Solar and heliospheric cosmic ray observations with PAMELA experiment

M. Casolino,
on behalf of PAMELA collaboration

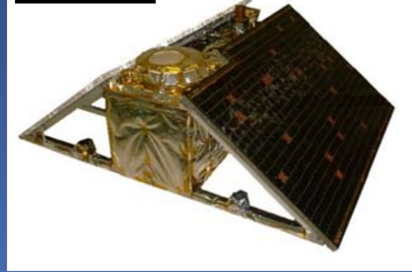
INFN & University of Rome Tor Vergata

Past, Present and Future Projects

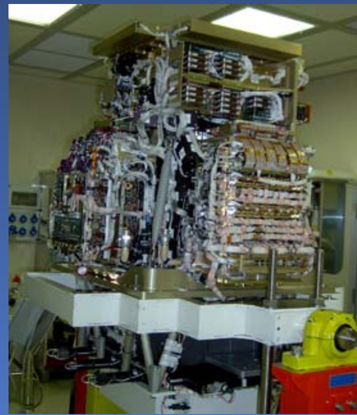
MASS-89, 91, TS-93, CAPRICE 94-97-98

NINA-1

NINA-2

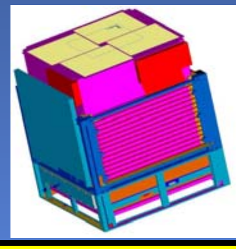


PAMELA



GLAST

AGILE



89 M 91 TS 93 C 94 C 97 C 98 PAMELA

9 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 ...

NINA-1 NINA-2 LAZIO-SIRAD

SILEYE-1 SILEYE-2 SILEYE-3 ALTEA

SILEYE-1

SILEYE-2

SILEYE-3/ ALTEINO:

LAZIO-SIRAD

SILEYE-4/ALTEA

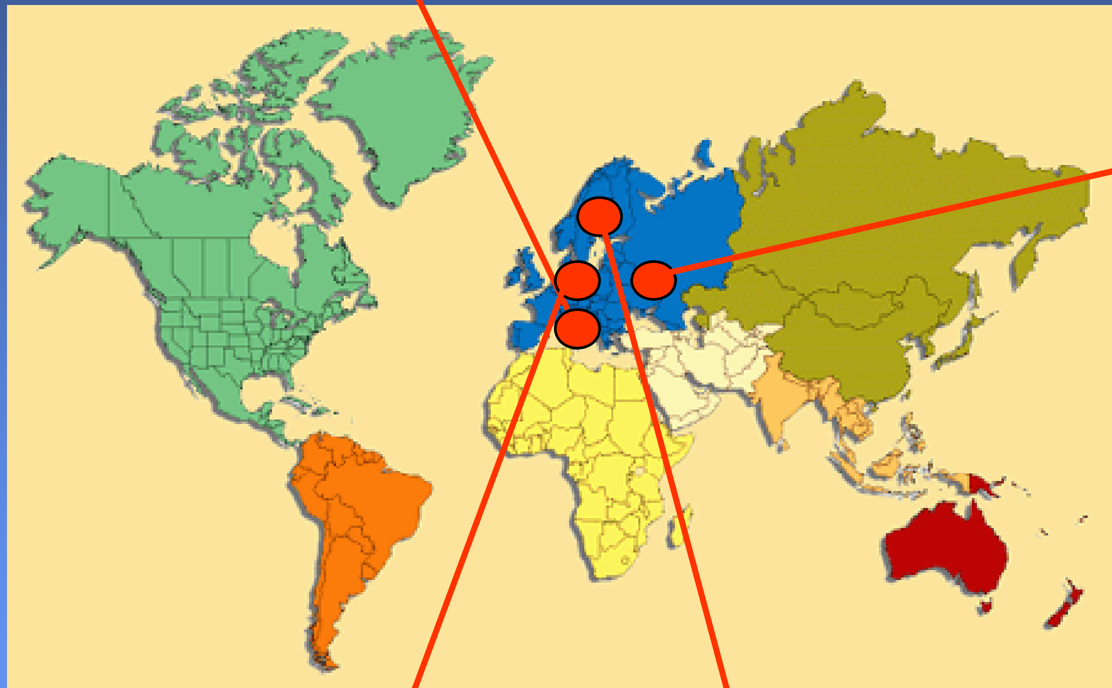
PAMELA Collaboration

Italy:

Bari Florence Frascati Naples Rome Trieste CNR, Florence

Russia:

Moscow
St. Petersburg



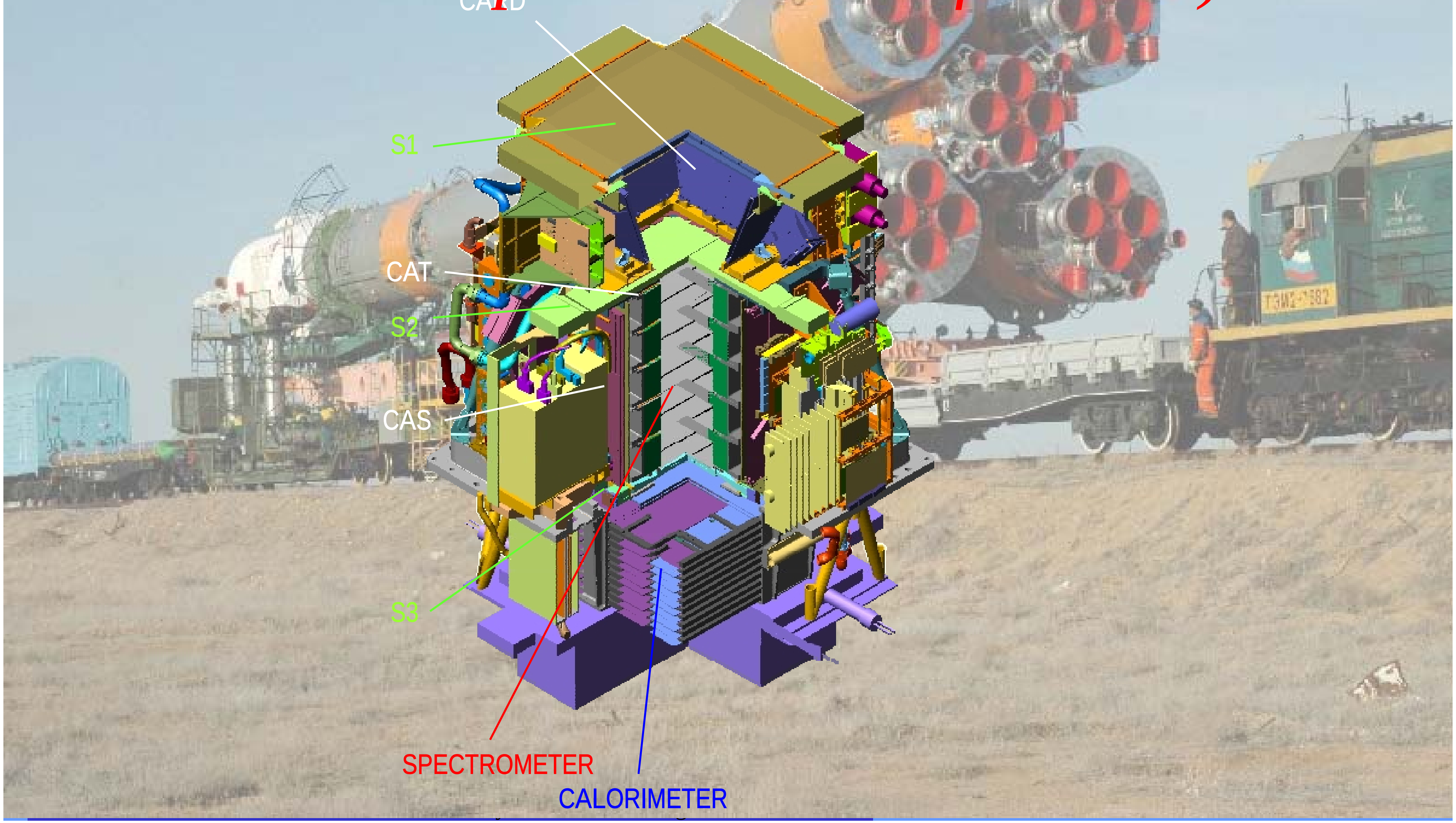
Germany:

Siegen

Sweden:

KTH, Stockholm

The Detector (see Rita Carbone afterwards and Paolo Papini's talk this afternoon)



Time of Flight
(three scintillators, 6 planes, 48 phototubes)

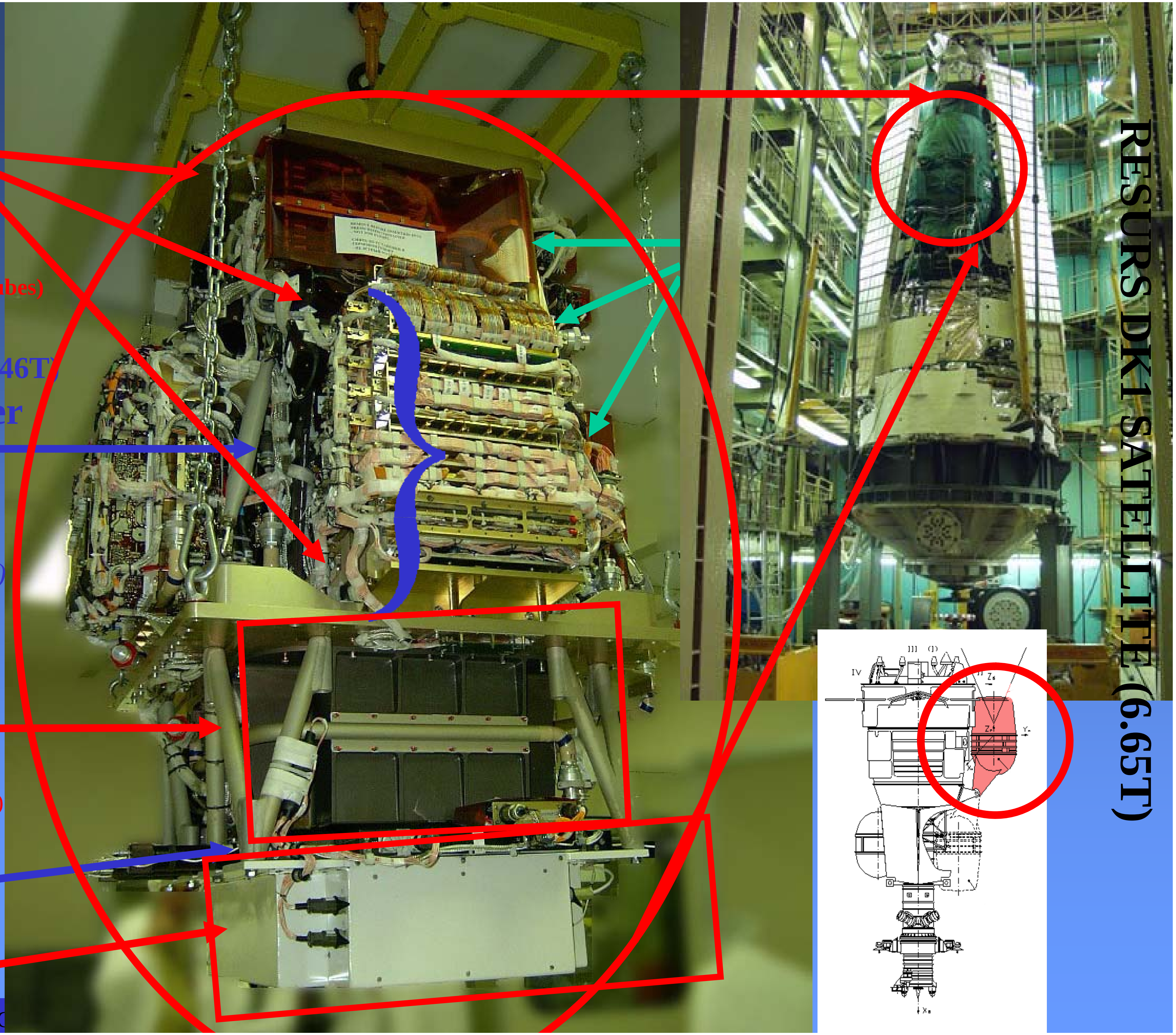
Magnetic (0.46T) Spectrometer Microstrip detector
(6 double sided microstrip planes)

Silicon Tungsten Tracking Calorimeter
(44 planes of 96 strip)

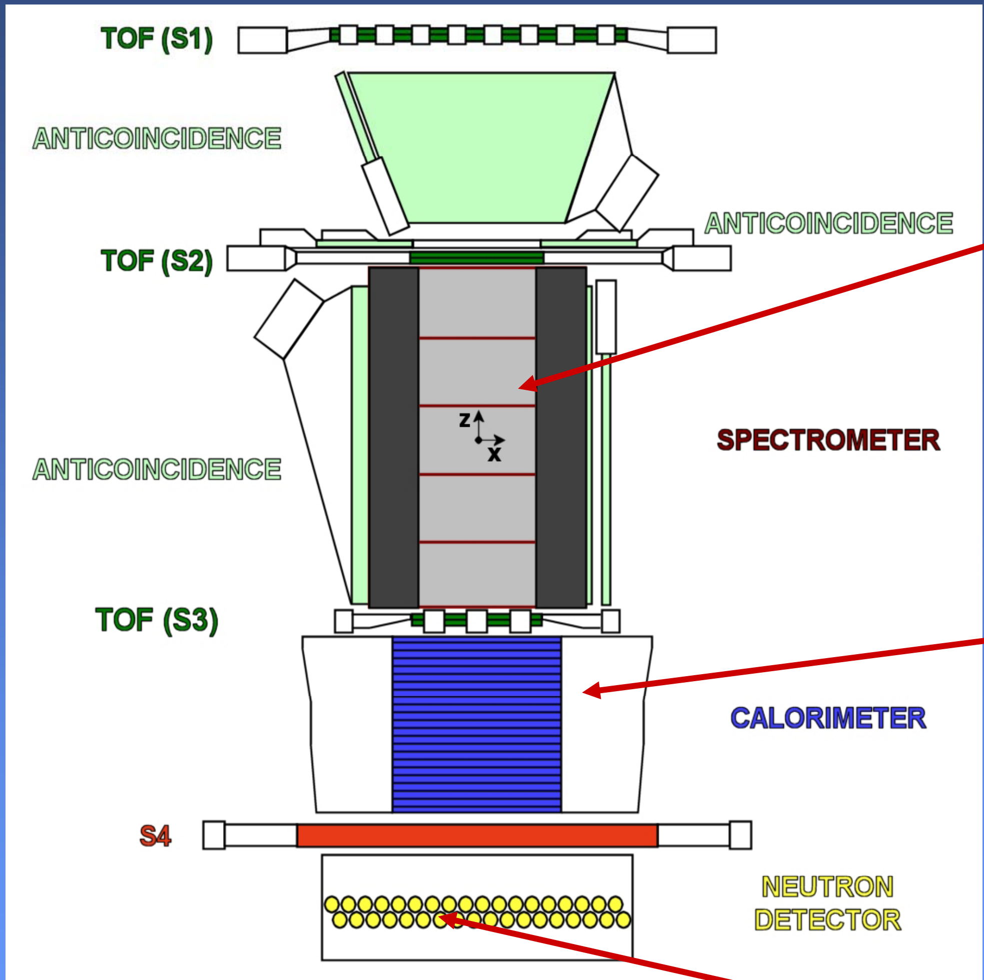
Shower Catcher Scintillator

Neutron Detector

M. C



The PAMELA apparatus



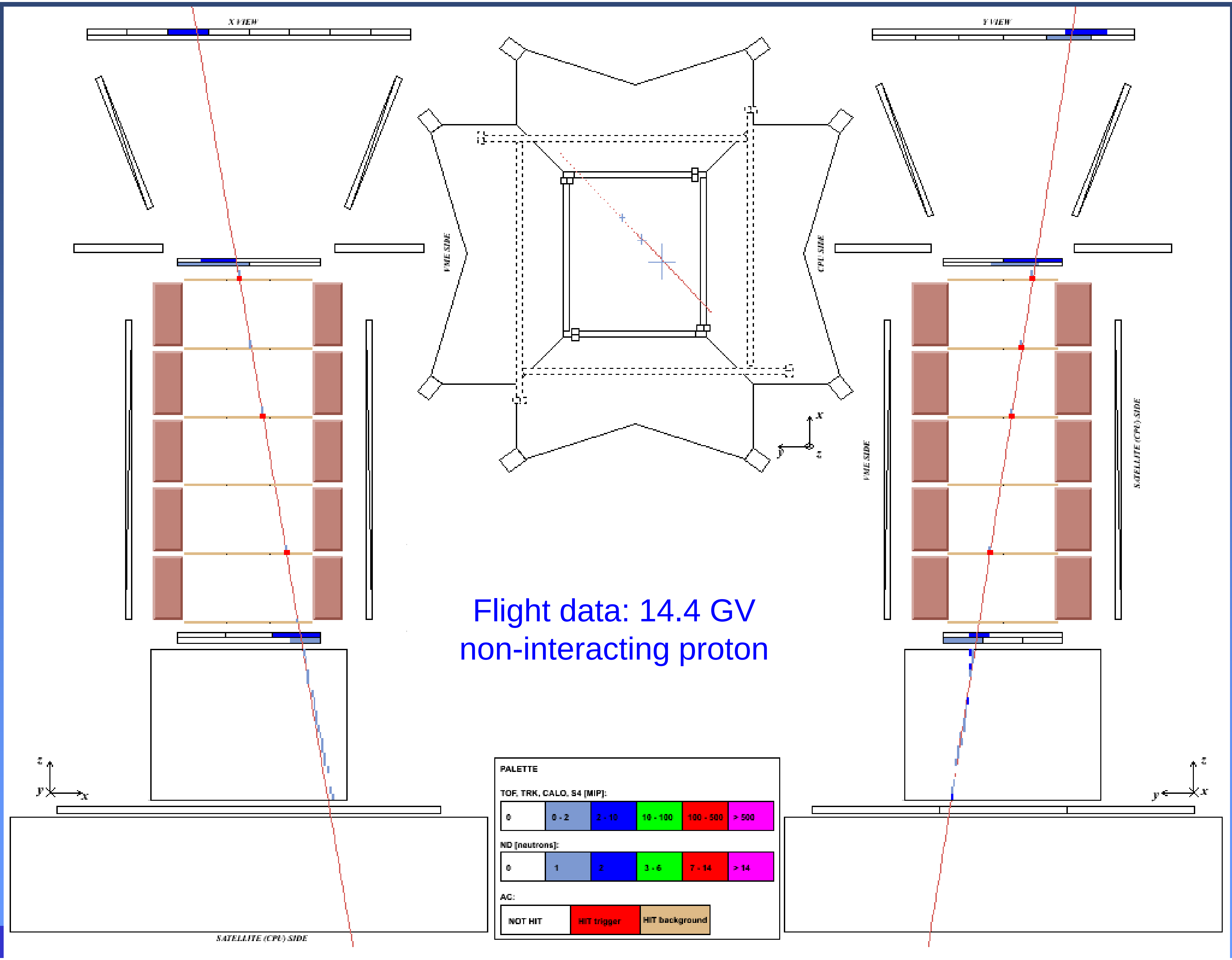
Spatial Resolution
- ≅ 2.8 μm bending view
- ≅ 13.1 μm non-bending view

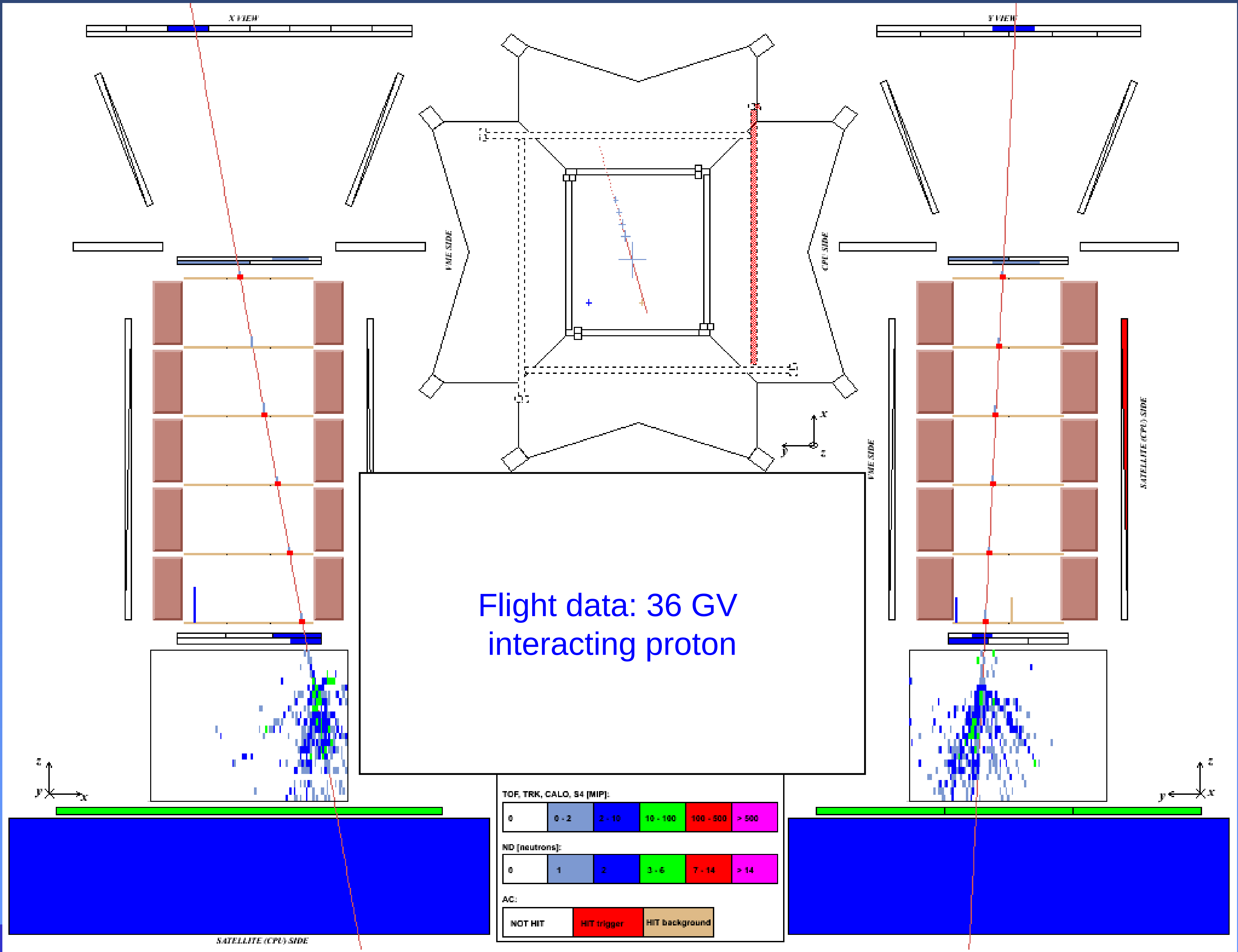
MDR from test beam data ≅ 1 TV

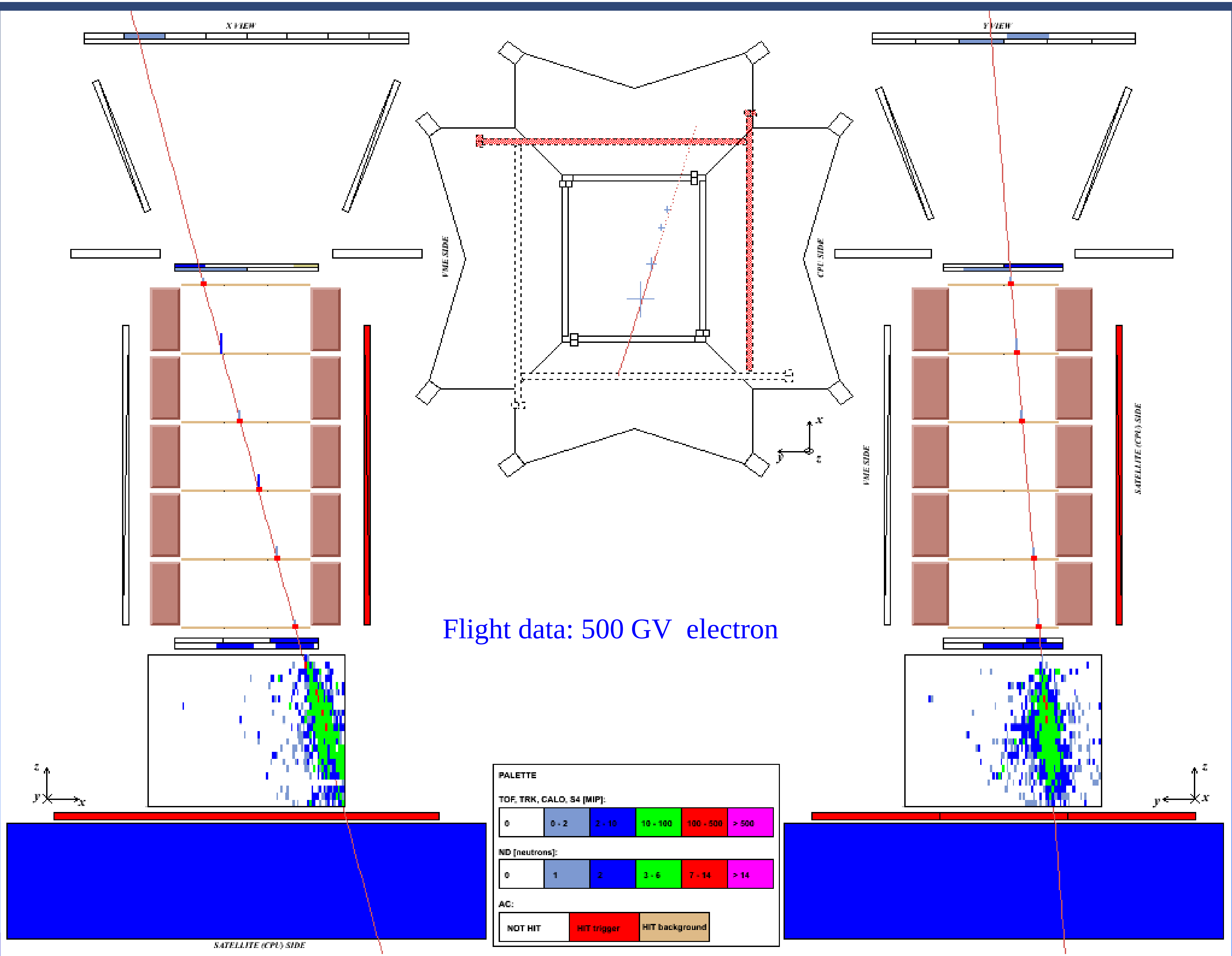
Calorimeter Performances:
- $\bar{p}/e^{+}$ selection eff. ~ 90%
- p rejection factor ~ 10^5
- e^- rejection factor > 10^4

