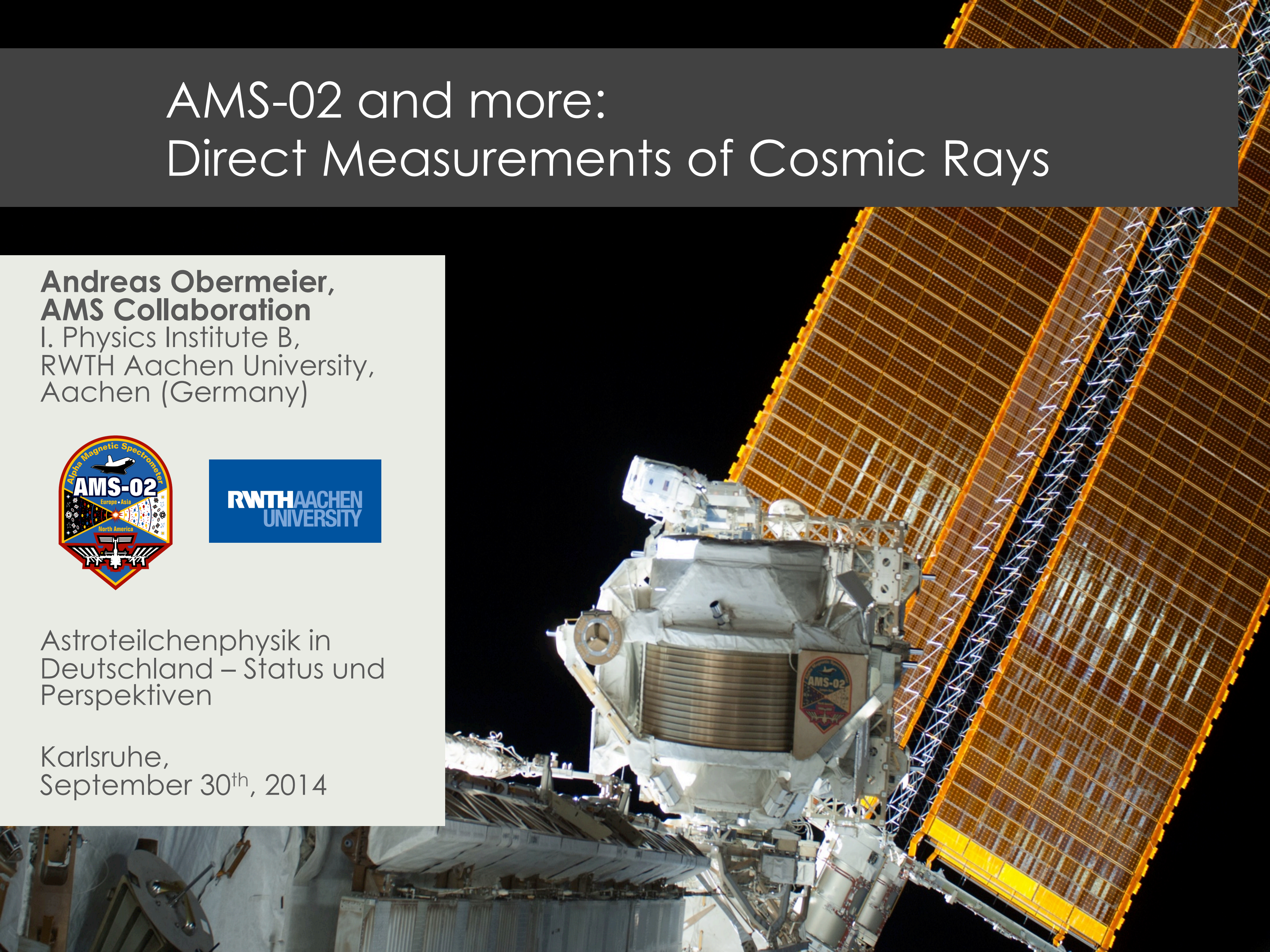

# AMS-02 and more:
# Direct Measurements of Cosmic Rays

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**AMS Collaboration**
I. Physics Institute B,
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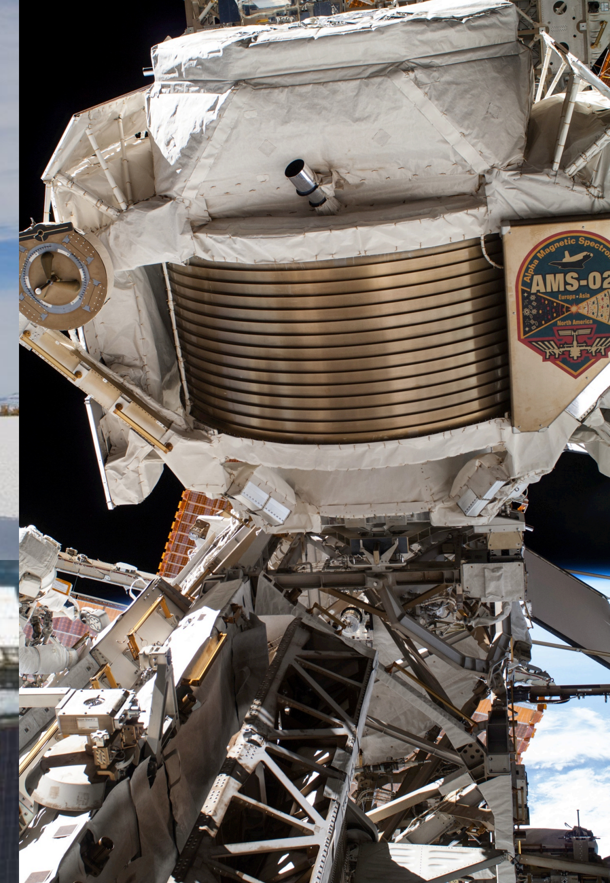
Aachen (Germany)

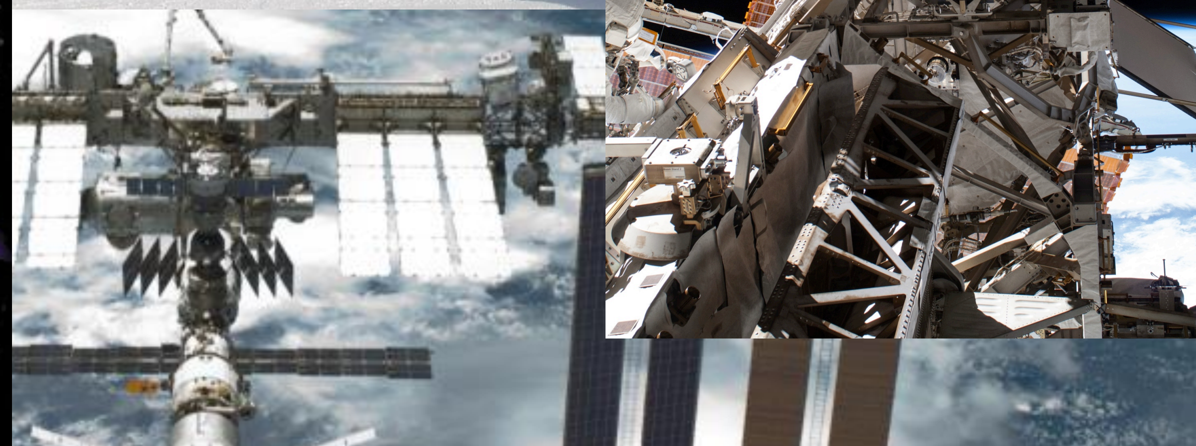
Astroteilchenphysik in Deutschland – Status und Perspektiven

Karlsruhe,
September 30th, 2014

# Direct Measurements of CR

- Conducted above the atmosphere
- Balloon or Space Experiments
- Limited: Size, Time, Weight, Power
- But: good Energy resolution, elemental or even isotopic detail



