Cosmic Ray Anisotropy Workshop 2011
28-29 October 2011
University of Wisconsin Pyle Center

The Elemental Composition of Galactic Cosmic Rays

Jörg R. Hörandel
Radboud University Nijmegen
http://particle.astro.ru.nl

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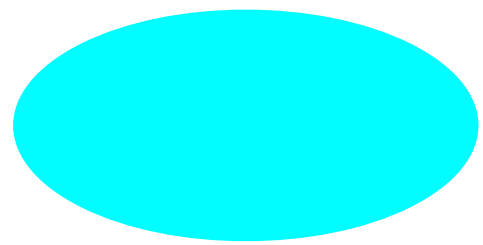
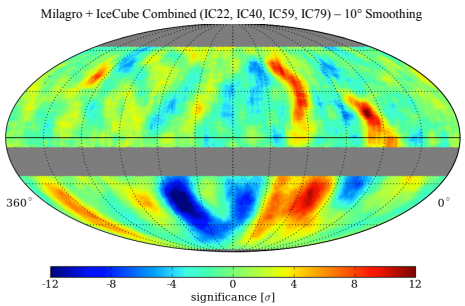
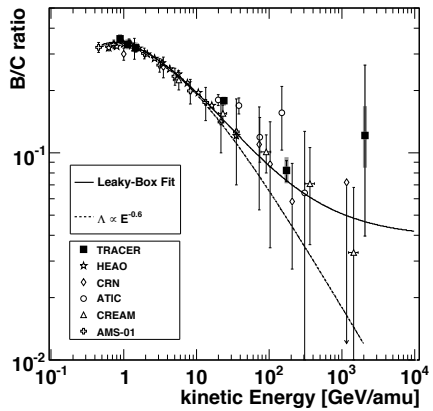
Are we about to change some paradigms of cosmic-ray astrophysics?

anisotropy





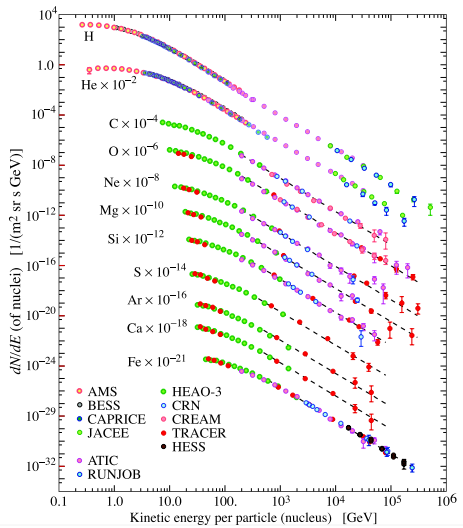
propagation



$$\Lambda_{esc} \propto E^{-\delta}$$

$$\delta = 0.33 \leftrightarrow \delta = 0.6$$

structures in energy spectra



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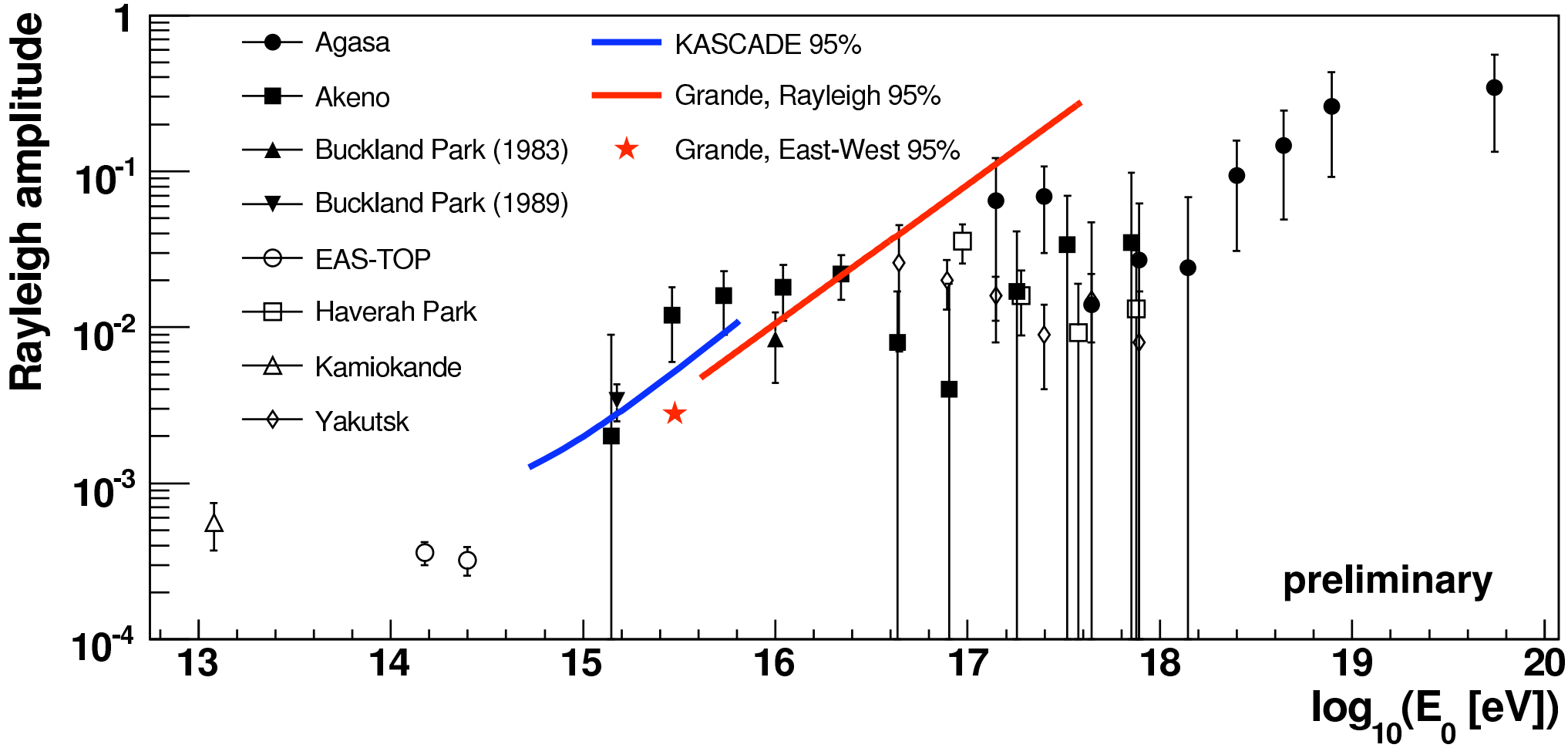
KASCADE & KASCADE-Grande anisotropy upper limits



KASCADE: 200 m x 200 m, 10^8 events (data 1998-2002) **9 more years of data**

KASCADE-Grande: ~0.5 km^2 (data 2004-2007)

S. Over et al., 30 ICRC 4 (2007) 223

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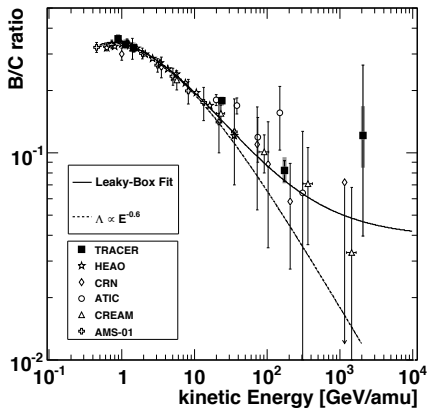

$$\Lambda_{esc} \propto E^{-\delta}$$

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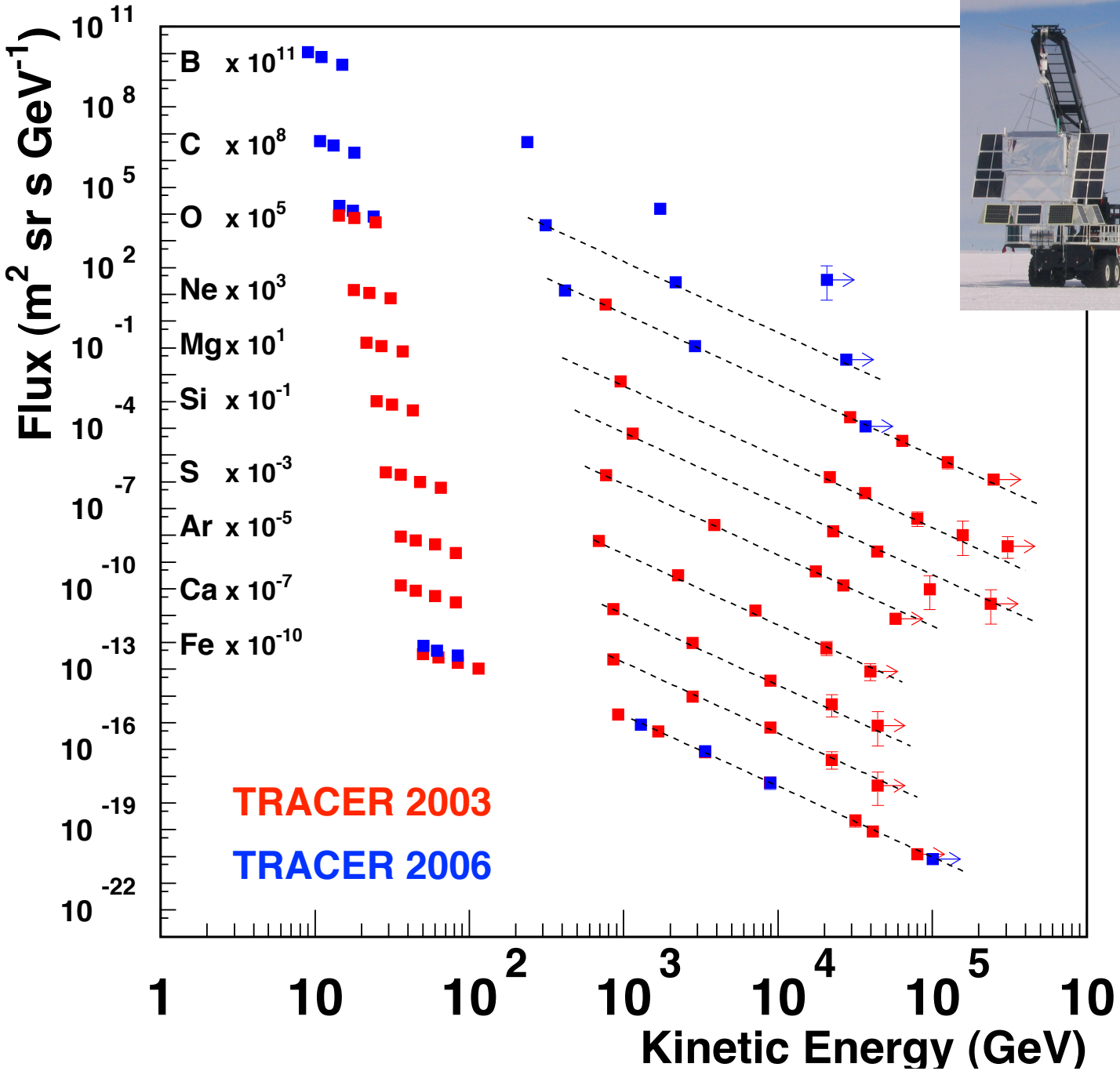
TRACER: Energy spectra for individual elements



P. Boyle et al., ICRC 2011

A. Obermeier ApJ in press, arXiv:1108.4838

TRACER: propagation of cosmic rays

Leaky-Box Propagation Parameters

- Continuity equation:

$$N_i(E) = \frac{1}{\Lambda_{esc}(E)^{-1} + \Lambda_i^{-1}} \times \left(\frac{Q_i(E)}{\beta c \rho} + \sum_{k>i} \frac{N_k}{\lambda_{k \to i}} \right)$$

- Source Spectrum:

$$Q_i(E) = n_i \cdot E^{-\alpha}$$

- Escape Path Length:

$$\Lambda_{esc}(E) = CE^{-\delta} + \Lambda_0$$

- Spallation Path Length:

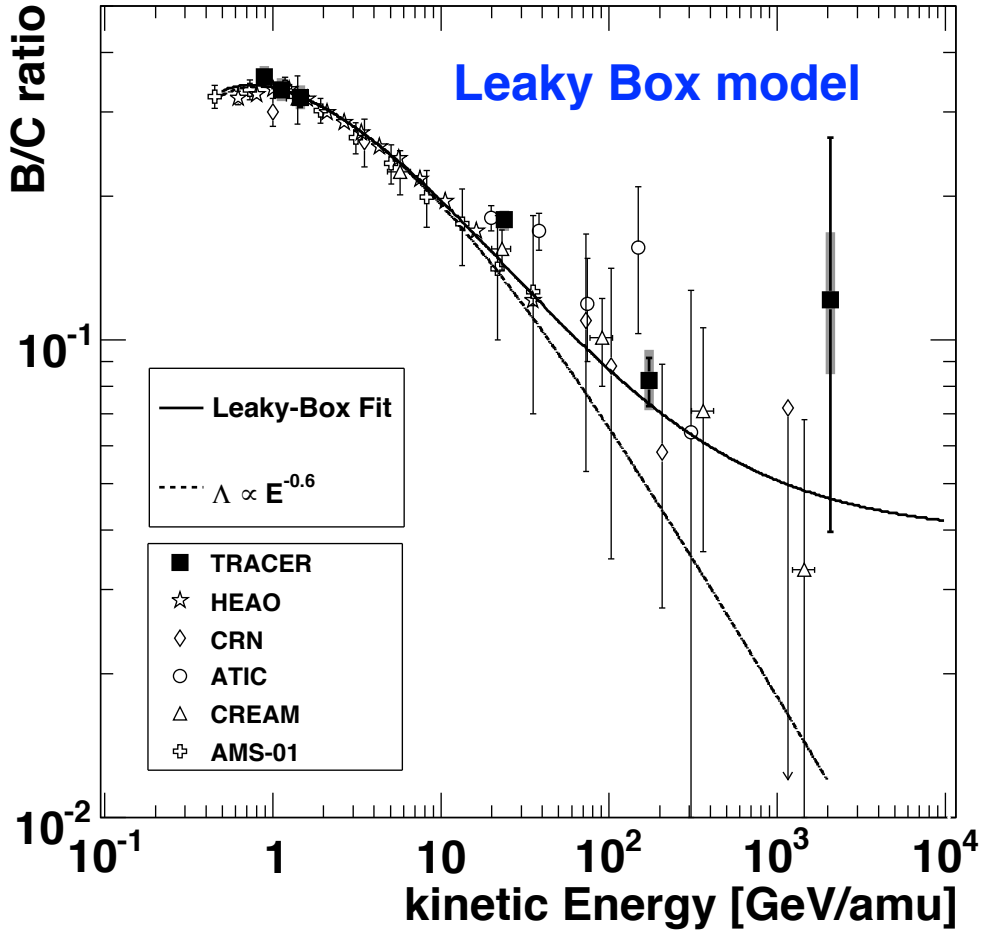
$$\Lambda_i = \frac{m}{\sigma(A)}$$

Boron to Carbon ratio

$$\frac{N_B}{N_C} = \frac{\lambda_{\to B}^{-1}}{\Lambda_{esc}(E)^{-1} + \Lambda_B^{-1}}$$

A. Obermeier et al., ICRC 2011

TRACER: propagation of cosmic rays



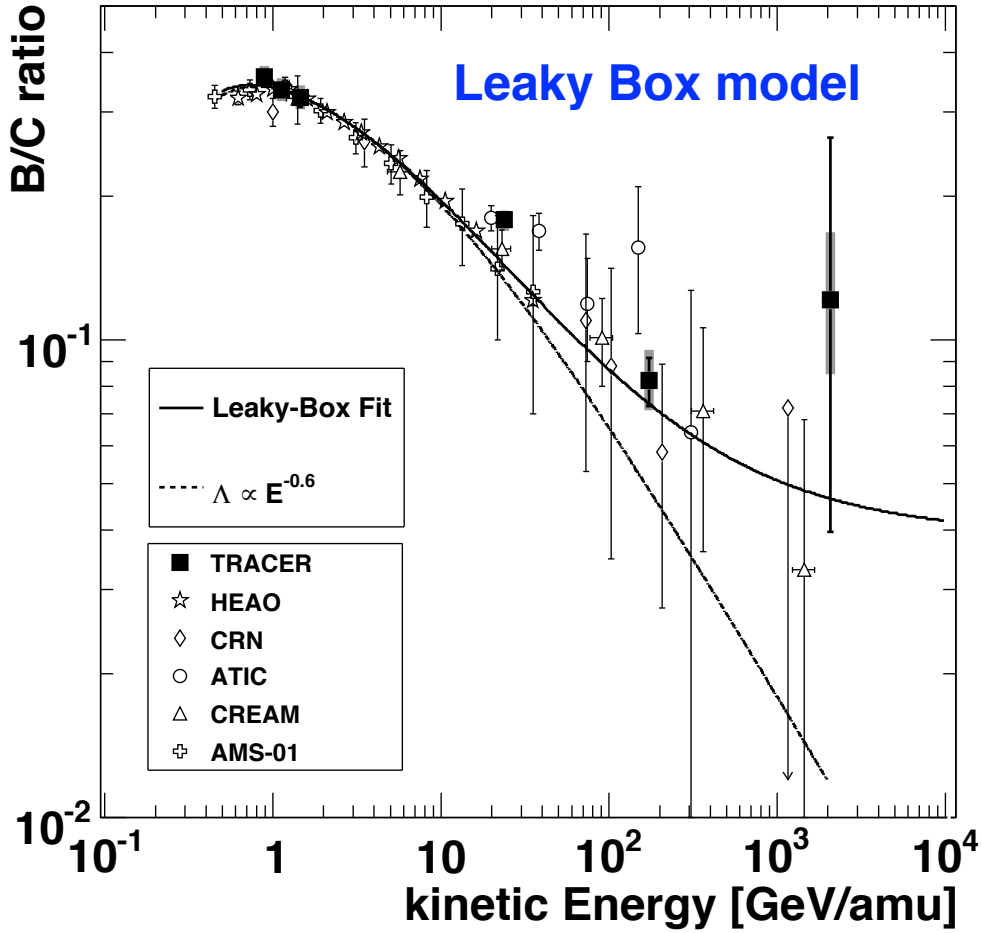
Escape Path Length:

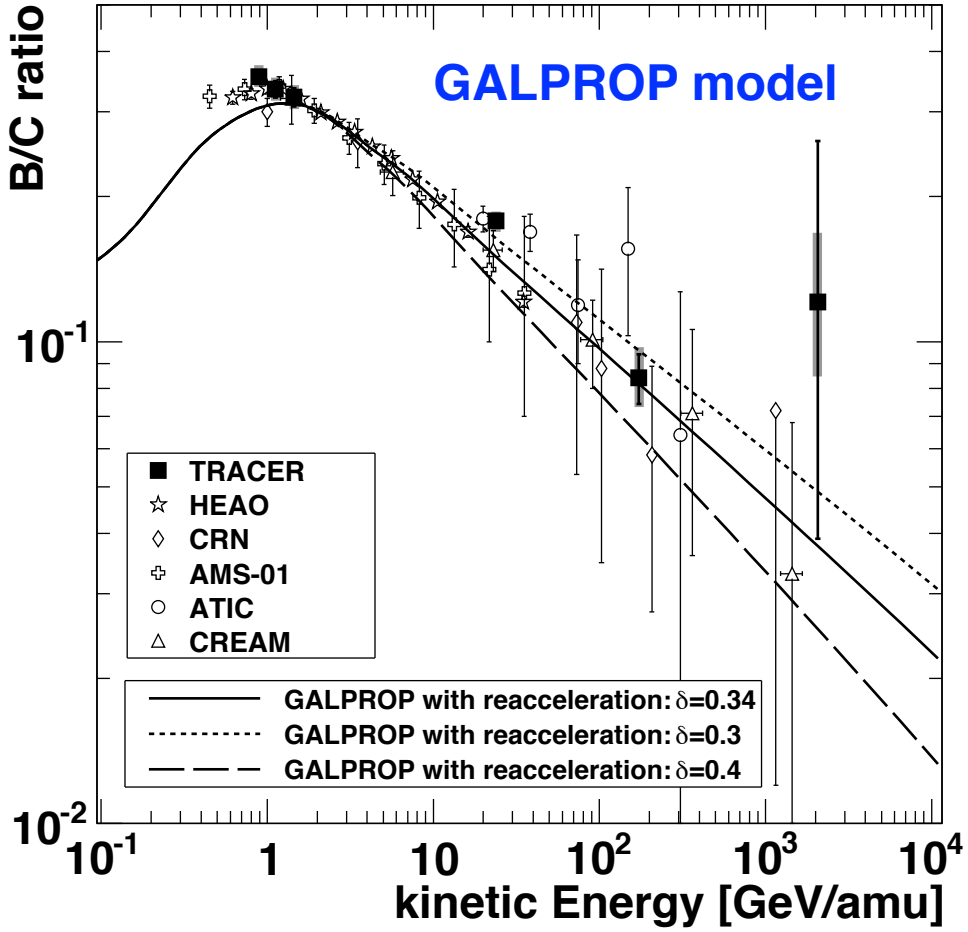
$$\Lambda_{esc}(E) = CE^{-\delta} + \Lambda_0$$

- Propagation index: $\delta = 0.64 \pm 0.02$.
- Residual path length: $\Lambda_0 = 0.7 \pm 0.2$ g/cm^2.

A. Obermeier et al., ICRC 2011

TRACER: propagation of cosmic rays





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- Propagation index: $\delta = 0.64 \pm 0.02$.
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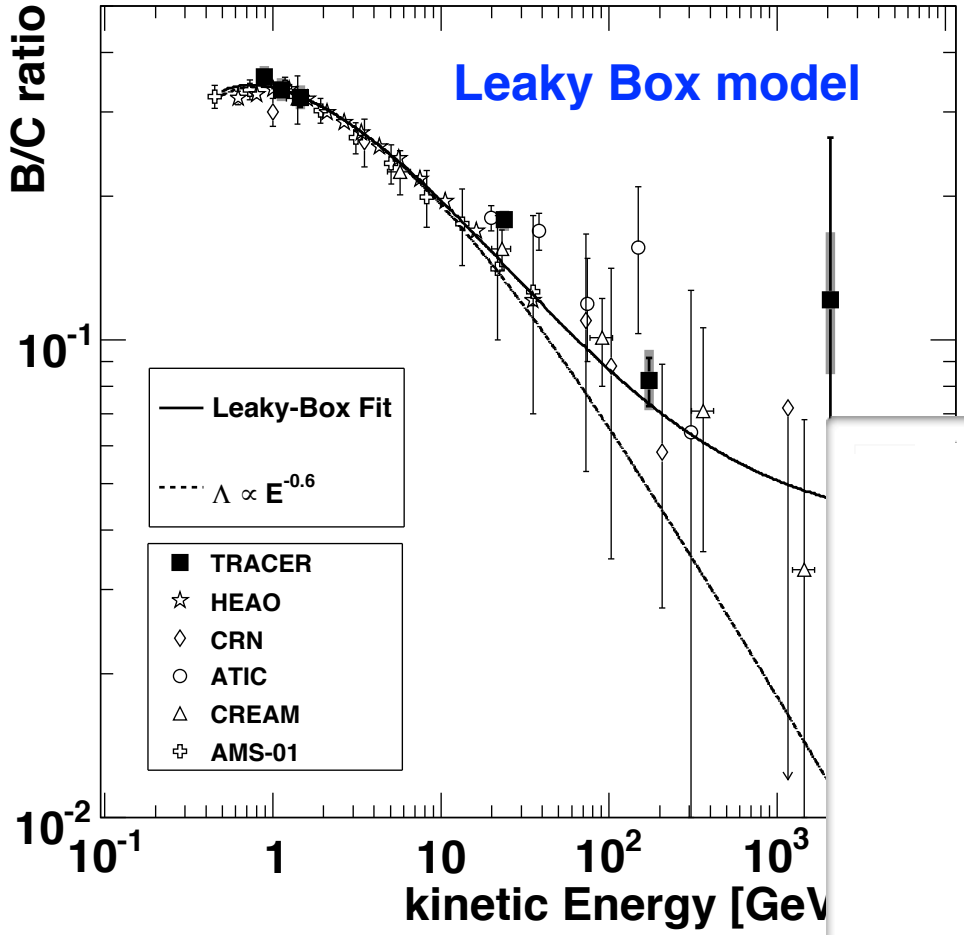
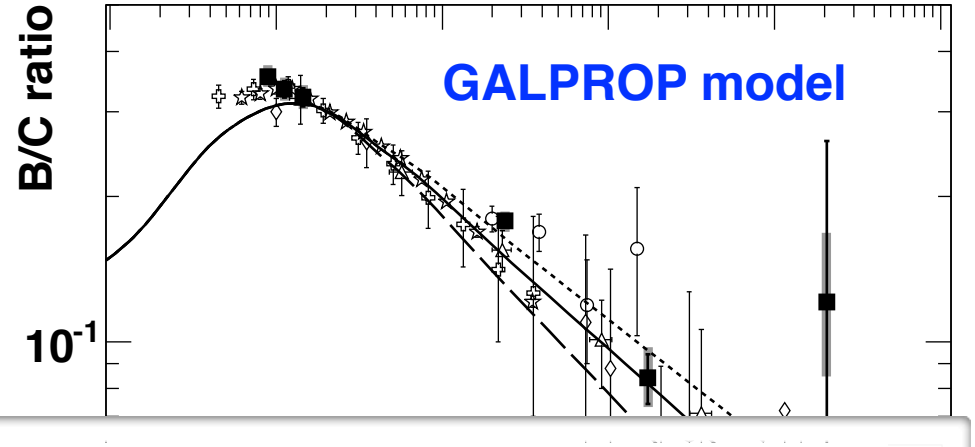
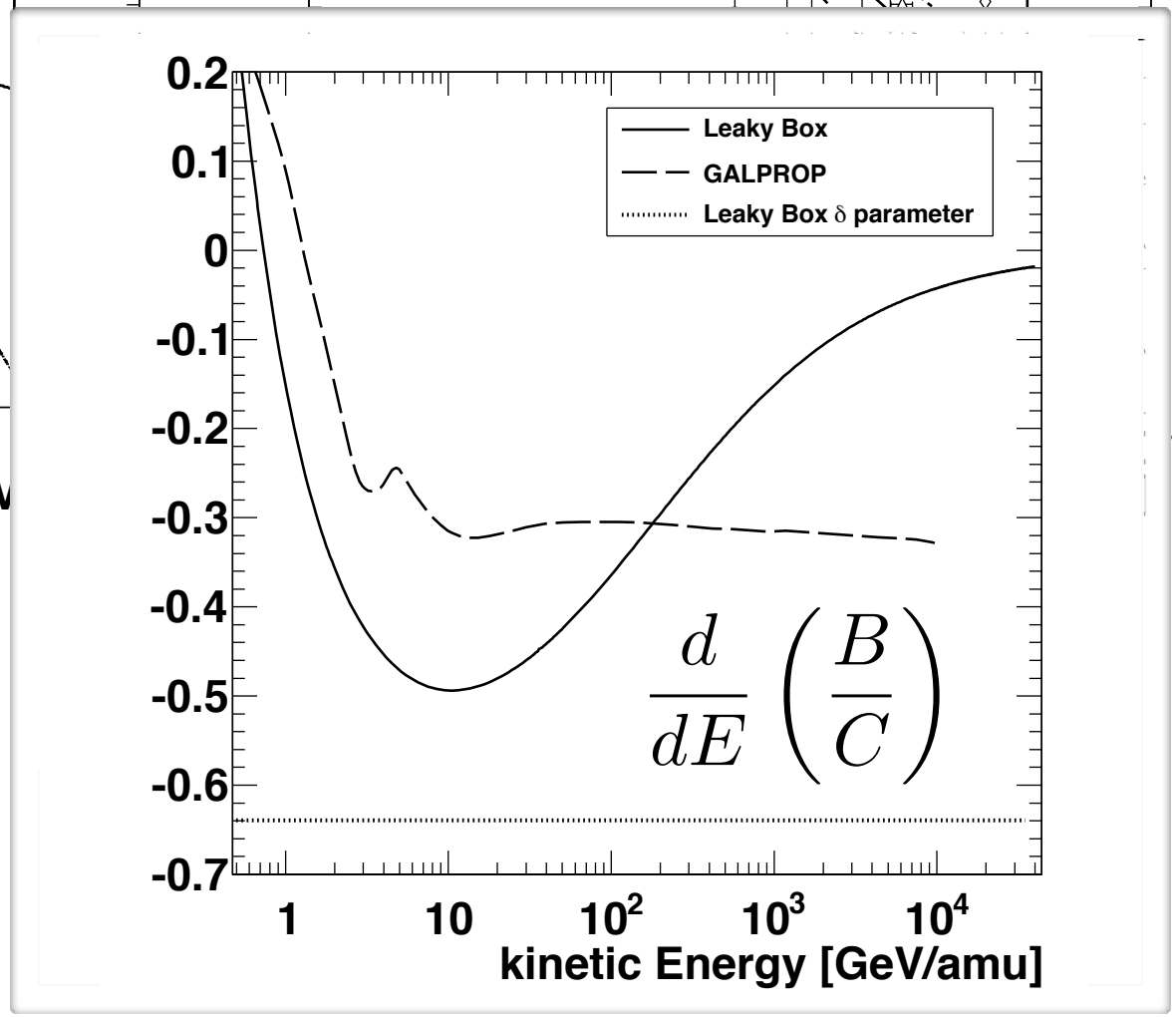
- Diffusion Index: $\delta = 0.34$.
- **Source index:** $\alpha = 2.34$.

A. Obermeier et al., ICRC 2011

TRACER: propagation of cosmic rays





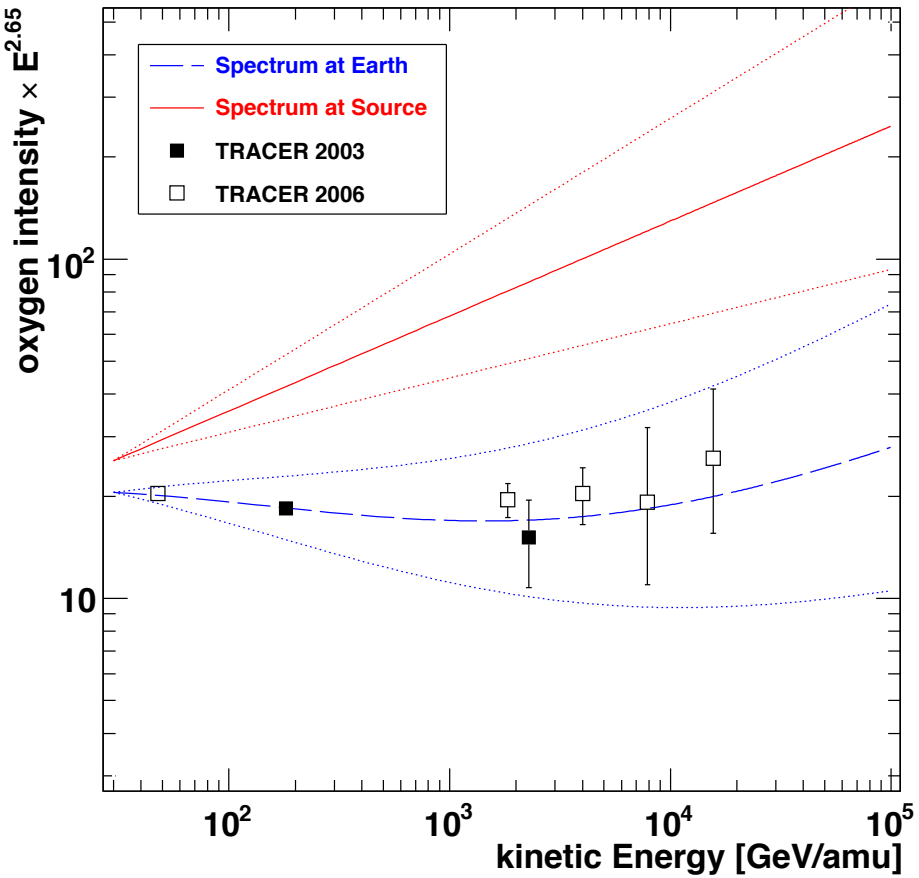


$$\Lambda(R) = \frac{26.7\beta}{(\beta R)^{\delta} + (0.714 \cdot \beta R)^{-1.4}} + \Lambda_0 \text{ g/cm}^2,$$

TRACER: propagation of cosmic rays

The Source Spectrum

- Fit to TRACER oxygen data.
- $\delta = 0.64$, $\Lambda_0 = 0.7$ g/cm^2



- Free parameter: α.
- Source spectrum: power law.

Result

- Source index: $\alpha = 2.37 \pm 0.12$.

- Agrees with previous results.
- Model predicts spectrum at Earth may not be a power law (Λ_0).

