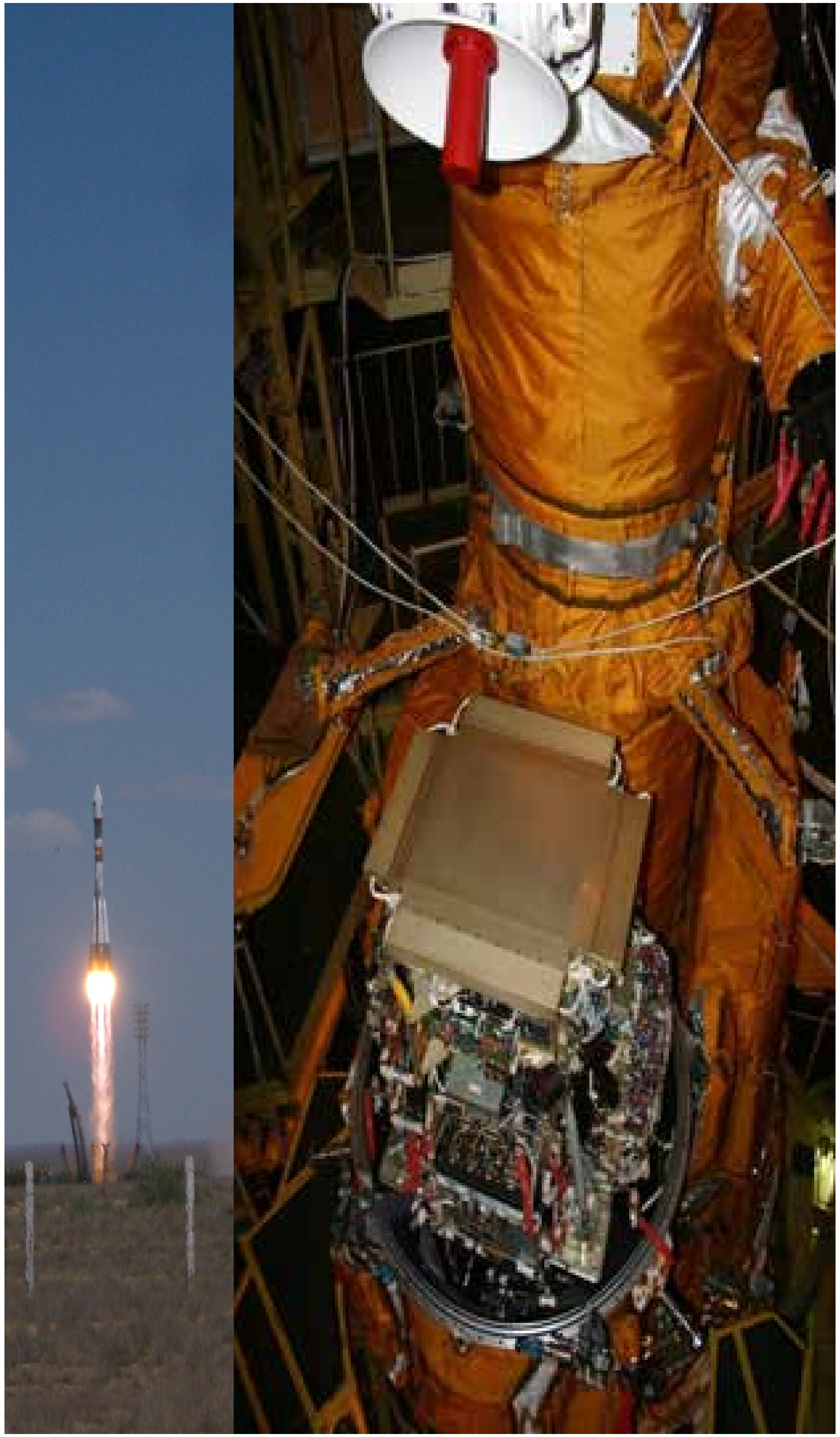


# Indirect Dark Matter Search:

# Balloons, Satellites, ISS


**Wolfgang Menn**

**Universität Siegen**


**ISAPP Summer Institute 2009**

**Karlsruhe Institute of Technology**

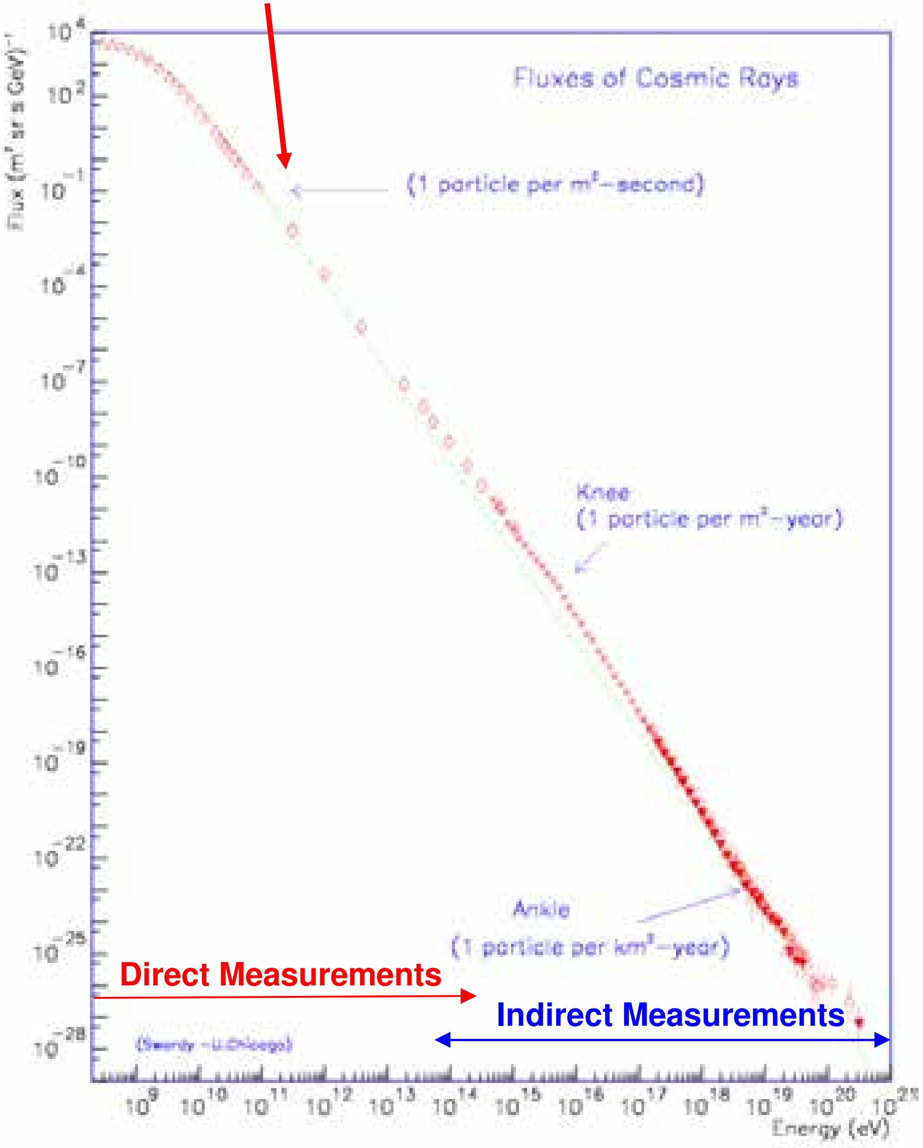
**29 July 2009**

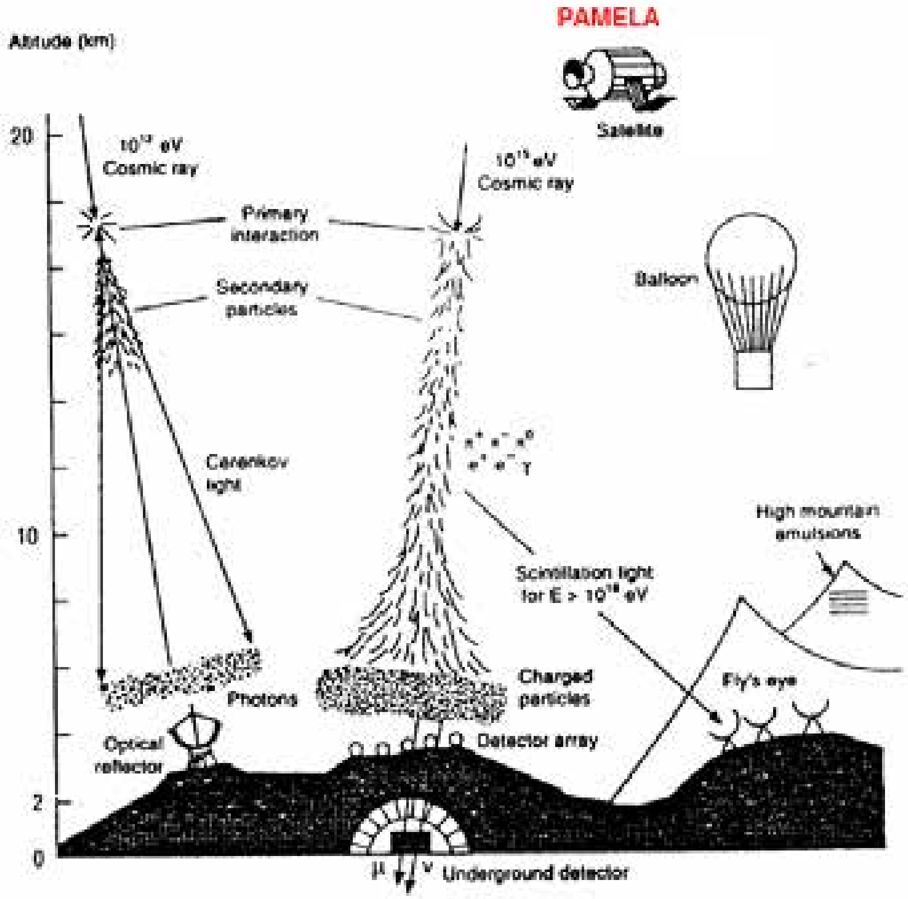
# Outline

- Brief introduction to cosmic rays
- Cosmic Rays, Antimatter, Dark Matter
- Gamma Ray Observations
- Particle Detectors
- Balloon Experiments 1979 – 2007, AMS-01
- The PAMELA Experiment
- PAMELA Results: Positrons
- Calorimeters: BETS, ATIC, FERMI
- PAMELA Results: Antiprotons
- Dark Matter Predictions
- Future Experiments
- Conclusions

# The Cosmic Ray Energy Spectrum and various Techniques of their Measurements

See Ralph Engel Talk



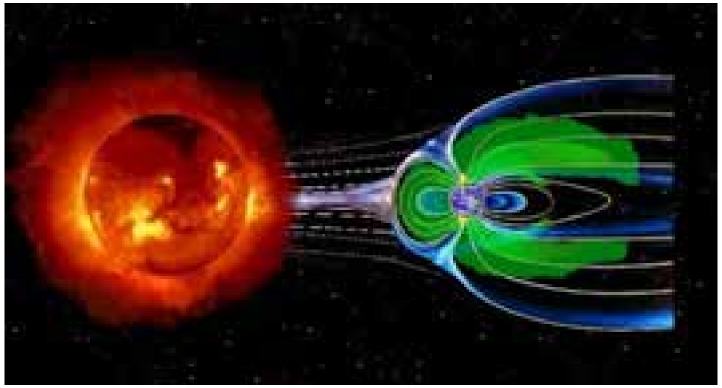



# Cosmic Ray Composition

**See Ralph Engel Talk**

- **Energetic particles produced in stars and accelerated by shocks from Supernova explosions**
- **Particles are retained in our galaxy by magnetic fields.**
- **Except for possibly highest energies, trajectory of charged particle is randomized by galactic magnetic field, *does not point to its sources***
- **~99% atomic nuclei, 1% electrons**
- **Cosmic ray nuclei:**
  **~89% protons, 10% He and 1% heavier nuclei**
- **Very small fraction antiprotons and positrons**

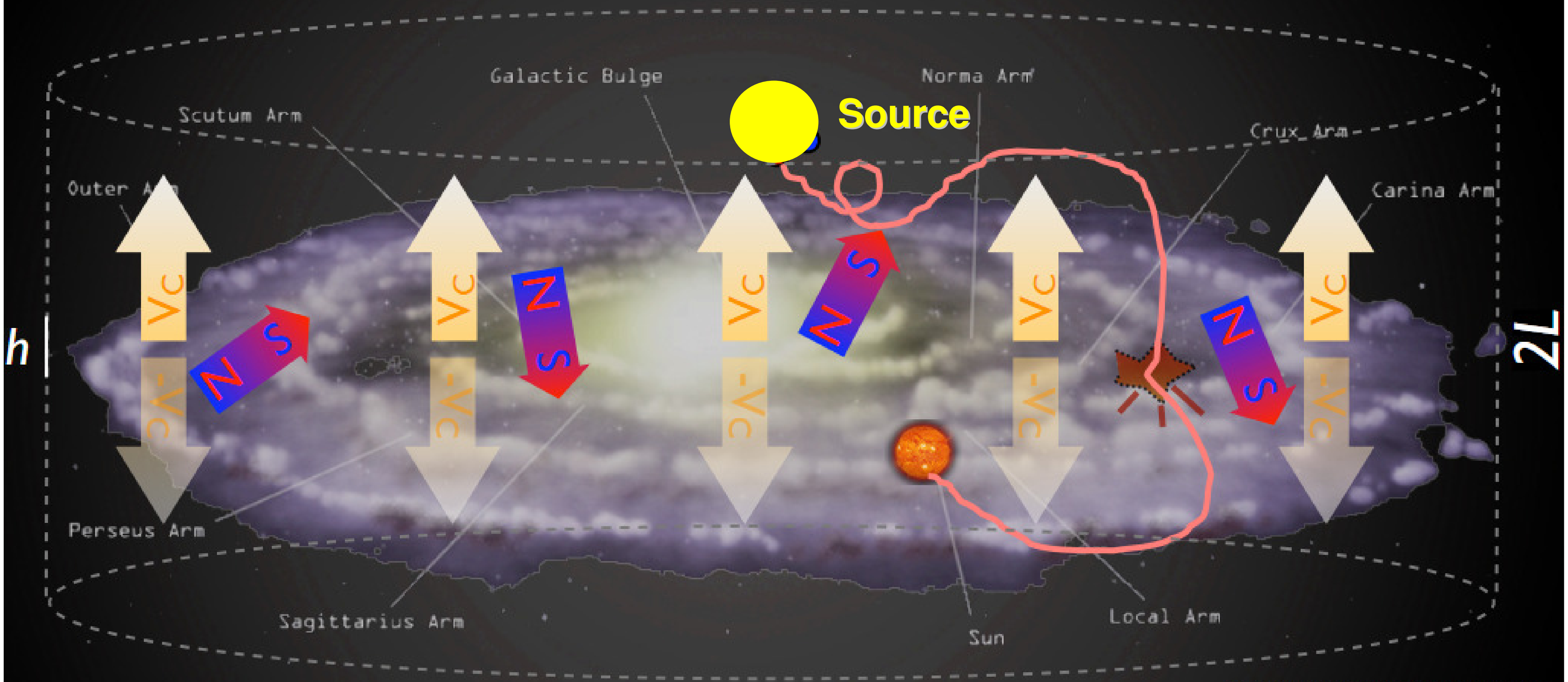
Kepler SNR (SN 1604)



Solar processes: Solar Wind, CME, …

# Cosmic Ray Model

**See Ralph Engel Talk: Leaky-Box-Model**




Salati, Chardonnay, Barrau, Donato, Taillet, Fornengo, Maurin, Brun... '90s, '00s

spectrum

$$\frac{\partial f}{\partial t} - K(E)\cdot\nabla^2 f - \frac{\partial}{\partial E}\left(b(E) f\right) + \frac{\partial}{\partial z}(V_c f) = Q_{\rm inj} - 2h\delta(z)\Gamma_{\rm spall} f$$

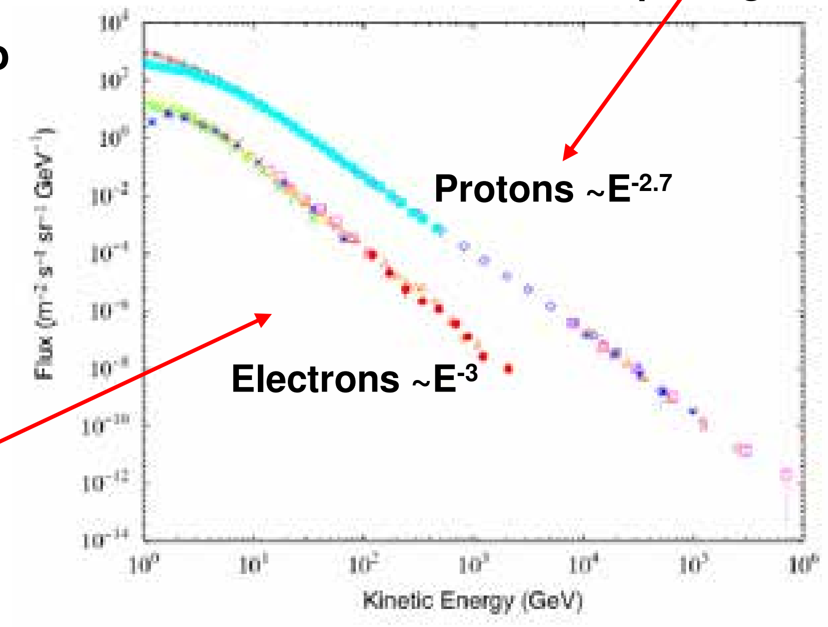
diffusion — energy loss — convective wind — source — spallations

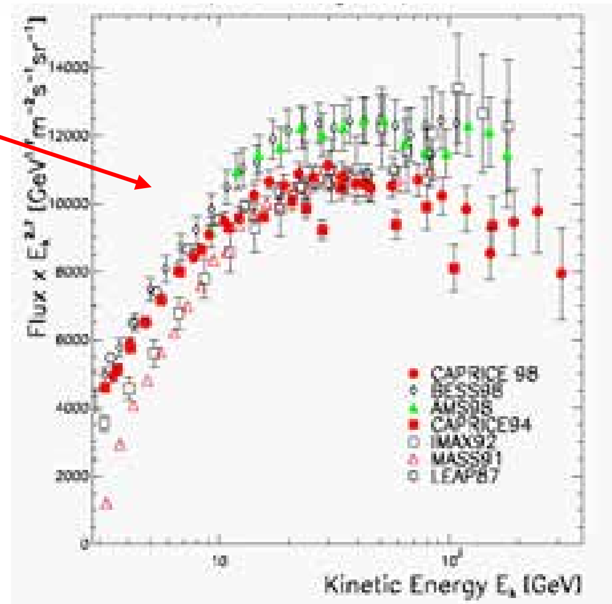
# Protons and Electrons

See Ralph Engel Talk

- Proton Propagation: Energy Loss not so important, Diffusion & nuclear interaction dominates
- Electron Propagation: Energy Loss (Synchrotron and inverse Compton processes) dominates
- Spectrum of Electrons steeper than Proton spectrum:

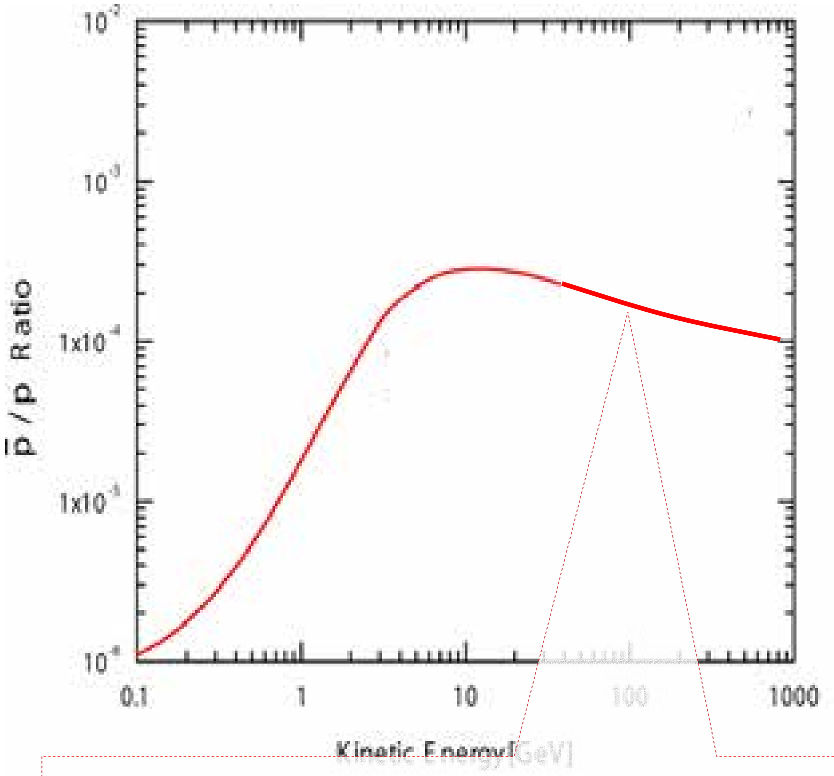
  Power-Law Index: p ~ -2.7, e ~ -3.0
- Ratio e/p: At 10 GeV ~ 1%, at 1 TeV ~ 0.1% ?
- Even the "simple" Proton Spectrum is not so well known, differences >20%…



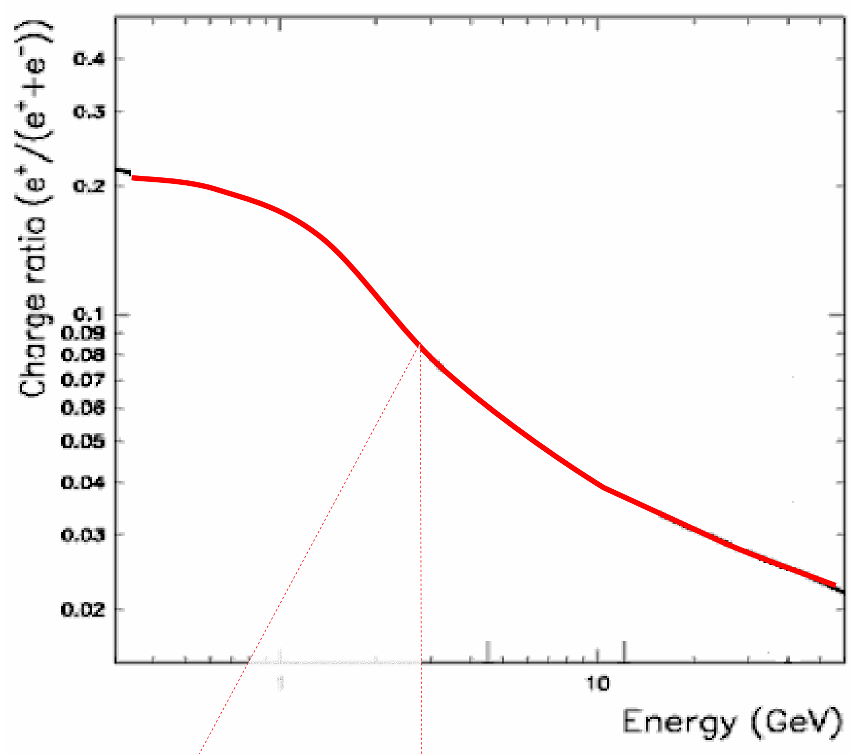
# Cosmic Ray Antimatter: Predictions for secondary production

**Antiprotons**



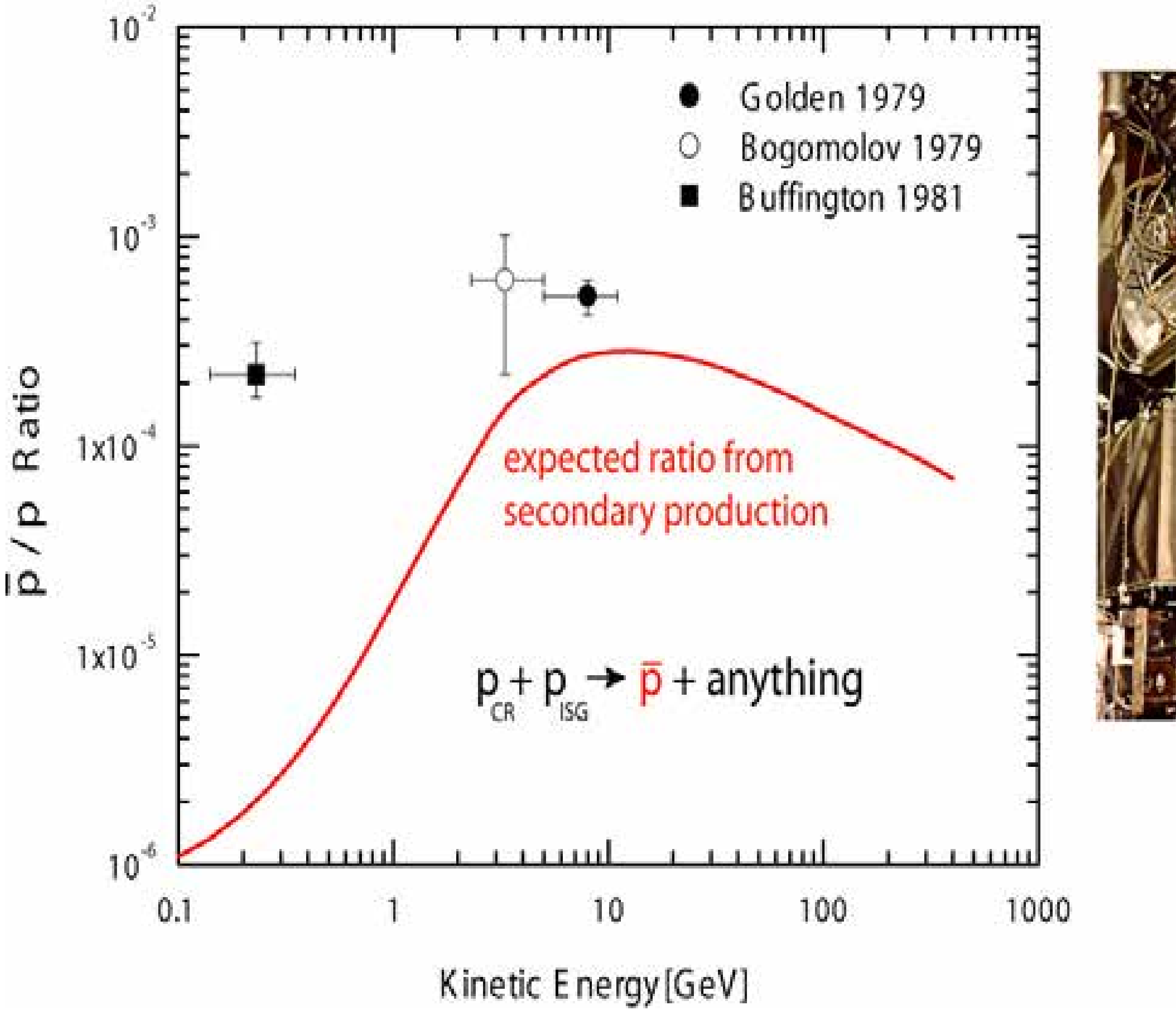

CR + ISM → p-bar + …
Propagation dominated by nuclear interactions
Kinematical threshold: $E_{th}$~5.6 GeV for the reaction pp→ pppp

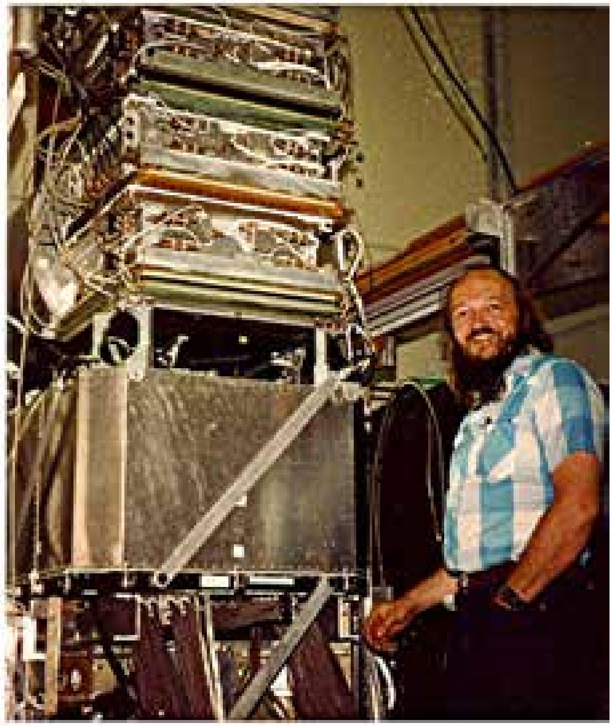
**Positrons**




CR + ISM → $\pi^{\pm}$ + x → $\mu^{\pm}$ + x → $e^{\pm}$ + x
CR + ISM → $\pi^0$ + x → $\gamma\gamma$ → $e^{\pm}$
Propagation dominated by energy losses (inverse Compton & synchrotron radiation)
Local origin (@100GeV 90% from <2kpc)

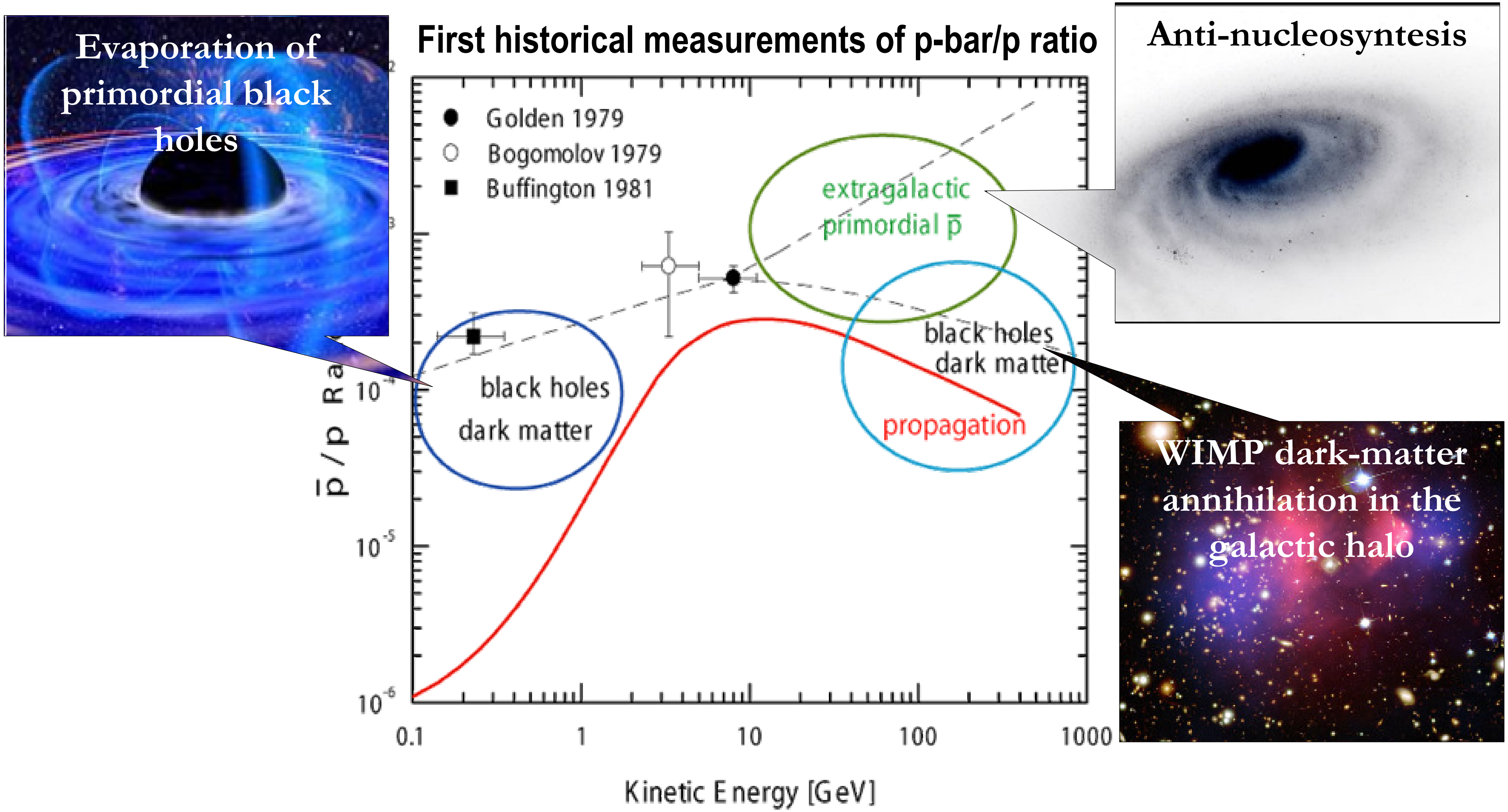
## The first historical Measurements on Galactic Antiprotons



**Robert L. Golden**

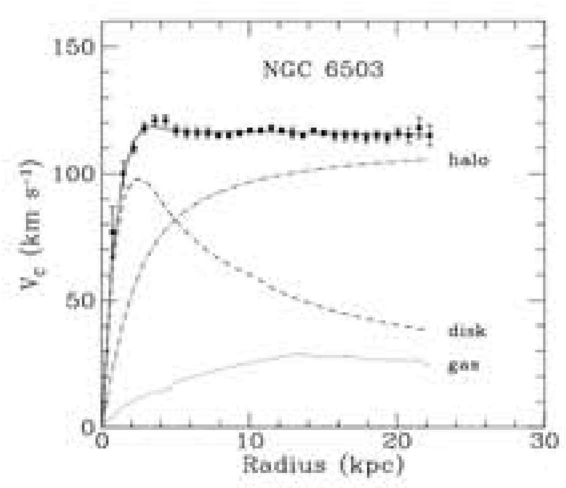
# The first historical measurements of the p/p – ratio and various ideas of theroretical interpretations



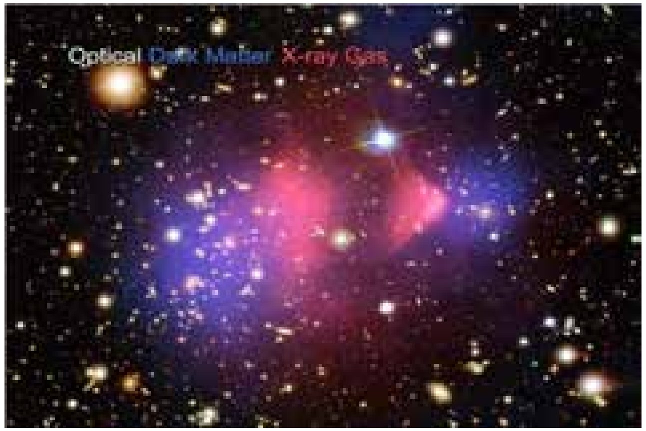
# Evidence for Dark Matter

See Hans Kraus talk!

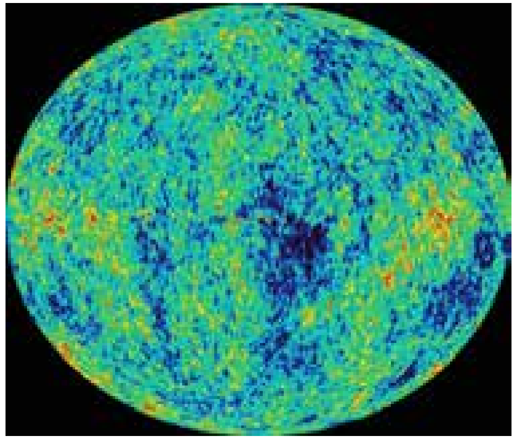
## Galaxy rotation curves




## Cluster of Galaxies




## CMB+SNIa



$$\Omega_{total} = \underbrace{\Omega_{total,baryon.}}_{\text{baryonic matter } 5\%} + \underbrace{\Omega_{dyn.}}_{\text{dark matter } 25\%} + \underbrace{\Omega_{required}}_{\text{dark energy } 70\%}$$

| baryonic matter | dark matter | dark energy |
|---|---|---|
| 5% | 25% | 70% |
| | ?? | ??? |
| stars, galaxies | candidates: | quintessence |

candidates:

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

# Neutralino Annihilations

## Background / Secondary Production

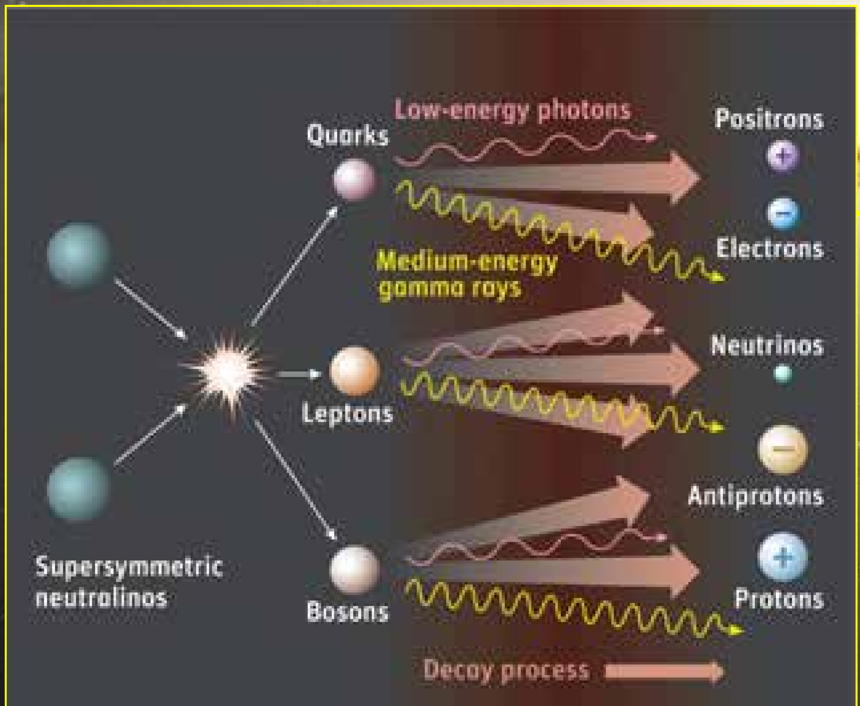
$CR + ISM \rightarrow \mathrm{pbar} + \ldots$

$CR + ISM \rightarrow \pi^{\pm} + x \rightarrow \mu^{\pm} + x \rightarrow e^{\pm} + x$

$CR + ISM \rightarrow \pi^{0} + x \rightarrow \gamma\gamma \rightarrow e^{\pm}$

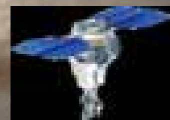
**Signal will distort the antiproton, positron and gamma spectra from purely secondary production**

## Signal




You are here

PAMELA



$\gamma$ FERMI, AMS-02

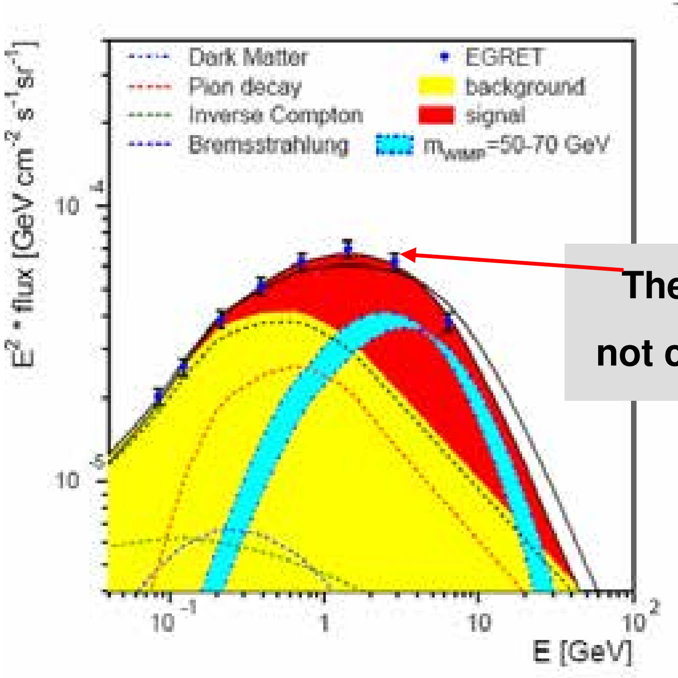
$\nu$ AMANDA/Ice Cube

$\bar{p}$, $e^{+}$, $\bar{D}$ } PAMELA, BESS, HEAT, AMS, etc.

# Just one slide:
# Gamma Ray Observations and Dark Matter

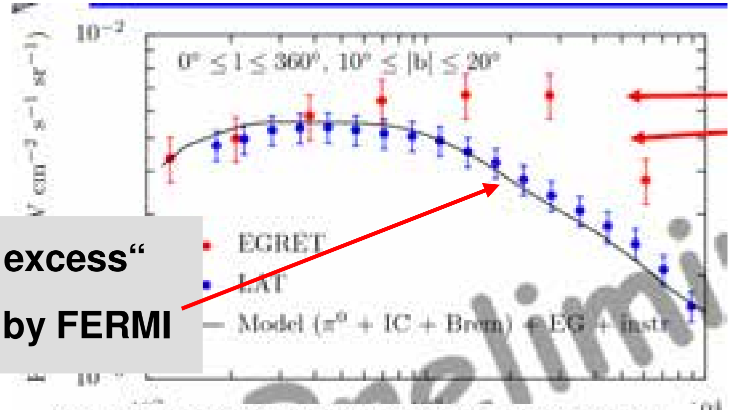
# Gamma Rays: EGRET, INTEGRAL, FERMI*

***More to FERMI later...**

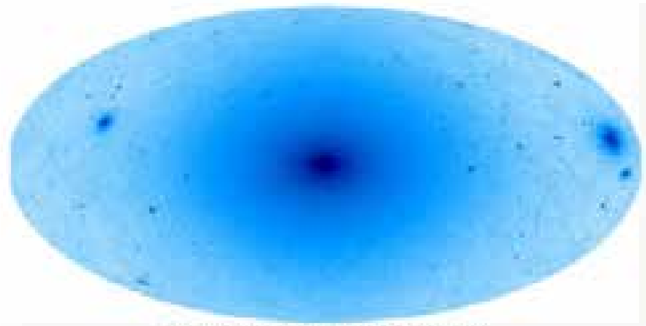



**The „EGRET excess“**

**not confirmed by FERMI**




**Could Fermi detect dark matter within a year?**



An enhanced view of dark matter?

The Fermi Gamma-ray Space Telescope could detect the telltale signs of dark-matter annihilation in as little as a year, if calculations by UK and US astrophysicists prove correct.

The calculations, which are the first to take into account the relative velocities of dark-matter particles, suggest that dark-matter annihilation is many times more prevalent than has been predicted before. If this is true, the annihilations could be producing enough gamma rays to expose several clumps or "subhaloes" of dark matter in Fermi's first year of data collection alone.

## Dark matter not responsible for gamma-ray distribution in Milky Way

**Over the past 5 years, gamma-ray measurements from the European satellite INTEGRAL have perplexed astronomers, leading some to argue that a great mystery existed.**

*Provided by University of California, San Diego*

July 9, 2009

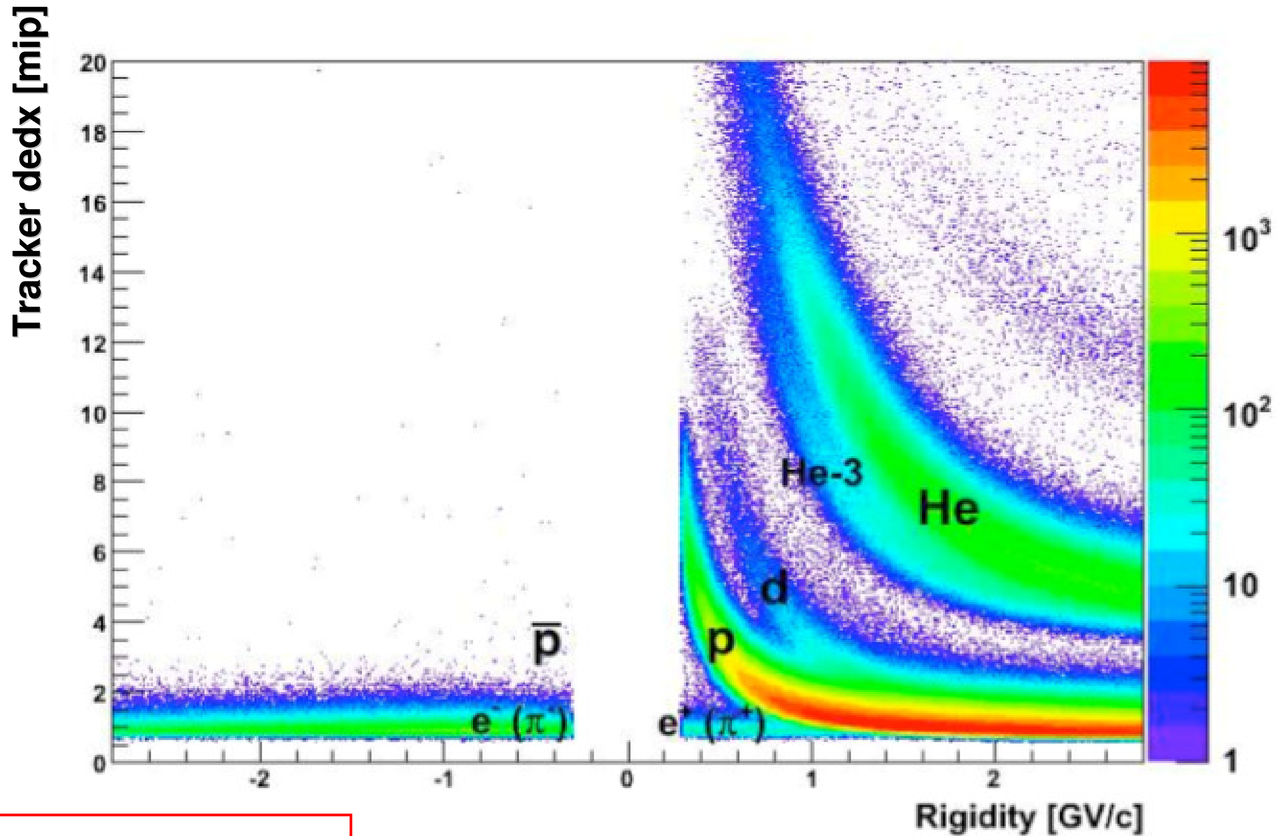
A team of astrophysicists has solved a mystery that led some scientists to speculate that the distribution of certain gamma rays in our Milky Way galaxy was evidence of a form of undetectable "dark matter" believed to make up much of the mass of the universe.

INTEGRAL.ESA (View Larger Image)

In two separate scientific papers, the astrophysicists show that this gamma-ray distribution can be explained by the way "antimatter positrons" from the radioactive decay of elements, created by massive star explosions in the galaxy, propagate through the galaxy. The scientists said the observed gamma-ray distribution is not evidence for dark matter.

# Now: Charged particles

## Particle identification = combination of measurements




$\bar{p}/p \leq 10^{-4} - 10^{-6}$

$p/e^+ \geq 10^3 - 10^4$

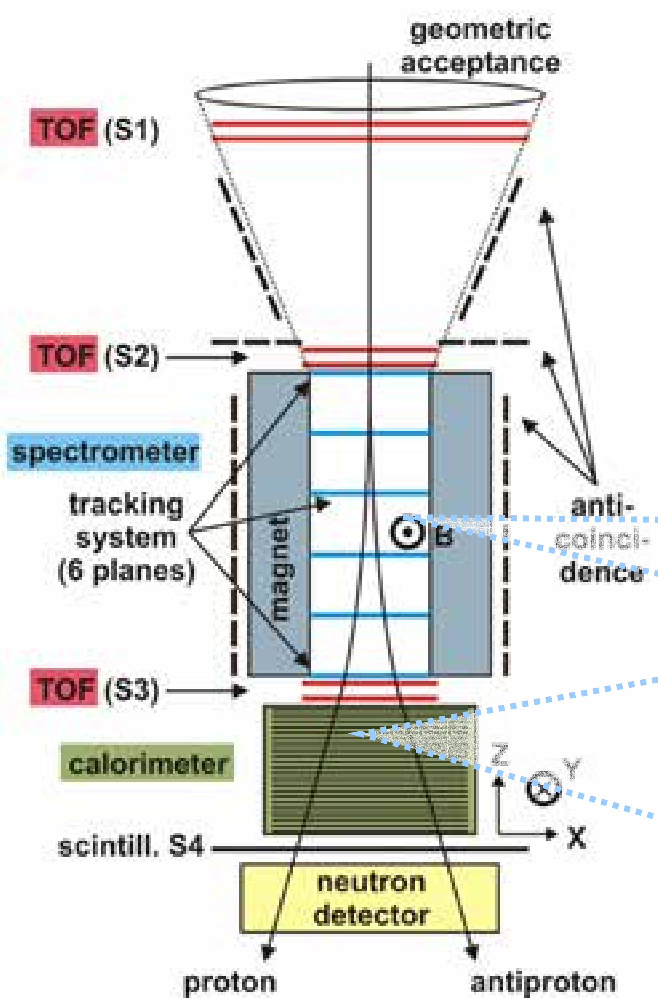
$\bar{p}/e^- \leq 10^{-3}$

**Not so easy….**
**Needs good "Rejection Power"**

# Common Cosmic Ray Detectors

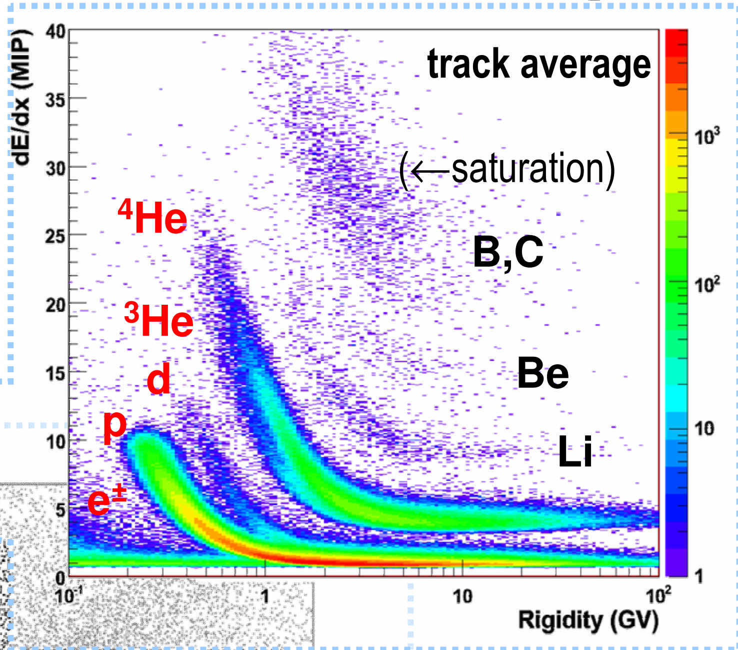
- Ionization energy loss - Particles lose energy by ionizing material through which they pass and produce detectable signals.
  - Scintillators measure light emitted by detector material - used to measure particle ***charge, velocity, and energy***
  - Gas detectors measure measure electrons and ions - used for ***tracking, particle charge, and energy***
  - Solid state detectors measure electrons and holes - used for ***tracking, particle charge and energy***

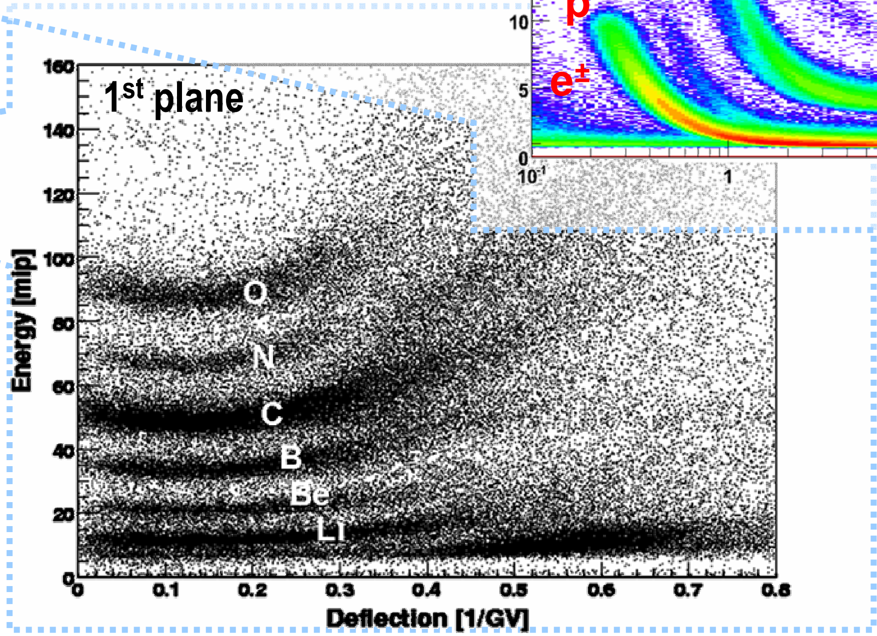
# Energy Loss: Charge Measurement



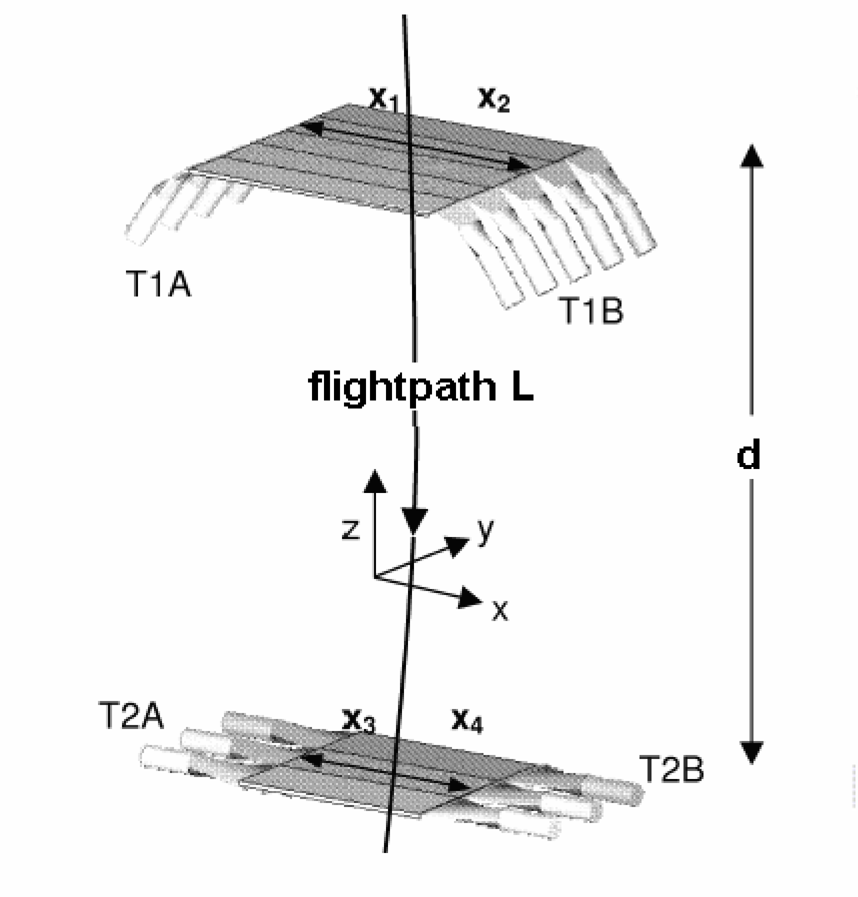

$$-\frac{dE}{dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

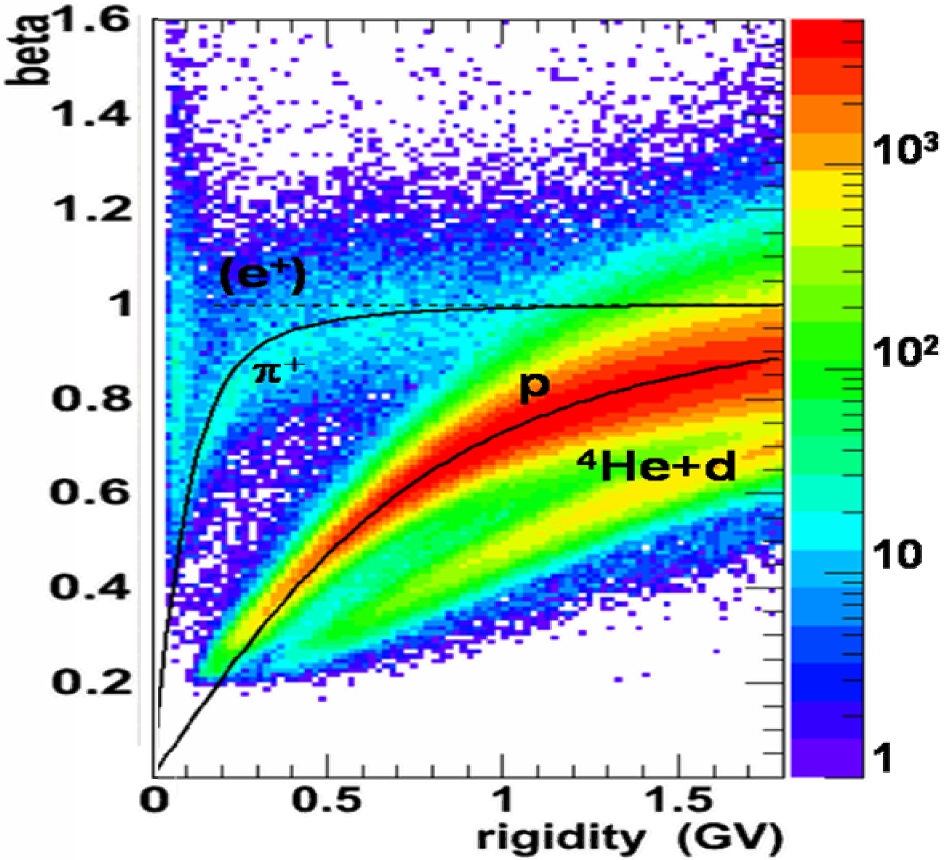
<u>Bethe Bloch</u>
ionization energy-loss
of heavy (M>>me)
charged particles



# Velocity Measurement: Time-of-Flight



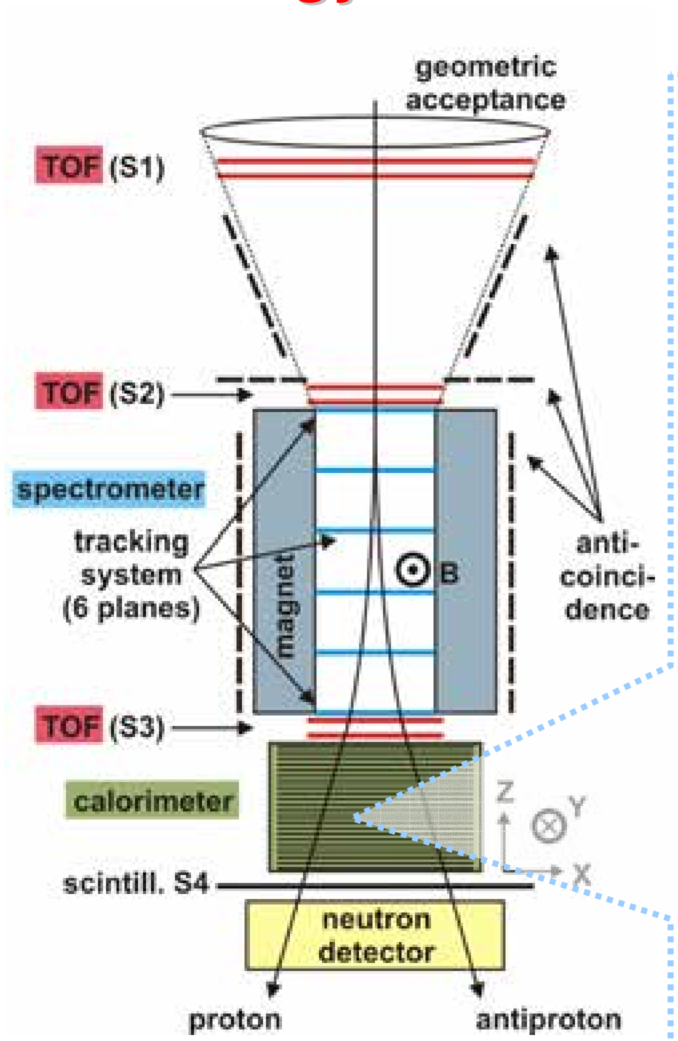

**Particle identification at low energy**

**Identify also Albedo-Particles (up-ward going, $\beta < 0$ )**

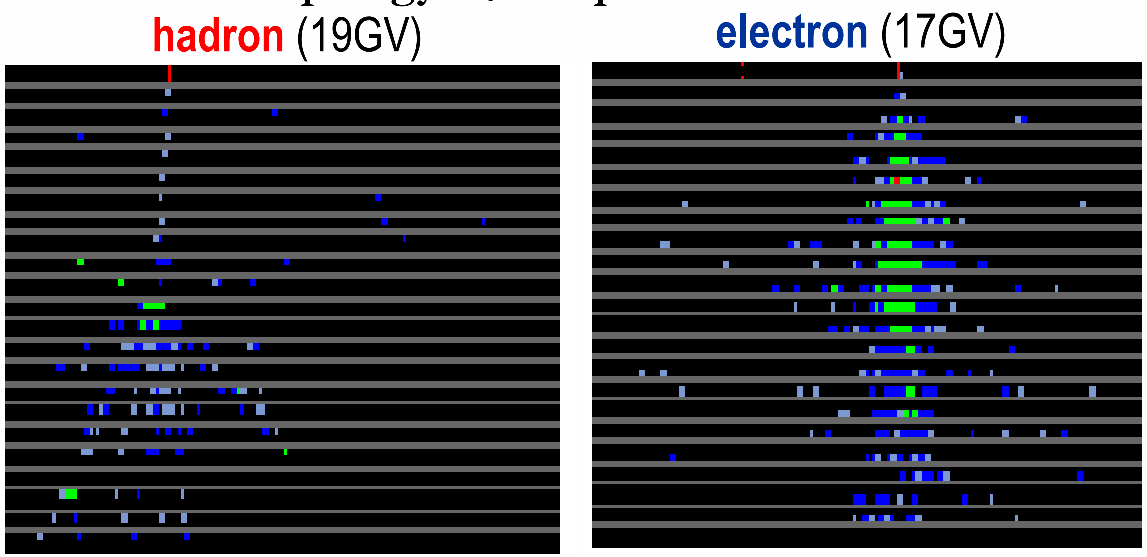
**Attention! They mimic antimatter!**

**Figure of Merit: Time Resolution around 100 – 300 ps**

# Calorimeter:
# Energy Measurement or Electron / Hadron Separation




- Interaction topology: e/h separation



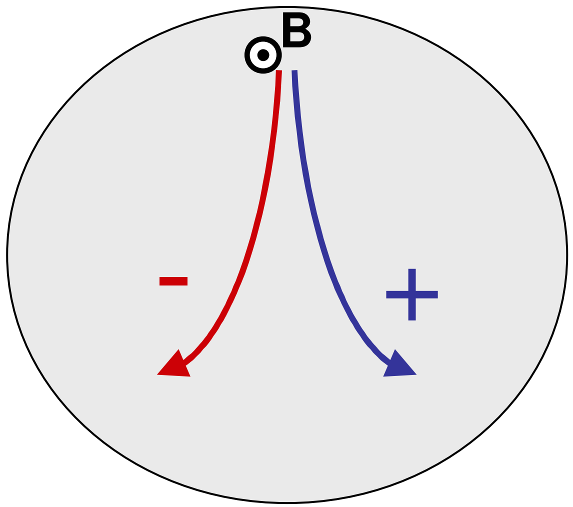

- **Energy measurement of electrons and positrons**
- **Full shower containment needs enough radiation lengths!**

**Figure of Merit:**

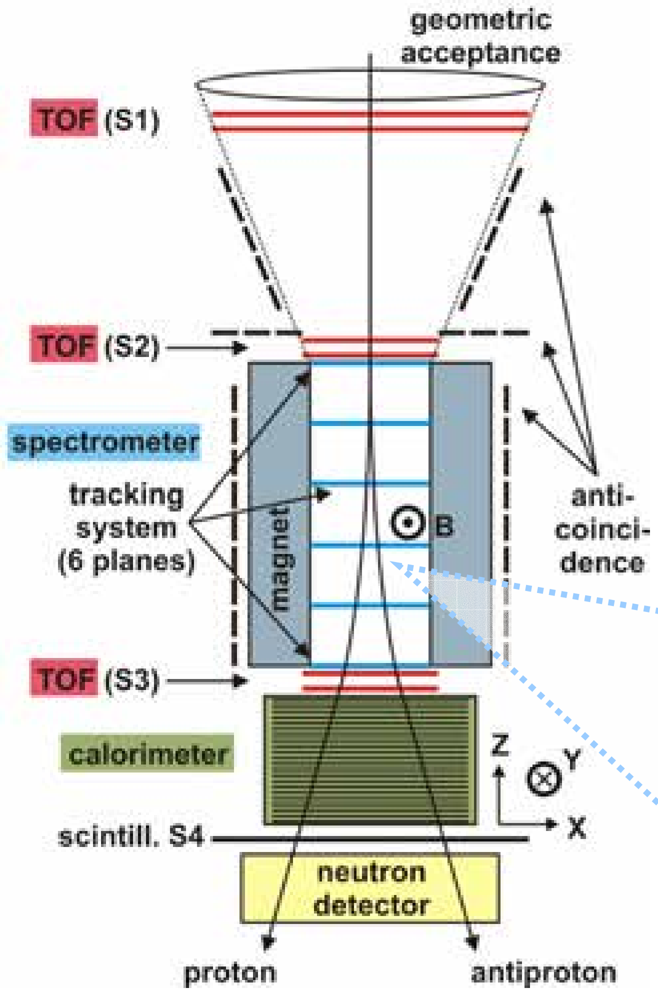
- **e/p Rejection around 100 – 100000**
- **Energy resolution (electrons) ~ 5%**

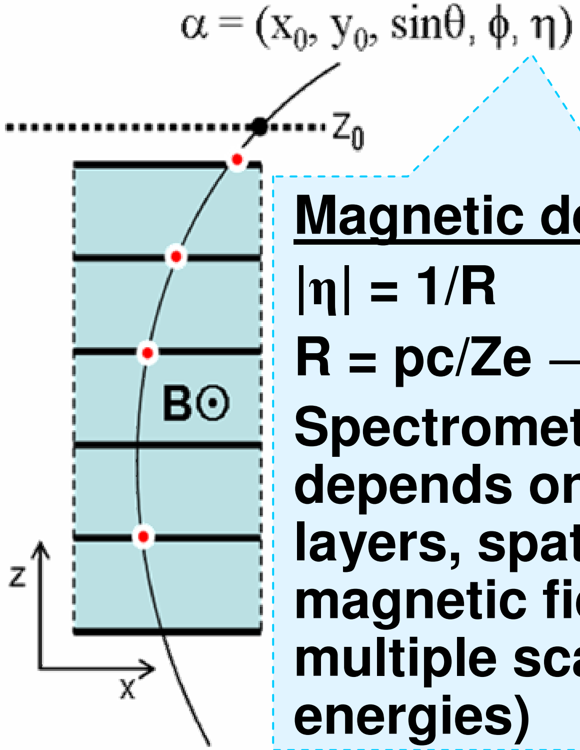
# Tracking in a magnetic field:
# Magnetic Spectrometers → Charge Sign

- Antimatter search with ionization techniques is limited to
  - particles *contained* in the instrument and
  - *requires clear annihilation signature* (limited energy range)
- Ionization and Cherenkov effects carry |**Z**| dependence but not charge sign
- Charge sign (*matter-antimatter separation*) for penetrating particles can be obtained by the curvature of a charged particle in a magnetic field.