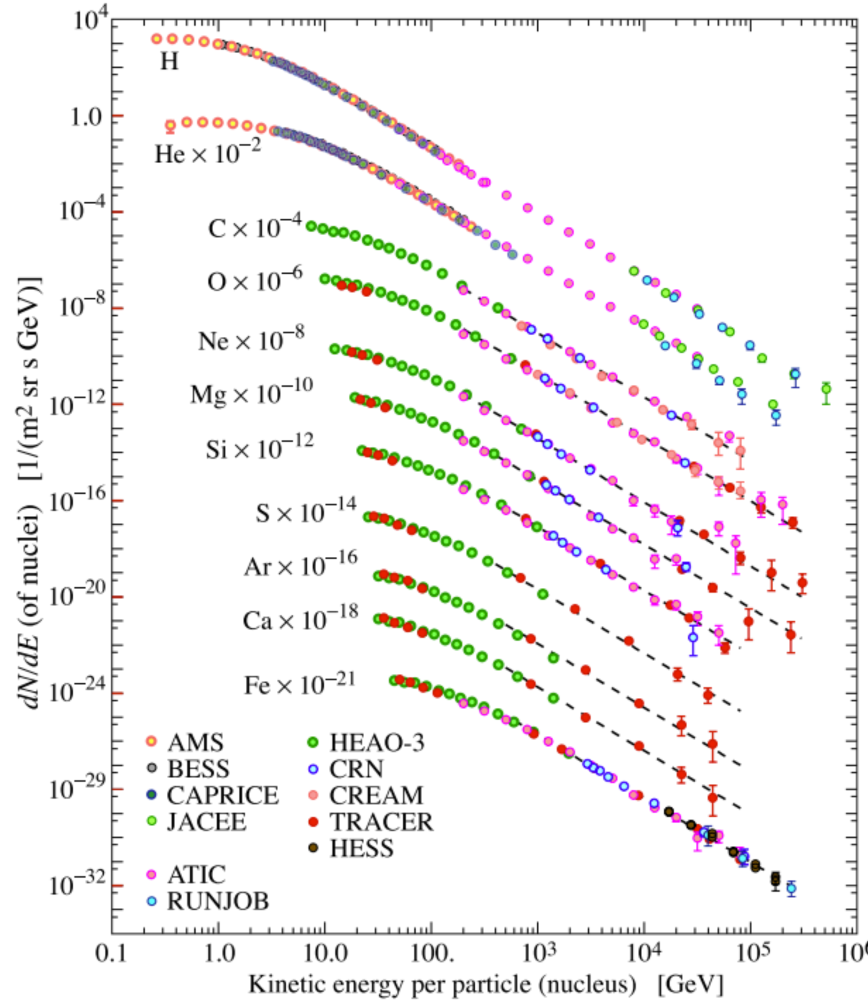


# Achievable Exposure

- Record circumpolar flight time (LDB):
  52 days (Super-TIGER)
- Total Exposure:
  ~ 350 m² sr days
- ULDB Flights might double that
- Expected Exposure for AMS-02 (10 years of operation time):
  200 m² sr days
- To reach 50 TeV/nucleon in energy spectra one needs about 4000 m² sr days

# The recent History: Energy Spectra

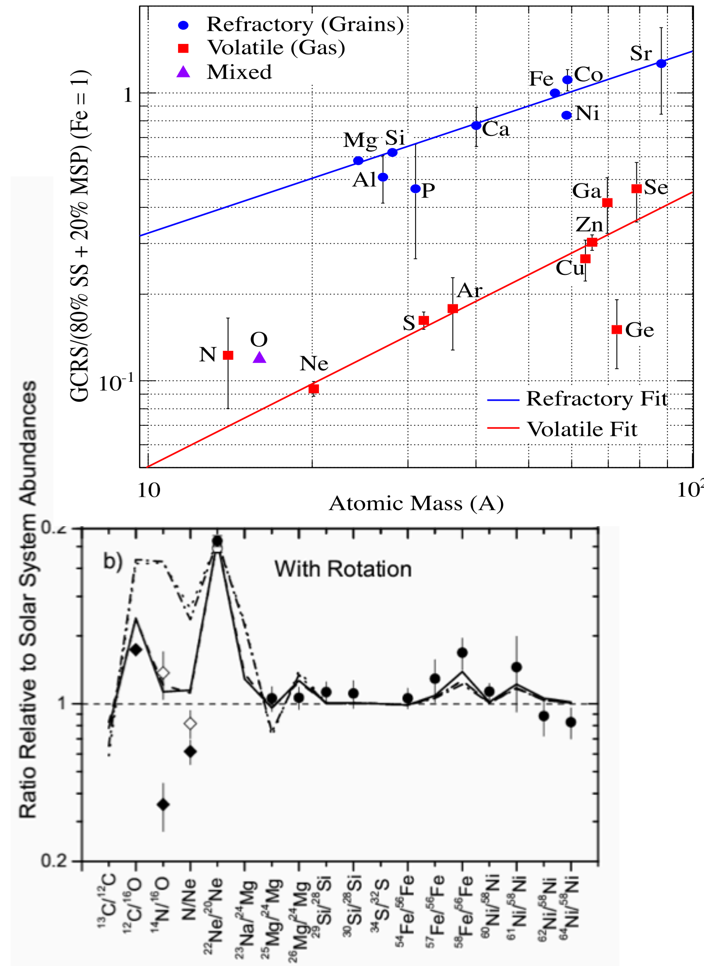
- Energy spectra of individual CR elements from H to Fe
- Up to a total energy of $10^5$ GeV
  Oxygen: 6 TeV/nucleon
  Iron: 4 TeV/nucleon
- Energy measurement with ECAL, TRD, magnetic Spectrometers, Cherenkov, direct Cherenkov (ICTs)




*P. Boyle & D. Müller, Particle Data Book (2011)*

# The recent History: TIGER/ACE-CRIS: OB origins

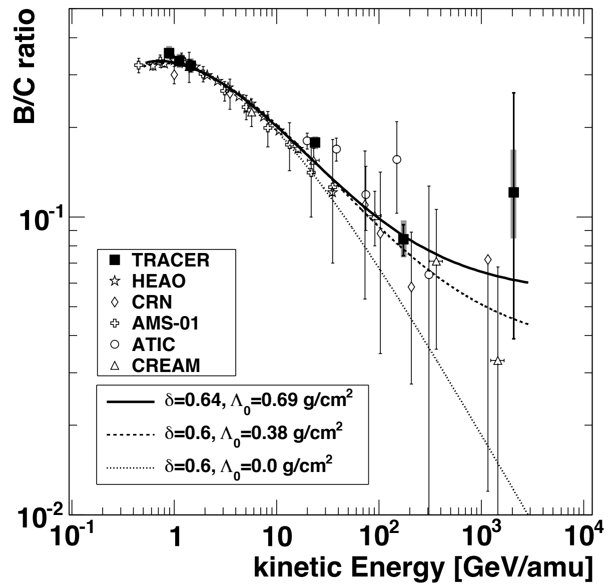
- Measured the relative abundance of CR elements/isotopes compared to the Solar System
- Abundances arrange themselves nicely when 20% admixture of heavy star ejecta is assumed
- Possible preferred origin of CR in OB associations

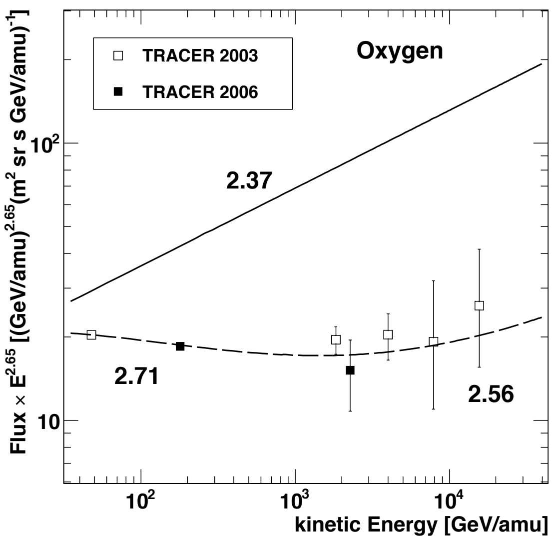



*B. Rauch et al., ApJ (2009) and W. Binns et al., Space Science Reviews (2007)*

# The recent History: TRACER: Galactic Propagation

- B/C ratio drops not to zero
- Residual path length or "nested" propagation models are preferred
- Impact on shape of source spectra