ND p/e separation capabilities >10 above 10 GeV/c, increasing with energy

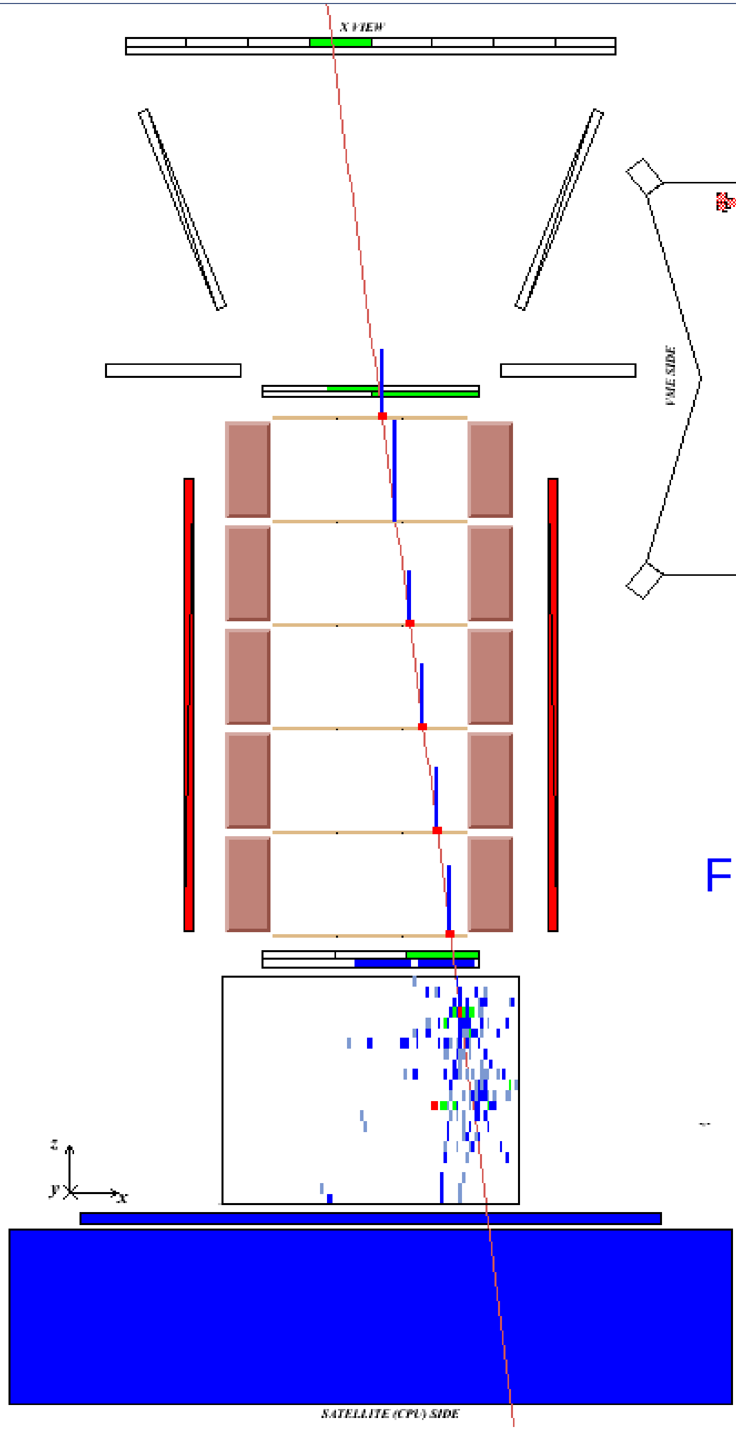
GF ~20.5 cm²sr
Mass: 470 kg
Size: 120x40x45 cm³
Power Budget: 360 W

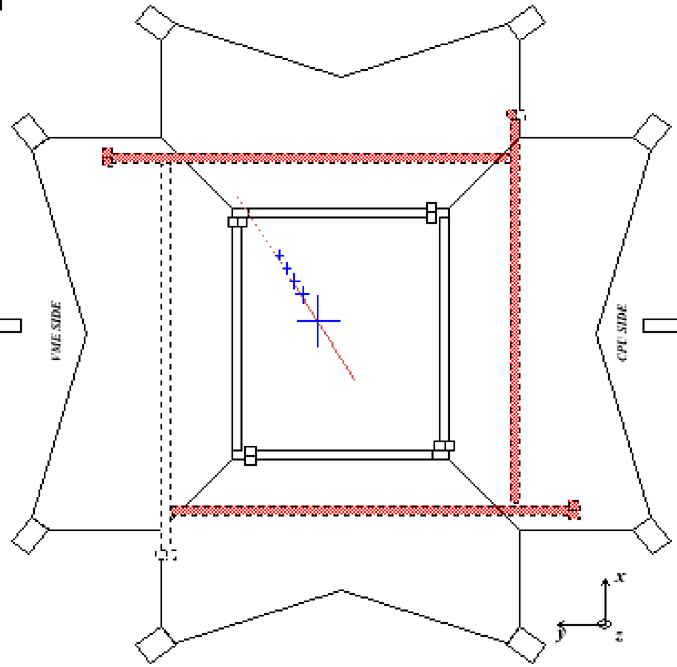

X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
Flight data: 14.4 GV
non-interacting proton
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background

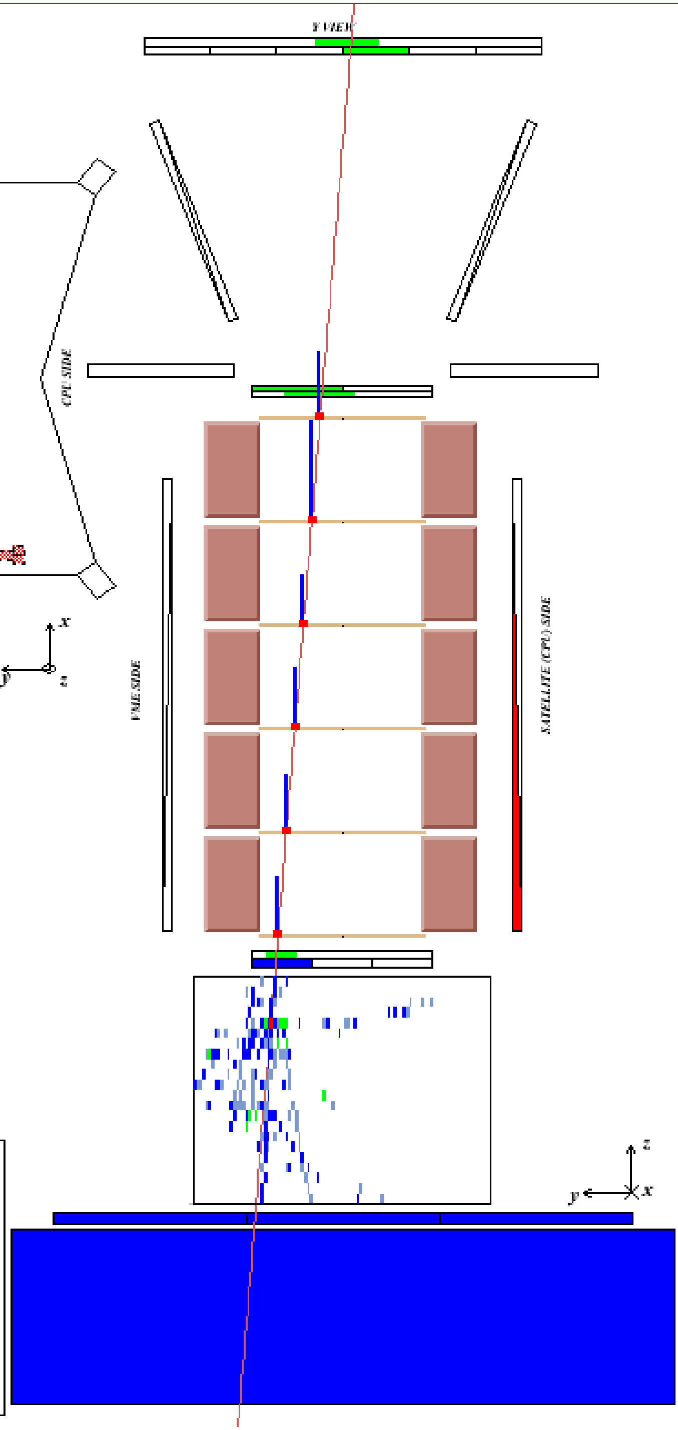

Flight data: 36 GV
interacting proton
X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background



Flight data: 500 GV electron







Flight data: 13 GV Interacting Helium Nucleus

PALETTE

TOF, TRK, CALO, S4 [MIP]:

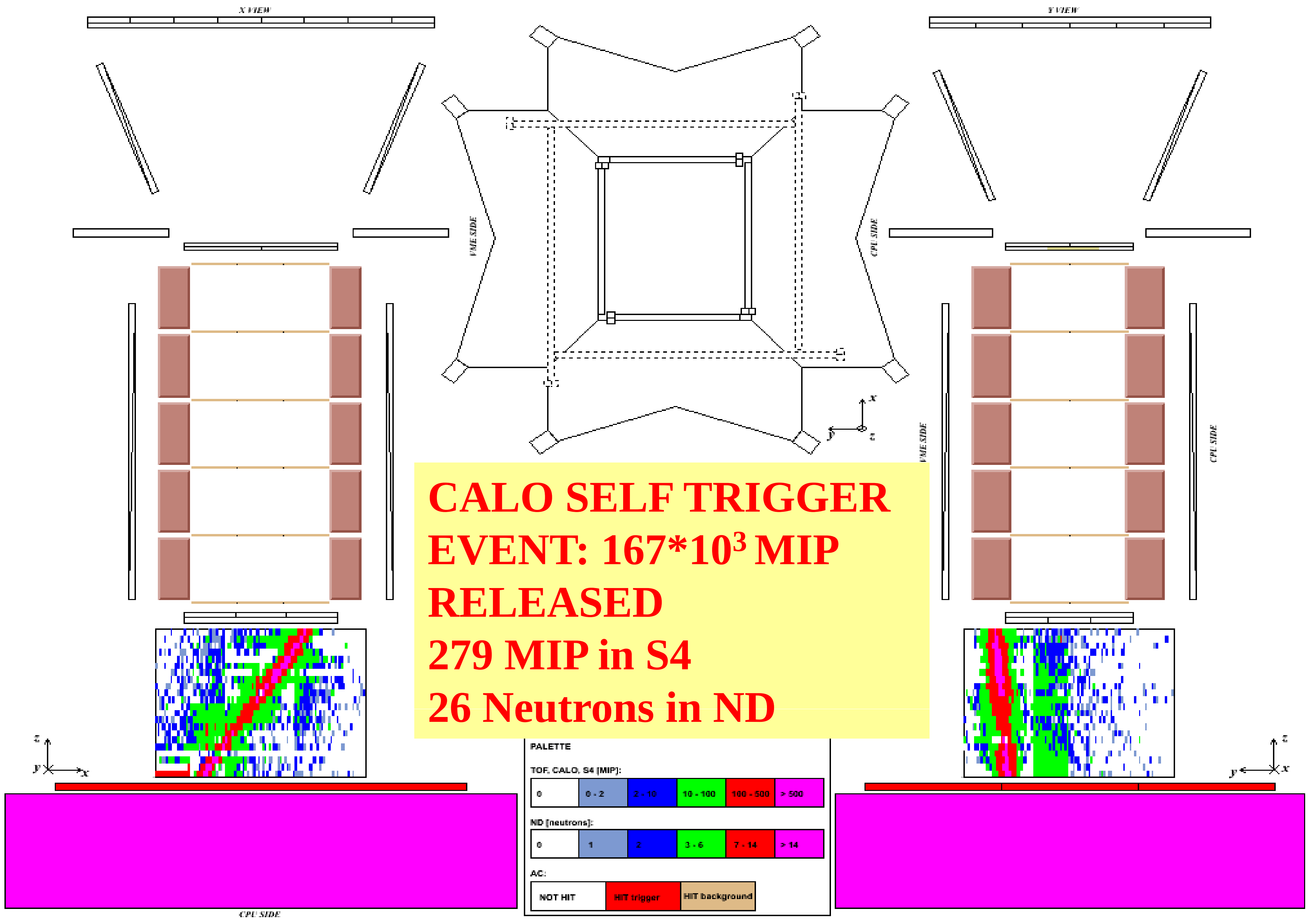
0	0 - 2	2 - 10	10 - 100	100 - 500	> 500

ND [neutrons]:

0	1	2	3 - 6	7 - 14	> 14

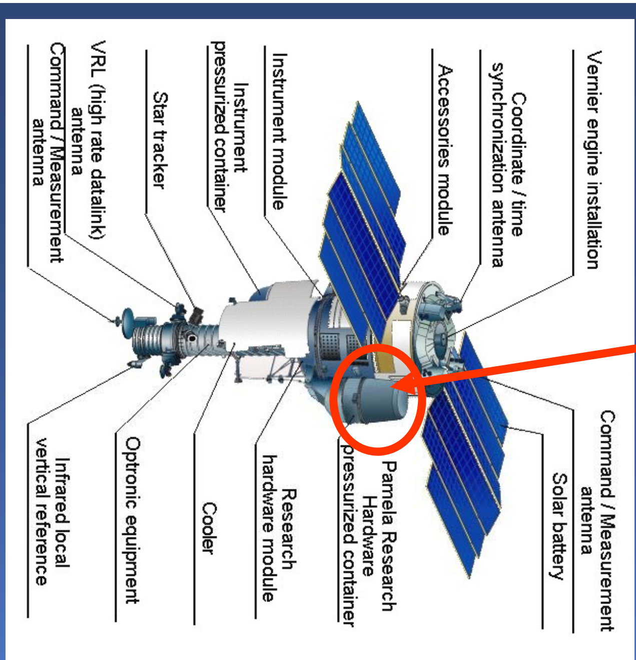
AC:

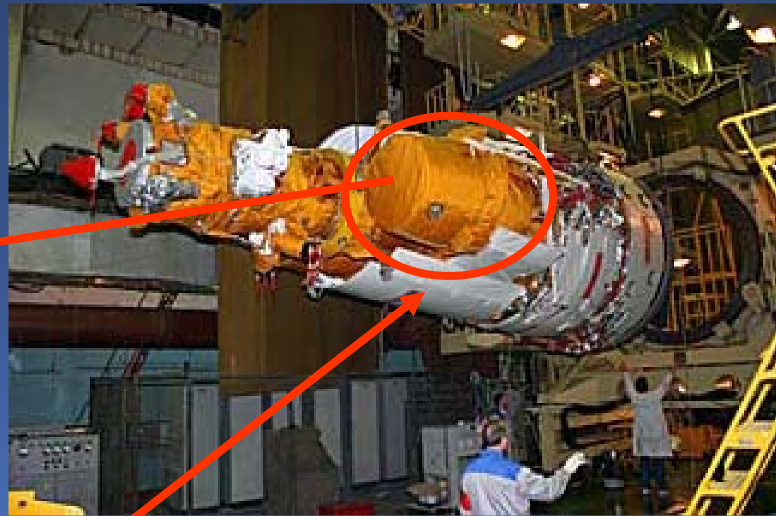
NOT HIT	HIT trigger	HIT background



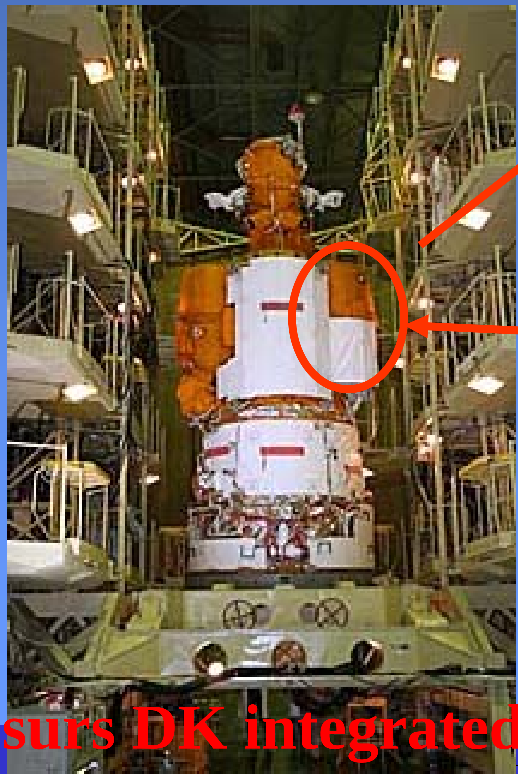
CALO SELF TRIGGER
EVENT: 167*10^3 MIP
RELEASED
279 MIP in S4
26 Neutrons in ND

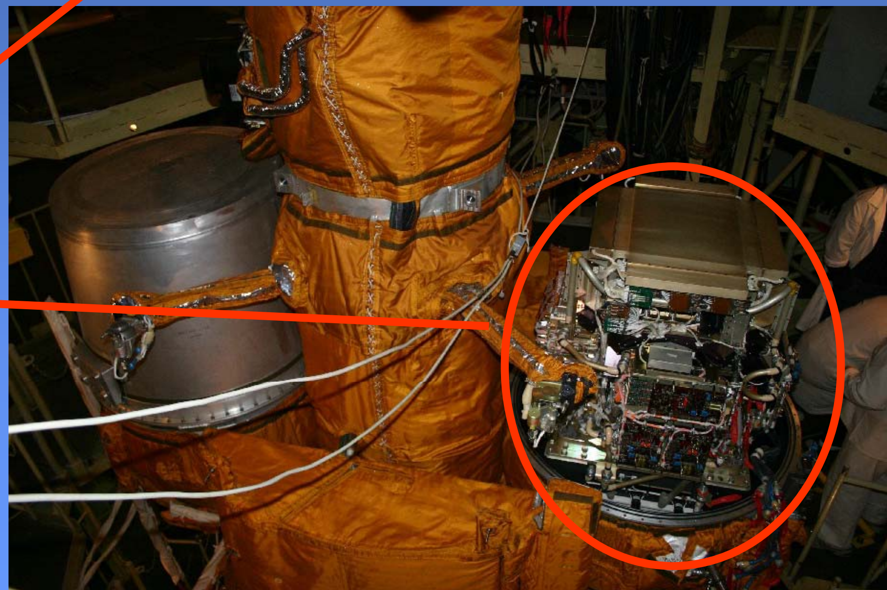
Integration in Baikonur cosmodrome, Spring 2006





Coupling to Soyuz





Pamela during integration in Baikonur

Resurs DK integrated

Transport from Progress building to Launch Pad 13-6-2005

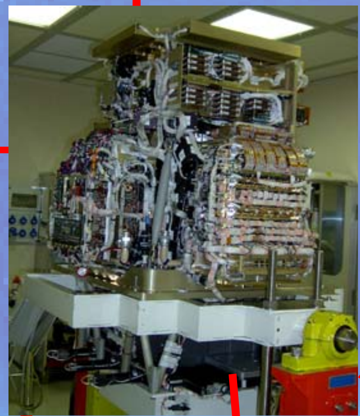
Gagarinsky Start

Launch on June 15th 2006 Soyuz-U rocket

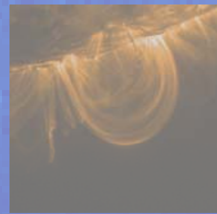
Other objectives: Pamela as a Space observatory at 1AU

Jovian electrons

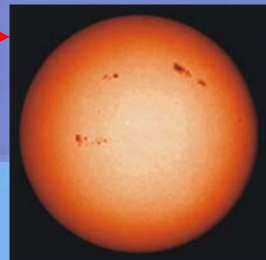
Galactic cosmic ray
Matter / Antimatter
/ Dark Matter



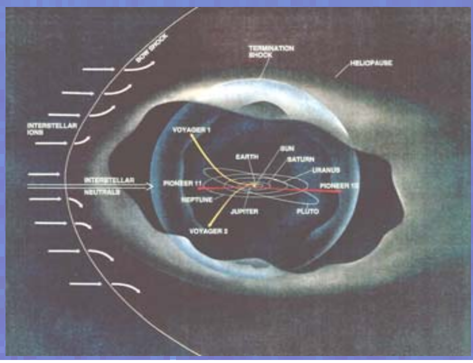
Solar Energetic particles



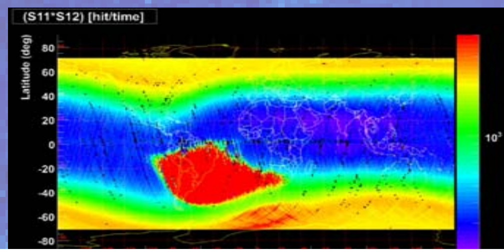
Solar Modulation



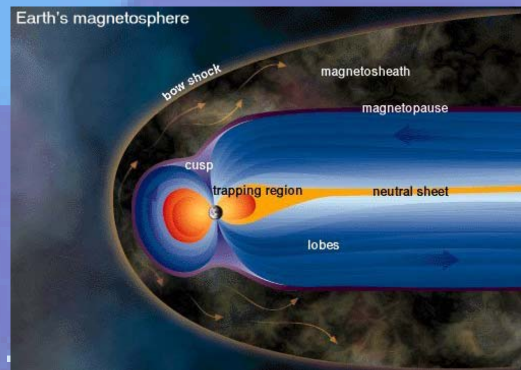
Interplanetary Physics,
Solar Wind Termination Shock



SAA, Albedo,
secondary particle



Magnetospheric physic



Pamela main objectives:

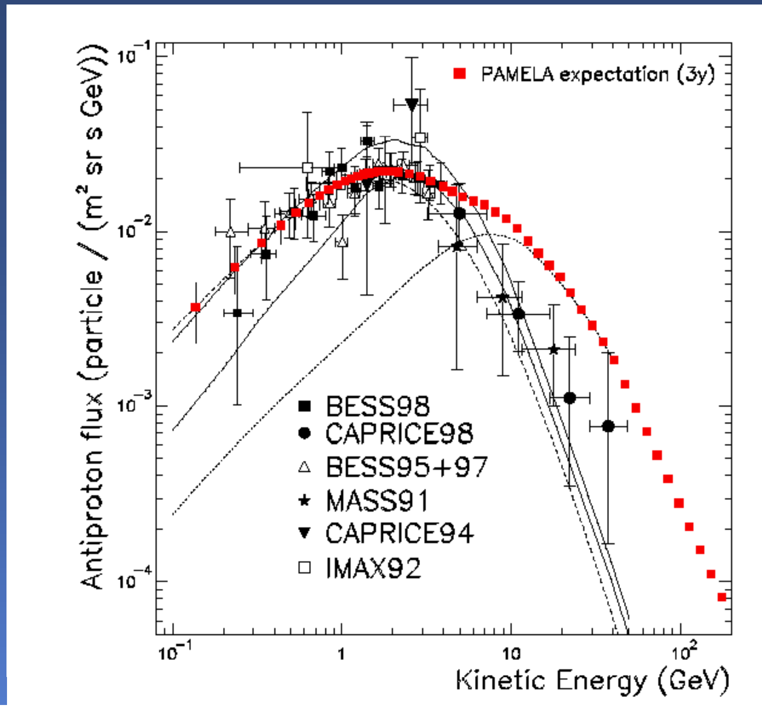
Study of antimatter component in cosmic rays:

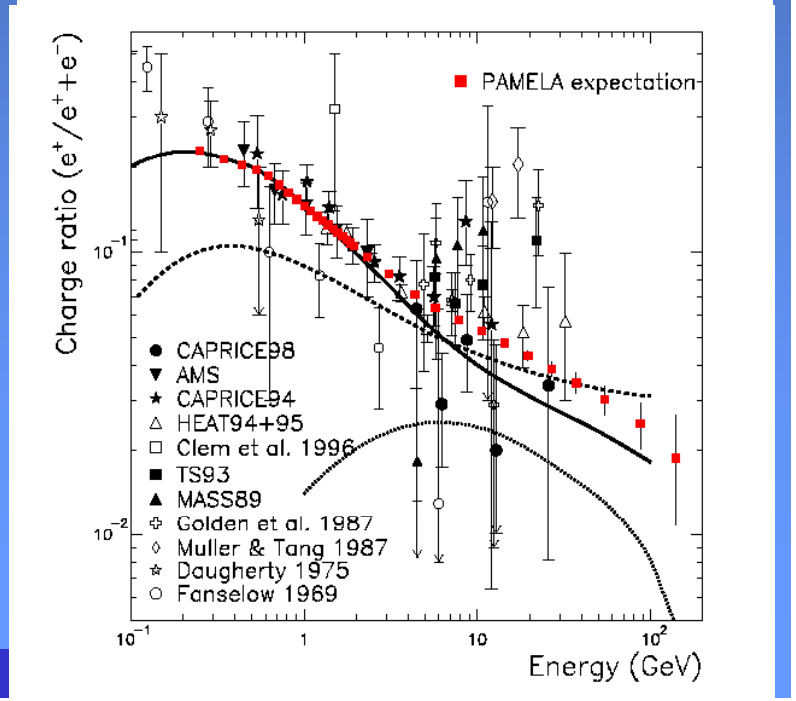
- Antiprotons (80MeV -190 GeV) ~ 10^4
- Positrons (50MeV - 270 GeV) ~ 10^5
- Search for Antihelium (some parts 10^{-8})

Study of galactic cosmic ray spectrum

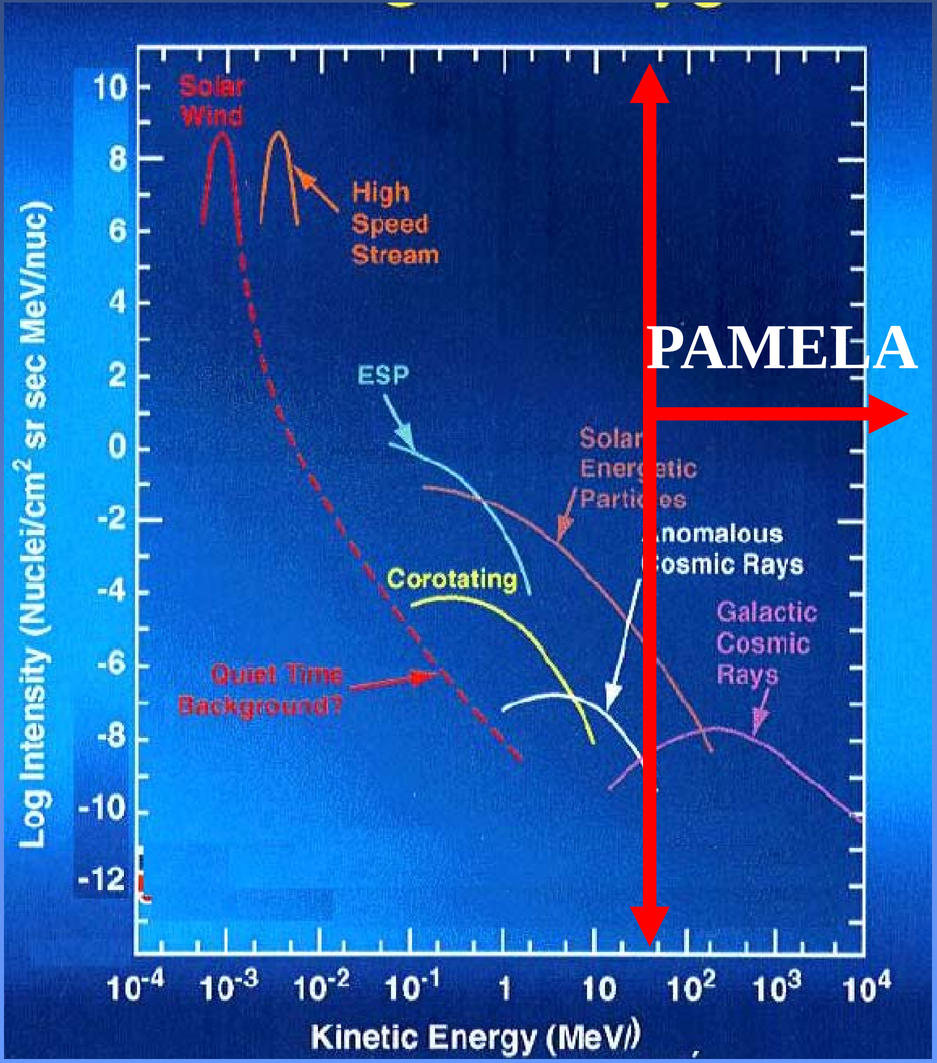
- Protons (80MeV - 700 GeV) ~ 10^8
- Electrons (50MeV – 400 GeV) ~ 10^6
- Electron+positron (up to 2TeV)
- Nuclei (He/Be/C) ~$10^{7/4/5}$

