The PAMELA Space Experiment

Mirko Boezio
INFN Trieste, Italy,
OKC Guest

On behalf of the PAMELA collaboration

Cosmic-Ray Backgrounds in DM Searches

January 25th 2010

PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

PAMELA Collaboration

LNF

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

Russia:

Ioffe Physico-Technical Institute

Moscow
St. Petersburg

Germany:

Universität Gesamthochschule Siegen

Siegen

Sweden:

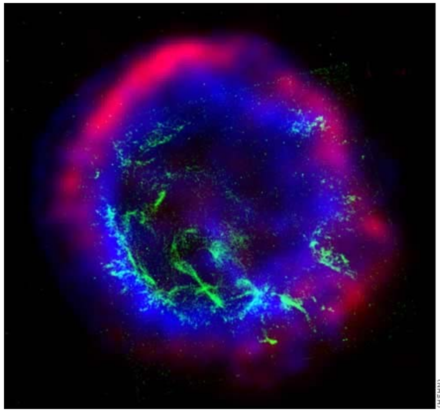
Kungl Tekniska Högskolan

KTH, Stockholm

Scientific goals

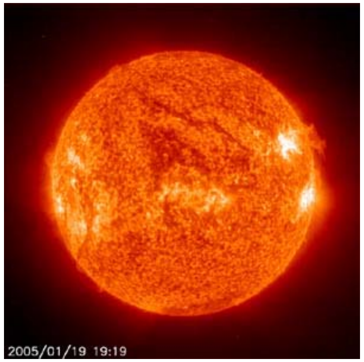
- **Search for dark matter annihilation**

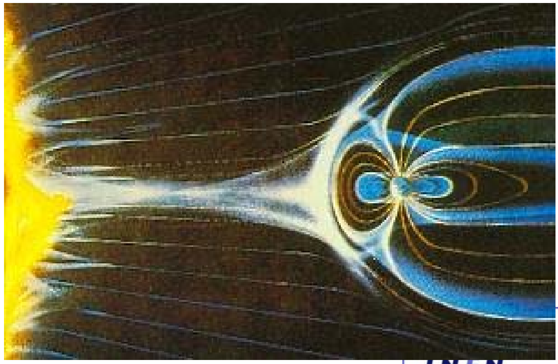
- **Search for antihelium (primordial antimatter)**
- **Search for new Matter in the Universe (Strangelets?)**



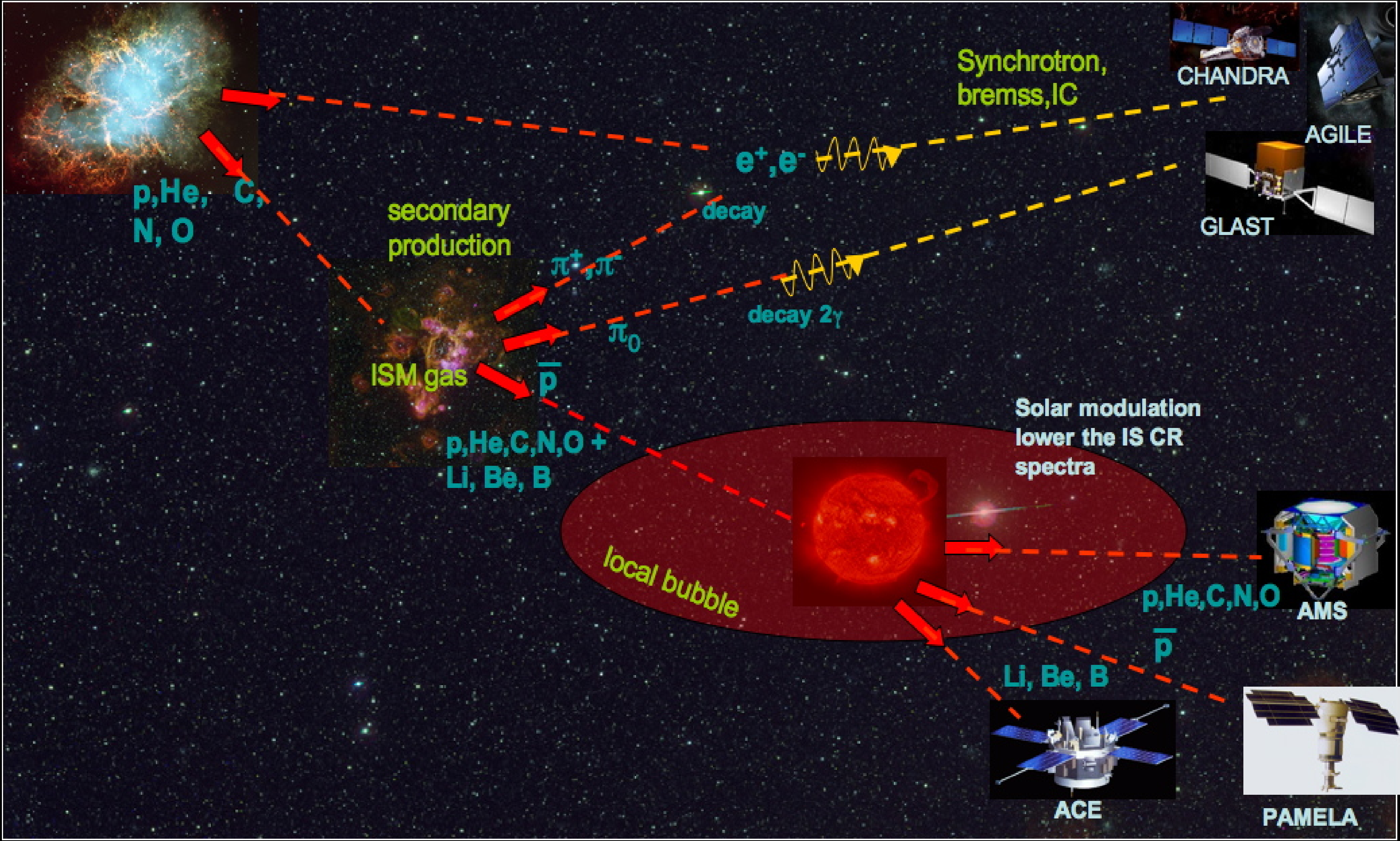
- **Study of cosmic-ray propagation (light nuclei and isotopes)**
- **Study of electron spectrum (local sources?)**

- **Study solar physics and solar modulation**
- **Study terrestrial magnetosphere**





COSMIC RAYS PRODUCTION MECHANISMS



PAMELA history

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

  Three models required by the RSA:

  - Mass-Dimensional and Thermal Model (MDTM)
  - Technological Model (TM)
  - Flight Model (FM)

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




1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

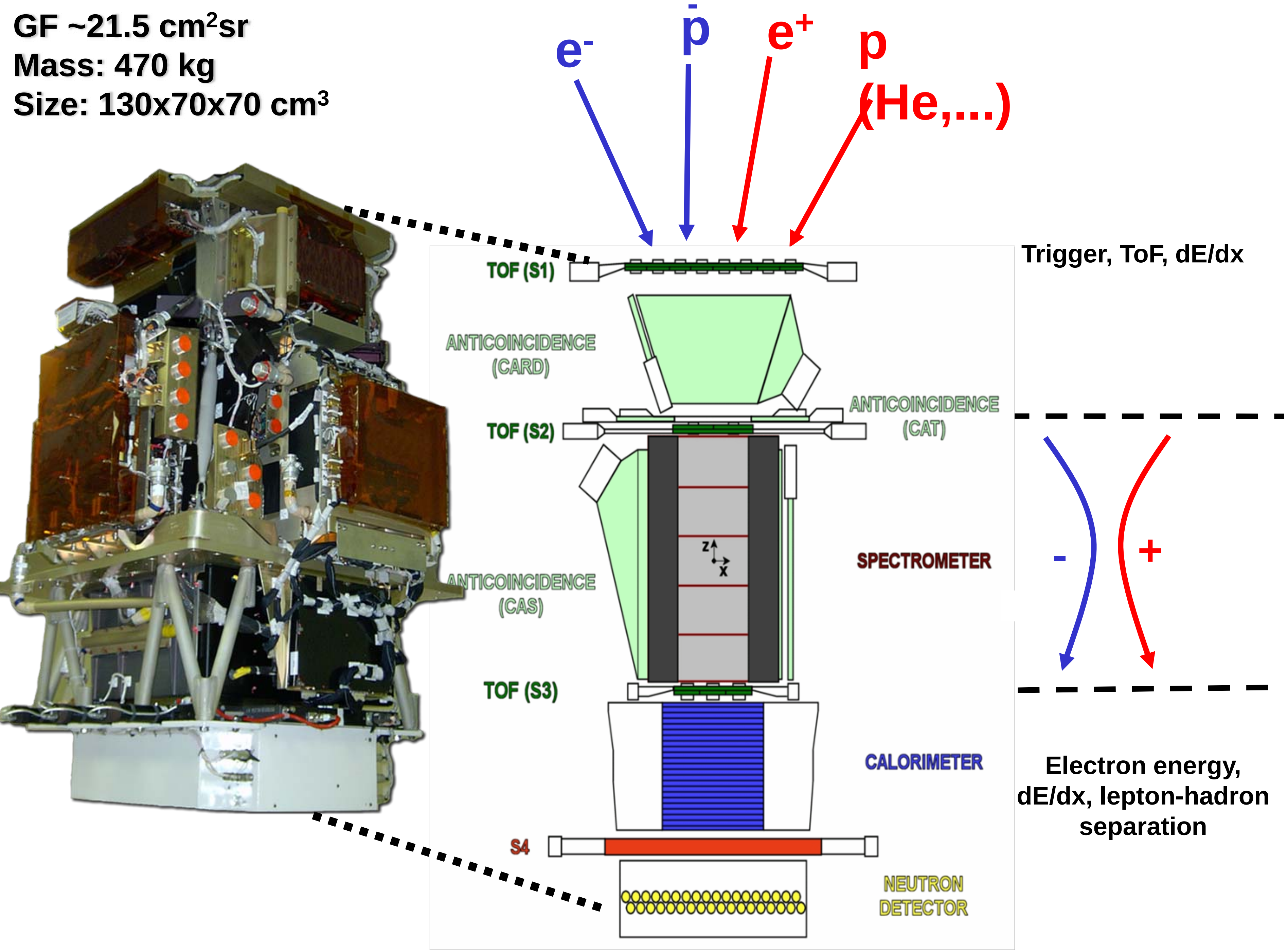
PAMELA apparatus

Design Performance

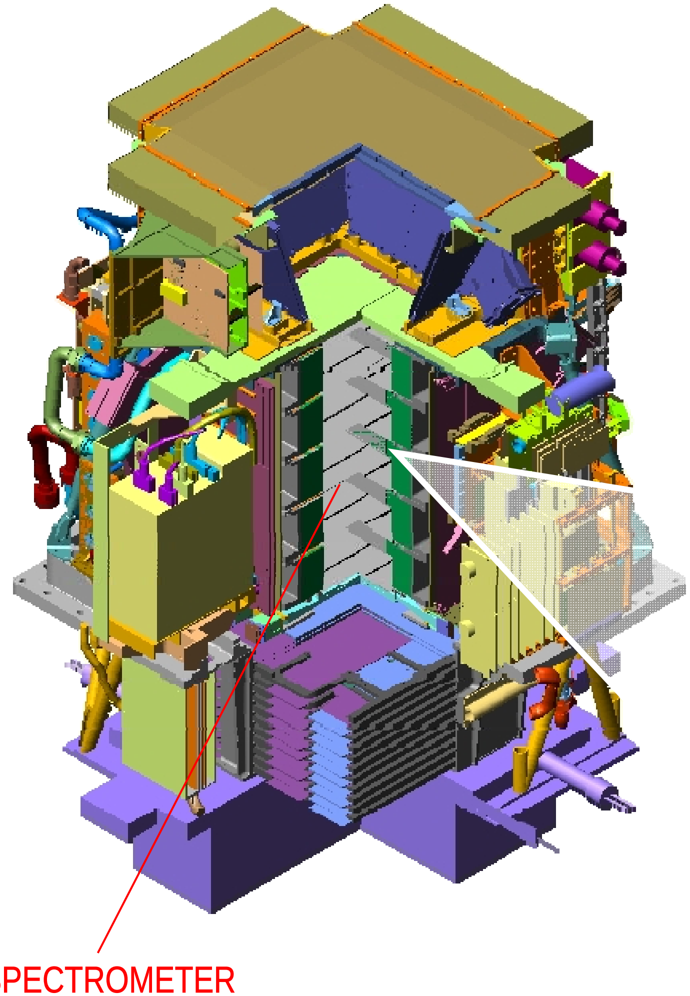
	energy range
• Antiprotons	80 MeV - 190 GeV
• Positrons	50 MeV – 300 GeV
• Electrons	up to 500 GeV
• Protons	up to 700 GeV
• Electrons+positrons	up to 2 TeV (from calorimeter)
• Light Nuclei (He/Be/C)	up to 200 GeV/n
• AntiNuclei search	sensitivity of 3×10^{-8} in $\overline{\mathrm{He}}$/He

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

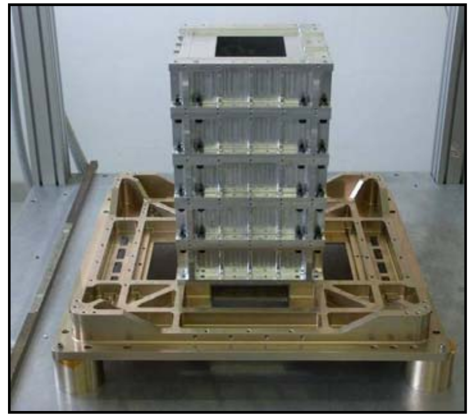
GF ~21.5 cm^2sr
Mass: 470 kg
Size: 130x70x70 cm^3

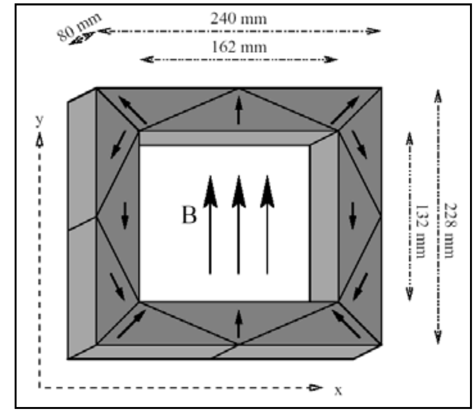


PAMELA



The magnet

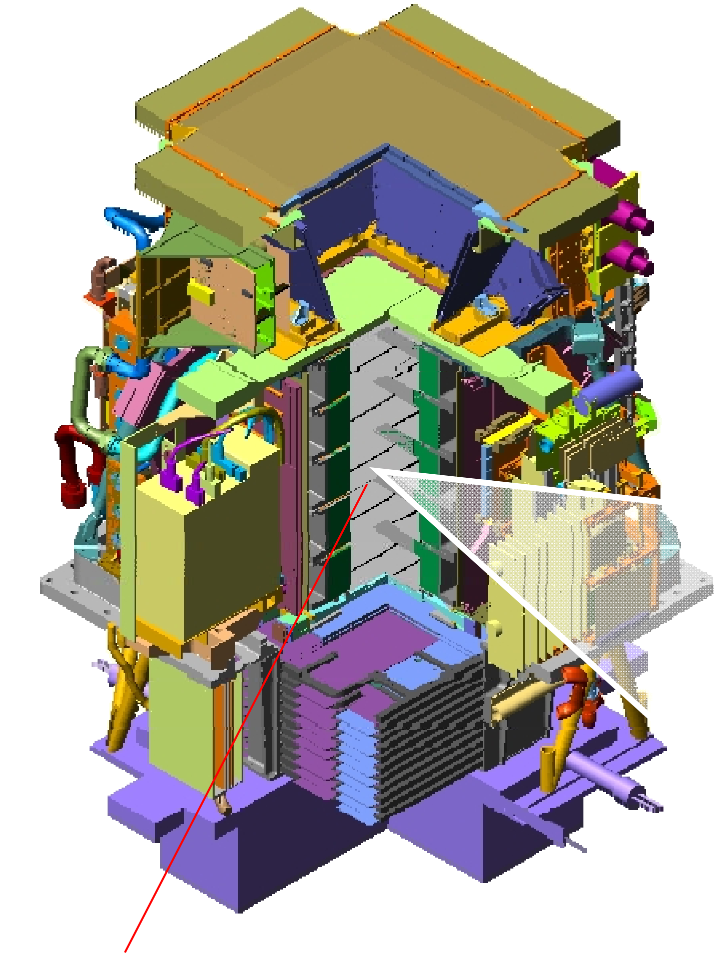




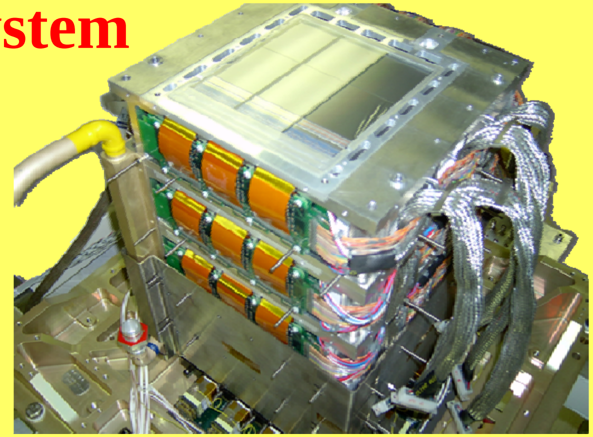
Characteristics:

- **5 modules of permanent magnet (Nd-B-Fe alloy) in aluminum mechanics**
- Cavity dimensions 162x132x445 cm^3
  →GF 21.5 cm^2sr
- Magnetic shields
- 5mm-step field-map
- **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