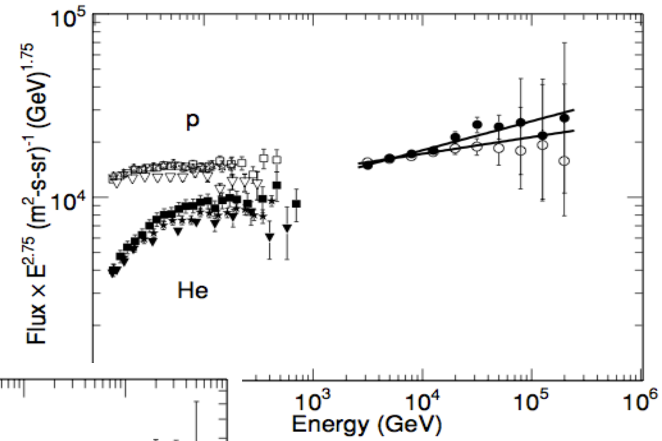


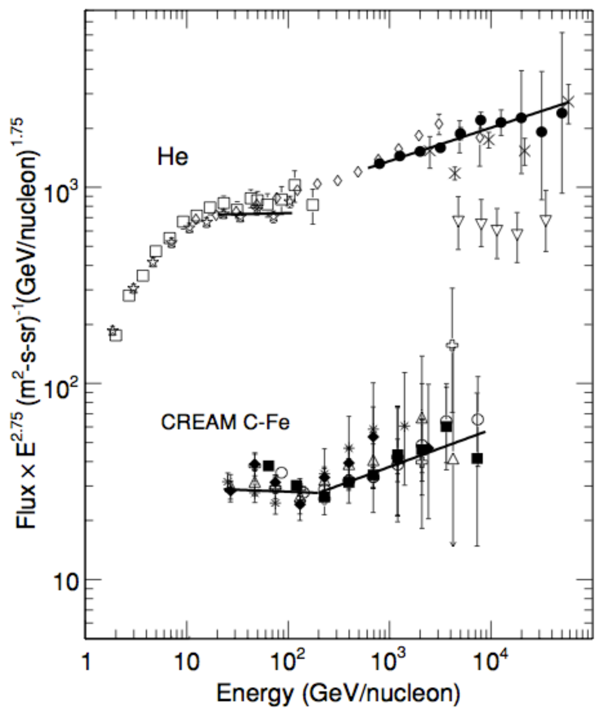




*A. Obermeier et al., ApJ (2011) and (2012)*

# The recent History:
# CREAM: "Discrepant" Hardening

- Different spectral indices for p and He at high energies
- Break in spectra of heavy nuclei at ~200 GeV/nucleon
- Hints at complex acceleration process at various sources

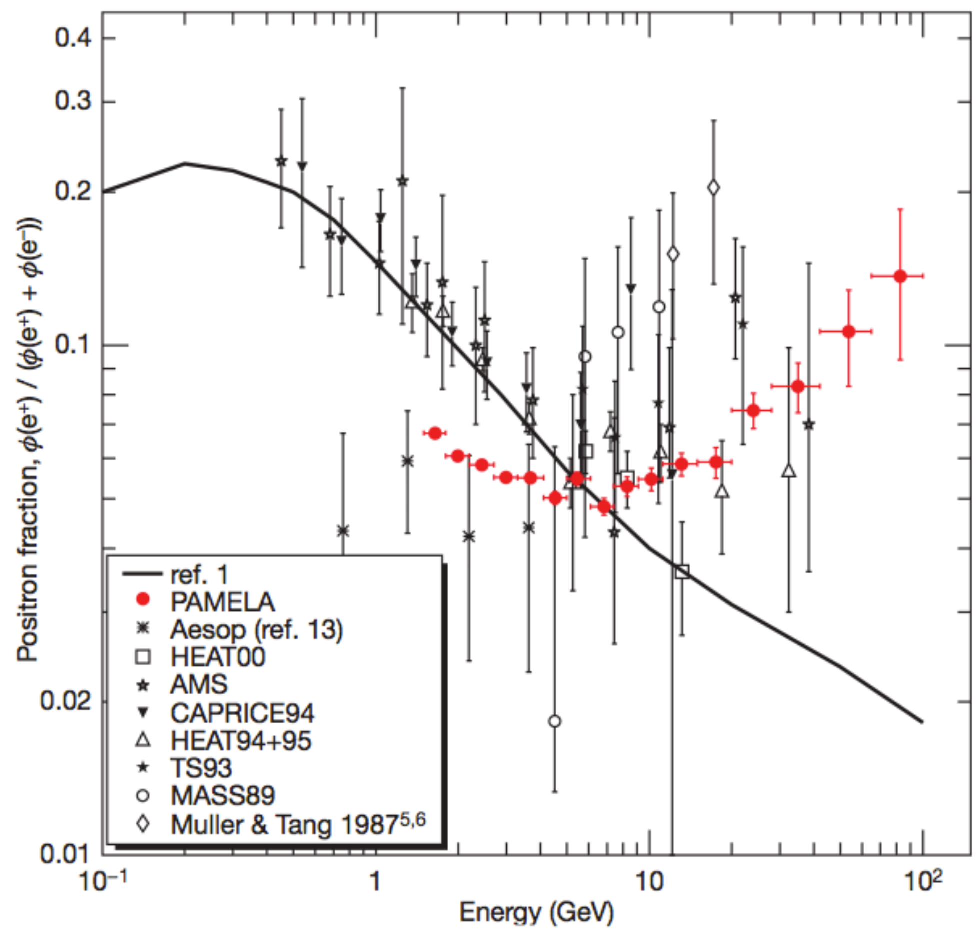



*H. Ahn et al., ApJ Letters (2010)*

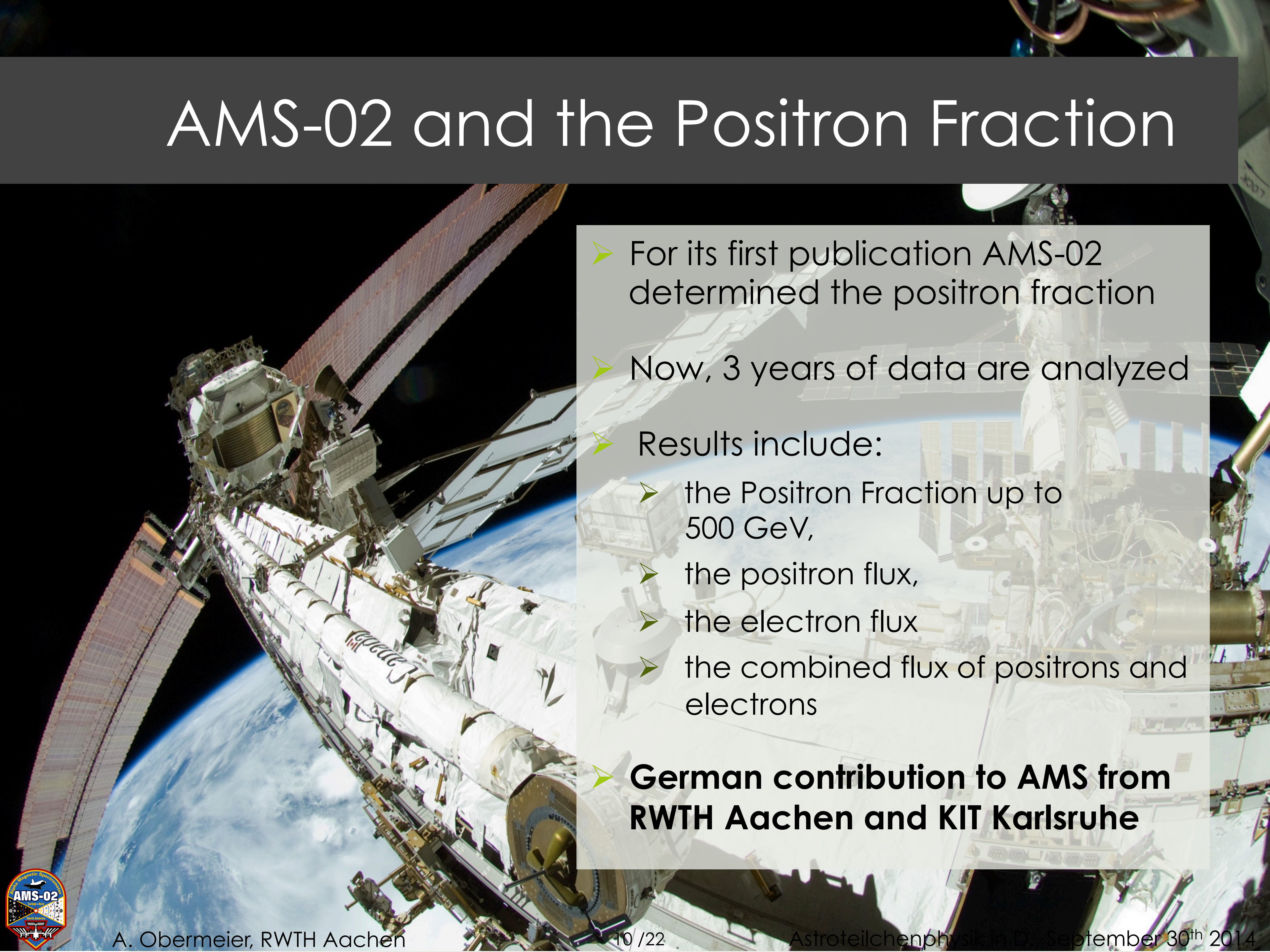
# The recent History: PAMELA: The Positron Fraction

