Latest Results from the PAMELA Space Experiment

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On behalf of the PAMELA collaboration

Neutrino Oscillation Workshop
Conca Specchiulla - Otranto
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Presentation outline

- Introduction
- PAMELA scientific goals and apparatus
- Latest PAMELA results on:
  - antiparticles (antiprotons and positrons)
    - galactic H and He spectra
    - B/C
    - electrons (e^-) spectrum
  - sub-cutoff spectra
- Summary

PAMELA Collaboration

Italy

Bari Florence Frascati Naples Rome Trieste CNR, Florence

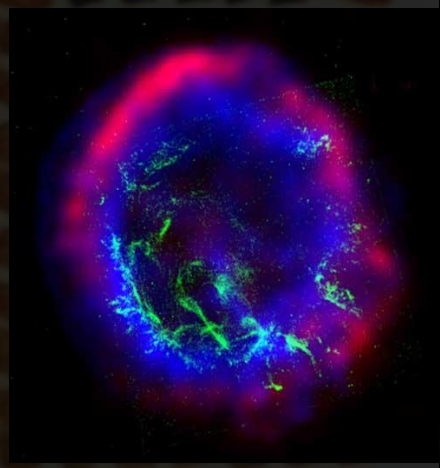
Germany: Siegen

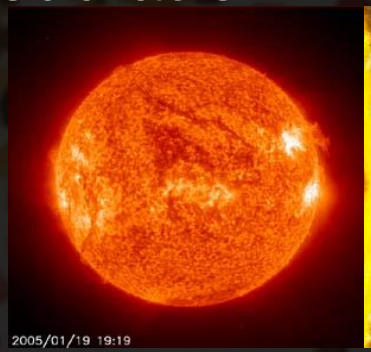
Sweden: KTH, Stockholm

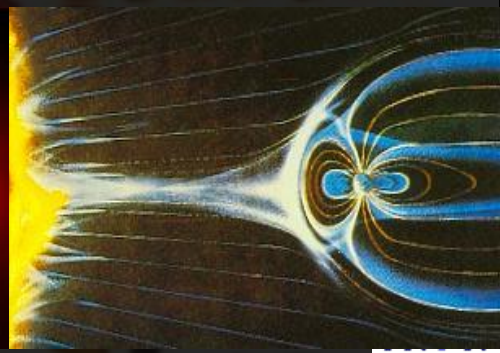
Russia: Moscow / St. Petersburg

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

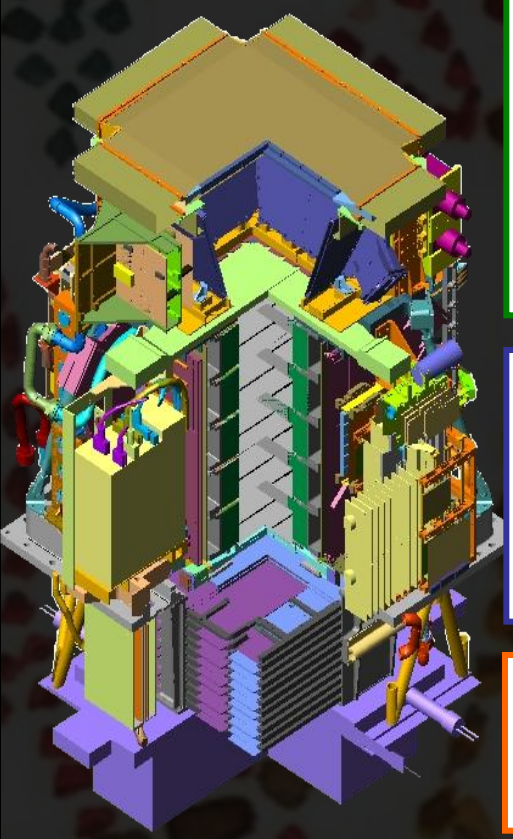






PAMELA apparatus

PAMELA detectors

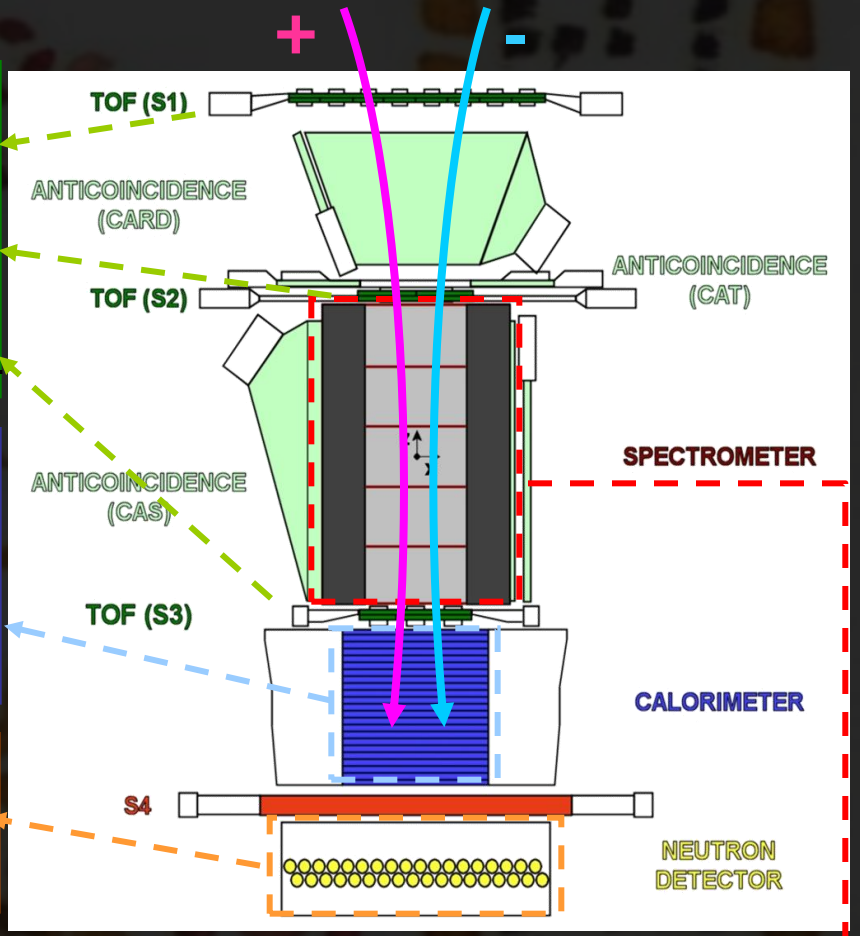


GF: 21.5 cm² sr
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W

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 λ_I)
- Discrimination e^+ / p, p-bar / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination



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

Design Performance

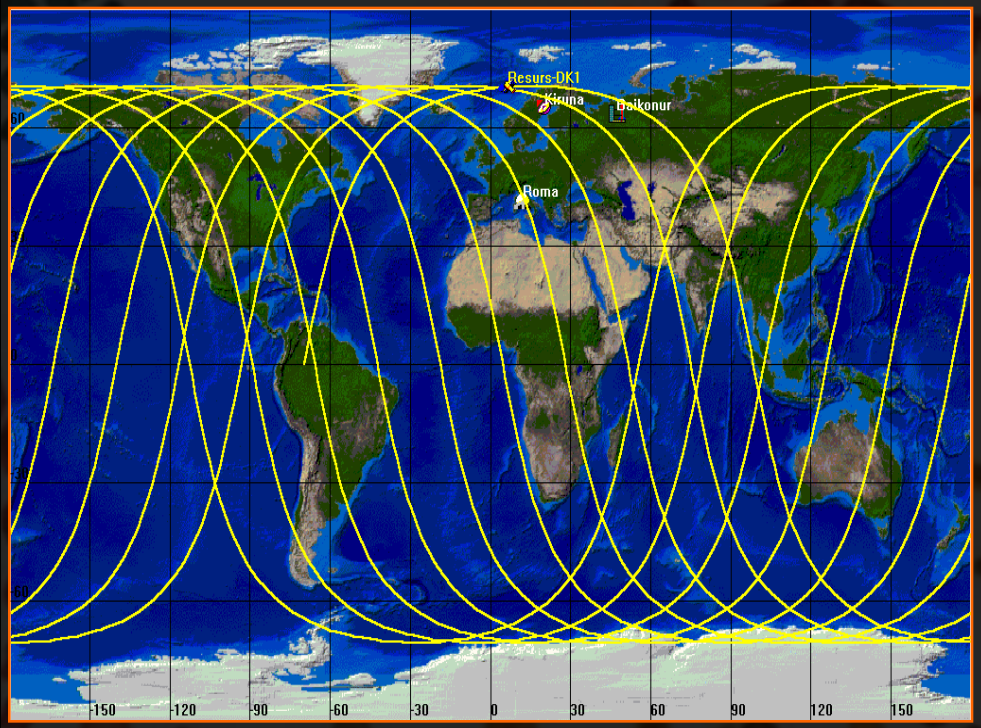
	energy range
• Antiprotons	80 MeV - 190 GeV
• Positrons	50 MeV – 300 GeV
• Electrons	up to 500 GeV
• Protons	up to 700 GeV
• Electrons+positrons	up to 2 TeV (calorimeter)
• Light Nuclei (He/Be/C)	up to 200 GeV/n
• Anti-Nuclei search	sensitivity of 3×10^{-8} in $\overline{\text{He}}$/He

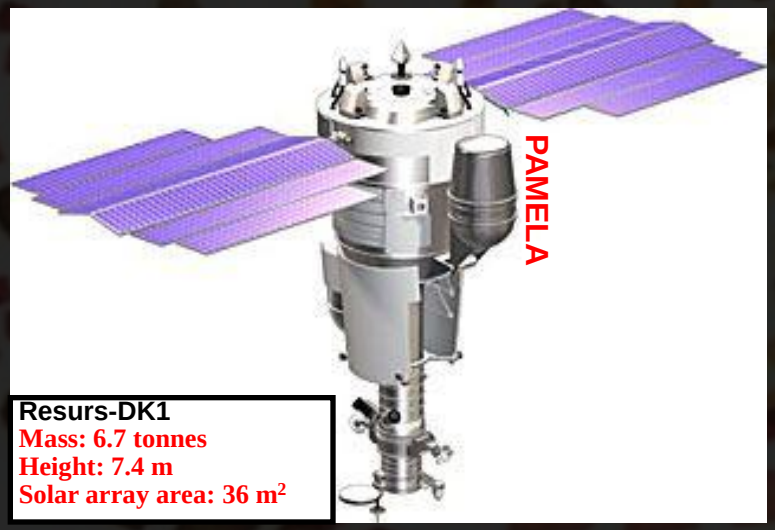
→ Simultaneous measurement of many cosmic-ray species

→ New energy range

→ Unprecedented statistics

Resurs-DK1 satellite and orbit





- Resurs-DK1: multi-spectral imaging of earth's surface
- PAMELA mounted inside a pressurized container
- Launch 15/06/2006 - lifetime >3 years (assisted), extended till end 2011
- 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