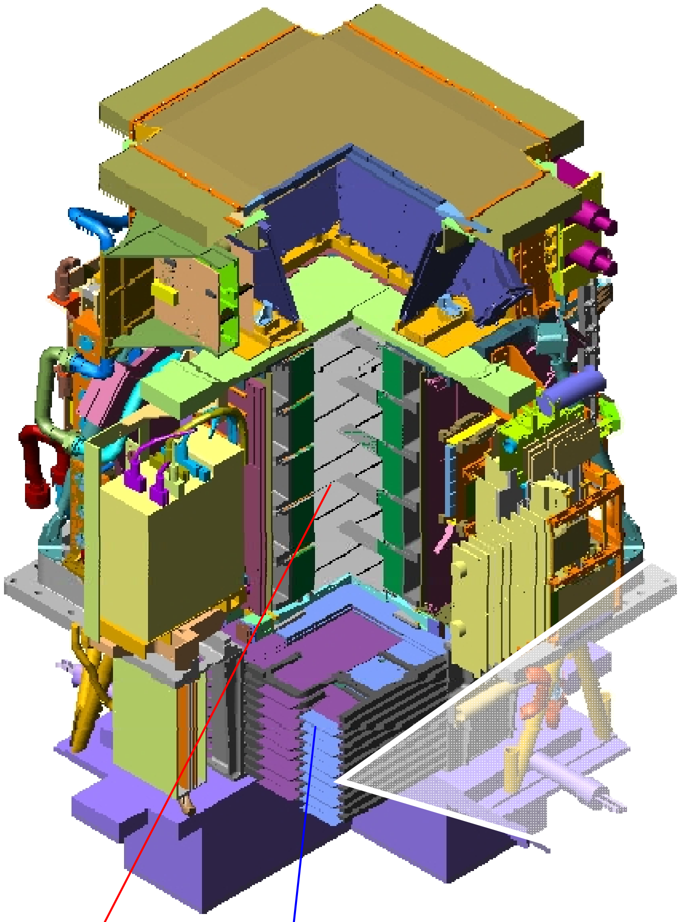
Characteristics:

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

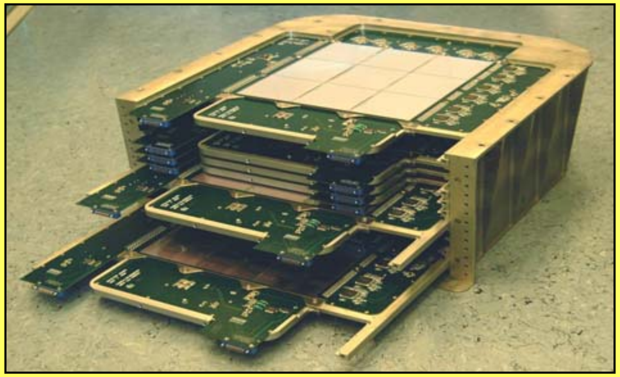
Performances:

- Spatial resolution: **3÷4 μm**
- **MDR ~1.2TV** (from flight data)

PAMELA



The electromagnetic calorimeter



Main tasks:

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

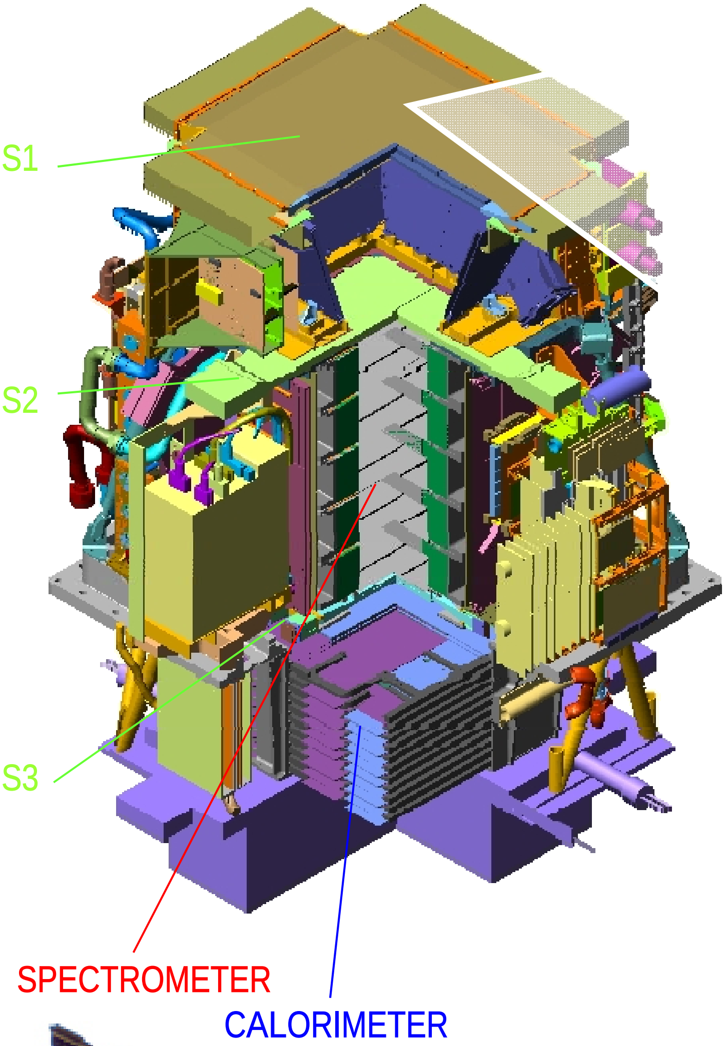
Characteristics:

- **44 Si layers (X/Y) +22 W planes**
- **16.3 X_o / 0.6 l_0**
- 4224 channels
- Dynamic range ~1100 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)

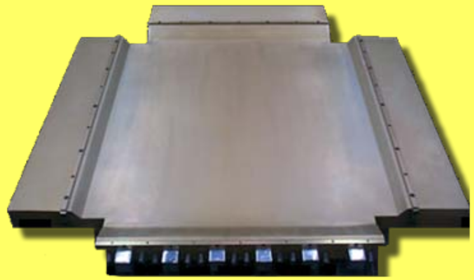
Performances:

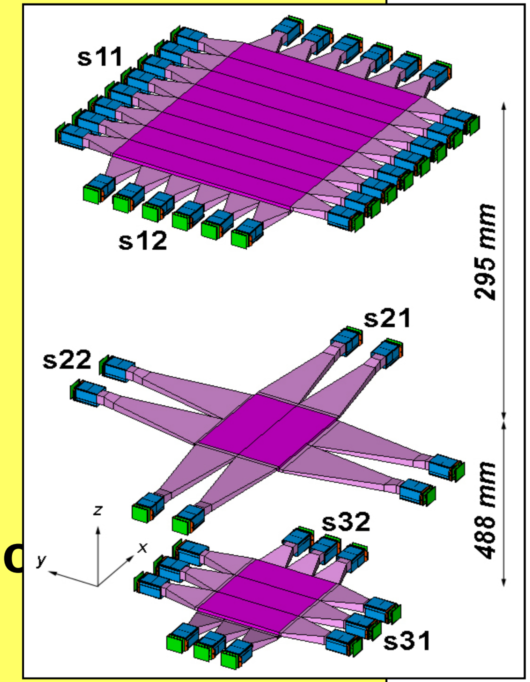
- p/e^+ selection efficiency ~90%
- p rejection factor **10^5**
- e rejection factor **>10^4**
- Energy resolution **~5%** @200GeV

PAMELA



The time-of-flight system



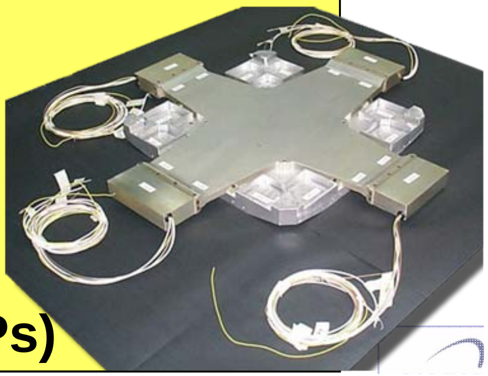


Main tasks:

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

Characteristics:

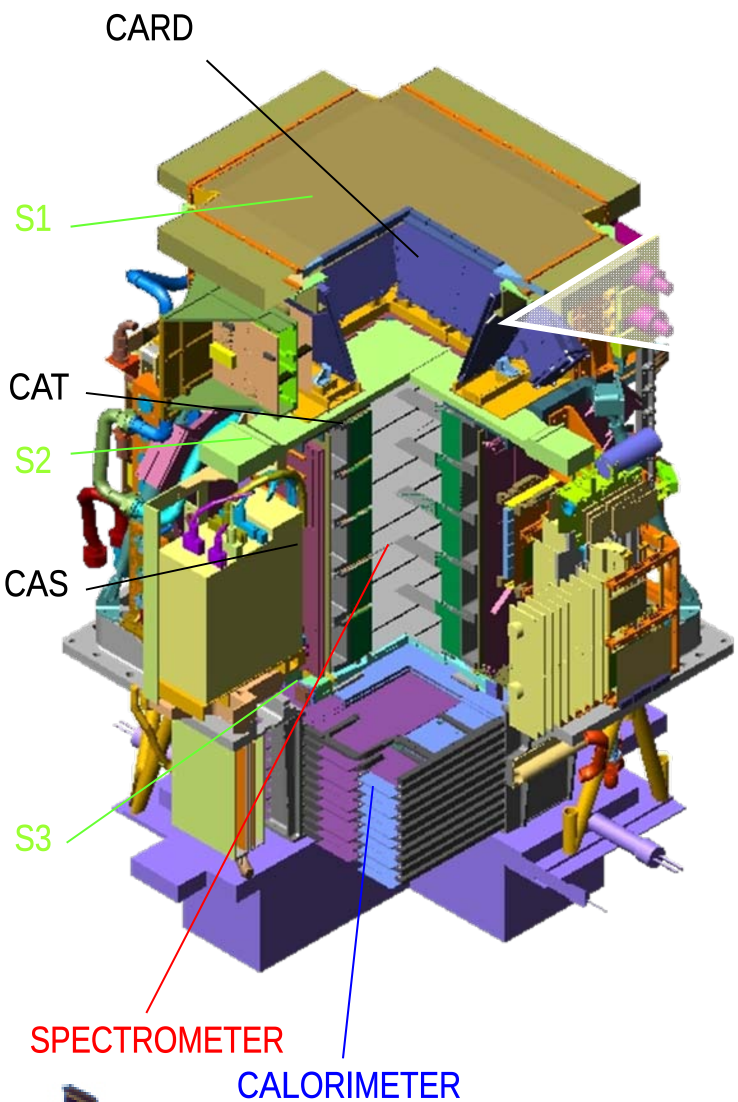
- 3 double-layer scintillator paddles
- X/Y segmentation
- Total: 48 Channels



Performances:

- σ_{paddle} ~ 110ps
- σ_{TOF} ~ 330ps (for MIPs)

PAMELA



The anticounter shields

Main tasks:

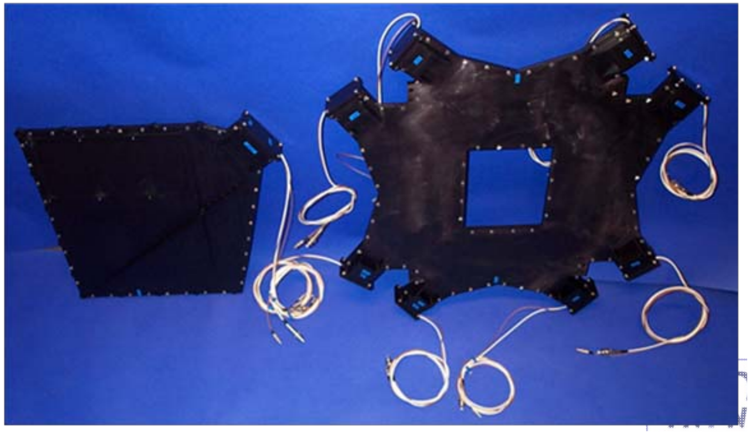
- **Rejection of events with particles interacting with the apparatus (off-line and second-level trigger)**

Characteristics:

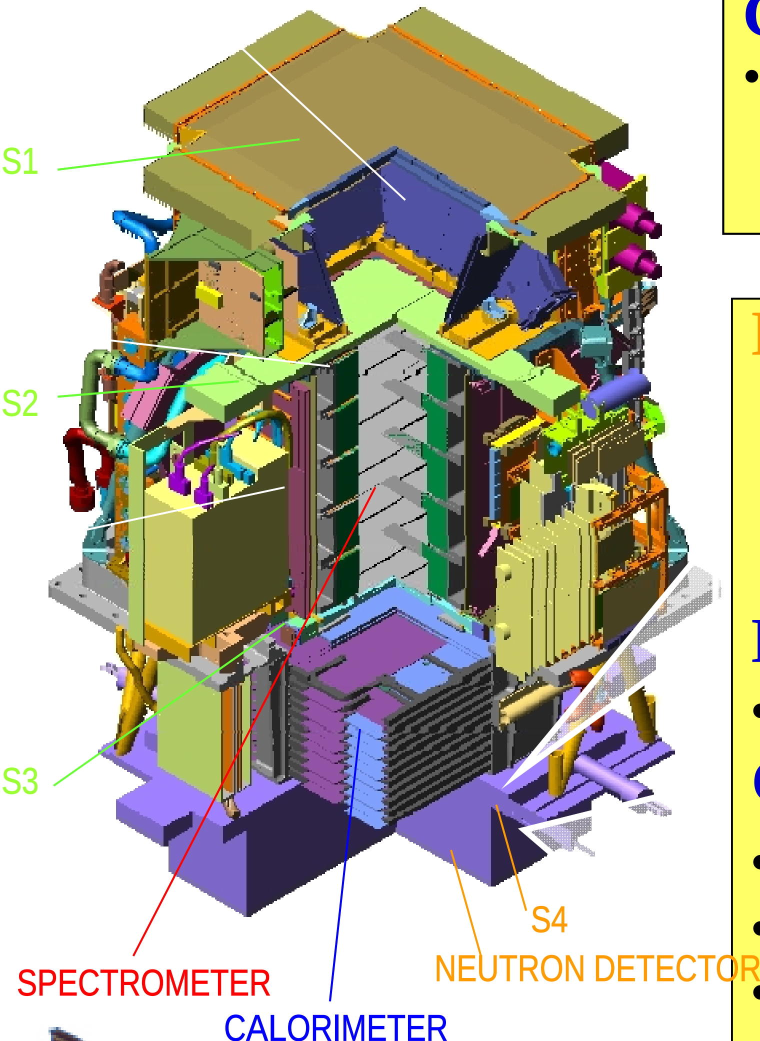
- **scintillator paddles 10mm thick**
- **4 up (CARD), 1 top (CAT), 4 side (CAS)**

Performances:

- **Efficiency > 99.9%**



PAMELA



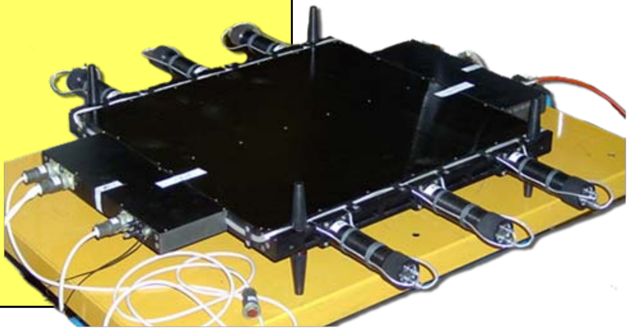
Shower-tail catcher (S4)

Main tasks:

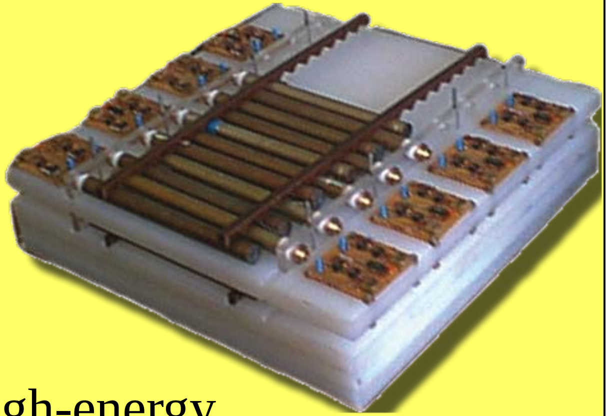
- **ND trigger**

Characteristics:

