Title: Dark matter indirect research with the Pamela Space Experiment

Date: Jan 14, 2009 02:00 PM

URL: http://pirsa.org/09010005

Abstract: The PAMELA satellite-borne experiment was launched from the Baikonur cosmodrome on the 15th of June 2006. It has been collecting data since July 2006. The instrument is composed of a silicon-microstrip magnetic spectrometer, a time-of-flight system, a silicon-tungsten electromagnetic calorimeter, an anticoincidence system, a shower tail counter scintillator and a neutron detector. The primary scientific goal is the measurement of the antiproton and positron energy spectrum in order to search for exotic sources, such as dark matter particle annihilations. PAMELA is also searching for primordial antinuclei (anti-helium), and testing cosmic-ray propagation models through precise measurements of the energy spectra of light nuclei and their isotopes. Moreover, PAMELA is investigating phenomena connected with solar and earth physics. The first results obtained in the explored research fields and in particular for antiproton-proton and positron-electron ratios will be presented.

Dark Matter Indirect Research with the Pamela Space Experiment

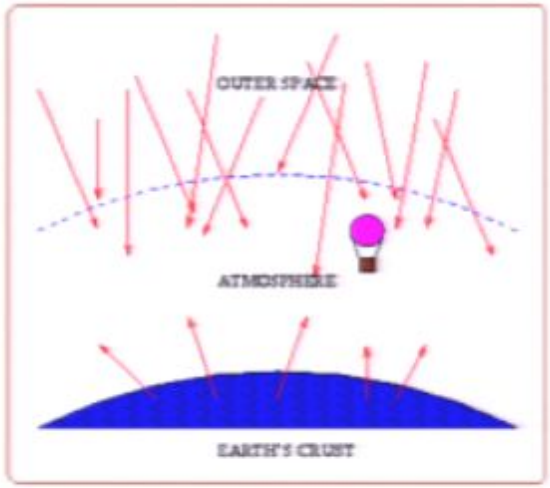
Piergiorgio Picozza
INFN and University of Rome Tor Vergata

Colloquium
Perimeter Institute for Theoretical Physics

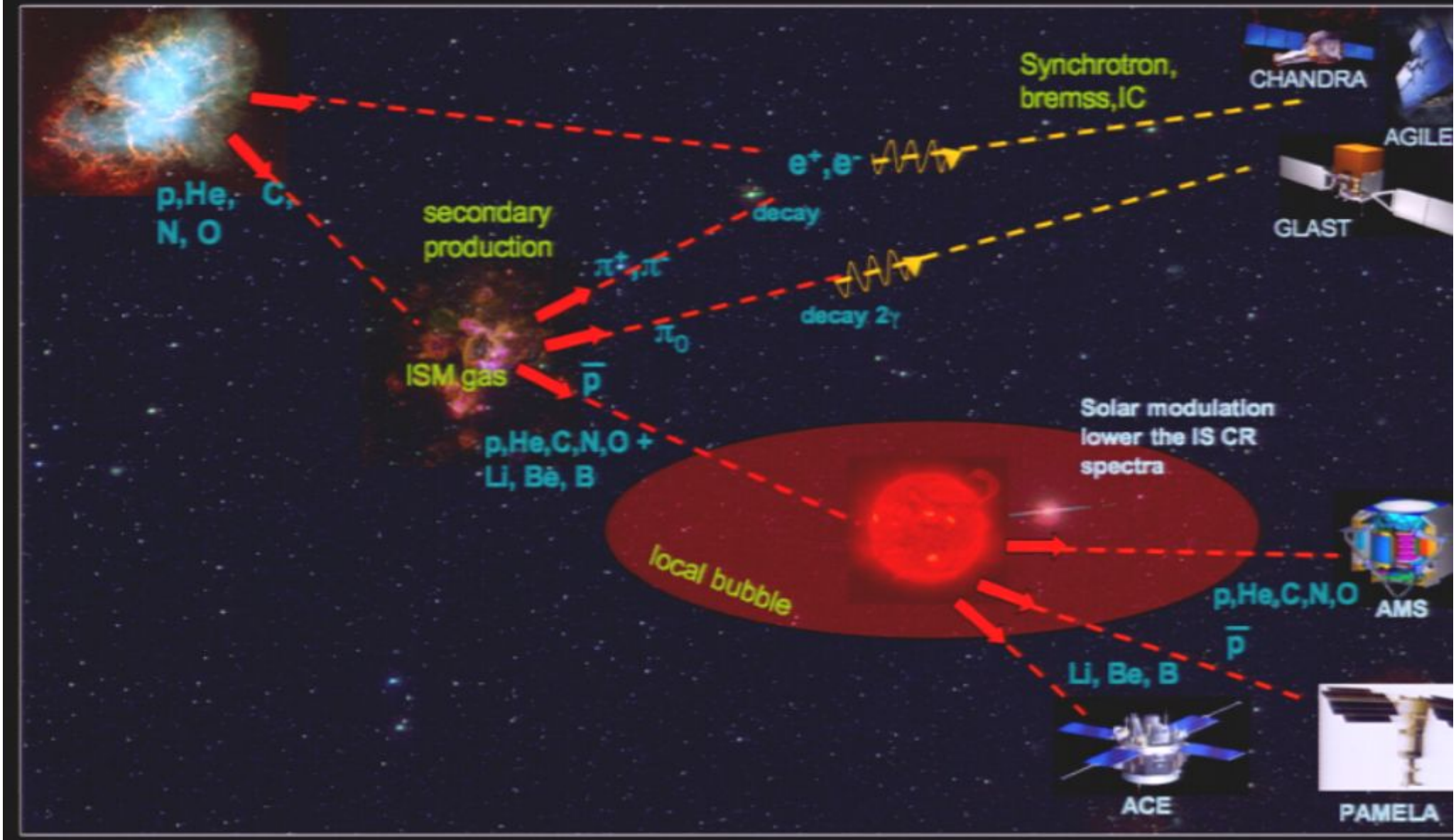
Waterloo, Canada
January 14th 2009

The discovery of cosmic rays

- Victor Hess ascended to 5000 m in a balloon in 1912
- ... and noticed that his electroscope discharged more rapidly as altitude increased
- Not expected, as background radiation was thought to be terrestrial
- NPP 1936 (with Carl 'e^+' Anderson)



COSMIC RAYS PRODUCTION MECHANISMS

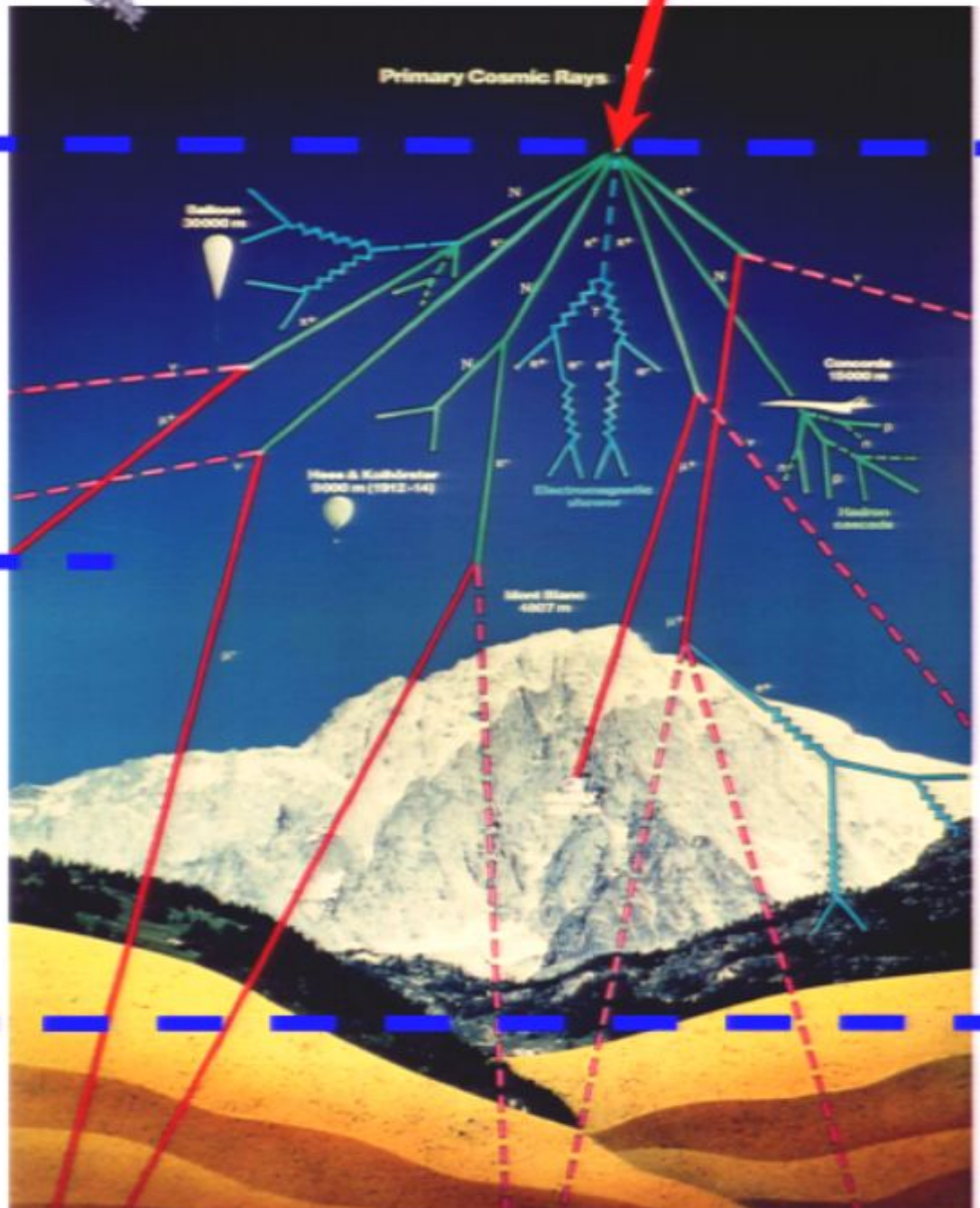


~500 km

Smaller detectors
but long duration.
PAMELA!

Primary cosmic ray

Top of atmosphere



~40 k

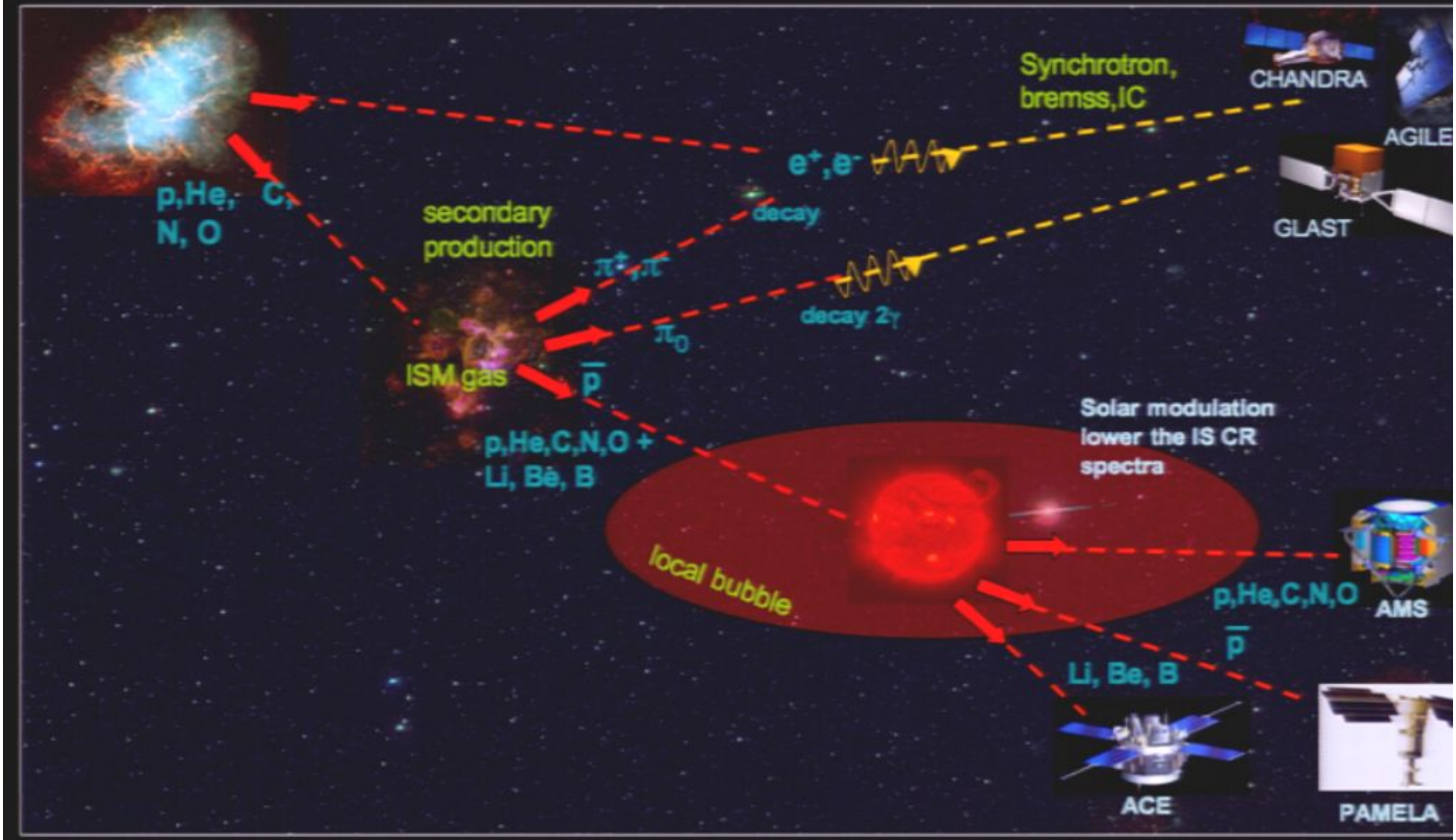
Large detectors but
short duration.
Atmospheric
overburden ~5 g/cm
Almost all data on
cosmic antiparticle
from here.

~5 km

Ground

0 m

COSMIC RAYS PRODUCTION MECHANISMS



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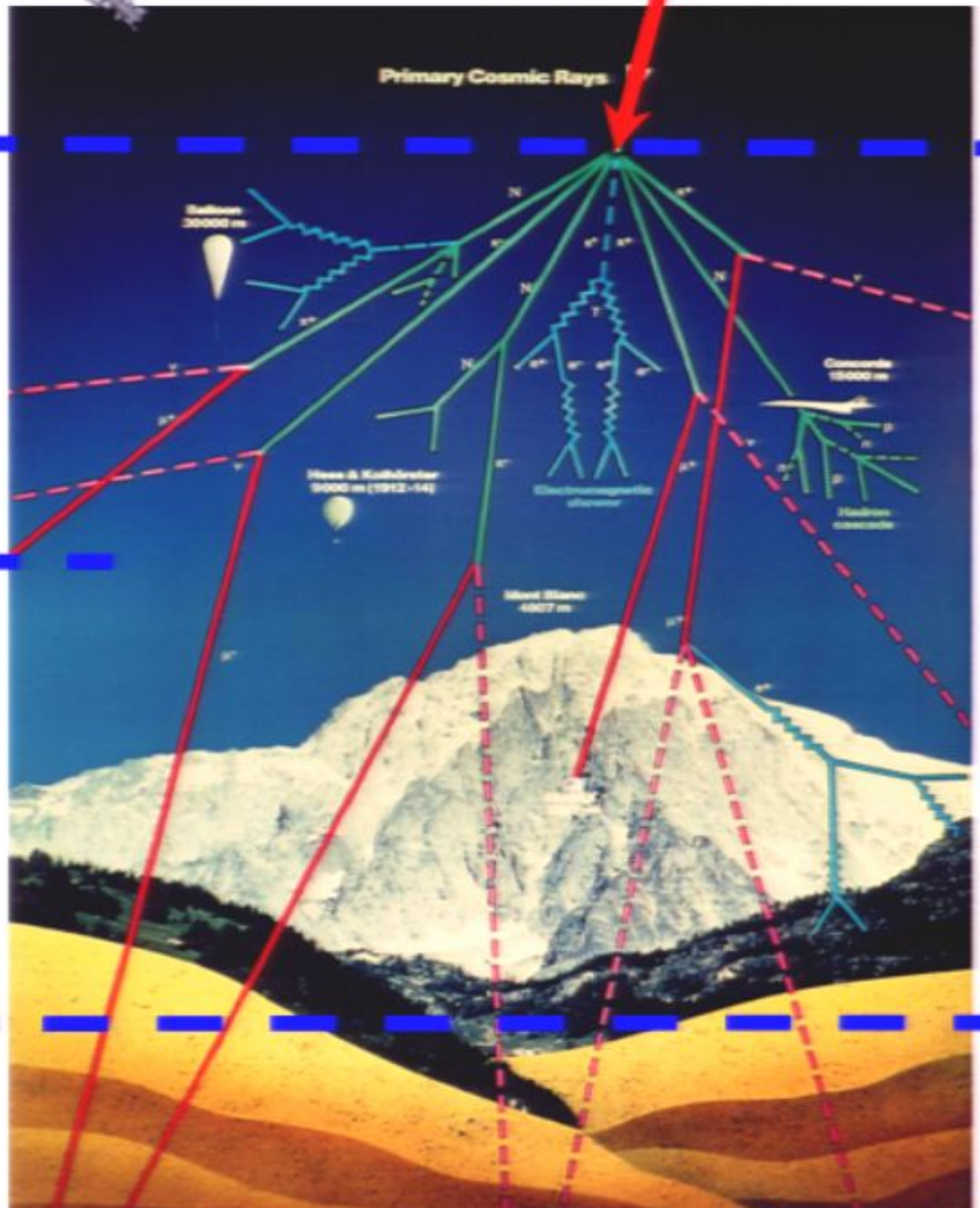

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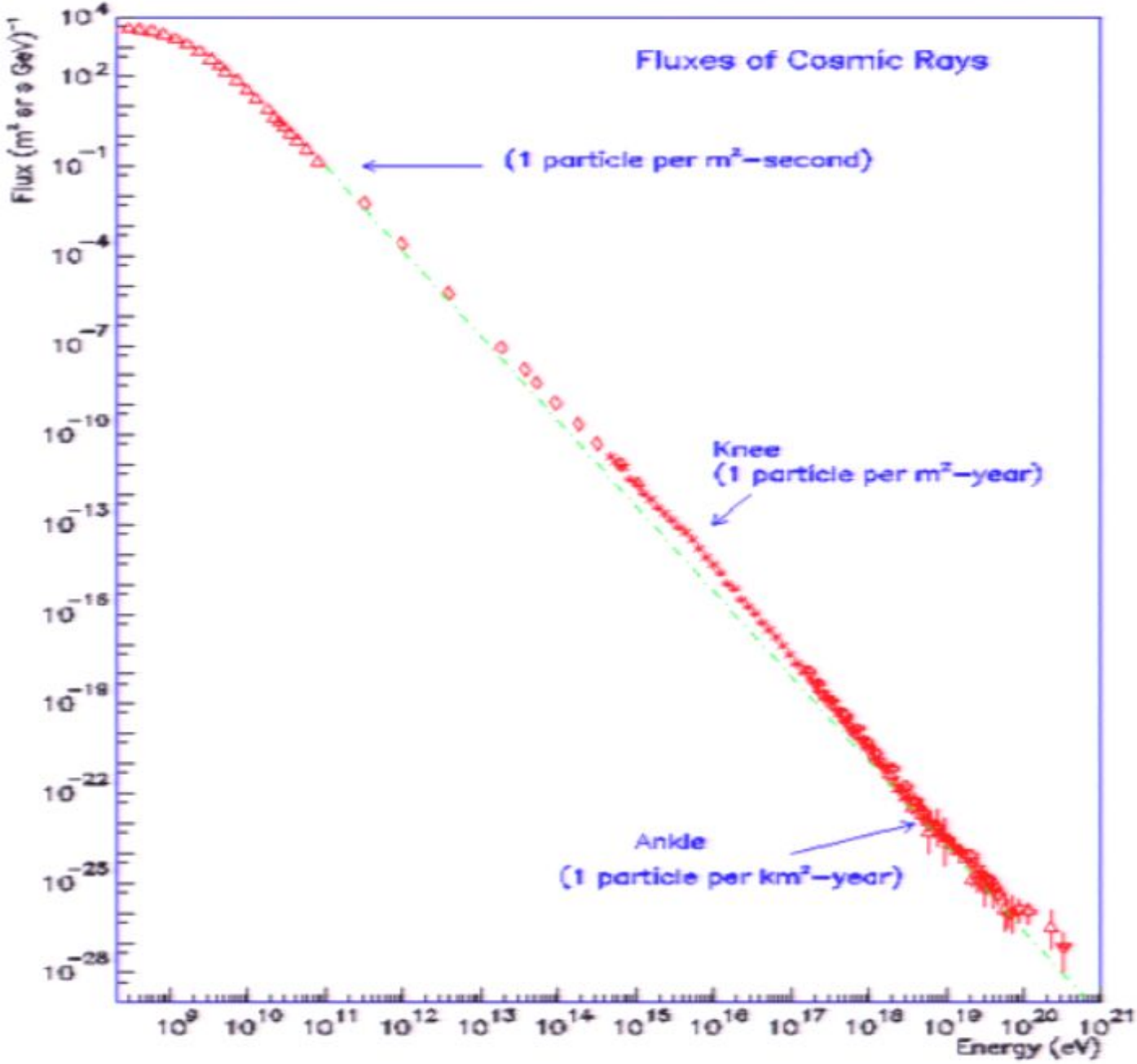
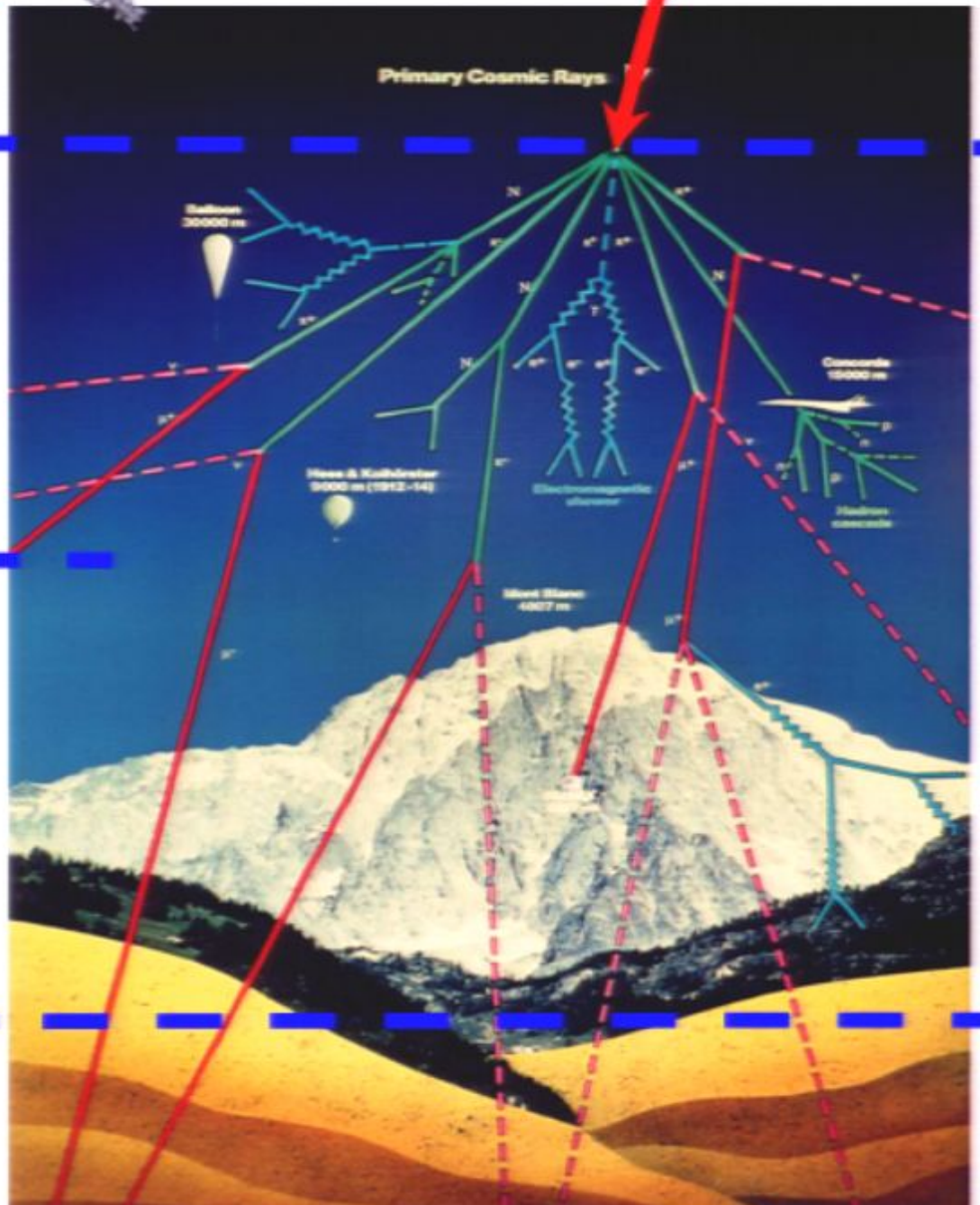

Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

~500 km

Smaller detectors
but long duration.
PAMELA!

Primary cosmic ray

Top of atmosphere



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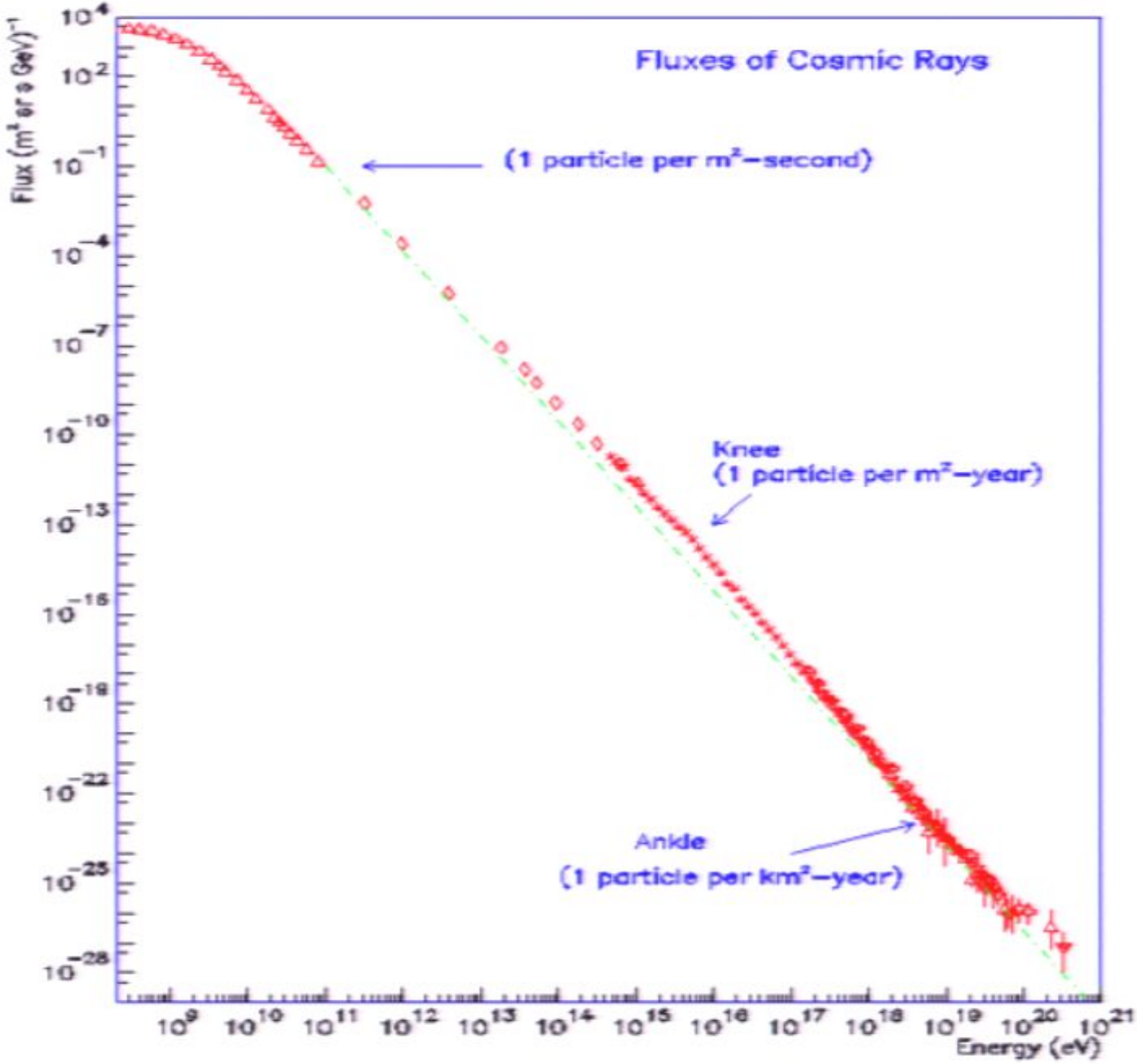
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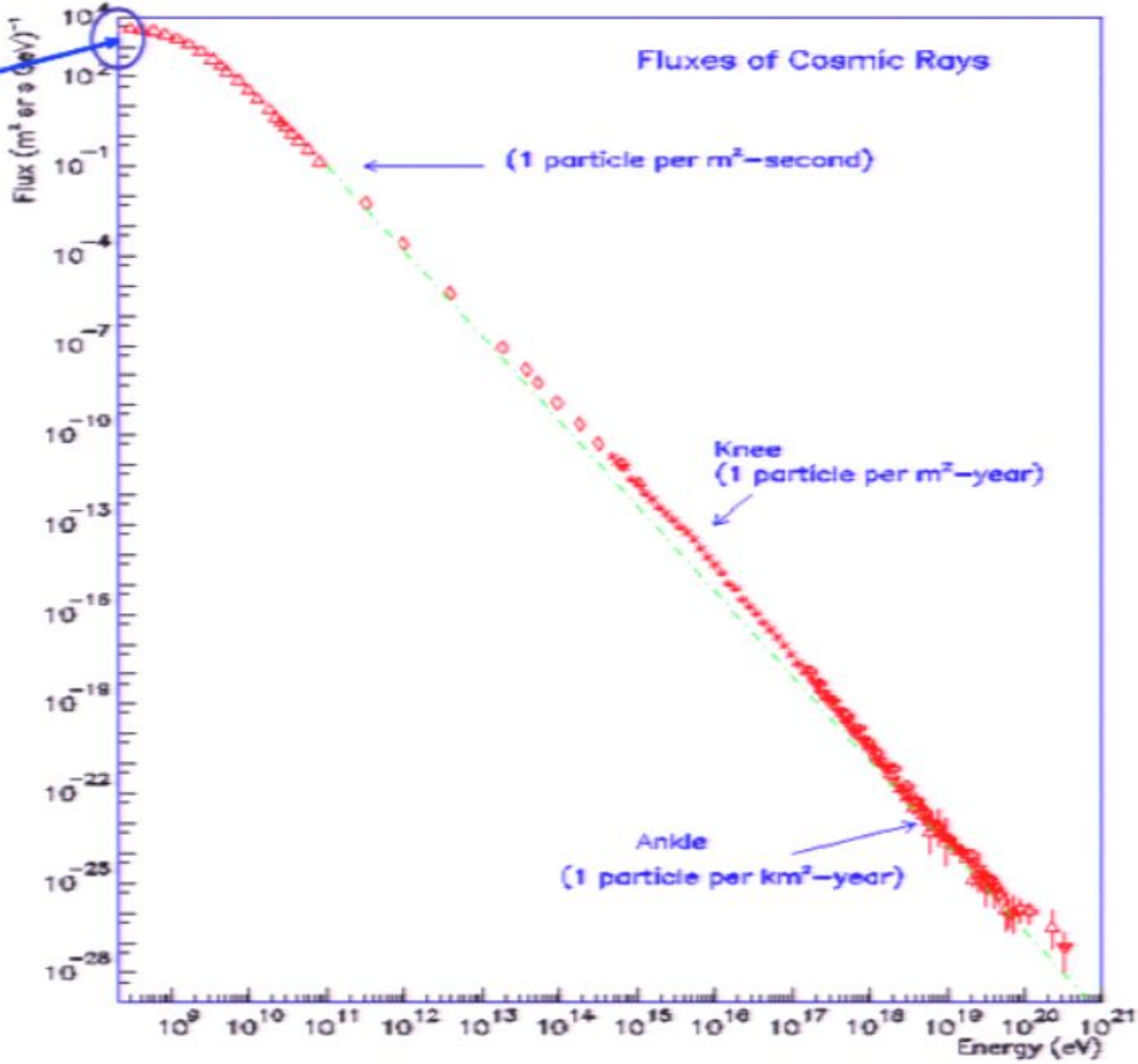
Energy (eV)

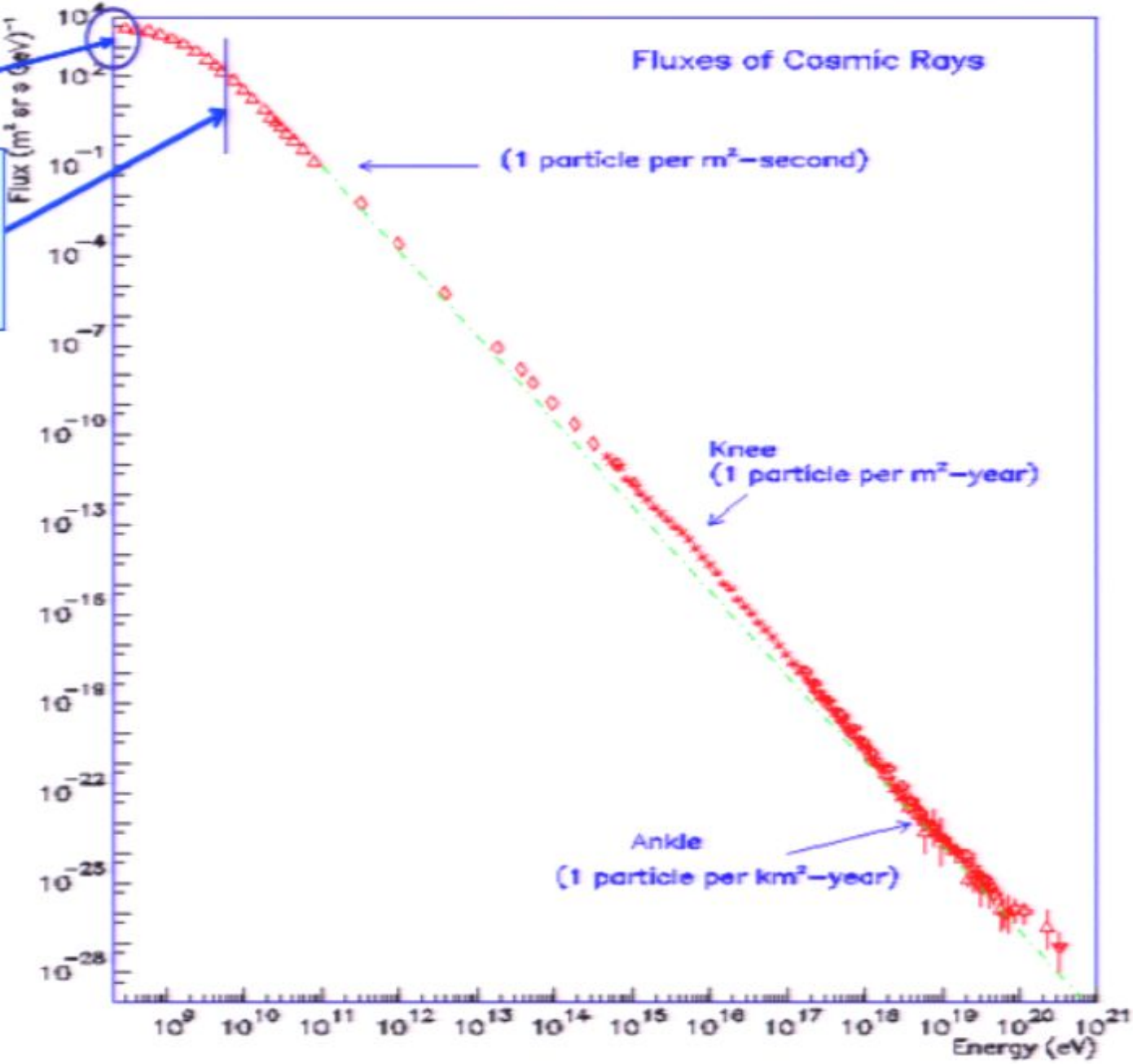
High Z
[ENTICE, ECCO]



High Z
[JENTICE, ECCO]

Isotopic composition
[ACE]

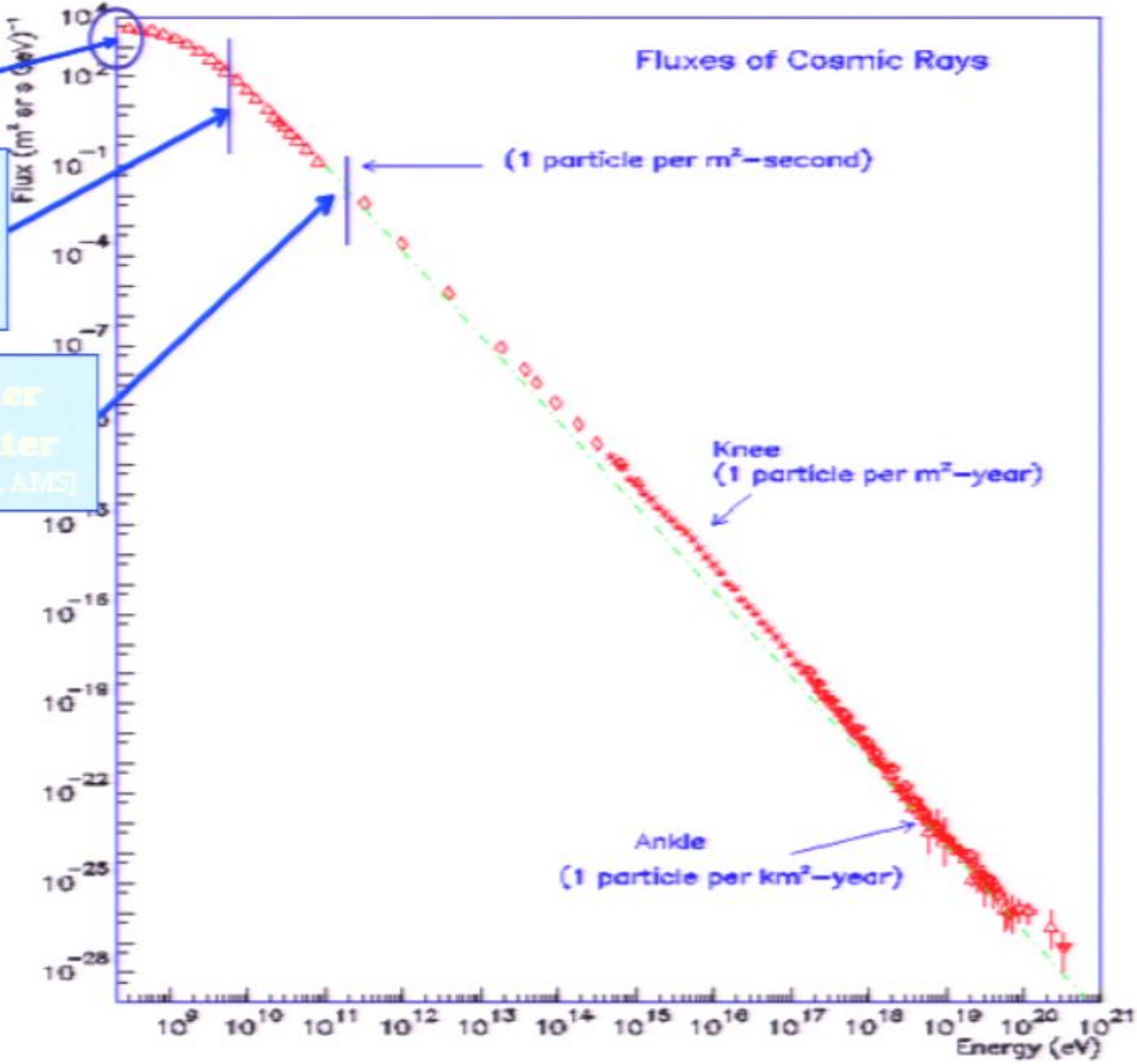
Solar Modulation

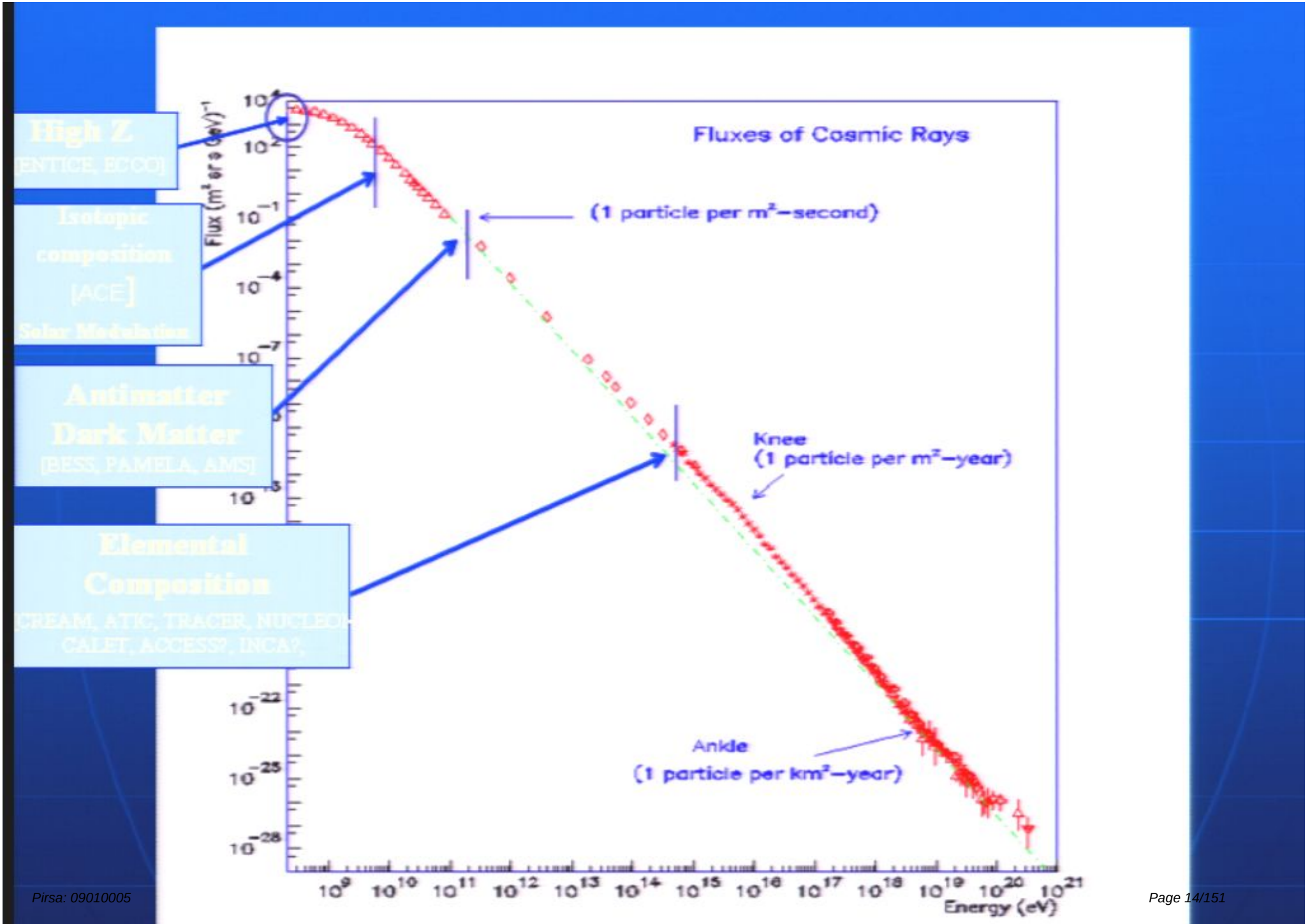


High Z
[JENTICE, ECCO]

Isotopic composition
[ACE]
Solar Modulation

Antimatter
Dark Matter
[BESS, PAMELA, AMS]




High Z
[ENTICE, ECCO]
Isotopic composition
[ACE]
Solar Modulation
Antimatter
Dark Matter
[BESS, PAMELA, AMS]
Elemental Composition
[CREAM, ATIC, TRACER, NUCLEON, CALET, ACCESS?, INCA?,
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(1 particle per m²–second)
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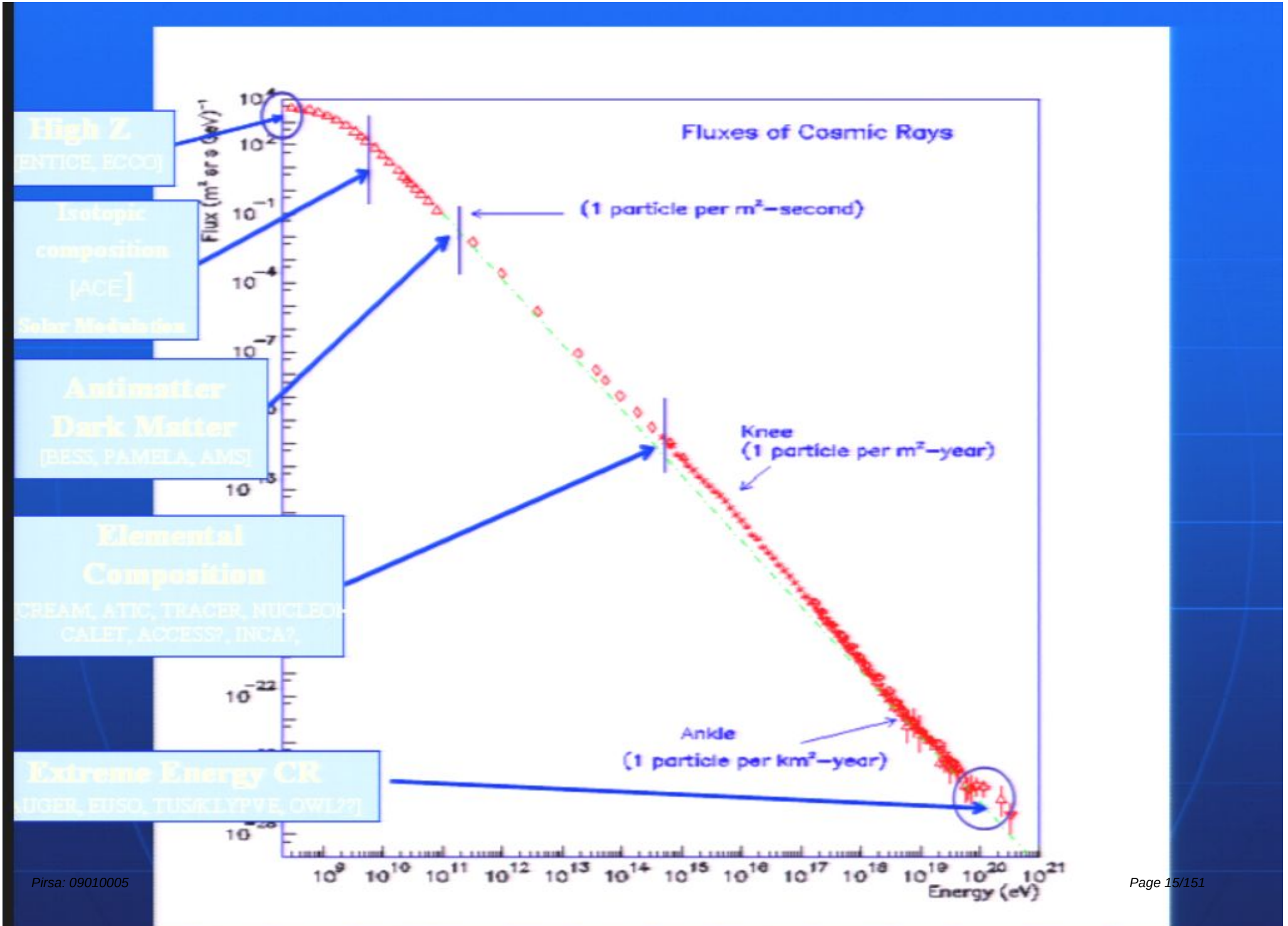
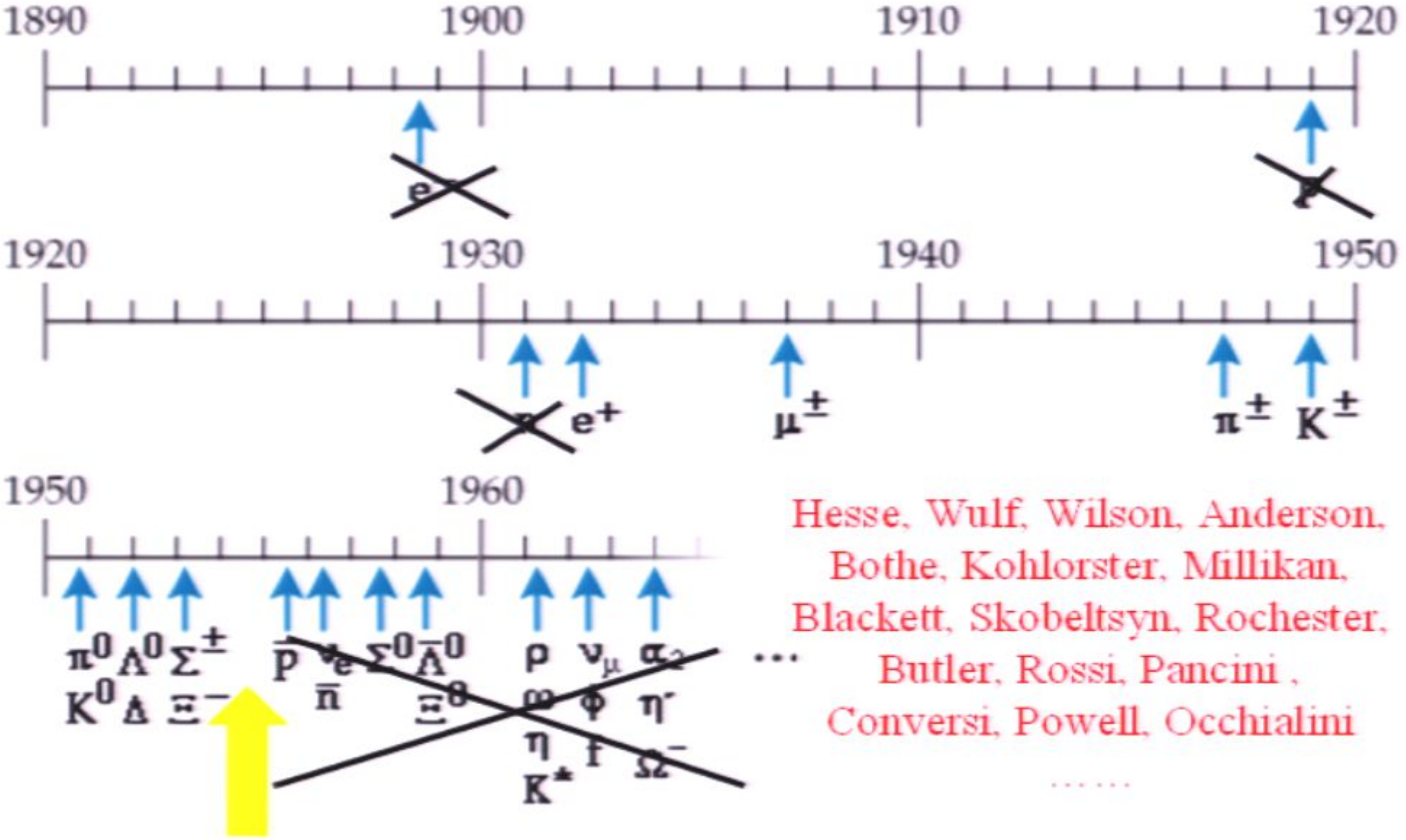

High Z
[ENTICE, ECCO]
Isotopic composition
[ACE]
Solar Modulation
Antimatter
Dark Matter
[BESS, PAMELA, AMS]
Elemental Composition
[CREAM, ATIC, TRACER, NUCLEON, CALET, ACCESS?, INCA?,
Extreme Energy CR
[AUGER, EUSO, TUS/KLYPVE, OWL??]
Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Energy (eV)

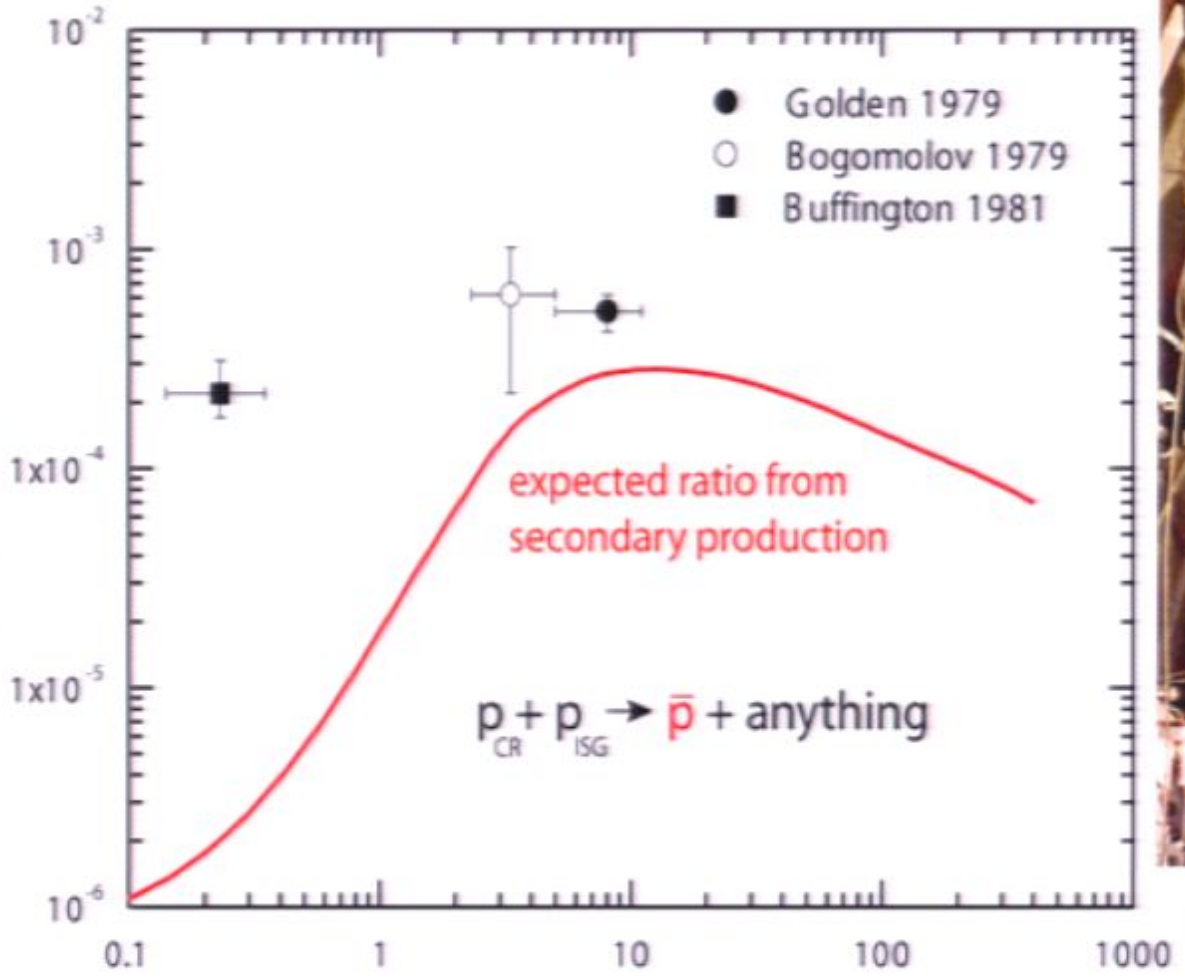
PARTICLE PHYSICS BIRTH WAS DUE TO COSMIC RAYS

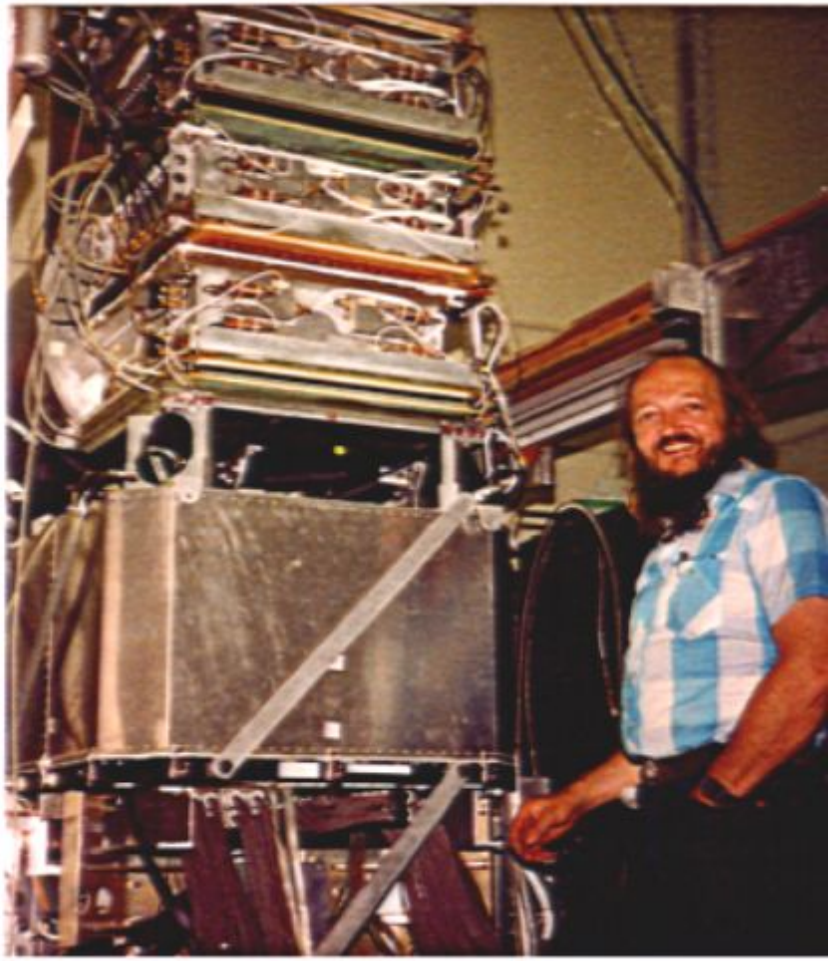


Hesse, Wulf, Wilson, Anderson,
Bothe, Kohlorster, Millikan,
Blackett, Skobeltsyn, Rochester,
Butler, Rossi, Pancini ,
Conversi, Powell, Occhialini
.....

