Detection of Antiparticles with the Pamela Space Instrument for Antimatter and Dark Matter Research

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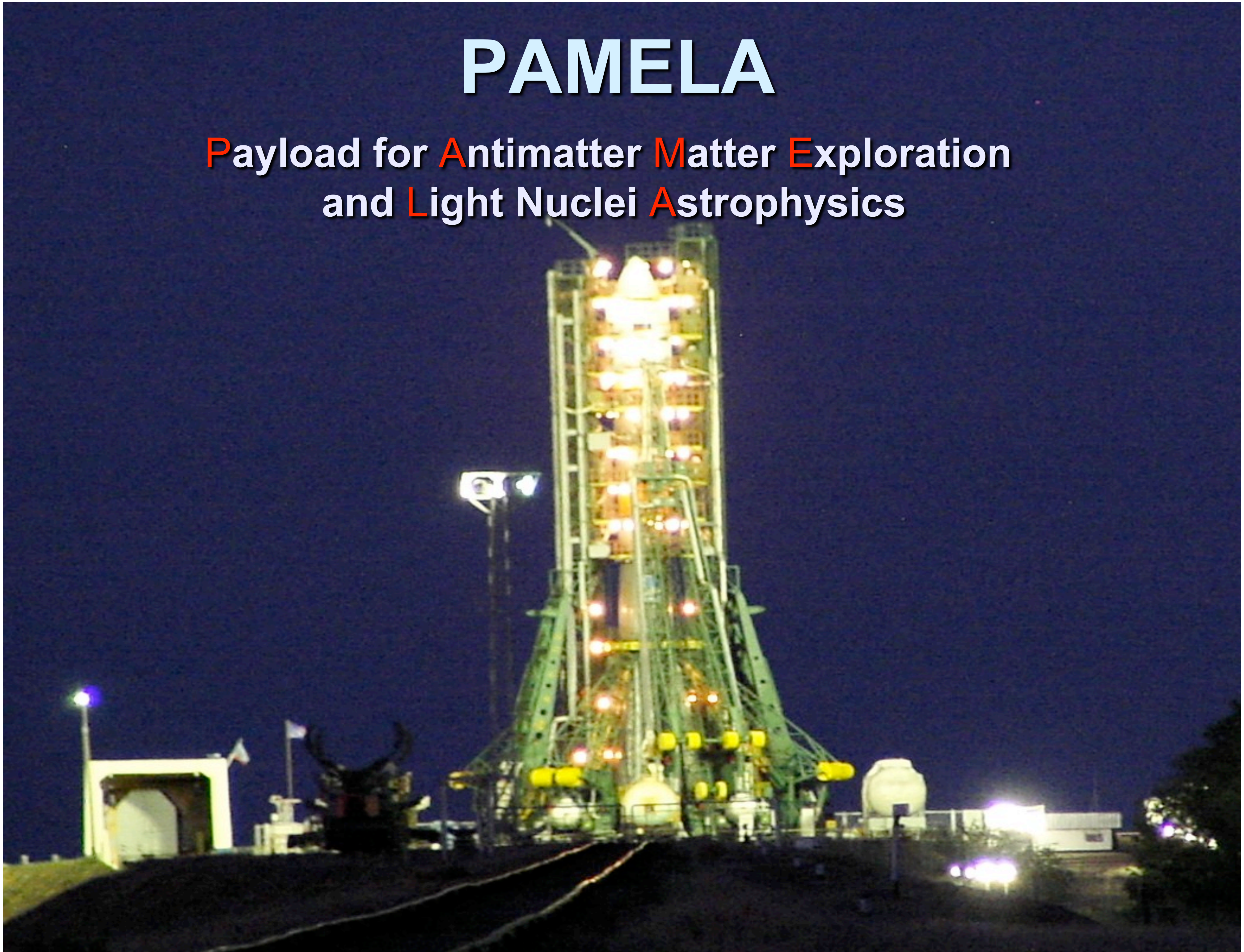
DESY

Zeuthen
February 25th, 2009

PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics



PAMELA Collaboration

Italy:

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

Russia:

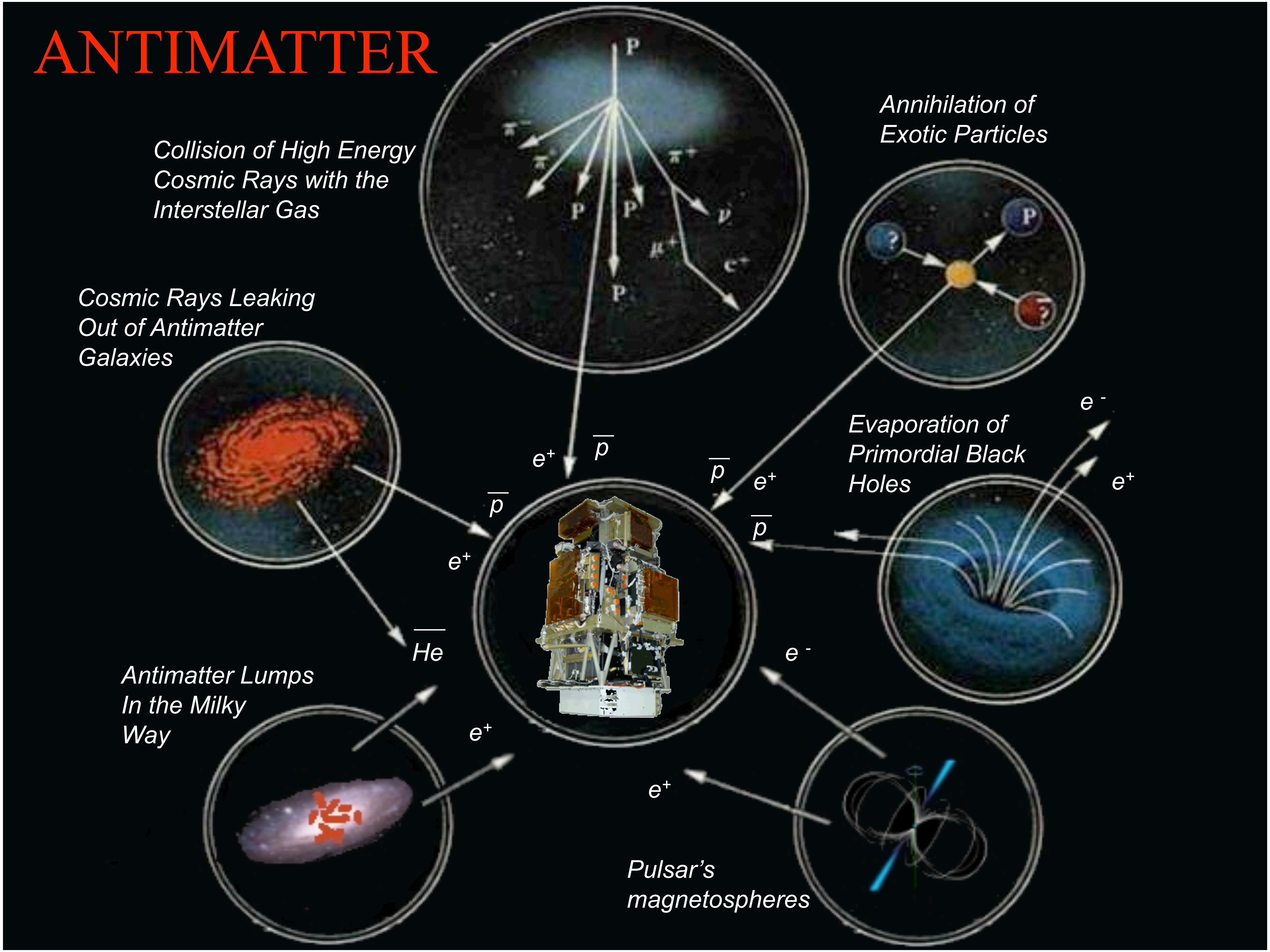
Moscow
St. Petersburg

Germany:

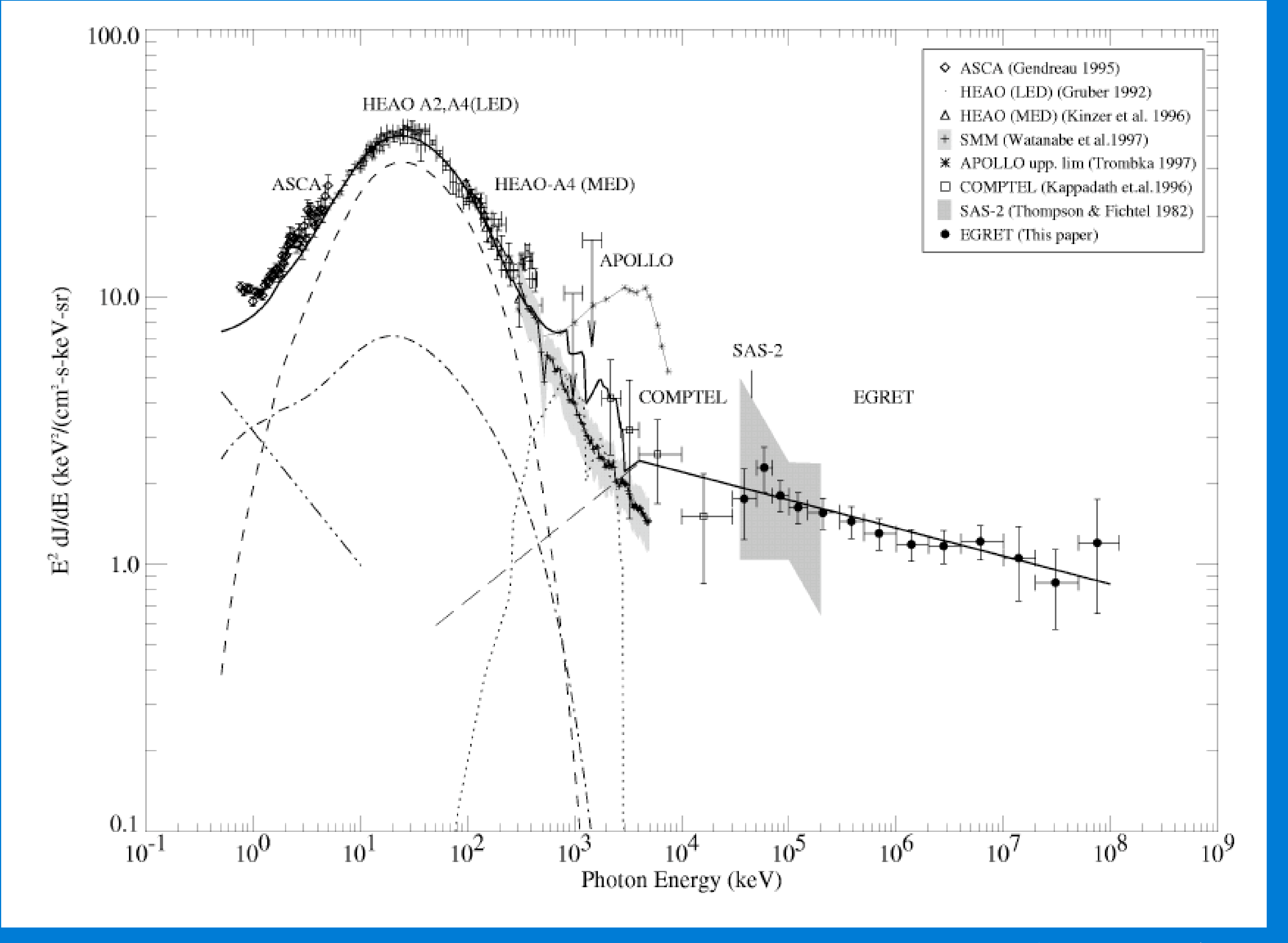
Siegen

Sweden:

KTH, Stockholm


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
e^+
$\bar{p}$
e^-
$\overline{He}$

Cosmic Diffuse Gamma

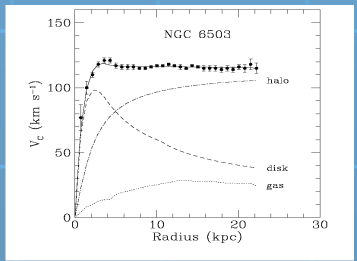


P. Sreekumar et al, astroph/9709257

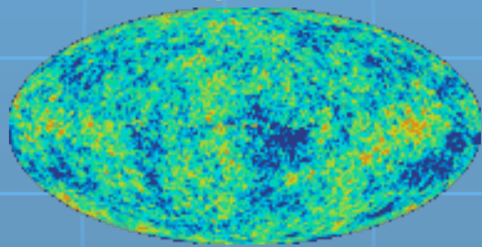
Dark Matter

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:

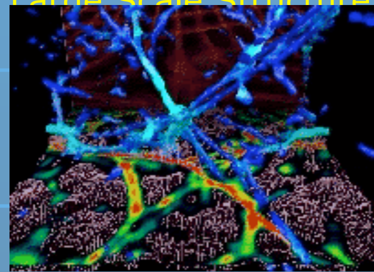
Rotation curves of galaxies



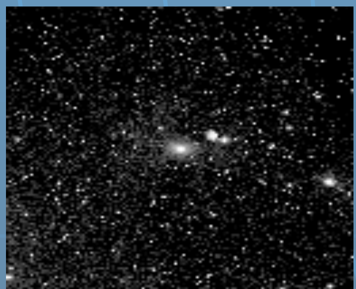
CMB



Large Scale Structure

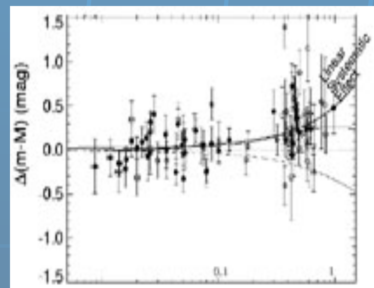


Galaxy clusters



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 →

$$\Omega_{total} = \frac{\rho_{total}}{\rho_{crit.}} = 1 \qquad \rho_{crit.} = \frac{3H^2(t)}{8\pi G}$$

(Universe is flat)

$$\Omega_{total} = \Omega_{total,baryon.} + \Omega_{dyn.} + \Omega_{required}$$

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

The SUSY Particle Spectrum

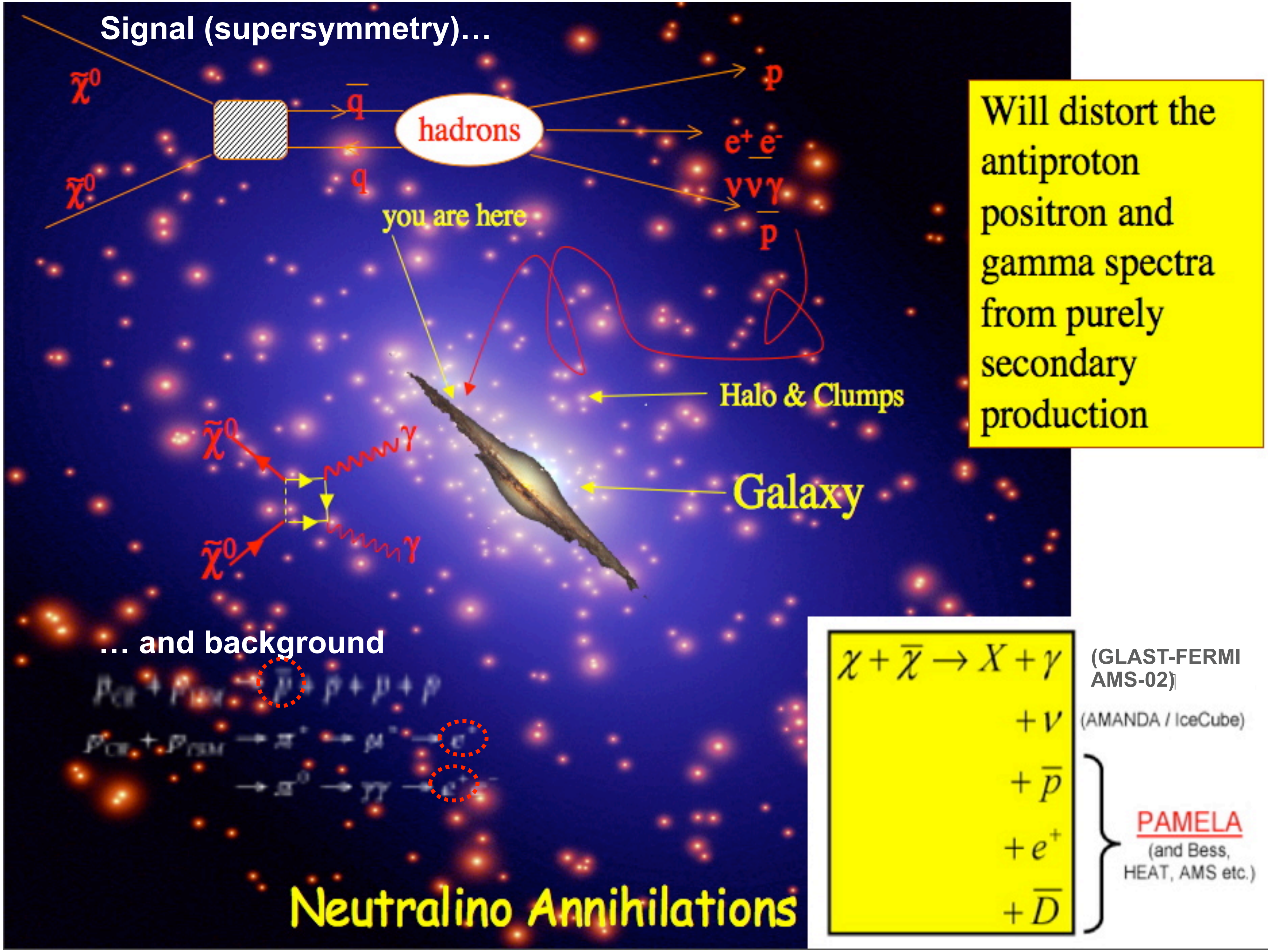
Standard Model

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 Z boson light Higgs heavy Higgs pseudoscalar Higgs	γ Z h H A	1 1 0 0 0	neutralinos	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$	1/2
W boson charged Higgs	$W^\pm$ $H^\pm$	1 1	charginos	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$	1/2
gluon	g	1	gluino	$\tilde{g}$	1/2
graviton	G	2	gravitino	$\tilde{G}$	3/2

'LSP' (usually)

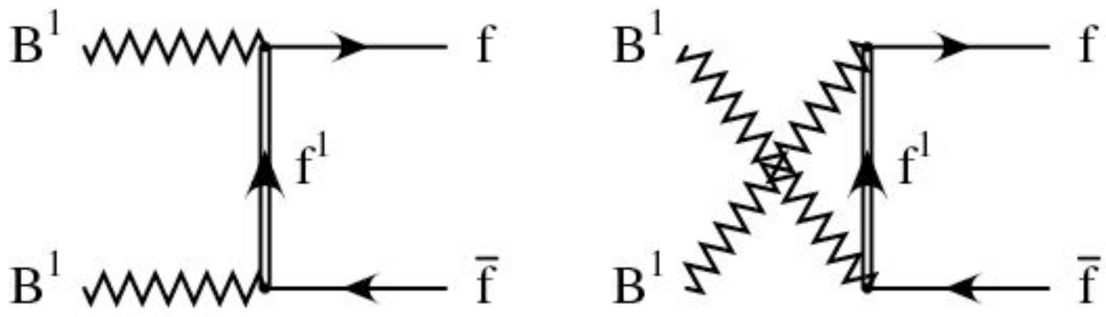
$$\chi = N_1\tilde{\gamma} + N_2\tilde{Z}^0 + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0; \sum_{i=1}^{4}|N_i|^2 = 1$$

Mark Pearce [pearce@particle.kth.se]


Signal (supersymmetry)…
$\tilde{\chi}^0$
$\tilde{\chi}^0$
$\bar{q}$
q
hadrons
p
$e^+ e^-$
ν ν γ
$\bar{p}$
you are here
Halo & Clumps
Galaxy
γ
γ
Will distort the antiproton positron and gamma spectra from purely secondary production
… and background
Neutralino Annihilations
$\chi + \bar{\chi} \rightarrow X + \gamma$
$+ \nu$
$+ \bar{p}$
$+ e^+$
$+ \bar{D}$
(GLAST-FERMI AMS-02)
(AMANDA / IceCube)
PAMELA
(and Bess, HEAT, AMS etc.)

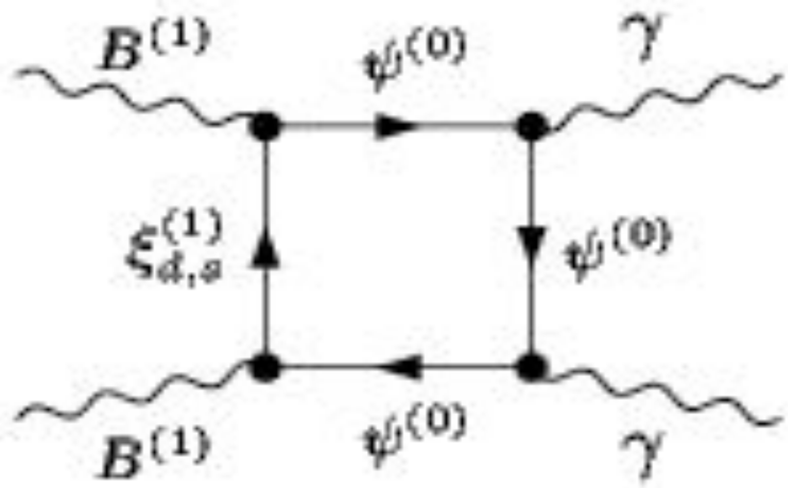
Another possible scenario:
KK Dark Matter

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



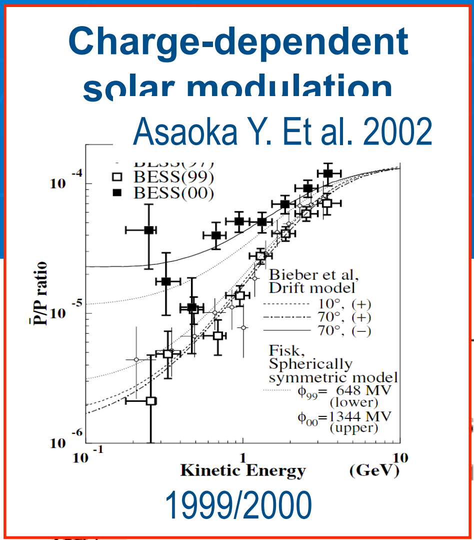
Bosonic Dark Matter:
fermionic final states
no longer helicity
suppressed.
e^+e^- final states
directly produced.

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

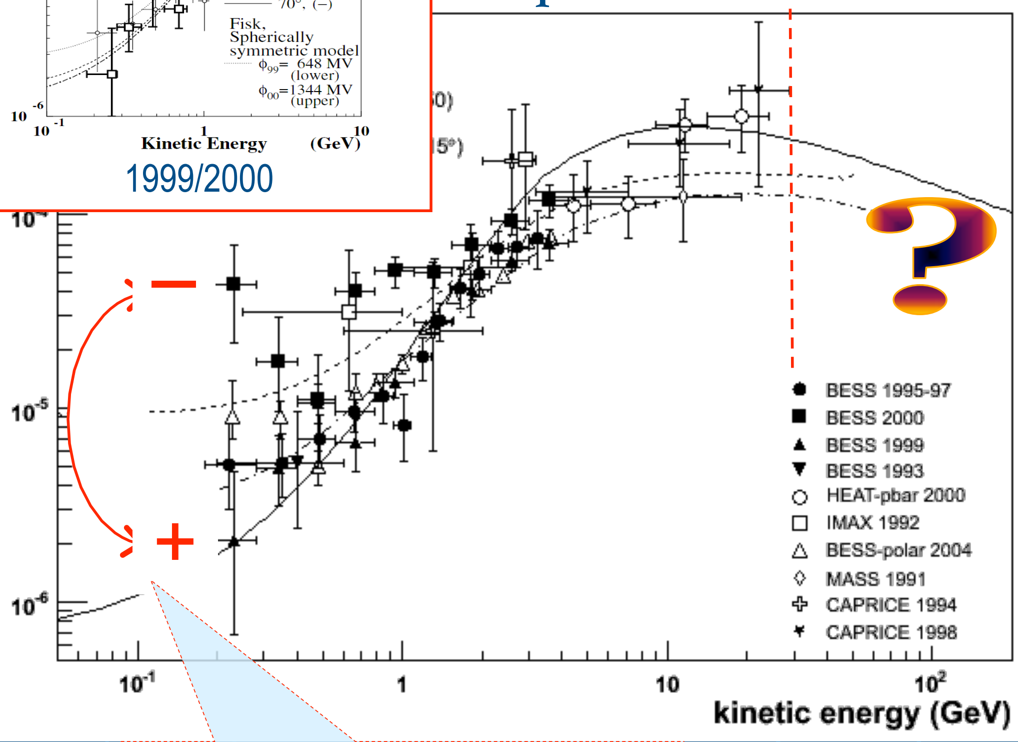


Cosmic Ray Antimatter

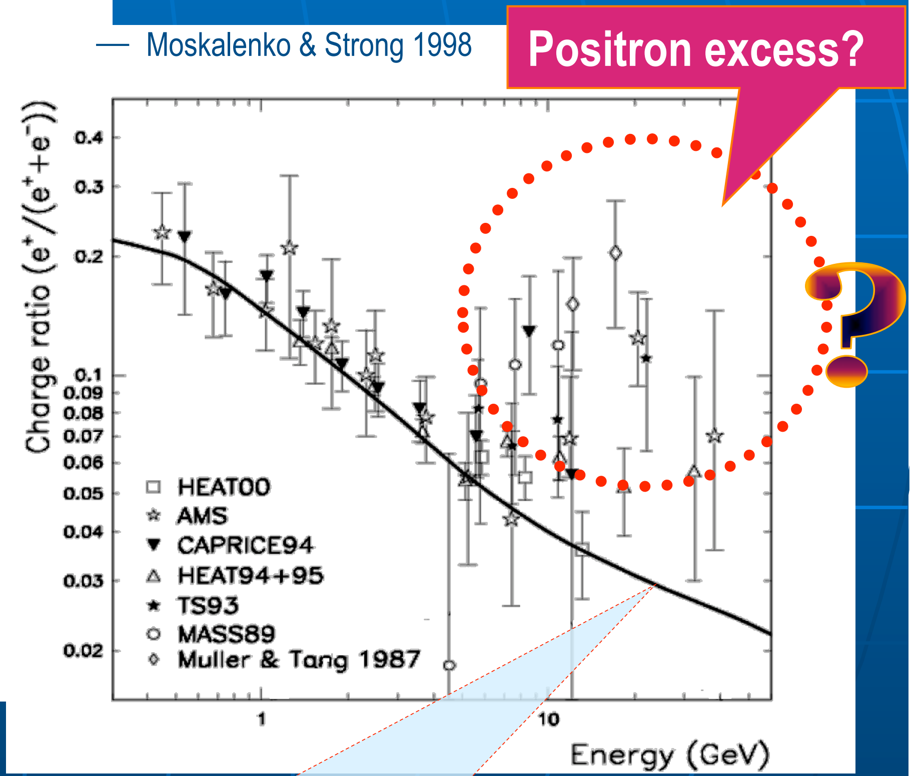
Present status



Antiprotons



Positrons

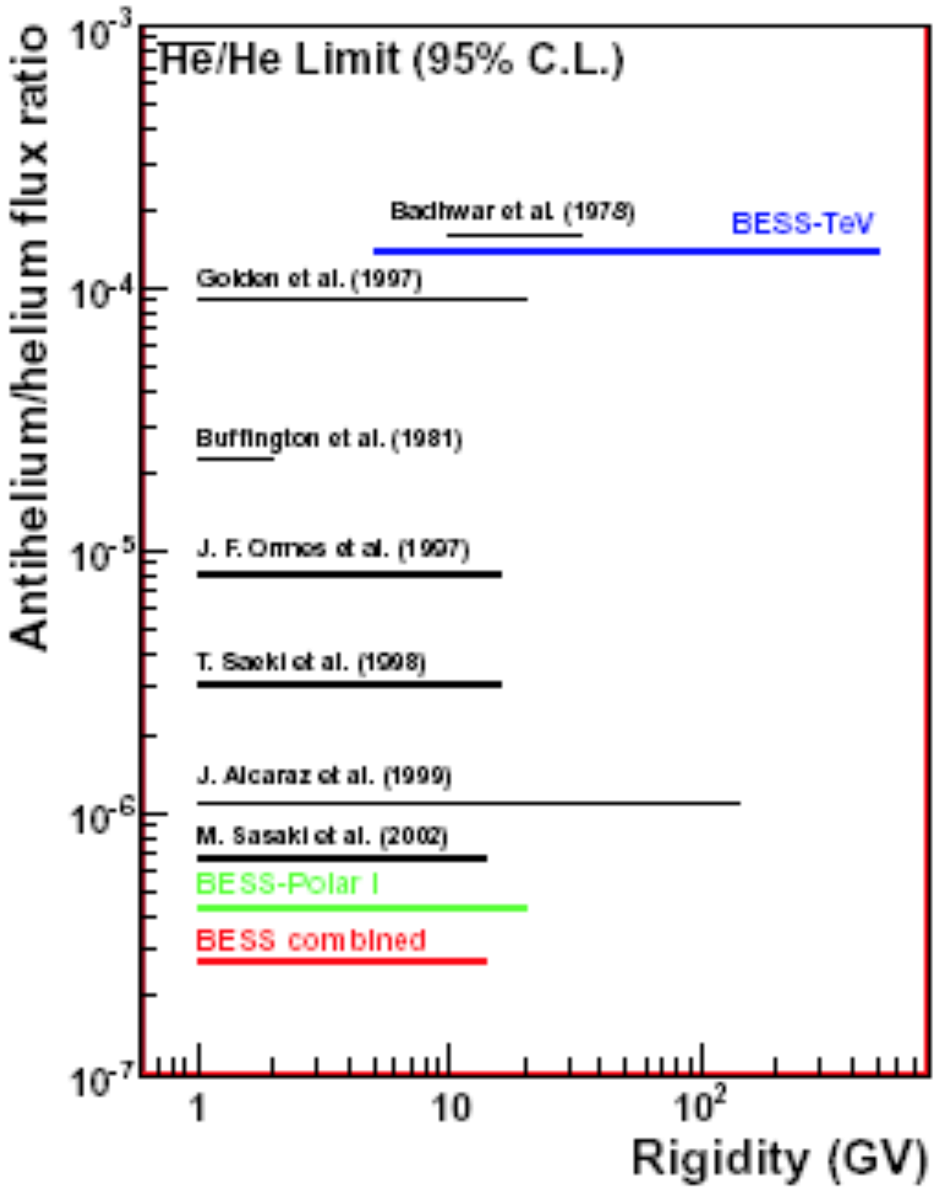


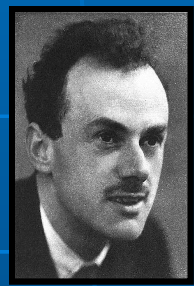
CR + ISM → p-bar + …

kinematic threshold:
5.6 GeV for the reaction
$pp \rightarrow \bar{p}ppp$

CR + ISM → $\pi^{\pm}$ + x → $\mu^{\pm}$ + x → $e^{\pm}$ + x
CR + ISM → π^{0} + x → $\gamma\gamma$ → $e^{\pm}$

Antimatter





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

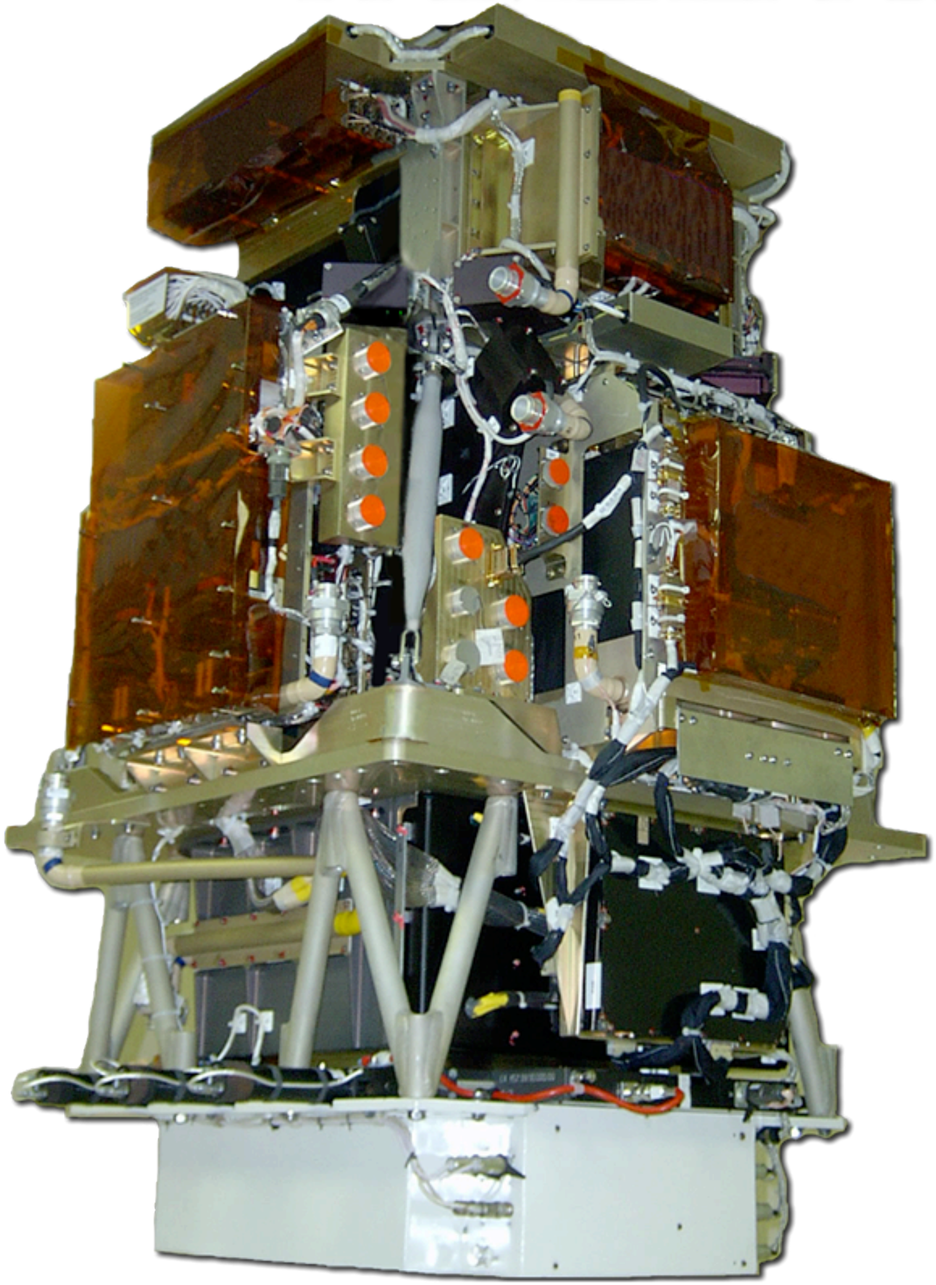
P. Dirac, Nobel lecture (1933)

What do we need?

