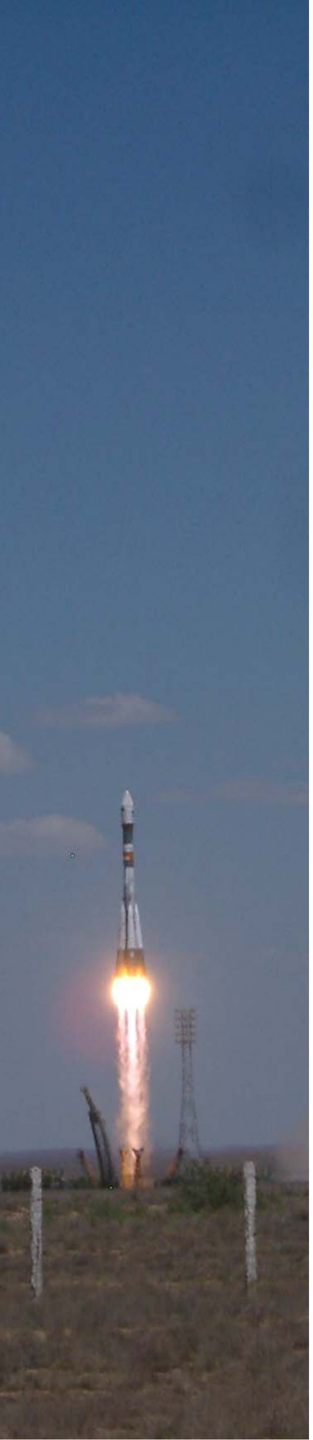


The cosmic-ray antiproton flux measured by PAMELA

Juan Wu

KTH, Stockholm

On behalf of the PAMELA collaboration

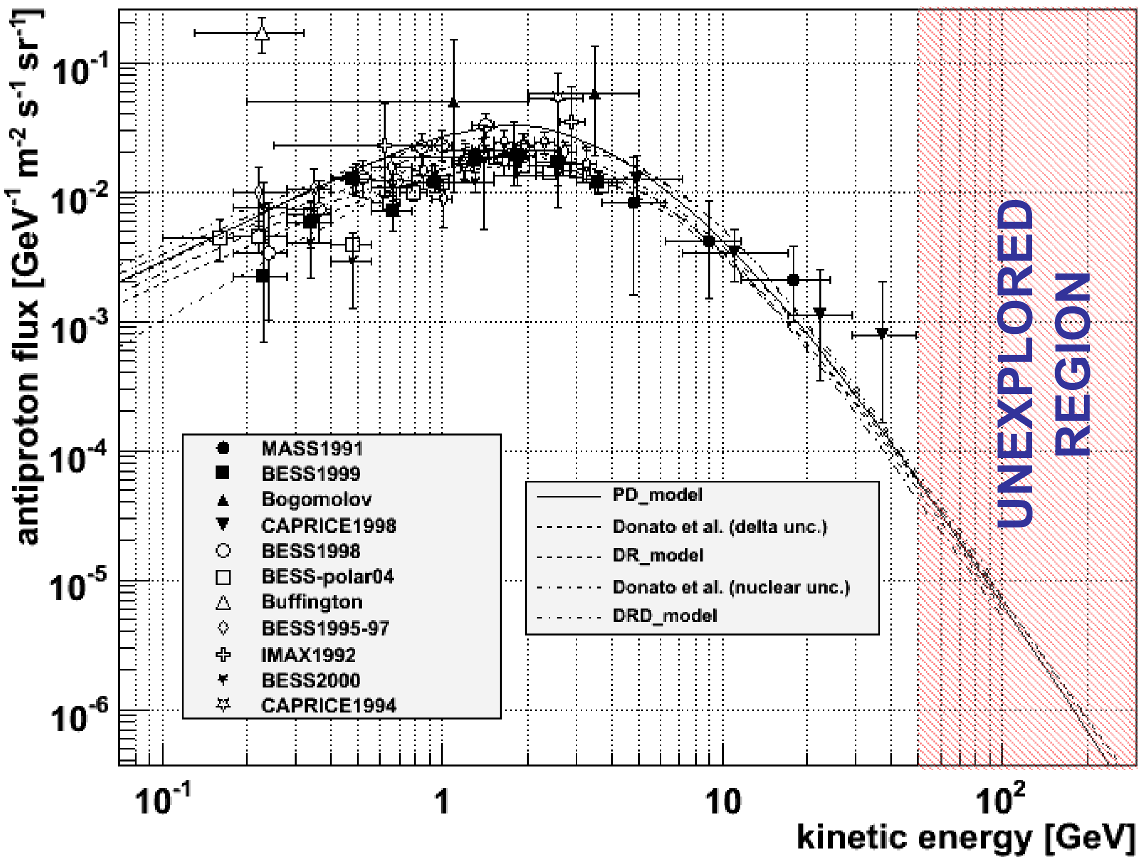
CR backgrounds in DM search

Outline

- Cosmic ray (CR) antiproton
- Antiproton identification
- Antiproton flux and antiproton-proton ratio

CR antiproton

Previous measurements of galactic antiprotons



- Previous measurements: all below 50GeV, low statistics

- Possible sources:

(1) Secondary production:
CR interaction with ISM
CR + ISM → p-bar + …

(2) Primary sources

-- evaporation of primordial black holes

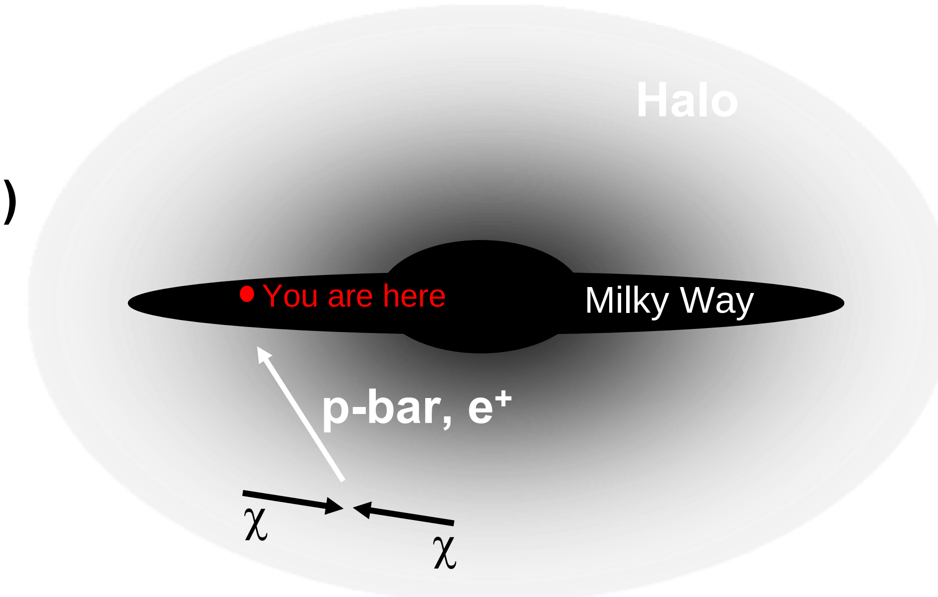
-- dark matter annihilation

-- new acceleration process (old SNR)

Cosmic-ray antimatter from Dark Matter annihilation

- **Annihilation of relic Weakly Interacting Massive Particles (WIMPs) gravitationally confined in the galactic halo**

