PAMELA SPACE MISSION

XII International Workshop
on Neutrino Telescopes

6 – 9 March 2007

Venice, Italy

Piergiorgio Picozza
Pamela Collaboration
INFN & University of Roma “Tor Vergata”

PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

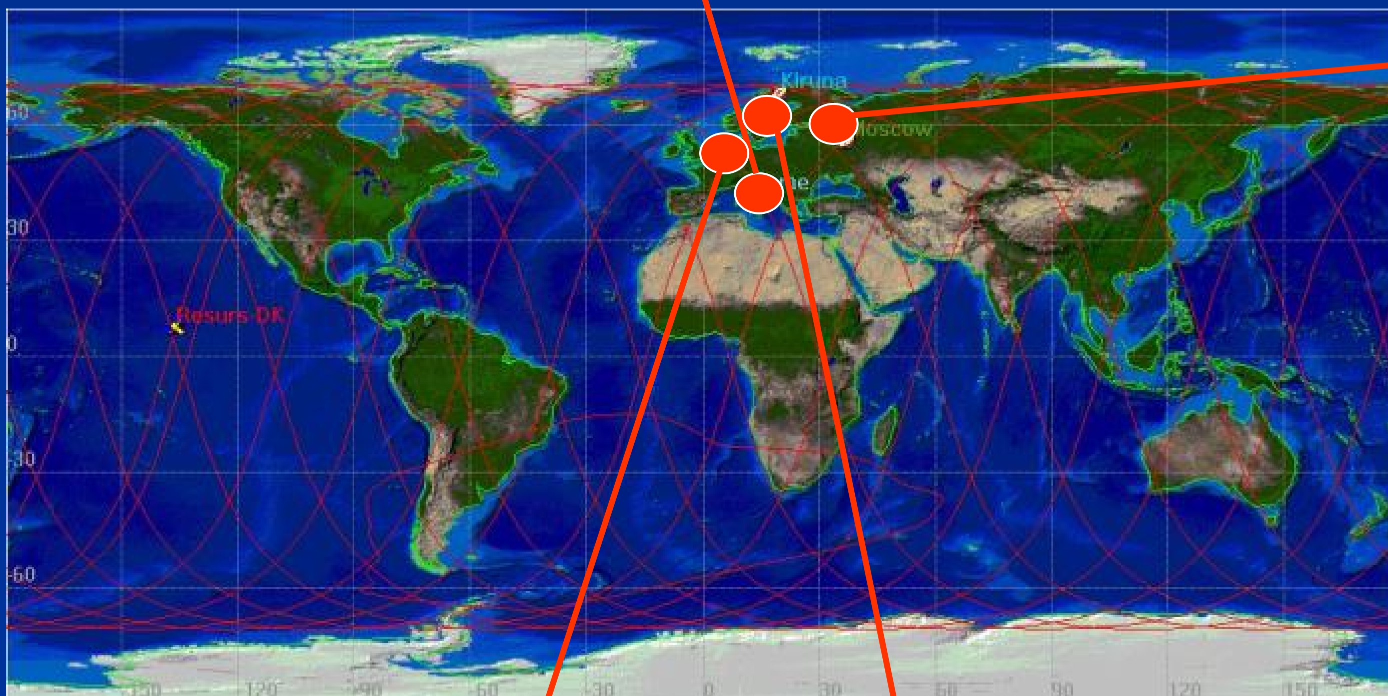
Launched in orbit on June 15, 2006, on board of the DK1 satellite by a Soyuz rocket from the Bajkonour launch site.

Since July 11, 2006, Pamela is in continuous data taking mode

PAMELA Collaboration

Italy: Bari, Florence, Frascati, Naples, Rome, Trieste, CNR, Florence

Russia: Moscow, St. Petersburg



Germany: Siegen

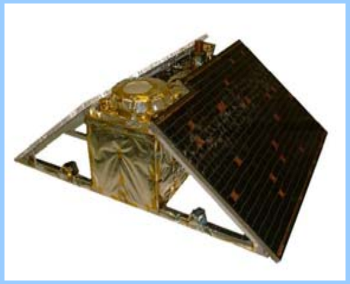
Sweden: KTH, Stockholm

WiZard   Russian Italian Missions

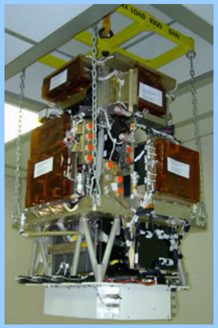
MASS-89, 91, TS-93, CAPRICE 94-97-98

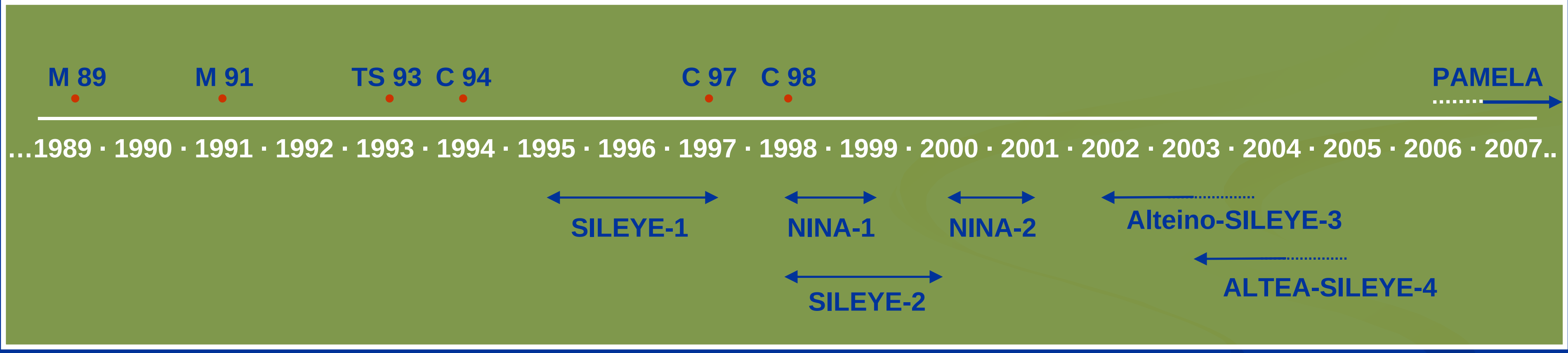
NINA-1

NINA-2



PAMELA





SILEYE-1

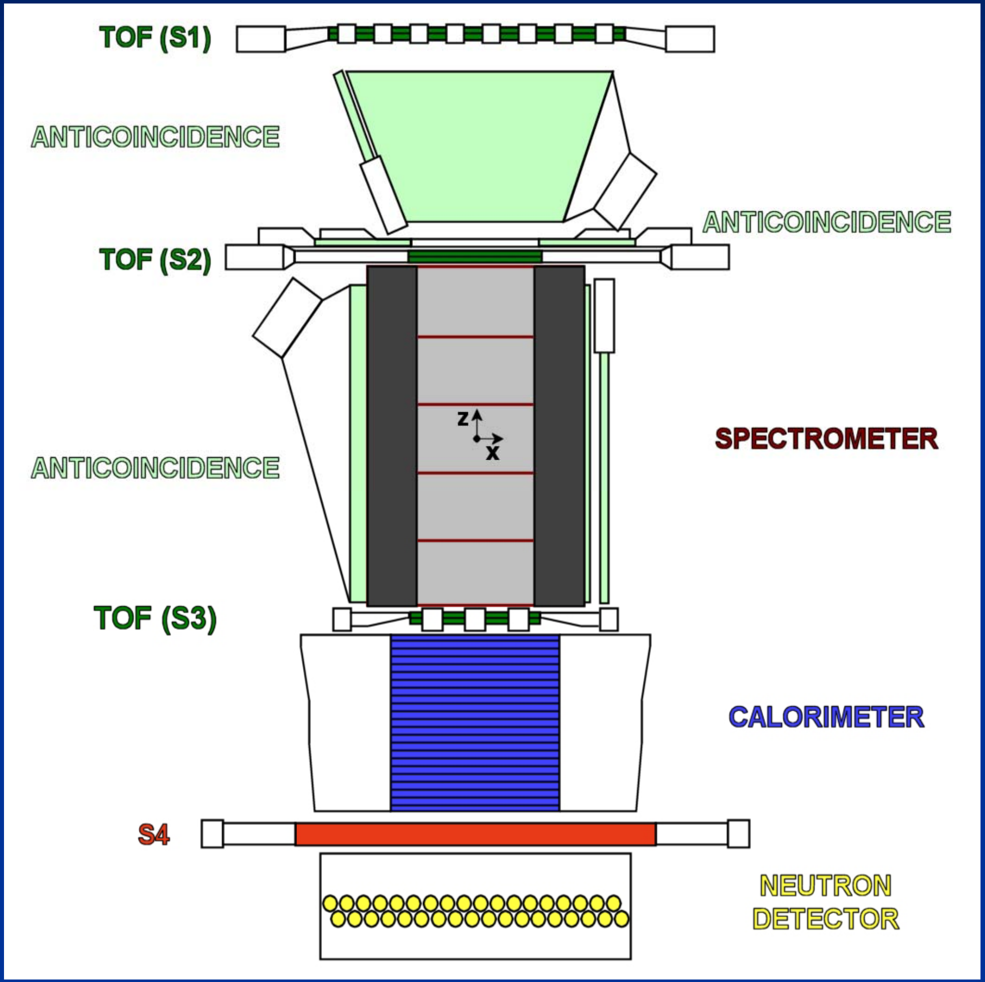
SILEYE-2

ALTEINO: SILEYE-3

LAZIO SIRAD

ALTEA: SILEYE-4

The PAMELA Instrument

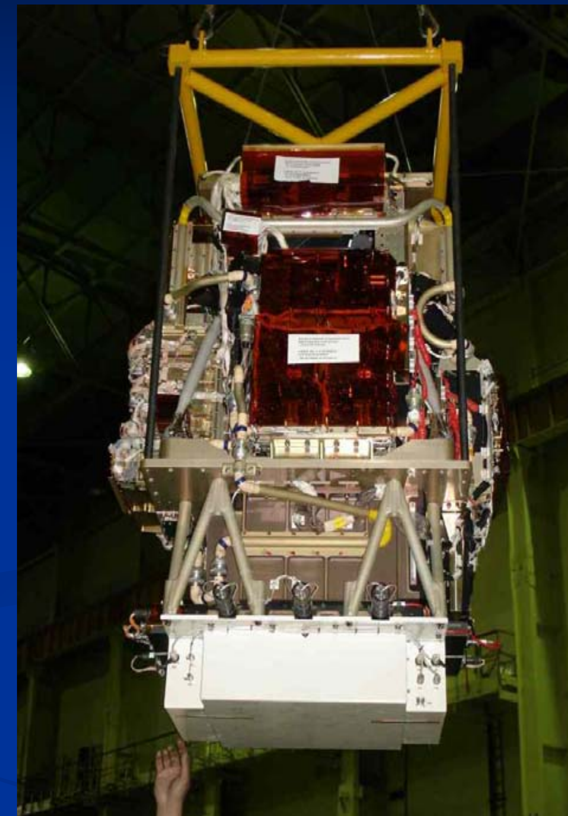


GF ~21.5 cm^{2}sr
Mass: 470 kg
Size: 120x70x70 cm^3
Power Budget: 360 W

PAMELA MODELS

Mass&Thermal Model
Full cycle of vibration/shock/ tranport tests

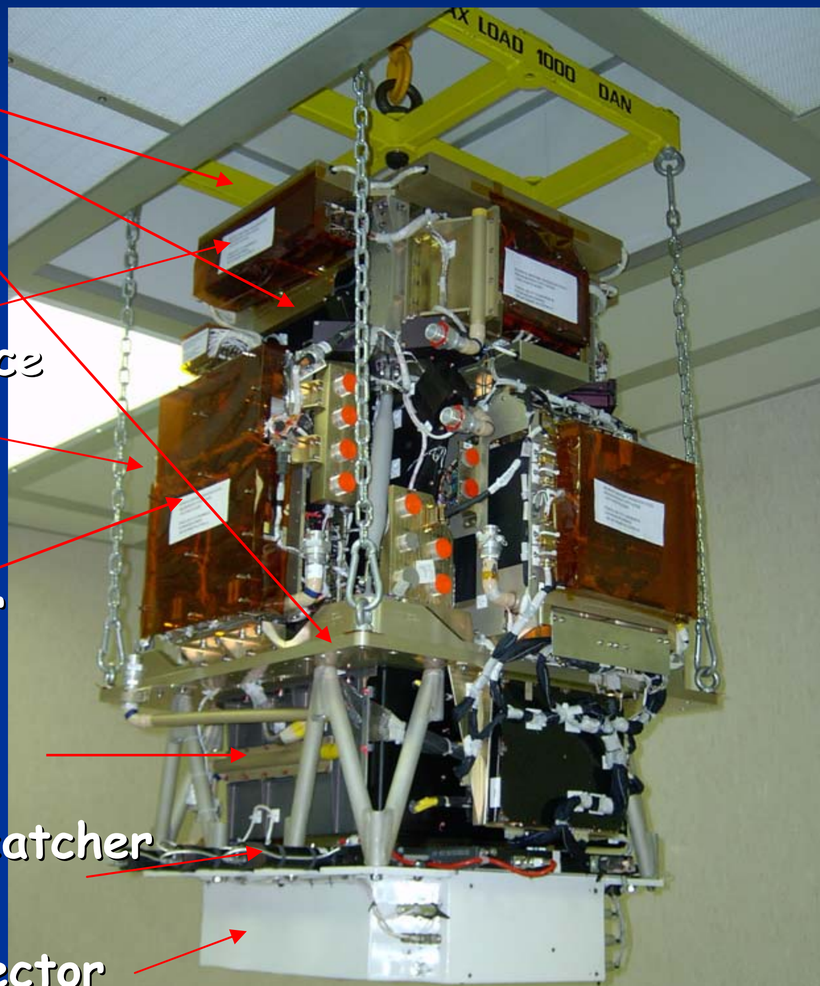
Technological Model
Preliminary Acceptance Tests with EGSE: power ON/OFF, telecommands, data transmission

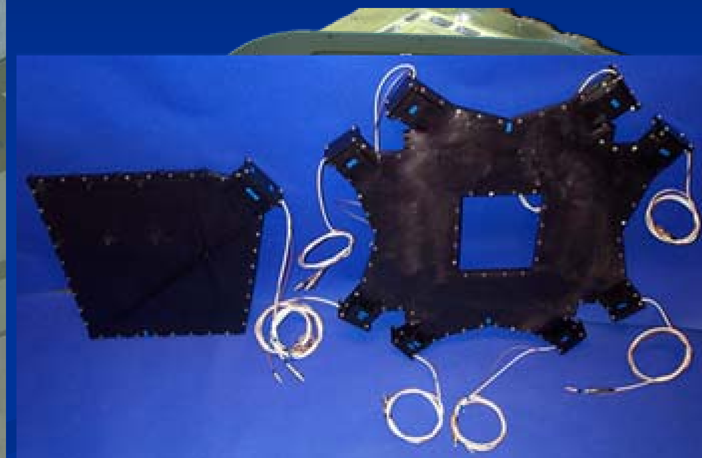


Flight Model
Integration, beam tests; pre-flight operations

PAMELA Instrument

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

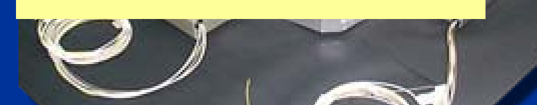




First level trigger
SHOWER TAIL CATCHER
NEUTRON DETECTOR
ANTICOINCIDENCE SHIELD

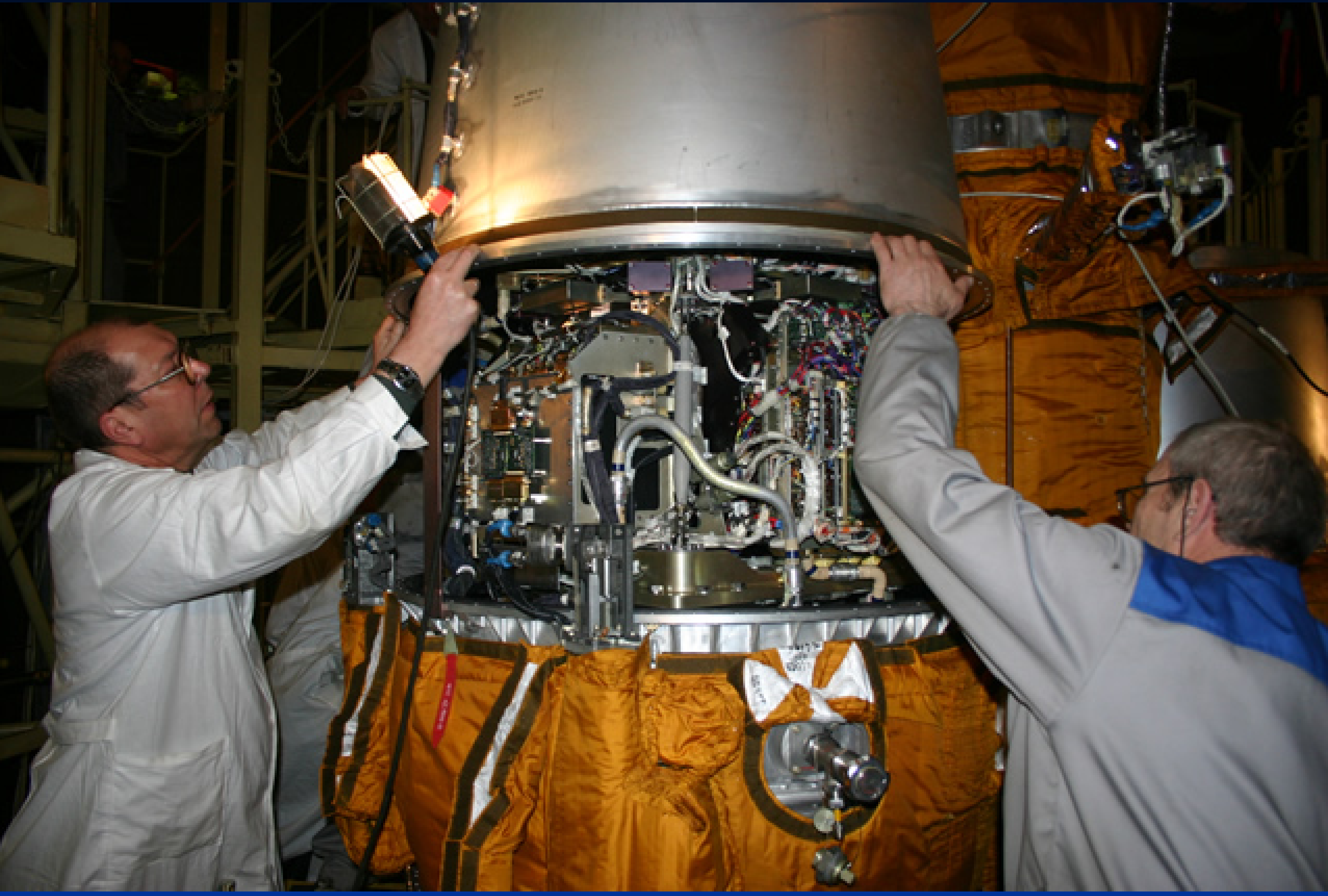
- Scintillator paddles 10 mm thick
- Dynamic range of 1÷1000 mip

components

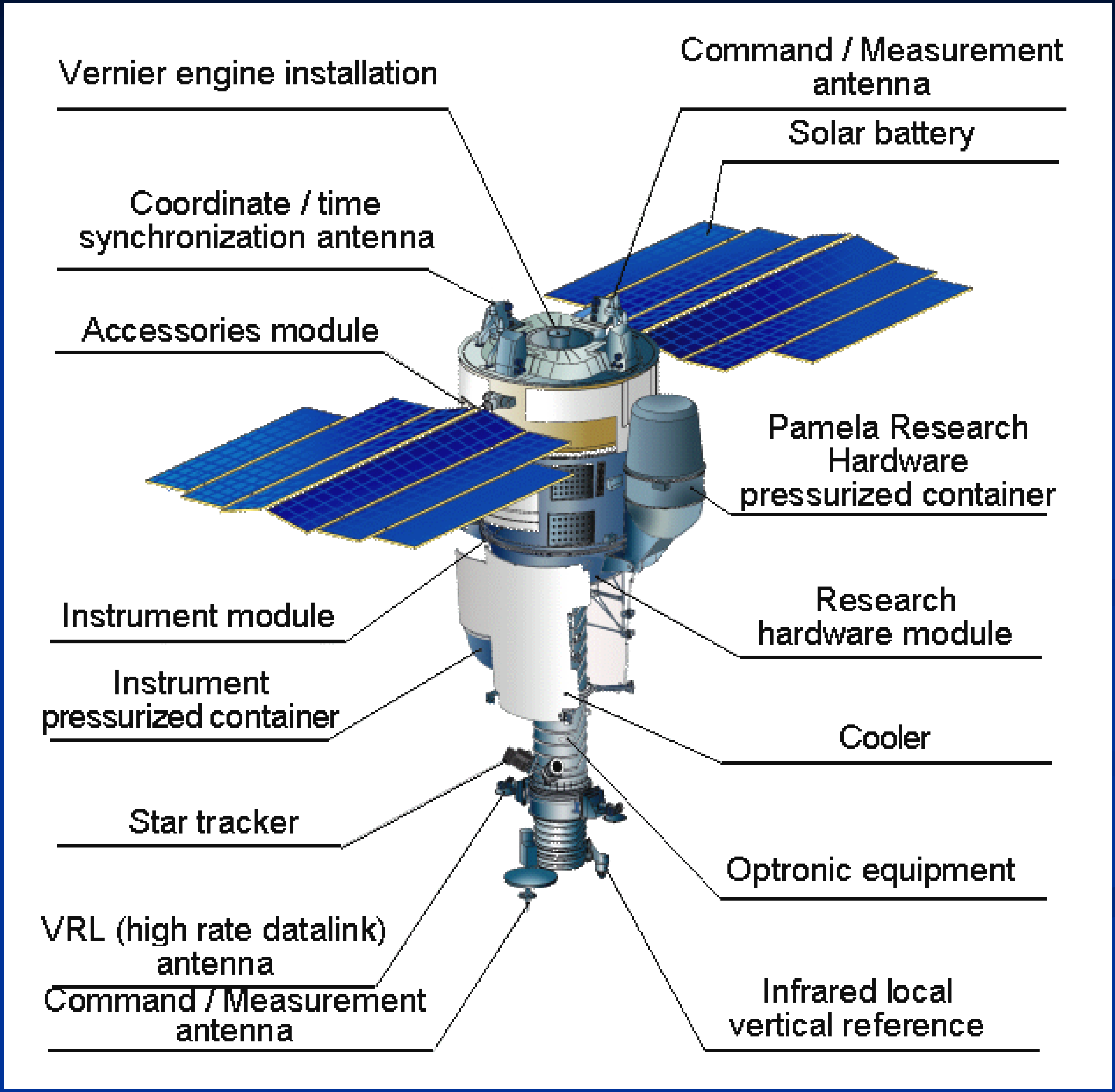


PAMELA nominal capabilities

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



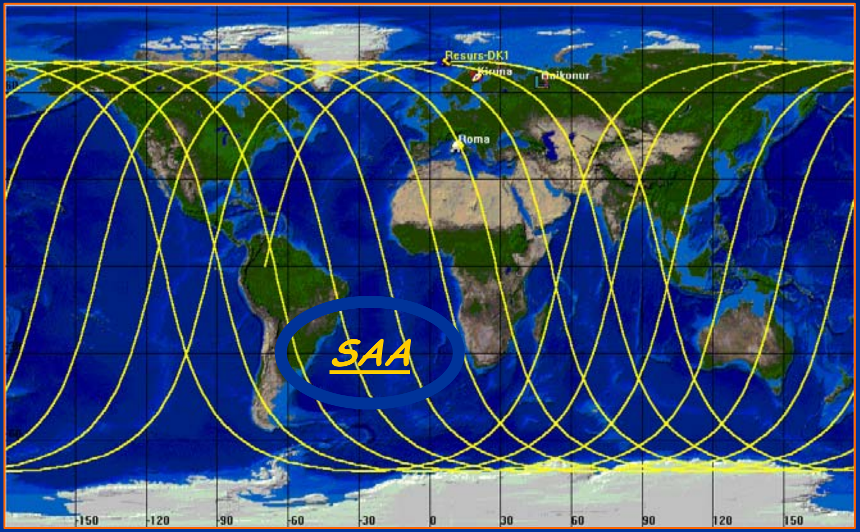
Resurs-DK1 Spacecraft TsSKB-Progress

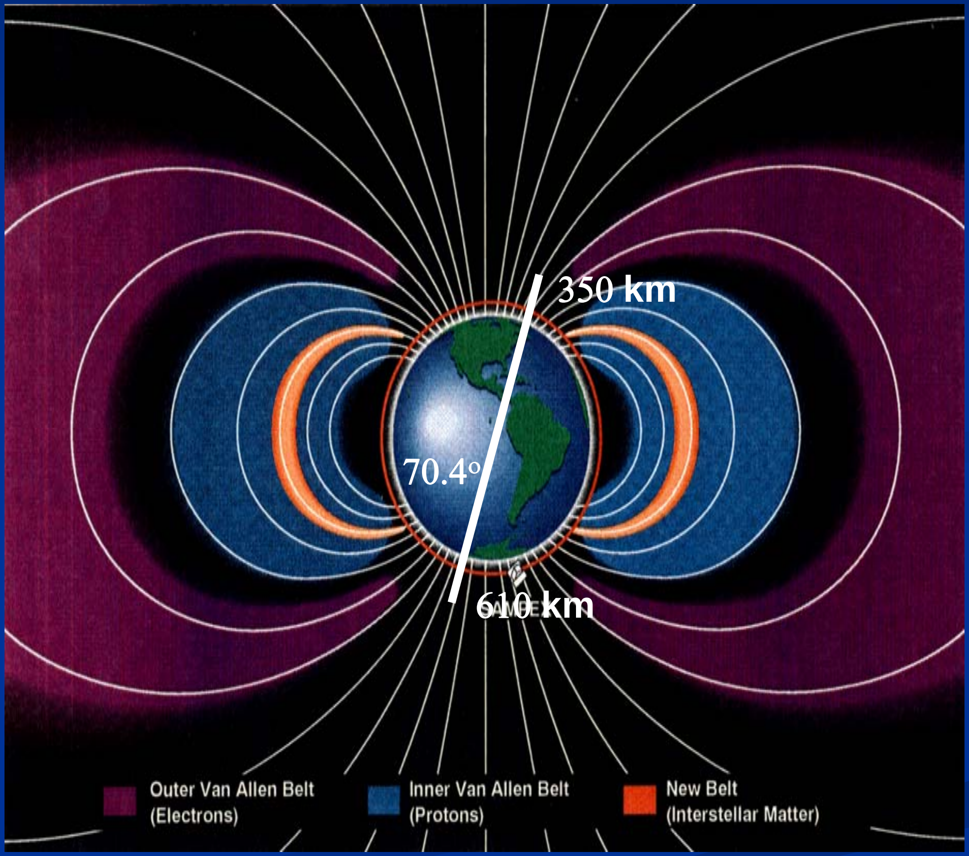


PAMELA

Launch
15/06/06

Orbit Characteristics

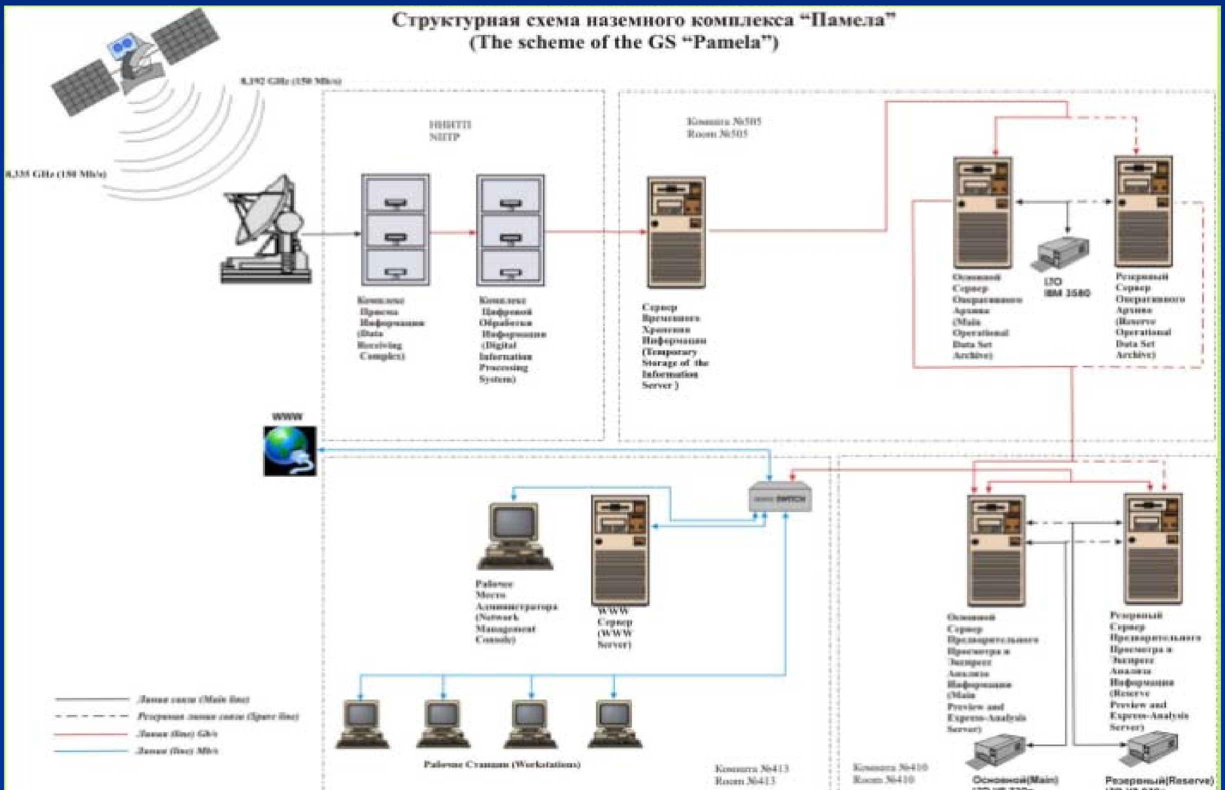




- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70º inclination)
- Lifetime >3 years (assisted)
- Radiation Belts - SAA
- Geomagnetic cutoff