Latest PAMELA results

Antiproton identification

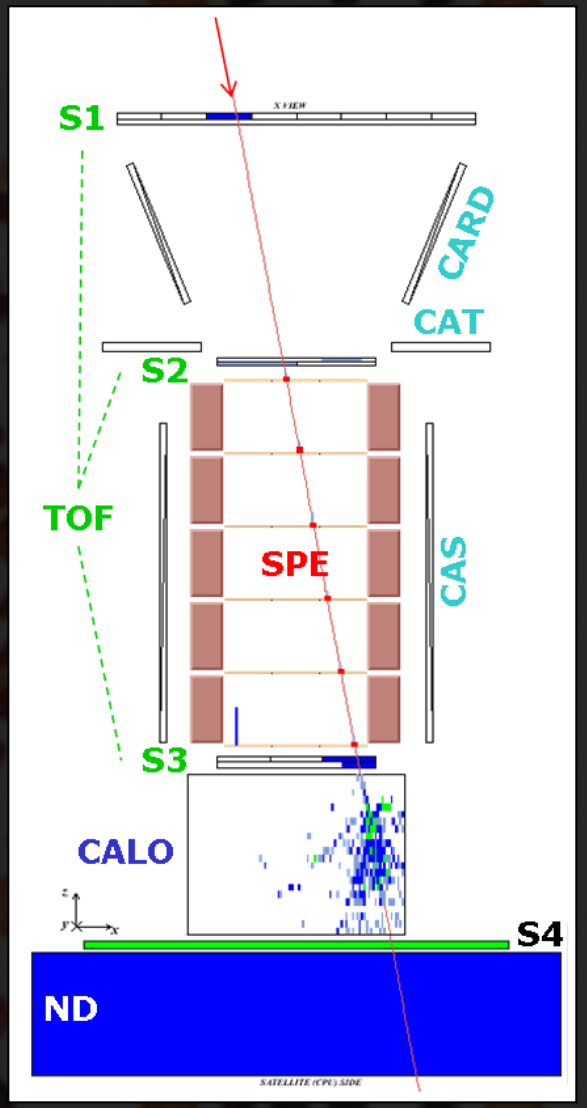
- Analyzed data July 2006 – January 2010 (~1200 days)
- Collected triggers ~10^9
- Identified **~ 10^8 protons** and **~ 10^3 antiprotons** between 1.5 and 100 GeV - more than ***100 p-bar above 20GeV***

- Antiproton/proton identification:
  - rigidity (R) → SPE
  - |Z|=1 (dE/dx vs R) → SPE&ToF
  - β vs R consistent with M_p → ToF
  - *p-bar/p separation (charge sign) → SPE*
  - *p-bar/e^- (and p/e^+) separation → CALO*

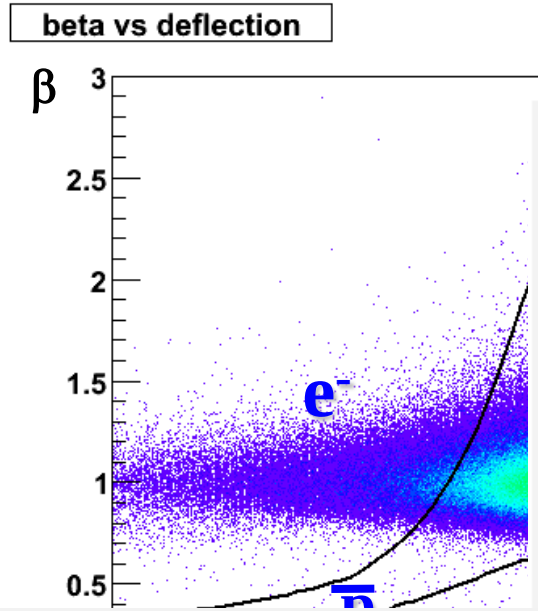
- *Dominant background →* ***spillover protons****:*
  - finite deflection resolution of the SPE

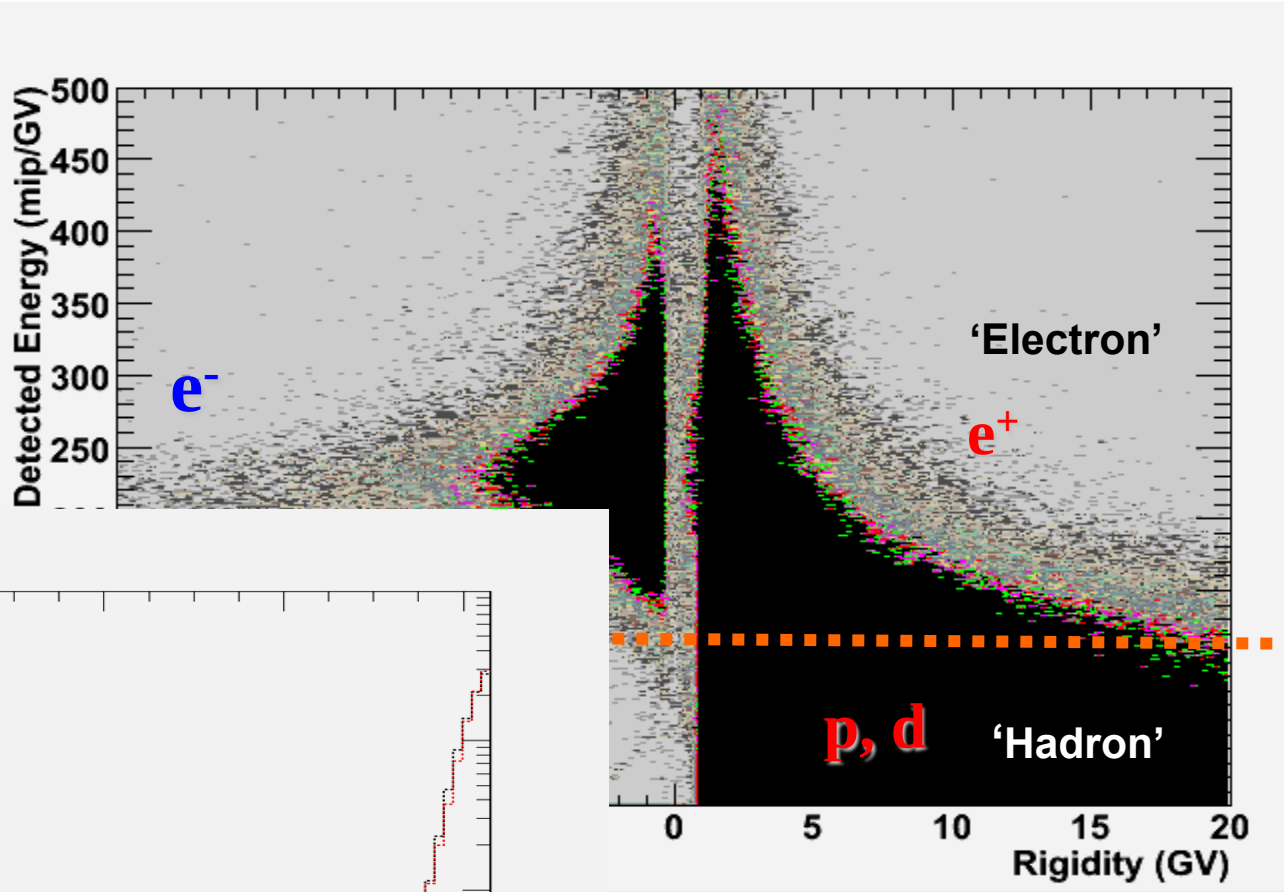
  ⇒ wrong assignment of charge-sign @ high energy

