Karlsruher Institut für Technologie

# Results from AMS-02 on the International Space Station

June 9th, 2015
**WIN2015, Heidelberg**

**Iris Gebauer** for the AMS collaboration

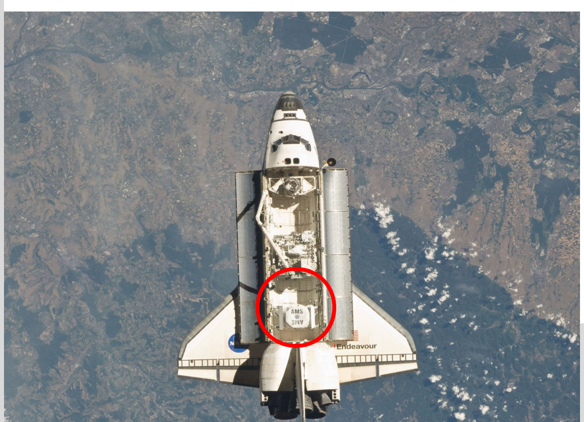
INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK

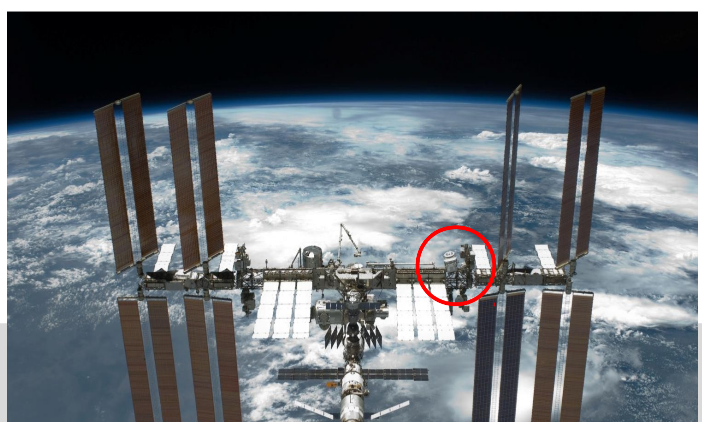

KIT – Universität des Landes Baden-Württemberg und
nationales Forschungszentrum in der Helmholtz-Gemeinschaft

www.kit.edu

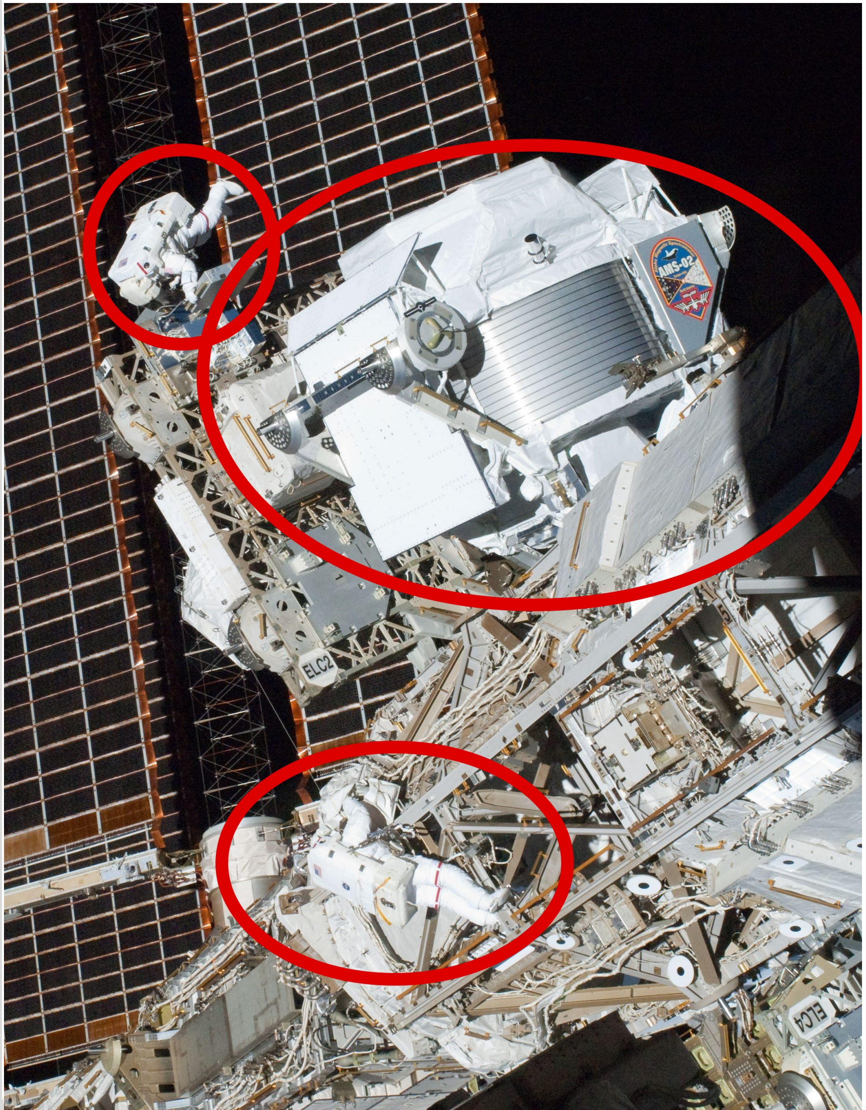

16th May 2011


19th May 2011





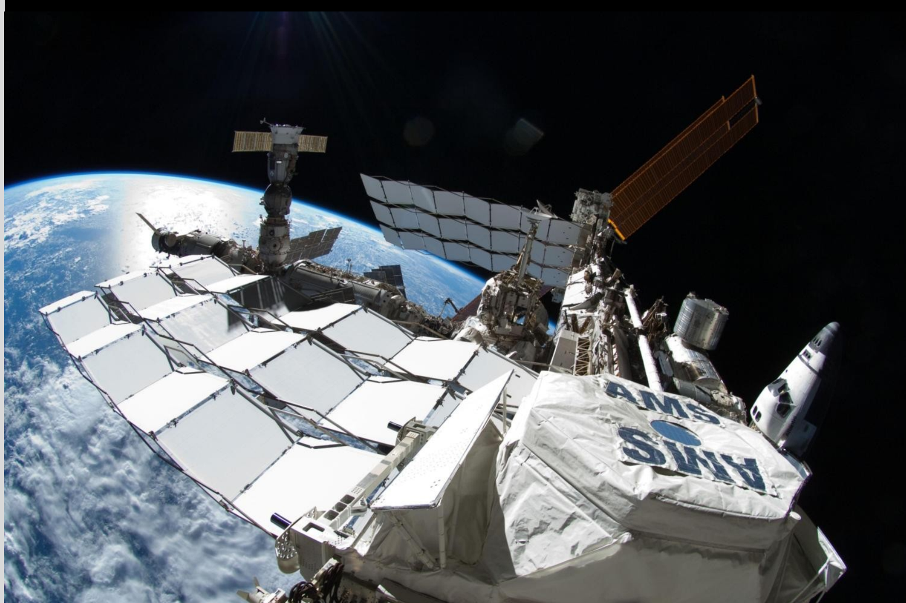
# **AMS-02:** THE ALPHA MAGNETIC SPECTROMETER 02




- **Volume** 64 $m^3$, height 4 m
- **Weight** 8500 kg
- **Power** 2500 W
- **Data downlink** 9 Mbps (minimum)
- **Magnetic field** 0.15 T (400 x Earth, PAMELA: 0.4 T, but H=44.5 cm)
- **Launch** May 16th, 2011 (Endeavour)
- **Data taking** as of May 19th, 2011
- **Construction** 1999-2010 (>3 PhD generations)
- **Mission duration:** until the end of ISS operation (currently 2024)

# **AMS-02** SCIENCE AGENDA

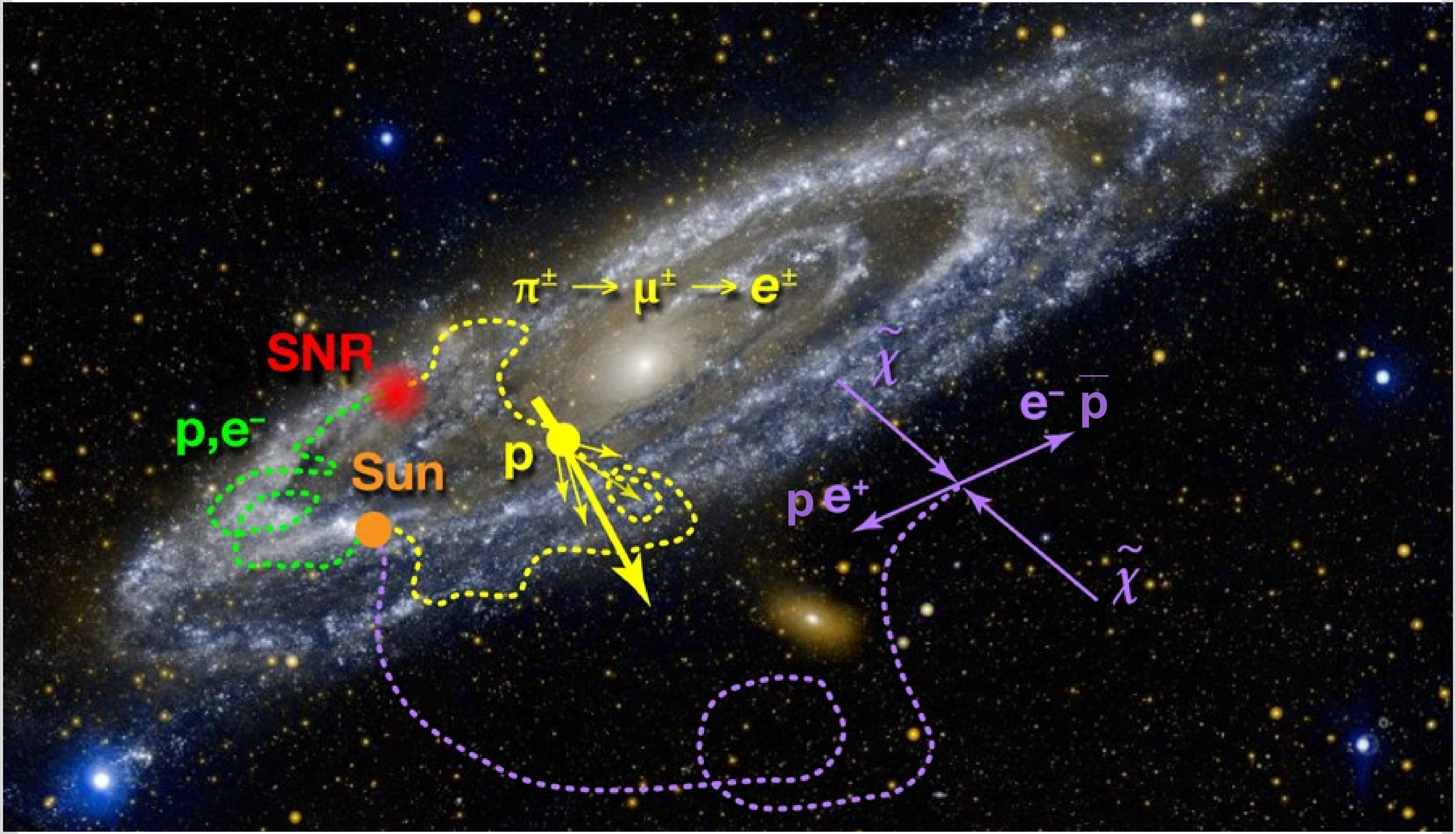
**Cosmic ray spectra up to TeV energies**
**Indirect Dark Matter search: $e^+$, $\bar{p}$, $\gamma$, …**
**Direct search for primordial antimatter: $\overline{He}$, $\overline{C}$, ….**
**Solar physics effects over 11 years solar cycle**
**Gamma ray physics (skymaps, photon spectra )**




**TODAY:**
**Proton flux measurement**
**Positron fraction and electron and positron fluxes**
**Antiproton/proton ratio**
**Nuclei**


Iris Gebauer
Institut für Experimentelle Kernphysik

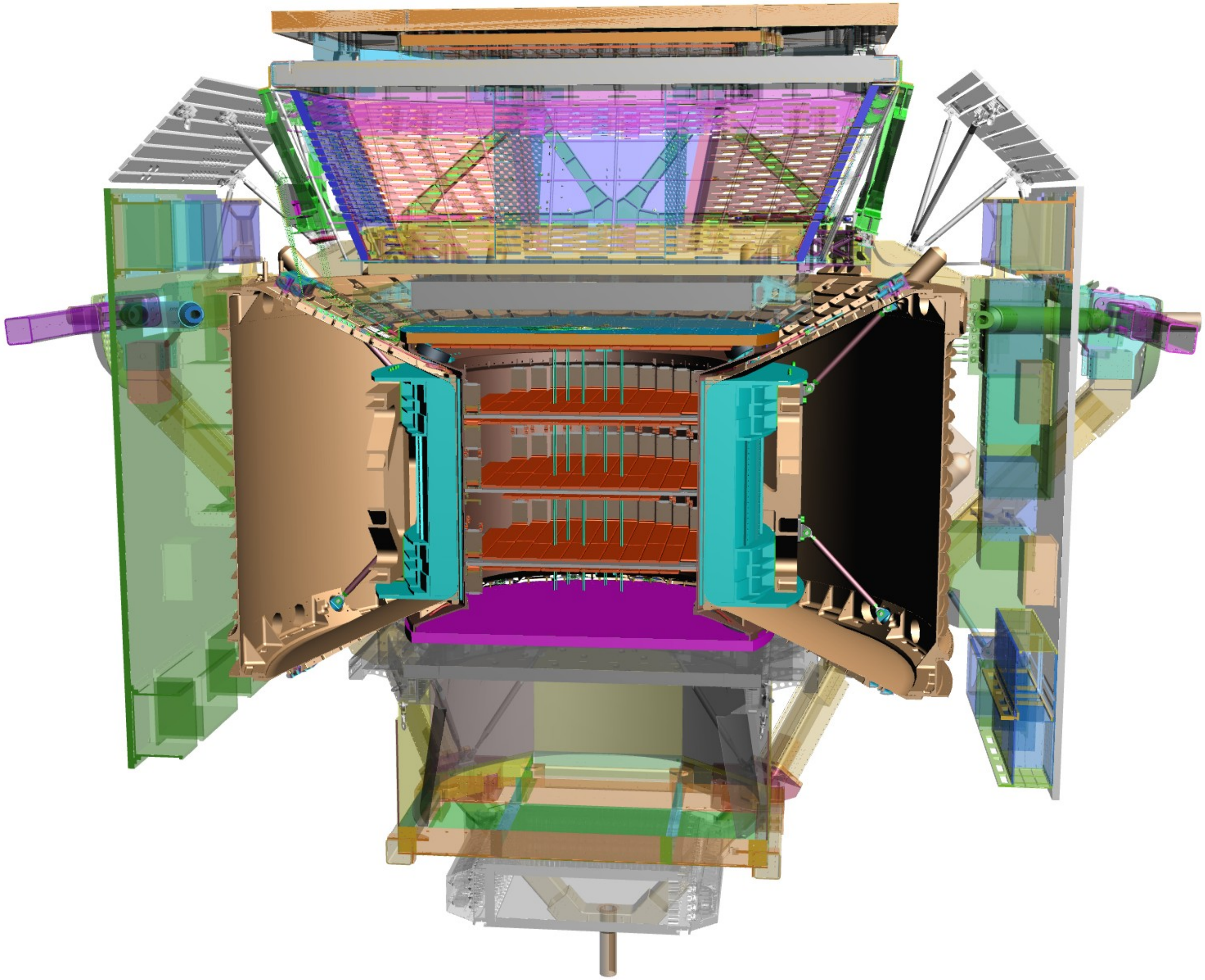
# GALACTIC COSMIC RAYS: FROM SOURCE TO US