Ground Station(s)

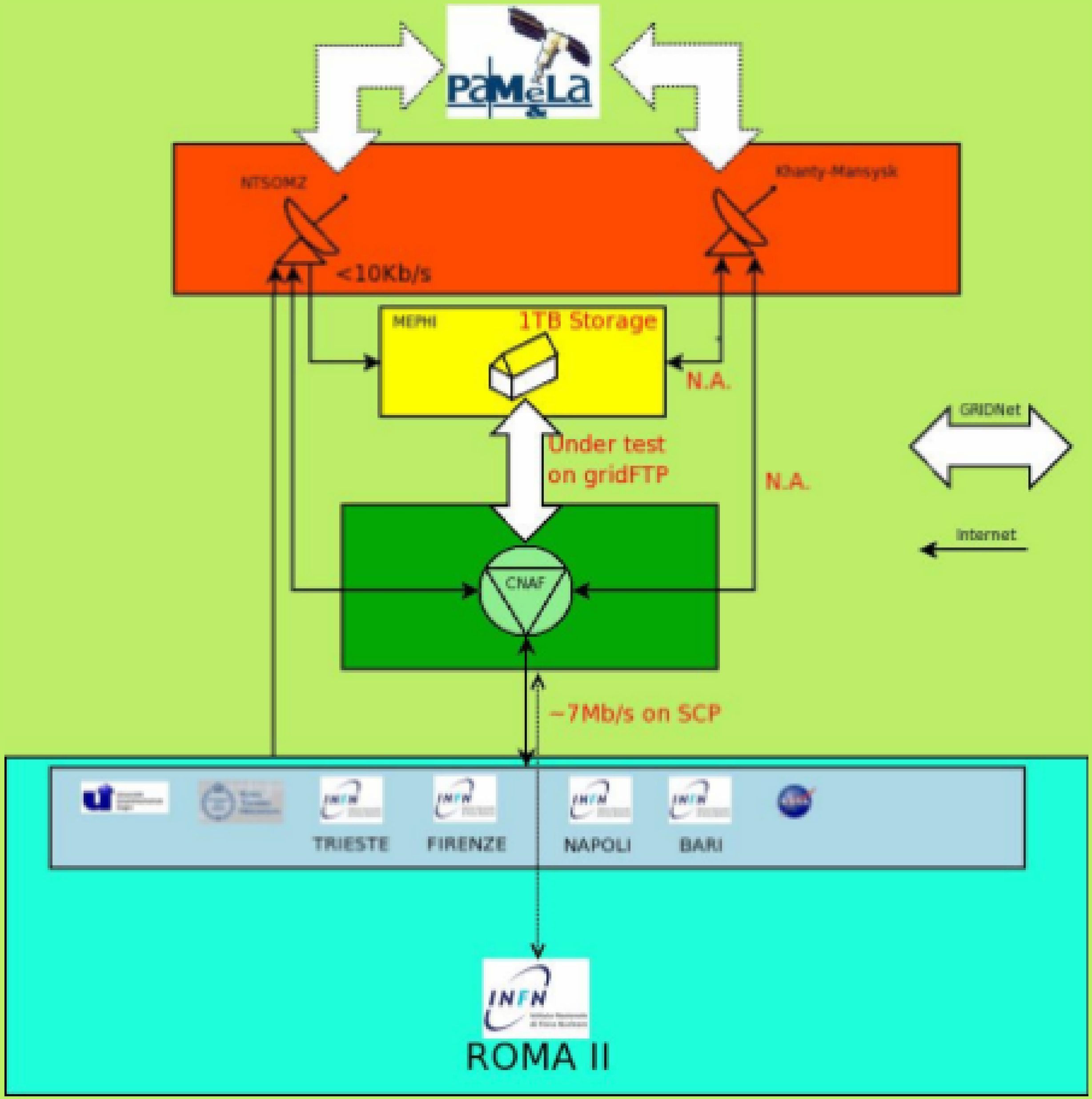
Main Station: Research Centre for Earth Operative Monitoring **"NtsOMZ"** (Moscow, Russia);



Scheme of PAMELA control room in NTsOMZ

Main antenna in NTsOMZ

Network Status



PAMELA status

First switch-on on June 21st 2006

- Detectors in nominal conditions (no problems due to the launch)
- Tested different trigger and hardware configurations
- Commissioning phase successfully ended on July 11th 2006

→ PAMELA in continuous data-taking mode

→ 16 Gigabytes of Data daily trasmitted to Ground

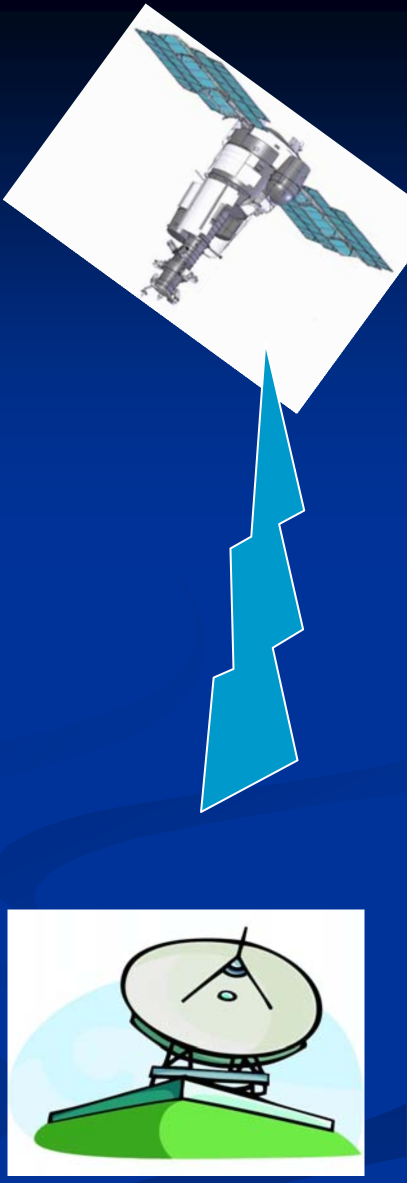
At January 30th 2007:

- PAMELA ON for 201 days
- 20880 acquisition runs
- 2.8 TB of raw data
- 344961274 triggers recorded

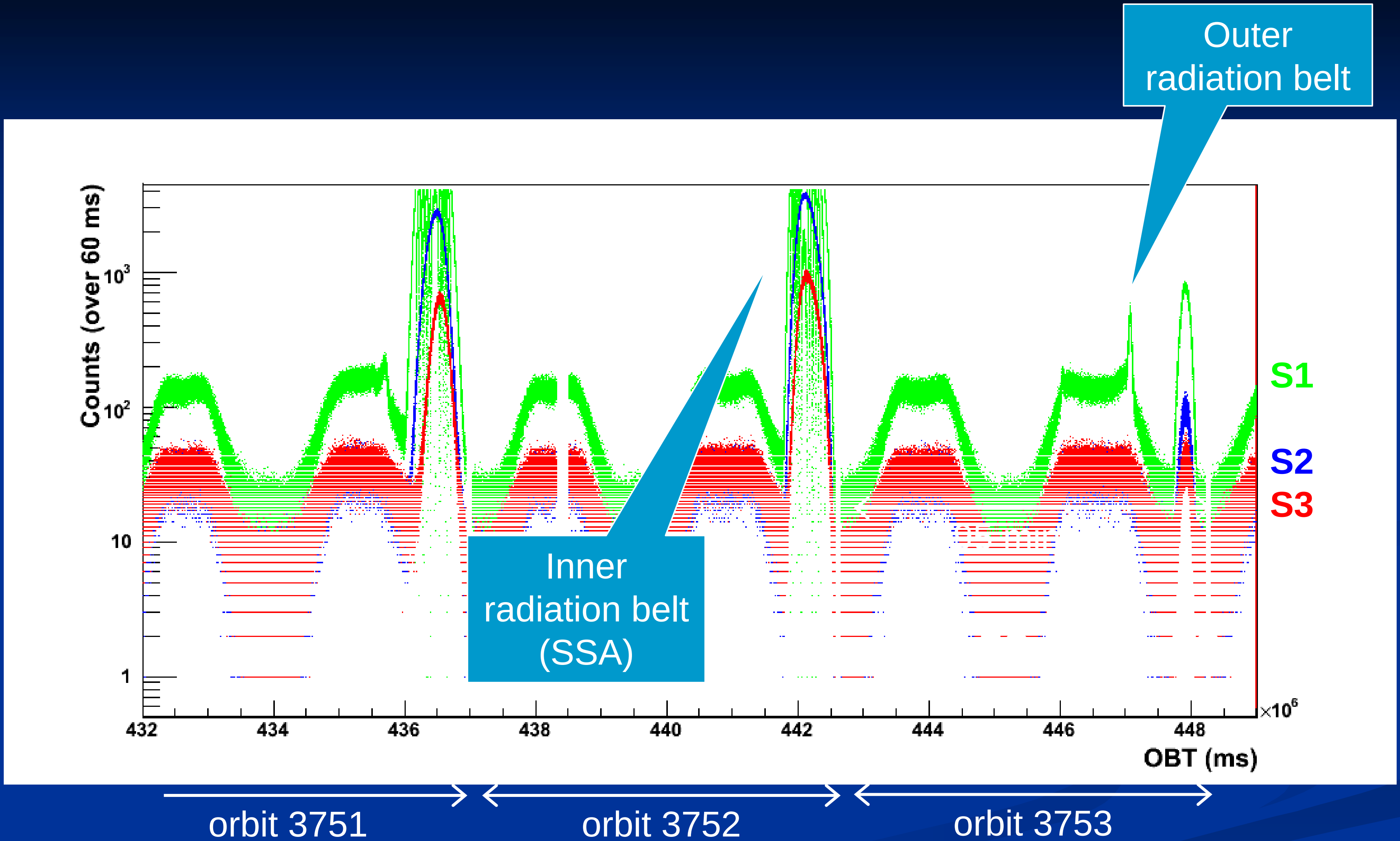
Remote control

- 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

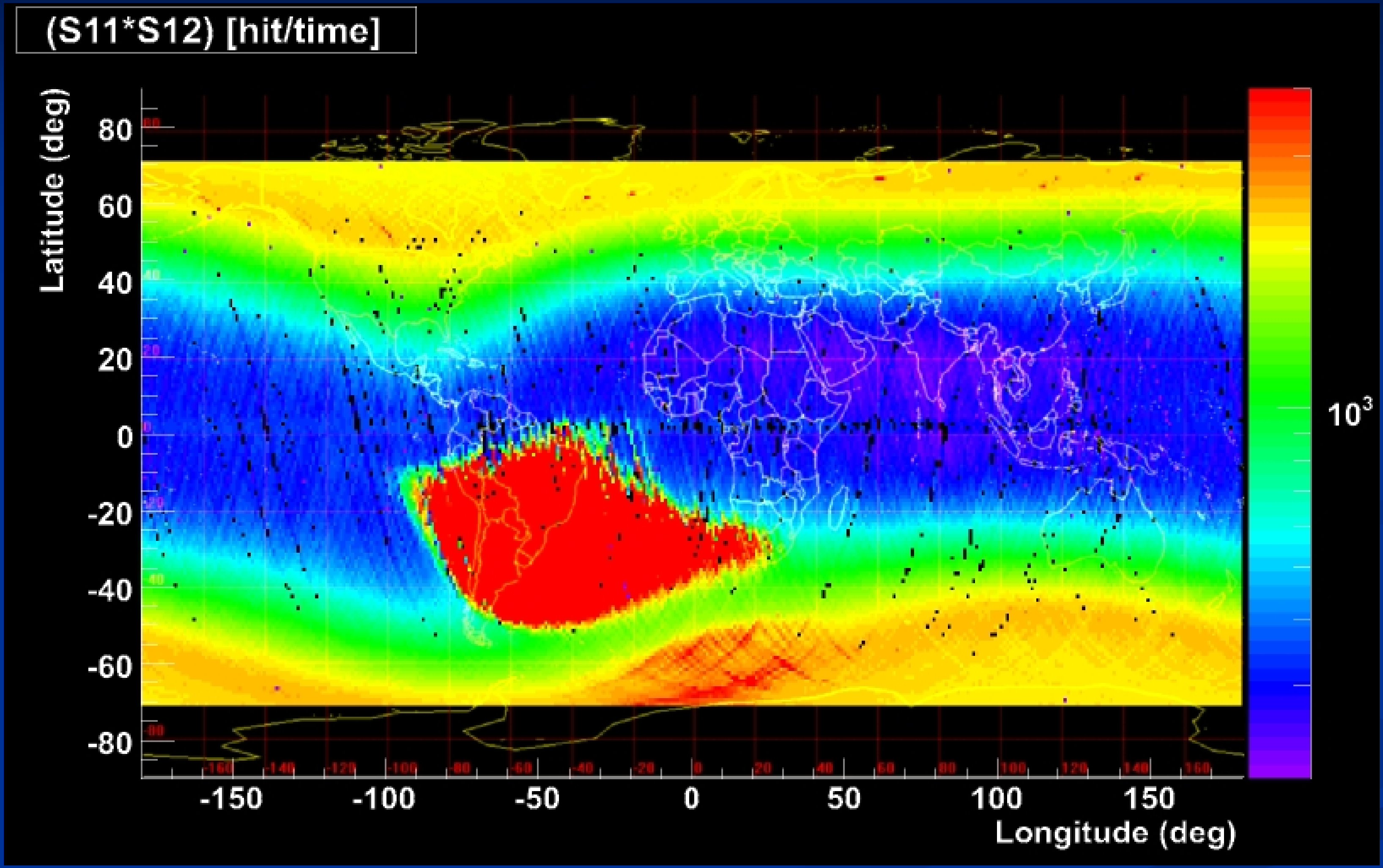
→ Extremely flexible system, designed to be easily adapted to space (unknown) conditions.



Orbital environment measured by Pamela

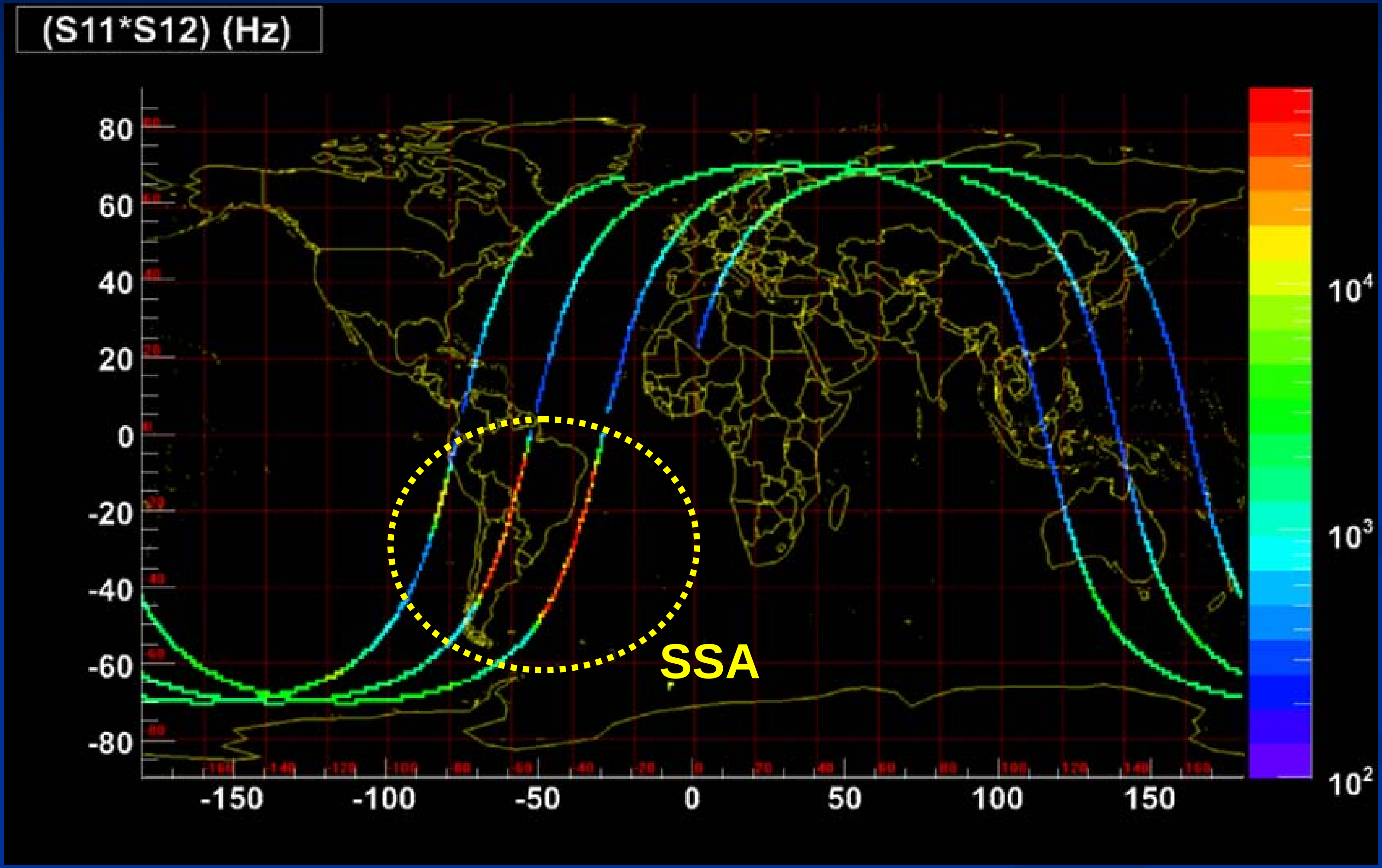

Outer radiation belt
Inner radiation belt (SSA)
Counts (over 60 ms)
OBT (ms)
S1
S2
S3
orbit 3751
orbit 3752
orbit 3753

Pamela World Maps: 350 – 650 km alt

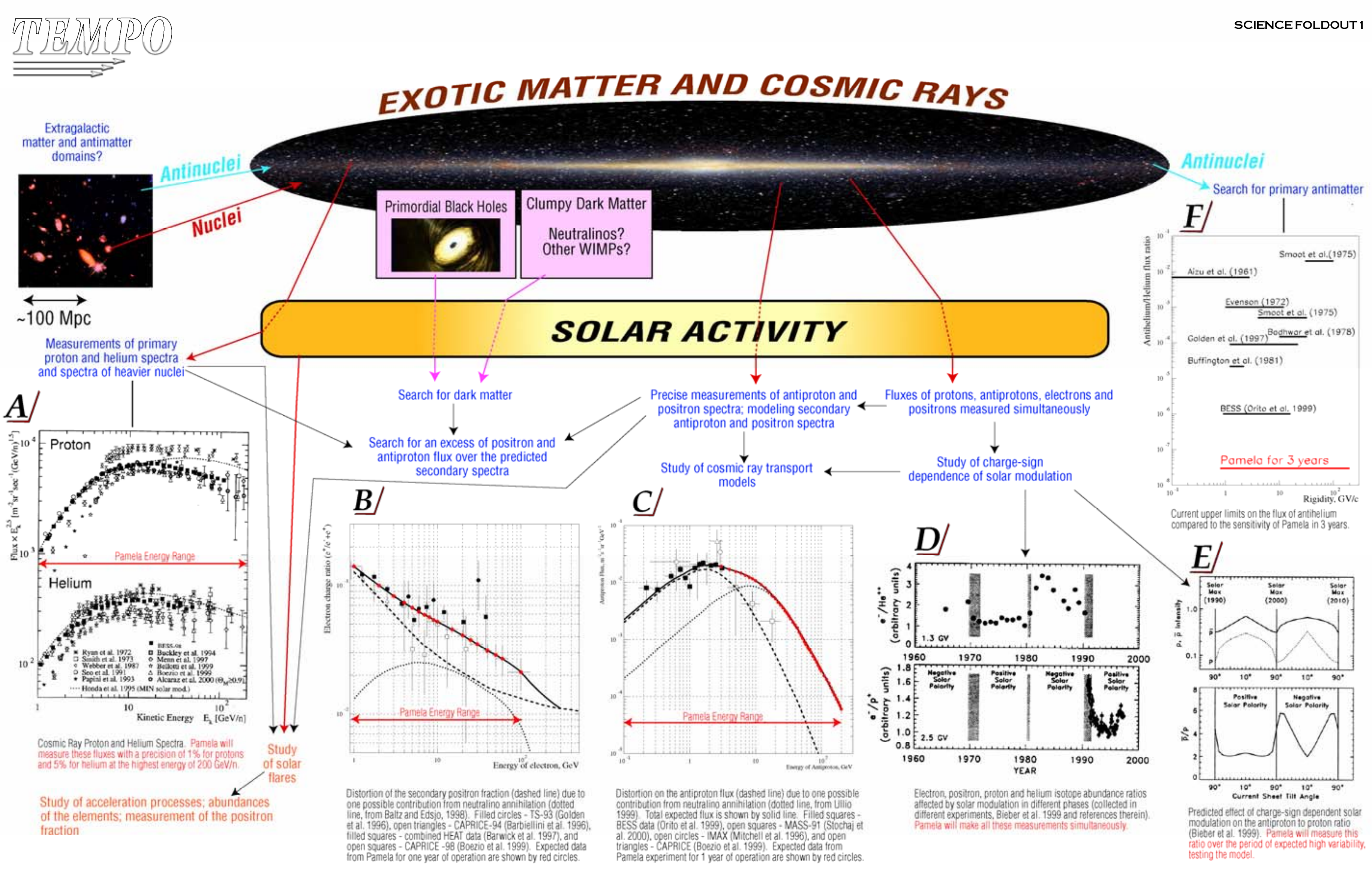


36 MeV p, 3.5 MeV e-

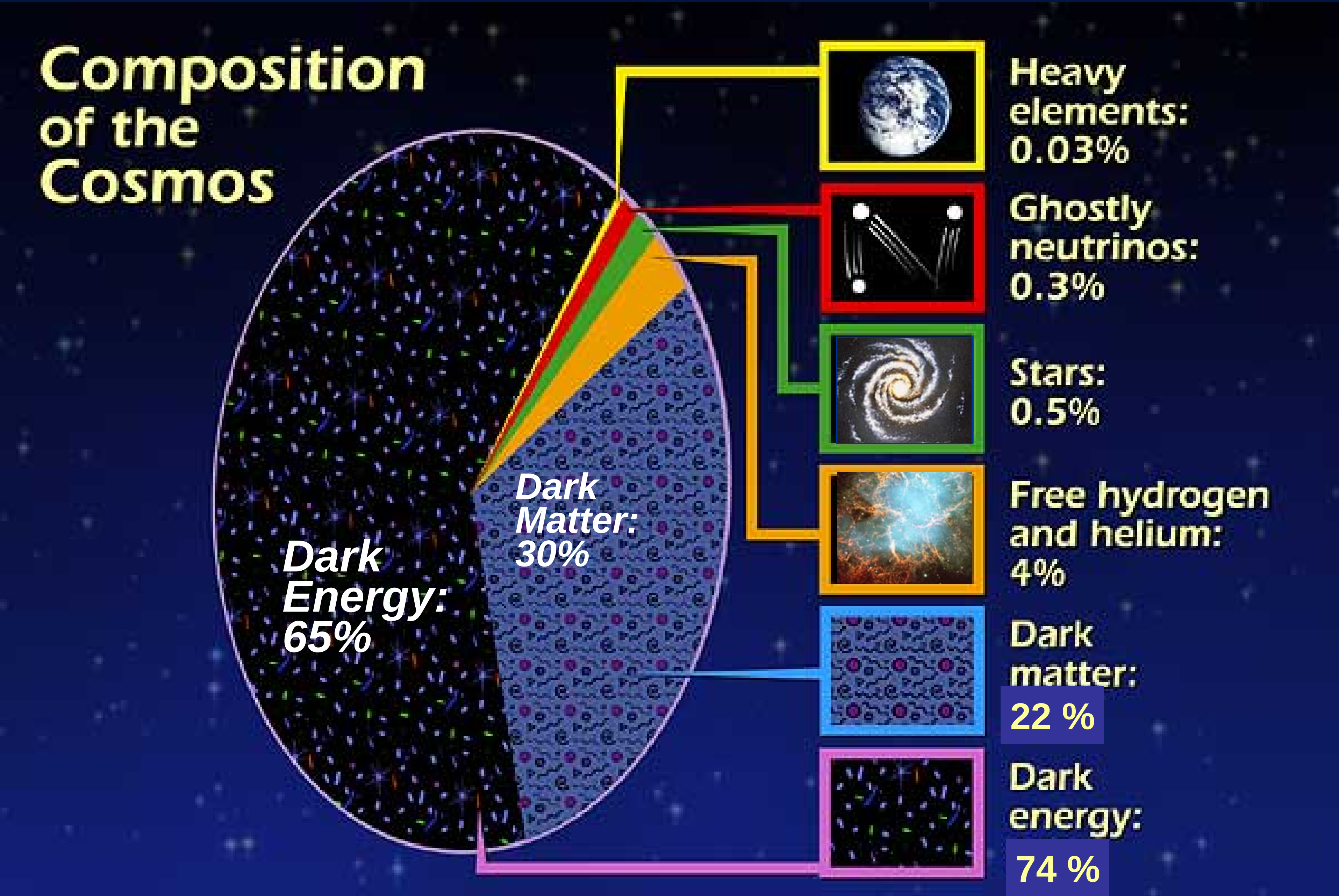
Download @orbit 3754 – 15/02/2007 07:35:00 MWT