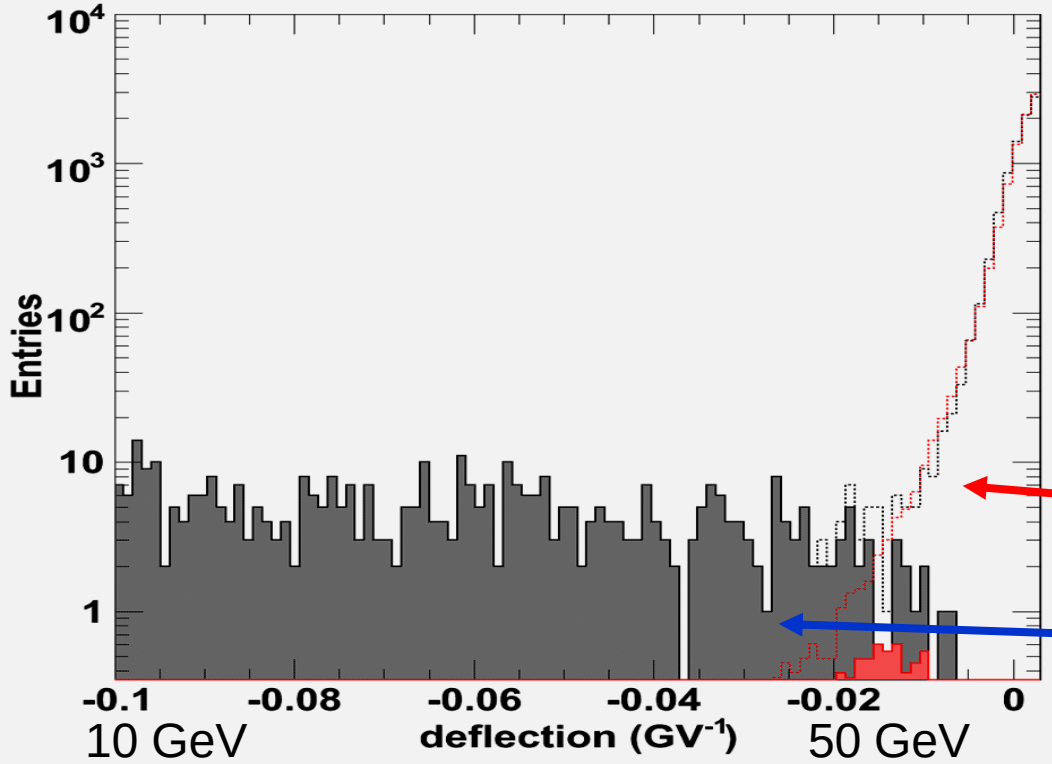
→ *Strong SPE selection required*



Calorimeter selection





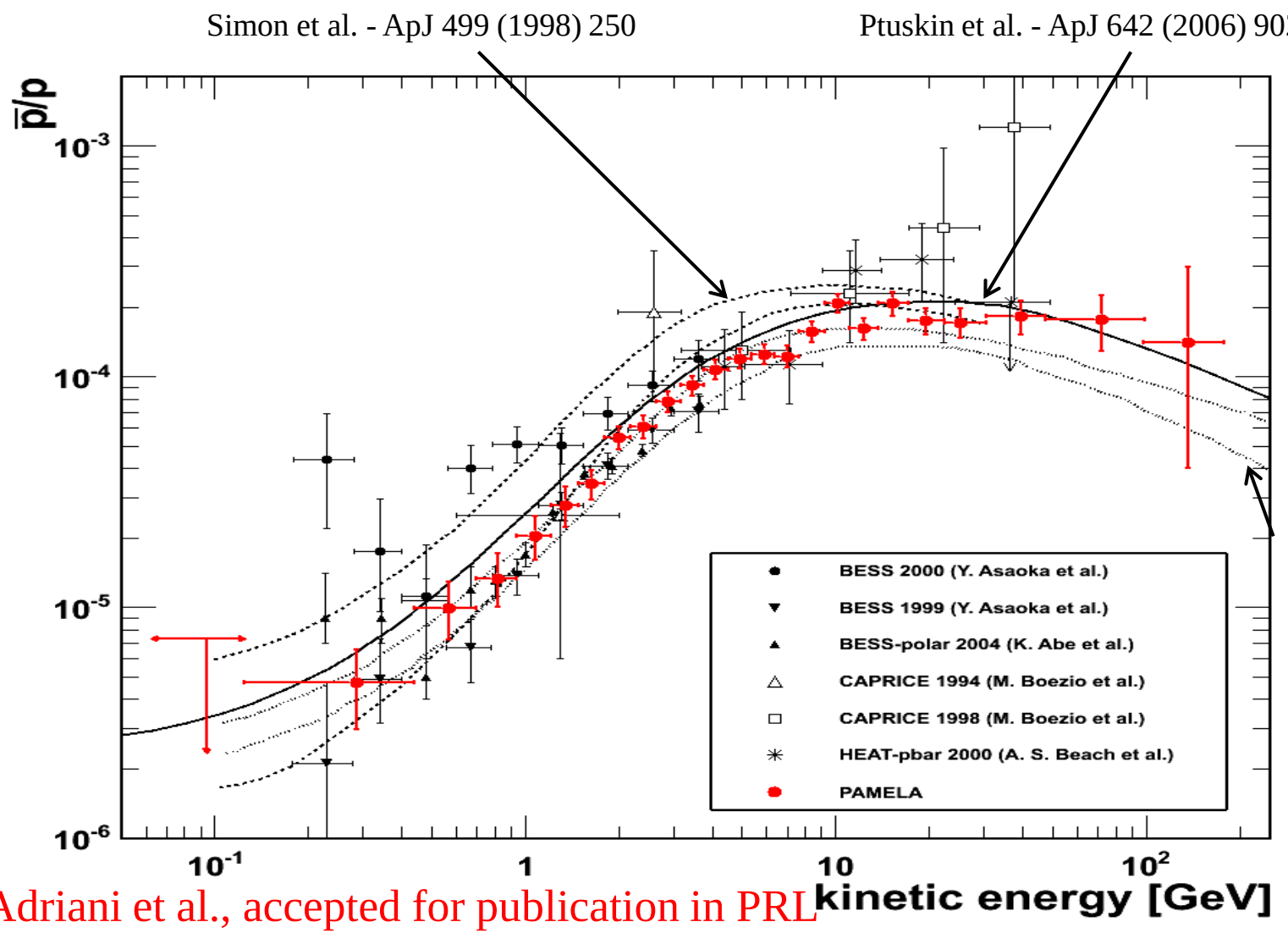


Tracker Identification

Protons (spillover)

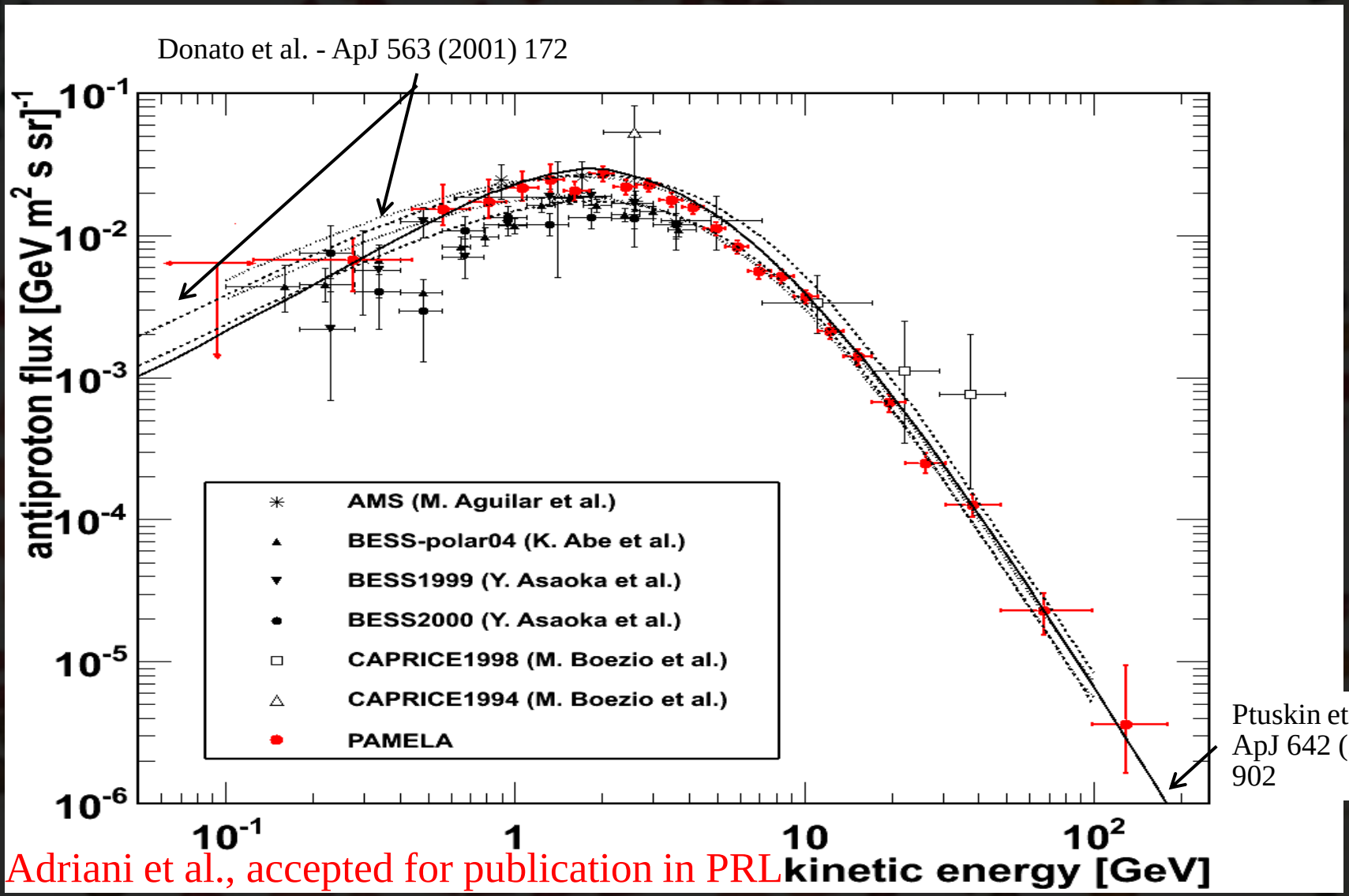
Antiprotons

PAMELA antiproton to proton ratio



Adriani et al., accepted for publication in PRL

PAMELA antiproton spectrum



Adriani et al., accepted for publication in PRL

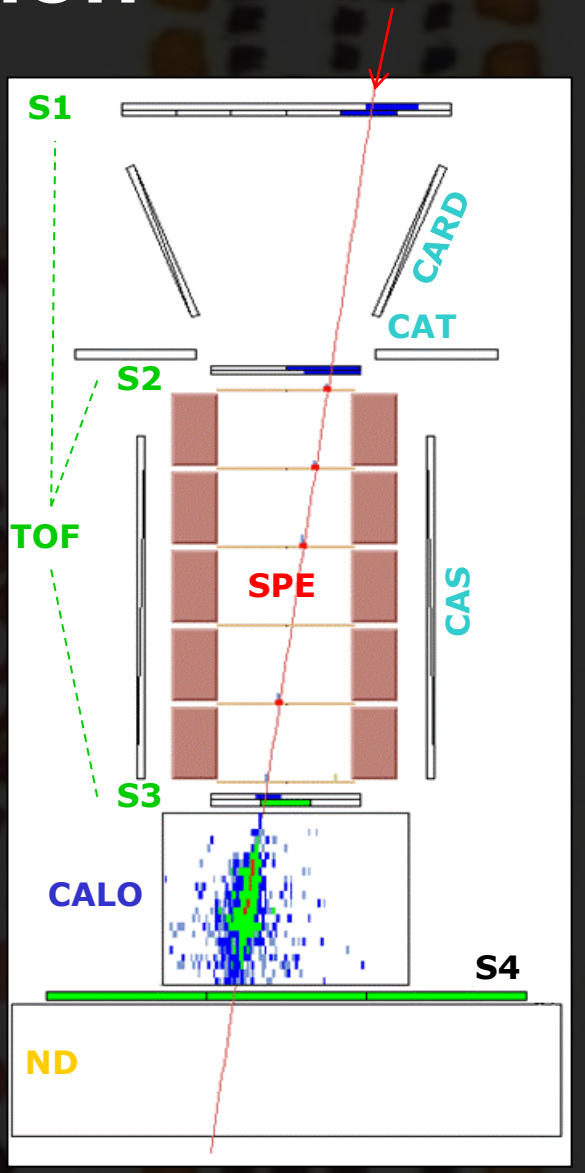
Positron identification

- Analyzed data July 2006 – January 2010 (~1200 days)
- Collected triggers ~10^8
- Identified ~ 10^4 electrons and positrons between 1.5 and 100 GeV – more than *180 positrons above 20GeV*

Electron/positron identification:
- rigidity (R) → SPE
- |Z|=1 (dE/dx=MIP) → SPE&ToF
- β=1 → ToF
- *e-/e+ separation (charge sign) → SPE*
- *e+/p (and e-/p-bar) separation → CALO*

- *Dominant background → **interacting protons**:*
  proton spectrum harder than positron
  ⇒ p/e+ increase for increasing energy (10^3 @1GV 10^4 @100GV)