GALPROP: $\alpha = 2.34$

A. Obermeier et al., ICRC 2011

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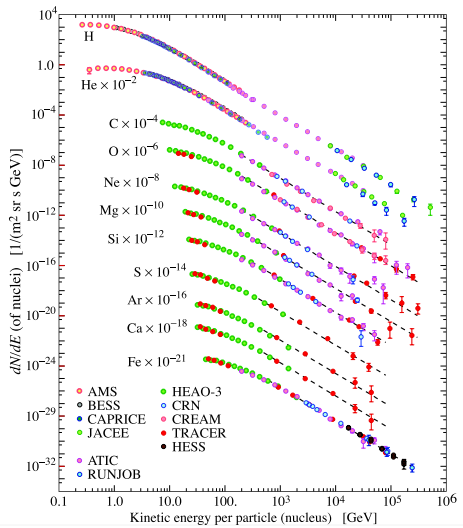

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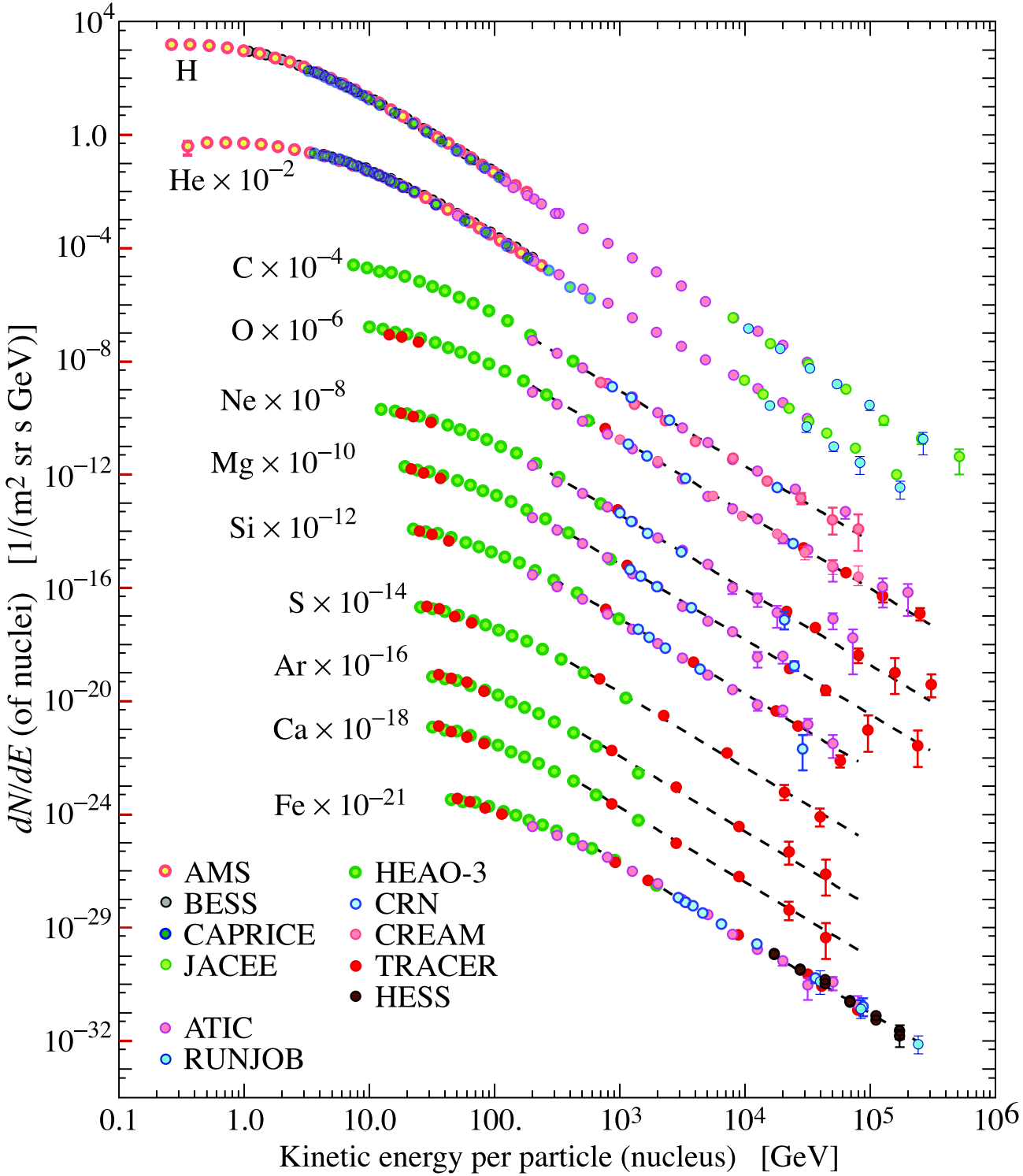
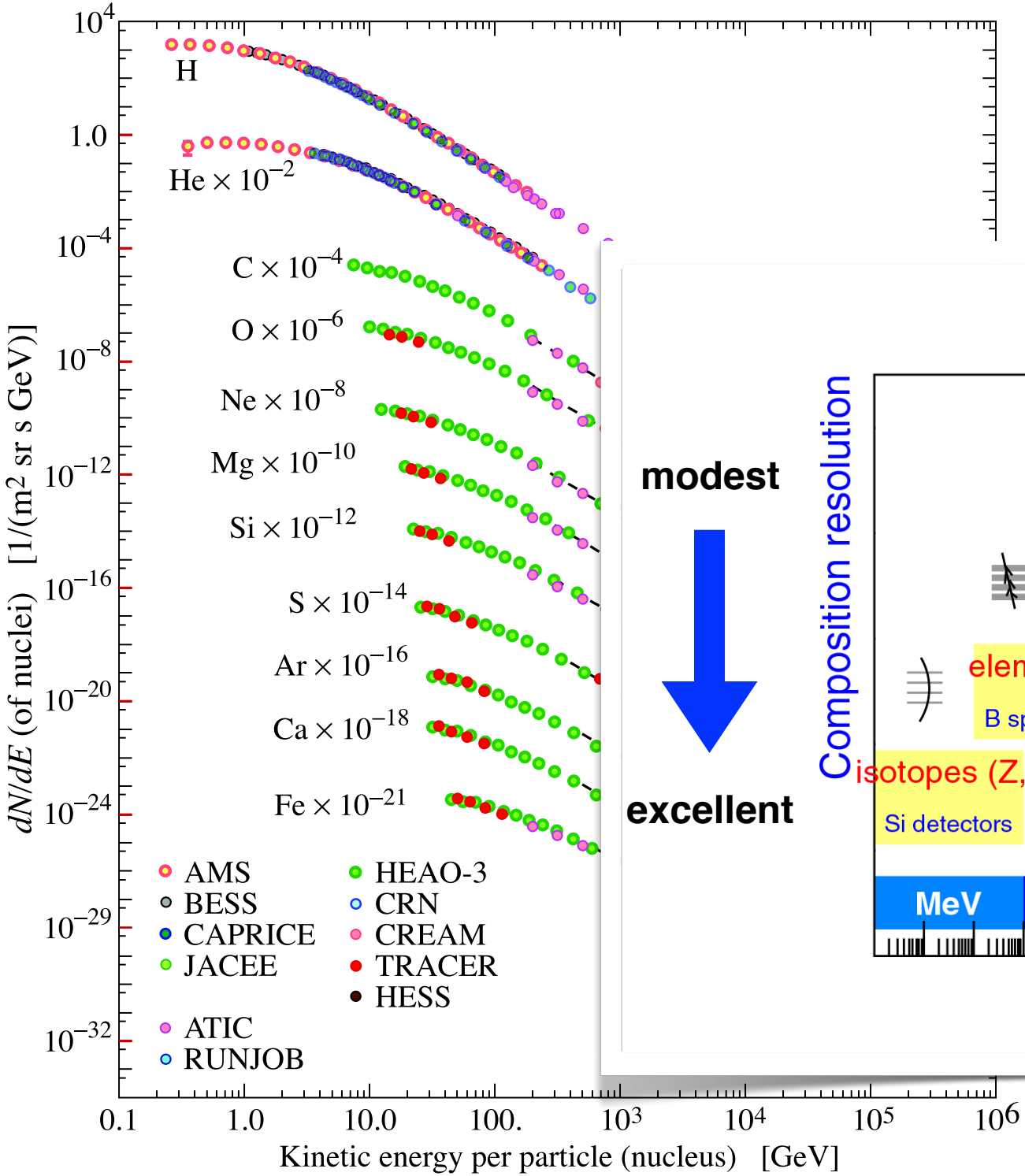
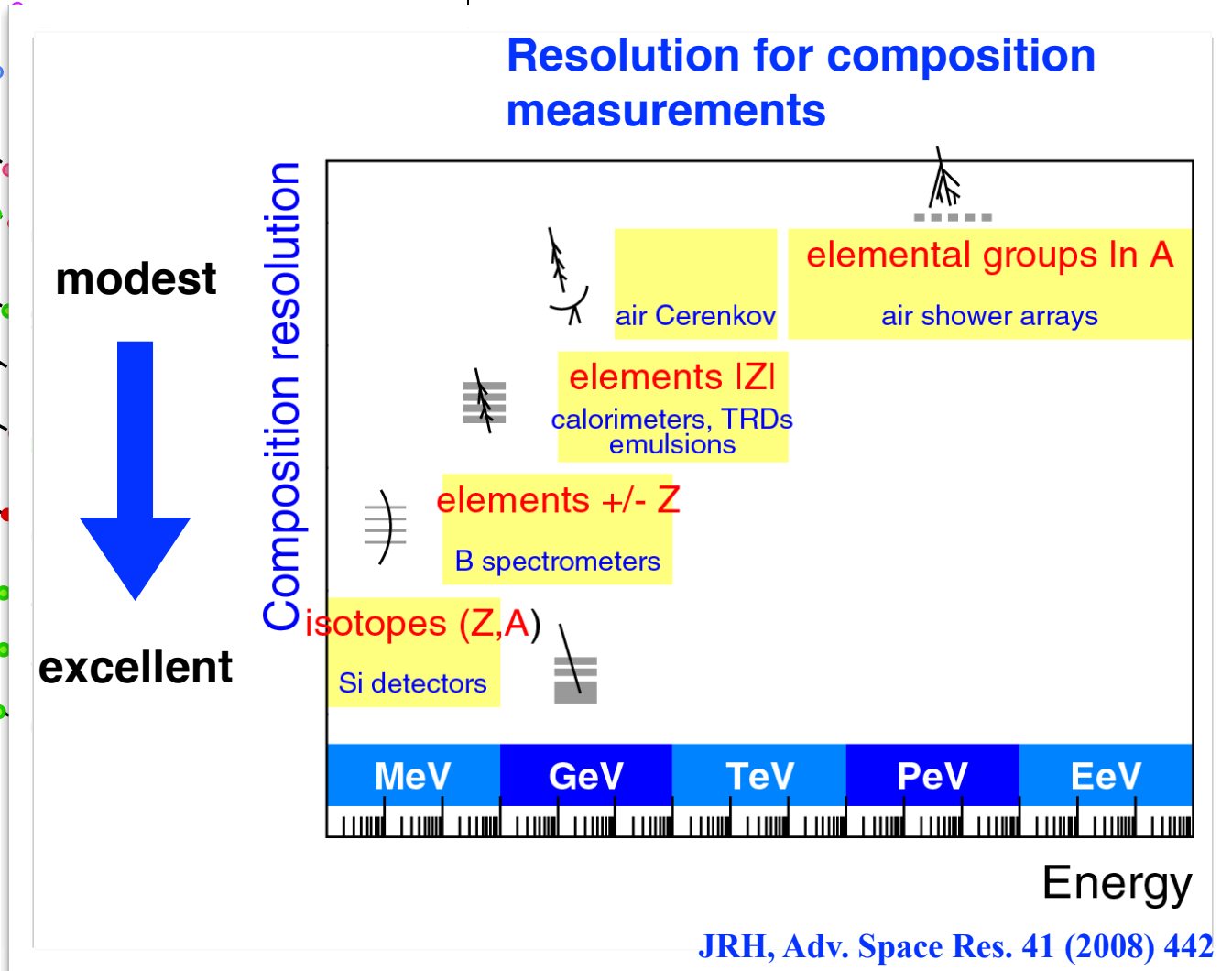
Energy spectra of main elements in cosmic rays



Particle Data Group

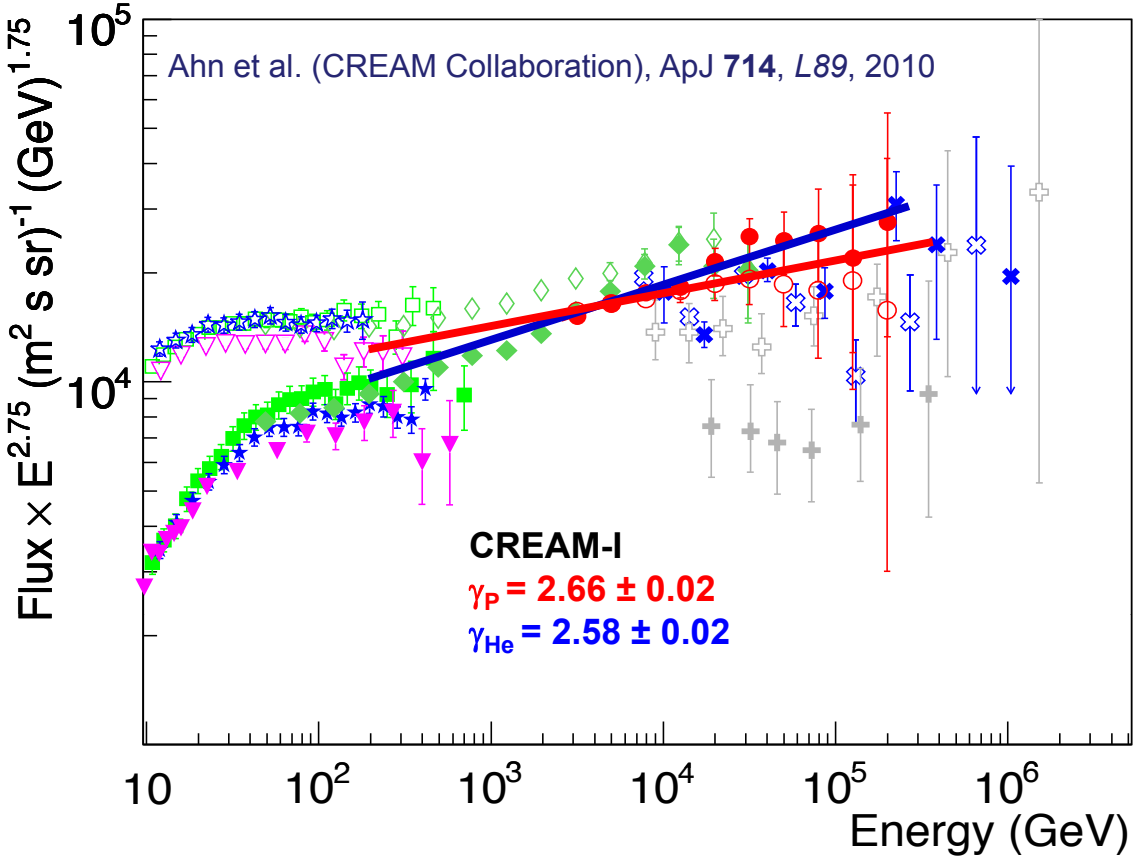
Energy spectra of main elements in cosmic rays

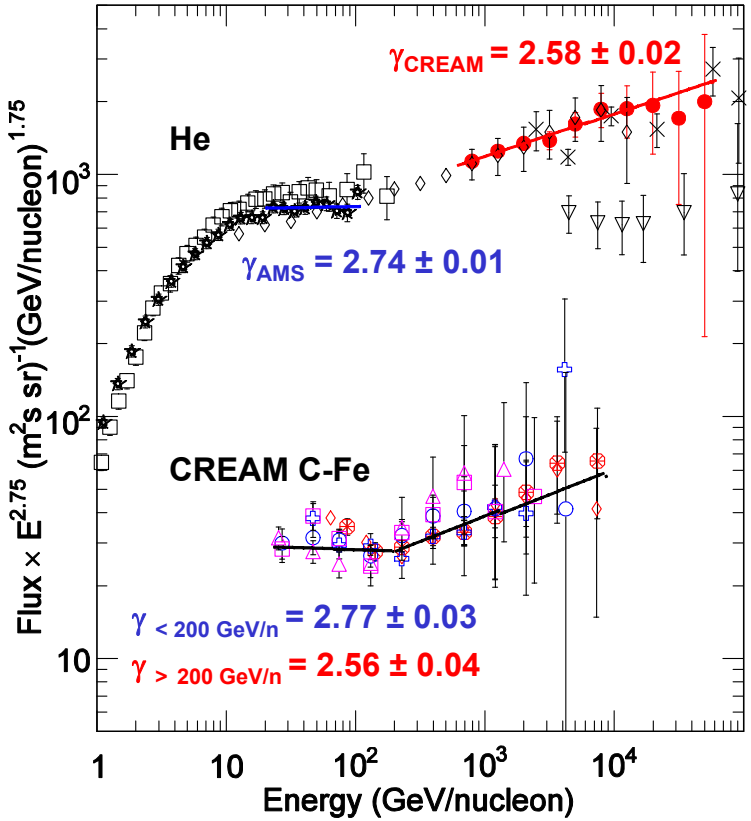




JRH, Adv. Space Res. 41 (2008) 442

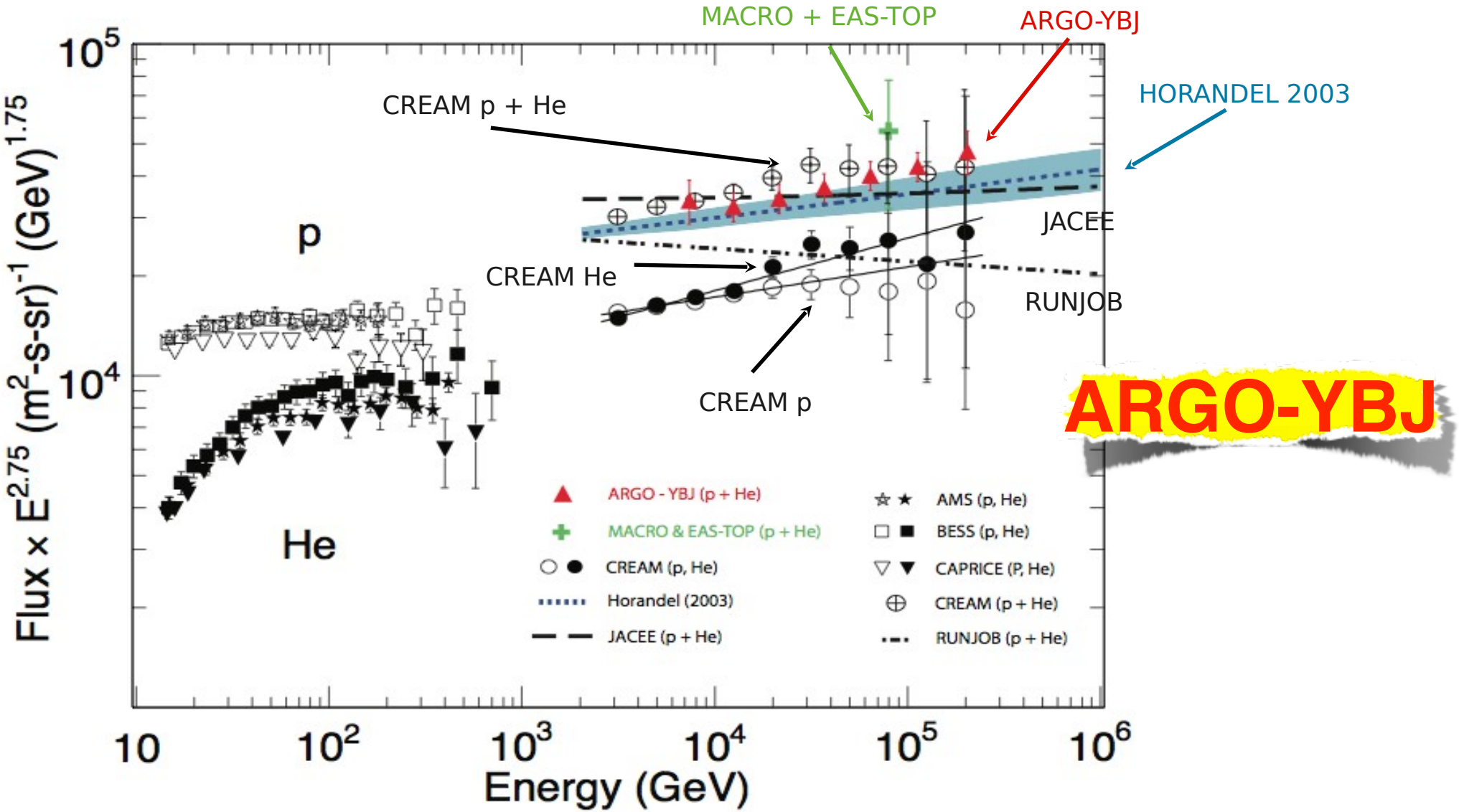
CREAM: are CR spectra not single power laws?