•Geom. Fact. 21.5 cm^2 sr,
400 cm^2 sr (in calo self trigger mode)





Cosmic ray energy ranges

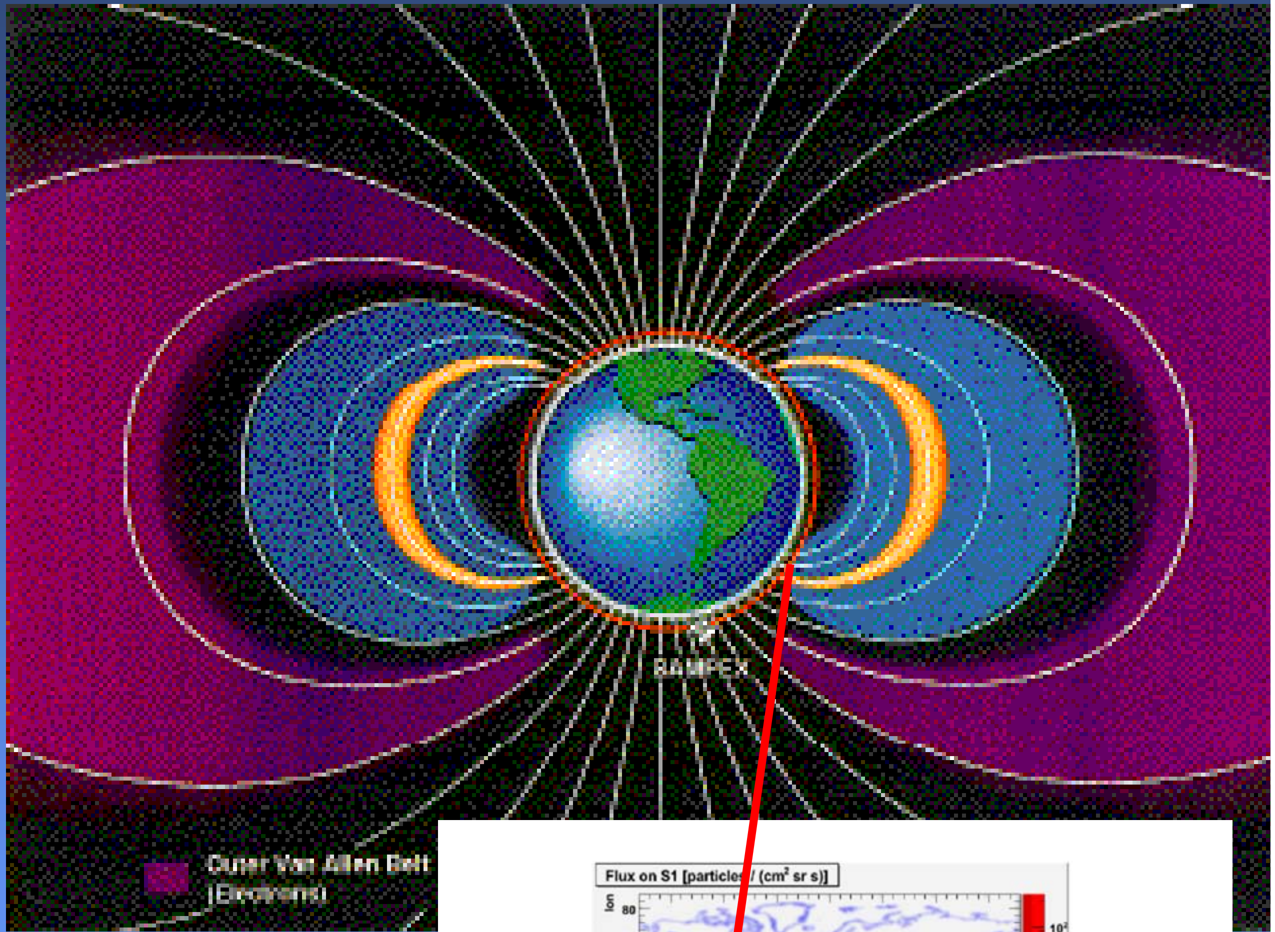


- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV)
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV)
- Nuclear composition of Gradual and Impulsive events
- ^3He and ^4He isotopic composition
- Electrons of jovian origin

Trapped, albedo and secondary particles

The polar orbit of Pamela is particularly suited to study:

- Trapped particle population in the SAA
- (different altitudes: 300 – 600 km)
- Trapped electrons
- Geomagnetic cutoff shifts due to solar events
- Albedo particles
- Secondary particles produced in the atmosphere…



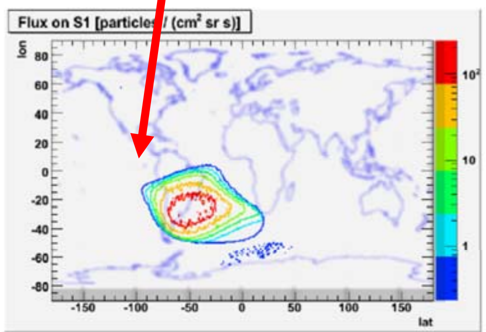
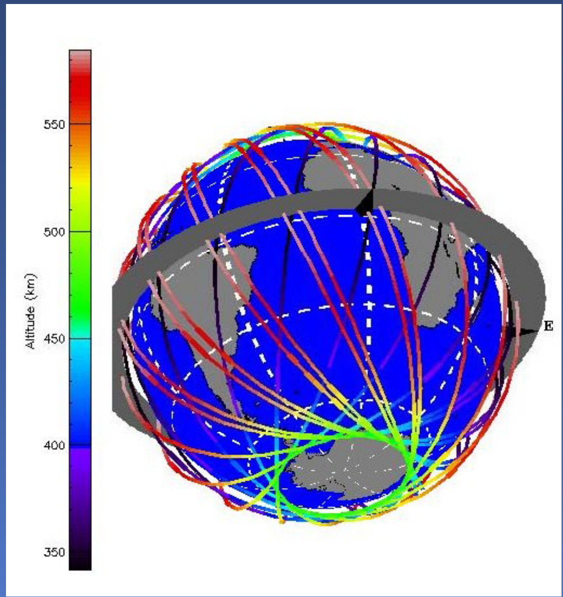
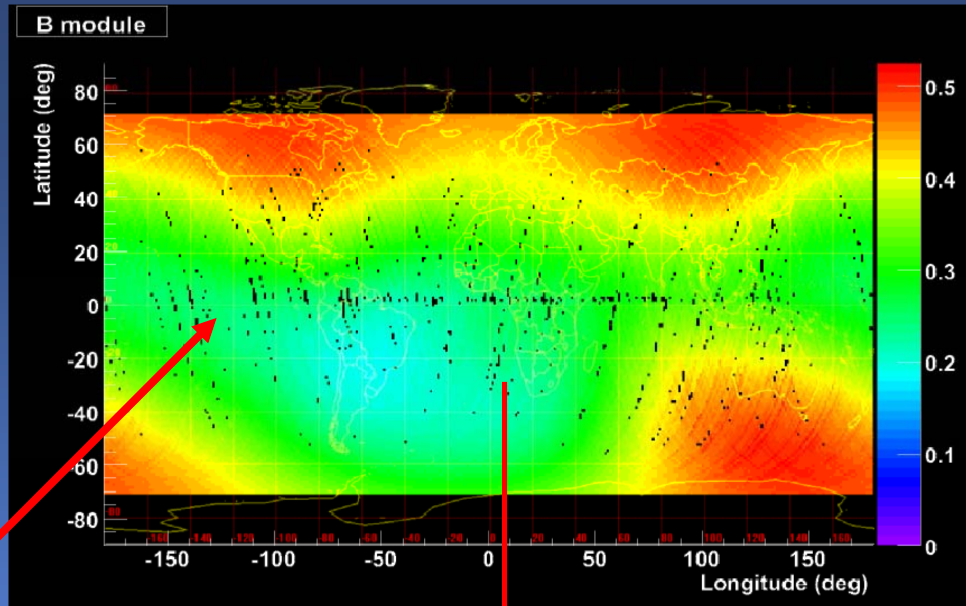


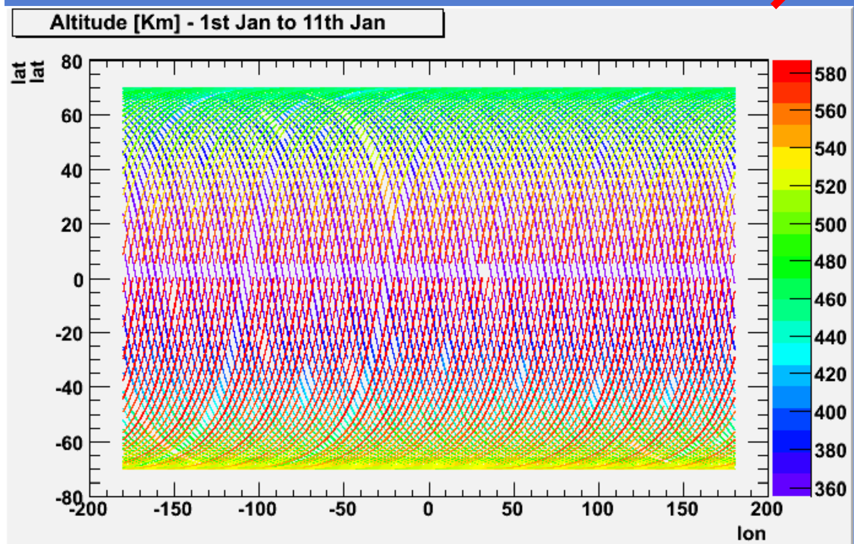
Figura 5.31: Flusso di particelle su S1 intorno all'anomalia del Sud Atlantico, mediato tra 350 e 610 km.

ORBIT: from glonass and TLE…

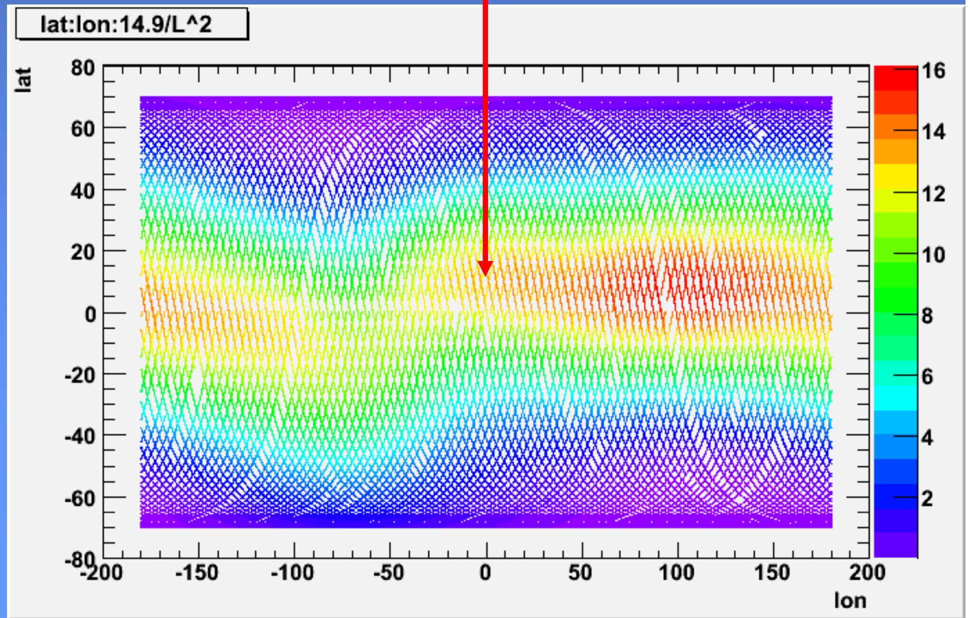


…to Magnetic Field (IGRF)





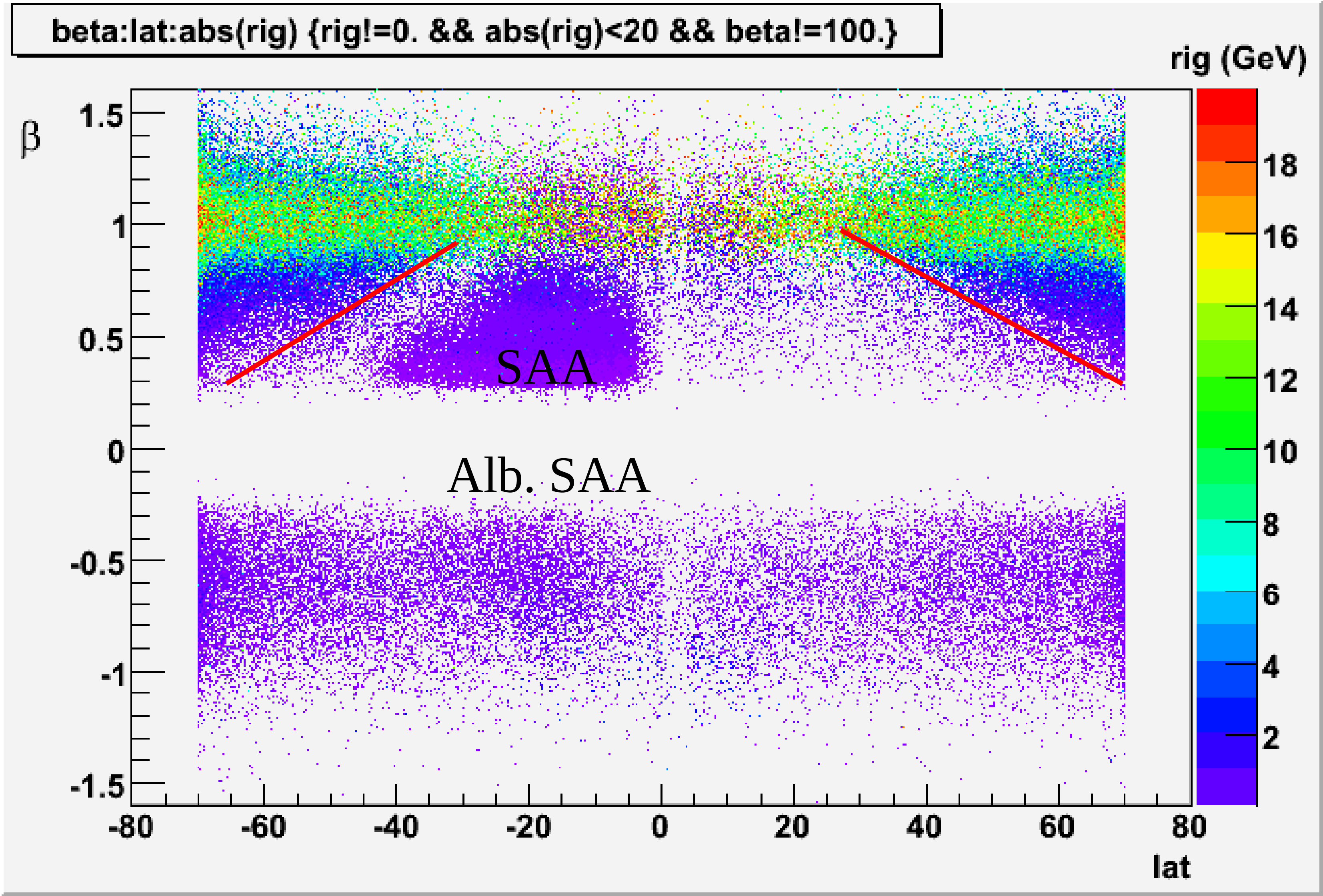
… to Geomagnetic cutoff (Stormer Vertical)



Some preliminary results

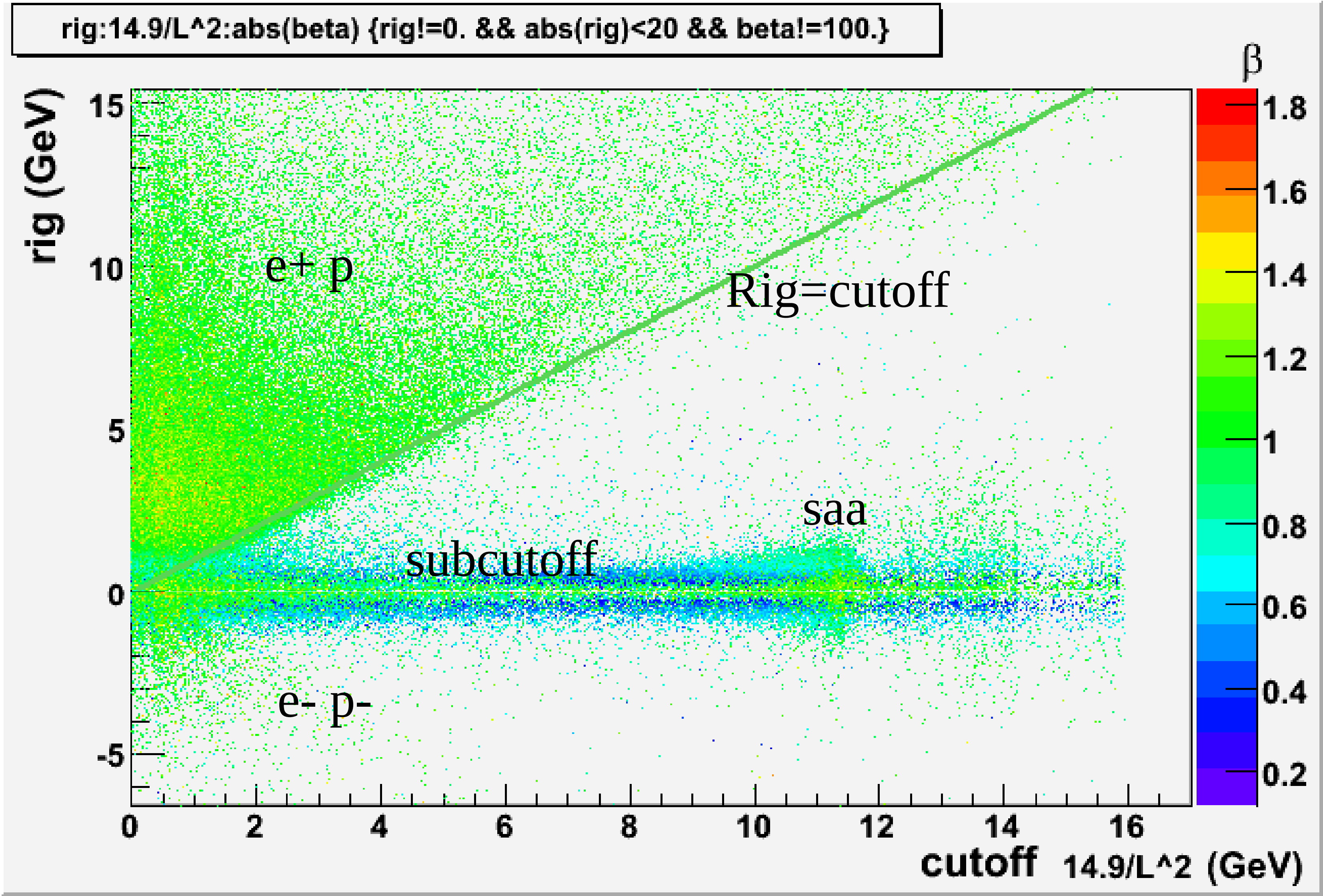
All results shown here are still part of a work in progress phase in which the various performances and response of the detectors are being estimated.

However the observations performed in various conditions show that the device is working correctly and is capable of meeting the science objectives.



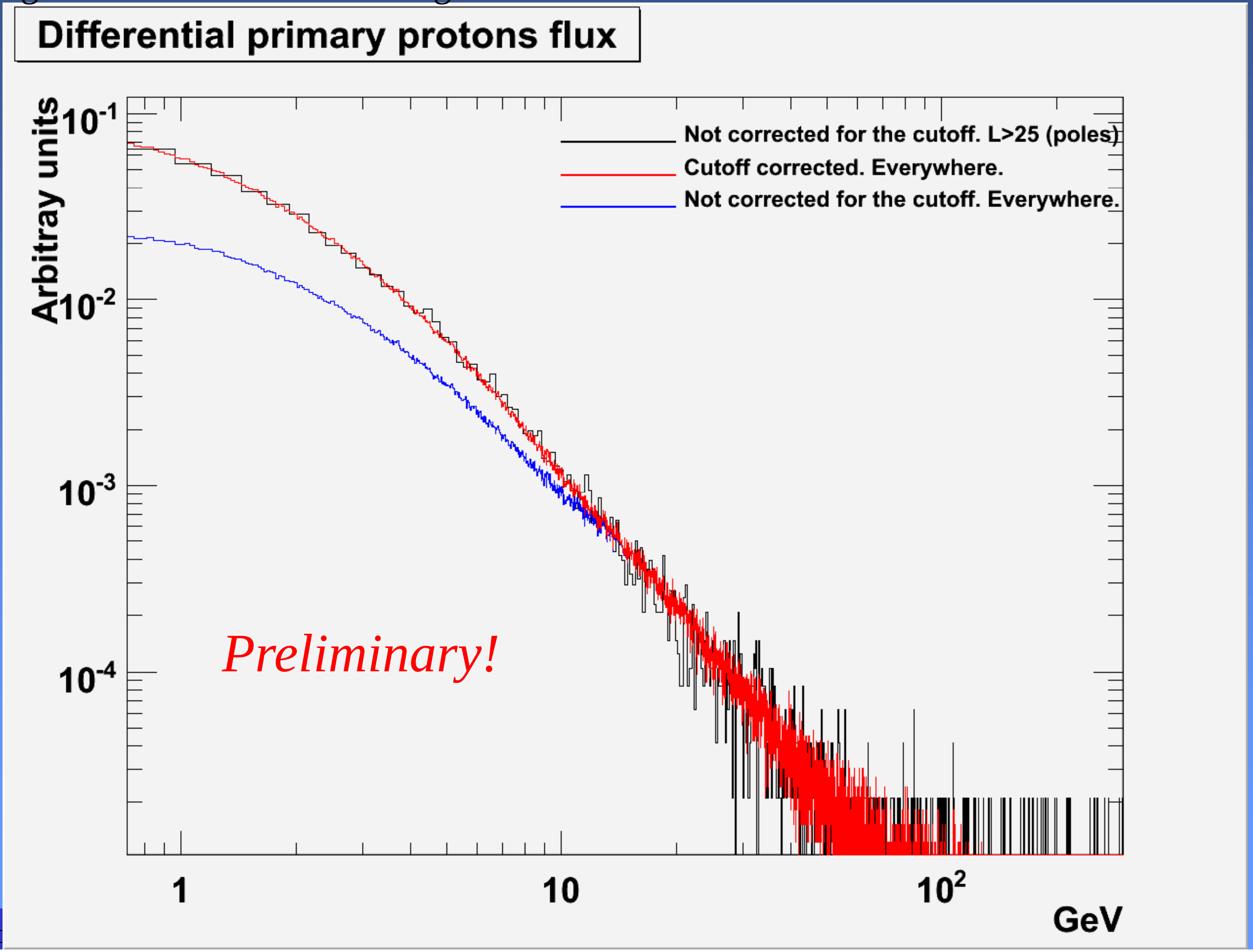
No albedo electrons

Particle rigidity vs Stormer Cutoff

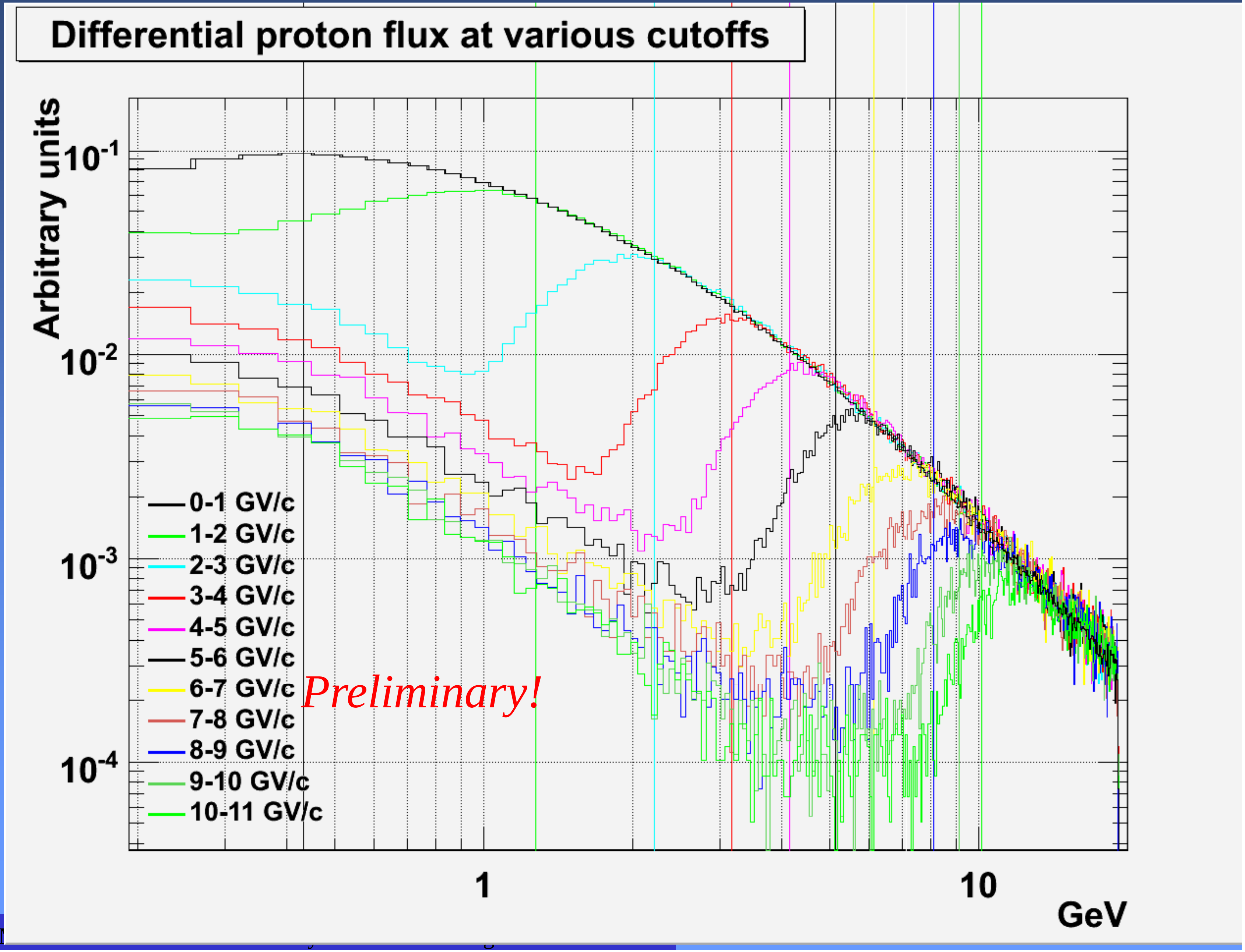


Cutoff correction

To obtain particle flux outside the magnetosphere the cutoff effect has to be removed
This requires to weight each rigidity bin by the time spent at that cutoff
The agreement with high latitude measurements is good.