→ Strong CALO selection required



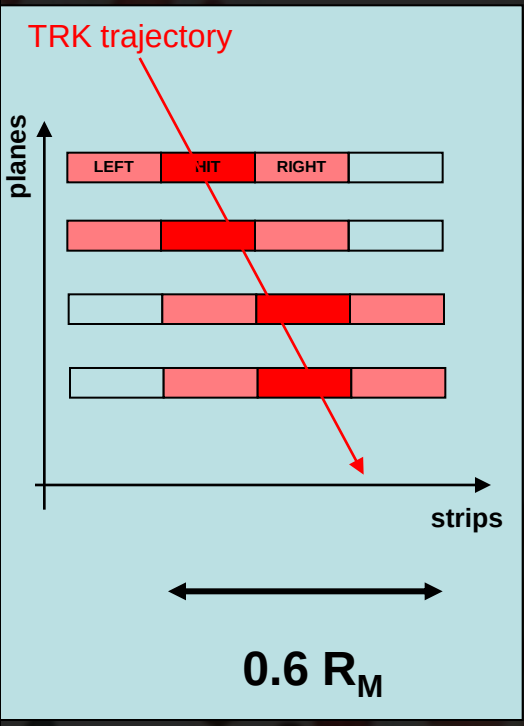
Positron selection

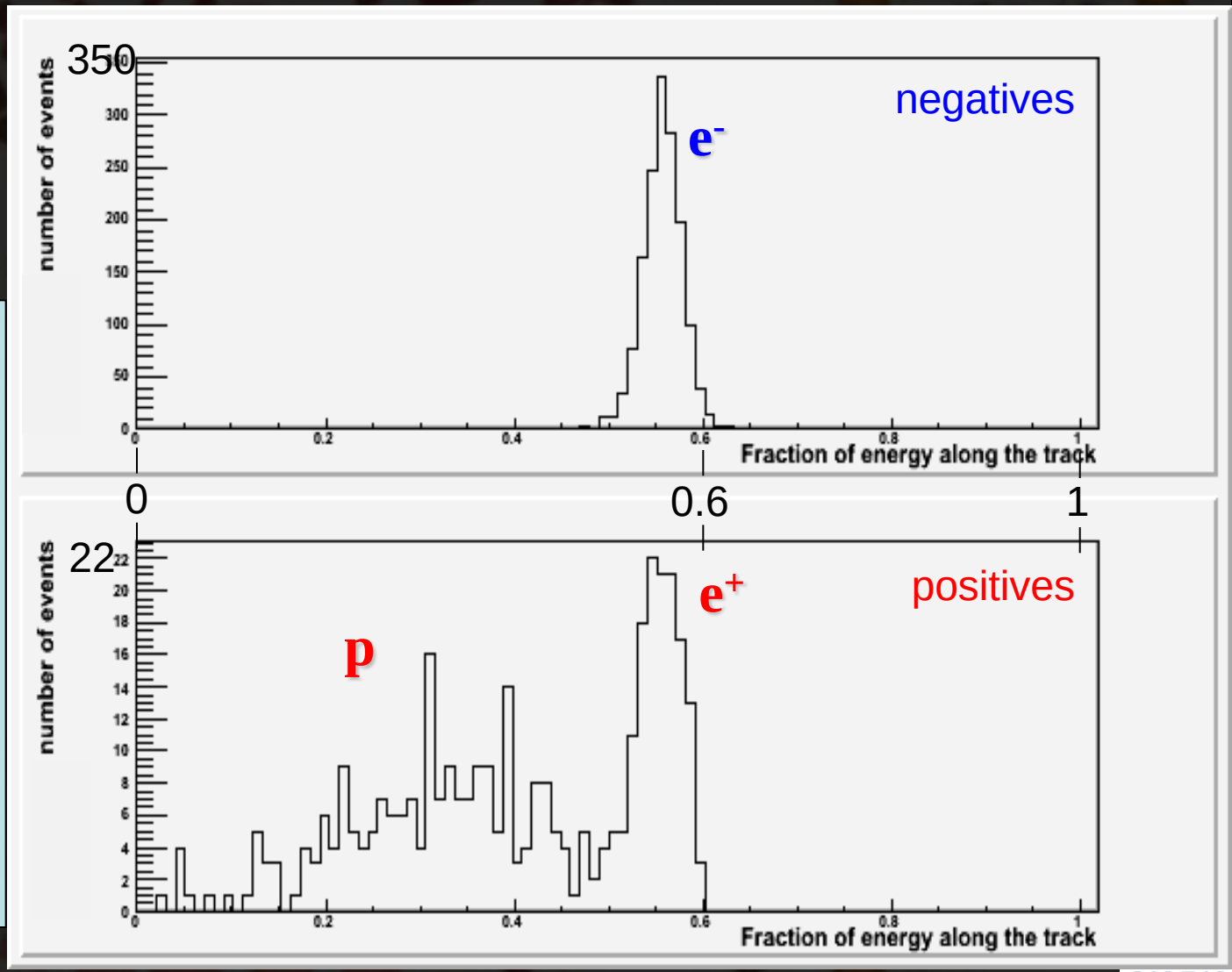
Fraction of energy released along the track (left, hit, right) in the calorimeter

Pre-selections:

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

Rigidity: 20-30 GV





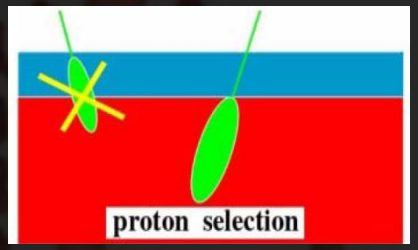
Background estimation from data

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

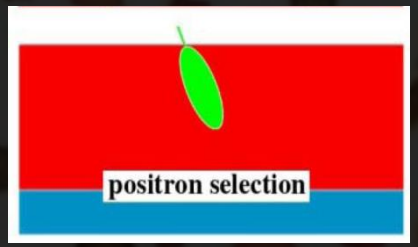
Pre-selections:

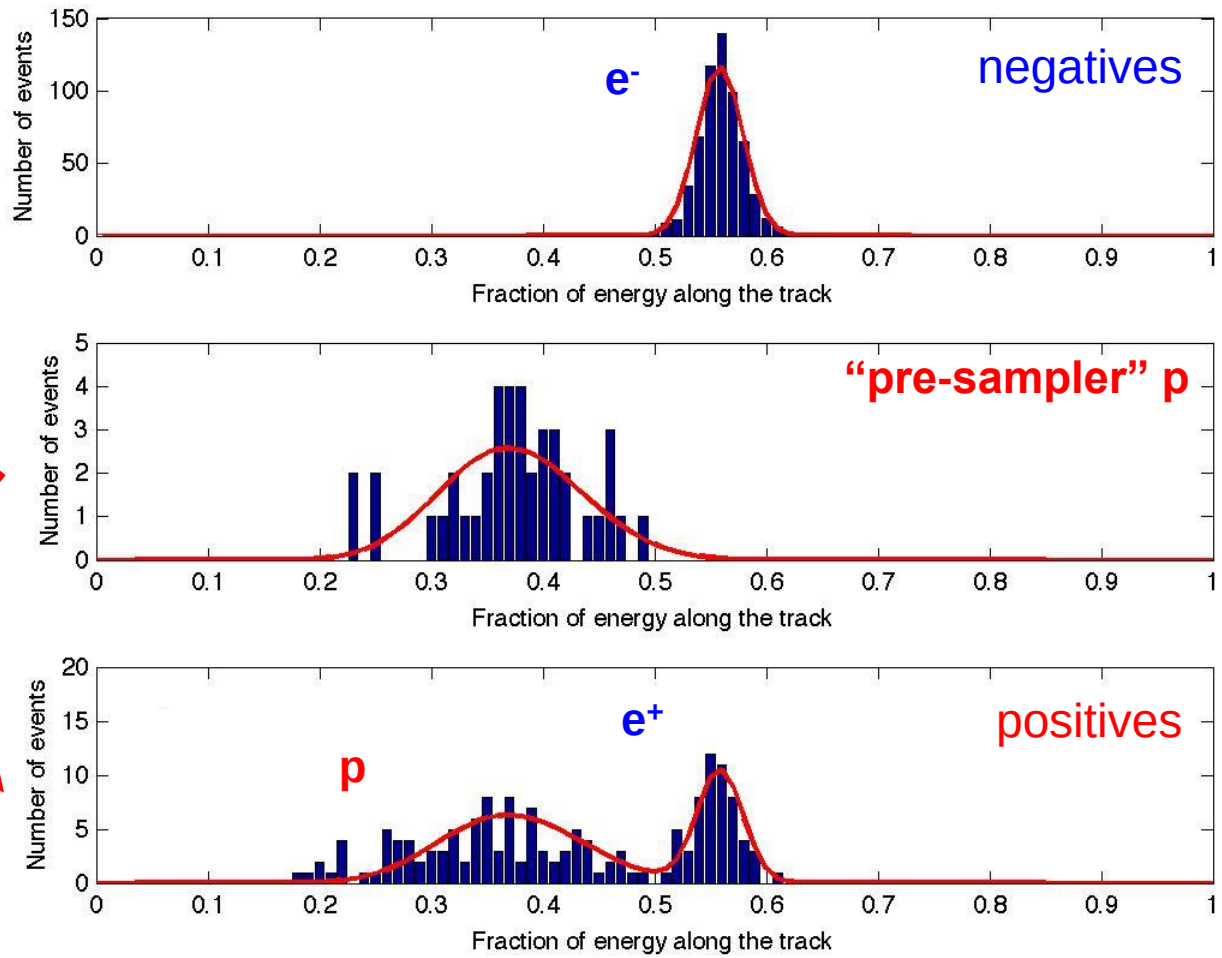
- **Energy-momentum match**
- **Starting point of shower**

