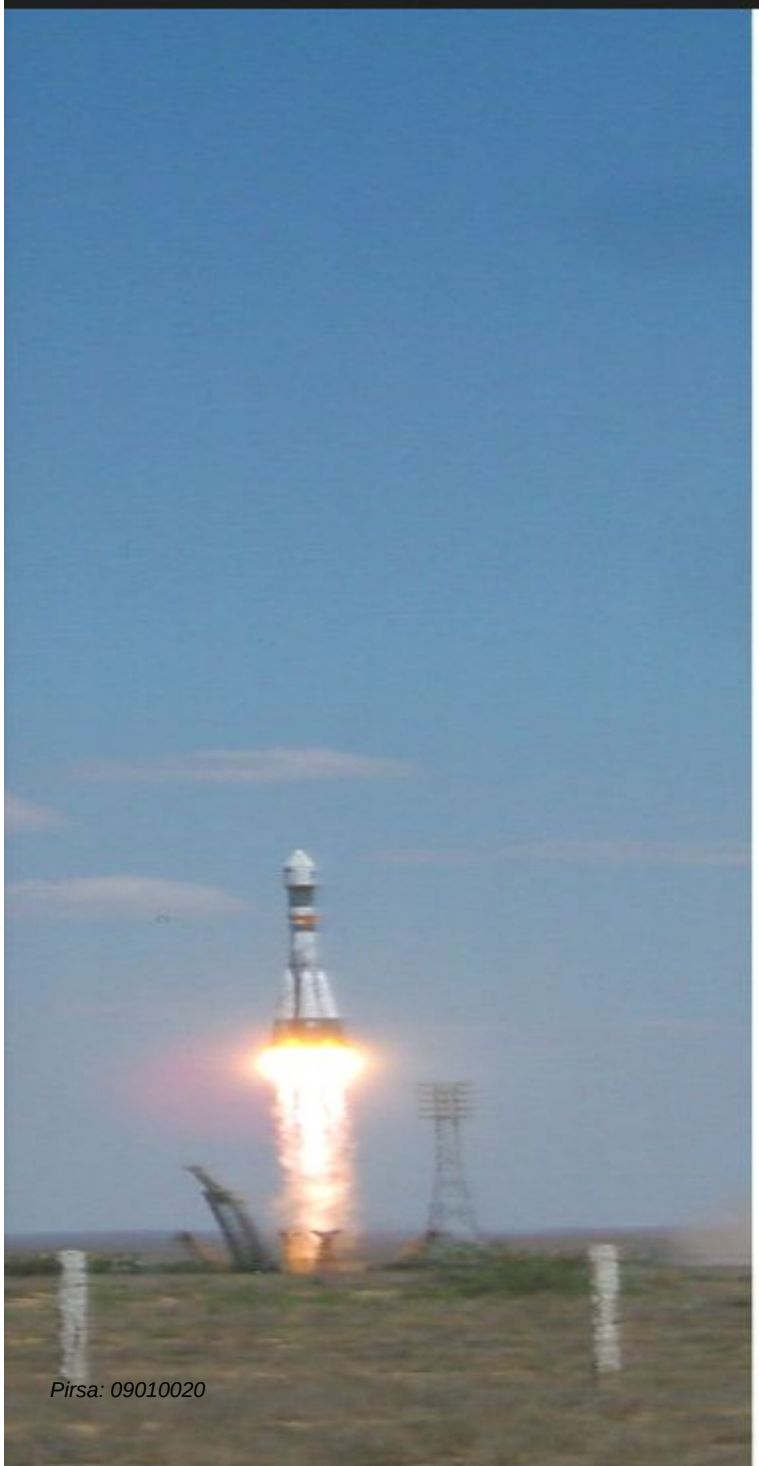
Title: Dark Matter indirect Research with the Pamela Space Experiment

Date: Jan 16, 2009 01:00 PM

URL: http://pirsa.org/09010020

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. (Technical details seminar)



Dark Matter Indirect Search with the PAMELA Space Experiment

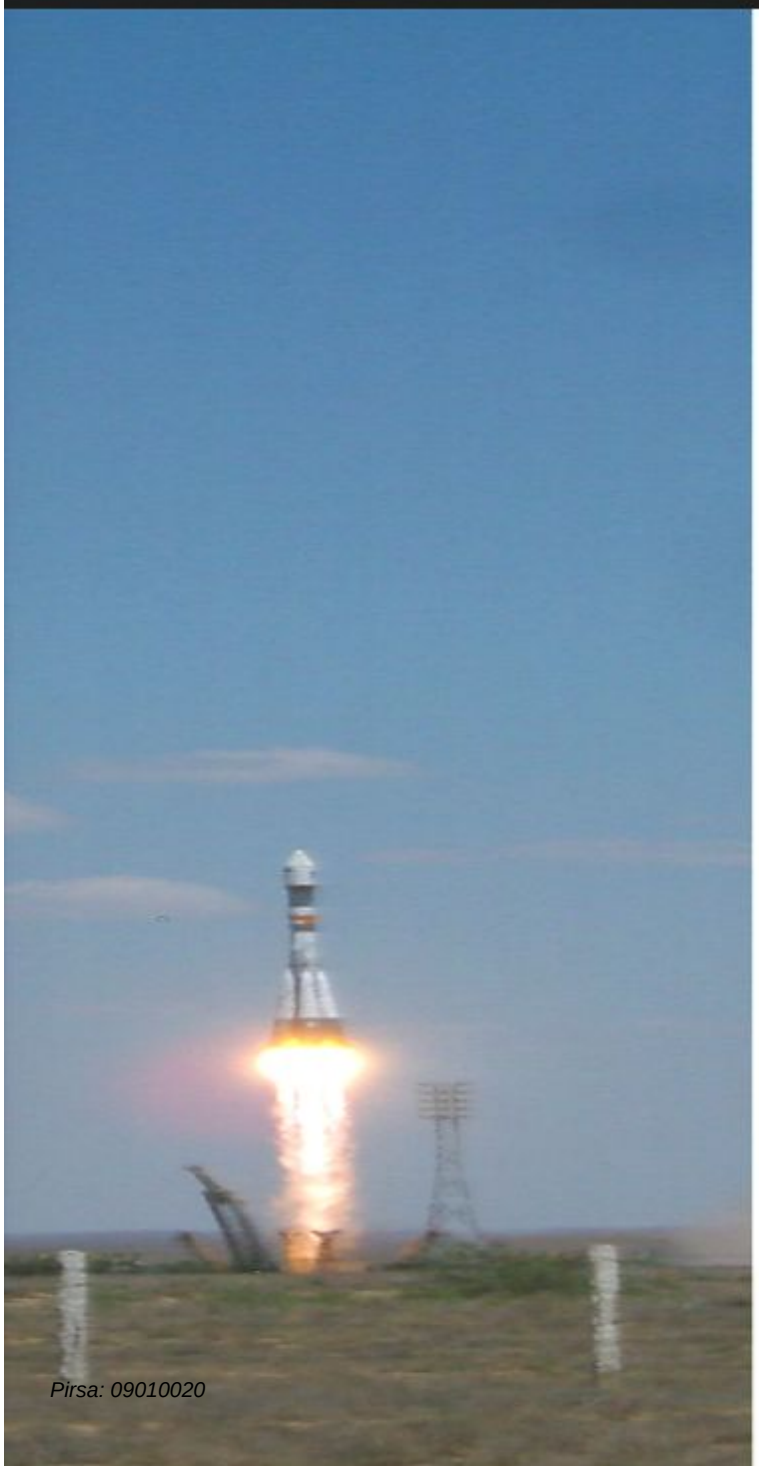
Mirko Boezio

INFN Trieste, Italy

On behalf of the PAMELA collaboration

Perimeter Institute Seminar

January 16th 2009



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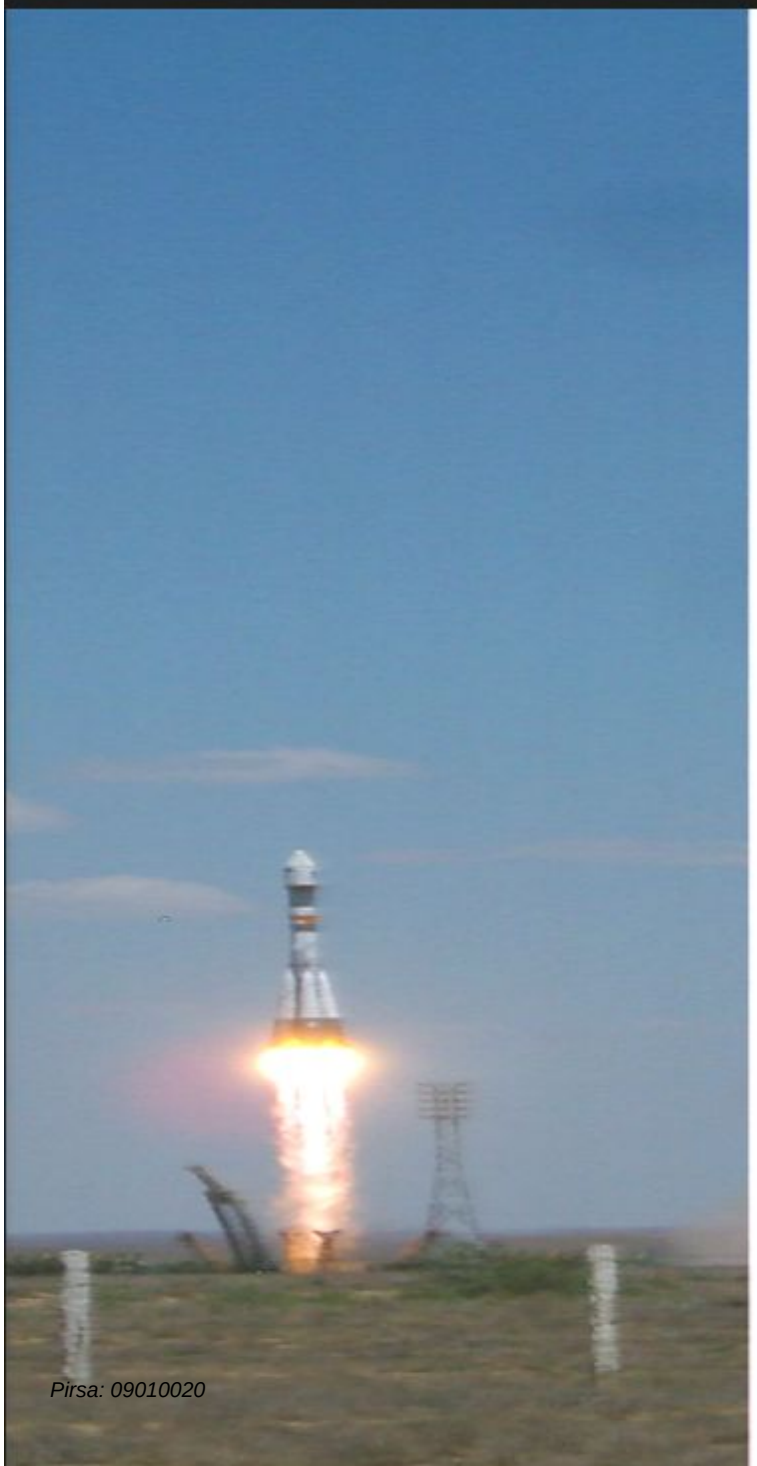

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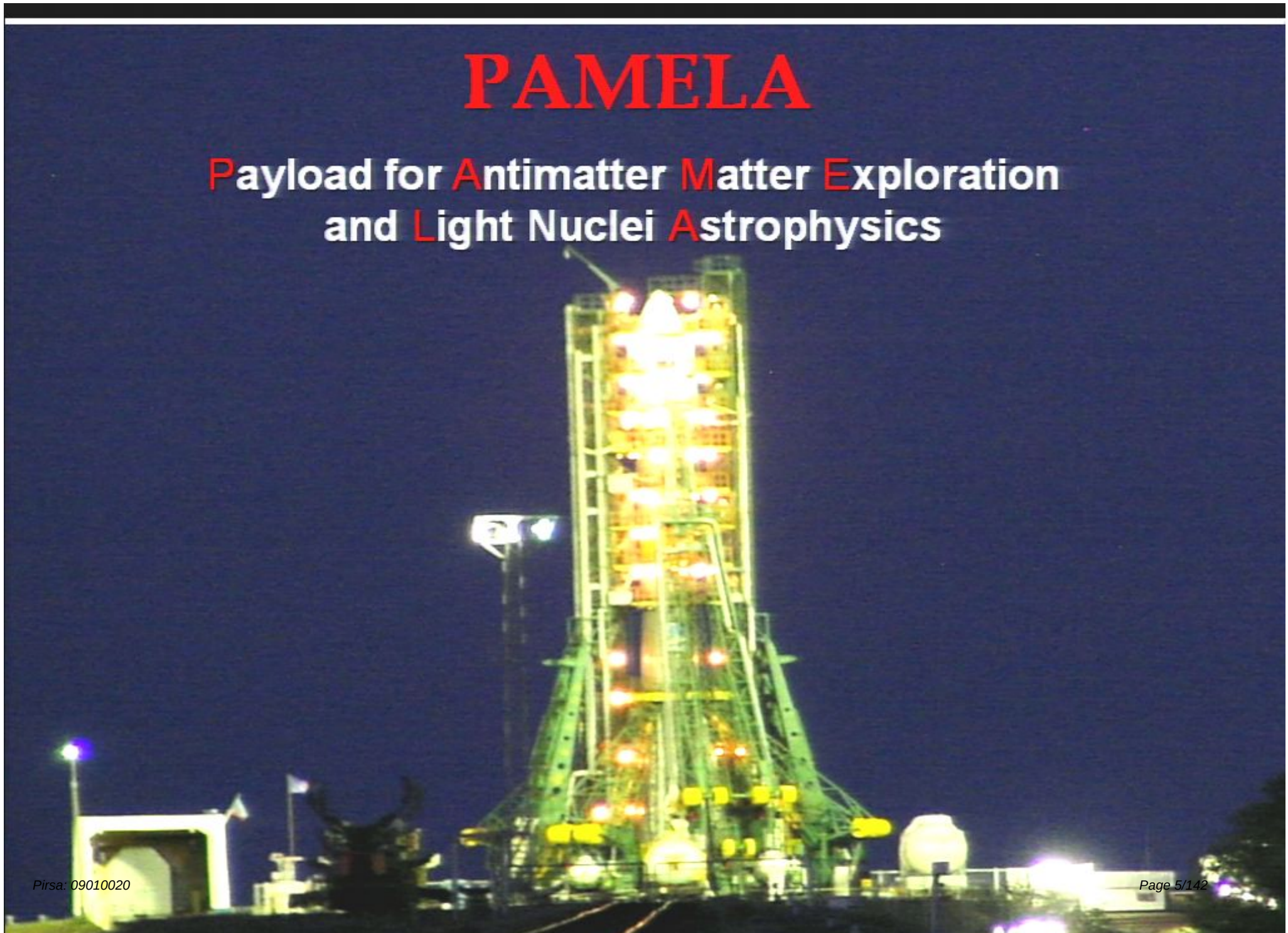
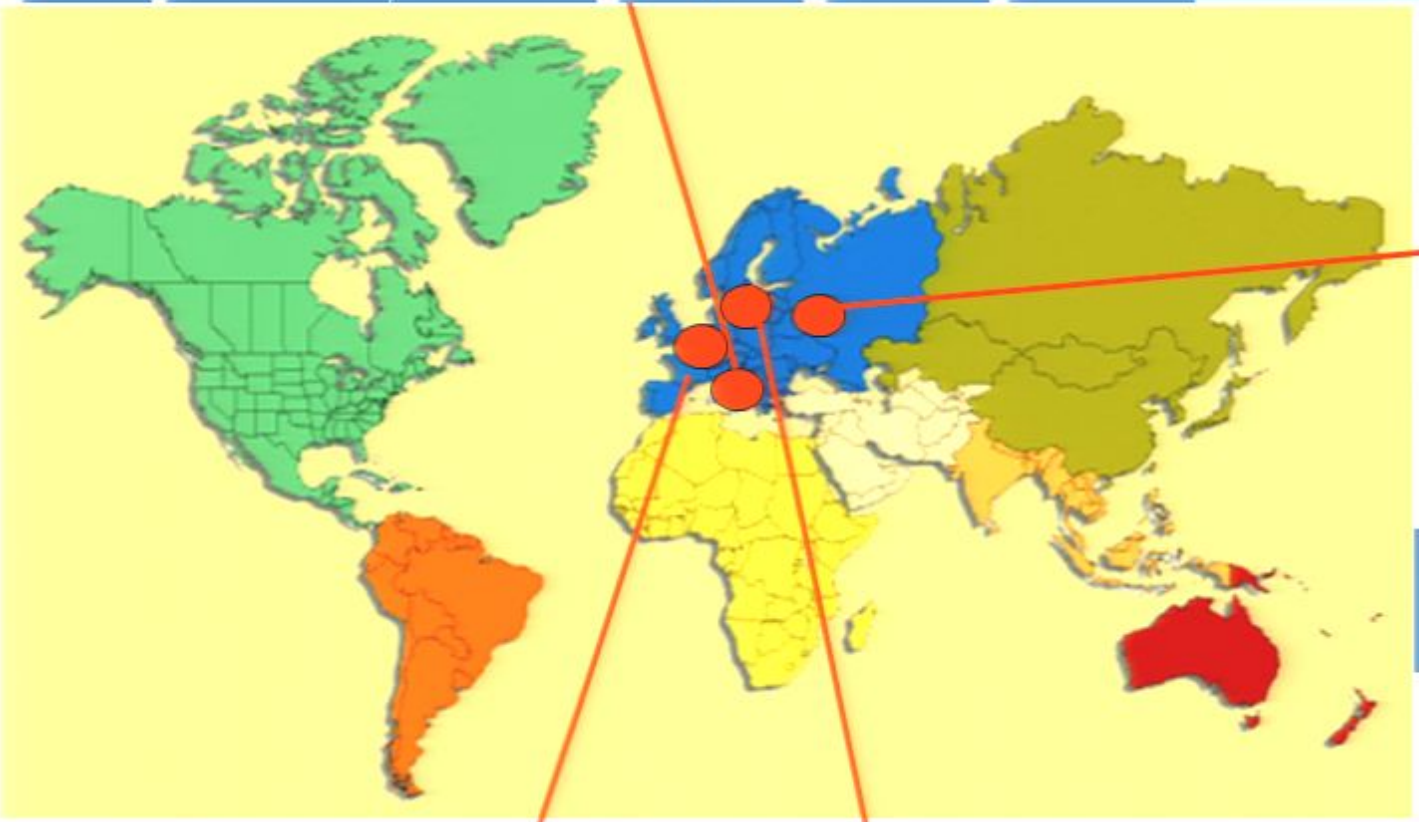
PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics



PAMELA Collaboration

Bari Florence Frascati Naples Rome Trieste CNR, Florence



Russia:

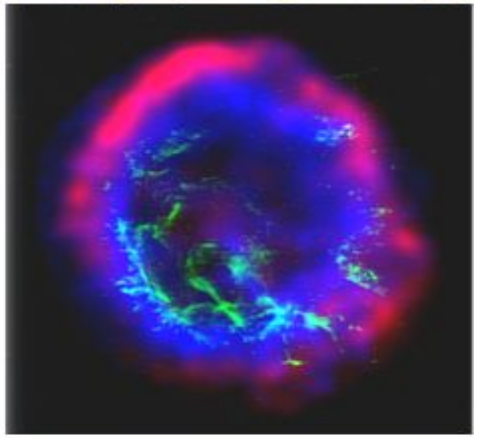
Moscow
St. Petersburg

Germany:

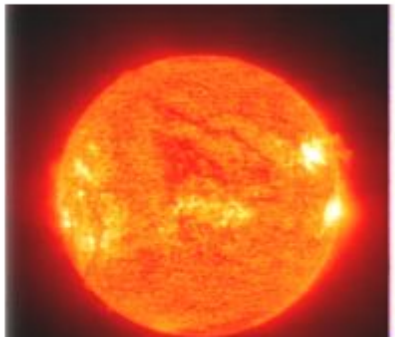
Sweden:

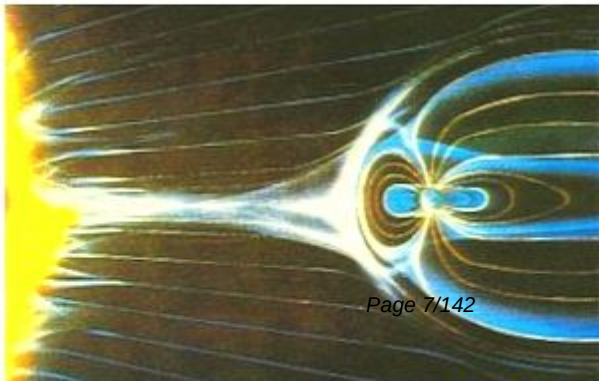
Scientific goals

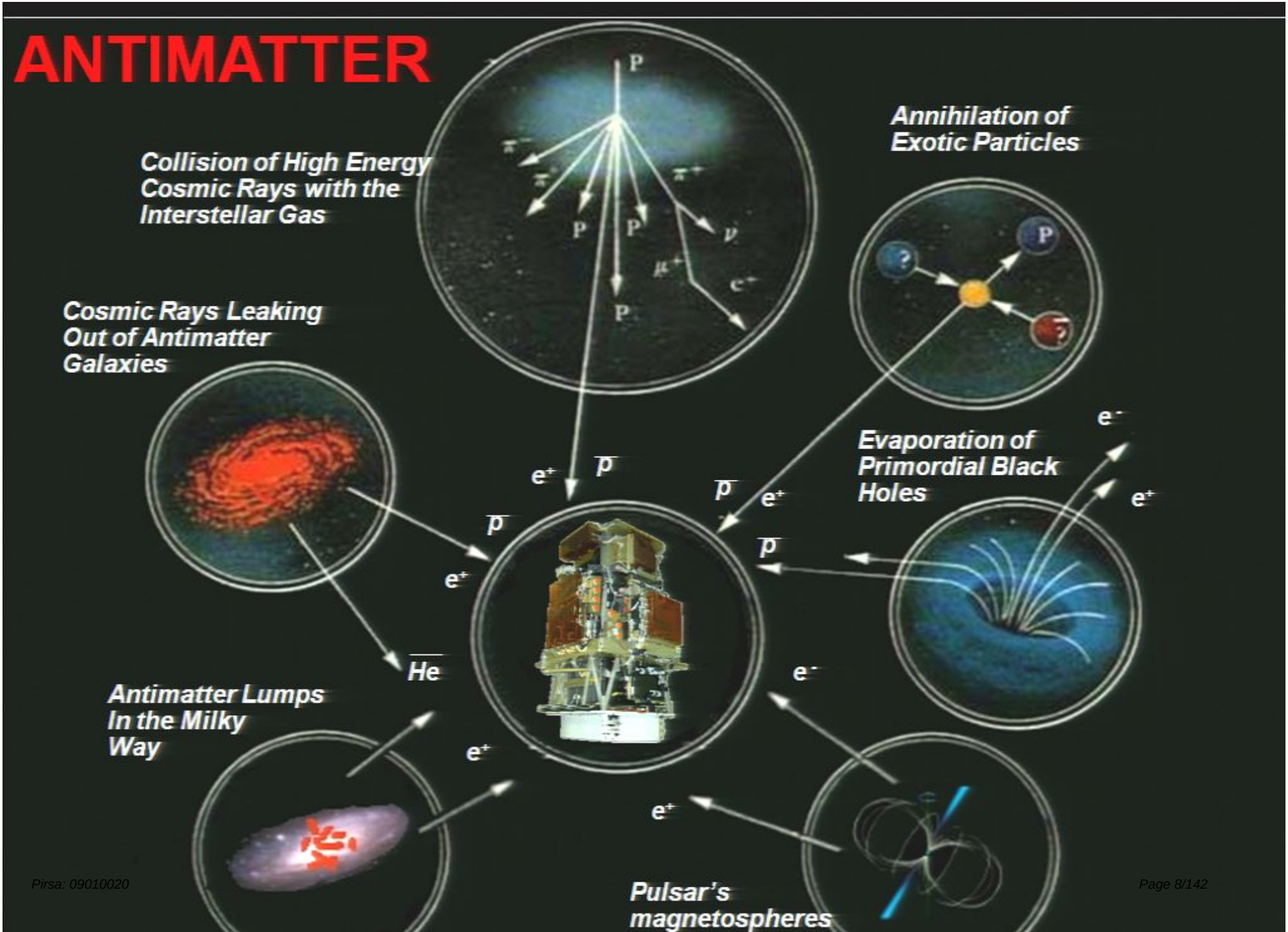
- **Search for dark matter annihilation**
- **Search for antihelium (primordial antimatter)**



- **Study of cosmic-ray propagation (light nuclei and isotopes)**
- **Study of electron spectrum (local sources?)**
- **Study solar physics and solar modulation**
- **Study terrestrial magnetosphere**






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-
p
He

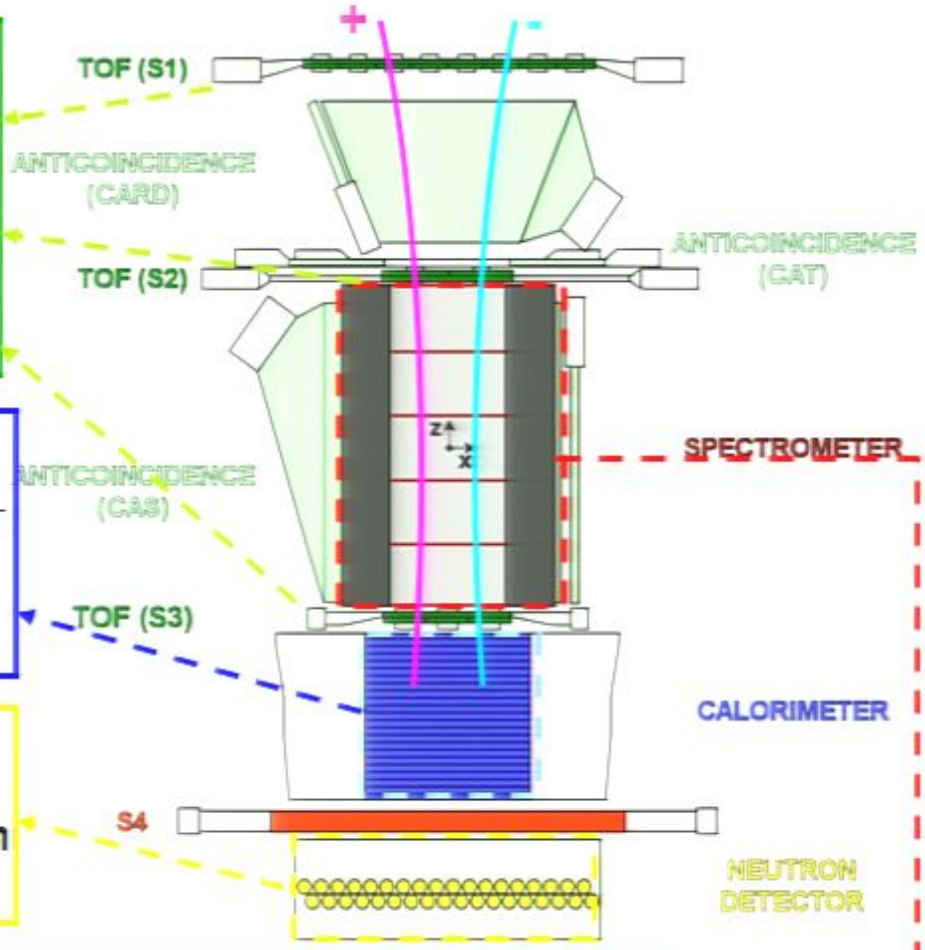
PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure

Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λI)
- Discrimination e+ / p, anti-p / e⁻ (shower topology)
- Direct E measurement for e⁻

Neutron detector
plastic scintillators + PMT:
- High-energy e/h discrimination



GF: 21.5 cm² sr
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W

Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

Design Performance

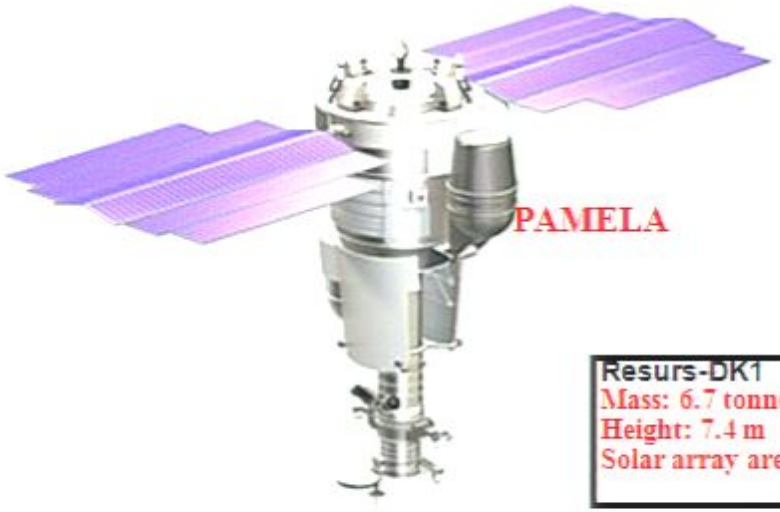
	energy range
• Antiprotons	80 MeV - 150 GeV
• Positrons	50 MeV – 300 GeV
• Electrons	up to 500 GeV
• Protons	up to 700 GeV
• Electrons+positrons	up to 2 TeV (from calorimeter)
• Light Nuclei (He/Be/C)	up to 200 GeV/n
• AntiNuclei search	sensitivity of 3×10^{-8} in $\overline{\text{He}}$/He

→ Simultaneous measurement of many cosmic-ray species

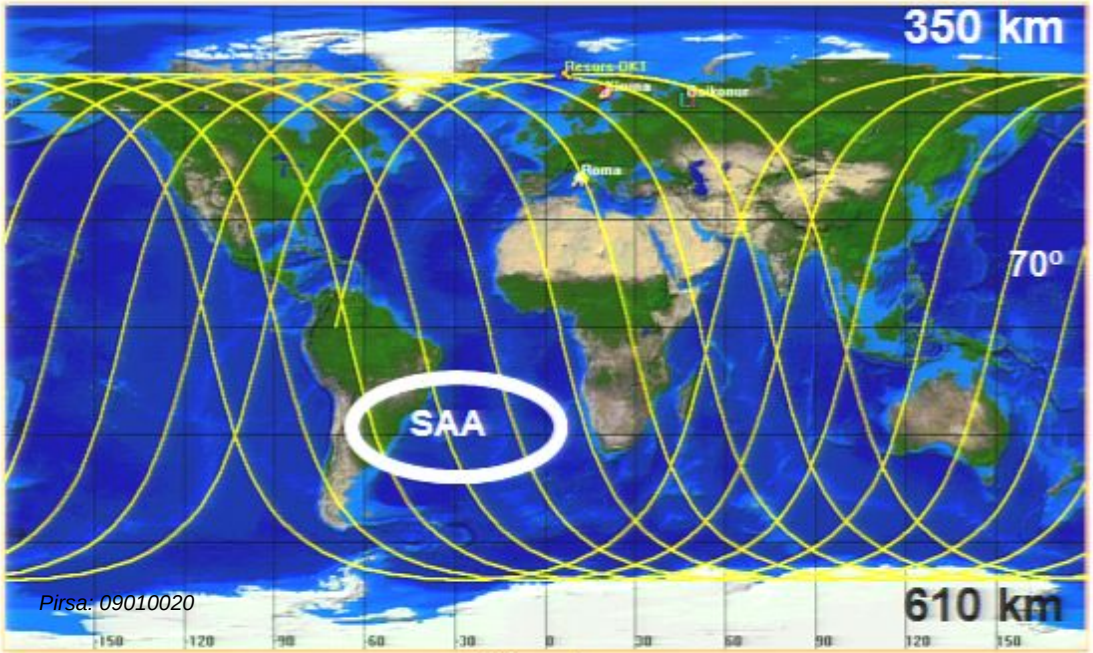
→ New energy range

→ Unprecedented statistics

Resurs-DK1 satellite + orbit



Resurs-DK1
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 m^2



~90 mins

- Resurs-DK1: multi-spectral imaging of earth's surface
- PAMELA mounted inside a pressurized container
- Lifetime >3 years (assisted)
- Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day
- Quasi-polar and elliptical orbit (70.0° ,350 km - 600 km)
- Traverses the South Atlantic Anomaly
- Crosses the outer (electron) Van Allen belt at south pole

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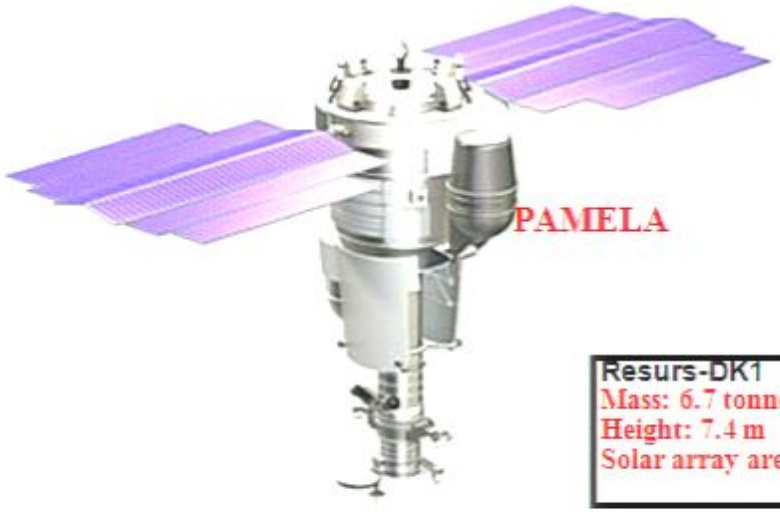

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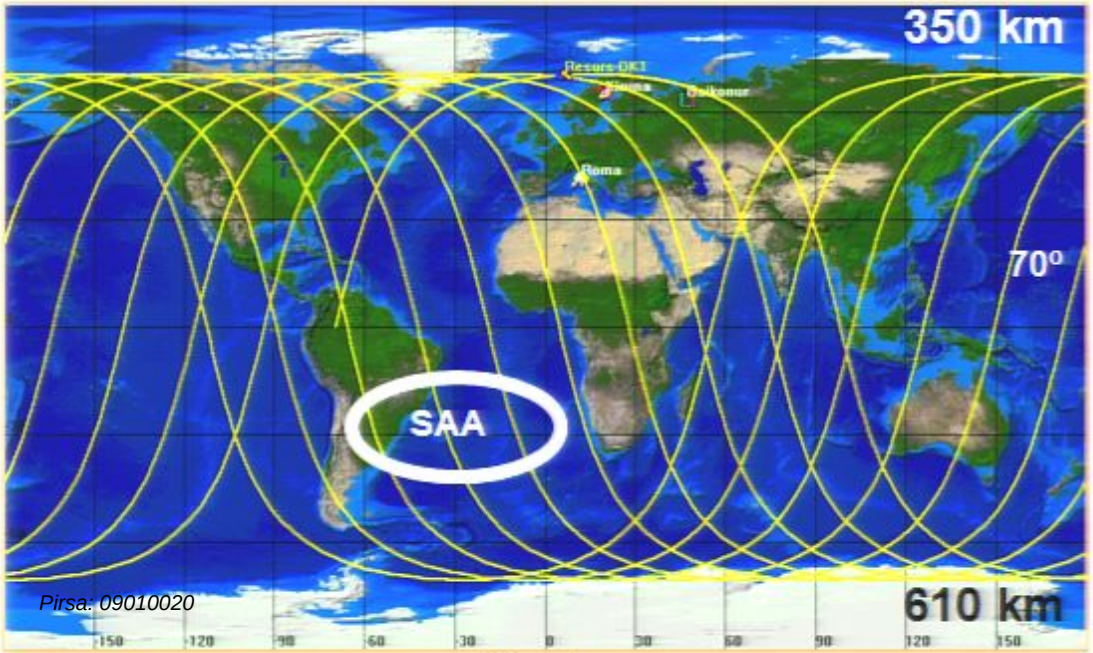

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PAMELA milestones

Launch from Baikonur → June 15th 2006, 0800 UTC.

'First light' → June 21st 2006, 0300 UTC.

- Detectors operated as expected after launch
- Different trigger and hardware configurations evaluated

→ PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006

Main antenna in NTsOMZ

Trigger rate* ~25Hz
Fraction of live time* ~ 75%
Event size (compressed mode) ~5kB
25 Hz x 5 kB/ev → ~ 10 GB/day
(*outside radiation belts)

Till ~now:
~700 days of data taking
~12 TByte of raw data downlinked
~12•10^8 triggers recorded and analyzed
(Data from April till now under analysis)

Resurs-DK1 satellite + orbit

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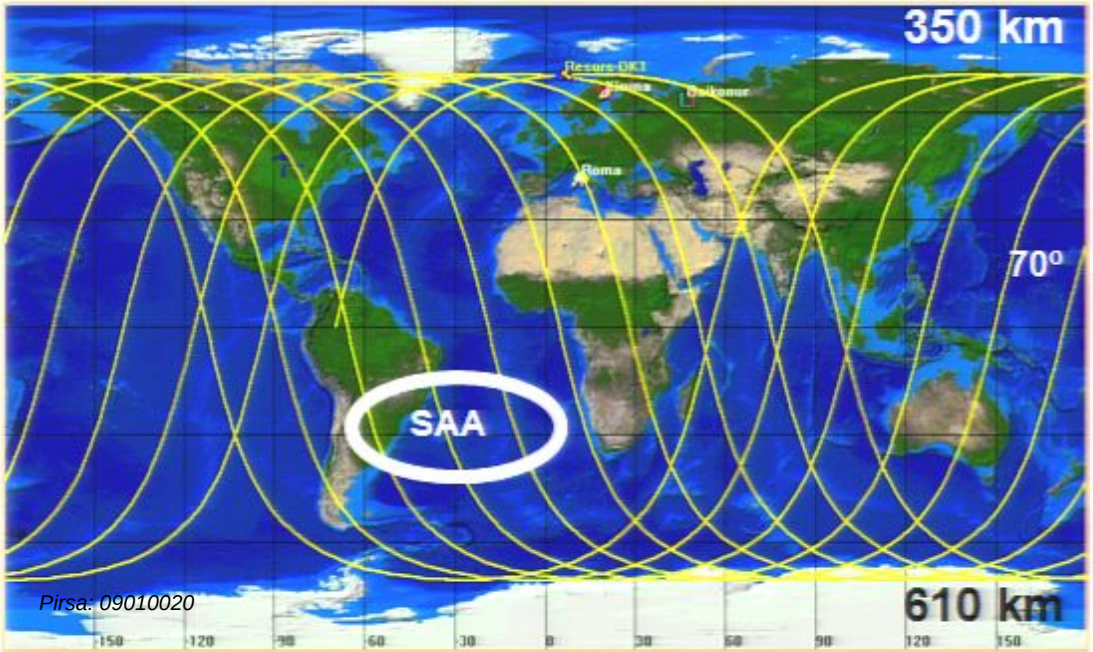

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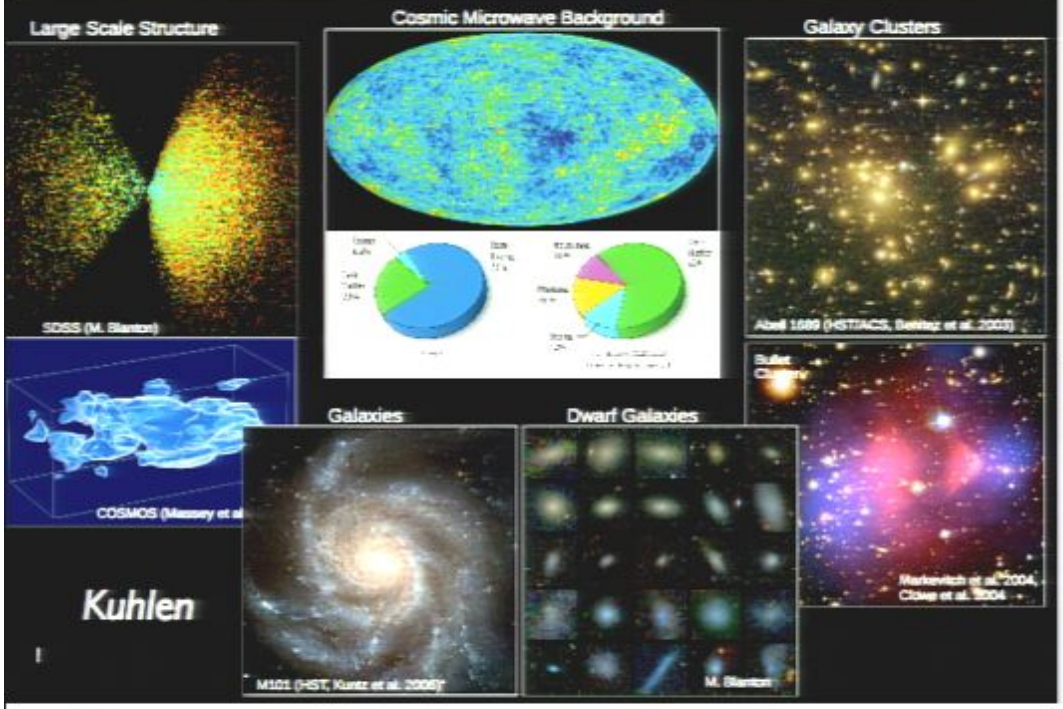
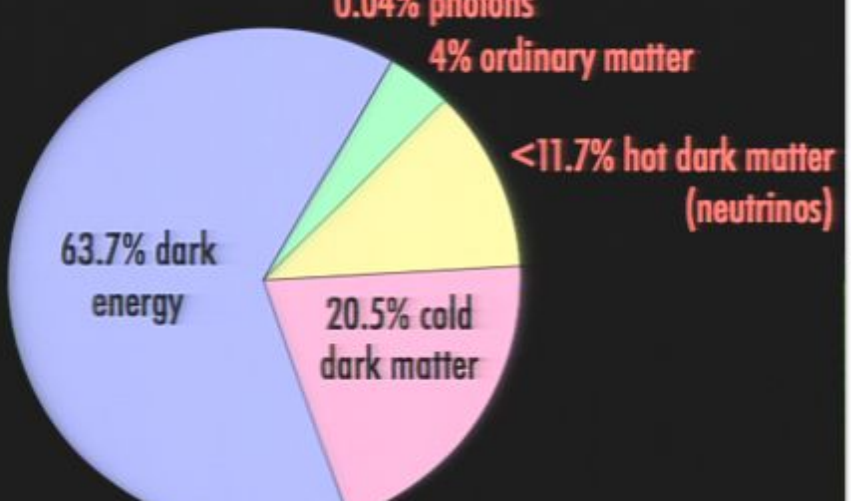
There's evidence for dark matter on many scales...

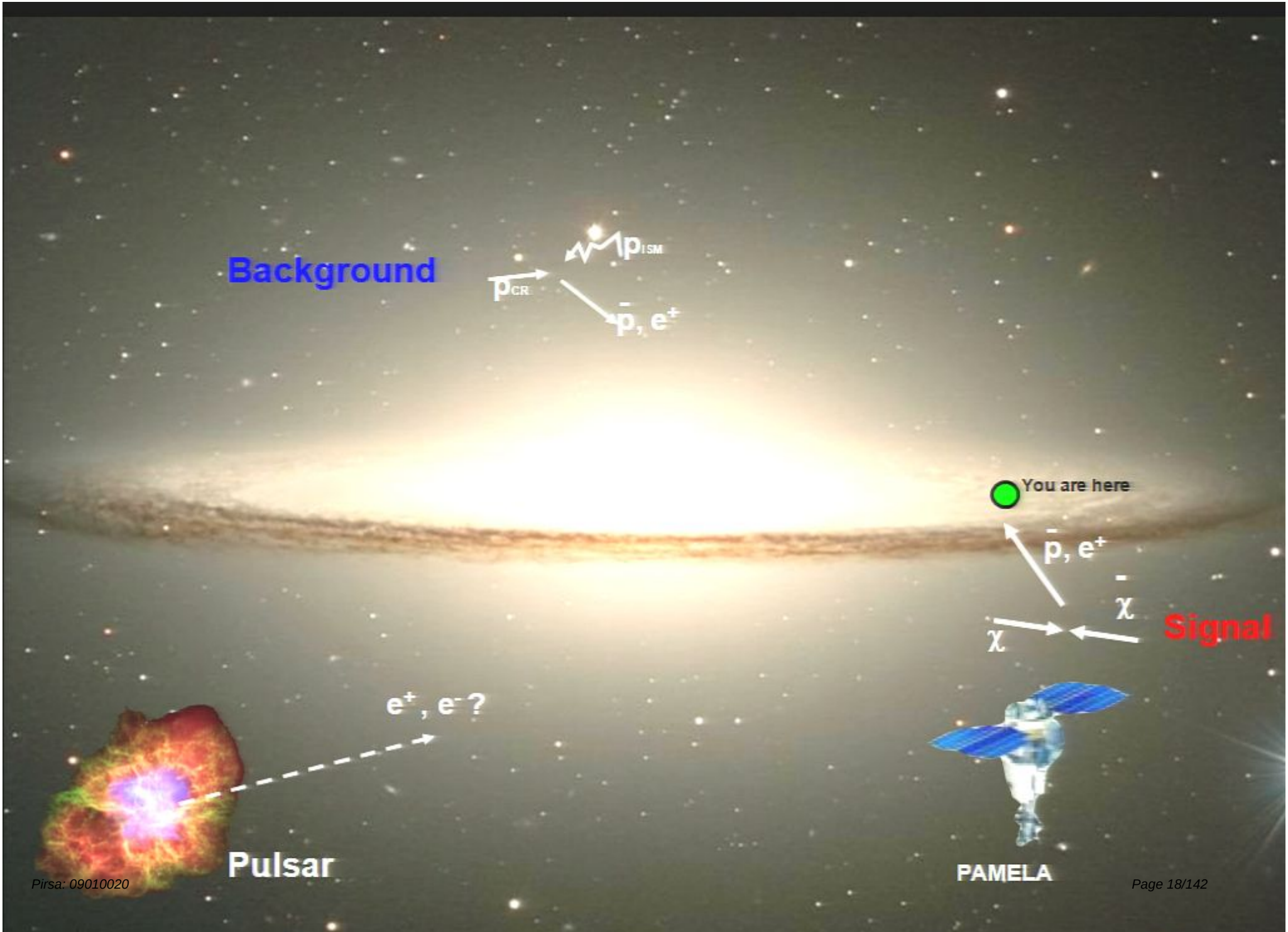


Searches for WIMP Dark Matter

The current content of the Universe

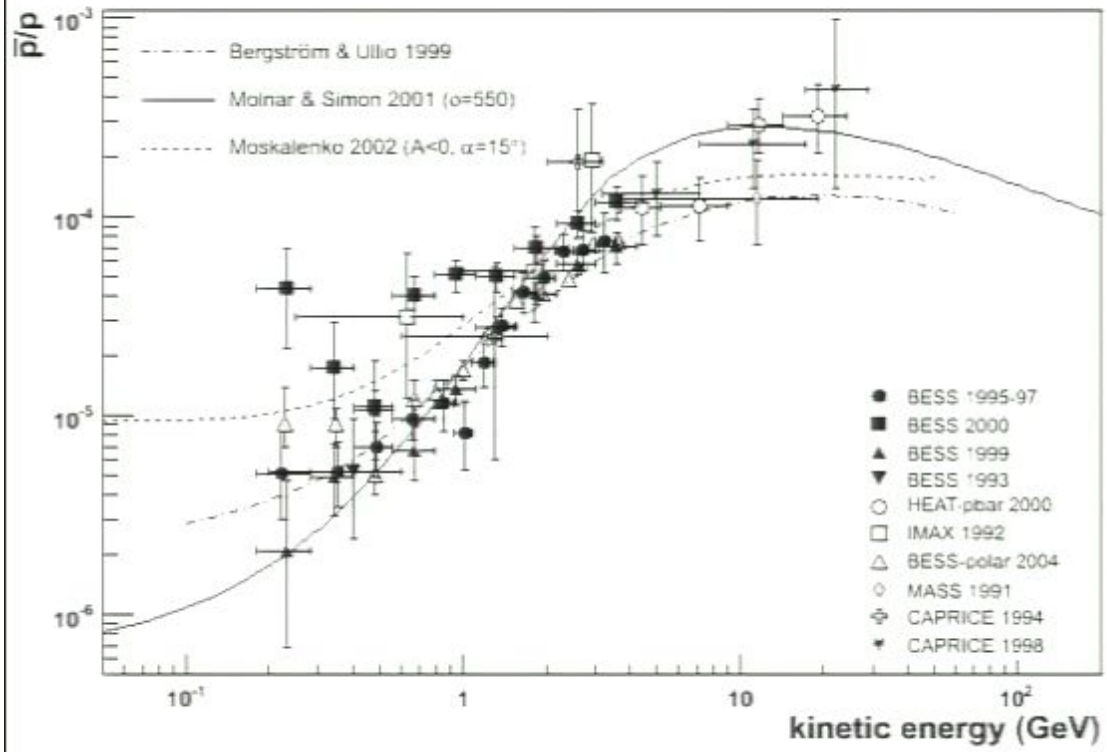


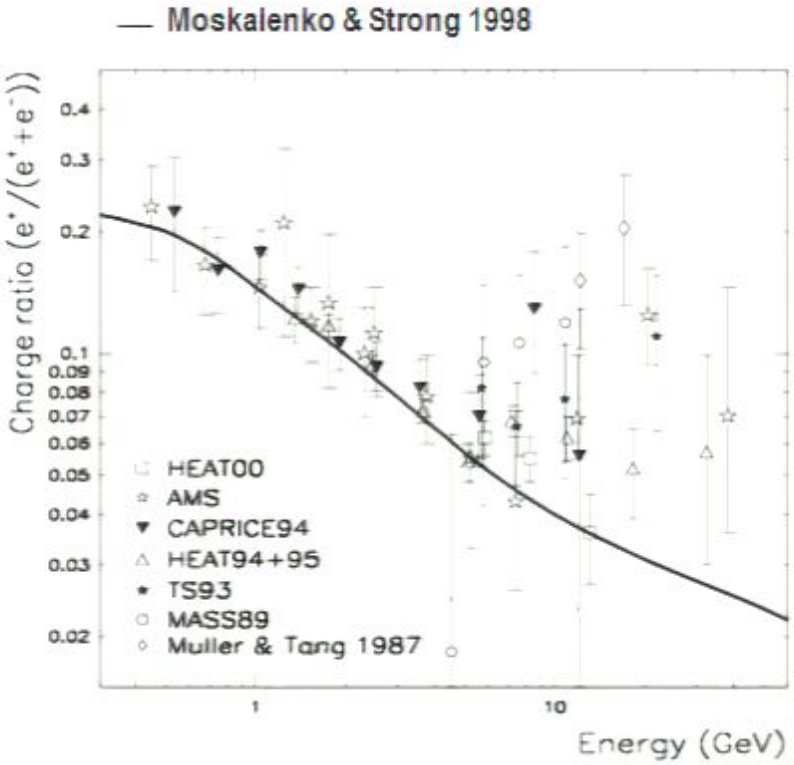
P. Gondolo, IDM 2008


Background
p_{ISM}
p_{CR}
$\bar{p}, e^+$
You are here
$\bar{p}, e^+$
$\bar{\chi}$
χ
Signal
e^+, e^- ?
Pulsar
PAMELA

CR Antimatter: available data

Why in space?





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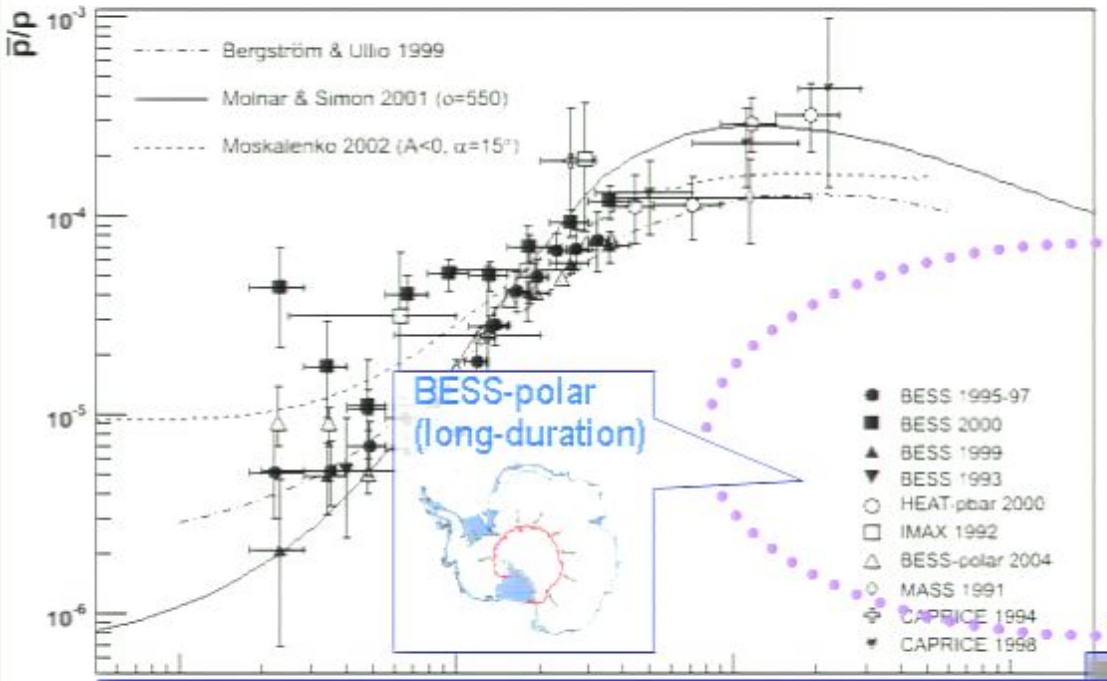

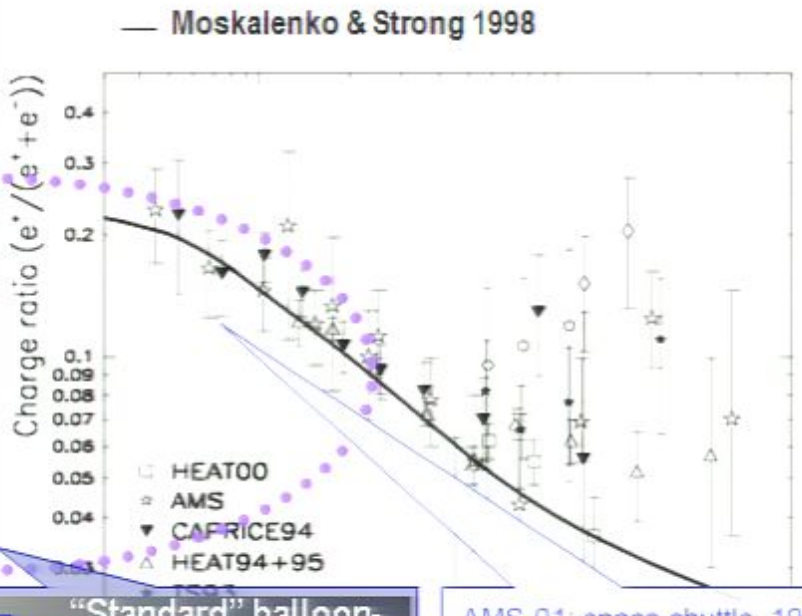

- low exposure (~days)
  ⇒ large statistical errors
- atmospheric secondaries (~5g/cm2)
  ⇒ additional systematic uncertainty @low-energy

AMS-01: space shuttle, 1998

CR Antimatter: available data

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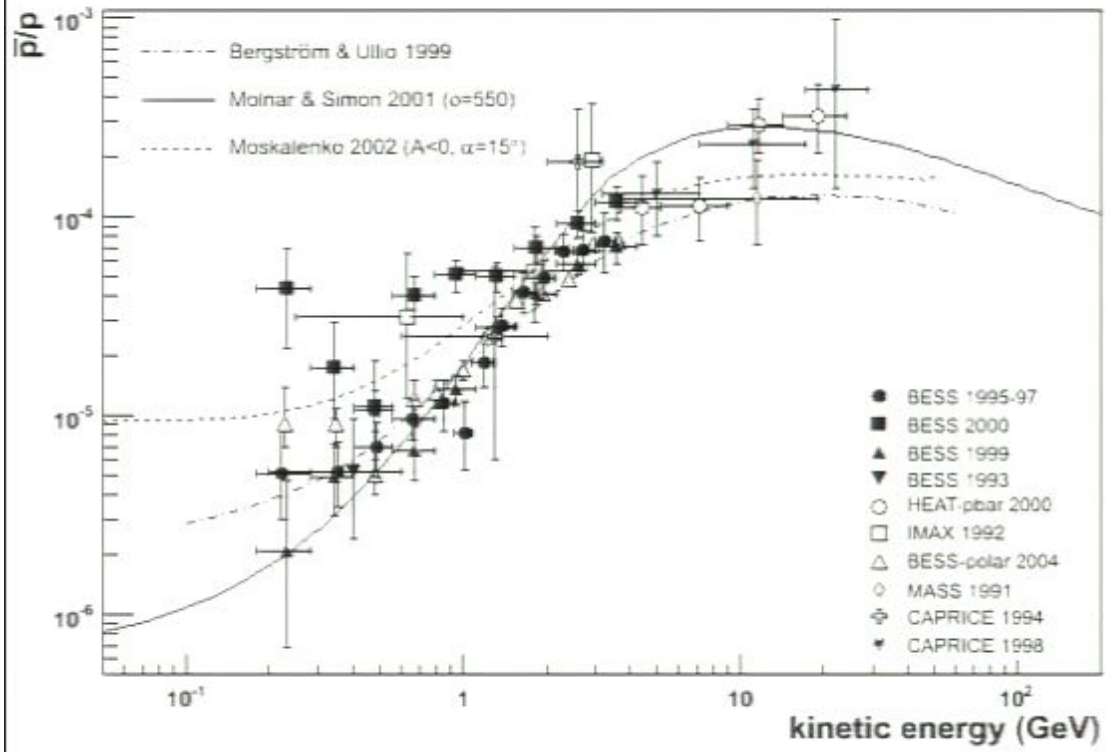

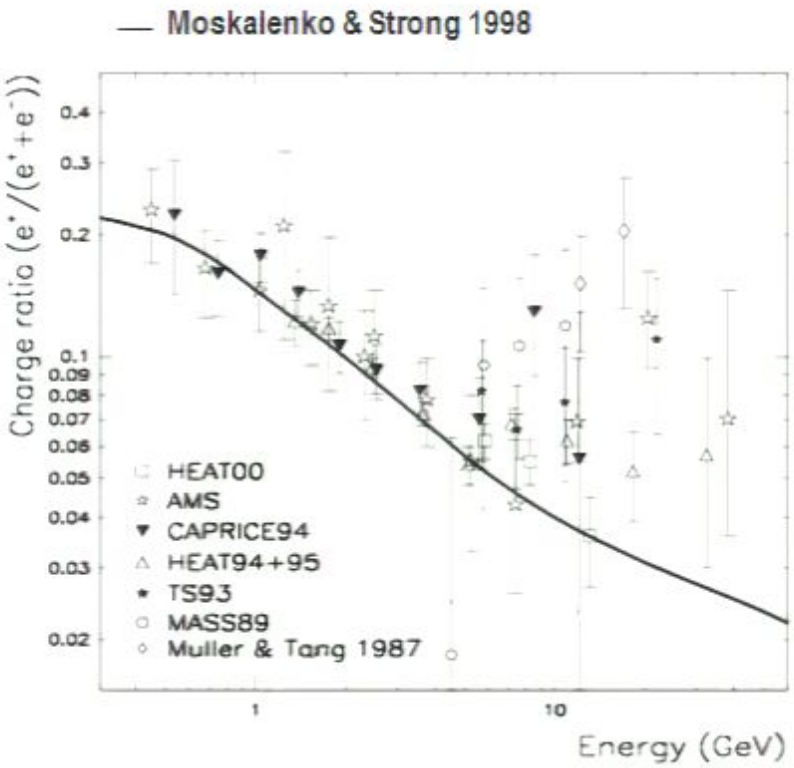

CR Antimatter: available data

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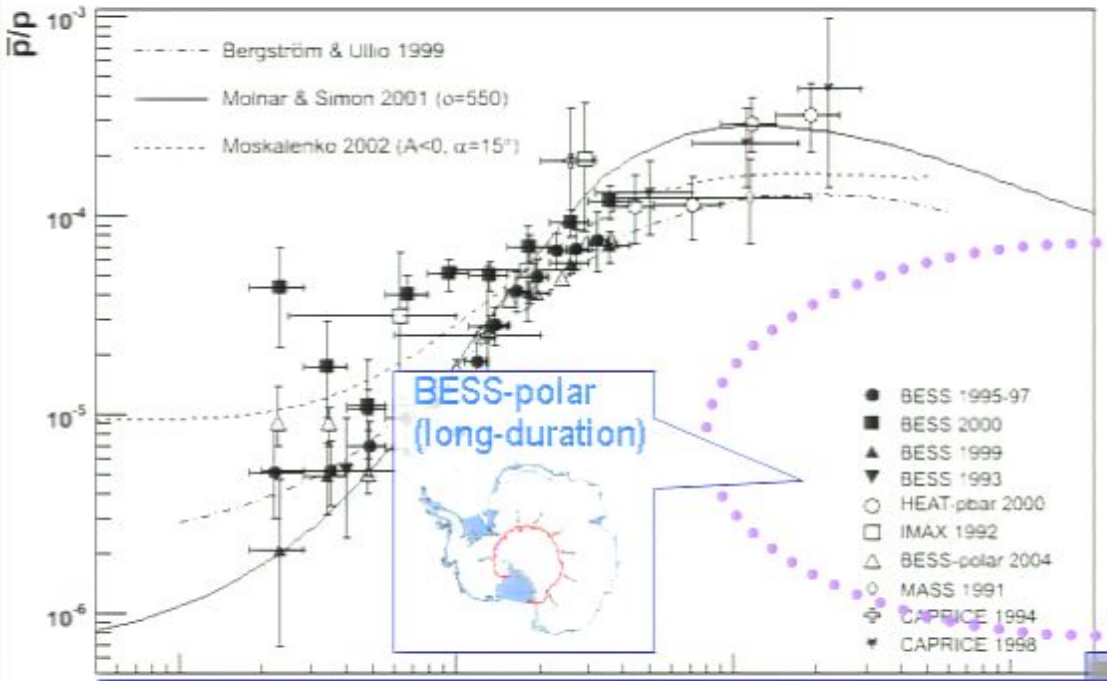

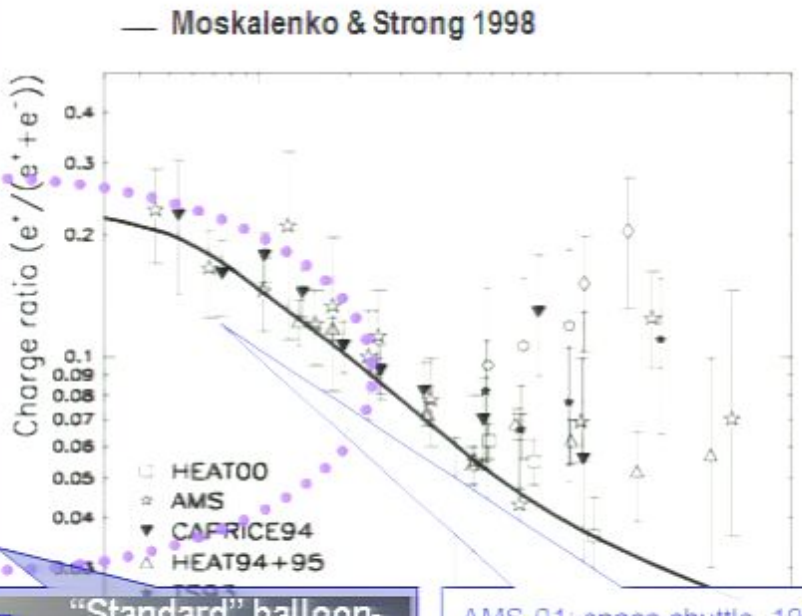

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Antiprotons

CR Antimatter: available data

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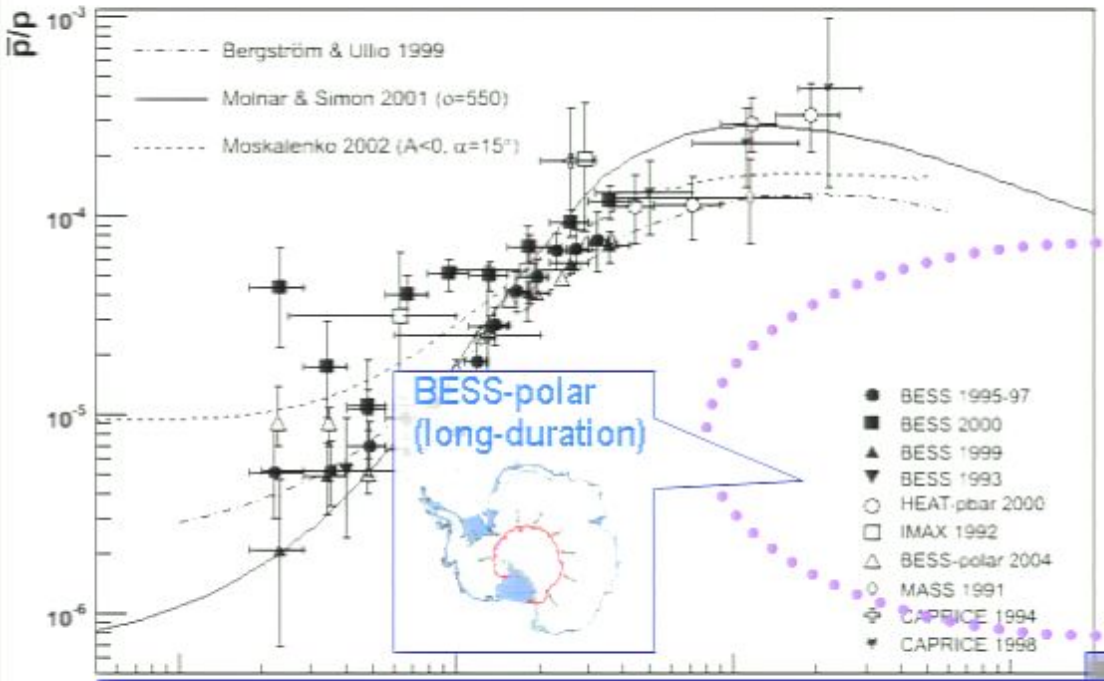