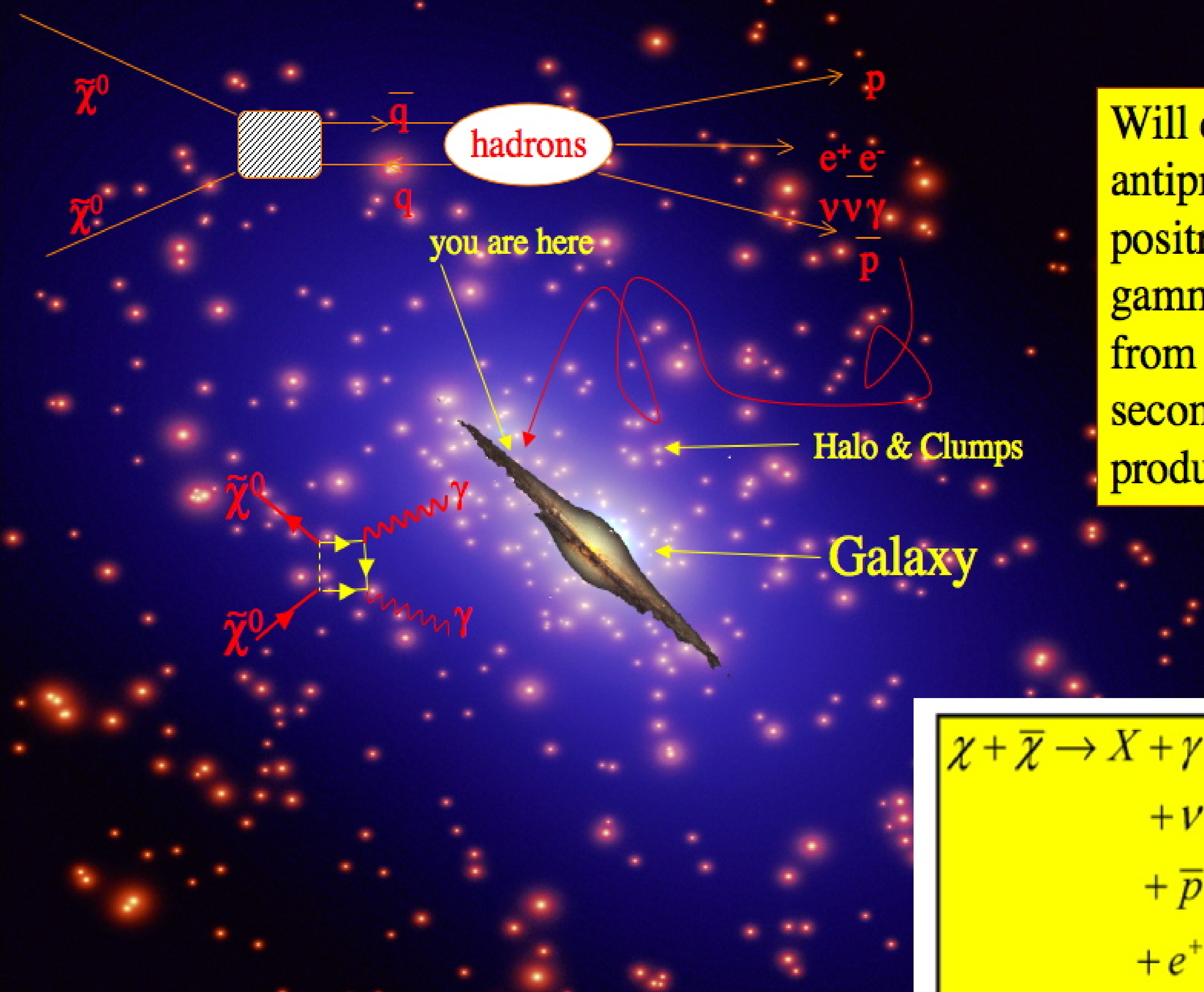
The Science of PAMELA



Energy budget of Universe



Neutralino Annihilations

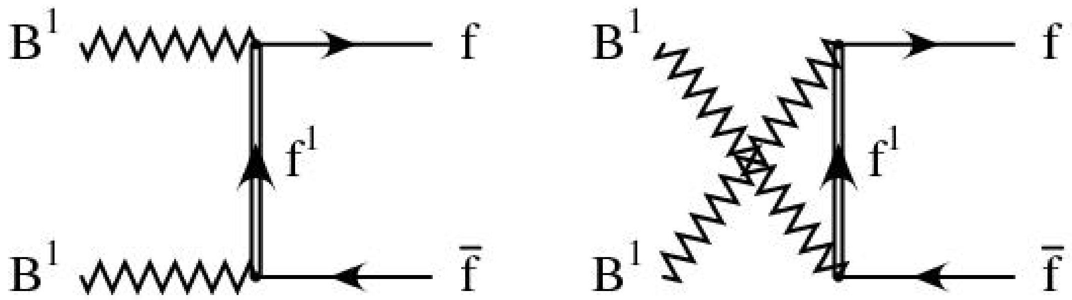


Will distort the antiproton positron and gamma spectra from purely secondary production

$$
\begin{aligned}
\chi + \bar{\chi} \rightarrow X &+ \gamma && \text{(GLAST)} \\
&+ \nu && \text{(AMANDA / IceCube)} \\
&+ \bar{p} && \\
&+ e^+ && \text{PAMELA (and Bess, HEAT, AMS etc.)} \\
&+ \bar{D} &&
\end{aligned}
$$

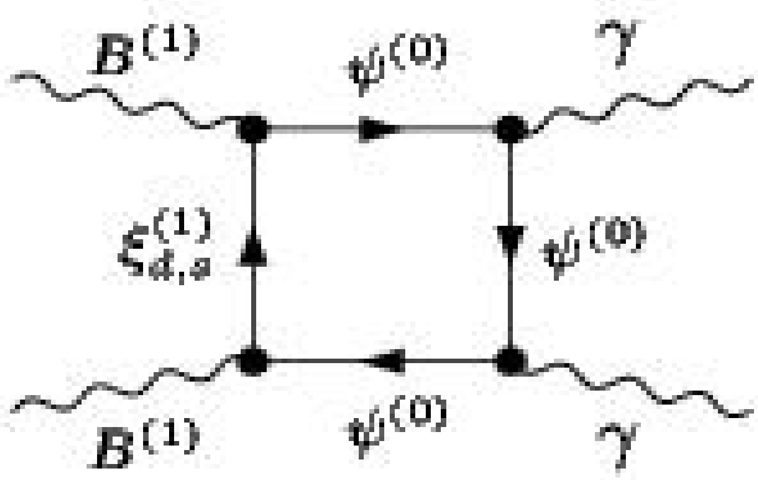
Another possible scenario:
KK Dark Matter

Lightest Kaluza-Klein Particle (LKP): $B^{(1)}$

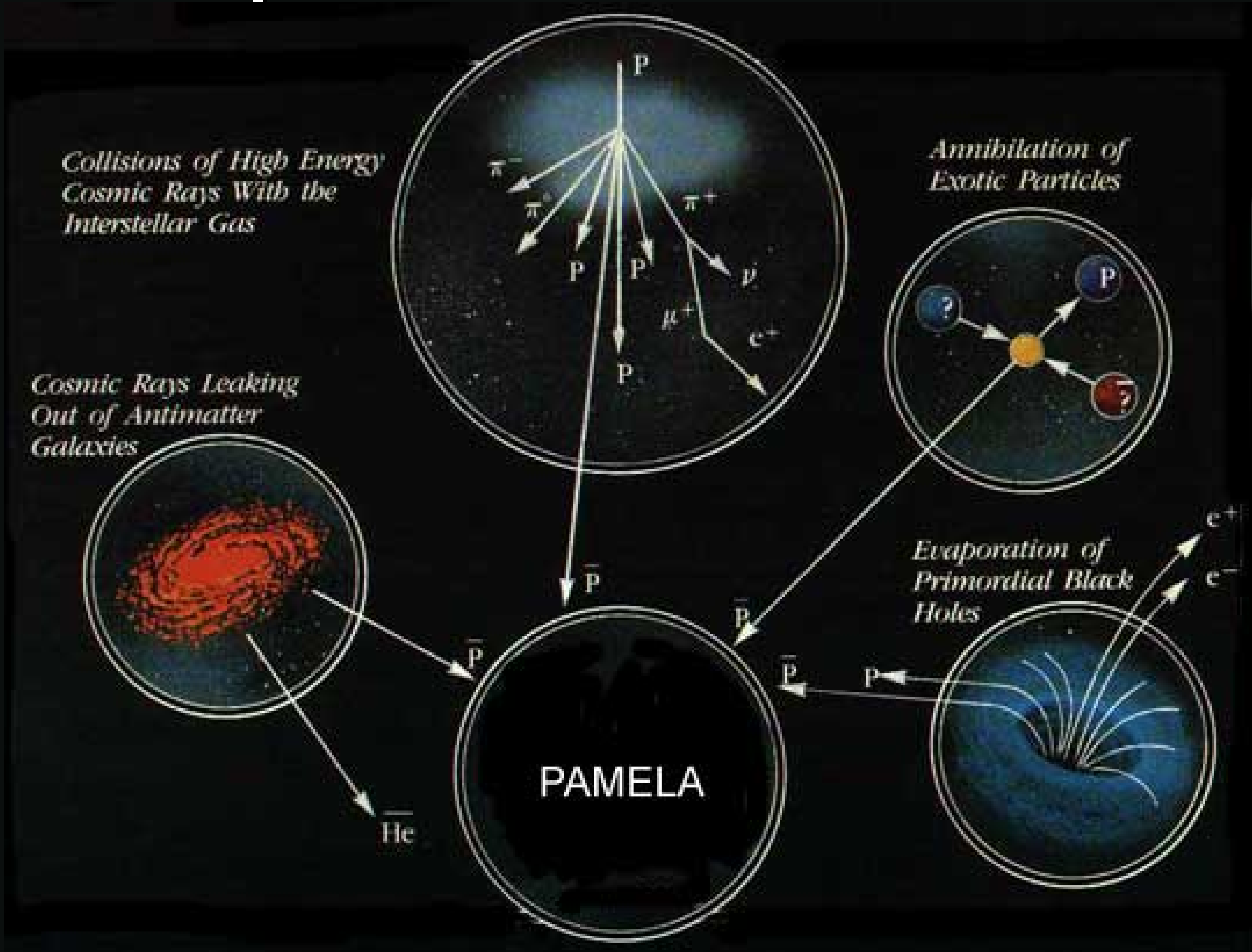


Bosonic Dark Matter:
fermionic final states
no longer helicity
suppressed.
e+e- final states
directly produced.

As in the neutralino case there are 1-loop processes that produces monoenergetic
γ γ in the final state.

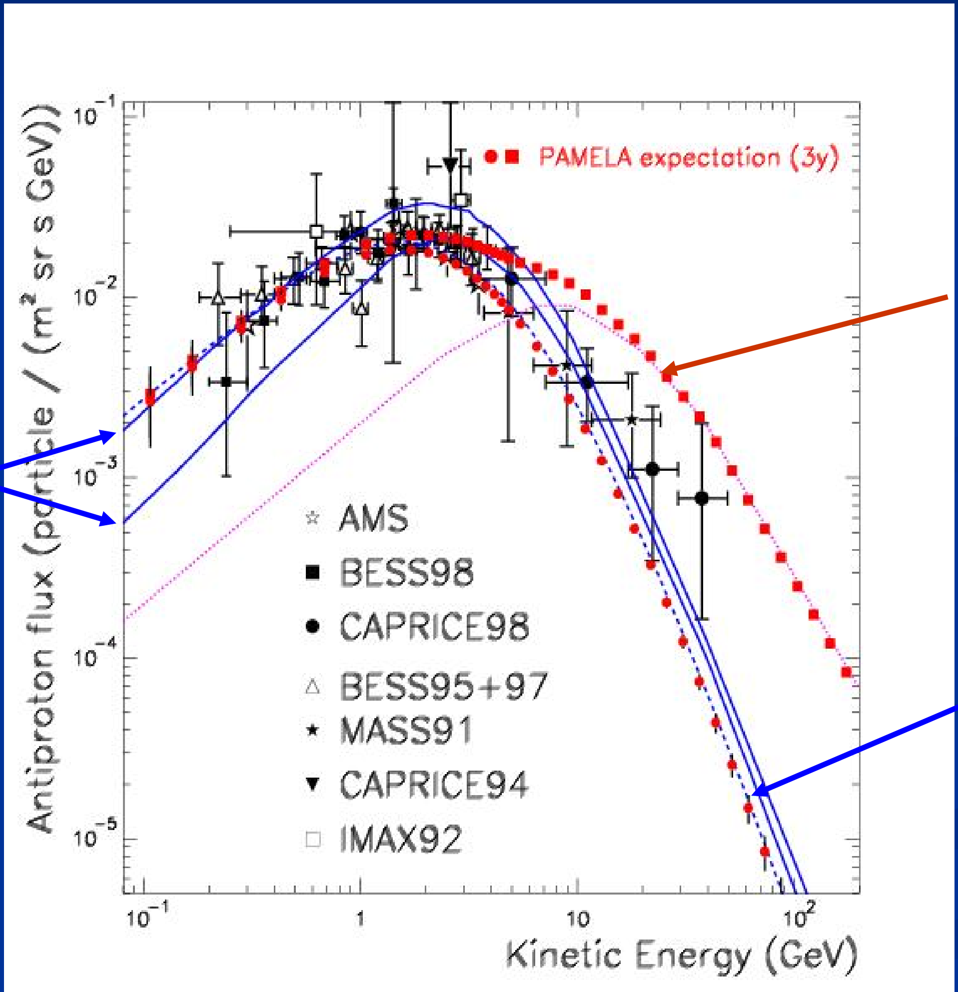


Antiparticles Measurements



Search of structures in antiproton spectrum

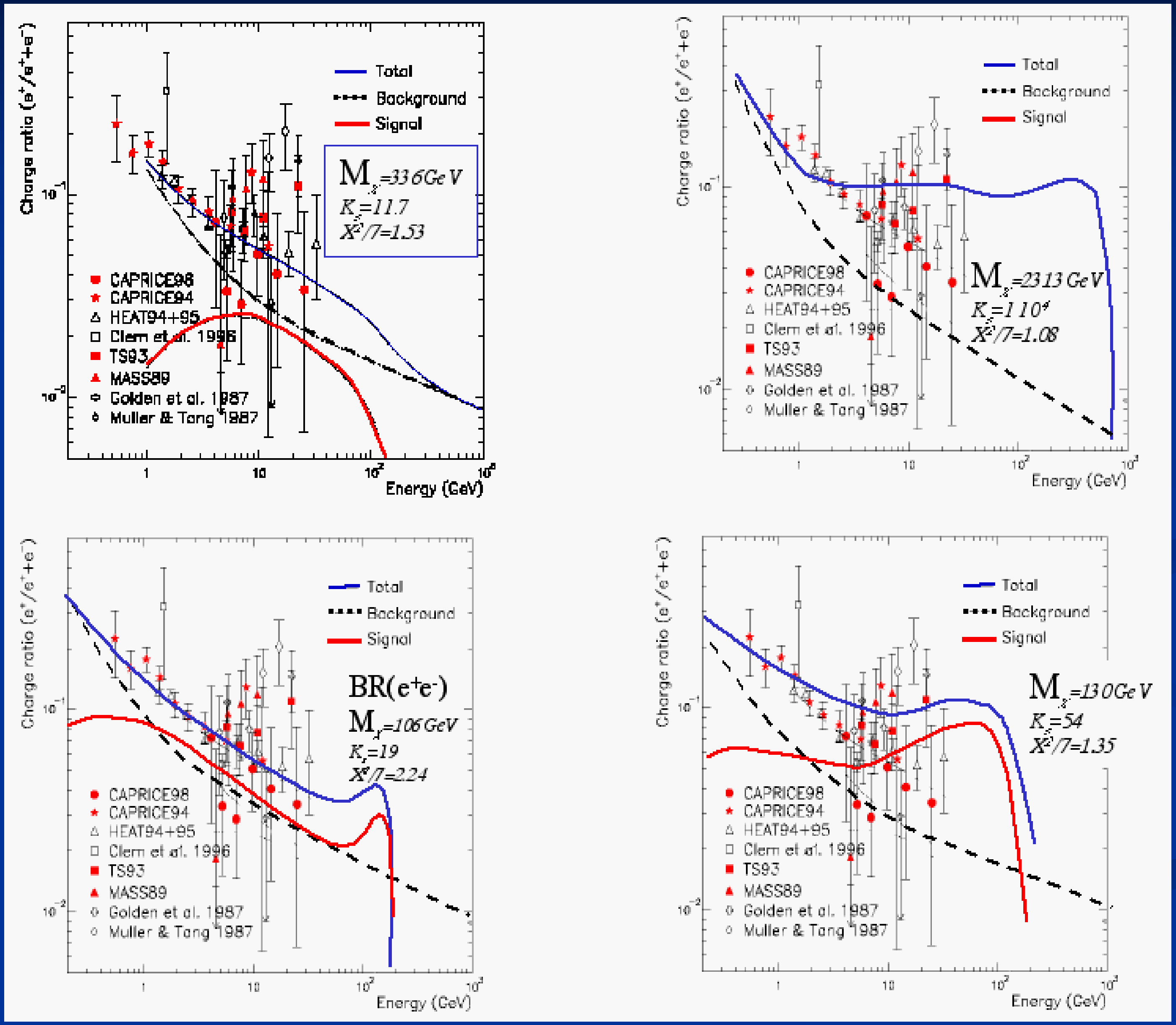
Secondary production
(upper and lower limits)
Simon et al.



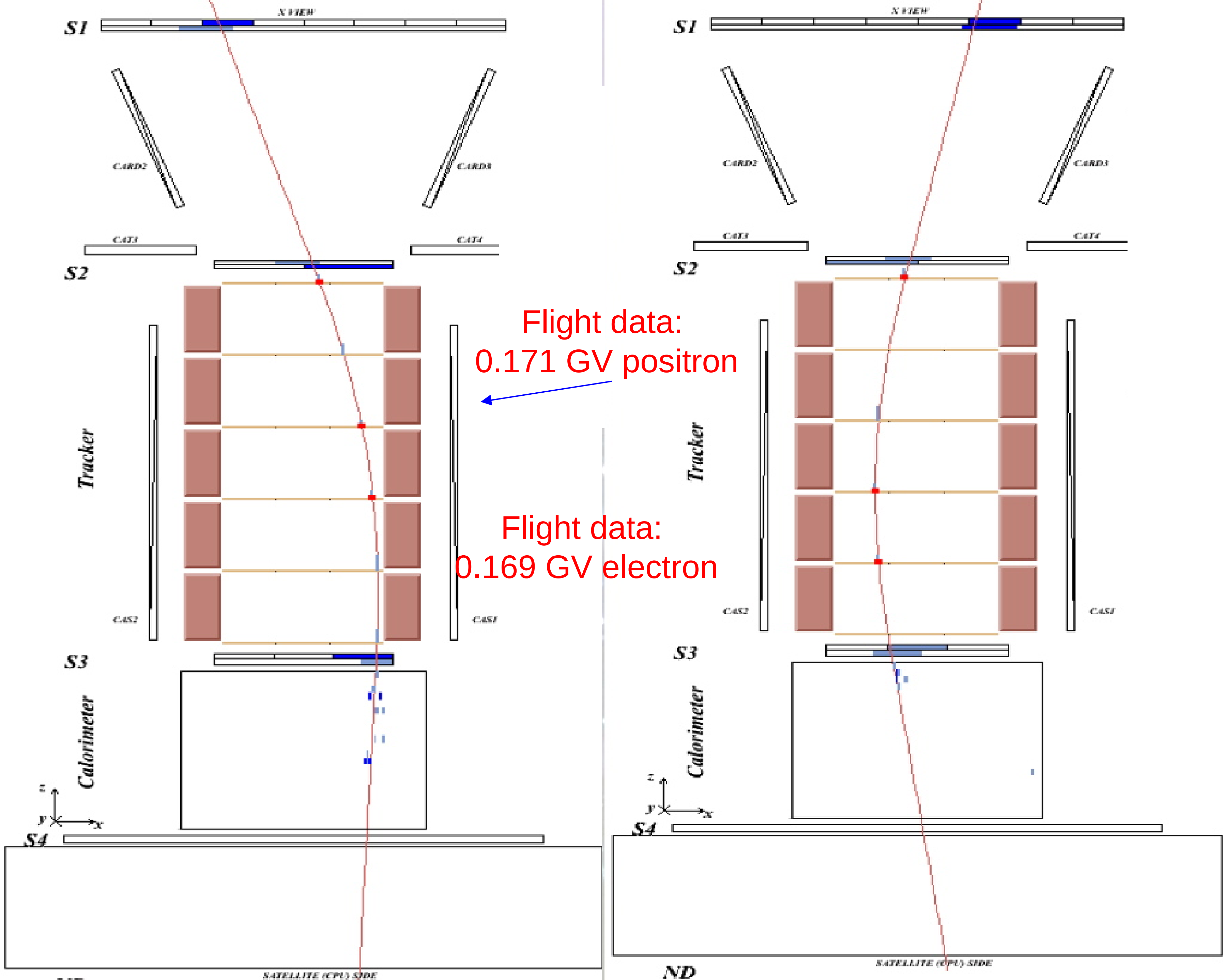
Primary production from $\chi\chi$ annihilation
($m(\chi)$ = ~ 1 TeV)
(astro-ph 9904086)

Secondary production
(CAPRICE94-based)
Bergström et al.

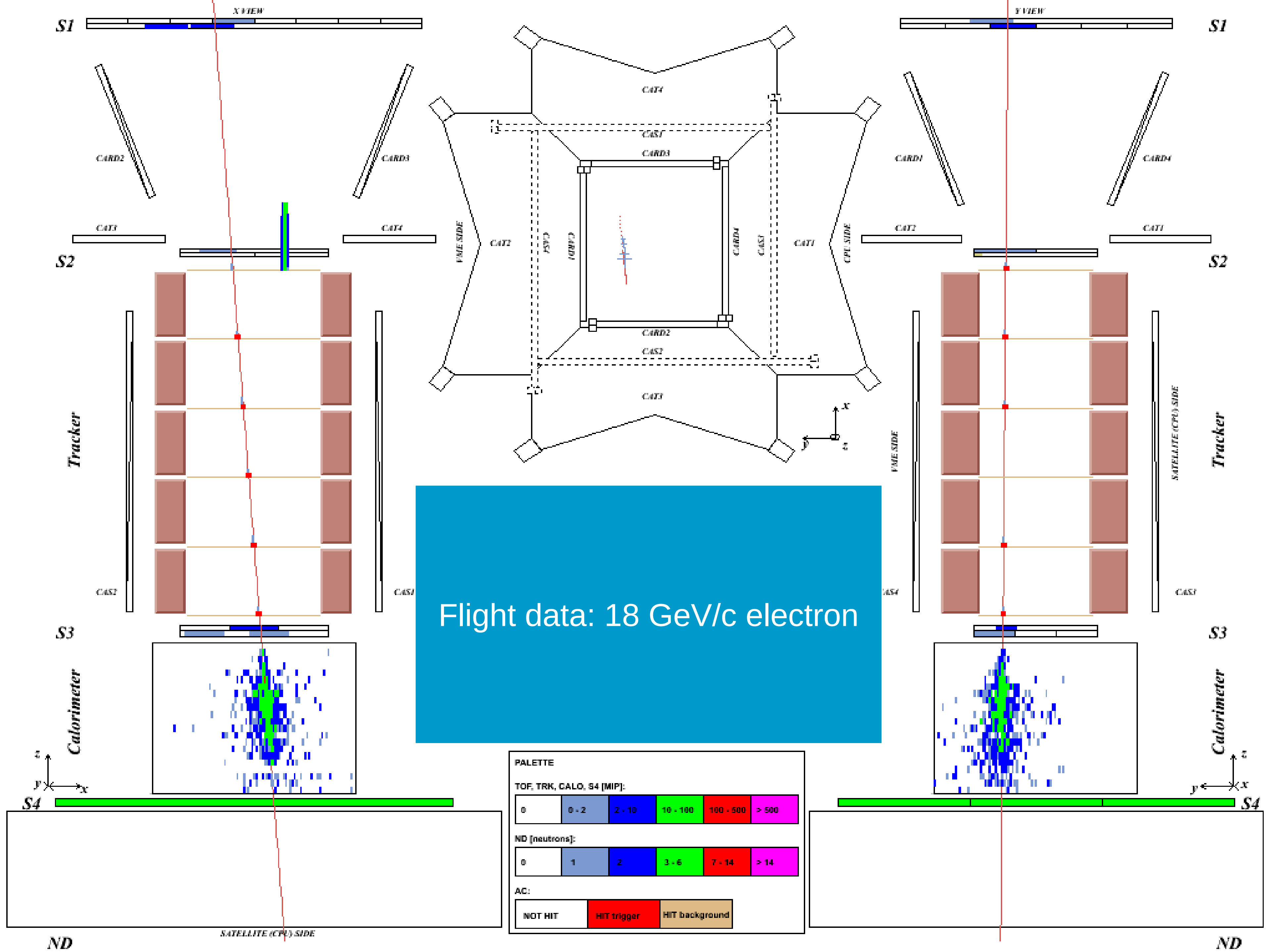
Distortion of the secondary positron fraction induced by a signal from a heavy neutralino.

