LATEST RESULTS FROM THE AMS-02 EXPERIMENT

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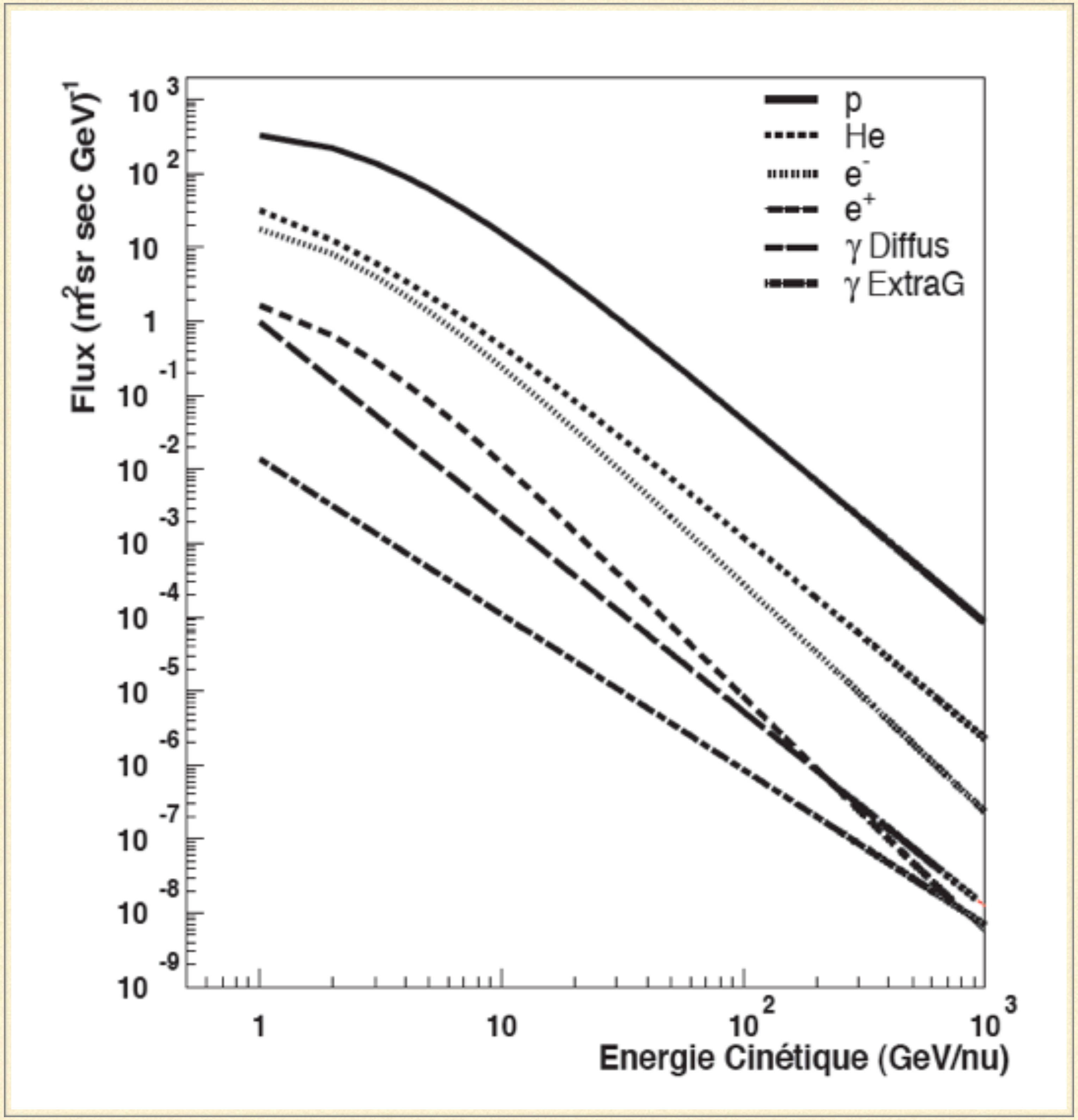
OUTLINE

- Introduction
- Latest results from the AMS-02 experiment:
  - Positron fraction [PRL 113, 121101 (2014)]
  - Electron and positron flux [PRL 113, 121102 (2014)]
  - Combined flux [PRL 113, 221102 (2014)]
- A new look at the positron fraction [arXiv:1410.3799]

ON BEHALF OF THE AMS-02 COLLABORATION

Physicists from 15 countries in America, Europe and Asia

COSMIC RAYS COMPOSITION

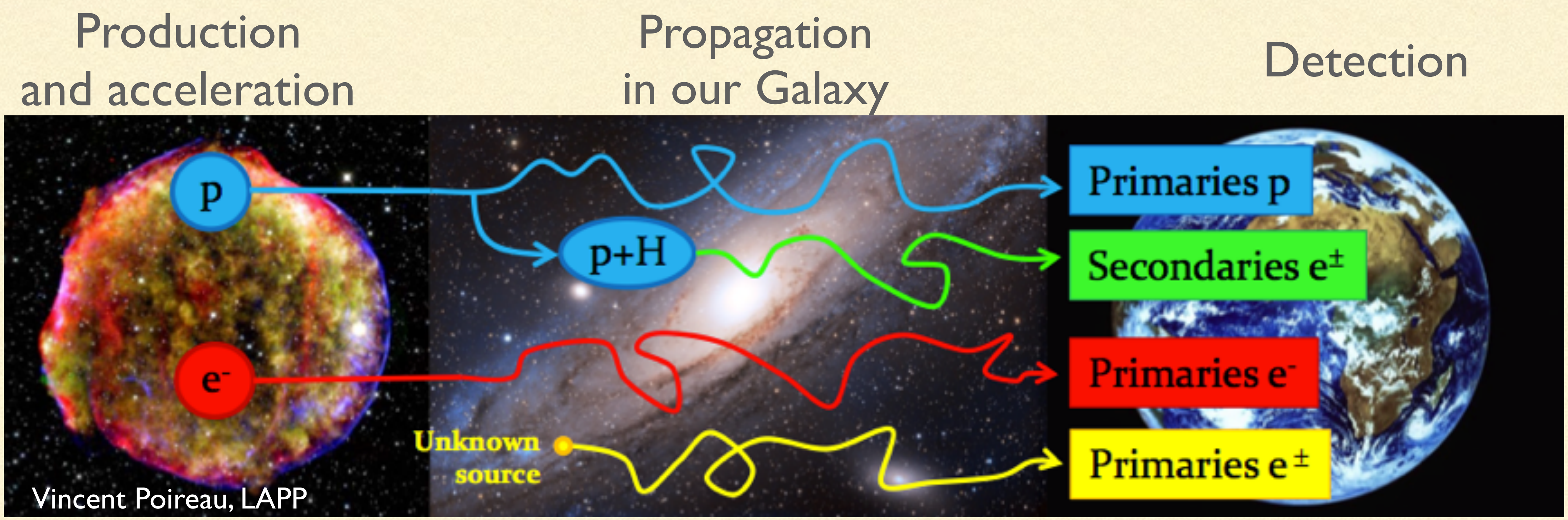


- 99% nucleons
  - 89% protons,
  - 10% He,
  - 1% heavier nuclei
- 1% electrons (0.1% e+)

A WINDOW ON THE NEARBY UNIVERSE

- Electrons (and e+) constitute only a tiny fraction (1%) of CRs
- Due to their low mass, they loose their energy by synchrotron radiation and by inverse Compton scattering on the Interstellar radiation field.
- Their horizon is limited to few kpc: <u>a window on the nearby Universe!</u>

COSMIC RAYS IN THE MILKY WAY



Primary cosmic rays:

- Produced directly in the source
- Known sources ($E < 10^{16}$ eV): SNRs
- Primary cosmic rays include e^-, p, He, C, …

$$
\begin{aligned}
&p + p_{\mathrm{ism}} \to \pi^+ + \ldots \\
&\qquad\qquad \hookrightarrow \mu^+ + \nu_\mu \\
&\qquad\qquad\quad \hookrightarrow e^+ + \nu_e + \overline{\nu}_\mu
\end{aligned}
$$

Secondary cosmic rays:

- Produced in the interaction of primaries in the interstellar medium
- Secondary cosmic rays include e^-, e^+, anti-p, B, …

AMS-02 is a particle physics detector in outer space

Scientific goals:

- Cosmic ray fluxes in the GeV to TeV region
- Search for primordial antimatter
- Indirect search for dark matter
- Cosmic rays propagation

THE LAUNCH OF AMS-02

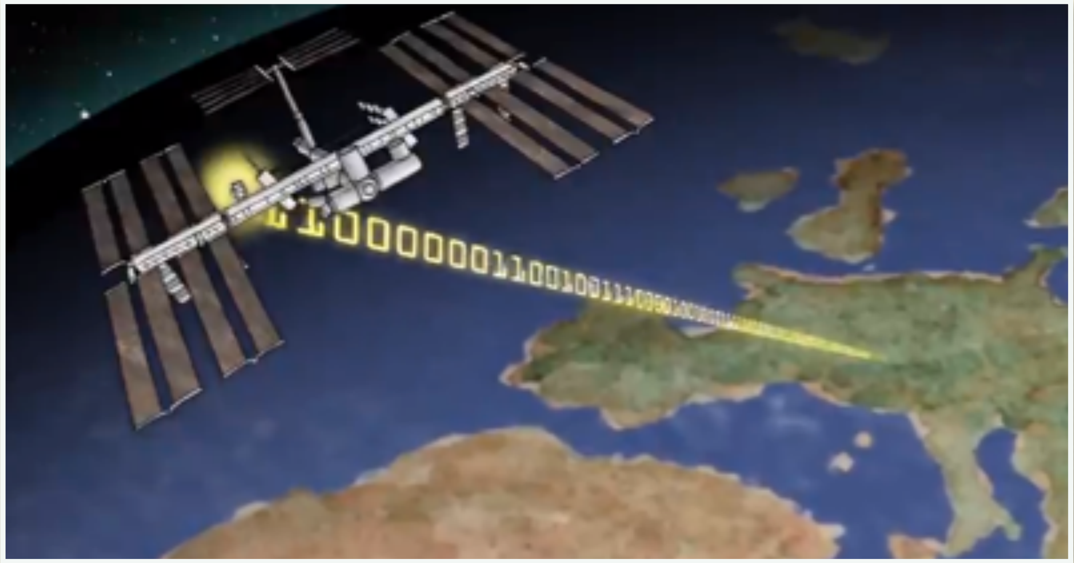
Cap Canaveral: May 16th 2011

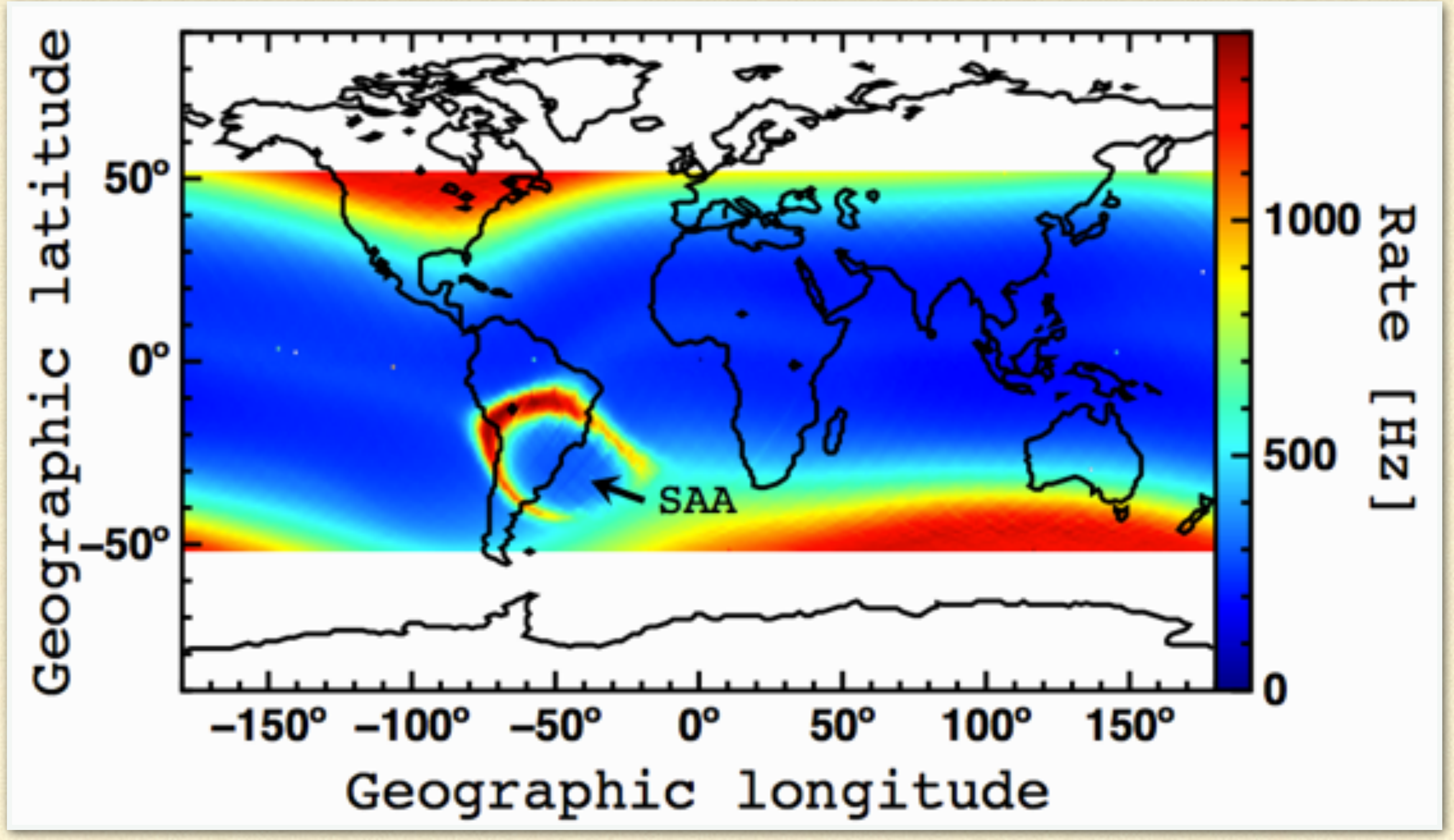
AMS-02 ONBOARD THE ISS

- Orbiting at 400 km altitude
- Detect cosmic rays before they interact with the atmosphere

DETECTOR OPERATIONS

- Continuous operation 7d/7 24h/24
- 54 millions particles/day
- 35 TB data/year
- Detector operation until ~ 2024

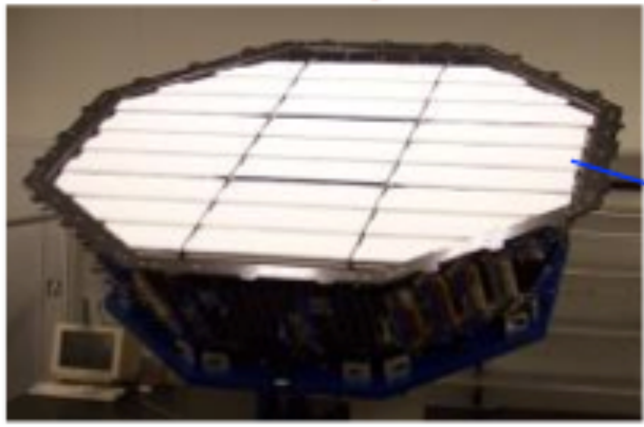




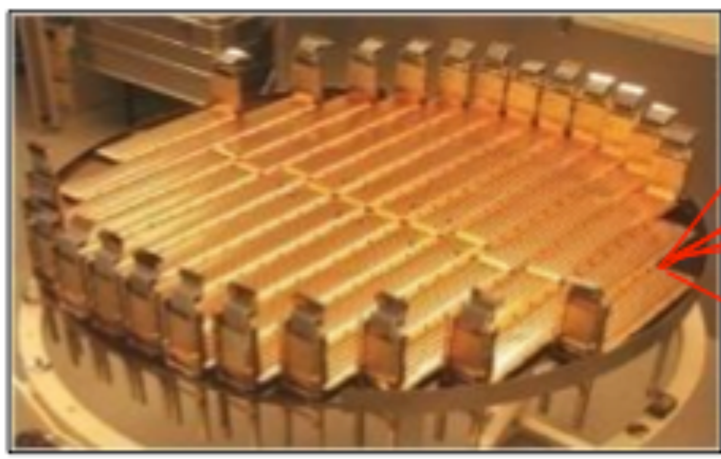
- Average rate ~ 700 Hz/orbit

AMS: A TeV precision, multipurpose spectrometer

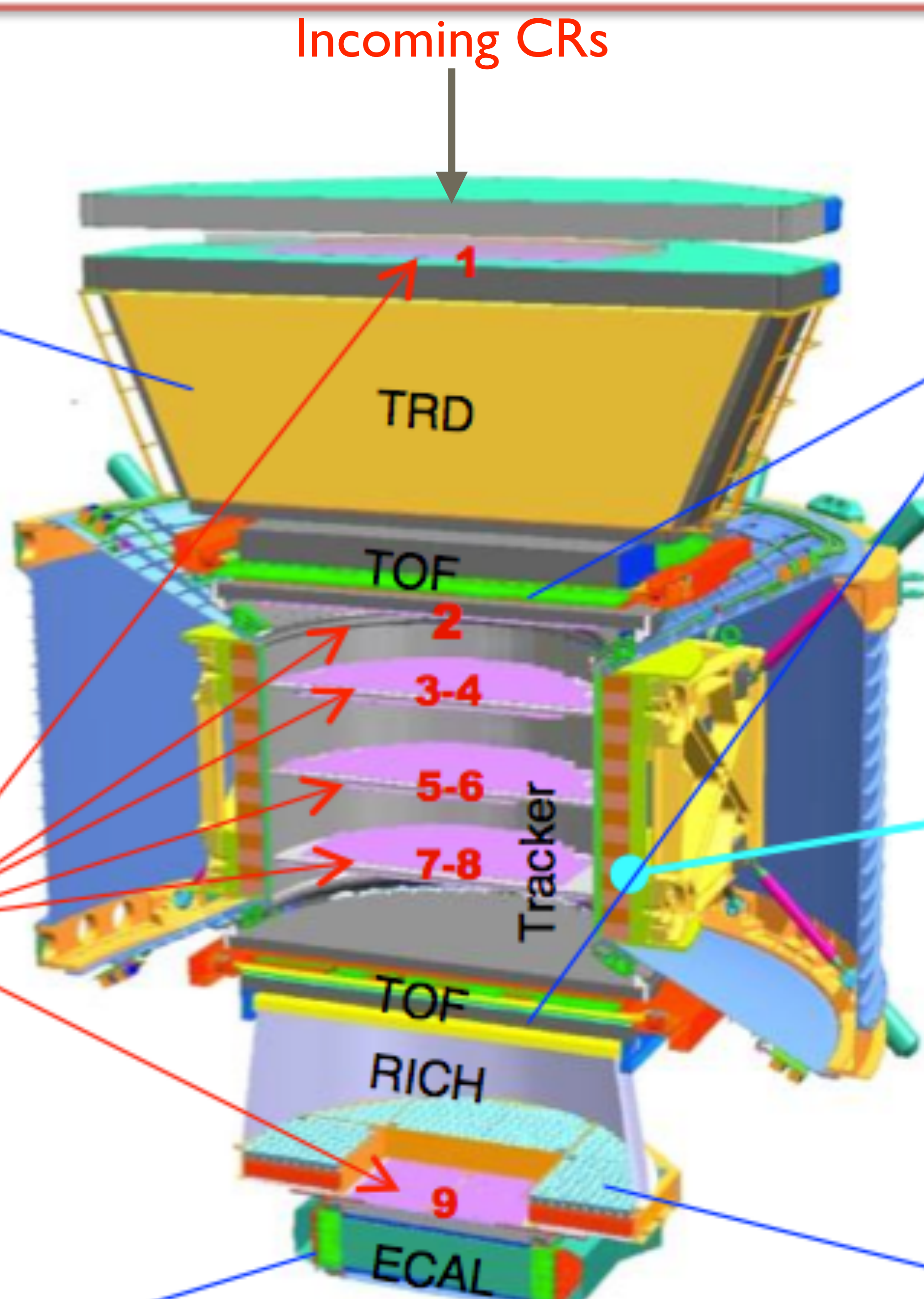
Transition Radiation Detector
Electron/proton, Z



