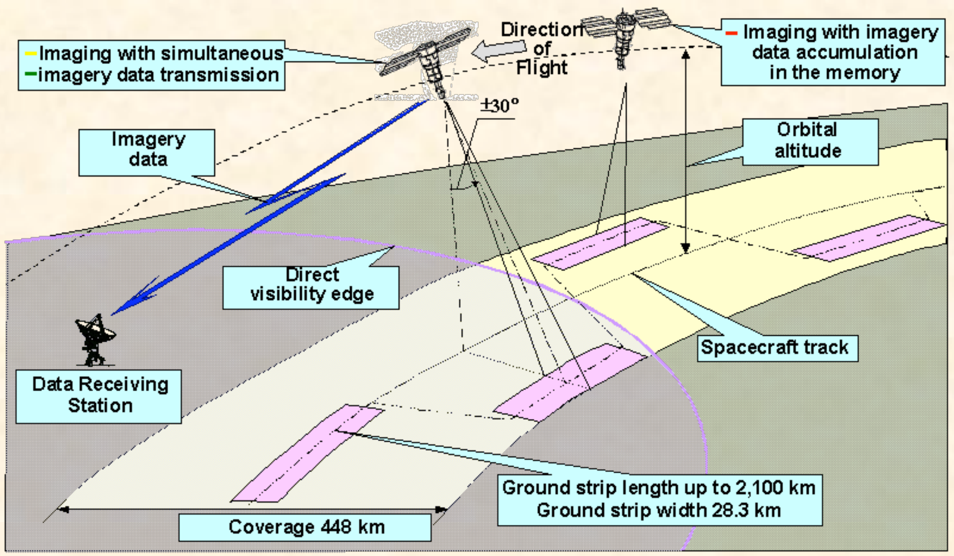


Mass: 6.7 tons
Height: 7.4 m
Solar array area: 36 m²

- Multi-spectral remote sensing of earth's surface
  - *-near-real-time high-quality images*
- Built by the Space factory TsSKB Progress in Samara (Russia)
- **Operational orbit parameters:**
  - **-inclination ~70°**
  - **-altitude ~ 360-600 km (elliptical)**
- **Active life >3 years**
- Data transmitted via Very high-speed Radio Link (VRL)



- PAMELA mounted inside a pressurized container
- moved from parking to data-taking position few times/year



PAMELA design performance

Magnetic curvature & trigger — spillover — shower containment — Maximum detectable rigidity (MDR)

	energy range	particles in 3 years
Antiprotons	**80 MeV ÷190 GeV**	$O(10^4)$
Positrons	**50 MeV ÷ 270 GeV**	$O(10^5)$
Electrons	up to 400 GeV	$O(10^6)$
Protons	up to 700 GeV	$O(10^8)$
Electrons+positrons	up to 2 TeV	(from calorimeter)
Light Nuclei	up to 200 GeV/n	He/Be/C: $O(10^{7/4/5})$
Anti-Nuclei search	sensitivity of 3×10^{-8} in anti-He/He	

→ **Unprecedented statistics and new energy range for cosmic ray physics**
(e.g. contemporary antiproton and positron maximum energy ~ 40 GeV)

→ **Simultaneous measurements of many species**

PAMELA milestones

Launch from Baikonur → June 15th 2006, 0800 UTC.

'First light' → June 21st 2006, 0300 UTC.

- Detectors operated as expected after launch
- Different trigger and hardware configurations evaluated

→ PAMELA in continuous data-taking mode since commissioning phase, ended on July 11th 2006


Main antenna in NTsOMZ

Trigger rate* **~25Hz**
Fraction of live time* **~ 73%**
Event size (compressed mode) ~ **5kB**
25 Hz x 5 kB/ev → **~ 10 GB/day**
(*outside radiation belts)

Till today:
~1044 days of data taking
~13 TByte of raw data downlinked
~10^9 triggers recorded and analysed

PAMELA results:
Antiprotons

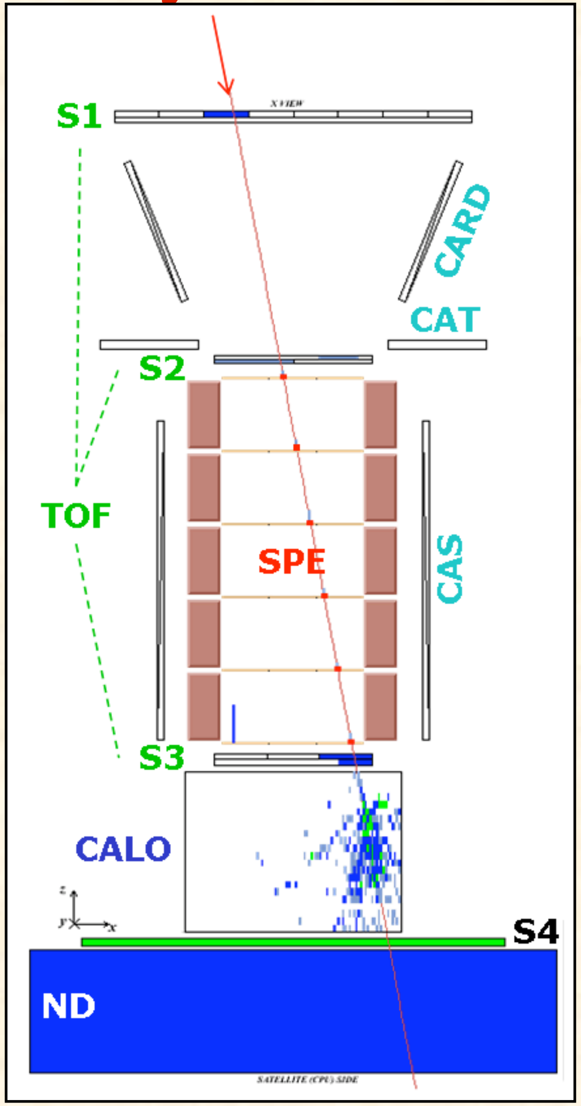
High-energy antiproton analysis

- Analyzed data July 2006 – February 2008 (~500 days)
- Collected triggers ~10^8
- Identified **~ 10^7 protons** and **~ 10^3 antiprotons** between 1.5 and 100 GeV (**6 p-bar between 50 and 100 GeV**)

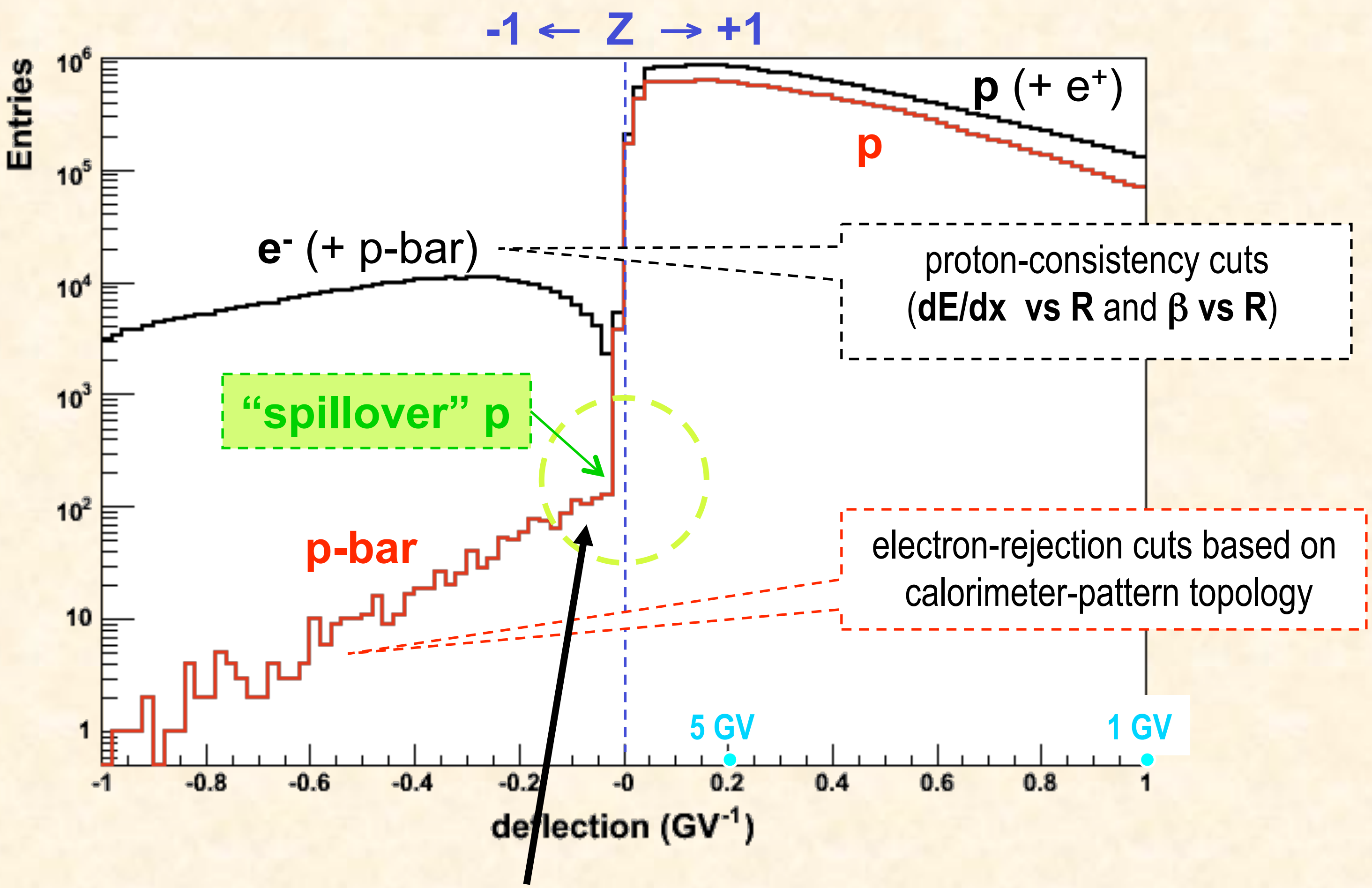
- Antiproton/proton identification:
  - rigidity (R) → SPE
  - |Z|=1 (dE/dx vs R) → SPE&ToF
  - β vs R consistent with M_p → ToF
  - p-bar/p separation (charge sign) → SPE
  - p-bar/e^- (and p/e^+) separation → CALO

- Dominant background → **spillover protons**:
  - finite deflection resolution of the SPE ⇒ wrong assignment of charge-sign @ high energy
  - proton spectrum harder than antiproton ⇒ p/p-bar increase for increasing energy (10^3 @1GV 10^4 @100GV)