E. Seo, ICRC 2011

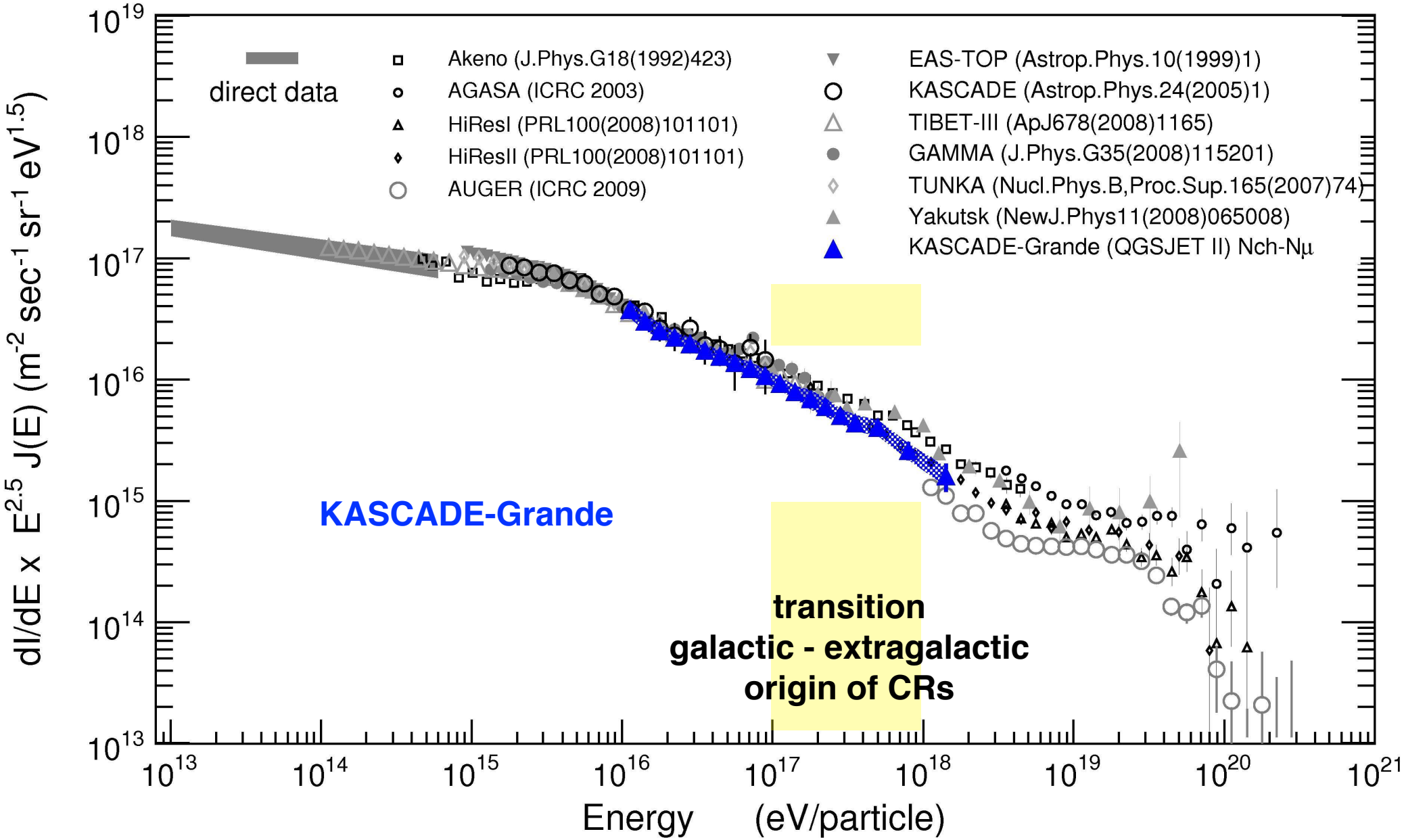
The light component spectrum



Unfolding the energy spectrum by a Bayesian approach
QGSJet II + FLUKA + EGS4 + GEANT3 --> 1-300 TeV

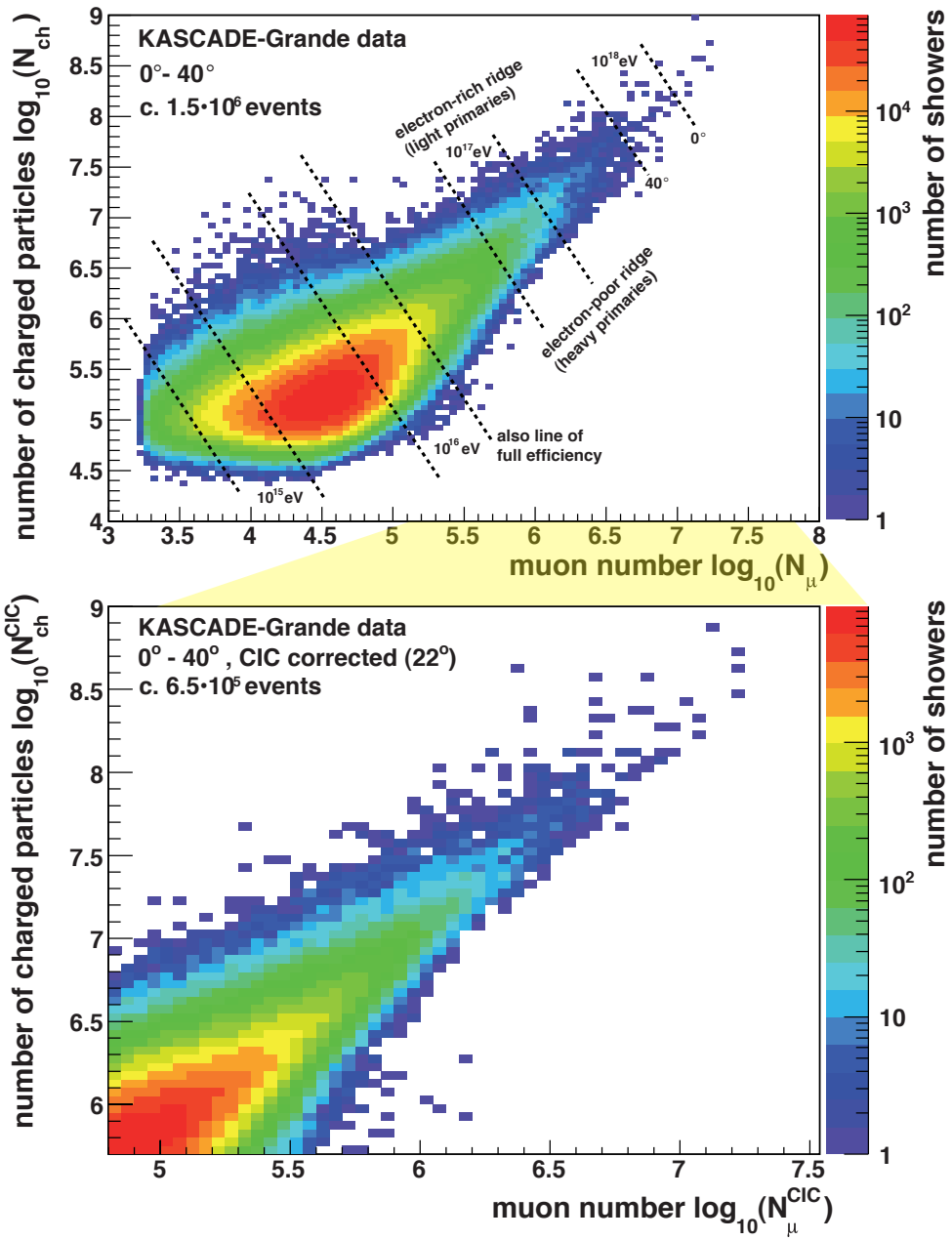
Mari S.M. et al. ICRC0220

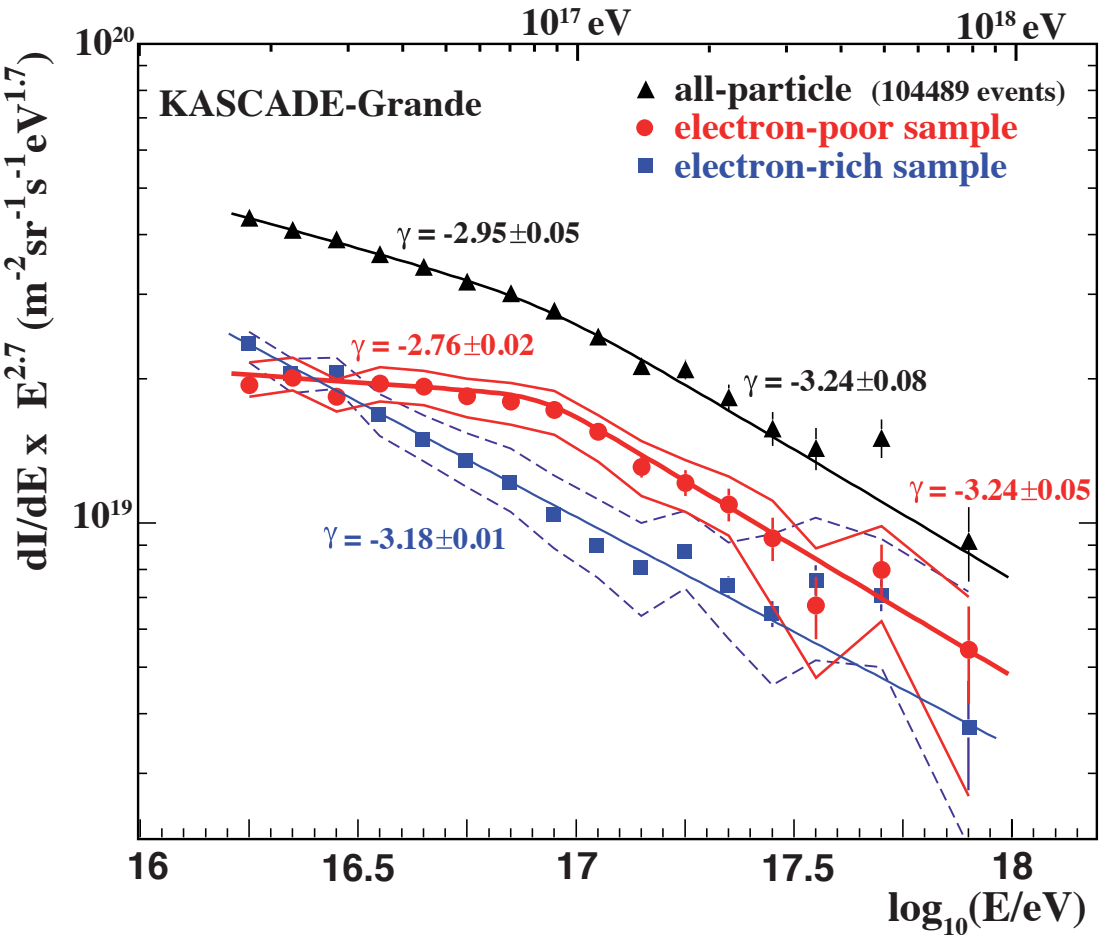
The all-particle energy spectrum



M. Bertaina, ECRS (2010)

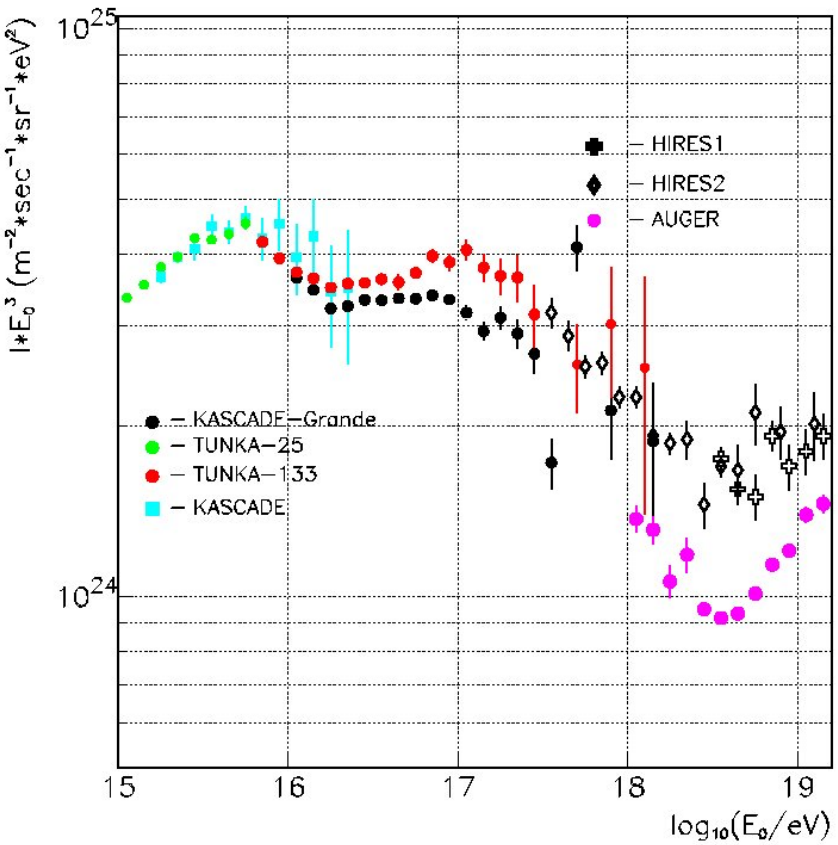
A knee-like structure in the spectrum of the heavy component of cosmic rays