- The Positron Fraction rises with energy
- Hinted at by previous experiments (e.g. HEAT), but first conclusive measurement by PAMELA
- Very difficult to explain by secondary production
- Possible primary sources: Pulsars or Dark Matter
- Sparked over 1000 citations!
- **German contribution to PAMELA from Siegen University**



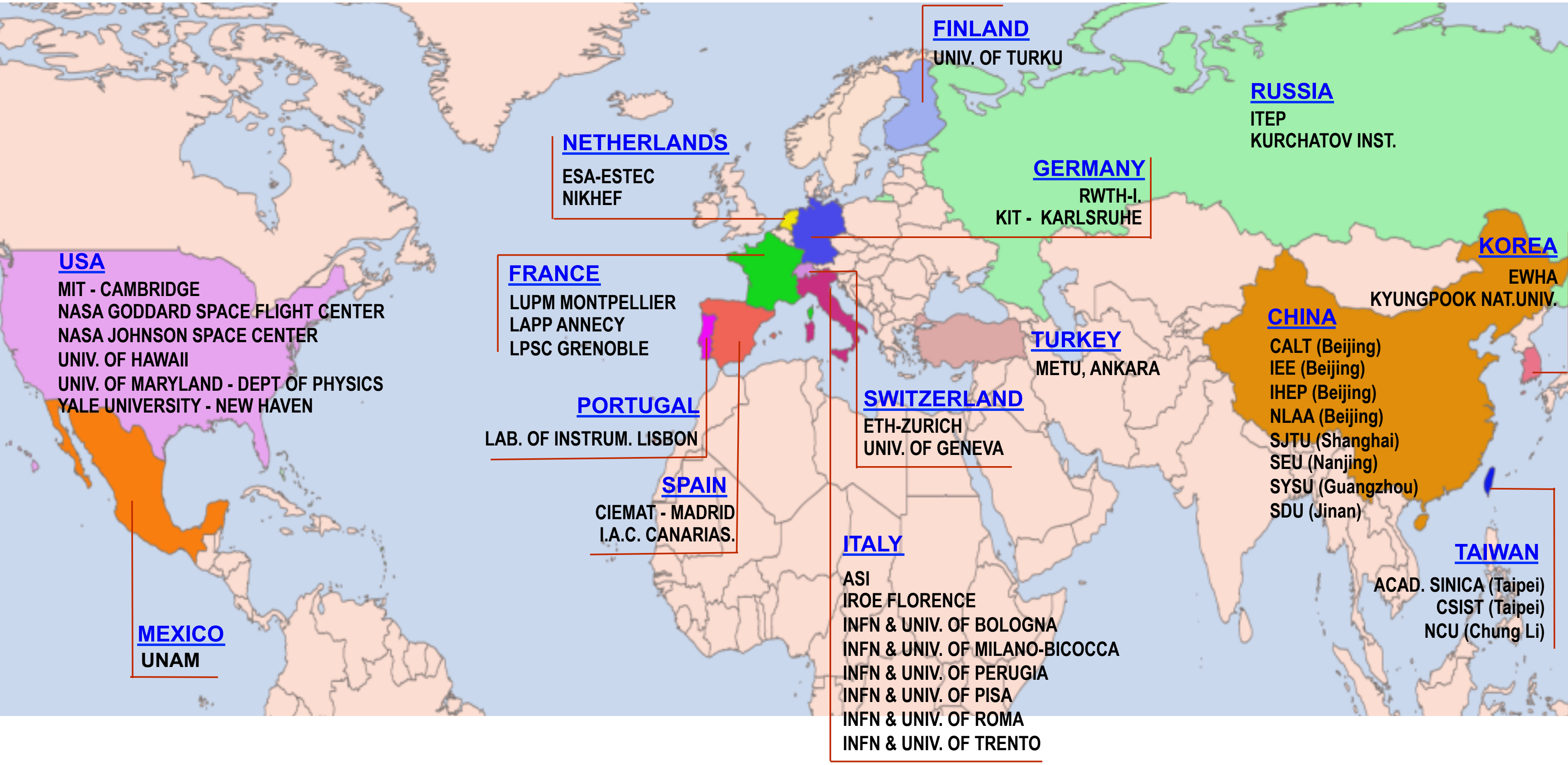

*O. Adriani et al., Nature (2009)*

# AMS-02 and the Positron Fraction

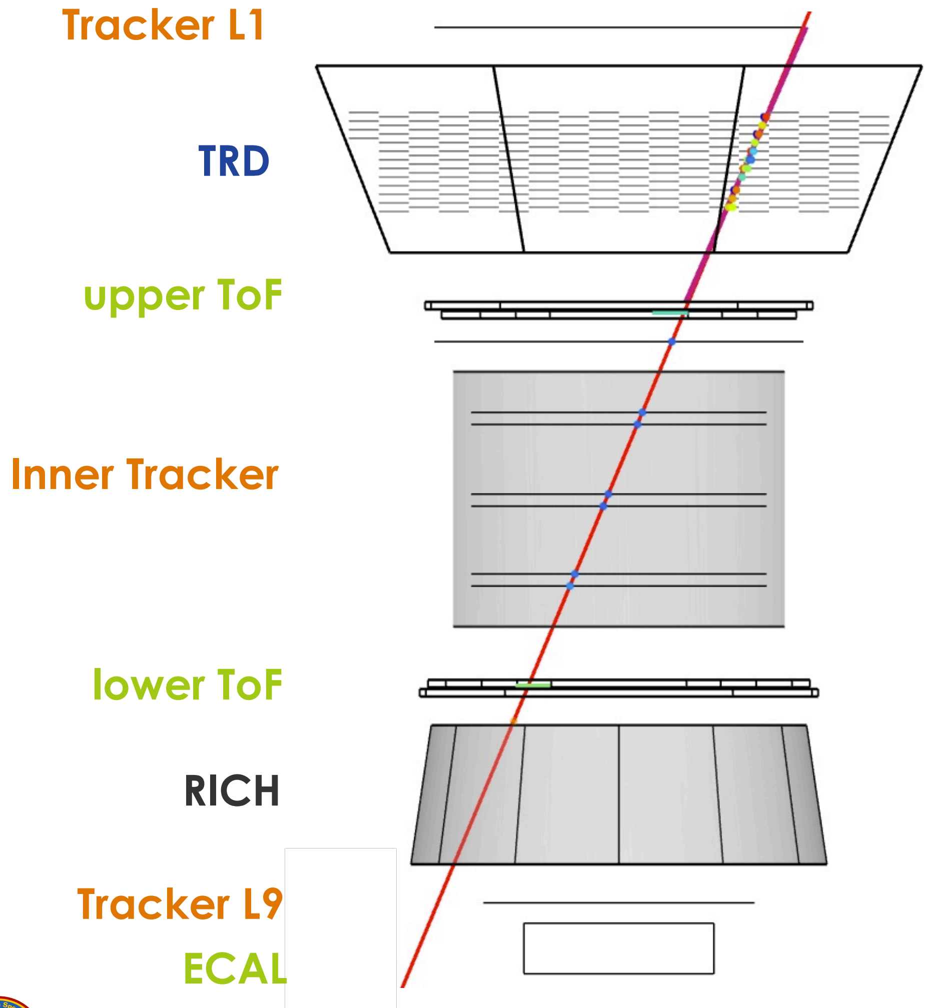


- For its first publication AMS-02 determined the positron fraction
- Now, 3 years of data are analyzed