→ Distortion of antiproton and positron spectra from purely secondary production



- **A plausible dark matter candidate is neutralino (χ), the Lightest SUSY Particle (LSP)**

Most likely processes:

- $\chi\chi$ → qq → hadrons→ p-bar, e^+,…
- $\chi\chi$ → W^+W^-,Z^0Z^0,… → e^+,…

$$\chi + \chi \rightarrow X + \gamma$$ **(Fermi LAT)**

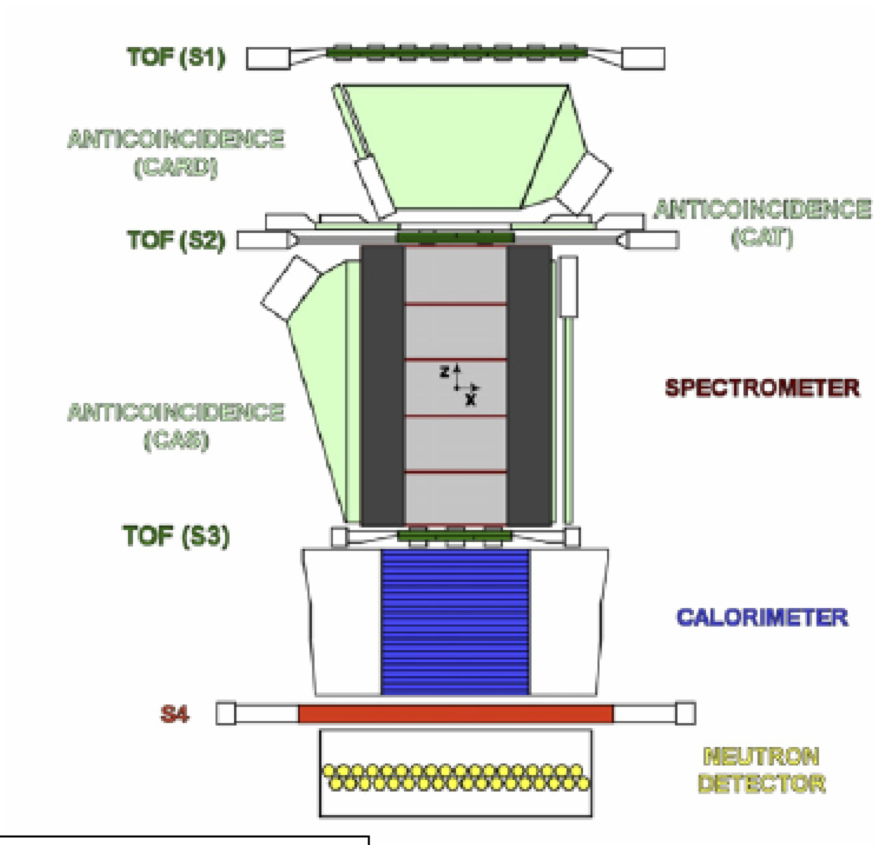
$$+ \nu$$ **(AMANDA / IceCube)**

$$+ \bar{p}$$

$$+ e^+$$

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

PAMELA Payload for Antimatter/Matter Exploration and Light-nuclei Astrophysics



Spectrometer (microstrip silicon tracking system + permanent magnet)

- *Rigidity*
- *Charge sign*
- *dE/dx*

Time-of-Flight (plastic scintillators)

- *Trigger*
- *Albedo rejection*
- *Mass identification at low energy*
- *dE/dx*

Anticoincidence (plastic scintillators)
- *remove "false" triggers*

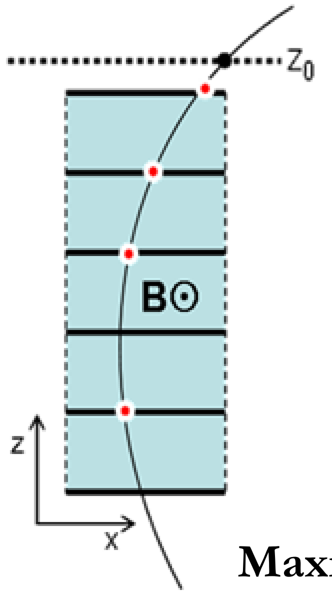
Calorimeter (22 Si-x/W/Si-y planes – 16.3 X0, 0.6 λI)
- *lepton-hadron separation*

Neutron detector (36 ^{3}He counters)
- **increase the lepton-hadron separation capability**

GF: 21.6 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360 W

Track reconstruction

$\alpha = (x_0, y_0, \sin\theta, \phi, \eta)$



Iterative χ^2 minimization as a function of track state-vector components α

Magnetic deflection

$|\eta| = 1/R$

$R = pc/Ze$ → magnetic rigidity

$\sigma_R/R = \sigma_\eta/\eta$

Maximum Detectable Rigidity (MDR)

def: @ R=MDR ⇒ $\sigma_R/R=1$

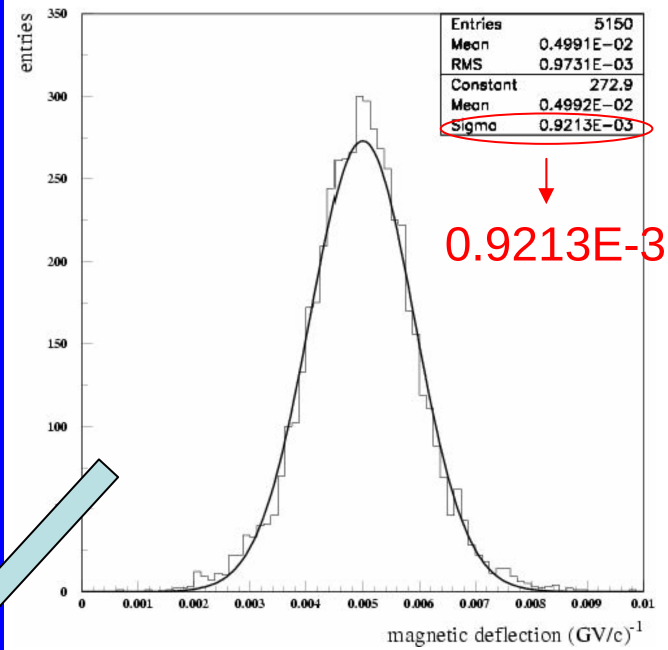
$MDR = 1/\sigma_\eta$

- Measured @ground with protons of known momentum

→ **MDR ≅1080 GV**

- Cross-check in flight with protons (alignment) and electrons (energy from calorimeter)