- **1 scintillator paddle 10mm thick**



Neutron detector

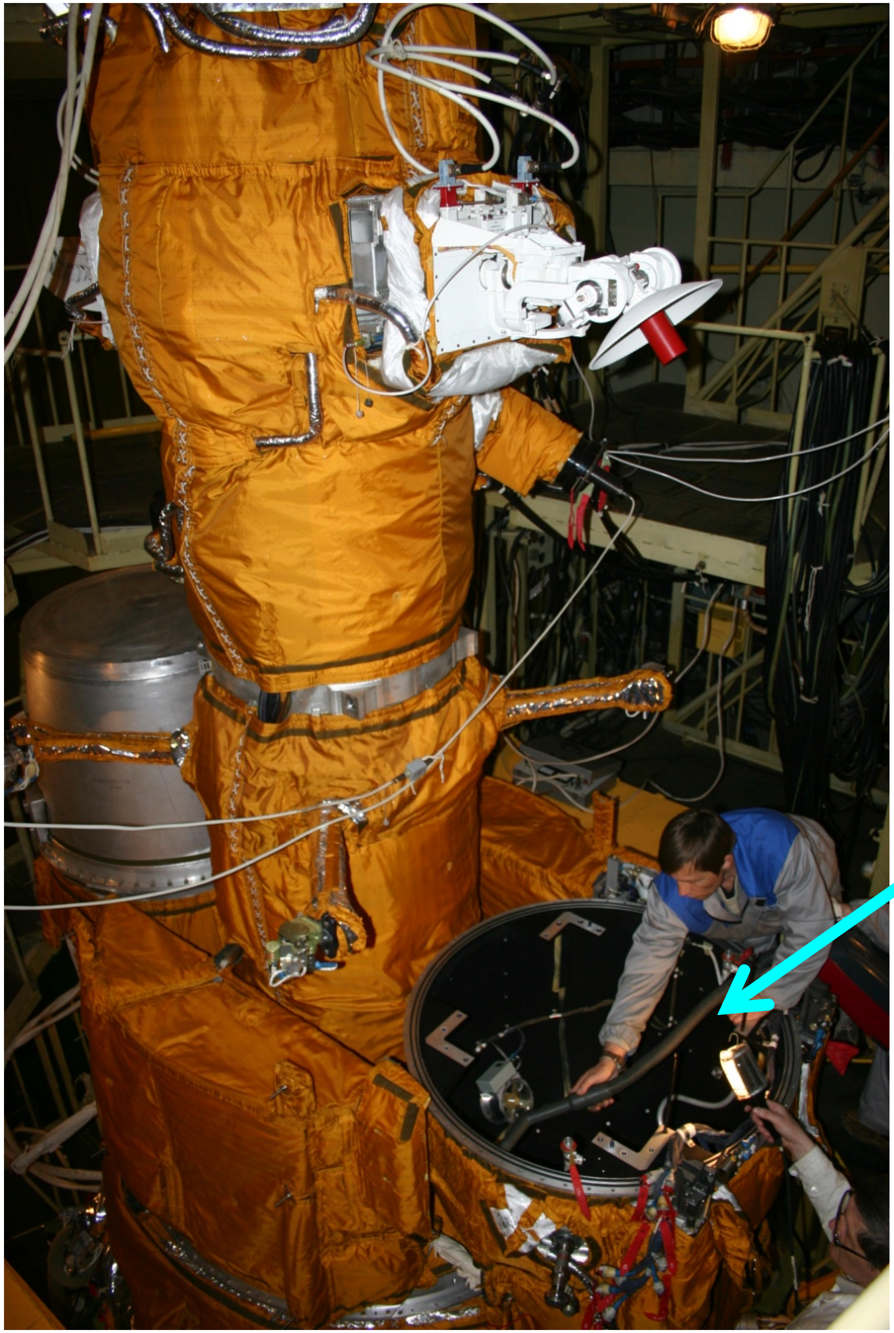


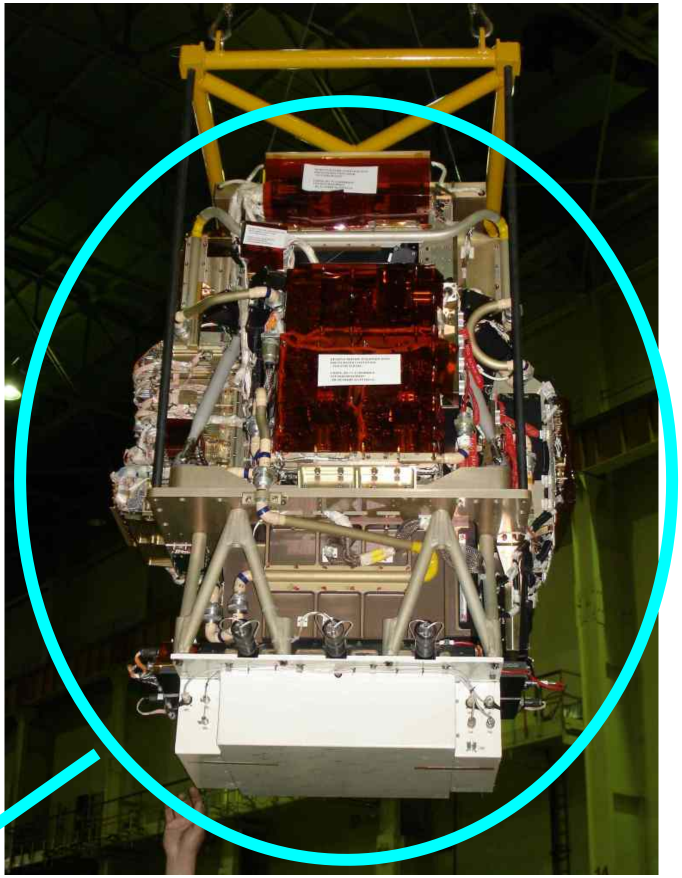
Main tasks:

- e/h discrimination @high-energy

Characteristics:

- **36 ^{3}He counters**: ^{3}He(n,p)T $\rightarrow$ Ep=780 keV
- 1cm thick polyetilene moderators
- n collected within 200 ms time-window



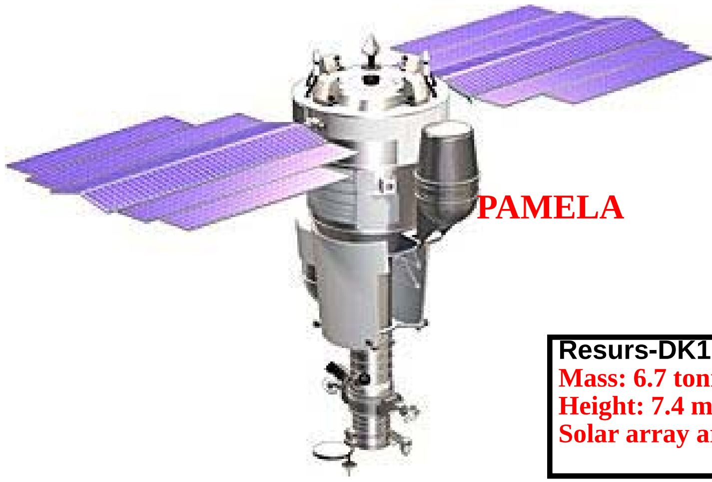


PAMELA INTEGRATION in the RESURS-DK1 satellite

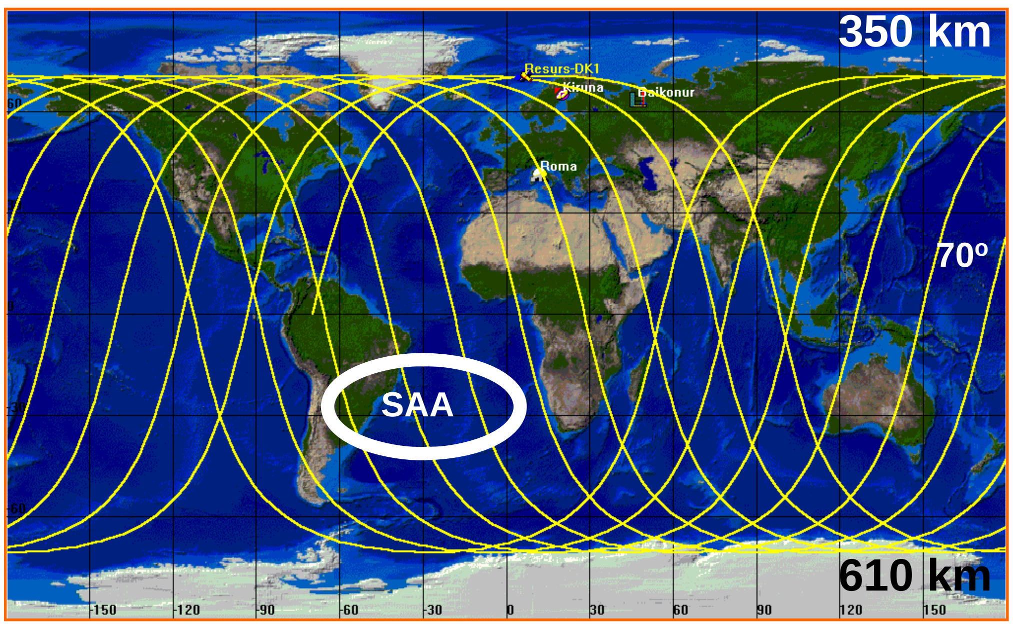
The Launch: 15th June 2006

The Launch: 15th June 2006

Resurs-DK1 satellite + orbit



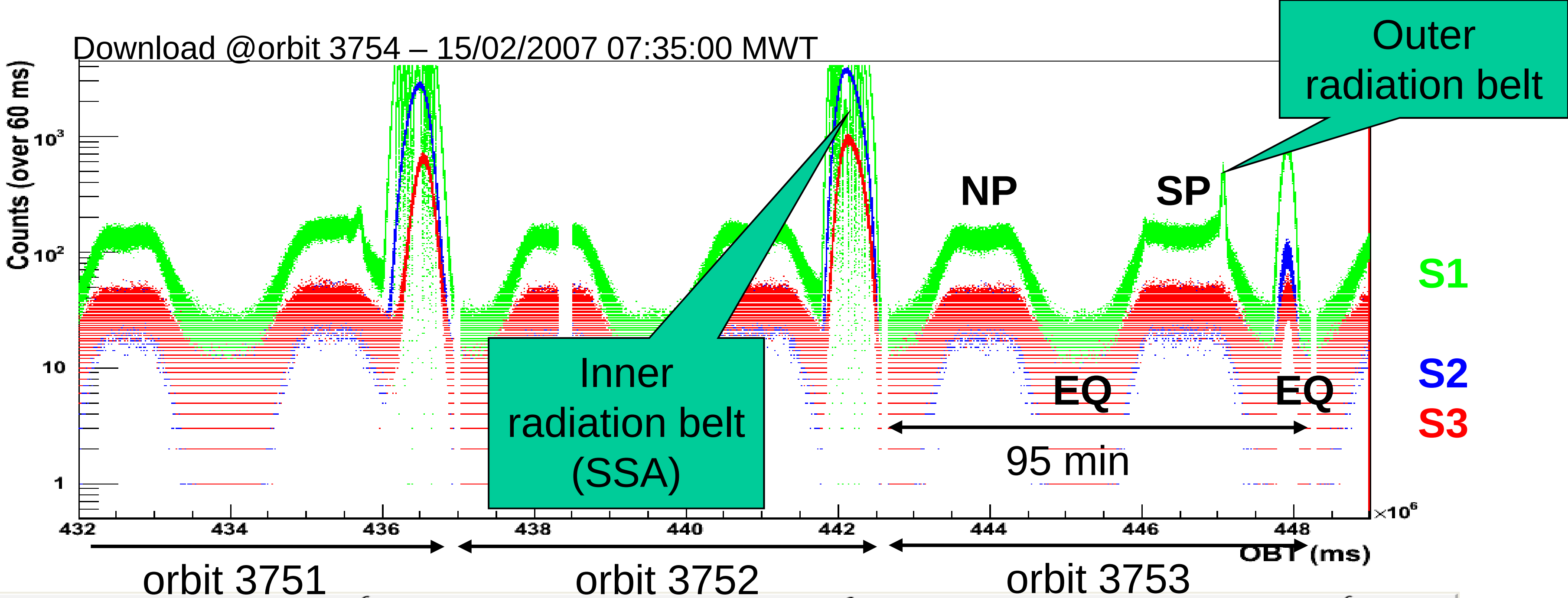
Resurs-DK1
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 m^2

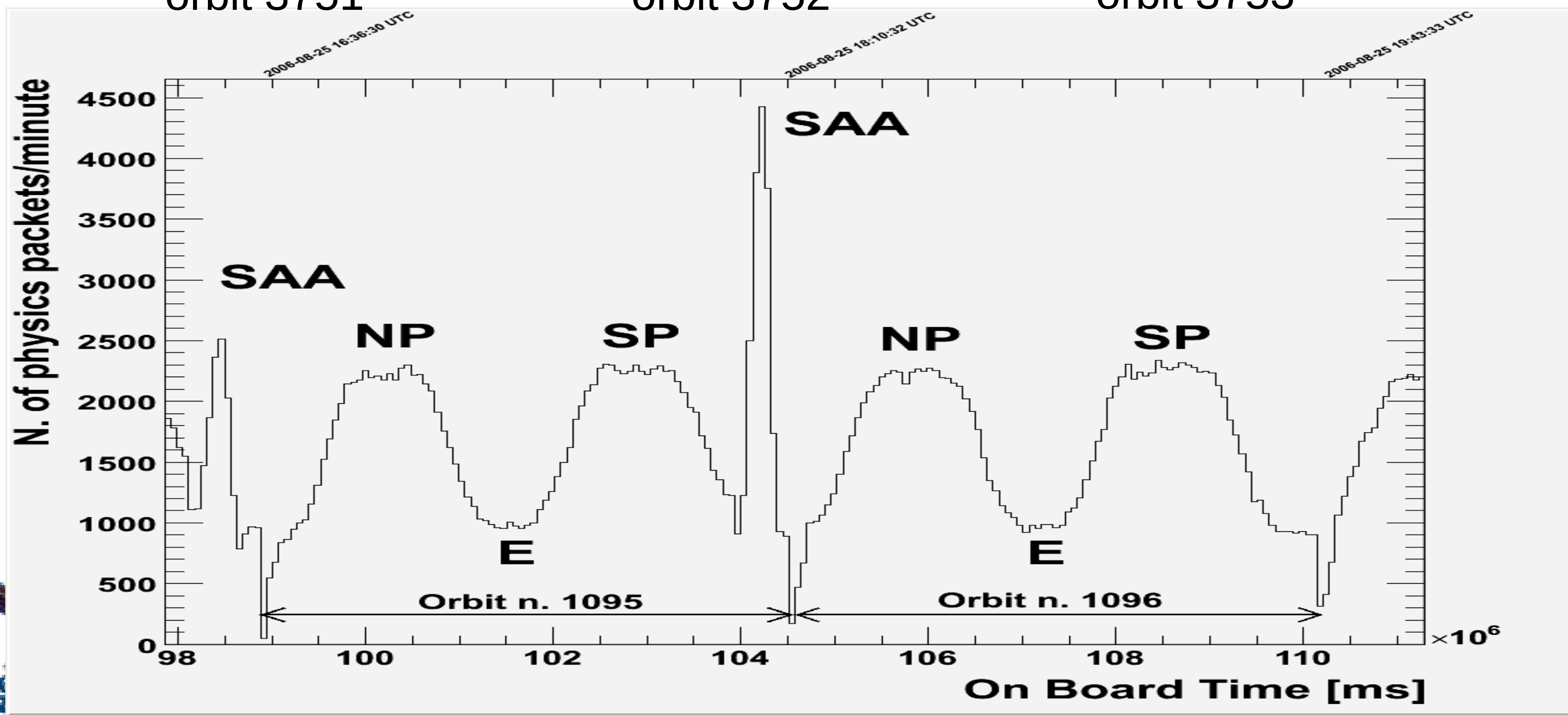


~90 mins

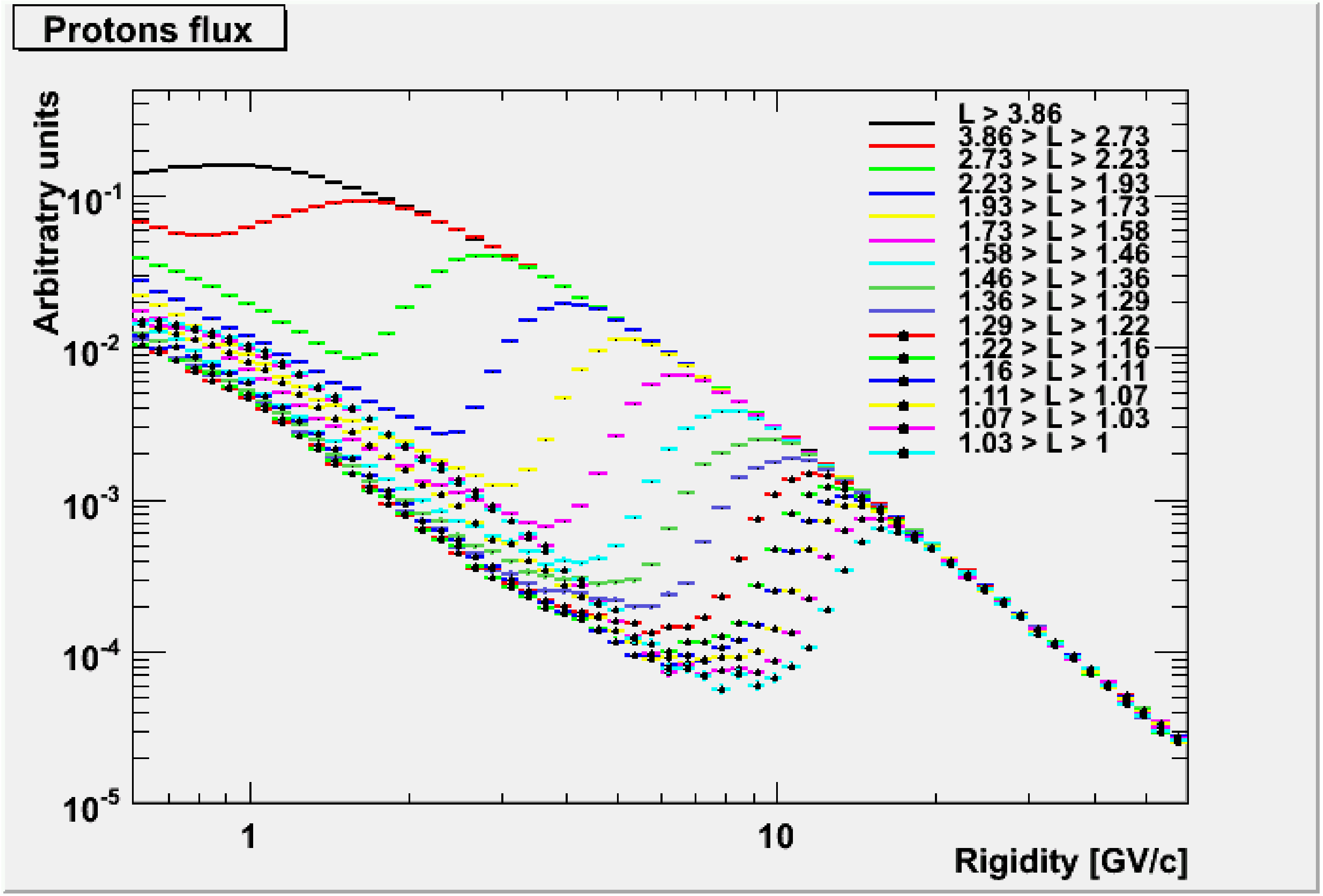
- **Resurs-DK1: multi-spectral imaging of earth's surface**
- **PAMELA mounted inside a pressurized container**
- **Lifetime >3 years (assisted, first time last February)**
- **Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day**
- **Quasi-polar and elliptical orbit (70.0°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