- Results include:
  - the Positron Fraction up to 500 GeV,
  - the positron flux,
  - the electron flux
  - the combined flux of positrons and electrons
- **German contribution to AMS from RWTH Aachen and KIT Karlsruhe**

# The AMS Collaboration



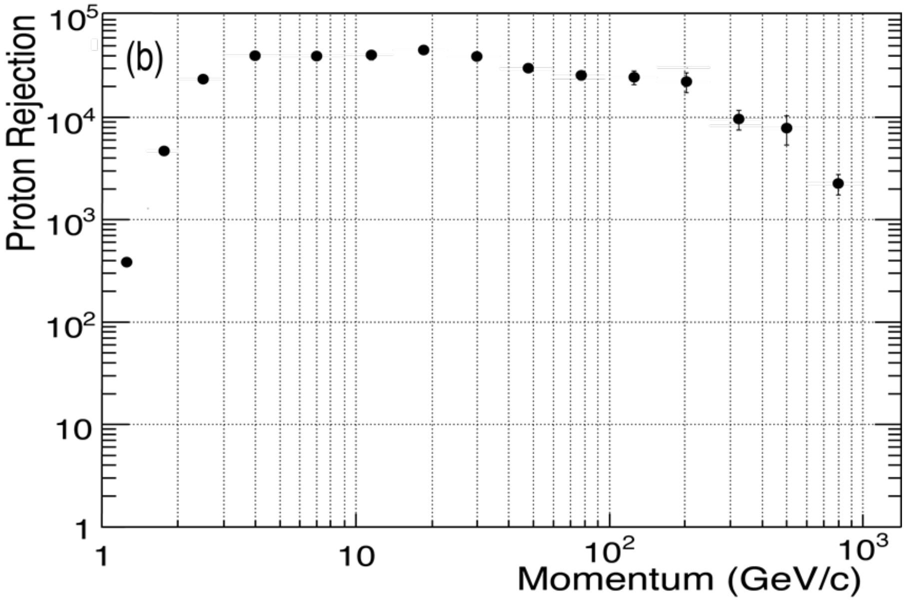
# The AMS-02 Detector



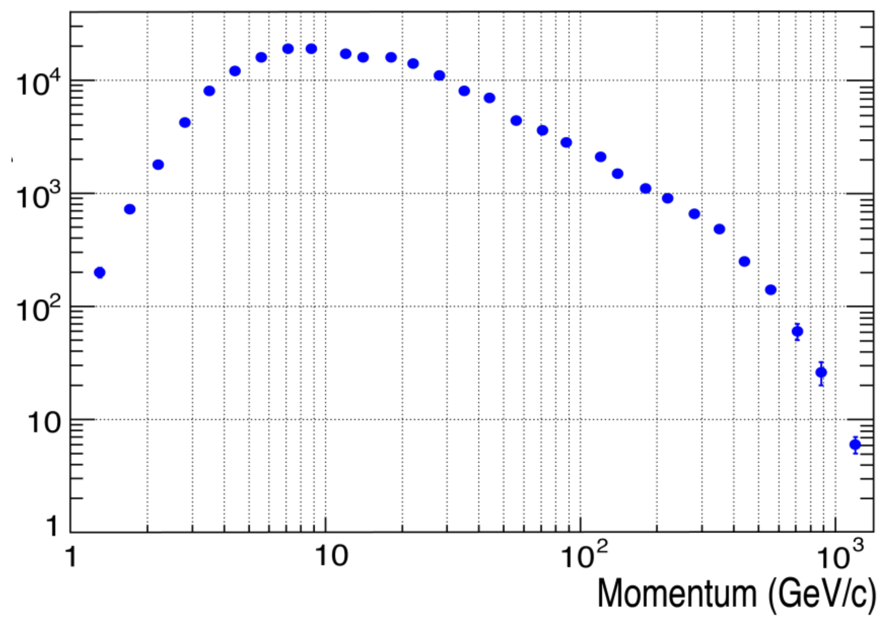

- ToF
  - Trigger, Velocity, Charge
- TRD
  - Heavy/light separation
- Tracker
  - precision Tracking, Charge, Charge-sign, Rigidity
- RICH
  - Velocity, Charge
- ECAL
  - Energy, heavy/light separation

