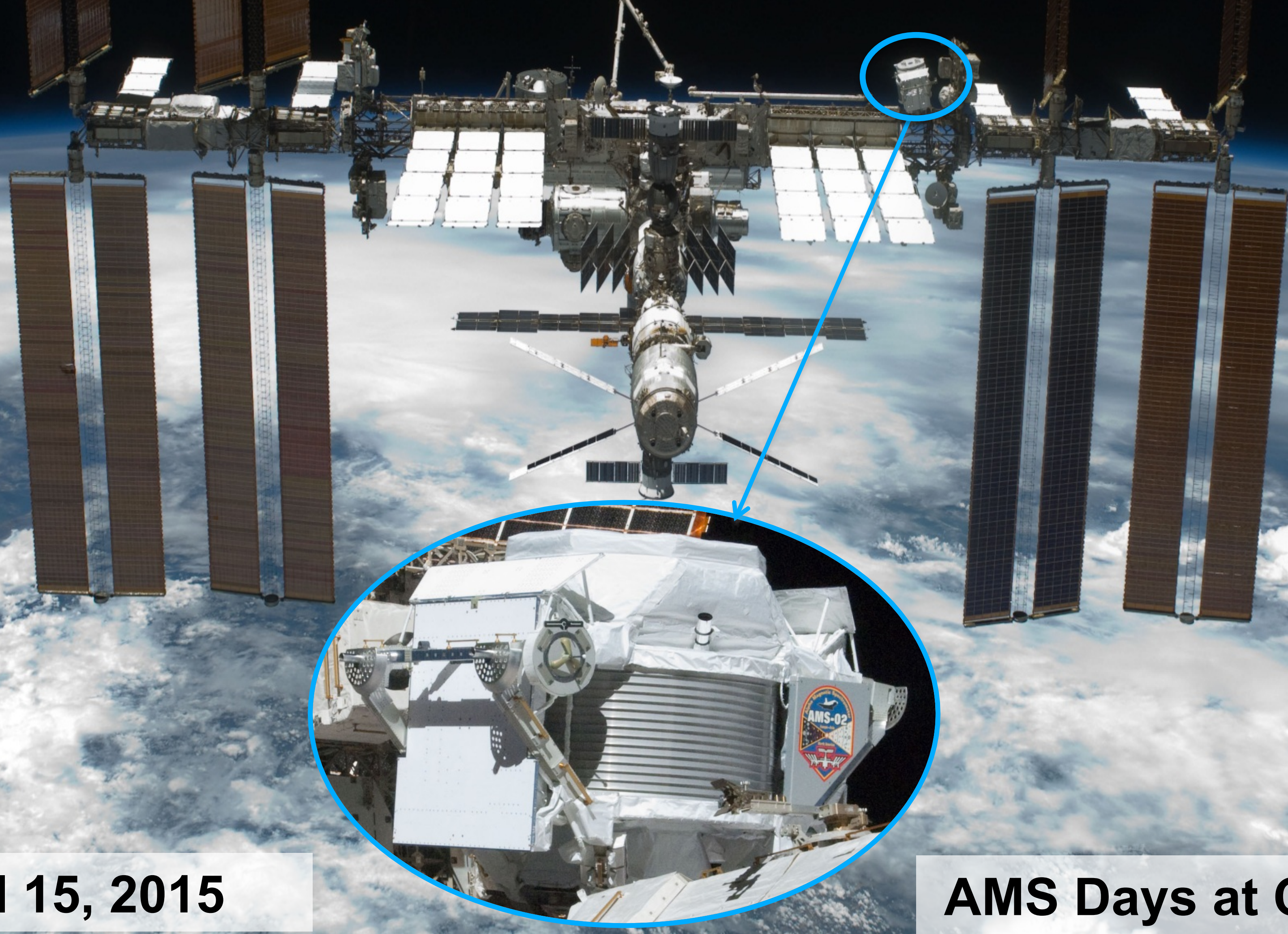
Latest results from the Alpha Magnetic Spectrometer: positron fraction and antiproton/proton ratio

Andrei Kounine / MIT



April 15, 2015

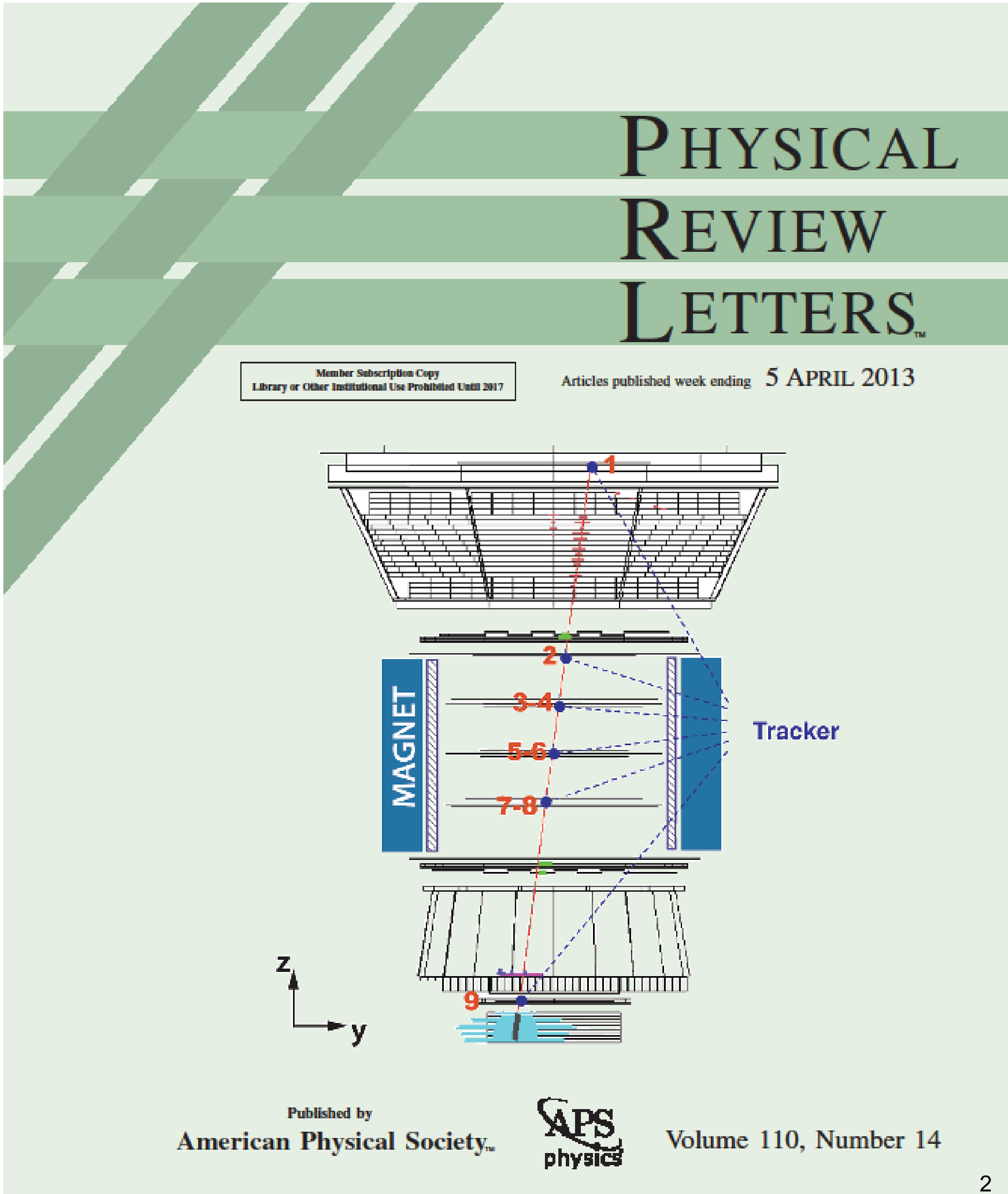
AMS Days at CERN

"First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV"

Analysis is based on 25 billion events collected during the first 18 months of operations: from May 19, 2011 to December 10, 2012

Selected by APS as a Highlight of the Year 2013

Cited >350 times

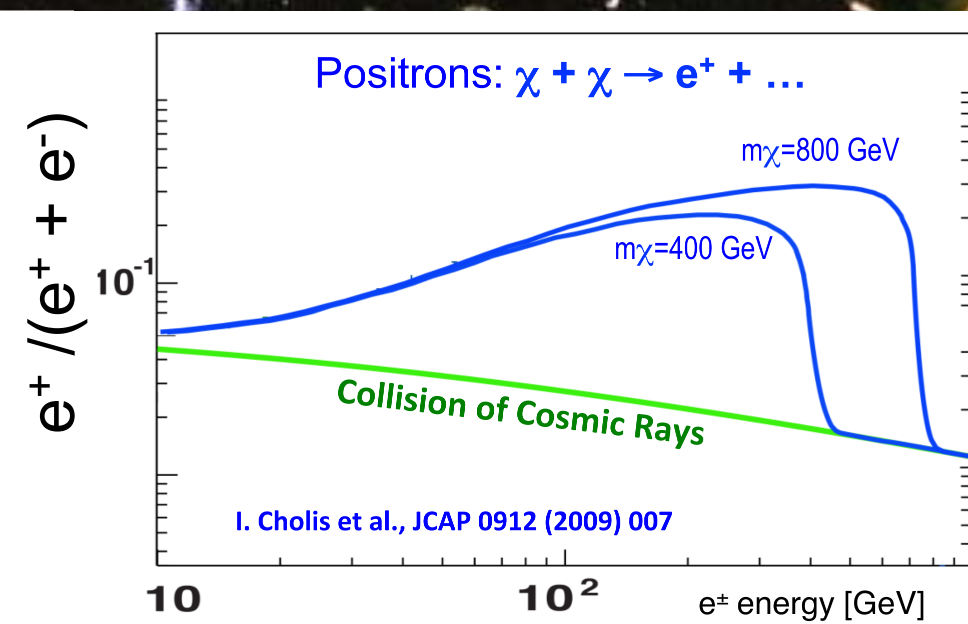


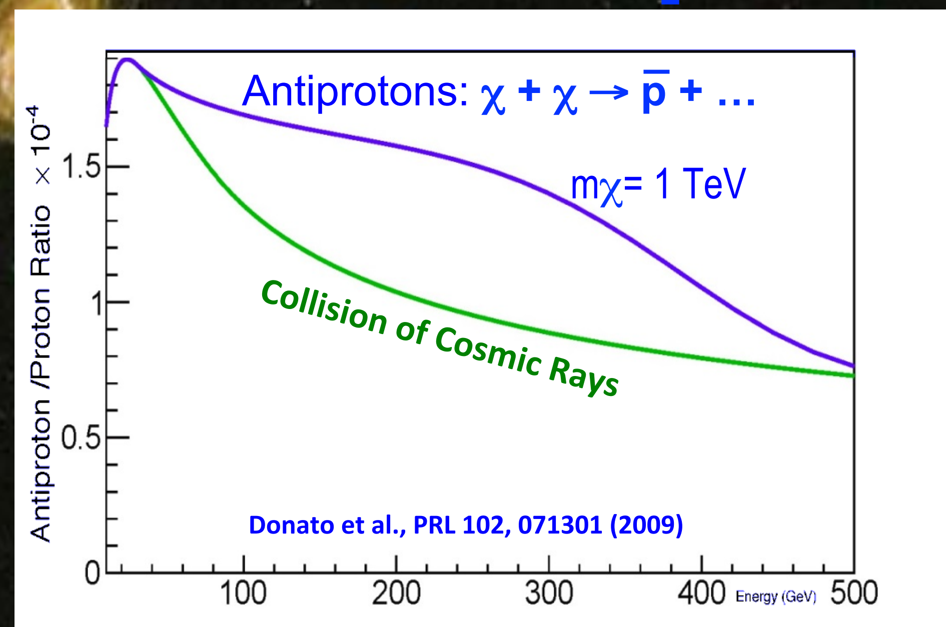
The Origin of Dark Matter

~ 90% of Matter in the Universe is not visible and is called Dark Matter

Collision of “ordinary” Cosmic Rays produce e+, $\bar{p}$..

Collisions of Dark Matter (neutralinos, χ) will produce additional e+, $\bar{p}$, …



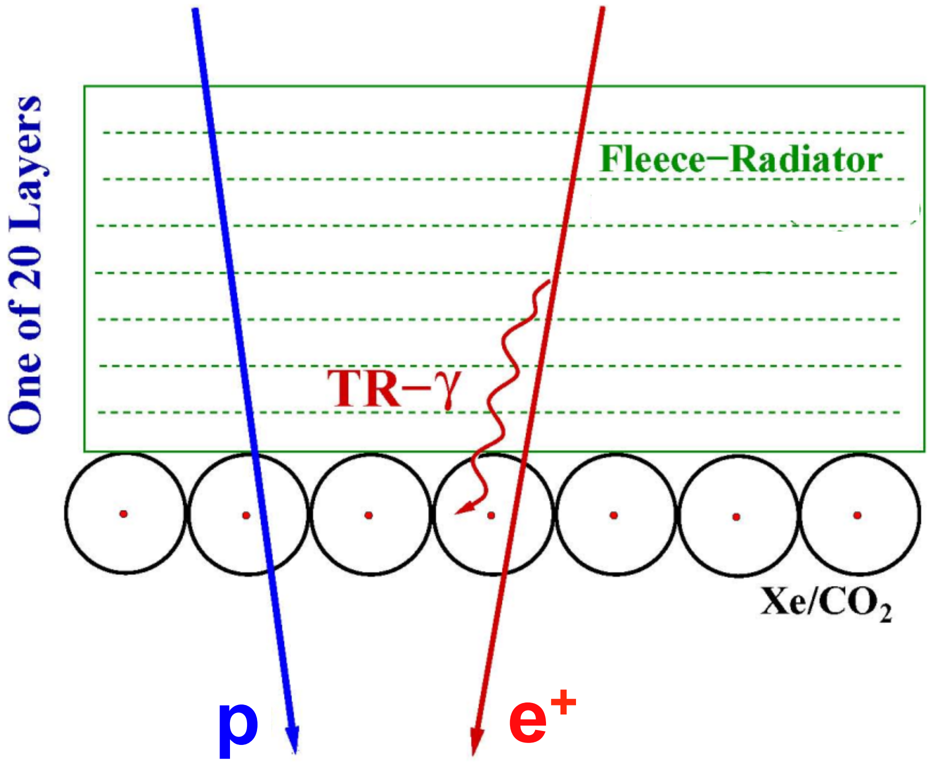


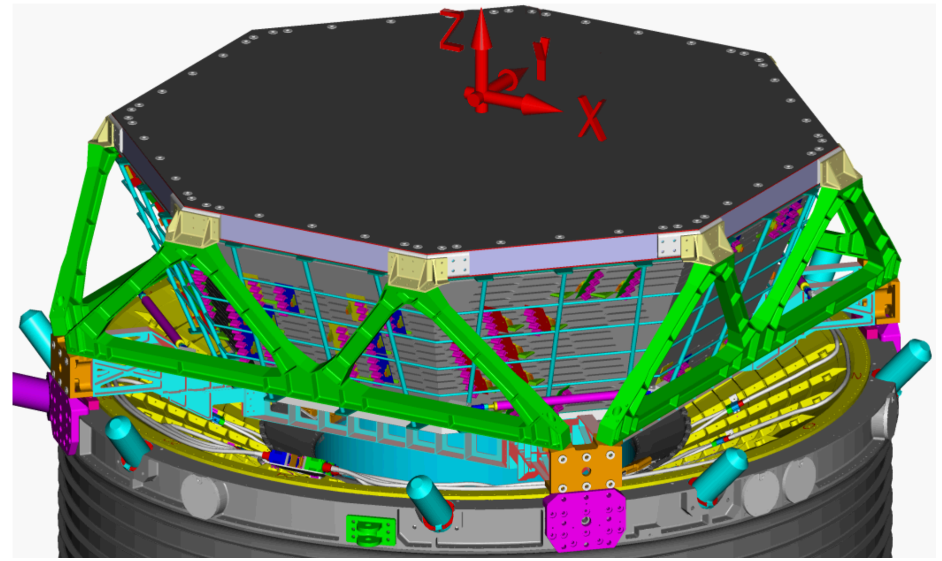
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001

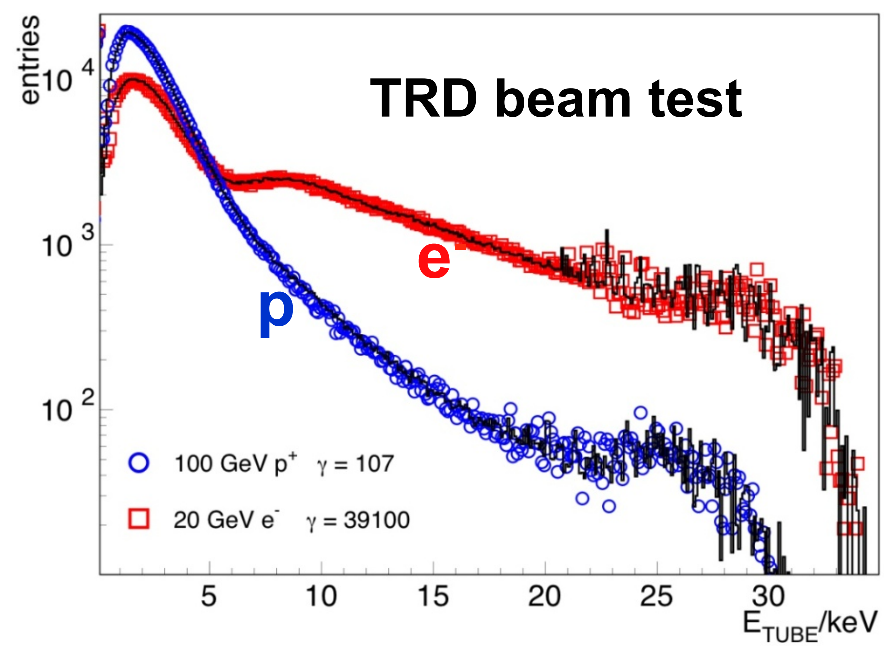
Transition Radiation Detector:

TRD

Identify e^+, reject P





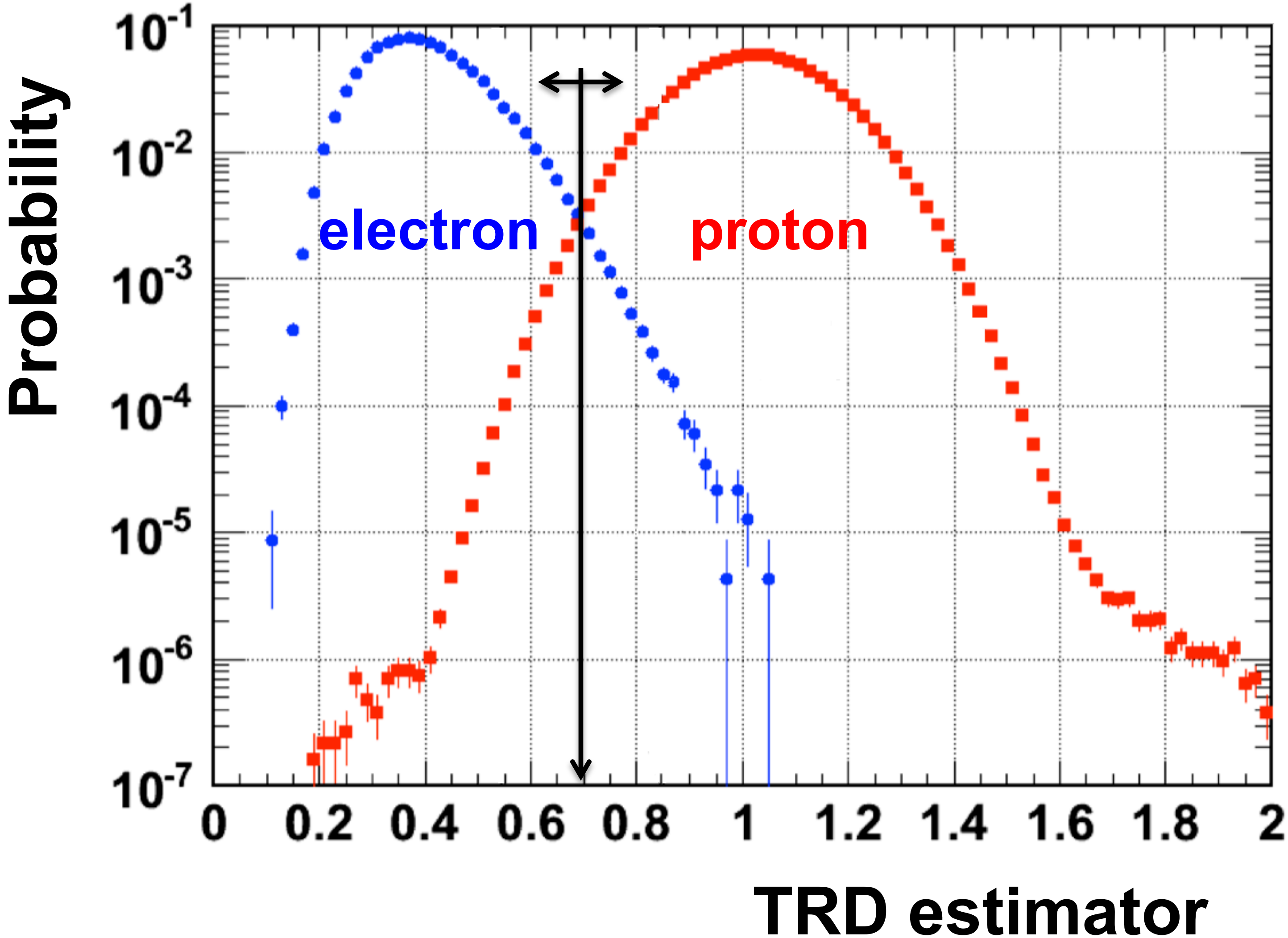


Leak rate: CO2 ≈ 5 μg/s

Storage: 5 kg, >30 years lifetime

TRD performance on ISS

TRD estimator = $-\ln(P_e/(P_e+P_p))$

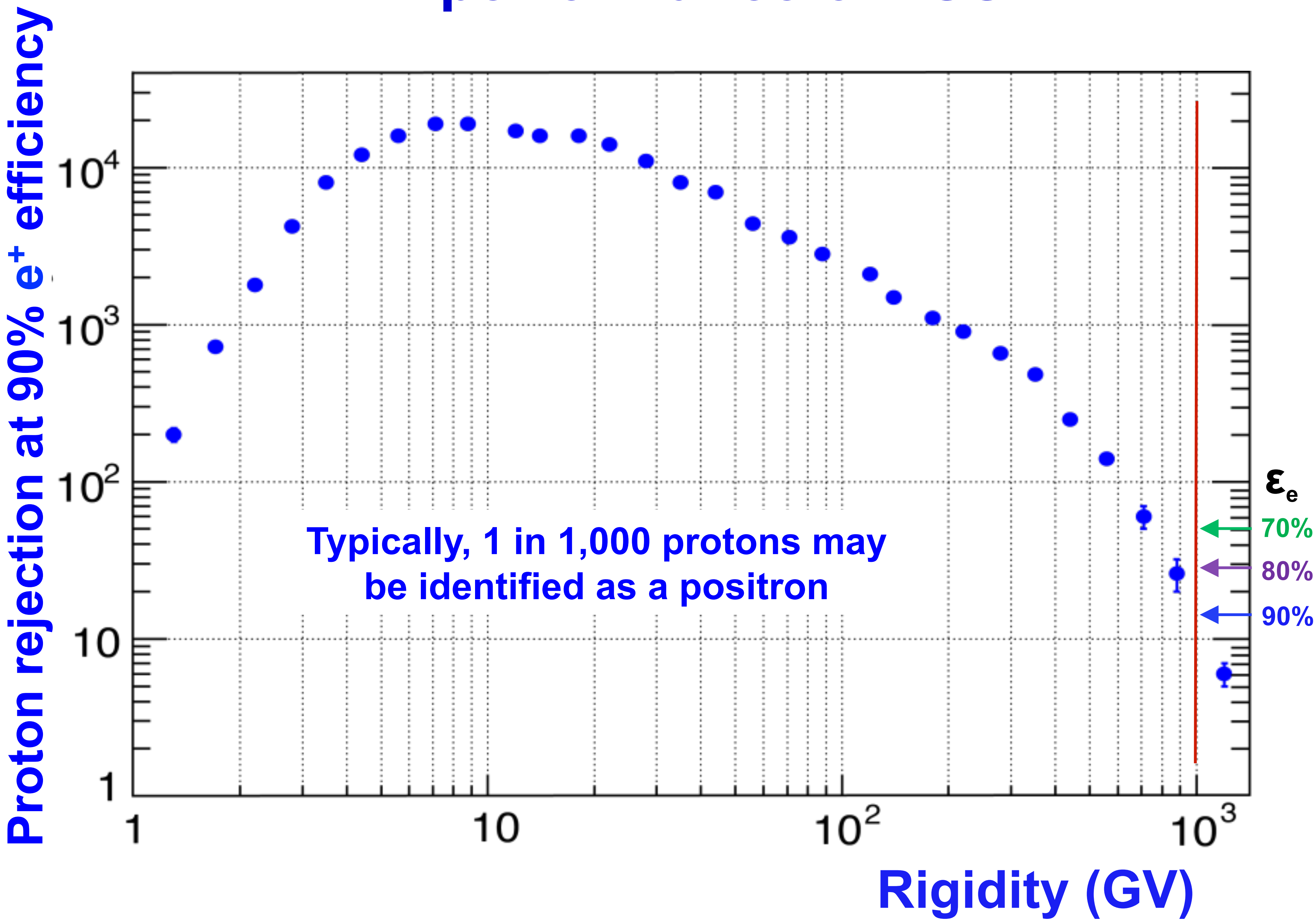


Normalized probabilities P_e and P_p

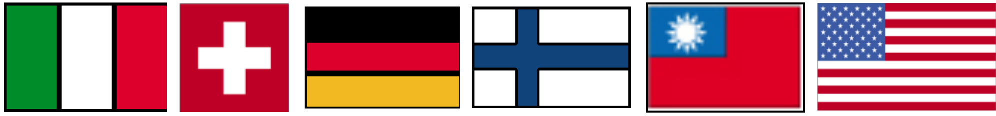
$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