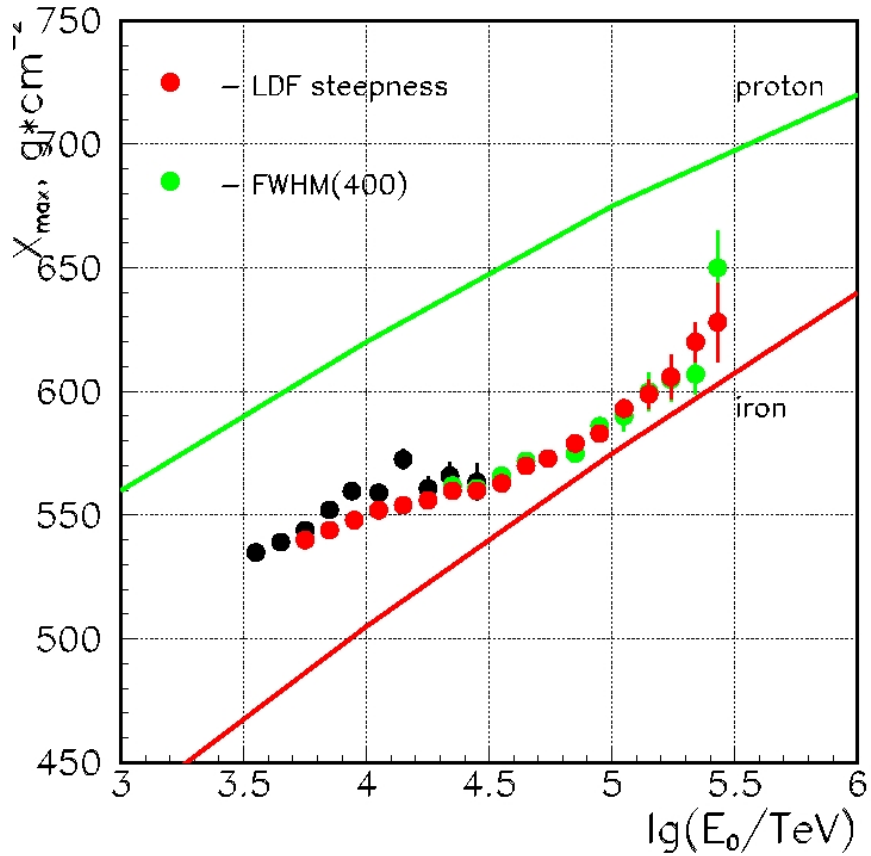


W.D. Apel et al, PRL 107 (2001) 171104

Spectrum and X_{max} from Tunka133

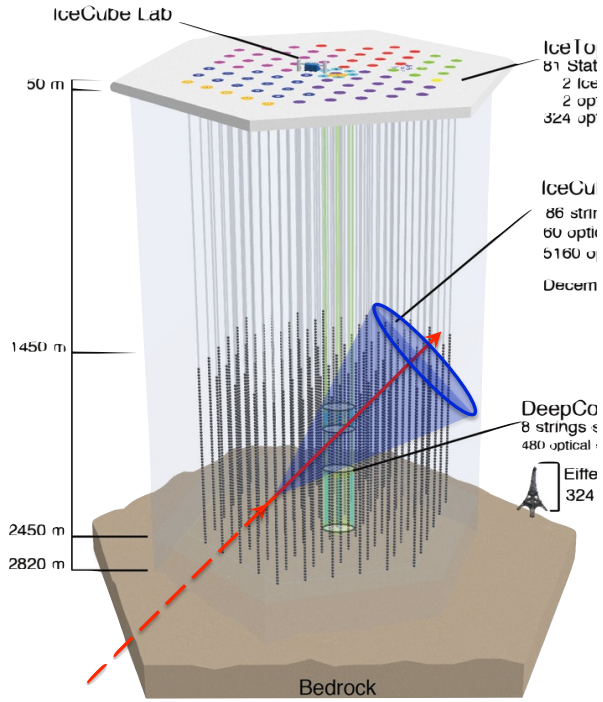


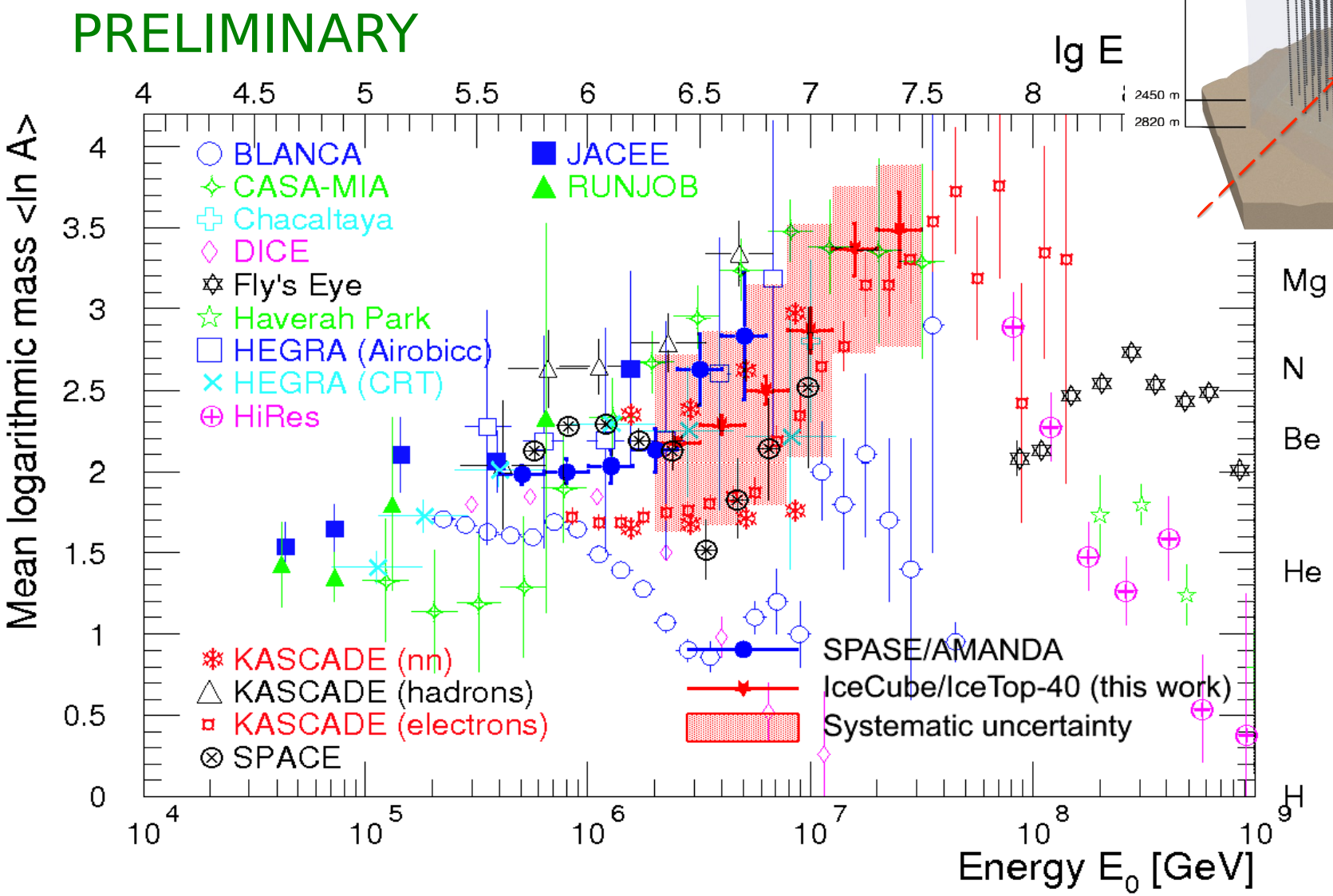
L.A. Kuzmichev [Tunka Coll.], icrc250



V. Prosin [Tunka Coll.], icrc184

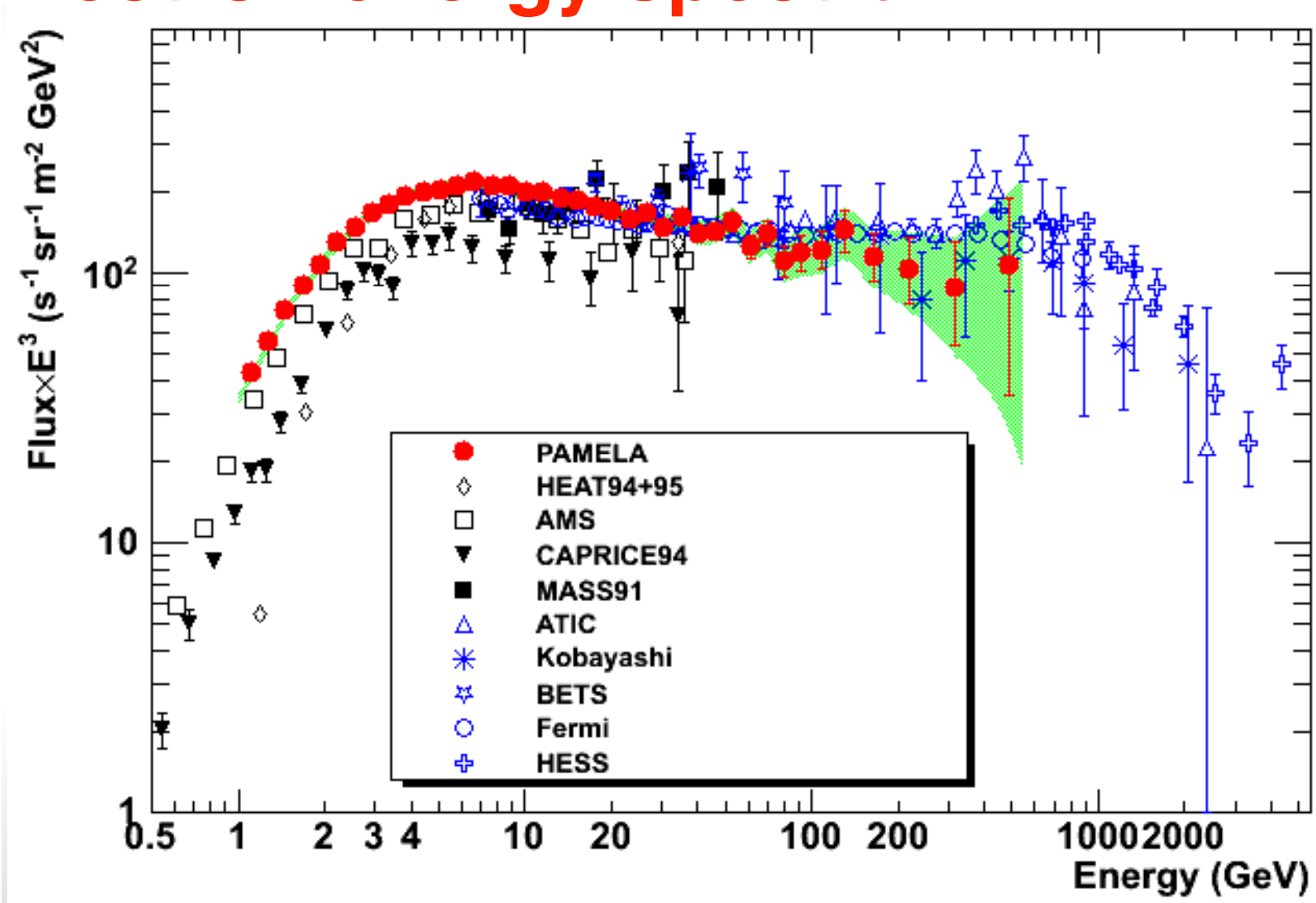
Composition: IceCube





IceCube, ICRC (2011)