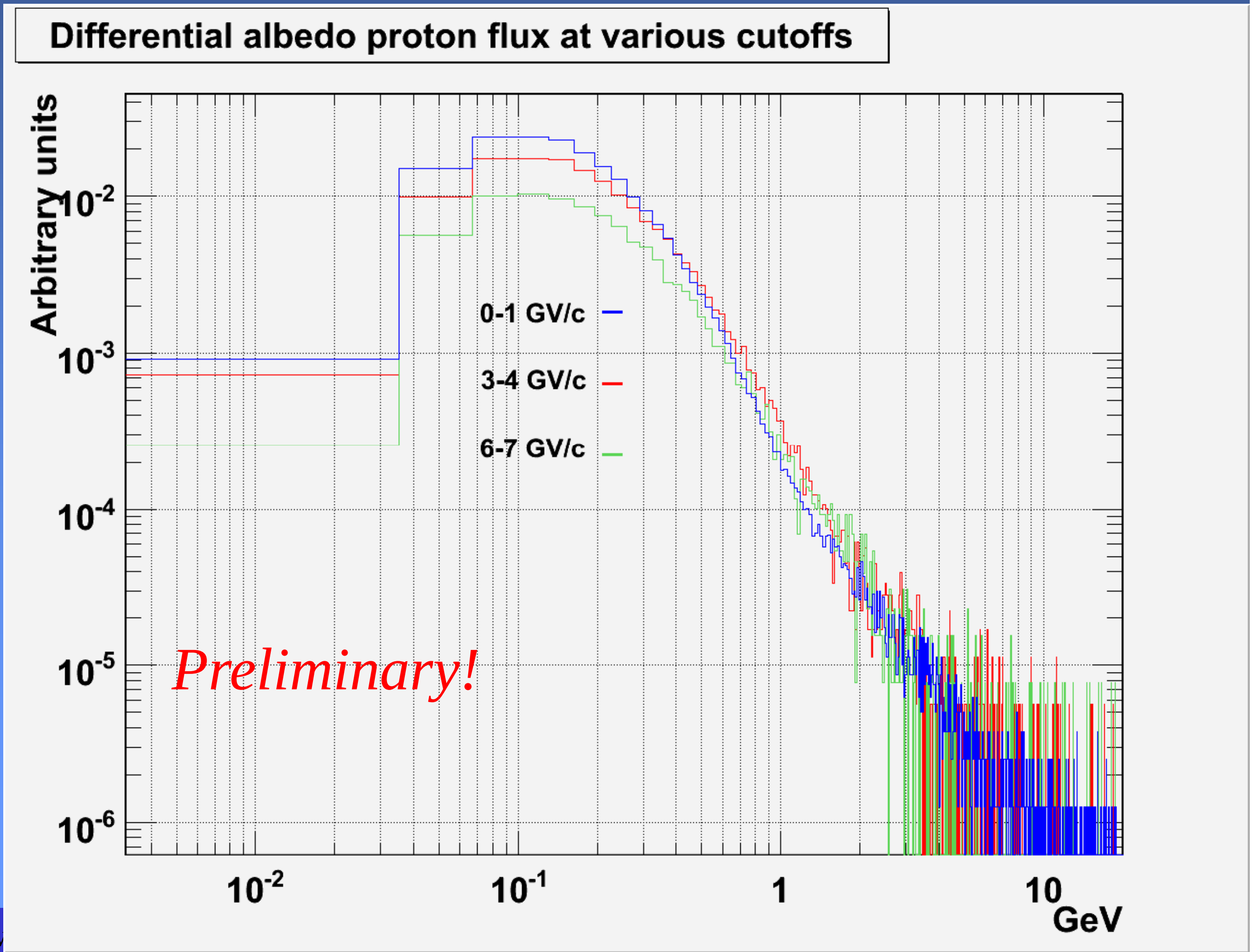
Primary and Albedo (sub-cutoff measurements)



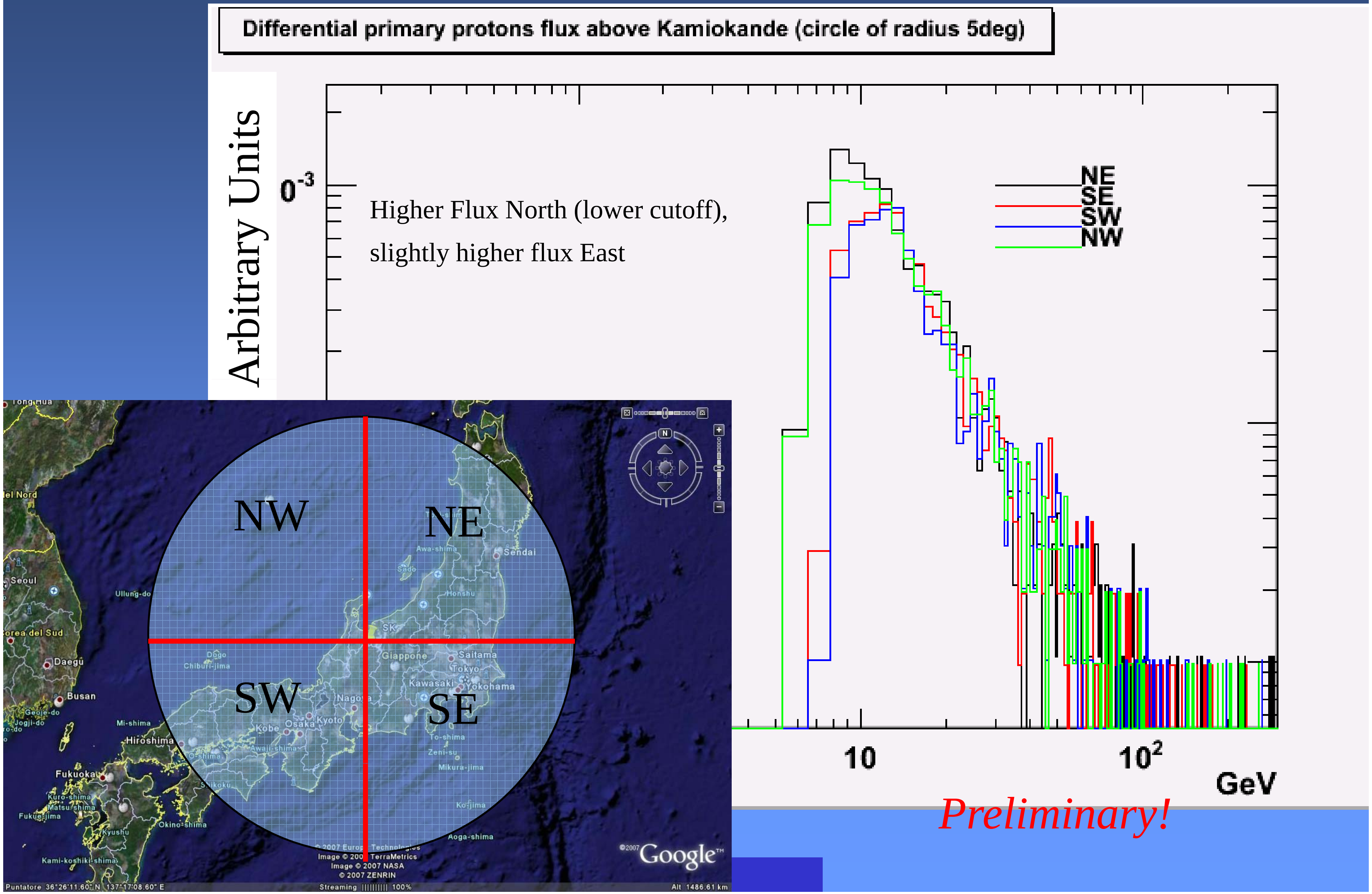
Albedo Protons

Identif with tof
Interaction with calo
- energy loss
- hadr. Int.

Mostly secondary
Lower flux due to earth shielding



An exercise…
Flux above Kamiokande



Preliminary!

Solar particle events

Multi-GeV event measurement in space:

energy spectrum cutoff

Acceleration

Propagation

H, He Isotopic ratios

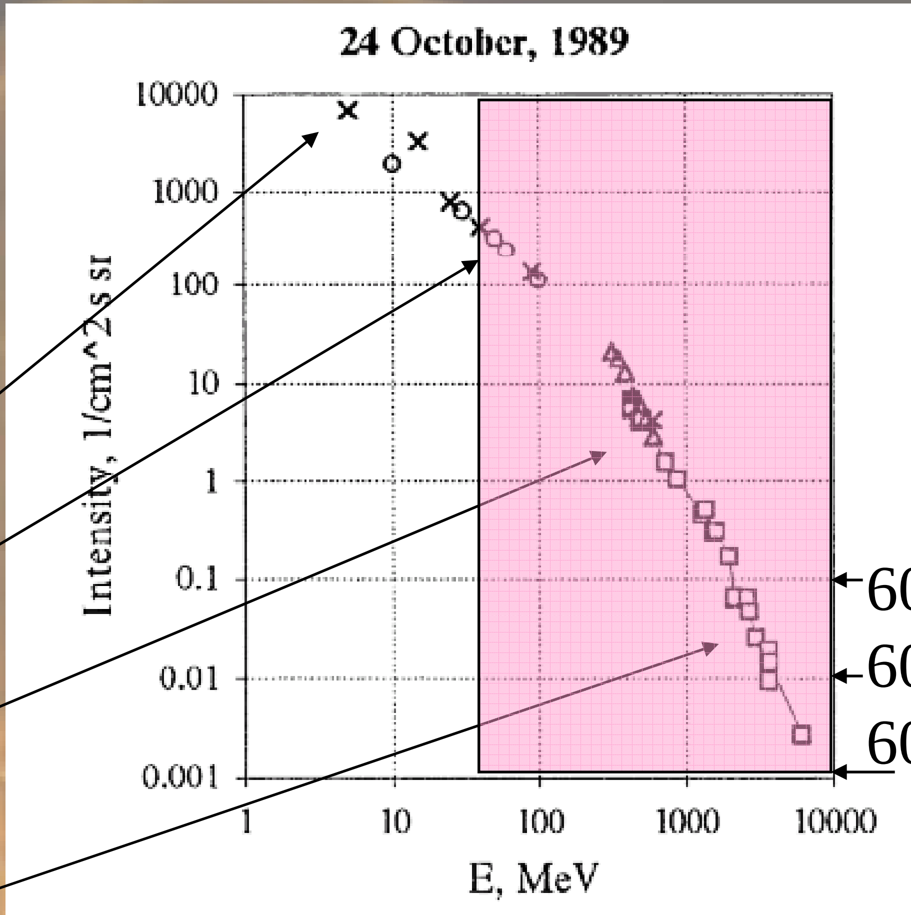
Nuclear component up to O

Meteor

Goes

Balloon

Neutron Monitor



From:
G. A. BAZILEVSKAYA and A. K. SVIRZHEVSKAYA
Space Science Reviews **85:** 431–521, 1998.

Pamela energy range

Electrons from Solar events

High energy component e[-] in SEPs (gradual/impulsive) >6000 e-/day (with 20% orbital live time)

•First measurement of high energy spectral indexes and breakdowns

•First direct measurement of positrons (very high energy ions impact the Sun producing both high energy (GeV) neutrons and pions with the pions decaying directly into photons or into secondary high energy positrons and electrons that in turn radiate).

•Propagation and acceleration effects (shock vs flare question)

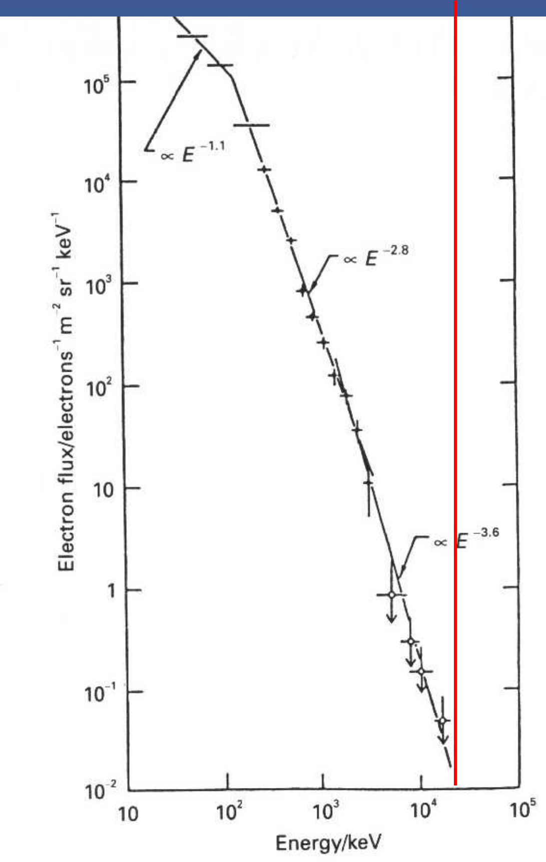


Figure 12.16. The energy spectrum of high energy electrons from the flare of 7 September 1973 as observed by the IMP 6/7 satellites. There is a change in slope of the spectrum at about 100 keV, the index being $\gamma \approx 1.1$ at low energies and about 2.8 at higher energies. (From Guzik, T. G. (1988). *Solar Physics*, **118**, 185.)

Neutrons from Solar Events

- **Produced in nuclear reactions at the flare site, high energy component can reach Earth before decaying.**
- **On the occurrence of solar events, neutrons are expected to reach Earth before protons as they have no charge (neutron/proton dispute on primaries during solar flares, see J. Ryan, rapp. Talk ICRC 2005).**
- **Neutron Detector: 36 ^{3}He counters arranged in two layers, surrounded by polyethilene (9.5 cm)moderator enveloped in thin cadmium layer. Dimesions: 60*55*15cm (10% eff for E<1MeV n)**
- **<u>Background counting</u>**

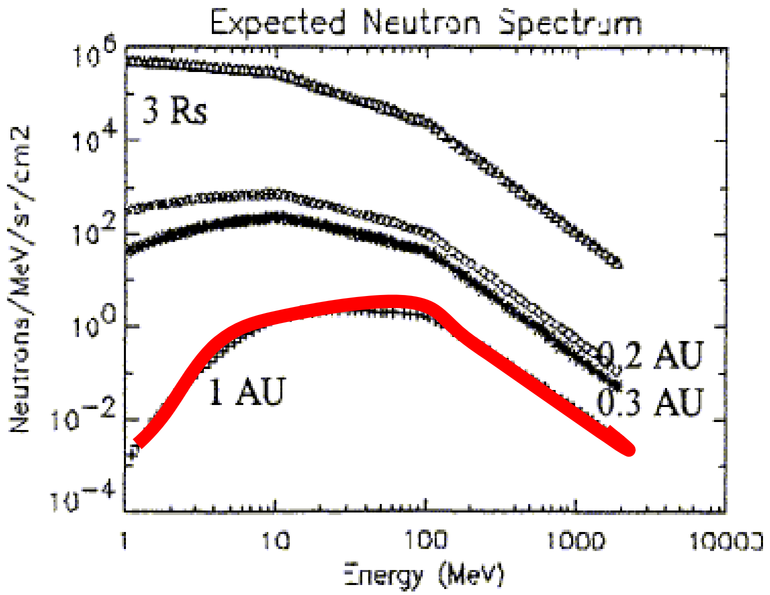


Figure 4: Expected neutron spectra for a 3 June like event at different distances from the solar surface. See text for details.

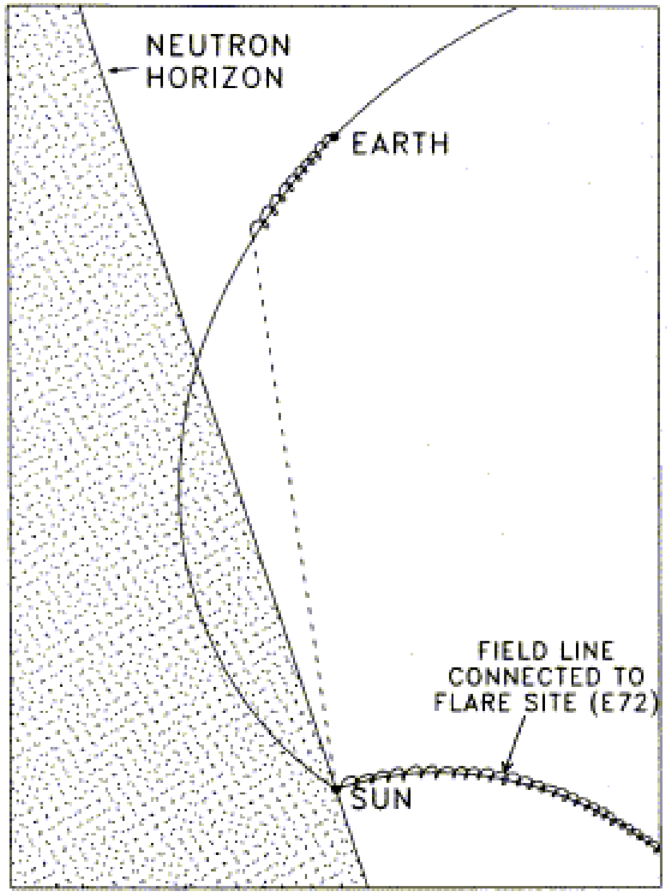
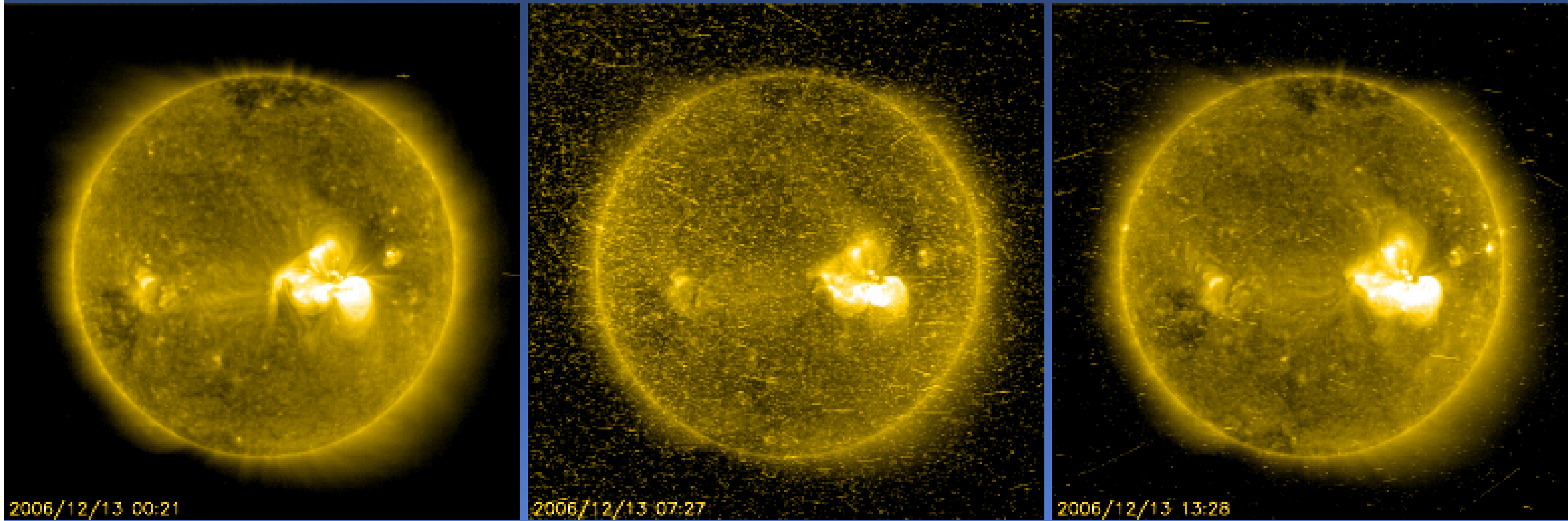


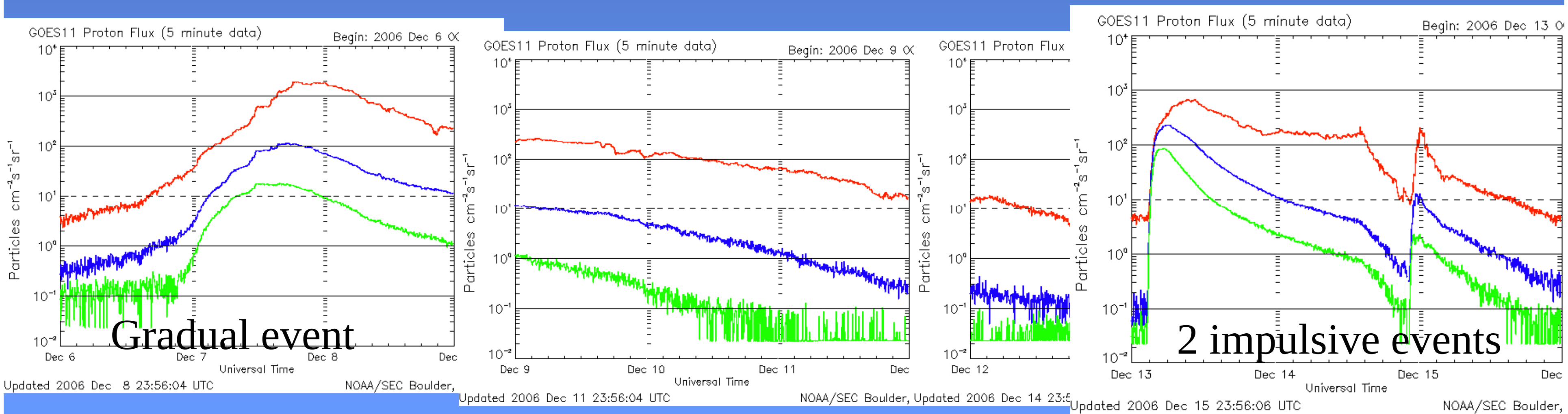
FIG. 2.—Solar system geometry at the time of the 1982 June 3 solar flare in a view perpendicular to the ecliptic plane. Protons from the flare are initially confined to field lines far from the Earth, while neutrons cross the field freely until they decay.

Vilmer, Maksimovic, Lin and Trotter, Proc of "Solar Encounter: the First Solar Orbiter Workshop", Tenerife, 14-18 may 2001 ESA SP-493

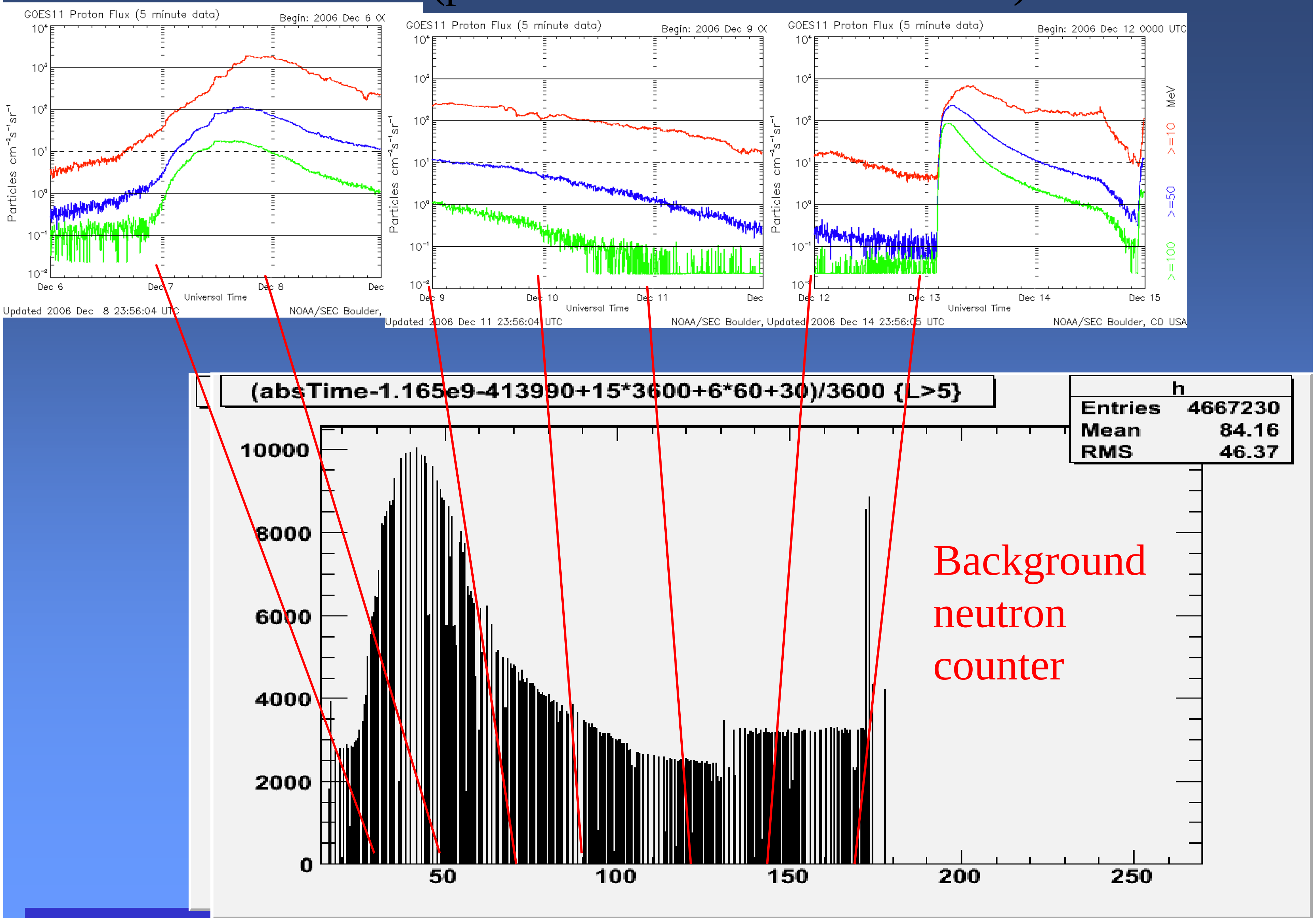
Evenson, Meyer and Pyle, ApJ 274, 875 1983

December 2006 Solar particle events



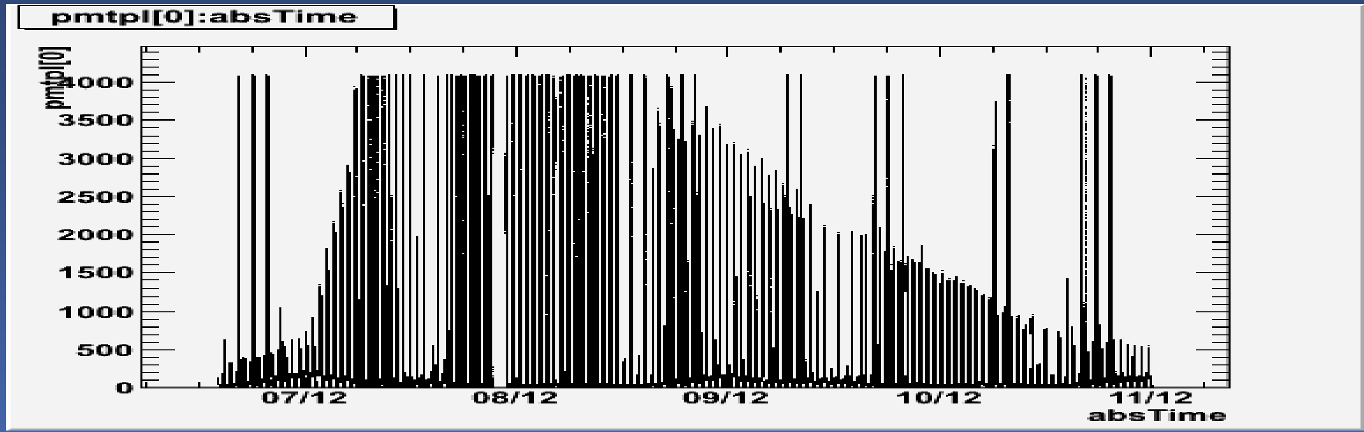


GOES Data (proton E<100 MeV Geost. Orbit)