SPS test beam data: proton 200 GeV/c



Simulation ⟹

x (bending) resolution = 2.7 μ m

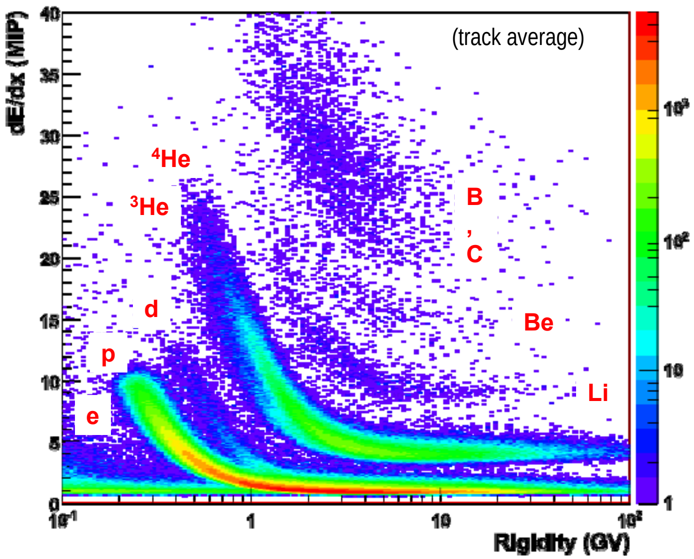
y (non-bending) resolution = 12 μ m

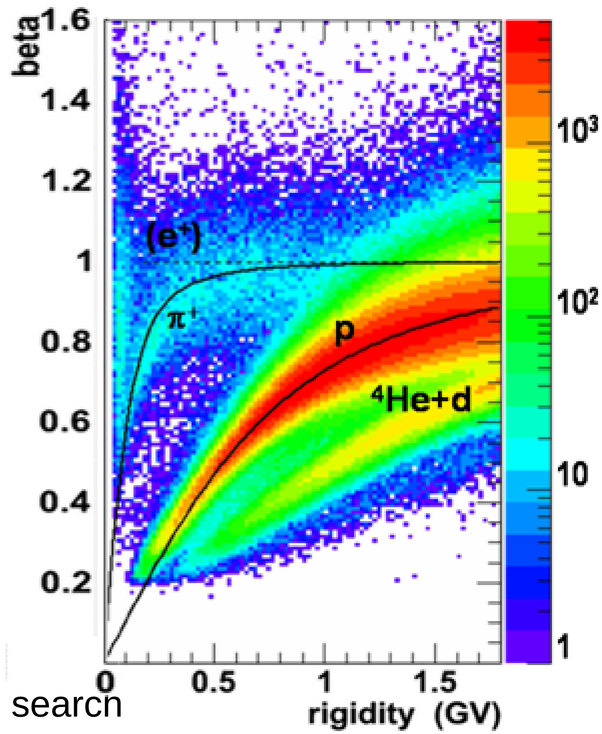
Antiproton Selection Ⅰ

- **A proton like *dE/dx* is used in tracker + ToF**

Bethe Bloch $$dE/dx \sim \frac{z^2}{\beta^2}$$

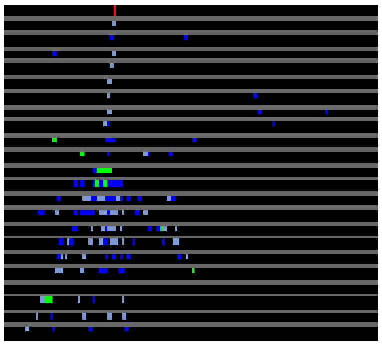
- **beta vs Rigidity consistent with mass of proton** $$\beta^2 = \frac{R^2}{R^2 + m^2}$$

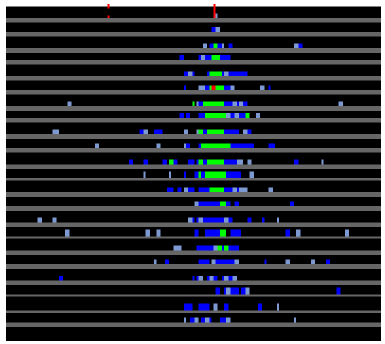


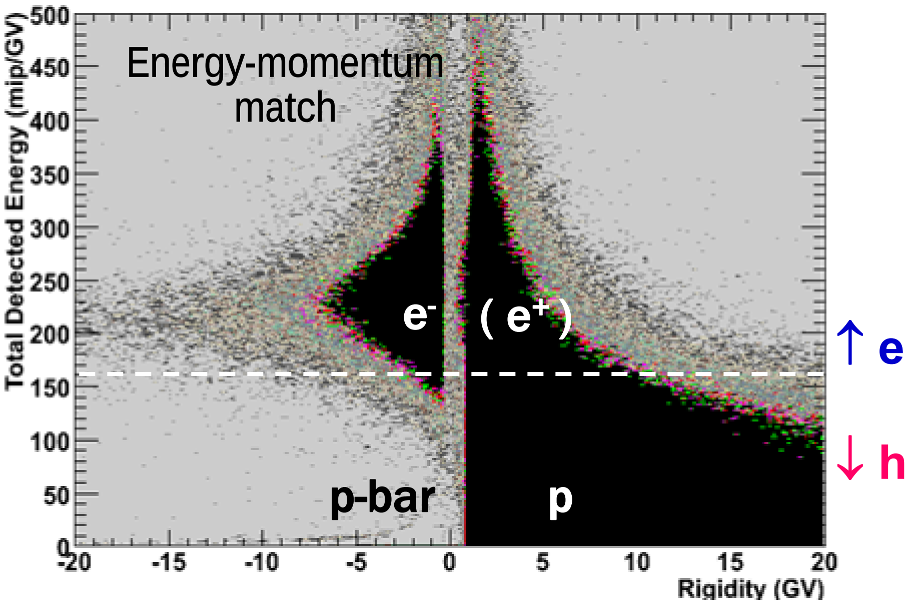


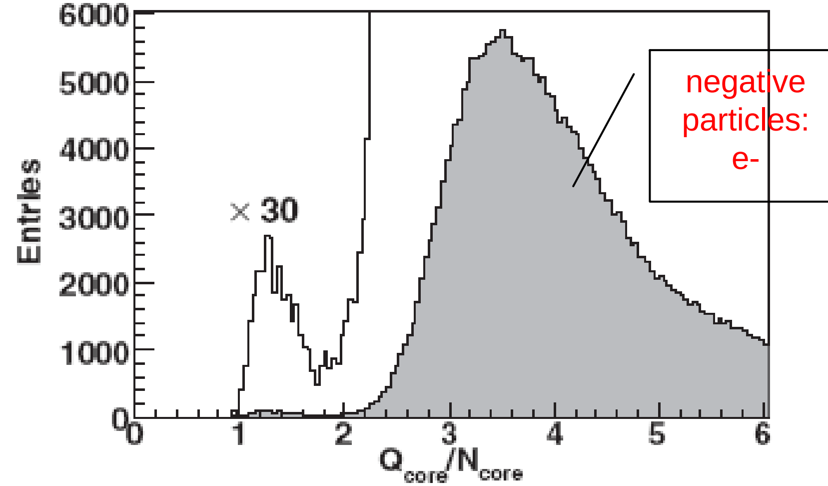
Antiproton Selection Ⅱ

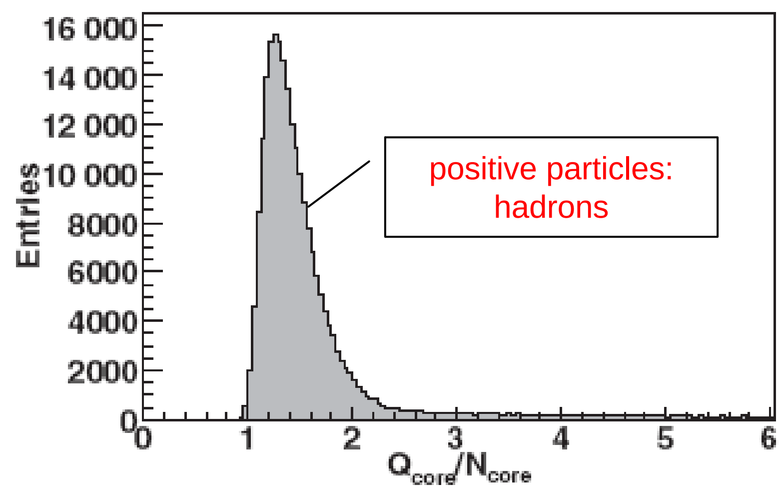
proton (R=19GV) electron (R=17GV)