Iris Gebauer
Institut für Experimentelle Kernphysik

# AMS-02 RESULTS





Iris Gebauer
Institut für Experimentelle Kernphysik

# PROTON FLUX MEASUREMENT

PRL 114, 171103 (2015) PHYSICAL REVIEW LETTERS week ending 1 MAY 2015

**Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station**

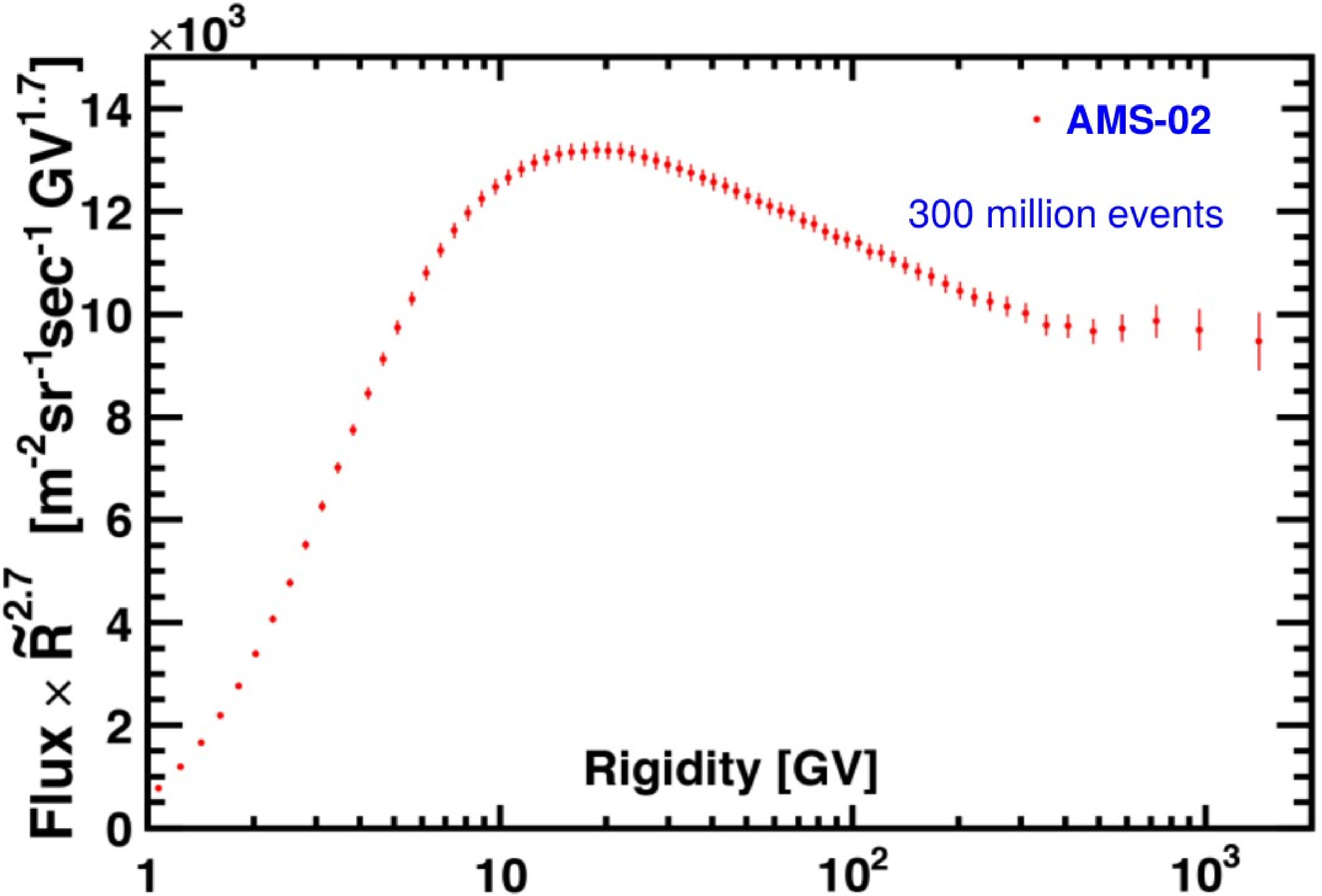
The isotropic proton flux $\Phi_i$ for the $i^{th}$ rigidity bin ($R_i$, $R_i+\Delta R_i$) is

$$\Phi_i = \frac{N_i}{A_i \epsilon_i T_i \Delta R_i}$$

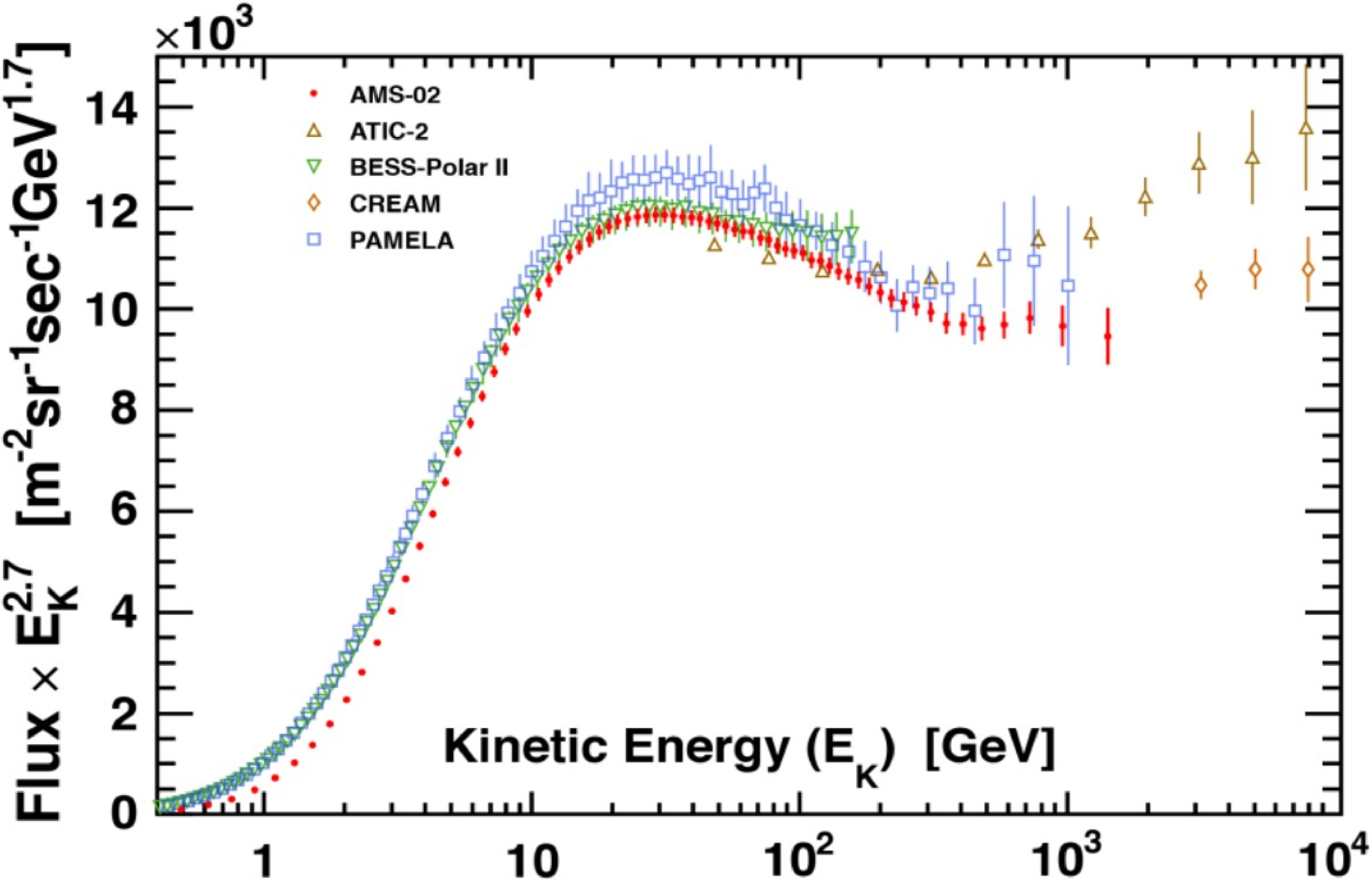
$N_i$ is the number of events, 300 million proton events have been selected;
$A_i$ is the effective acceptance;
$\varepsilon_i$ is the trigger efficiency;
$T_i$ is the measurement time (which depends in geomagnetic cutoff, orbit and operations).

**To match the statistics, extensive systematic error studies were made.**

# AMS-02 PROTON FLUX



# AMS-02 PROTON FLUX

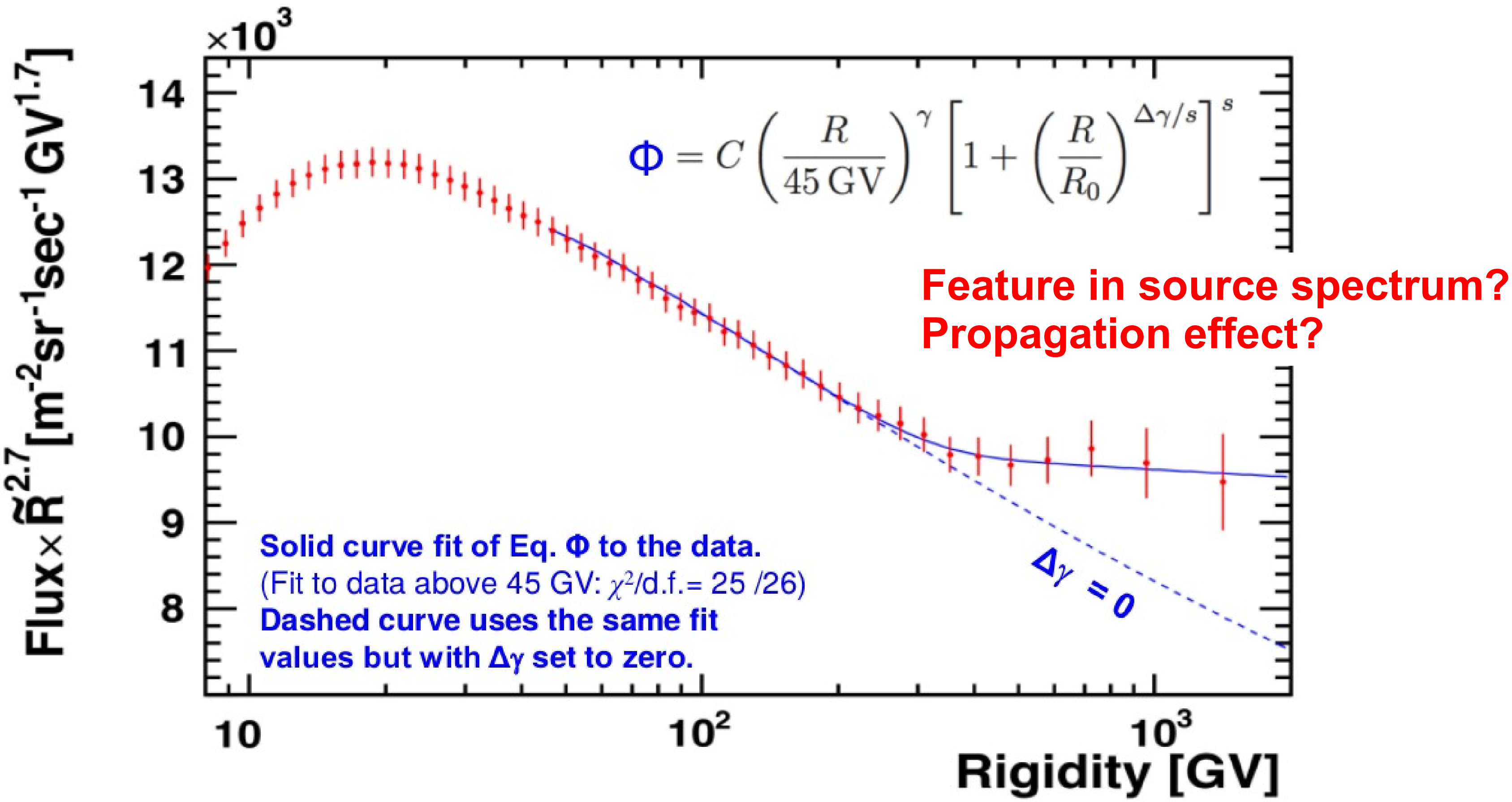





Iris Gebauer
Institut für Experimentelle Kernphysik

# AMS-02 PROTON FLUX FIT TO TWO POWER LAWS:

$R^{\gamma}$, $R^{\gamma+\Delta\gamma}$ with a characteristic transition rigidity $R_0$ and smoothness s.

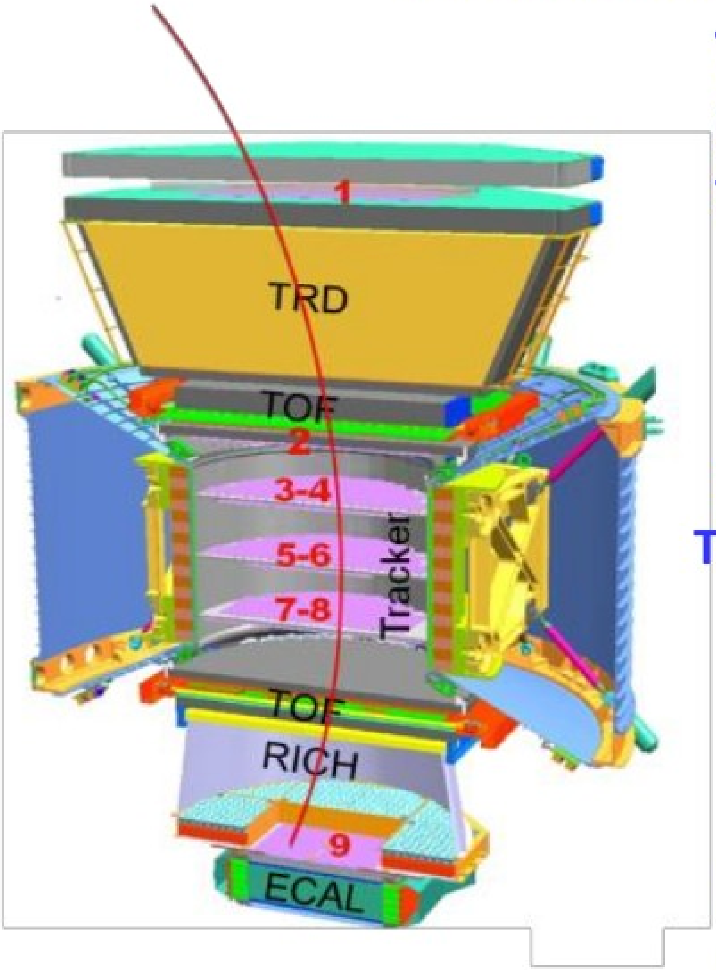



$$R_0 = 336 \pm^{68}_{44}(fit) \pm^{66}_{28}(sys) \pm 1(sol)\,GV$$

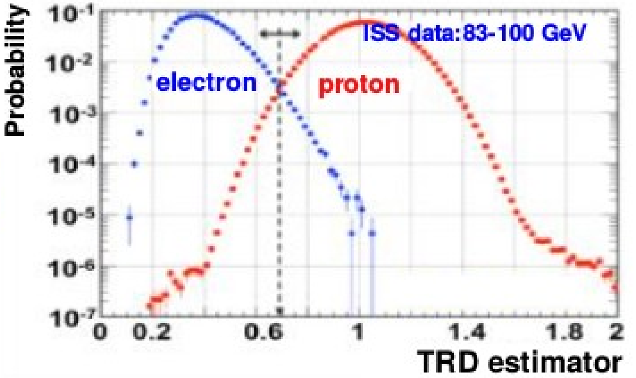
$$\gamma = -2.845 \pm 0.02(fit) \pm^{0.003}_{0.004}(sys) \pm^{0.004}_{0.003}(sol) \quad \Delta\gamma = 0.133 \pm^{0.032}_{0.021} \pm^{0.046}_{0.030}(sys) \pm 0.005(sol)$$

