Looking for Dark Matter in Cosmic Rays with Pamela Experiment

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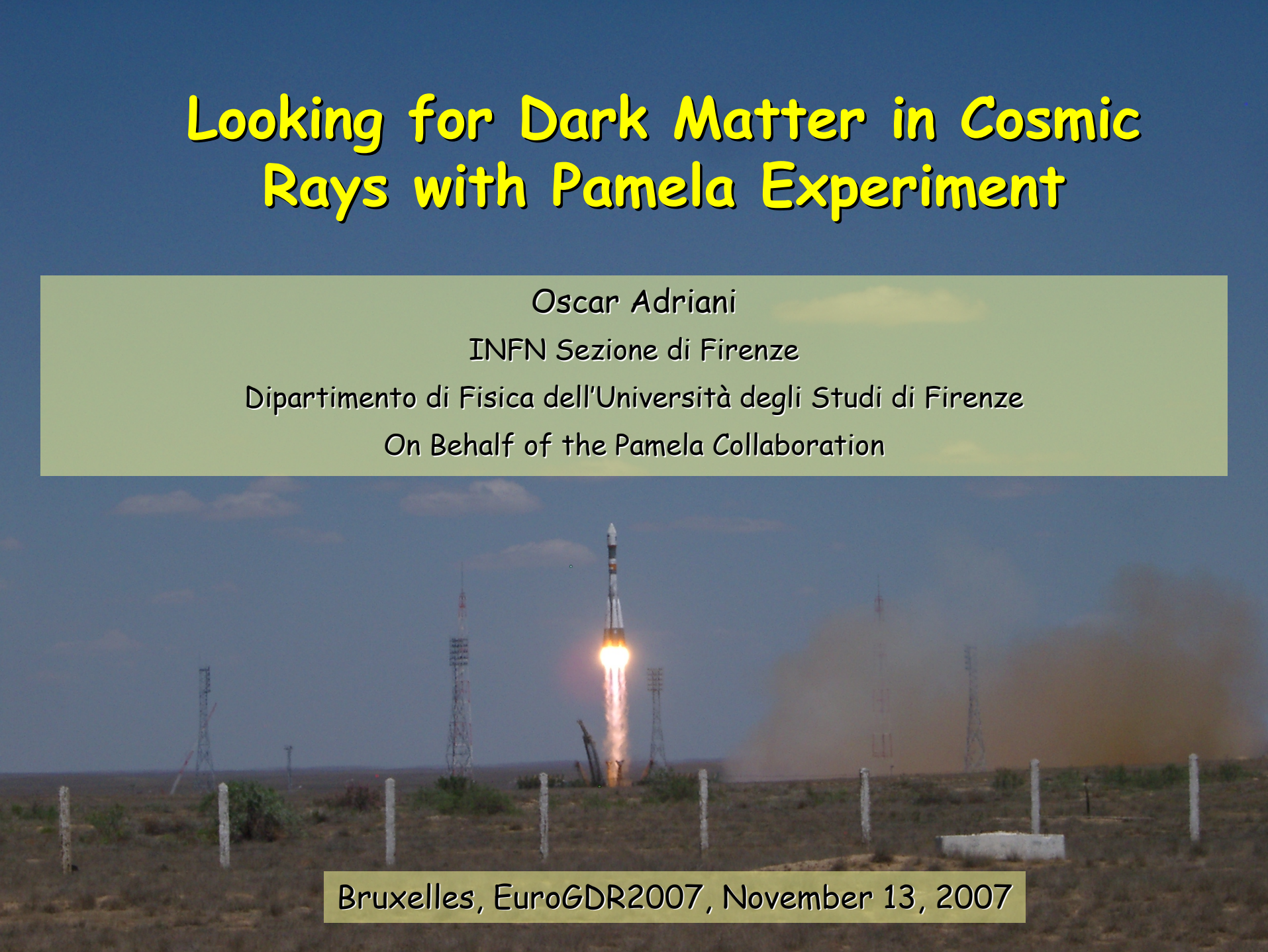
On Behalf of the Pamela Collaboration

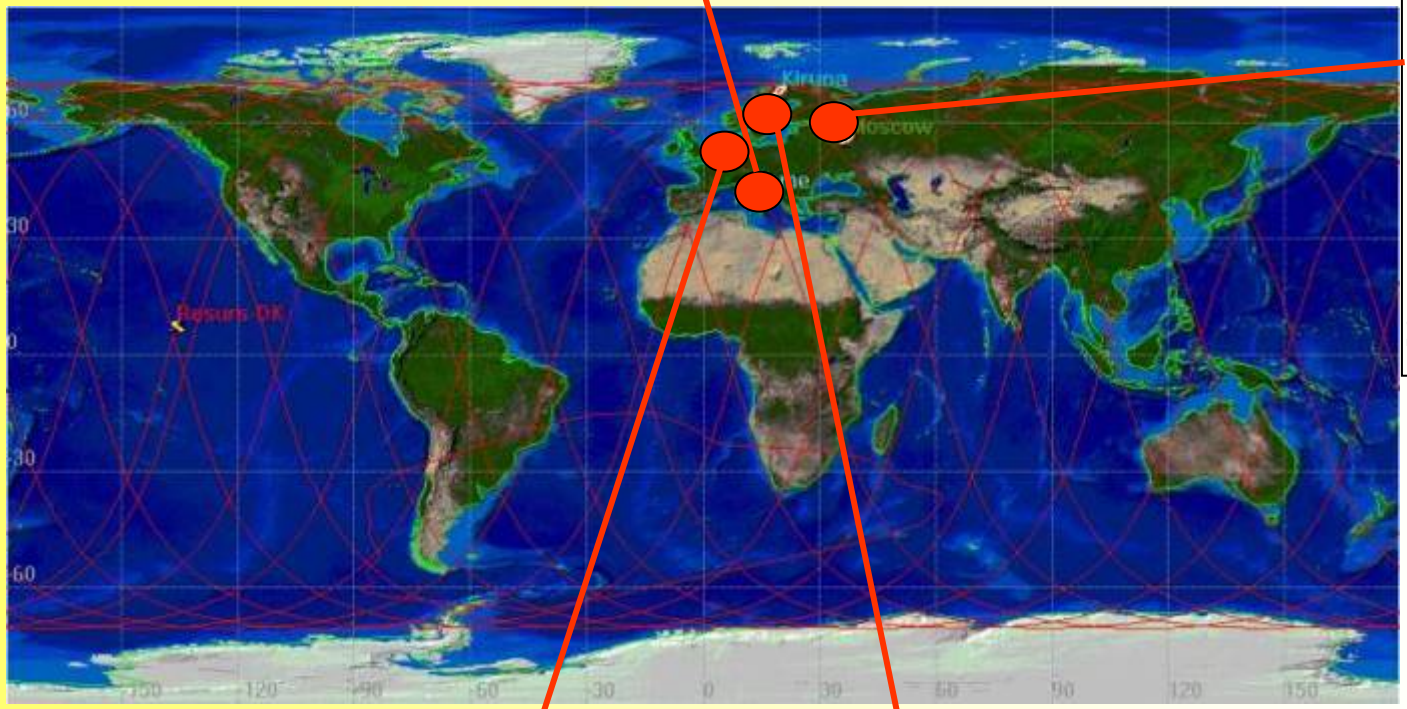


Bruxelles, EuroGDR2007, November 13, 2007

PAMELA Collaboration

Italy:

Bari Florence Frascati Naples Rome Trieste CNR, Florence



Russia:

Moscow
St. Petersburg

Germany:

Siegen

Sweden:

KTH, Stockholm

Pamela's scientific objectives

- ✓ Study antiparticles in cosmic rays
- ✓ Search for antimatter
- ✓ Search for dark matter
- ✓ Study cosmic-ray propagation
- ✓ Study solar physics and solar modulation
- ✓ Study the electron spectrum (local sources?)

PAMELA nominal capabilities

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

→ **Simultaneous measurement of many cosmic-ray species**

→ **New energy range**

→ **Unprecedented statistics**

PAMELA in Space

On **June 15th 2006** at 08:00 UTC the RESURS DK-1 satellite housing the PAMELA apparatus was successfully launched in space from the Russian cosmodrome of Baikonur.

PAMELA was switched on for the first time on **June 21st**.

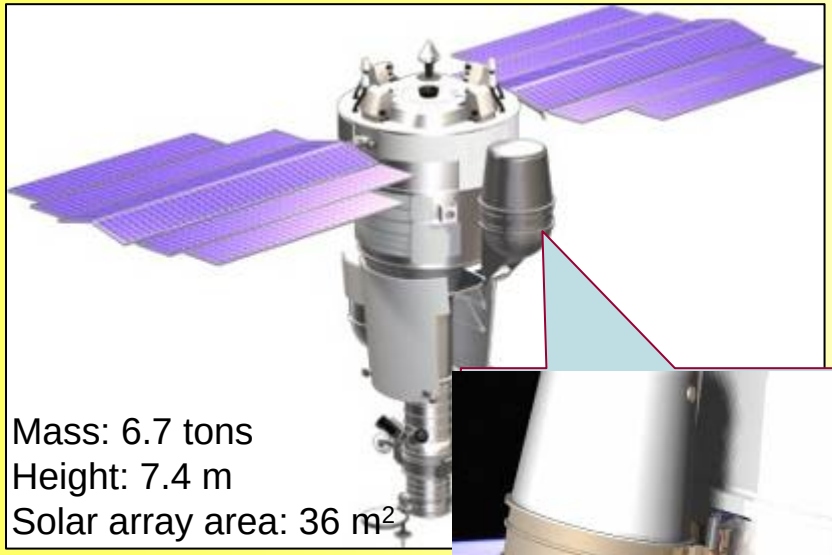
In the following days PAMELA was on for several hours and continuously since the **11th of July**.

On September the 15th the commission phase of the RESURS was completed.

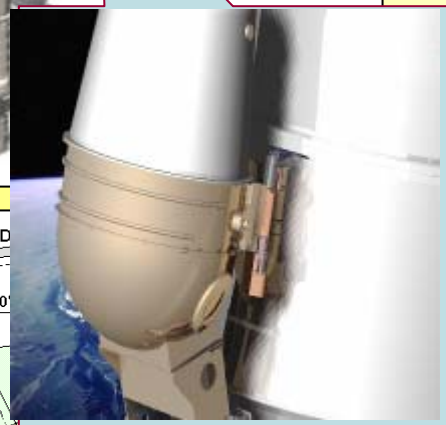
PAMELA flight

- Detectors operated as expected after launch
- Tested different trigger and hardware configurations
- As of August 30, 2007 PAMELA has collected data for about 30 million seconds corresponding to more than 340 days (8100 hours) of continuous data taking (life time ~70%)
- The amount of data collected is ~5.8 TB, corresponding to more than 700 million events

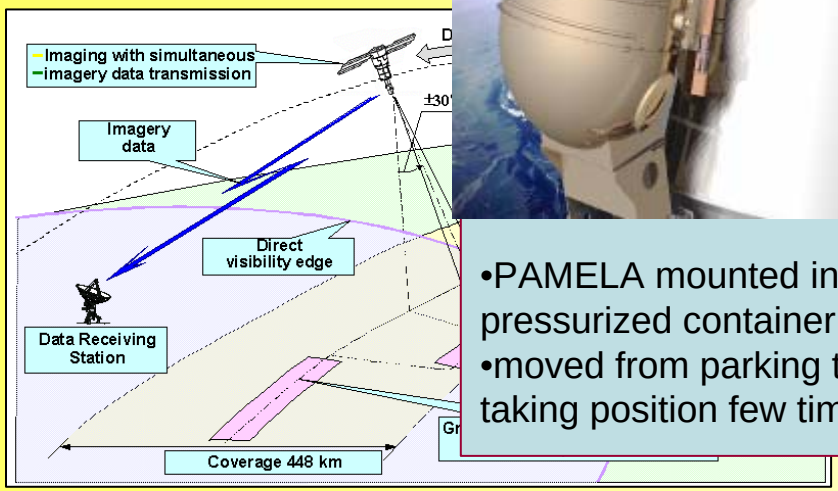
The Resurs DK-1 spacecraft



Mass: 6.7 tons
Height: 7.4 m
Solar array area: 36 m^2



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



- Multi-spectral remote sensing of earth's surface
  → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)

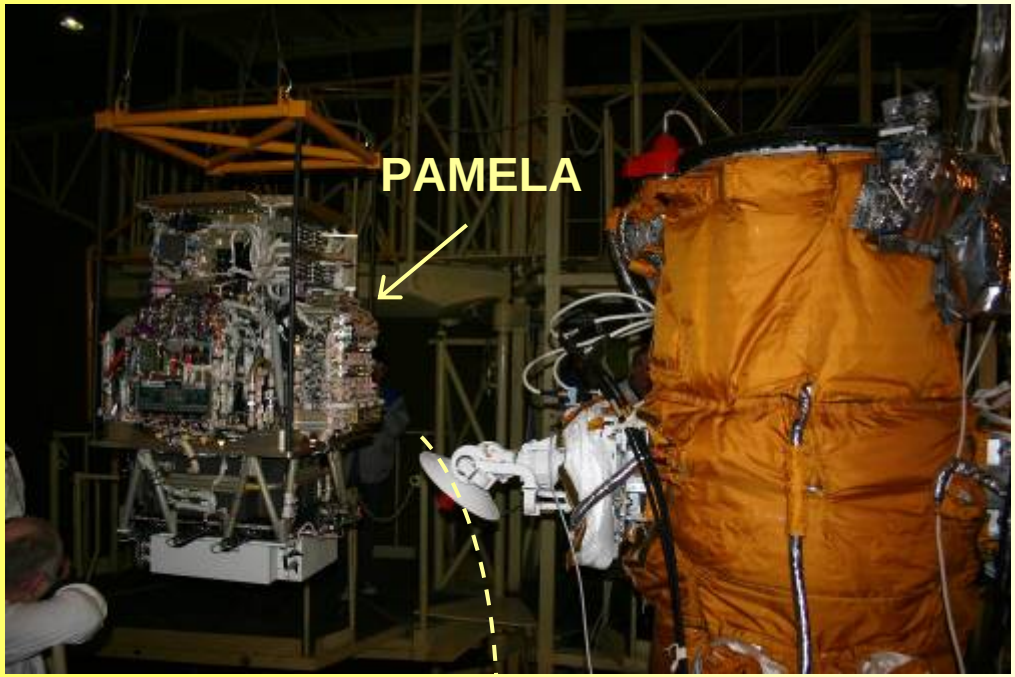
Operational orbit parameters:

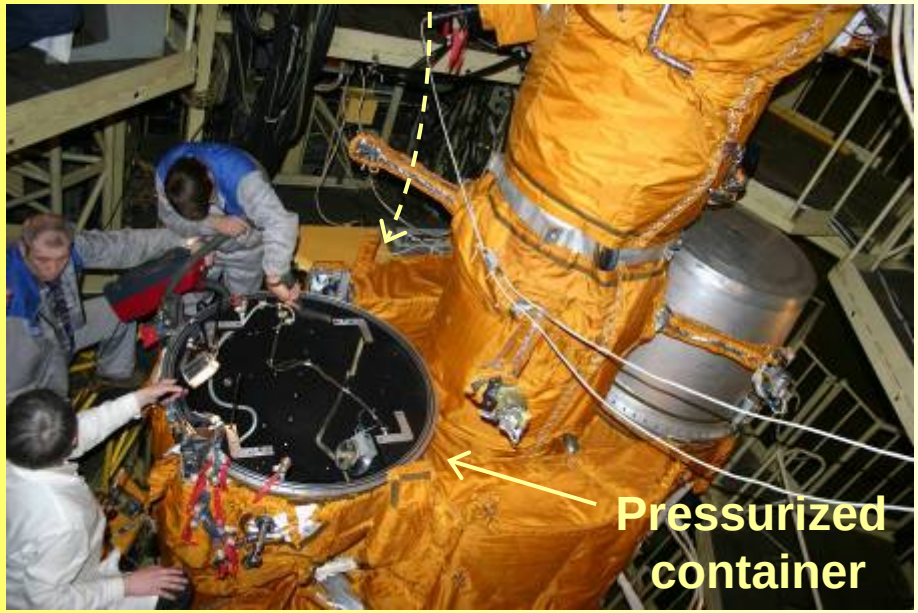
- inclination ~70^o
- altitude ~ 360-600 km (elliptical)

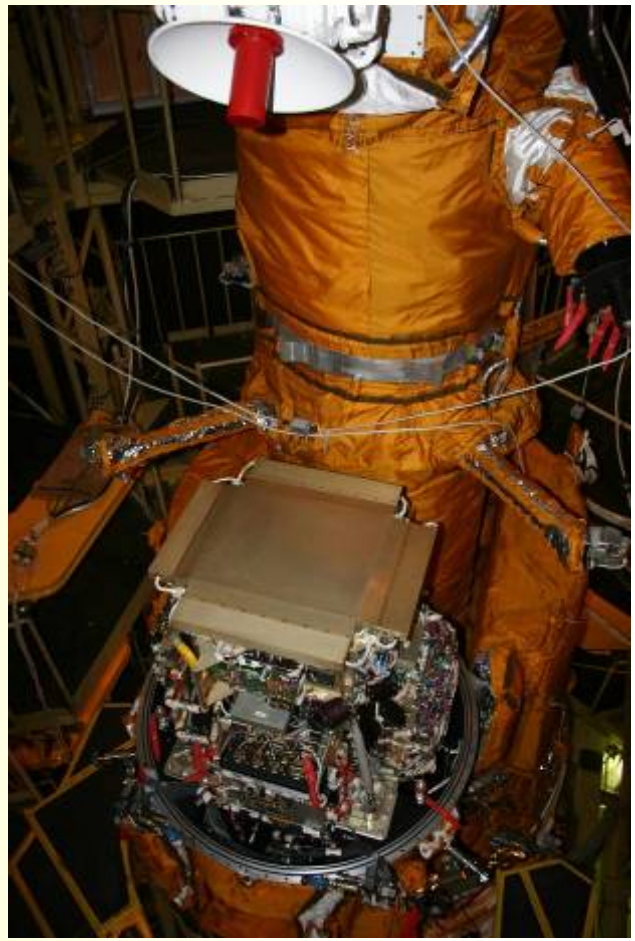
Active life >3 years

Data transmitted via Very high-speed Radio Link (VRL)

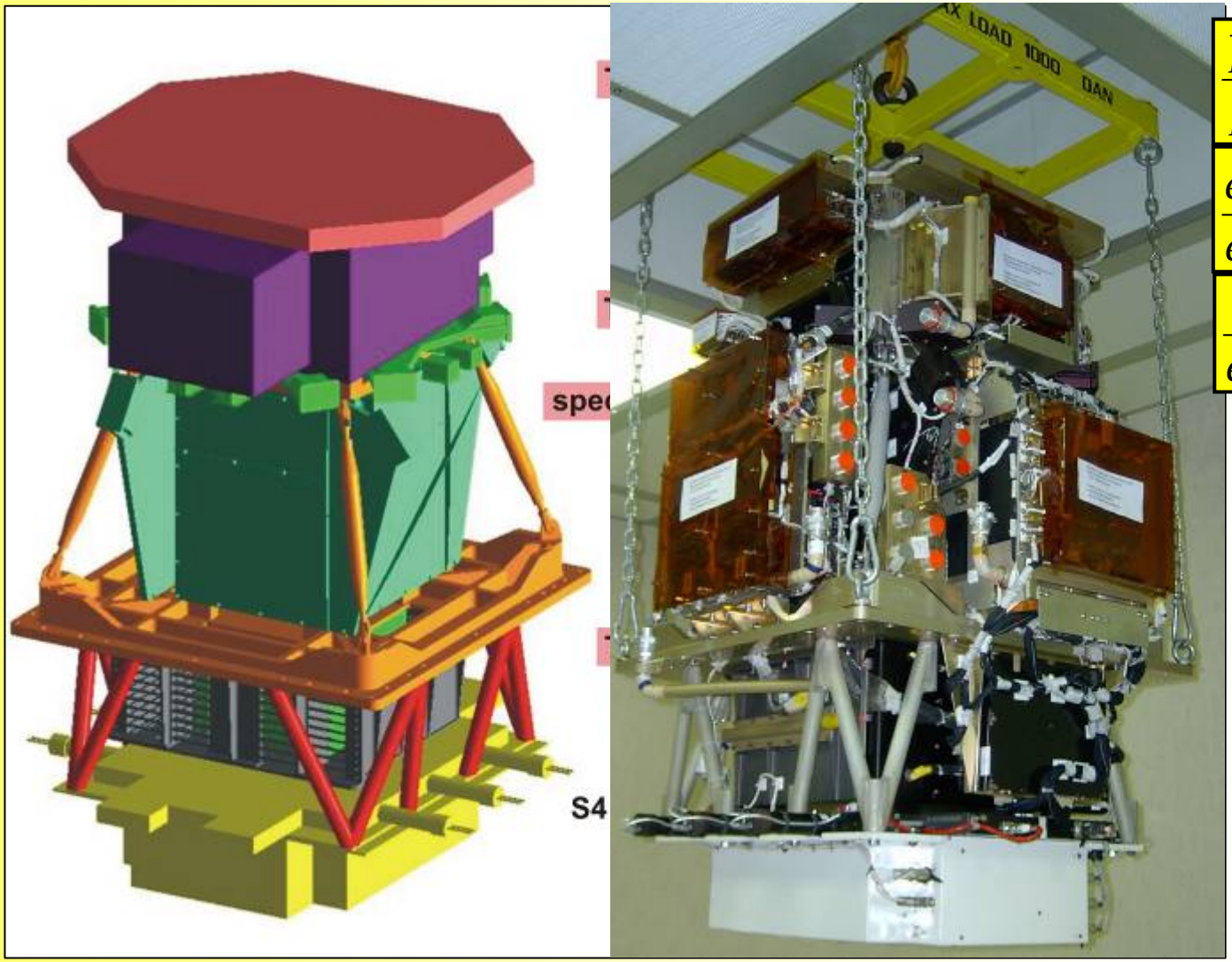
March 2006 @Baykonur
Integration with satellite