Silicon Tracker
Z, P

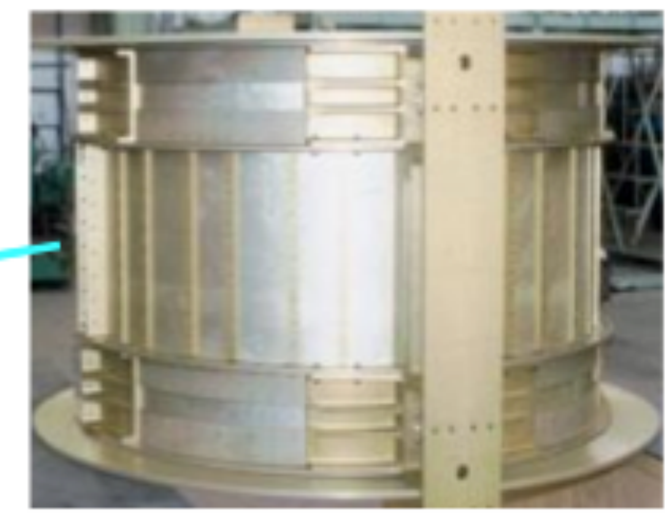


Electromagnetic Calorimeter
E of electrons

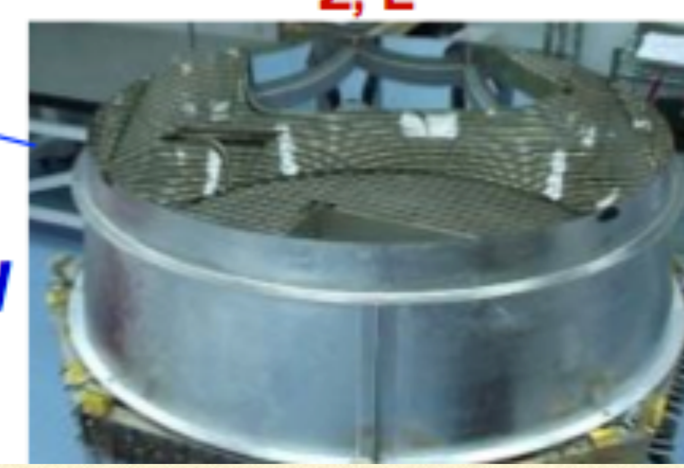


Time of Flight
Z, E

Magnet
±Z



Ring Imaging Cherenkov
Z, E

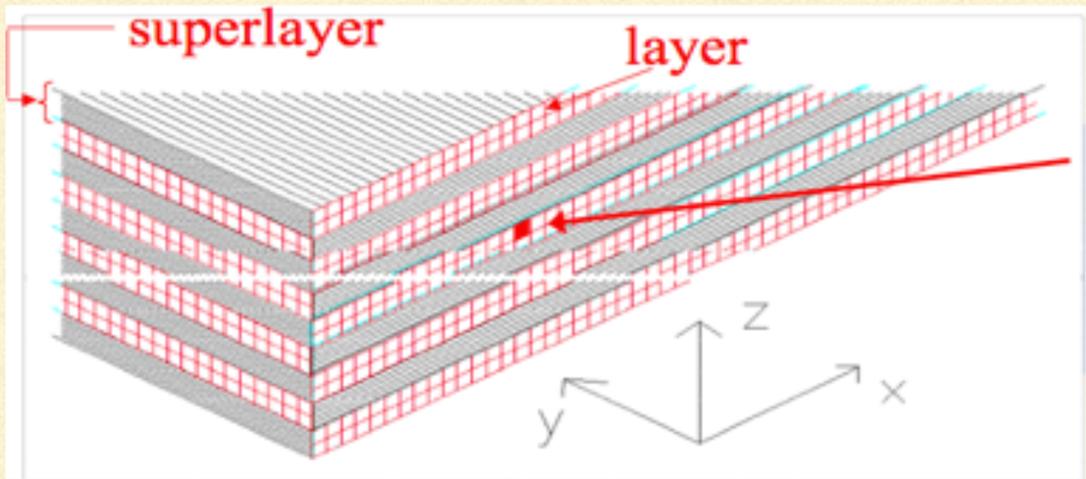


The Charge and Energy are measured independently by several detectors

ENERGY MEASUREMENT

The AMS-02 electromagnetic calorimeter:

a 3-D sampling calorimeter made out of lead and scintillating fibers

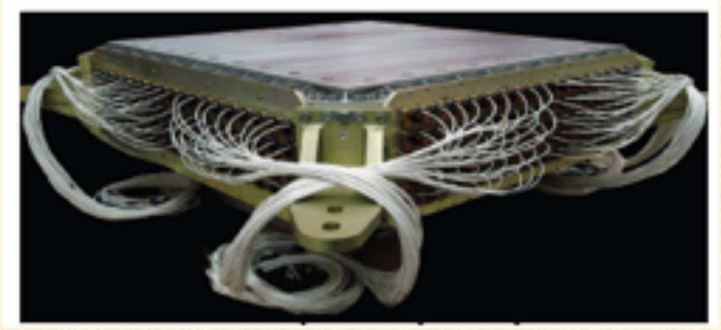


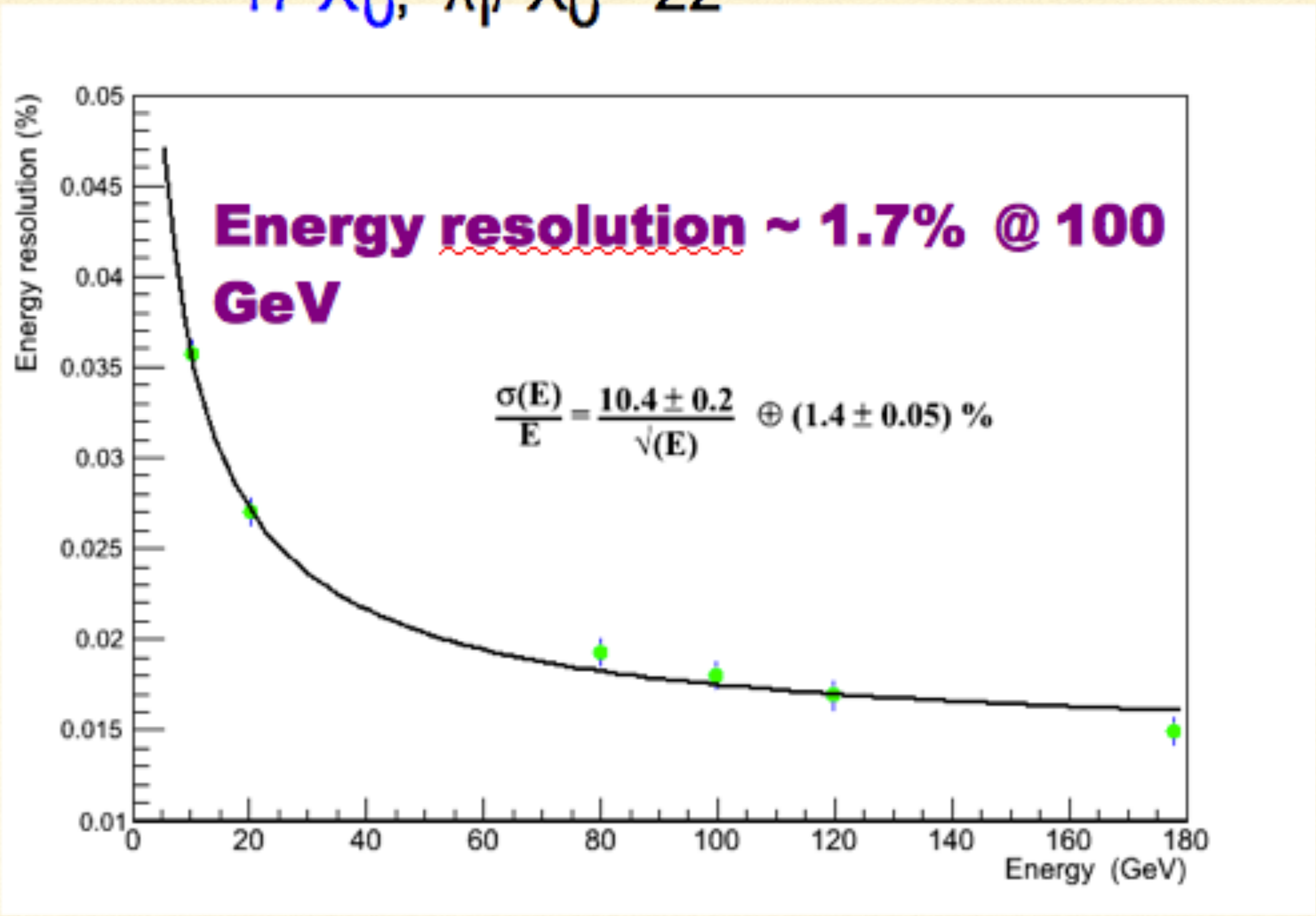
High granularity: ~ 0.9 x 0.9 cm

18 Longitudinal samplings

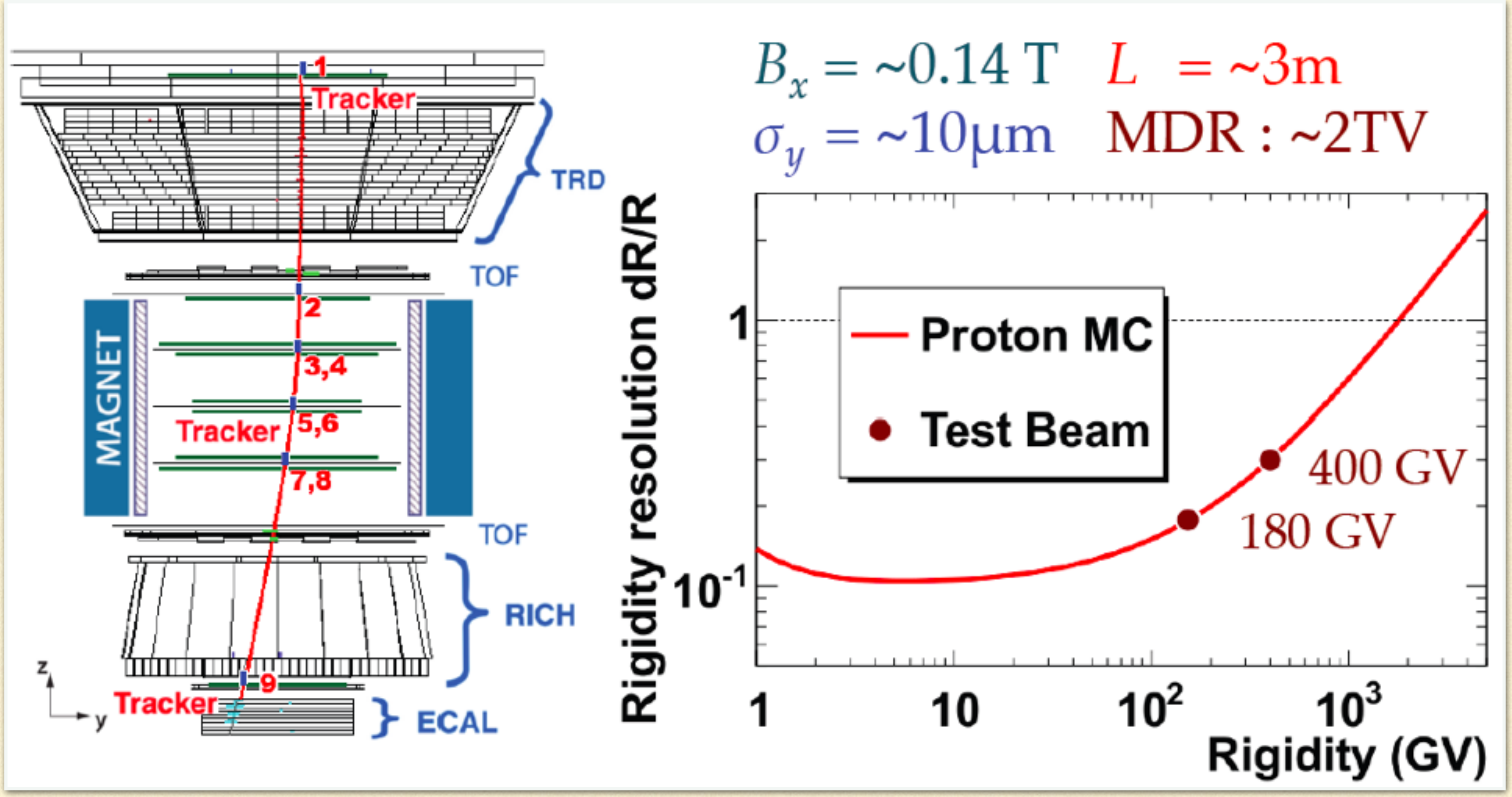
72 Lateral samplings

17 X_0, $\lambda_I / X_0 \sim 22$

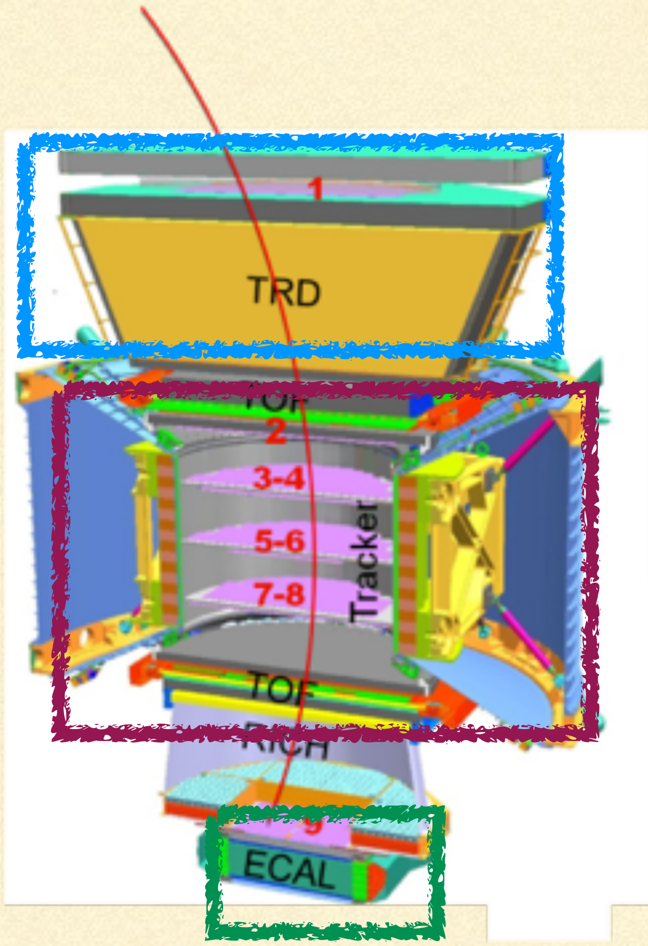


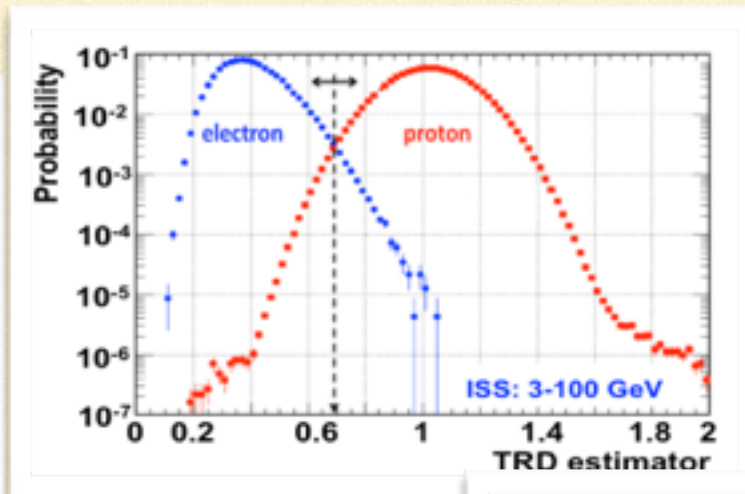


MOMENTUM MEASUREMENT

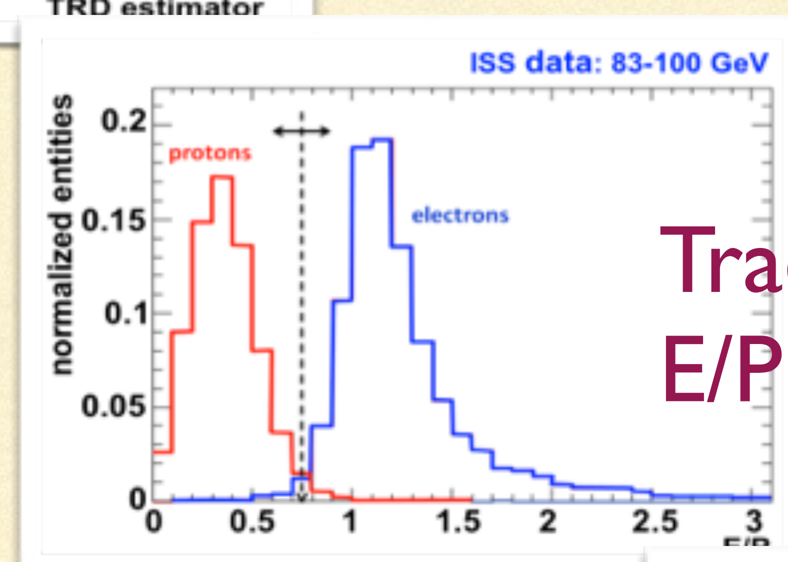


LEPTONS IDENTIFICATION





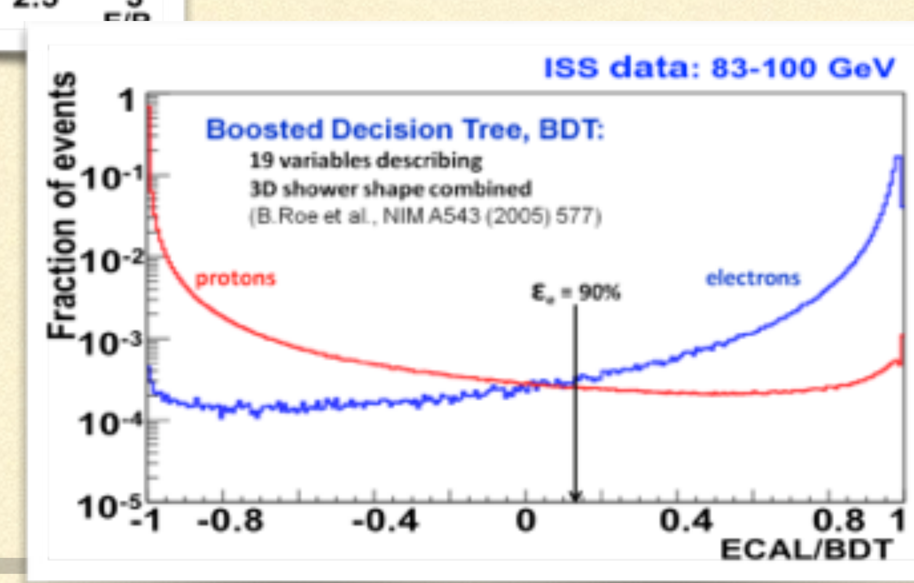
Transition Radiation Detector



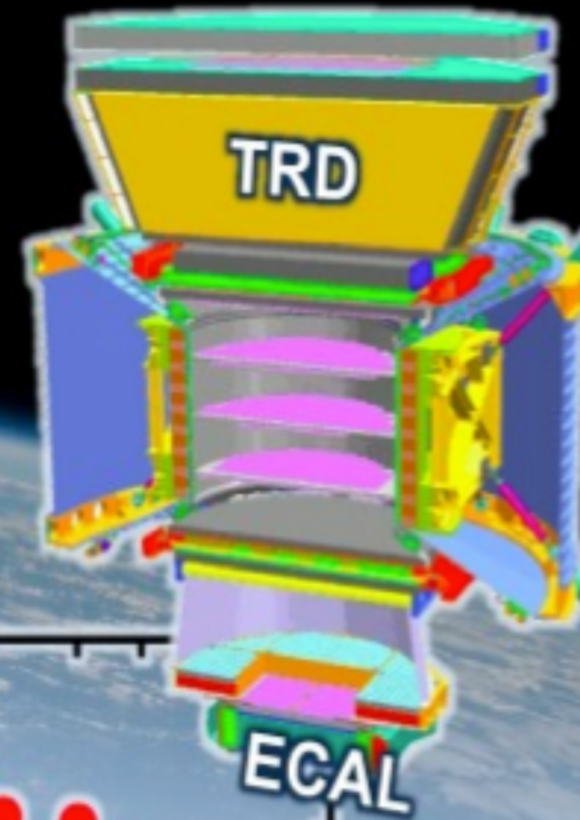
Tracker:
E/P ~ 1 for e^+ and e^-

Acc(p) ~ 0.5 m^2sr
Acc(e) ~ 0.04 m^2sr

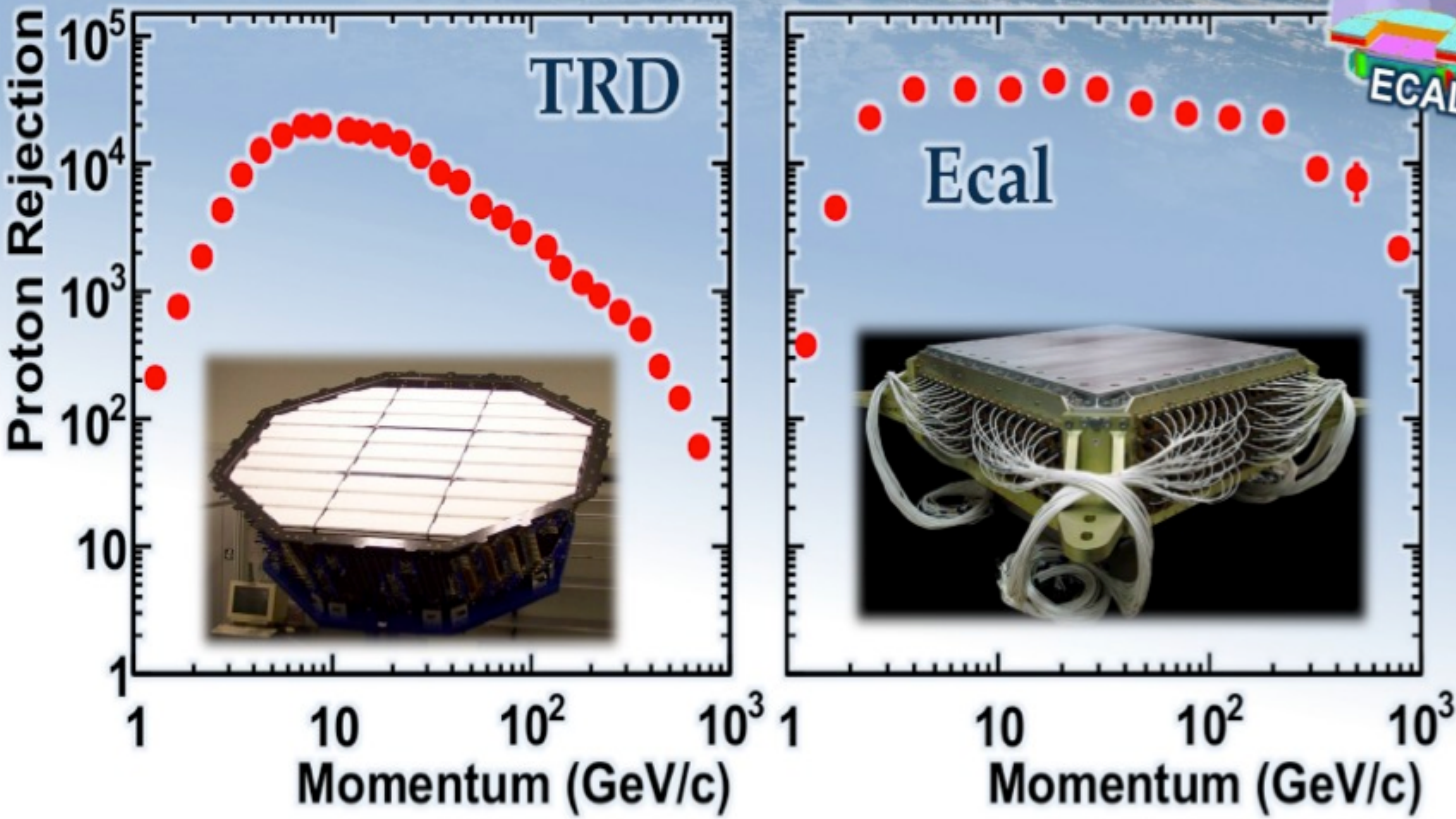
ECAL estimator: based on shower shape



Proton rejection



With 90 % e^+ efficiency



The positron fraction measurement

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

Energy range from 0.5 to 500 GeV based on 10.9 million positron and electron events.

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

THE POSITRON FRACTION

Defined as : $$F = \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} = \frac{N_{e^+}}{N_{e^+} + N_{e^-}}$$

- Acceptance and efficiencies simplify in the ratio
- A ratio of number of counts

Challenge :

- **Proton rejection of the order of 10^6 is required**

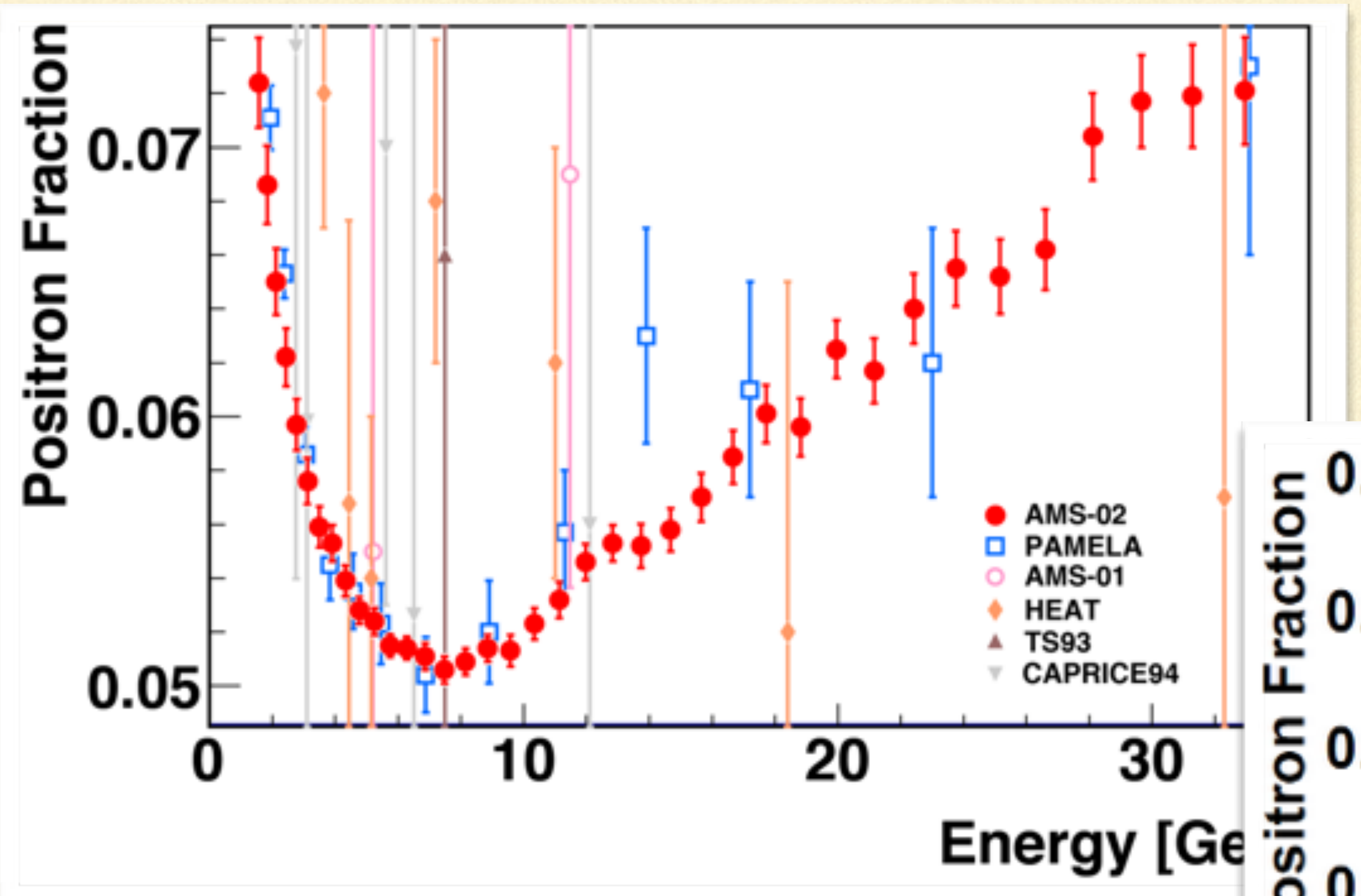
What we do expect :

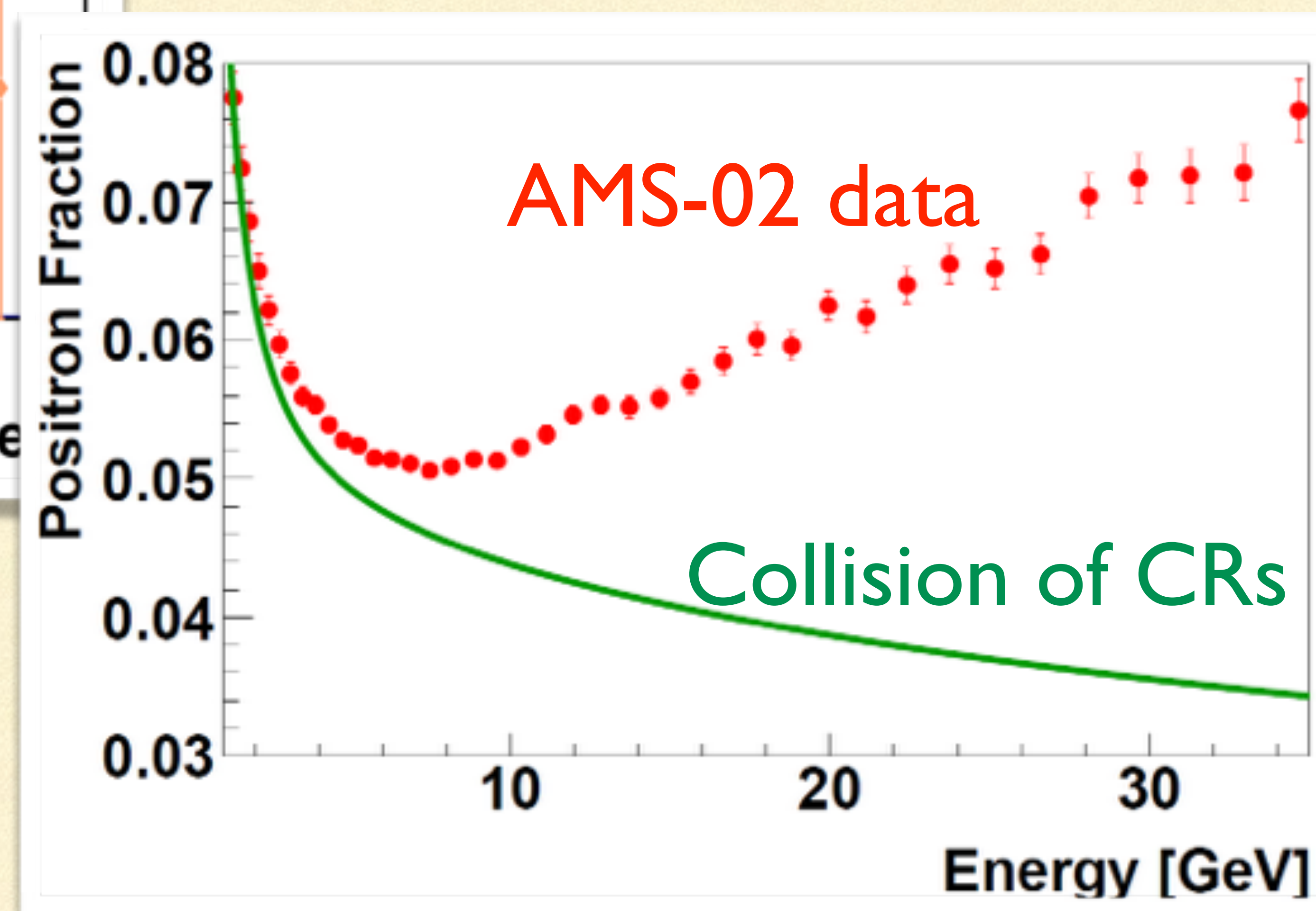
- Positrons are secondaries, produced in protons interactions with the Interstellar medium.