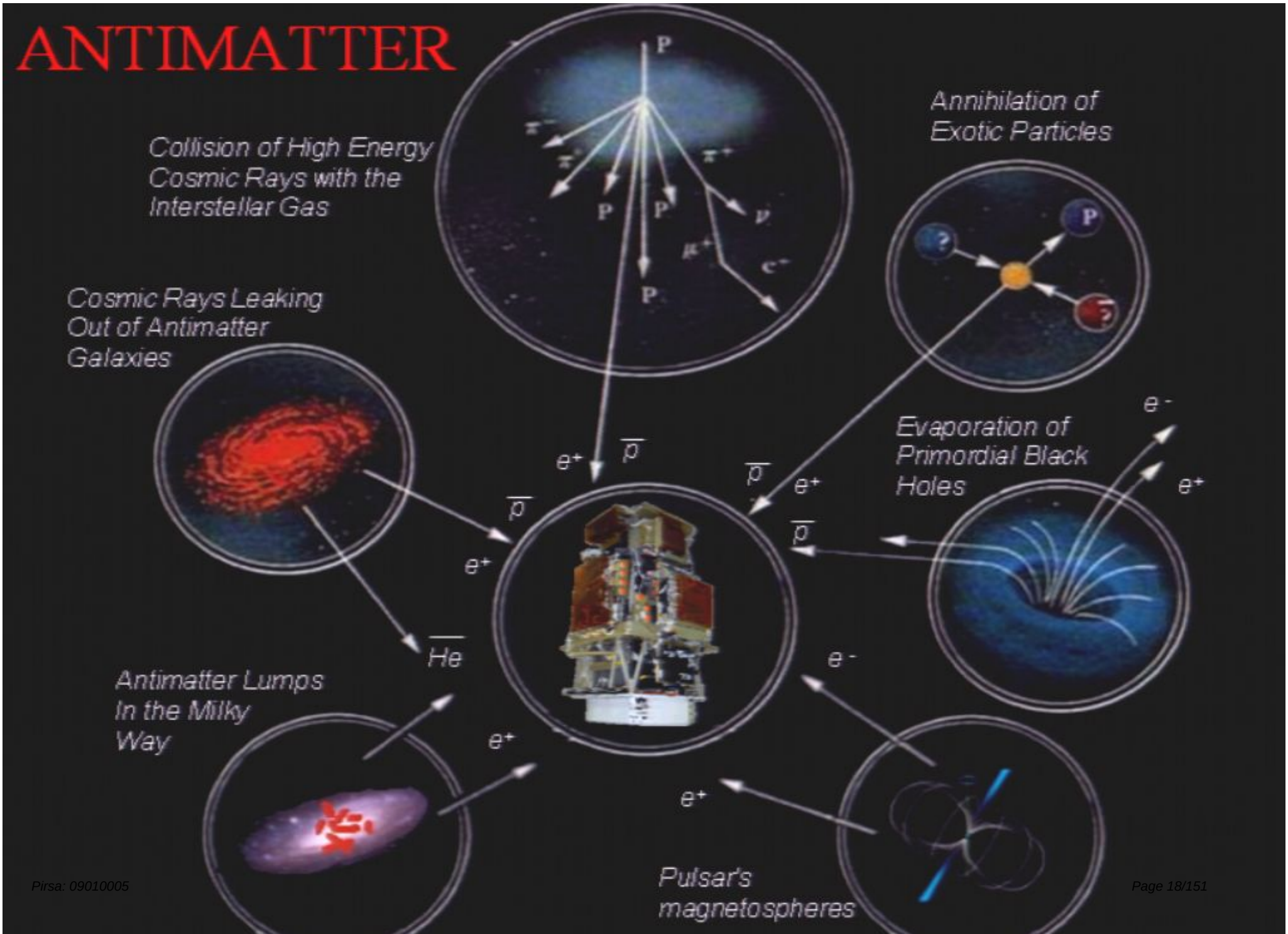
Advent of accelerators

The first historical measurements on galactic antiprotons



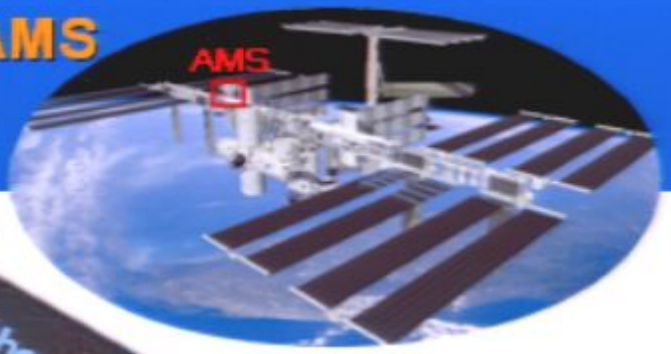


Robert L. Golden


ANTIMATTER
Collision of High Energy Cosmic Rays with the Interstellar Gas
Annihilation of Exotic Particles
Cosmic Rays Leaking Out of Antimatter Galaxies
Evaporation of Primordial Black Holes
Antimatter Lumps In the Milky Way
Pulsar's magnetospheres
P
e+
e -
He

Search for the existence of Antimatter in the Univers

PAMELA AMS
n Space



Search for the existence of anti Universe

Search for the origin of the Univ

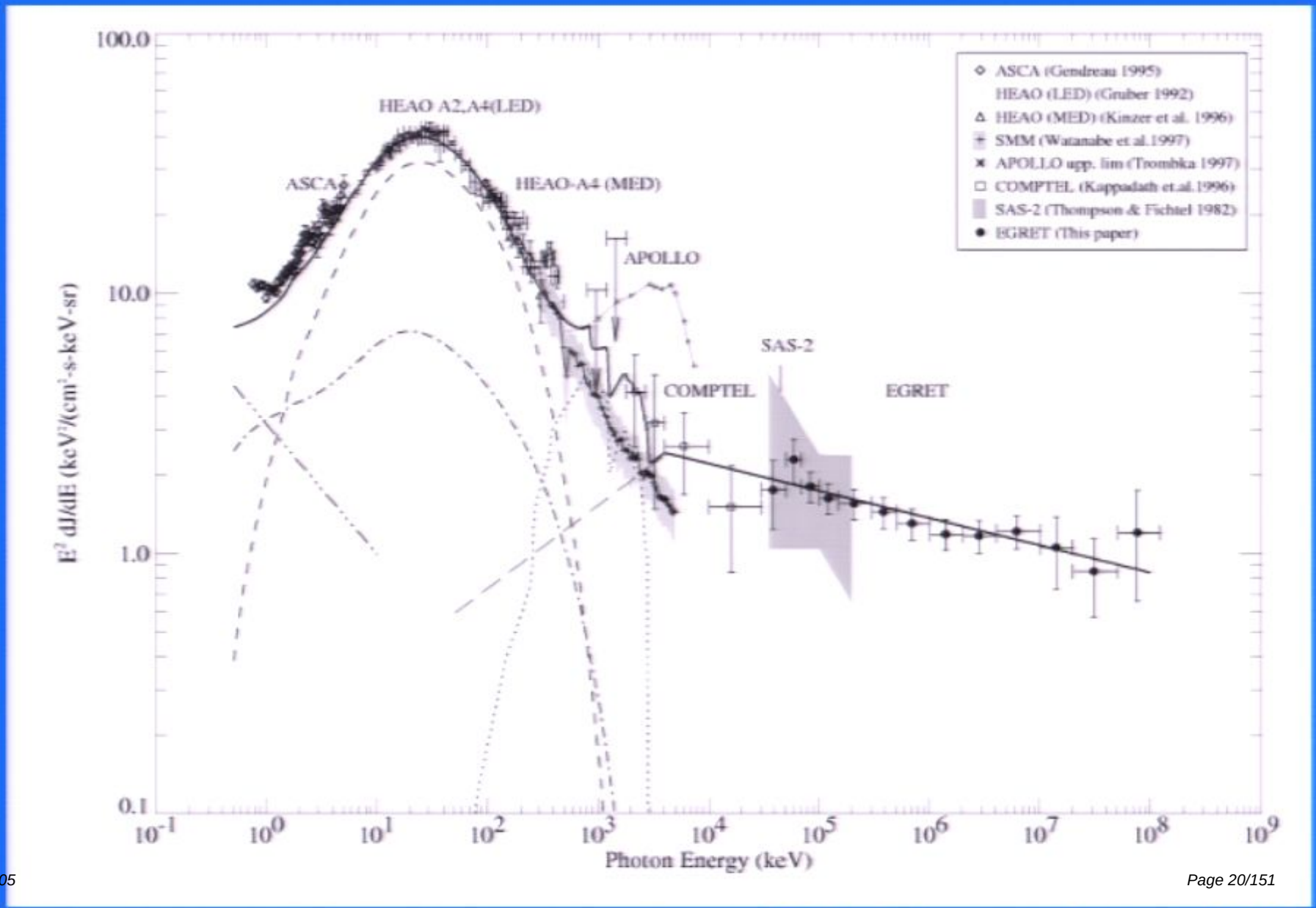
Accelerators

Anti-Universe

Universe

The Big Bang origin of the Universe requires
matter and antimatter
to be equally abundant at the very hot beginning

Cosmic Diffuse Gamma



Antimatter Direct research

- **Antimatter** which has escaped as a cosmic ray from a distant antigalaxy

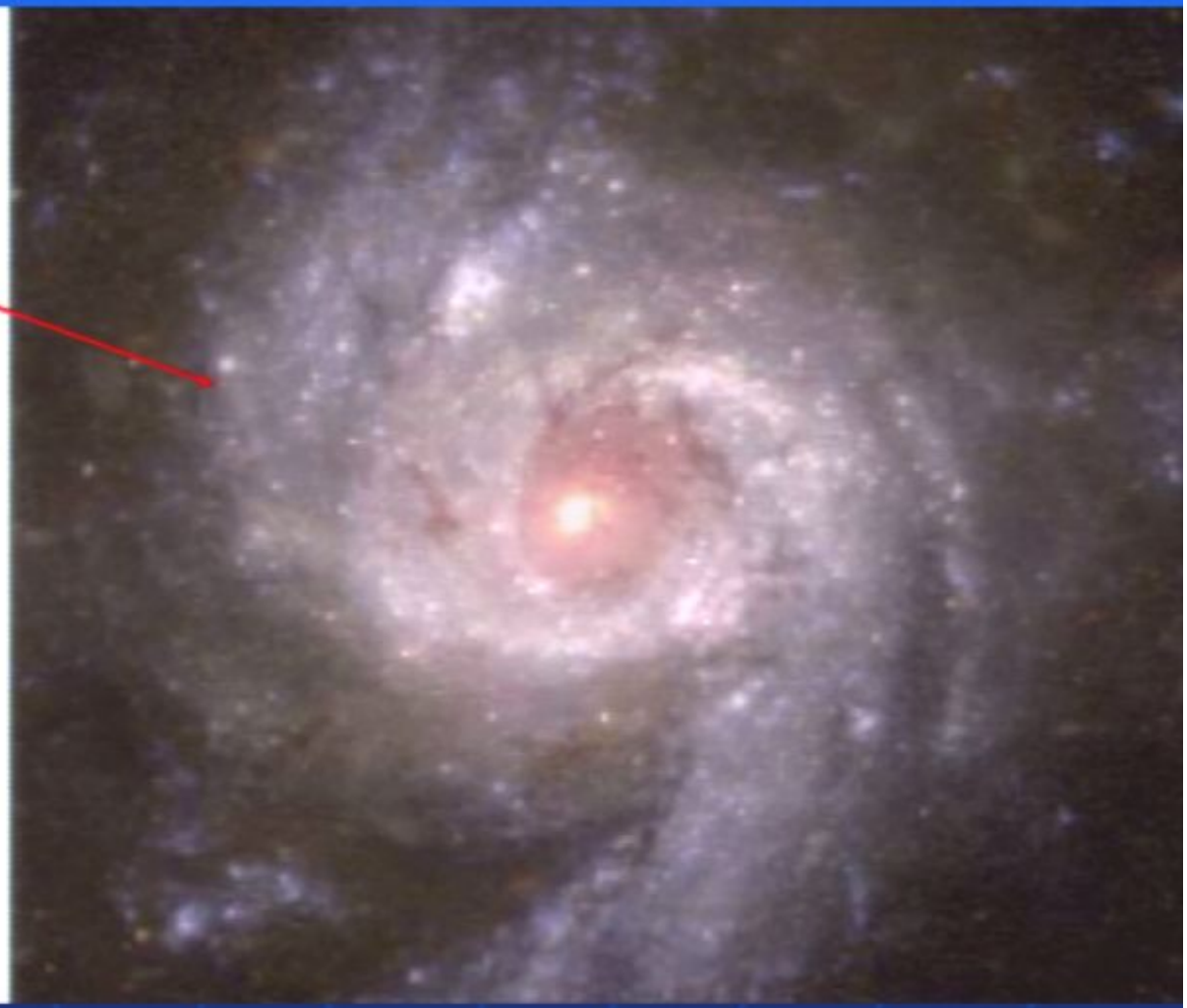
  Sreitmatter, R. E., Nuovo Cimento, 19, 835 (1996)

- **Antimatter** from globular clusters of antistars in our Galaxy as antistellar wind or anti-supernovae explosion

  K. M. Belotsky et al., Phys. Atom. Nucl. 63, 233 (2000), astro-ph/9807027

Dark Matter

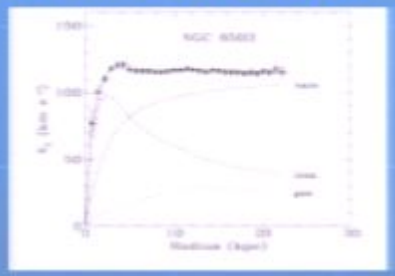
The peripheral stars of the galaxy M63 rotate around the center so fast that they would fly away in space without the presence of additional mass inside the galaxy. This is indirect evidence for the presence of dark matter



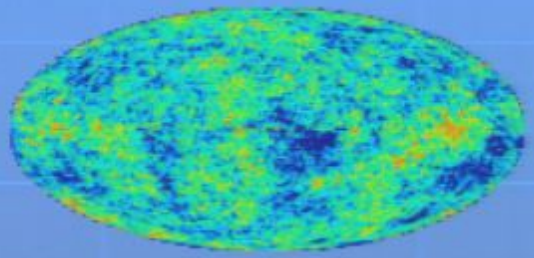
Dark Matter

Evidence for the existence of an unseen, "*dark*", component in the energy density of the Universe comes from several independent observations at different length scales:

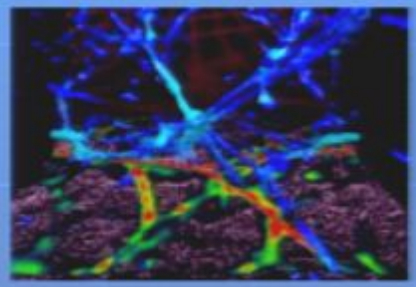
Rotation curves of galaxies



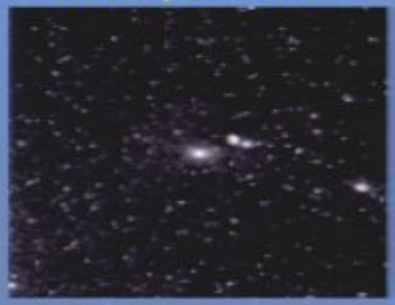
CMB



Large Scale Structure

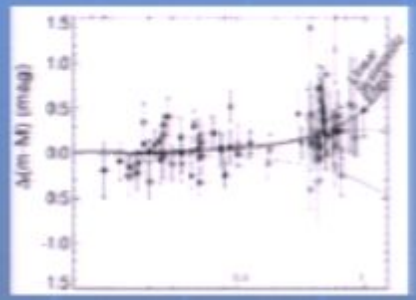


Galaxy clusters



Lensing

SN Ia



Bertone, Hooper & Silk, hep-ph/0404175. Bergstrom, hep-ph/0002126. Jungman et al, hep-ph/9506380

Matter in the Universe

Microwave Anisotropy

WMAP - NASA - Explorer Mission

$$\Omega_{total} = \frac{\rho_{total}}{\rho_{crit.}} = 1$$

(Universe is flat)

$$\rho_{crit.} = \frac{3H^2(t)}{8\pi G}$$

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

baryonic matter	dark matter	dark energy
4%	23%	73%
	??	???
stars, galaxies	candidates:	quintessence
	• WIMPs	
	• Q-balls	
	• axions	

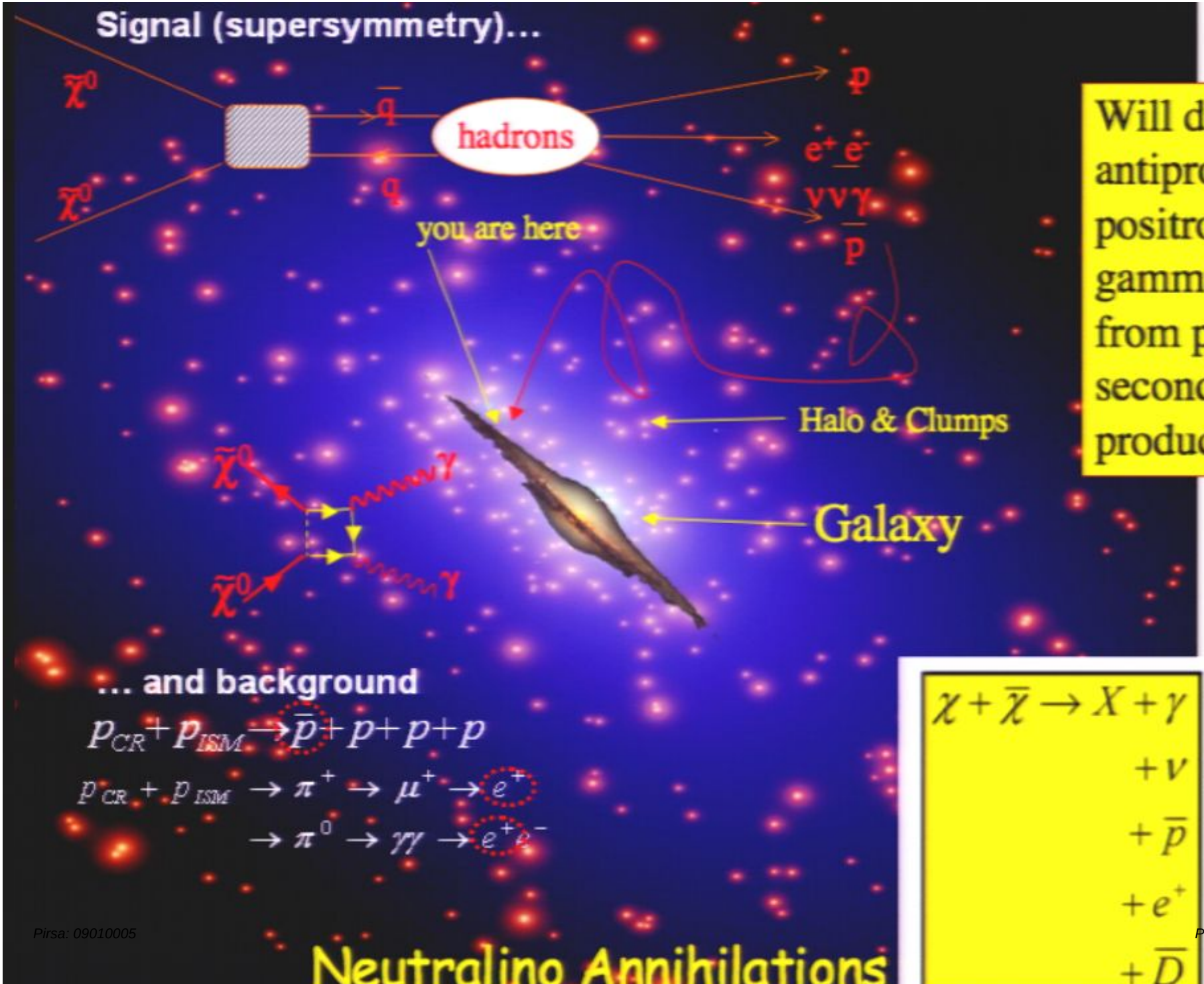
The SUSY Particle Spectrum

Standard Model

Particles			Sparticles		
Name	Symbol	Spin	Name	Symbol	Spin
leptons	l, ν	1/2	sleptons	$\tilde{l}_R, \tilde{l}_L, \tilde{\nu}_L$	0
quarks	q_L, q_R	1/2	squarks	$\tilde{q}_L, \tilde{q}_R (\tilde{b}_{1,2}, \tilde{t}_{1,2})$	0
photon	γ	1	neutralinos	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$	1/2
Z boson	Z	1			
light Higgs	h	0			
heavy Higgs	H	0			
pseudoscalar Higgs	A	0			
W boson	$W^{\pm}$	1	charginos	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$	1/2
charged Higgs	$H^{\pm}$	1			
gluon	g	1	gluino	$\tilde{g}$	1/2
graviton	G	2	gravitino	$\tilde{G}$	3/2

'LSP' (usually)

$$\chi = N_1\tilde{\gamma} + N_2\tilde{Z}^0 + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0; \sum_{i=1}^{4} |N_i|^2 = 1$$



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

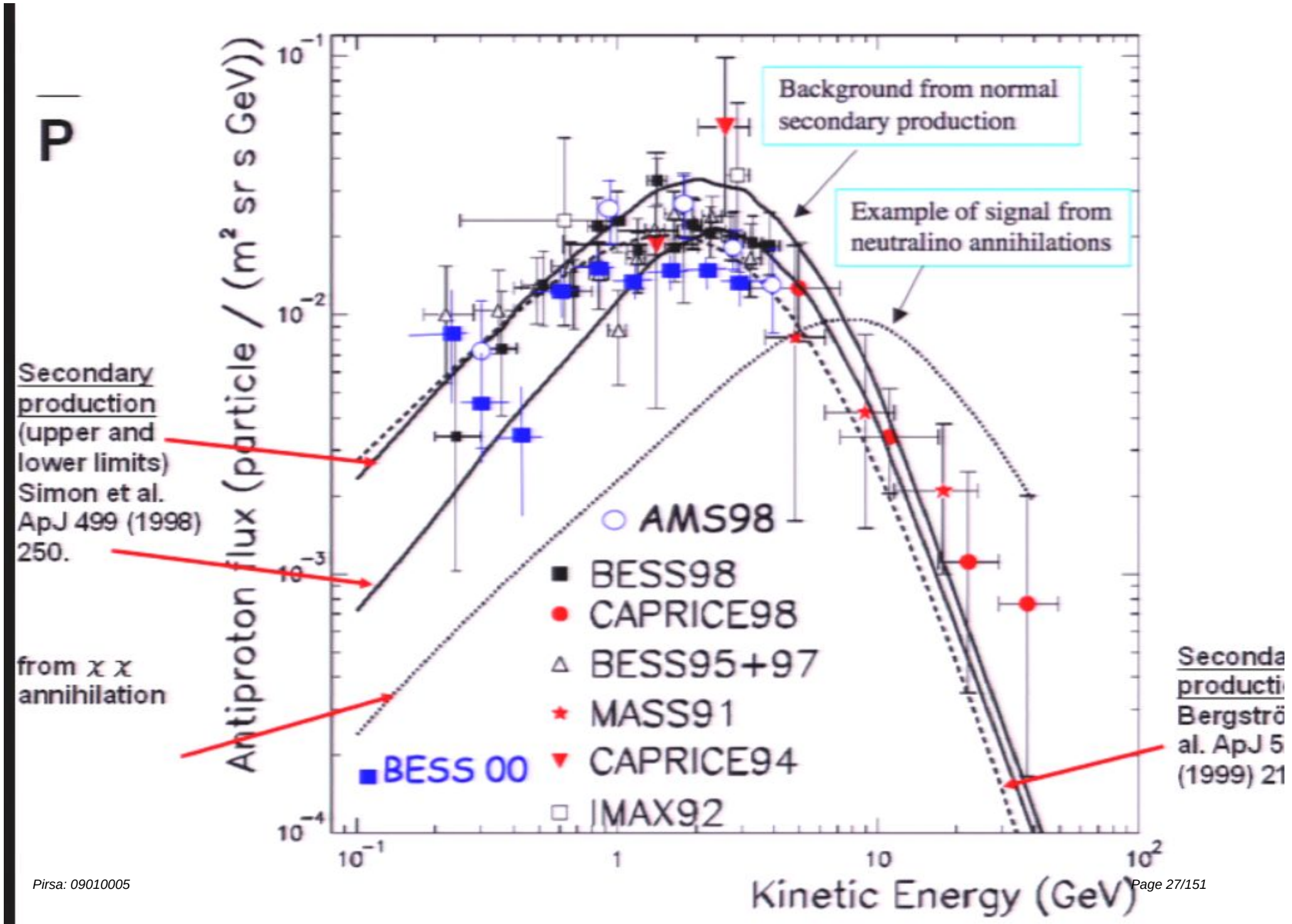
$\chi + \bar{\chi} \rightarrow X + \gamma$ (GLAST-FER AMS-02)

$+ \nu$ (AMANDA / IceC

$+ \bar{p}$

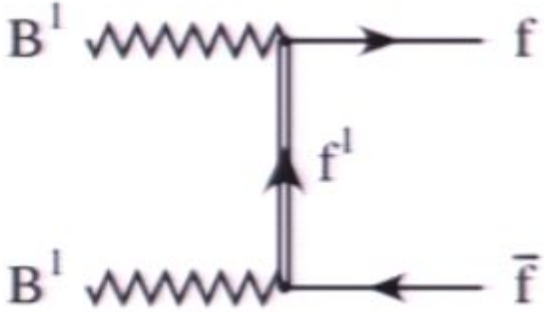
$+ e^+$ PAME (and Bes PEAT, AMS

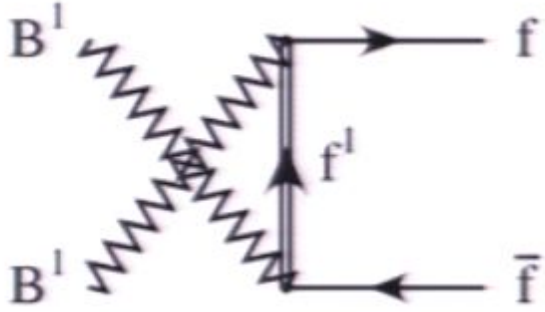
$+ \bar{D}$


$\bar{P}$
Background from normal secondary production
Example of signal from neutralino annihilations
Secondary production (upper and lower limits) Simon et al. ApJ 499 (1998) 250.
from $\chi\chi$ annihilation
Seconda
producti
Bergströ
al. ApJ 5
(1999) 21
AMS98
BESS98
CAPRICE98
BESS95+97
MASS91
CAPRICE94
IMAX92
BESS 00
Antiproton flux (particle / (m² sr s GeV))
Kinetic Energy (GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^{2}

Another possible scenario:
KK Dark Matter

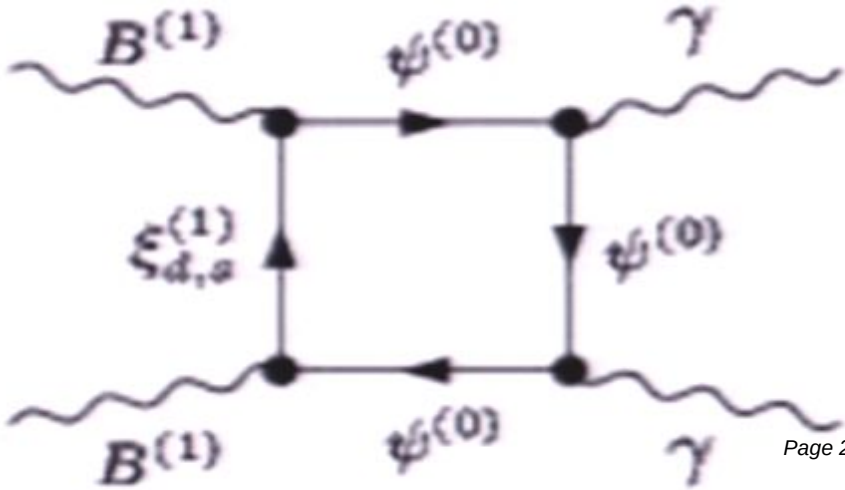
Lightest Kaluza-Klein Particle (LKP): $B^{(1)}$





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 $\gamma\gamma$ in the final state.



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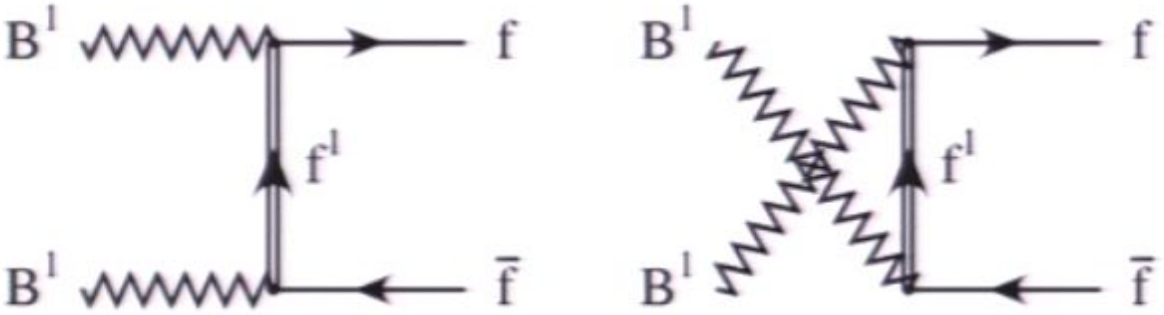

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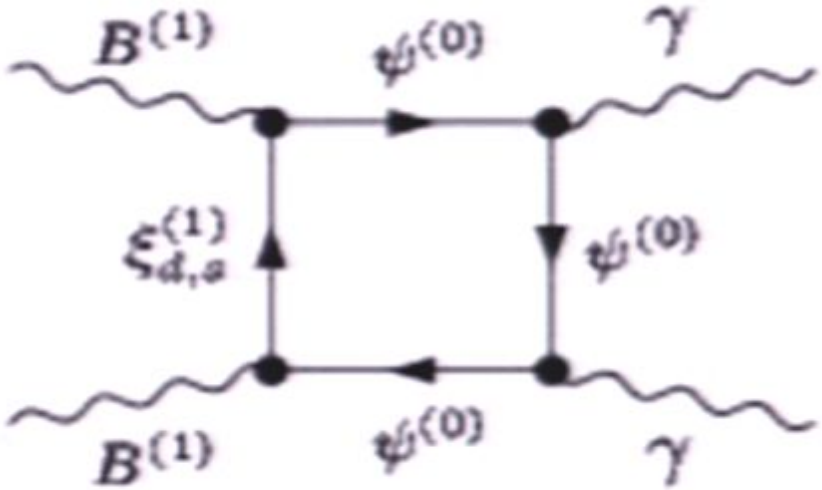

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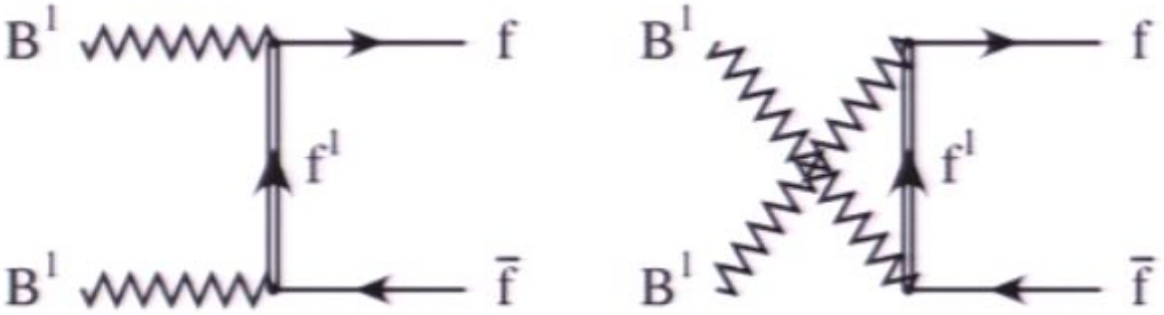

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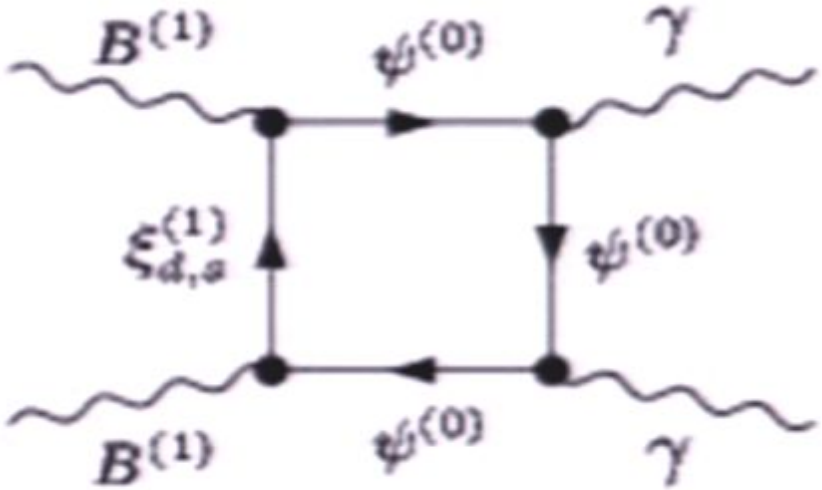
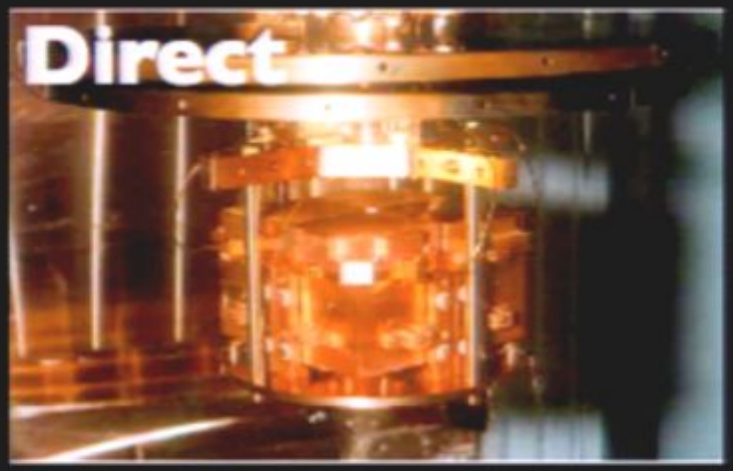
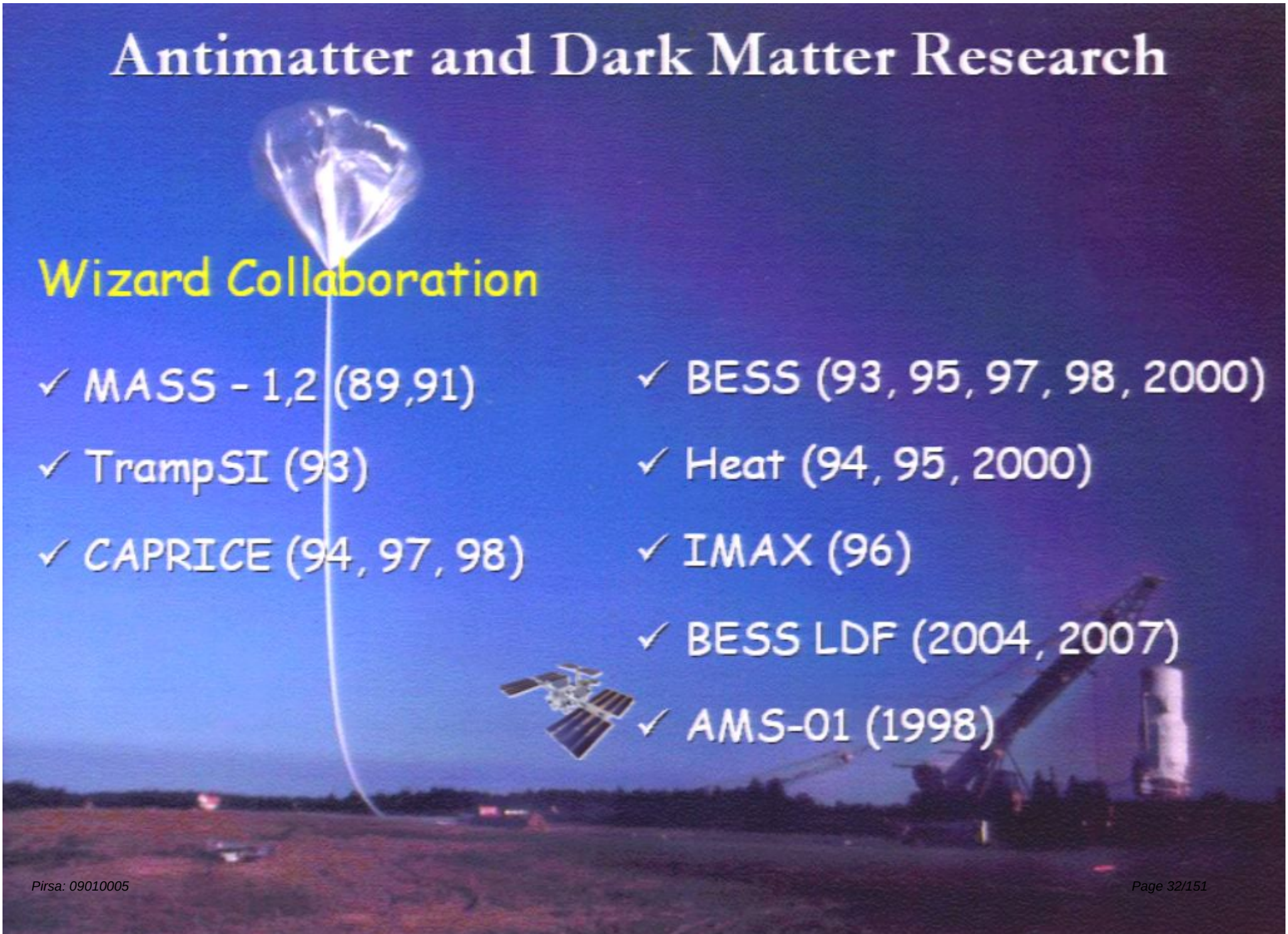


Searches for WIMP Dark Matter



Antimatter and Dark Matter Research



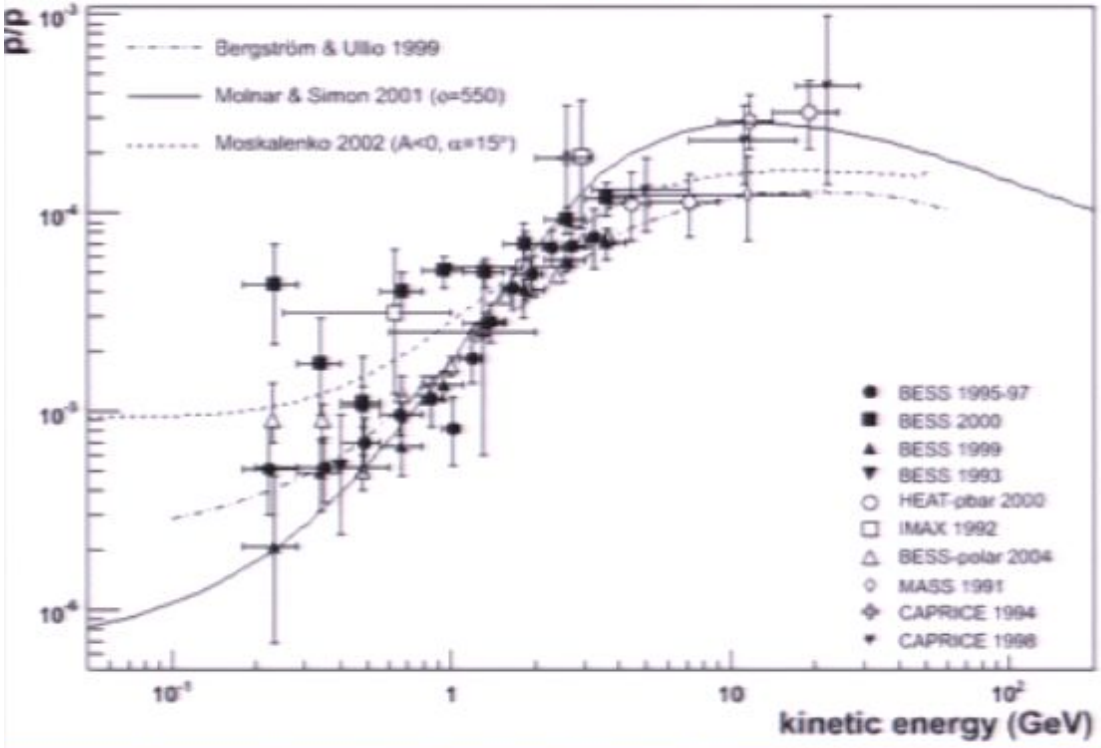
Wizard Collaboration

- ✓ MASS - 1,2 (89,91)
- ✓ TrampSI (93)
- ✓ CAPRICE (94, 97, 98)
- ✓ BESS (93, 95, 97, 98, 2000)
- ✓ Heat (94, 95, 2000)
- ✓ IMAX (96)
- ✓ BESS LDF (2004, 2007)
- ✓ AMS-01 (1998)

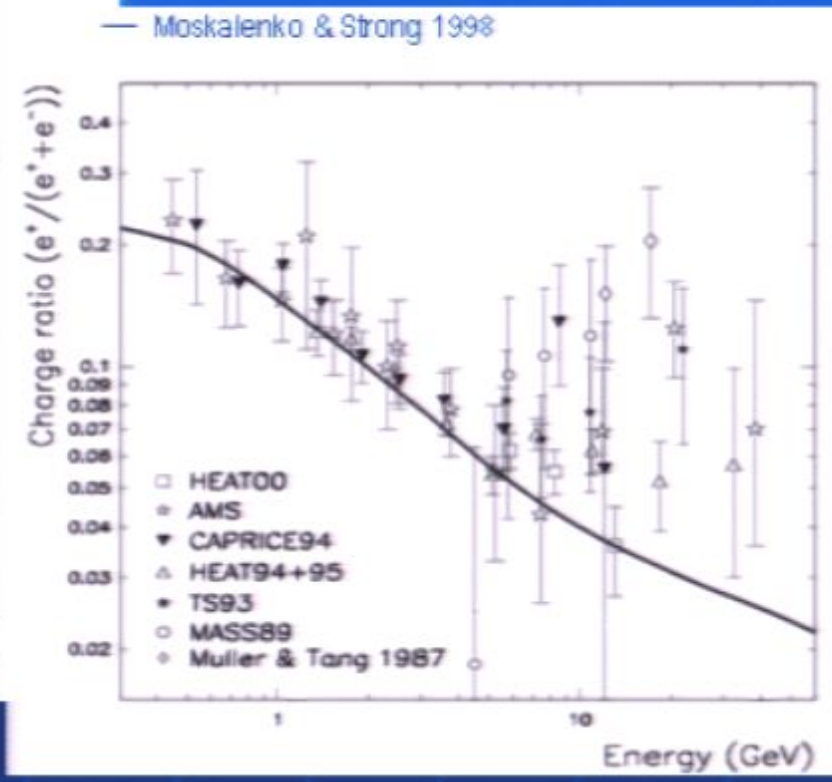
Cosmic Ray Antimatter

Present status

Antiprotons



Positrons

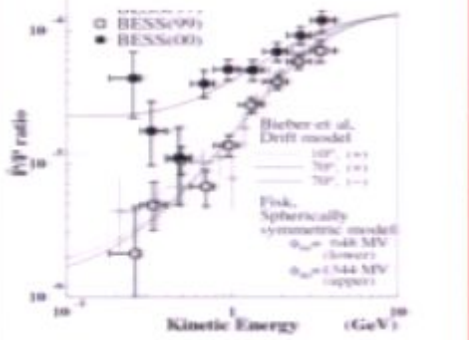


Cosmic Ray Antimatter

Present status

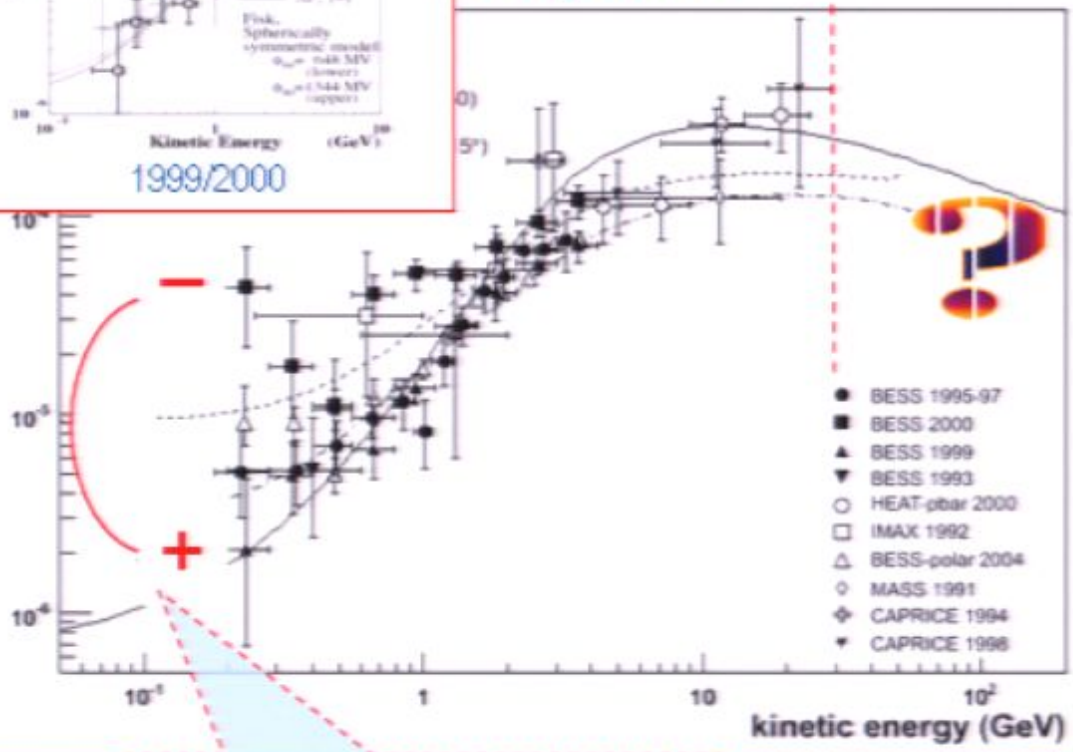
Charge-dependent solar modulation

Asaoka Y. Et al. 2002

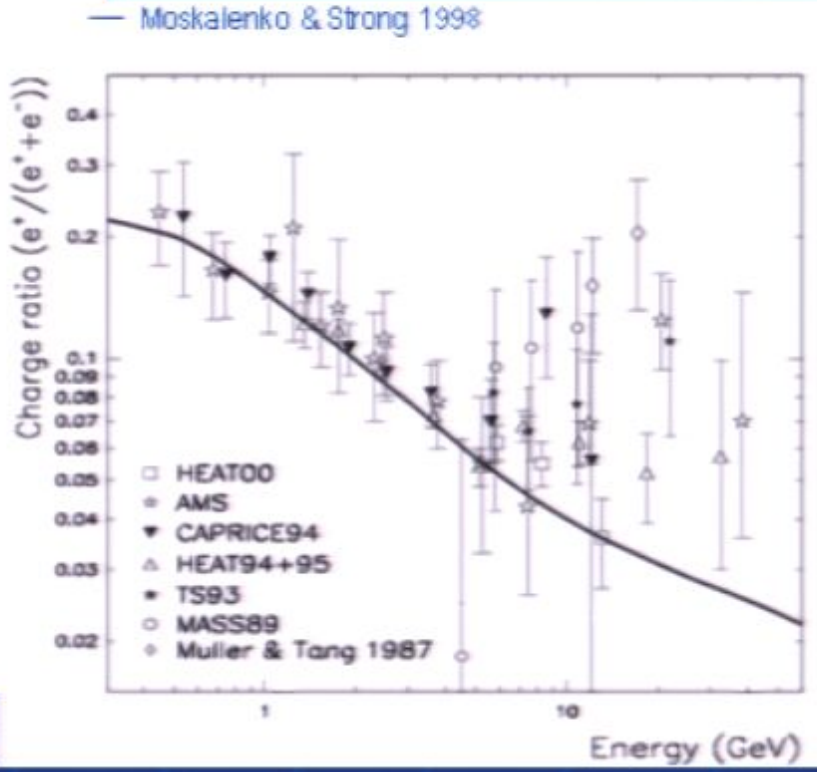


1999/2000

Antiprotons



Positrons



CR + ISM → **p-bar** + …

kinematic threshold:

5.6 GeV for the reaction

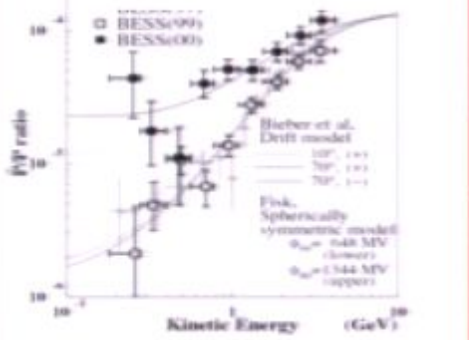
$pp \rightarrow \bar{p}ppp$

Cosmic Ray Antimatter

Present status

Charge-dependent solar modulation

Asaoka Y. Et al. 2002



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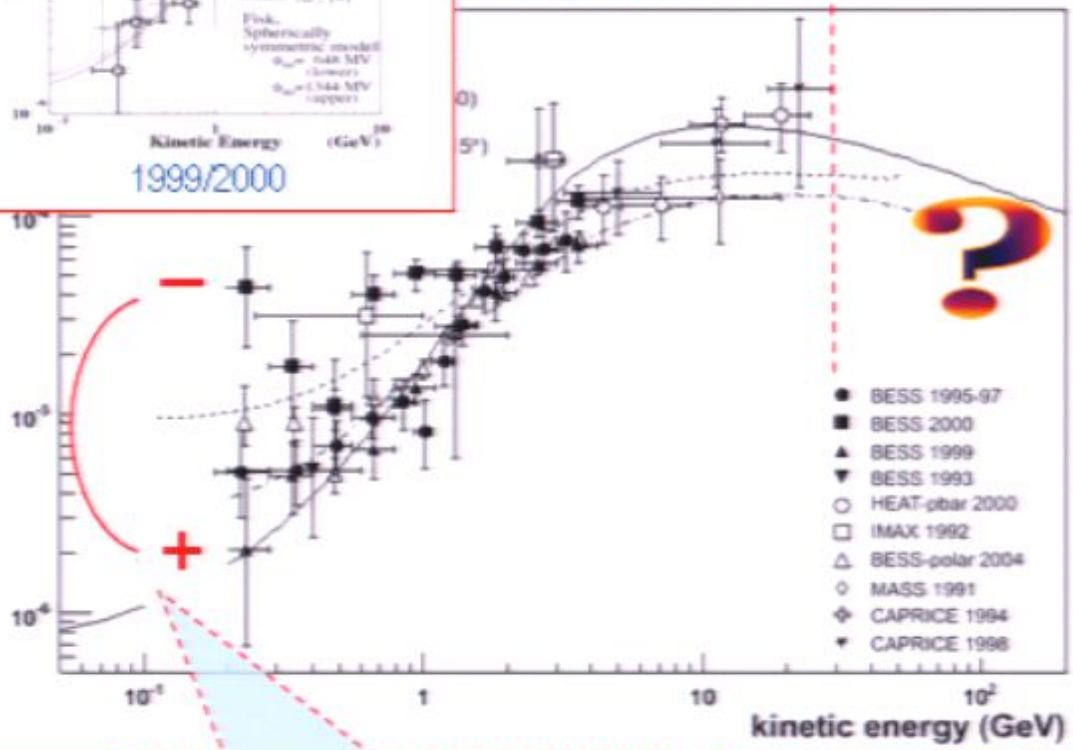
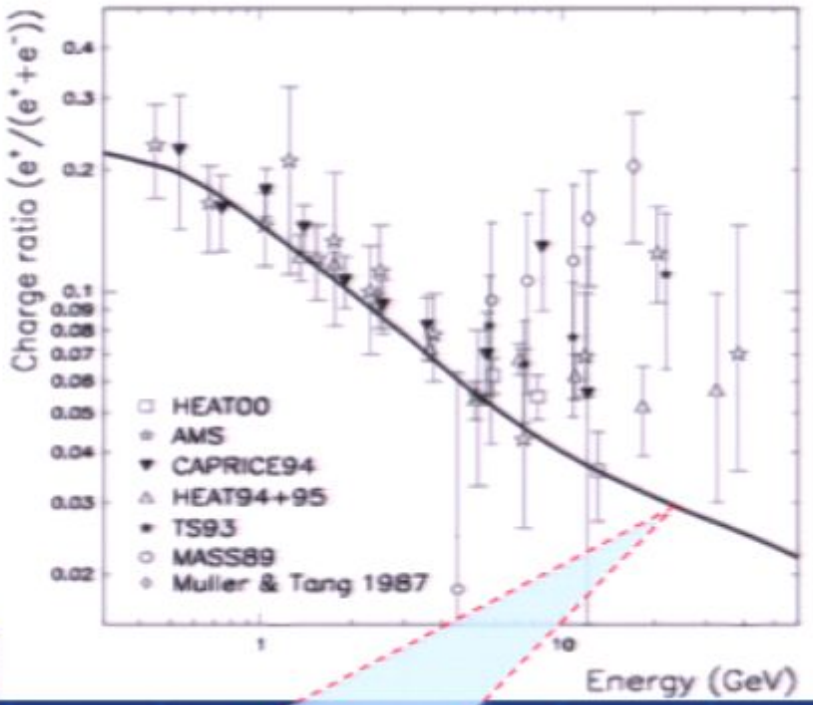


Positrons

— Moskalenko & Strong 1998



$CR + ISM \rightarrow \mathbf{p\text{-}bar} + \ldots$

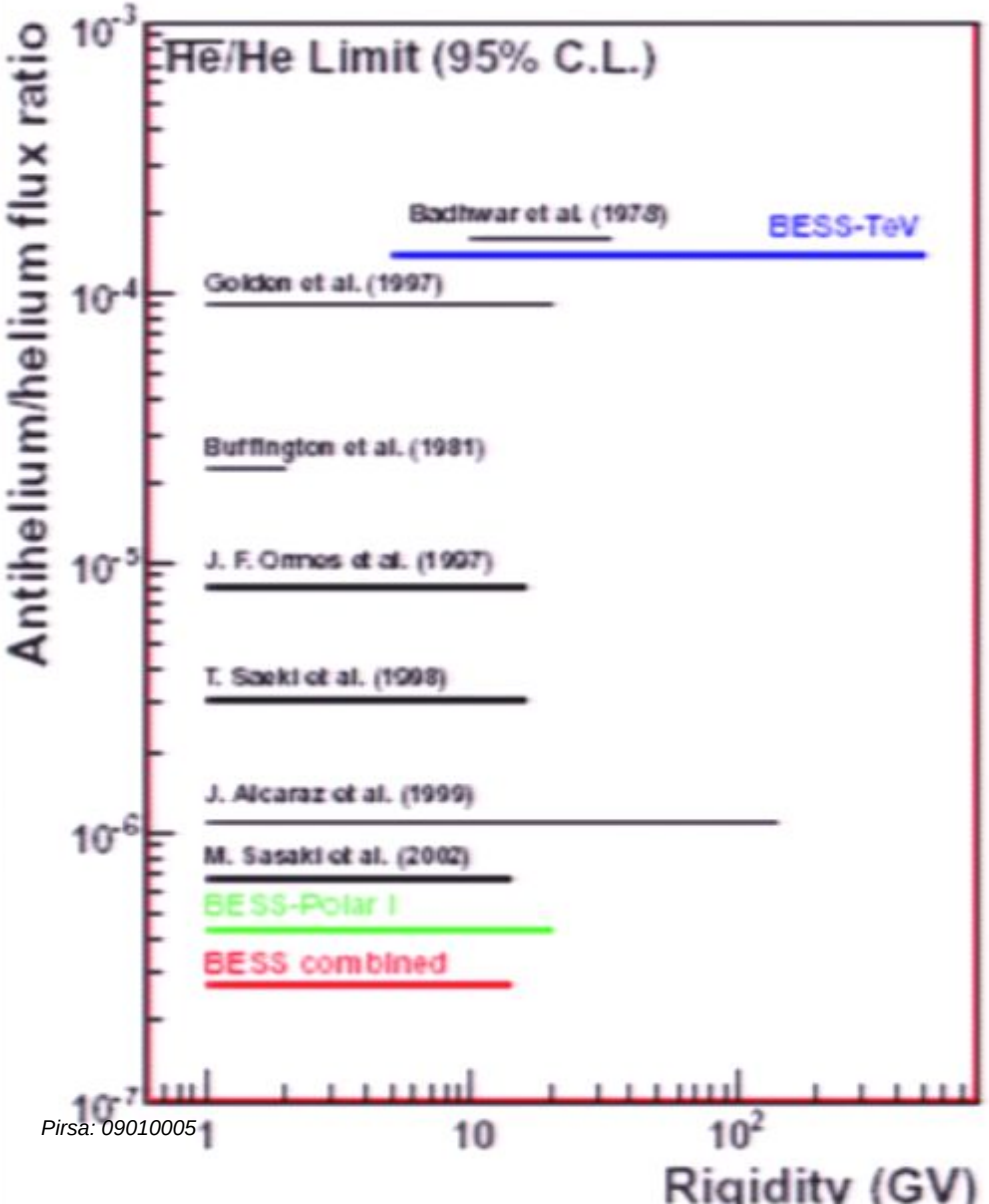
kinematic threshold:
5.6 GeV for the reaction

$pp \rightarrow \bar{p}ppp$

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

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

Antimatter



"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"

P. Dirac, Nobel lecture (1933)

What do we need?

- Measurements at higher energies
- Better knowledge of background
- High statistics
- Continuous monitoring of solar modulation

Long Duration Flights


PAMELA
Payload for Antimatter Matter Exploration
and Light Nuclei Astrophysics

Pamela as a Space Observatory at 1AU

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Search for antihelium (primordial antimatter)

Search for new Matter in the Universe (Strangelets?)

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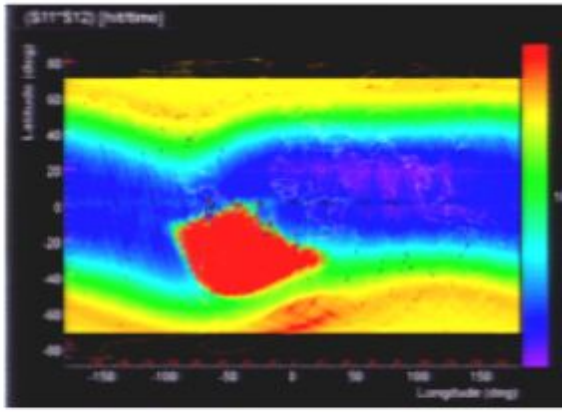
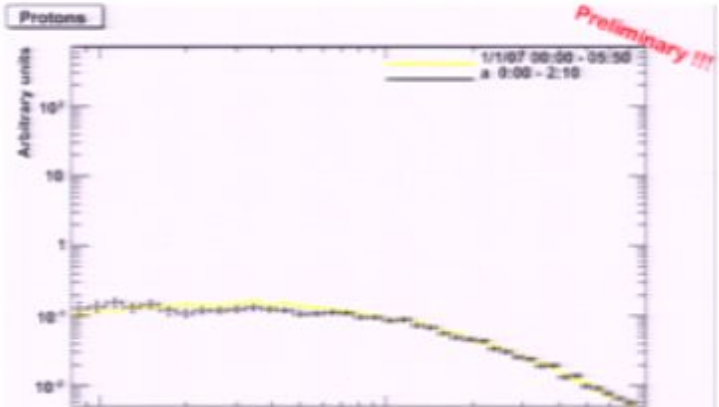
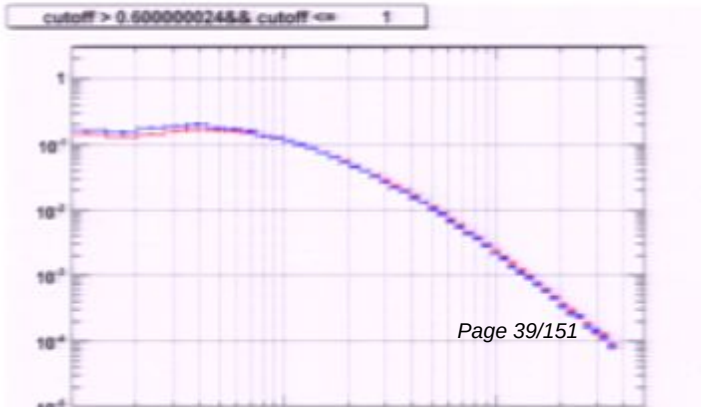
Study of solar physics and solar modulation

Study of terrestrial magnetosphere

Study of high energy electron spectrum (local sources?)