The PAMELA apparatus

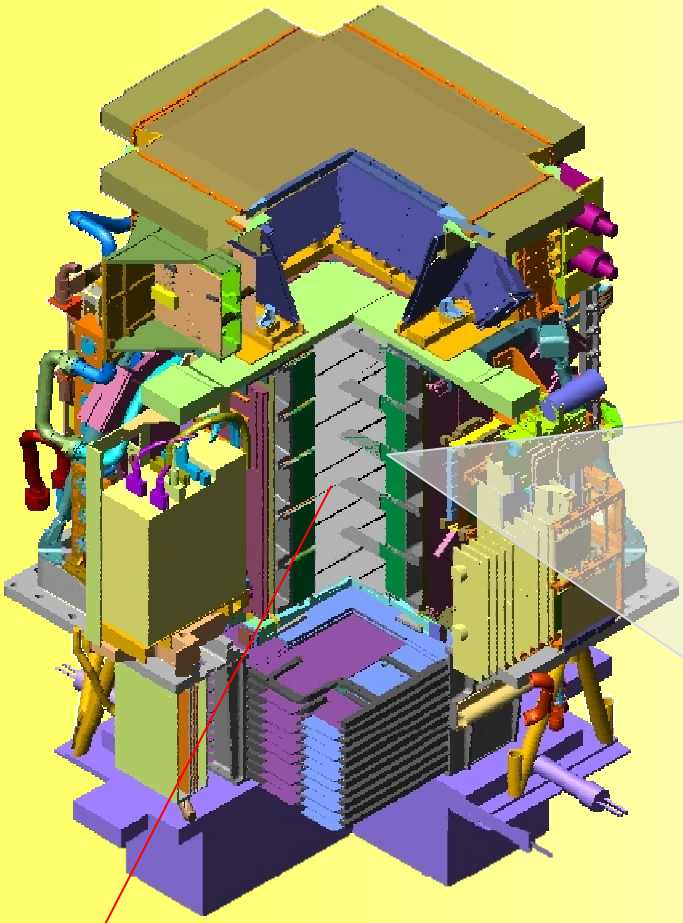


$$\frac{\bar{p}}{p} \sim O(10^{-4})$$

$$\frac{e^+}{e^-} \sim O(0.1)$$

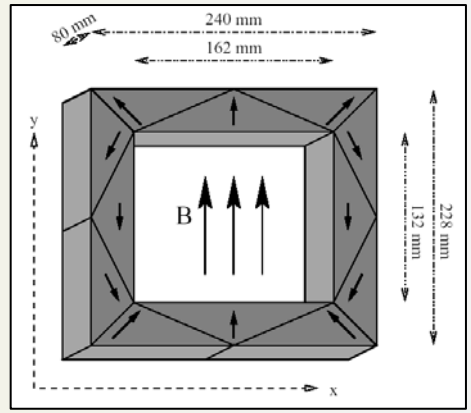
$$\frac{p}{e^-} \sim O(200)$$

Mass ~450 kg Power ~360 W Geometrical Factor ~20.5 cm²sr



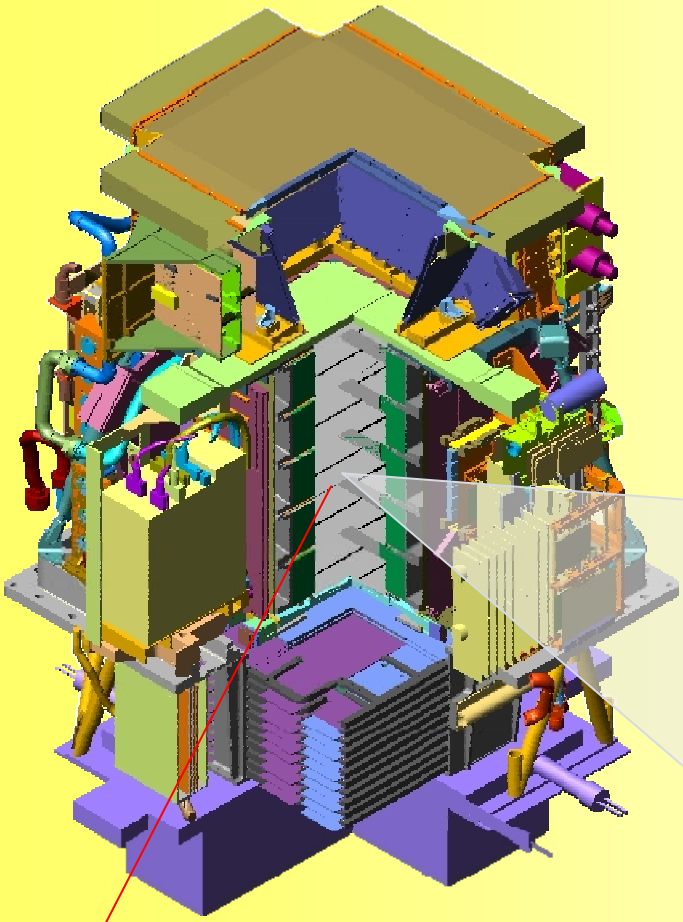
SPECTROMETER

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)



SPECTROMETER

The tracking system

Main tasks:

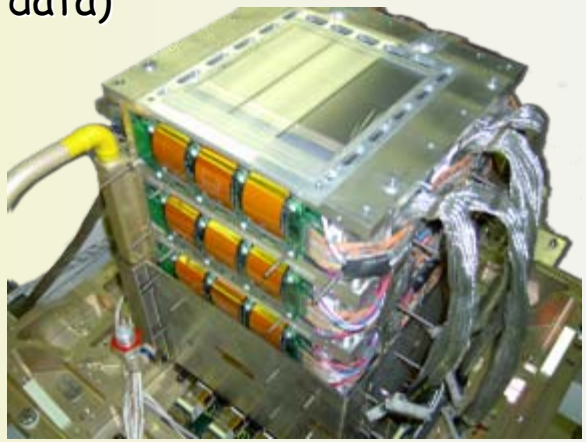
- Rigidity measurement
- Sign of electric charge
- dE/dx

Characteristics:

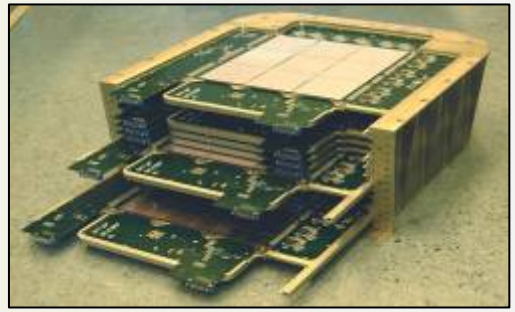
- 6 planes double-side (x&y view) microstrip Si sensors
- 36864 channels
- Dynamic range 10 MIP

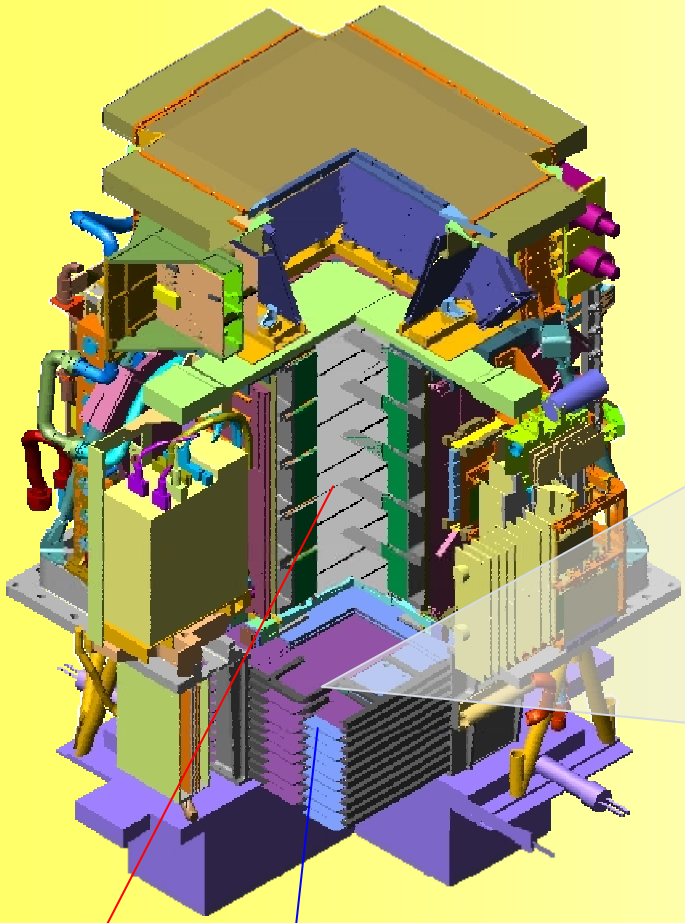
Performances:

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



The electromagnetic calorimeter





Main tasks:

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

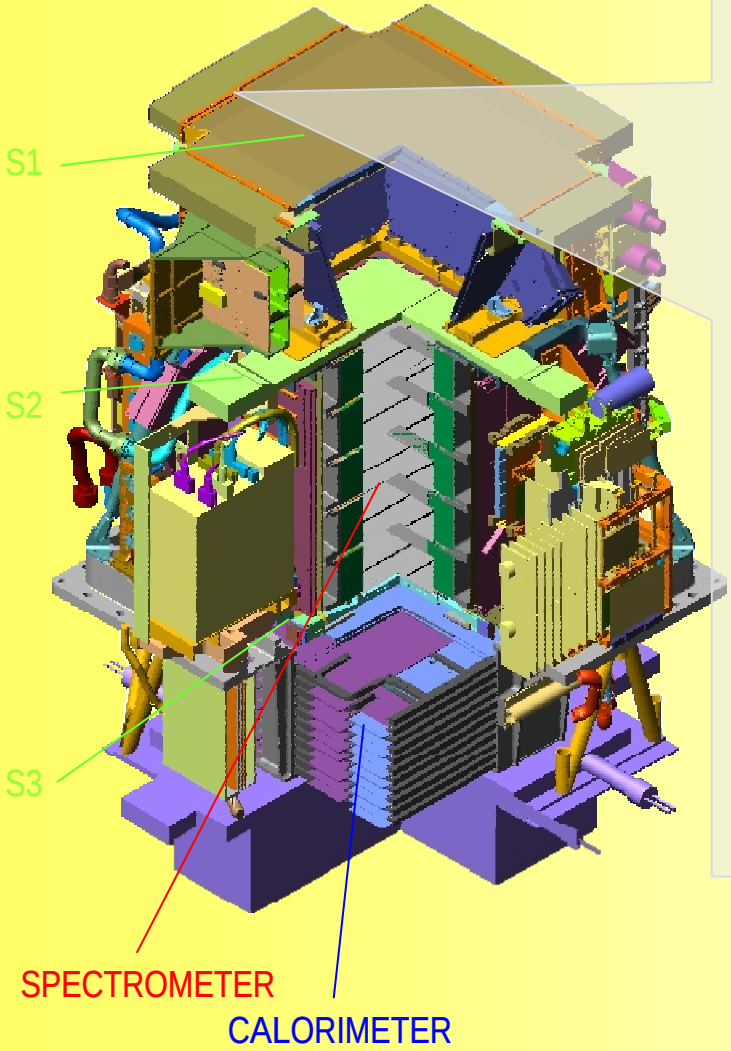
Characteristics:

- 44 Si layers (X/Y) +22 W planes
- 16.3 X_o / 0.6 λ_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)

Performances:

- p-bar and e^+ selection efficienecy ~ 90%
- p rejection factor $>10^5$
- e^- rejection factor > 10^4
- Energy resolution ~5% @200GeV

The time-of-flight system



Main tasks:

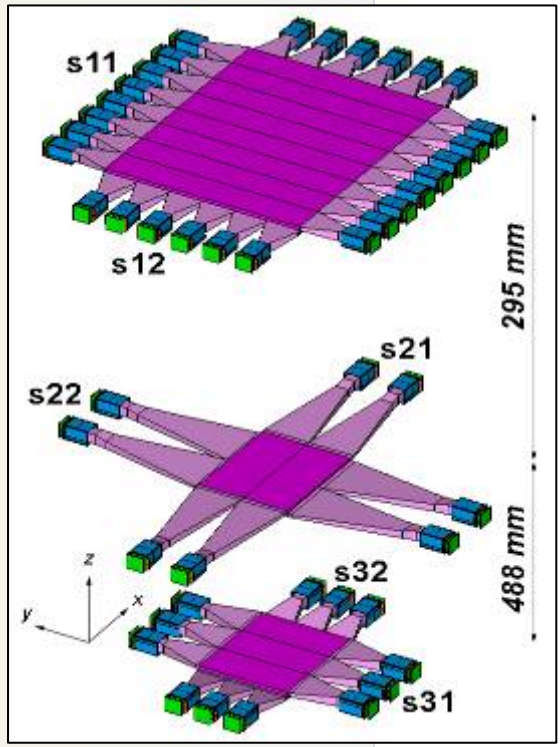
- First-level trigger
- Albedo rejection
- dE/dx
- Particle identification (<1 GeV/c)

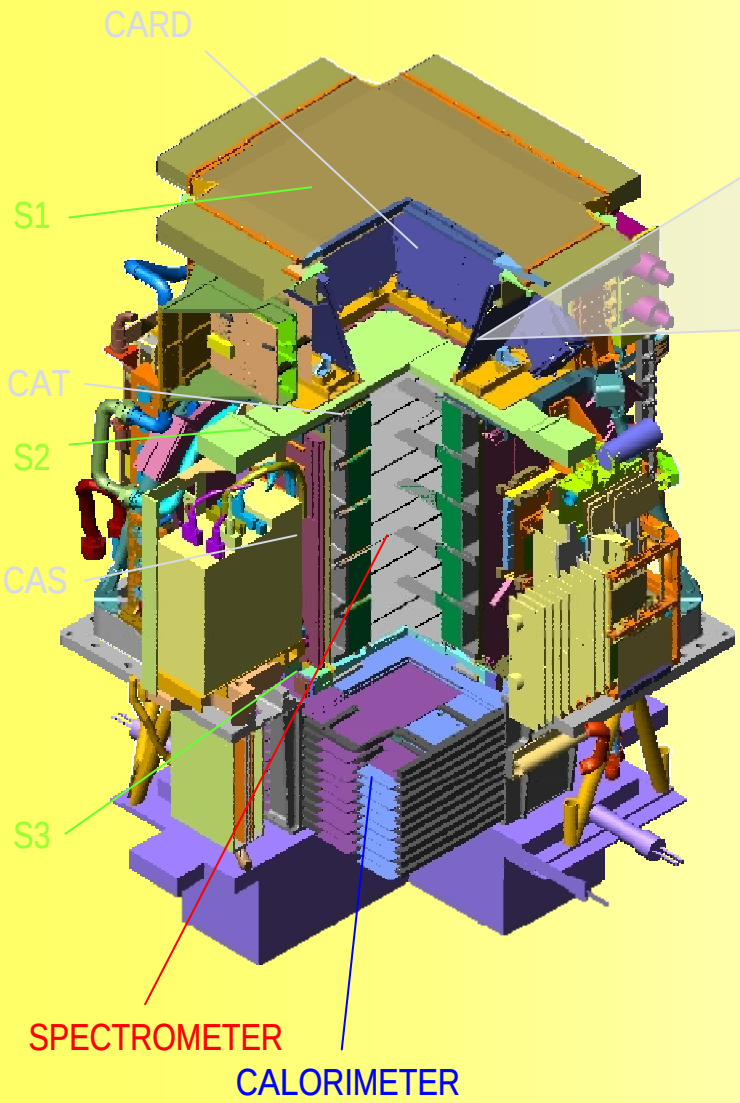
Characteristics:

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

Performances:

- σ(paddle) ~ 110ps
- σ(TOF) ~ 330ps (for MIPs)





The anticounter shields

Main tasks:

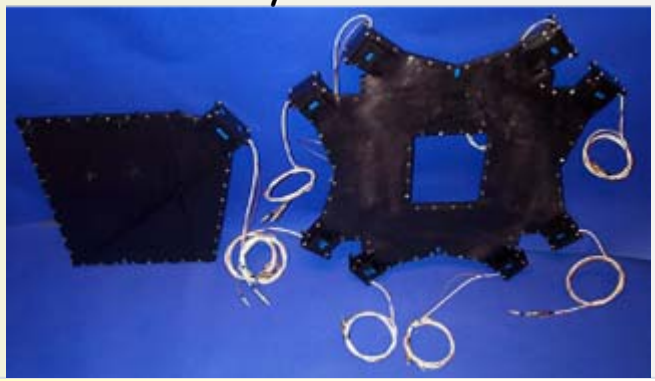
- Rejection of events with particles interacting with the apparatus (off-line and second-level trigger)

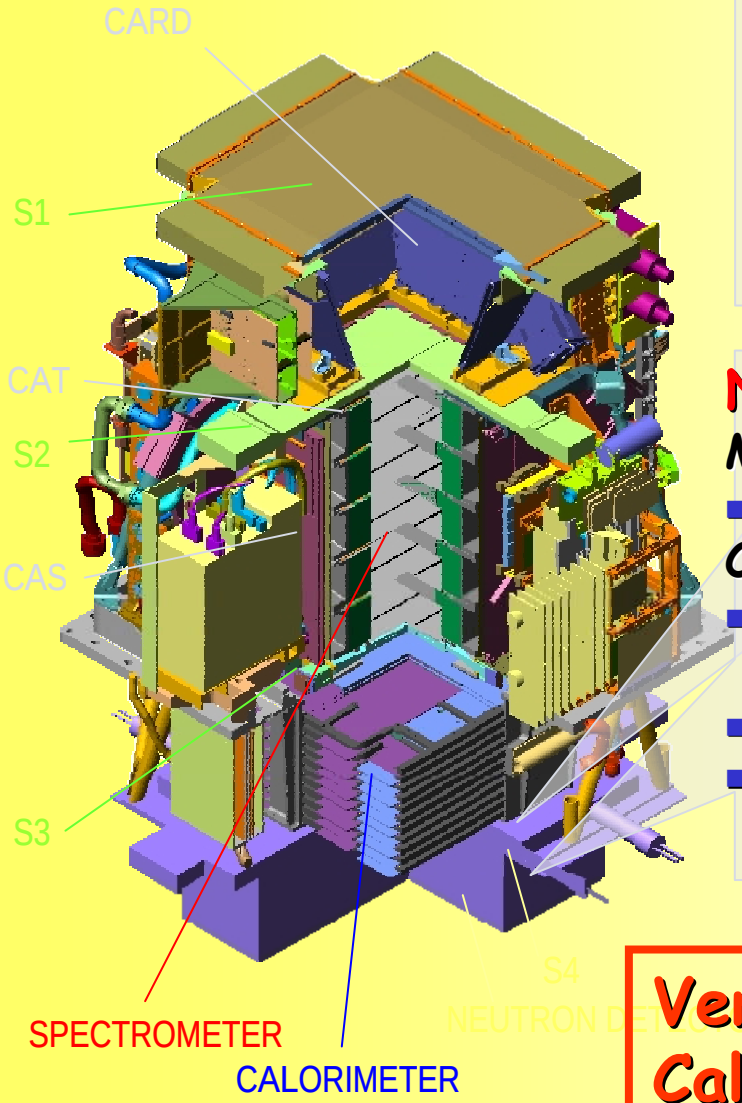
Characteristics:

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

Performances:

- Efficiency > 99.9%





Shower-tail catcher (S4)

Main tasks:

- ND trigger

Characteristics:

- 1 scintillator paddle 10mm thick

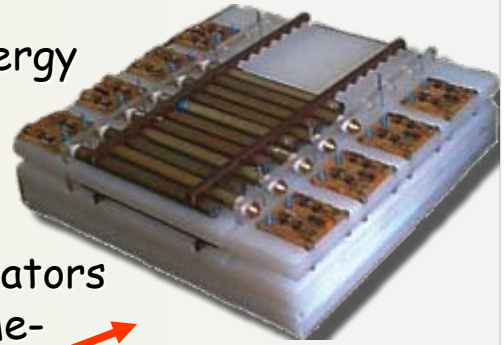
Neutron detector

Main tasks:

- e/h discrimination @high-energy

Characteristics:

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



Very important to help the Calorimeter in the particle separation

DAQ and data link with earth

Data acquisition

- Trigger configurations

  High-radiation environment

  → (S21 AND S22) AND (S31 AND S32) OR CALORIMETER

  Low-radiation environment

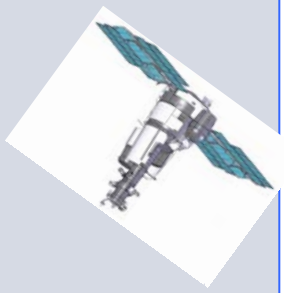
  → (S11 OR S12) AND (S21 OR S22) AND (S31 OR S32) OR CALORIMETER

- 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)

Data transmission

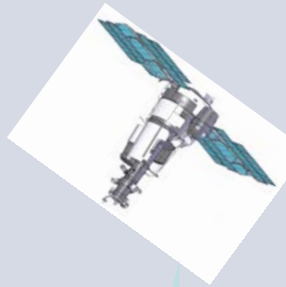


- Collected data stored in PAMELA mass-memory (2GB)
- Download (PAMELA → satellite)
  7-8 per day → 14-16 GB
- Downlink (satellite→ ground)
  2-3 sessions per day
- Error rate $<10^{-9}$

Main downlink station:
Research Centre for Earth operative monitoring"NtsOMZ" (Moscow, Russia)