- **If positrons are ONLY secondaries, the positron fraction is expected to decrease with energy.**

LOW ENERGY POSITRON FRACTION

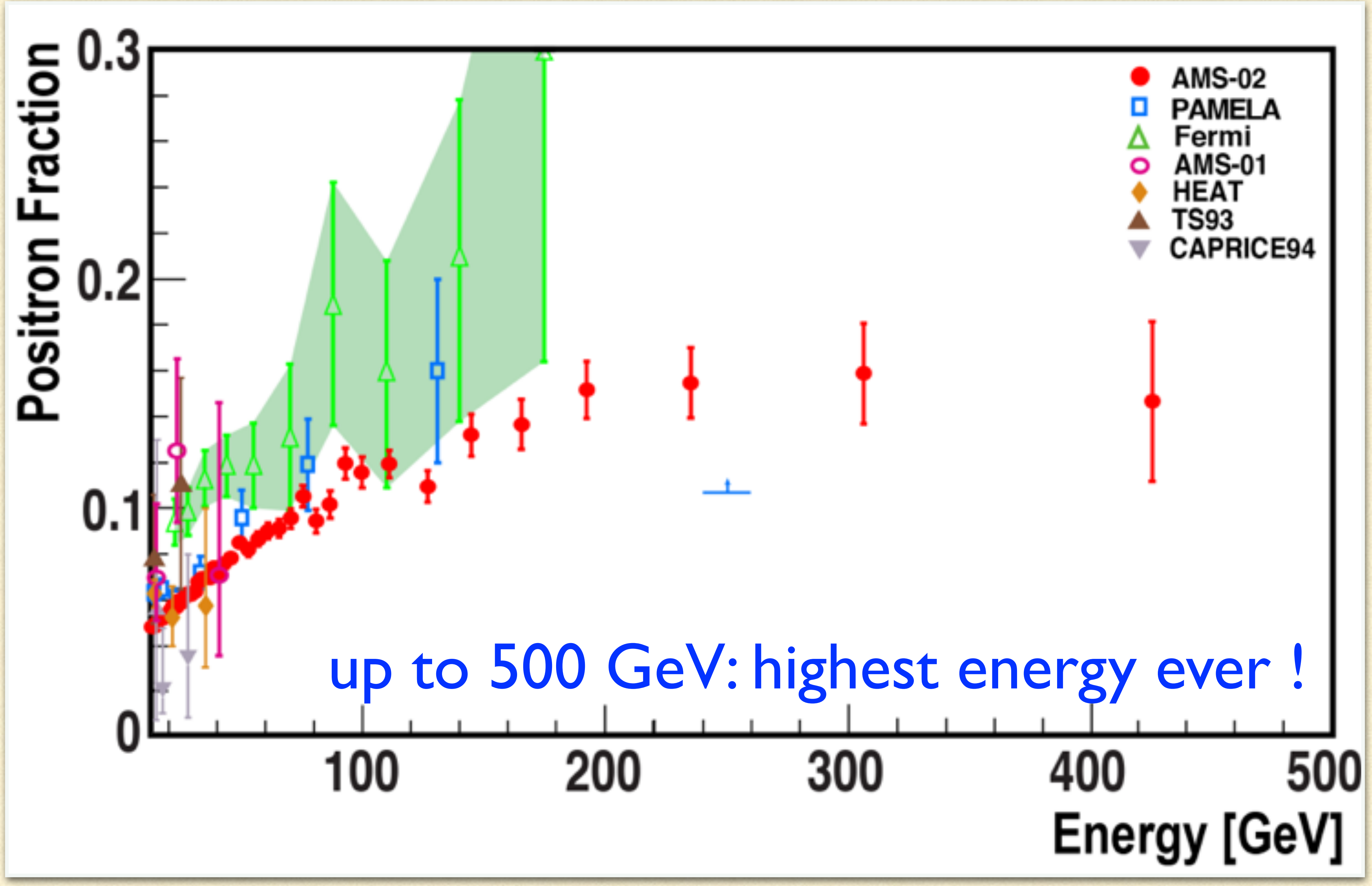
Fraction begins to increase above 10 GeV





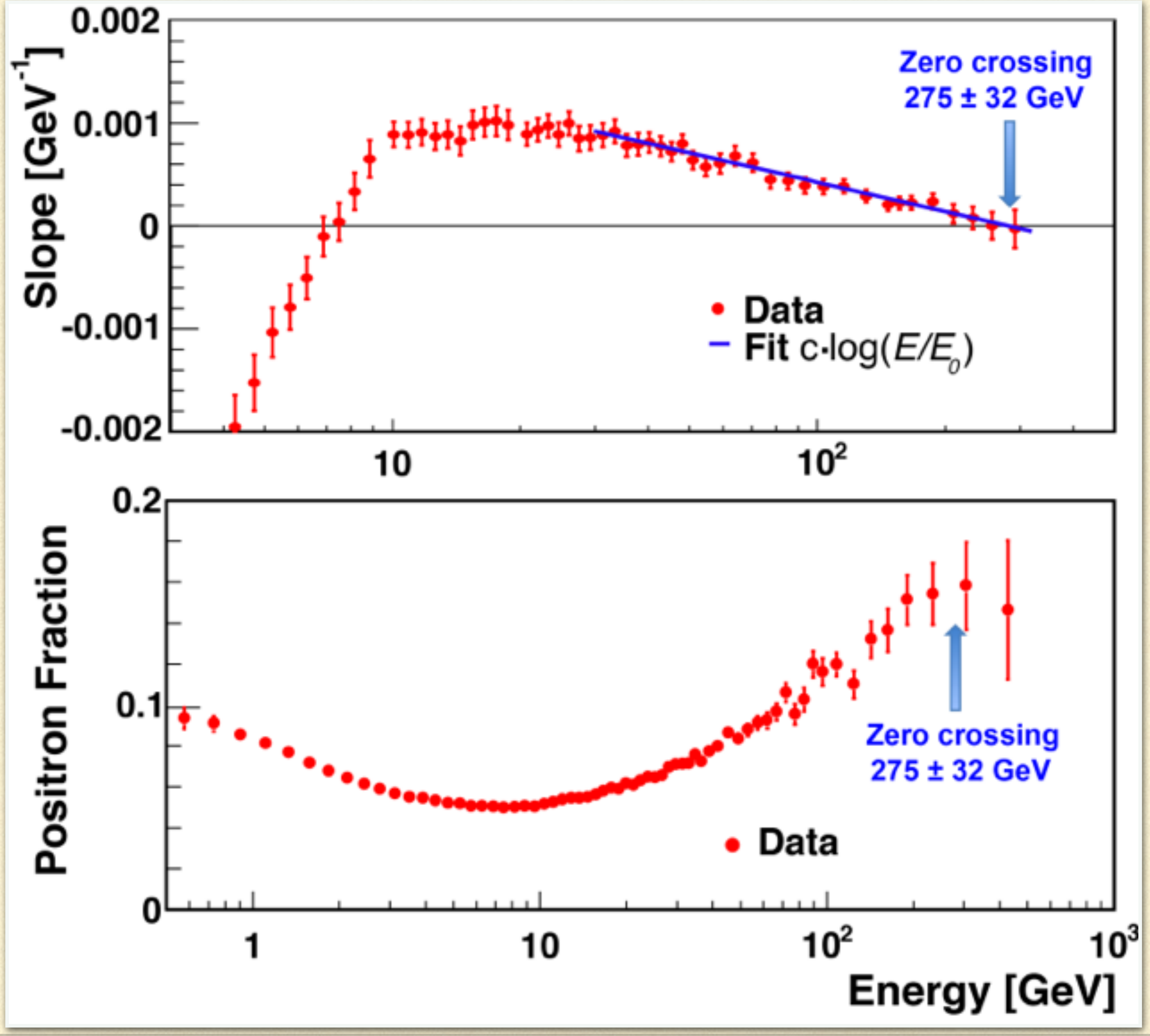
Incompatible with
pure secondary hypothesis

POSITRON FRACTION IN 2014



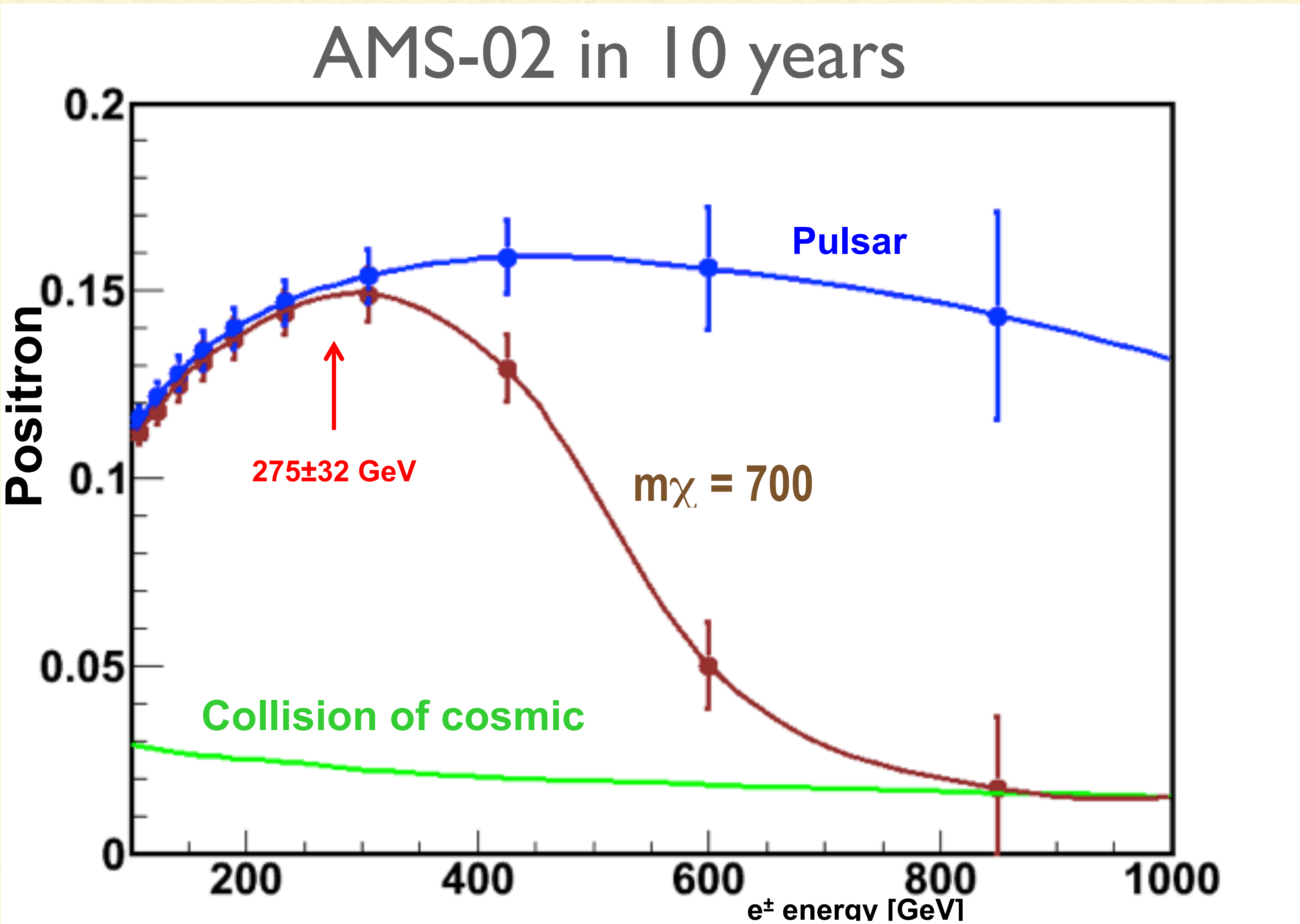
- No sharp structure
- With the current sensitivity, the flux is isotropic

THE POSITRON FRACTION SLOPE



EXPECTED SENSITIVITY

Current cosmic ray data suggest the existence of an unknown nearby source of positrons and electrons



In the near future, AMS will extend its energy range, and will be able to discriminate between the dark matter and pulsar hypothesis

ELECTRONS AND POSITRONS FLUXES

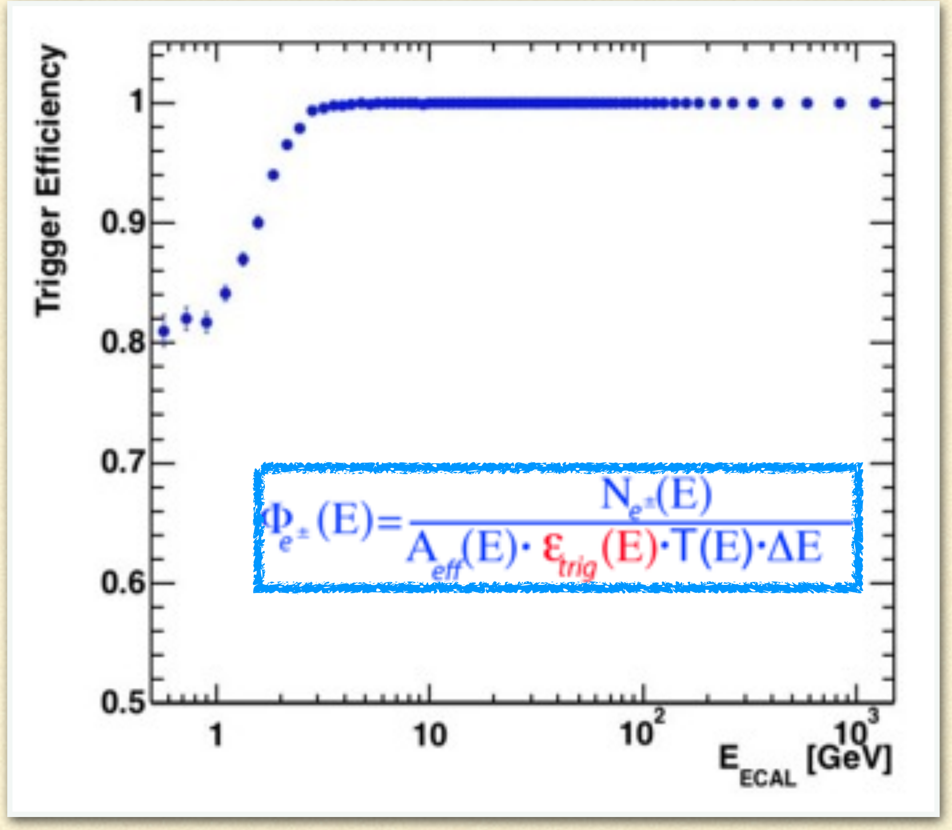
PHYSICAL REVIEW LETTERS

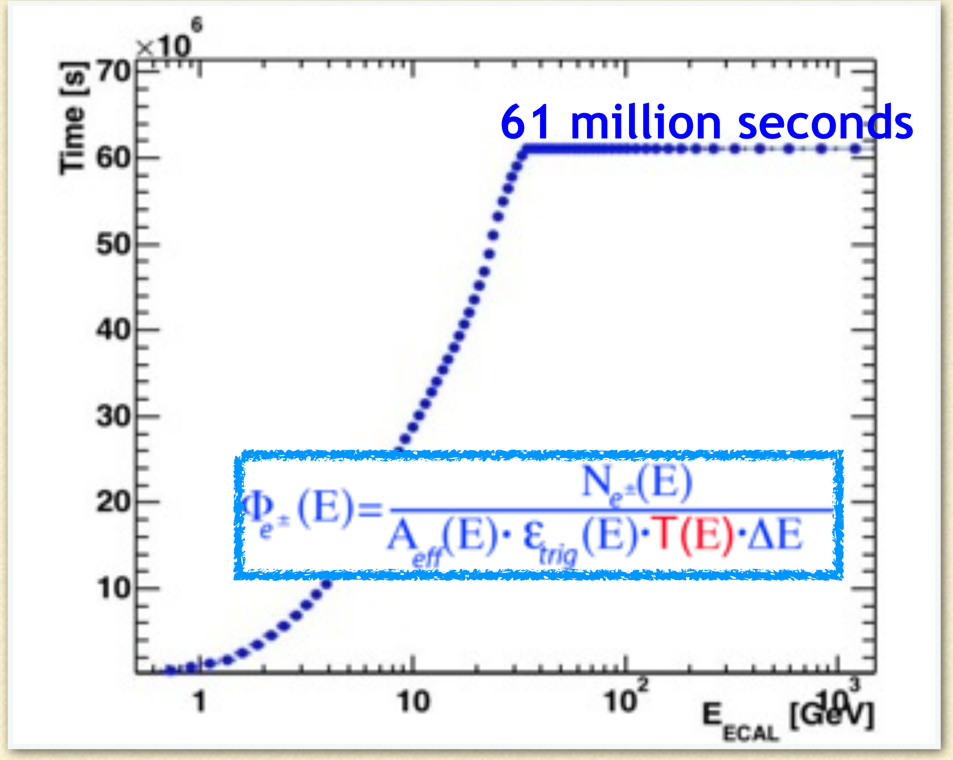
Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

THE FLUX MEASUREMENT

$$\Phi_{e^\pm}(E)=\frac{N_{e^\pm}(E)}{A_{eff}(E)\cdot \varepsilon_{trig}(E)\cdot T(E)\cdot \Delta E}$$