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

Long Duration Flights

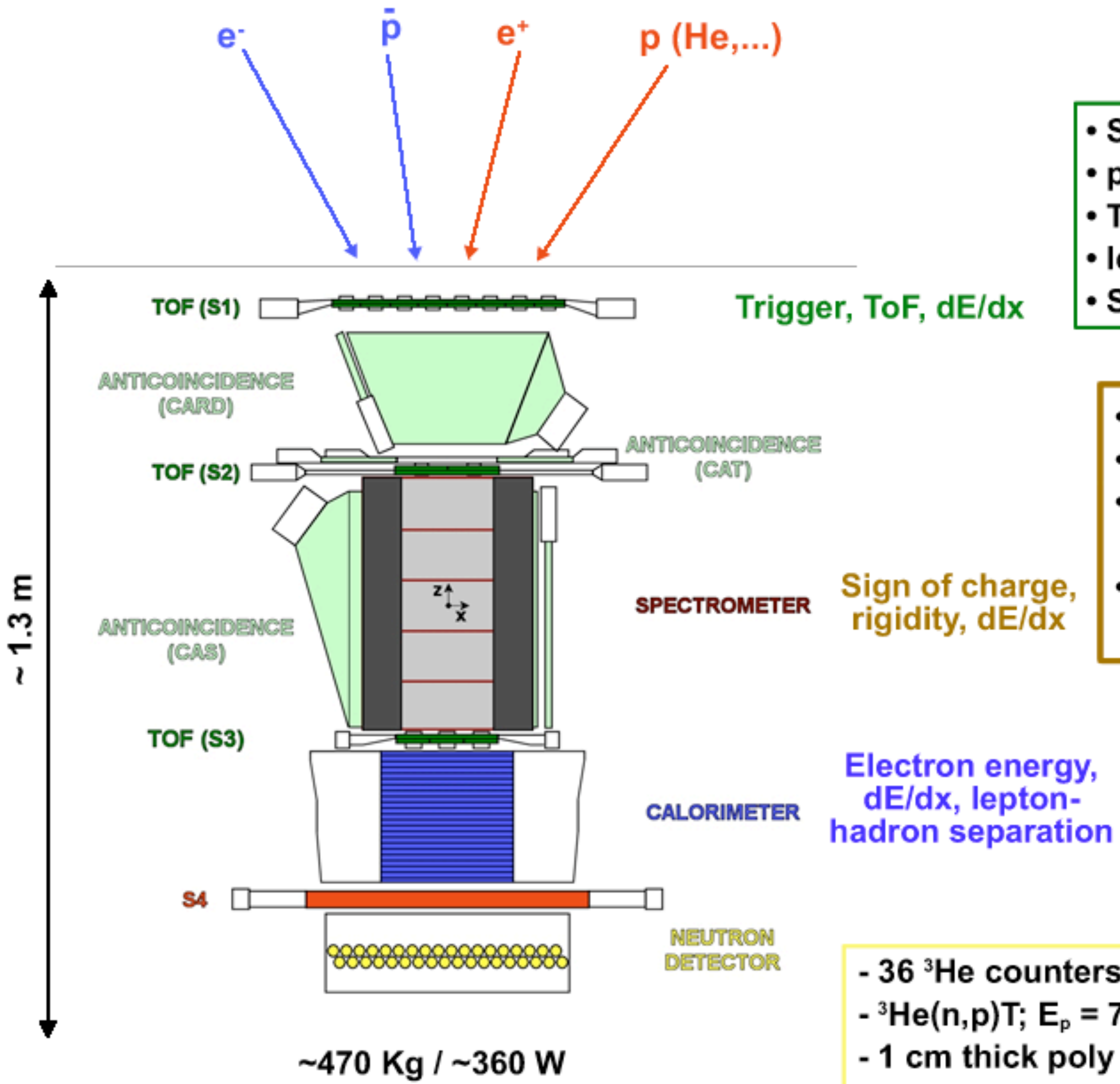
PAMELA *Instrument*



GF ~21.5 cm^{2}sr

Mass: 470 kg

Size: 130x70x70 cm^3



- 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)

- 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)

- 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

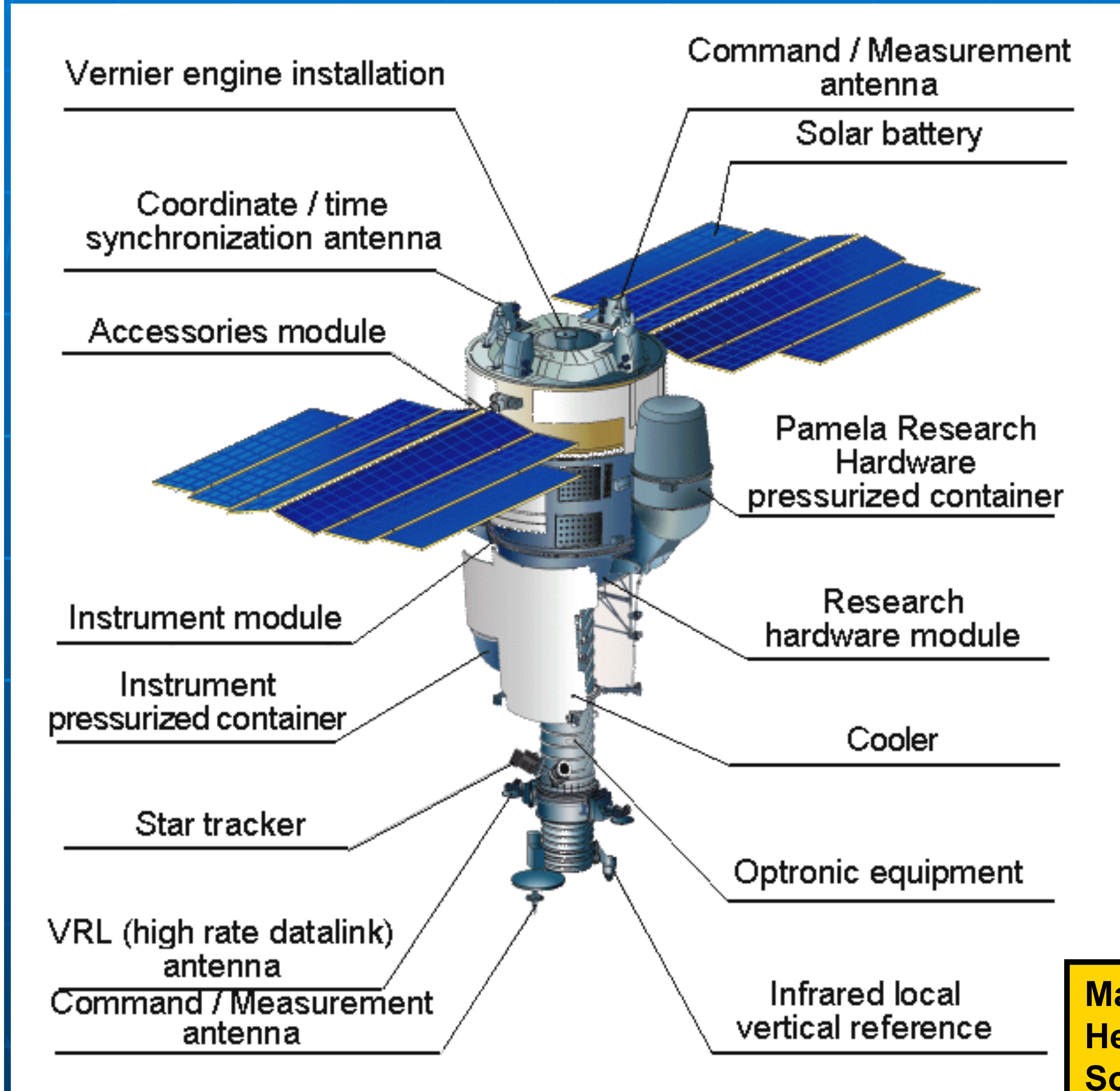
- 36 ^{3}He counters
- ^{3}He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

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 $\overline{He}/He$

→ **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

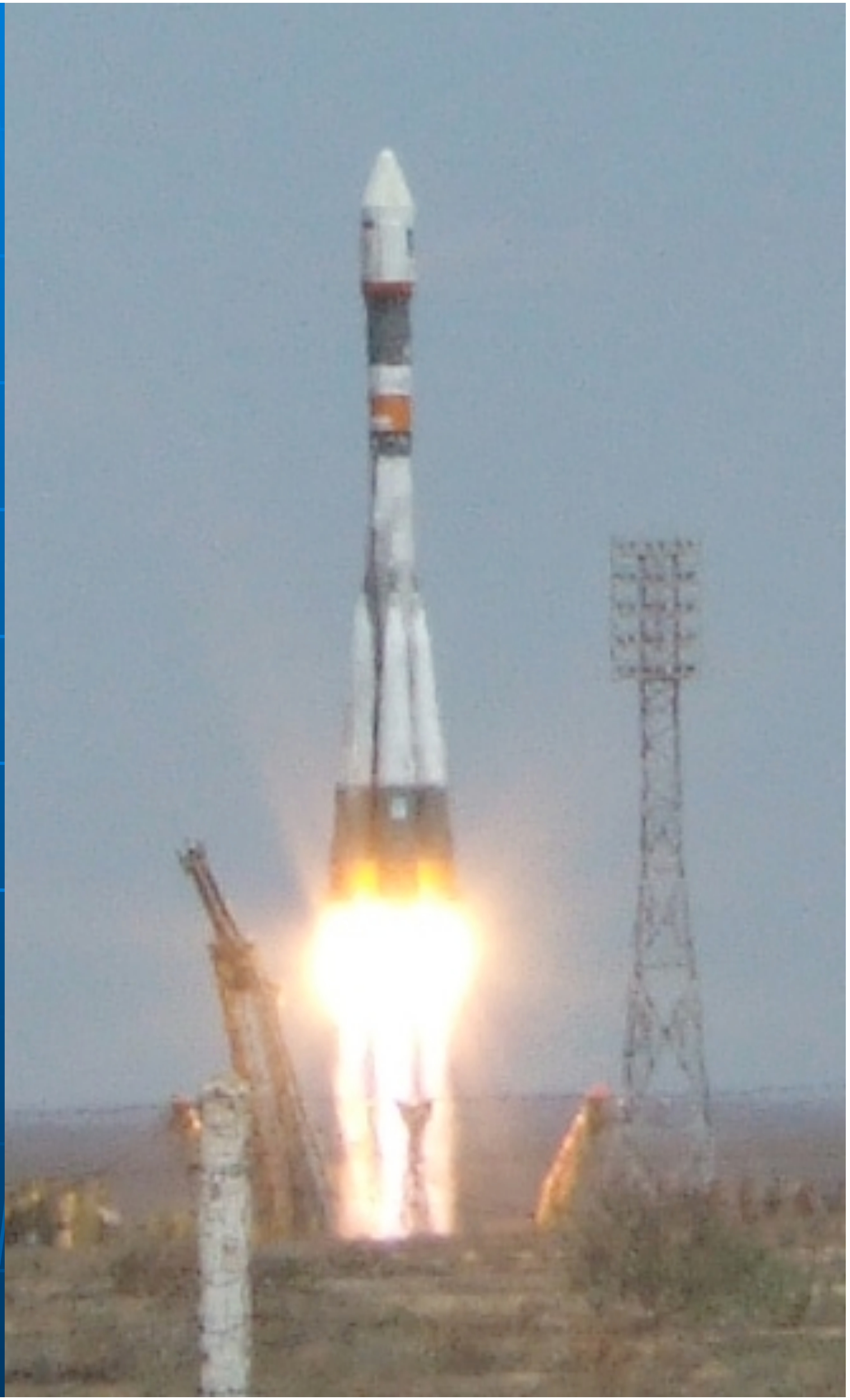
- **PAMELA mounted inside a pressurized container**

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

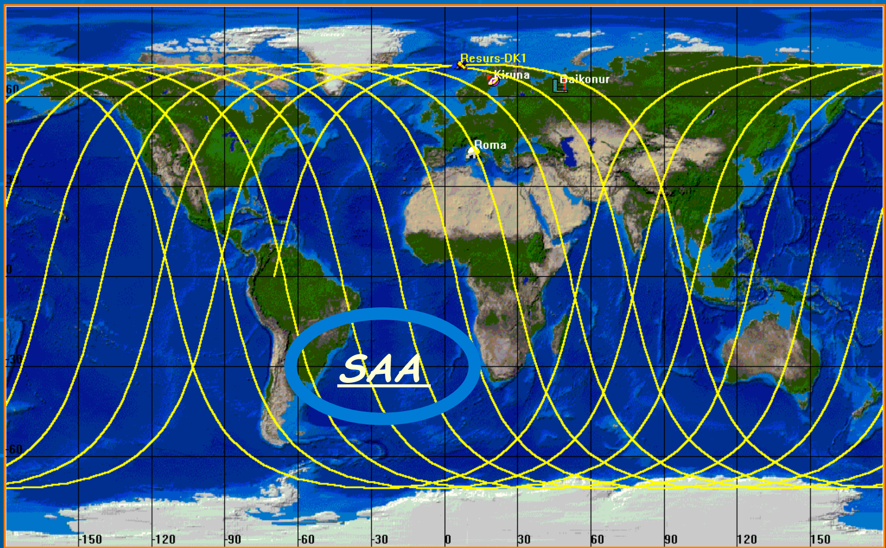
PAMELA

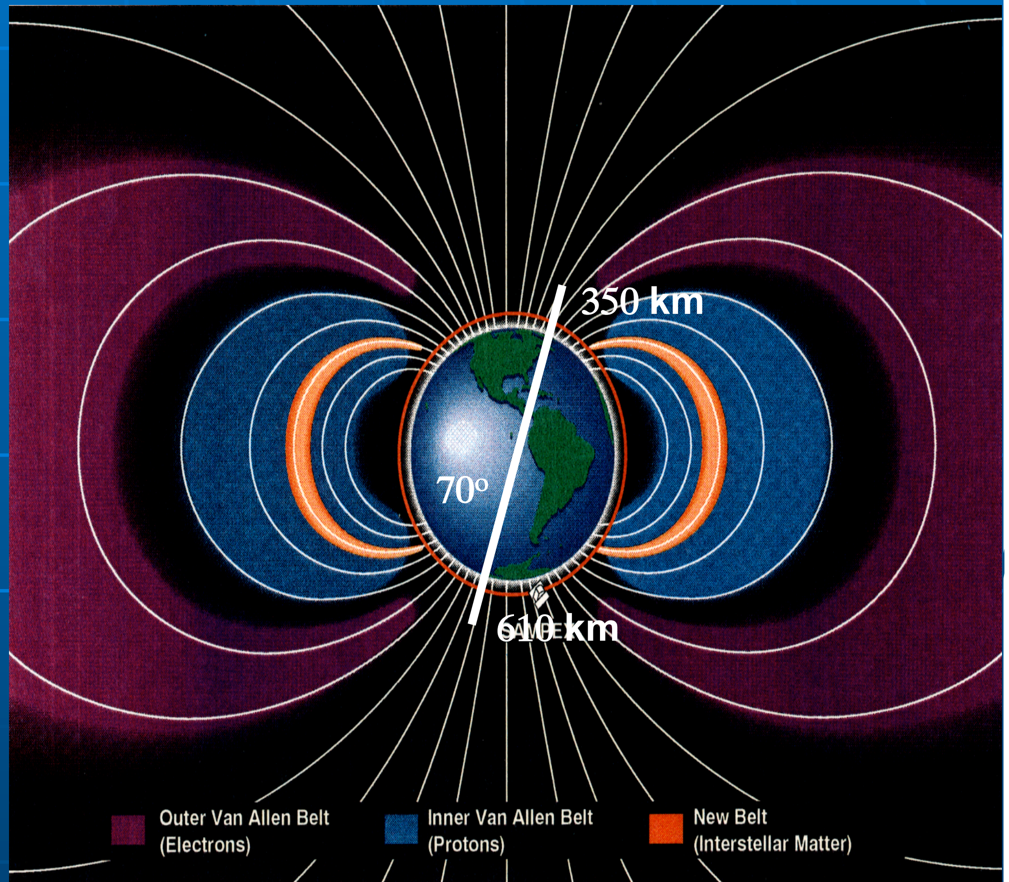
Launch 15/06/06

16 Gigabytes trasmitted daily to Ground NTsOMZ Moscow



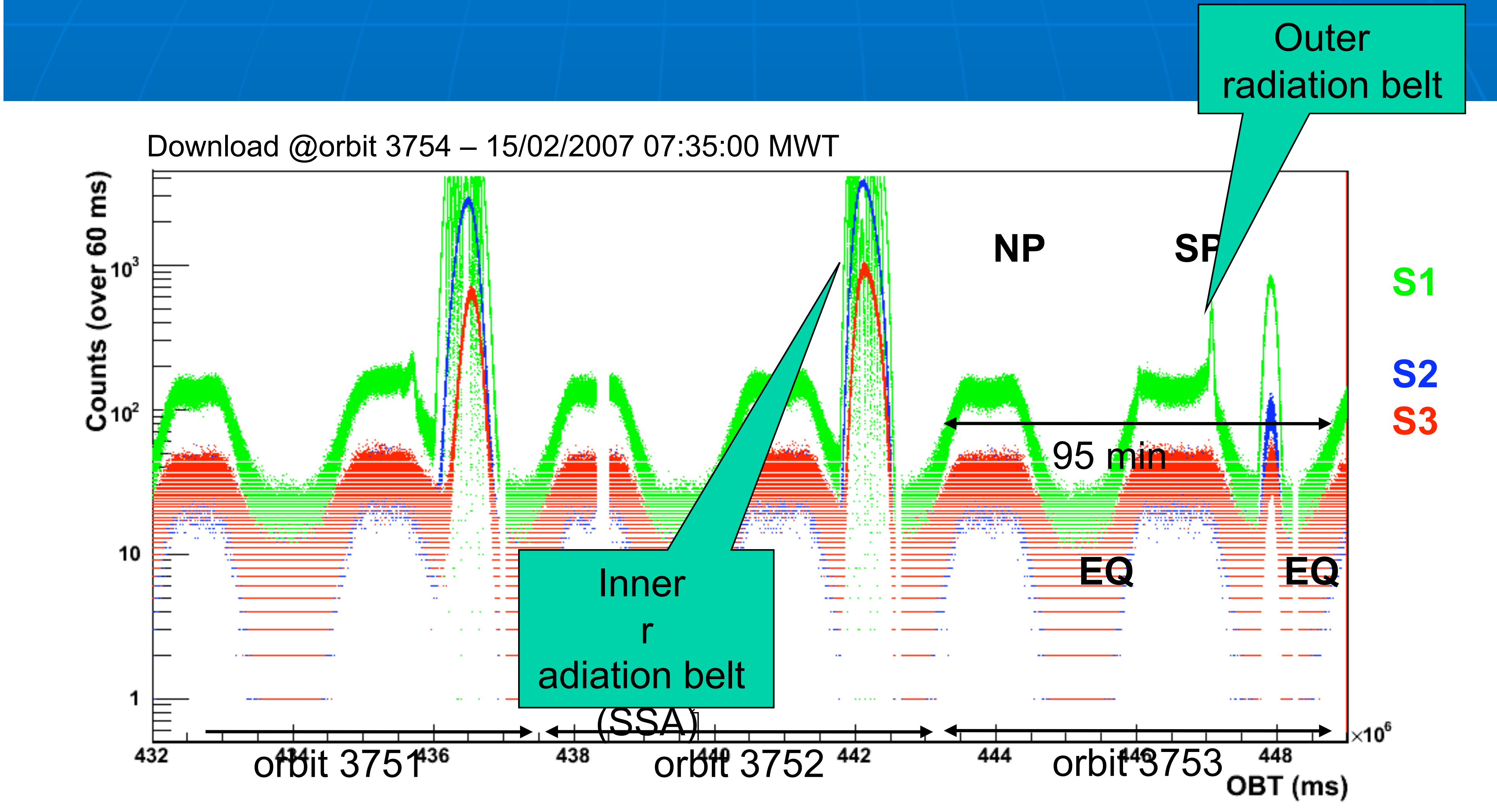
Orbit Characteristics





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

PAMELA Orbit



The Physics of PAMELA

Search for dark matter annihilation

Search for antihelium (primordial antimatter)

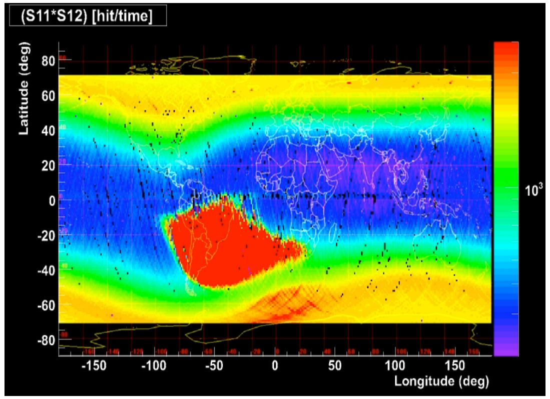
Search for new Matter in the Universe (Strangelets?)

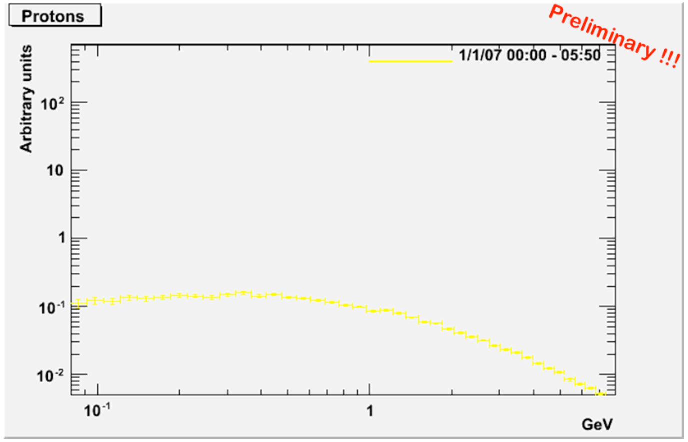
Study of cosmic-ray propagation

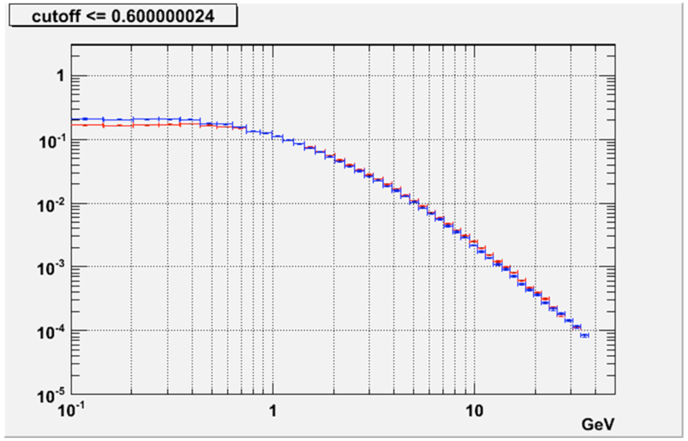
Study of solar physics and solar modulation

Study of terrestrial magnetosphere

Study of high energy electron spectrum (local sources?)



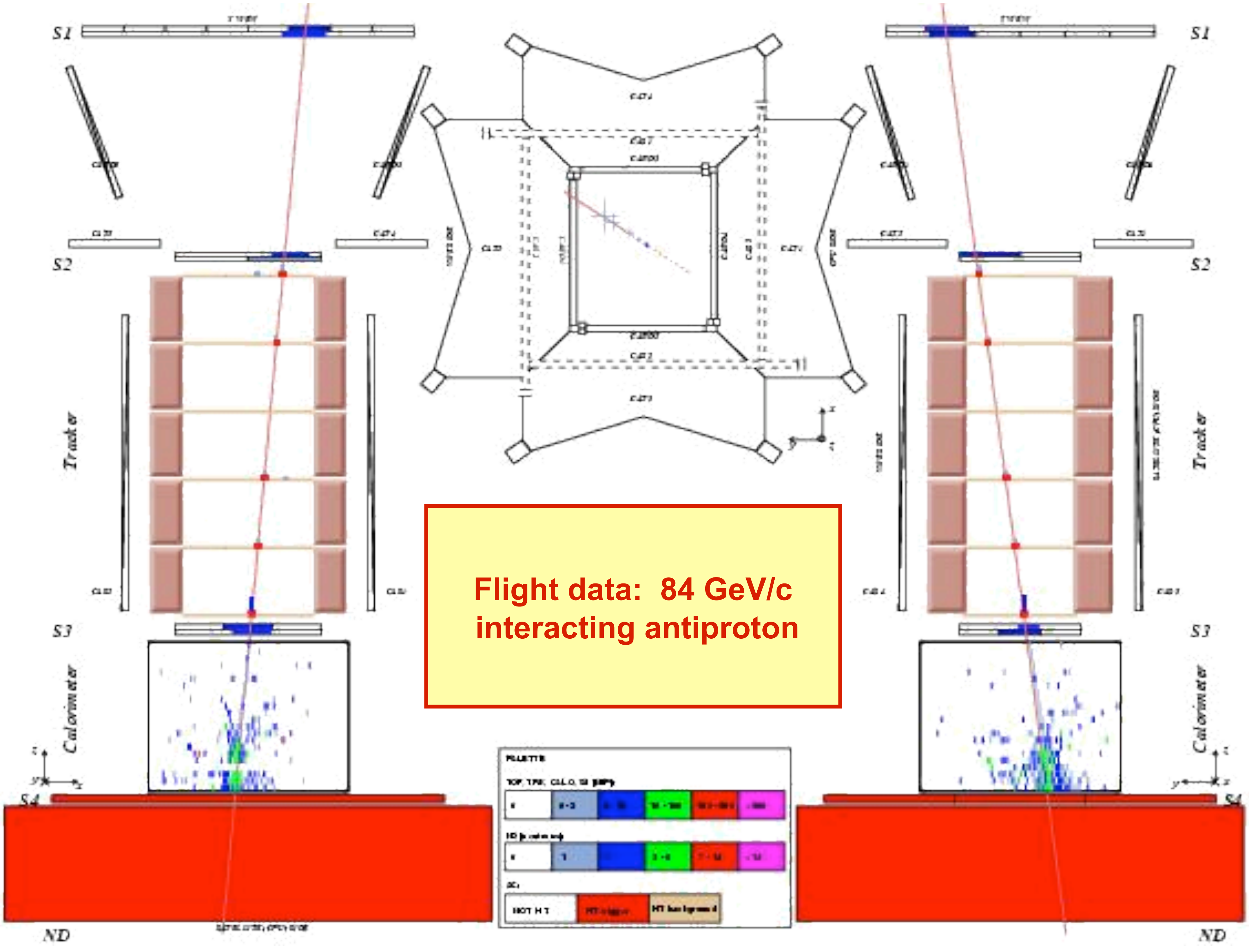




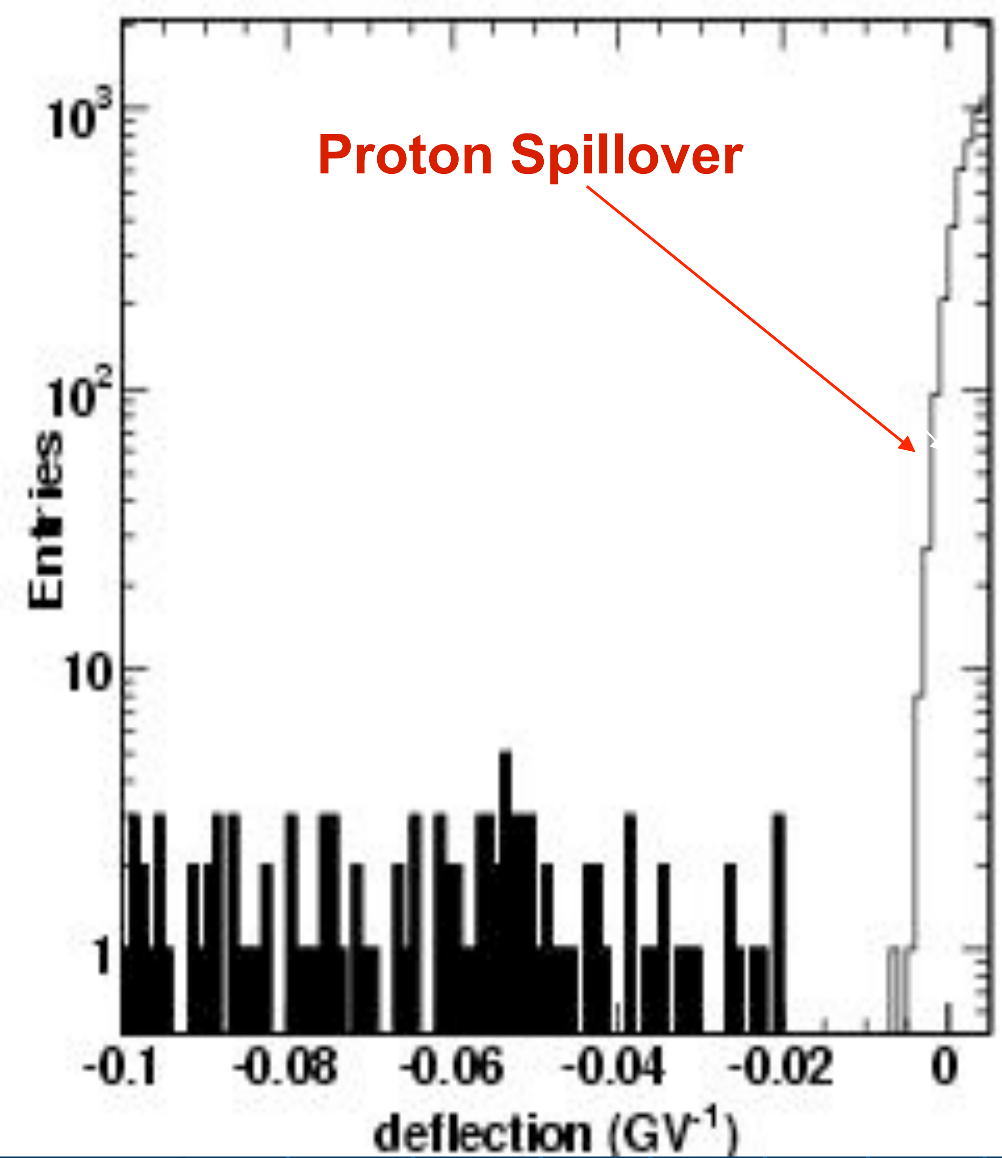
PAMELA Status

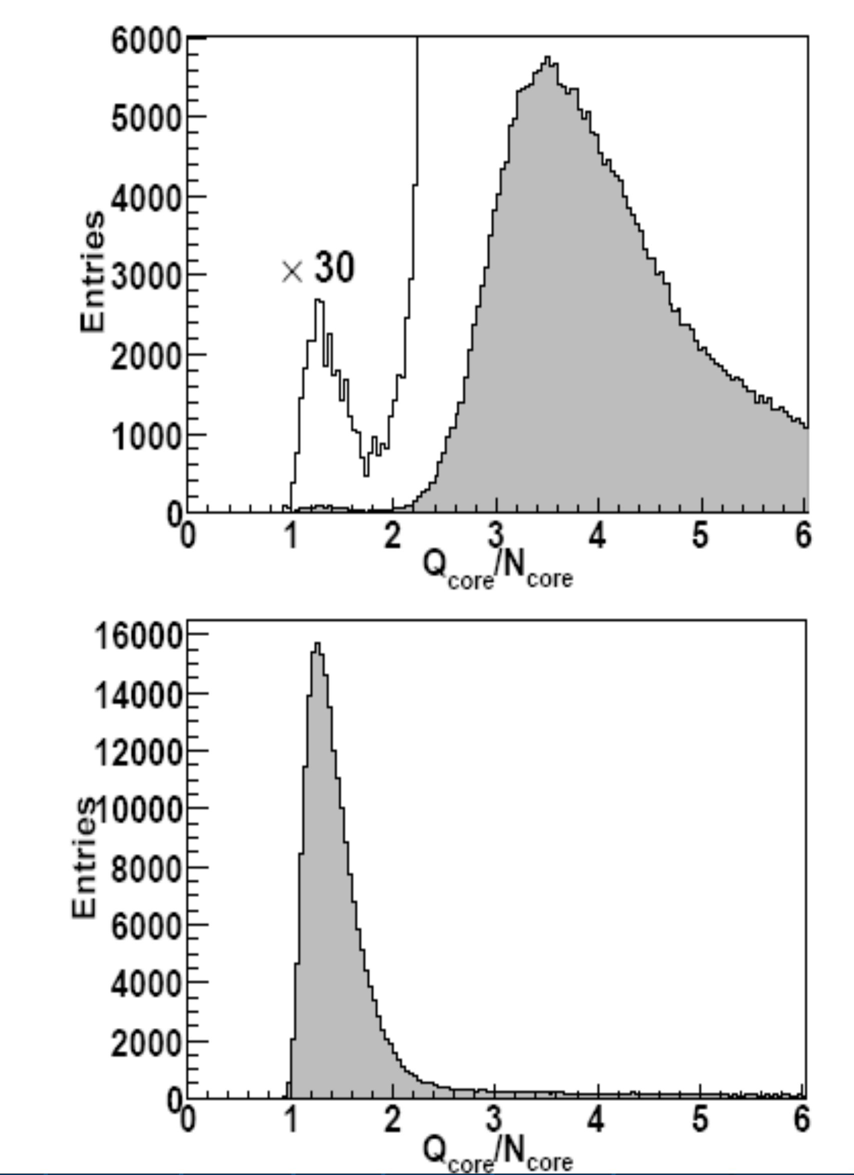
- ~1000 days of flight
- data taking ~73% live-time
- ~13 TBytes of raw data downlinked
- $>10^9$ triggers recorded and under analysis

Antiprotons


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

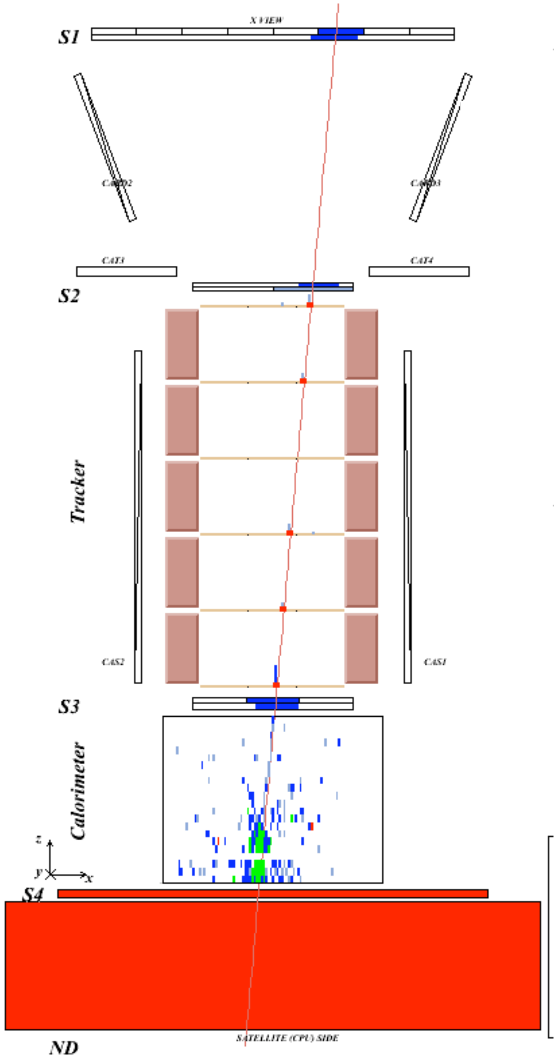
PAMELA antiproton discrimination





Positrons

Proton / positron discrimination



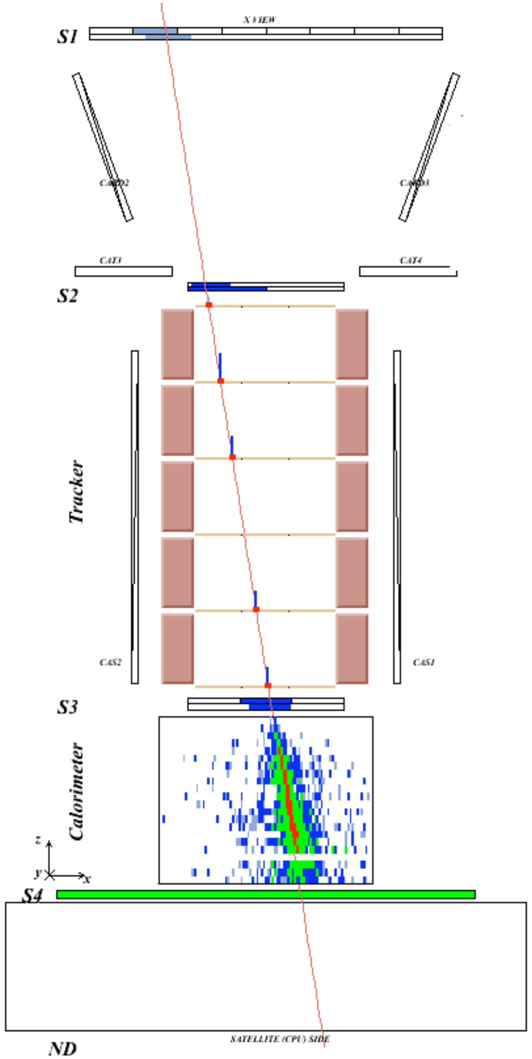
Proton

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

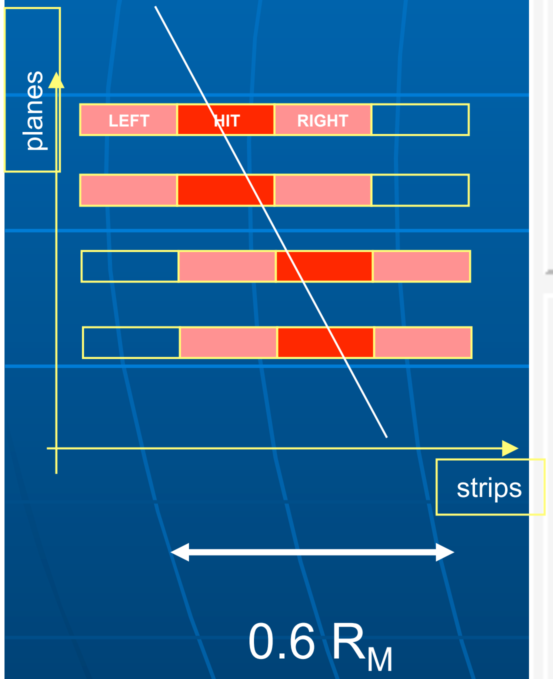
Interaction pattern in calorimeter:
electron-like or proton-like, electron energy

