Cosmic-ray spectral anomaly at GeV-TeV energies:

Re-acceleration by weak shocks

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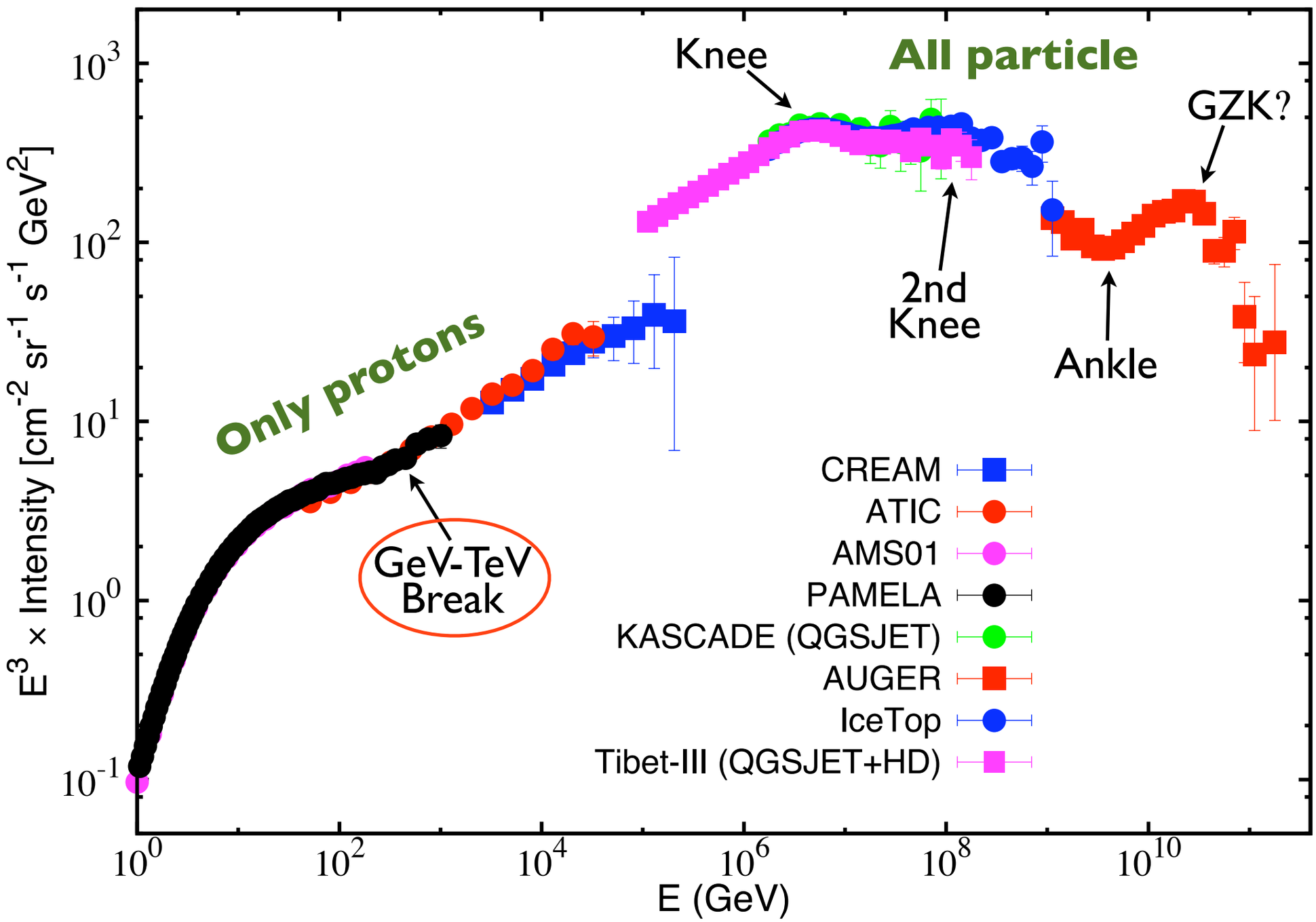