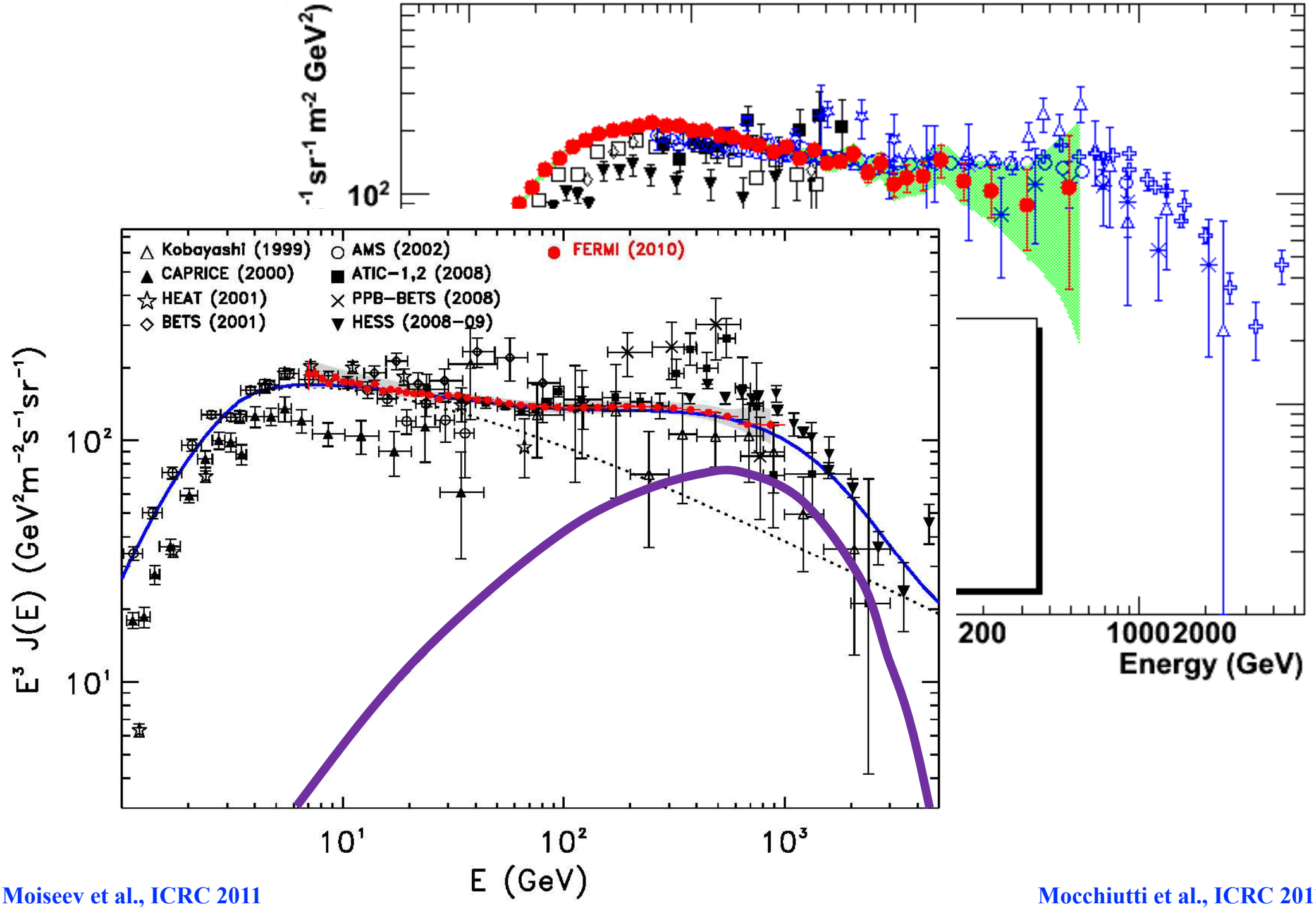
Electron energy spectrum



Moiseev et al., ICRC 2011

Mocchiutti et al., ICRC 2011

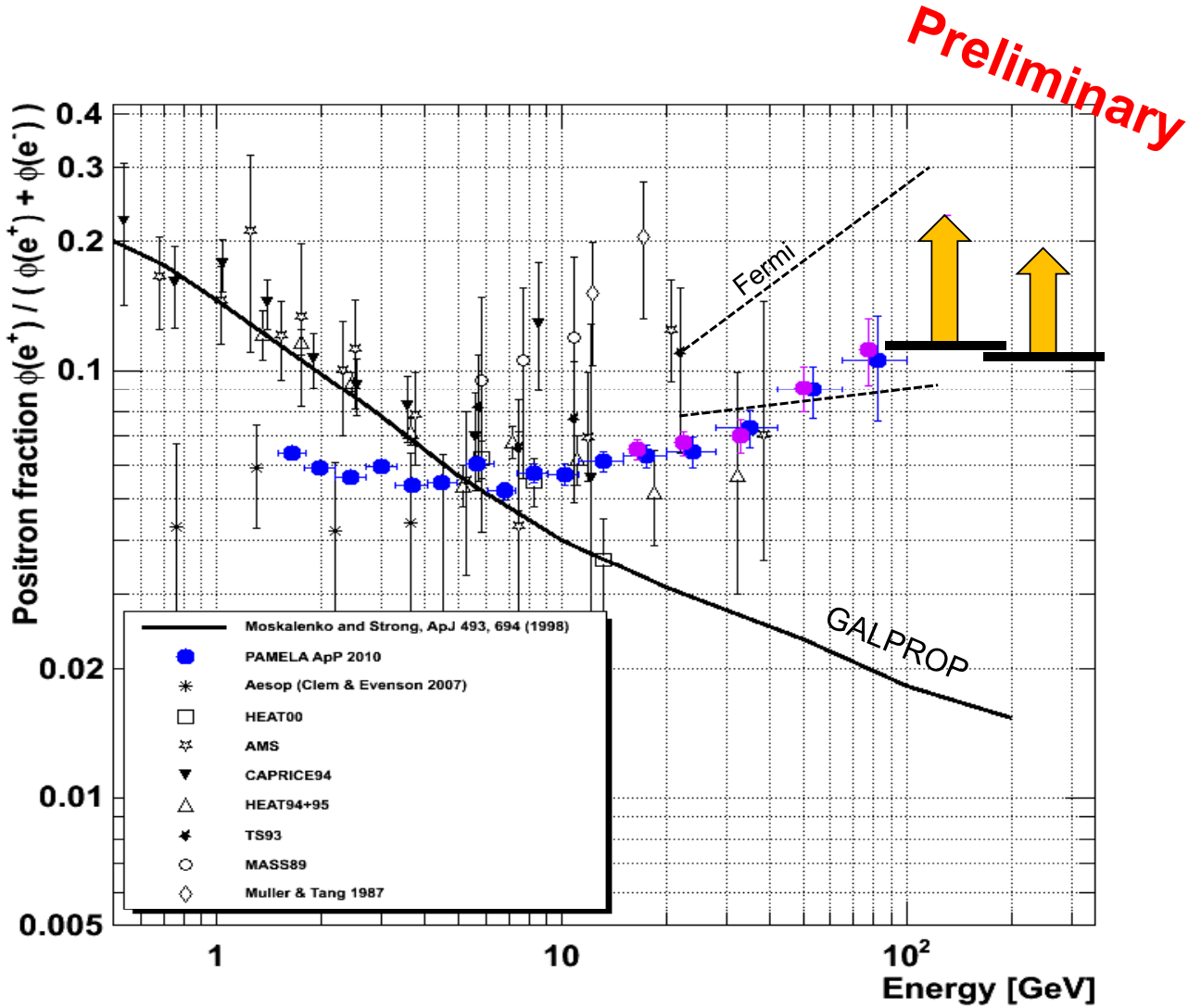
Electron energy spectrum



Moiseev et al., ICRC 2011

Mocchiutti et al., ICRC 2011

Positron-to-Electron fraction



Mocchiutti et al., ICRC 2011

Vandenbroucke et al., ICRC 2011

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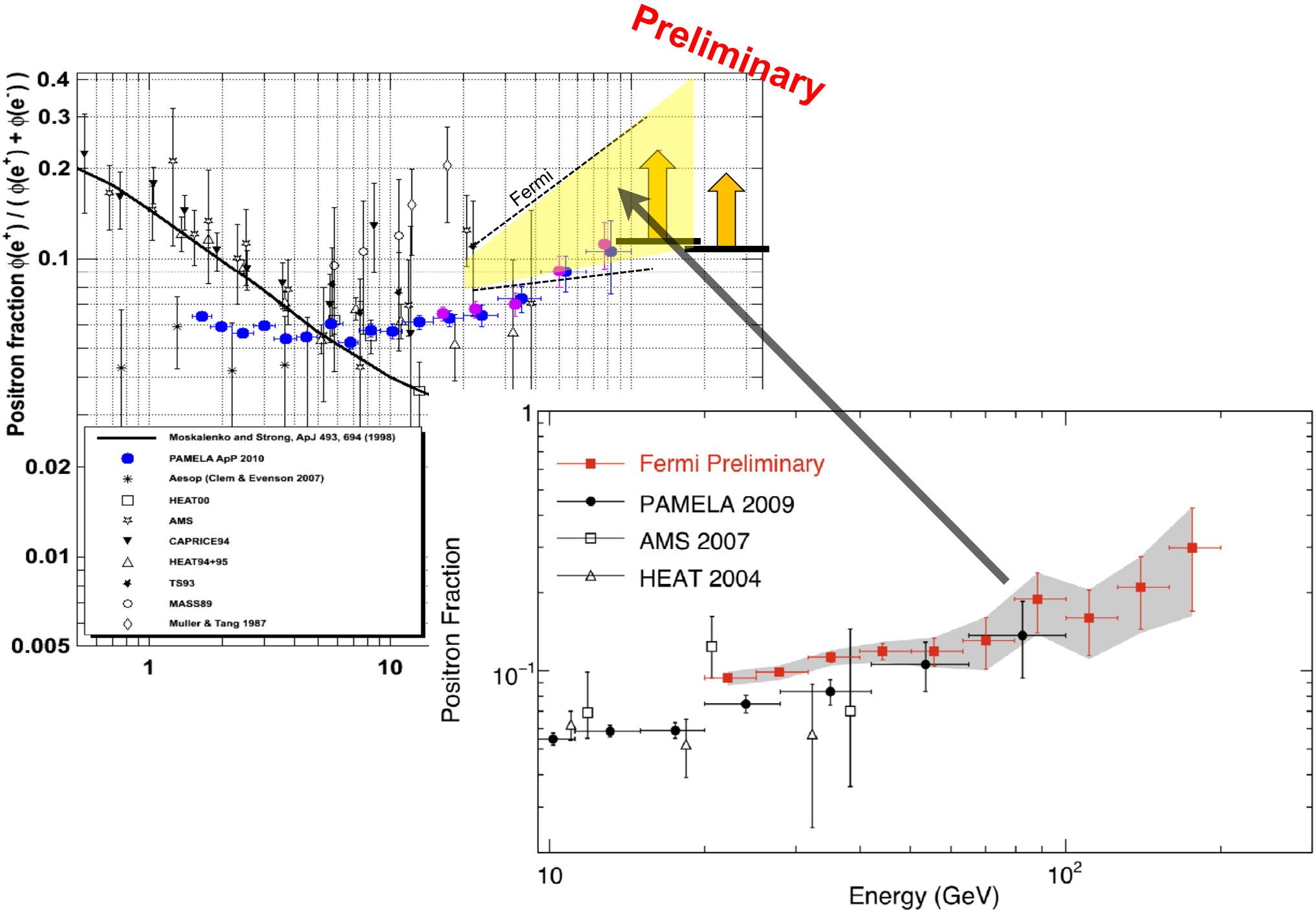
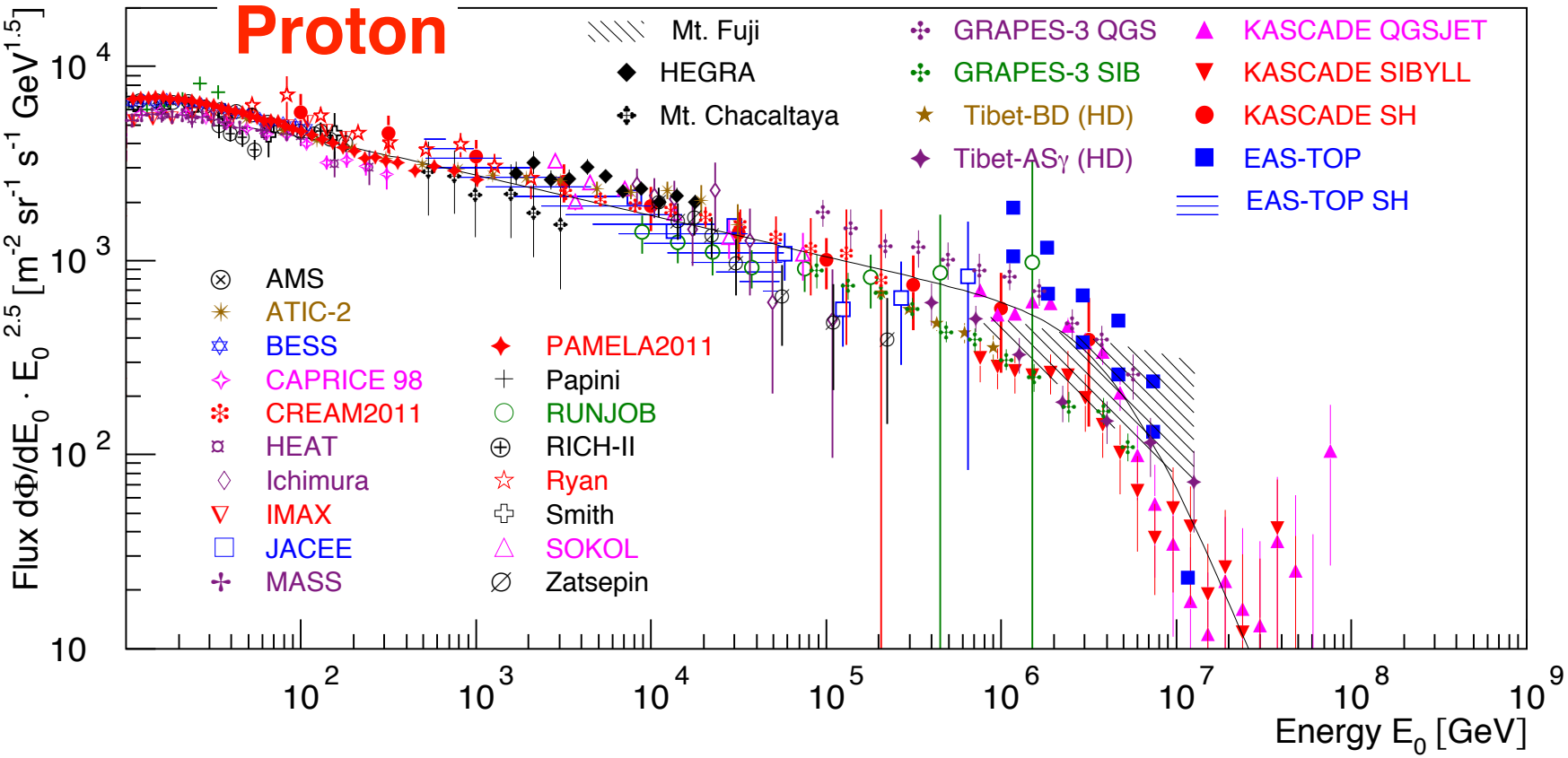
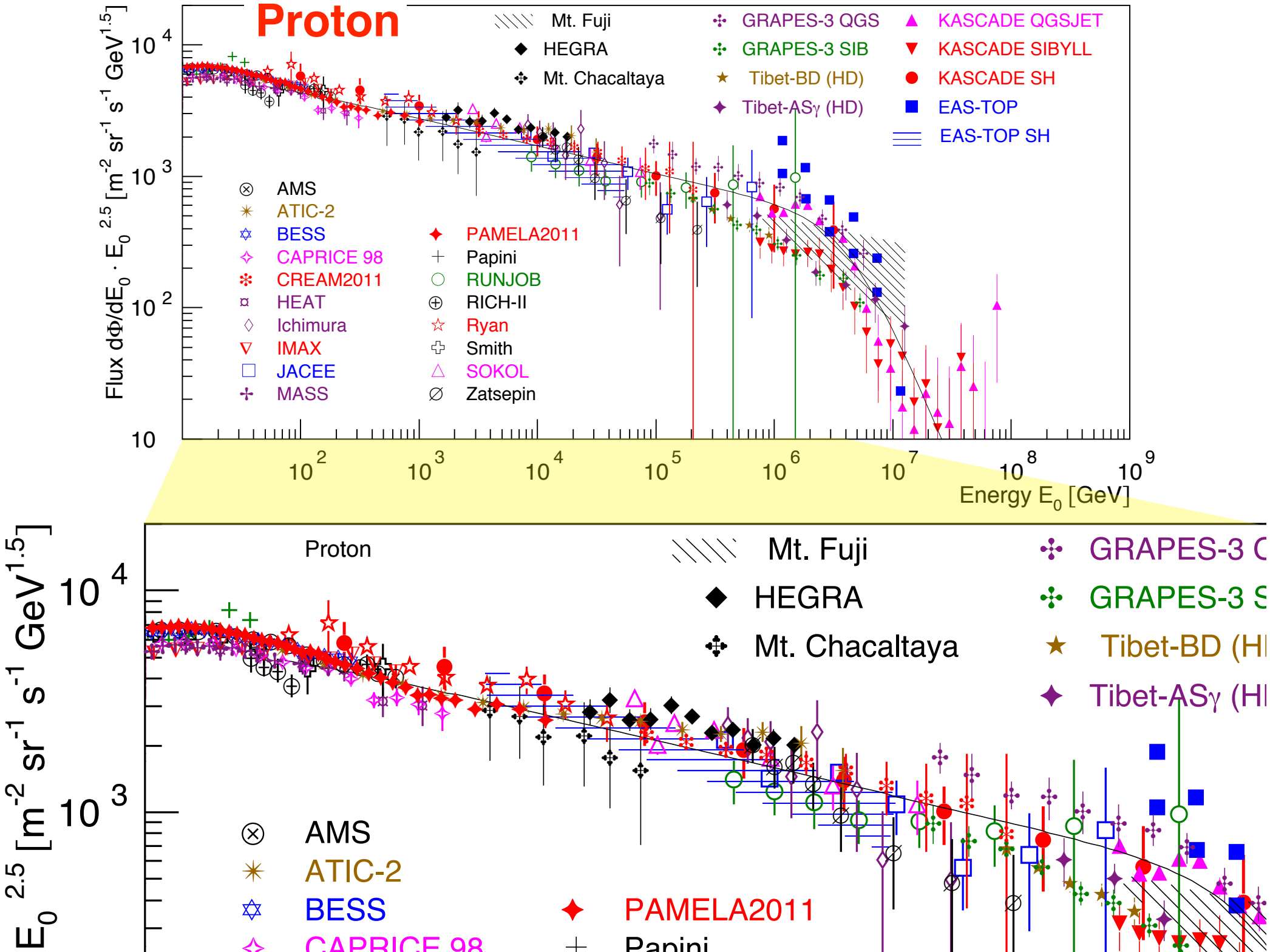