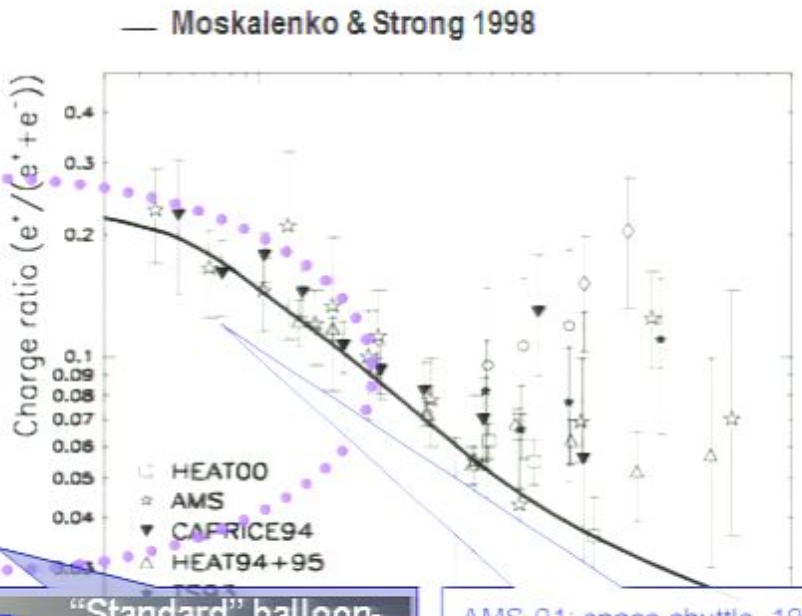

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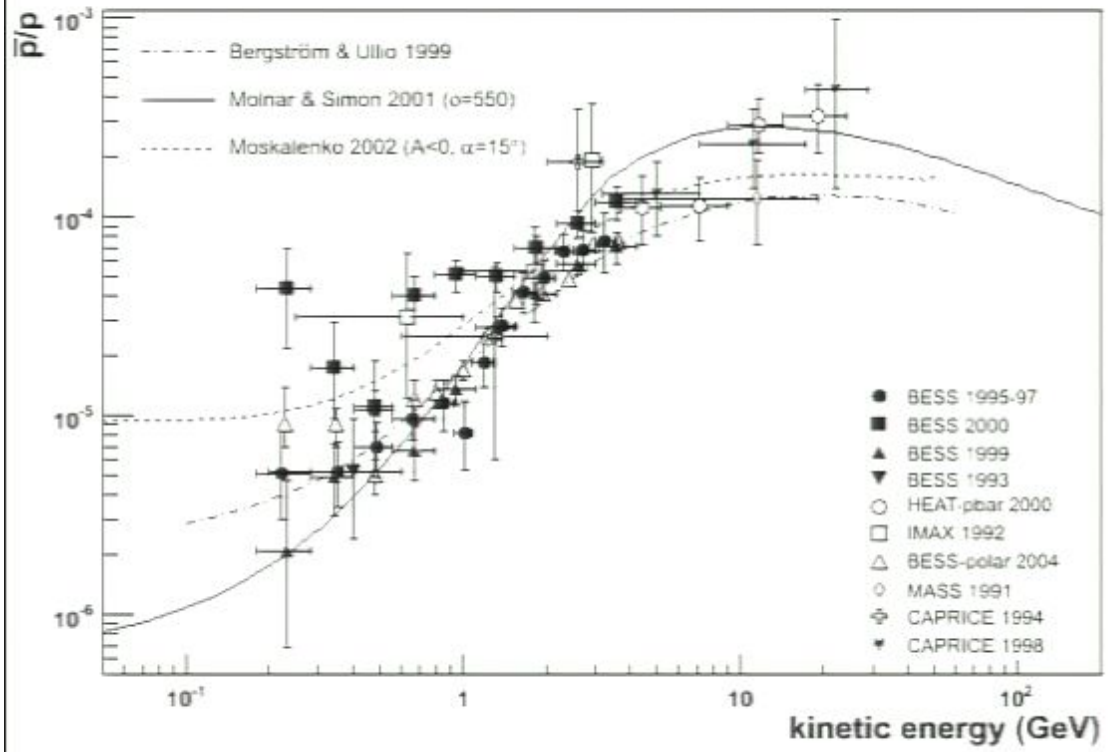
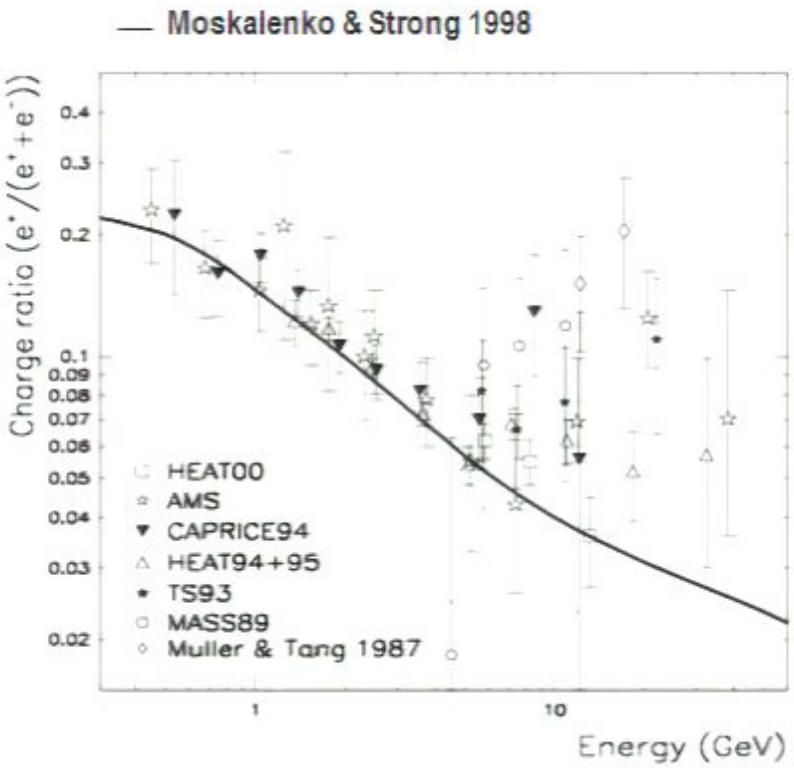
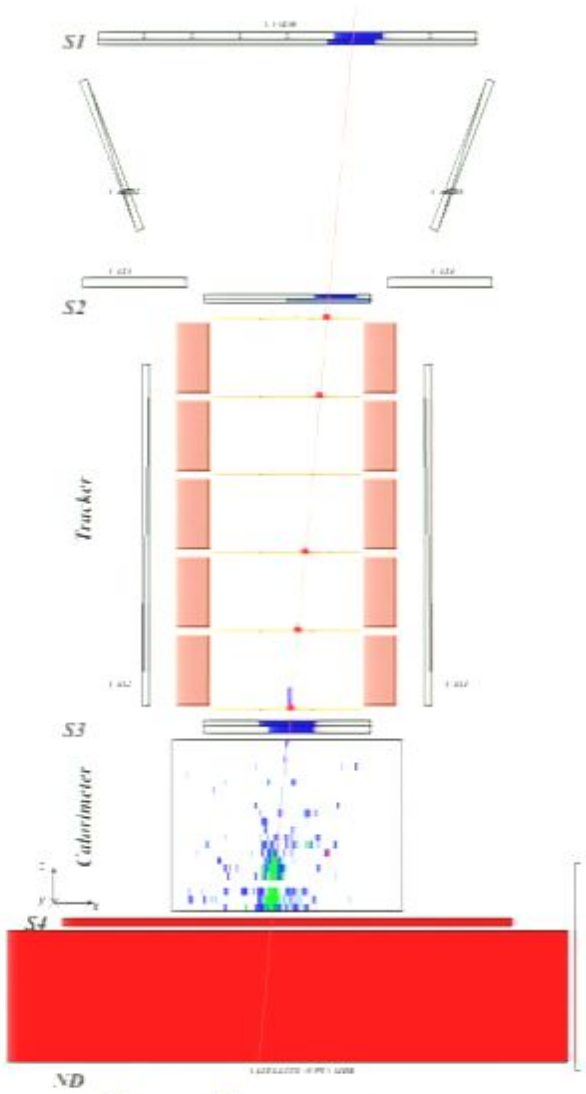




Antiprotons

Antiproton/ positron identification

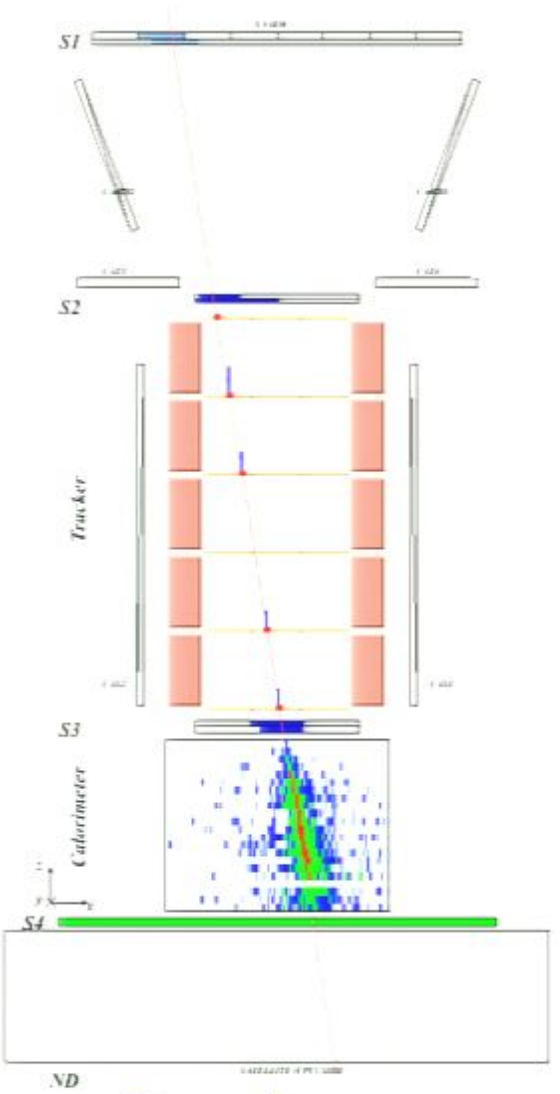


Time-of-flight: trigger, albedo rejection, mass determination (up to 1 GeV)

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



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

Positron
(NB: $p/e^+ \sim 10^{3\text{-}4}$)

Antiprotons

CR Antimatter: available data

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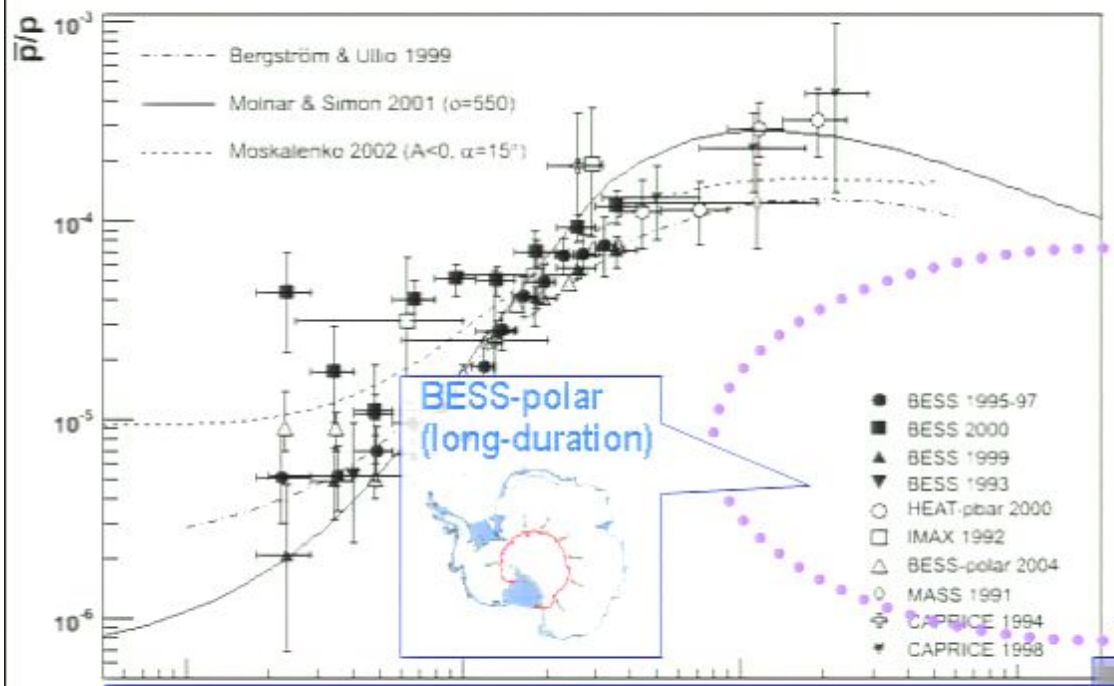

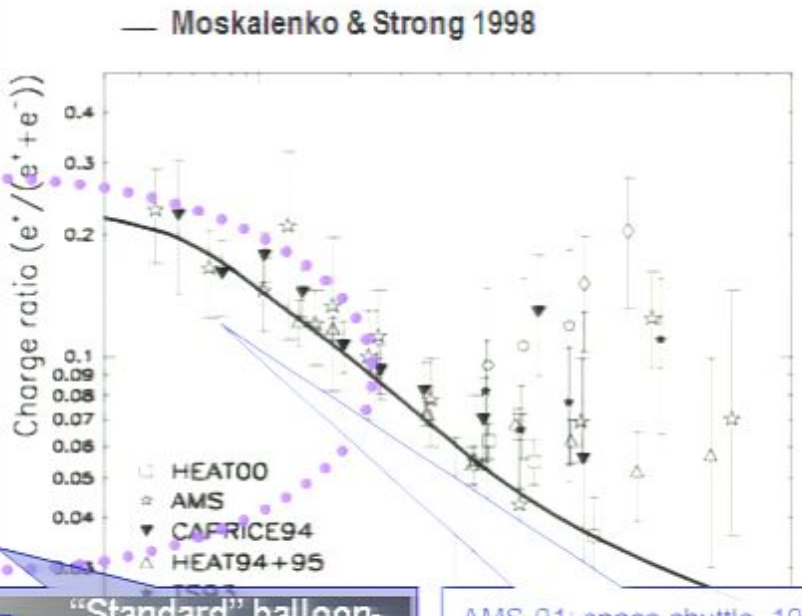

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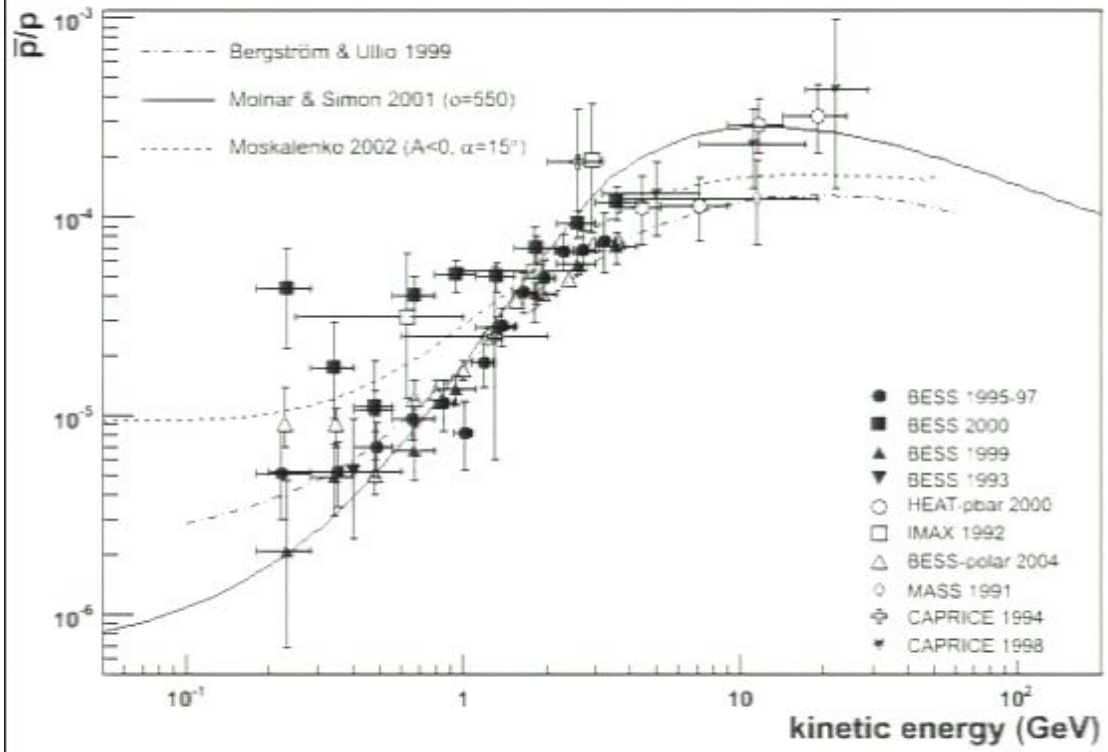

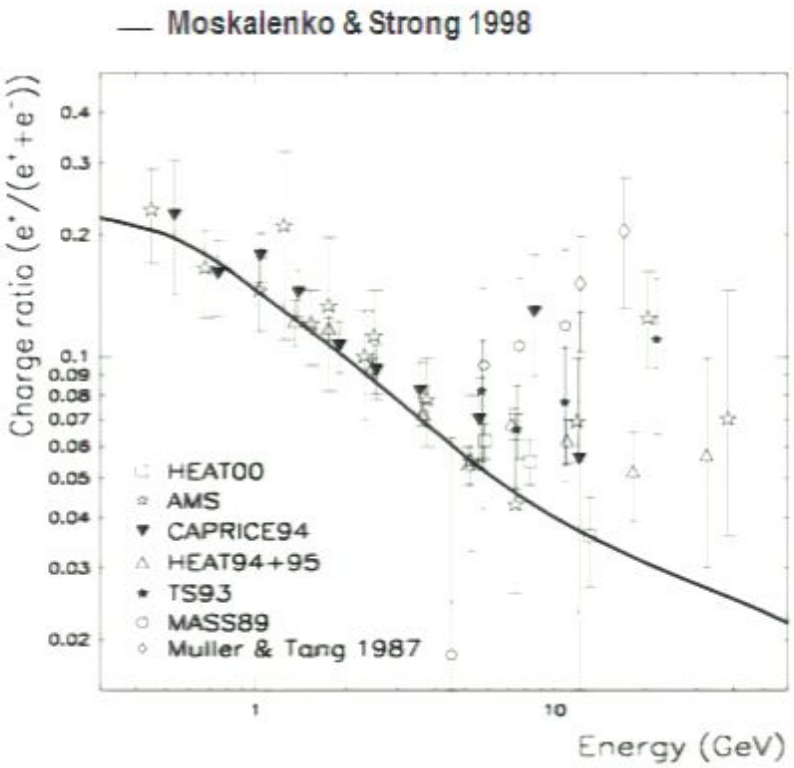

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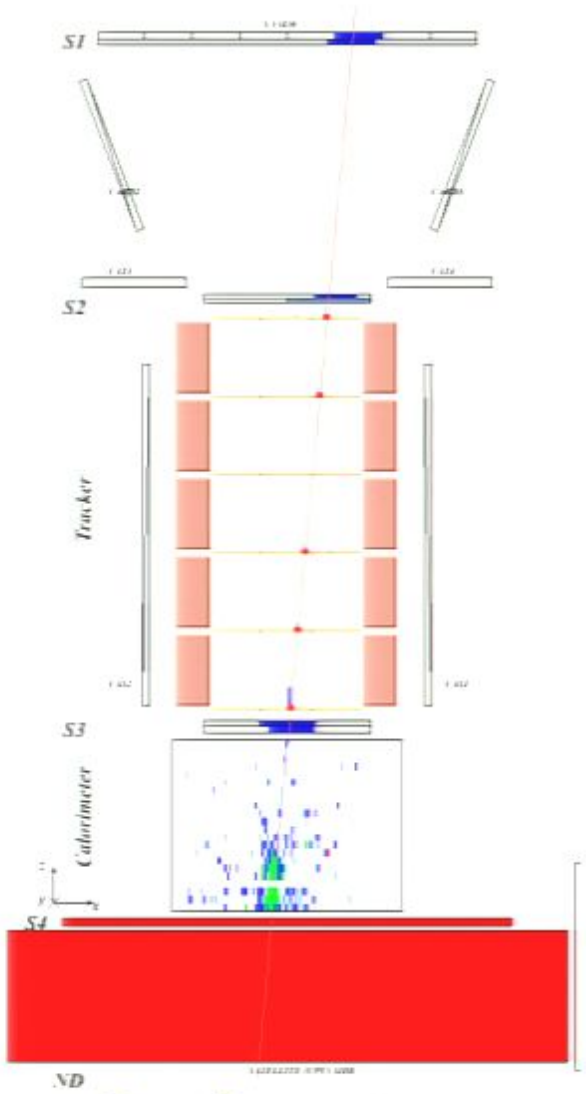

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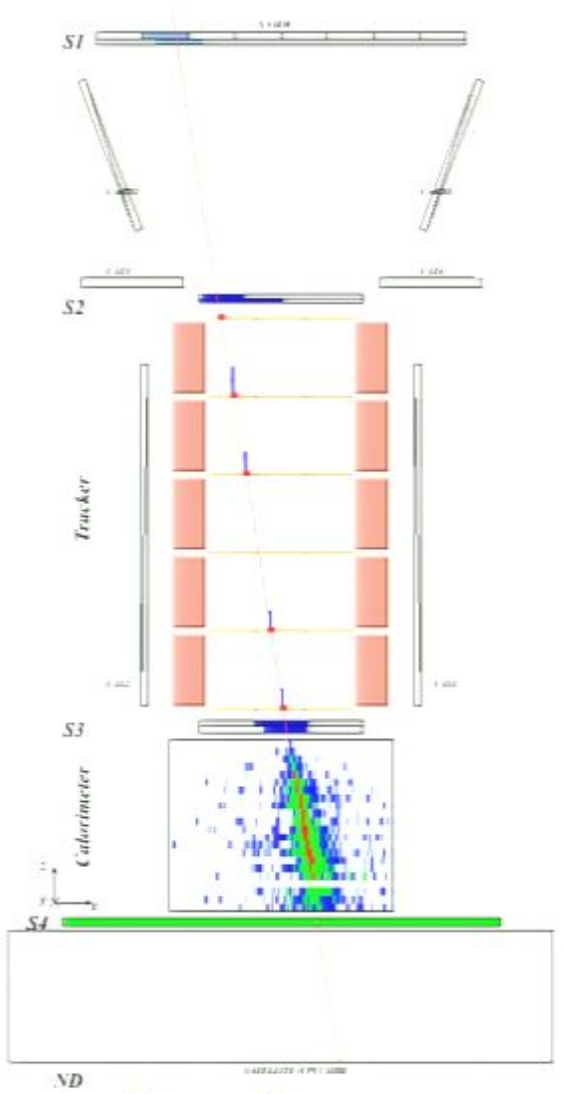
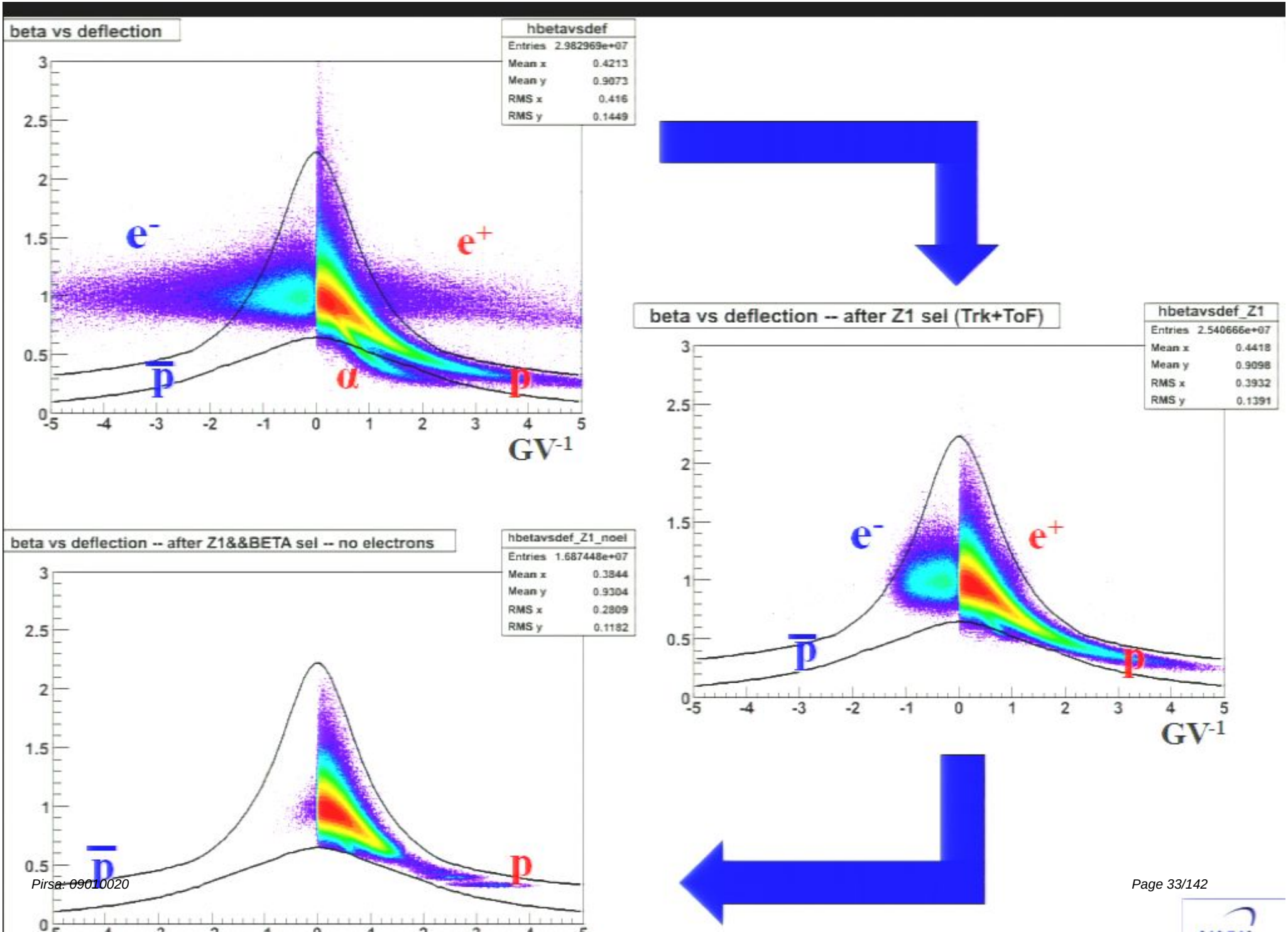


Antiproton (NB: $e^-/\bar{p} \sim 10^2$)

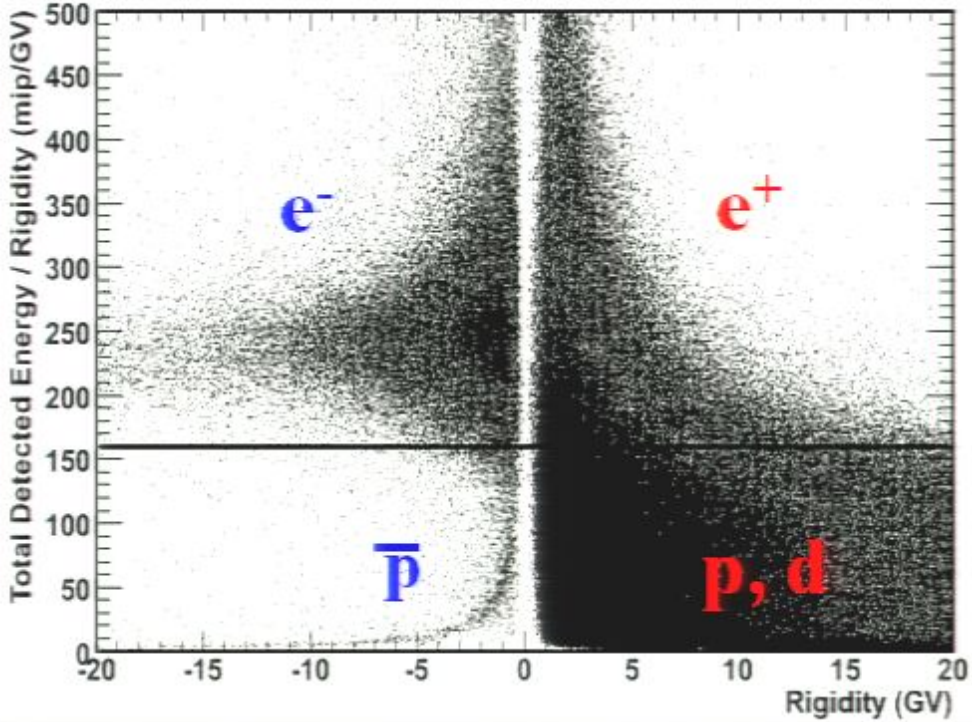
Positron (NB: $p/e^+ \sim 10^{3\text{-}4}$)

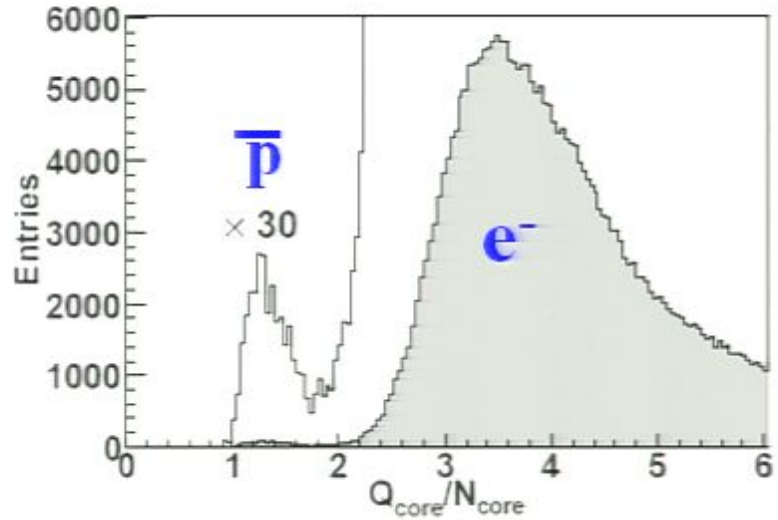
Analysis 'recipe'

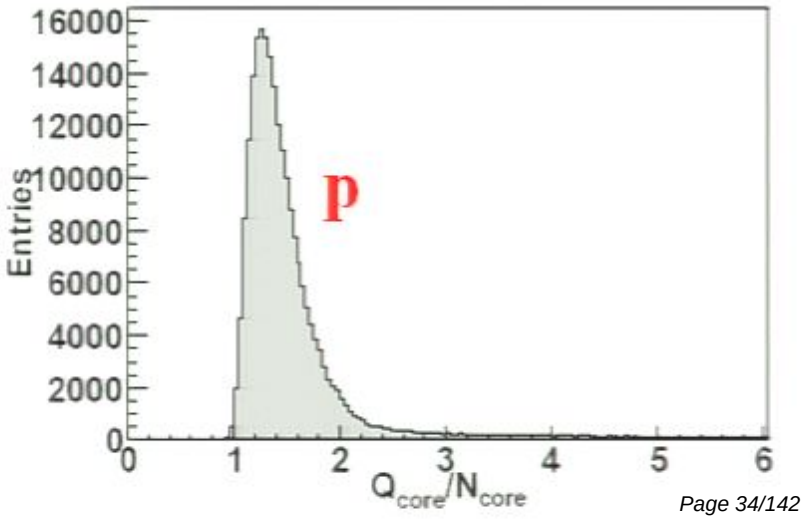
- Select downward-going particles with ToF ($\Delta t \sim 0.3$ ns)
- Select MIPs with dE/dx (ToF + tracker)
- Multiplicity cuts on S1/S2, AC to reject interactions
- Quality cuts on tracker fit, derive rigidity
- Check rigidity is compatible with geomagnetic location
- Use shower topology to reject electrons
- Use ToF β for particle ID, < 1 GeV/c


beta vs deflection
hbetavsdef
Entries 2.982969e+07
Mean x 0.4213
Mean y 0.9073
RMS x 0.416
RMS y 0.1449
e-
e+
p̄
α
p
GV-1
beta vs deflection -- after Z1 sel (Trk+ToF)
hbetavsdef_Z1
Entries 2.540666e+07
Mean x 0.4418
Mean y 0.9098
RMS x 0.3932
RMS y 0.1391
e-
e+
p̄
p
GV-1
beta vs deflection -- after Z1&&BETA sel -- no electrons
hbetavsdef_Z1_noel
Entries 1.687448e+07
Mean x 0.3844
Mean y 0.9304
RMS x 0.2809
RMS y 0.1182
p̄
p

Calorimeter Selection

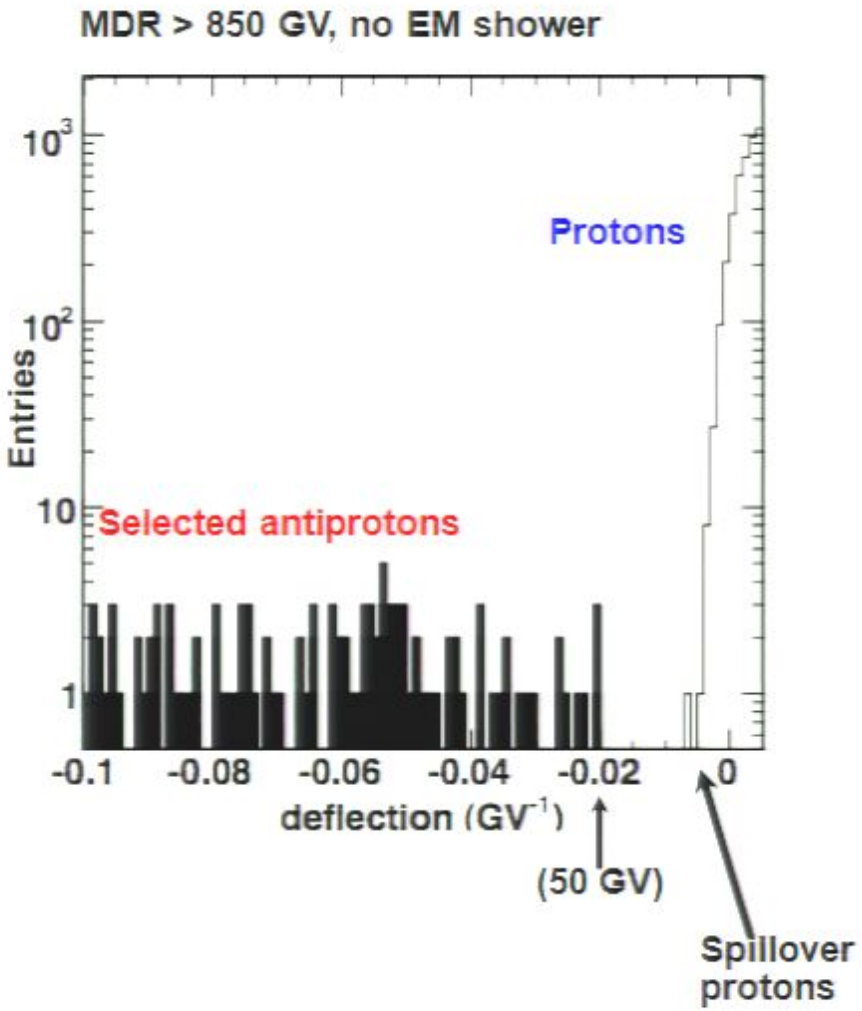






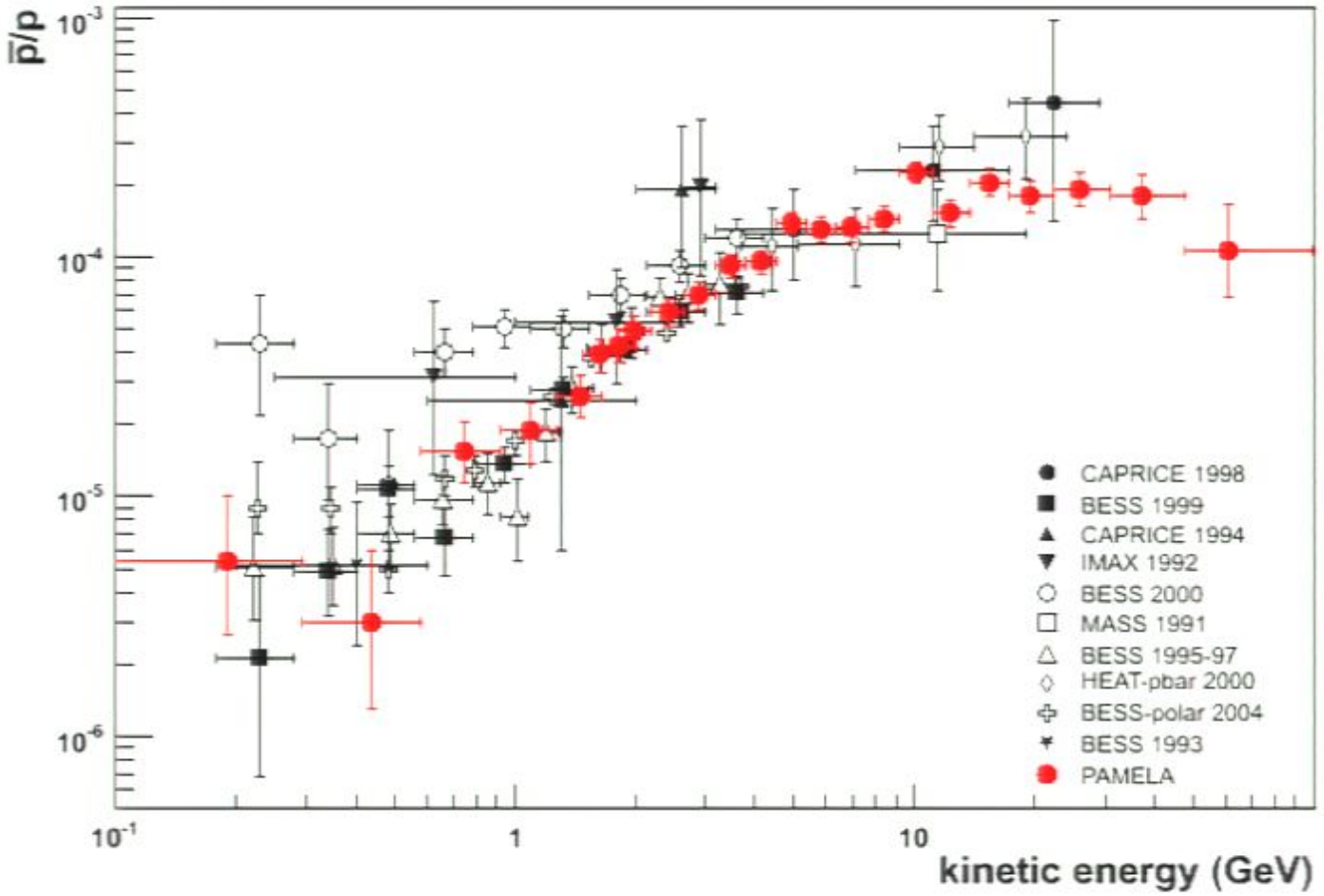
Proton Background

- Spectrometer tracking information is crucial for high-energy antiproton selection
- Finite spectrometer resolution - high rigidity protons may be assigned wrong sign-of-charge
- Also background from scattered protons
- Eliminate 'spillover' using strict track cuts (χ^2, lever arm, no δ-rays, etc)
- MDR > 10 × reconstructed rigidity
- Spillover limit for antiprotons expected to be ~200 GeV.

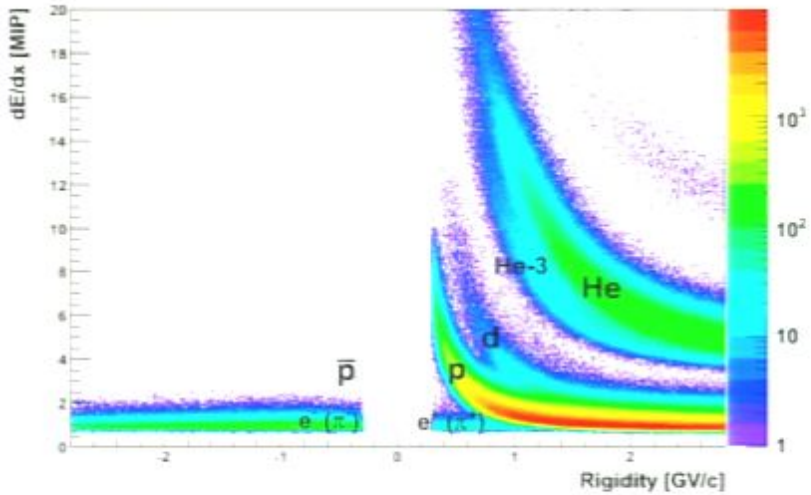


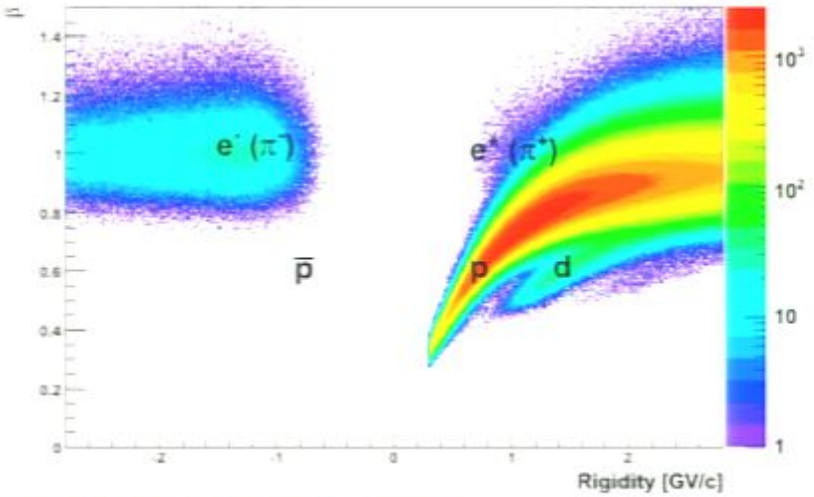
Antiproton to proton flux ratio

Astro-ph 0810.4994, to appear in PRL



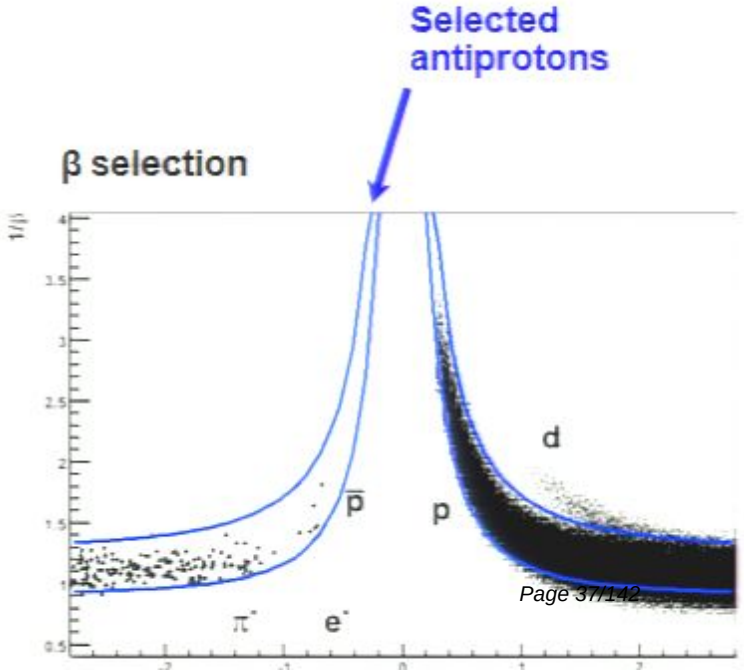
Low energy antiproton selection



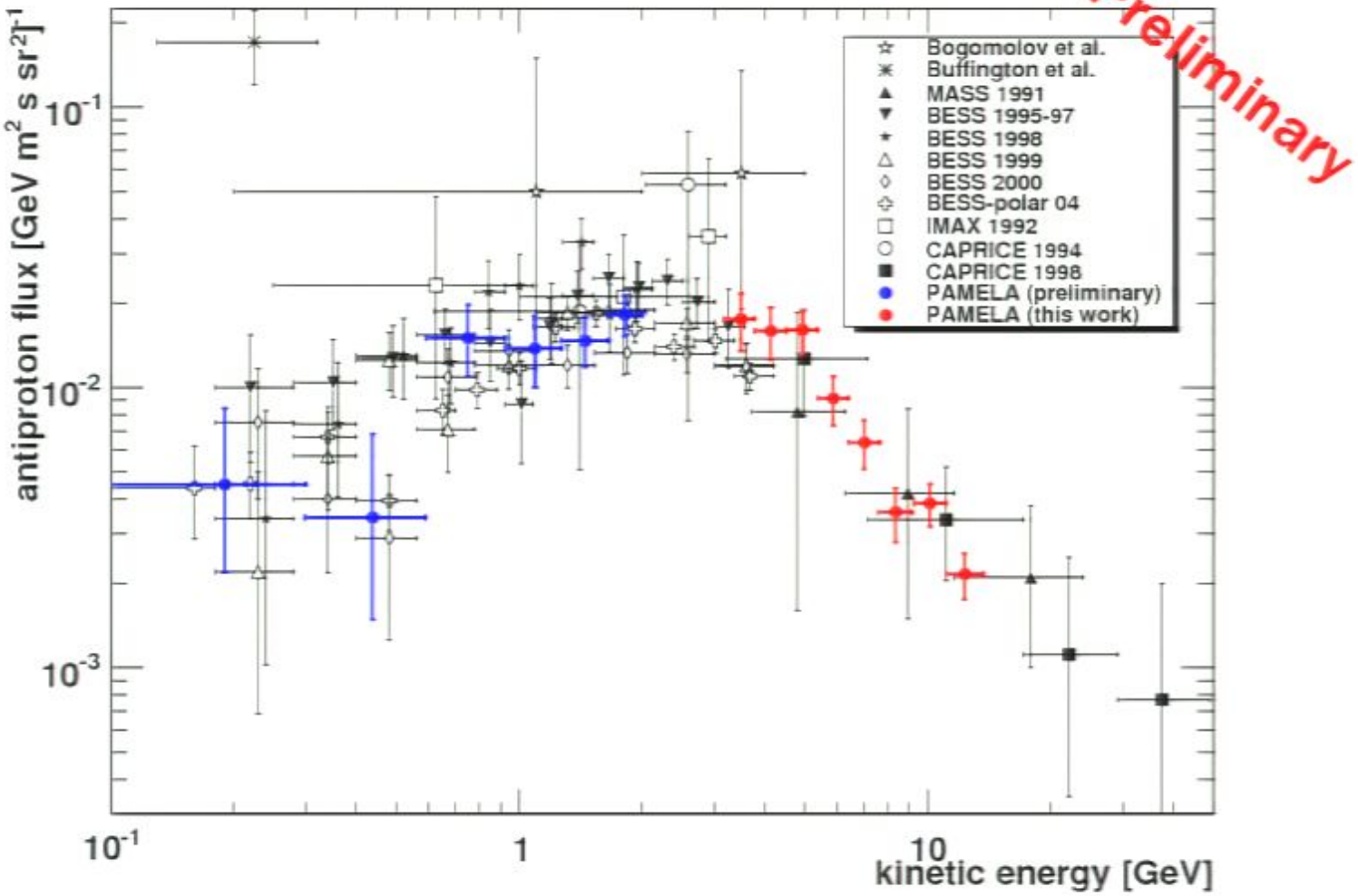


Selected with tracker dE/dx

Calorimeter interaction topology

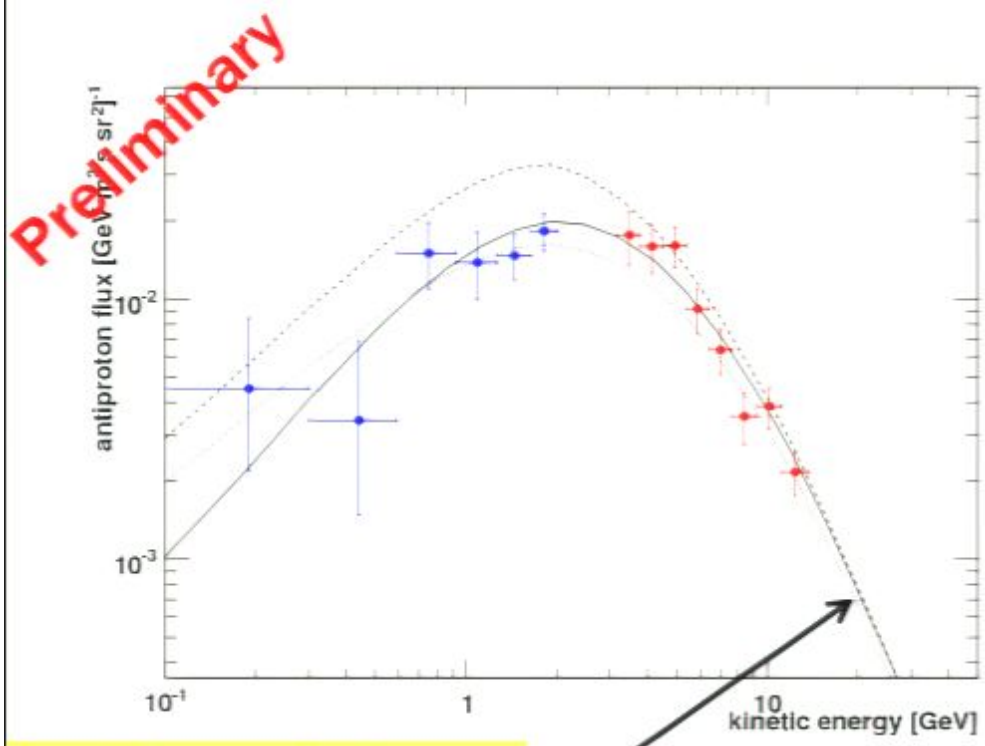


Antiproton Flux

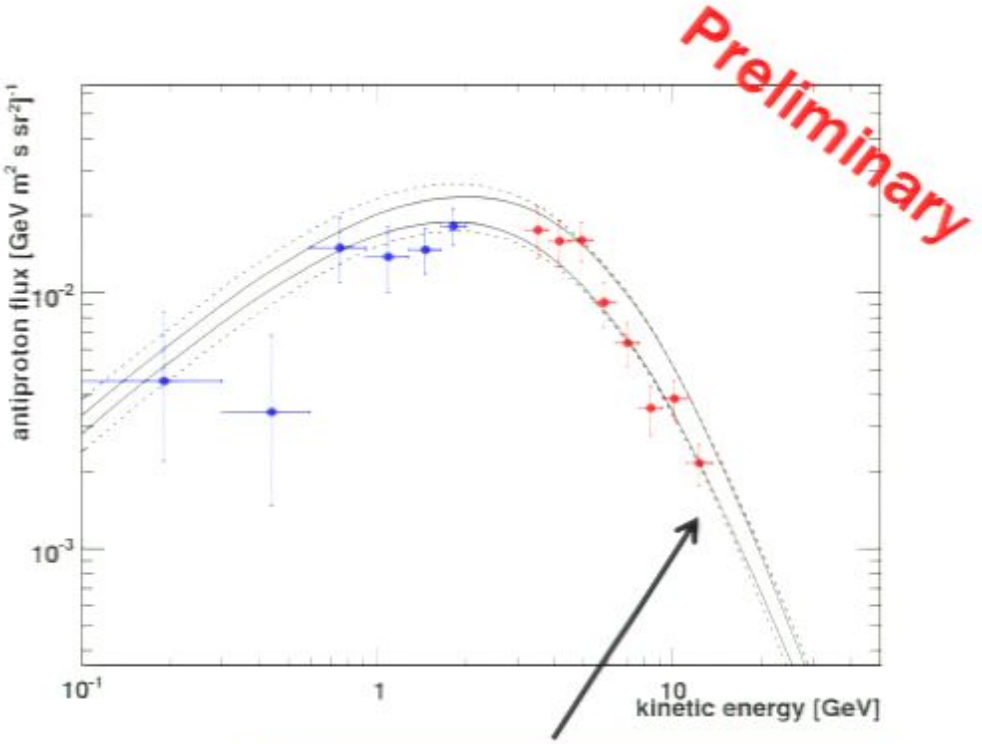


From Petter Hofverberg's and Alessandro Bruno's PhD Thesis

Antiproton Flux



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

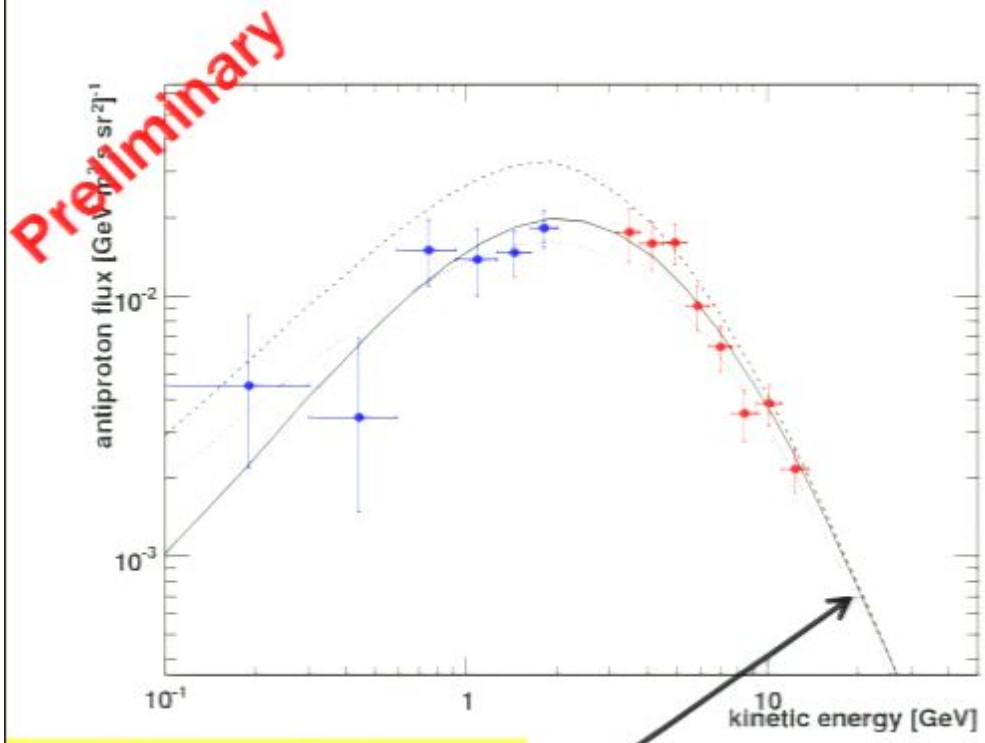


Secondary production:
F. Donato et al., 563 (2001) 172

From Petter Hofverberg's and Alessandro Bruno's PhD Thesis

Positrons

Antiproton Flux



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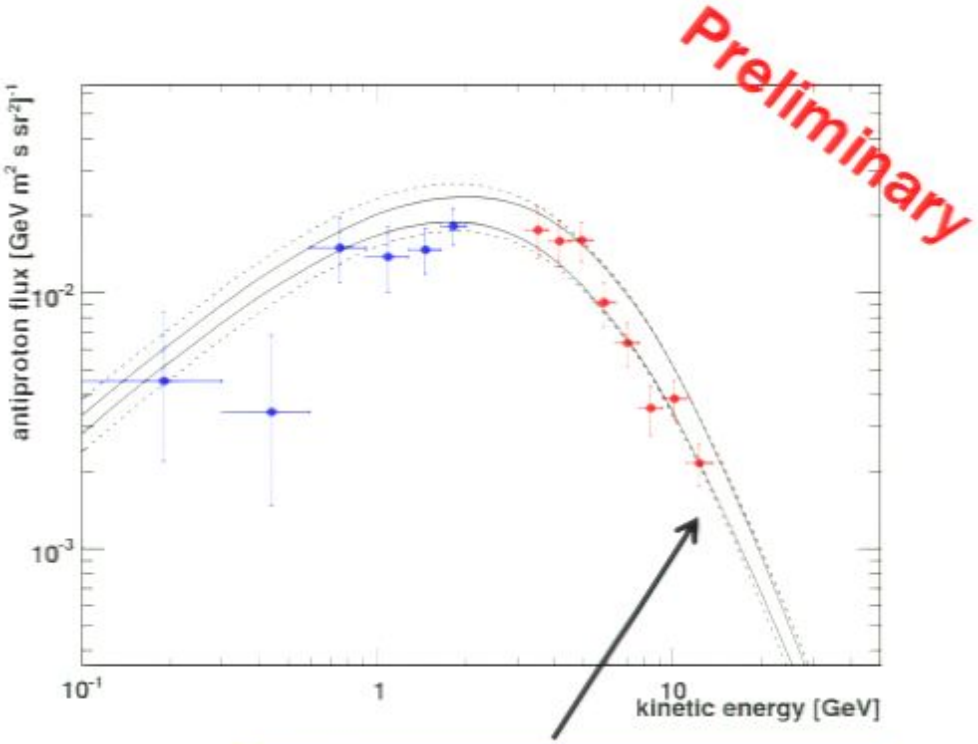
642 (2006) 902



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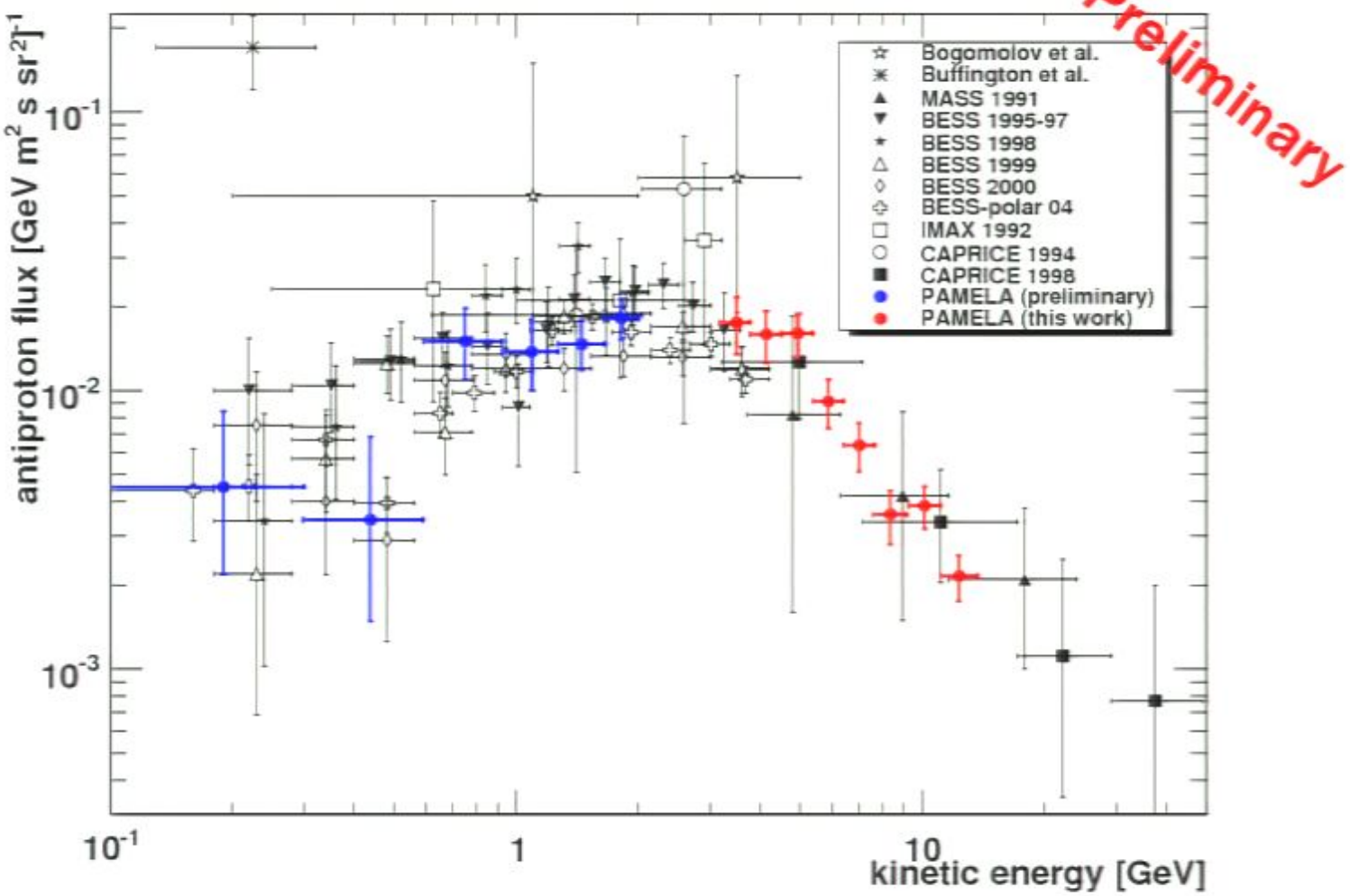
F. Donato et al., 563 (2001) 172

From Petter Hofverberg's and Alessandro Bruno's PhD Thesis

Antiproton Flux



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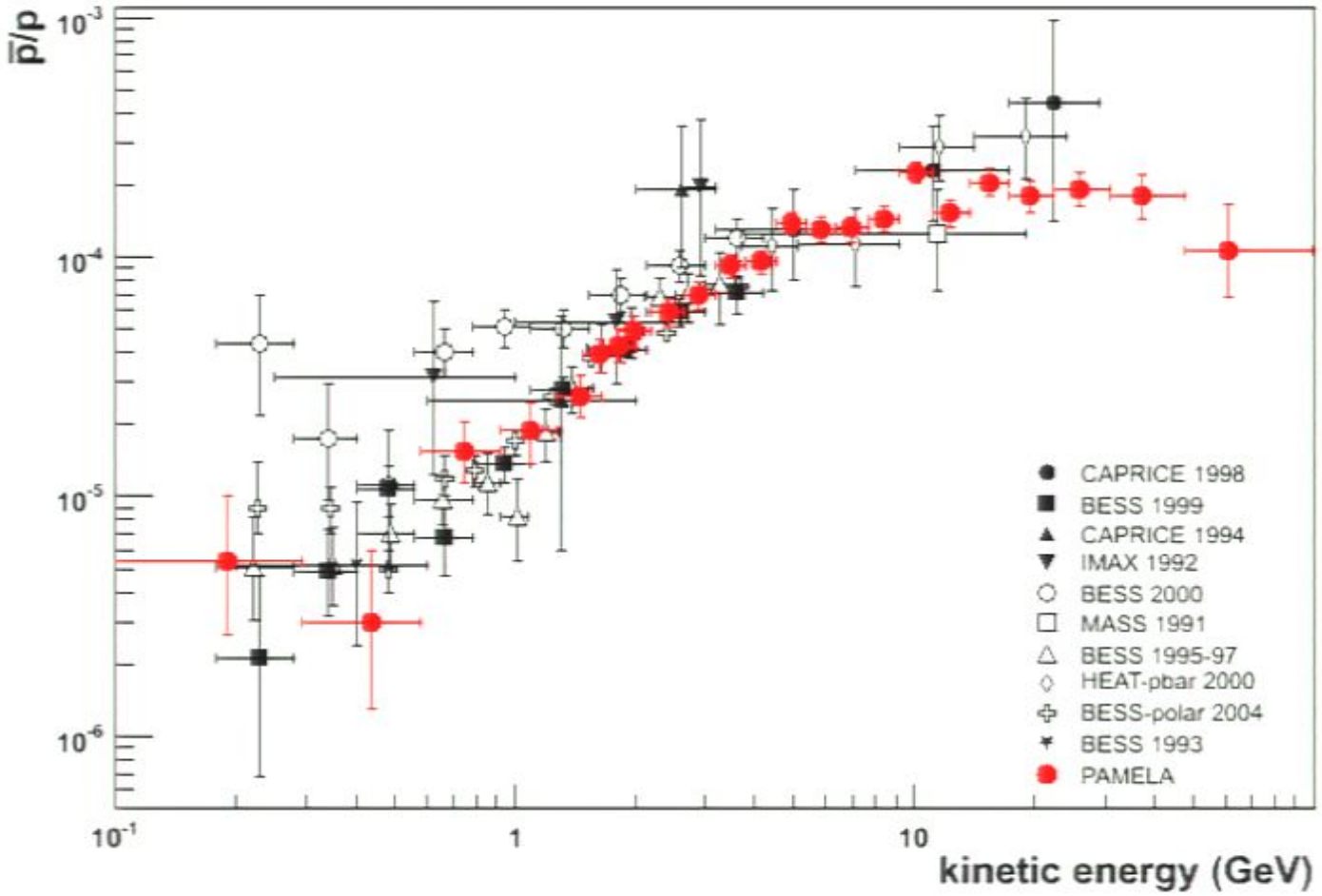
Astro-ph 0810.4994, to appear in PRL



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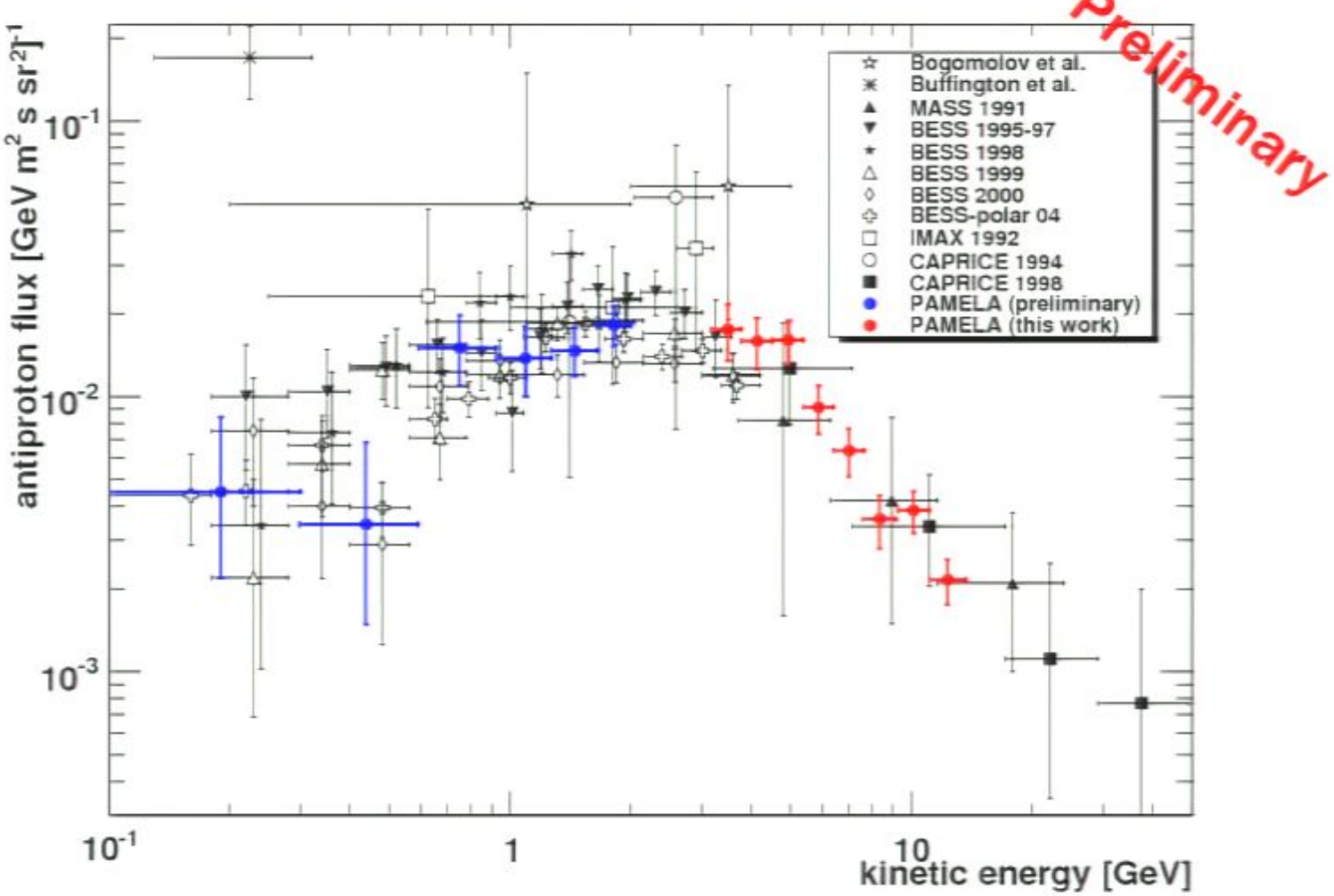