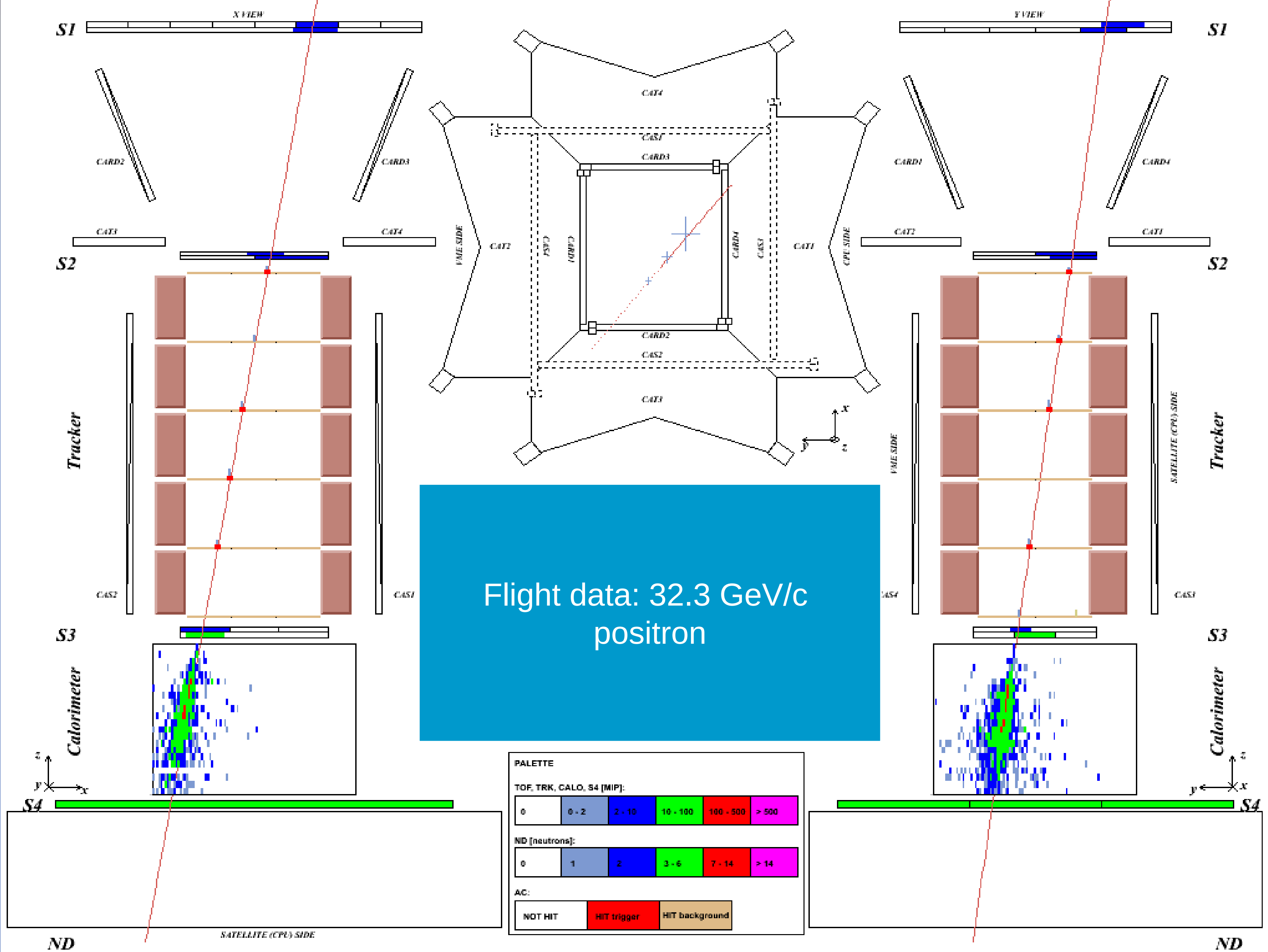


Baltz & Edsjö
Phys.Rev. D59 (1999)
astro-ph 9808243

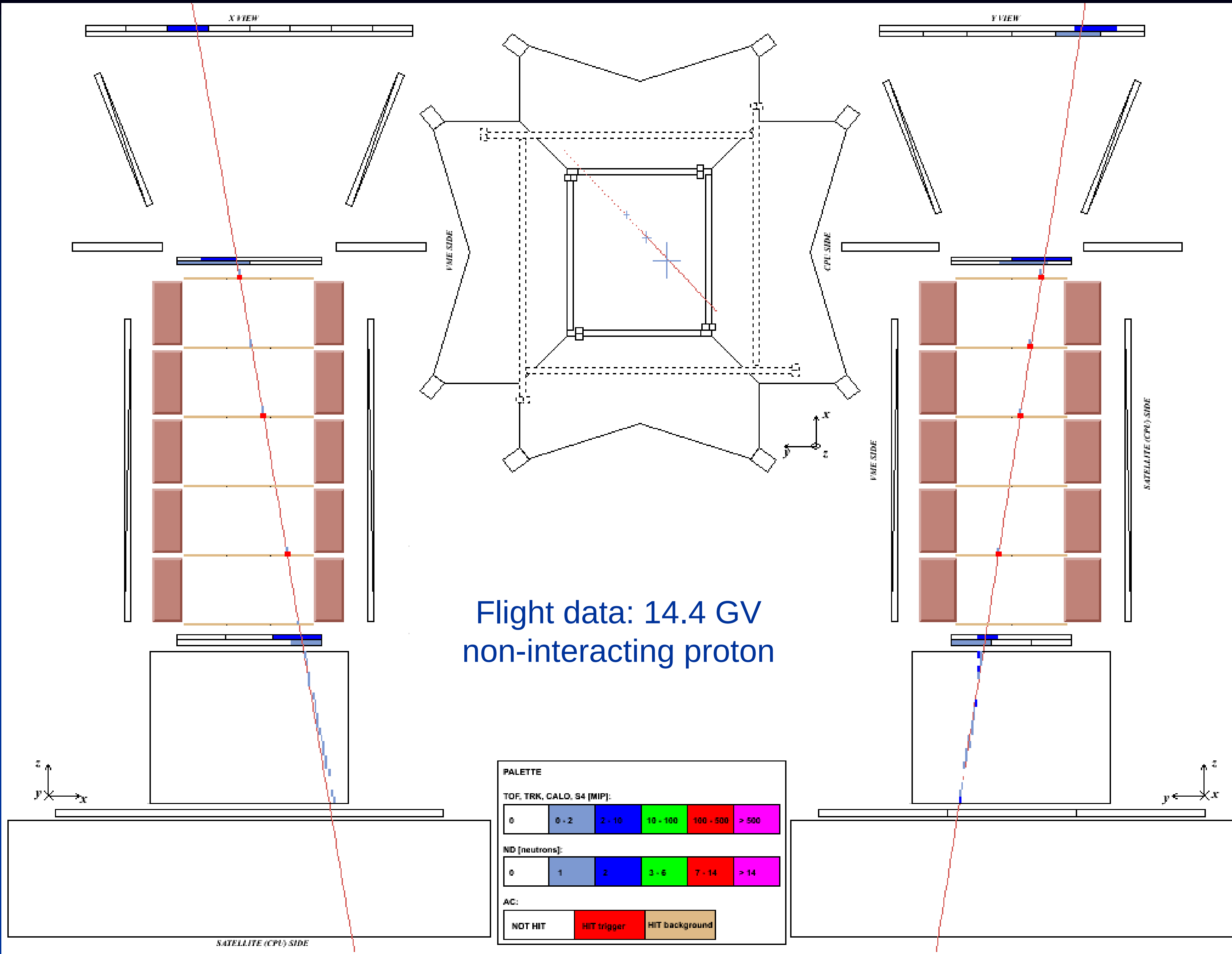

Flight data:
0.171 GV positron
Flight data:
0.169 GV electron
S1
X VIEW
CARD2
CARD3
CAT3
CAT4
S2
Tracker
CAS2
CAS1
S3
Calorimeter
S4
SATELLITE (CPU) SIDE
ND
S1
X VIEW
CARD2
CARD3
CAT3
CAT4
S2
Tracker
CAS2
CAS1
S3
Calorimeter
S4
SATELLITE (CPU) SIDE
ND

Flight data: 18 GeV/c electron

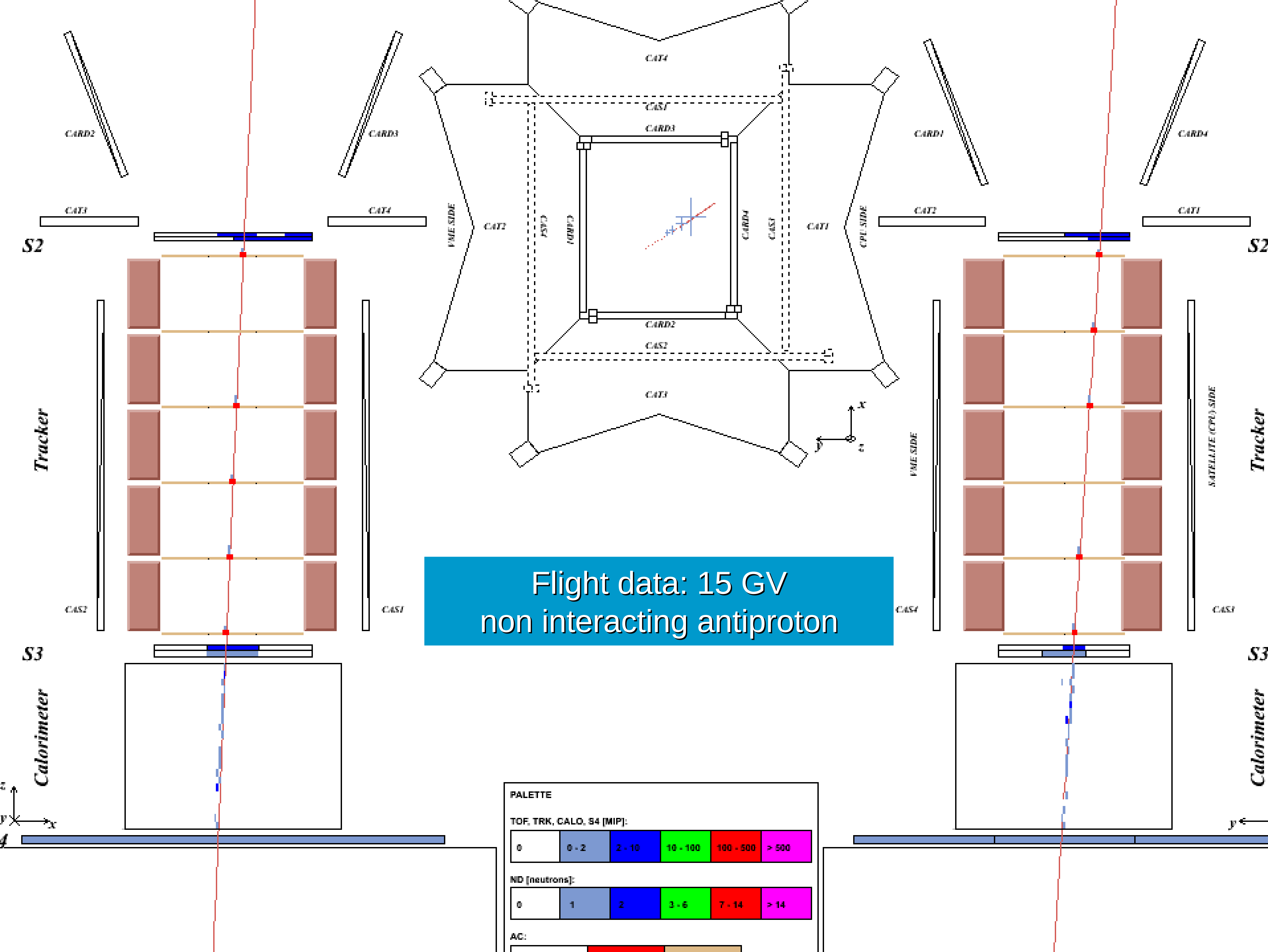




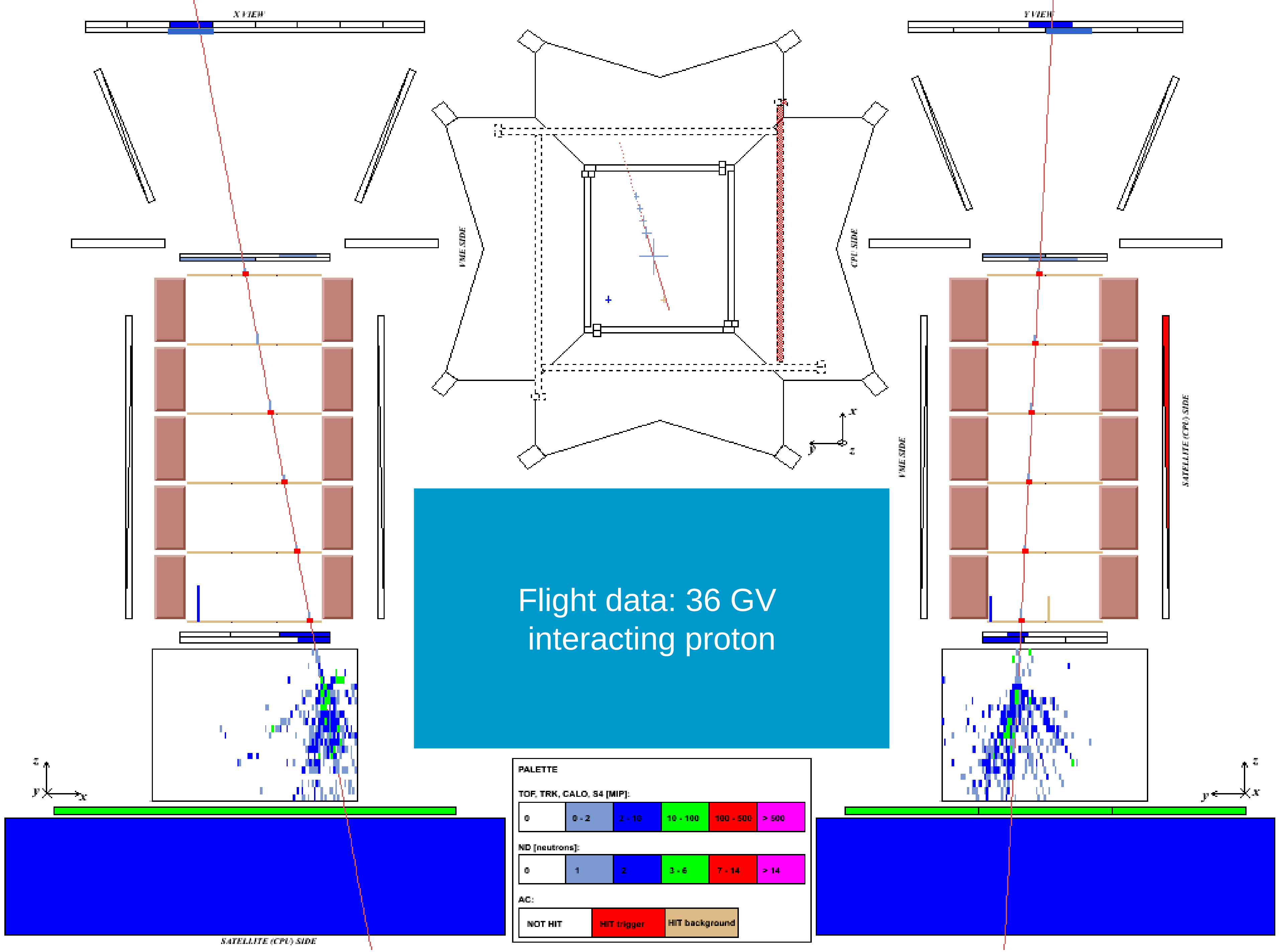
Flight data: 32.3 GeV/c positron

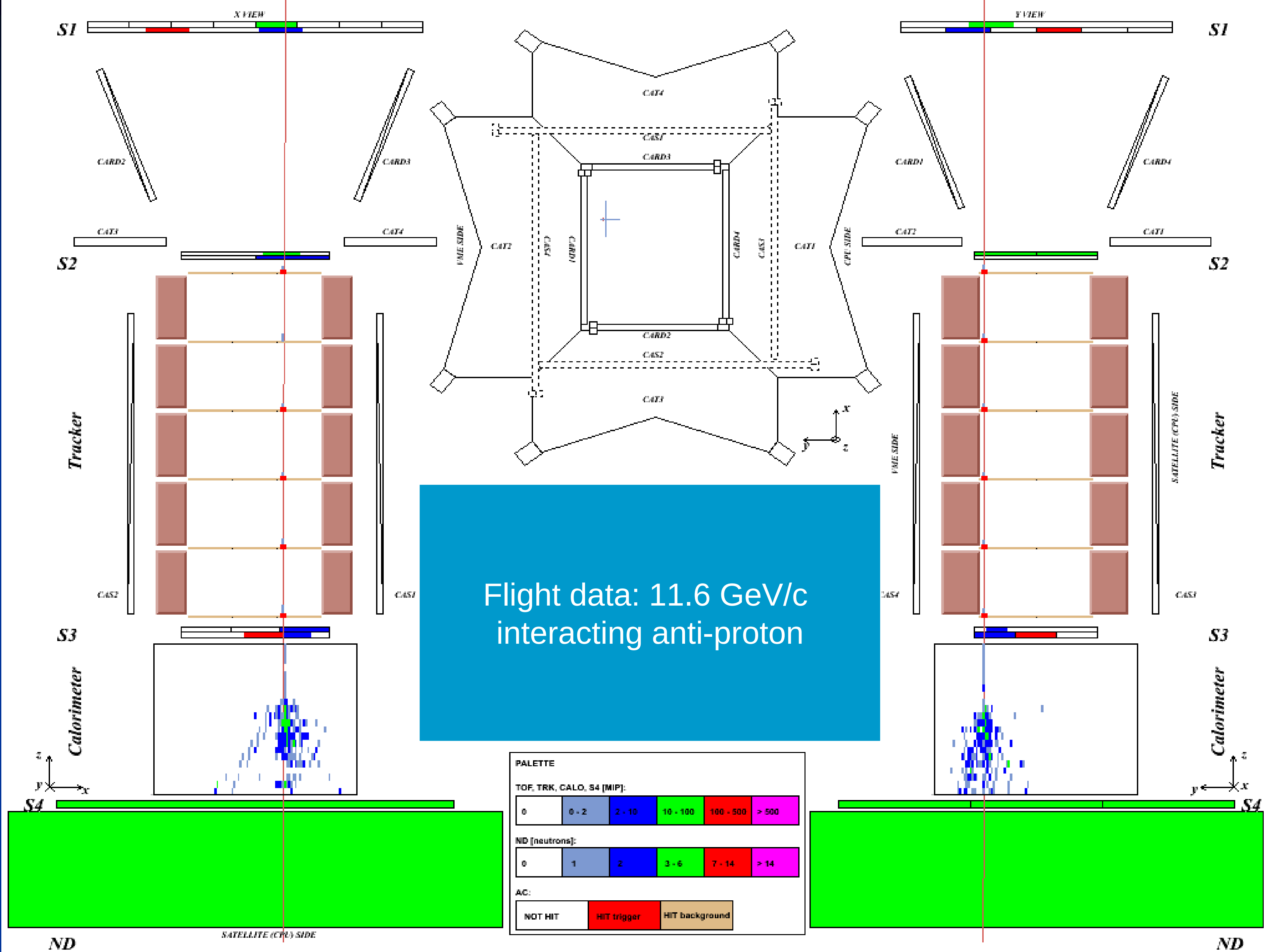


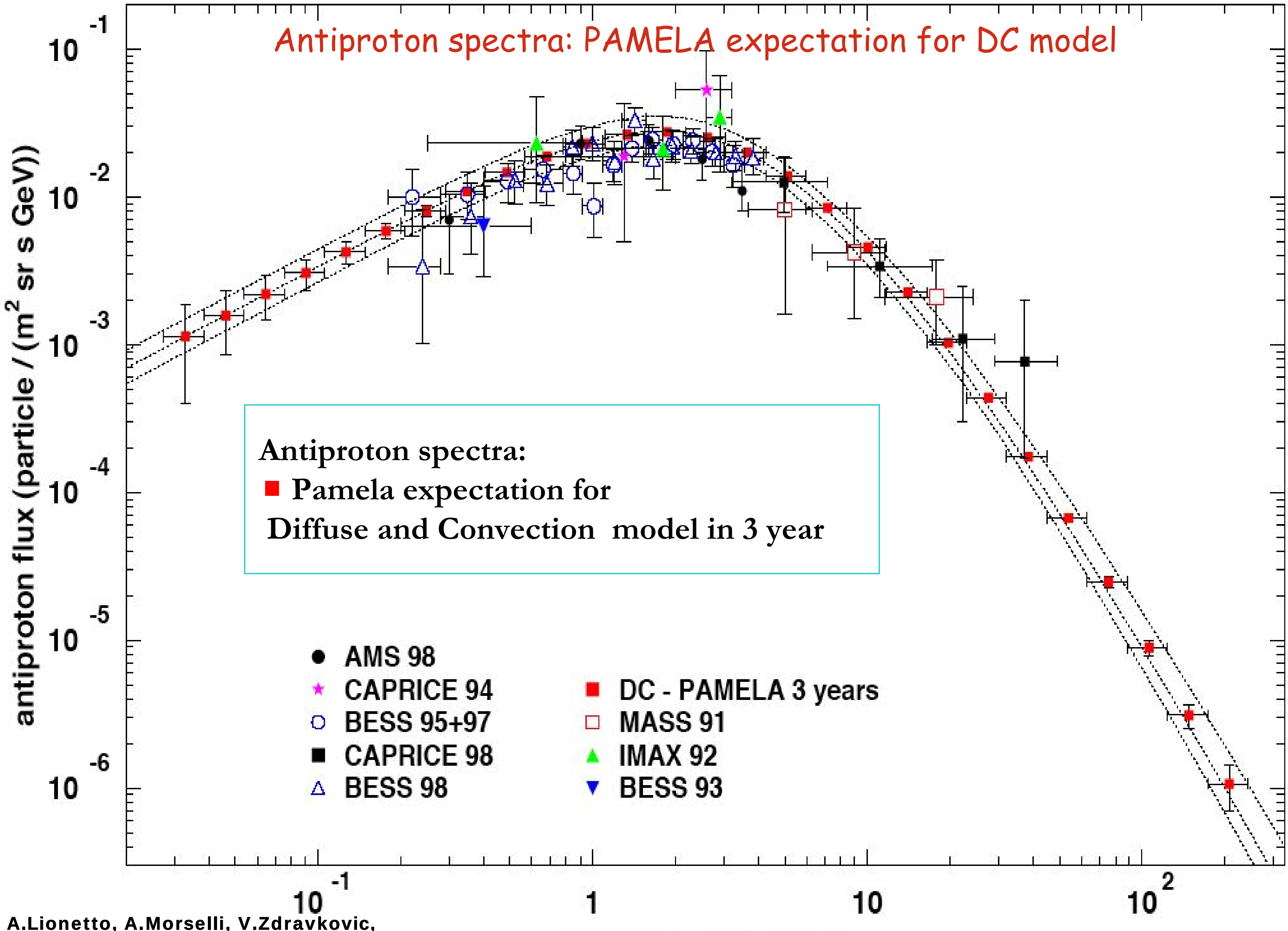
Flight data: 14.4 GV
non-interacting proton


Flight data: 15 GV
non interacting antiproton
S2
Tracker
S3
Calorimeter
CARD2
CARD3
CAT3
CAT4
CAS2
CAS1
CAT4
CAS1
CARD3
CAT2
CARD1
CARD4
CAS4
CAS3
CAT1
CARD2
CAS2
CAT3
VME SIDE
CPU SIDE
CARD1
CARD4
CAT2
CAT1
SATELLITE (CPU) SIDE
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:

Flight data: 36 GV interacting proton

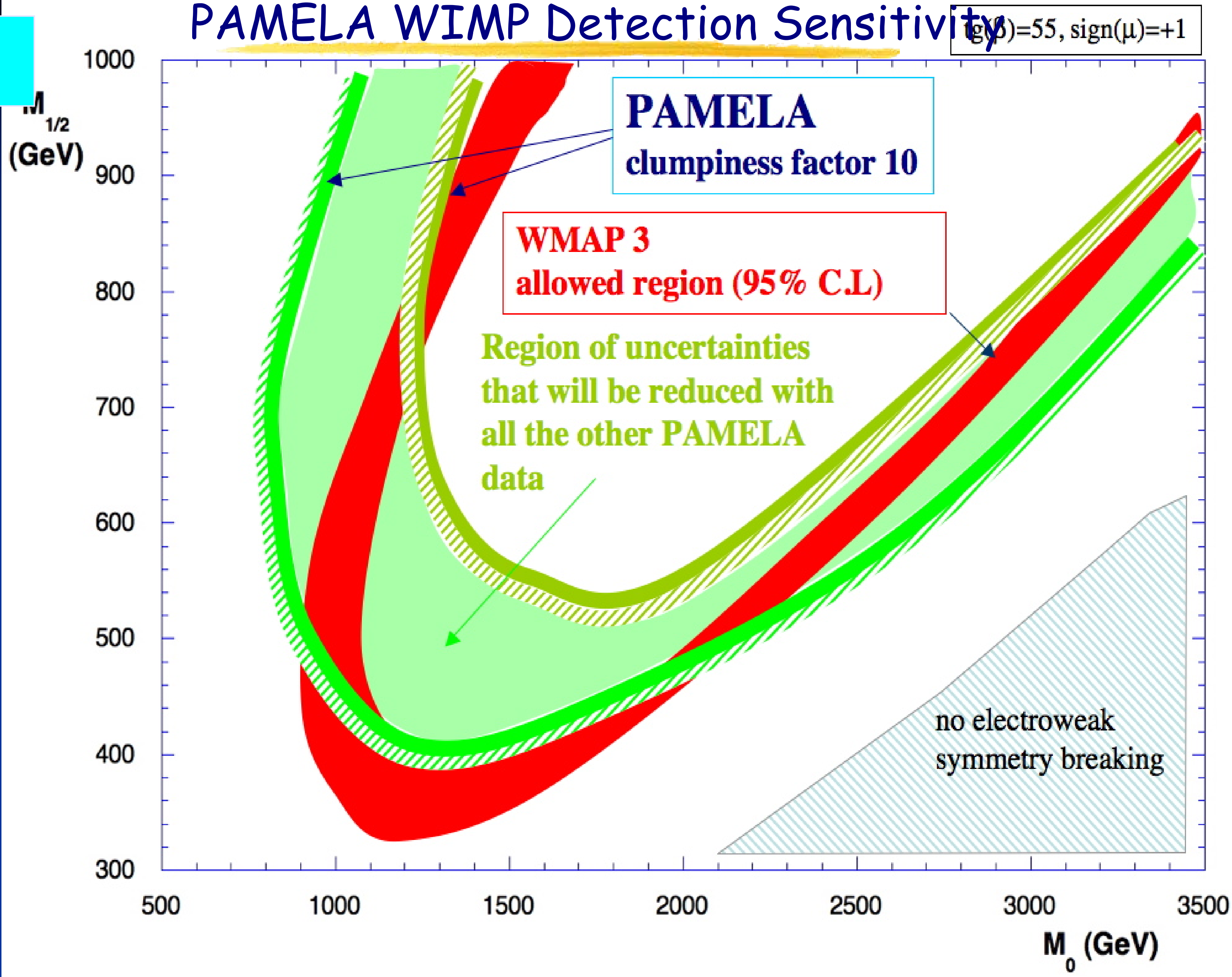



X VIEW
Y VIEW
S1
S2
S3
S4
ND
Tracker
Calorimeter
CARD1
CARD2
CARD3
CARD4
CAT1
CAT2
CAT3
CAT4
CAS1
CAS2
CAS3
CAS4
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
Flight data: 11.6 GeV/c
interacting anti-proton
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background