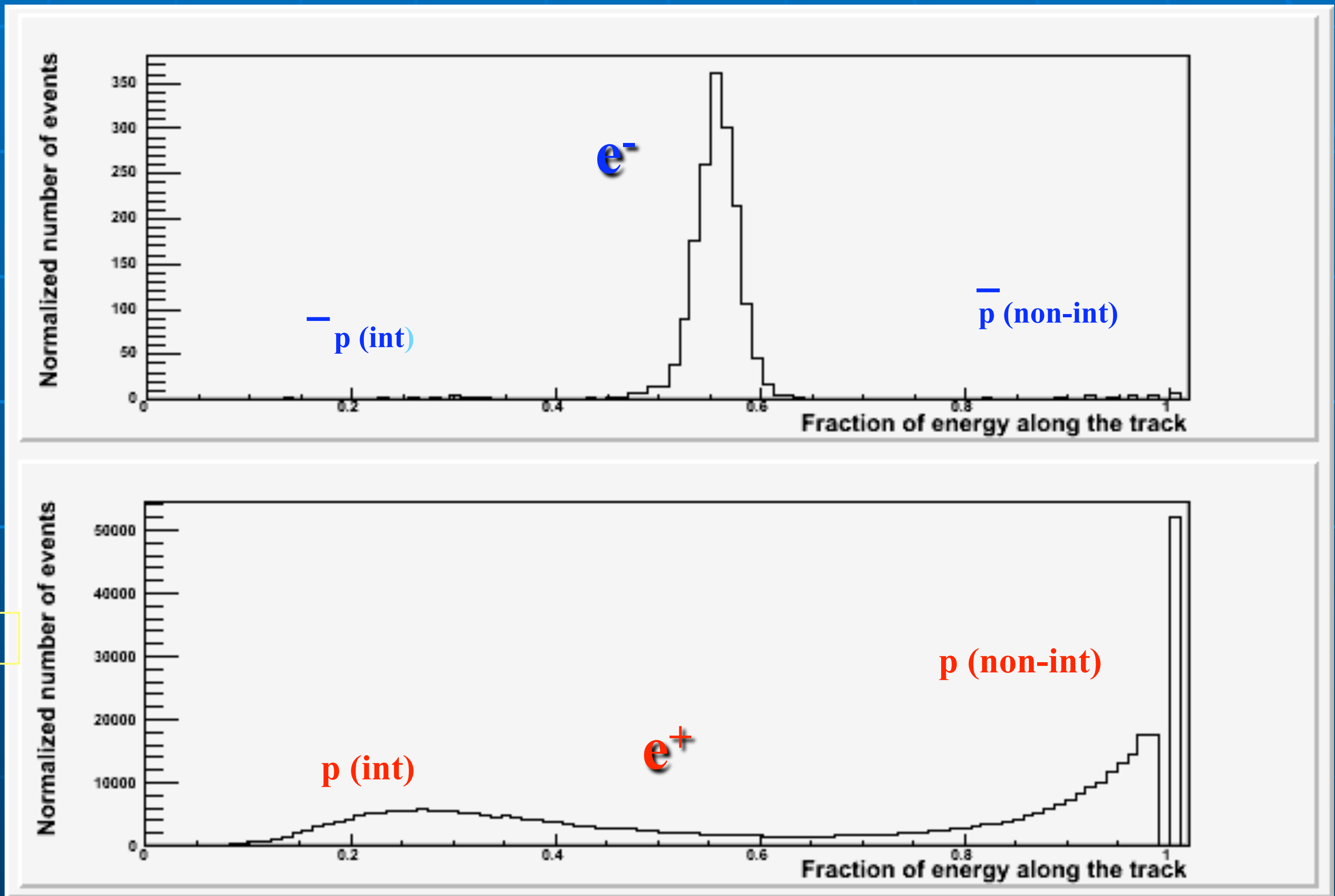


Positron

Positron selection with calorimeter

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

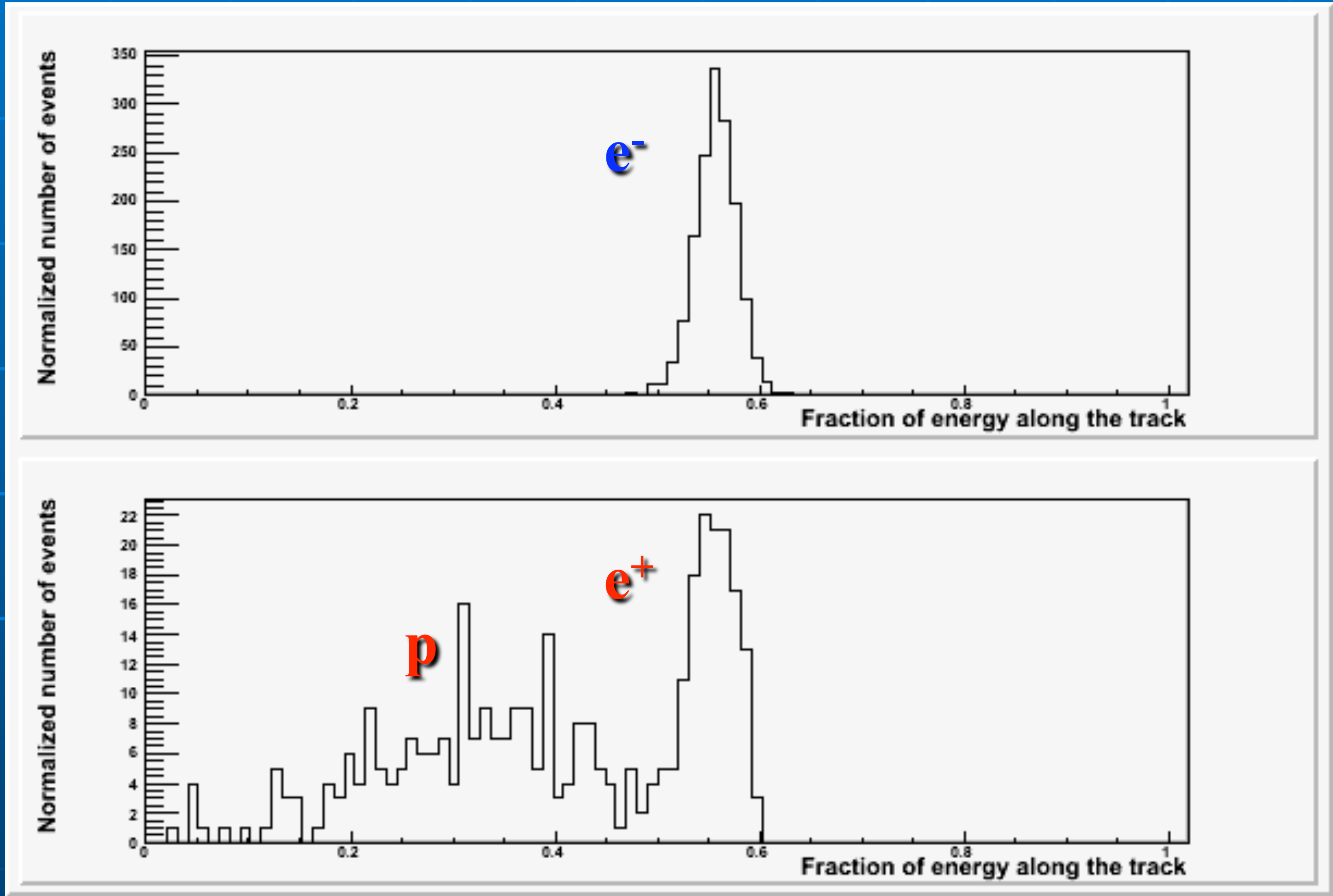




Rigidity: 20-30 GV

Positron selection with calorimeter

Rigidity: 20-30 GV



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

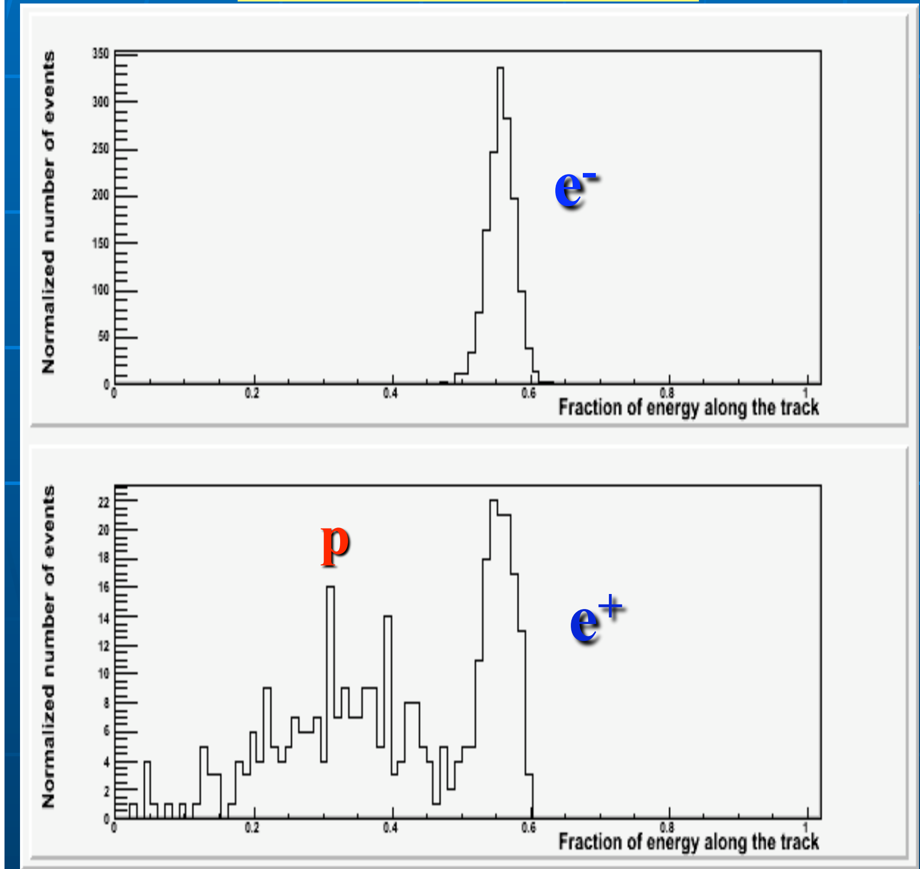
+

- Energy-momentum match
- Starting point of shower

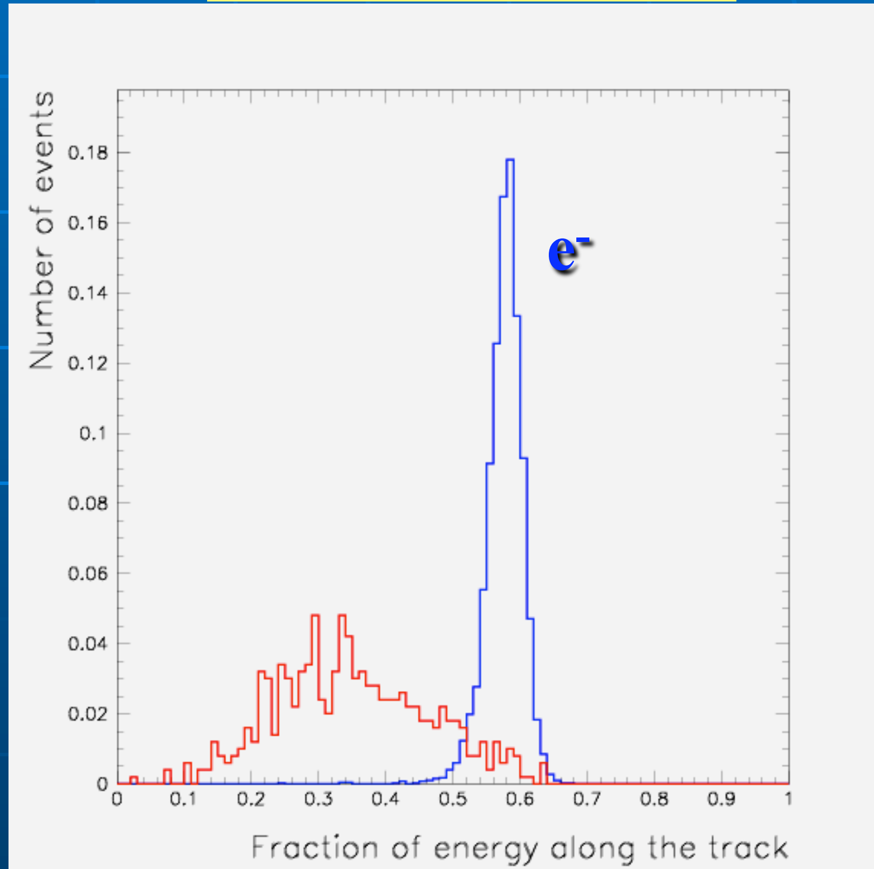
Positron selection with calorimeter

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

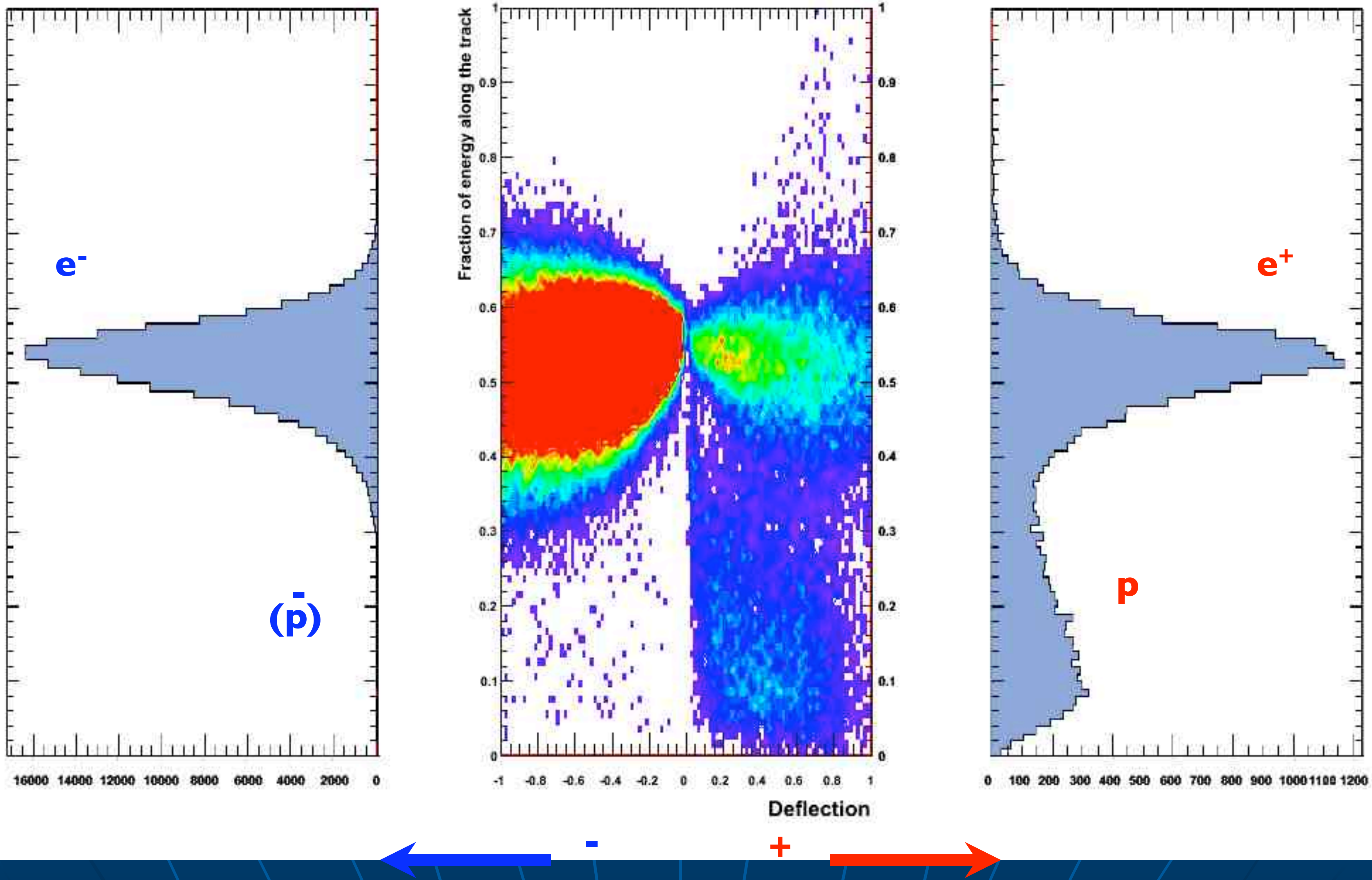
Flight data:
rigidity: 20-30 GV



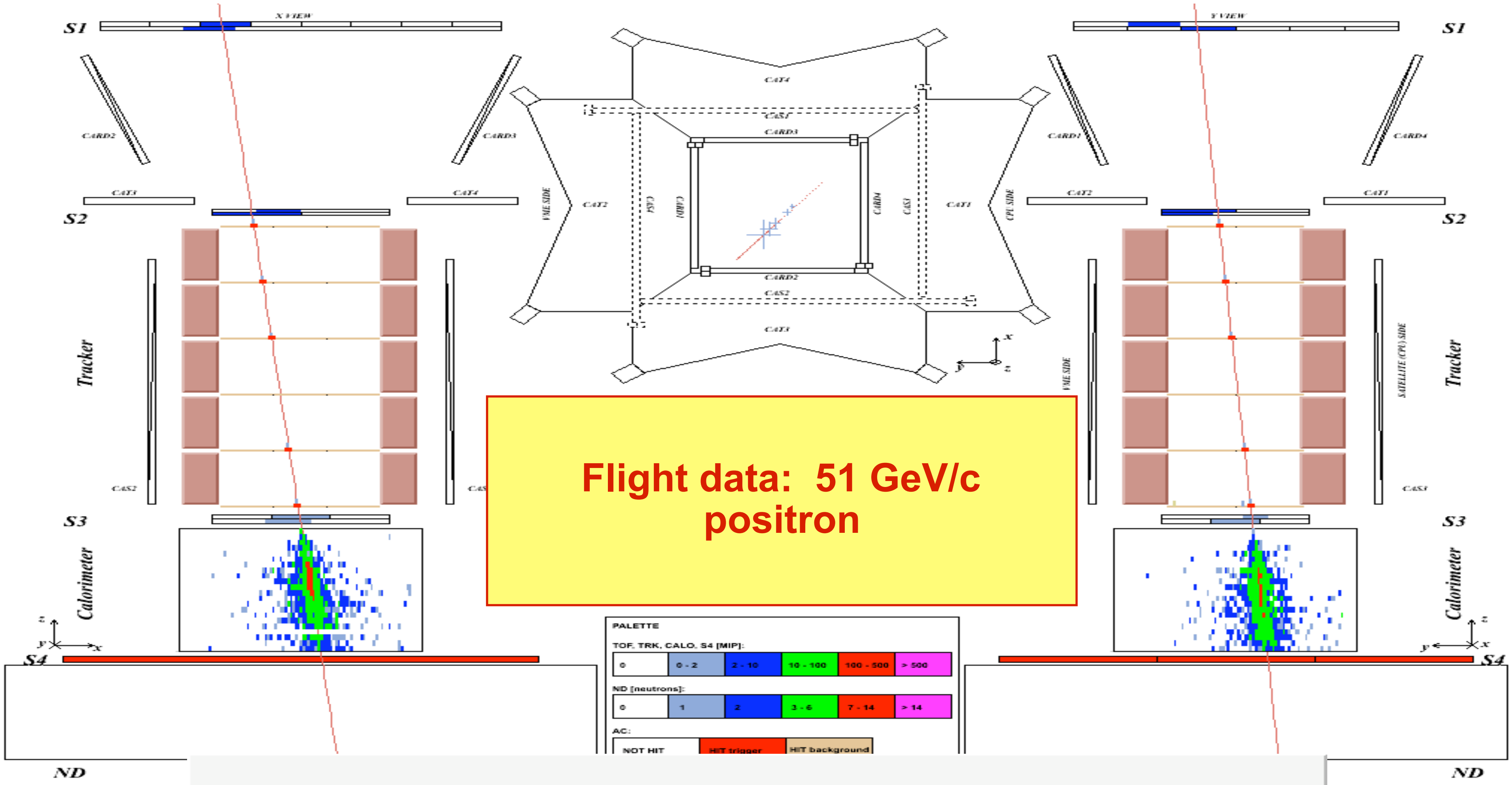
Test beam data
Momentum: 50GeV/c



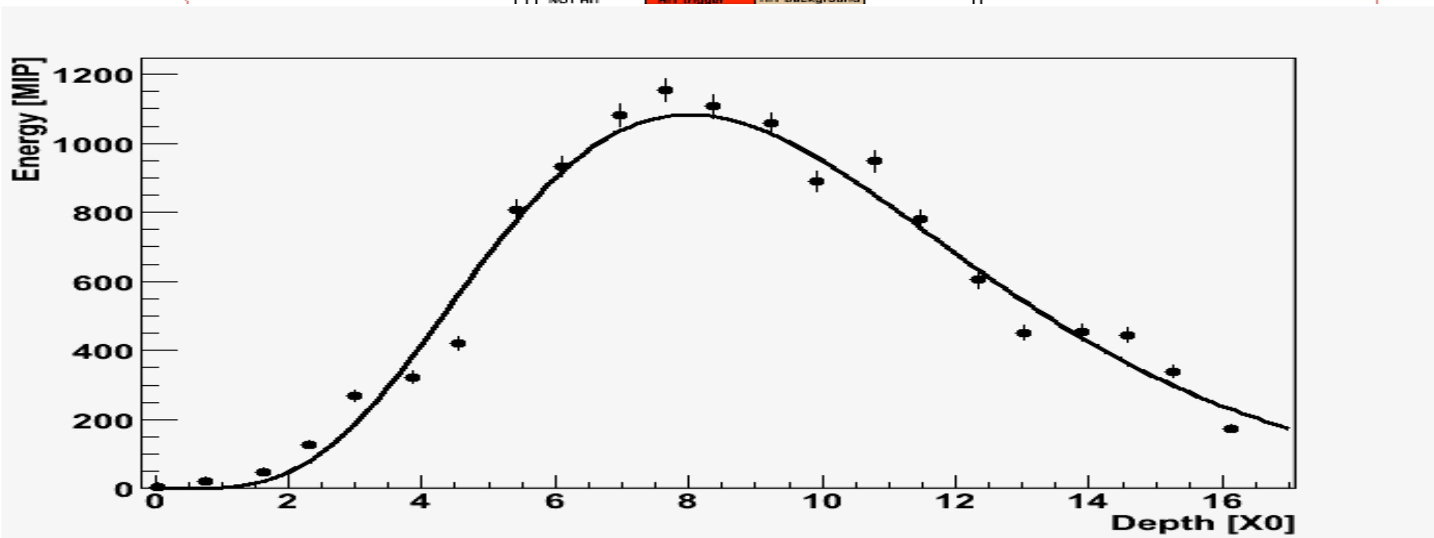
- **Energy-momentum match**
- **Starting point of shower**



e-
(p̄)
e+
p
Fraction of energy along the track
Deflection
16000 14000 12000 10000 8000 6000 4000 2000 0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
-
+

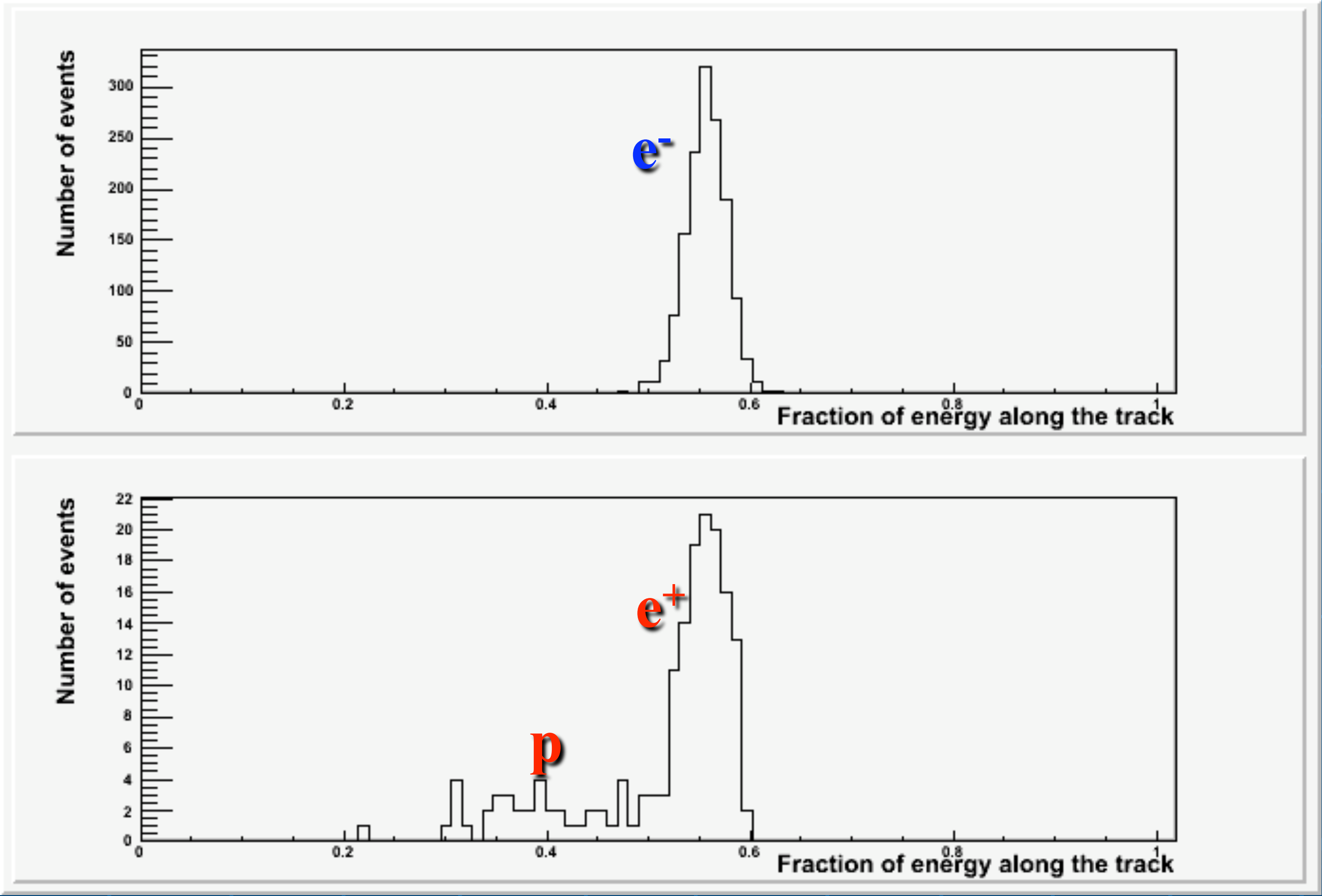


Flight data: 51 GeV/c positron



Positron selection with calorimeter

Rigidity: 20-30 GV



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

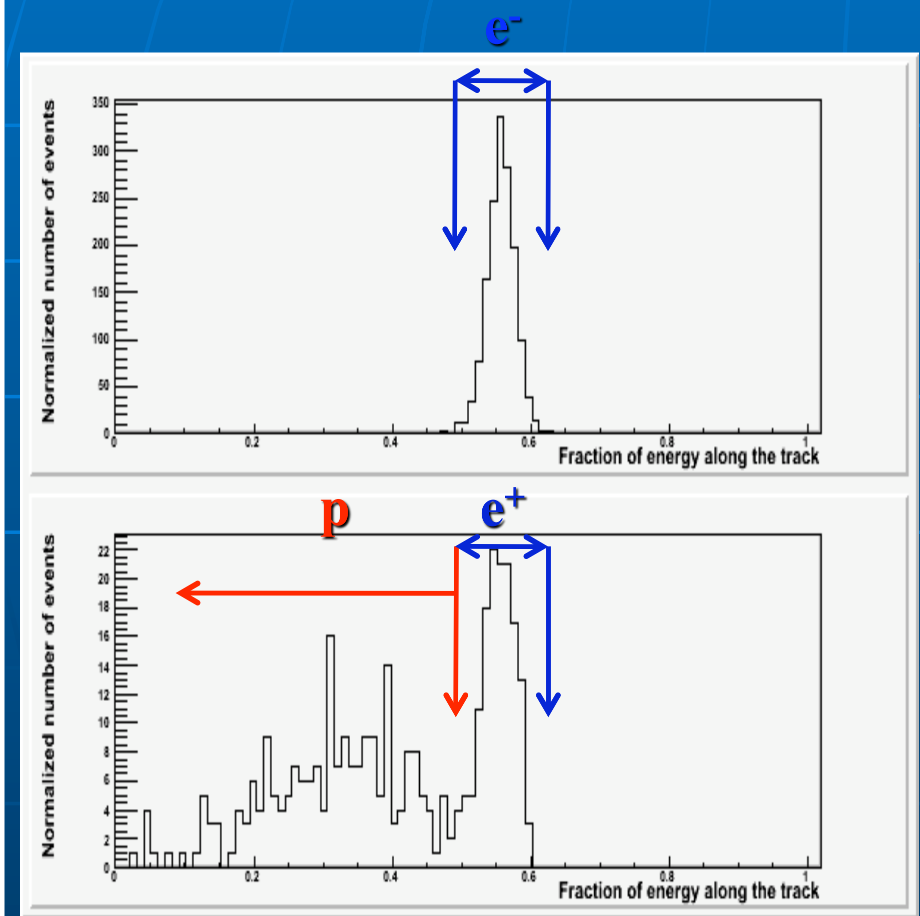
+

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

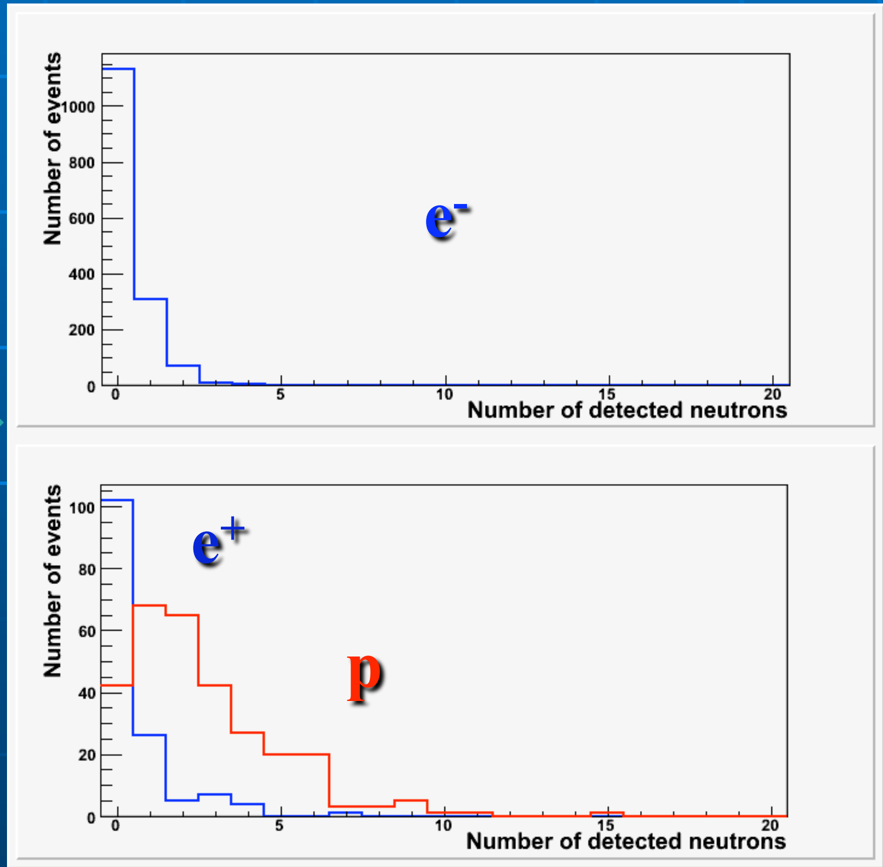
Positron selection

Rigidity: 20-30 GV

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



Neutrons detected by ND

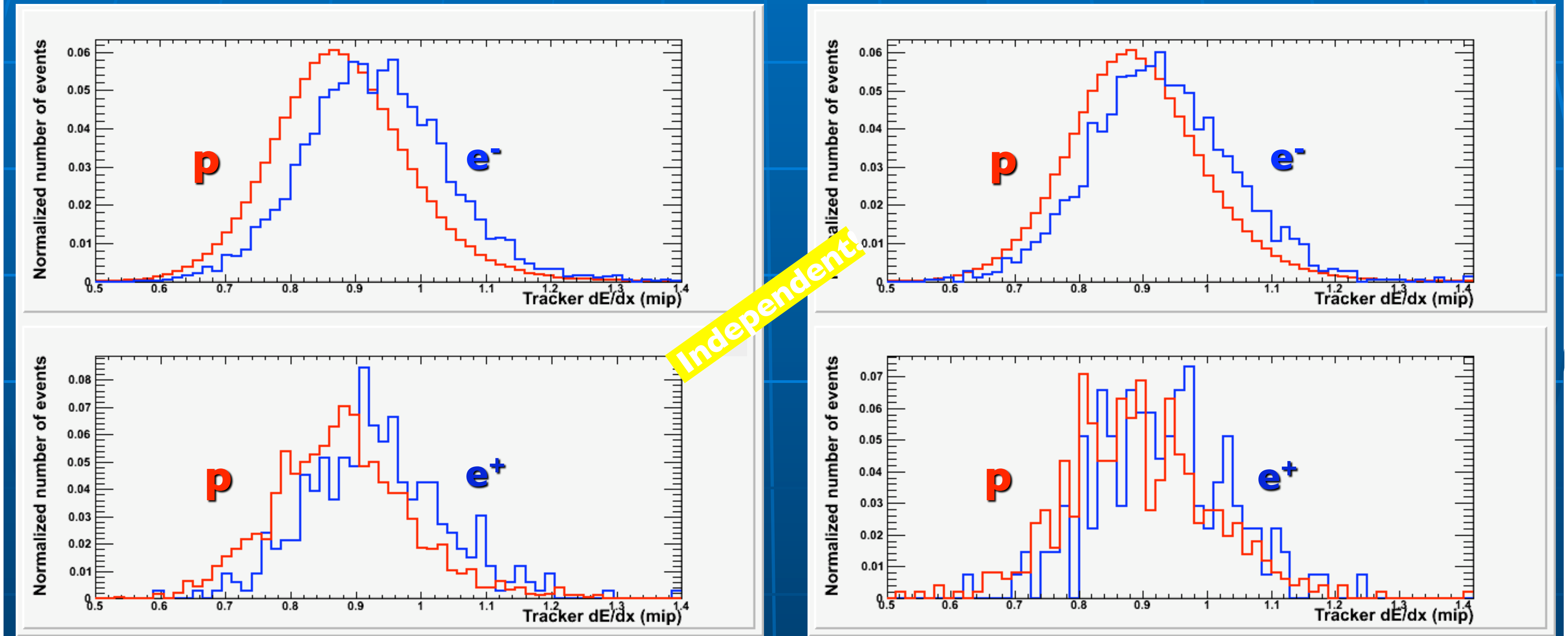


- Energy-momentum match
- Starting point of shower

Positron selection with dE/dX

Energy loss in silicon tracker detectors: $-\frac{dE}{dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$

TOP: positive (mostly p) and negative events (mostly e^-)



BOTTOM: positive events identified as p and e^+ by transverse profile method

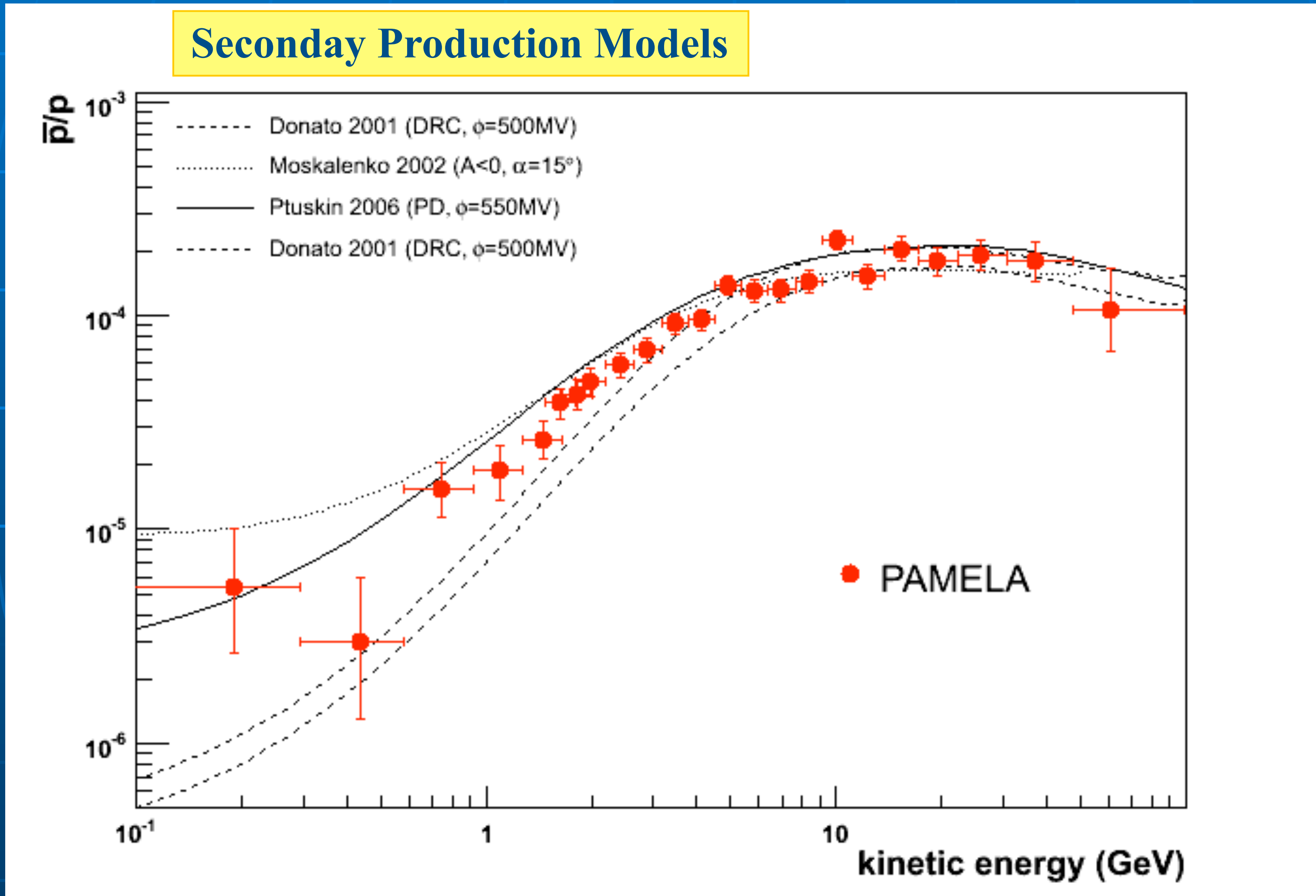
Rigidity: 10-15 GV

Rigidity: 15-20 GV

RESULTS

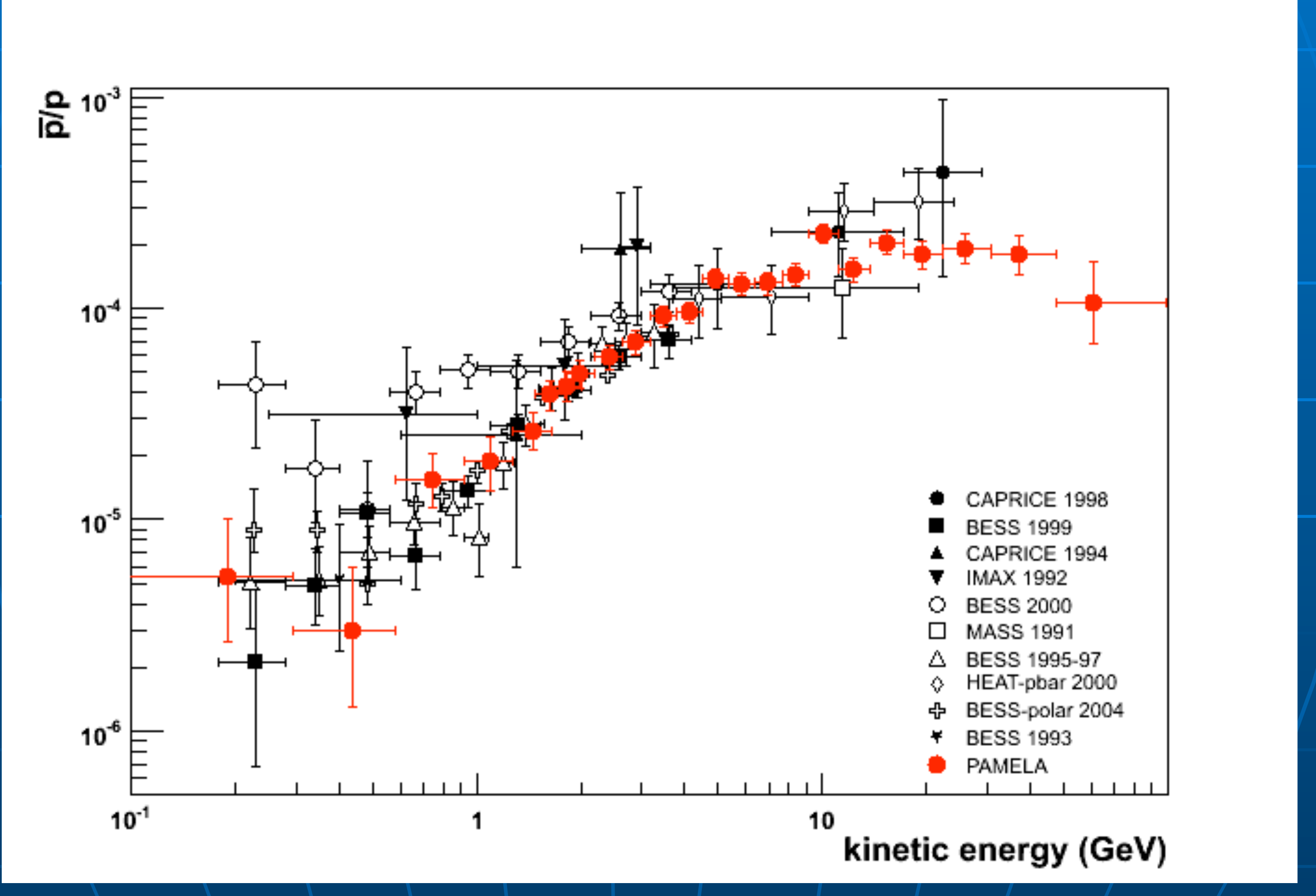
Antiproton to proton ratio

PRL 102, 051101 (2009)