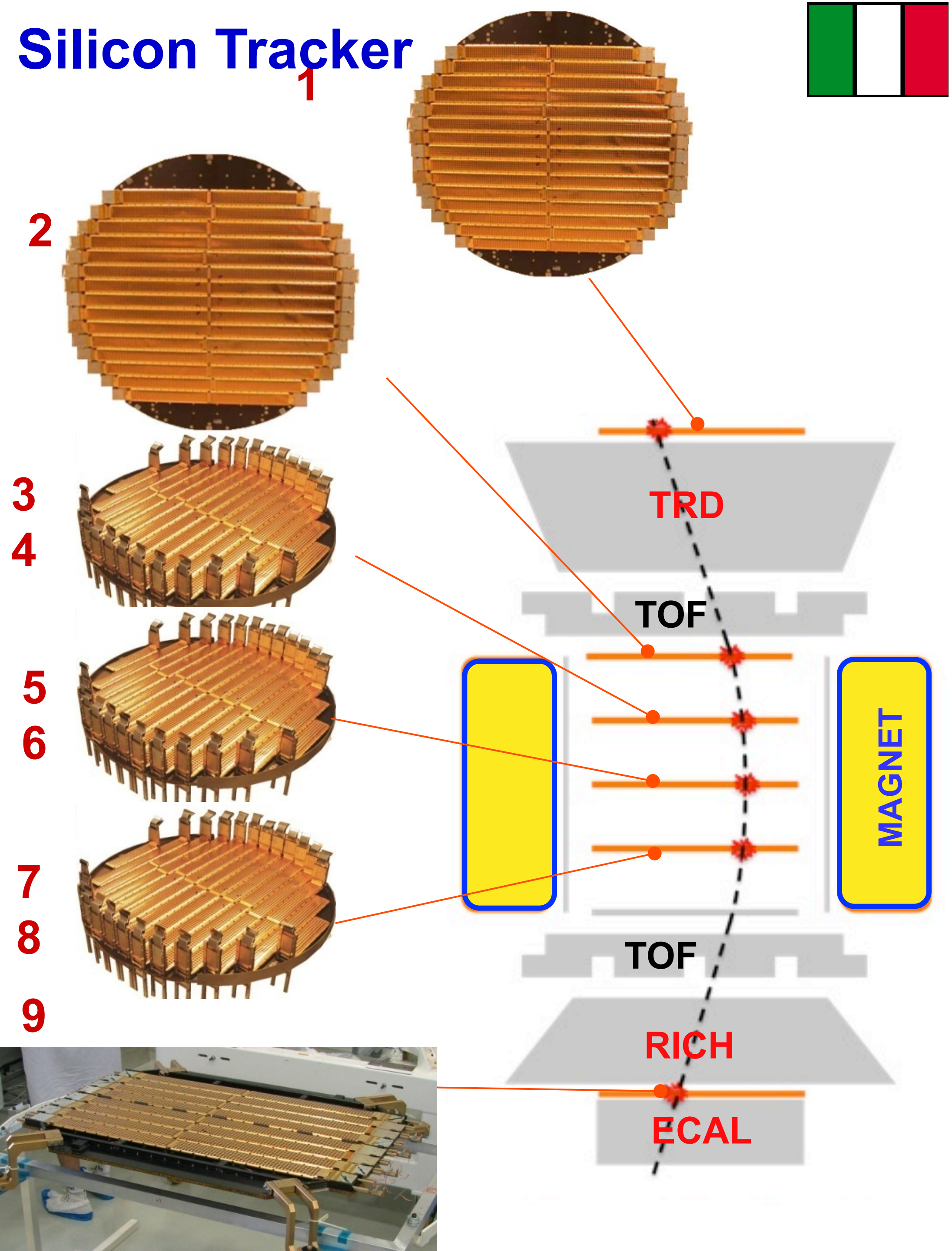
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

TRD performance on ISS

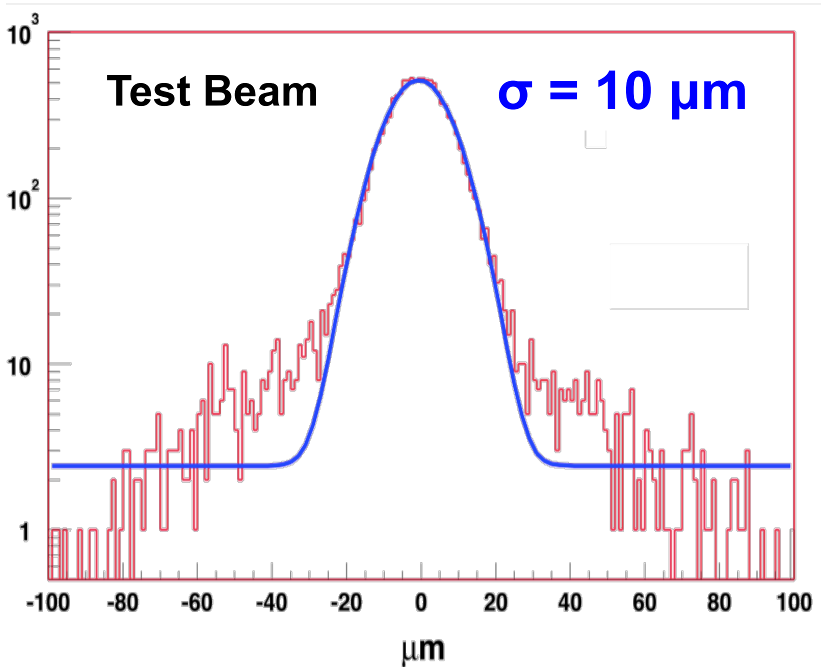


Silicon Tracker



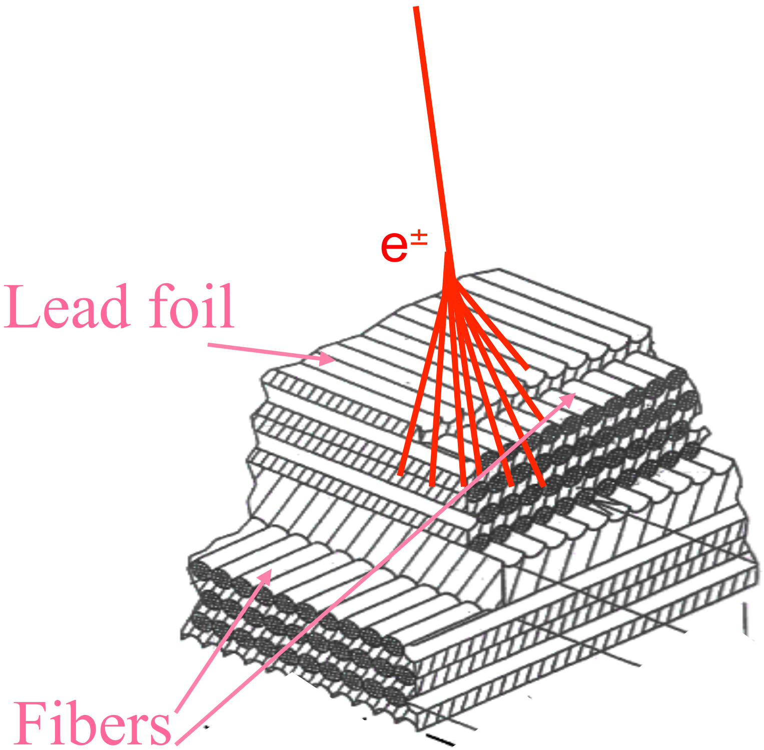


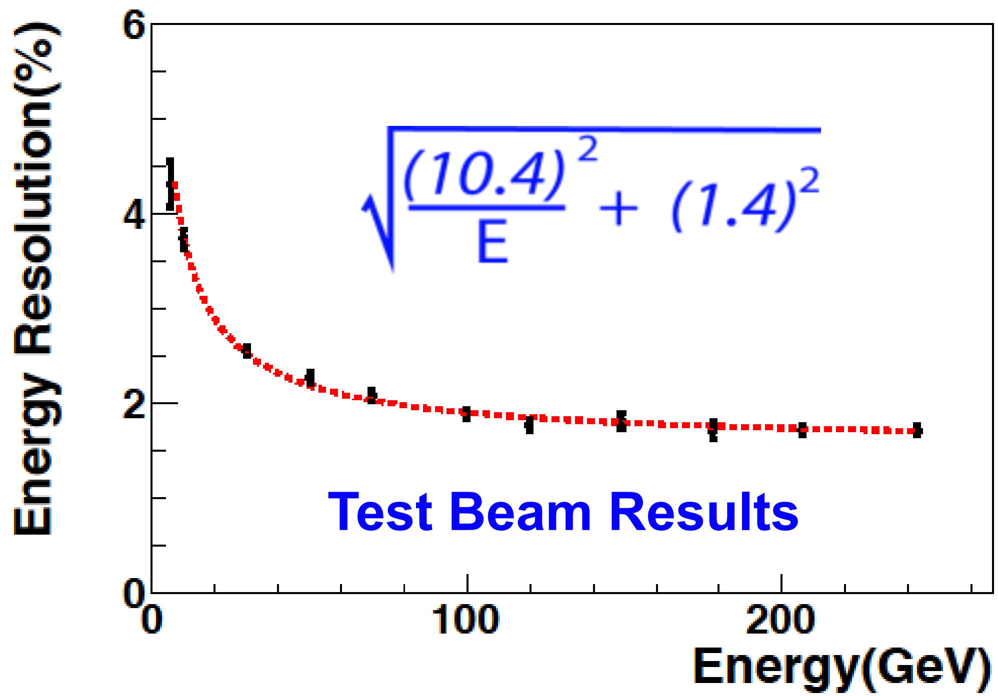
MDR$_P$ = 2.0 TV

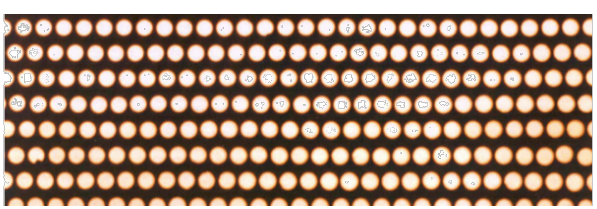


Calorimeter (ECAL)

A precision, 17 X_0, TeV, 3-dimensional measurement of the directions and energies of light rays and electrons

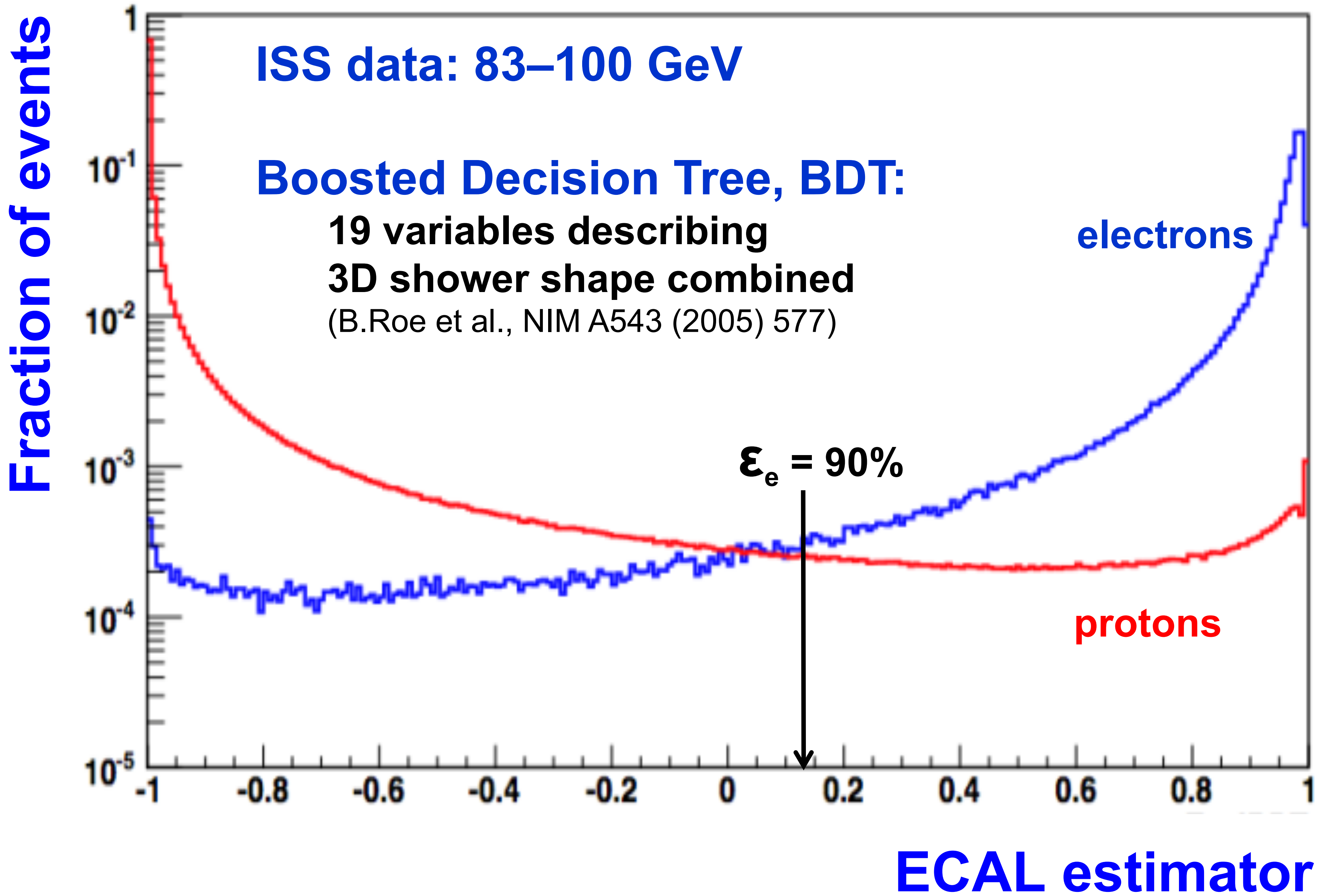




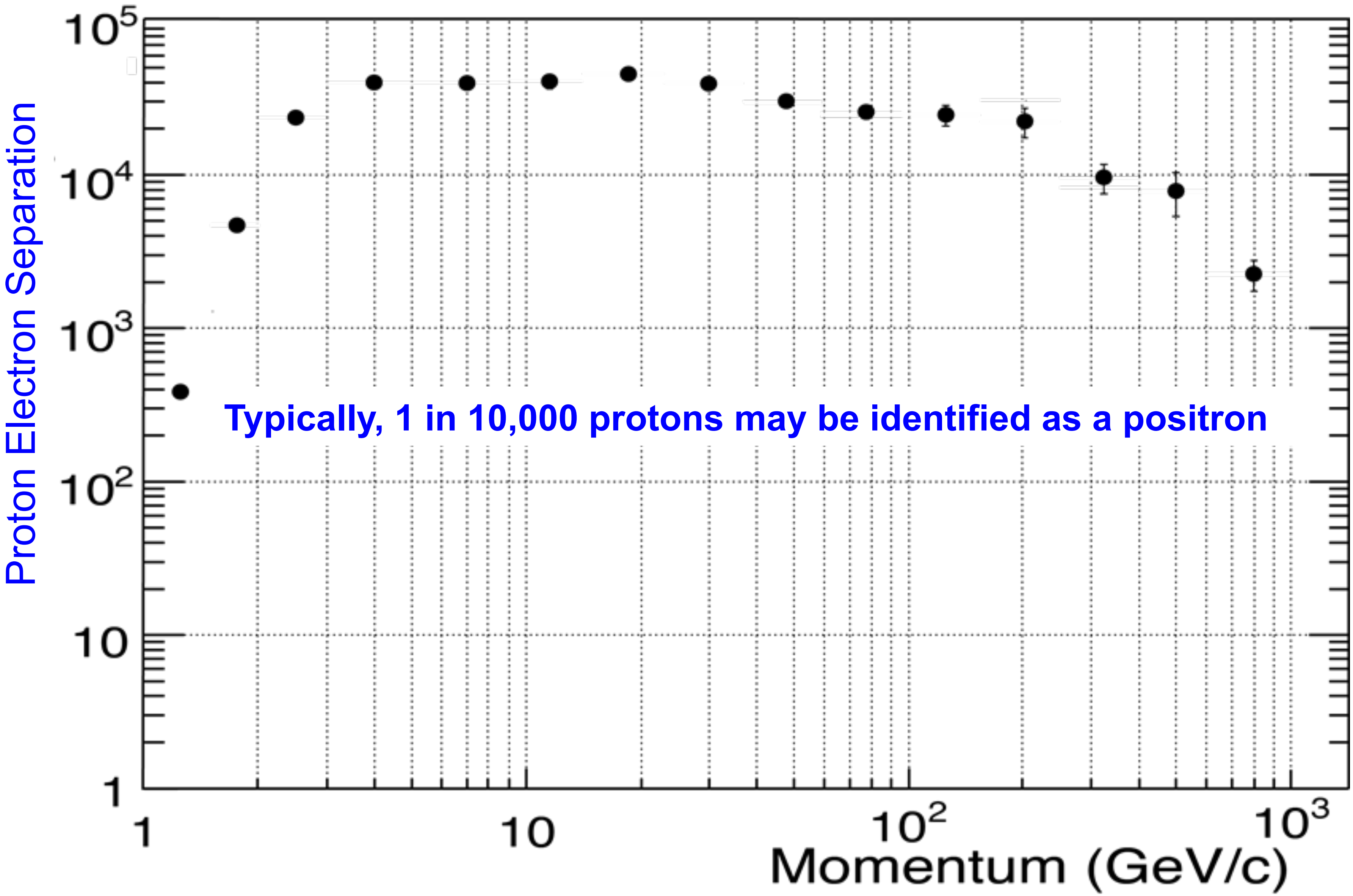


50 000 fibers, $\phi = 1$ mm distributed uniformly Inside 1,200 lb of lead

Separation of protons and electrons with ECAL



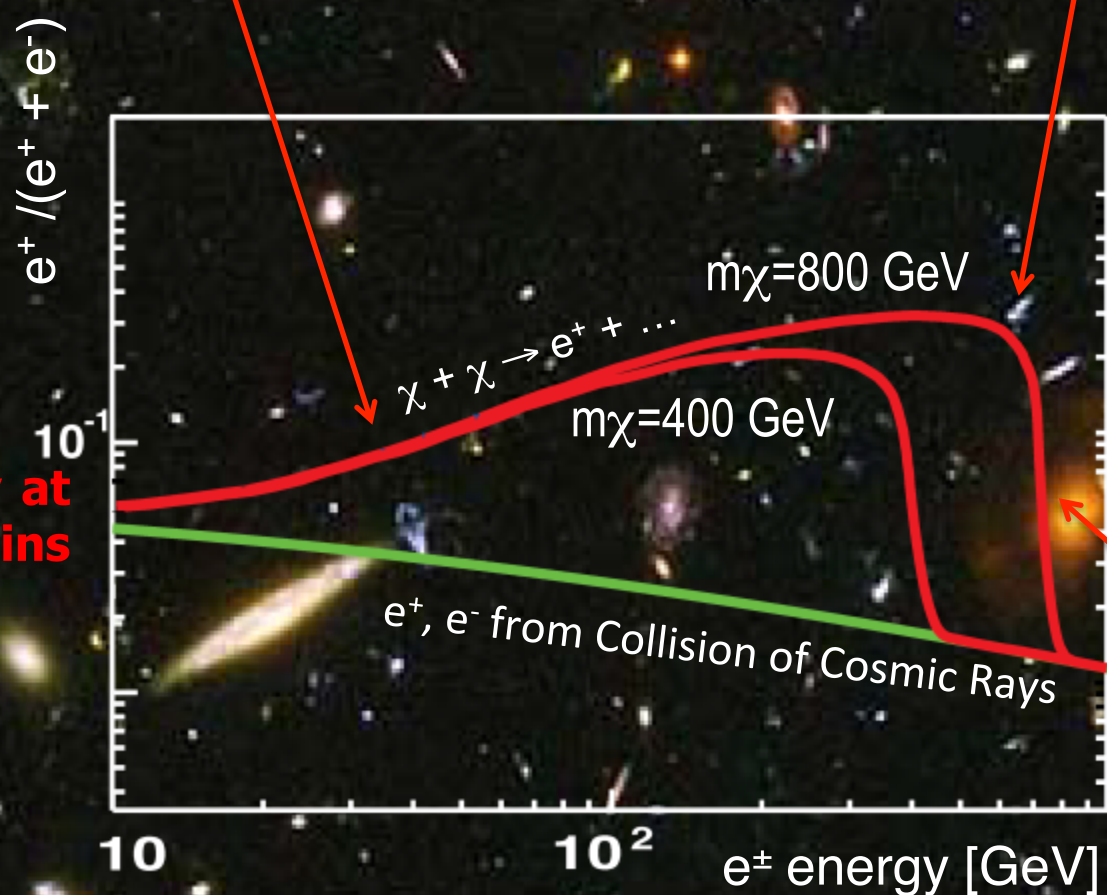
ECAL Performance in space



2. The rate of increase with energy
3. The existence of sharp structures.

4. The energy beyond which it ceases to increase.

5. Isotropy.



1. The energy at which it begins to increase.

6. The rate at which it falls beyond the turning point.

New Results on the Positron Fraction

Energy range from 0.5 to 500 GeV based on 10.9 million positron and electron events selected from the sample of 41 billion events.

This measurement extends the energy range of our previous observation and increases its precision.