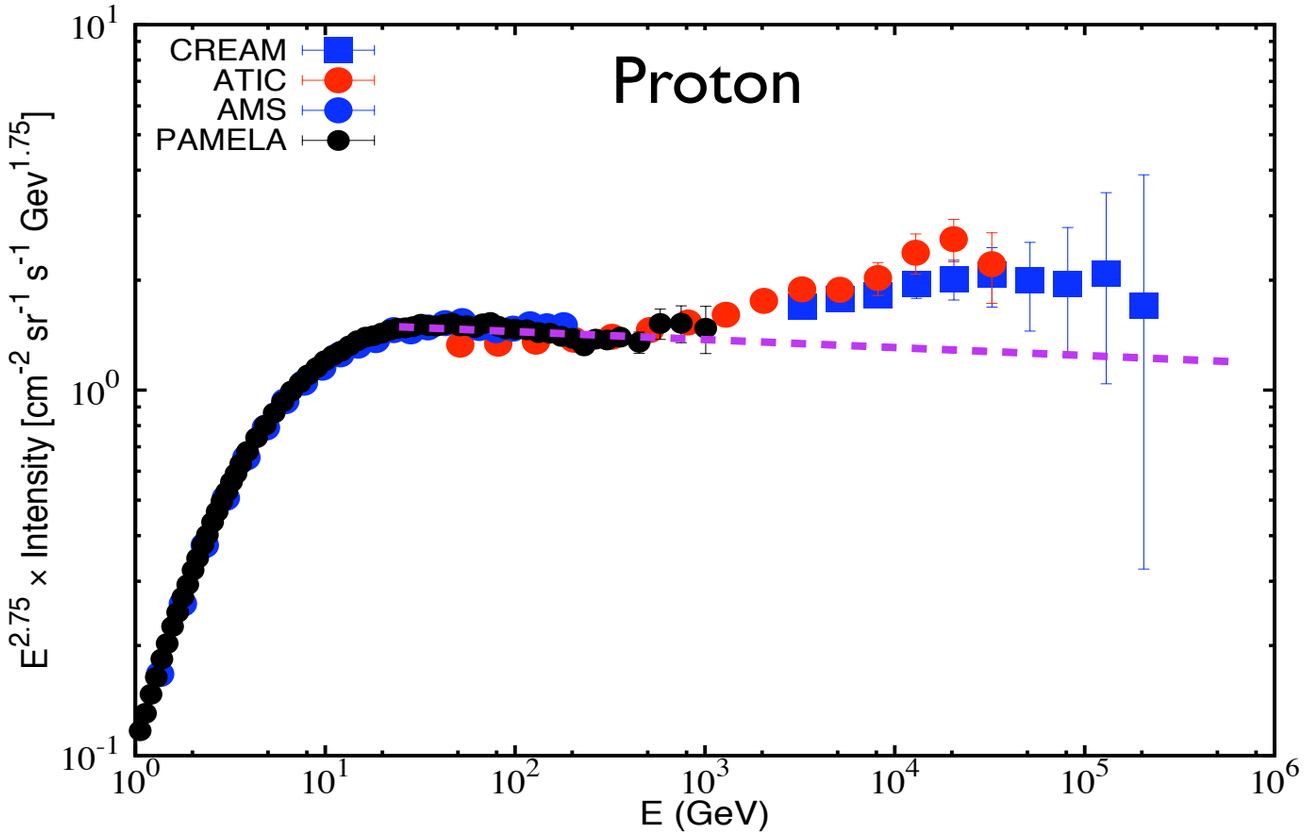
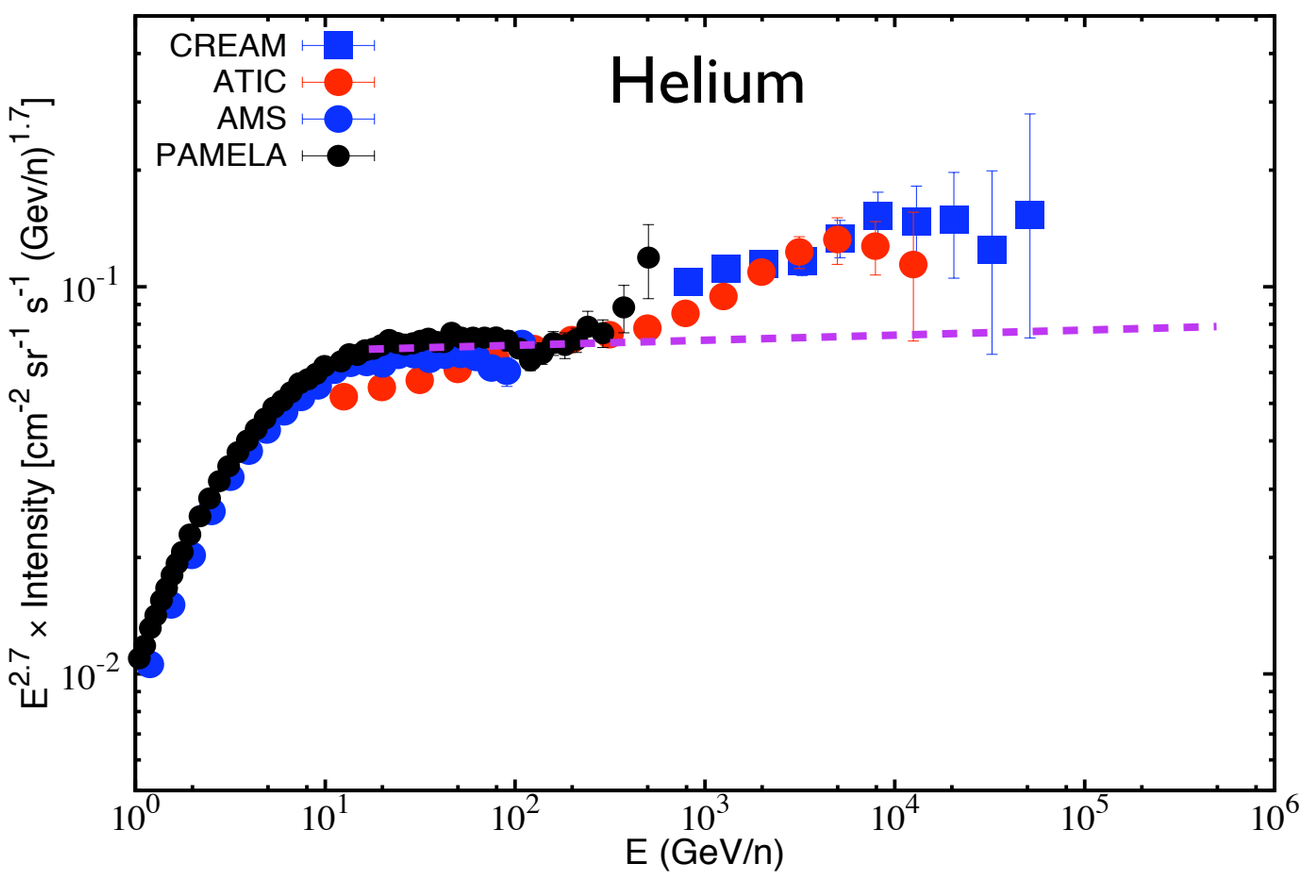
Cosmic-ray spectrum