Rigidity: 28-42 GV



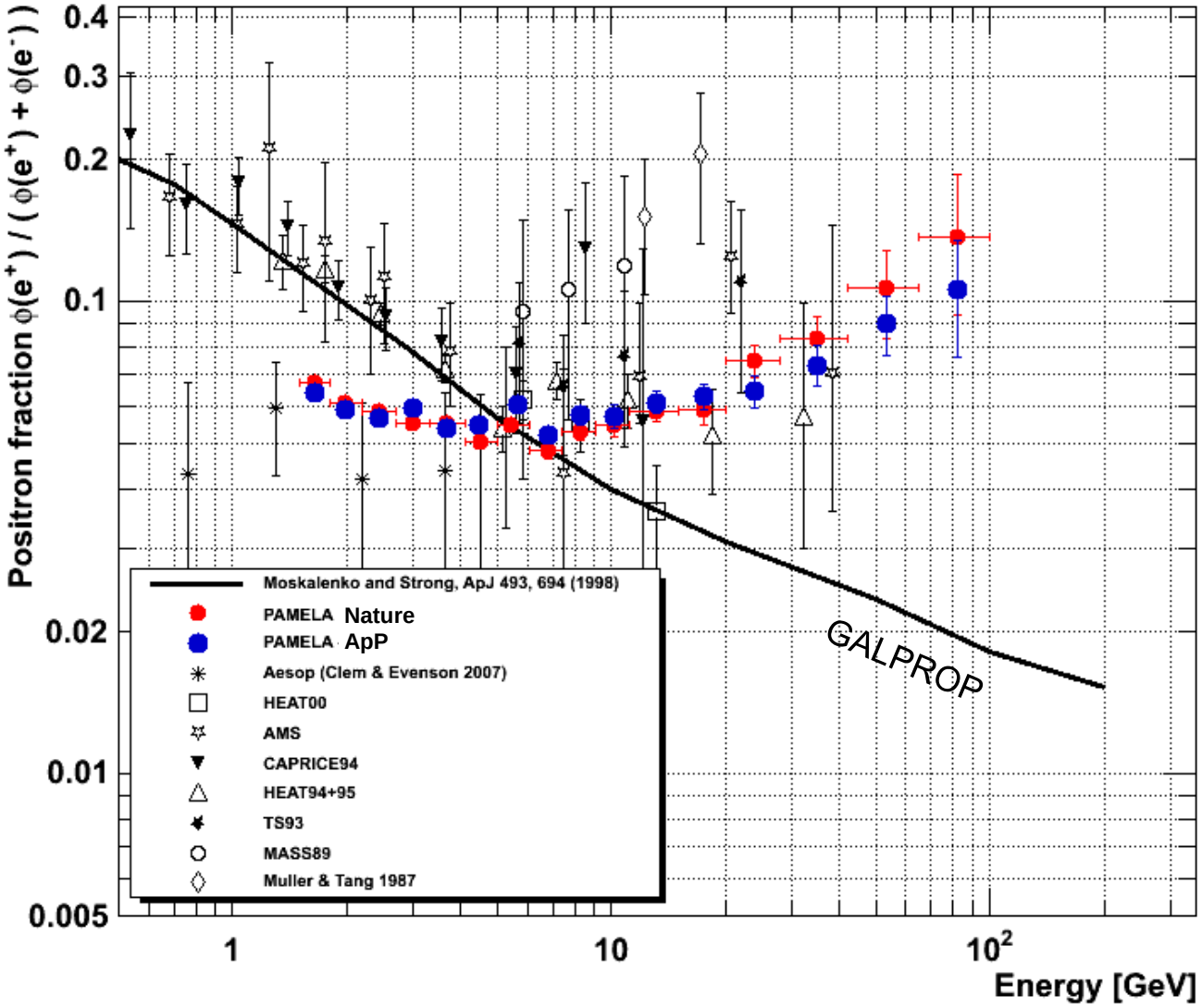
pre-sampler





Positron to Electron Fraction

Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522



Extending the positron fraction measurement

Background suppression method, full calorimeter:

- No proton sample from flight data
- Simulations & Test beam data needed
- Strong selections to reject protons using TMVA (Toolkit for MultiVariate data Analysis)

" 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 decision trees, ..."

Positron to Electron Fraction

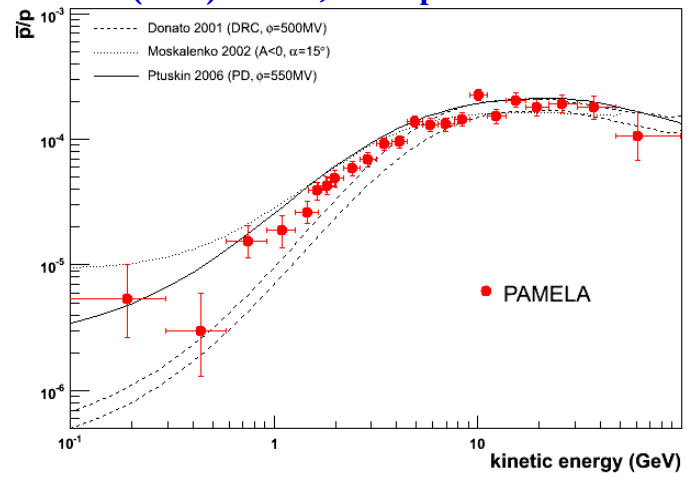
Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522

Preliminary

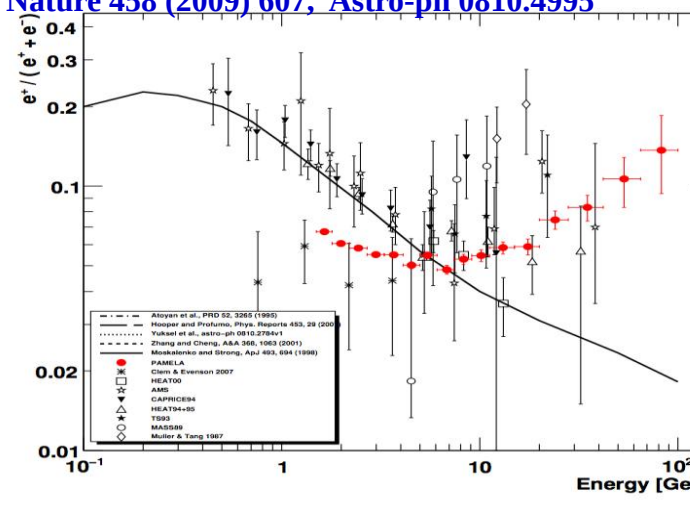
TMVA analysis for data with E>15 GeV

During first week after PAMELA results posted on arXiv (October 28, 2008)

PRL 102 (2009) 051101, Astro-ph 0810.4994



Nature 458 (2009) 607, Astro-ph 0810.4995



⇒

1. 0808.3725 DM
2. 0808.3867 DM
3. 0809.2409 DM
4. 0810.2784 Pulsar
5. [illegible]4846 DM / pulsar
6. [illegible]DM
7. [illegible]
8. [illegible]
9. 0810.[illegible]
10. 0810.539[illegible]
11. 0810.5557 DM
12. 0810.4147 DM
13. 0811.0250 DM
14. 0811.0477 DM

...

PAMELA data cited by >500 papers on arXiv (at present)

Reasons for the positron fraction to rise

(slide adapted from I. Moskalenko talk, PAMELA Workshop, Rome, May 2009)

- Main reason – primary positrons are perhaps unavoidable
- There is no deficit in papers explaining the PAMELA positron excess (>200 papers since Oct 2008!):
  - Various species of the dark matter (~170)
  - Pulsars
  - SNRs
  - Microquasar
  - …

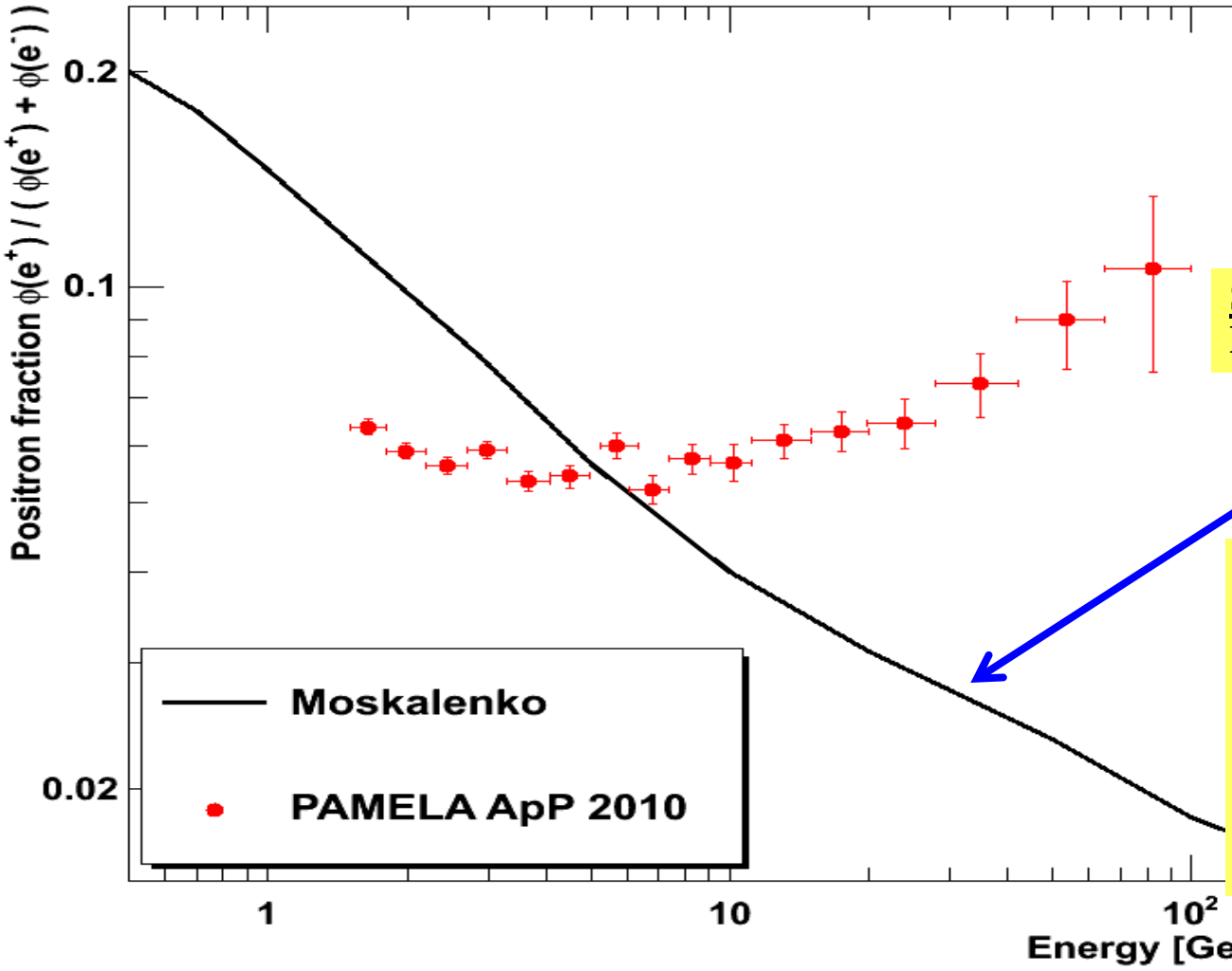
- Perhaps we have to discuss a deficit of positrons, not their excess!

Unfortunately, they could be all wrong!