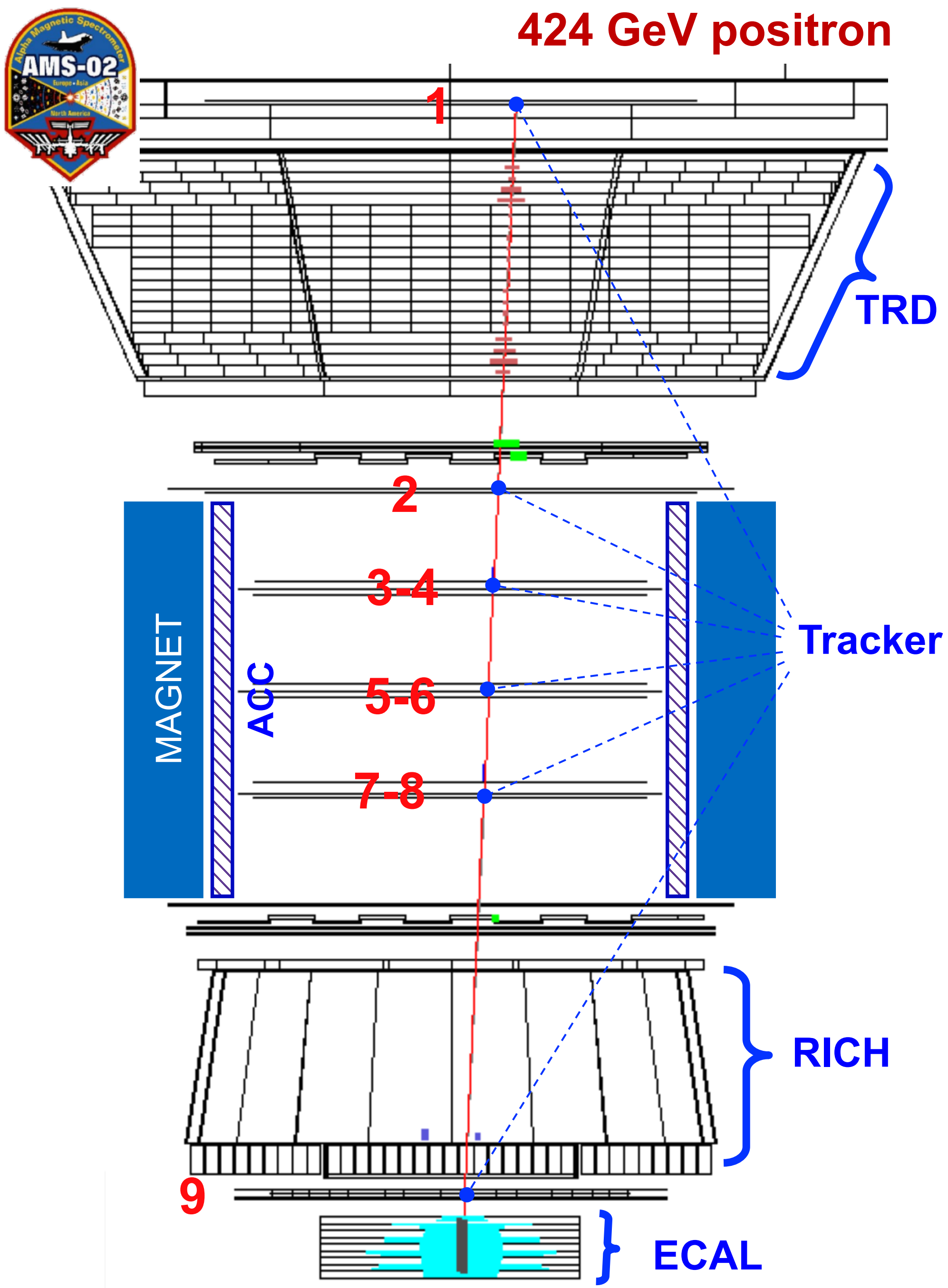
PHYSICAL REVIEW LETTERS

High Statistics Measurement of the Positron Fraction in Primary Cosmic rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

PRL 113, 121101 (2014)

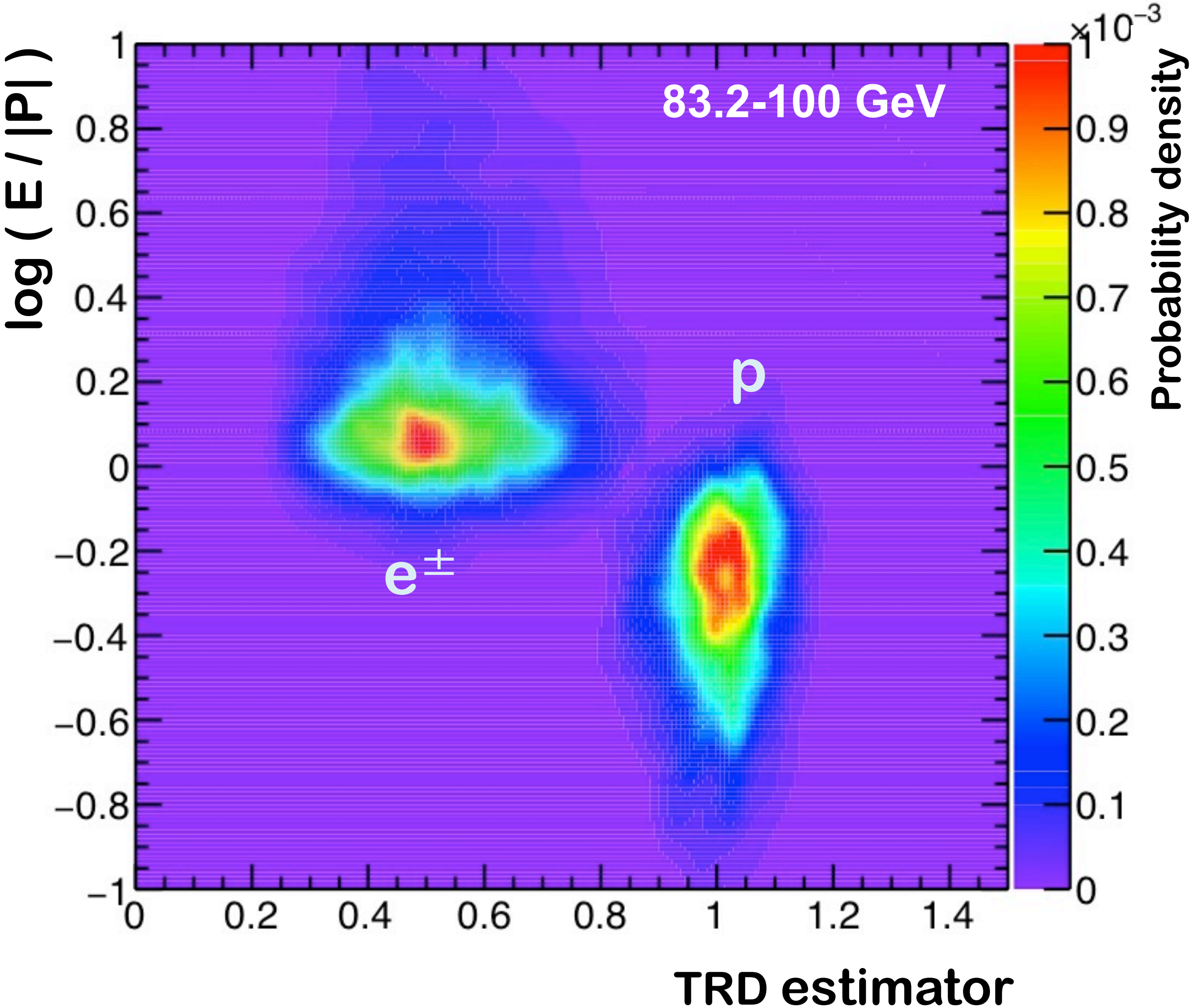
Event selection.

- **DAQ:**
  - livetime > 50% (no SAA)
- **Geomagnetic cutoff:**
  - E>1.2·max cutoff
- **TRACKER:**
  - Track quality
  - geometrical match with ECAL shower
- **TRD:**
  - at least 15 hits
- **TOF:**
  - downgoing particle,
  - $\beta>0.8$, $0.8<Z<1.4$
- **ECAL:**
  - shower axis within the fiducial ECAL volume
  - electromagnetic shape of the shower



Analysis: 2D fit to measure $Ne^{\pm}$ and Np

2D reference spectra for the signal and the background are fitted to data in the [TRD estimator- log(E/|P|)] plane.



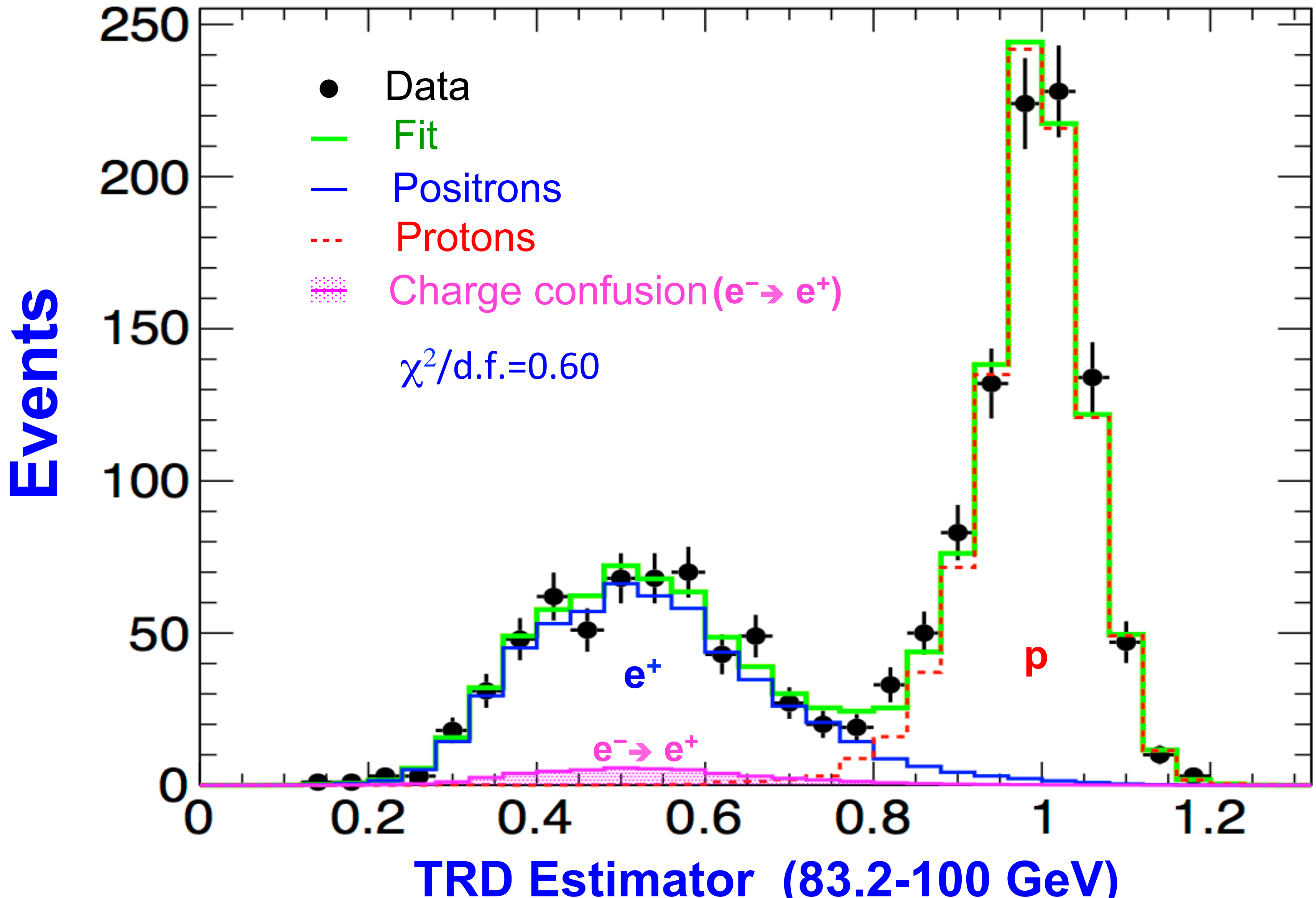
The method combines information from

- **TRD**
- **ECAL**
- **Tracker.**

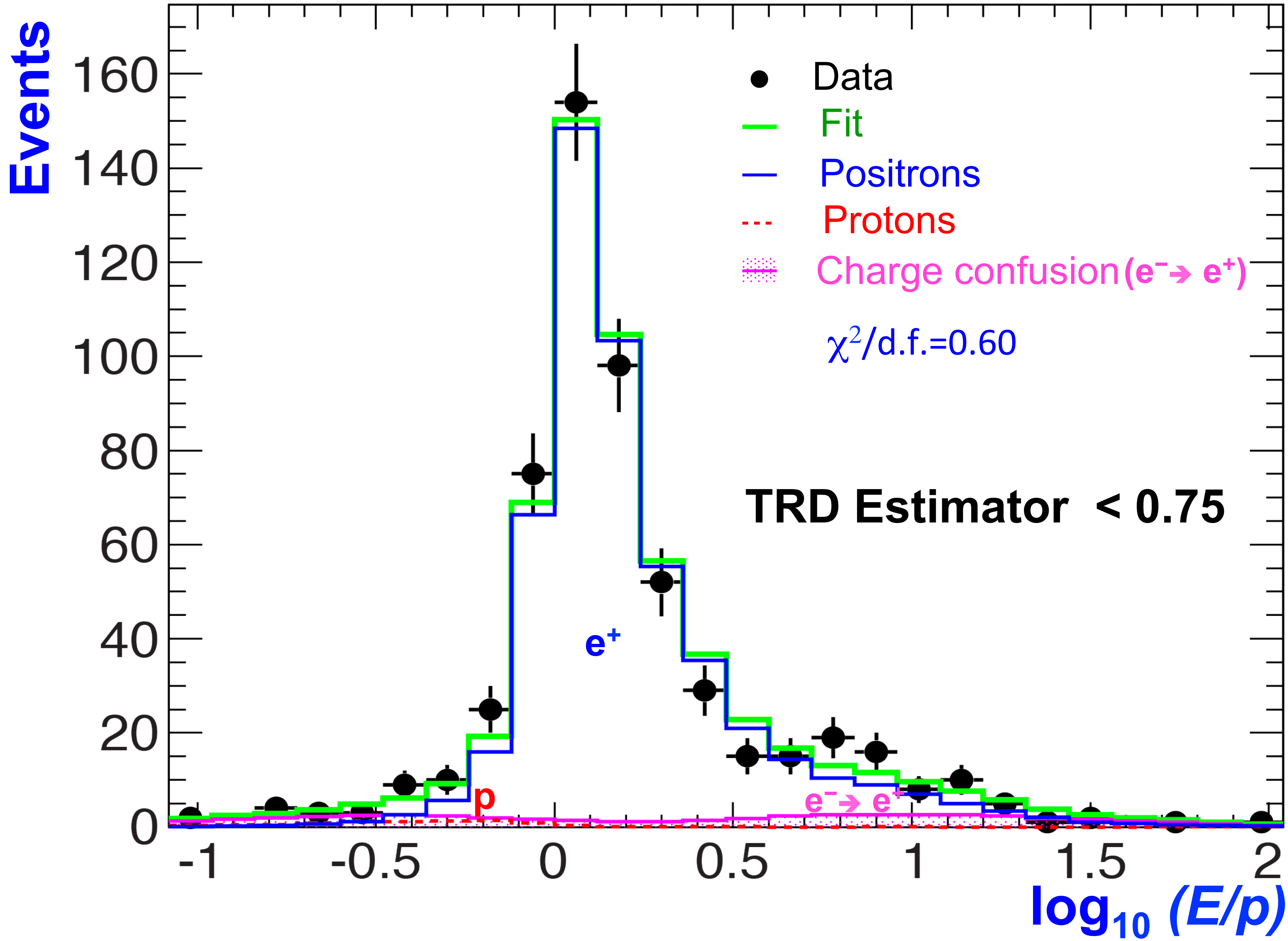
It provides better statistical accuracy compared to cut-based analysis.

Results of the fit:

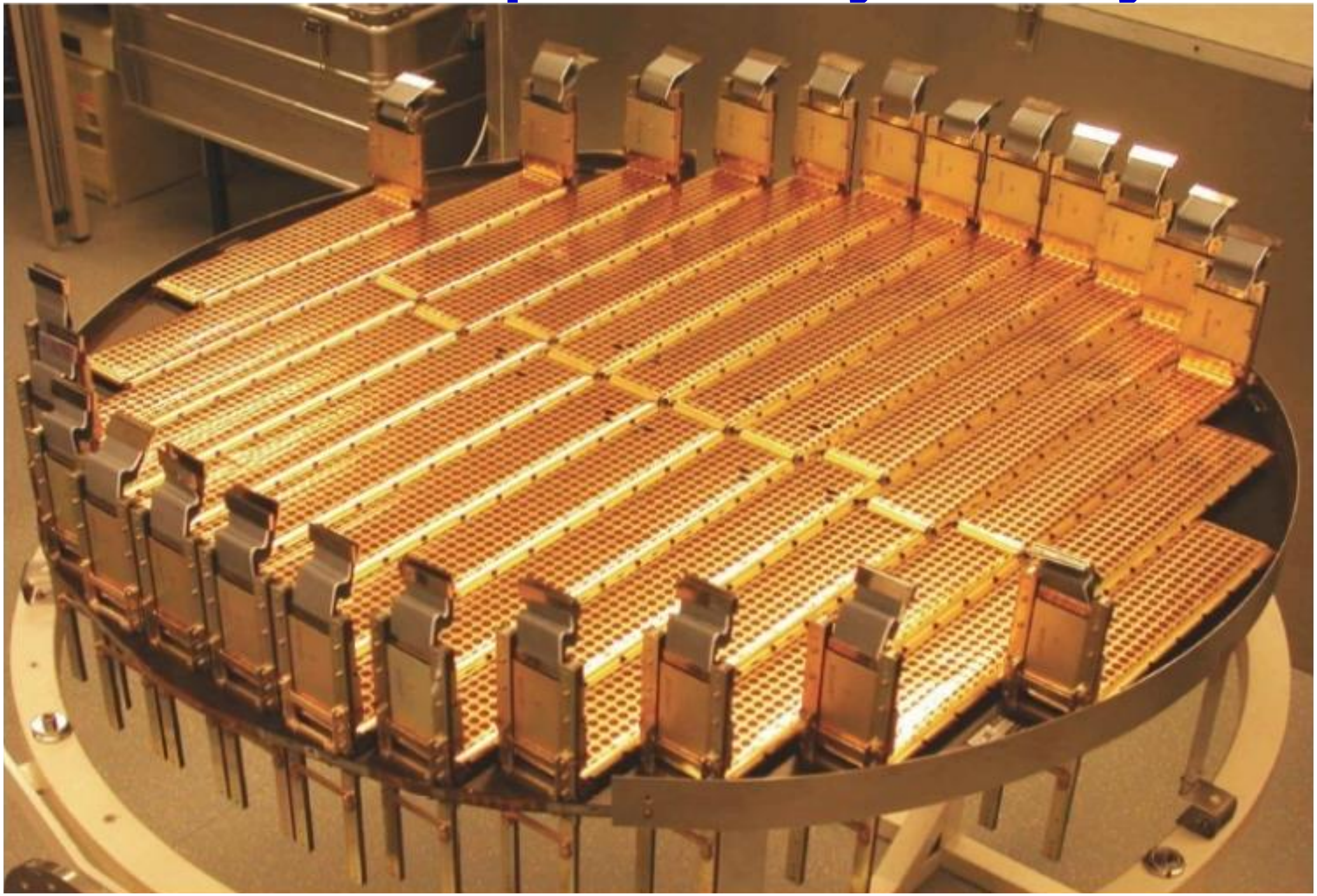
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



Results of the fit: in the signal region only 1 % of protons

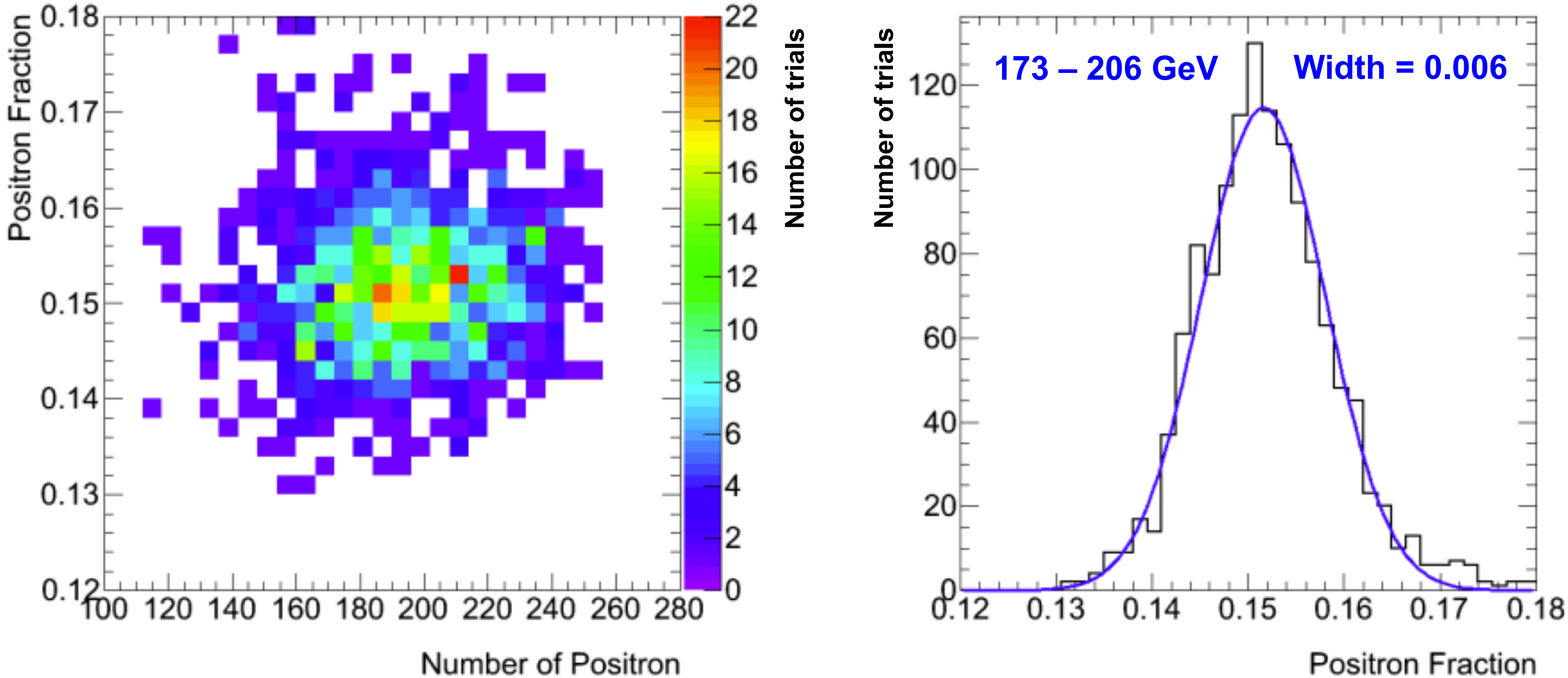


Systematic error on the positron fraction: 1. Acceptance asymmetry



Difference between positron and electron acceptance due to known minute tracker asymmetry

Systematic error on the positron fraction: 2. Selection dependence

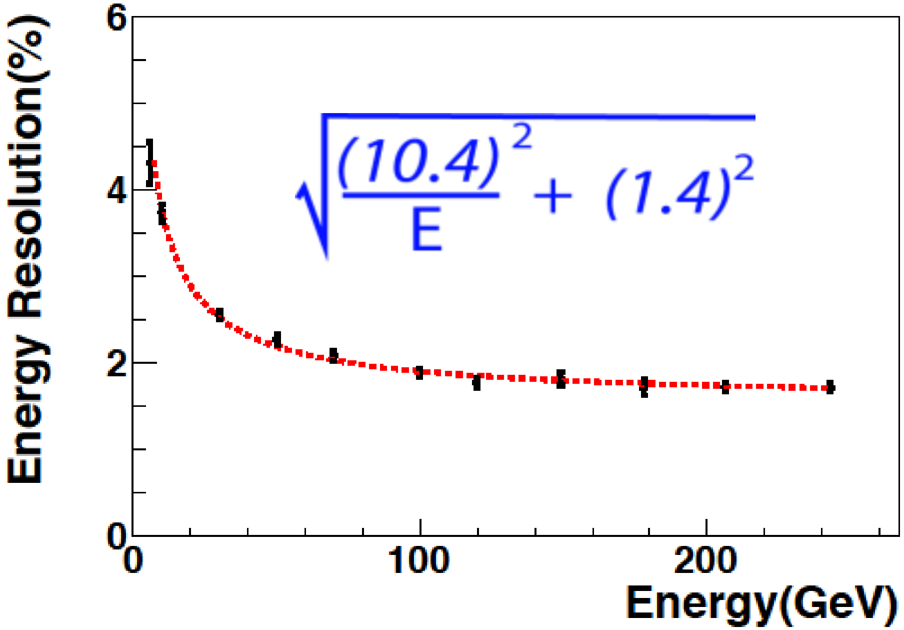


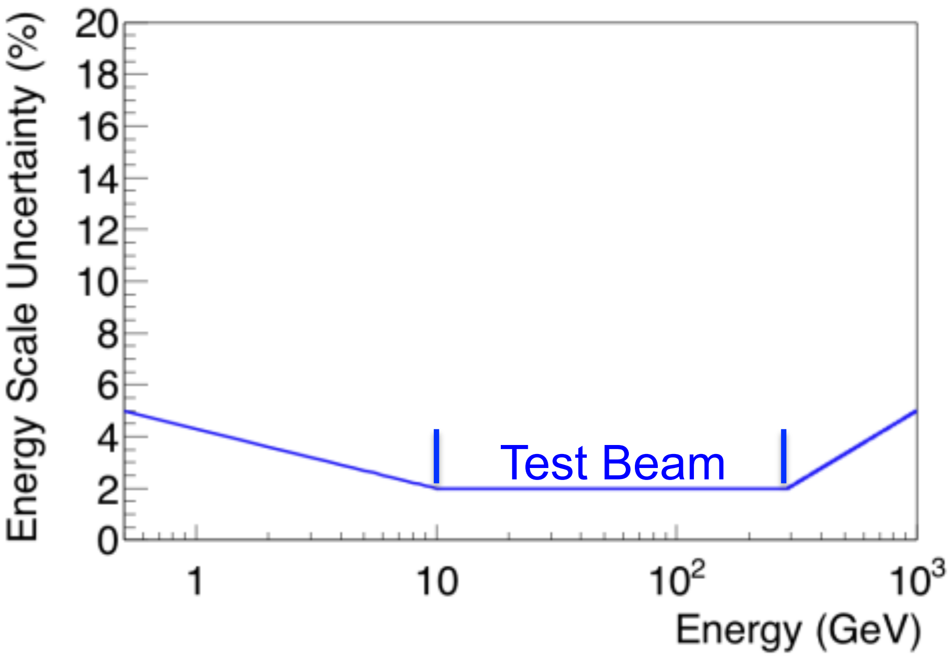
The measurement is stable over wide variations of the cuts in the ECAL Shower Shape , E/p matching, etc.