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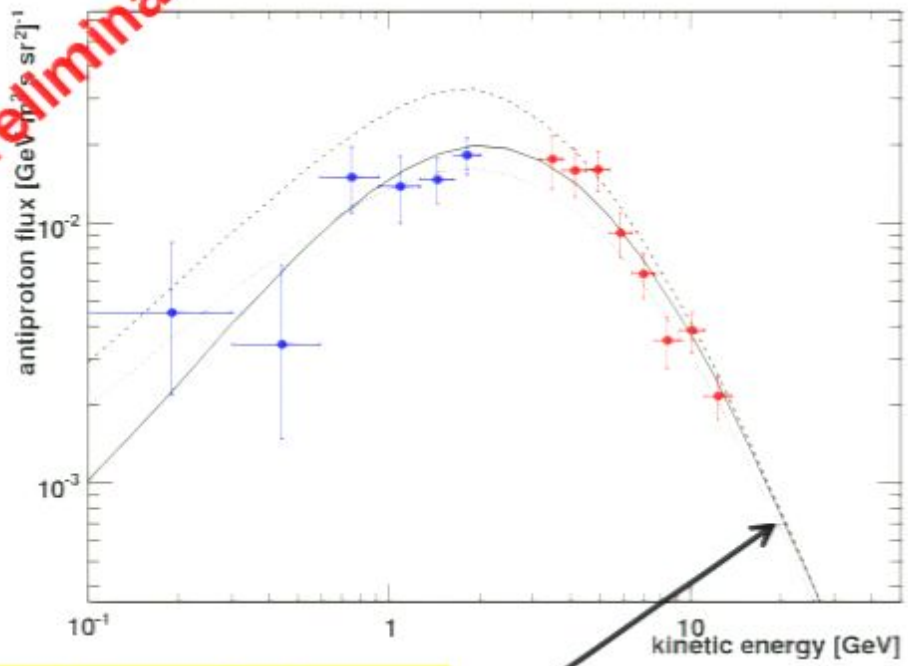
Antiproton Flux

Preliminary



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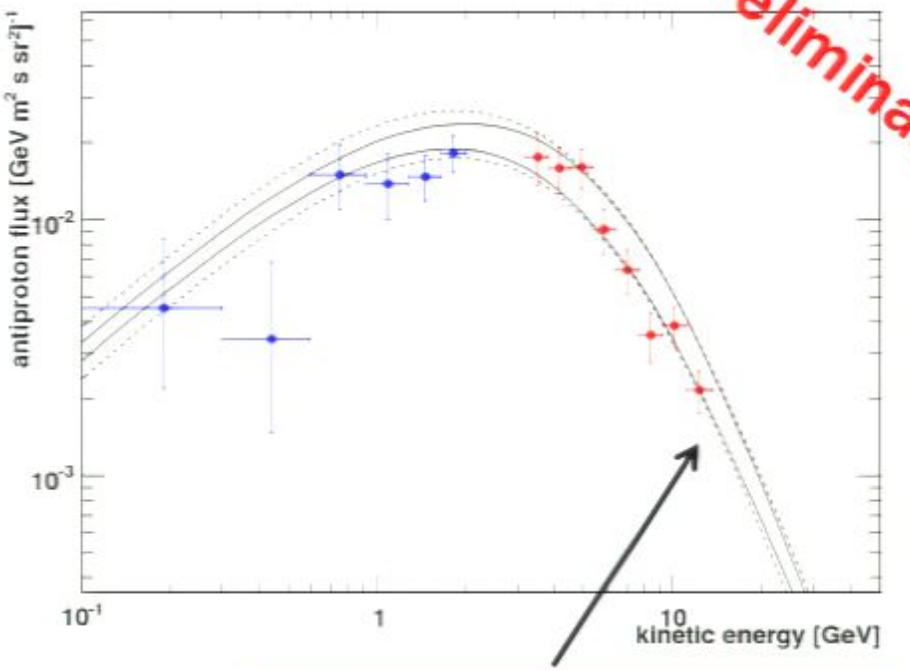
Preliminary



Secondary production:
F. Donato et al., 563 (2001) 172

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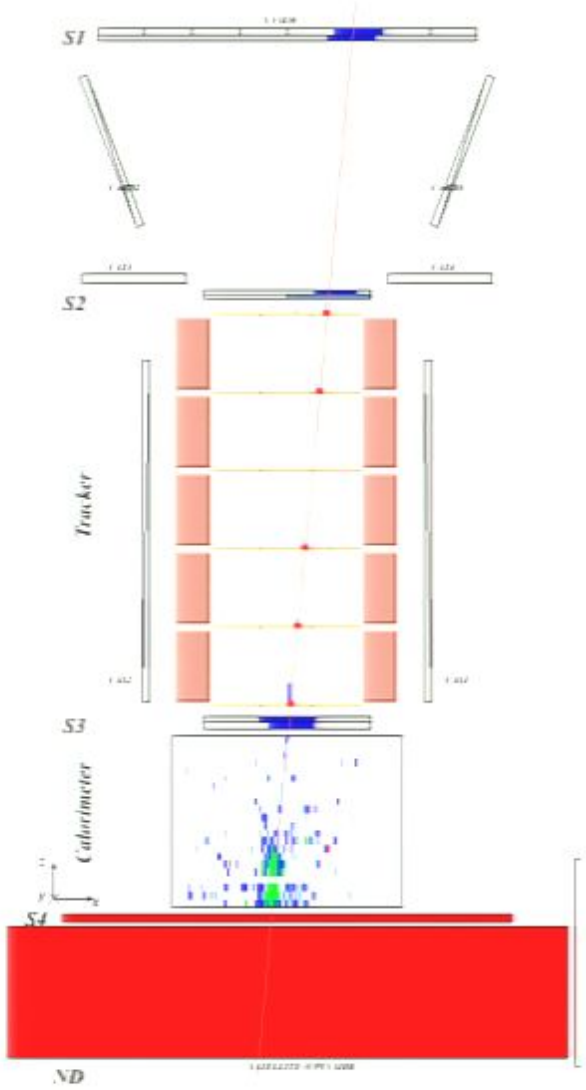
Proton / positron discrimination

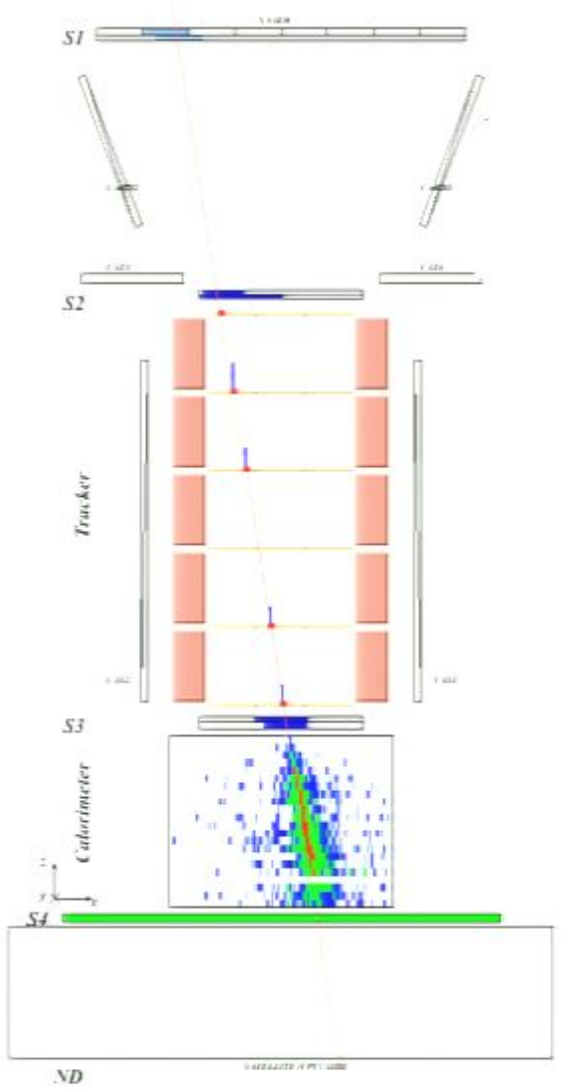


Time-of-flight: trigger, albedo rejection, mass determination (up to 1 GeV)

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

Analysis key points:

- test beam data
- simulation
- flight data dE/dx
- flight data neutron detector
- from flight data pure proton sample ("pre-sampler method"):
  - flight data background suppression with "standard" cuts
  - flight data background suppression with multi-variate data analysis (TMVA)
  - flight data background estimation

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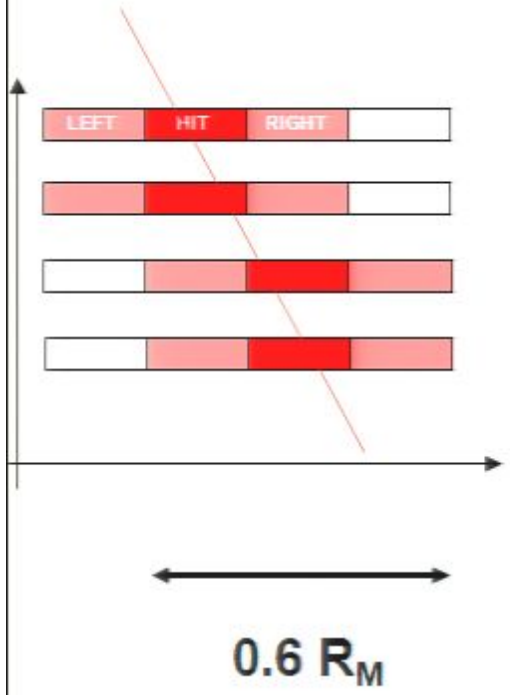
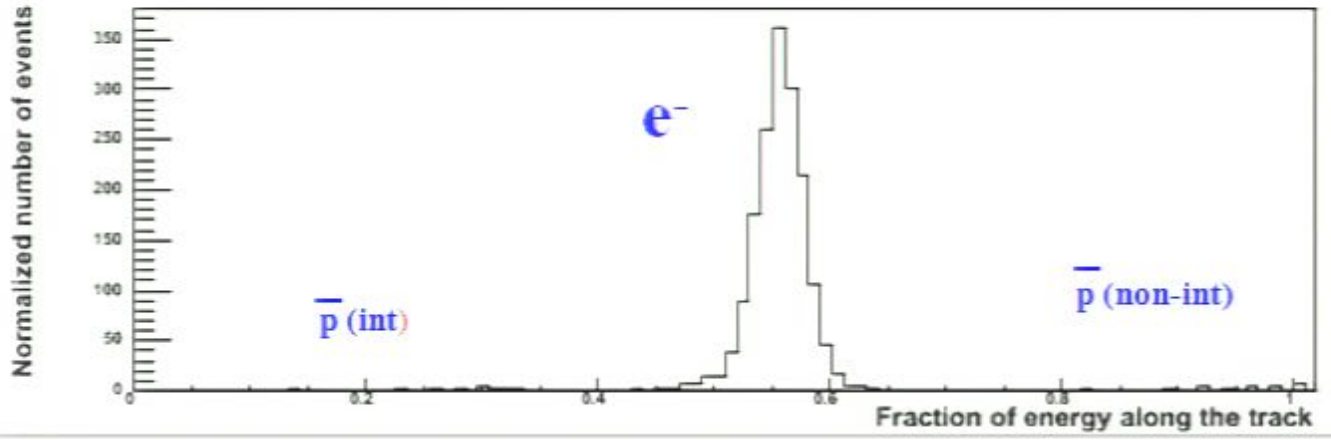
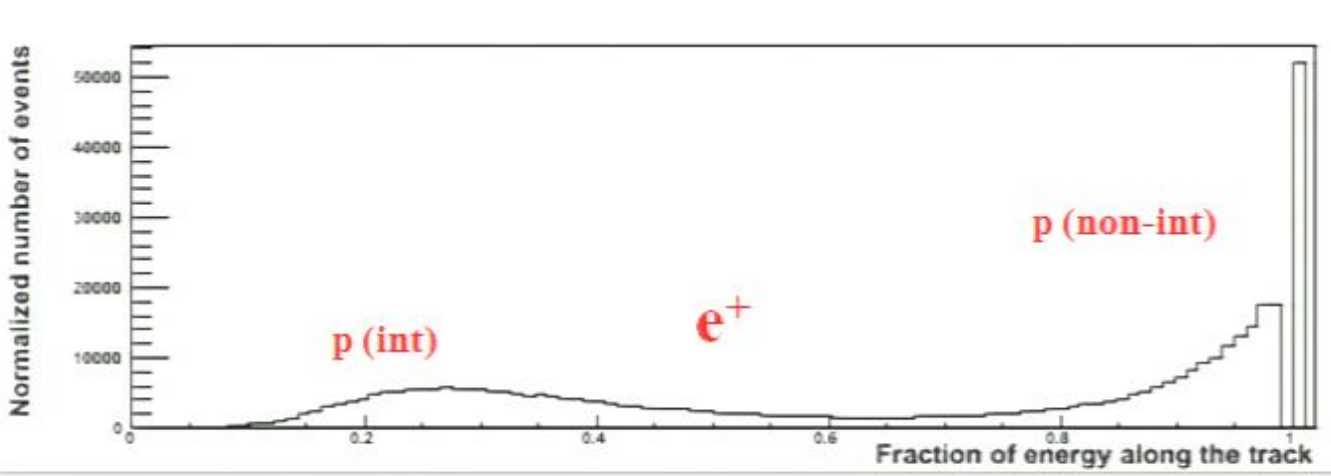
Final results make no use of test-beam and/or simulation calibrations.
The measurement is based only on flight data with the "background estimation" method

Positron selection with calorimeter

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







Rigidity: 20-30 GV

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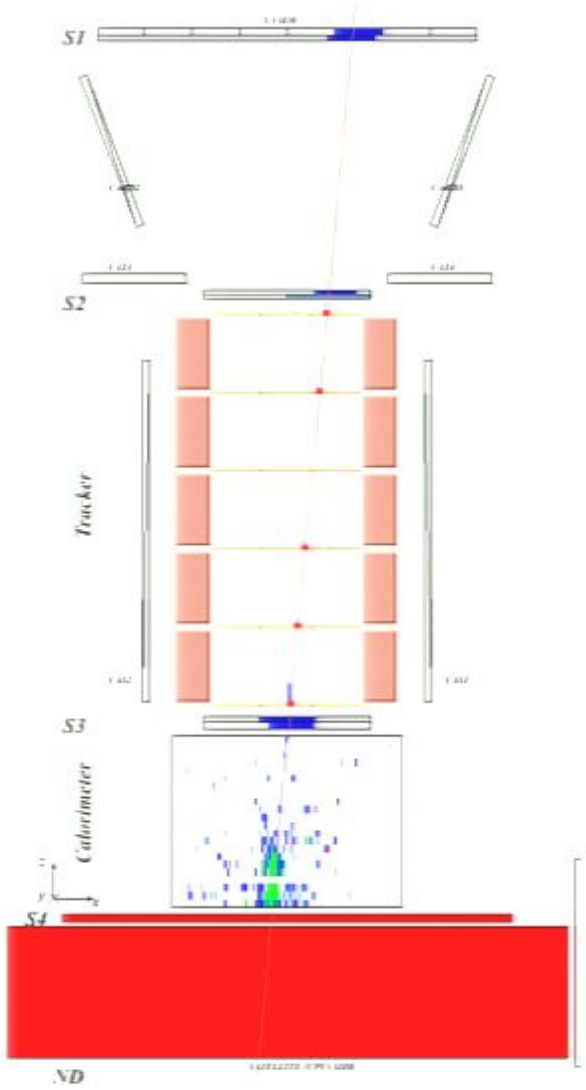

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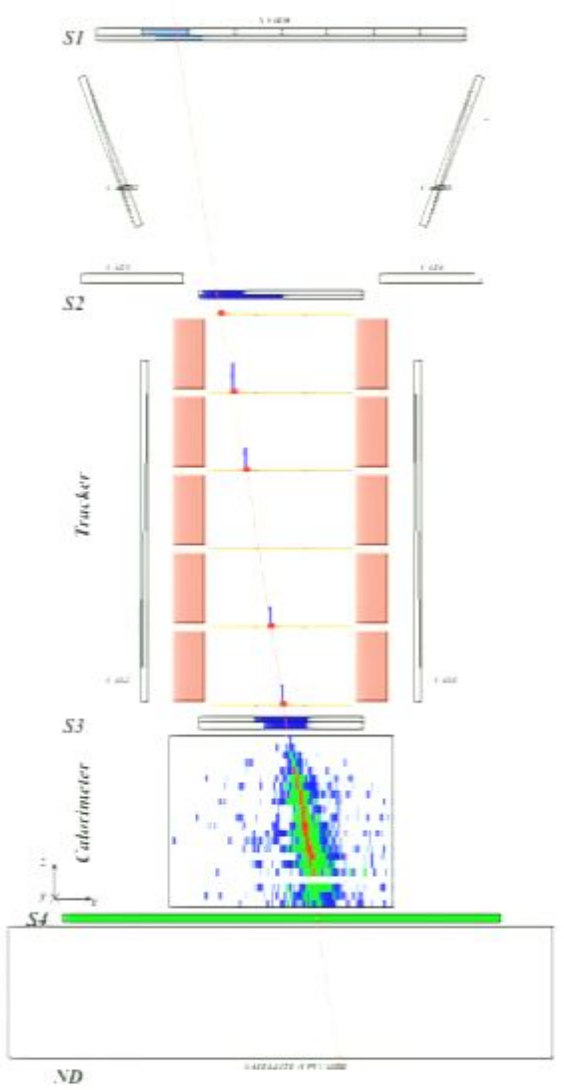
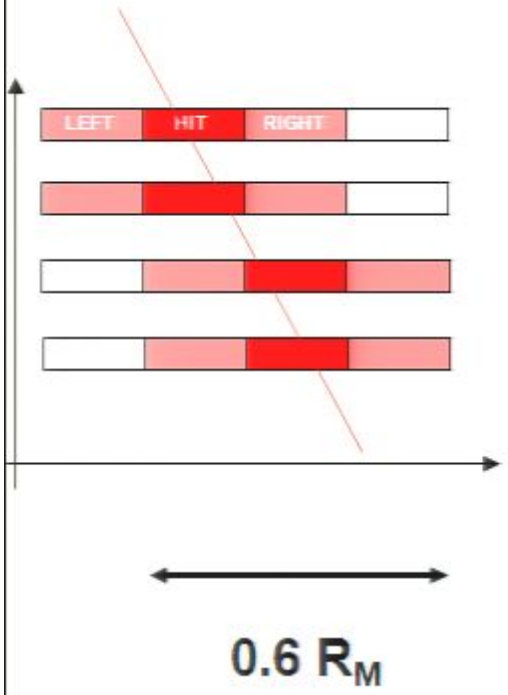


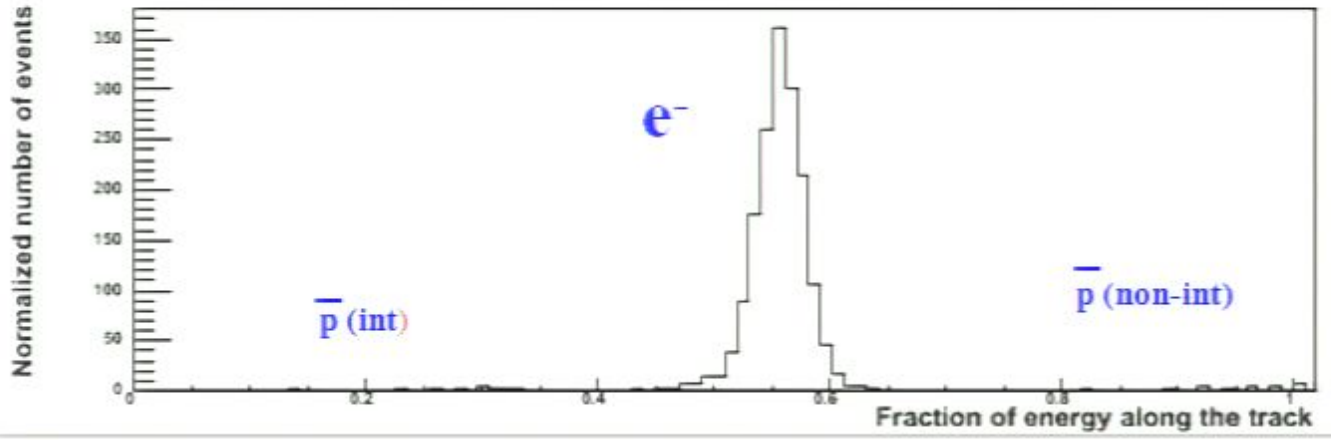
Proton

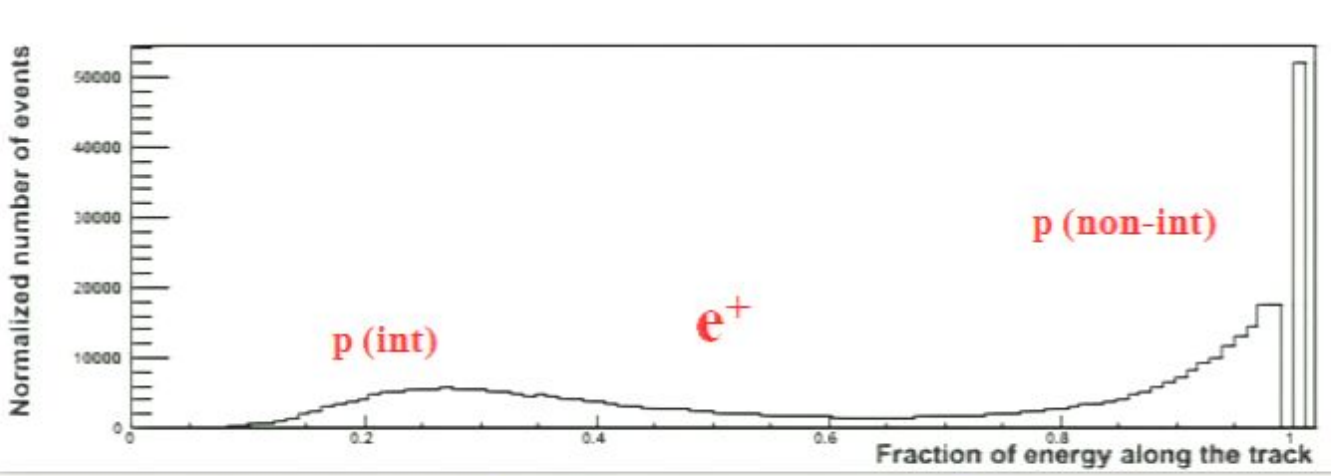
Positron

Positron selection with calorimeter

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

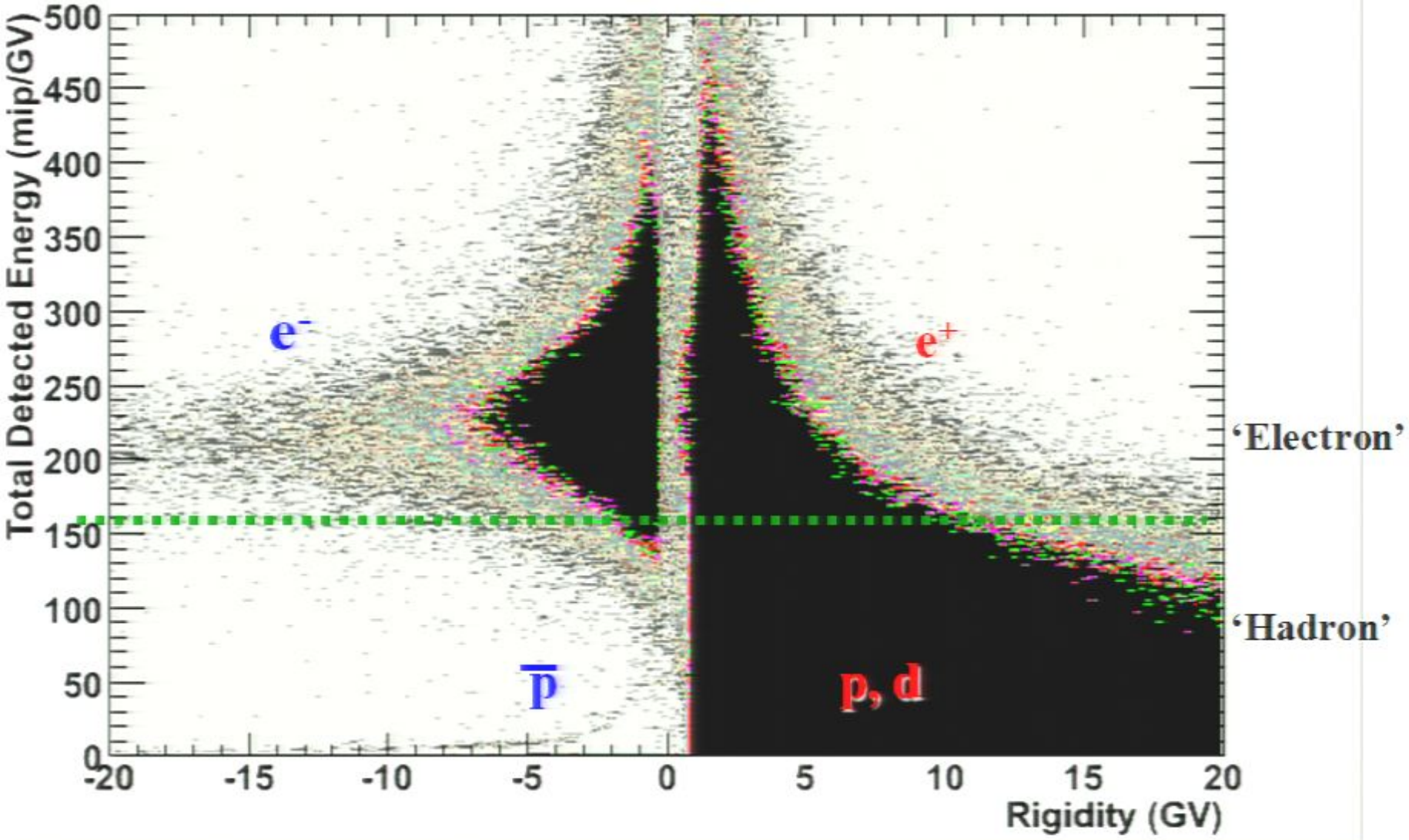






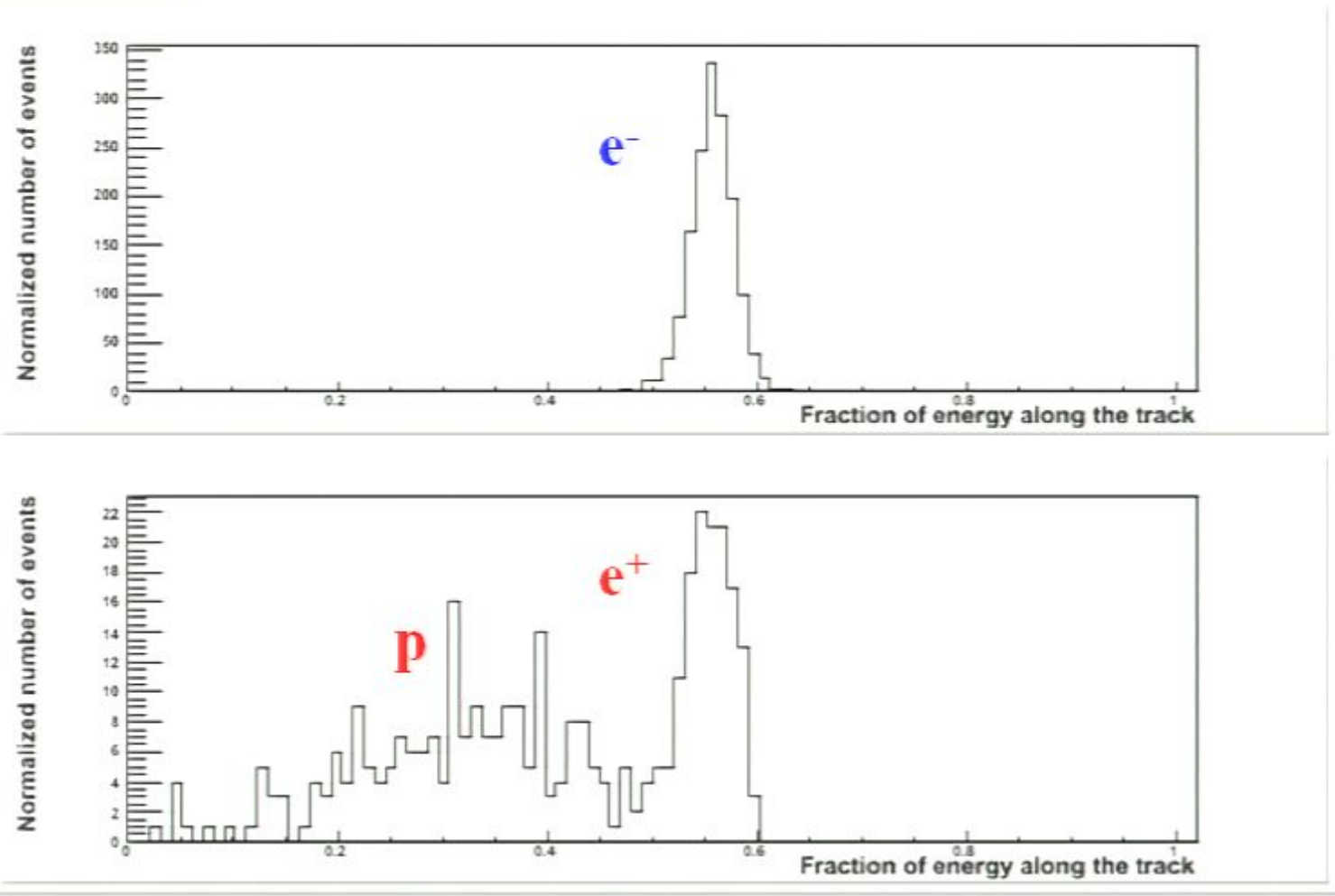
Rigidity: 20-30 GV

Antiparticle selection



Positron selection with calorimeter

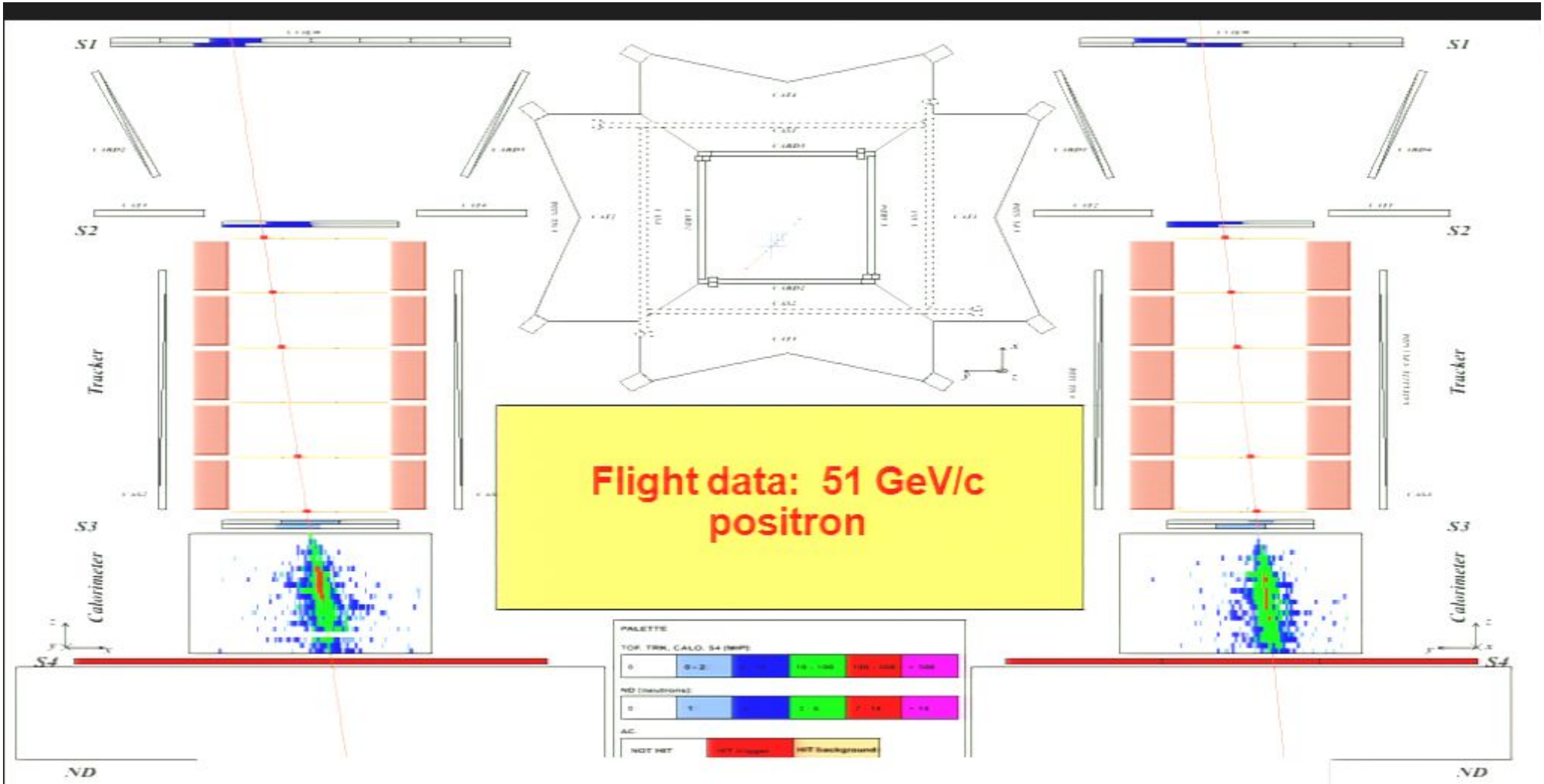
Rigidity: 20-30 GV

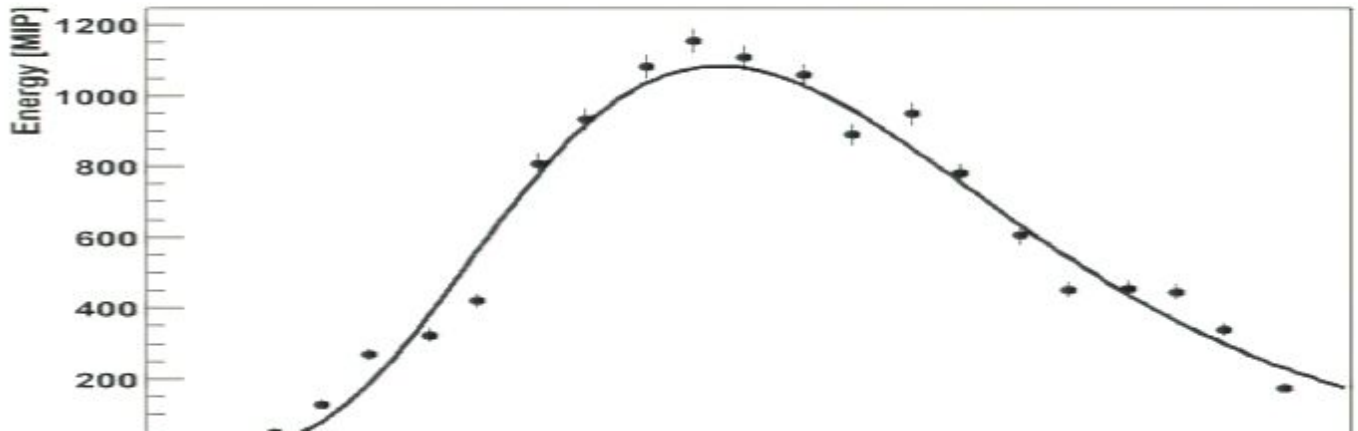


Fraction of charge released along the calorimeter track (left, hit, right)

+

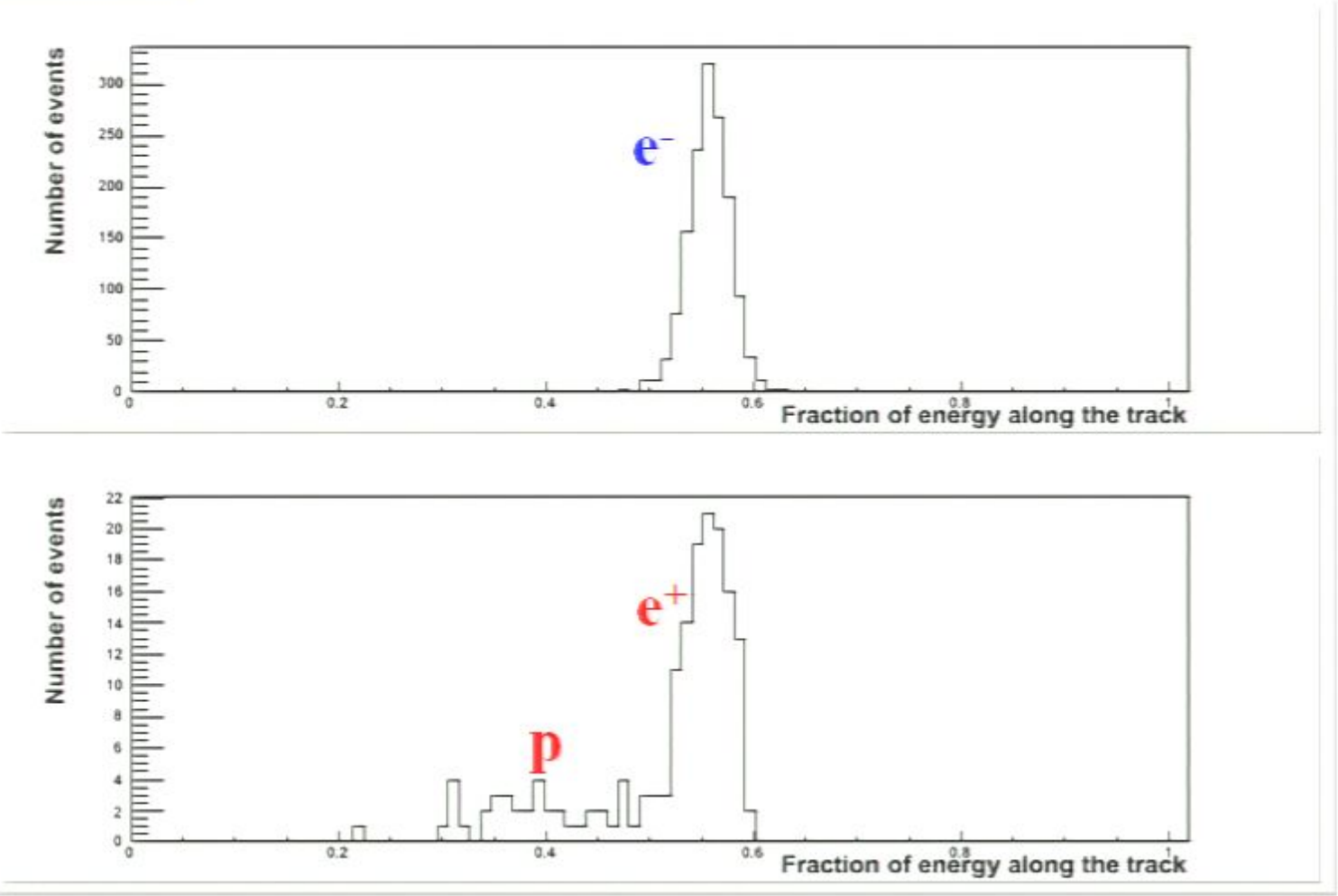
- Energy-momentum match
- Starting point of shower


S1
S2
S3
S4
Tracker
Calorimeter
ND
Flight data: 51 GeV/c positron
PALETTE
TOF, TRK, CALO, S4 (MIP)
ND (neutrons)
AC
NOT HIT
HIT background


Energy [MIP]
1200
1000
800
600
400
200

Positron selection with calorimeter

Rigidity: 20-30 GV



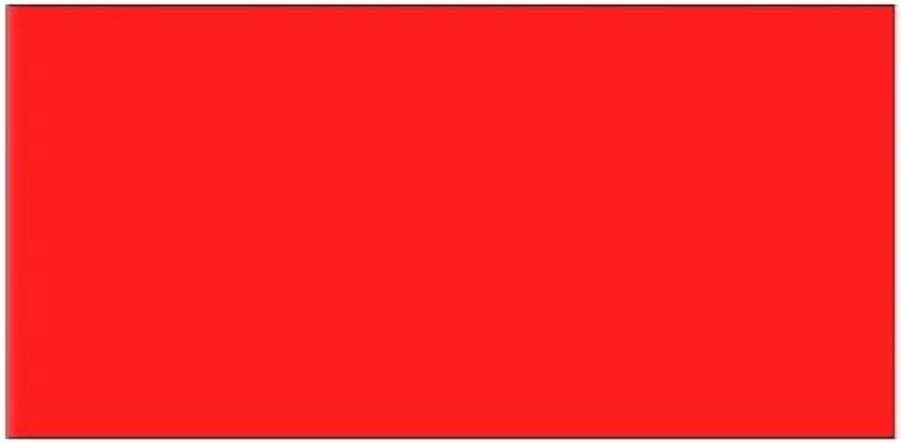
Fraction of charge released along the calorimeter track (left, hit, right)

+

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

The "pre-sampler" method

CALORIMETER: 22 W planes: 16.3 X_0



The "pre-sampler" method

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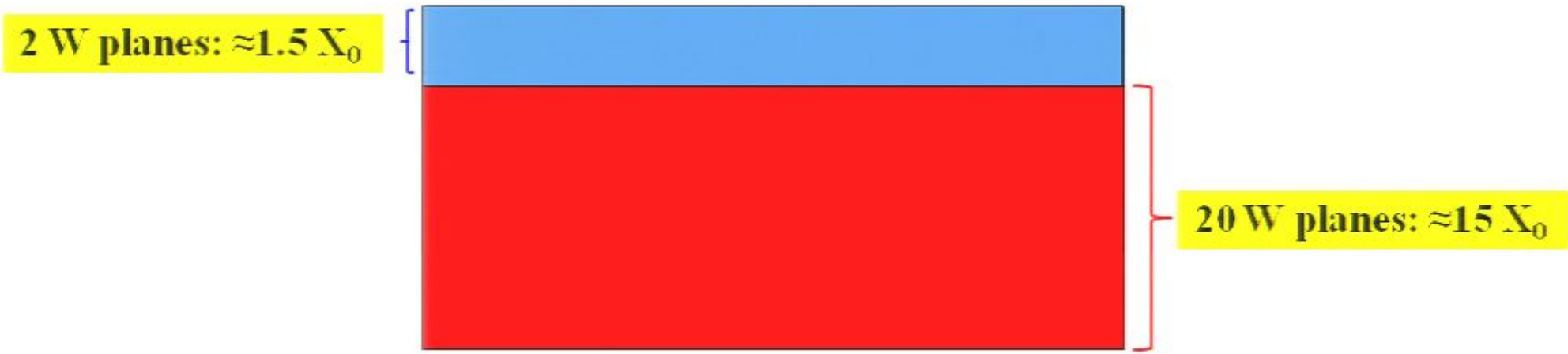

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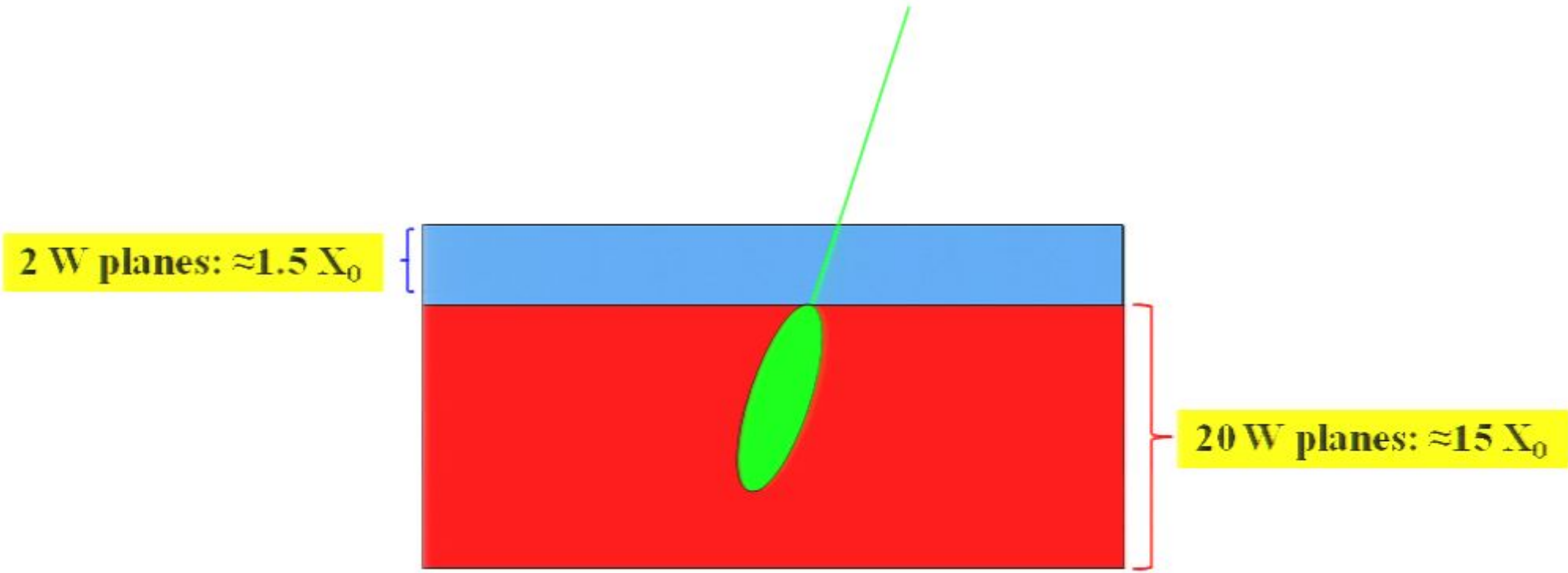
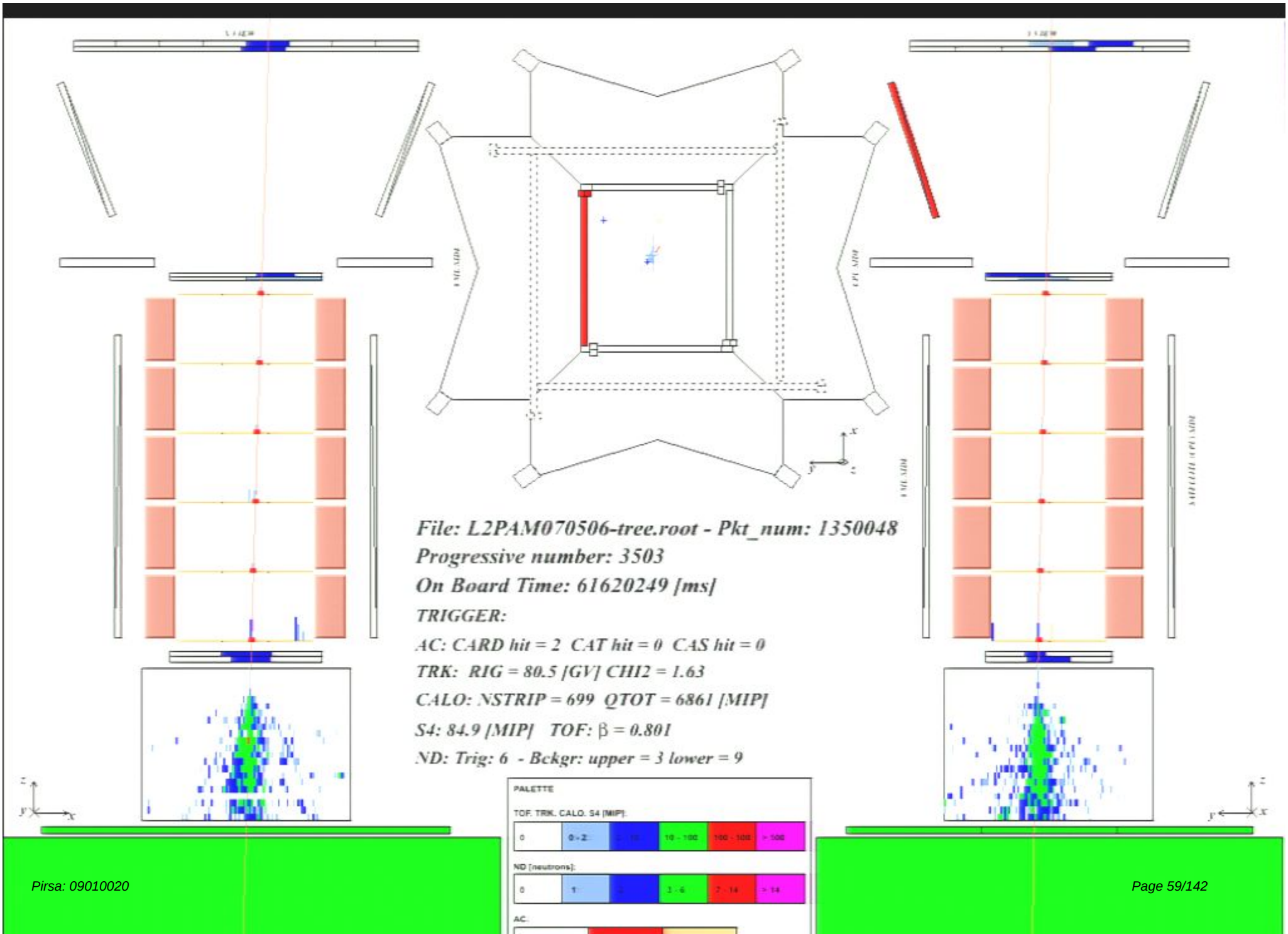
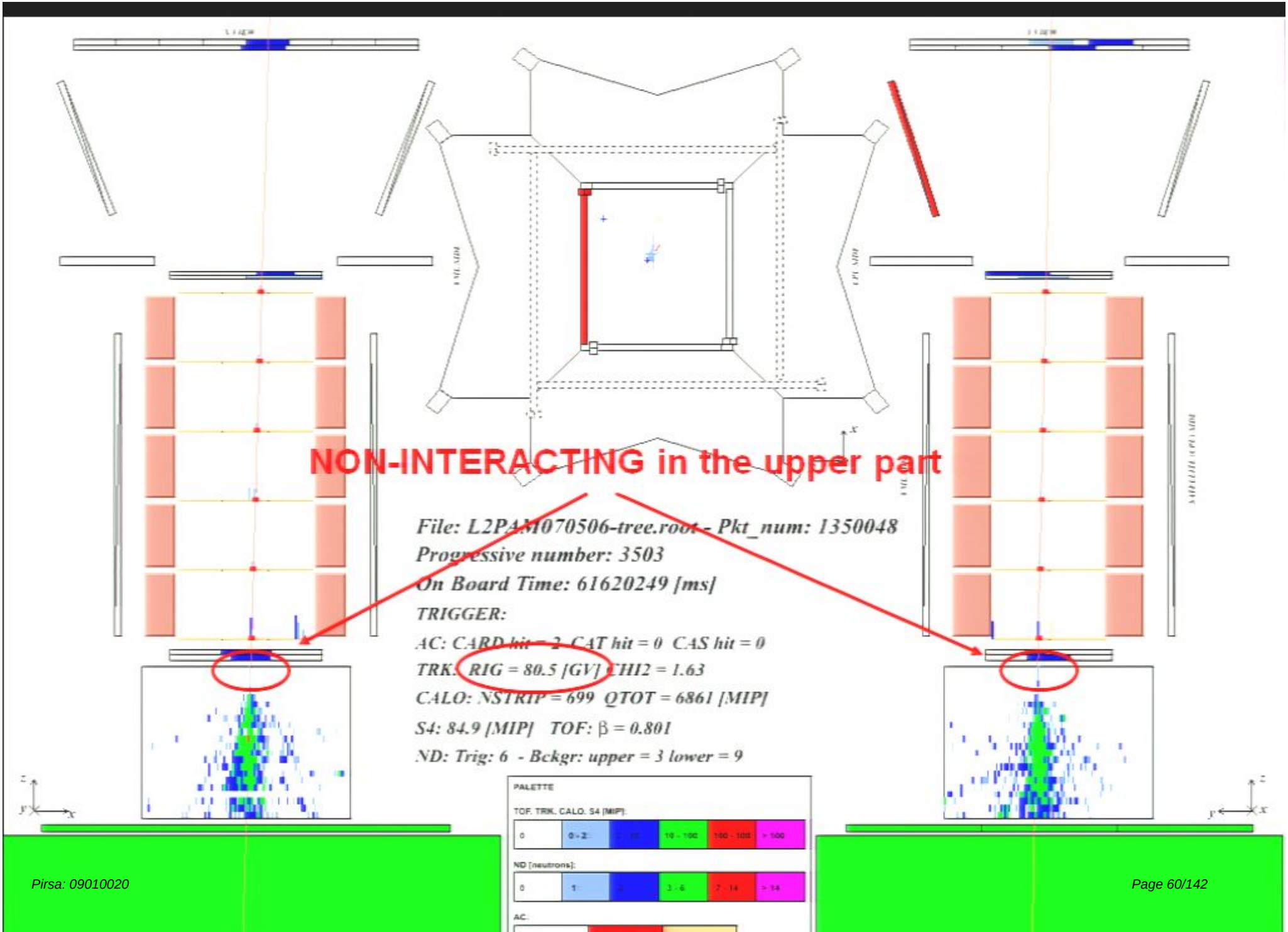



File: L2PAM070506-tree.root - Pkt_num: 1350048
Progressive number: 3503
On Board Time: 61620249 [ms]
TRIGGER:
AC: CARD hit = 2 CAT hit = 0 CAS hit = 0
TRK: RIG = 80.5 [GV] CHI2 = 1.63
CALO: NSTRIP = 699 QTOT = 6861 [MIP]
S4: 84.9 [MIP] TOF: β = 0.801
ND: Trig: 6 - Bckgr: upper = 3 lower = 9
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 ÷ 2
10 ÷ 100
100 ÷ 500
> 500
ND [neutrons]:
0
1
3 ÷ 6
7 ÷ 14
> 14
AC:


NON-INTERACTING in the upper part
File: L2PAM070506-tree.root - Pkt_num: 1350048
Progressive number: 3503
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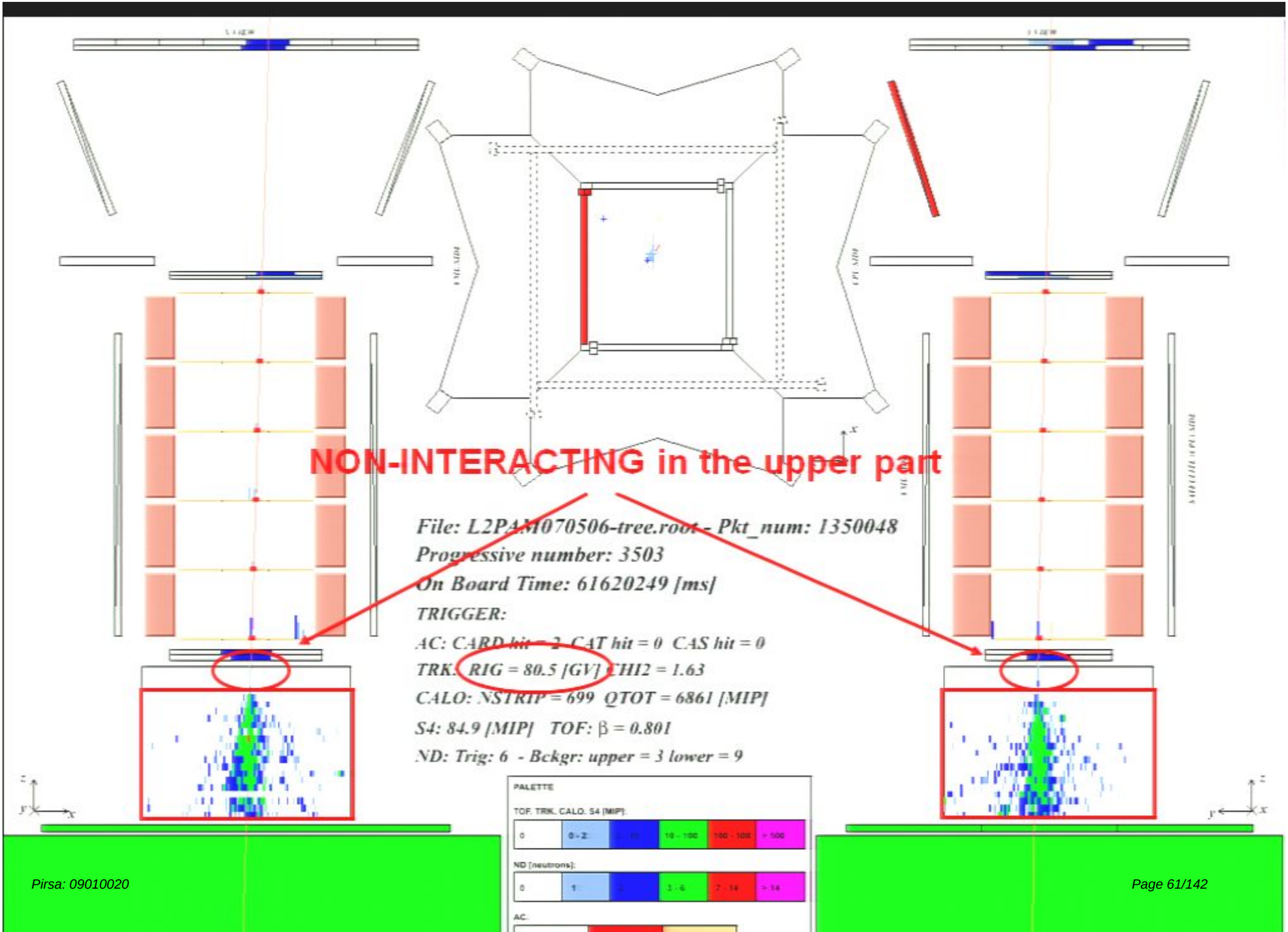
PALETTE
TOF, TRK, CALO, S4 [MIP]:
ND [neutrons]:
AC:


NON-INTERACTING in the upper part
File: L2PAM070506-tree.root - Pkt_num: 1350048
Progressive number: 3503
On Board Time: 61620249 [ms]
TRIGGER:
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TRK: RIG = 80.5 [GV] CHI2 = 1.63
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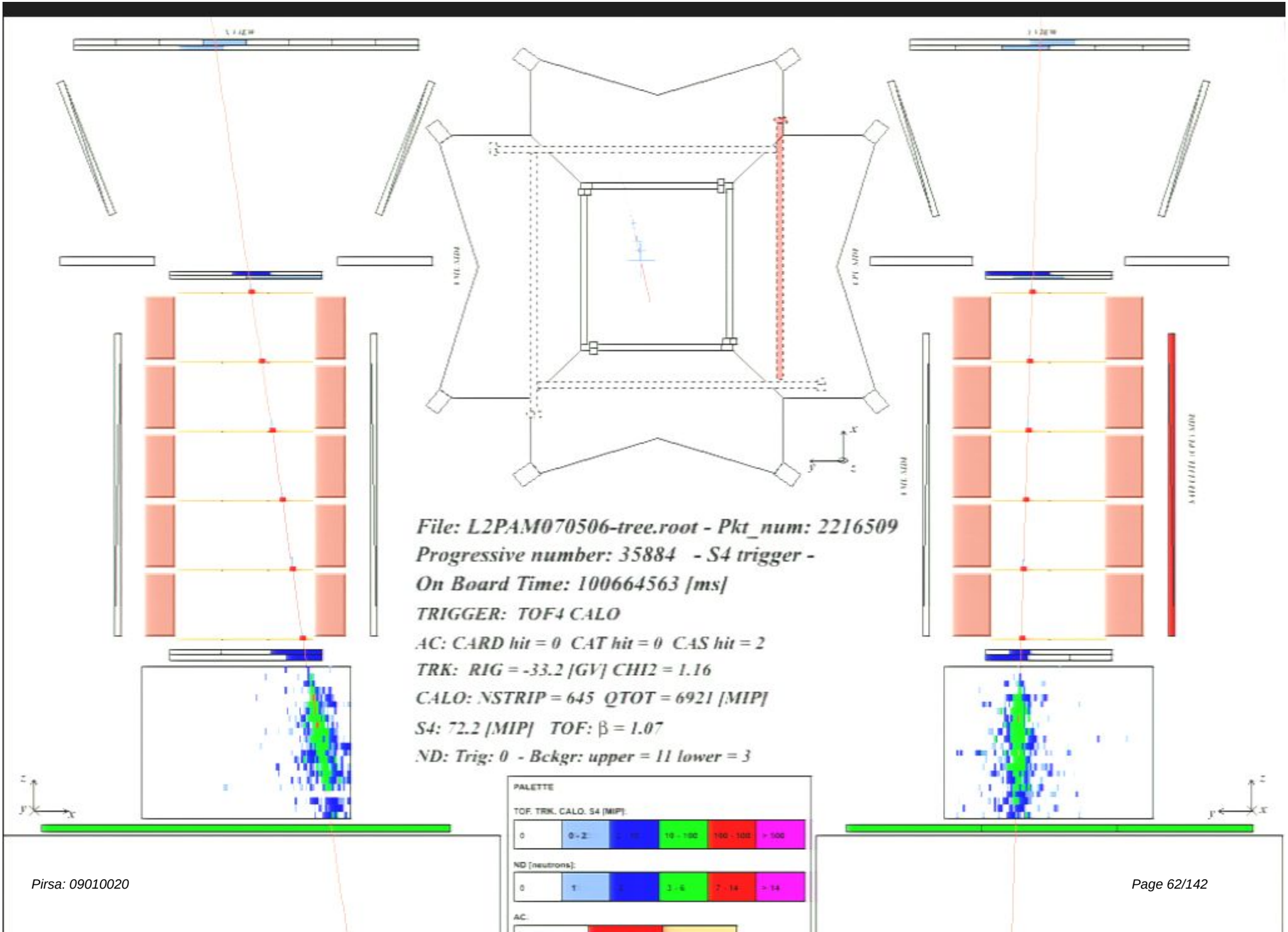
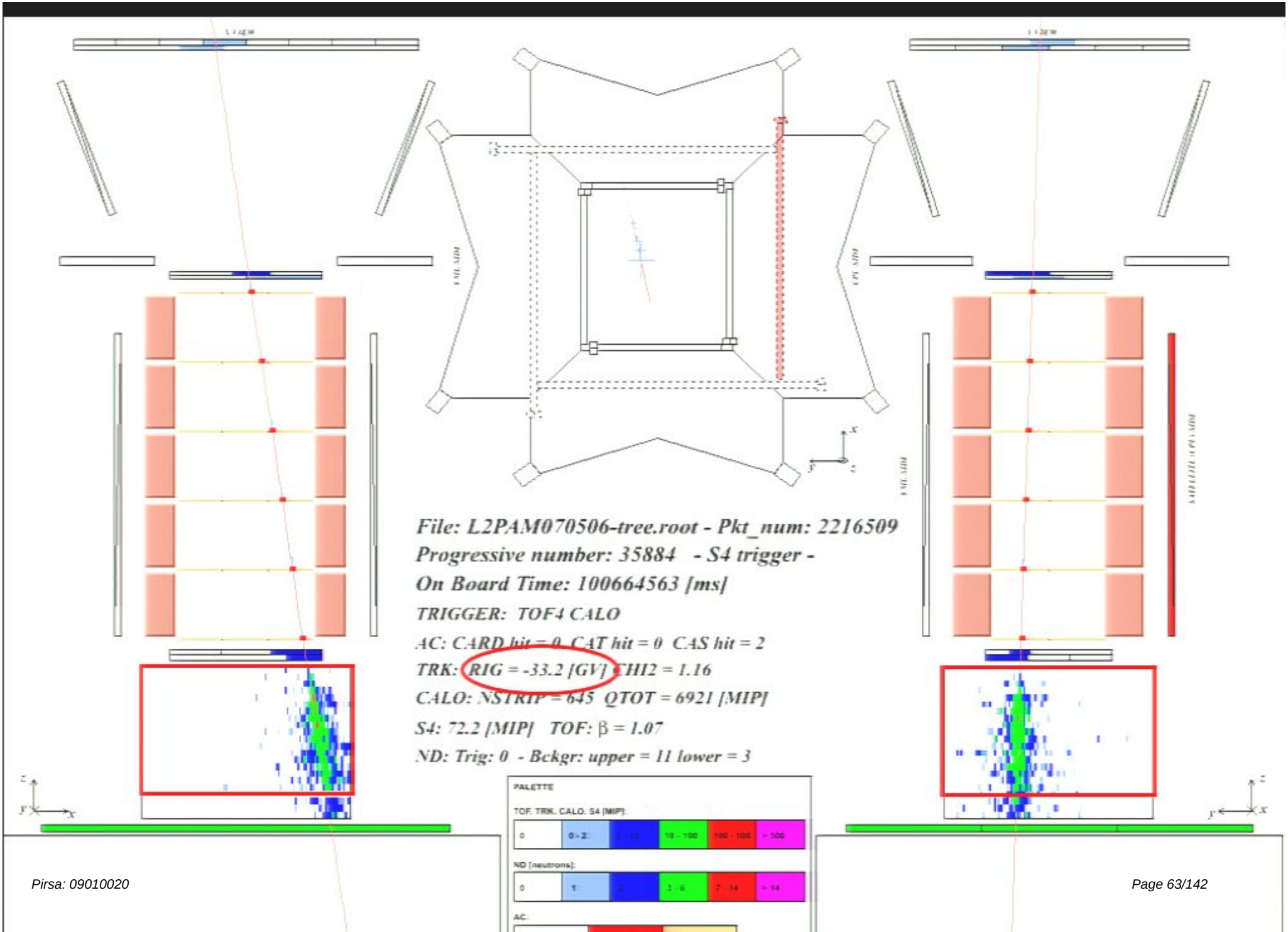
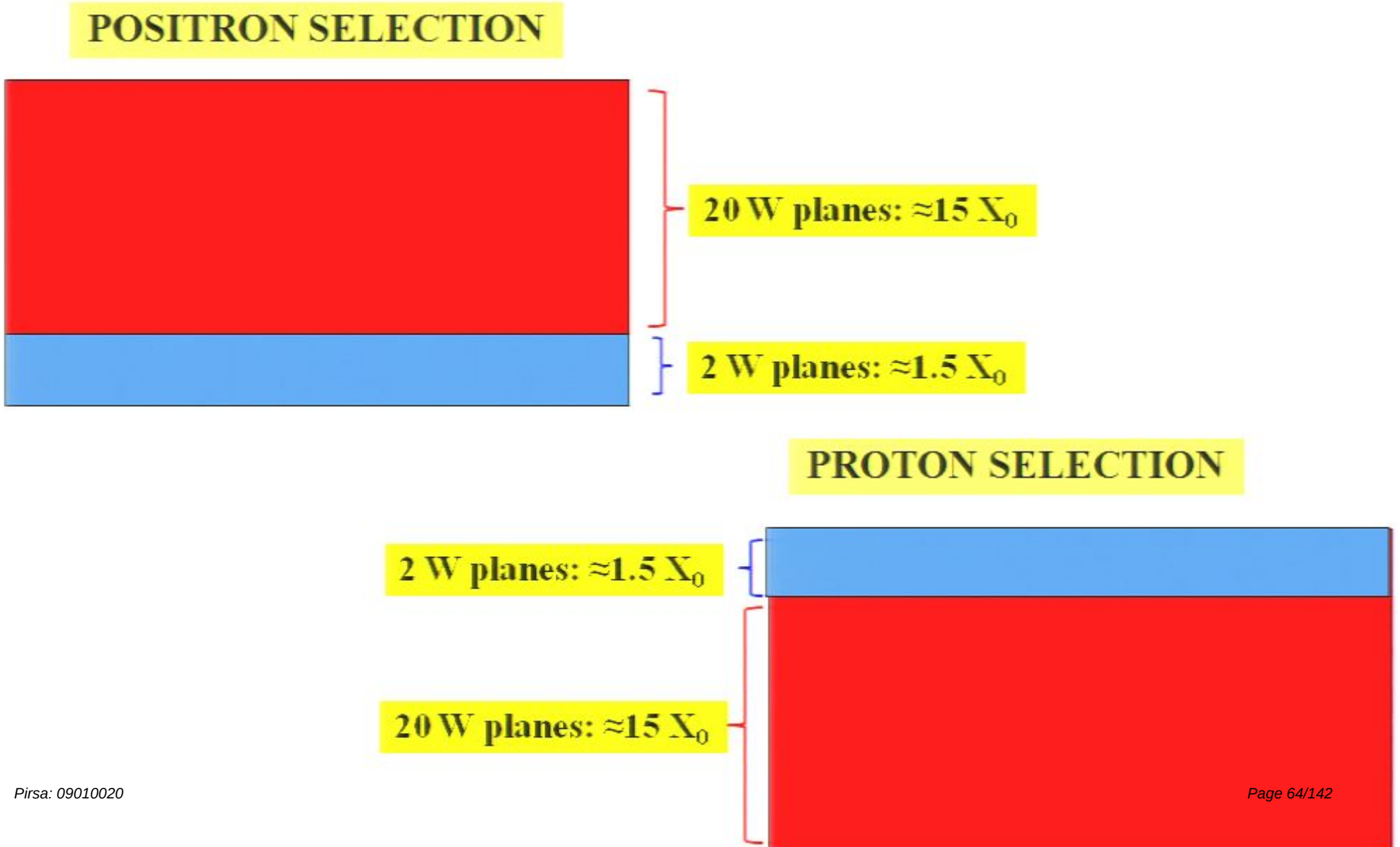
ND: Trig: 6 - Bckgr: upper = 3 lower = 9
PALETTE
TOF, TRK, CALO, S4 [MIP]:
ND [neutrons]:
AC:


File: L2PAM070506-tree.root - Pkt_num: 2216509
Progressive number: 35884 - S4 trigger -
On Board Time: 100664563 [ms]
TRIGGER: TOF4 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 2
TRK: RIG = -33.2 [GV] CHI2 = 1.16
CALO: NSTRIP = 645 QTOT = 6921 [MIP]
S4: 72.2 [MIP] TOF: β = 1.07
ND: Trig: 0 - Bckgr: upper = 11 lower = 3
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
10 - 100
100 - 300
> 300
ND [neutrons]:
0
1
3 - 6
7 - 14
> 14
AC:


File: L2PAM070506-tree.root - Pkt_num: 2216509
Progressive number: 35884 - S4 trigger -
On Board Time: 100664563 [ms]
TRIGGER: TOF4 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 2
TRK: RIG = -33.2 [GV] CHI2 = 1.16
CALO: NSTRIP = 645 QTOT = 6921 [MIP]
S4: 72.2 [MIP] TOF: β = 1.07
ND: Trig: 0 - Bckgr: upper = 11 lower = 3
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
10 - 100
100 - 300
> 300
ND [neutrons]:
0
1
3 - 6
7 - 14
> 14
AC:

The "pre-sampler" method

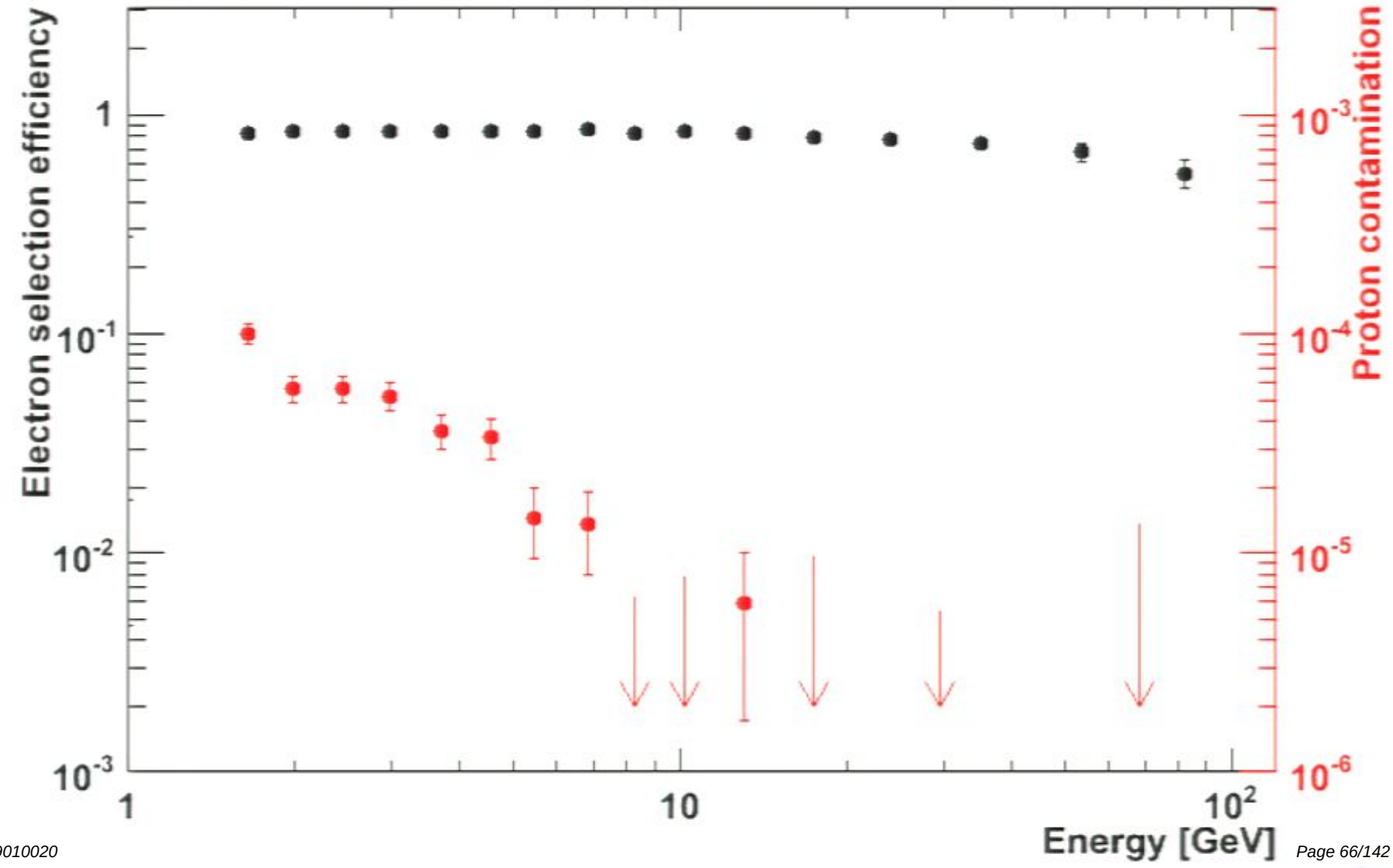


Positron selection with calorimeter

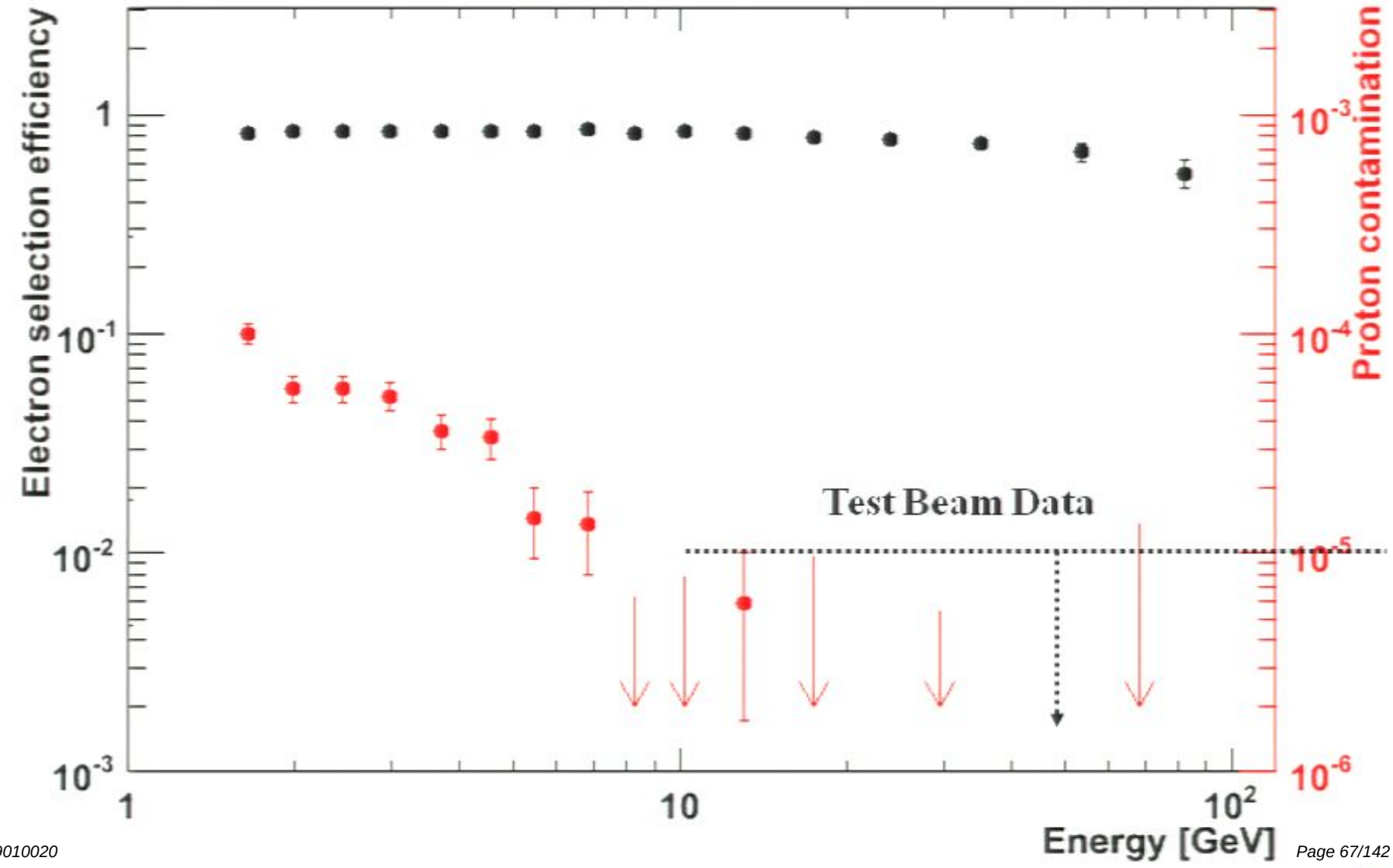
TMVA: Toolkit for MultiVariate data Analysis
http://tmva.sourceforge.net/

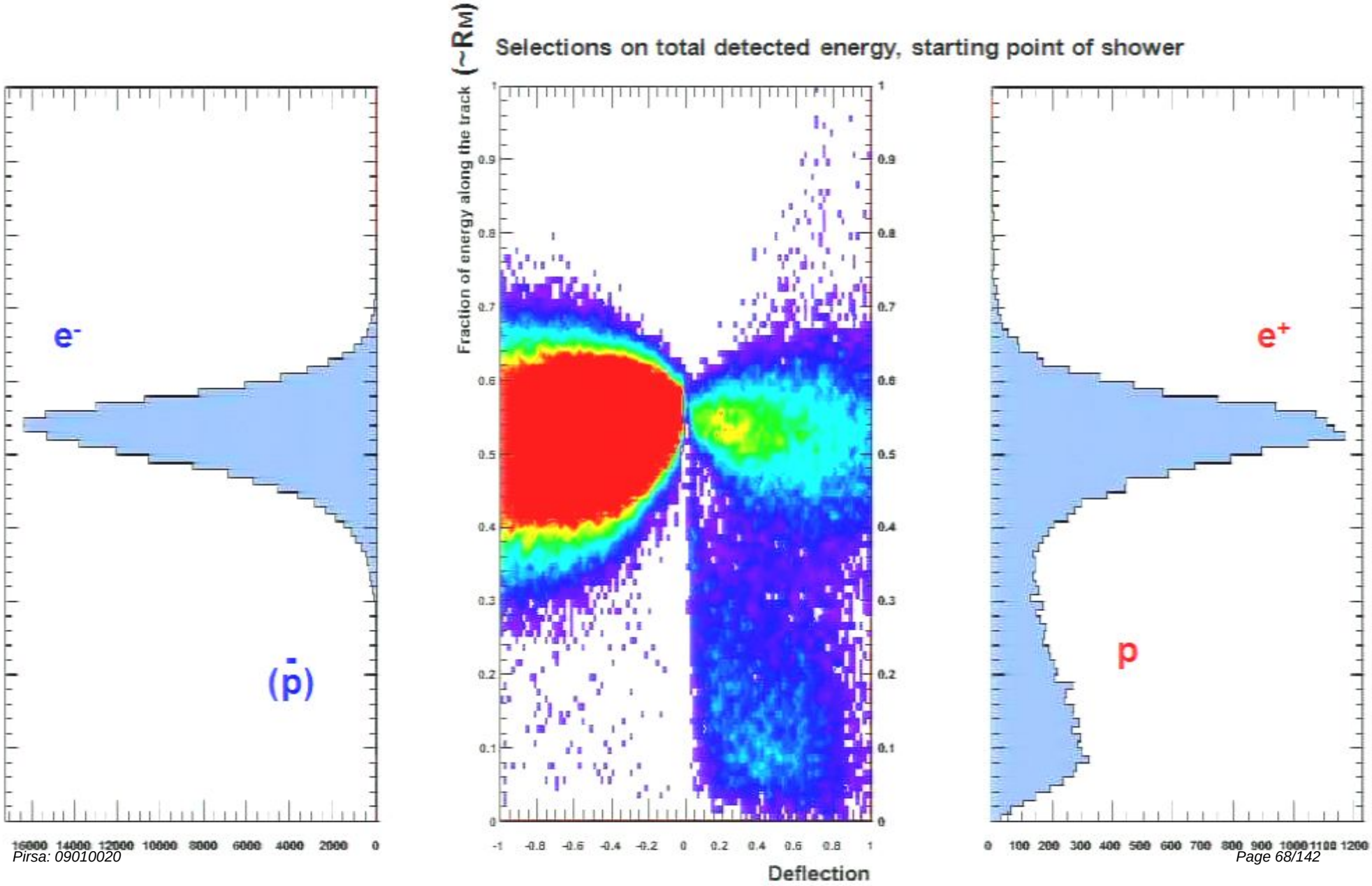
TMVA host large variety of multivariate classification algorithms (cut optimization with genetic algorithm, linear and non-linear discriminant and neural networks, support vector machine, boosted decisional trees, ...)

Positron selection with calorimeter



Positron selection with calorimeter

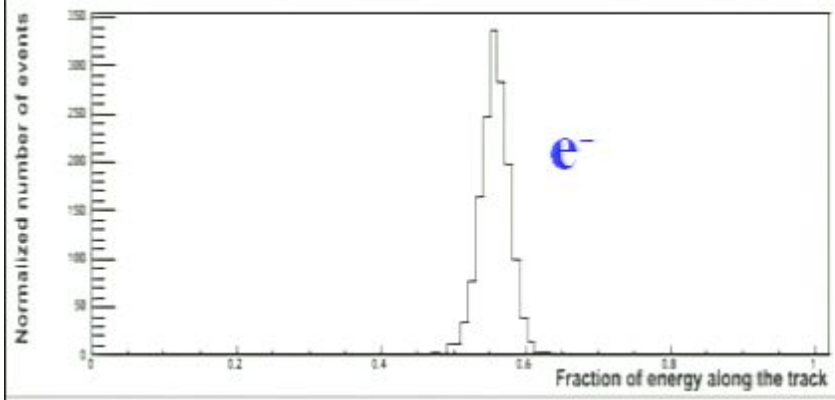


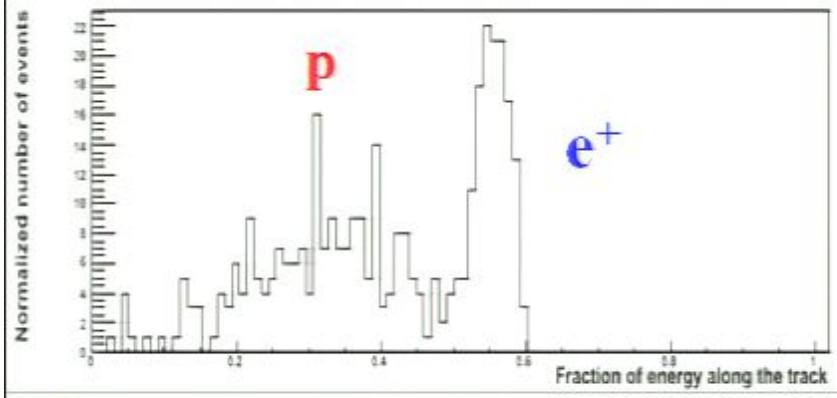

Selections on total detected energy, starting point of shower
Fraction of energy along the track (~RM)
Deflection
e-
(p̄)
e+
p

Positron selection with calorimeter

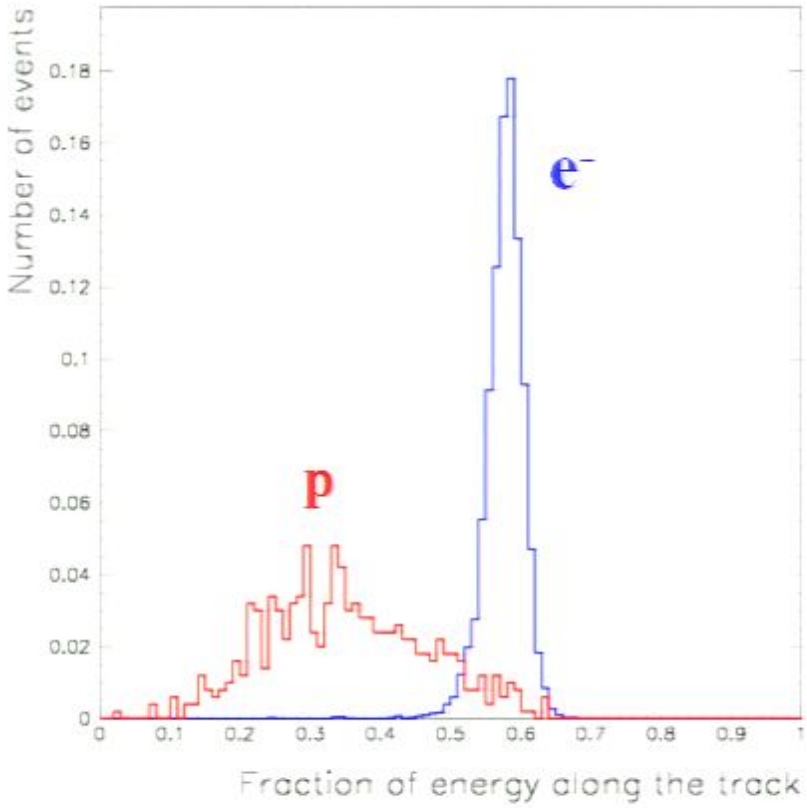
Fraction of charge released along the calorimeter track (left, hit, right)

Flight data:
rigidity: 20-30 GV





Test beam data
Momentum: 50GeV/c

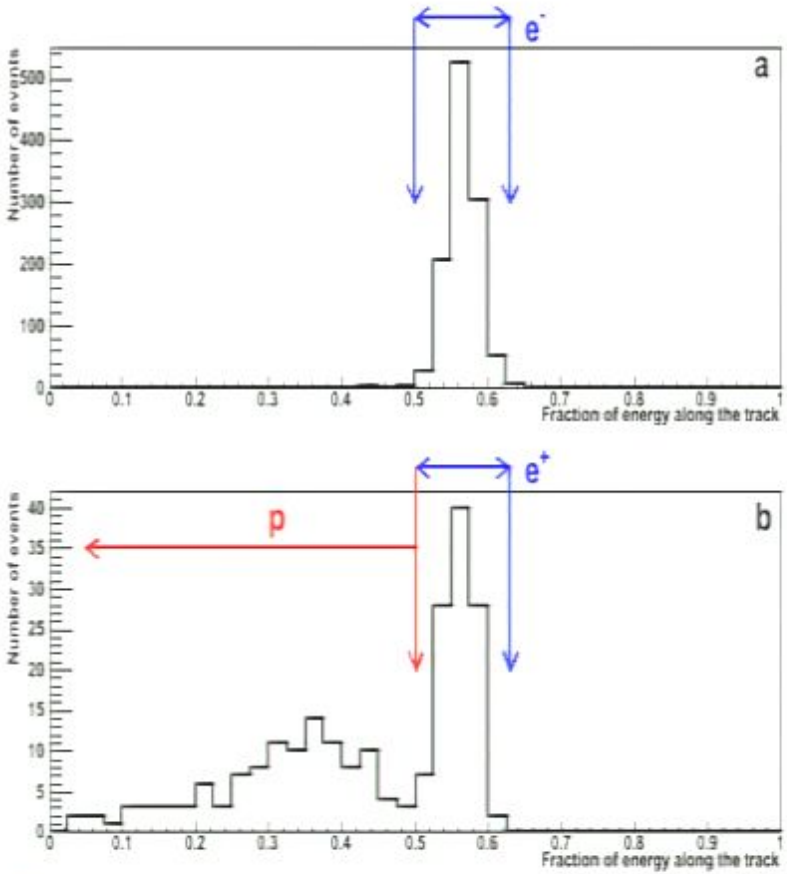


•Energy-momentum match

Positron selection

Rigidity: 20-28 GV

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

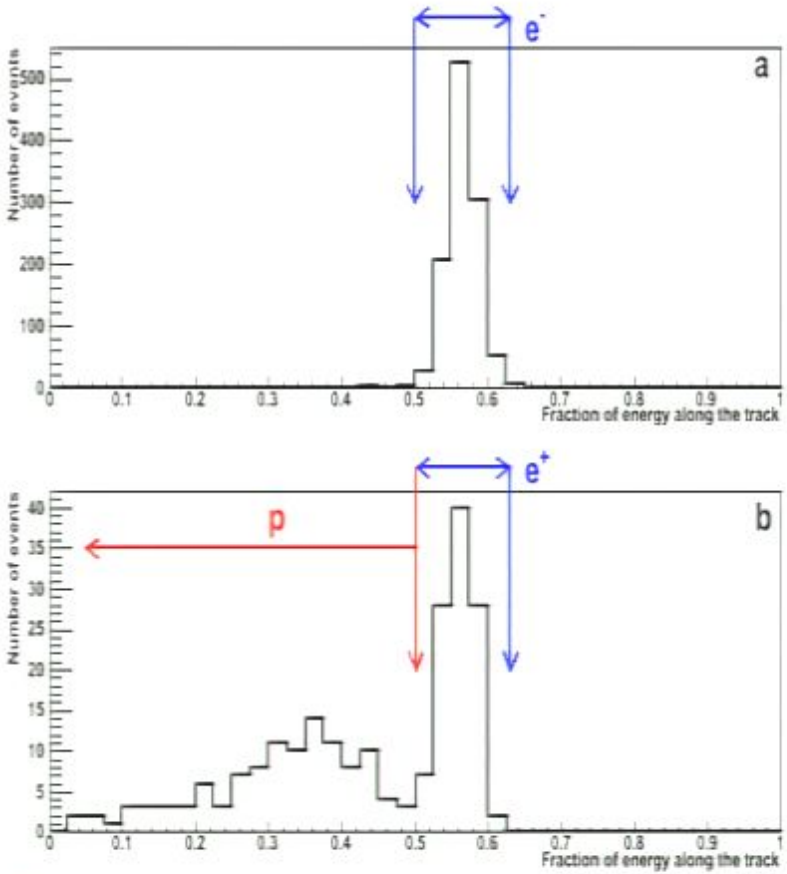


•Energy-momentum match

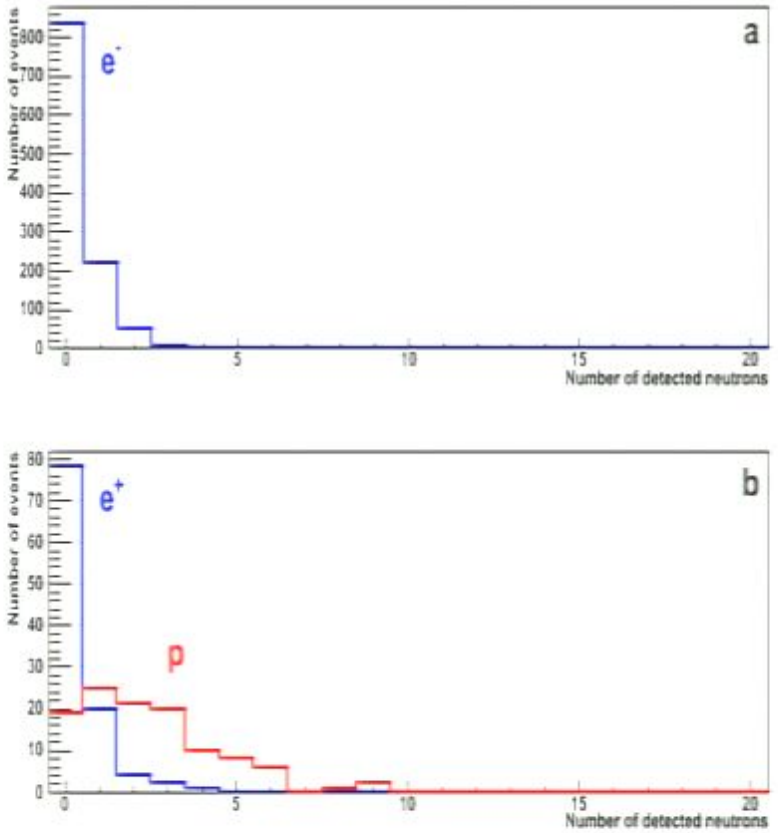
Positron selection

Rigidity: 20-28 GV

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



Neutrons detected by ND

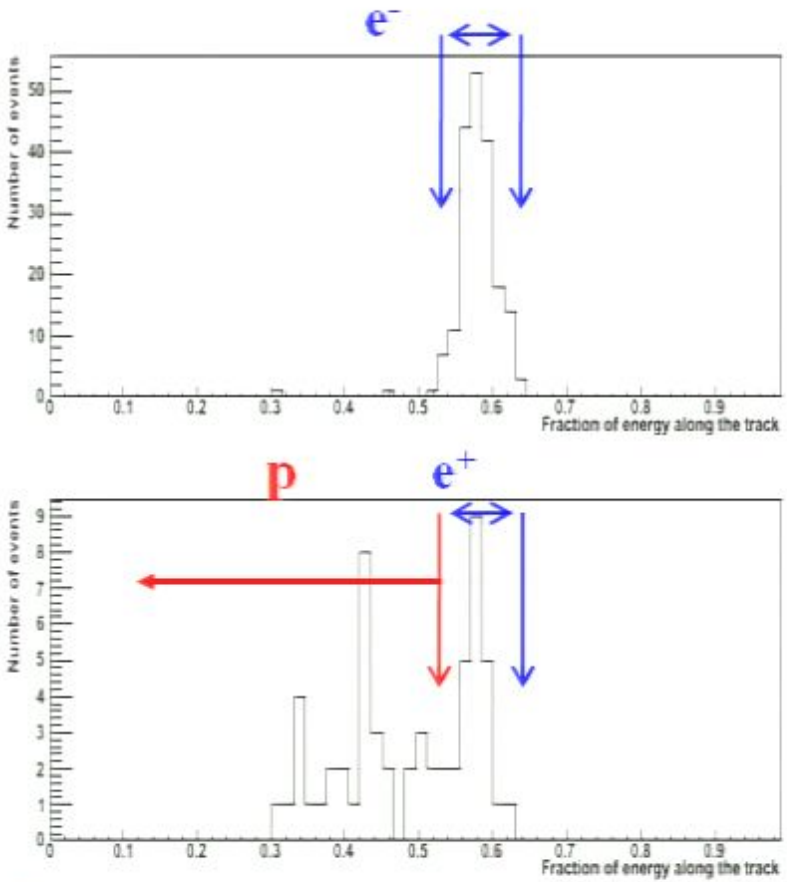


•Energy-momentum match

Positron selection with calorimeter

Rigidity: 42-65 GV

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

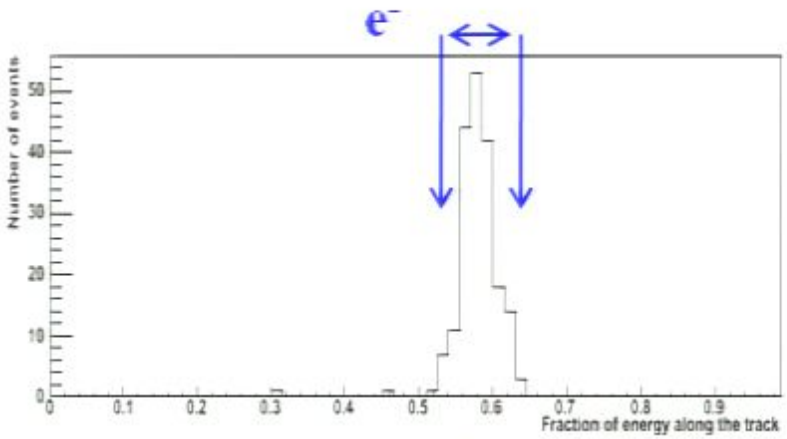


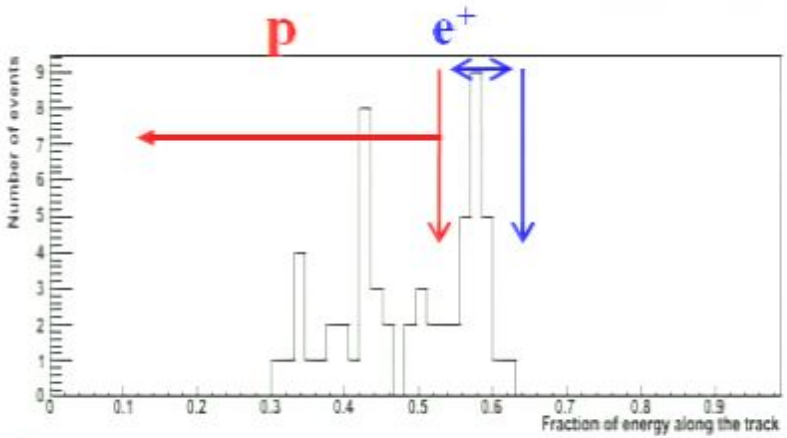
•Energy-momentum match

Positron selection with calorimeter

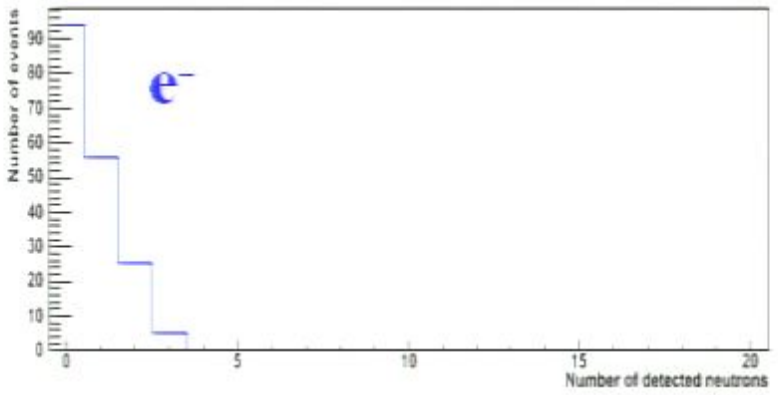
Rigidity: 42-65 GV

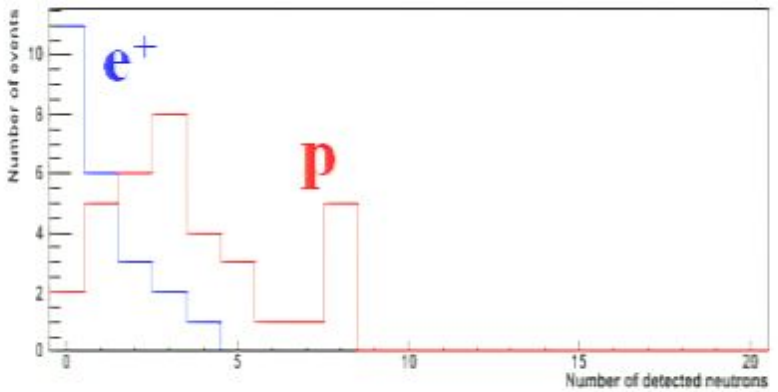
Fraction of charge released along the calorimeter track (left, hit, right)





Neutrons detected by ND



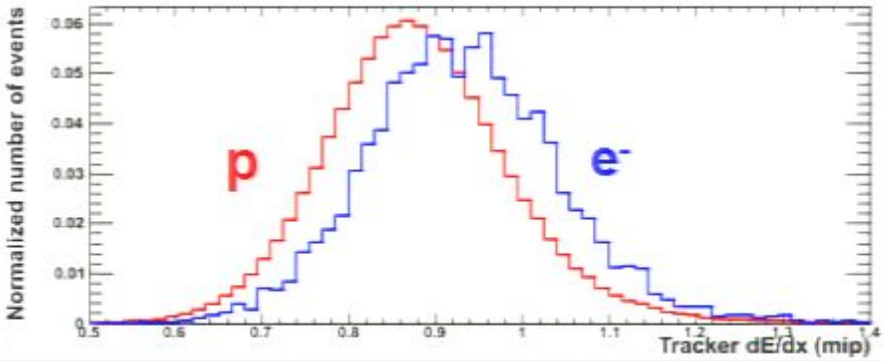


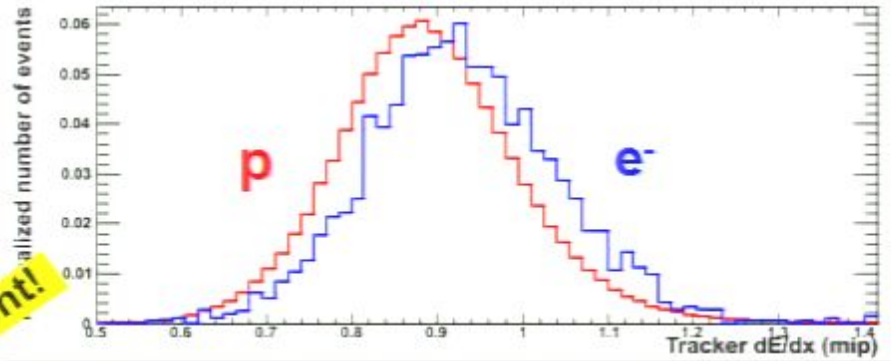
•Energy-momentum match

Positron selection with dE/dX

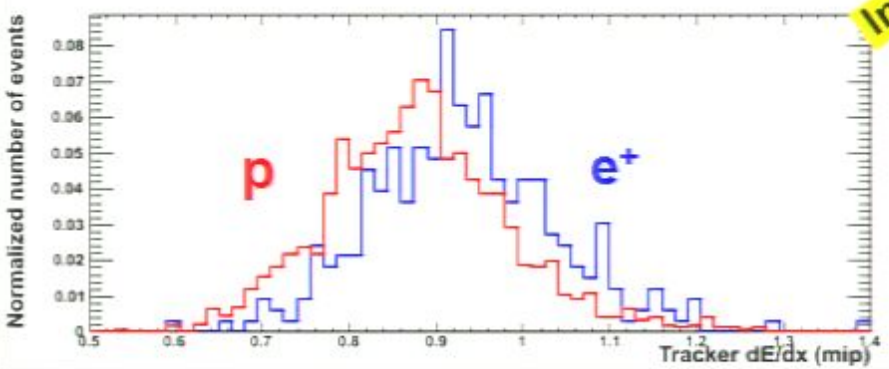
Energy loss in silicon tracker detectors: $-\frac{dE}{dx} = Kz^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$

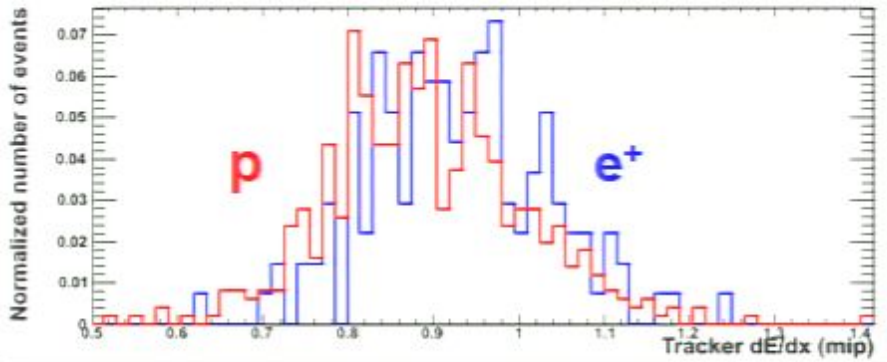
TOP: positive (mostly p) and negative events (mostly e⁻)





Independent!



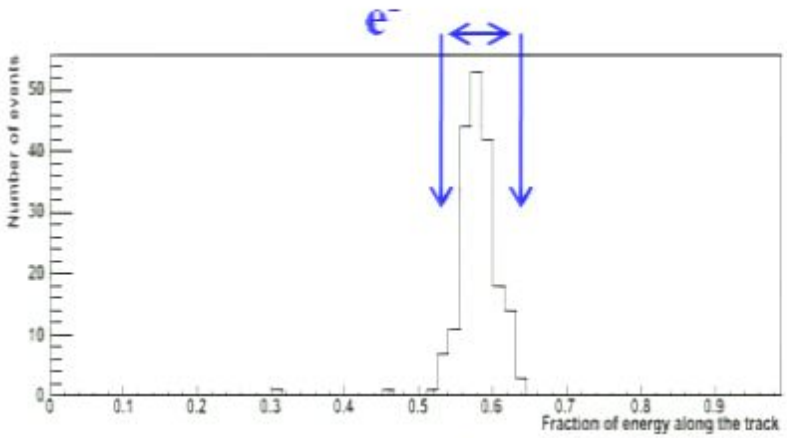


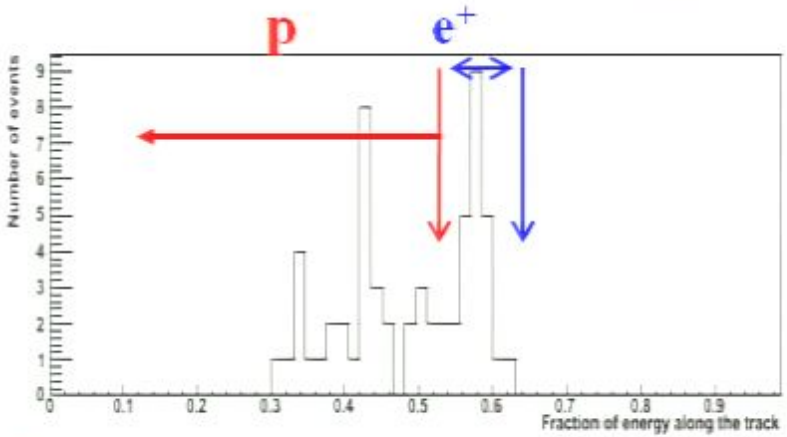
BOTTOM: positive events identified as p and e⁺ by transverse profile method

Positron selection with calorimeter

Rigidity: 42-65 GV

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

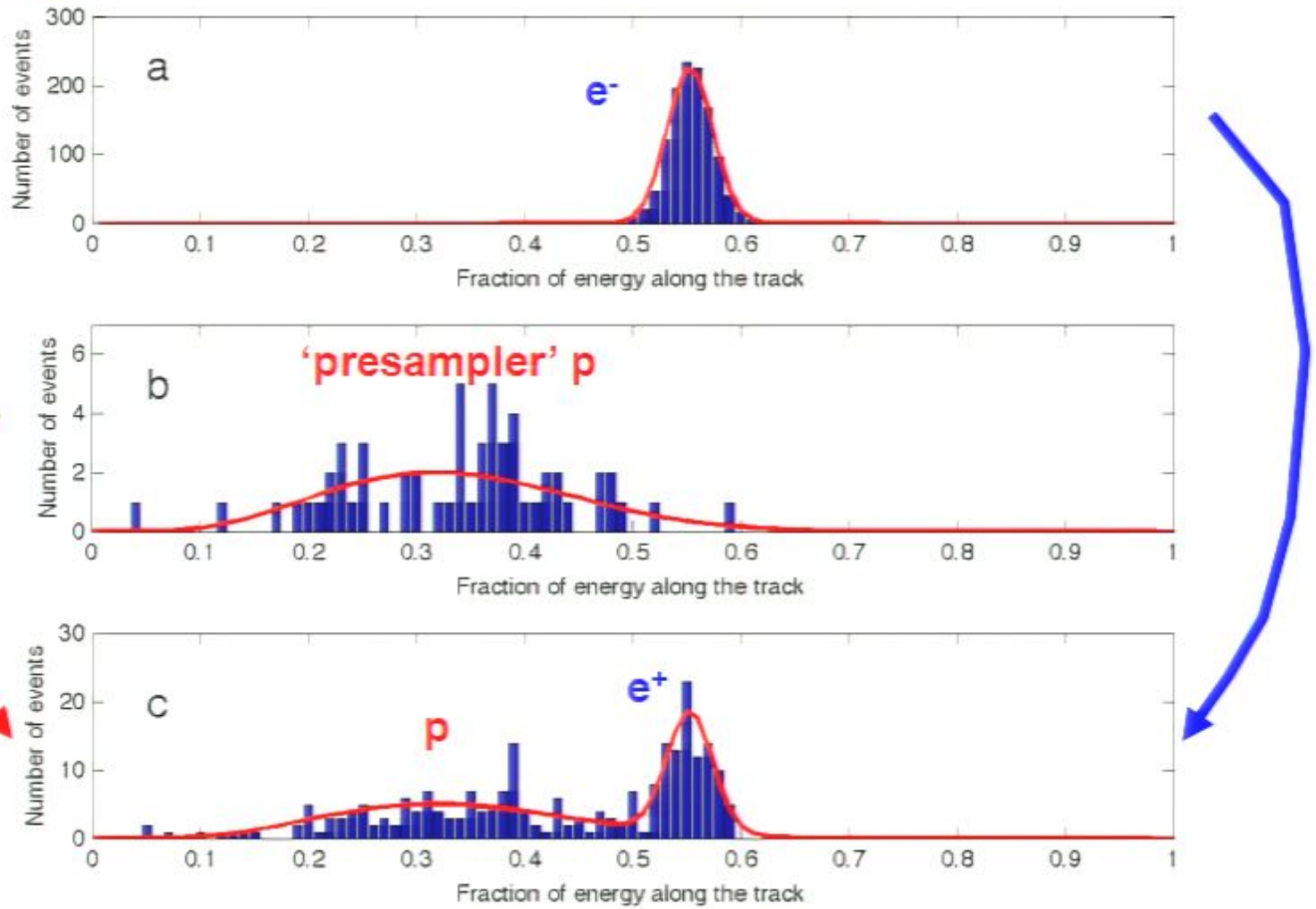


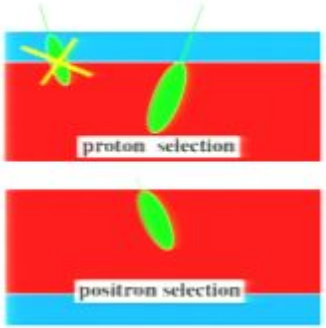


•Energy-momentum match

e^+ background estimation from data

Rigidity: 20-28 GV

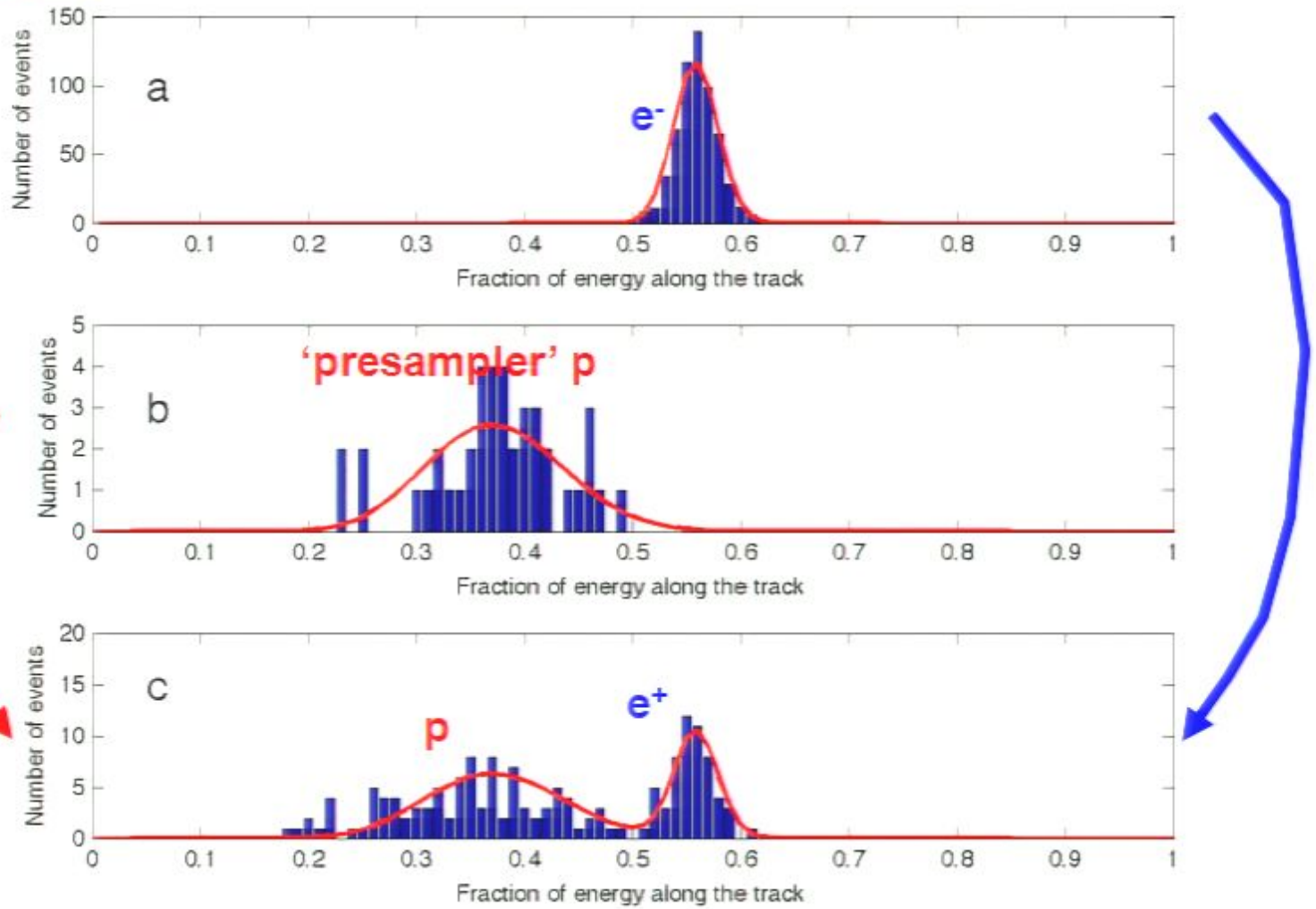


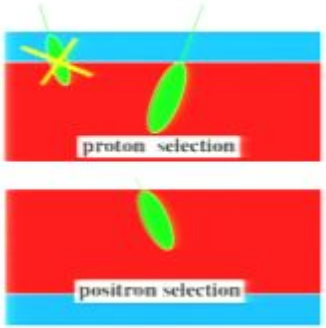


+ • Energy-momentum match
• Starting point of shower

e^+ background estimation from data

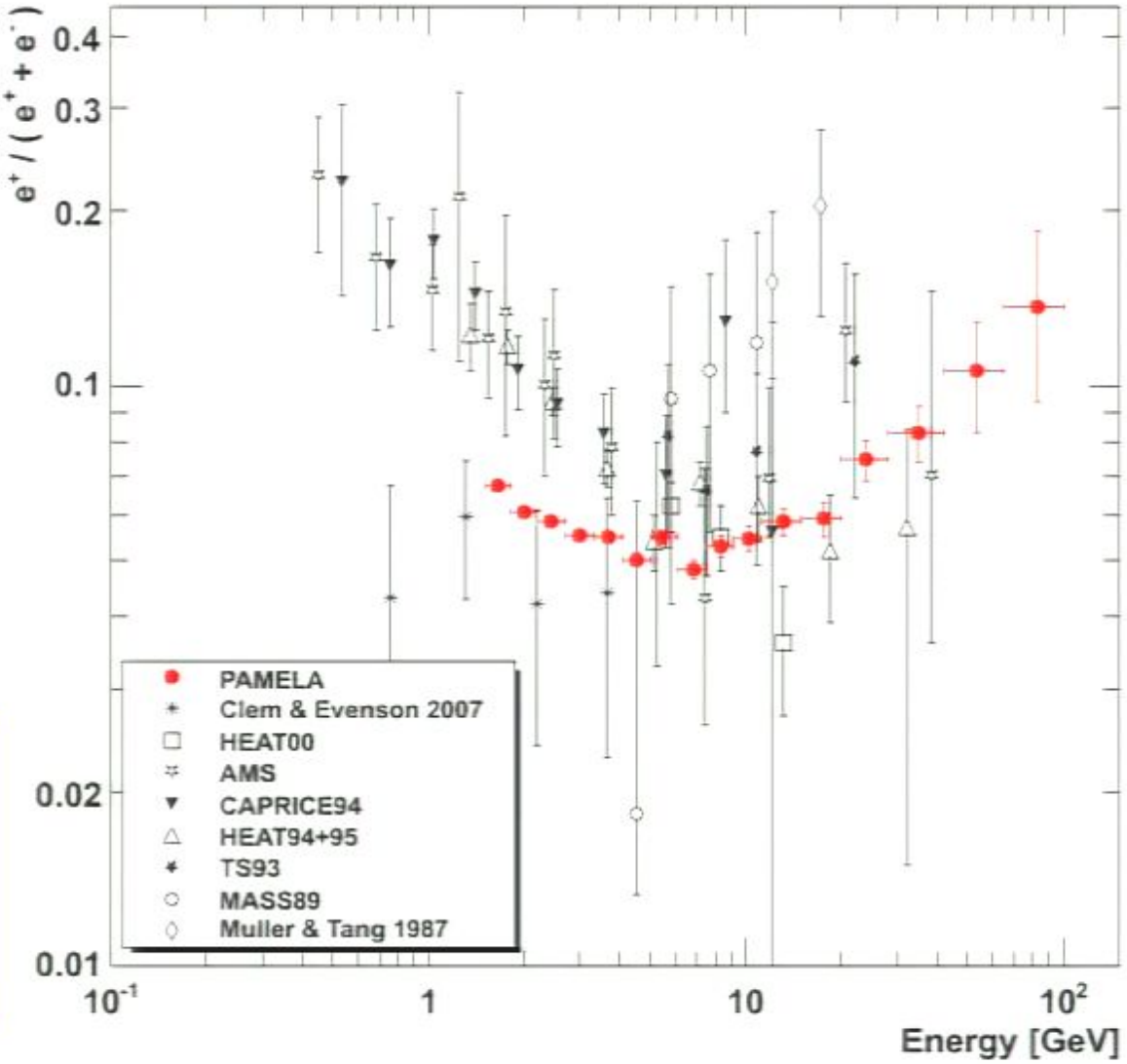
Rigidity: 28-42 GV





+ • Energy-momentum match
• Starting point of shower

Positron to Electron Fraction



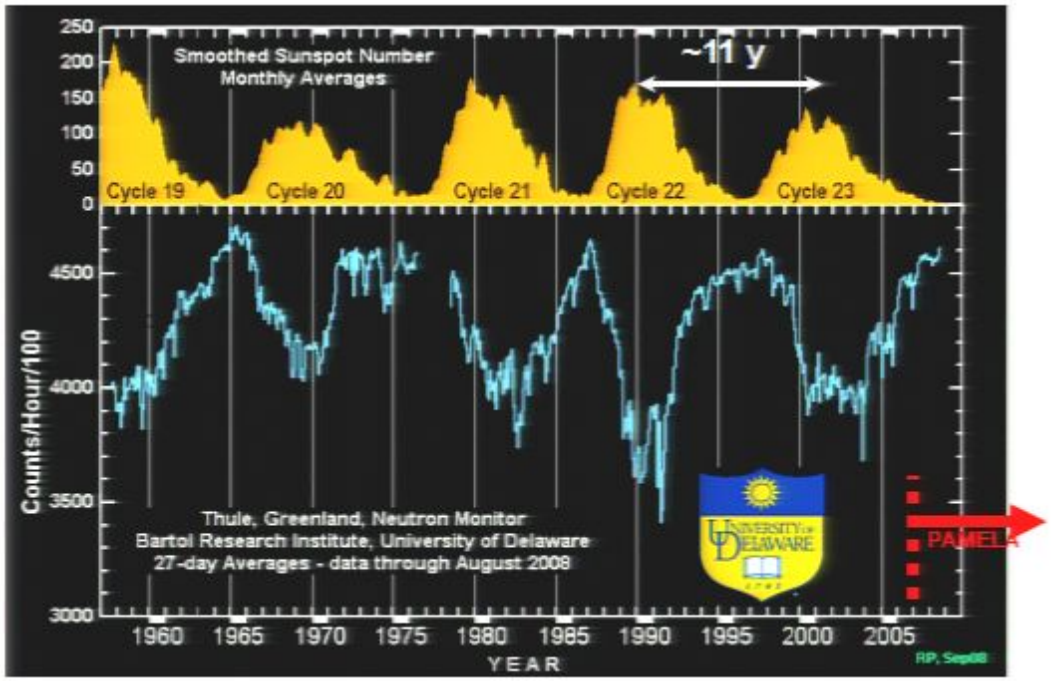
End 2007:
~10 000 e^+ > 1.5 GeV

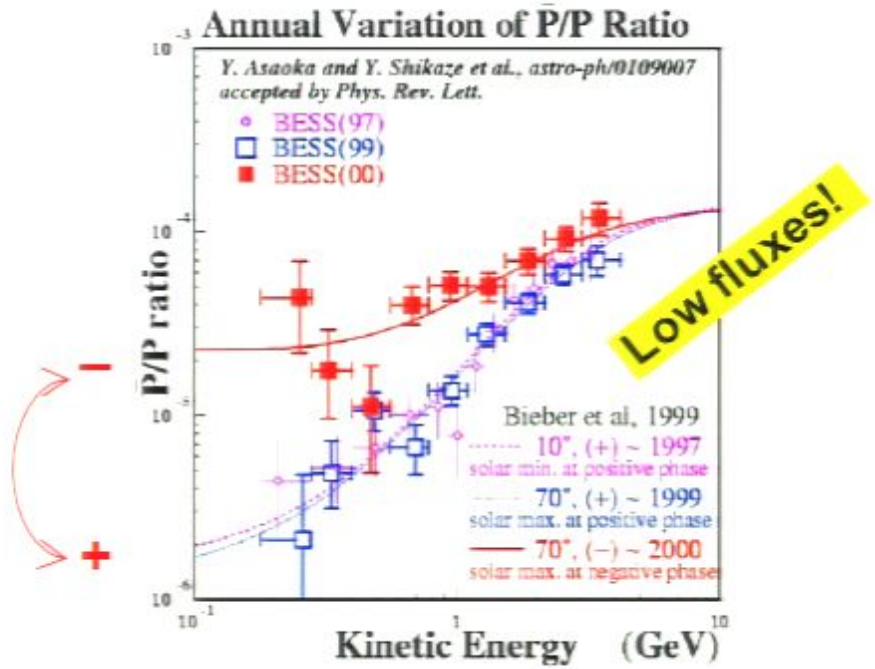
~2000 > 5 GeV

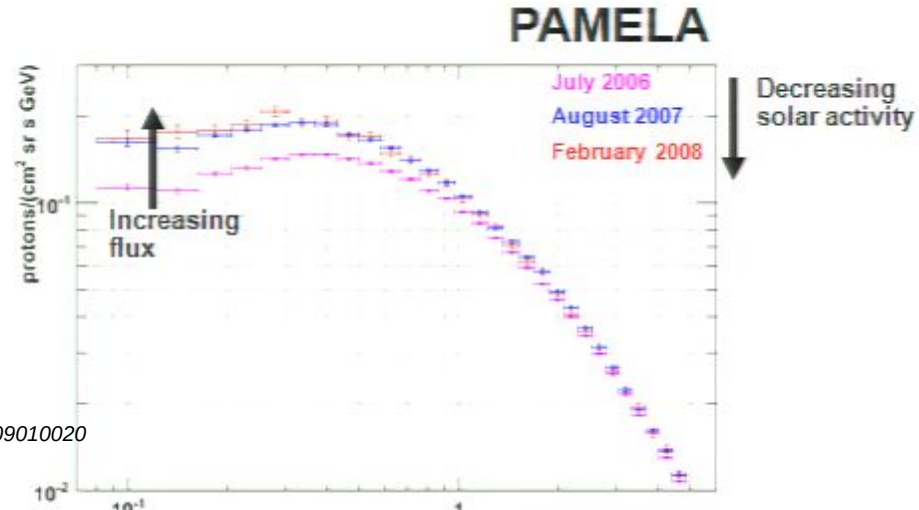
Astro-ph 0810.4995

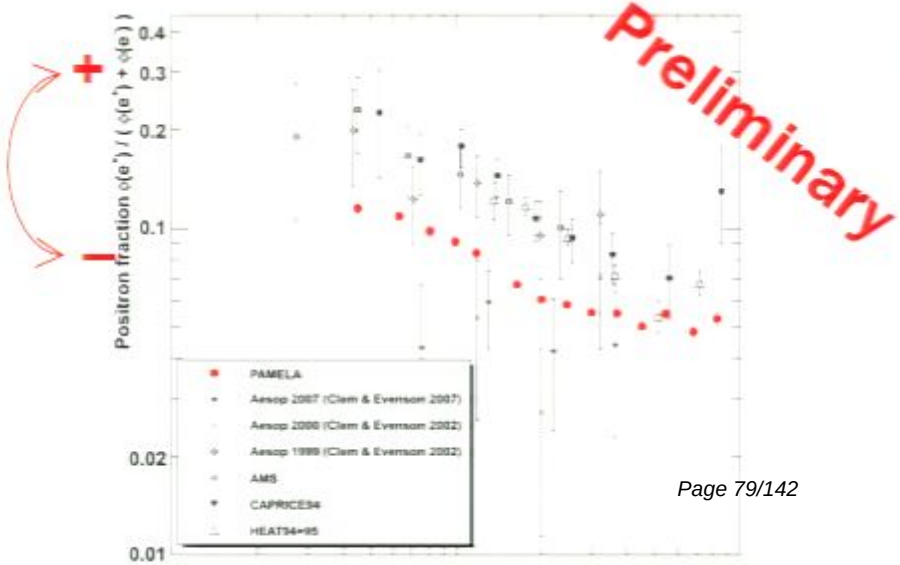
Solar modulation

A^+ A^- A^+ A^-

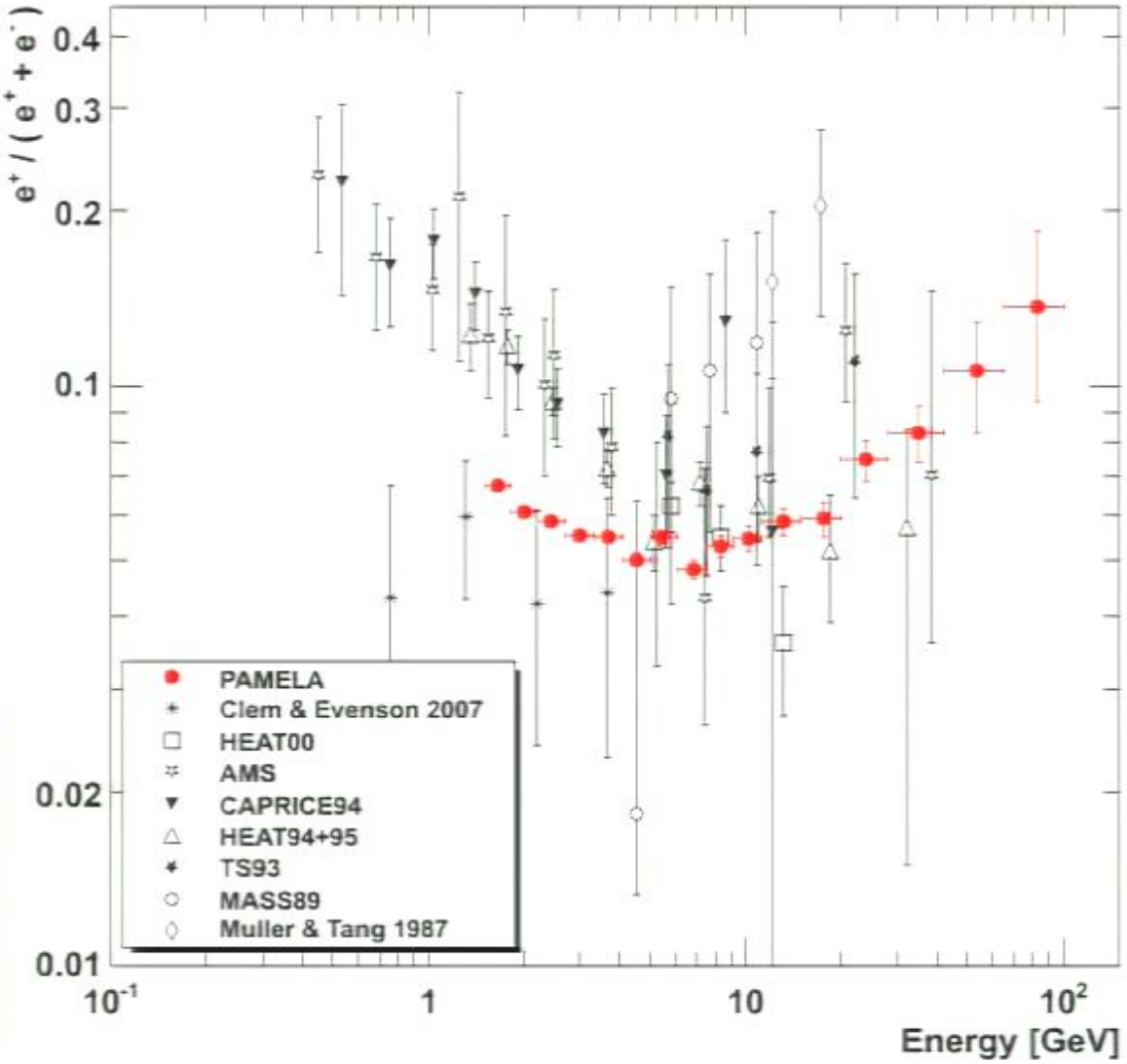








Positron to Electron Fraction



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

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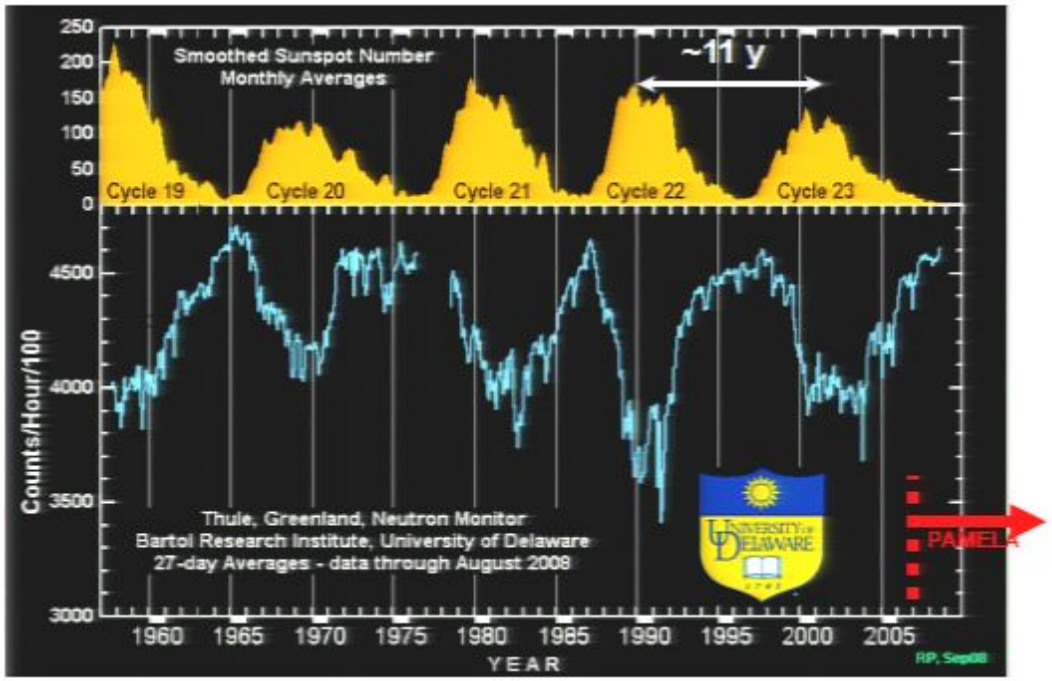
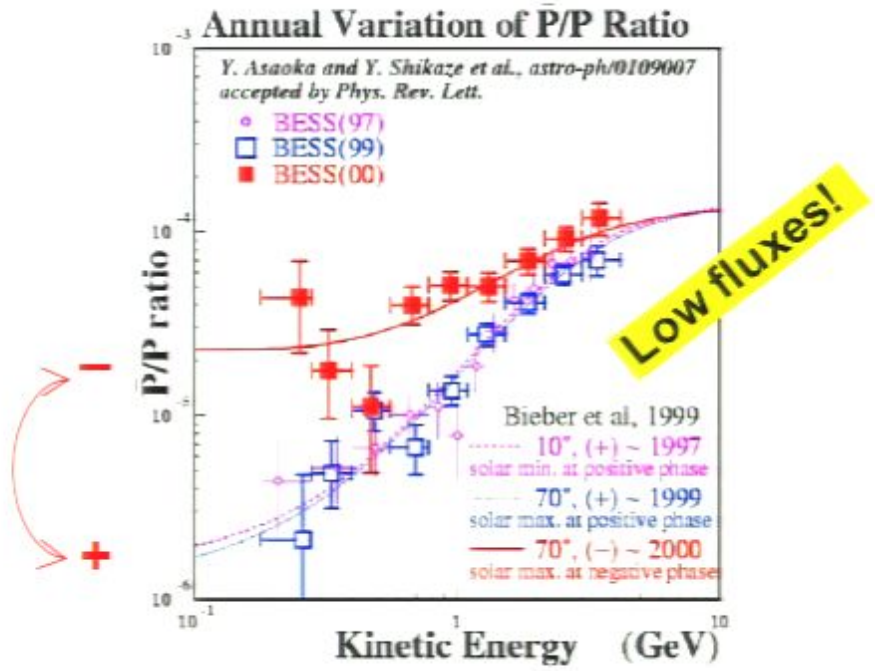
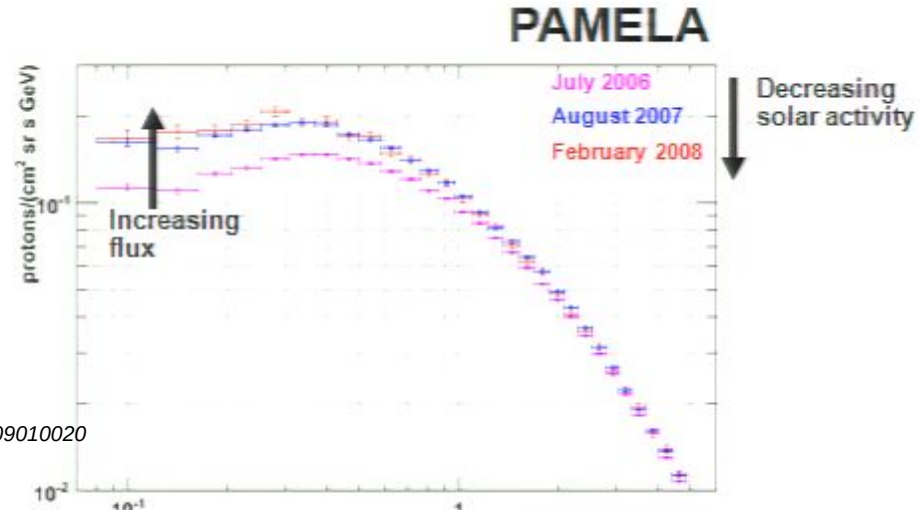
Astro-ph 0810.4995