→ **Required strong SPE selection**



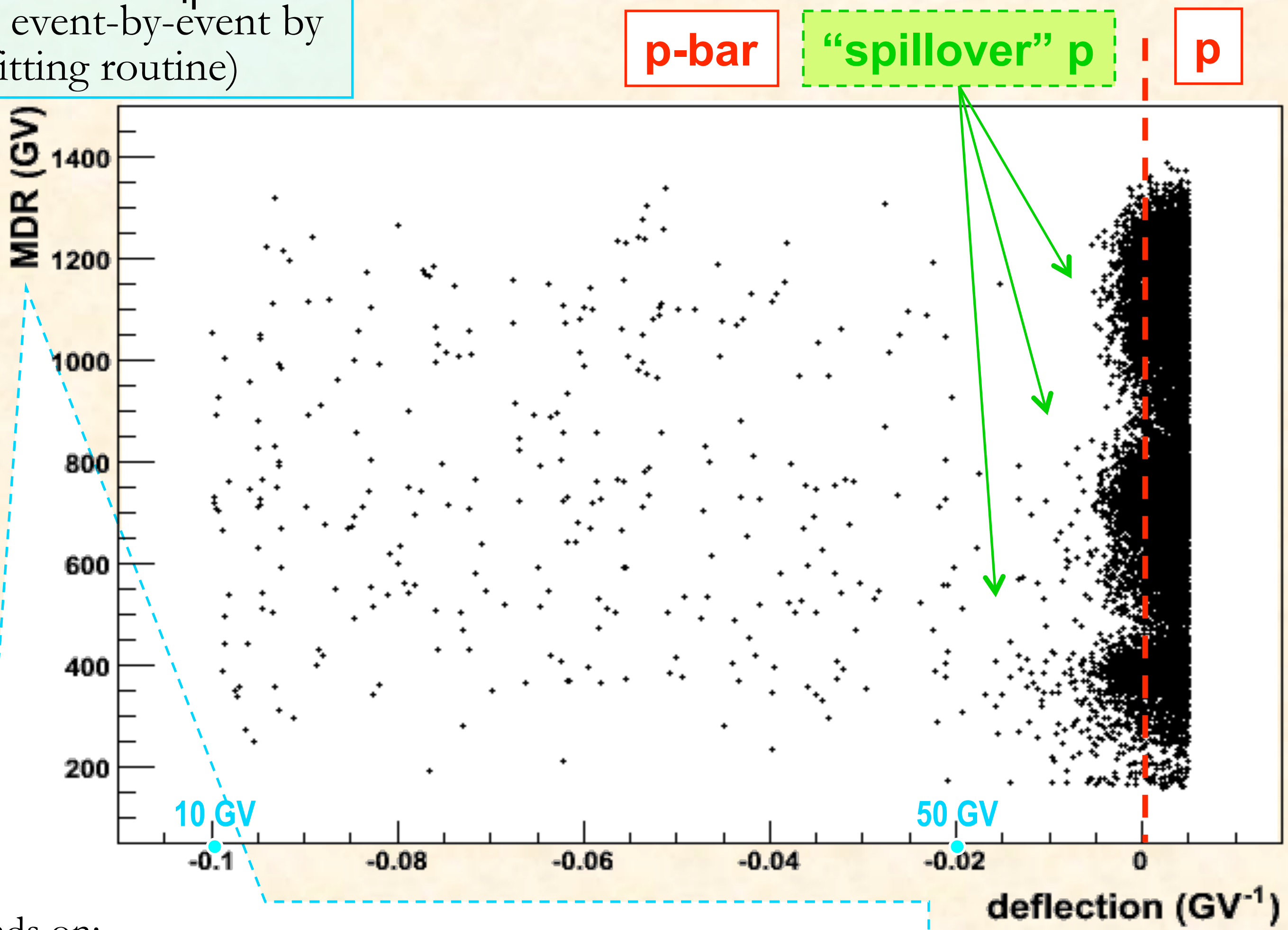
Antiproton identification



Let's focus on this region of deflection

Proton-spillover background

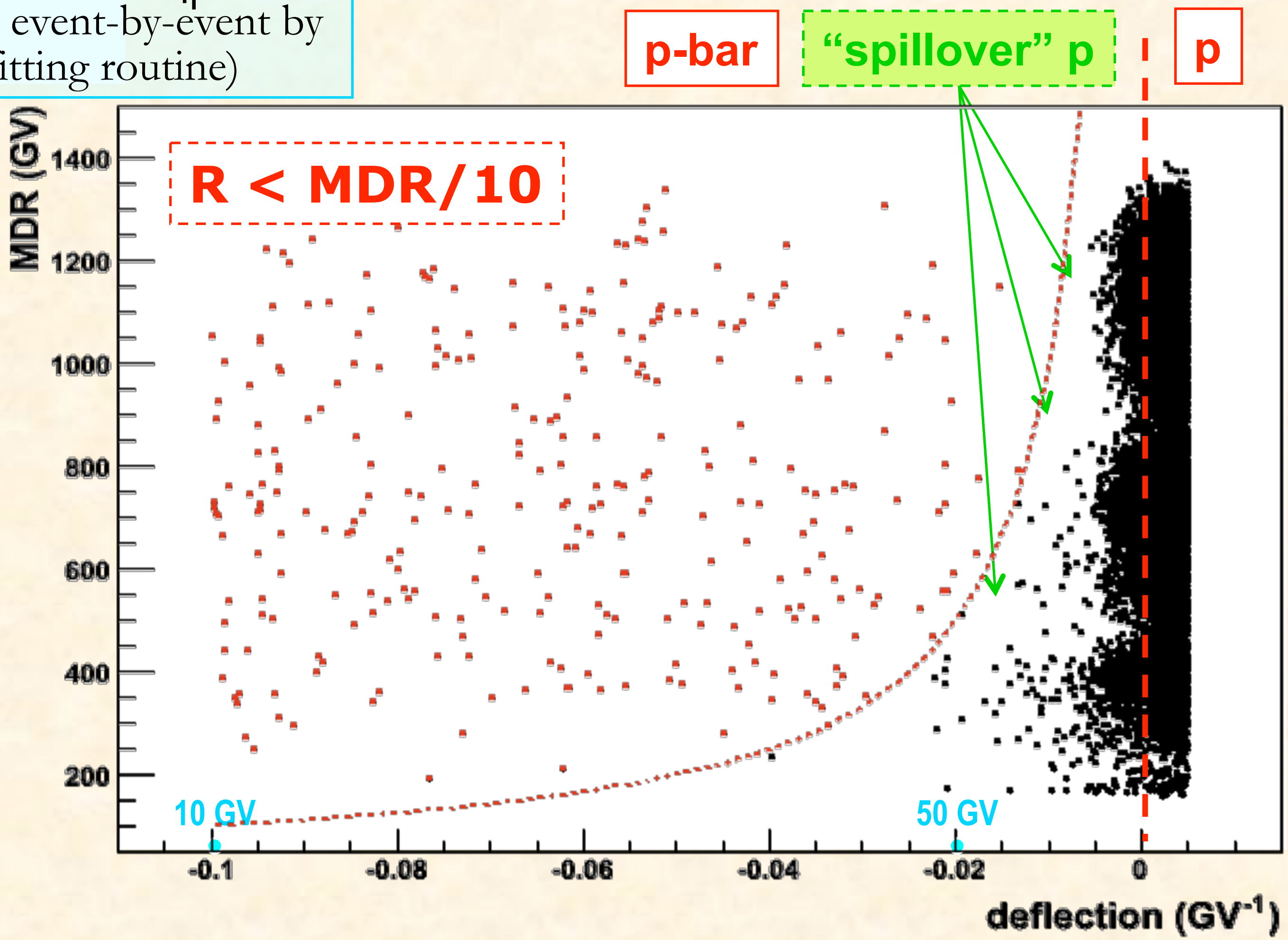
MDR = 1/σ_η
(evaluated event-by-event by the fitting routine)



MDR depends on:
- number and distribution of fitted points along the trajectory
- spatial resolution of the single position measurements
- magnetic field intensity along the trajectory

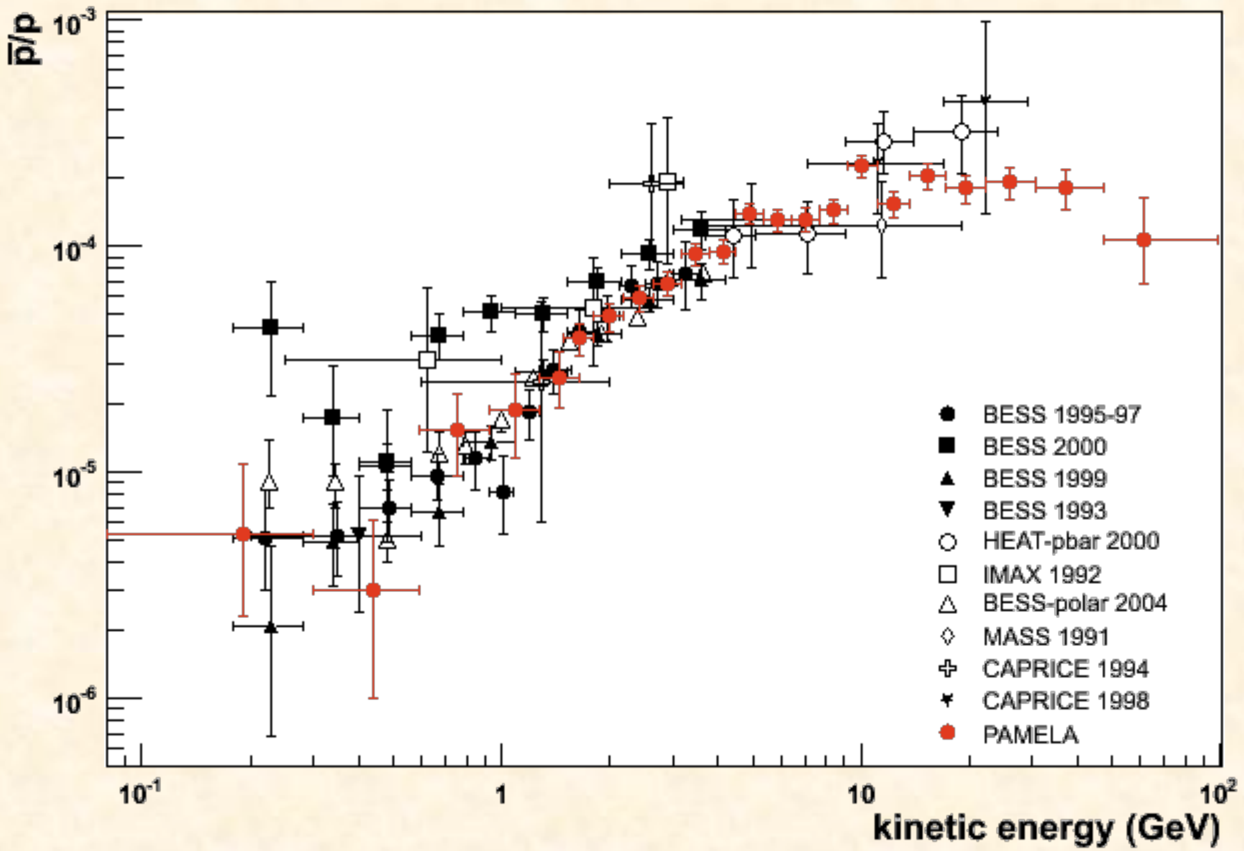
Proton-spillover background

MDR = $1/\sigma_\eta$
(evaluated event-by-event by the fitting routine)