A.Lionetto, A.Morselli, V.Zdravkovic, JCAP09(2005)010 mSUGRA

PAMELA WIMP Detection Sensitivity



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

loss term: fragmentation

coefficient in the impulse space, quasi-linear MHD:

loss term: radioactive decay

diffusion coefficient is function of rigidity

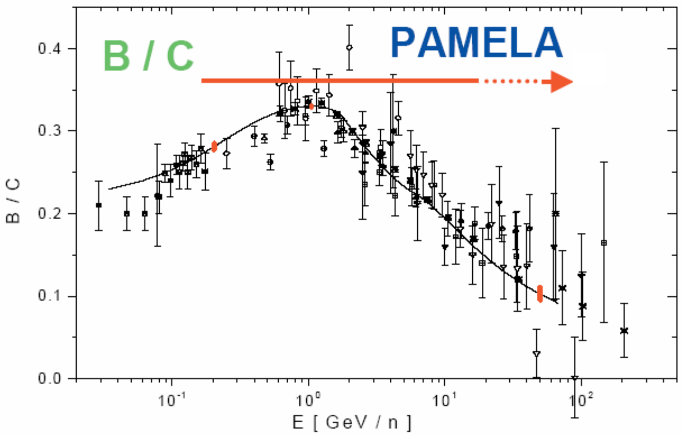
$$D_{xx} = \beta D_0(\rho/\rho_0)^{\delta}$$

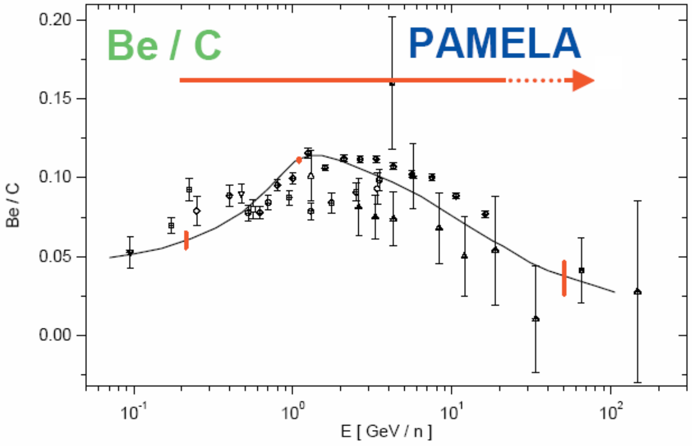
primary spectra injection index

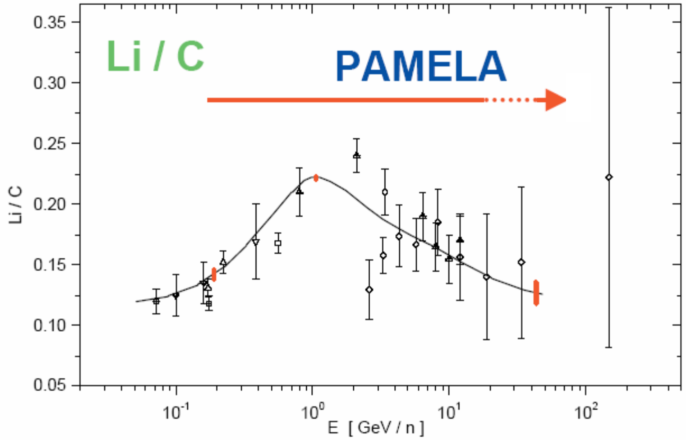
$$dq(p)/dp \propto p^{-\gamma}$$

implemented in Galprop (Strong & Moskalenko, available on the Web)

Secondary to Primary ratios

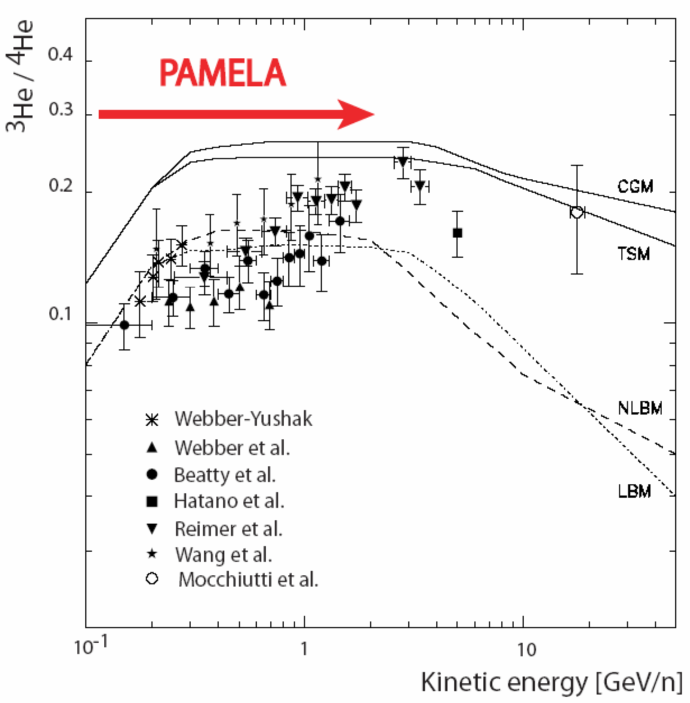




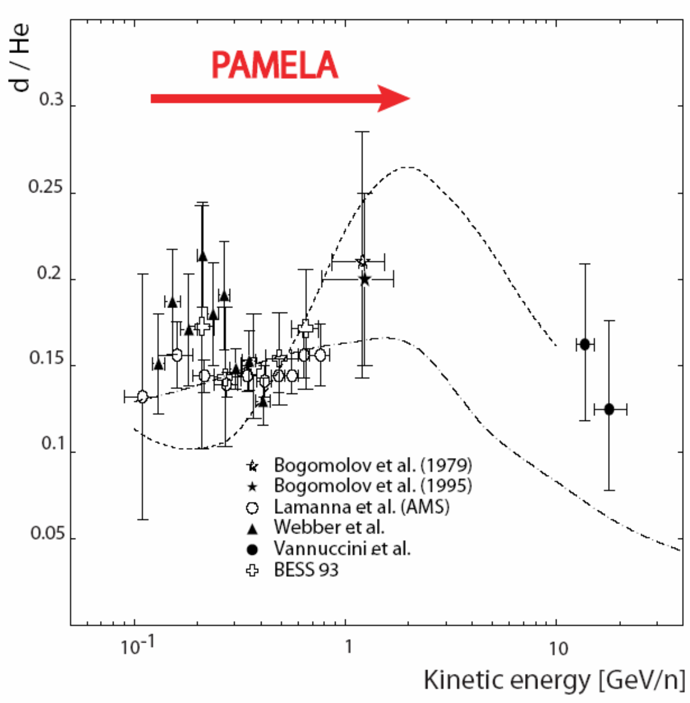


Helium and Hydrogen Isotopes

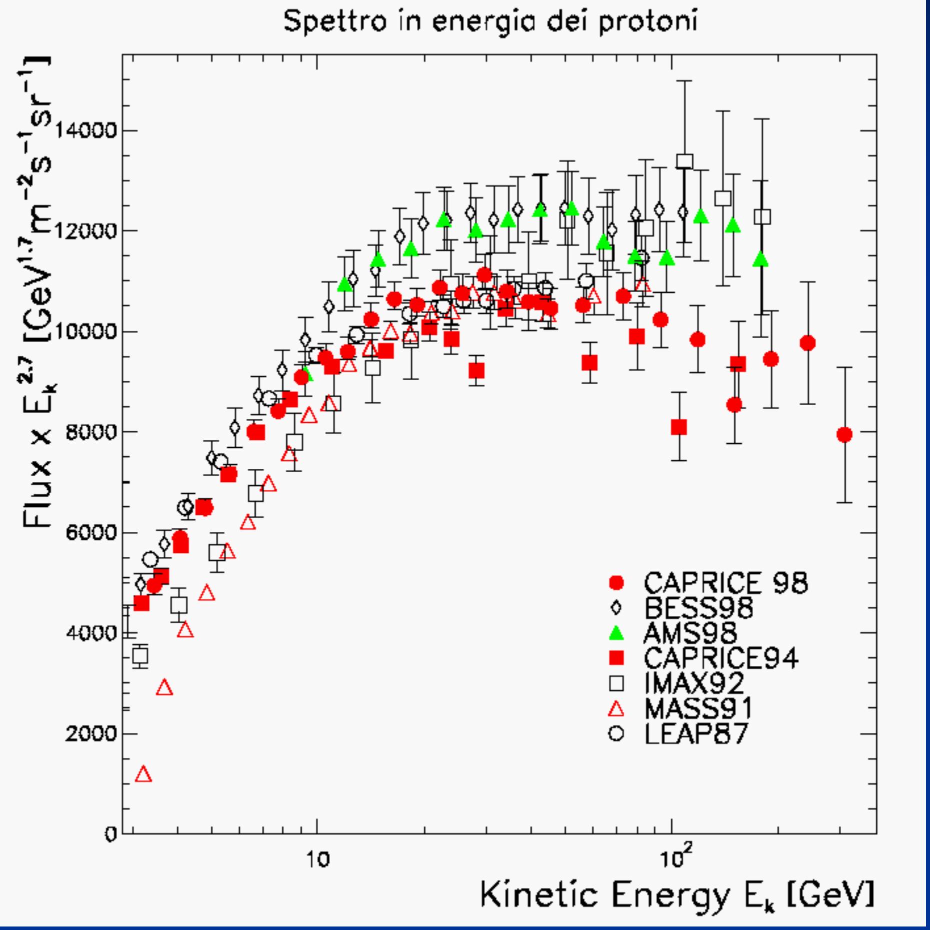
The current situation of the 3He / 4He ratio



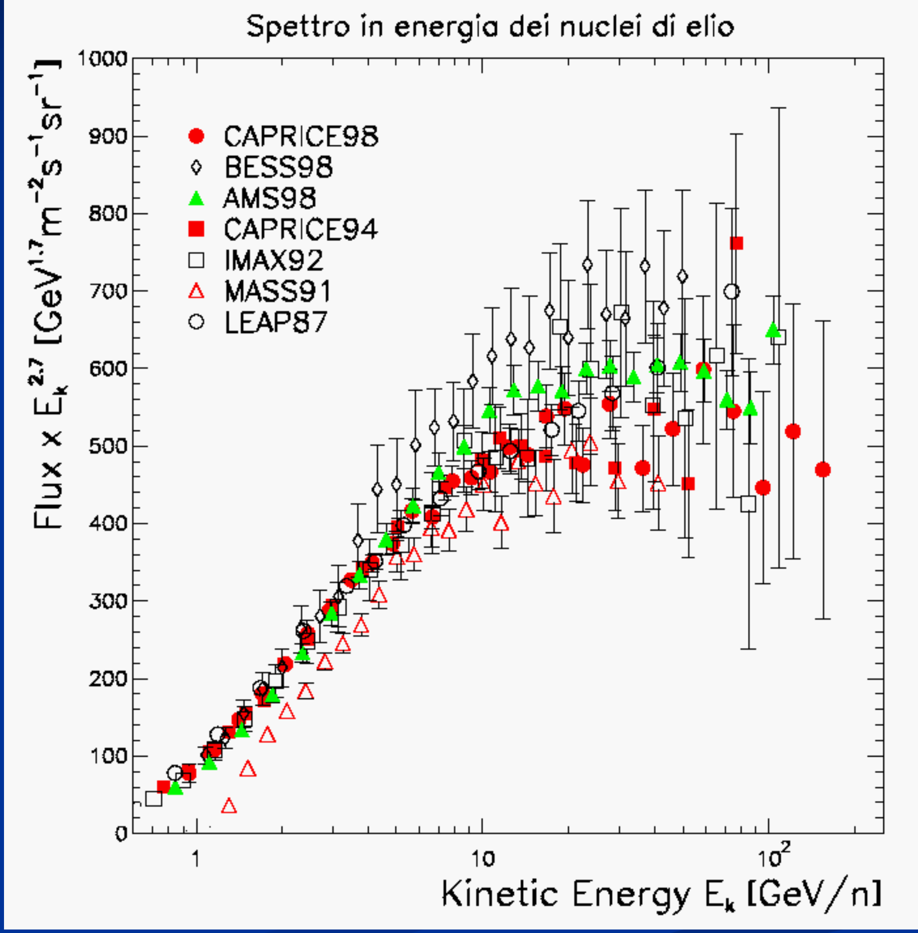
The current situation of the d / He ratio