GeV-TeV spectral anomaly



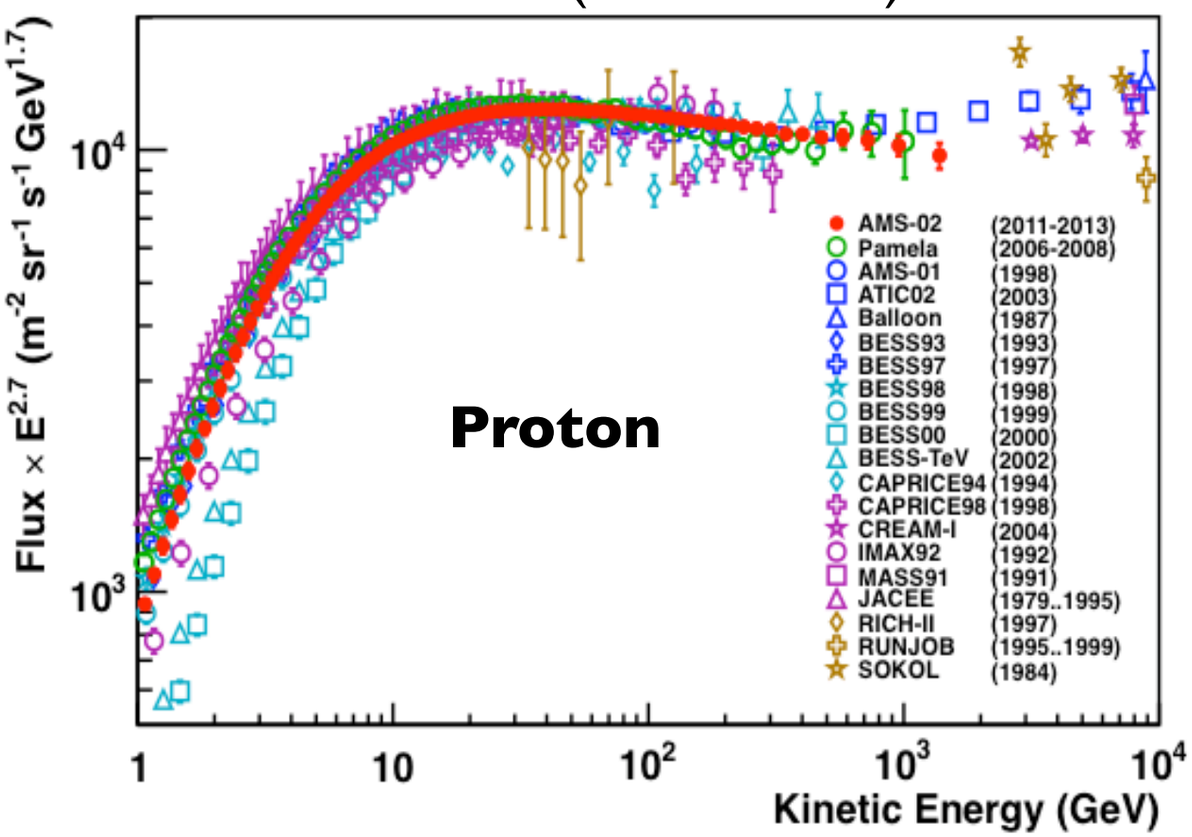


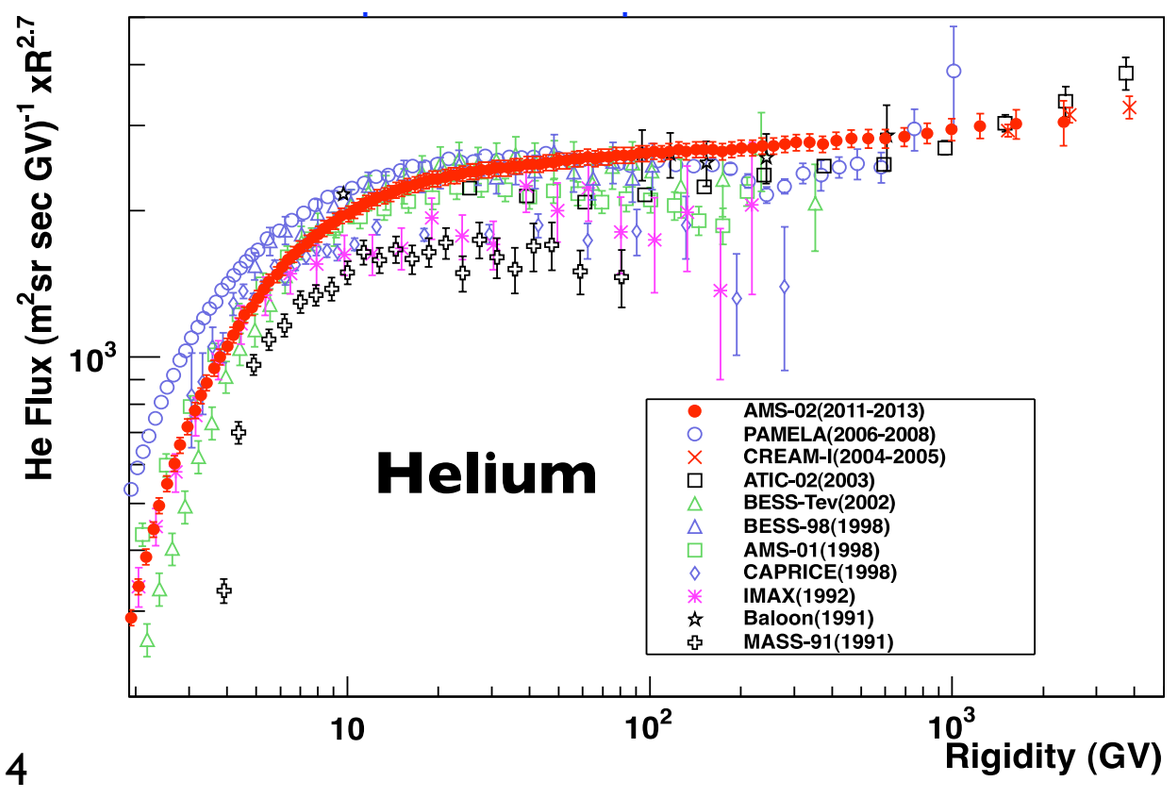
***Recent measurements by CREAM, ATIC and PAMELA have found cosmic-ray spectral hardening at TeV energies**