See W. Gillard's talk


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


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

Subcutoff particles



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

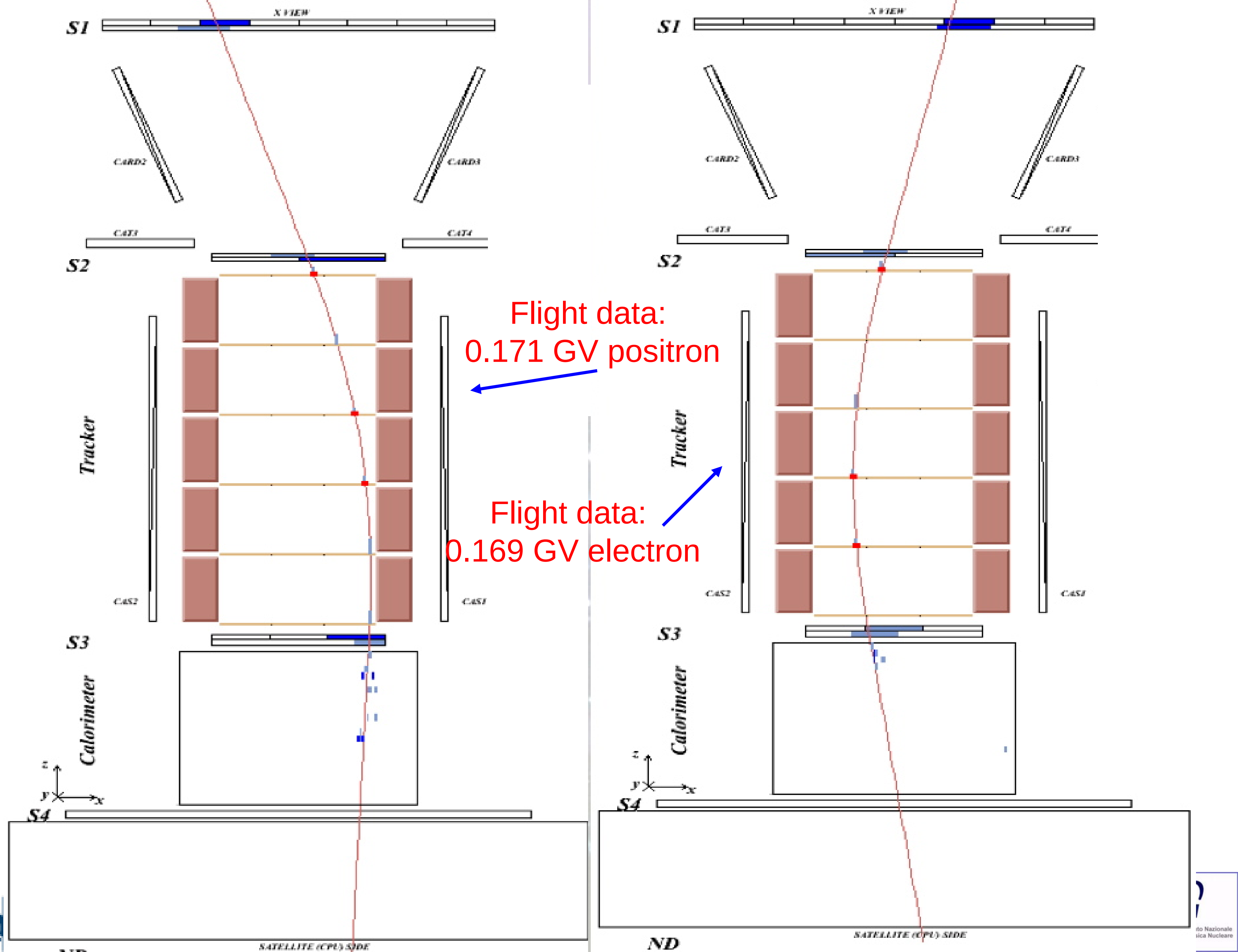
→ **PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006**

Main antenna in NTsOMZ

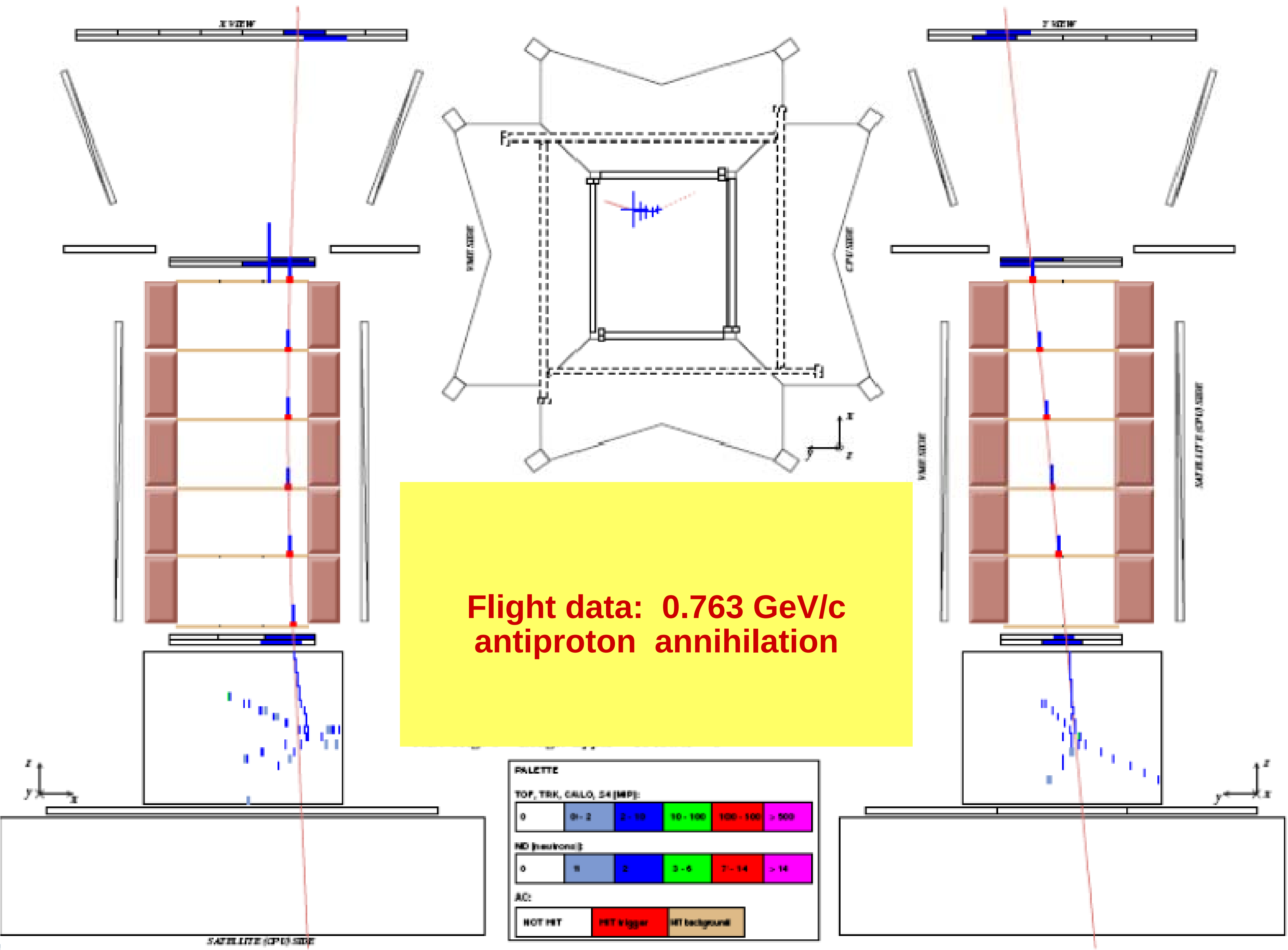
Trigger rate* ~25Hz
Fraction of live time* ~ 75%
Event size (compressed mode) ~5kB
25 Hz x 5 kB/ev → ~ 10 GB/day
(*outside radiation belts)

Till ~now:
~1200 days of data taking
~18 TByte of raw data downlinked
>10^9 triggers recorded and analyzed
(Data from April till December 2008 under analysis)

Antiparticles with PAMELA

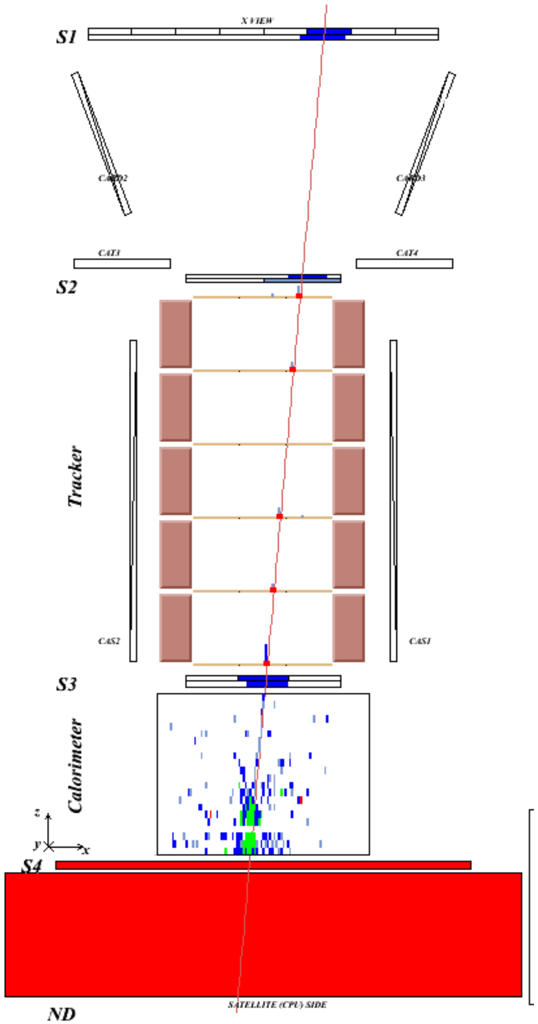


S1
X VIEW
CARD2
CARD3
CAT3
CAT4
S2
Tracker
CAS2
CAS1
S3
Calorimeter
S4
SATELLITE (CPU) SIDE
ND
Flight data:
0.171 GV positron
Flight data:
0.169 GV electron



Flight data: 0.763 GeV/c antiproton annihilation

Antiproton / positron identification



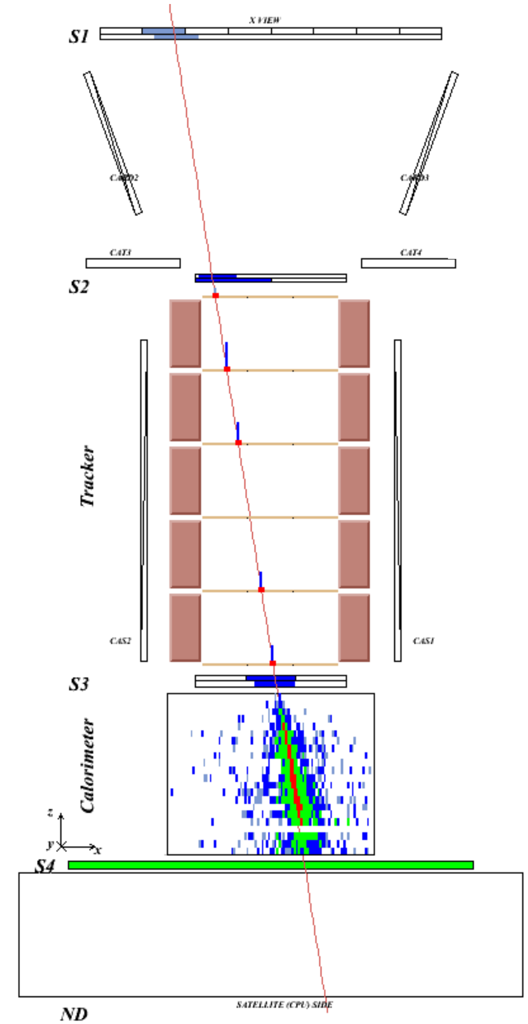
Antiproton
(NB: $e^-/\bar{p} \sim 10^2$)

Time-of-flight: trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer: sign of charge

Ionisation energy loss (dE/dx): magnitude of charge

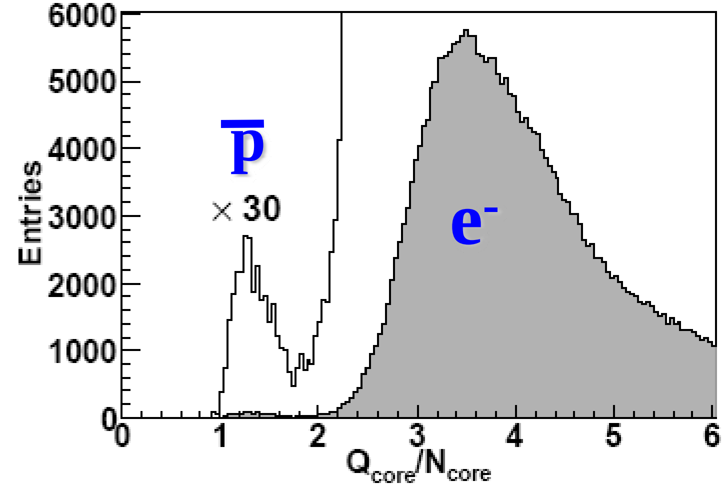
Interaction pattern in calorimeter: electron-like or proton-like, electron energy



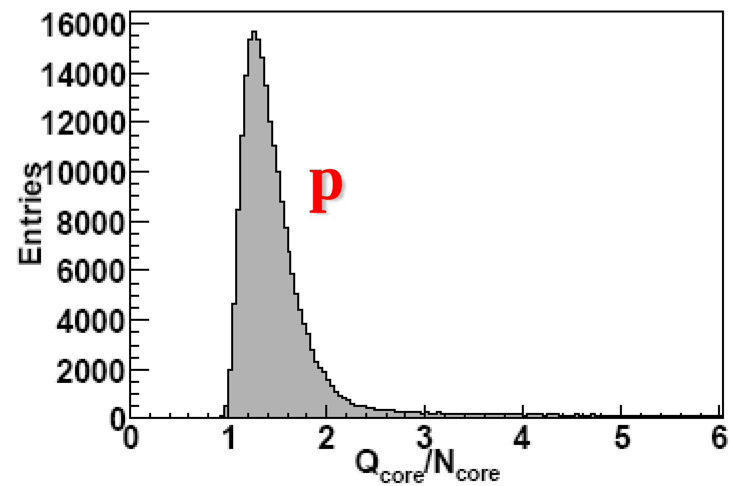
Positron
(NB: $p/e^+ \sim 10^{3-4}$)

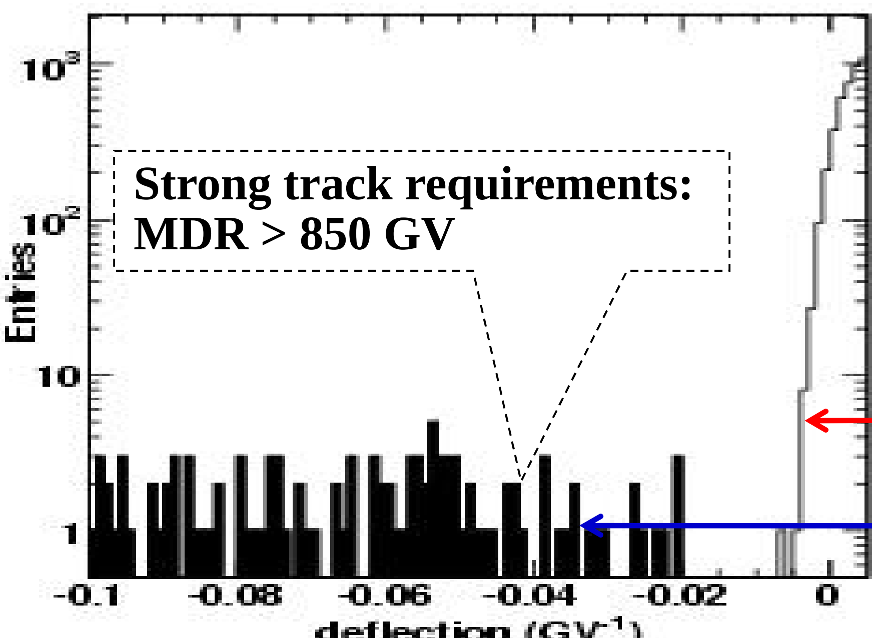
ANTIPROTONS

See J. Wu's talk



Calorimeter selection





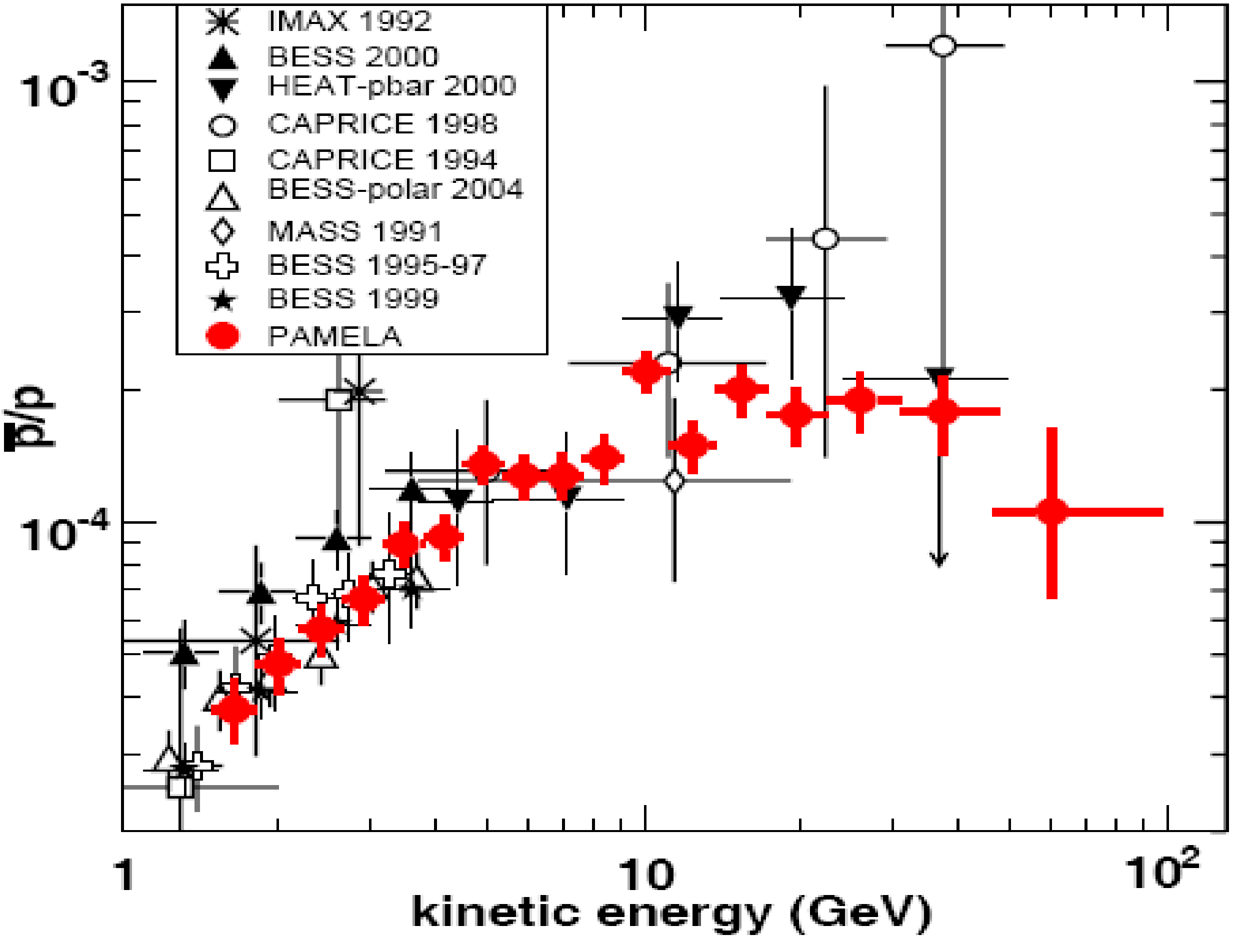
Tracker Identification

Protons (& spillover)