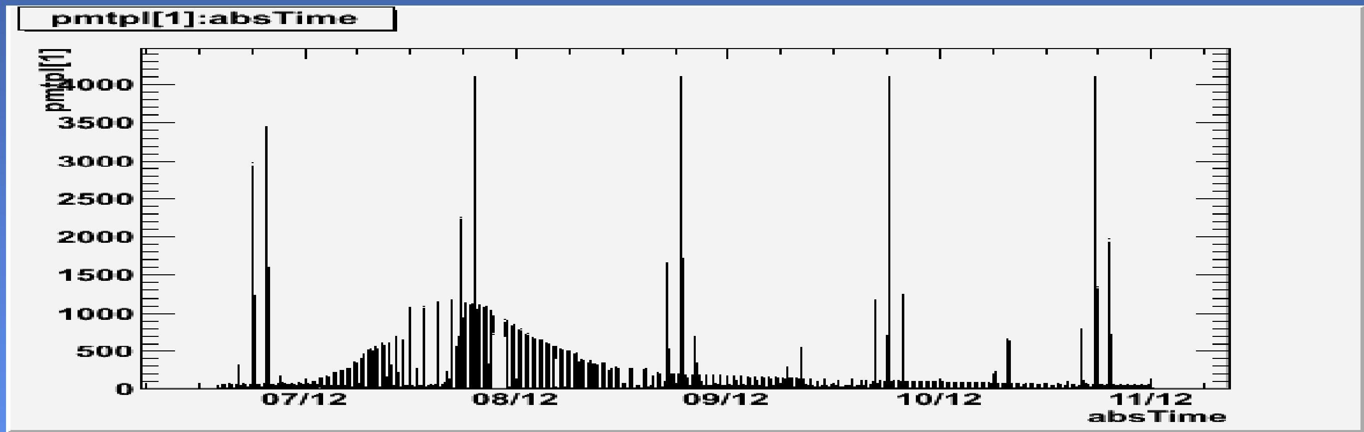


Scintillator counters

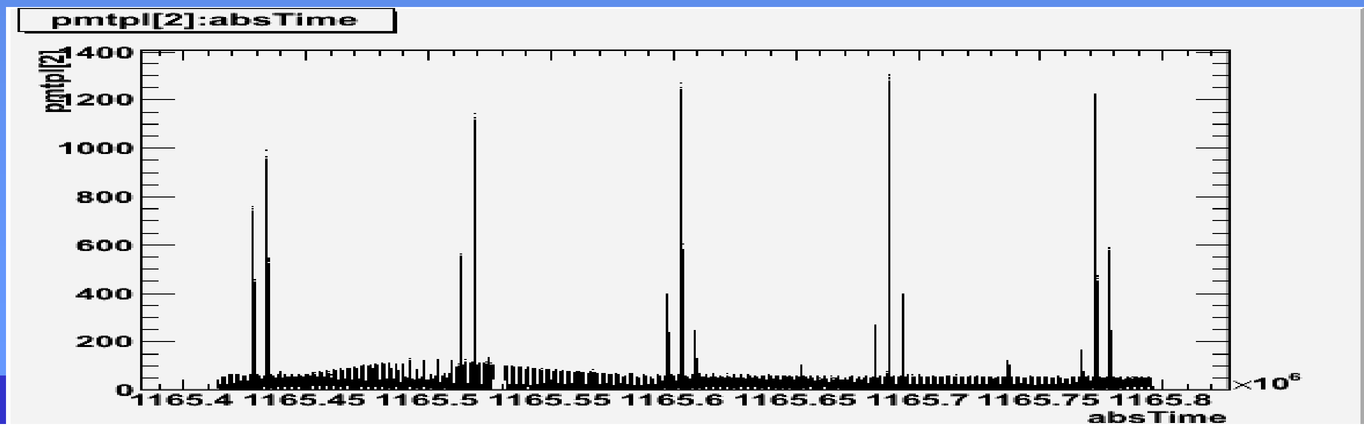
S1



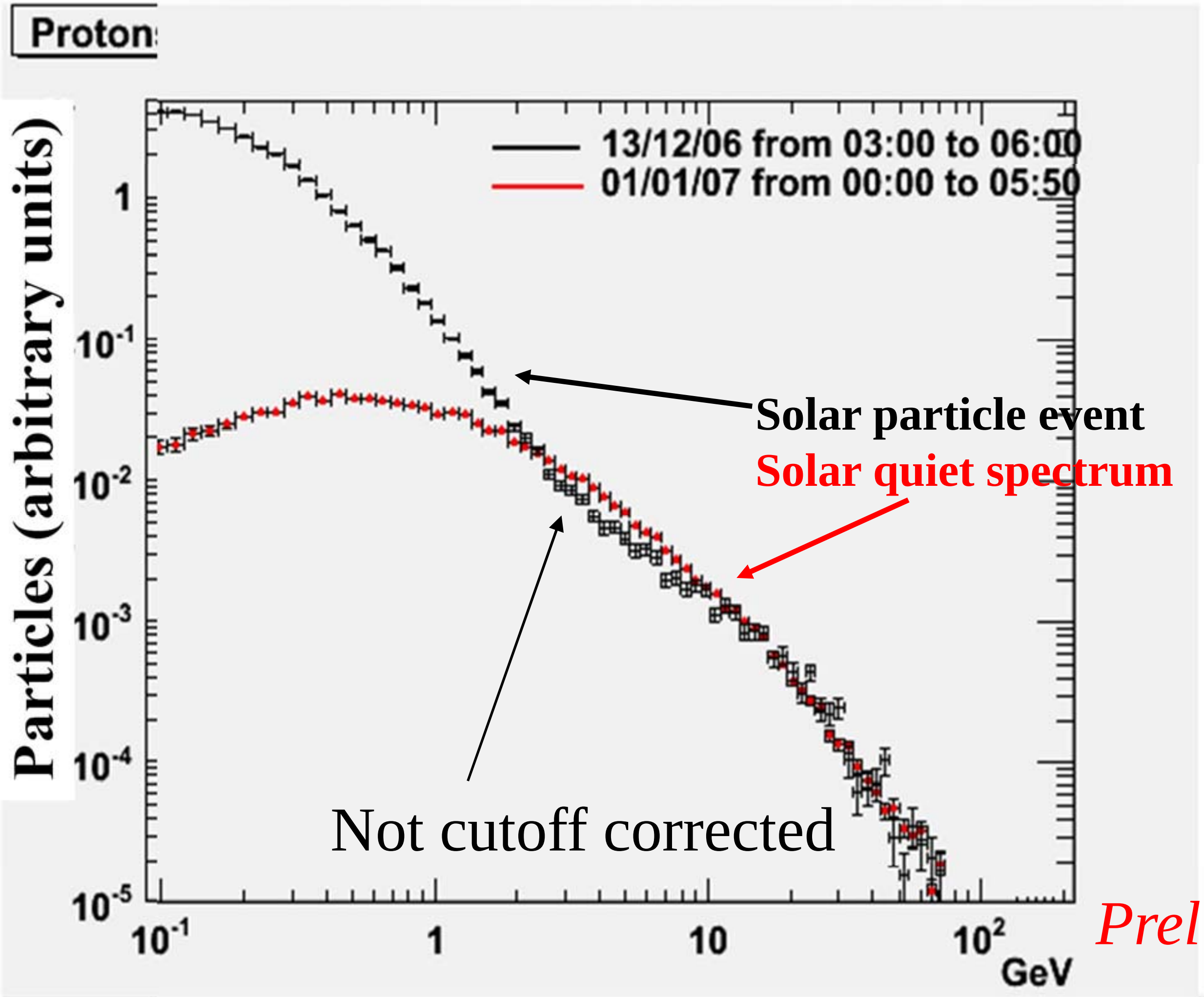
S2

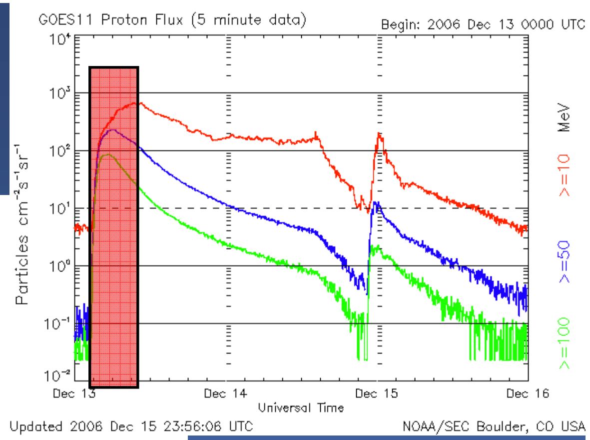


S3



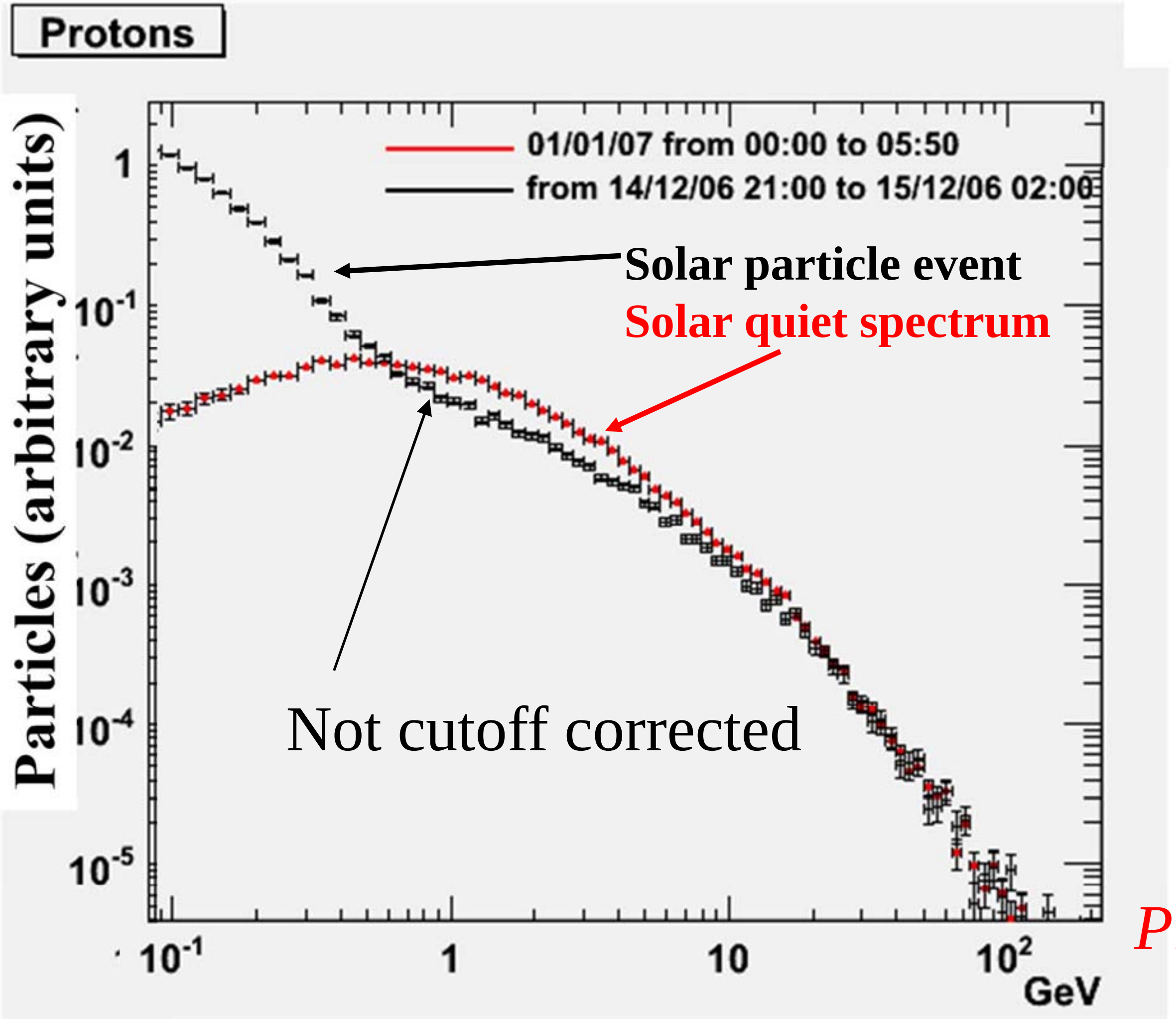
13 december 2006 differential spectrum

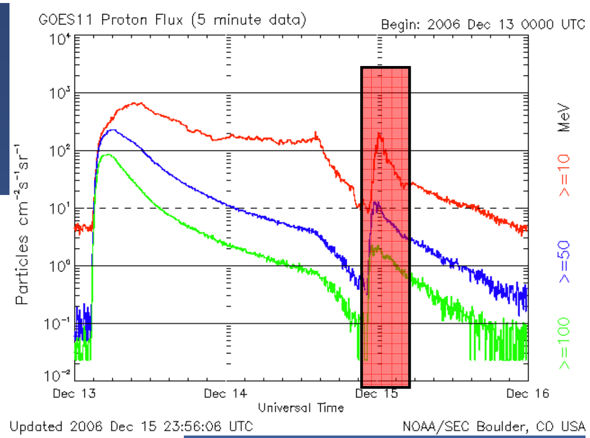




Preliminary!

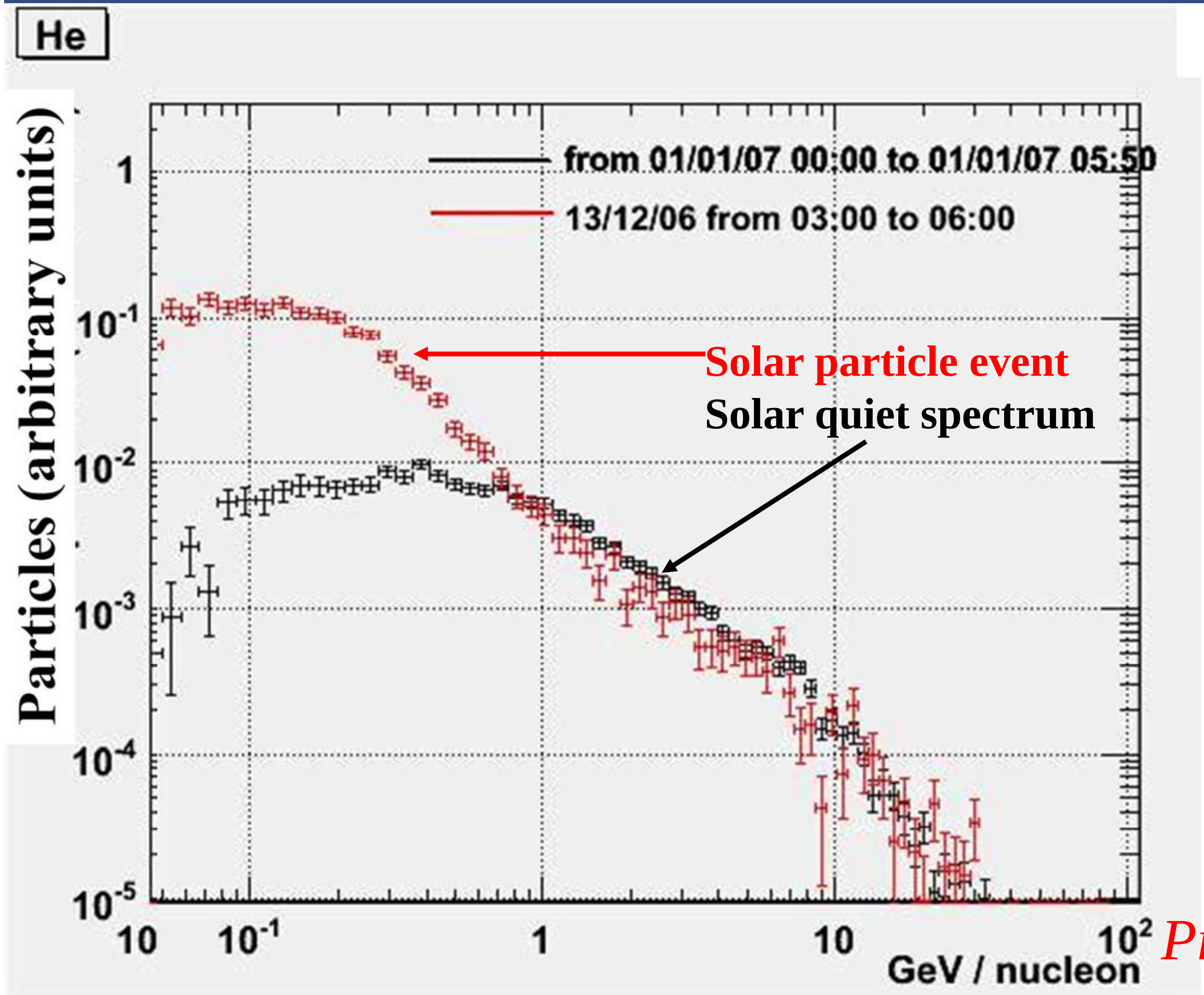
15 december 2006 differential spectrum

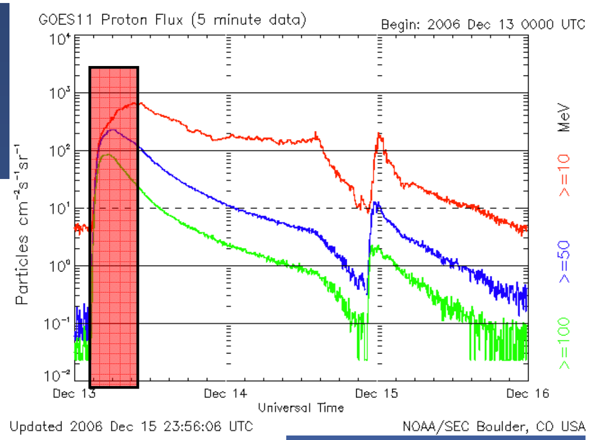




Preliminary!

13 december 2006 He differential spectrum





Preliminary!

Observation of Jovian Electrons: Pioneer, Voyager, Ulysses…

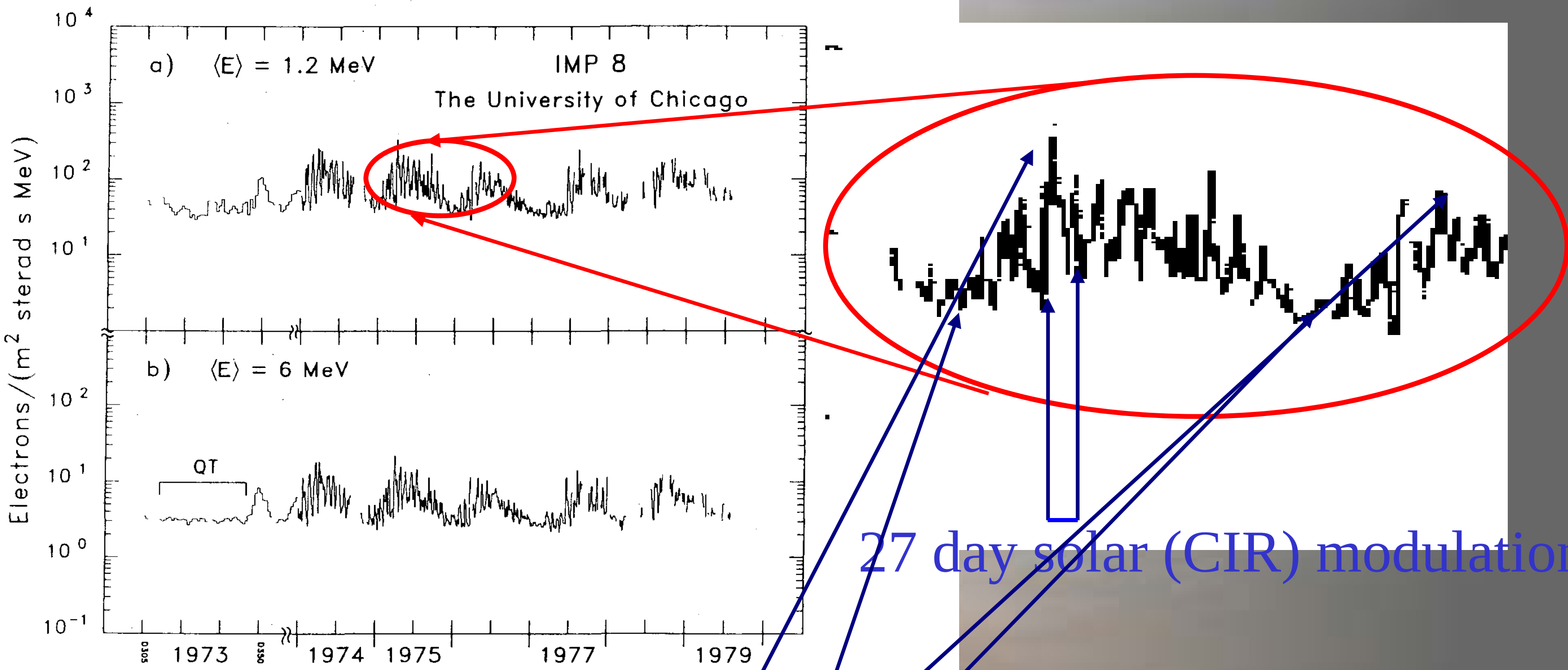


FIG. 8.—The University of Chicago *IMP 8* electron differential fluxes for mean energies of (*a*) 1.2 MeV and (*b*) 6 MeV. Solar flares events and geomagnetospheric bursts have been deleted. The fluxes in 1973, with an extended quiet-time (QT) interval, were averaged in 1 day intervals and are shown on an expanded time scale. After 1973 the fluxes were averaged in 3 day intervals.

- *Jupiter is a source of high energy electrons*
- *Electrons propagate in interplanetary space following local field lines of the solar wind.*
- *Up to 40 MeV jovian electron are dominant population*
- *They are modulated by Jupiter-Earth synodic period (13 months)*
- *Short term (27 day) modulation by CIRs (Coronal Interaction Regions)*

13 month Jupiter -Earth sinodic period

(Opposed field line)

(Same field line)

Jovian electrons

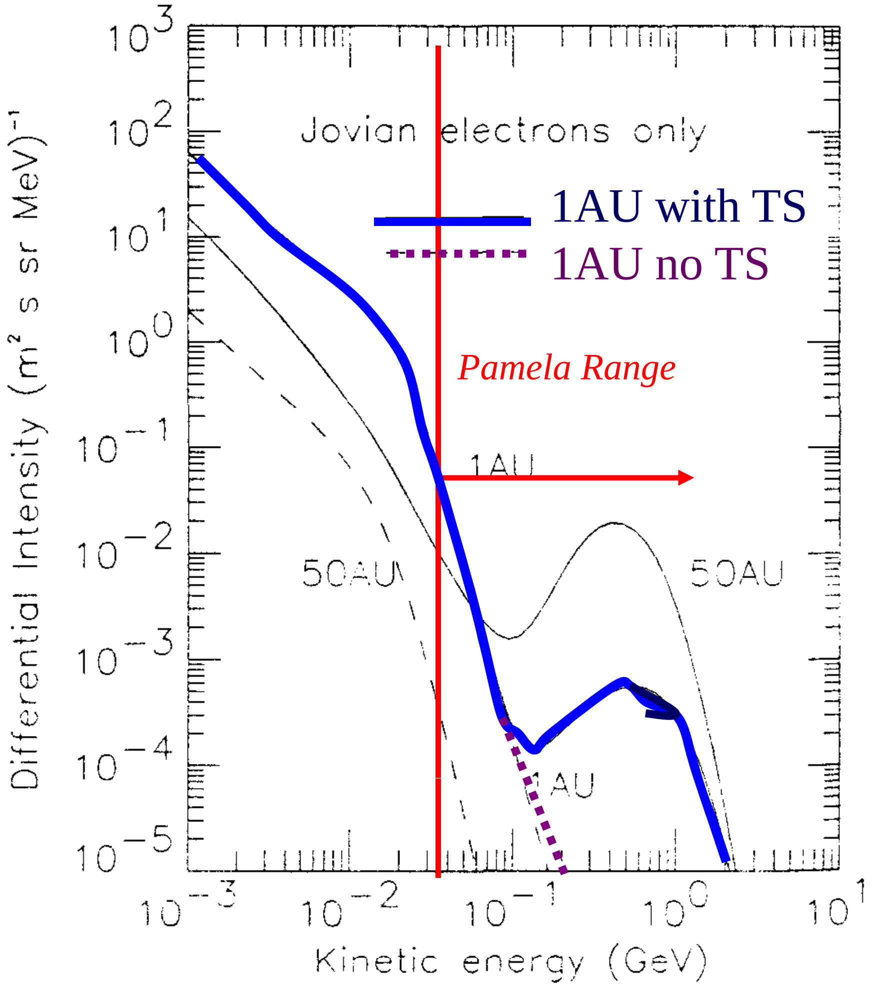


Figure 5. Modulated Jovian electron spectra at 1 and 50 AU compared for a model with and without a TS. The dashed lines are nonshock spectra showing how the Jovian source spectrum is modulated without a TS. The solid lines show the corresponding situation after these electrons have been reaccelerated at the TS, with r_s = 90 AU and r_b = 120 AU.