# PHYSICS OF 11 MILLION $e^+$, $e^-$ EVENTS

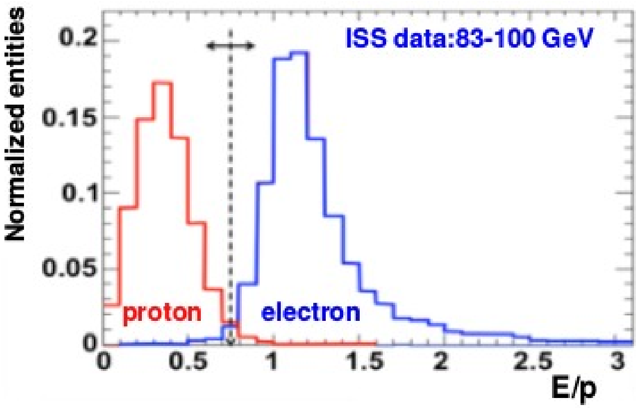
**Measuring electrons and positrons**



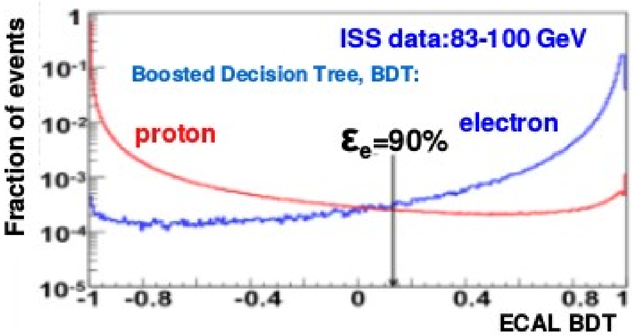

**TRD**
(transition radiation)
to identify $e^{\pm}$



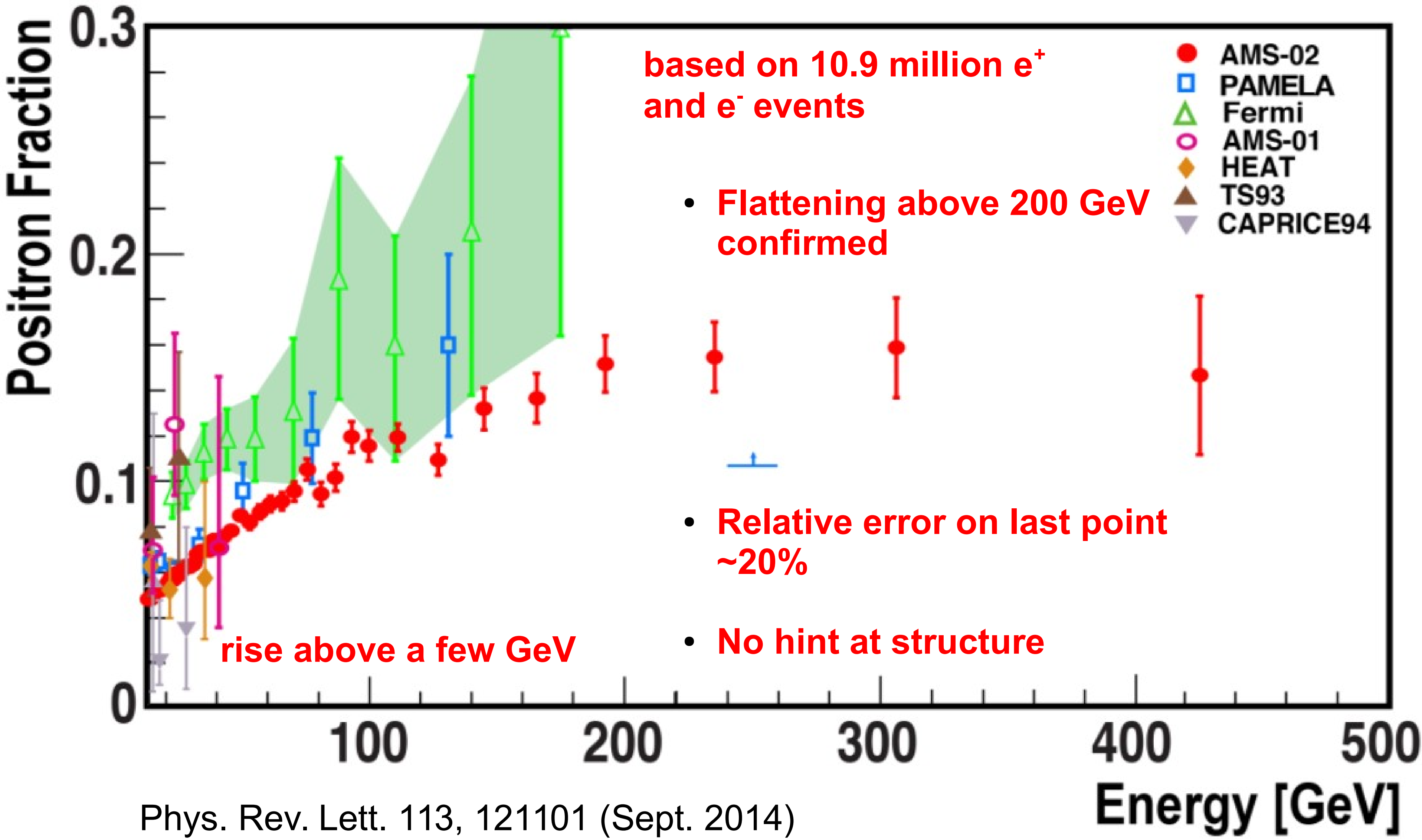

**ECAL measures E**
**Tracker measures p**
**$e^{\pm}$: E=p**
**proton: E<p**




**ECAL**
(shower shape)
to separate $e^{\pm}$
from protons



# AMS-02 POSITRON FRACTION MEASUREMENT

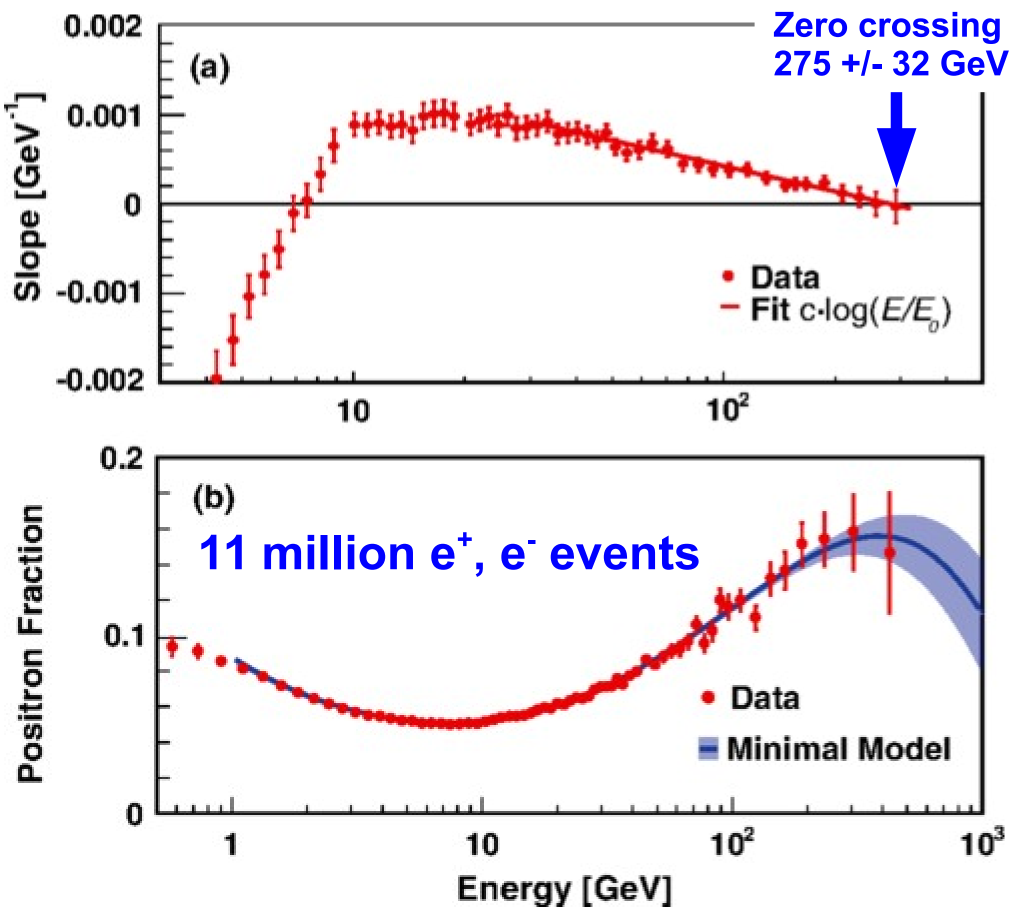



- Flattening above 200 GeV confirmed
- Relative error on last point ~20%
- No hint at structure

Phys. Rev. Lett. 113, 121101 (Sept. 2014)

# IS THERE A MAXIMUM IN THE POSITRON FRACTION?

There is an energy beyond which it ceases to increase




- Above 200 GeV the fraction no longer exhibits an increase with energy

- "Minimal model":

$$\Phi_{e+} = C_{e+} E^{-\gamma_{e+}} + C_c E^{-\gamma_c} e^{-E\zeta_c}$$

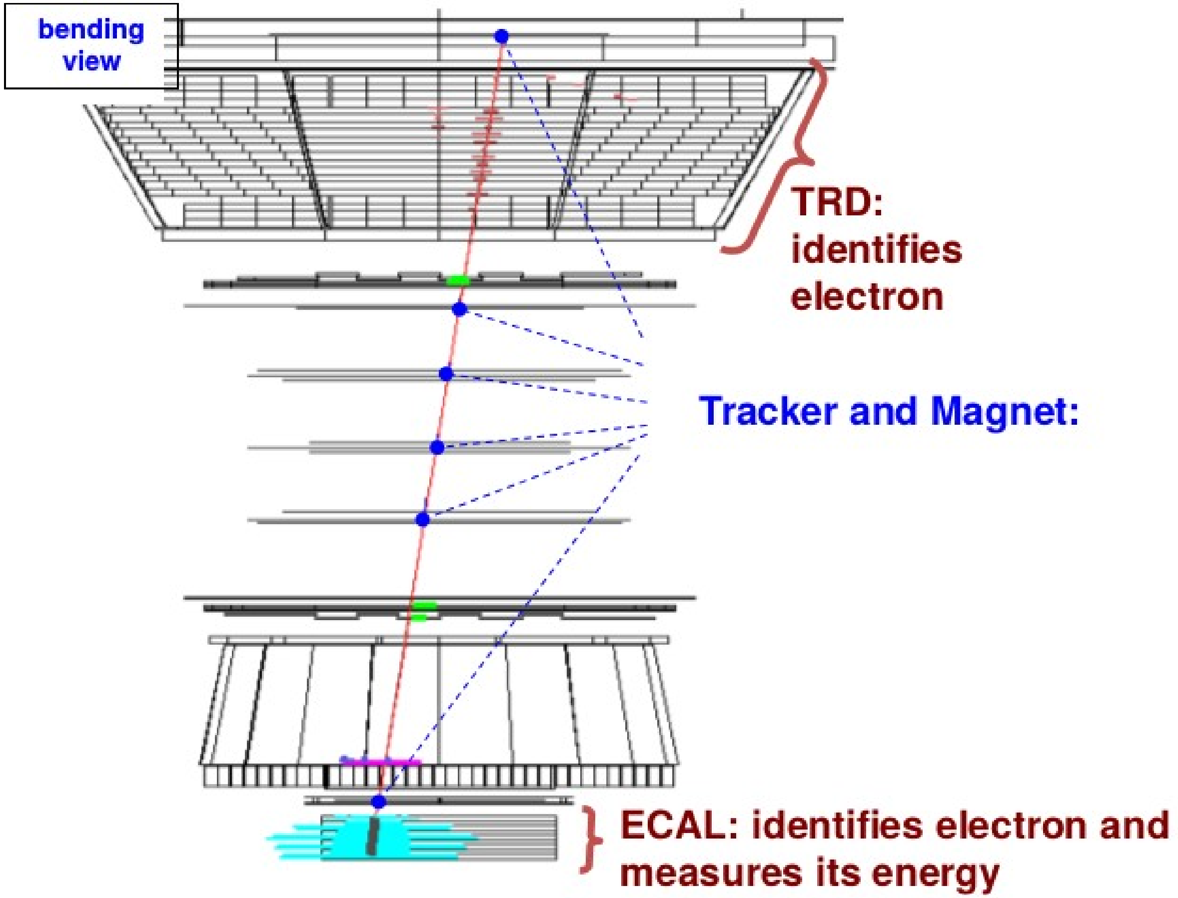
$$\Phi_{e-} = C_{e-} E^{-\gamma_{e-}} + C_c E^{-\gamma_c} e^{-E\zeta_c}$$

**common source**



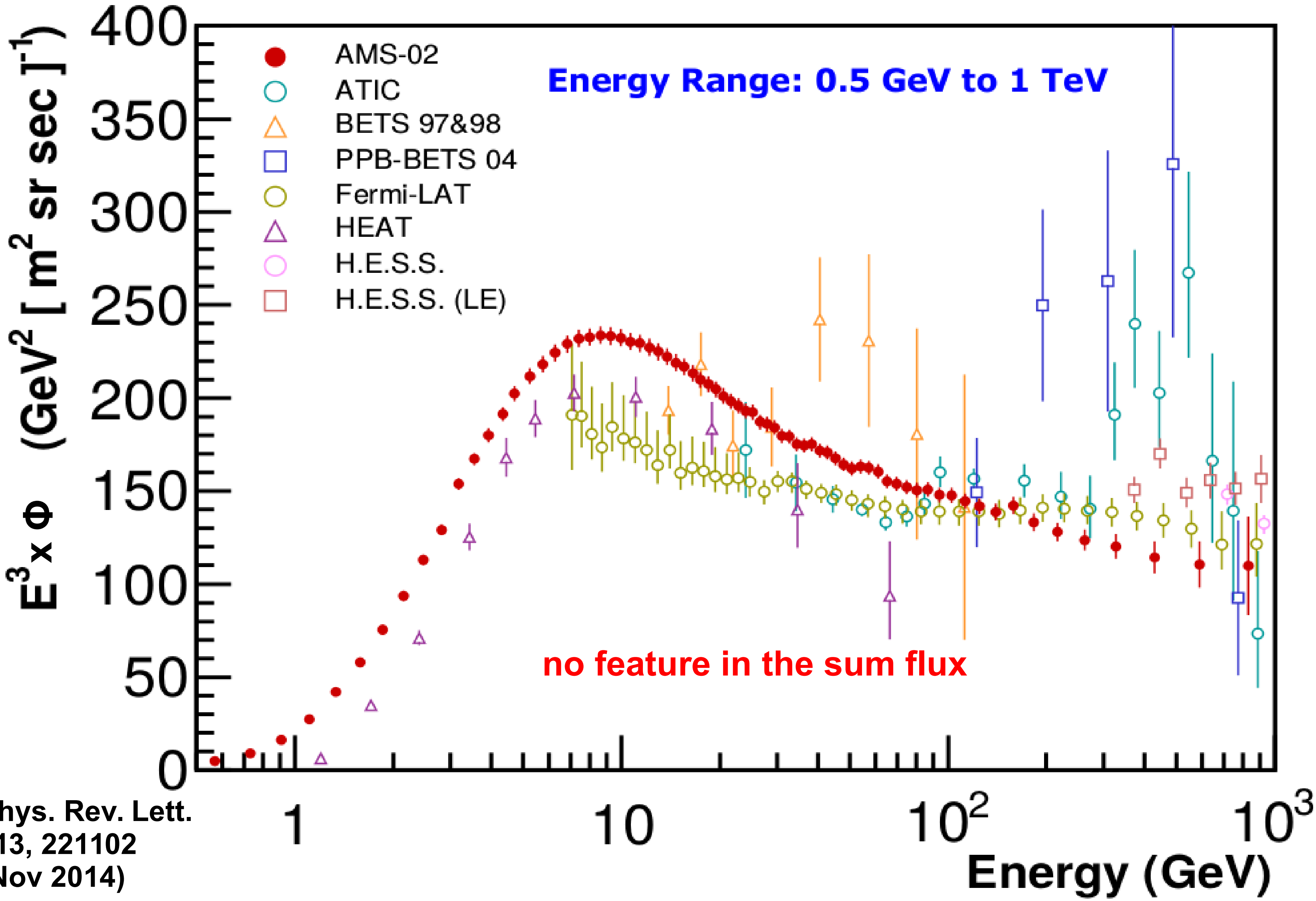
Iris Gebauer
Institut für Experimentelle Kernphysik

# COMBINED ($e^+ + e^-$) FLUX: EVENT SELECTION



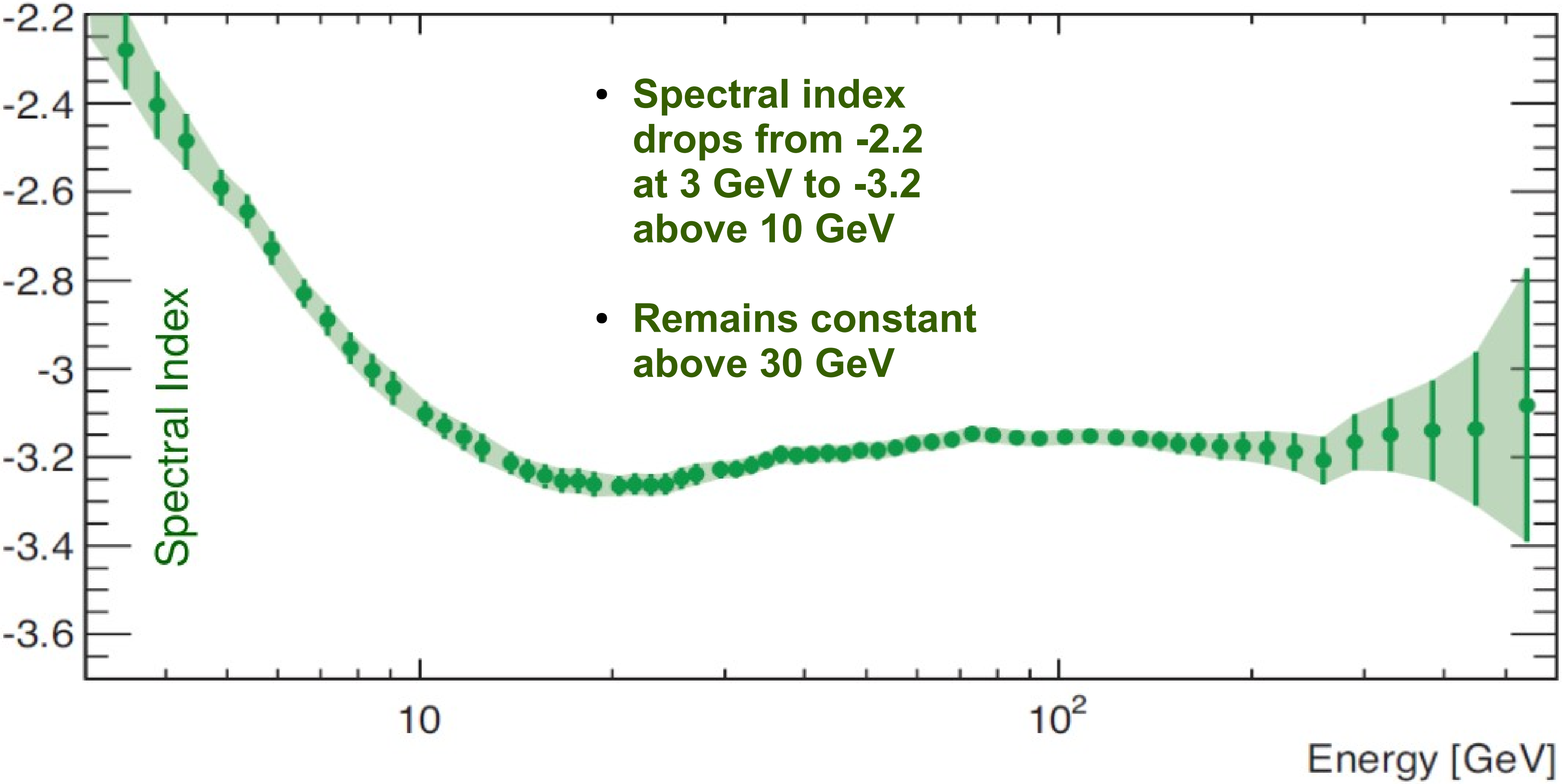

**Independent of charge sign measurement → no charge confusion**
**High selection efficiency: 70 % @ TeV**
**Small systematics on acceptance: 2% @ TeV**