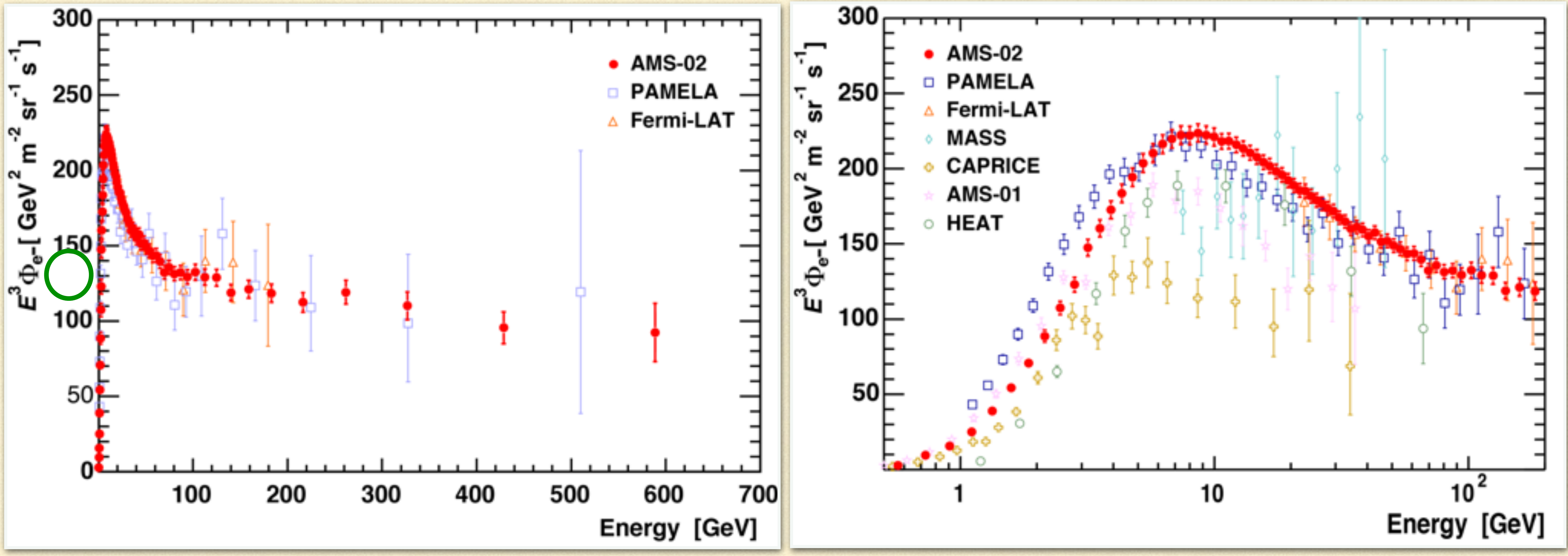
- **$N_{e\pm}$** is the number of signal events
- **ε_{trig}** is the trigger efficiency
- **T** is the exposure time
- **A_{eff}** is the effective acceptance





ELECTRON FLUX

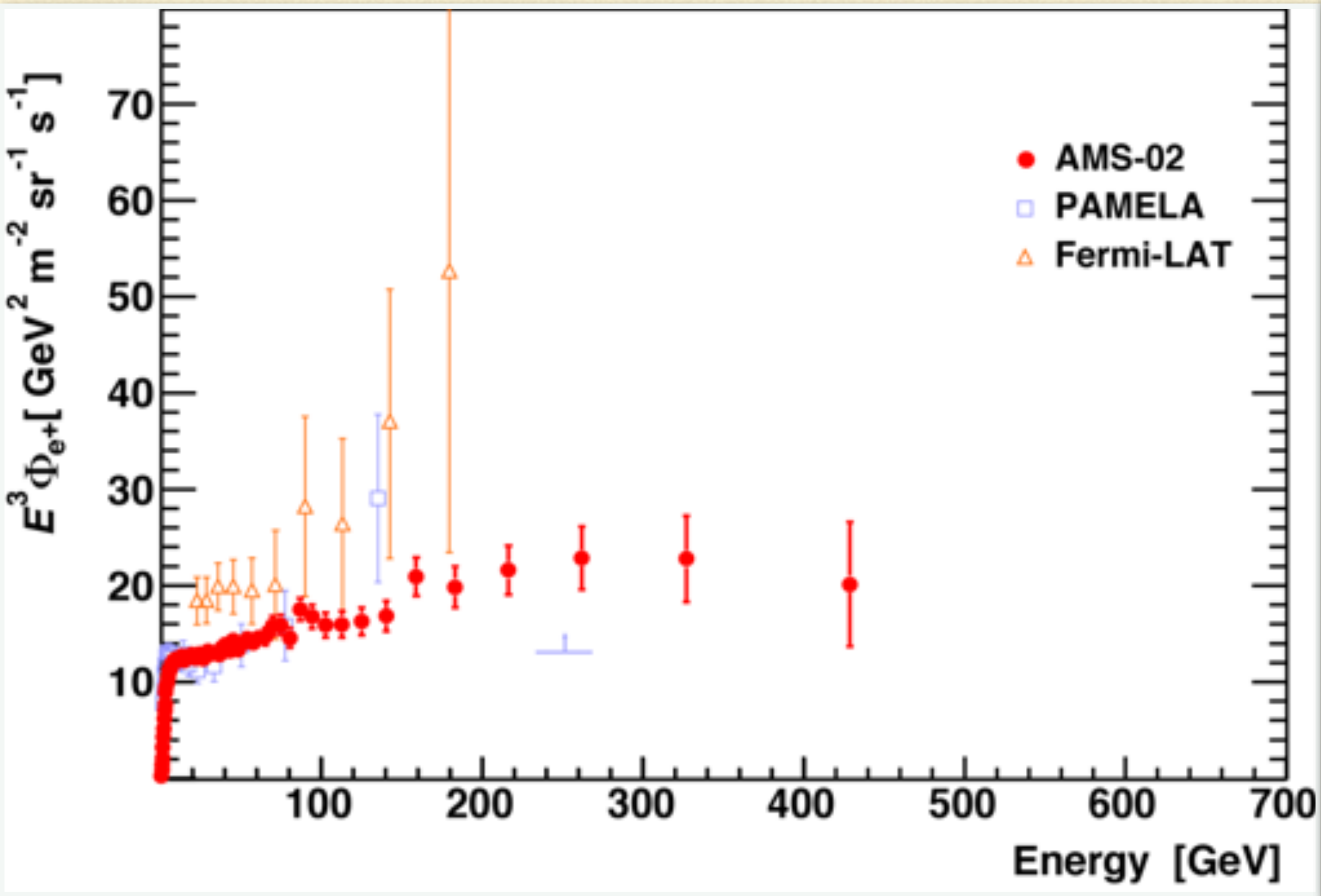
Rescaled by E^3

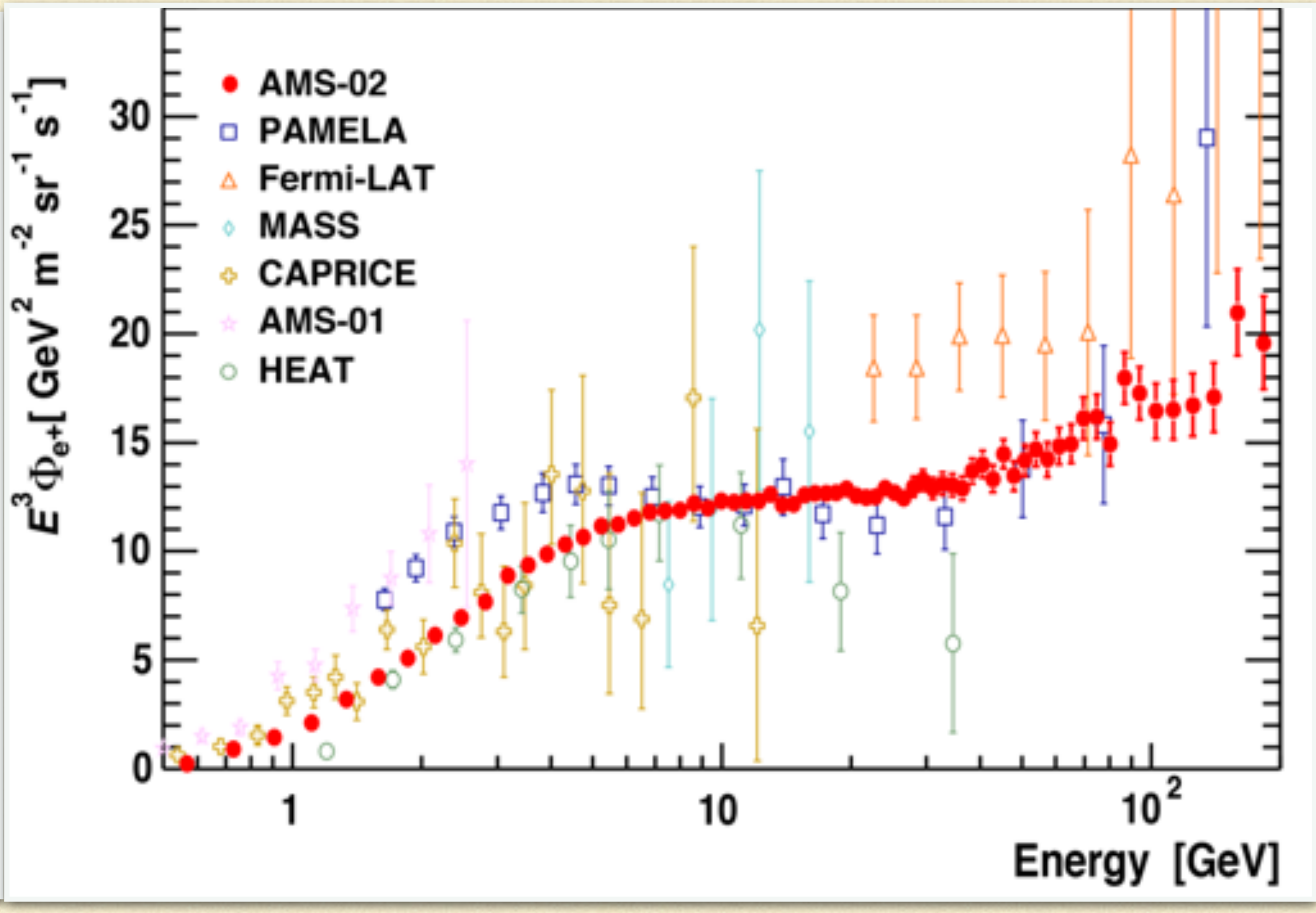


Above > 10 GeV: spectral index > 3

POSITRON FLUX

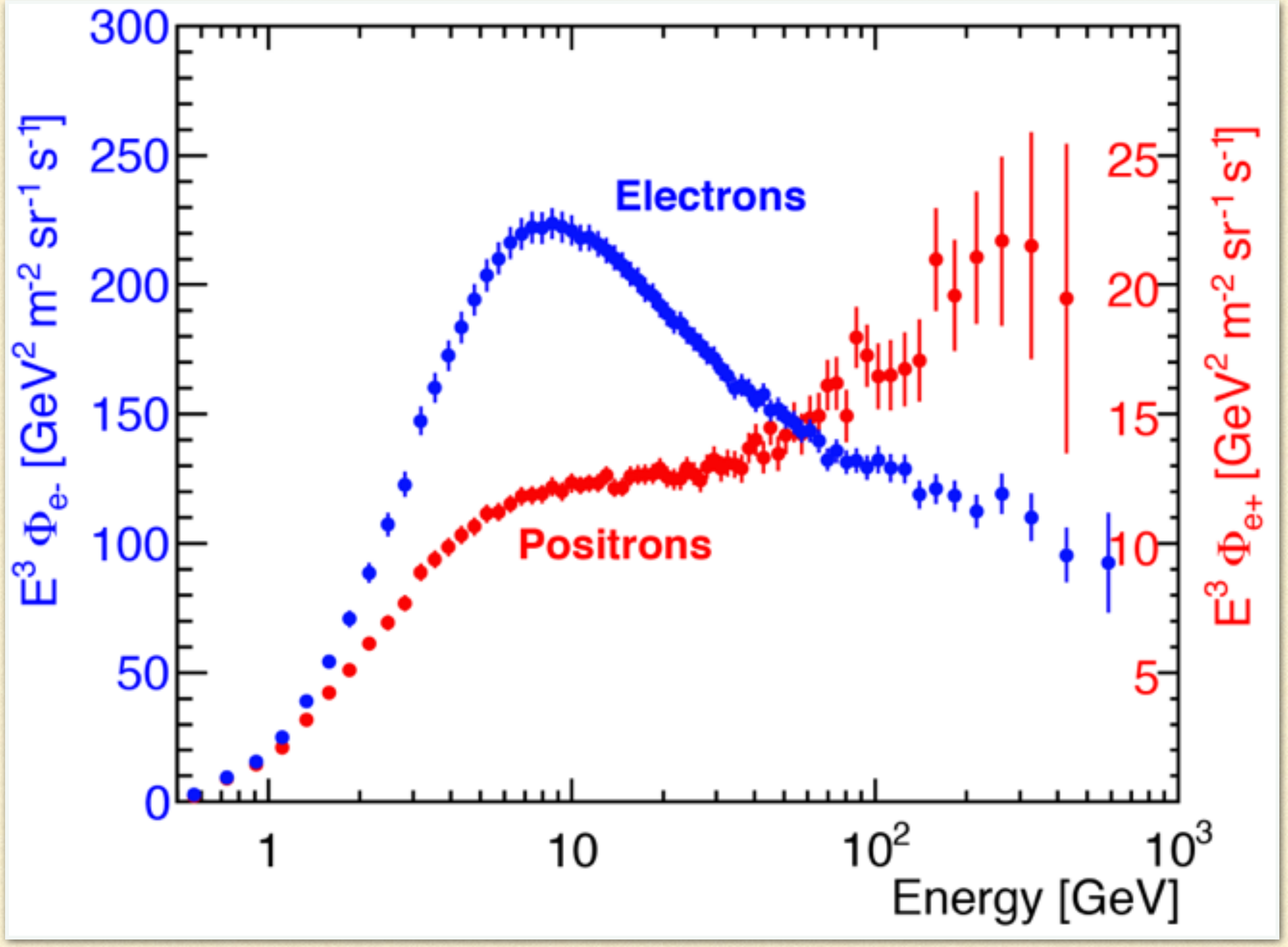
Rescaled by E^3





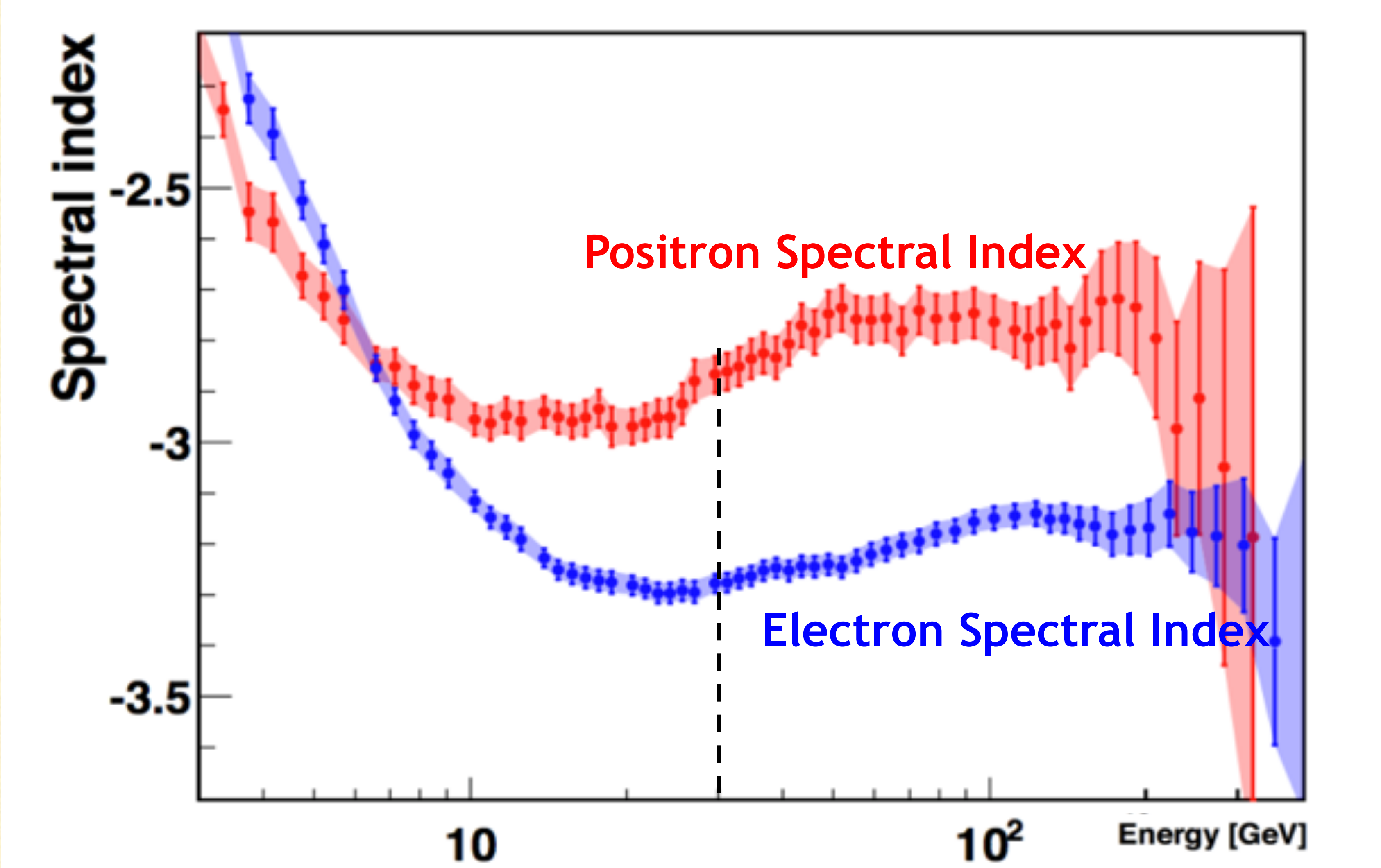
- Raising up to 10 GeV
- flat up to 30 GeV, then raising again

ELECTRONS AND POSITRONS COMPARED



The electron flux and the positron flux are different in their magnitude and energy dependence.