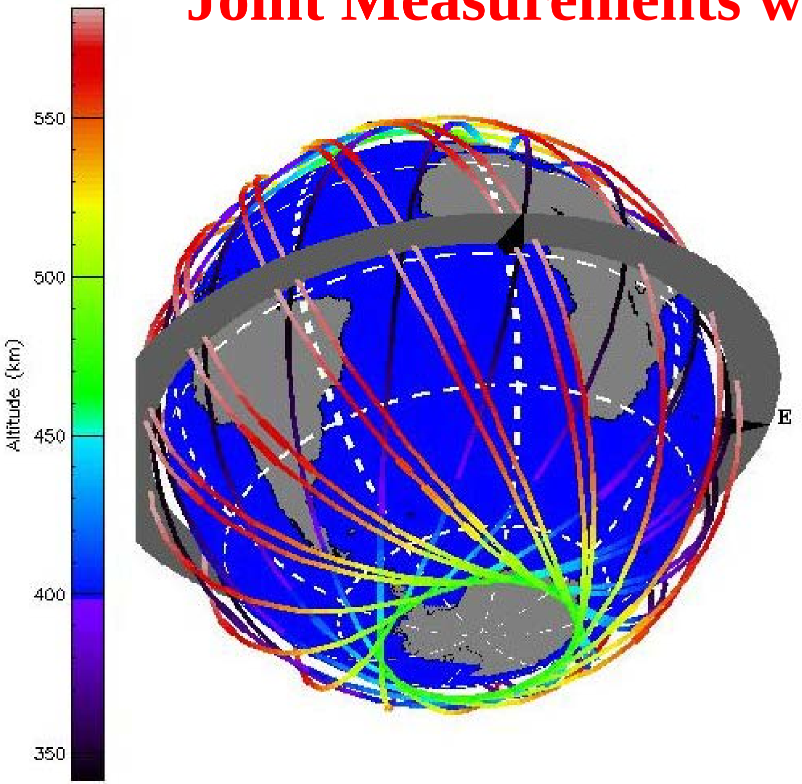
- Jovian electrons dominate at low energies
- They are reaccelerated by the Termination Shock
- Very sensitive to Shock Position
- Short (27d) and long (399d) term modulation
- Electron – Positron measurement

allows separation of the two populations

- *Pamela e^- ≅ 50000/month*
- *Jovian component ≅ 1% (600/month)*
- *First high energy (>50 MeV) measurement of primary Jovian component*

Poitgieter & Ferrera JGR 107, A7 10.1029/2001JA009040, 2002

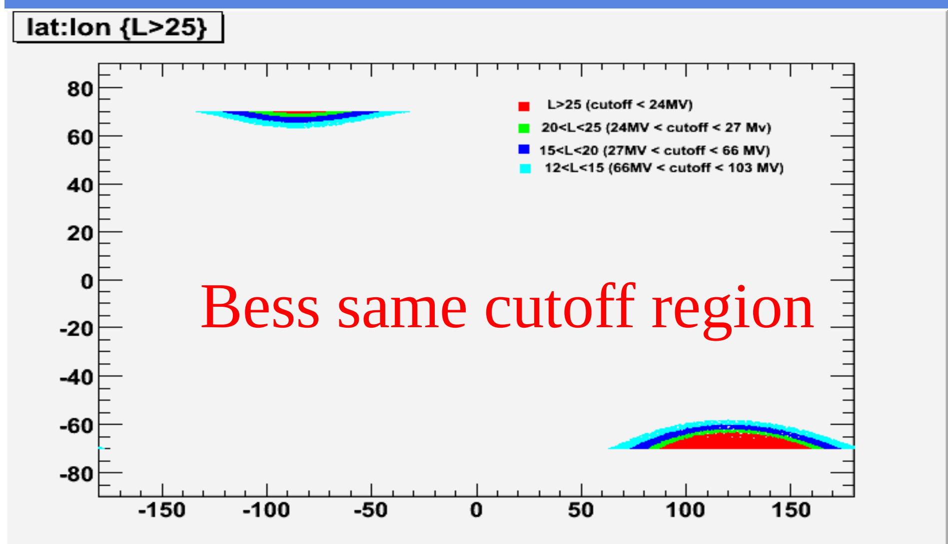
Joint Measurements with BESS (dec 2007) and AMS (2009)

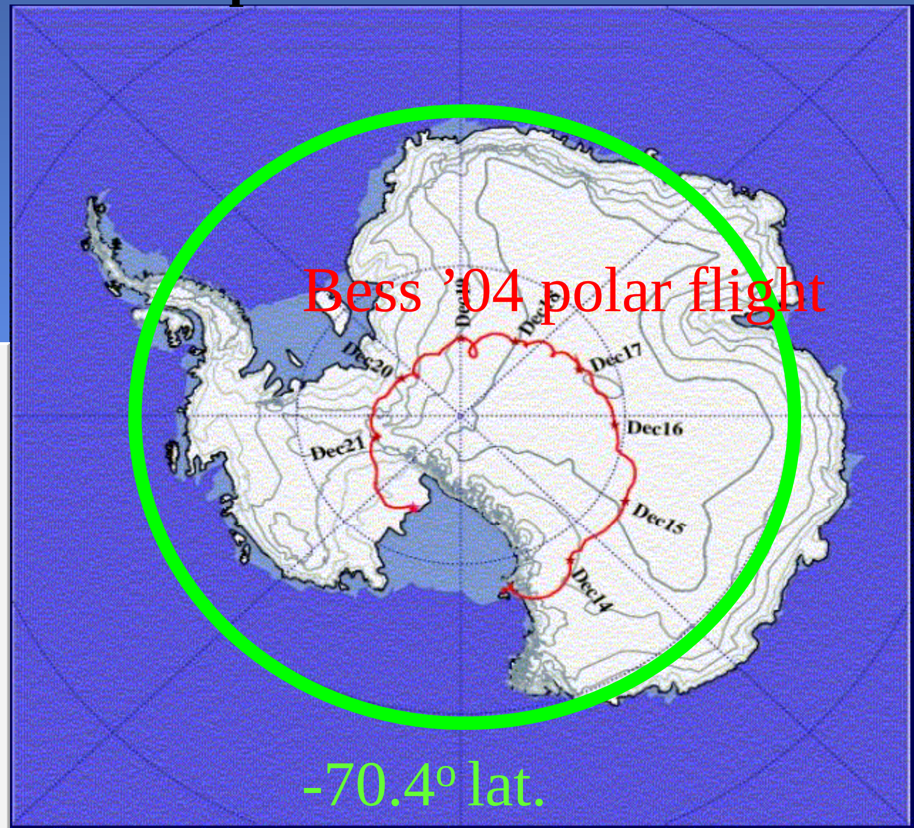


Permanence time with L>12 (Cutoff 100 MV) = 13%

Good Proton – Electron Statistics during 20 day BESS flight

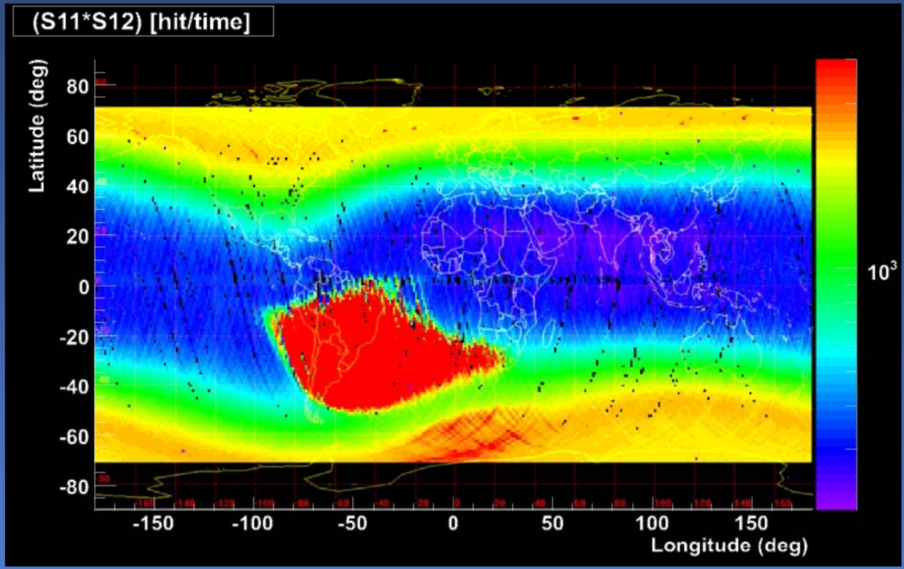
1. **Reduce systematics**
2. **Same time different cutoff regions**
3. **Time dependent events**





(minimum Pamela orbit)

Extension of Pamela energy range

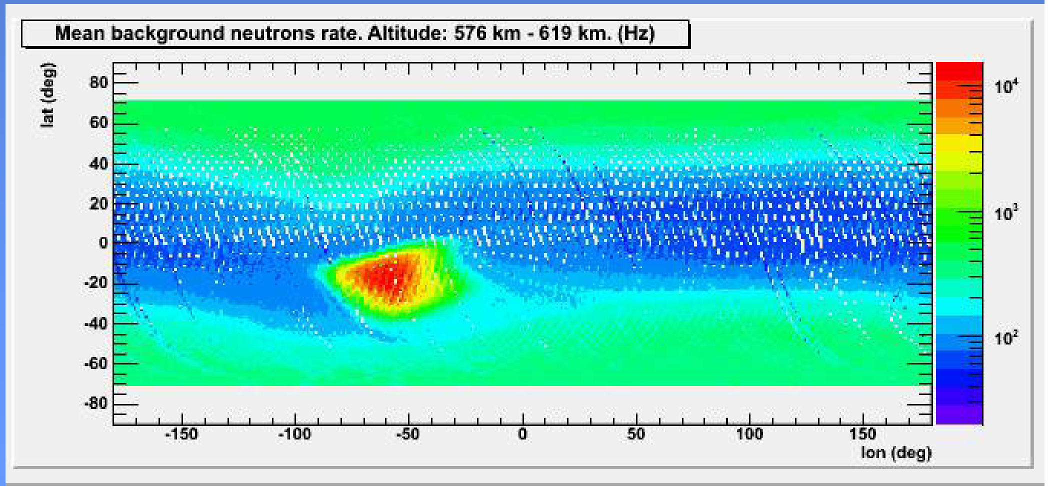


All particle flux:

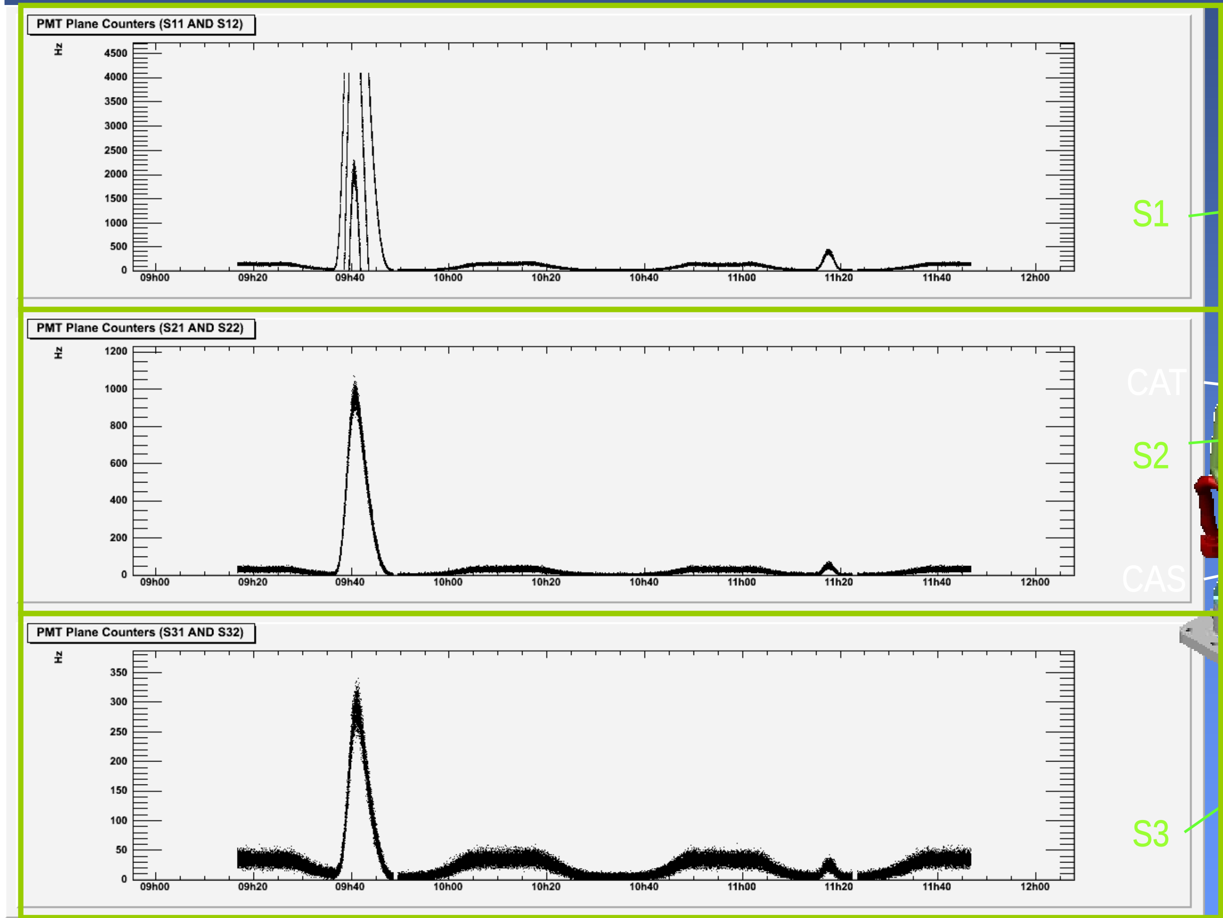
S11&S12: 36 MeV p, 3.5 MeV e-
S1&S2: 63 MeV p, 9.5 MeV e-
S2&S3: 80 MeV p, 50 MeV e-

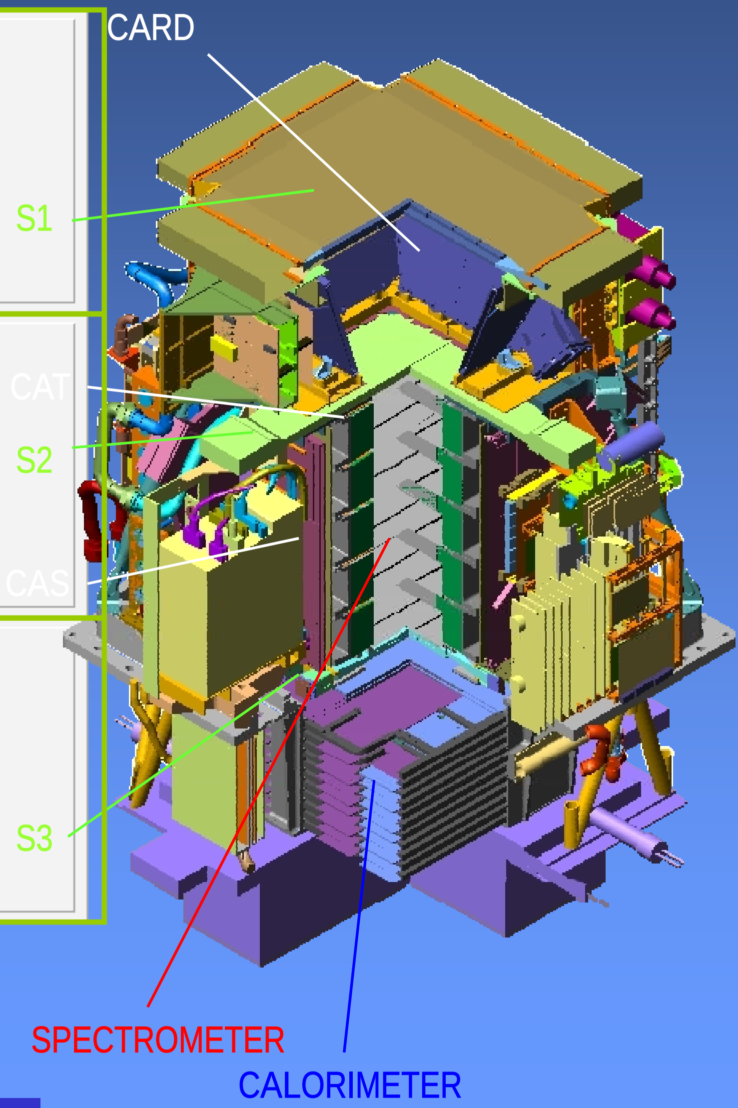
Neutron flux

Background estim. in satellite
Attitude dependence?