# Magnetic Spectrometer & Track Reconstruction




**<u>Magnetic deflection</u>**

$|\eta| = 1/R$

$R = pc/Ze \rightarrow$ **<u>magnetic rigidity</u>**

**Spectrometer resolution depends on: number of layers, spatial resolution, magnetic field, "Lever Arm", multiple scattering (at low energies)**

**Figure of merit at high energies:**

**Maximum Detectable Rigidity (MDR):**

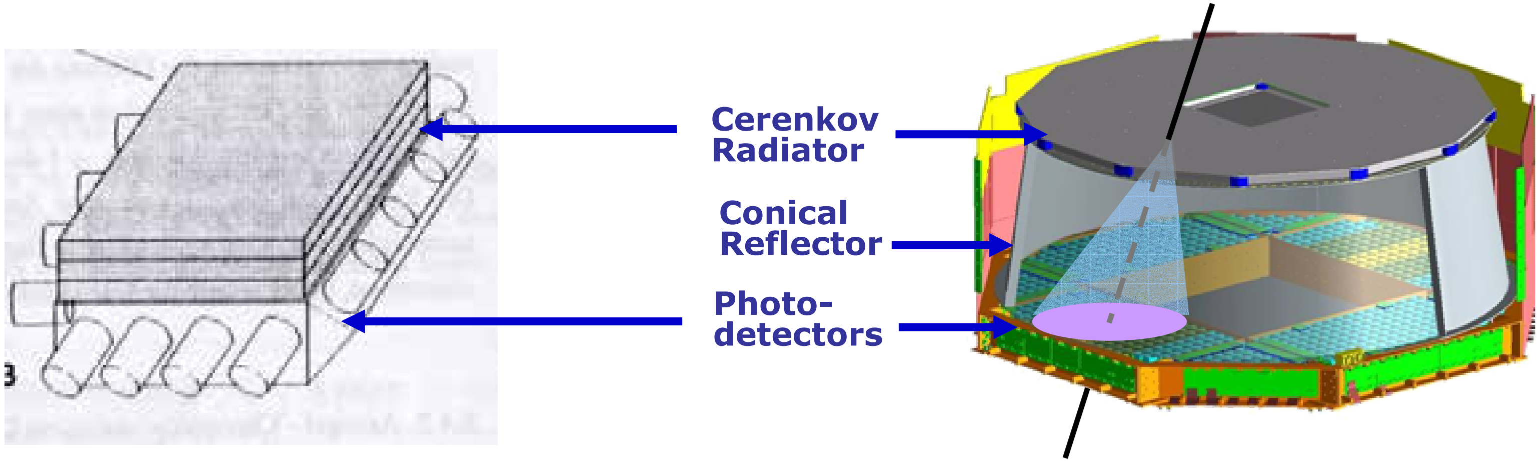
**R=MDR when measurement error = 100%**

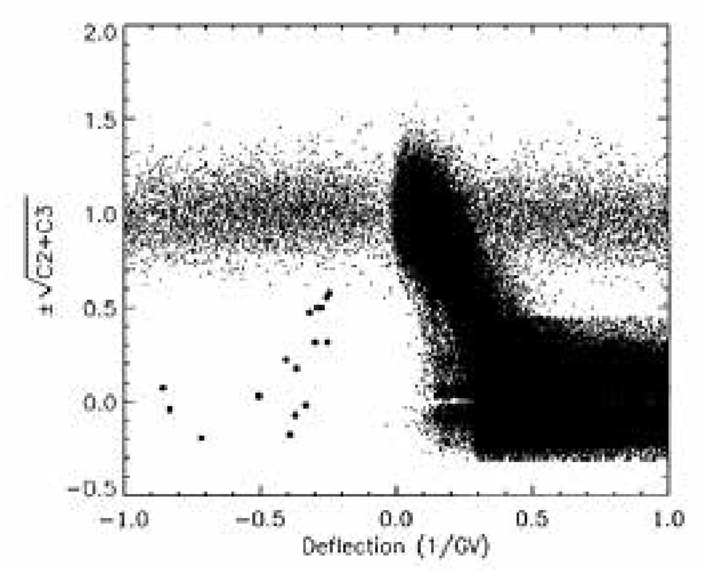
# Basic Detector Physics

- Cherenkov radiation is emitted by particles passing through a transparent medium faster than the local speed of light ($v_c$)
  - ***Velocity threshold detectors*** differentiate particle speeds above or below $v_c$
  - Can measure ***velocity*** using *total light signal or Cherenkov ring* (above $v_c$)

# Velocity Measurement: Cherenkov Detectors

**Total light signal** | **Cherenkov Ring:RICH**



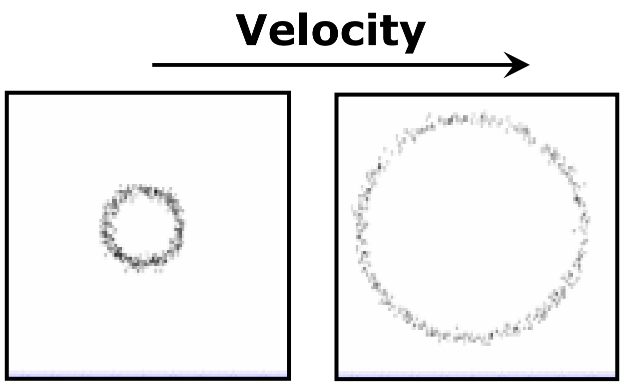
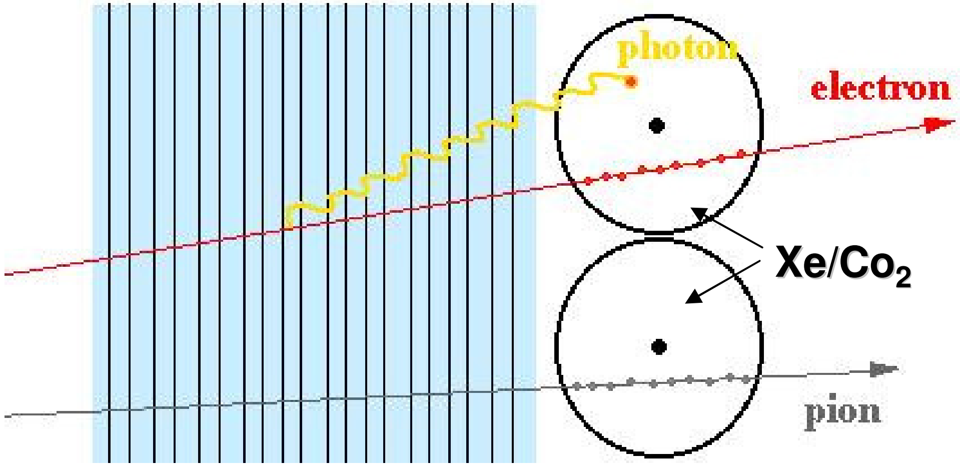



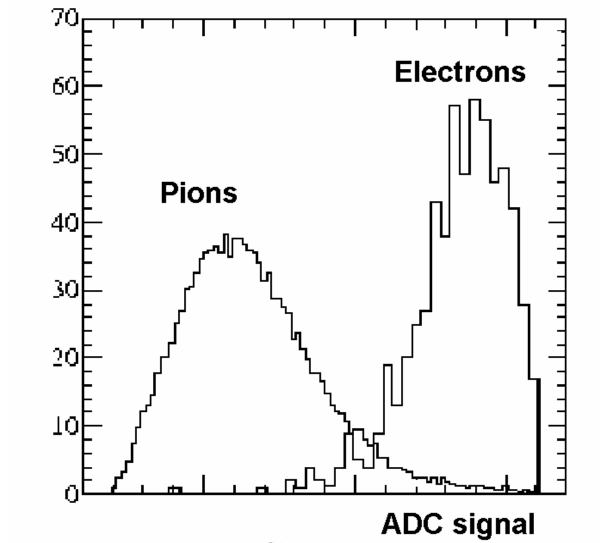

**Figure of Merit: Number of photoelectrons, angular resolution (RICH)**

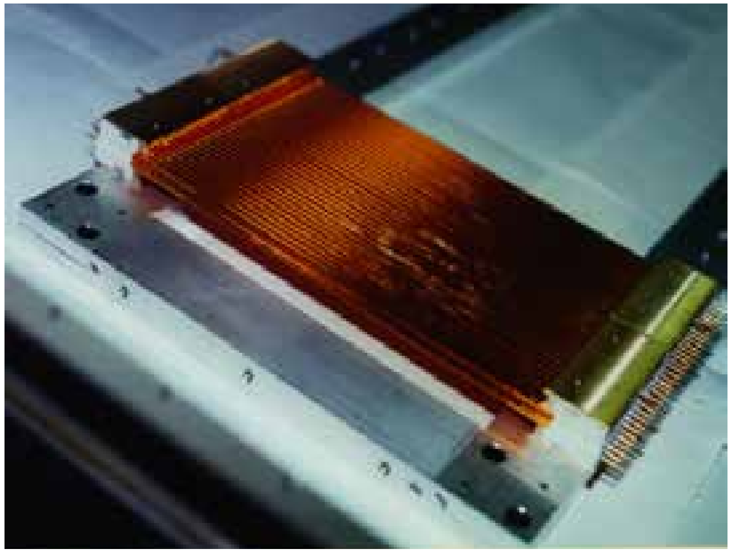
# Basic Detector Physics

- Transition Radiation is produced by relativistic charged particles when they cross the interface of two media of different dielectric constants.
  - Total energy loss of a charged particle on the transition depends on its Lorentz factor $\gamma$

# TRD: Transition Radiation Detector



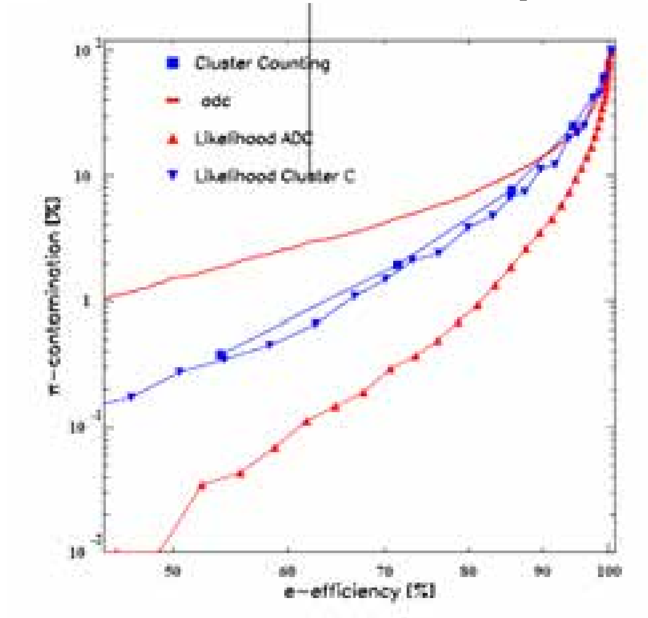
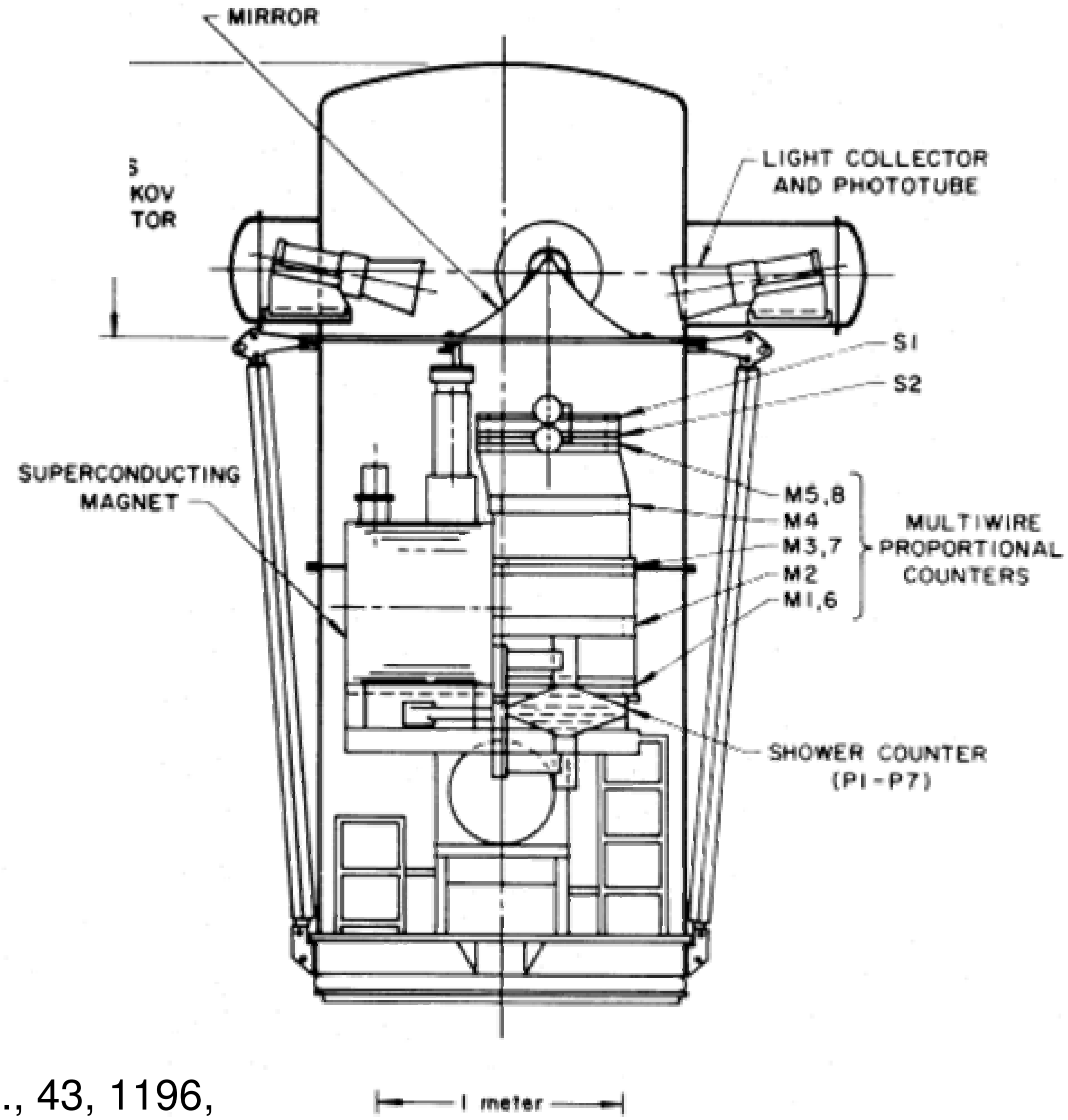



**Figure of Merit: e/p rejection factor >= 100**

# Balloon Instruments for Antimatter Search
# 1979 - 2007

# Golden: First Antiprotons Reported, 1979

- 315 $cm^2$ sr
- Superconducting Magnet
  Multi-Wire counters
  Spectrometer MDR 120 GV
- Gas Cherenkov Counter
- Time-of-Flight
- Shower Counter (7 $X_0$)



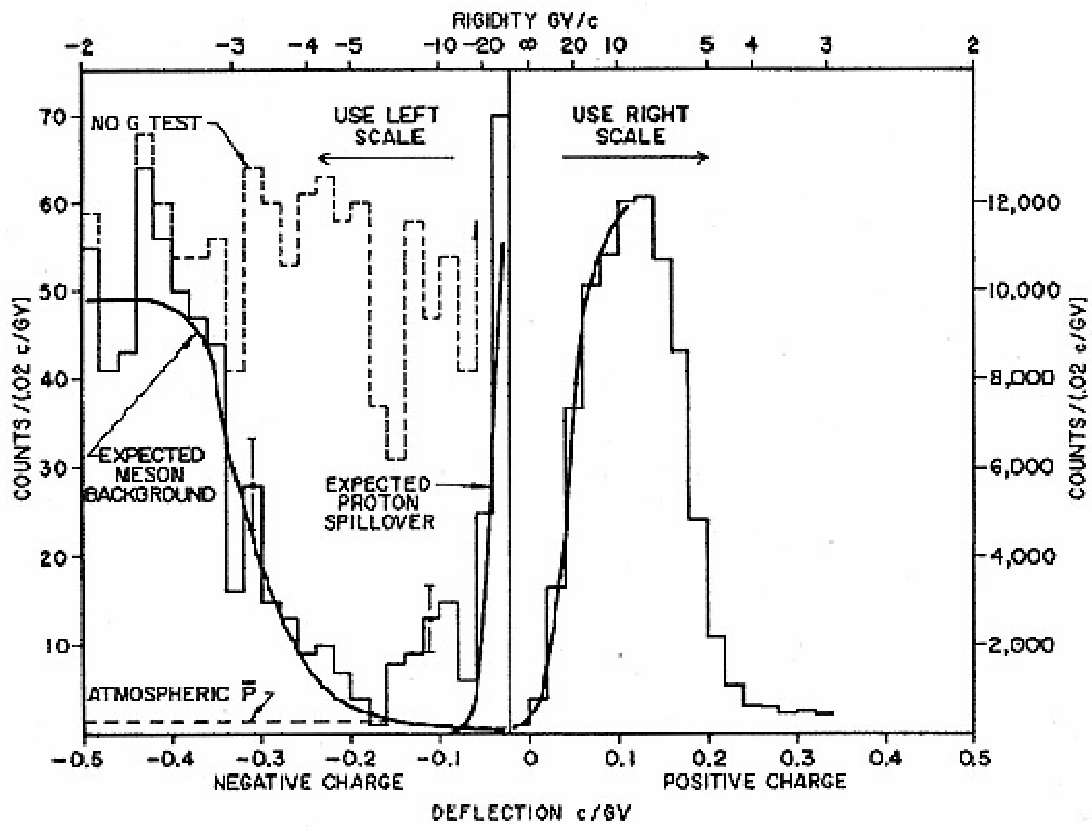

Golden, R.L. et al. 1979, Phys. Rev. Lett., 43, 1196,
"Evidence for the existence of cosmic-ray antiprotons"

# Golden: Antiprotons Reported, 1979

- Negative Deflection = 1/R
- No Cherenkov Response thus **not** a $\mu^-$ nor $e^-$

- It must be antiprotons

- $\overline{p}$/p ratio
  5 x $10^{-4}$
- Rigidity 5.6 -12 GV/c

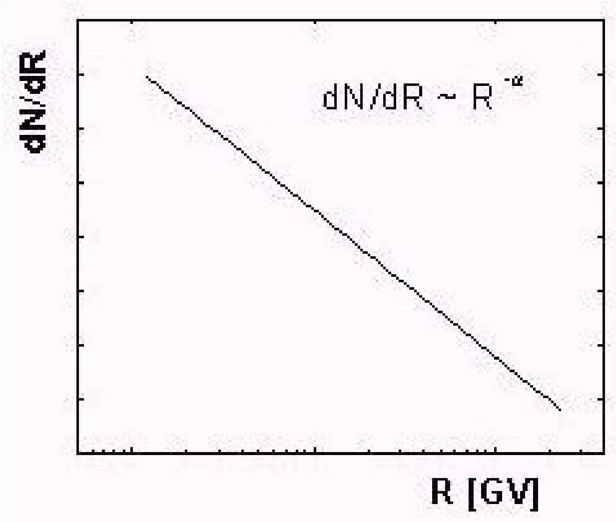



**“ratio consistent with secondary production” (in the ISM) -- a little high**

Golden, R.L. et al. 1979, Phys. Rev. Lett., 43, 1196,
“Evidence for the existence of cosmic-ray antiprotons”

# Antiproton Measurements and the effect of the "Spillover"

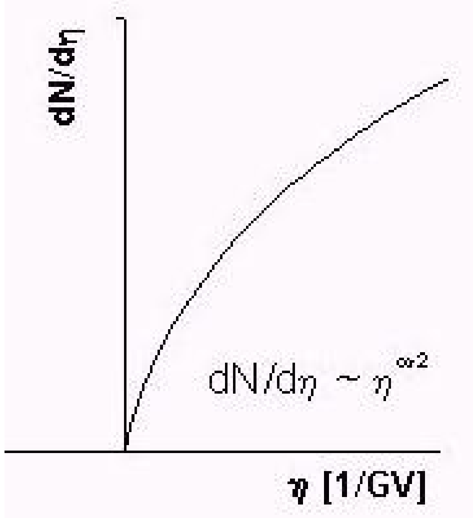
**Proton Spectrum dN/dR**

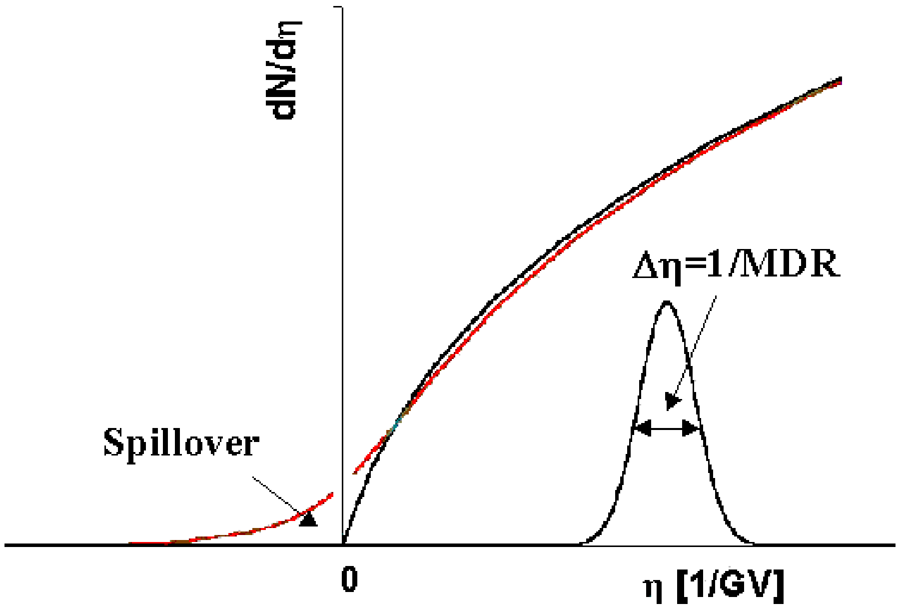



**η = 1/R**

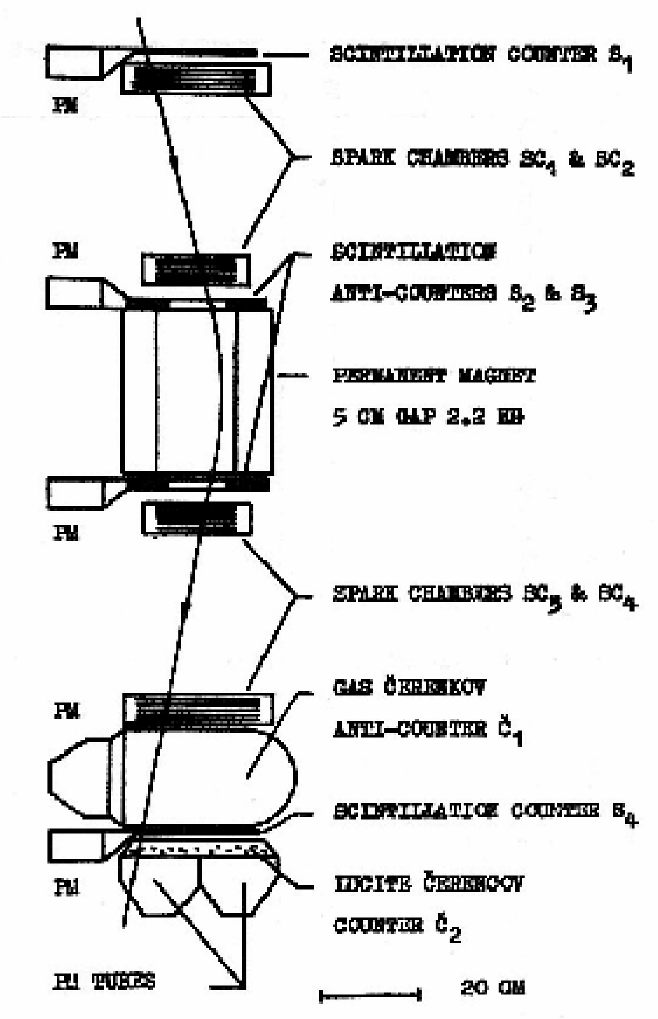
**η = „Deflection"**

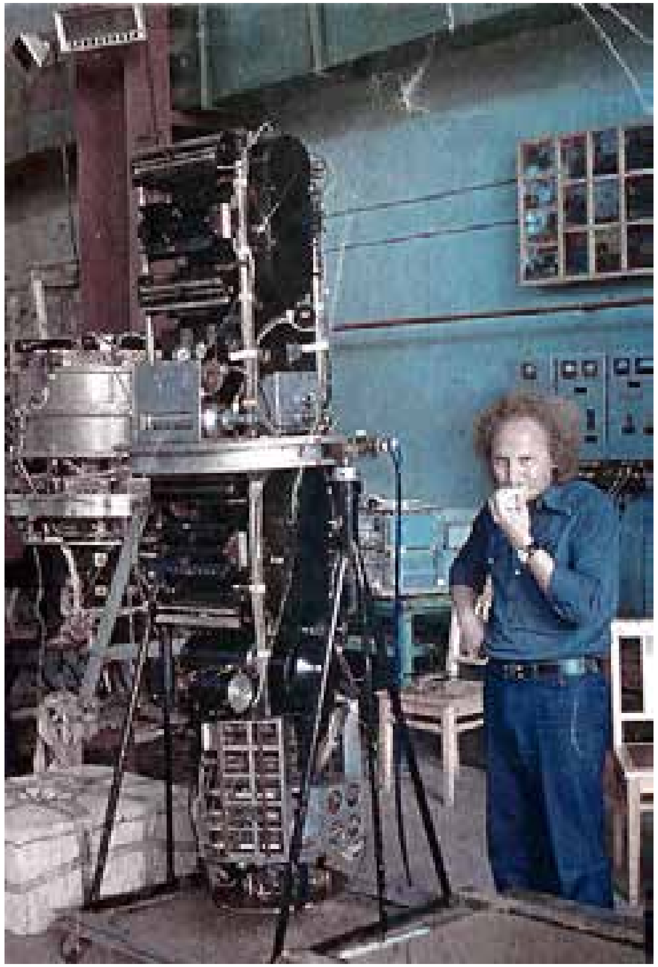
**Proton Spectrum dN/dη**



# Bogomolov: Antiprotons Reported, 1979



- $\bar{p}/p$ 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"

# Buffington: Antiproton Excess, 1981

- $\overline{p}/p$ ratio
  2.2 x $10^{-4}$
- 130-330 MeV

**NOT consistent with secondary production**

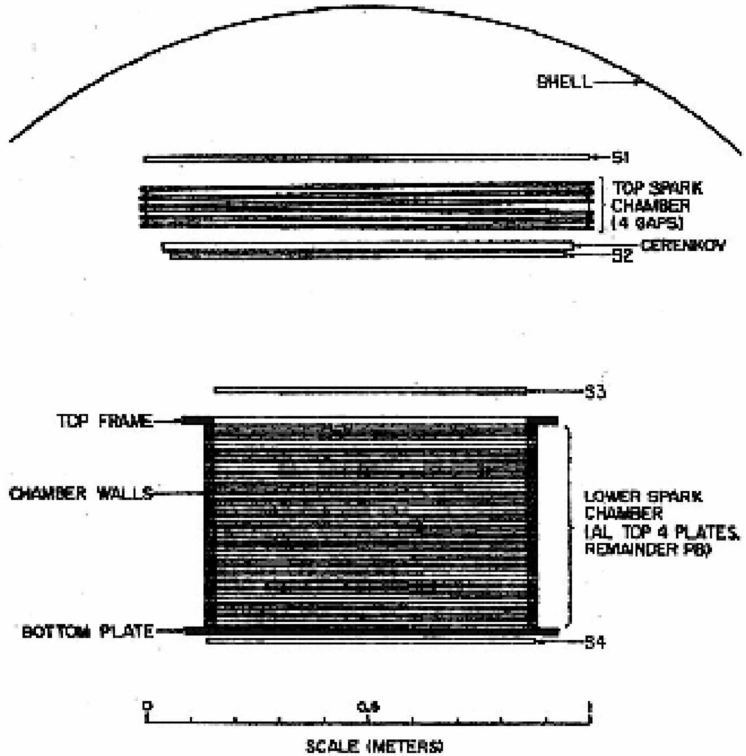



FIG. 1.—Schematic diagram of the apparatus. The trigger scintillators ($S_1 \rightarrow S_4$) and Cerenkov counter are plastic; the top spark chamber contains foam and aluminum; and the bottom spark chamber contains lead and aluminum. The steel plate beneath the lead chamber is 1.3 cm thick. The entire experiment is enclosed within two hemispherical shells which provide a pressurized environment for balloon flight. The shell is 2.4 m in diameter and is typically 0.7 g $cm^{-2}$ thick.

Buffington, A., Schindler, S. M. & Pennypacker, C. R. 1981, ApJ 248, 1179,
"A measurement of the cosmic-ray antiproton flux and a search for antihelium"

# Buffington: Antiproton Excess, 1981

- $\overline{p}/p$ ratio
  2.2 x $10^{-4}$
- 130-330 MeV

**NOT consistent with secondary production**

COSMIC-RAY ANTIPROTON FLUX

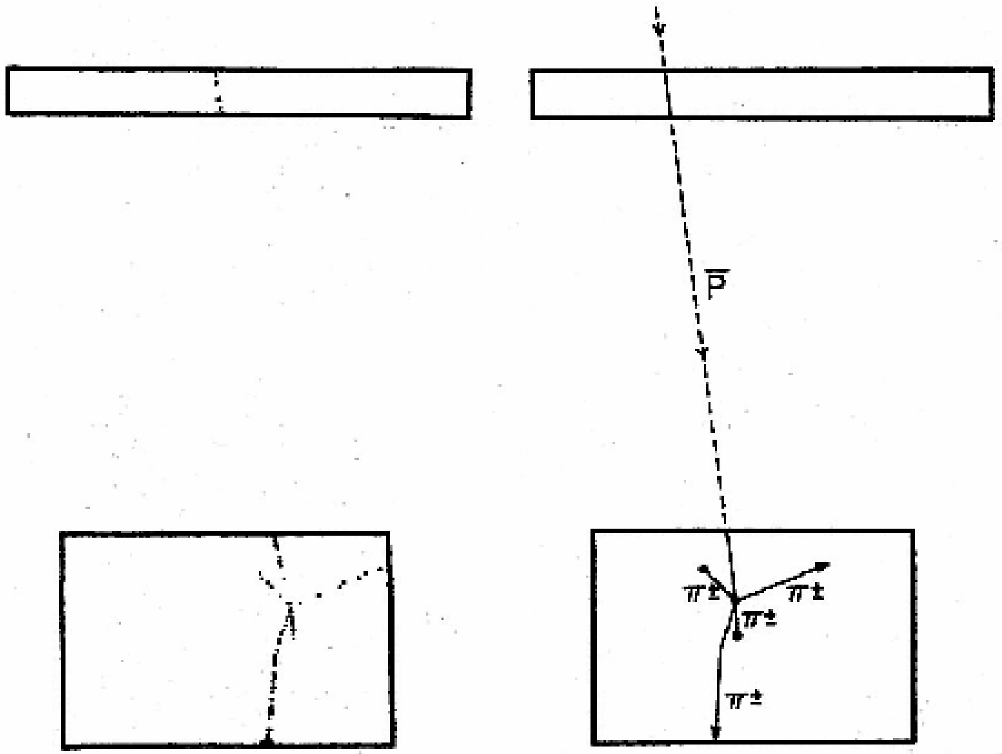
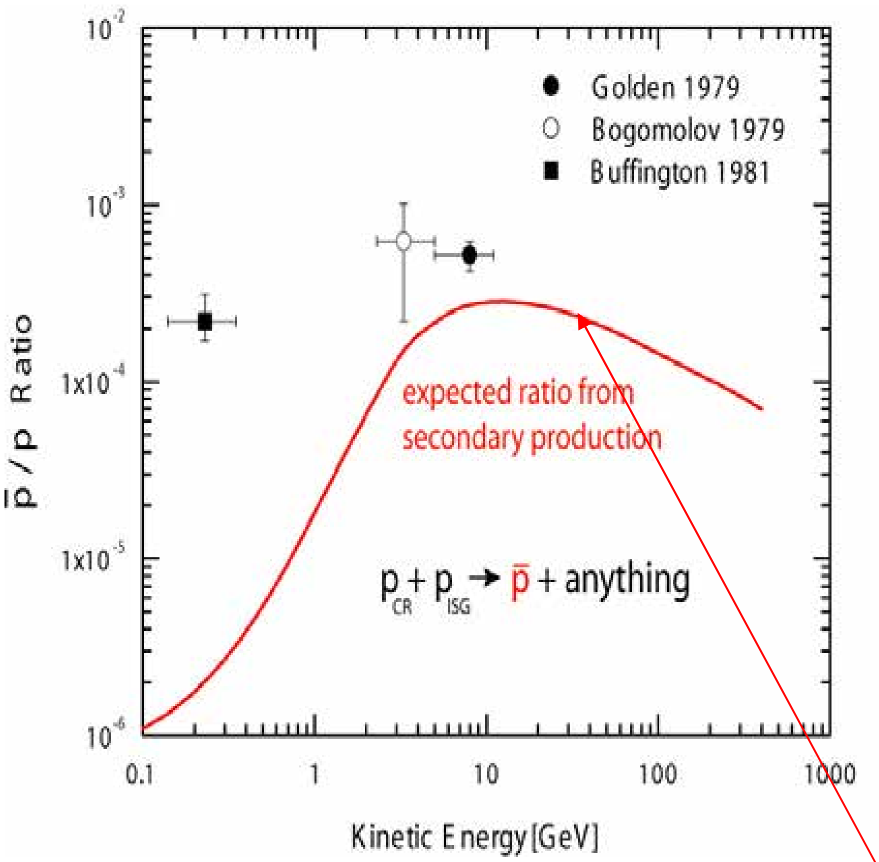
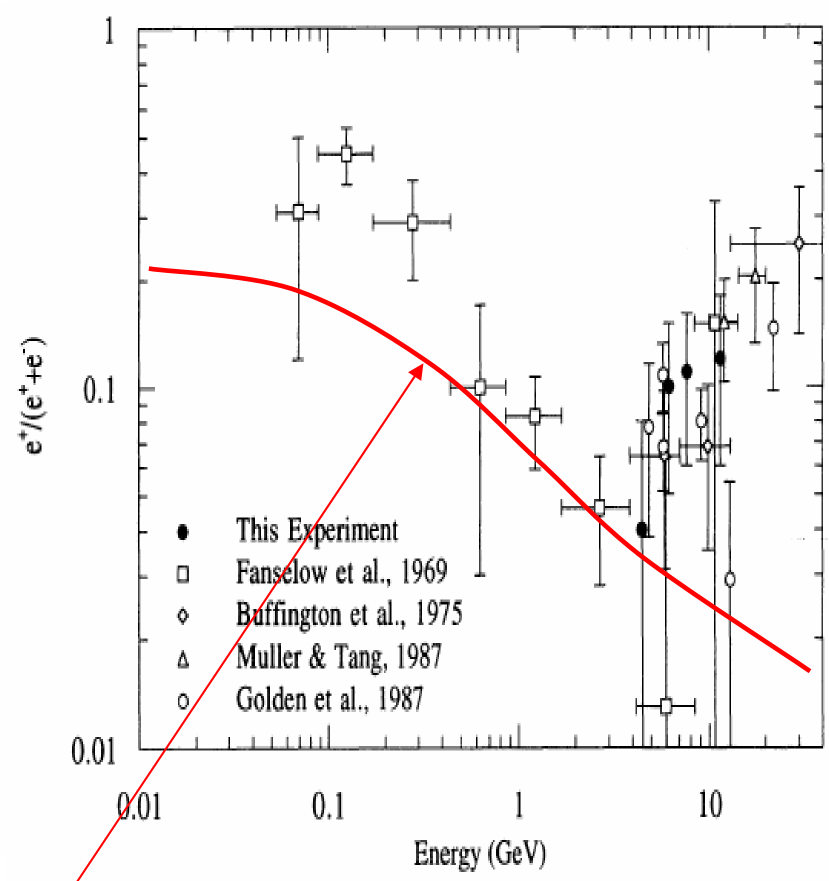



FIG. 5.—Example of an antiproton annihilation. To the left are shown the sparks marking the event topology, with the flight optical format rearranged to correspond to the apparatus (Fig. 1) and with two unassociated tracks and a few random sparks removed. To the right is a tracing of the topology inferred from the sparks. Two of the daughter pions stop within the chamber, one escapes out the side, and the fourth scatters and escapes out the bottom, where it passes through scintillator $S_4$. These pions together deposited at least 450 MeV of energy in the spark chamber, neglecting their masses and whatever kinetic energy was carried away by the two escaping particles.


Buffington, A., Schindler, S. M. & Pennypacker, C. R. 1981, ApJ 248, 1179,
"A measurement of the cosmic-ray antiproton flux and a search for antihelium"

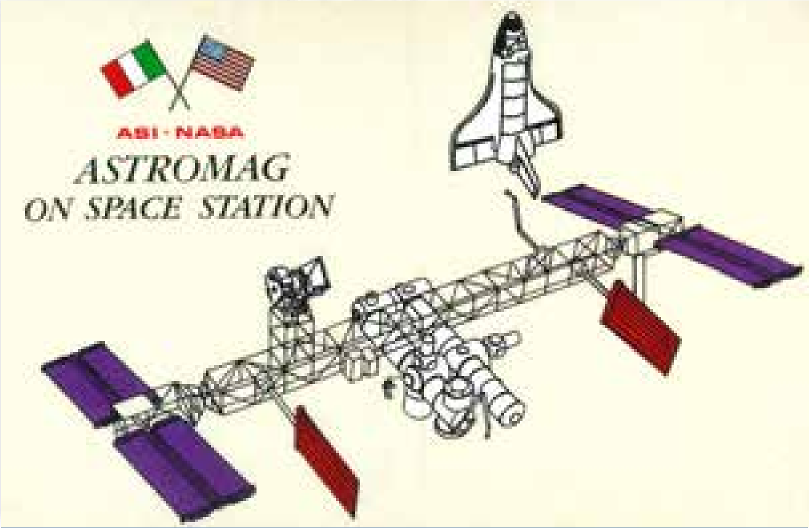
# Antiproton & Positron Measurements '87




Secondary production

# Magnetic Spectrometers for Antimatter Search in the ASTROMAG Era: BALLOONS




- LEAP
- PBAR
- MASS
- IMAX
- BESS
- TS-93
- CAPRICE
- HEAT

# LEAP & PBAR: Antiprotons at low energies

## LEAP and PBAR: Magnet Spectrometer, ToF, Cherenkov

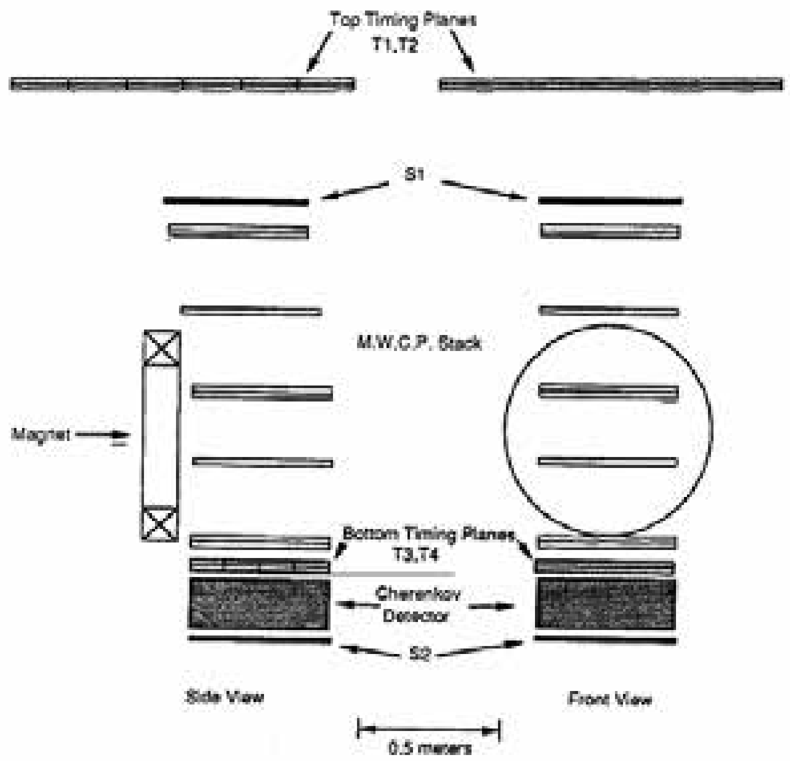



Figure 1. The LEAP instrument

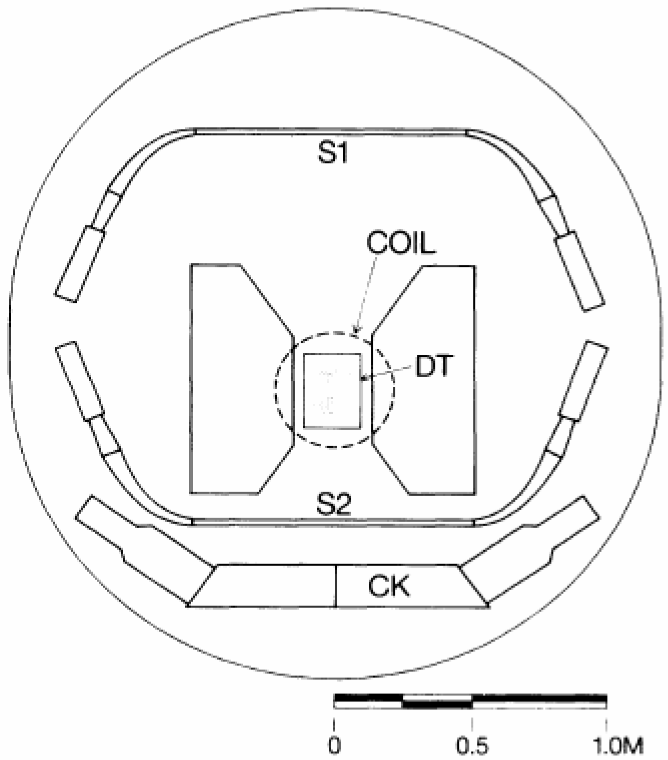


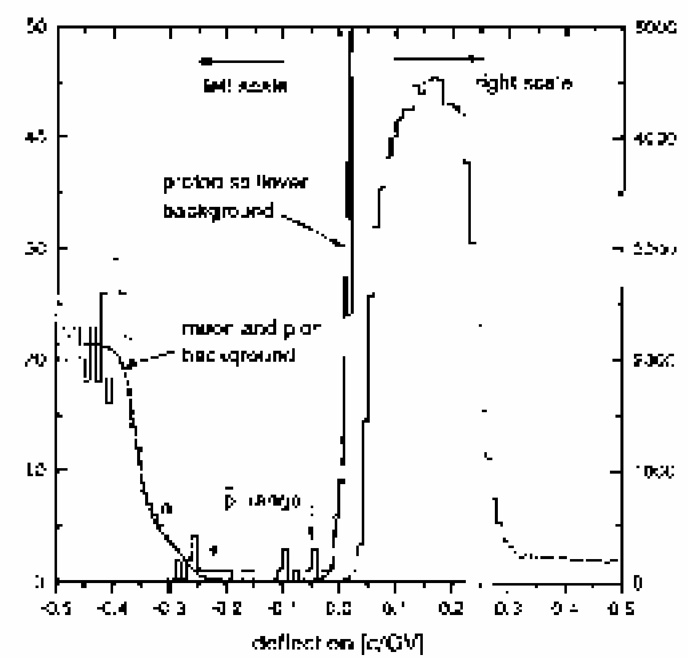

FIG. 1. Schematic of the PBAR instrument.

**No Antiproton at low energies found!**

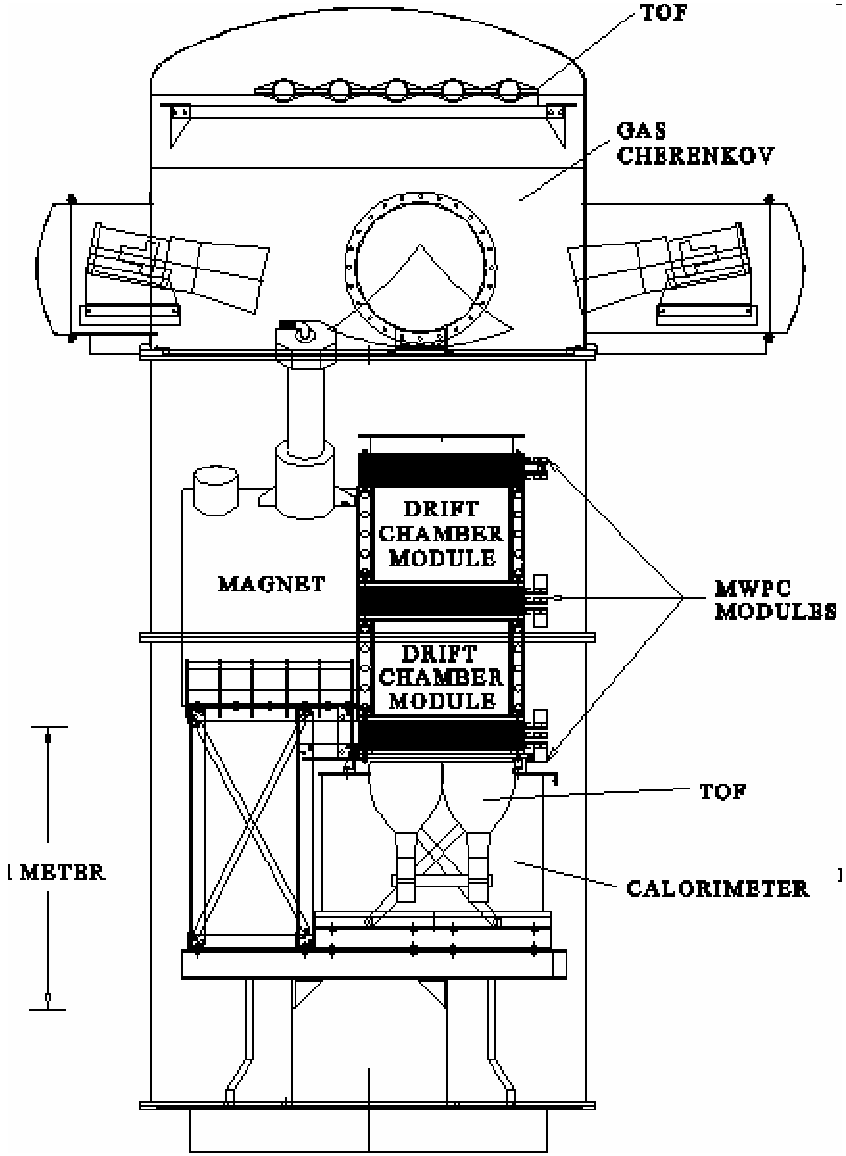
# 1991: MASS-2 Experiment

- **Magnet Spectrometer (MDR 200 GV)**
- **Time-of-Flight**
- **Gas-Cherenkov ( γ ~ 25, 18 pe's)**
- **Calorimeter: Brass Streamer Tubes**

**7.3 $X_0$ / 0.75 $I_0$**

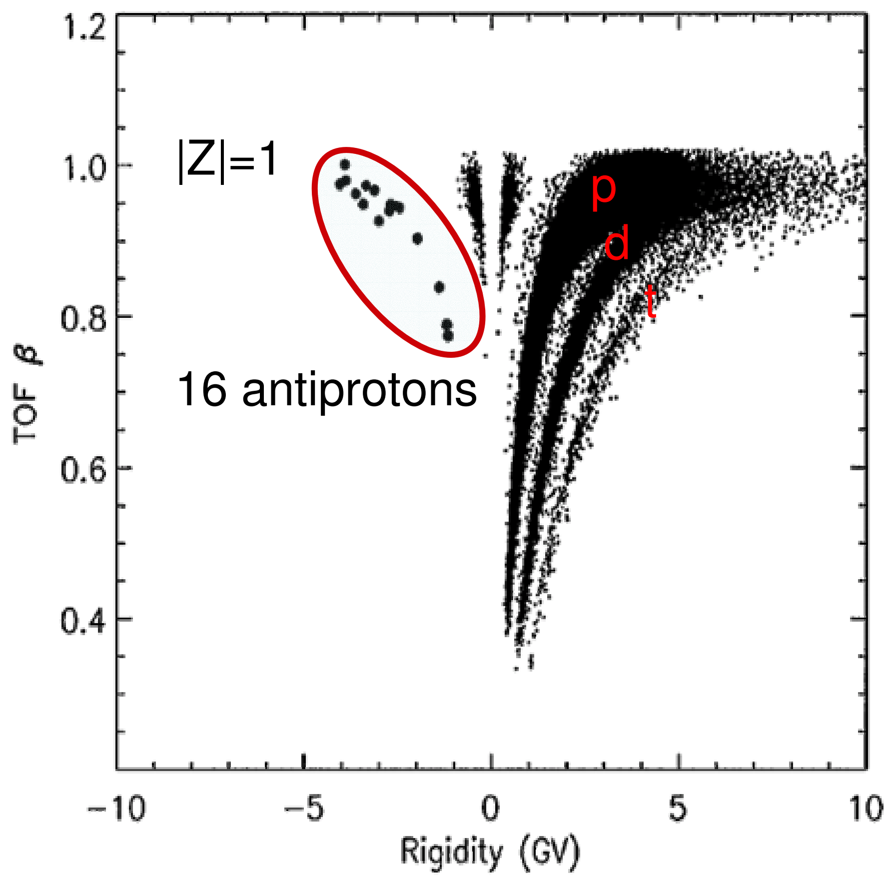


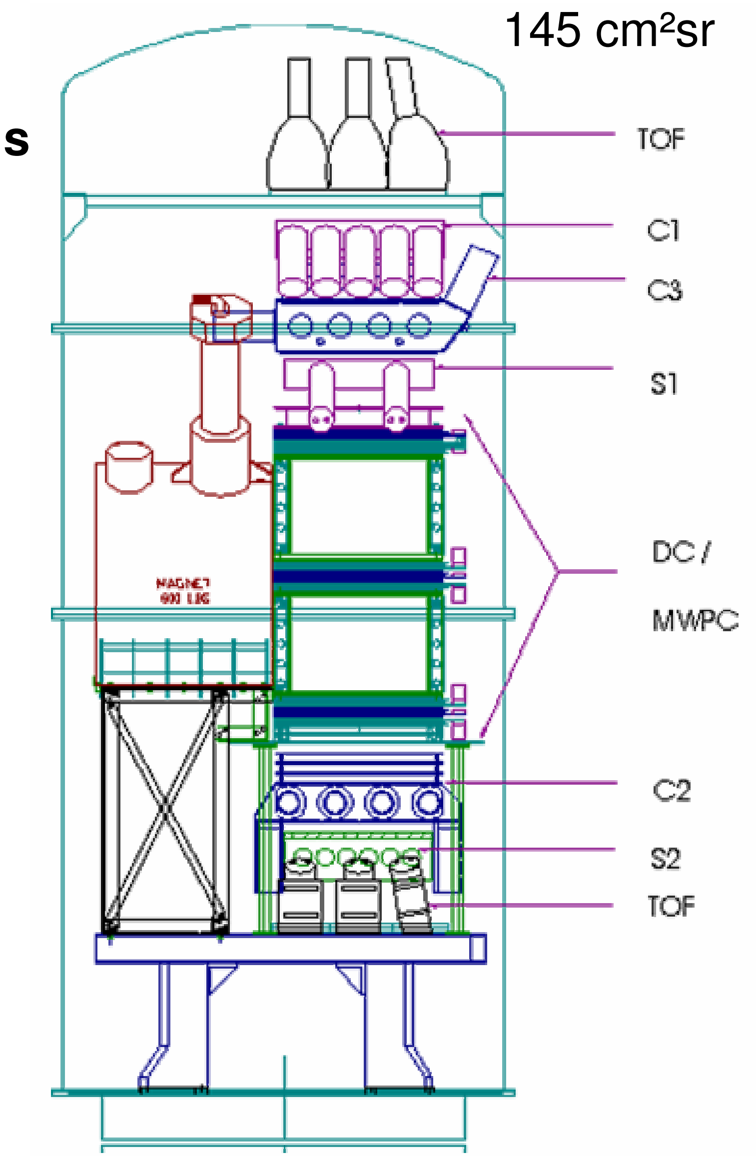

140 cm²sr



# 1992: IMAX Experiment: First mass-identified antiprotons

- **Magnet Spectrometer (MDR 200 GV)**
- **Time-of-Flight**
- **Two Aerogel-Cherenkov (n=1.05) 11 & 12 pe's**
- **Two Additional Scintillator Counters**

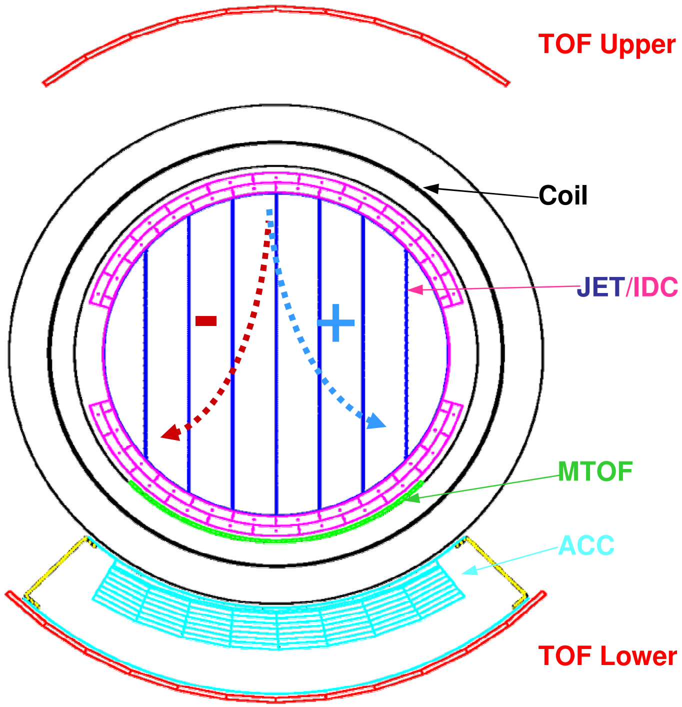


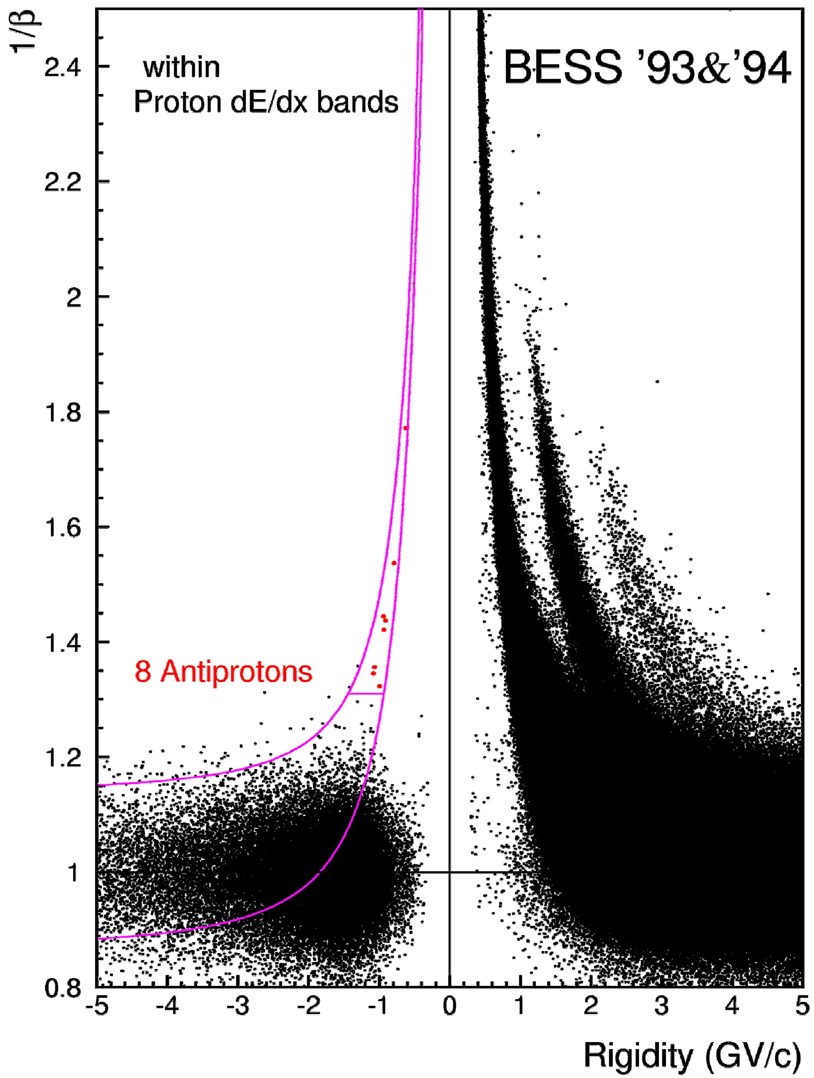



# 1993: BESS Experiment: More mass-identified antiprotons

- Magnet Spectrometer (MDR 200 GV)
- Large Acceptance: 3000 cm²sr
- Time-of-Flight (300 ps)
- Later Versions:

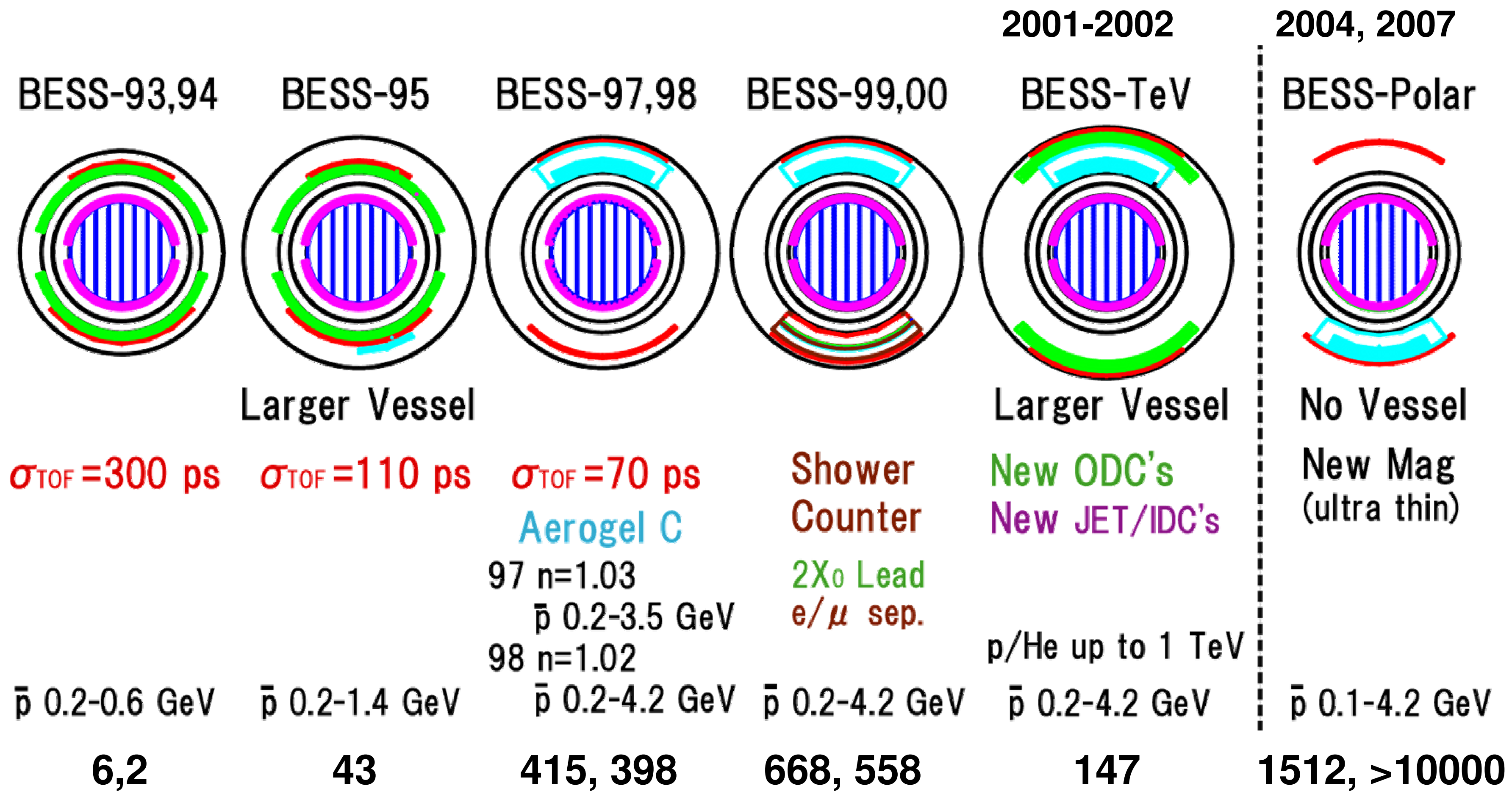
  Aerogel-Cherenkov (n=1.02, 1.03)



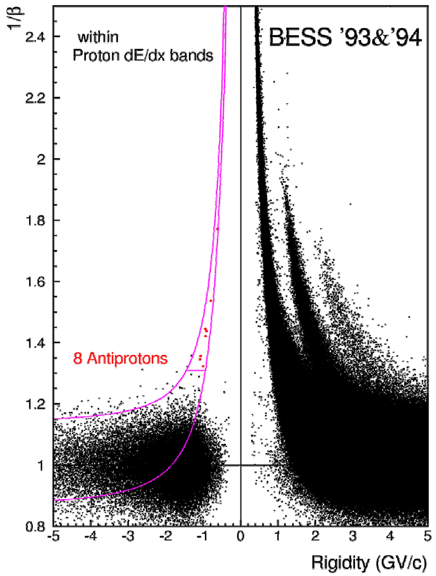



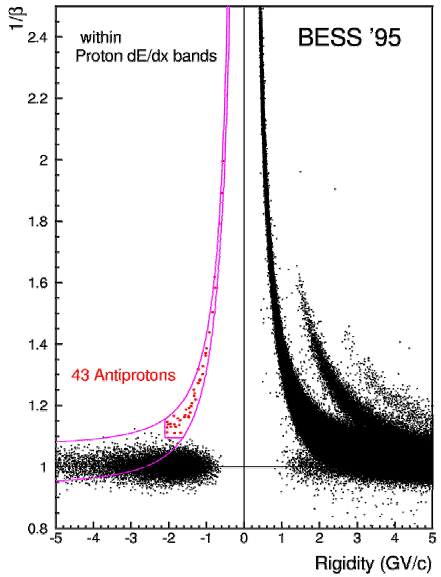
# 1993-2007:Evolution of the BESS Instrument

**Nine northern latitude BESS flights (1+ days) 1993-2002 and Two multi-day (8.5 & 24.5 days) Antarctica flights in 2004, 2007.**



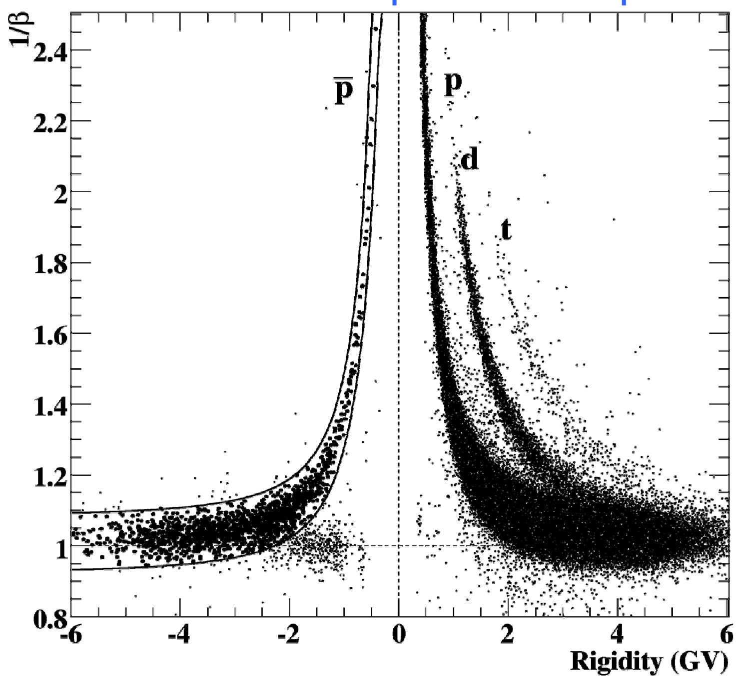
# BESS: Improvement of Particle ID

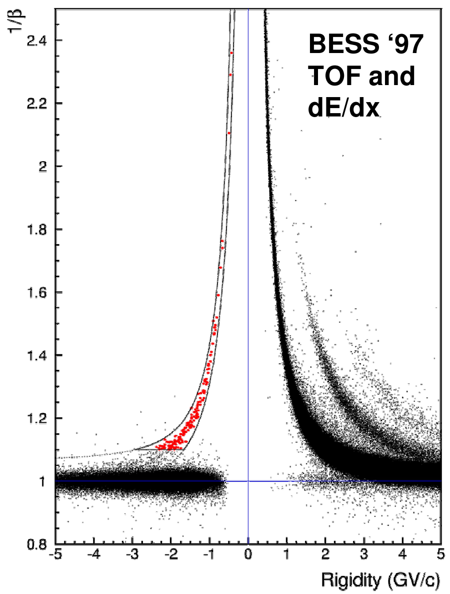


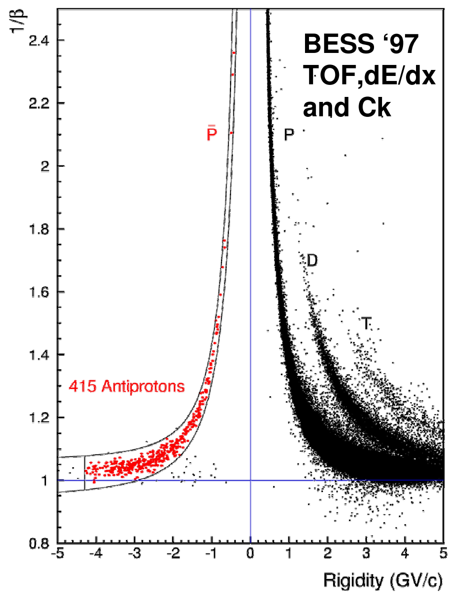




|Z| =1

BESS-Polar particle ID plot



# 1993: TS-93 ($e^+$)

- **Magnet Spectrometer (MDR 200 GV)**
- **Time-of-Flight**
- **TRD:10 layers of carbon fiber radiators, each followed by a MWPC, p rejection ~ 77**
- **Si-W Calorimeter:**

**5 $X_0$, e/p rejection ~ 450**

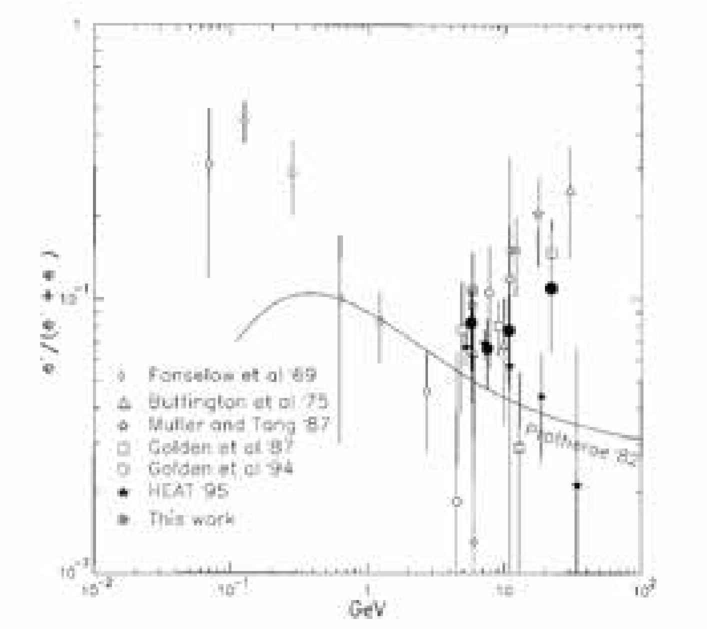
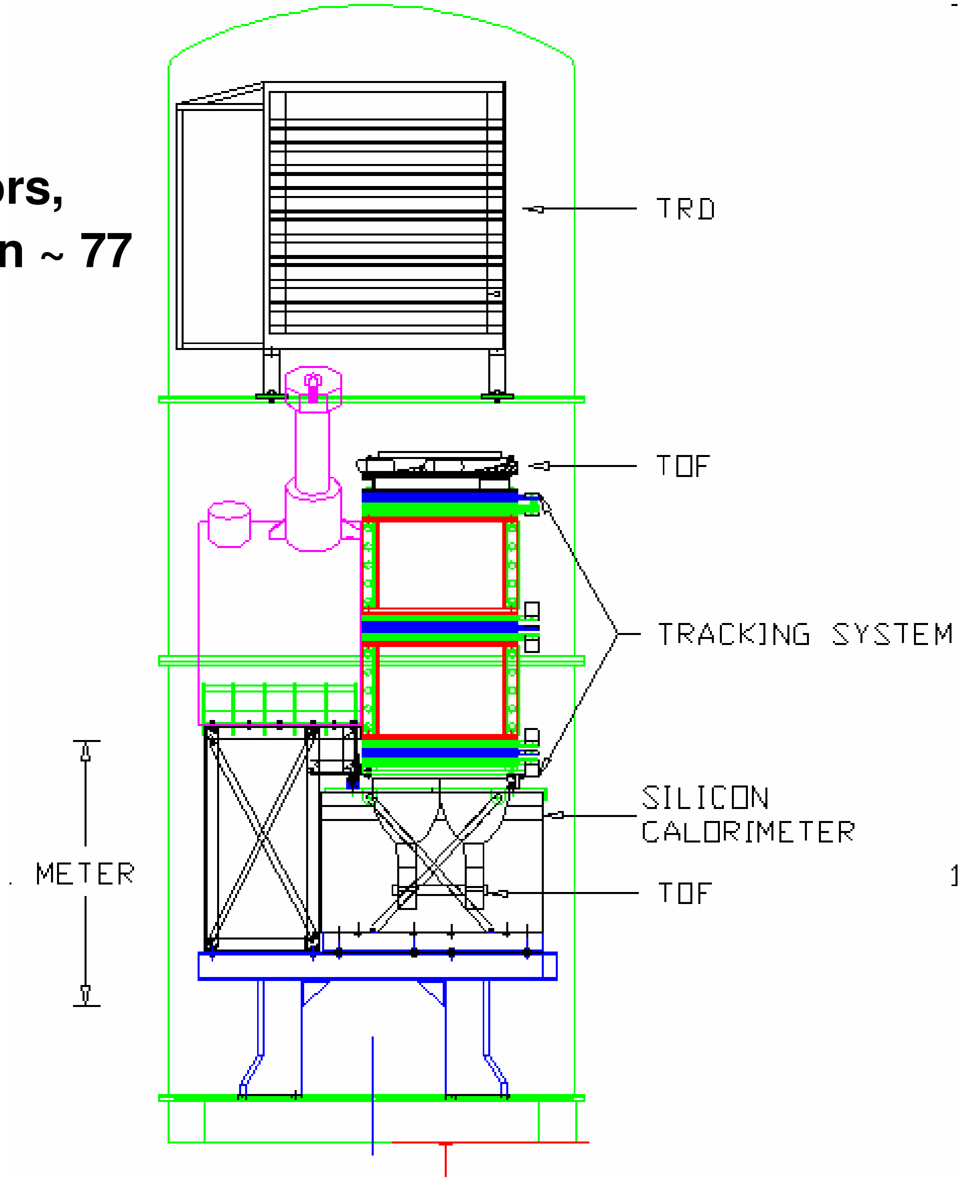



FIG. 3.—Positron fraction, $[e^+/(e^+ + e^-)]$, as observed in this experiment compared with other published data and the simple leaky box model.

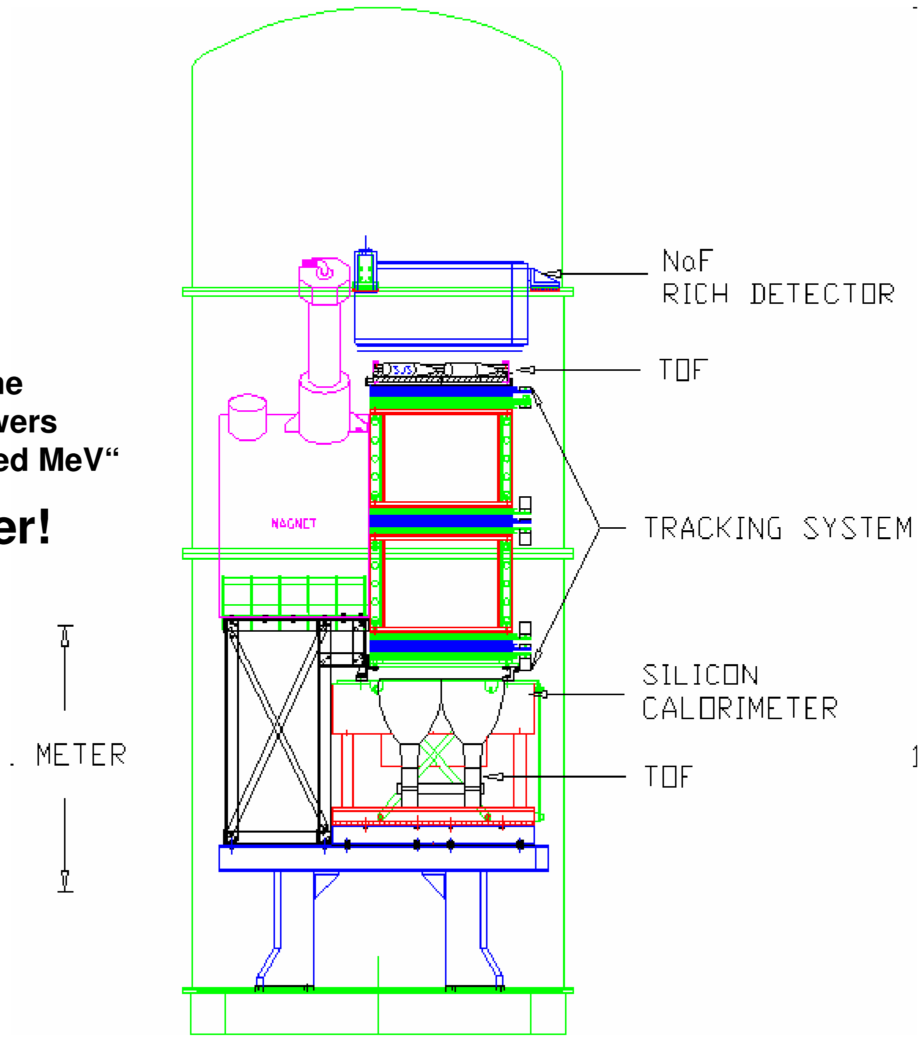


# CAPRICE-I ($\bar{p}$ and $e^+$)

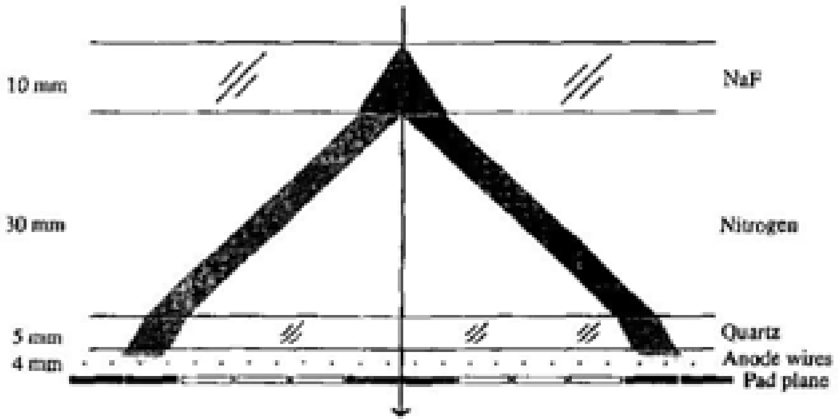
- **Magnet Spectrometer (MDR 200 GV)**
- **Time-of-Flight**
- **NaF-RICH ($\gamma$ = 1.5)**
- **Improved Si-W Calorimeter:**
  **7.3 $X_0$, 0.33 $I_0$, e/p rejection ~ $10^4$**

**„Because of the limited thickness (7 radiation lengths), the calorimeter did not fully contain the electromagnetic showers induced by electrons with energy larger than a few hundred MeV“**

- **High granularity gives rejection power!**




## RICH-Detector



# CAPRICE-I

## Electron

## Antiproton

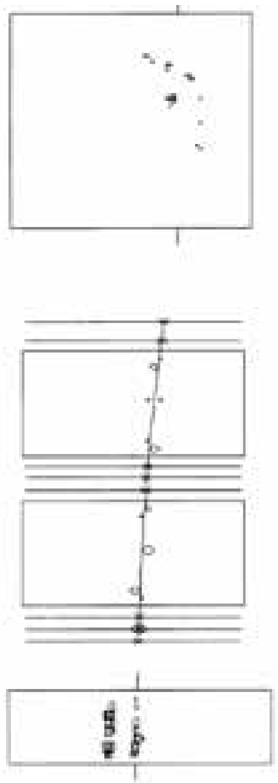


FIG. 2.—Display of a single 1.3 GV electron in the CAPRICE apparatus. The electron emits, according to an extrapolation of the track, a bremsstrahlung photon in the RICH. The instrument is shown in the bending (x) view (left) and in the nonbending (y) view (right). From top to bottom is displayed the RICH seen from above, the tracking stack of multiwire proportional chambers and drift chambers, with the imaging calorimeter at the bottom. Crosses indicate hits in the MWPC, and circles indicate hits in the DC with the radius proportional to the drift time. Note that the figure is not to scale. The calorimeter is significantly thinner than shown in the figure. The RICH shows the detected Cherenkov light image where the ionization of the chamber gas by the electron is shown as a cluster of pads hit in the center surrounded by the signals from the Cherenkov light. Because of total reflection in the NaF crystals, only part of the Cherenkov ring is detected. The tracking stack shows the trajectory of the electron as it is deflected by the magnetic field. The calorimeter shows the two electromagnetic showers produced by the electron and by the bremsstrahlung photon, respectively. In the nonbending view, the two showers overlap.

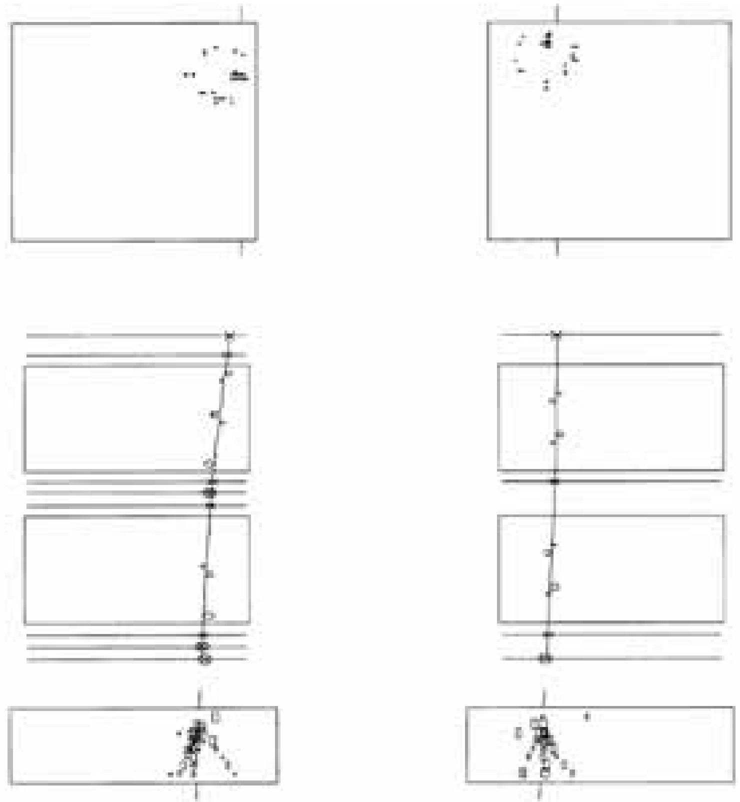
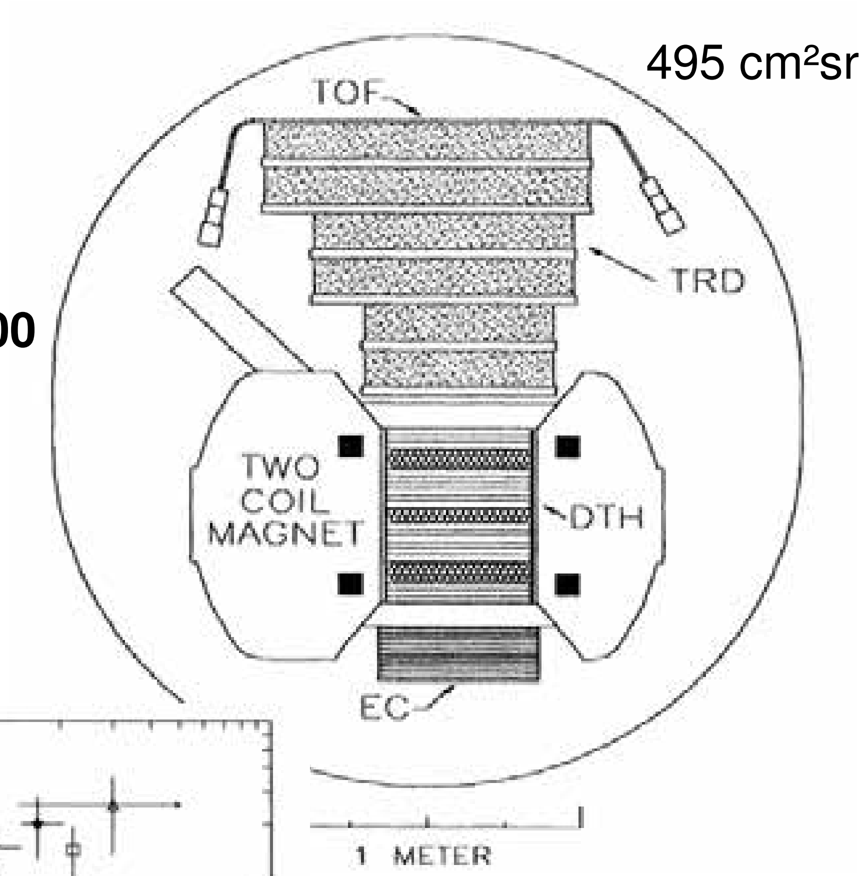


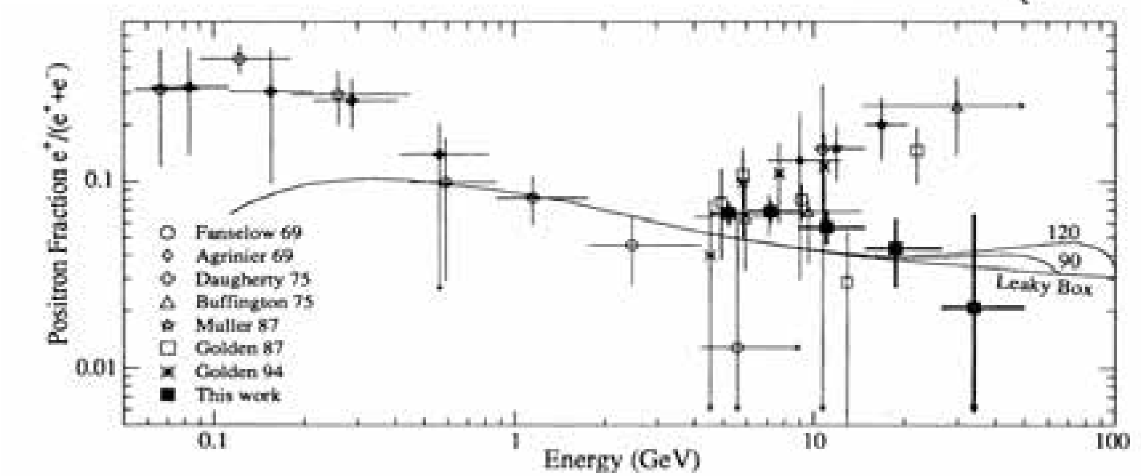
FIG. 3.—Display as in Fig. 2 of a single 2.2 GV antiproton traversing the CAPRICE apparatus. The antiproton interacts in the calorimeter, showing clearly several charged particles emerging from the vertex of interaction; this could be an annihilation in flight.

# 1994 & 1995: HEAT ($e^+$)

- **Superconducting Magnet**
- **Drift Tube Tracker MDR ~ 170 GV**
- **Time-of-Flight σ = 0.75 ns**
- **TRD: plastic fiber radiators & MWPC Xe/$CH_4$; proton rejection ~200**
- **Shower Counter 9 $X_0$ proton rejection ~100**

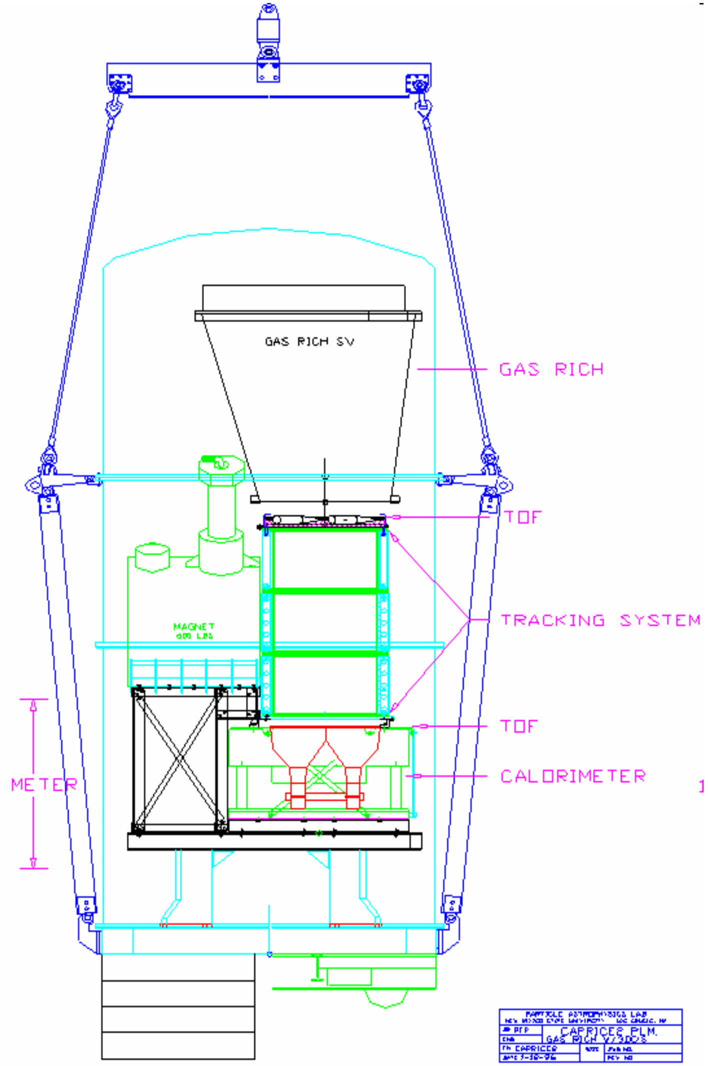
495 $cm^2 sr$



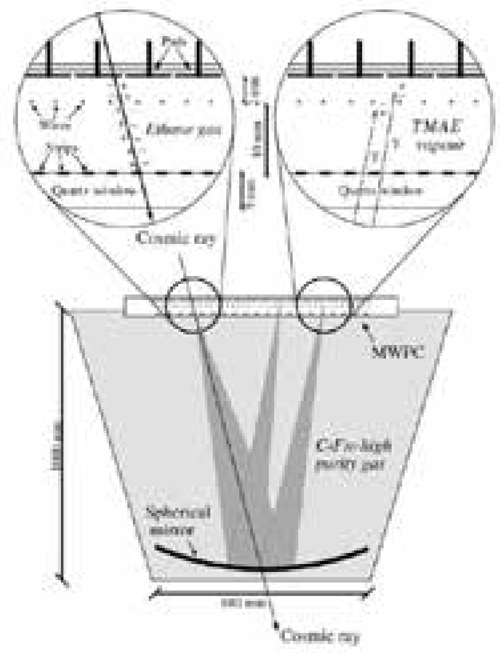



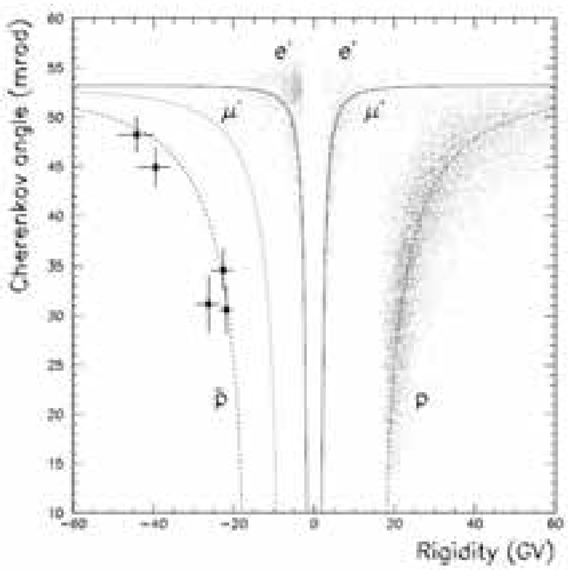
# CAPRICE-II ($\bar{p}$ and $e^+$)

- Improved Magnet Spectrometer (MDR 330 GV)
- Time-of-Flight
- Gas-RICH  $C_4F_{10}$-Gas  (~12 photoelectrons)
- Si-W Calorimeter:
  7.3 $X_0$, e/p rejection ~ $10^4$



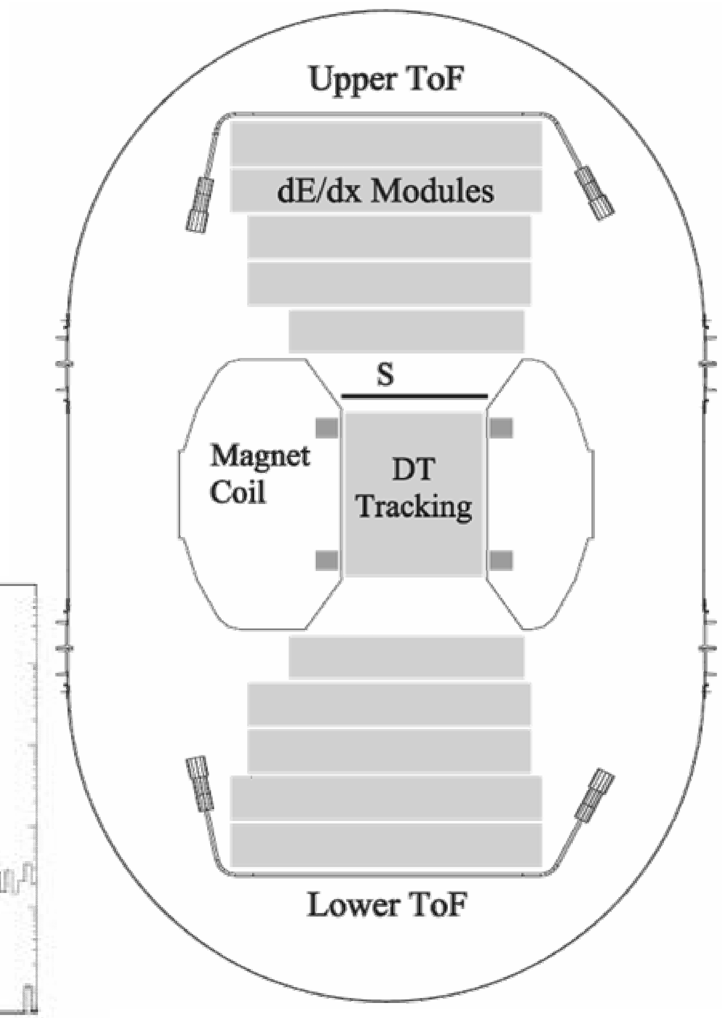

## Gas-RICH



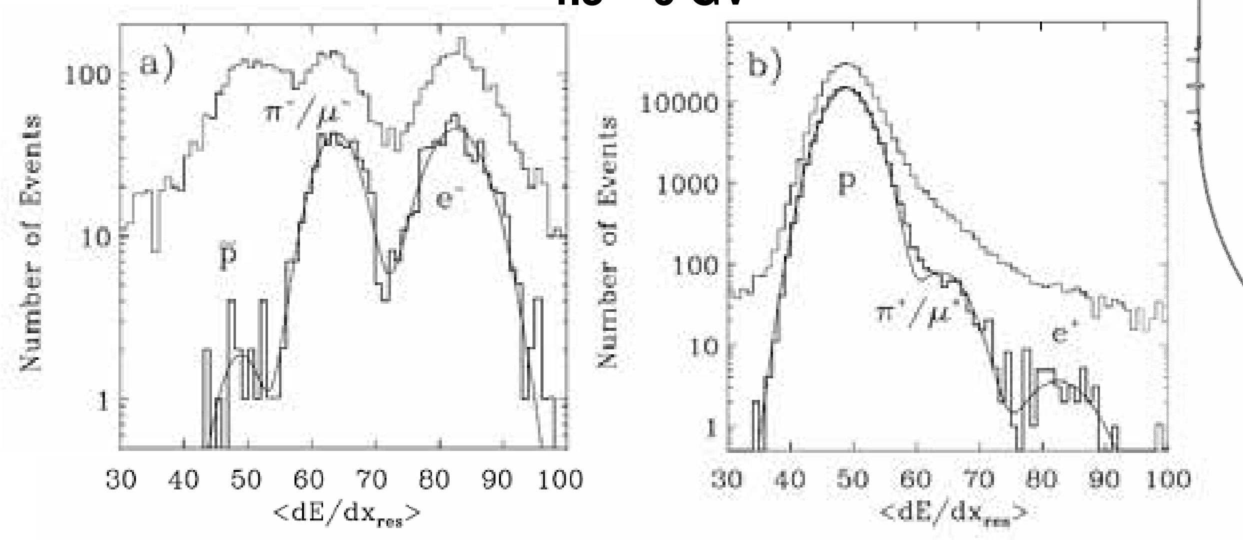



# HEAT-pbar ($\bar{p}$ and $e^+$)

- Superconducting Magnet
- Drift Tube Tracker
- multiple dE/dx measurements with 140 MWPCs filled with $Xe/CH_4$
- Flight in 2000, 22 hours, 4.5 – 50 GV
- 71 antiprotons

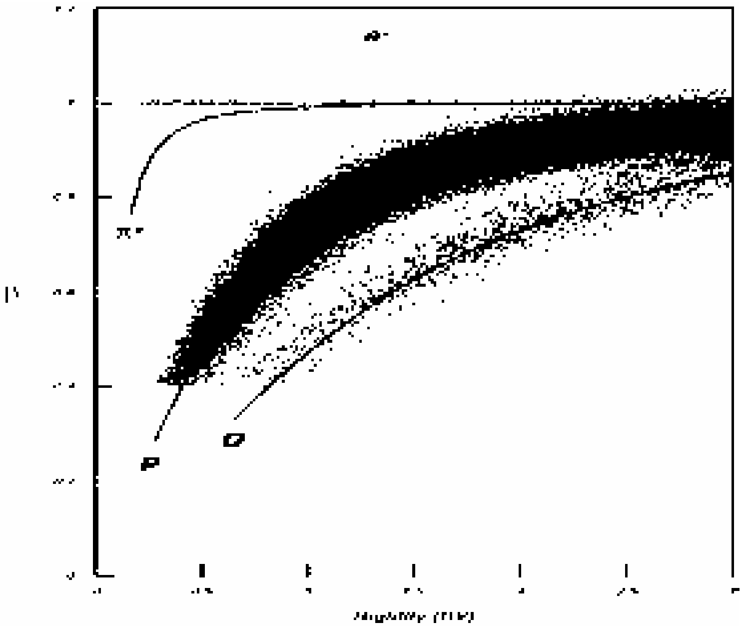



**4.5 – 6 GV**



# Antimatter Experiment in Space: AMS-01(1998)

- Originally developed for Anti-Nuclei search
- Geometry factor: 8200 cm² sr
- Permanent Magnet (B = 0.15 T)
- Silicon-Tracker σ ~10 μm → MDR ~ 500GV
- Time-of-Flight σ ~120 ps
- Two Aerogel Cherenkov n=1.035, 3.5 & 4 pe's



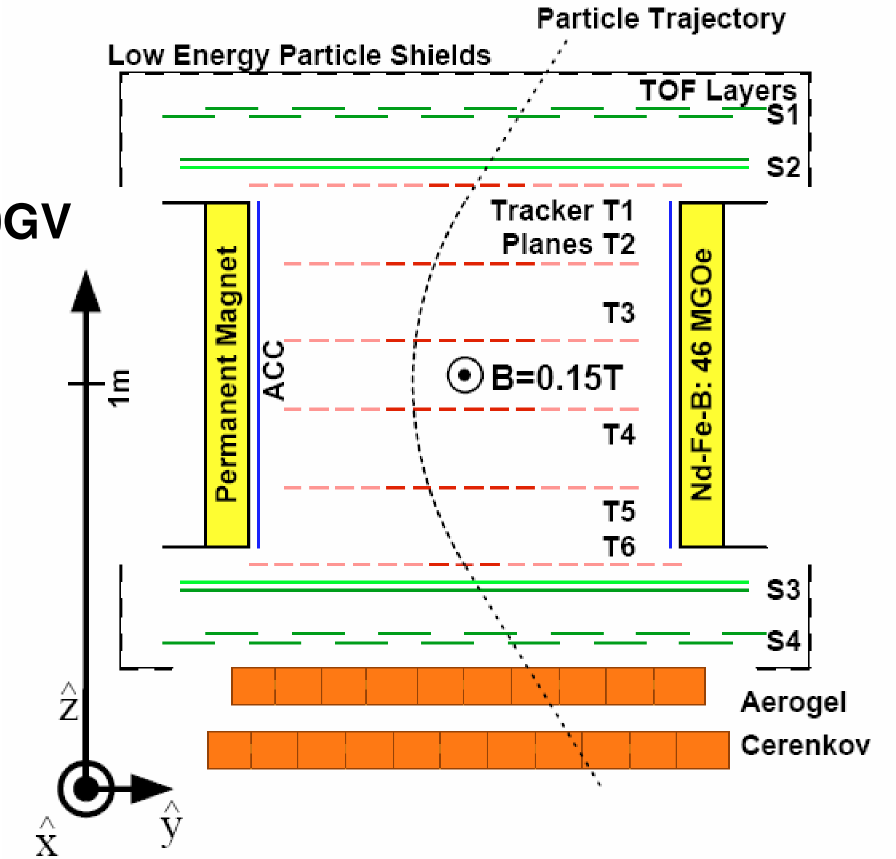




Figure 1: Schematic view of AMS as flown on STS–91.

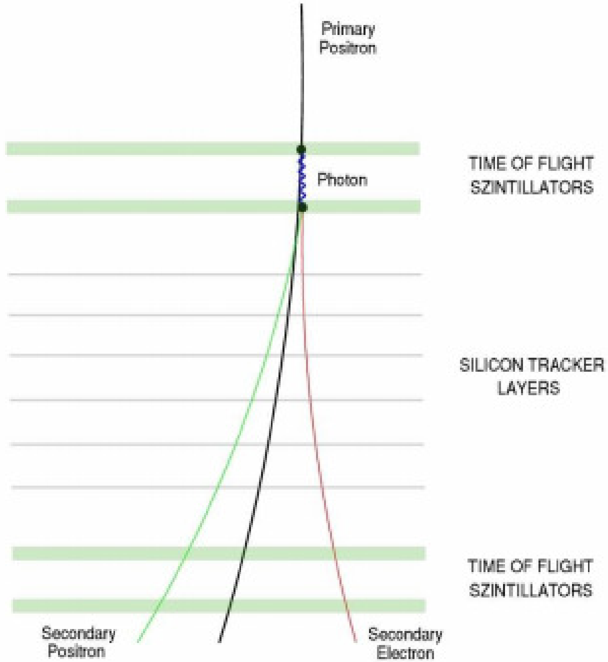
**Detectors and particle identification method similar to IMAX or BESS**

# Antimatter Experiment in Space: AMS-01(1998)

**Extending $e^+$ analysis up to 40 GeV using multi-track analysis**

## Signature of converted bremsstrahlung

- Primary $e^+$, $e^-$ radiate bremsstrahlung $\gamma$
- $\gamma$ converts to $e^+e^-$ pair

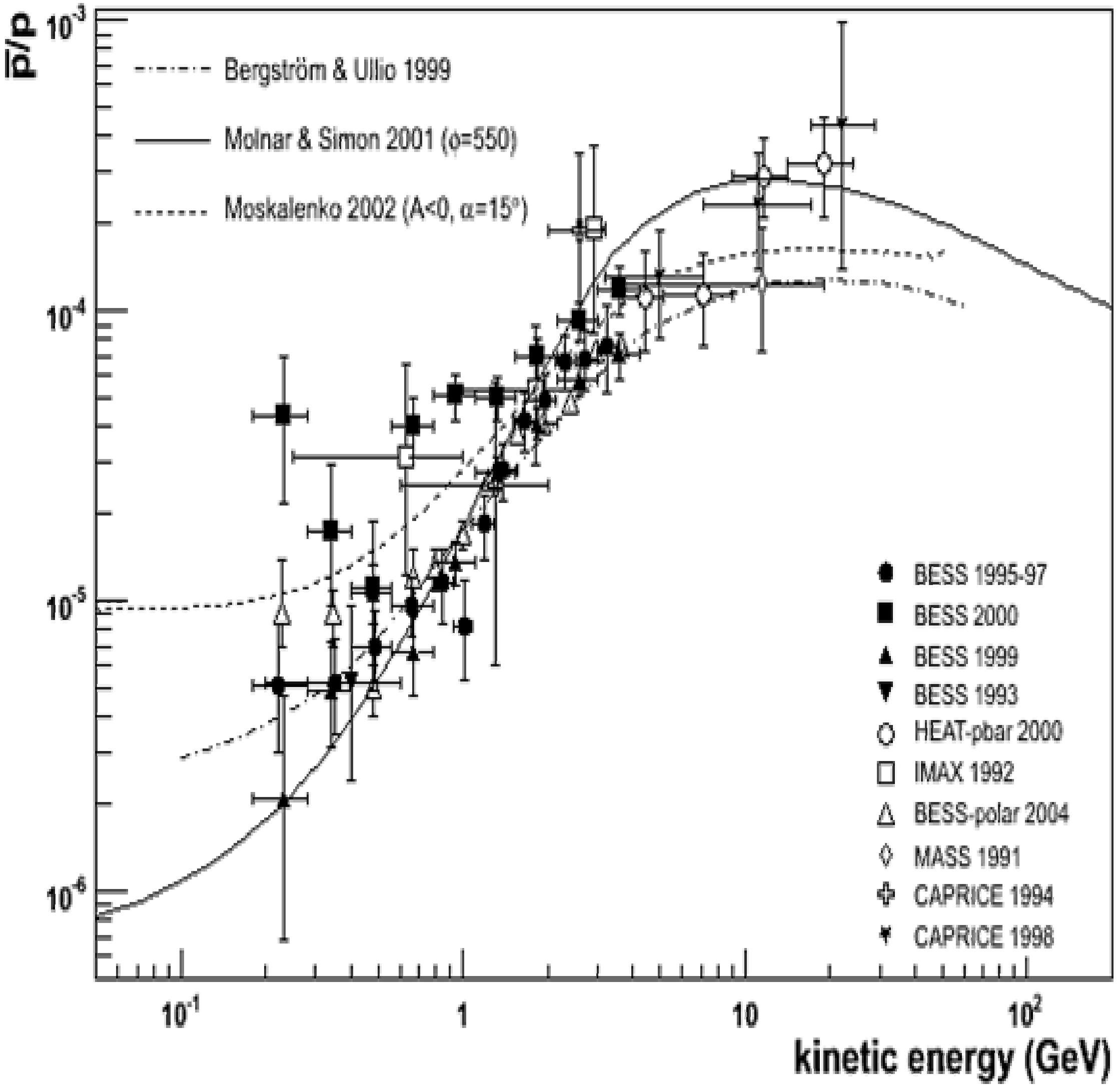



3 track signature, middle track is primary in >90% of events due to higher momentum

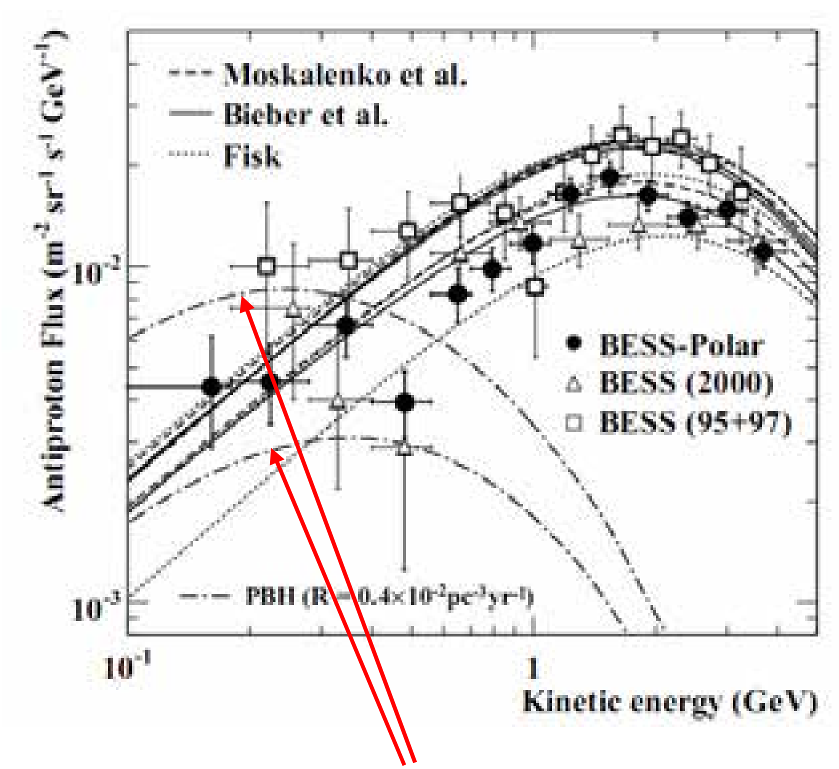
Small opening angles at vertices ($\propto \gamma^{-1} \approx 0$)

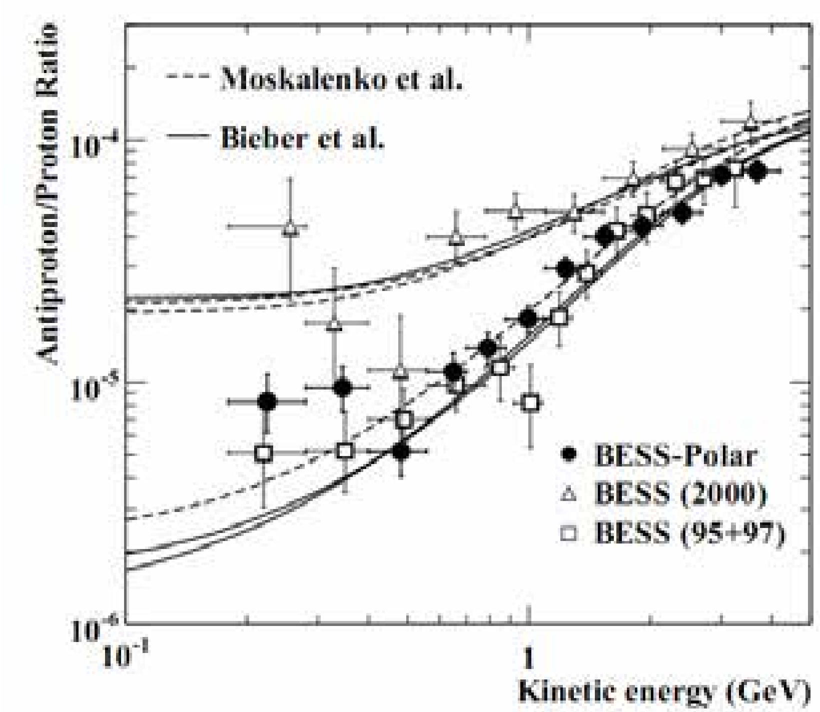
Bremsstrahlung yields "built-in" proton rejection by a factor of $10^6$ ($\sigma \propto 1/m^2$)

# Cosmic Ray Antiprotons ca. 2000



# BESS Antiprotons at low energy

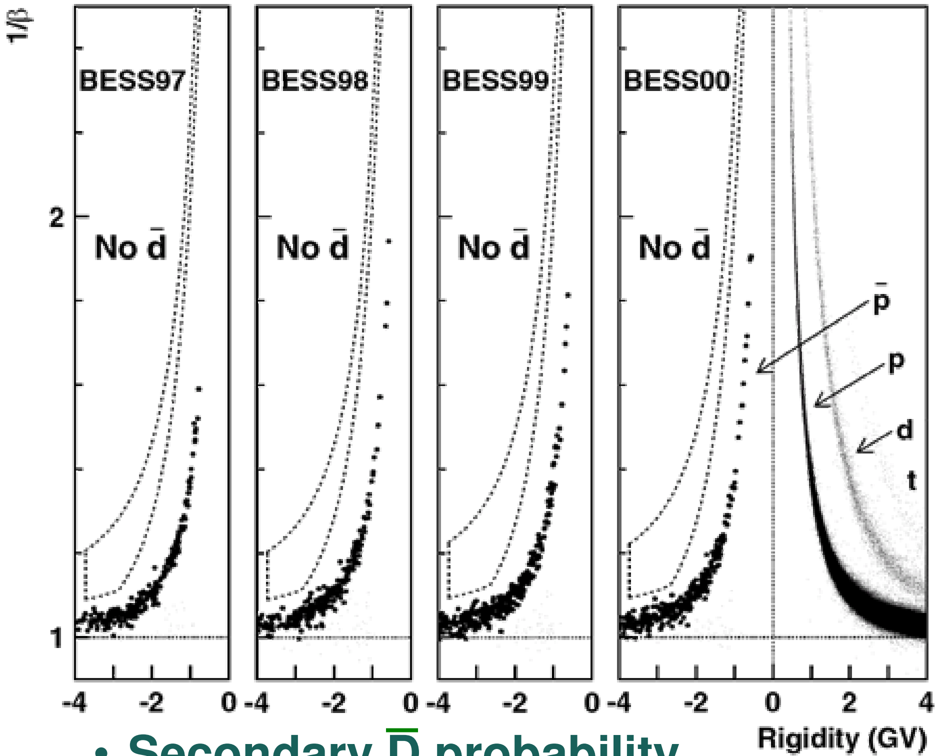


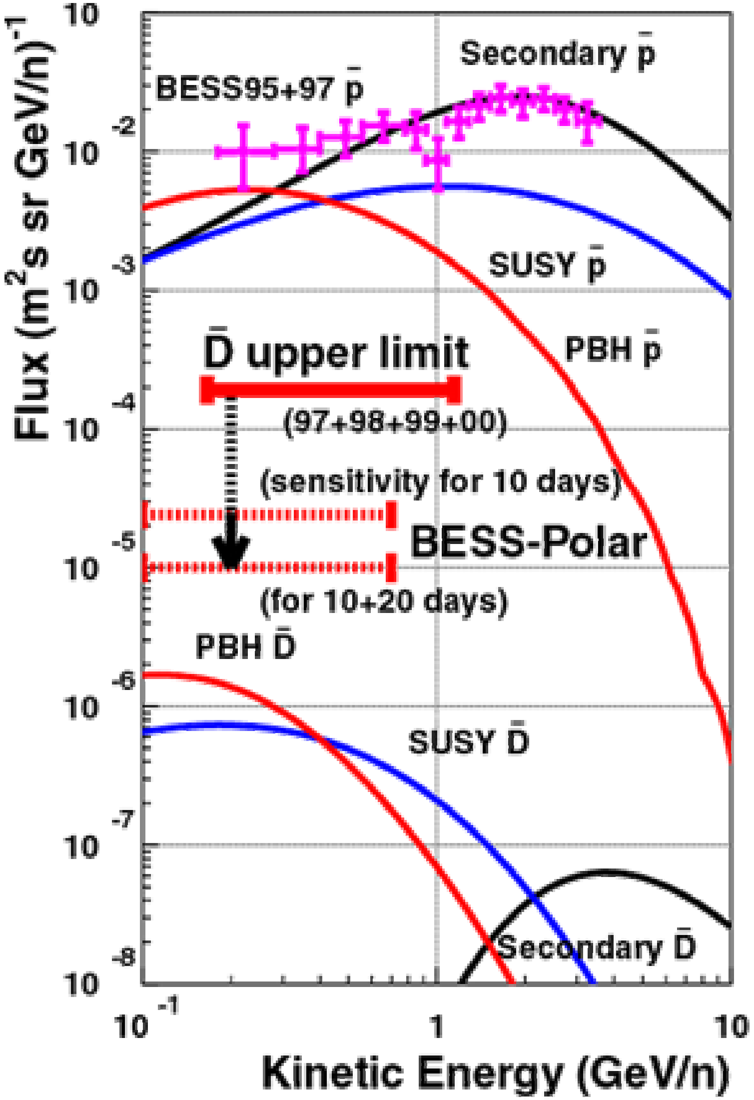




calculations of antiproton spectra from evaporation of primordial black holes modulated by 550 MV(top) and 850 MV(bot)

**No clear evidence for primary signal…**

# BESS: Antideuteron Search



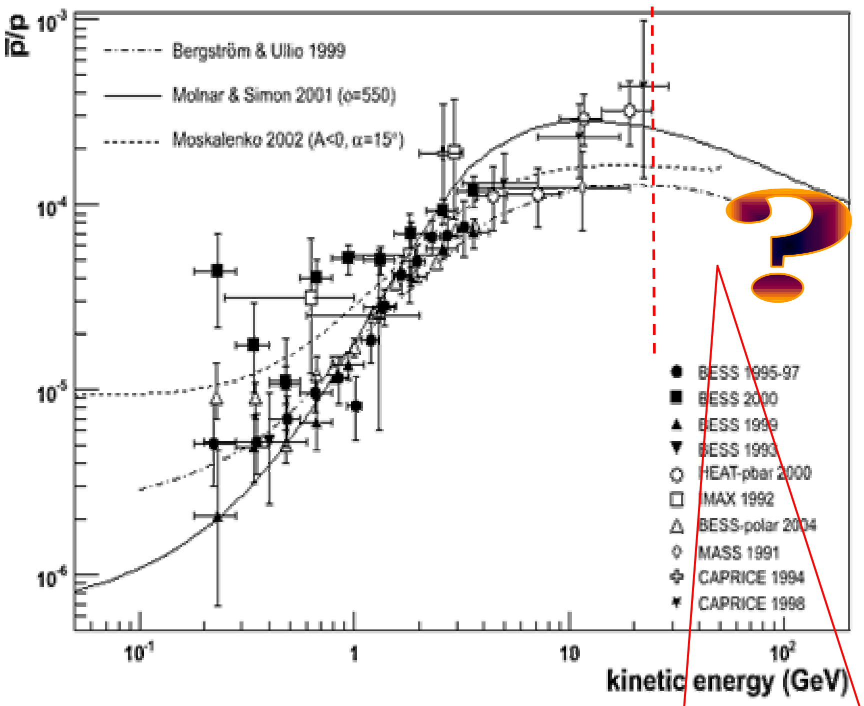




- Secondary $\bar{D}$ probability is negligible at low energies due to kinematics.
- Any observed D probably has a Primary Origin !
- $\bar{D}$ upper limit (first reported), 1.92 x $10^{-4}$ (m$^2$ s sr GeV/n)$^{-1}$

Reference: Fuke, H et al. 2005, PRL **95,** 081101, **Search for Cosmic-Ray Antideuterons**

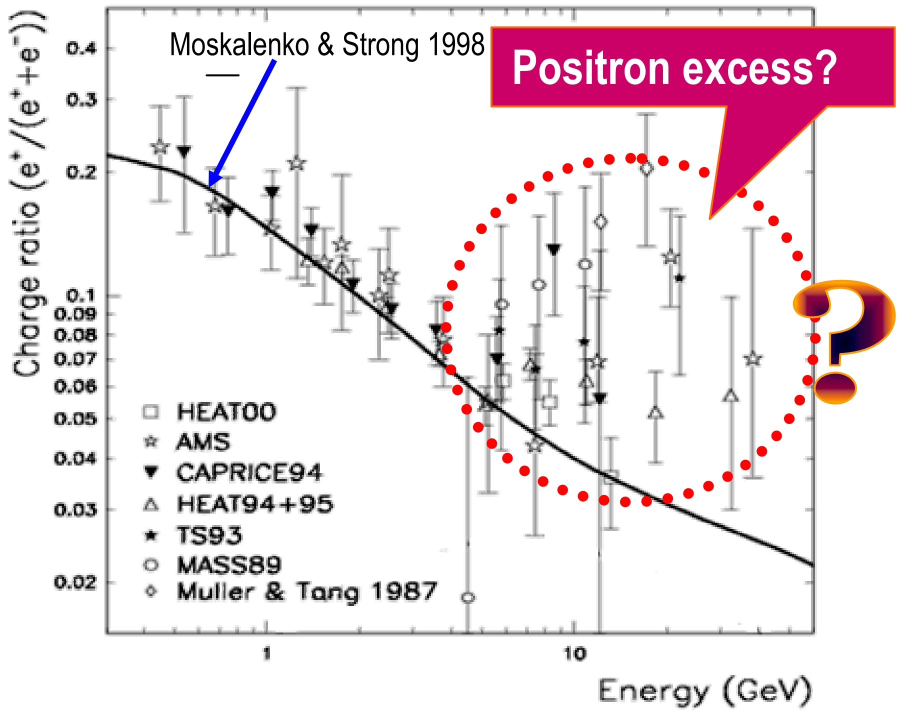
# Cosmic Ray Antimatter ca. 2000

**Antiprotons**

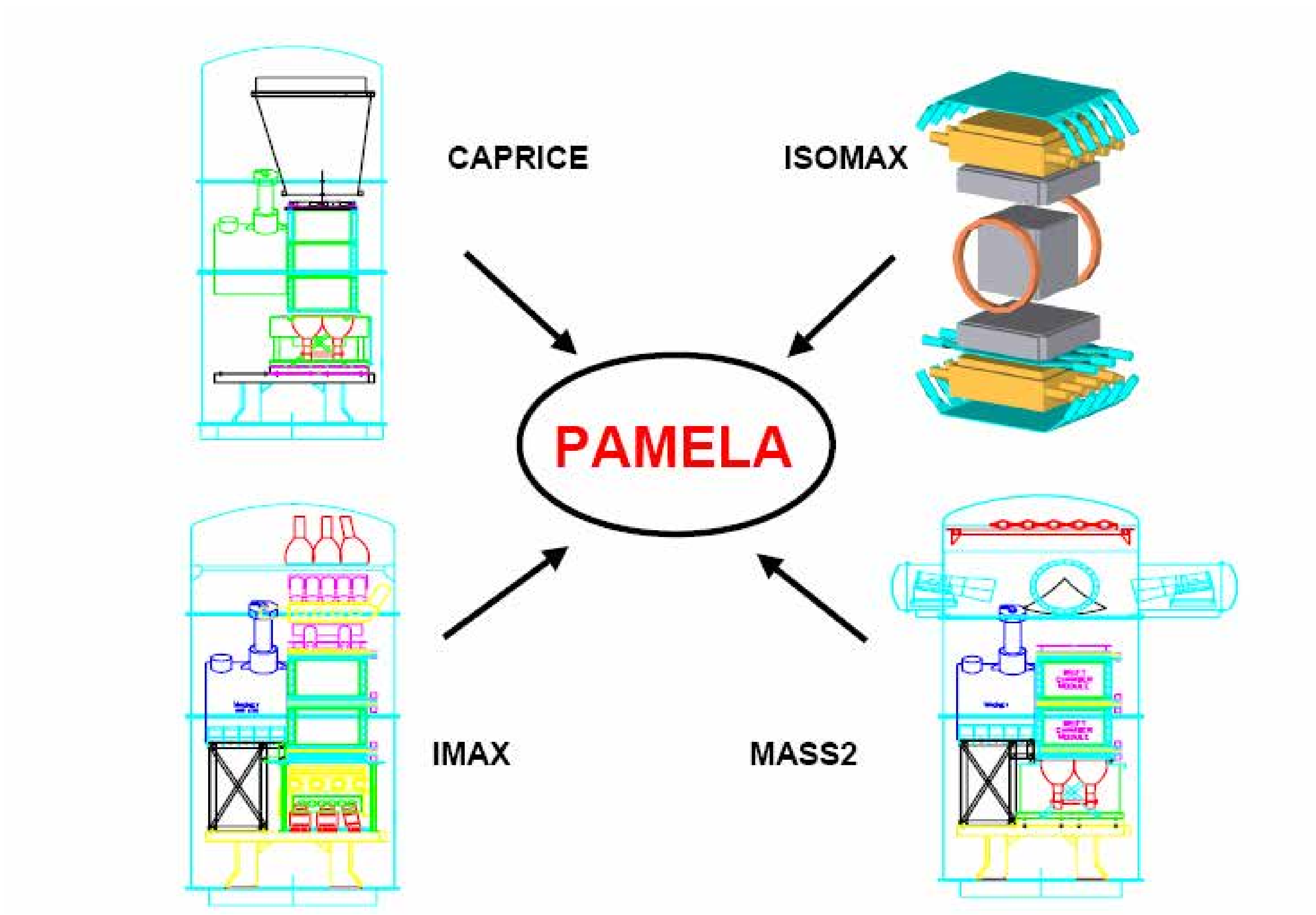



atmospheric secondaries (~5g/cm²)