For each energy bin, over 1,000 sets of cuts (trials) were analyzed.

Systematic error on the positron fraction:
3. Absolute energy scale and Bin-to-bin migration

Absolute energy scale at the top of AMS is calibrated in the $e^{\pm}$ beams and verified in space using minimum ionizing particles and the ratio E/p.

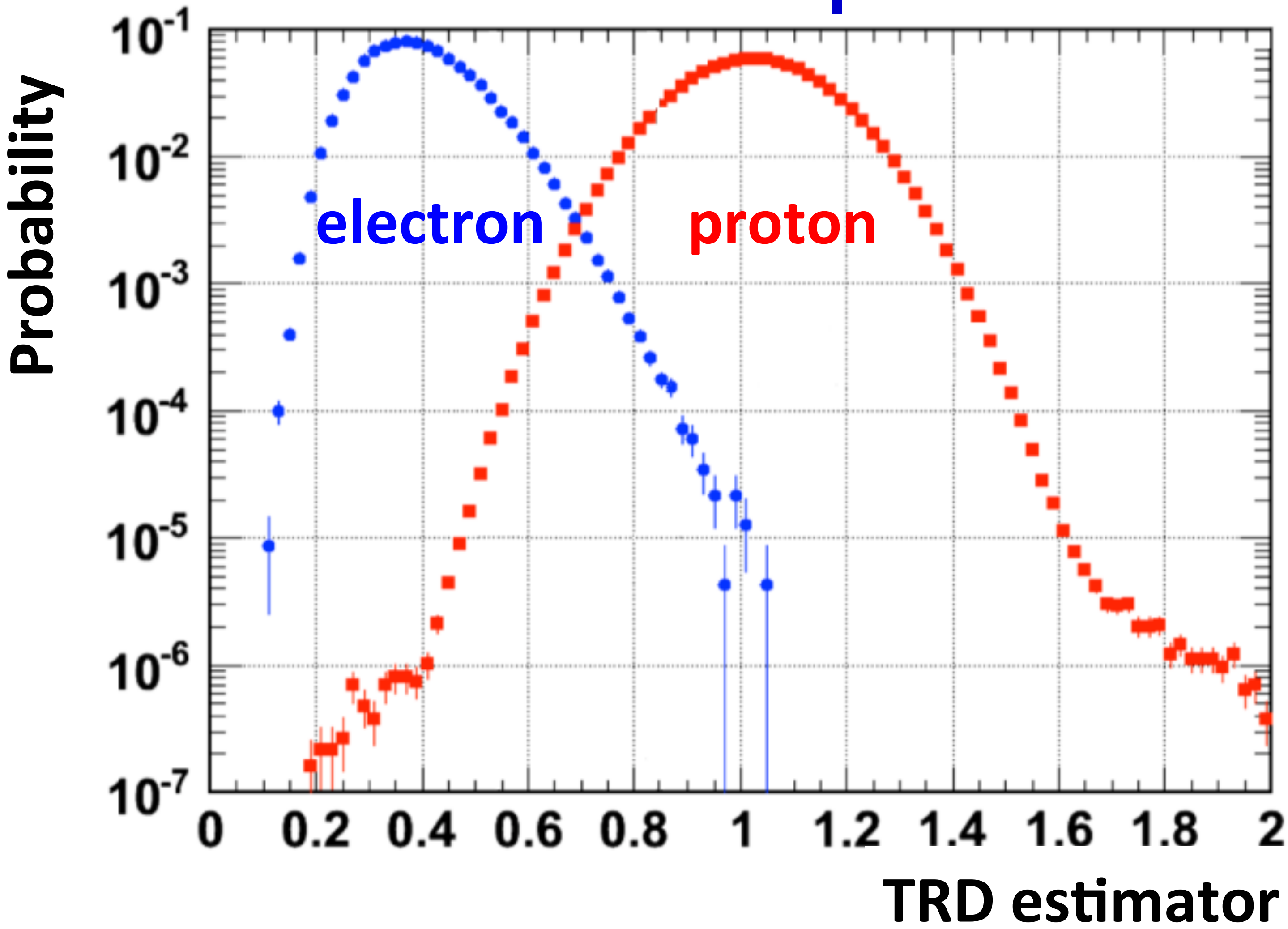




Bin width: 2σ at 5 GeV; 4σ at 50 GeV; 8σ at 100 GeV; 19σ at 300 GeV.

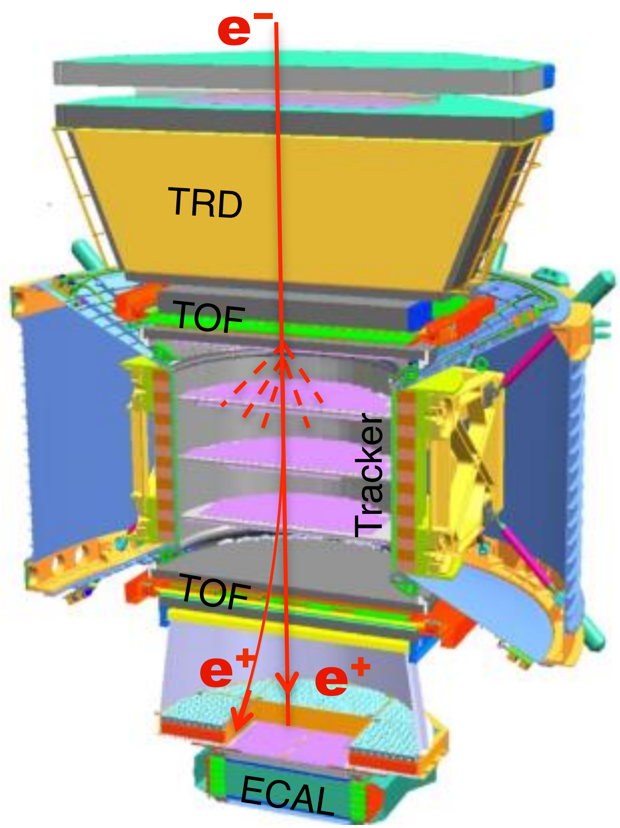
For the positron fraction, these errors are negligible above 5 GeV.

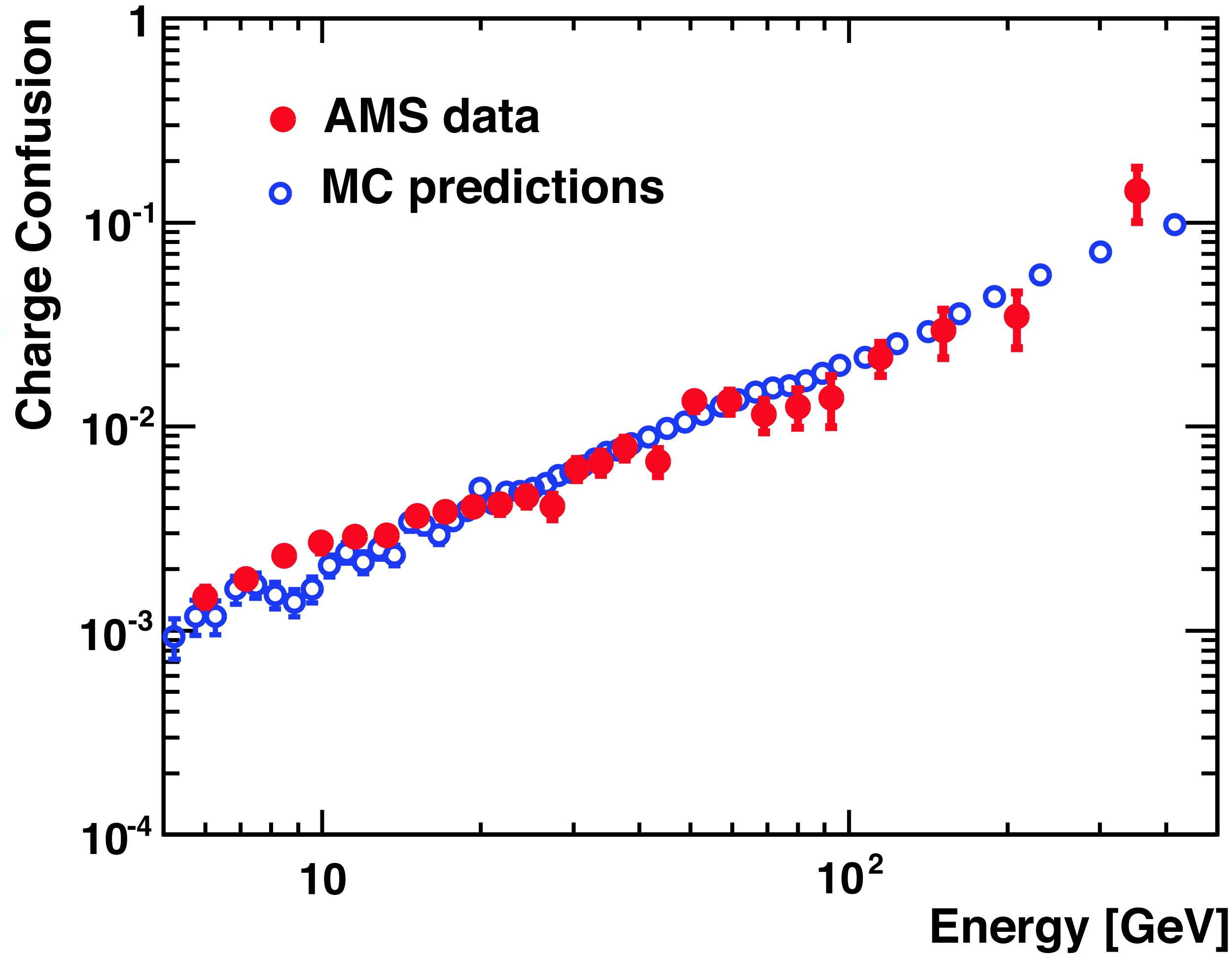
Systematic error on the positron fraction: 4. Reference spectra



Definition of the reference spectra is based on pure samples of electrons and protons of finite statistics.

Systematic error on the positron fraction:
5. Charge confusion

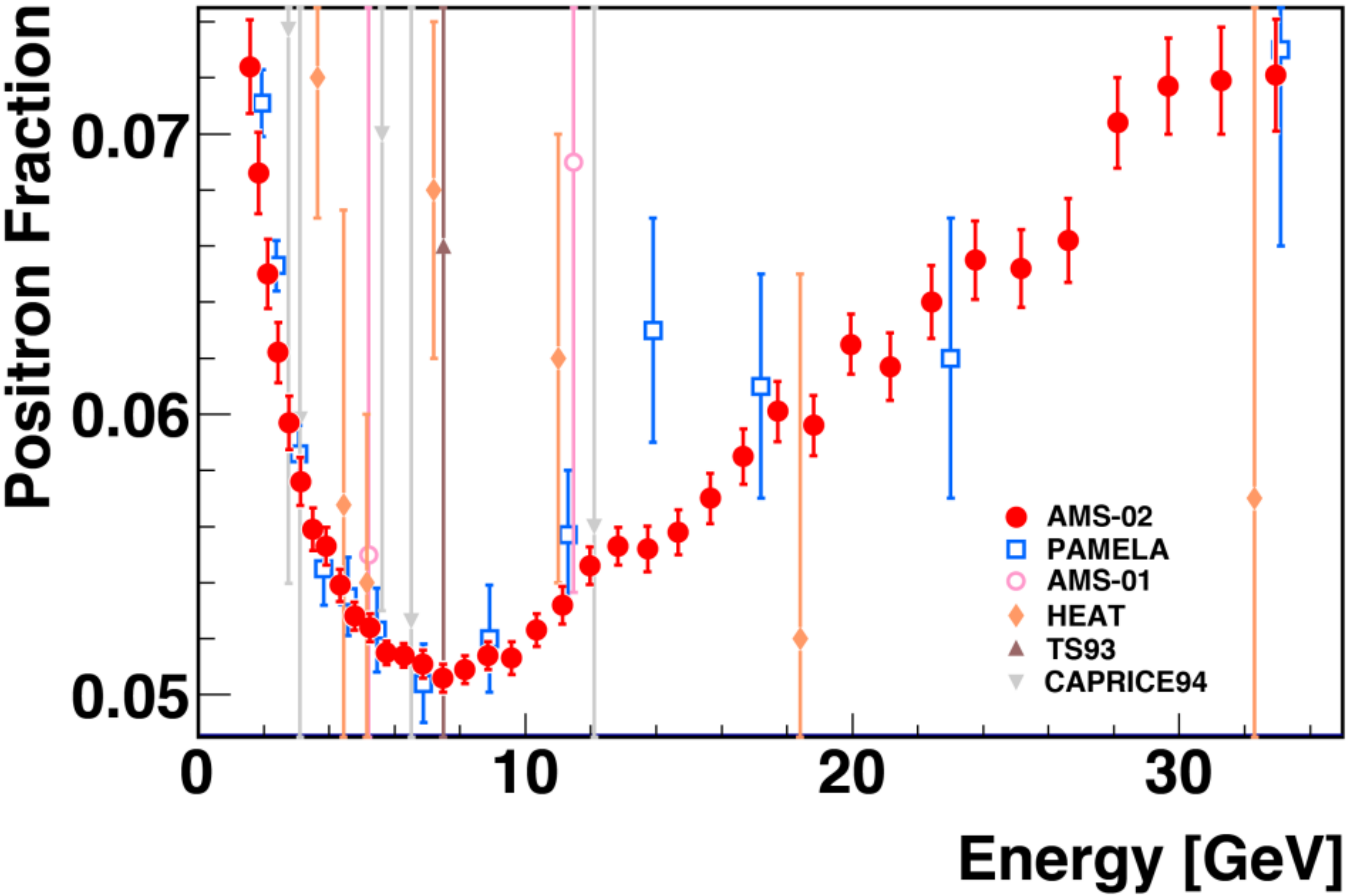




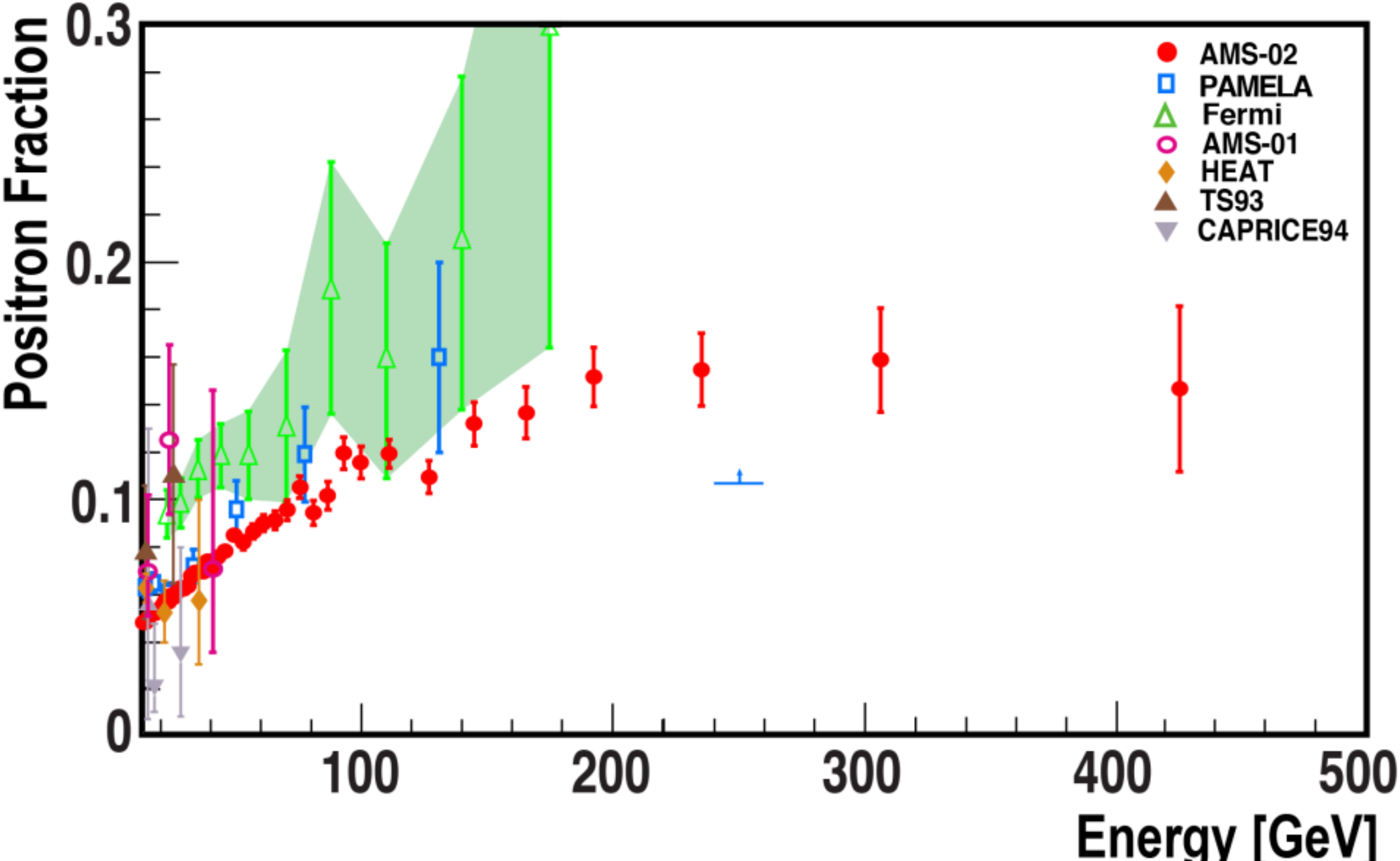
Two sources: 1) large angle scattering and 2) production of secondary tracks along the path of the primary track. Both are well reproduced by the Monte Carlo. The small difference is taken as a systematic error.

Energy [GeV]	N_{e^+}	Fraction	σ_{stat}	σ_{acc}	σ_{sel}	σ_{mig}	σ_{ref}	$\sigma_{c.c.}$	σ_{syst}
16.15–17.18	4689	0.0585	0.0009	0.0001	0.0001	0.0003	0.0001	0.0002	0.0004
17.18–18.25	4016	0.0601	0.0010	0.0001	0.0001	0.0003	0.0001	0.0002	0.0004
18.25–19.37	3906	0.0596	0.0010	0.0001	0.0001	0.0003	0.0001	0.0002	0.0004
19.37–20.54	3777	0.0625	0.0010 1.8%	0.0001	0.0001	0.0003	0.0001	0.0002	0.0004 0.8%
20.54–21.76	3244	0.0617	0.0011	0.0001	0.0001	0.0004	0.0001	0.0002	0.0005
21.76–23.07	2910	0.0640	0.0012	0.0001	0.0001	0.0004	0.0001	0.0002	0.0005
23.07–24.45	2813	0.0655	0.0013	0.0001	0.0002	0.0004	0.0001	0.0002	0.0005
24.45–25.87	2631	0.0652	0.0013	0.0001	0.0002	0.0004	0.0001	0.0002	0.0005
25.87–27.34	2397	0.0662	0.0014	0.0001	0.0002	0.0004	0.0001	0.0002	0.0005
27.34–28.87	2325	0.0704	0.0015	0.0001	0.0002	0.0005	0.0001	0.0002	0.0006
28.87–30.45	2040	0.0717	0.0016	0.0001	0.0002	0.0005	0.0001	0.0002	0.0006
30.45–32.10	1706	0.0719	0.0018	0.0001	0.0003	0.0005	0.0001	0.0002	0.0006
32.10–33.80	1530	0.0721	0.0019	0.0001	0.0003	0.0005	0.0001	0.0002	0.0006
33.80–35.57	1496	0.0766	0.0021	0.0001	0.0003	0.0005	0.0001	0.0002	0.0007
35.57–37.40	1327	0.0732	0.0021	0.0001	0.0003	0.0005	0.0001	0.0002	0.0007
37.40–40.00	1607	0.0781	0.0020	0.0001	0.0004	0.0006	0.0001	0.0002	0.0007
40.00–43.39	1616	0.0806	0.0021	0.0001	0.0004	0.0006	0.0001	0.0002	0.0008
43.39–47.01	1401	0.0872	0.0024	0.0001	0.0005	0.0006	0.0001	0.0003	0.0008
47.01–50.87	1116	0.0840	0.0027	0.0002	0.0005	0.0006	0.0001	0.0003	0.0009
50.87–54.98	1041	0.0887	0.0028	0.0002	0.0006	0.0007	0.0001	0.0003	0.0010
54.98–59.36	837	0.0921	0.0032	0.0002	0.0007	0.0007	0.0001	0.0004	0.0010
59.36–64.03	710	0.0933	0.0037	0.0002	0.0007	0.0007	0.0001	0.0004	0.0011
64.03–69.00	644	0.0974	0.0039	0.0002	0.0008	0.0007	0.0002	0.0005	0.0012
69.00–74.30	606	0.1069	0.0044	0.0002	0.0009	0.0007	0.0002	0.0006	0.0013
74.30–80.00	450	0.0963	0.0047	0.0002	0.0010	0.0007	0.0002	0.0006	0.0014
80.00–86.00	381	0.1034	0.0056	0.0002	0.0011	0.0007	0.0002	0.0007	0.0015
86.00–92.50	398	0.1207	0.0063	0.0002	0.0011	0.0007	0.0003	0.0009	0.0016
92.50–100.0	358	0.1169	0.0063 4.5%	0.0002	0.0013	0.0007	0.0003	0.0010	0.0018 1.5%
100.0–115.1	524	0.1205	0.0054	0.0002	0.0014	0.0007	0.0004	0.0013	0.0021
115.1–132.1	365	0.1110	0.0062	0.0002	0.0017	0.0007	0.0005	0.0018	0.0026
132.1–151.5	271	0.1327	0.0083	0.0002	0.0020	0.0007	0.0006	0.0024	0.0032
151.5–173.5	228	0.1374	0.0097	0.0002	0.0023	0.0007	0.0007	0.0031	0.0040
173.5–206.0	225	0.1521	0.0109	0.0002	0.0027	0.0007	0.0008	0.0044	0.0053
206.0–260.0	178	0.1550	0.0124	0.0003	0.0034	0.0007	0.0011	0.0076	0.0084
260.0–350.0	135	0.1590	0.0168 19%	0.0003	0.0045	0.0007	0.0015	0.0123	0.0132 13%
350.0–500.0	72	0.1471	0.0278	0.0003	0.0064	0.0007	0.0022	0.0182	0.0194

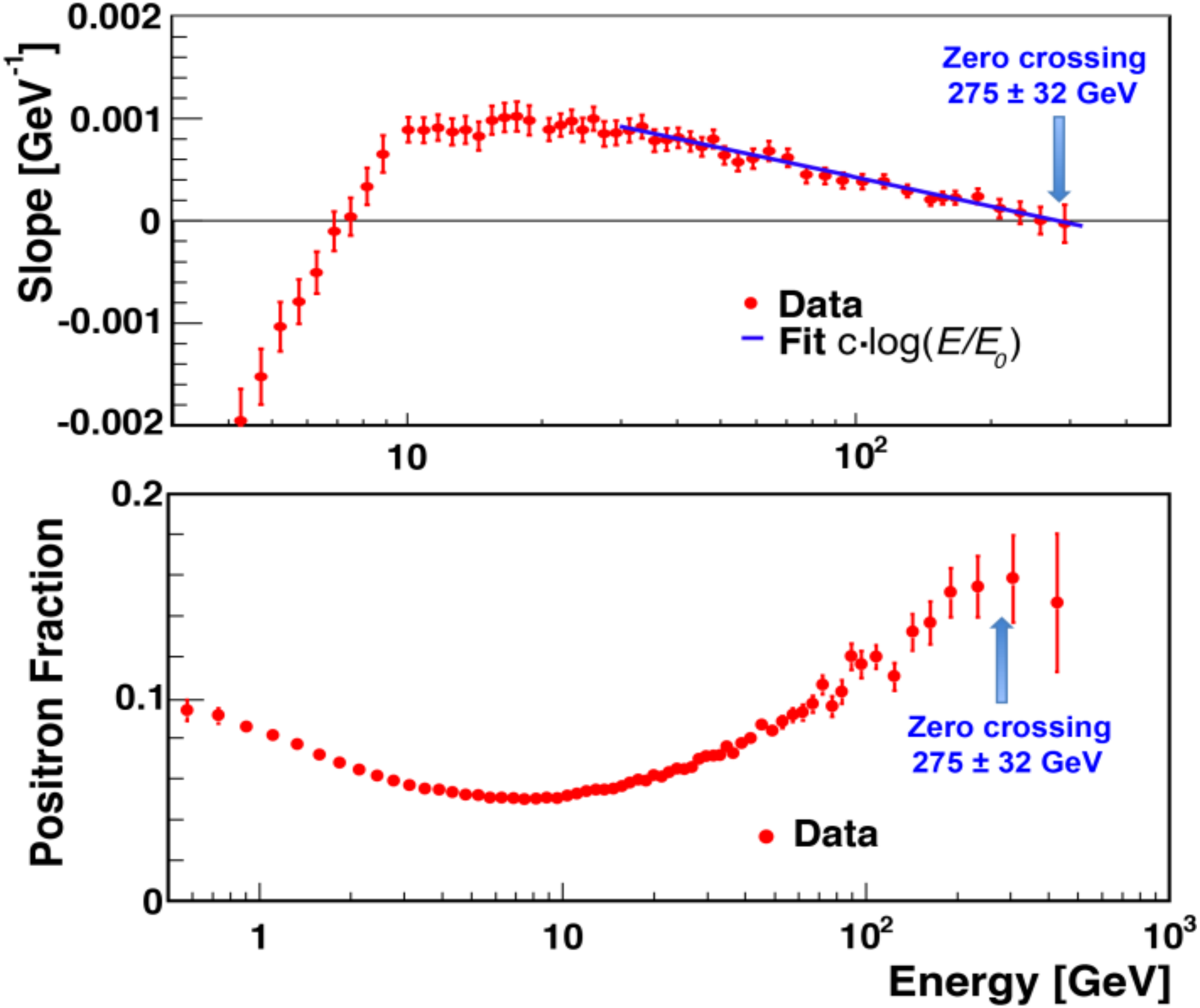
(i) The energy at which it begins to increase.