AMS-02 **$e^+$+$e^-$** FLUX




**Phys. Rev. Lett. 113, 221102 (Nov 2014)**

$$\gamma = d \log(\Phi) / d \log(E)$$



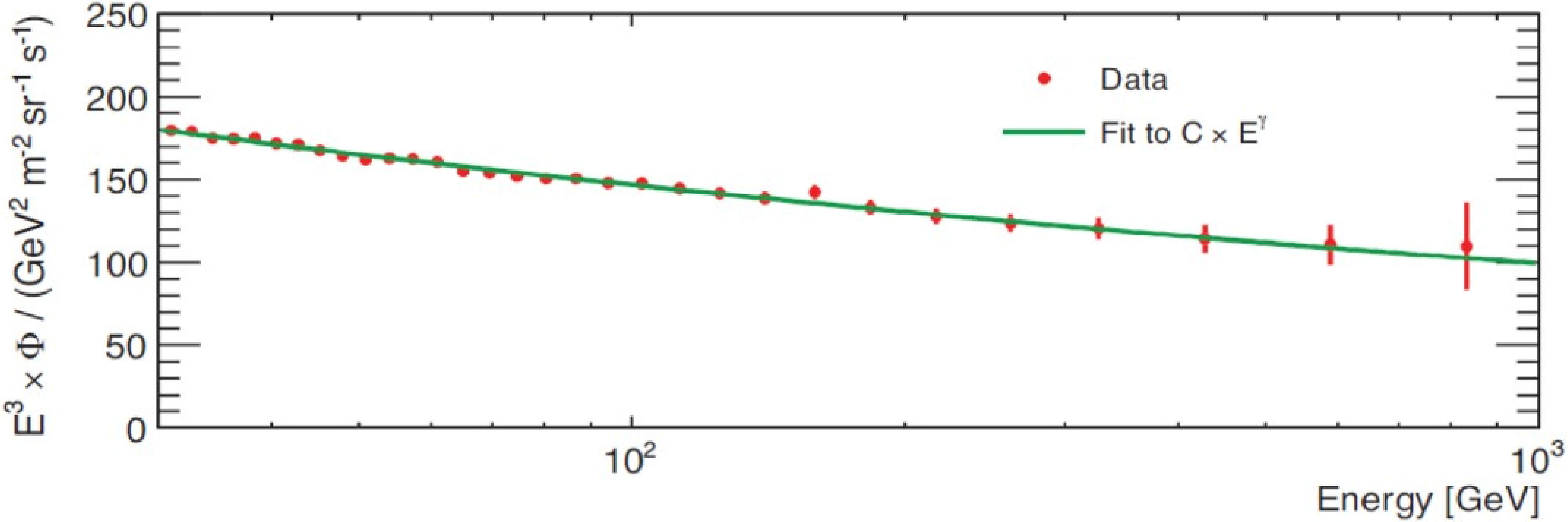

- **Spectral index drops from -2.2 at 3 GeV to -3.2 above 10 GeV**
- **Remains constant above 30 GeV**

AMS-02 $e^{+}$+$e^{-}$ FLUX

$$\Phi(e^{+}+e^{-}) = C\,E^{\gamma}$$

$\gamma = -3.170 \pm 0.008$ (stat + syst.) $\pm 0.008$ (energy scale)

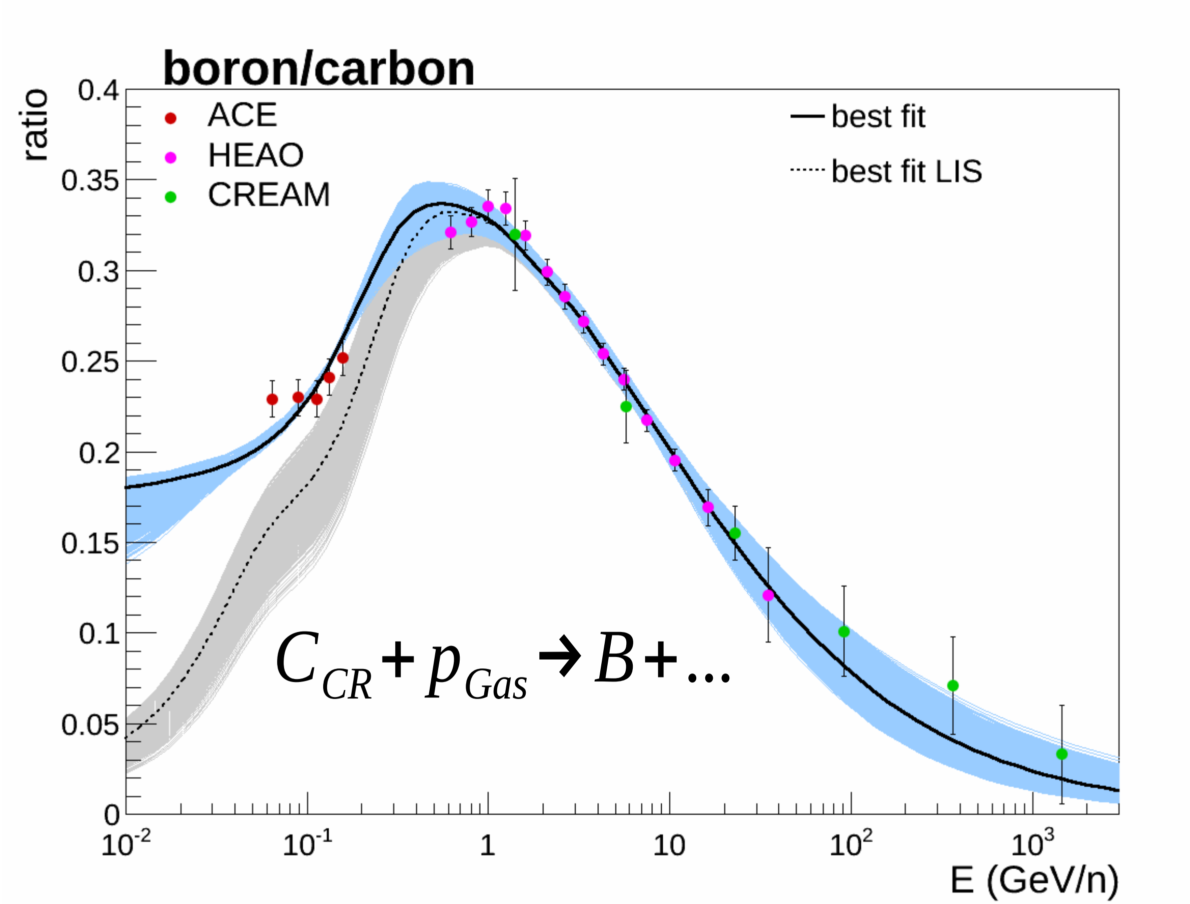
$E > 30$ GeV




**The flux is consistent with a single power law above 30 GeV.**

# WHAT DO WE LEARN FROM THE NEW DATA?

Models based on 15 mio. DRAGON runs.



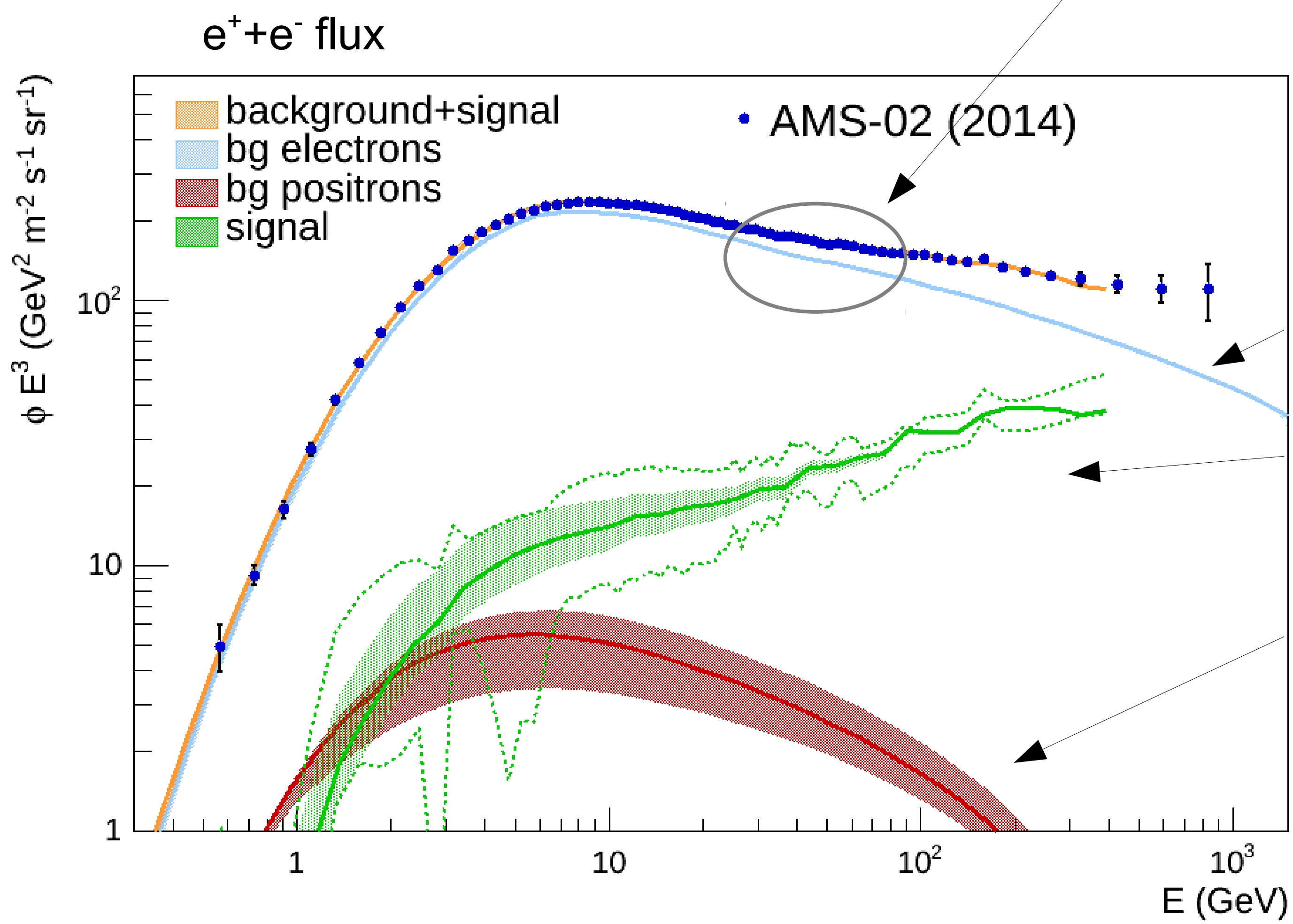

**B/C fixed →cosmic ray interaction rate fixed → positrons fixed**



Iris Gebauer
Institut für Experimentelle Kernphysik

# WHAT DO WE LEARN FROM THE NEW DATA?

Estimating the additional source contribution from data

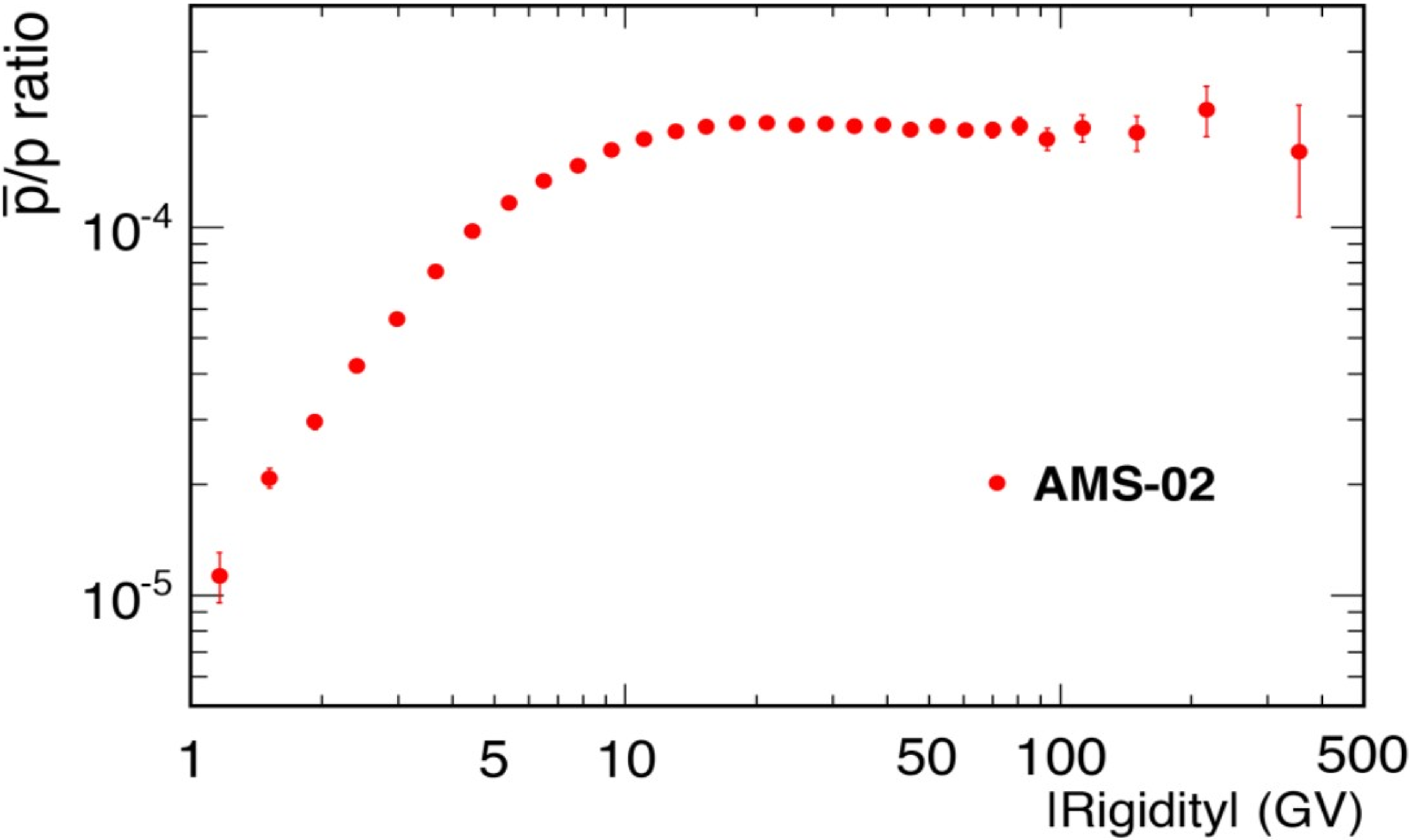



**Primary $e^-$**: tuned for electron data

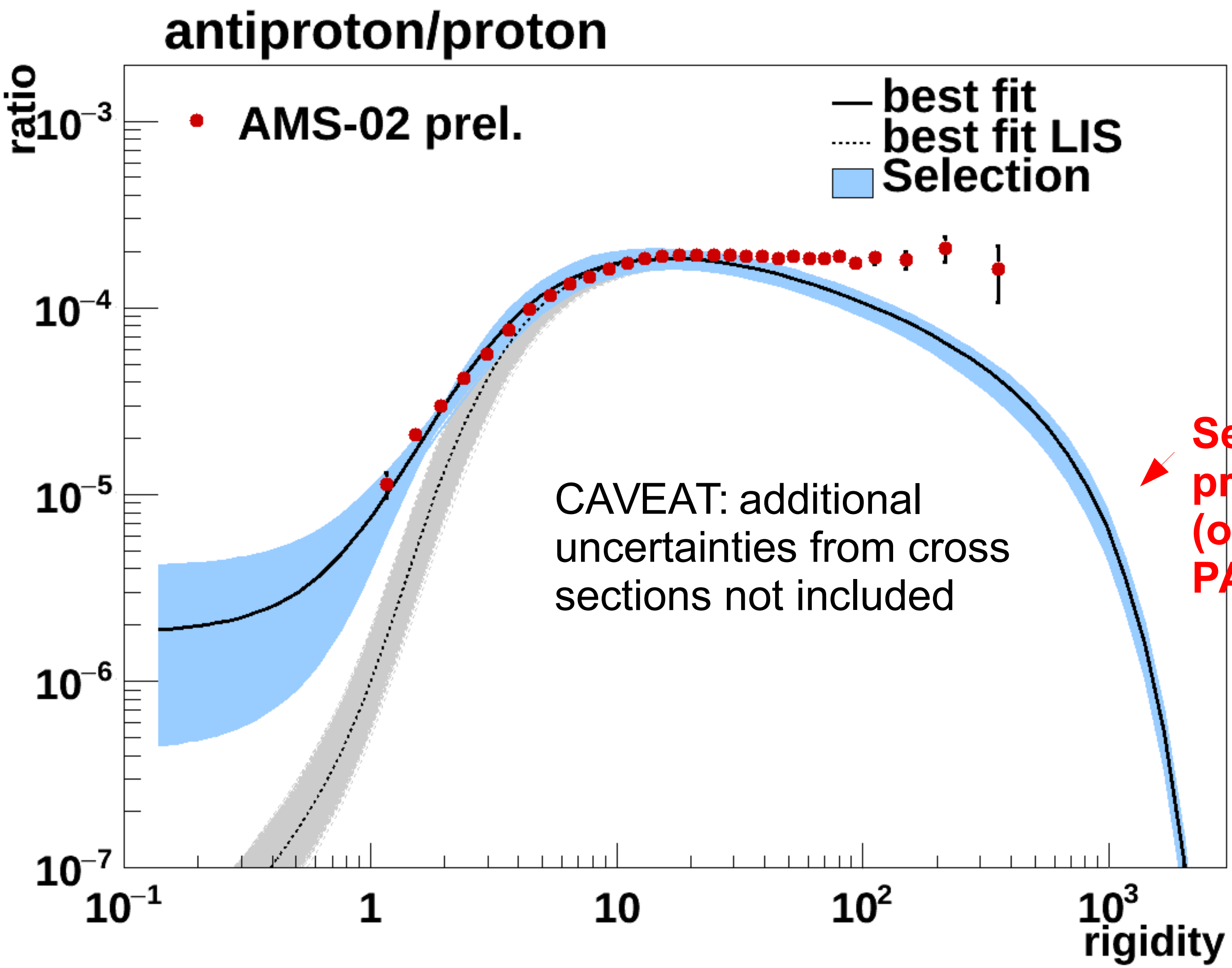
**Signal**: calculated from $e^+ + e^-$ data