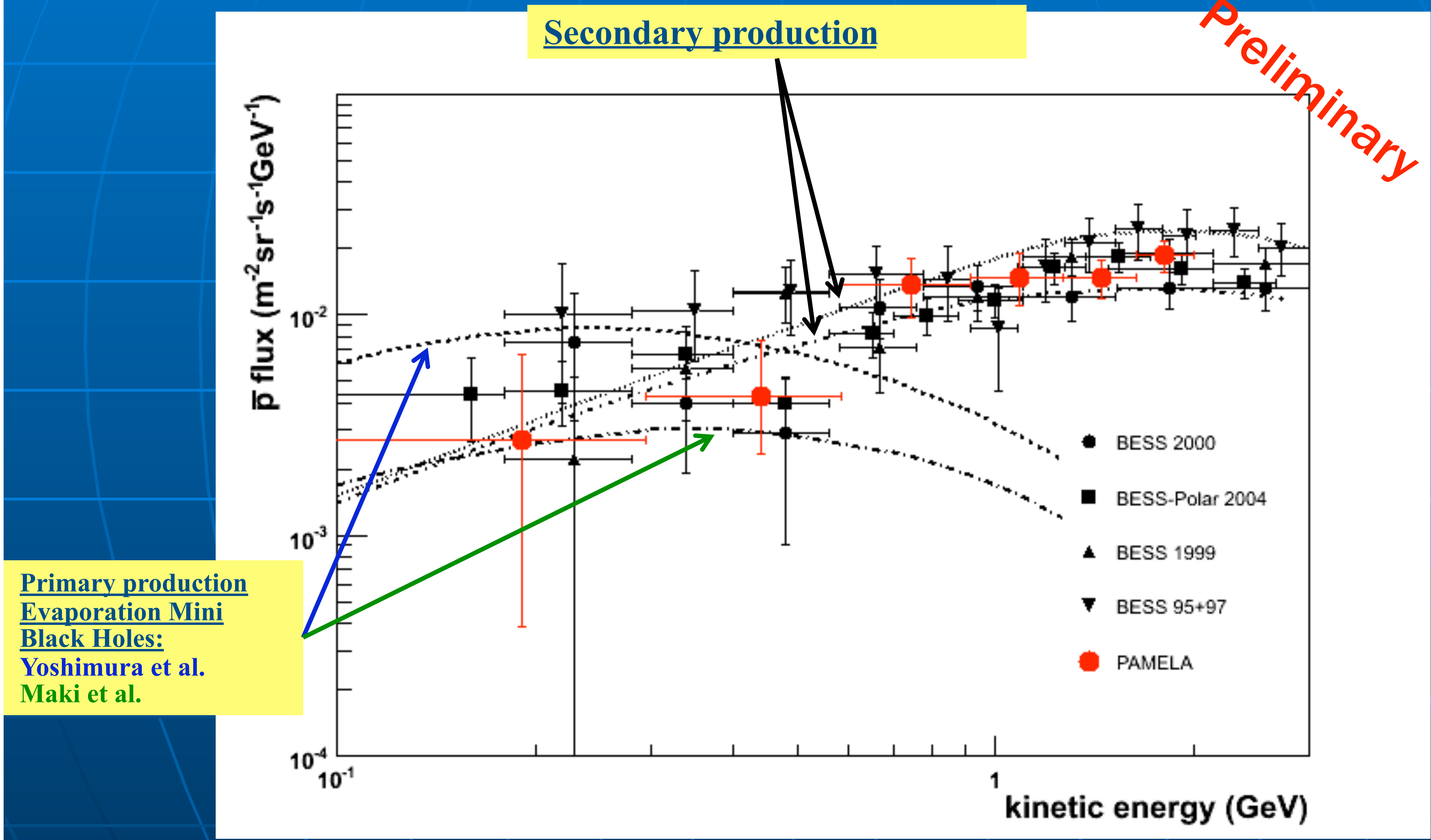


Antiproton to proton ratio

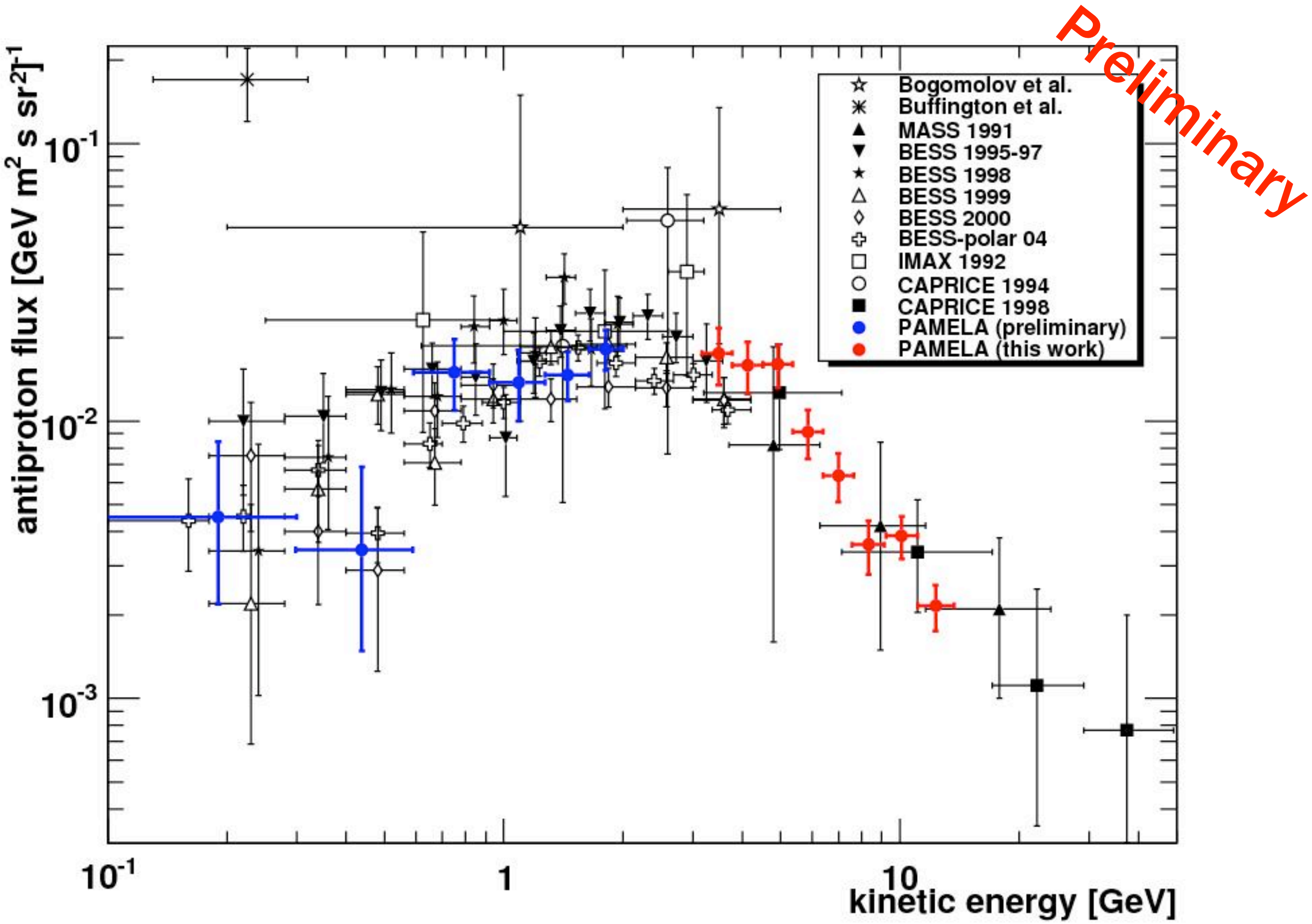
PRL 102, 051101 (2009)



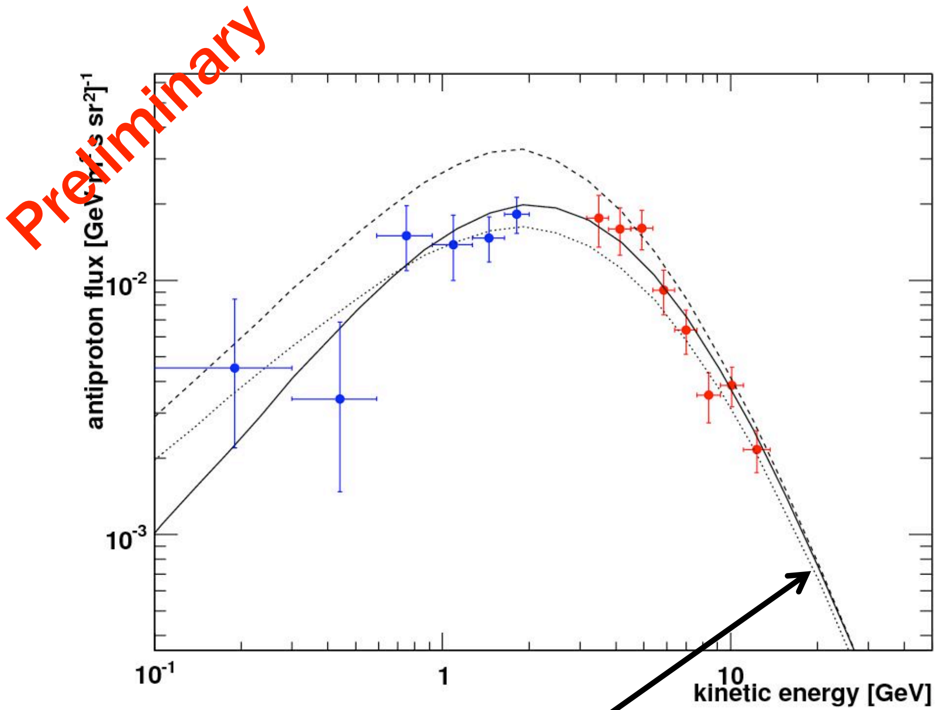
Antiproton Flux



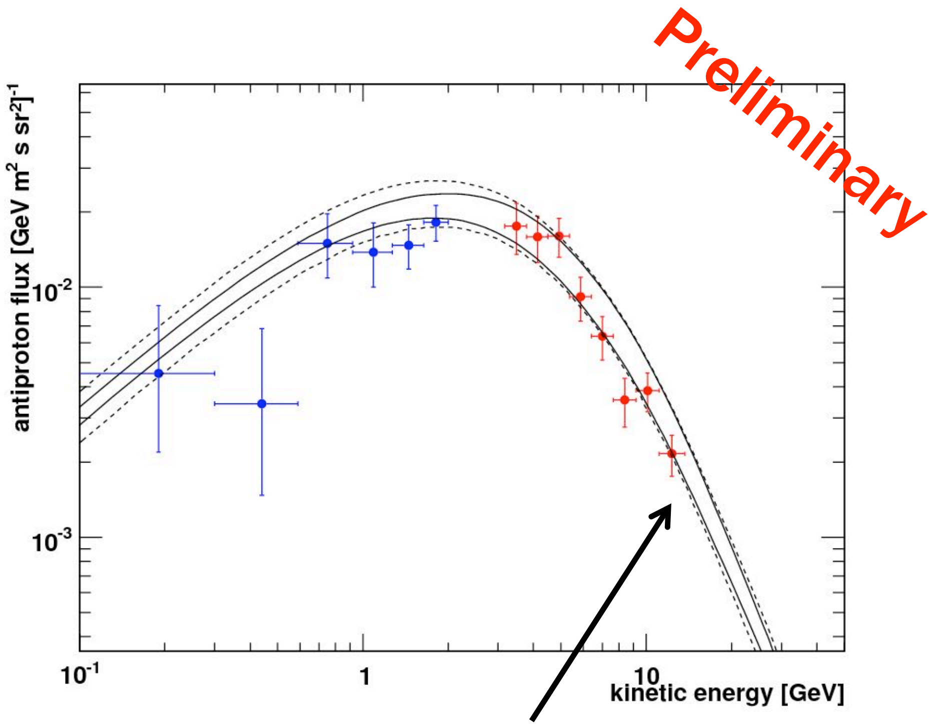
Antiproton Flux



Antiproton Flux



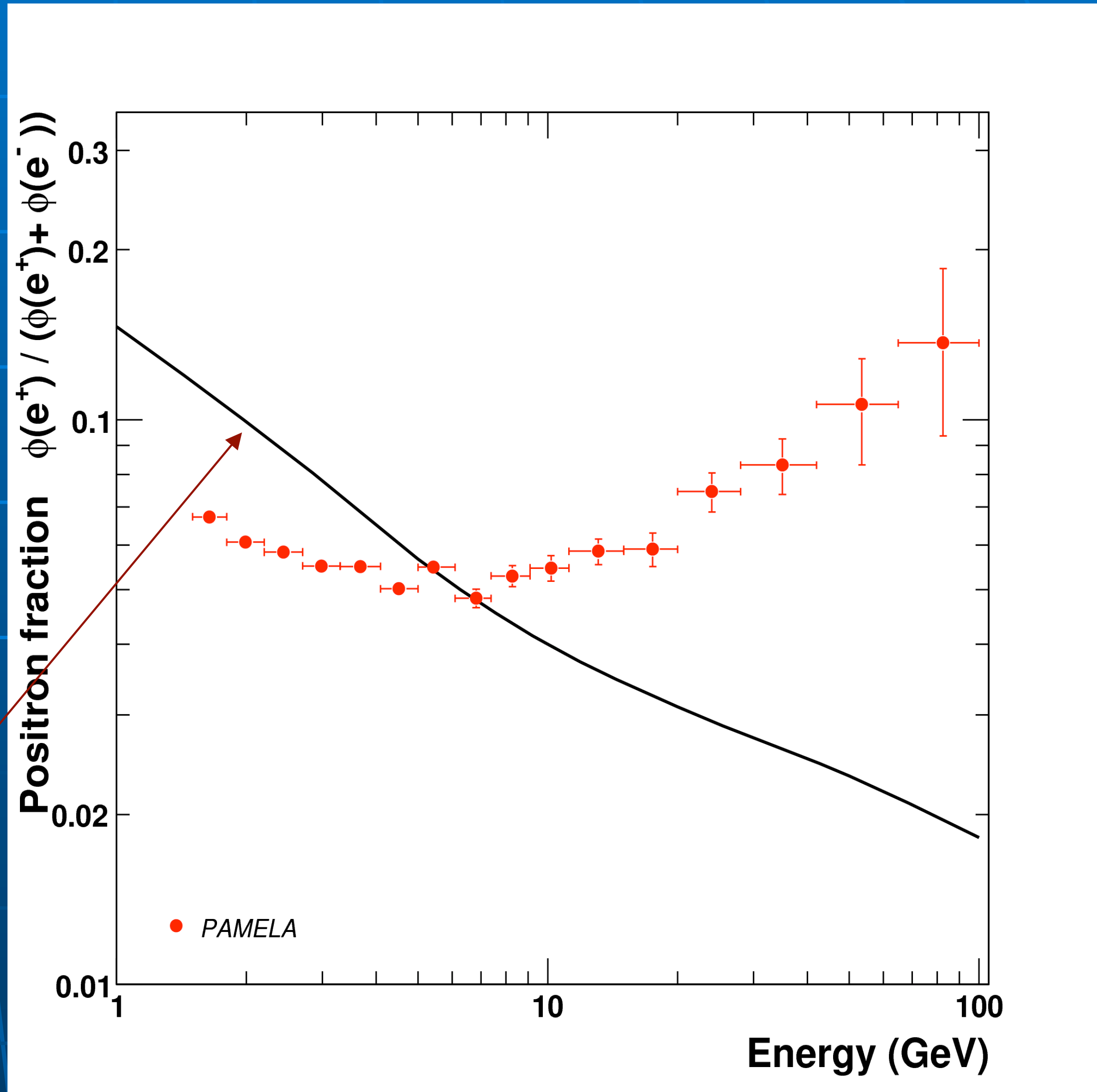
Secondary production:
V. S. Ptuskin et al, ApJ 642 (2006) 902



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

Positrons to all electrons ratio

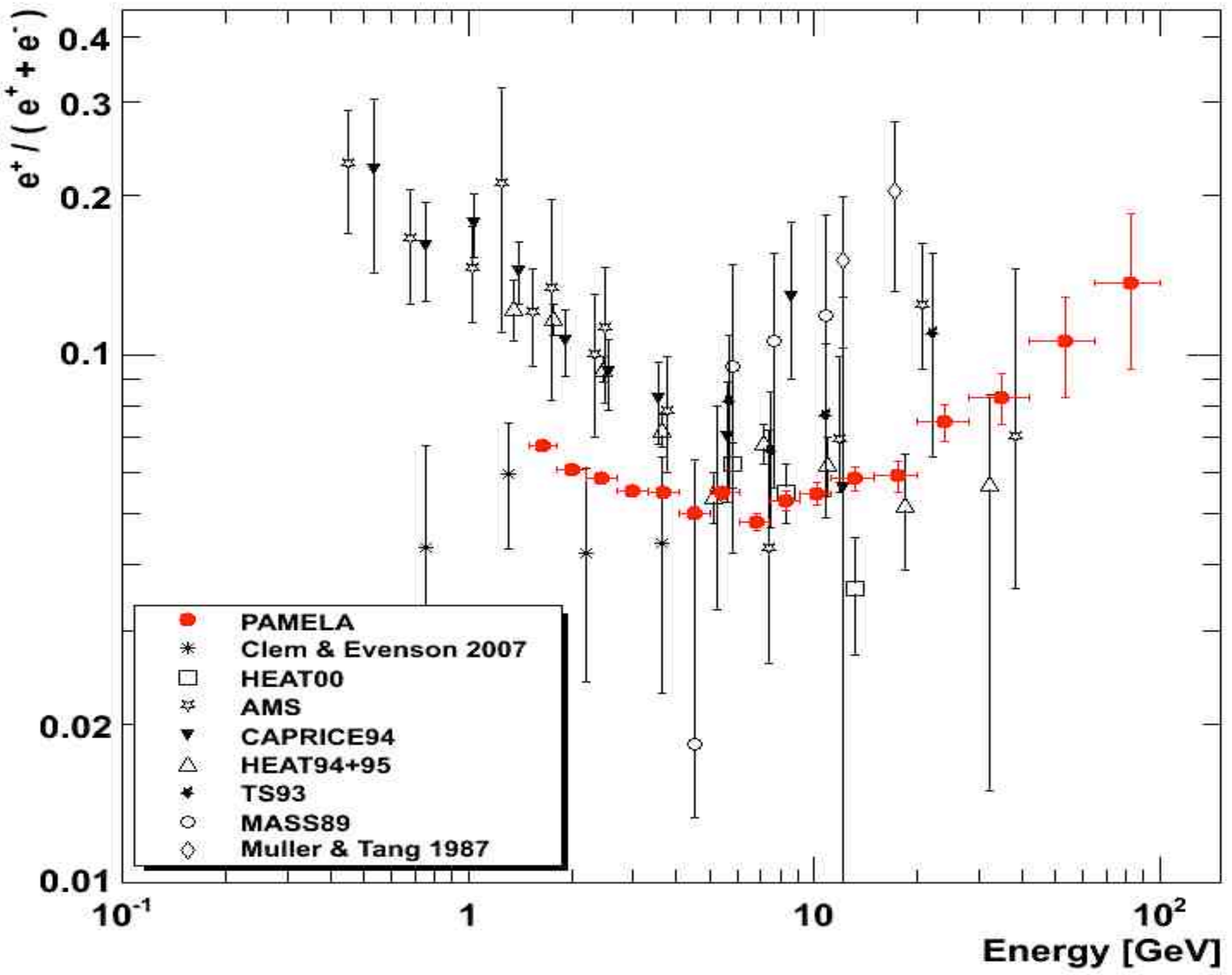
$$R(E) = \frac{\Phi_{e+}}{\Phi_{e+} + \Phi_{e-}}$$



Secondary production
Moskalenko & Strong 98

Positron to Electron Ratio

astro-ph 0810.4995

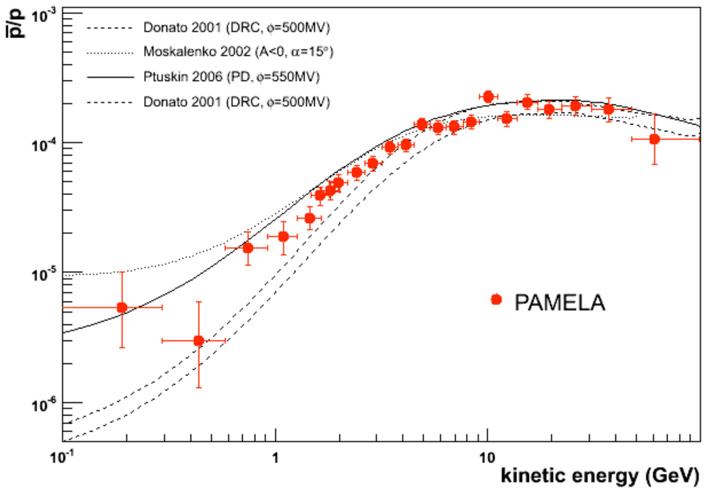


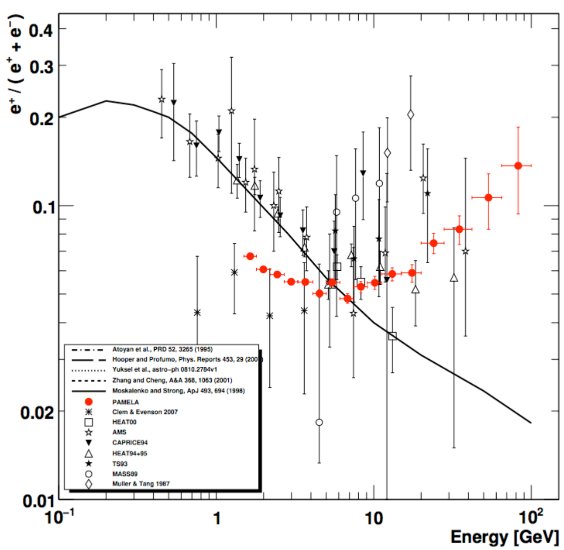
End 2007:
~10 000 e^+ > 1.5 GeV

~2000 > 5 GeV

Interpretation

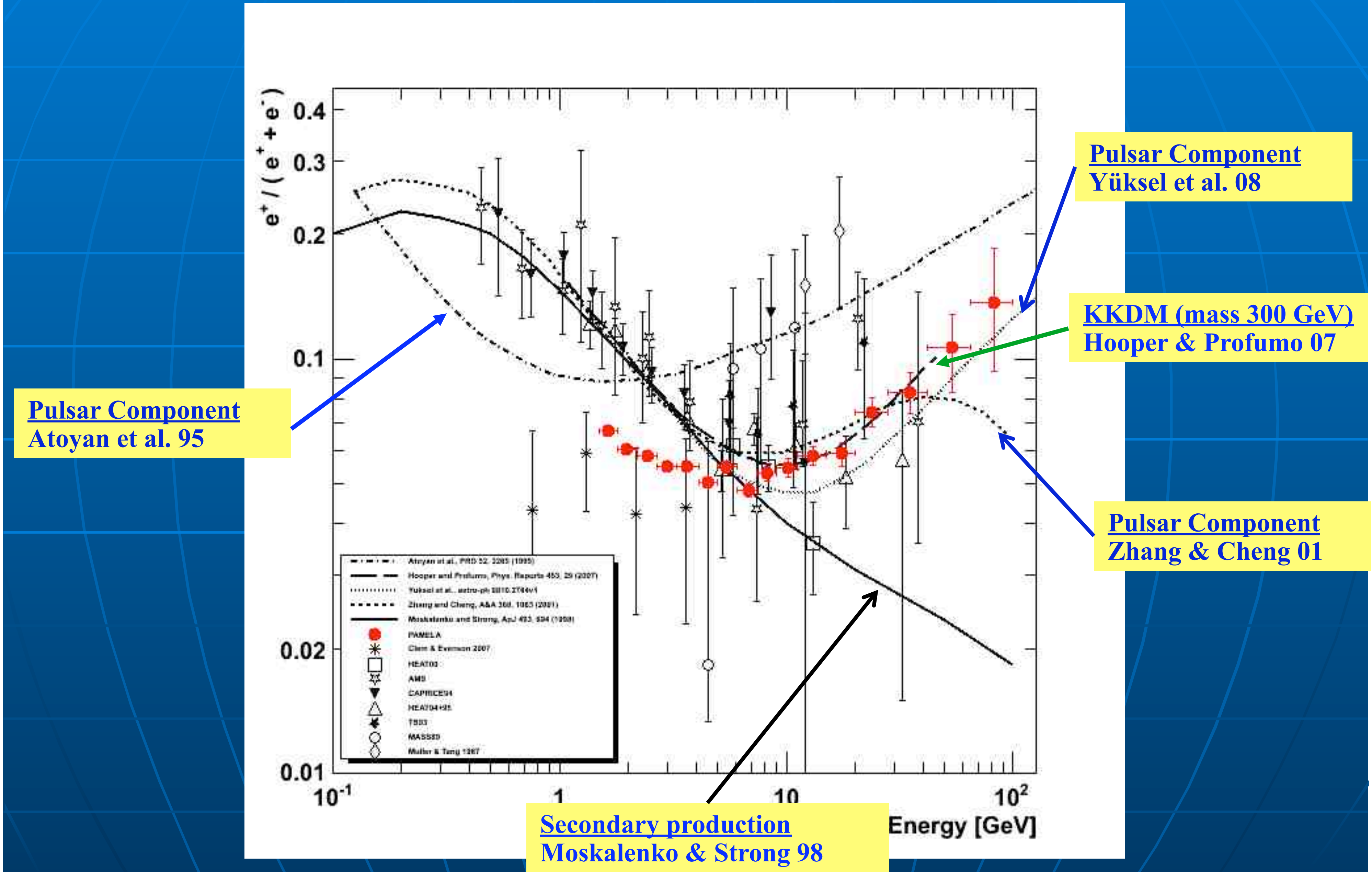
During first week after PAMELA results posted on arXiv





- 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

PAMELA Positron Fraction



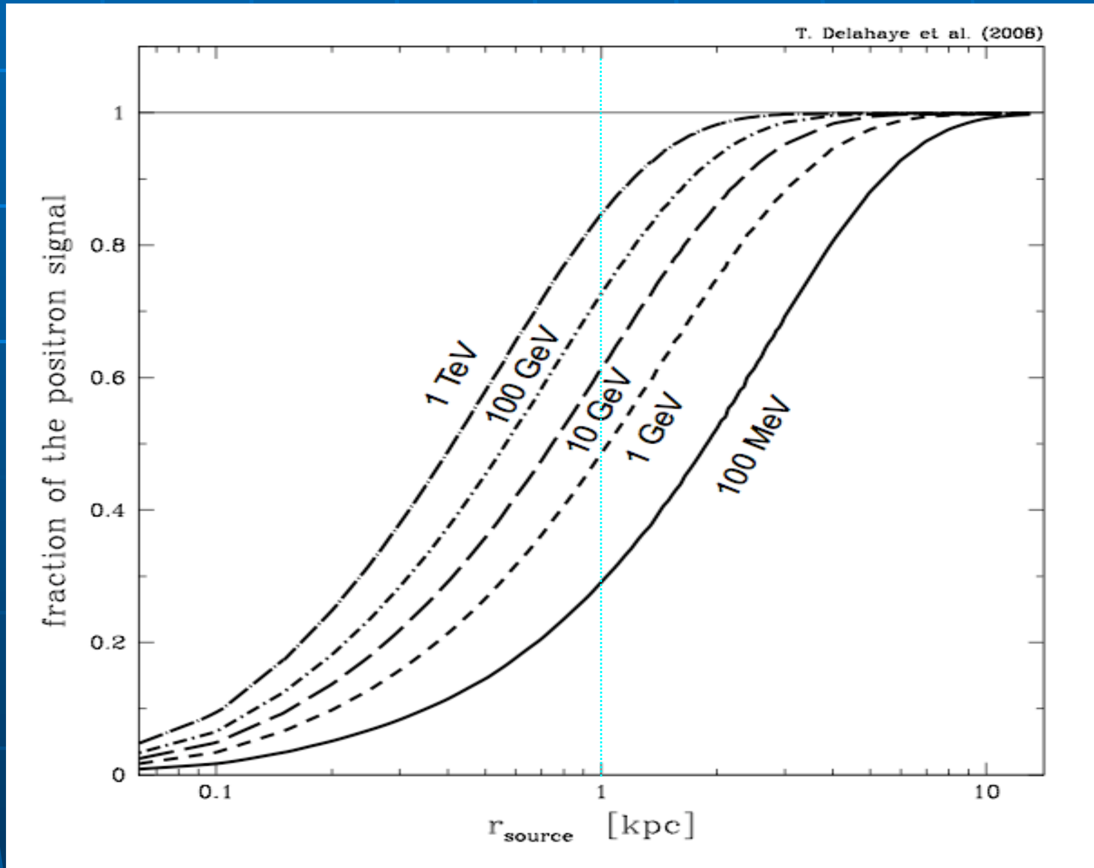
Positrons detection

Where do positrons come from?

Mostly locally within 1 Kpc, due to the energy losses by Synchrotron Radiation and Inverse Compton

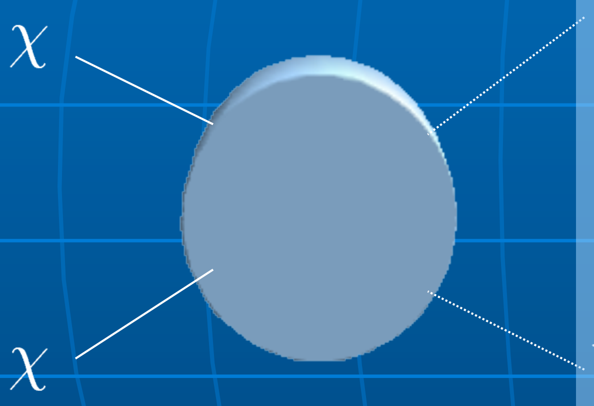
Typical lifetime

$$\tau \simeq 5 \cdot 10^5 \mathrm{yr} \left(\frac{1\,\mathrm{TeV}}{E} \right)$$



DM annihilations

DM particles are stable. They can annihilate in pairs.



$W^-, Z^0, b, \tau^-, t, h^0, \ldots \Rightarrow e^{\mp}, p^{(-)}, D^{(-)}, \ldots$

$W^+, Z^0, \bar{b}, \tau^+, \bar{t}, h^0, \ldots \Rightarrow e^{\pm}, p^{(-)}, D^{(-)}, \ldots$

Primary annihilation channels

Decay

Final states

$\text{flux} \propto n^2 \sigma_{\text{annihilation}}$

astro& cosmo

particle

reference cross section:

$\sigma = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$

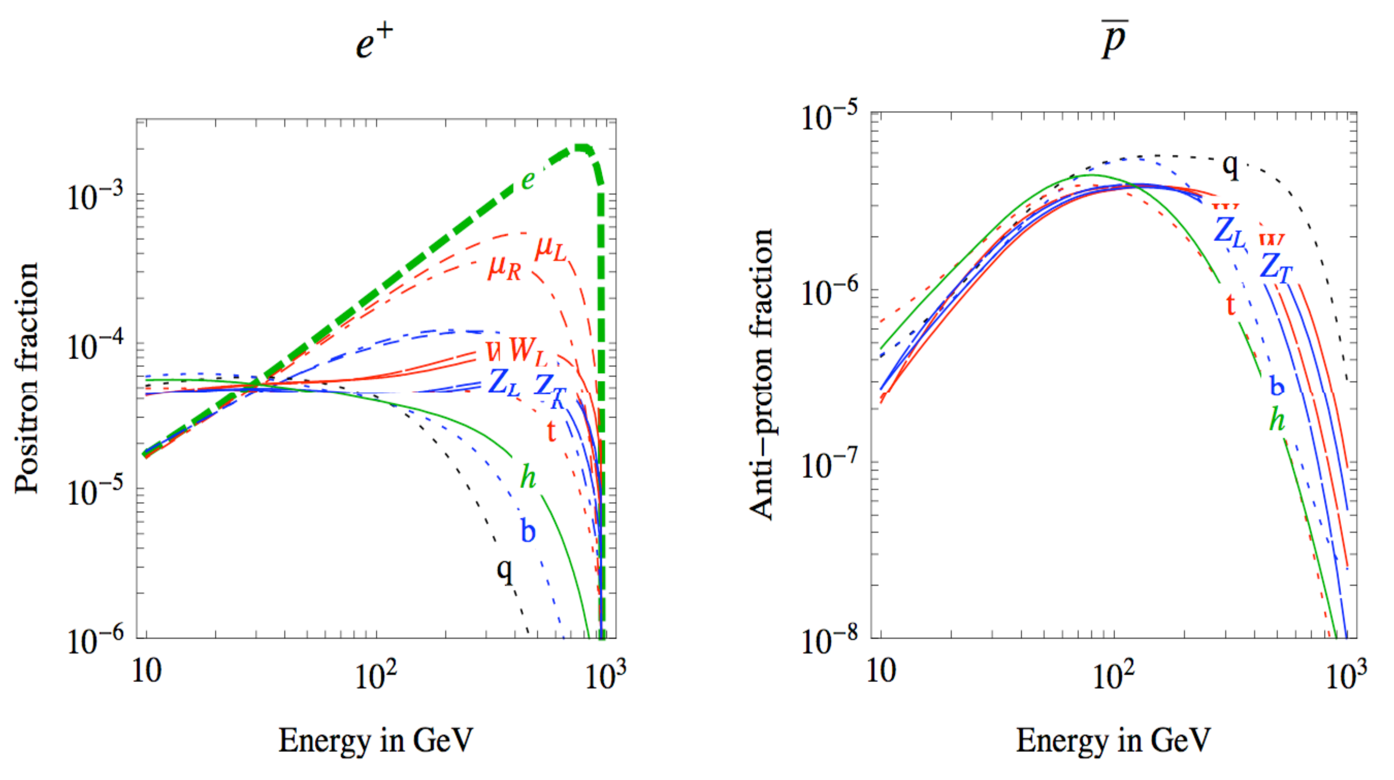
$\sigma_a = \langle \sigma v \rangle$

DM annihilations

Resulting spectrum for positrons and antiprotons

The flux shape is completely determined by:

1) WIMP mass
2) Annihilations channels

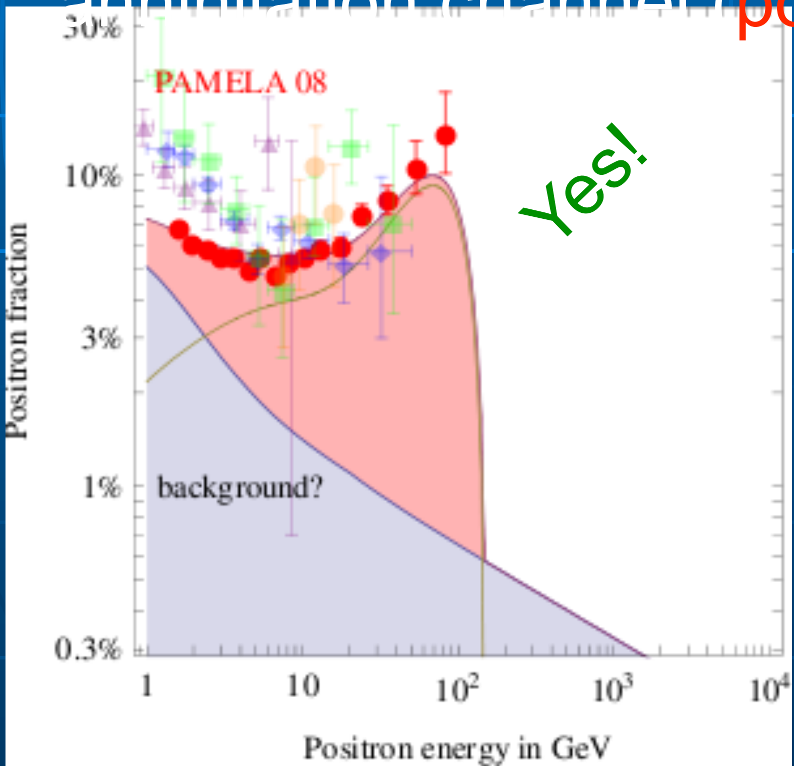


Data fitting

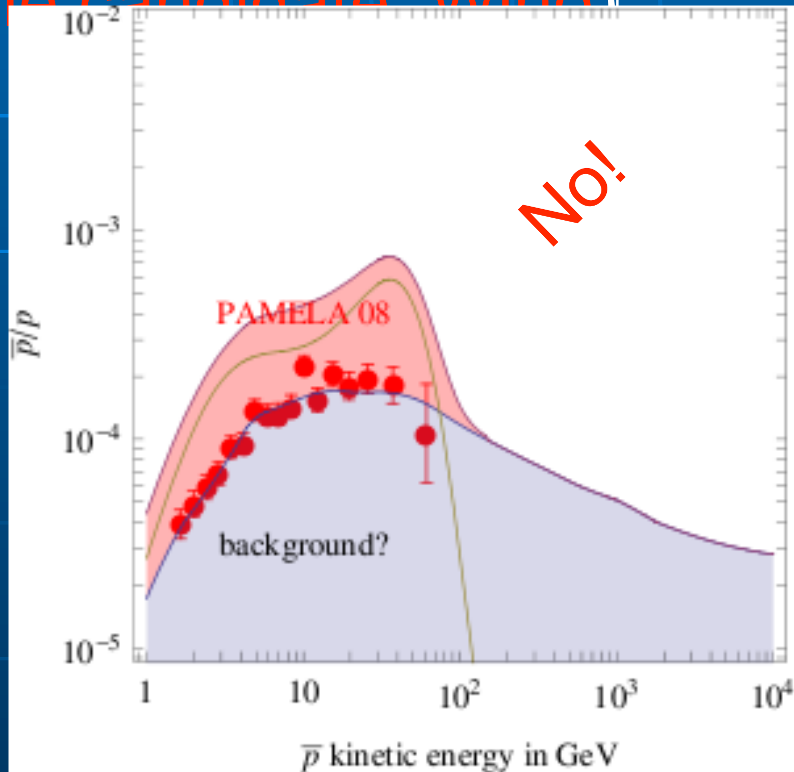
Which DM spectra can fit the data?

DM with $m_\chi \simeq 150\,\mathrm{GeV}$ and W^+W^- dominant annihilation channel (possible candidate: Wino)

positrons



antiprotons



Data fitting

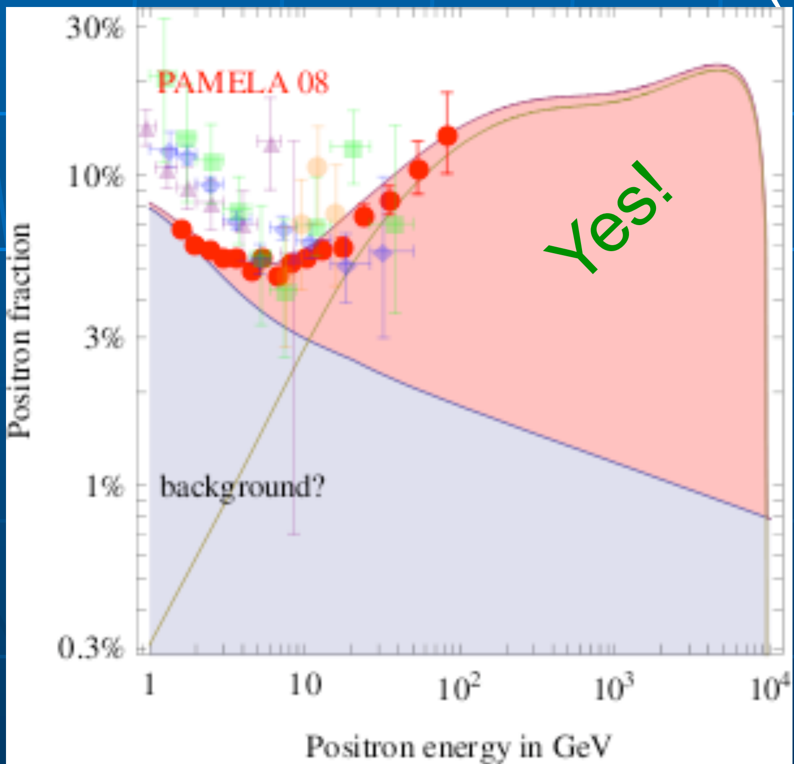
Which DM spectra can fit the data?