(ii) The rate of increase with energy.
(iii) The non-existence of sharp structures.

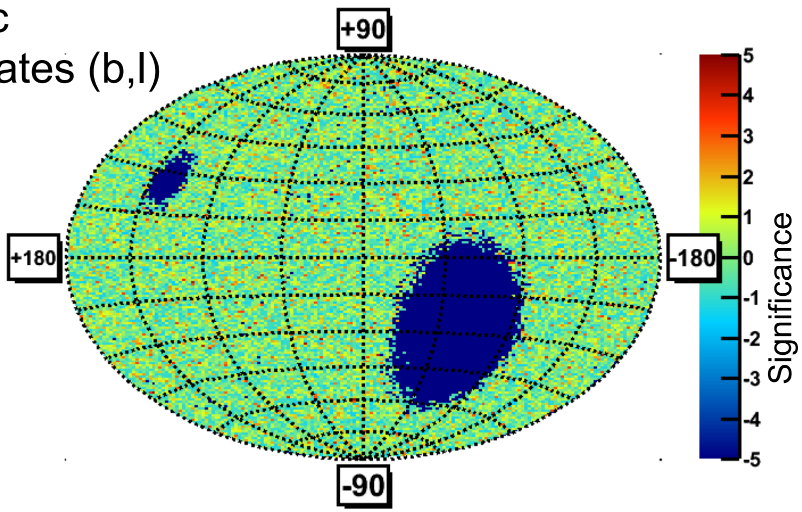


(iv) The energy beyond which it ceases to increase.



(v) The isotropy.

Galactic coordinates (b,l)



The fluctuations of the ratio e^+/e^- are isotropic.

The anisotropy in galactic coordinates: $\delta \leq 0.030$ at the 95% confidence level

$\delta = 3\sqrt{C_1/4\pi}$ C_1 is the dipole moment

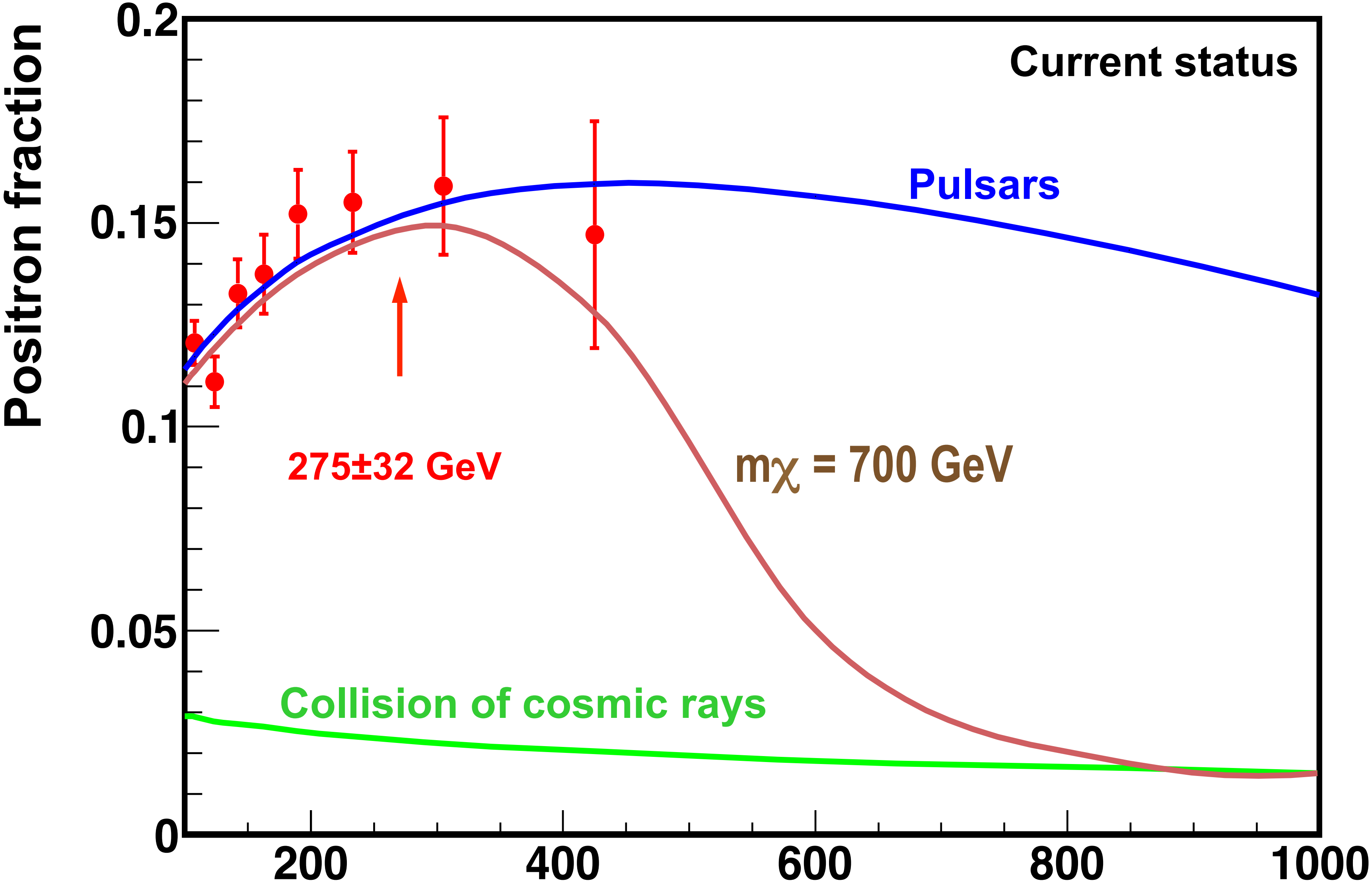
Arrival directions of electrons and positrons are used to build a sky map in galactic coordinates, (b, l), containing the number of observed positrons and electrons. The fluctuations of the observed positron ratio are described using a spherical harmonic expansion

$$\frac{r_e(b,l)}{< r_e >} - 1 = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\pi/2 - b, l),$$

where $r_e(b,l)$ denotes the positron ratio at (b,l); $< r_e >$ is the average ratio over the sky map; $Y_{\ell m}$ are spherical harmonic functions and $a_{\ell m}$ are the corresponding weights. The coefficients of the angular power spectrum of the fluctuations are defined as

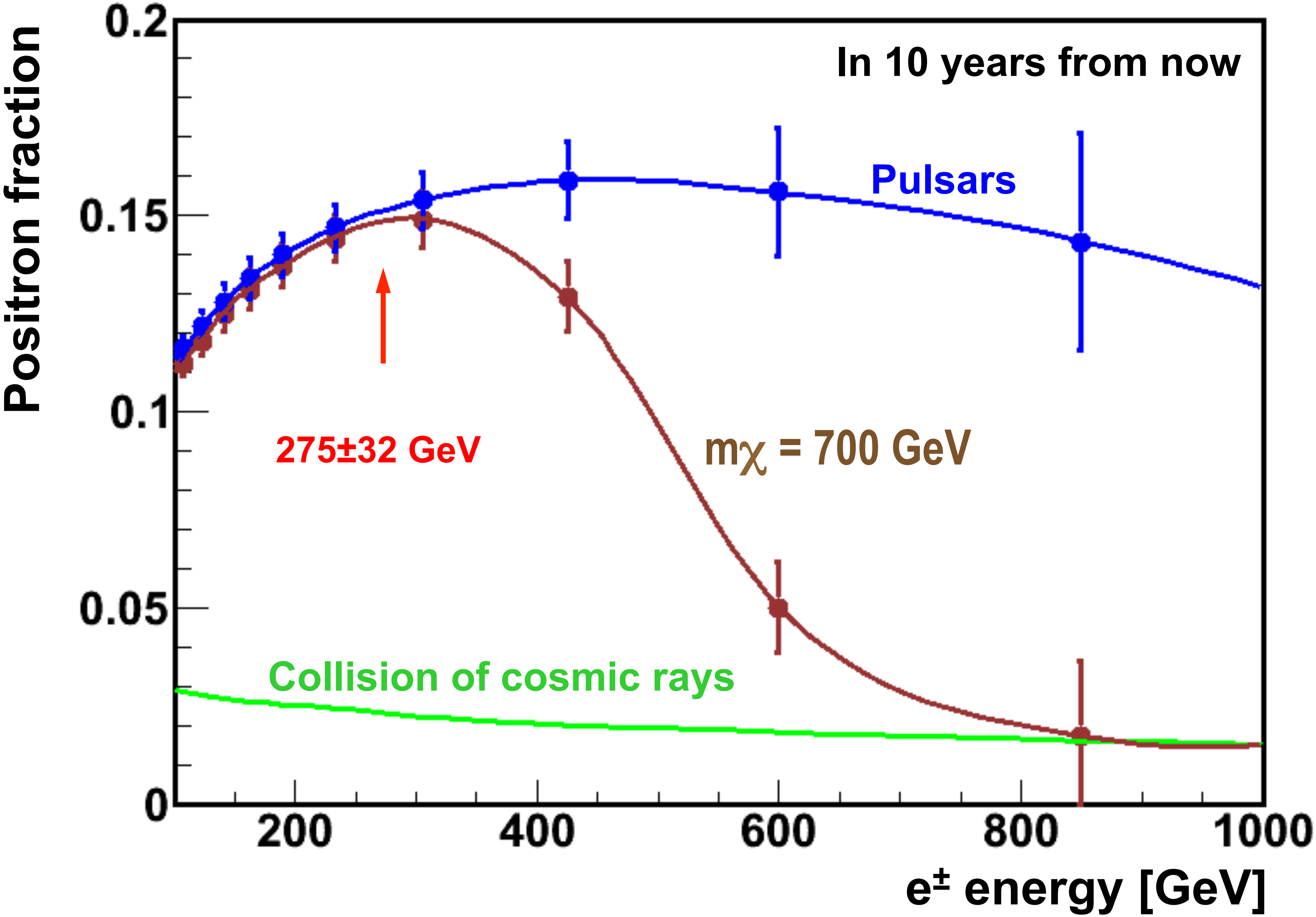
$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2. \qquad \delta = 3\sqrt{C_1/4\pi}$$

(vi) The expected rate at which it falls beyond the turning point.



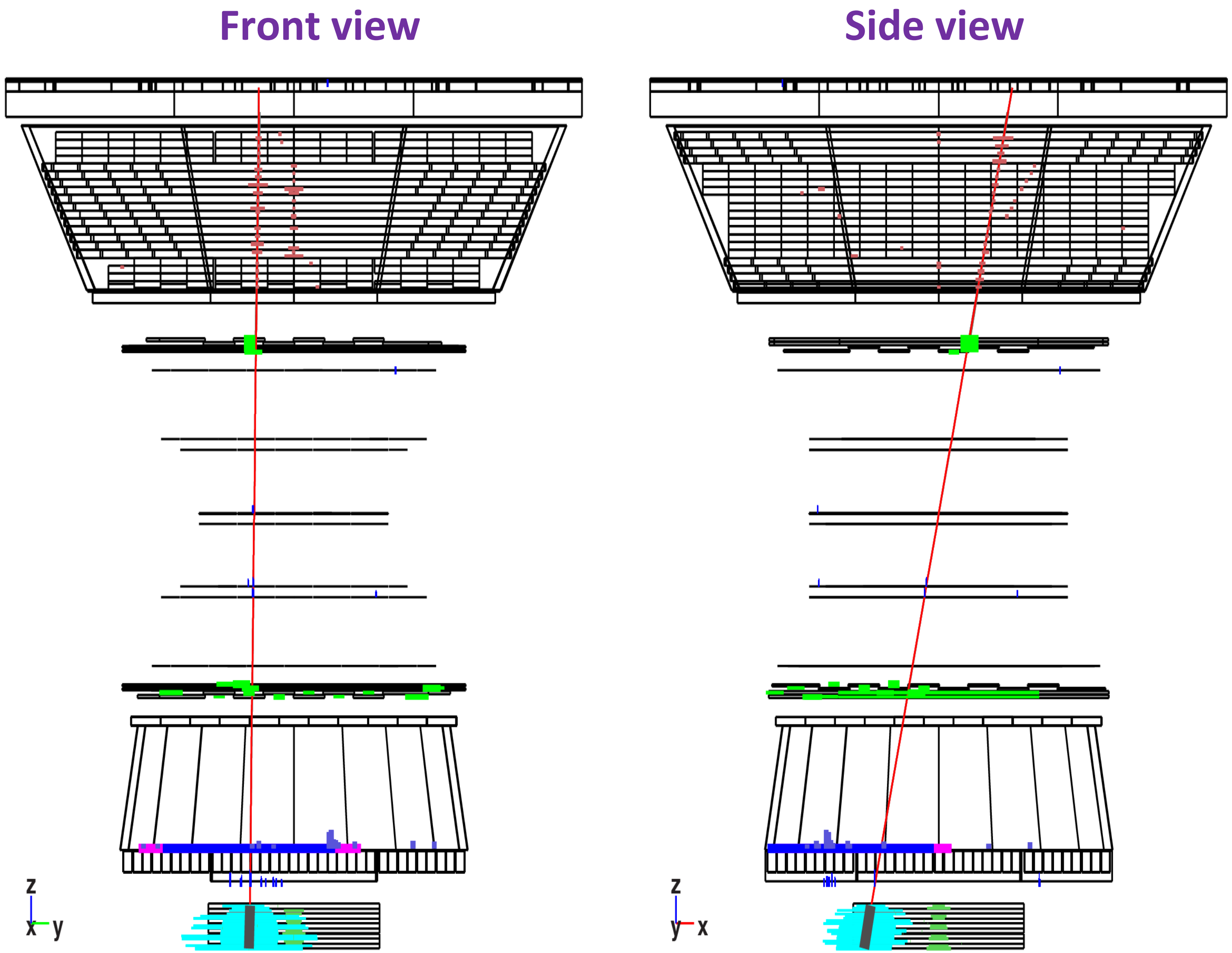
I. Cholis and D. Hooper, Phys.Rev. D88 (2013) 023013
J. Kopp, Phys. Rev. D 88 (2013) 076013

(vi) The expected rate at which it falls beyond the turning point.

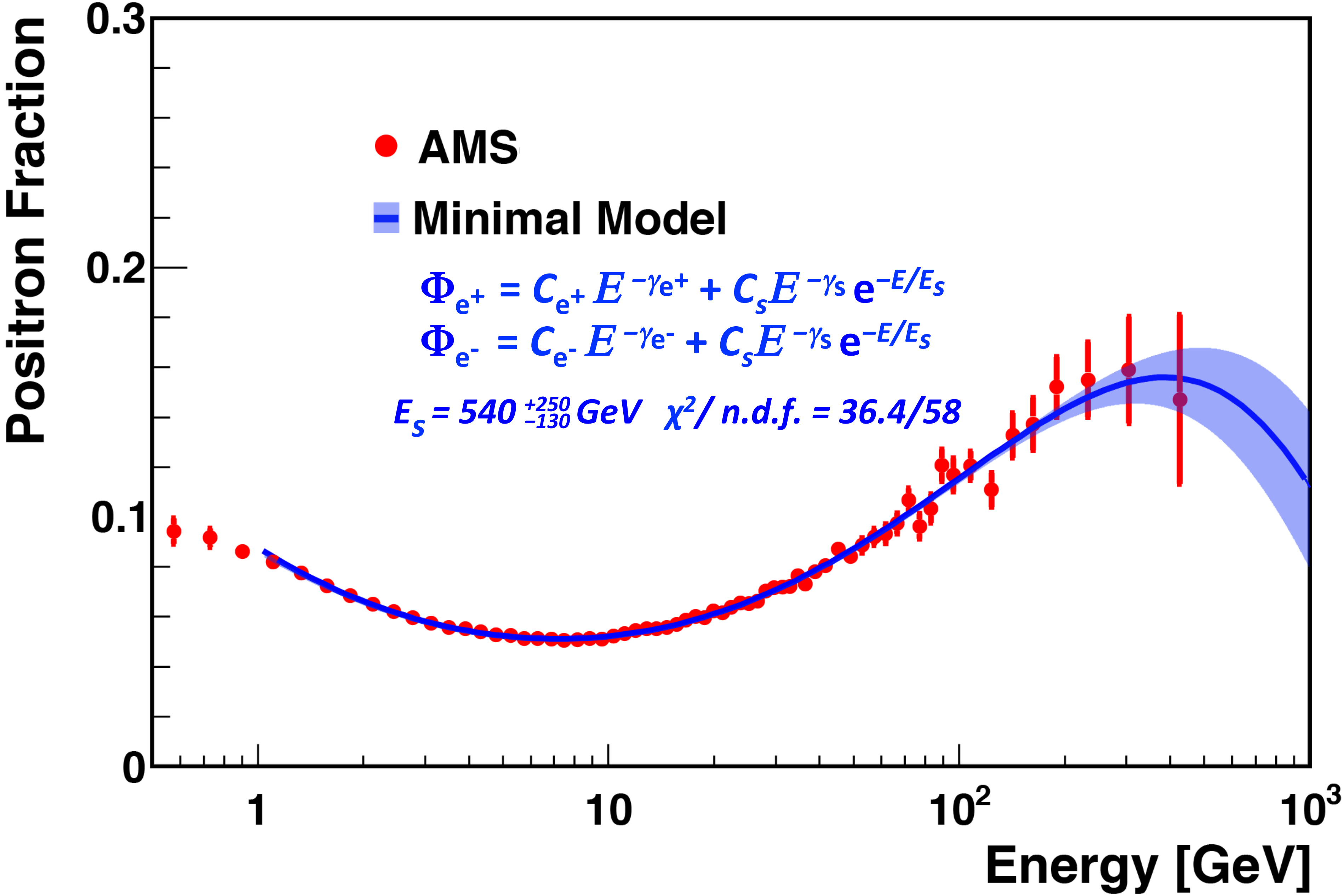


AMS measures positrons up to ~1 TeV

Positron E=870 GeV



Minimal Model: Fit to the data



Many models proposed to explain the physics origin of the source term:

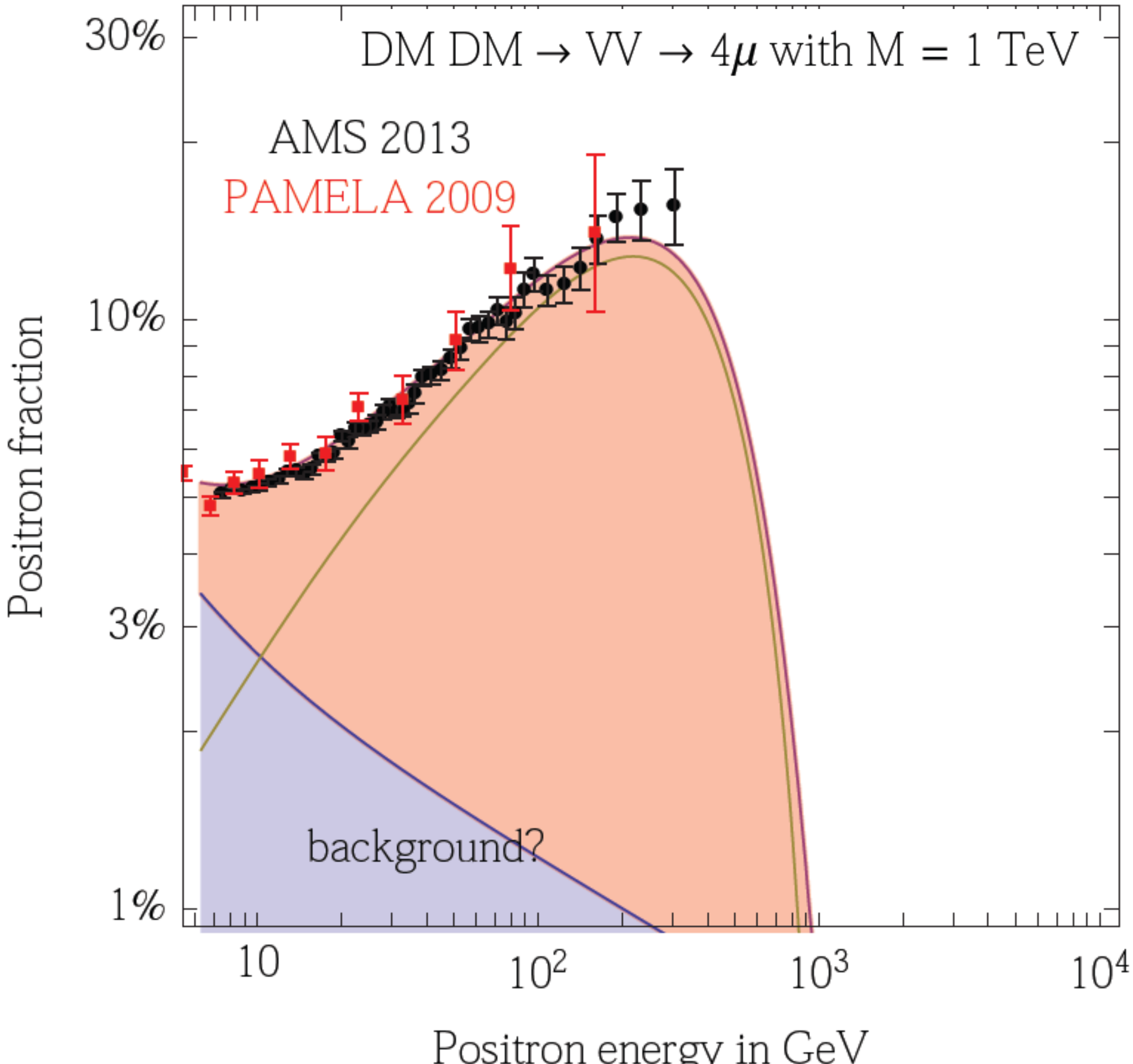
1) Particle origin: Dark Matter
2) Astrophysics origin: Pulsars, SNRs
3) Secondaries: peculiarities of propagation