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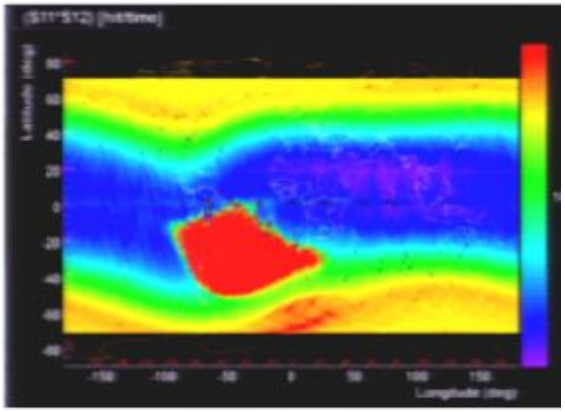

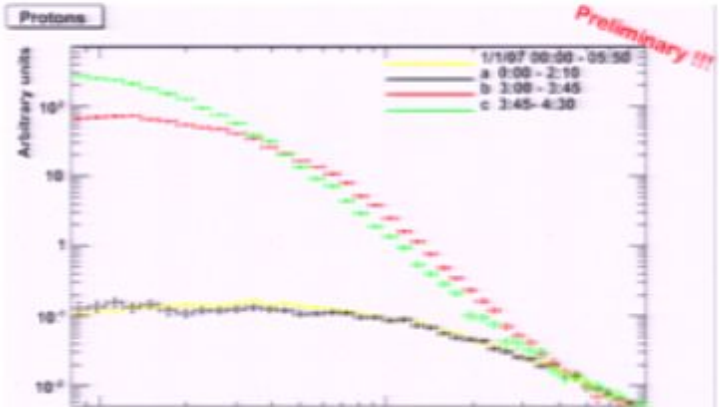

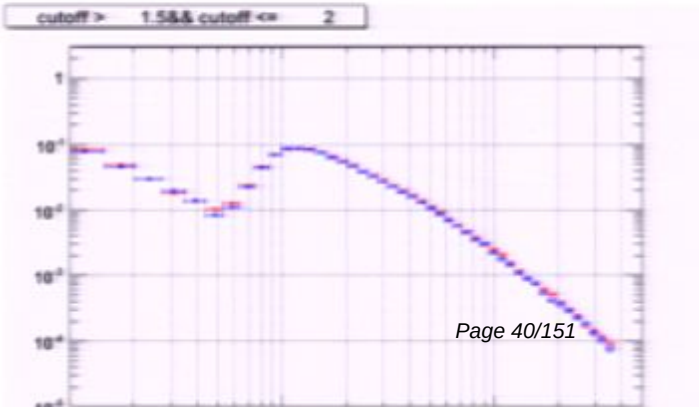

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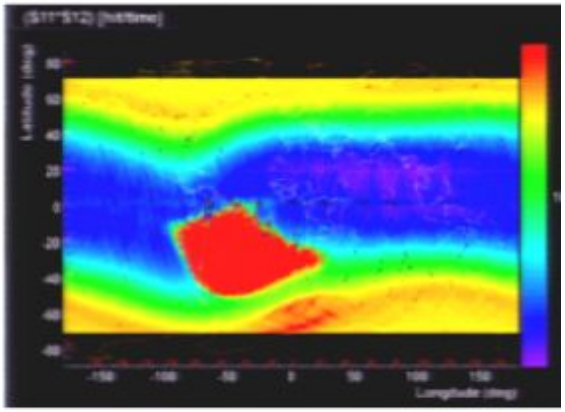

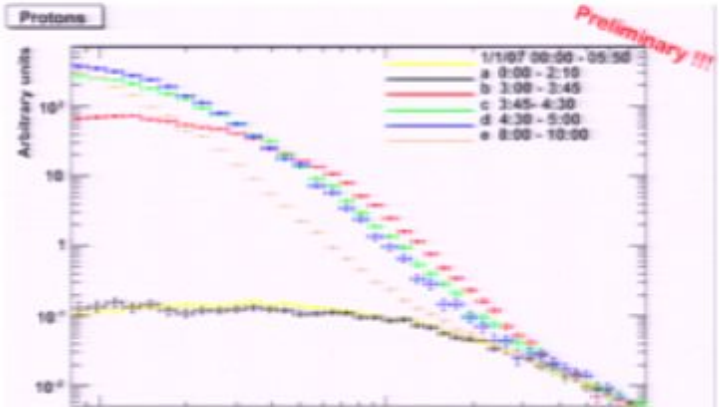

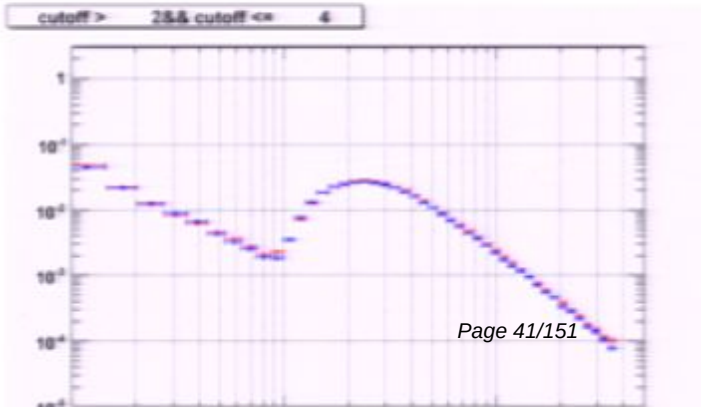

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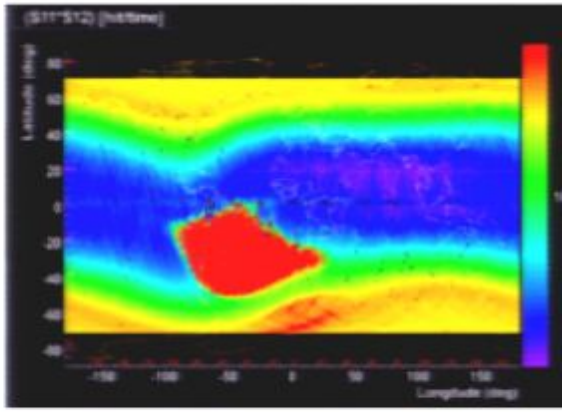

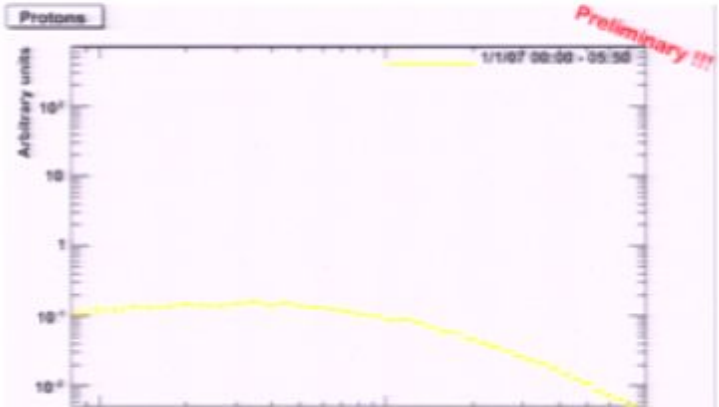

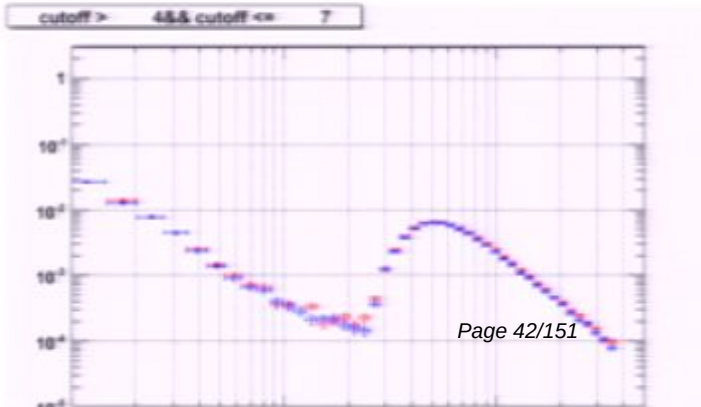

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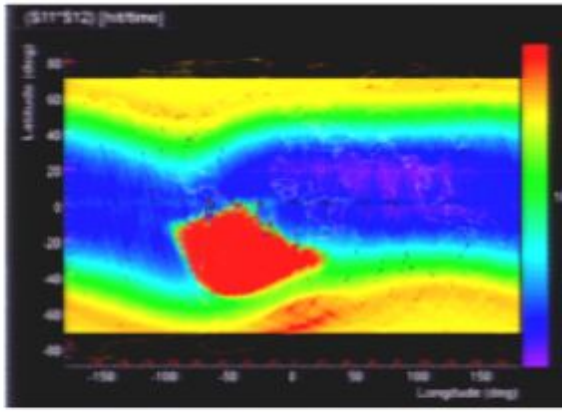

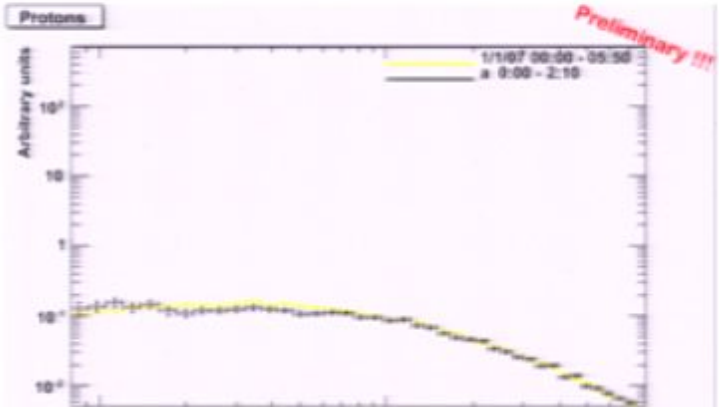

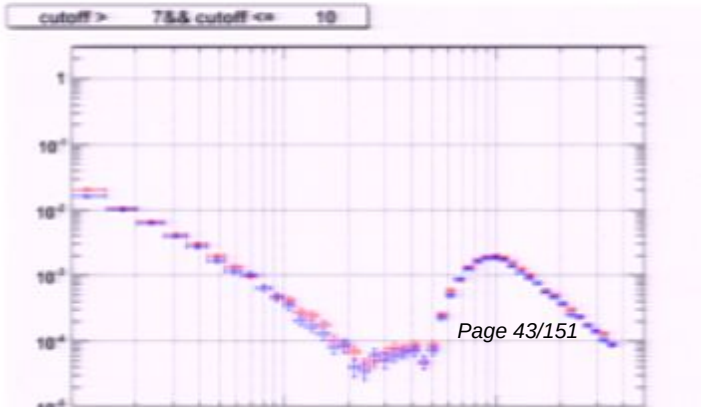

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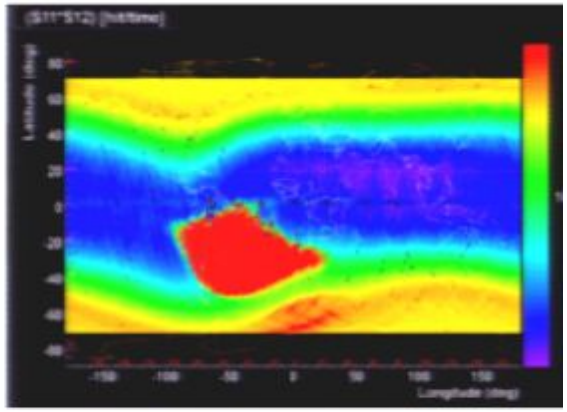

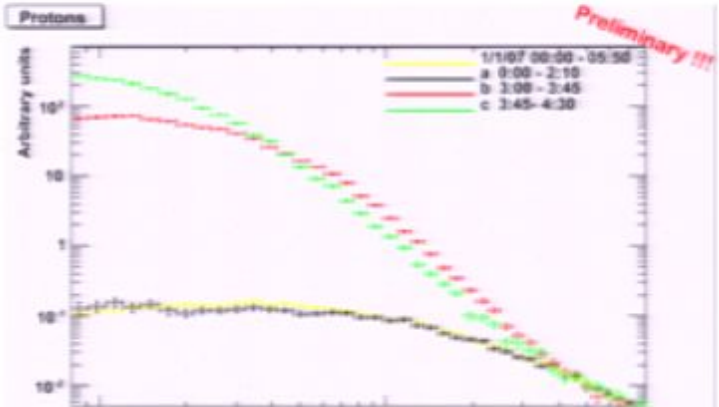

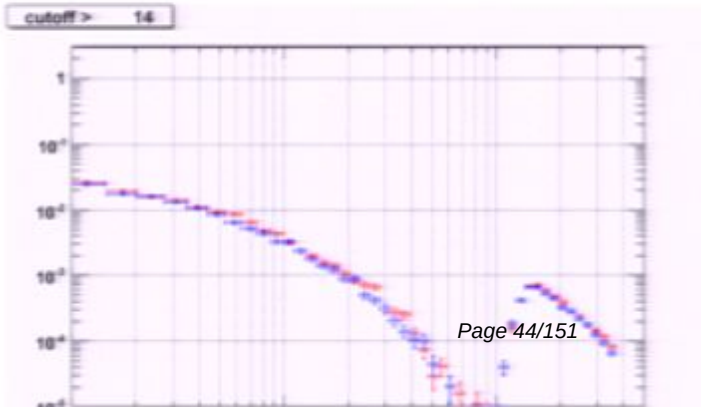

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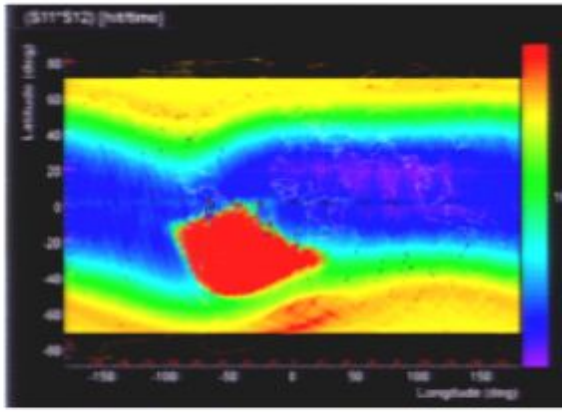

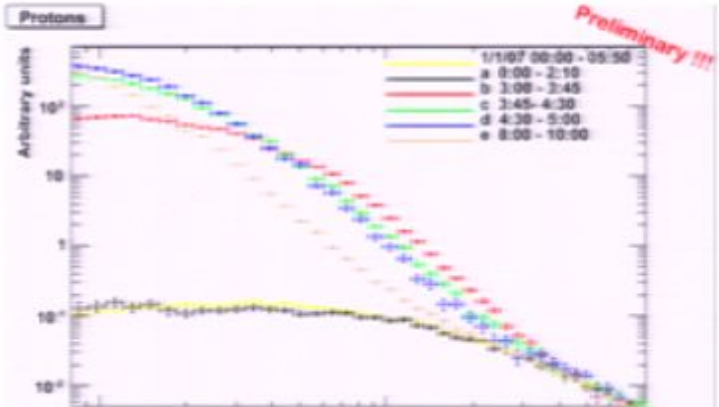

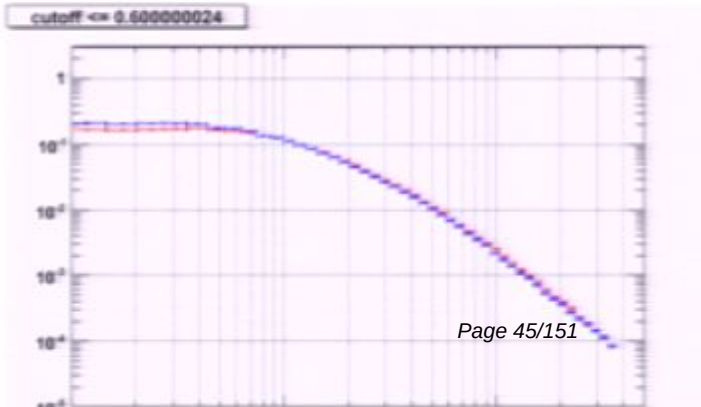

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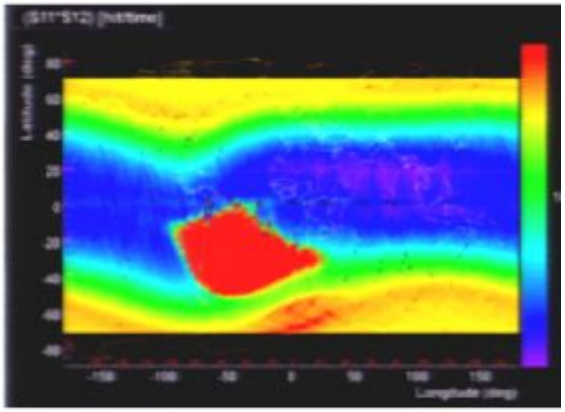

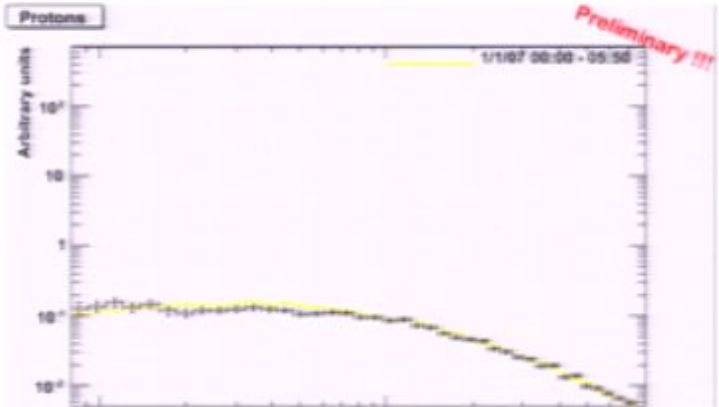

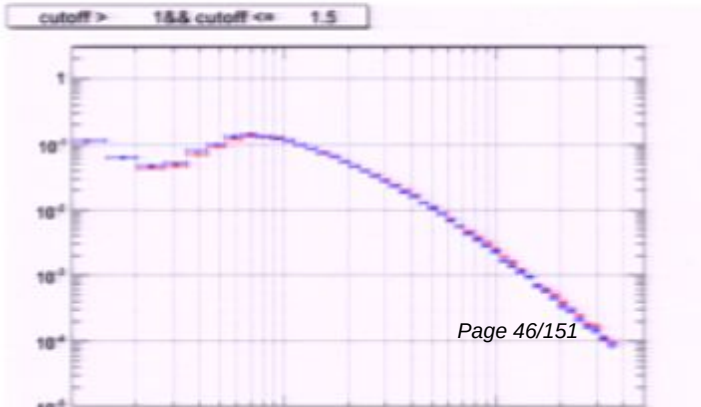

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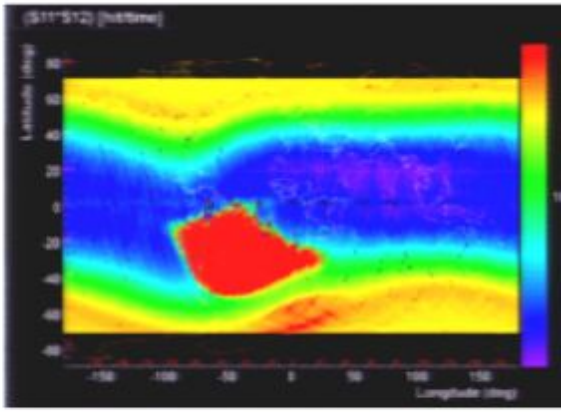

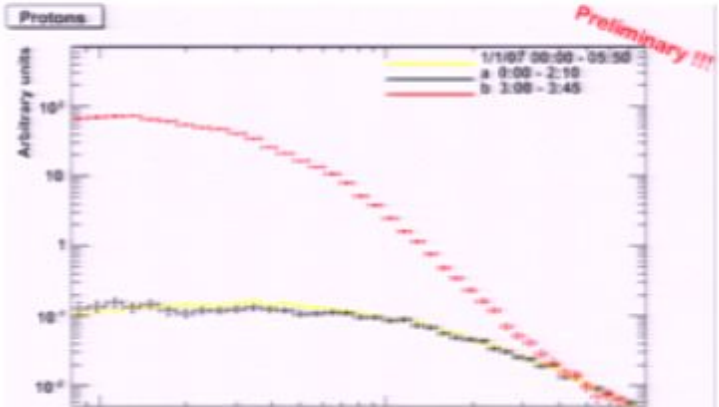

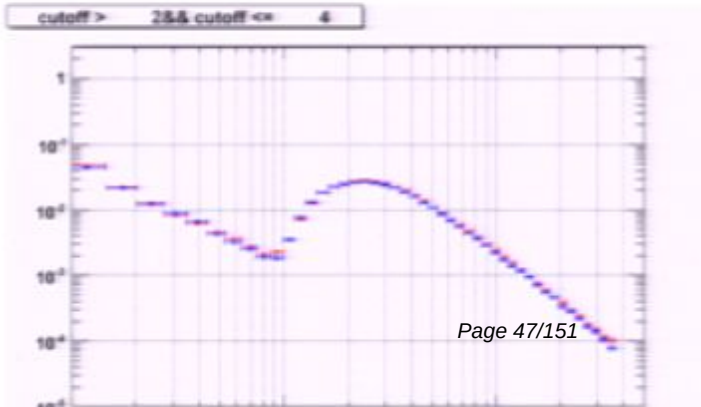

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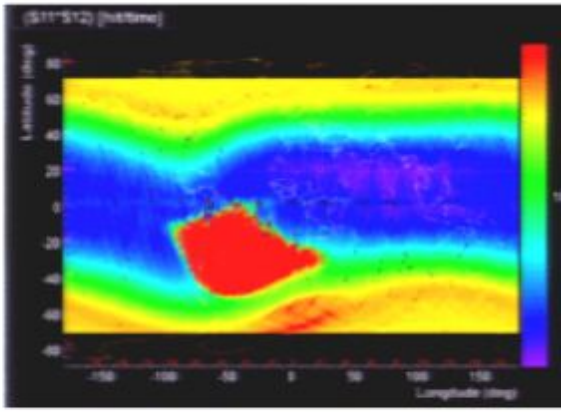

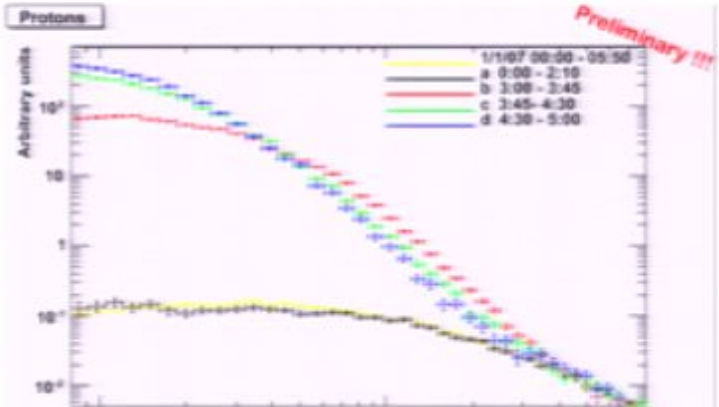

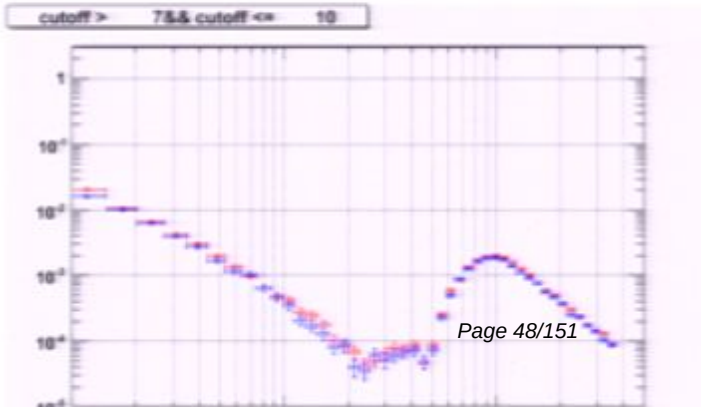

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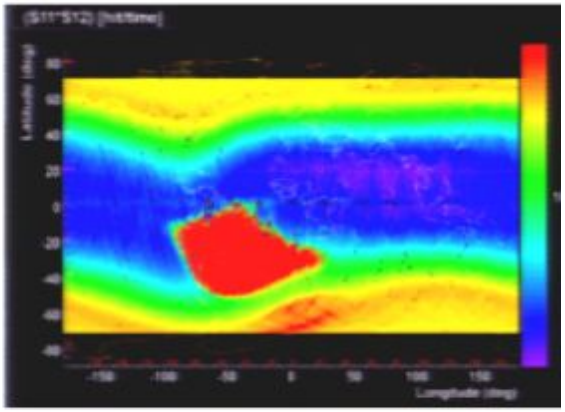

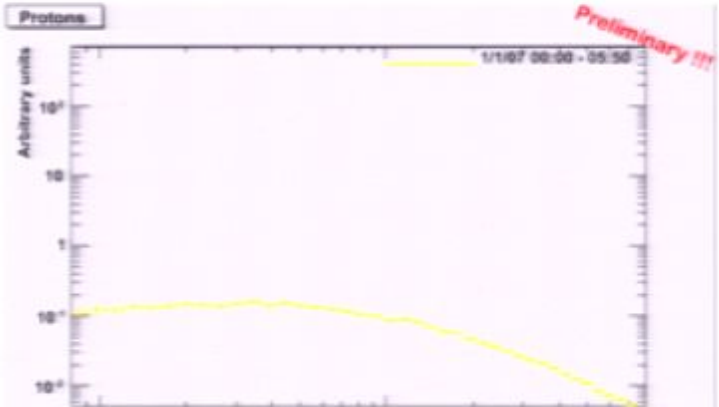

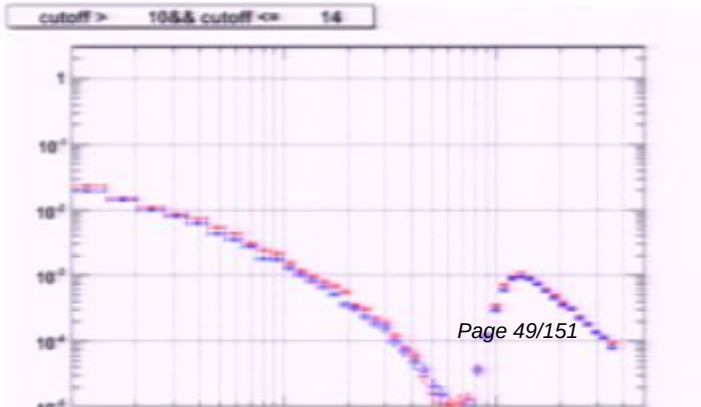

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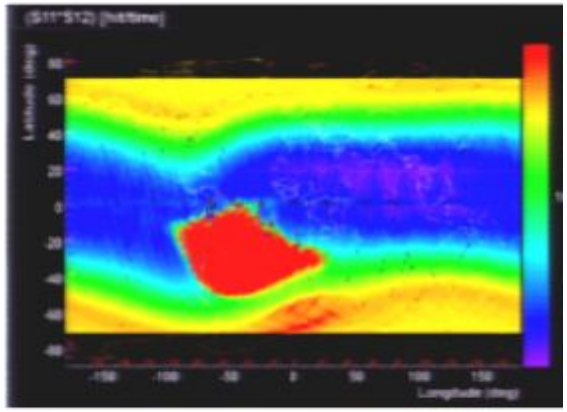

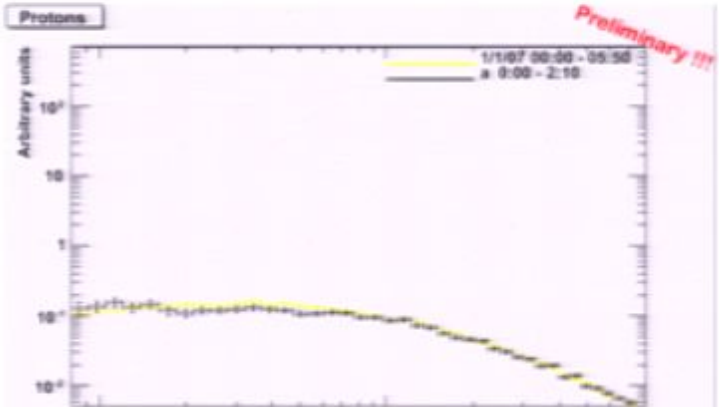

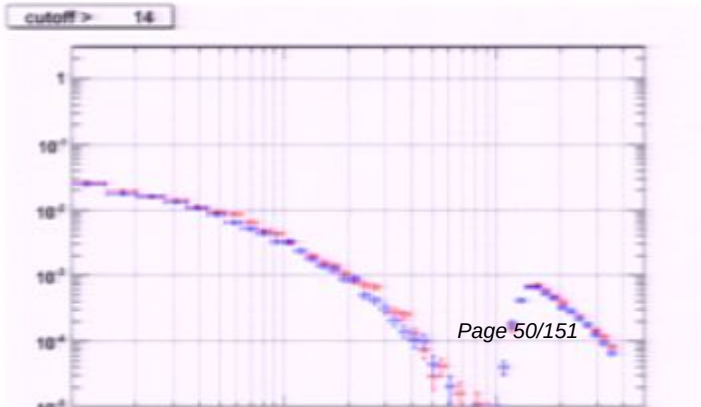

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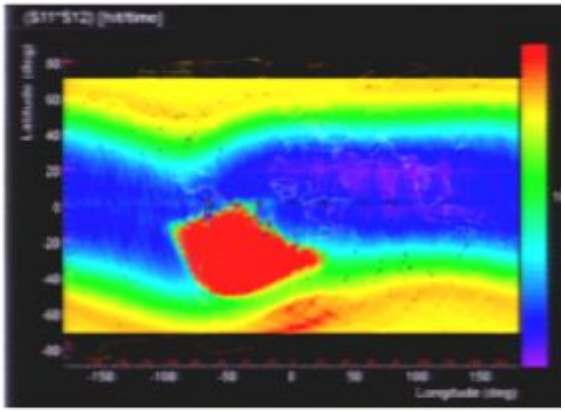

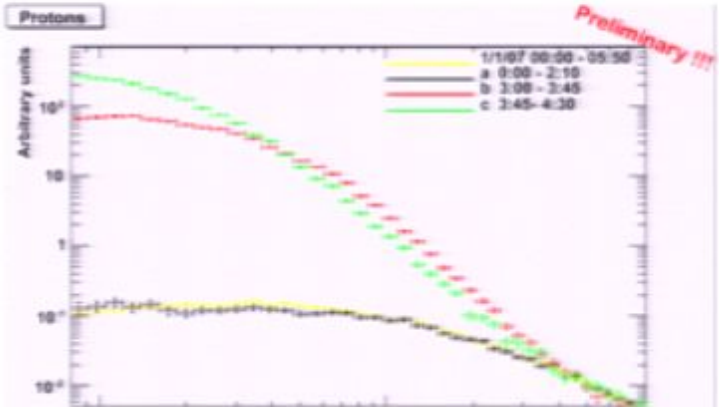

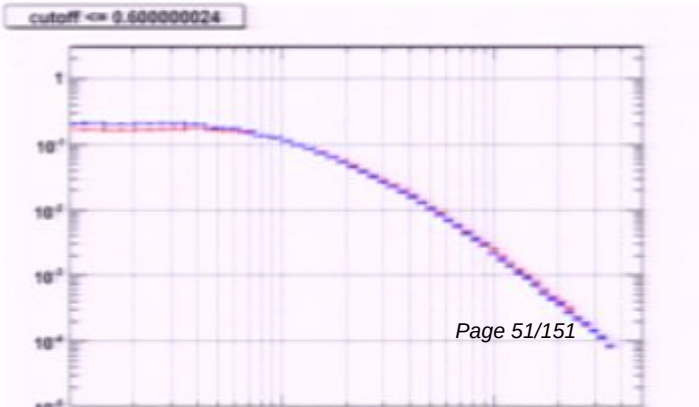

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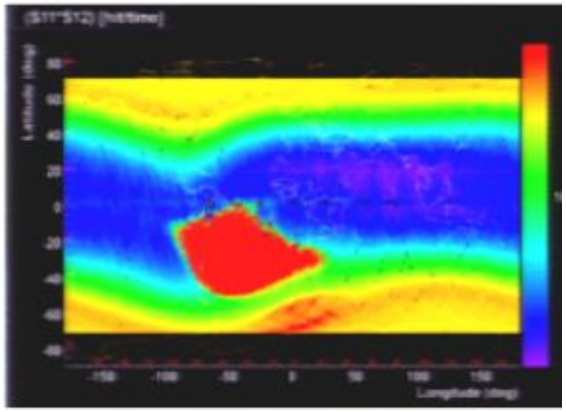

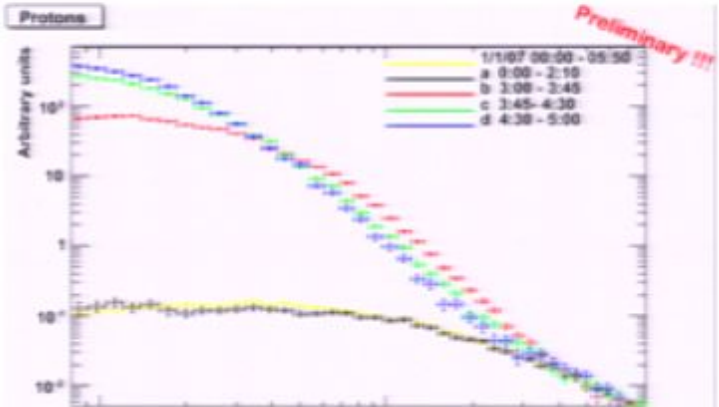

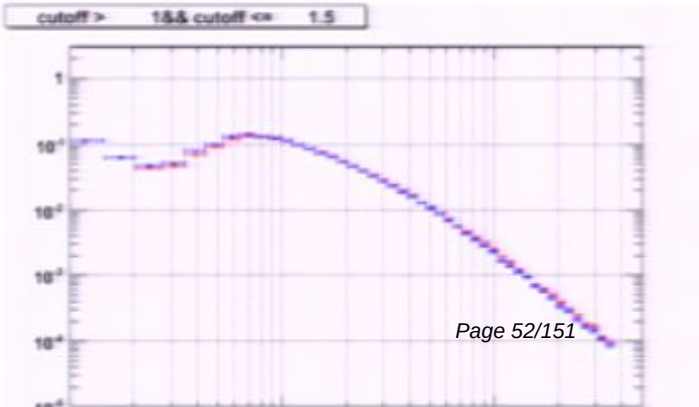

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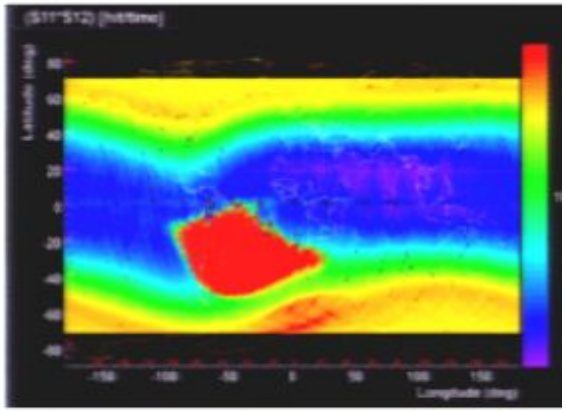

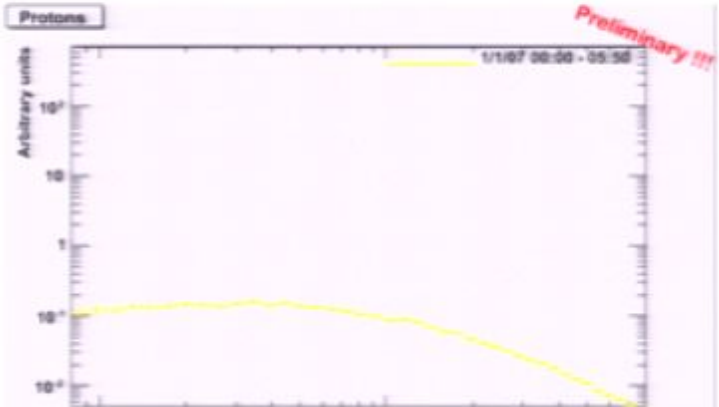

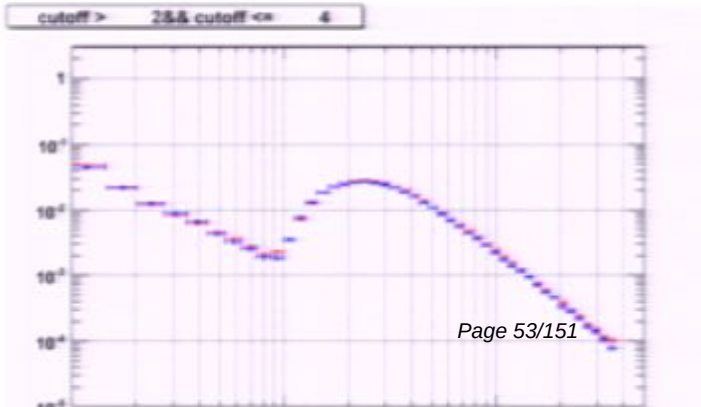

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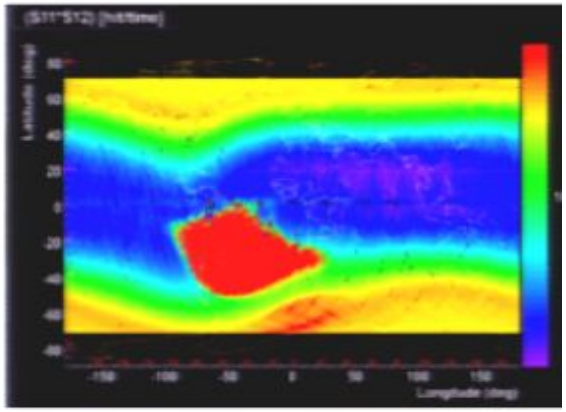

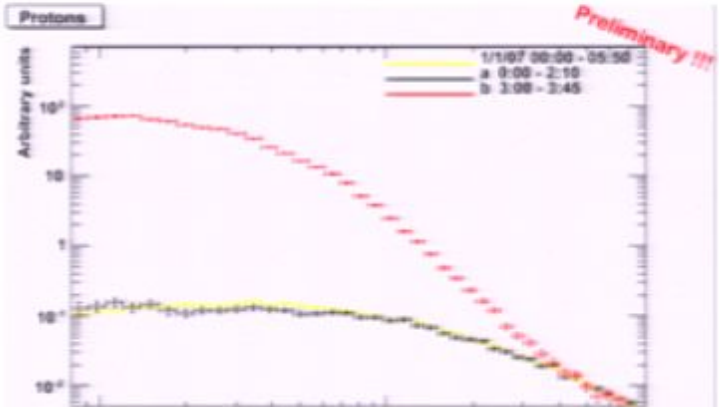

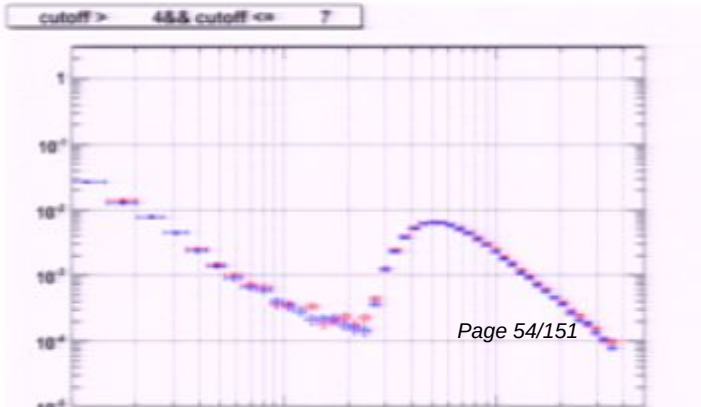

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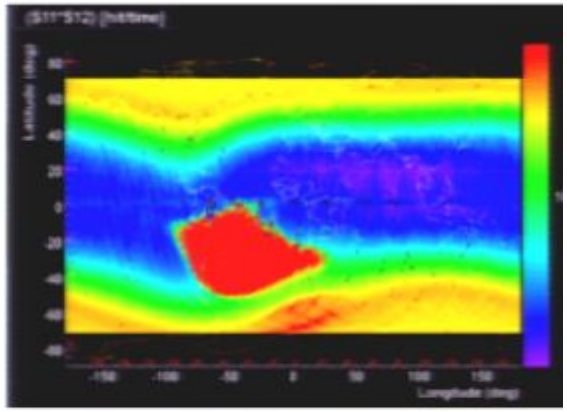

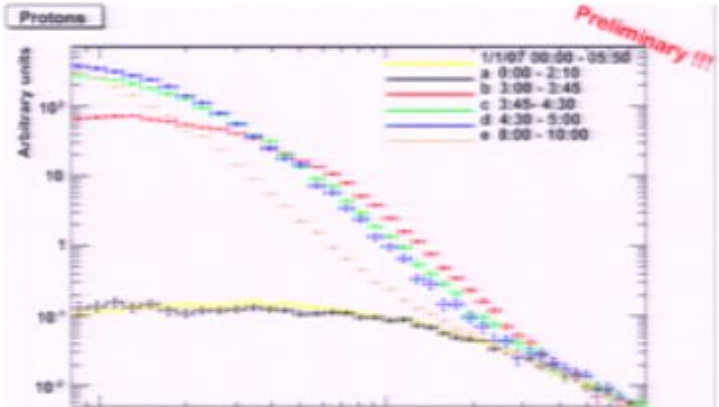

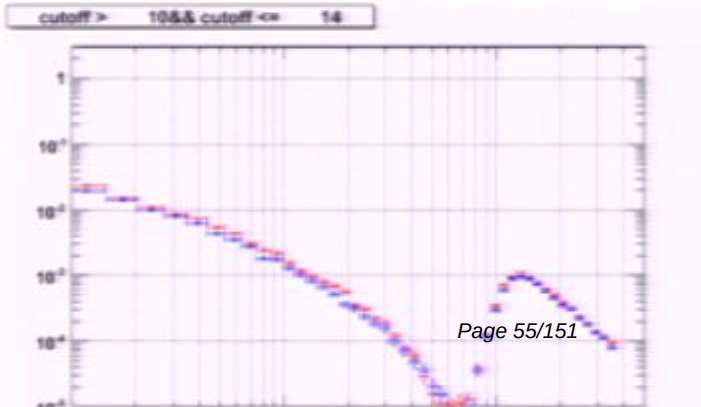

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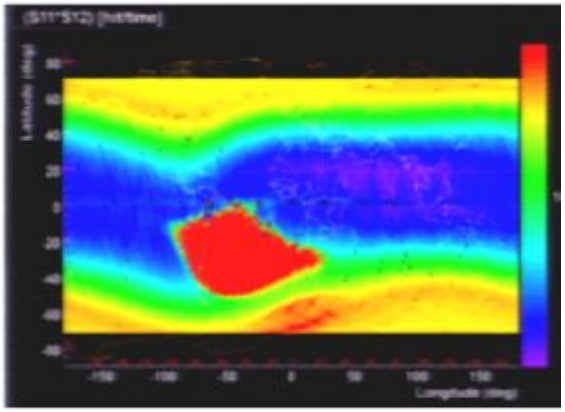

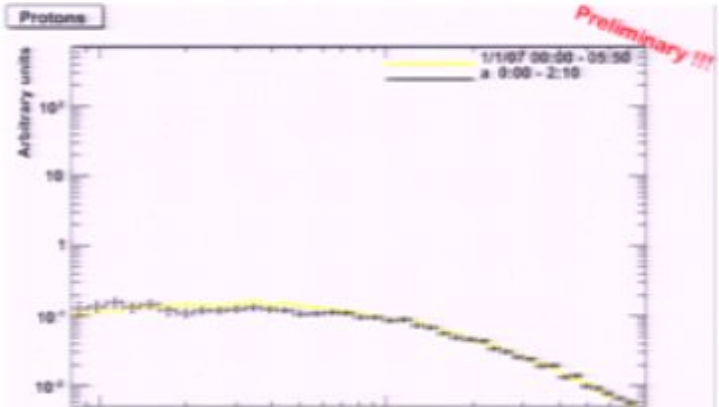

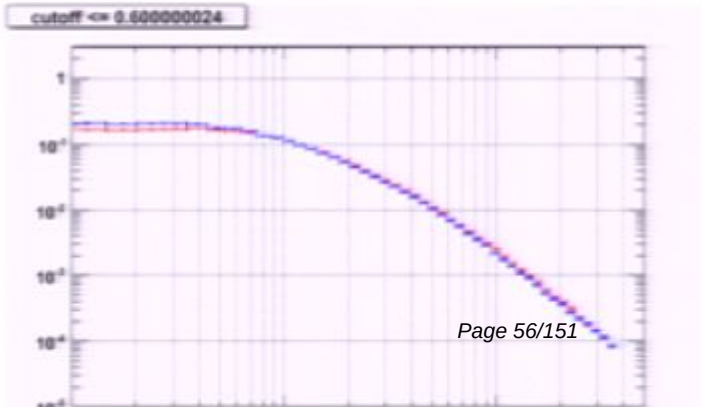

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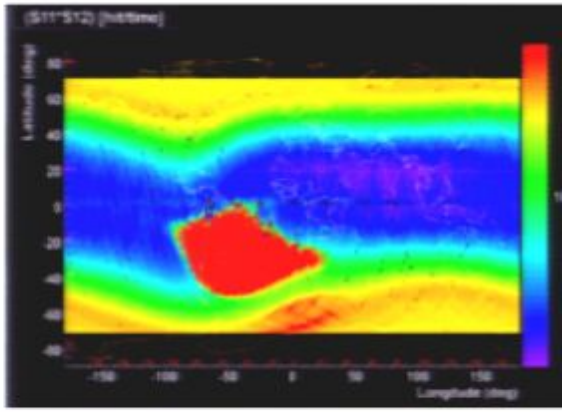

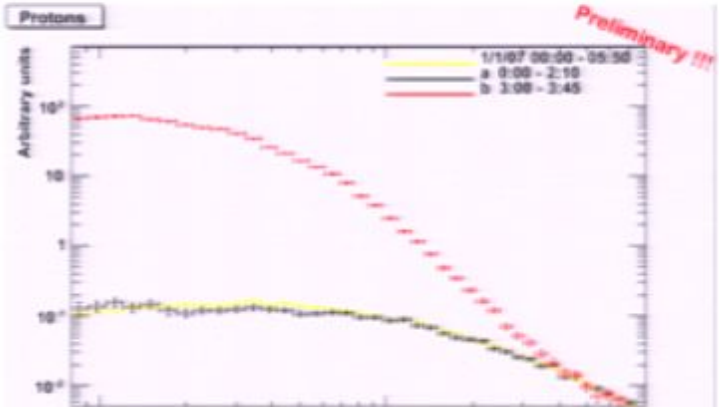

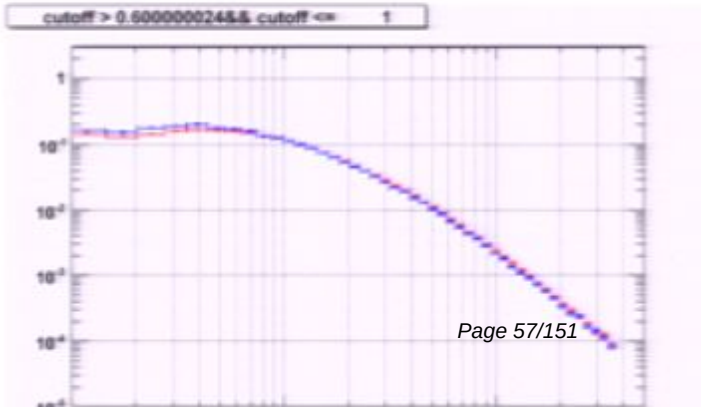

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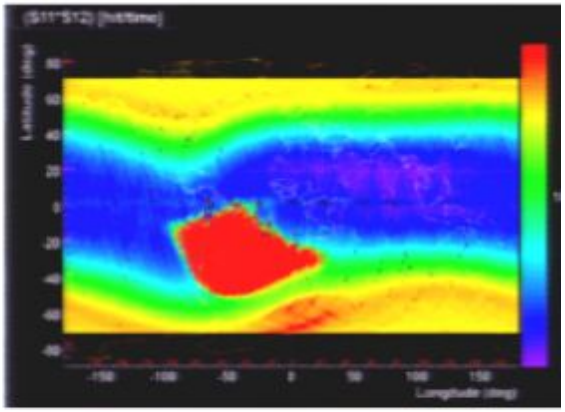

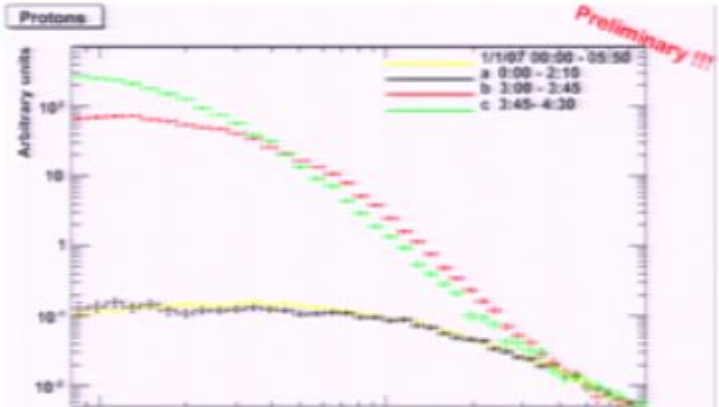

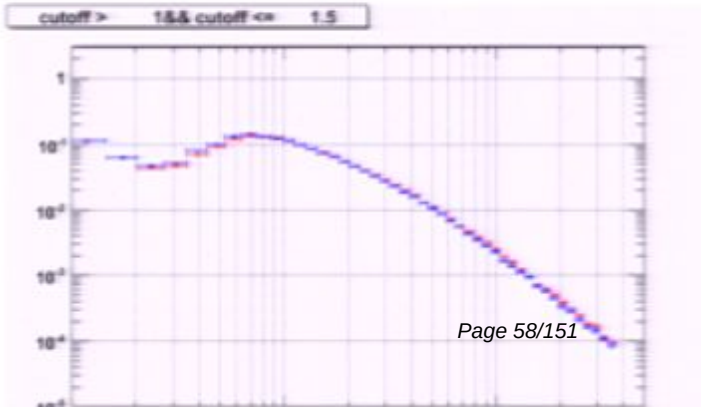

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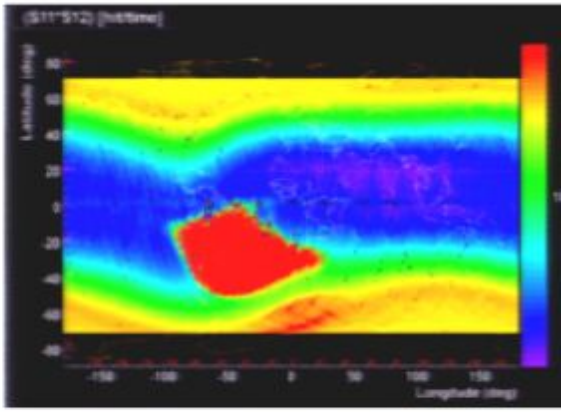

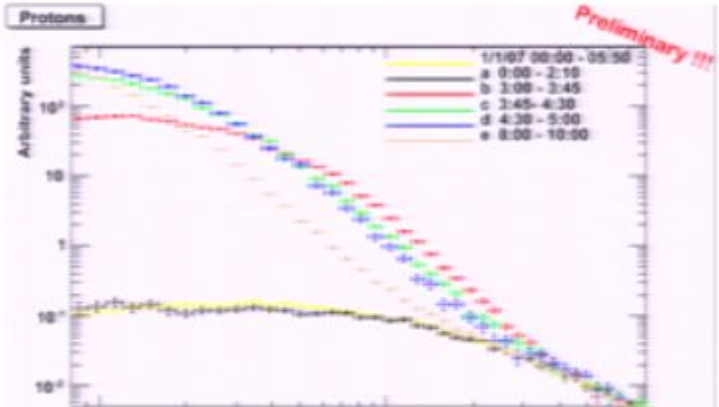

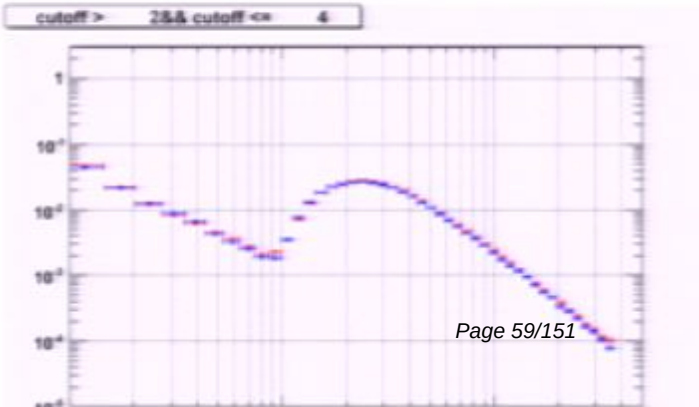

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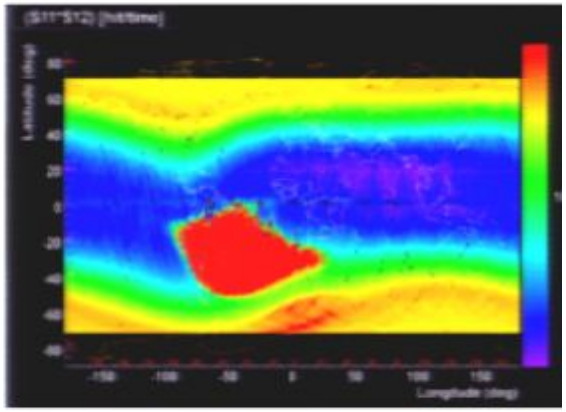

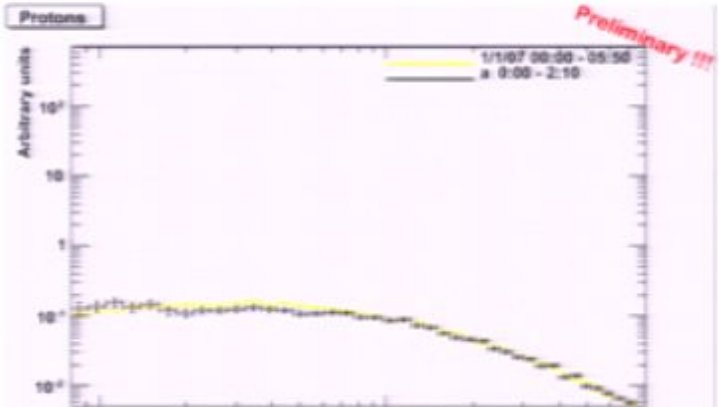

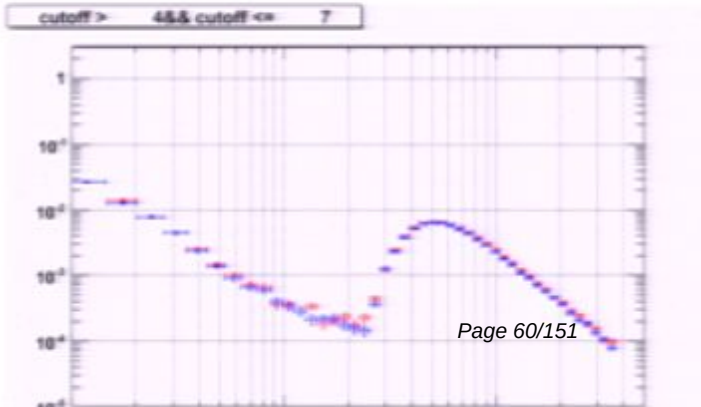

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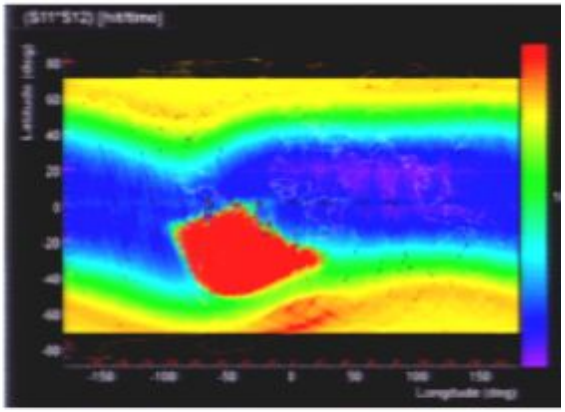

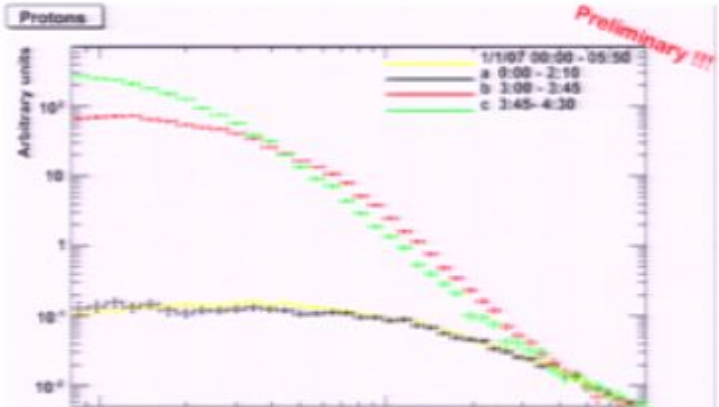

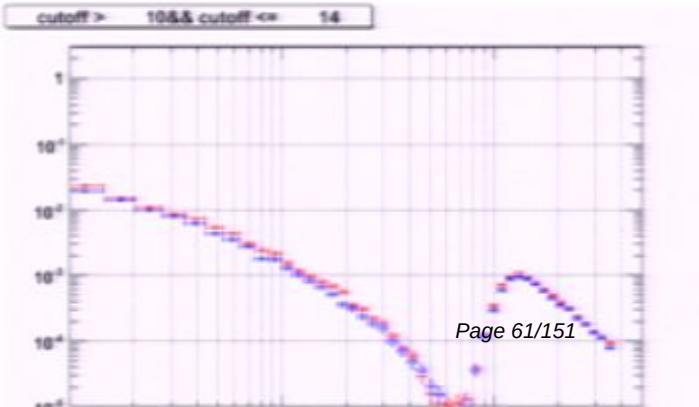

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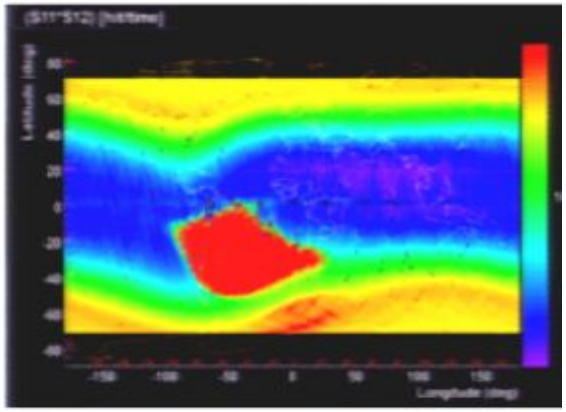

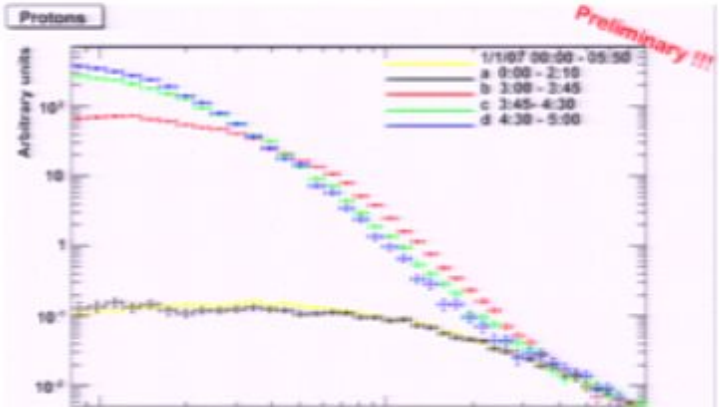

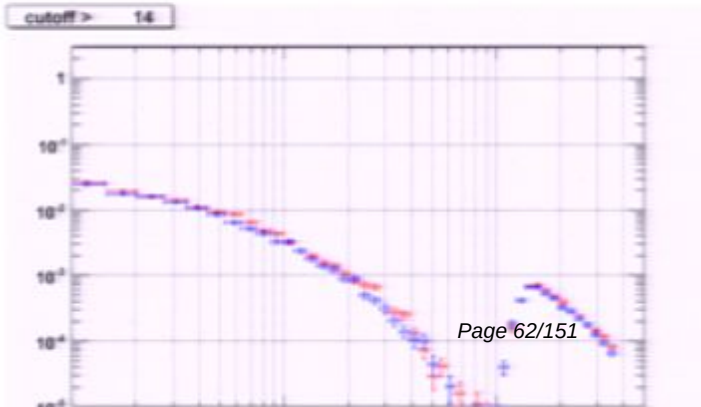

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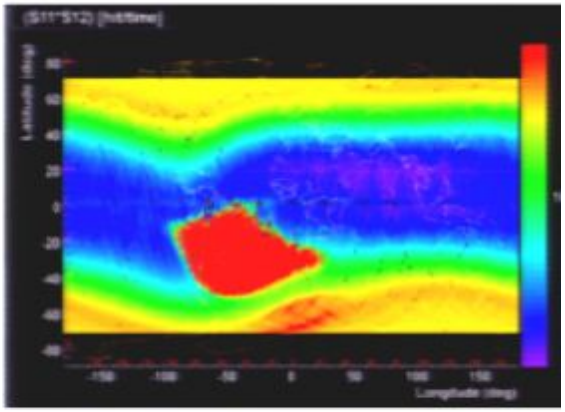

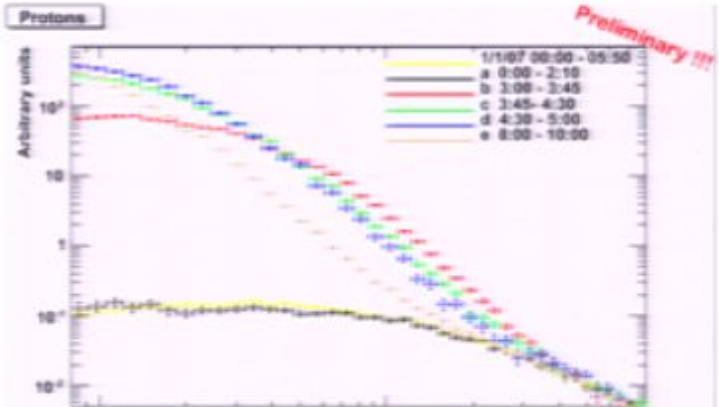

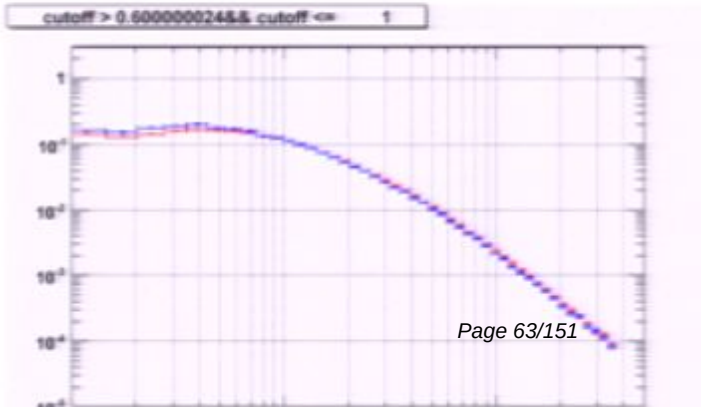

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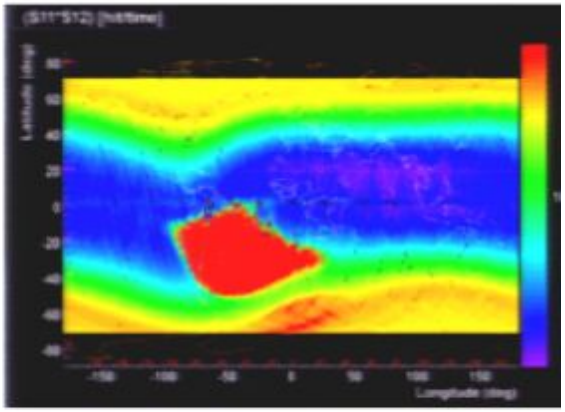