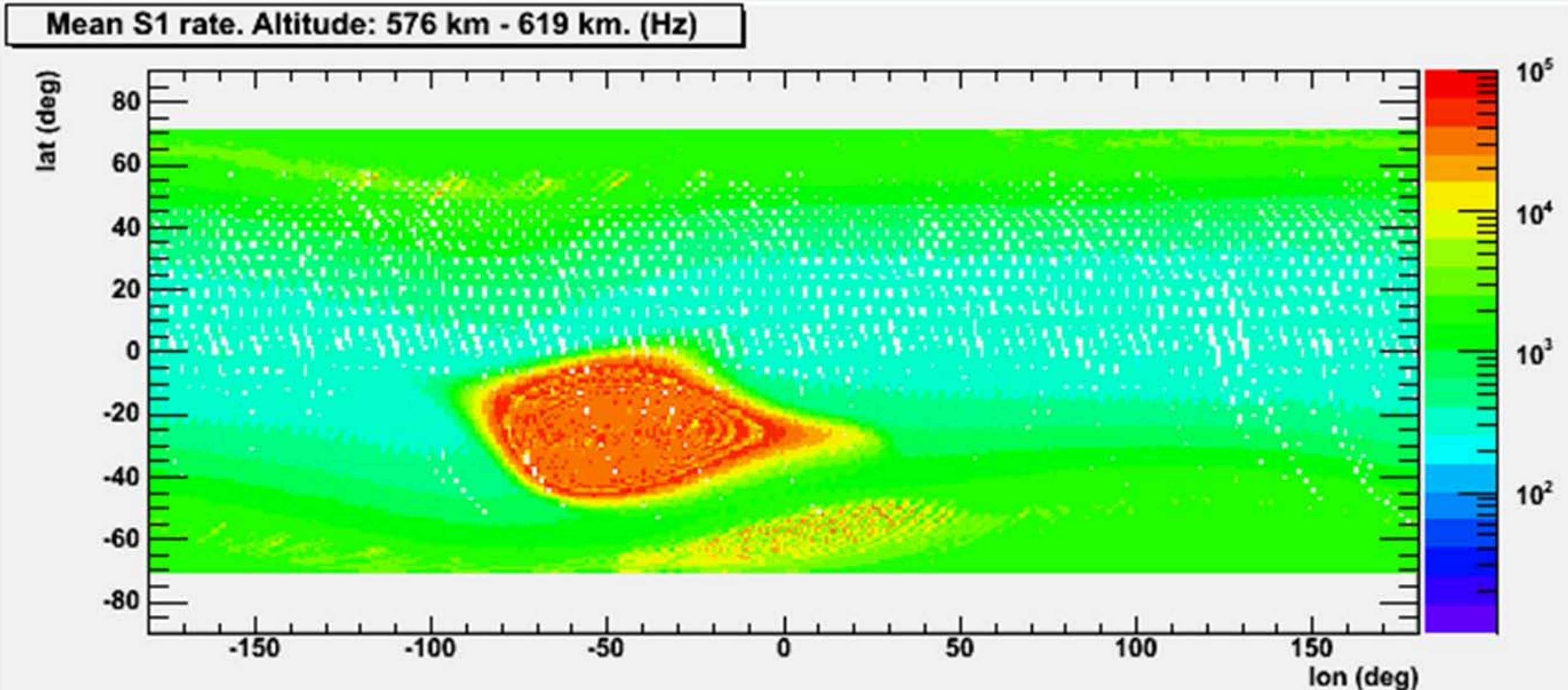


Scintillator counters

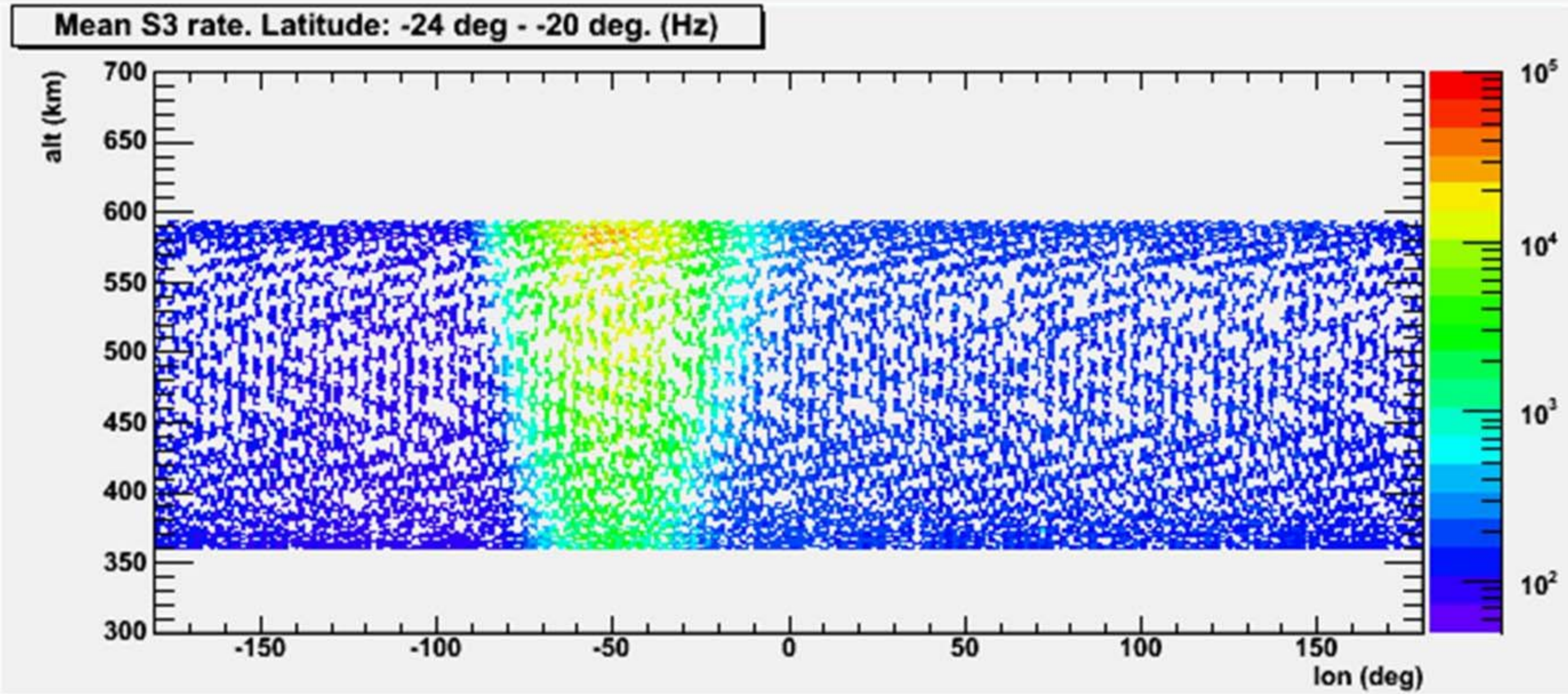




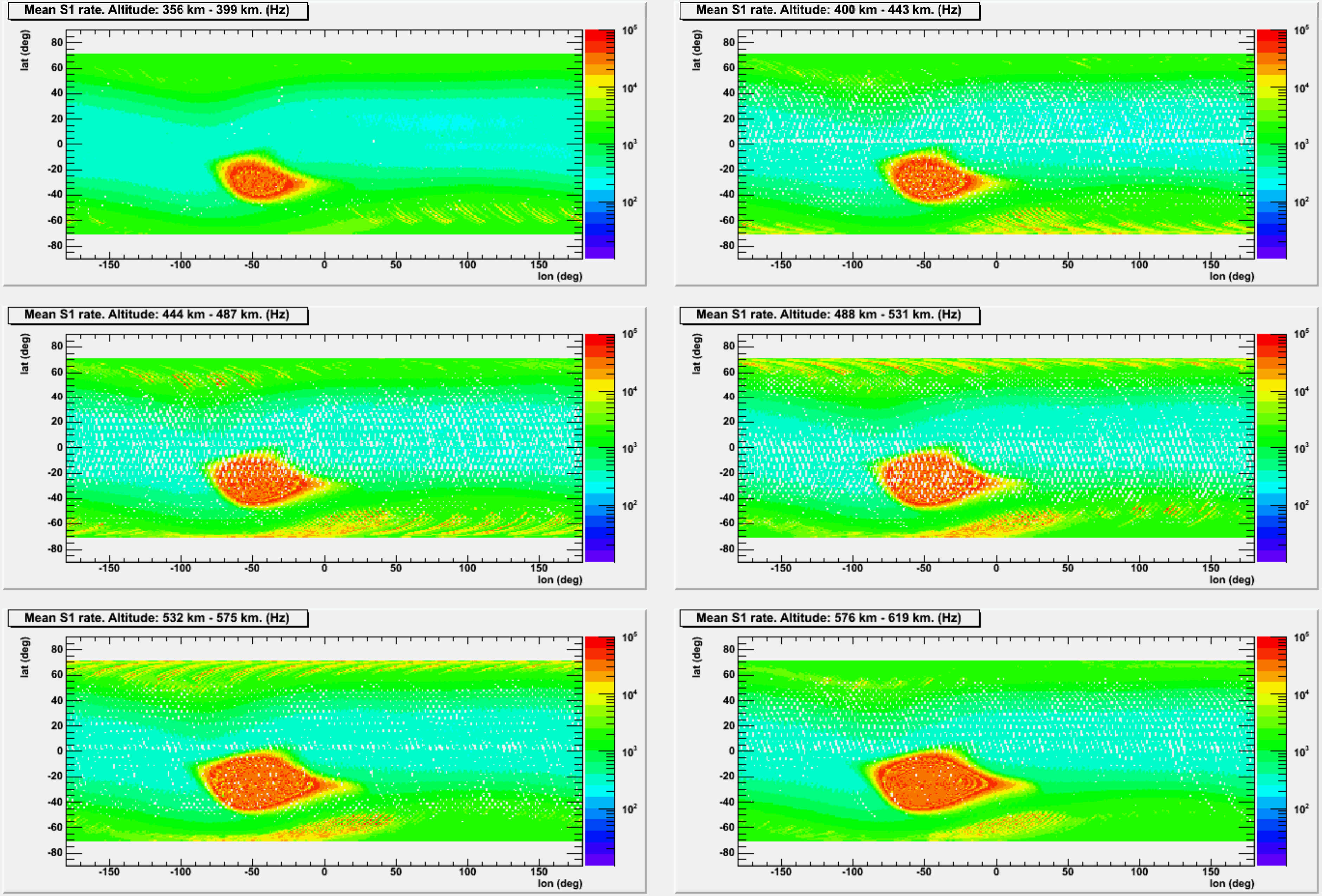
Pamela maps at various altitudes



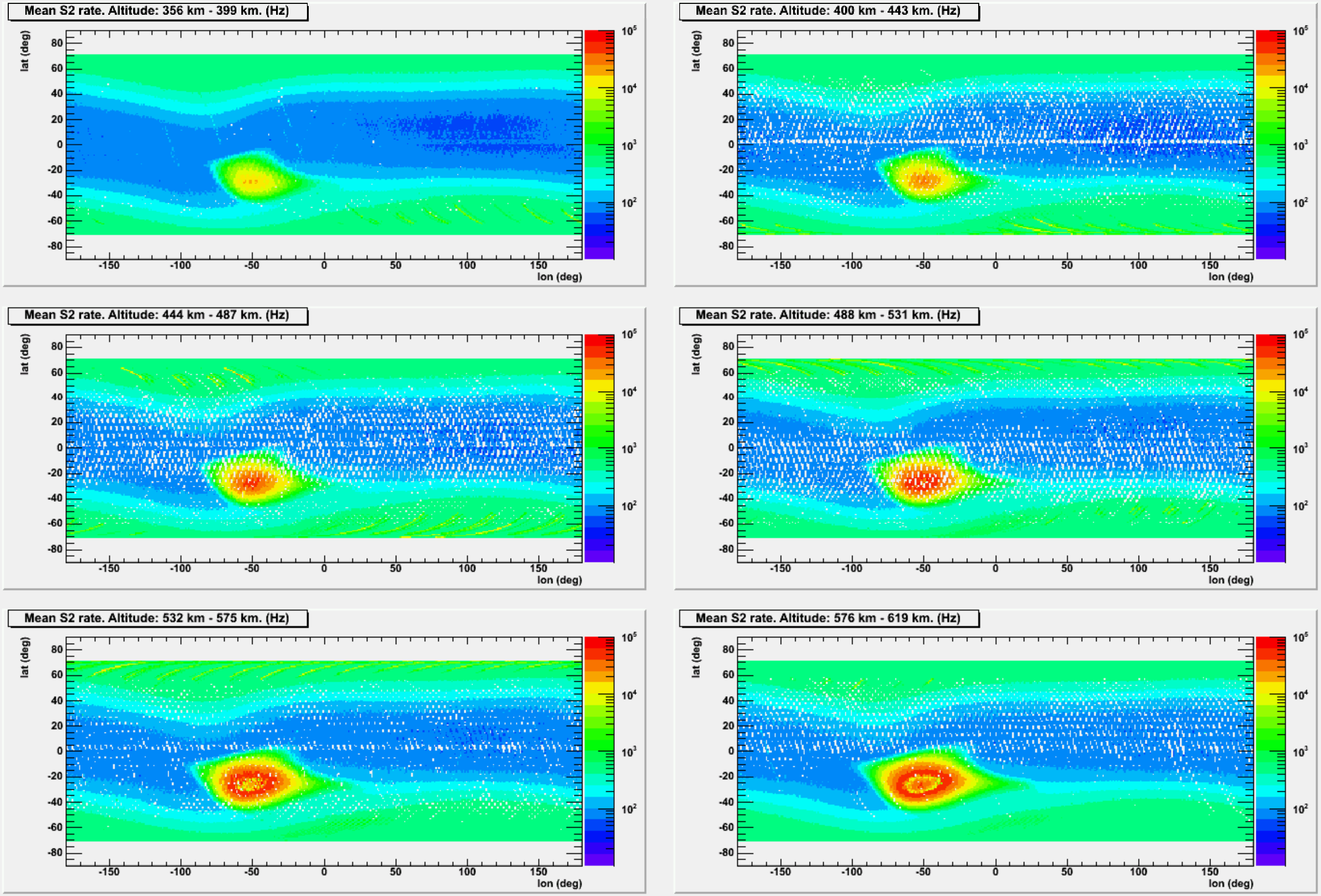
Pamela maps at various latitudes



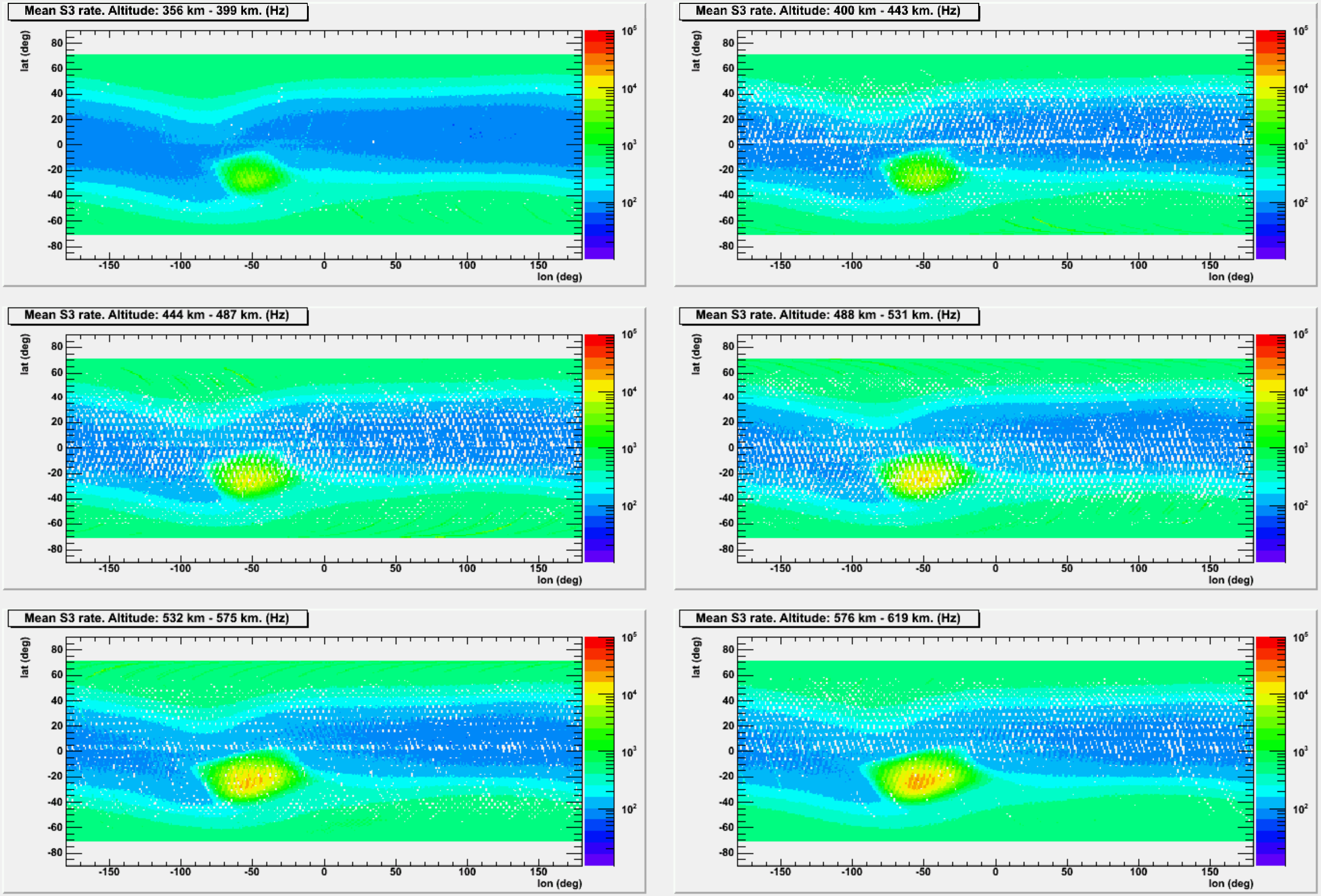
Top Scintillator: E> 35 MeV



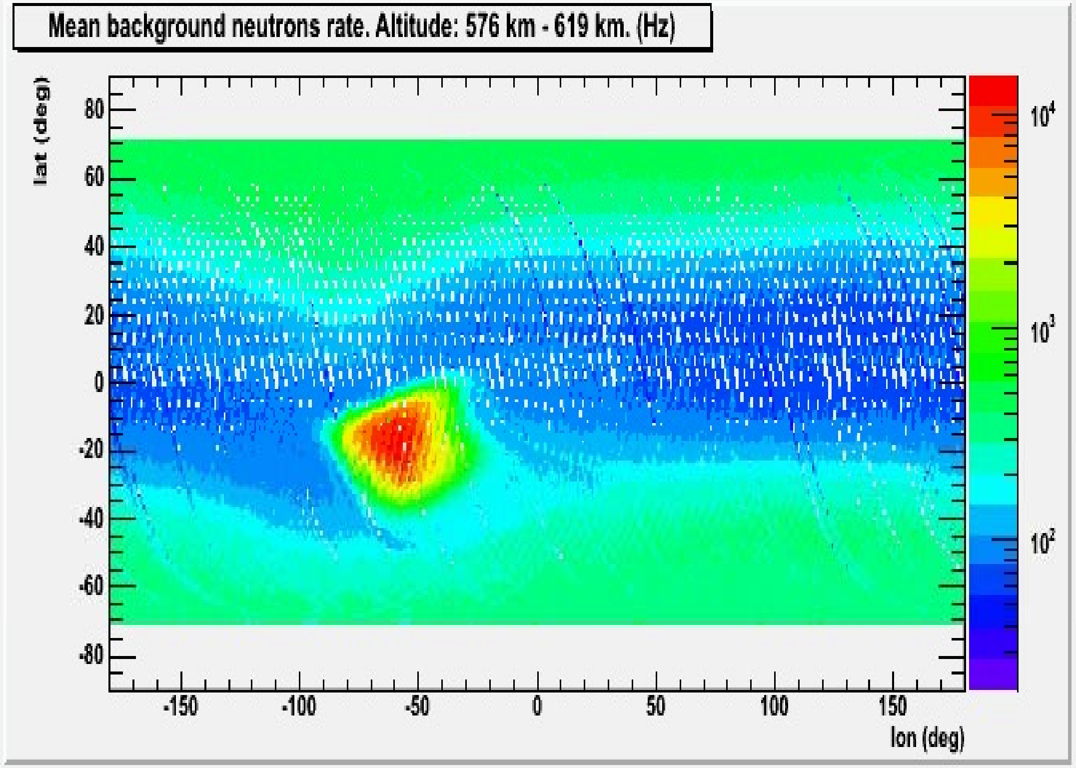
Centre Scintillator: E>60 MeV

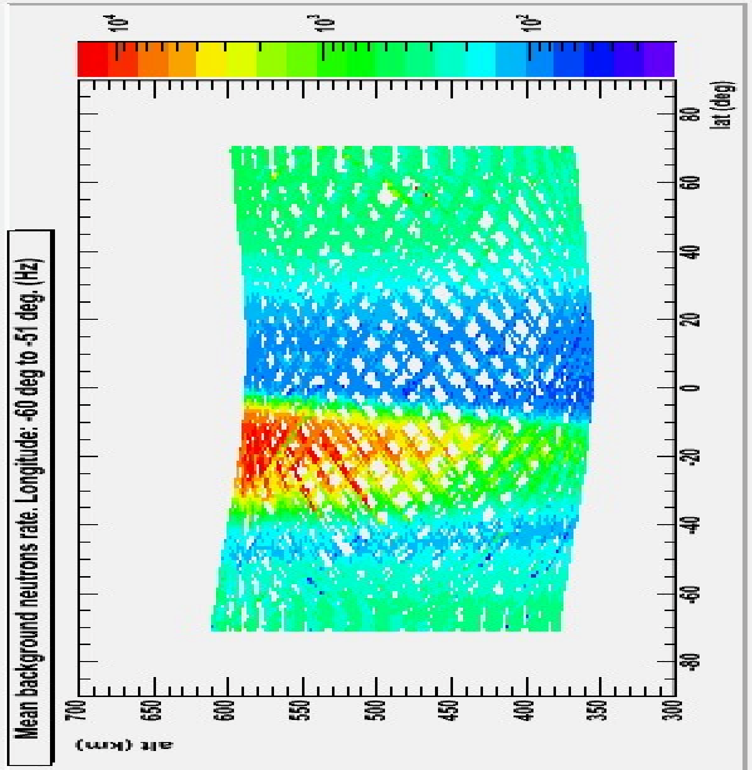


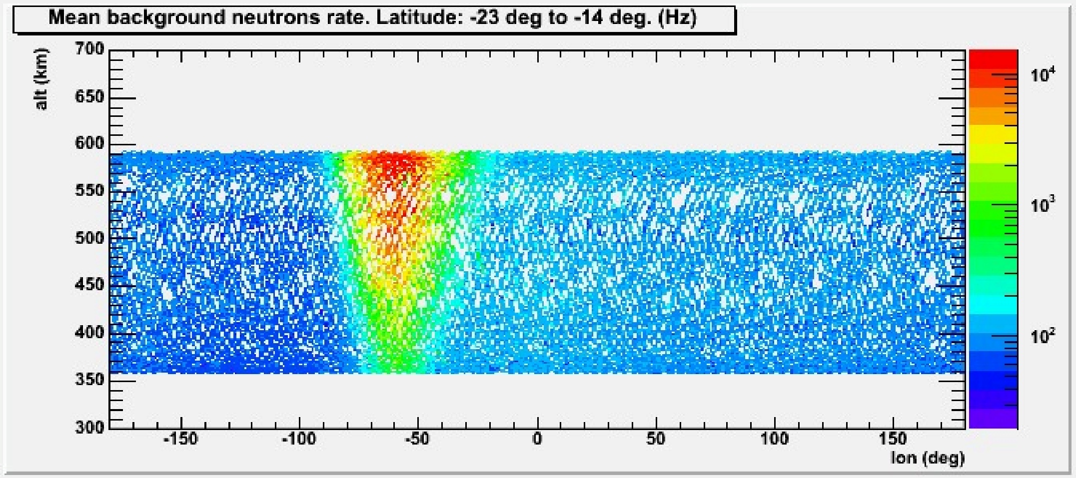
Bottom Scintillator: E>80 MeV



Neutron Tomography. Orthogonal projections







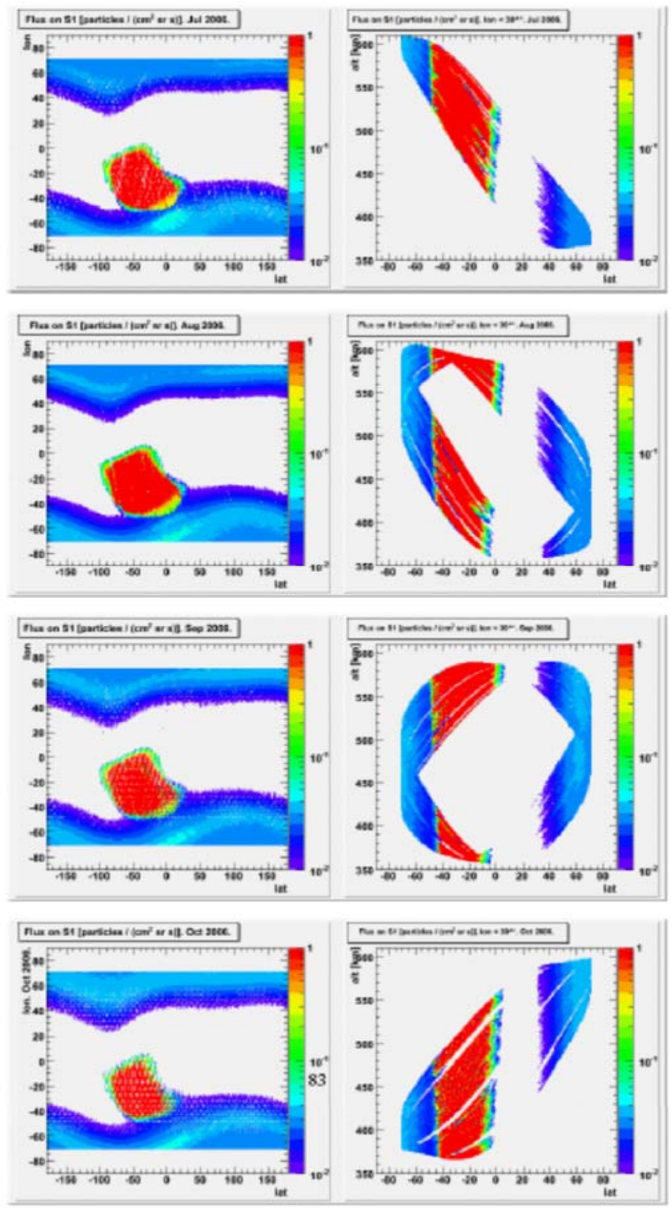
Temporal variations

JULY 2006

AUG 2006

SEPT 2006

OCT 2006



Temporal variations (2)

NOV 2006

DEC 2006

JAN 2007

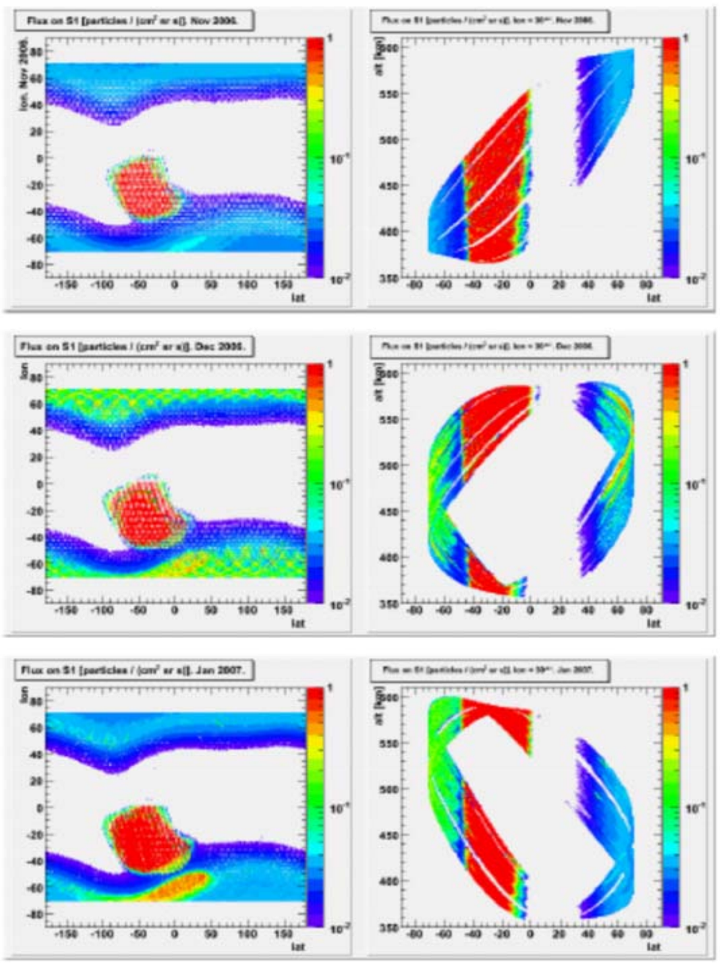
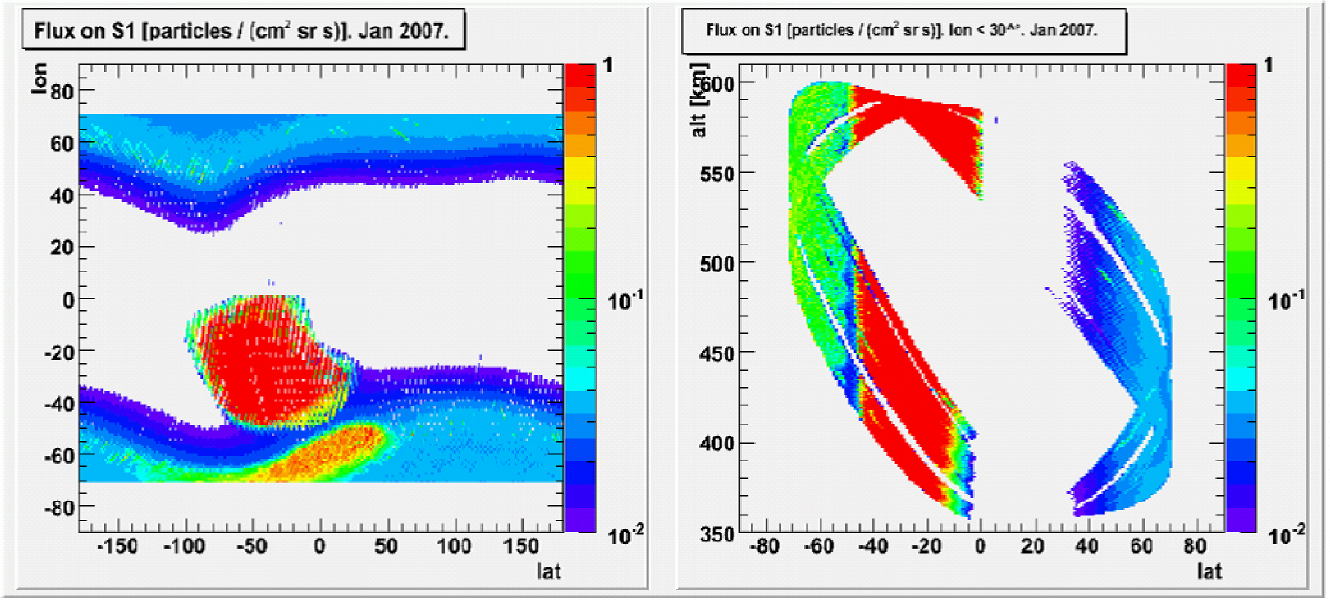


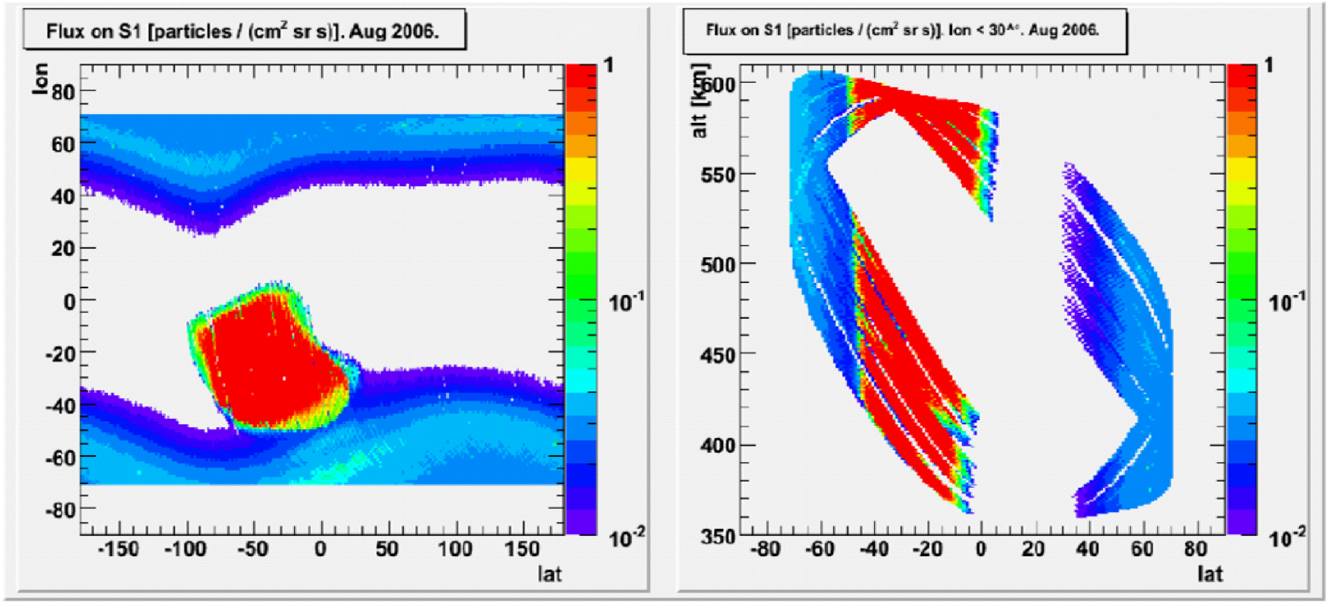
Figura 5.32: Flussi di particelle sullo scintillatore S1, in *particelle*/($cm^2 sr s$), ne corso dei mesi. A sinistra il flusso è mostrato in funzione di latitudine e longitudine, mediato su tutte le altezze. A destra si mostra il flusso in funzione di altitudine e latitudine, mediato in longitudine; per evitare che questa media appiattisca la visualizzazione delle fasce di elettroni ci si limita ad una longitudine minore di 30° *ovest*. La scala di colore, che rapppresenta il flusso, è tagliata, sia in alto che in basso, allo scopo di far risaltare le fasce di elettroni.

84

Electron injection by December 2006 events



Increase of Trapped electrons in Dec- Jan Due to electron immission by solar particle event