DM with $m_\chi \simeq 10\,\mathrm{TeV}$ and W^+W^- domin

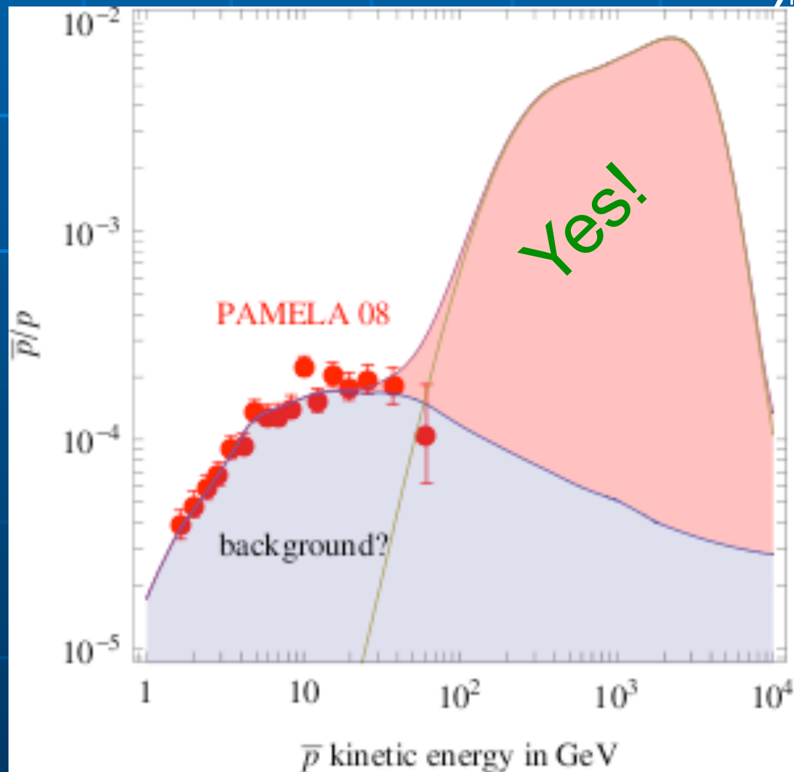
a But B≈10^4 No!

nt annihilation channel (no “natural” SUSY candidate)

positrons



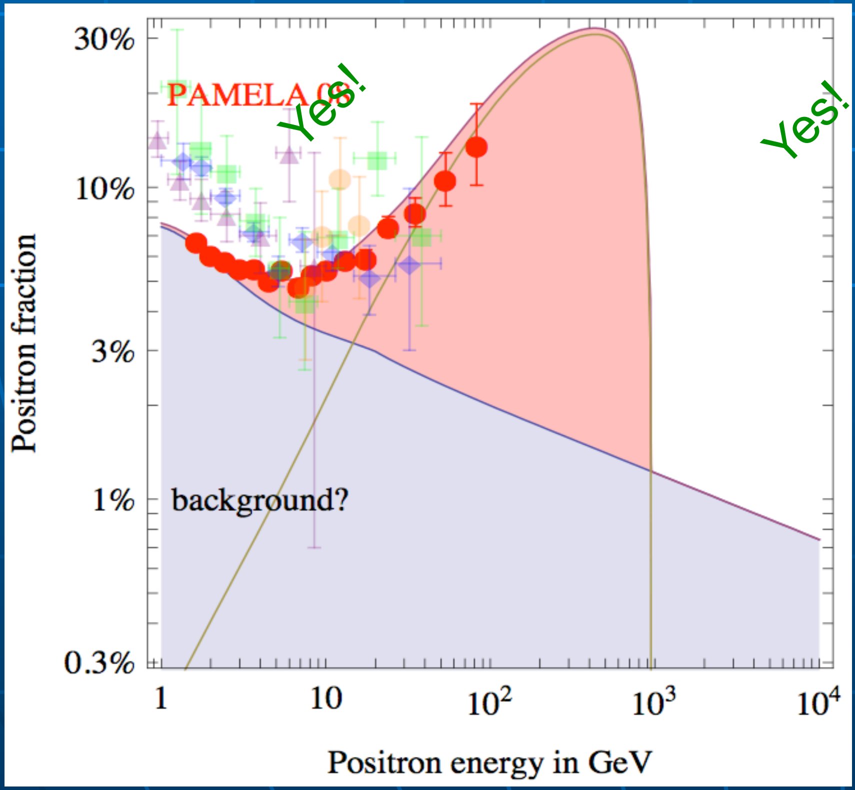
antiprotons



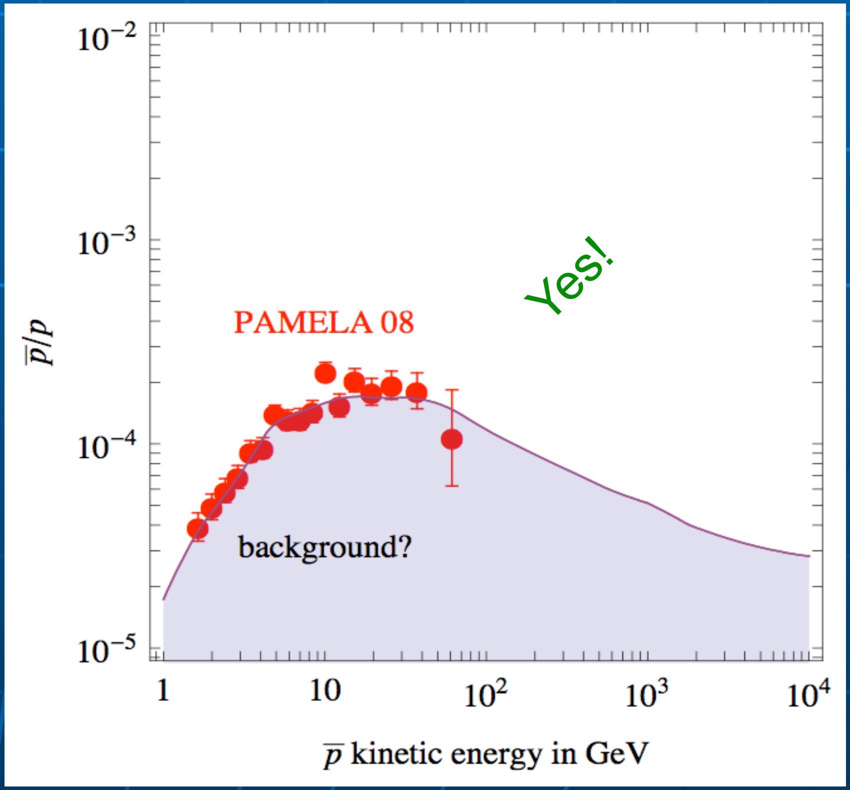
Data fitting

DM with $m_\chi \simeq 1\,\mathrm{TeV}$ and $\mu^+\mu^-$ dominant annihilation channel

positrons



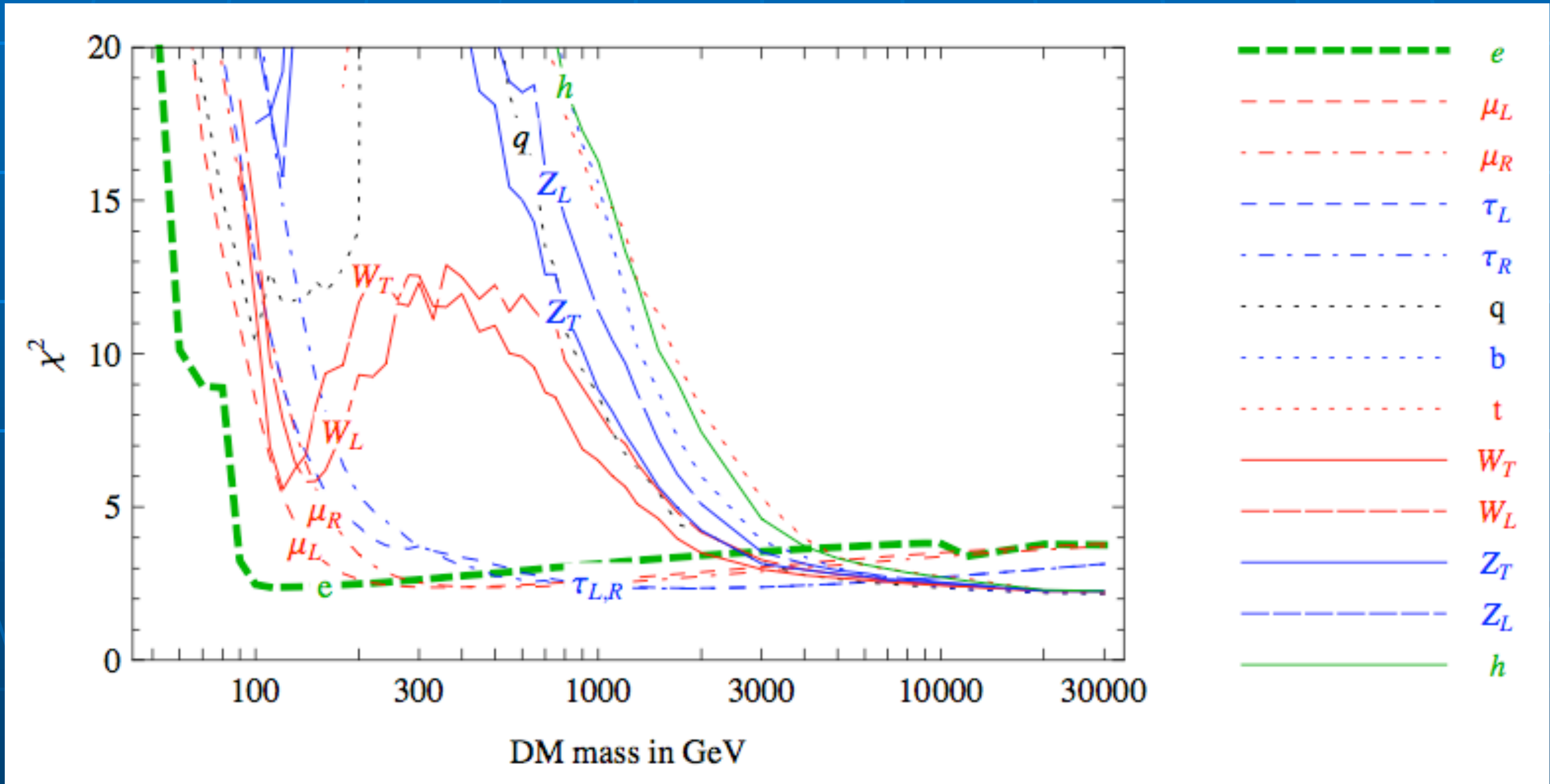
antiprotons



Model independent results

Which DM spectra can fit the data?

Fit of PAMELA positrons (only)

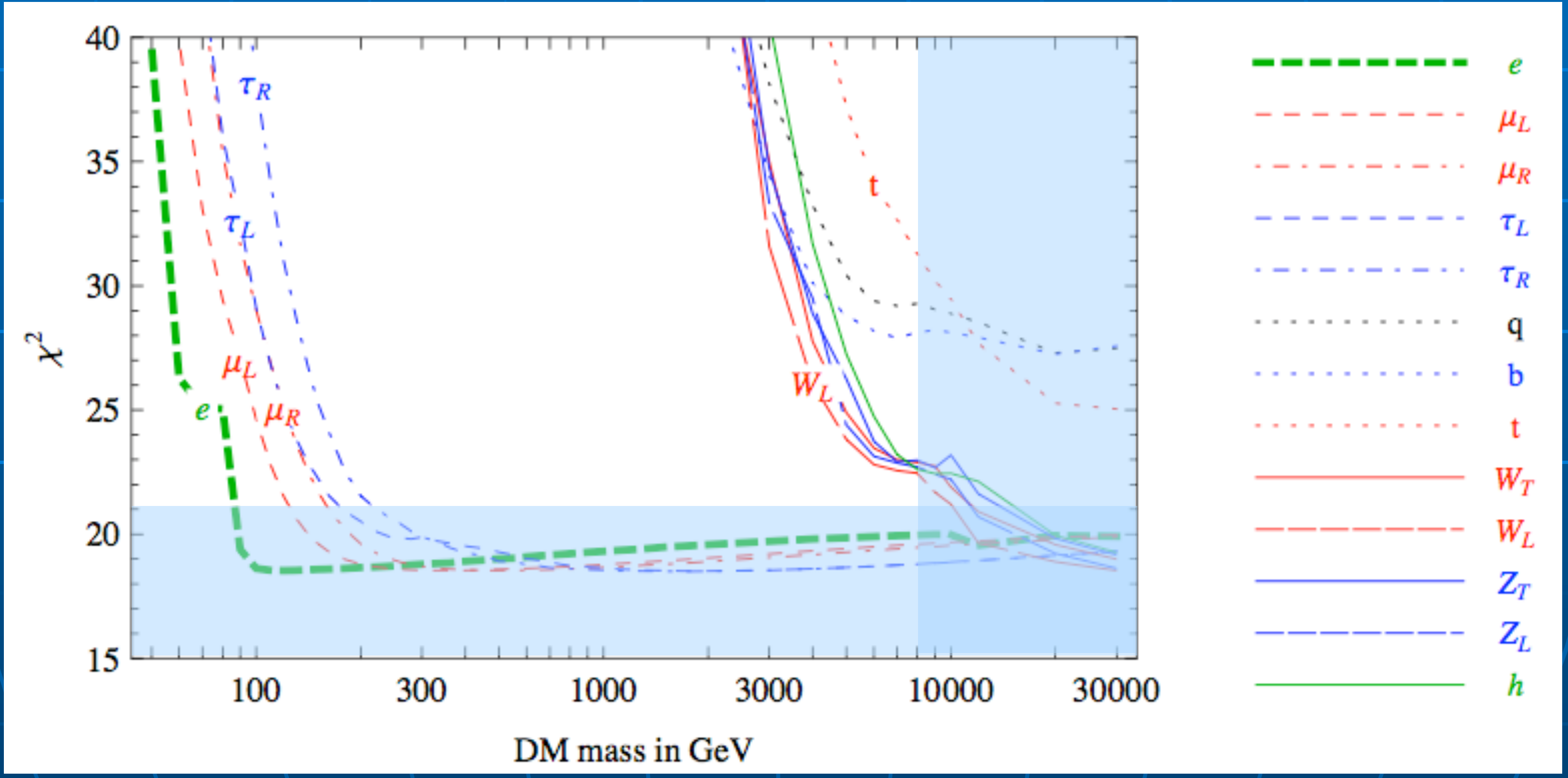


Lepton channels (e,μ,...) favored but also W

Model independent results

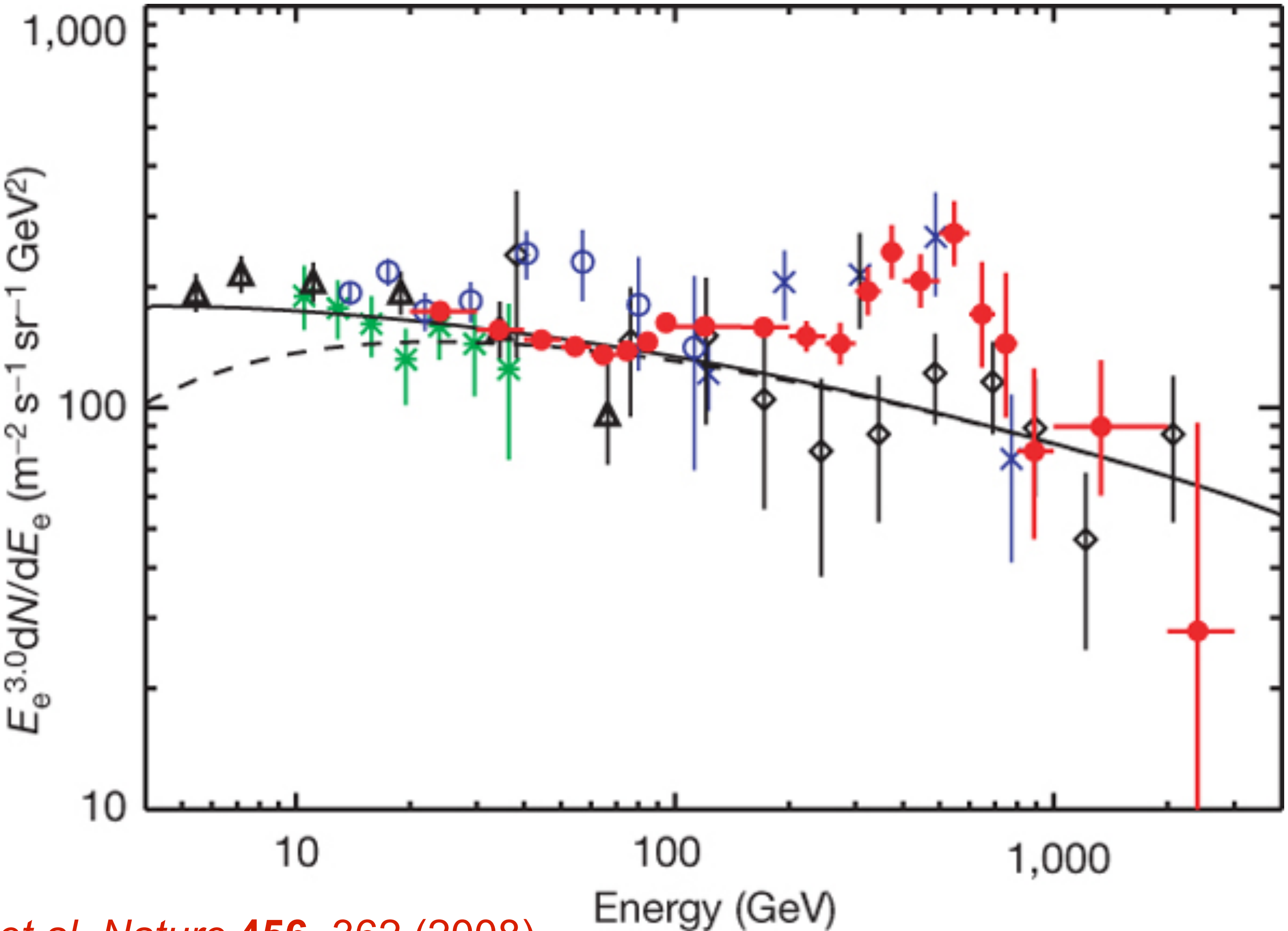
Which DM spectra can fit the data?

Fit of PAMELA positrons+antiprotons



Annihilations into quarks, gauge and Higgs bosons hardly constrained and $m_\chi \gtrsim 10\,\mathrm{TeV}$

ATIC Results



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

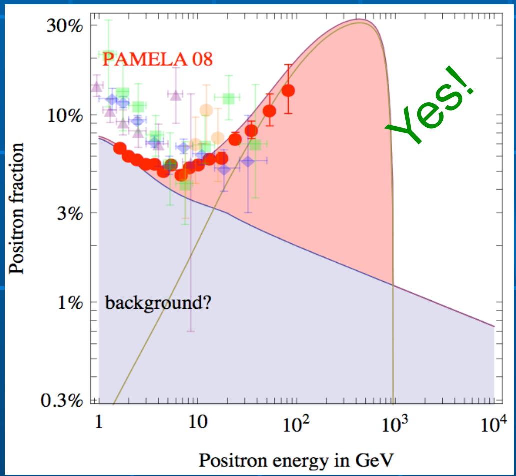
nature

Data fitting

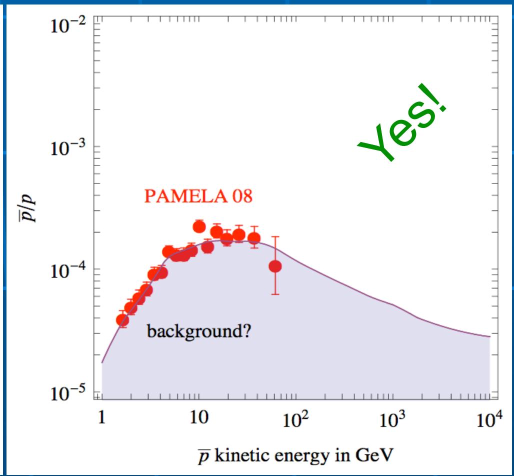
What if we consider ATIC and PPB-BETS data?

DM with $m_\chi \simeq 1\,\mathrm{TeV}$ and $\mu^+\mu^-$ dominant annihilation channel

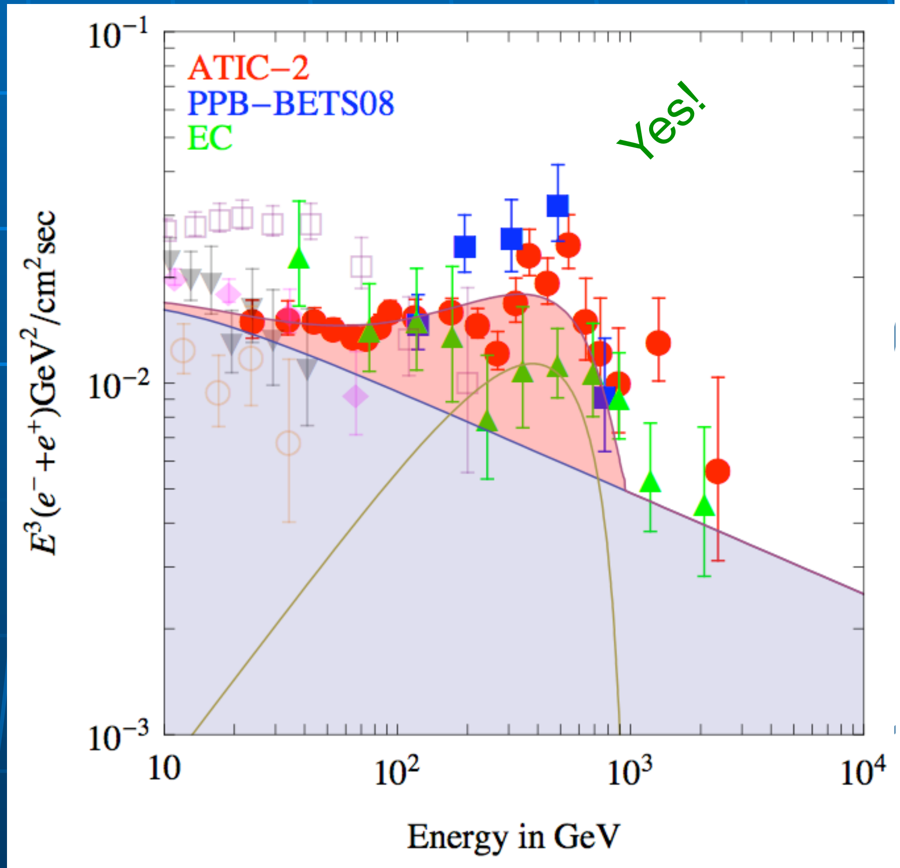
positrons



antiprotons



electron+positrons

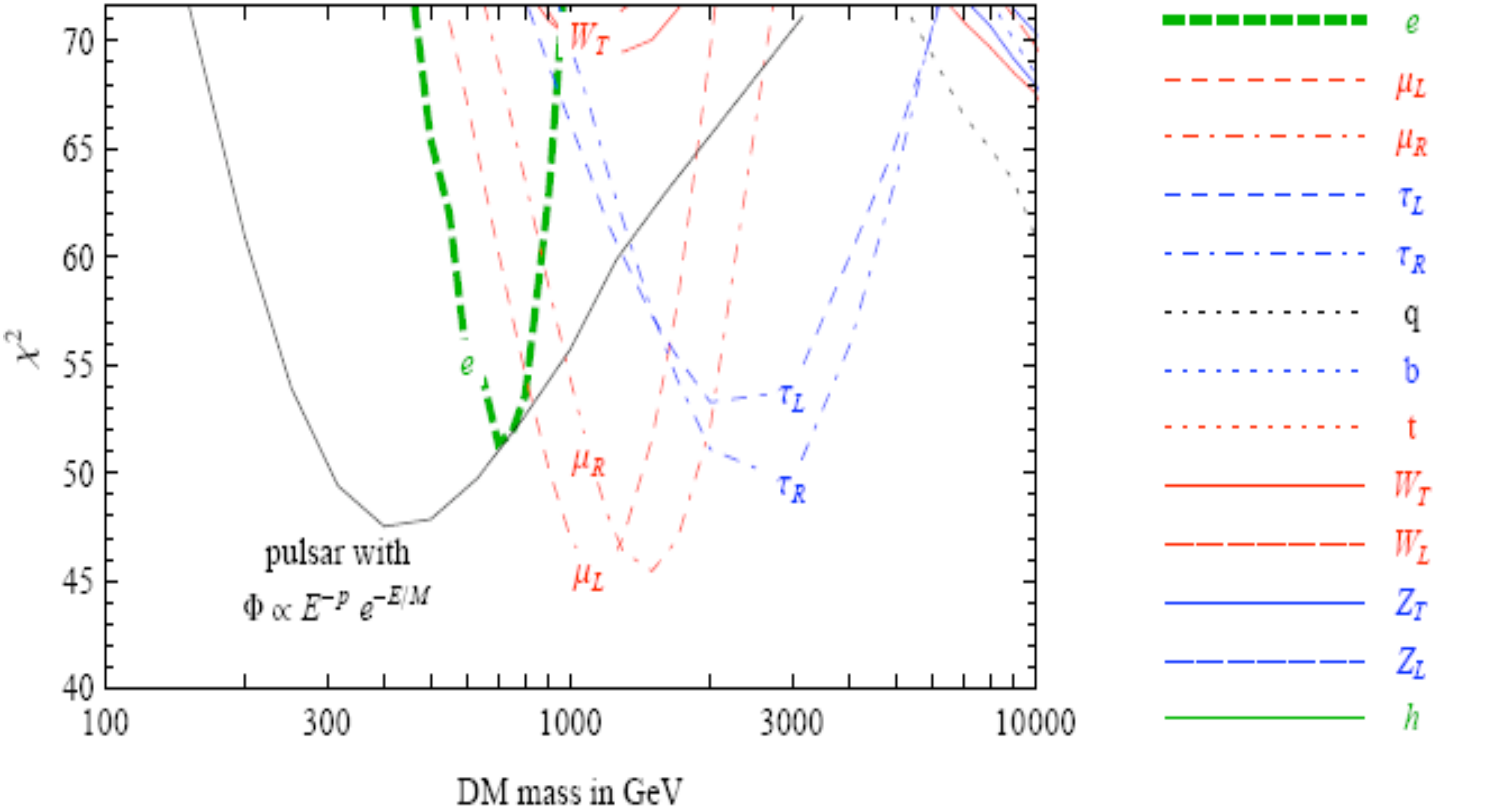


DM identification for the first time!?!?

Yes: Arkani-Hamed et al. arXiv: 0810.0713

+tons of other

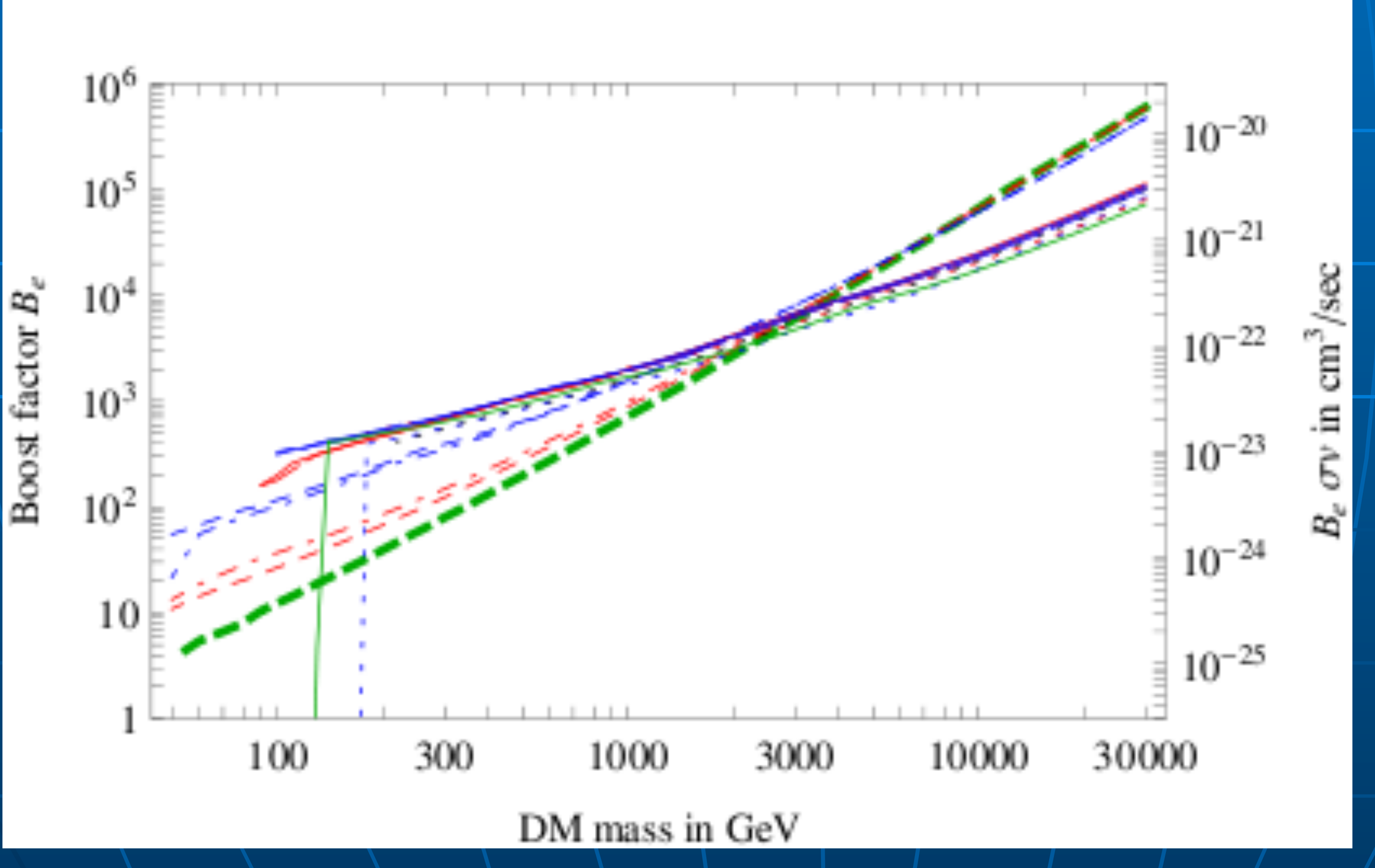
Pamela + ATIC Data



Model independent results

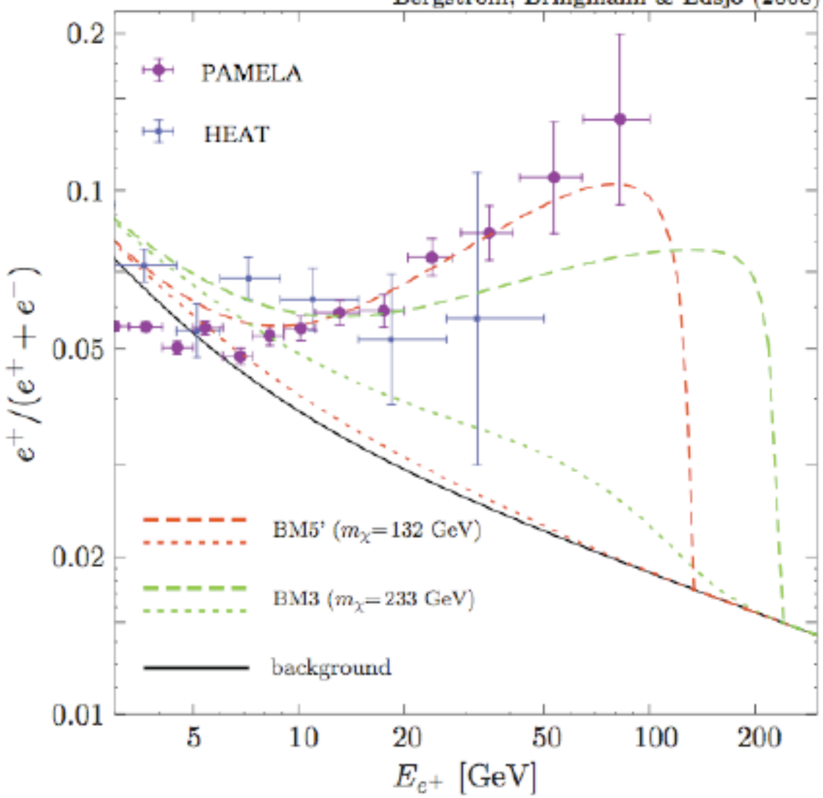
Which DM spectra can fit the data?

Boost required by PAMELA



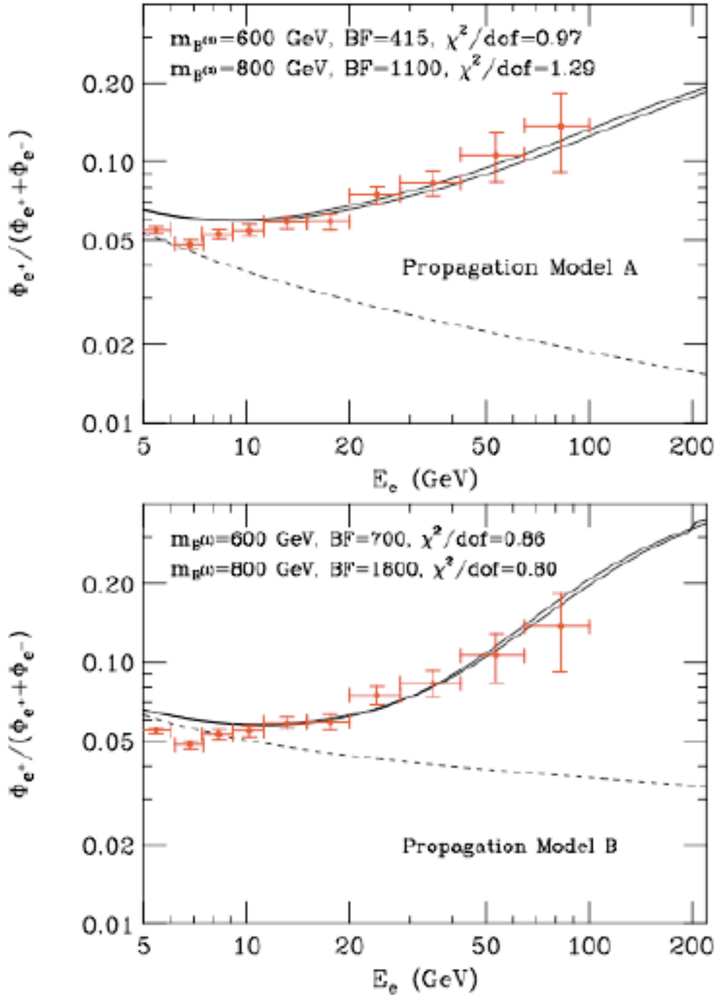
Example: Dark Matter

arXiv:0808.3725



Majorana DM with **new** internal bremsstrahlung correction. NB: requires annihilation cross-section to be 'boosted' by >1000.