**Secondary $e^+$**: transport model prediction (15 Mio models)

ANTIPROTON/PROTON RATIO



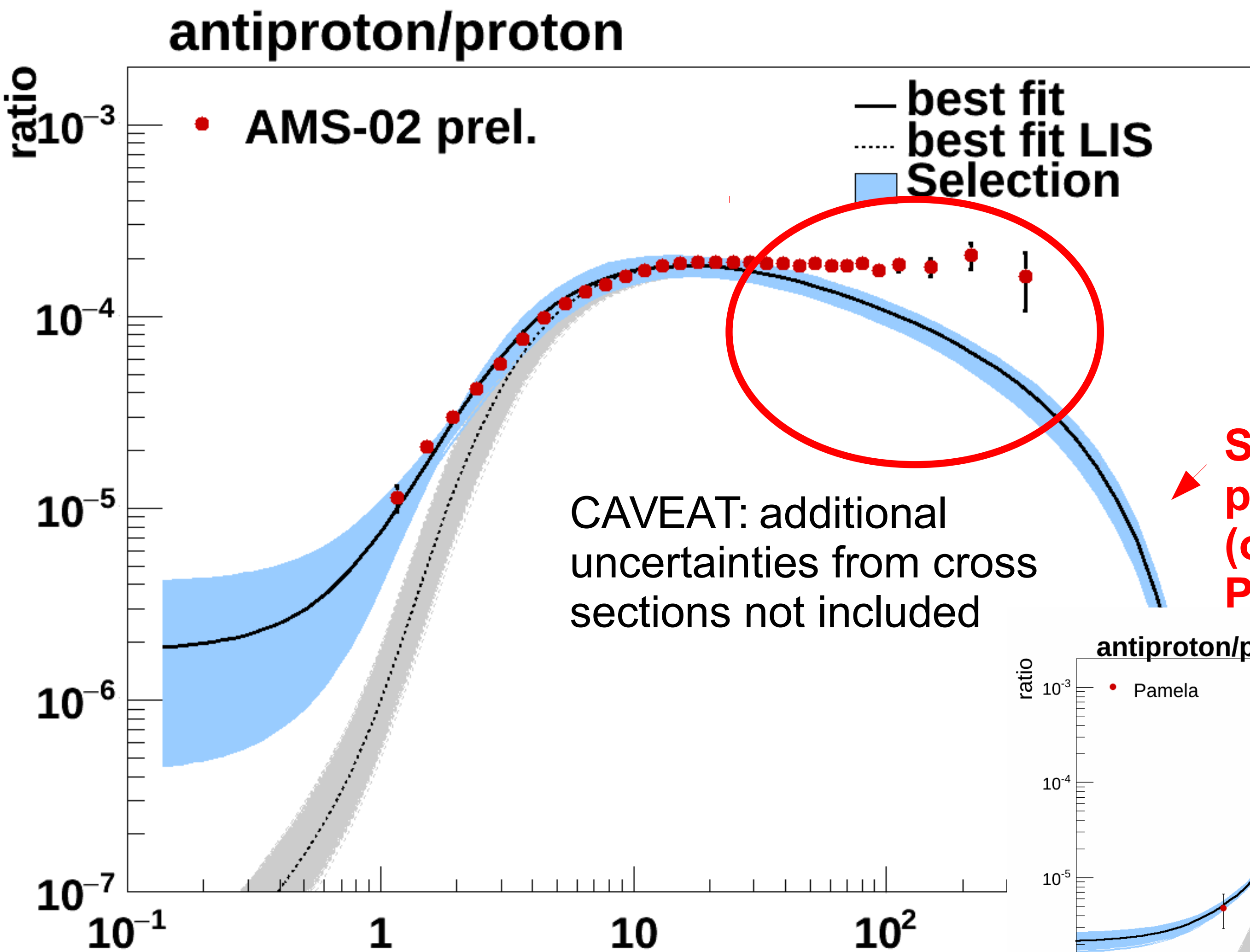
# ANTIPROTON/PROTON RATIO



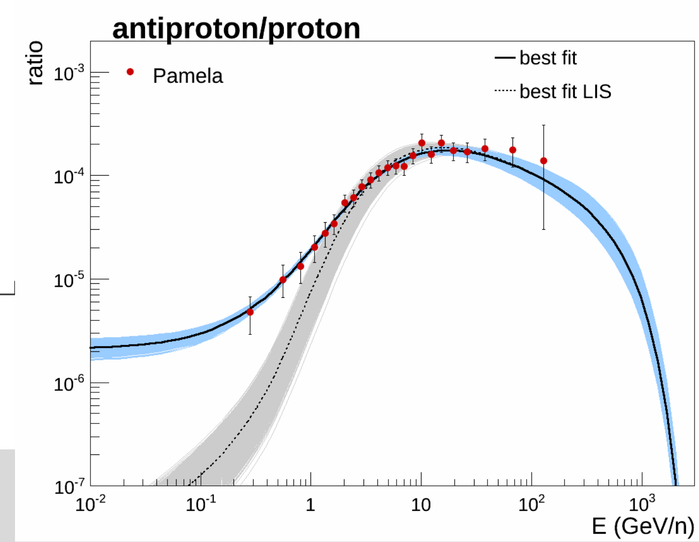

Secondary production (optimized for PAMELA)


Iris Gebauer
Institut für Experimentelle Kernphysik

# ANTIPROTON/PROTON RATIO

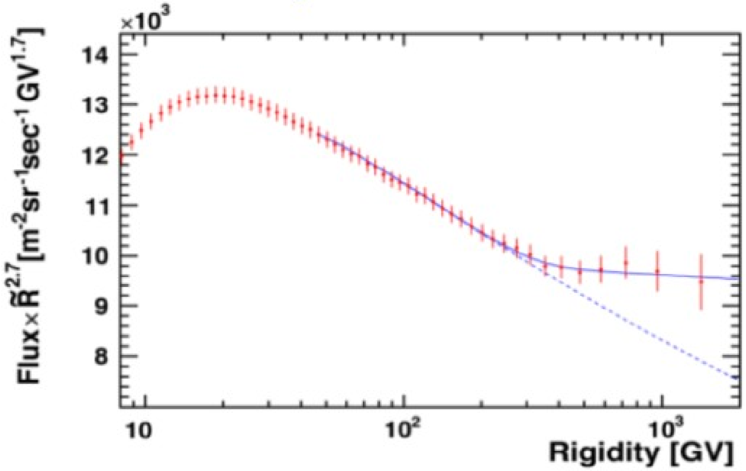



Secondary production (optimized for PAMELA)

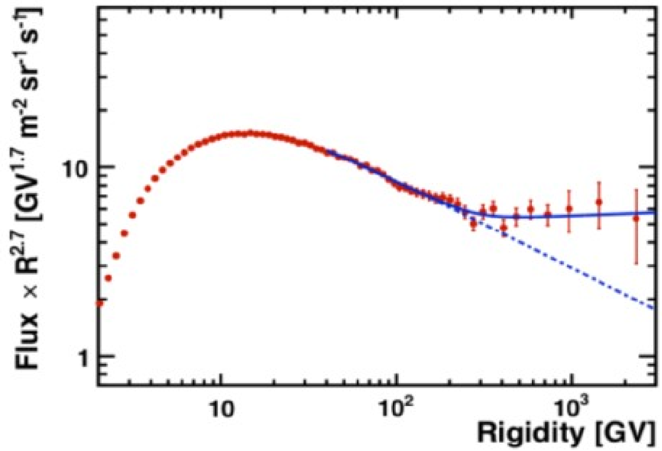


# AMS-02 NUCLEI MEASUREMENTS

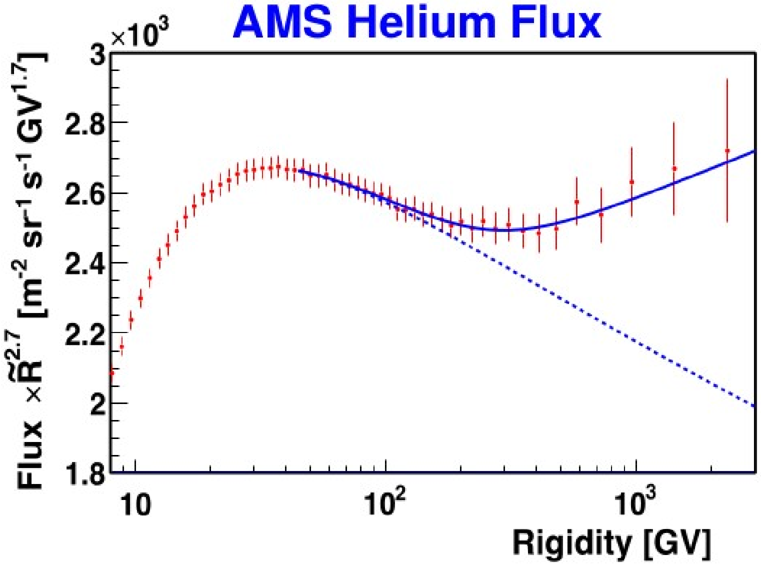
## AMS proton flux



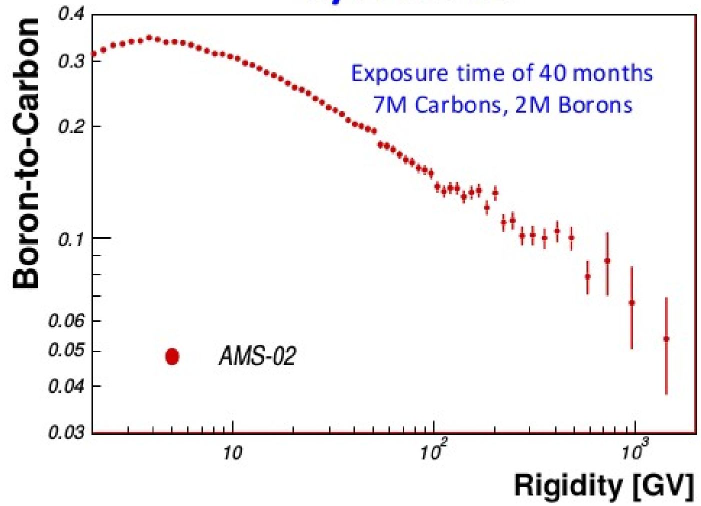

## Lithium flux




## AMS Helium Flux




## B/C Ratio







Iris Gebauer
Institut für Experimentelle Kernphysik

# SUMMARY

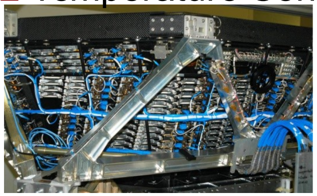
**AMS-02 is operating stable on the ISS since May 2011.**

**The latest AMS measurements of the positron fraction, the antiproton/proton ratio, the behavior of the fluxes of electrons, positrons, protons, helium, and other nuclei provide precise and unexpected information.**

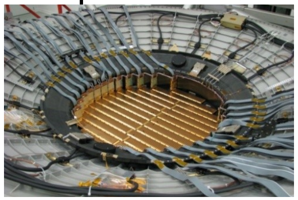
**The accuracy and characteristics of the data, require a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination.**

# OPERATING AMS-02 ON THE ISS

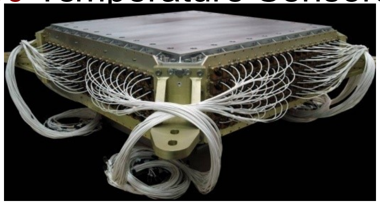
**TRD**
24 Heaters
8 Pressure Sensors
482 Temperature Sensors

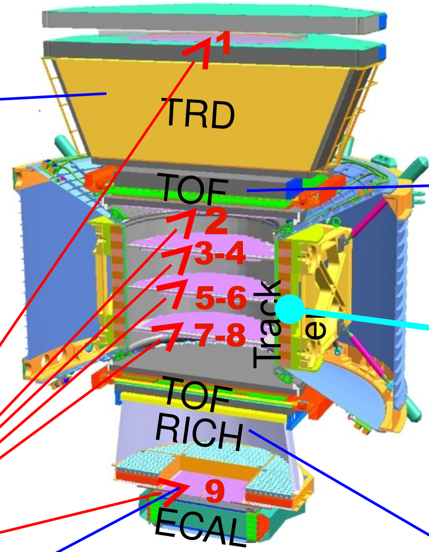


**Silicon Tracker**
4 Pressure Sensors
32 Heaters
142 Temperature Sensors



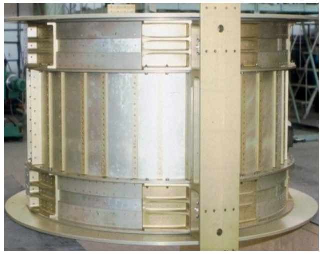
**ECAL**
80 Temperature Sensors



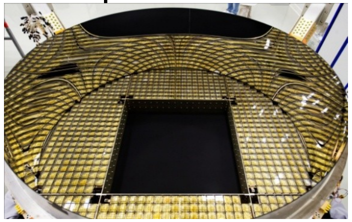



**TOF & ACC**
64 Temperature Sensors

**Magnet**
68 Temperature Sensors



**RICH**
96 Temperature Sensors



**1118 temperature sensors**
**5 radiators**
**298 thermostatically controlled heaters**

# POCC: PAYLOAD OPERATIONS CONTROL CENTER


CERN, Geneve


CSIST, Taiwan

**POCC**

**P**ayload **O**perations **C**ontrol **C**enter

Monitoring + Commanding

Communication with NASA

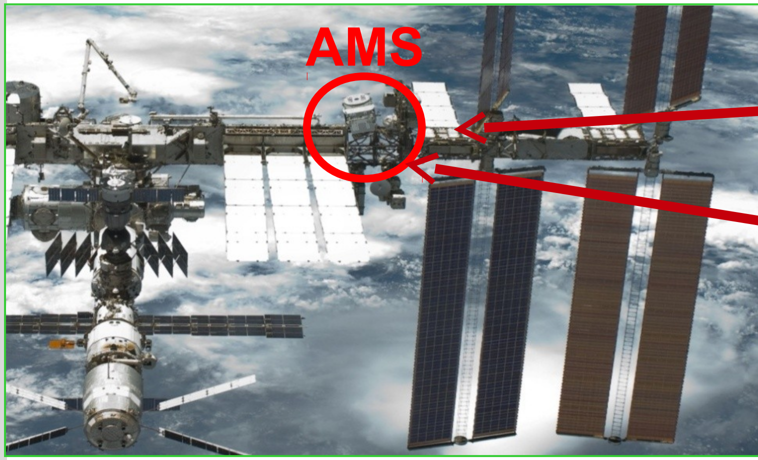
4 positions monitoring
11 Subdetectors (24/7)

LEAD position monitoring the entire system

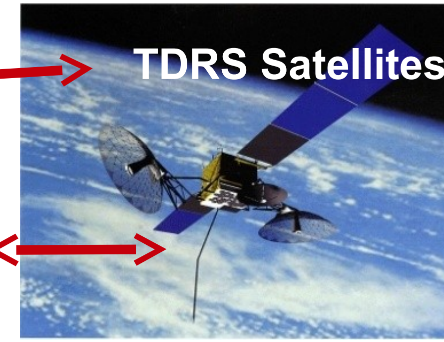


Iris Gebauer
Institut für Experimentelle Kernphysik

# AMS-02 ↔ GROUND








**Ku-Band**
**High Rate (down):**
**Events <10Mbit/s>**

## Flight Operations

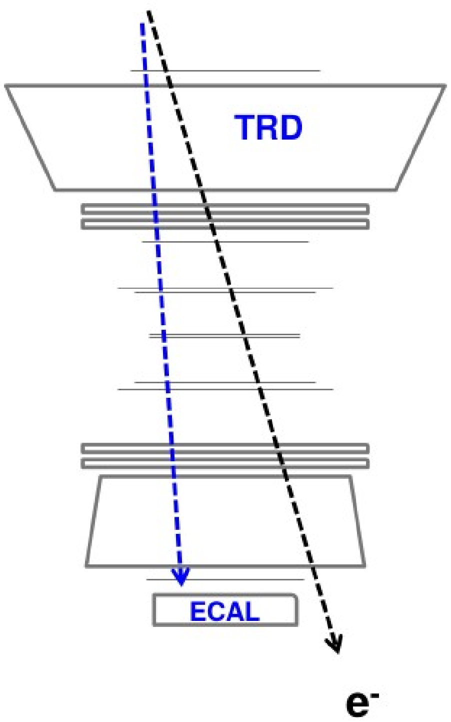
## Ground Operations

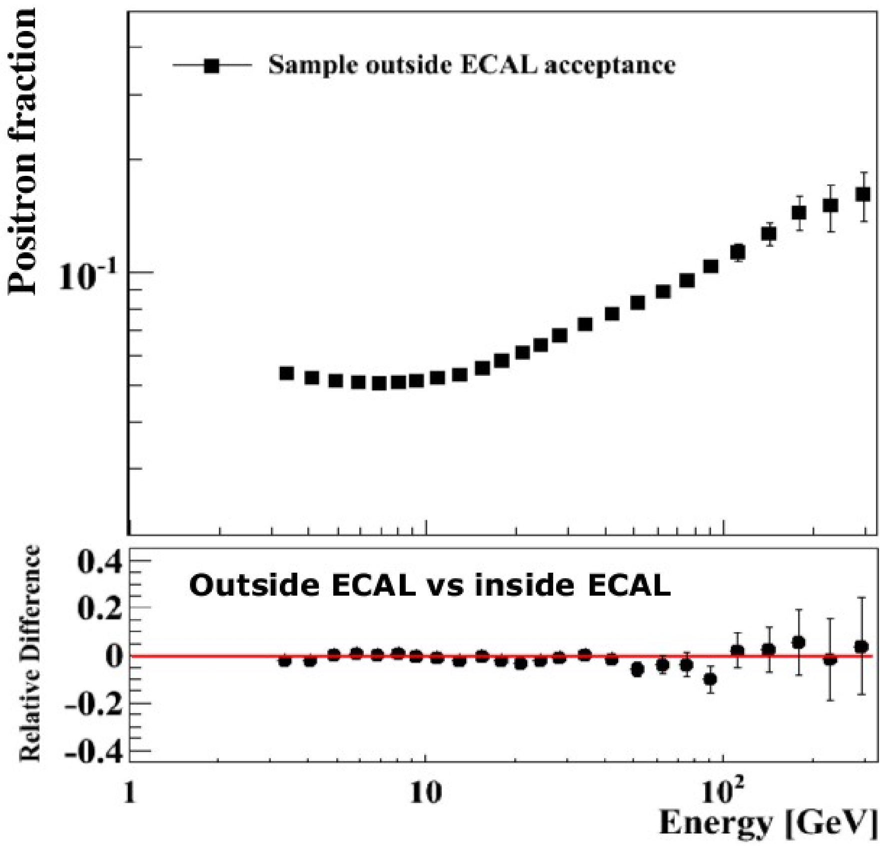
**S-Band**
**Low Rate (up & down):**
**Commanding: 1 Kbit/s**
**Monitoring: 30 Kbit/s**