Reason – we do not know precisely the background and thus can't get an idea of the spectrum of the primary positron component

PAMELA Positron Fraction

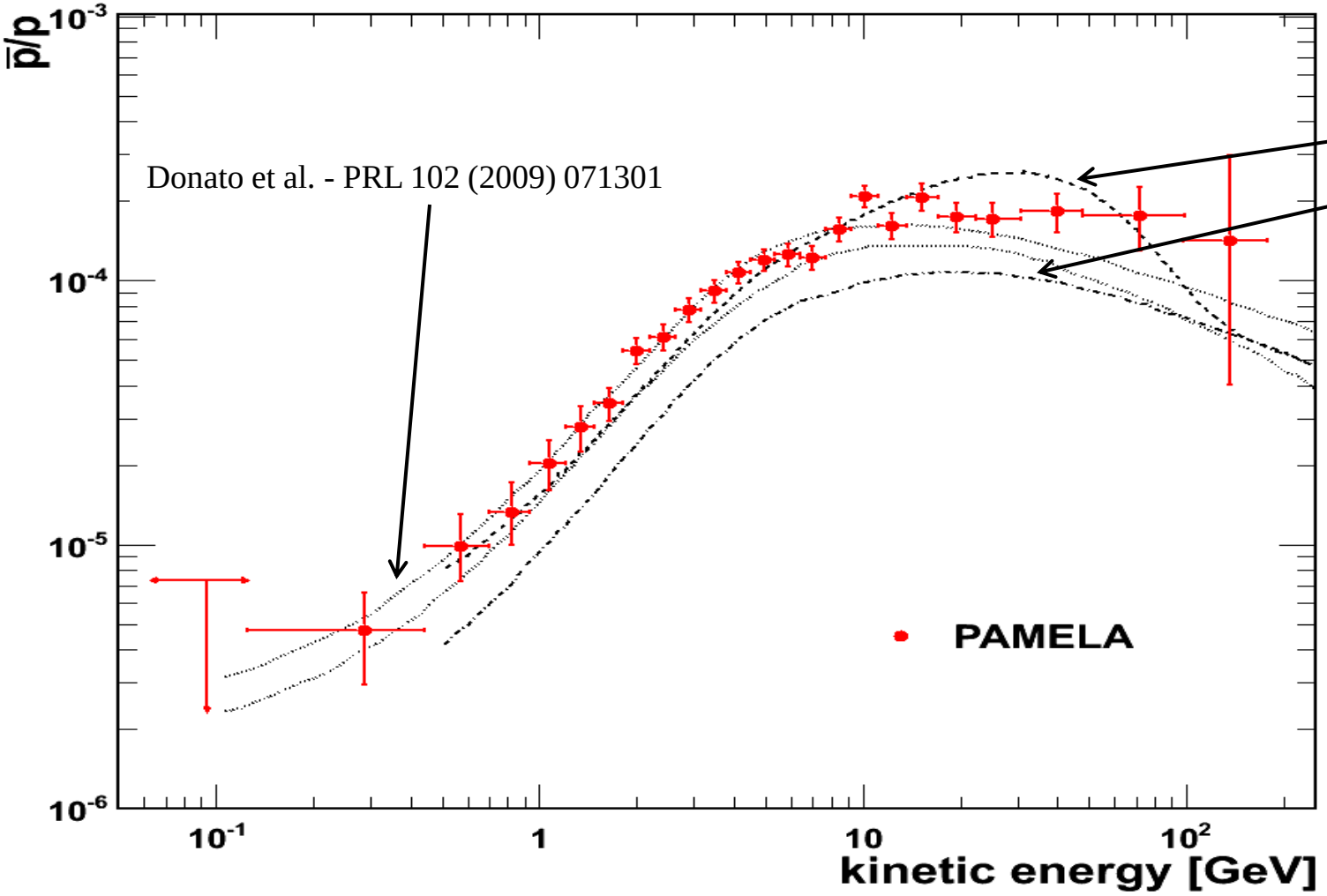
Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522



Secondary production
Moskalenko & Strong 98

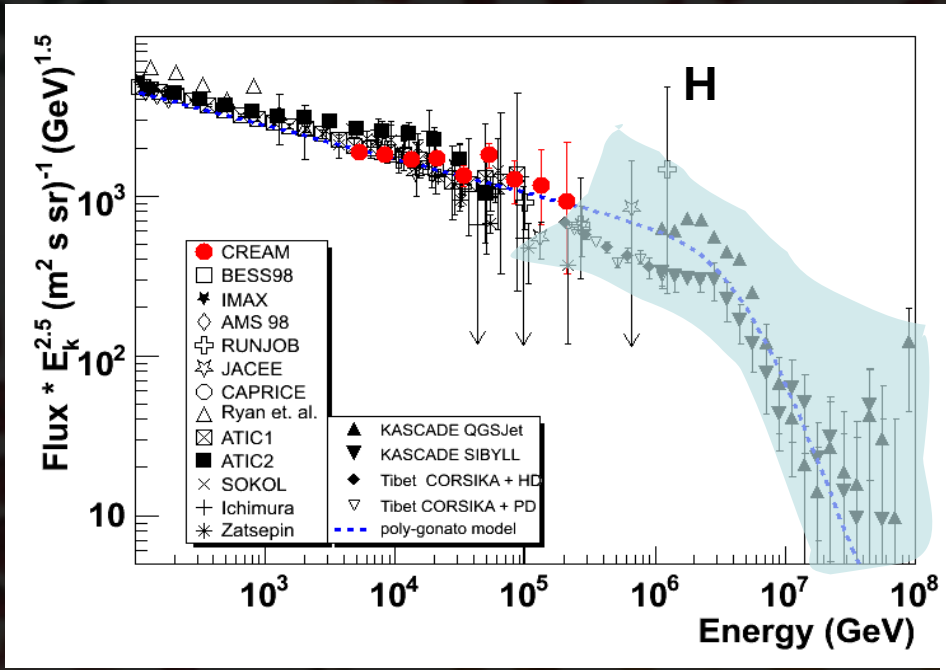
But uncertainties on:
- **Charge dependent solar modulation (low energy)**
- **Secondary production (primary fluxes, cross section)**

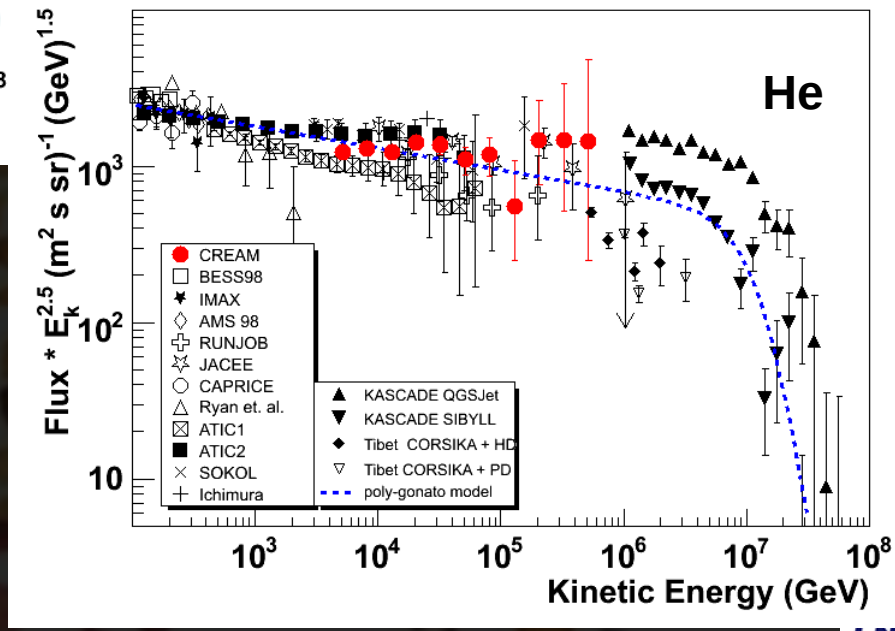
Antiproton to proton ratio



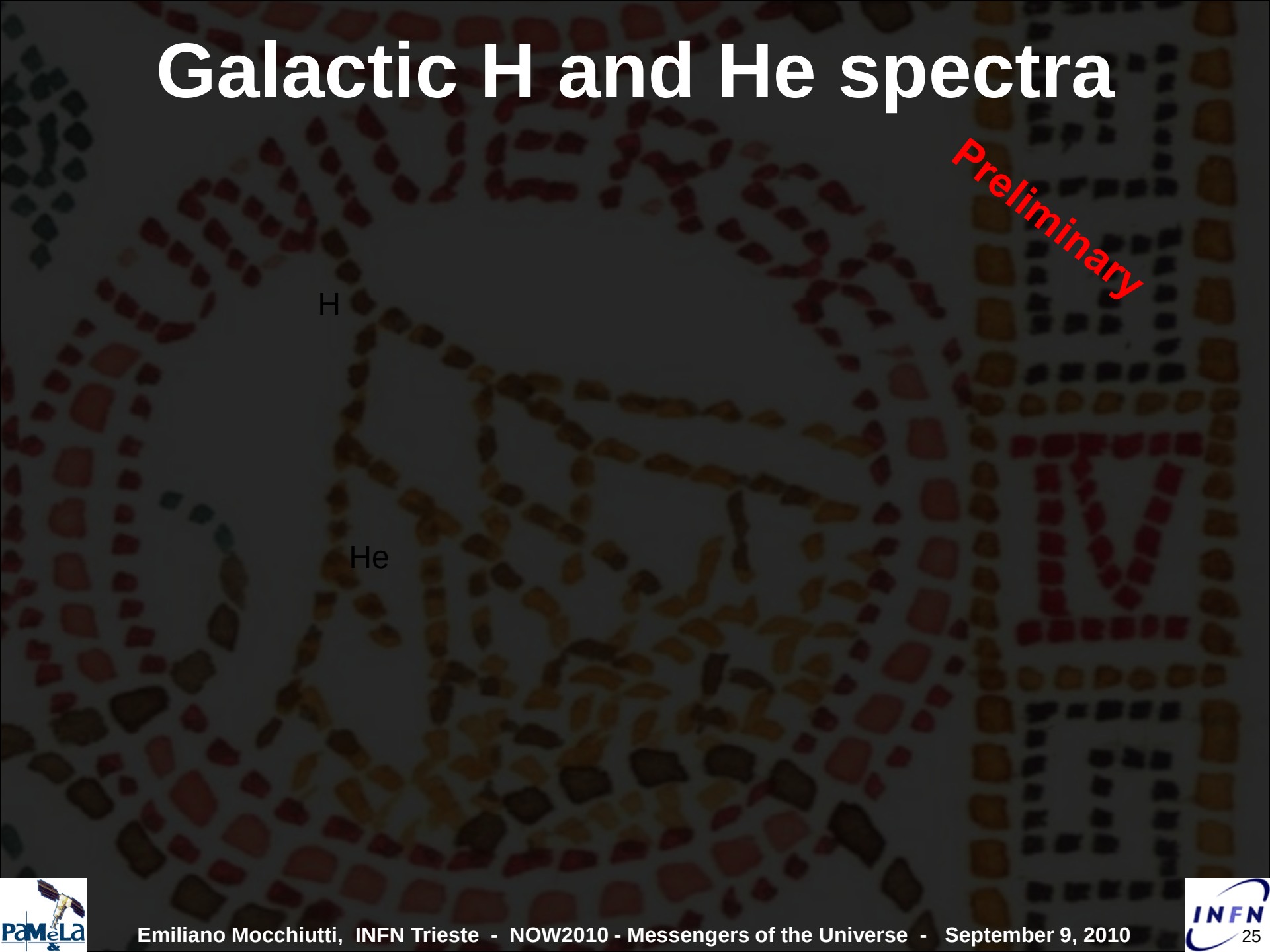
Kane et al. - Phys. Lett. B 681 (2009) 151:
- Secondaries plus primary component
- Only secondaries