Spare downlink station:
Khanty-Mansiysk West Siberia

Remote control

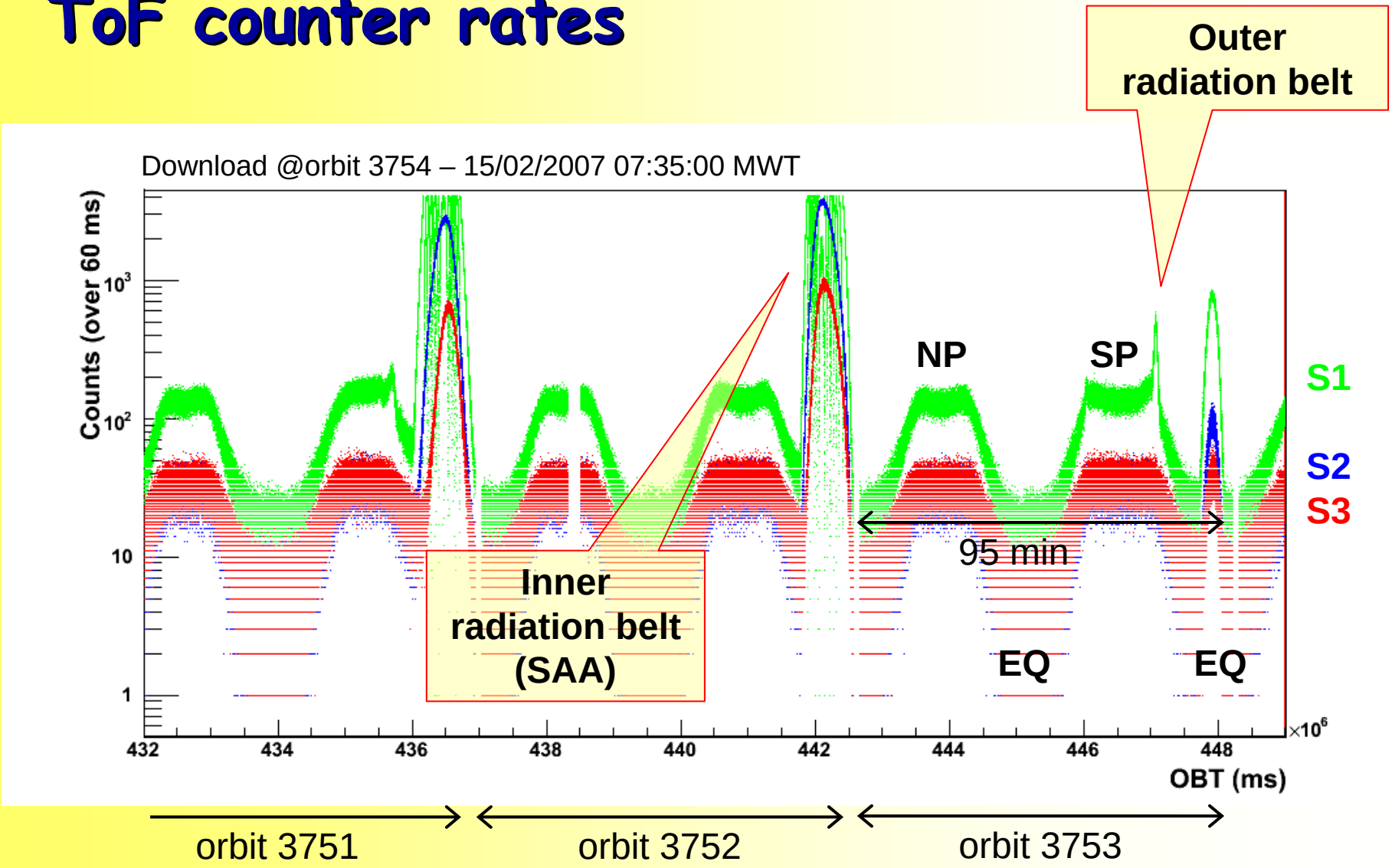


- Macrocommands: commands to PAMELA cpu
  - System configuration (hundreds of modifiable parameters):
  - Calibration (ascending node)
  - Download to satellite mass memory
  - …
- Telecommands: hardware lines to handle power modules

→ Extremely flexible system, designed to be easily adapted to space (unknown) conditions.