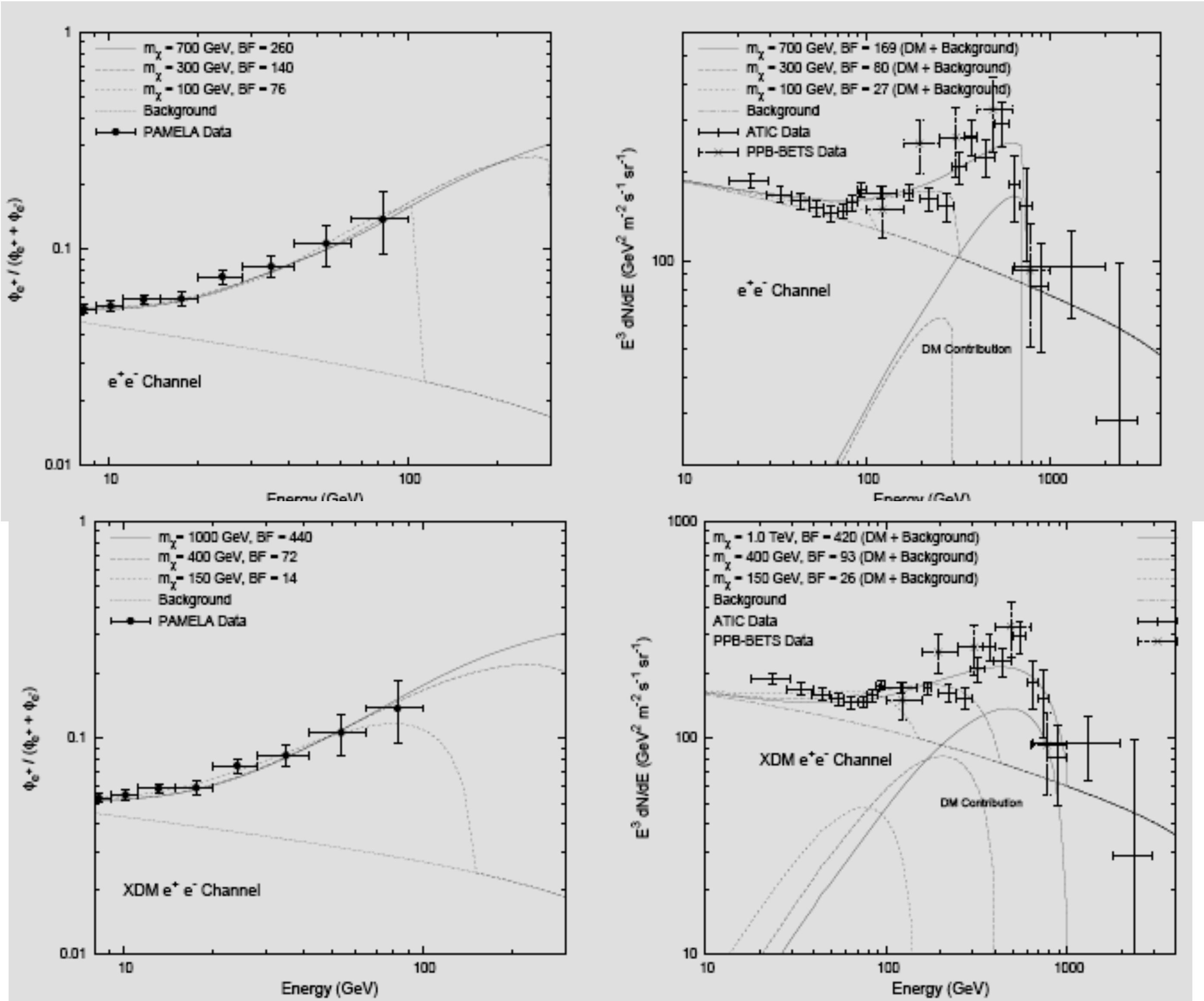
Hooper and Zurek
arXiv:0902.0593v1



Kaluza-Klein dark matter

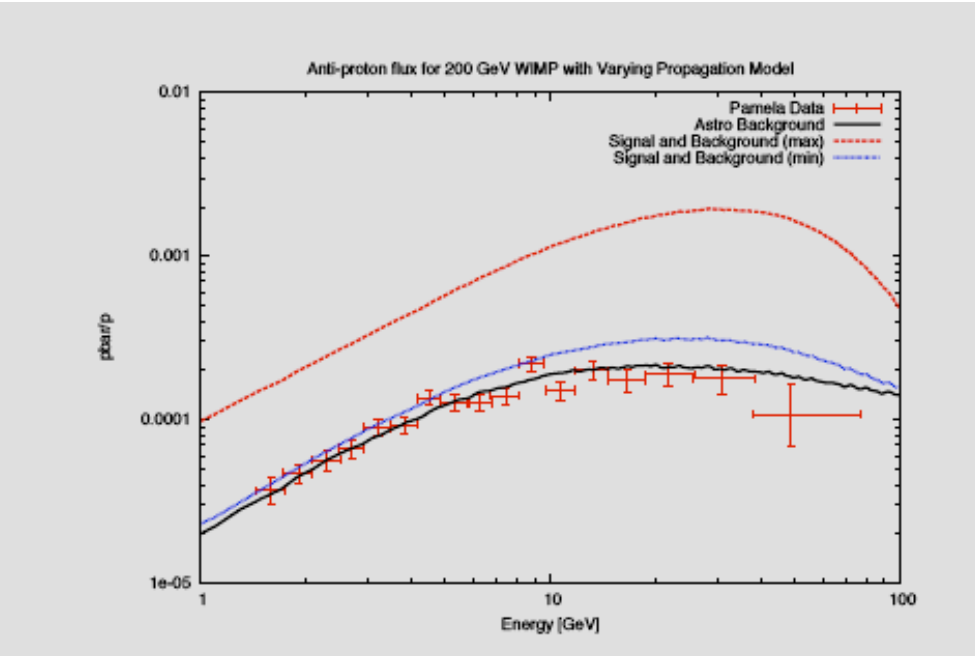
Example: DM

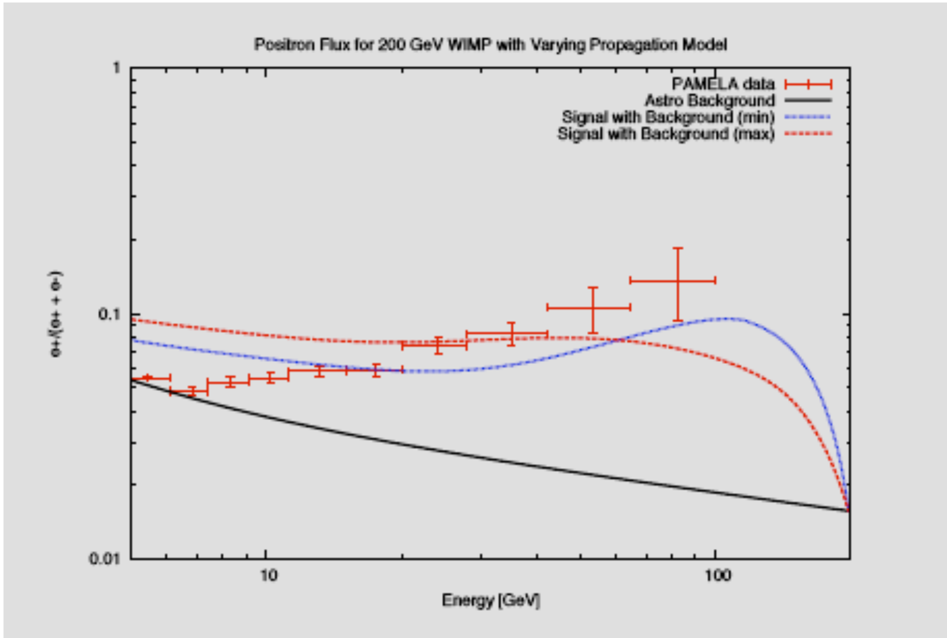
I. Cholis et al. arXiv:0811.3641v1



- Propose a new light boson ($m_\Phi \leq$ GeV), such that $\chi\chi \rightarrow \Phi\Phi$; $\Phi \rightarrow e^+e^-$, $\mu^+\mu^-$, ...
- Light boson, so decays to antiprotons are kinematically suppressed

Example: e^+ & $\bar{p}$ DM





P. Grajek et al., arXiv: 0812.4555v1

Enhancement

How to reconcile $\sigma = 3 \cdot 10^{-26} \mathrm{cm}^3/\mathrm{sec}$ with $\sigma \simeq 10^{-23} \mathrm{cm}^3/\mathrm{sec}$?

- DM is produced non-thermally: the annihilation cross section today is unrelated to the production process

	at freeze-out	***today***
- astrophysical boost	no clumps	clumps
- resonance effect	off-resonance	on-resonance
- Sommerfeld effect	$v/c \simeq 0.1$	$v/c \simeq 10^{-3}$

+ (Wimponium)

Dark Matter
Some Conclusions (from M. Cirelli)

- PAMELA Data:

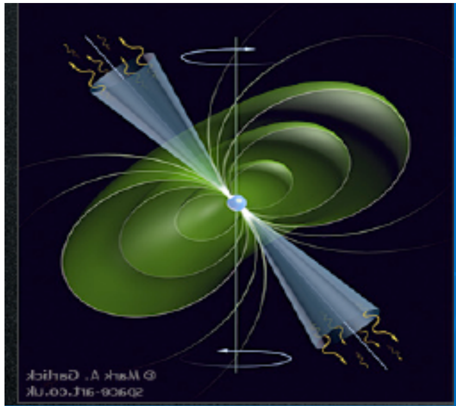
  DM must – annihilate into leptons (e.g. $\mu^+\mu^-$)

  or into W^+W^- with mass ≥ 10 TeV

- Adding balloon data (ATIC, PPB-BETS):

  DM must - annihilate into $\mu^+\mu^-$
  and have M_{DM} ~ 1TeV

- Problem: Large Boost Factor



Astrophysical Explanation
Pulsars

- Mechanism: the spinning $\vec{\mathbf{B}}$ of the pulsar strips e^- that accelerated at the polar cap or at the outer gap emit γ that make production of $e^\pm$ that are trapped in the cloud, further accelerated and later released at $\tau \sim 10^5$ years.

$$E_{tot} \simeq 10^{46}\ \mathrm{erg}$$

- Young ($T < 10^5$ years) and nearby (< 1kpc)
- If not: too much diffusion, low energy, too low flux.

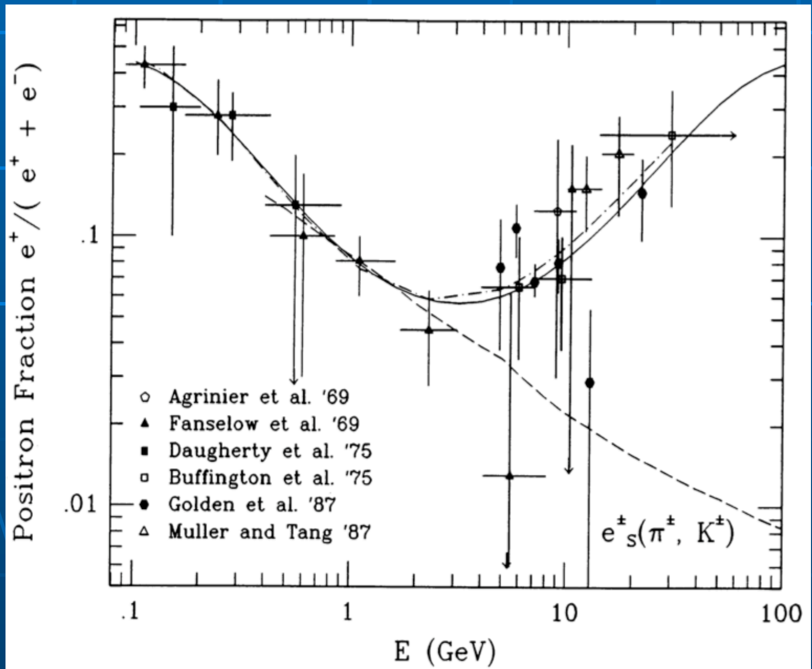
- Geminga: 157 parsecs from Earth and 370,000 years old
- B0656+14: 290 parsecs from Earth and 110,000 years old.

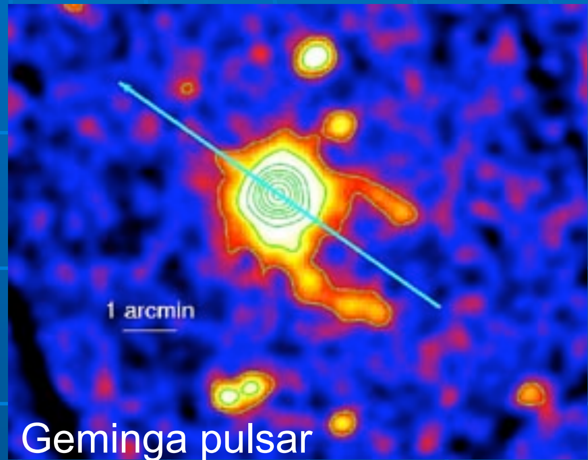
- Diffuse mature pulsars

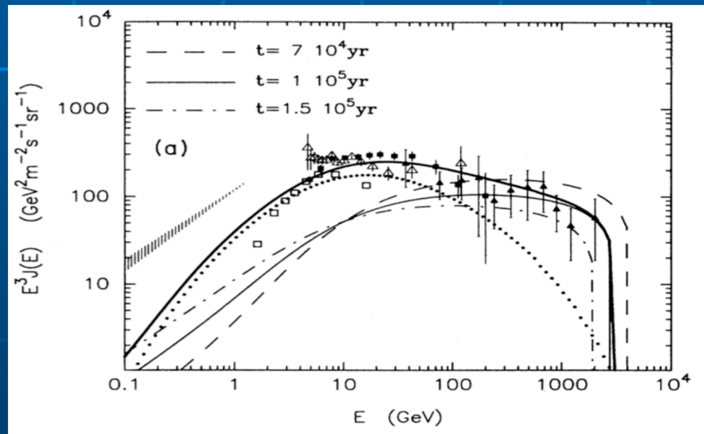
Astrophysical explanations?

Are there "standard" astrophysical explanations of the PAMELA data?

Young, nearby pulsars

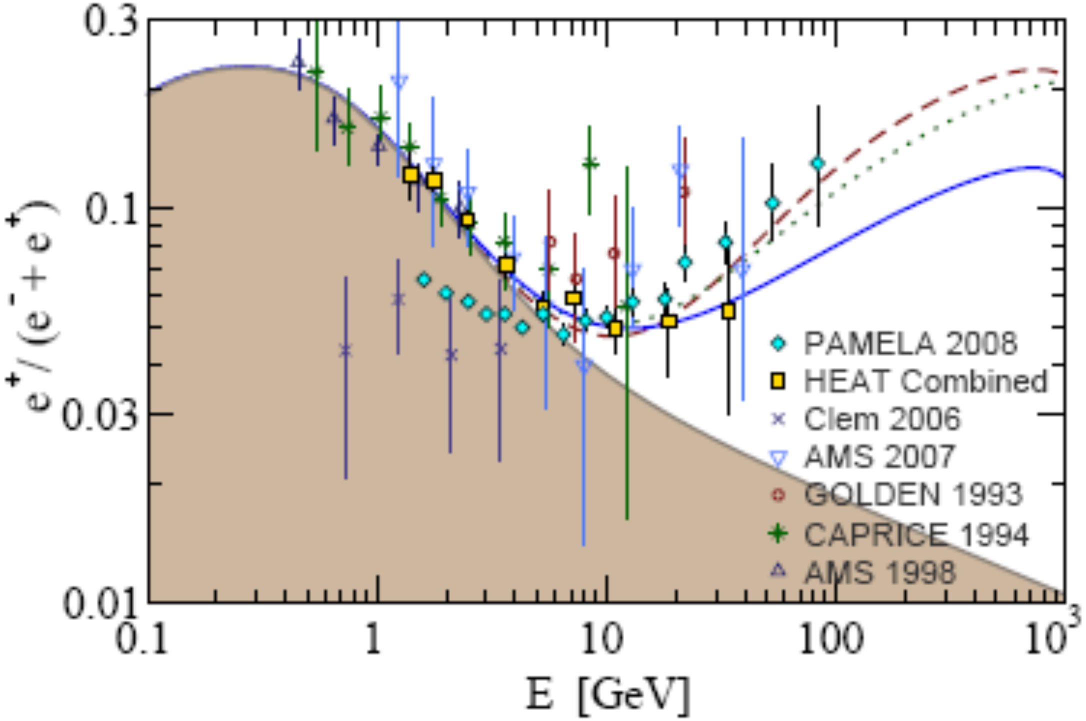


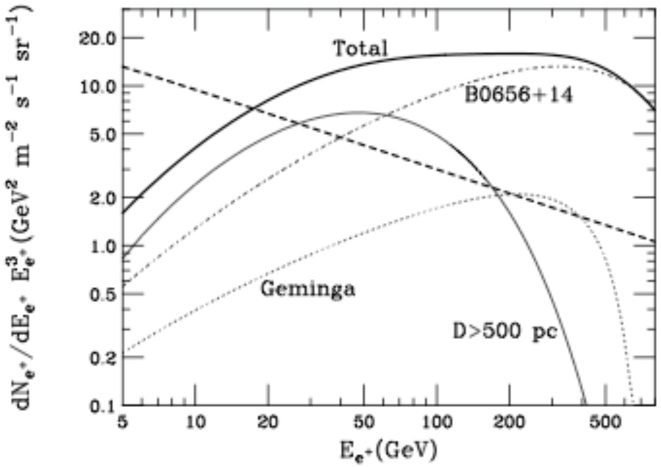


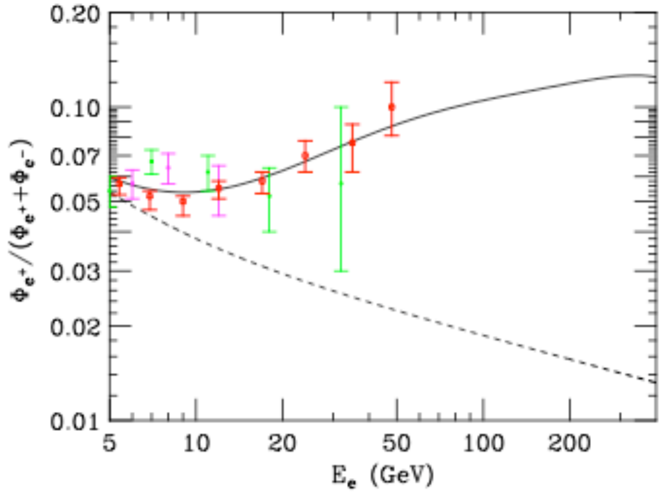


Not a new idea: Boulares, ApJ 342 (1989), Atoyan et al (1995)

Example: pulsars







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

diffuse mature &nearby young pulsars
Hooper, Blasi, and Serpico
arXiv:0810.1527

Astrophysical explanation?

see S.Profumo, 0812.4457

the electron spectrum has a steep deepening!

T.Delahaye et al., 09.2008
Casadei, Bindi 2008

- difficult to get PAMELA slope
- does not explain ATIC or HESS

CR proton collisions on giant molecular clouds produce e^+e^-!

Dogiel, Sharov 1990

- does not work at E > 30 GeV

Coutu et al (HEAT), 1990

Gamma Ray Bursts produce e^+e^-!

Ioka 0812.4851

- maybe, constrained by gammas

β^+ decays of ^{56}Co in SN produce e^+!

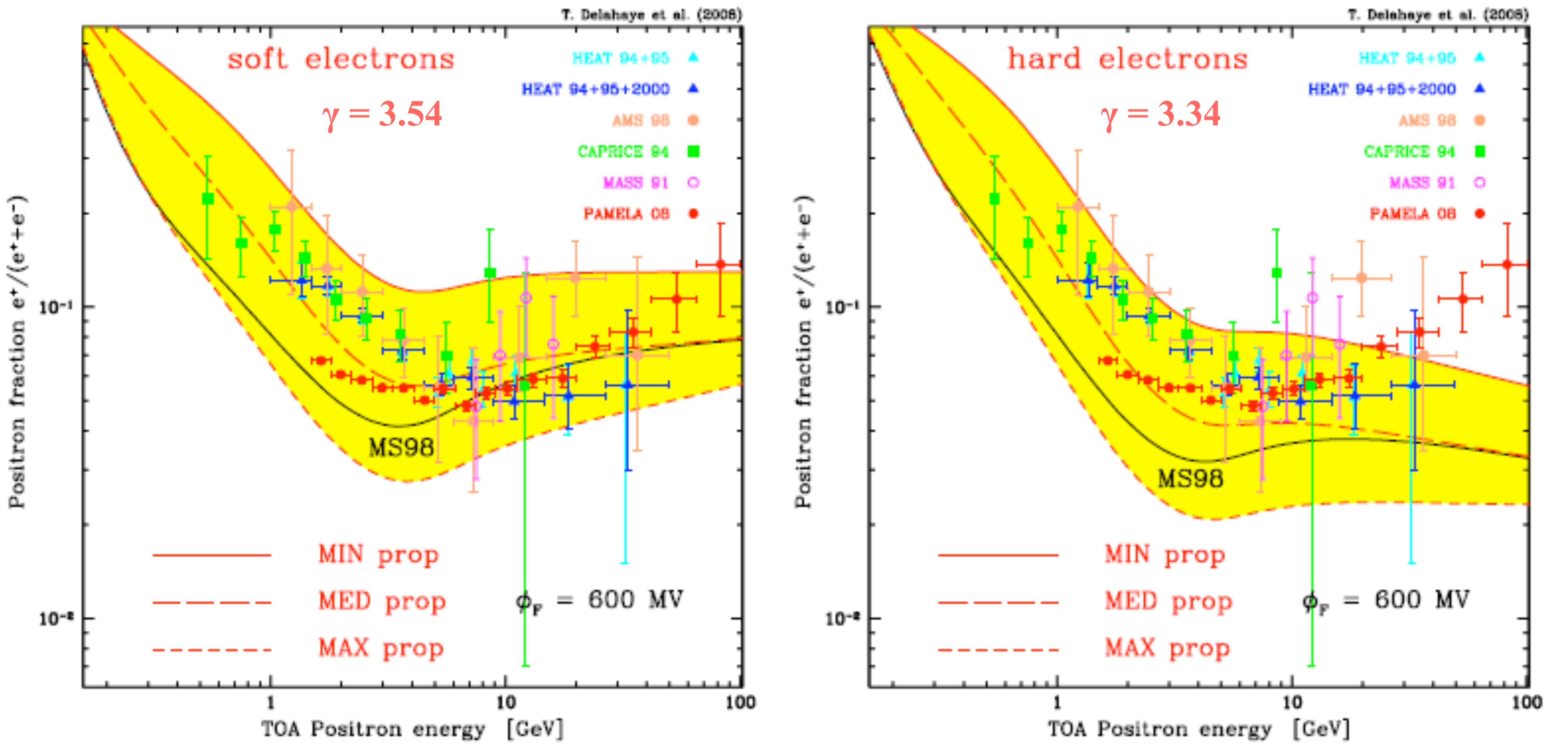
ICRC 1990

- low energy and low flux

...

[back]

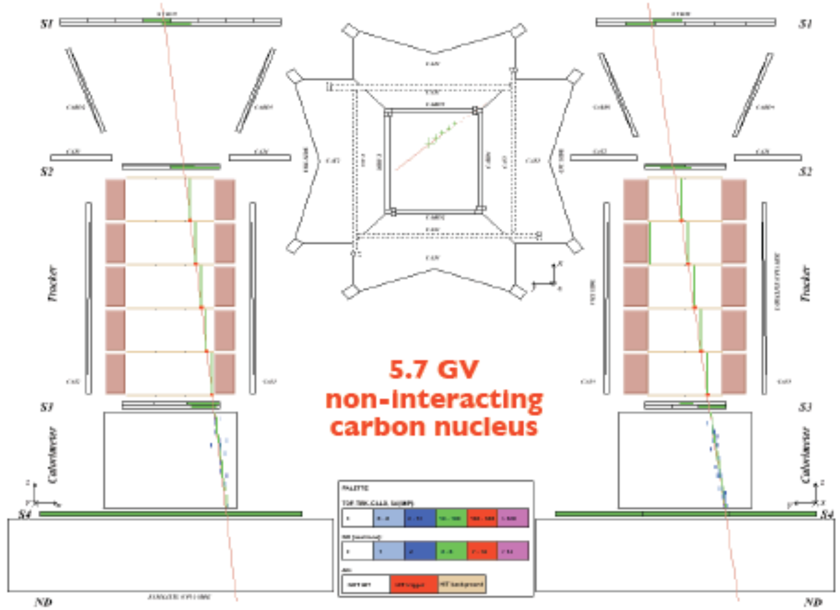
Standard Positron Fraction
Theoretical Uncertainties

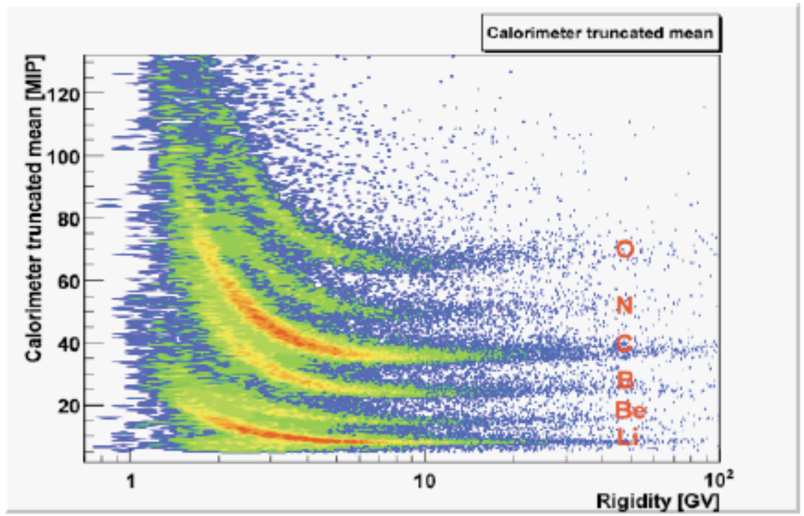


T. Delahaye et al., arXiv: 0809.5268v3

Nuclei identification

- **Important input to secondary production + propagation models**
  - Secondary to primary ratios:
    - B / C
    - Be / C
    - Li / C
  - Helium and hydrogen isotopes:
    - ^{3}He / ^{4}He
    - d / He

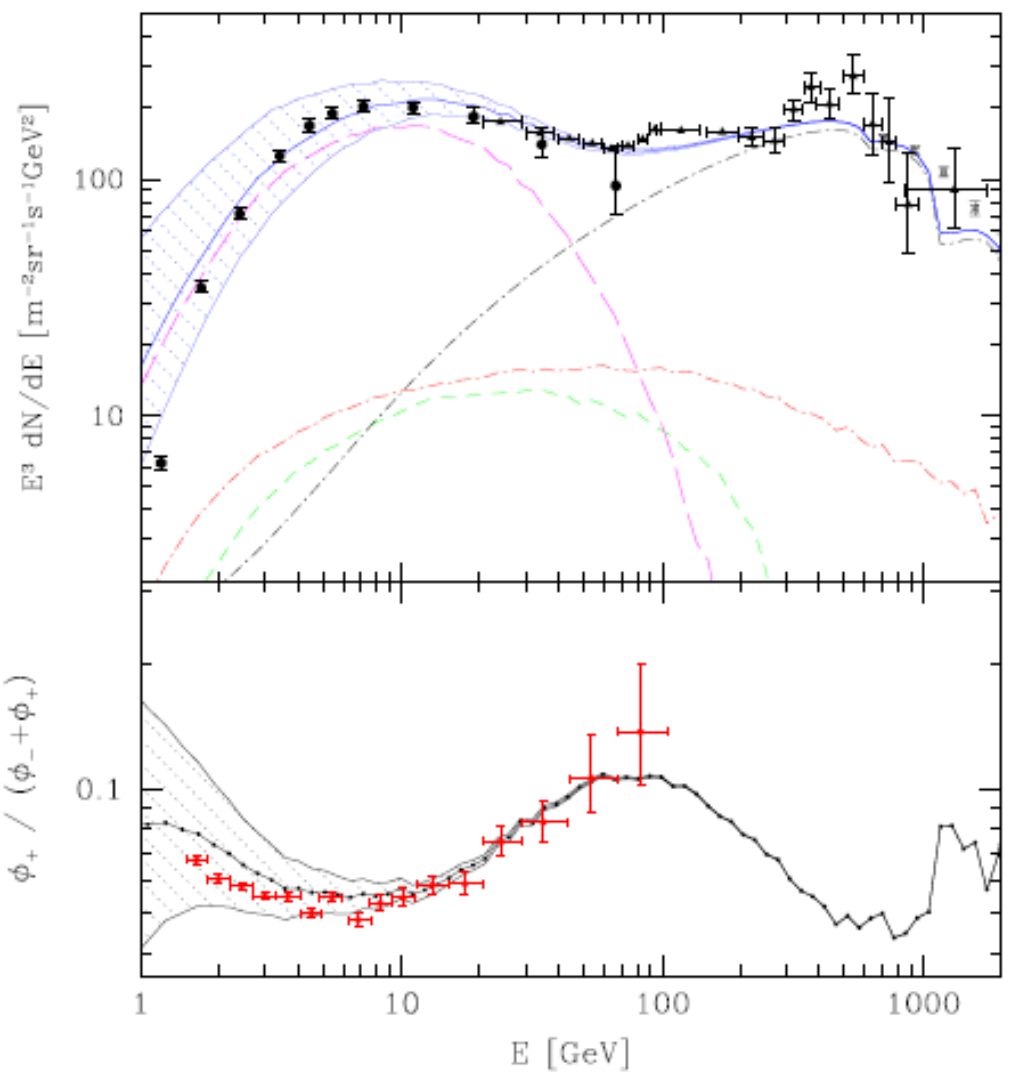




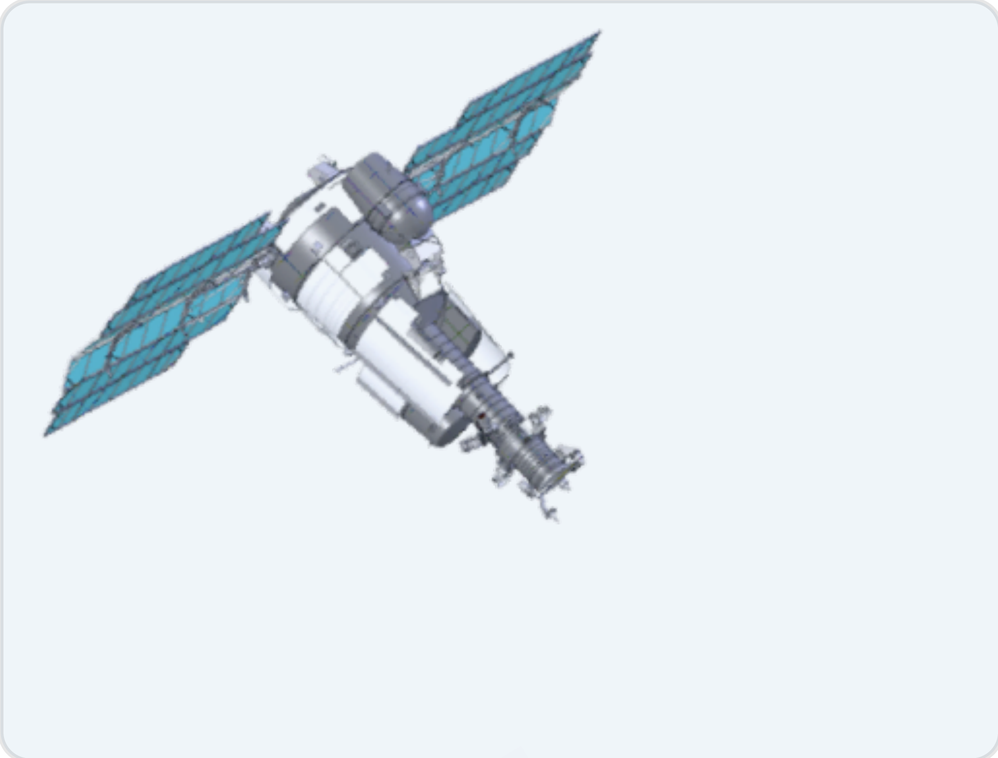
Truncated mean of multiple dE/dx measurements in different silicon planes

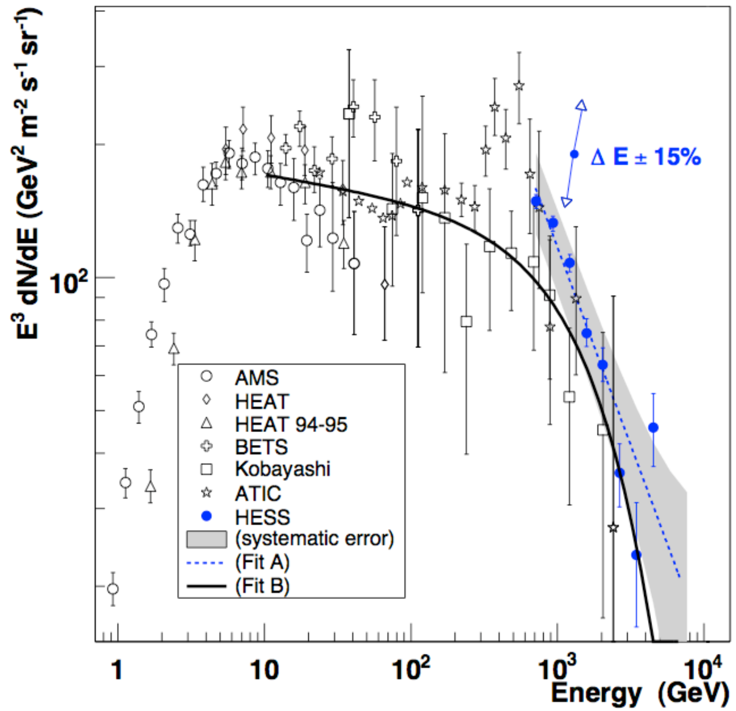
Explanation with supernovae remnants

Shaviz and al. astro-ph.HE 0902.0376



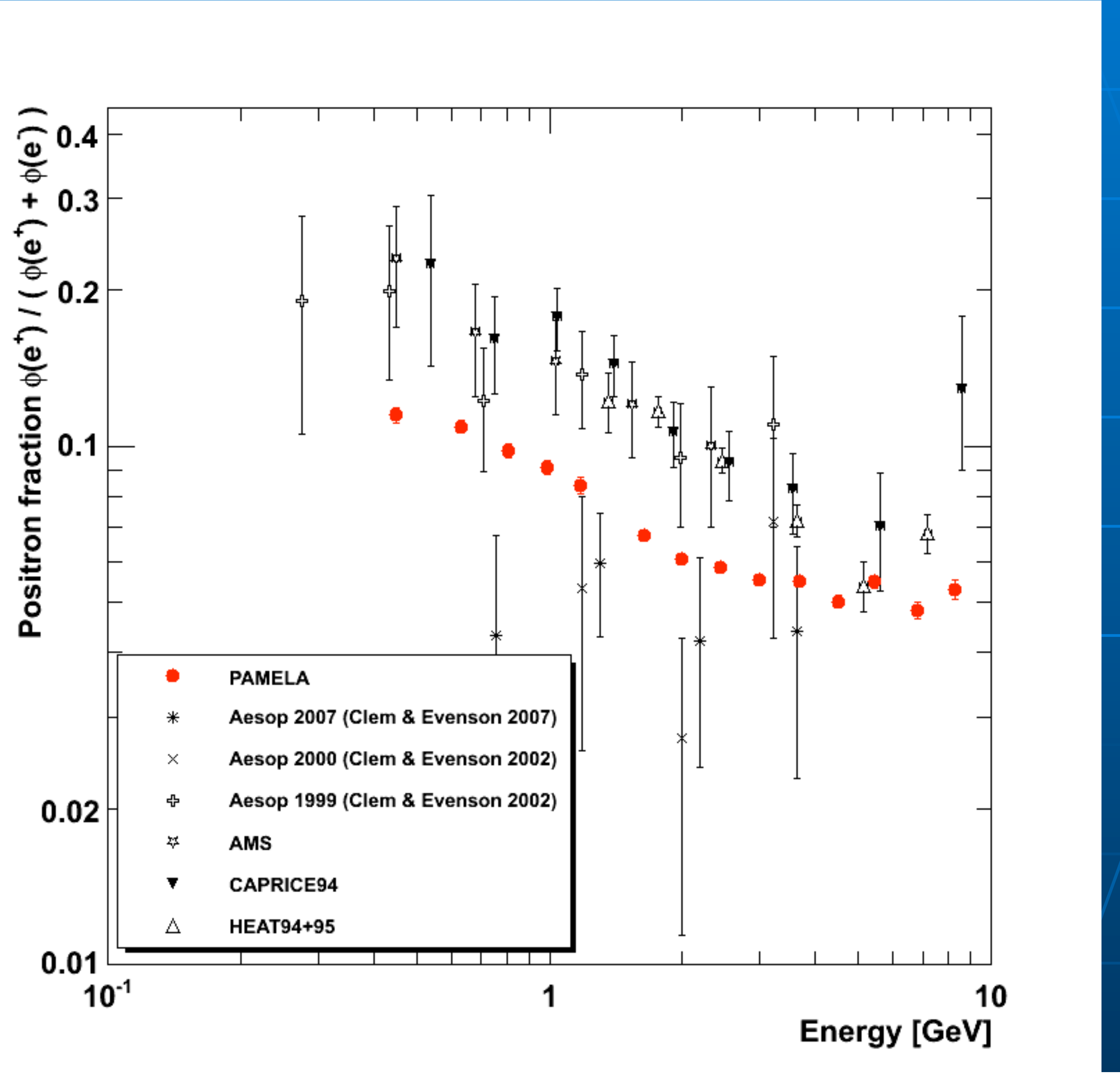
Future observations of electrons





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

Positron Fraction



Solar Modulation of galactic cosmic rays

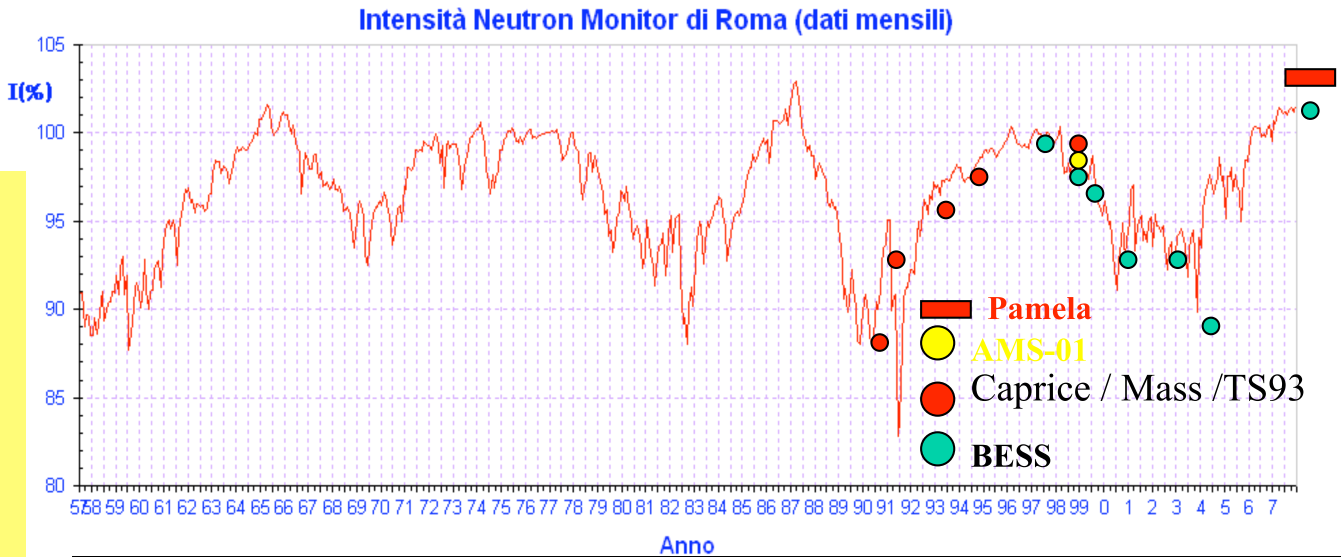
- **Study of charge sign dependent effects**

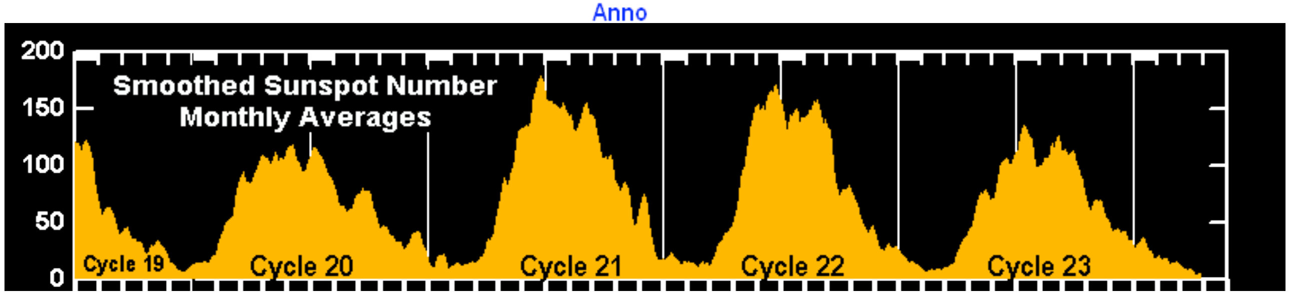
Asaoka Y. et al. 2002, Phys. Rev. Lett. 88, 051101),