**Positrons**



# From balloon experiments to PAMELA…



# PAMELA Design Performance

| | |
|---|---|
| • Antiprotons | 80 MeV - 150 GeV |
| • Positrons | 50 MeV - 300 GeV |
| • Limit on Antinuclei | ~$10^{-8}$ ($\overline{He}$/He) |
| • Protons | 80 MeV - 700 GeV |
| • Electrons | 50 MeV - 500 GeV |
| • Electrons+Positrons | up to 2 TeV (Calorimeter) |
| • Light Nuclei | up to 200 GeV/n |
| • Solar Flare Particles | E > 50 MeV |

→ Unprecedented statistics
→ New energy range for cosmic ray physics
→ Simultaneous measurements of many species

# The PAMELA Collaboration

**Italy**

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

**Russia**

Ioffe Physico-Technical Institute

Moscow
St. Petersburg

**Germany**

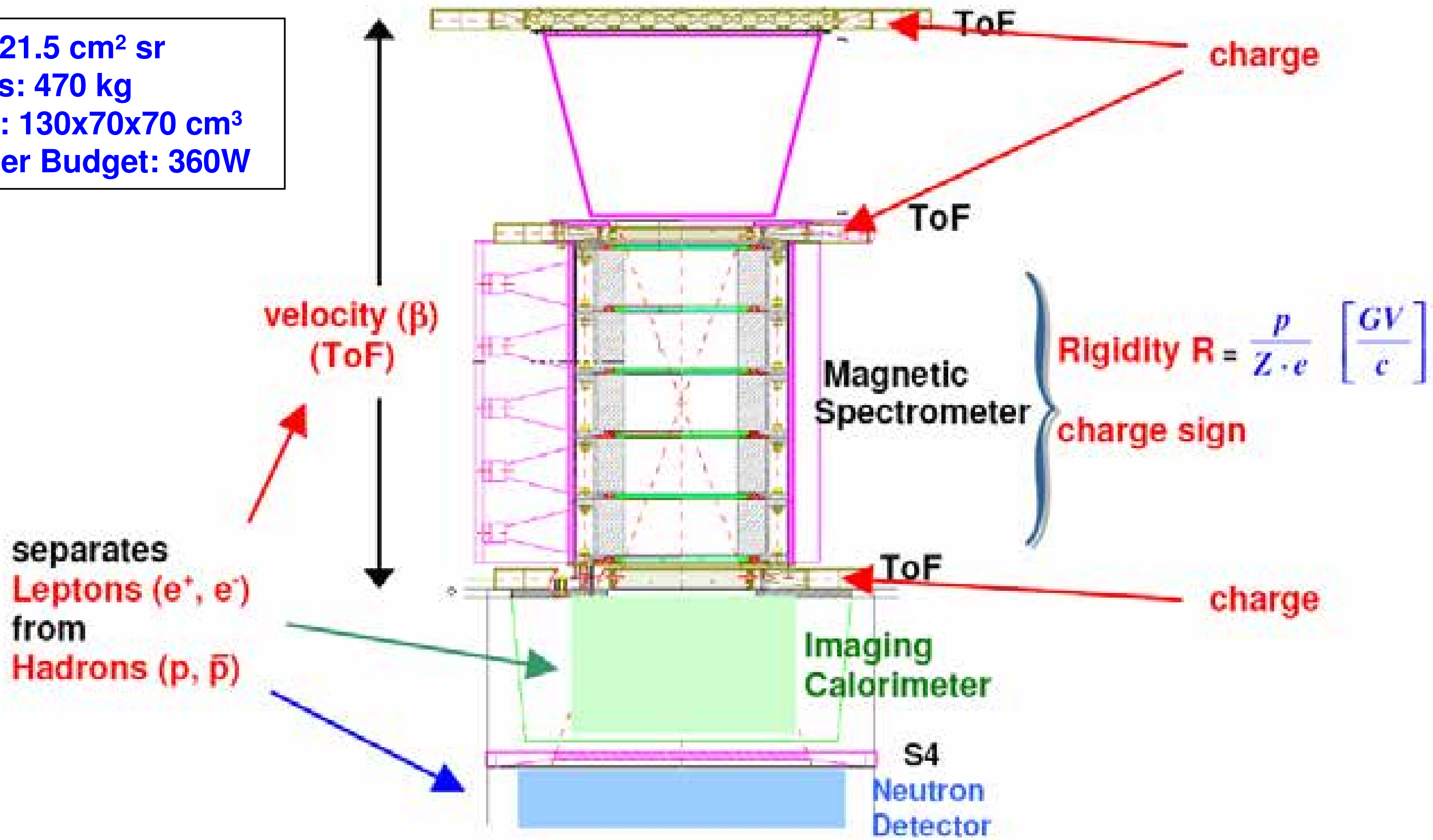
Siegen

**Sweden**

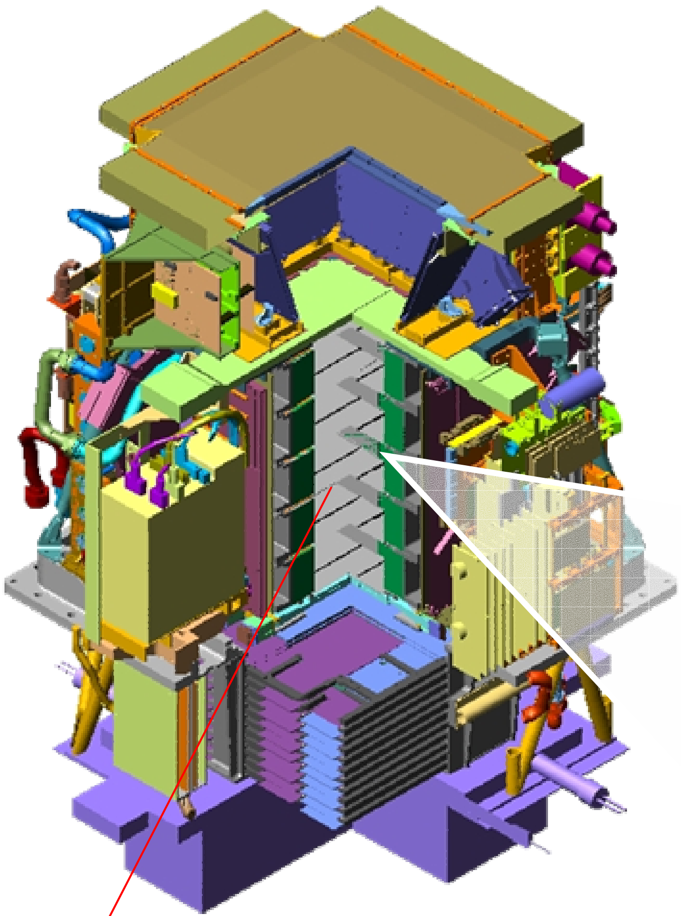
KTH, Stockholm

# PAMELA and its Measured Quantities

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

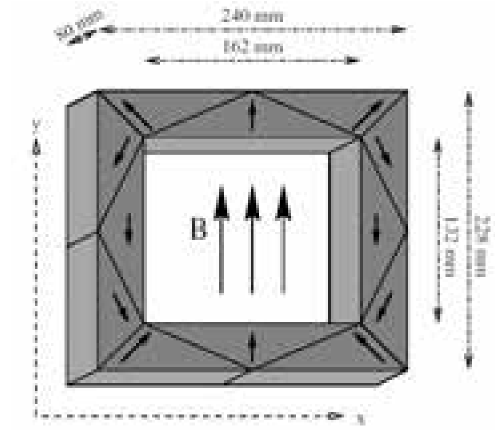


# PAMELA



SPECTROMETER

## The magnet

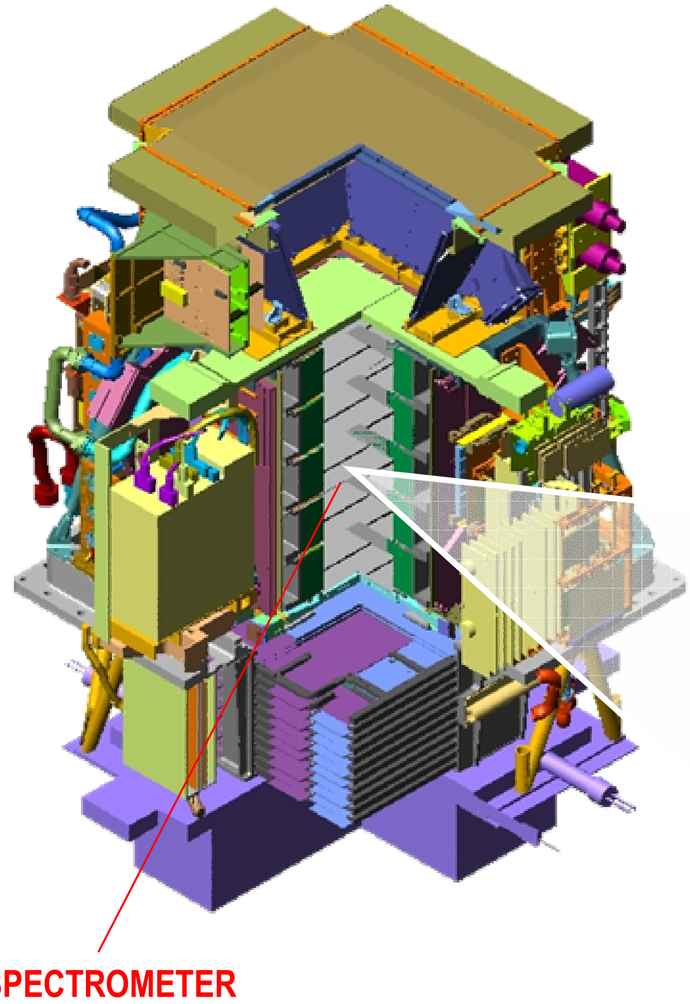



**Characteristics:**

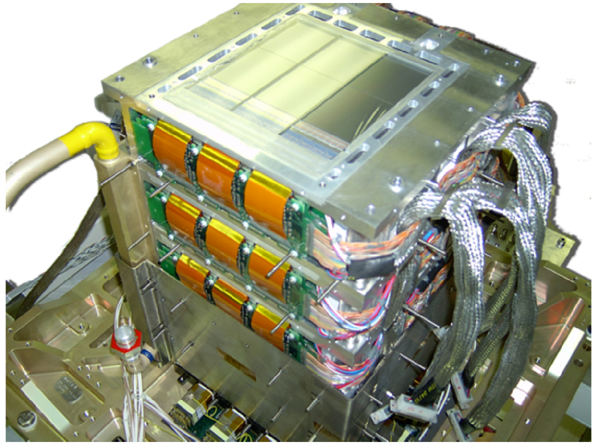
- **5 modules of permanent magnet Nd-B-Fe alloy (Vacuumschmelze Hanau) in aluminum mechanics**
- **Cavity 16.2x13.2x44.5 cm$^3$**

  **→GF 21.5 cm$^2$sr**
- **B=0.43 T (average along axis), B=0.48 T (@center)**

# PAMELA




## The tracking system



**Main tasks:**

- Rigidity measurement
- Sign of electric charge
- dE/dx

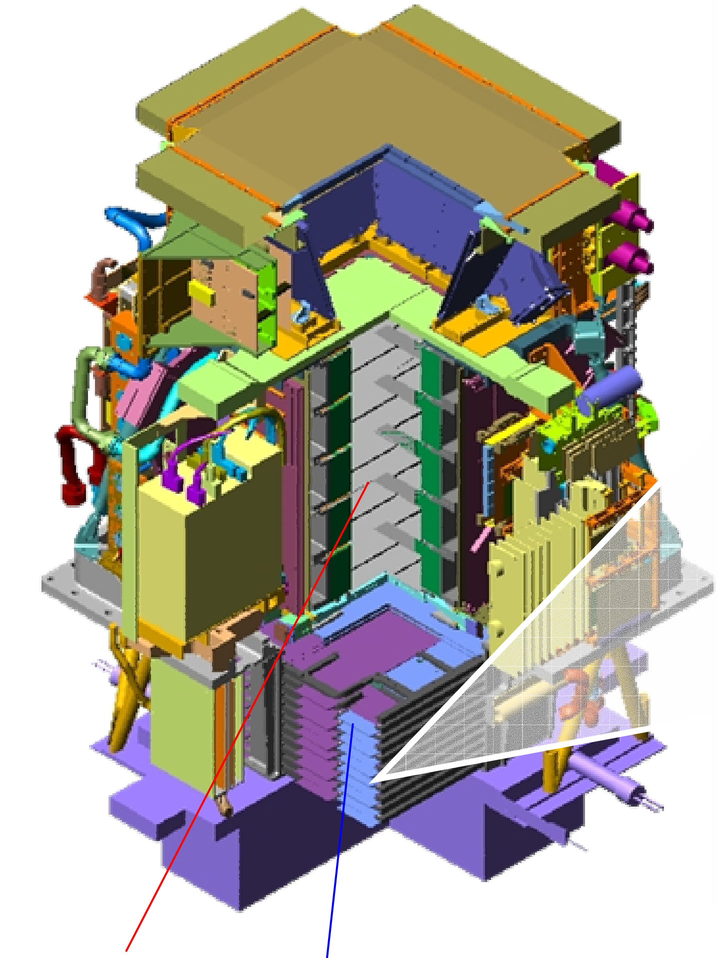
**Characteristics:**

- **6 planes double-side (x&y view) microstrip Si sensors**
- 36864 channels
- Dynamic range 10 MIP

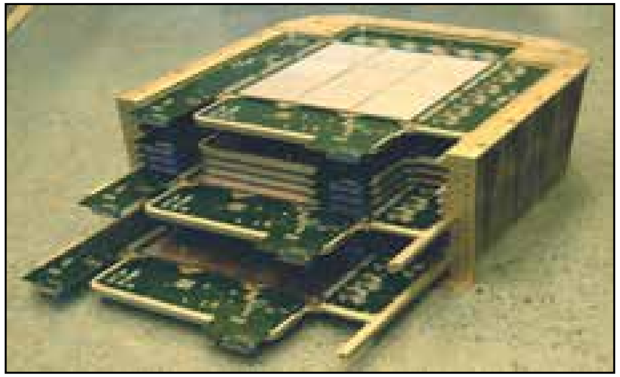
**Performances:**

- Spatial resolution: **3÷4 μm**
- **MDR ~1TV** (from test beam data)

# PAMELA




## The electromagnetic calorimeter



**Main tasks:**

- e/h discrimination
- $e^{+/-}$ energy measurement

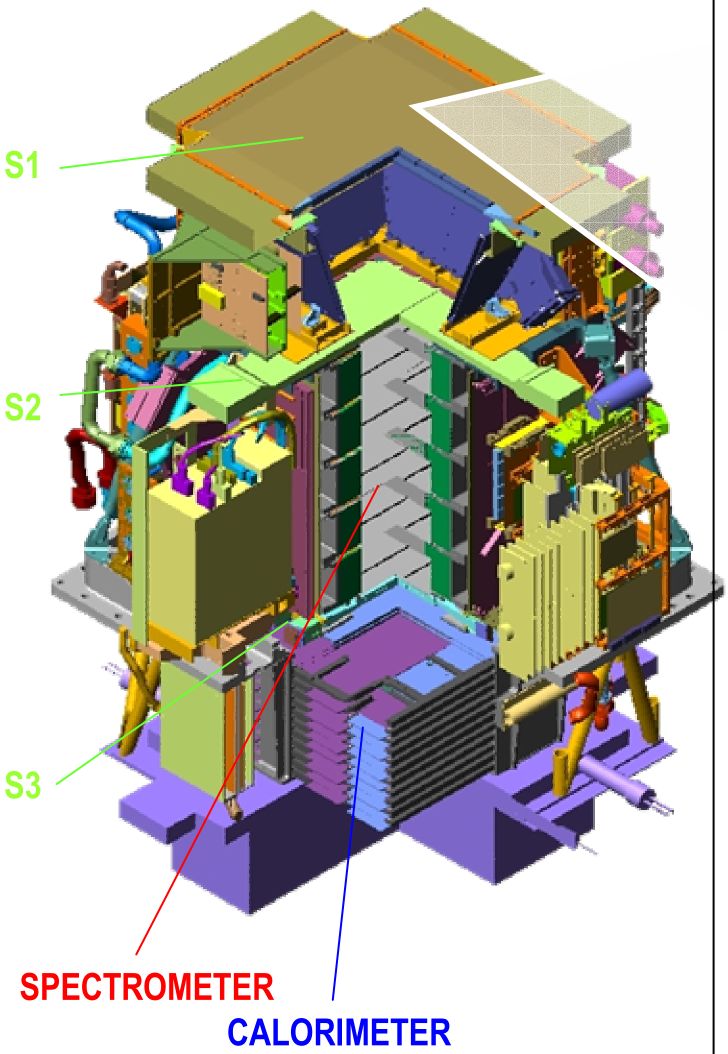
**Characteristics:**

- **44 Si layers (X/Y) +22 W planes**
- **$16.3\ X_o$ / $0.6\ I_0$**
- 4224 channels
- Dynamic range ~1100 mip
- Self-trigger mode (> 300 GeV GF~600 $cm^2$ sr)

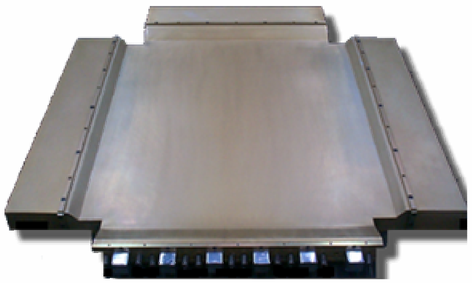
**Performances:**

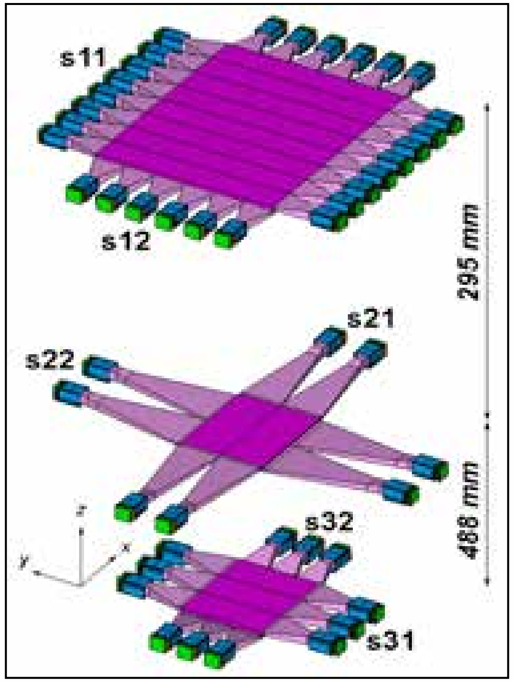
- Energy resolution **~5%** @200GeV

# PAMELA




## The time-of-flight system



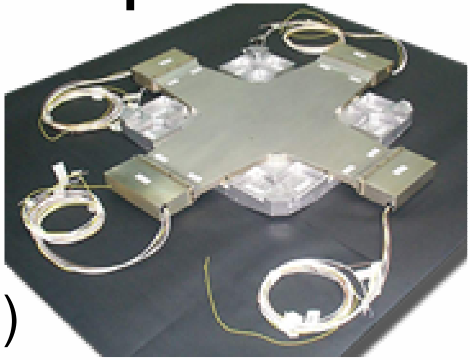



### Main tasks:

- First-level trigger
- Albedo rejection
- dE/dx
- Particle identification (<1GeV/c)

### Characteristics:

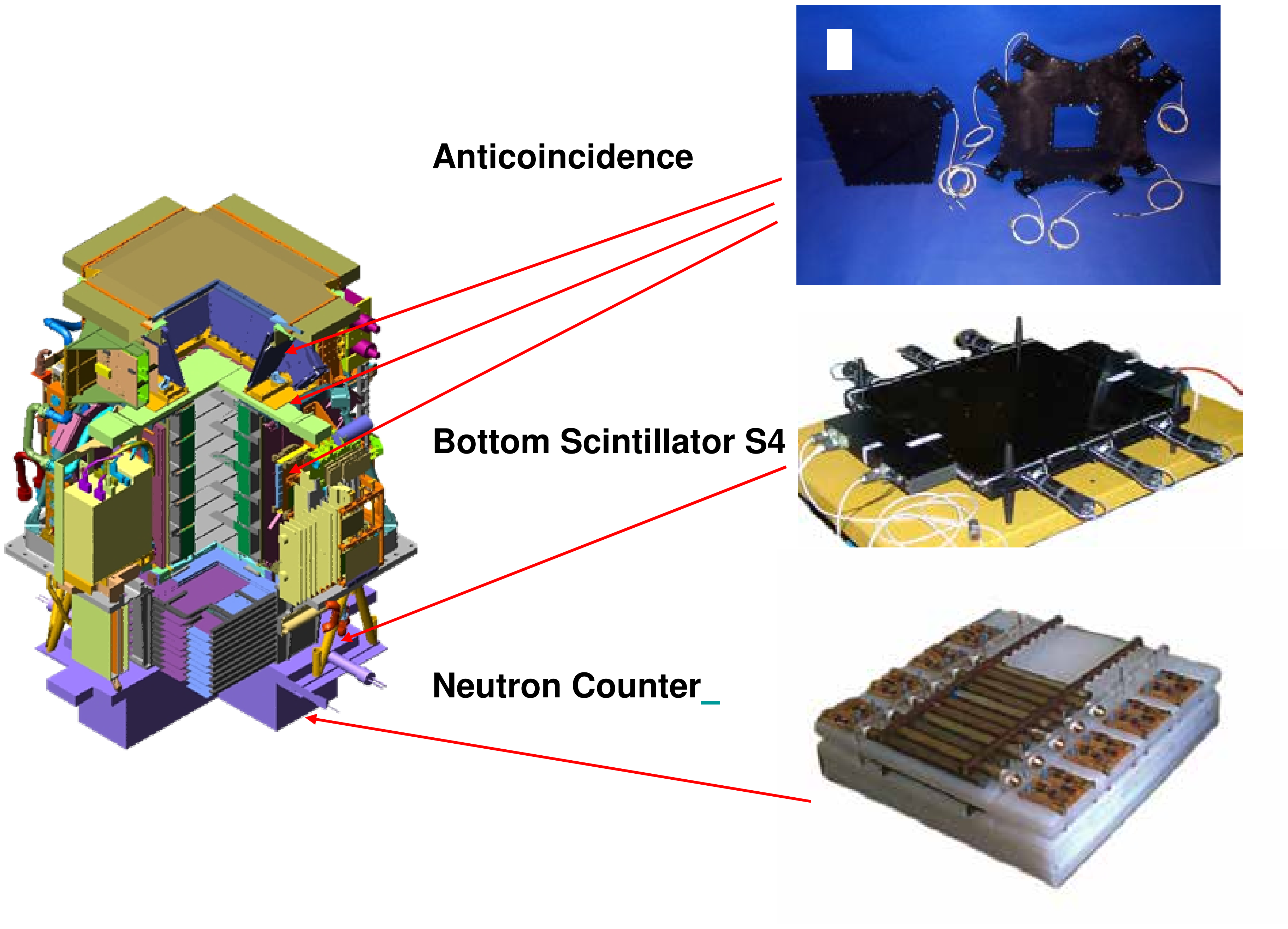
- **3 double-layer scintillator paddles**
- X/Y segmentation
- Total: 48 Channels



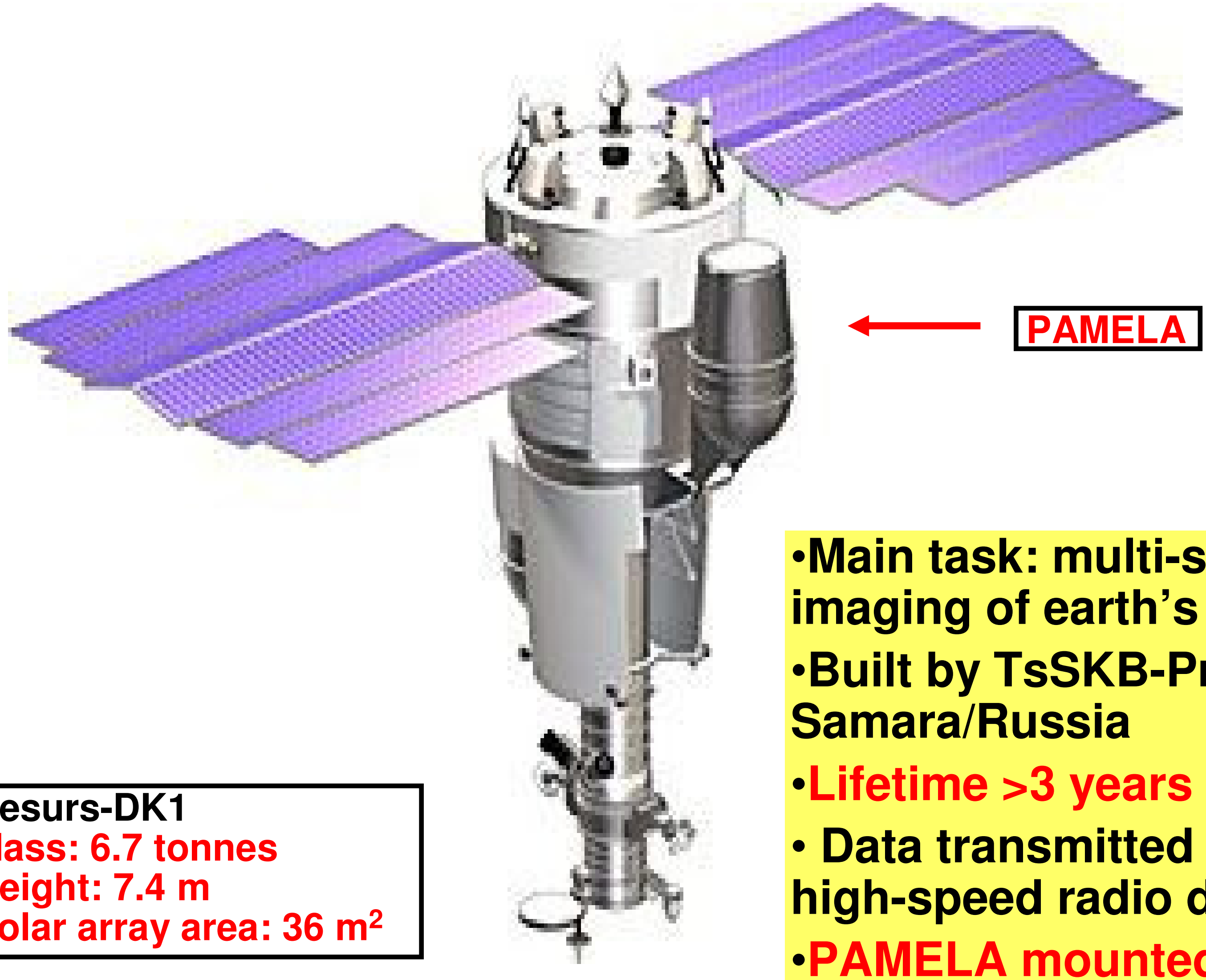
### Performances:

- $\sigma_{paddle}$ ~ 150ps
- $\sigma_{TOF}$ ~ **330ps** (for MIPs)

# PAMELA

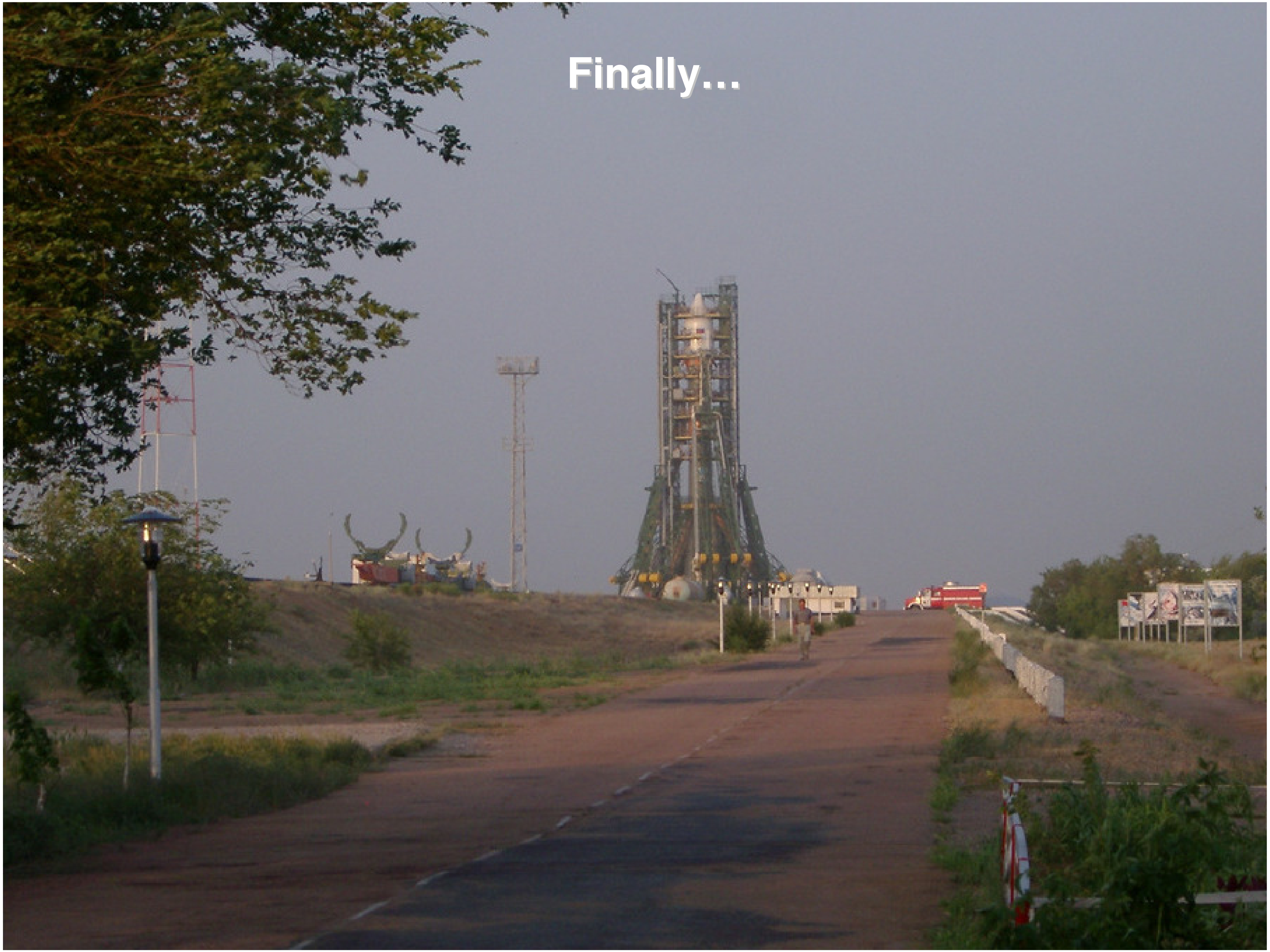


# Resurs-DK1 Satellite




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

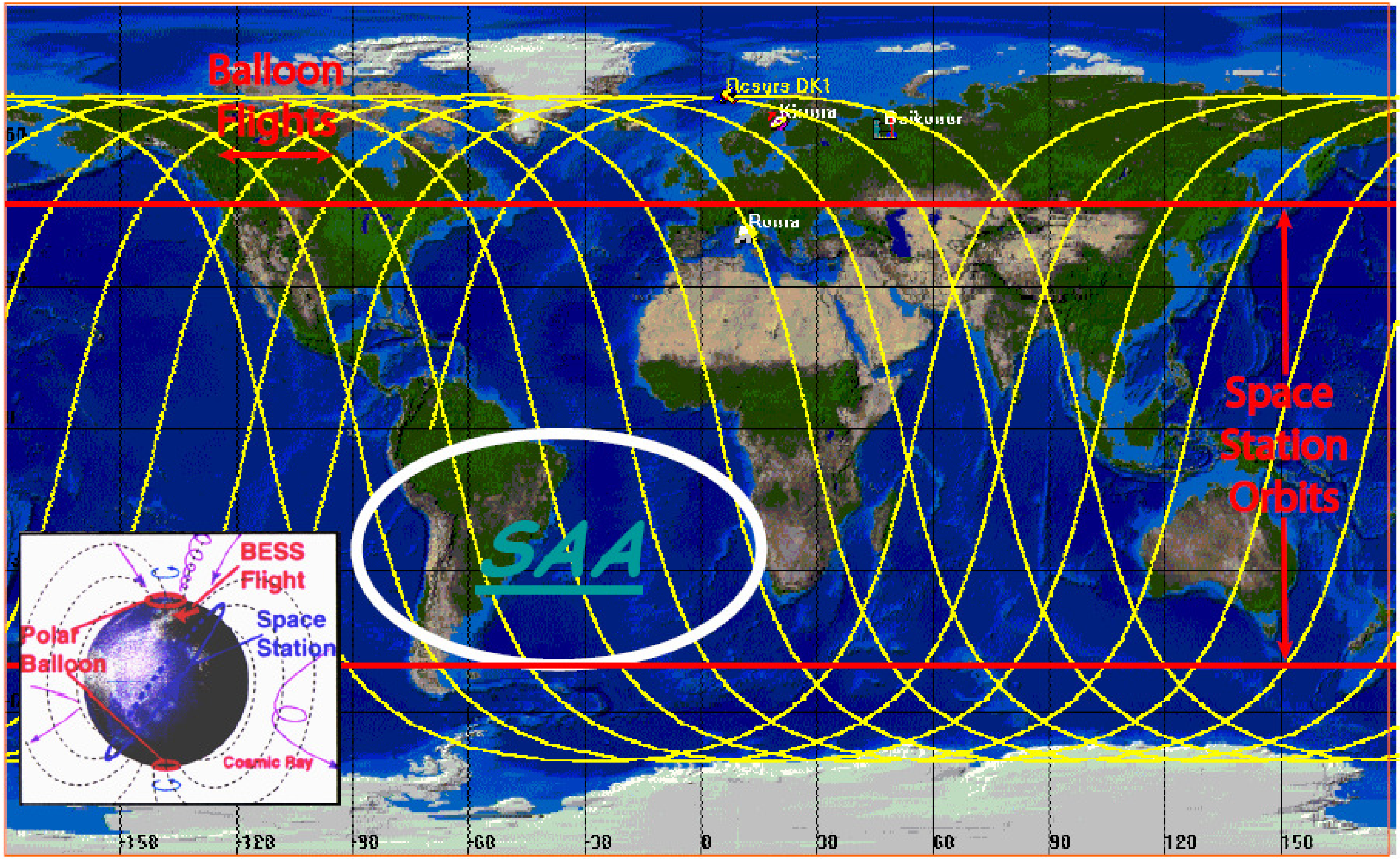
- Main task: multi-spectral imaging of earth's surface
- Built by TsSKB-Progress in Samara/Russia
- Lifetime >3 years (assisted)
- Data transmitted ground via high-speed radio downlink.
- PAMELA mounted inside a pressurized container


Finally…


Launch from Baikonur June 15th 2006

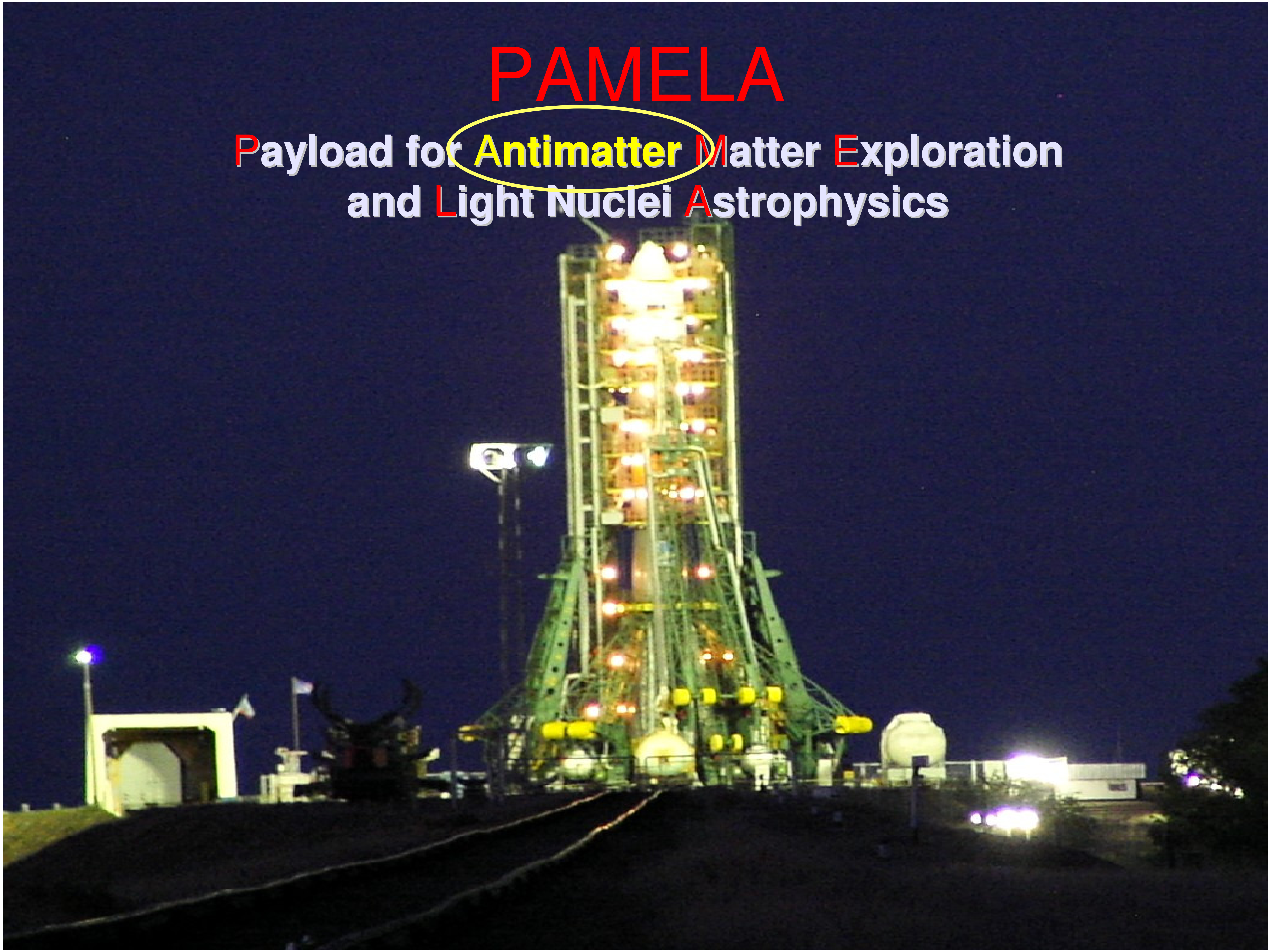
# PAMELA Orbit Characteristics

**Quasi-polar (70.4°)** **Elliptical (350 – 600 km)**



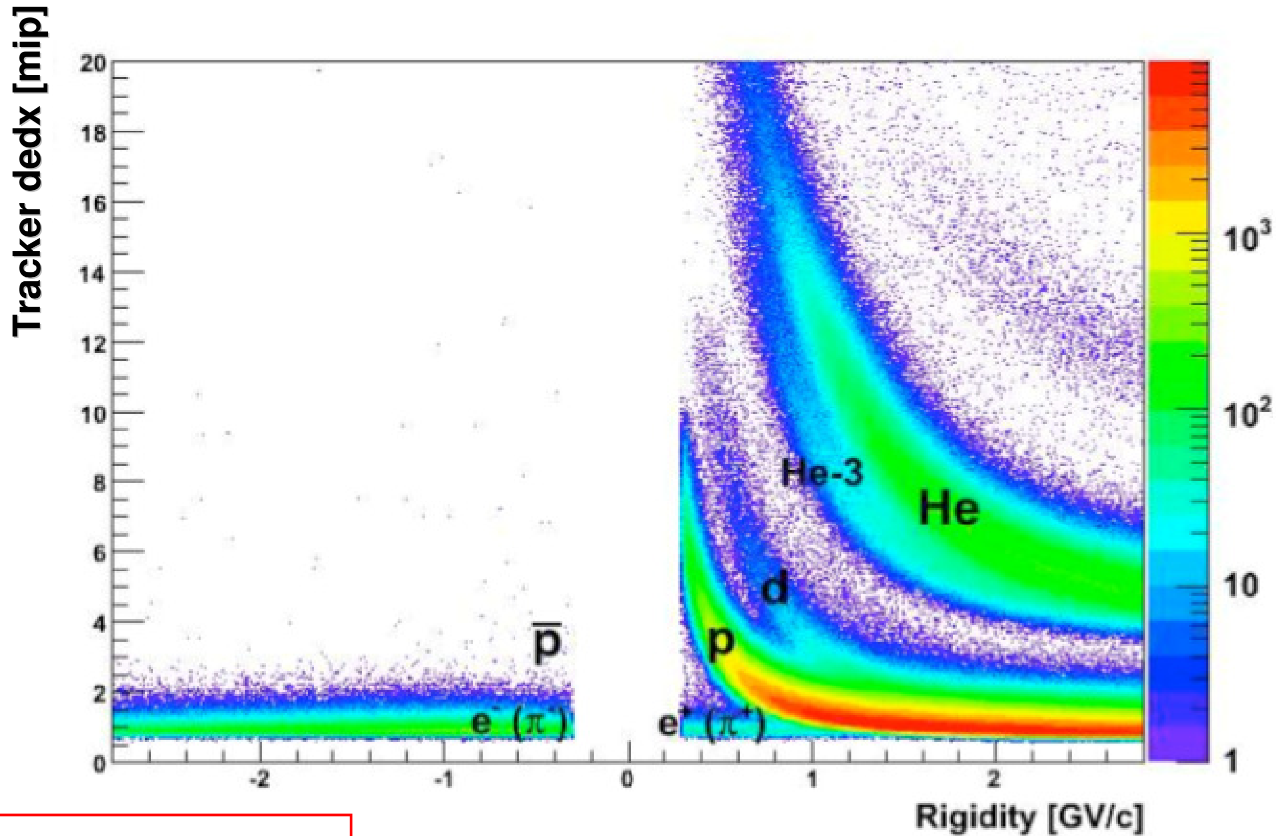
# PAMELA

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



# Reminder: Charged particles

**Particle identification = combination of measurements**



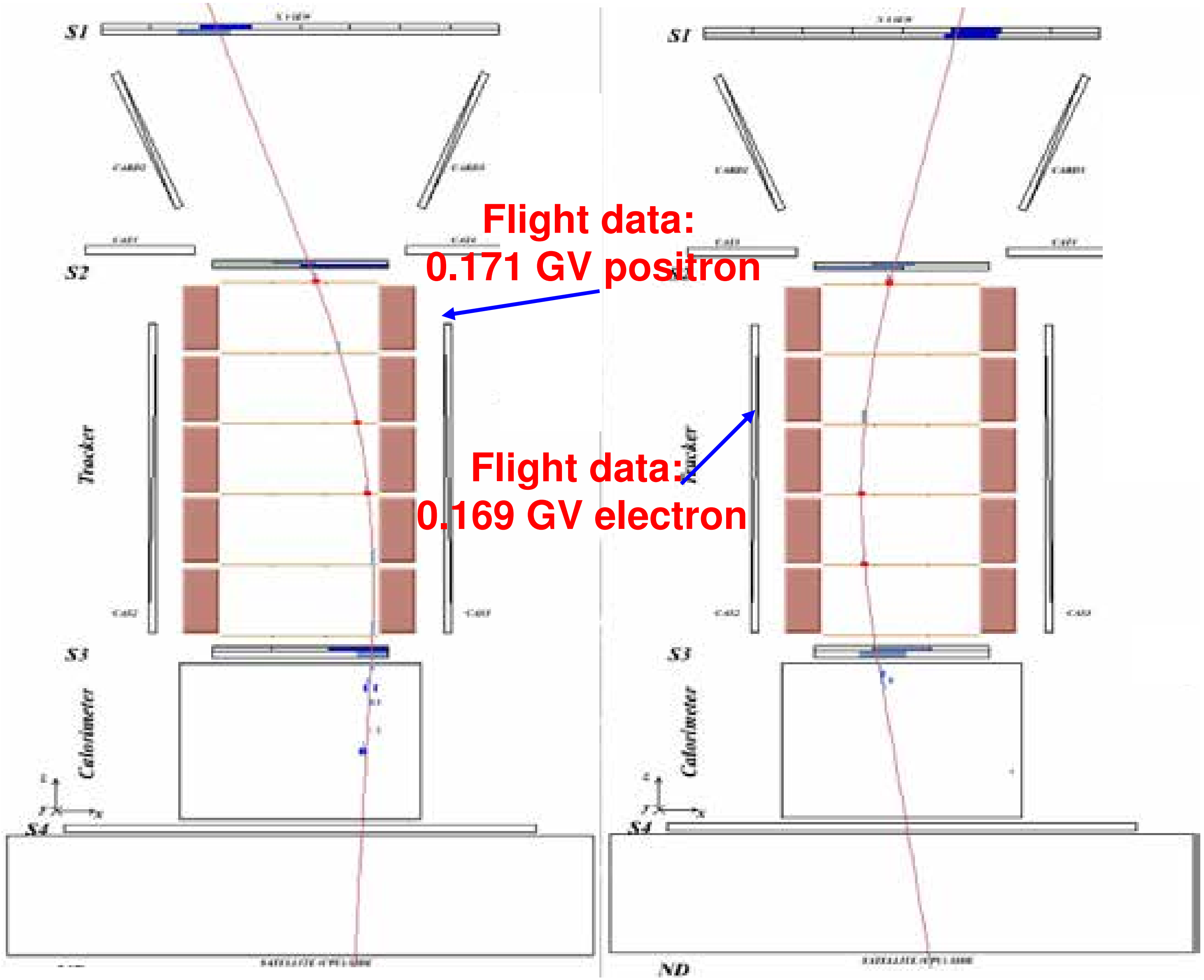

$\bar{p}/p \leq 10^{-4} - 10^{-6}$

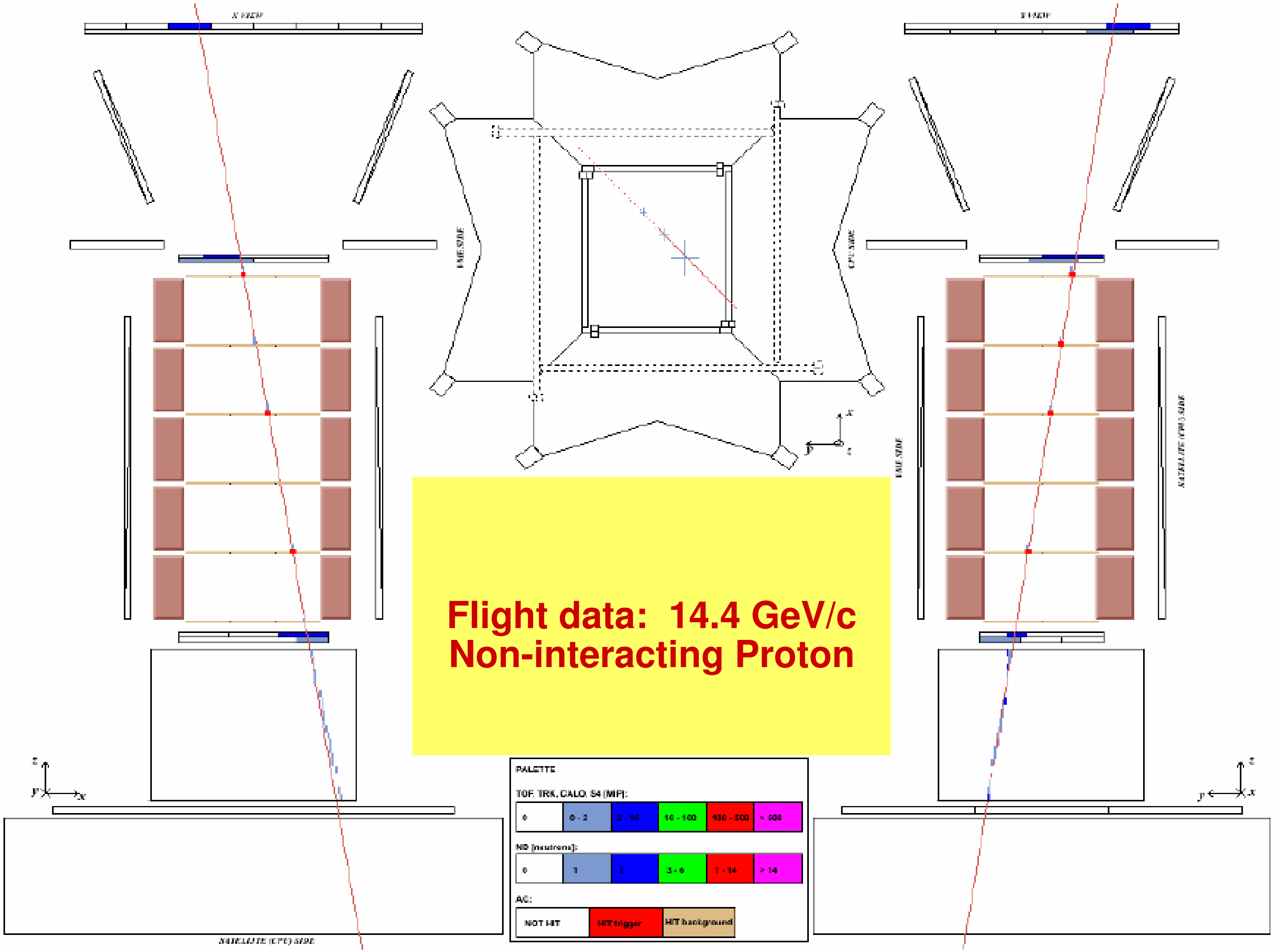
$p/e^{+} \geq 10^{3} - 10^{4}$

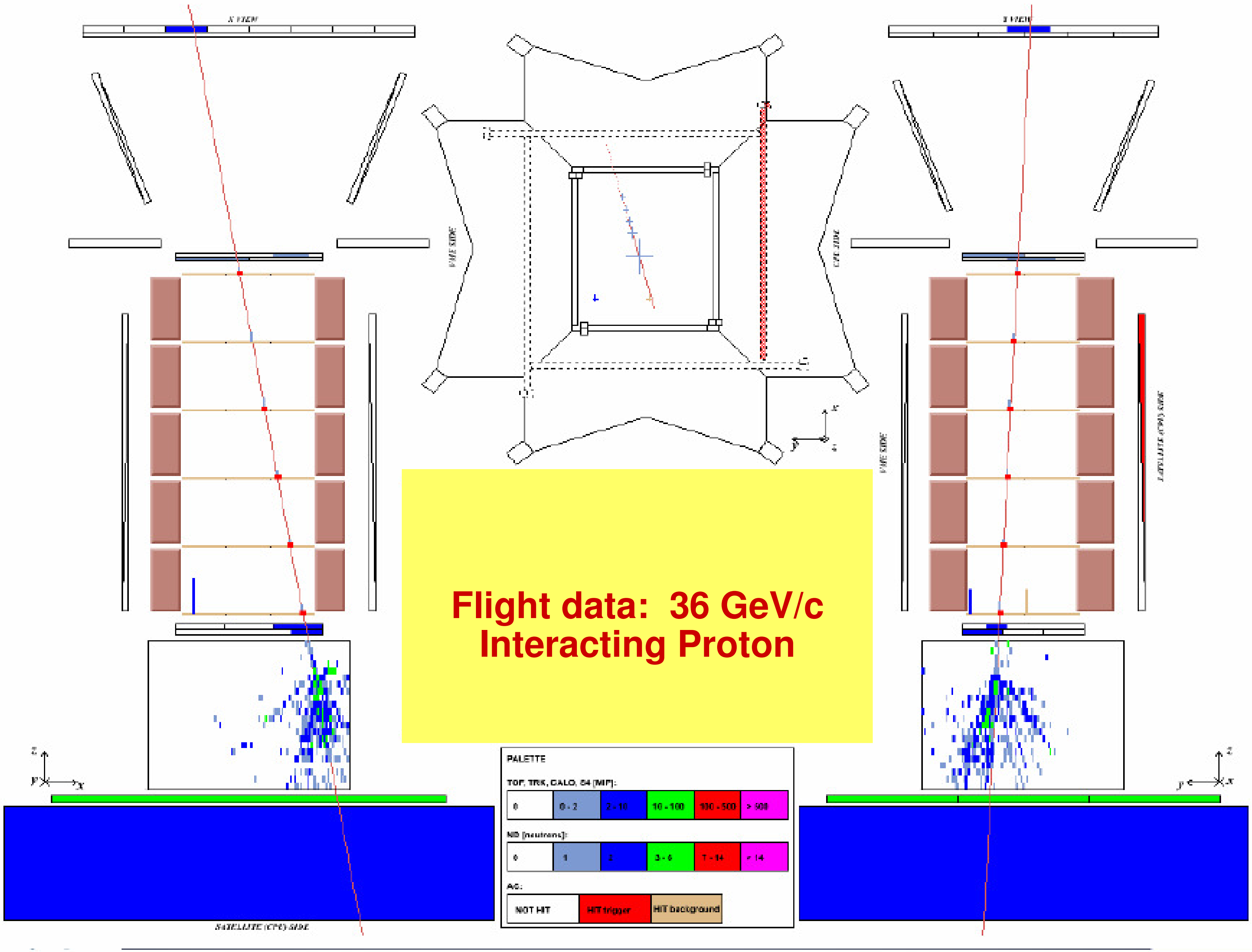
$\bar{p}/e^{-} \leq 10^{-3}$

**Not so easy….**
**Needs good "Rejection Power"**

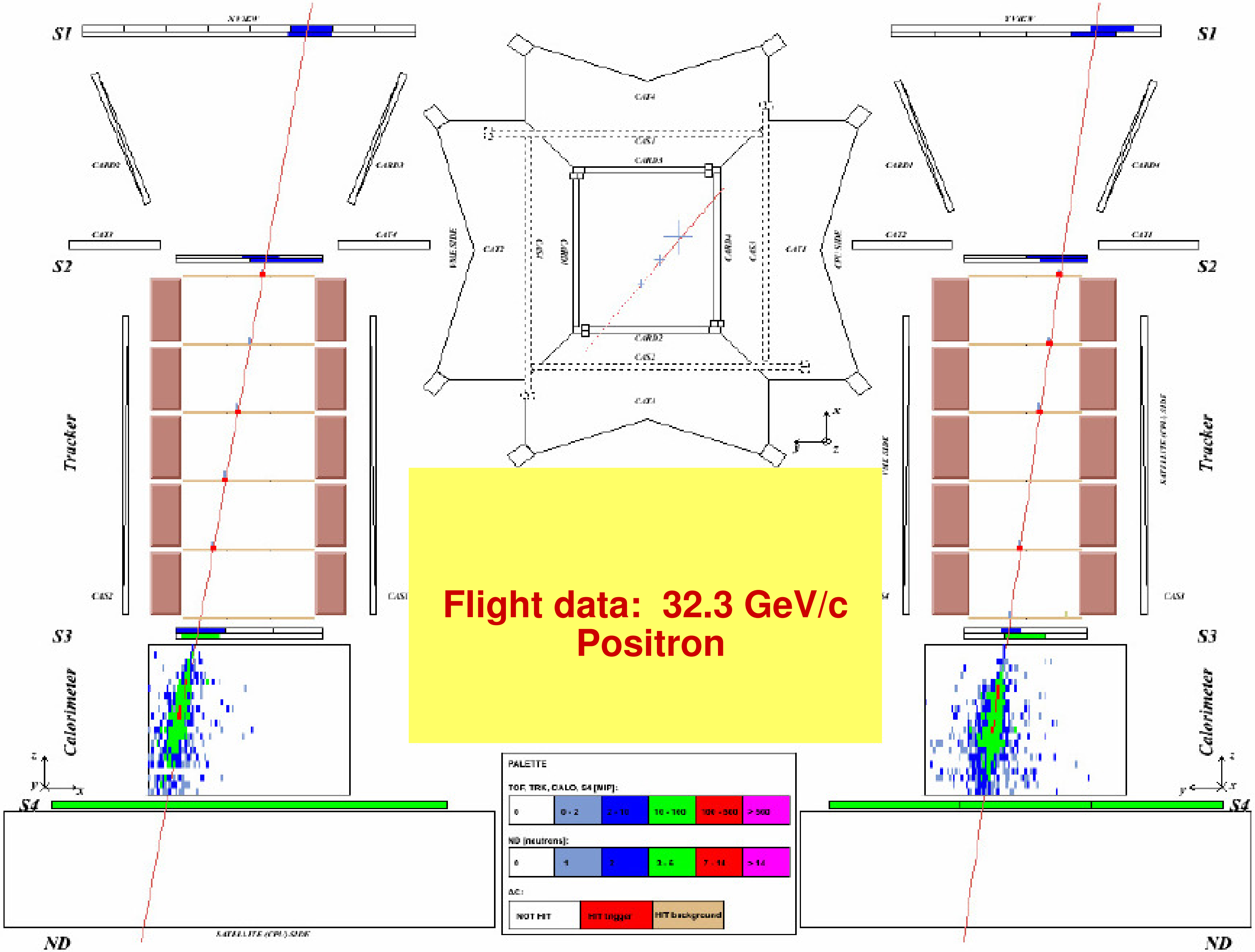
# Bending direction determines the charge sign




Flight data: 14.4 GeV/c
Non-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

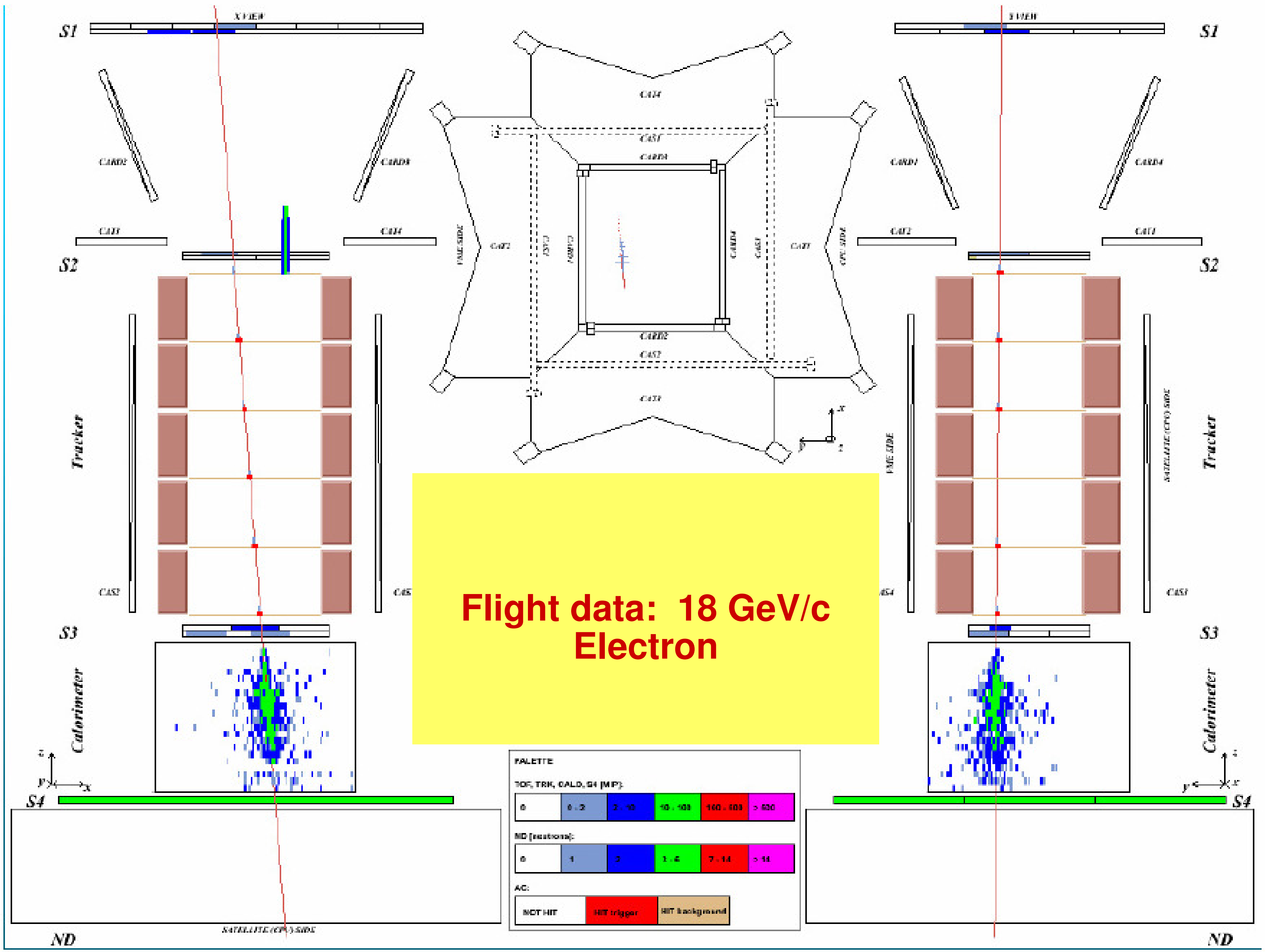


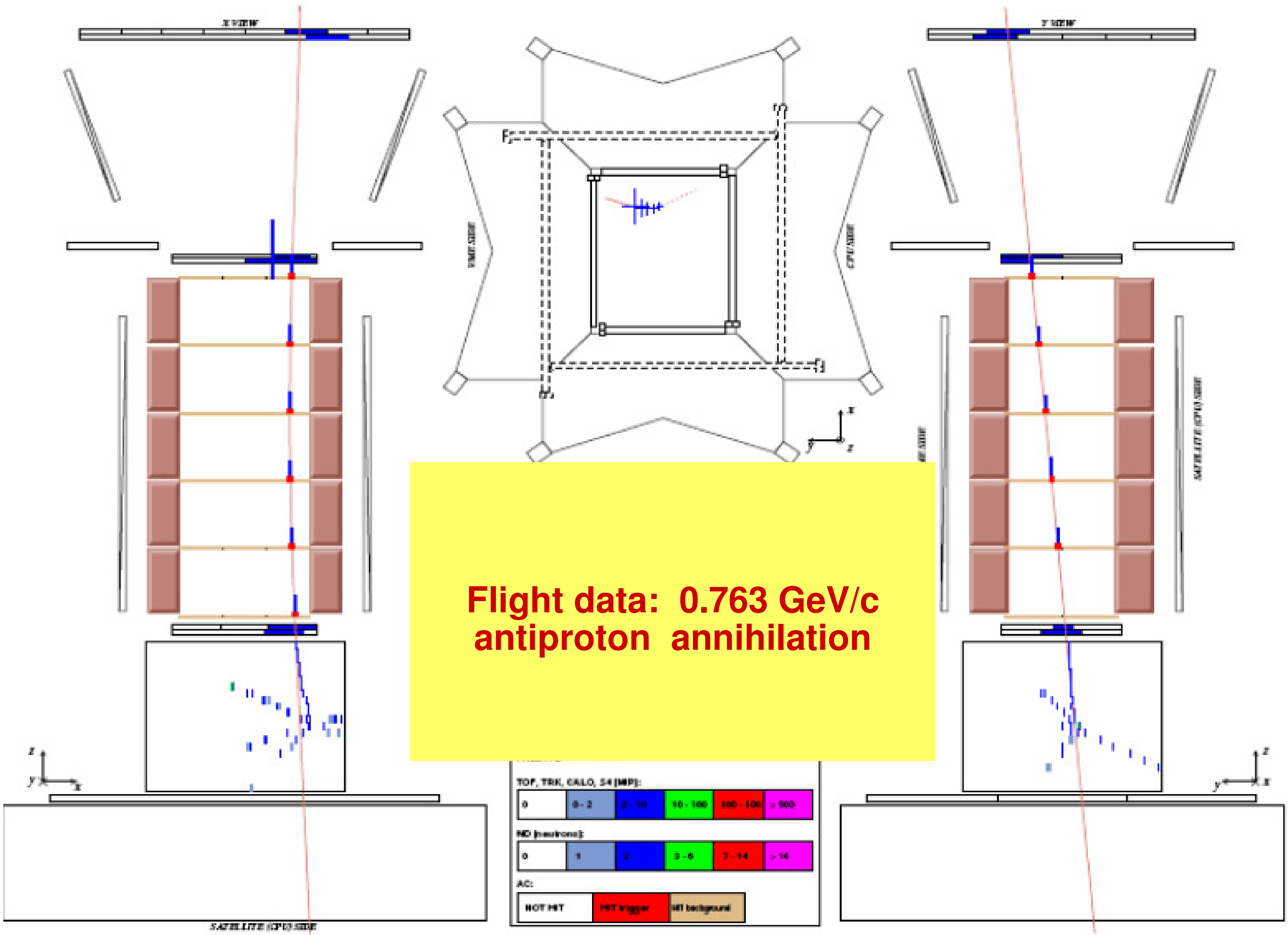
Flight data: 36 GeV/c
Interacting Proton
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
AC:
NOT HIT
HIT trigger
HIT background



Flight data: 32.3 GeV/c
Positron
S1
S2
S3
S4
ND
Tracker
Calorimeter
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

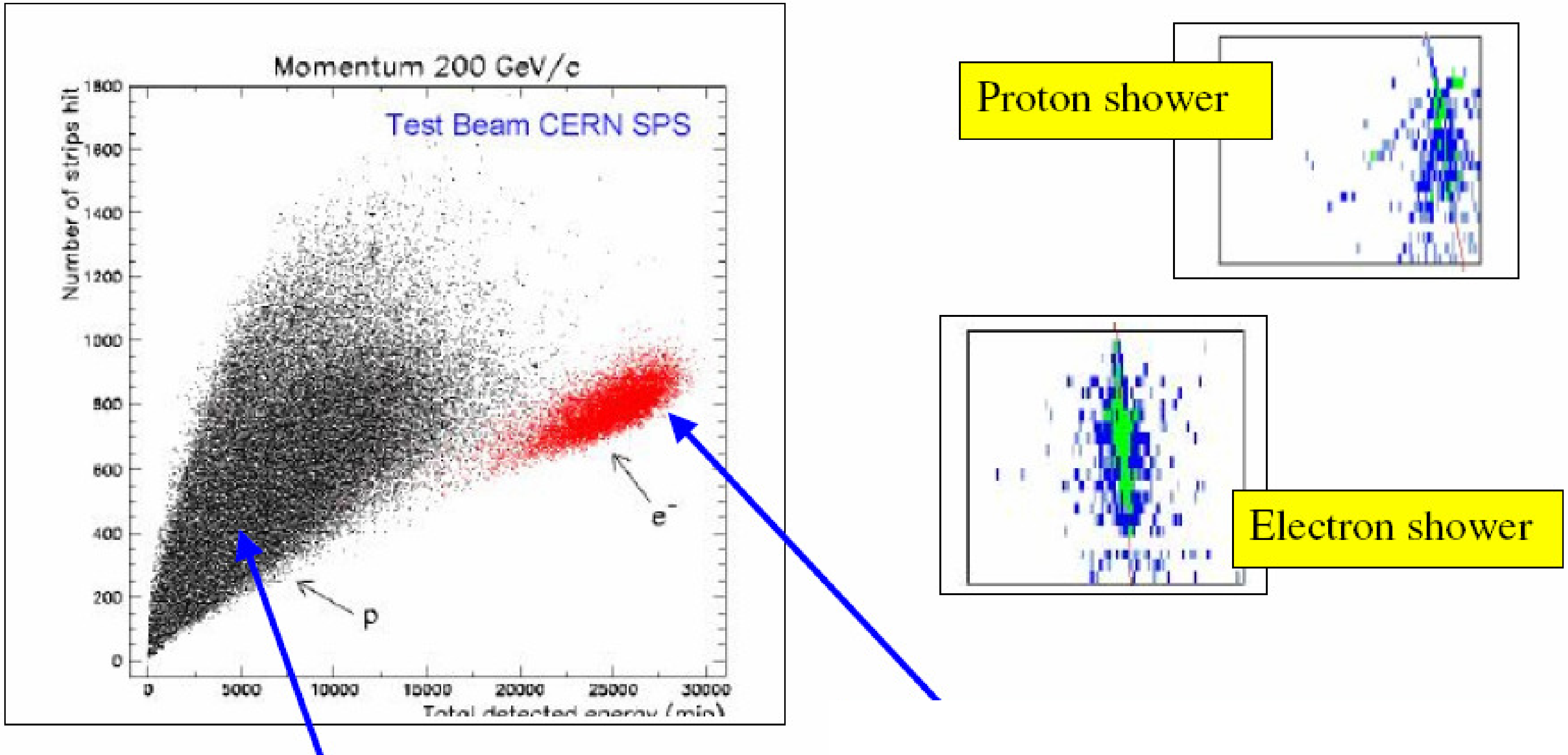
# Flight data: 18 GeV/c Electron






**Flight data: 0.763 GeV/c antiproton annihilation**

# Calorimeter
# separates the hadron shower from the electron shower




**Protons:**

- shower is widely spread in energy deposit and shower size
- Most protons interact well deep in the calorimeter or do not interact at all.