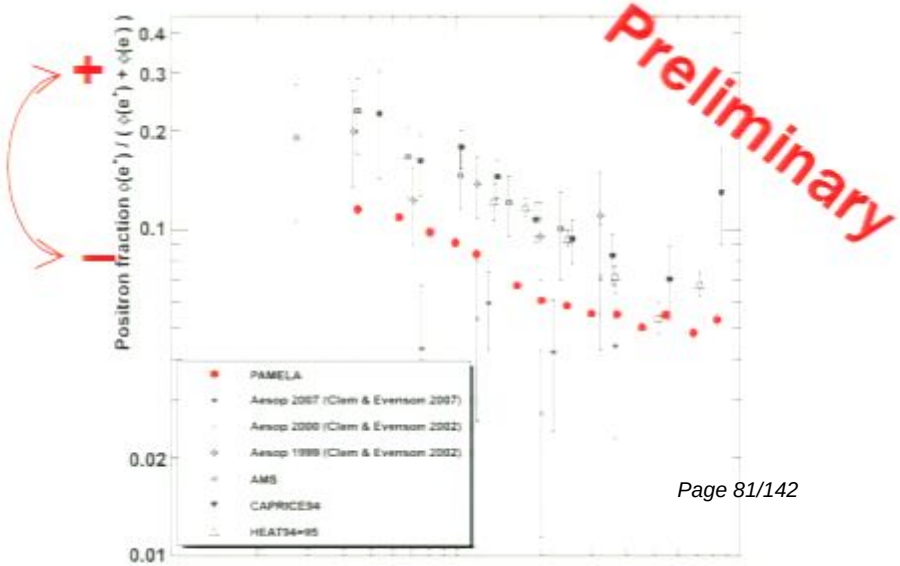
Solar modulation

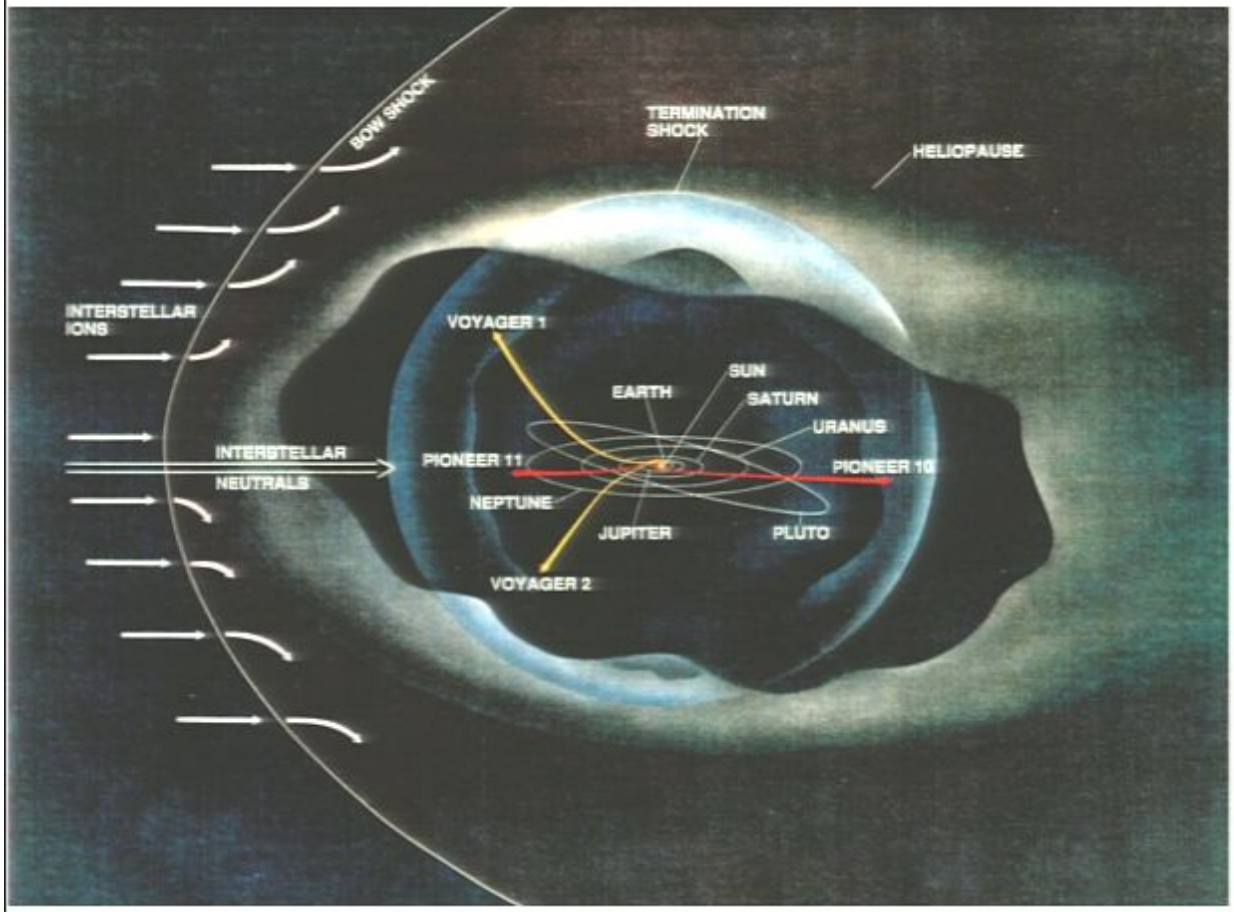
A^+ A^- A^+ A^-

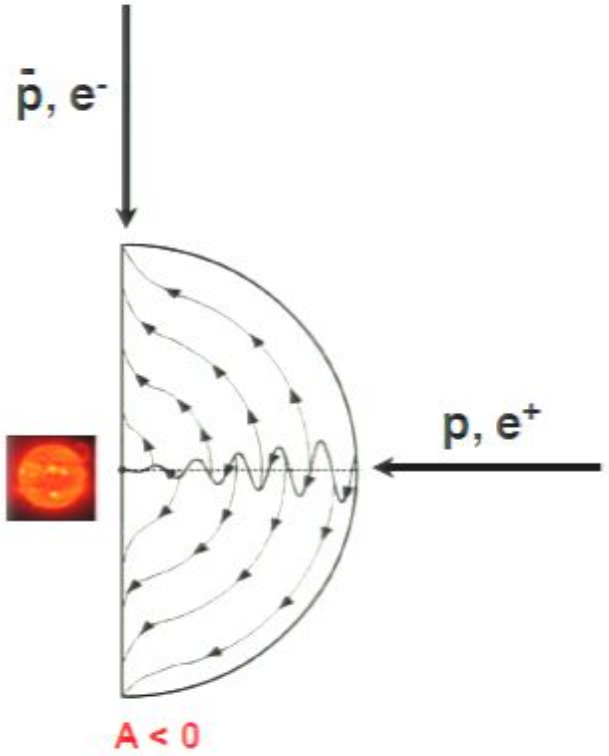




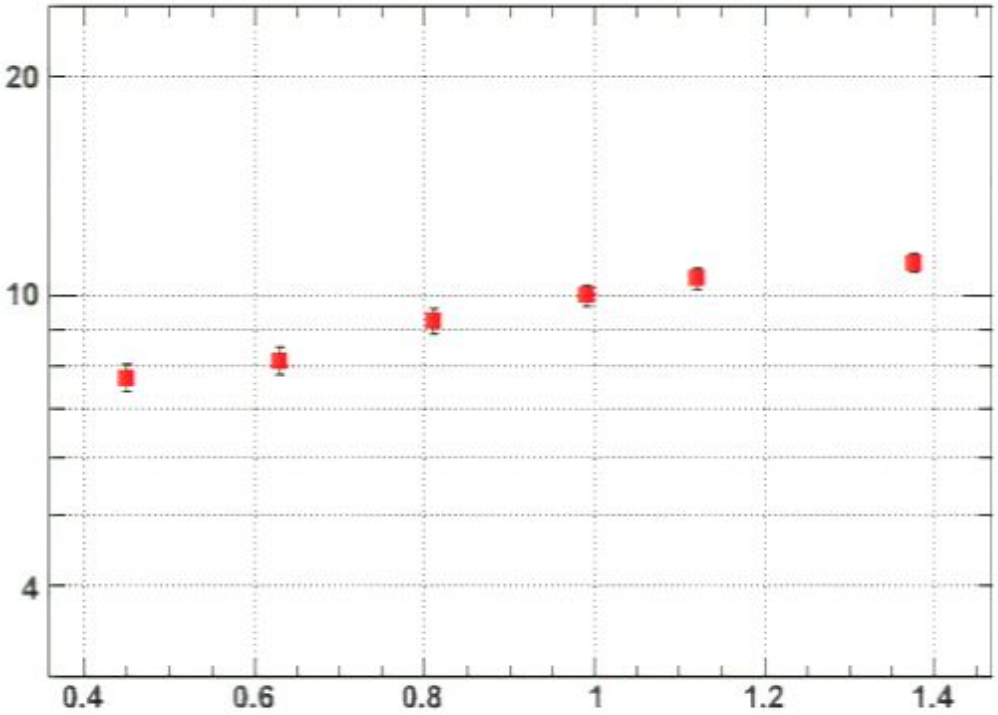




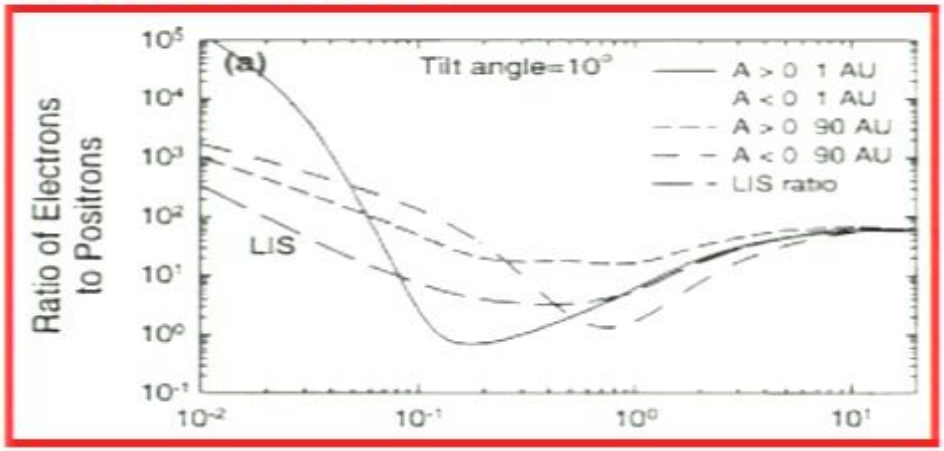

BOW SHOCK
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR IONS
VOYAGER 1
SUN
EARTH
SATURN
URANUS
INTERSTELLAR NEUTRALS
PIONEER 11
PIONEER 10
NEPTUNE
JUPITER
PLUTO
VOYAGER 2

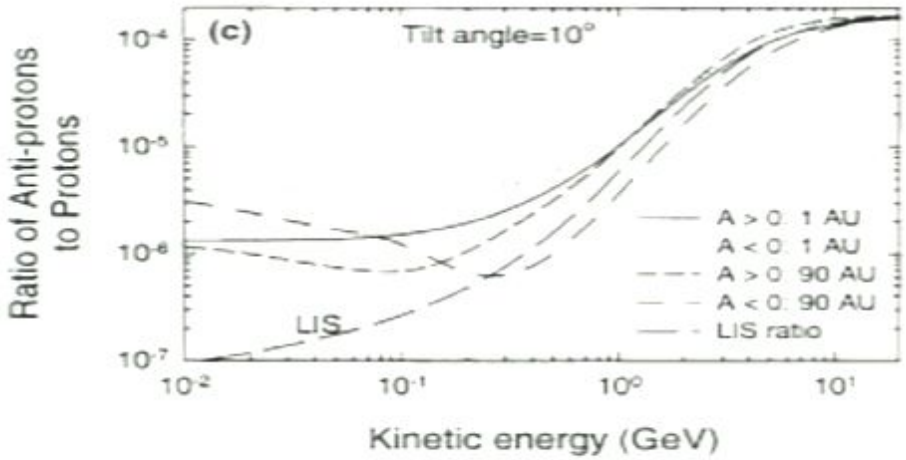

p̄, e⁻
p, e⁺
A < 0

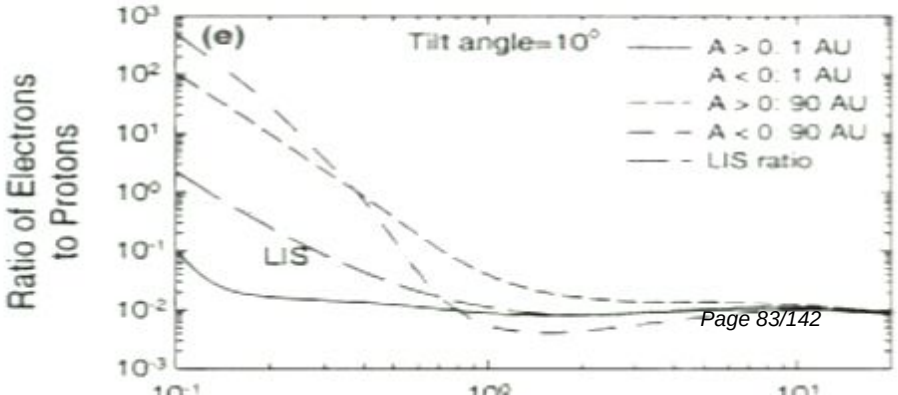
Electron to positron ratio

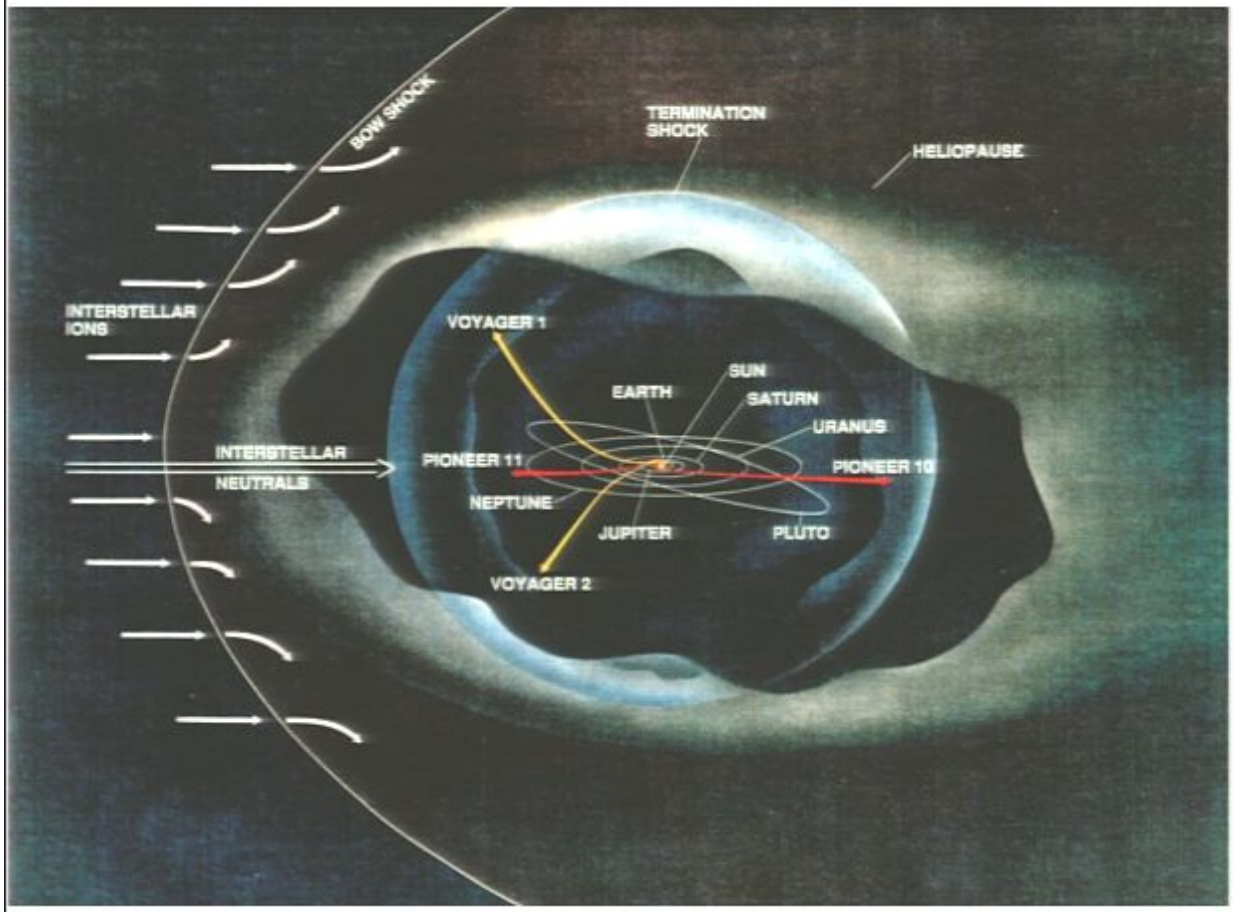


Preliminary PAMELA results








BOW SHOCK
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR IONS
VOYAGER 1
SUN
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SATURN
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PIONEER 10
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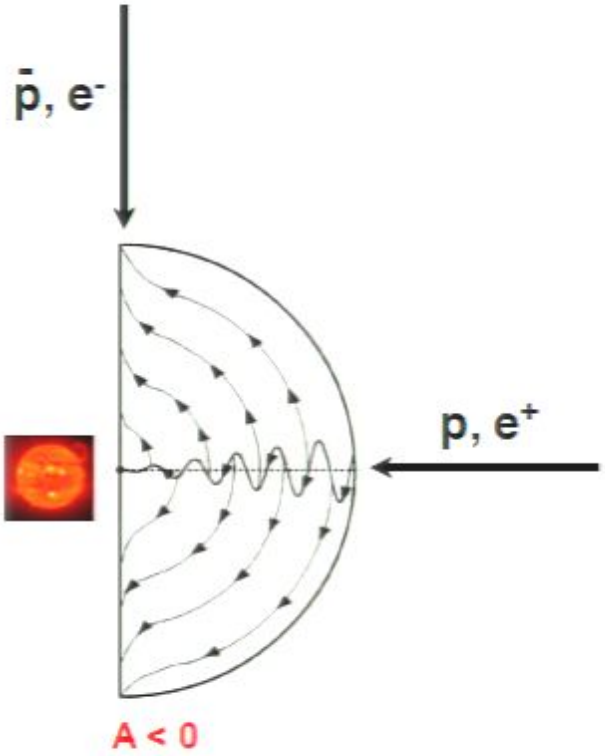
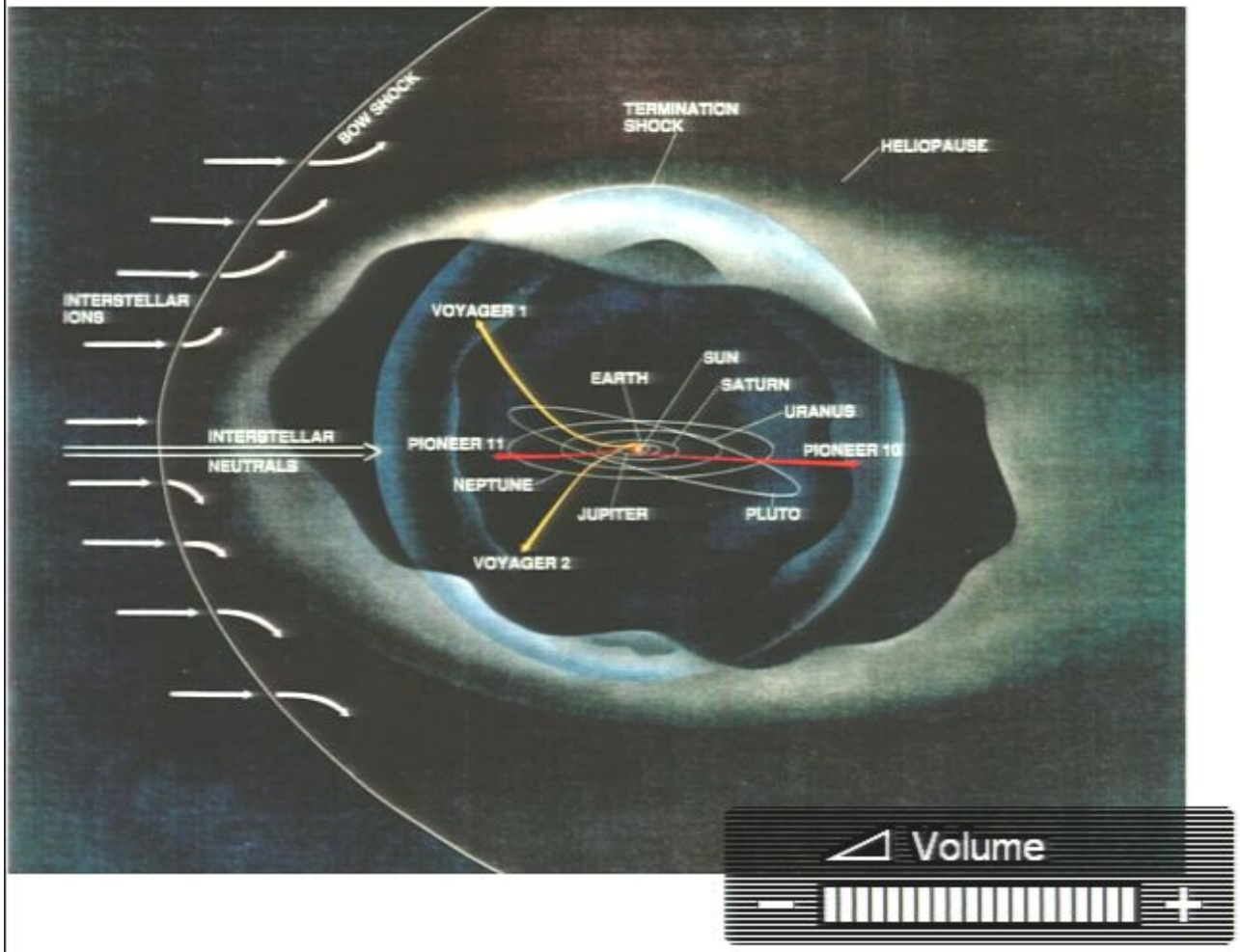
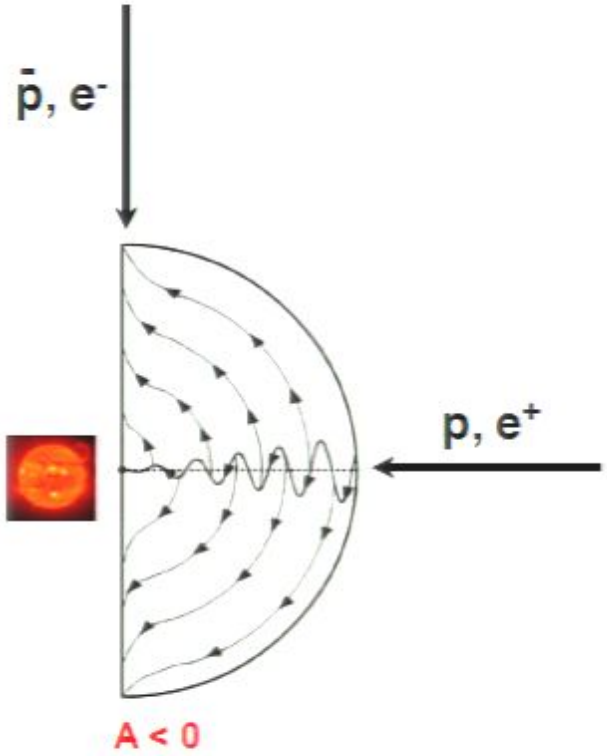
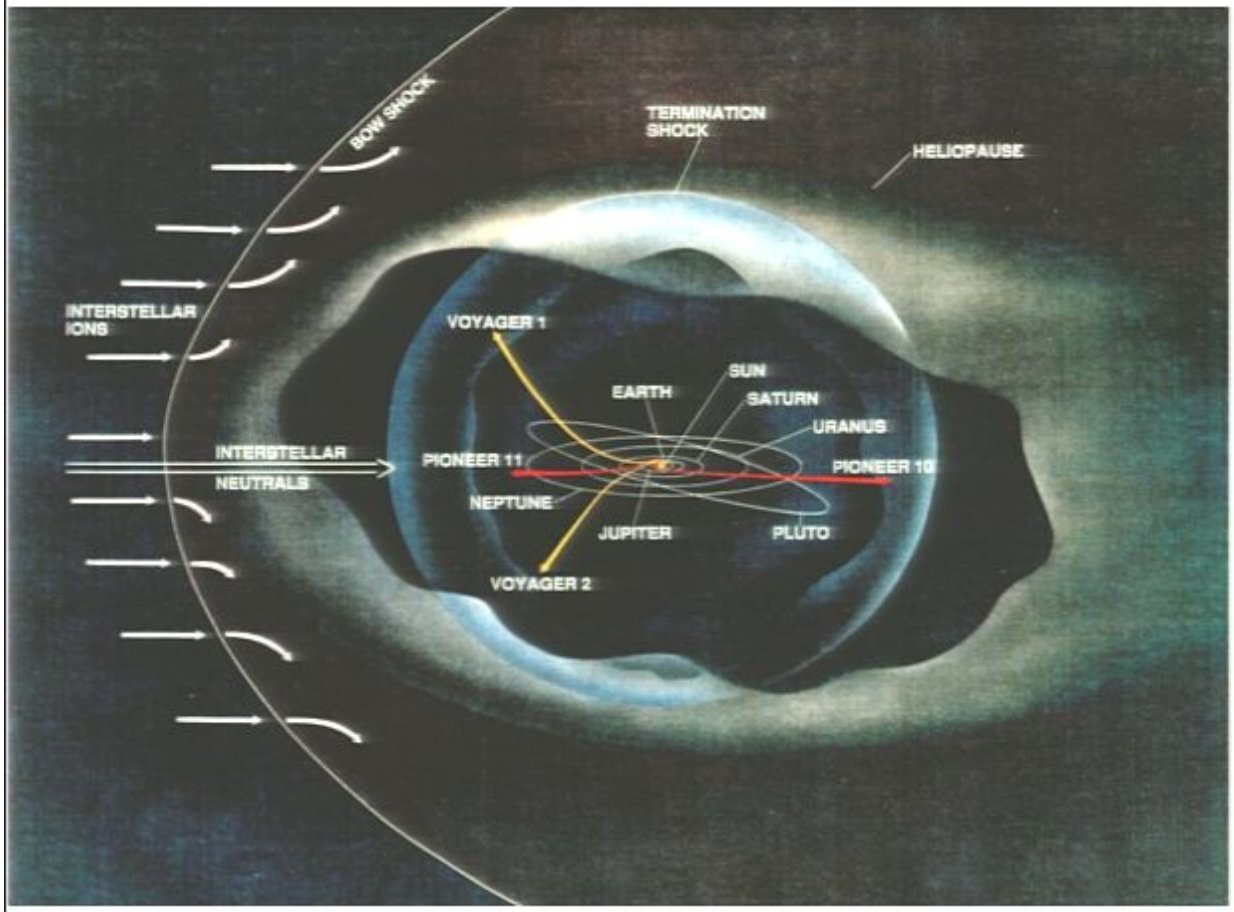
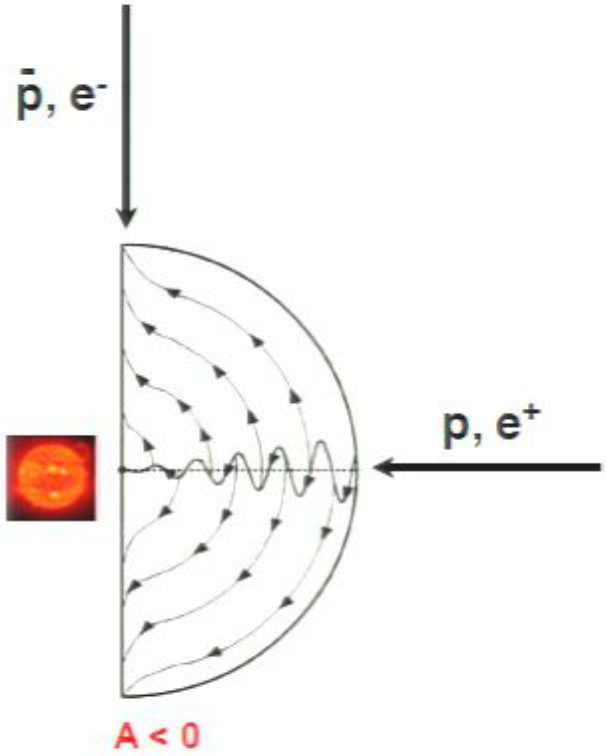
PLUTO
VOYAGER 2


p̄, e⁻
p, e⁺
A < 0

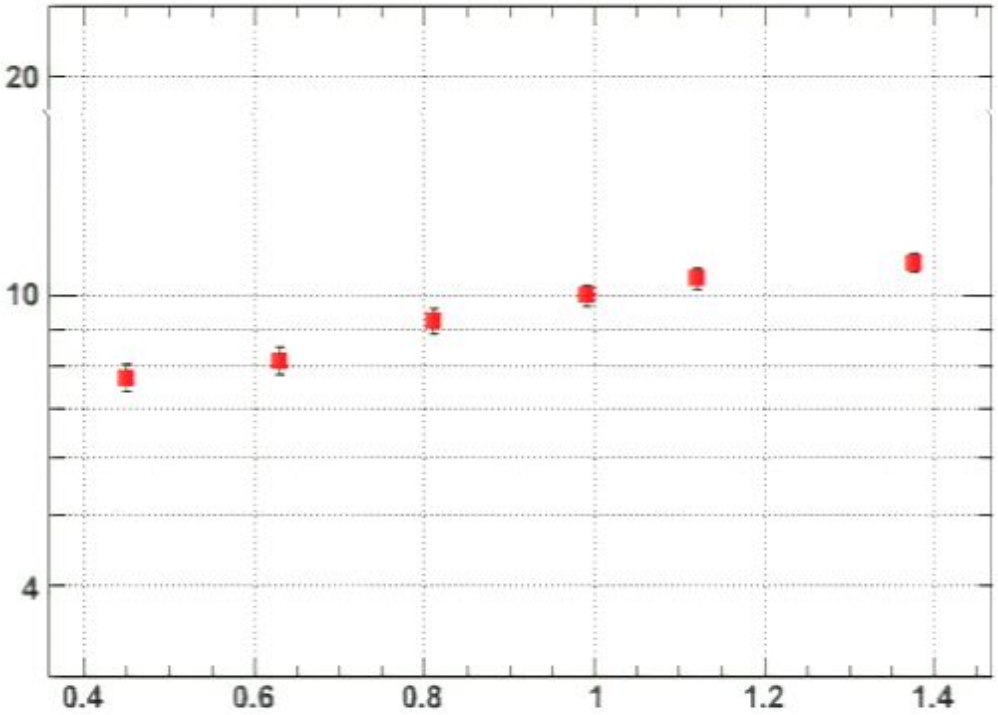

BOW SHOCK
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR IONS
VOYAGER 1
SUN
EARTH
SATURN
URANUS
INTERSTELLAR NEUTRALS
PIONEER 11
PIONEER 10
NEPTUNE
JUPITER
PLUTO
VOYAGER 2
Volume


p̄, e⁻
p, e⁺
A < 0

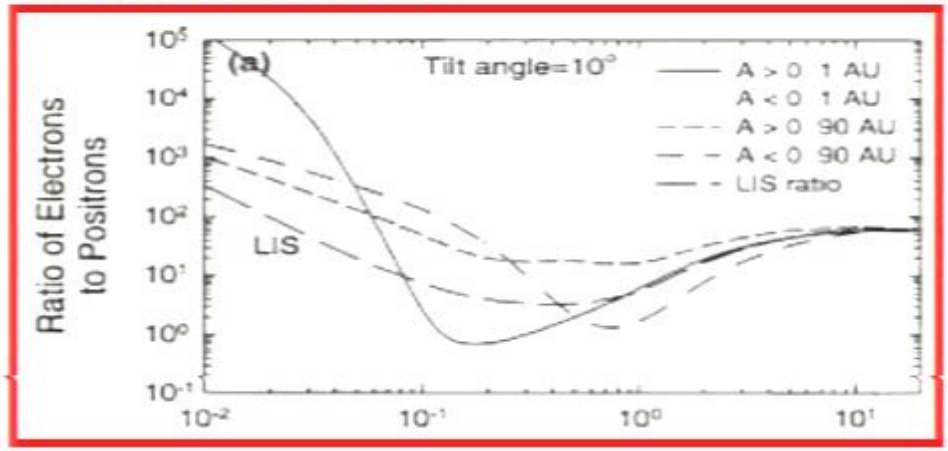

BOW SHOCK
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR IONS
VOYAGER 1
SUN
EARTH
SATURN
URANUS
INTERSTELLAR NEUTRALS
PIONEER 11
PIONEER 10
NEPTUNE
JUPITER
PLUTO
VOYAGER 2

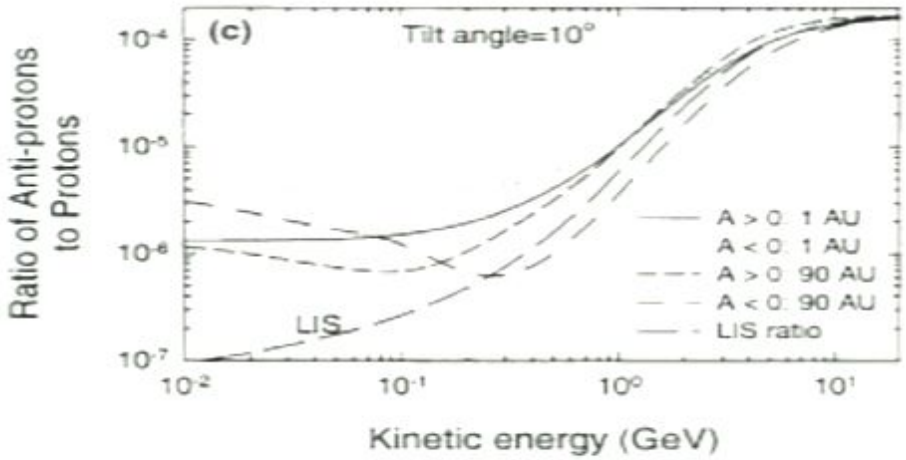

p̄, e⁻
p, e⁺
A < 0

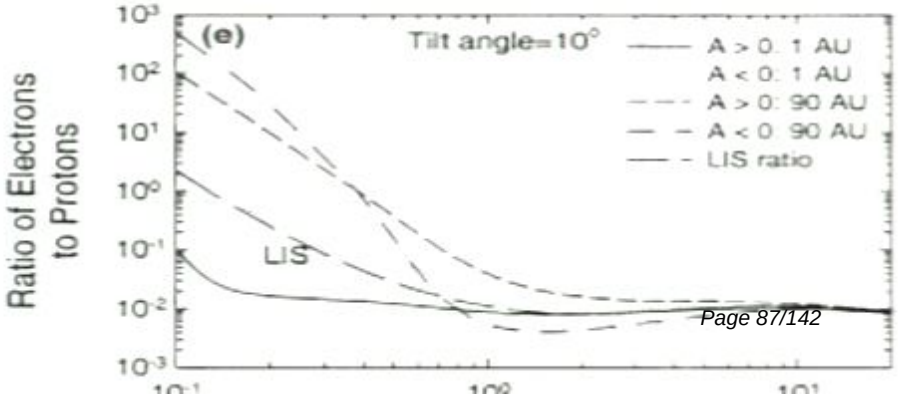
Electron to positron ratio



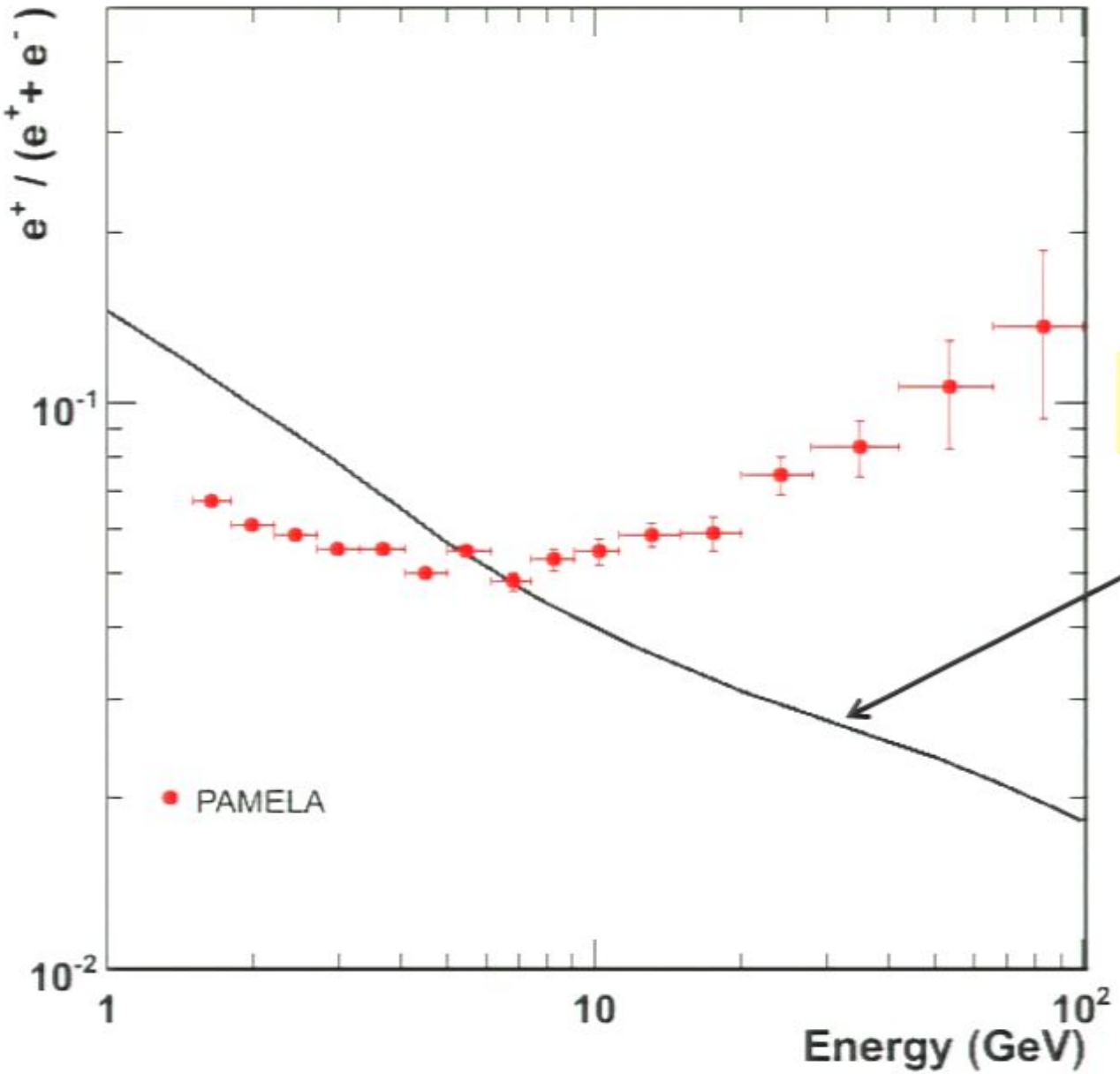
Preliminary PAMELA results



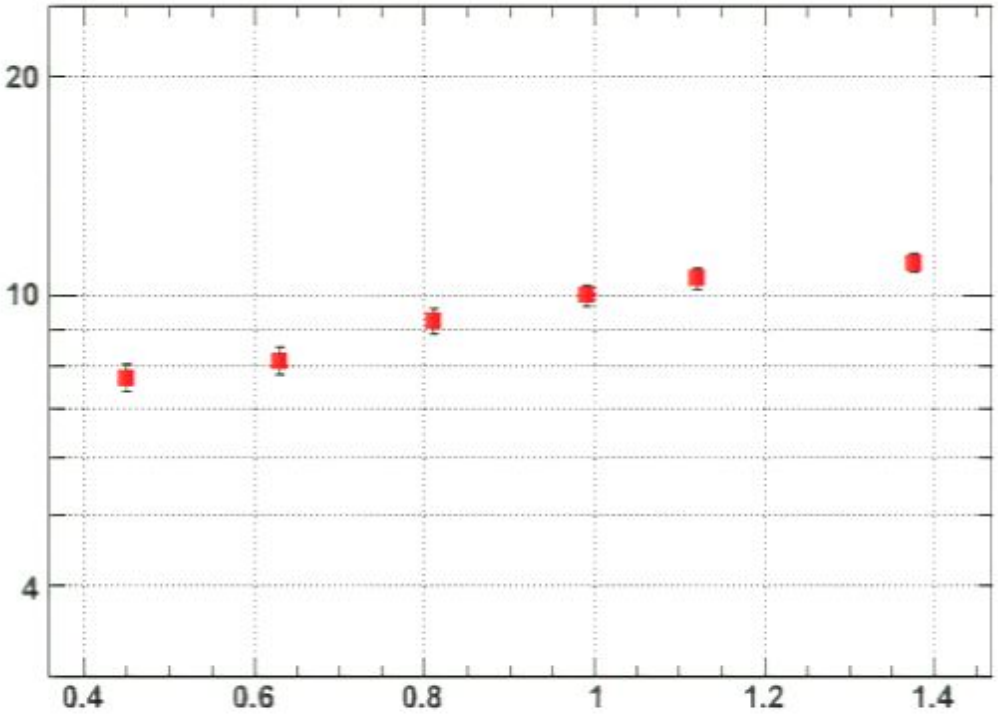




PAMELA Positron Fraction



Electron to positron ratio



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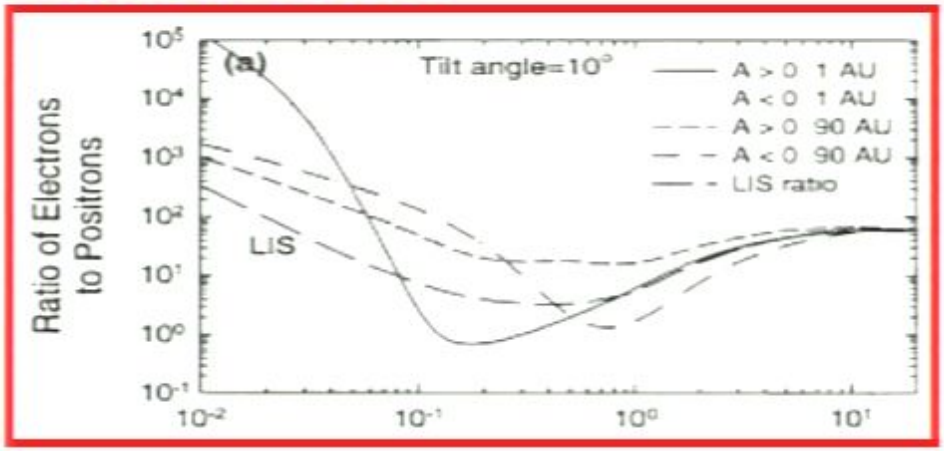

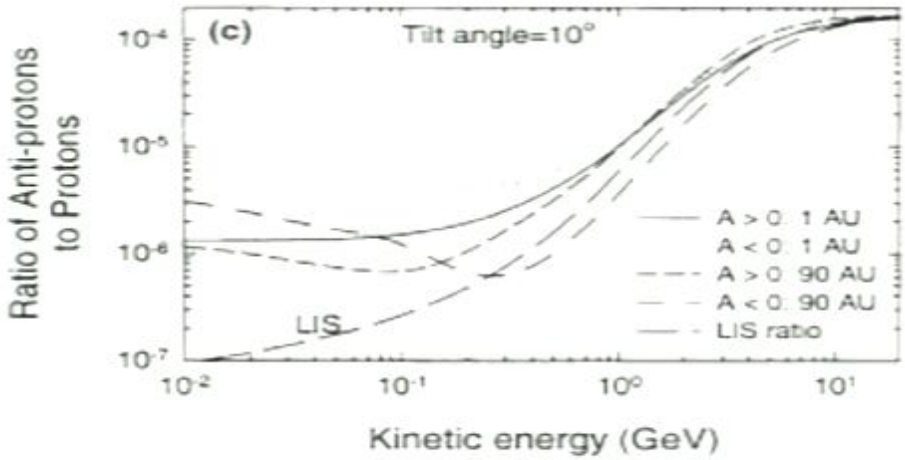

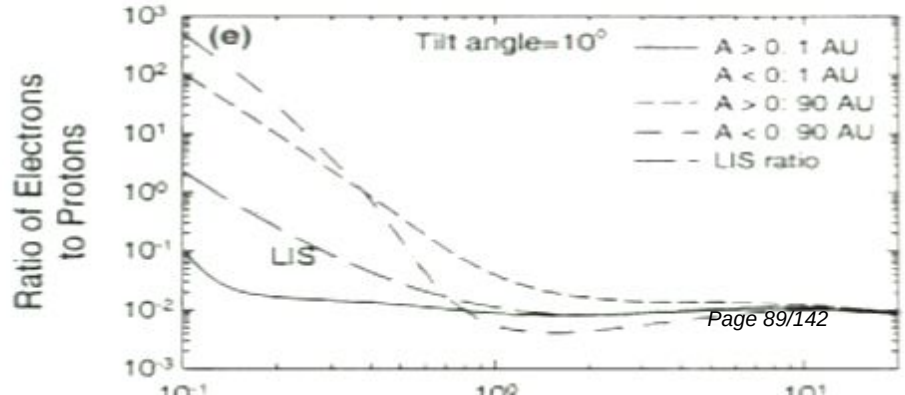

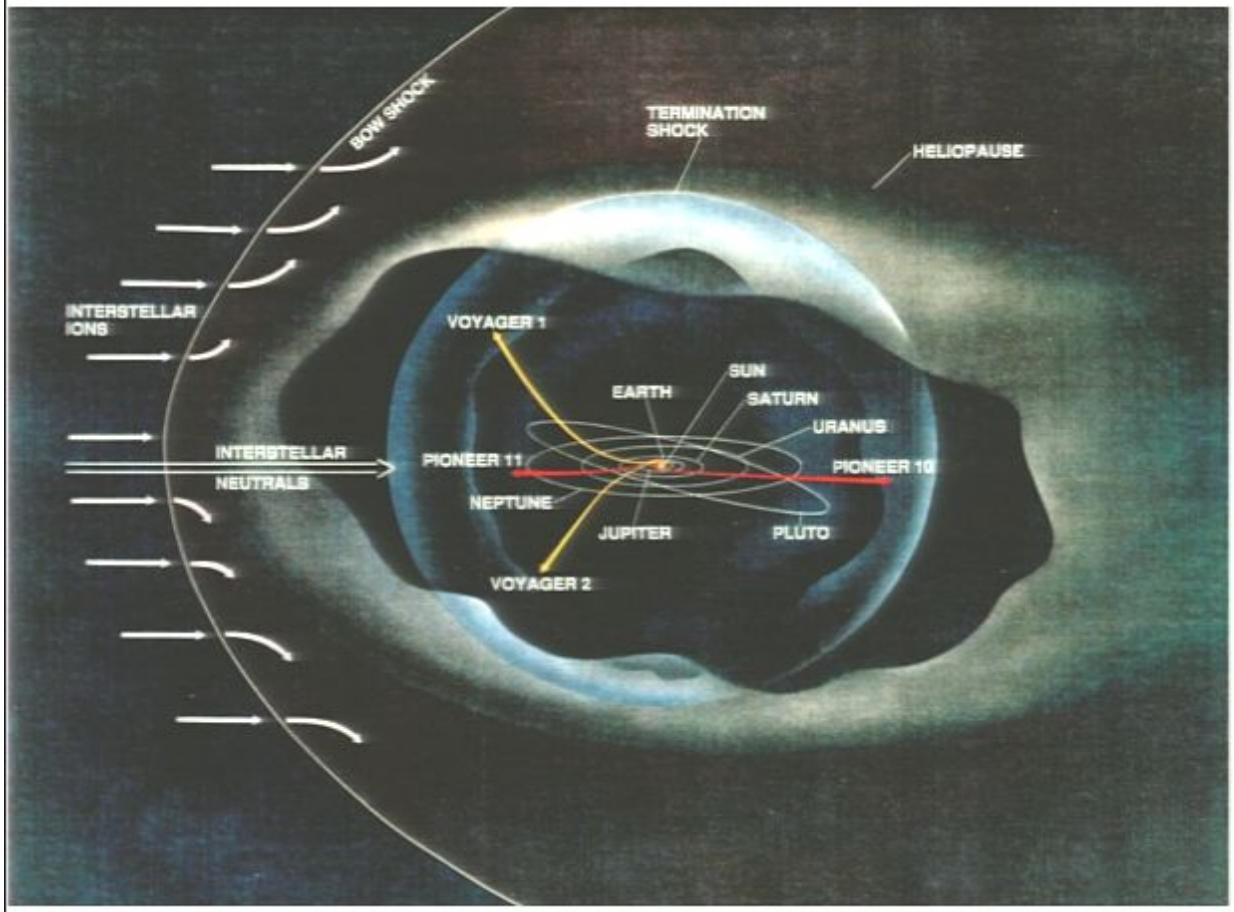
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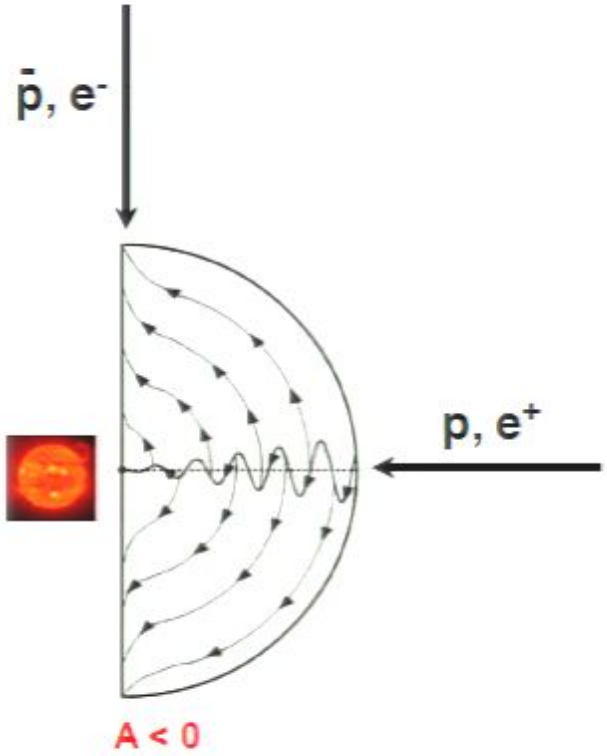
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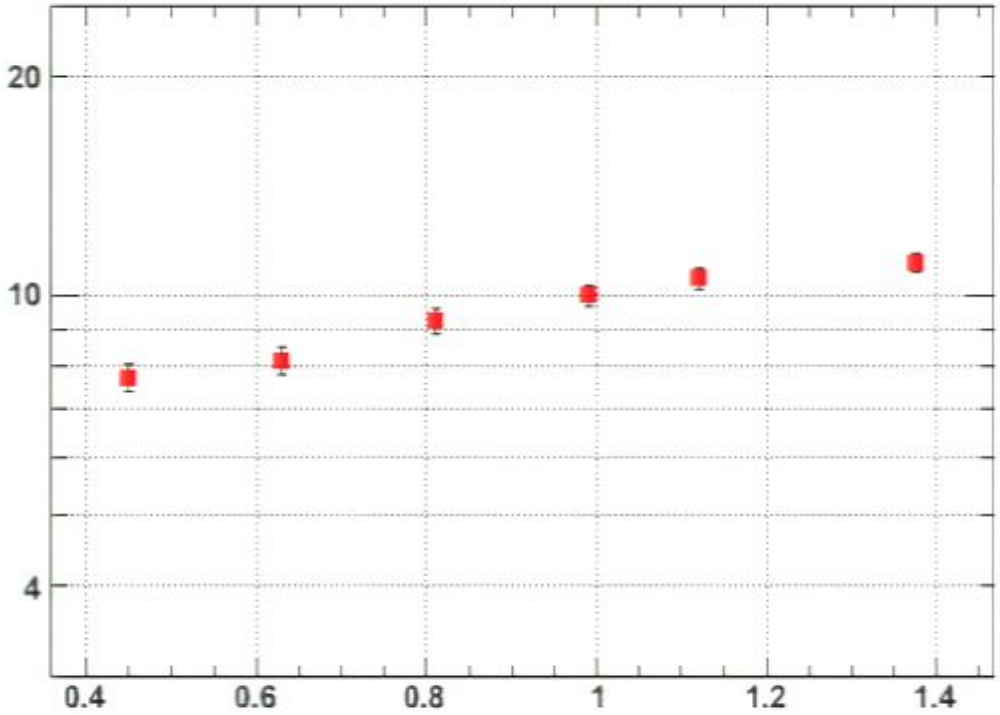

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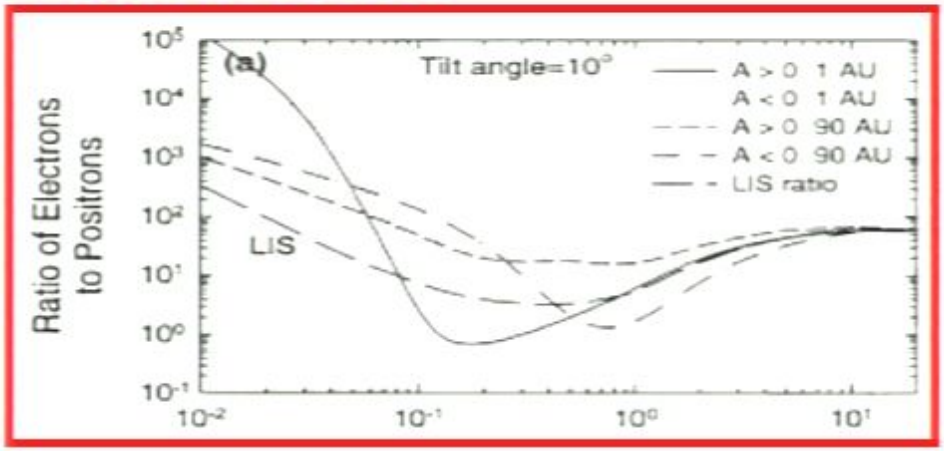

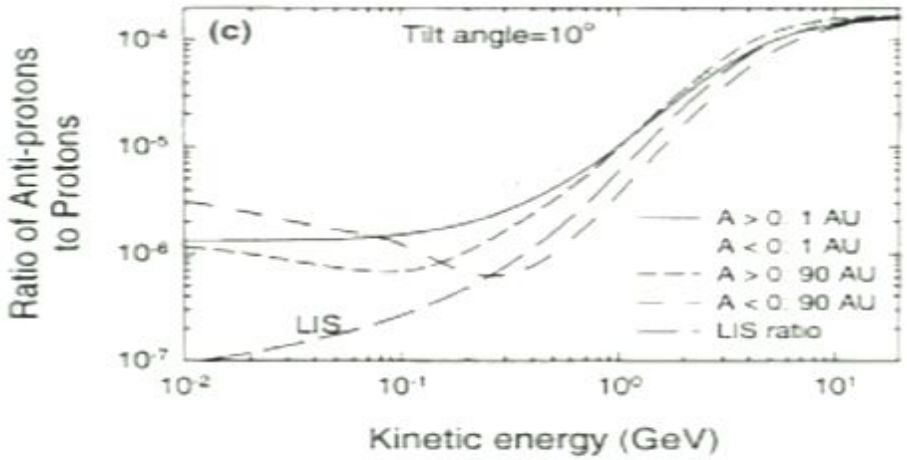

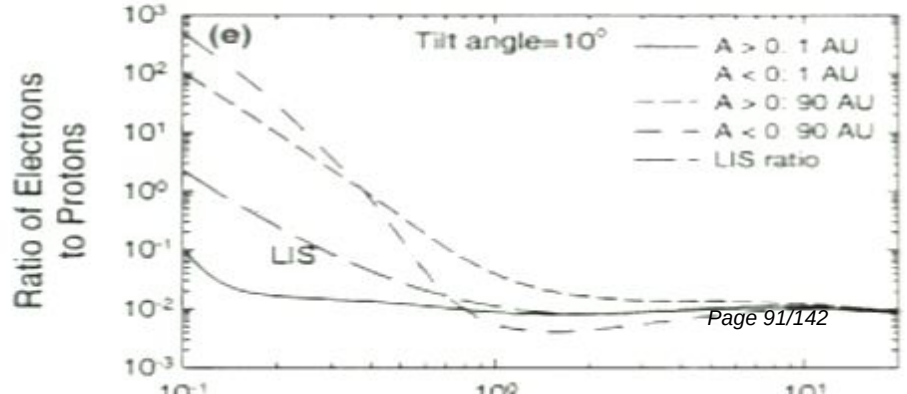

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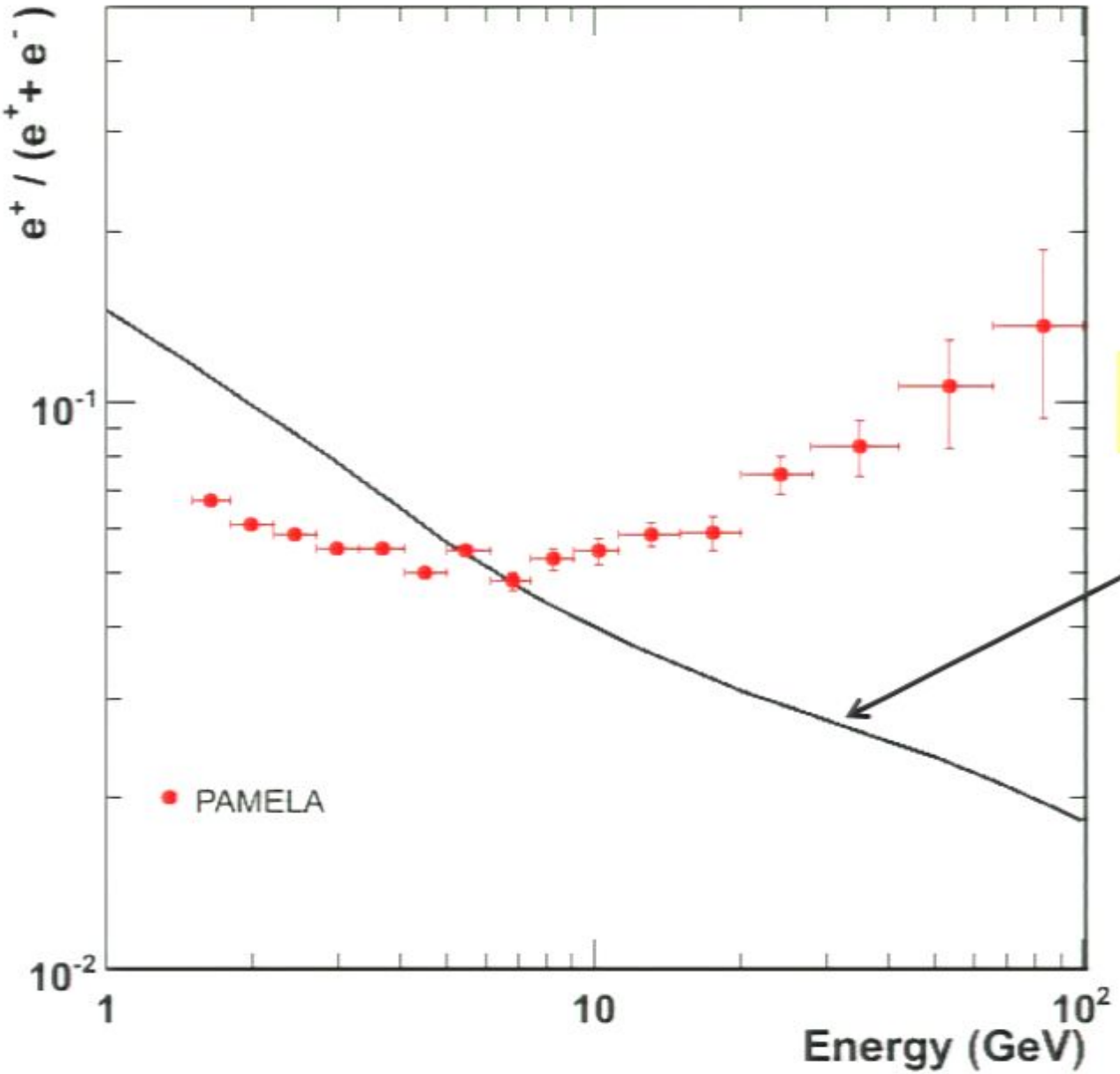
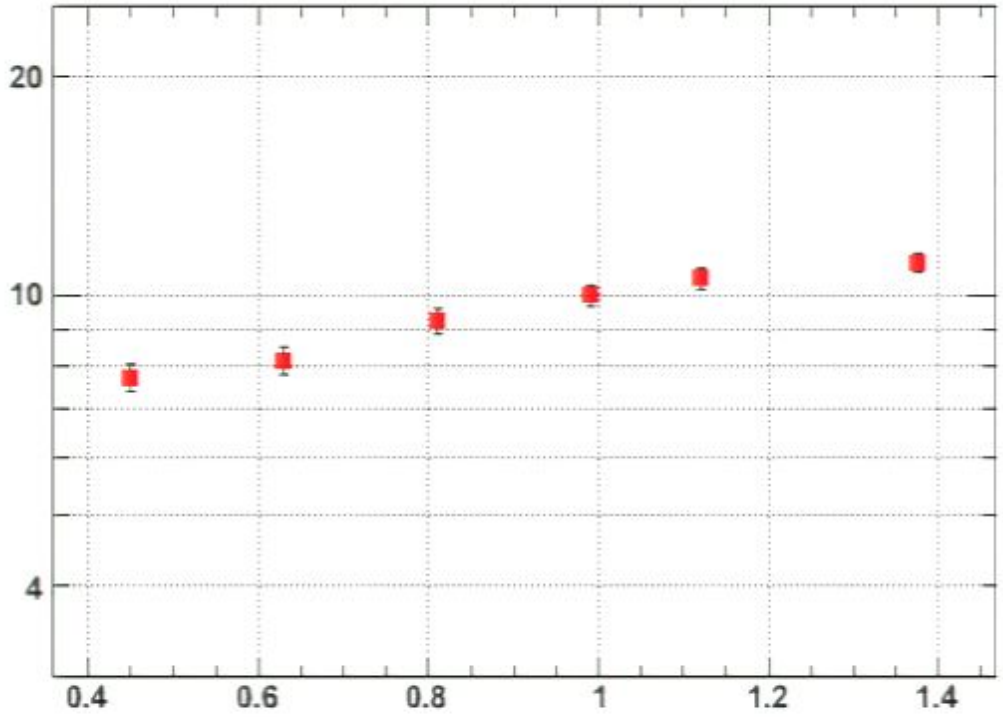