(Panov+ 2007, Yoon+ 2011, Adriani+ 2011)

Pre. results from AMS02

AMS02 (ICRC 2013)





Pre. results from AMS02

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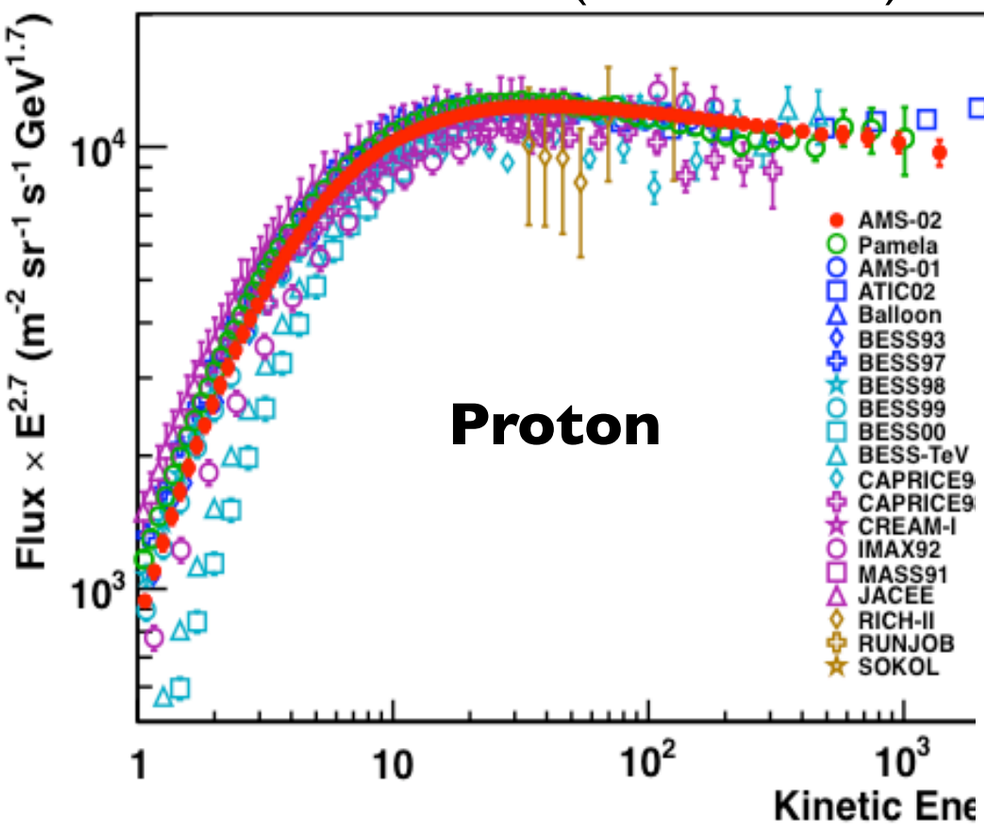
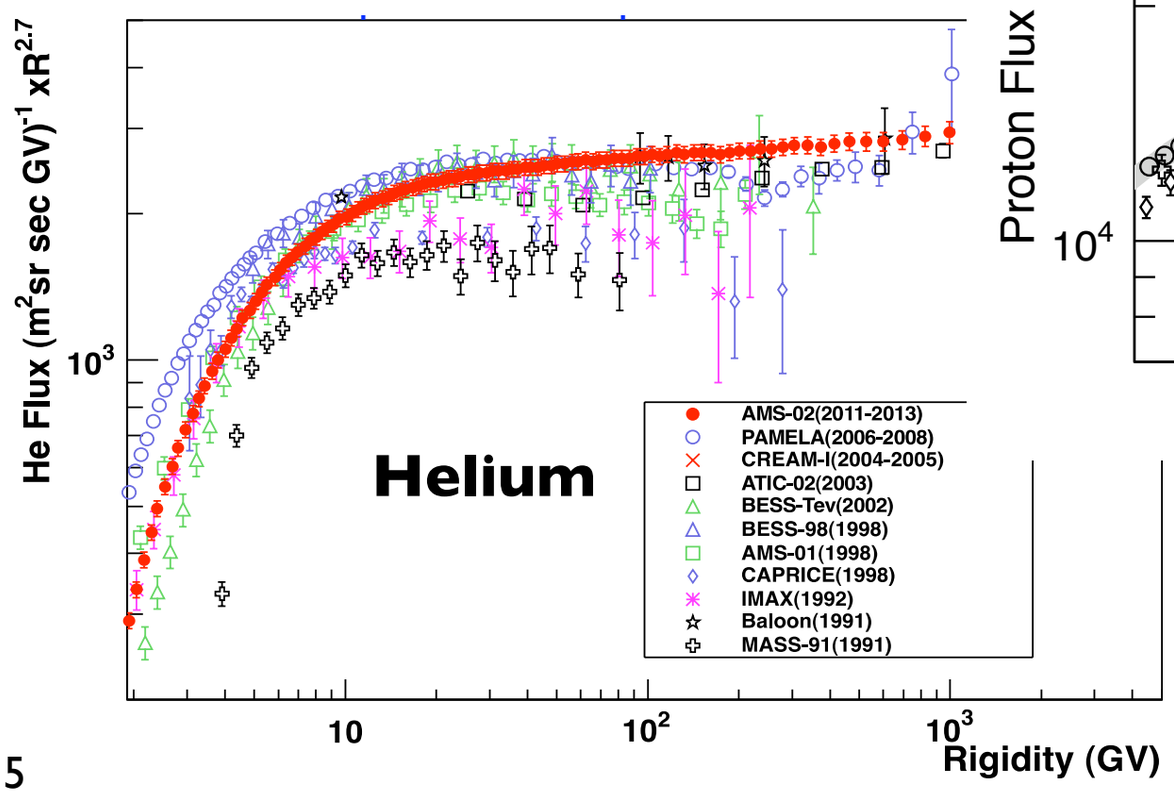
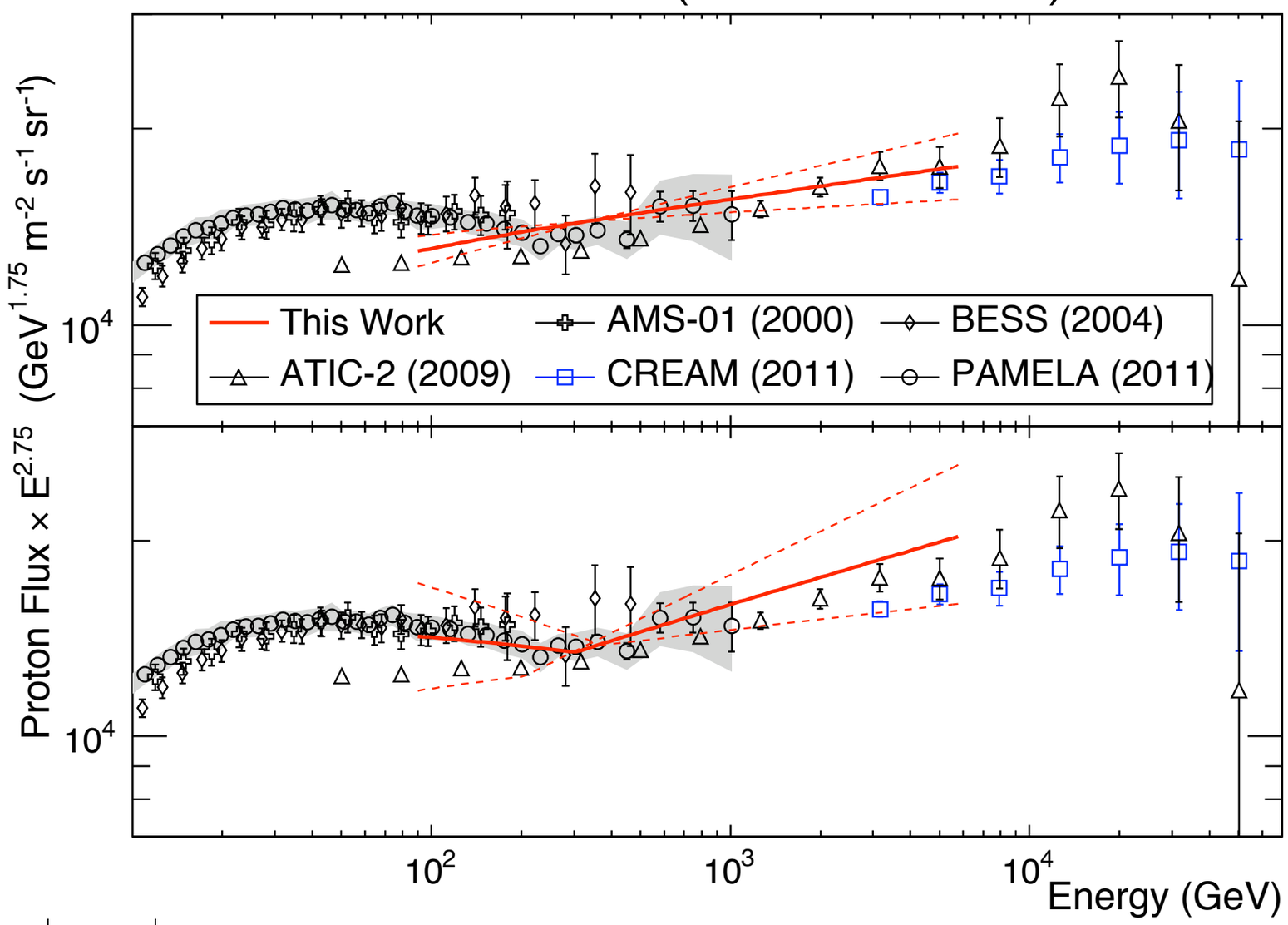