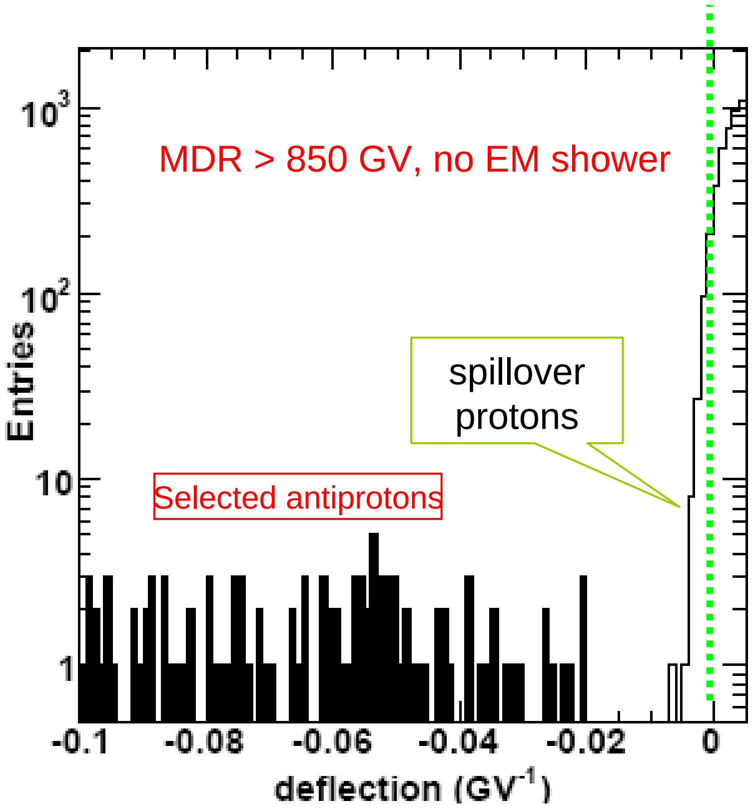


Antiproton Selection III

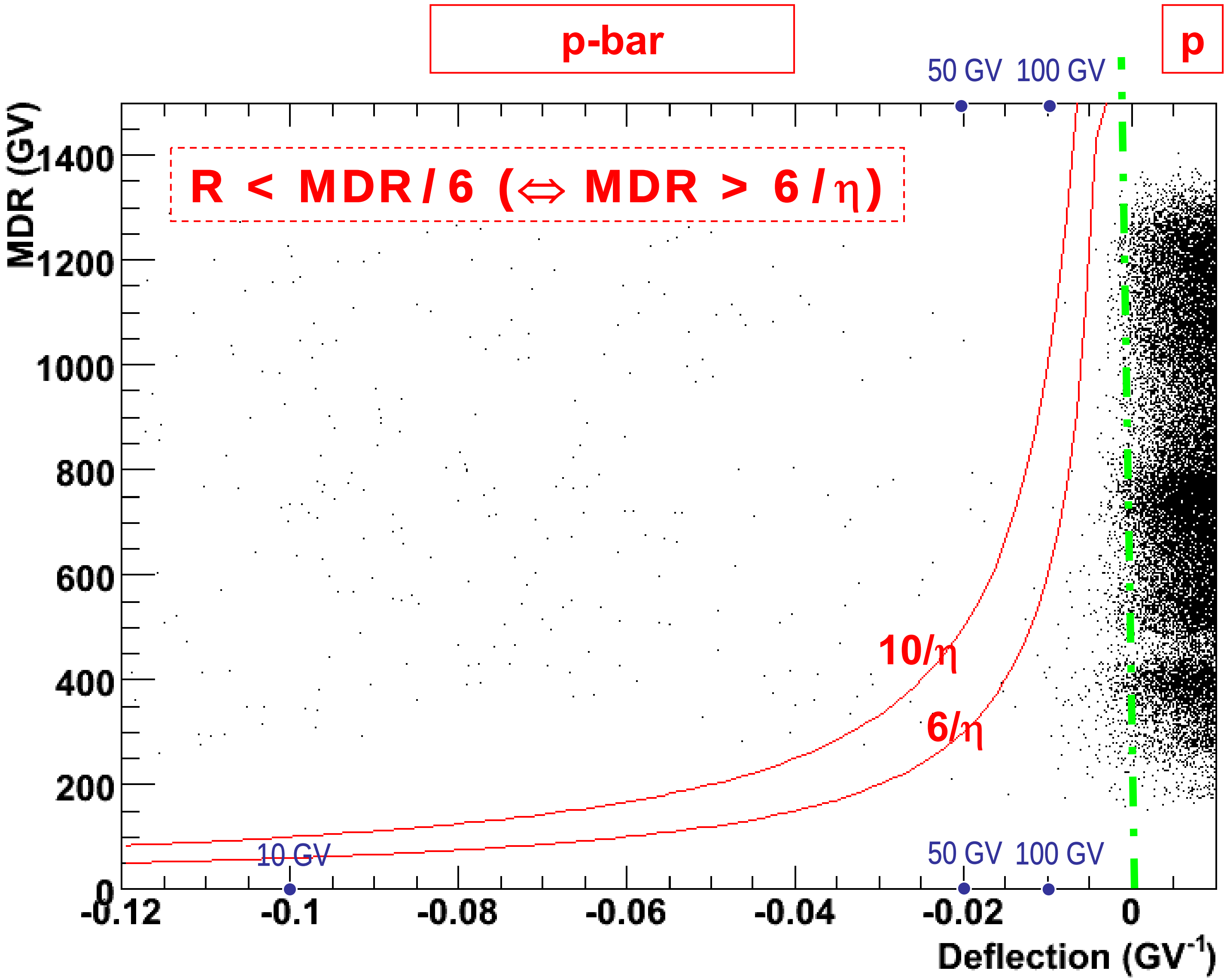
- **Spectrometer tracking information is crucial for high energy antiproton selection**

- **High rigidity protons may be assigned wrong sign-of-charge due to finite spectrometer resolution**