In this meeting we look forward to new ideas

to match our latest data on e^+, e^-, $\bar{p}/p$, He, Li, B/C, …

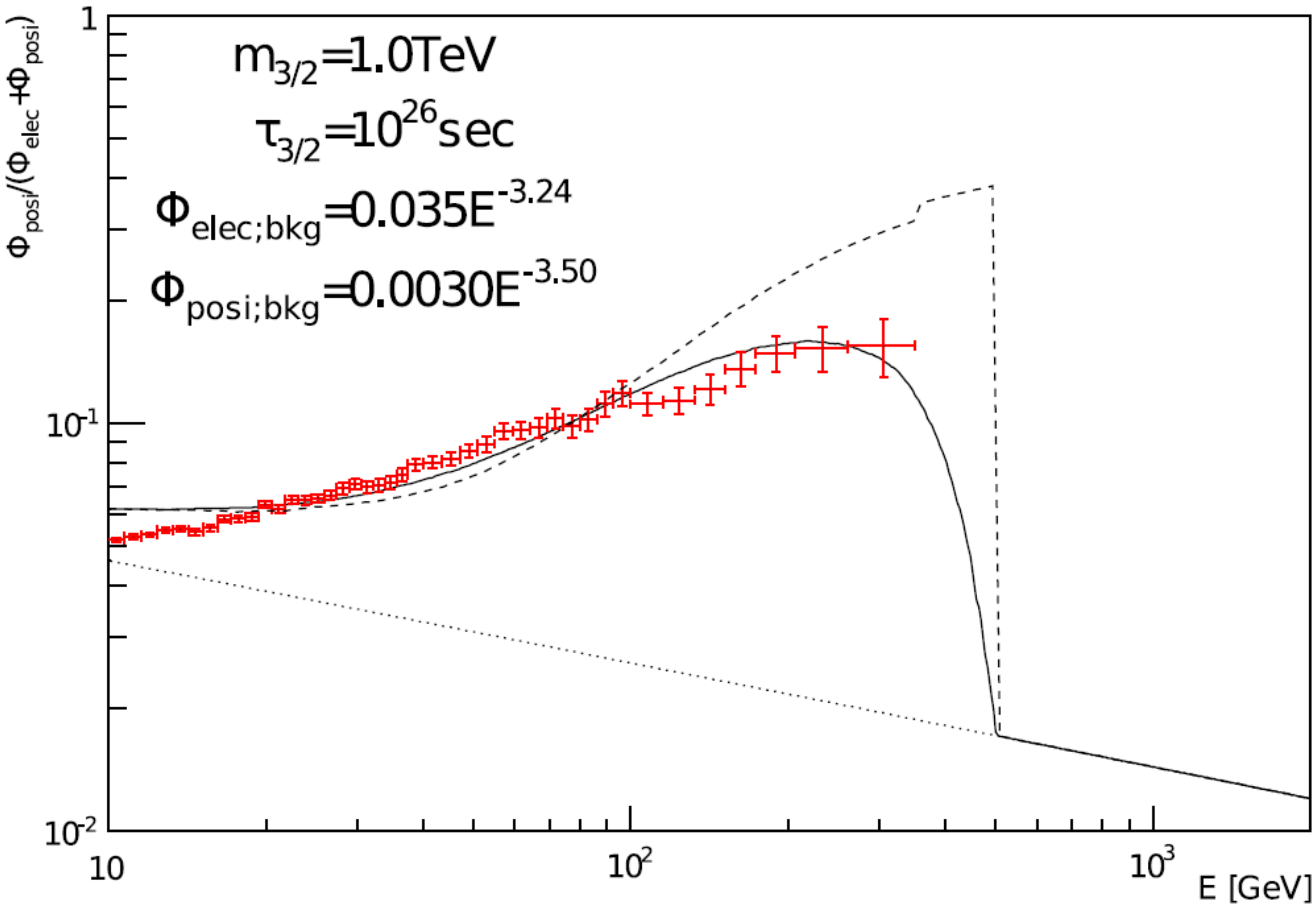
Dark Matter model with intermediate state

M.Cirelli, M.Kadastik, M.Raidal and A.Strumia, Nucl.Phys. B873 (2013) 530



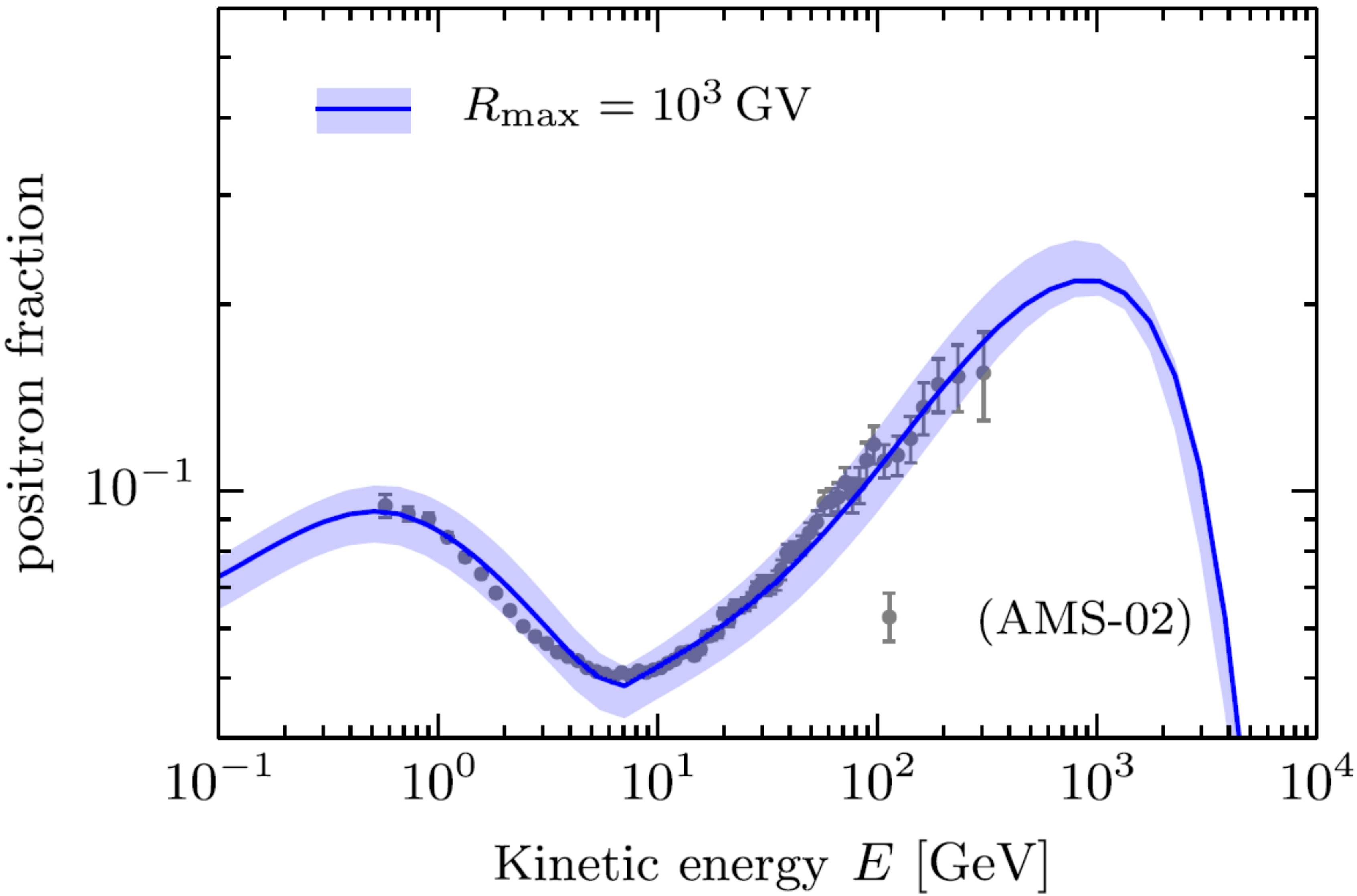
Dark Matter model with gravitino

M. Ibe, S. Iwamoto, T. Moroi and N. Yokozaki, JHEP 1308 (2013) 029



Acceleration in SNRs

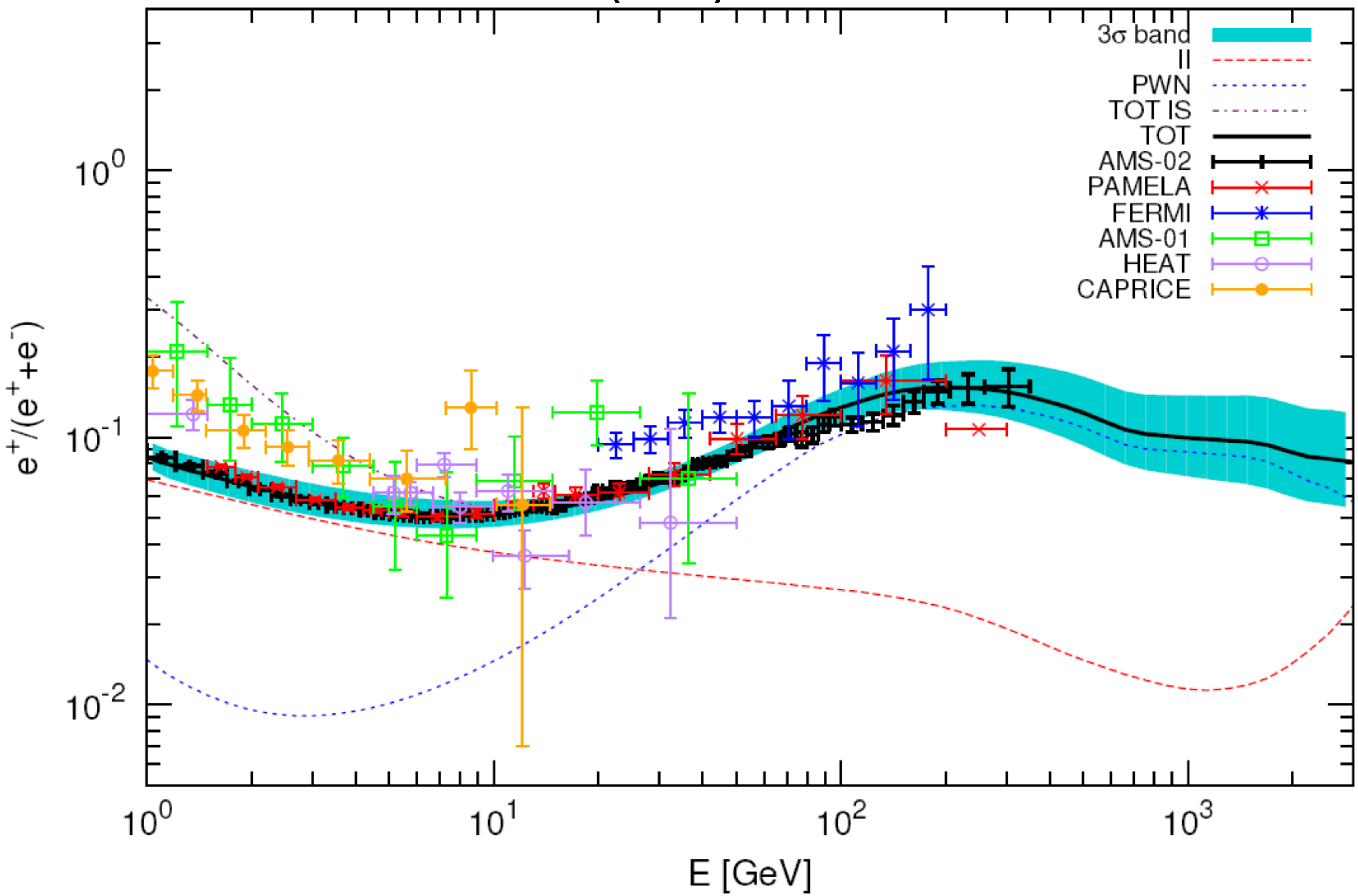
P. Mertsch and S. Sarkar, Phys.Rev. D 90 (2014) 061301(R)



S. Sarkar talk on April 16

Production in Pulsars

M. DiMauro, F. Donato, N. Fornengo, R. Lineros, A. Vittino, JCAP 1404 (2014) 006

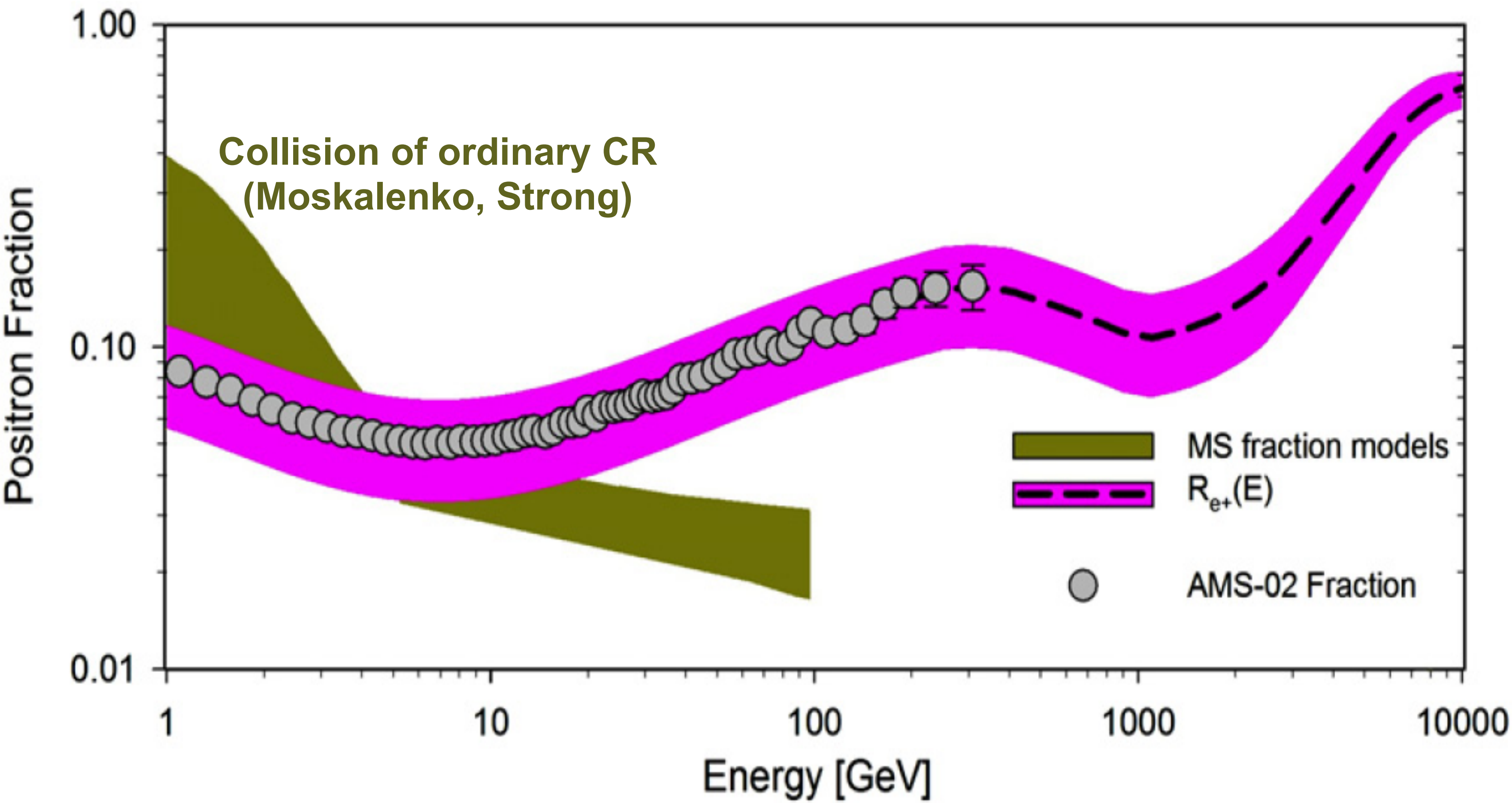


Propagation of secondaries

1) R.Cowsik, B.Burch, and T.Madziwa-Nussinov, Ap.J. 786 (2014) 124
2) K. Blum, B. Katz and E. Waxman, Phys.Rev.Lett. 111 (2013) 211101

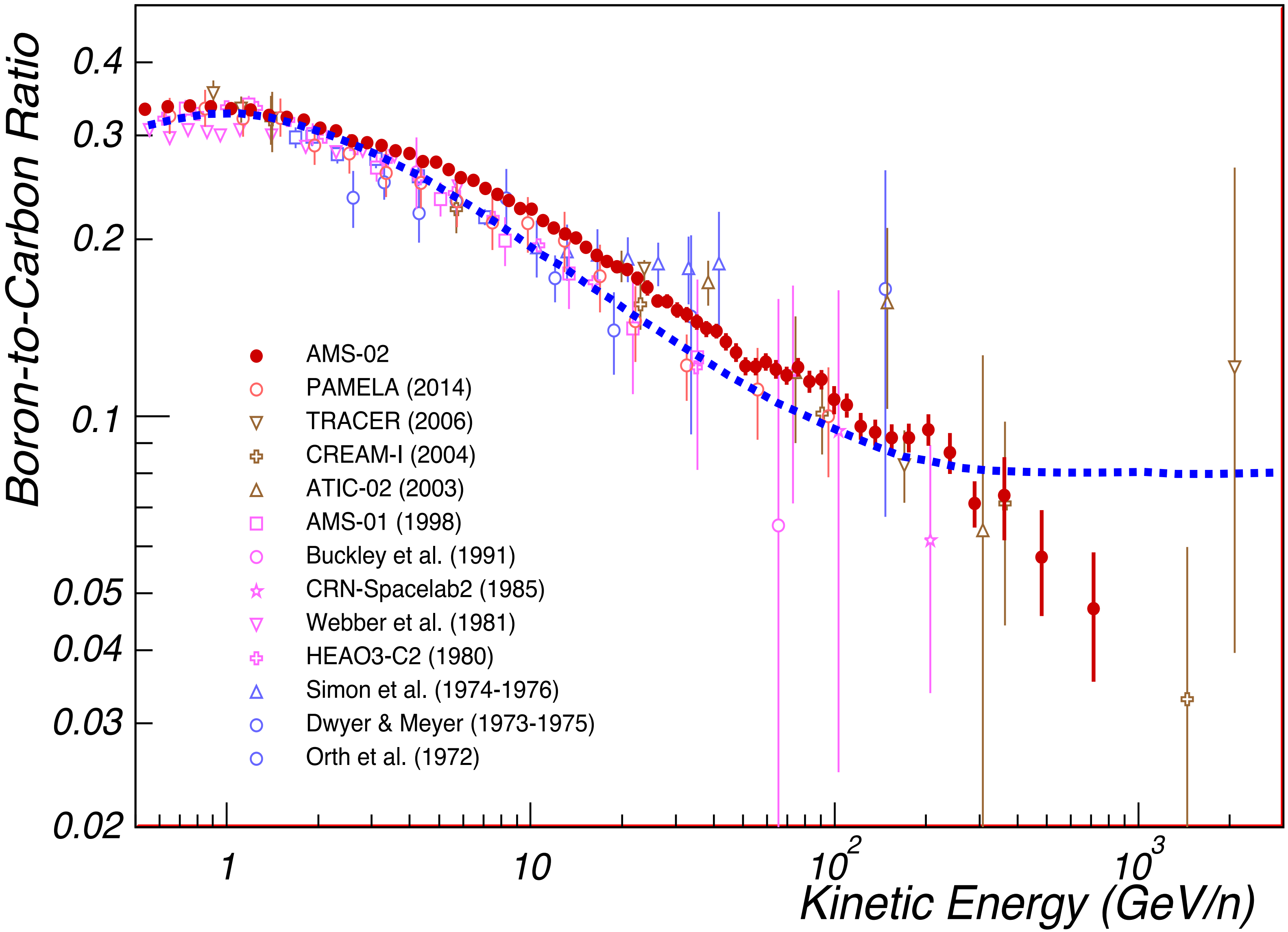
Propagation of secondaries

R. Cowsik, B. Burch, and T. Madziwa-Nussinov, Ap. J. 786 (2014) 124



Propagation of secondaries

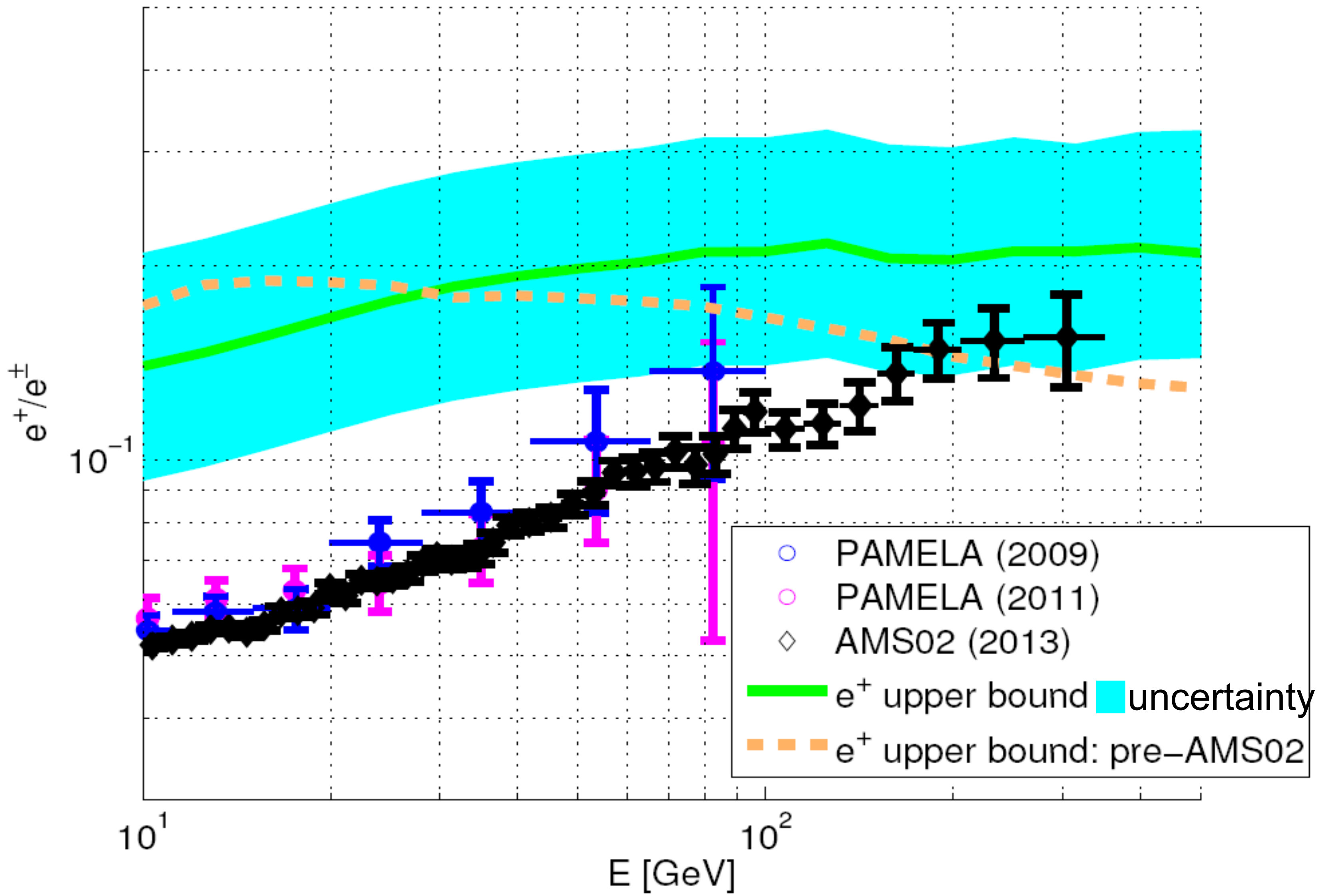
R. Cowsik, B. Burch, and T. Madziwa-Nussinov, Ap. J. 786 (2014) 124



A. Oliva talk on April 17

Propagation of secondaries

K. Blum, B. Katz and E. Waxman, Phys. Rev. Lett. 111 (2013) 211101



K. Blum talk this afternoon

Positron fraction – modeling of the cosmic rays

Observation:

Models based on very different assumptions describe observed trends in the data

Dream:

Model prediction accuracy is comparable to the precision of the experimental data.