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

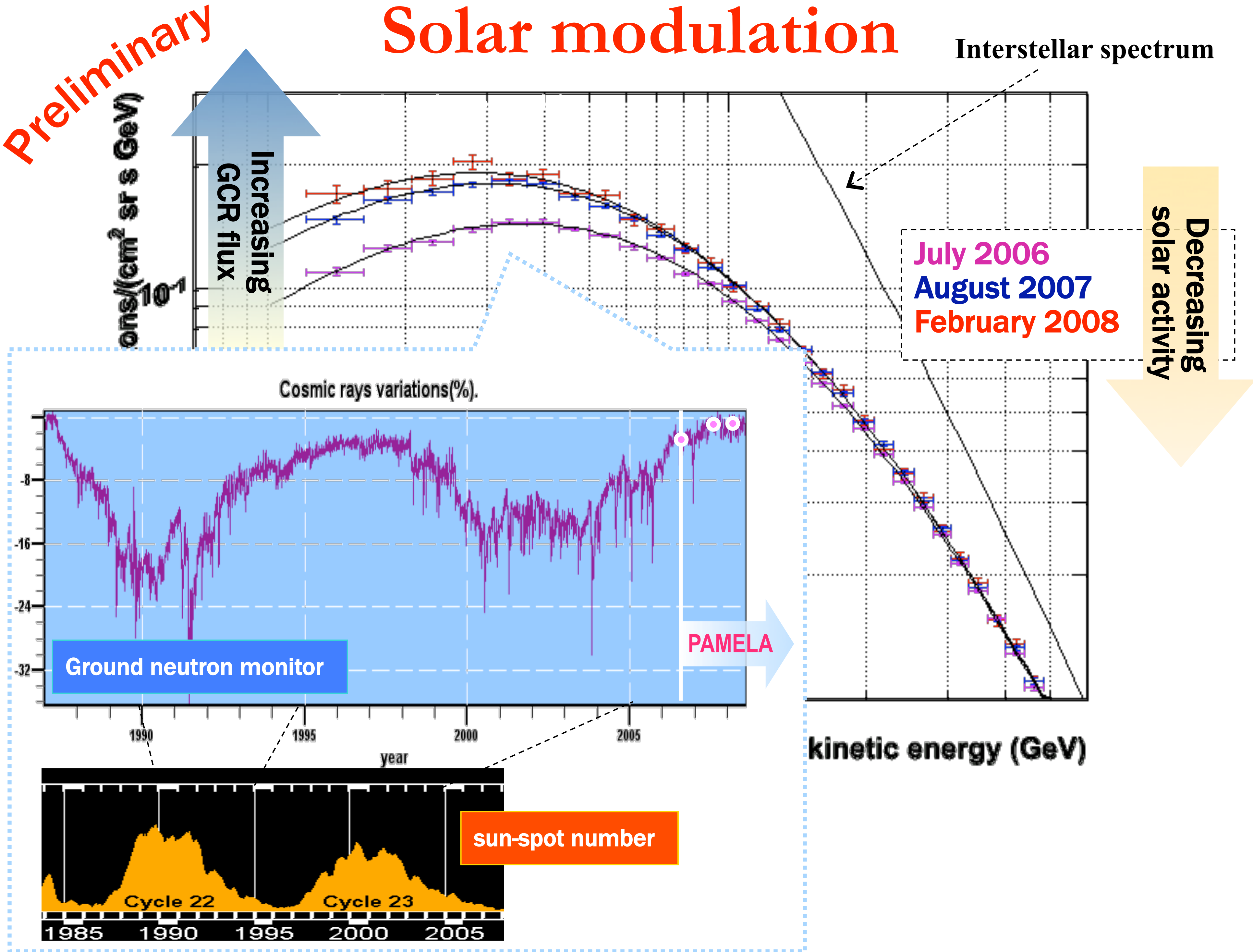
J. Clem et al. 30th ICRC 2007

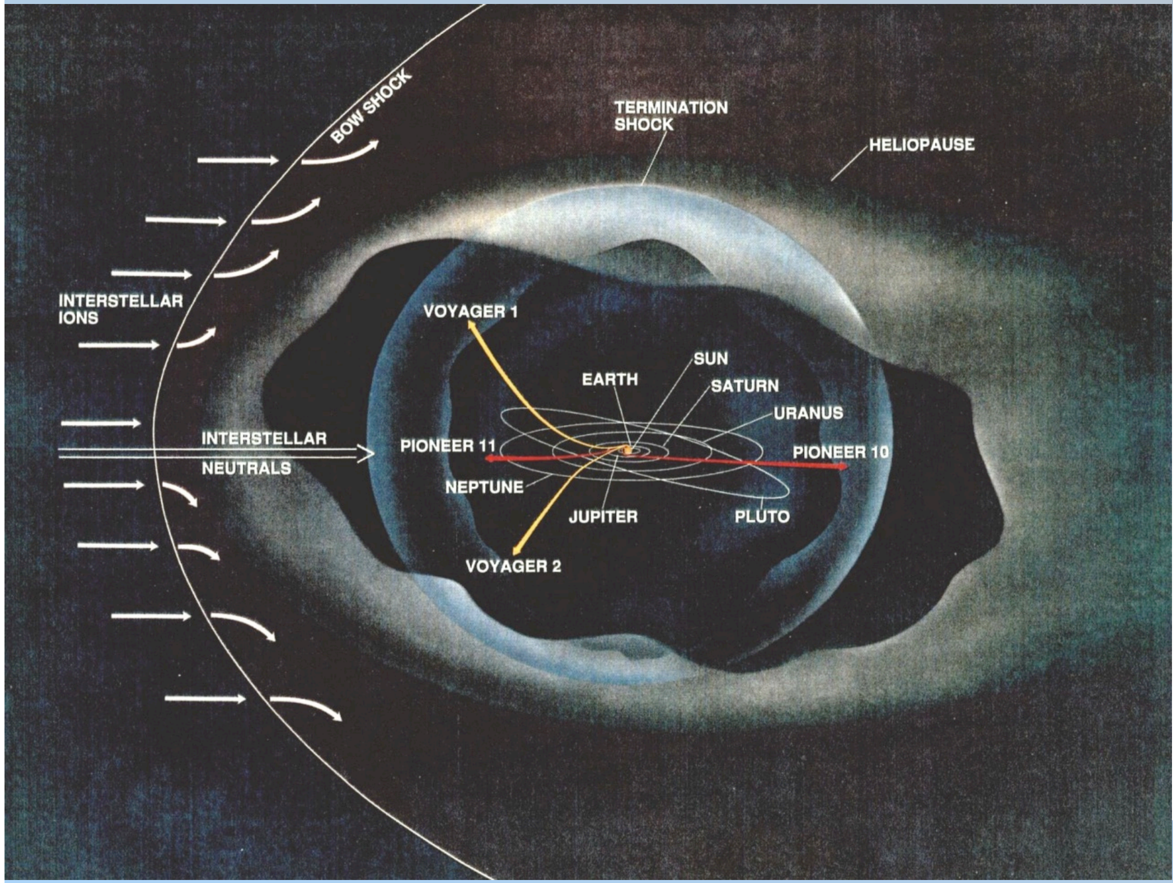
U.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)

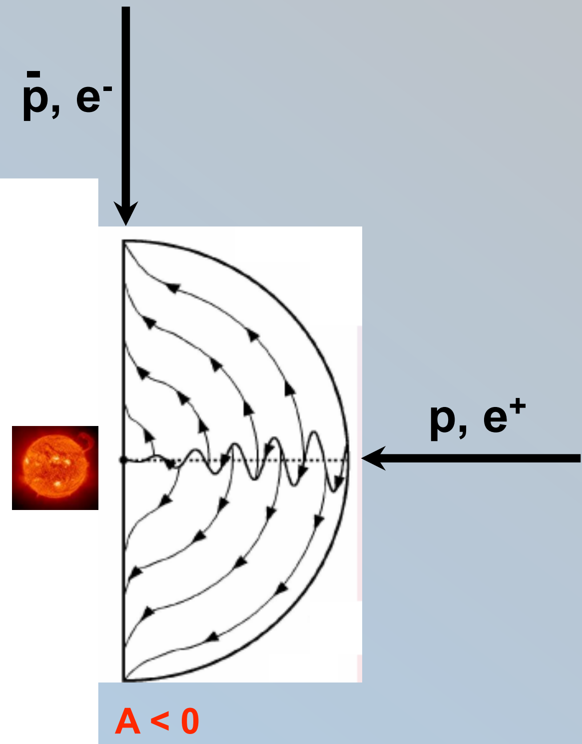




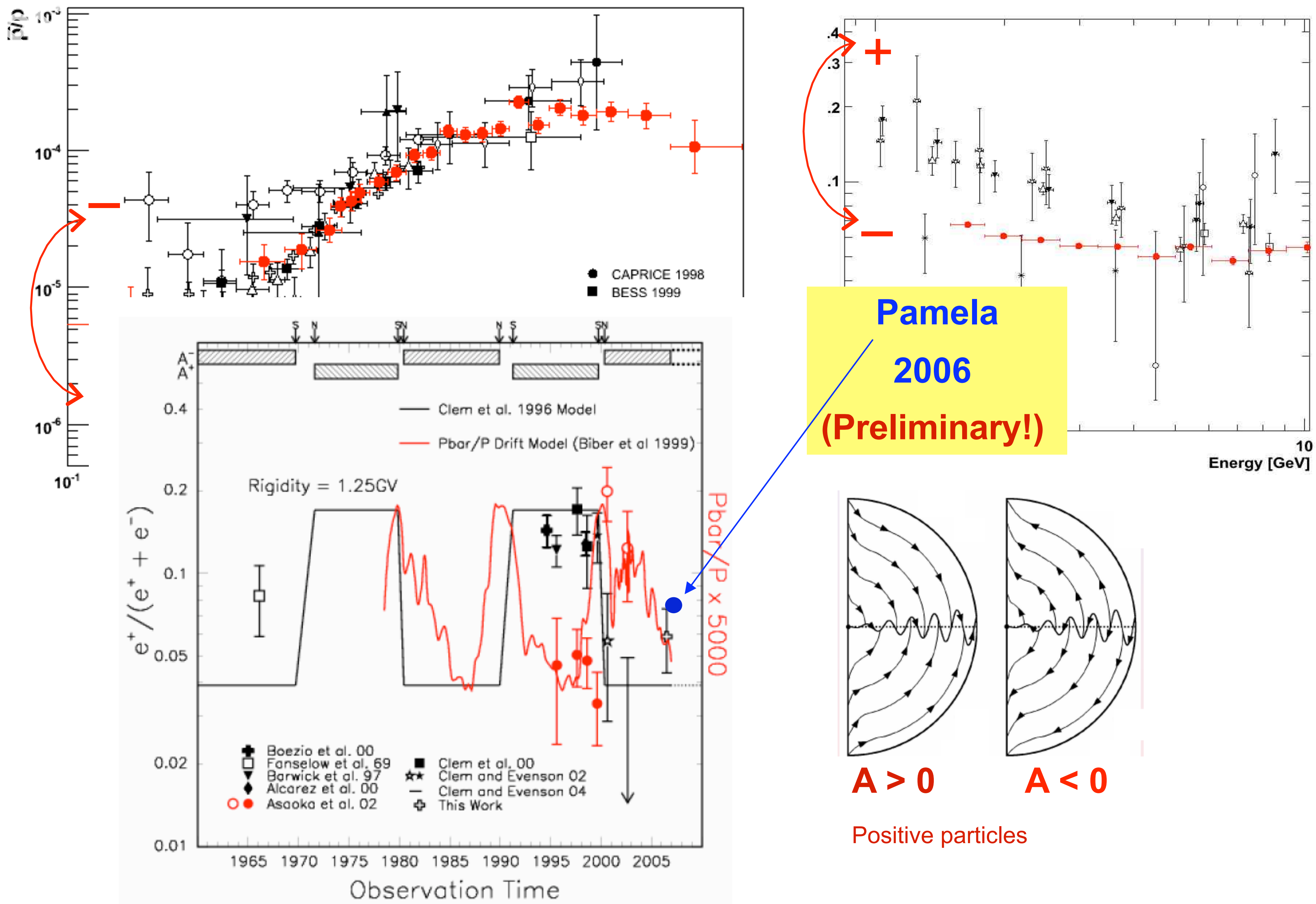
Solar modulation




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


p̄, e-
p, e+
A < 0

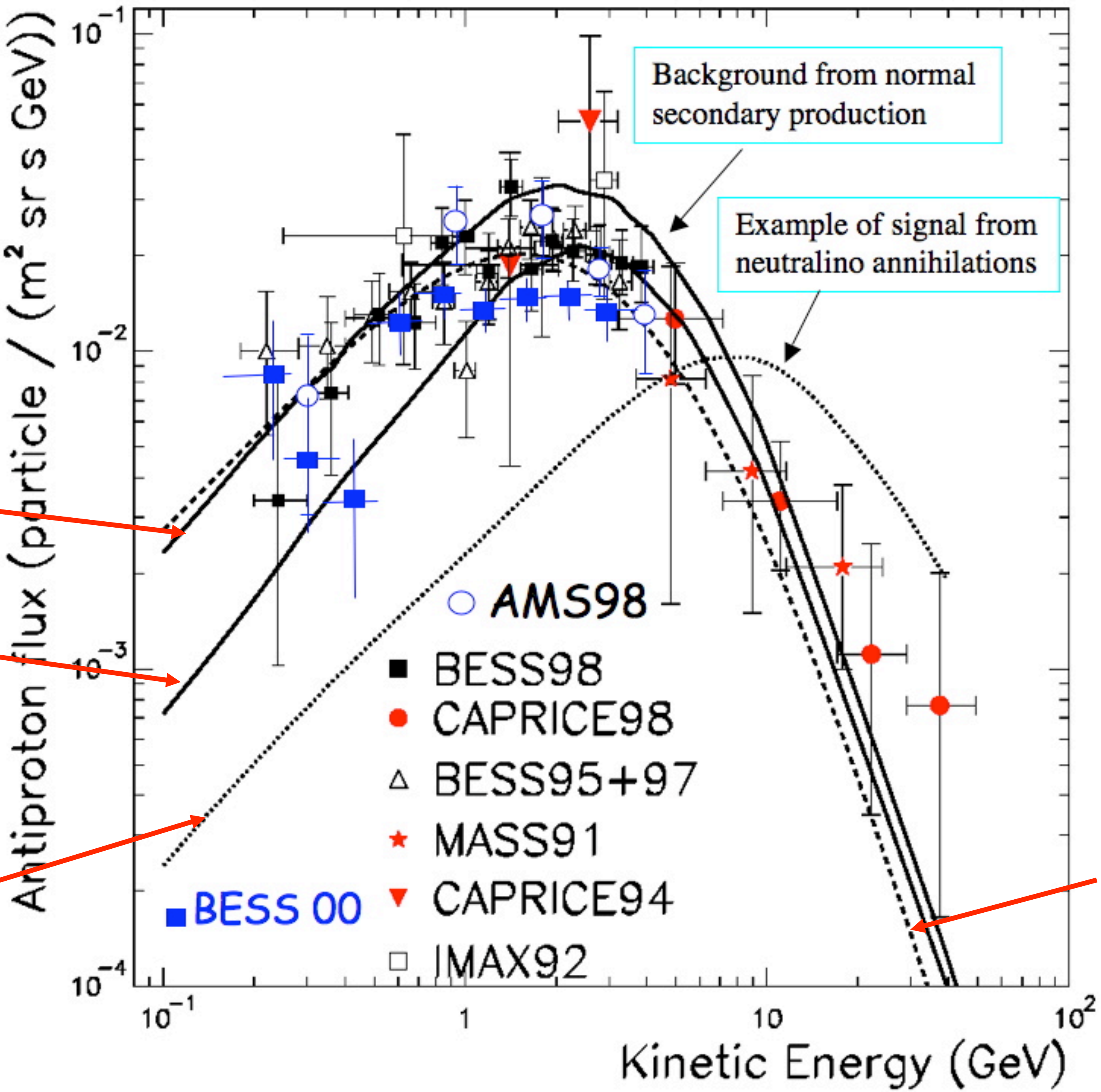
Charge dependent solar modulation



$\overline{\mathrm{P}}$

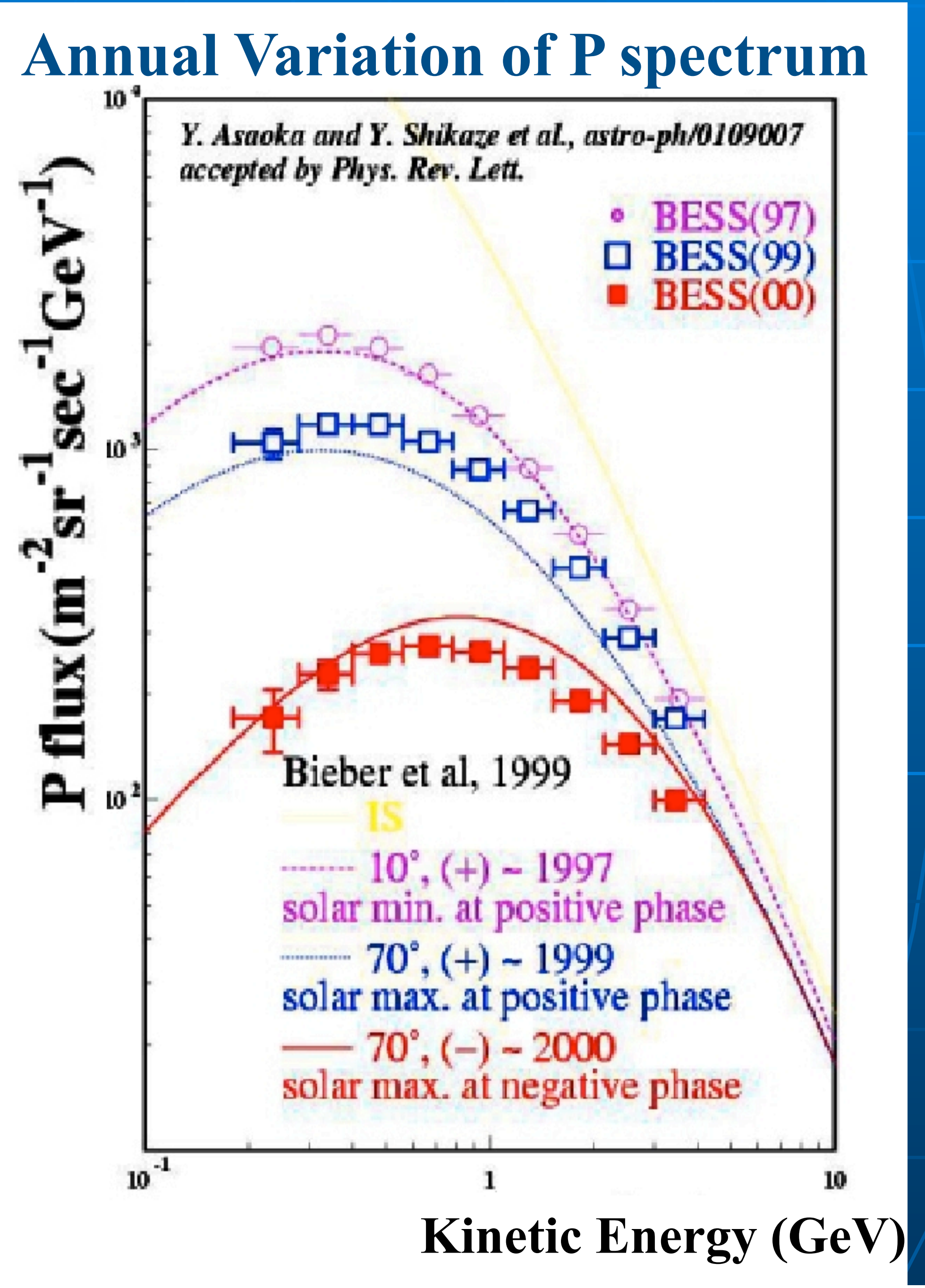
Secondary production (upper and lower limits) Simon et al. ApJ 499 (1998) 250.

from xx annihilation



Secondary production Bergström et al. ApJ 526 (1999) 215

Proton fluxes at TOA



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

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

Observed data by BESS

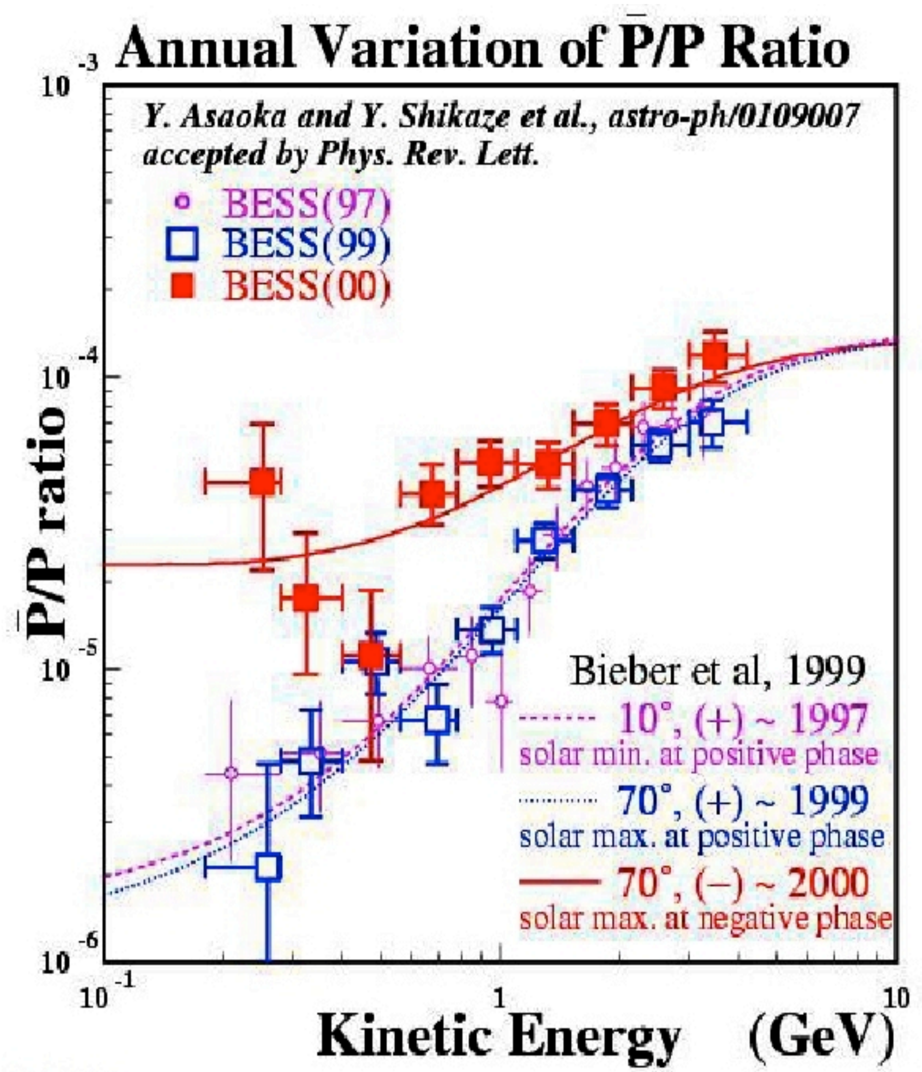
Charge dependent model

prediction(Bieber et al.)

Charge dependent solar modulation model well follows

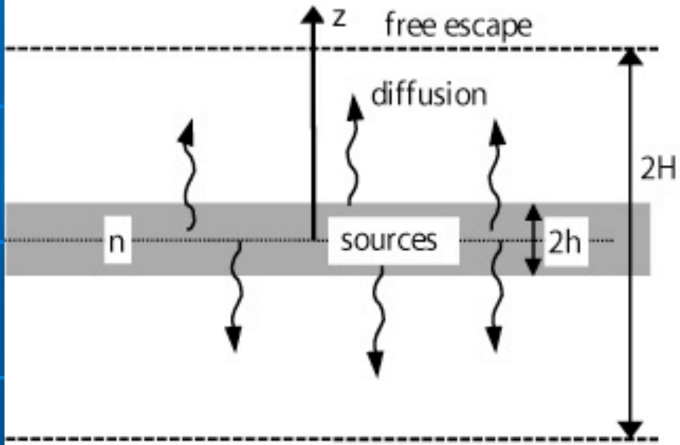
the suddenly increase of $\bar{p}/p$ ratio observed by BESS

at the solar polarity reversal between 1999 and 2000



Cosmic-Ray Propagation

Diffusion Halo Model



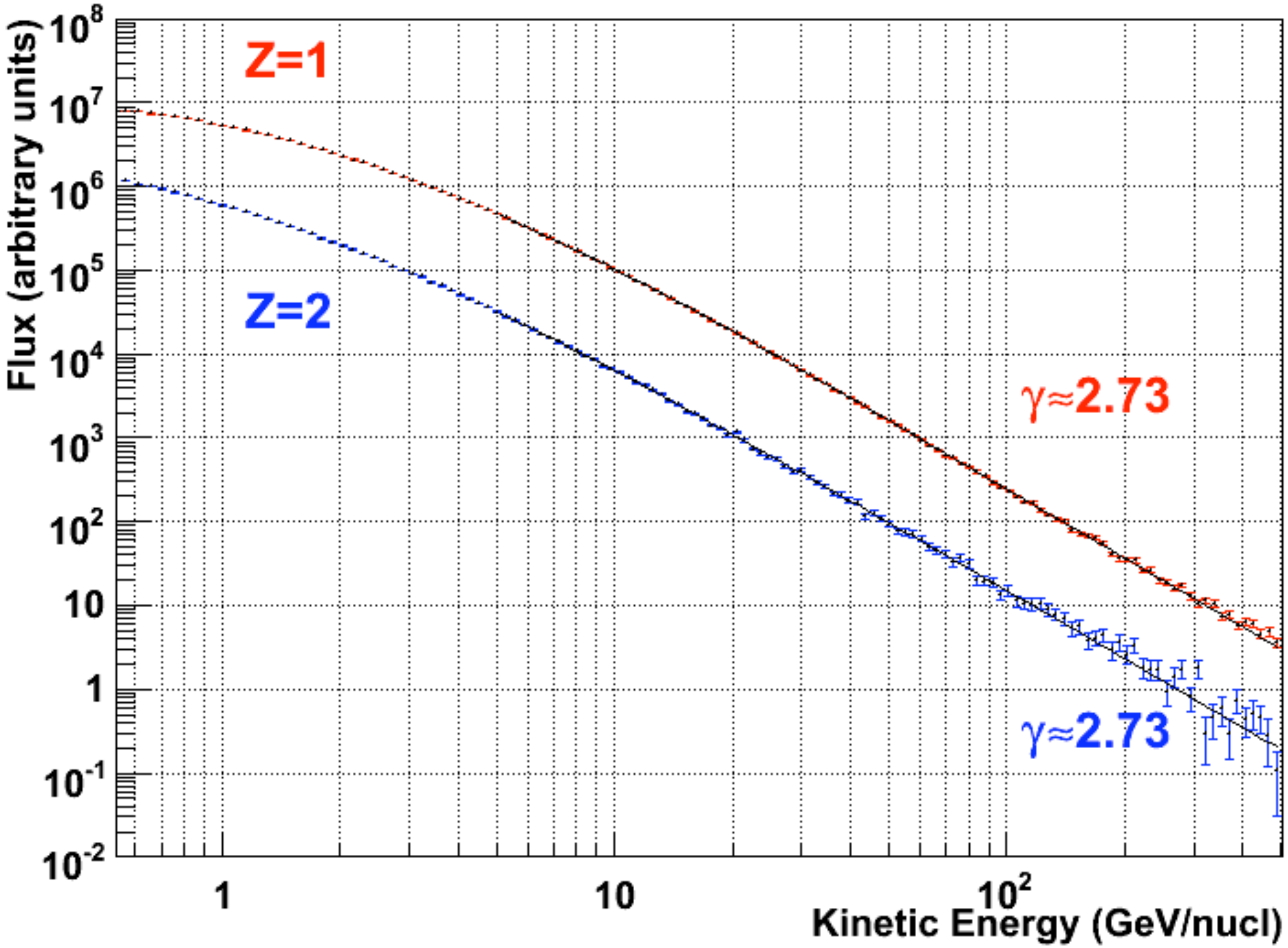
$$\frac{\partial N_i(E,z,t)}{\partial t} = \underbrace{D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t)}_{\text{diffusion}} \underbrace{- N_i(E,z,t)\left\{\frac{1}{\tau_i^{\text{int}}(E,z)} + \frac{1}{\gamma(E)\tau_i^{dec}}\right\}}_{\text{interaction and decay}}$$

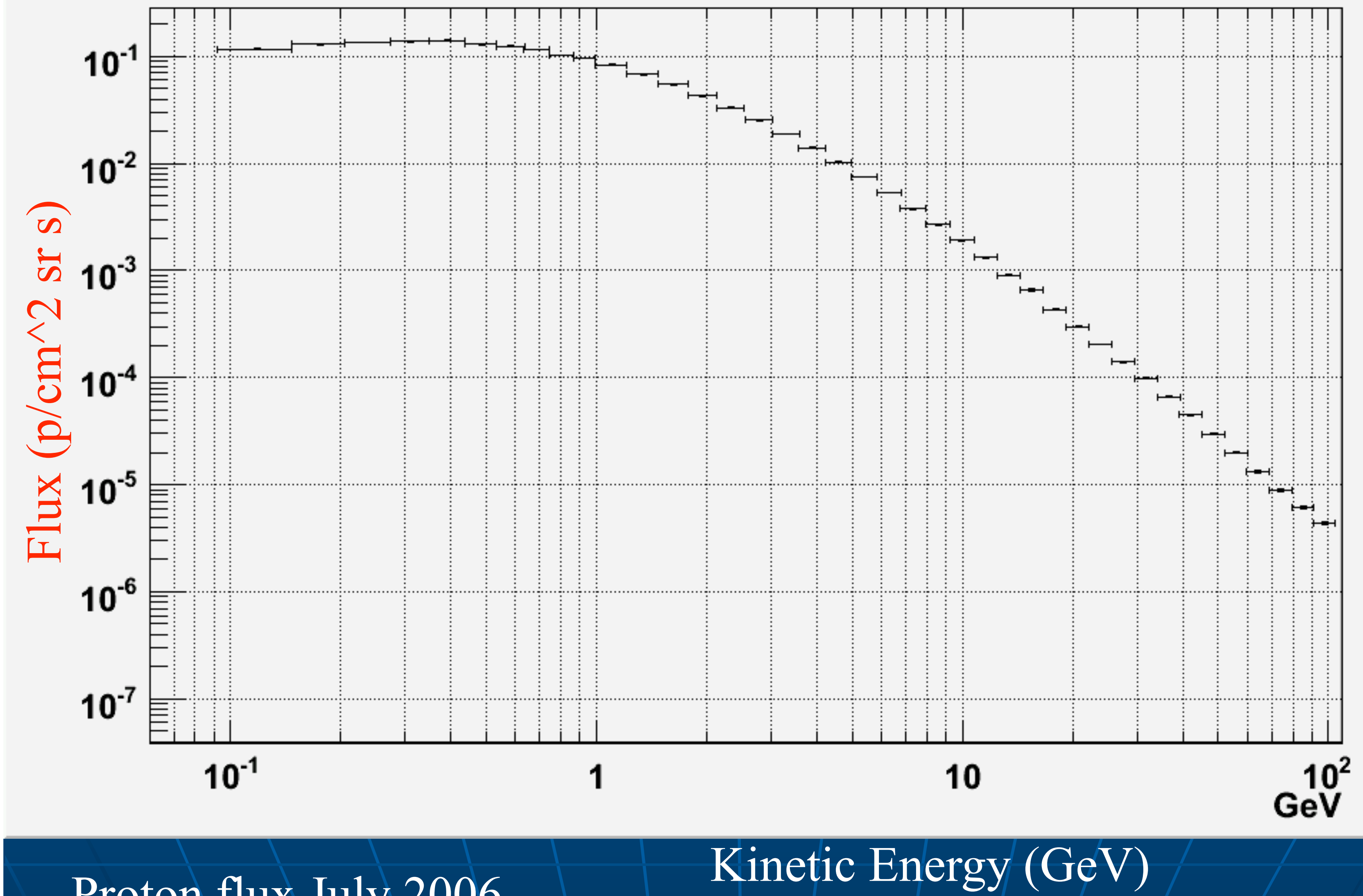
$$+ \underbrace{\sum_{k>i}\frac{N_k(E,z,t)}{\tau_{\text{int}}^{k\rightarrow i}(E,z)}}_{\text{secondary production}} + \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

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

Galactic H and He spectra

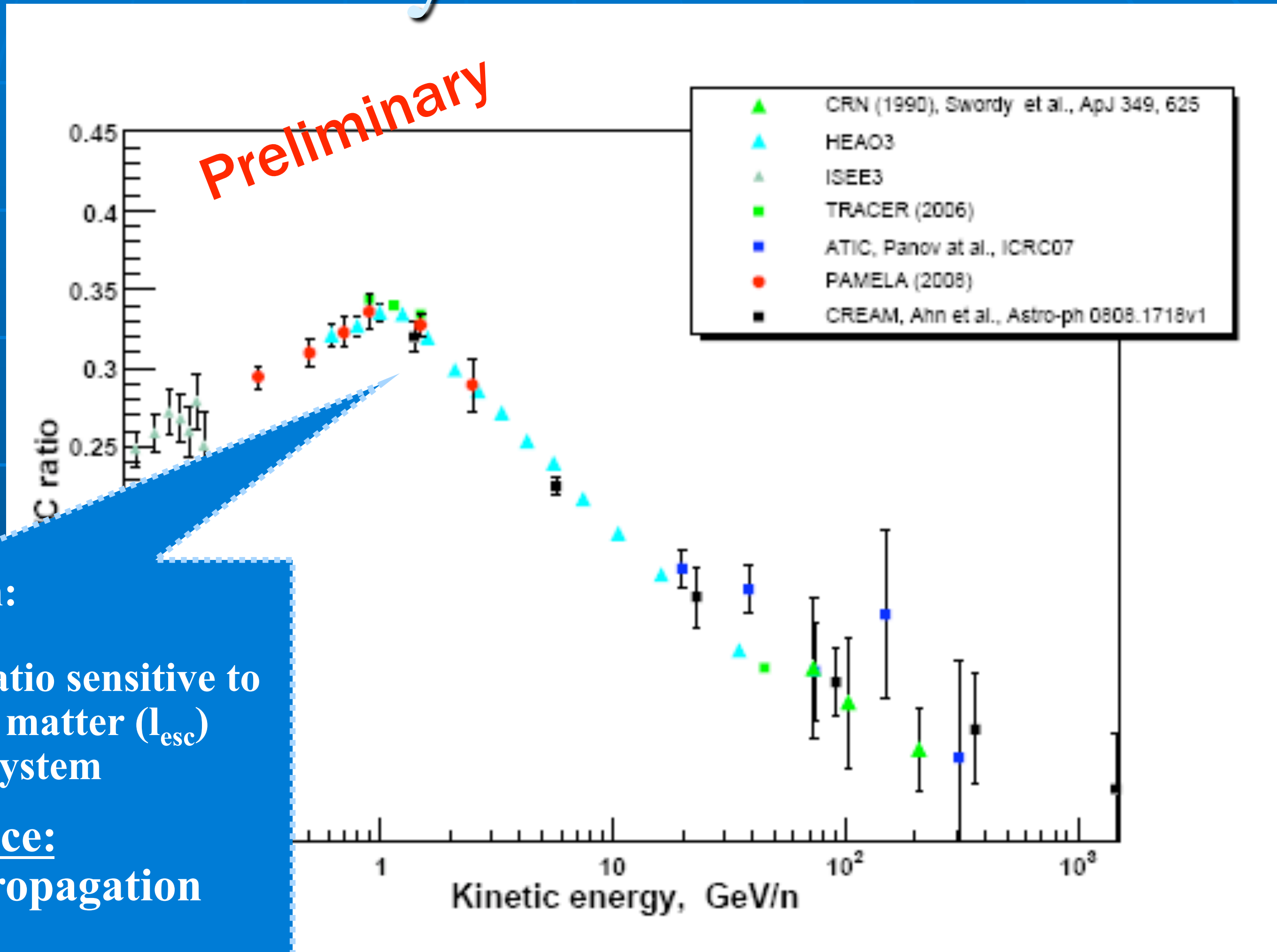
Preliminary !!!