Secondary production
Moskalenko & Strong 98

Electron to positron ratio



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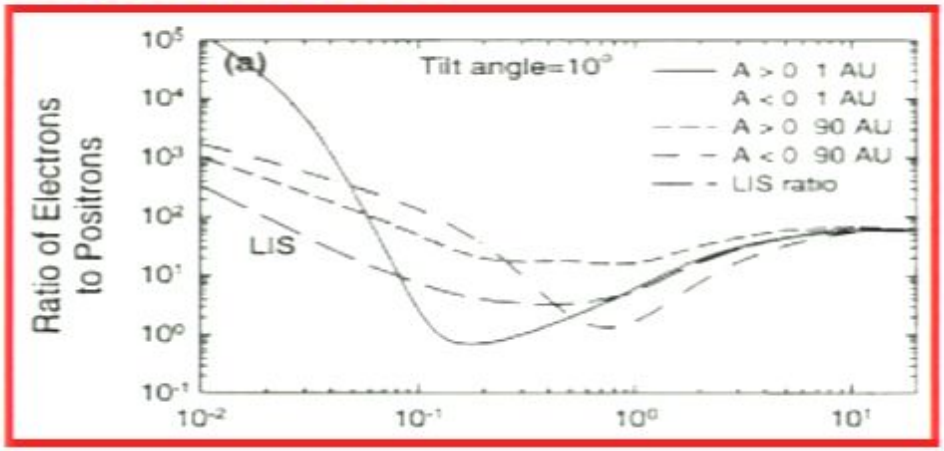
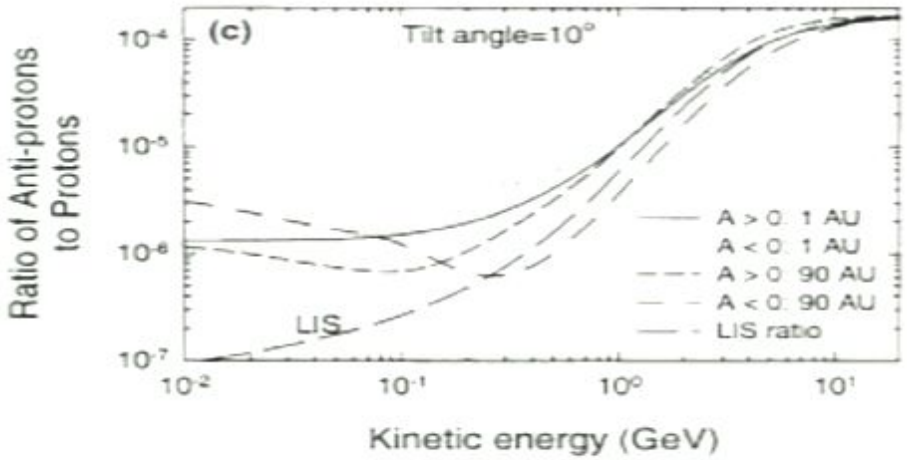
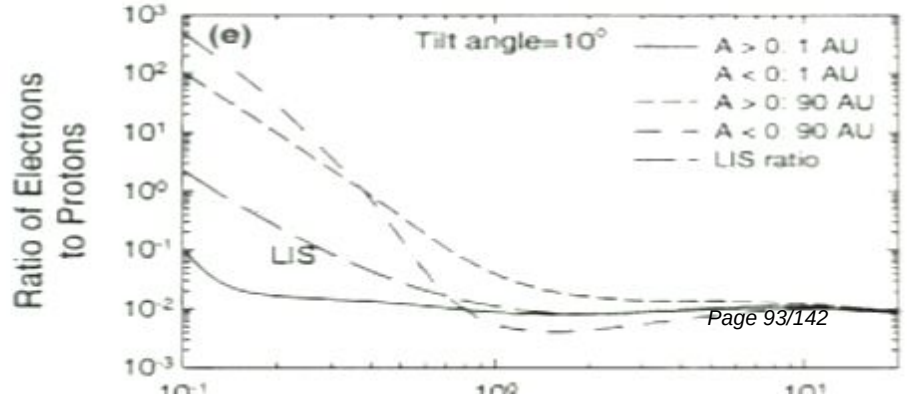
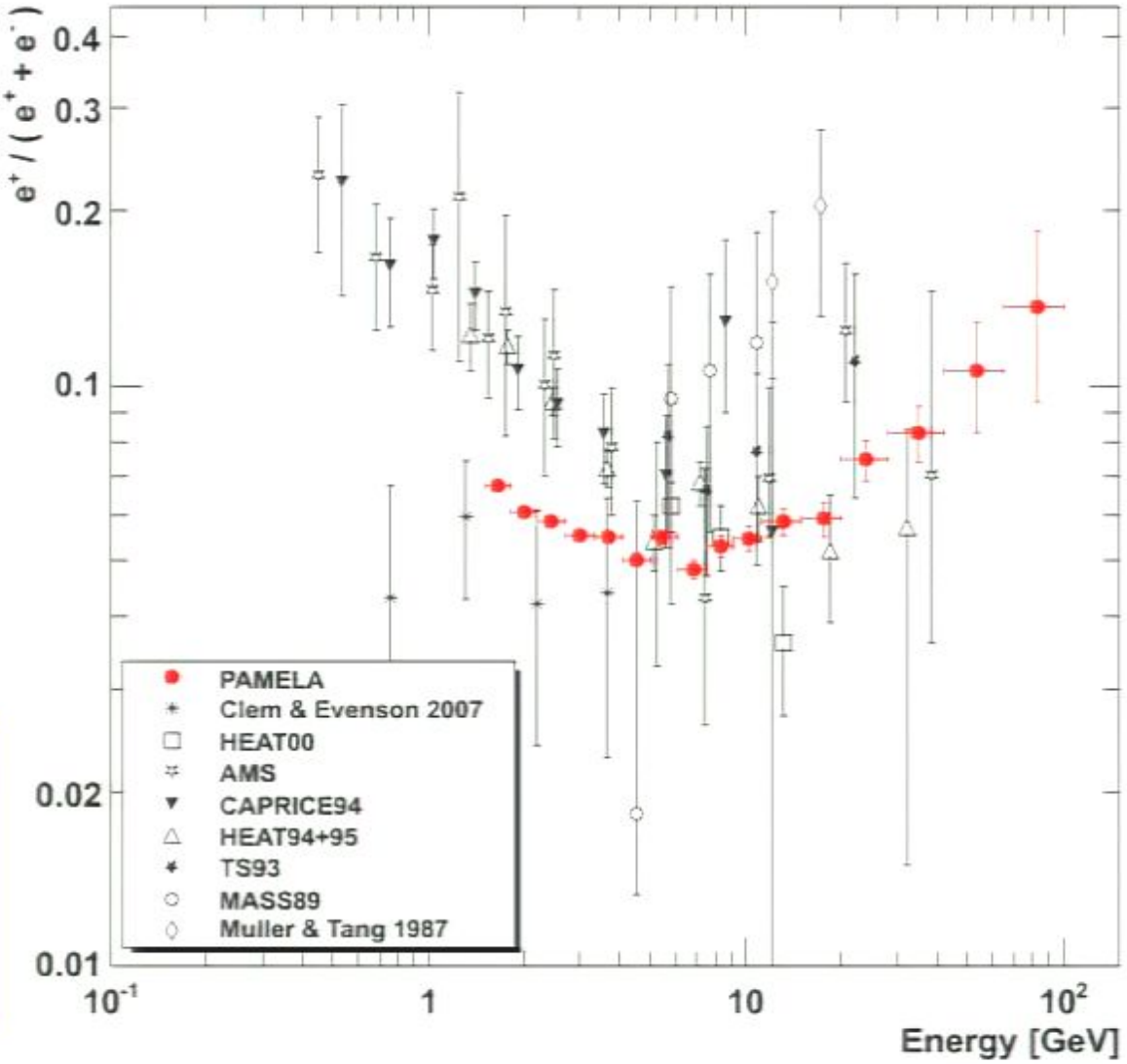






Positron to Electron Fraction

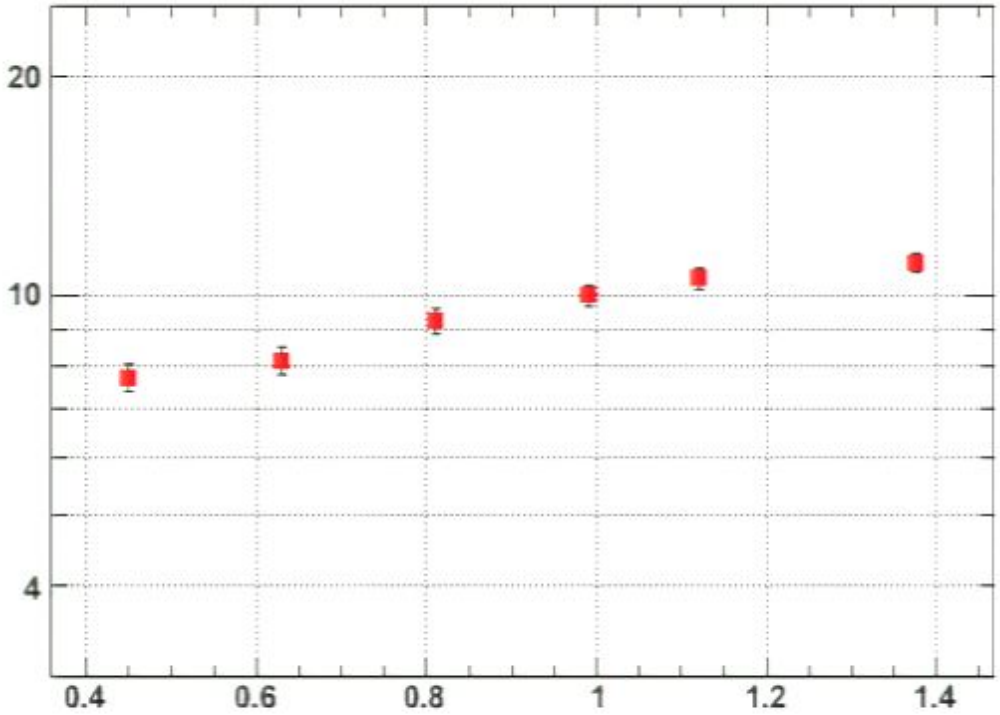


End 2007:
~10 000 e^+ > 1.5 GeV

~2000 > 5 GeV

Astro-ph 0810.4995

Electron to positron ratio



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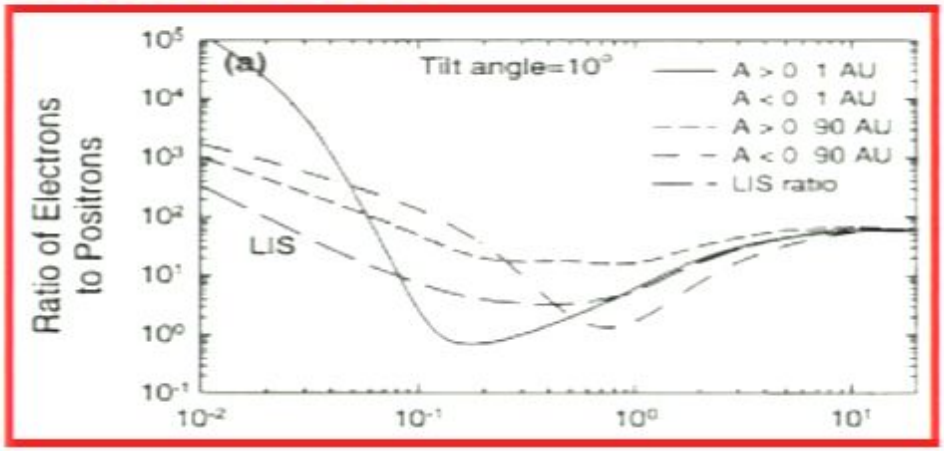

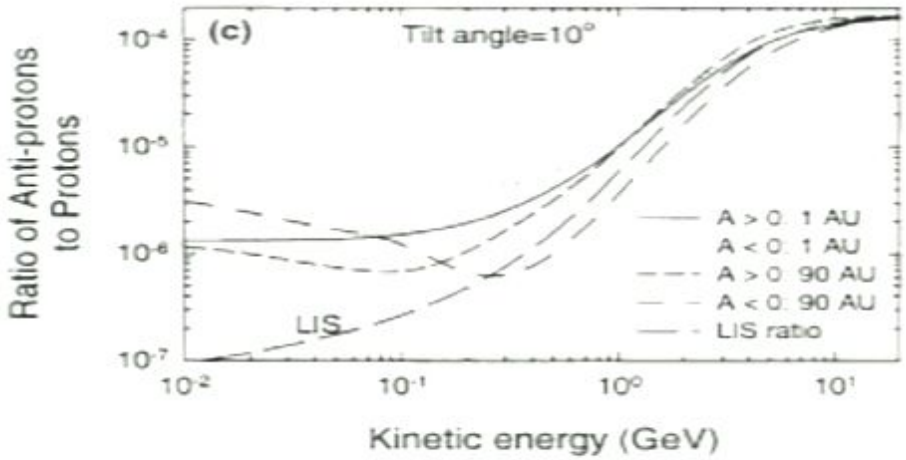

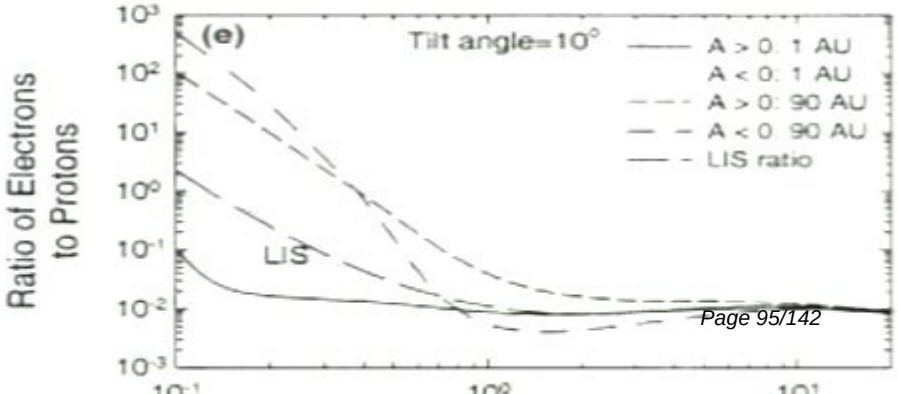

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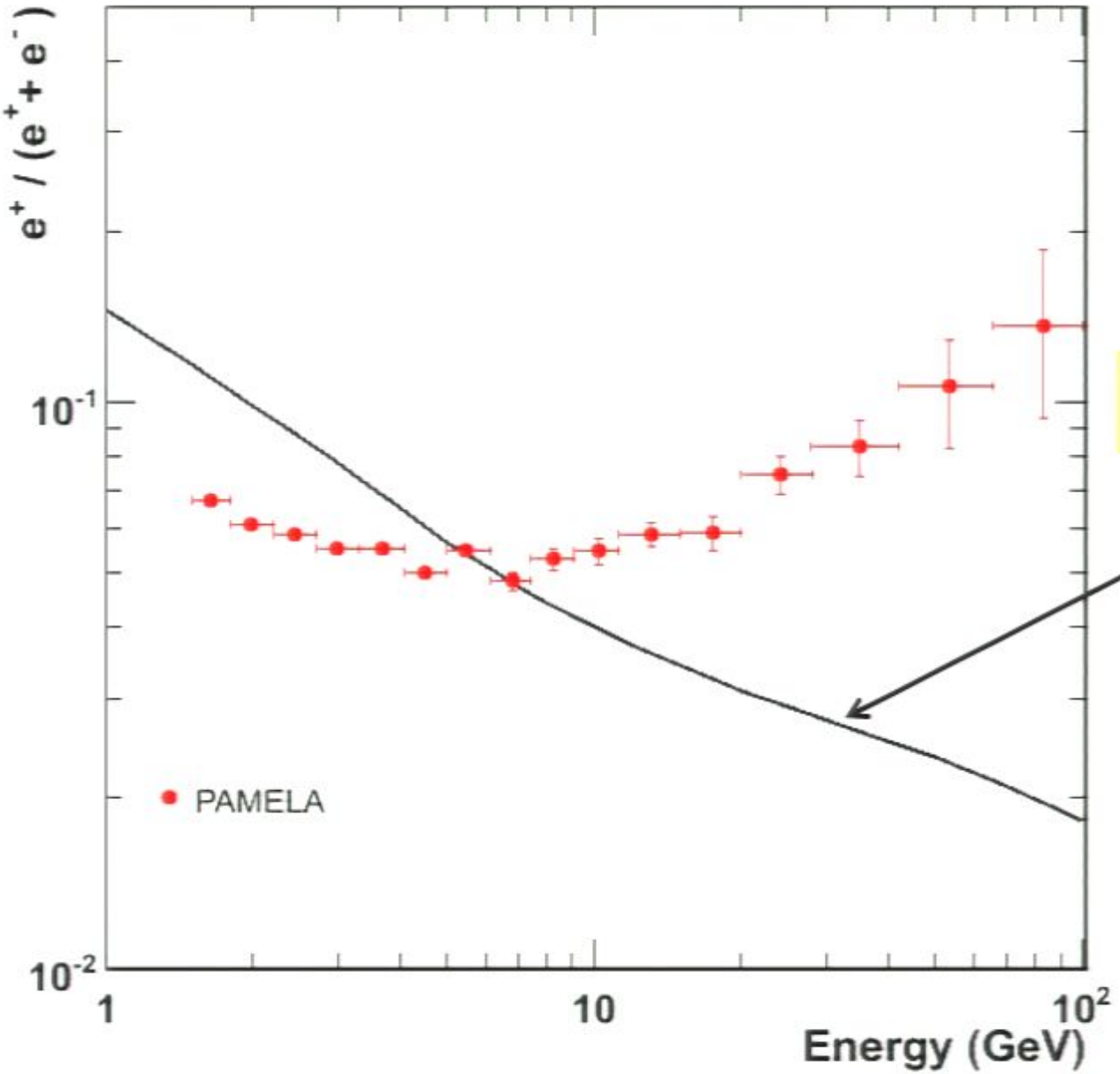

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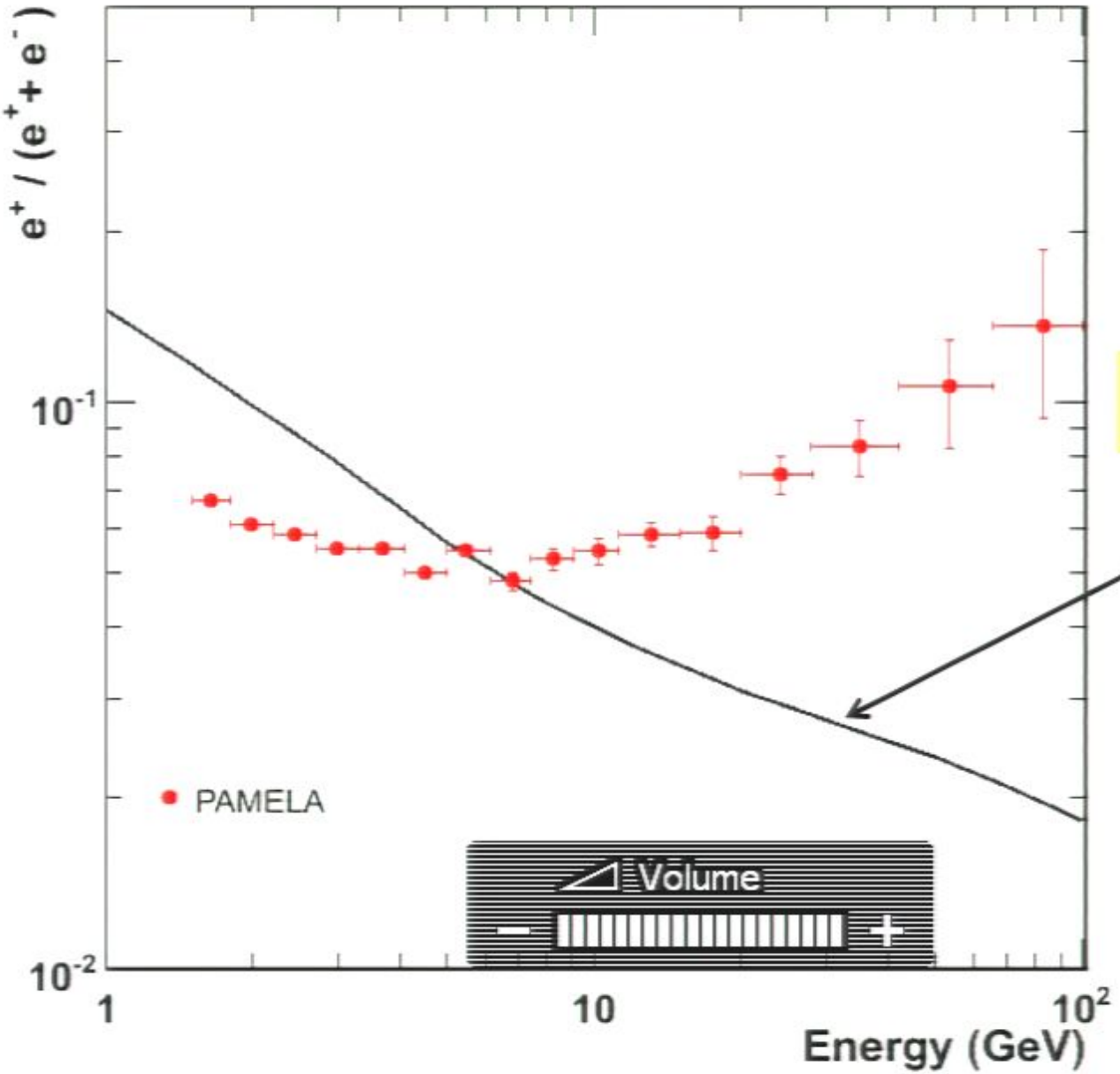
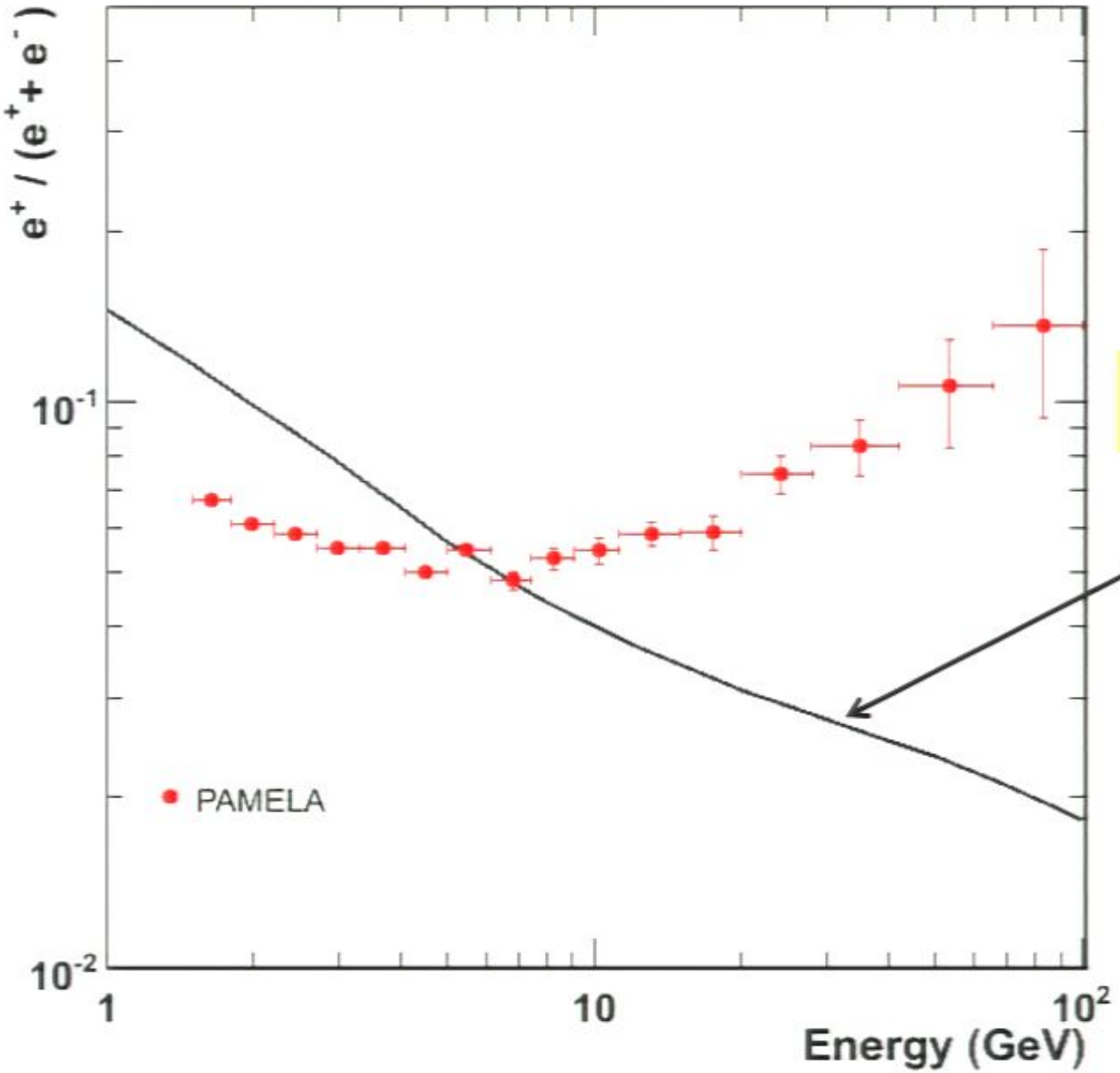
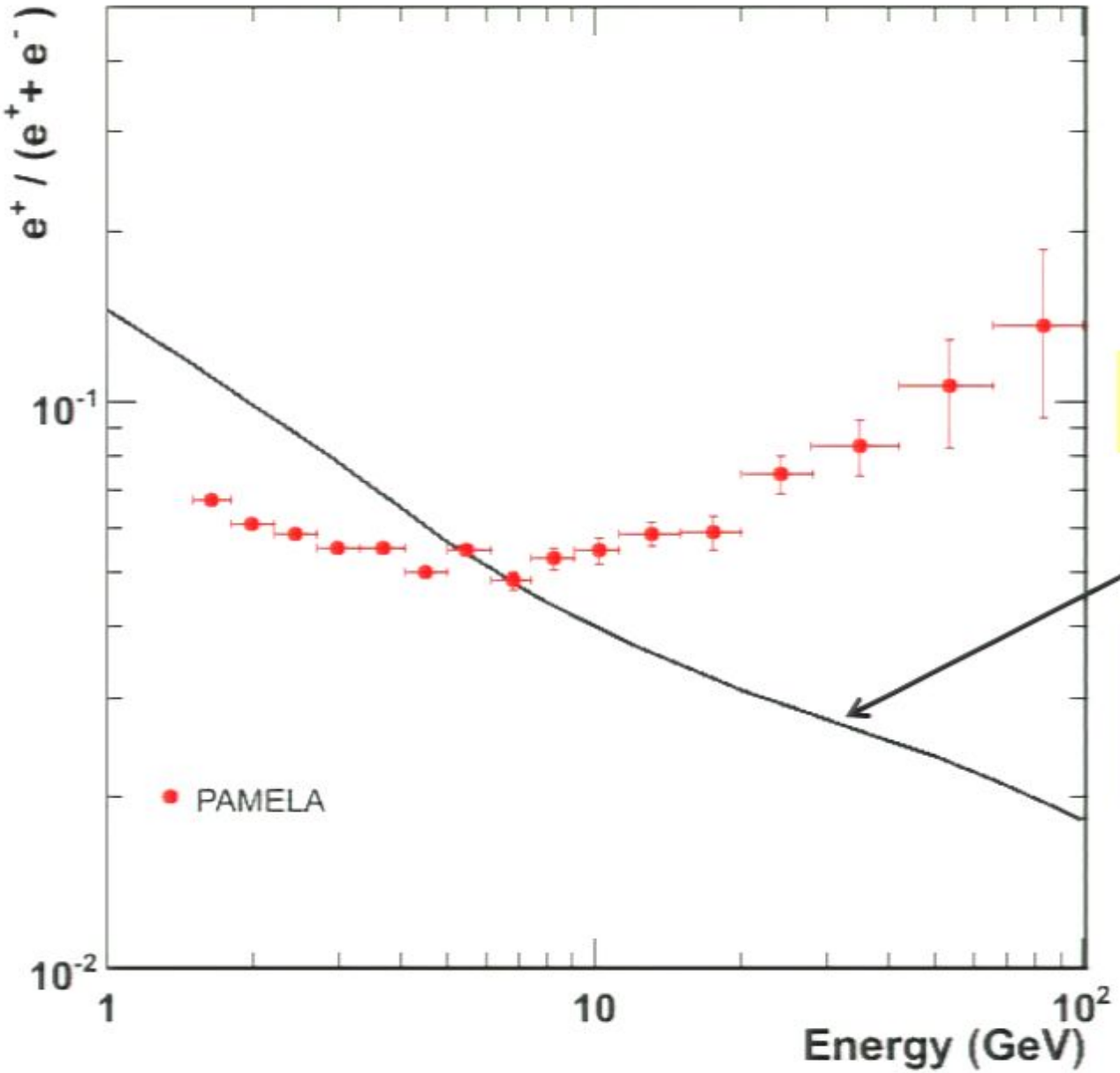


Secondary production
Moskalenko & Strong 98

PAMELA Positron Fraction



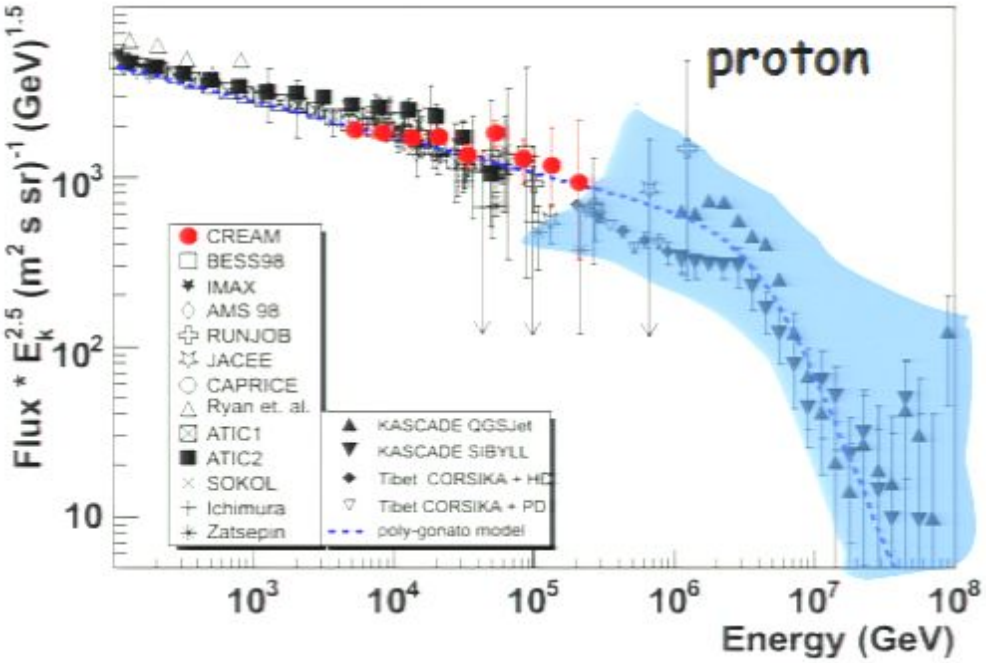
PAMELA Positron Fraction

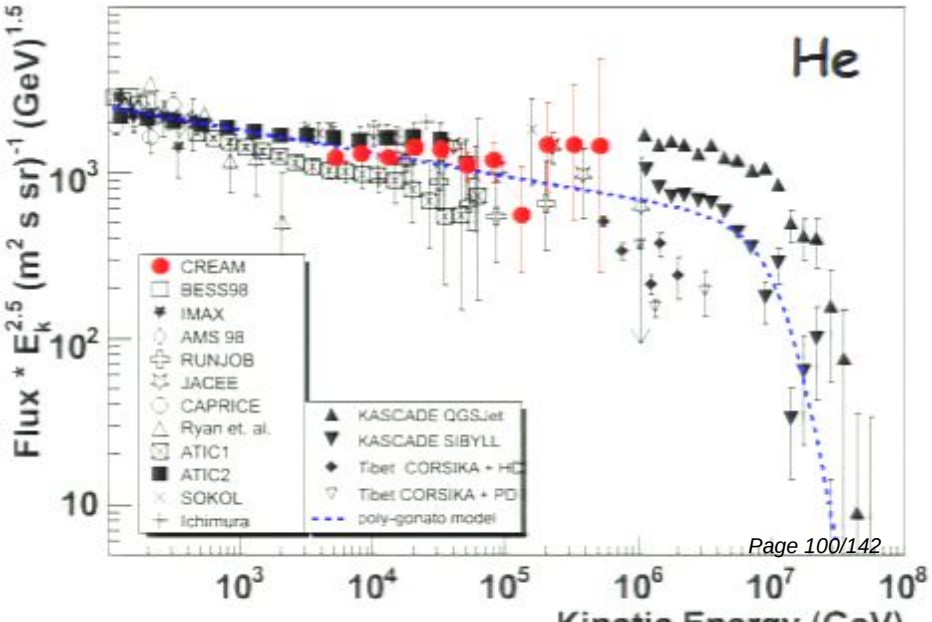


Secondary production
Moskalenko & Strong 98

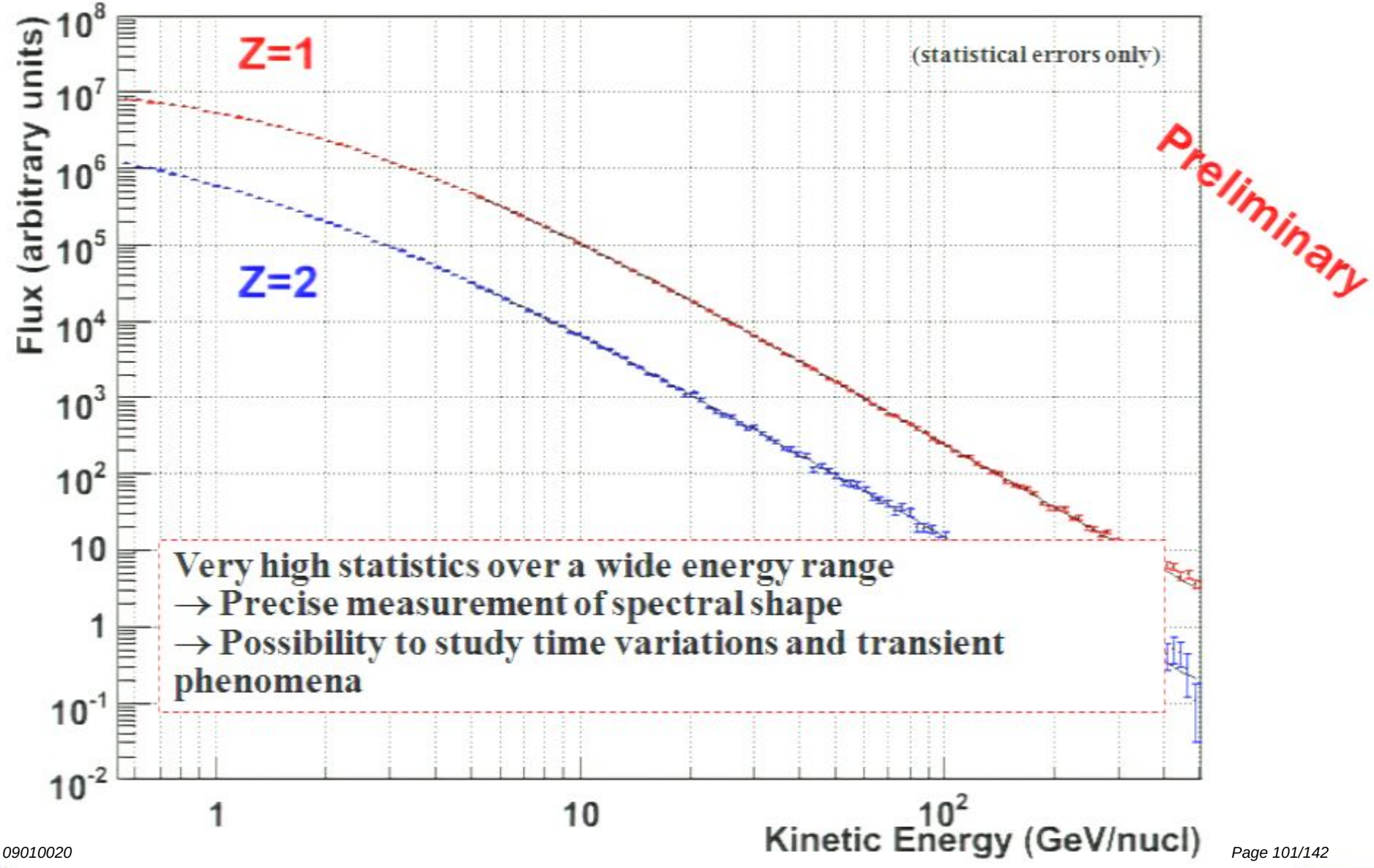
But uncertainties on:
- **Secondary production (primary fluxes, cross section)**

Galactic H and He spectra





Galactic H and He spectra



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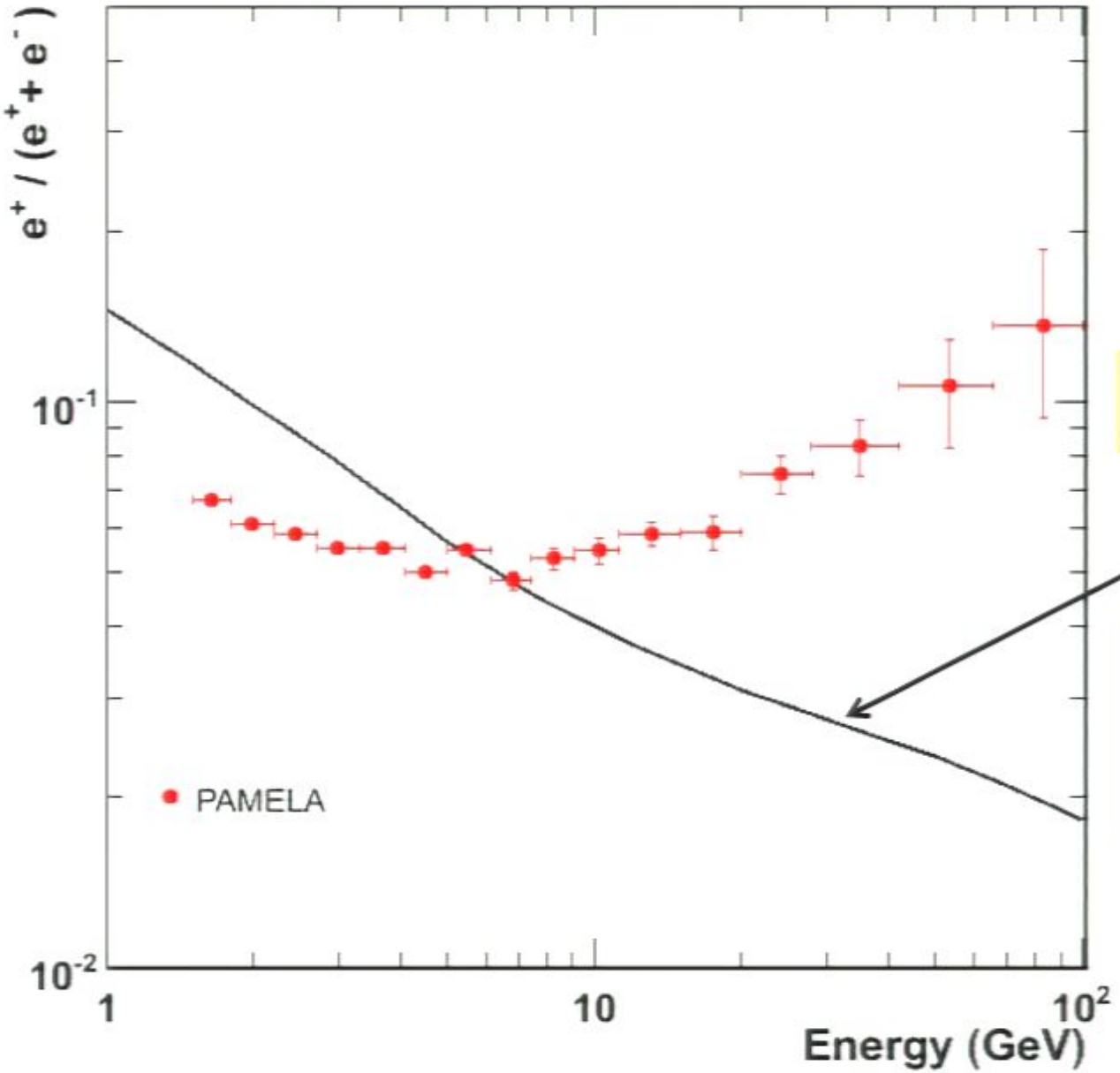
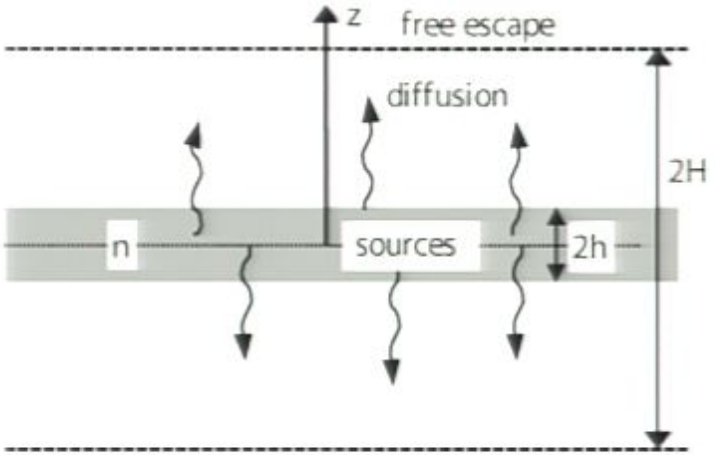


Secondary production
Moskalenko & Strong 98

But uncertainties on:
- **Secondary production (primary fluxes, cross section)**
- **Propagation models**

Diffusion Halo Model

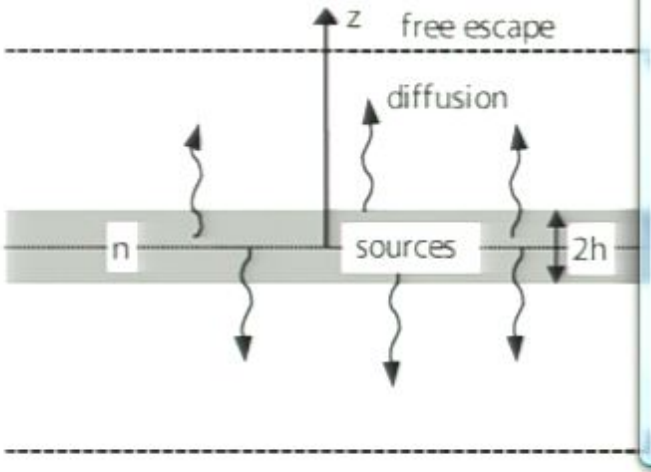
$$\frac{\partial N_i(E,z,t)}{\partial t} = \underbrace{D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t)}_{\text{diffusion}} \underbrace{- N_i(E,z,t)\left\{\frac{1}{\tau_i^{\text{int}}(E,z)} + \frac{1}{\gamma(E)\tau_i^{\text{dec}}}\right\}}_{\text{interaction and decay}}$$

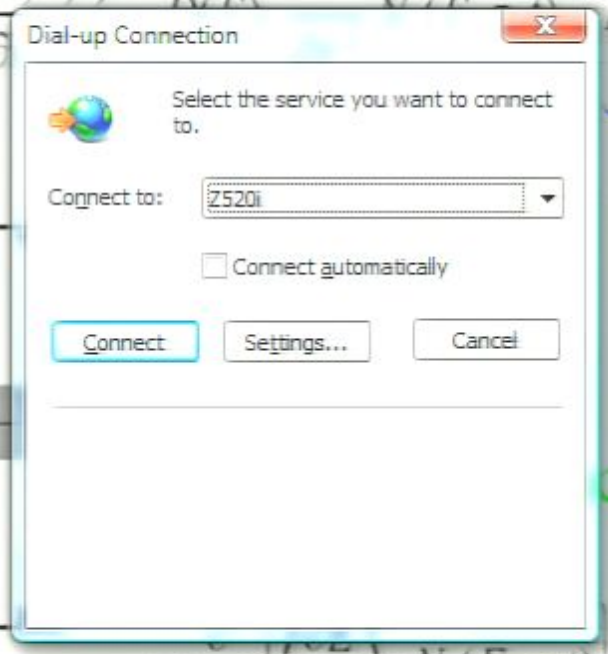


$$+ \underbrace{\sum_{A>A_i} \frac{N_A(E,z,t)}{\tau_{\text{int}}^{A\to A_i}(E,z)}}_{\text{secondary production}} + \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

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

Diffusion Halo Model





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

$$+ \quad \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

ction

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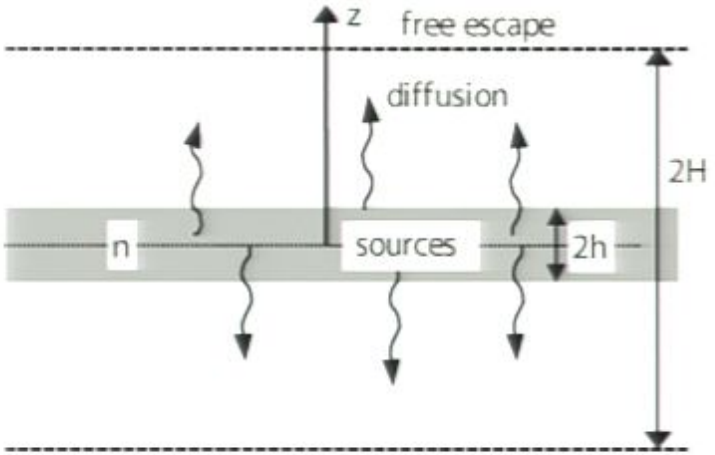
Diffusion Halo Model

$$\frac{\partial N_i(E,z,t)}{\partial t} = D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t) - N_i(E,z,t)\left\{\frac{1}{\tau_i^{\mathrm{int}}(E,z)} + \frac{1}{\gamma(E)\tau_i^{\mathrm{dec}}}\right\}$$

diffusion — interaction and decay



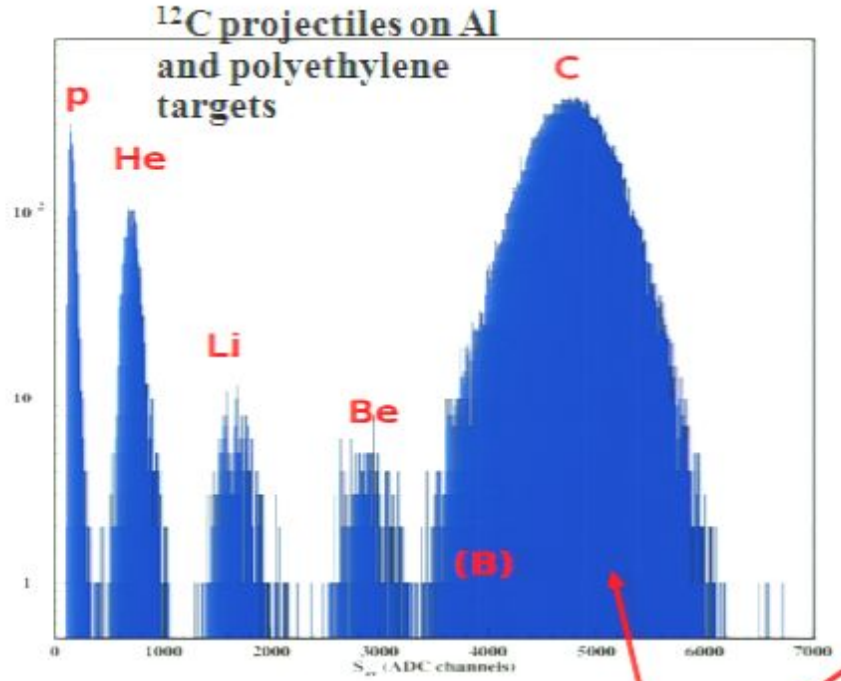
$$+ \sum_{k>i}\frac{N_k(E,z,t)}{\tau_{\mathrm{int}}^{k\to i}(E,z)} + Q_i(E,z)$$

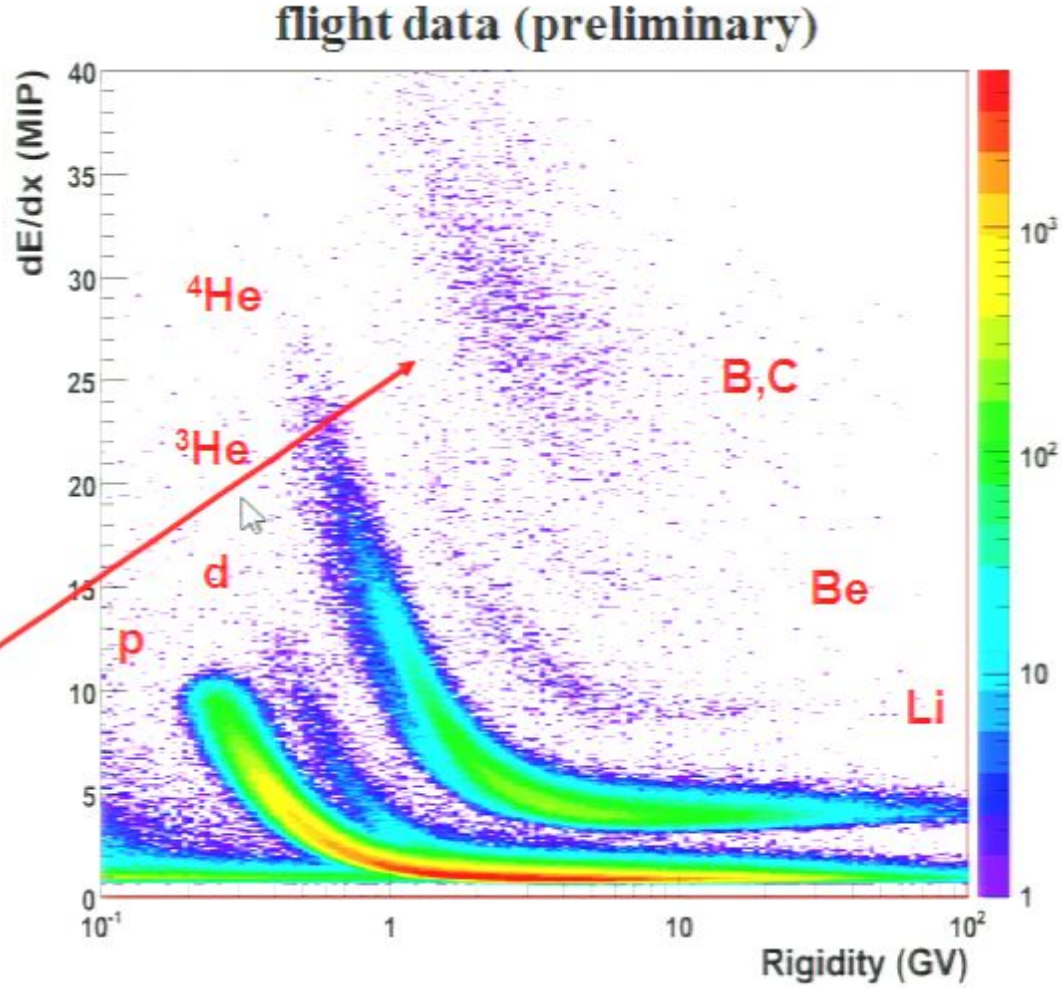
secondary production — primary sources

$$-\frac{\partial}{\partial E}\left\{\left\langle\frac{\partial E}{\partial t}\right\rangle\cdot N_i(E,z,t)\right\} + \frac{1}{2}\frac{\partial^2}{\partial E^2}\left\{\left\langle\frac{\Delta E^2}{\Delta t}\right\rangle\cdot N_i(E,z,t)\right\}$$

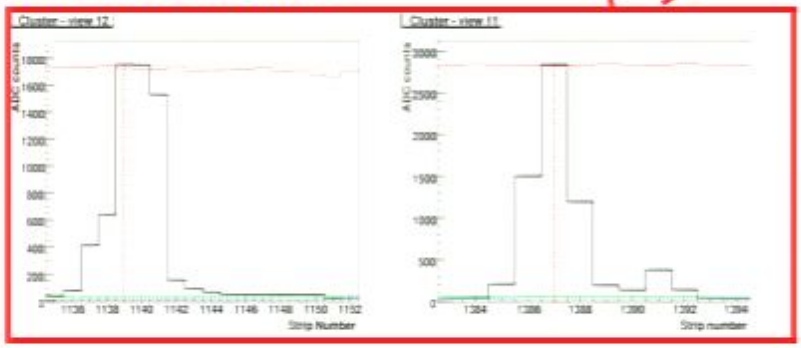
energy changing processes
(ionisation, reacceleration)

Charge identification capabilities (tracker)



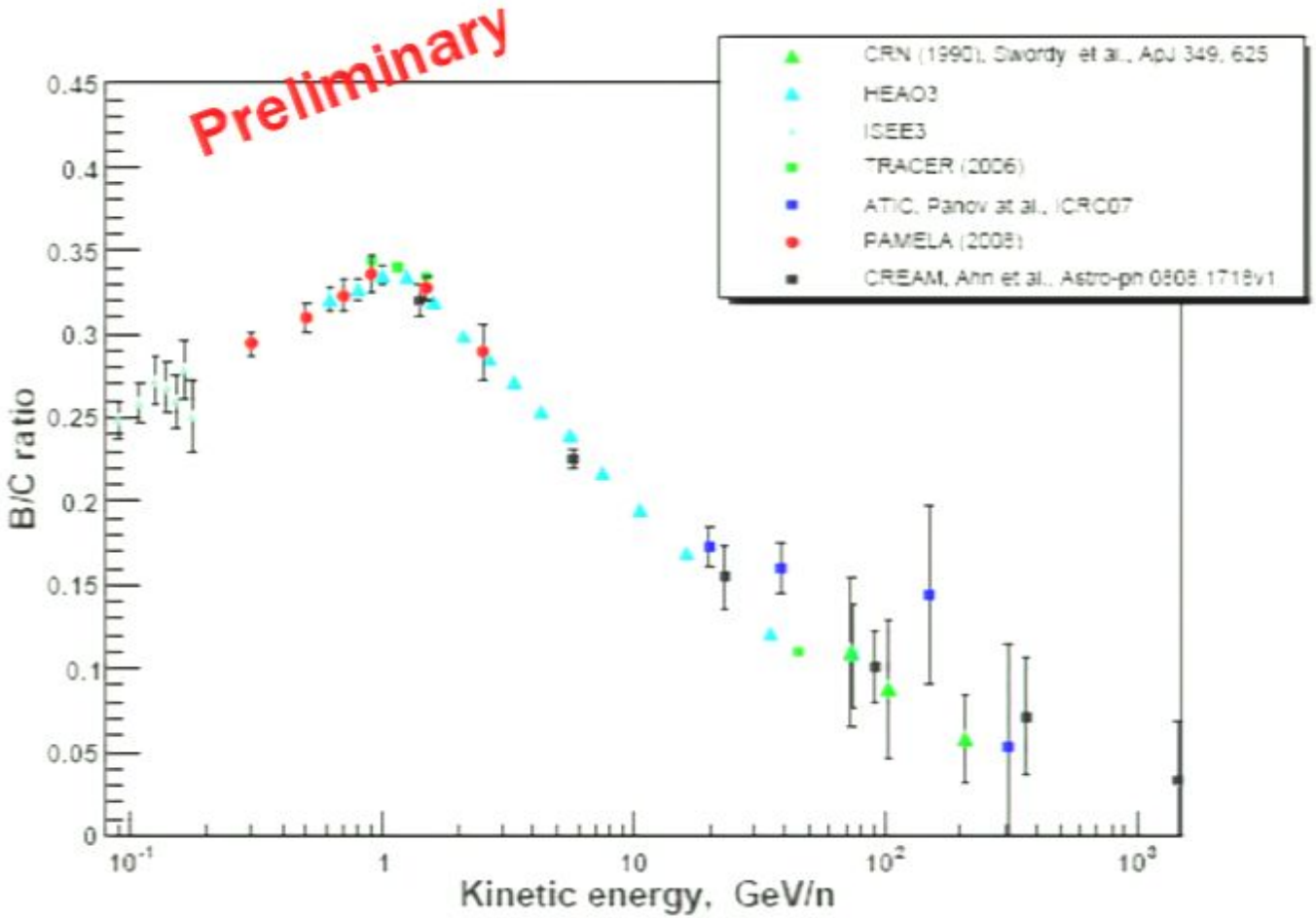


Saturated clusters



- Good charge discrimination of H and He

Secondary nuclei



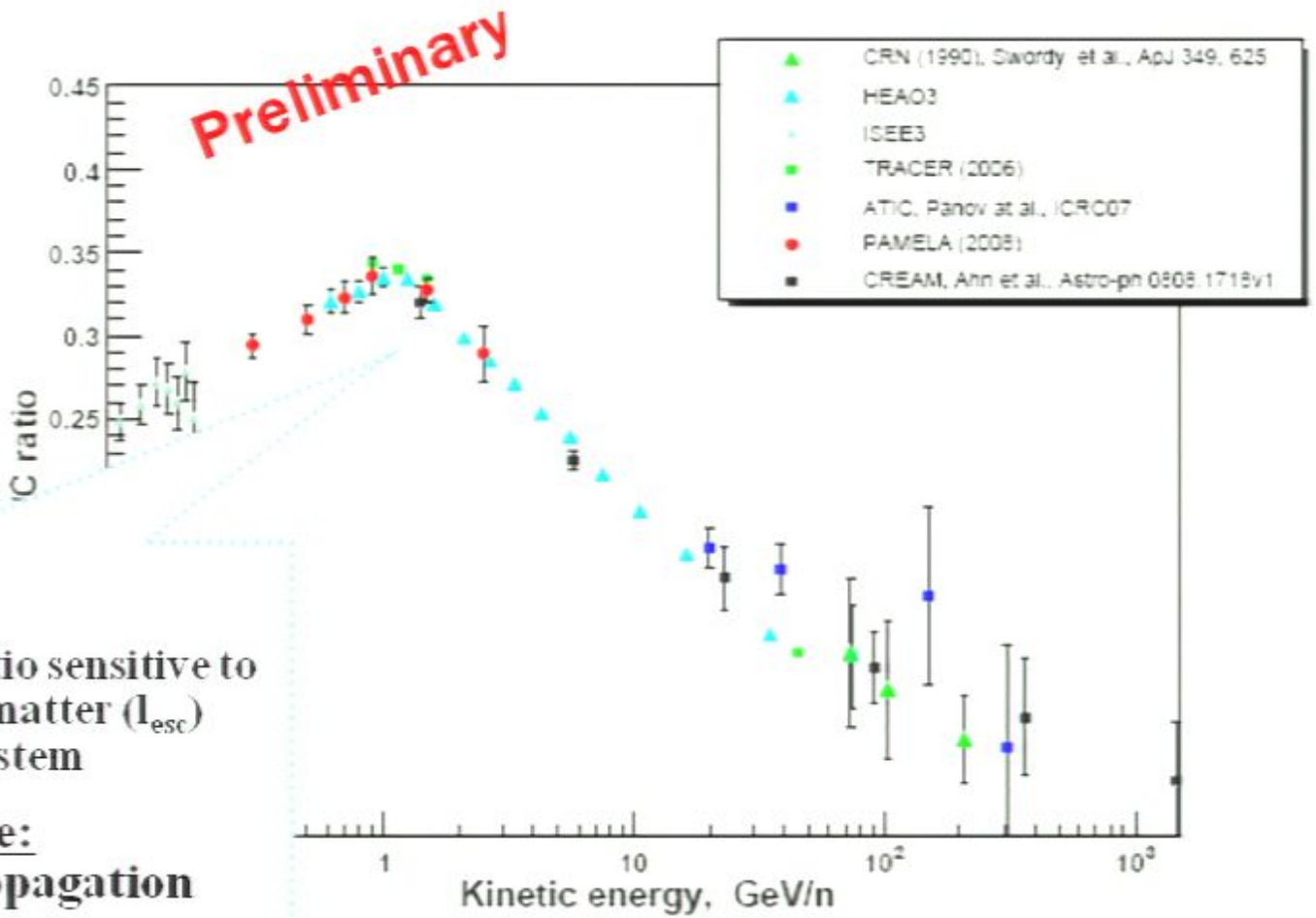
Secondary nuclei

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

- 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)



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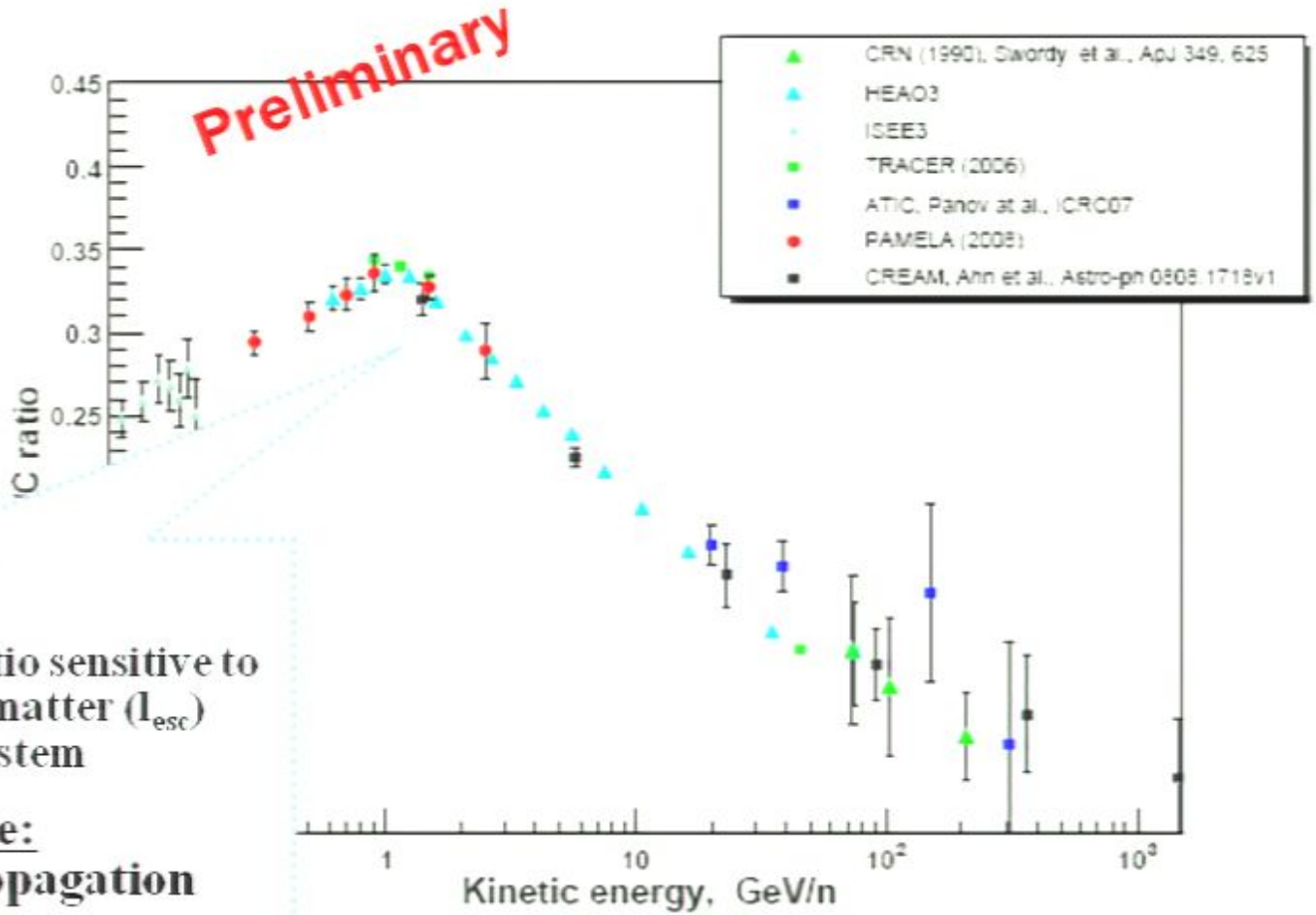

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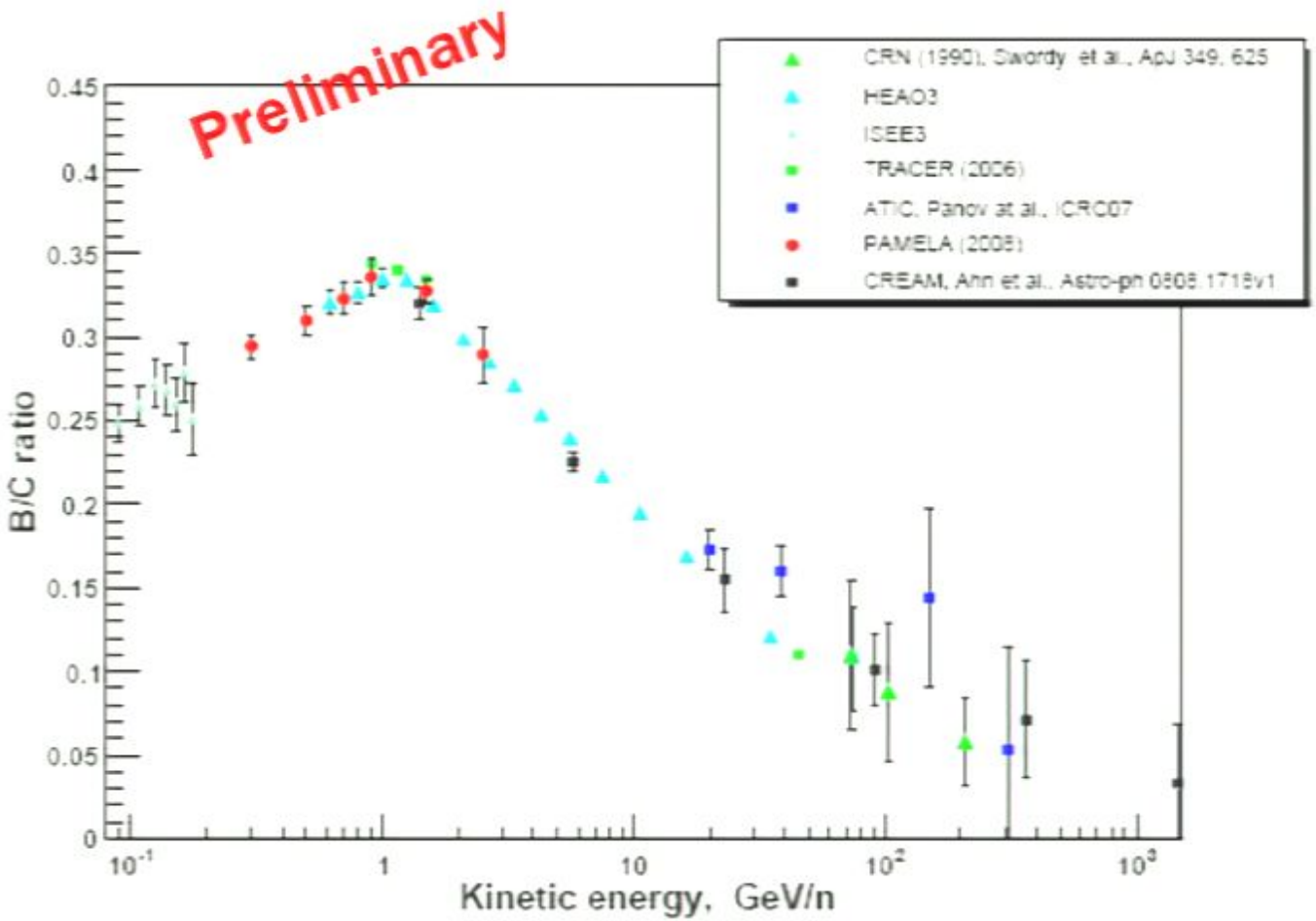