# Proton Rejection of AMS-02

ECAL



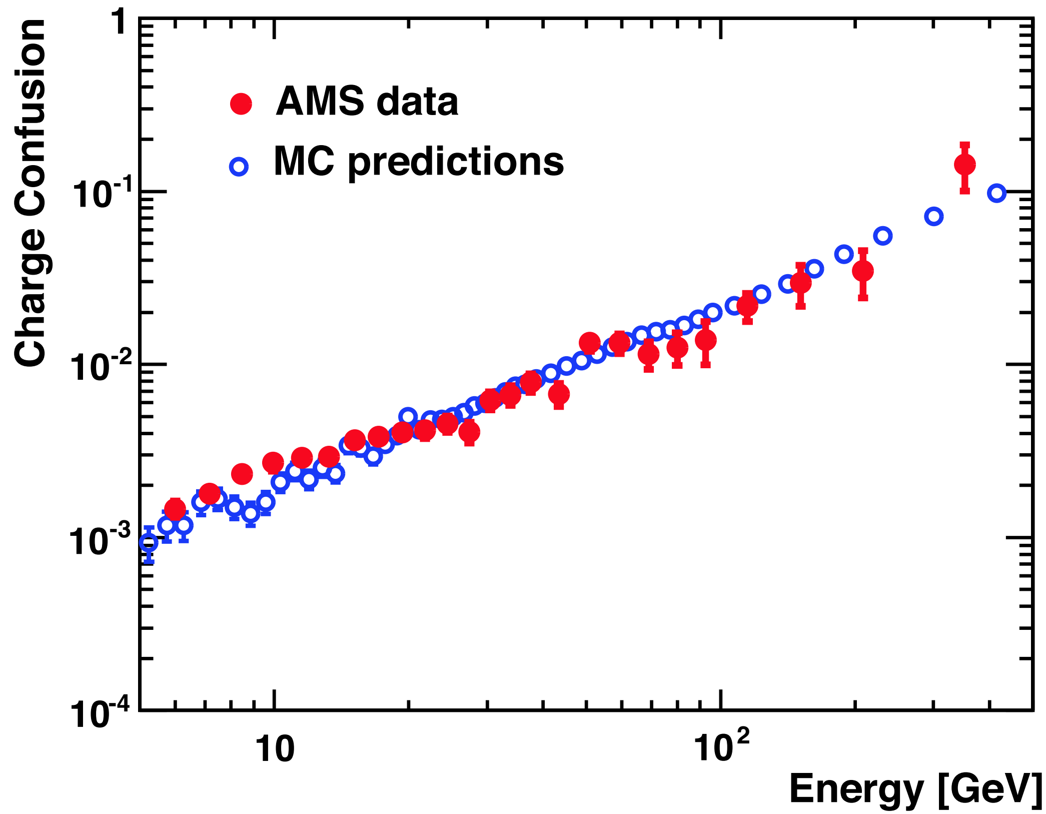

TRD




- At 90% electron efficiency
- Combined: Above $10^6$ up to 500 GeV

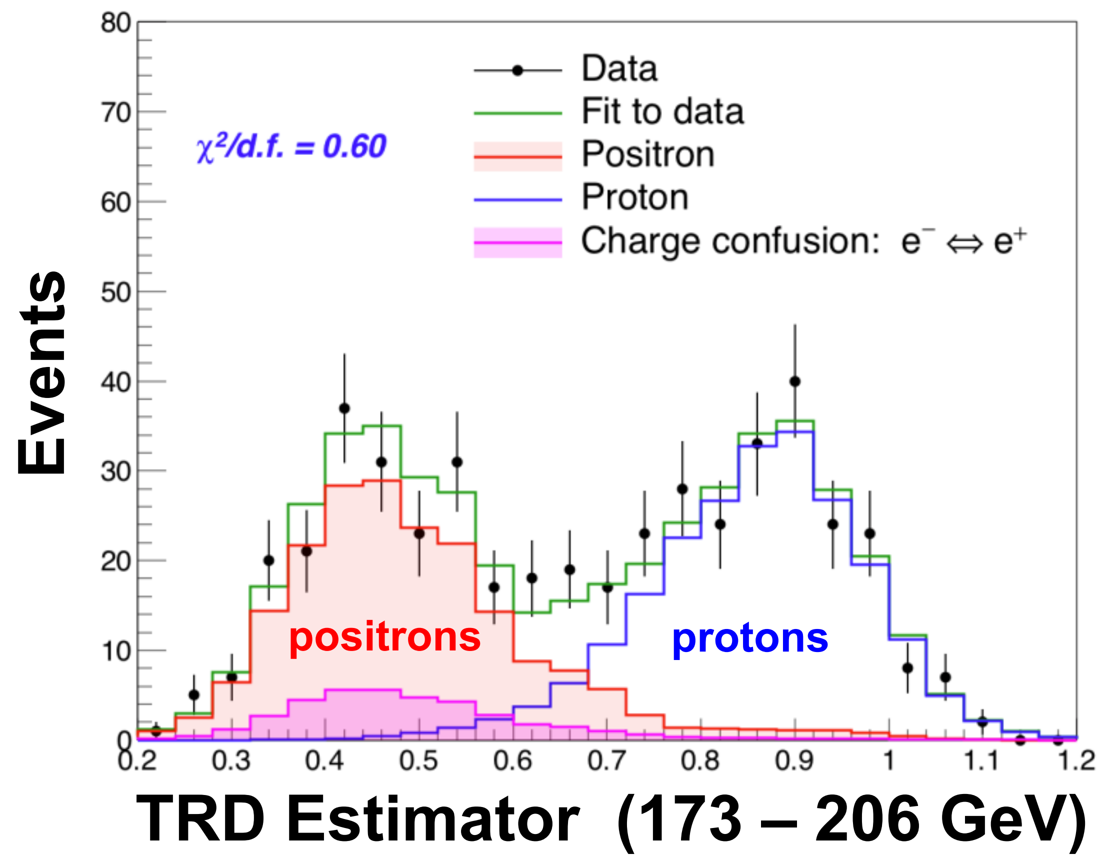
# Most important systematic: Charge Confusion

- Only the tracker determines the charge sign
- Electrons incorrectly identified as positrons
- Due to:
  - Elastic or inelastic scattering
  - Tracker resolution
- Largest systematic uncertainty at high energies

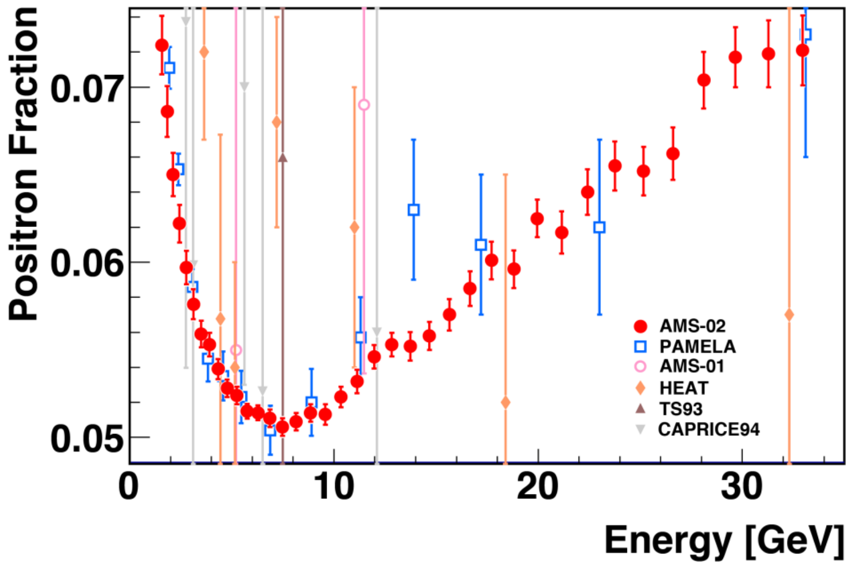


# Analysis based on Template Fits

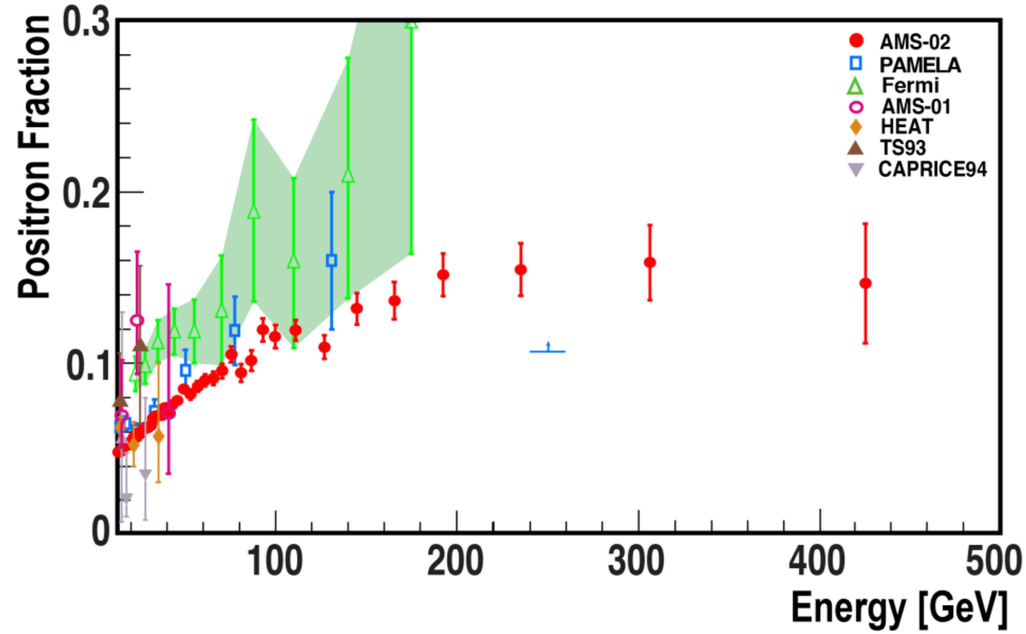
- 2D Template Fits in ECAL Estimator and TRD Estimator space
- Projection onto TRD Estimator is shown
- Charge Confusion fixed
- Efficient and background free determination of the number of positrons/ electrons