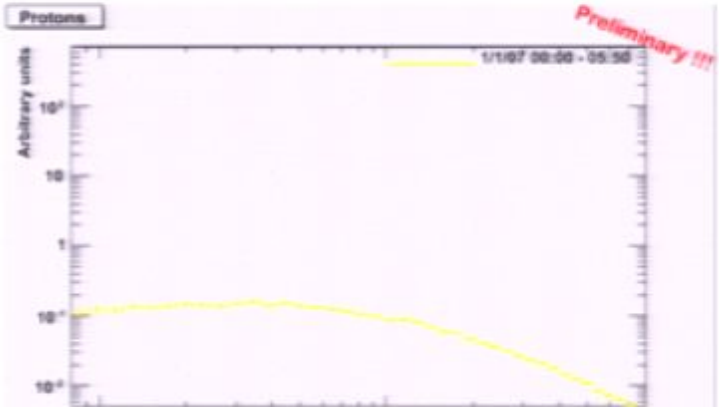

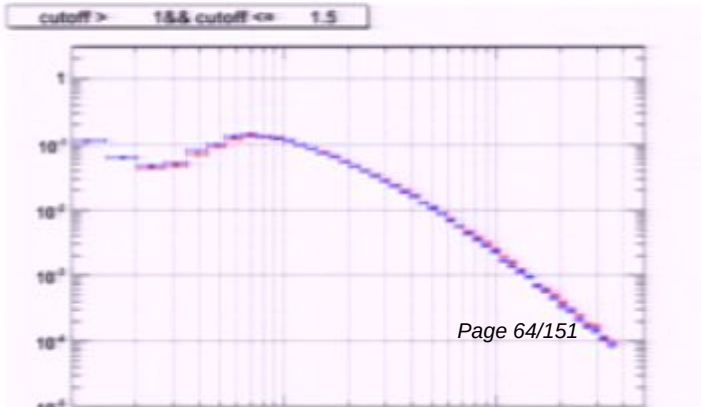

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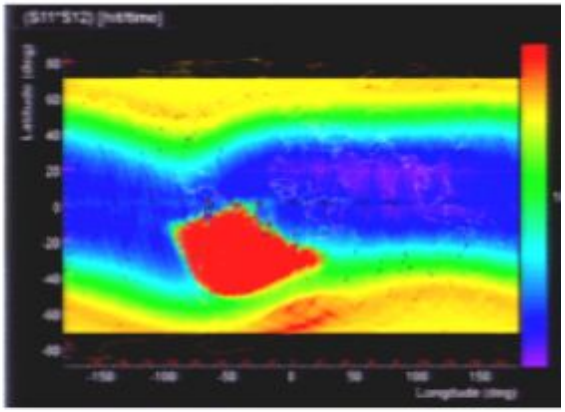

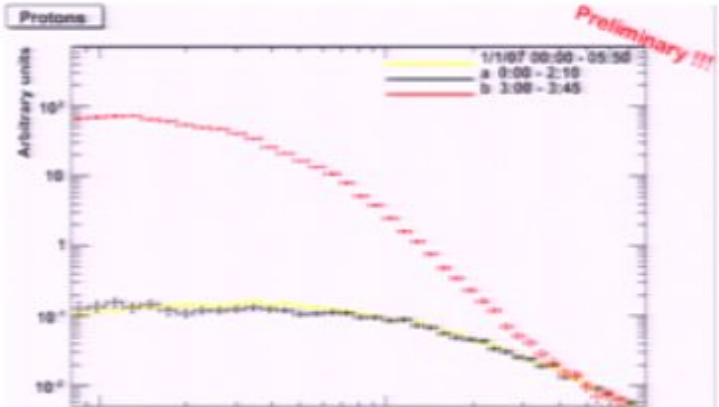

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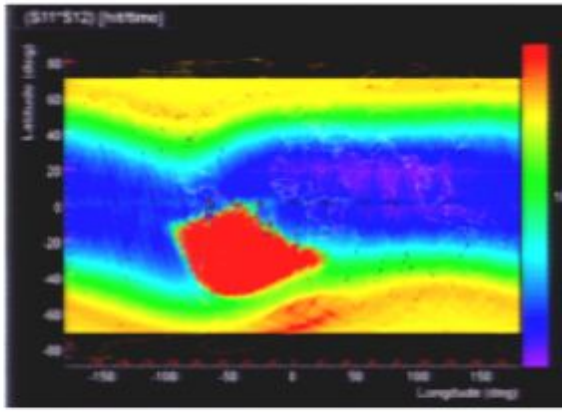

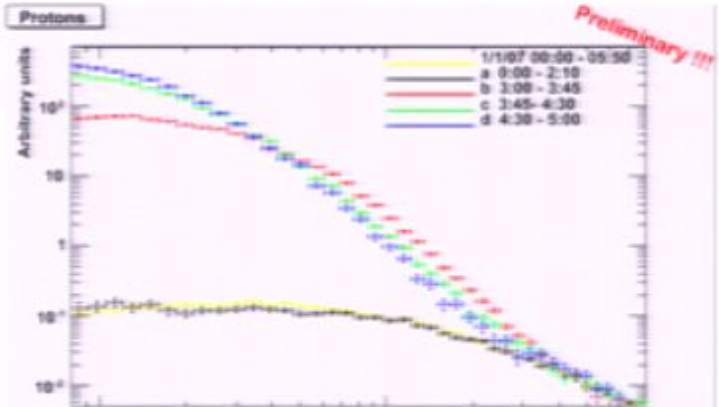

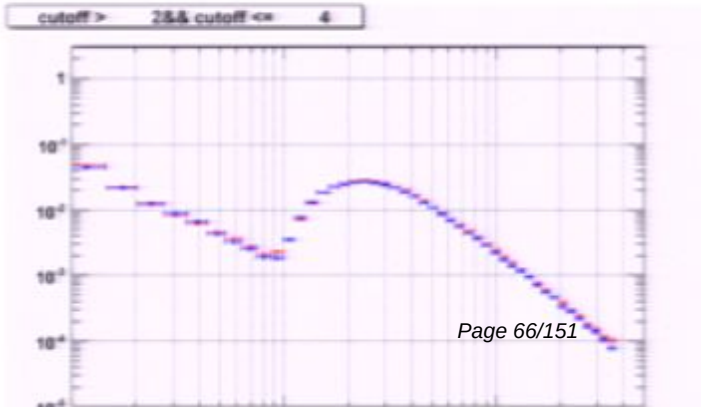

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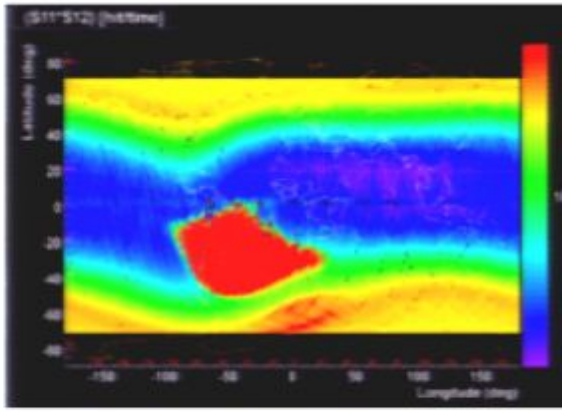

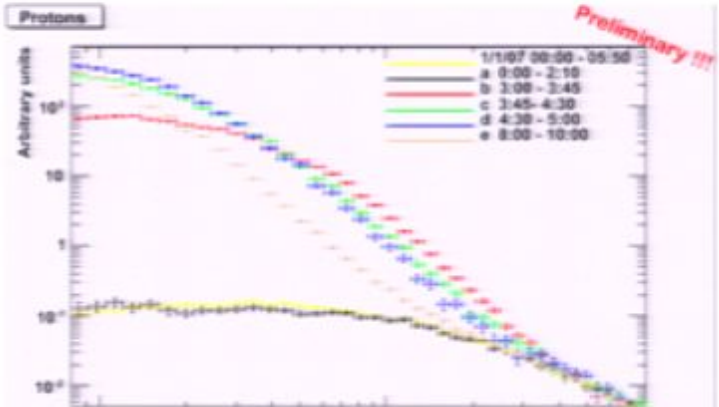

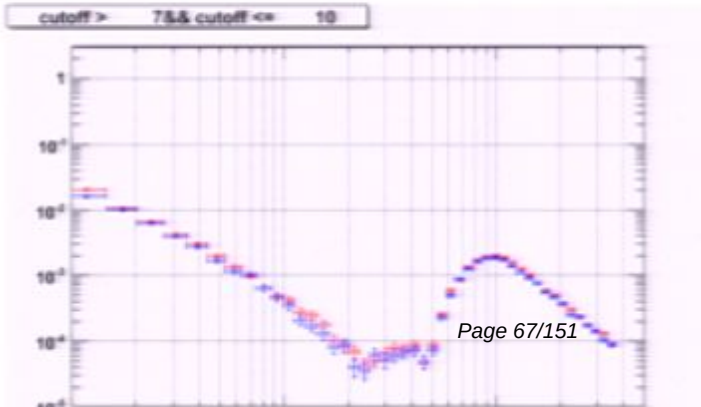

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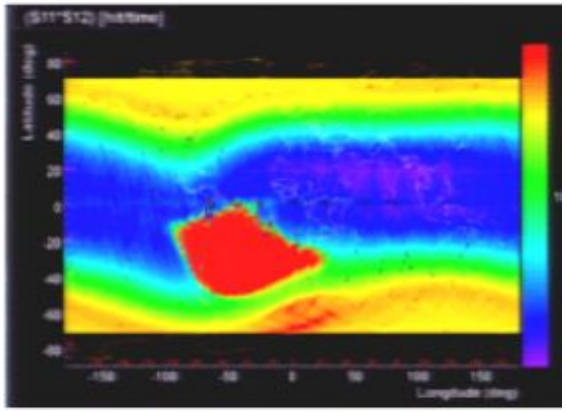

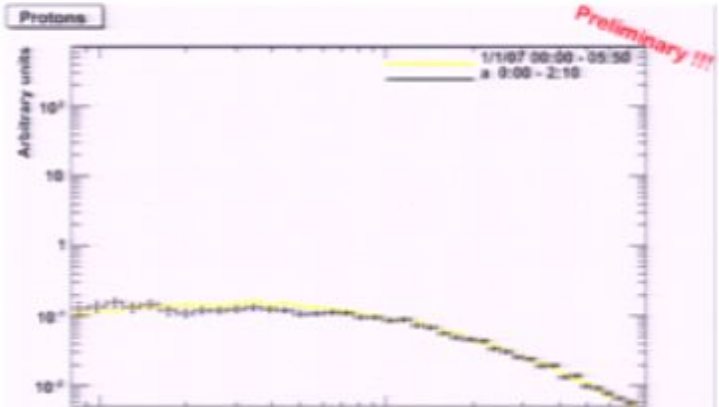

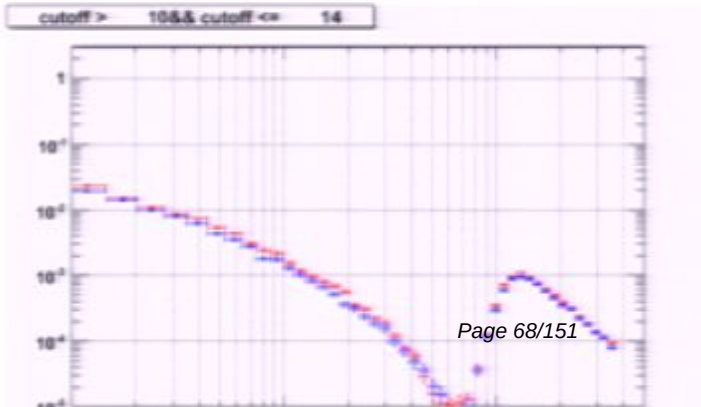

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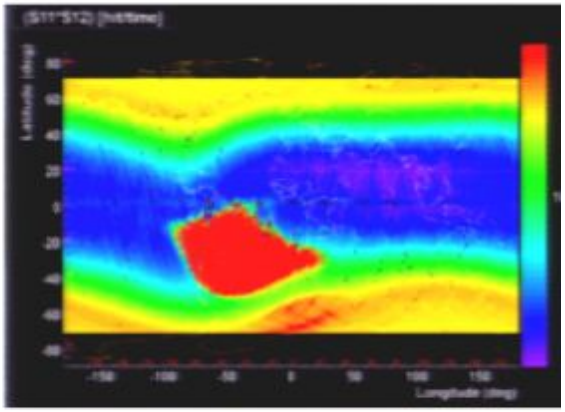

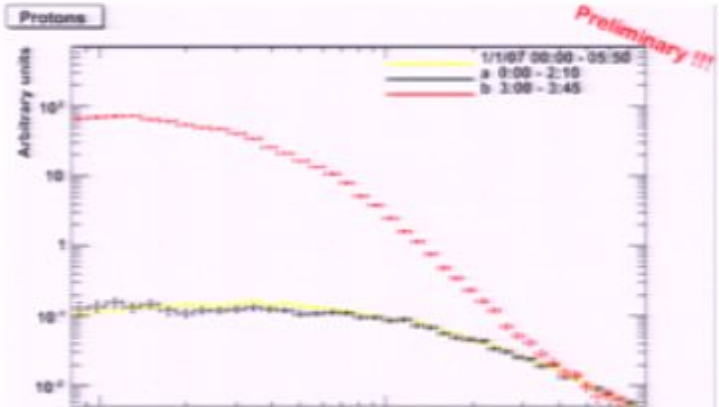

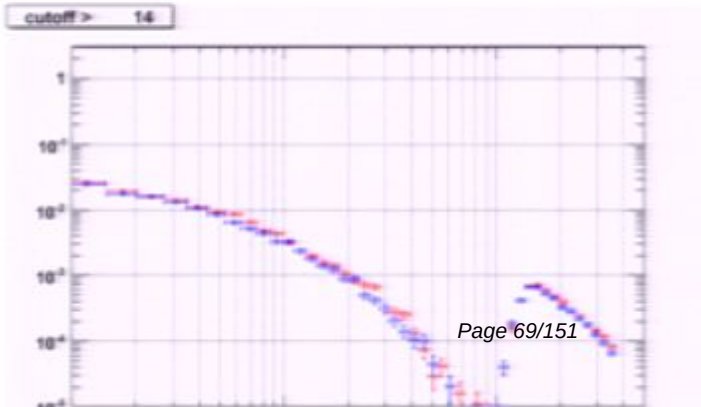

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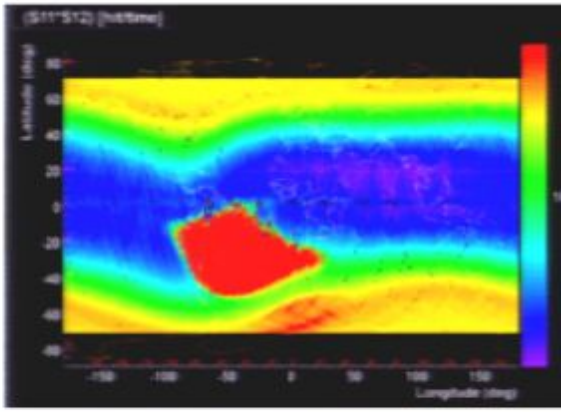

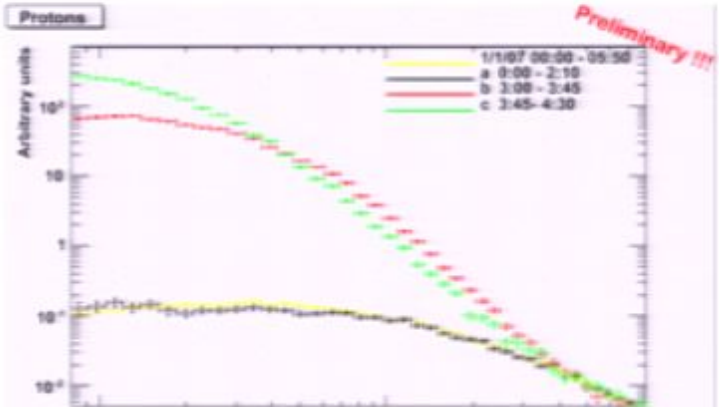

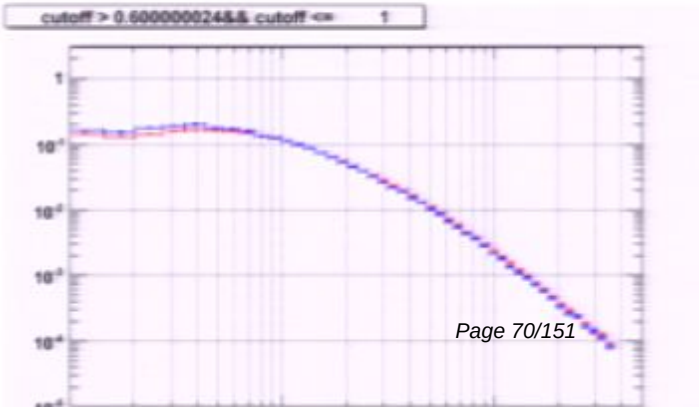

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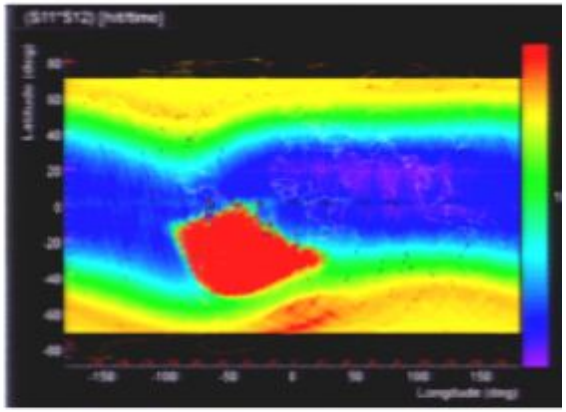

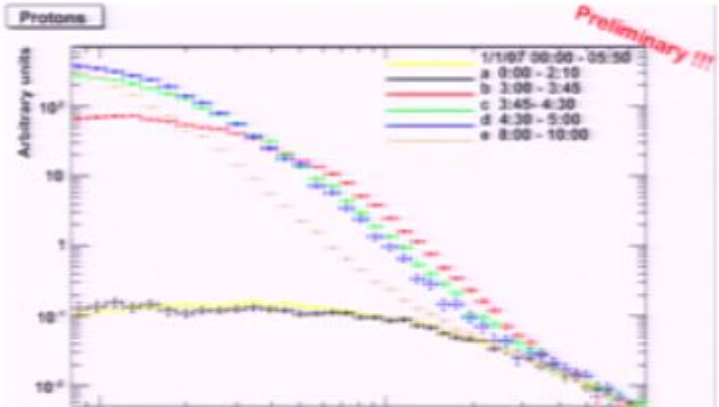

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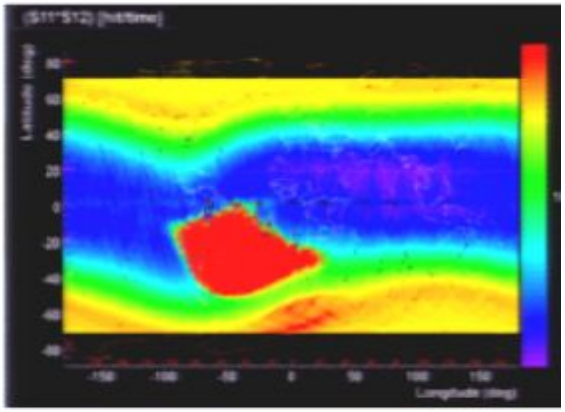

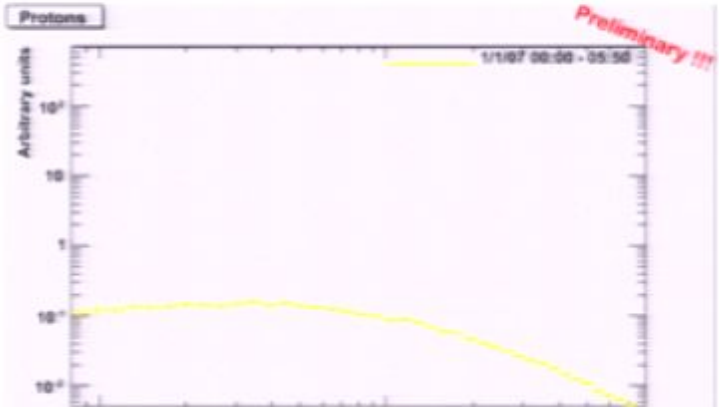

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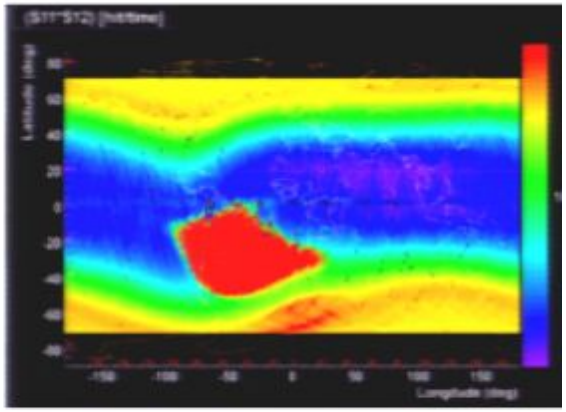

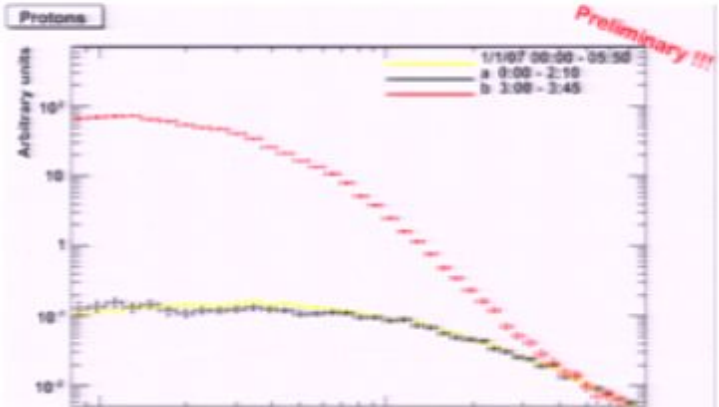

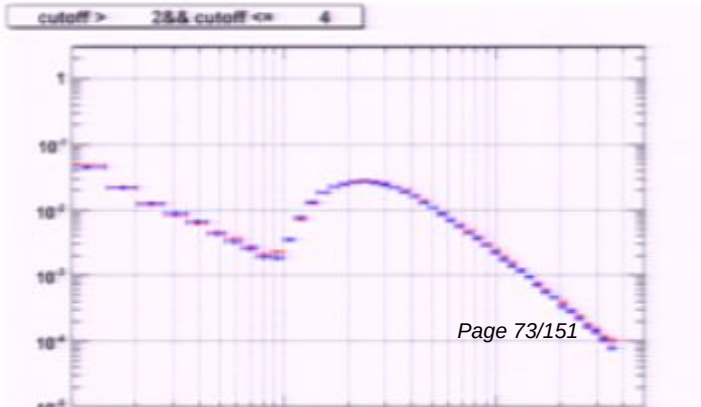

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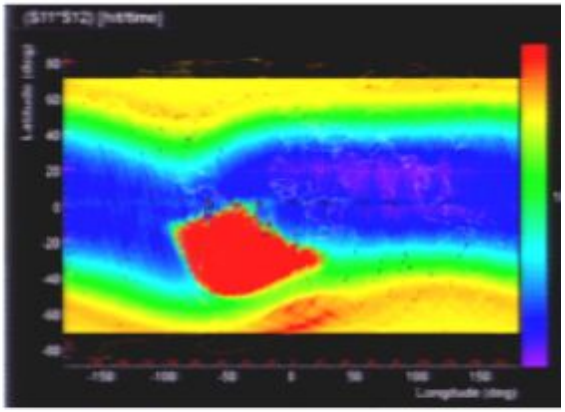

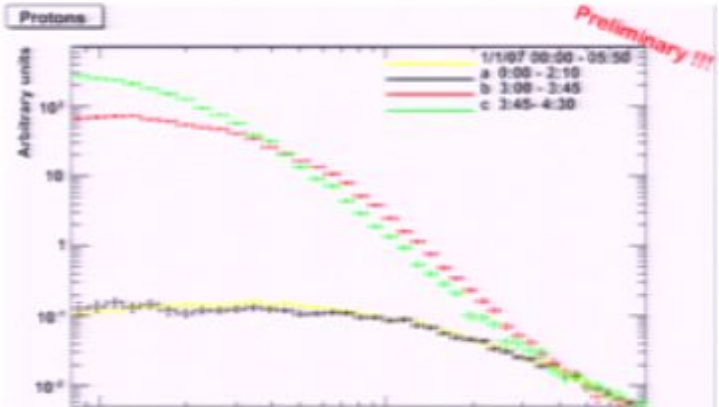

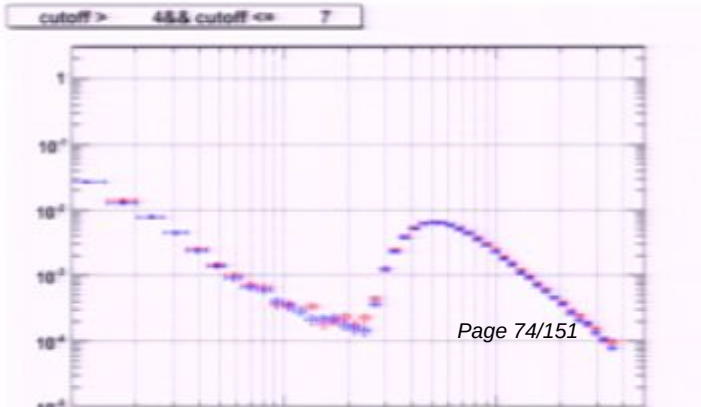

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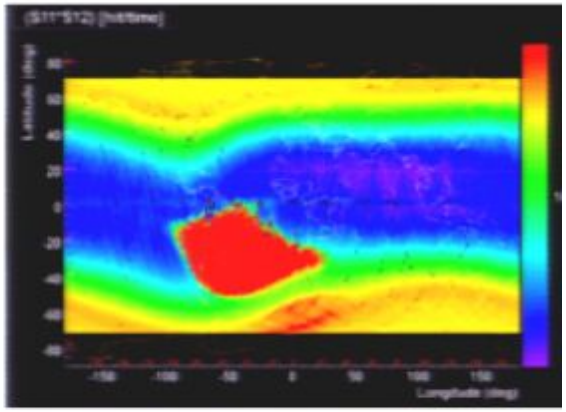

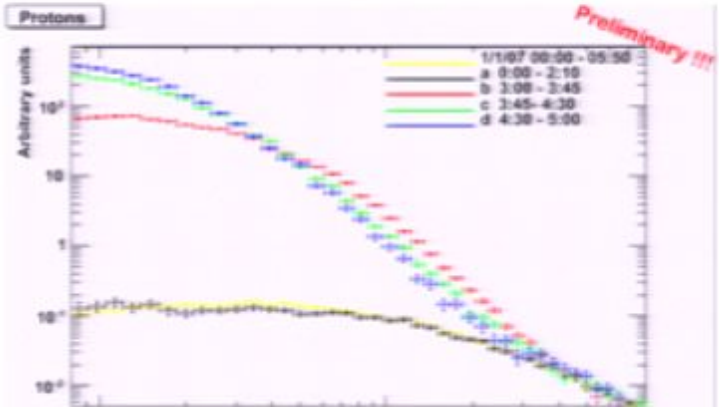

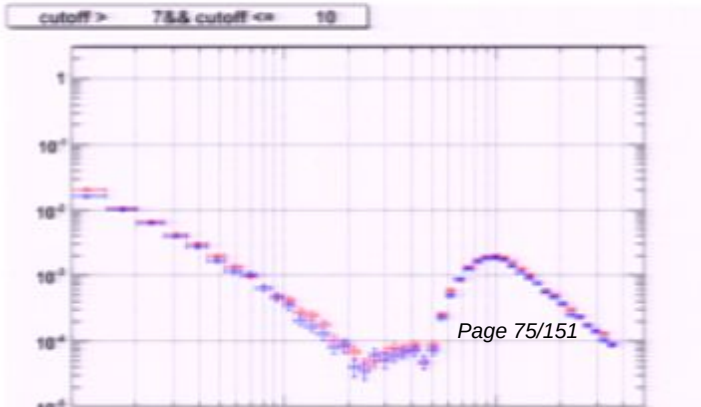

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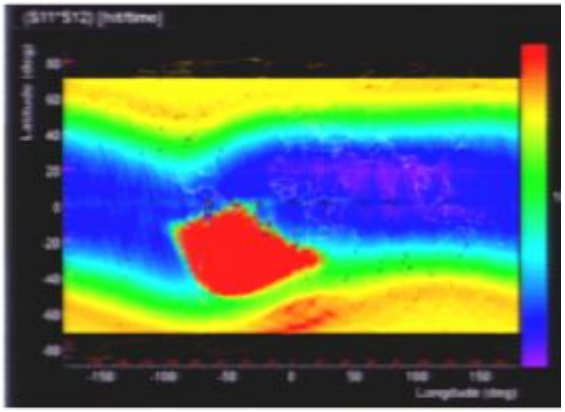

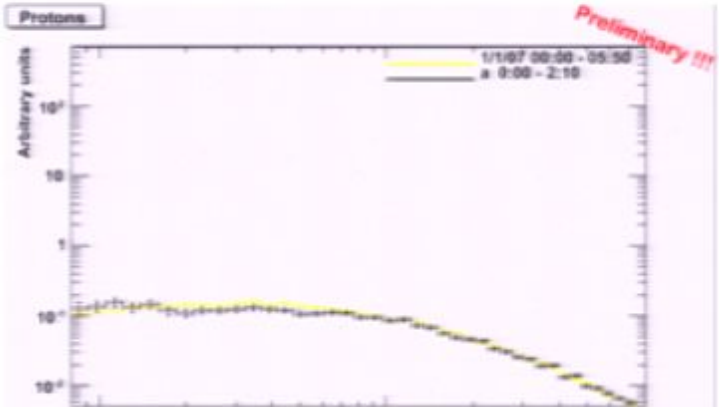

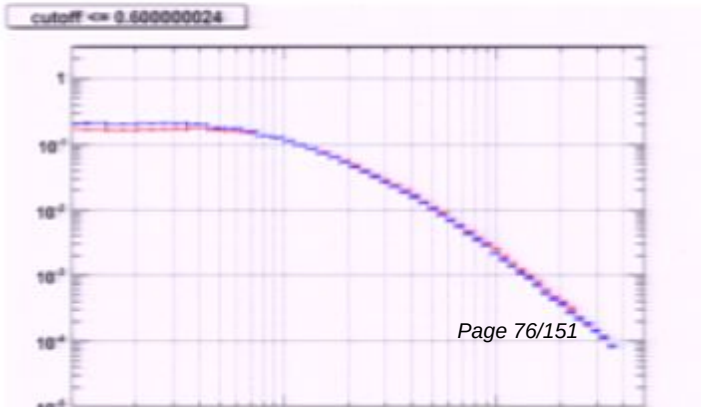

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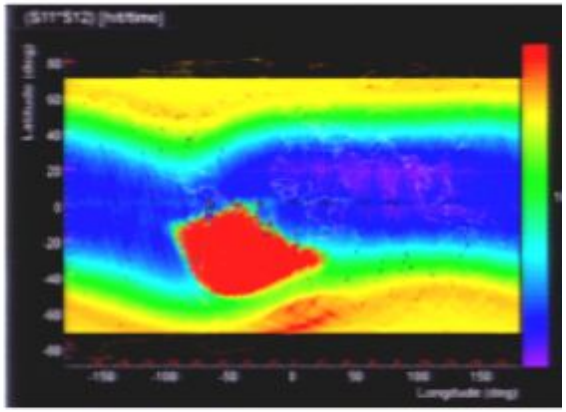

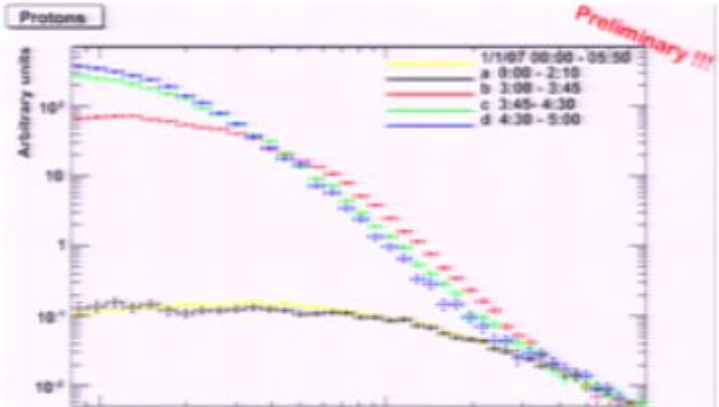

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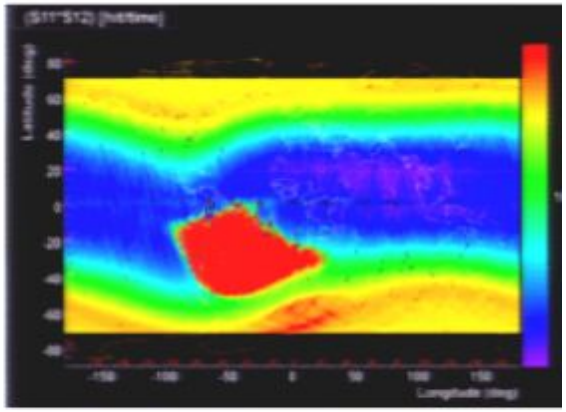

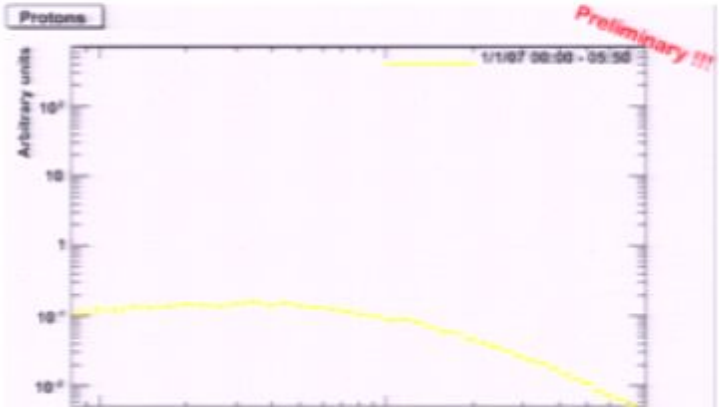

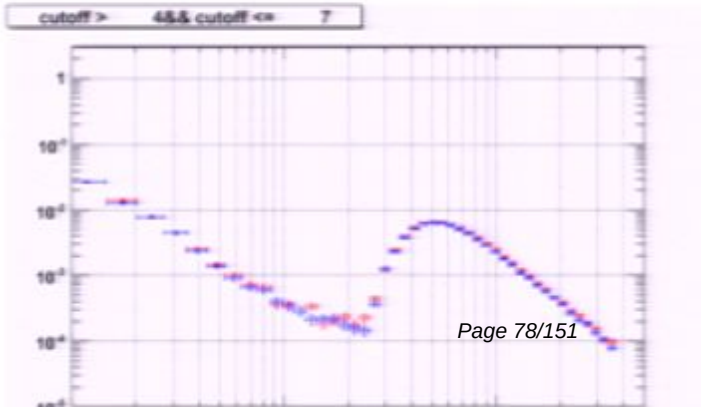

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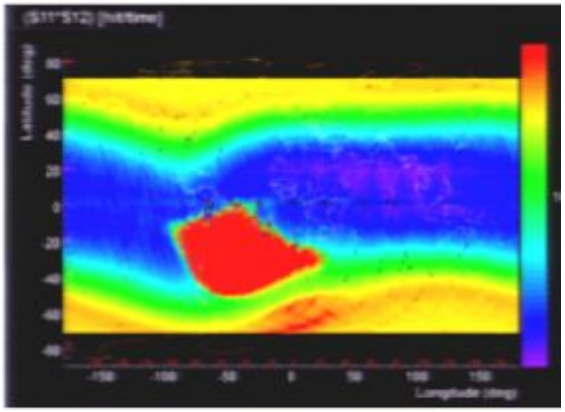

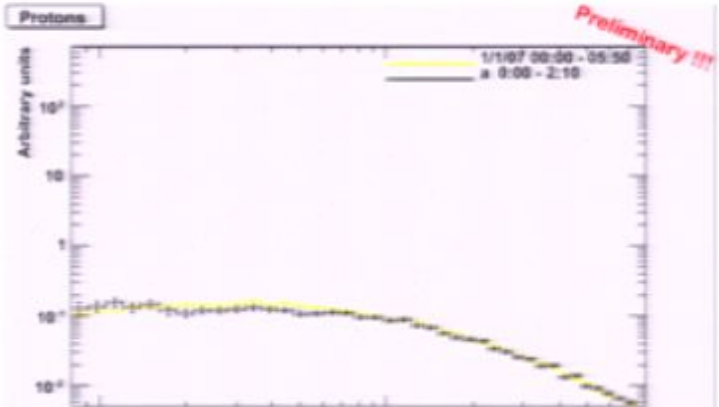

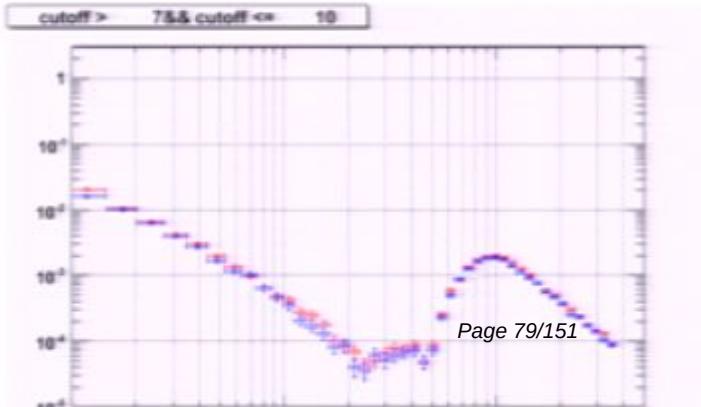

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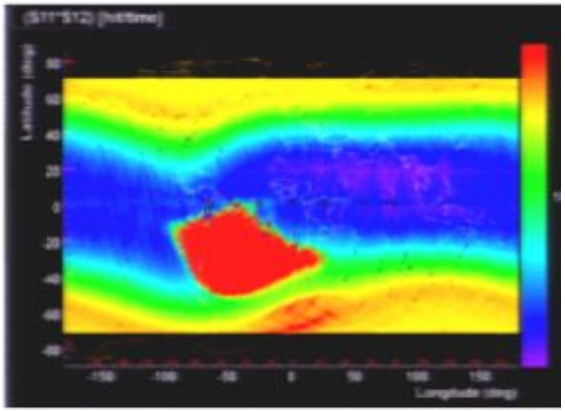

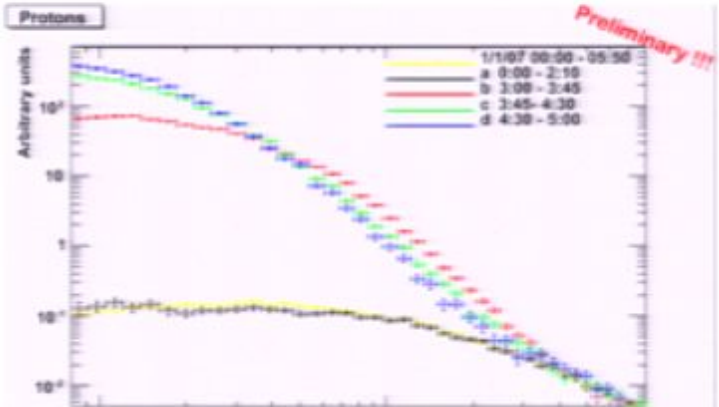

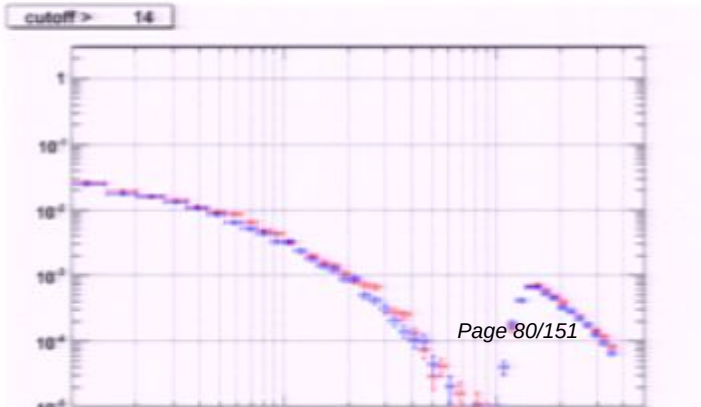

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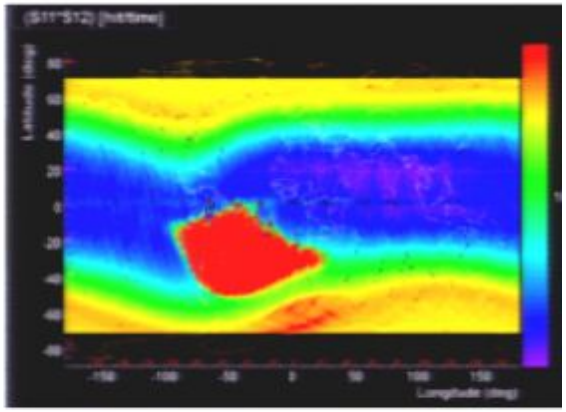

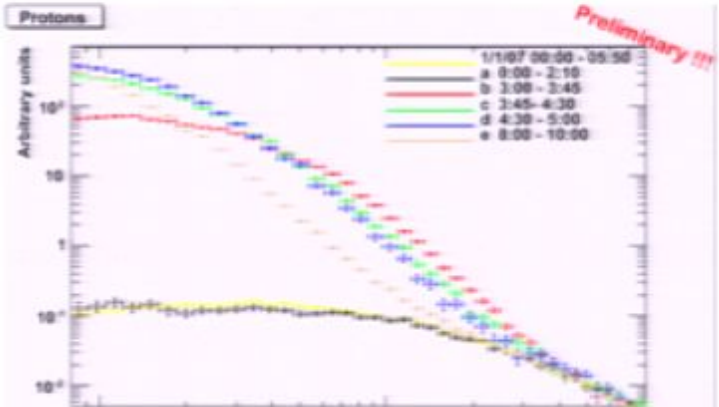

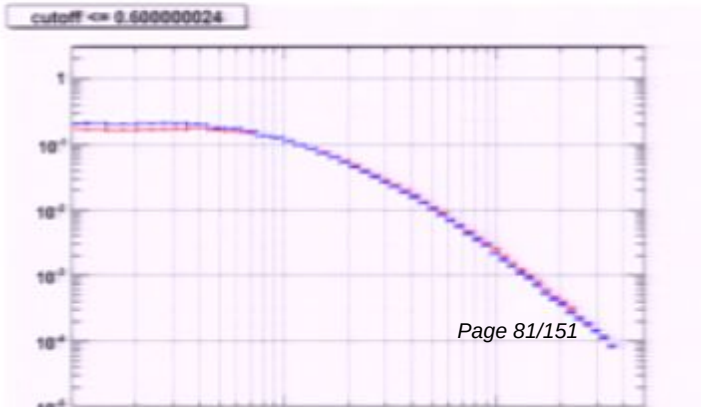

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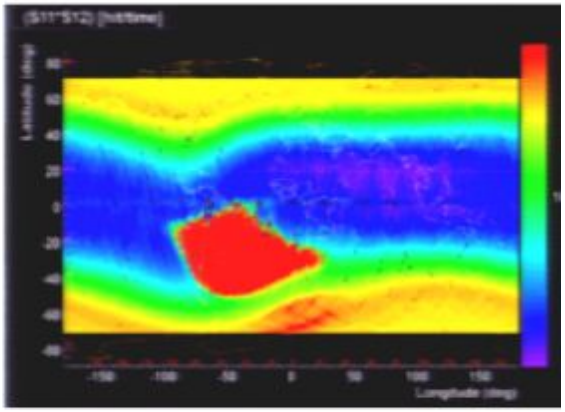

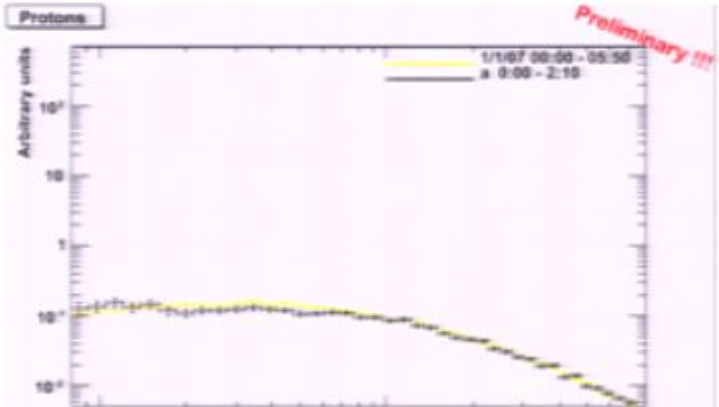

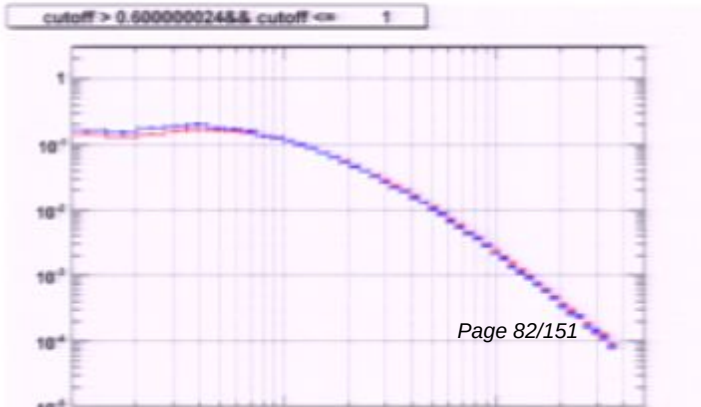

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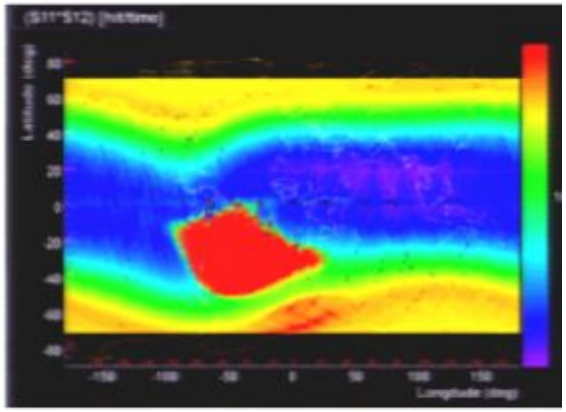

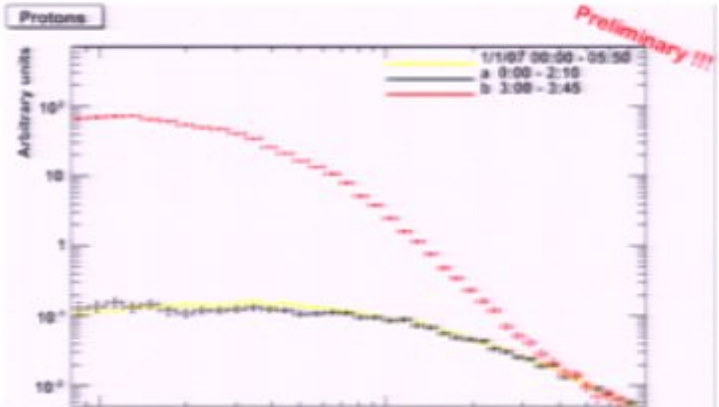

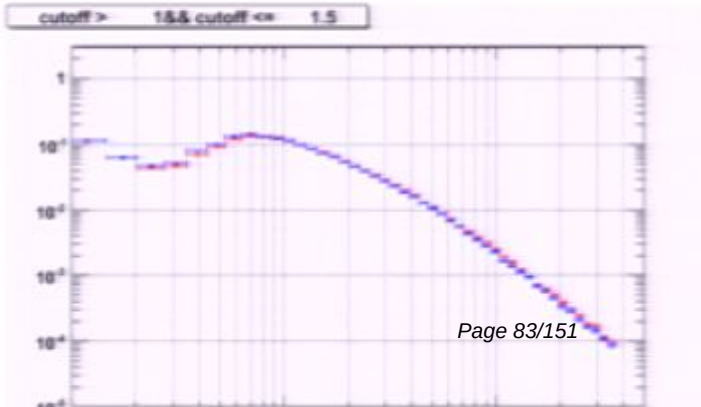

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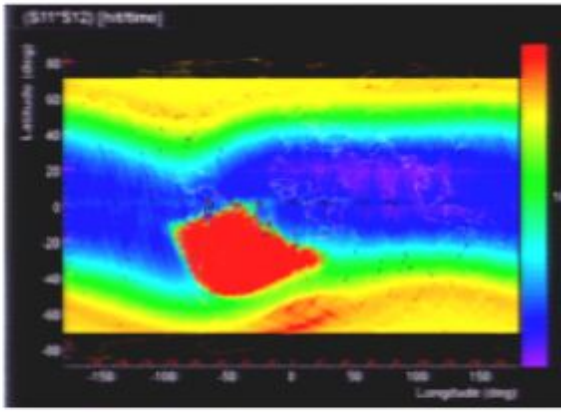
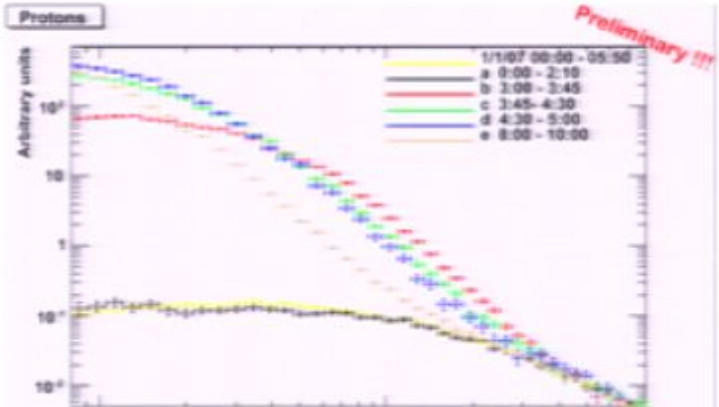
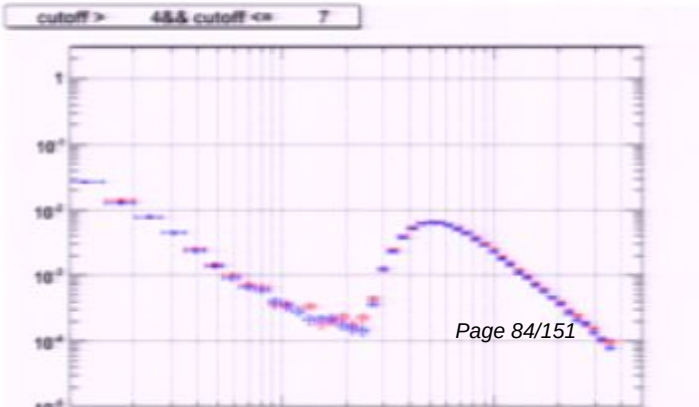


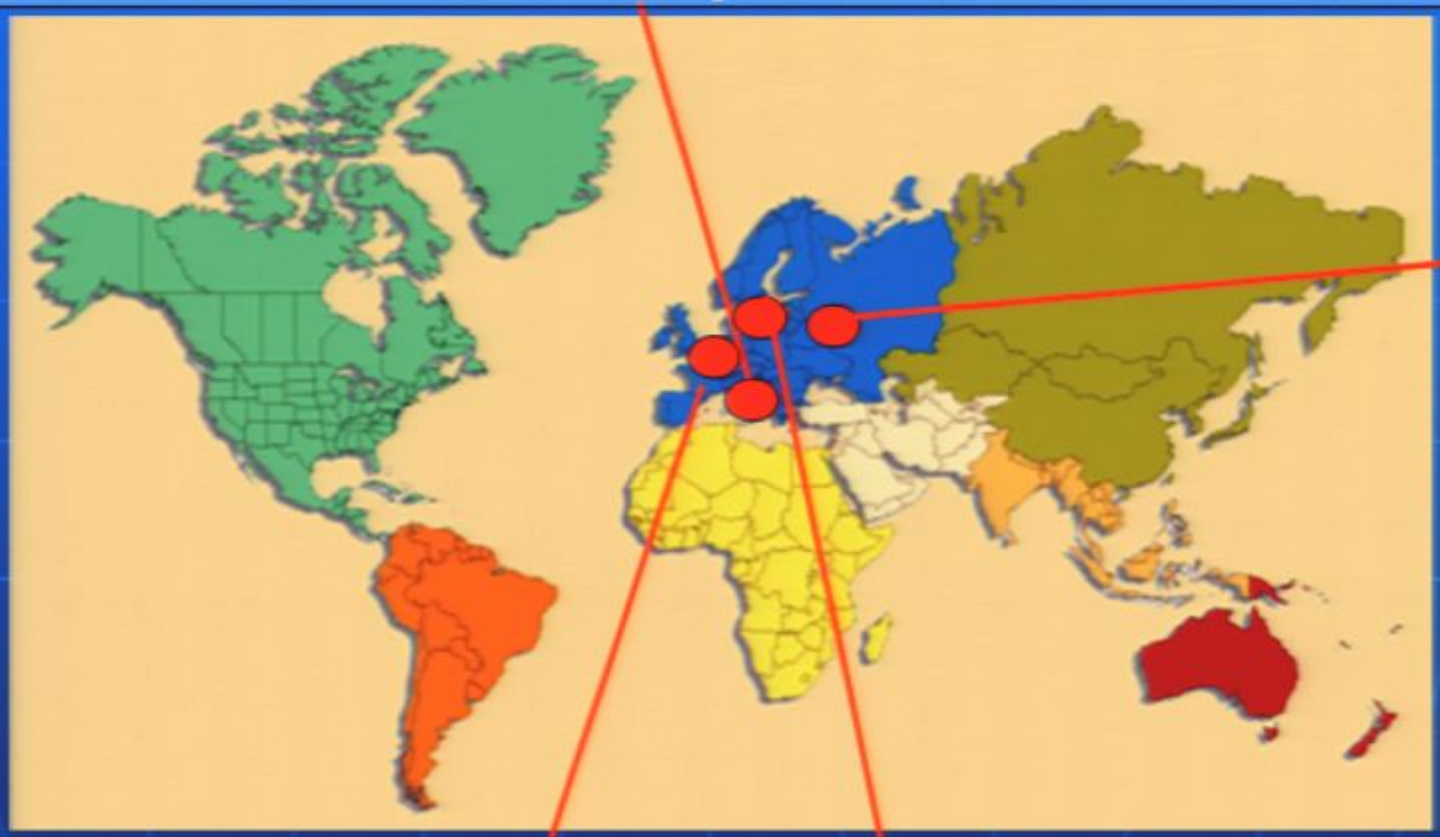




PAMELA Collaboration

Italy:

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



Russia:

Moscow
St. Petersburg

Germany:

Siegen

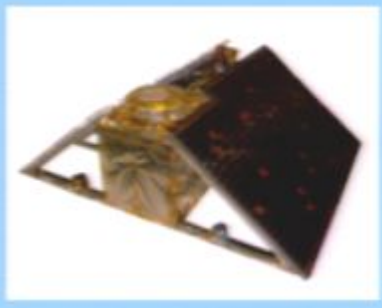
Sweden:

WiZard Russian Italian Missions (RIM)

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

NINA-1

NINA-2



PAMELA

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

..1989 · 1990 · 1991 · 1992 · 1993 · 1994 · 1995 · 1996 · 1997 · 1998 · 1999 · 2000 · 2001 · 2002 · 2003 · 2004 · 2005 · 2006 · 007..