Pions (from interactions in dome) : about 3% in the pbar sample

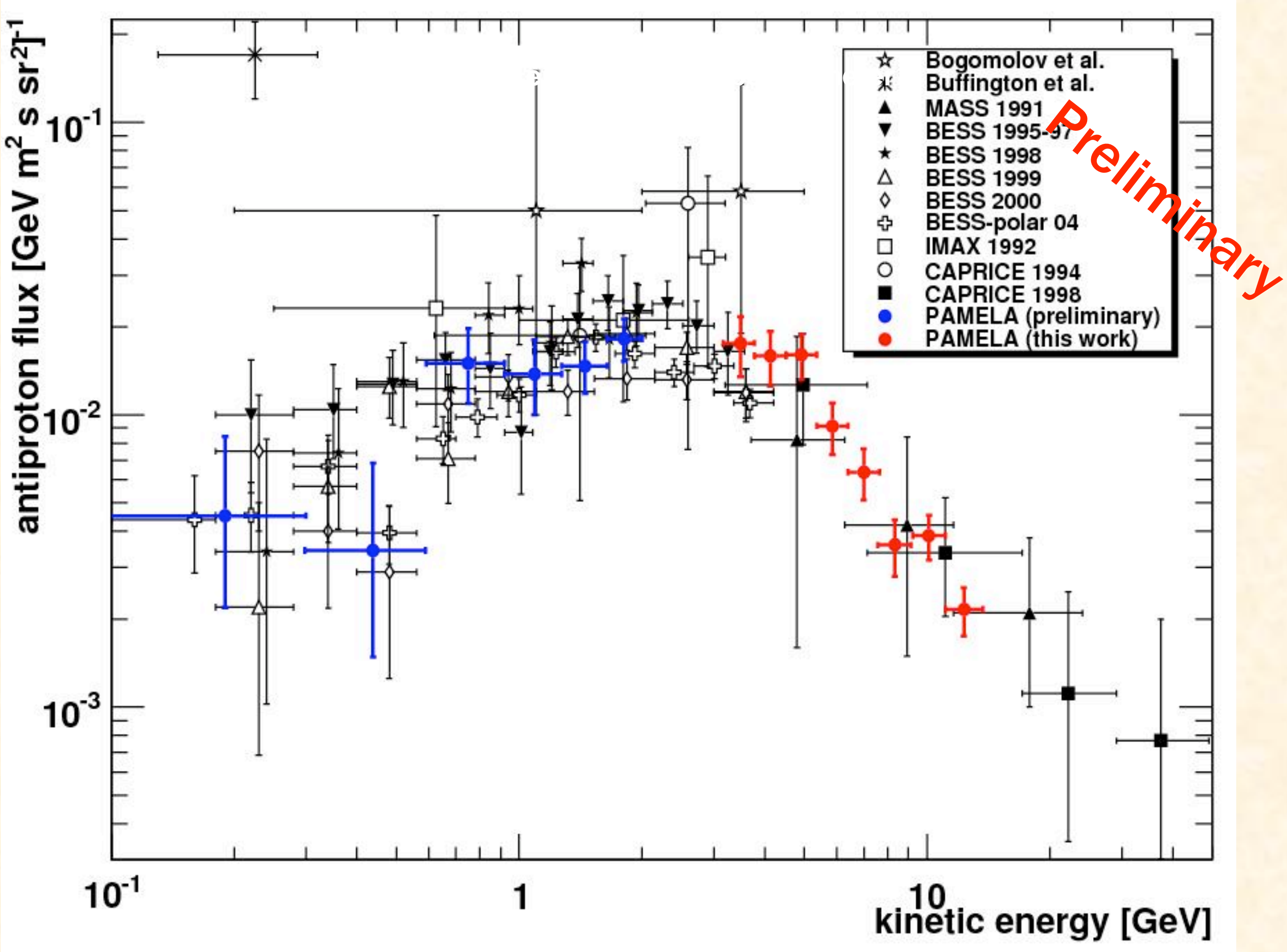
PAMELA: Antiproton-to-proton ratio



preliminary
(Petter Hofverberg's PhD Thesis)

PRL 102, 051101 (2009)

PAMELA: Antiproton Flux



PAMELA results:
Positrons

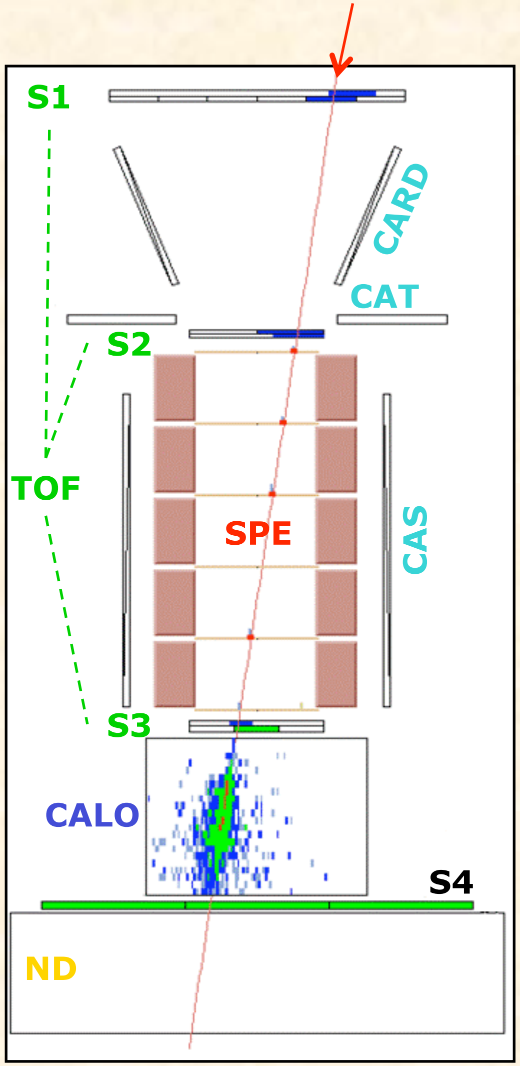
High-energy positron analysis

- Analyzed data July 2006 – February 2008 (~500 days)
- Collected triggers ~10^8
- Identified **~ 150 10^3 electrons** and **~ 9.5 10^3 positrons** between 1.5 and 100 GeV (**11 positrons above 65 GeV**)

- Electron/positron identification:
  - rigidity (R) → SPE
  - |Z|=1 (dE/dx=MIP) → SPE&ToF
  - β=1 → ToF
  - e^-/e^+ separation (charge sign) → SPE
  - e^+/p (and e^-/p-bar) separation → CALO

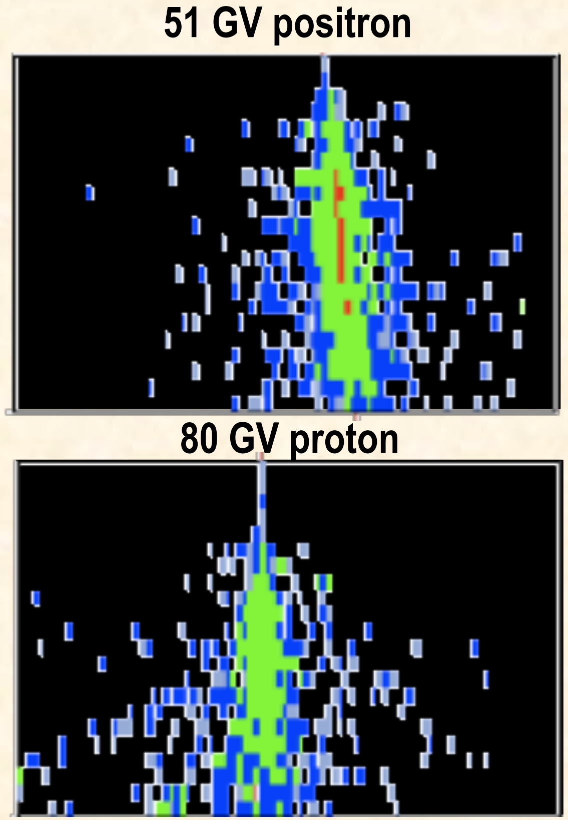
- Dominant background → **interacting protons**:
  - fluctuations in hadronic shower development ⇒ $\pi_0 \rightarrow \gamma\gamma$ might mimic pure em showers
  - proton spectrum harder than positron ⇒ p/e^+ increase for increasing energy (10^3 @1GV 10^4 @100GV)

→ Required strong CALO selection



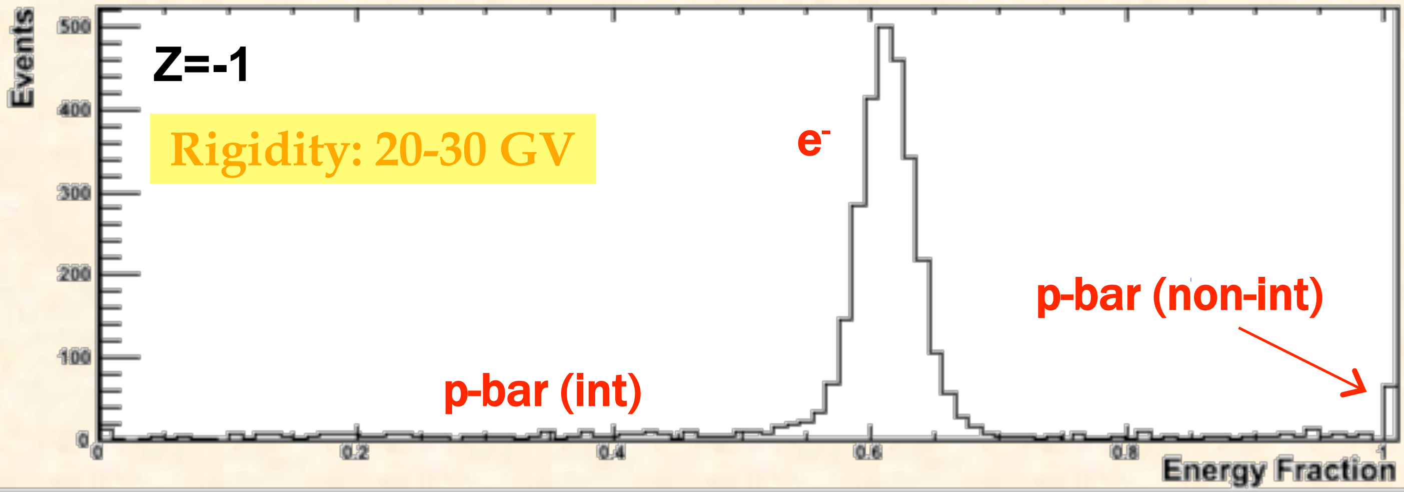
Positron identification with CALO

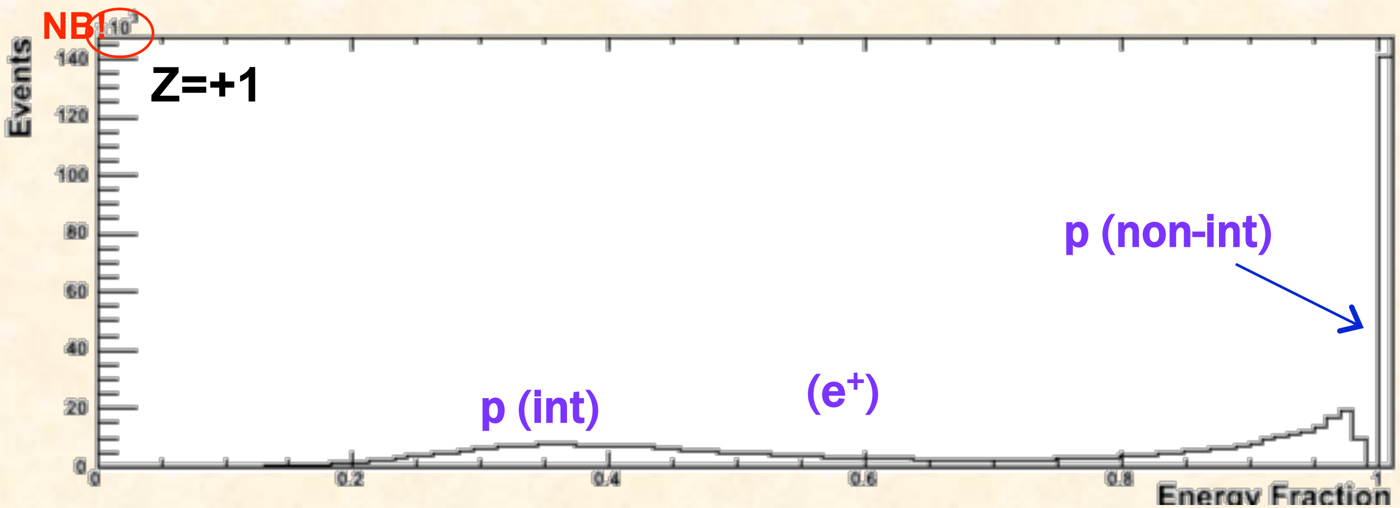
- Identification based on:
  - **Shower topology** (lateral and longitudinal profile, shower starting point)
  - **Total detected energy** (energy-rigidity match)
- Analysis key points:
  - **Tuning/check of selection criteria with:**
    - test-beam data
    - simulation
    - flight data → dE/dx from SPE & neutron yield from ND
  - **Selection of pure proton sample from flight data** ("pre-sampler" method):
    - *Background-suppression method*
    - *Background-estimation method*