New AMS measurements:

New precision measurements of CR

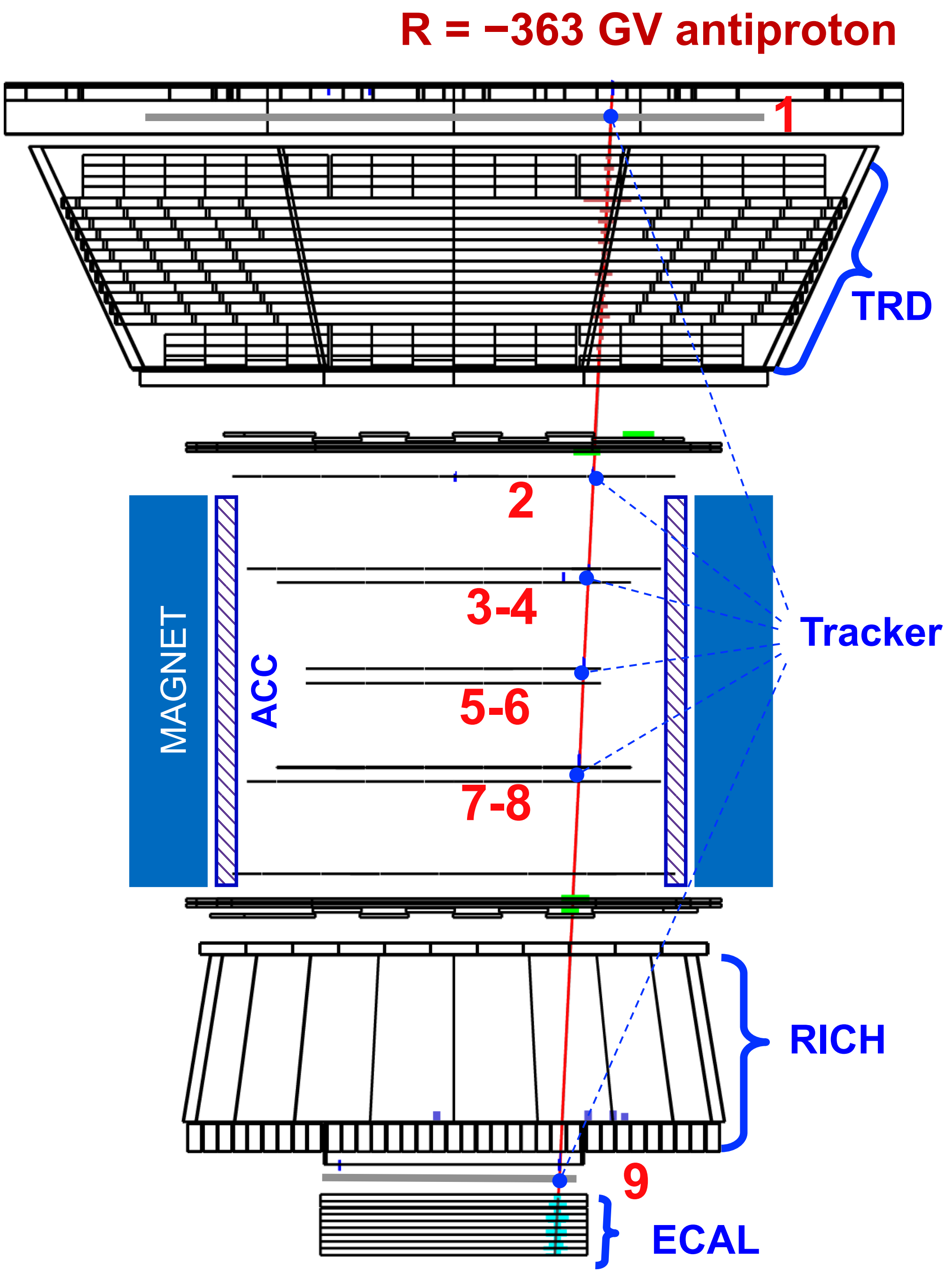
New results on the $\bar{p}/p$ ratio

Status Report

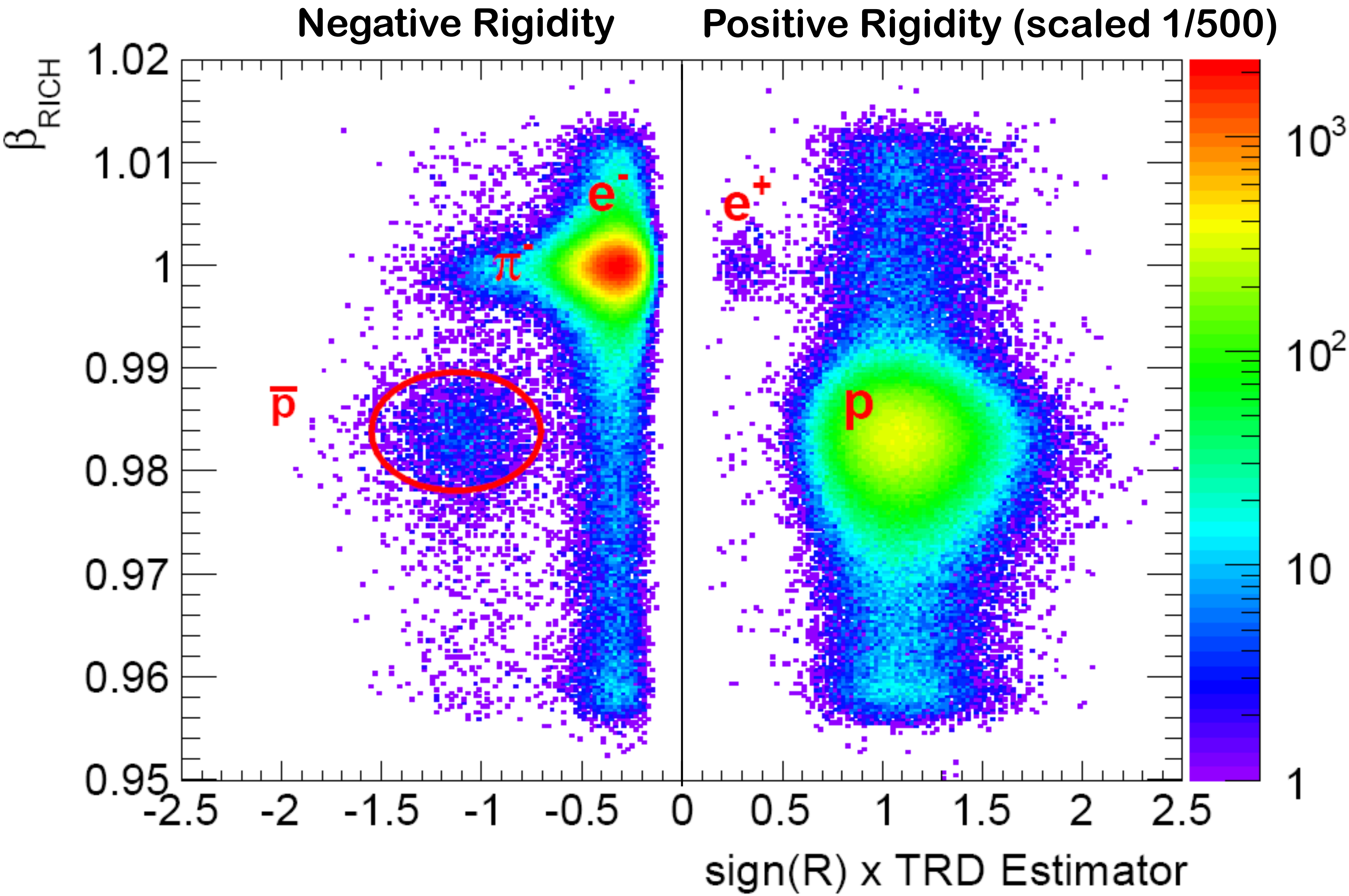
Rigidity range from 1 to 450 GV is studied using 290,000 antiprotons selected from the data sample of 54 billion events.

Event selection.

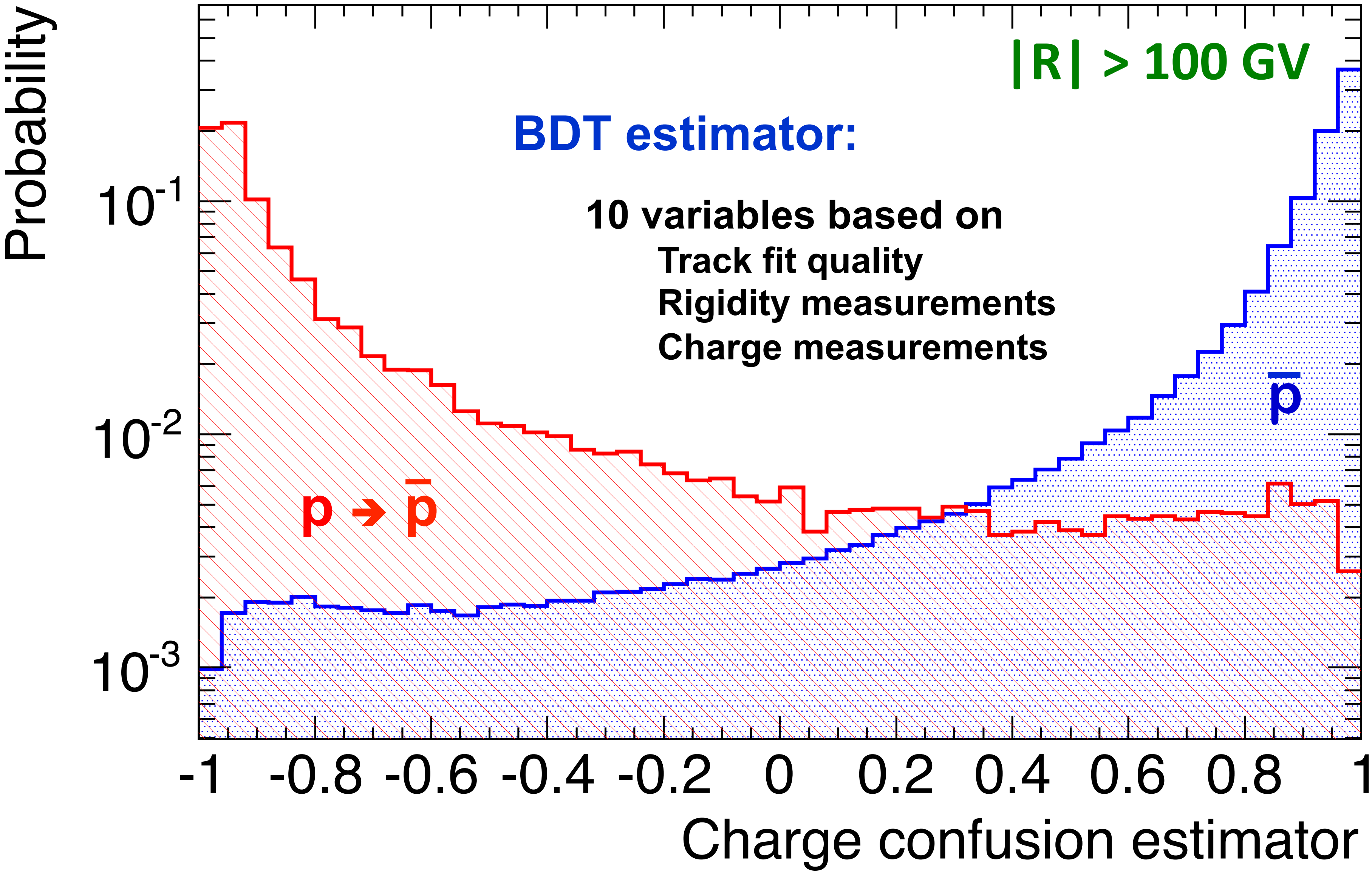
- **DAQ:**
  - livetime > 50% (no SAA)
- **Geomagnetic cutoff:**
  |R| > 1.2·max cutoff
- **TOF:**
  - downgoing particle
  - β>0.3
- **TRD:**
  at least 12 hits
- **TRACKER:**
  - Track quality
  - 0.8 < |Q| < 1.2
- **ECAL:**
  - Hadron shower shape



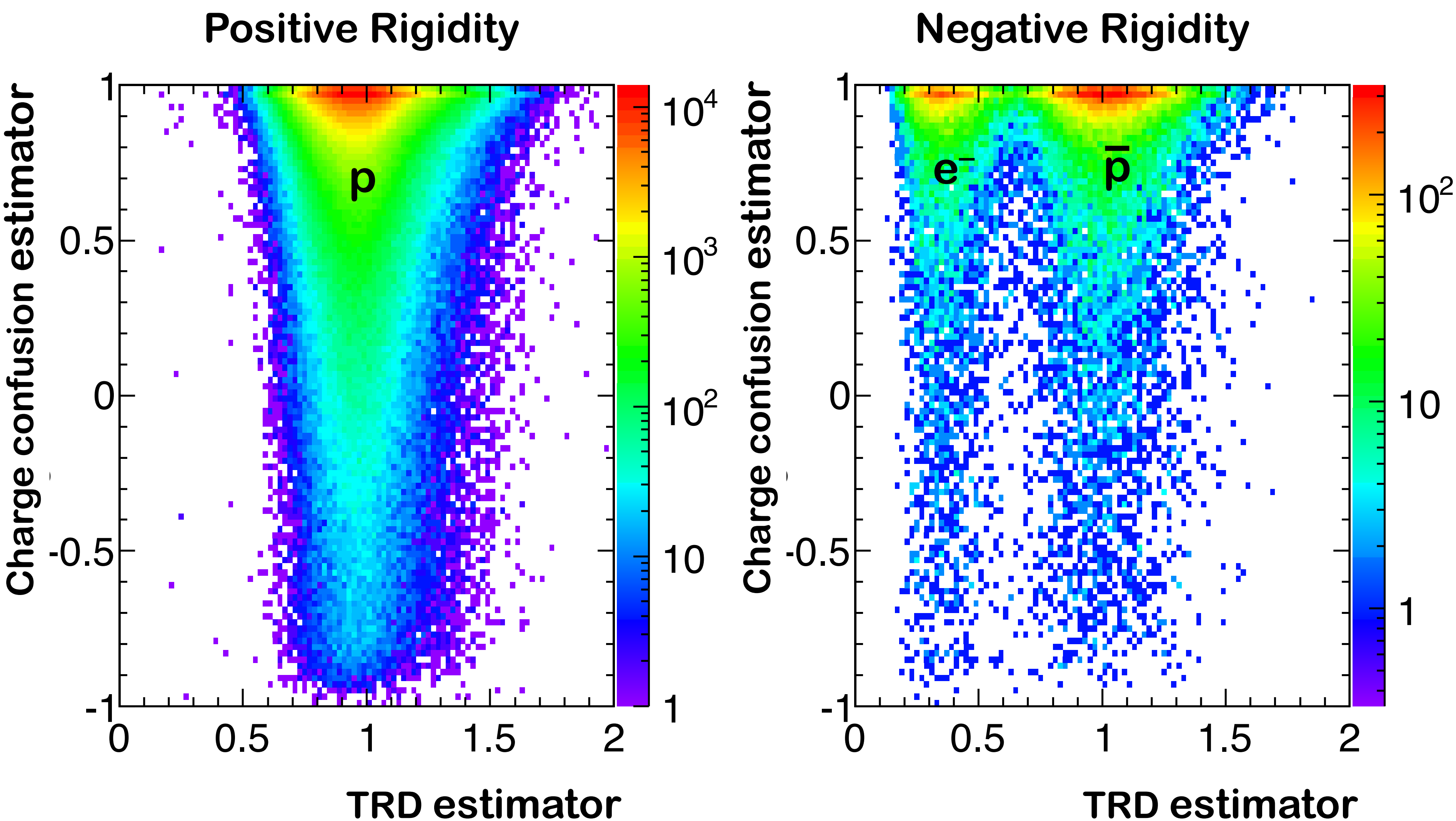
$\bar{p}$ identification below 10 GV



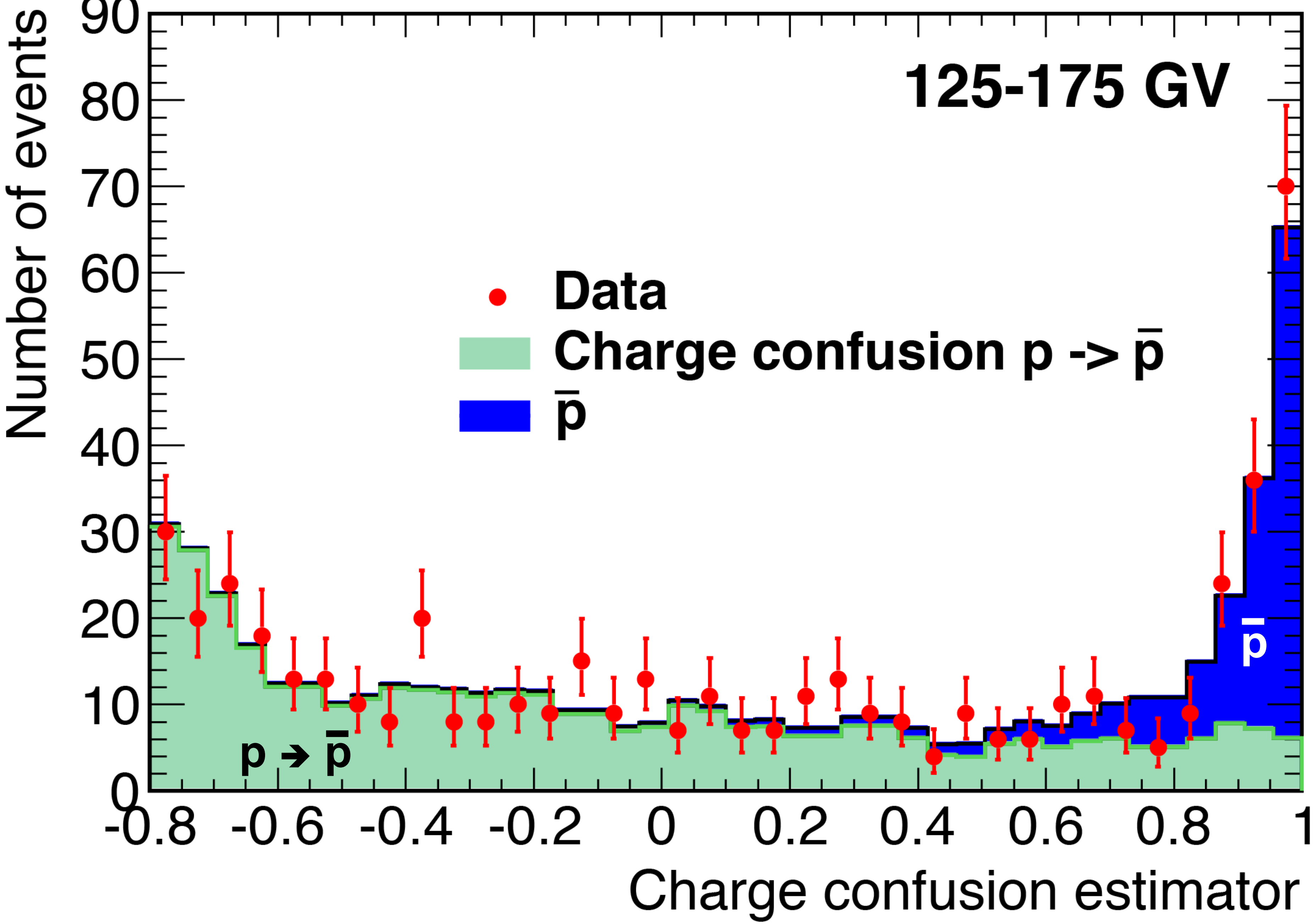
Charge confusion estimator at high rigidities



$\bar{p}$ identification at high rigidities



Anti-proton identification



Major systematic errors

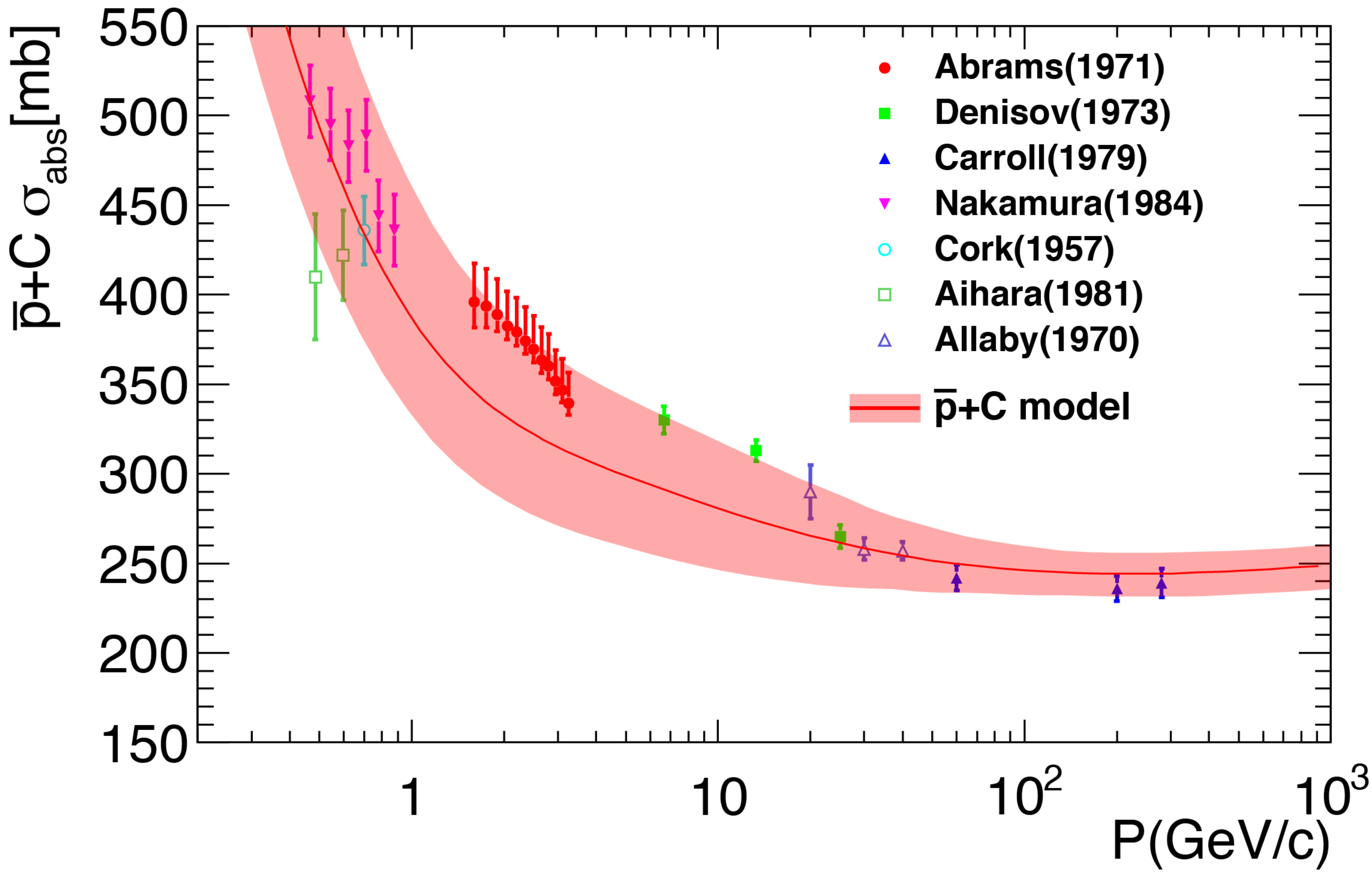
1. Acceptance asymmetry
   and bin-to-bin migration

2. Selection uncertainty

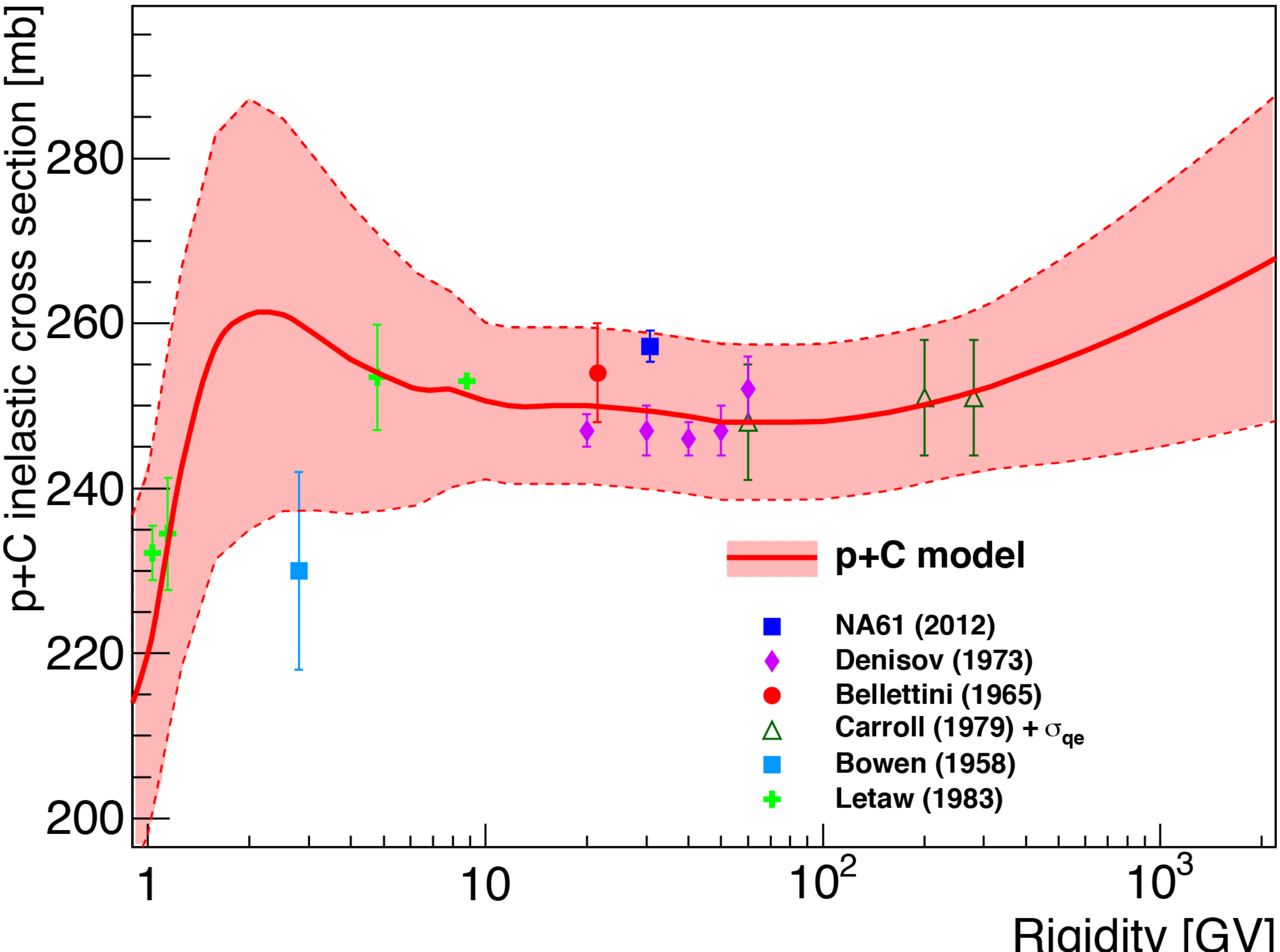
3. Uncertainty in the
   reference spectra and
   charge confusion