Proton flux July 2006

Secondary nuclei



LBM

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

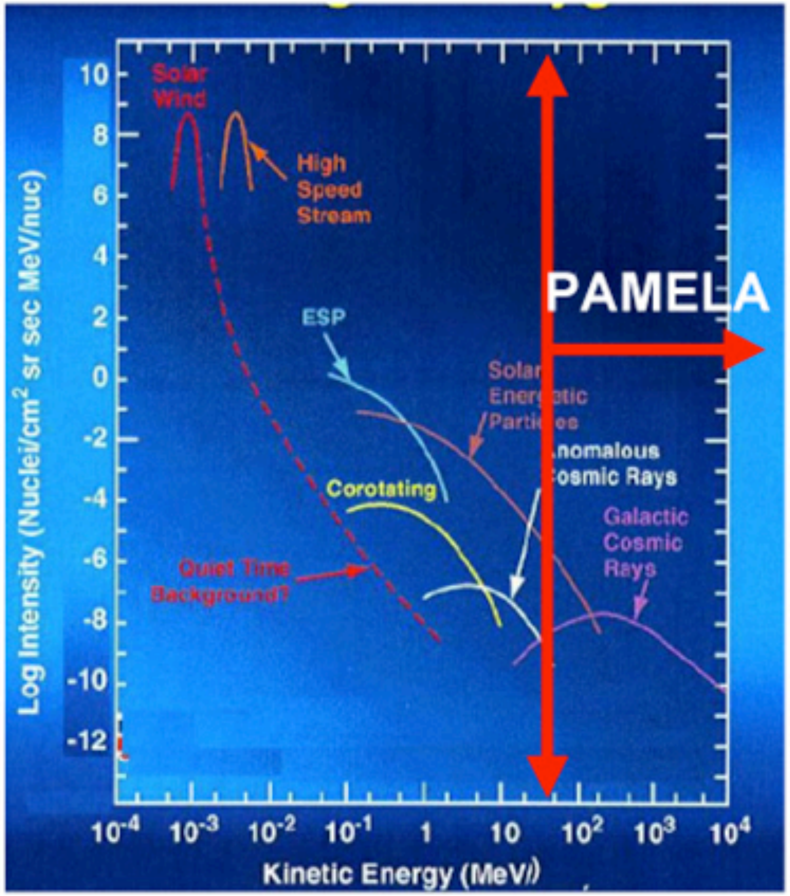
- **B nuclei of secondary origin:**
  CNO + ISM → B + …
- **Local secondary/primary ratio sensitive to average amount of traversed matter (l_{esc}) from the source to the solar system**

<u>Local secondary abundance:</u>

⇒ study of galactic CR propagation

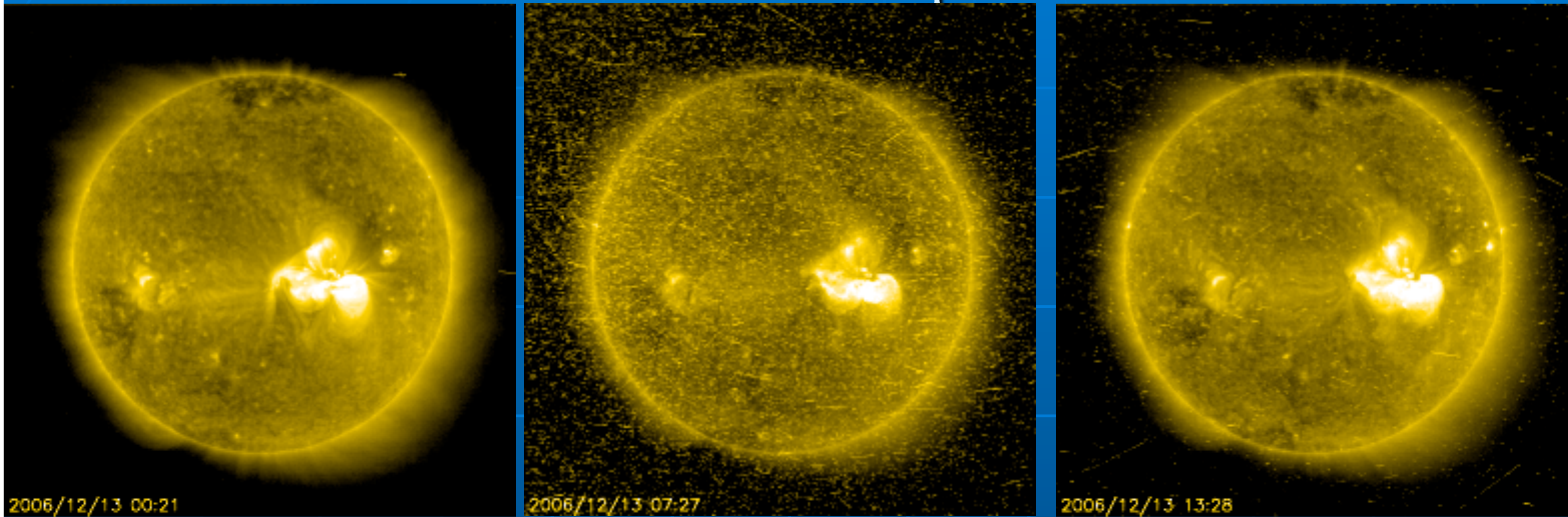
(B/C used for tuning of propagation models)

Solar Physics with PAMELA



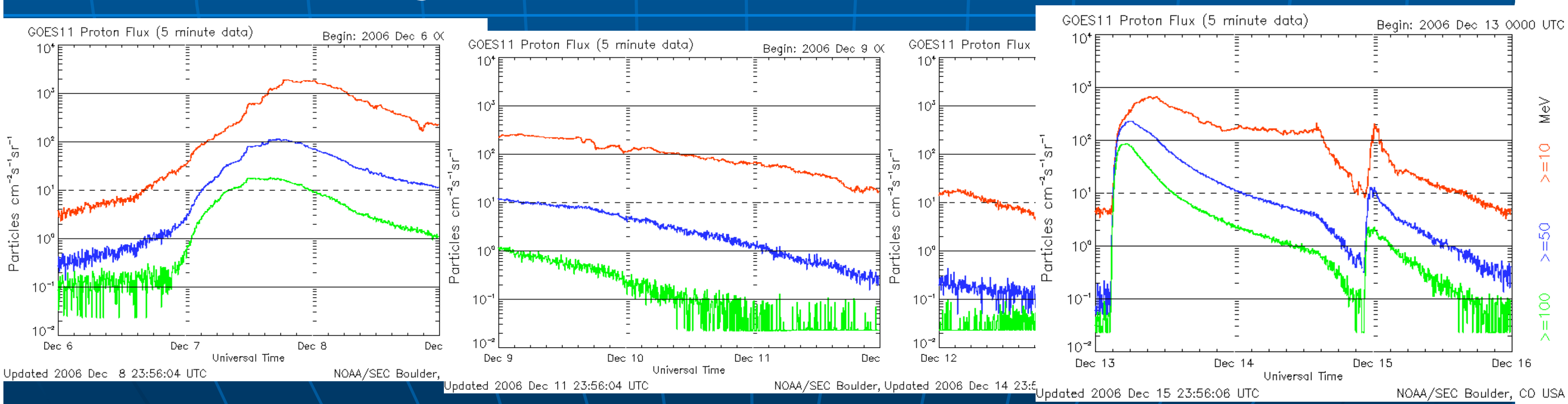
- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV)
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV)
- Nuclear composition of Gradual and Impulsive events
- ^3He and ^4He isotopic composition

December 2006 Solar particle events

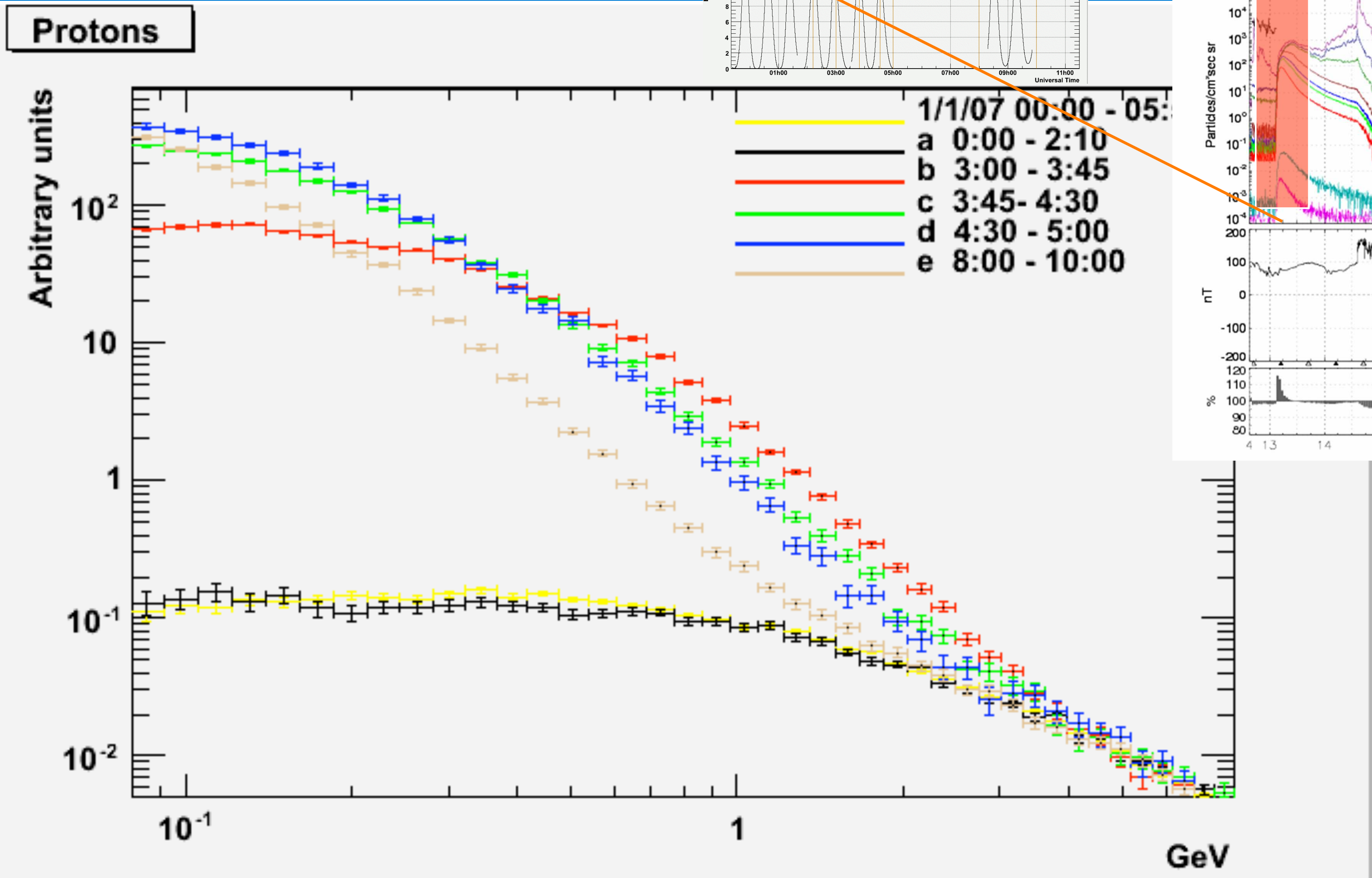


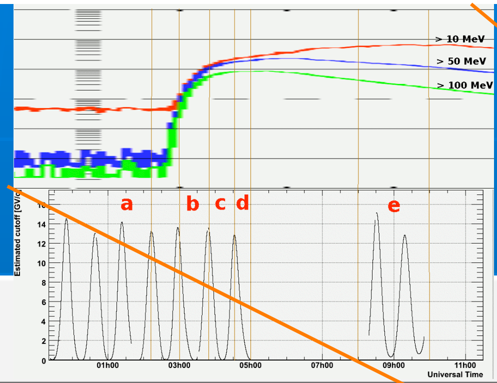
Dec 13th largest CME since 2003, anomalous at sol min

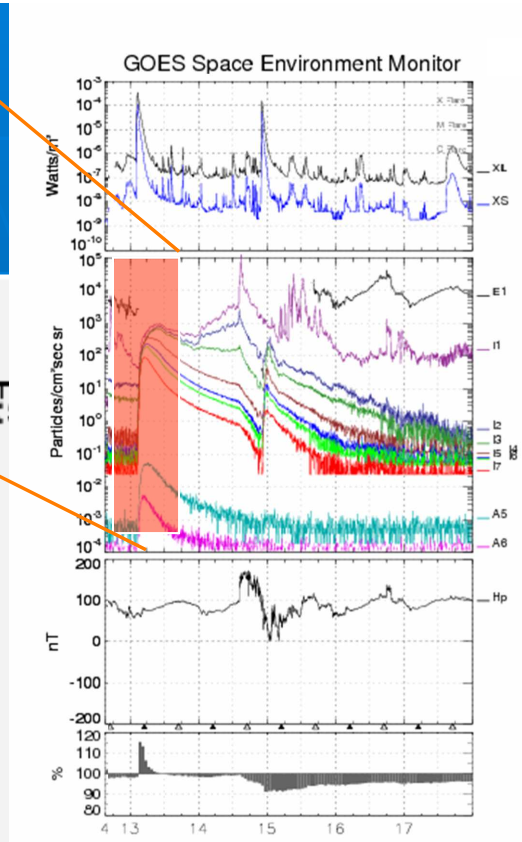
X3.4 solar flare



December 13th 2006 event

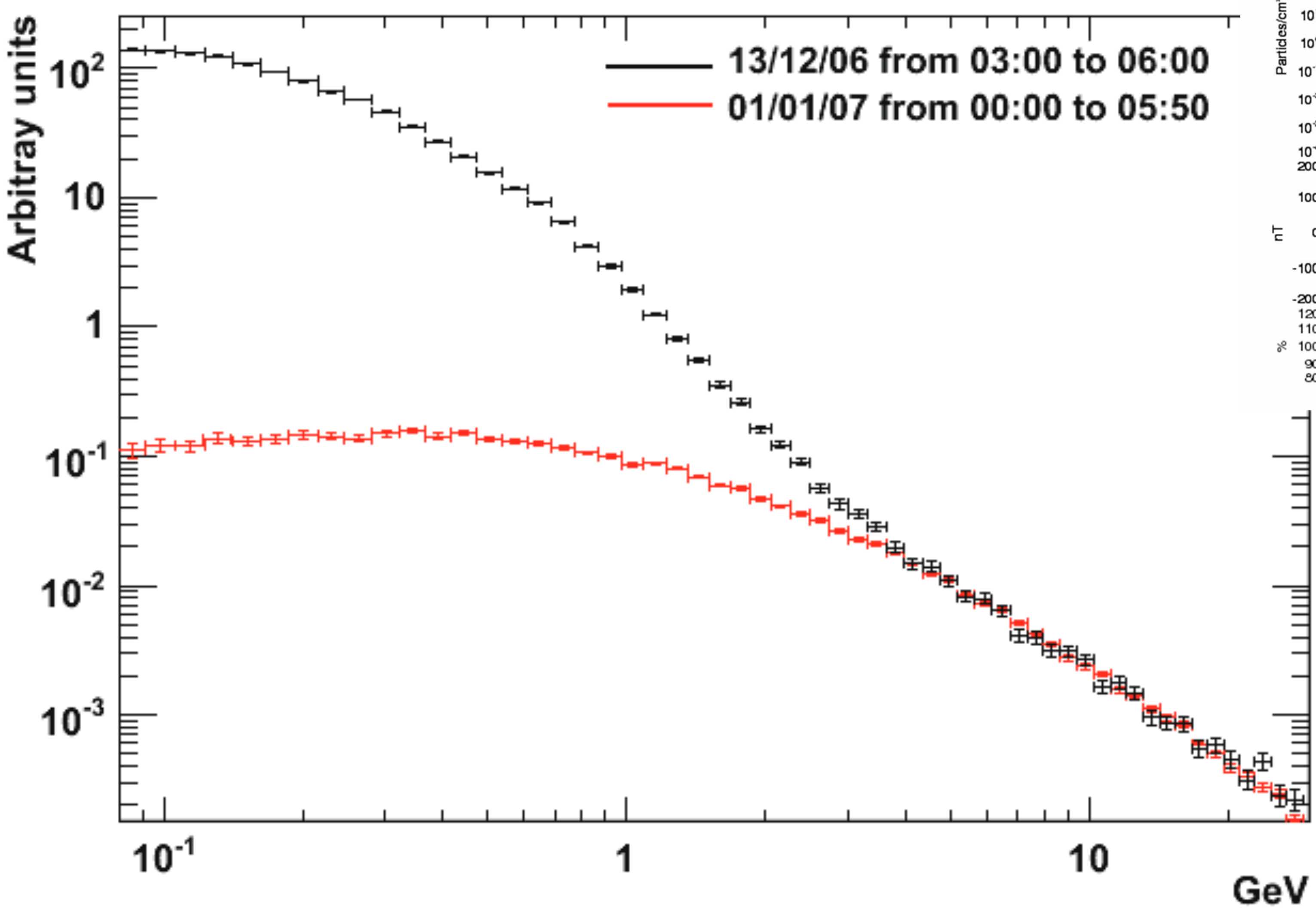


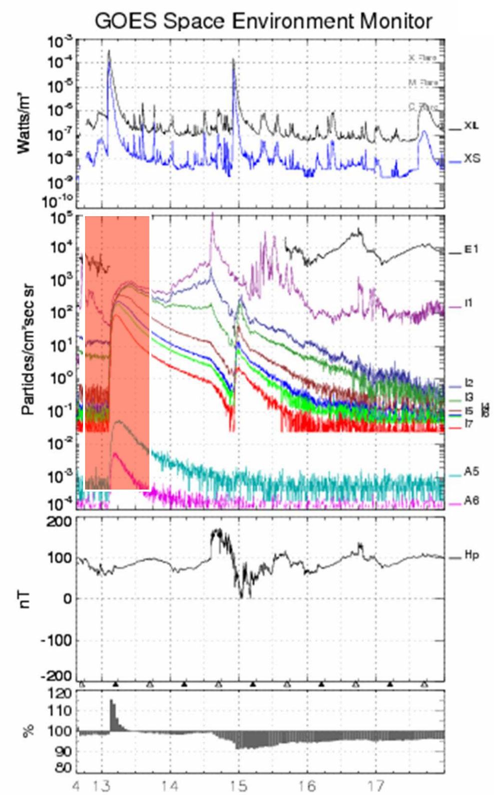




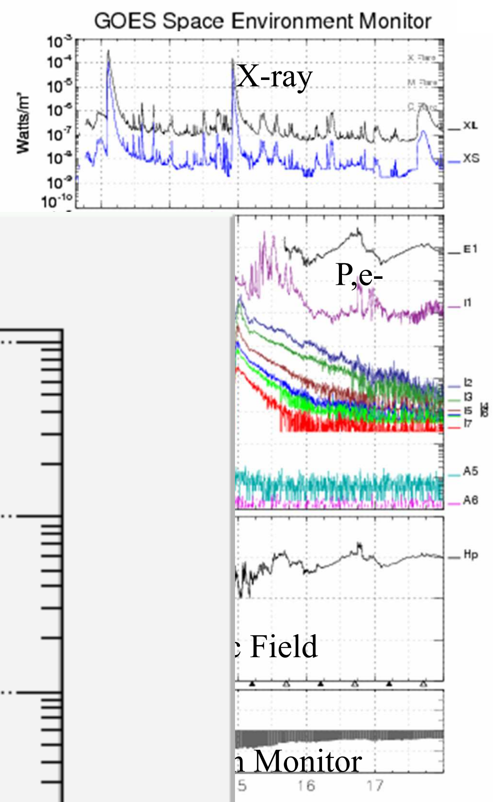
Preliminary!

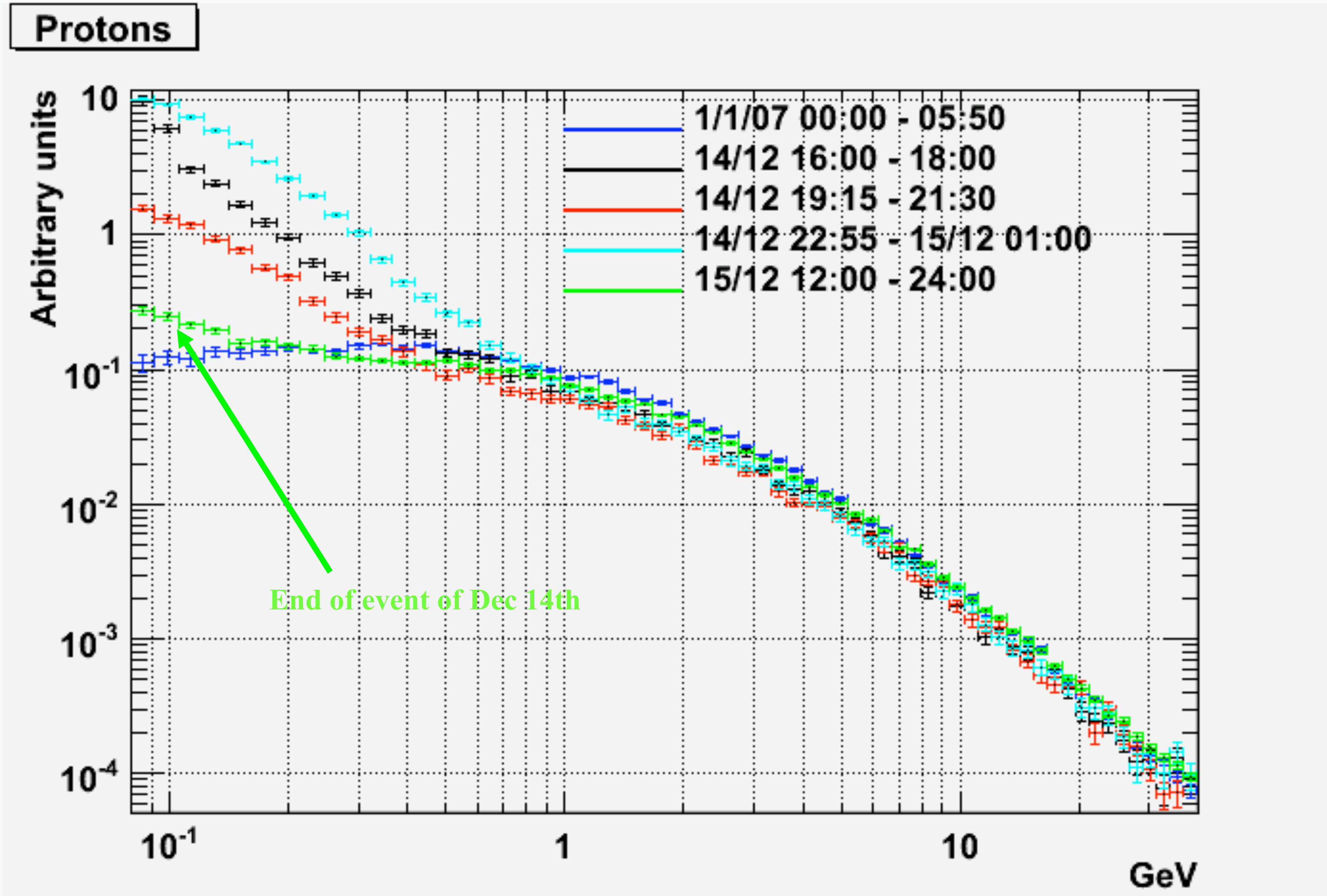
December 13th 2006 He differential spectrum





December 14th 2006 event





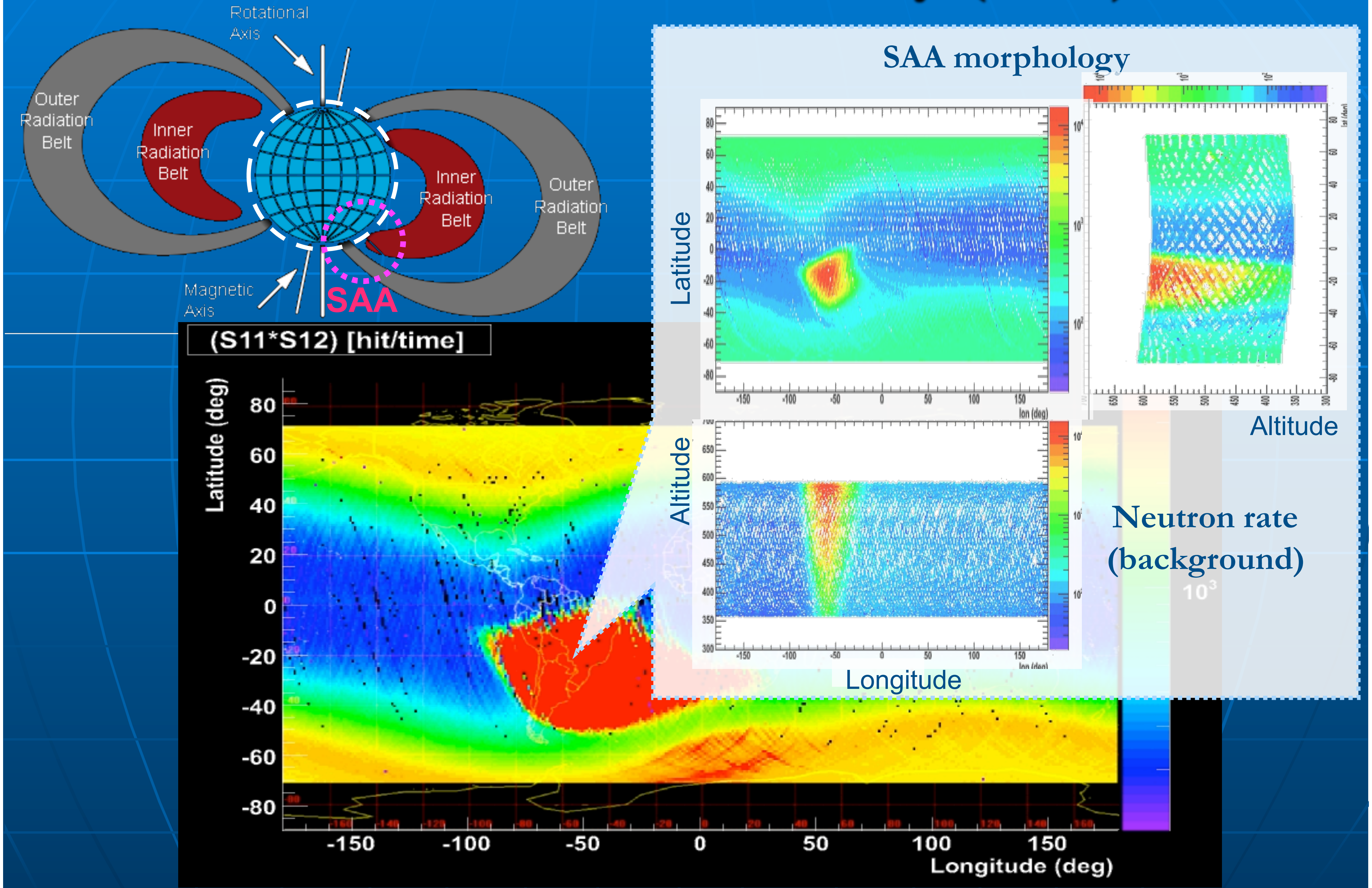
Preliminary!

Radiation Belts

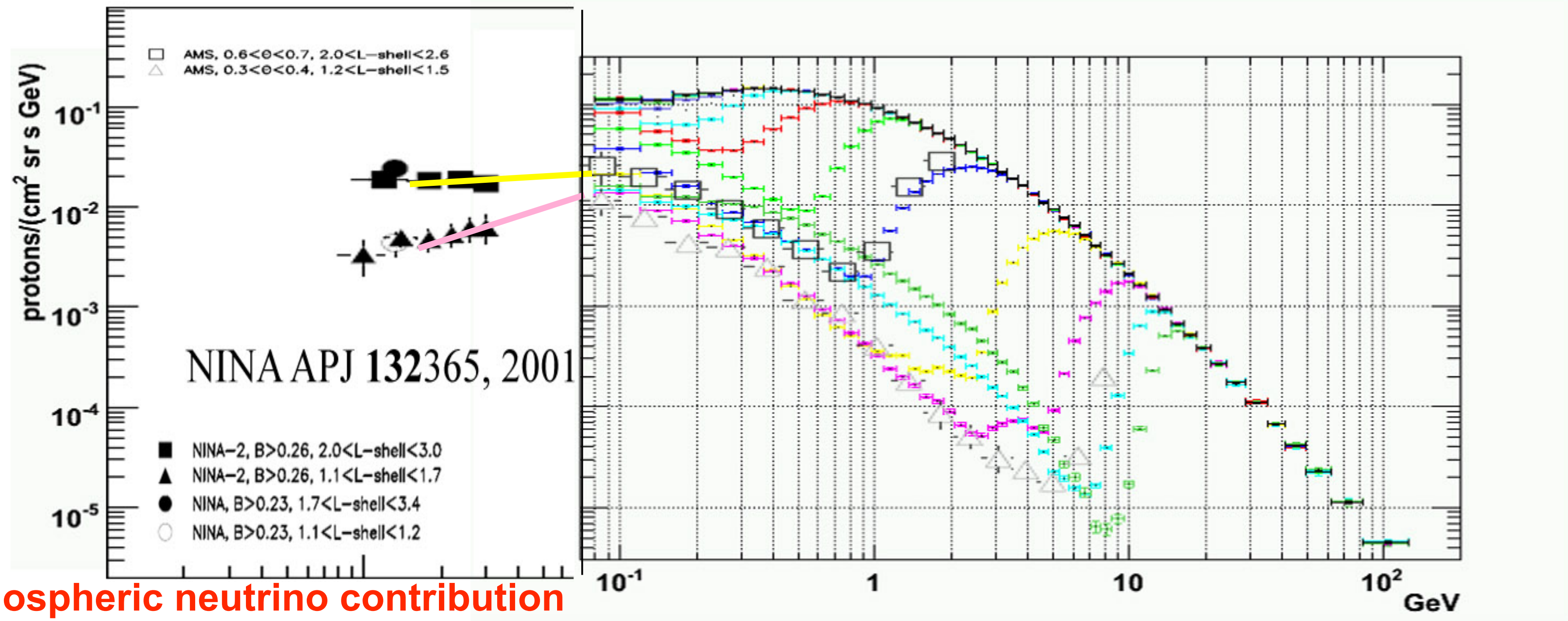
South Atlantic Anomaly

Secondary production from CR interaction with atmosphere

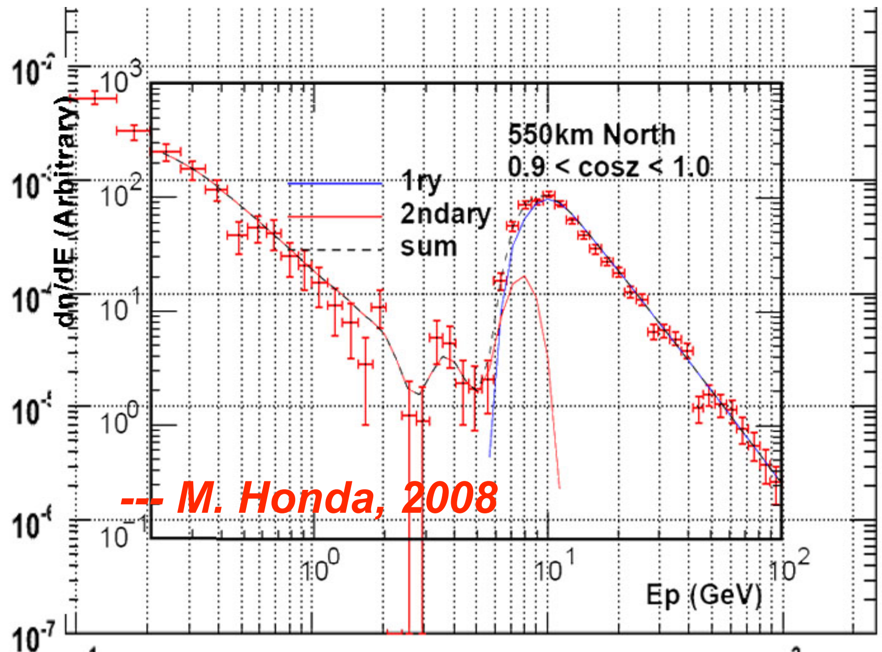
South-Atlantic Anomaly (SAA)



Proton flux at various cutoffs

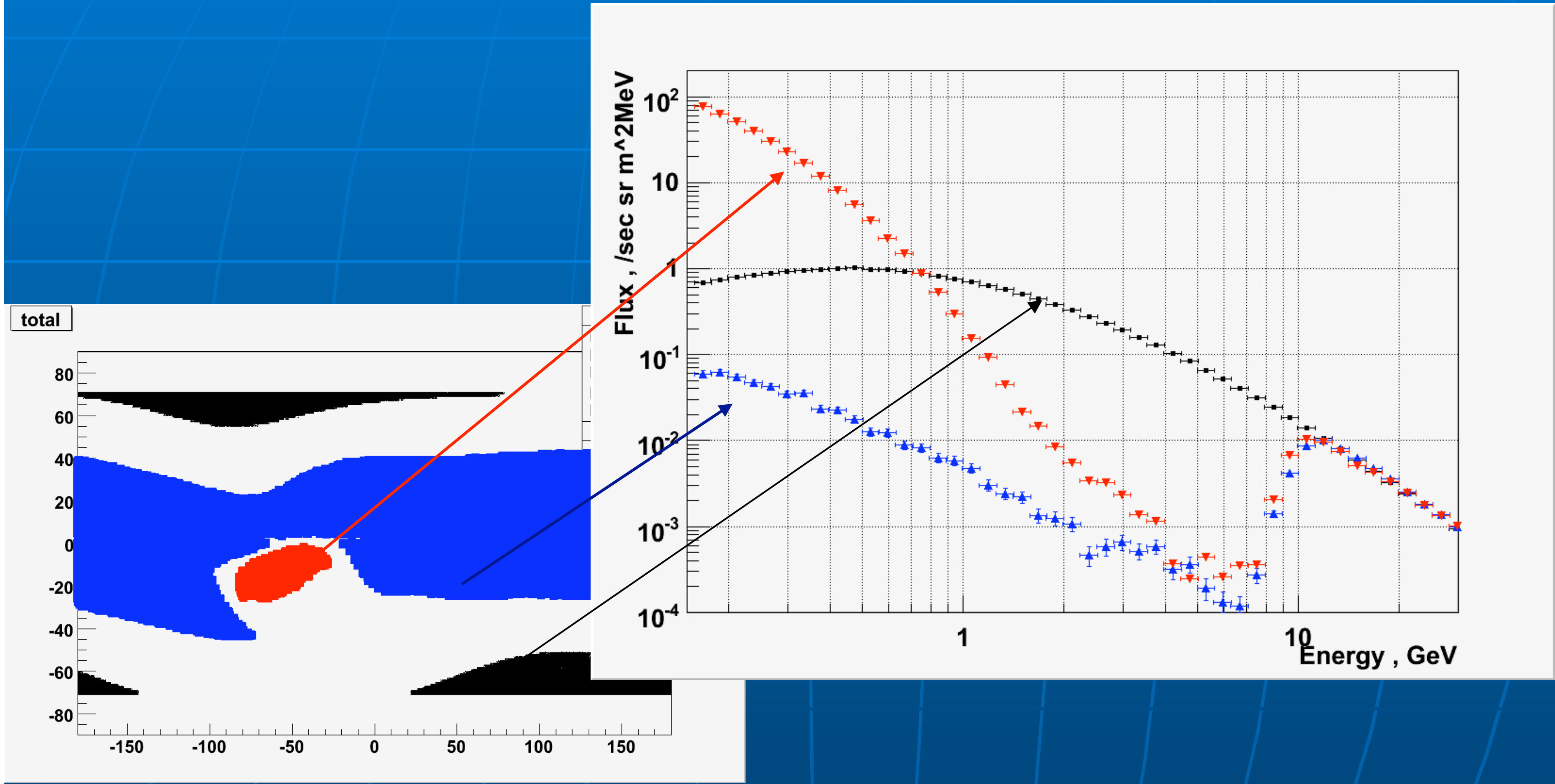


→Atmospheric neutrino contribution
→Astronaut dose on board International Space Station
→Indirect measurement of cross section in the atmosphere nell'atmosfera
→ Agile e Glast background estimation



•*Grigorov, Sov. Phys. Dokl. 22, 305 1977*
•*NINA ApJ Supp.132 365, 2001*
•*AMS Phys. Lett. B 472 2000.215,*
Phys. Lett. B 484 2000.10–22
•*Lipari, Astrop. Ph. 14, 171, 2000*
•*Huang et al, Pys Rev. D 68, 053008 2003*
•*Sanuki et al, Phys Rev D75 043005 2007*
•*Honda et al, Phys Rev D75 043006 2007*

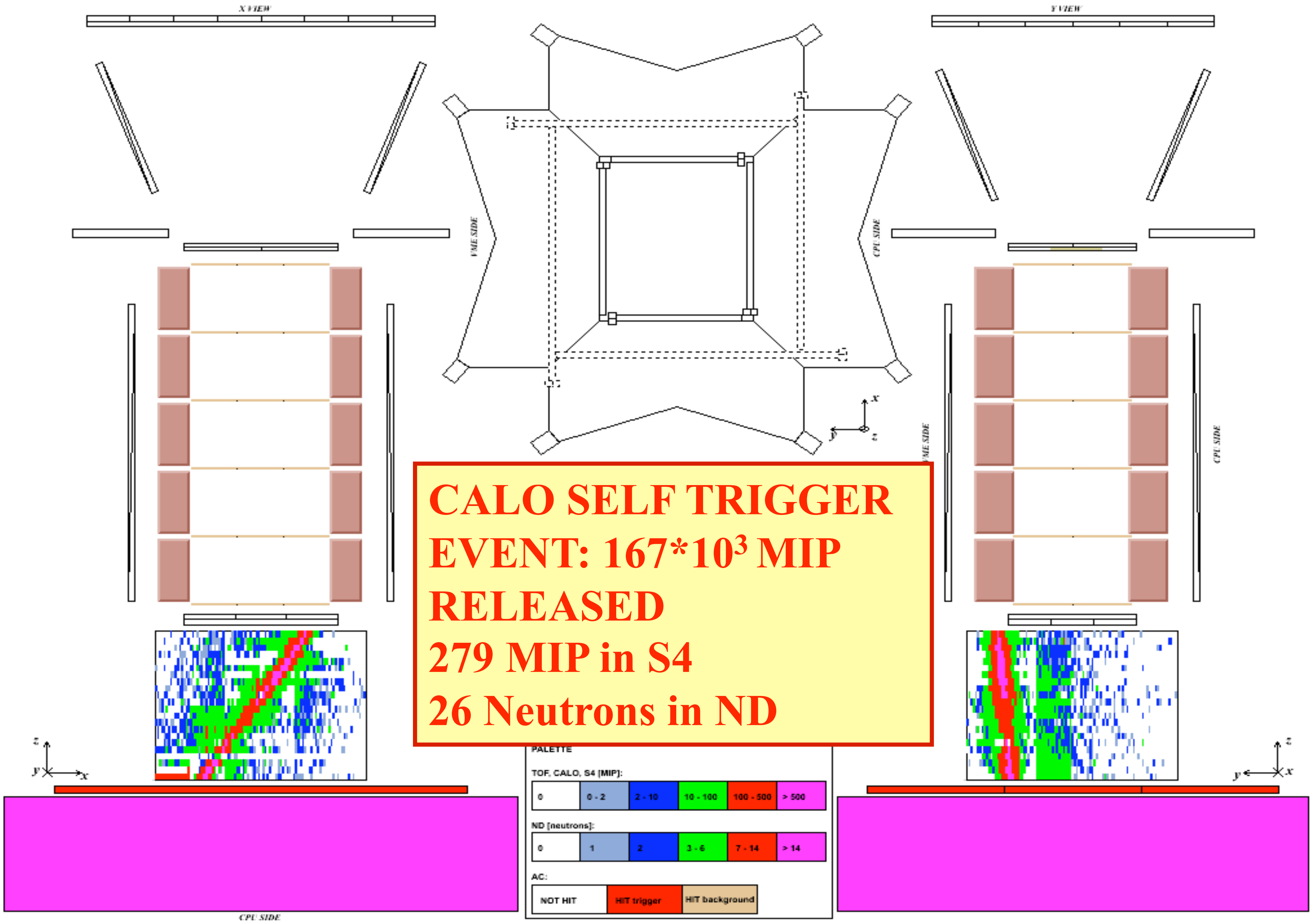
Proton spectrum in SAA, polar and equatorial regions



Other Objectives

High Energy electrons

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

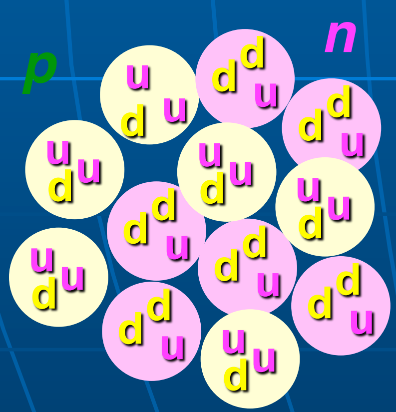

X VIEW
Y VIEW
VME SIDE
CPU SIDE
CALO SELF TRIGGER
EVENT: 167*10³ MIP
RELEASED
279 MIP in S4
26 Neutrons in ND
PALETTE
TOF, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background
CPU SIDE

Search for New Matter in the Universe:

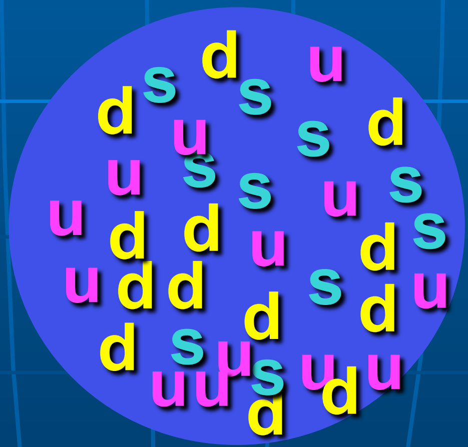
An example is the search for "strangelets".

There are six types of Quarks found in accelerators.
All matter on Earth is made out of only two types of quarks. "Strangelets" are new types of matter composed of three types of quarks which should exist in the cosmos.

Carbon Nucleus



Strangelet



i. A stable, single "super nucleon" with three types of quarks

ii. "Neutron" stars may be one big strangelet

AMS courtesy

Thanks!

PAMELA Physics Workshop
11-12 May 2009

ROMA

http:// pamela.roma2.infn.it /workshop09