# The Positron Fraction

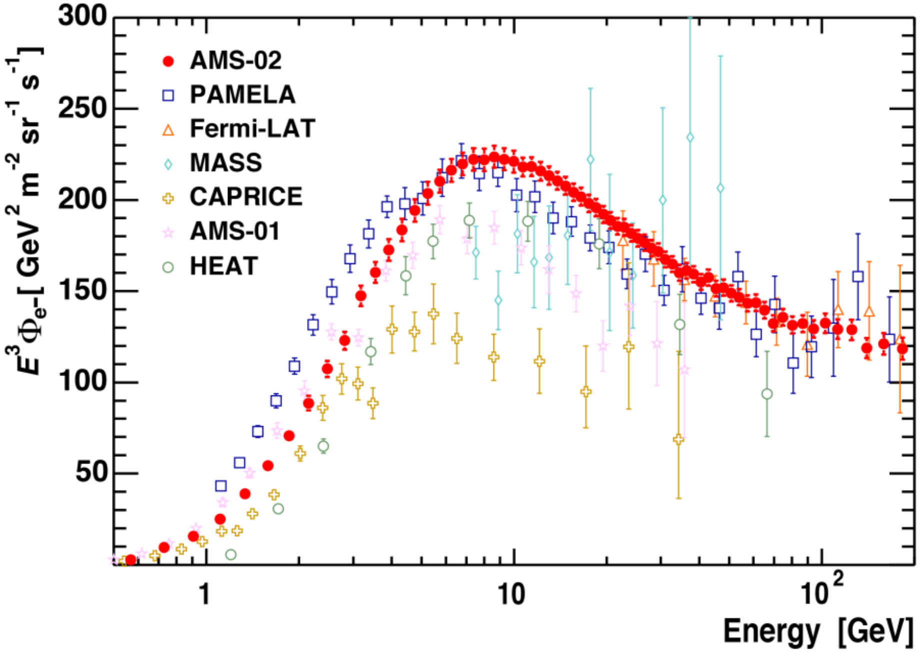



- Positron Fraction measured up to 500 GeV
- Increase confirmed
- Hint at an end to the increase



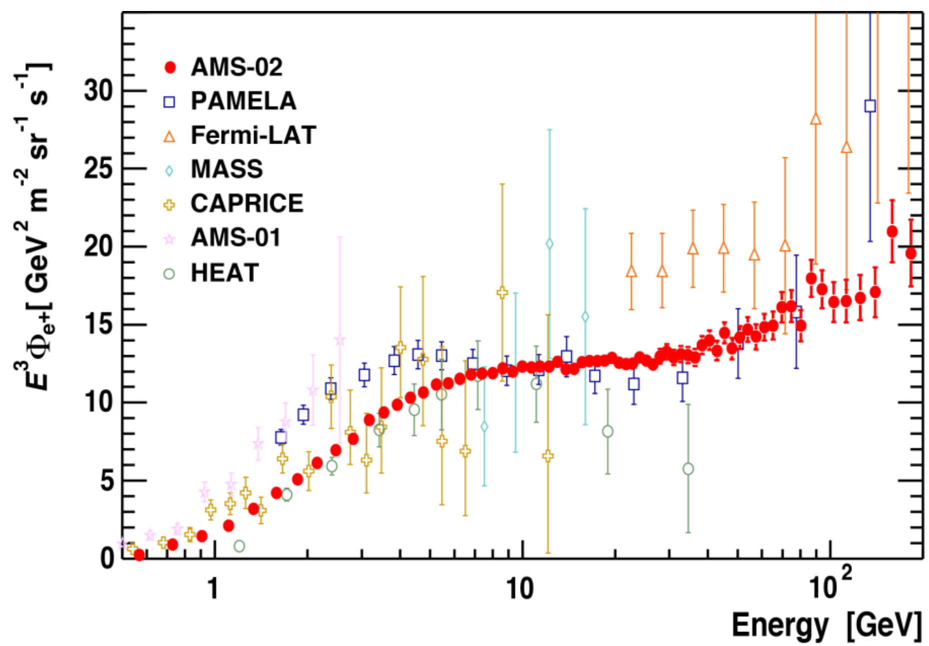

*M. Aguilar et al., PRL (2013) with already more than 200 citations; And L. Accardo et al., PRL (2014)*

# The Electron and Positron Flux

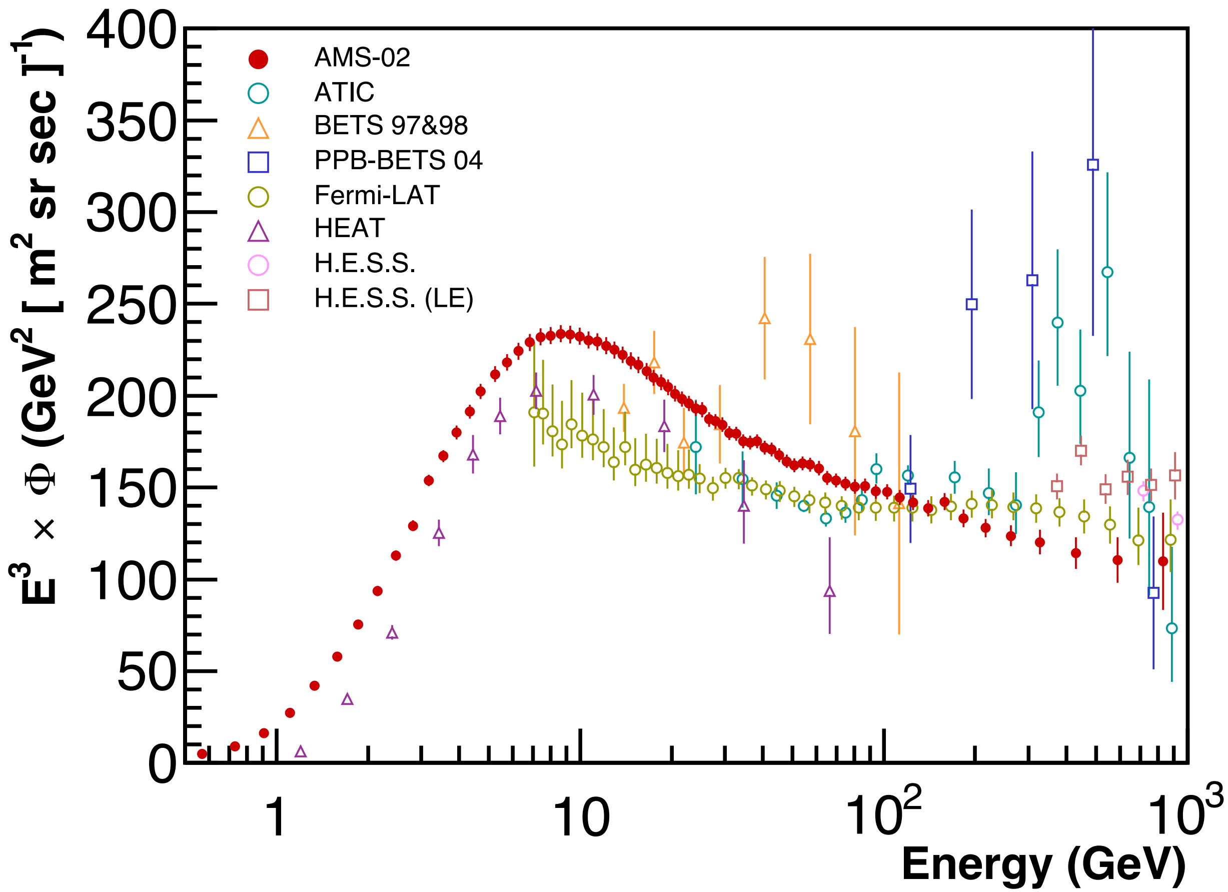



- Individual Fluxes measured up to 200 GeV
- Smooth development with energy
- Different shape for electrons and positrons