SPECTRAL INDEX



- The spectral indices of electrons and positrons are different
- Both spectra cannot be described by single power laws
- Change of behavior at ~30GeV

The rise in the positron fraction is actually due to an excess of positrons, not the loss of electrons (the positron flux is harder).

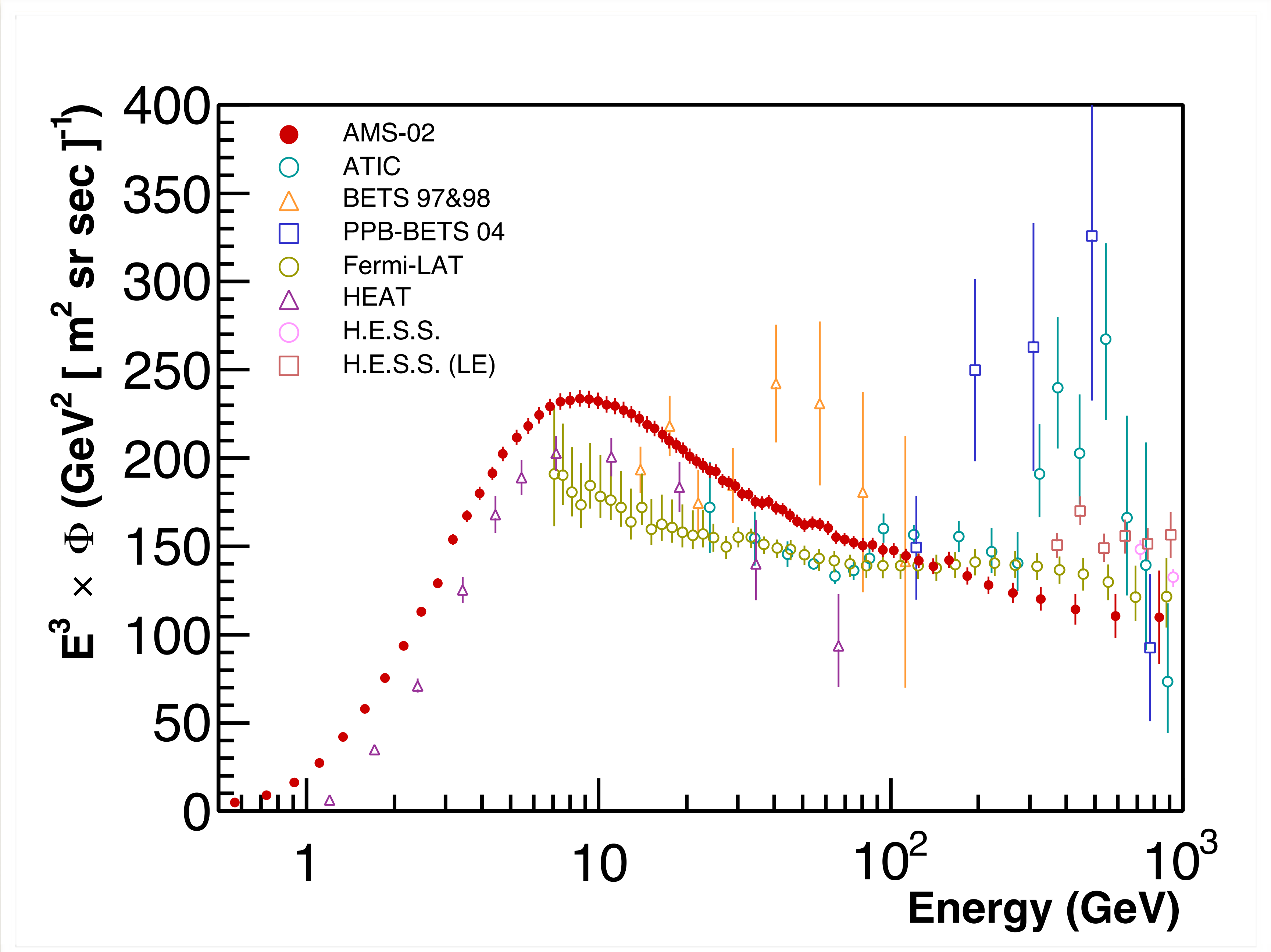
COMBINED FLUX

PRL **113**, 221102 (2014) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2014

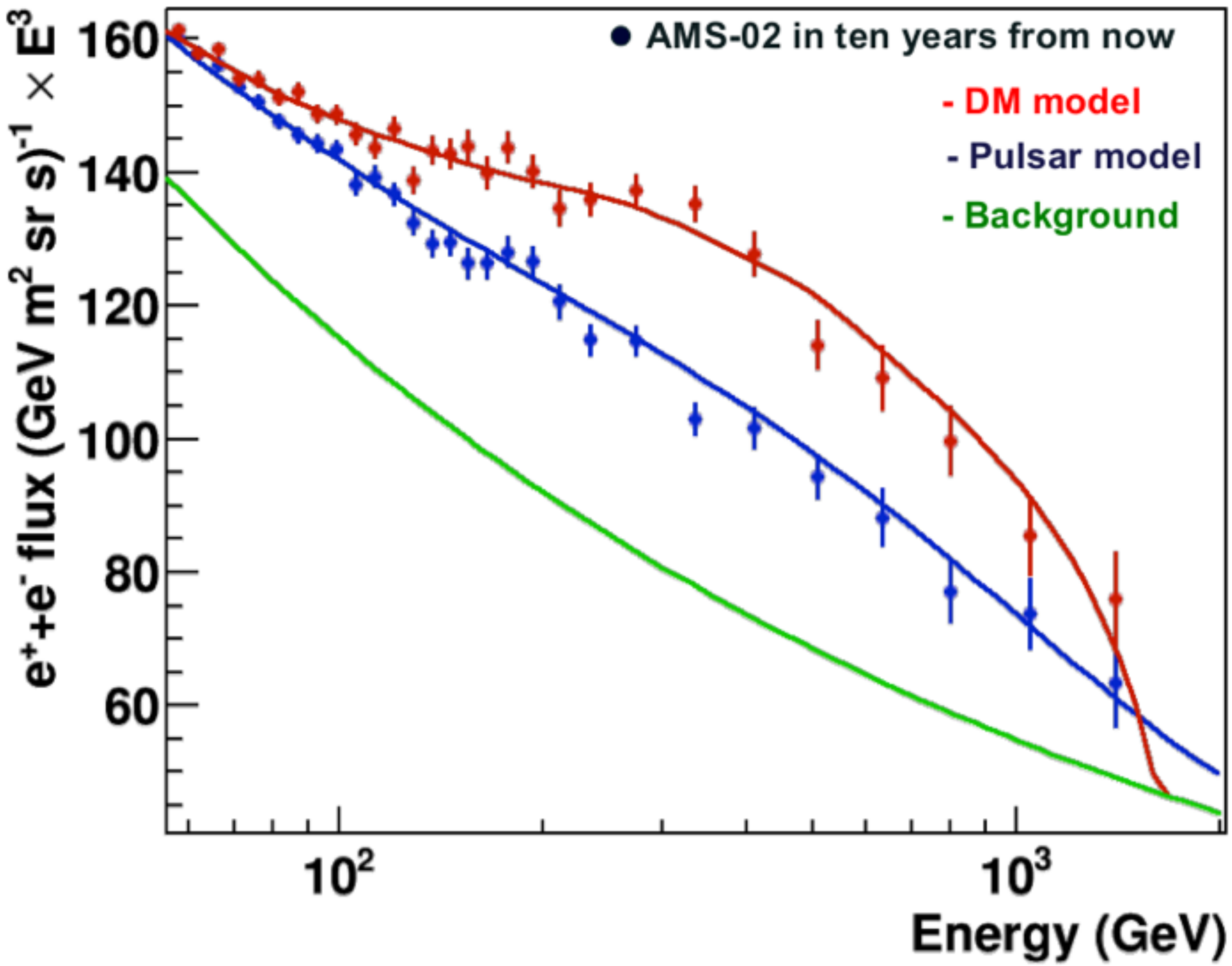
Precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station

COMBINED FLUX

- TRD and ECAL are the key detectors in the $(e^+ + e^-)$ measurement
- Independent of charge sign measurement (no charge confusion)
- High selection efficiency : 70% @ 1TeV



AMS data and phenomenological models: what can we say in 10 years from now?"



MINIMAL MODEL TO FIT AMS DATA

$$\Phi_{e^+} = \underbrace{C_{e^+} E^{-\gamma_{e^+}}}_{\text{Diffuse Term}} + \underbrace{C_s E^{-\gamma_s} e^{-E/E_s}}_{\text{Source Term}}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Positrons:

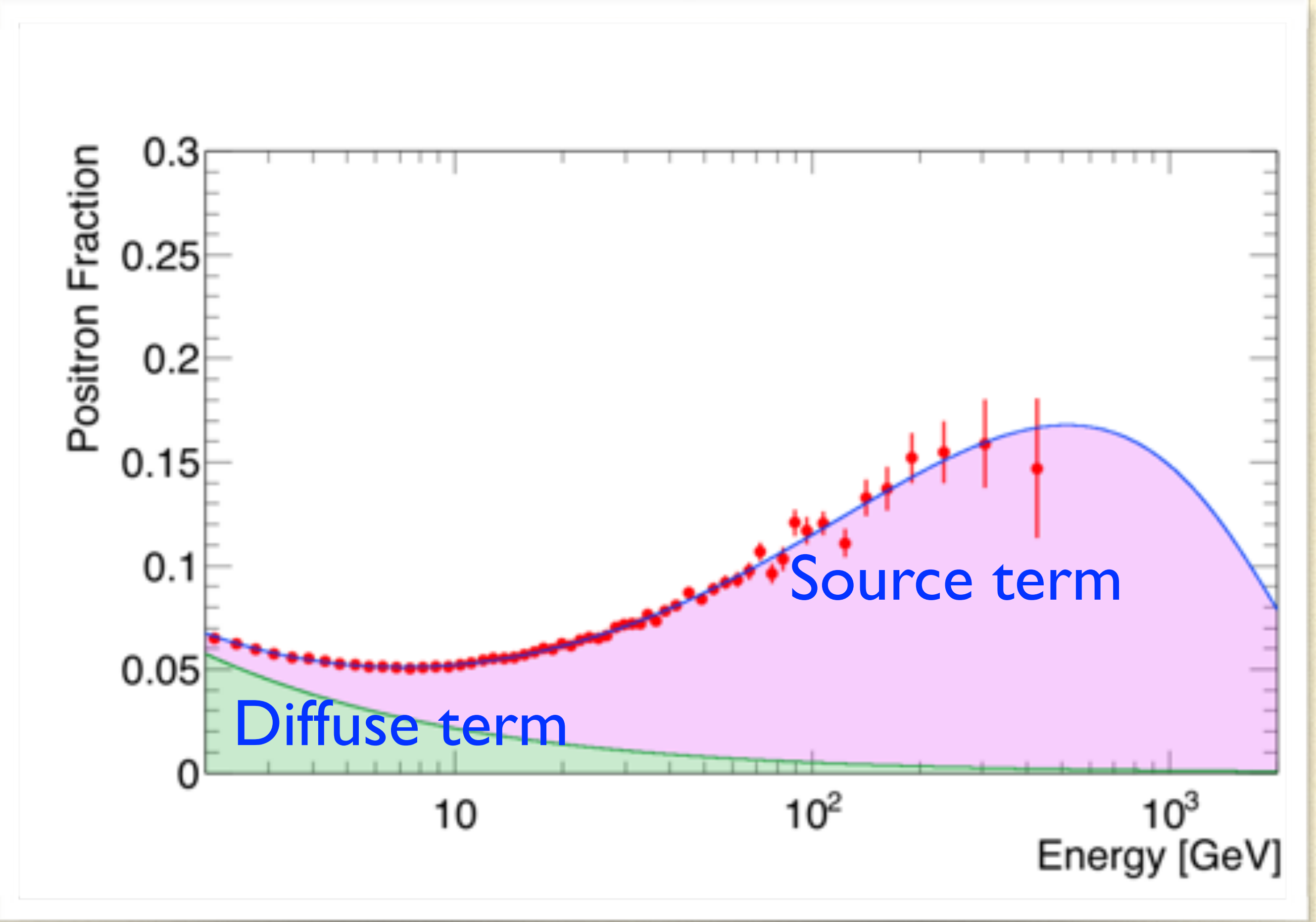
- Diffuse term: secondary production
- Source term

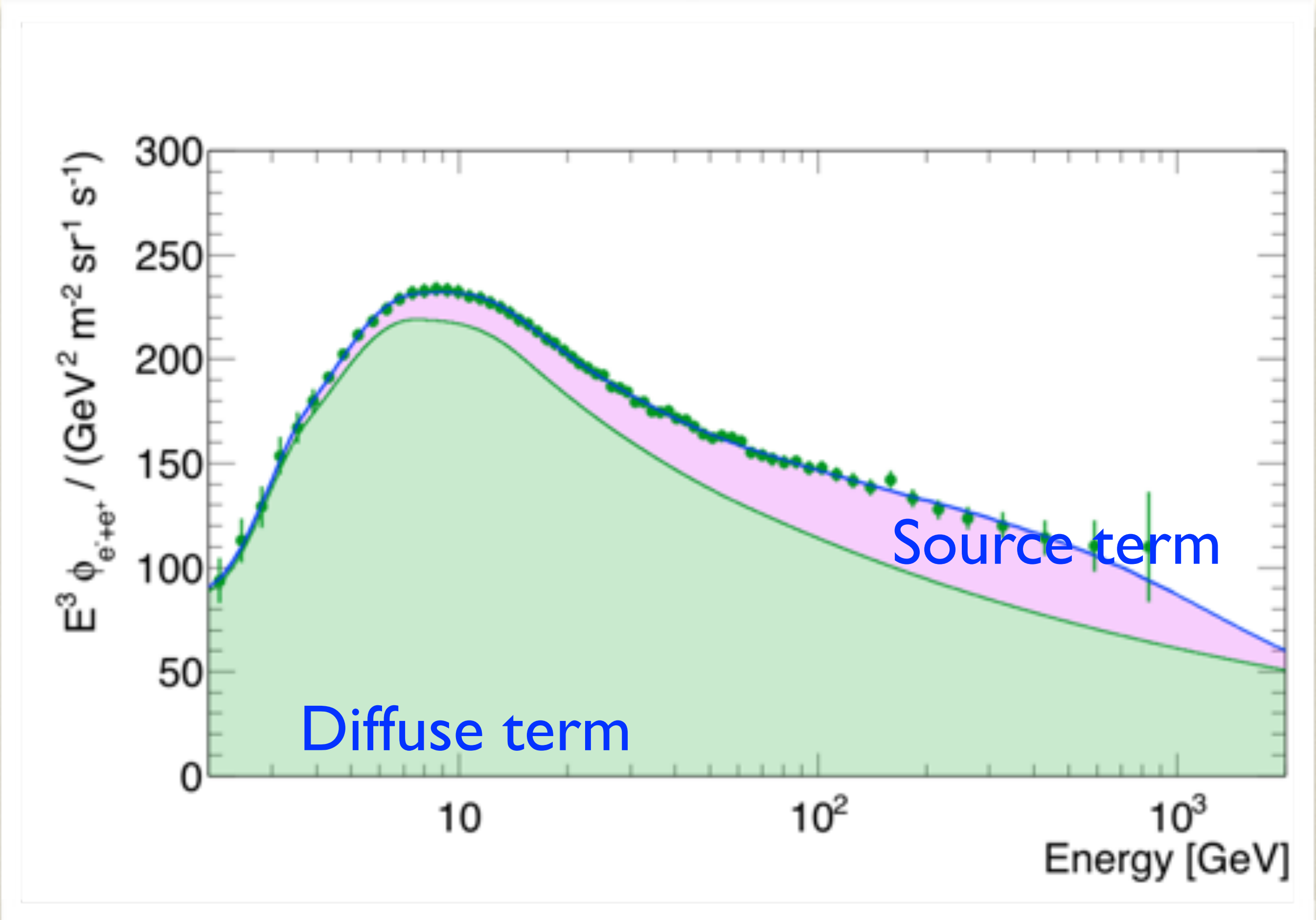
+

Electrons:

- Diffuse term: Primary and secondary production
- Source term

RESULTS FROM THE FIT





- Simultaneous fit to
  - Positron fraction from 2 GeV
  - Combined flux from 2 GeV
- Fits are satisfactory: data can be described by a common source of e^+ and e^-