**Electrons:**

- shower is narrow in energy deposit and shower size
- electrons interact in the first calorimeter layers

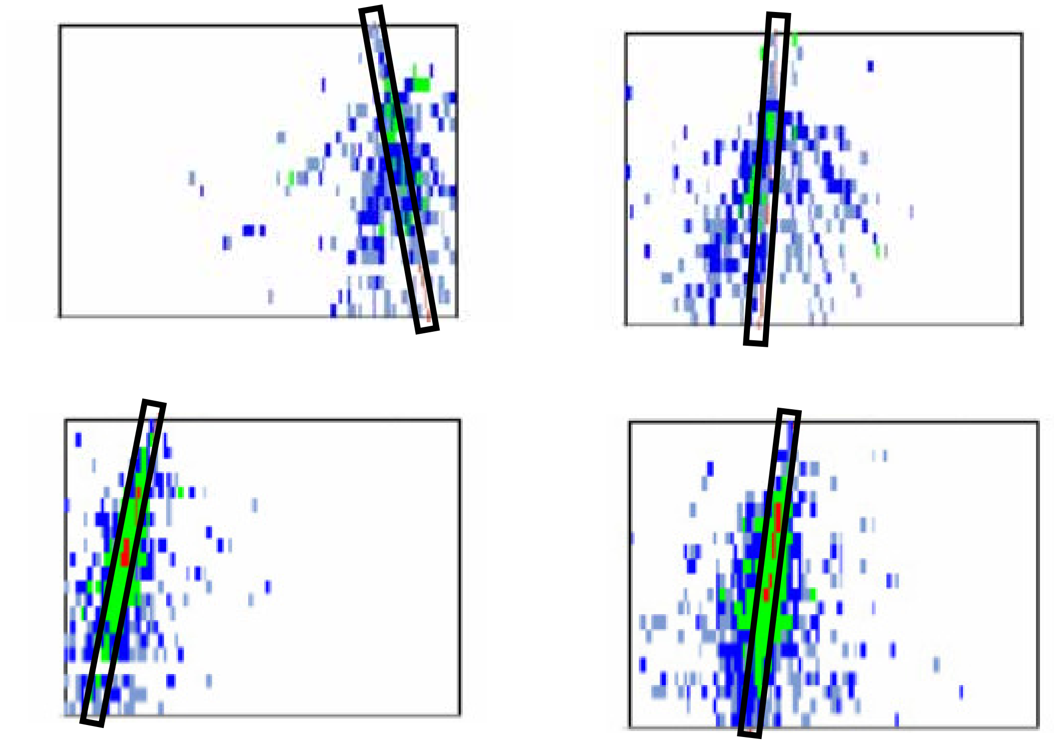
# Now, Positrons…

# Fraction of charge released along the calorimeter track

**Define a radius of 0.6 $R_M$ around the calorimeter track:**

Protons

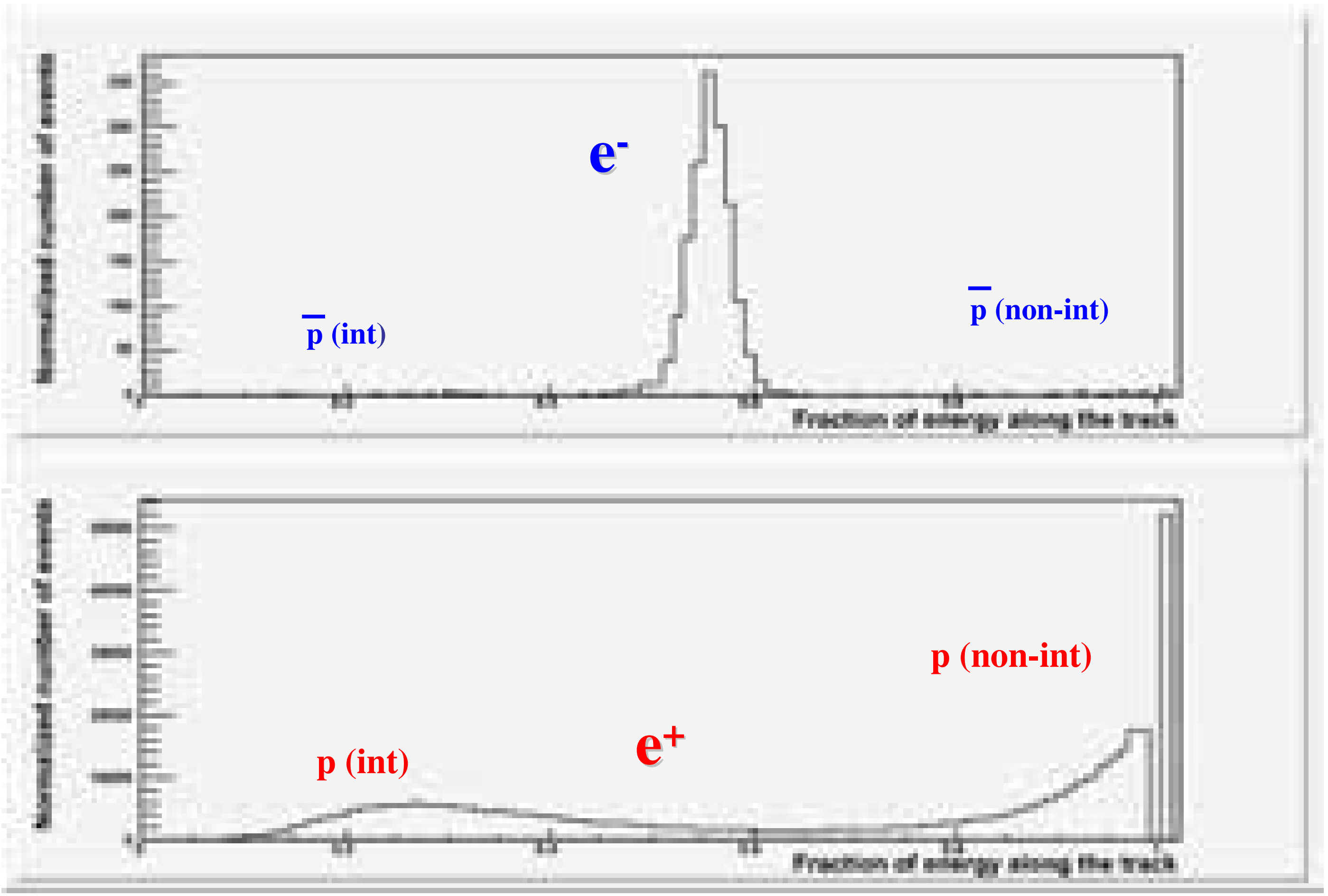
Electrons



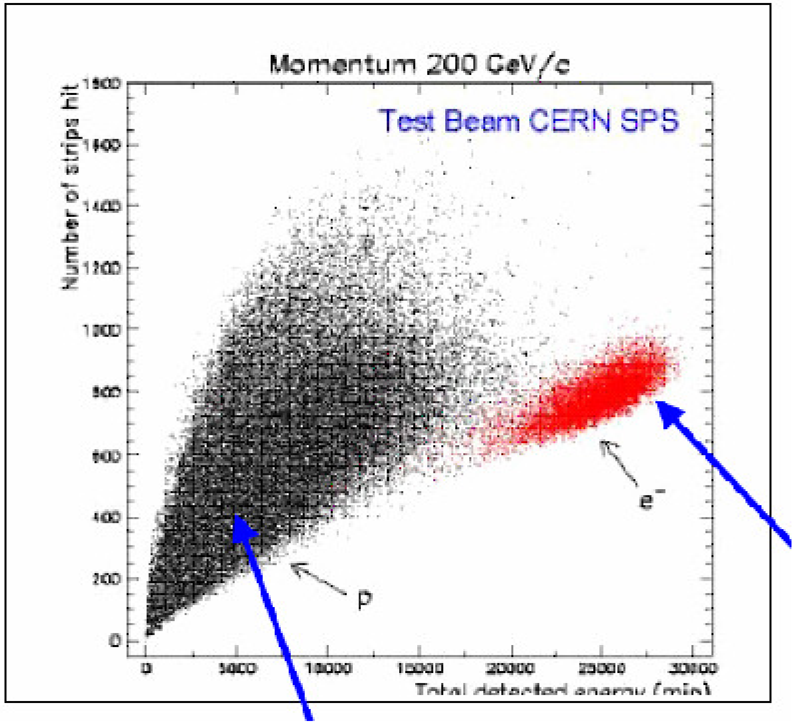
X-view y-view

# Fraction of charge released along the calorimeter track for negative and positive rigidities

Rigidity: 20-30 GV



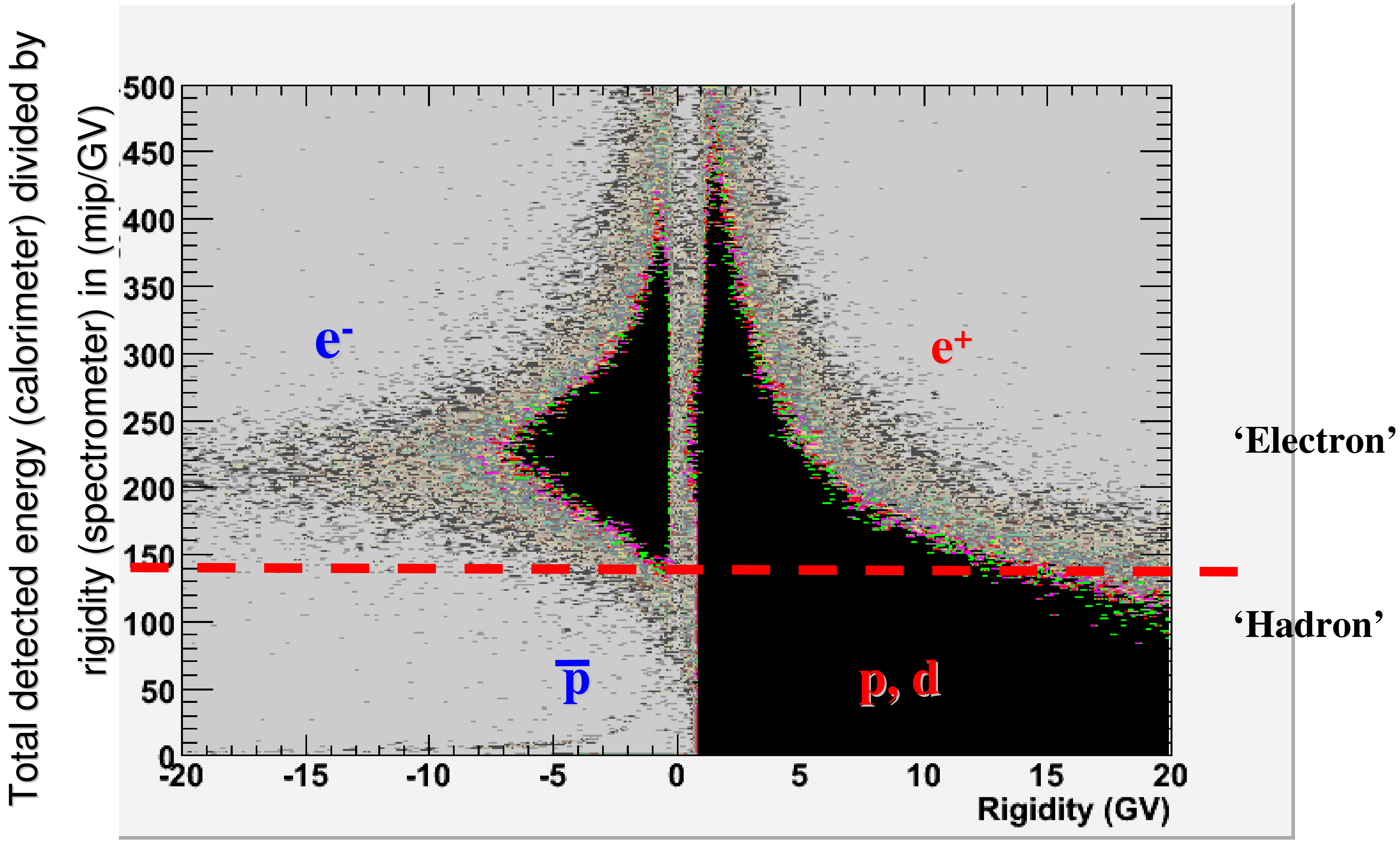
# Reminder: CERN Beam-Test




**At the beam-test we knew the incoming momentum.**
**In PAMELA we have the spectrometer!**

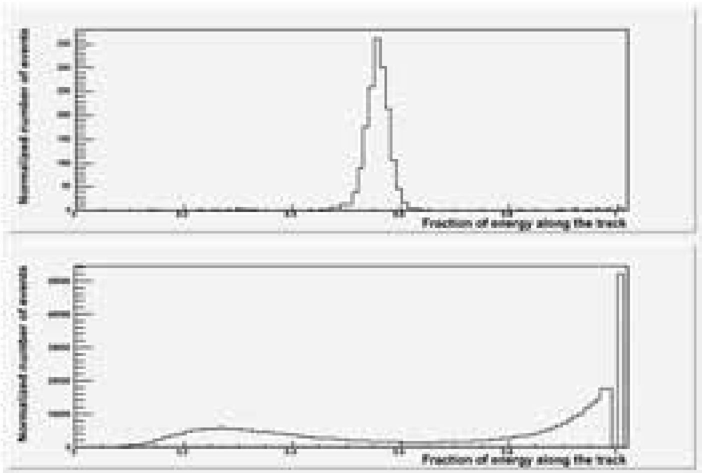
# Antiparticle Selection: “Energy-Momentum-Match”

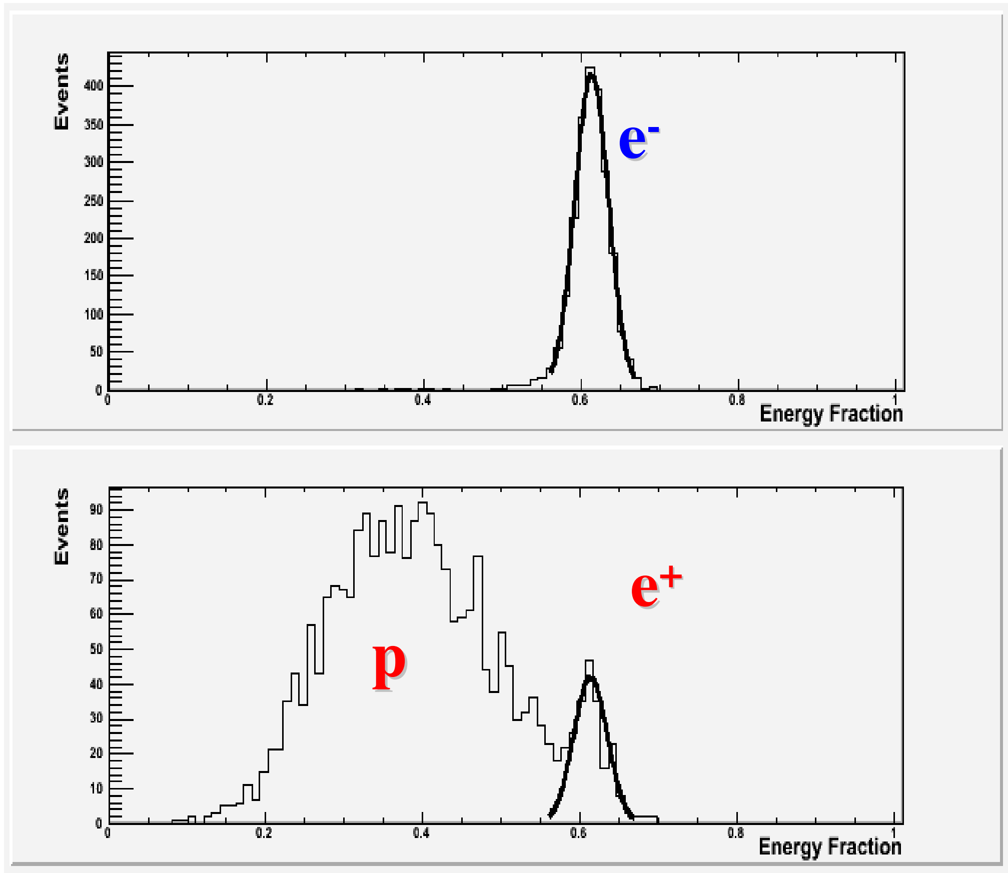
## Combining calorimeter and magnetic spectrometer



# Positron Selection with the Calorimeter

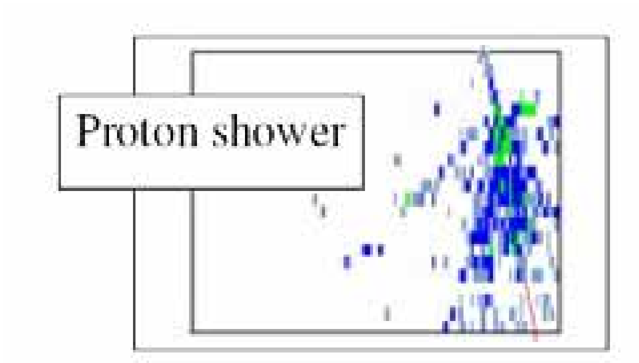
Rigidity: 20-30 GV



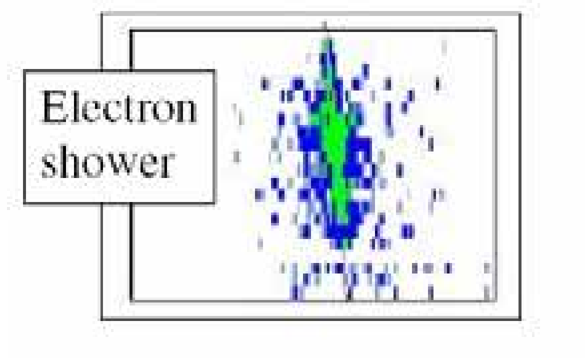




**Energy-Momentum-Match**

# Positron Selection with the Calorimeter




**starting point of shower**




**Protons:**

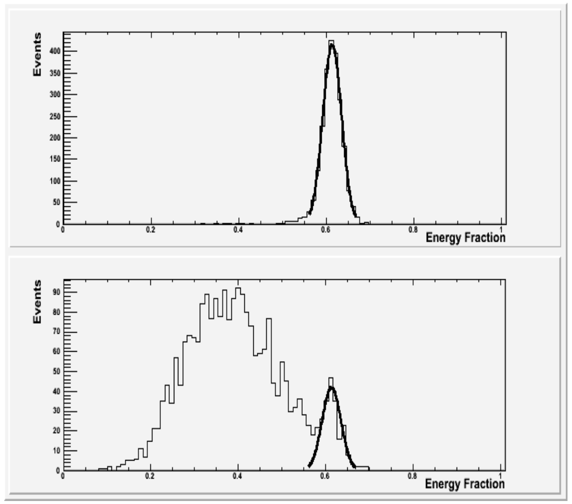
- **Most protons interact well deep in the calorimeter or do not interact at all.**

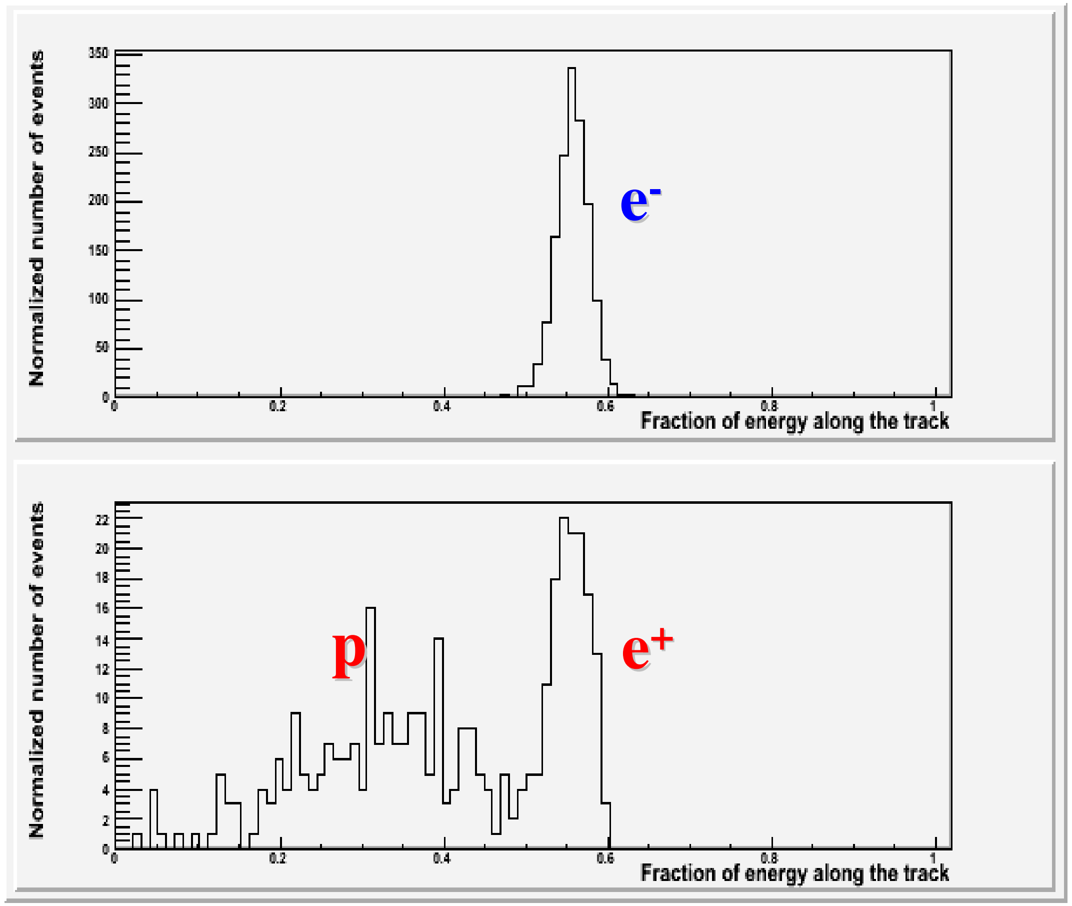
**Electrons:**

- **electrons interact in the first calorimeter layers**

# Positron Selection with the Calorimeter

**Rigidity: 20-30 GV**

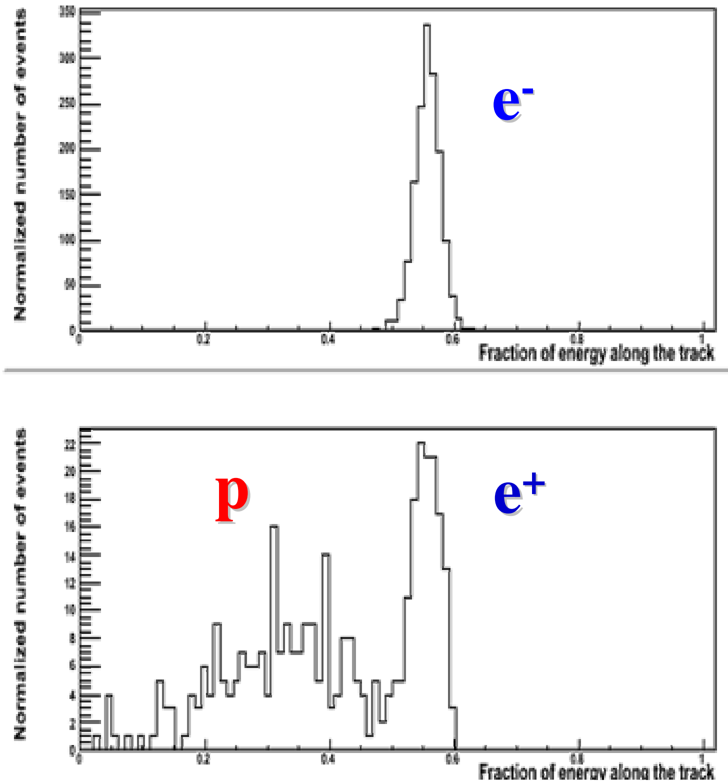



**Energy-Momentum-Match**
**Starting Point of Shower**

# Check of calorimeter selection: Compare with test beam data…

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




Fraction of charge released along the calorimeter track

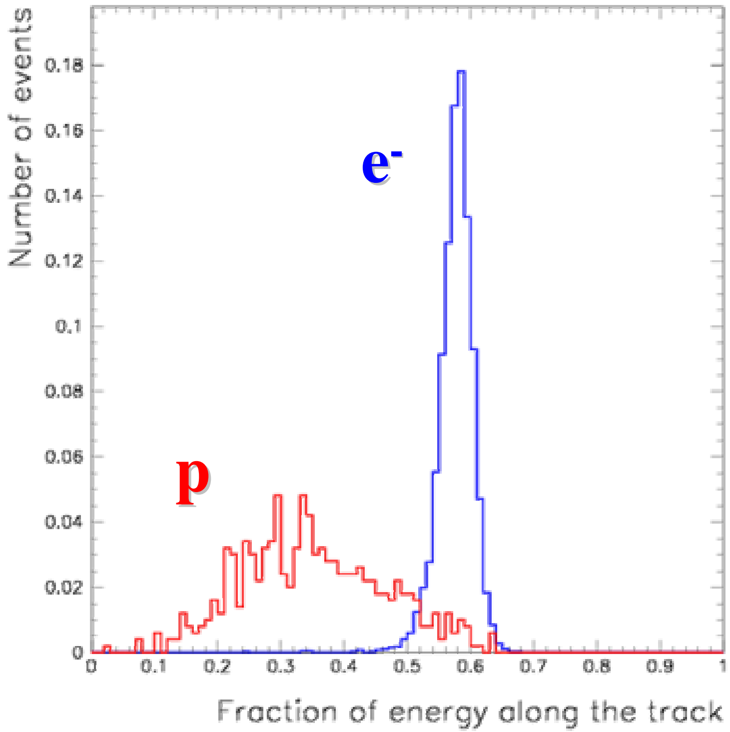
+

Constraints on:

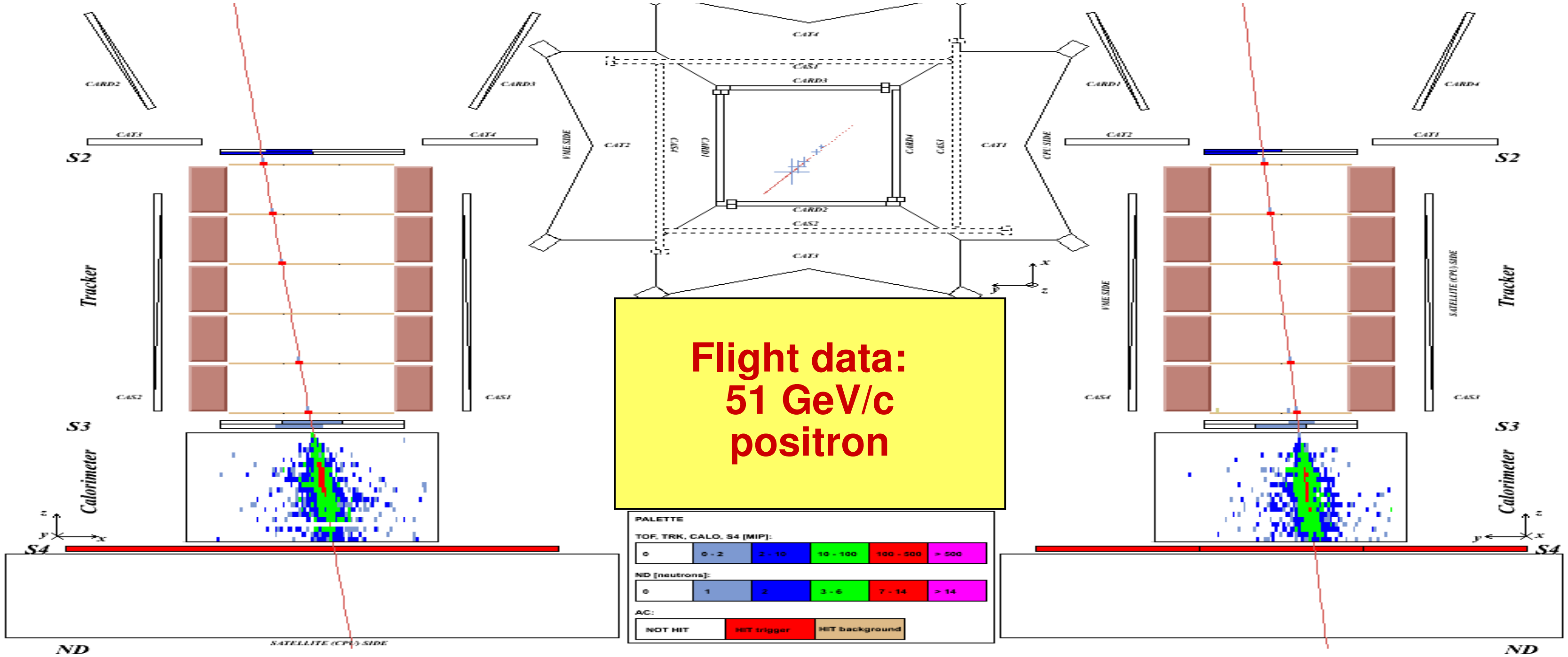
Energy-momentum match

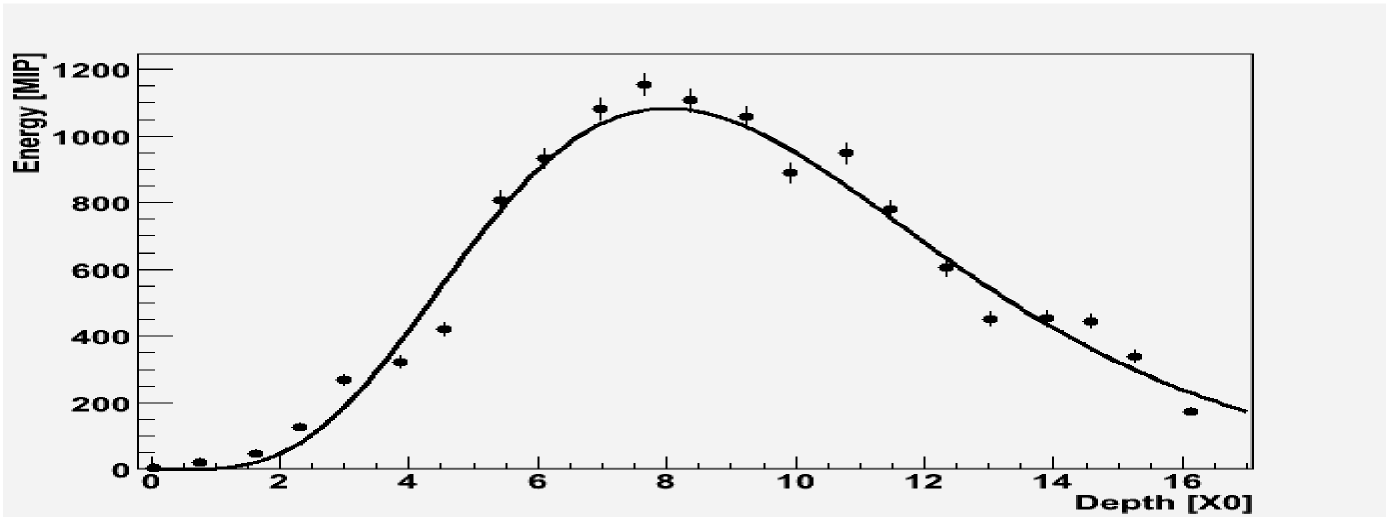
Shower starting-point

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



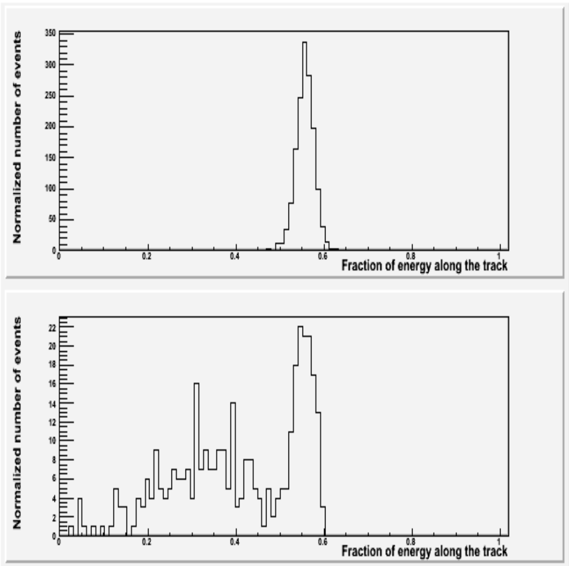
# Positron Selection with the Calorimeter Longitudinal Profile