# VERIFICATION OF POSITRON FRACTION

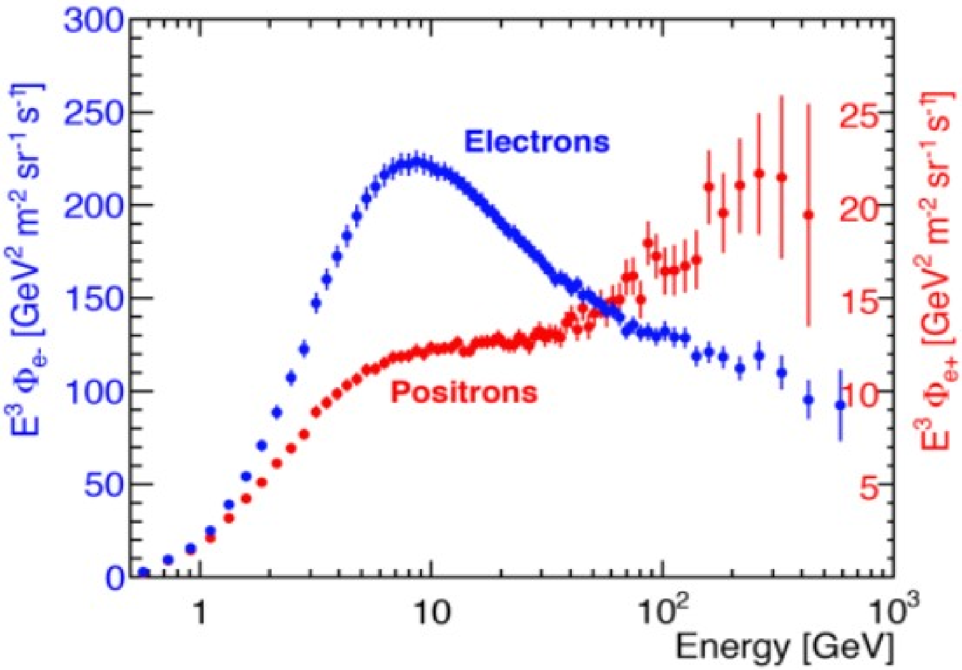
Using two independent samples:
Positron fraction analysis with TRD only

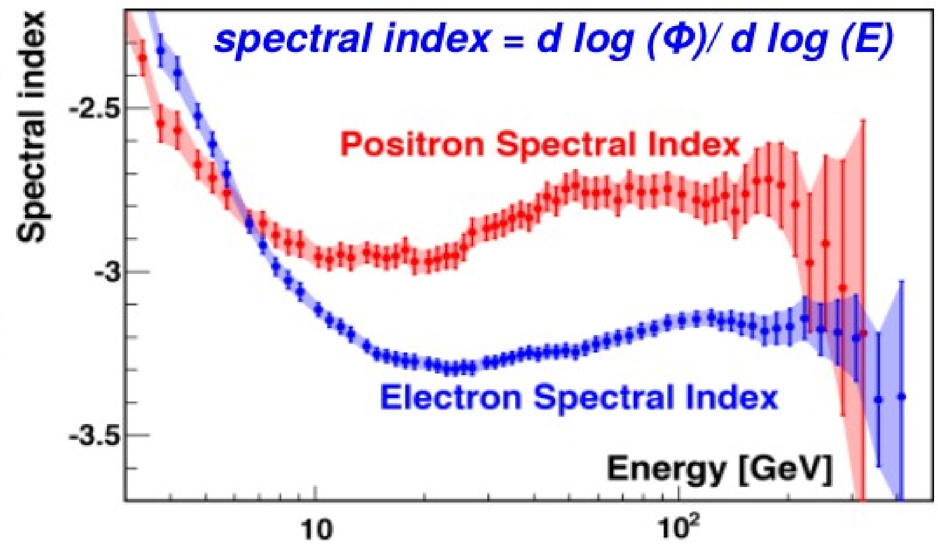



Good agreement between TRD only and full sample.

# ELECTRON AND POSITRON FLUXES



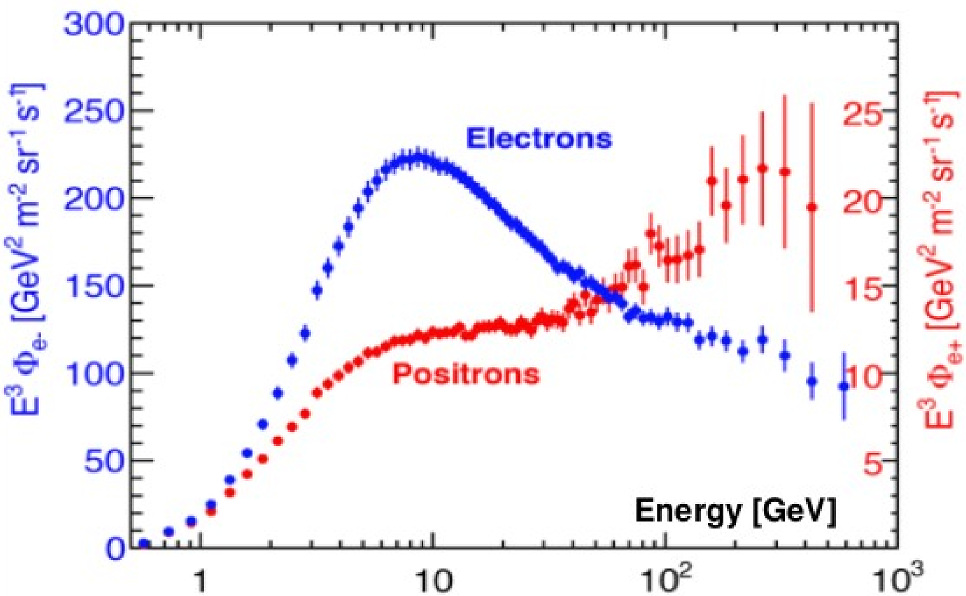



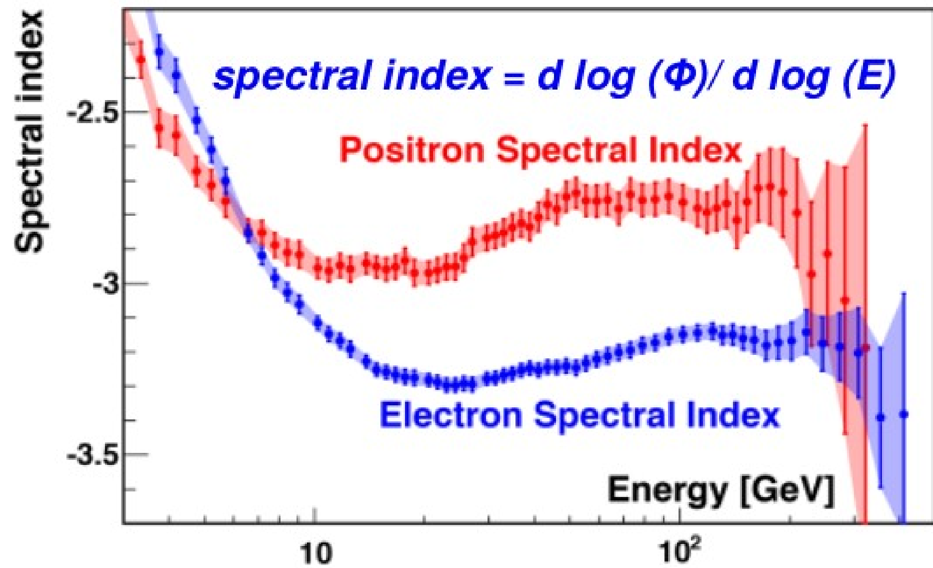

**Phys. Rev. Lett. 113, 121102 (Sept. 2014)**

# ELECTRON AND POSITRON FLUXES

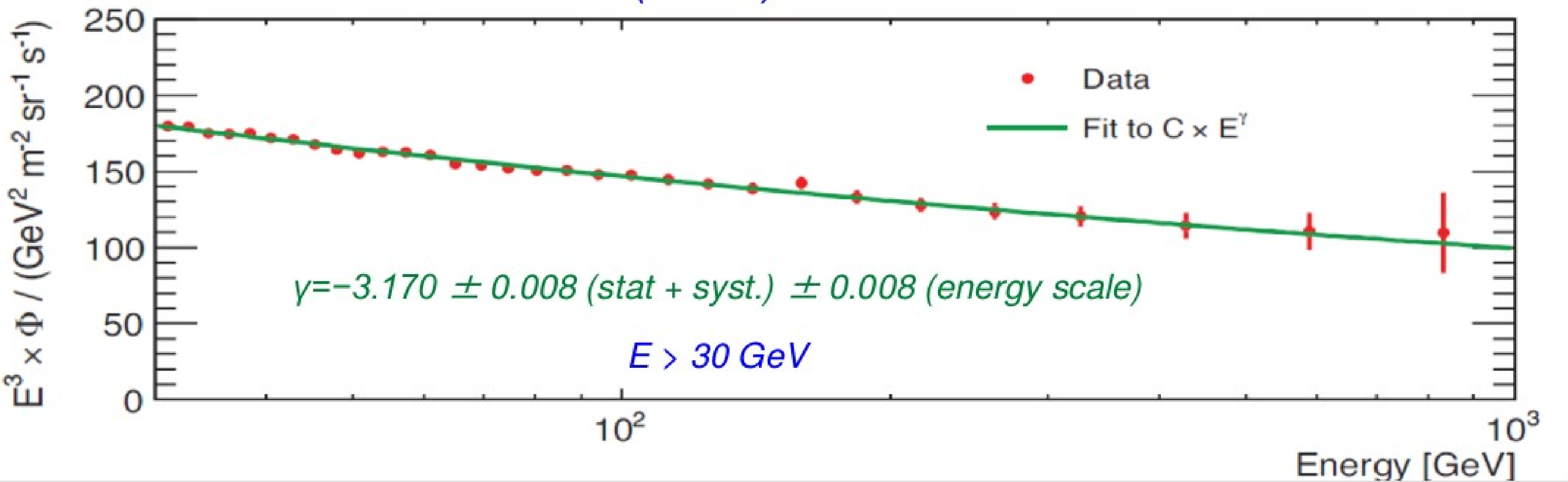
**Phys. Rev. Lett. 113, 121102 (Sept. 2014)**

Karlsruhe Institute of Technology




$$\Phi(e^{+}+e^{-}) = C\,E^{\gamma}$$



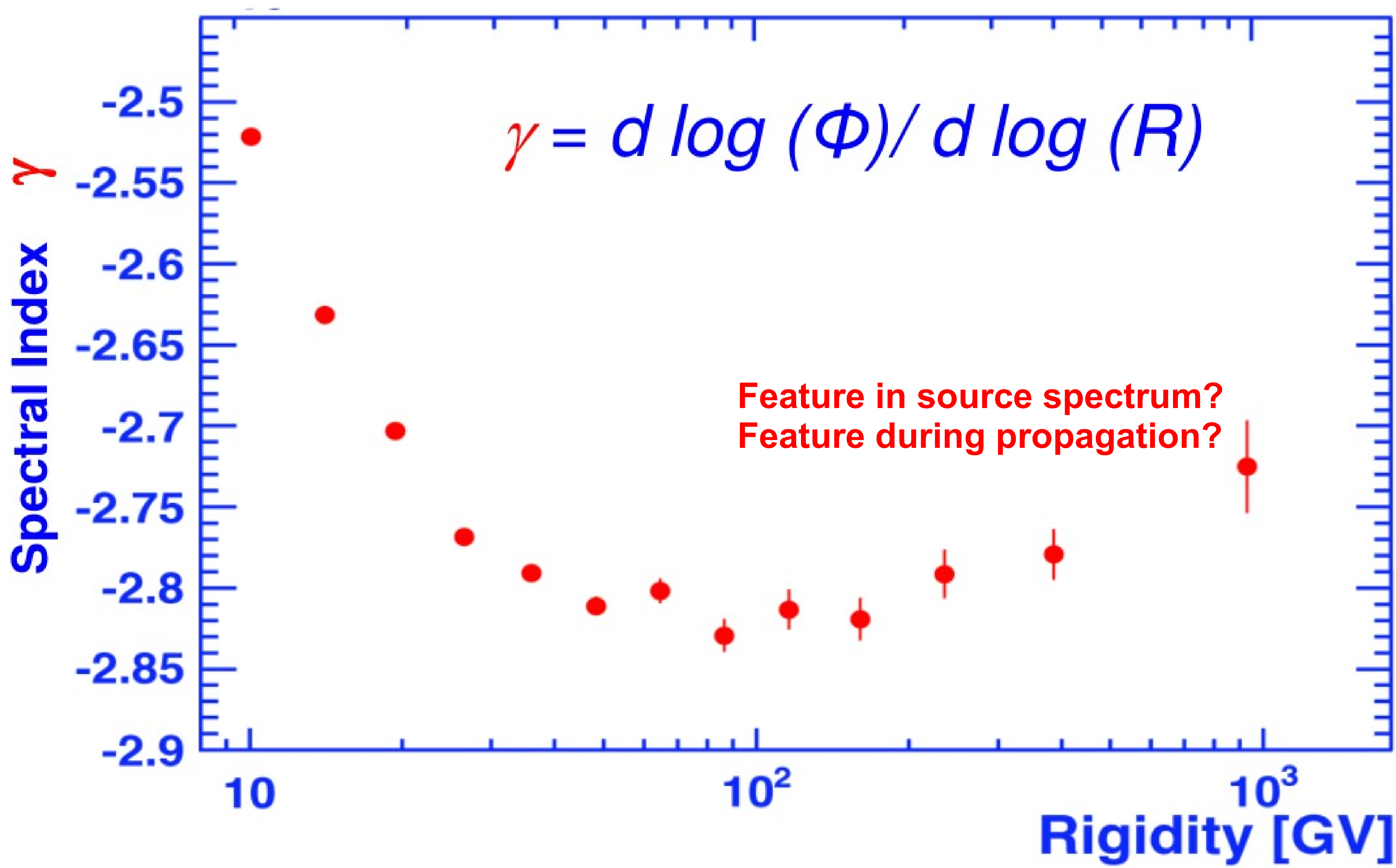
# SYSTEMATIC ERRORS ON THE PROTON FLUX

- $\sigma_{trig}$: trigger efficiency
- $\sigma_{acc}$: I) the acceptance and event selection
  II) background contamination
  III) geomagnetic cutoff
- $\sigma_{unf}$: I) unfolding
  II) rigidity resolution function
- $\sigma_{scale}$ : the absolute rigidity scale