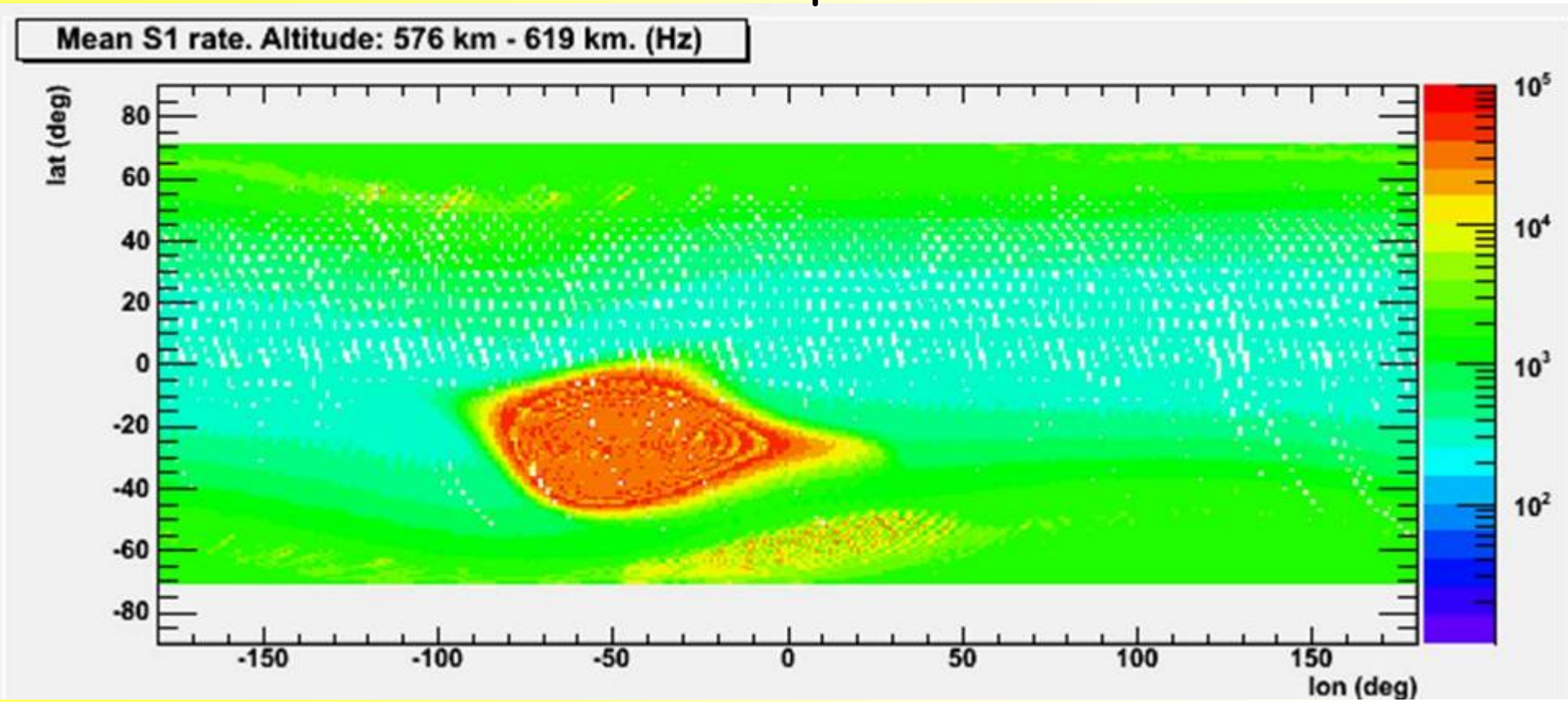
Orbital environment

ToF counter rates

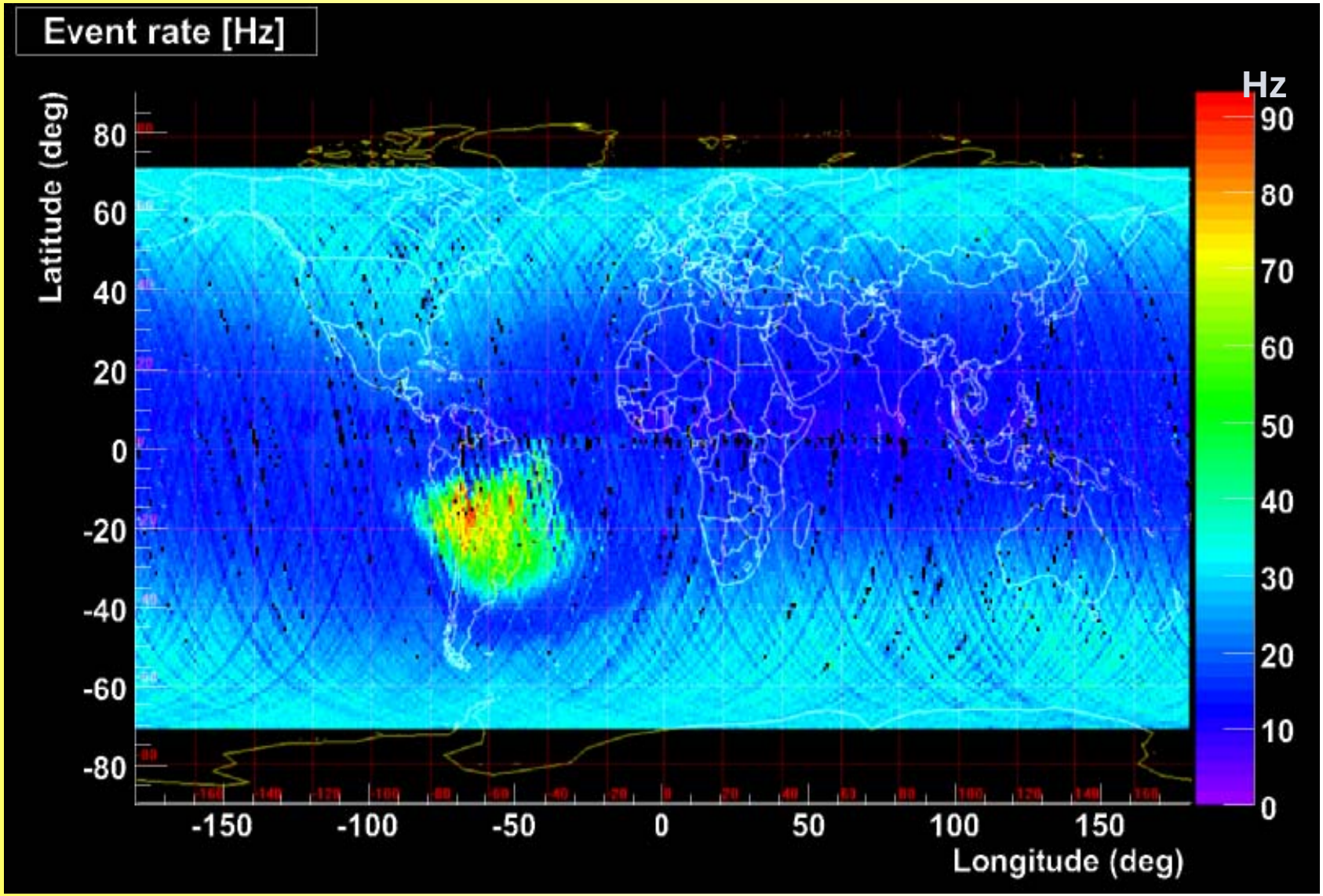


Pamela maps at various altitudes

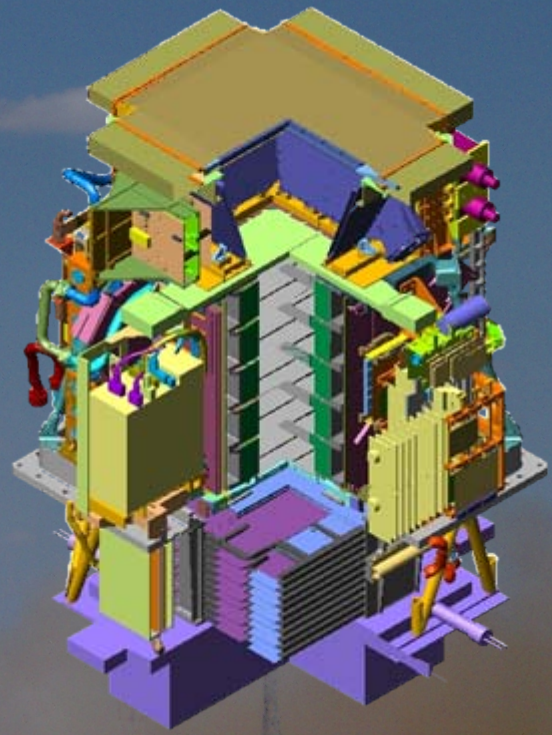
Top Counter Rate

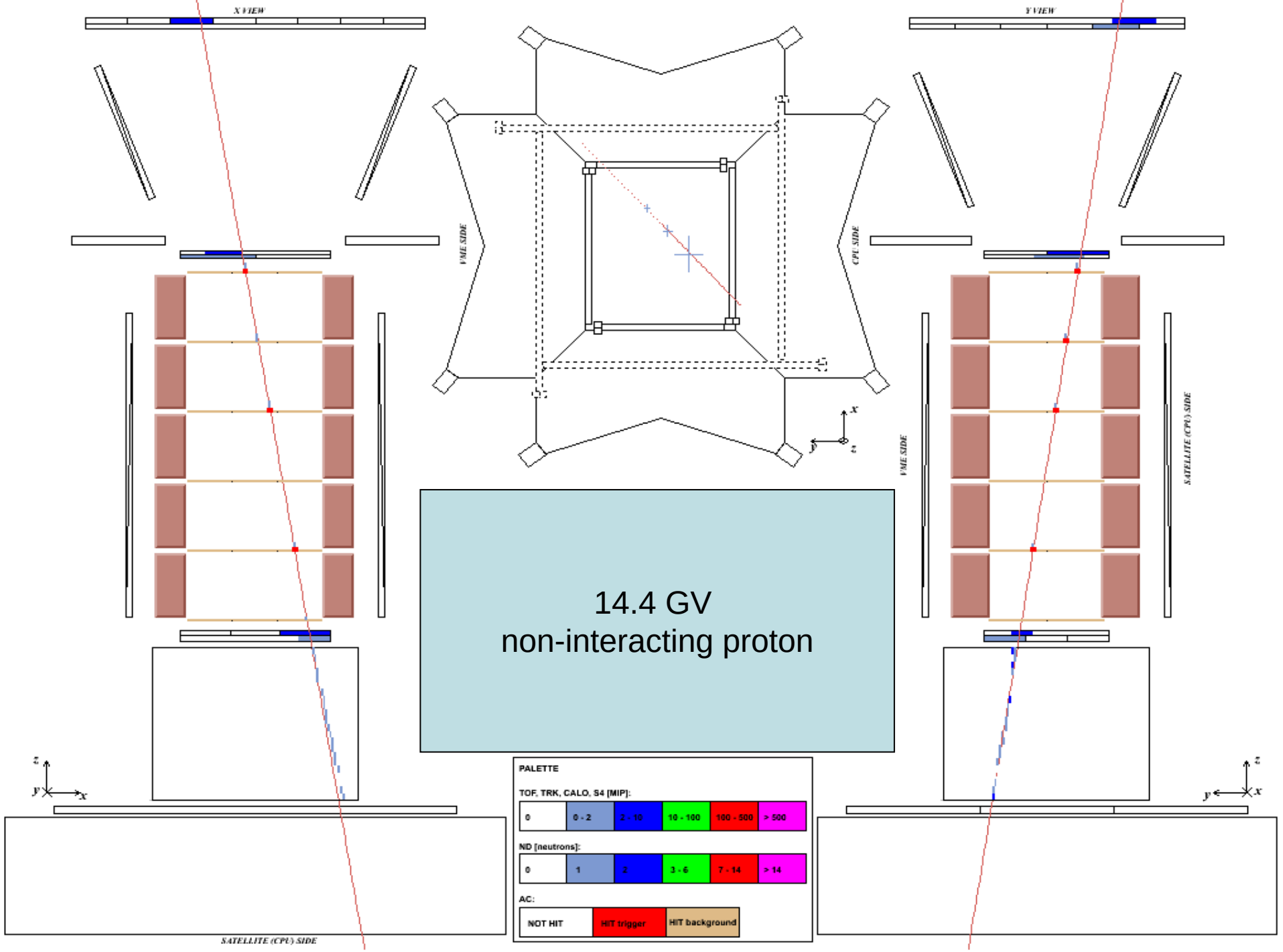


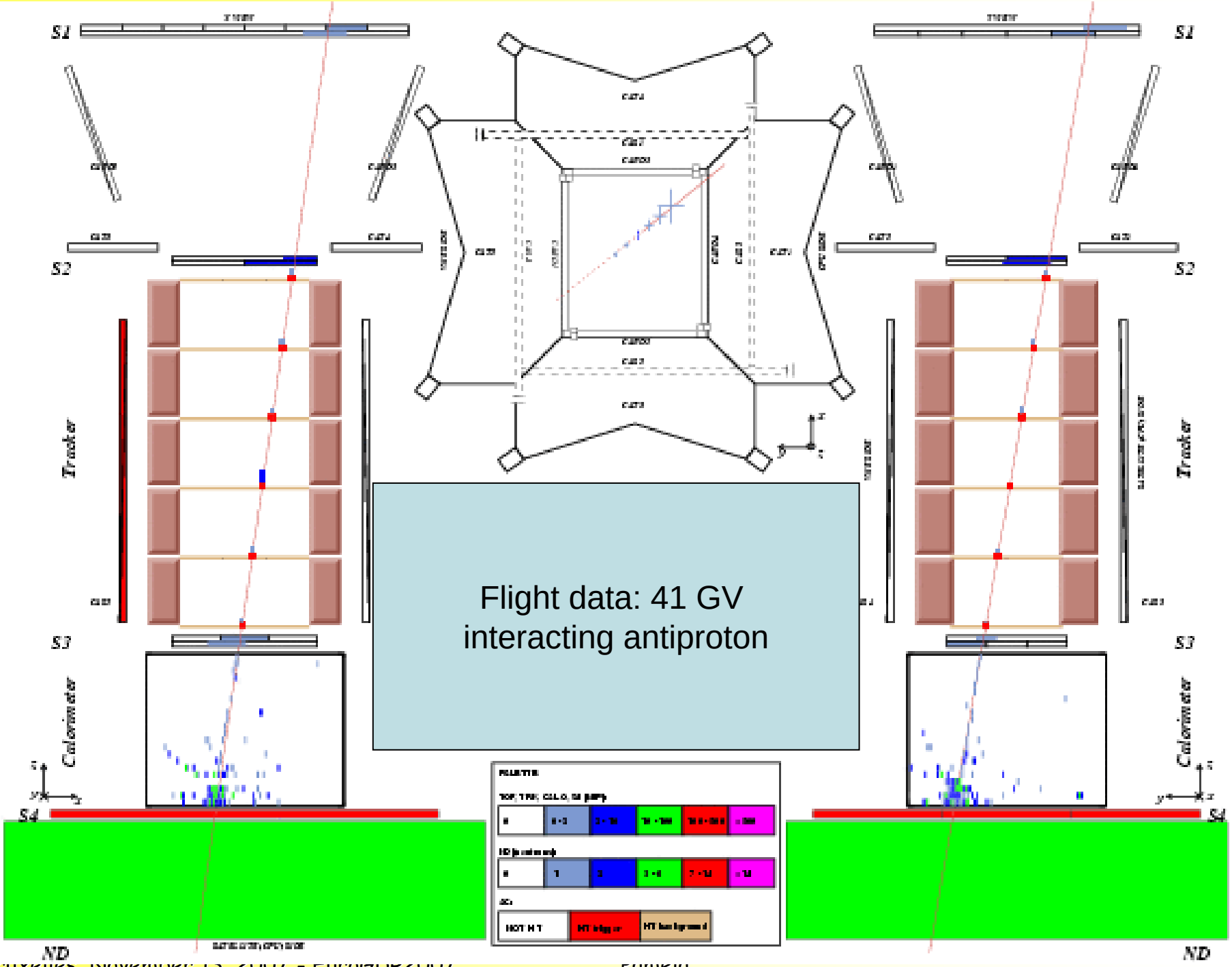
Trigger rate

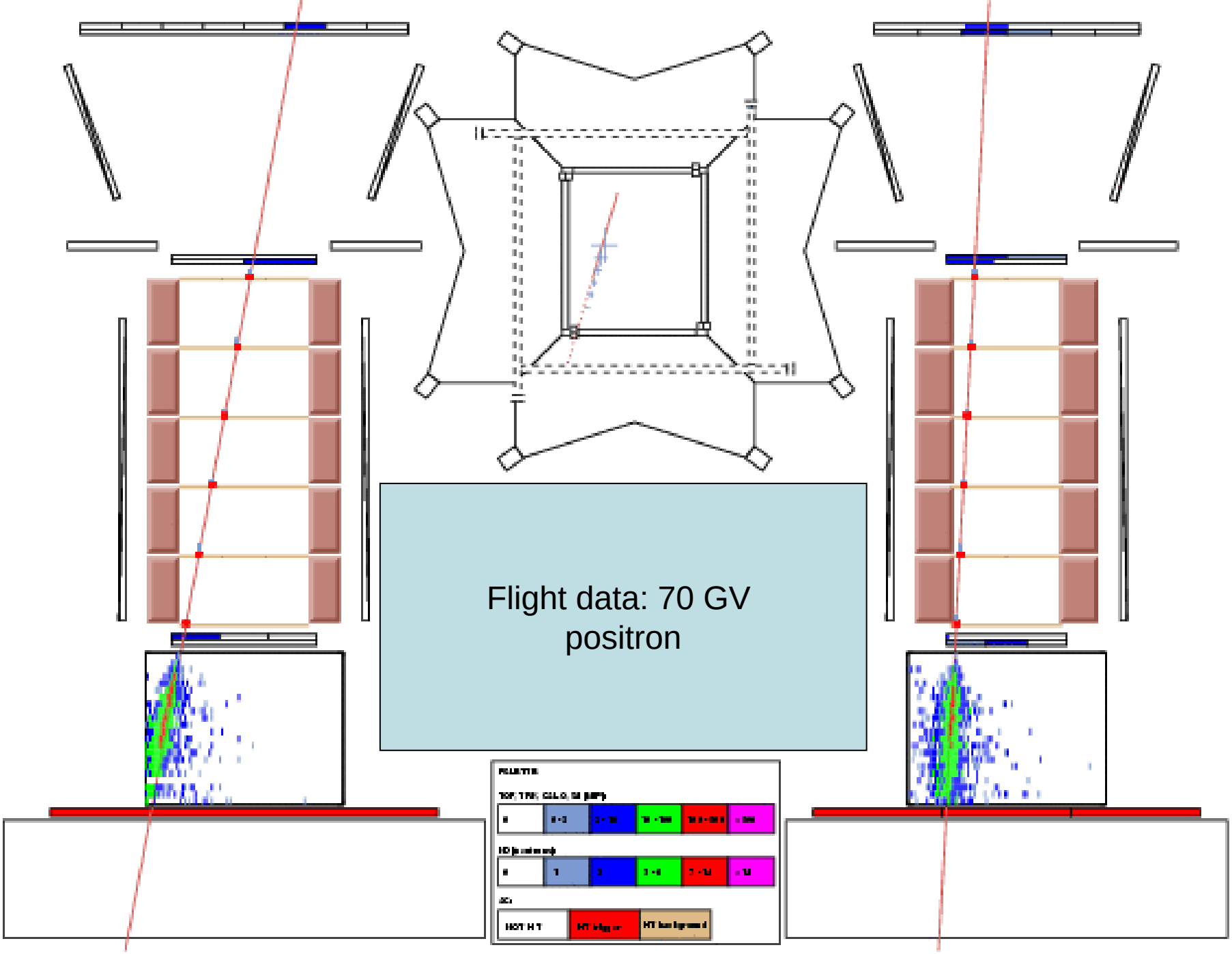


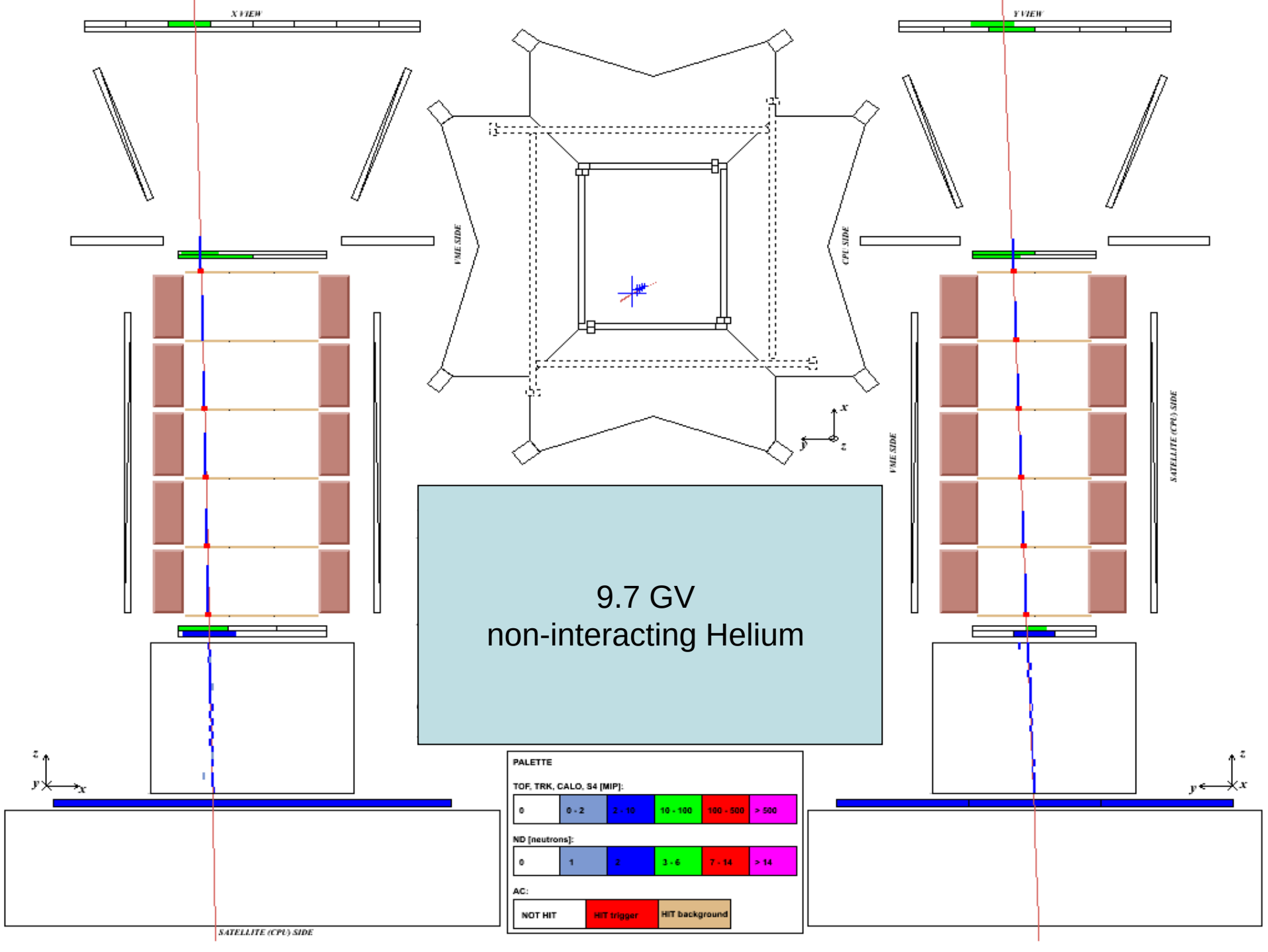
In Flight detector performances

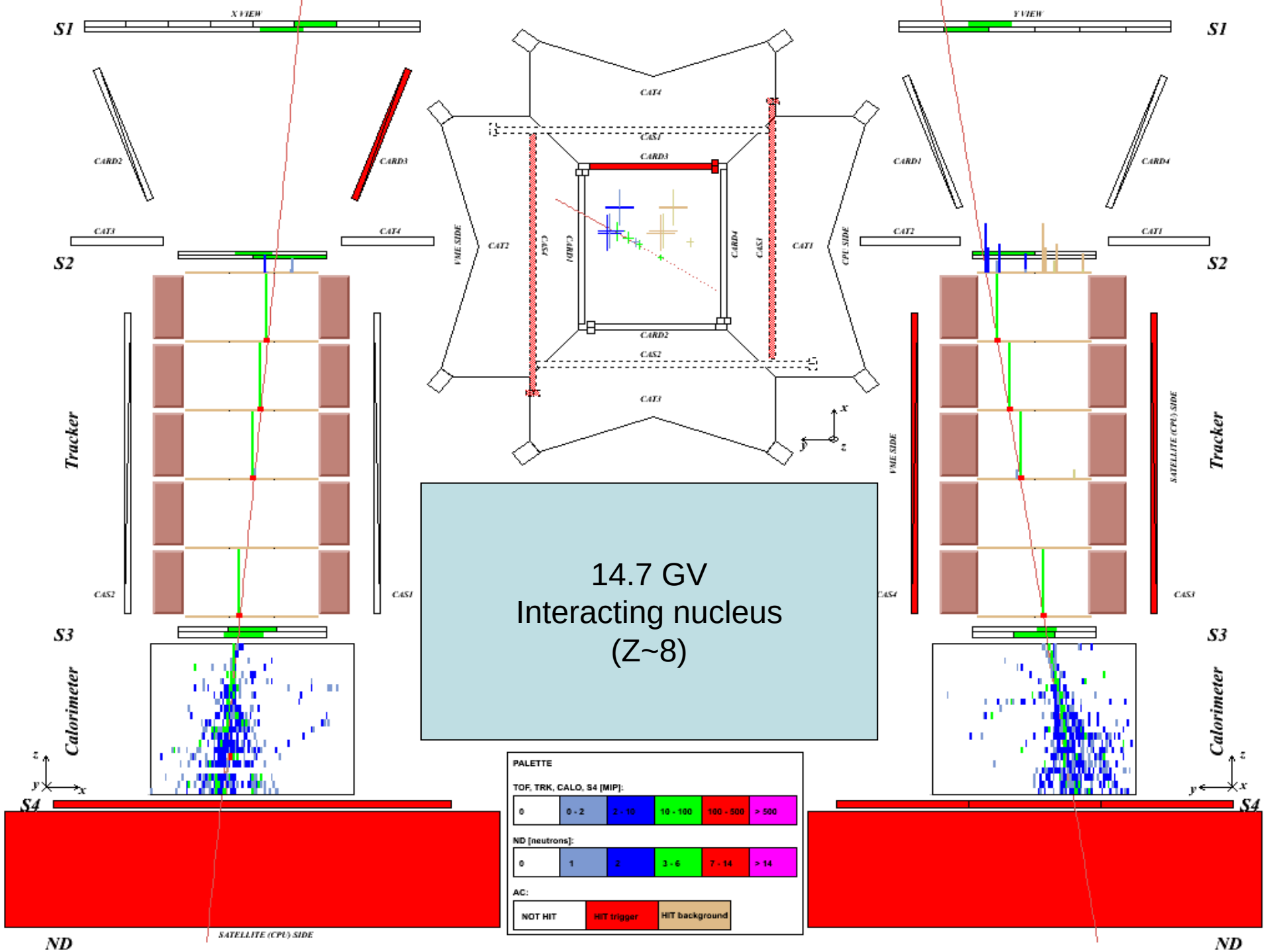


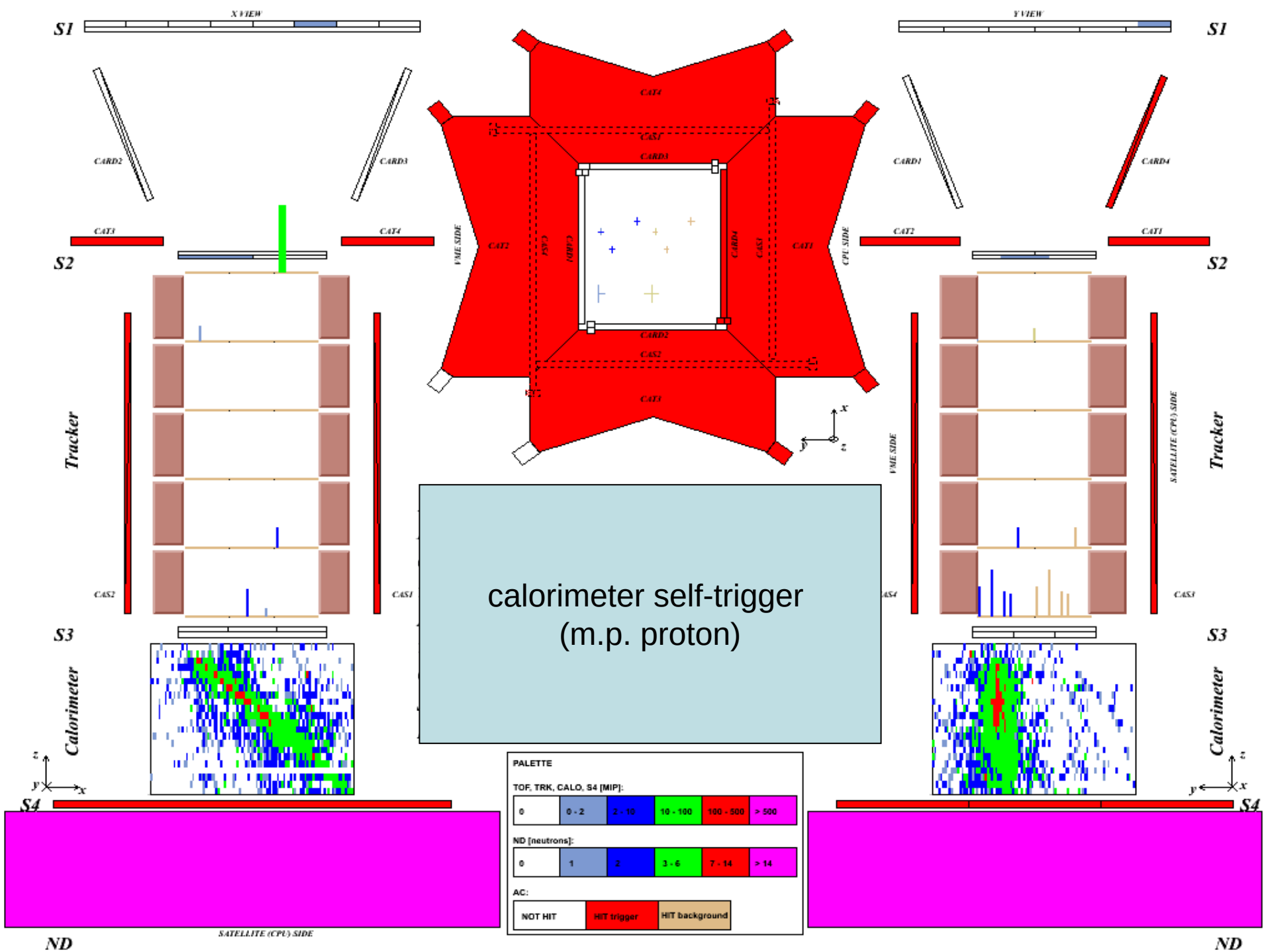

X VIEW
Y VIEW
VME SIDE
CPU SIDE
VME SIDE
SATELLITE (CPU) SIDE
SATELLITE (CPU) SIDE
14.4 GV
non-interacting proton
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background


S1
S2
S3
S4
Tracker
Calorimeter
ND
Flight data: 41 GV
interacting antiproton

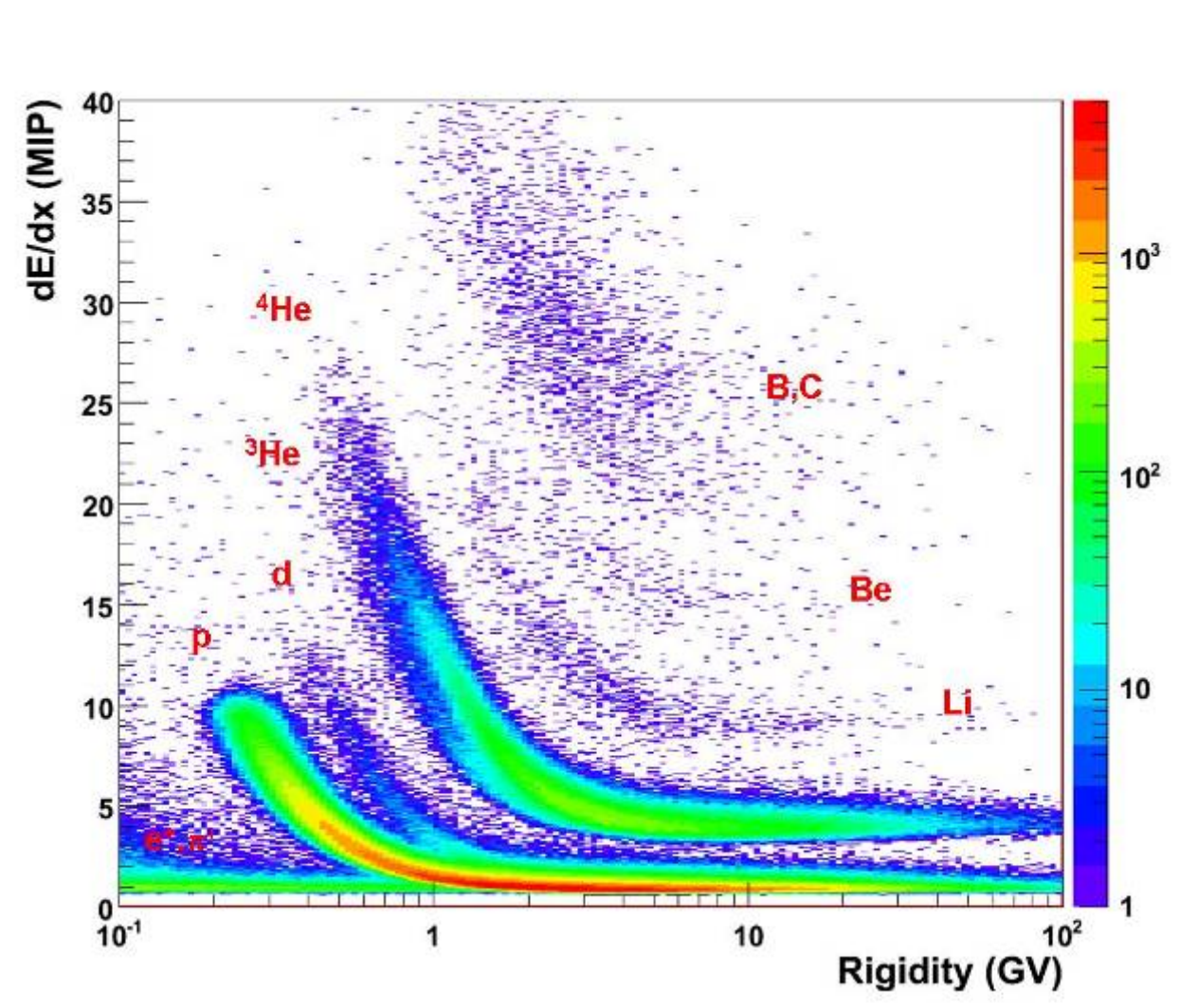

Flight data: 70 GV
positron


X VIEW
Y VIEW
VME SIDE
CPE SIDE
VME SIDE
SATELLITE (CPU) SIDE
9.7 GV
non-interacting Helium
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
NID [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
A/C:
NOT HIT
HIT trigger
HIT background
SATELLITE (CPU) SIDE


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

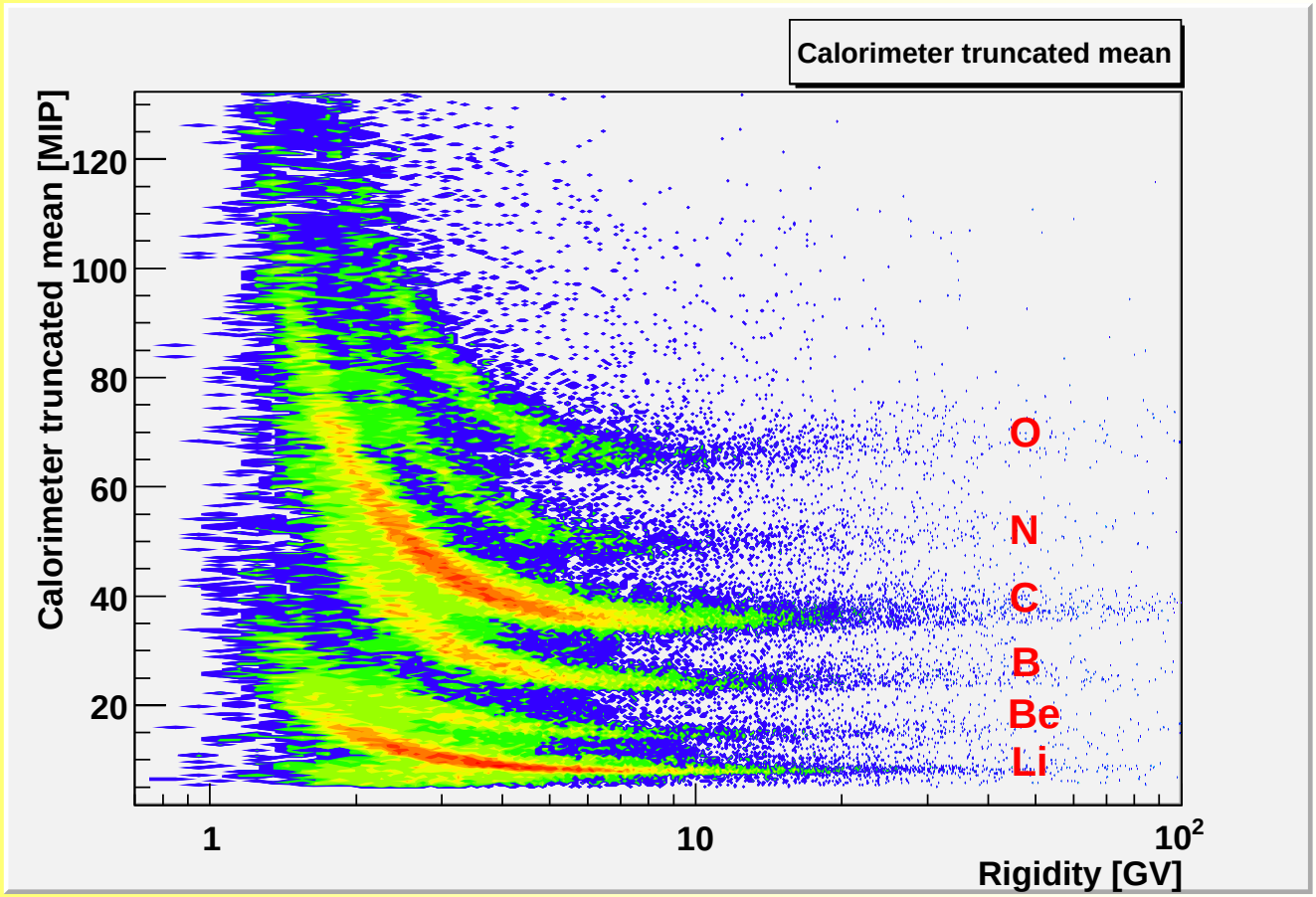

S1
X VIEW
Y VIEW
S1
CARD2
CARD3
CARD1
CARD4
CAT3
CAT4
CAT2
CAT1
S2
S2
VME SIDE
CPU SIDE
CAT4
CAS1
CARD3
CAT2
CAS1
(CARD)
CARD4
CAS1
CAT1
CARD2
CAS2
CAT3
x
y
z
Tracker
Tracker
VME SIDE
SATELLITE (CPU) SIDE
CAS2
CAS1
CAS4
CAS3
S3
S3
Calorimeter
Calorimeter
z
y
x
z
y
x
S4
S4
ND
SATELLITE (CPU) SIDE
ND
calorimeter self-trigger
(m.p. 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