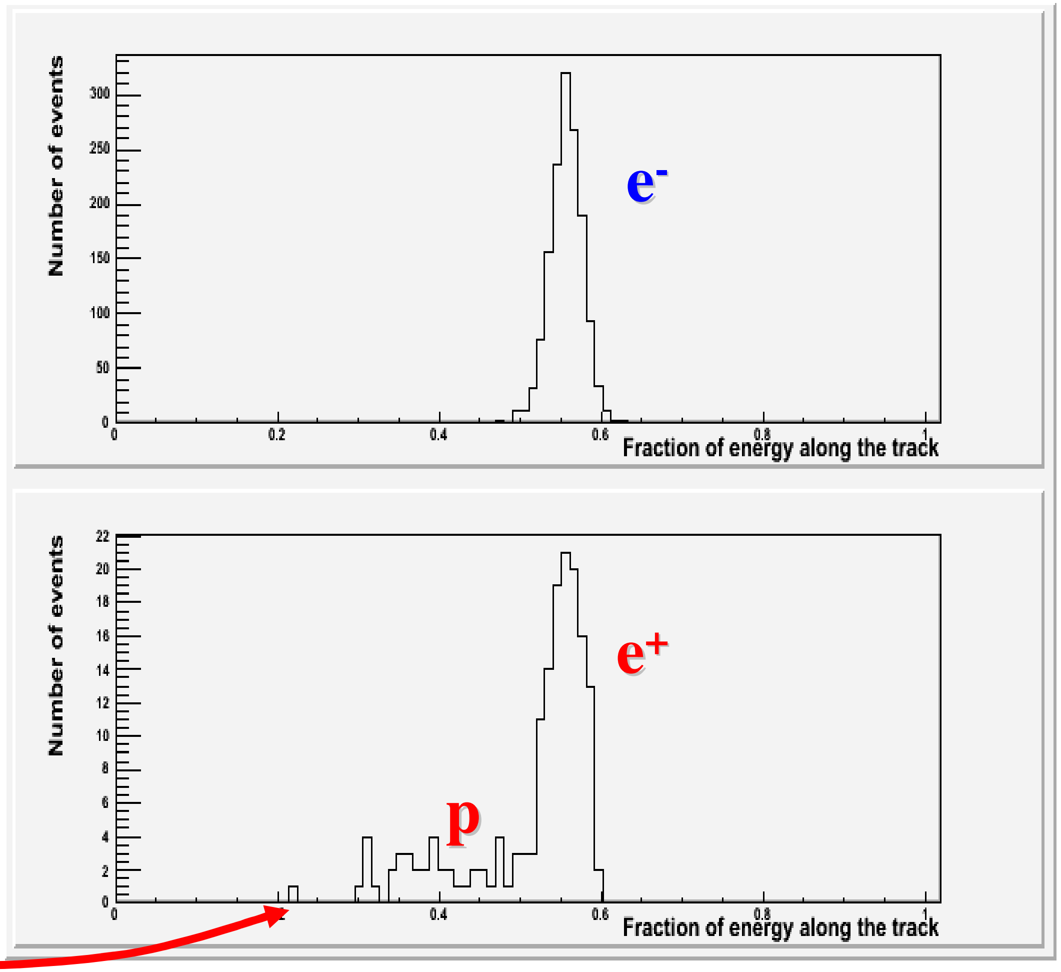


# Positron Selection with the Calorimeter

Rigidity: 20-30 GV

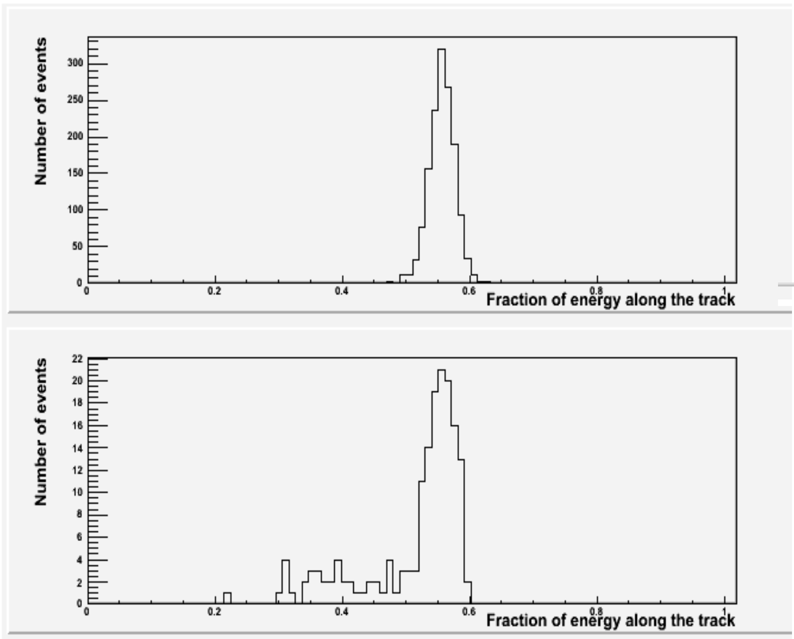


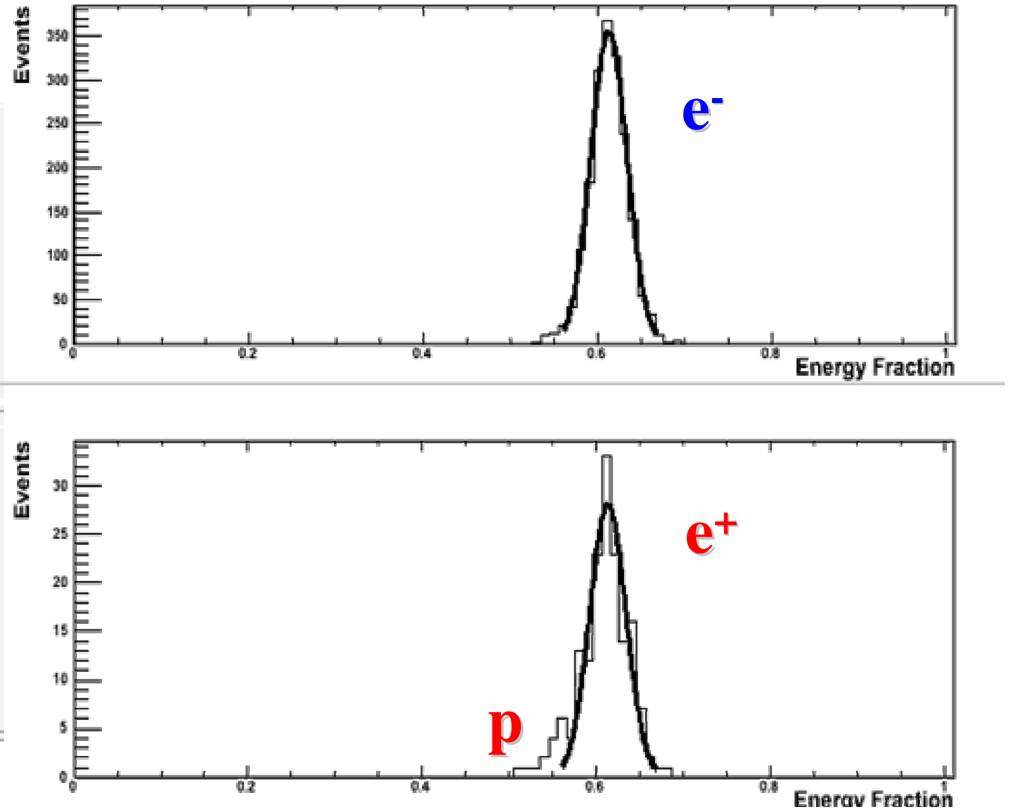




**Energy-Momentum-Match**
**Starting Point of Shower**
**Longitudinal profile**

# Positron Selection with the Calorimeter

Rigidity: 20-30 GV



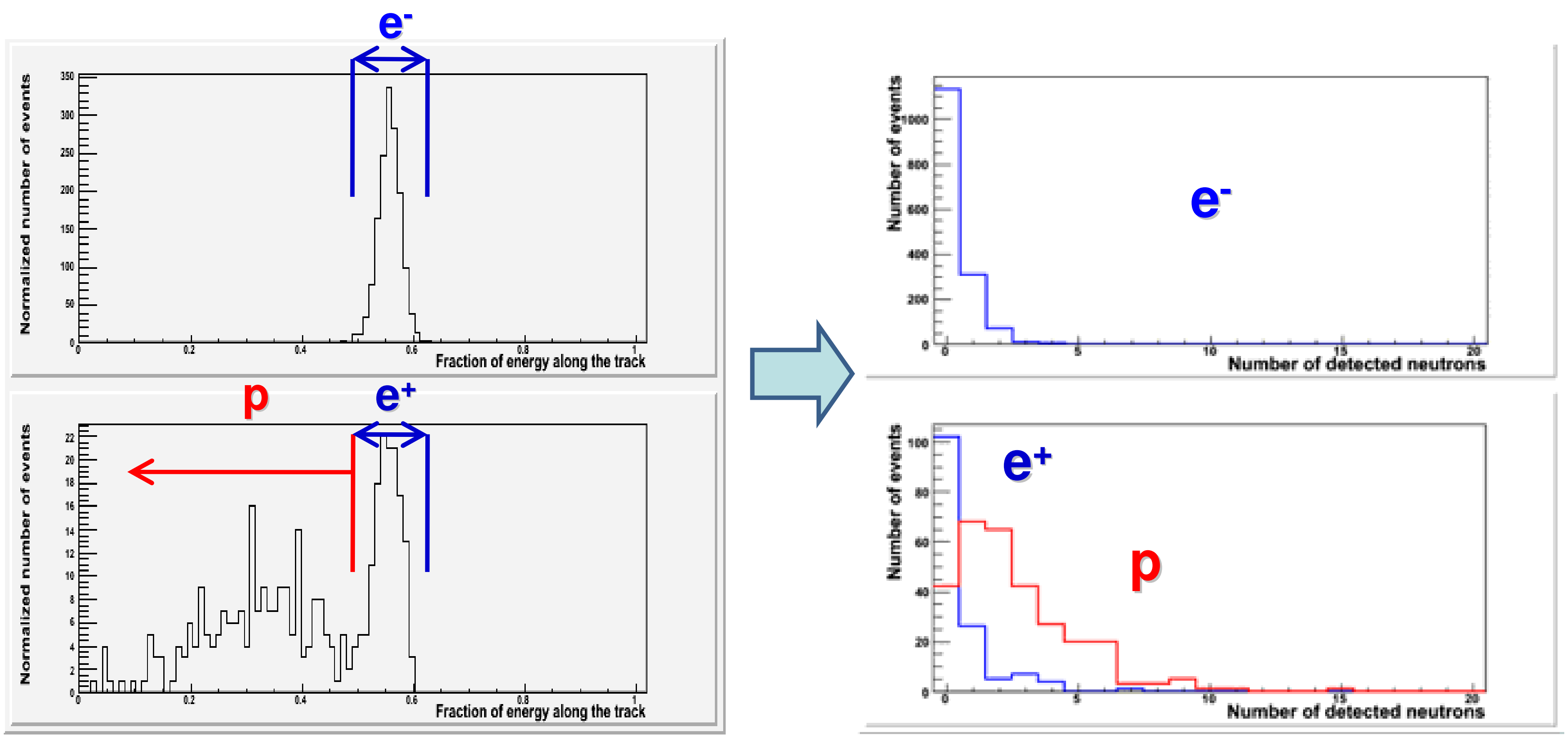

**Energy-Momentum-Match**
**Starting Point of Shower**
**Longitudinal profile**
**Lateral profile**

# Proton Rejection with the Neutron Counter

## Rigidity: 20-30 GV

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

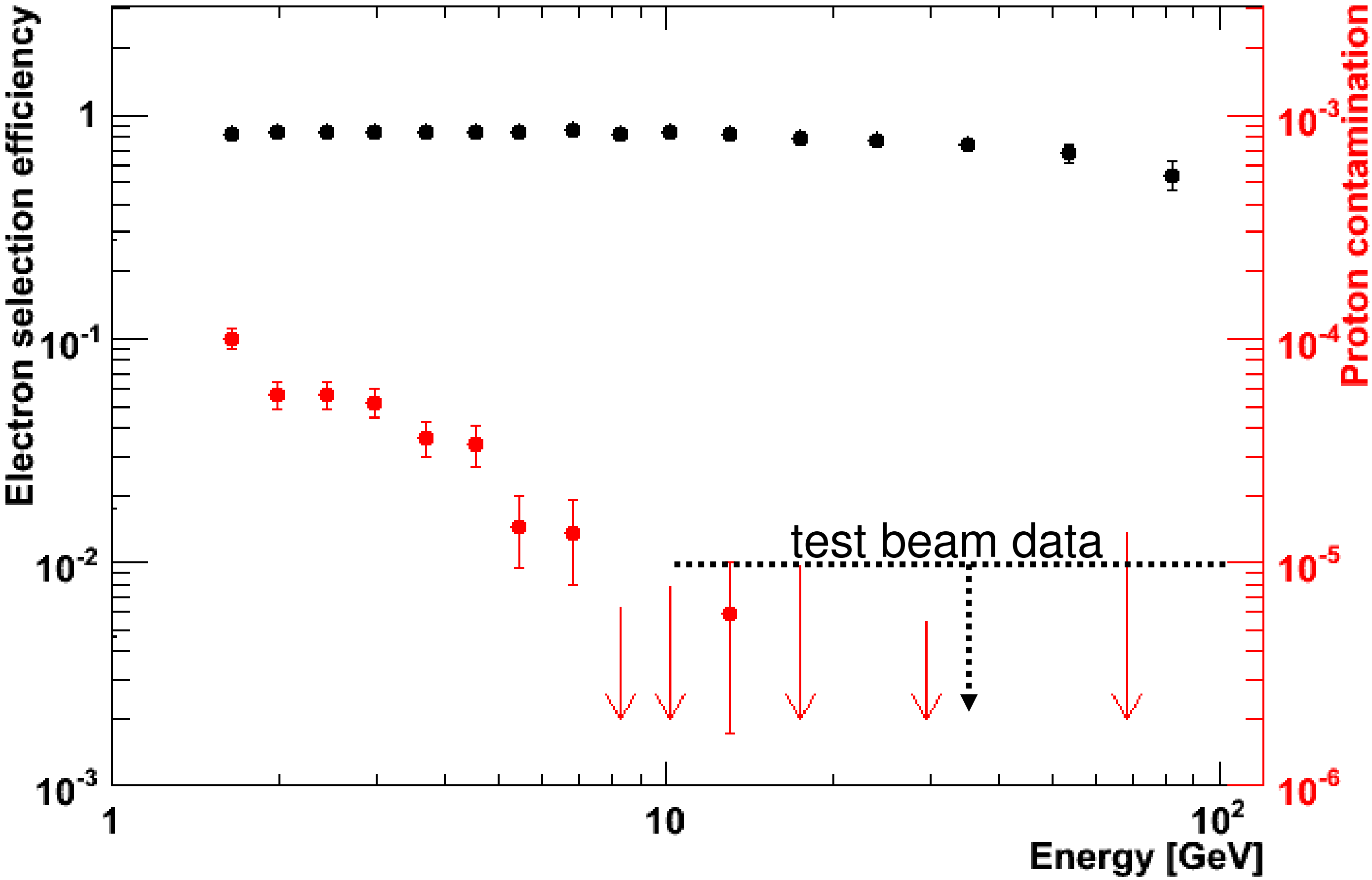
**Neutrons detected by ND**




•Energy-momentum match

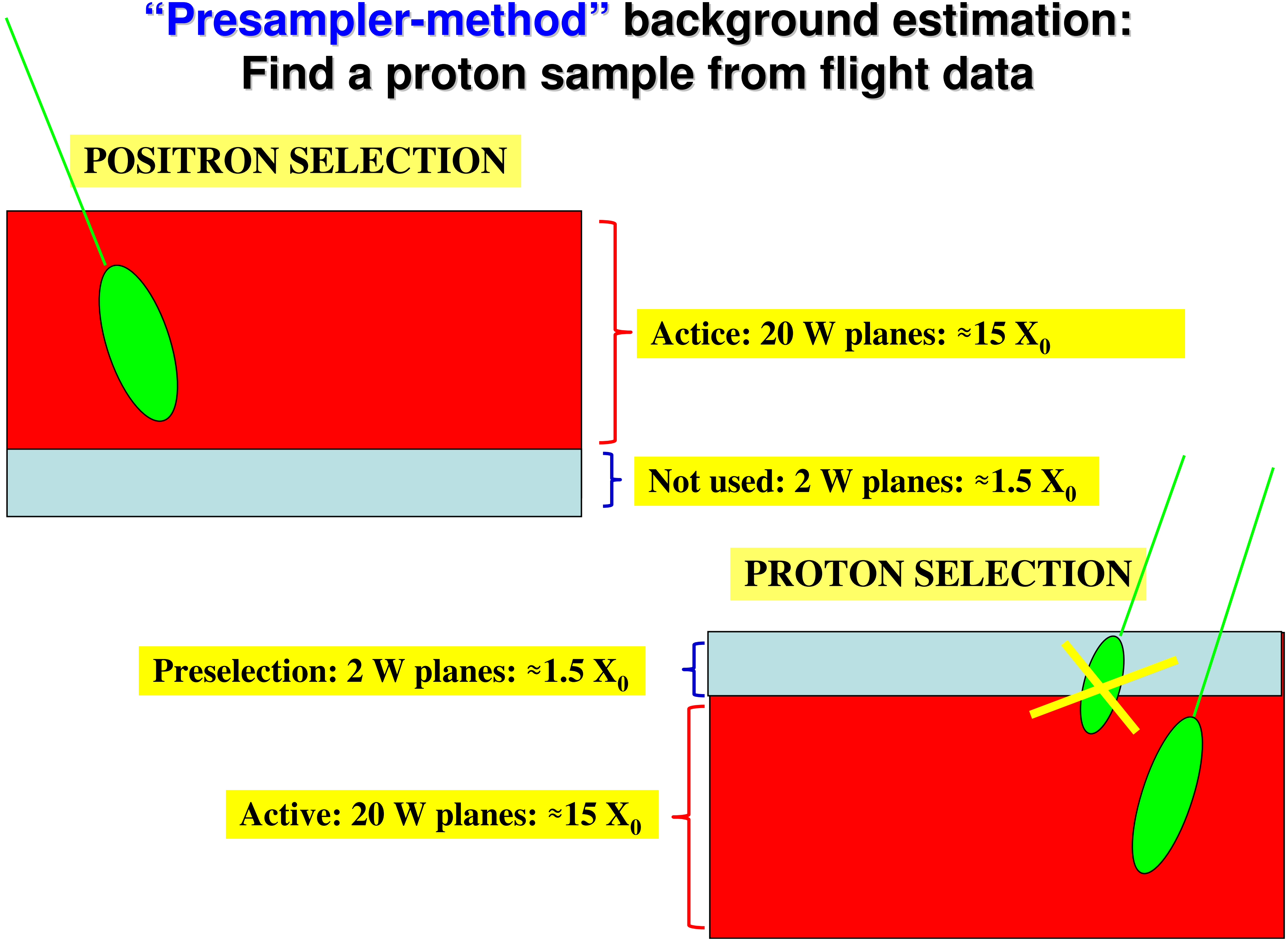
•Starting point of shower

# Positron Selection with the Calorimeter
# Proton Rejection Power

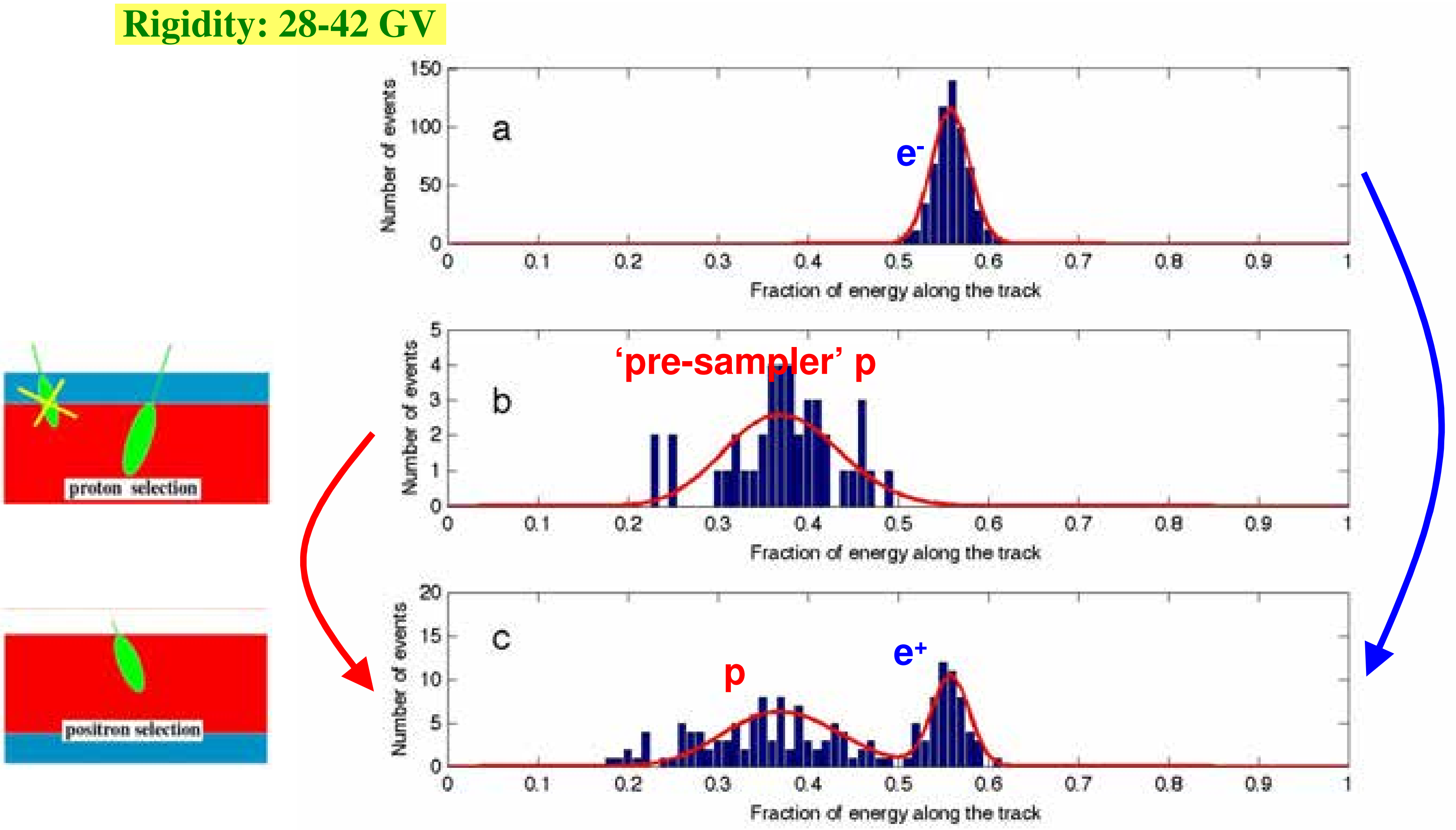



**This is NOT used in the actual analysis !!!**

# "Presampler-method" background estimation: Find a proton sample from flight data



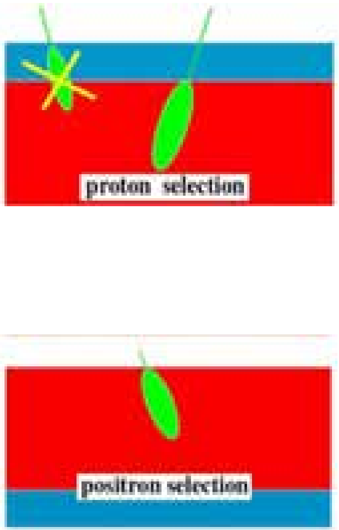
# Background estimation from data

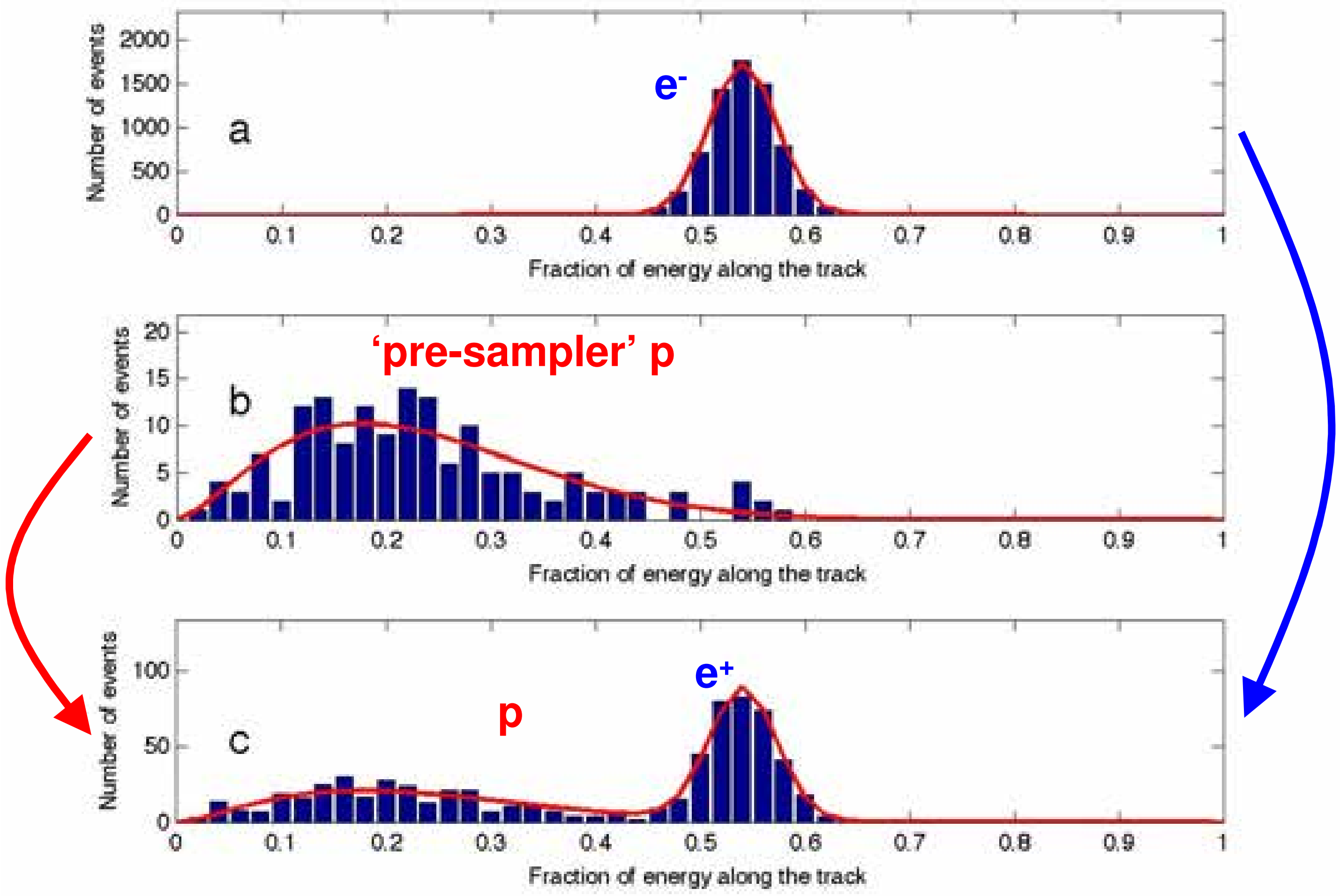



+ • Energy-momentum match
• Starting point of shower

# Background estimation from data

**Rigidity: 20-28 GV**

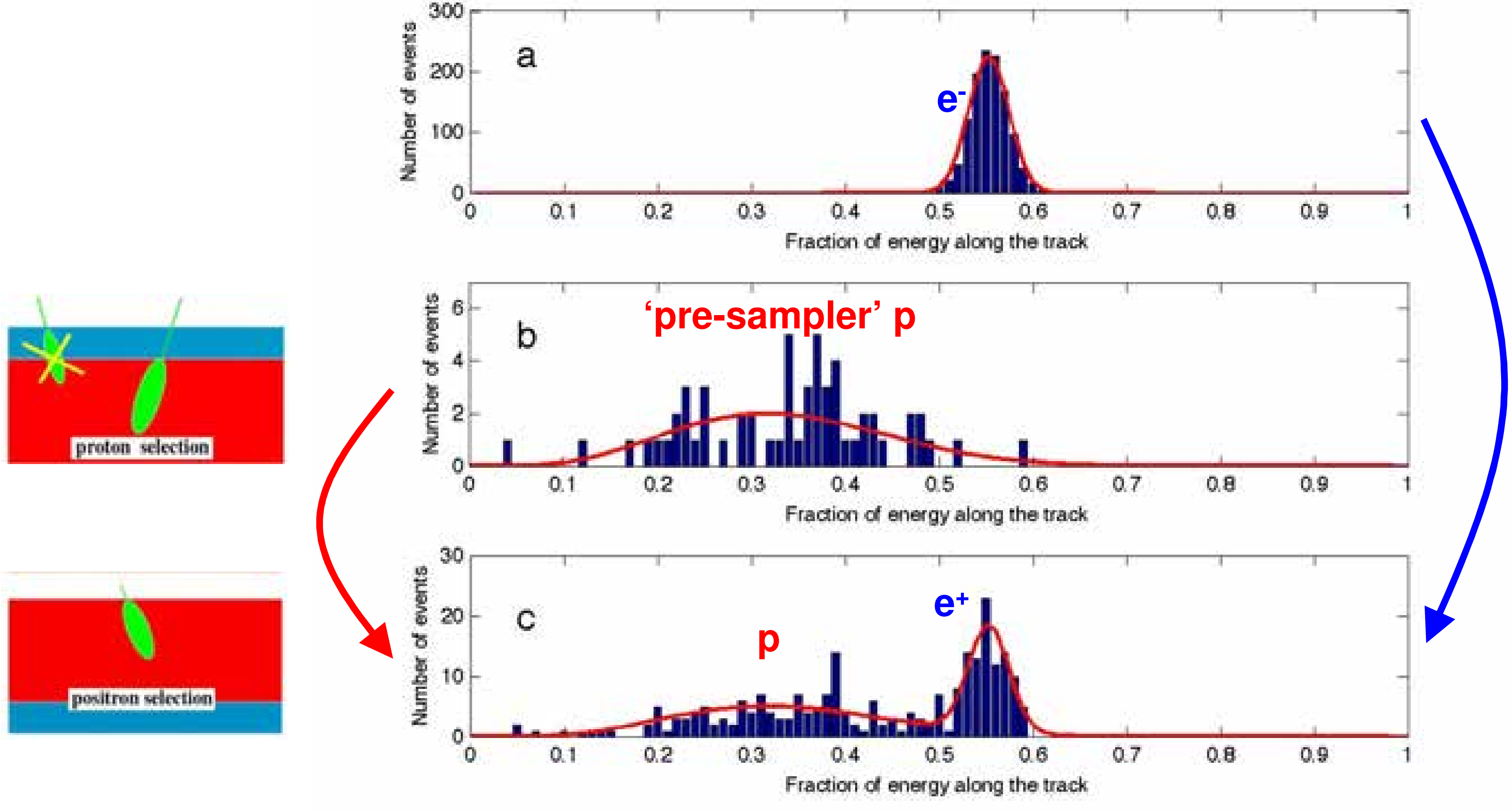



\+ • Energy-momentum match
•Starting point of shower

# Background estimation from data

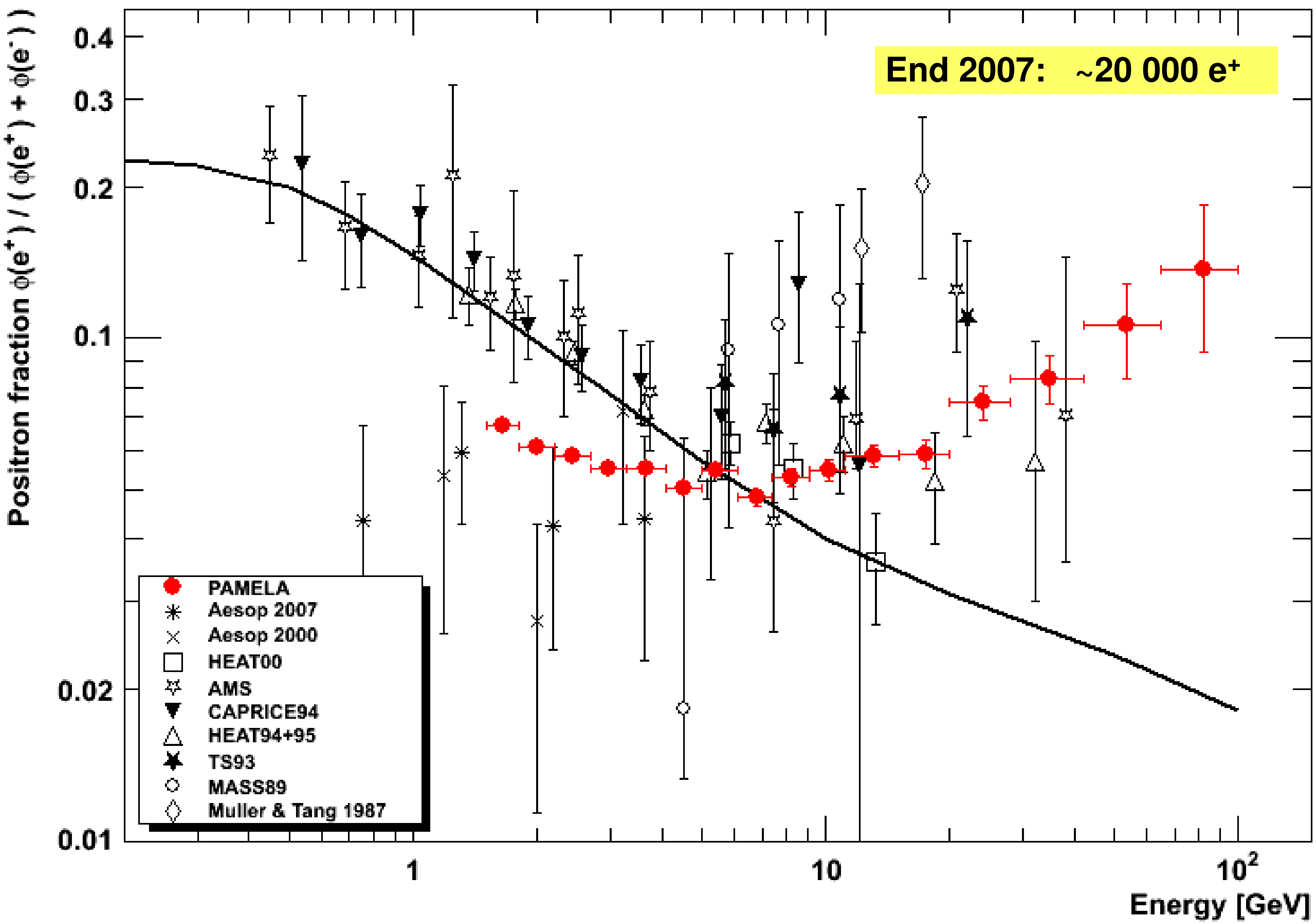
Rigidity: 6.1-7.4 GV




+ 
- Energy-momentum match
- Starting point of shower

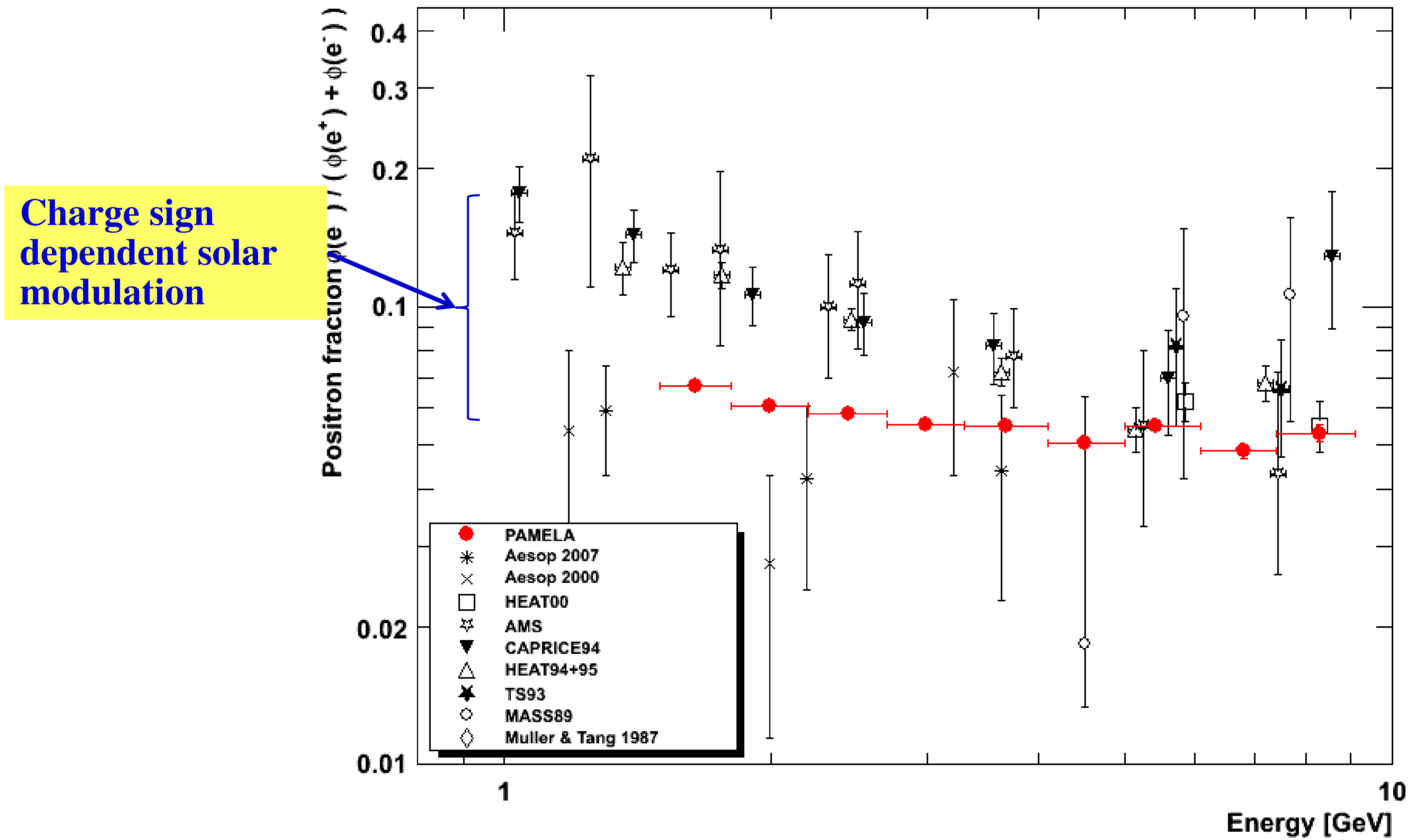
# PAMELA Positron Fraction

astro-ph 0810.4995



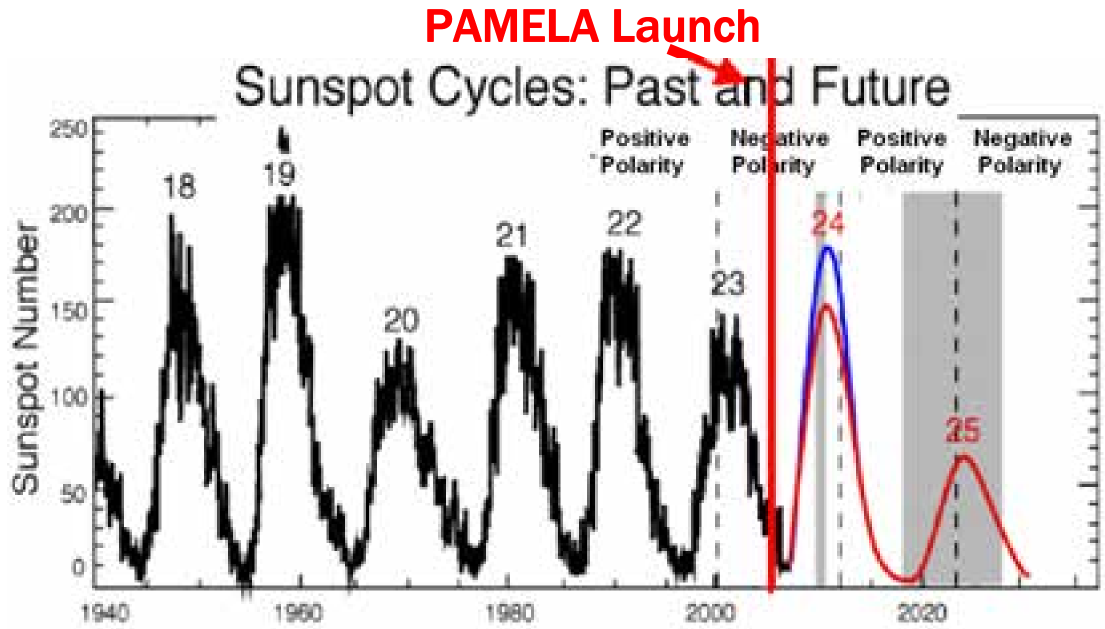
# PAMELA Positron Fraction at low energies

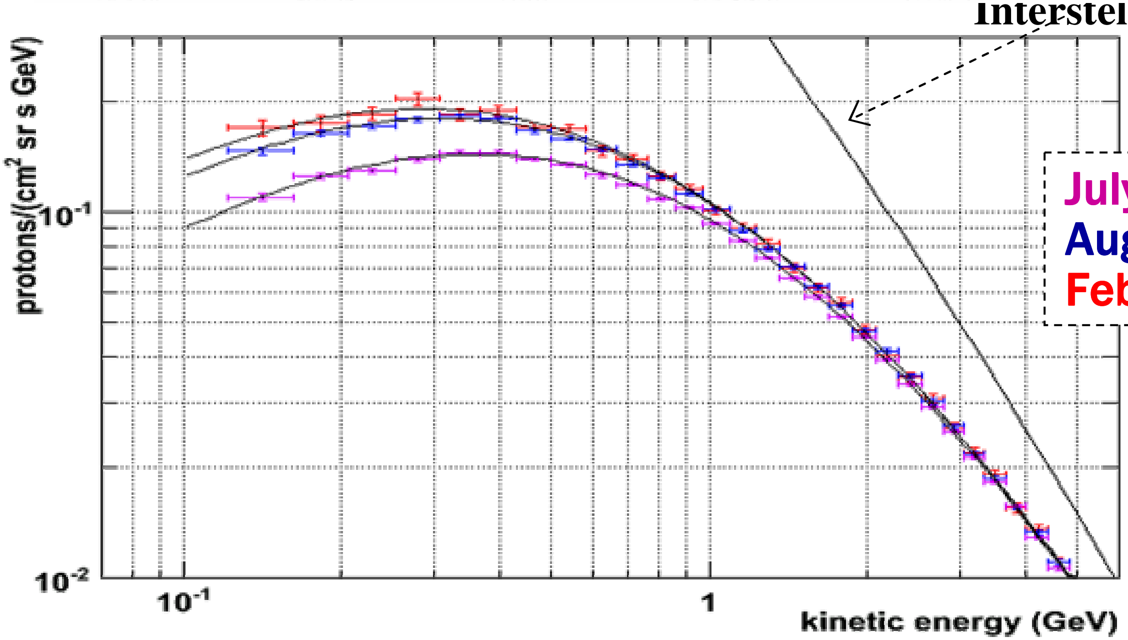
astro-ph 0810.4995



# PAMELA measures solar modulation

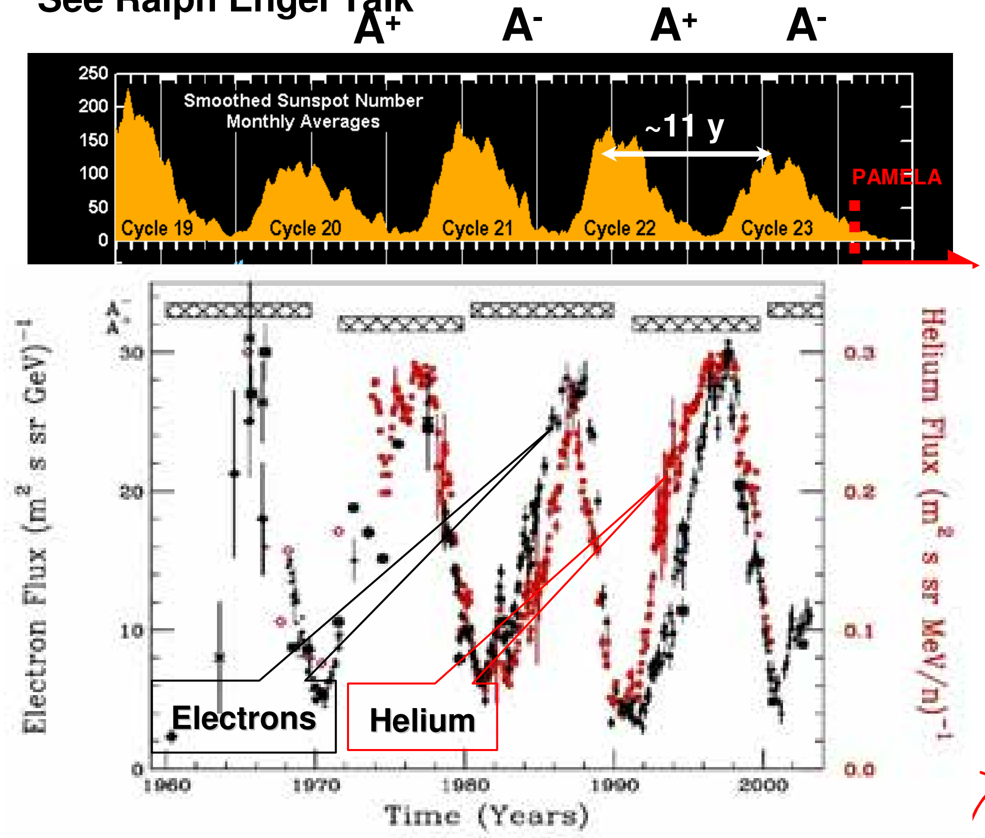
See Ralph Engel Talk

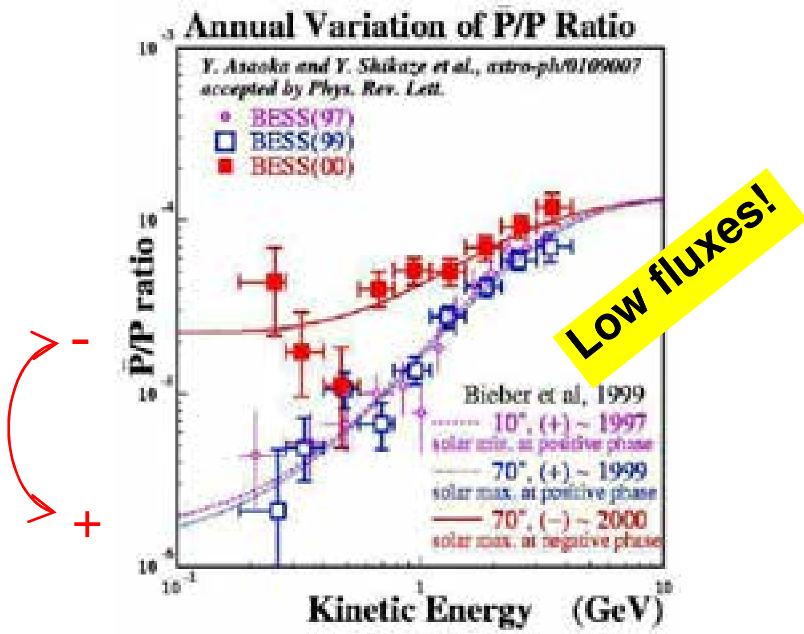


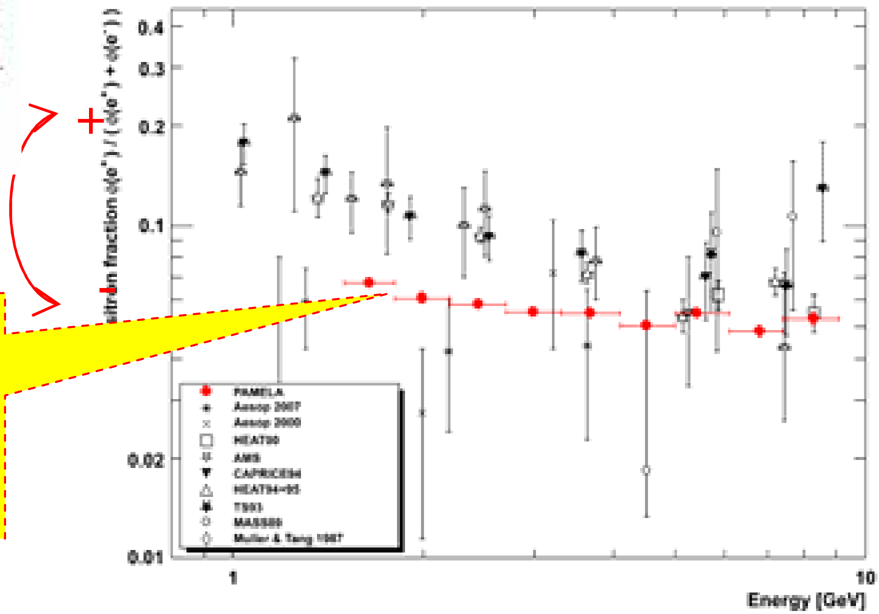



# Charge Dependent Solar Modulation

See Ralph Engel Talk



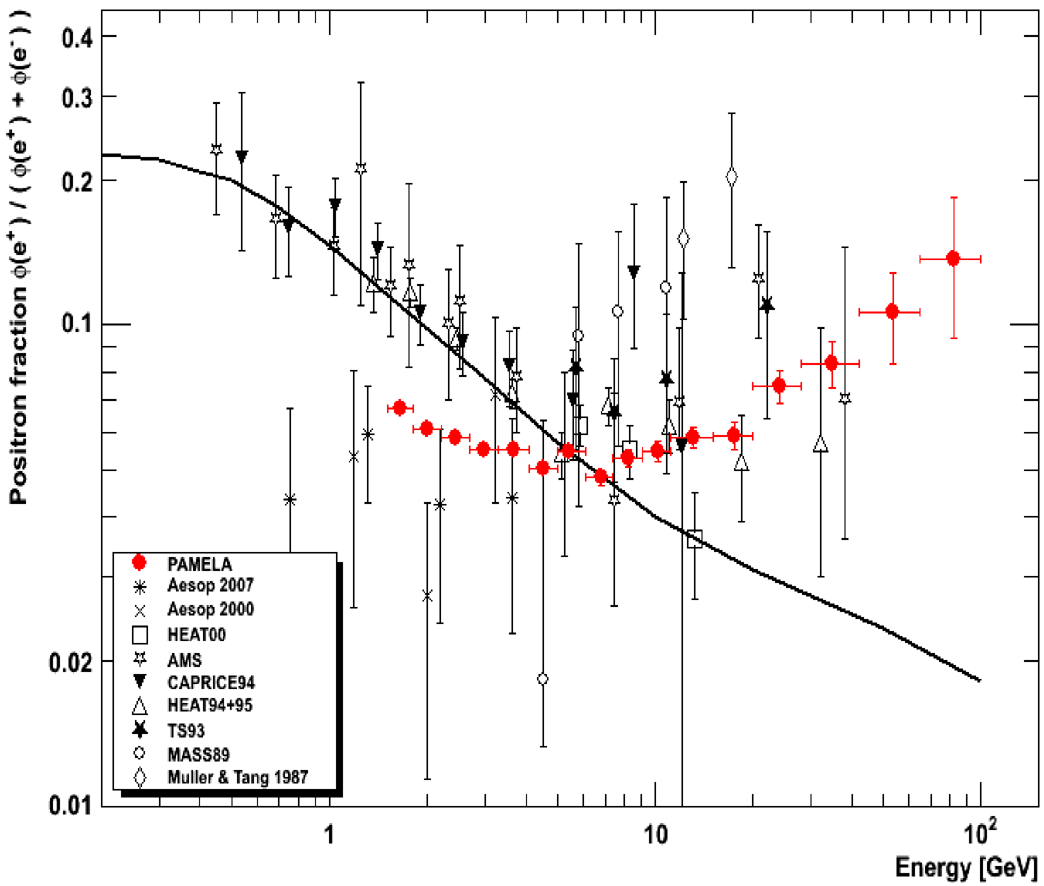




PAMELA measurements confirm the charge dependent solar modulation

# During first week PAMELA results posted on arXiv…

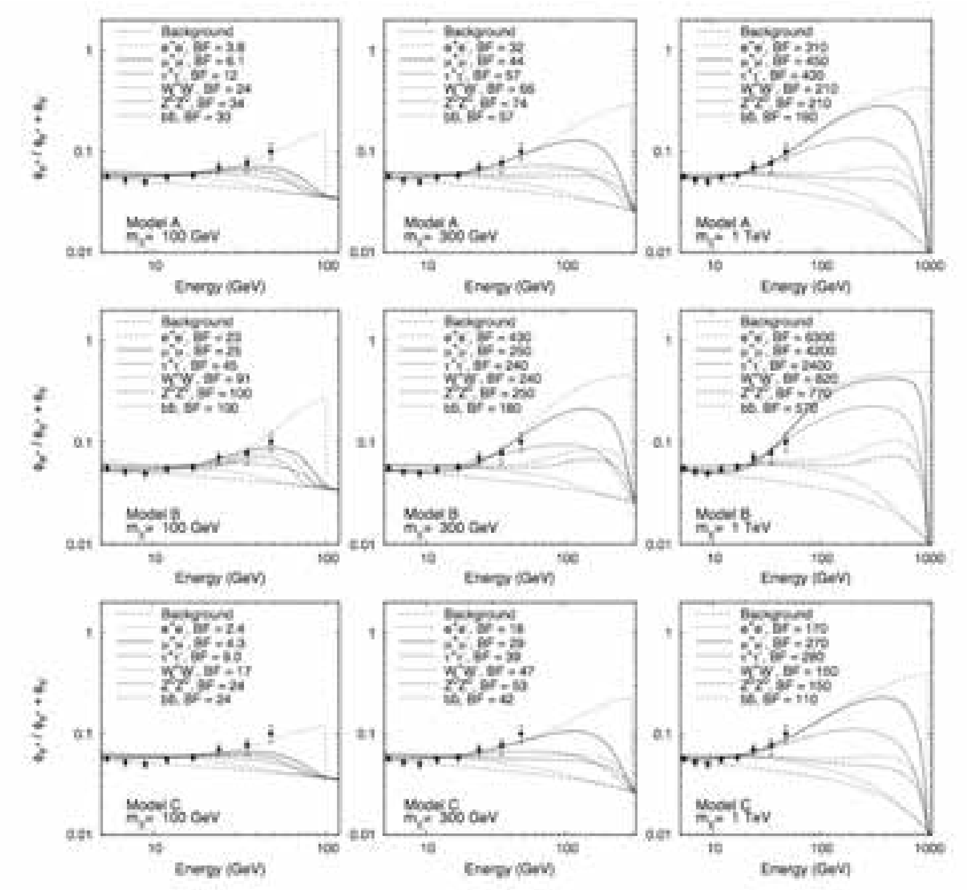
*Nature 458, 607-609*




- 0808.3725 DM
- 0808.3867 DM
- 0809.2409 DM
- 0810.2784 Pulsar
- 0810.4846 DM / pulsar
- 0810.5292 DM
- 0810.5344 DM
- 0810.5167 DM
- 0810.5304 DM
- 0810.5397 DM
- 0810.5557 DM
- 0810.4147 DM
- 0811.0250 DM
- 0811.0477 DM

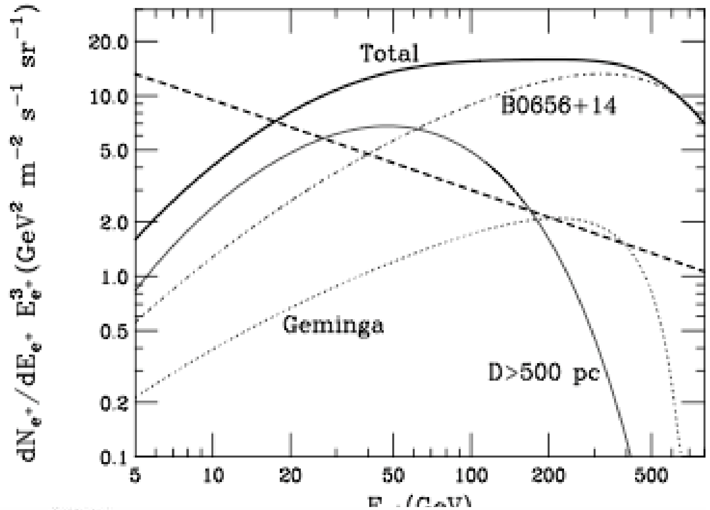
# PAMELA Positron Measurements
# and ideas of interpretation

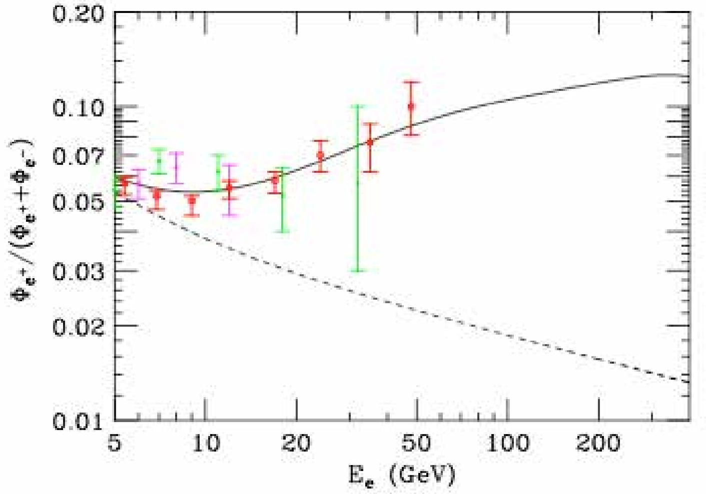
## Dark Matter




Cholis, Goodenough, Hooper, Simet, and Weiner
**arXiv:0809.1683**

## Pulsars

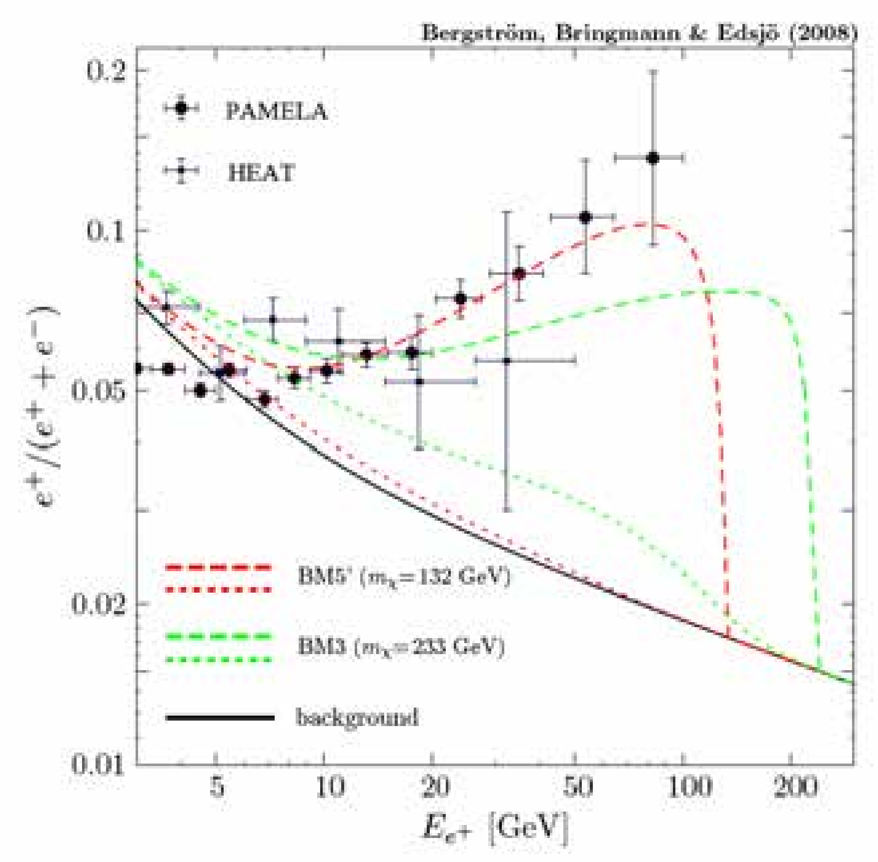



Hooper, Blasi, and Serpico
**arXiv:0810.1527**

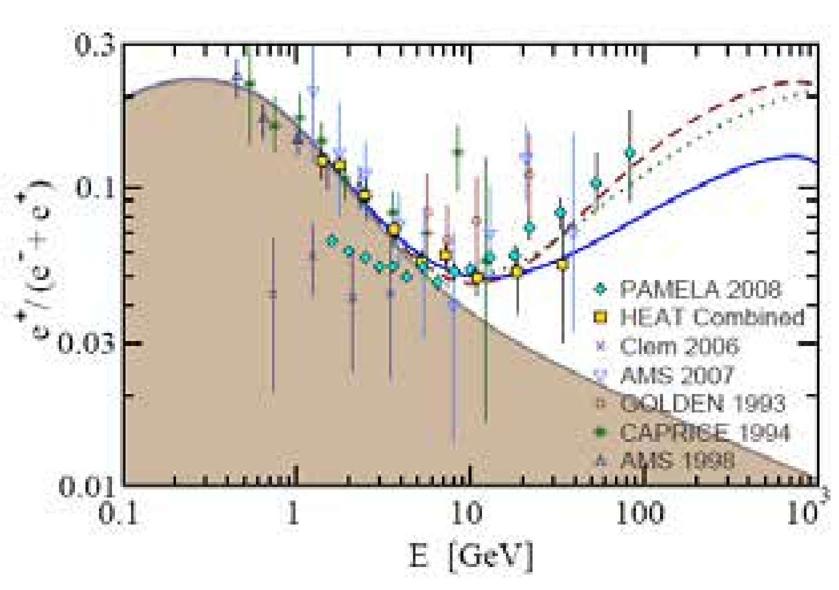
# PAMELA Positron Measurements
## and more ideas of interpretation…

### Dark Matter




Bergström, Bringmann, Edsjö
**arXiv:0808.3725**

### Pulsars

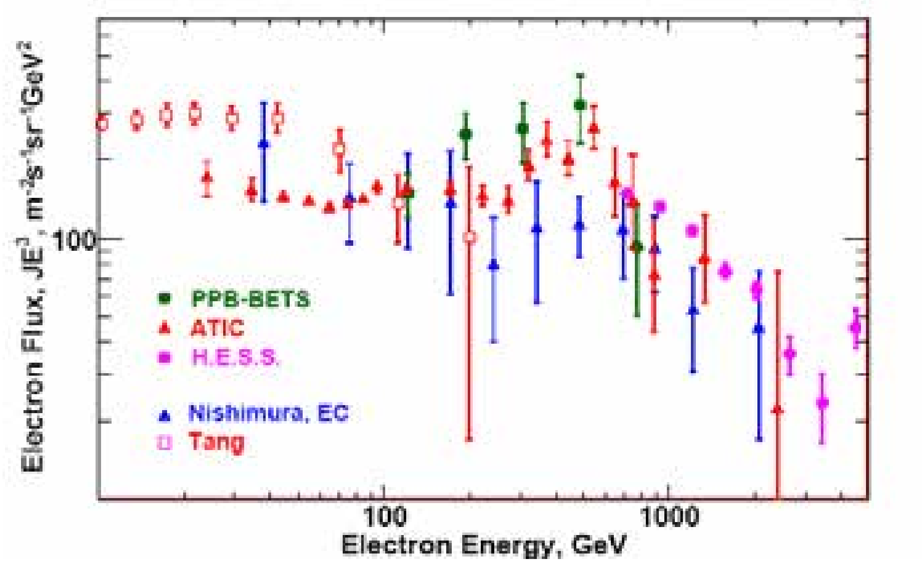


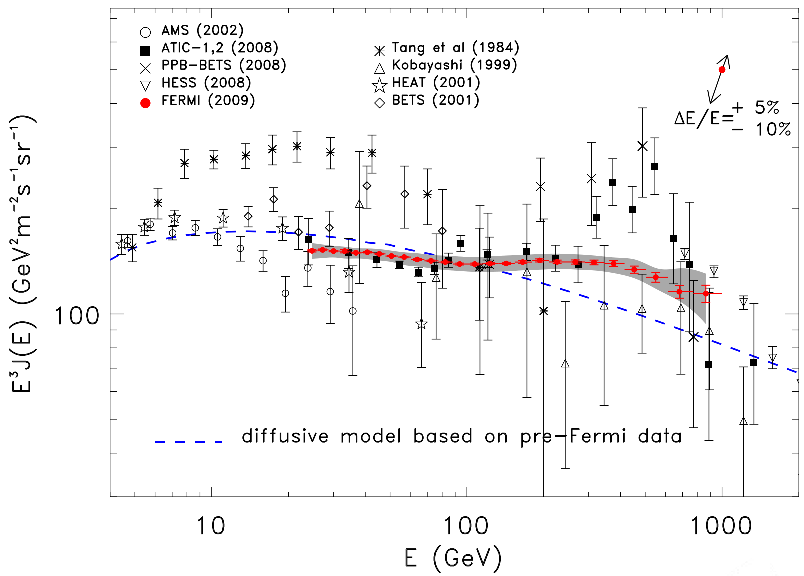

Yüksel, Kistler Stanev
**arXiv:0810.2784**

## Recent Measurements with Calorimeters: Spectrum of electrons plus positrons

## PPB-BETS, ATIC, FERMI

# $e^{+}+e^{-}$ Measurements with Calorimeters: PPB-BETS, ATIC, FERMI



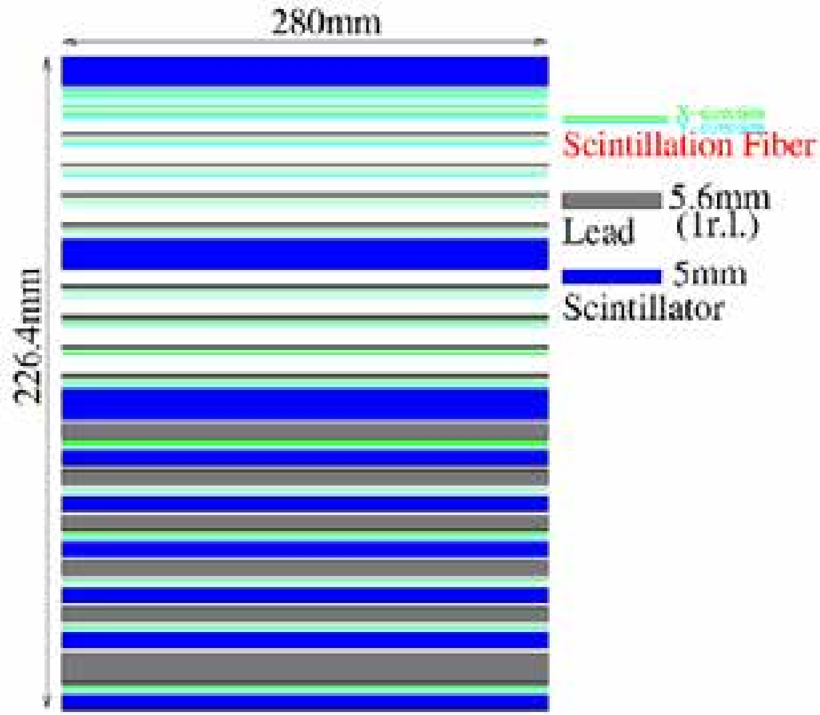

**PPB-BETS**

**ATIC**

**GLAST/FERMI**

# PPB-BETS Detector "Imaging Calorimeter"

| BETS | PPB-BETS |
|---|---|
| Lead thickness 7.1 r.l | 9 r.l |
| Number of plastic scintillators 3 | 9 |
| Maximum shower energy observed without saturation in CCD 100 GeV | 1000 GeV |
| Telemetry | Telemetry via Satellite |
| Battery | Solar Battery |




Side view of the detector

From: S. Torii / Electron-Positron Workshop08

# Selection of Electron Events

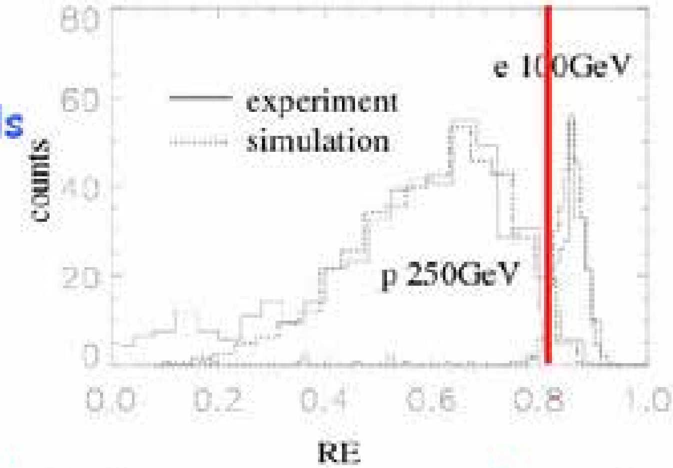
Reduction of proton backgrounds:

- On-board Trigger by the 1st and 2nd levels
  ~ 95 % (1/20)
- Selection of Contained Events in Detector
  ~ 90 % (1/10)
- Shower Image Analysis
  ~95 % (1/20)

Total Rejection Power of Protons:

$0.05 \times 0.1 \times 0.05 = 2.5\times 10^{-4}$ (~1/4000)

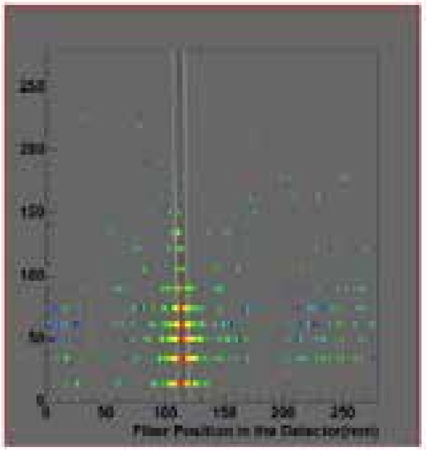
CERN Beam Test

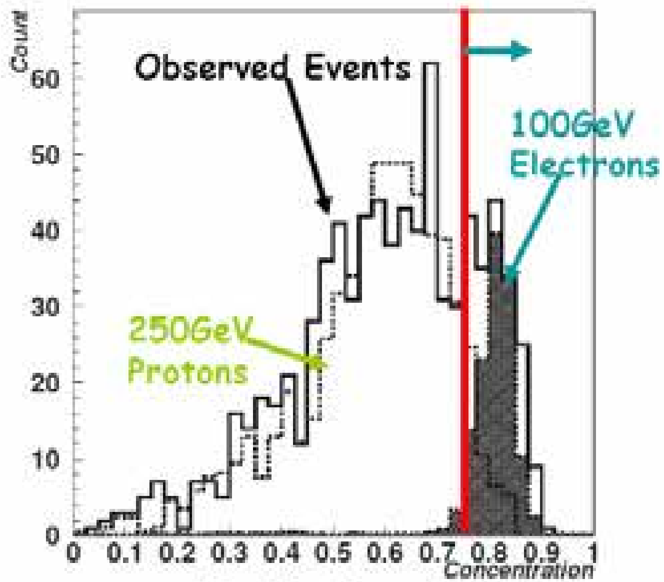



RE parameter:

Energy Concentration in Shower

$$\mathrm{RE} = \frac{\text{within 5 mm from the axis}}{\text{Total}}$$

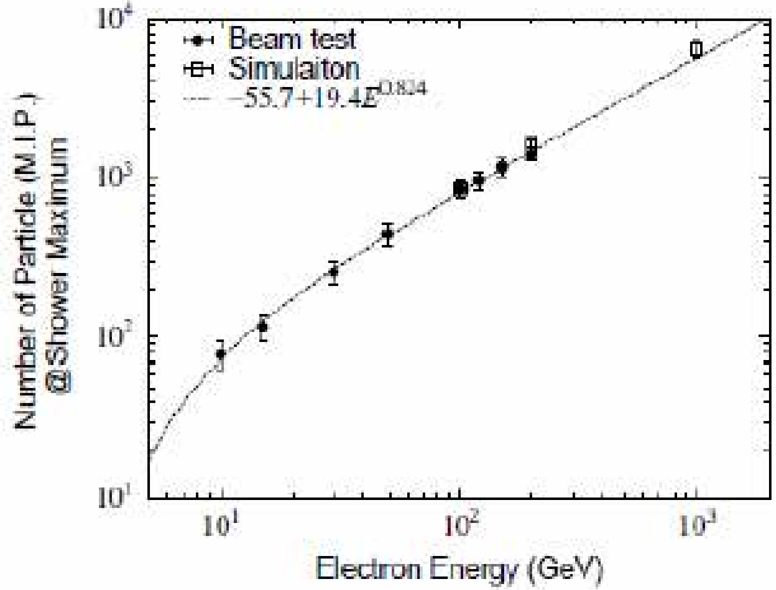




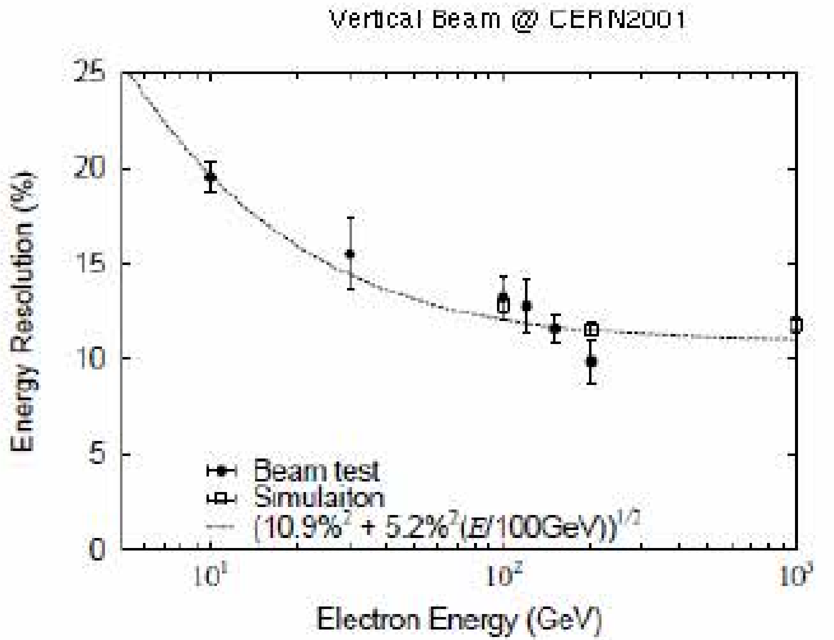

R.E. distributions

From: S. Torii / Electron-Positron Workshop08

# Energy Resolution by the Beam Test




Relation of pulse height and electron beam energy @ 9 r.l.




Dependence of energy resolution on beam energies.

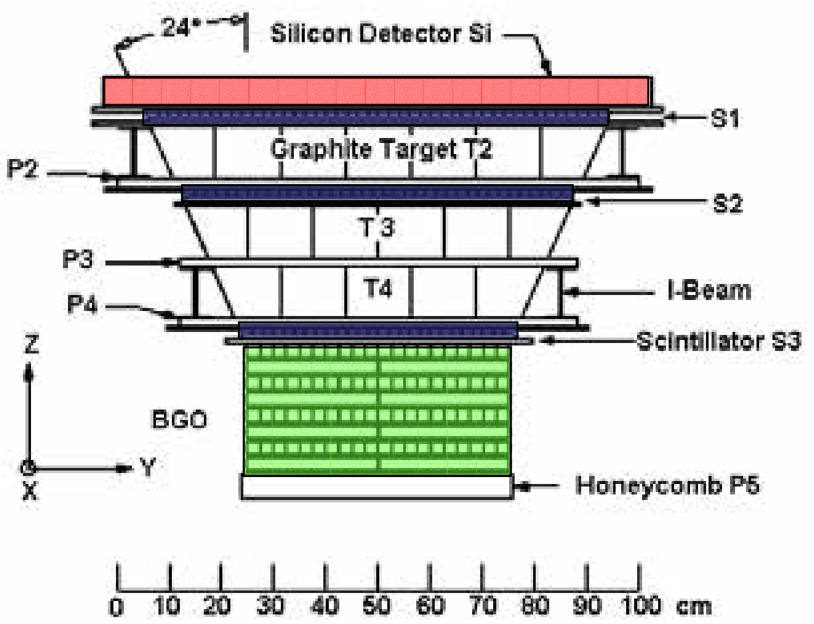
Energy Resolution ~12% @100GeV

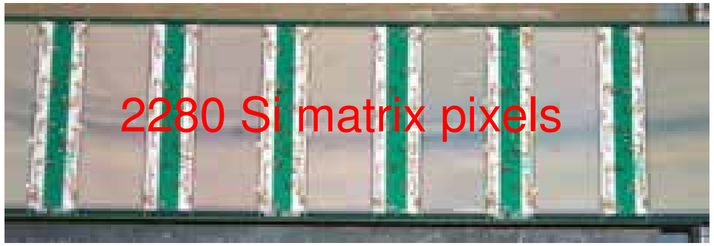
From: S. Torii / Electron-Positron Workshop08

# The ATIC Instrument

Advanced Thin Ionization Calorimeter

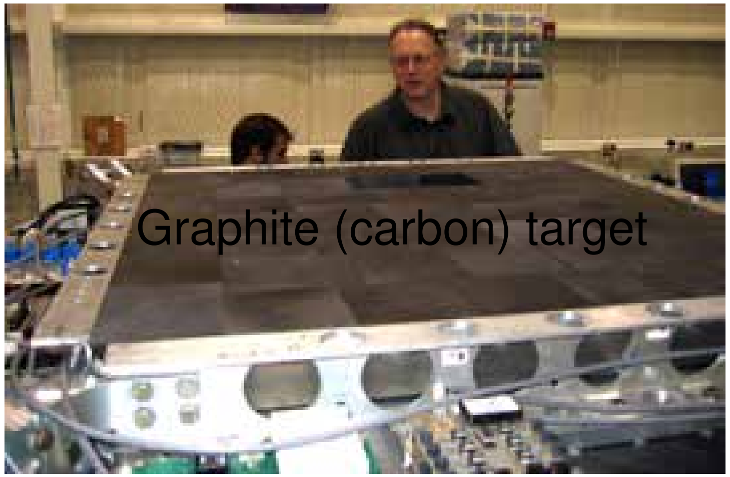
**From: J. Isbert**
**PAMELA Workshop 09**





BGO calorimeter,
ATIC 1+2, 18.4 $X_0$,
in 4 XY, planes,
ATIC 4, 22.9 $X_0$,
in 5 XY planes,



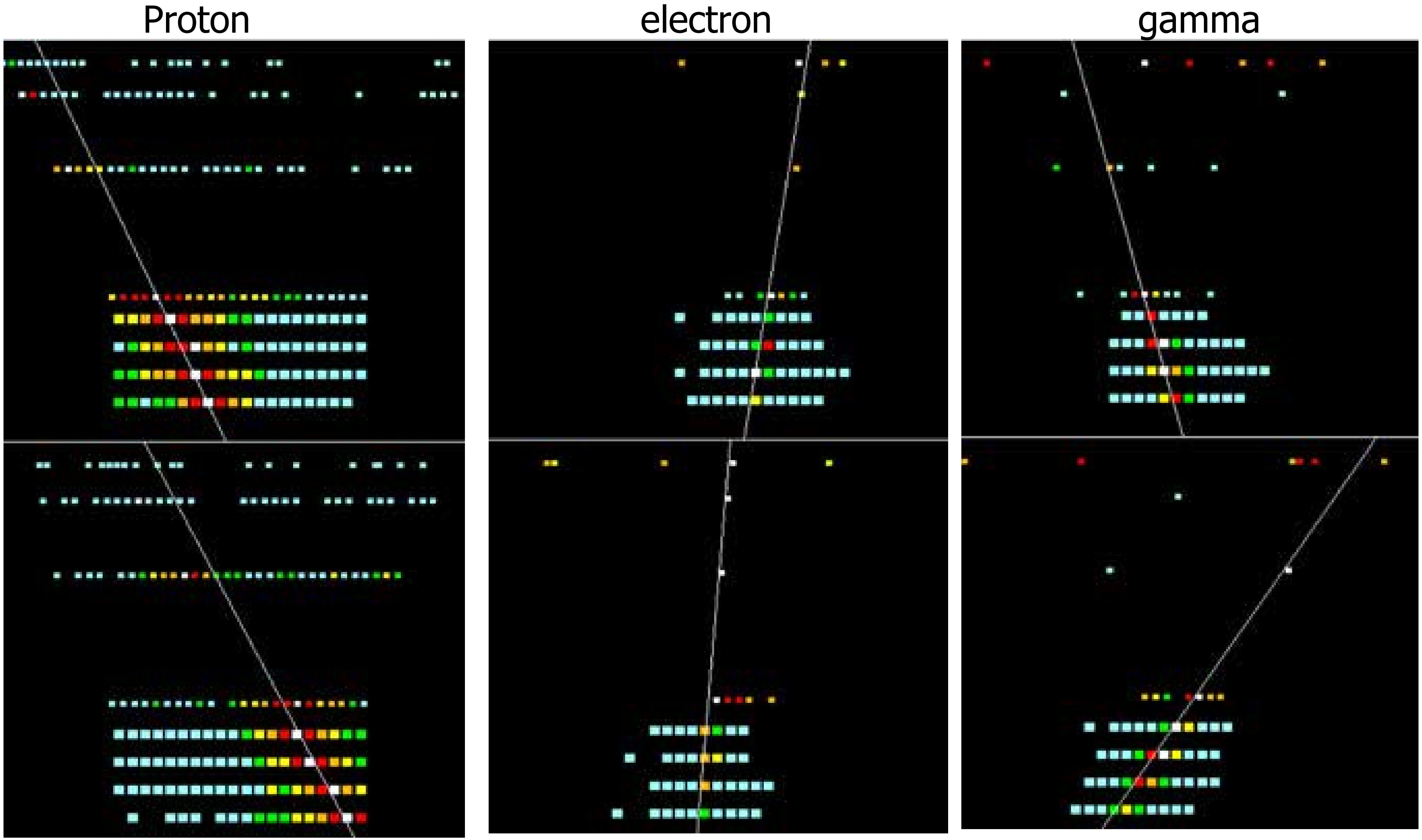
# p,e,γ Shower image in ATIC (from Flight data)

From: J. Isbert
PAMELA Workshop 09

Energy deposit in BGO ~ 250 GeV

Electron and gamma-ray showers are narrower than proton showers

Gamma shower: No signal in the Si matrix detectors around shower axis



# ATIC Summary

Chang et al. **Nature 456, 362-365 (2008)**

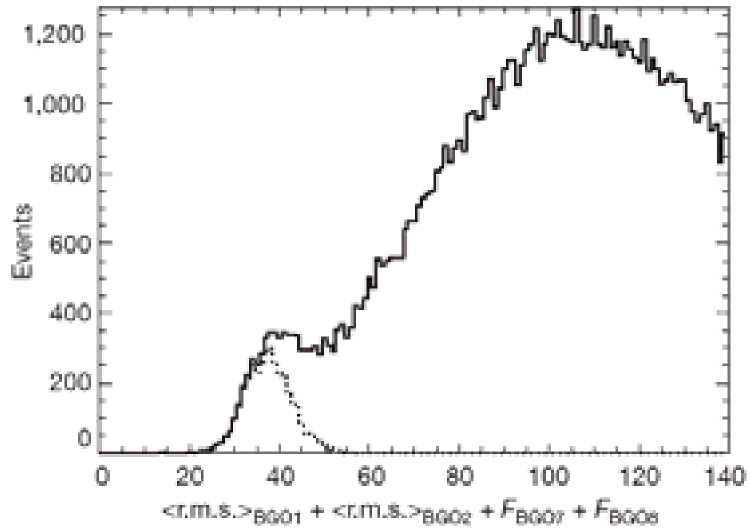



**Figure 1 | Separation of electrons from protons in the ATIC instrument.**

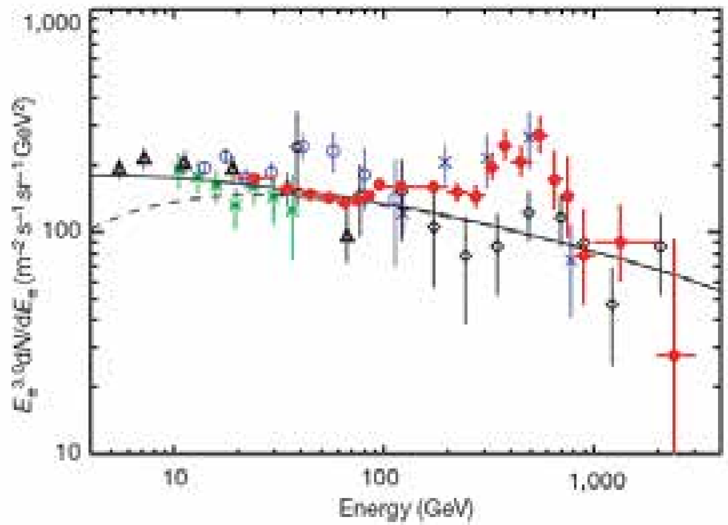



**Figure 3 | ATIC results showing agreement with previous data at lower energy and with the imaging calorimeter PPB-BETS at higher energy.** The electron differential energy spectrum measured by ATIC (scaled by $E^3$) at the top of the atmosphere (red filled circles) is compared with previous observations from the Alpha Magnetic Spectrometer AMS (green stars)[11], HEAT (open black triangles)[10], BETS (open blue circles)[12], PPB-BETS (blue crosses)[16] and emulsion chambers (black open diamonds)[4,8,9], with uncertainties of one standard deviation. The GALPROP code calculates a power-law spectral index of −3.2 in the low-energy region (solid curve)[14]. (The dashed curve is the solar modulated electron spectrum and shows that modulation is unimportant above ~20 GeV.) From several hundred to ~800 GeV, ATIC observes an 'enhancement' in the electron intensity over the GALPROP curve. Above 800 GeV, the ATIC data returns to the solid line. The PPB-BETS data also seem to indicate an enhancement and, as discussed in Supplementary Information section 3, within the uncertainties the emulsion chamber results are not in conflict with the ATIC data.