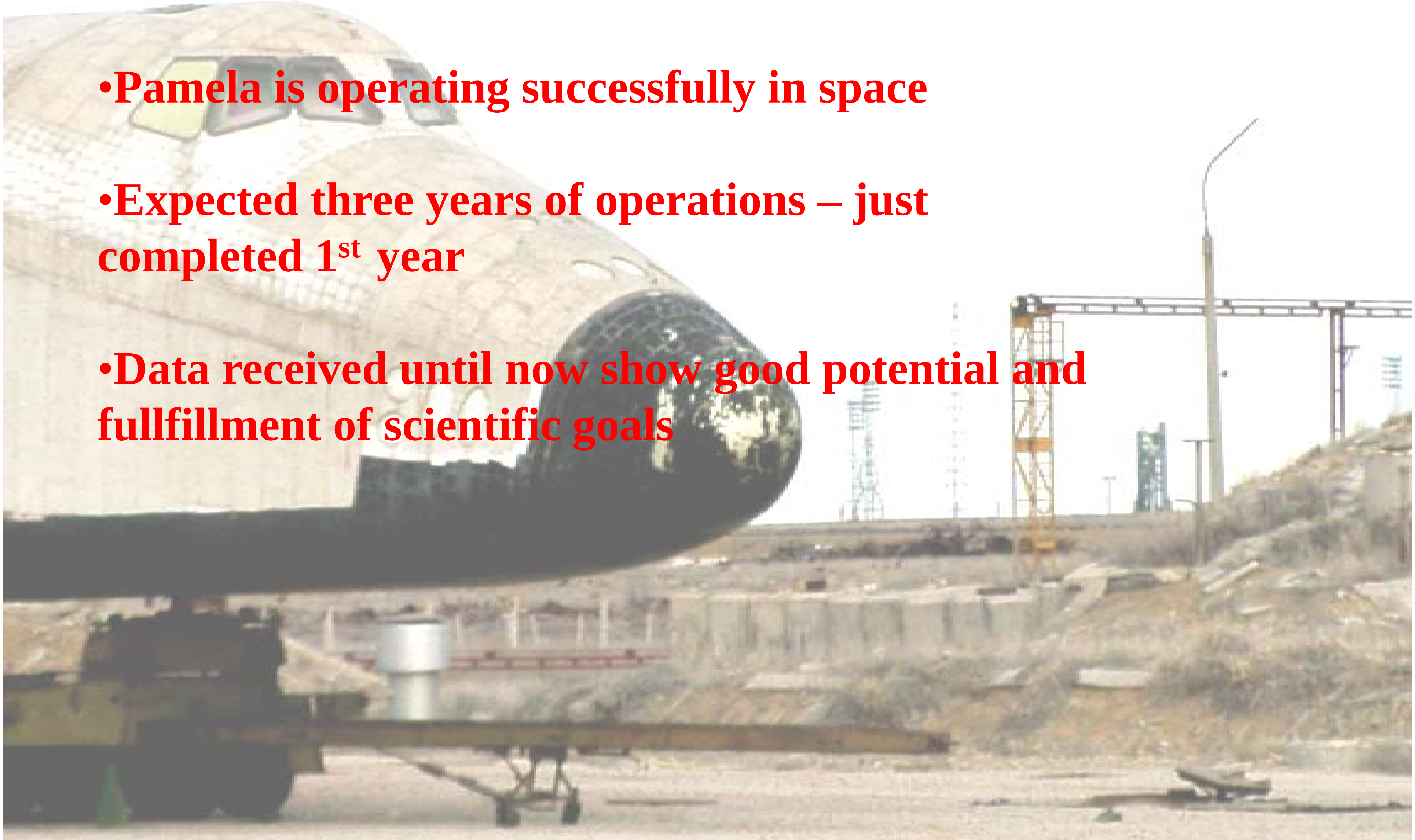


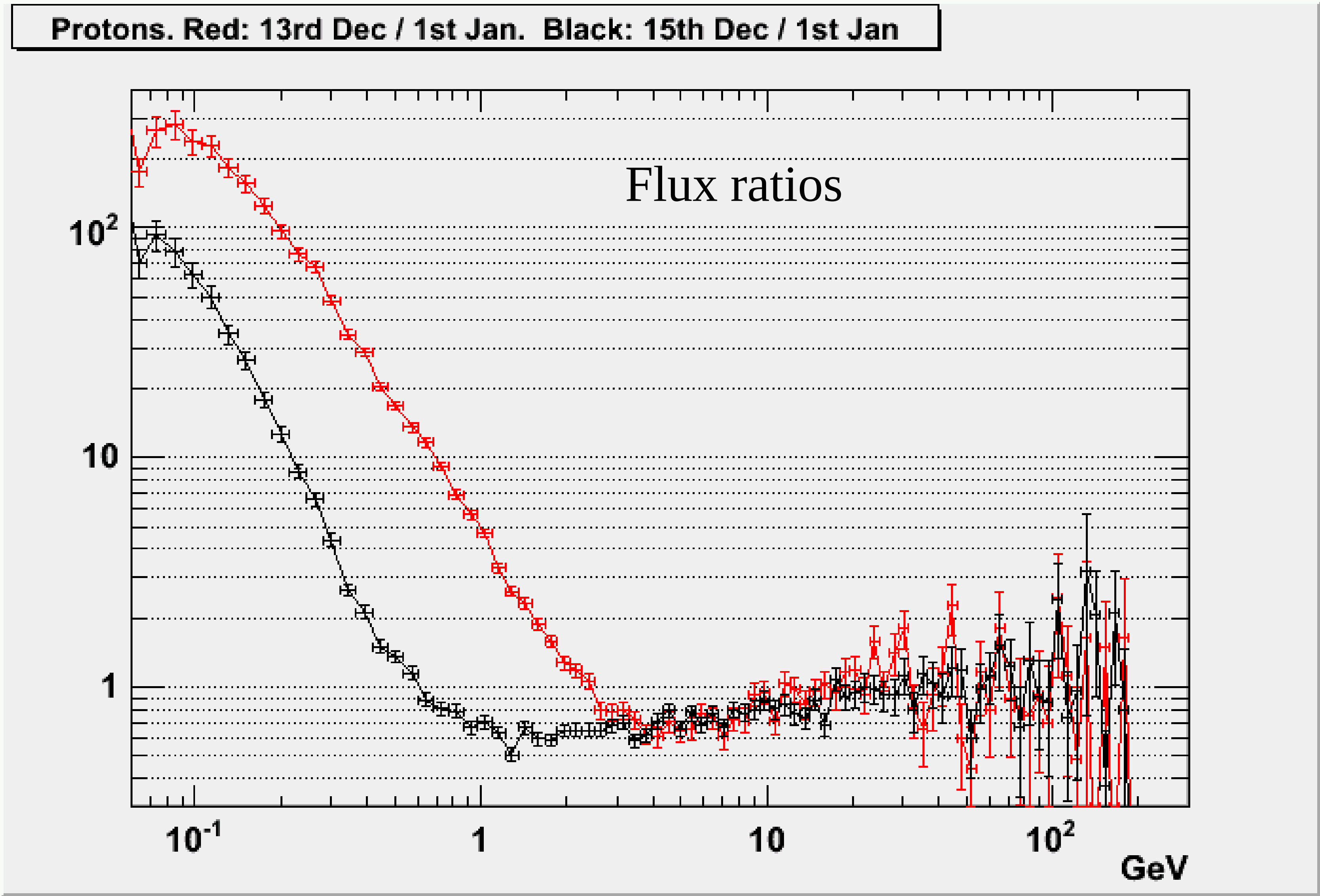
Conclusions

- **Pamela is operating successfully in space**

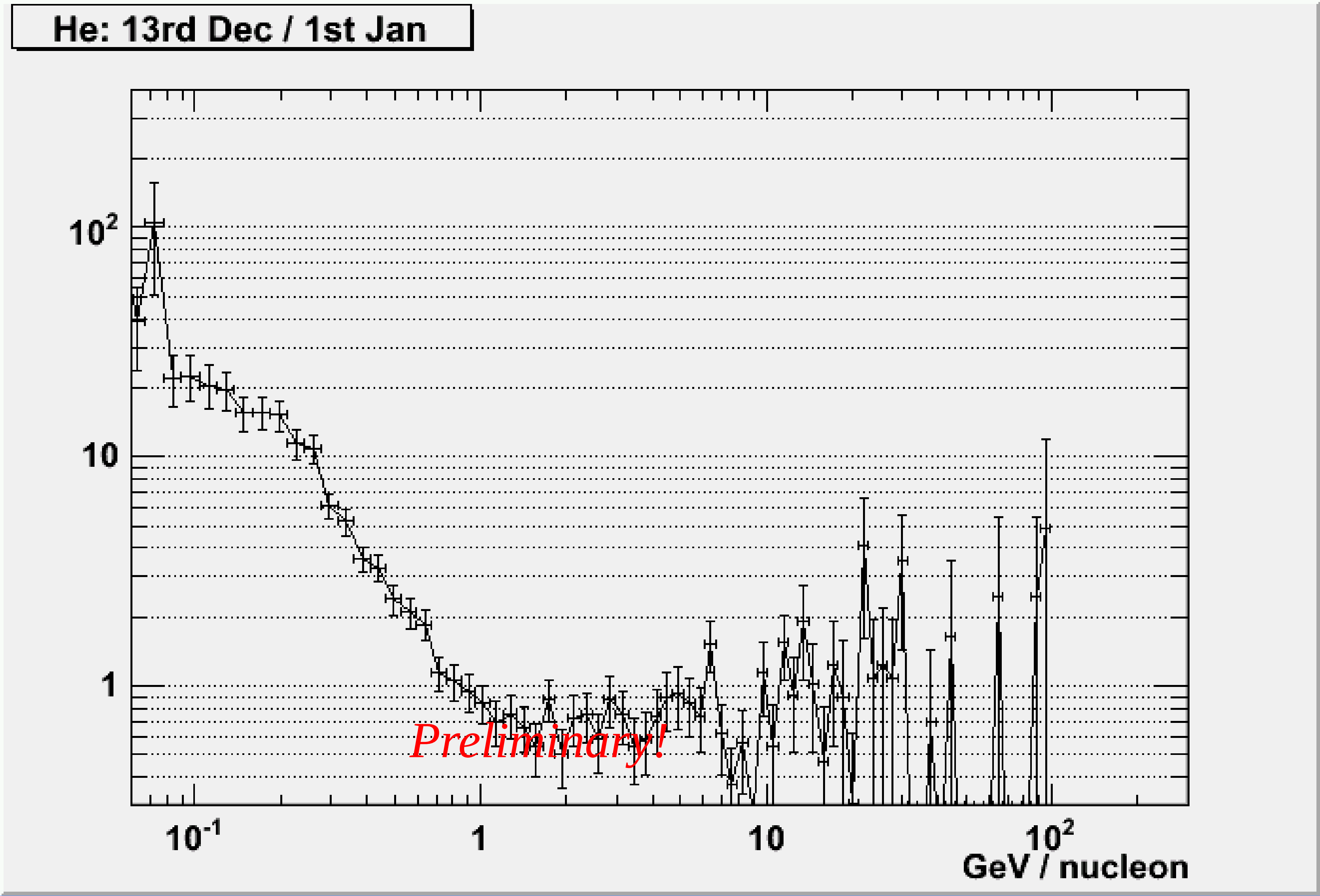
- **Expected three years of operations – just completed 1st year**

- **Data received until now show good potential and fullfillment of scientific goals**

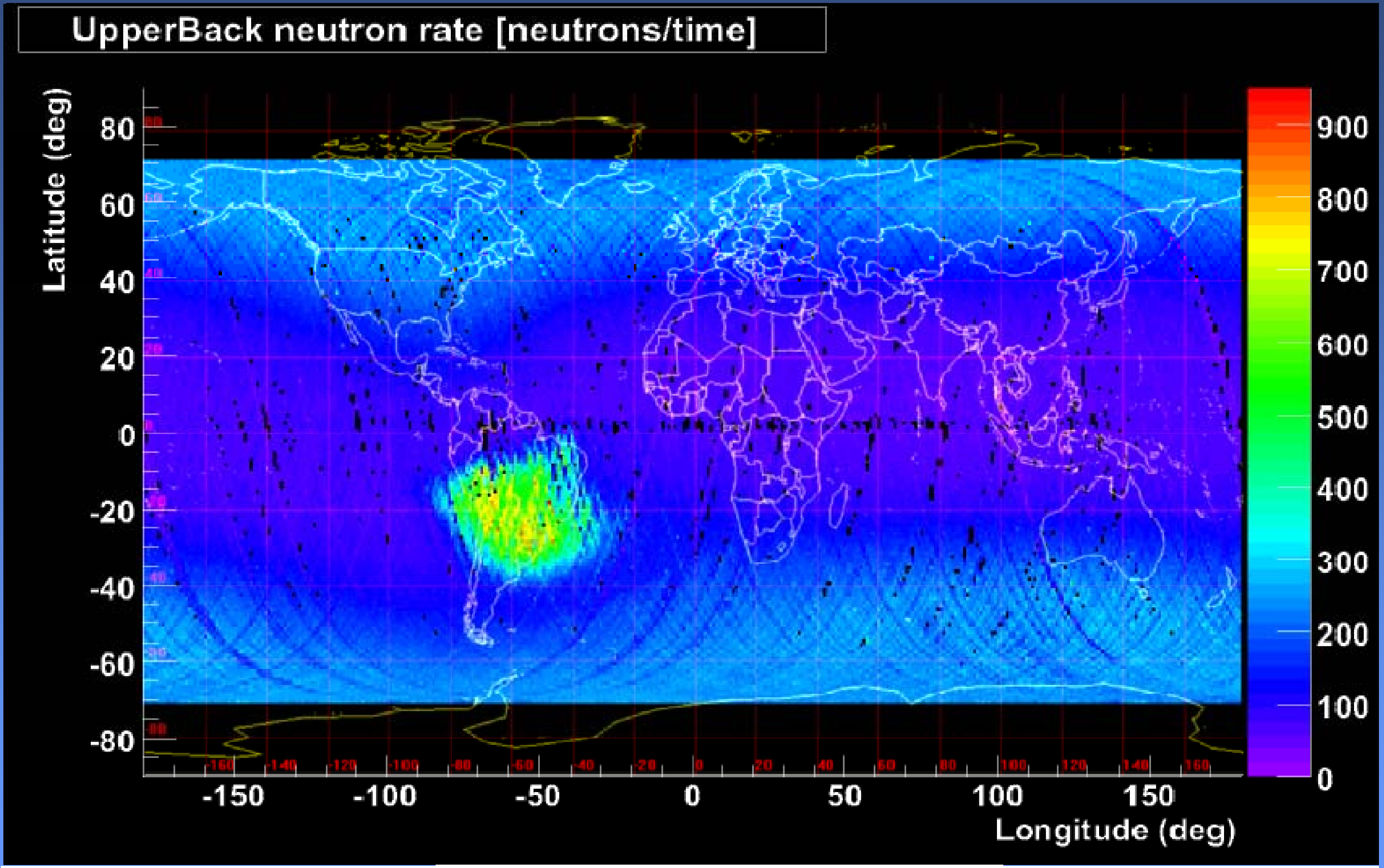




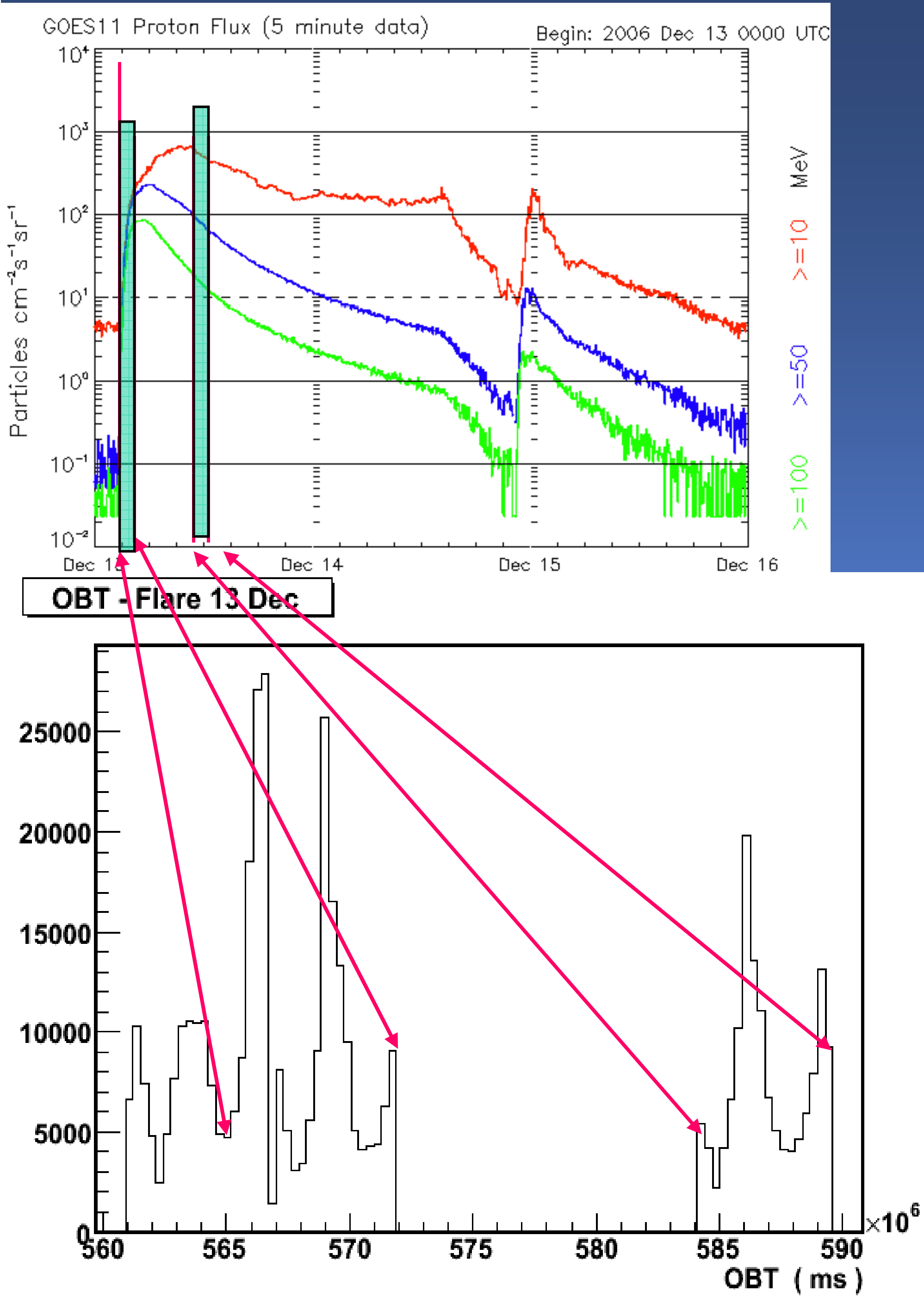
Preliminary!


He: 13rd Dec / 1st Jan
10²
10
1
10⁻¹
1
10
10²
GeV / nucleon
Preliminary!

Pamela World Maps: 350 – 650 km alt



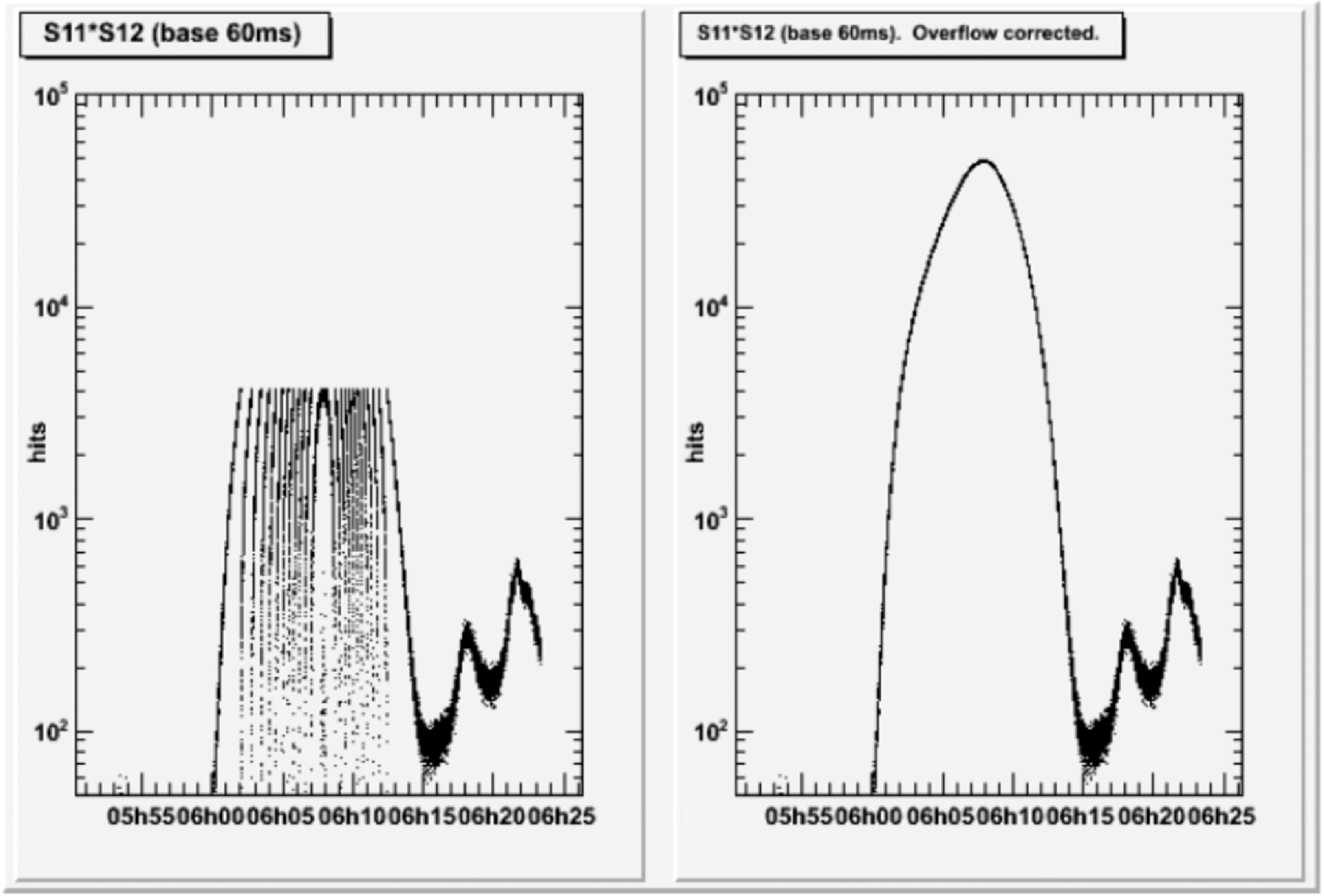
Neutron Map



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 fill (11:15-12.55UTC)



Counting rate corrected for overflow

Not good for plane trigger because time sampling is too high

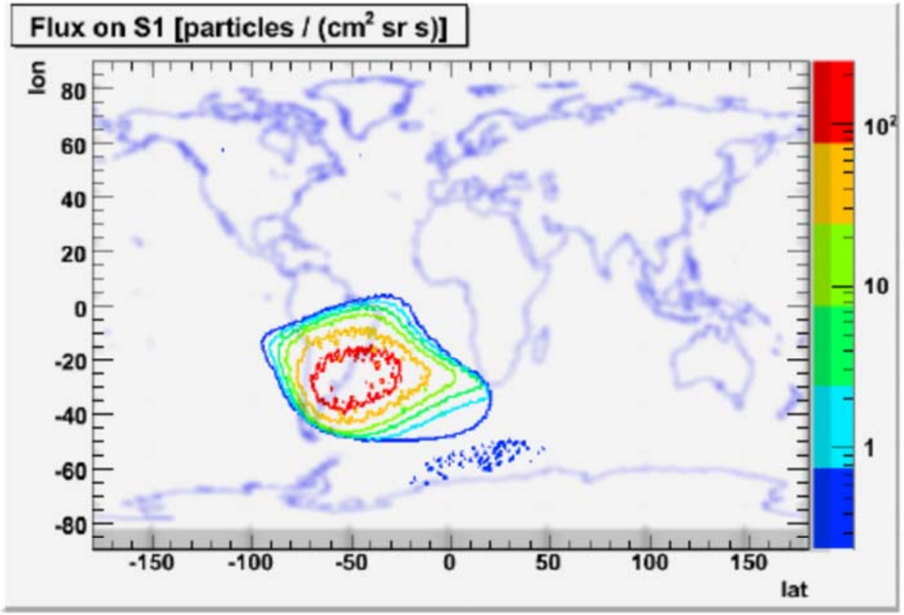
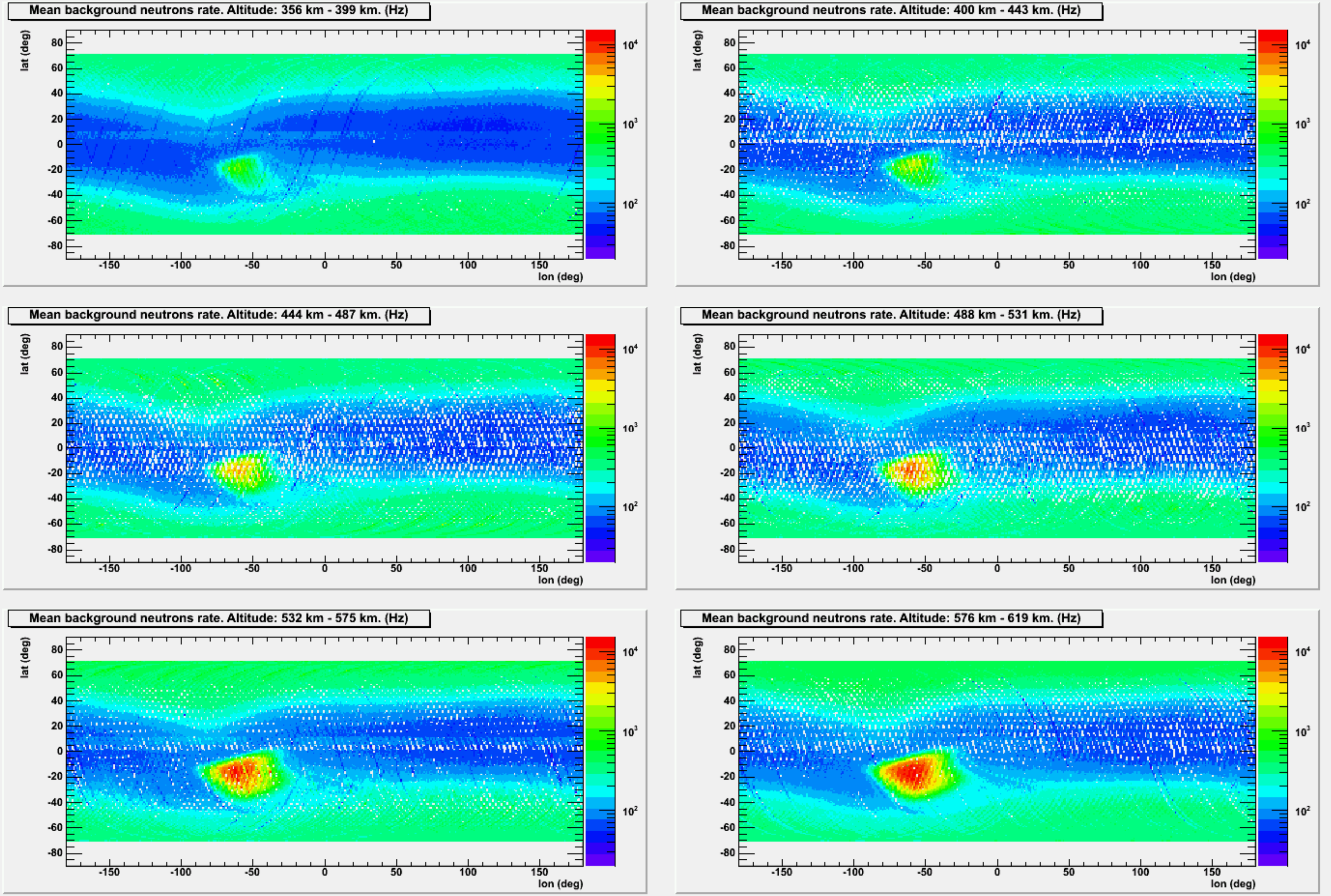
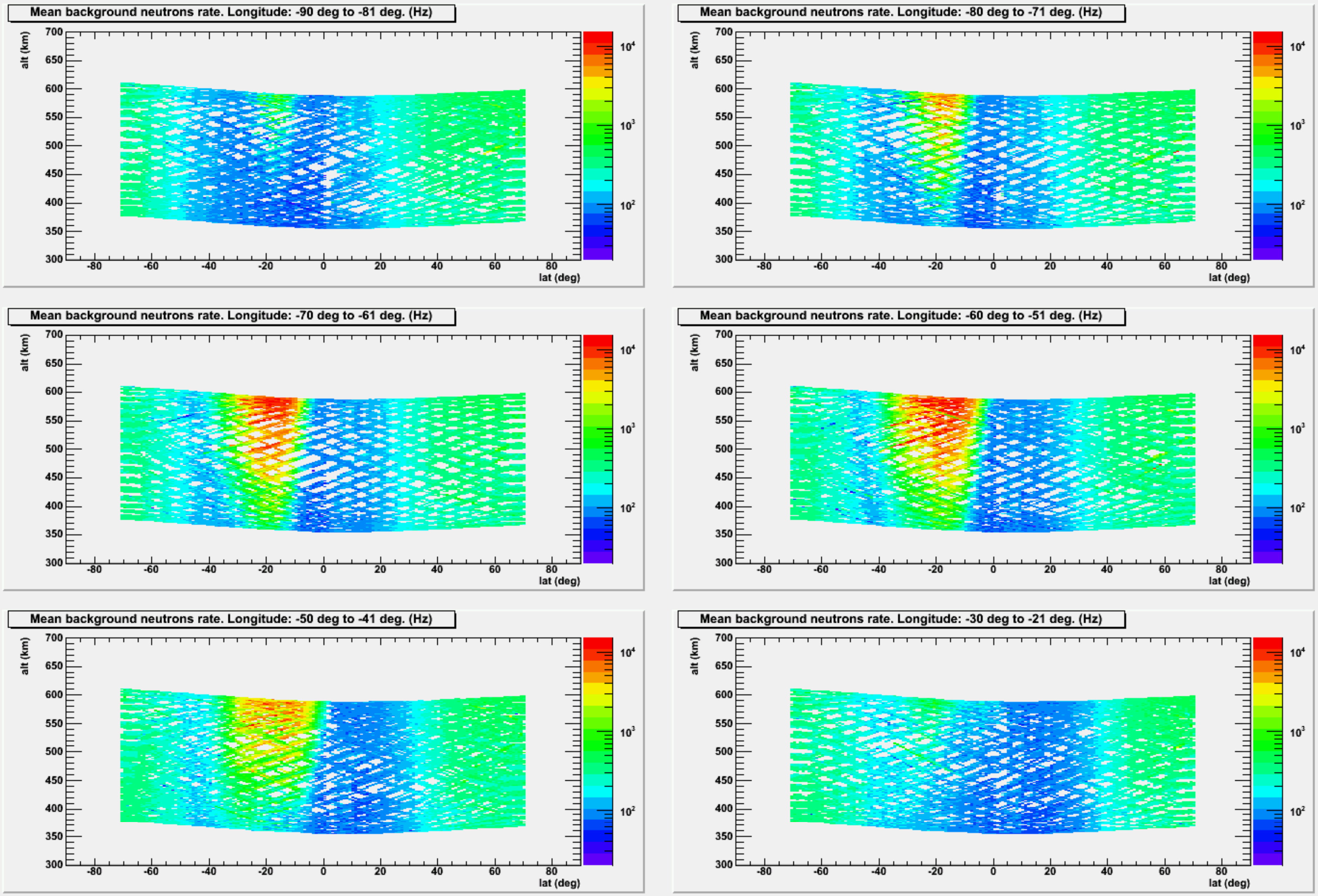


Figura 5.31: Flusso di particelle su S1 intorno all'anomalia del Sud Atlantico, mediato tra 350 e 610 km.

Neutron Altitude Maps



Latitude maps



Longitude Maps