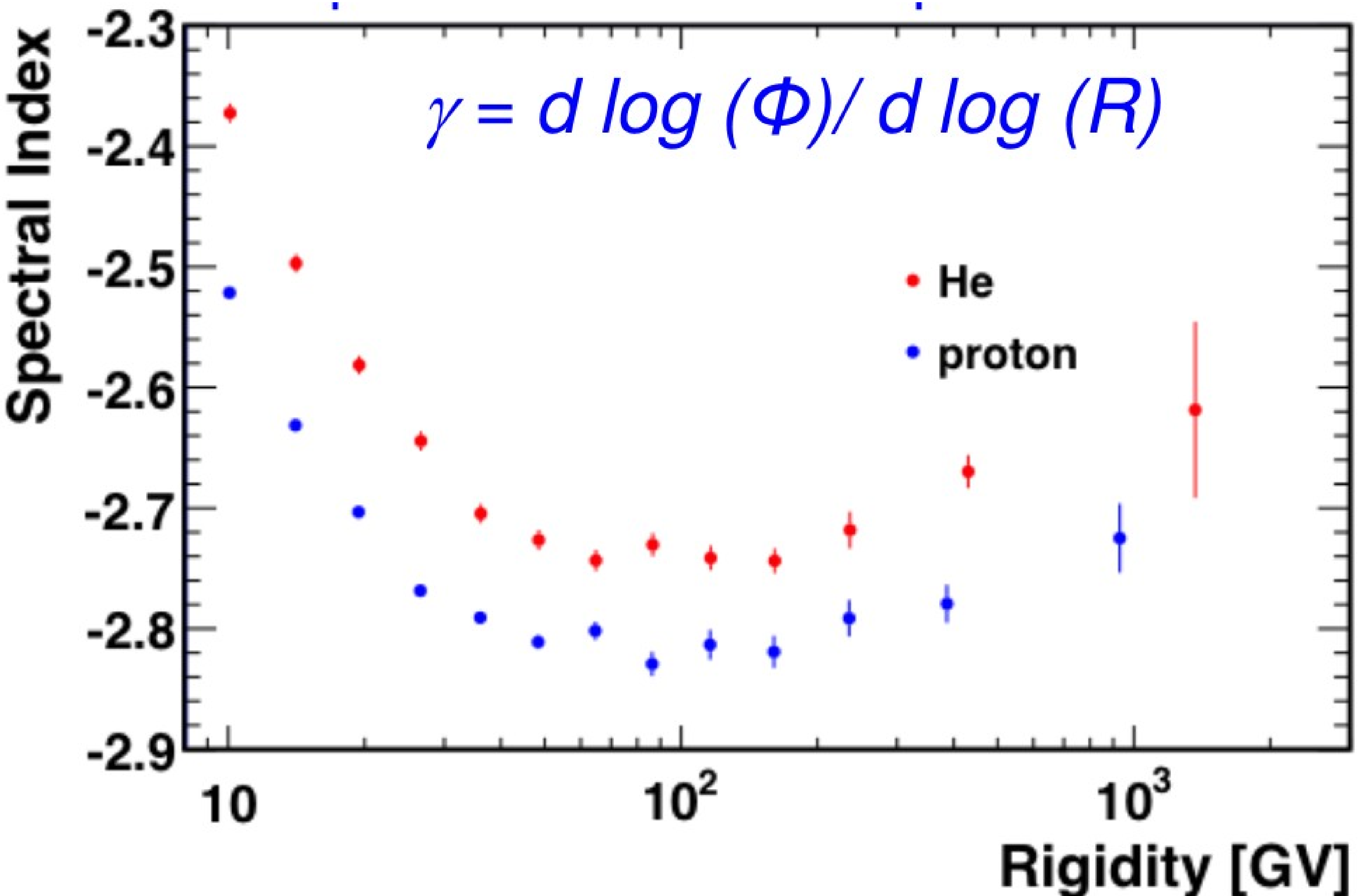
| Rigidity [GV] | $\Phi$ | $\sigma_{stat.}$ | $\sigma_{trig.}$ | $\sigma_{acc.}$ | $\sigma_{unf.}$ | $\sigma_{scale}$ | $\sigma_{syst.}$ |
|---|---|---|---|---|---|---|---|
| 100 – 108 | (4.085 | 0.007 | 0.006 | 0.040 | 0.035 | 0.022 | 0.058) $\times 10^{-2}$ |
| 108 – 116 | (3.294 | 0.007 | 0.005 | 0.033 | 0.028 | 0.018 | 0.047) $\times 10^{-2}$ |
| 116 – 125 | (2.698 | 0.006 | 0.004 | 0.027 | 0.023 | 0.016 | 0.039) $\times 10^{-2}$ |
| 125 – 135 | (2.174 | 0.005 | 0.004 | 0.022 | 0.019 | 0.013 | 0.032) $\times 10^{-2}$ |
| 135 – 147 | (1.727 | 0.004 | 0.003 | 0.018 | 0.016 | 0.011 | 0.026) $\times 10^{-2}$ |
| 147 – 160 | (1.358 | 0.003 | 0.003 | 0.014 | 0.013 | 0.009 | 0.021) $\times 10^{-2}$ |
| 160 – 175 | (1.065 | 0.003 | 0.002 | 0.011 | 0.010 | 0.007 | 0.017) $\times 10^{-2}$ |
| 175 – 192 | (8.212 | 0.023 | 0.017 | 0.087 | 0.079 | 0.059 | 0.133) $\times 10^{-3}$ |
| 192 – 211 | (6.299 | 0.019 | 0.014 | 0.068 | 0.062 | 0.047 | 0.104) $\times 10^{-3}$ |
| 211 – 233 | (4.793 | 0.015 | 0.011 | 0.053 | 0.049 | 0.039 | 0.083) $\times 10^{-3}$ |
| 233 – 259 | (3.605 | 0.012 | 0.009 | 0.040 | 0.039 | 0.031 | 0.065) $\times 10^{-3}$ |
| 259 – 291 | (2.647 | 0.009 | 0.007 | 0.030 | 0.029 | 0.024 | 0.049) $\times 10^{-3}$ |
| 291 – 330 | (1.884 | 0.007 | 0.006 | 0.022 | 0.022 | 0.019 | 0.037) $\times 10^{-3}$ |

# AMS-02 PROTON FLUX SPECTRAL INDEX VARIATION:

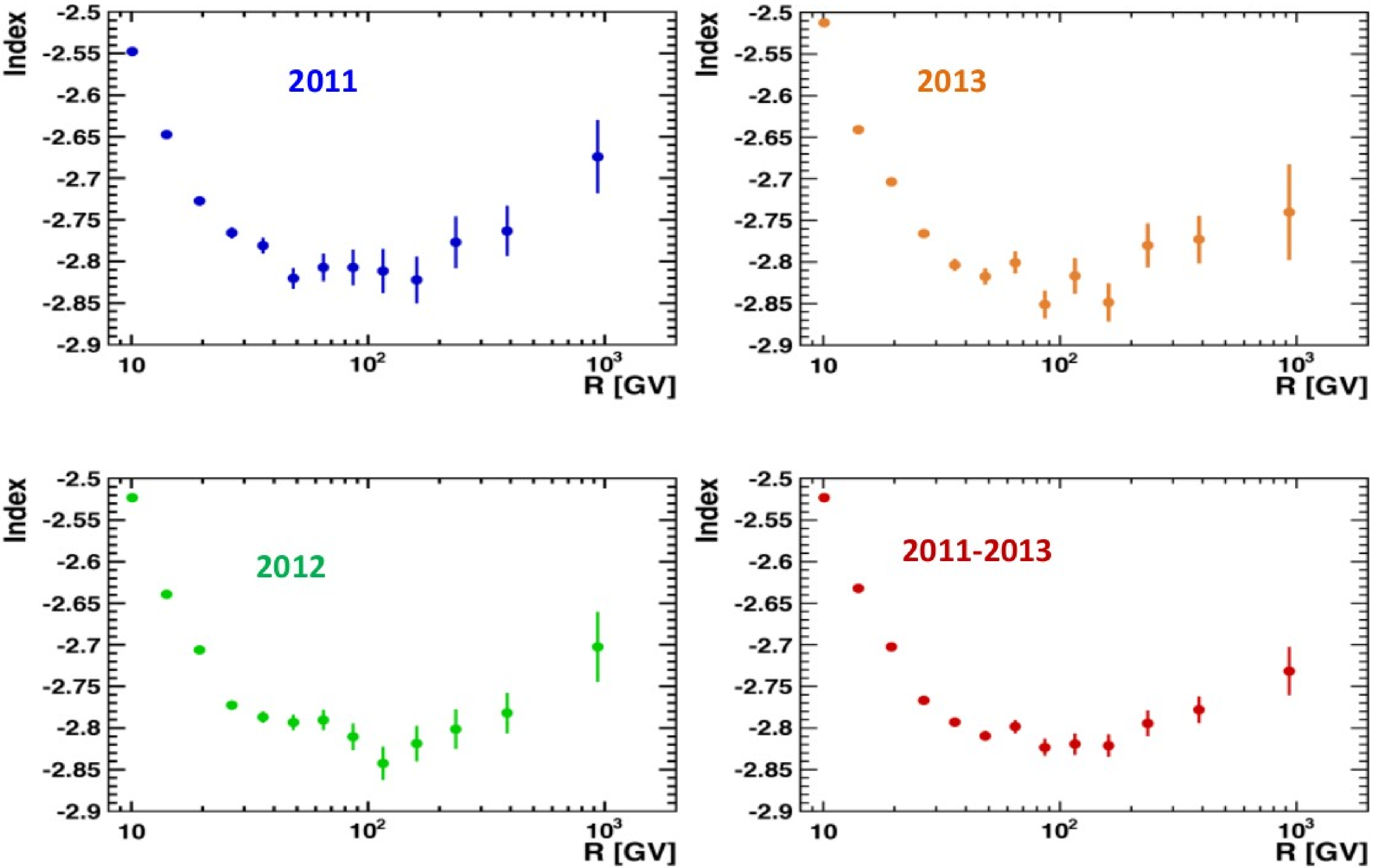
Model independent measurement of spectral index