- **The ATIC 22 $X_0$ BGO calorimeter essentially fully contains the electron shower**
- **energy resolution ~ 2 %.**
- **e/p rejection ~ 5000**

**From: J. Isbert**
**PAMELA Workshop 09**

From: A. Moiseev
PAMELA Workshop 09

# FERMI / LAT Instrument Overview

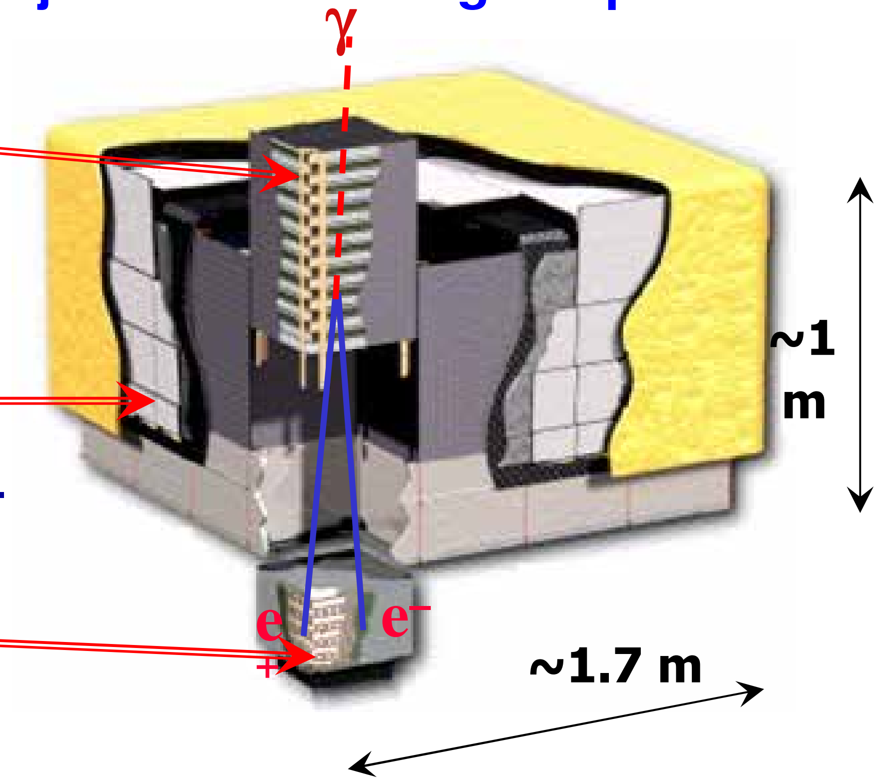
**Pair-conversion gamma-ray telescope:** 16 identical "towers" providing conversion of γ into $e^+e^-$ pair and determination of its arrival direction (Tracker) and energy (Calorimeter). Covered by segmented AntiCoincidence Detector which rejects the charged particles background

**Silicon-stripped tracker:** 18 double-plane single-side (x and y) interleaved with 3.5% $X_0$ thick (first 12) and 18% $X_0$ thick (next 4) tungsten converters. Strips pitch is 228 μm; total $8.8\times10^5$ readout channels

**Segmented Anticoincidence Detector:** 89 plastic scintillator tiles and 8 flexible scintillator ribbons. Segmentation reduces self-veto effect at high energy.

**Hodoscopic CsI Calorimeter** Array of 1536 CsI(Tl) crystals in 8 layers.

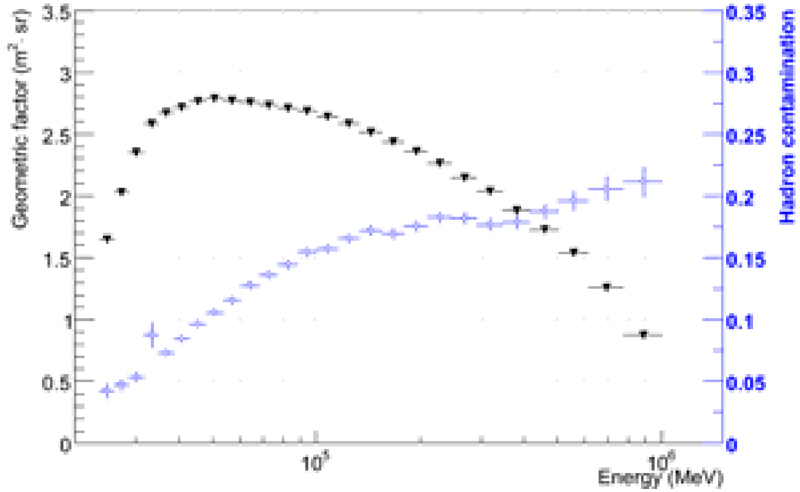
**Electronics System** Includes flexible, robust hardware trigger and software filters.



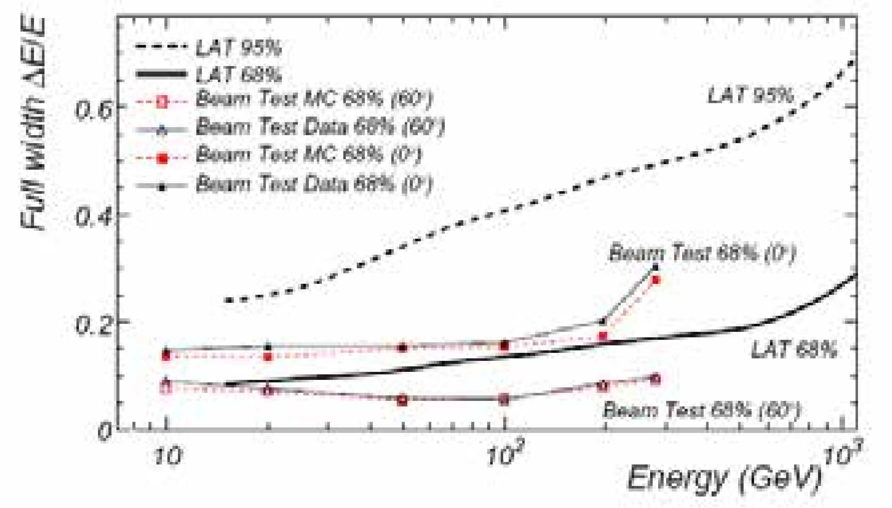
# FERMI Challenges

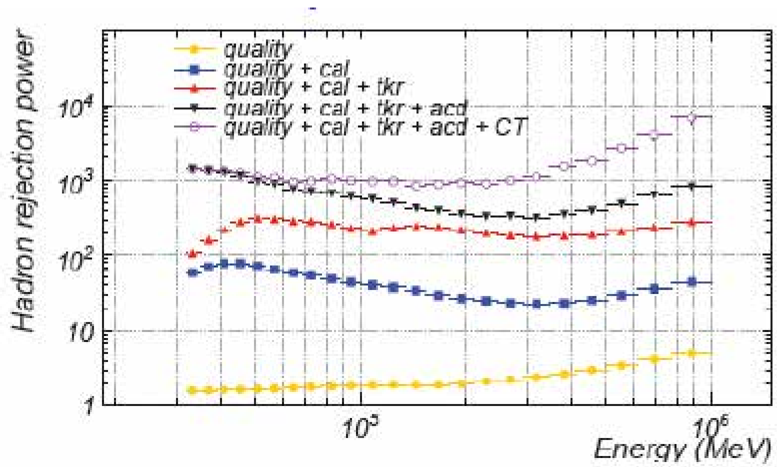
## Thin Calorimeter: W 1.5 $X_0$ + CsI 8.6 $X_0$

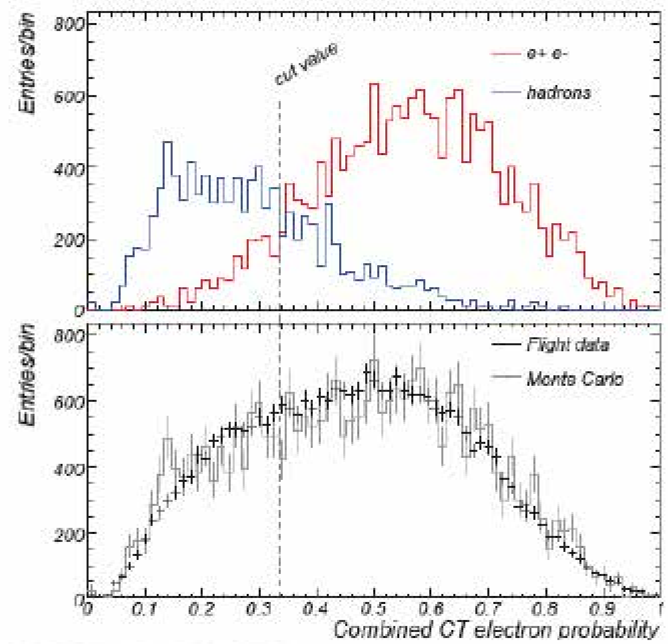
**Geometry factor depends strongly on energy**




**Energy resolution 5% – 30%**

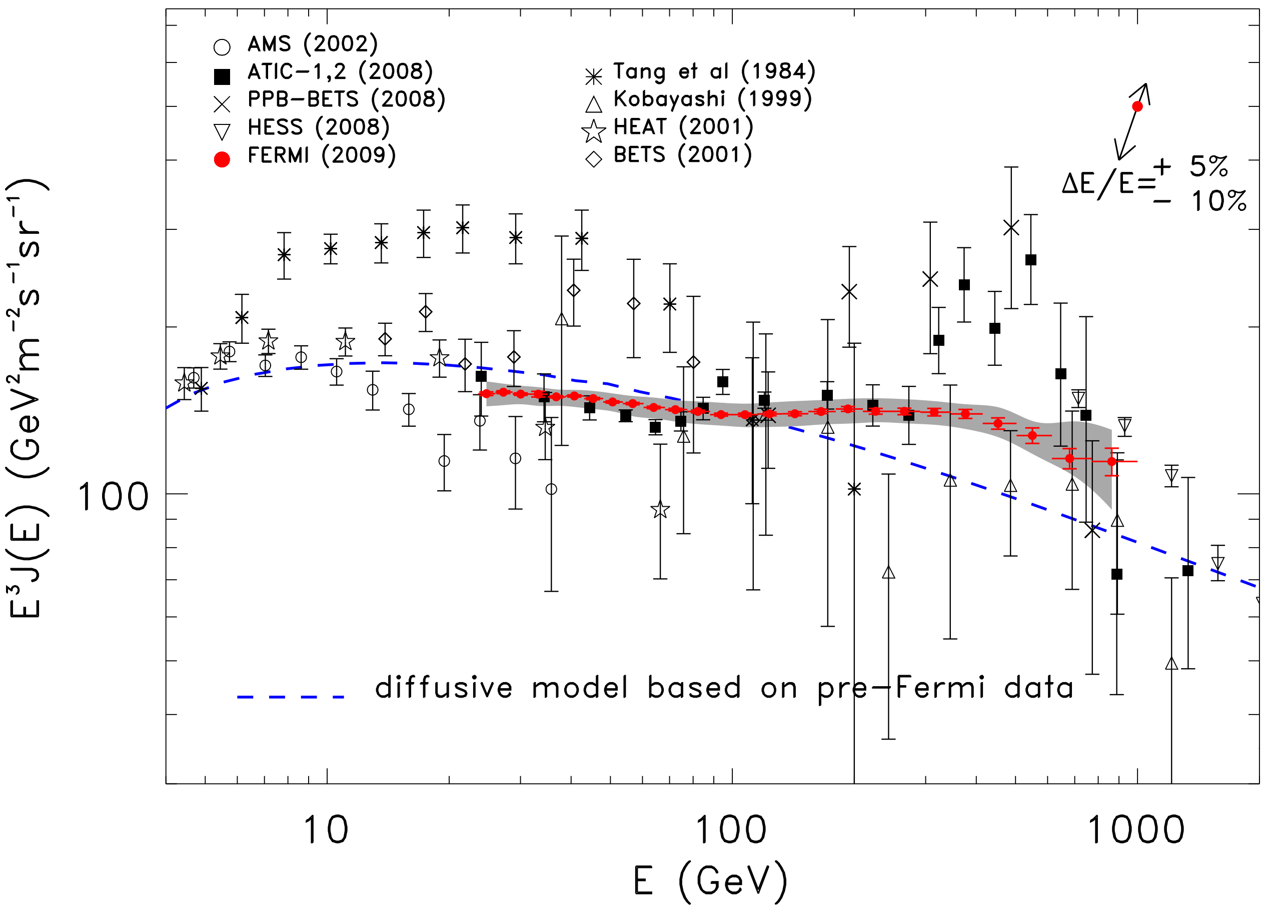


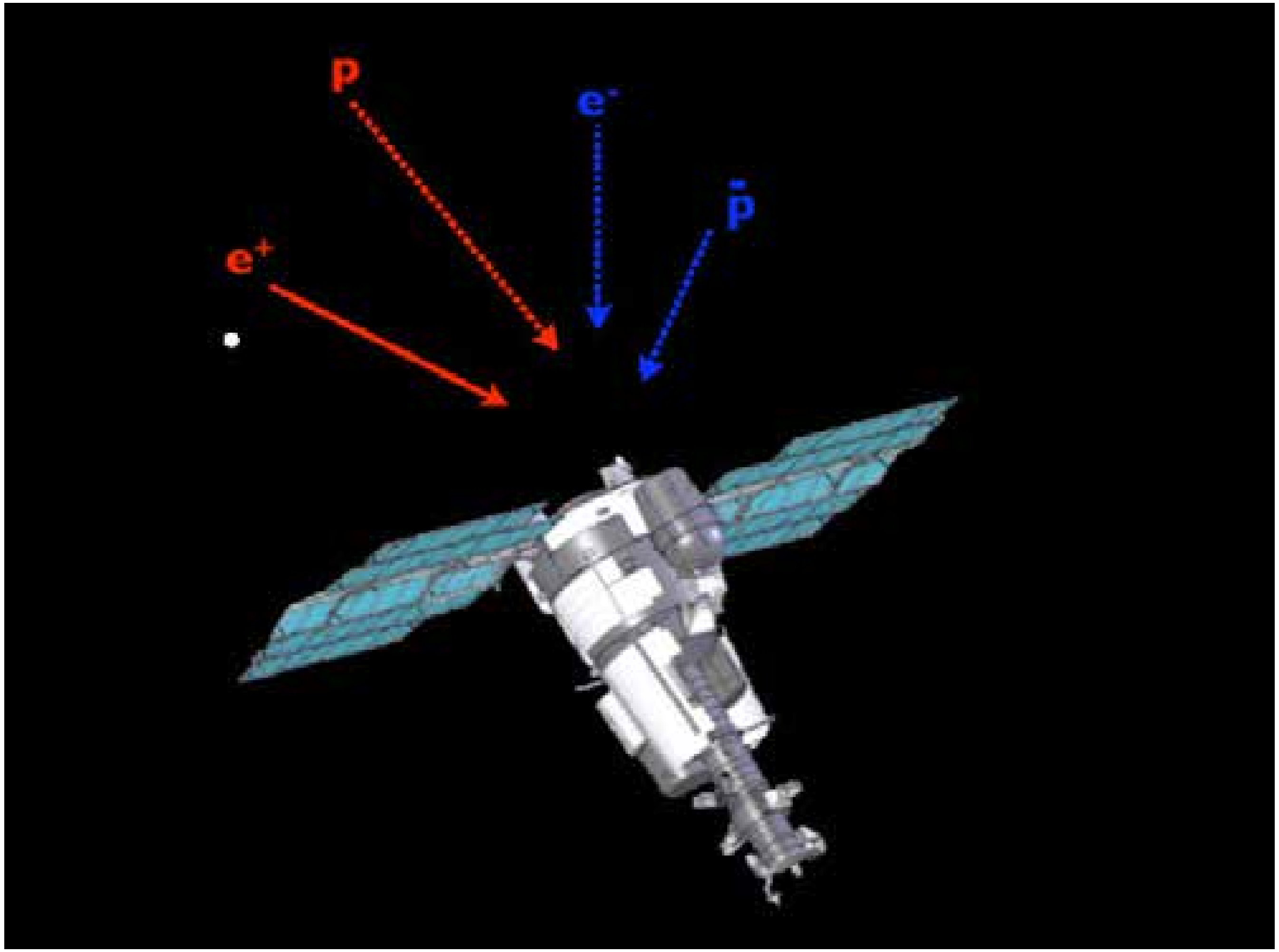

**Proton rejection power ($10^3$ - $10^4$) depends on strongly on simulations**

# $e^+ + e^-$ spectra May 2009

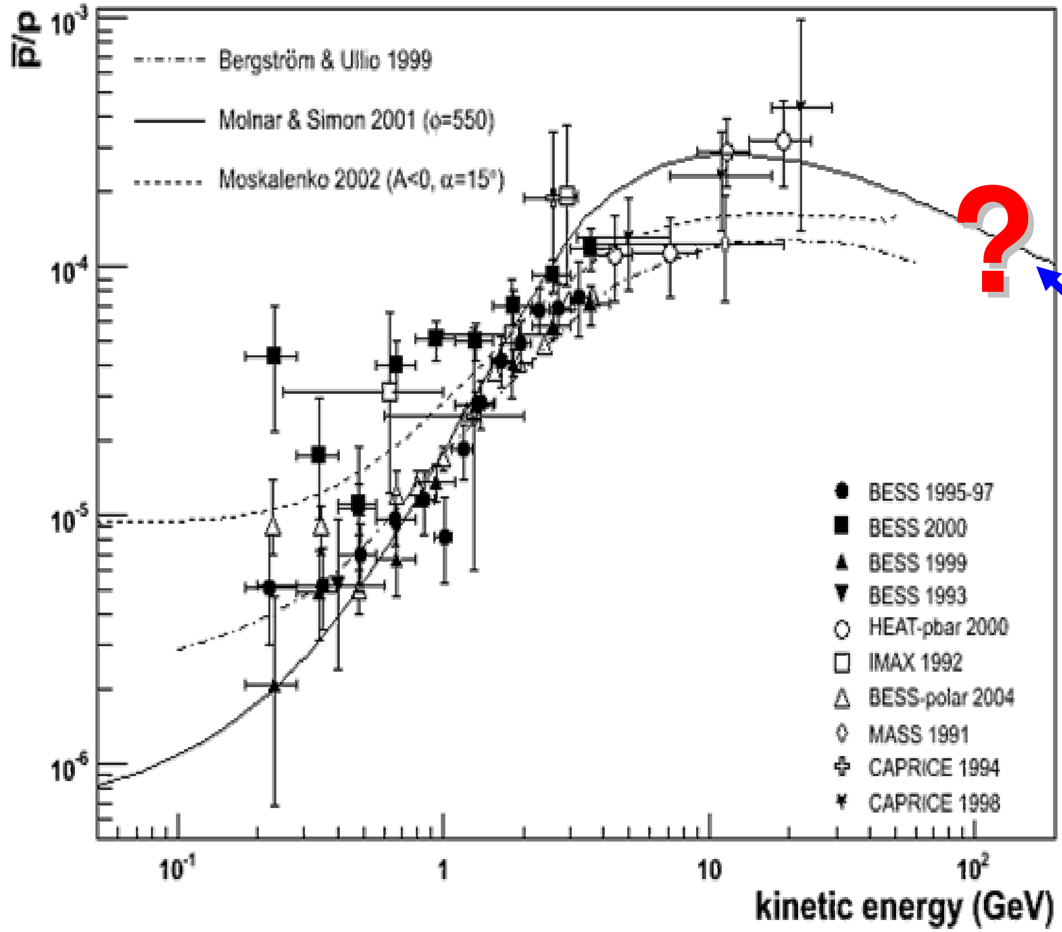



**PAMELA $e^+$, $e^-$, $e^+ + e^-$ spectra: Work in progress…**

# How about Antiprotons?

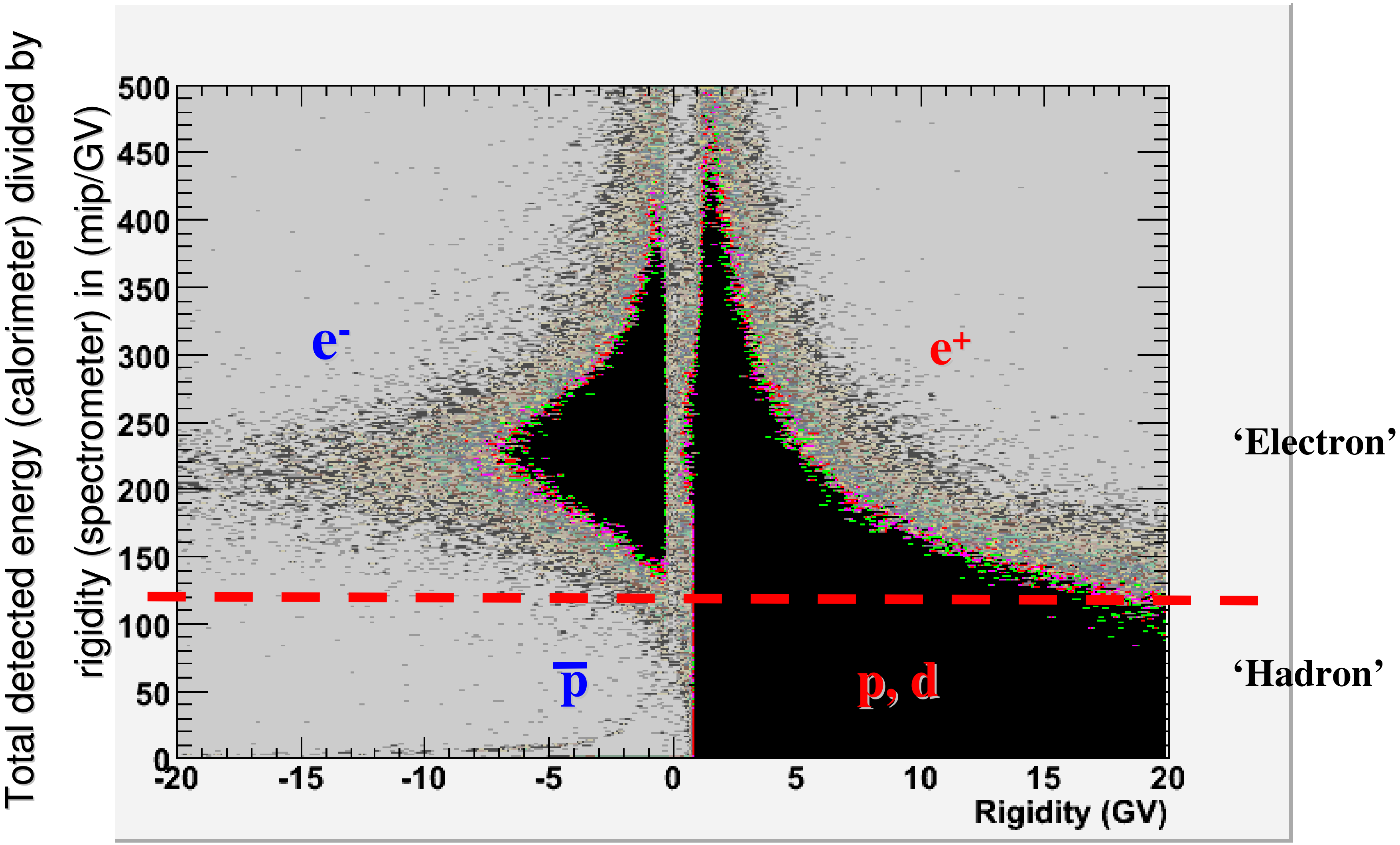


# Antiprotons to proton ratio: Current status

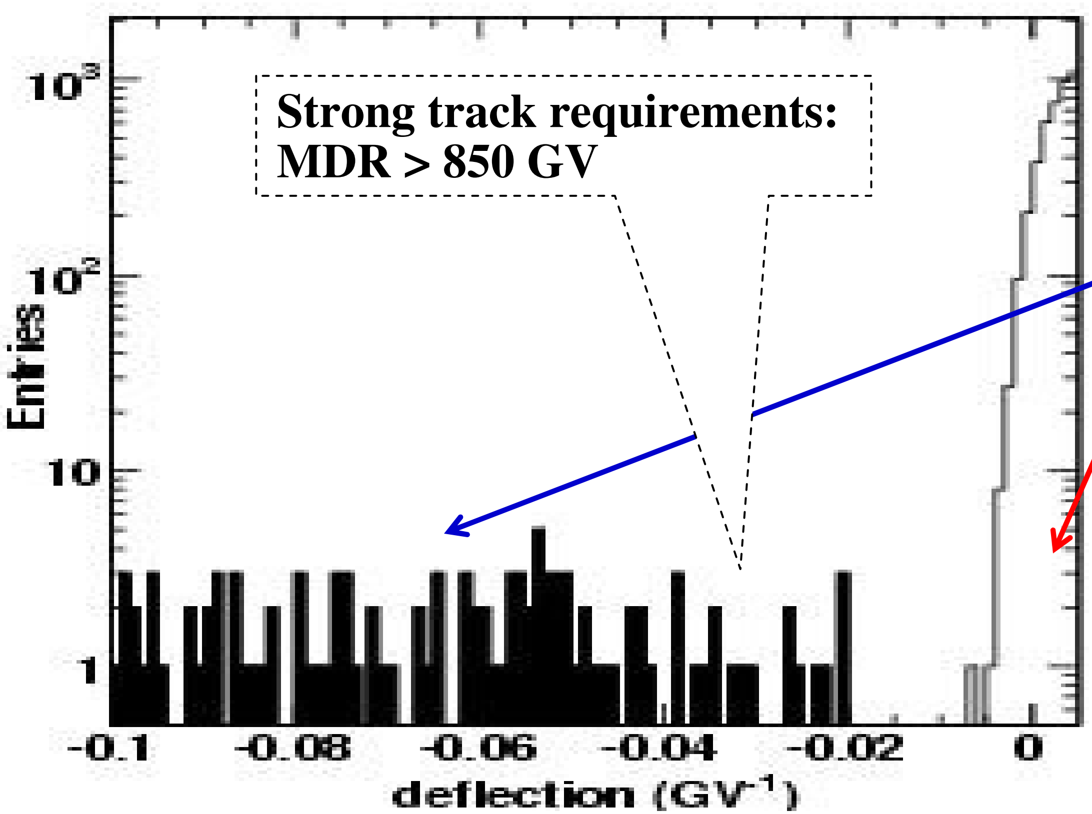



A **decrease** would clearly indicate a **secondary production**

# Electron Rejection with the Calorimeter: Energy-Momentum-Match



# Deflection spectrum of the remaining Protons and Antiprotons



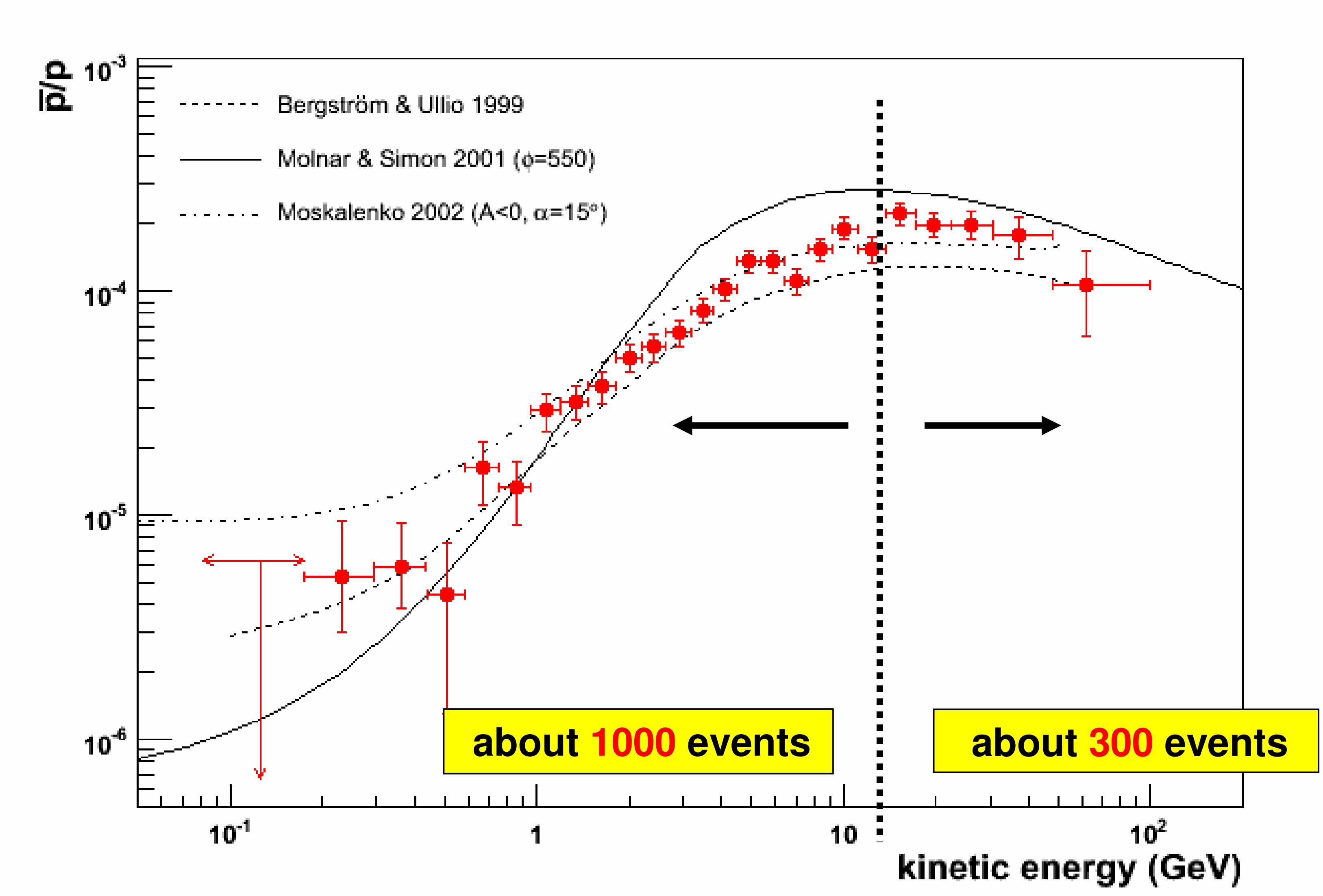

**Tracker Identification**

**Antiprotons**

**Protons (& spillover)**

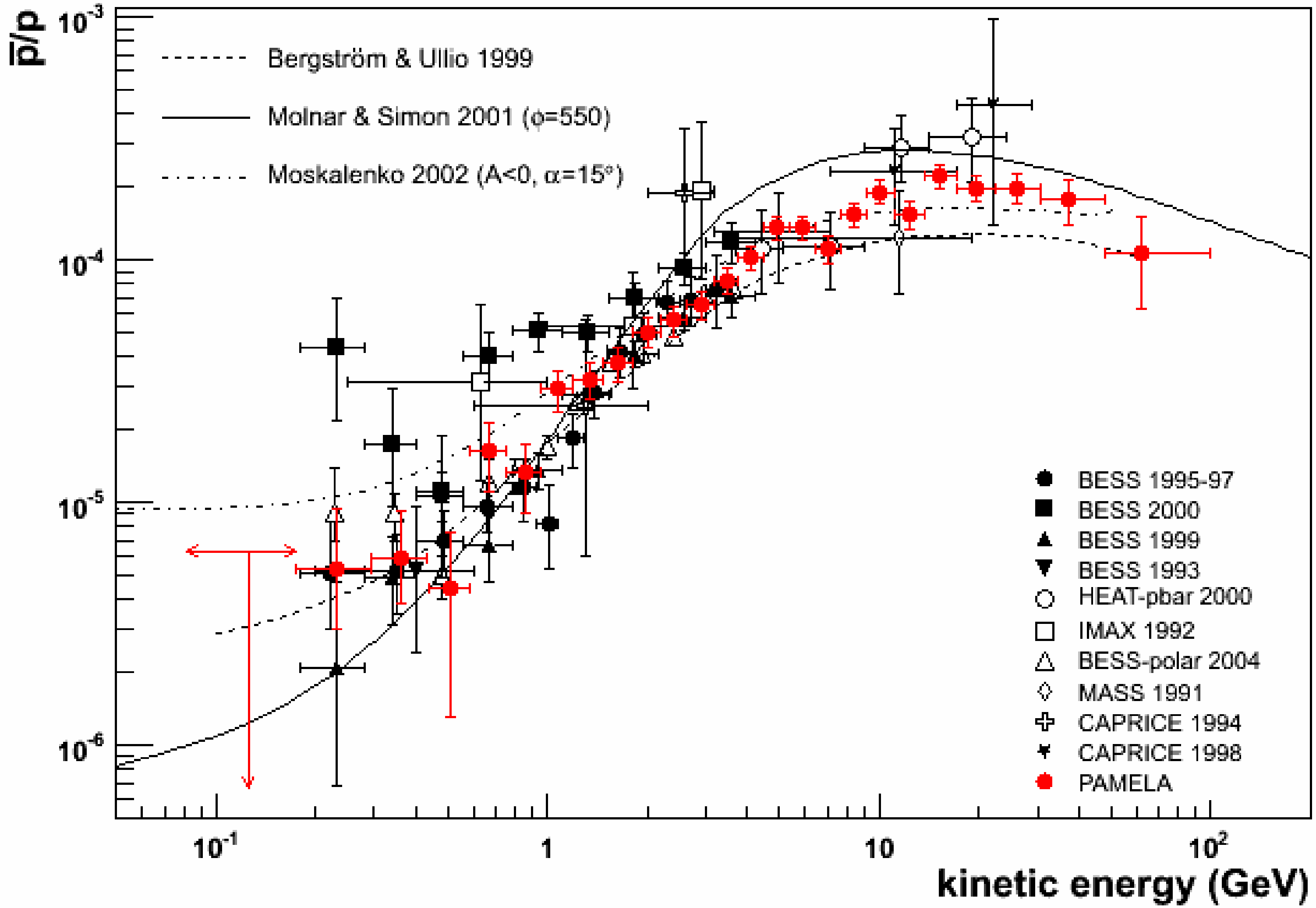
**Deflection = 1/Rigidity**

# PAMELA Antiproton to Proton Ratio

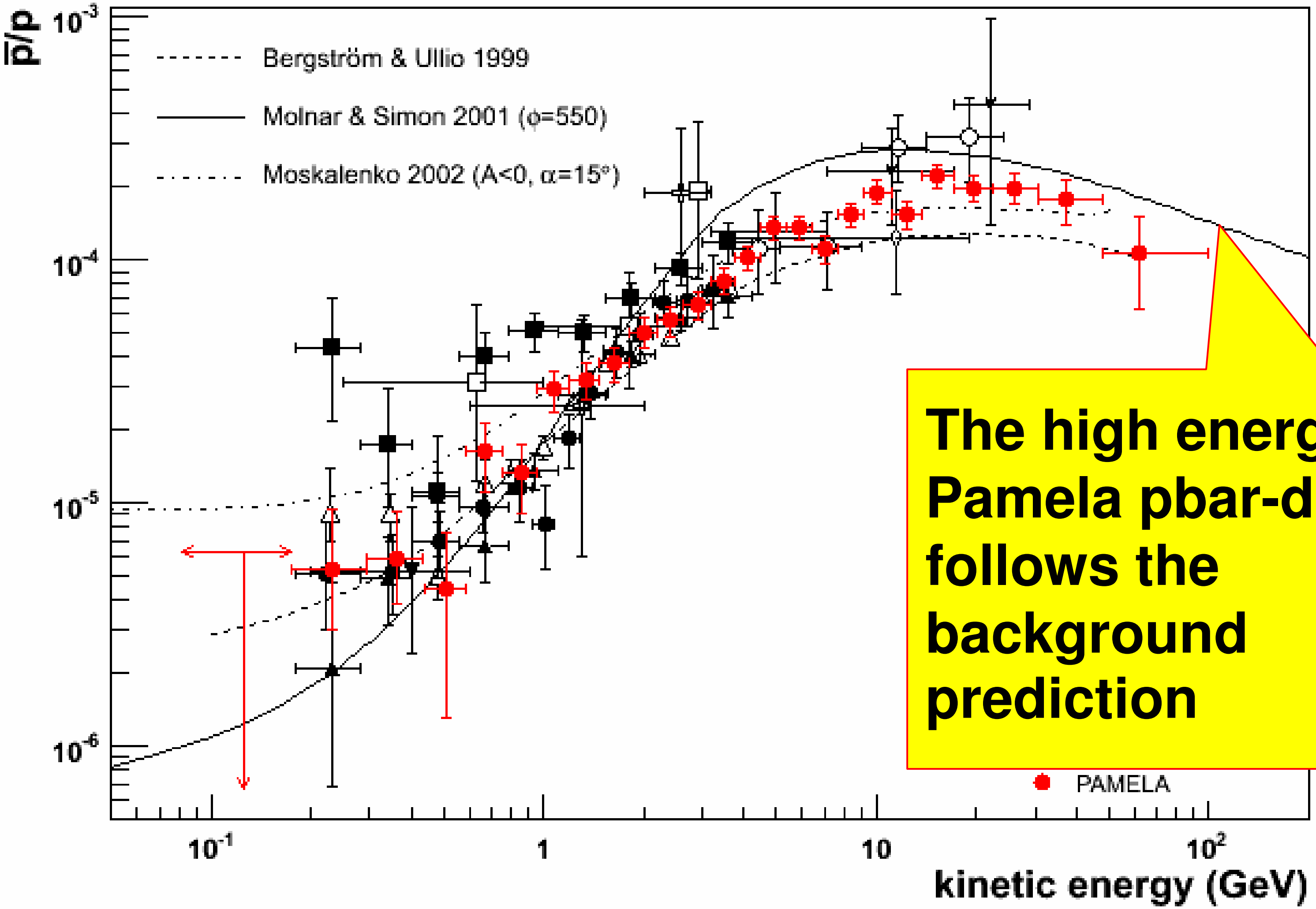



R>1 GV: PRL 102, 051101 (2009)
R<1 GV: P. Hofverberg, KTH, PhD Thesis, 2008-11-28

# PAMELA and the measured Antiproton to Proton Ratio

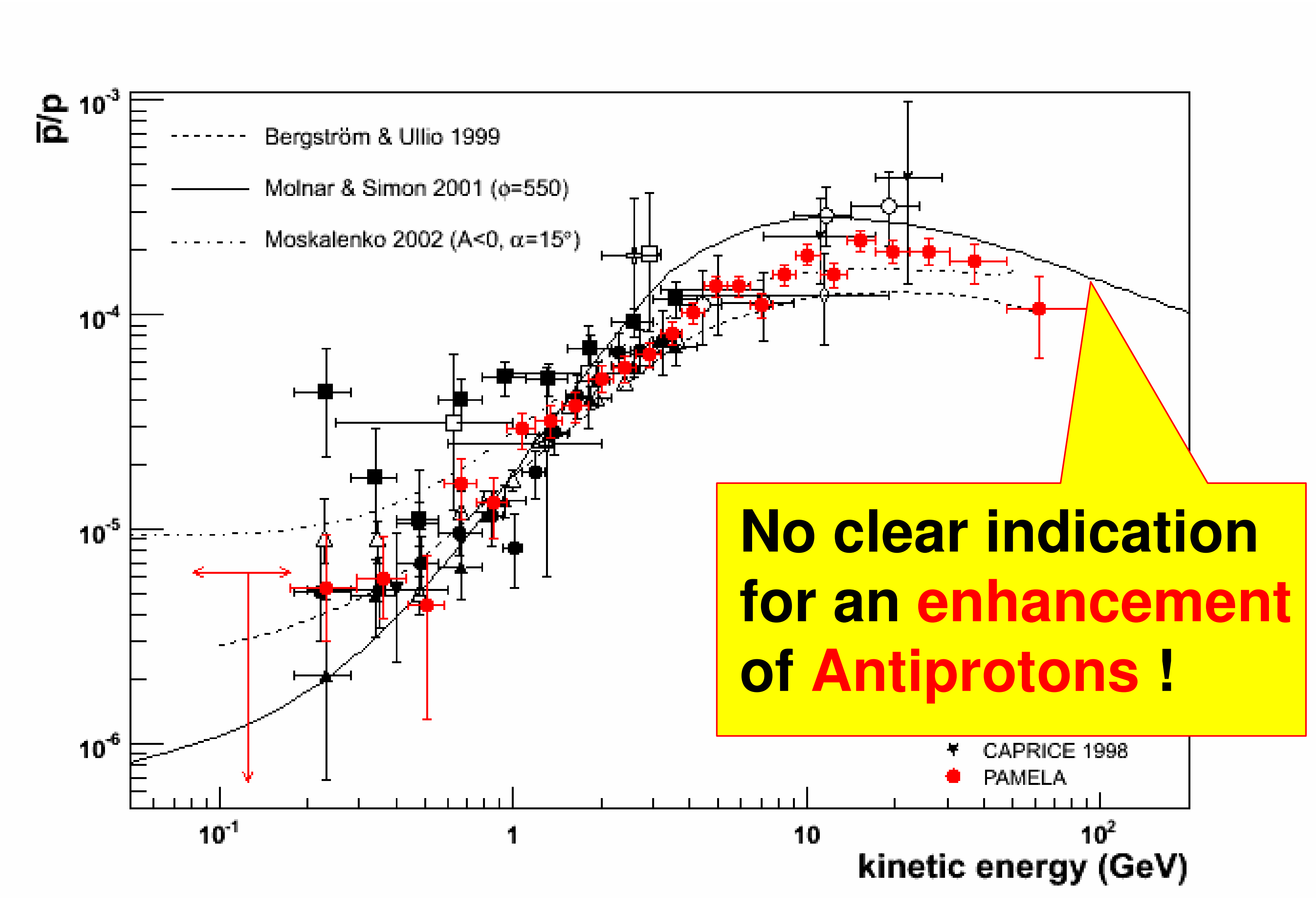


# PAMELA and the measured Antiproton to Proton Ratio




**The high energy Pamela pbar-data follows the background prediction**

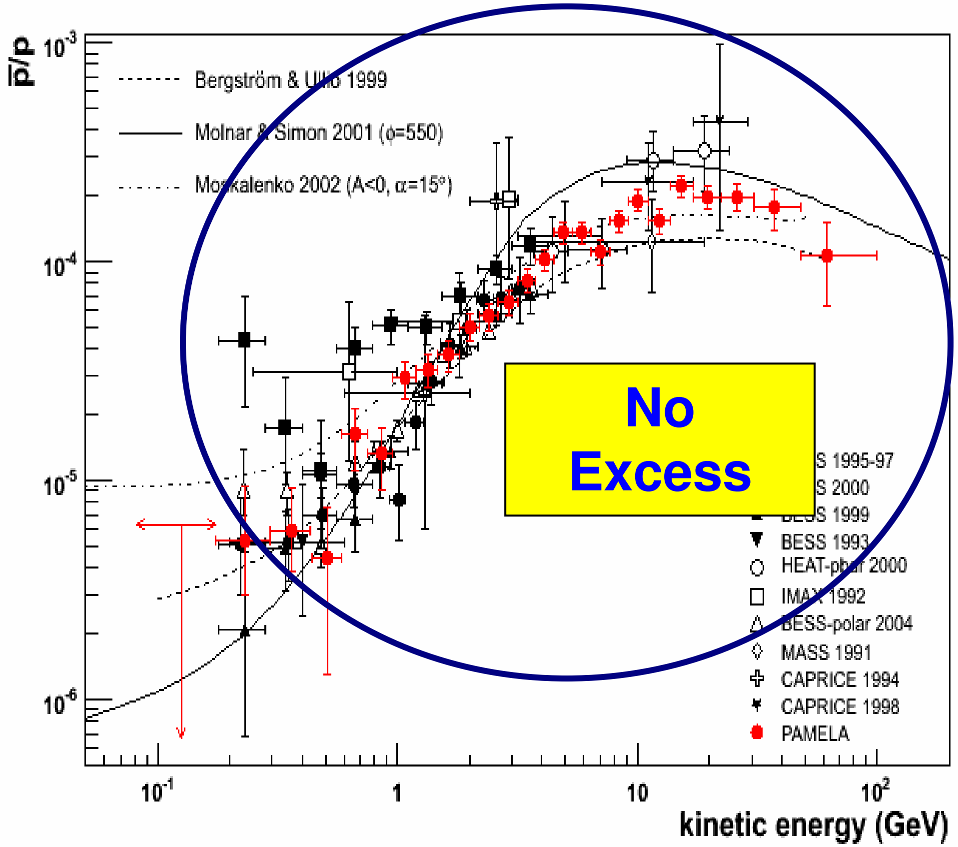
# PAMELA and the measured Antiproton to Proton Ratio



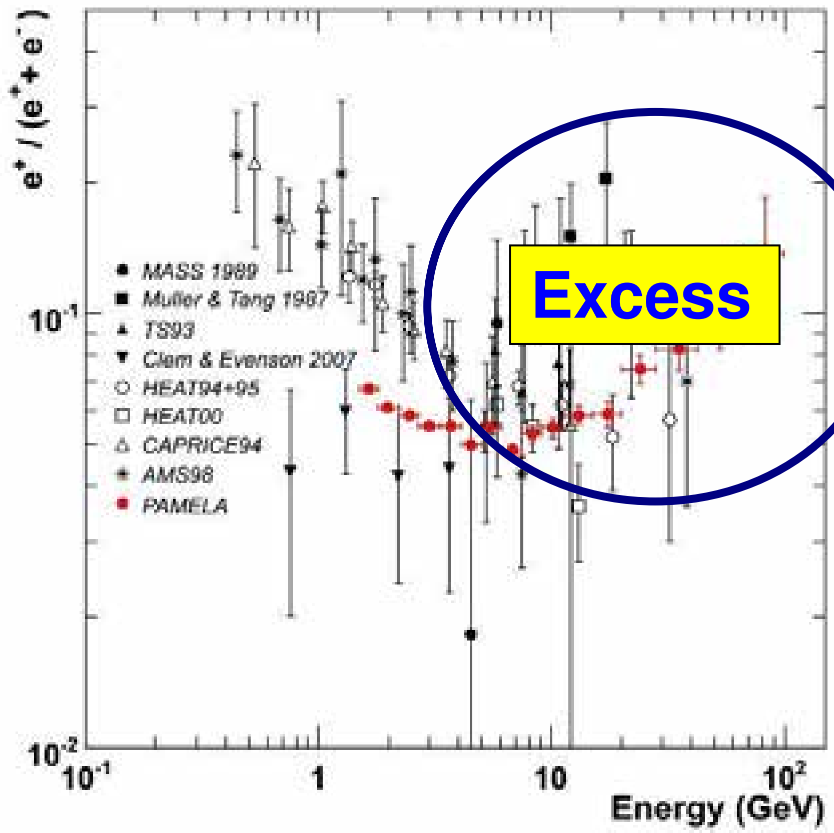
# Dark Matter (and other) Interpretations

**have to bring these two observations into a common theoretical framework**

## Antiprotons




## Positrons

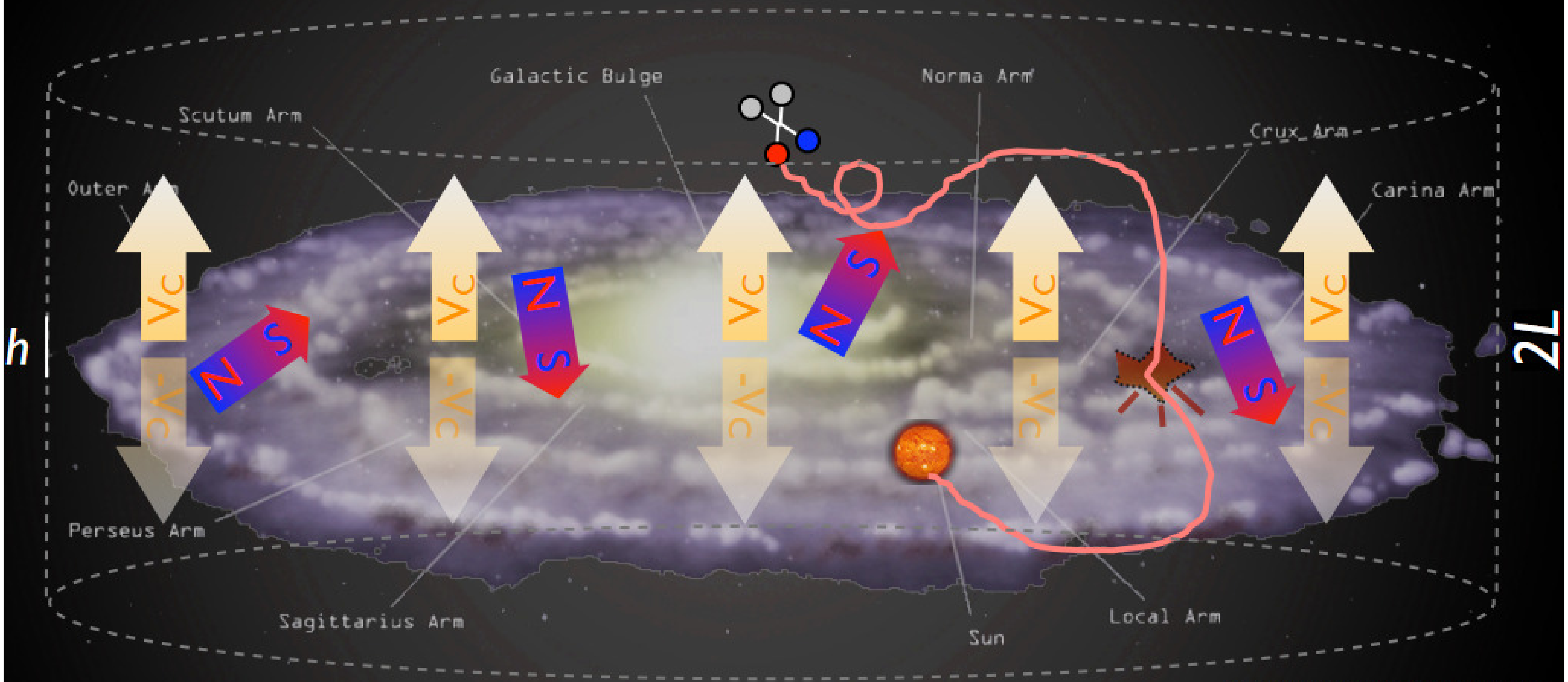


## Following slides taken from Marco Cirelli

http://www.marcocirelli.net/talks/8.DMinCR.Roma2.pdf

# Indirect Detection

$\bar{p}$ and $e^+$ from DM annihilations in halo




Salati, Chardonnay, Barrau, Donato, Taillet, Fornengo, Maurin, Brun... '90s, '00s

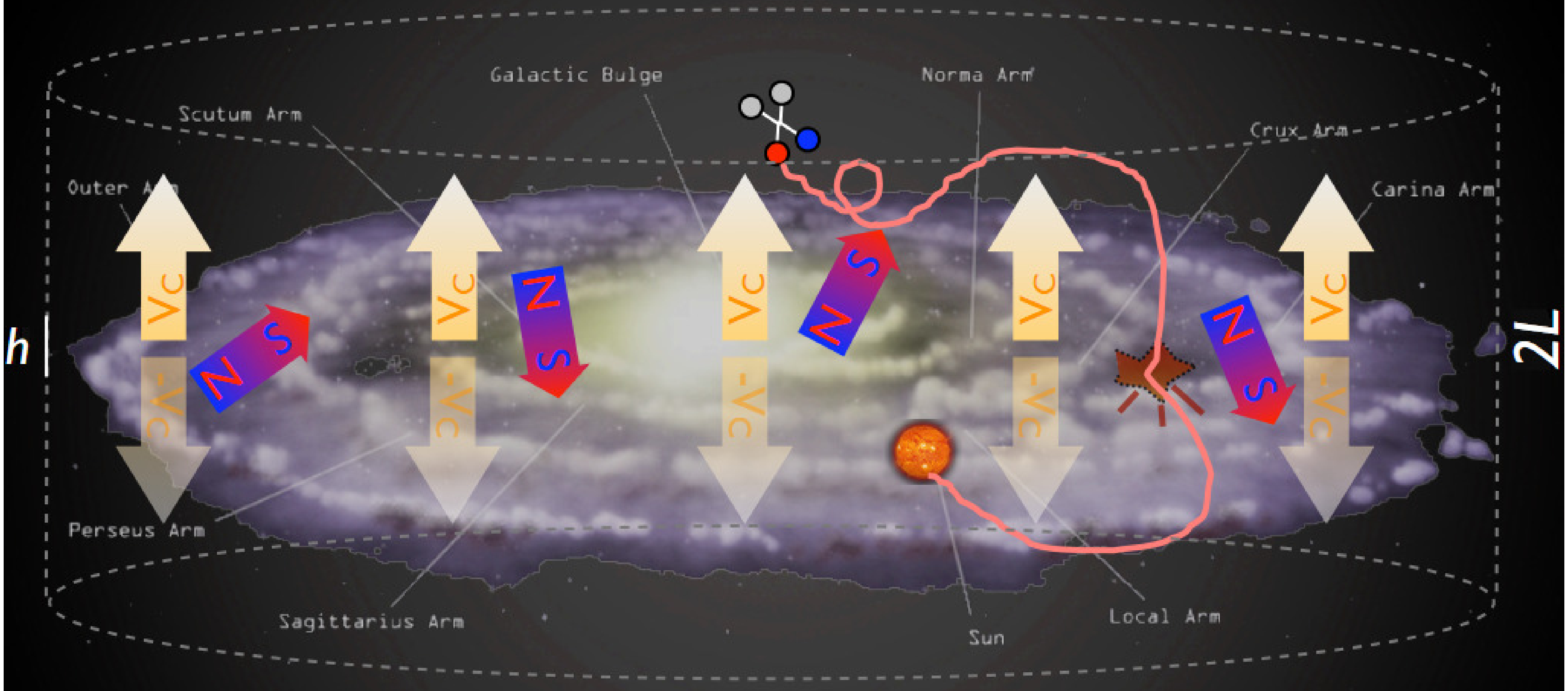
spectrum

$$\frac{\partial f}{\partial t} - K(E)\cdot\nabla^2 f - \frac{\partial}{\partial E}(b(E)f) + \frac{\partial}{\partial z}(V_c f) = Q_{\rm inj} - 2h\delta(z)\Gamma_{\rm spall} f$$

diffusion energy loss convective wind source spallations

# Indirect Detection

## $\bar{p}$ and $e^+$ from DM annihilations in halo




What sets the overall expected flux?

$$\text{flux} \propto n^2 \, \sigma_{\text{annihilation}}$$

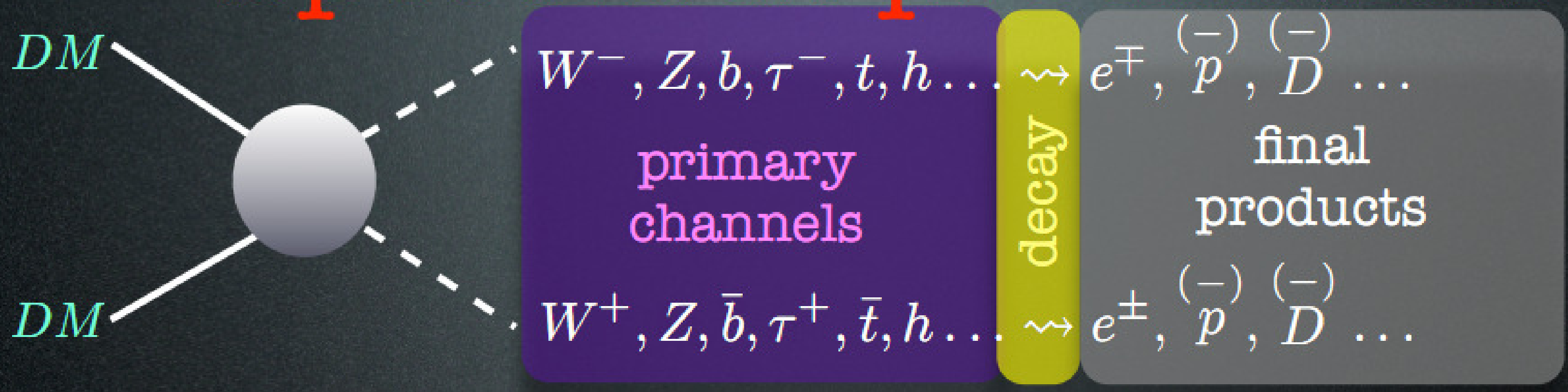
astro& cosmo

particle

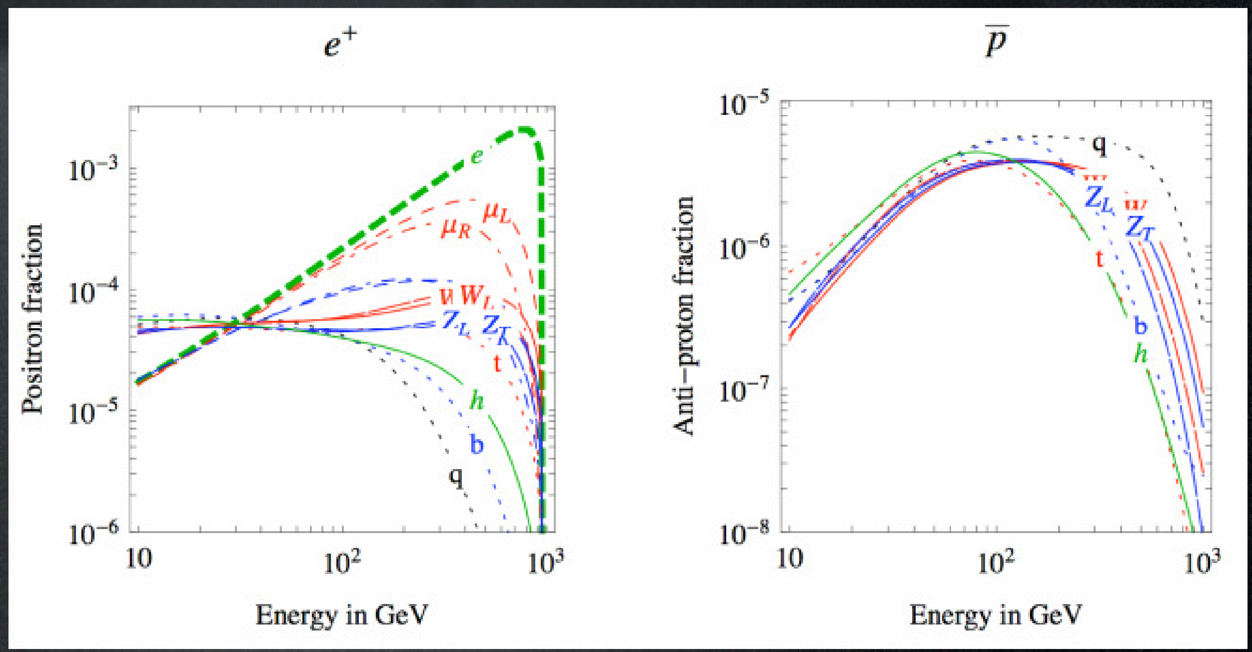
reference cross section:

$\sigma = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$

# Spectra at production




[PYTHIA 8]




So what are the particle physics parameters?