Charge measurement with Tracker



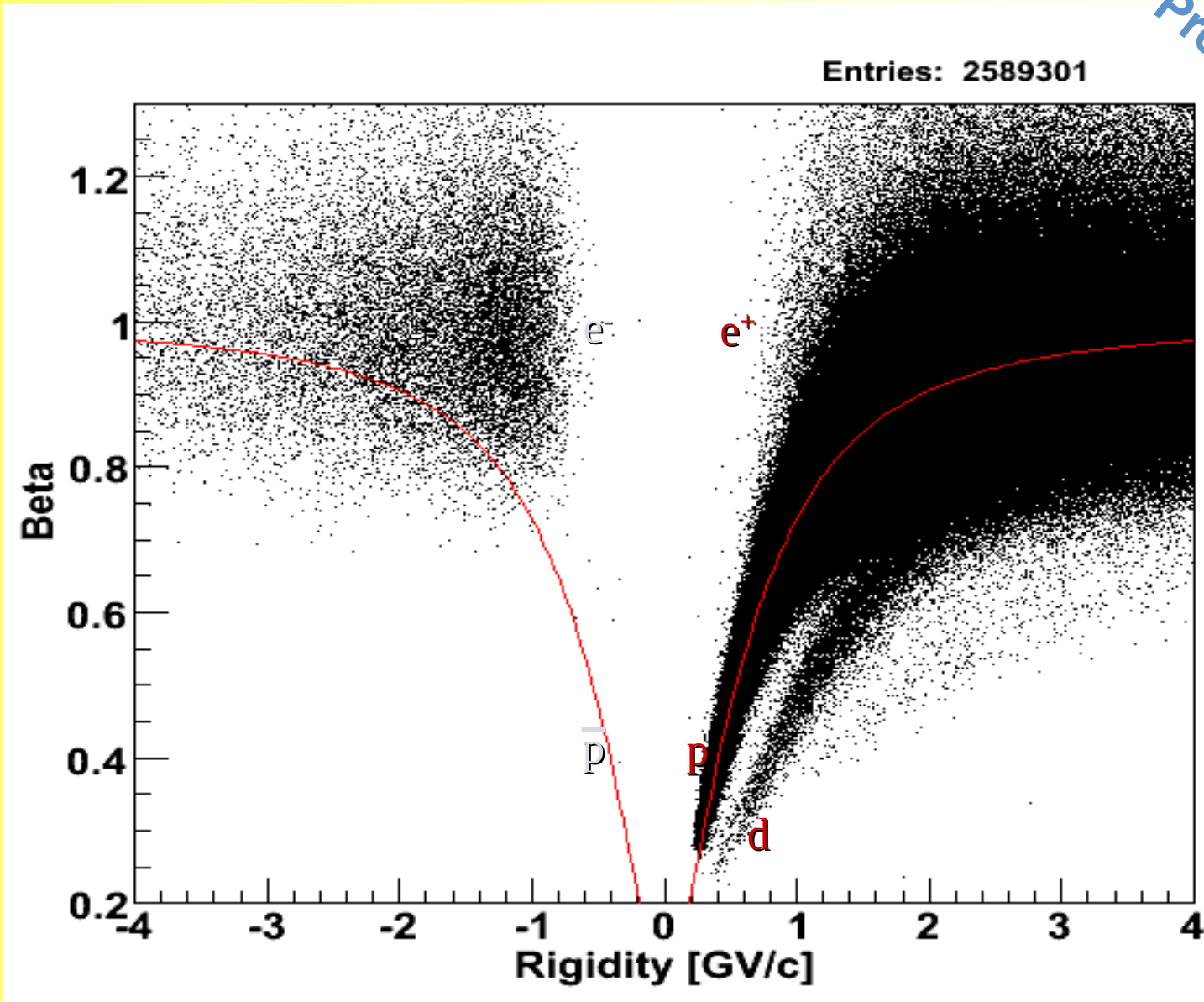
Mean of six ionization losses vs rigidity

Charge measurement with Calorimeter



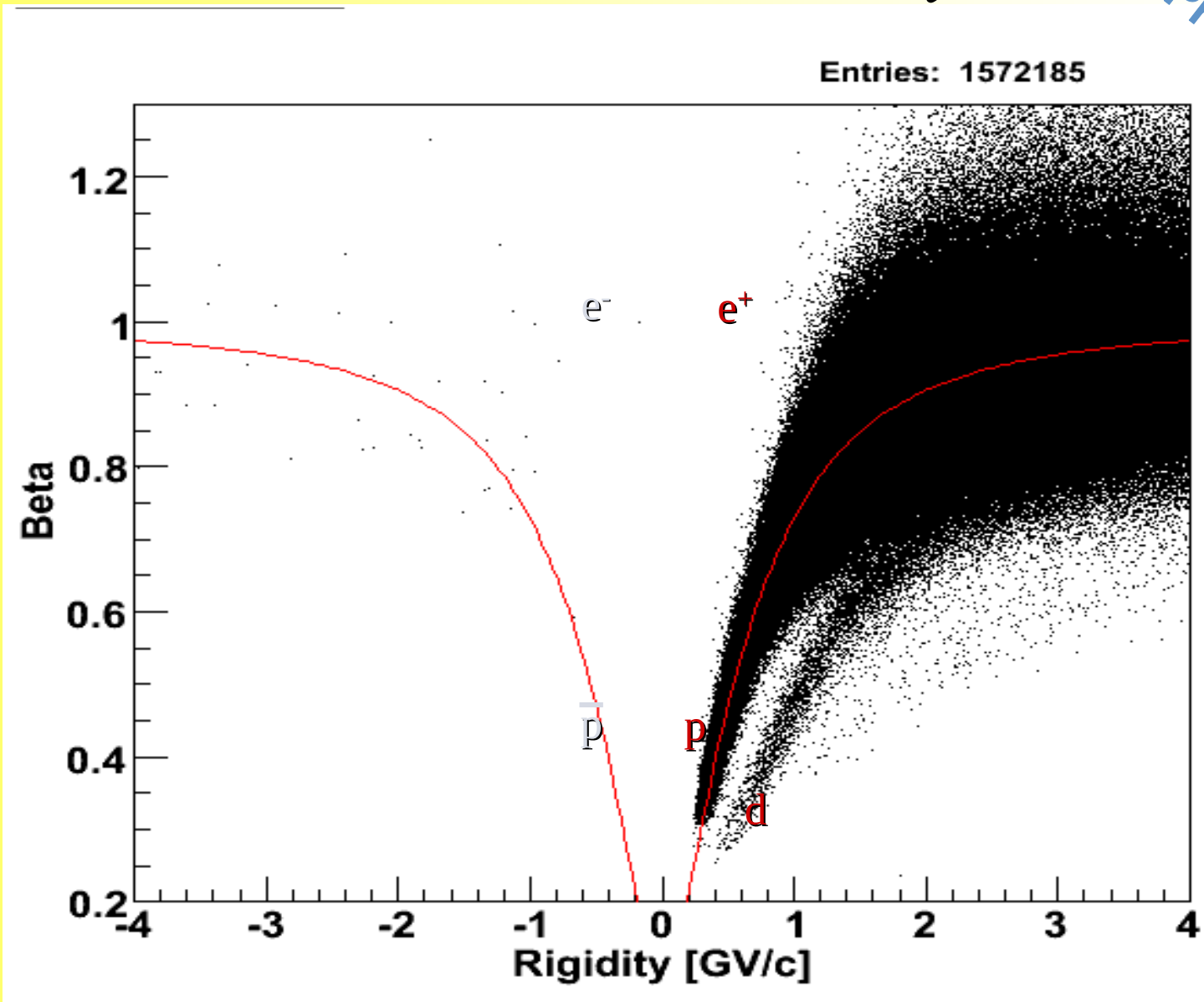
Truncated mean of multiple dE/dx measurements in different silicon planes

ToF β vs Rigidity



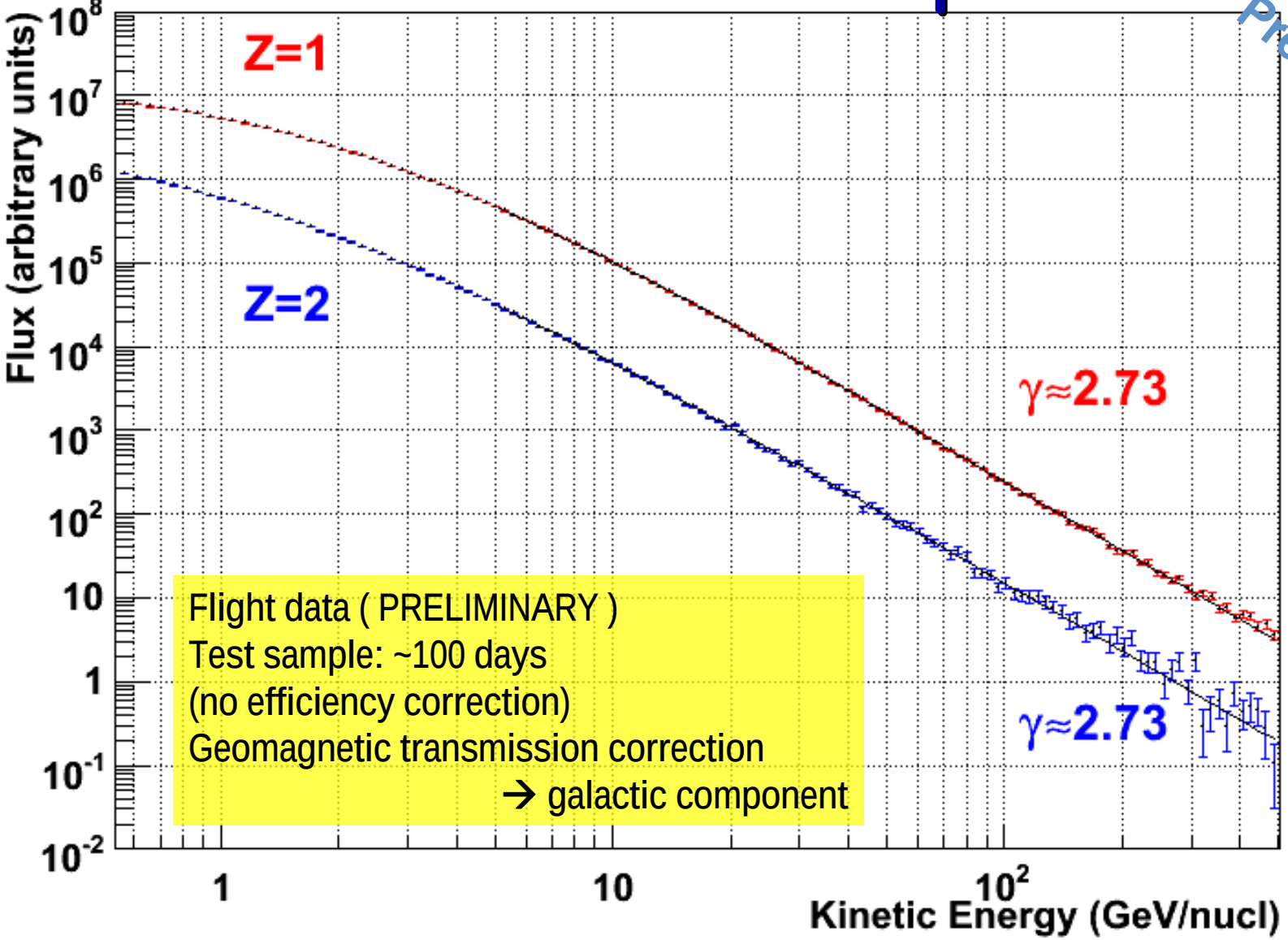
Preliminary !!!

ToF β for p-like events (calorimeter based selection)



Preliminary !!!

Galactic H and He spectra



Preliminary !!!

Pamela vs Dark Matter

Indirect Search!!!!

Cosmic-ray Antimatter from Dark Matter annihilation

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

Annihilation of relic χ gravitationally confined in the galactic halo

→ **Distortion of antiprot… spe…**

M…

- …p,
- χ… ,… → e^+,…

direc… …itron peak Ee+~Mχ/2

other … …sses ⇒ positron continuum Ee+~Mχ/20

PAMELA will try to indirectly look for Dark Matter by precisely measuring the antiproton and positron spectra!!!!

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

$+\nu$ (AMANDA / IceCube)

$+\bar{p}$

$+e^+$

$+\bar{D}$

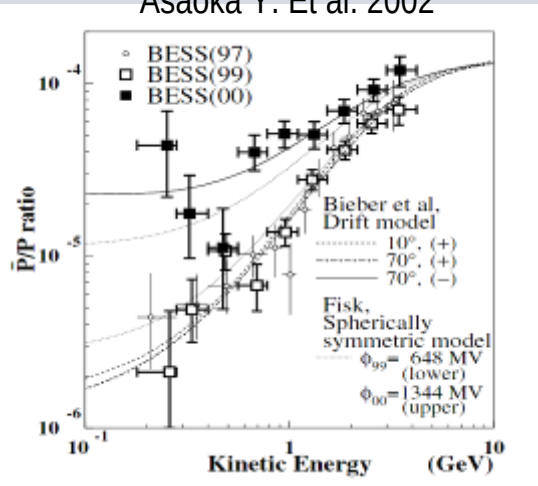
PAMELA (and Bess, HEAT, AMS etc.)

A short review on existing antiparticle data

Antiprotons

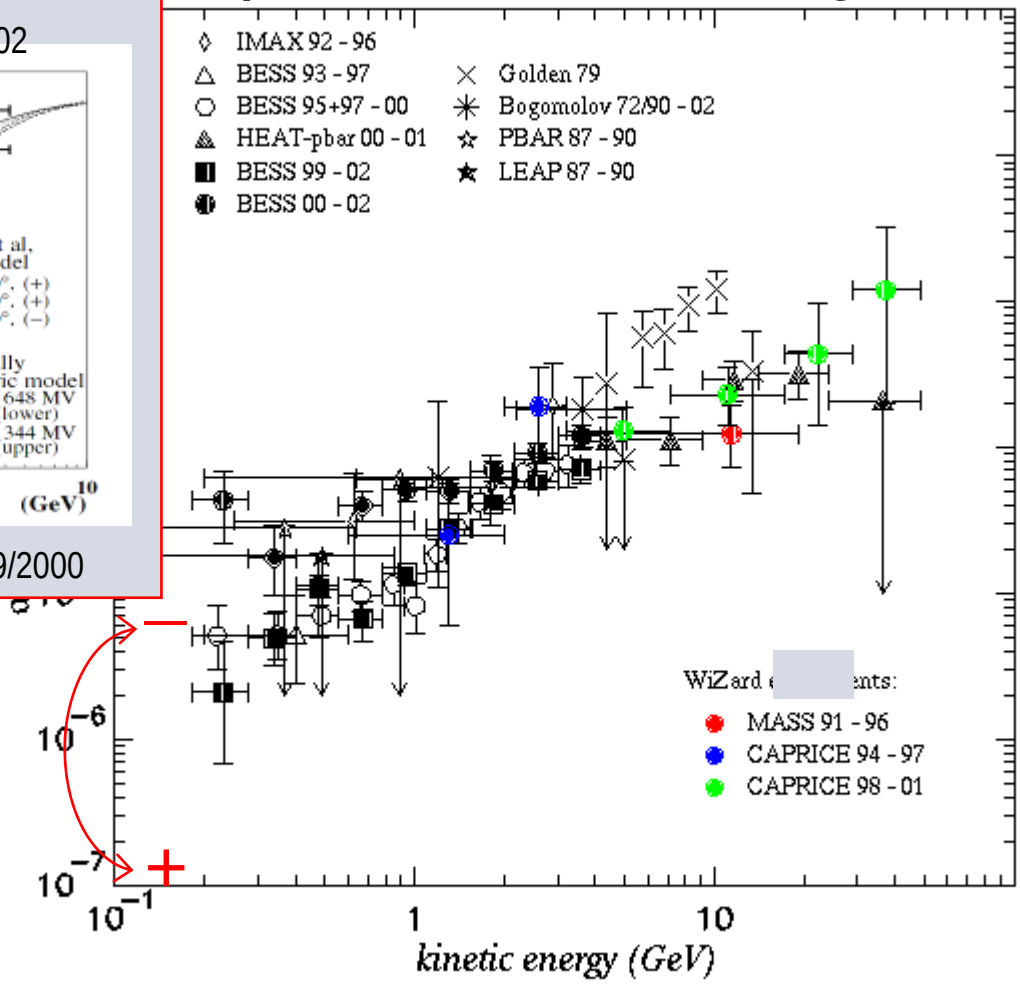
Charge-dependent solar modulation

Asaoka Y. Et al. 2002



Solar polarity reversal 1999/2000

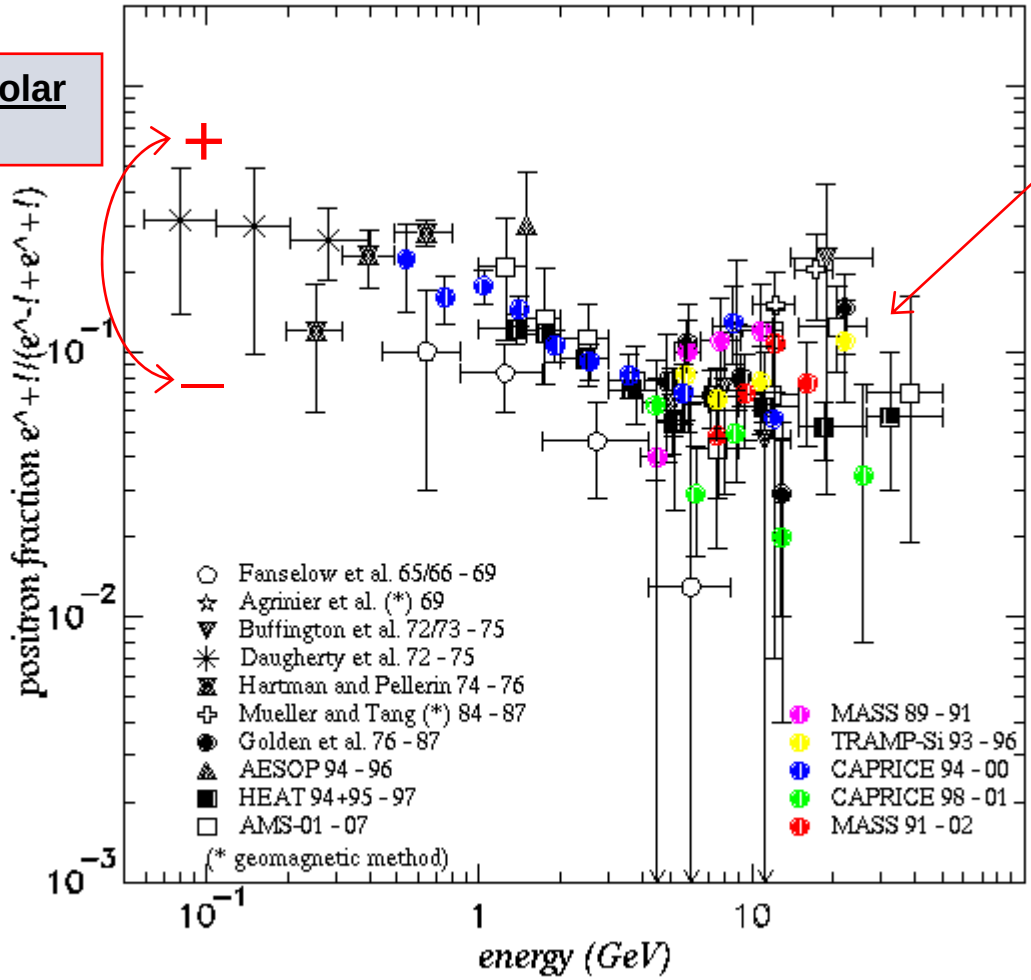
Experimental scenario during 90s



Positrons

Experimental scenario until 90s

Charge-dependent solar modulation



…?…

Difficult interpretation due to large uncertainties in propagation models

What we can learn from existing data?