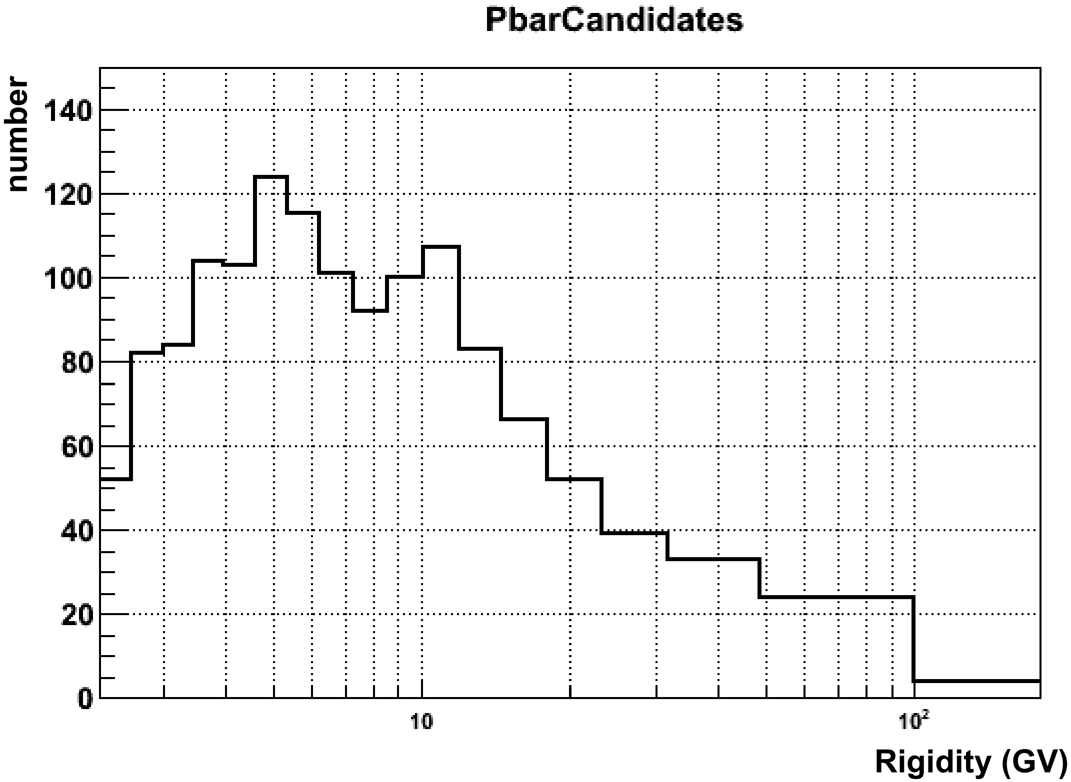
- **A spillover rejection requires strong track requirements:**
chi2 with ~75% efficiency, no bad strips, no δ -rays,
mdr>6 * constructed rigidity.



Antiproton Selection III



Seleted antirproton sample



This analysis:

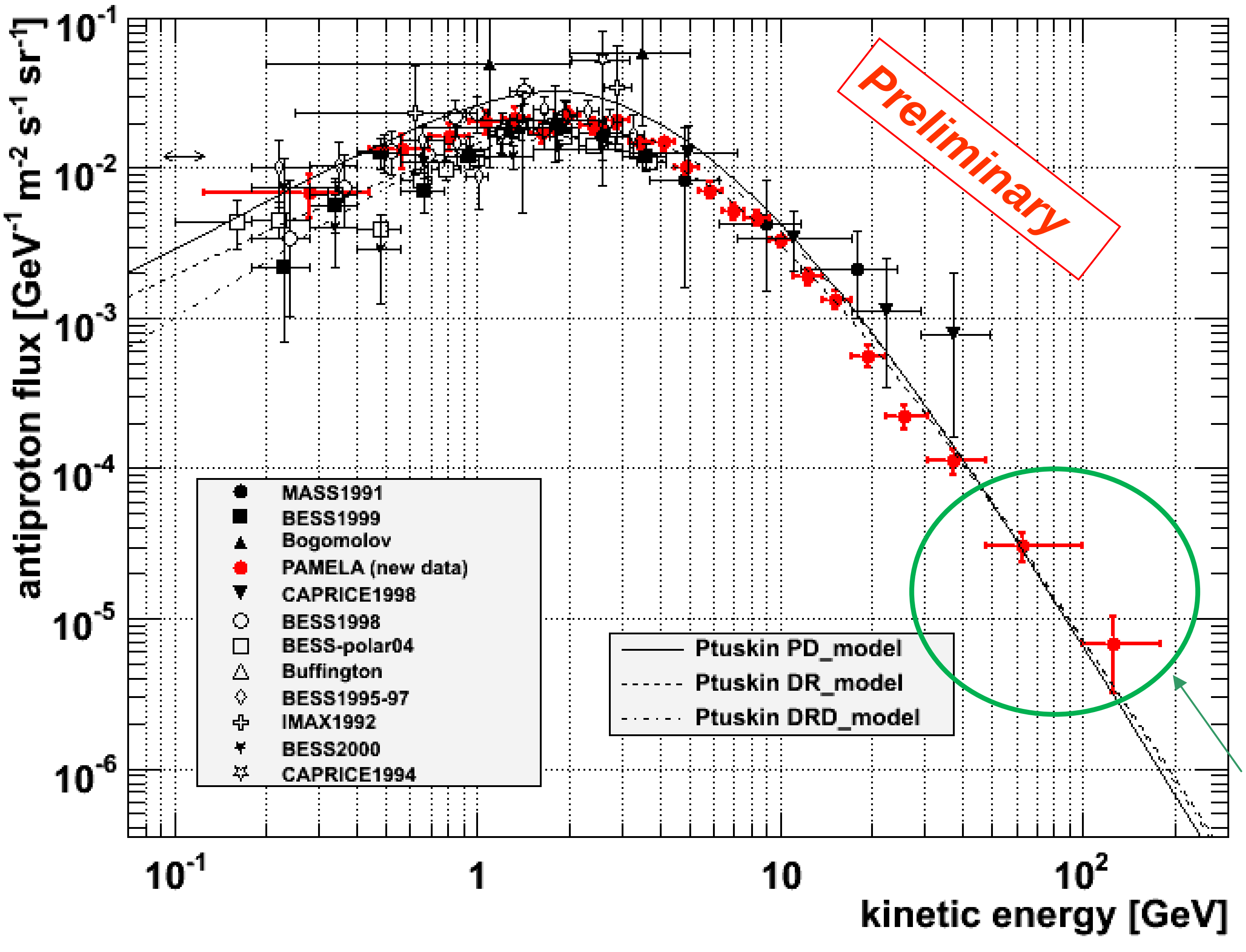
- data from June 2006 to Dec 2008 (~800 days)
- Collected triggers: ~1.5 x 10^9
- Before PAMELA: 2 antiprotons above 30 GeV

  PAMELA: ~ 60 antiprotons above 30 GeV

- The absolute differential flux of a particle species in a given energy bin is defined as:

$$F(bin) = \frac{1}{G \times \Delta E(bin) \times LT(bin)} \times \frac{N_{sel}(bin)}{\varepsilon(bin)}$$