Antiprotons

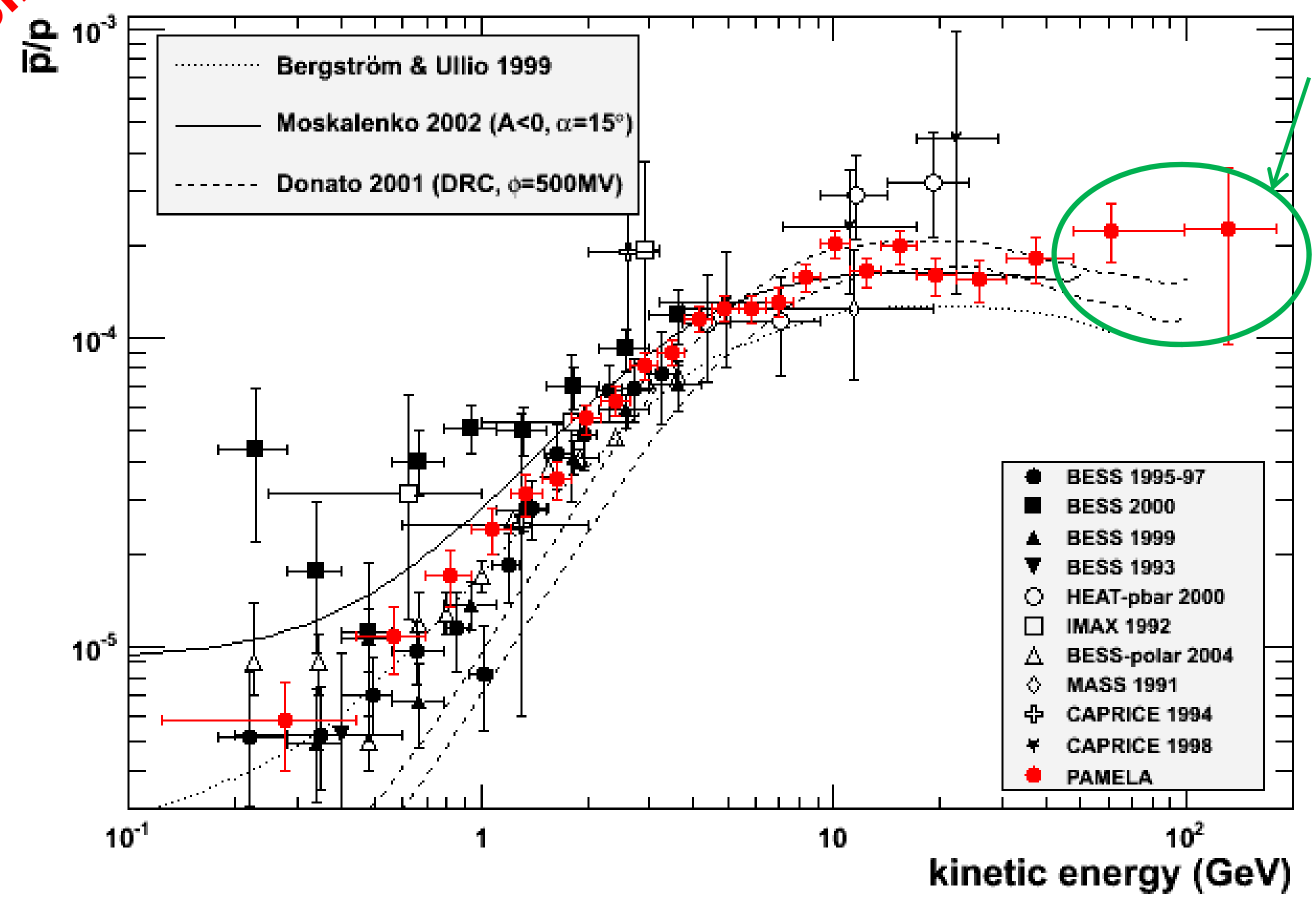
Antiproton to proton flux ratio

PRL 102, (2009) 051101, Astro-ph 0810.4994



Antiproton to proton flux ratio

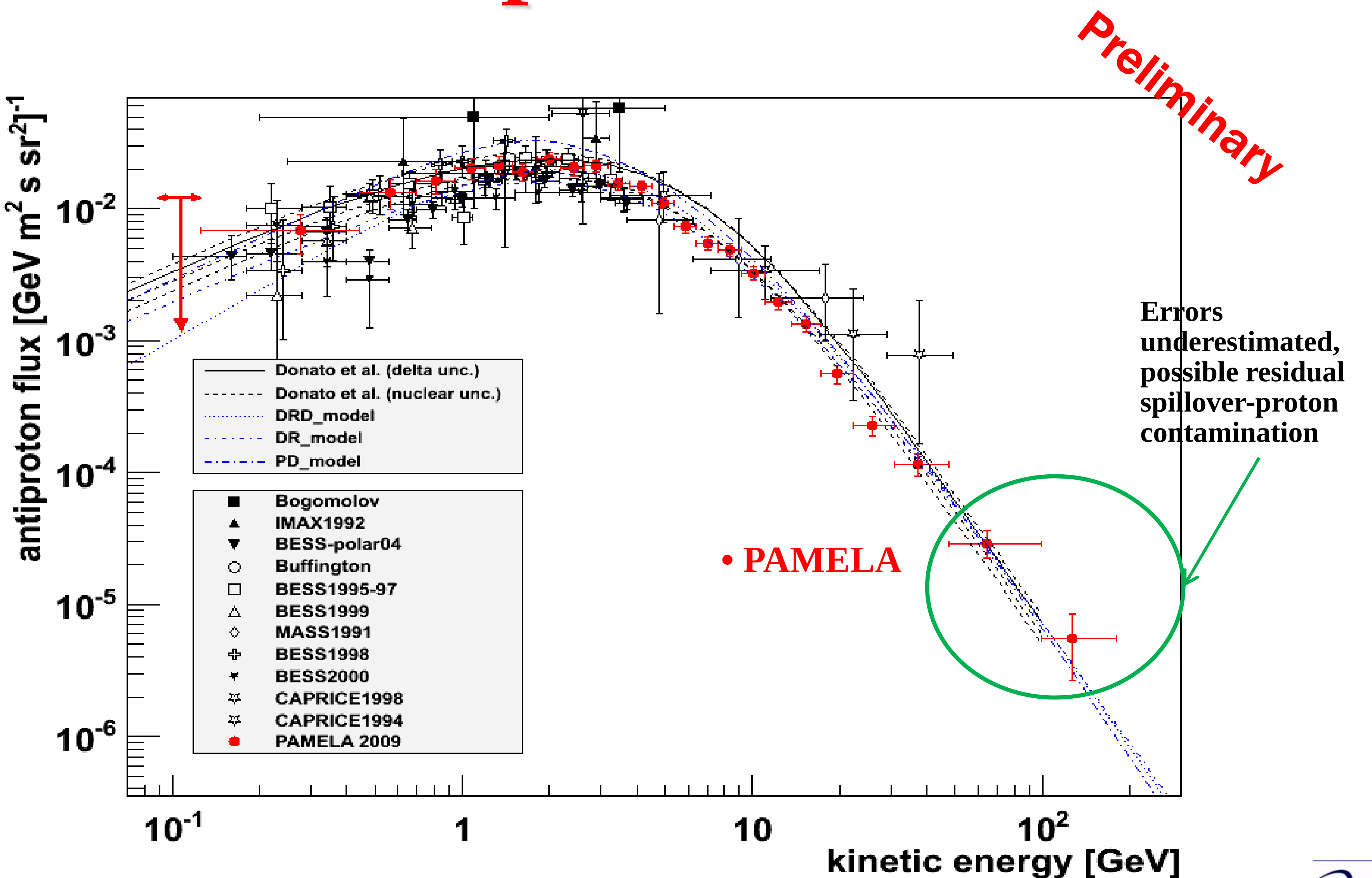
Preliminary



Errors might be underestimated, possible residual spillover-proton contamination

See J. Wu's talk

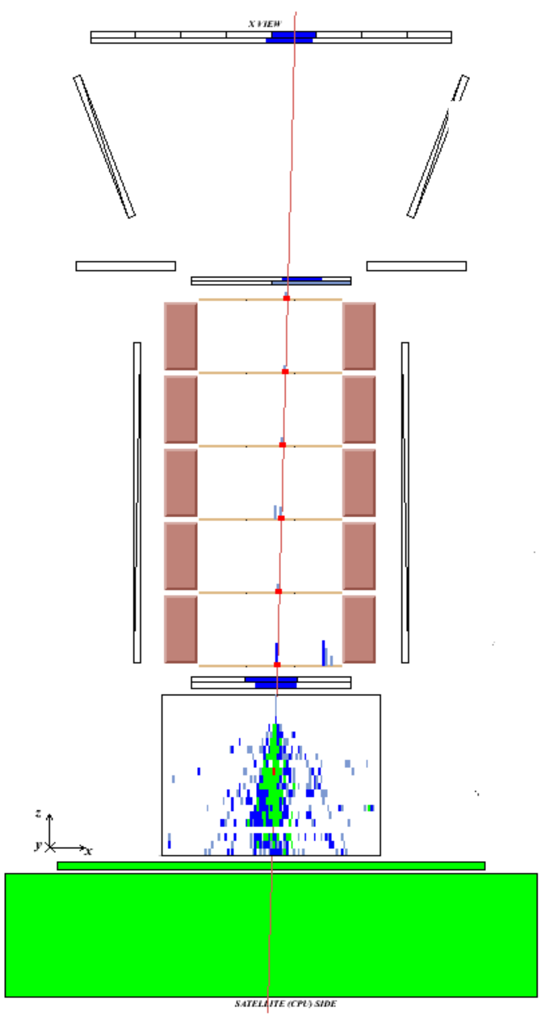
Antiproton Flux



See J. Wu's talk

POSITRONS

Proton / positron discrimination

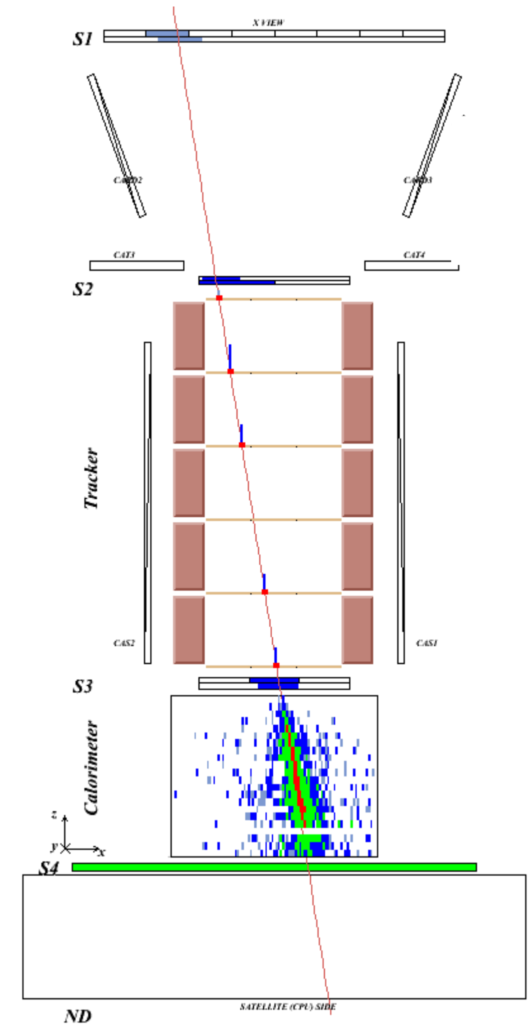


Time-of-flight:
trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer:
sign of charge

Ionisation energy loss (dE/dx):
magnitude of charge

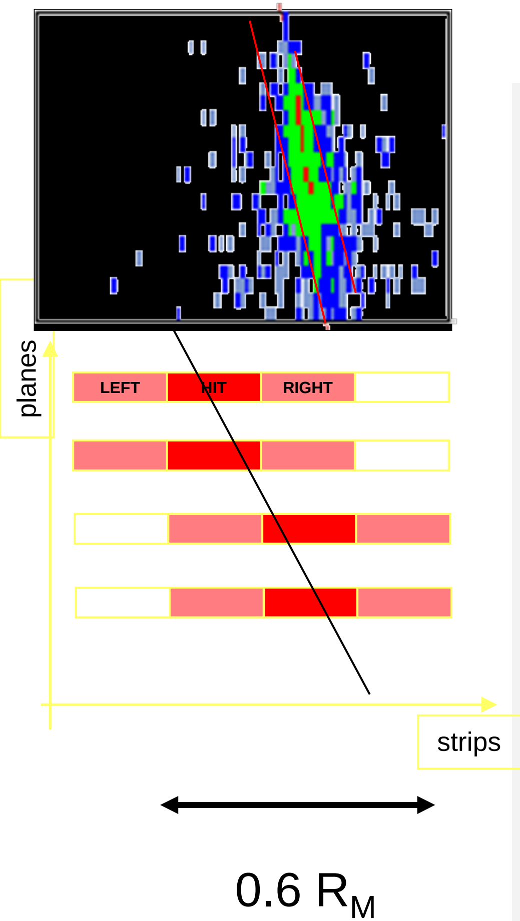
Interaction pattern in calorimeter:
electron-like or proton-like, electron energy