Situation is not clear:

- Big statistical uncertainties
- Big systematic uncertanties (poorly known propagation models used during 90s)
- Many different experiments each covering a small energy range
- Different modulation effects (different places, different years)

Pamela really has a good chance to look for Dark Matter!!!! (thanks also to the improved models…)

Secondary production of Antiparticles

- $pp \rightarrow ppp\bar{p}$ is the main antiproton source
- In order to look for Dark Matter with good sensitivity we need to precisely know the secondary produced pbar spectrum
- Propagation equation for CR in our Galaxy should be solved
- Many very precise and fine tunable models exists in literature now (big effort in the last few years!!!!!)
- Lionetto/Morselli/Zdravkovic model used as example in the next slides

Propagation Equation for Cosmic Rays in the Milky Way

$$\frac{\partial \psi(\mathbf{r},p,t)}{\partial t} = q(\mathbf{r},p) + \nabla\cdot(D_{xx}\nabla\psi - \mathbf{V}\psi) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi - \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\nabla\cdot\mathbf{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

convection velocity field that corresponds to galactic wind and it has a cylindrical symmetry, as the geometry of the galaxy. It's z-component is the only one different from zero and increases linearly with the distance from the galactic plane

diffusion coefficient is function of rigidity

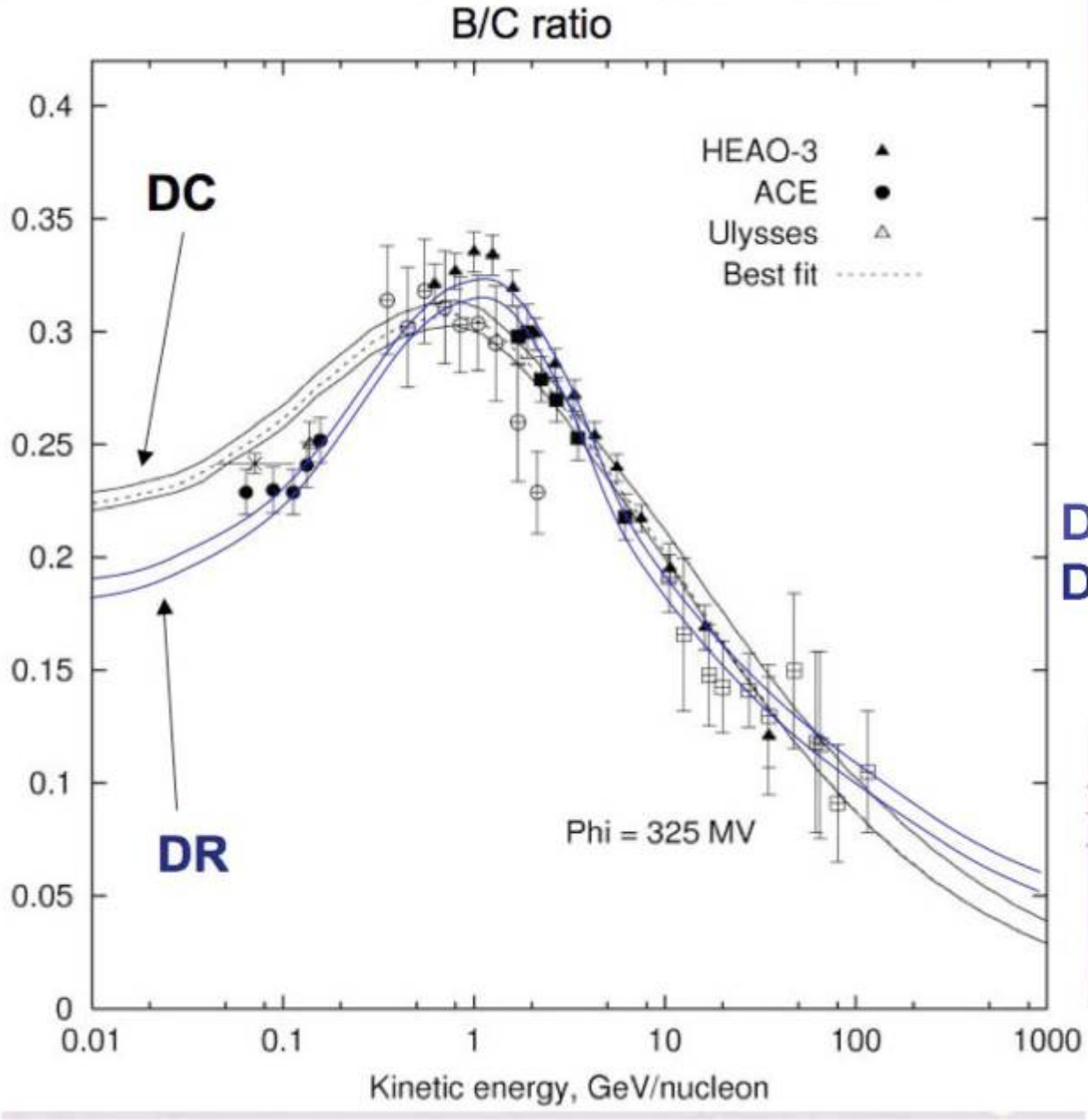
loss term: fragmentation

diffusion coefficient in the impulse space, quasi-linear MHD: $D_{pp}(D_{xx}, v_A)$

loss term: radioactive decay

Inputs and Cross Checks for the Models:
- **Secondary/primary (B/C, Be/C, Li/C etc.)**
- **Absolute fluxes of p, e^-, He**
- **Nuclear Cross Sections**

Pamela can also help to improve the models!



Enveloping curves of all the good fits of the experimental B/C data

Dashed line: Best fit

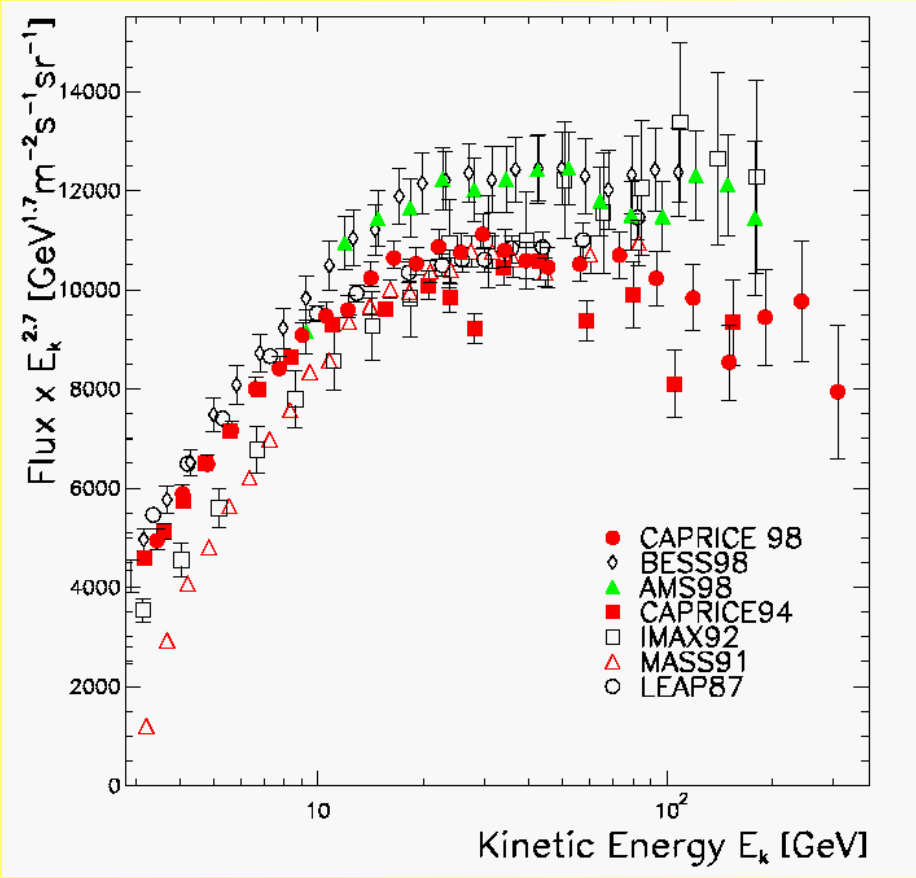
DR: diffusion+ reacceleration

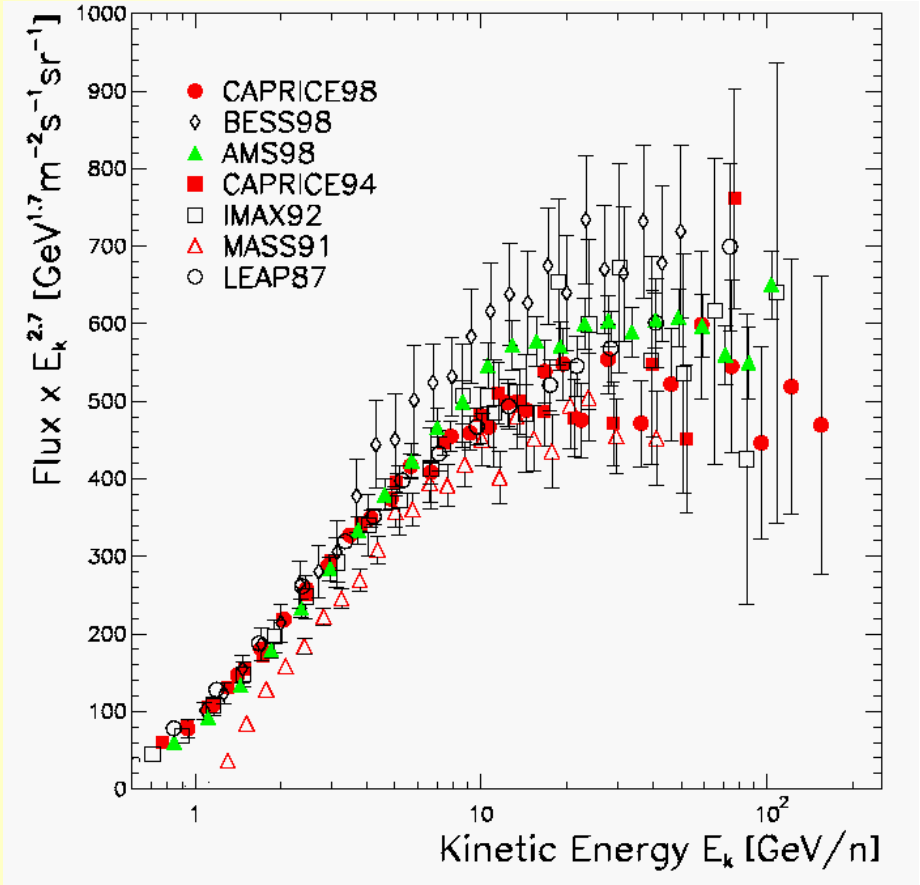
DC: diffusion+convection

In DC model problem with the ACE data at low energy

A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 astro-ph/0502406

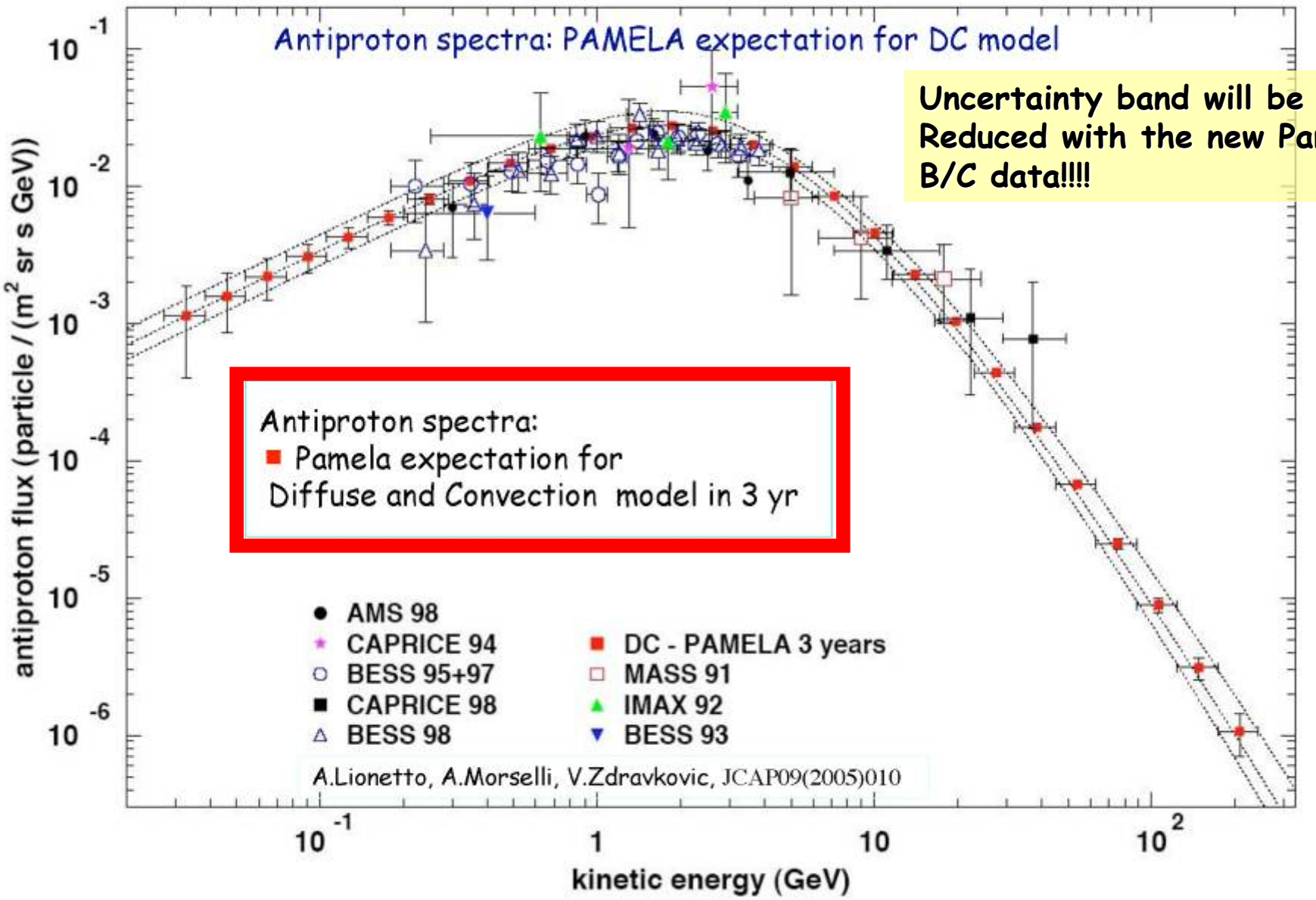
Primary spectra: H and He



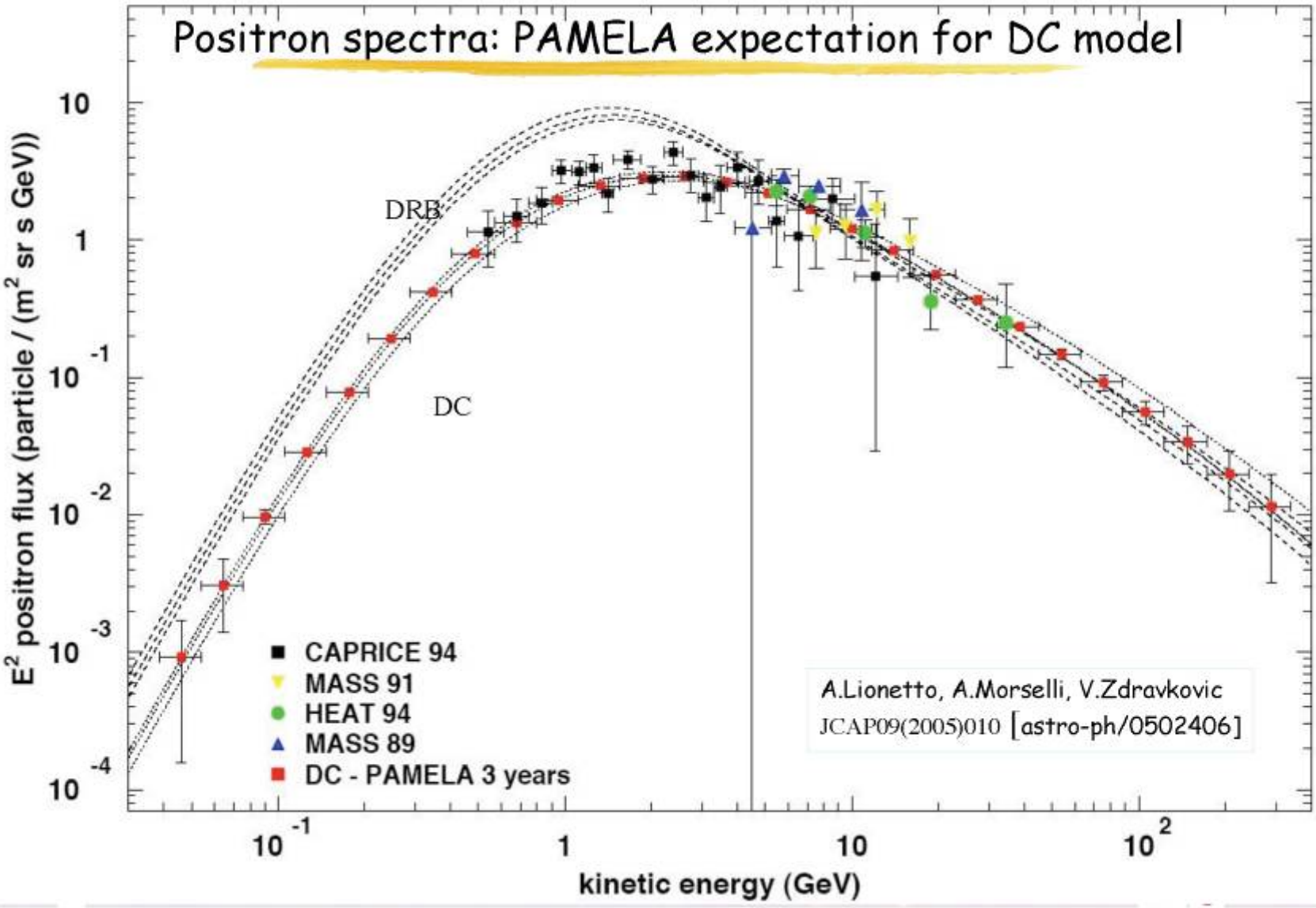


Cosmic-ray propagation calculations affected by uncertainty on primary flux.

Expected pbar spectrum from secondary origin



Expected e^+ spectrum from secondary origin



What we can expect from Dark Matter?

- Antiparticles secondary spectra will be distorted by the Dark Matter annihilation induced antiparticles
- The effect heavily depends on the characteristics of the Dark Matter composing particles!
- Effect more evident in the high energy part of the spectra
- Detailed analysis exists to understand which part of the SUSY parameter space is accessible to Pamela data
- I will not cover this part in detail!!!!

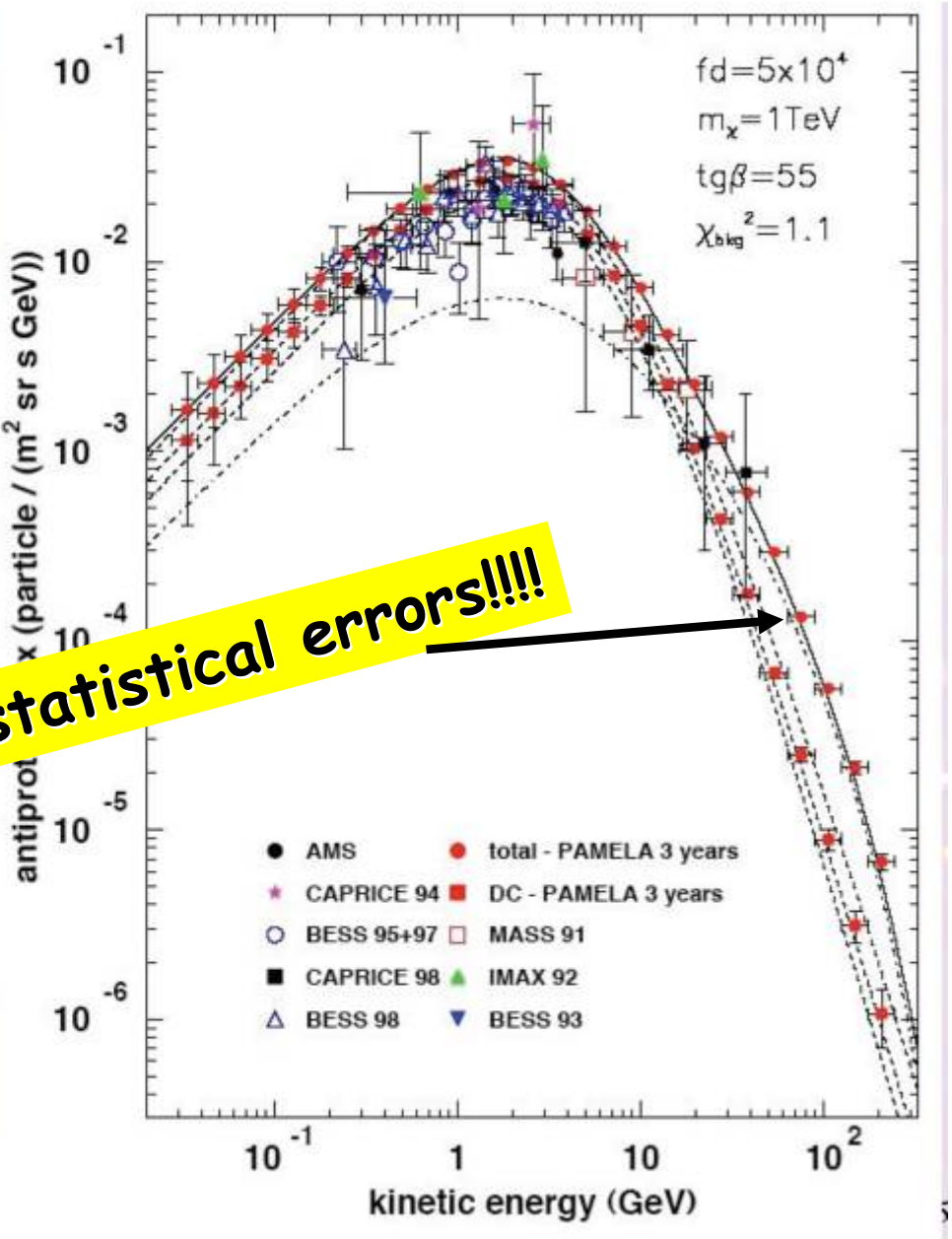
PAMELA:
Cosmic-Ray Antiparticle Measurements: Antiprotons

an example in mSUGRA

fd: Clumpiness factors needed to disentangle a neutralino induced component in the antiproton flux

f = the dark m… conc… …mps
d … density due to a clump with respect to the local halo density

A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]



Please notice the small statistical errors!!!!