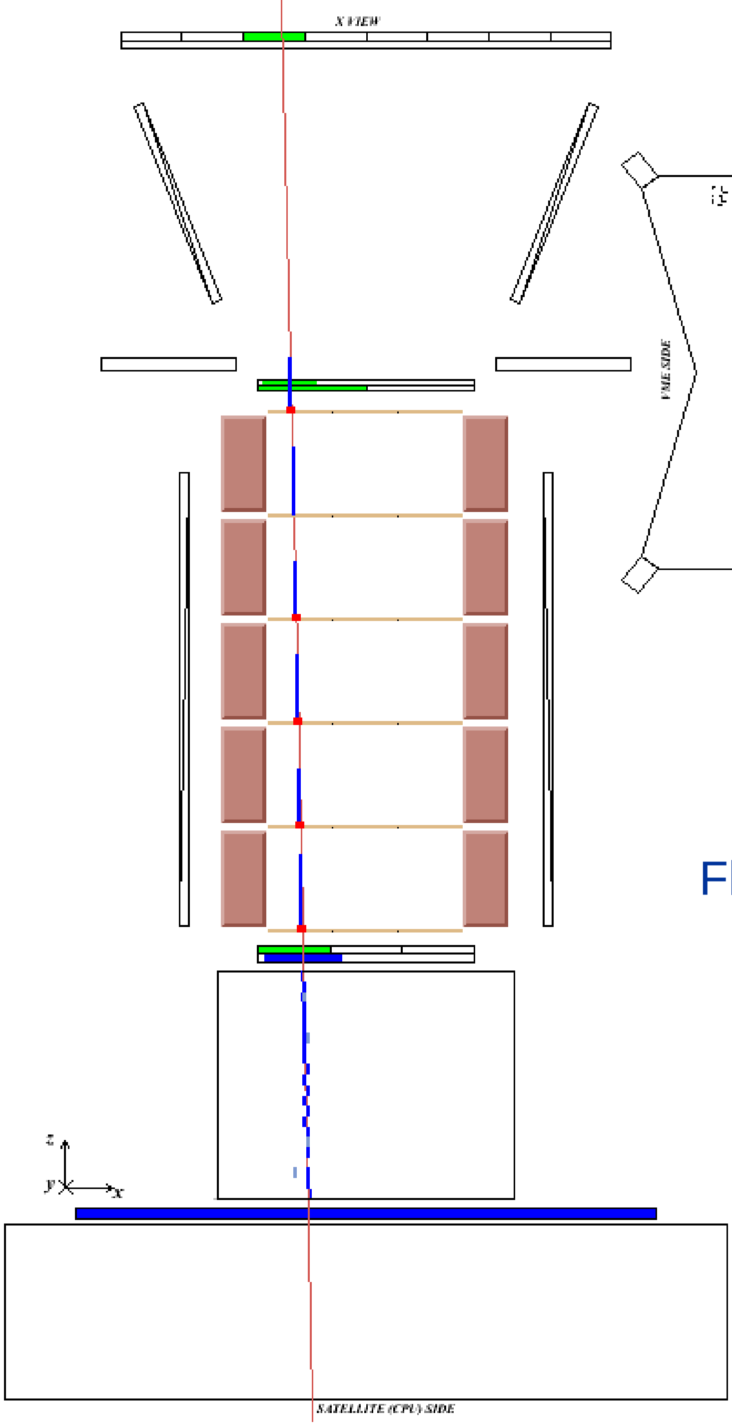


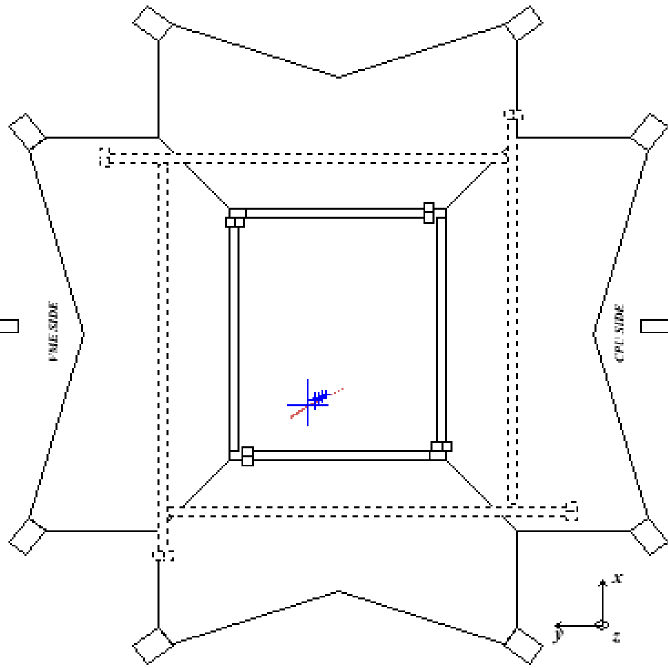
Protons

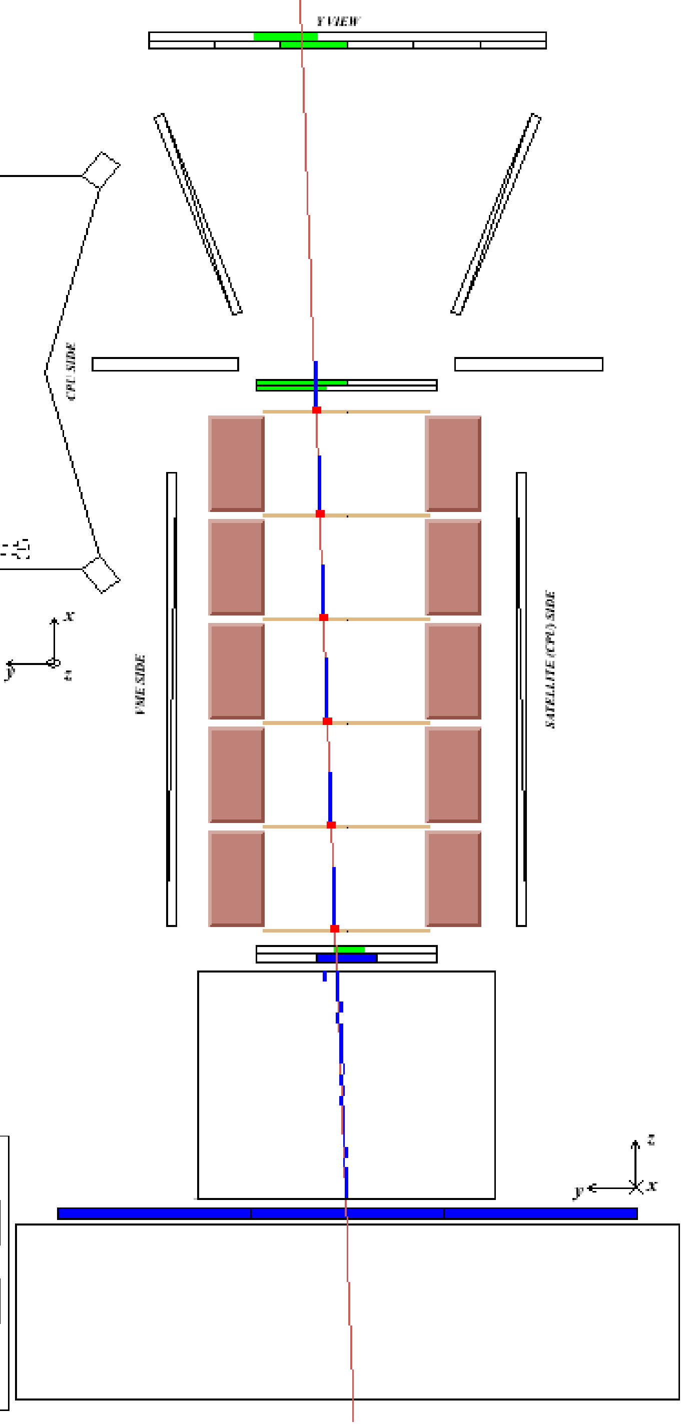


Helium

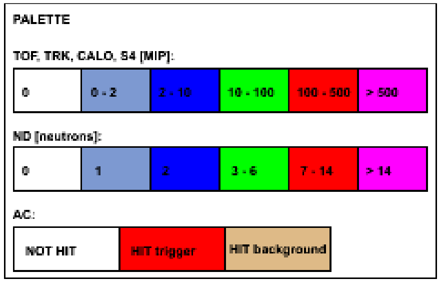


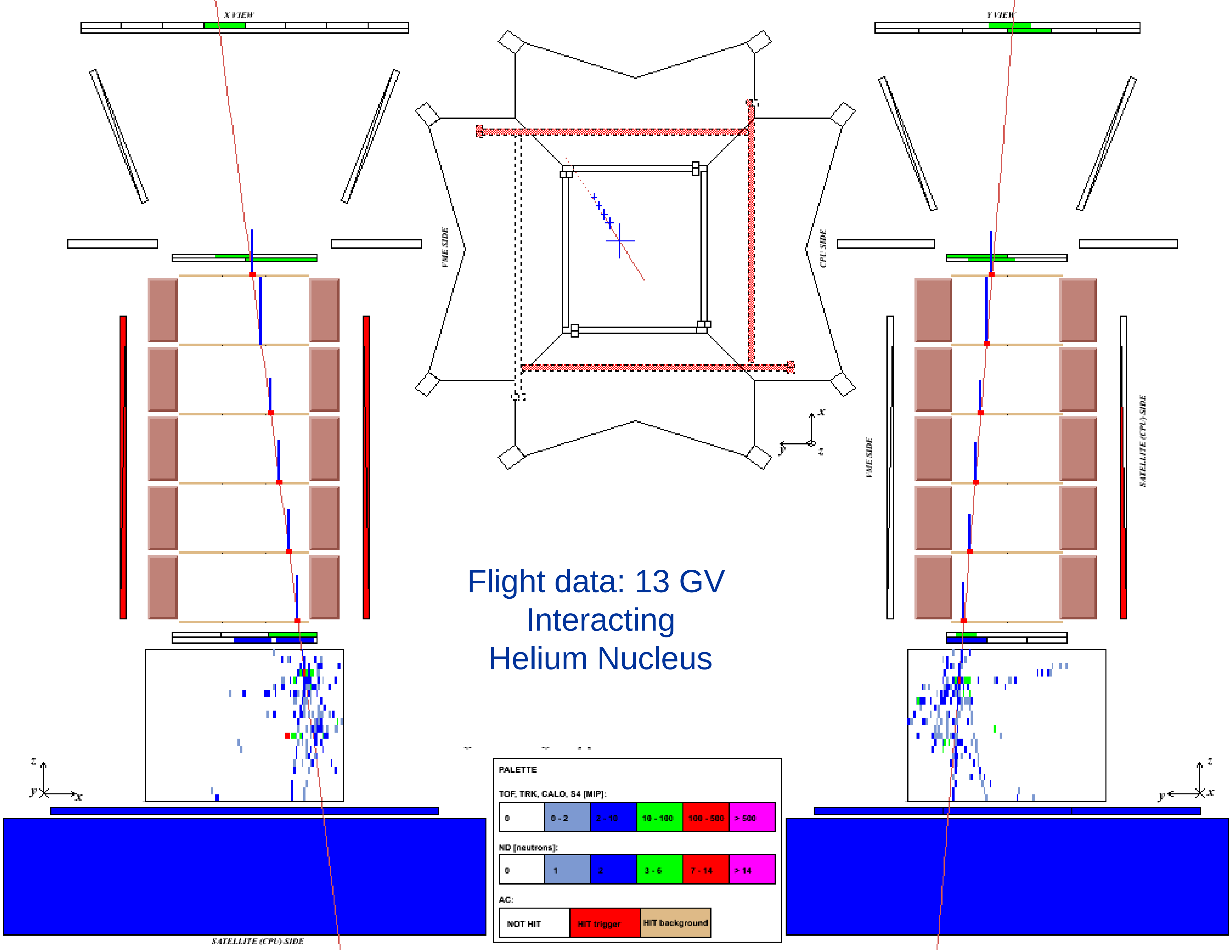




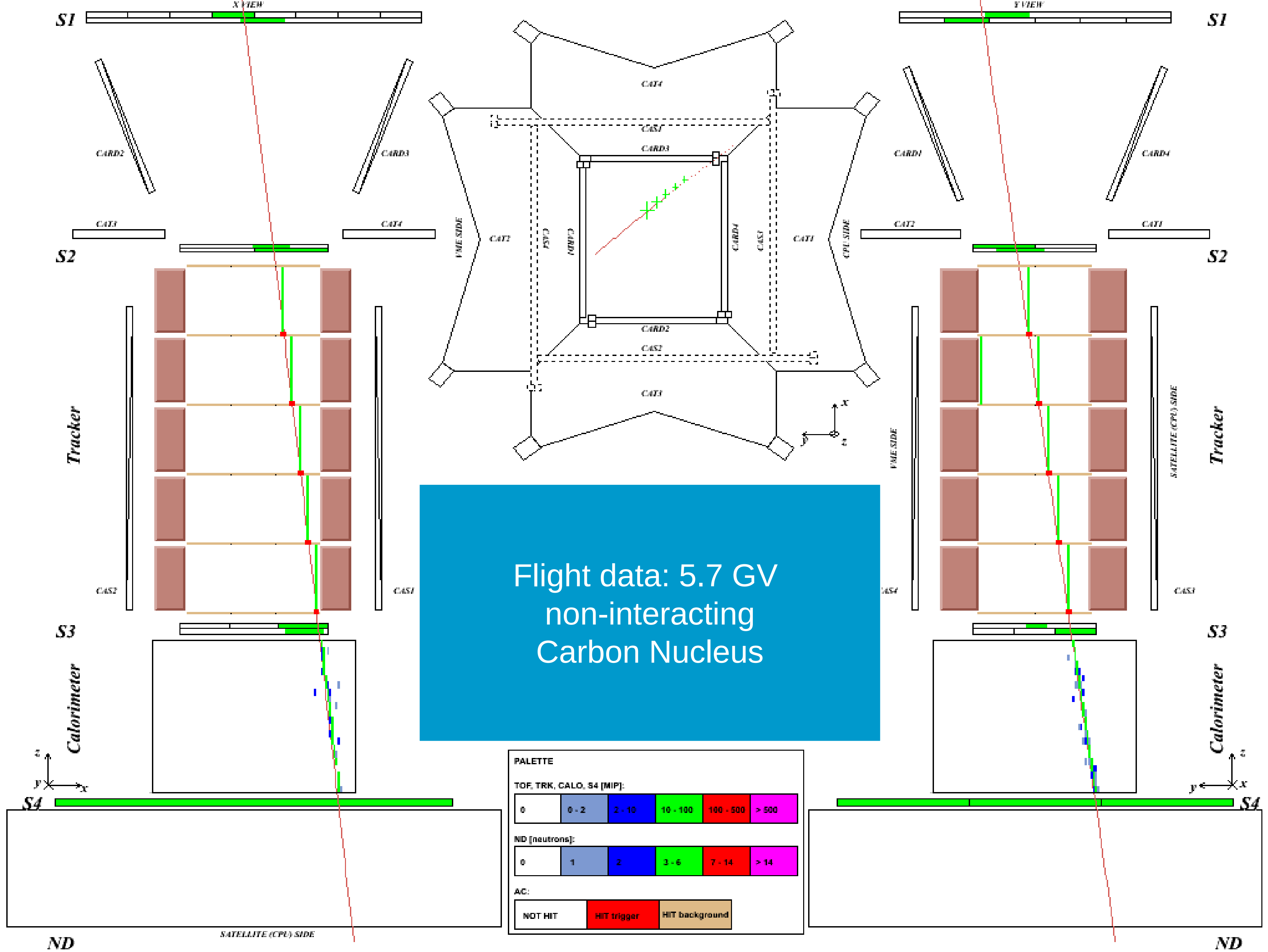


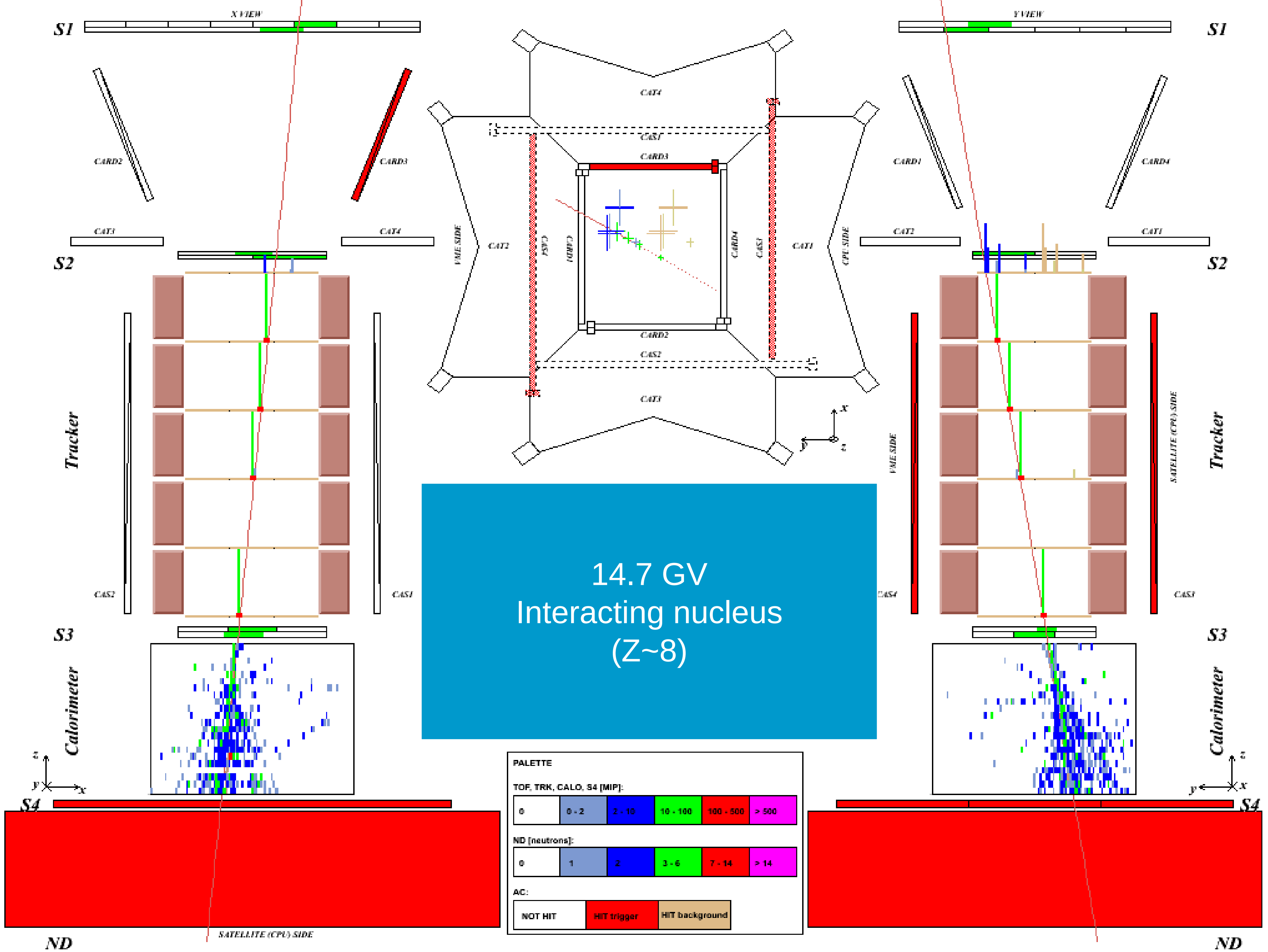
Flight data: 9.7 GV non-interacting Helium Nucleus

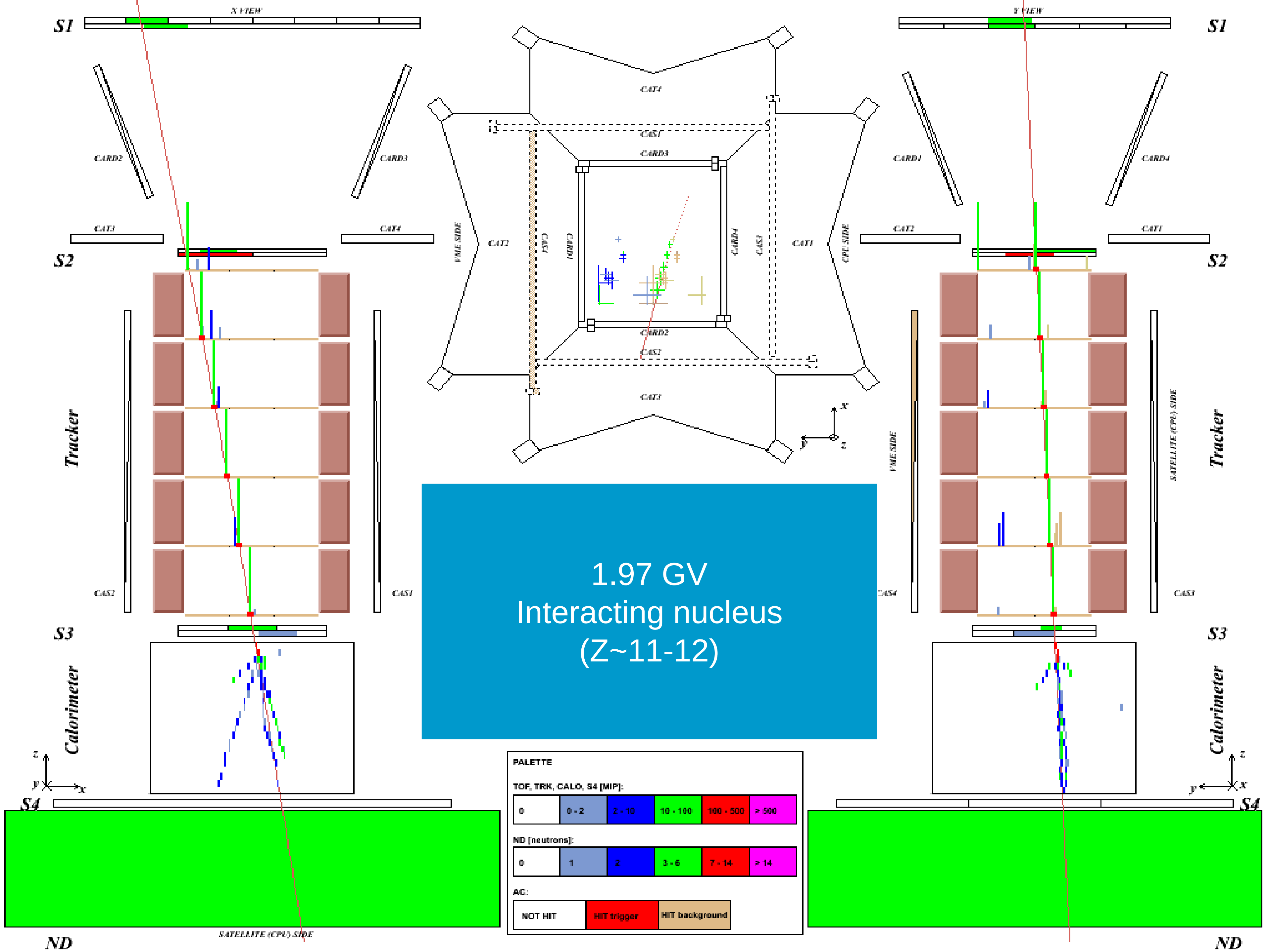


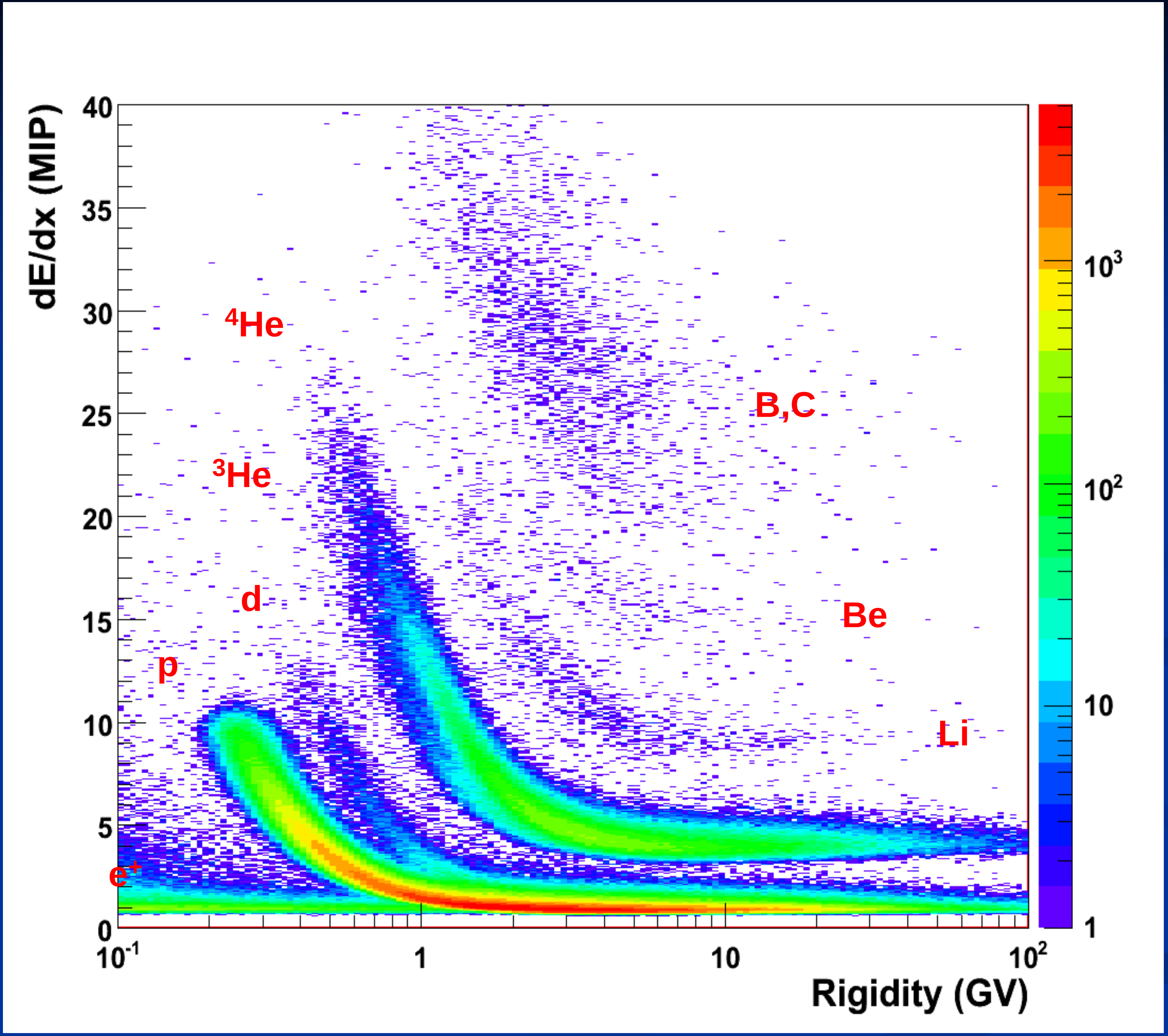


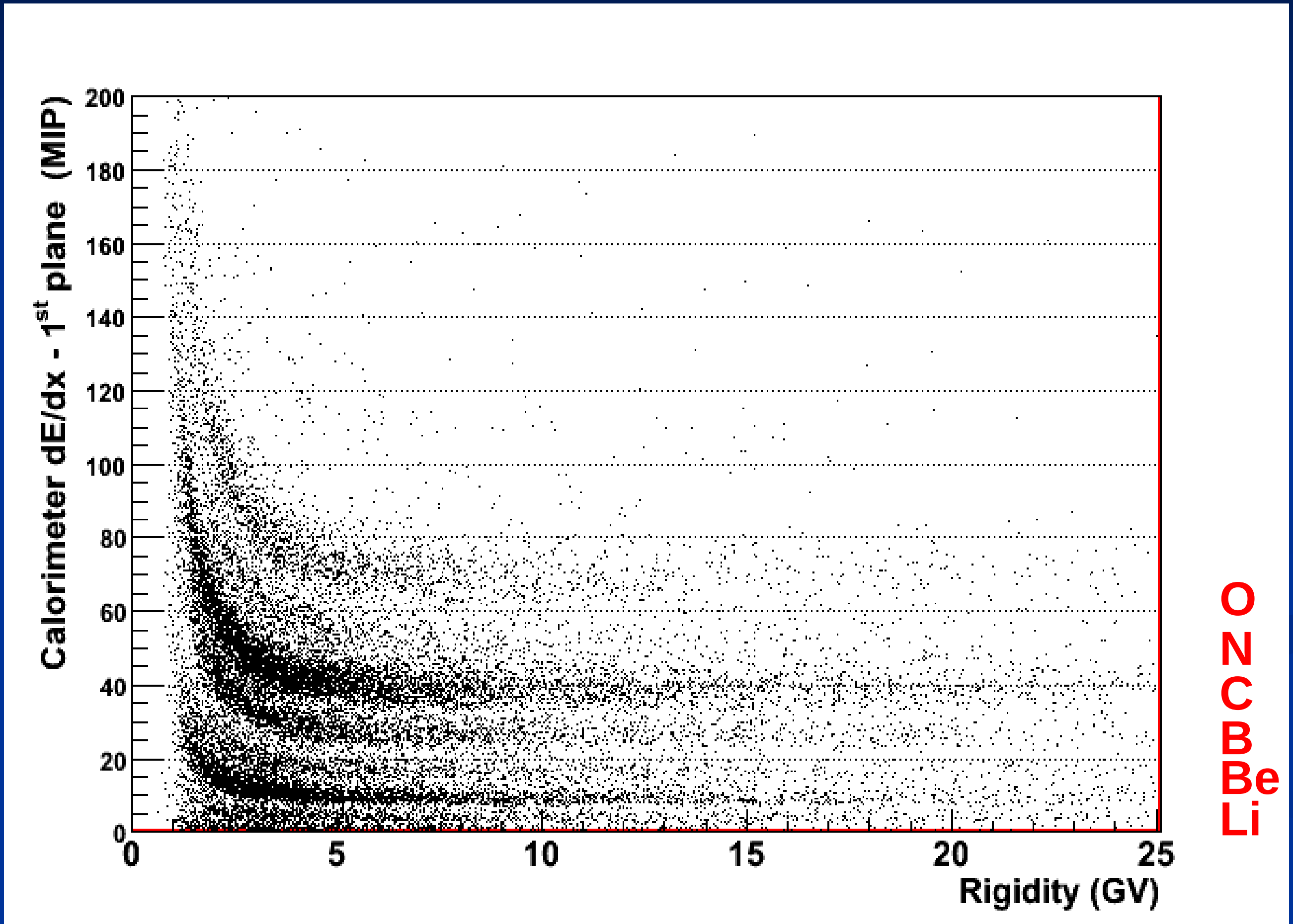
Flight data: 13 GV Interacting Helium Nucleus


Flight data: 5.7 GV non-interacting Carbon Nucleus
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
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


14.7 GV
Interacting nucleus
(Z~8)
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
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

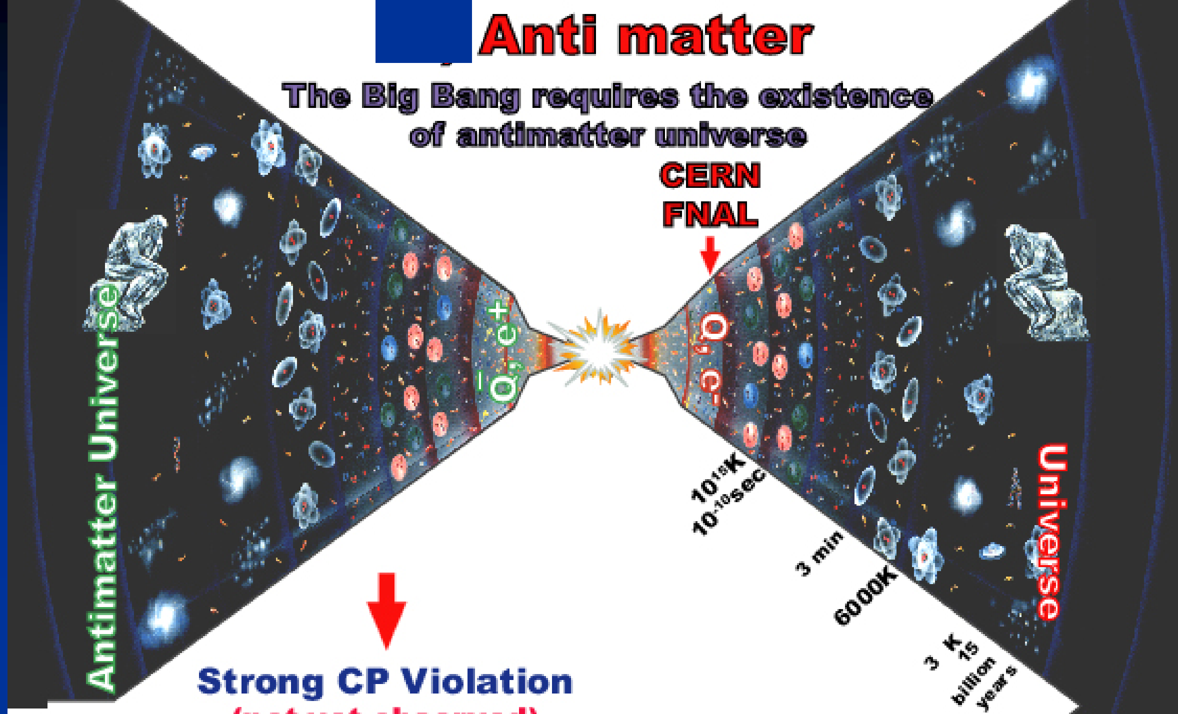

1.97 GV
Interacting nucleus
(Z~11-12)
X VIEW
Y VIEW
S1
S2
S3
S4
ND
Tracker
Calorimeter
CARD1
CARD2
CARD3
CARD4
CAT1
CAT2
CAT3
CAT4
CAS1
CAS2
CAS3
CAS4
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background


dE/dx (MIP)
40
35
30
25
20
15
10
5
0
^{4}He
^{3}He
d
p
e^+
B,C
Be
Li
10^{-1}
1
10
10^2
Rigidity (GV)
10^3
10^2
10
1

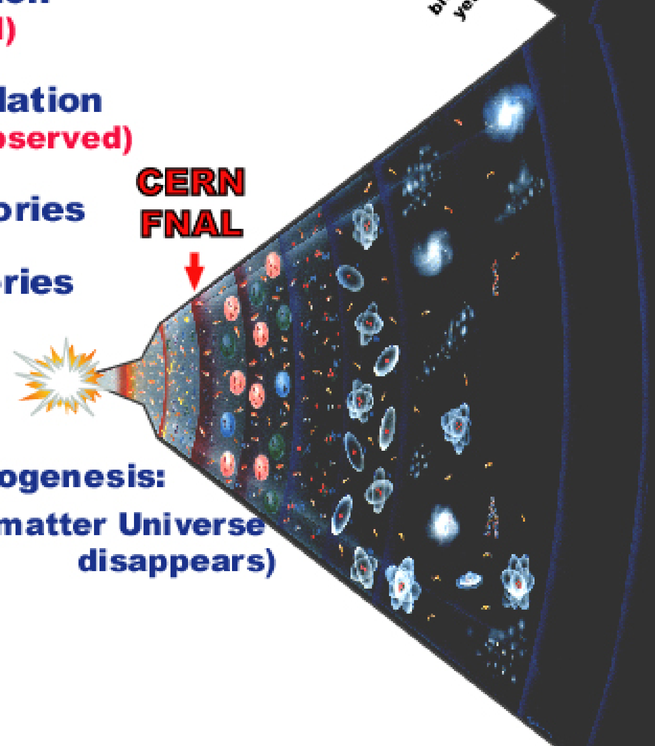

Calorimeter dE/dx - 1st plane (MIP)
Rigidity (GV)
0
5
10
15
20
25
200
180
160
140
120
100
80
60
40
20
0
O
N
C
B
Be
Li

Anti matter

The Big Bang requires the existence of antimatter universe



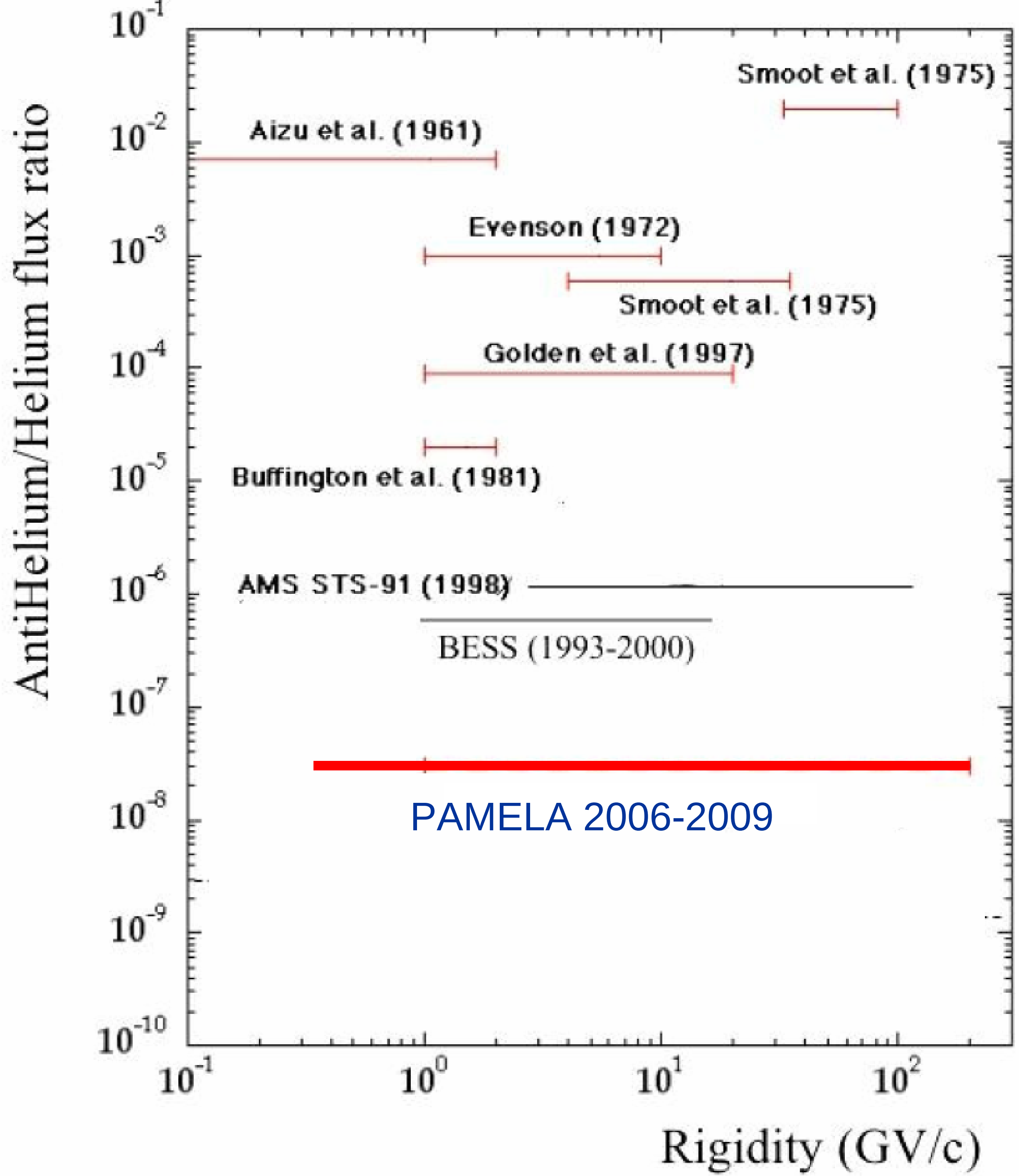
Strong CP Violation
(not yet observed)
and
Baryon Number Violation
(Proton decay not yet observed)
Then
Grand Unified Theories
or
Electroweak Theories
predicts