*M. Aguilar et al., PRL (2014)*



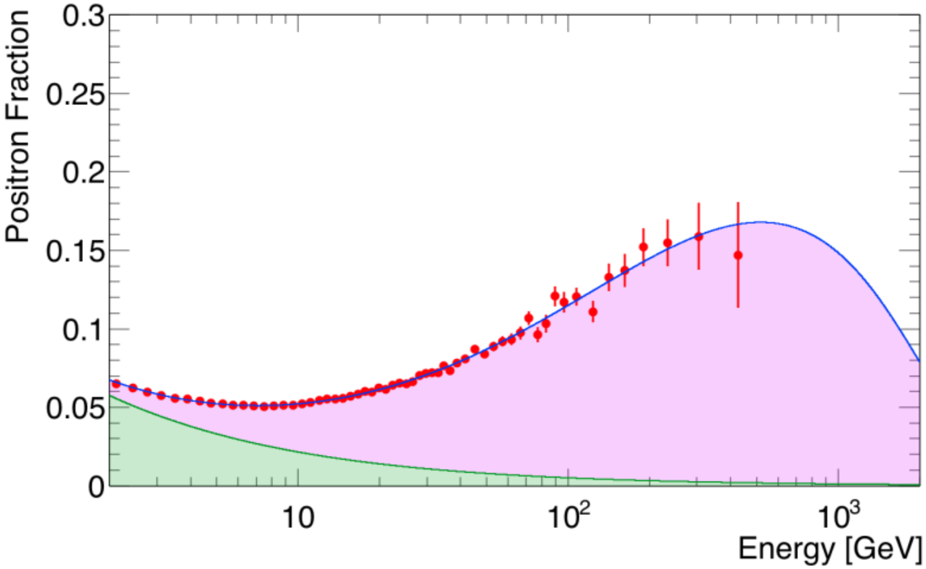
# The Electron + Positron Flux




- Combined Flux measured up to 1 TeV with more than 10 million events!
- No small scale features

*M. Aguilar et al., PRL (2014), submitted*

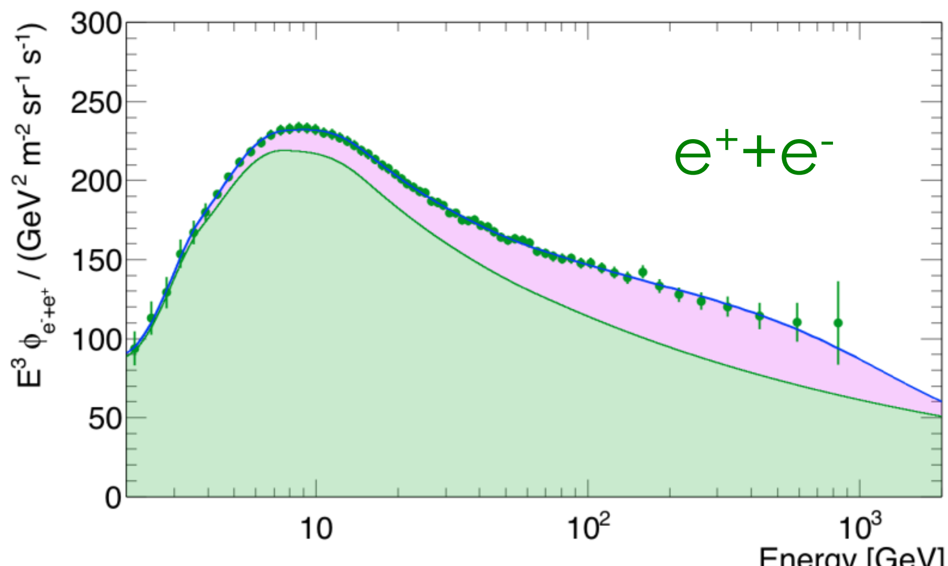
# Fitting a minimal Model to Positron Fraction and Combined Flux




**Diffuse Flux** **Source Flux**

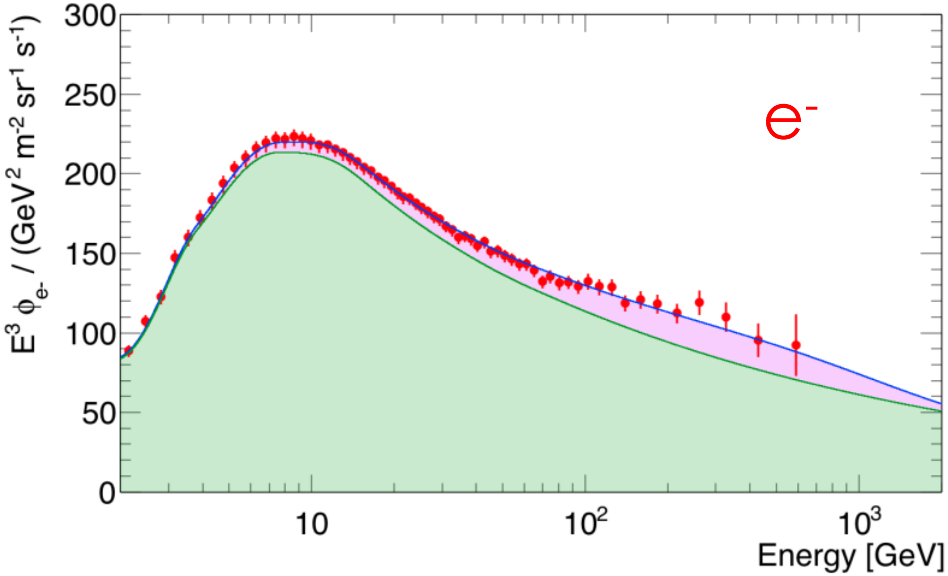
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

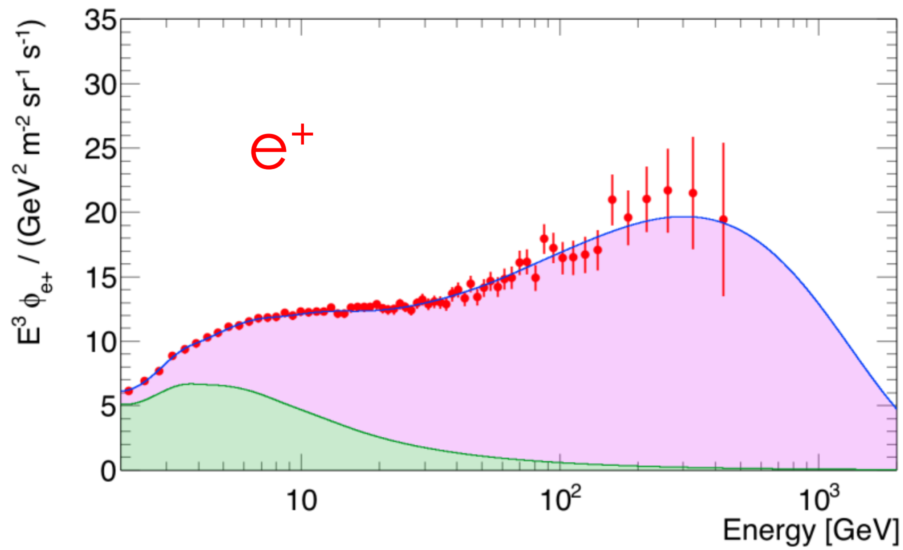
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$




*Courtesy of A. Kounine*

# The Fit Result in the individual Fluxes




*Courtesy of A. Kounine*

# Outlook

## Future AMS-02 Science Program

- Energy spectra of protons and helium
- Spectra of heavy nuclei
- B/C ratio
- Anti-protons, anti-helium
- Isotopes at low-energies
- Anisotropies, time dependent fluxes
- Strange unexpected things…

## Other Experiments: Active and Planned

- **Super-TIGER:** Balloon-borne, 52 day Antarctic flight; Measurement of ultra-heavy CR
- **ISS-Cream:** Planned for installation on ISS for 3 years; Measurement of elemental spectra
- **Calet:** Designed for ISS to explore highest energies electrons
- **GAPS:** Balloon-borne, will be flown to search for anti-deuterons

# Conclusion

- Direct measurement of cosmic radiation is a vital component of cosmic ray research.
- It provides elemental information and can even resolve isotopes. This has led to important insights in the past and will continue to do so.
- The challenge to reach higher exposure factors needs new ideas. This is exciting!
- In Germany only few institutes take part in direct measurements, although the cost of ballooning is small and it is a great opportunity to train young scientists.

- Future Experiments will need to focus on areas not covered by AMS-02. E.g. Isotopes and beyond 1 TeV/nucleon
- Vernon Jones at COSPAR 2014: “There is enough ballooning capacity for more and new astropyhsics payloads.”