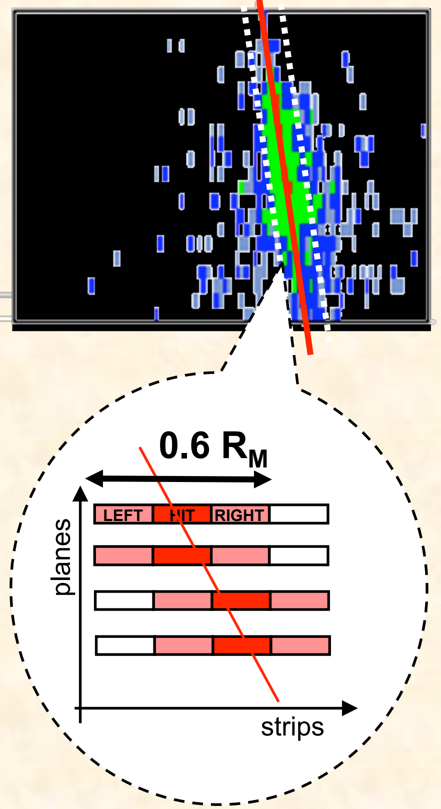
Final results make <u>NO USE</u> of test-beam and/or simulation calibrations. The measurement is based only on flight data with the <u>background-estimation</u> method

Positron identification



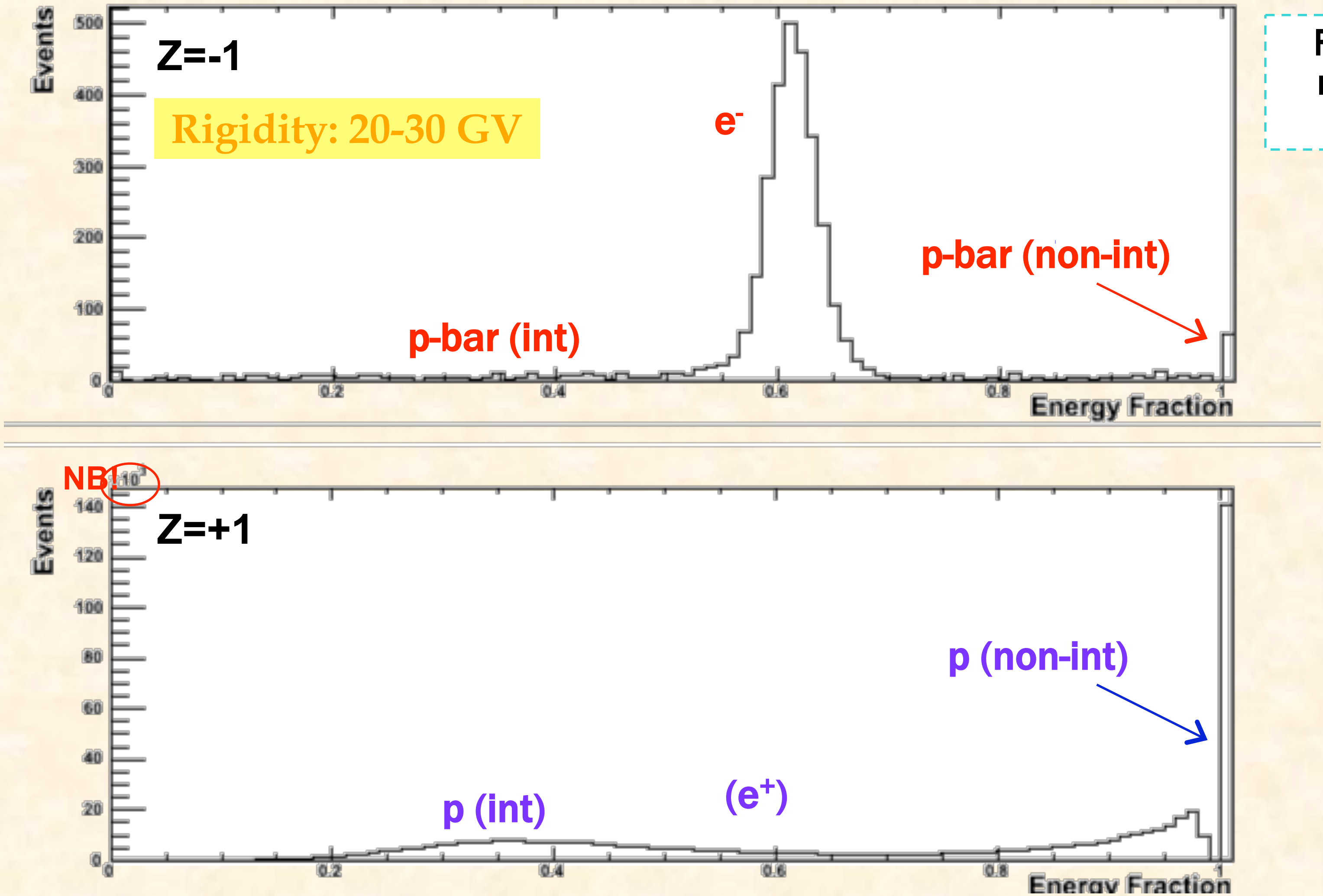


Charge released along the calorimeter track / total charge released in calorimeter



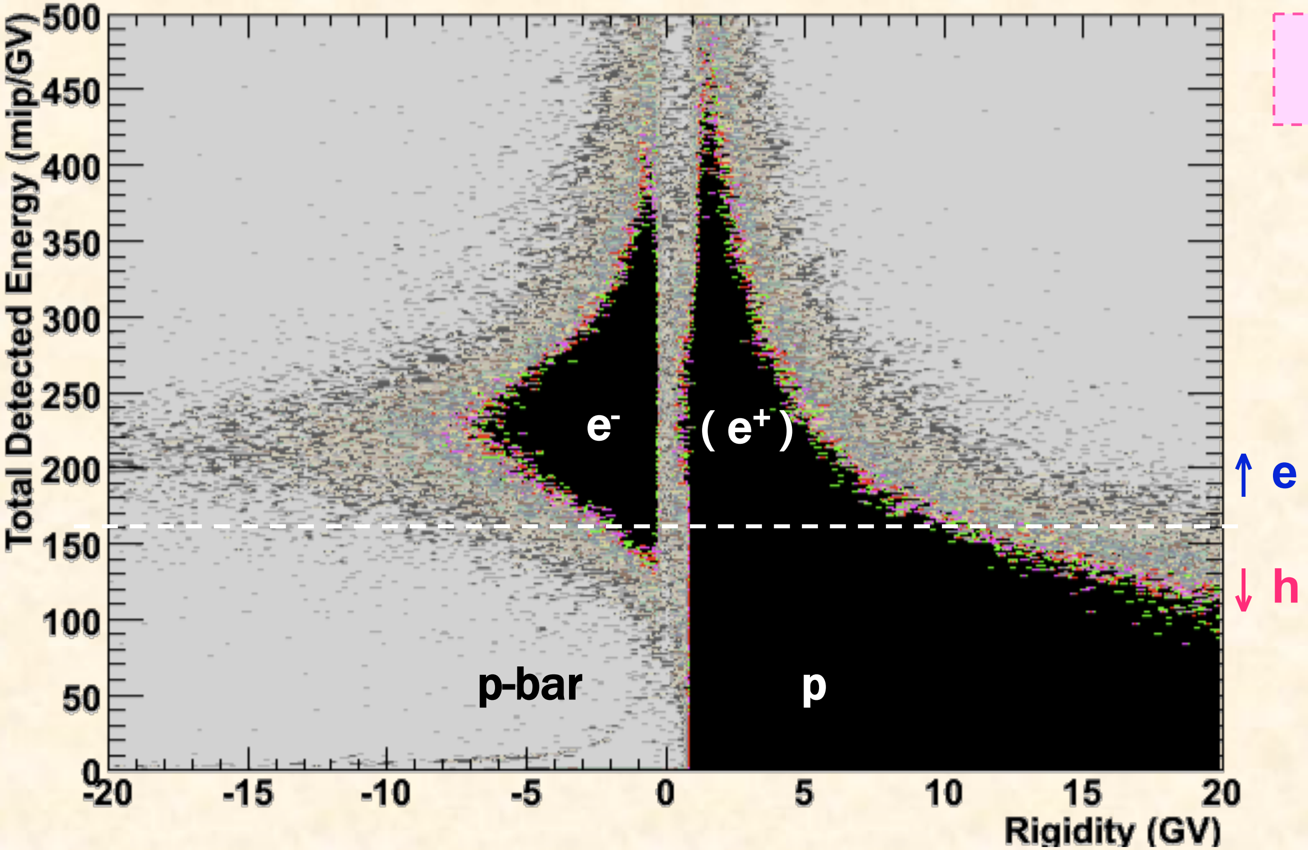
N.B: for em showers 90% of E contained in 1 R_M !

Positron identification



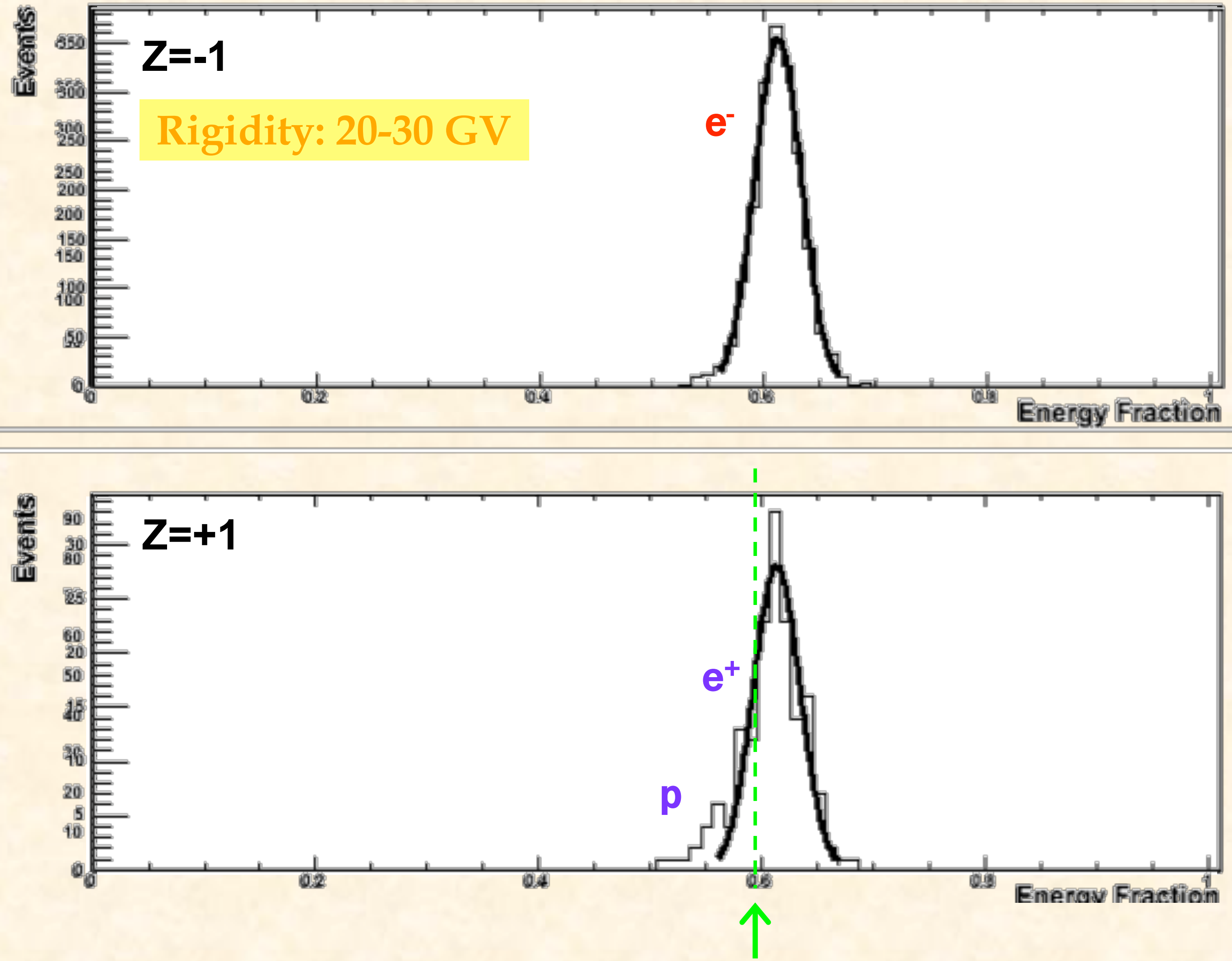
Fraction of charge released along the calorimeter track