1. Dark Matter mass
2. primary channel(s)

# Results

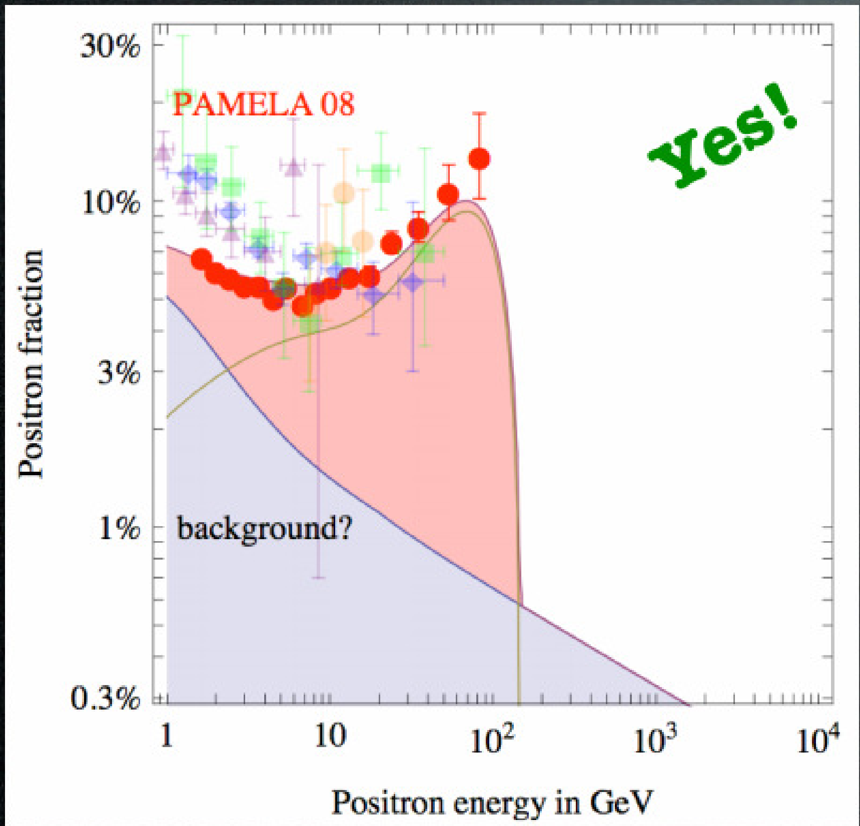
## Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 150\,{\rm GeV}$

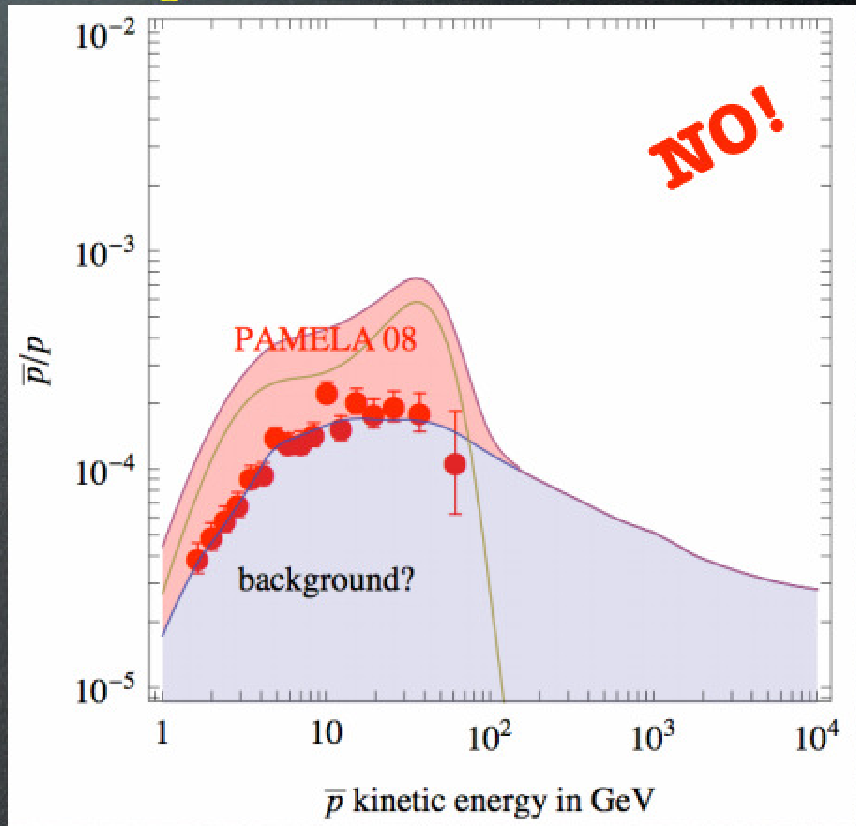
-annihilation $\rm DM\ DM \to W^+W^-$

(a possible SuperSymmetric candidate: wino)

**Positrons:**




**Anti-protons:**




[insisting on Winos]

# Results

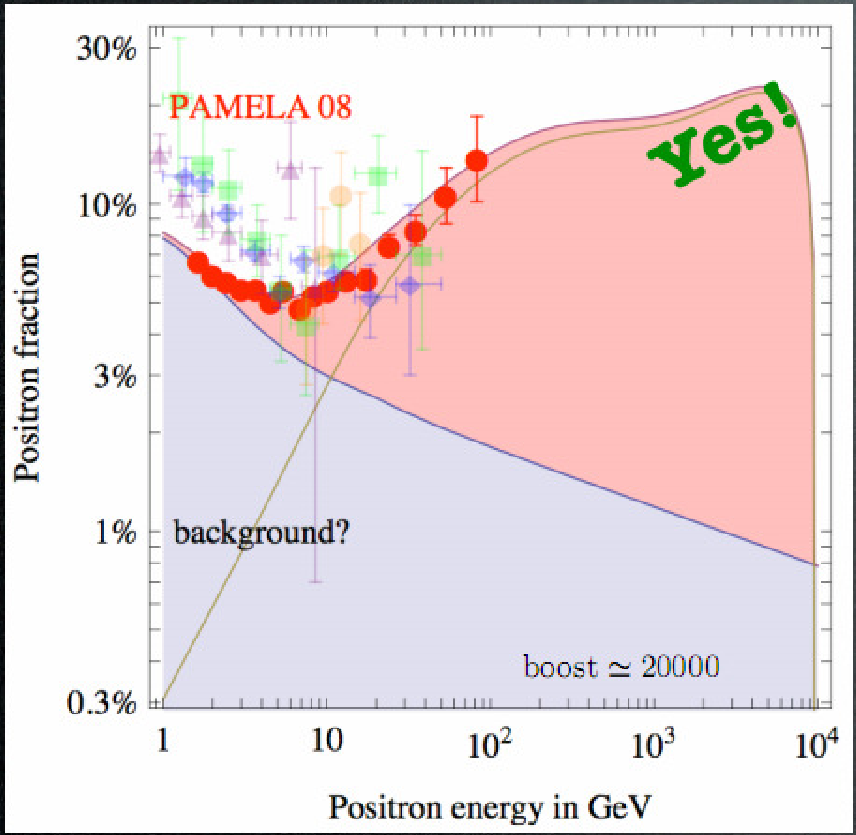
## Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 10\,\text{TeV}$

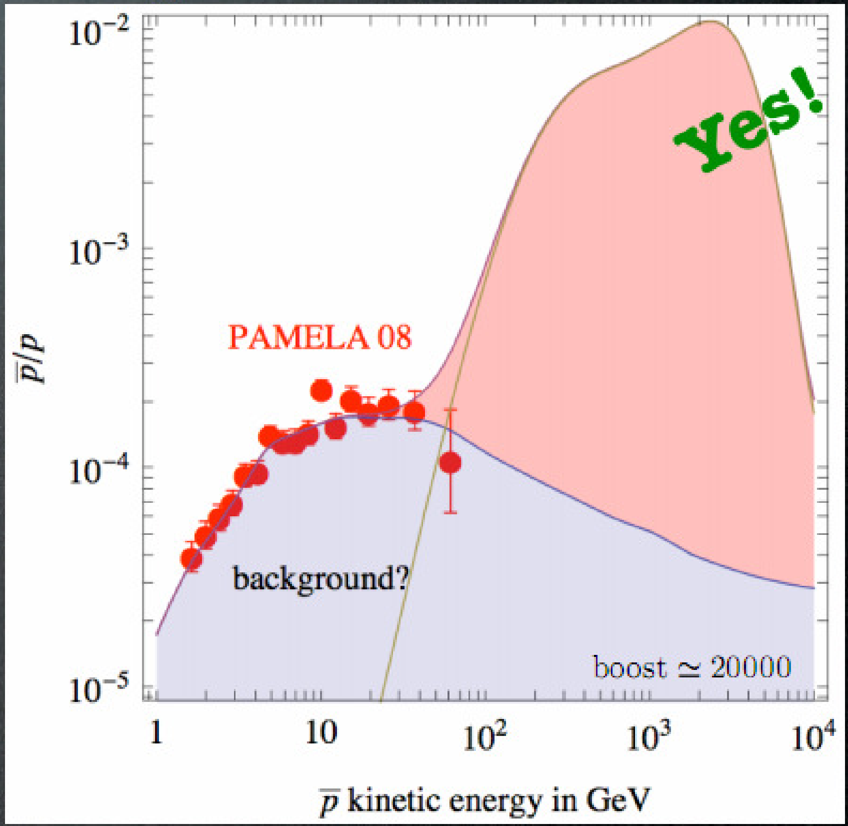
-annihilation $\text{DM DM} \to W^+W^-$

but...: -boost $B = 2 \cdot 10^4$ No...

Positrons:




Anti-protons:



# Results

## Which DM spectra can fit the data?

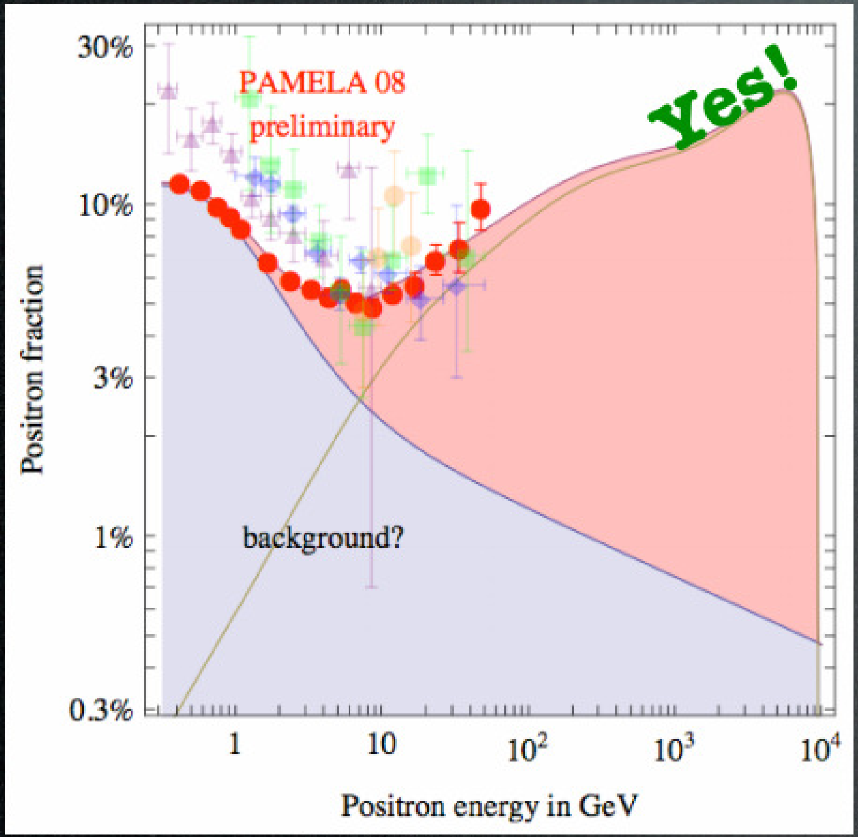
E.g. Minimal DM: -mass $M_{\rm DM} = 9.7\,{\rm TeV}$

[Cirelli, Strumia et al. 2006]

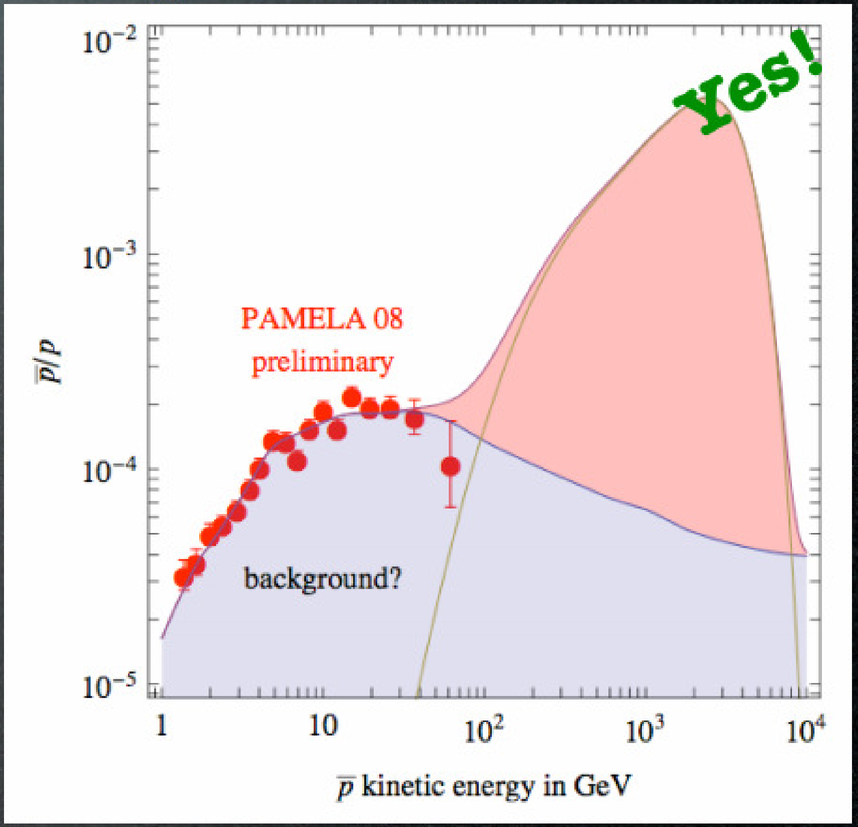
-annihilation $\rm DM\ DM \to W^+W^-$

-boost $B \simeq 30$ Yes!

Positrons:




Anti-protons:



# Dark Matter Interpretations Nov. 2008

Cirelli et al.   0809.2409

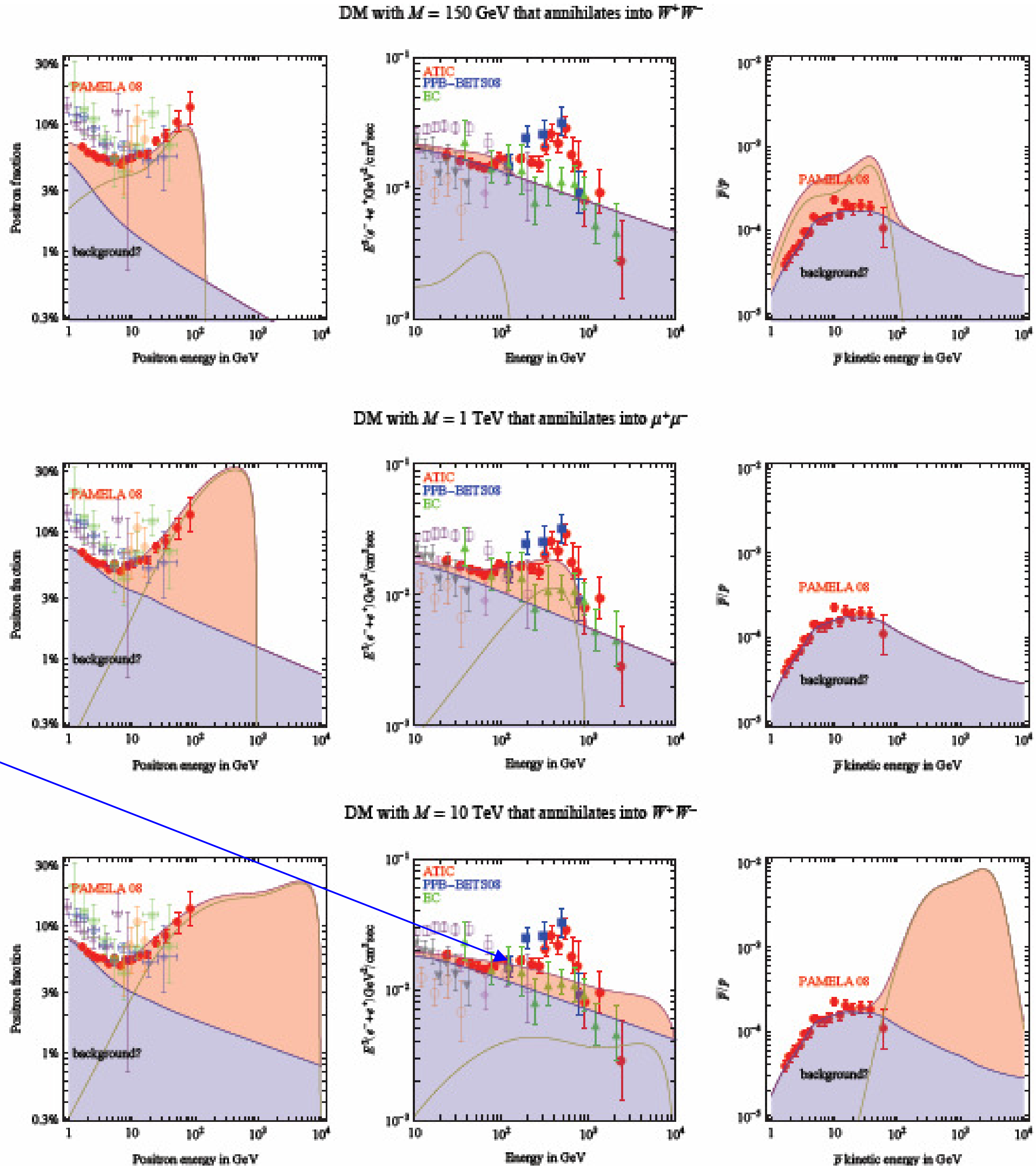
*„disfavored by the current $e^+ + e^-$ excess"*

May 2009:

ATIC vs. FERMI ... ??

**PAMELA:**

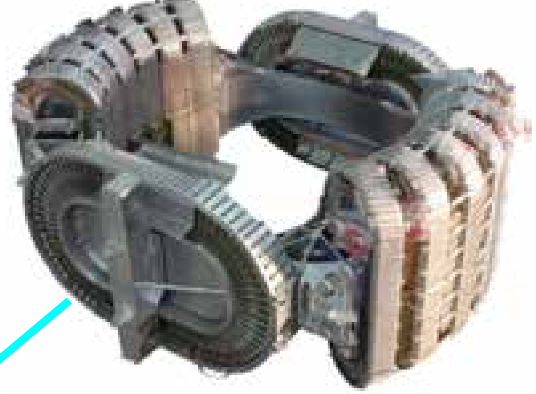
**Work in progress...**

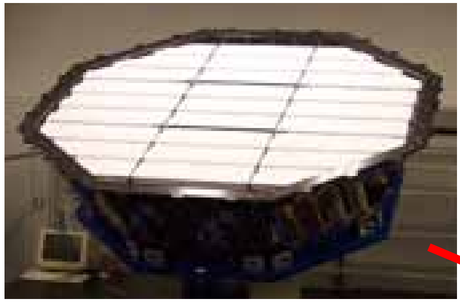


# Future Experiments

# AMS-02 on ISS

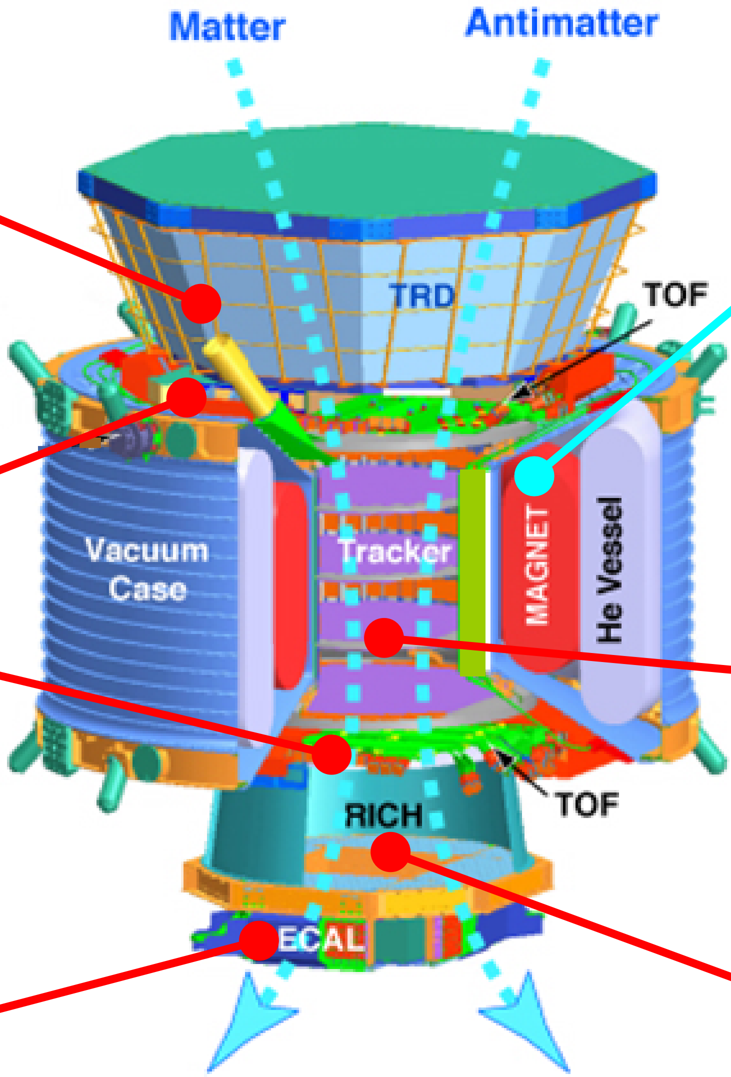
Magnet

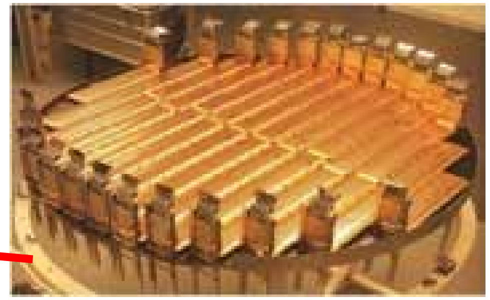




Time of Flight

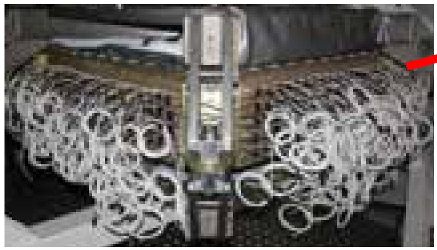
Silicon Tracker

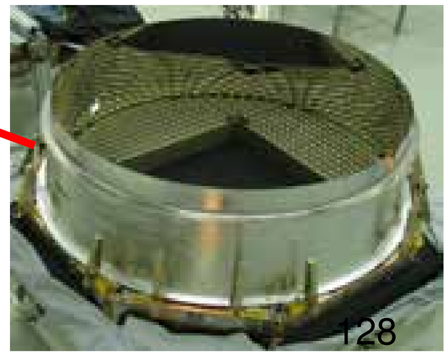


RICH

Calorimeter

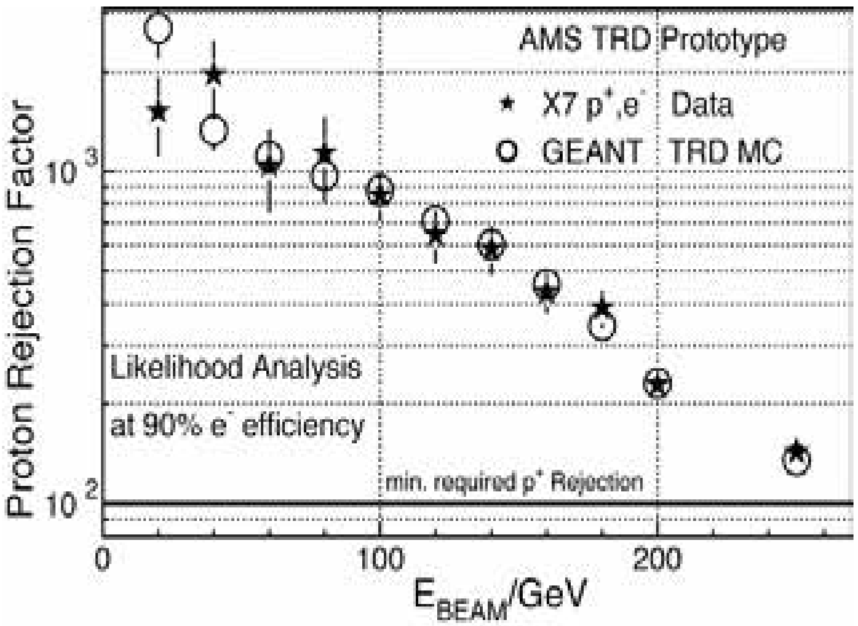


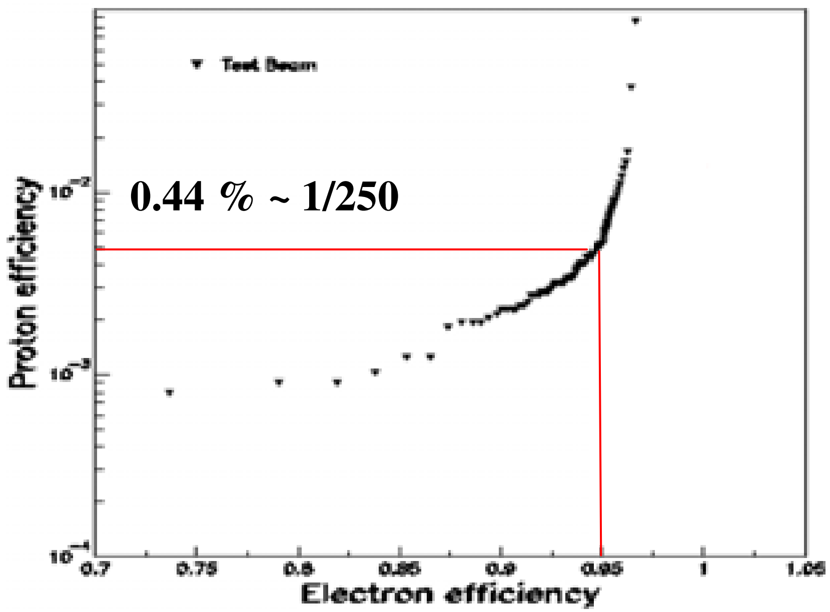


Manifested on STS-134
September 2010

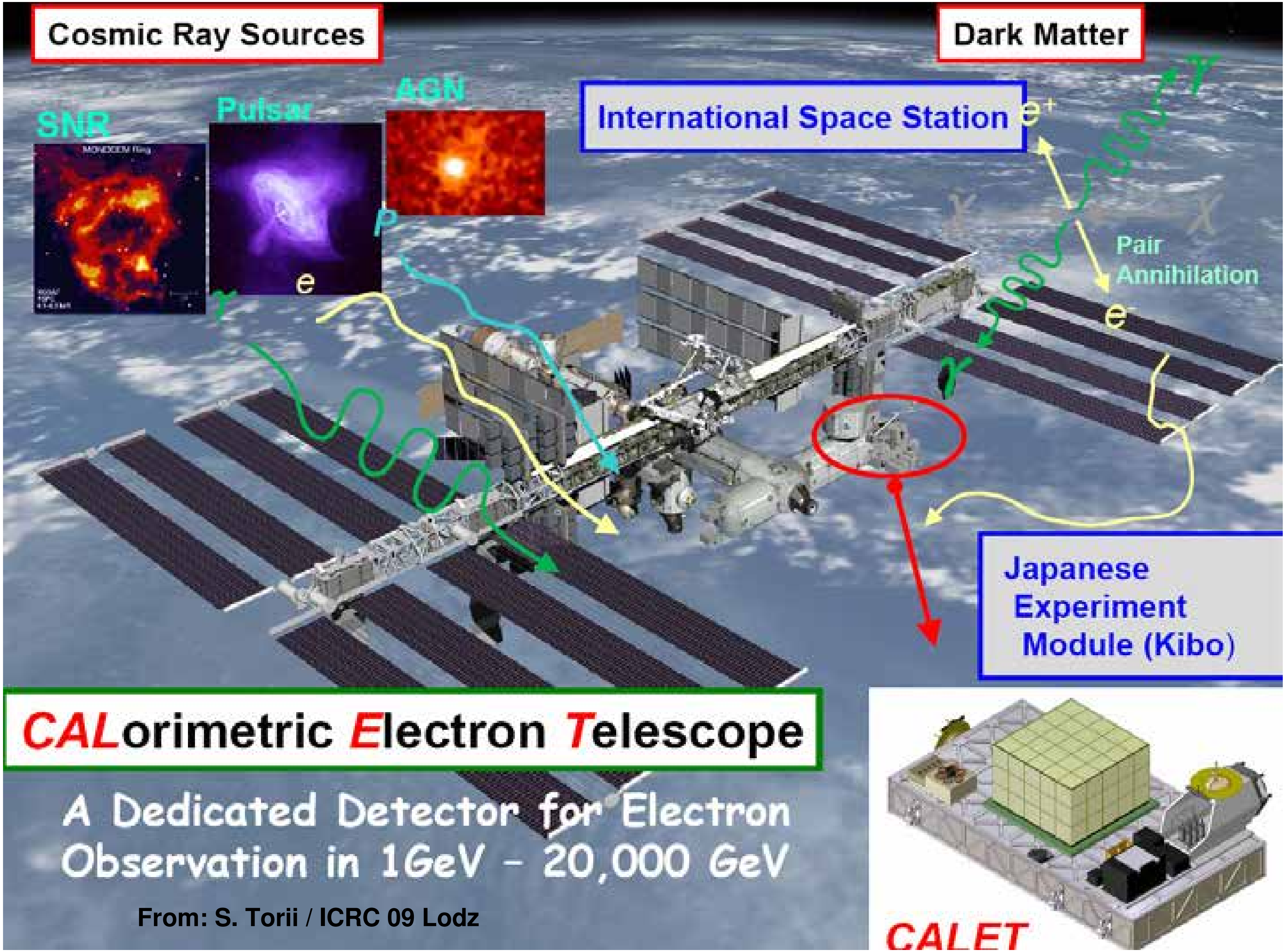
# AMS-02 Detectors

- Slightly smaller geometry factor (~5000 cm²sr) than AMS-01 (~500 cm² sr using Calorimeter)
- Superconducting Magnet 0.86 T
- 8 layers of Silicon Tracker σ~10 μm => MDR ~ 2600 GV
- Time-of-Flight σ ~ 120 ps
- Aerogel-RICH Cherenkov n=1.03, 8 photoelectrons
- TRD: PE 10 μm fiber fleece + straw tubes Xe/$CO_2$
- ECAL: lead/scintillating fibre 17 $X_0$, proton rejection ~250 (x 20 applying energy/momentum match) ~ 5000



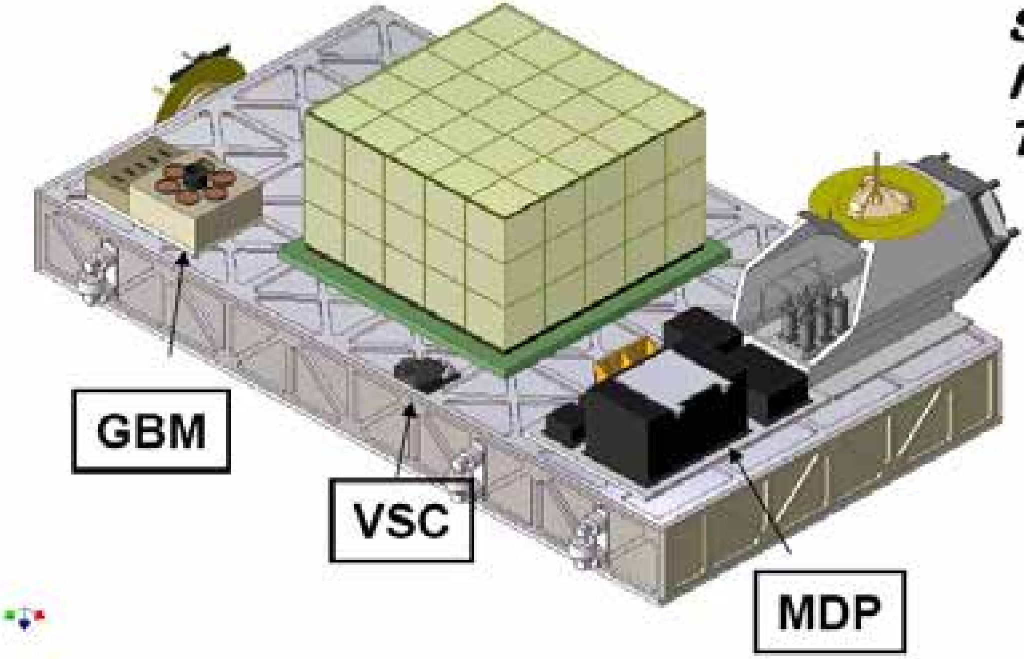



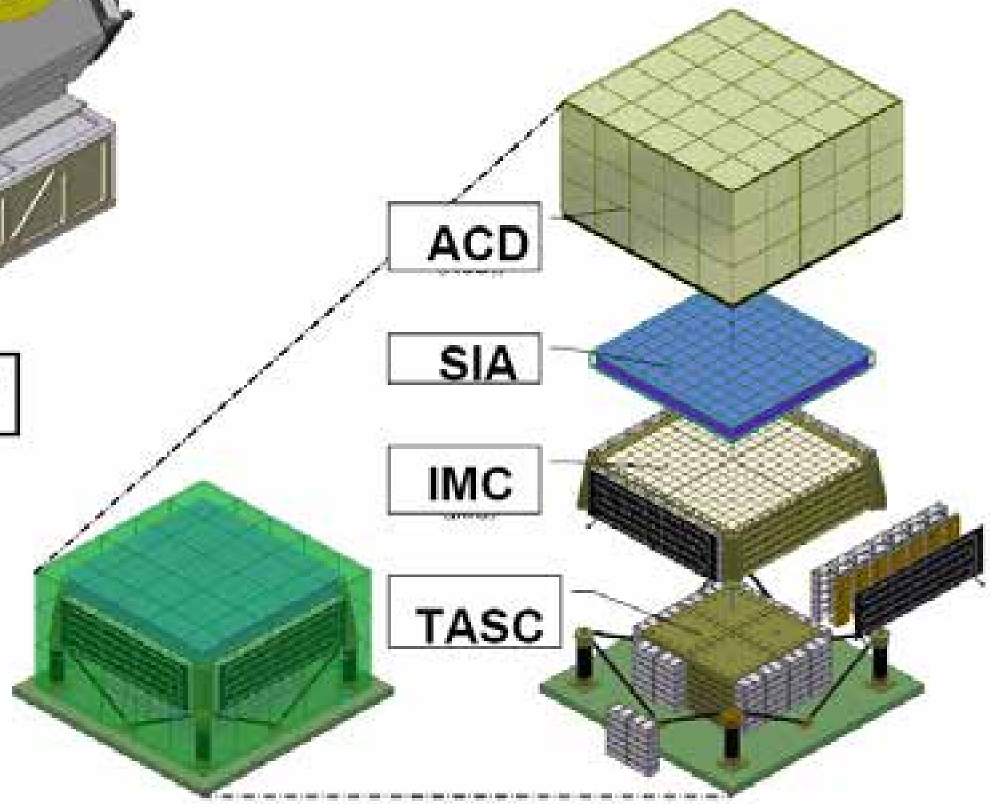
# Proposed Experiments


Cosmic Ray Sources
Dark Matter
SNR
Pulsar
AGN
International Space Station
Pair
Annihilation
Japanese
Experiment
Module (Kibo)
CALorimetric Electron Telescope
A Dedicated Detector for Electron
Observation in 1GeV - 20,000 GeV
From: S. Torii / ICRC 09 Lodz
CALET

# Schematic Structure of the CALET Payload

***ACD: Anti-coincidence Detector***
***S IA:  Silicon Pixel Array***
***IMC: Imaging Calorimeter***
***TASC: Total Absorption Calorimeter***



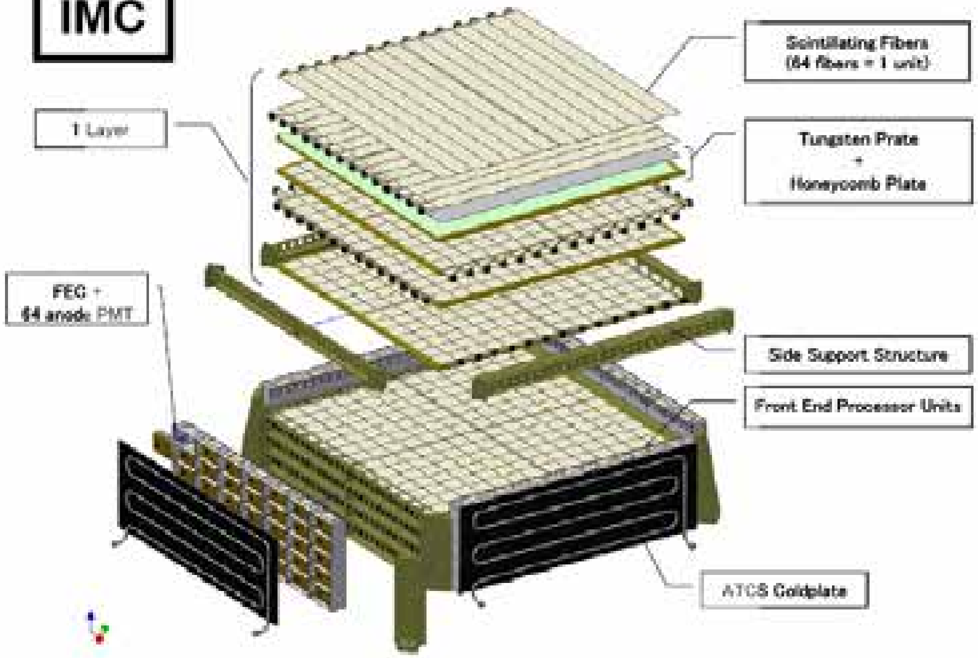




***GBM: Gamma-Ray Burst Monitor***
A.Yoshida et al. OG 2.7 (Oral)
***VSC: Visual Sky Sensor***
***MDP: Mission Data Processor***

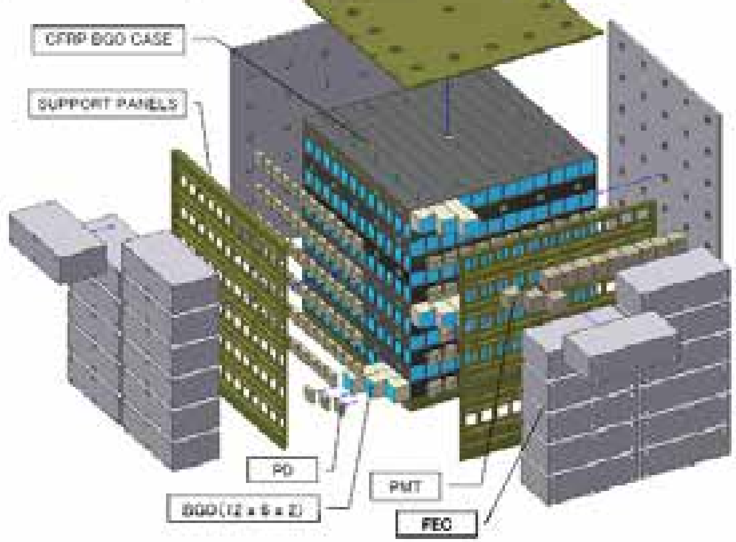
**From: S. Torii / ICRC 09 Lodz**

# Details of Each Component

**IMC**




**TASC**



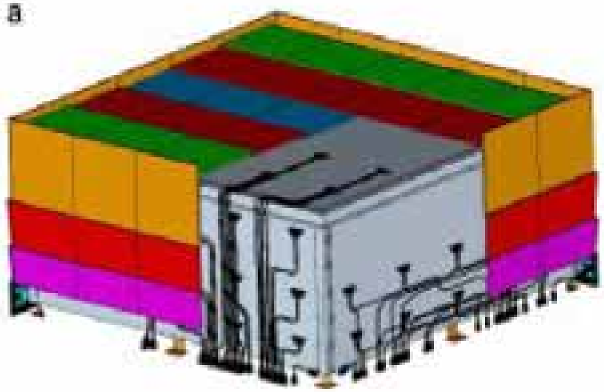

a

**SIA**

**Co-PI:**
**Pier S. Marrocchesi**

- Silicon Pixel Array x 2 layers ( Pixel ~1cm x 1cm)
- Charge resolution: 0.1e for p, 0.35e for Fe

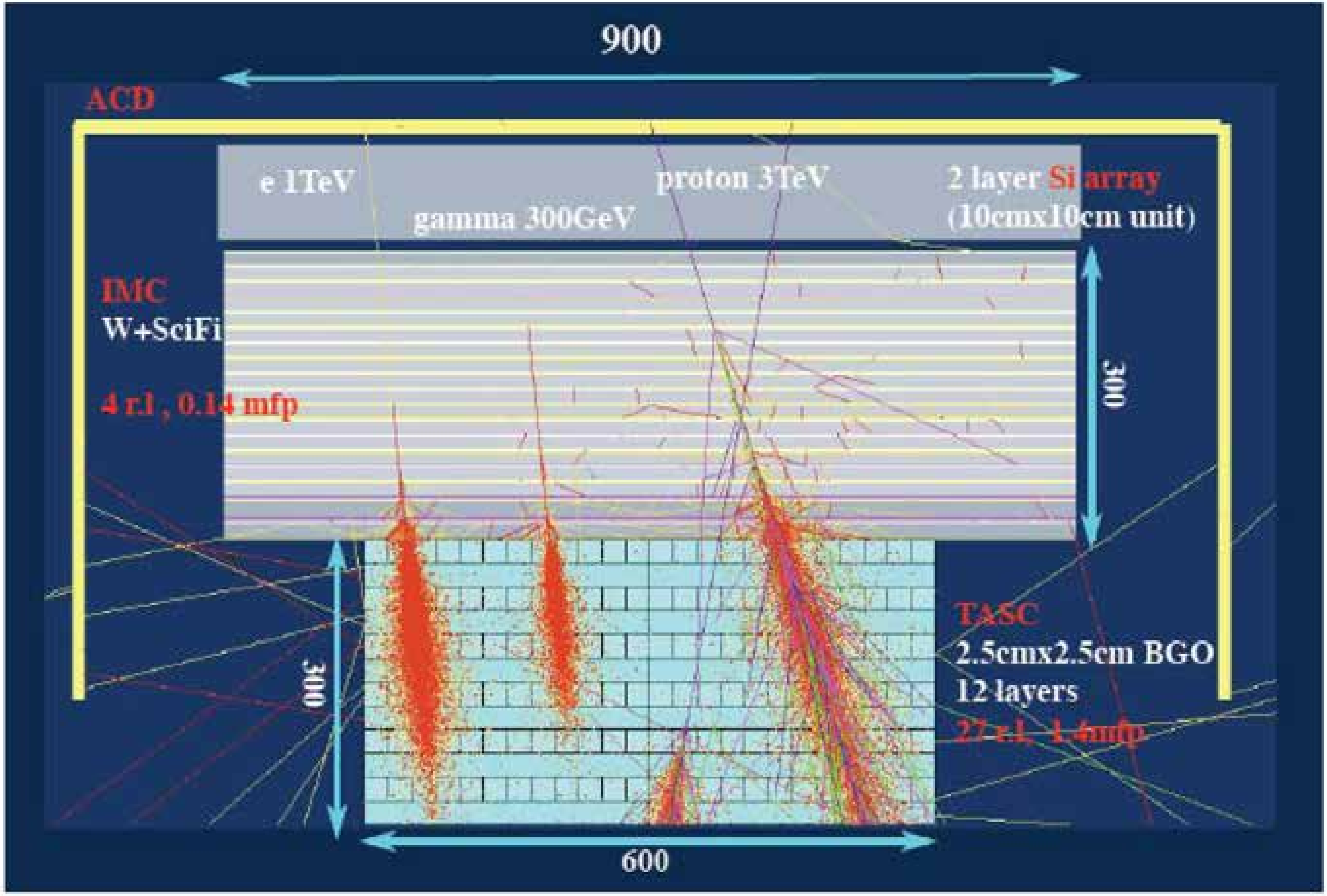
**SACS(ACD)**



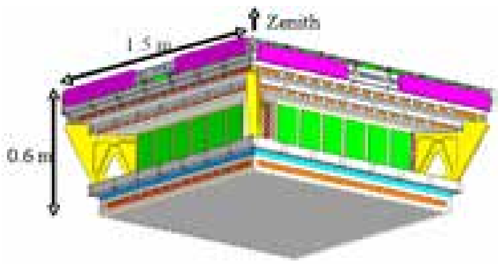
- Segmented Plastic Scintillators for Anti-Coincidence

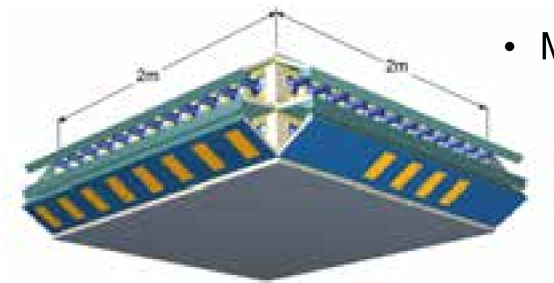
**From: S. Torii / ICRC 09 Lodz**

# Examples of Simulation Events

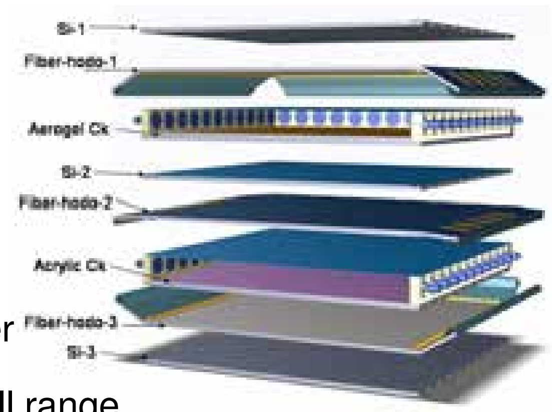


# Orbiting Astrophysical Observatory in Space (OASIS)



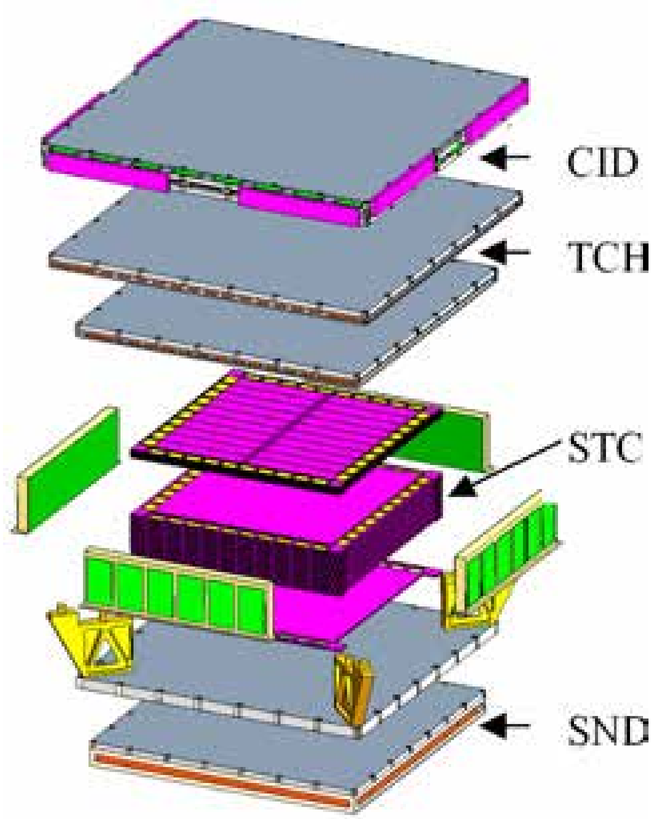

- Orbiting galactic cosmic ray (GCR) observatory
  - Astrophysics Strategic Mission Concept Study
  - Development in GSFC Instrument Design Lab, Mission Design Lab
- High Energy Particle Calorimeter Telescope (HEPCaT) - this talk
  - 2 Imaging calorimeter modules to measure high energy electrons and nuclei (1≤Z≤28)
- Energetic Trans-Iron Composition Experiment (ENTICE) - see Binns, paper 441, OG1.5 poster
  - 4 dE/dx vs. Cherenkov modules measure element composition 10 ≤ Z to actinides
  - dE/dx - 3 silicon detector arrays
  - Velocity and charge - 2 Cherenkov
    - Acrylic n=1.5
    - Silica-aerogel n=1.043, 1.025
  - Trajectory - 3 scintillating optical fiber hodoscope
  - Individual element resolution over full range
  - Four modules with $16 m^2$ collecting area
  - 60 m2 sr yr exposure, $10^{10}$ GCR, >100 actinides
- Mission - see Christl, paper 1151, OG1.5
  - EELV launch (e.g. Atlas V 551, 5 m fairing)
  - Near sun-synchronous orbit, orbital and gravity gradient stabilized
  - 5 yr nominal exposure




**From: J. W. Mitchell / ICRC 09 Lodz**

# HEPCAT Instrumentation

- Silicon-pad charge identification detector (CID) determines particle charge
  - 4 CID layers give 100% coverage and redundancy
  - ~1 $cm^2$ pads limit backsplash contamination
- Plastic scintillator tirgger-charge hodoscopes (TCH) give fast trigger, rough trajectory, and additional charge meaurement
- Silicon-tungsten calorimeter (STC) measures particle energy and provides electron/proton discrimination
  - 32 absorber layers graded in thickness ( 8 0.5 $X_0$, 24 1.5 $X_0$)
    40 $X_0$ total 1.7 $\lambda$
  - Silicon-strip detector layers between each absorber alternate X and Y
  - SSD - 8 cm x 8 cm x 380 $\mu$m, 32 strips
- Borated plastic scintillator neutron detector (SND) measures vaporization neutron flux from STC and penetrating particles
  - Neutron and charged particle signals separated by time
- Front-end electronics use commercial ASICS
  - $>10^7$ dynamic range (mip to shower max) by reading out SSD strips and back-side
- Geometry factor 1.25 $m^2$ sr/module (2.5 $m^2$ sr total)
  - FOV ±60°
  - STC 0.83 m x 0.83 m x 0.38 m
  - CID and TCH sized to span STC FOV
- Extensive simulations using detailed GEANT4 model

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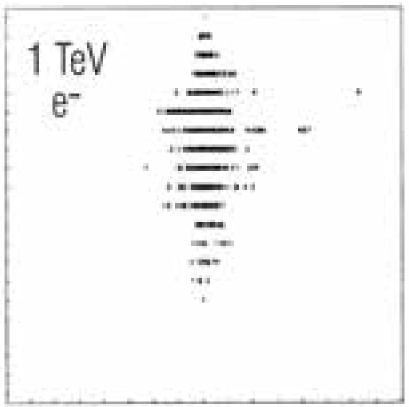
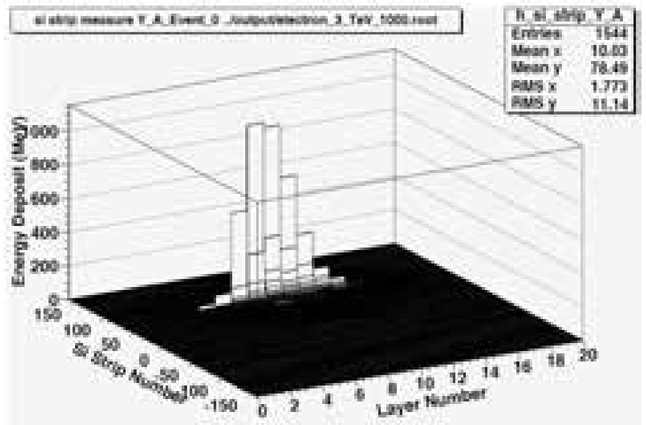
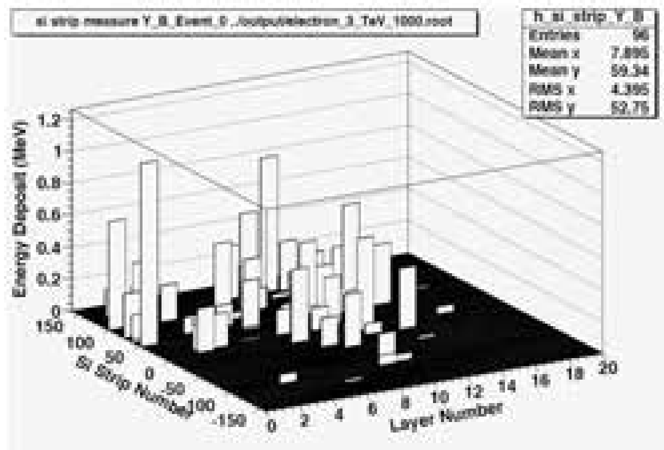
# Electron/Proton Discrimination

- Protons >$10^3$ more abundant at HEPCaT energies and spectrum ~2.7 vs >3
- Requires discrimination power ≥$10^4$
  - Distinguished from proton background by shower topology, penetration, neutron content
  - Topology considerations: starting point, lateral distribution, longitudinal development, containment
  - Electron/proton separation at ~$10^5$ level requires nearly full containment of shower

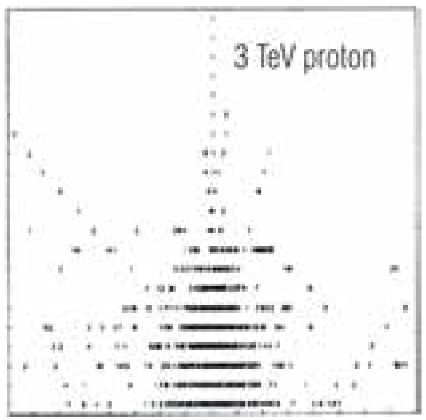


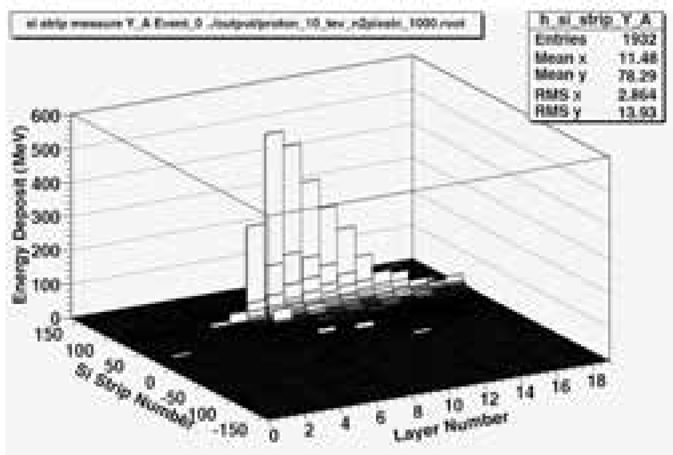




3 TeV electron

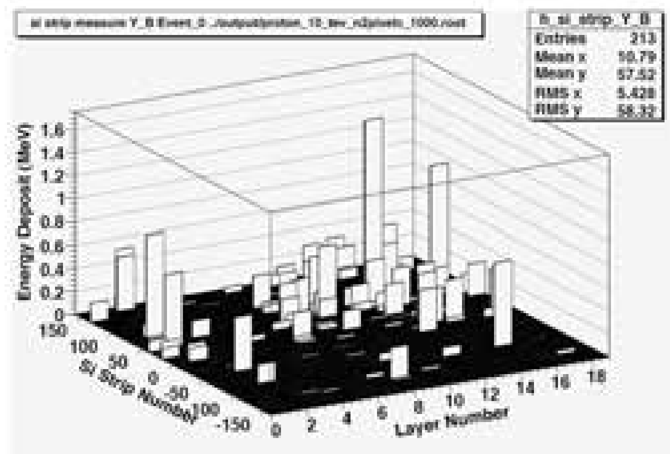



3 TeV electron low signals




10 TeV proton




10 TeV proton low signals

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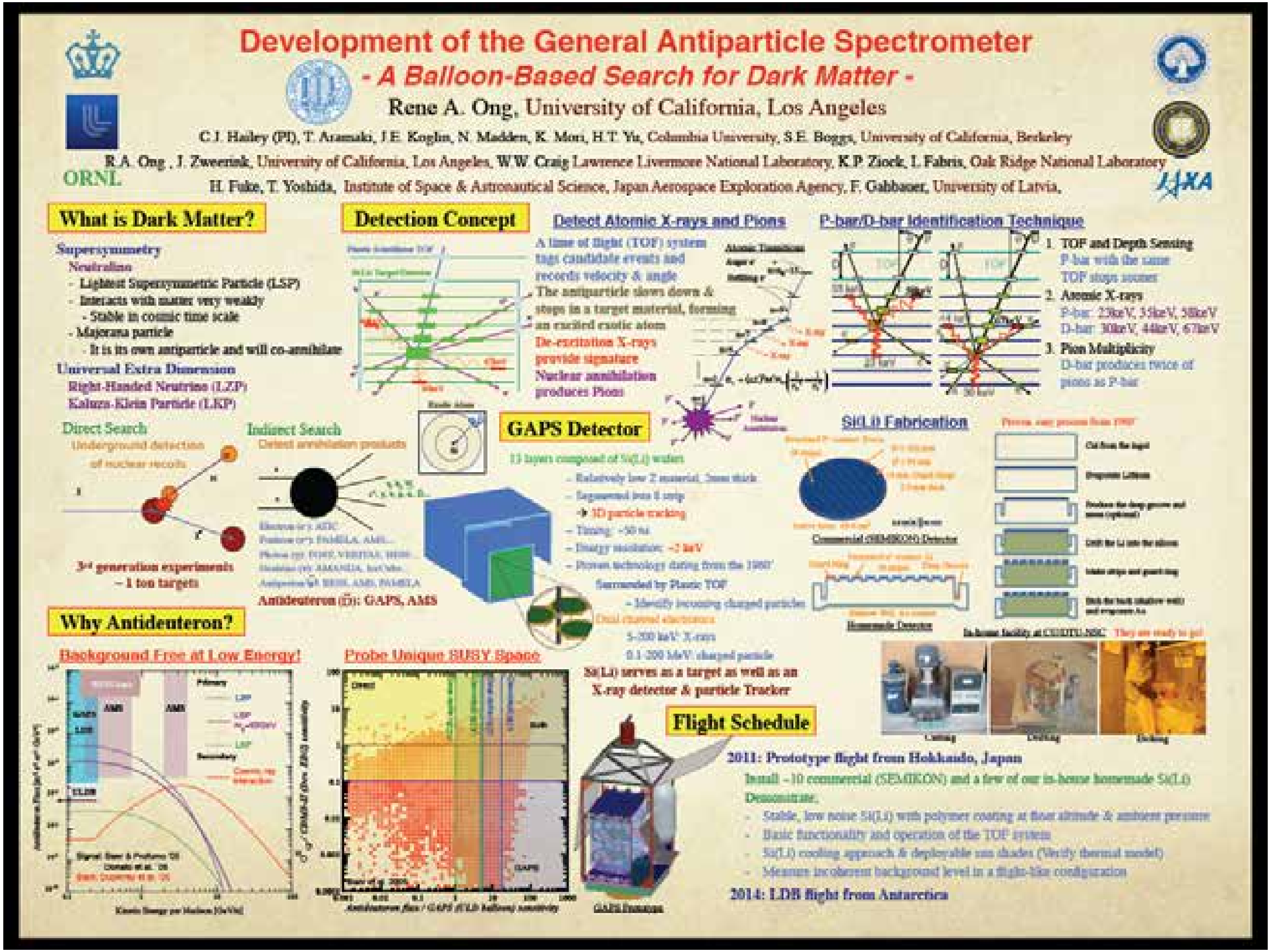
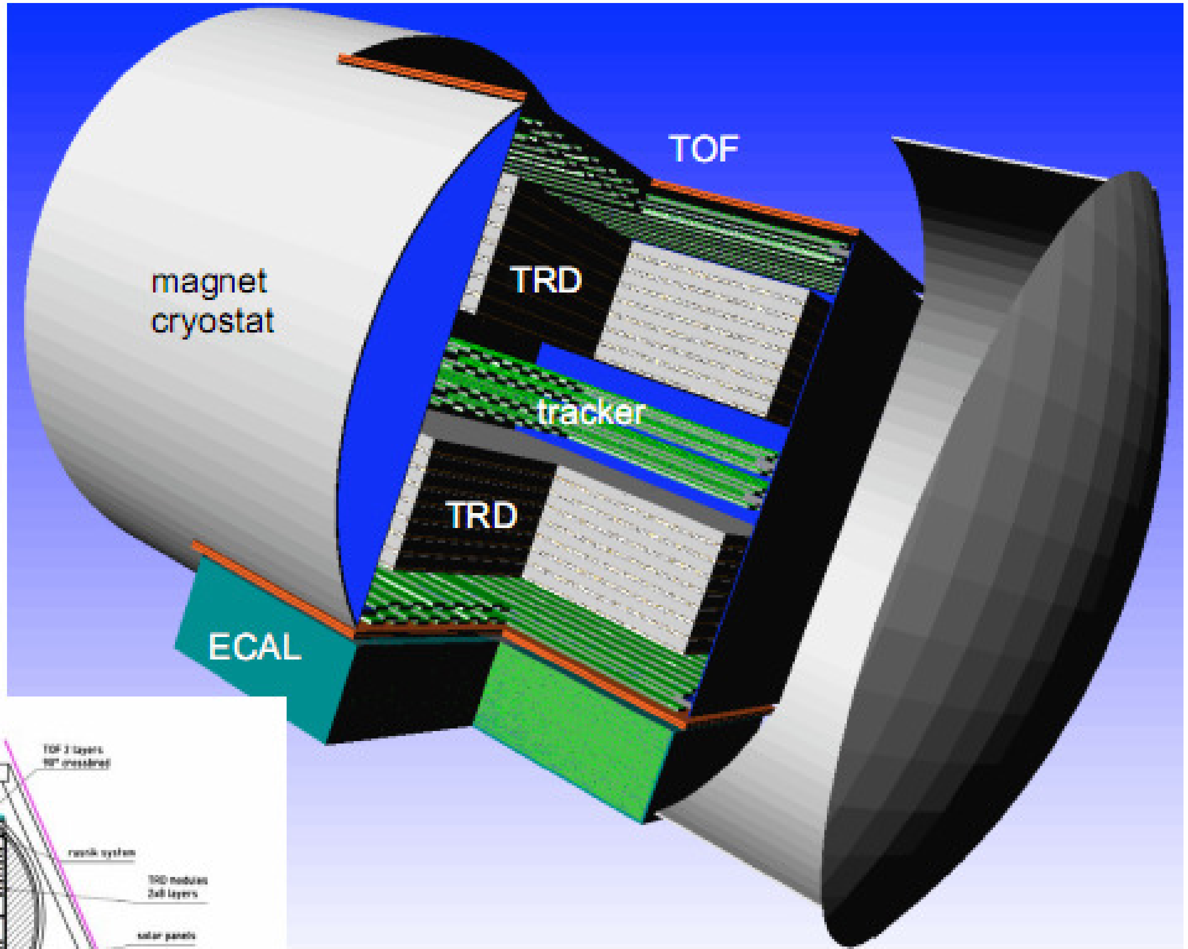
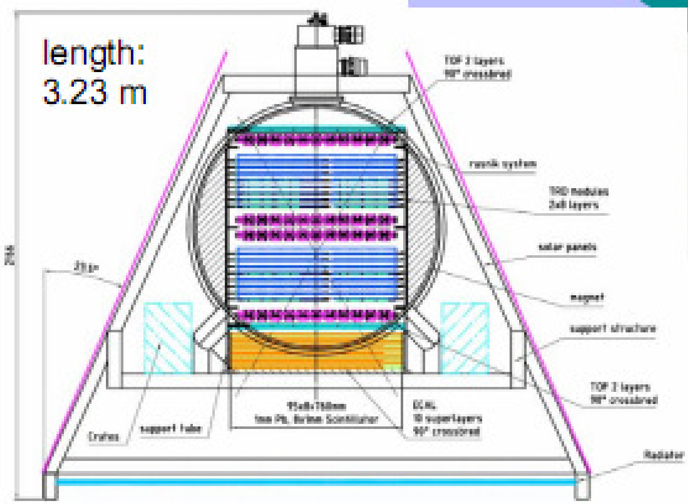
# GAPS – General Antiparticle Spectrometer



# PEBS - Positron Electron Balloon Spectrometer

Positron acceptance:
tracker+ECAL
width=0.76m,
length=1m
2500 $cm^2 sr$



# Conclusions

- Indirect Dark Matter search is powerful and promising
- PAMELA results can be a breakthrough: excess in positrons, no excess in antiprotons
- DM models must predict huge annihilations into leptons with negligible hadronic production: Not the “usual” framework!
- Astrophysical explanation? Only nearby pulsars?
- Future data (PAMELA, ATIC, GLAST/Fermi, AMS-02) will be crucial