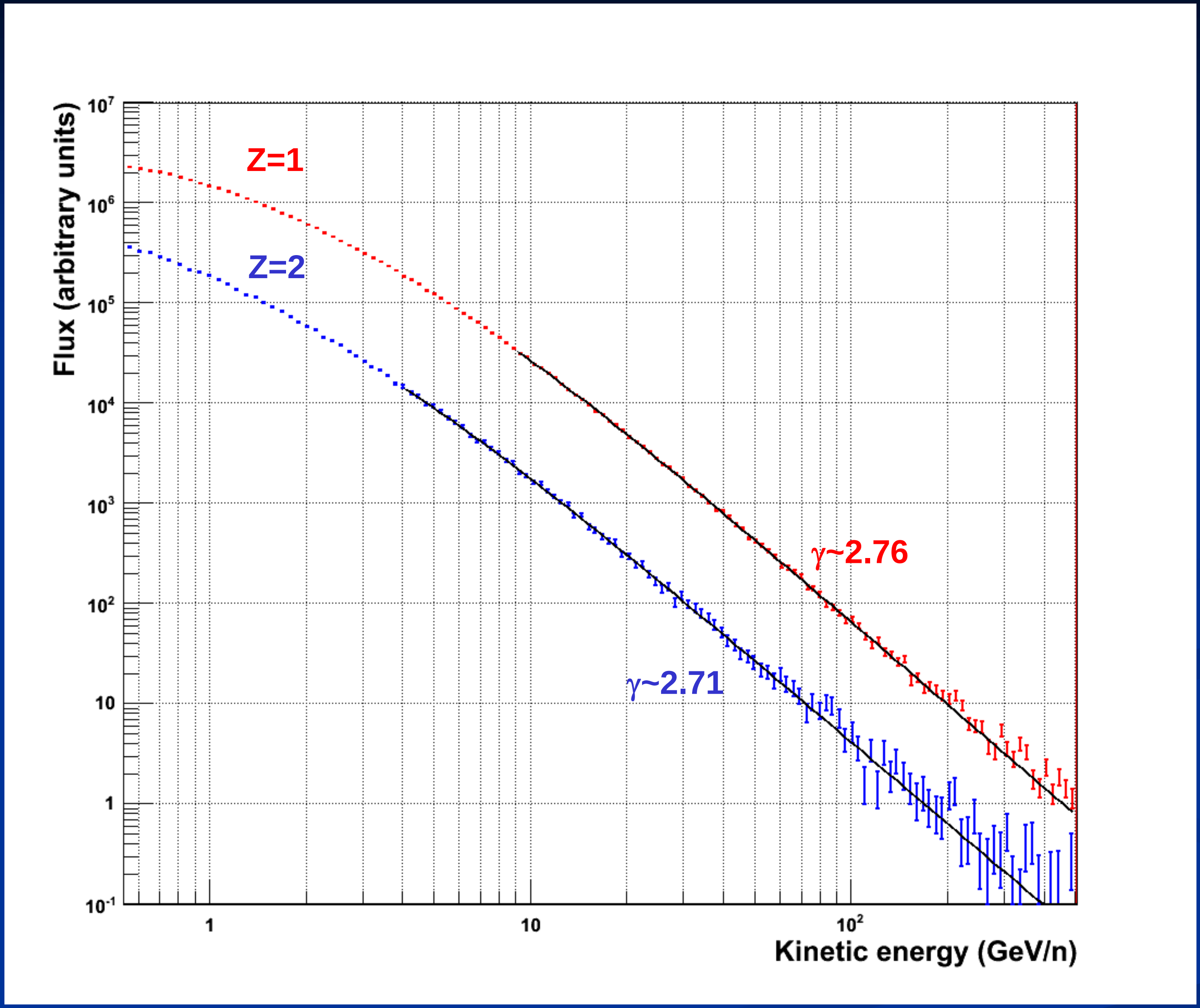


Magnetic Monopole
or
Light Higgs
or
Massive neutrinos

Baryogenesis:
(Antimatter Universe disappears)

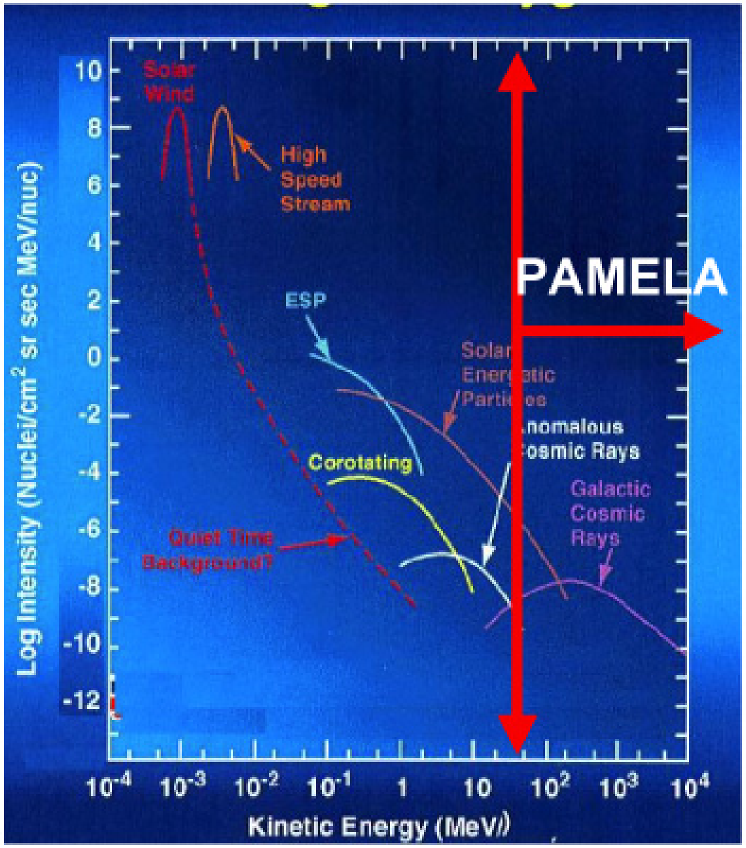
Cosmic-ray Antimatter Search





Flux (arbitrary units)
Kinetic energy (GeV/n)
Z=1
Z=2
γ~2.76
γ~2.71
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
1
10
10^2

Solar Physics with PAMELA



- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV)
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV)
- Nuclear composition of Gradual and Impulsive events
- ^3He and ^4He isotopic composition

Comparison of $\bar{p}/p$ ratio with model

Time variation of $\bar{p}/p$ ratio at solar maximum

Observed data by BESS

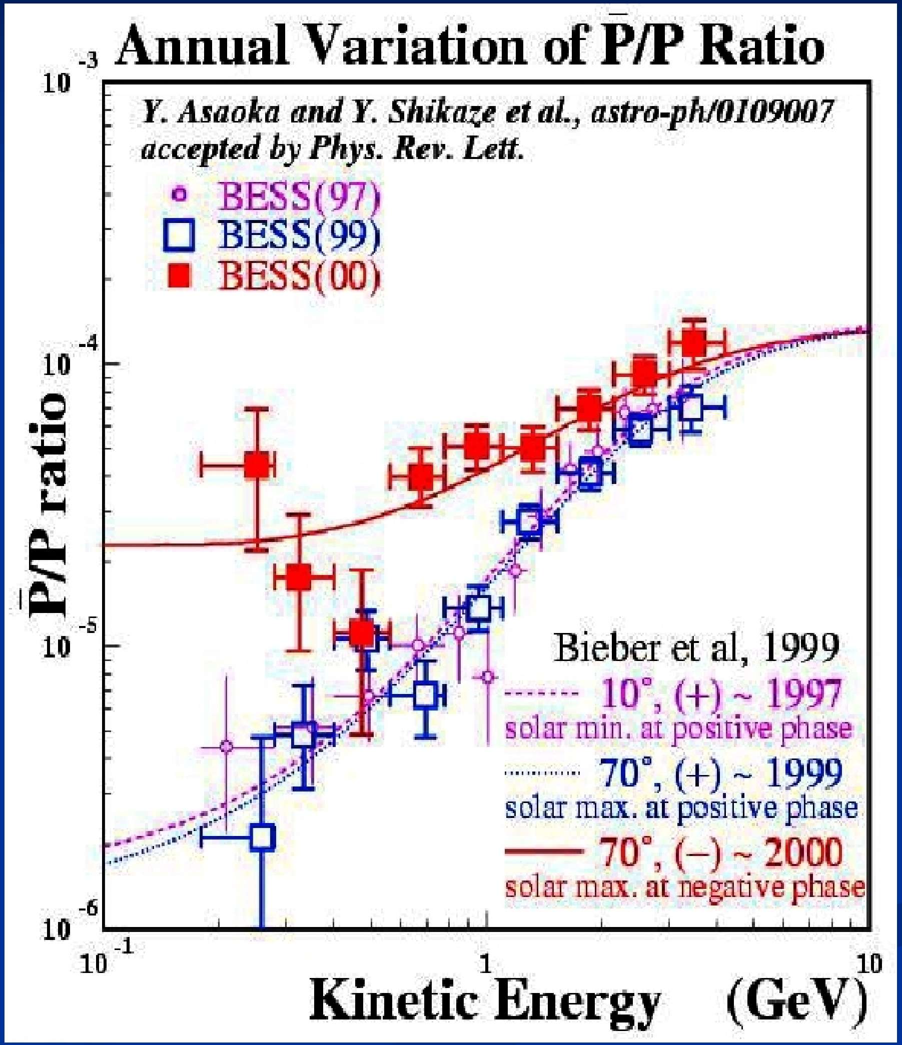
Charge dependent model

prediction(Bieber et al.)

Charge dependent solar modulation model well follows

the suddenly increase of $\bar{p}/p$ ratio observed by BESS

at the solar polarity reversal between 1999 and 2000



Comparison of $\bar{p}/p$ ratio with model

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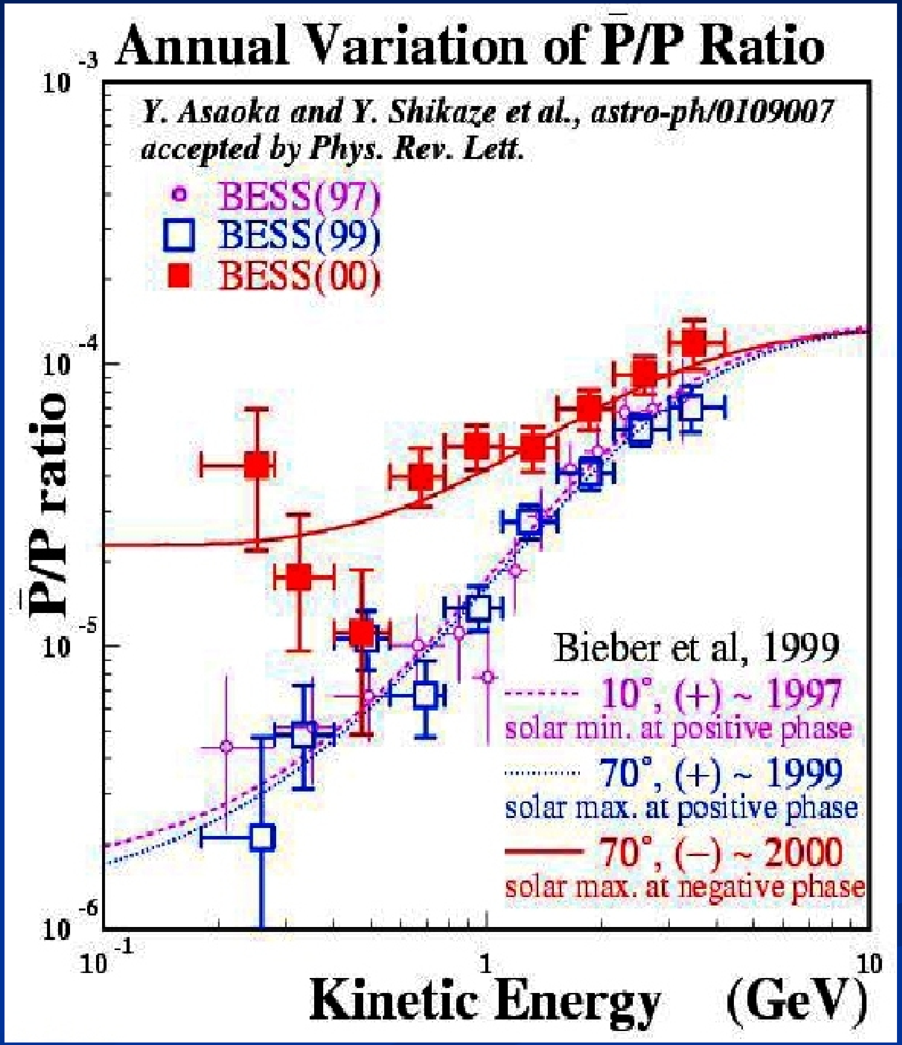
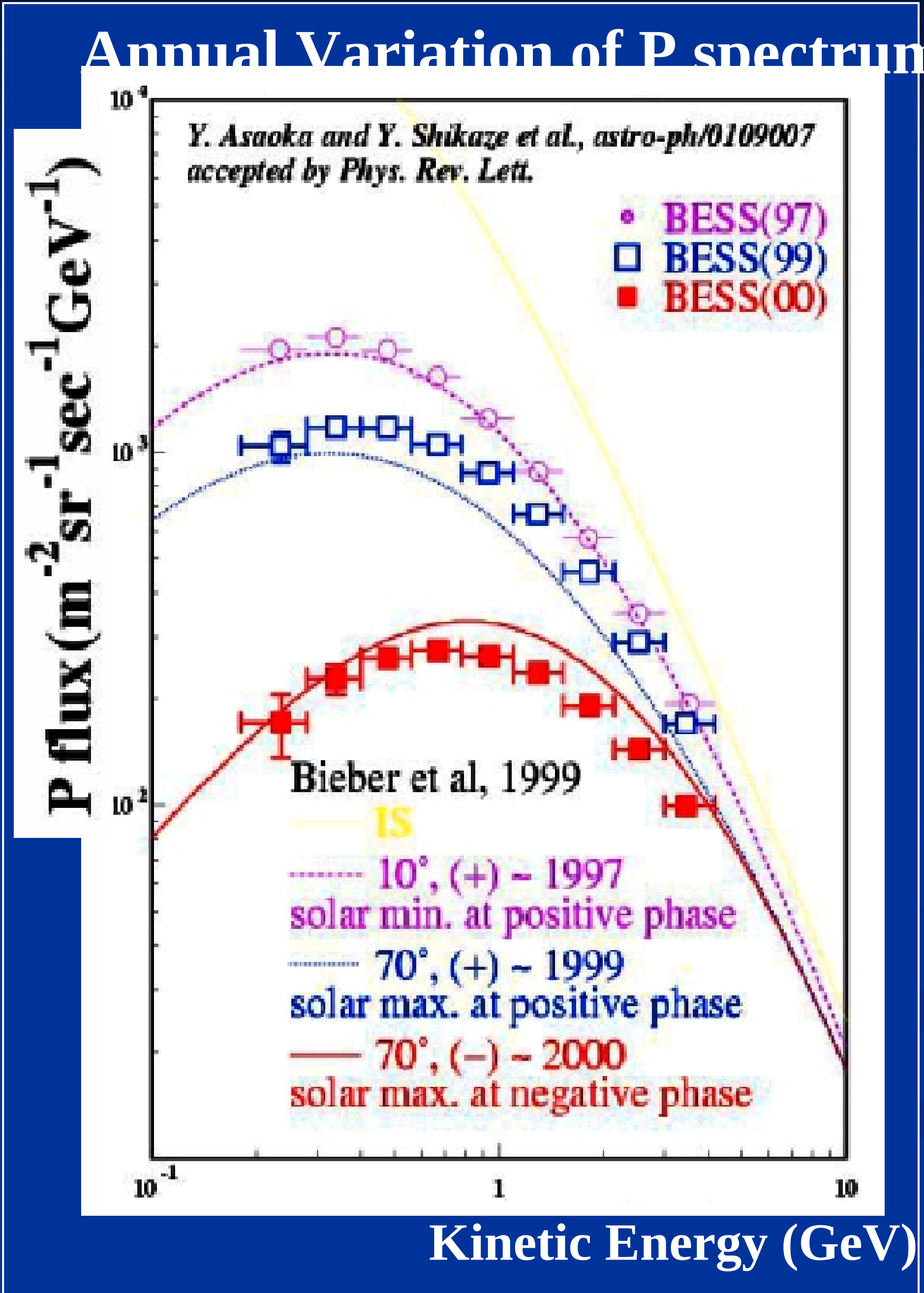
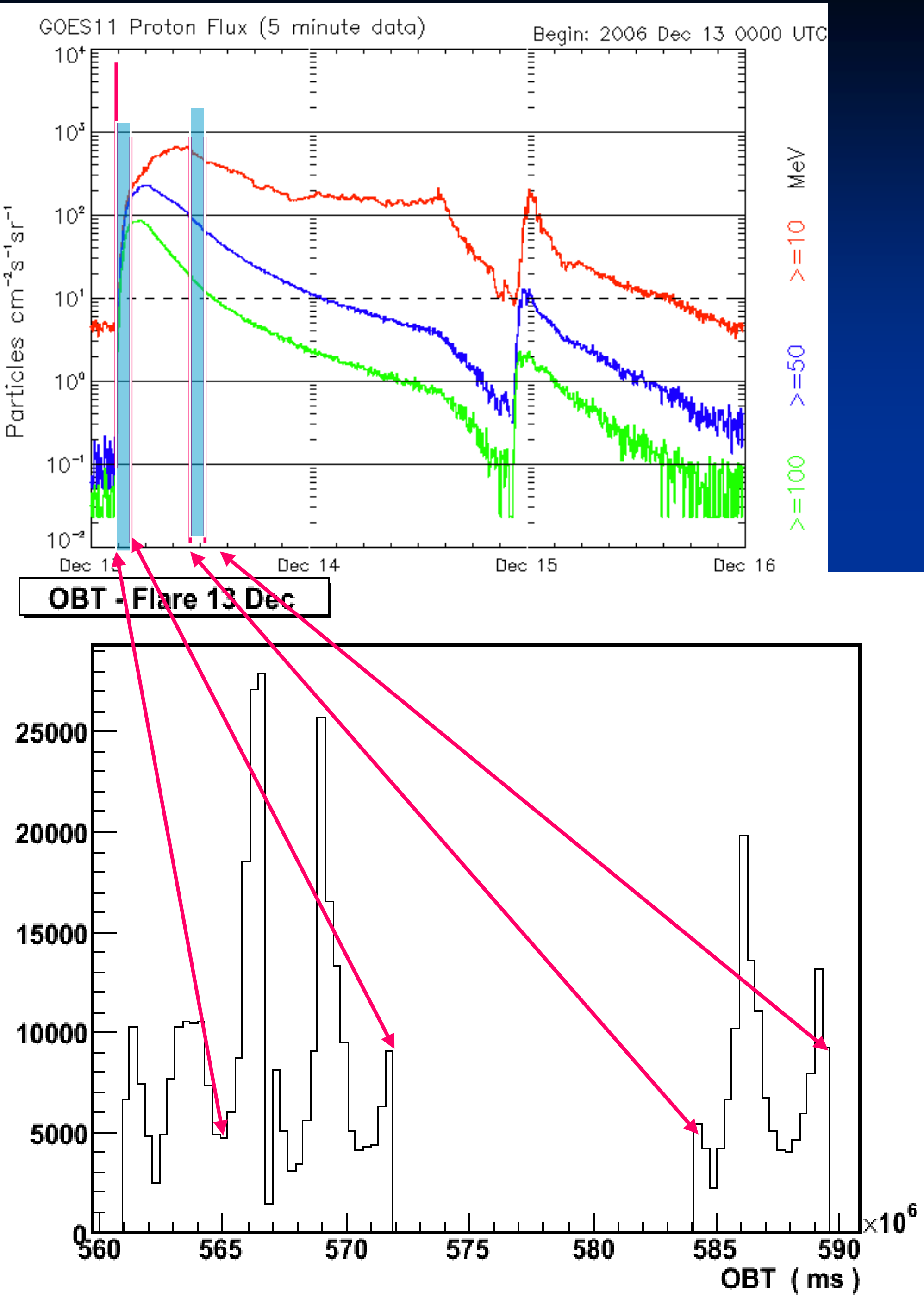


Proton fluxes at TOA

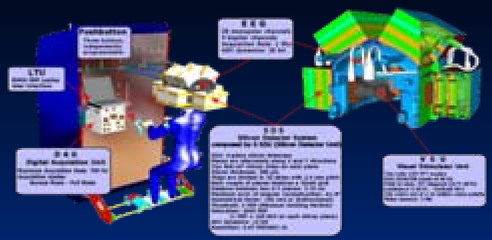


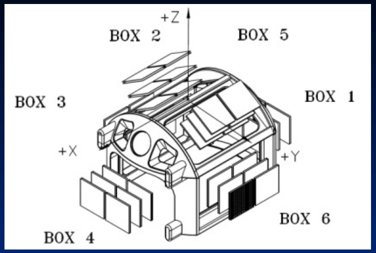


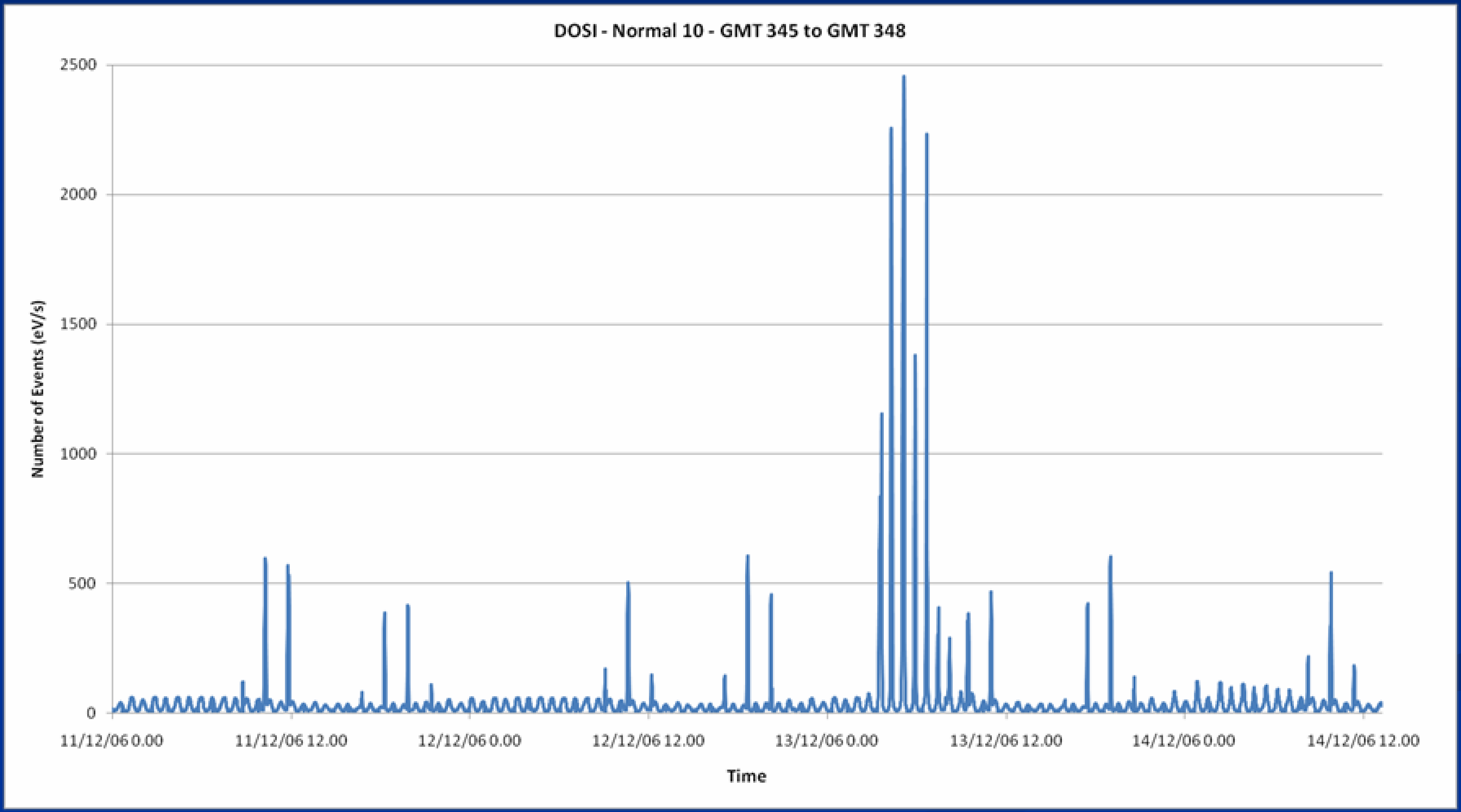
Impulsive event
13/12/2006
CME already on 6/12