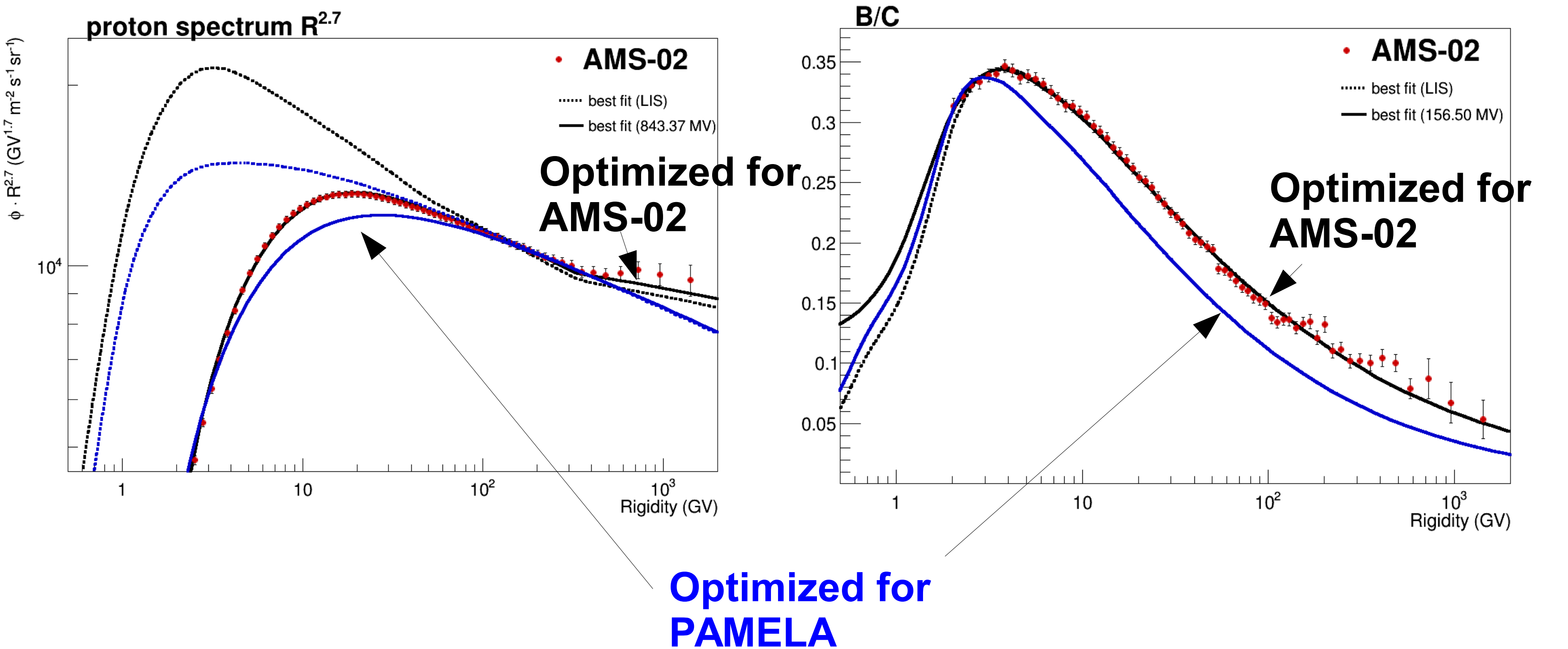
# PROTONS AND HELIUM: SPECTRAL INDEX



# SPECTRAL INDEX OF THE PROTON FLUX FOR 2011-2013



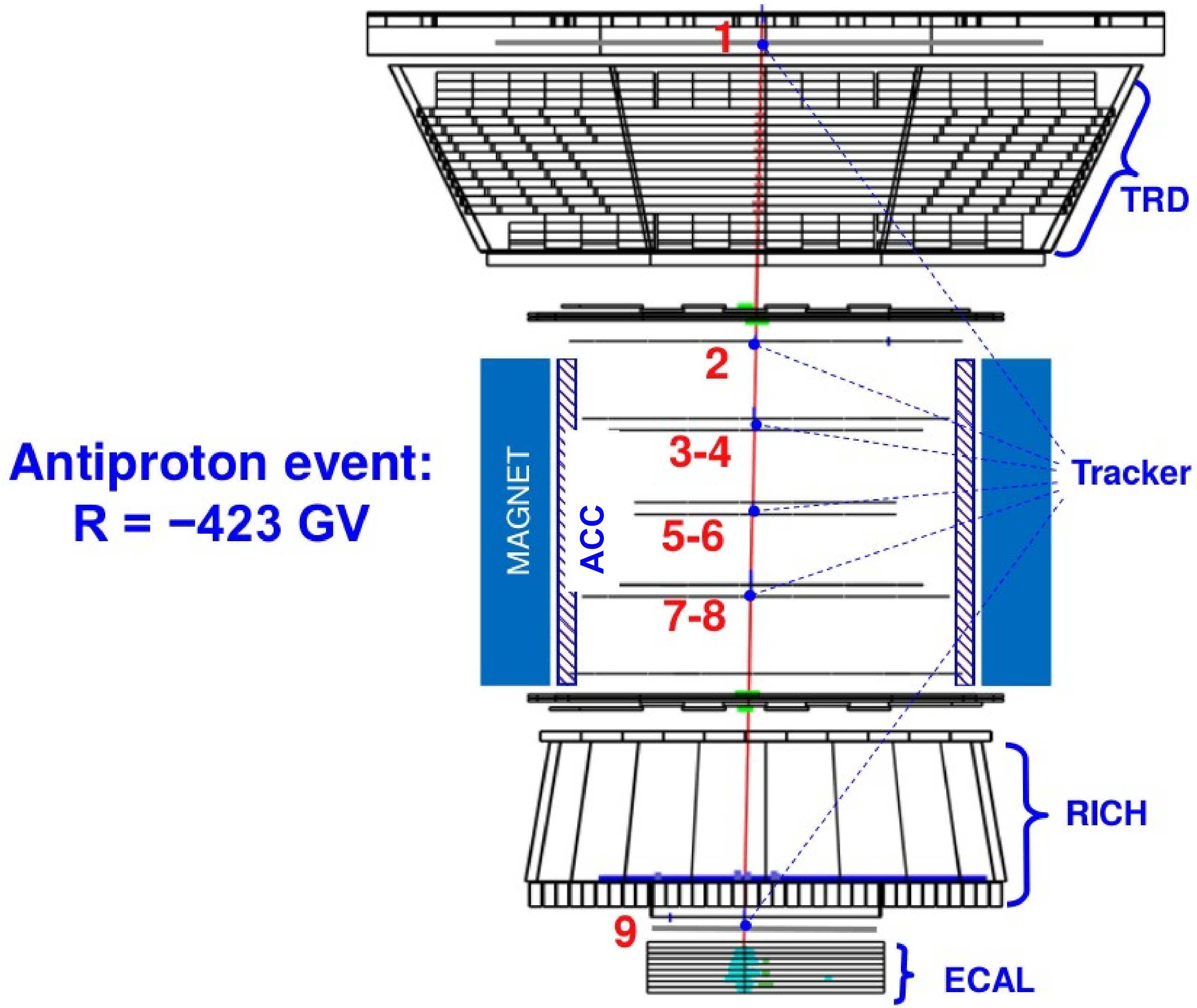
# TRANSPORT MODELS IN THE AMS-02 ERA






Iris Gebauer
Institut für Experimentelle Kernphysik

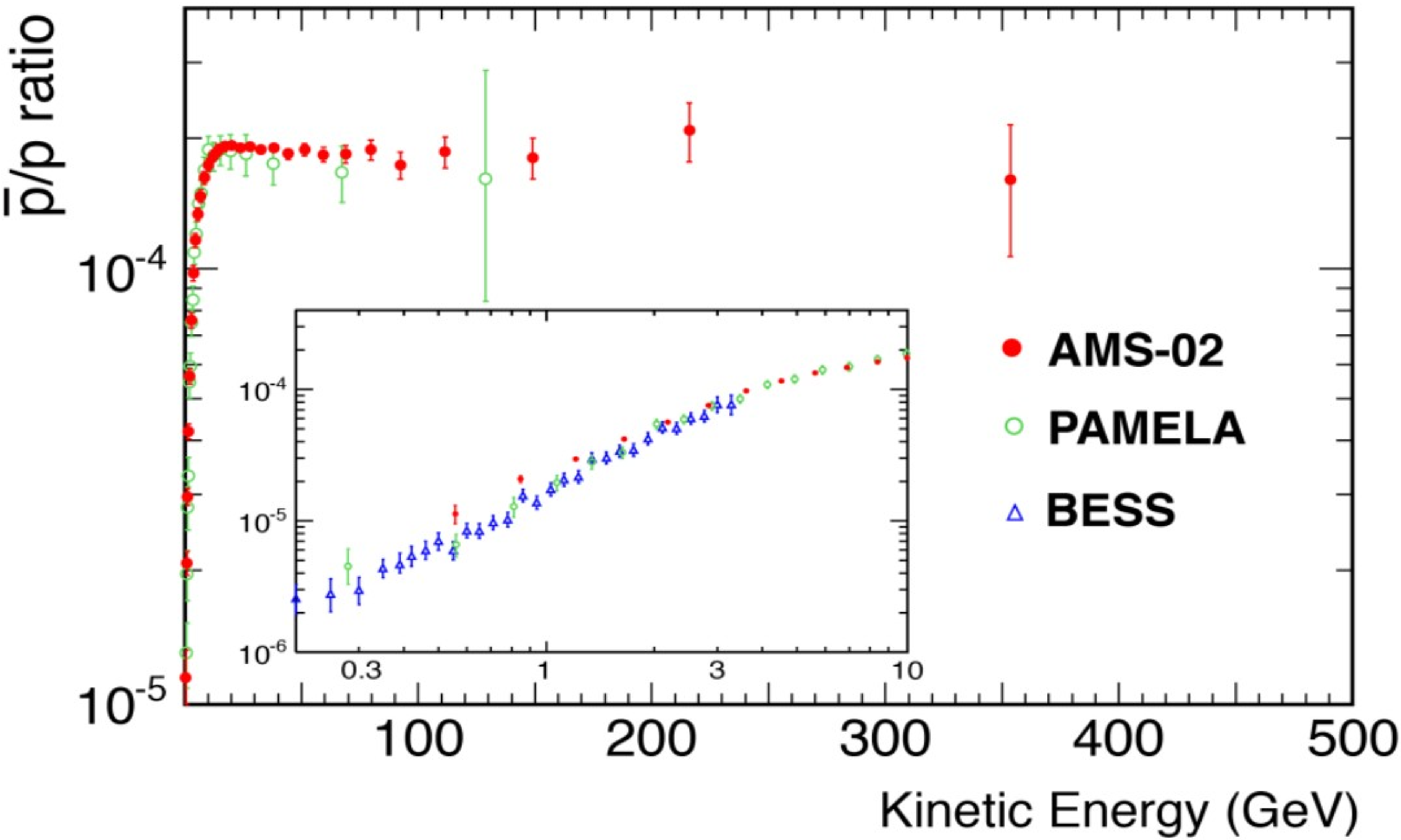
ANTIPROTON/PROTON RATIO





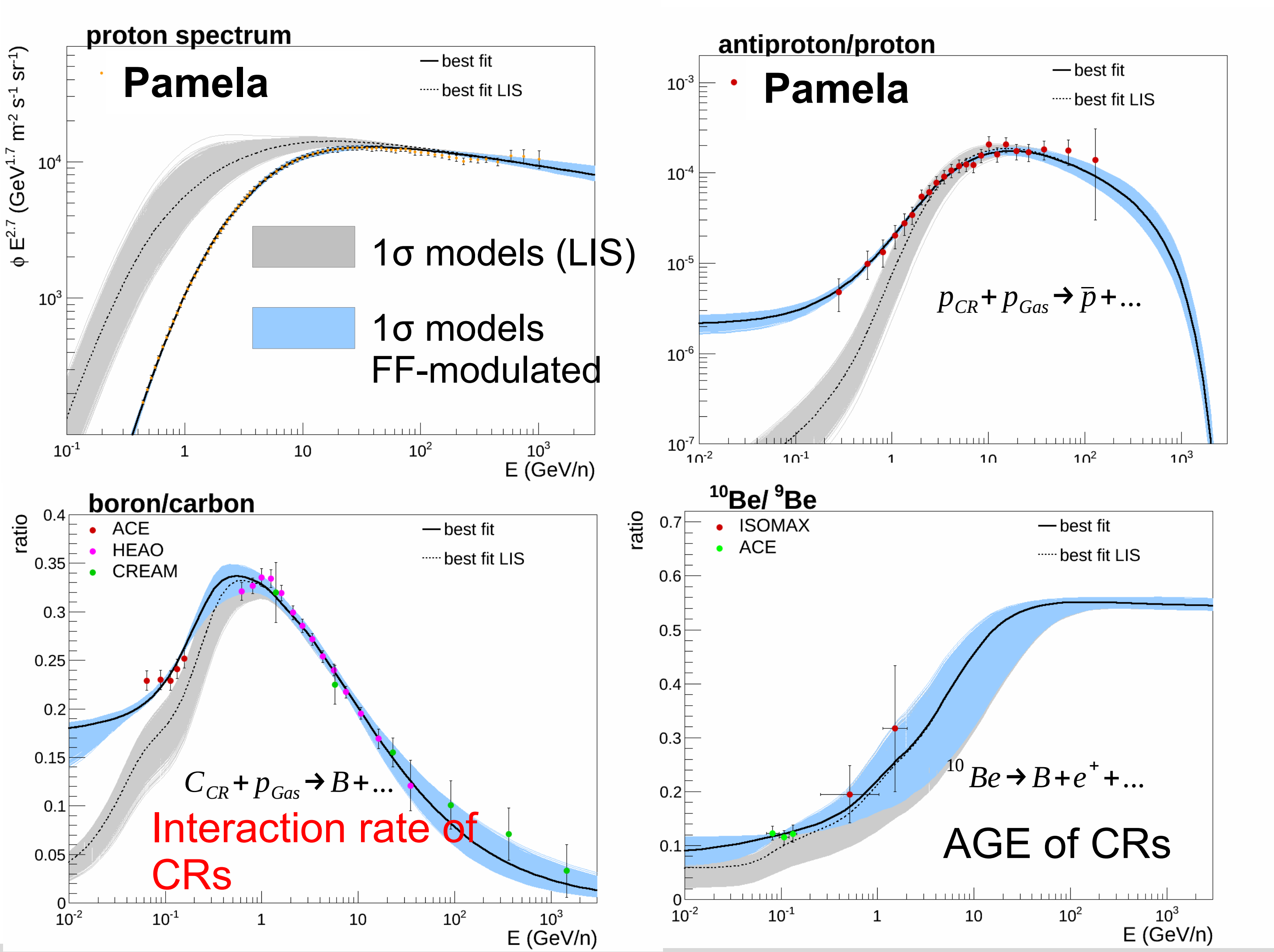

Iris Gebauer
Institut für Experimentelle Kernphysik

# ANTIPROTON-PROTON RATIO



# WHAT DO WE LEARN FROM THE NEW DATA?

Models based on 15 mio. DRAGON runs.

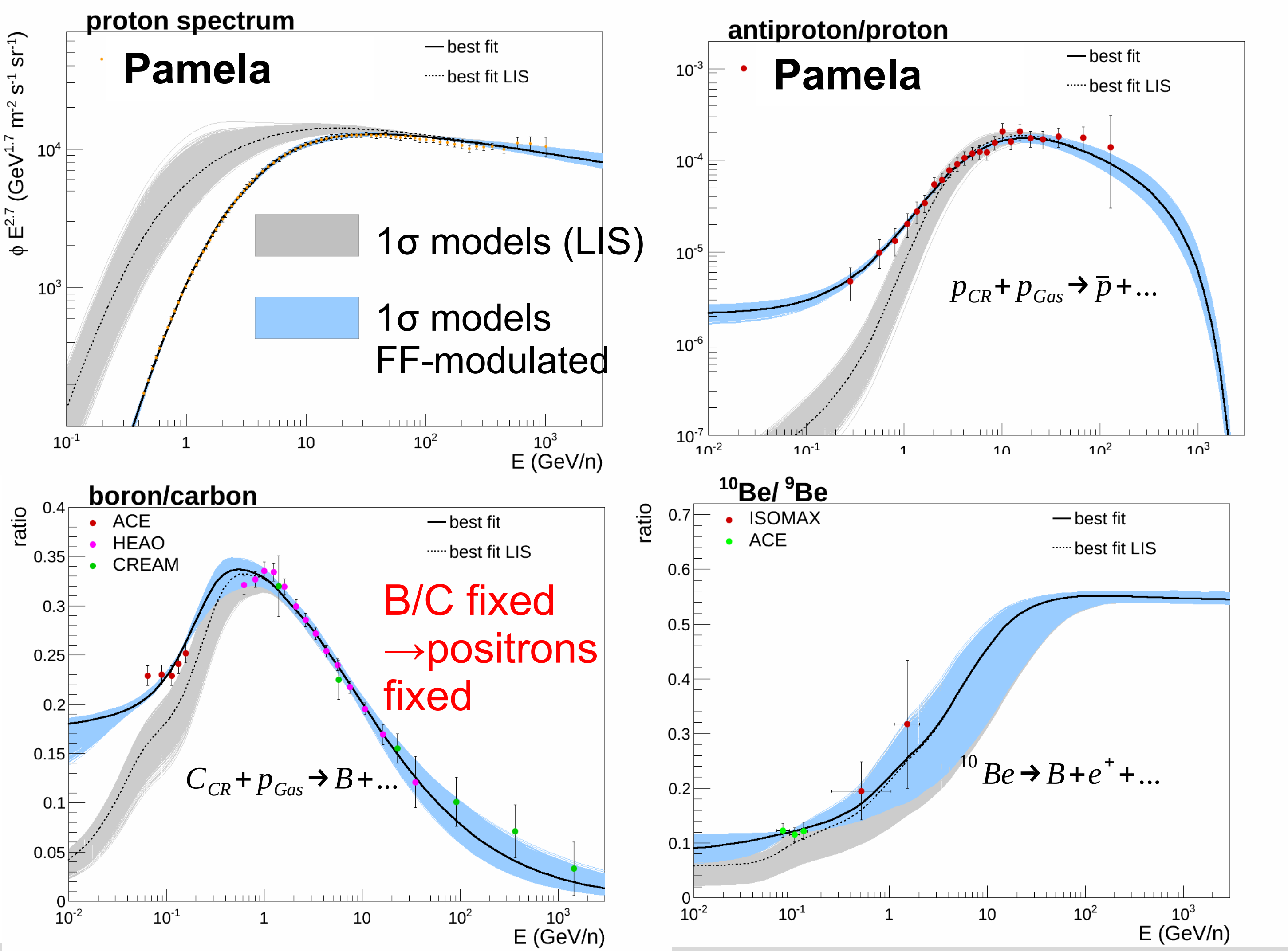




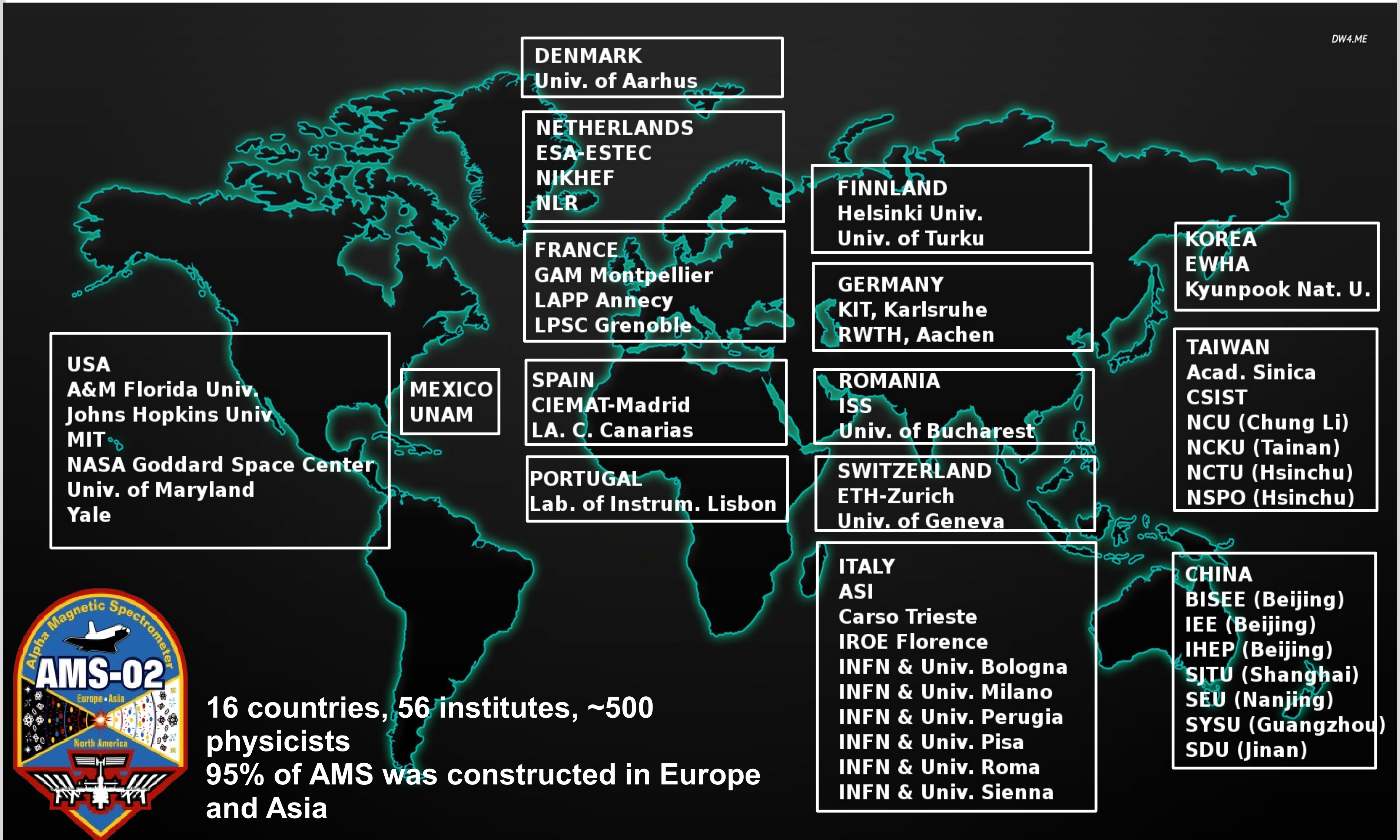

Iris Gebauer
Institut für Experimentelle Kernphysik

# WHAT DO WE LEARN FROM THE NEW DATA?

Models based on 15 mio. DRAGON runs.



# AMS-02 COLLABORATION




**DENMARK**
Univ. of Aarhus

**NETHERLANDS**
ESA-ESTEC
NIKHEF
NLR

**FRANCE**
GAM Montpellier
LAPP Annecy
LPSC Grenoble

**SPAIN**
CIEMAT-Madrid
I.A. C. Canarias

**PORTUGAL**
Lab. of Instrum. Lisbon

**USA**
A&M Florida Univ.
Johns Hopkins Univ
MIT
NASA Goddard Space Center
Univ. of Maryland
Yale

**MEXICO**
UNAM

**FINNLAND**
Helsinki Univ.
Univ. of Turku

**GERMANY**
KIT, Karlsruhe
RWTH, Aachen

**ROMANIA**
ISS
Univ. of Bucharest

**SWITZERLAND**
ETH-Zurich
Univ. of Geneva

**ITALY**
ASI
Carso Trieste
IROE Florence
INFN & Univ. Bologna
INFN & Univ. Milano
INFN & Univ. Perugia
INFN & Univ. Pisa
INFN & Univ. Roma
INFN & Univ. Sienna

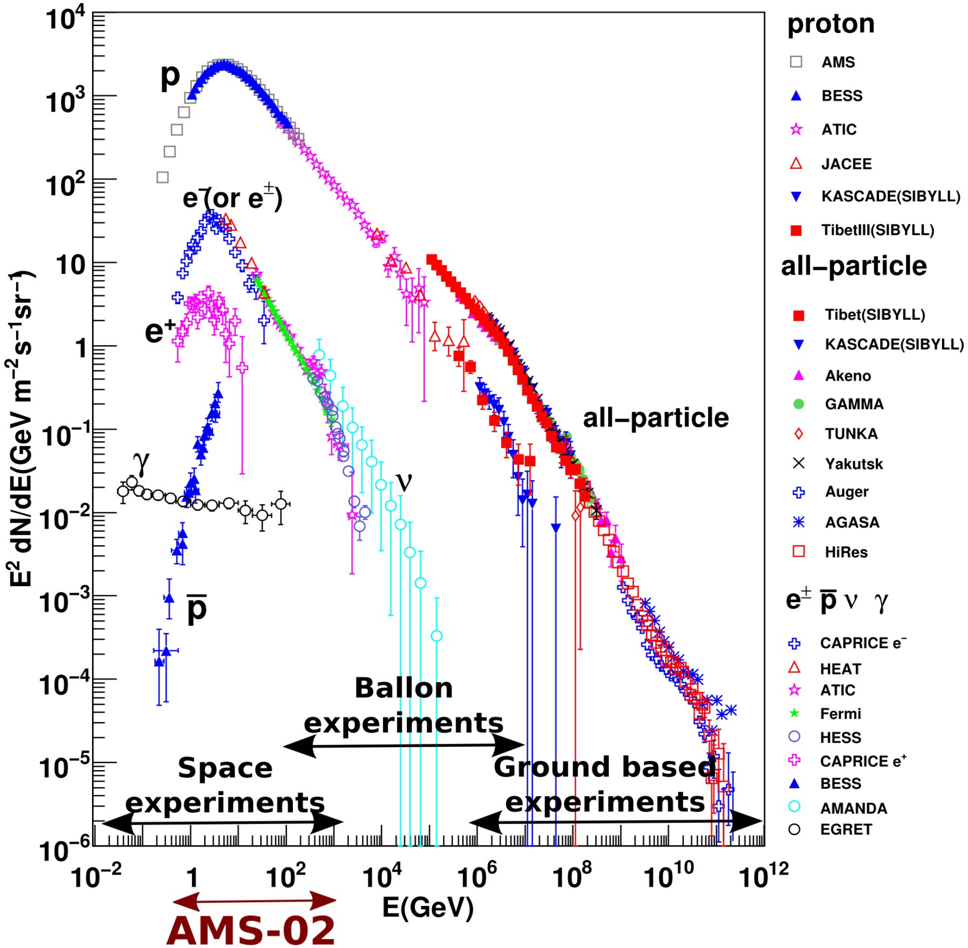
**KOREA**
EWHA
Kyunpook Nat. U.

**TAIWAN**
Acad. Sinica
CSIST
NCU (Chung Li)
NCKU (Tainan)
NCTU (Hsinchu)
NSPO (Hsinchu)

**CHINA**
BISEE (Beijing)
IEE (Beijing)
IHEP (Beijing)
SJTU (Shanghai)
SEU (Nanjing)
SYSU (Guangzhou)
SDU (Jinan)

16 countries, 56 institutes, ~500 physicists
95% of AMS was constructed in Europe and Asia

# CHARGED COSMIC RAYS




Protons ~90% He ~10%, heavy nuclei (mainly C) ~1%, $e^-$ ~1%, traces of e+, anti-p, …

Power law:

$$\Phi(E)\,dE \propto E^{-\gamma}\,dE$$

$\gamma \approx 2.6 - 2.7$

$\gamma \approx 3$, $E > 10^{15}$eV



Iris Gebauer
Institut für Experimentelle Kernphysik