SILEYE-1

NINA-1

NINA-2

SILEYE-2

Alteino-SILEYE-3

LAZIO-SIRAD

ALTEA-SILEYE-4

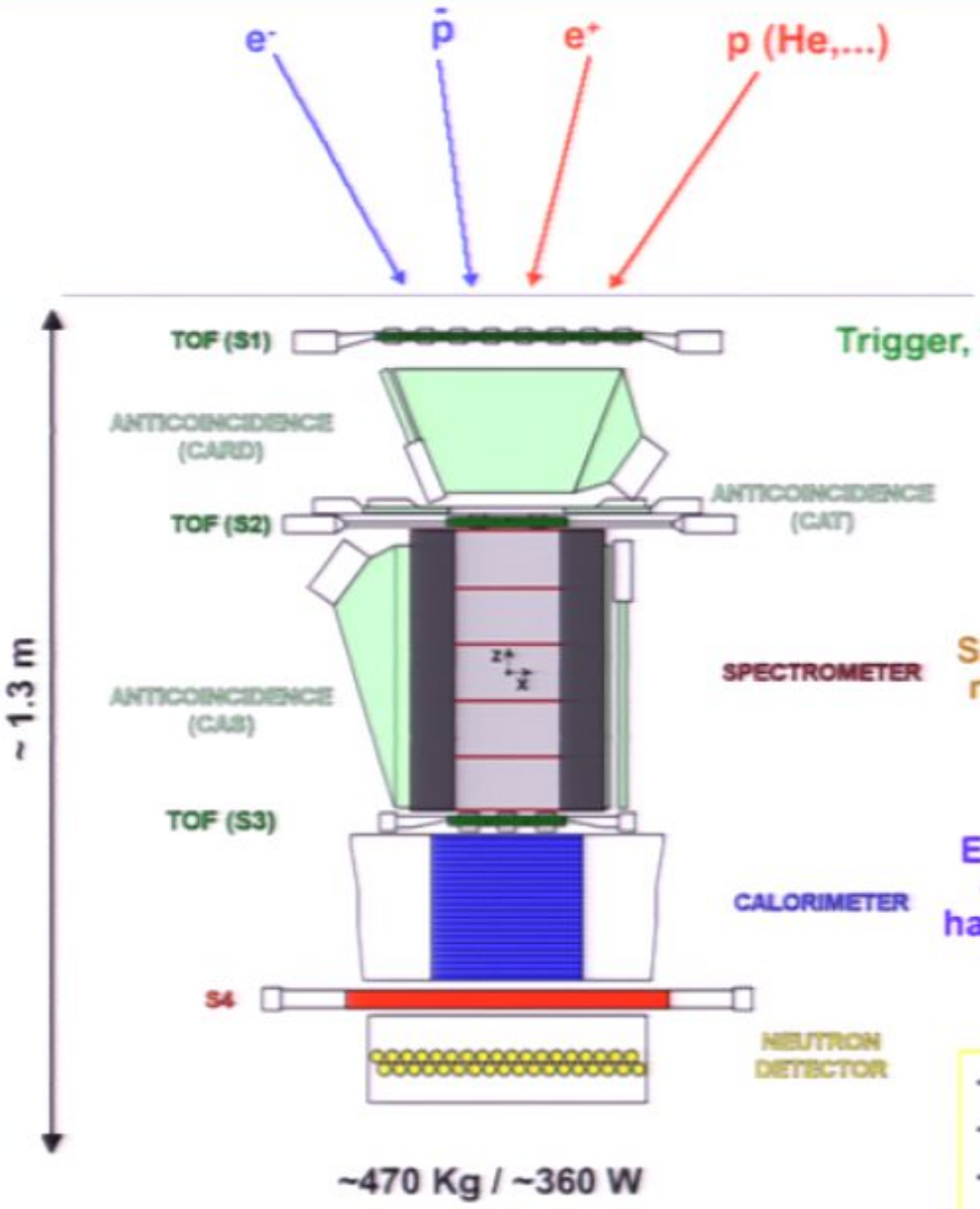
SILEYE-1

SILEYE-2

ALTEINO: SILEYE-3

LAZIO

ALTEA:



~470 Kg / ~360 W

Trigger, ToF, dE/dx

- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

Sign of charge, rigidity, dE/dx

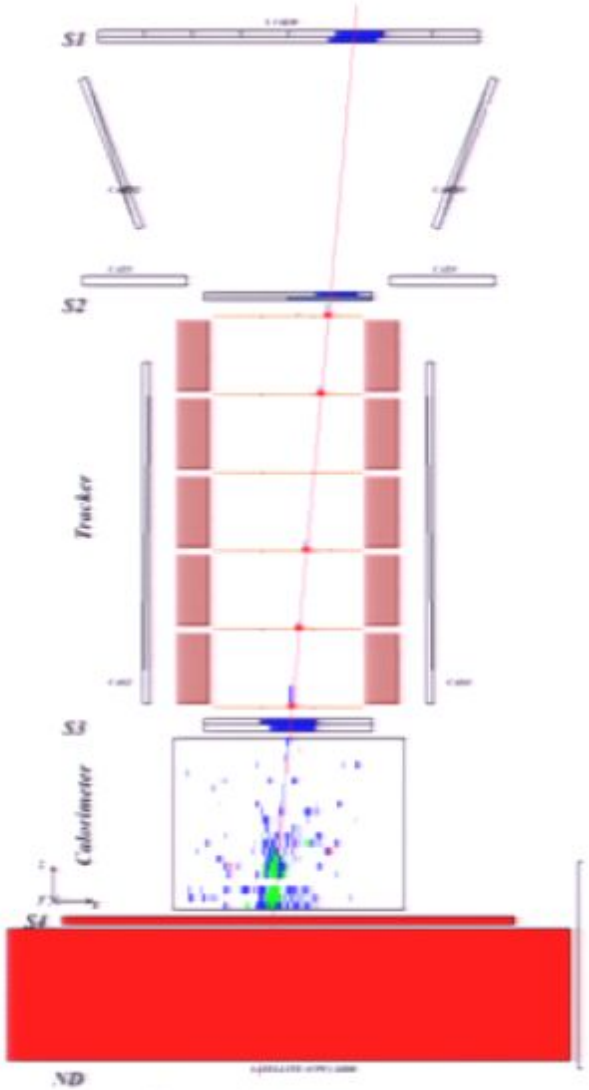
- Permanent magnet, 0.43 T
- 21.5 cm^2 sr
- 6 planes double-sided silicon strip detectors (300 μm)
- 3 μm resolution in bending view → MDR ~800 GV (6 plane) ~500 GV (5 plane)

Electron energy, dE/dx, lepton-hadron separation

- 44 Si-x / W / Si-y planes (380)
- 16.3 X0 / 0.6 L
- dE/E ~5.5 % (10 - 300 GeV)
- Self trigger > 300 GeV / 600 cm^2 sr

- 36 ^{3}He counters
- ^{3}He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

Antiproton / positron identification



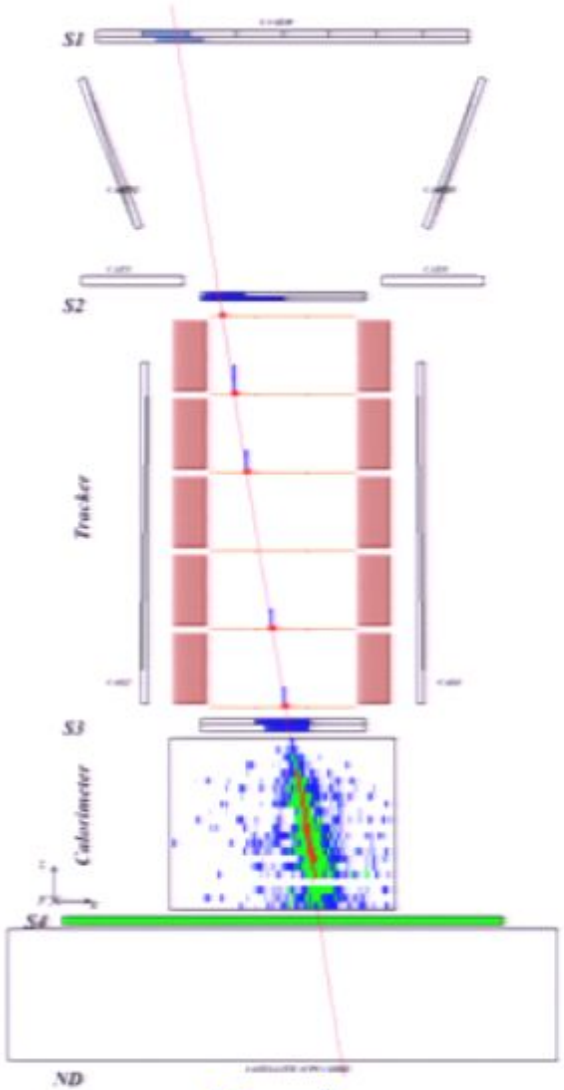
Antiproton
(NB: $e^-/\bar{p} \sim 10^2$)

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

Bending in spectrometer: sign of charge

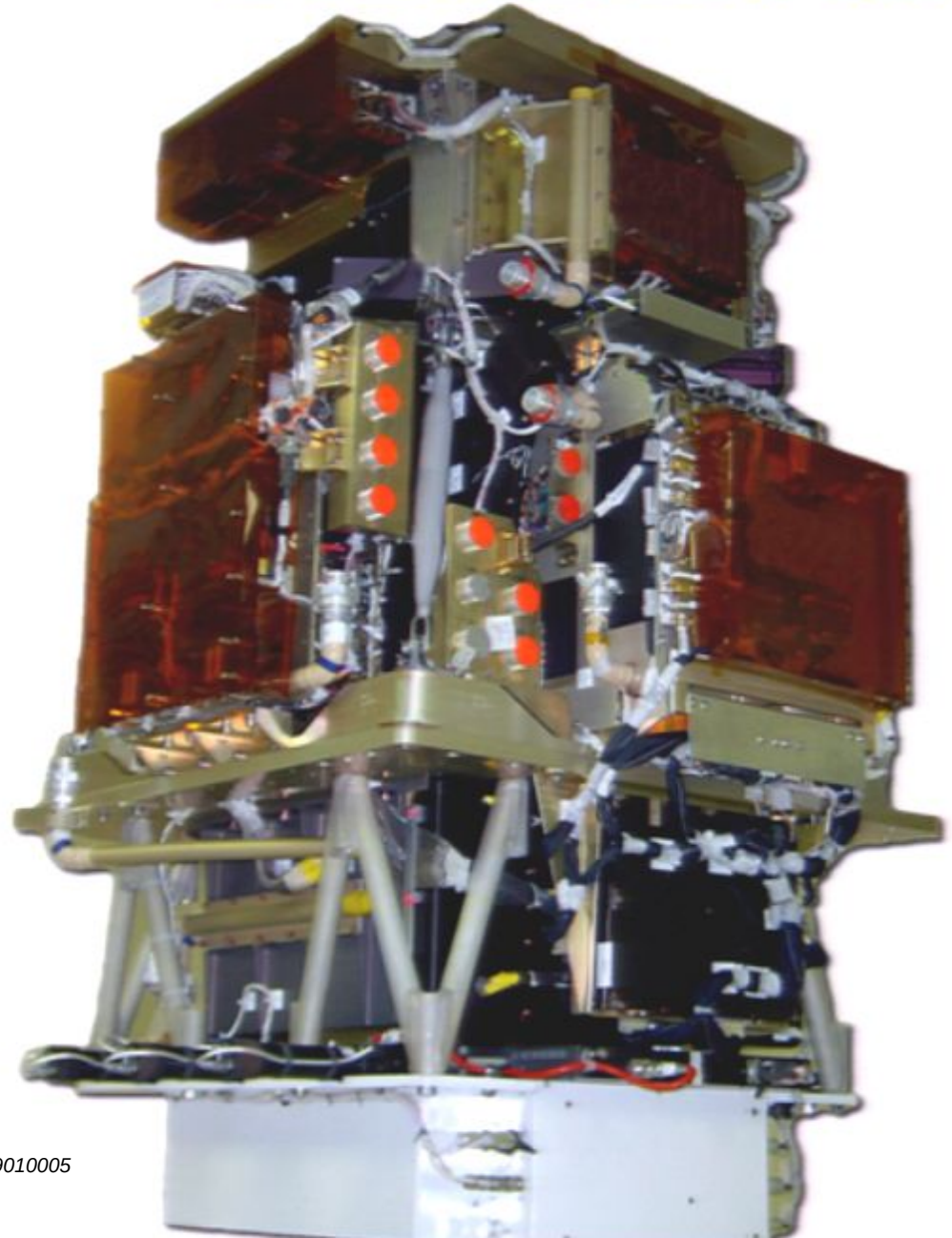
Ionisation energy loss (dE/dx): magnitude of charge

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



Positron
(NB: $p/e^+ \sim 10^{2-4}$)

PAMELA Instrument



GF ~21.5 cm^2sr

Mass: 470 kg

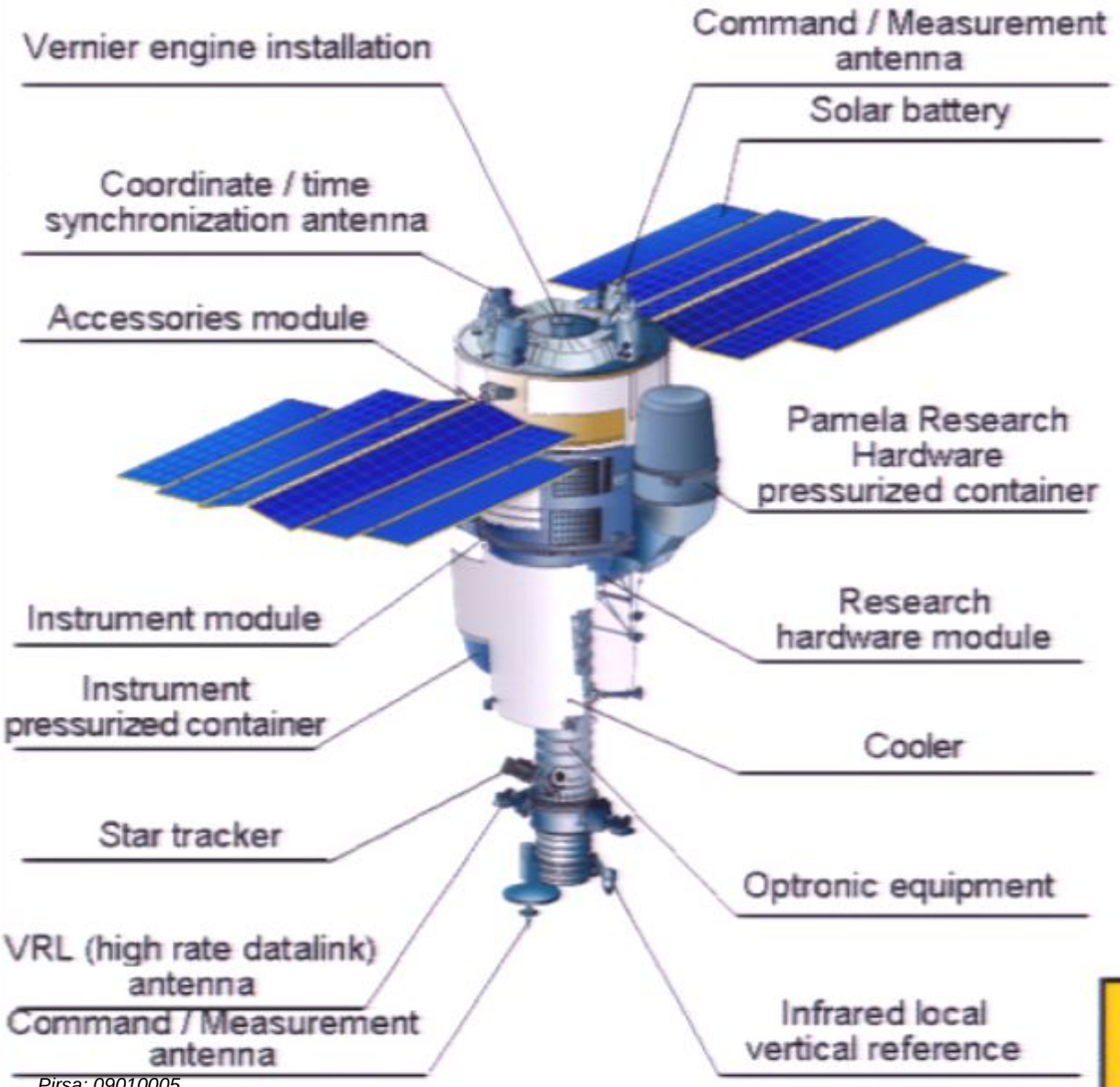
Size: 130x70x70 cm^3

Design Performance

Energy range	
Antiprotons	80 MeV - 150 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 $\overline{\text{He}}/\text{He}$

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

Resurs-DK1 satellite



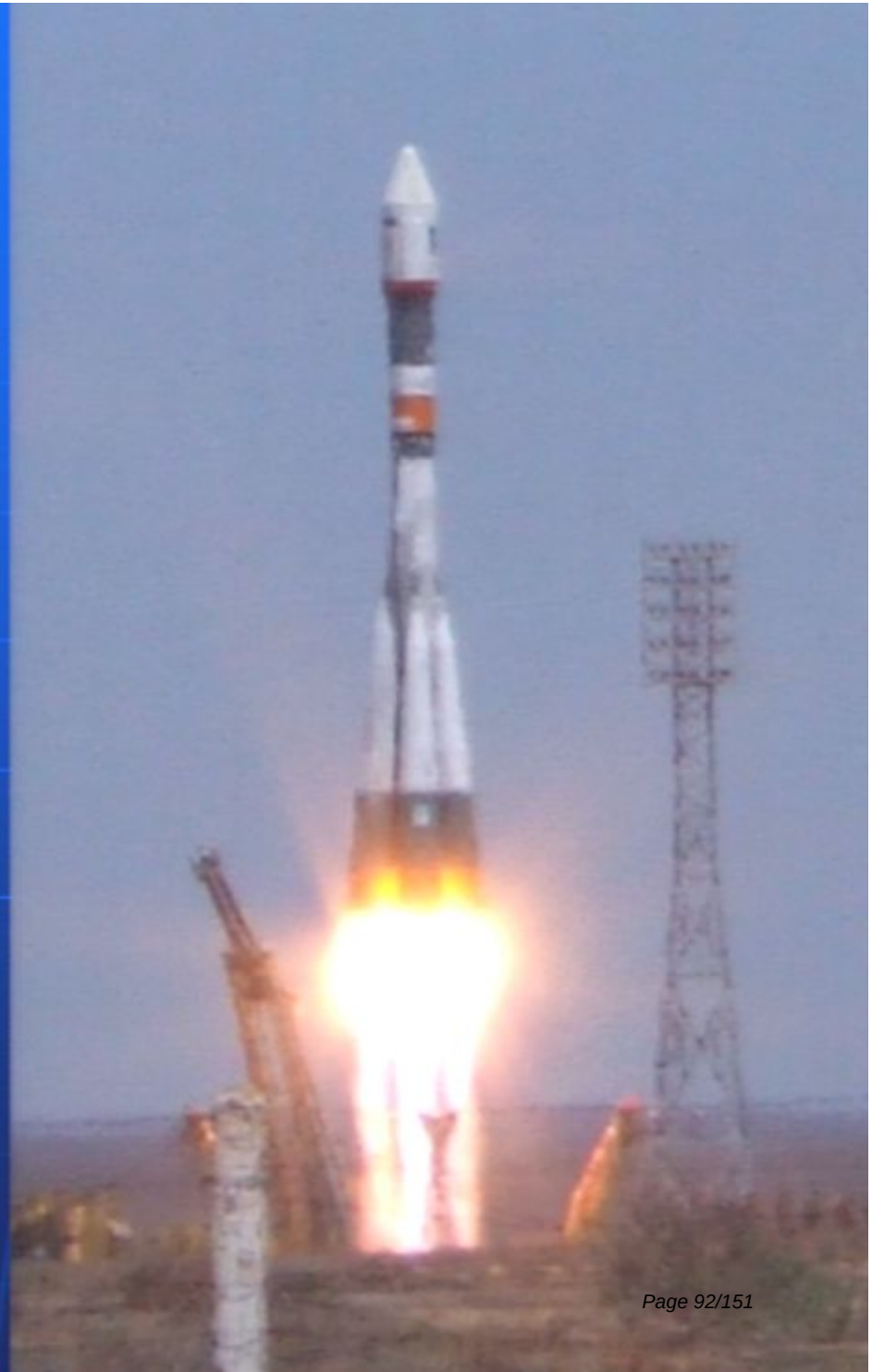
- **Main task**: multi-spectral remote sensing of earth's surface
- Built by TsSKB Progress in Samara, Russia
- **Lifetime >3 years (assisted)**
- Data transmitted to ground via high-speed radio downlink
- **PAMELA mounted inside a pressurized container**

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

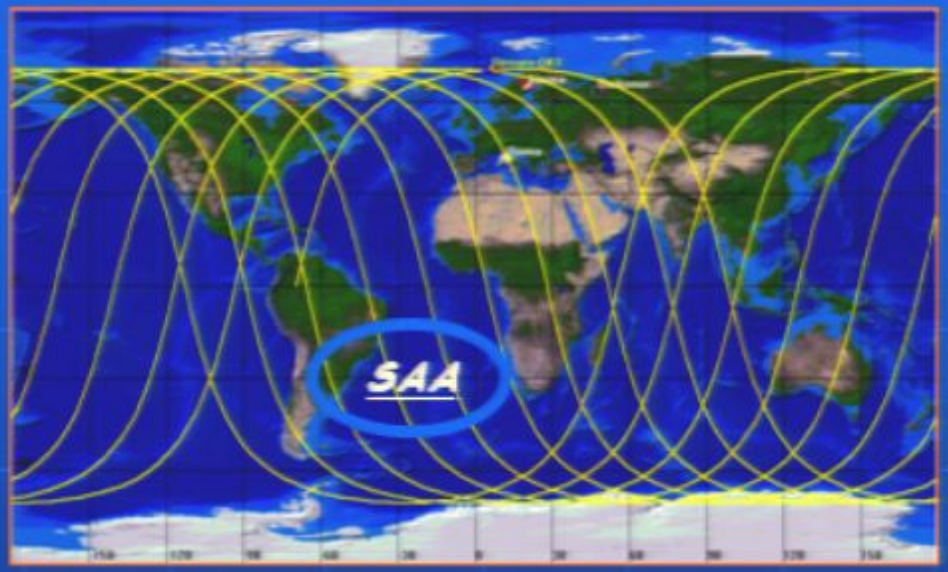
PAMELA

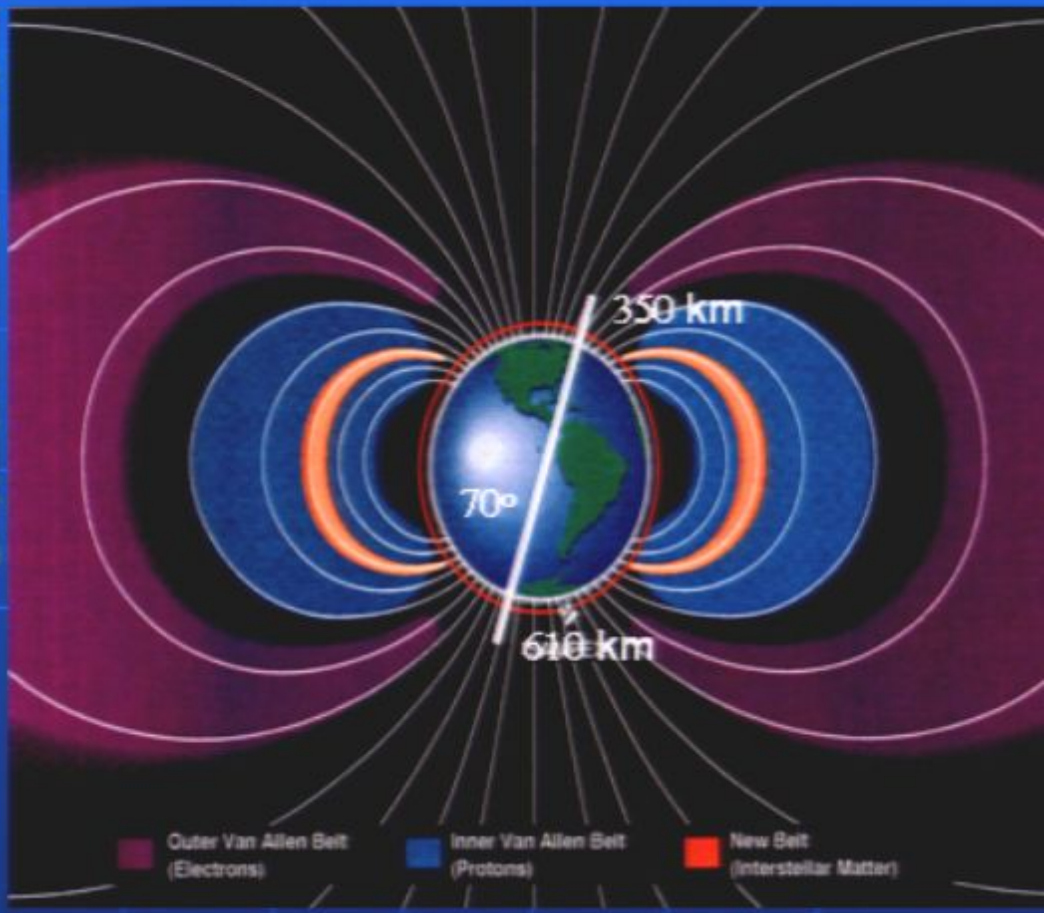
Launch 15/06/06

16 Gigabytes trasmitted daily to Ground NTsOMZ Moscow



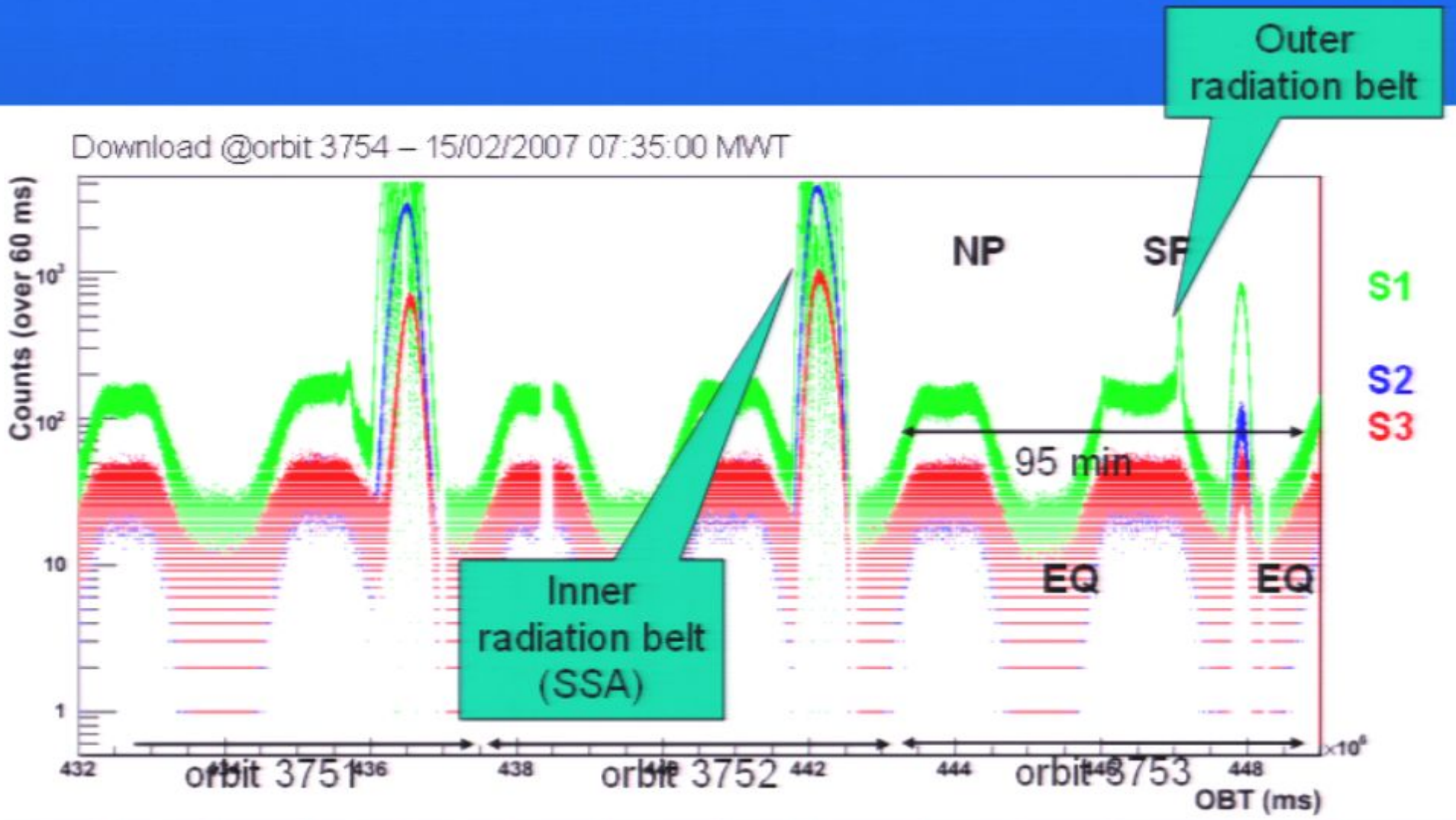
Orbit Characteristics

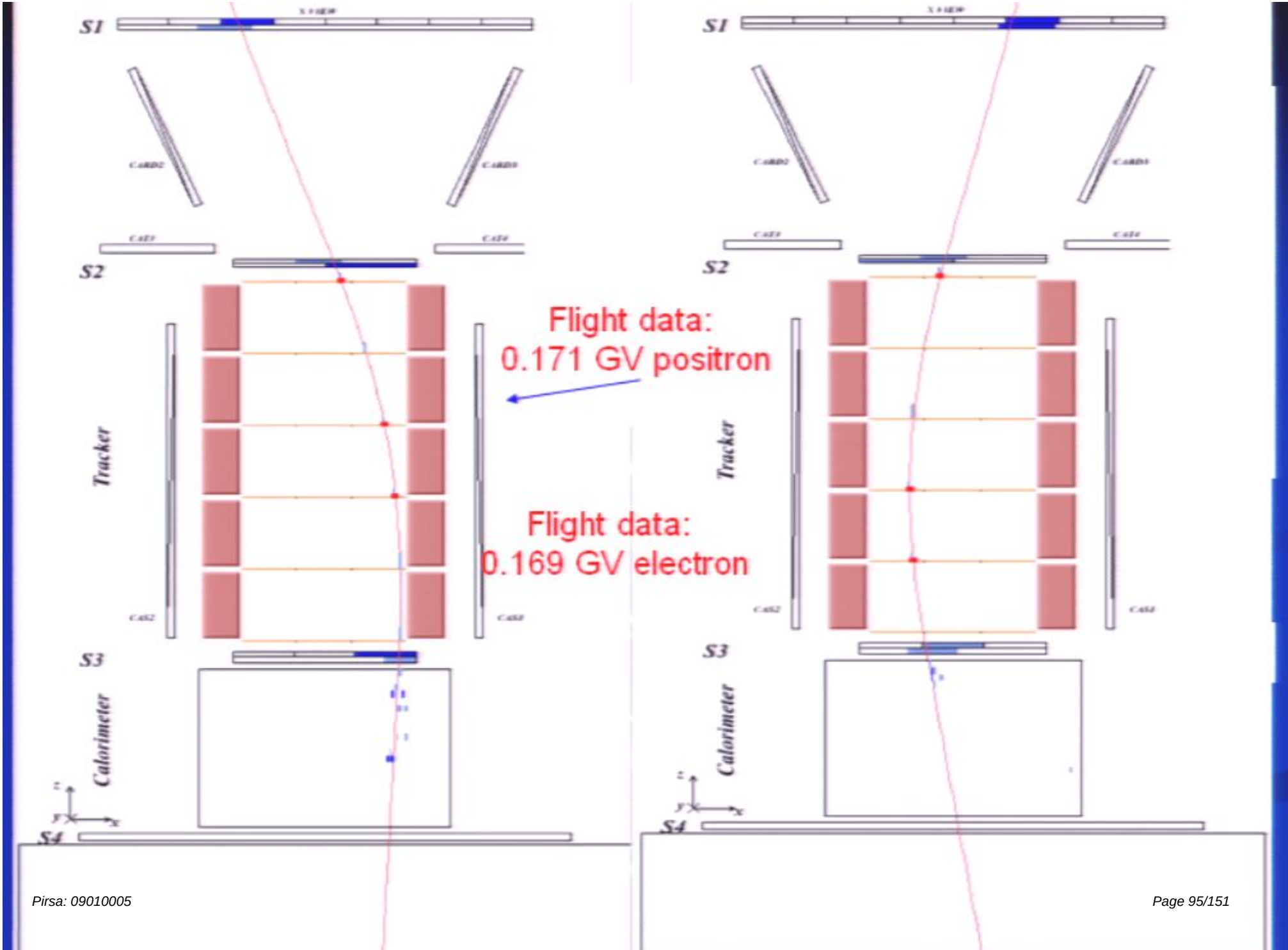


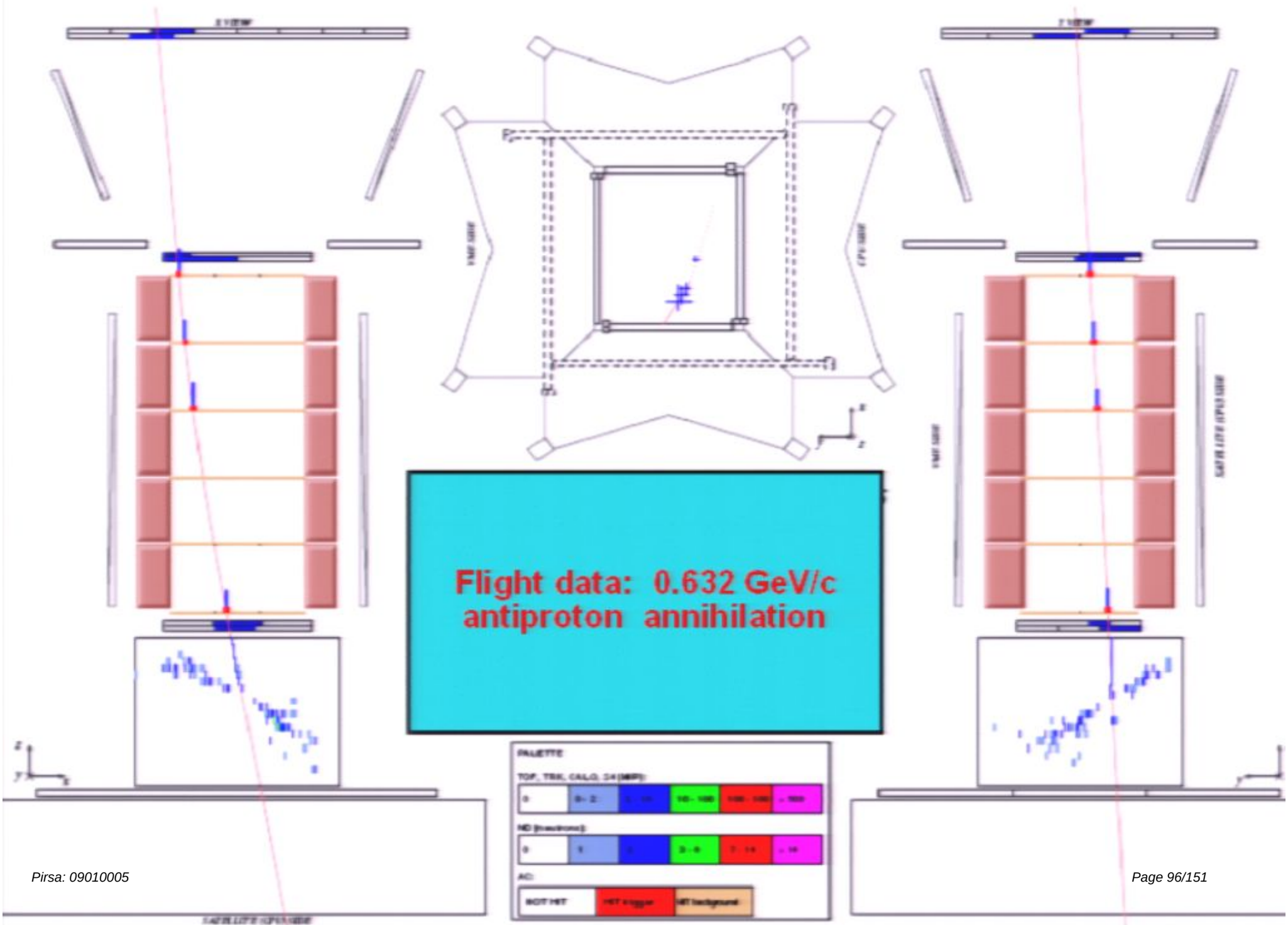


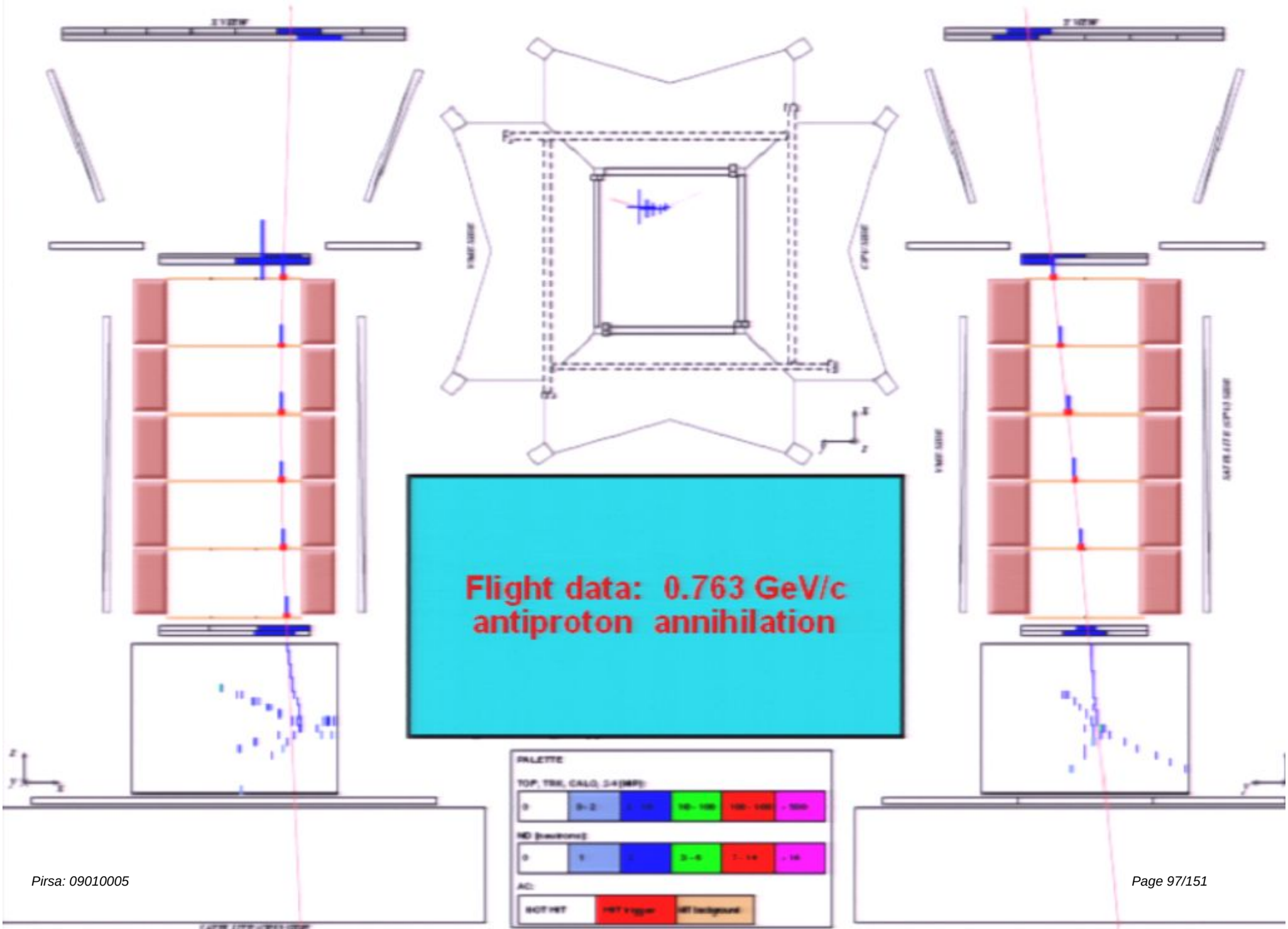
- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70° inclination)
- SAA crossed

PAMELA Orbit




S1
S2
S3
S4
Tracker
Calorimeter
Flight data:
0.171 GV positron
Flight data:
0.169 GV electron

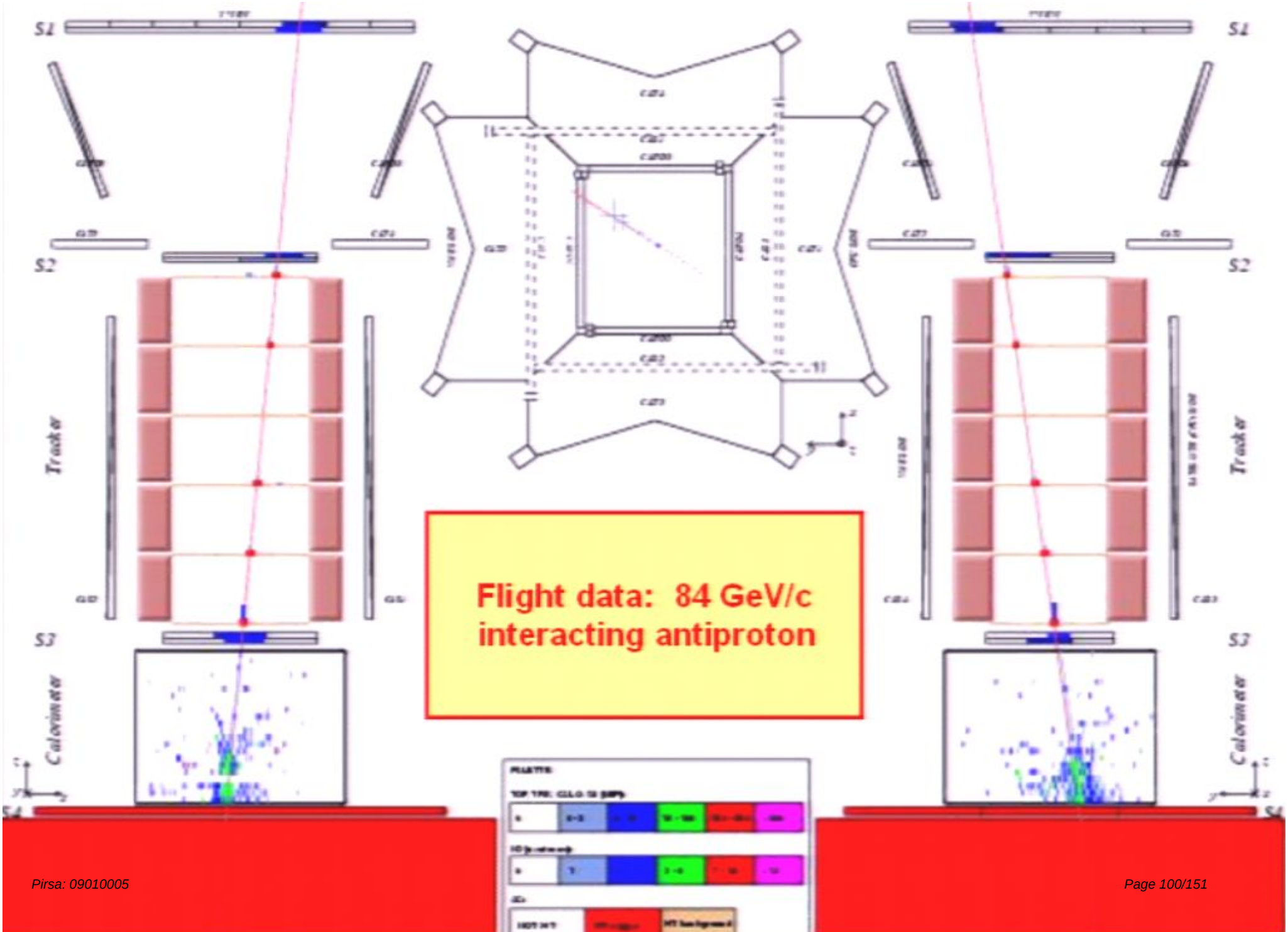

Flight data: 0.632 GeV/c
antiproton annihilation


Flight data: 0.763 GeV/c
antiproton annihilation

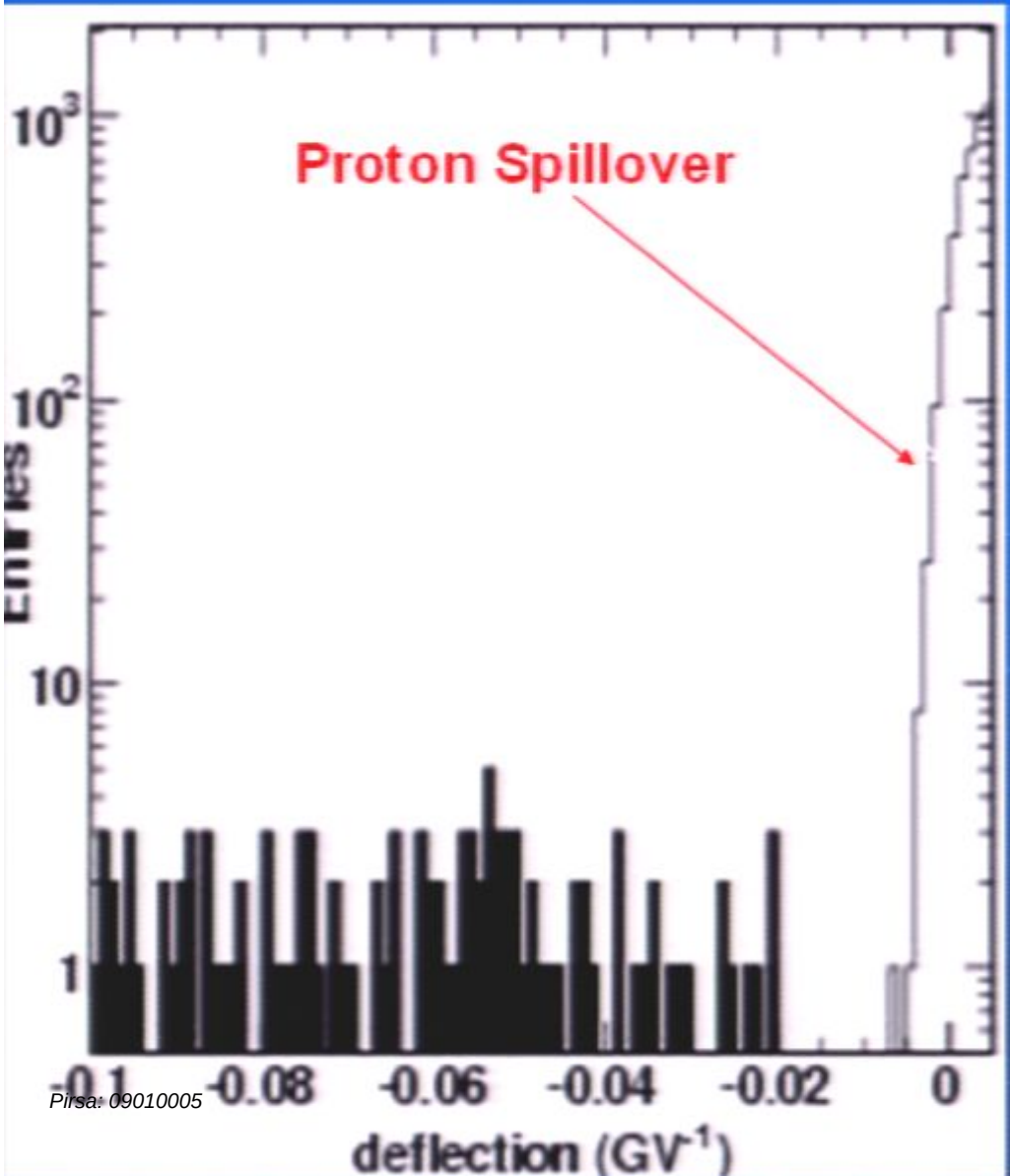
PAMELA Status

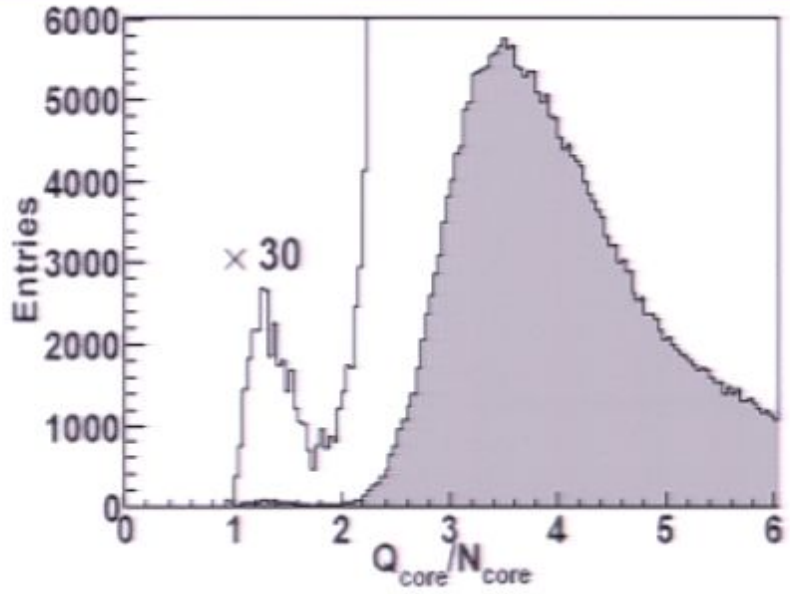
- ~700 days of data taking (~73% live-time)
- ~12 TBytes of raw data downlinked
- $>10^9$ triggers recorded and under analysis

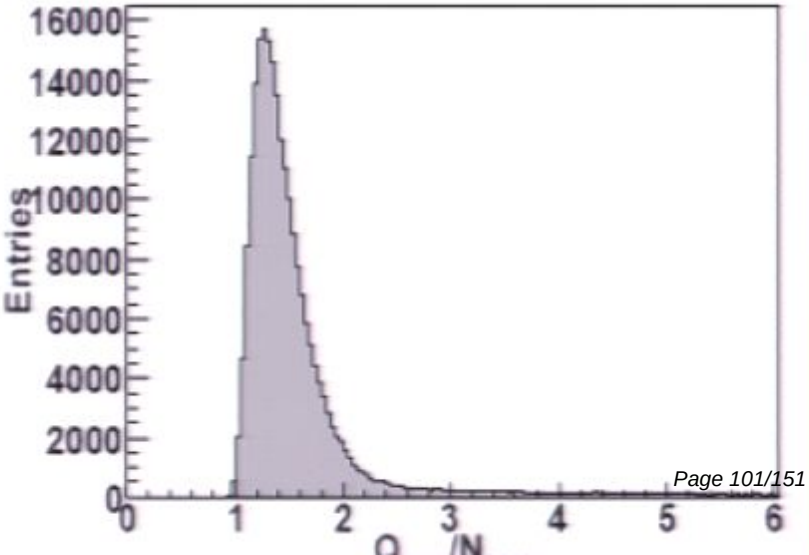
Antiprotons


S1
S2
Tracker
S3
Calorimeter
S4
Flight data: 84 GeV/c
interacting antiproton

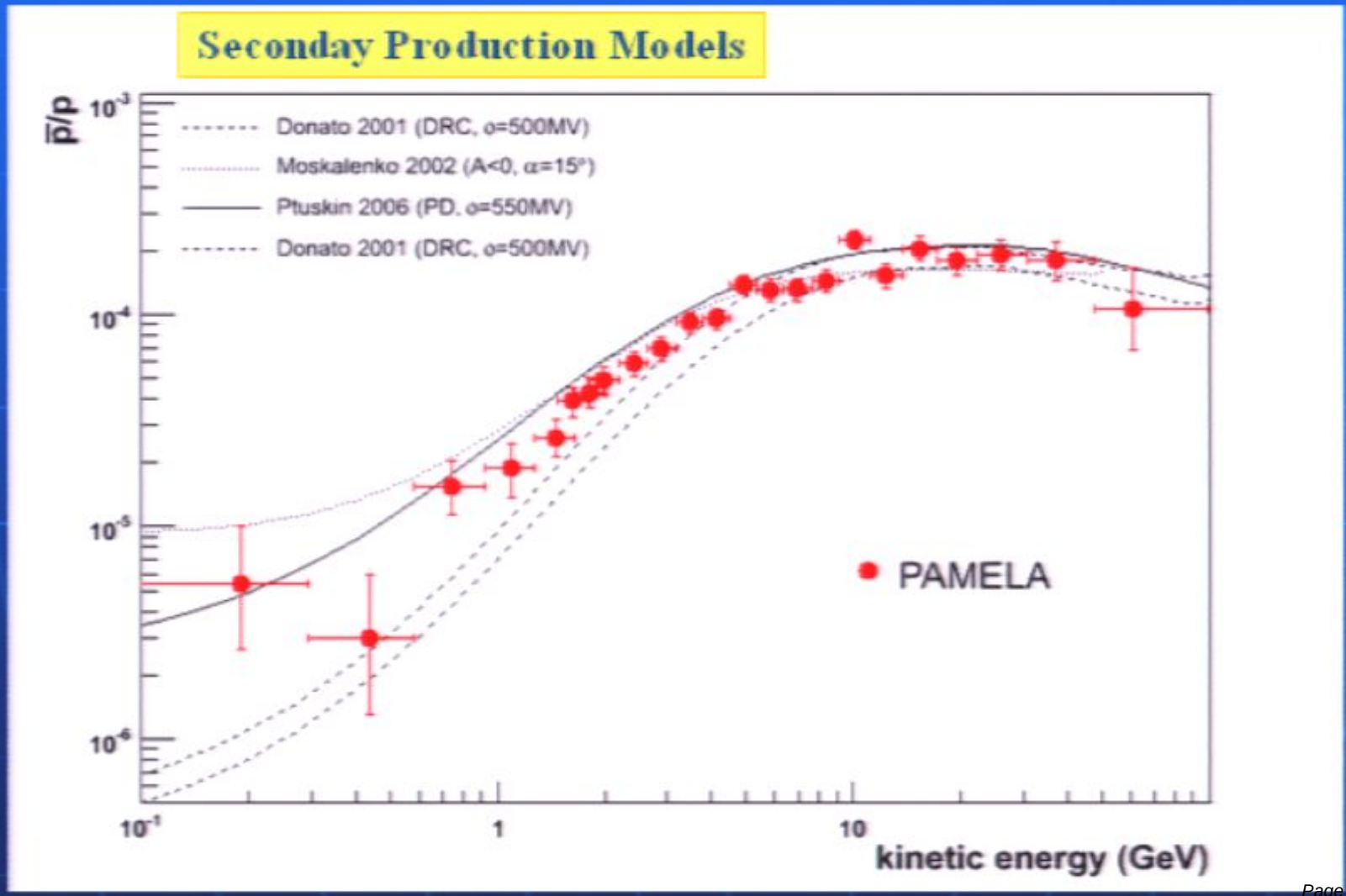
PAMELA antiproton discrimination





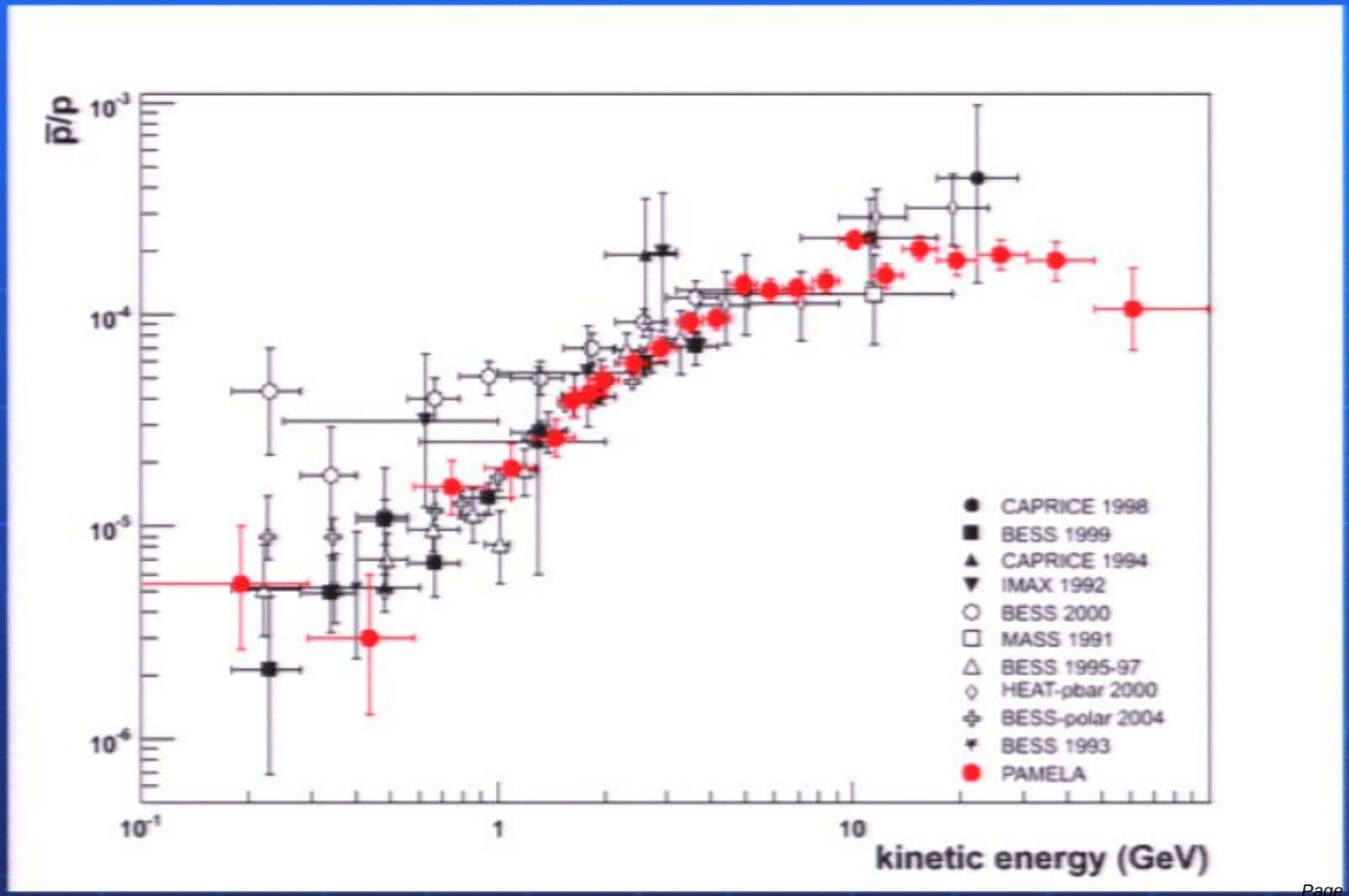


Antiproton to proton ratio

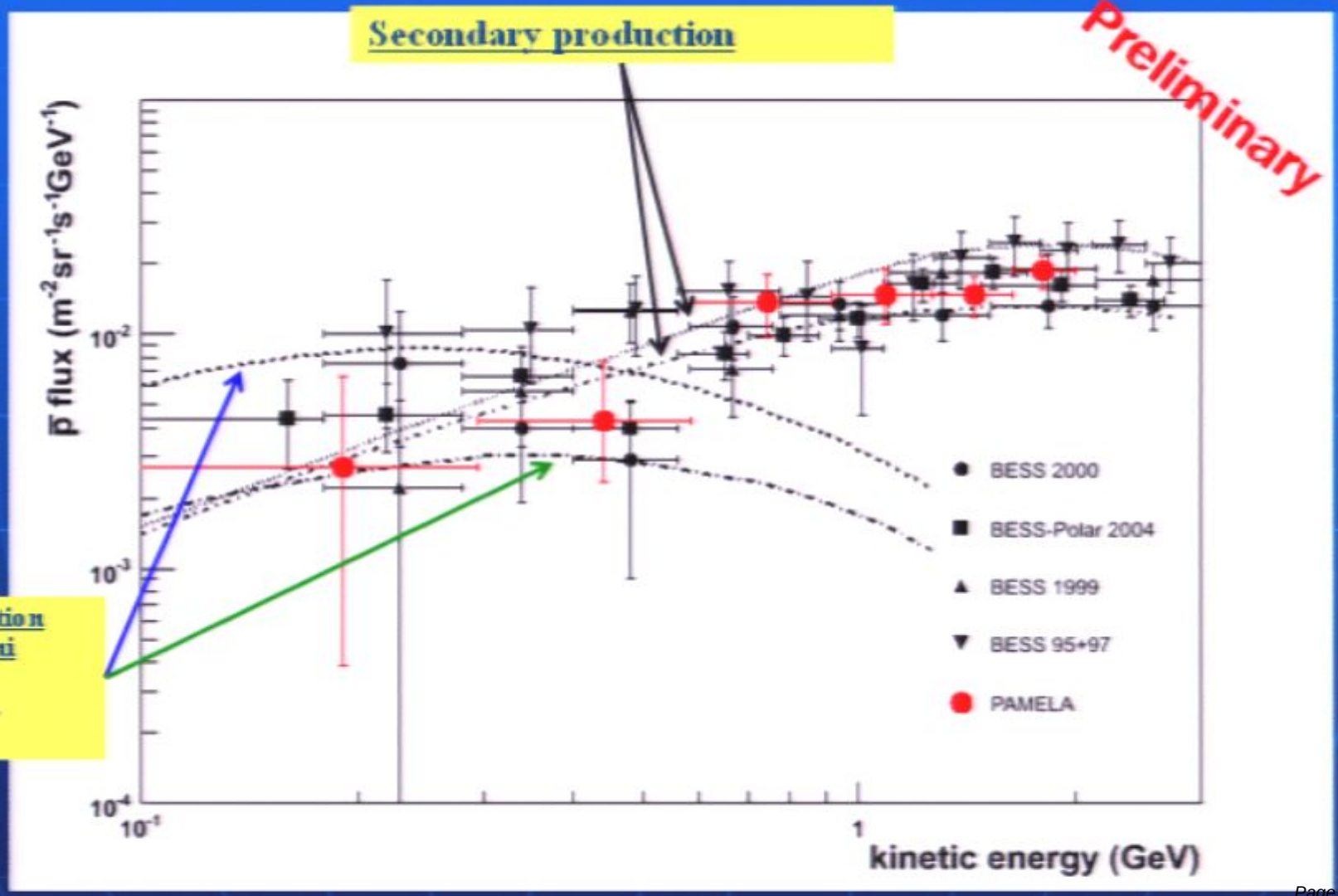


Antiproton to proton ratio

astro-ph 0810.4994

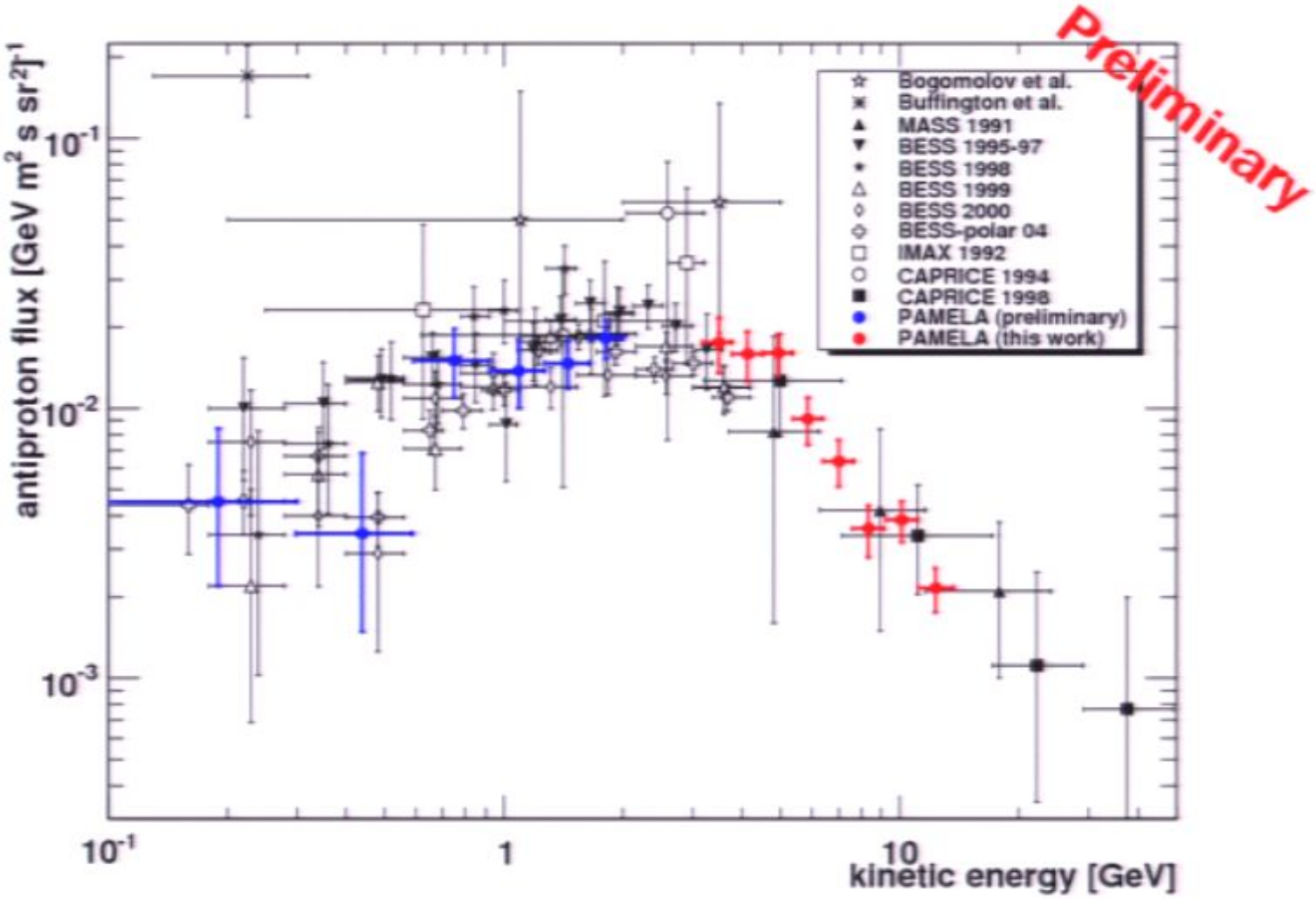


Antiproton Flux

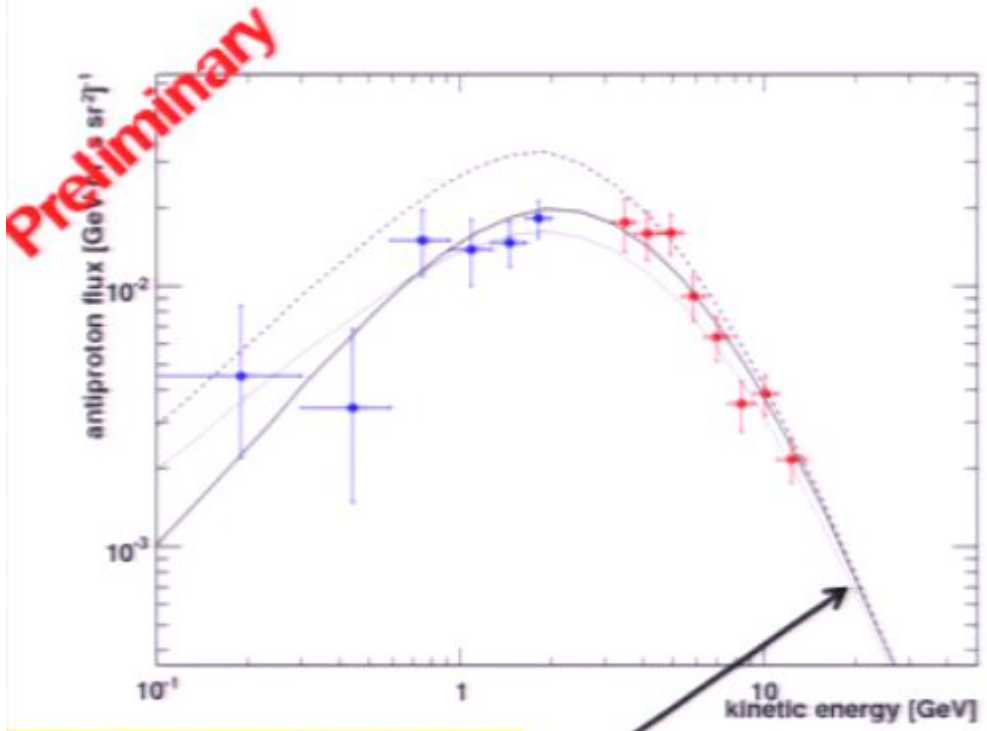


rimary production
vaporation Mini
lack Holes:
oshimura et al.
laki et al.