Galactic H and He spectra





Galactic H and He spectra

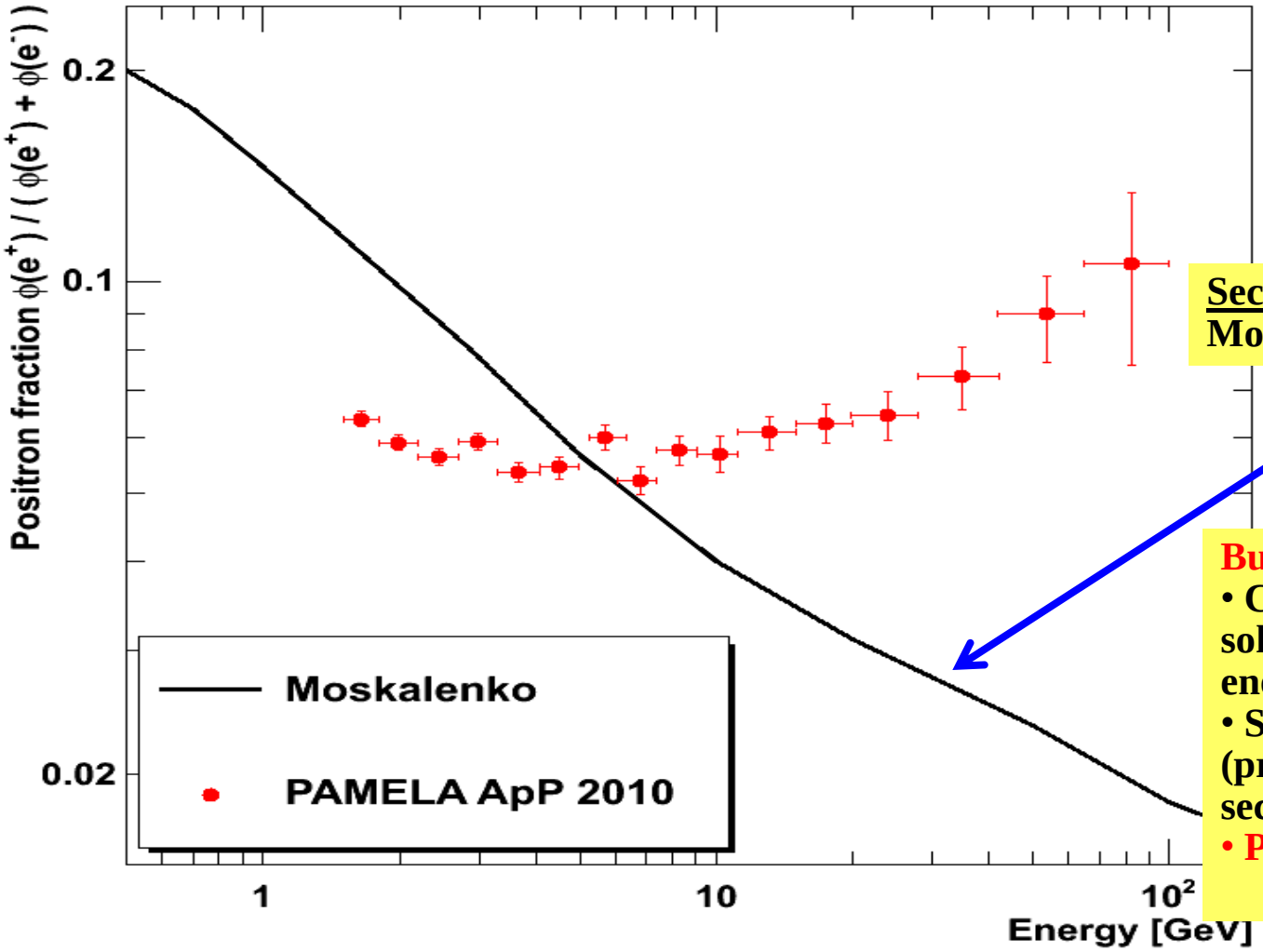


Galactic H and He spectra

Preliminary

PAMELA Positron Fraction

Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522



Secondary production
Moskalenko & Strong 98

But uncertainties on:
- **Charge dependent solar modulation (low energy)**
- **Secondary production (primary fluxes, cross section)**
- **Propagation models**

PAMELA secondary nuclei

Preliminary!!

LBM

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

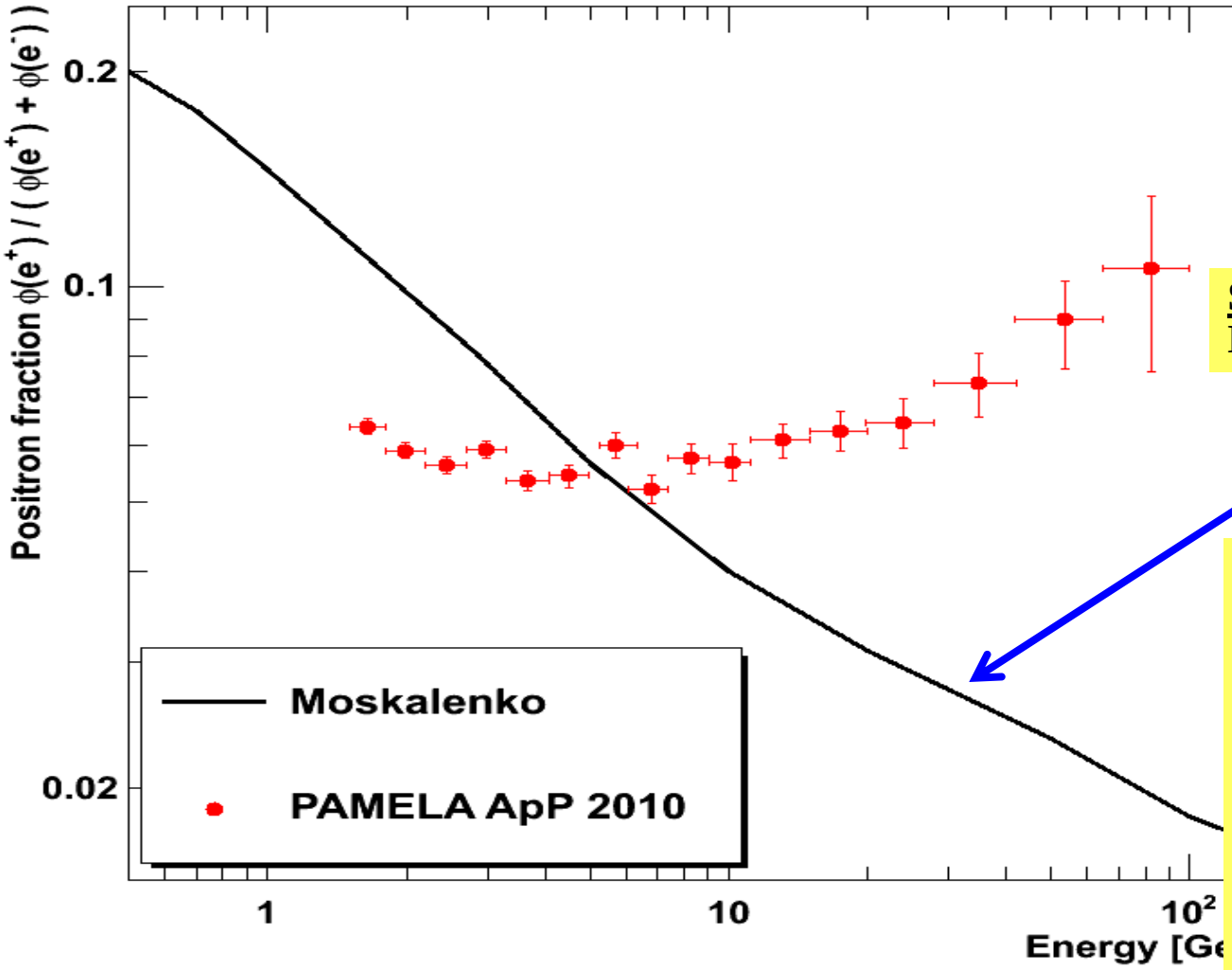
- **B nuclei of secondary origin:**
  CNO + ISM → B + …
- **Local secondary/primary ratio sensitive to average amount of traversed matter (λ_{esc}) from the source to the solar system**

<u>Local secondary abundance:</u>
⇒ study of galactic CR propagation

(B/C used for tuning of propagation models)

PAMELA Positron Fraction

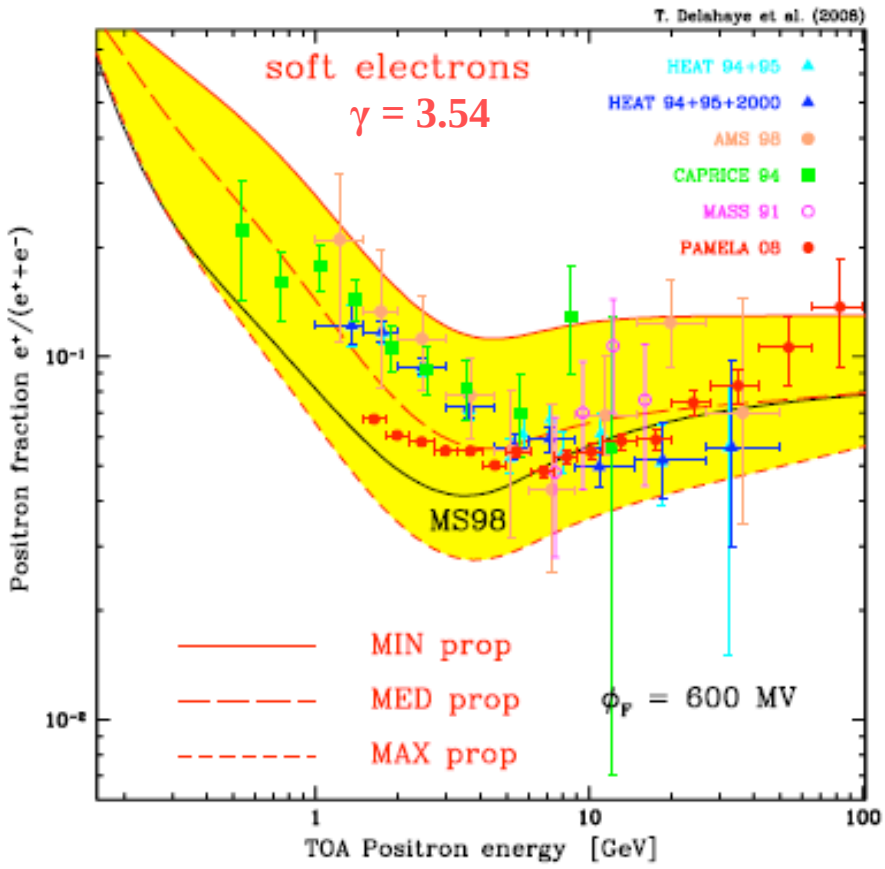
Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522