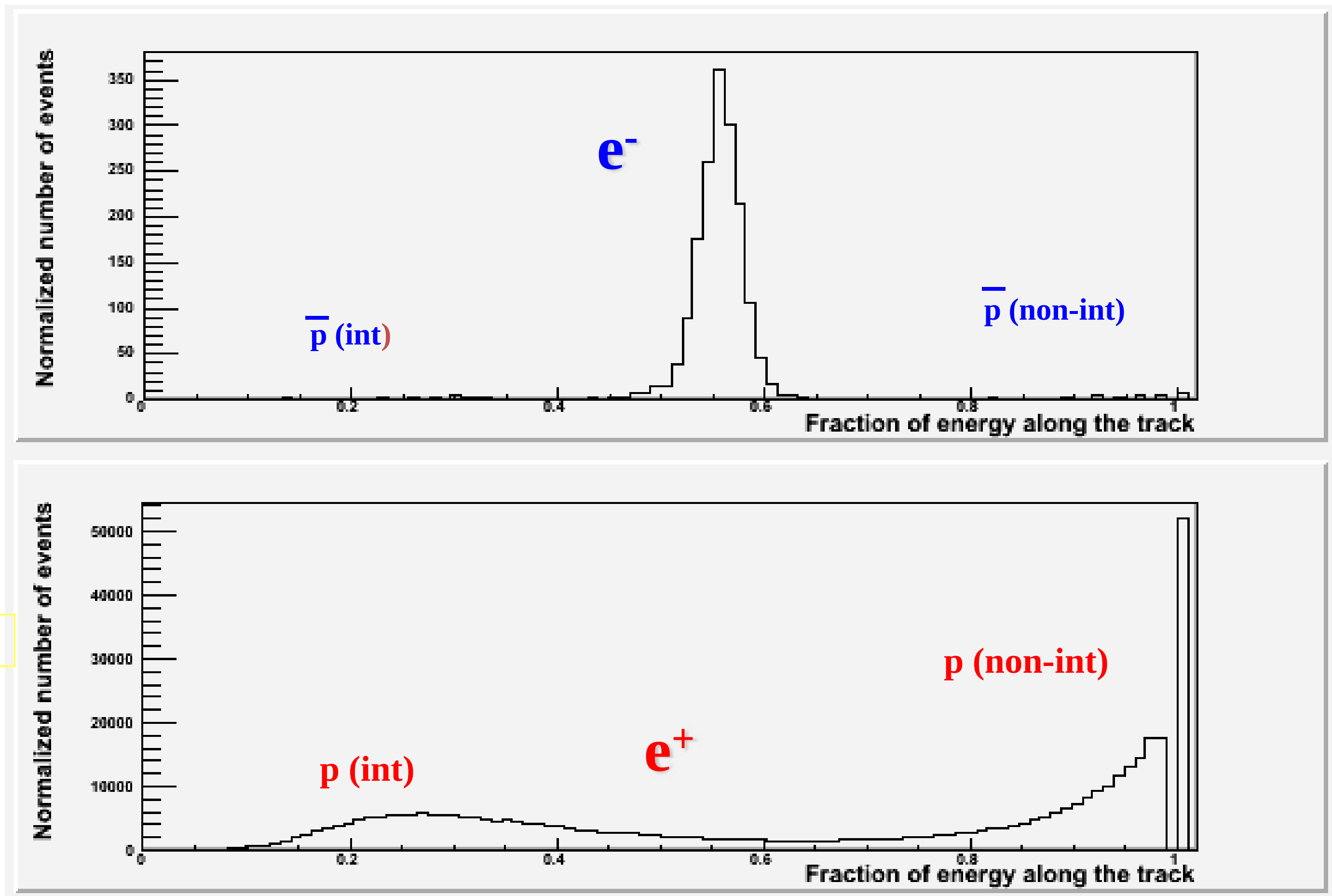


Proton **Positron**

Positron selection with calorimeter

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



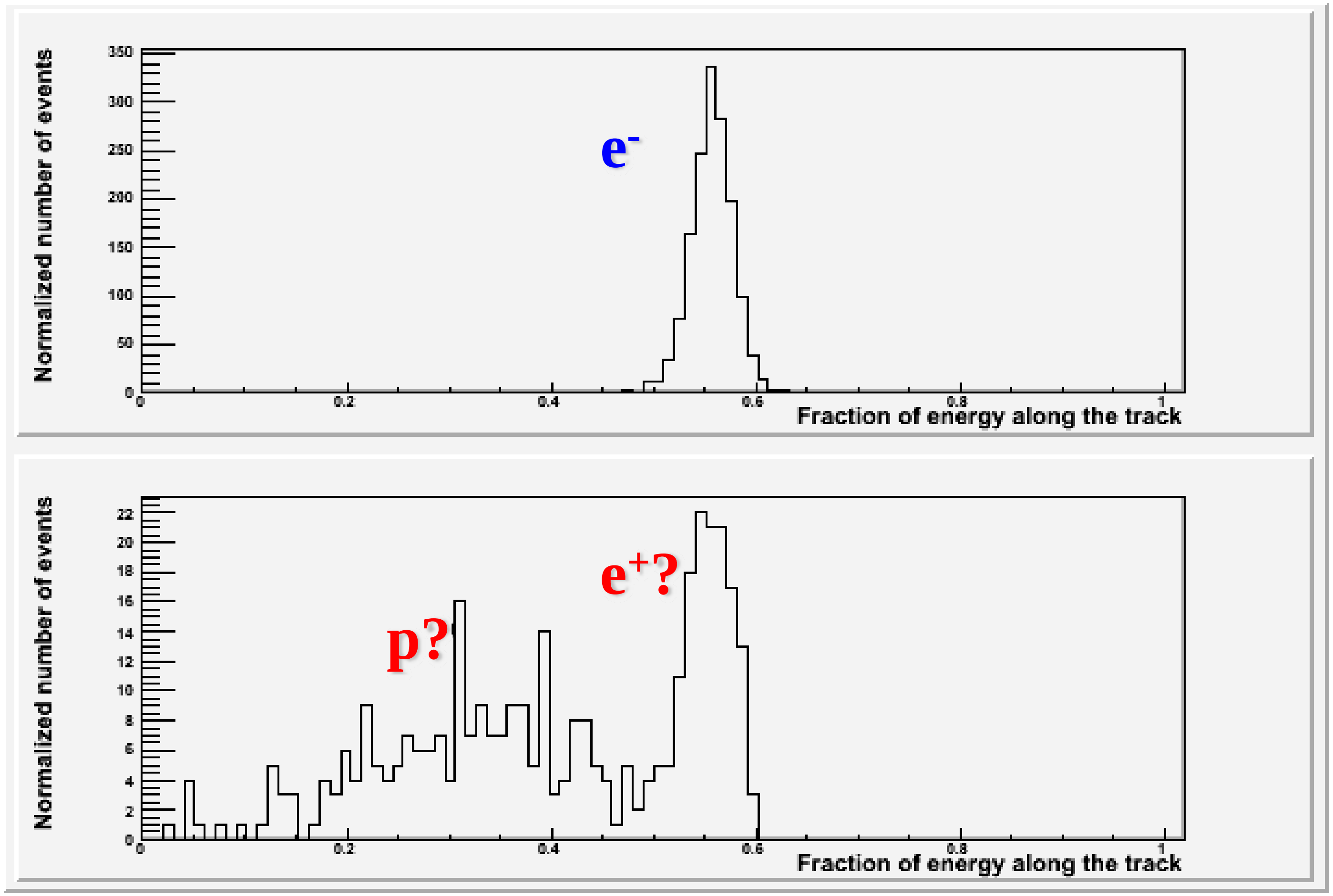


for em showers 90% of E contained in 1 R_M

Rigidity: 20-30 GV

Positron selection with calorimeter

Rigidity: 20-30 GV

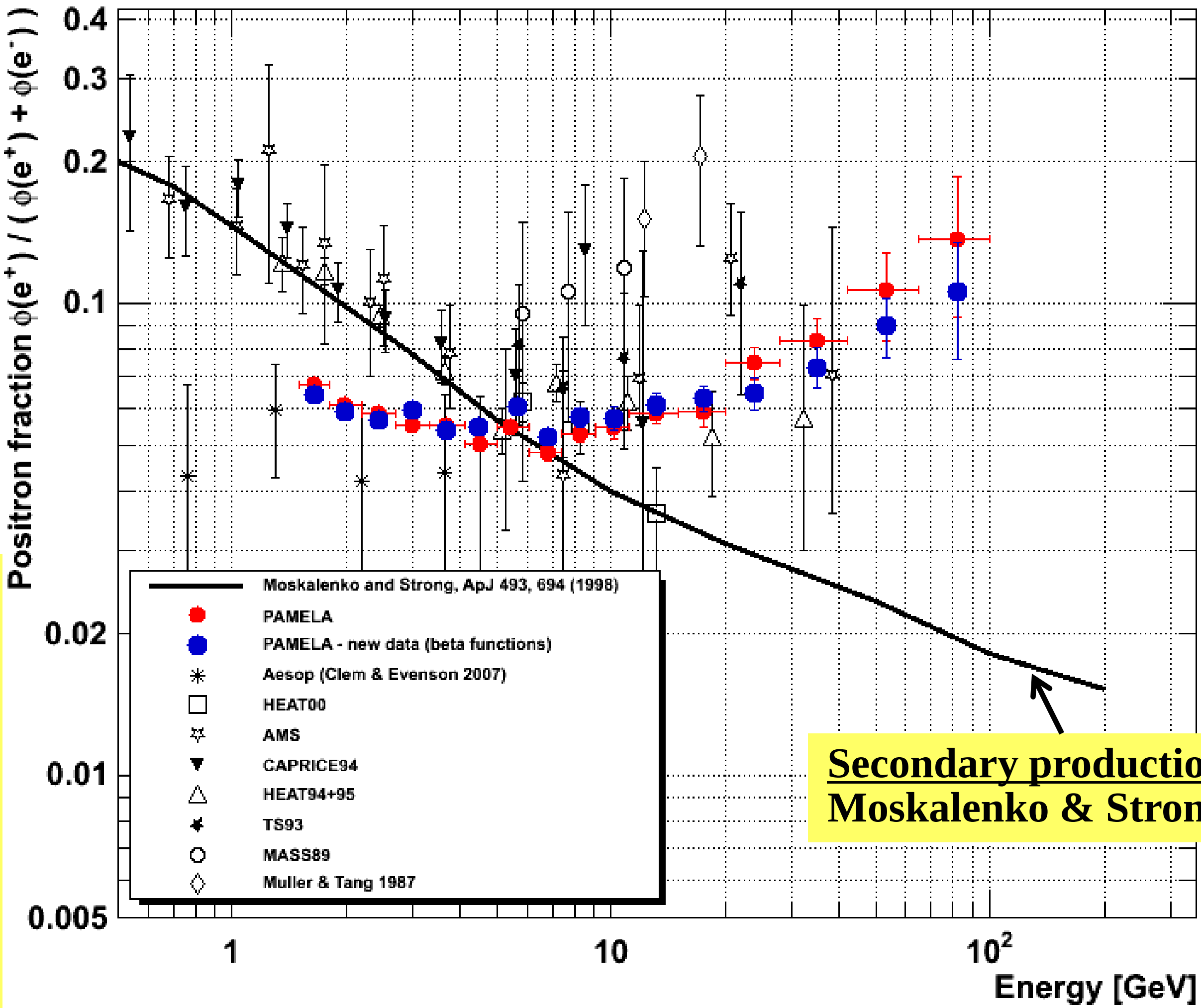


Fraction of charge released along the calorimeter track (left, hit, right)

+

- Energy-momentum match
- Starting point of shower

Positron to Electron Fraction



In Nature article published data acquired till February 2008

New data reduction: data till end of 2008. With same approach of Nature paper ~30% increase in statistics better understanding of systematics.

Secondary production
Moskalenko & Strong 98

Solar Modulation of galactic cosmic rays

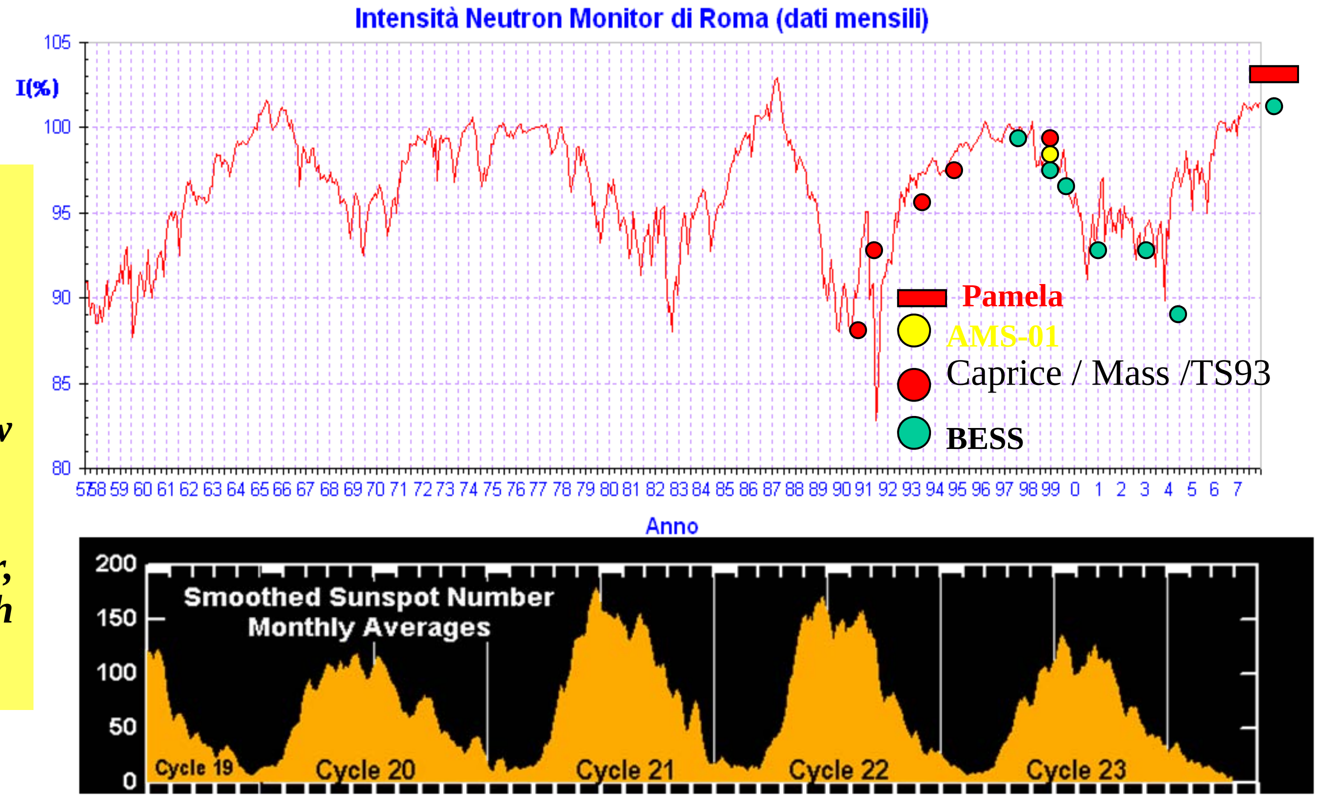
- **Study of charge sign dependent effects**

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

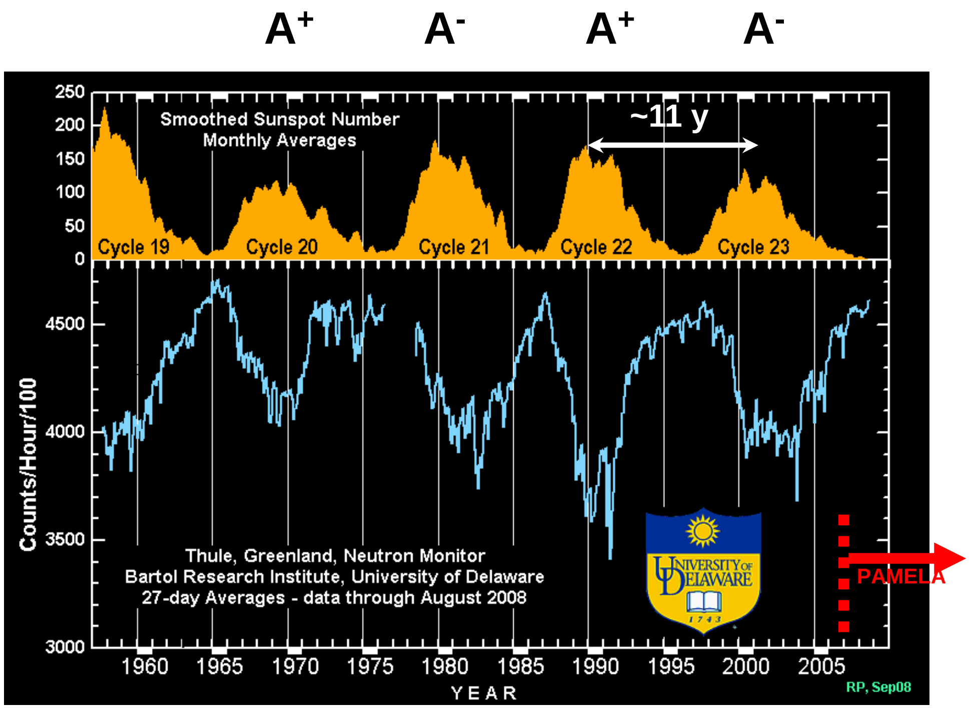
Bieber, J.W., et al. Physi-cal Review Letters, 84, 674, 1999.

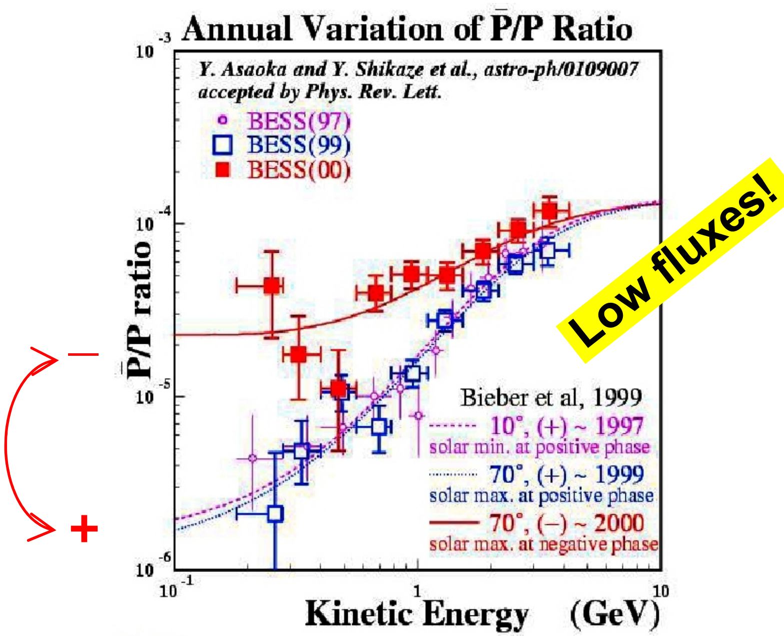
J. Clem et al. 30th ICRC 2007

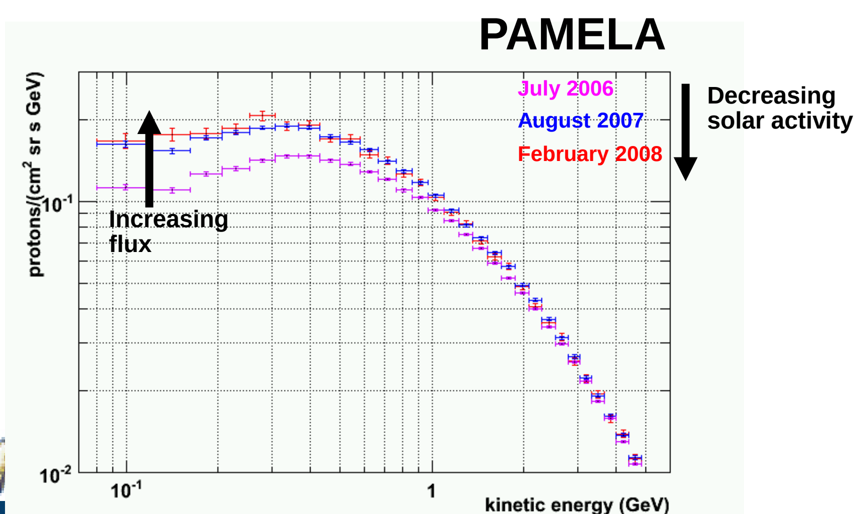
U.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)