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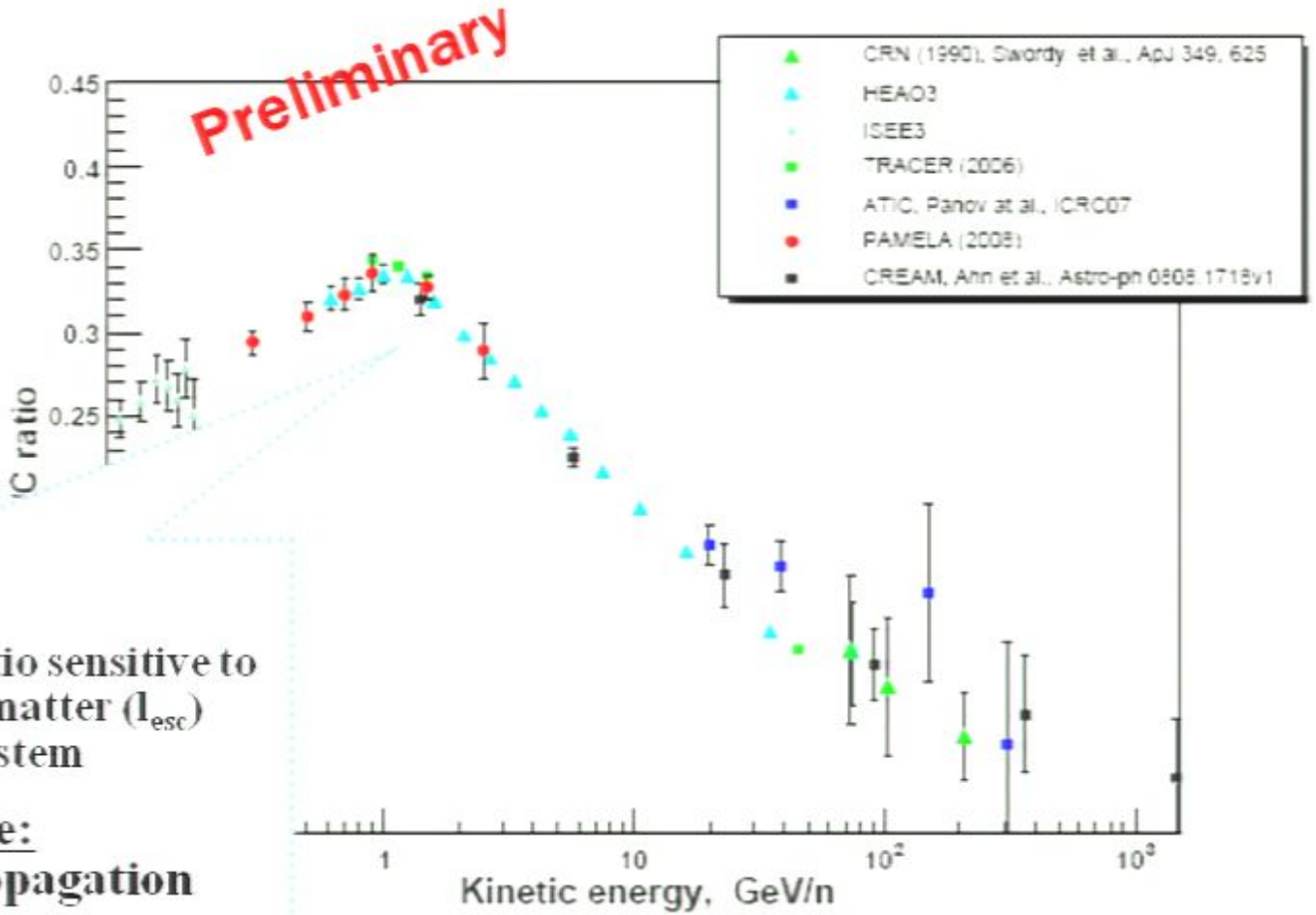
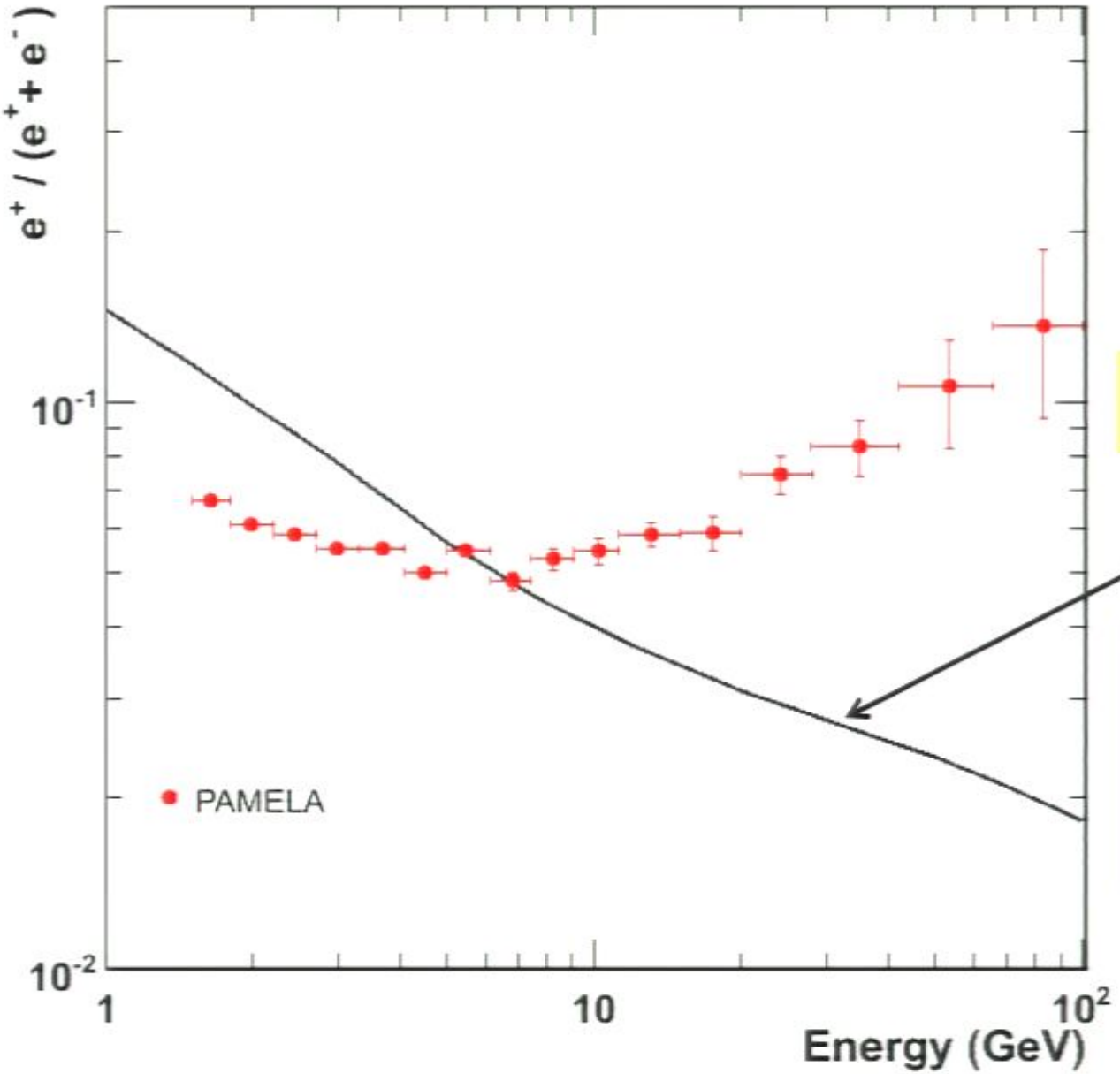
⇒ study of galactic CR propagation

(B/C used for tuning of propagation models)



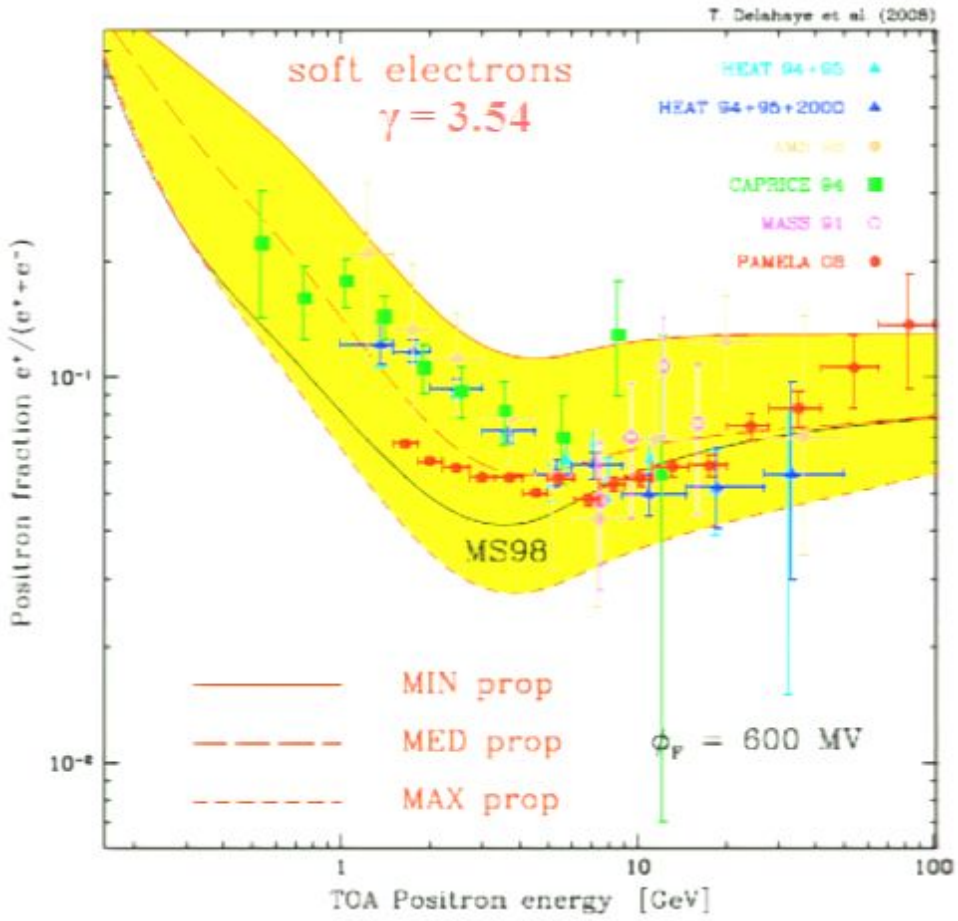
PAMELA Positron Fraction

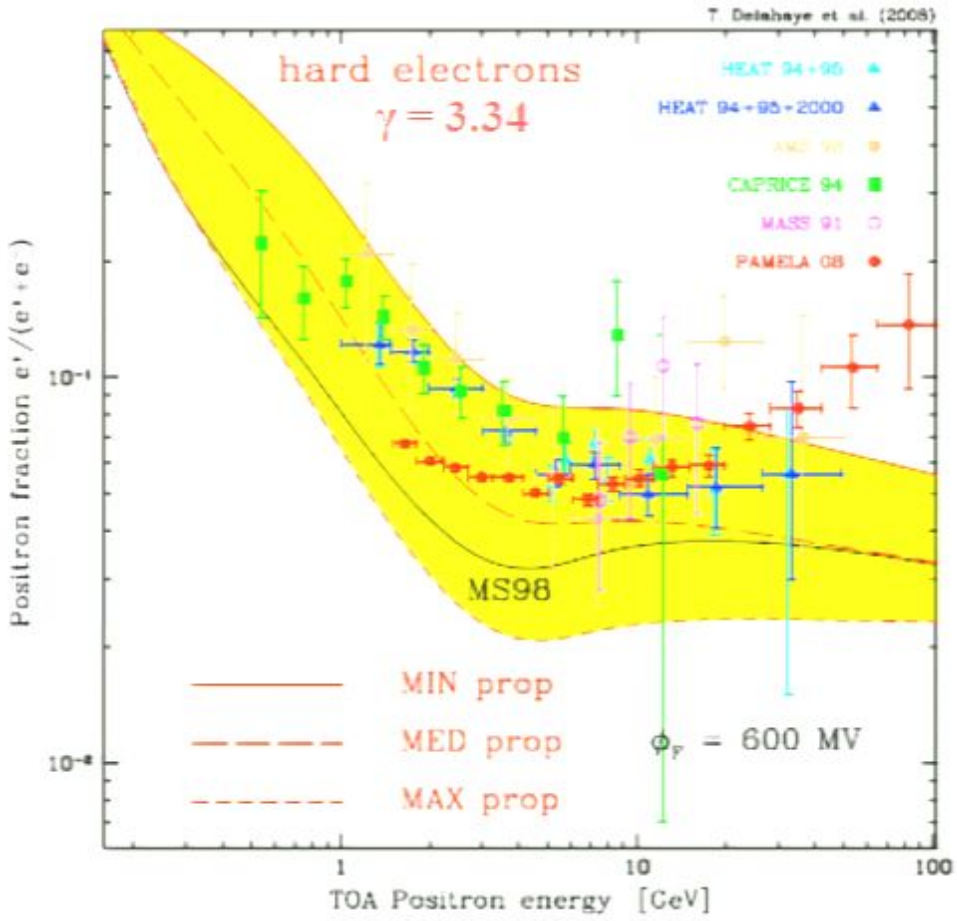


Secondary production
Moskalenko & Strong 98

But uncertainties on:
- **Secondary production (primary fluxes, cross section)**
- **Propagation models**
- **Electron spectrum**

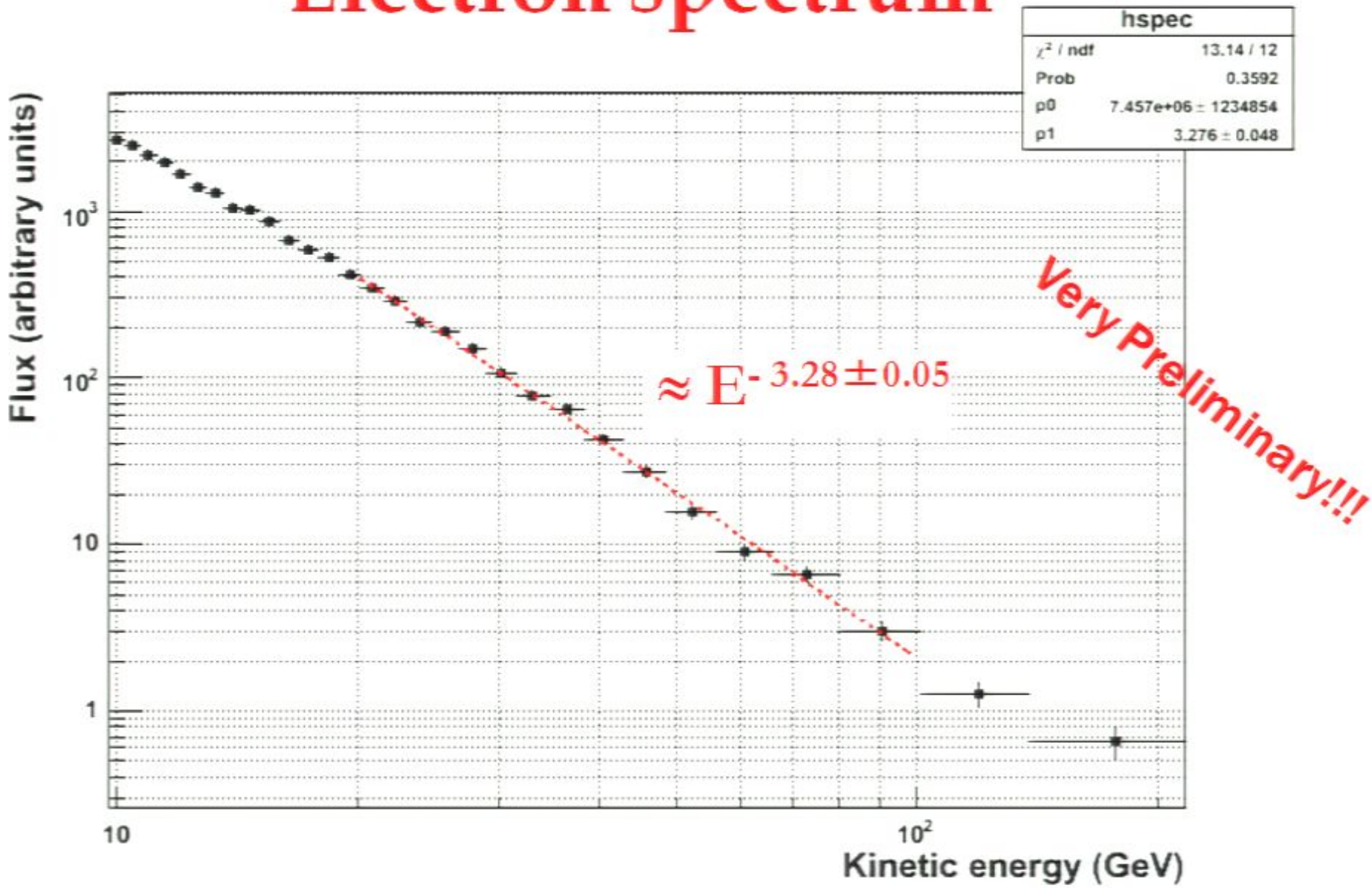
Theoretical uncertainties on "standard" positron fraction





T. Delahaye et al., arXiv: 0809.5268v3

Electron spectrum



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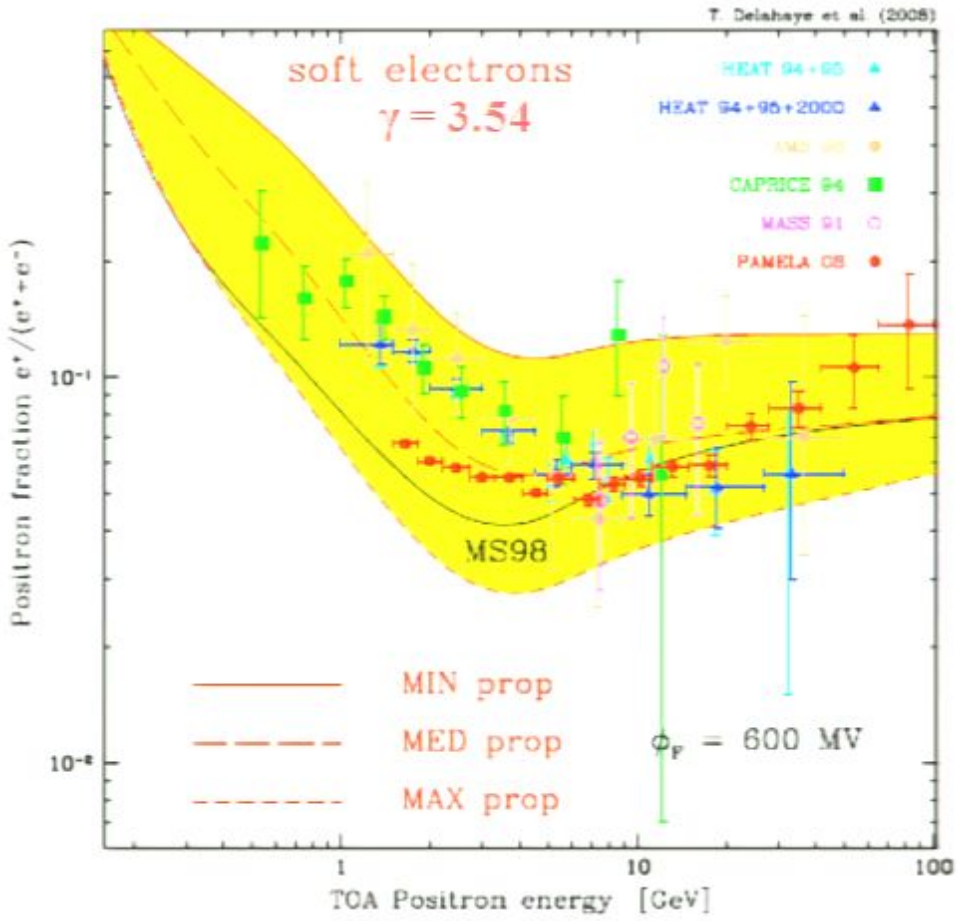
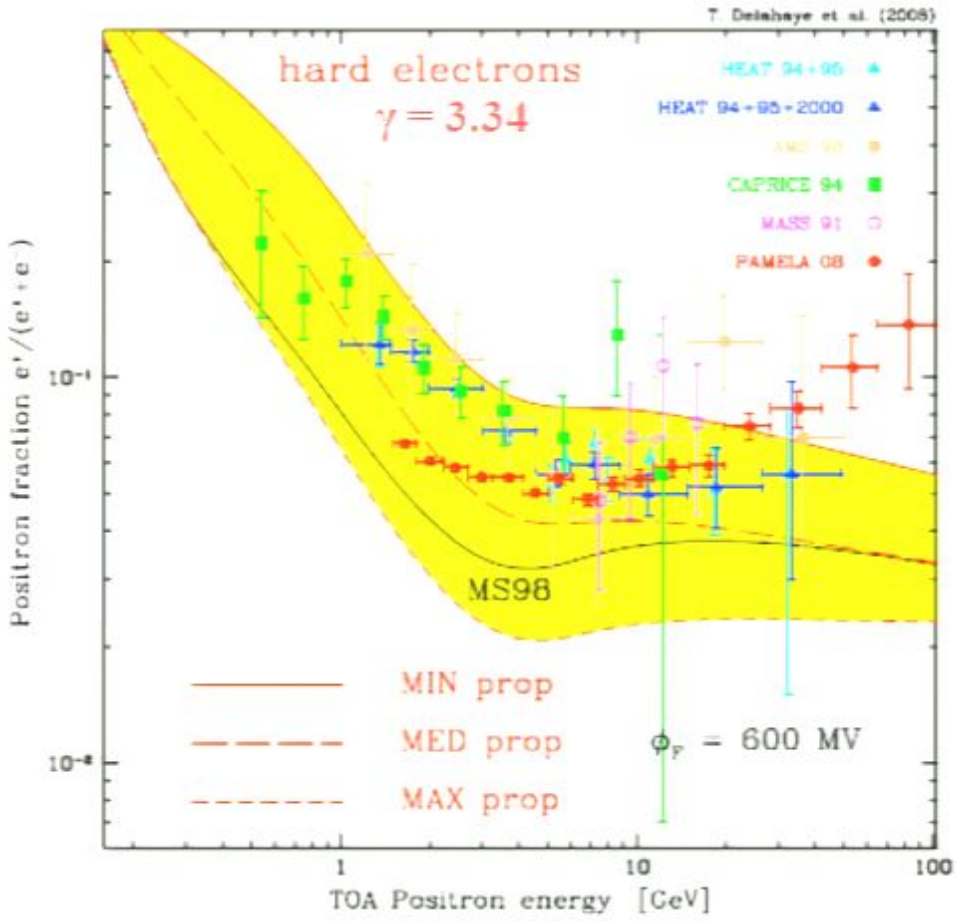
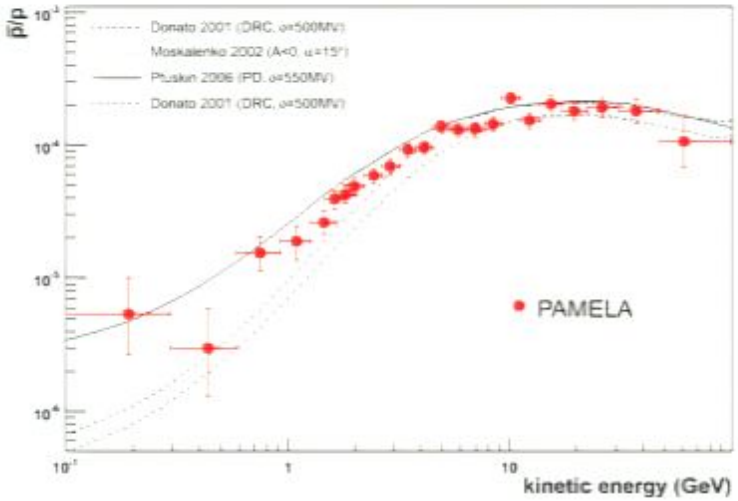




T. Delahaye et al., arXiv: 0809.5268v3

During first week after PAMELA results posted on arXiv

arXiv 0810.4994, accepted for publication in PRL



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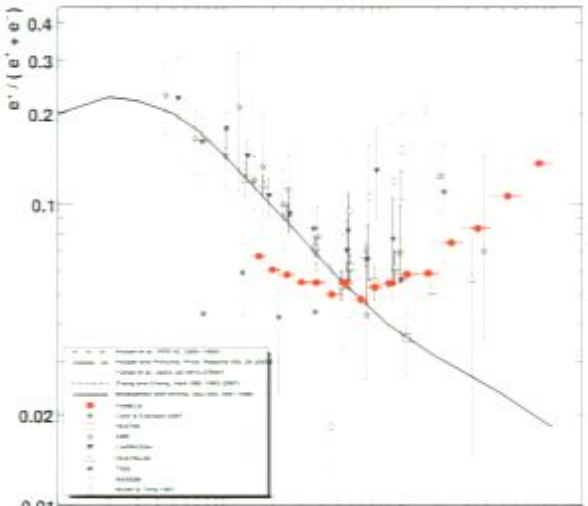

- 0808.3725 DM
- 0808.3867 DM
- 0809.2409 DM
- 0810.2784 Pulsar
- 0810.4846 DM / pulsar
- 0810.5292 DM
- 0810.5344 DM
- 0810.5167 DM
- 0810.5304 DM
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- 0811.0250 DM
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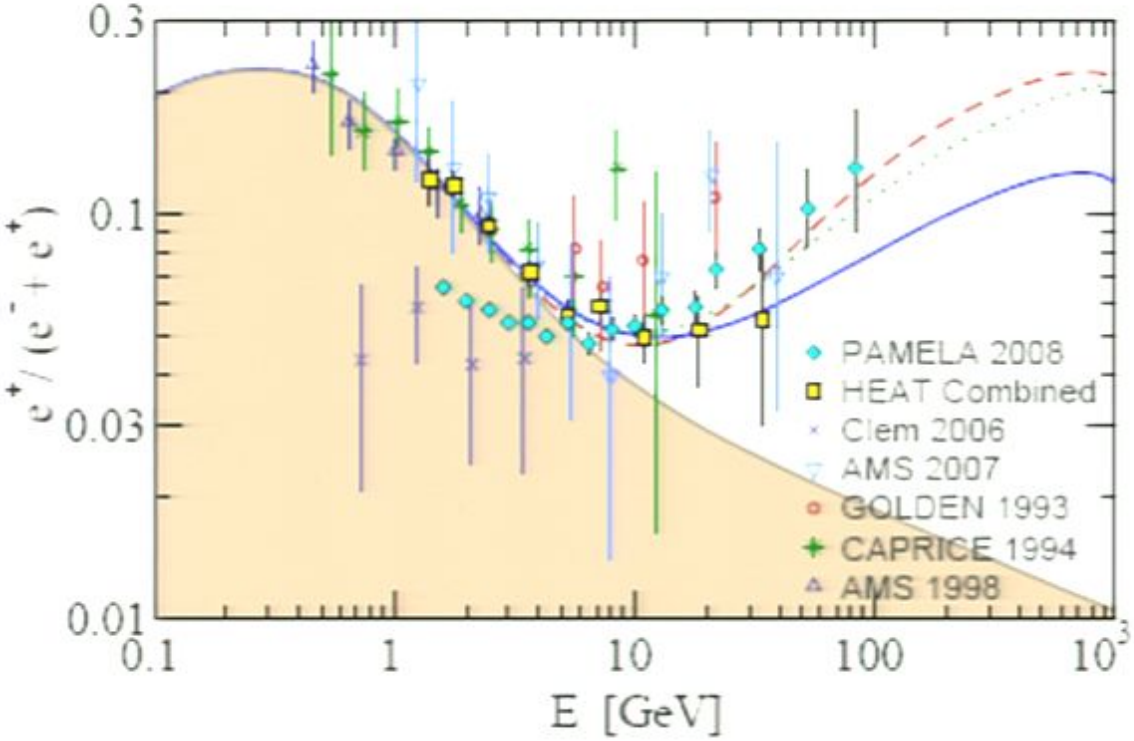
Example: pulsars



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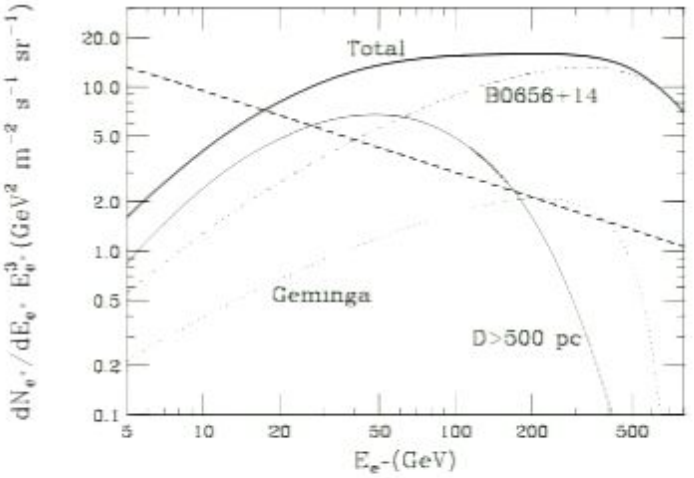

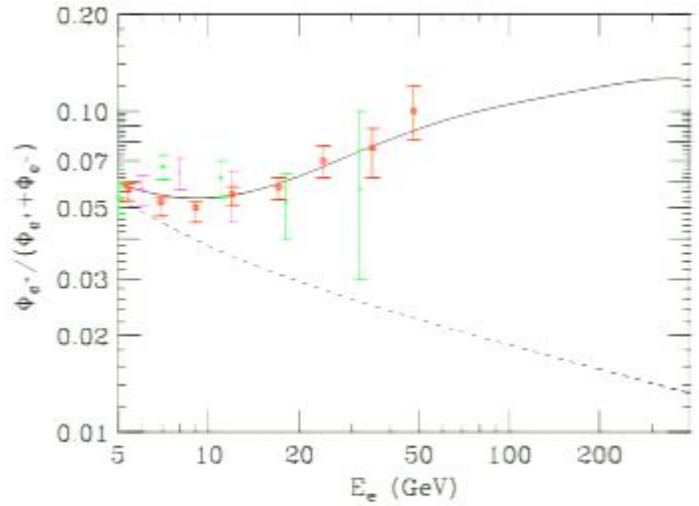

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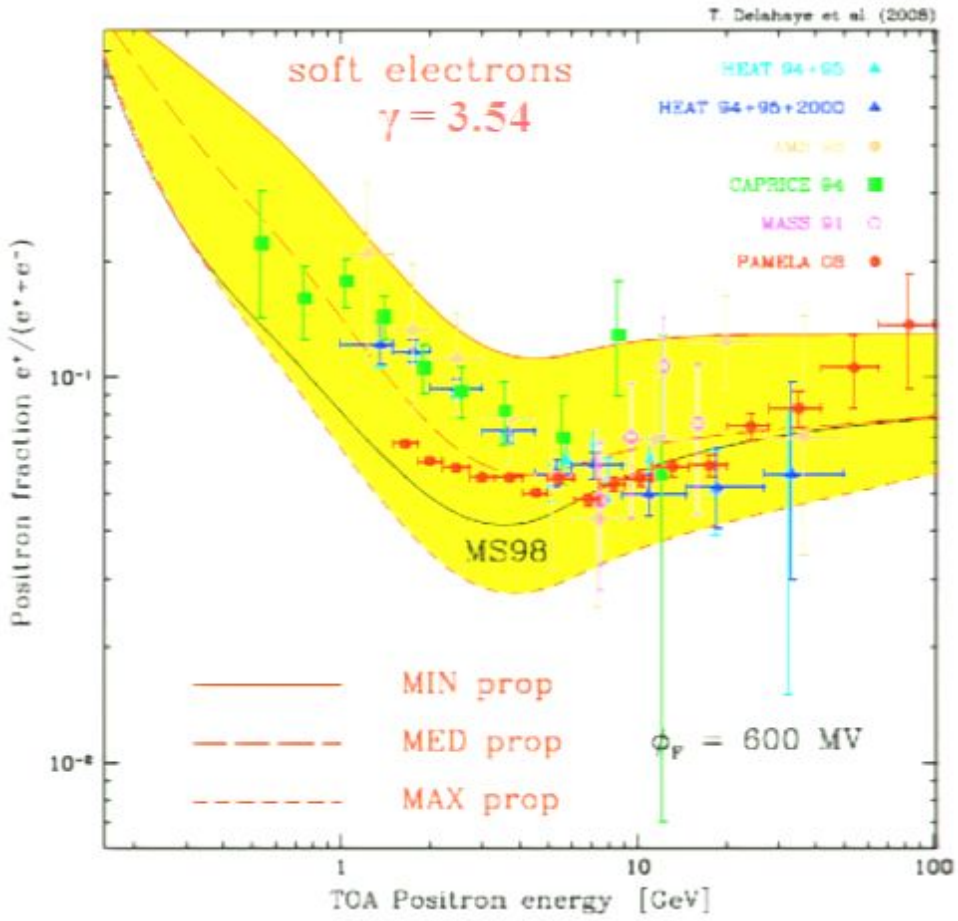

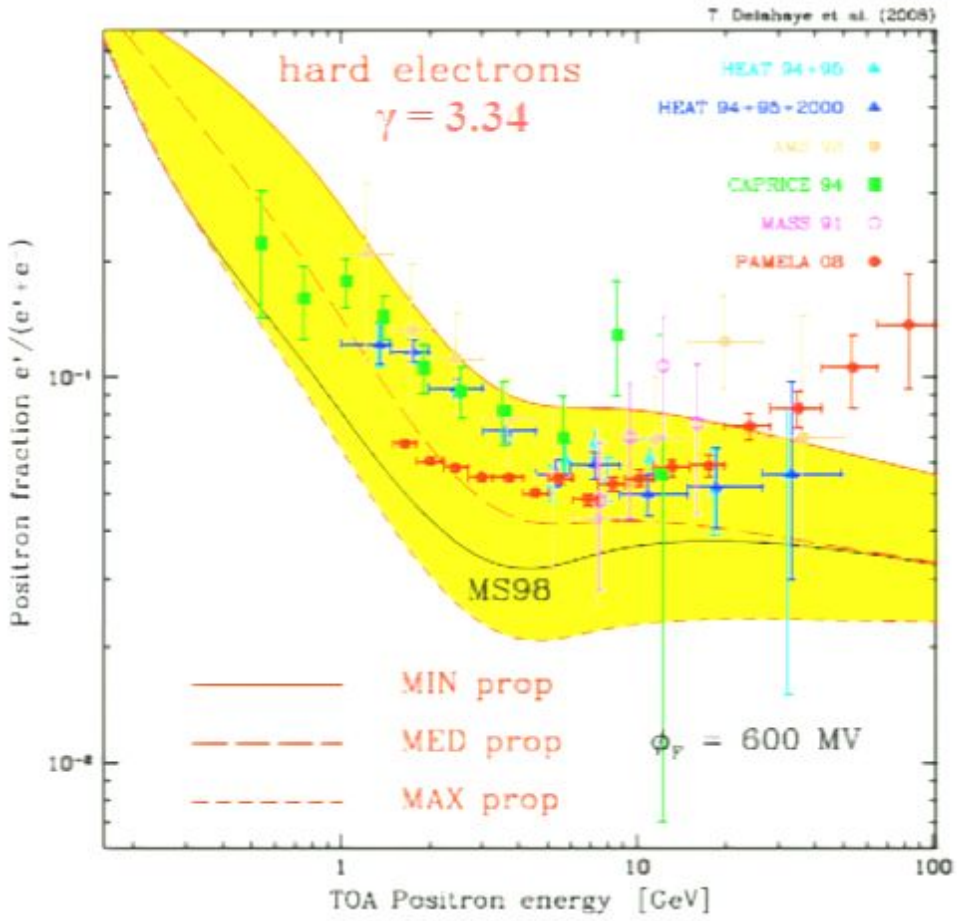

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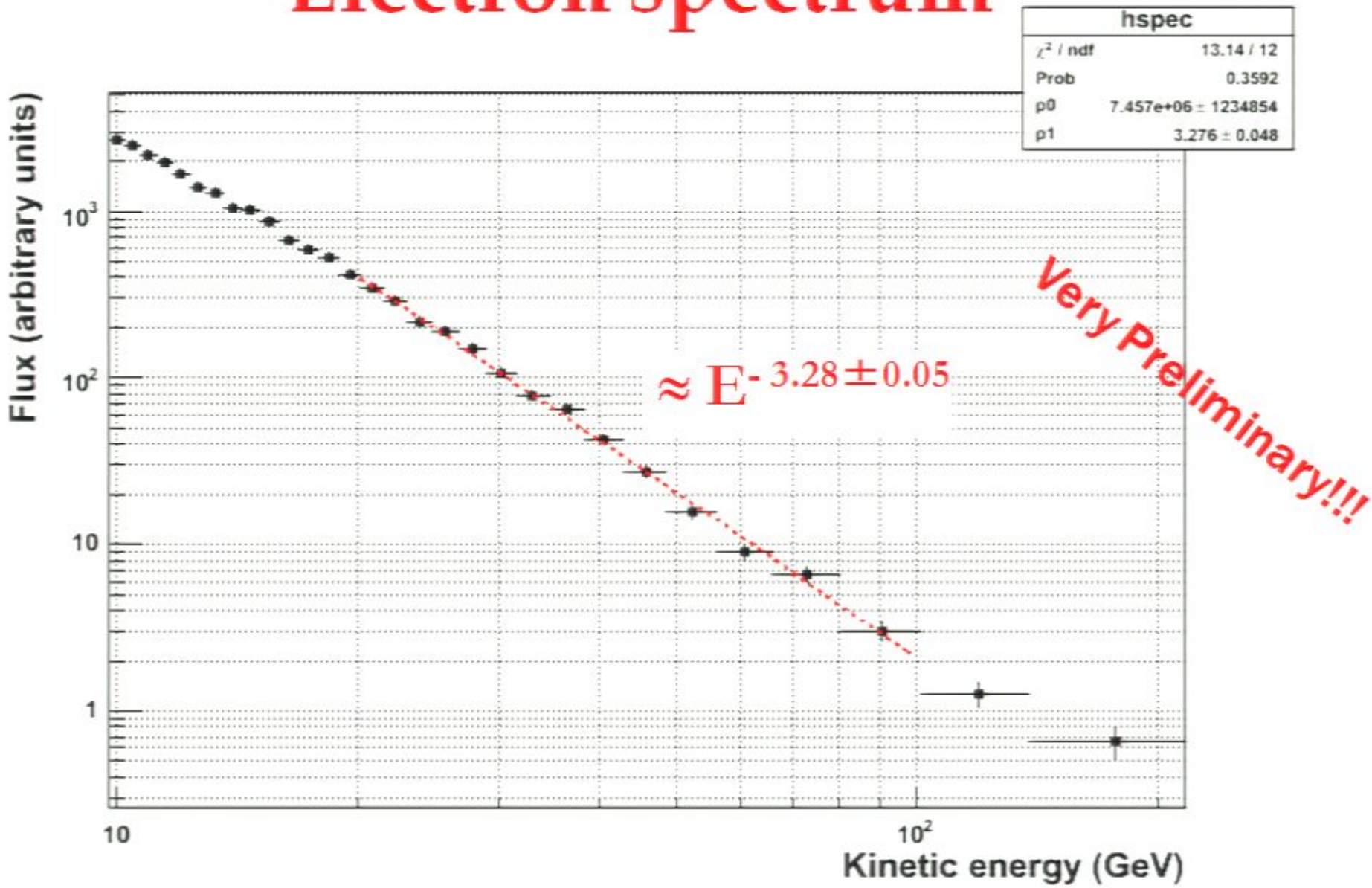
Electron spectrum



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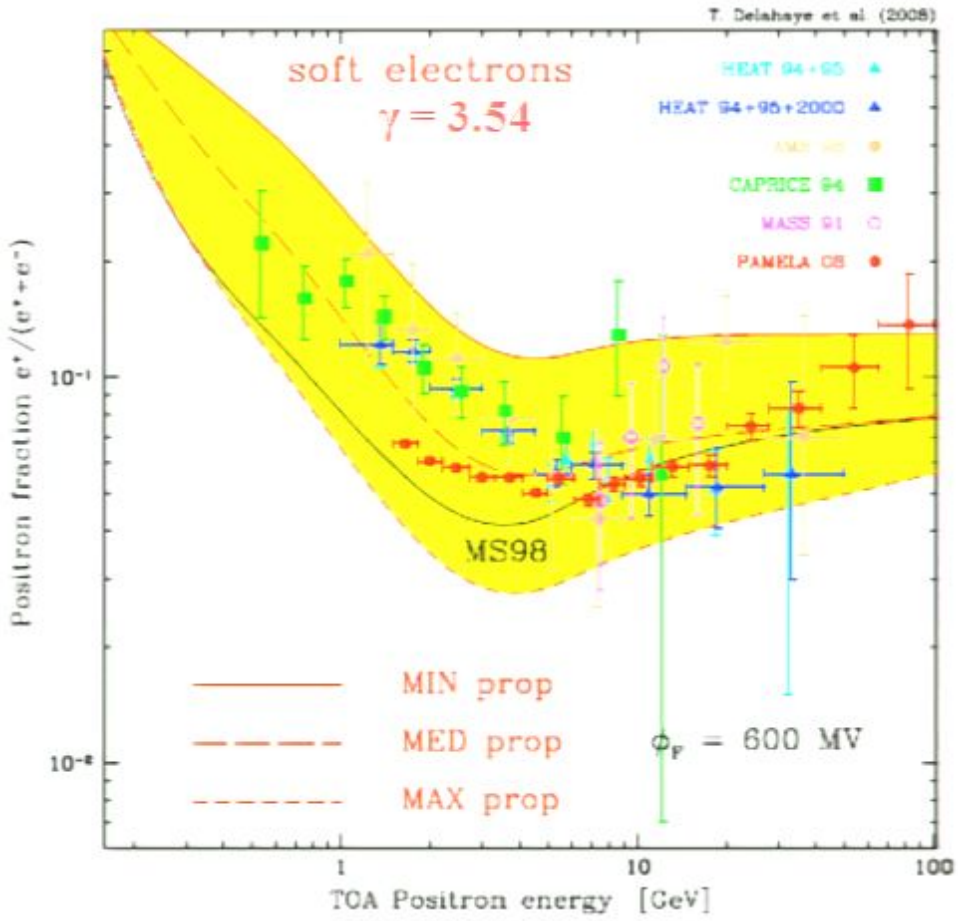

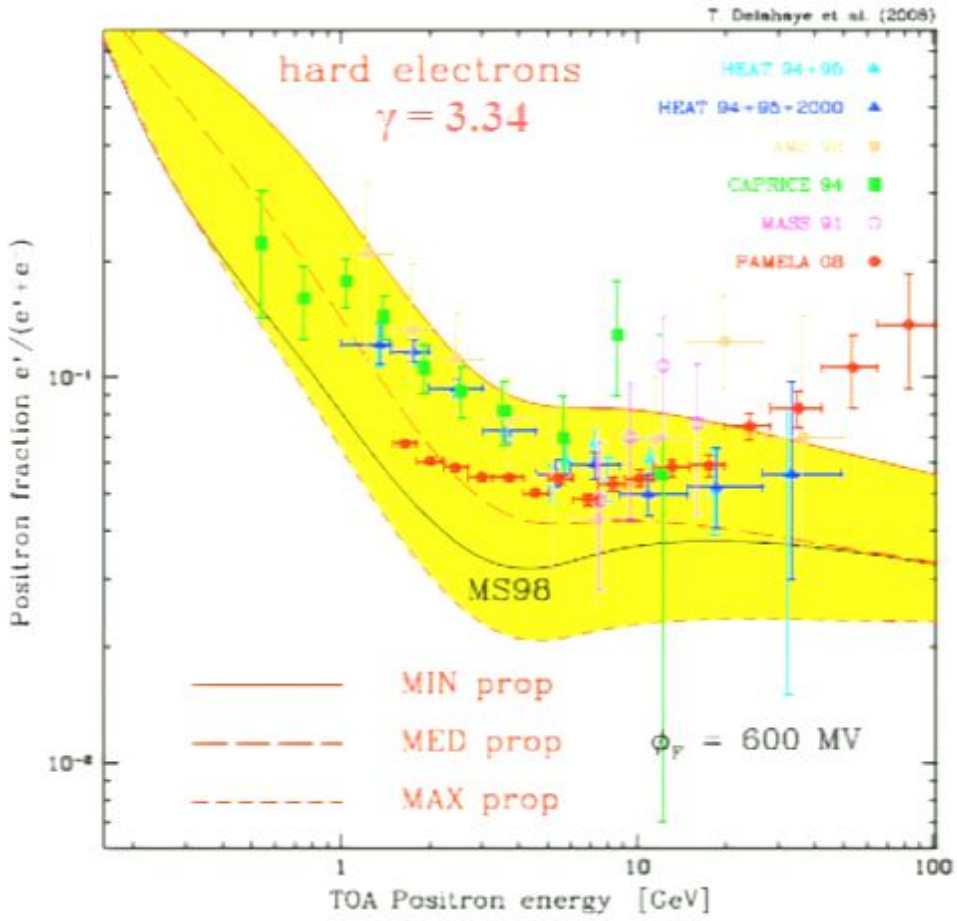

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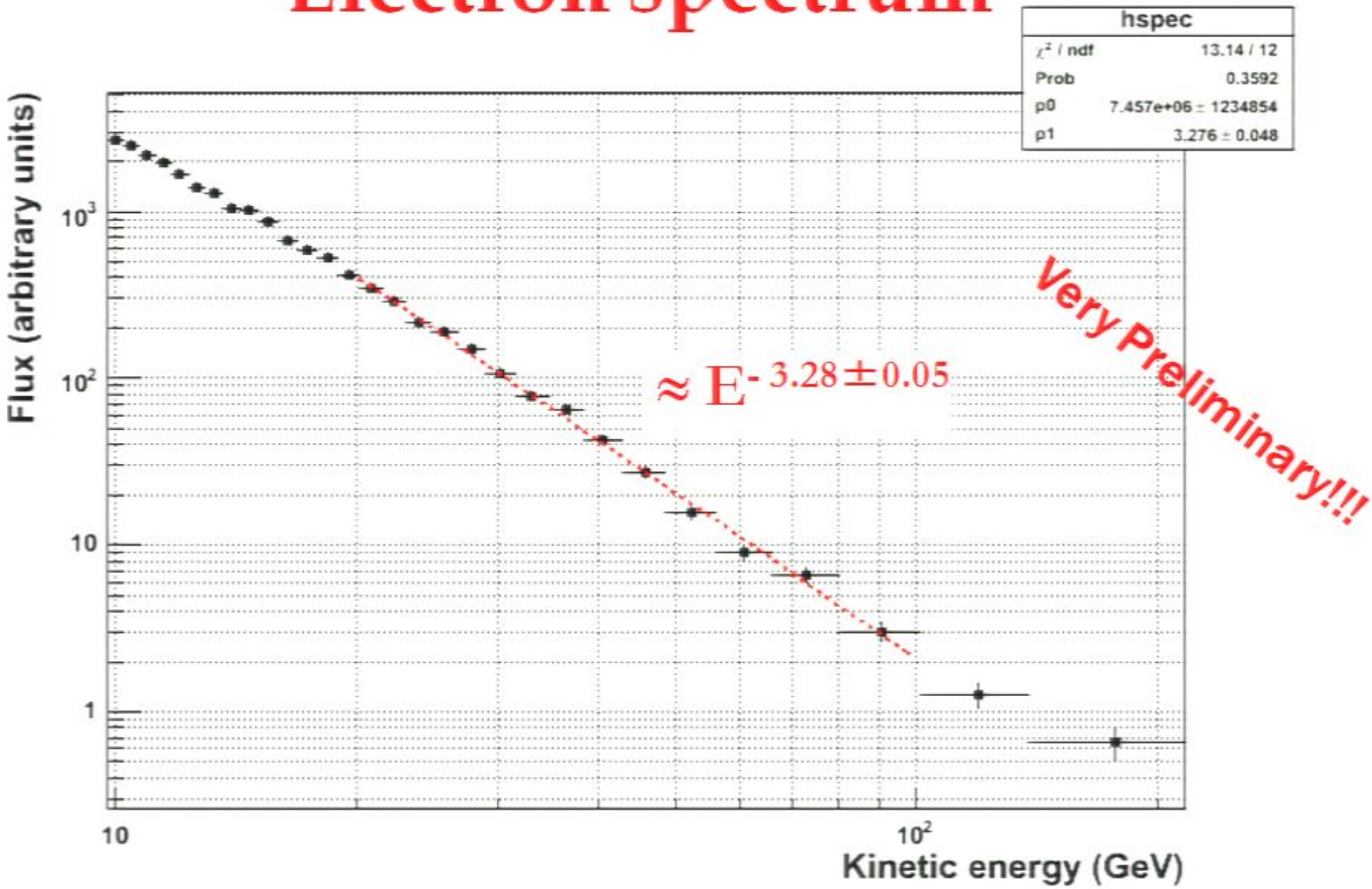
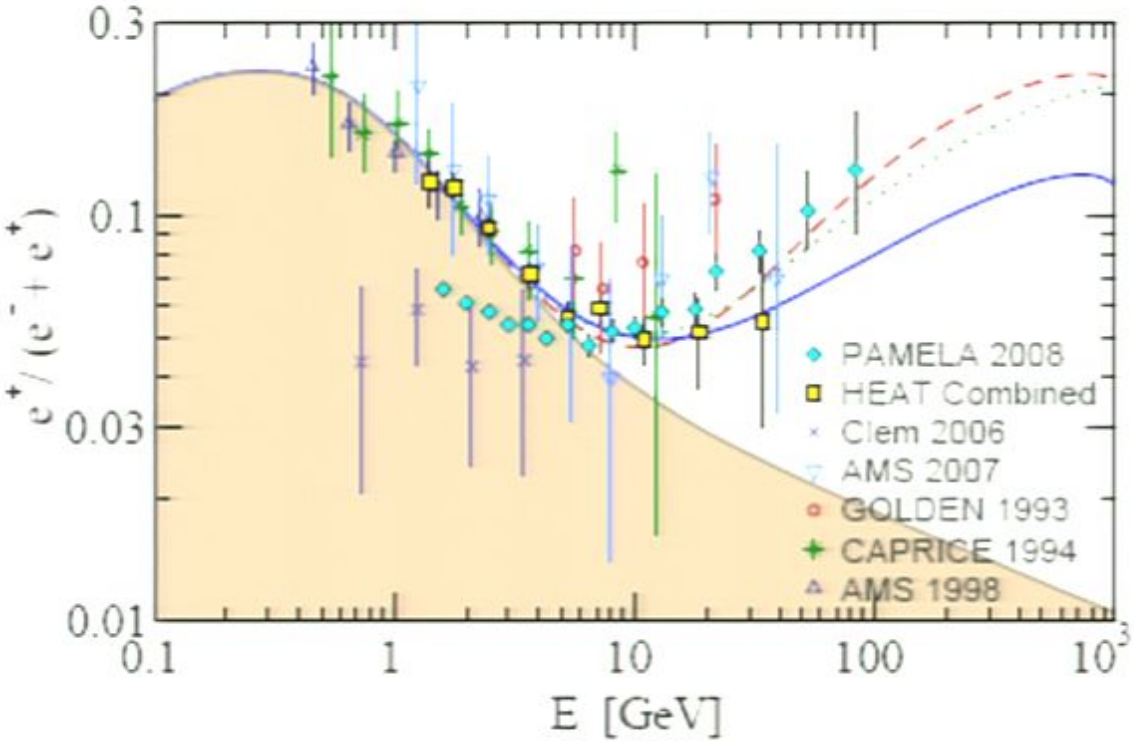
Electron spectrum



Example: pulsars



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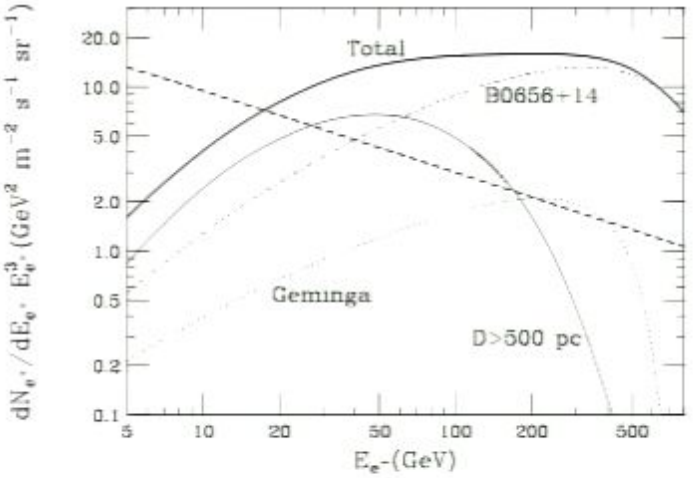
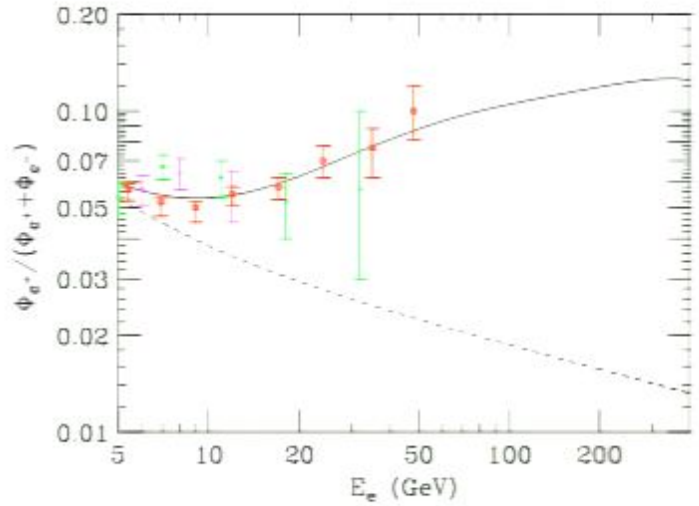
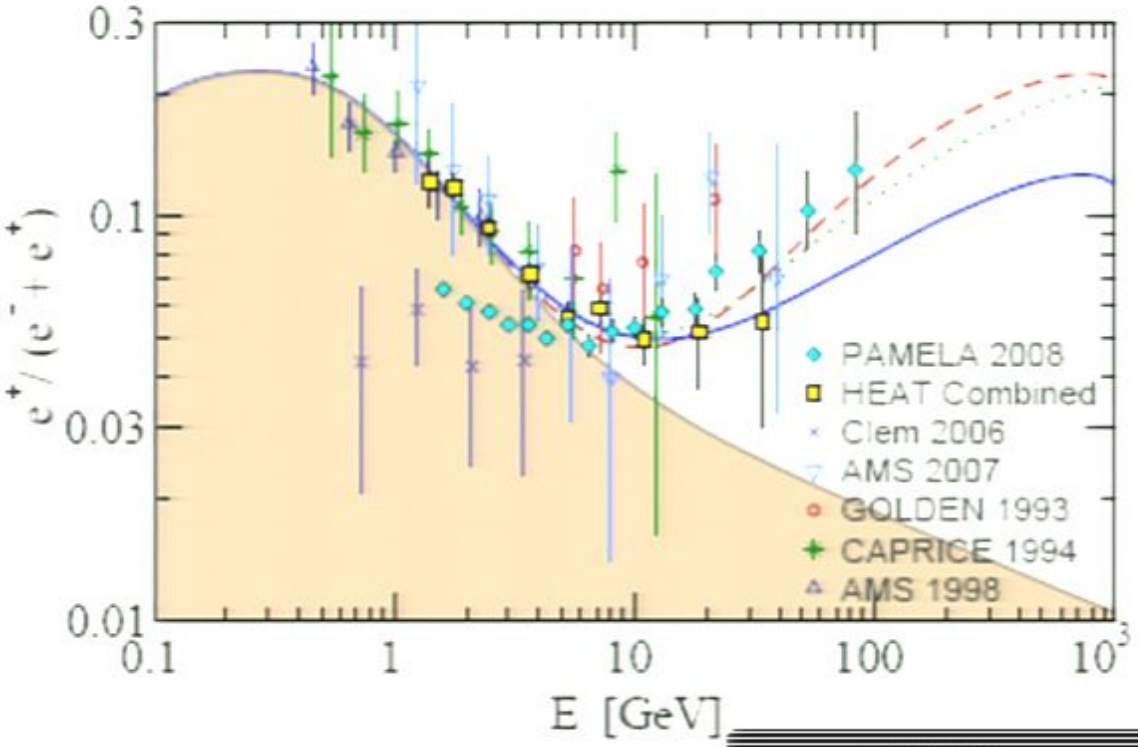
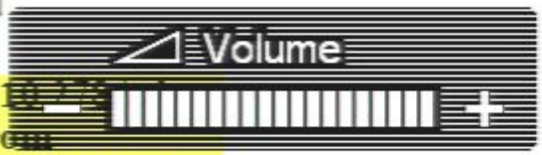




Hooper, Blasi, and Serpico
arXiv:0810.1527

Example: pulsars





H. Yüksak et al., arXiv:081[illegible]
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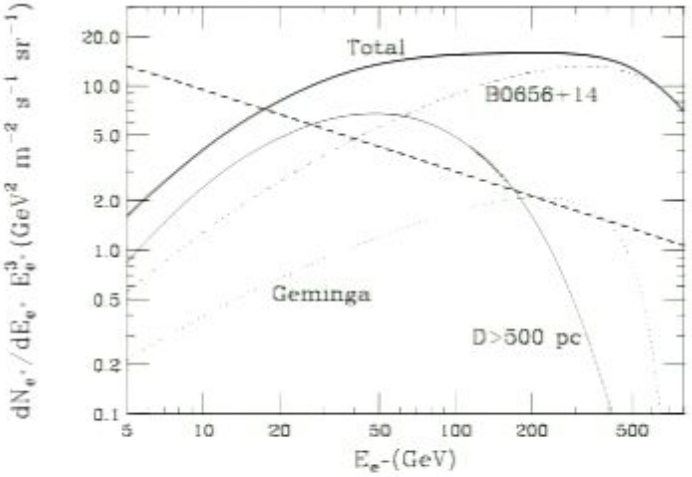

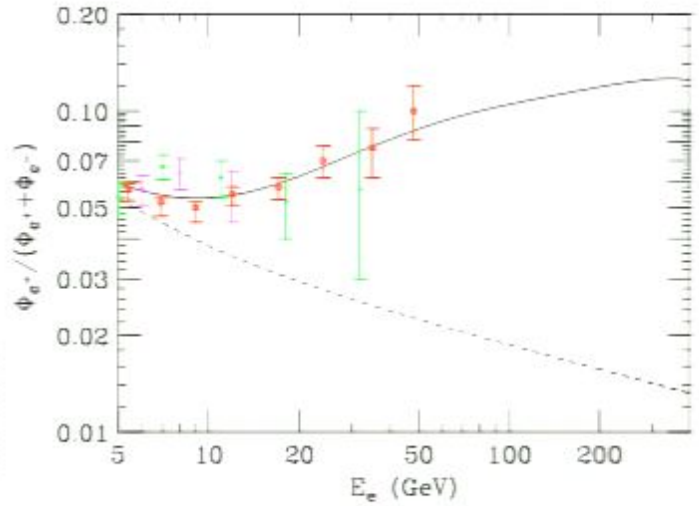

Hooper, Blasi, and Serpico
arXiv:0810.1527

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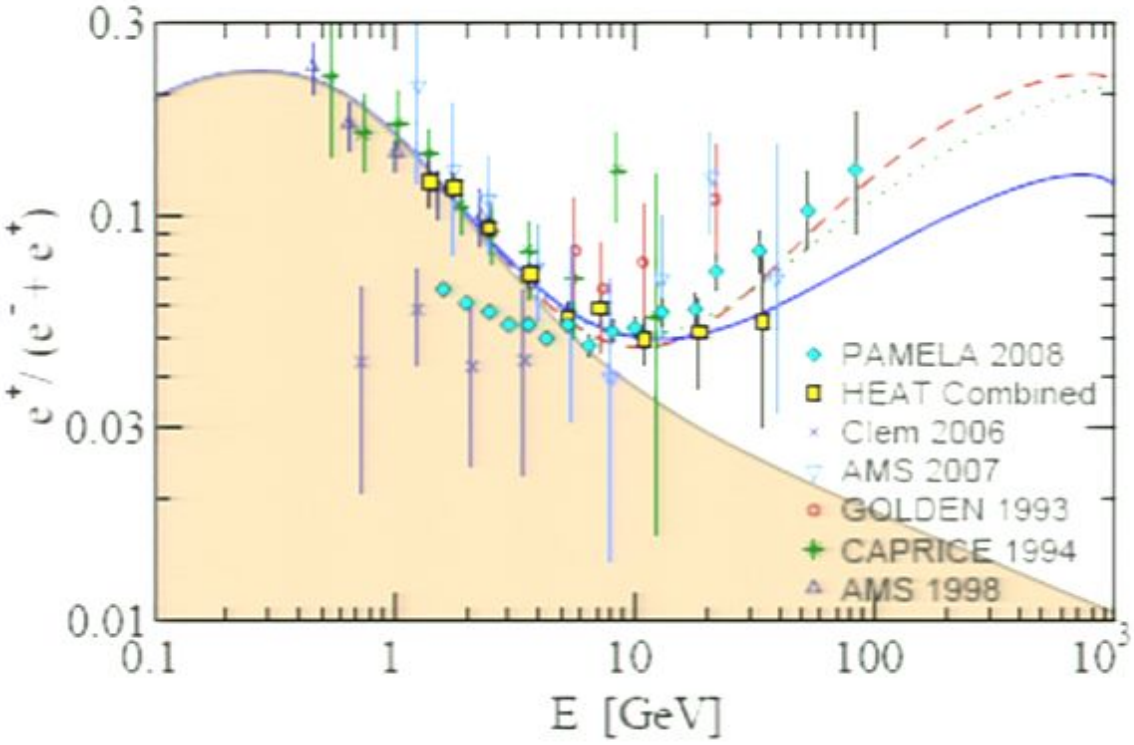

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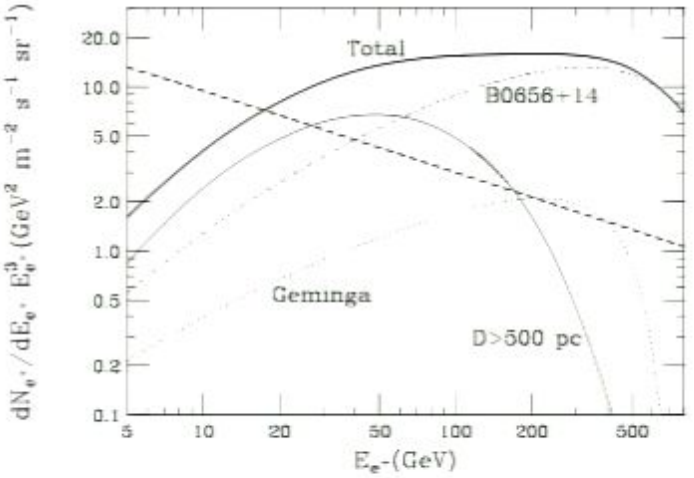

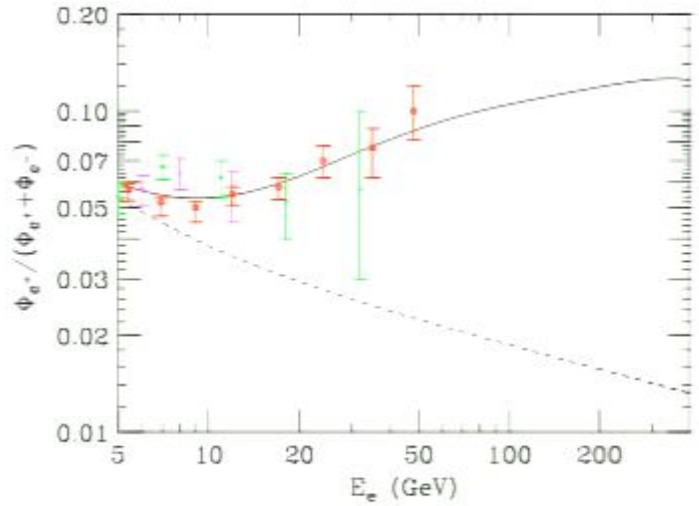

Hooper, Blasi, and Serpico
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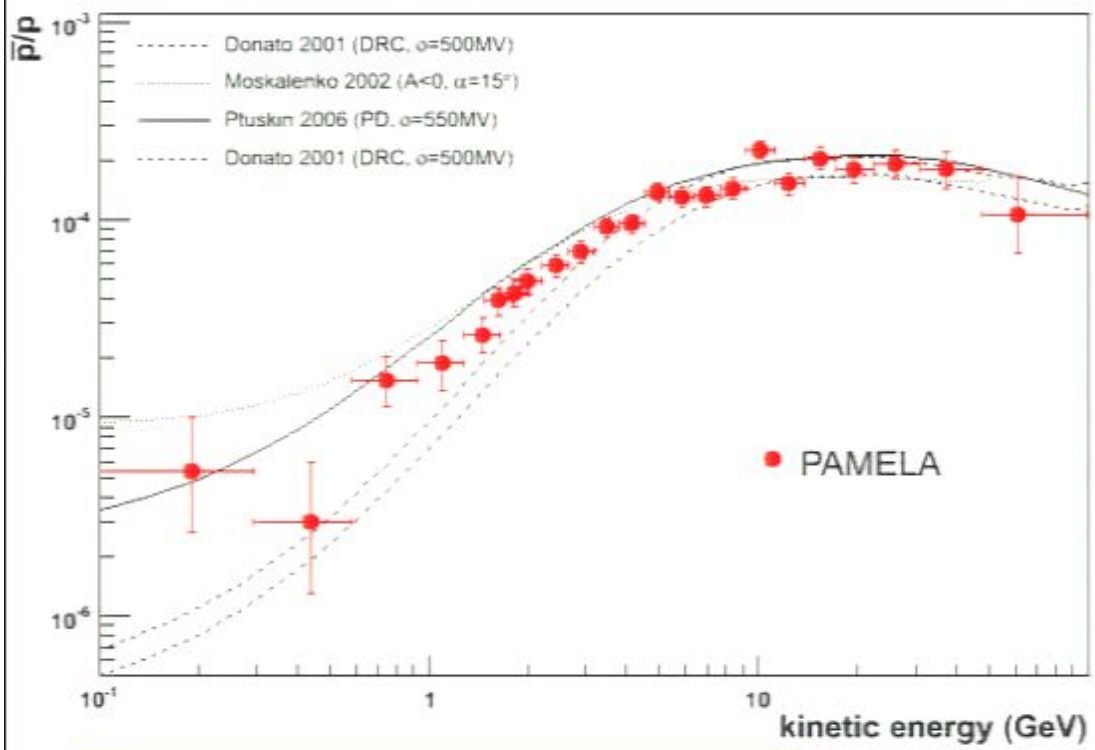
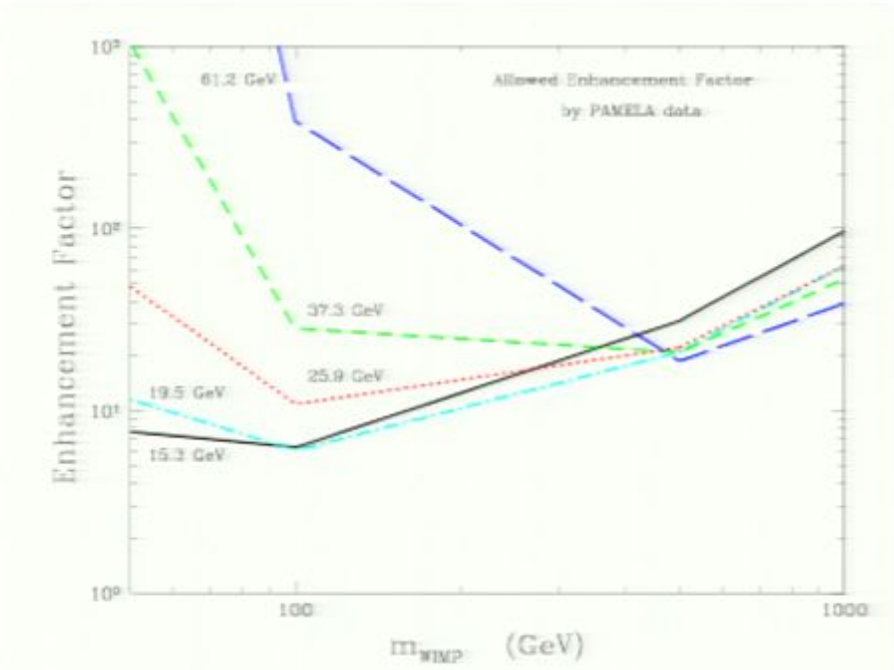
PAMELA $\bar{p}/p$ implication on DM