Systematic errors:

1. Acceptance asymmetry and bin-to-bin migration

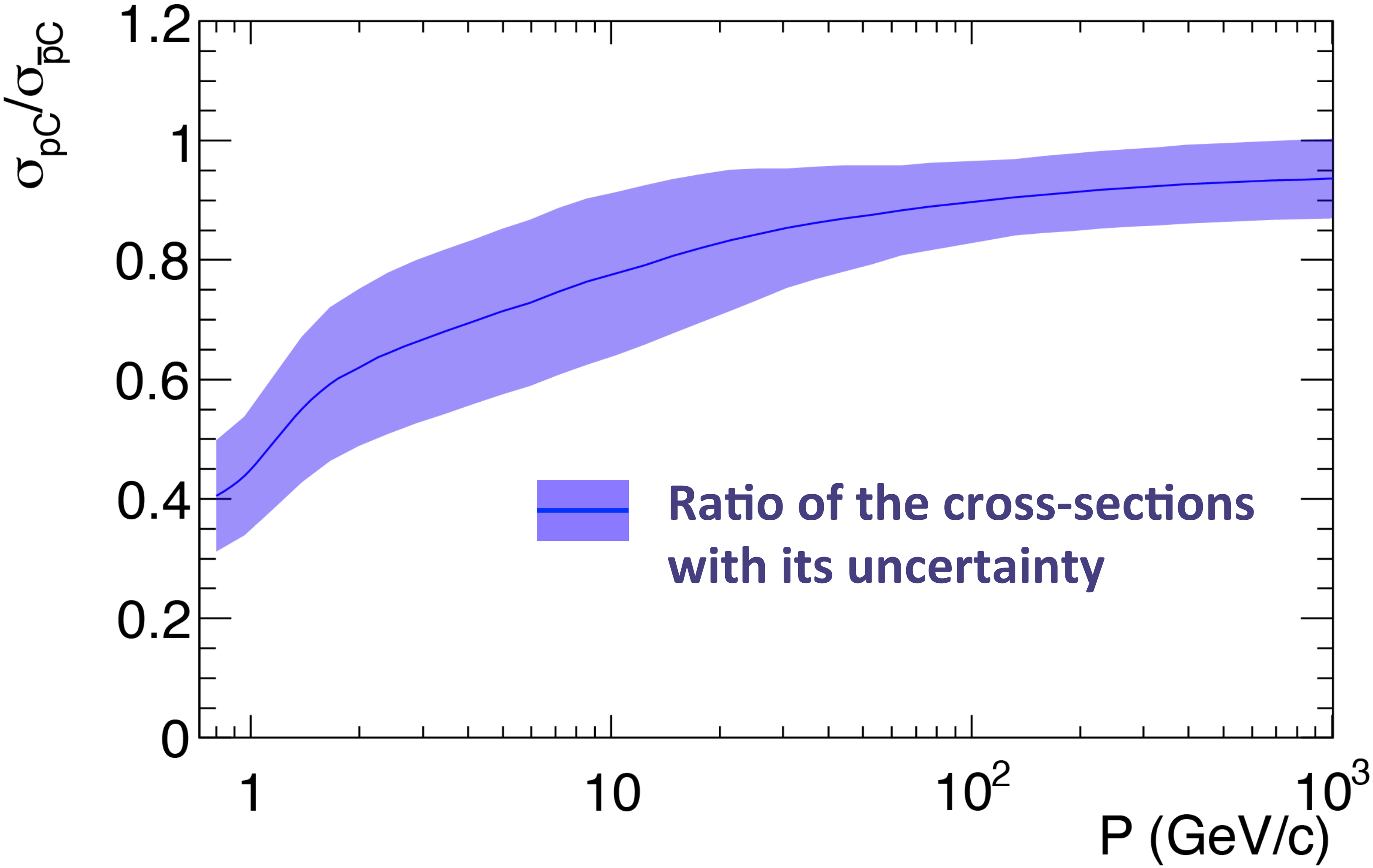


Systematic errors:
1. Acceptance asymmetry and bin-to-bin migration



Systematic errors:

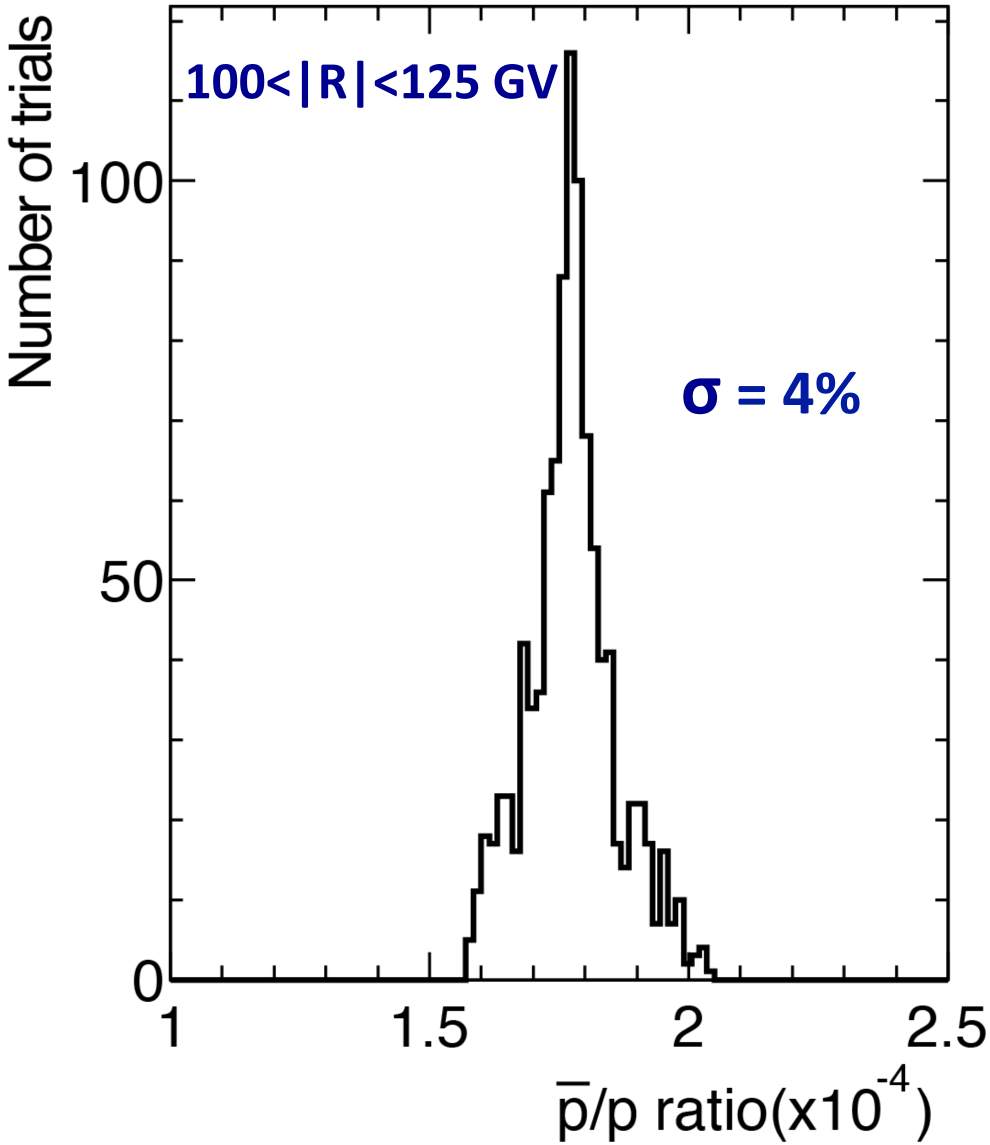
1. Acceptance asymmetry and bin-to-bin migration



Acceptance asymmetry is due to $\bar{p}N$ / pN crossection difference

Bin-to-bin migration is small – large bin width and good resolution

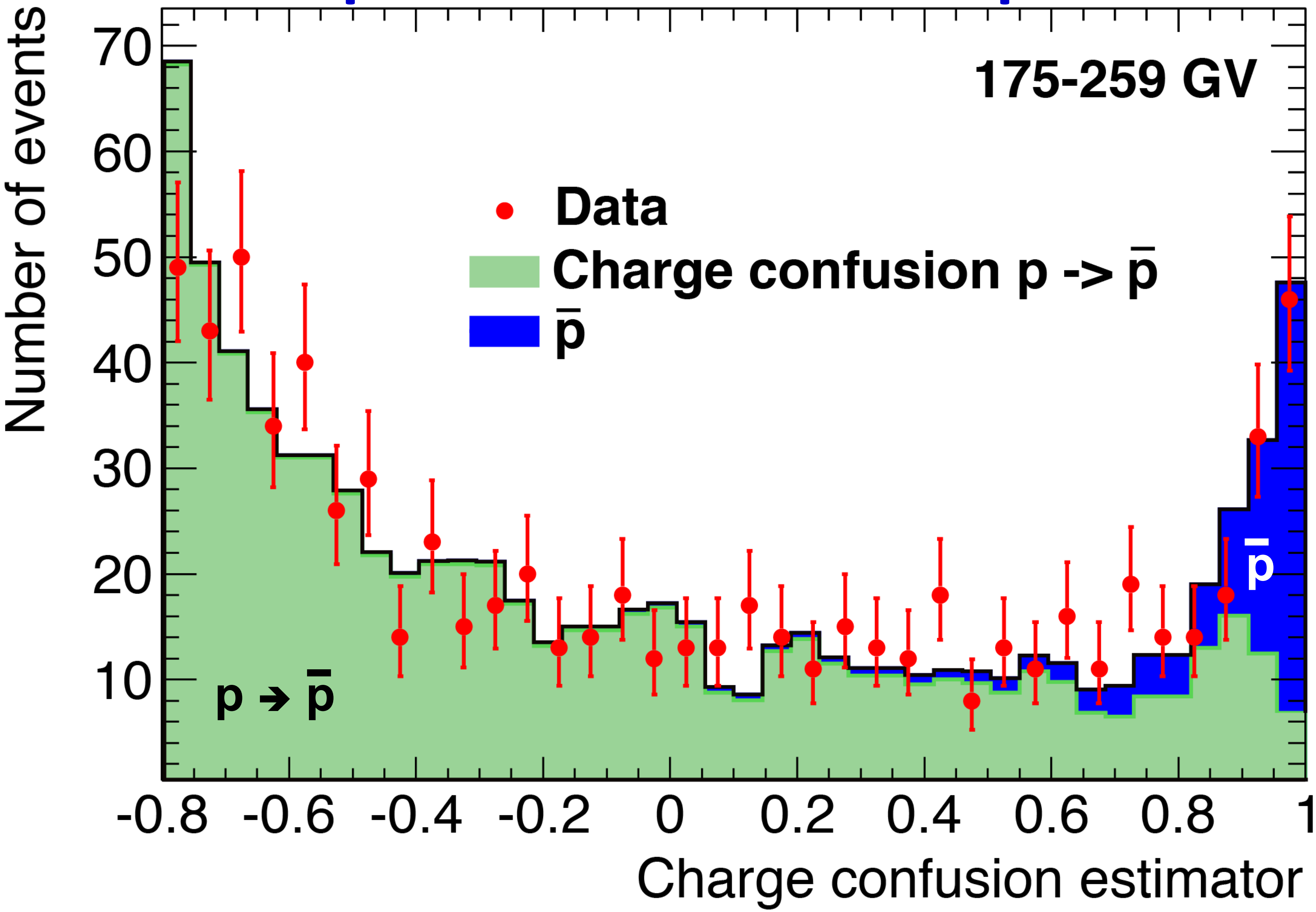
Systematic errors:
2. Selection uncertainty



Stability of the measurement is tested over wide variations of cuts

For each rigidity bin, over 1,000 sets of cuts were analyzed.

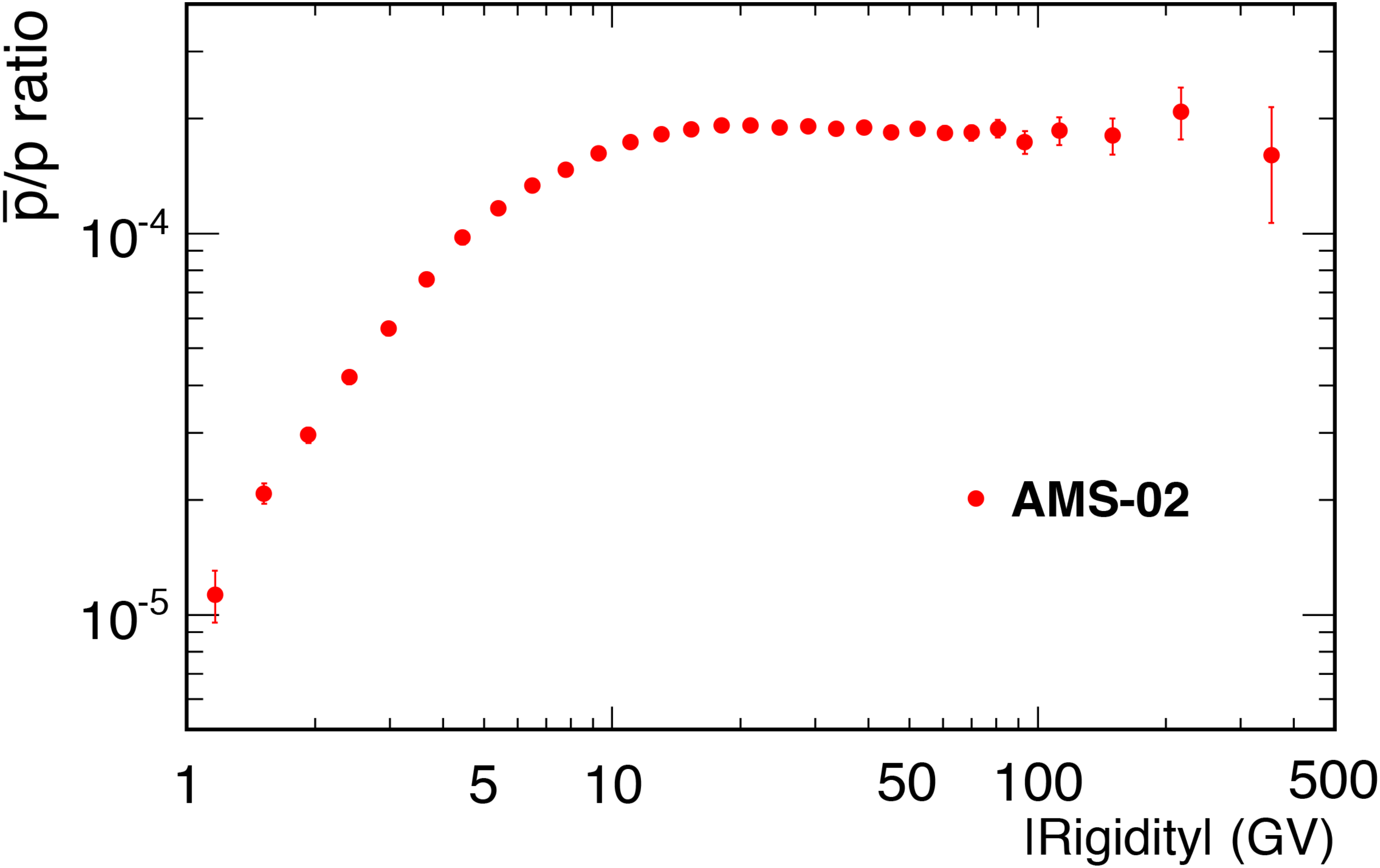
Systematic uncertainty
3. Shapes of the reference spectra



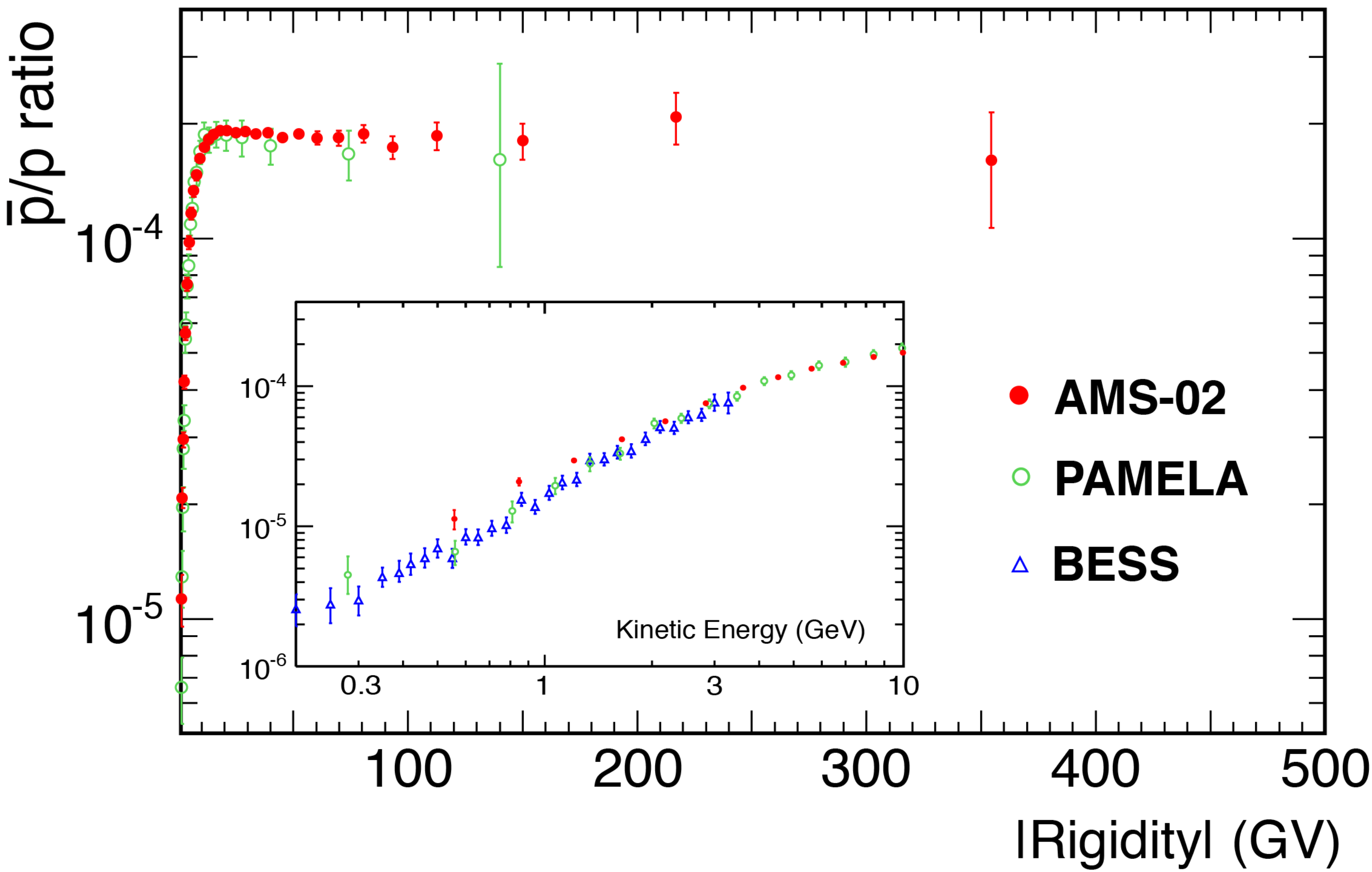
Statistical and systematic uncertainties in the rigidity bin 175-259 GV

$\bar{p}/p$ ratio	2.00 ($\times 10^{-4}$)	
Statistical error	0.29	14.4%
Systematic error	0.15	7.3%
Acceptance	0.03	1.4%
Selection	0.04	2.1%
Ref. spectra	0.14	6.9%
Total error	0.32	15.5%

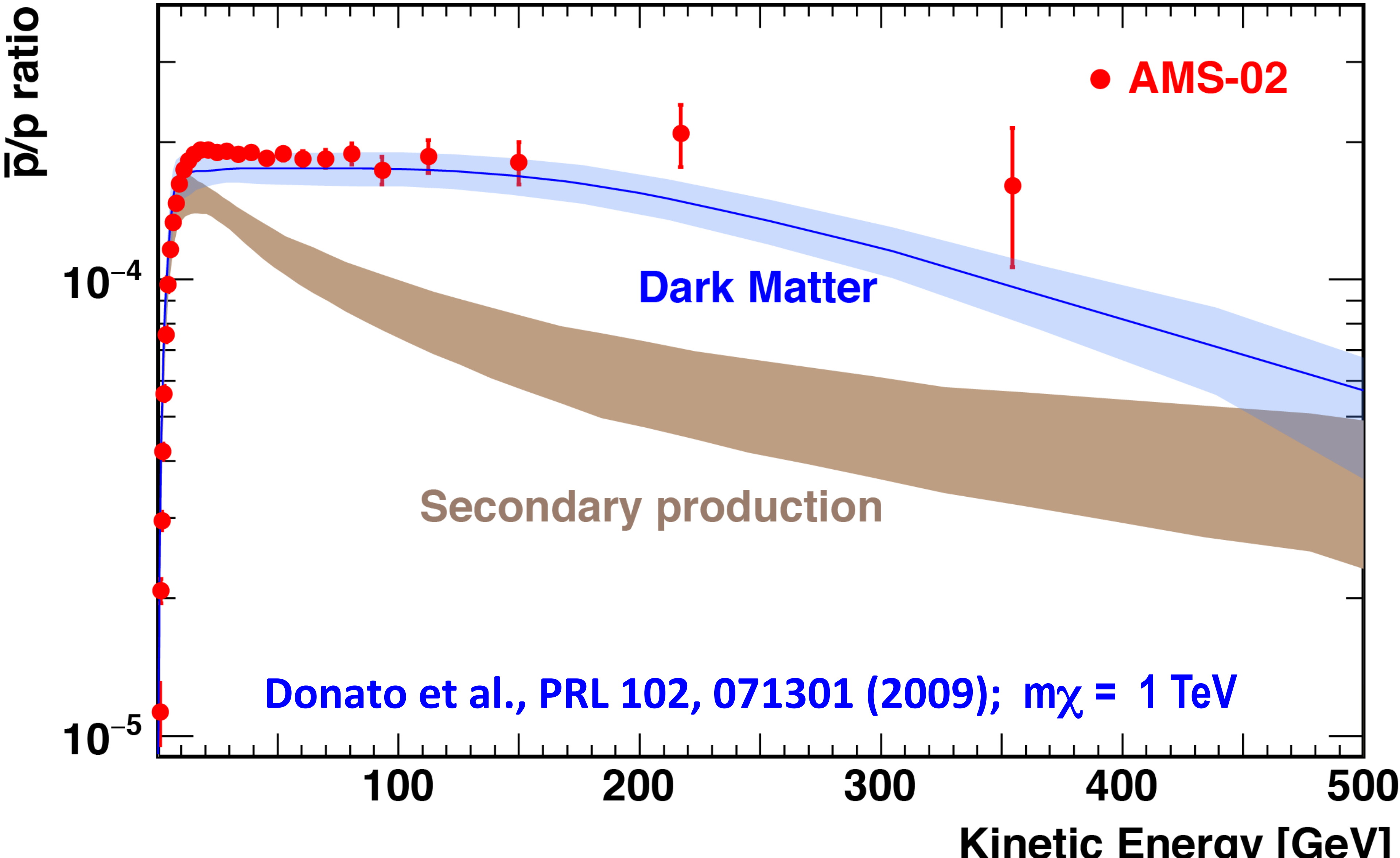
AMS $\bar{p}/p$ results



AMS $\bar{p}/p$ results



AMS $\bar{p}/p$ results and modeling



Conclusions

1. Positron fraction is measured from 0.5 to 500 GeV:
   - Reaches its minimum at 7.8 GeV;
   - Steadily increases from 10 to ~250 GeV, no fine structures;
   - At 275±32 GeV the slope crosses zero, i.e the fraction reaches its max;
   - The positron to electron ratio is consistent with isotropy; $\delta \leq 0.03$ at the 95% *C.L*
   - Exact behavior of the positron fraction at high energies requires more statistics.

2. Antiprotons analysis status is presented:
   - Rigidity range explored: 1 − 450 GV