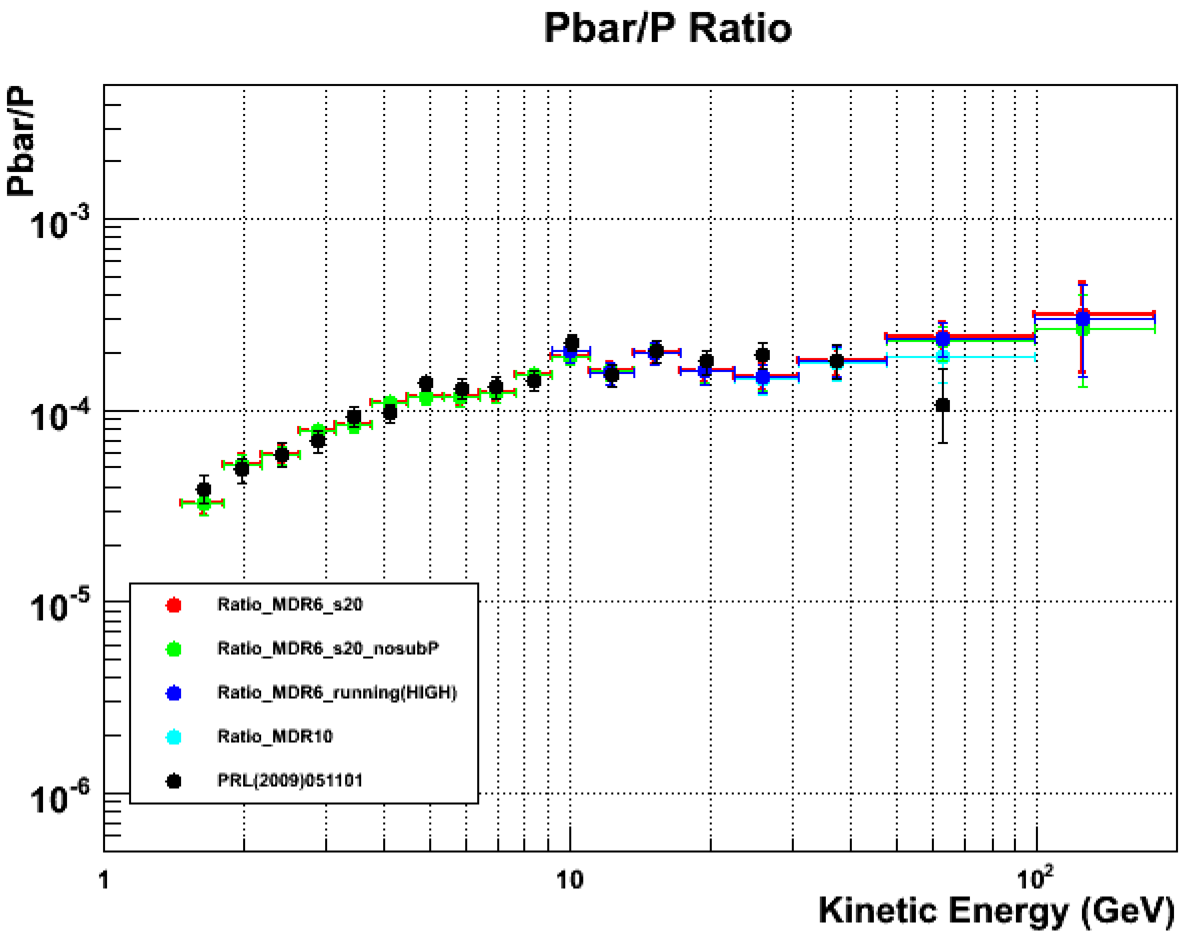
Antiproton flux



- All data generally agree with secondary models —> **antiprotons (at least) primarily secondary production.**
- No evidence of primary or exotic components of antiprotons.

Errors underestimated, possible residual spillover-proton contamination

Antiproton-proton ratio



(1)

MDR6 is consistent with MDR10

(2)

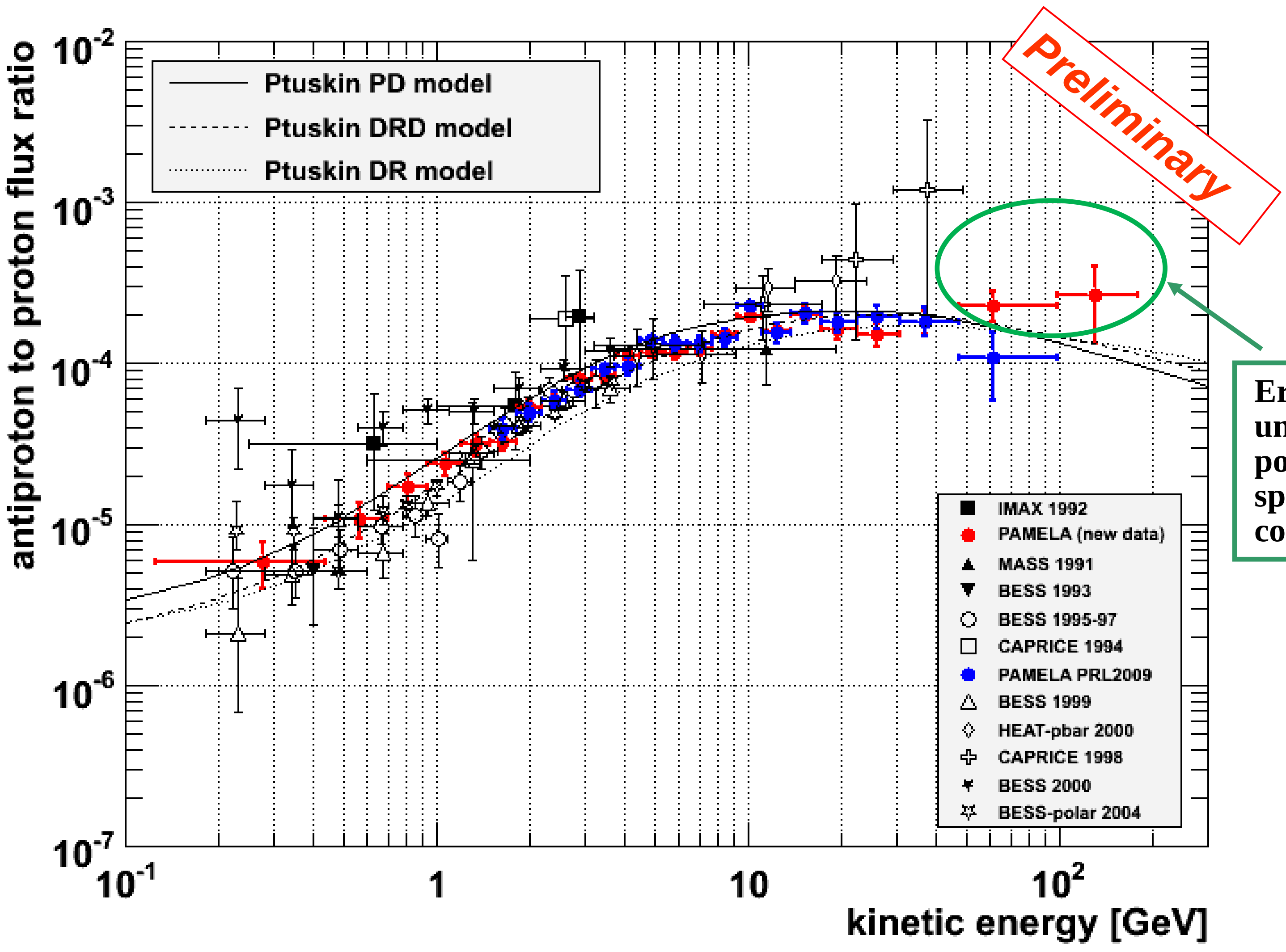
MDR>6*rigbin$_{upperlimit}$

AND

MDR>6*rigbin(event):

give same results

Antiproton-proton ratio



Errors might be underestimated, possible residual spillover-proton contamination

Summary

- The antiproton flux and antiproton-to-proton flux ratio extended to 180 GeV have been presented with highly improved statistics compared to previous experiments.