Pamela ON before and at onset of event

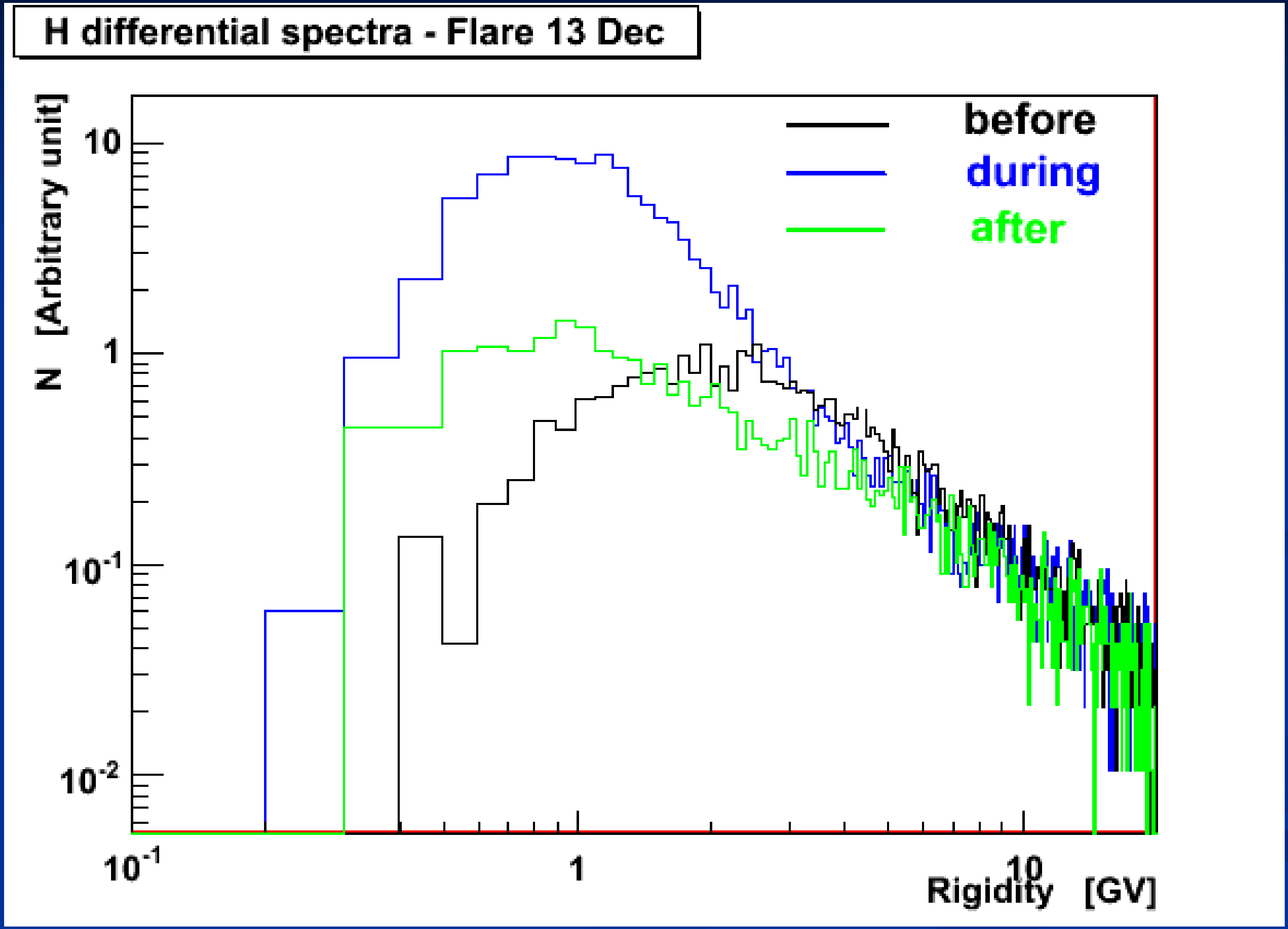
Time division:
Before shock (3UTC)
During shock before Memory fill (3UTC-4.55UTC)
After Memory download (11:15-12.55UTC)

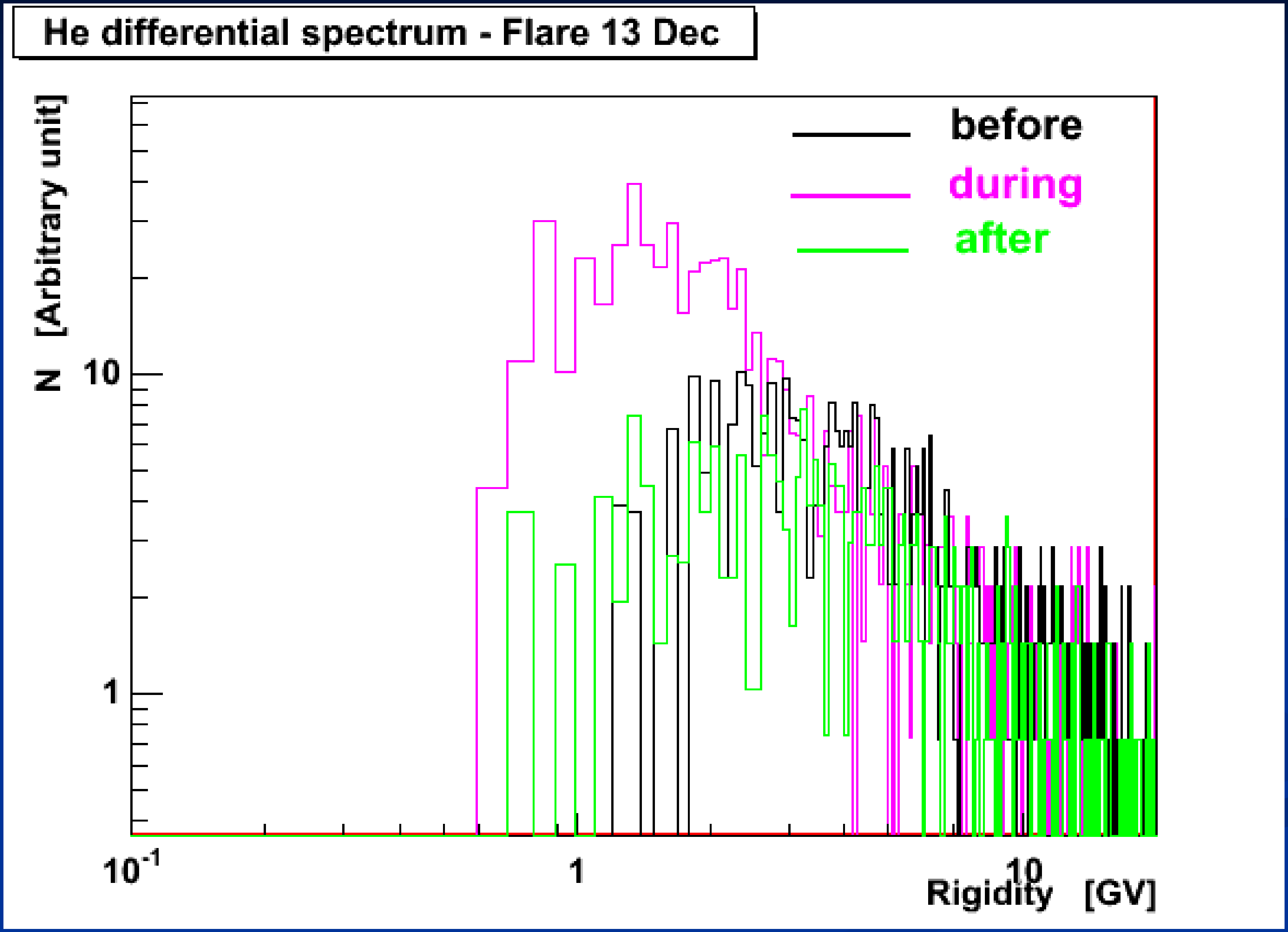


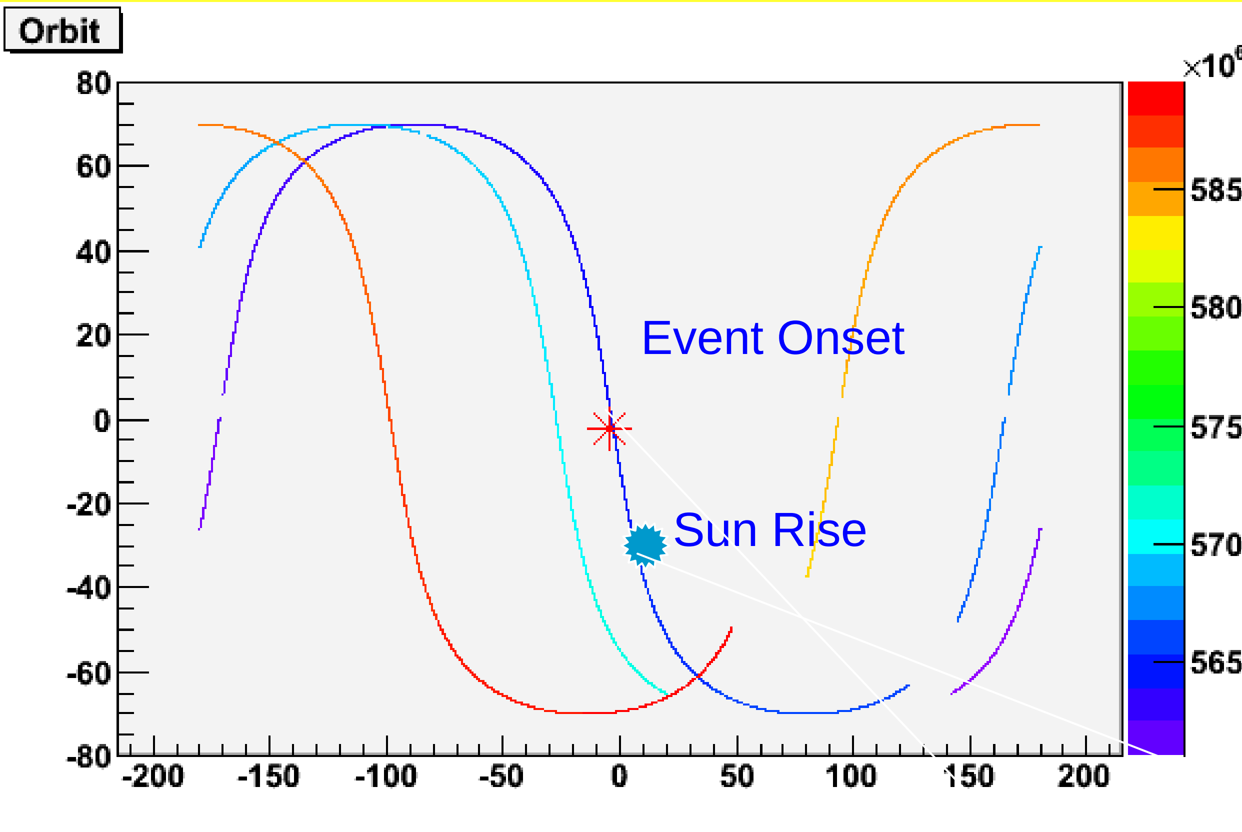




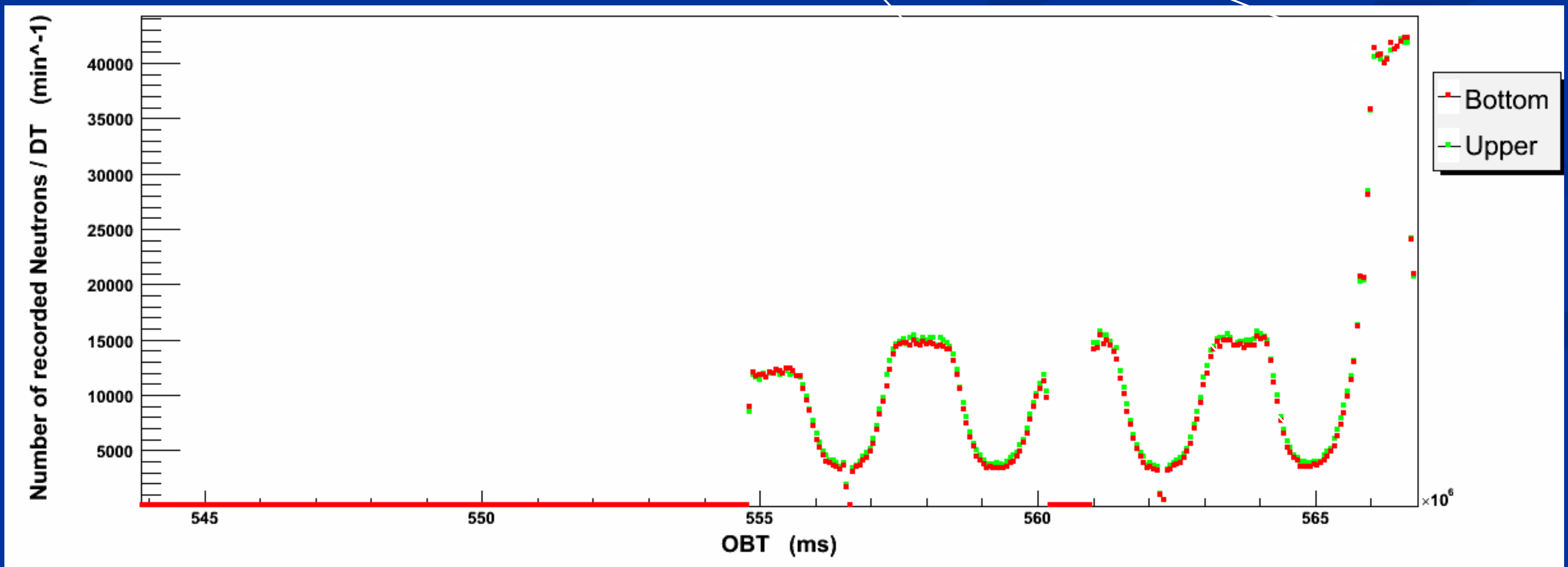
Plot of the particle rate at 10 MIP threshold in Normal mode for the period of days ranging from 12/11/2006 to 12/14/2006. This period of time includes a Solar Flare event revealing its presence with an abrupt rate increasing in correspondence of December the 13th.


H differential spectra - Flare 13 Dec
before
during
after
N [Arbitrary unit]
10
1
10^{-1}
10^{-2}
10^{-1}
1
10
Rigidity [GV]


He differential spectrum - Flare 13 Dec
N [Arbitrary unit]
10
1
10^{-1}
1
10
Rigidity [GV]
before
during
after



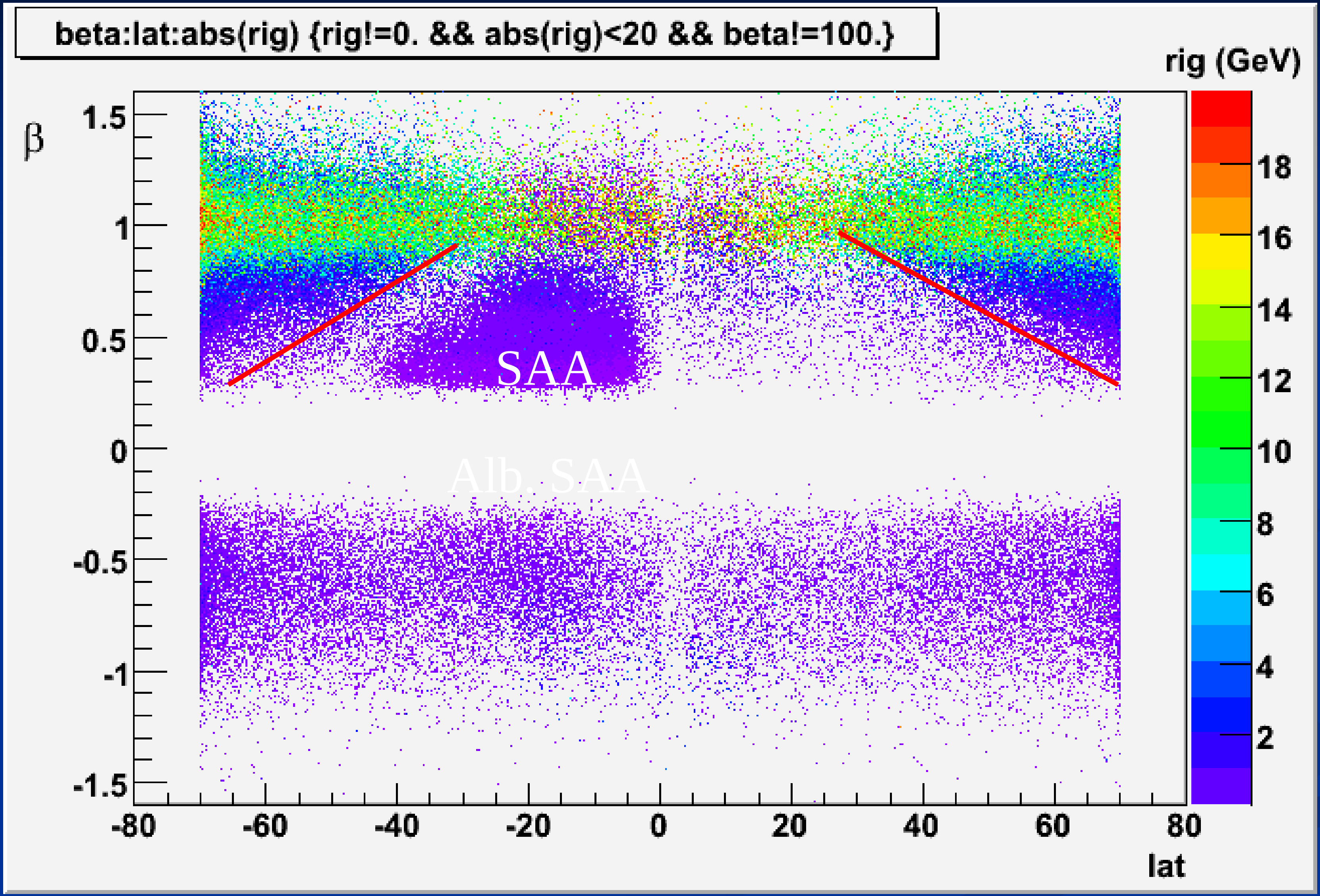
Neutron increase only at sunrise



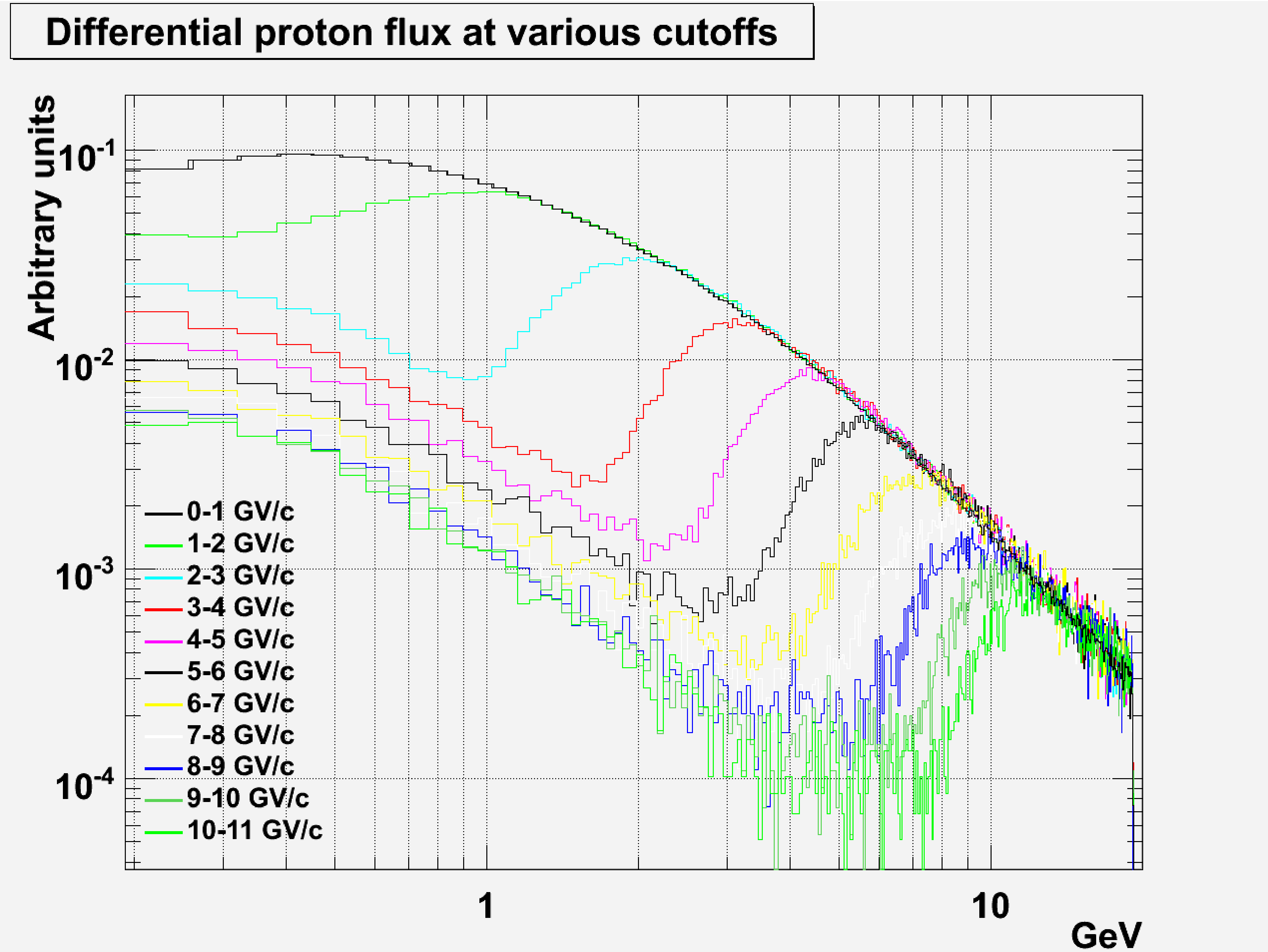
High Energy Radiation Belts

- High energy from ~ 1 GeV to ~ 10 GeV
- Content of e^+, e^-, p, 3He
- Low L- shell ⇔ low altitude
- Life time O(seconds)

⇒ Secondary production from CR interaction with atmosphere



No albedo electrons



Differential proton flux at various cutoffs
Arbitrary units
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
GeV
0-1 GV/c
1-2 GV/c
2-3 GV/c
3-4 GV/c
4-5 GV/c
5-6 GV/c
6-7 GV/c
7-8 GV/c
8-9 GV/c
9-10 GV/c
10-11 GV/c

High Energy electrons

- The study of primary electrons is especially important because they give information on the nearest sources of cosmic rays
- Electrons with energy above 100 MeV rapidly loss their energy due to synchrotron radiation and inverse Compton processes
- The discovery of primary electrons with energy above 10^{12} eV will evidence the existence of cosmic ray sources in the nearby interstellar space ($r \leq 300$ pc)

Earliest example of the interplay between particles physics and cosmology

"We must regard it rather an accident that the Earth and presumably the whole Solar System contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about"

Dirac Nobel Speech (1933)

- wizard.roma2.infn.it/pamela

PAMELA

PAMELA Flight Model delivered to Russia, April 2005

Antonov 72 in Genoa airport

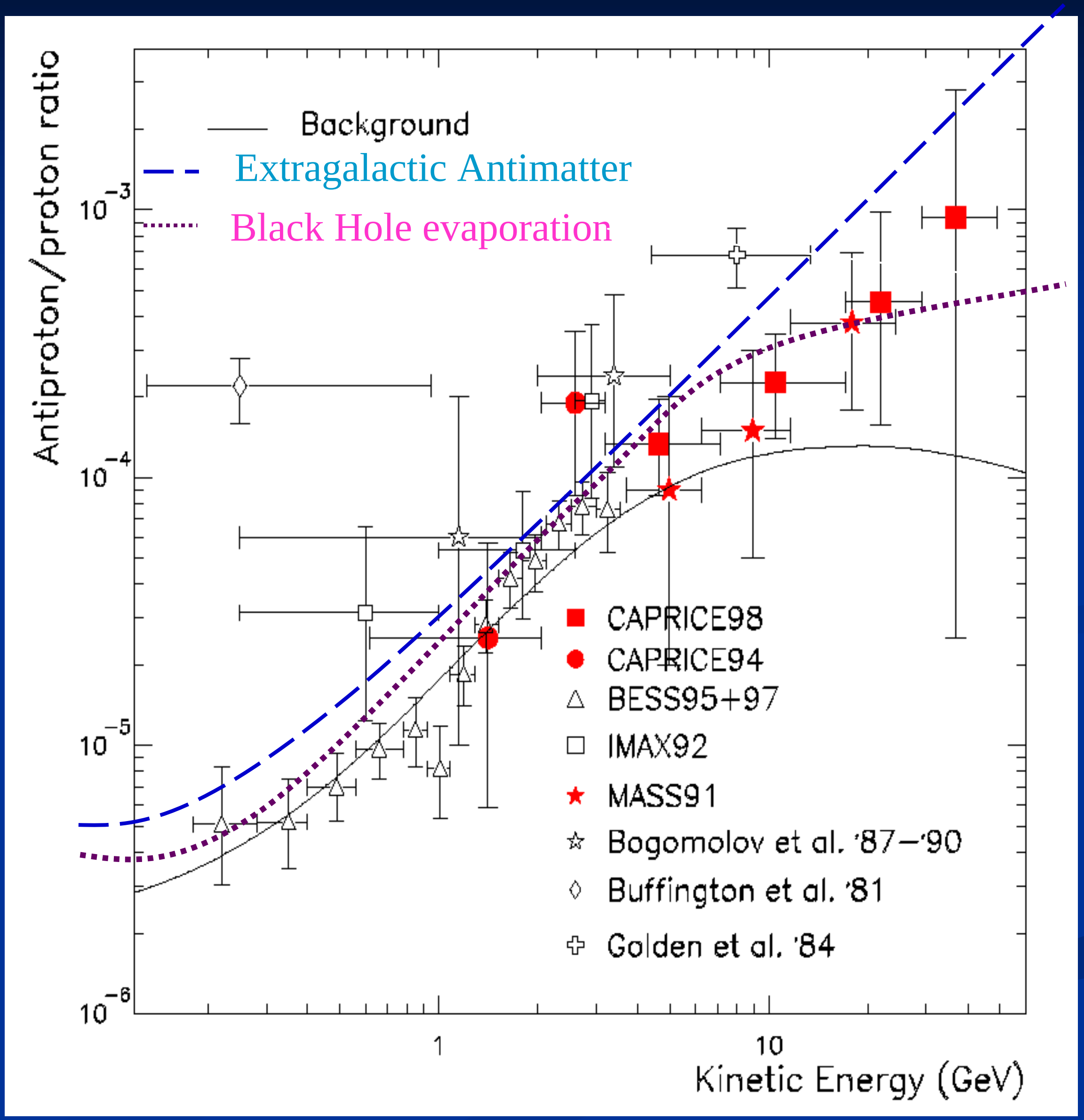
PAMELA onboard during flight

Launch preparation

- May 2005 – March 2006 TsSKB-Progress Factory
  - Full qualification tests
    - Mechanical interfaces
    - Cooling loop
    - Power supply tests
    - Interface with VRL
    - Electrical tests
- March 2006 @ Baykonur
  - 60 days work before launch
    - Standalone tests
    - Insertion into pressurized container
    - Electrical tests with satellite
    - Test of the downlink

Distortion on the secondary antiproton flux induced by an Extragalactic Antimatter and Black Hole evaporation components

- Background from normal secondary production
- Mass91 data from XXVI ICRC, OG.1.1.21 , 1999
- Caprice94 data from ApJ , 487, 415, 1997
- Caprice98 data from ApJ Letters 534, L177, 2000



GLAST, PAMELA, LHC, LC Sensitivities to Dark Matter Search

mSUGRA

Sensitivity plot for 5 years observation of mSUGRA for GLAST for tg(b)=55 and for other experiments. GLAST 3σ sensitivity is shown at the blue line and below for truncated NFW halo profile

accelerator limits @ 100 fb^{-1} from H.Baer et al., hep-ph/0405210