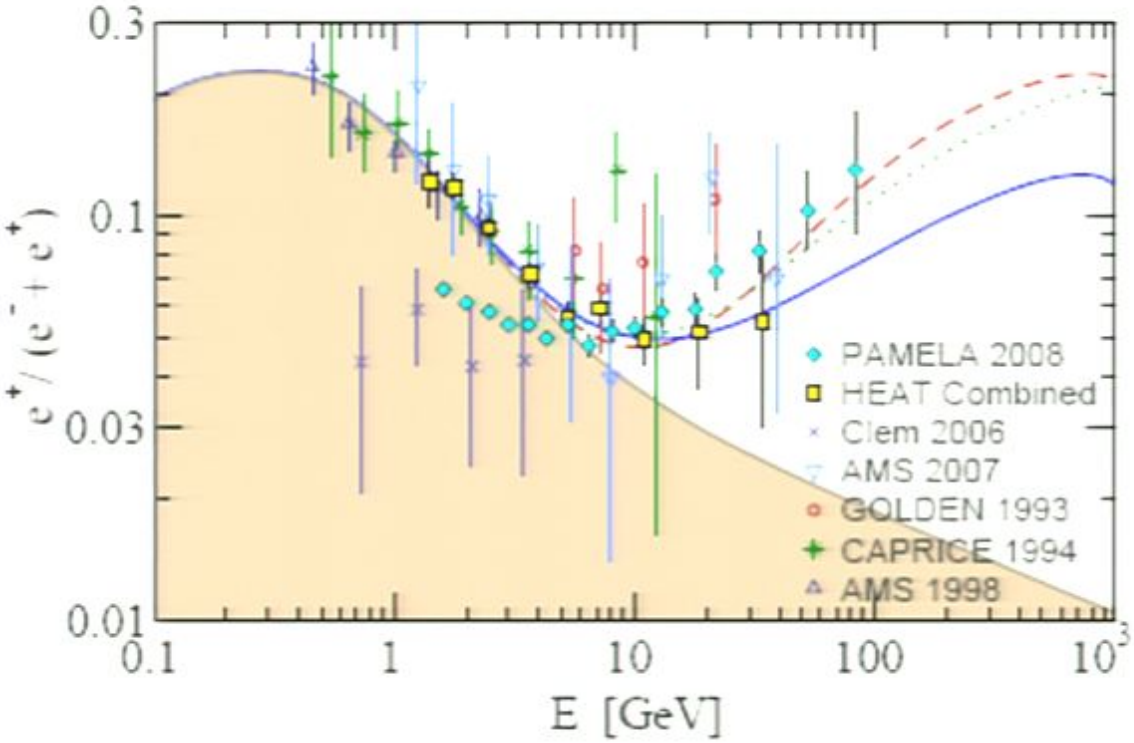
Secondary Production Models

Donato et al., arXiv: 0810.5292v1



Upper limit for enhancement factor for thermal WIMP DM flux as a function of the WIMP mass

Example: pulsars



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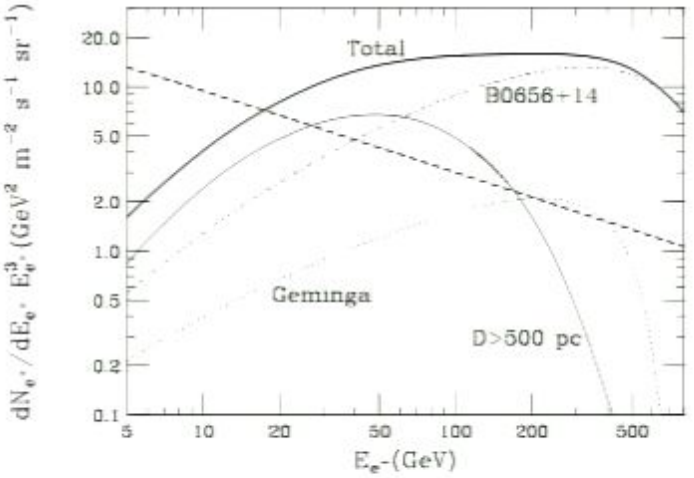

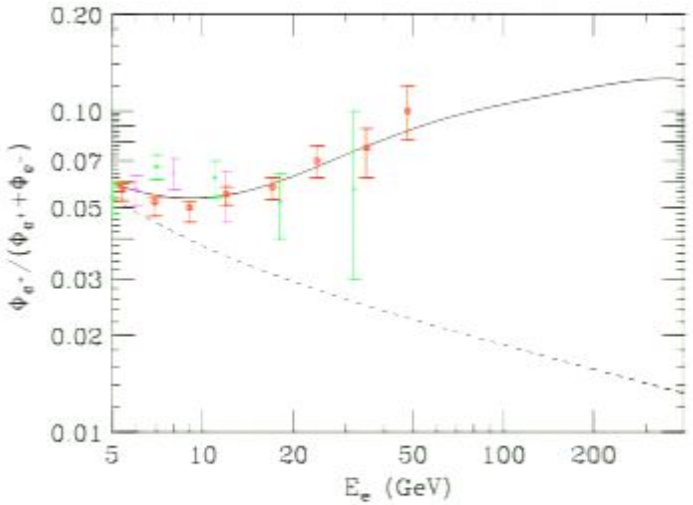

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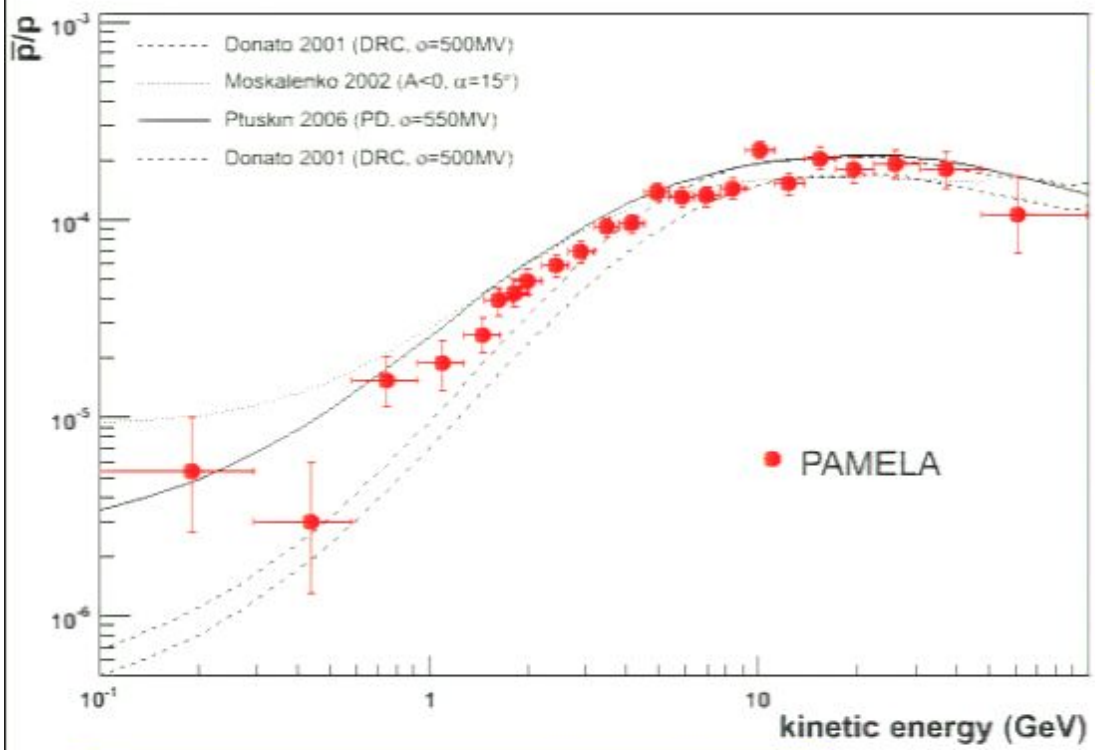

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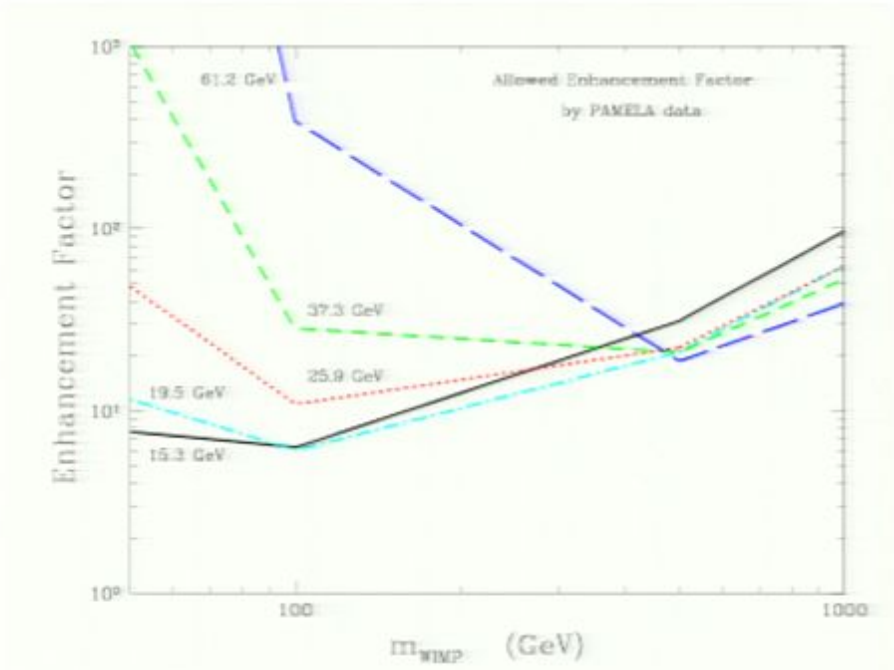

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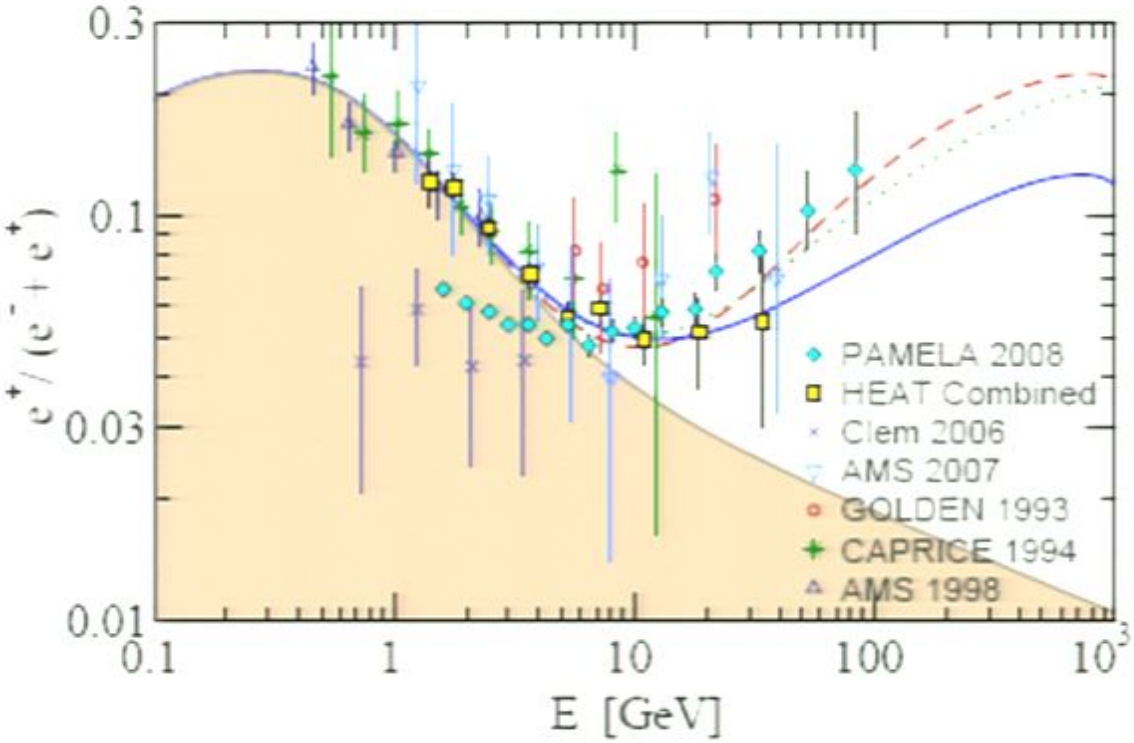

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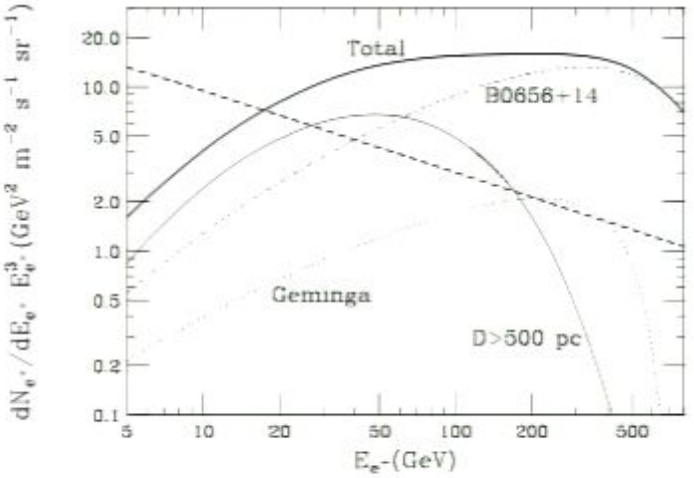

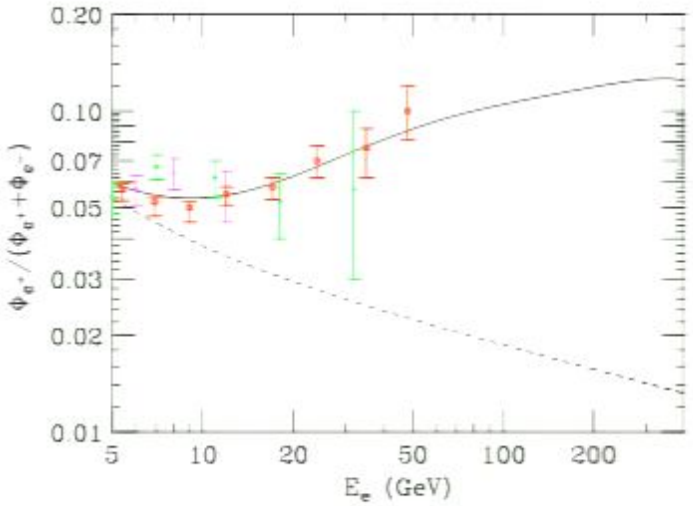

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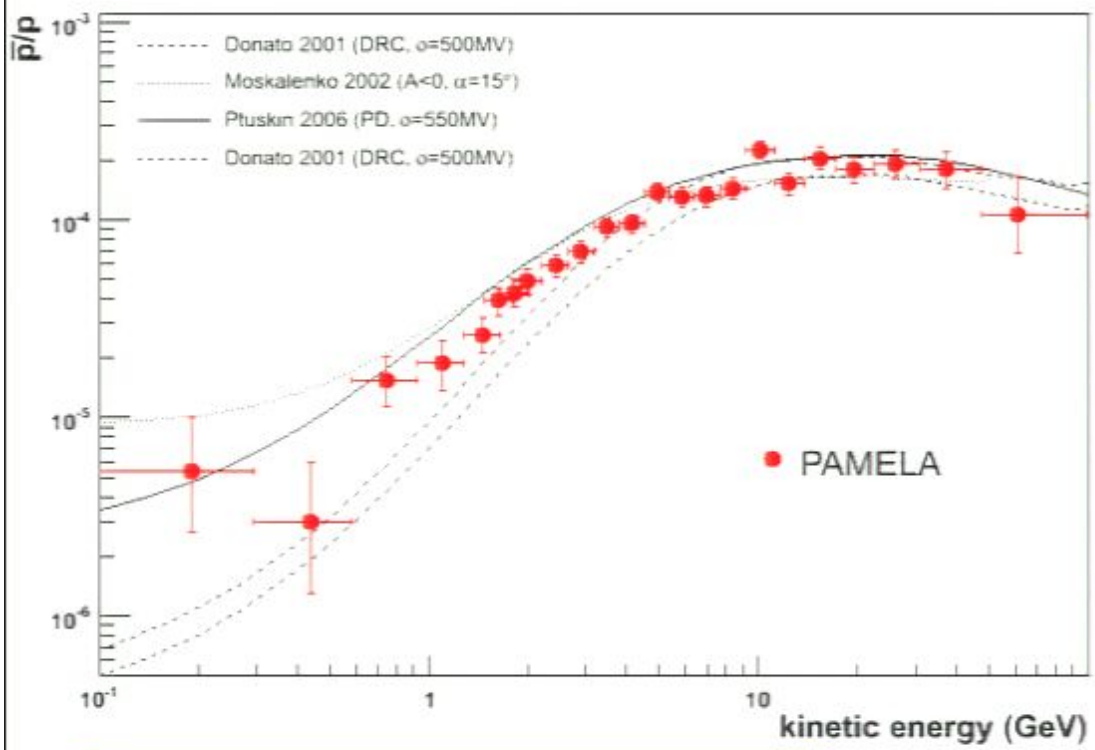

Secondary Production Models

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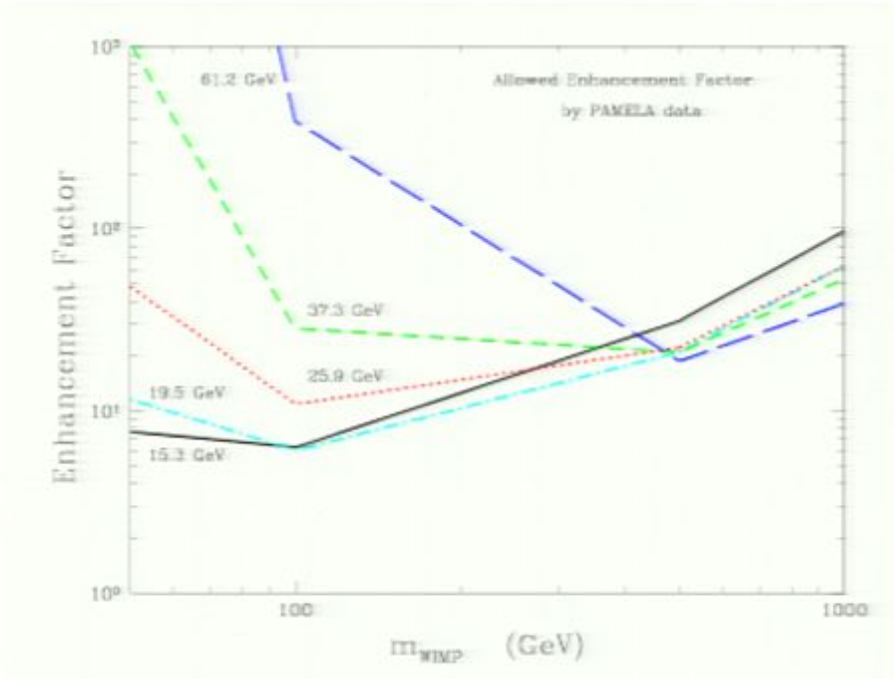

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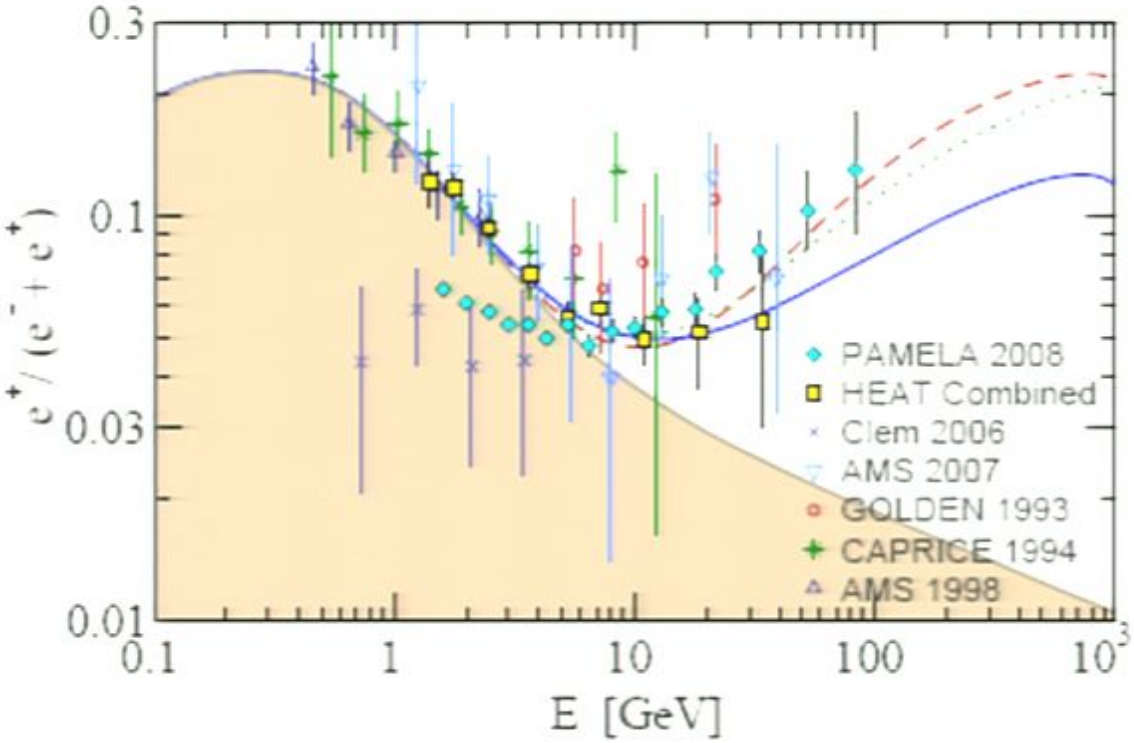

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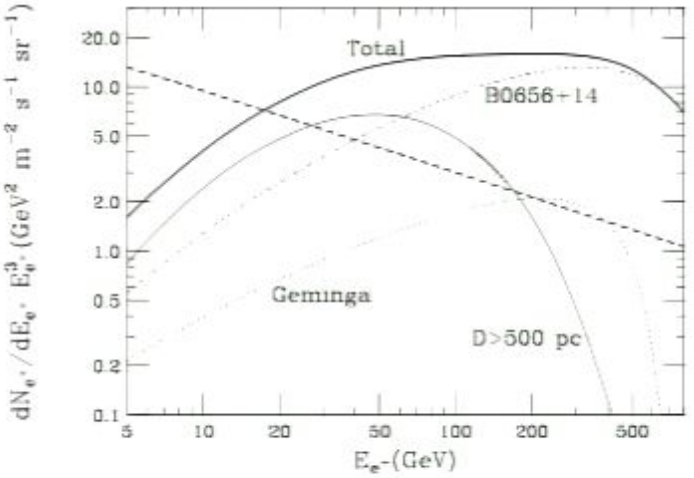

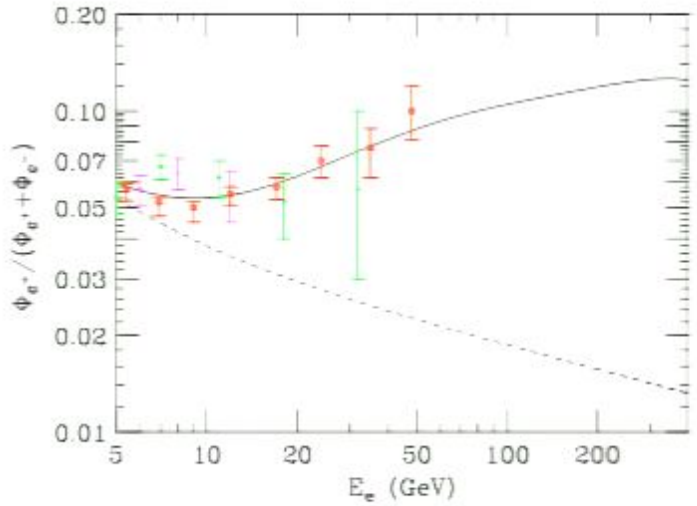

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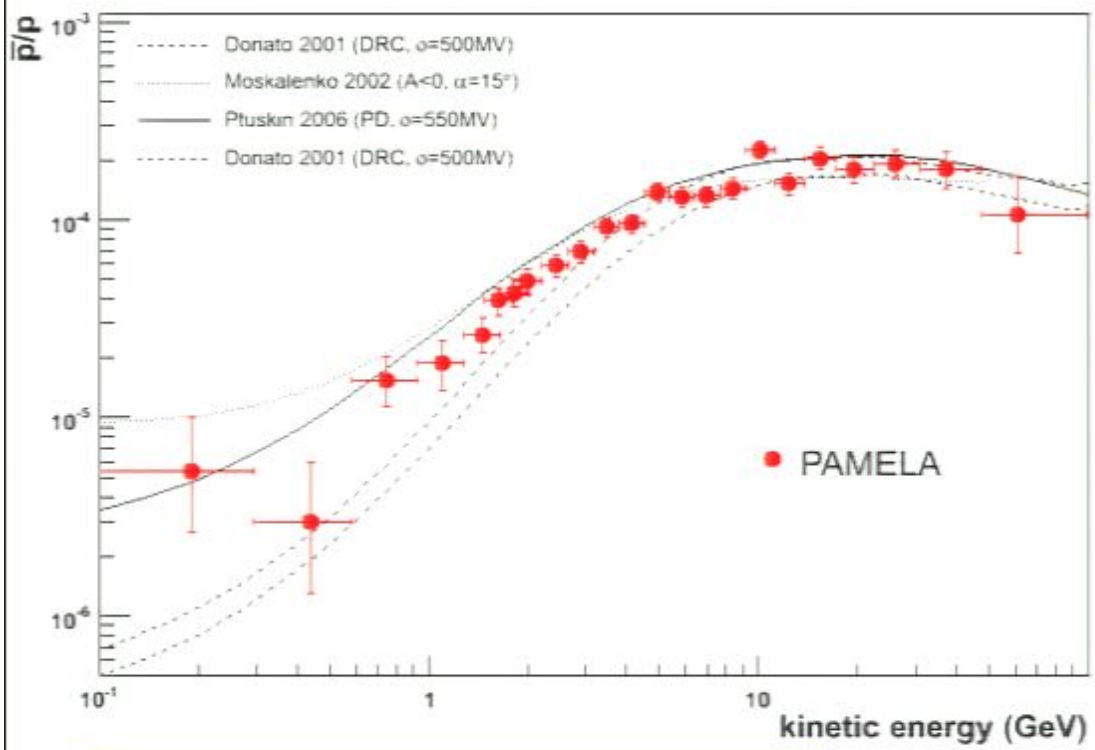
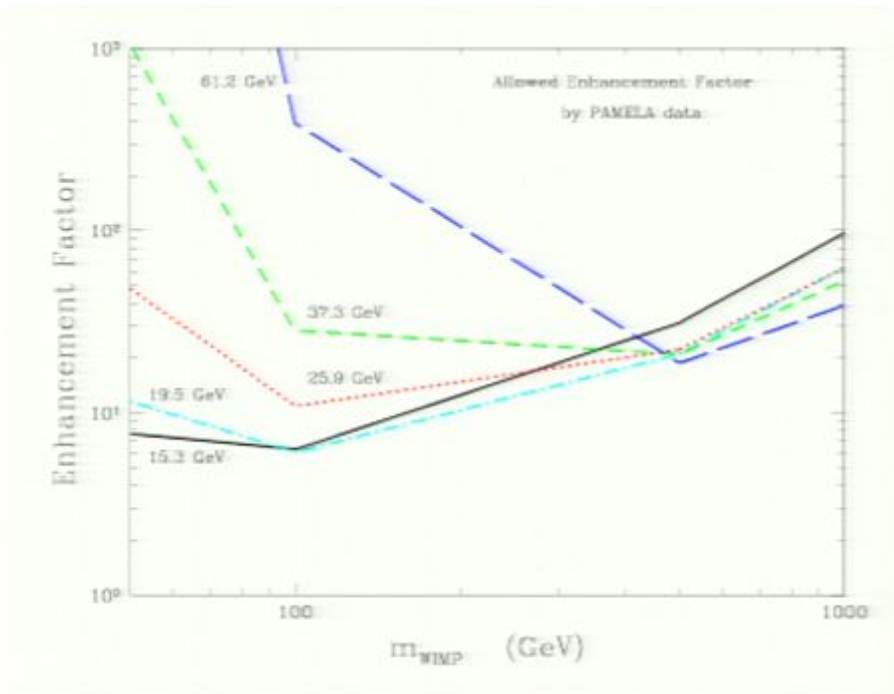


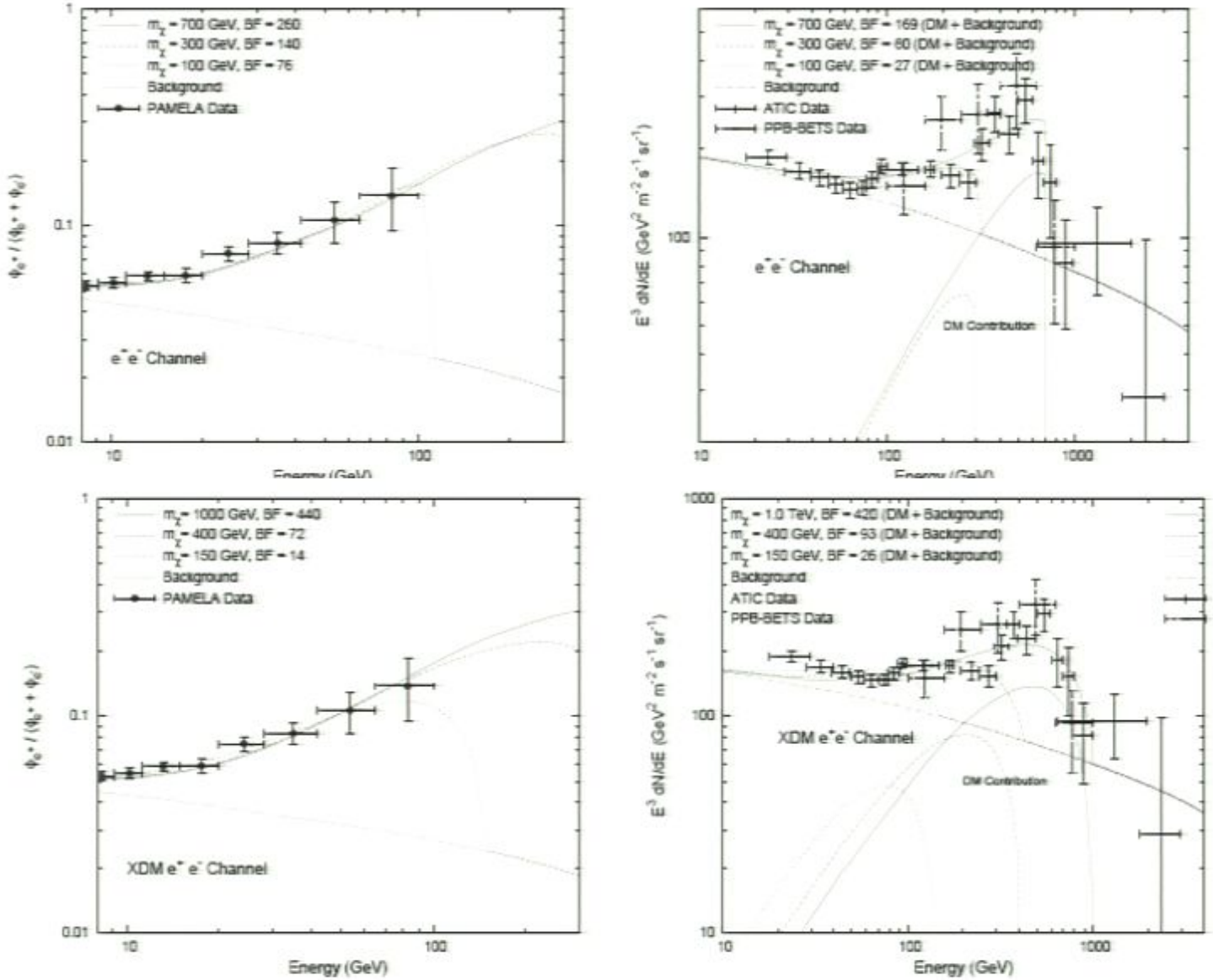
Secondary Production Models

Donato et al., arXiv: 0810.5292v1



Upper limit for enhancement factor for thermal WIMP DM flux as a function of the WIMP mass

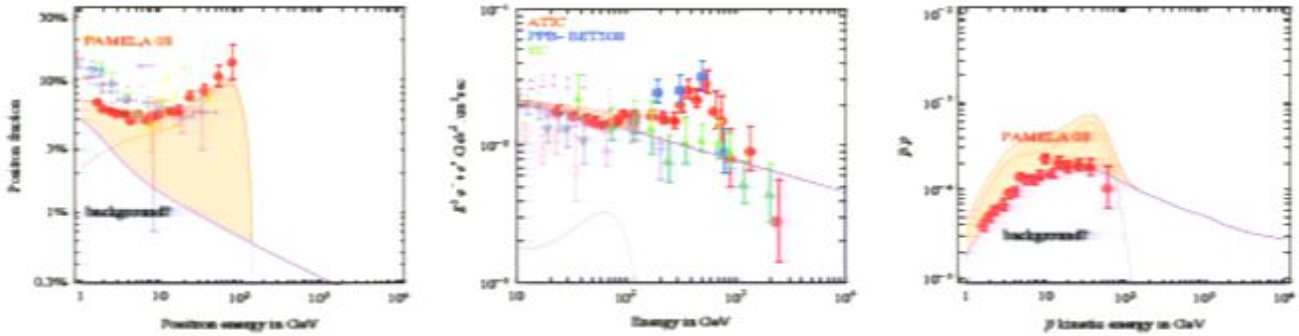
Example: DM



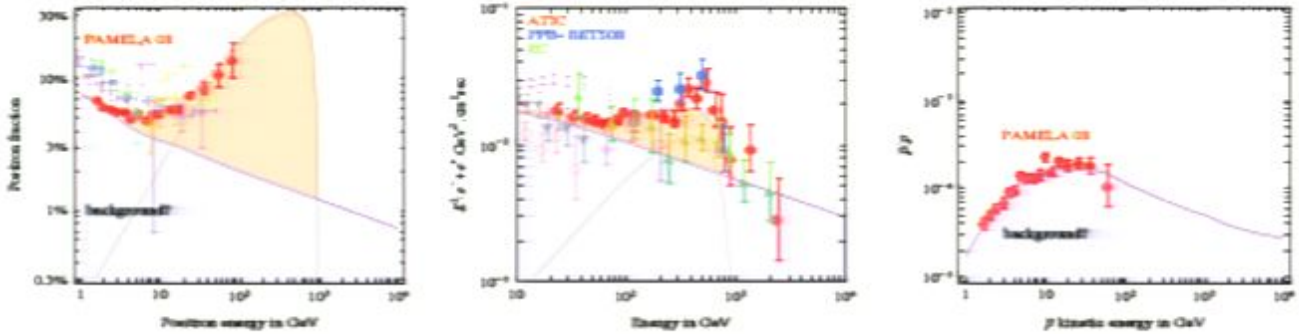
I. Cholis et al. arXiv:0811.3641v1

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

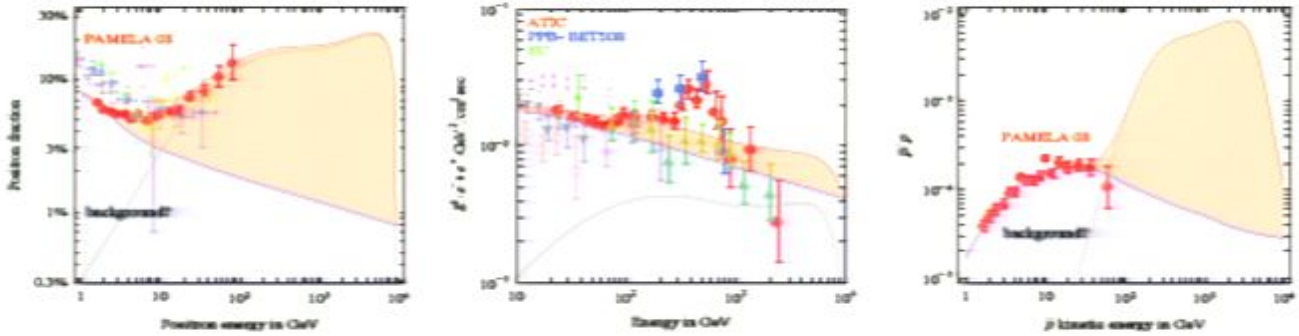
DM with M = 150 GeV that annihilates into W^+W^-



DM with M = 1 TeV that annihilates into $\mu^+\mu^-$

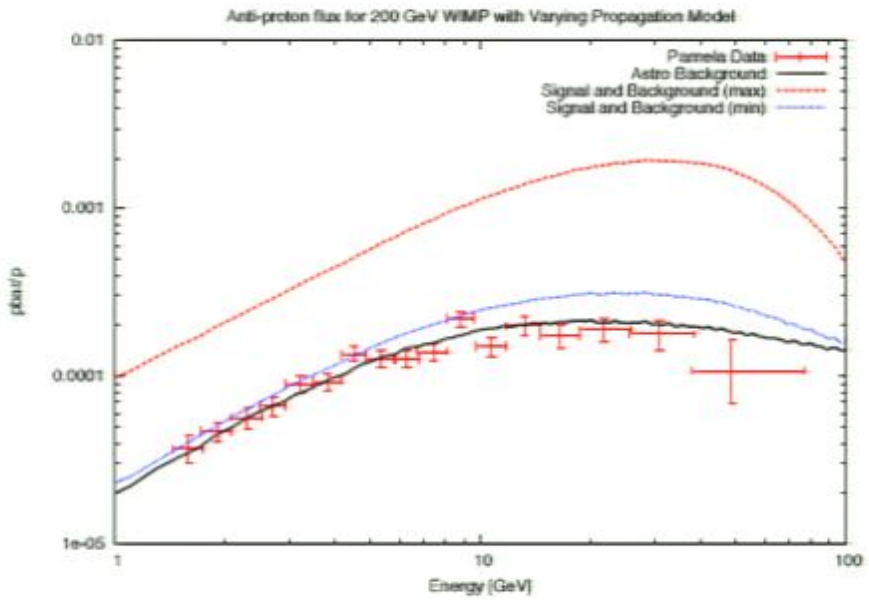


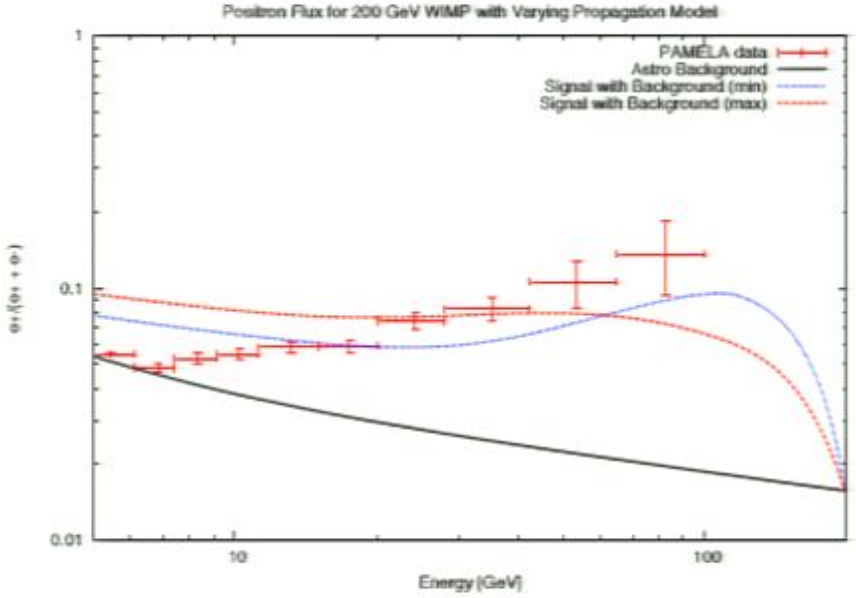
DM with M = 10 TeV that annihilates into W^+W^-



M. Cirelli et al., arXiv: 0809.2409v3

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

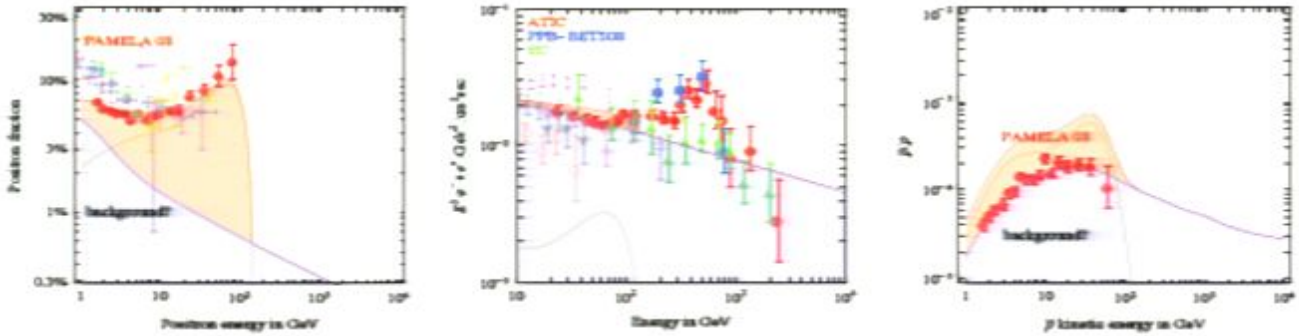




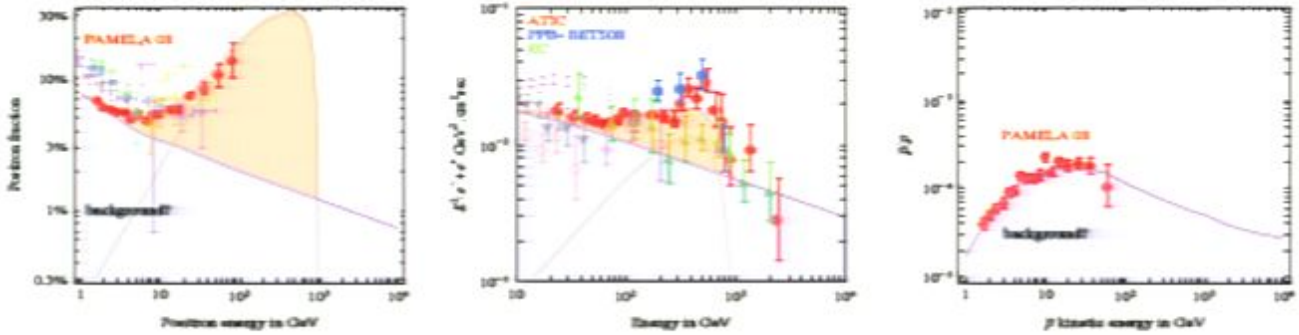
P. Grajek et al., arXiv: 0812.4555v1
Non-thermal wino-like neutralino
Varying propagation model, no boost factor

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

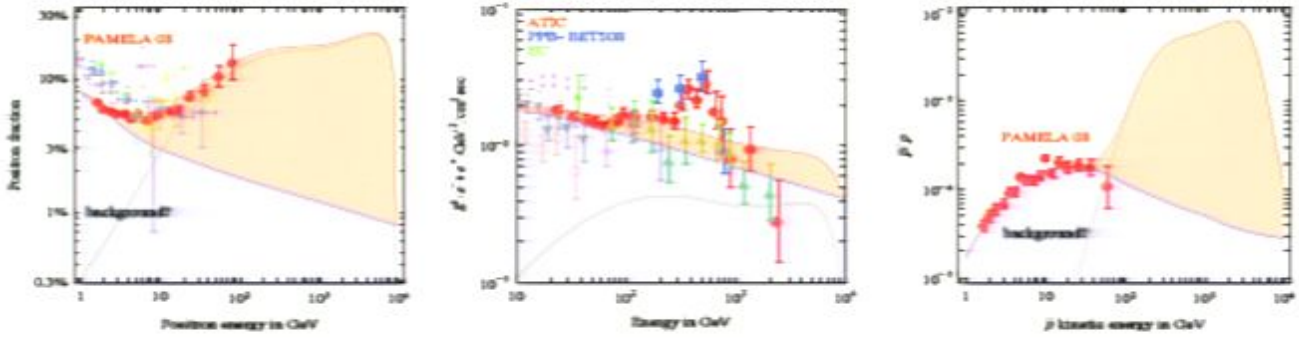
DM with M = 150 GeV that annihilates into W^+W^-



DM with M = 1 TeV that annihilates into $\mu^+\mu^-$



DM with M = 10 TeV that annihilates into W^+W^-



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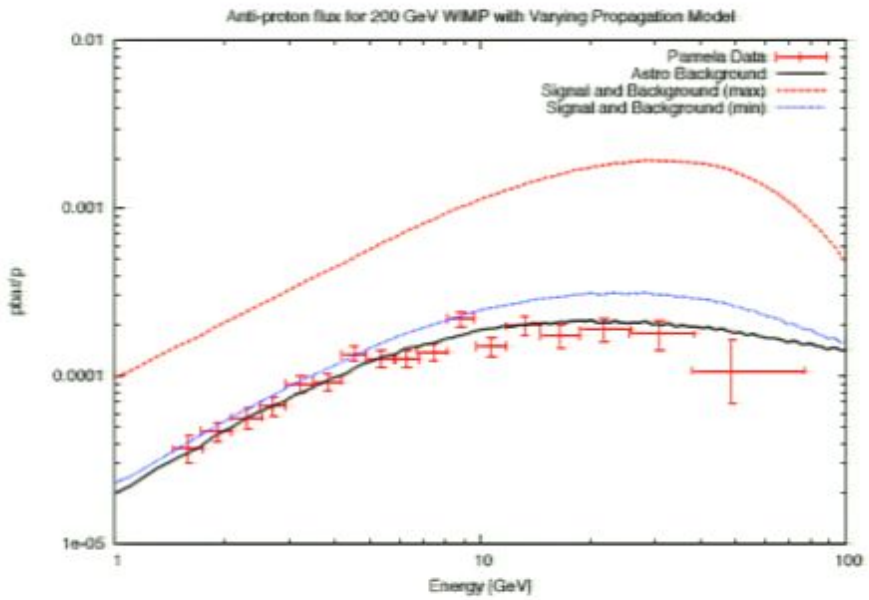
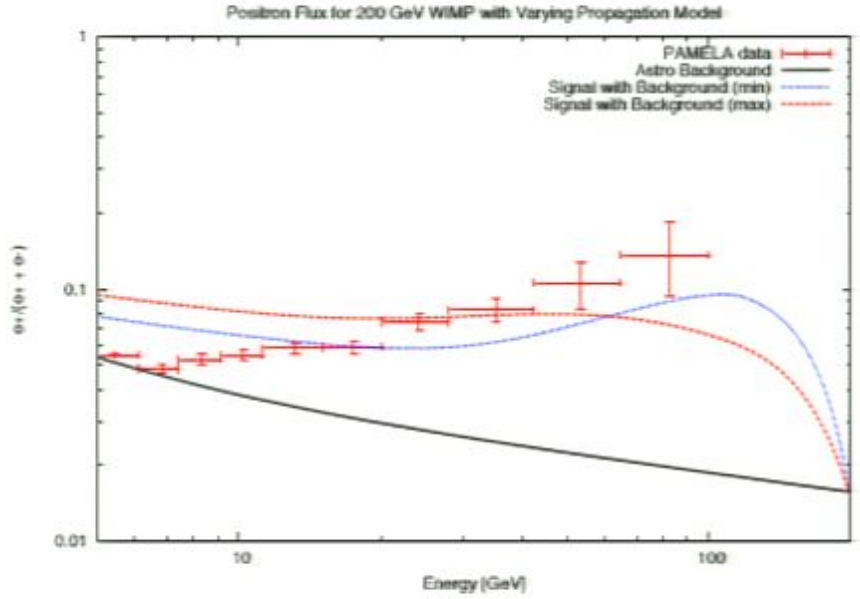
Example: e^+ & $\bar{p}$ DM





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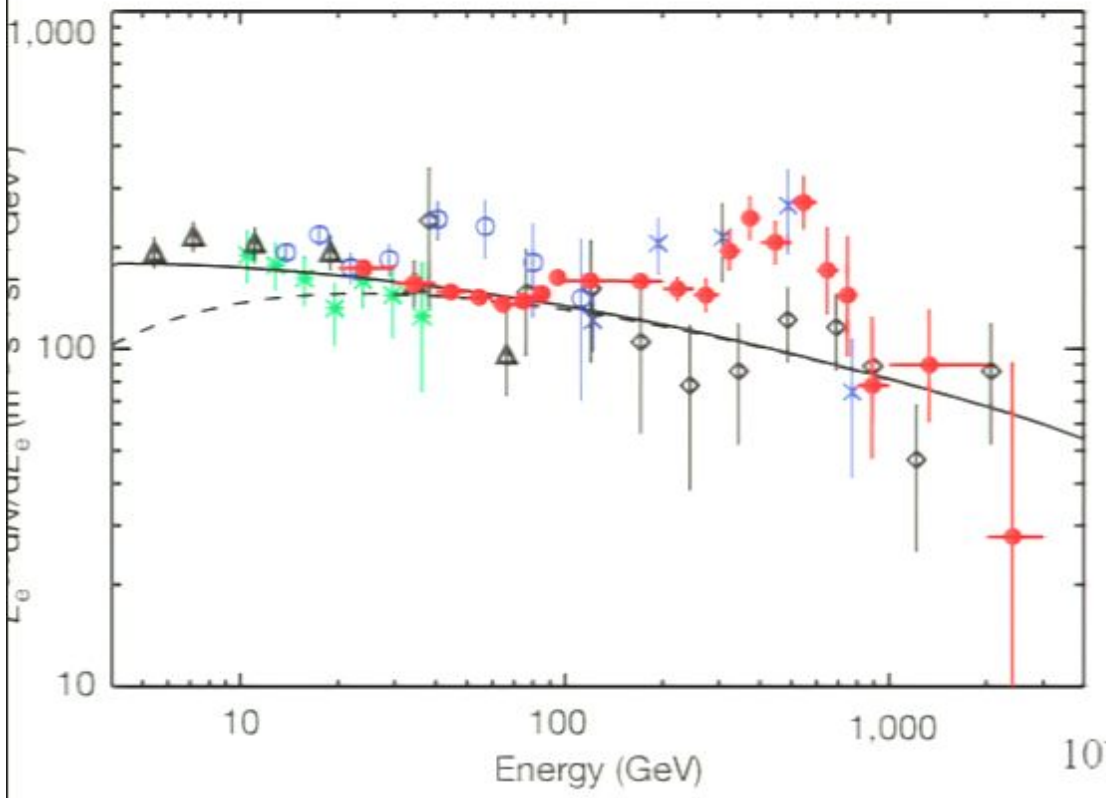

J. Chang *et al. Nature* 456, 362-365 (2008)

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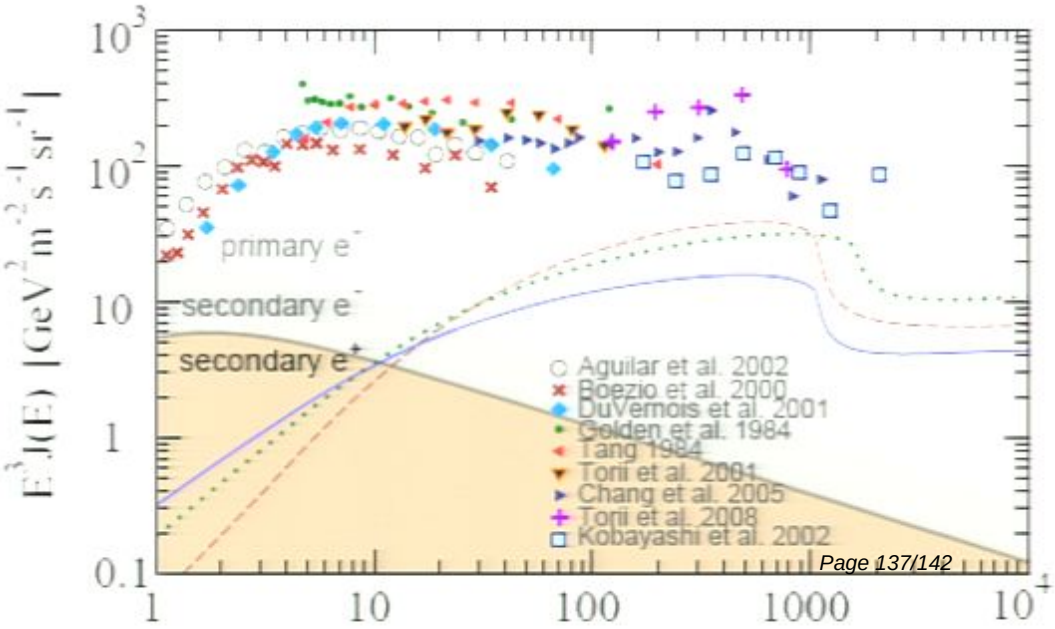
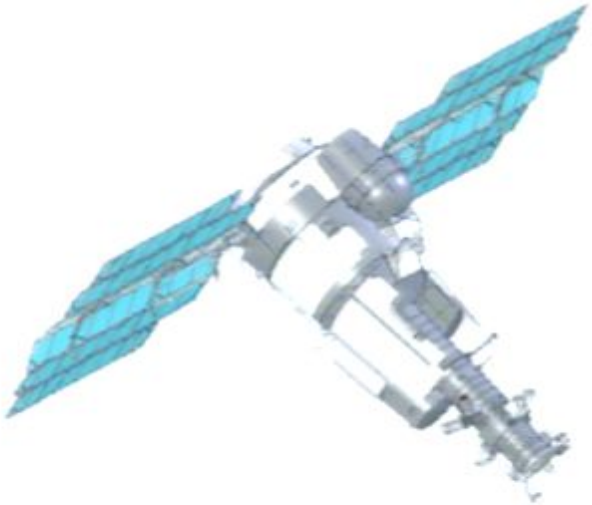
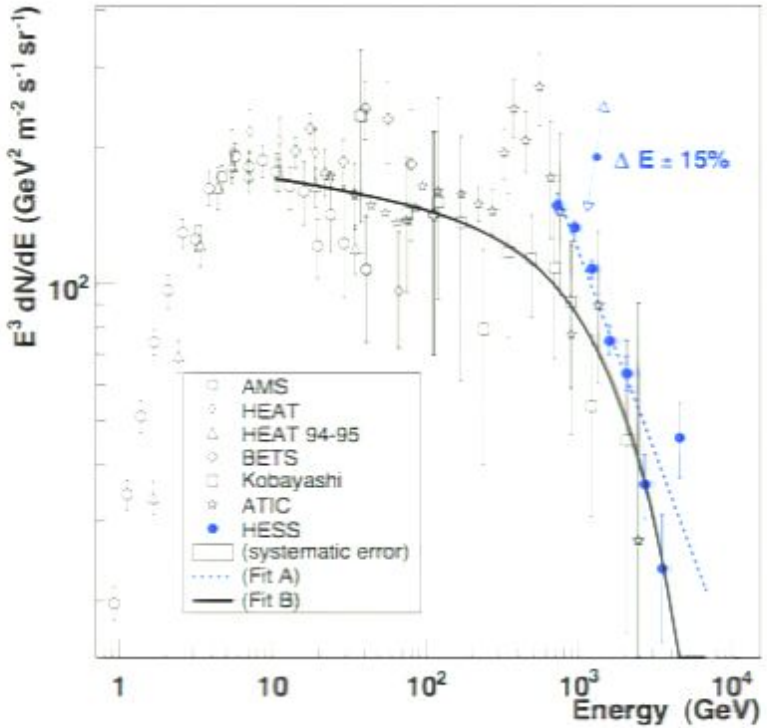
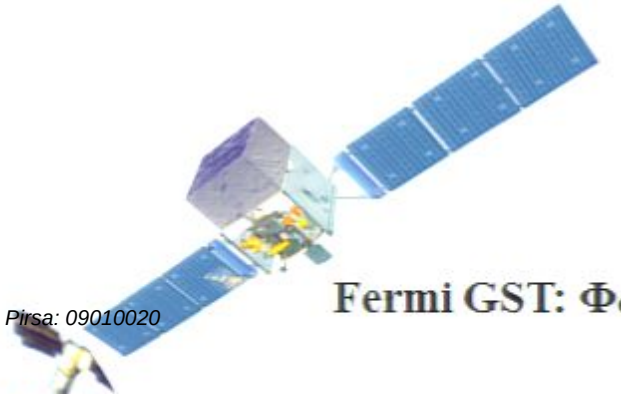


Future observations of electrons



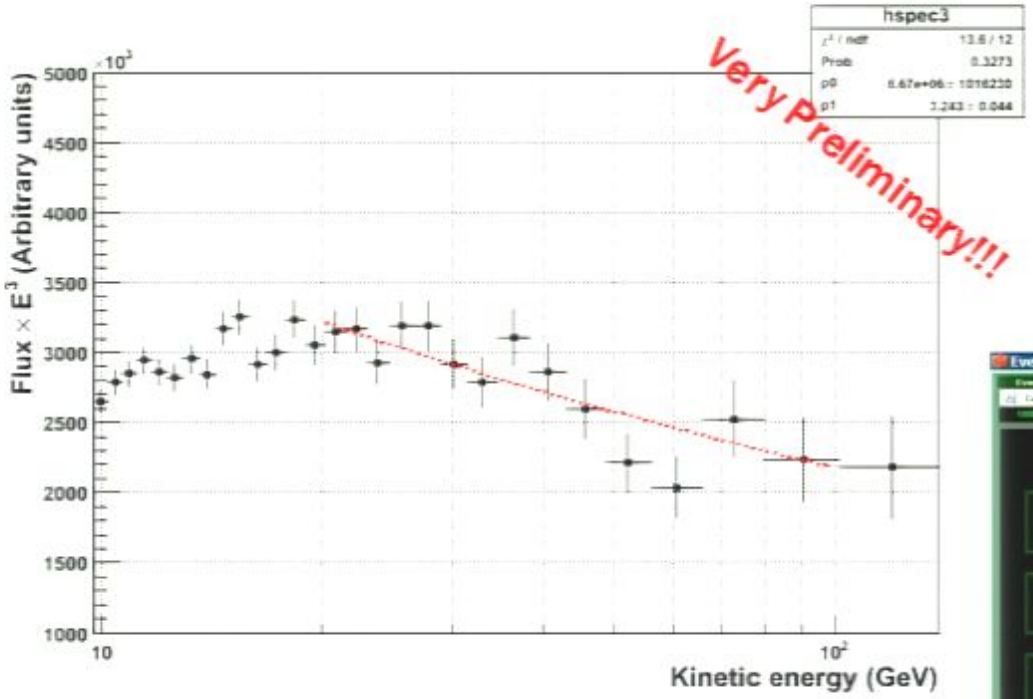
$\Phi_{e^\pm}$ up to ~1TeV
Φ_{e^+} up to ~300 GeV
Φ_{e^-} up to ~500 GeV

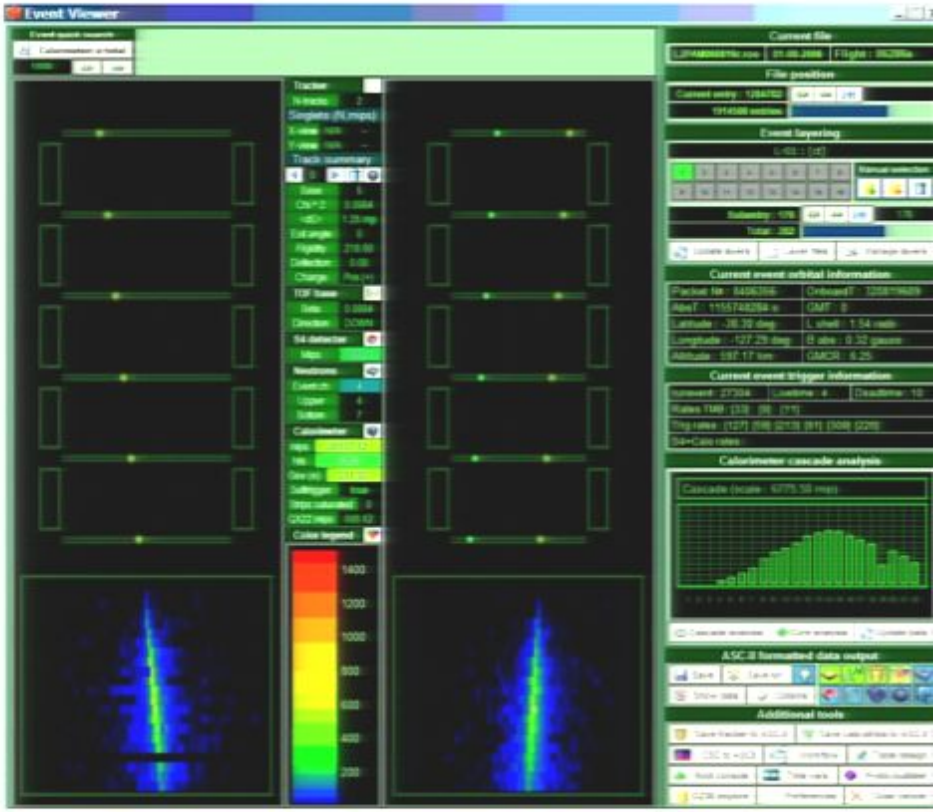




Fermi GST: $\Phi_{e^\pm}$ up to ~700 GeV

Electron (e^- & e^-+e^+) measurement with PAMELA





Rig tracker = 219 GV

Ecalo (pr. long.) = 202 GeV

Ecalo (det. energy) = 190 GeV

Neutrons = 4

Summary

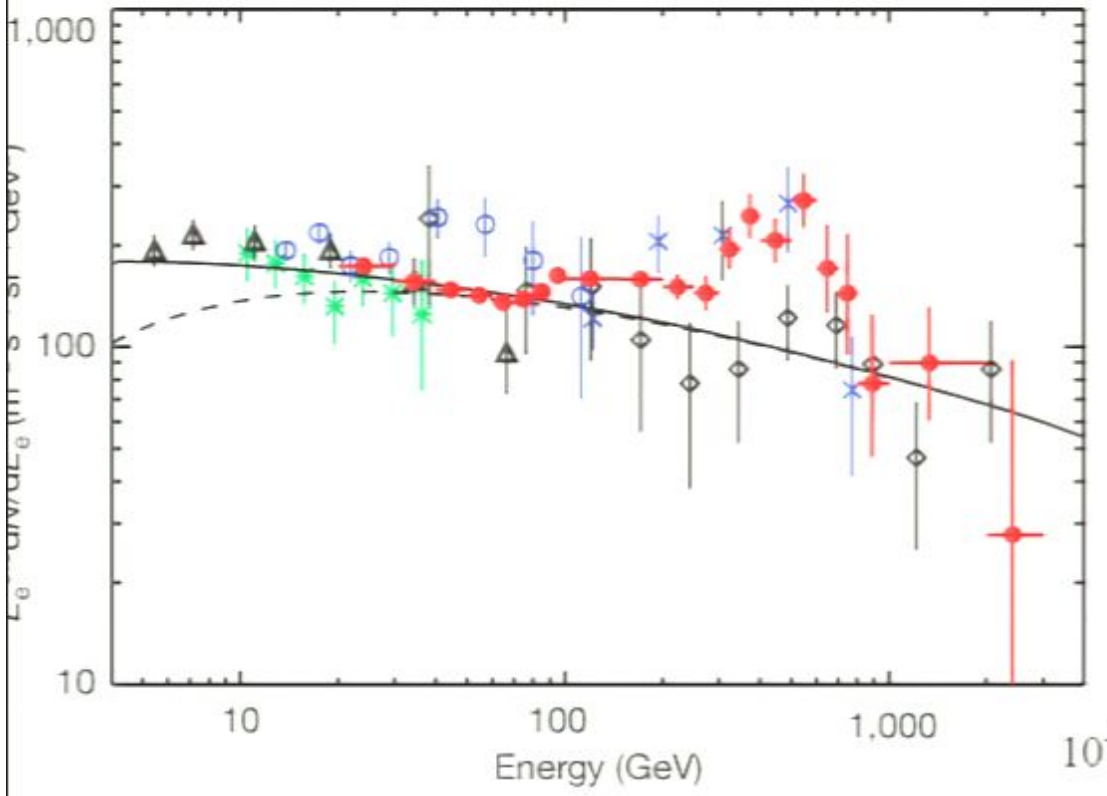
- PAMELA has been in orbit and studying cosmic rays for ~30 months. >10^9 triggers registered, and >10 TB of data has been down-linked.

- Antiproton-to-proton flux ratio (~100 MeV - ~100 GeV) shows no significant deviations from secondary production expectations. Additional high energy data in preparation (up to ~150 GeV).

- High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy. Primary source?
Data at higher energies will help to resolve origin of rise (spillover limit ~300 GeV).

- Analysis ongoing to measure the e^- spectrum up to ~500 GeV, e^+ spectrum up to ~300 GeV and all electrum ($e^- + e^+$) spectrum up to ~1 TV.

- Furthemore:
  - PAMELA is going to provide measurements on elemental spectra and low mass isotopes with an unprecedented statistical precision and is helping to improve the understanding of particle propagation in the interstellar medium
  - PAMELA is able to measure the high energy tail of solar particles.
  - PAMELA is going to set a new lower limit for finding Antihelium



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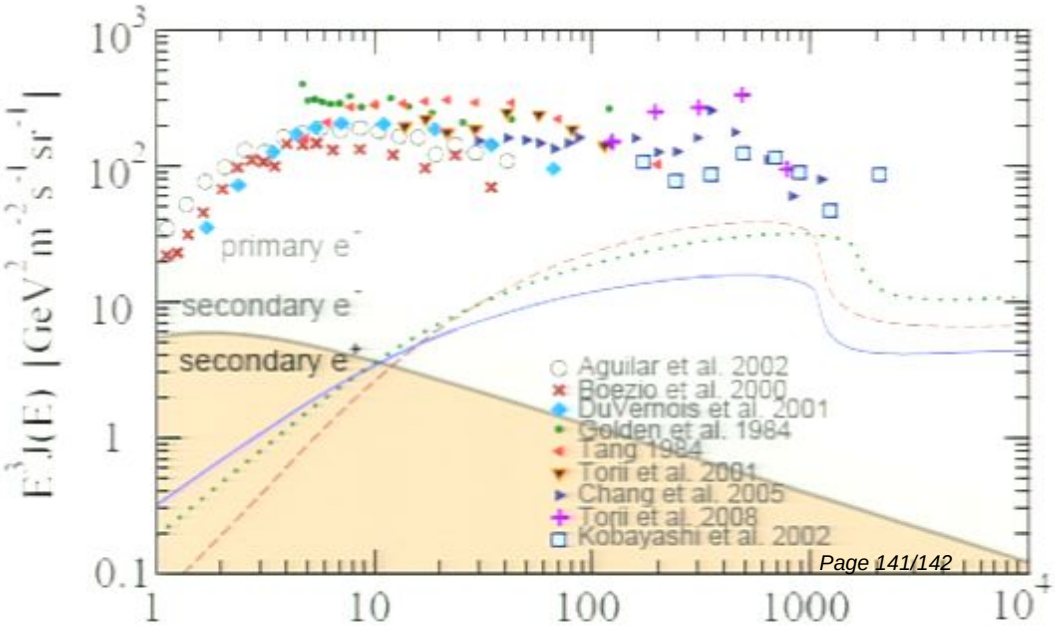

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