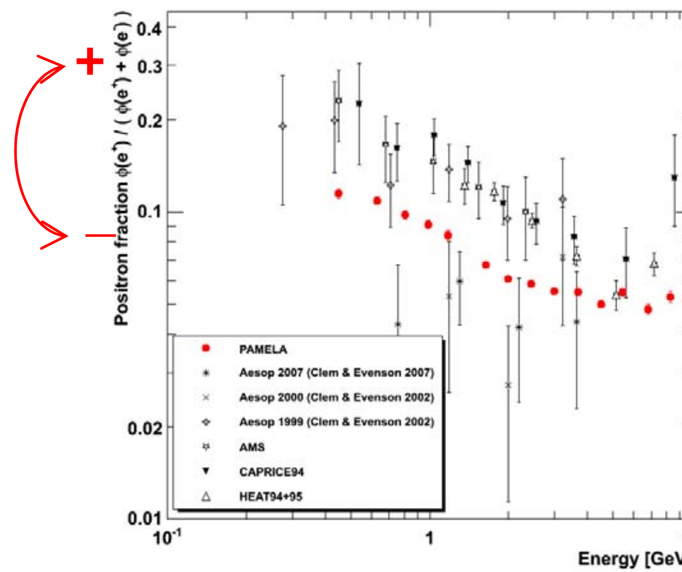


Solar modulation

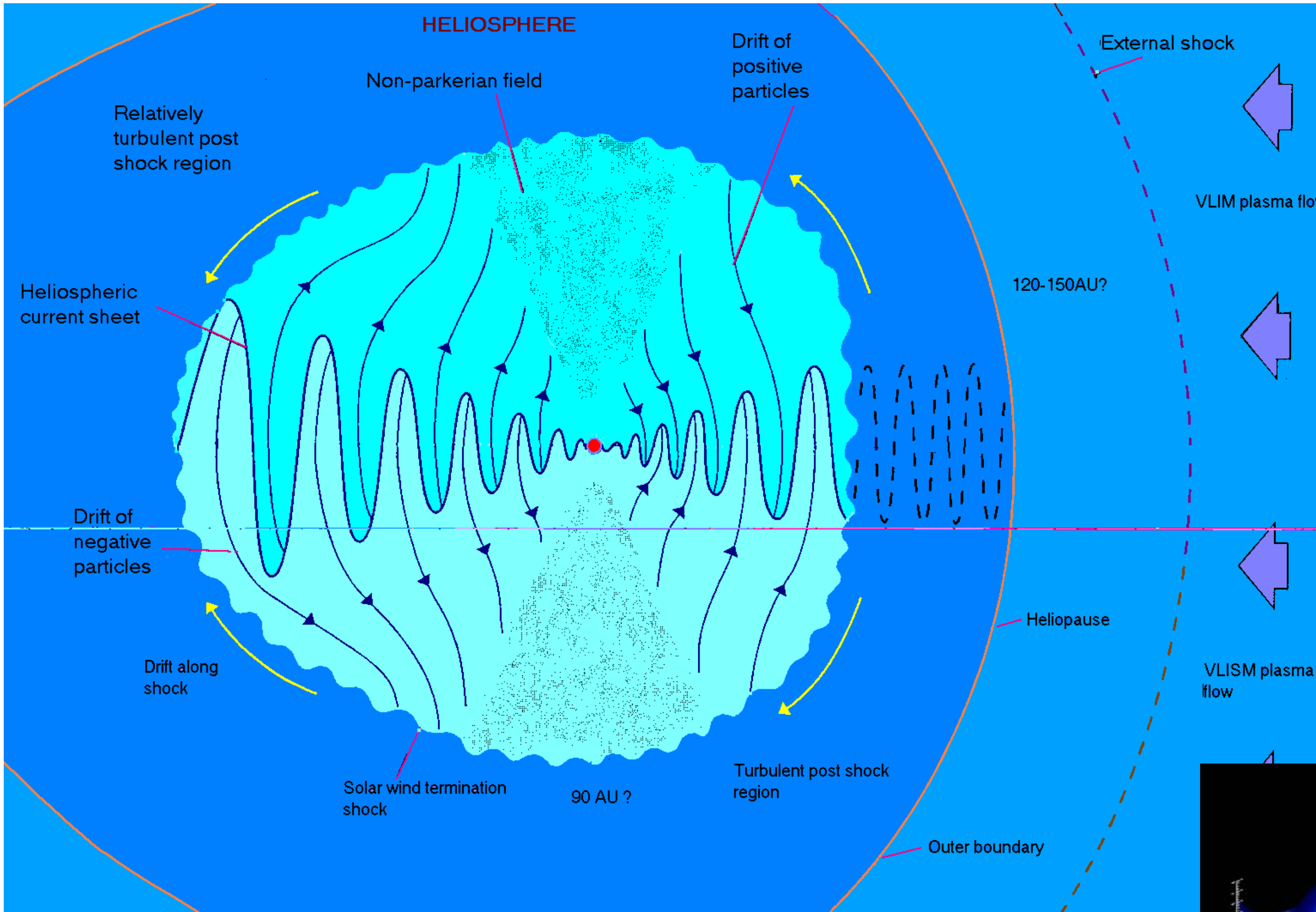


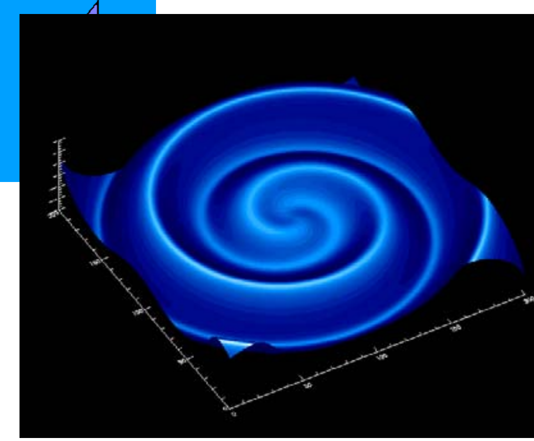






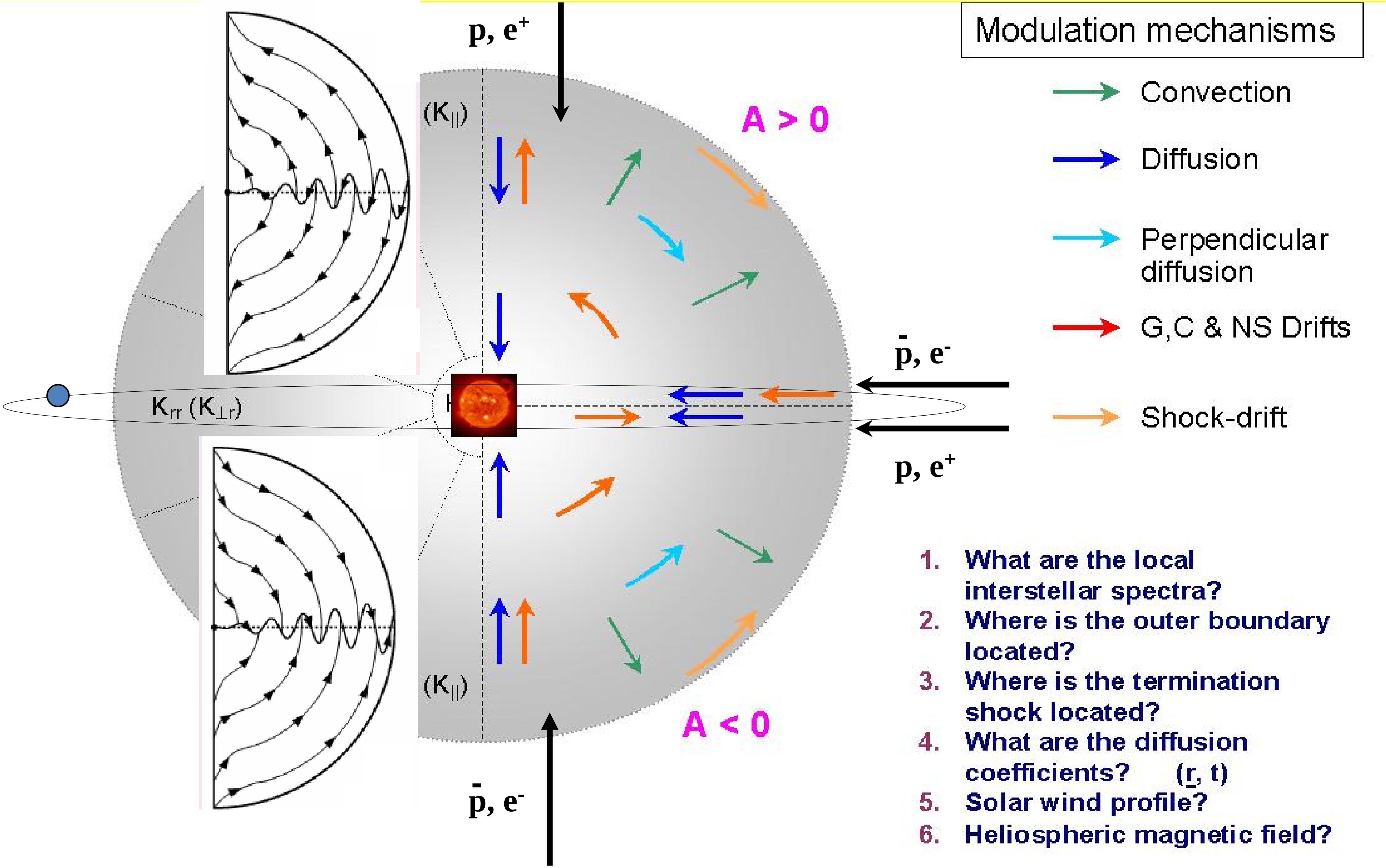
Heliosphere & Cosmic Ray Modulation Mechanisms





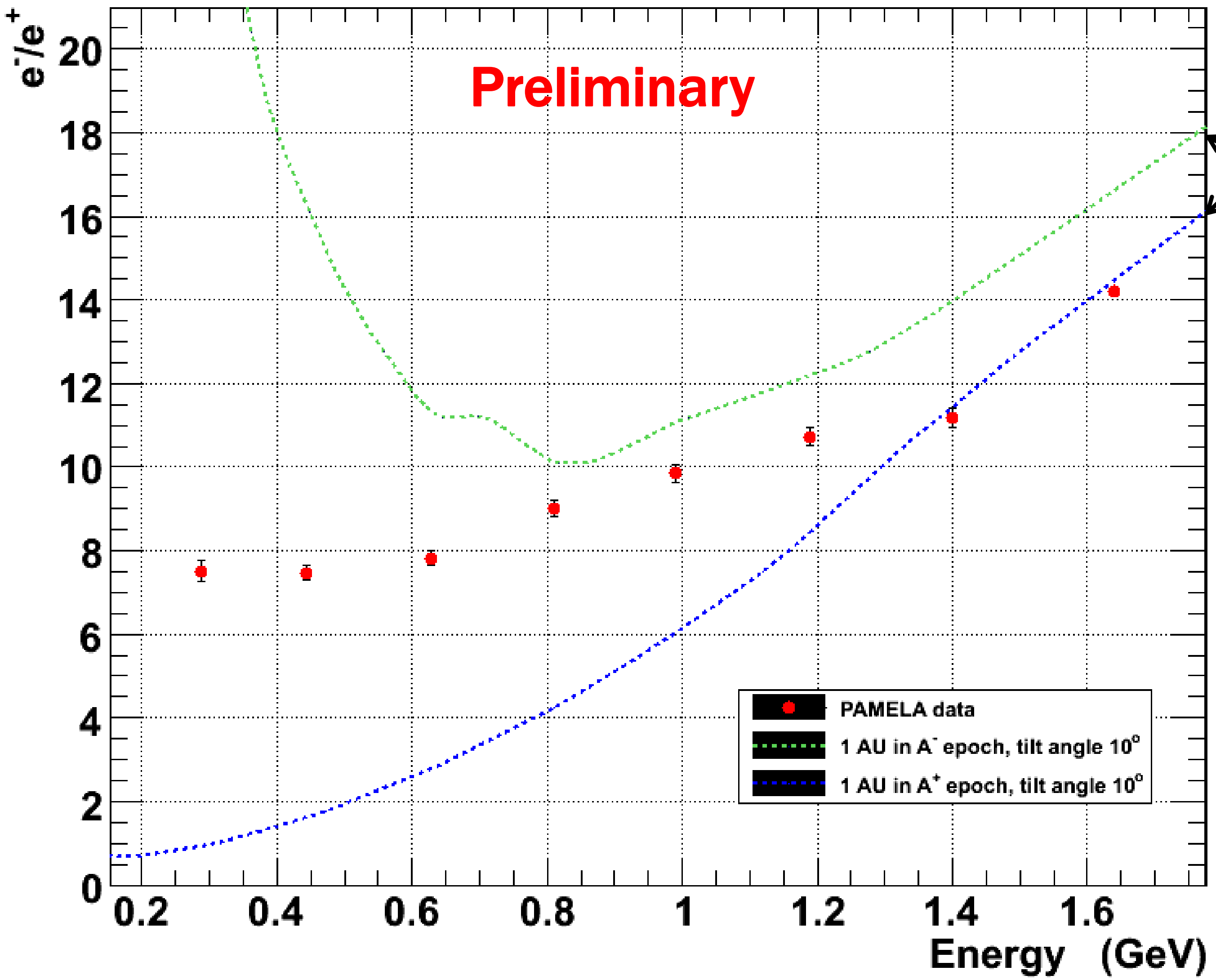
Mirko Boezio, OKC Stockholm, 2010/01/25

Charge dependent solar modulation



1. What are the local interstellar spectra?
2. Where is the outer boundary located?
3. Where is the termination shock located?
4. What are the diffusion coefficients? (r, t)
5. Solar wind profile?
6. Heliospheric magnetic field?

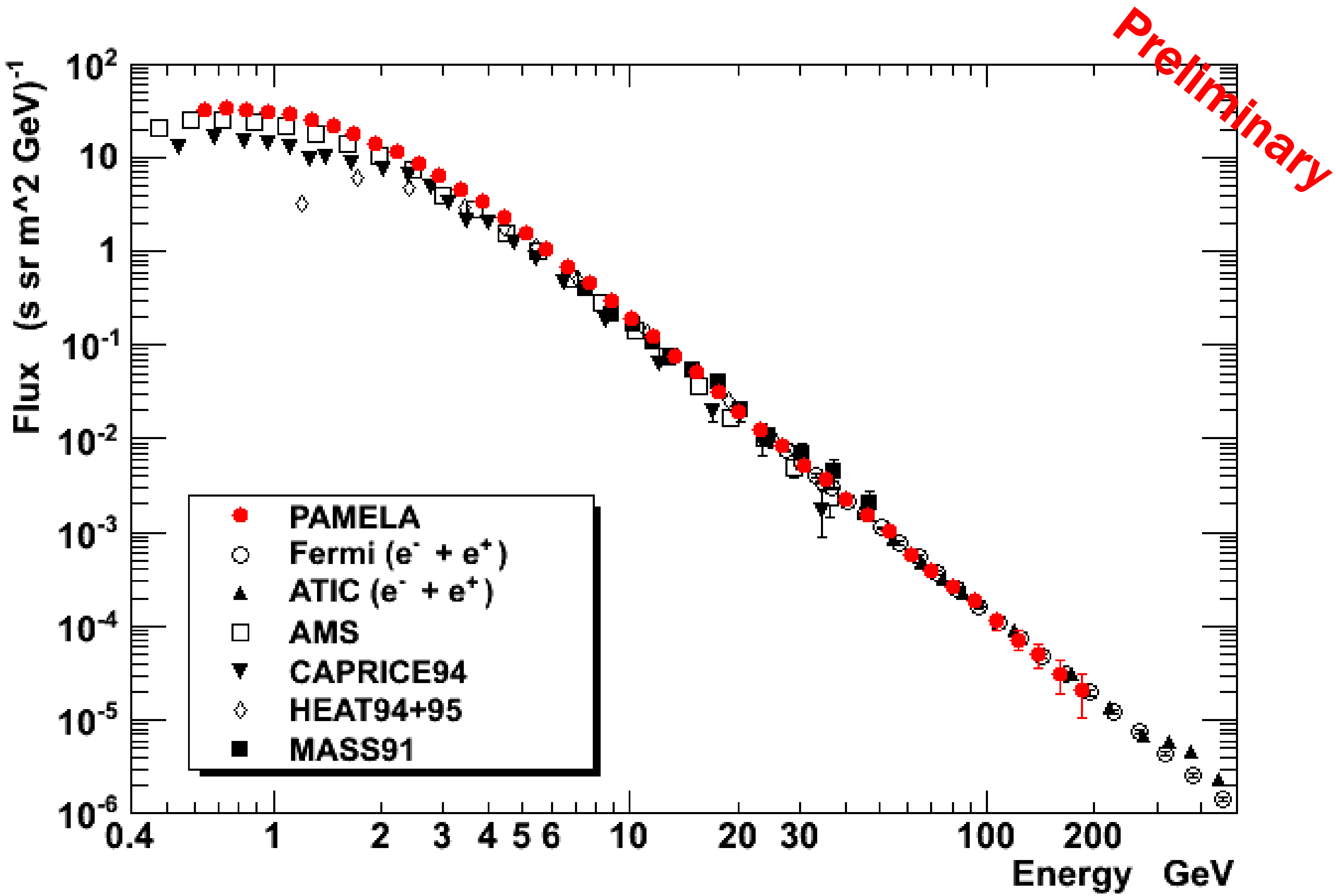
PAMELA electron to positron ratio and theoretical models