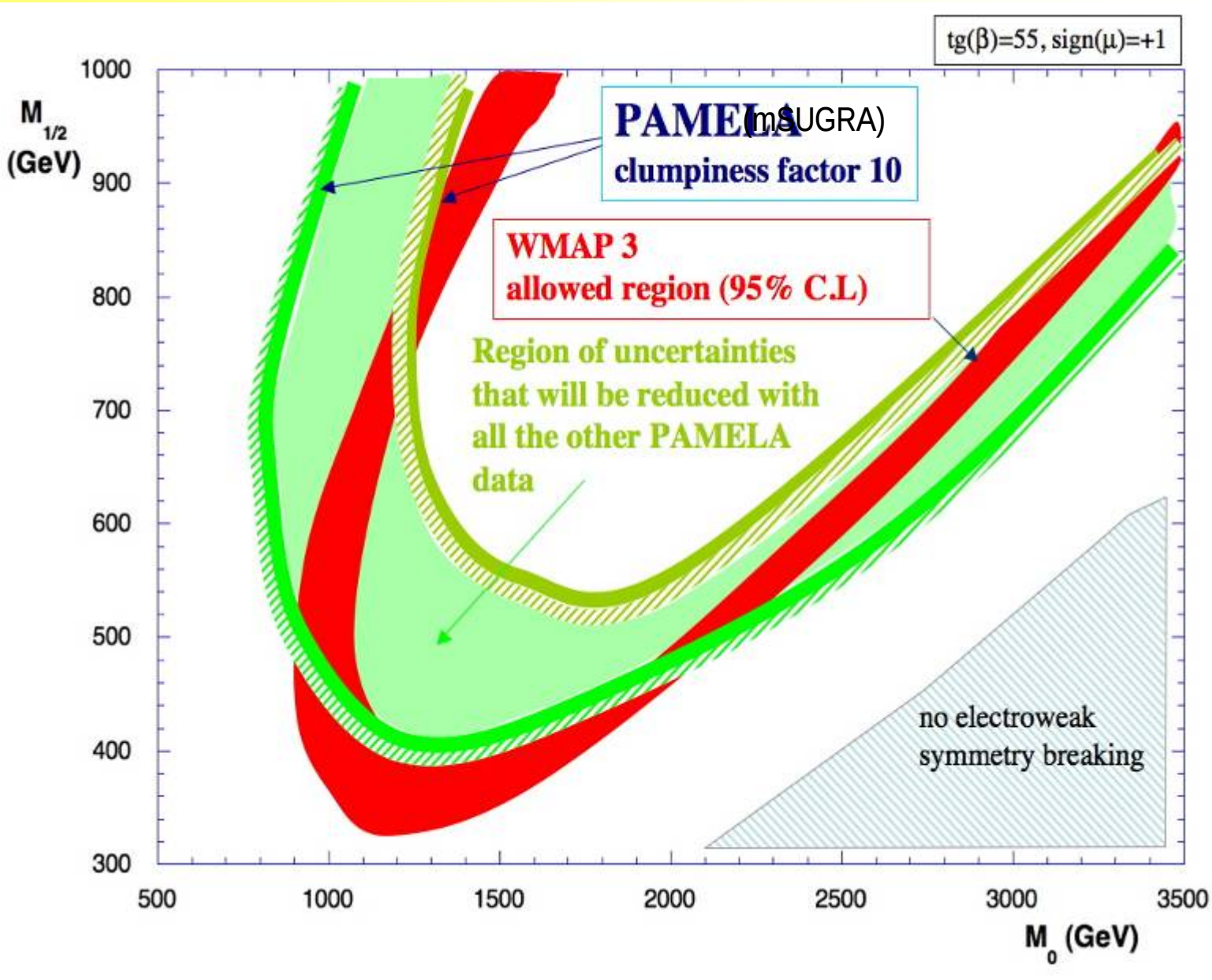
Conclusions

- Pamela is in orbit since June 15, 2006
- Data are continously transmitted to ground
- The detector is well performing, according to what we were expecting
- PAMELA is measuring antiparticles with an unprecedented statistical precision
- PAMELA will allow a careful and extensive indirect search for dark matter!!! (allowing also a precise calibration of the models)
- Results are coming soon!

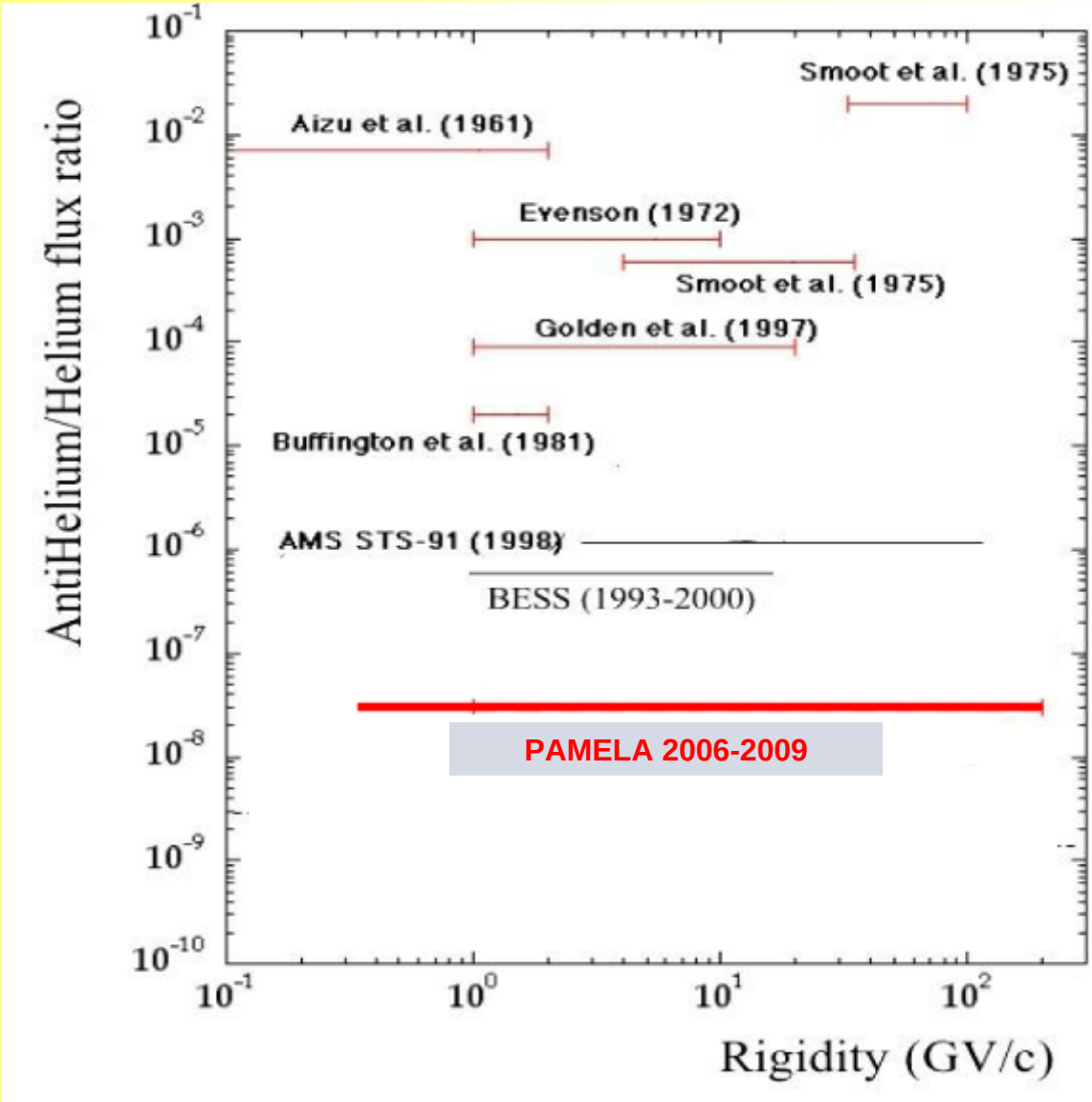
Spare slides

Antiprotons

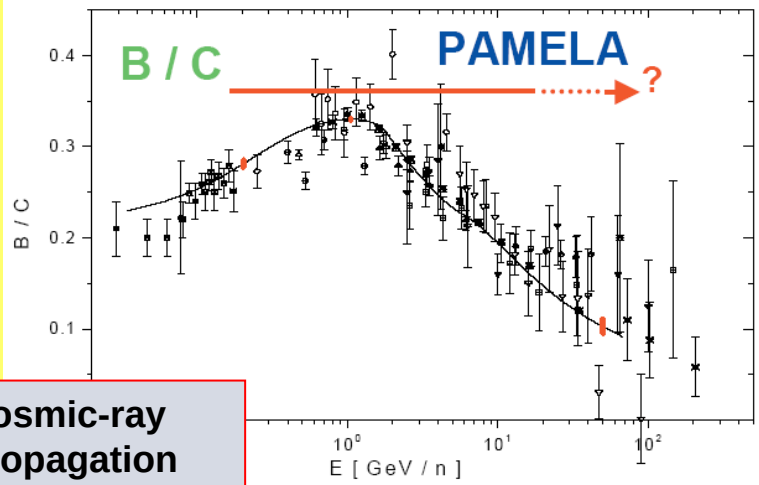
(Lionetto,Morselli &.Zdravkovic 2005)

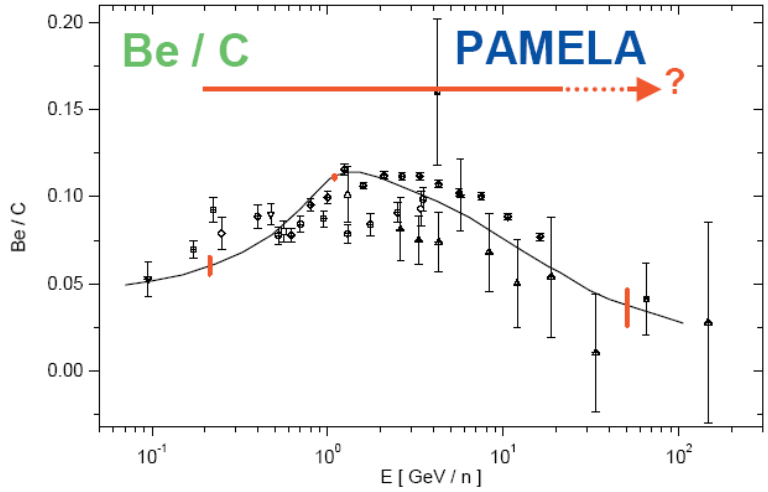


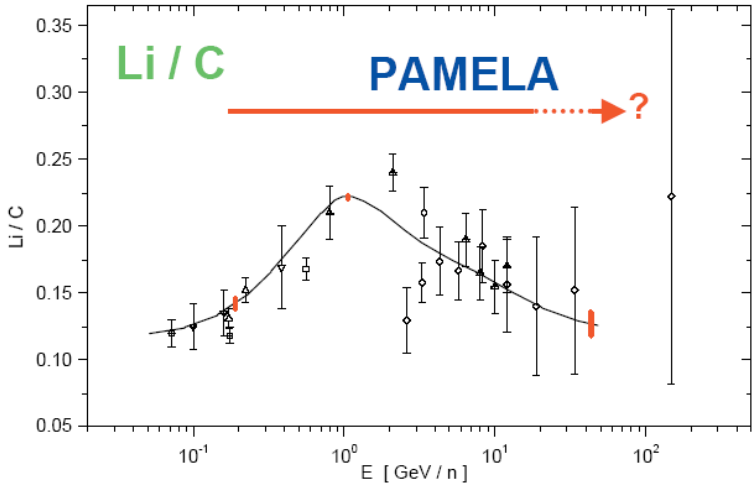
Extragalactic Cosmic-ray Antimatter Search



Secondary-to-primary ratio

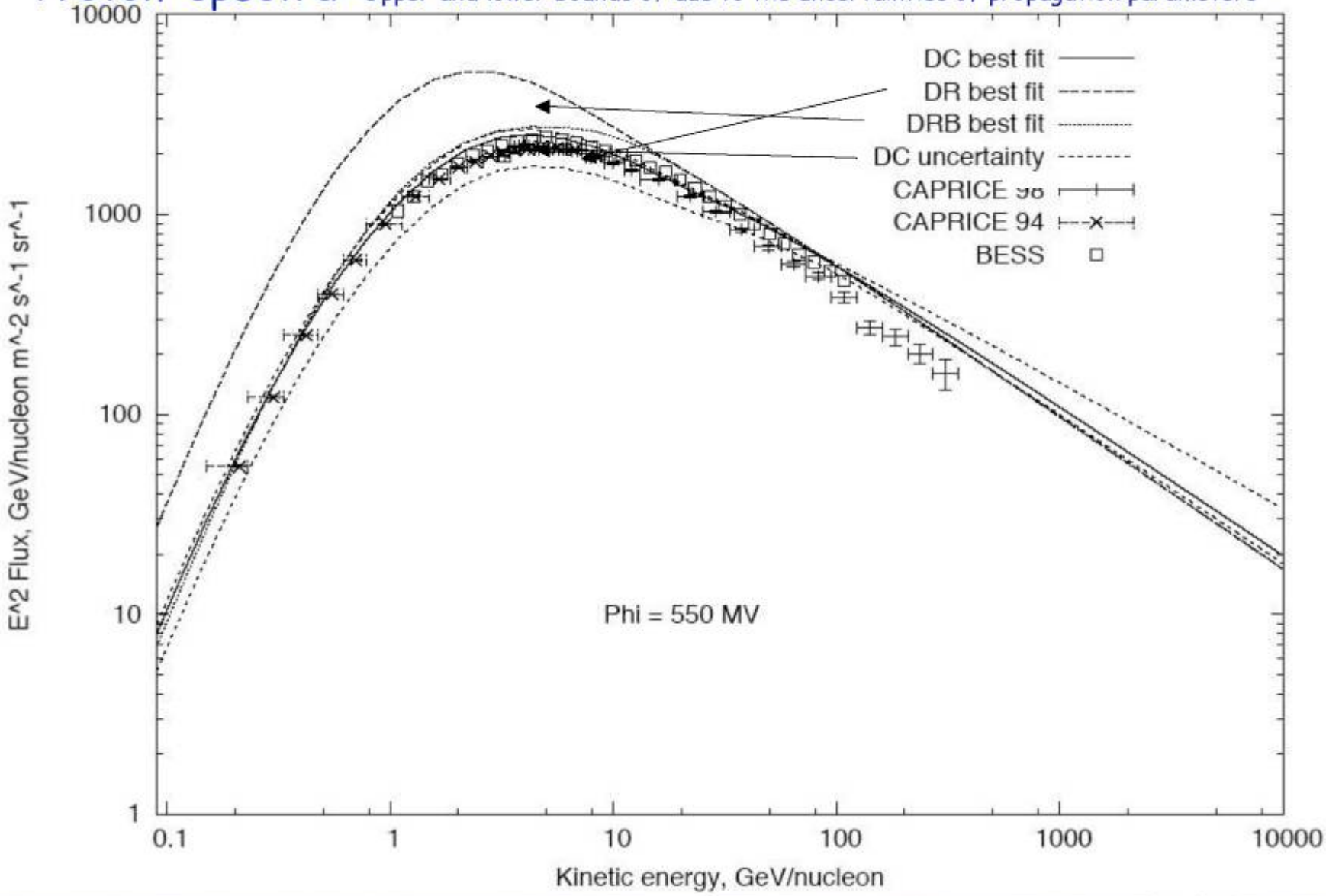


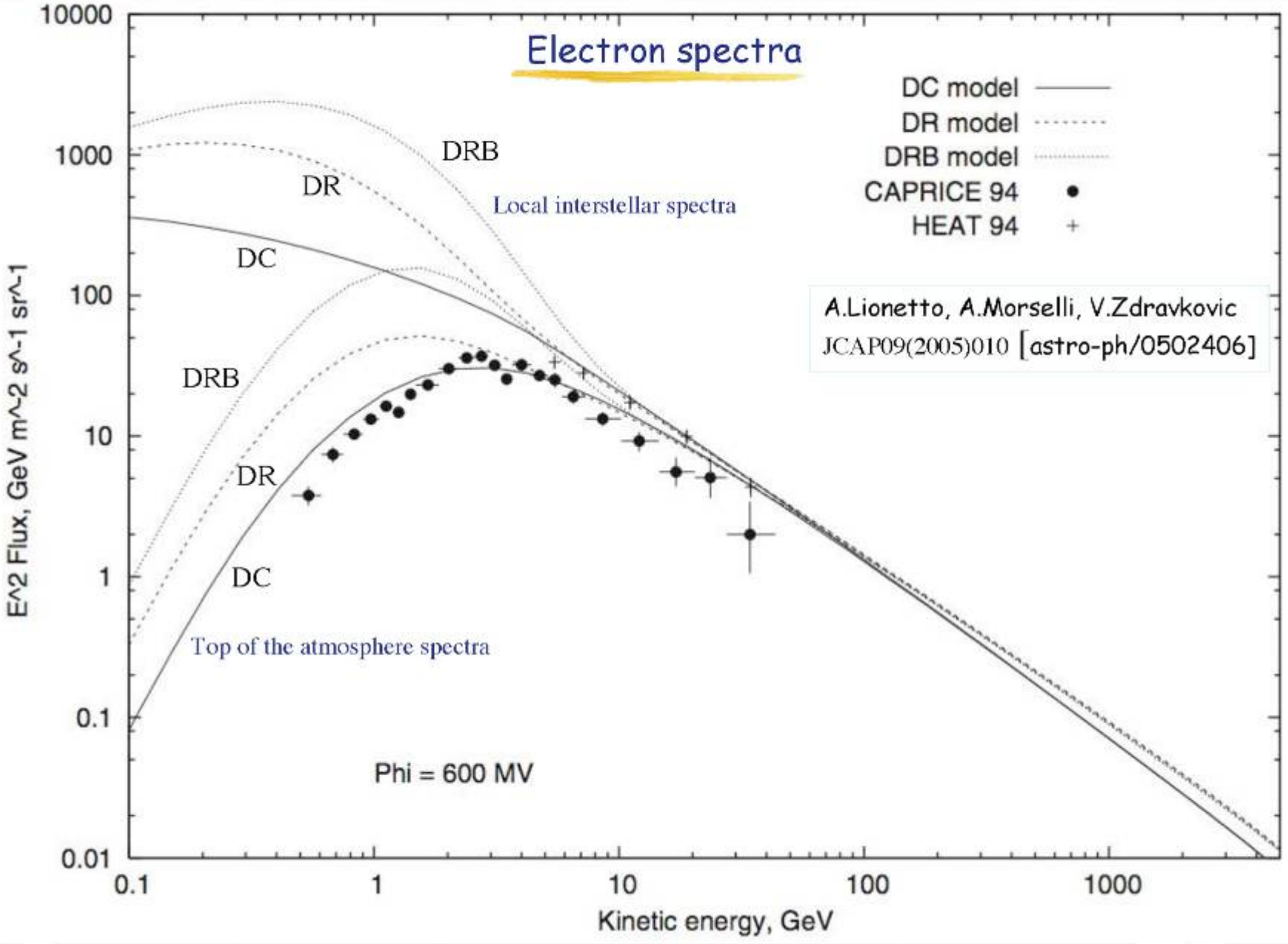




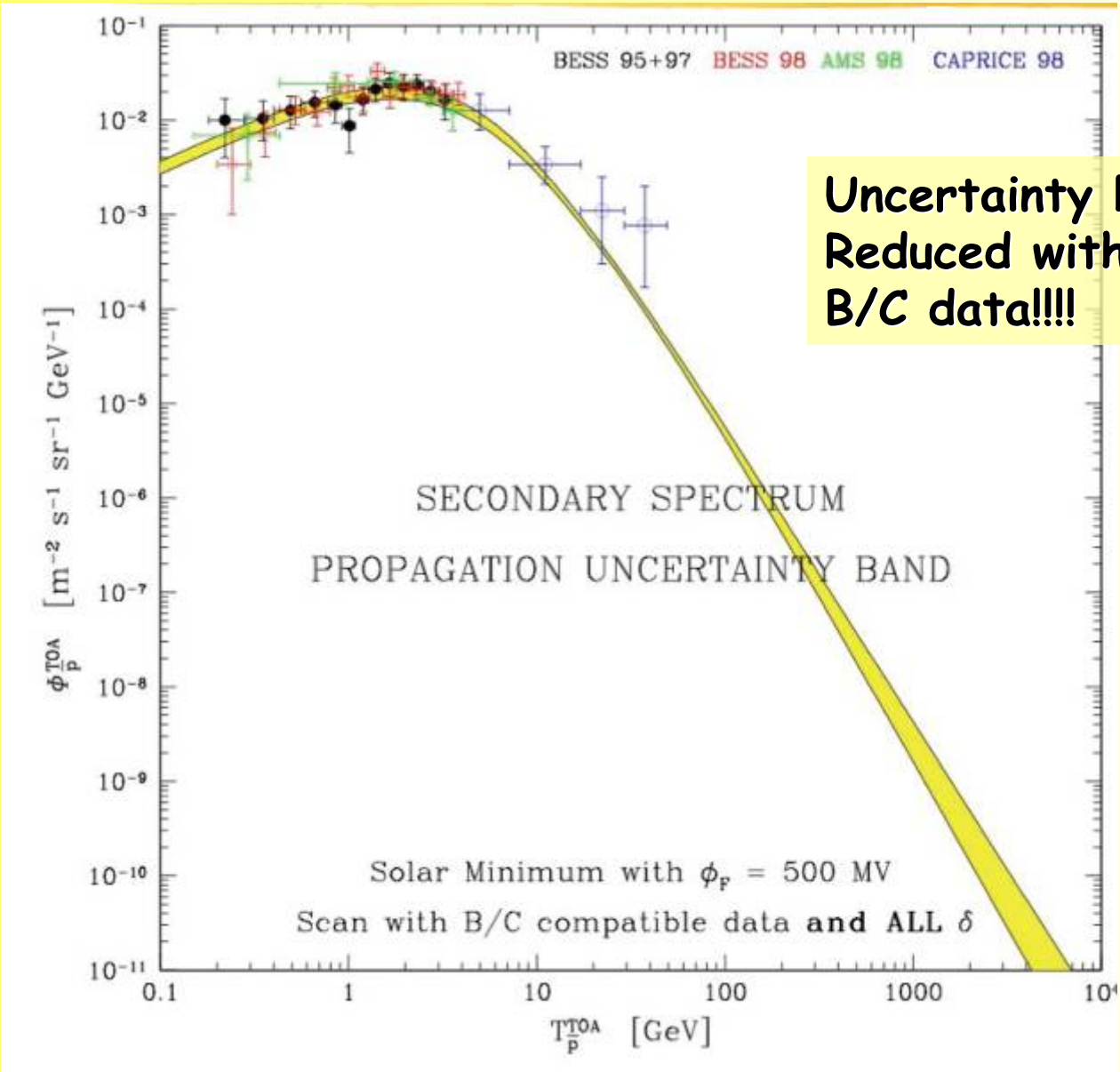
Cosmic-ray propagation parameters often tuned on B/C data