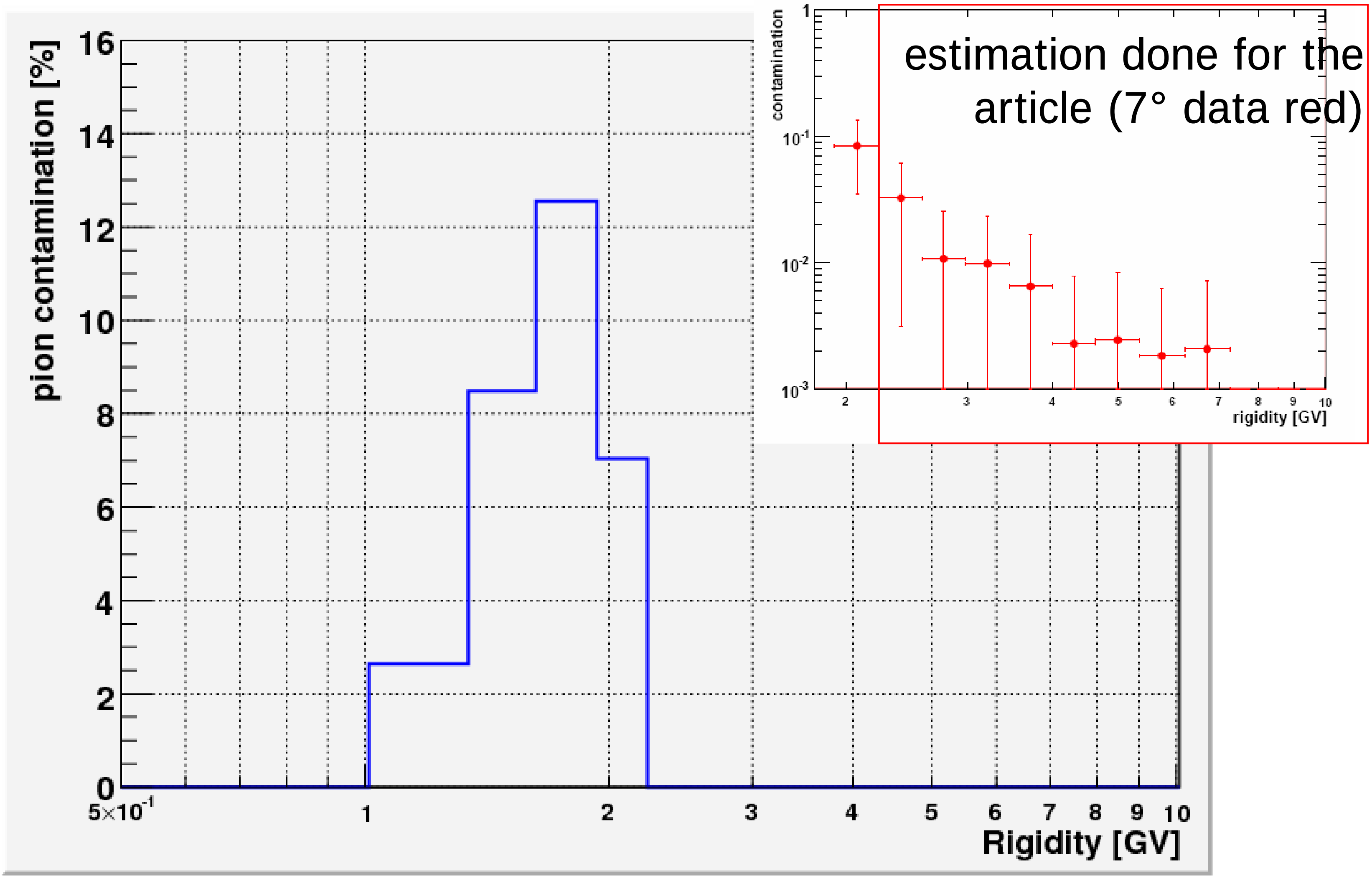
- The estimation of the proton spillover for the highest energy bin is in progress

- While PAMELA observed a dramatic rise in the positron fraction >10 GeV (nature07942), the measured antiproton-to-proton flux ratio and antiproton energy spectrum show no significant deviations from secondary production expectations.

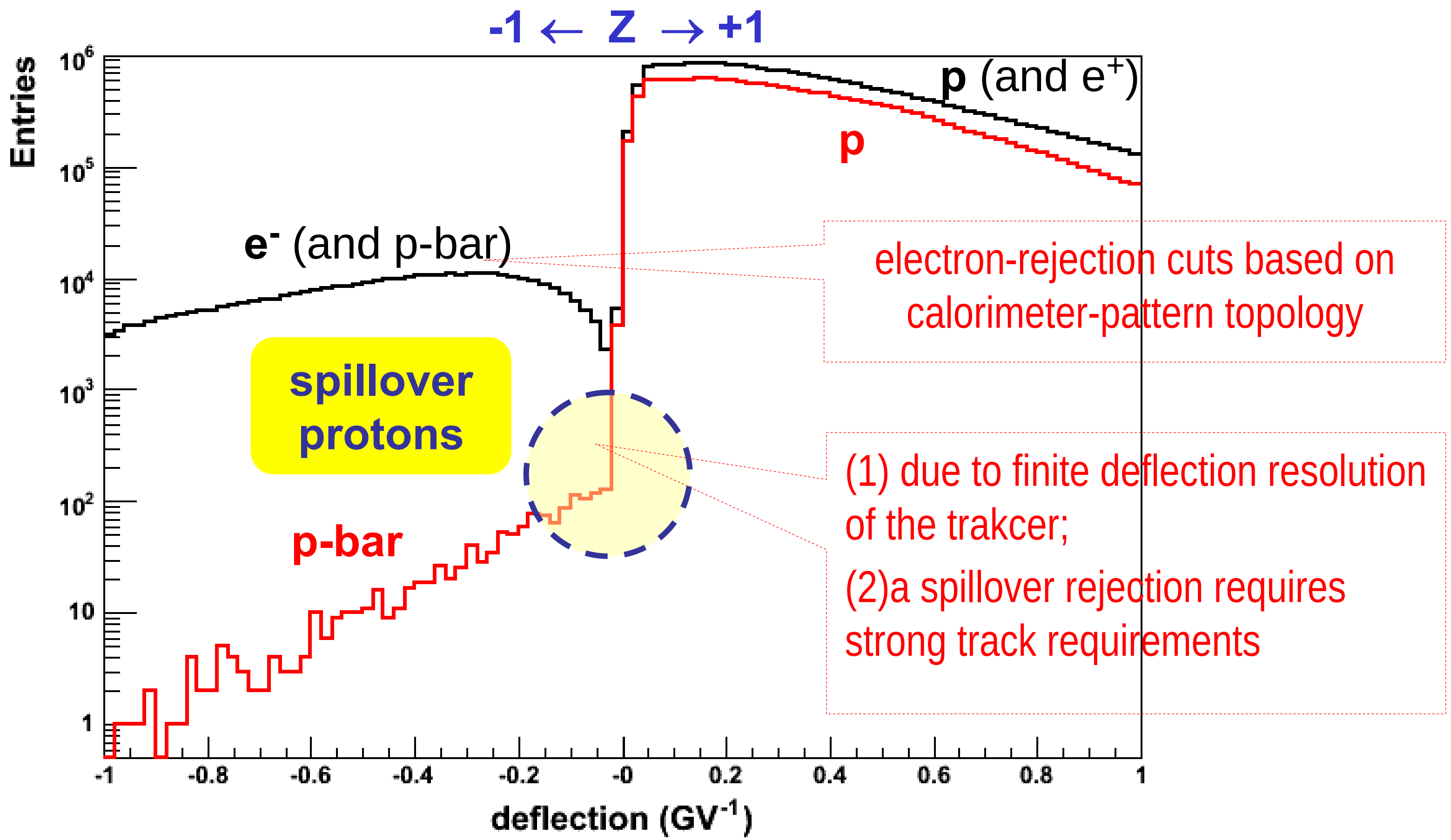
  - useful parameters for secondary production calculations
  - place constraints on dark matter models