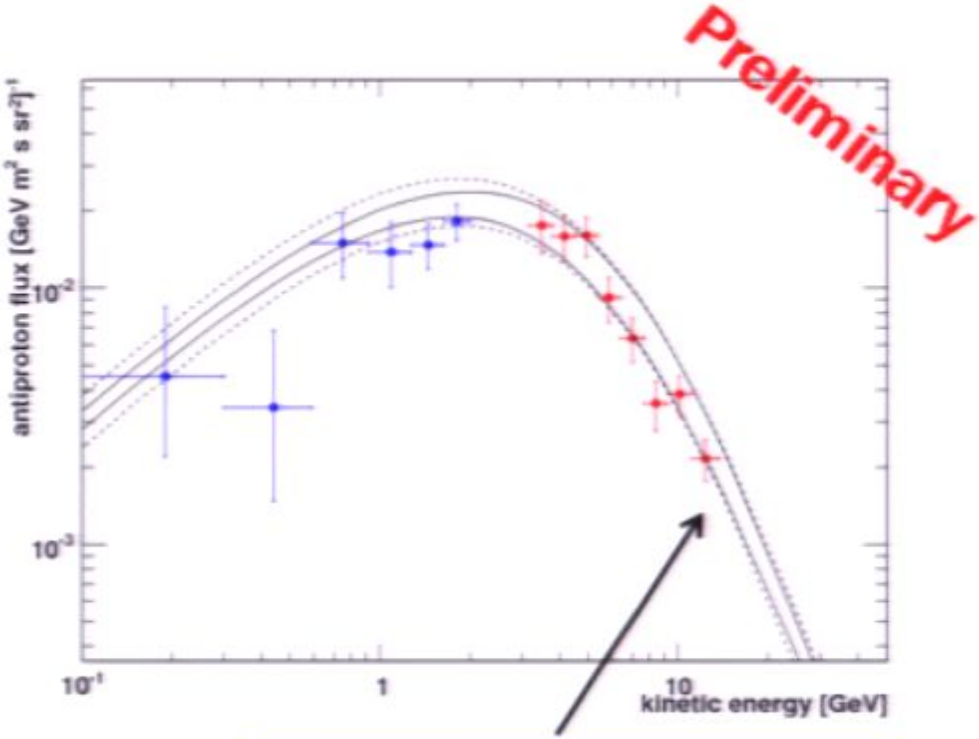
Antiproton Flux



Antiproton Flux



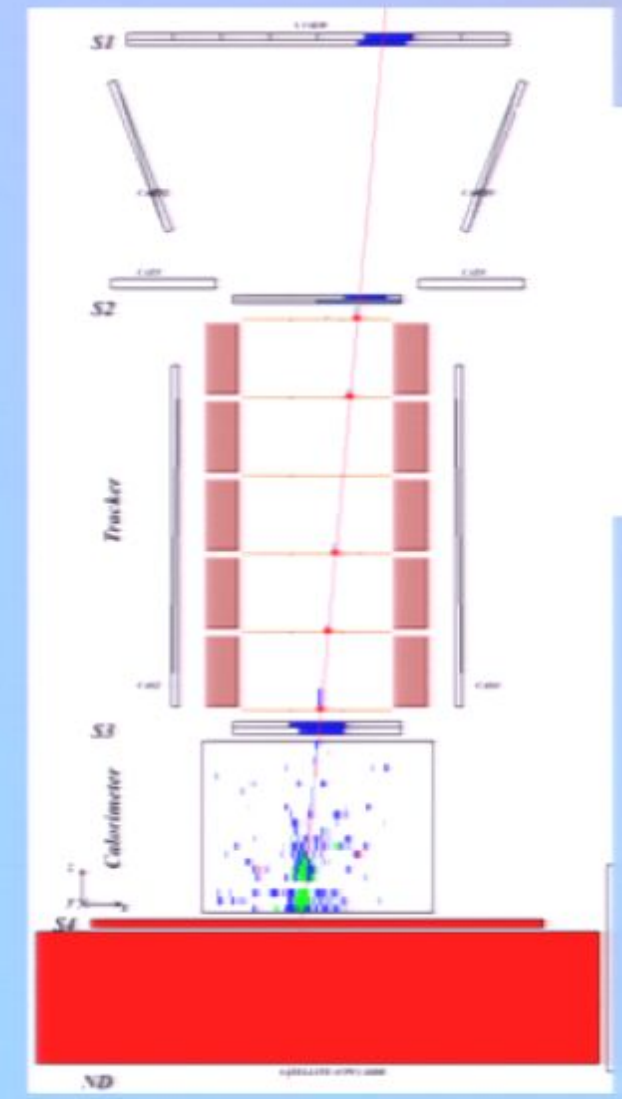
Secondary production:
V. S. Ptuskin et al, ApJ 642 (2006) 902



Secondary production:
F. Donato et al., 536 (2001) 172

Positrons

Proton / positron discrimination

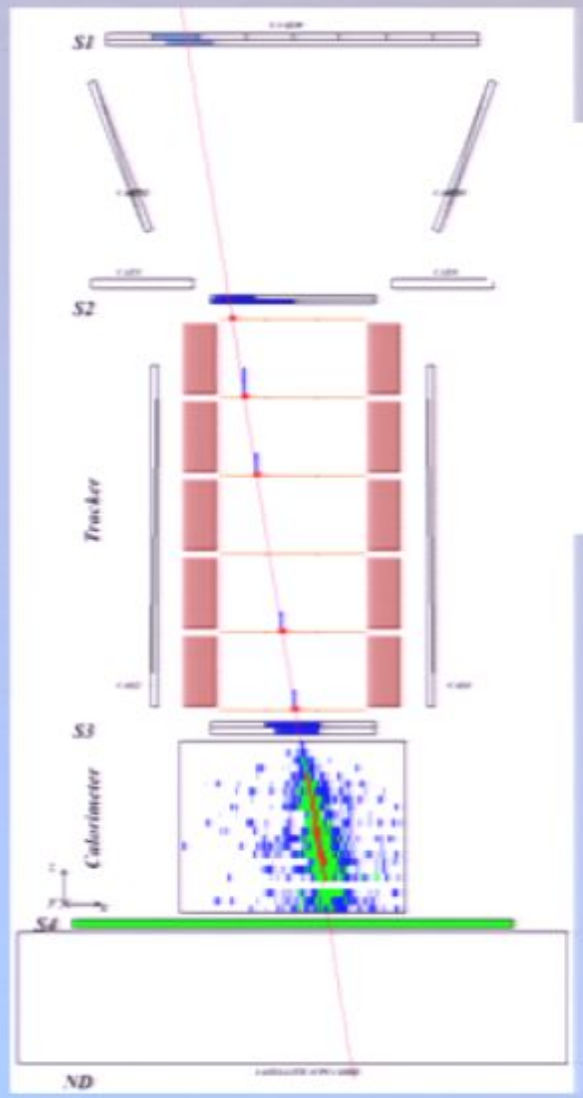


Time-of-flight: trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer: sign of charge

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

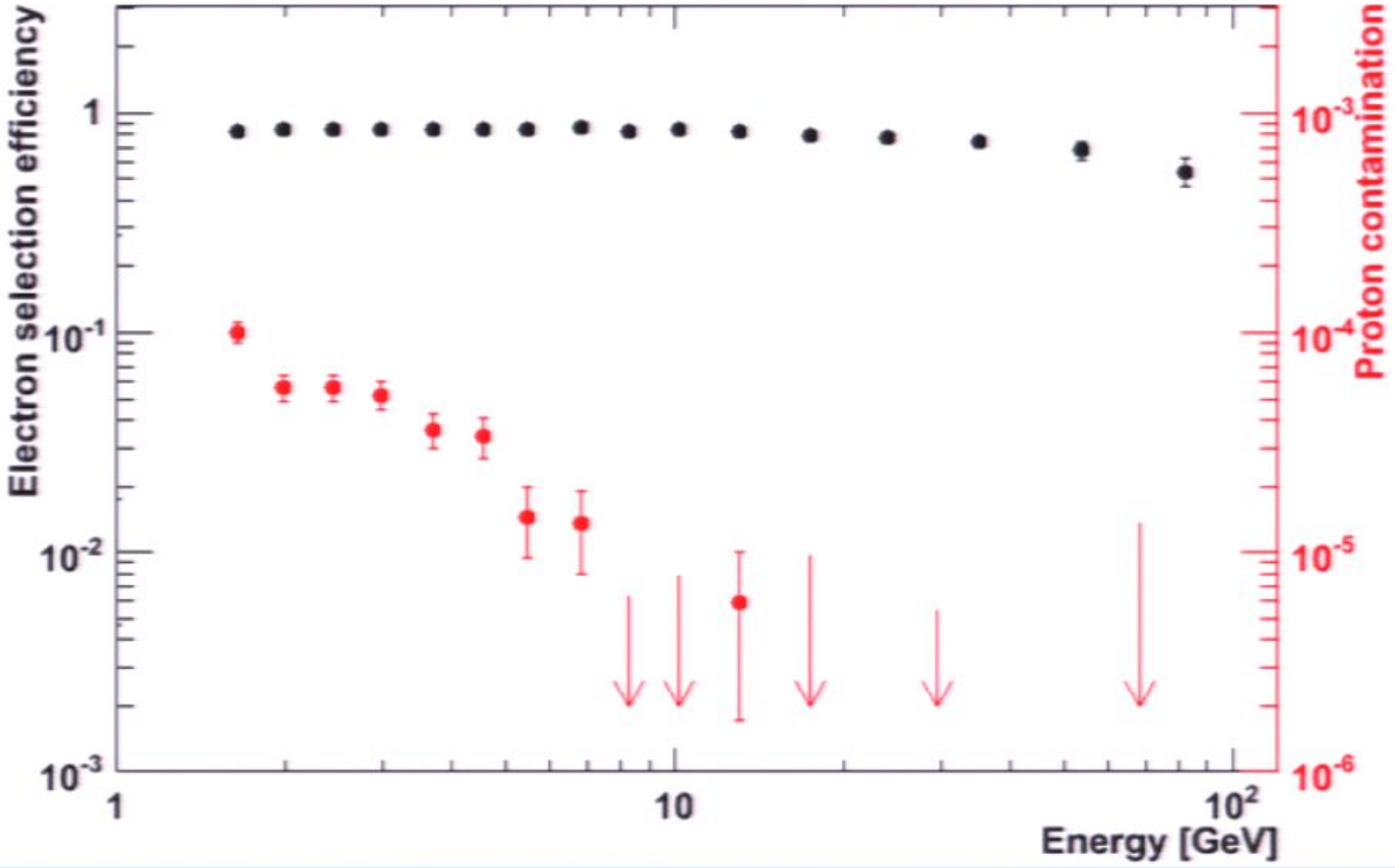
Interaction pattern in calorimeter: electron-like or proton-like, electron energy



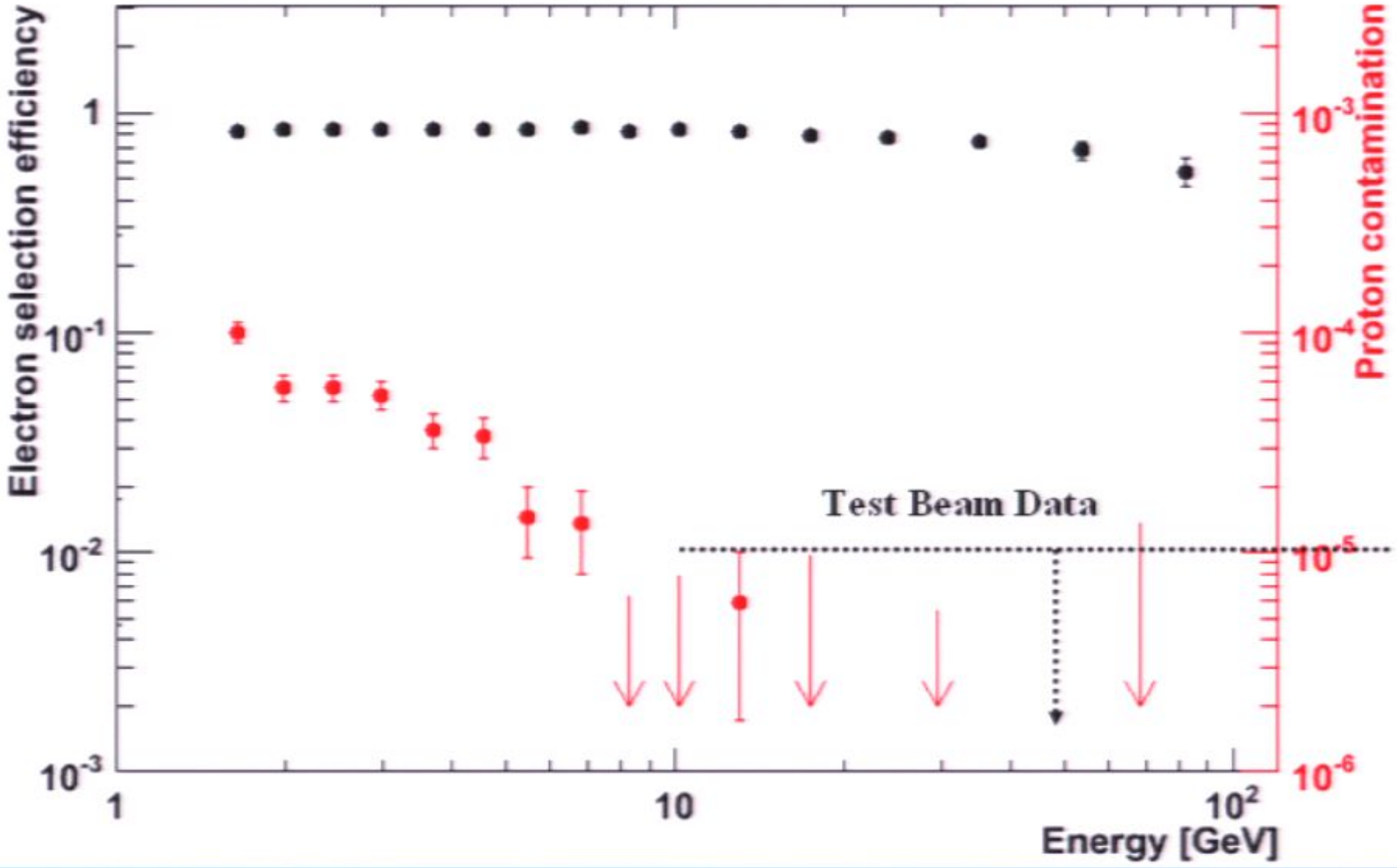
Proton

Positron

Positron selection with calorimeter

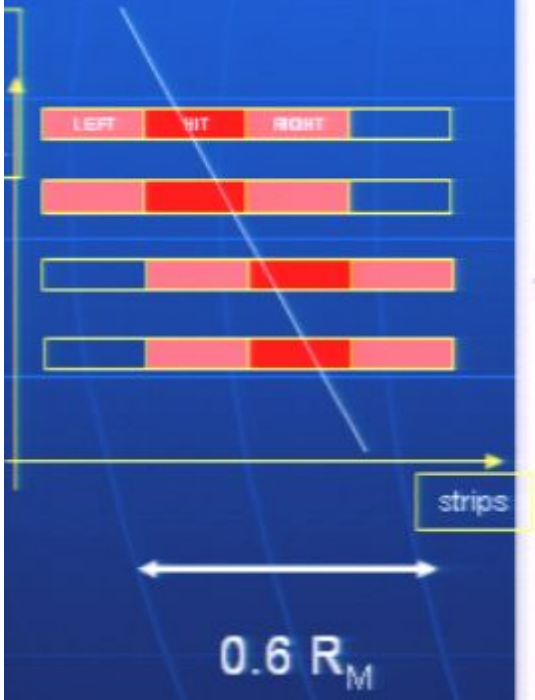


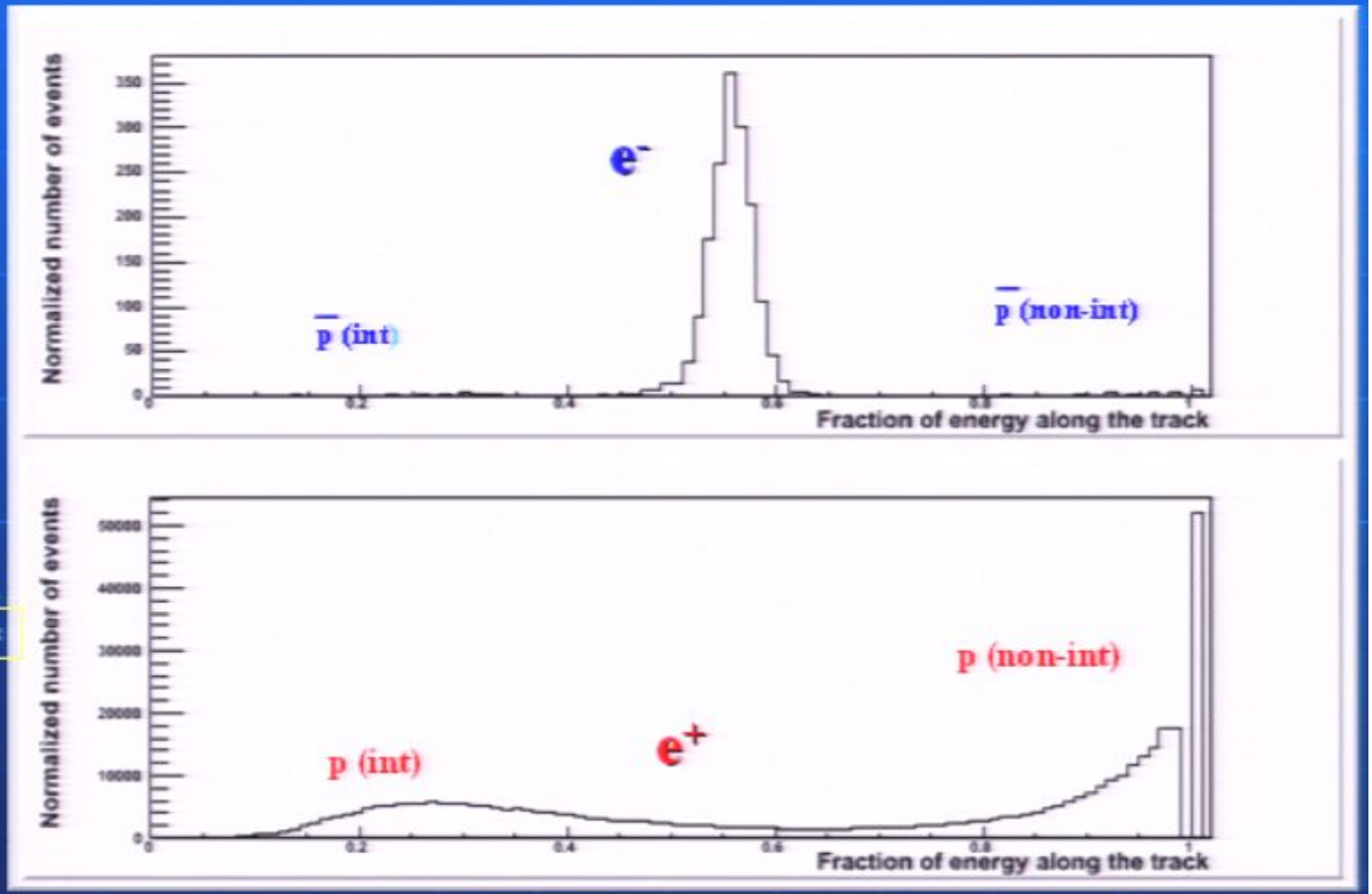
Positron selection with calorimeter



Positron selection with calorimeter

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

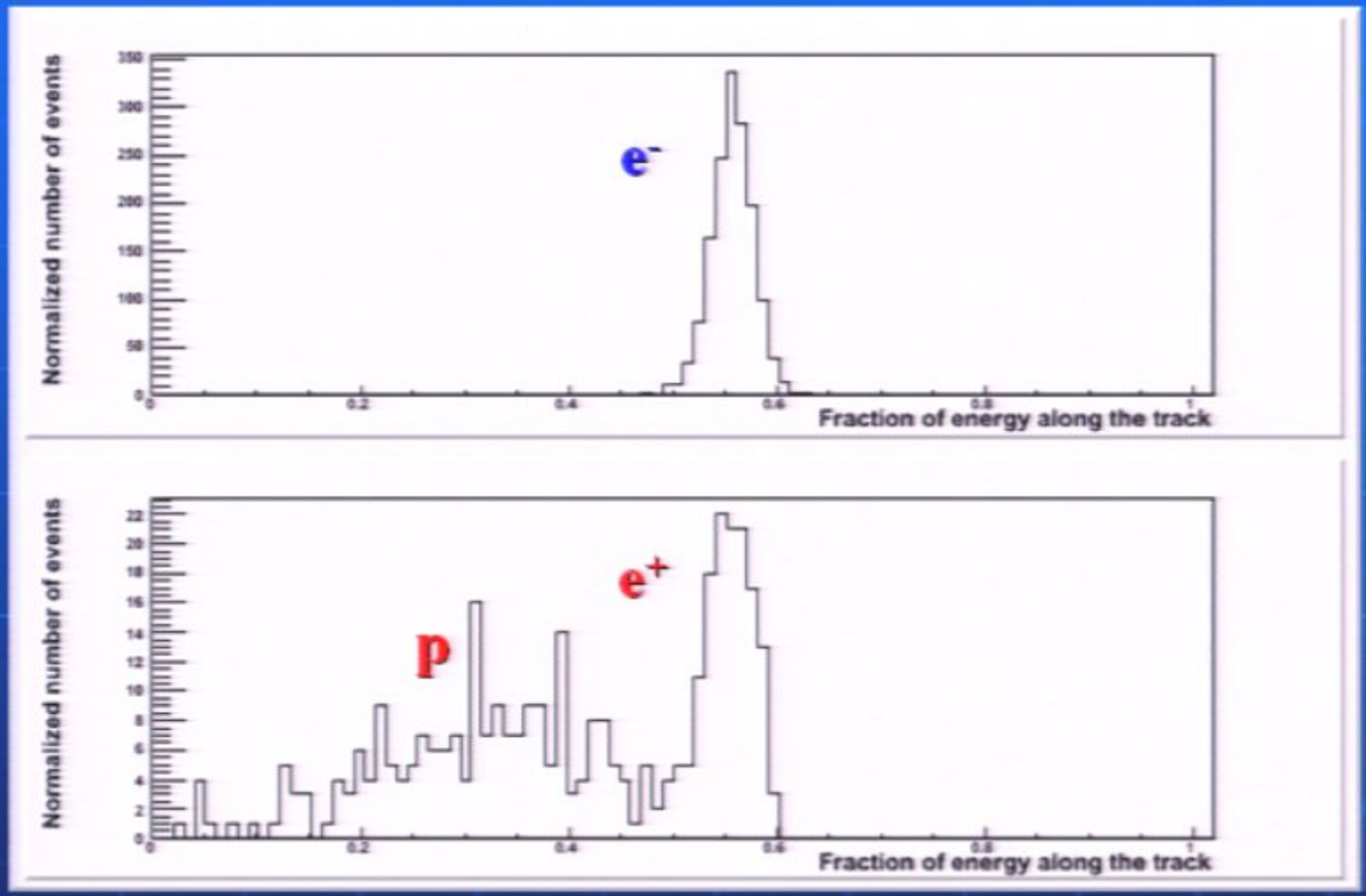




Rigidity: 20-30 GV

Positron selection with calorimeter

Rigidity: 20-30 GV



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

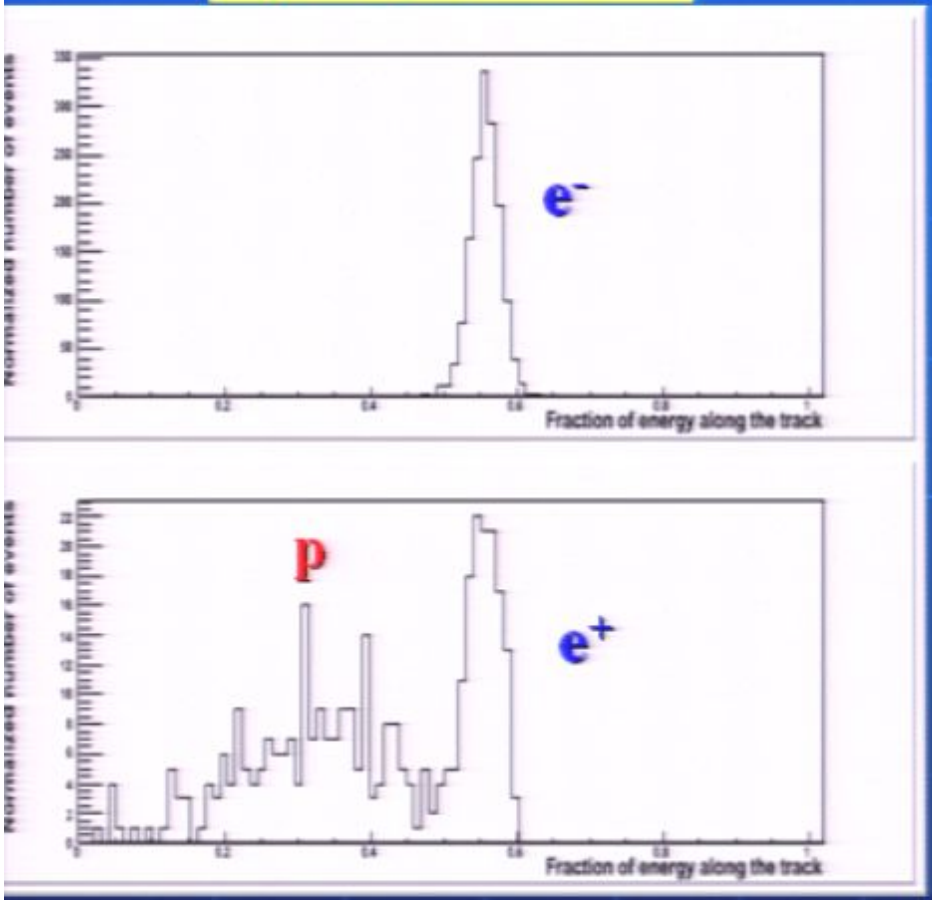
+

- Energy-momentum match
- Starting point of shower

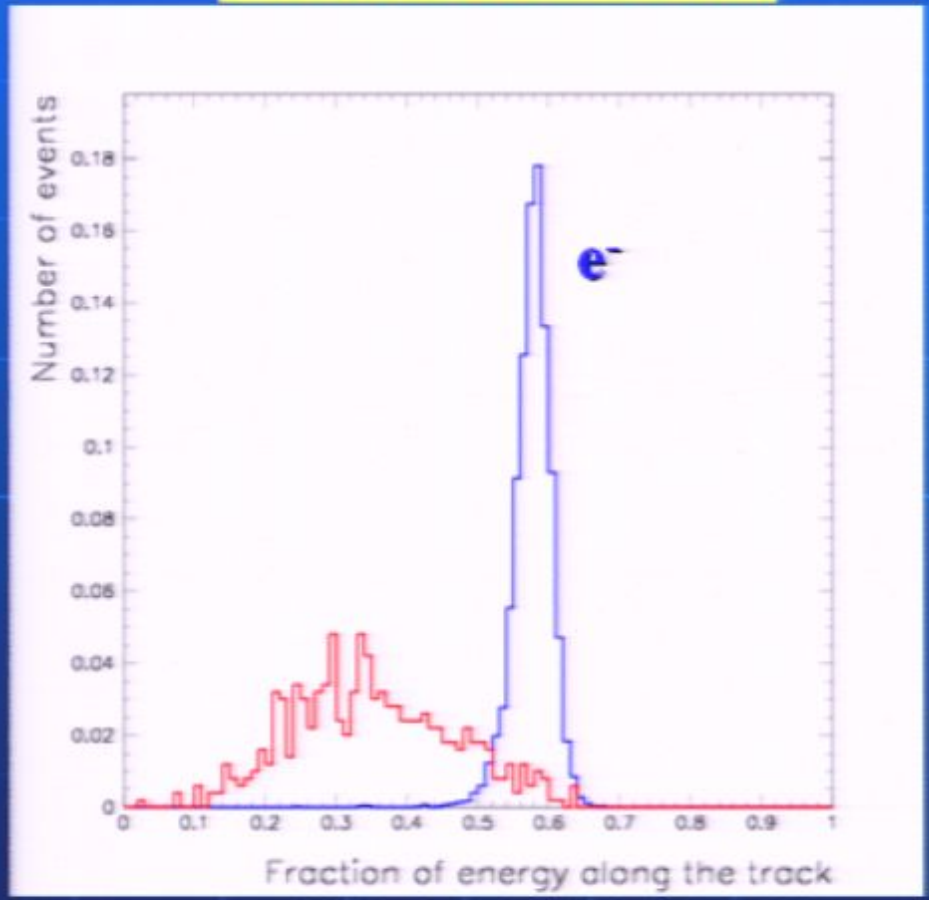
Positron selection with calorimeter

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

Flight data: rigidity: 20-30 GV

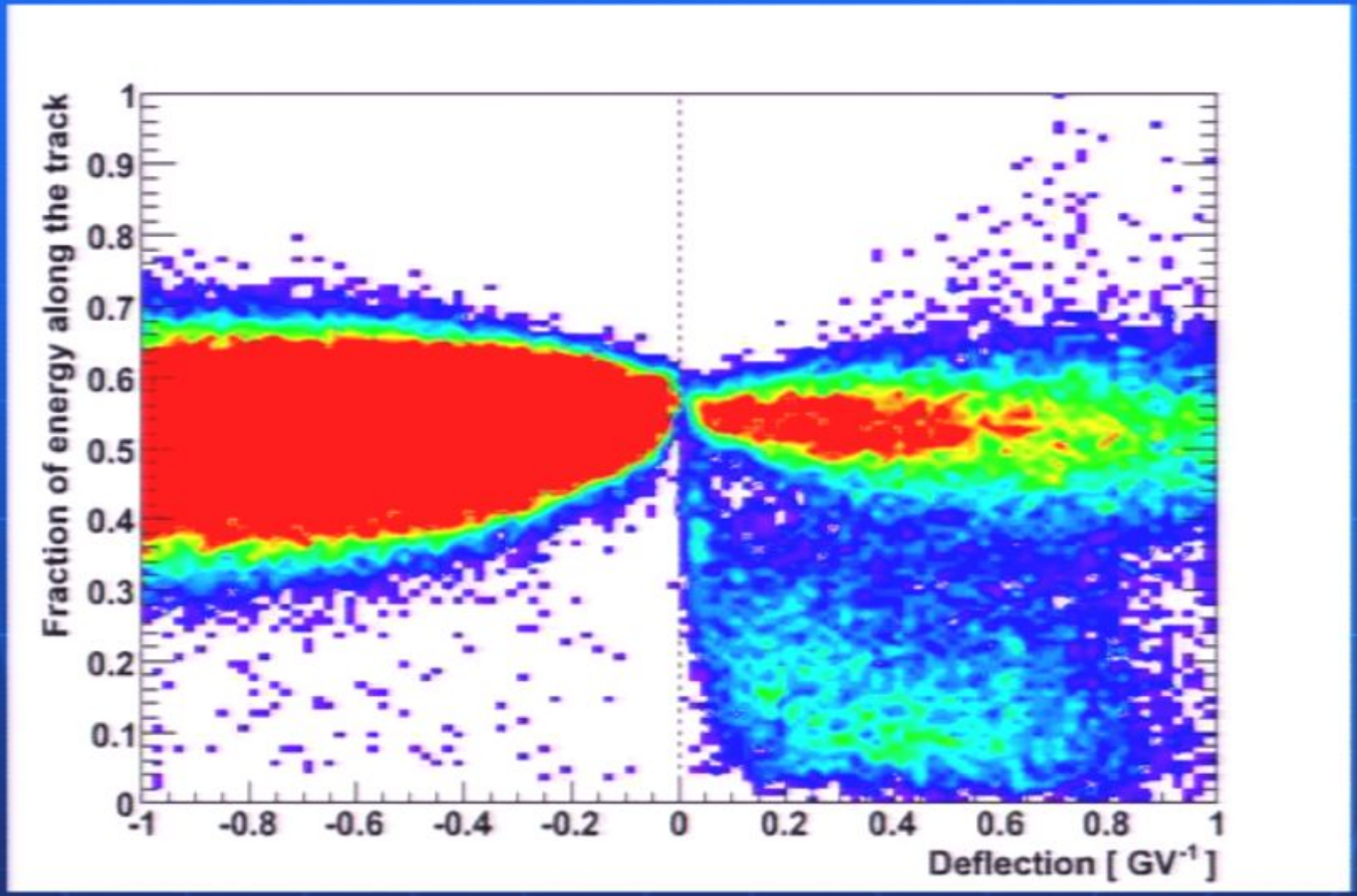


Test beam data Momentum: 50GeV/c



- Energy-momentum match
- Starting point of shower

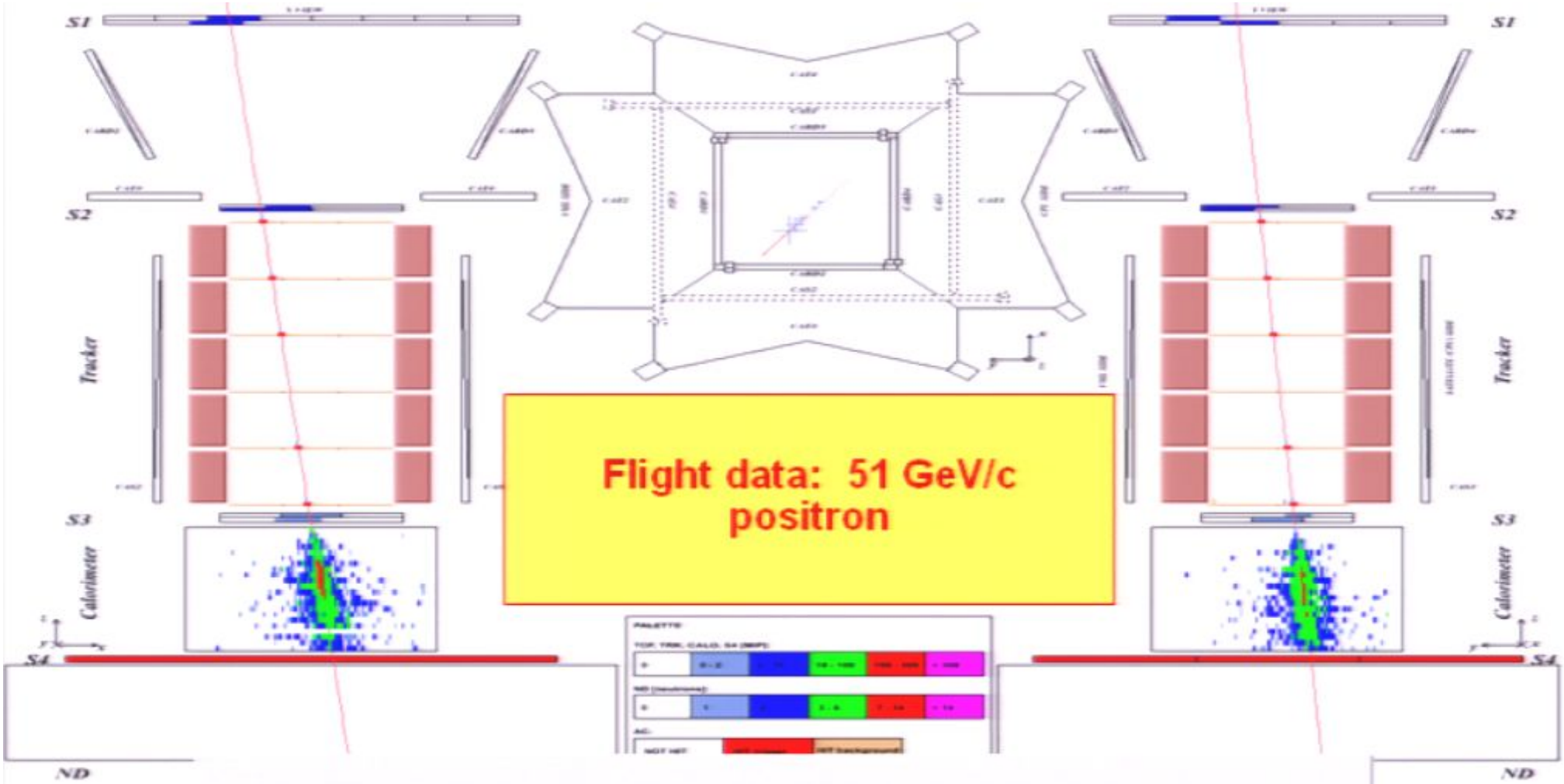
Positron selection with calorimeter

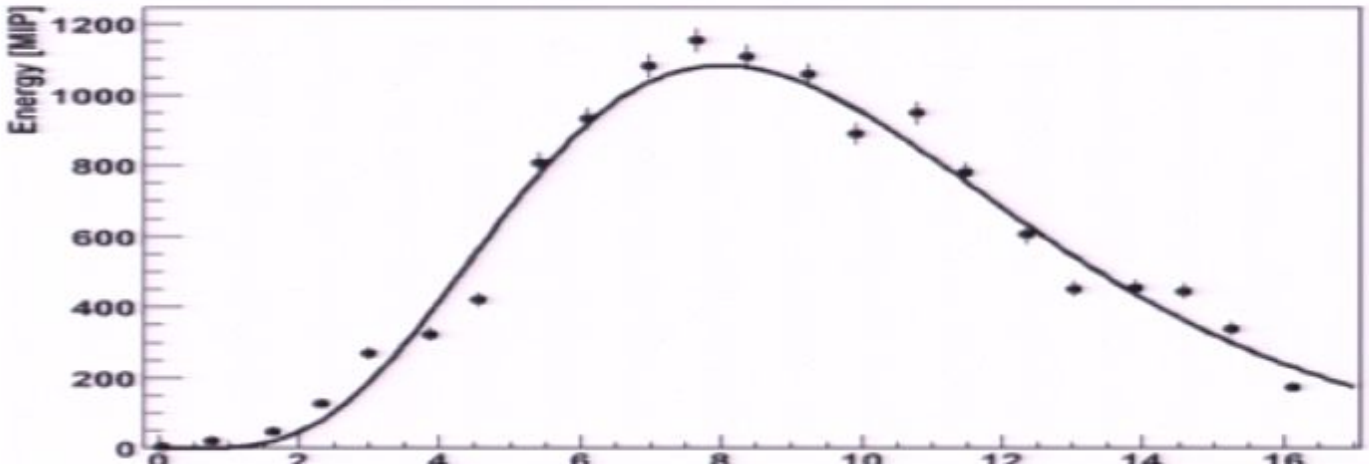


Fraction of charge released along the calorimeter track (left, hit, right)

+

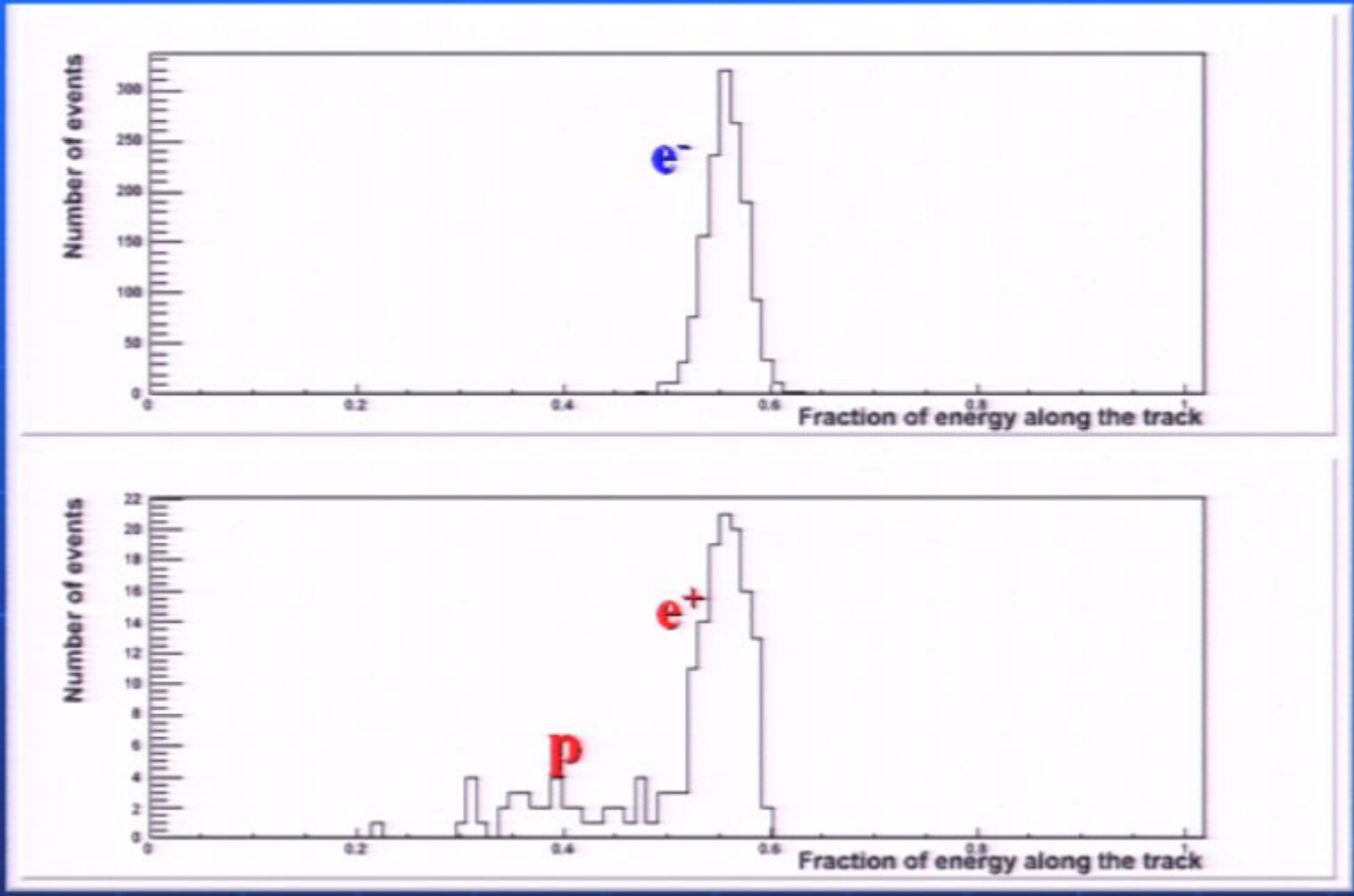
- Energy-momentum match
- Starting point of shower


S1
S2
S3
S4
Tracker
Calorimeter
ND
Flight data: 51 GeV/c
positron


Energy [MIP]
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
16

Positron selection with calorimeter

Rigidity: 20-30 GV



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

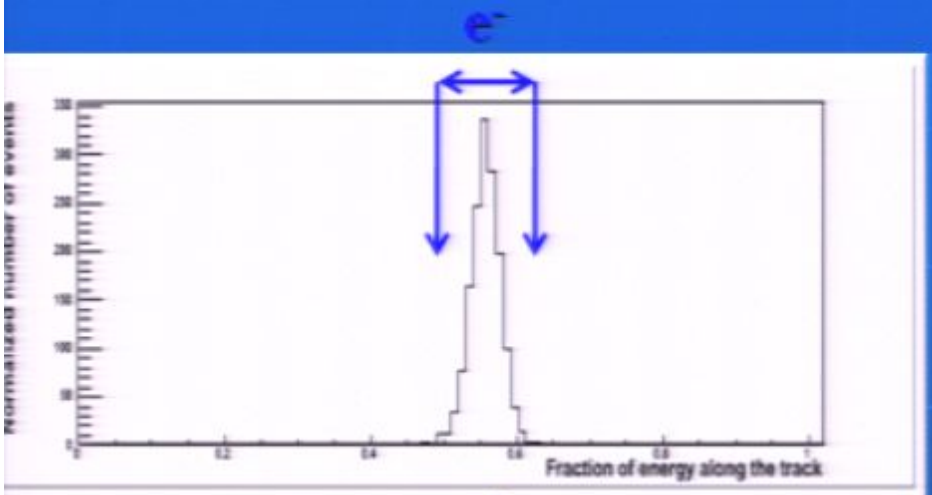
+

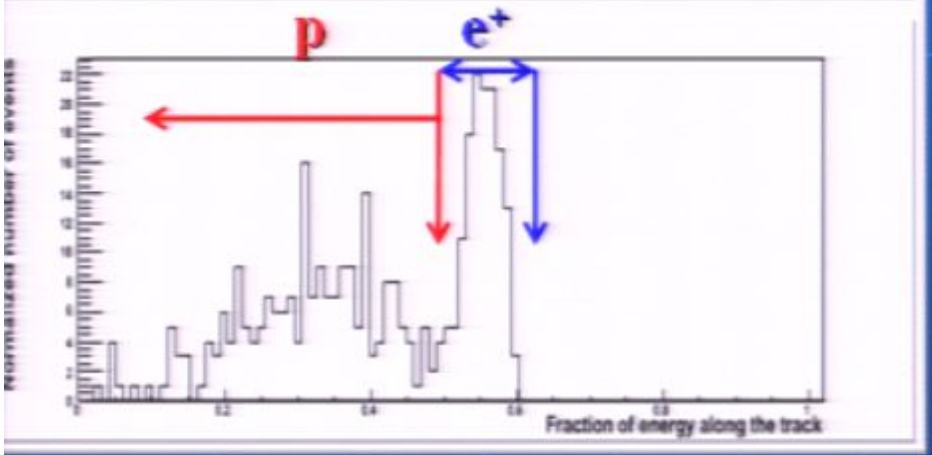
- Energy-momentum match
- Starting point of shower
- Longitudinal profile

Positron selection

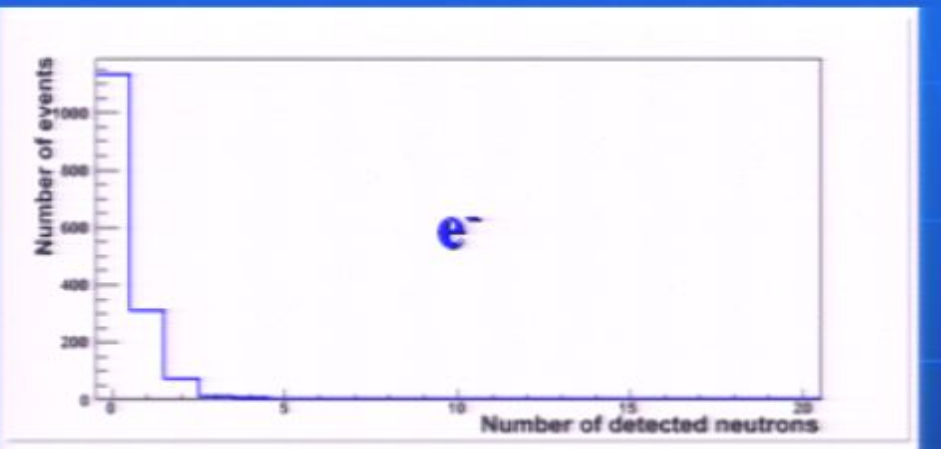
Rigidity: 20-30 GV

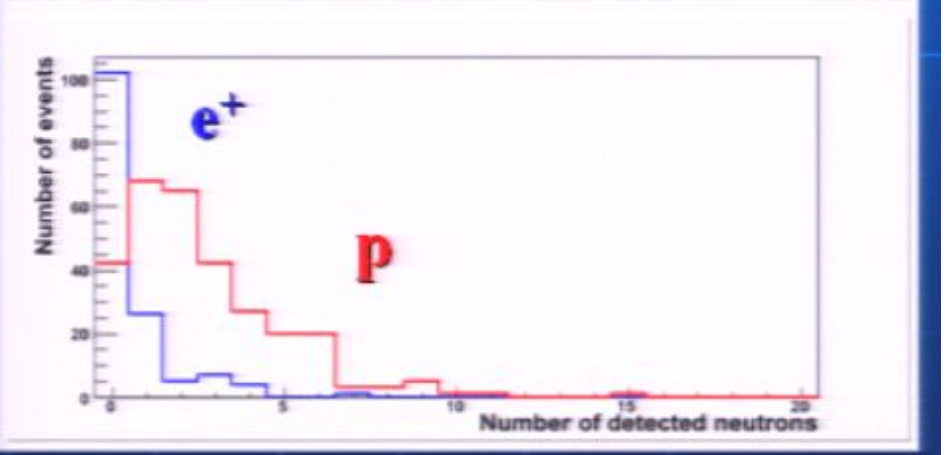
Fraction of charge released along the calorimeter track (left, hit, right)





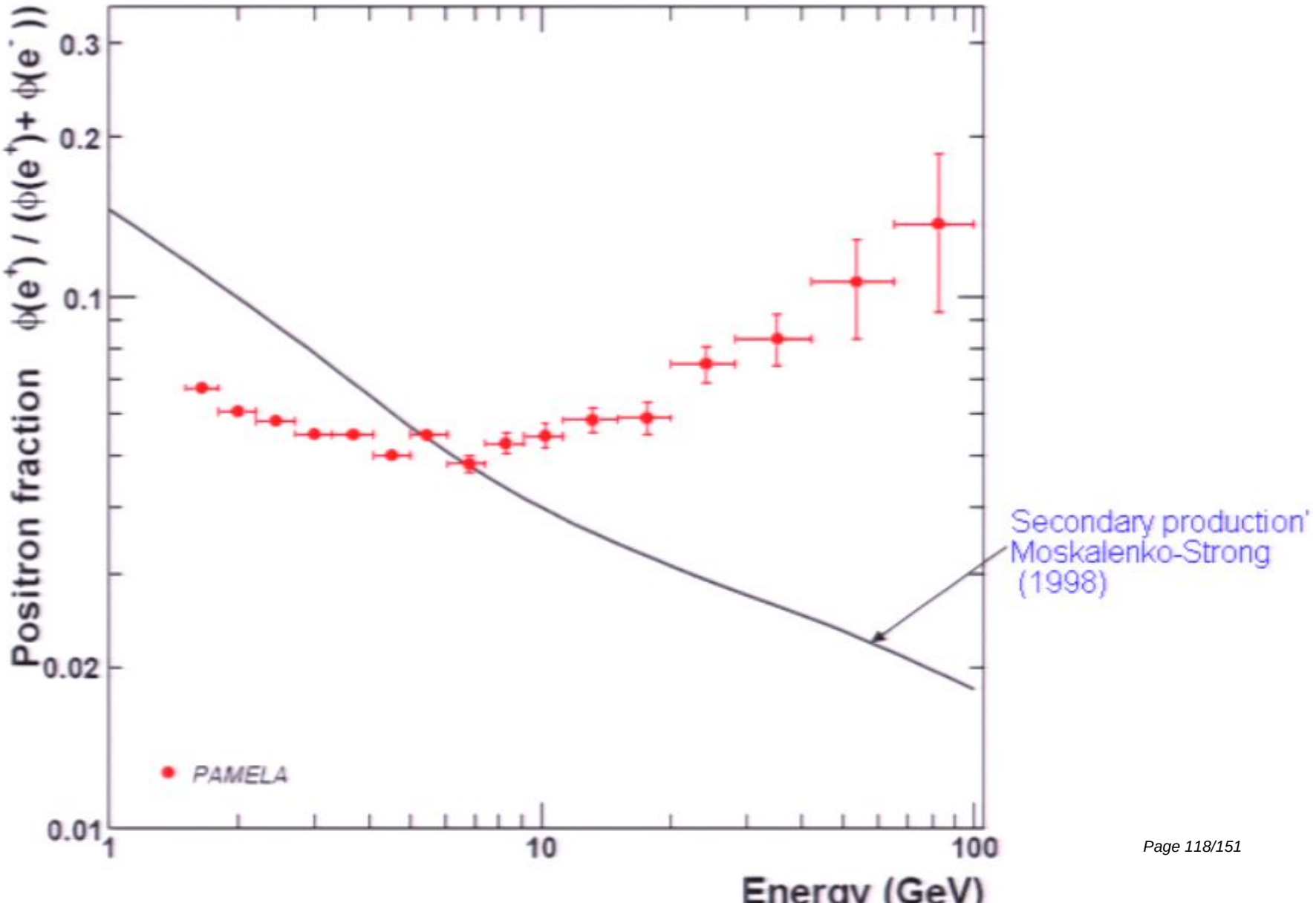
Neutrons detected by ND





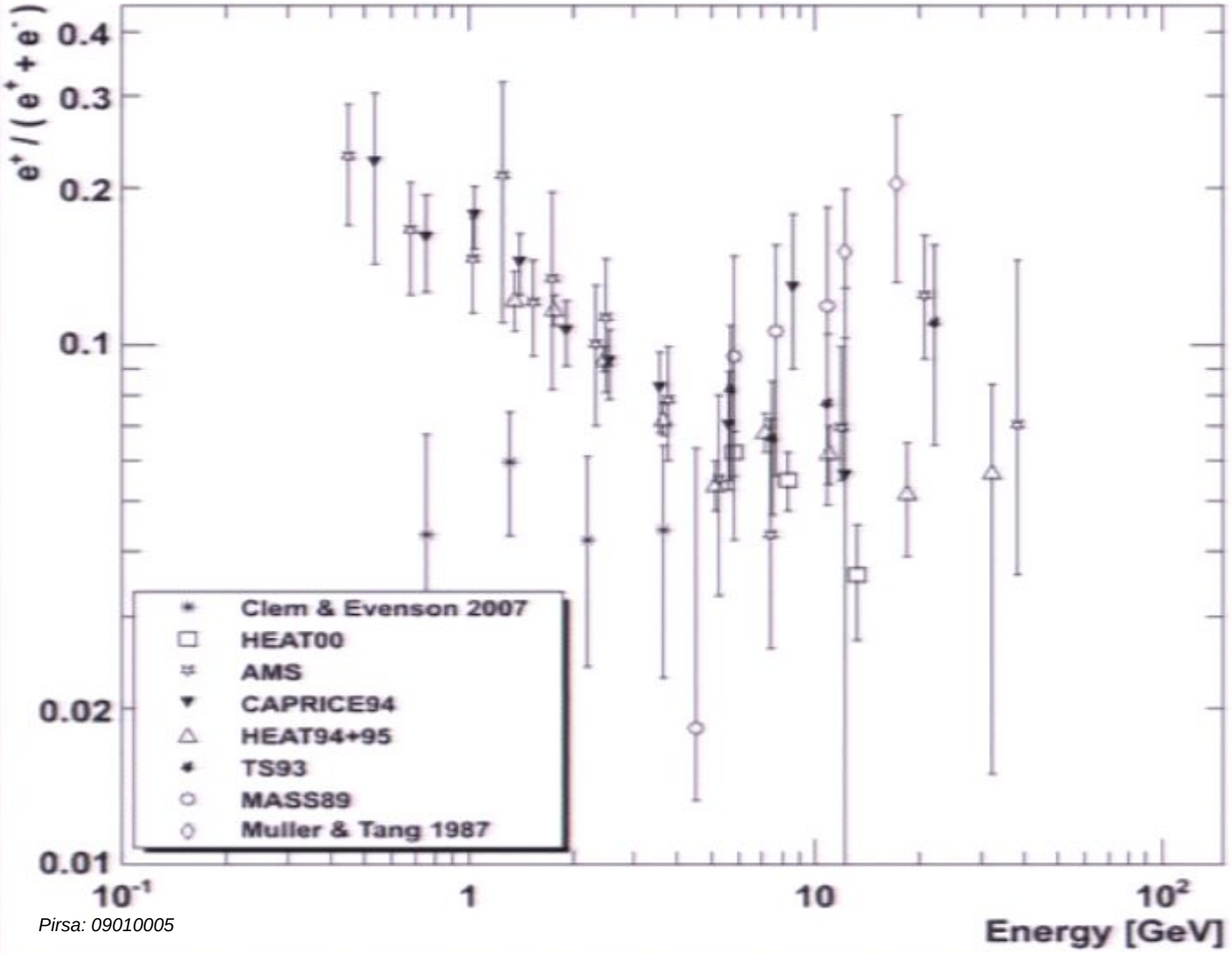
Energy-momentum match
Starting point of shower