Mocchiutti et al., ICRC 2011

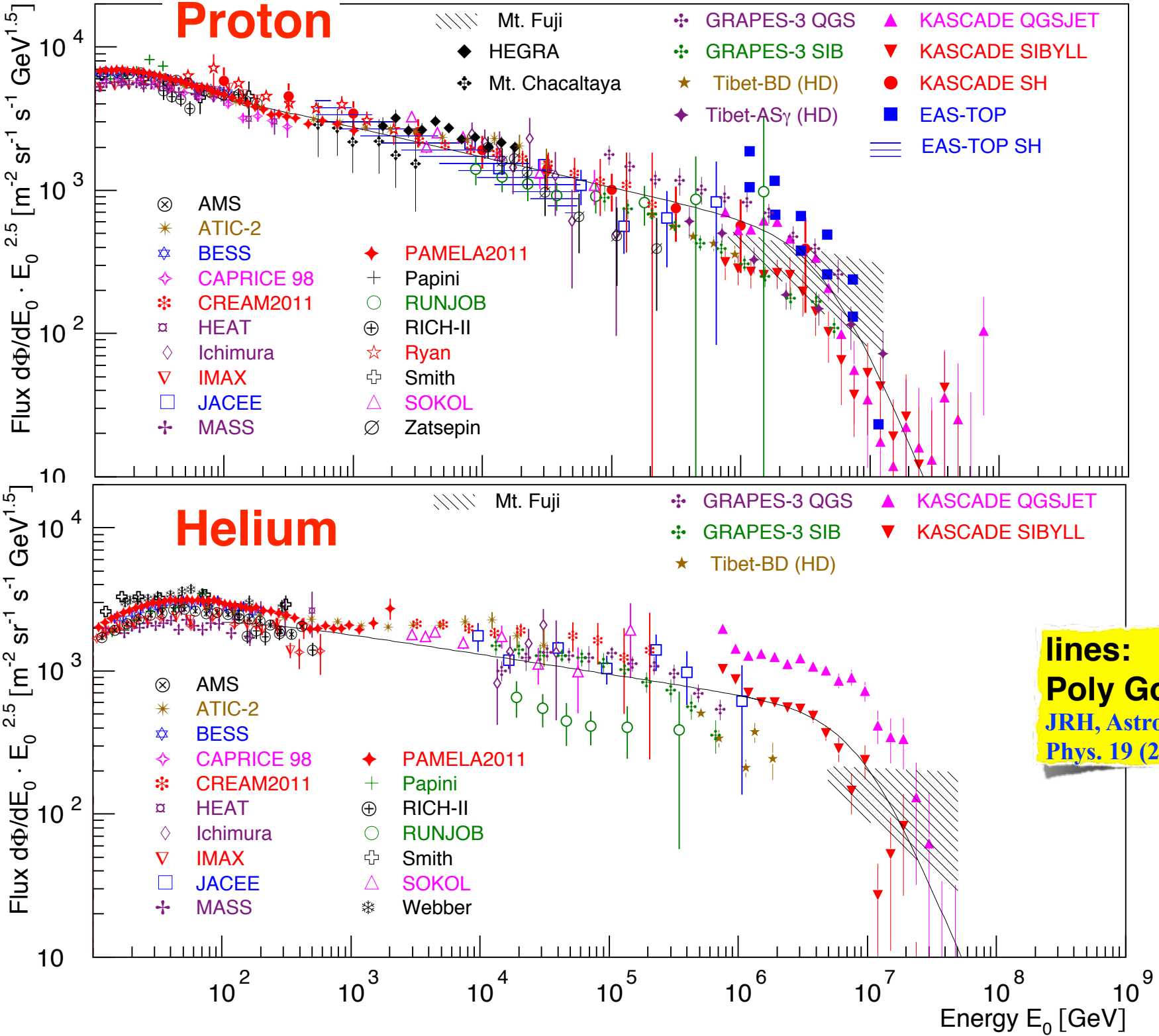
Vandenbroucke et al., ICRC 2011

Cosmic Ray Energy Spectra



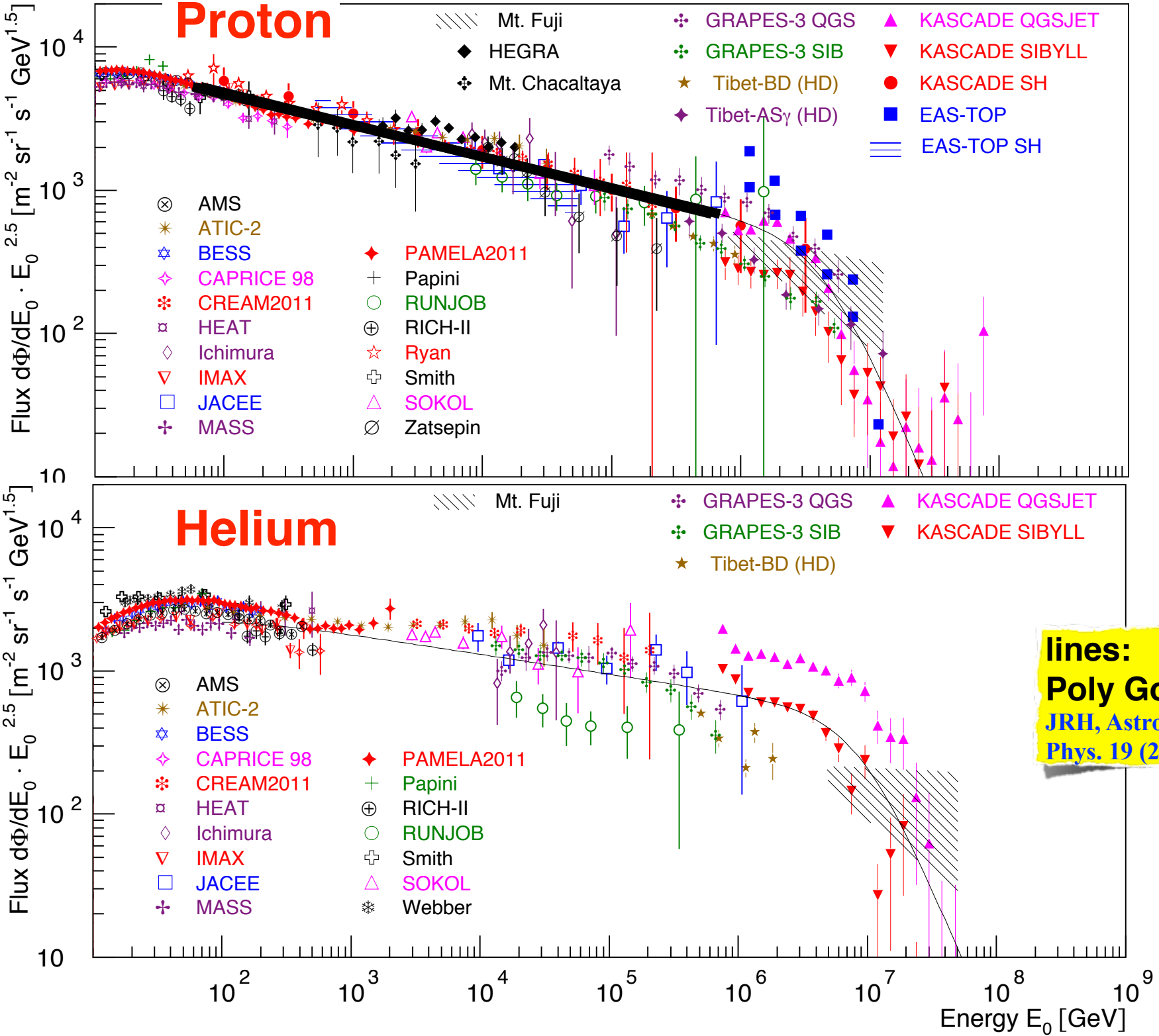

Proton
Mt. Fuji
HEGRA
Mt. Chacaltaya
GRAPES-3 QGS
GRAPES-3 SIB
Tibet-BD (HD)
Tibet-ASγ (HD)
KASCADE QGSJET
KASCADE SIBYLL
KASCADE SH
EAS-TOP
EAS-TOP SH
AMS
ATIC-2
BESS
CAPRICE 98
CREAM2011
HEAT
Ichimura
IMAX
JACEE
MASS
PAMELA2011
Papini
RUNJOB
RICH-II
Ryan
Smith
SOKOL
Zatsepin
Flux dΦ/dE0 · E0 2.5 [m-2 sr-1 s-1 GeV1.5]
Energy E0 [GeV]

Cosmic Ray Energy Spectra



lines:
Poly Gonato
JRH, Astropart. Phys. 19 (2003) 193

Cosmic Ray Energy Spectra



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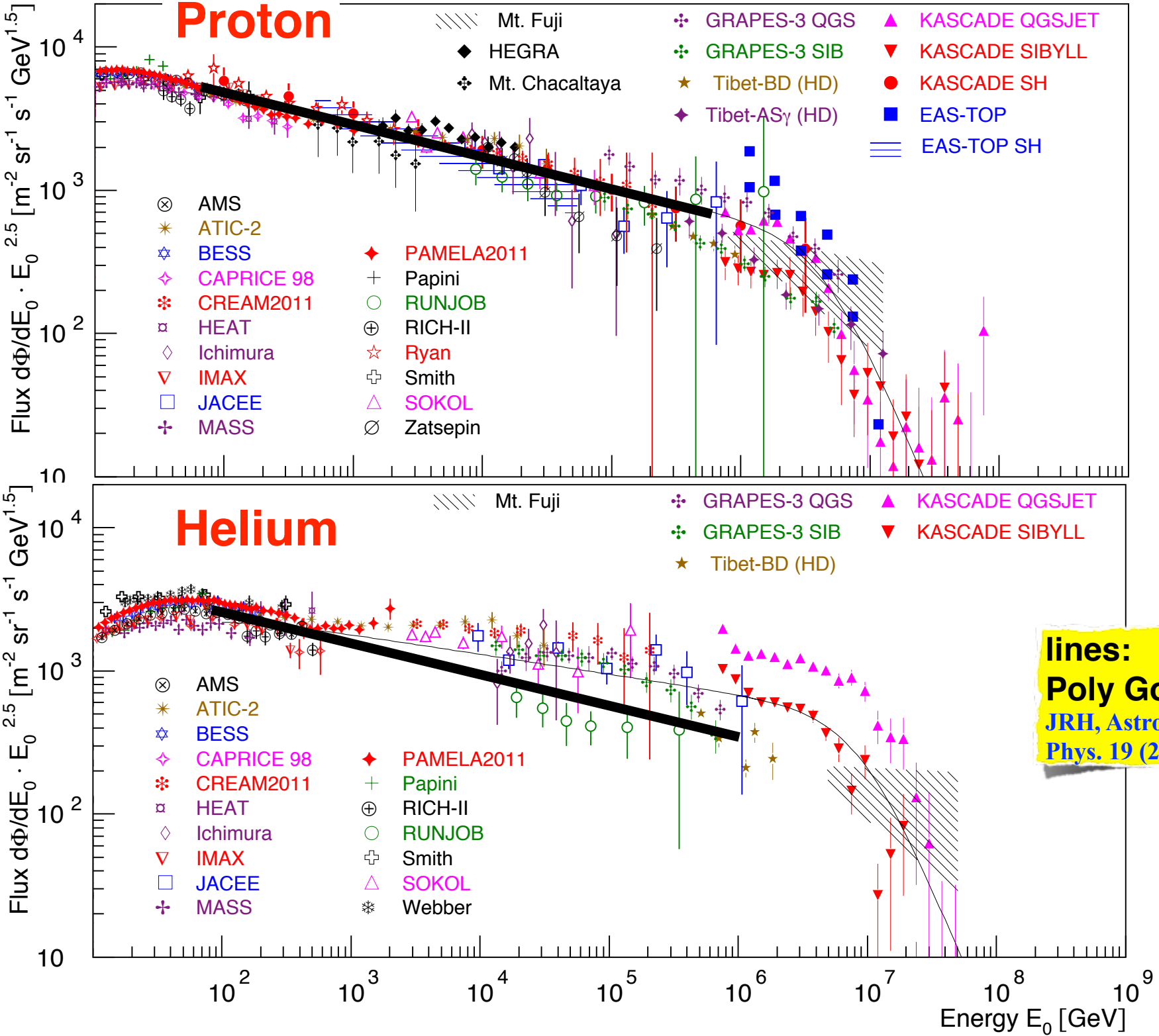
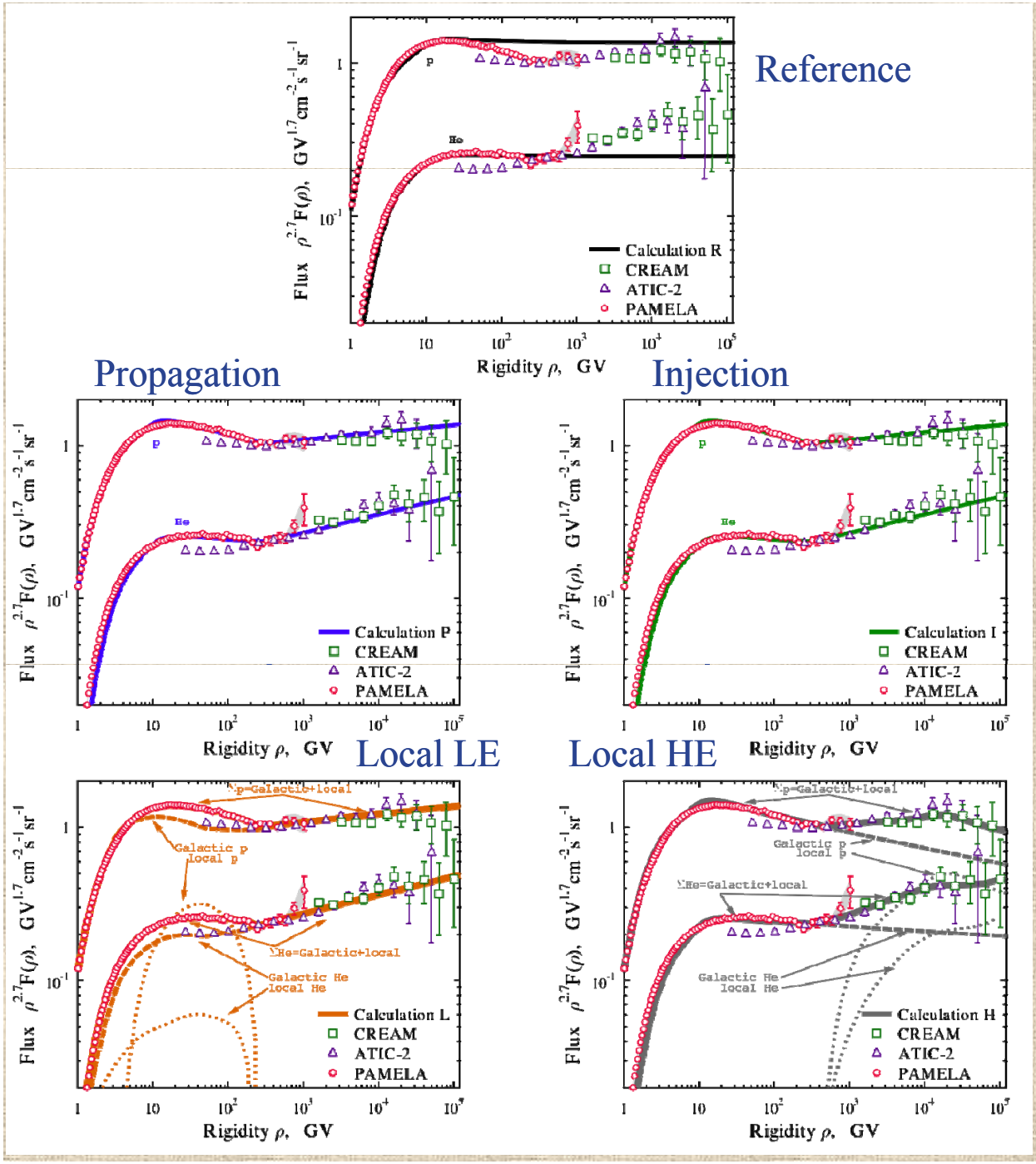
Cosmic Ray Energy Spectra



lines:
Poly Gonato
JRH, Astropart. Phys. 19 (2003) 193

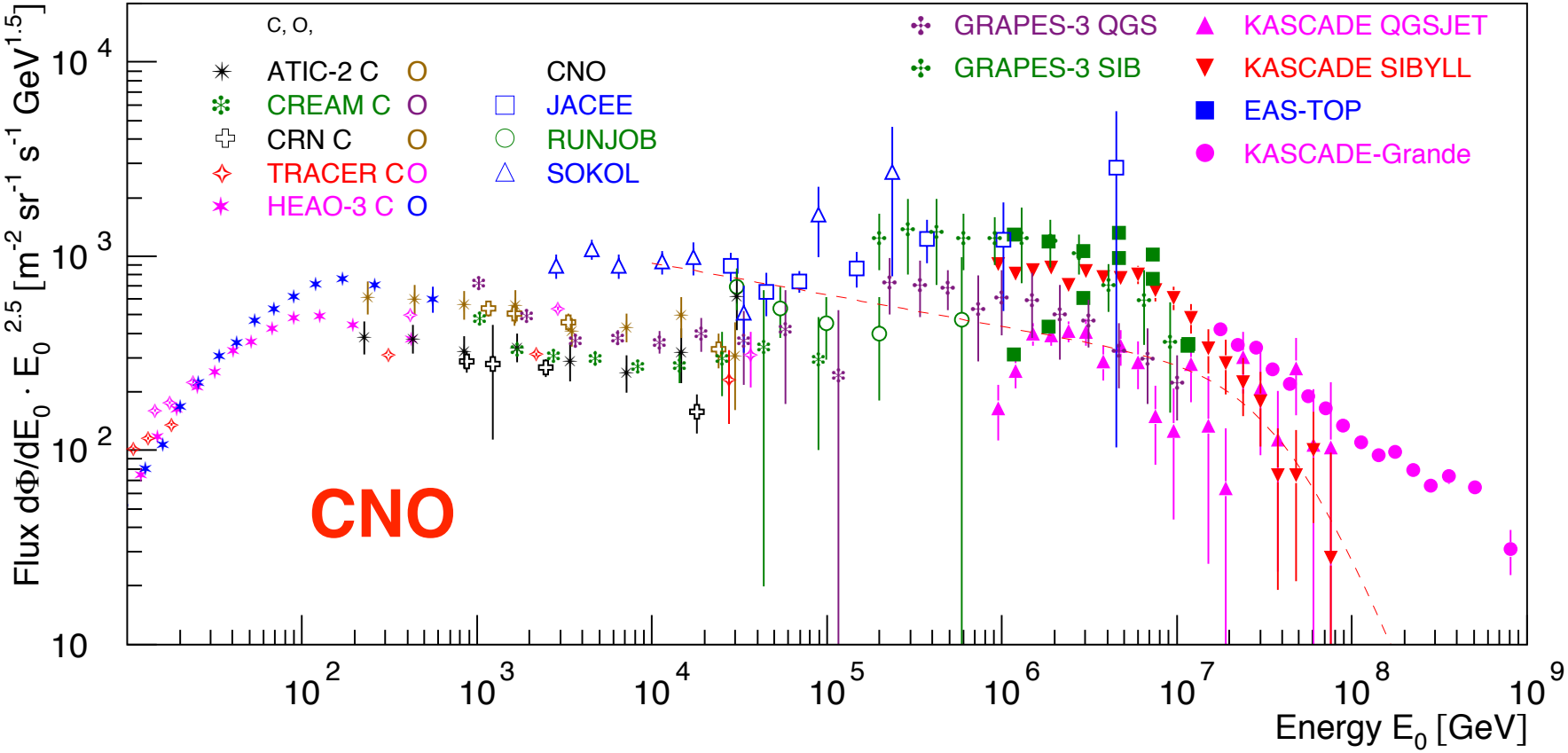
P and He spectra in different scenarios



- All scenarios are tuned to the data, except the Reference scenario
- Scenarios L and H: the local source component is calculated by the subtraction of the propagated Galactic spectrum from the data
- The local source is assumed to be close to us, so no propagation; only primary CR species

Moskalenko et al., ICRC 2011

Cosmic Ray Energy Spectra



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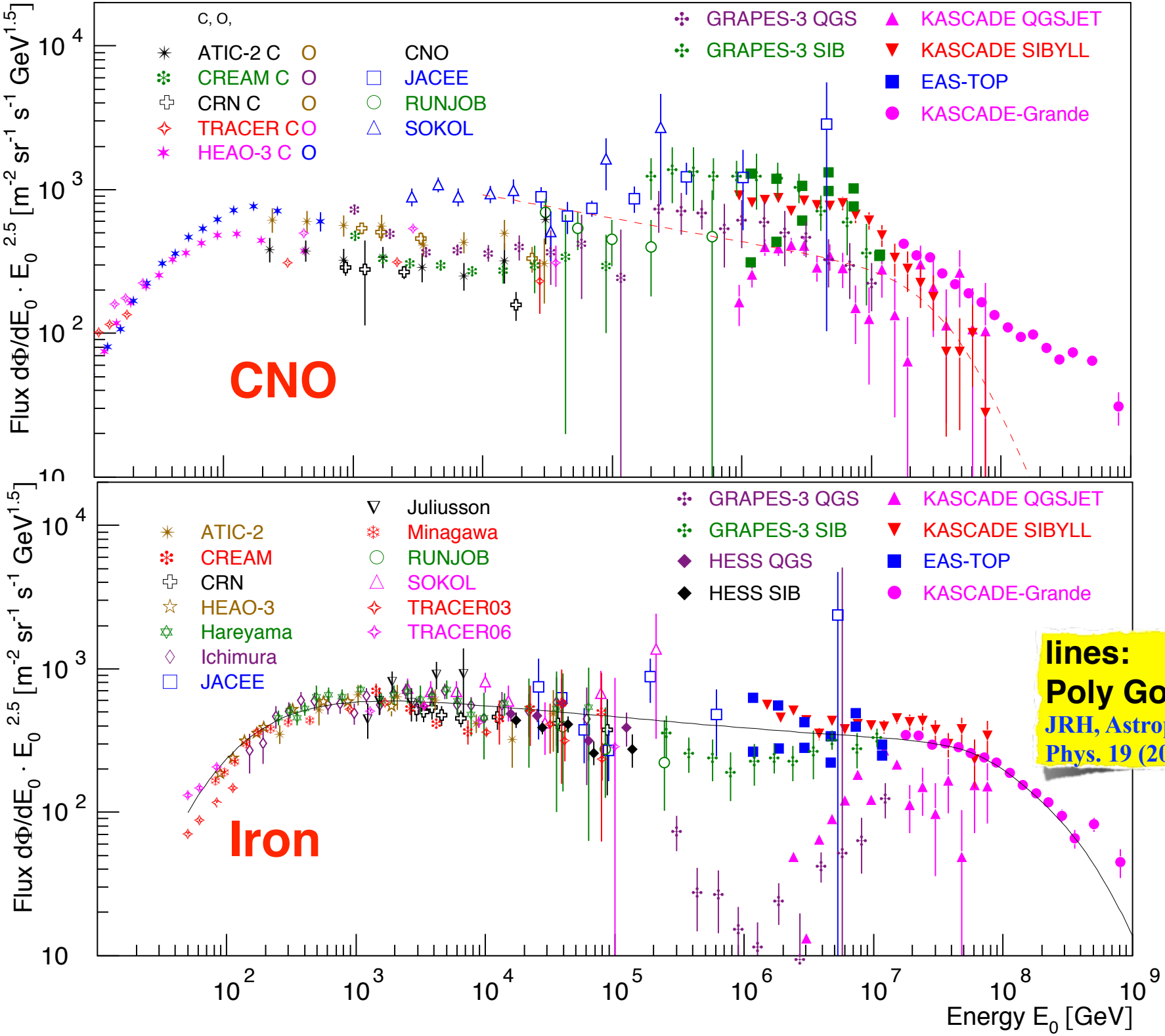