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

ELECTRONS

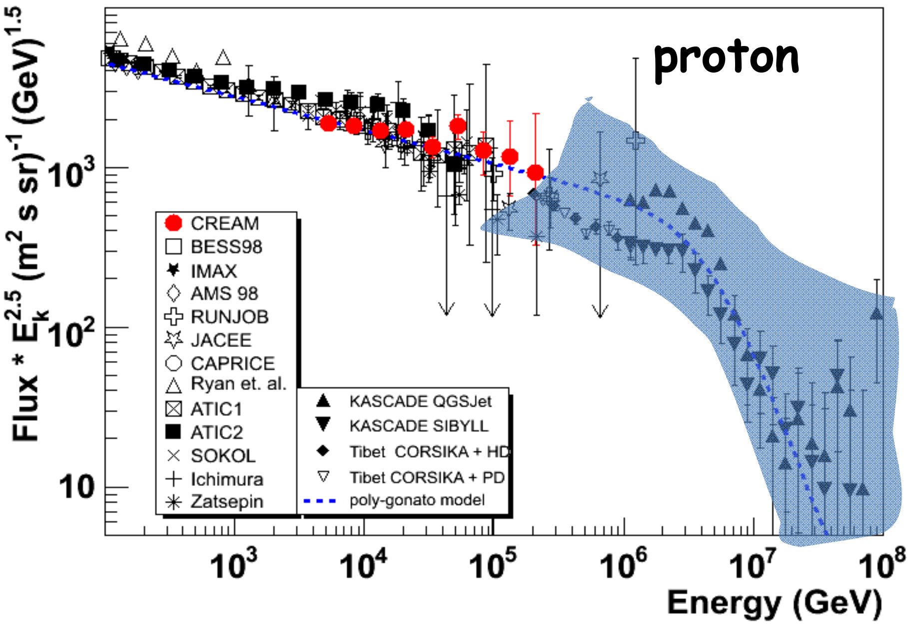
PAMELA Electron (e^-) Spectrum

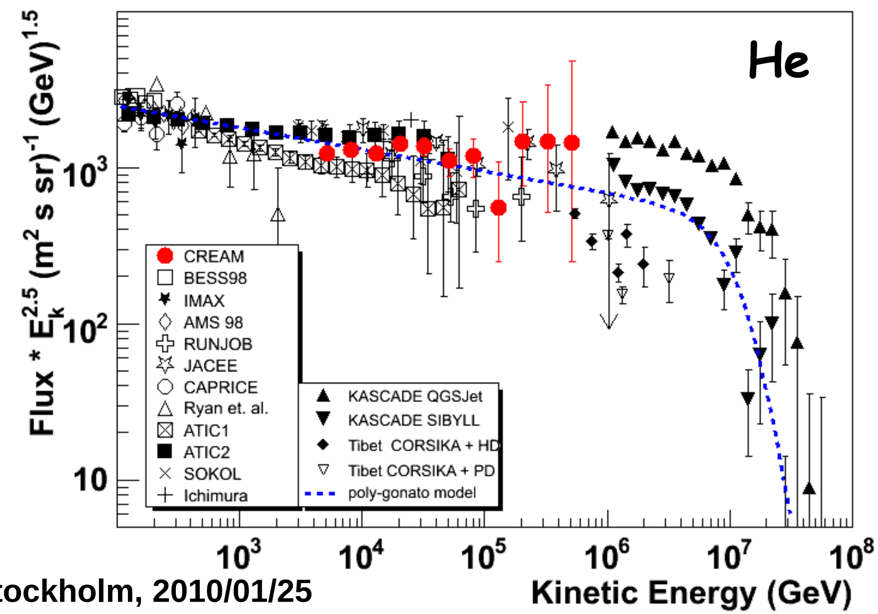


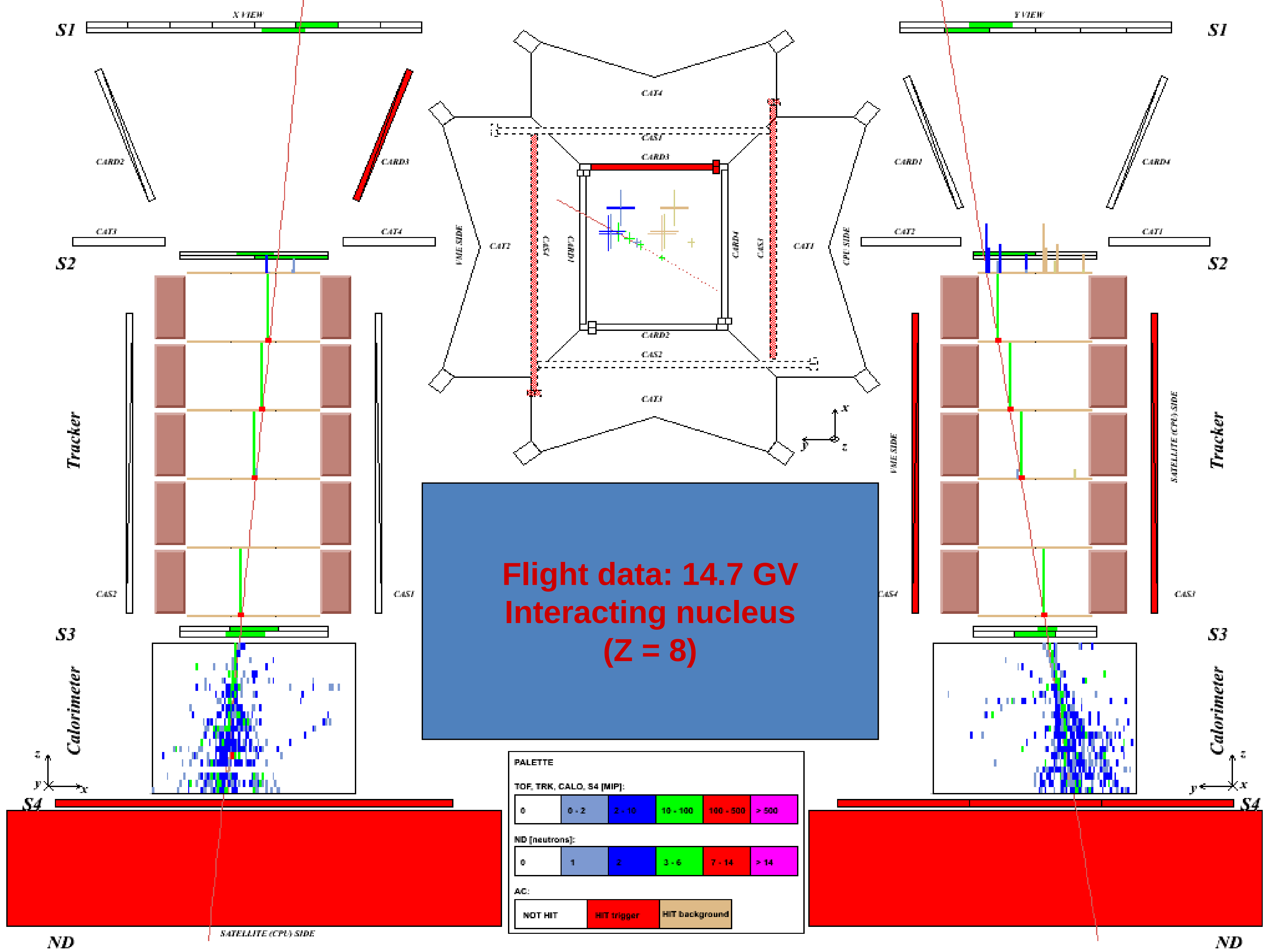
See E. Mocchiutti's talk

PROTONS AND HEAVIER NUCLEI

Galactic H and He spectra

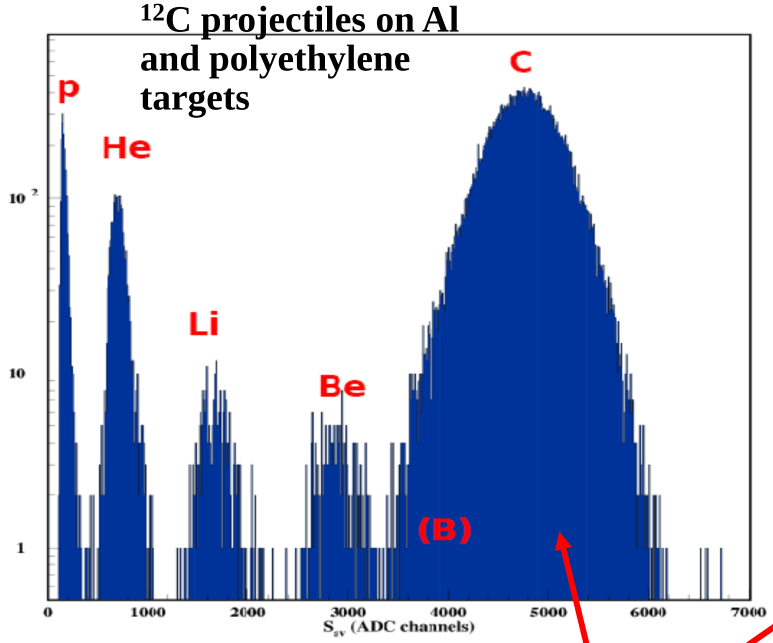




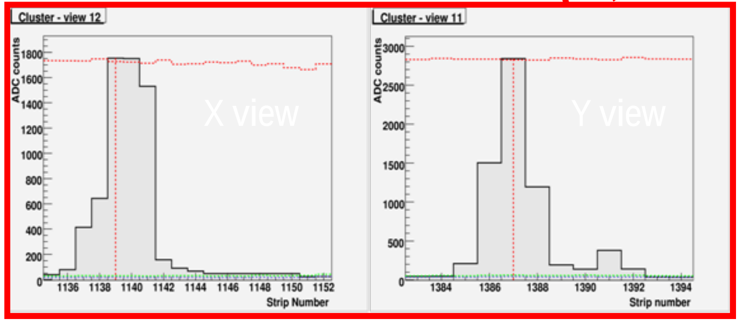


X VIEW
Y VIEW
S1
S2
S3
S4
ND
Tracker
Calorimeter
CARD1
CARD2
CARD3
CARD4
CAT1
CAT2
CAT3
CAT4
CAS1
CAS2
CAS3
CAS4
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
Flight data: 14.7 GV
Interacting nucleus
(Z = 8)
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background

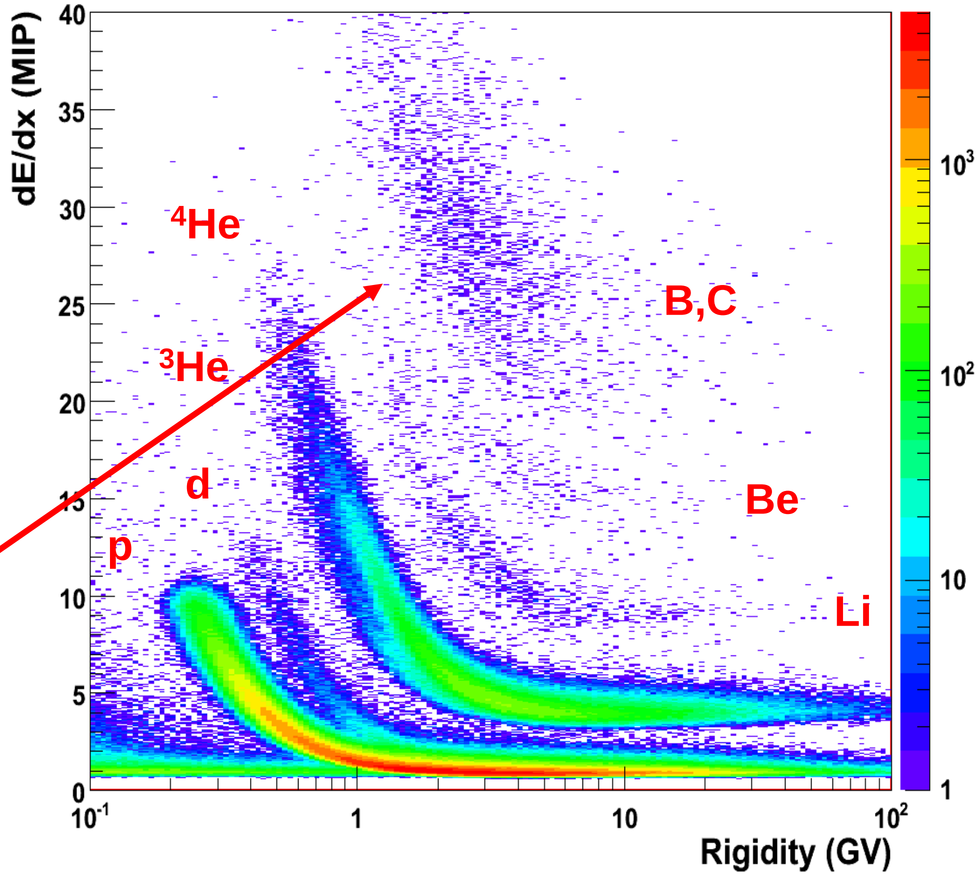
Charge identification capabilities (tracker)



Saturated clusters

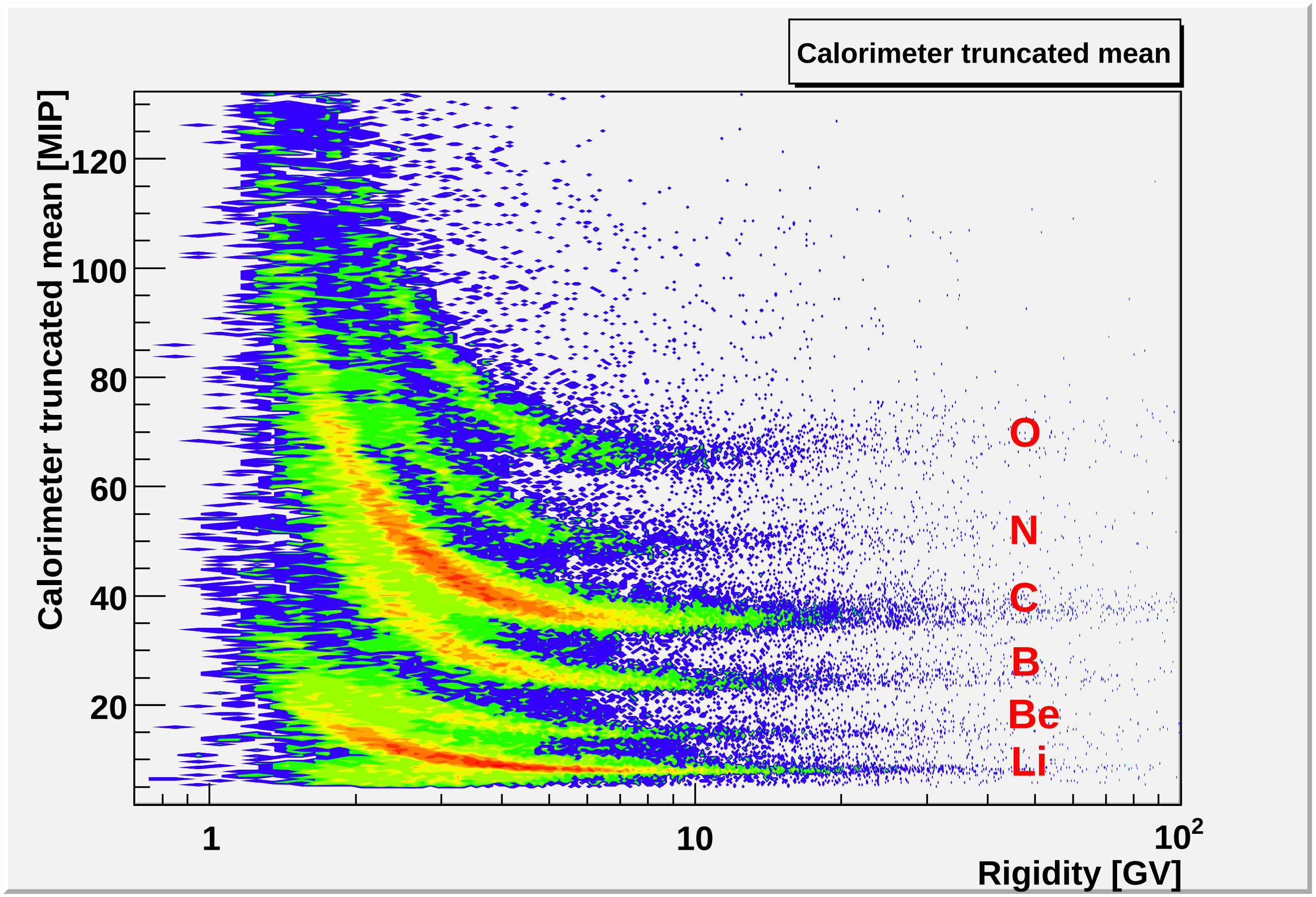


flight data (preliminary)



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

Charge identification capabilities (calorimeter)



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

Summary

- PAMELA has been in orbit and studying cosmic rays for ~42 months. >10^9 triggers registered and >18 TB of data has been down-linked.

- Antiproton-to-proton flux ratio and antiproton energy spectrum (~100 MeV - ~200 GeV) show no significant deviations from secondary production expectations.

- High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy. Primary source?
Data at higher energies might help to resolve origin of rise (spillover limit ~300 GeV).

- e^- spectrum up to ~200 GeV shows spectral features that may point to additional components. Analysis is ongoing to increase the statistics and expand the measurement of the e^- spectrum up to ~500 GeV and e^+ spectrum up to ~300 GeV (all electrum (e^- + e^+) spectrum up to ~1 TV).

- Furthermore:
    - PAMELA is going to provide measurements on elemental spectra and low mass isotopes with an unprecedented statistical precision and is helping to improve the understanding of particle propagation in the interstellar medium
    - PAMELA is able to measure the high energy tail of solar particles.
    - PAMELA is going to set a new lower limit for finding Antihelium

http://pamela.roma2.infn.it

INFN Istituto Nazionale di Fisica Nucleare

Thanks!