Proton spectra: Upper and lower bounds of due to the uncertainties of propagation parameters




Electron spectra
DC model
DR model
DRB model
CAPRICE 94
HEAT 94
DRB
DR
DC
Local interstellar spectra
A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]
DRB
DR
DC
Top of the atmosphere spectra
Phi = 600 MV
E^2 Flux, GeV m^-2 s^-1 sr^-1
Kinetic energy, GeV
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000

Expected pbar spectrum from secondary origin

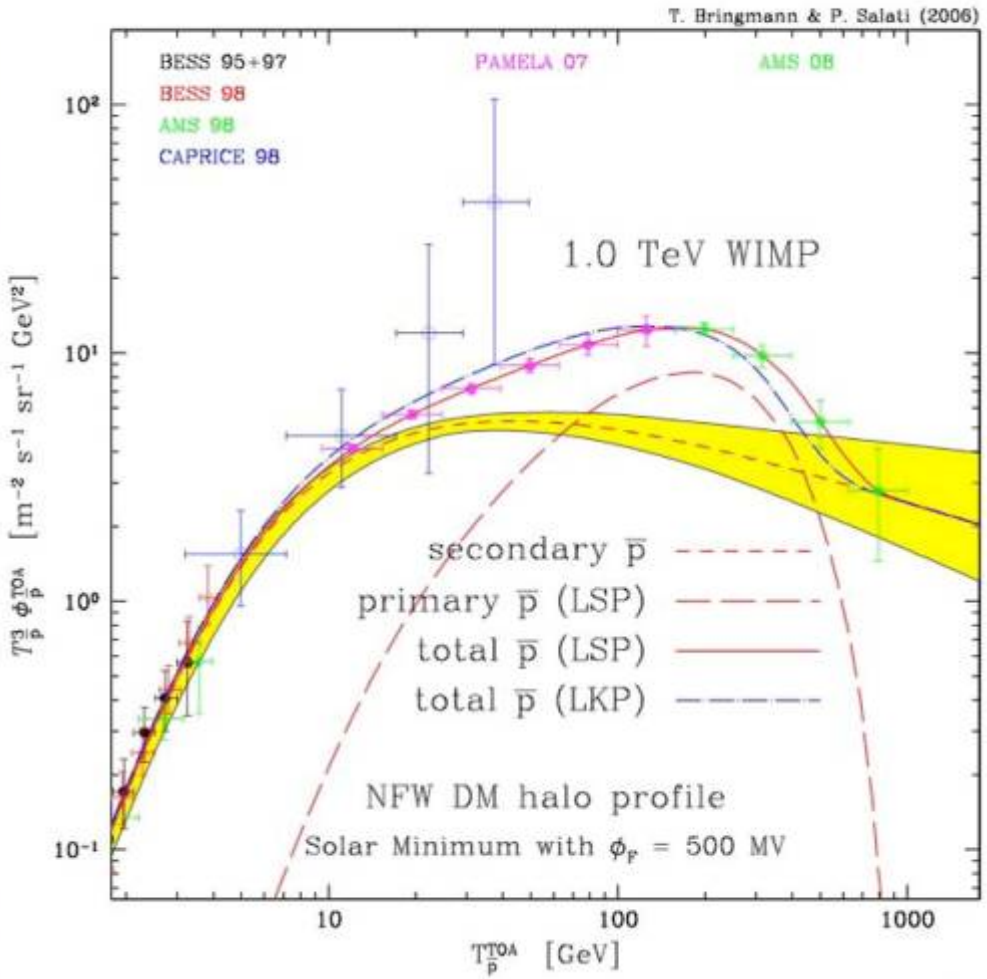


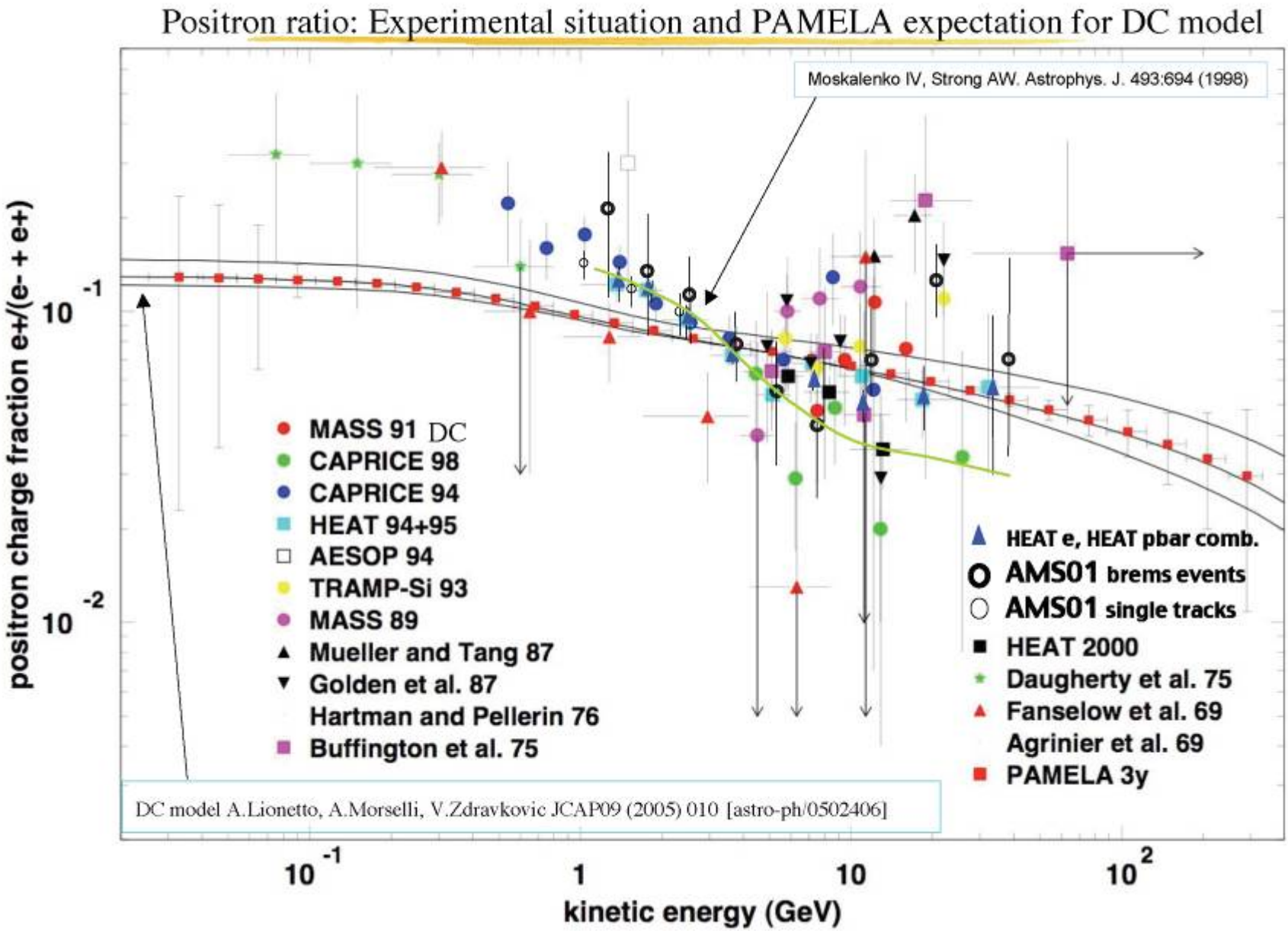
Uncertainty band will be Reduced with the new Pamela B/C data!!!!

Torsten Bringmann, Pierre Salati, astro/ph 0612514

Antiproton spectra

Torsten Bringmann,
Pierre Salati,
astro/ph 0612514

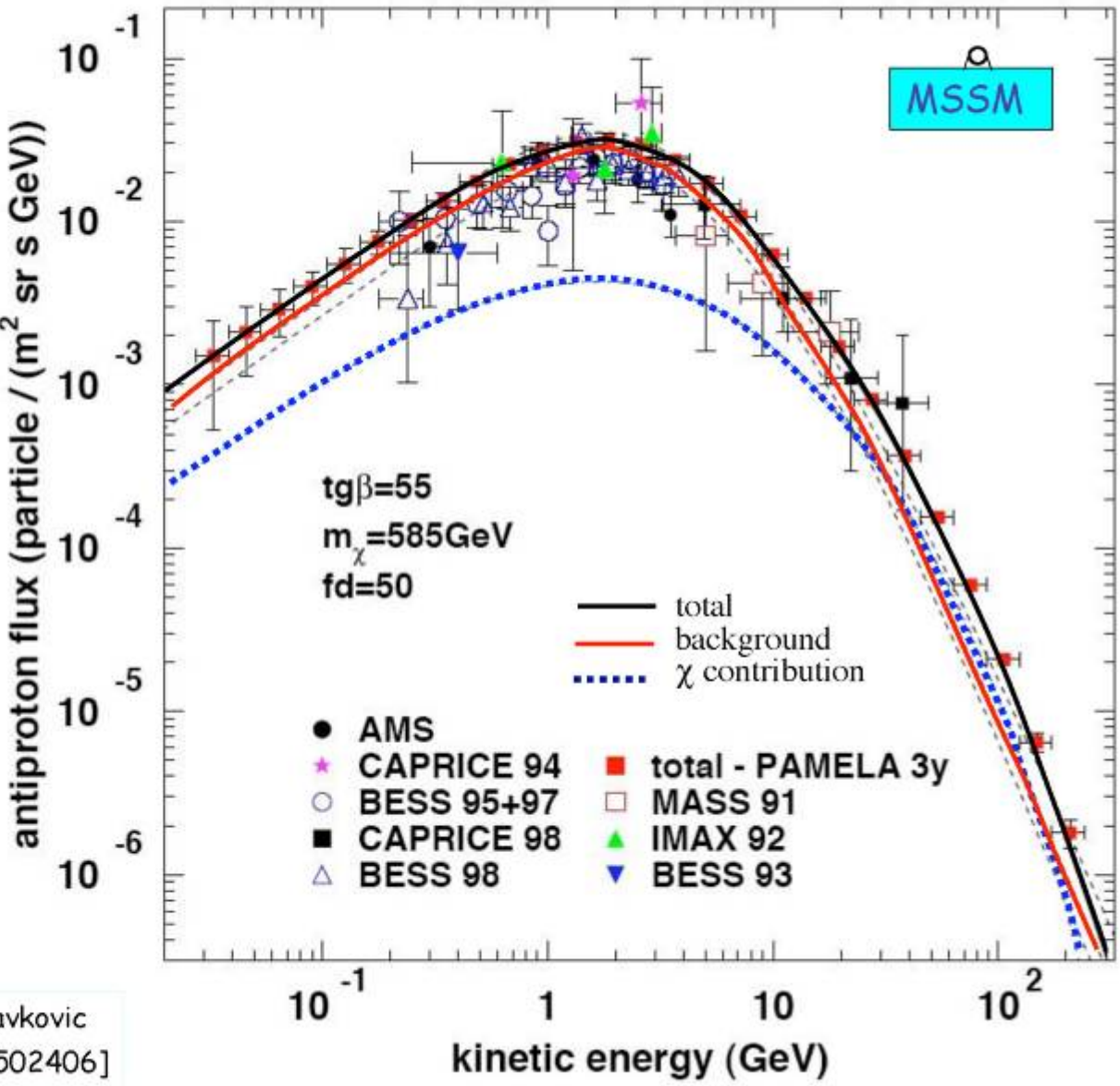



Positron ratio: Experimental situation and PAMELA expectation for DC model
Moskalenko IV, Strong AW. Astrophys. J. 493:694 (1998)
positron charge fraction e+/(e- + e+)
10 -1
10 -2
MASS 91 DC
CAPRICE 98
CAPRICE 94
HEAT 94+95
AESOP 94
TRAMP-Si 93
MASS 89
Mueller and Tang 87
Golden et al. 87
Hartman and Pellerin 76
Buffington et al. 75
HEAT e, HEAT pbar comb.
AMS01 brems events
AMS01 single tracks
HEAT 2000
Daugherty et al. 75
Fanselow et al. 69
Agrinier et al. 69
PAMELA 3y
DC model A.Lionetto, A.Morselli, V.Zdravkovic JCAP09 (2005) 010 [astro-ph/0502406]
10 -1
1
10
10 2
kinetic energy (GeV)

PAMELA:

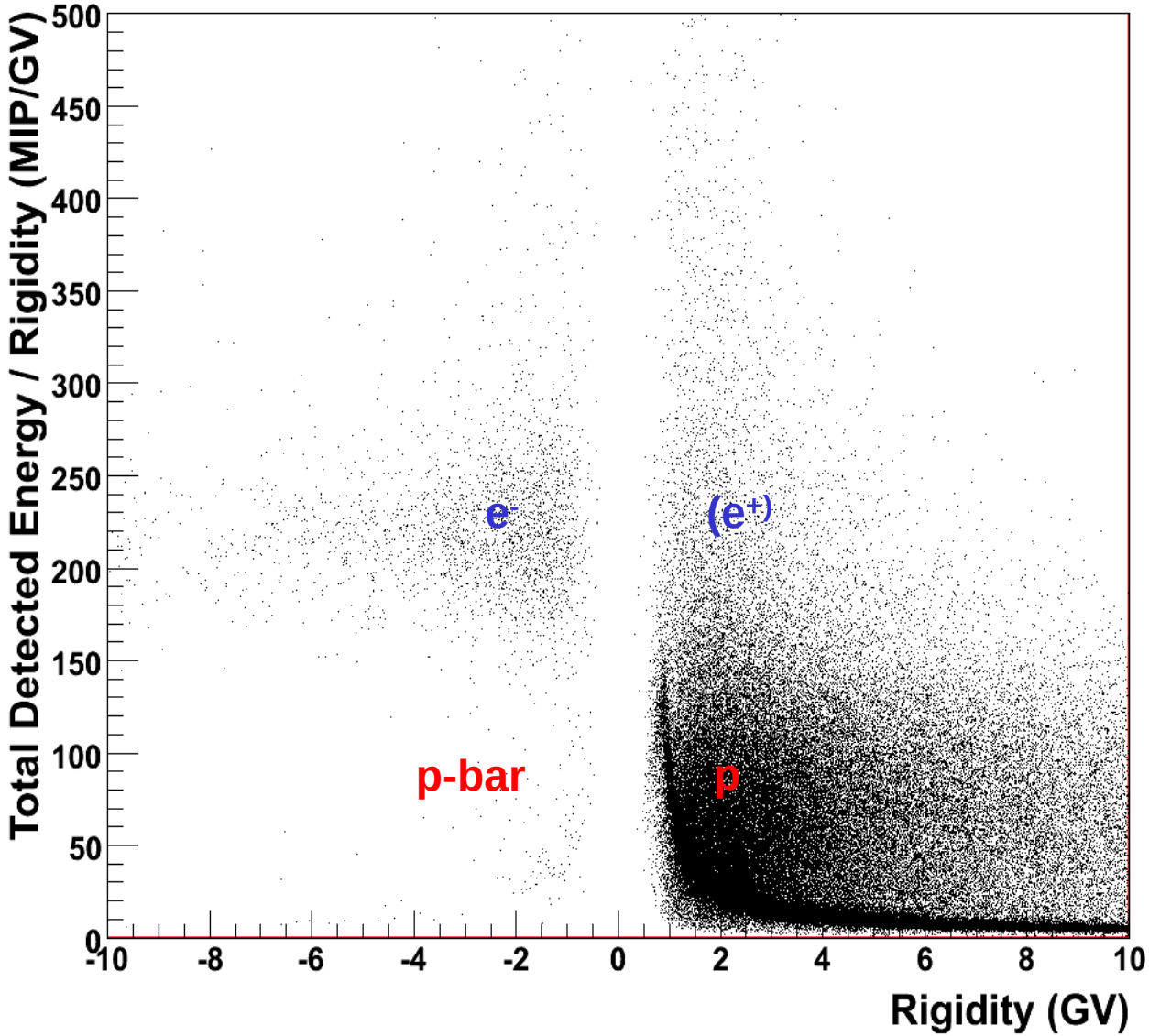
Cosmic-Ray Antiparticle Measurements: Antiprotons

fd: Clumpiness factors needed to disentangle a neutralino induced component in the antiproton flux



A.Lionetto, A.Morselli, V.Zdravkovic
JCAP09(2005)010 [astro-ph/0502406]

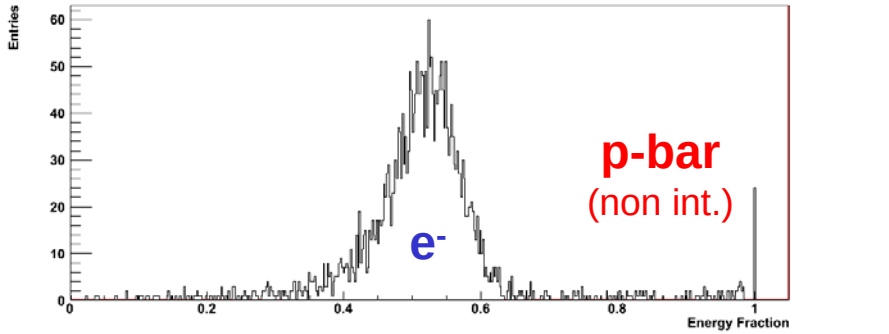
Preliminary !!!

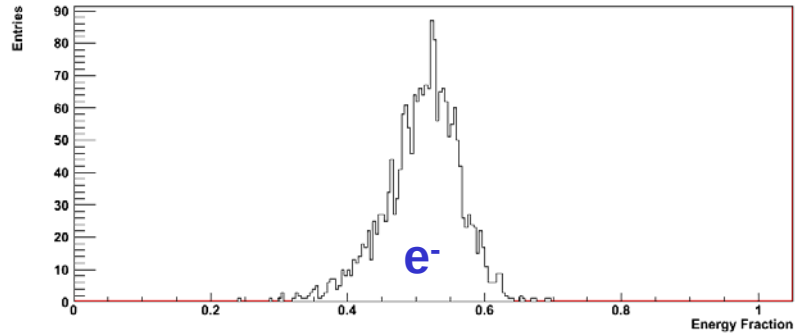


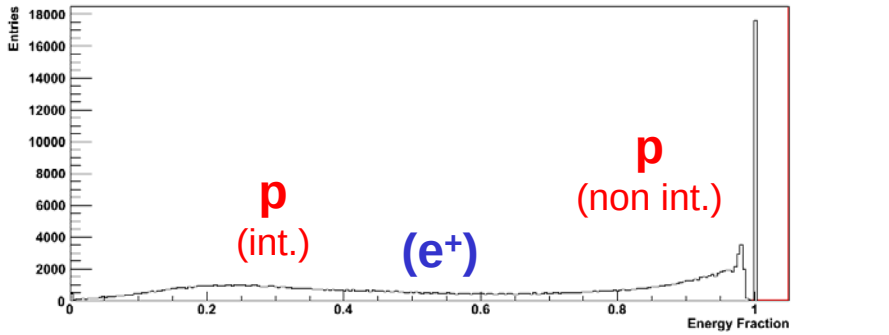
Positron selection

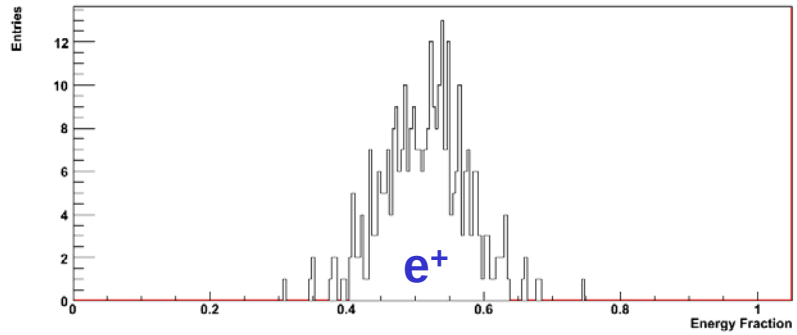
Preliminary !!!

Fraction of charge released along the track









Many selection criteria provided by the calorimeter:

- total energy release
- longitudinal and later shower development
- shower topology
- …