Positron identification



Energy-momentum match

Positron identification



Fraction of charge released along the calorimeter track

+

Constraints on:

- Energy-momentum match
- Shower starting-point
- Longitudinal profile
- Lateral profile

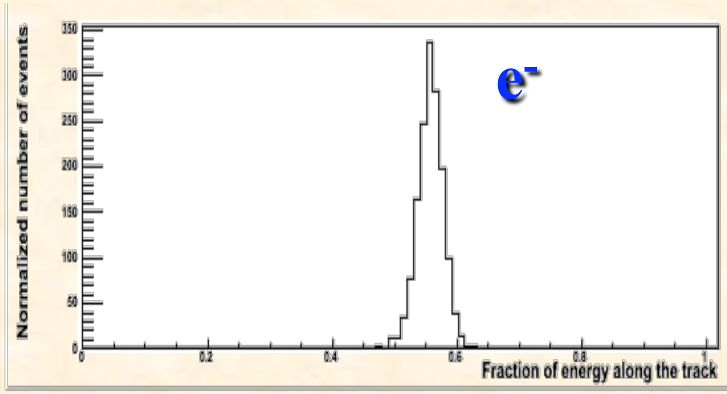
⇩

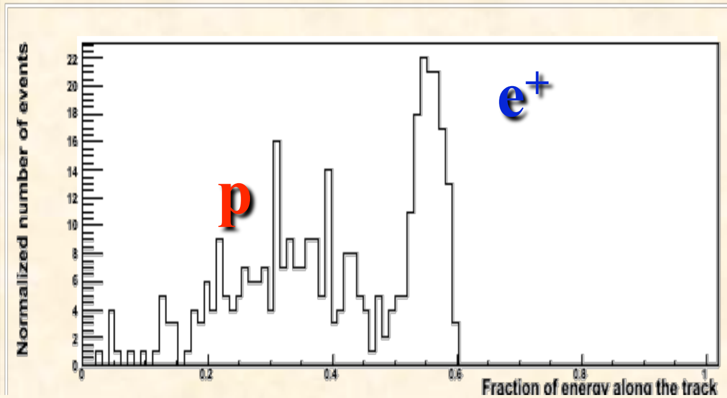
BK-suppression method

Check of calorimeter selection

Flight data
Rigidity: 20-30 GV

Test beam data
Momentum: 50GeV/c





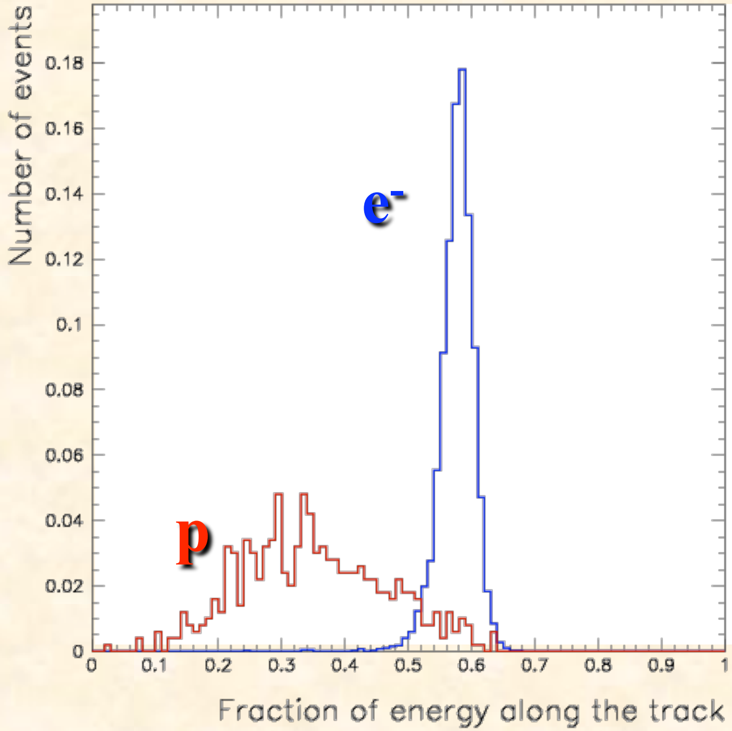
Fraction of charge released along the calorimeter track

+

Constraints on:

Energy-momentum match

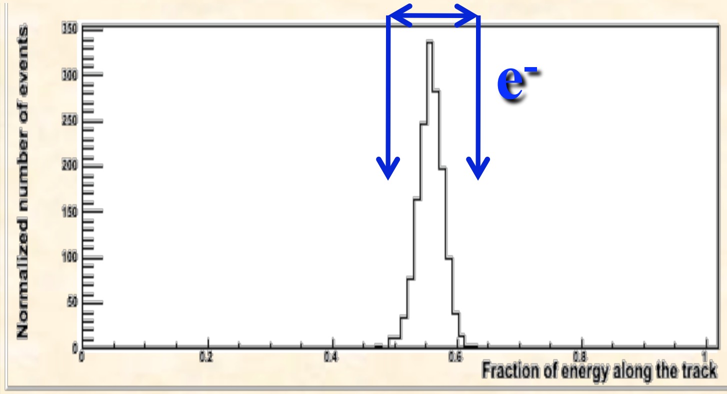
Shower starting-point

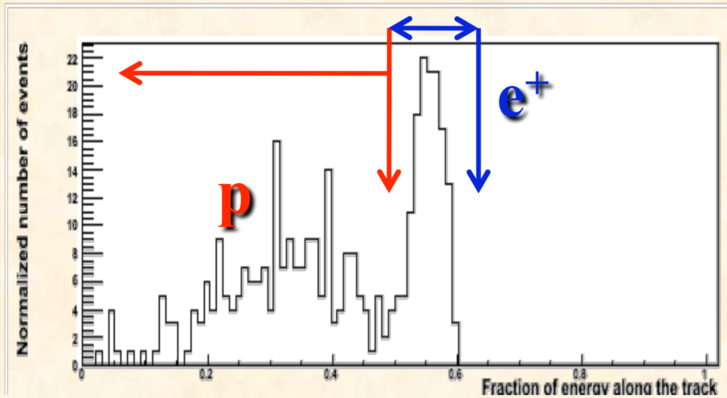


Check of calorimeter selection

Flight data
Rigidity: 20-30 GV

Flight data
Neutron yield in ND





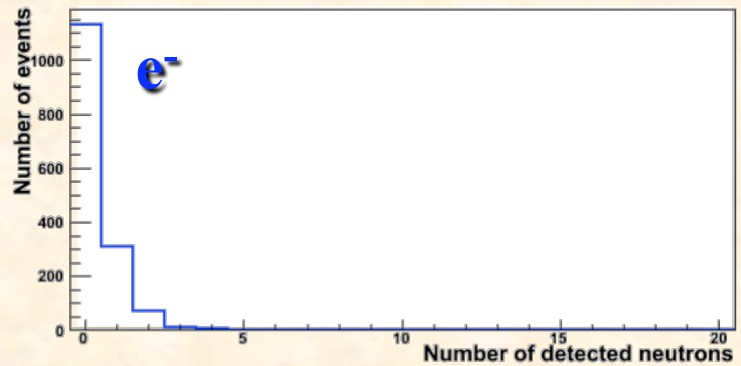
Fraction of charge released along the calorimeter track

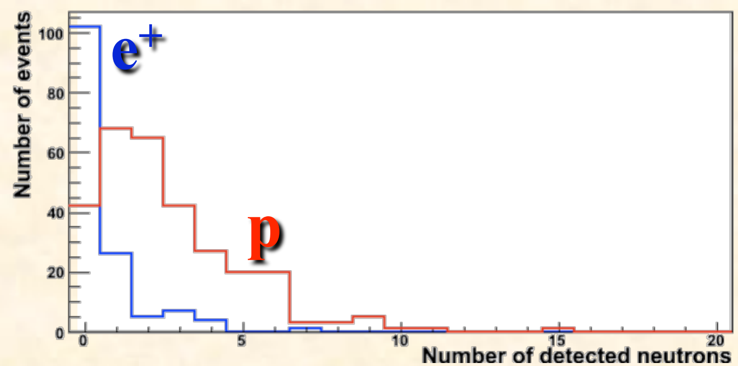
+

Constraints on:

Energy-momentum match

Shower starting-point





Check of calorimeter selection

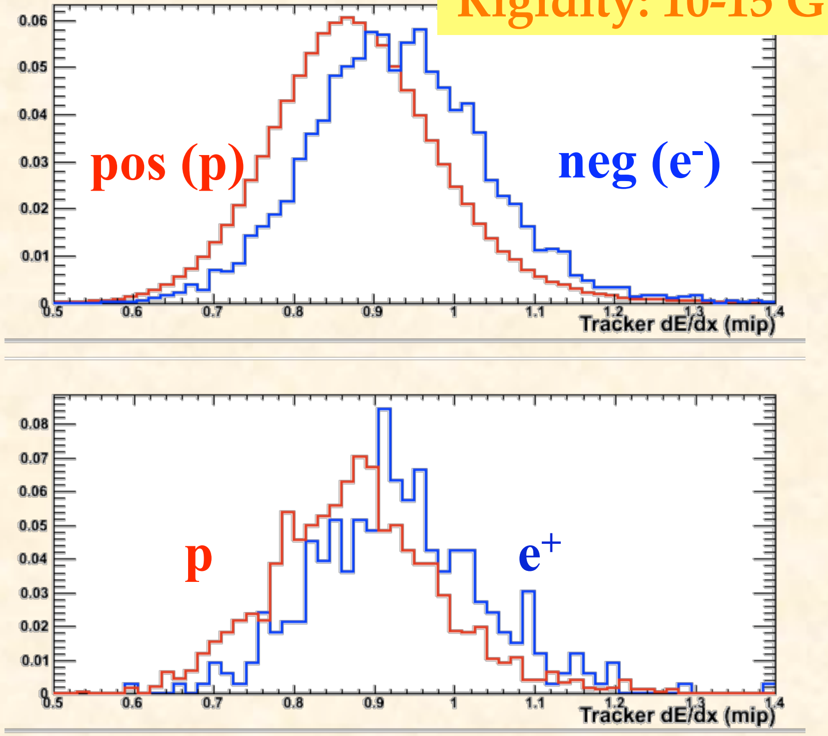
Energy loss in silicon tracker detectors:

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

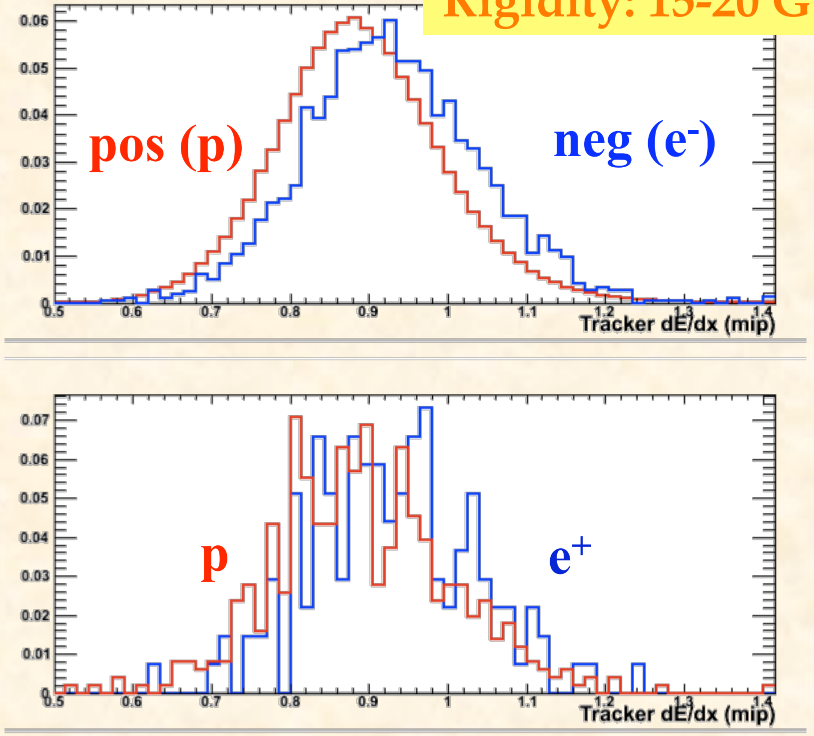
Relativistic rise

- Top: positive (mostly p) and negative events (mostly e^-)
- Bottom: positive events identified as p and e^+ by trasversal profile method

Rigidity: 10-15 GV



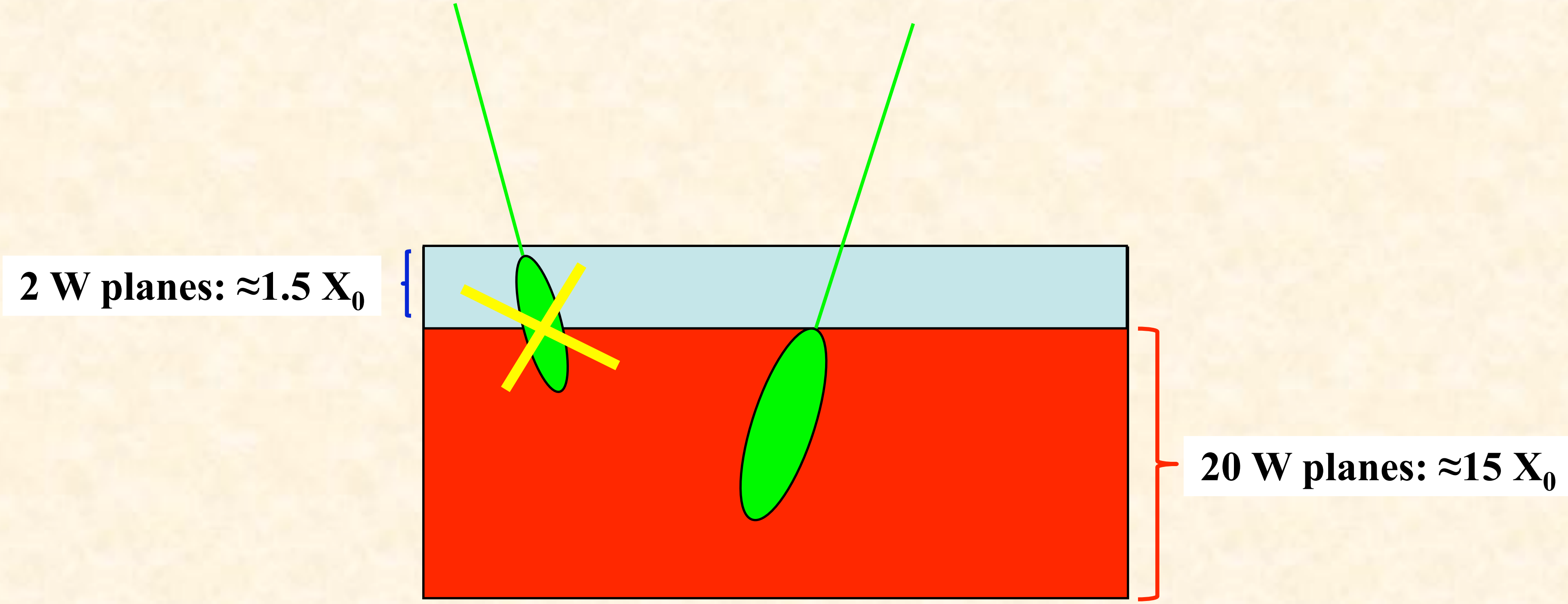
Rigidity: 15-20 GV



The "pre-sampler" method

Selection of a pure sample of protons from flight data

CALORIMETER: 22 W planes: 16.3 X_0



Only 2% of electrons and positrons do not interact in the first 2 CALO planes

Proton background evaluation

Rigidity: 20-28 GV

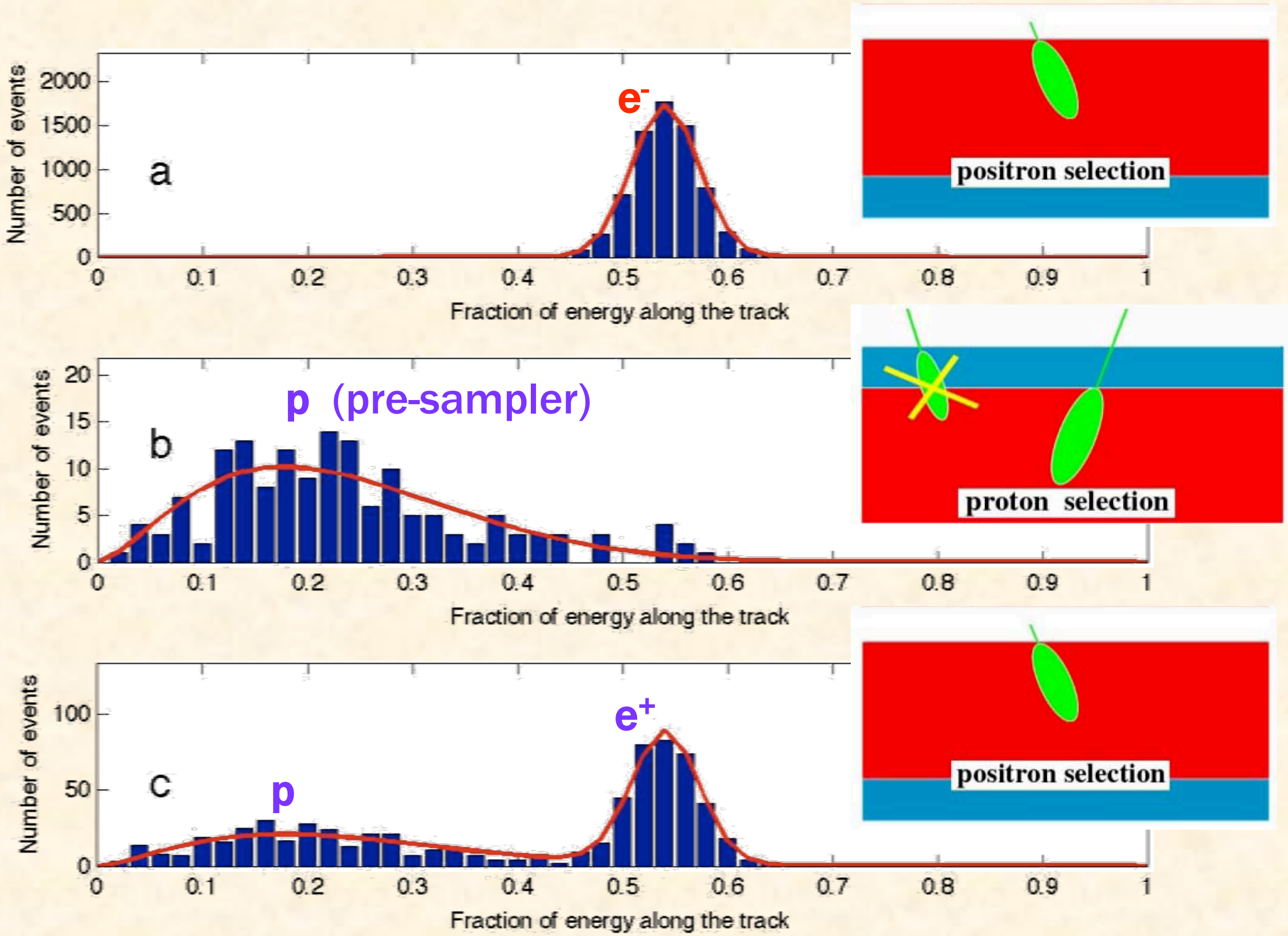
Fraction of charge released along the calorimeter track (left, hit, right)

\+

Constraints on:

Energy-momentum match

Shower starting-point



Proton background evaluation

Rigidity: 28-42 GV

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

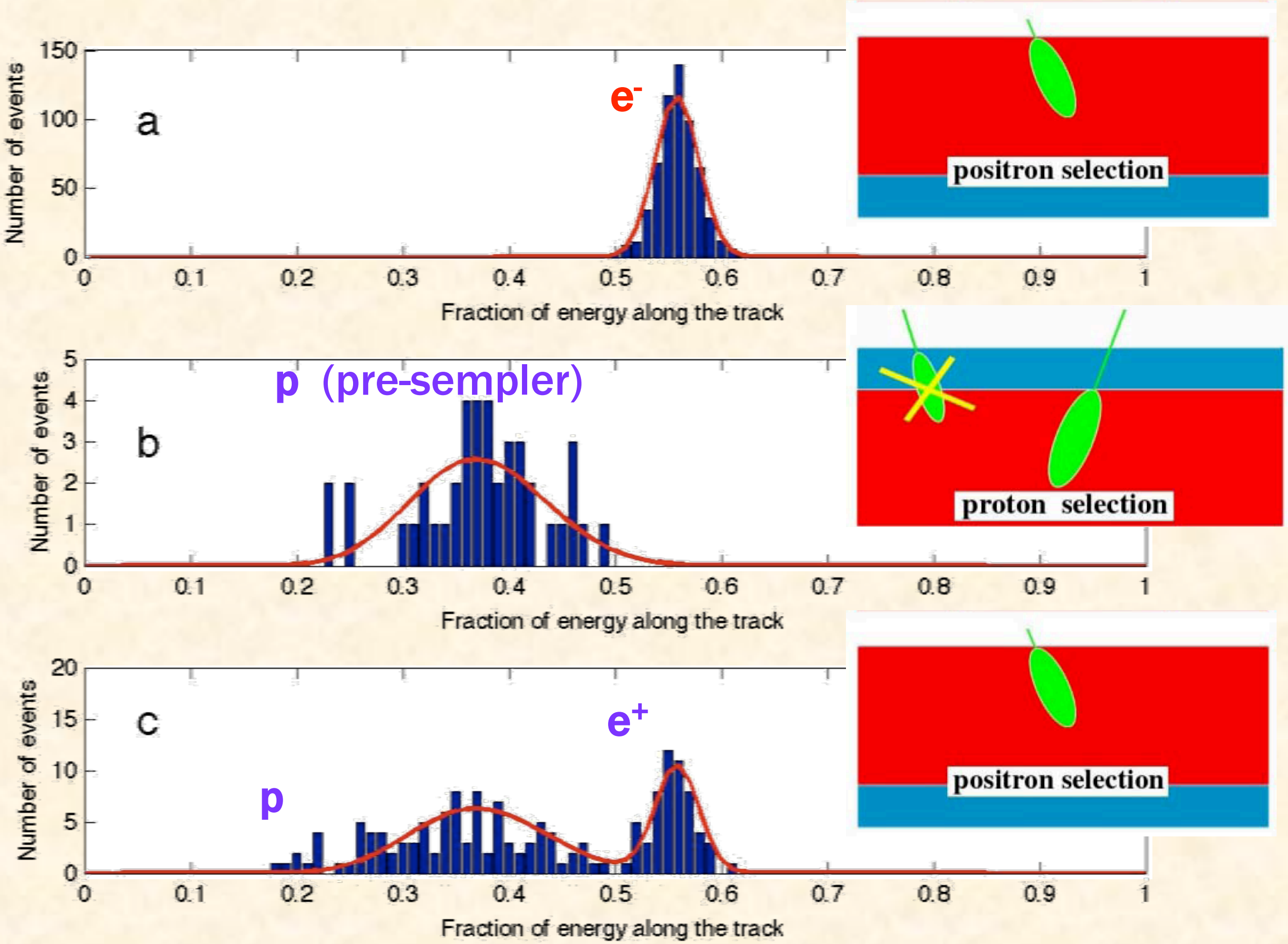
+

Constraints on:

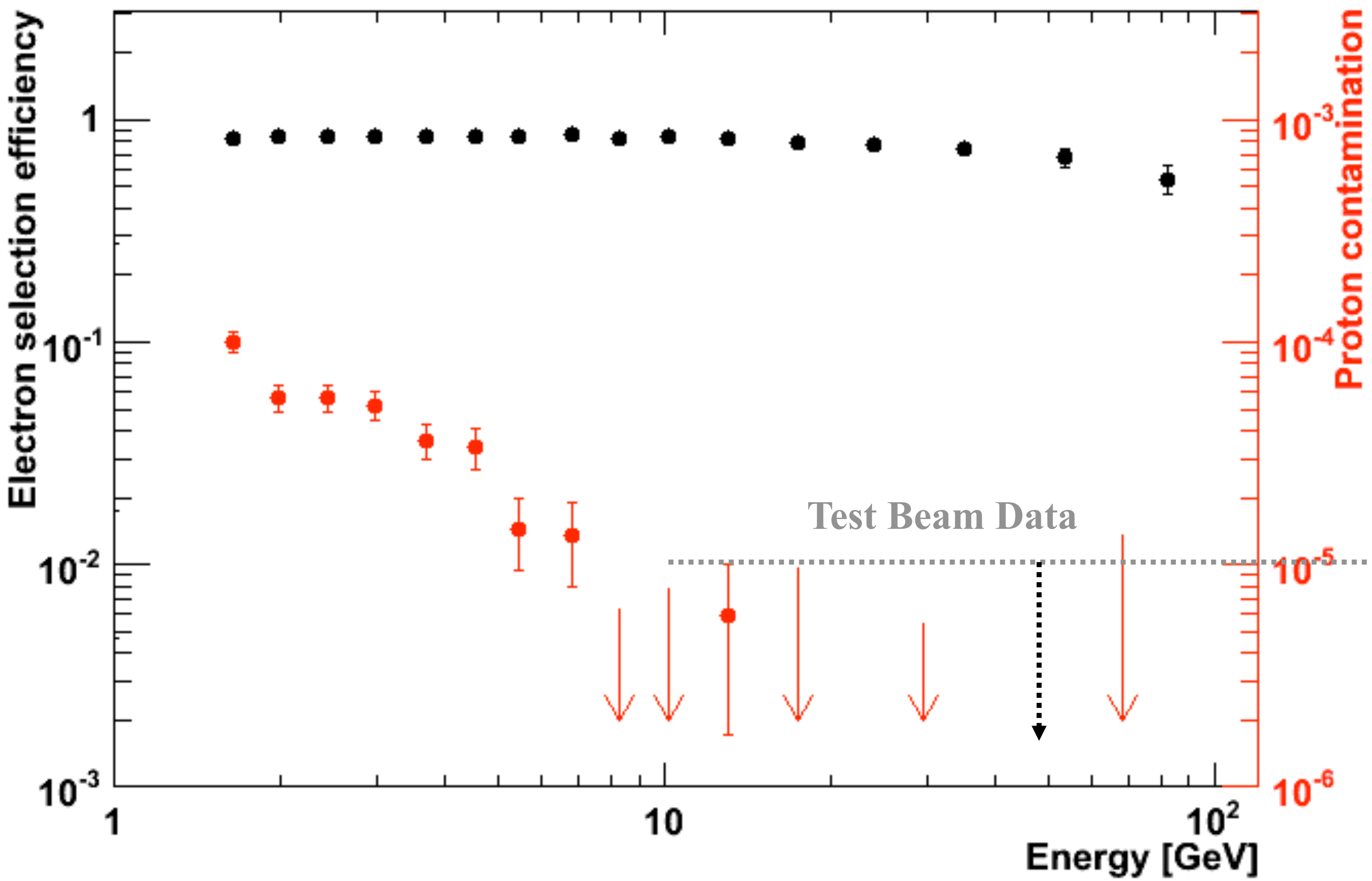
Energy-momentum match

Shower starting-point

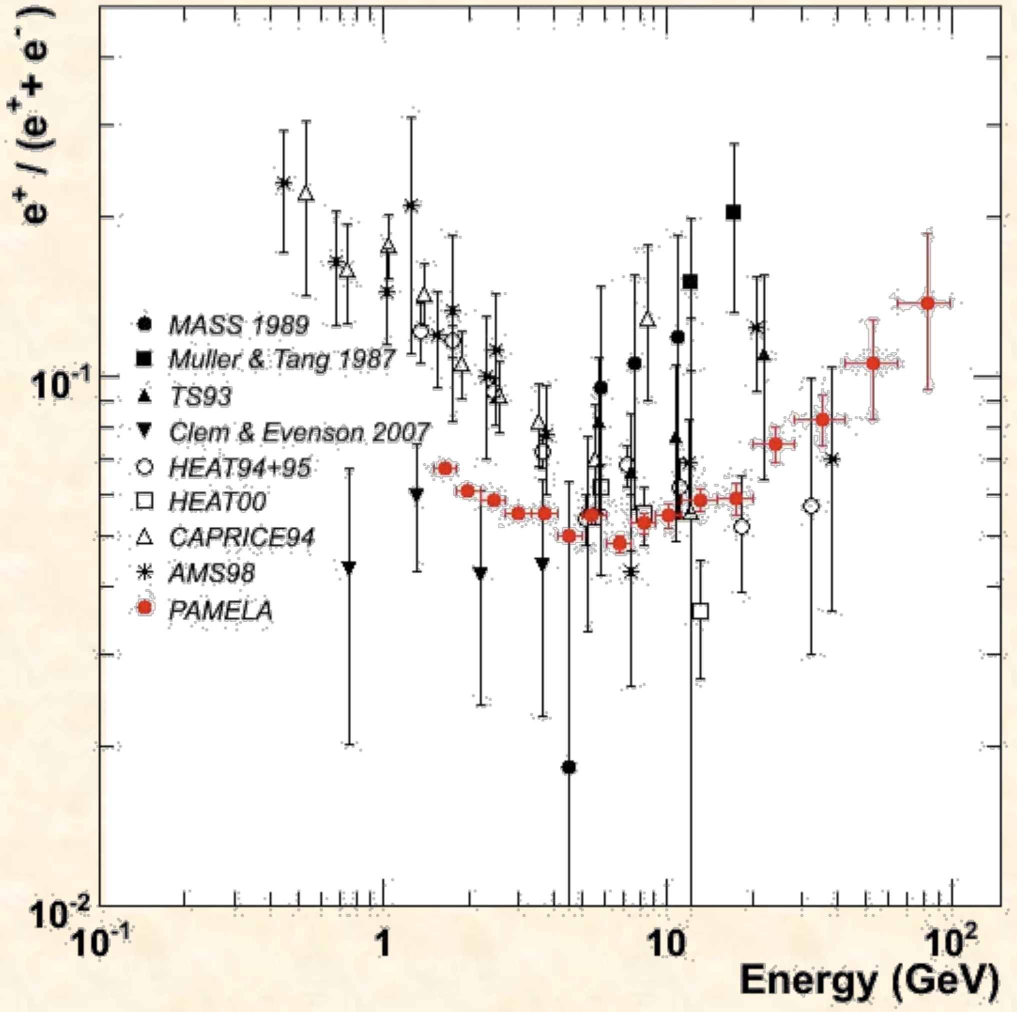
BK-estimation method



Positron selection with calorimeter



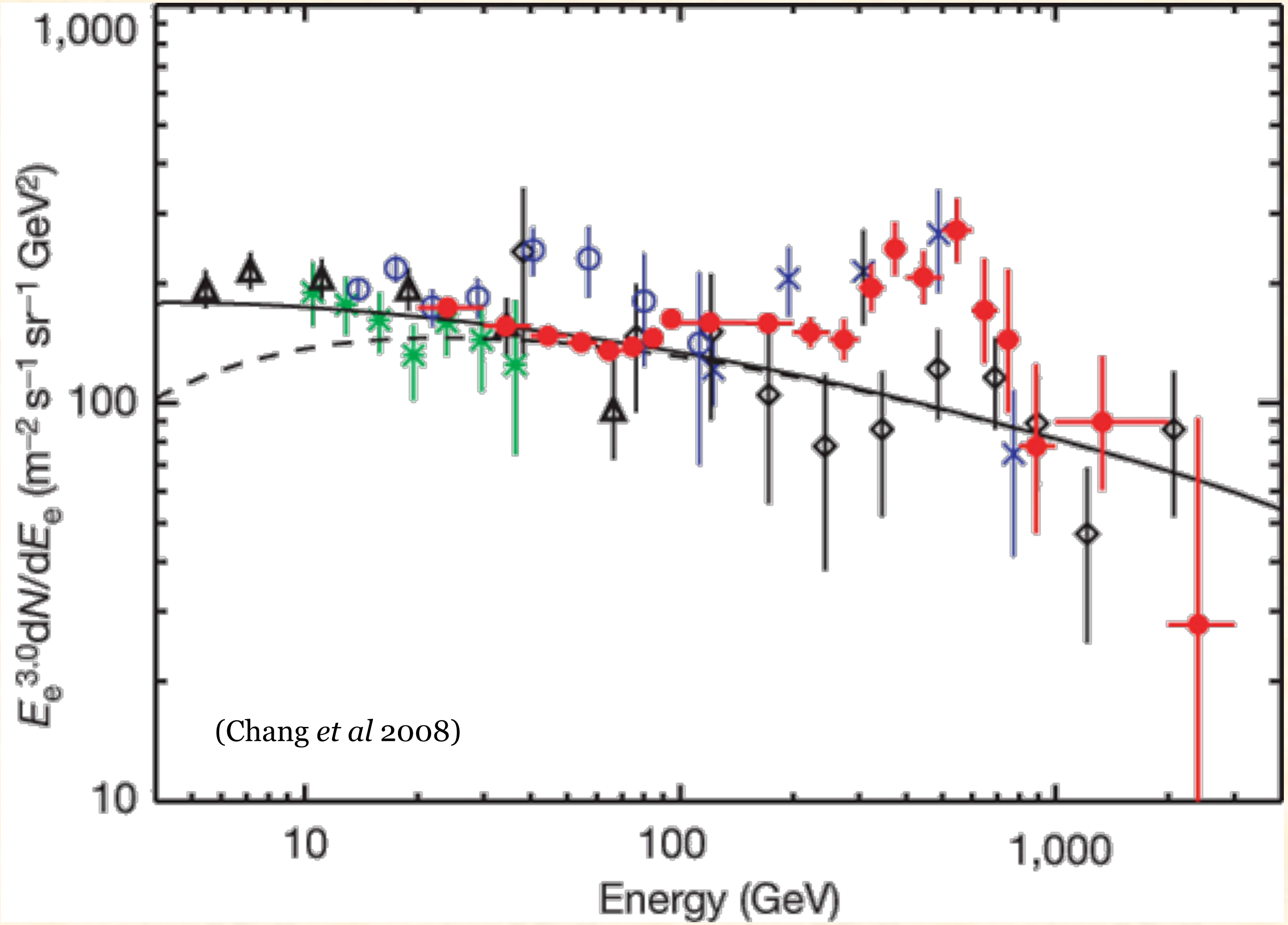
PAMELA: Positron fraction



NATURE 458 (2009)

More than 100 articles published after the release: we'll hear more in this workshop!