Spares

Fraction of pi- in the antiproton sample



Antiproton selection



Antiproton selection III

Minimal track requirements

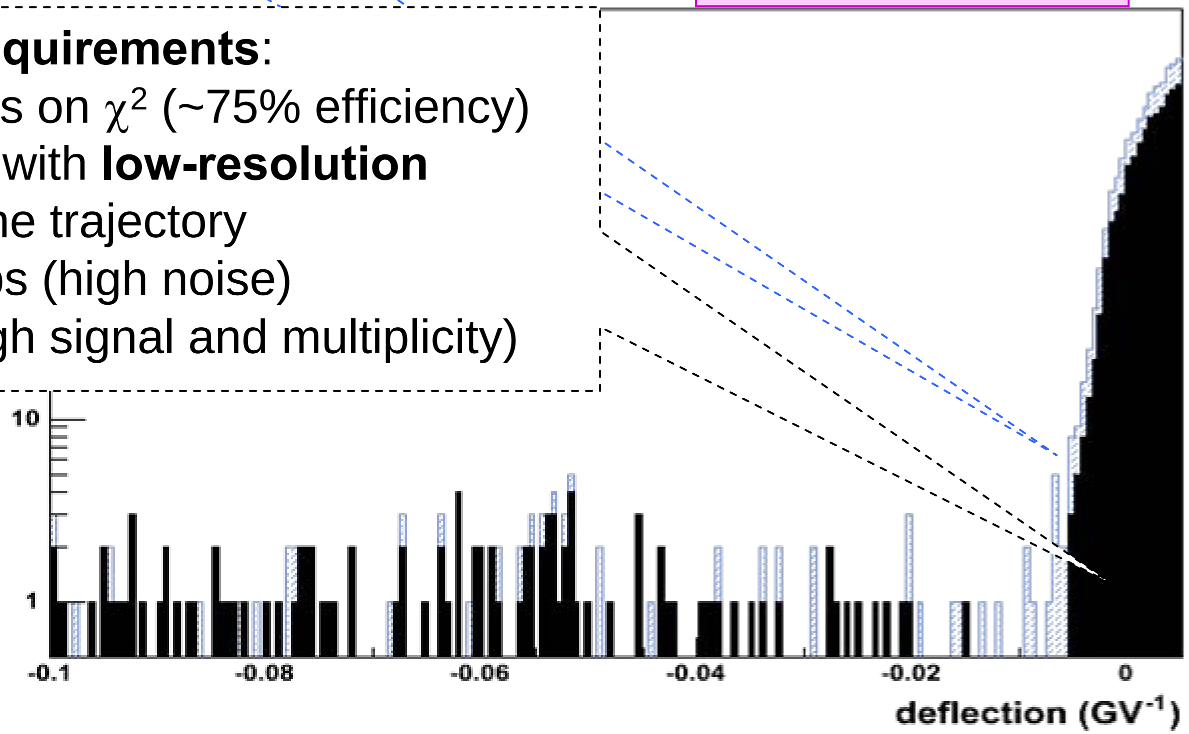
MDR > 850 GV

Strong track requirements:

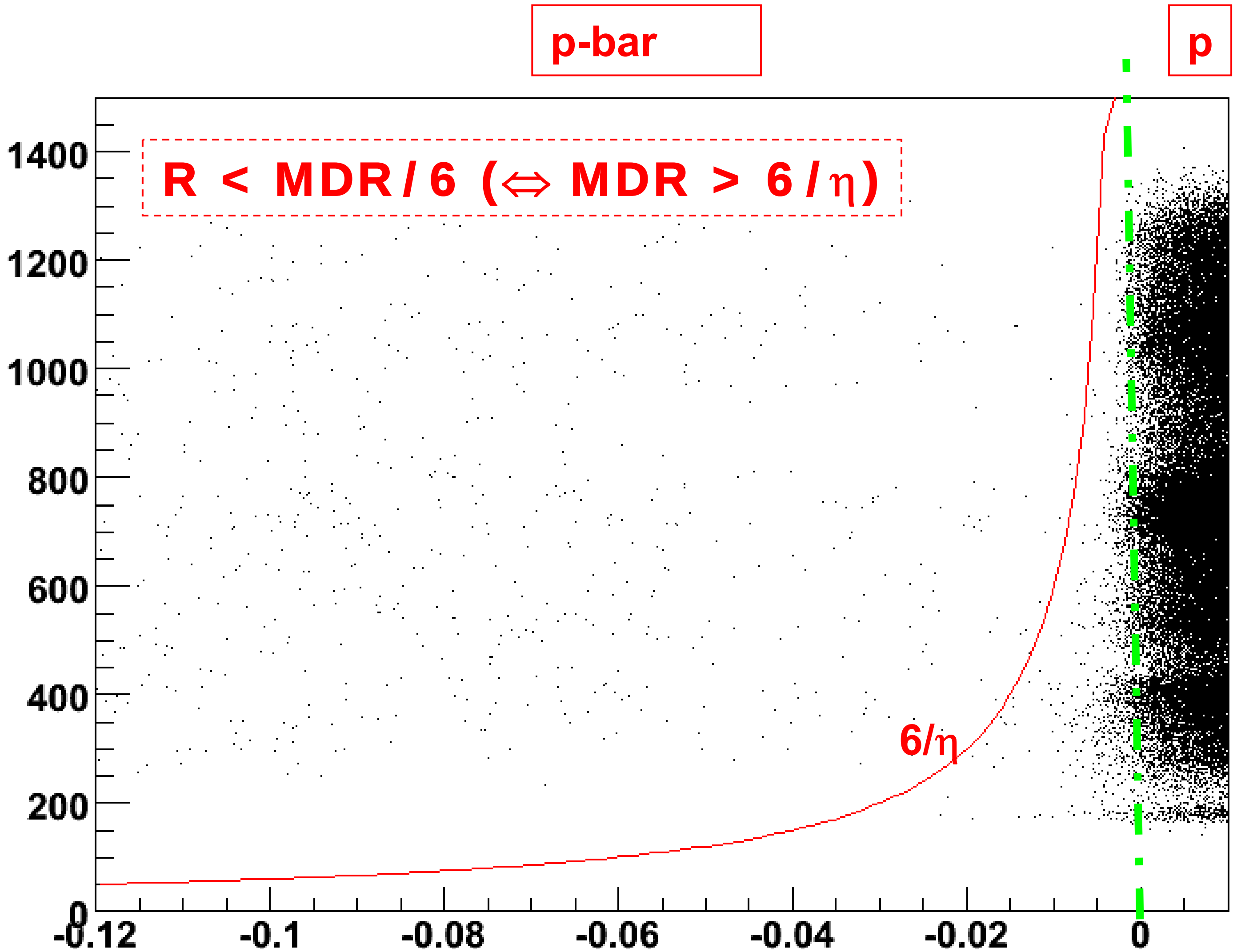
•strict constraints on χ^2 (~75% efficiency)

•rejected tracks with **low-resolution** clusters along the trajectory

- faulty strips (high noise)
- δ-rays (high signal and multiplicity)



Antiproton Selection



absolute antiproton flux

- The absolute differential flux of a particle species in a given energy bin is defined as:

$$F(bin) = \frac{1}{G \times \Delta E(bin) \times LT(bin)} \times \frac{N_{sel}(bin)}{\varepsilon(bin)}$$

  - G: geometric factor (m^2 sr) for the instrument acceptance;
  - N_{sel} : number of selected events;
  - ε : combined efficiency of all the selection cuts;
  - LT: live time