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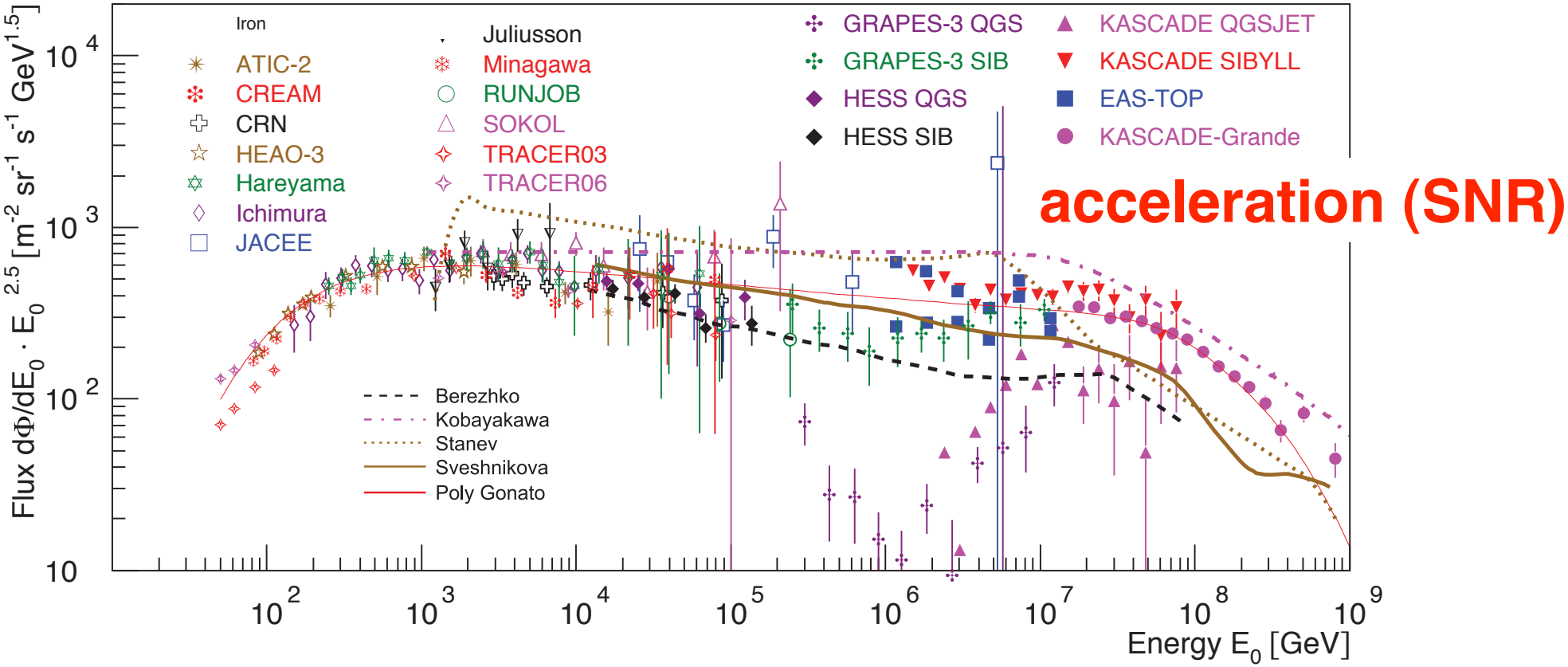
JRH, Astropart. Phys. 19 (2003) 193

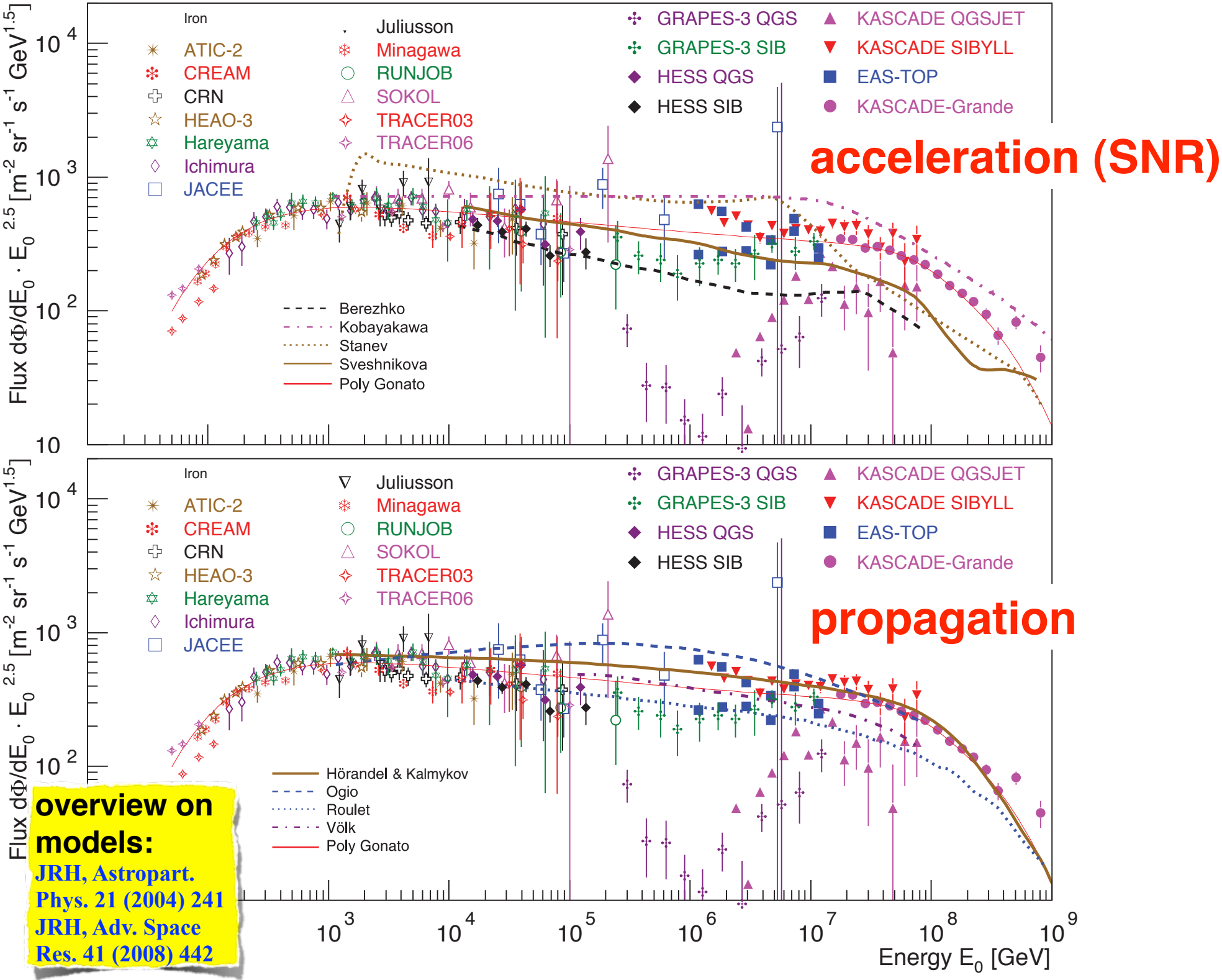
Comparison to models (Fe group)



acceleration (SNR)

overview on models:
JRH, Astropart. Phys. 21 (2004) 241
JRH, Adv. Space Res. 41 (2008) 442

Comparison to models (Fe group)



overview on models:

JRH, Astropart. Phys. 21 (2004) 241

JRH, Adv. Space Res. 41 (2008) 442

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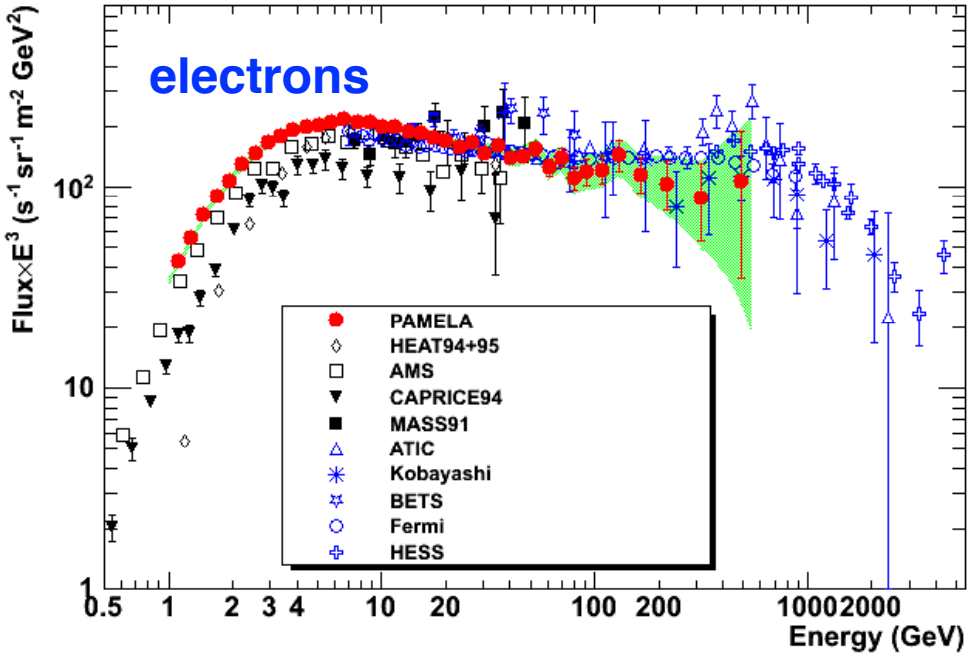

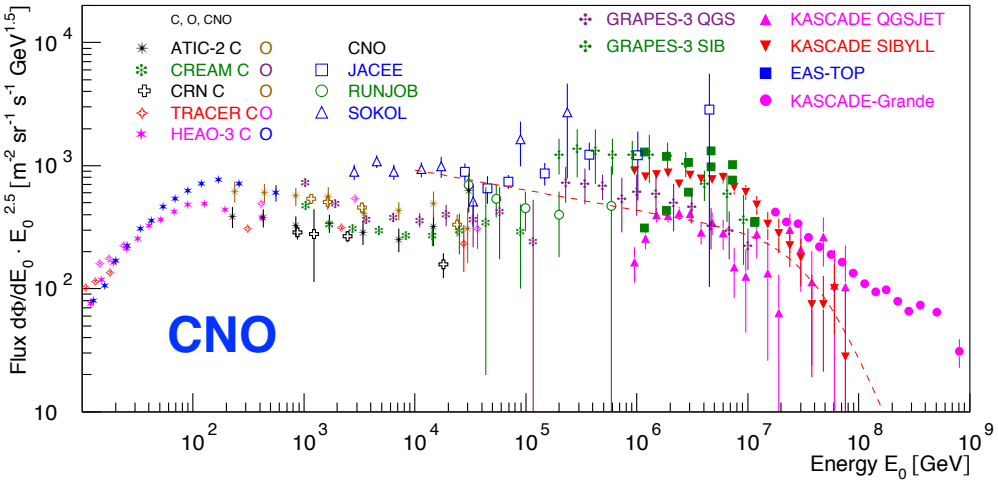

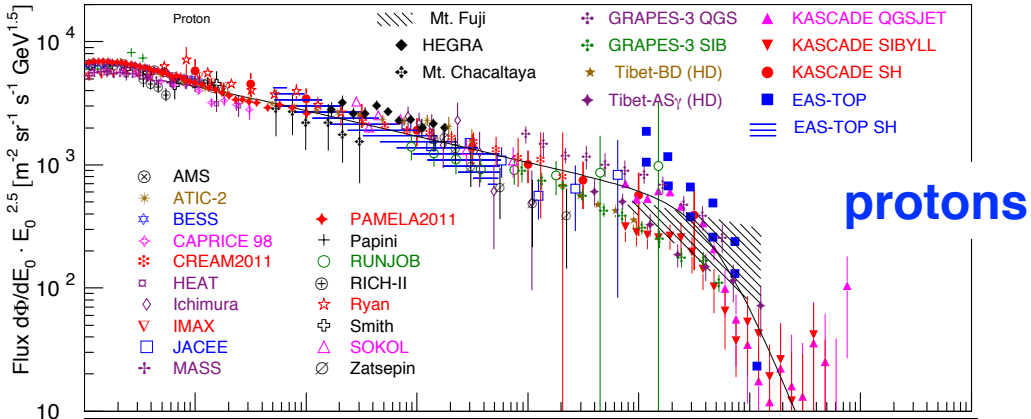

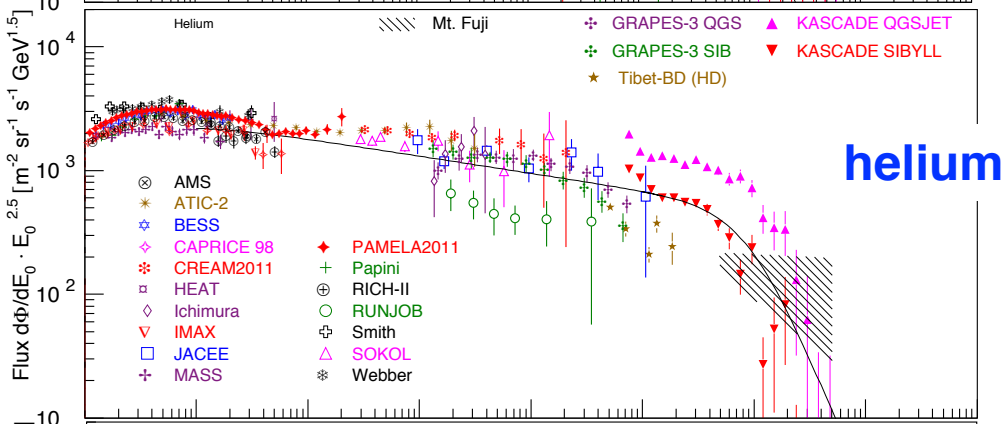

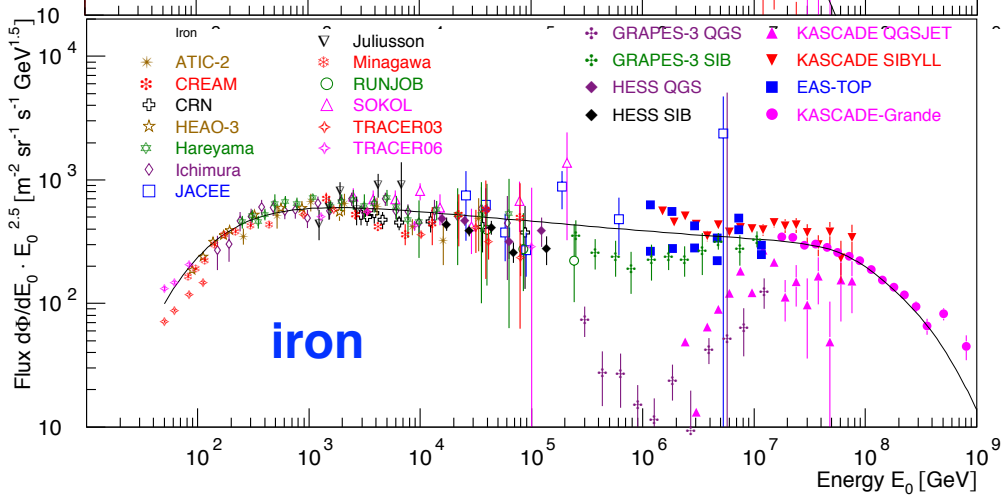

Jörg R. Hörandel
Radboud University Nijmegen