PAMELA work in progress:
Electron flux



PAMELA positron excess might be connected with ATIC electron+positron structures (next talks)

PAMELA electron flux measurements

Key points wrt other experiments (ATIC, HESS, FERMI) :

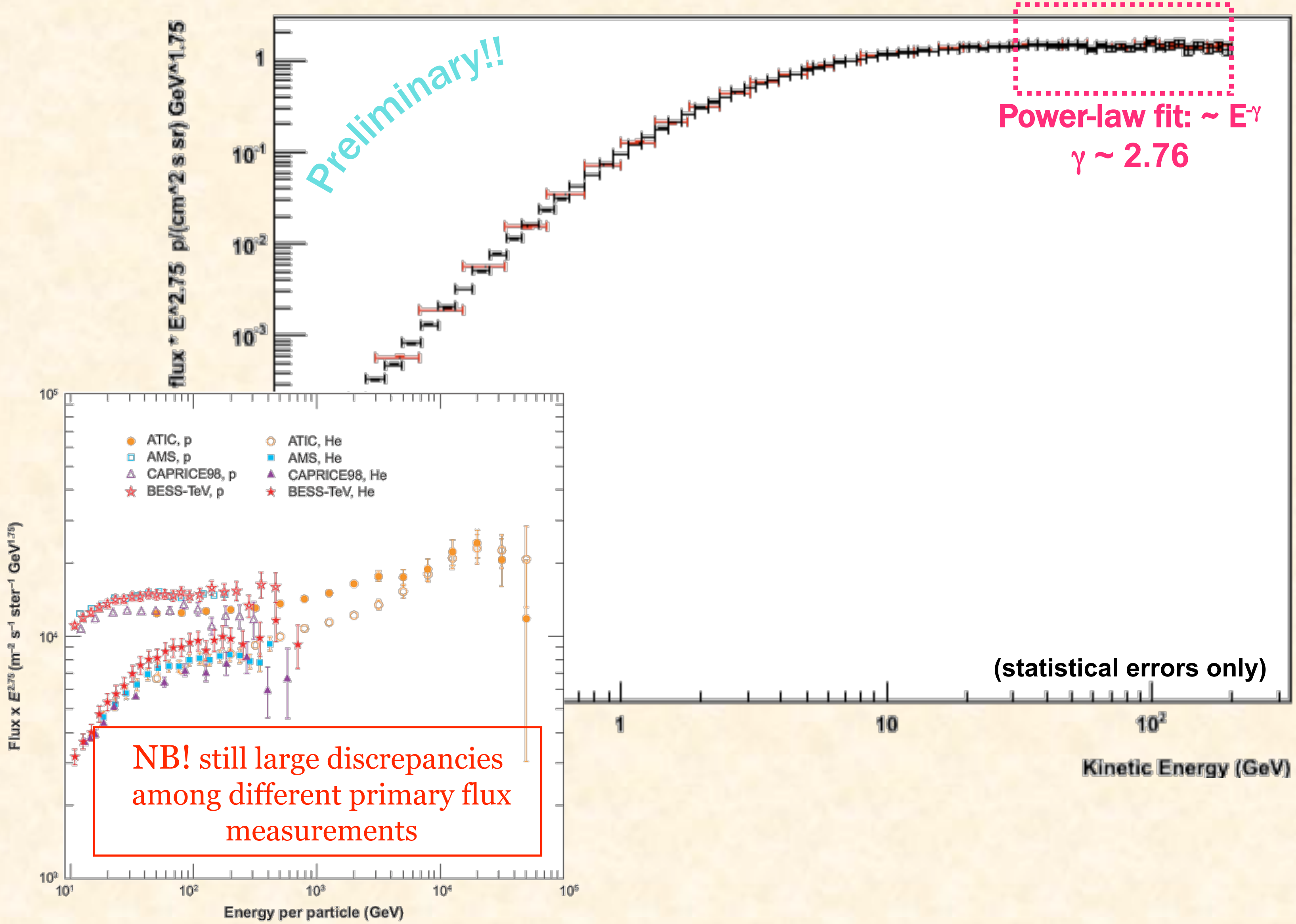
- Combination of CALO and SPECTROMETER allow **energy self-calibration in flight** → no dependence on ground calibrations or MC simulations
- Very deep CALO (16 X_0) → **containment of the shower maximum beyond 1 TeV**
- Neutron detector **help proton rejection**, especially at high energy
- **No atmospheric contamination**

But ..

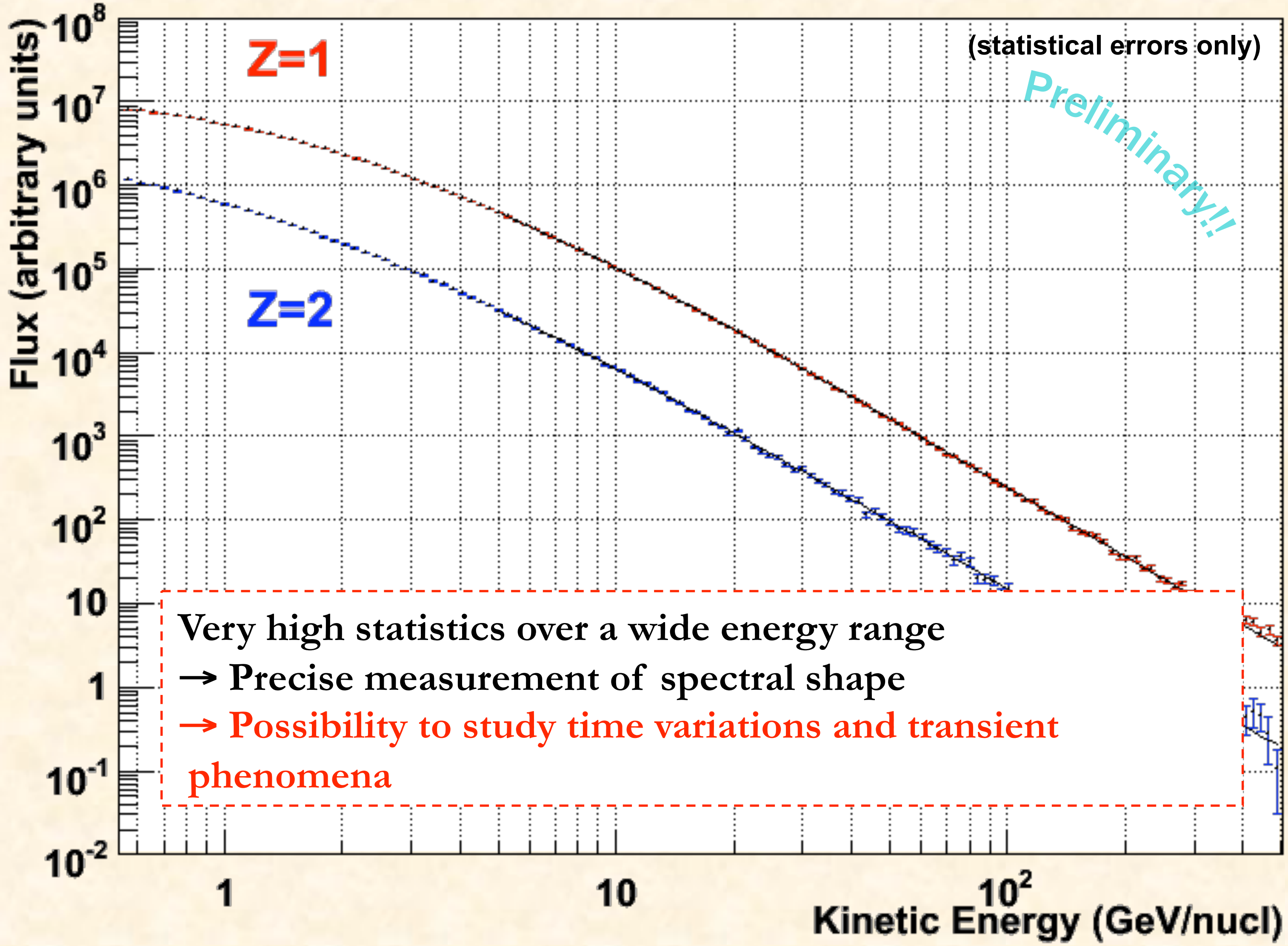
- Smaller acceptance → **lower statistics**

PAMELA work in progress:
Protons and light nuclei

Proton flux


Preliminary!!
Power-law fit: ~ E^-γ
γ ~ 2.76
(statistical errors only)
flux * E^2.75 p/(cm^2 s sr) GeV^1.75
Kinetic Energy (GeV)
ATIC, p
AMS, p
CAPRICE98, p
BESS-TeV, p
ATIC, He
AMS, He
CAPRICE98, He
BESS-TeV, He
Energy per particle (GeV)
NB! still large discrepancies among different primary flux measurements

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

Light nuclei

Statistics collected until December 2008:

- **120.000 C nuclei**
- **45.000 B nuclei**
- **16.000 Be nuclei**
- **30.000 Li nuclei**

between 200 MeV/n and 100 GeV/n, with quite stringent selection cuts (30% efficiency and 0.01% contamination among species).

Secondary/Primary ratios in progress !

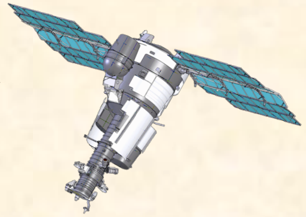
PAMELA is also studying …

Solar physics

Magnetospheric physics

Work in progress !! No time to talk about it ..

The future of PAMELA (I)



The PAMELA Collaboration made official request for prolongation of the mission until end 2011.

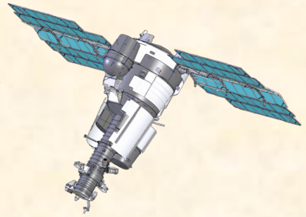
*** High energy antiprotons ***

- Estimated increase of the current statistics by 100%;
- Release of selection cuts (very strict until now):

-> possibility to reach the nominal limit of 200 GeV

6.5 antiproton events between 100-200 GeV expected by end 2011

The future of PAMELA (II)



* High energy positrons and electrons *

- Estimated increase of the current statistics by 100%;
- Release of selection cuts (very strict until now):

→ possibility to go beyond 100 GeV

→ possibility to perform *anisotropy studies* of the incoming direction of e+ and e-, to study astrophysics sources *(few percent level above 10 GeV)*

Most updated PAMELA results will be shown at the

which will take place on the **11th&12th of May, 2009** in Rome

You are all welcome !!