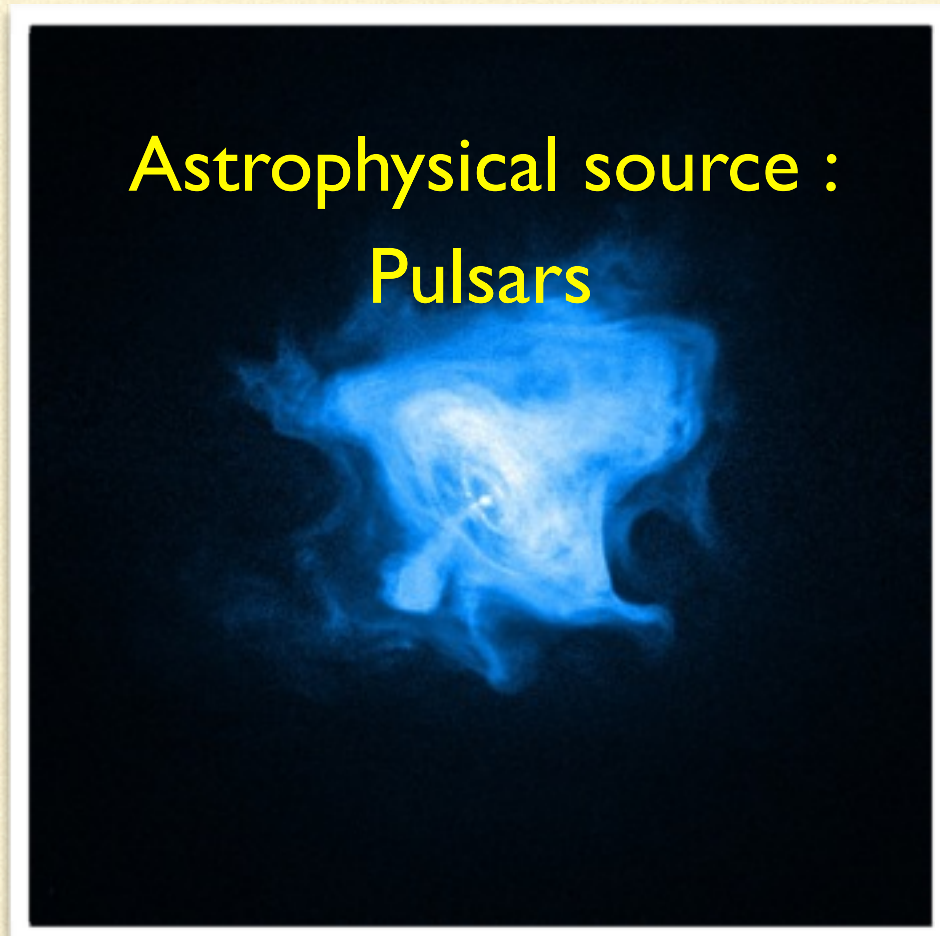
SUMMARY ABOUT AMS-02 RESULTS

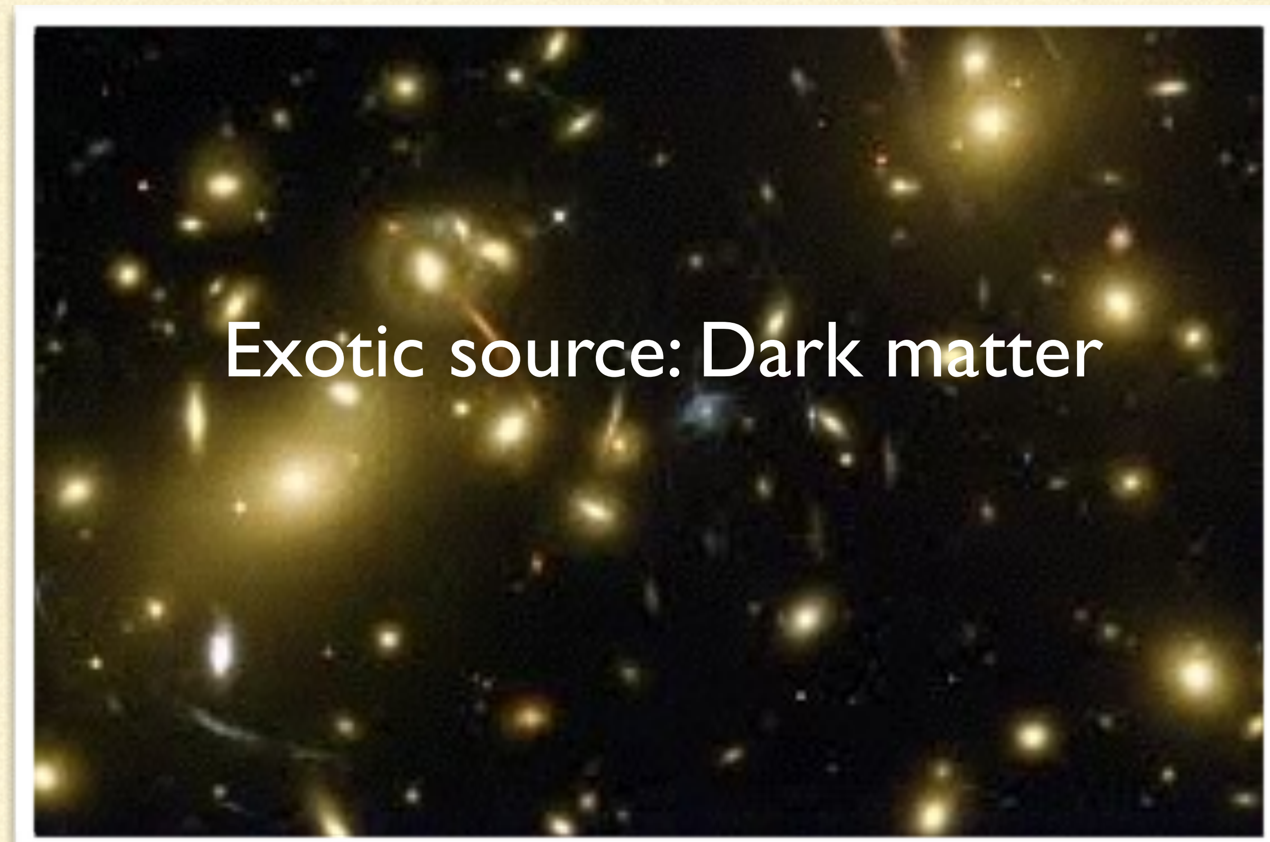
- The AMS-02 experiment operates onboard the ISS since May 2011
  - All the detectors are working as expected
  - More than 54 billions events were recorded so far. This is much more than all the cosmic rays collected in the last 100 years.
- The AMS-02 Collaboration has published cosmic rays electrons and positron fuxes of *unprecedented quality and precision.*

- AMS-02 is expected to collect data at least until 2024
- Many important measurements are yet to come:
  - Protons, helium, antiproton, B/C, heavier nuclei, ….

A NEW LOOK AT THE POSITRON FRACTION

Current cosmic ray data suggest the existence of
an unknown nearby source of positrons and electrons





These hypotheses are probed in light of the latest AMS-02 positron fraction measurements.

A new look at the cosmic ray positron fraction

M. Boudaud[1], S. Aupetit[1], S. Caroff[2], A. Putze[1,2], G. Belanger[1], Y. Genolini[1], C. Goy[2], V. Poireau[2], V. Poulin[1], S. Rosier[2], P. Salati[1], L. Tao[2], and M. Vecchi[2,3,*]

arXiv:1410.3799, submitted to A&A

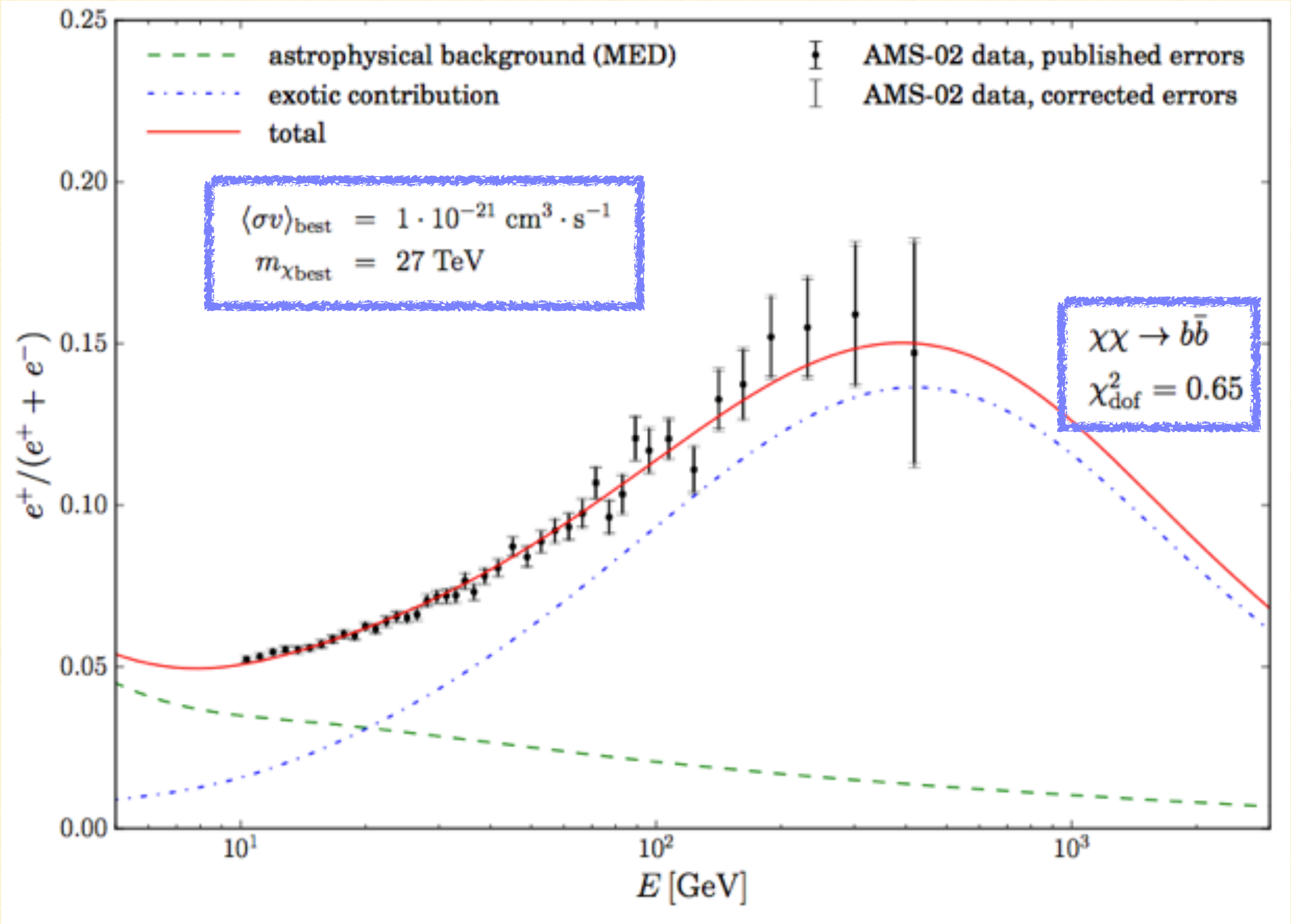
The authors are members of the
Cosmic Rays Alpine Collaboration

POSITRONS FROM DM ANNIHILATION

DM source term

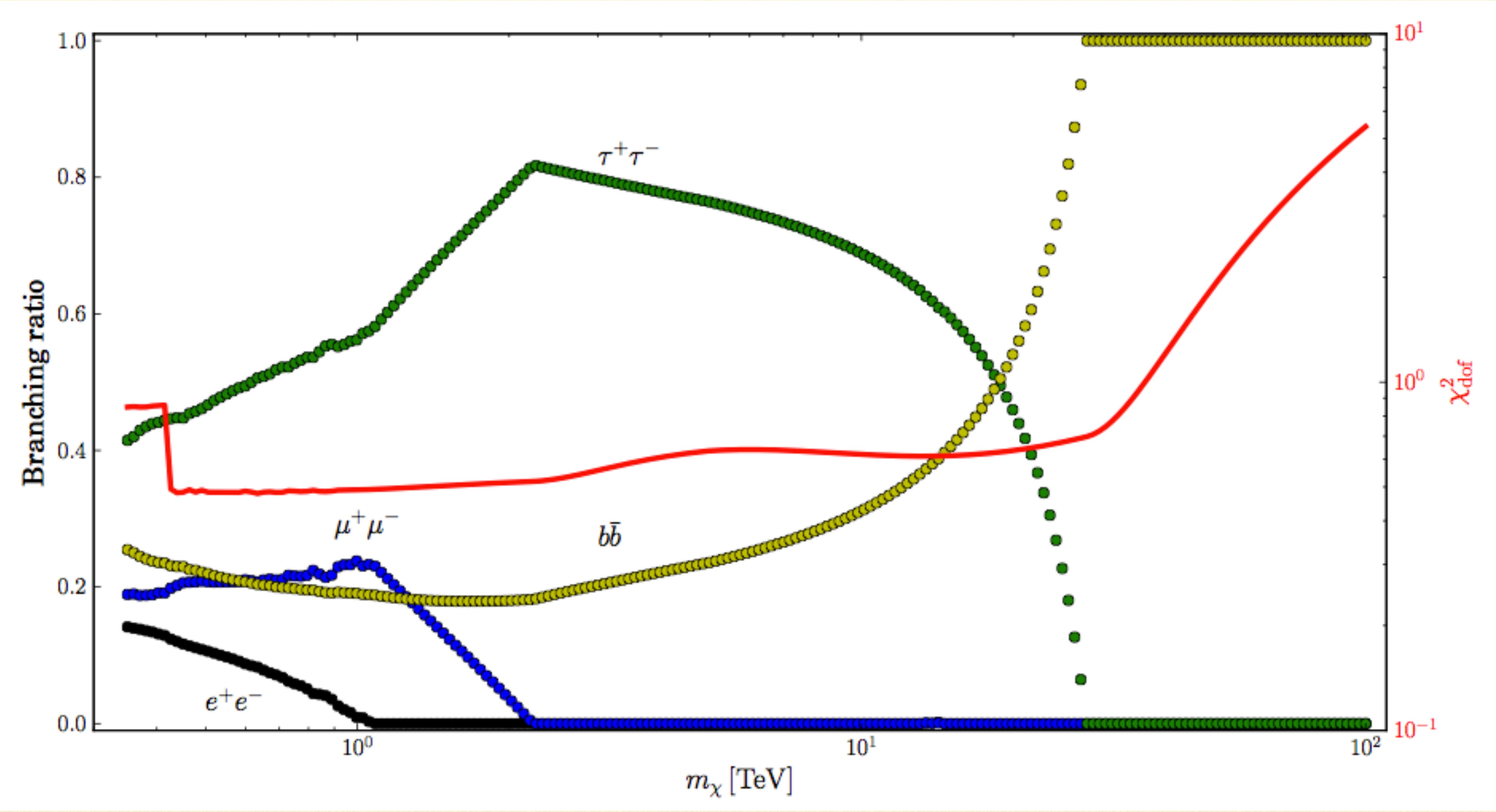
$$q_{e^+}^{\mathrm{DM}}(\mathbf{x}_S, E_S) = \frac{1}{2}\langle\sigma v\rangle \left\{\frac{\rho_\chi(\mathbf{x}_S)}{m_\chi}\right\}^2 \left\{g(E_S) \equiv \sum_i B_i \left.\frac{dN_{e^+}}{dE_S}\right|_i\right\}$$