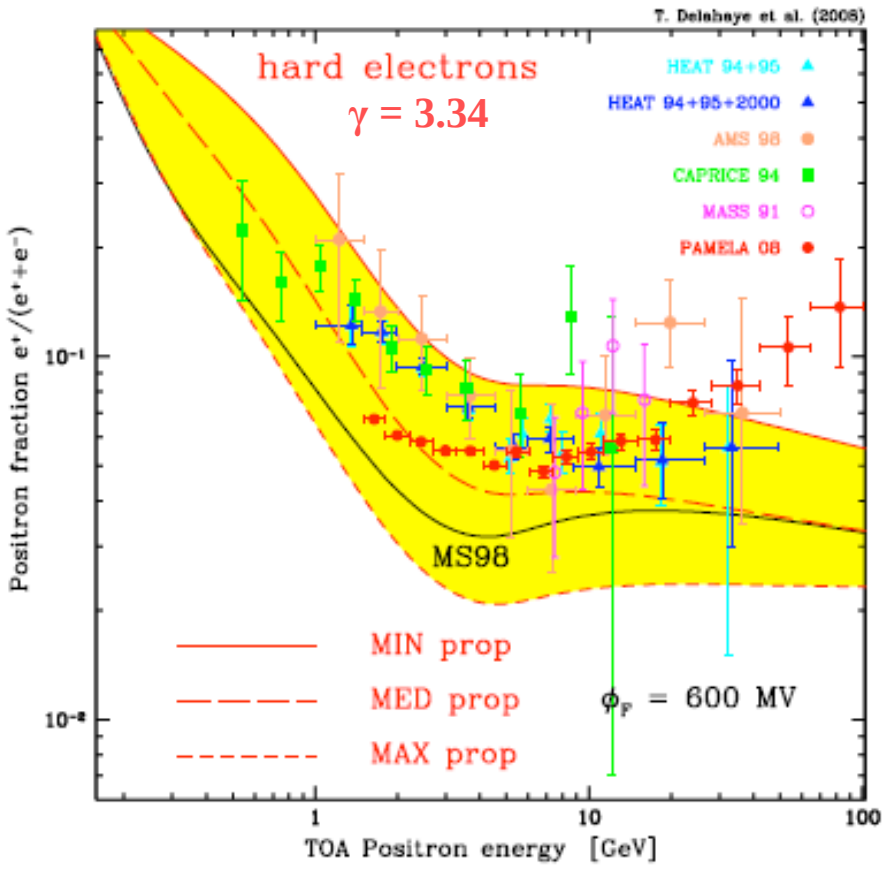


Secondary production
Moskalenko & Strong 98

But uncertainties on:
- **Charge dependent solar modulation (low energy)**
- **Secondary production (primary fluxes, cross section)**
- **Propagation models**
- **Electron (e-) spectrum**

Theoretical uncertainties on “standard” positron fraction



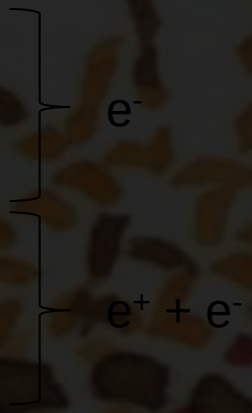


T. Delahaye et al., arXiv: 0809.5268v3

Average of pre-PAMELA experiments: γ ~ 3.3

PAMELA electron (e^-) spectrum

Preliminary



Comments on electrons and positrons background

- Background is not known precisely but the positron fraction is expected to decrease with increasing energy.

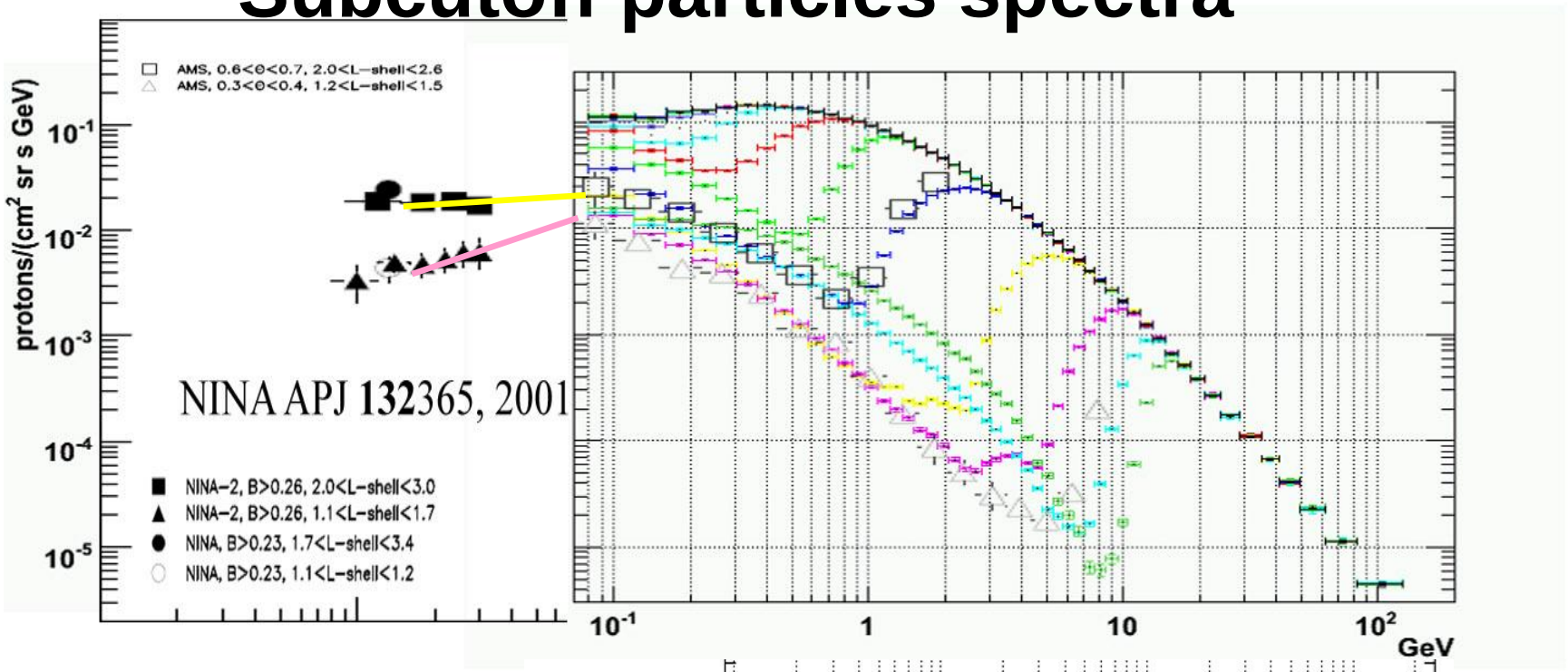
- PAMELA is providing useful set of data needed to better understand the positron measurement, for the first time a single experiment is measuring (with same systematic errors) a wide set of data.

Comparing pulsars with DM

L. Bergström

	Pulsars	Dark Matter
Known to exist?	√	√
Free parameters	Many (order of 100 ?)	4 for PAMELA-consistent models. (2 for branching ratio between different leptons, Mass, E_F)
Basic mechanism to give required flux known?	Maybe. (An unclear point is the escape probability – could be less than 1%)	Yes. Sommerfeld enhancement plus substructure boost
Predictions for electron spectrum	Should show some ”bumpiness” due to different pulsars contributing	Should have universal shape at energies from 100 – 600 GeV, the high-energy spectrum will depend on where in the decay chain e^+e^- are created
”Smoking gun” signature	Bumpiness, perhaps anisotropy (small, percent level)	Diffuse gamma-ray could show an excess starting between 100 – 300 GeV

Subcutoff particles spectra

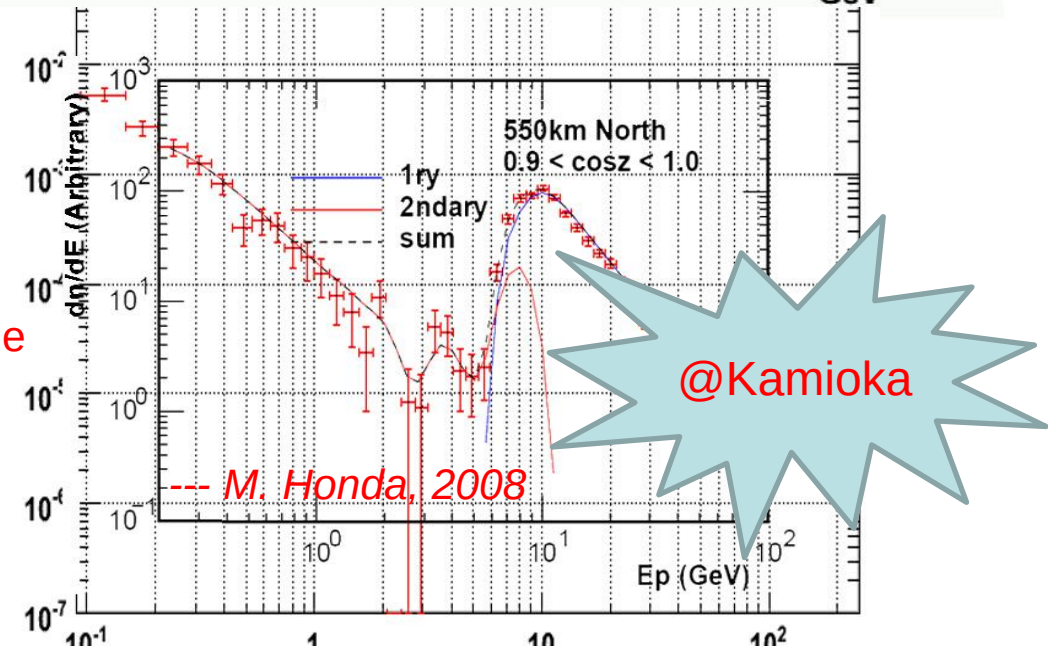


→Atmospheric neutrino contribution

→Astronaut dose on board ISS

→Indirect measurement of cross section in the atmosphere

→ Agile e Glast background estimation



Summary

- PAMELA has been in orbit and studying cosmic rays for ~4 years. >10^9 triggers registered and >20 TB of data has been down-linked, mission extended up to end 2011.
- Antiproton-to-proton flux ratio and antiproton energy spectrum (~100 MeV - ~200 GeV) show no significant deviations from secondary production expectations.
- High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy (primary source?)
- Primary cosmic rays spectra show spectral features that may point to additional components (local source?)
- Analysis ongoing to finalize and release latest data and to measure the e^+ spectrum up to ~300 GeV and the all electrum ($e^- + e^+$) spectrum up to ~1 TV.