Positron to Electron Ratio



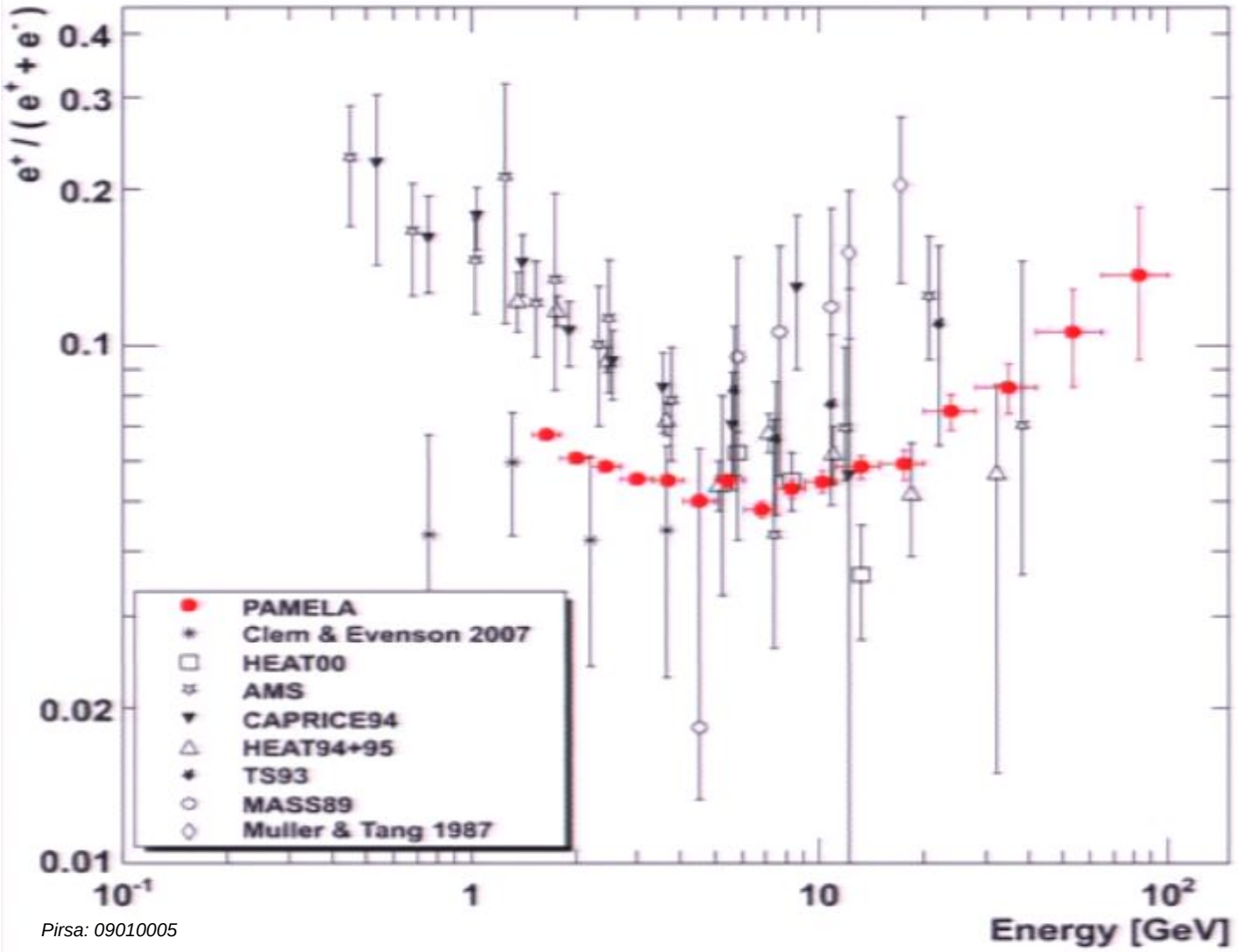
Positron to Electron Ratio

astro-ph 0810.4995



Positron to Electron Ratio

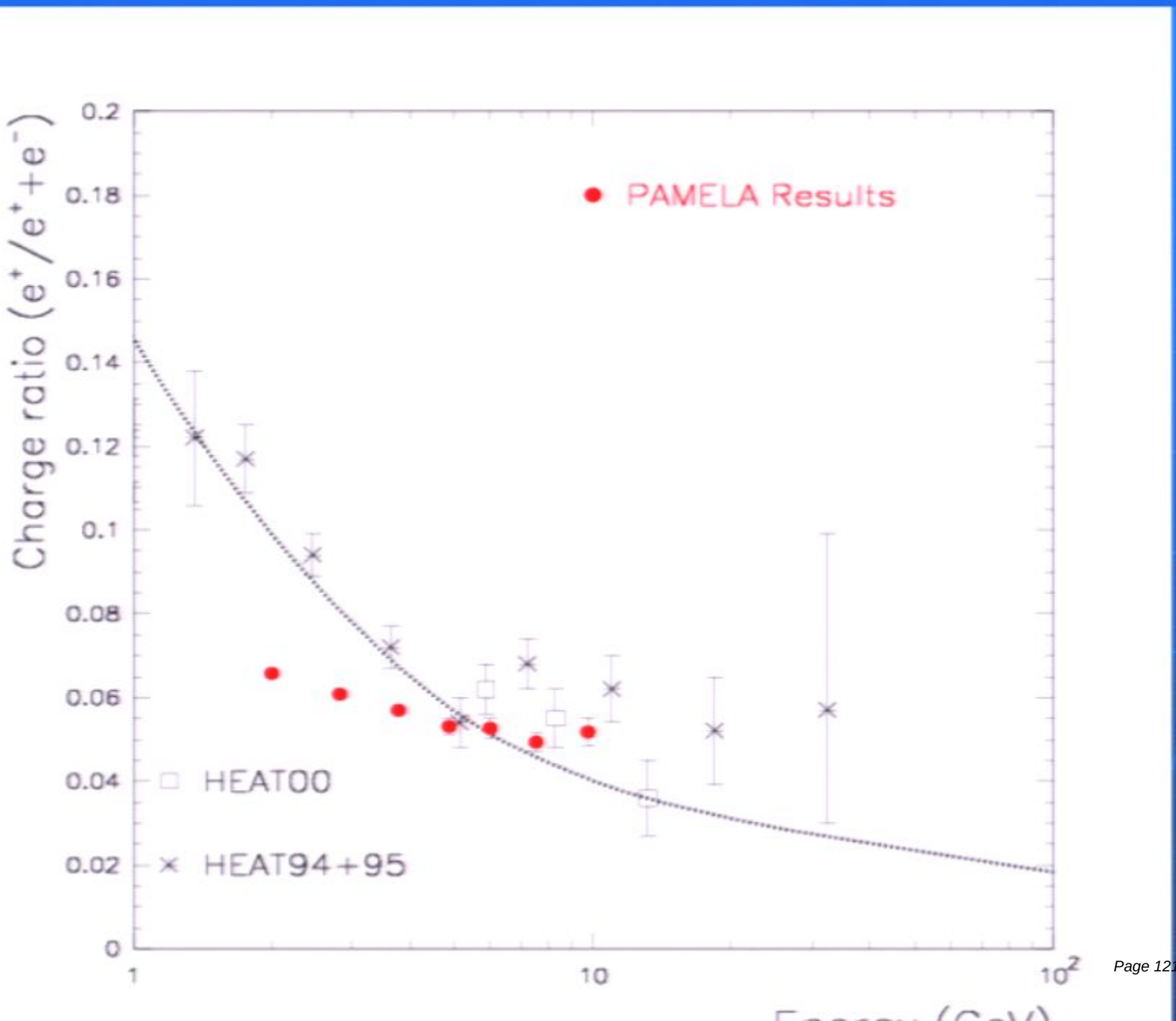
astro-ph 0810.4995



End 2007:

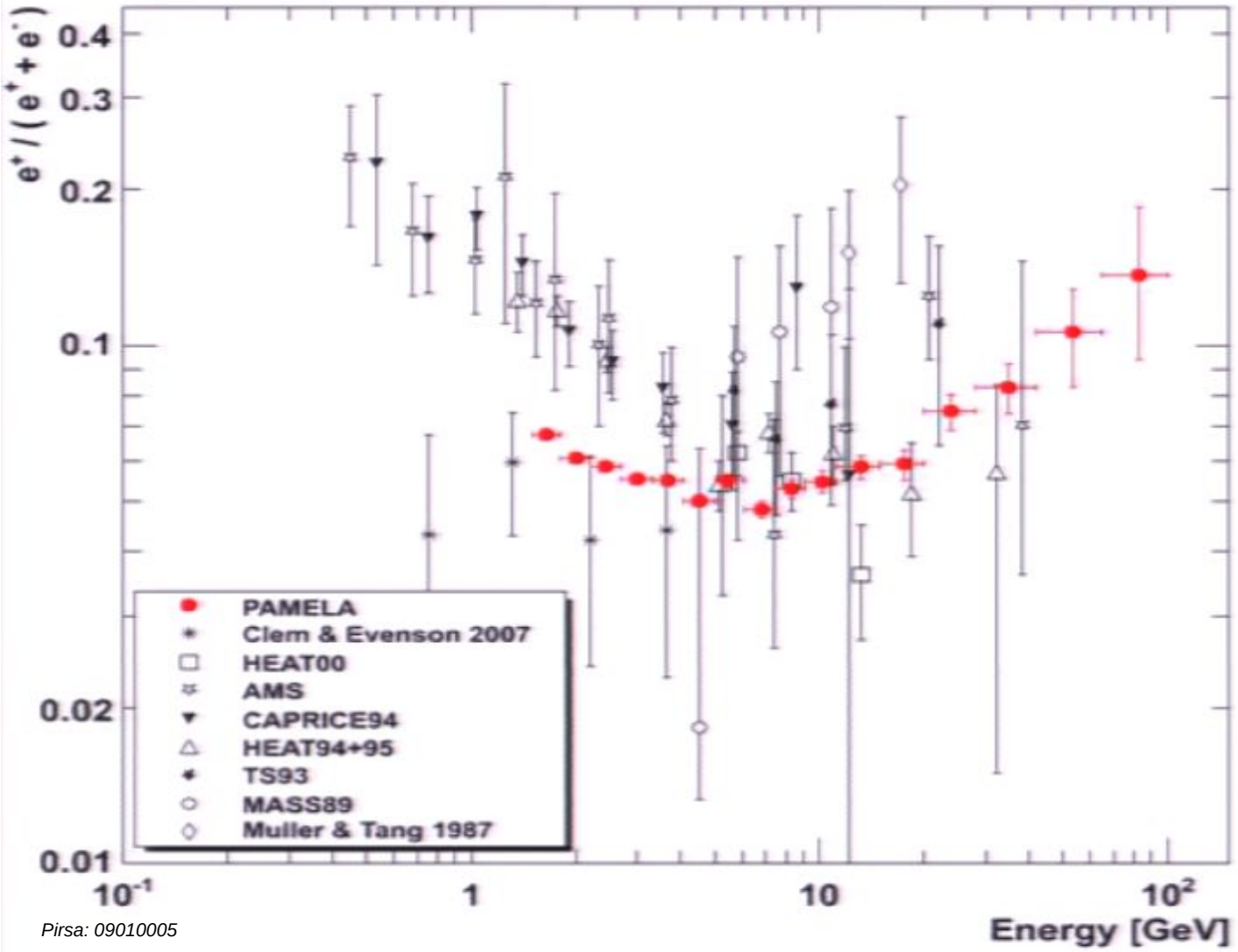
~10 000 $e^+ > 1.5$ GeV

~2000 > 5 GeV


Charge ratio ($e^+/e^+ + e^-$)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
PAMELA Results
HEAT00
HEAT94+95
1
10
10^2

Positron to Electron Ratio

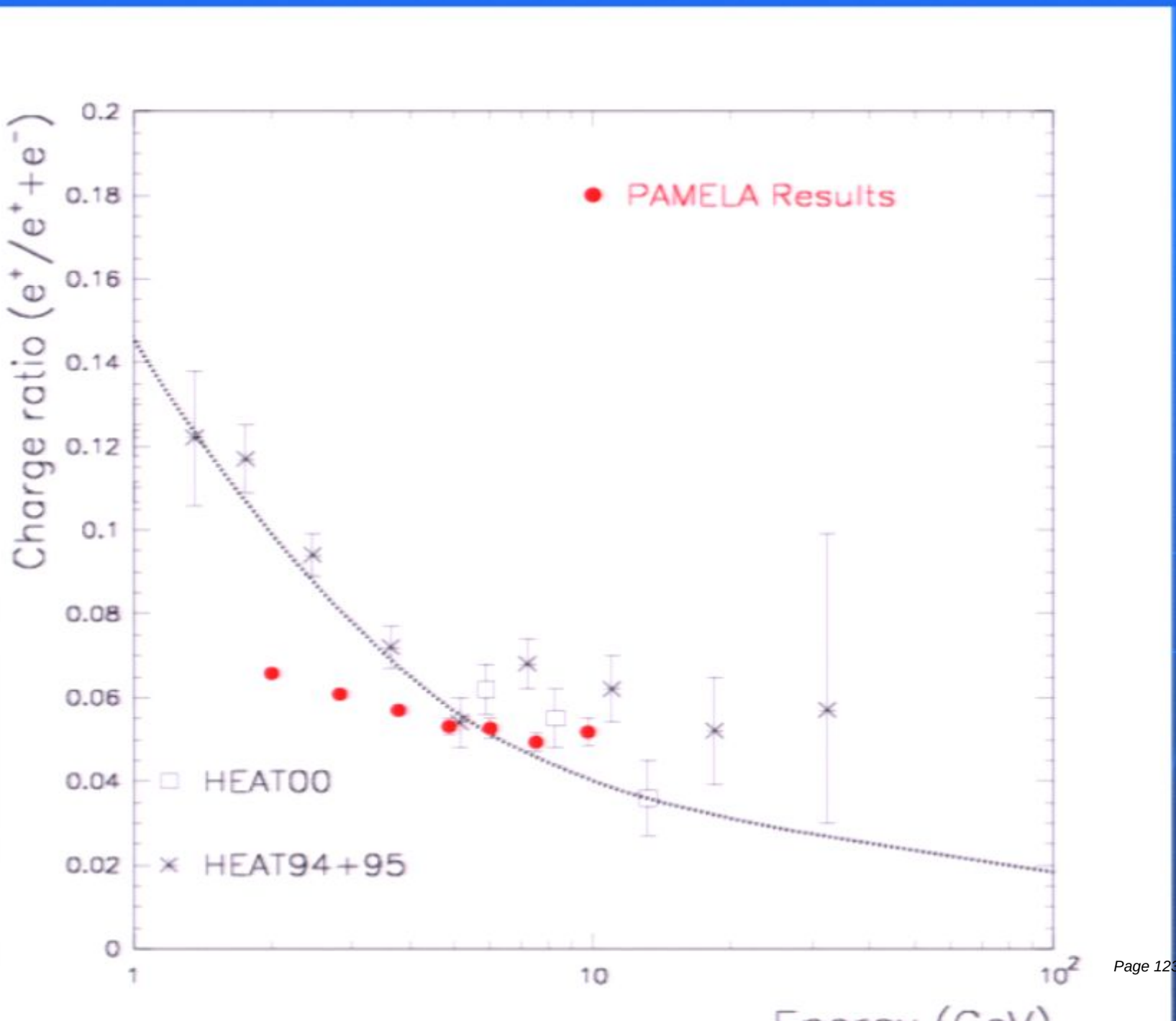
astro-ph 0810.4995



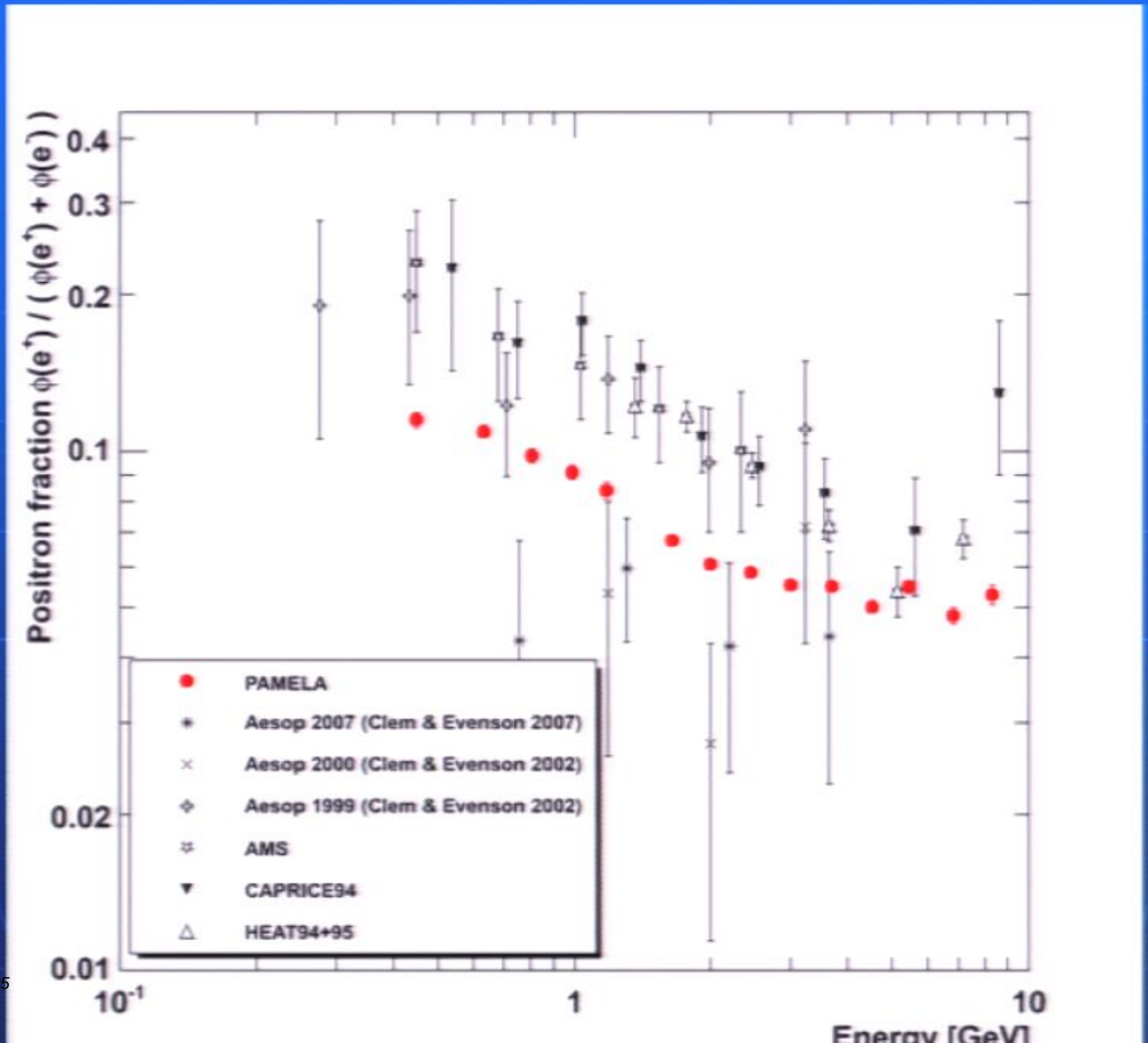
End 2007:

~10 000 $e^+ > 1.5$ GeV

~2000 > 5 GeV


Charge ratio (e^+/e^++e^-)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
PAMELA Results
HEAT00
HEAT94+95
1
10
10^2

Positron Fraction



Solar Modulation of galactic cosmic rays

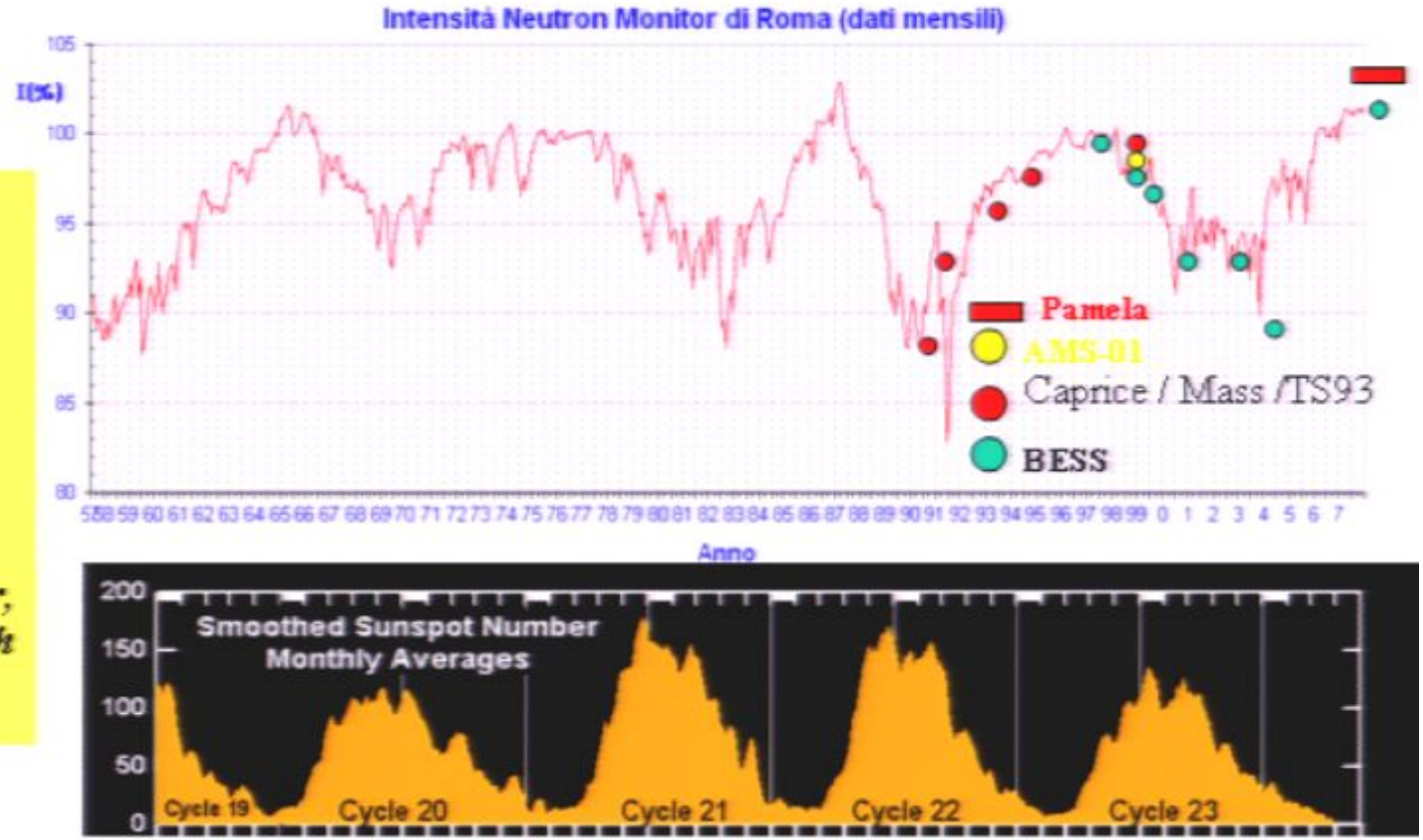
Study of charge sign dependent effects

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

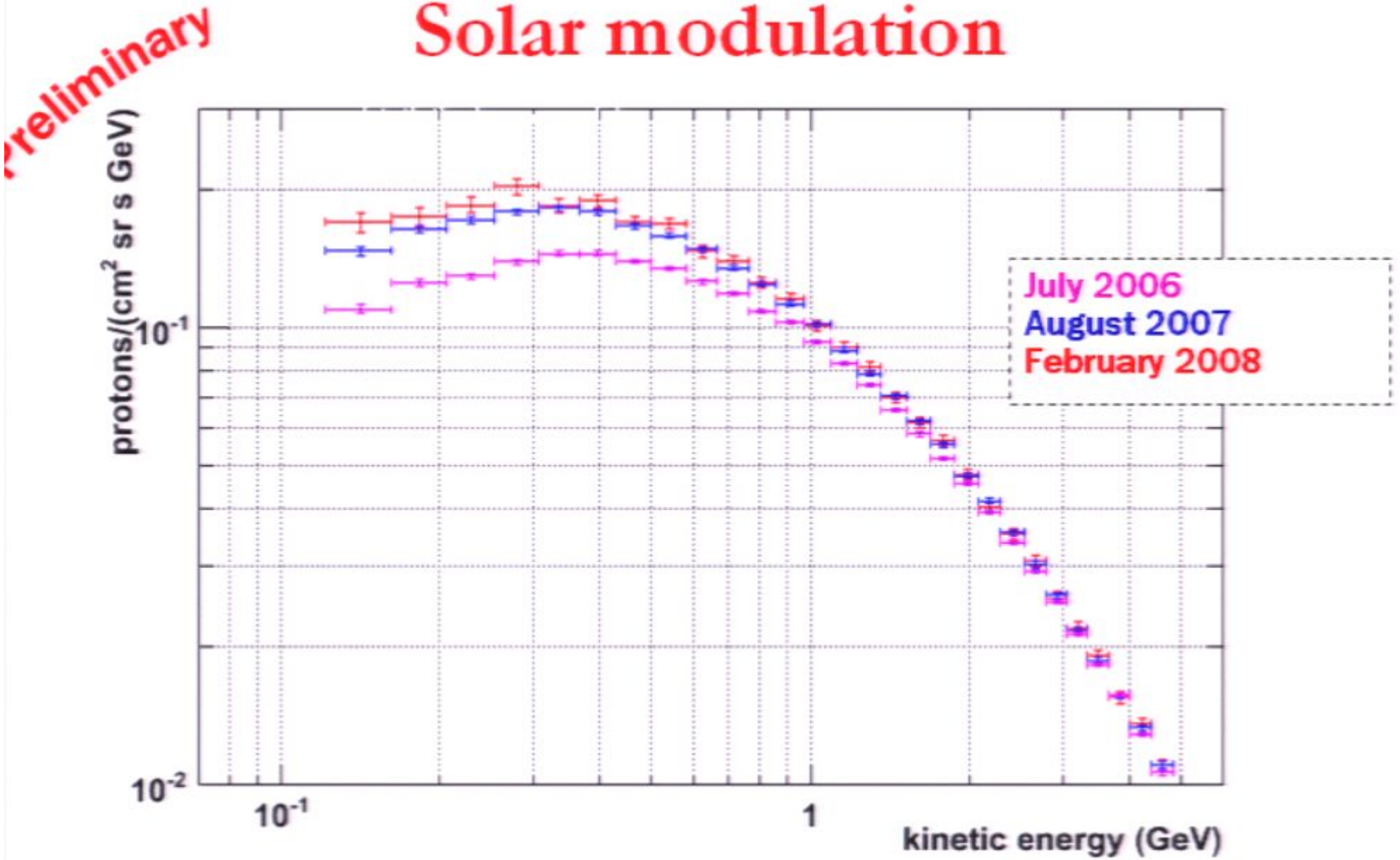
Sieber, J.W., et al. Physi-cai Review Letters, 84, 674, 1999.

J. Clem et al. 30th ICRC 2007

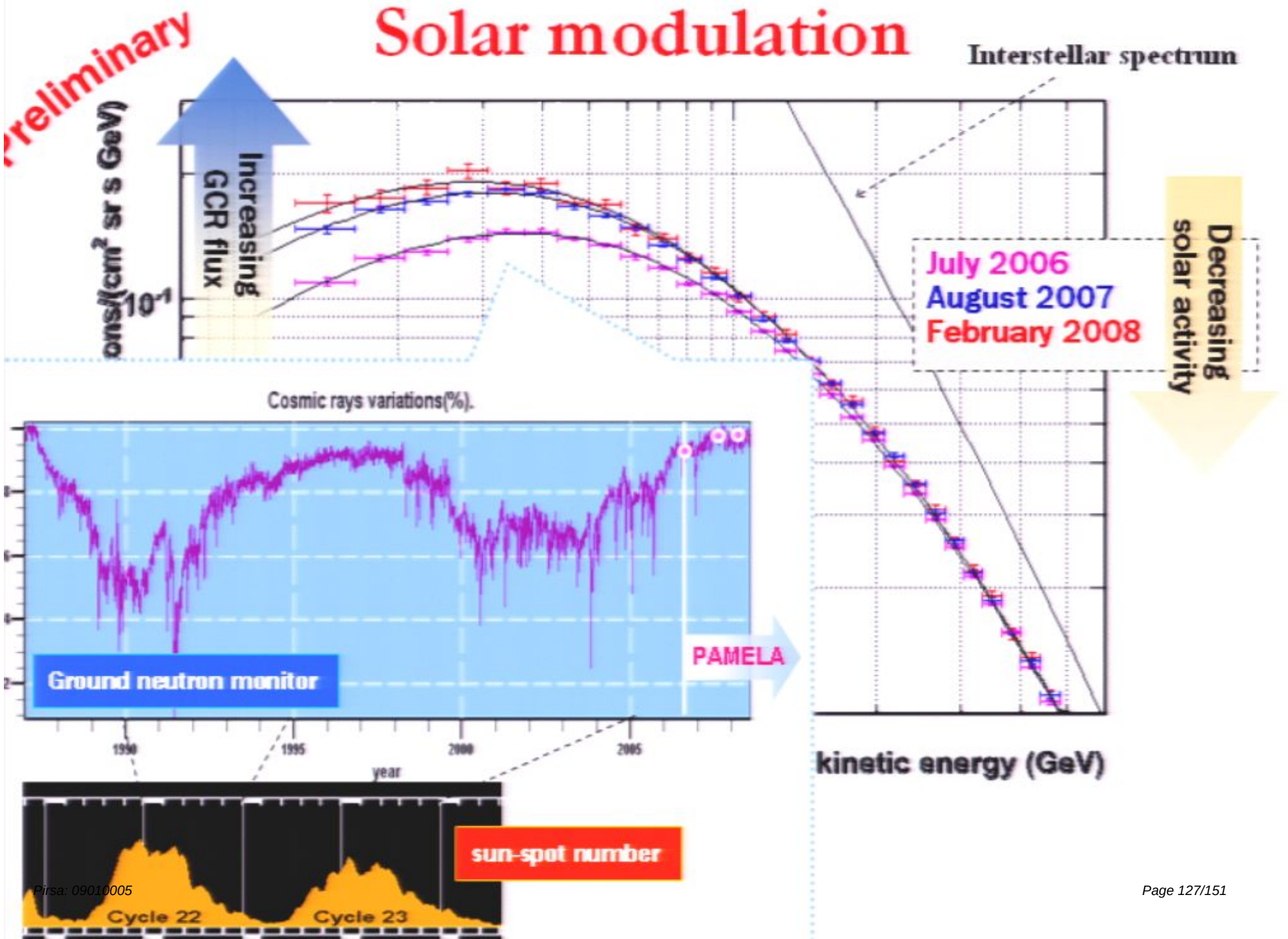
J.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)

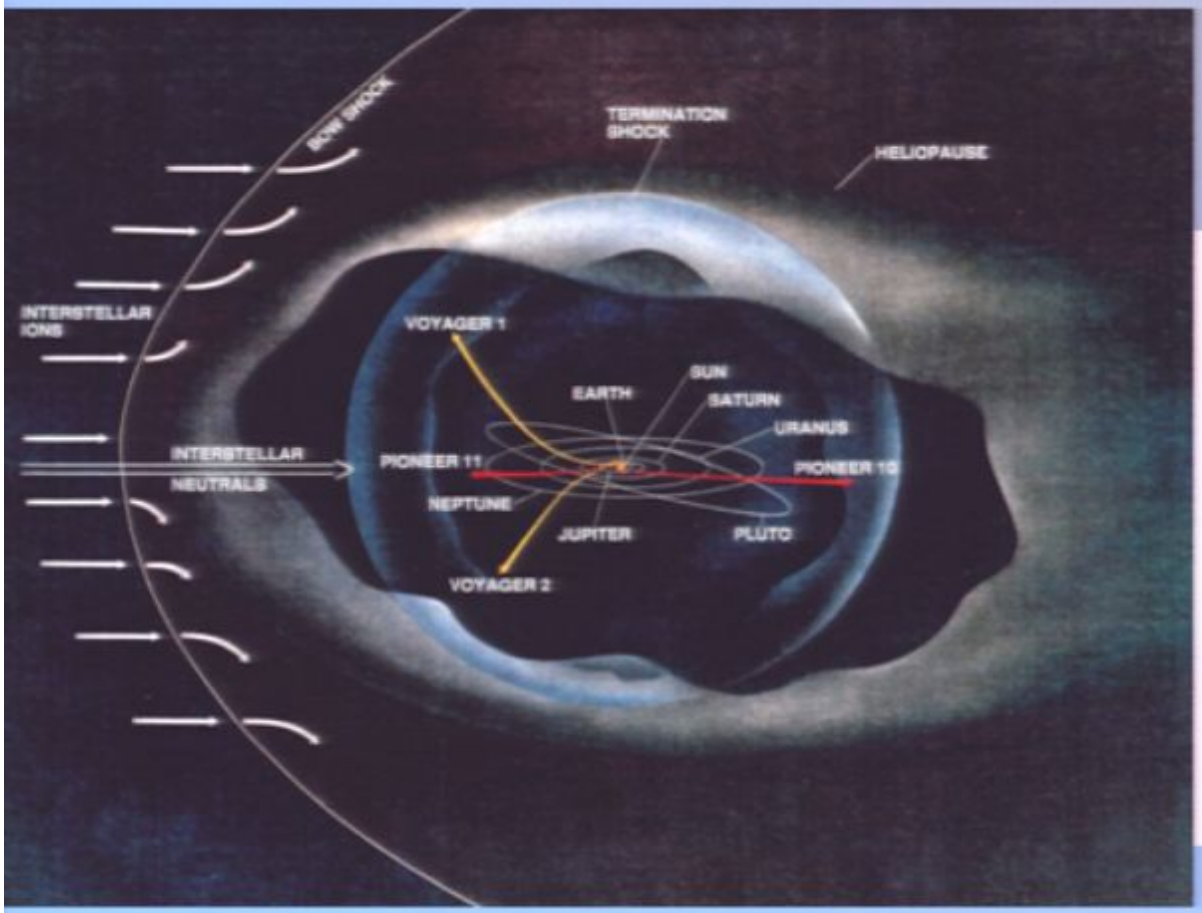


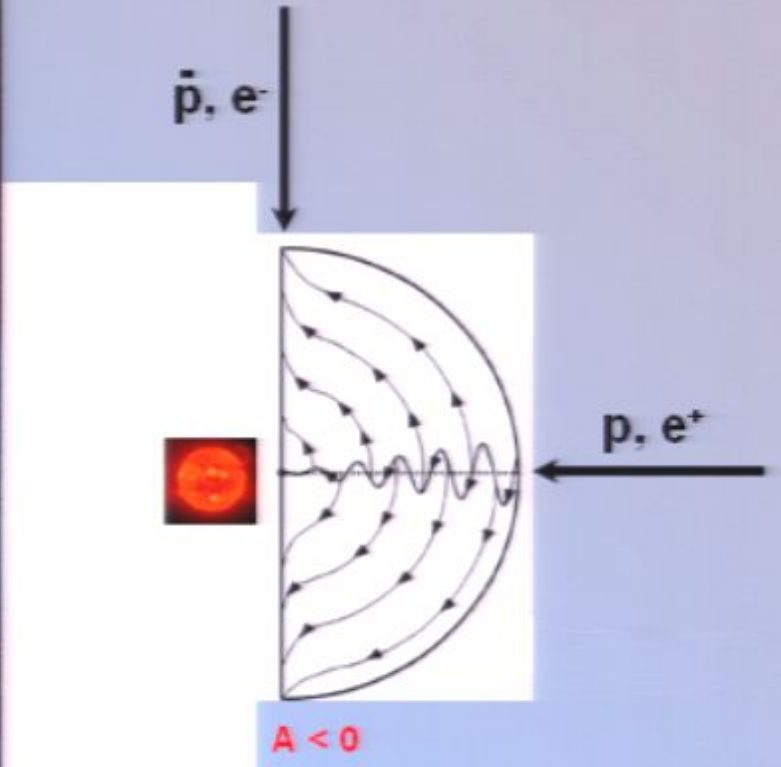
Solar modulation



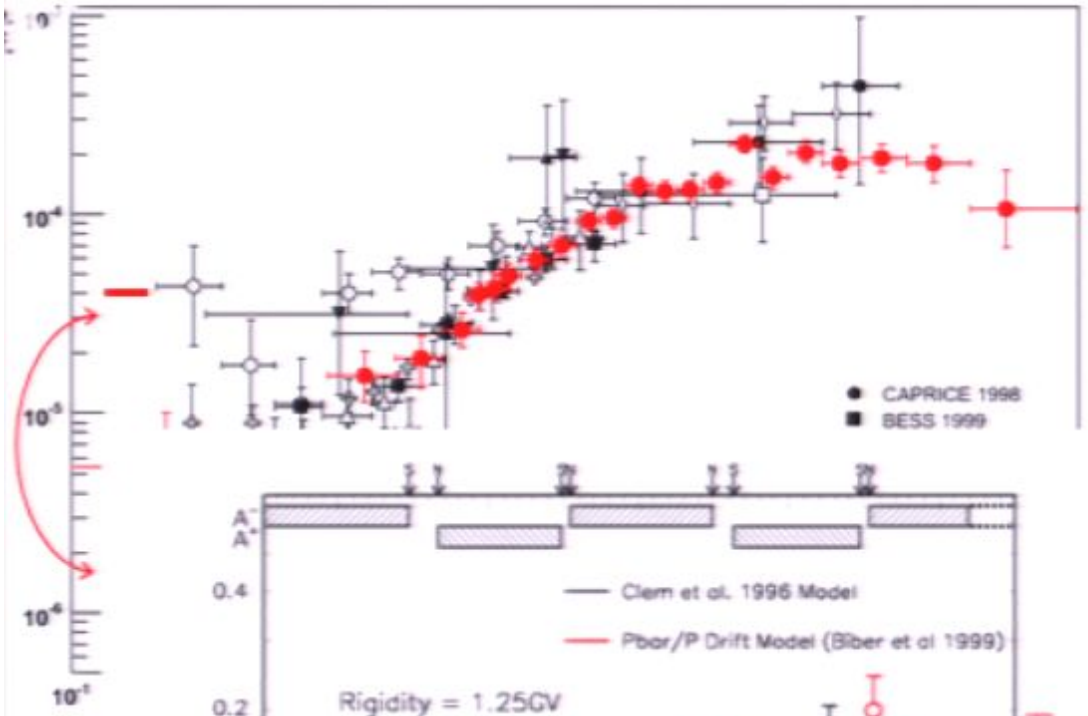
Solar modulation

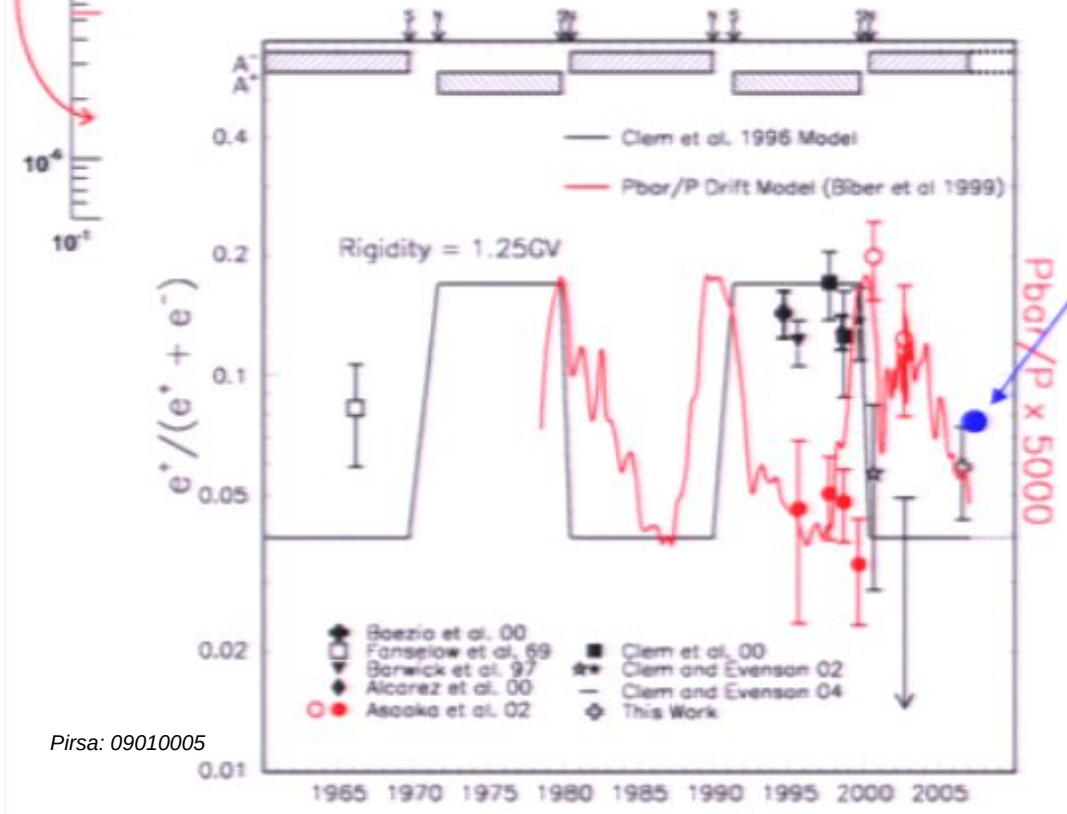


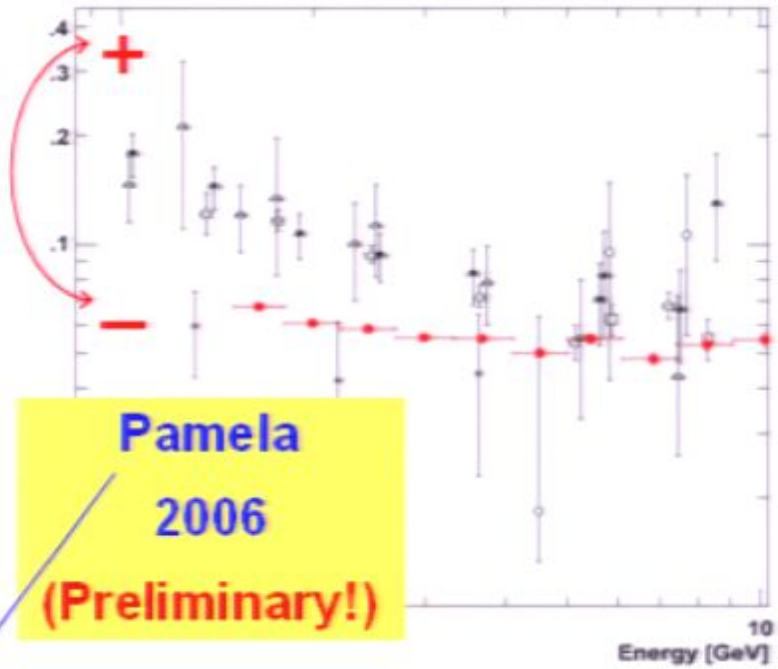

BOW SHOCK
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR IONS
VOYAGER 1
EARTH
SUN
SATURN
URANUS
INTERSTELLAR NEUTRALS
PIONEER 11
PIONEER 10
NEPTUNE
JUPITER
PLUTO
VOYAGER 2


p̄, e⁻
p, e⁺
A < 0

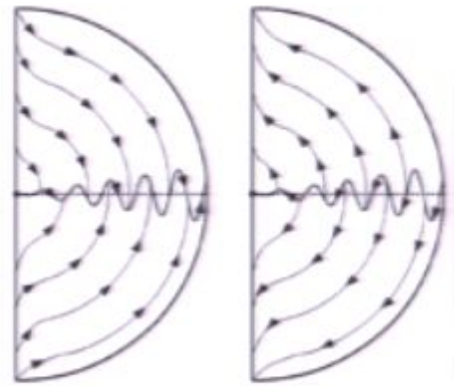
Charge dependent solar modulation







Pamela
2006
(Preliminary!)



A > 0 **A < 0**

Positive particles

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

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

Observed data by BESS

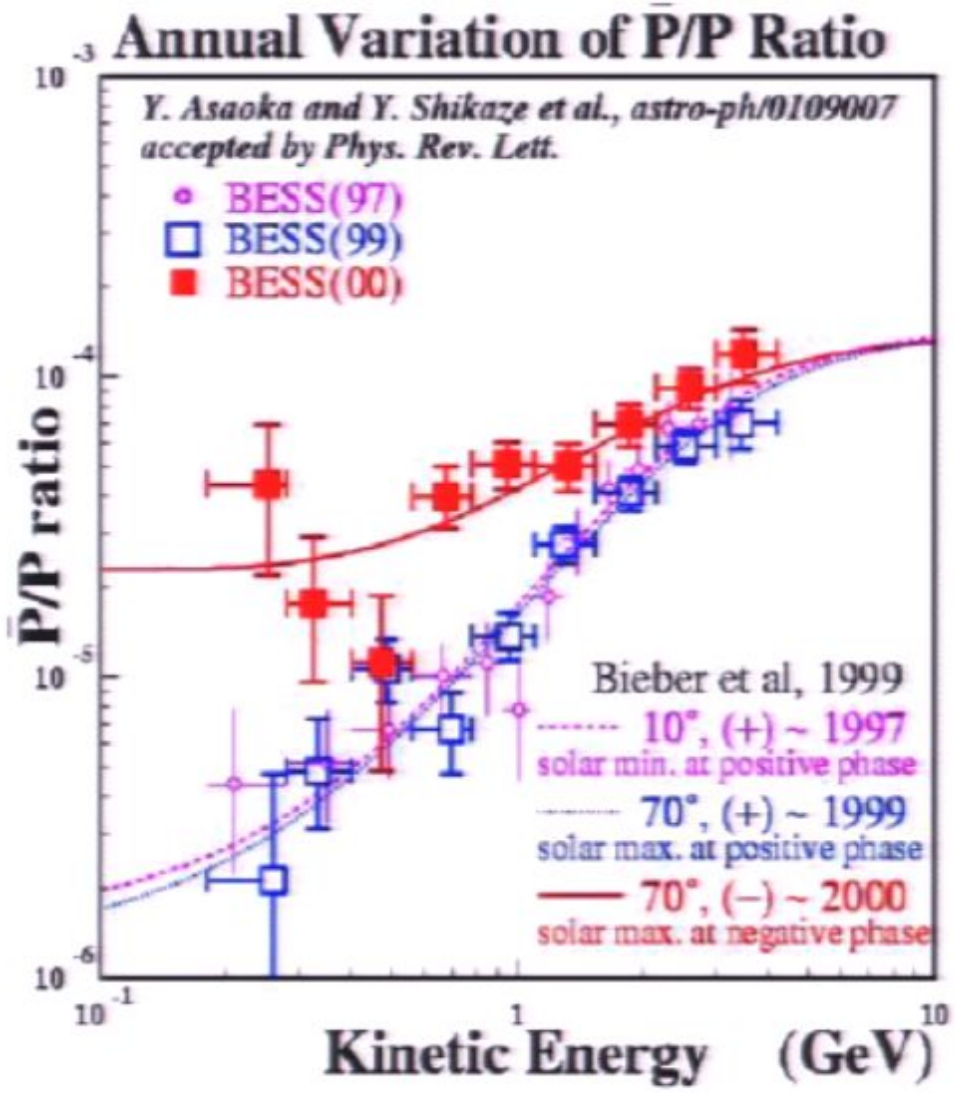
Charge dependent model

prediction(Bieber et al.)

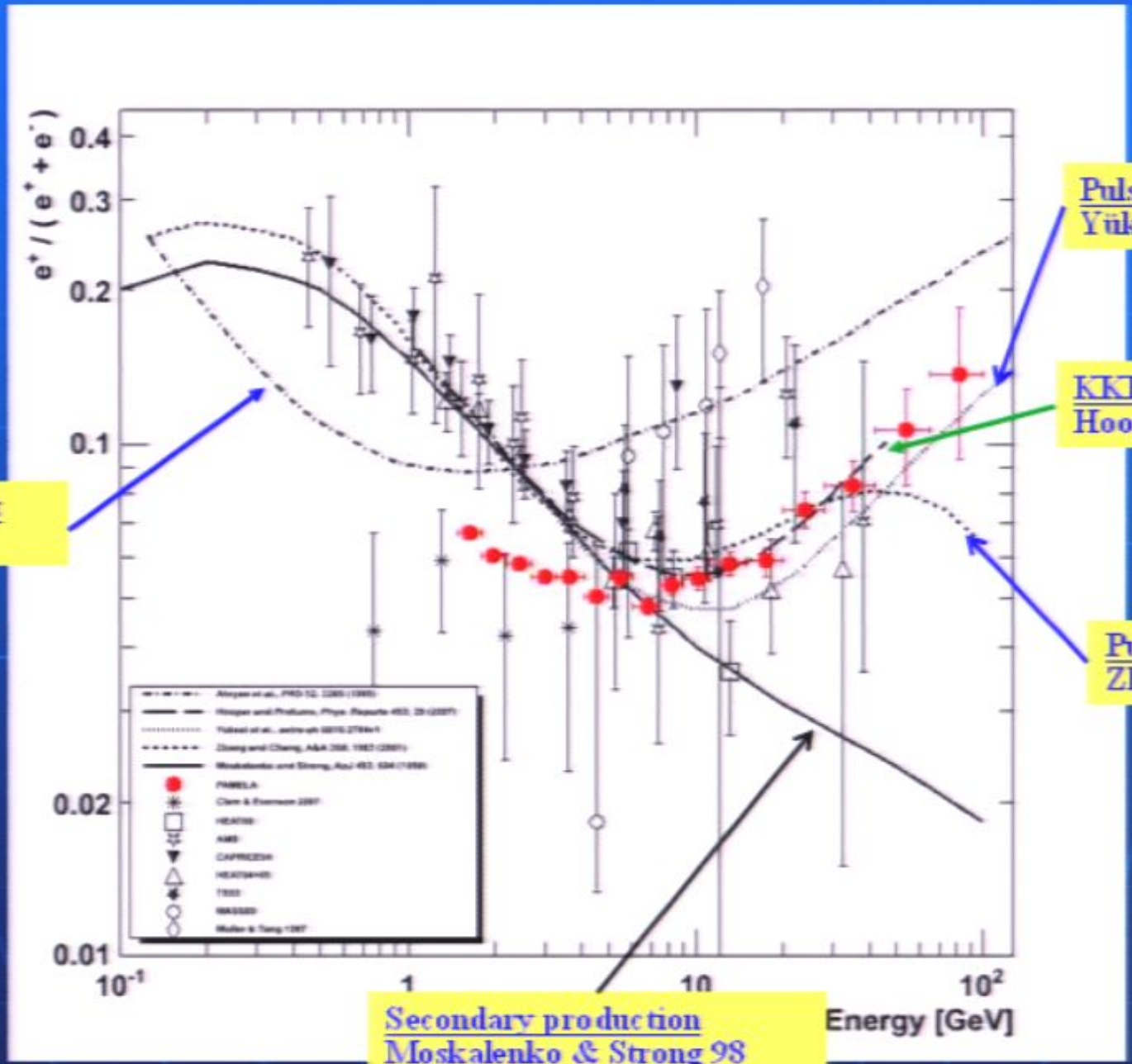
Charge dependent solar modulation model well follows

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

at the solar polarity reversal between 1999 and 2000



PAMELA Positron Fraction



Pulsar Component
Atoyan et al. 95

Pulsar Component
Yüksel et al. 08

KKDM (mass 300 GeV)
Hooper & Profumo 07

Pulsar Component
Zhang & Cheng 01

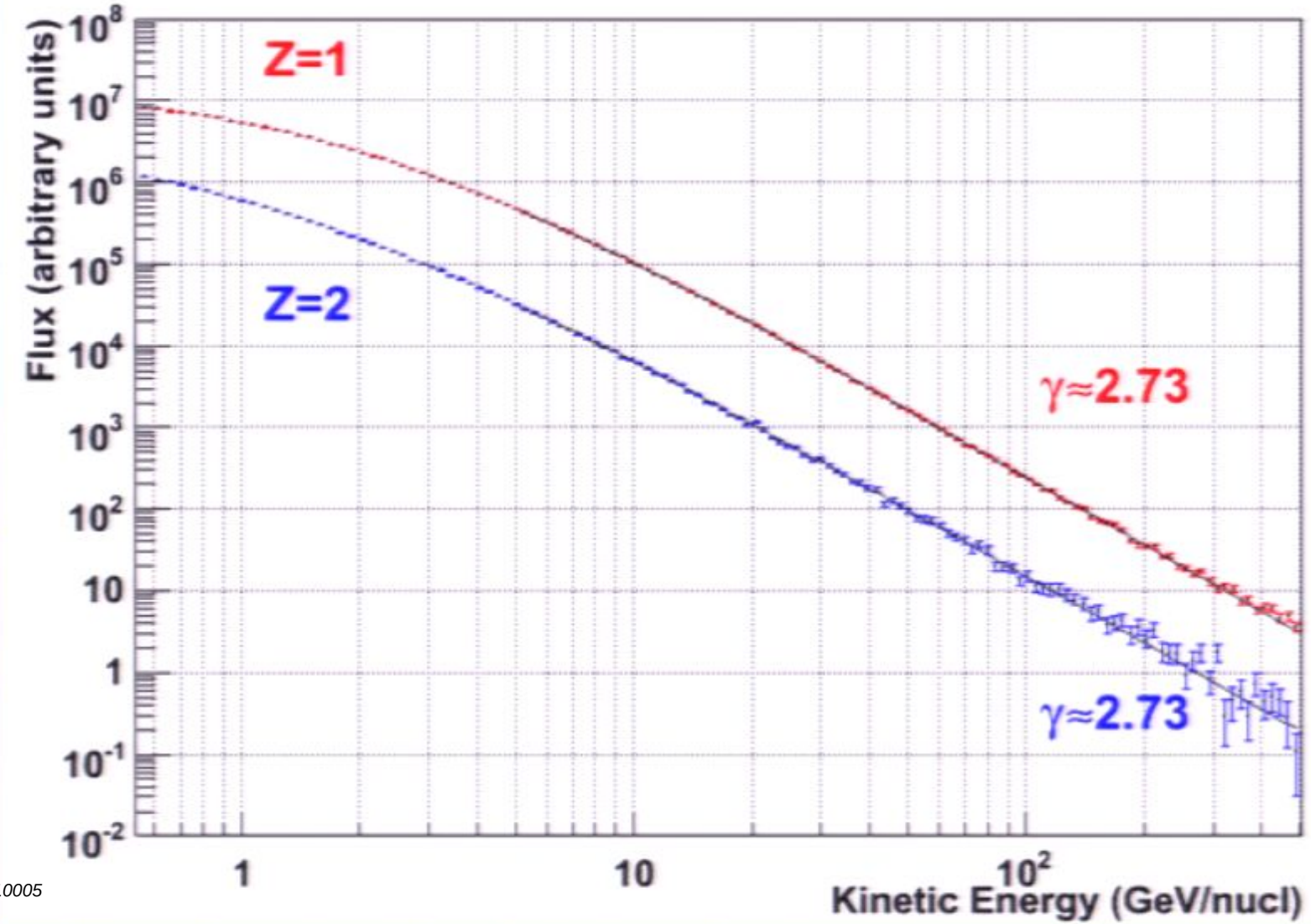
Secondary production
Moskalenko & Strong 98

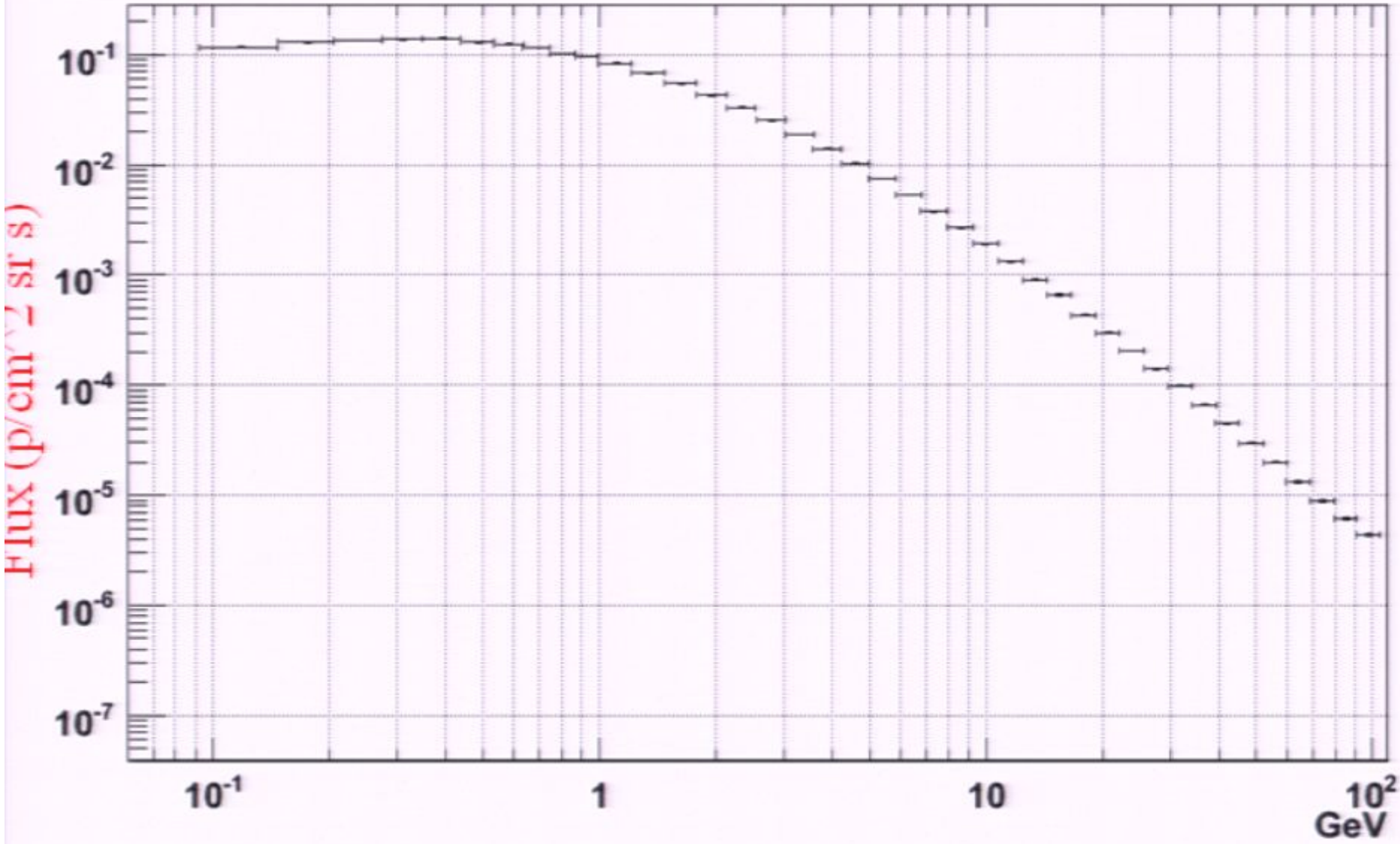
Secondary particles?

- Spectral feature in the proton flux responsible for secondaries
- Role of Helium nuclei in secondary production
- Difference between local and ISM spectrum of protons
- Anomalous energy-dependent behaviour of the diffusion coefficient
- Anomalous primary electron source spectrum

Galactic H and He spectra

Preliminary !!!