AMS-02 data are used to set constraints on m_χ & $\langle\sigma v\rangle$



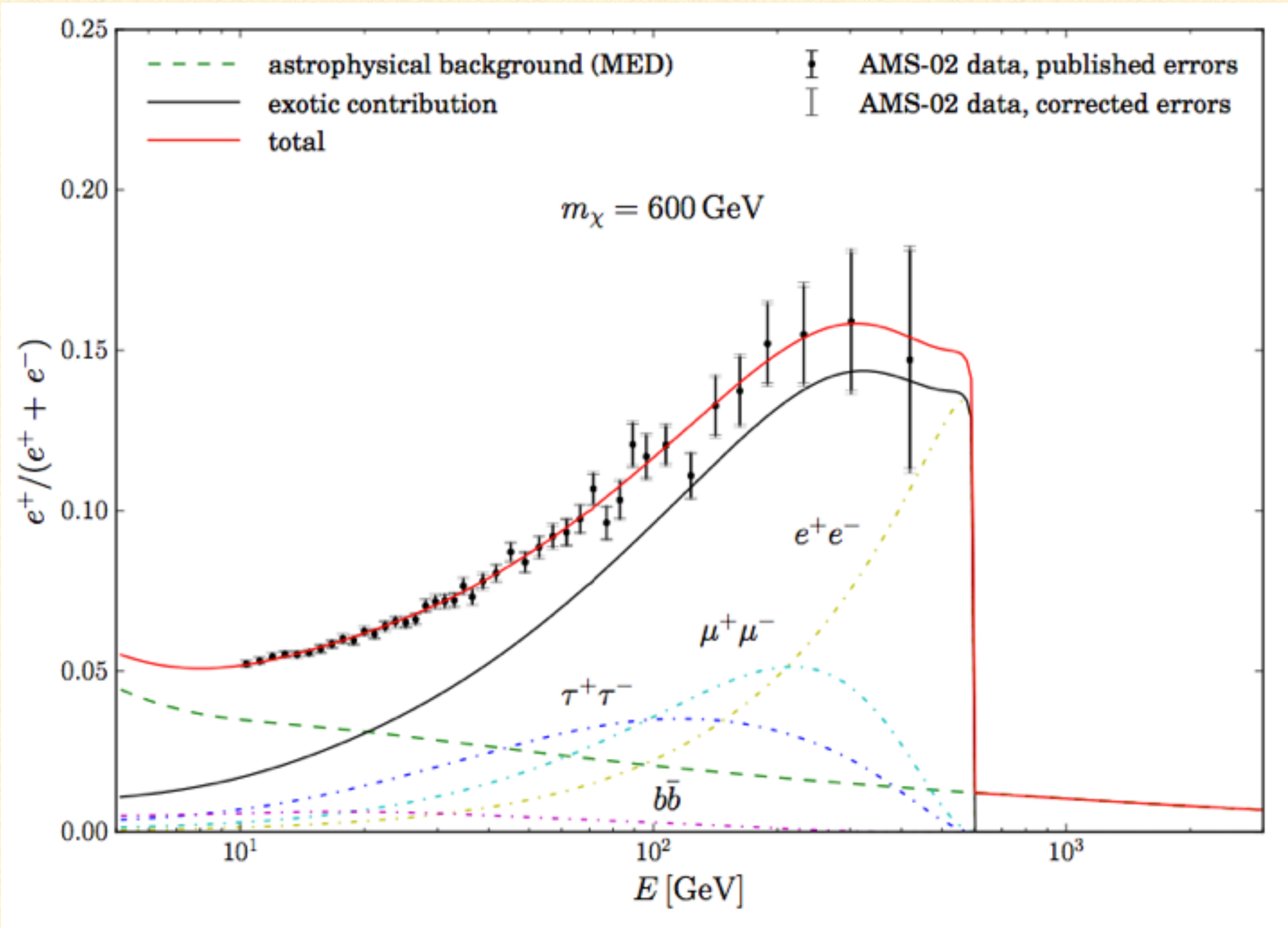
COMBINATION OF CHANNELS

Given a fixed value of m_{DM}, study of different combinations of channels



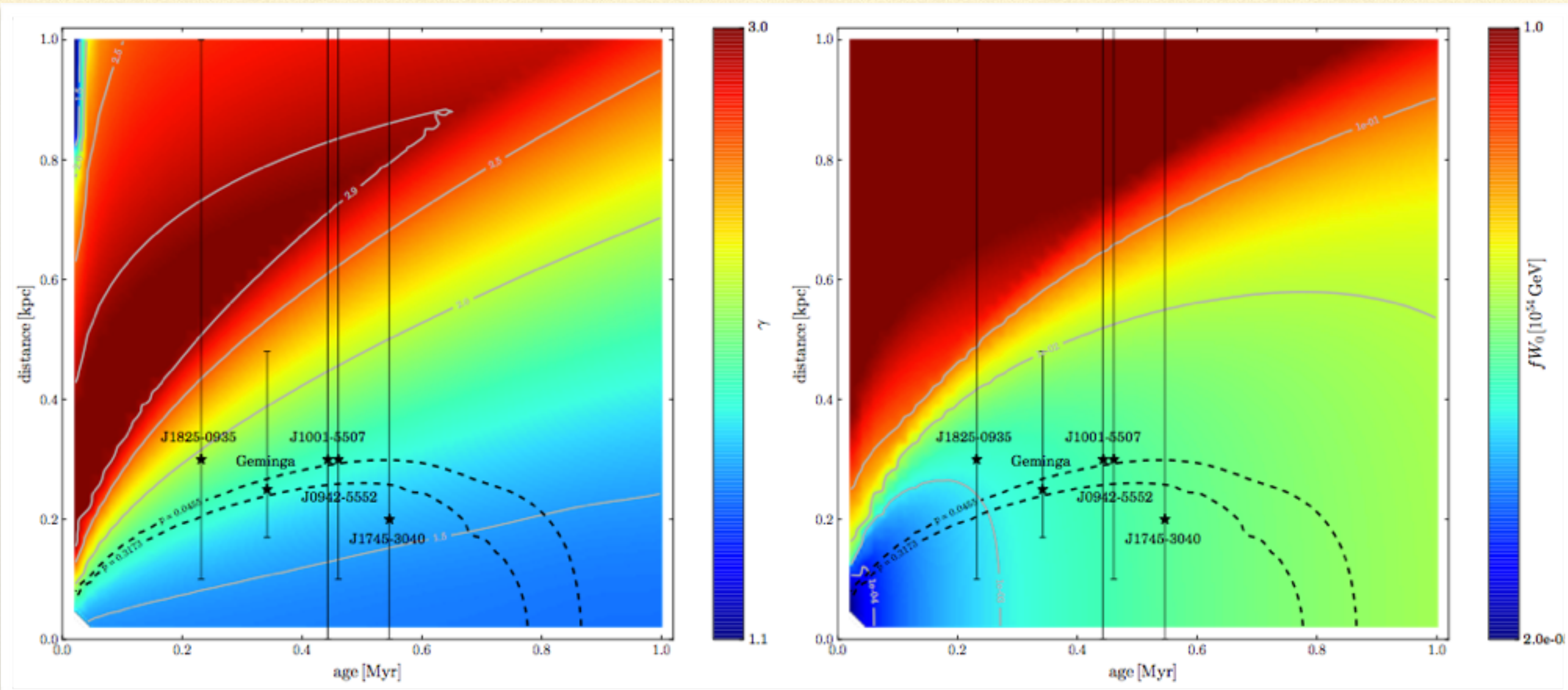
COMBINATION OF CHANNELS (II)

Given a fixed value of m_{DM}, best fit on combinations of channels.



POSITRONS FROM NEARBY PULSARS

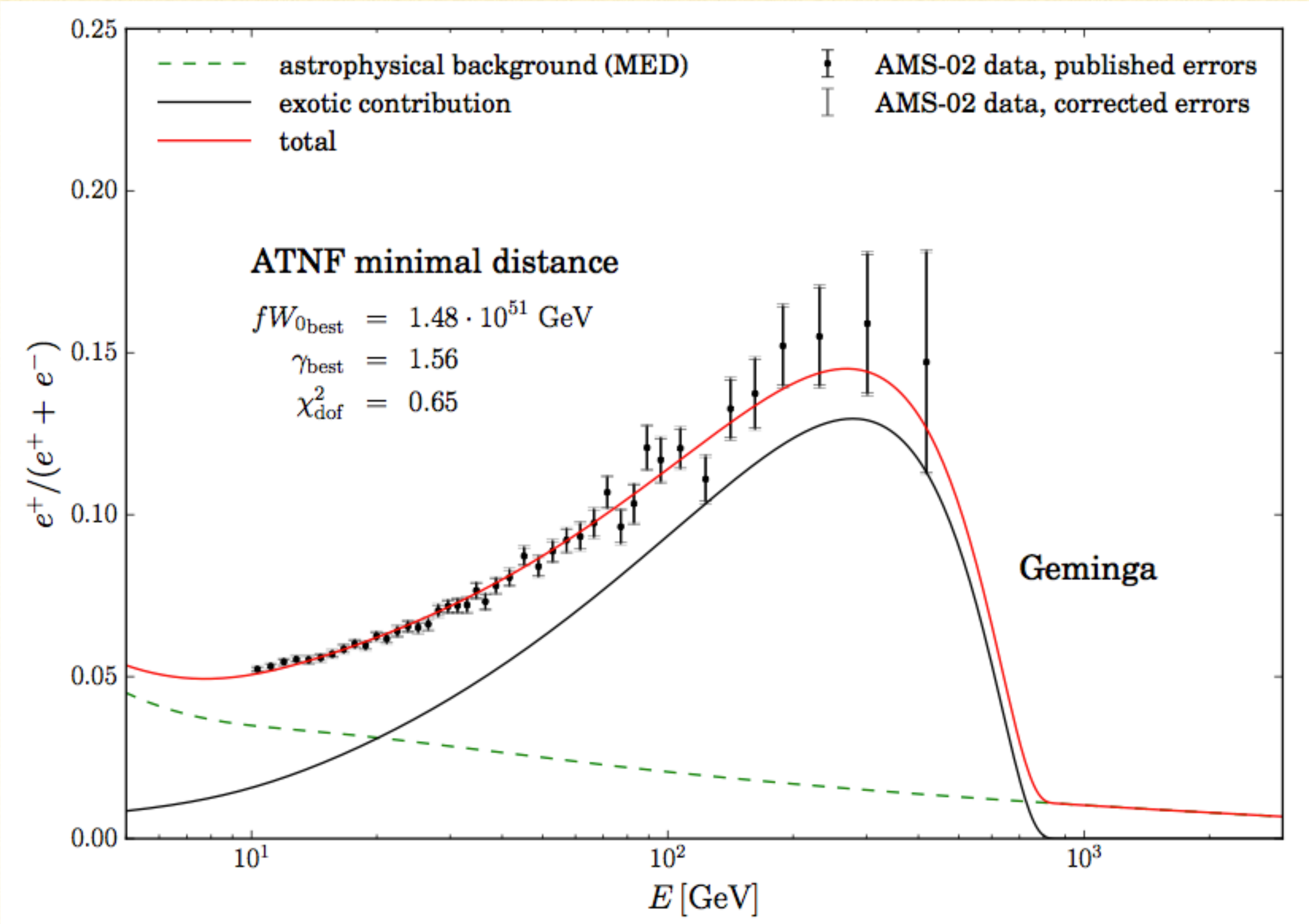
- Source term: $$g(E) = Q_0 \left(\frac{E_0}{E}\right)^{\gamma} \exp(-E/E_C)\,.$$
- Free parameters: the spectral index γ and released energy *fW0*



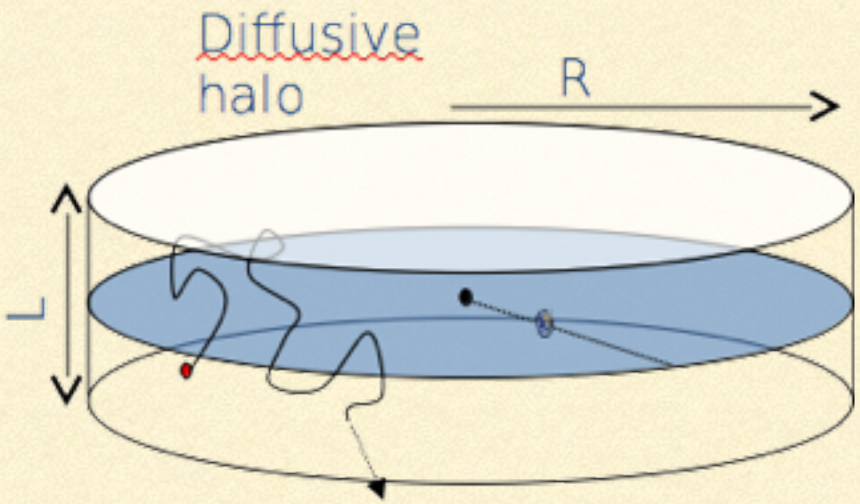
★ = Pulsars from ATNF catalogue fulfilling the goodness-of-fit criteria

See also: Linden & Profumo (2013) and Cholis & Hooper (2013)

POSITRON FRACTION FROM A SINGLE PULSAR



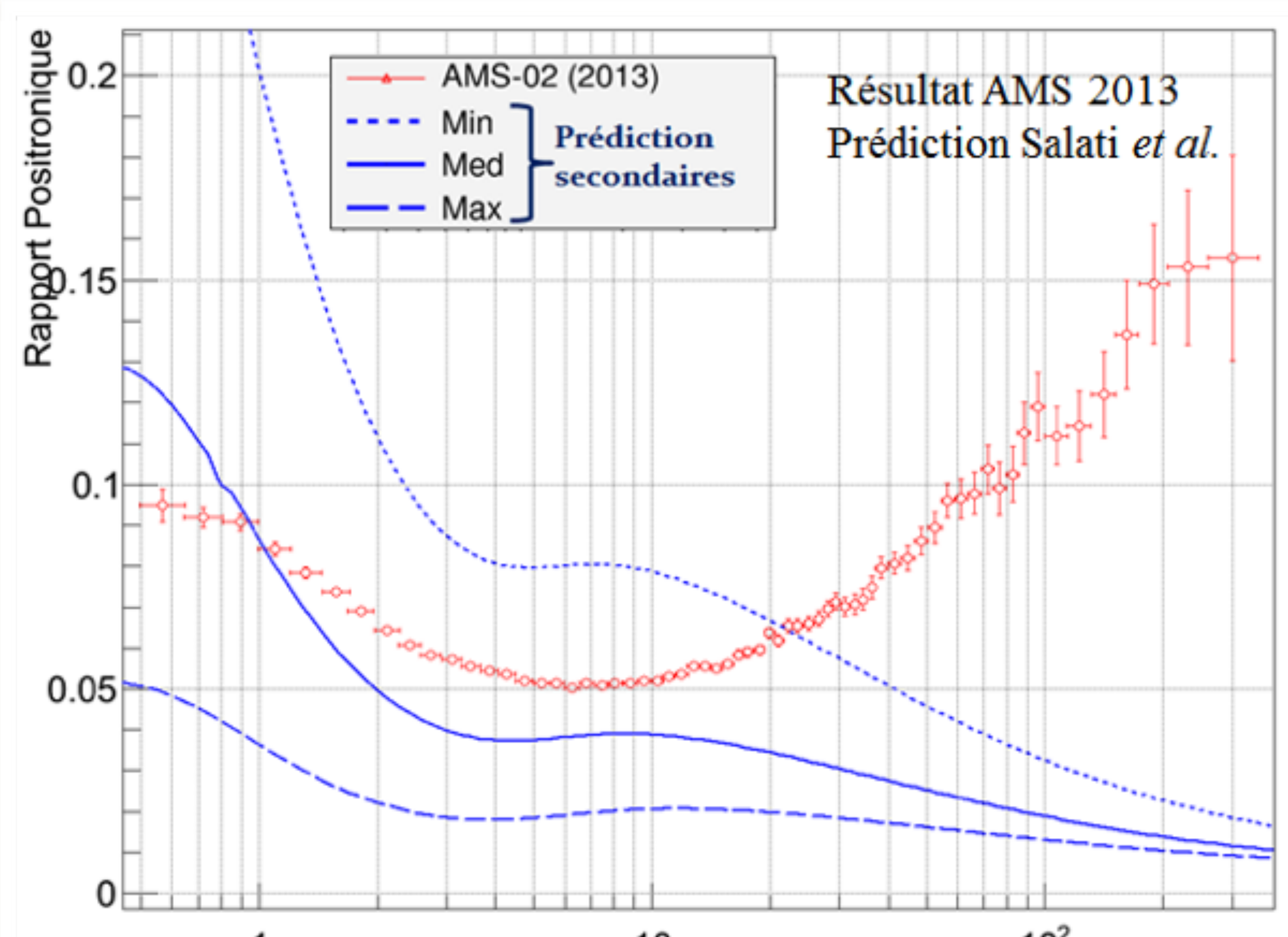
THE EFFECT OF COSMIC RAYS PROPAGATION



Modèle	δ	K_0 [kpc^2/Myr]	L [kpc]
min	0.85	0.0016	1
med	0.70	0.0112	4
max	0.46	0.0765	15

K: diffusion term
δ:diffusion index
α: index emission for the source j

Maurin et al, 2001
Donato et al, 2004

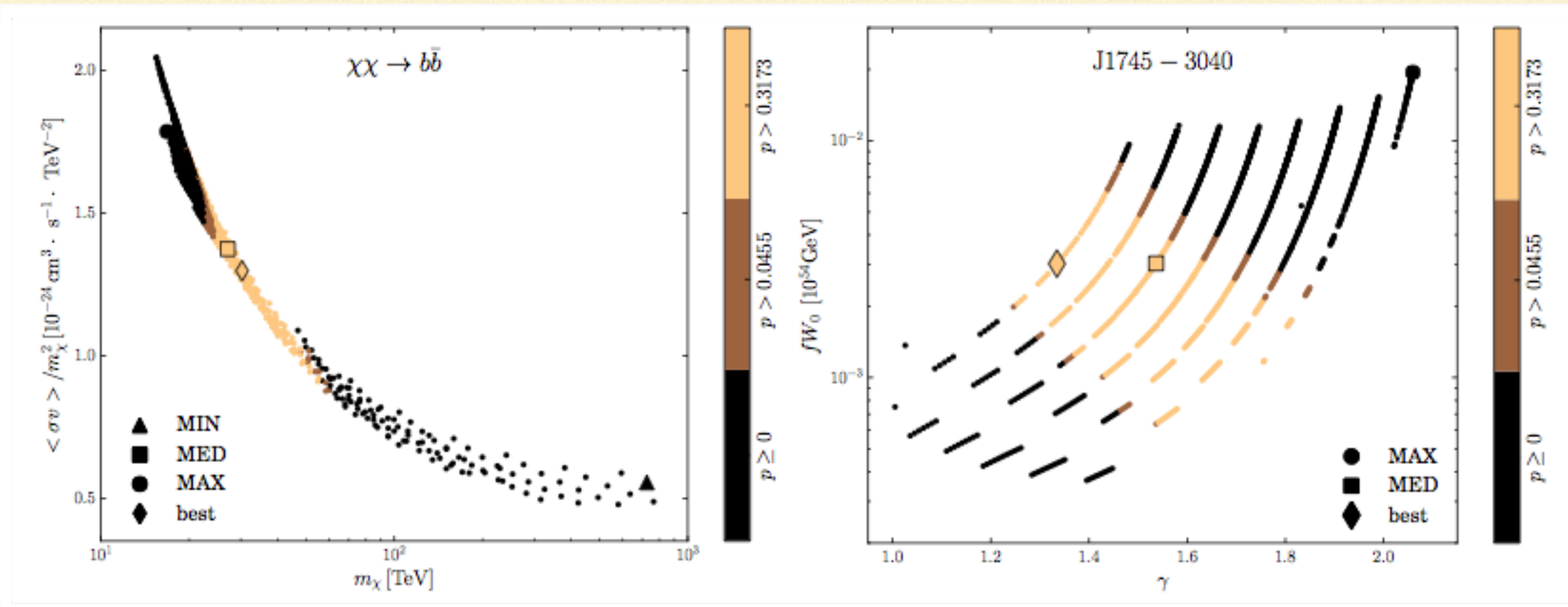


Courtesy S. Caroff LAPP

See also Moskalenko & Strong (1998) and Gaggero et al. (2013)

THE EFFECT OF COSMIC RAYS PROPAGATION

A set of 1623 combination of the transport parameters $\{\delta, K_0, L, V_c, V_A\}$ is used to study the uncertainties on the propagation of CRs and the effect on the modelling of the positron fraction with an additional contribution



SUMMARY ABOUT AMS-02 DATA INTERPRETATION

- A model independent analysis is performed studying several annihilation channels for WIMP DM particles with m_{DM} in the GeV to TeV range
- A Dark Matter interpretation is consistent with the AMS-02 data, but requires:
  - Large masses, i.e. $m_{DM} > 500$ GeV
  - A large enhancement of the annihilation cross section
  - A strong suppression of annihilation into p-pbar [PAMELA data]
- Leptons as the final state are disfavoured
- Excellent agreement for quark, gauge boson, or Higgs boson pairs, with best-fit $m_{DM} \sim o(10)$ TeV range
- Young nearby pulsars can also fit the positron fraction
- The presented results are obtained using the set of propagation parameters that best fit the Boron-to-Carbon ratio. The uncertainties in the propagation parameters are very significant.

THANK YOU FOR YOUR ATTENTION !