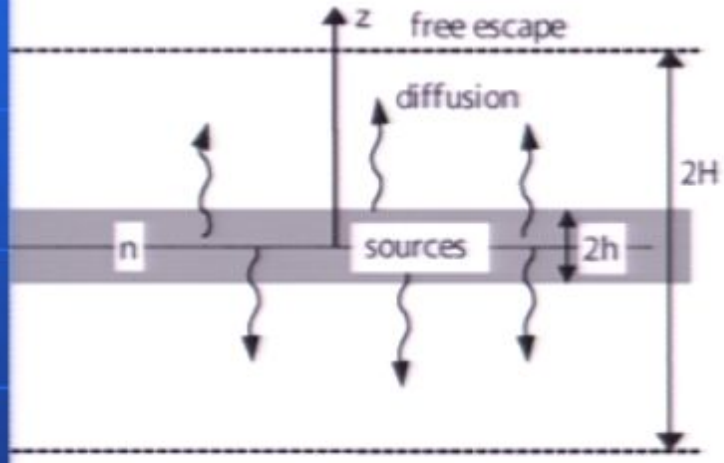


Kinetic Energy (GeV)

Proton flux July 2006

Diffusion Halo Model

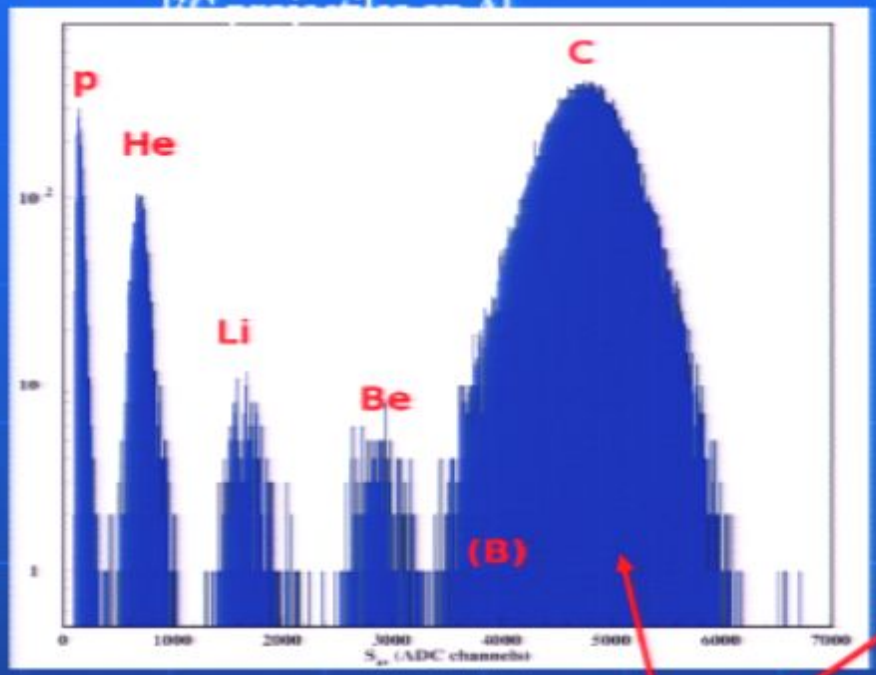
$$\frac{\partial N_i(E,z,t)}{\partial t} = \underbrace{D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t)}_{\text{diffusion}} - \underbrace{N_i(E,z,t)\left\{\frac{1}{\tau_i^{\text{int}}(E,z)}+\frac{1}{\gamma(E)\tau_i^{dec}}\right\}}_{\text{interaction and decay}}$$



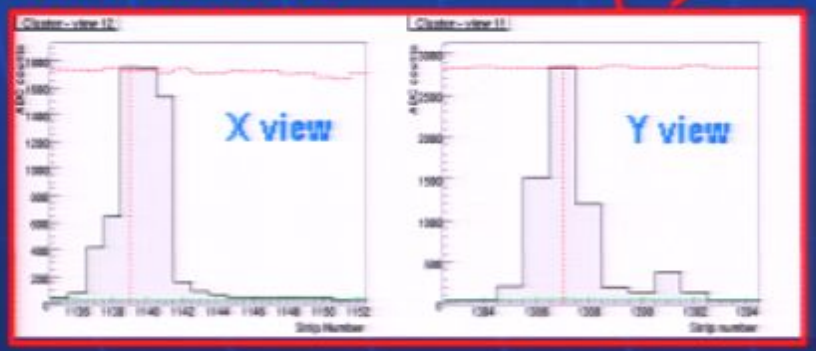
$$+ \underbrace{\sum_{k>i}\frac{N_k(E,z,t)}{\tau_{\text{int}}^{k\to i}(E,z)}}_{\text{secondary production}} + \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

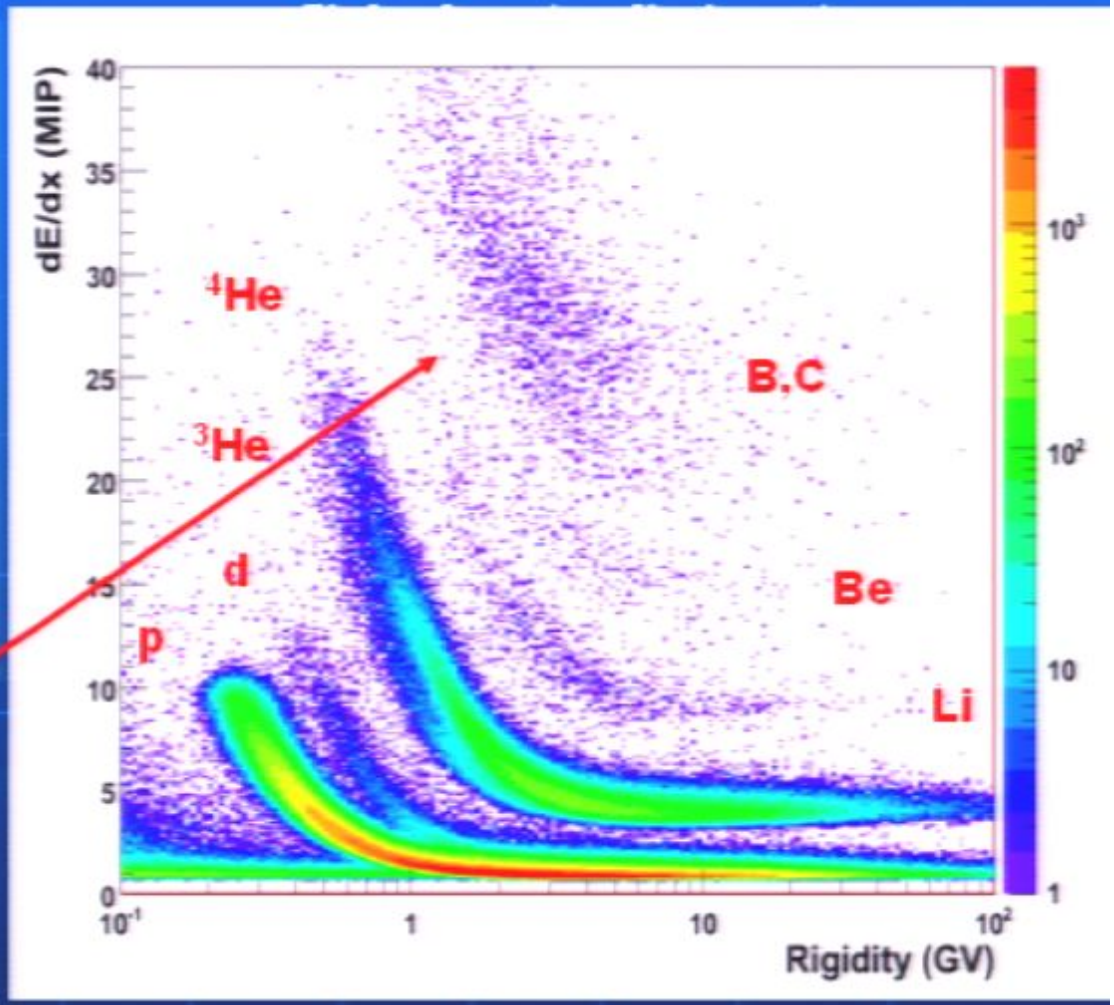
$$\underbrace{-\frac{\partial}{\partial E}\left\{\left\langle\frac{\partial E}{\partial t}\right\rangle\cdot N_i(E,z,t)\right\}+\frac{1}{2}\frac{\partial^2}{\partial E^2}\left\{\left\langle\frac{\Delta E^2}{\Delta t}\right\rangle\cdot N_i(E,z,t)\right\}}_{\text{energy changing processes (ionisation, reacceleration)}}$$

Charge identification capabilities (tracker)



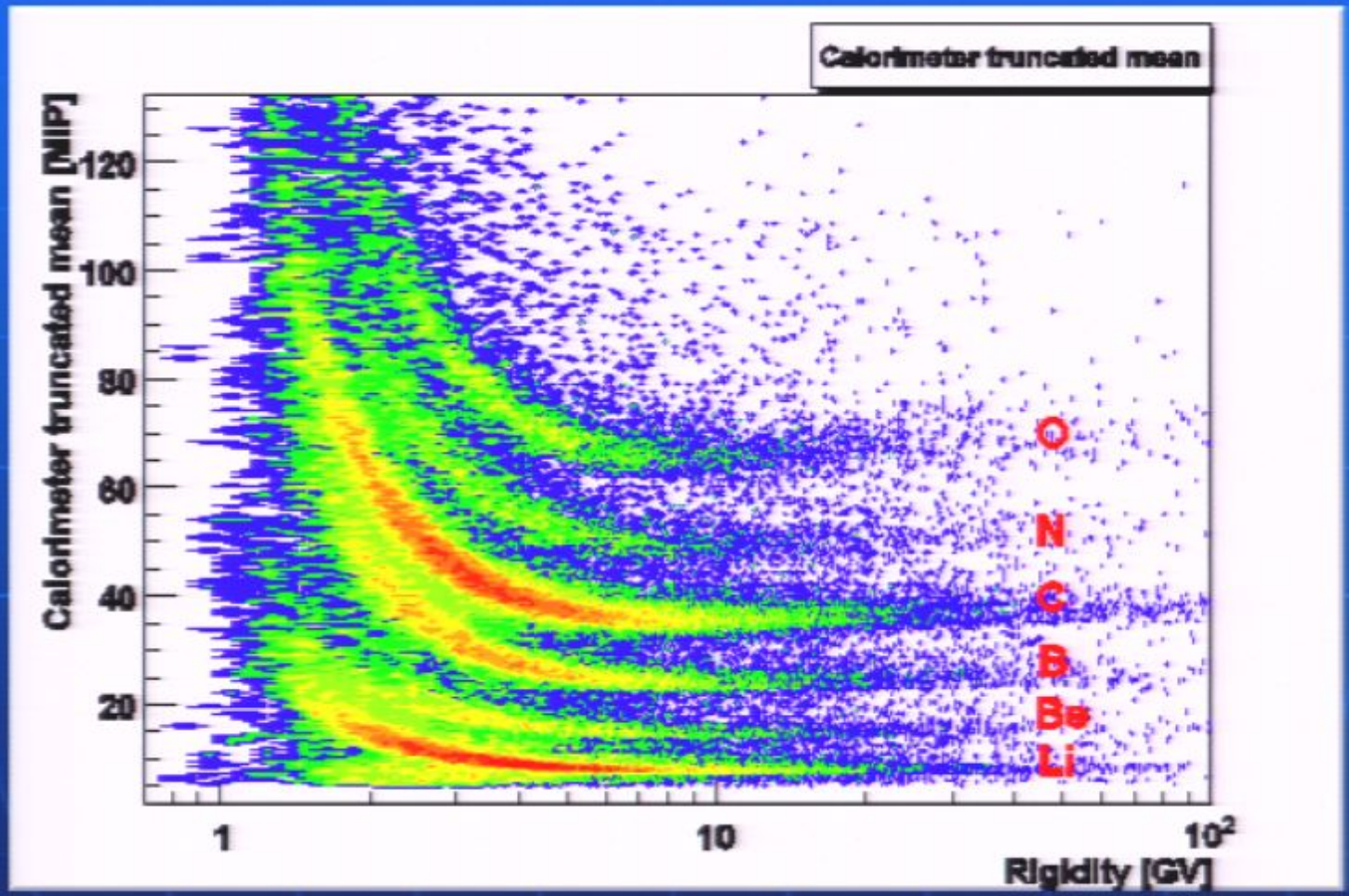
Saturated clusters





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

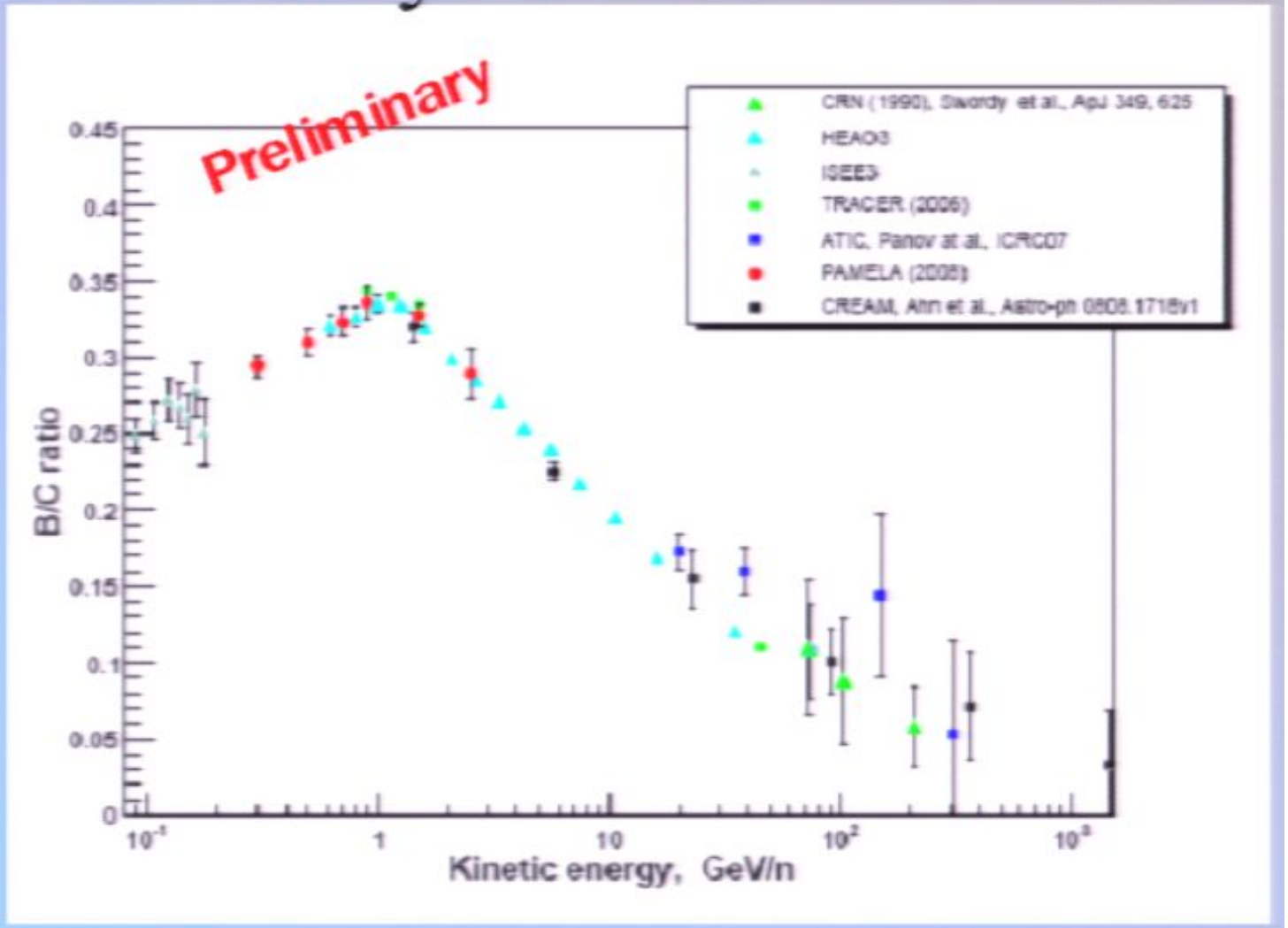
Charge identification capabilities (calorimeter)



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

Preliminary!!

Secondary nuclei



Secondary nuclei

Preliminary!!

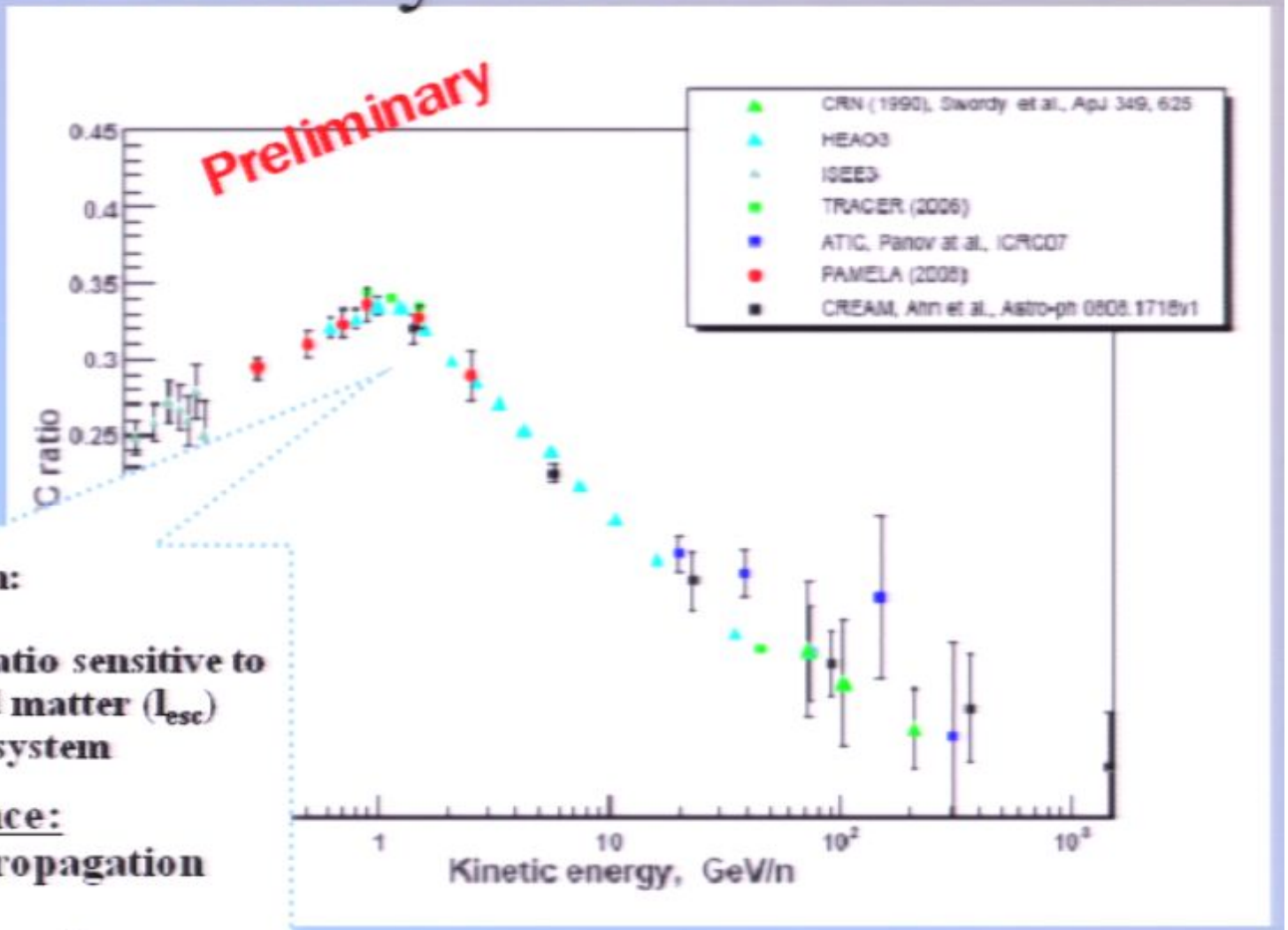
LBM

$$\frac{N_S}{N_P} \propto \lambda_{esc} \cdot \sigma_{P \to S}$$

- **B nuclei of secondary origin:**
  $CNO + ISM \rightarrow B + \ldots$
- **Local secondary/primary ratio sensitive to average amount of traversed matter (l_{esc}) from the source to the solar system**

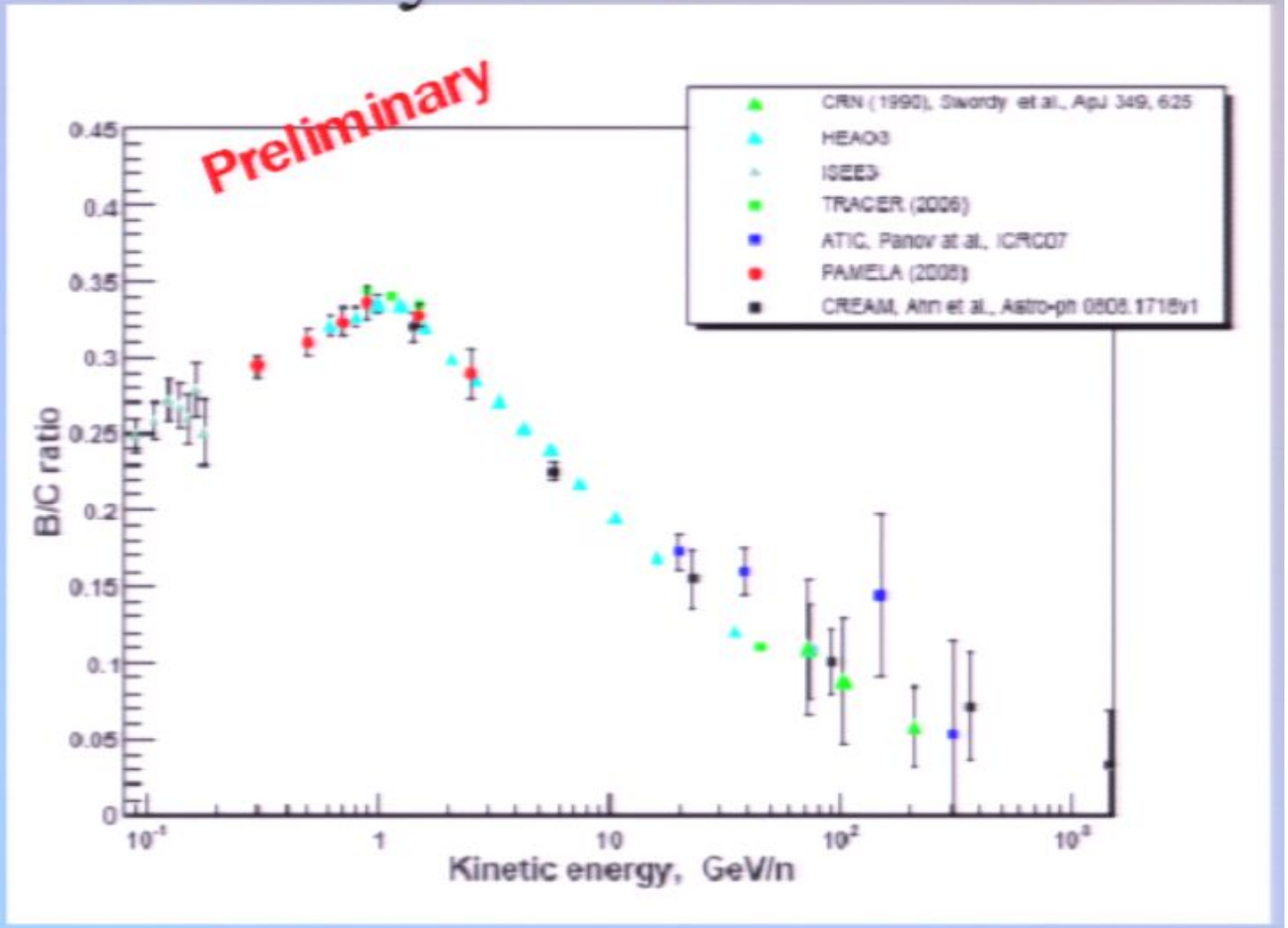
Local secondary abundance:
⇒ **study of galactic CR propagation**

(B/C used for tuning of propagation models)



Preliminary!!

Secondary nuclei



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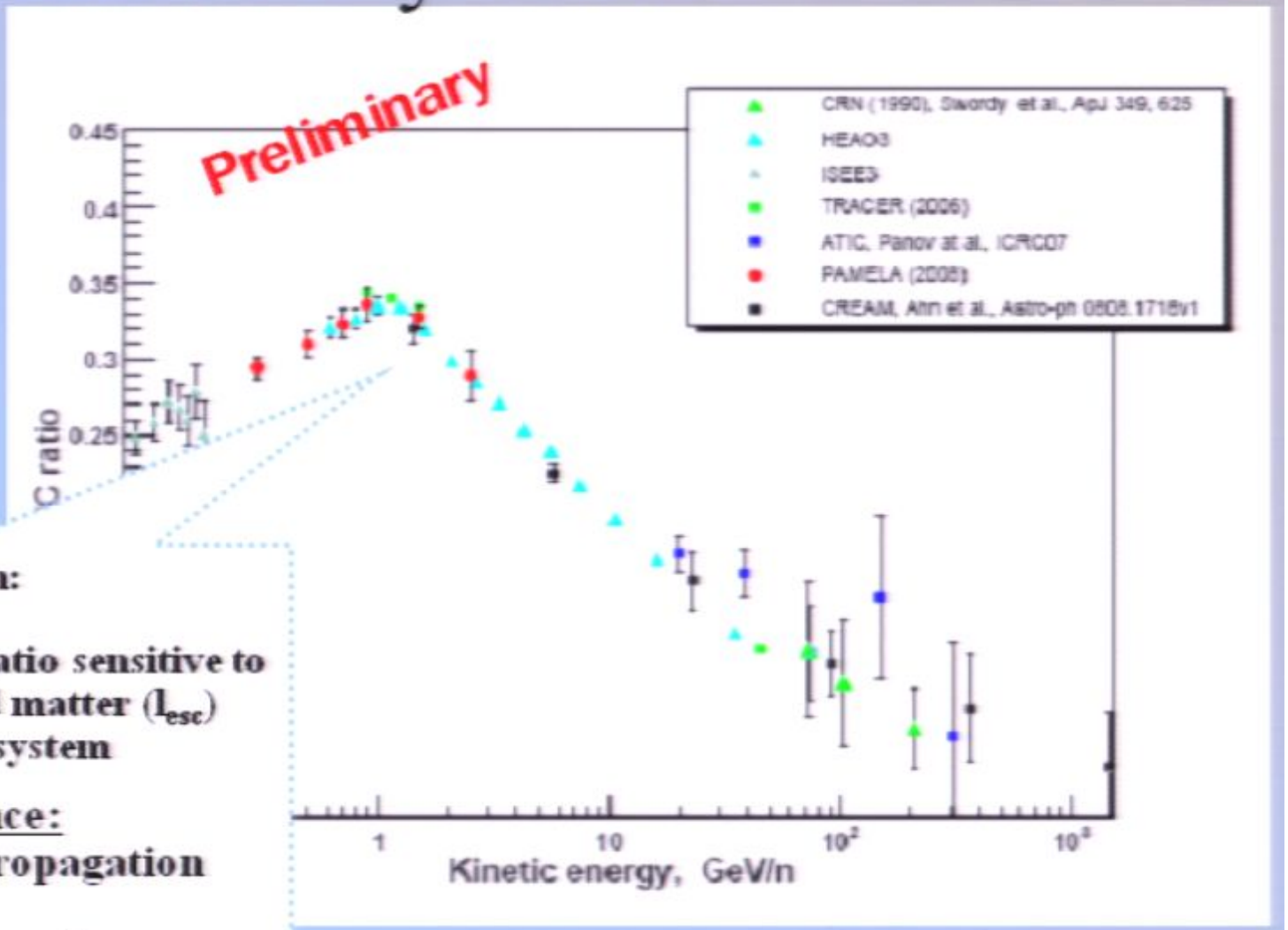
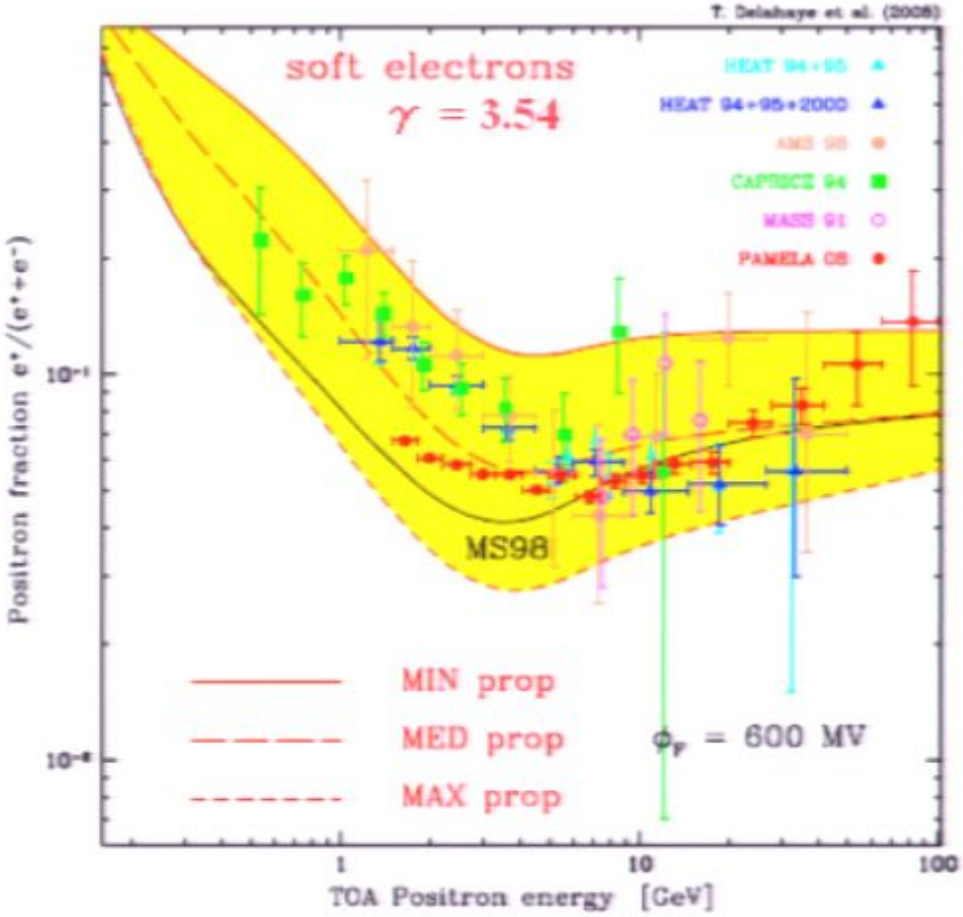
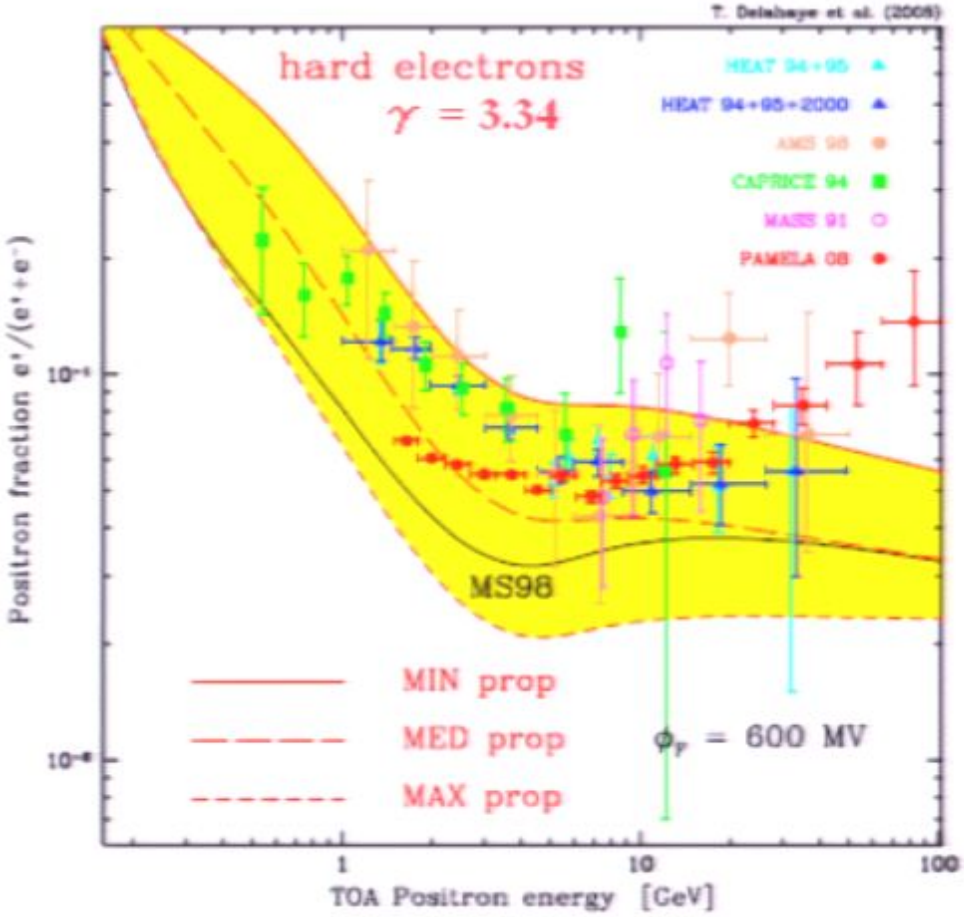


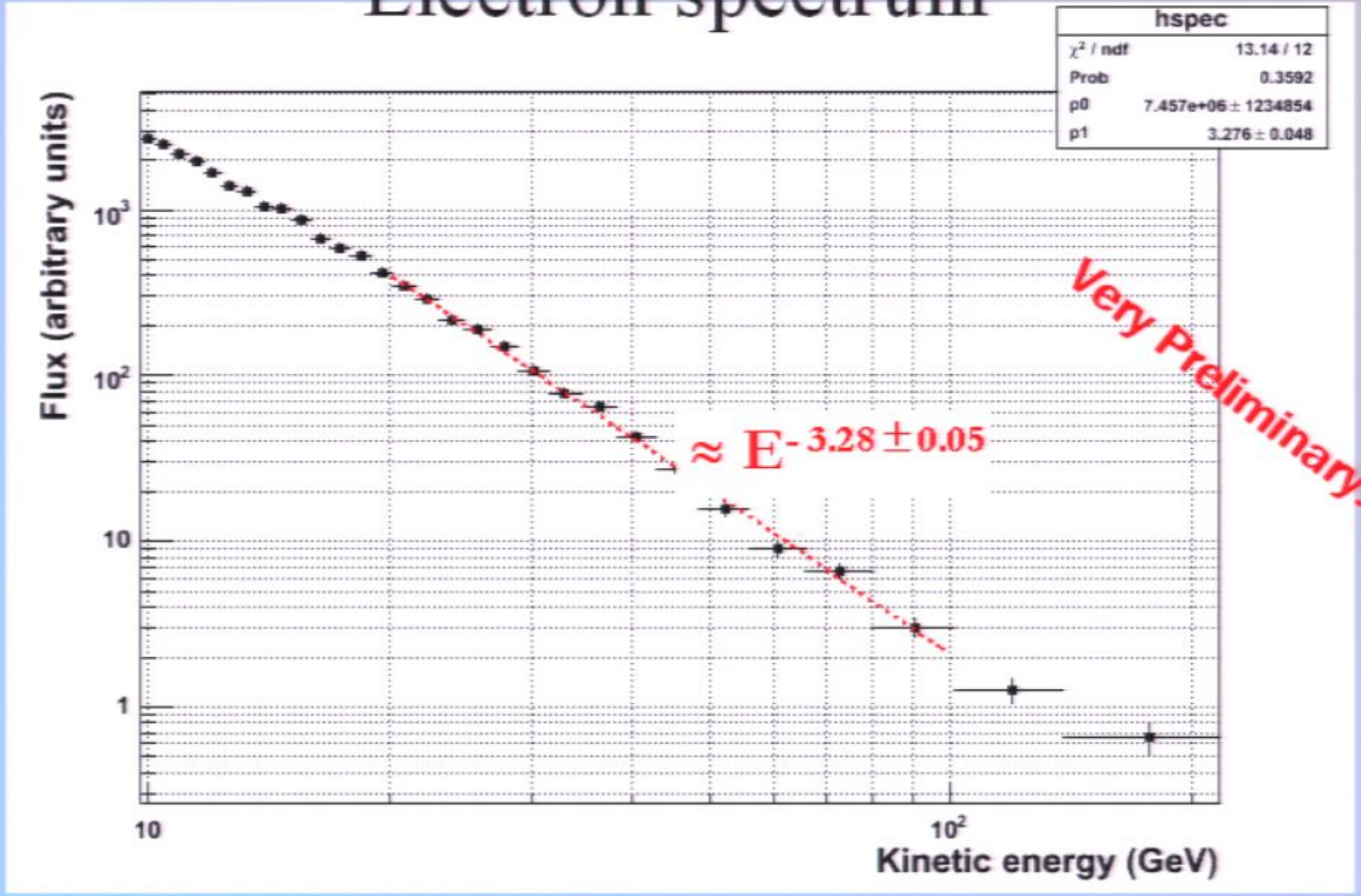
Theoretical uncertainties on "standard" positron fraction



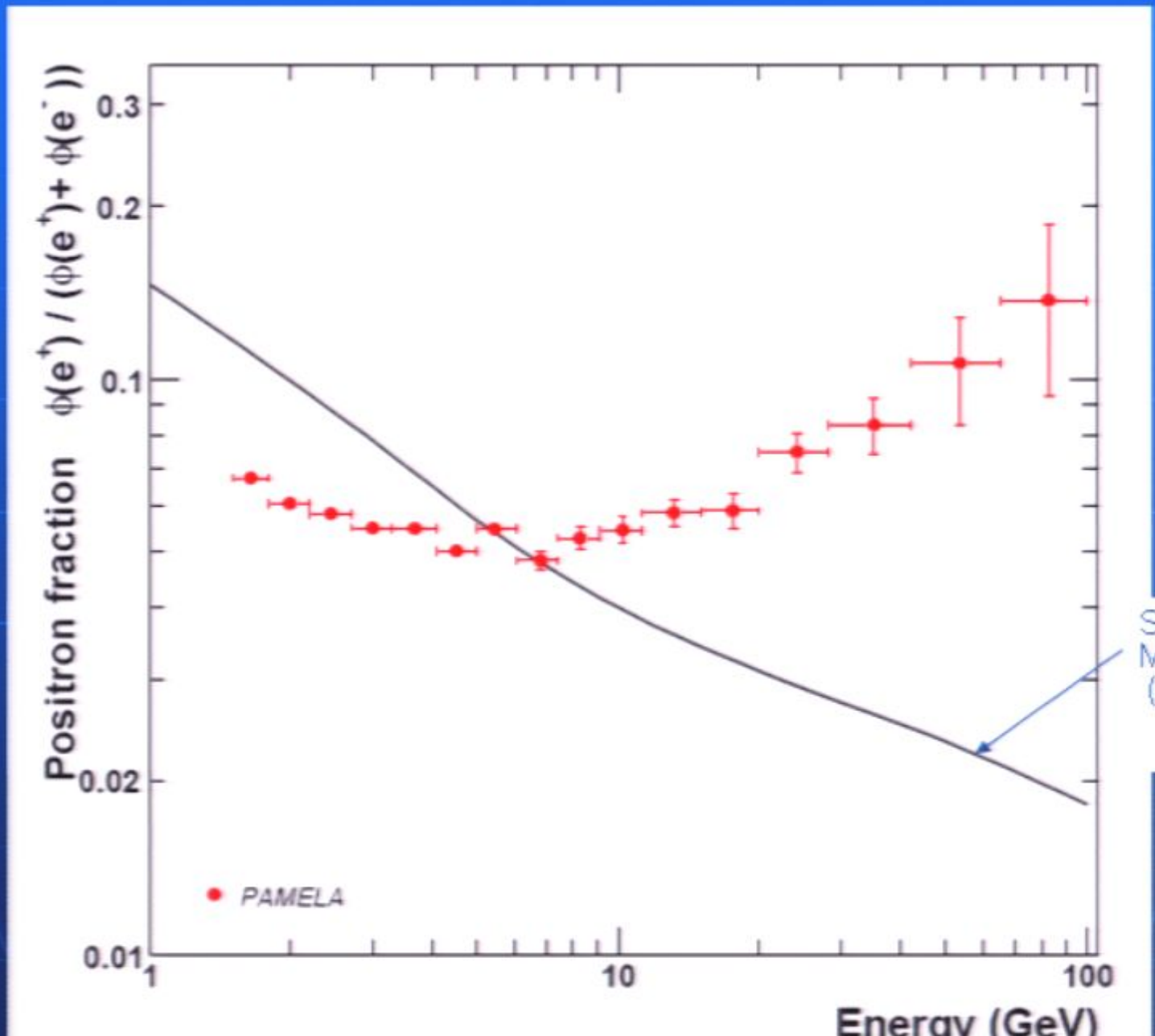


T. Delahaye et al., arXiv: 0809.5268v3

Electron spectrum

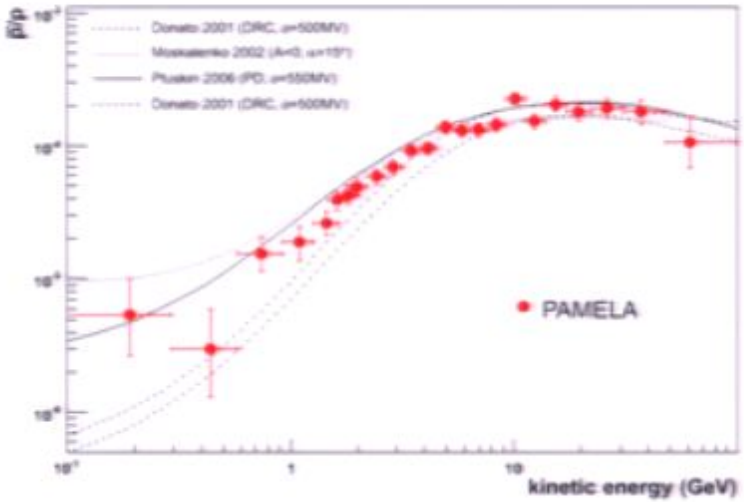


Positron to Electron Ratio

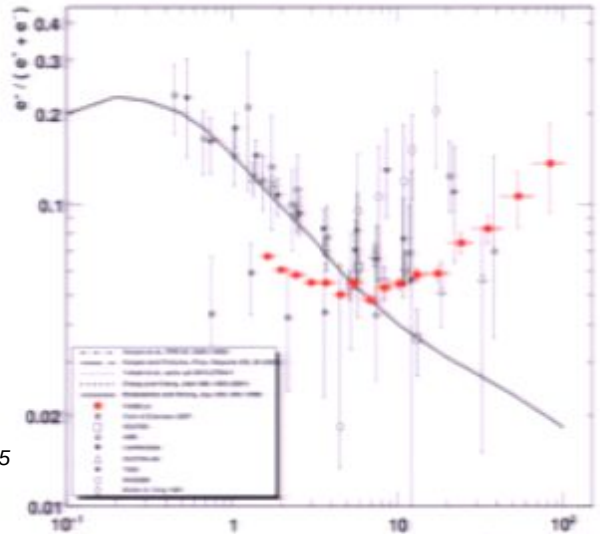


During first week after PAMELA results posted on arXiv

PRL, under review (arXiv 0810.4994)

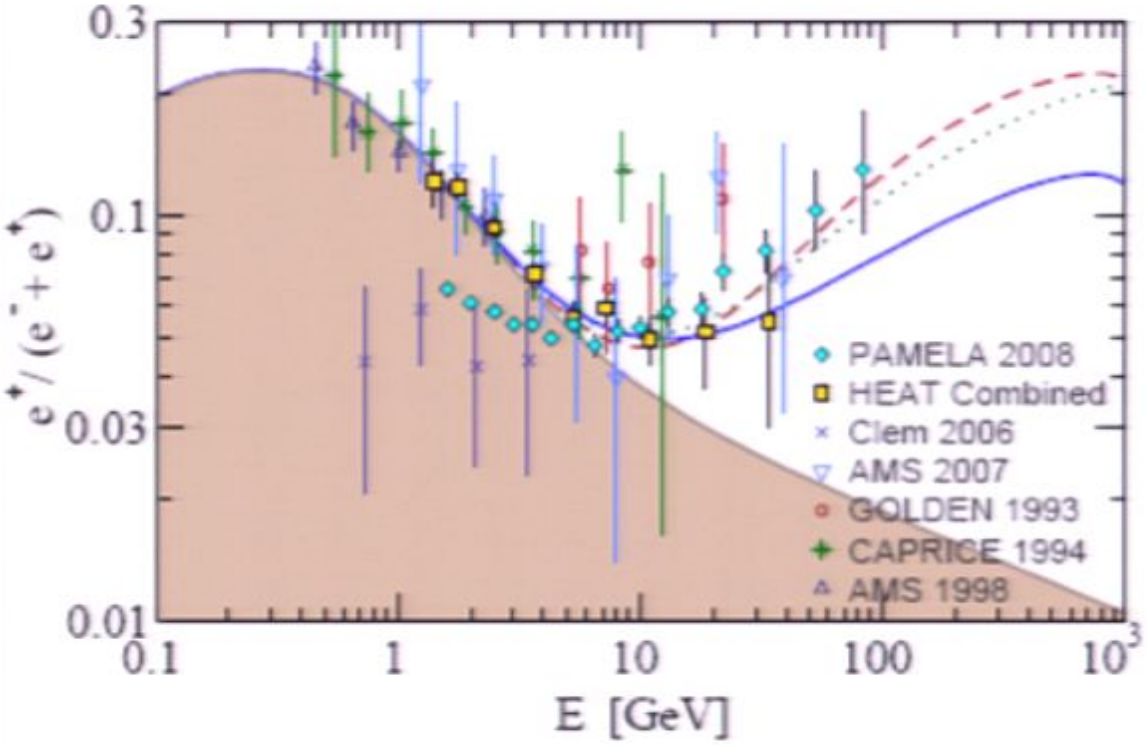


arXiv 0810.4995)

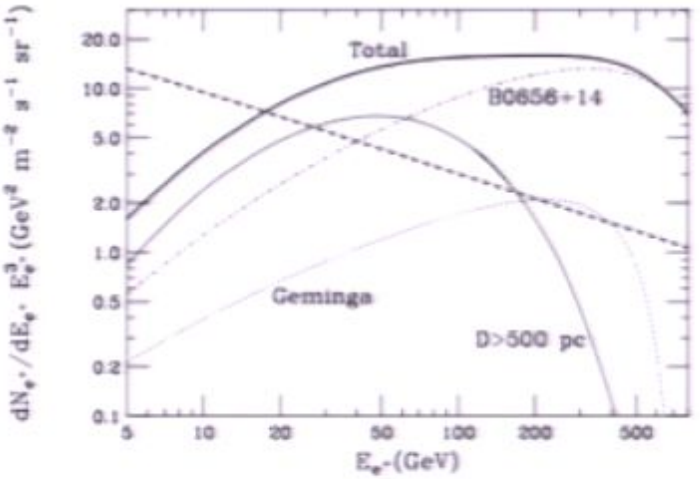


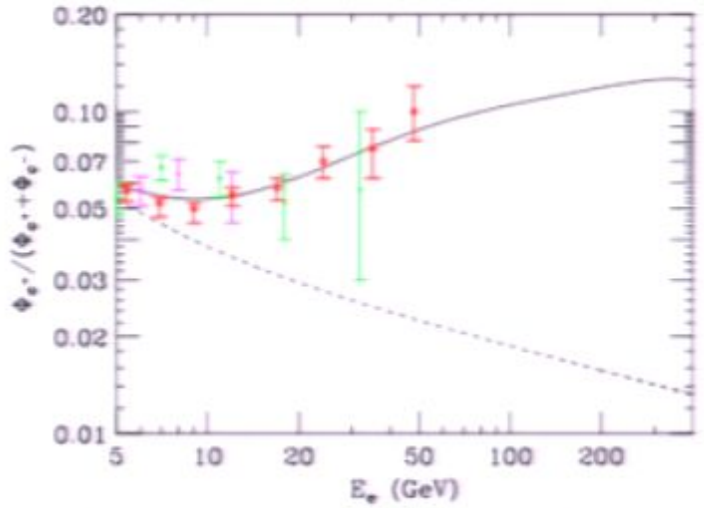
- 0808.3725 DM
- 0808.3867 DM
- 0809.2409 DM
- 0810.2784 Pulsar
- 0810.4846 DM / pulsar
- 0810.5292 DM
- 0810.5344 DM
- 0810.5167 DM
- 0810.5304 DM
- 0810.5397 DM
- 0810.5557 DM
- 0810.4147 DM
- 0811.0250 DM
- 0811.0477 DM

Example: pulsars



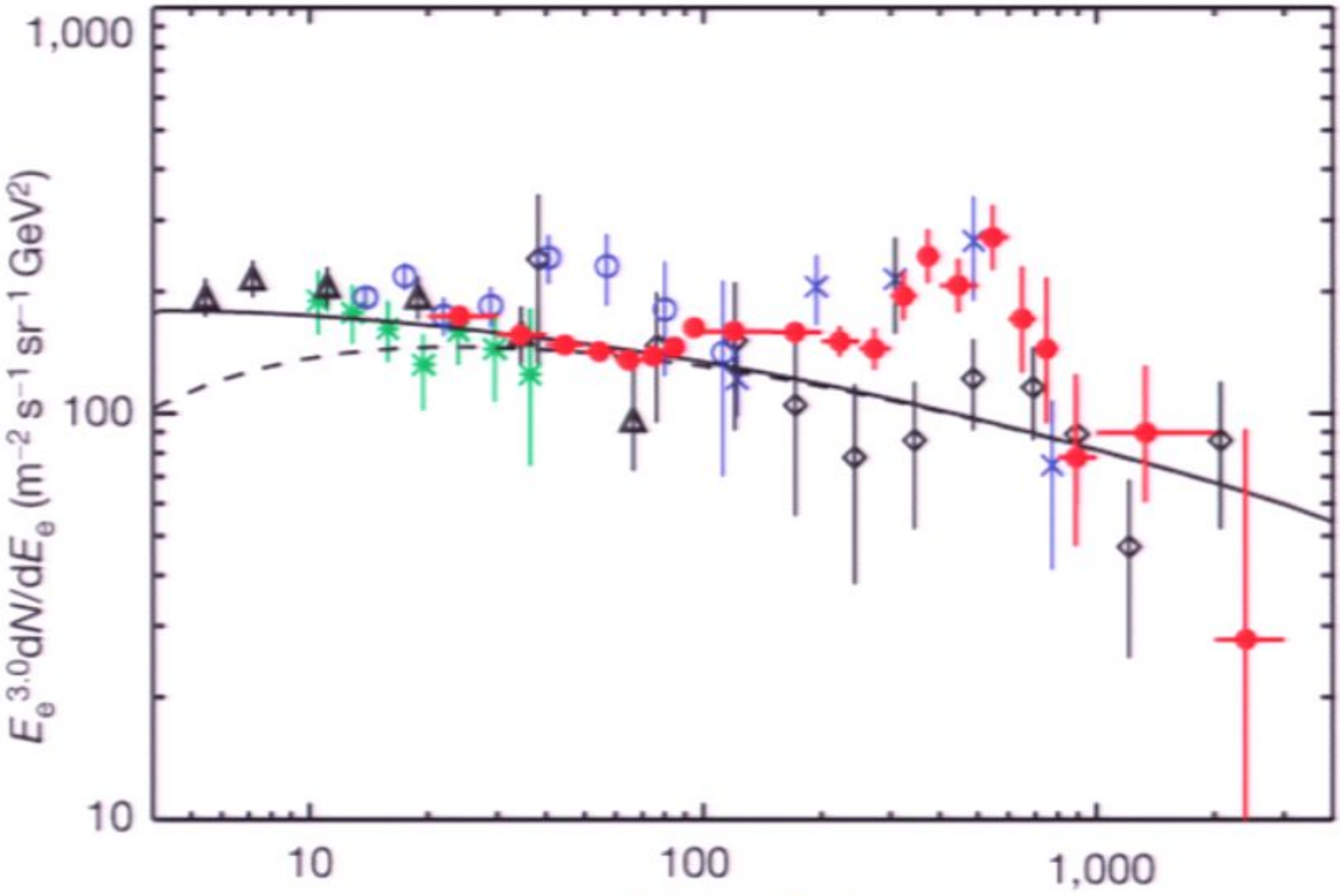
H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar





Hooper, Blasi, and Serpico
arXiv:0810.1527

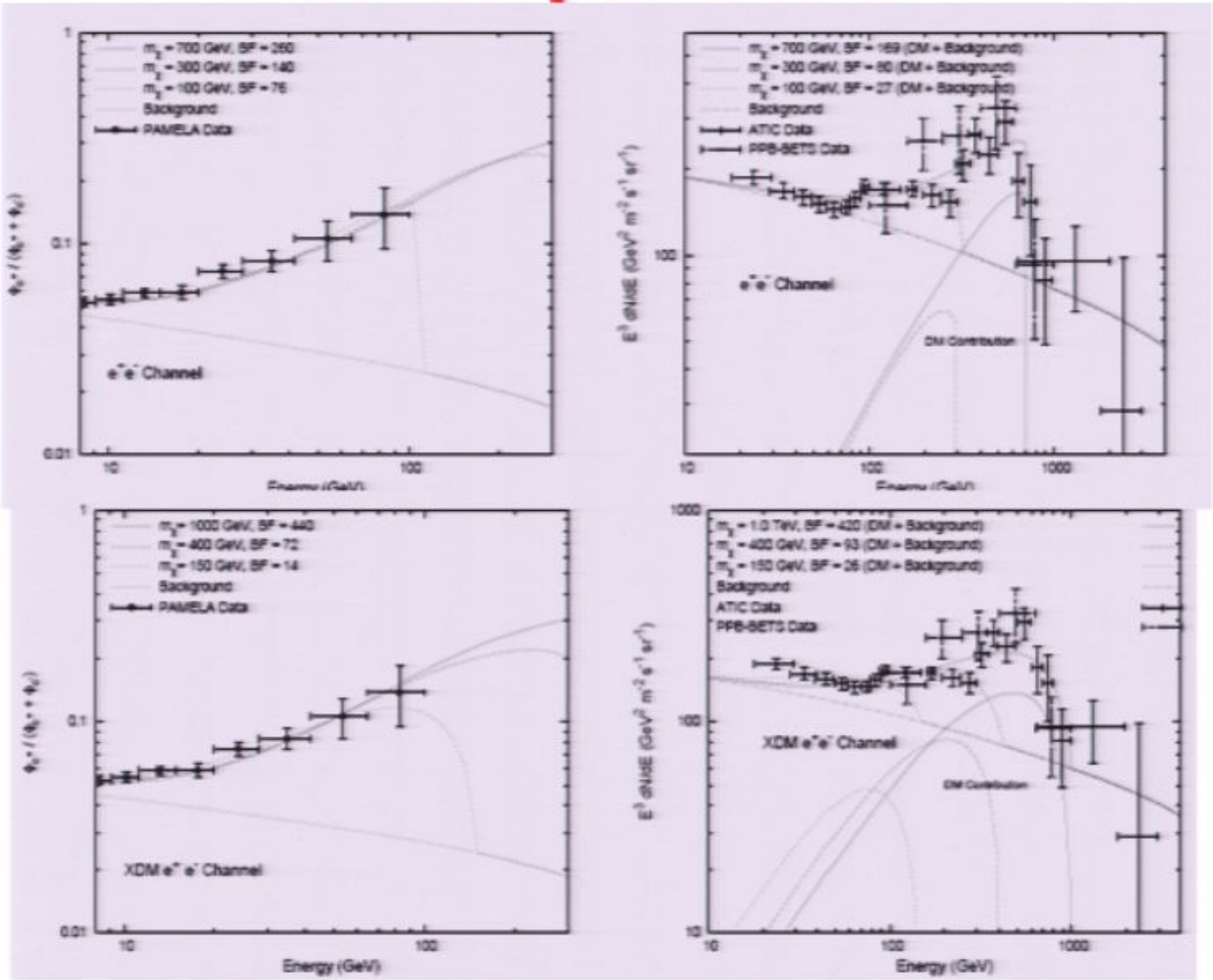
ATIC Results



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

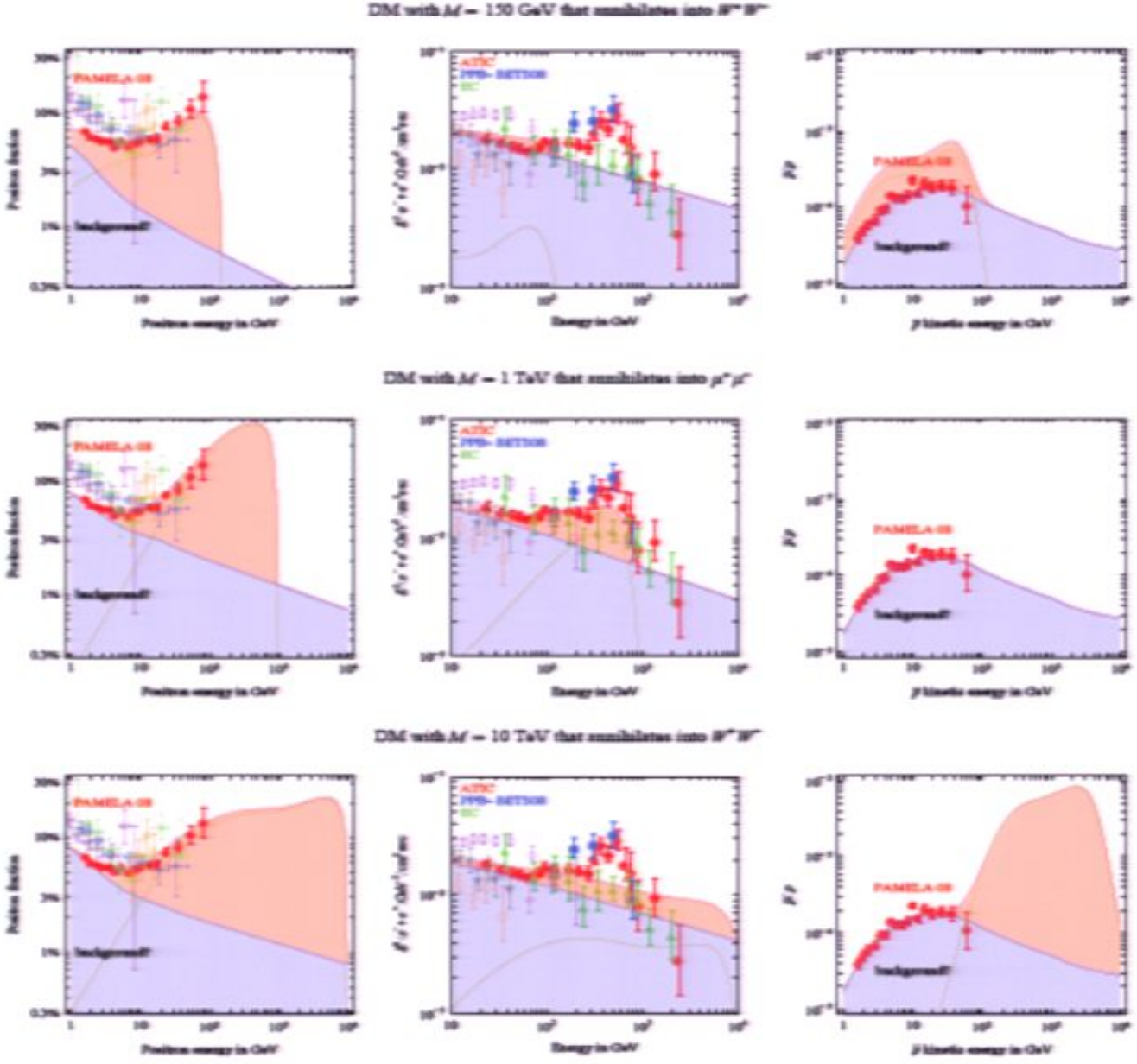
Nature

Example: DM



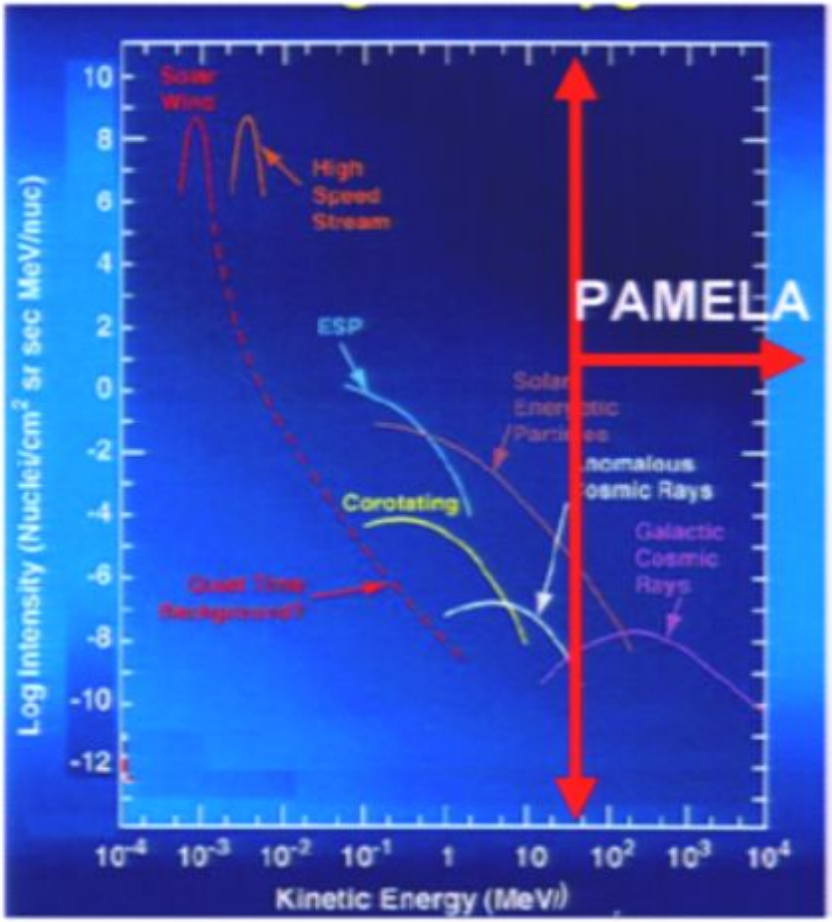
I. Cholis et al. arXiv:0811.3641v1

Example: e^-, $e^- + e^+$, $\bar{p}$ with DM



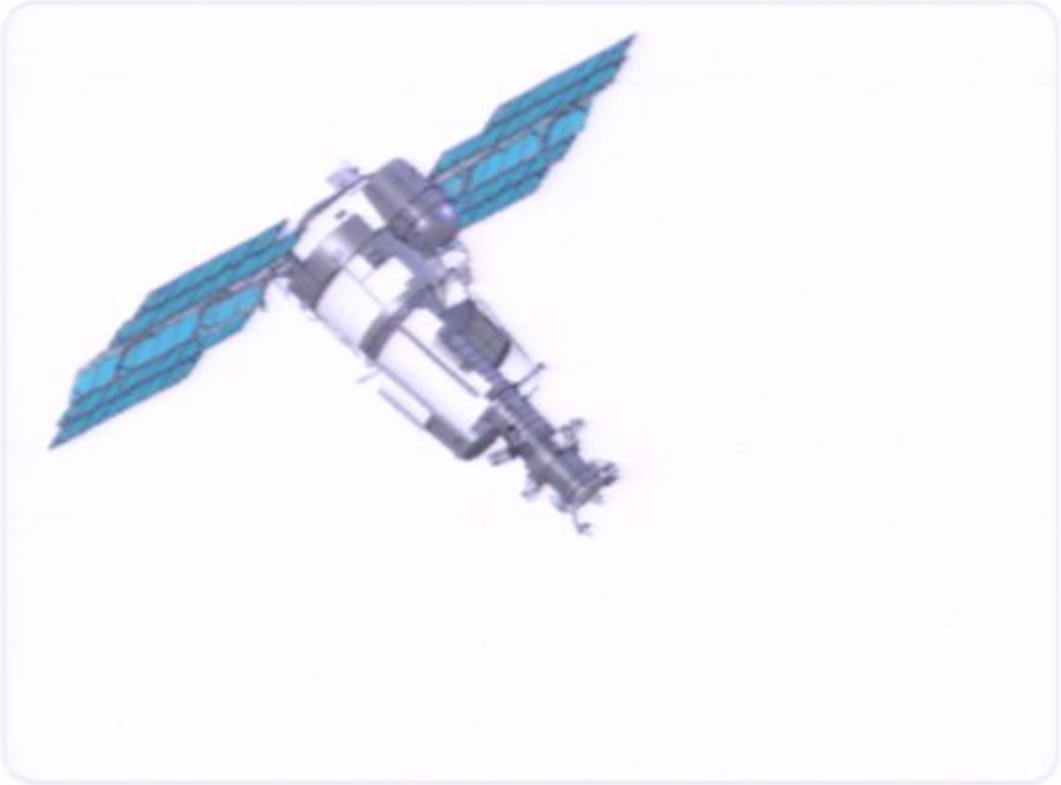
M. Cirelli et al., arXiv: 0809.2409v3

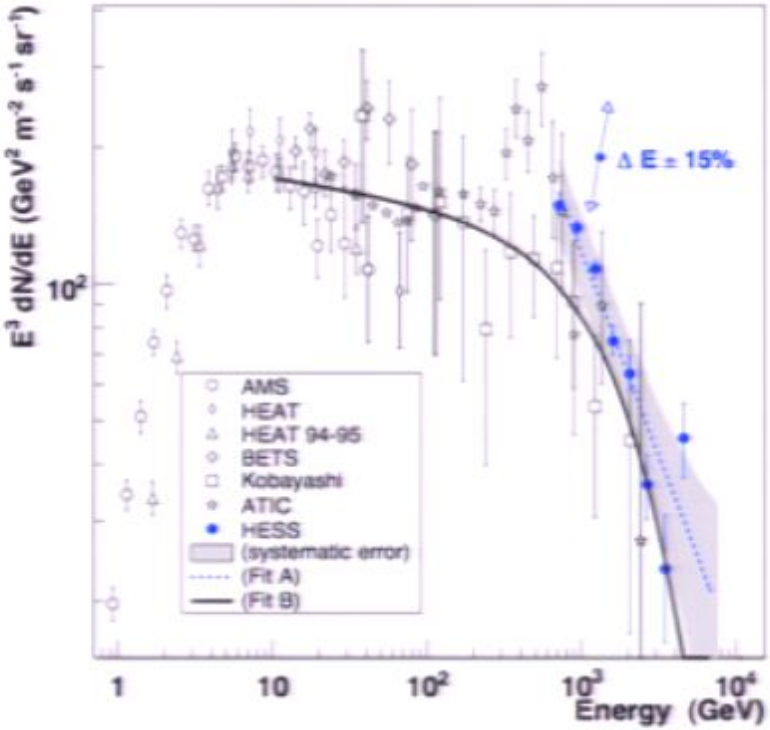
Solar Physics with PAMELA



- 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
- ^{3}He and ^{4}He isotopic composition

Future observations of electrons





Fermi GST: $\Phi_{e^\pm}$ up to ~700 GeV