FERMI (arXiv:1403.5372)



Possible explanations

(1) Injection source spectrum *(Biermann+ 2010; Ohira+ 2011; Yuan+ 2011; Ptuskin+ 2013)*

(2) Propagation effect *(Tomassetti 2012; Blasi+ 2012; Evoli & Yan 2014)*

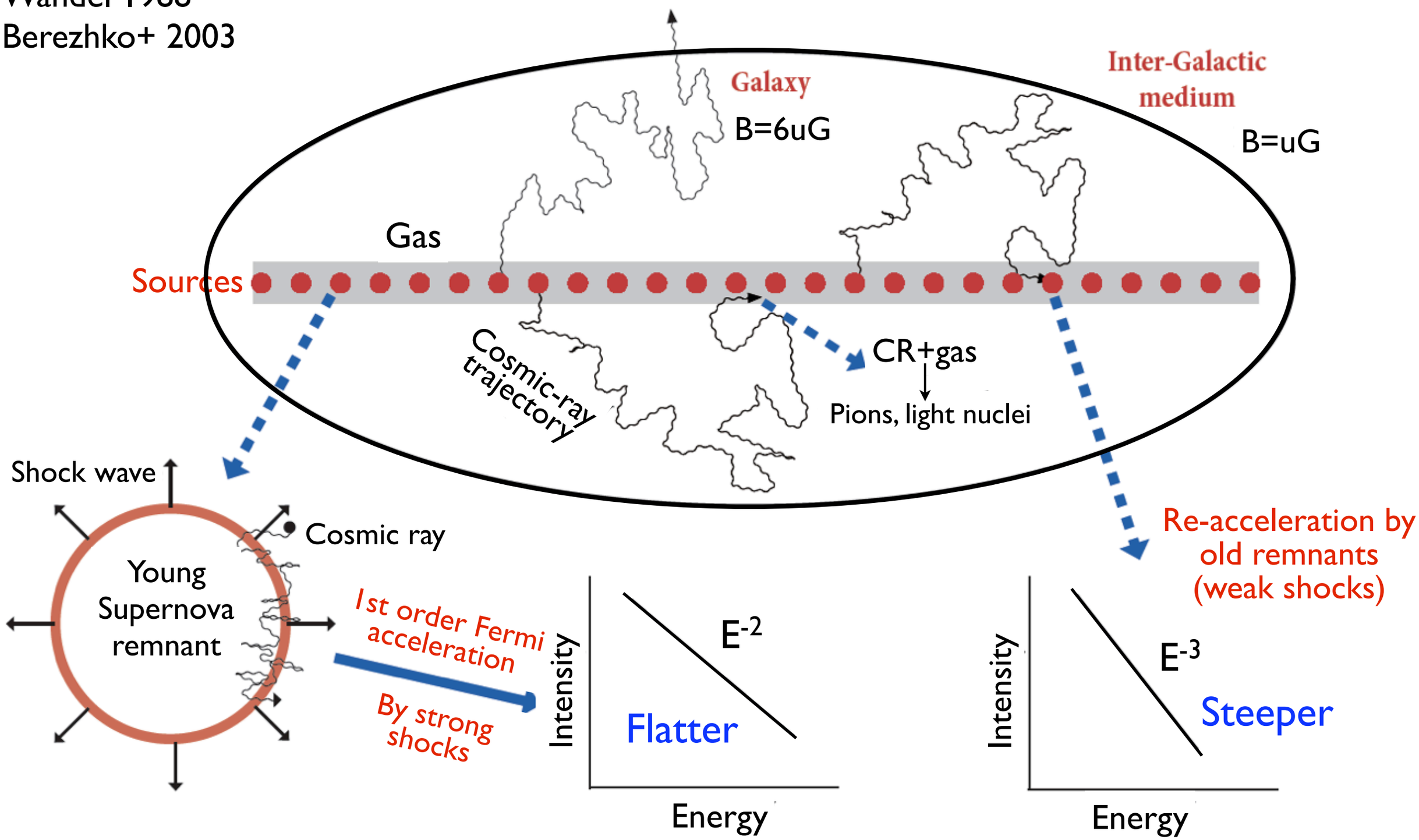
(3) Nearby sources *(Thoudam & Hörandel 2012, 2013; Erlykin & Wolfendale 2012; Bernard+ 2012)*

(4) Re-acceleration effect *(Thoudam & Hörandel, 2014, A&A, in press, arXiv:1404.3630)*

(5) .....

The re-acceleration model

Wandel 1988
Berezhko+ 2003



The propagation equation

(arXiv:1404.3630)

$$\nabla \cdot (D\nabla N) - [\bar{n}v\sigma + \xi]\,\delta(z)N + \left[\xi s p^{-s} \int_{p_0}^{p} du\; N(u)u^{s-1}\right]\delta(z) = -Q\delta(z)$$

Diffusion
($D \propto p^a$)

Loss: Inelastic
+
Re-acceleration

Re-acceleration
$\xi = \eta V v$

Source
$Q \propto p^{-q}$

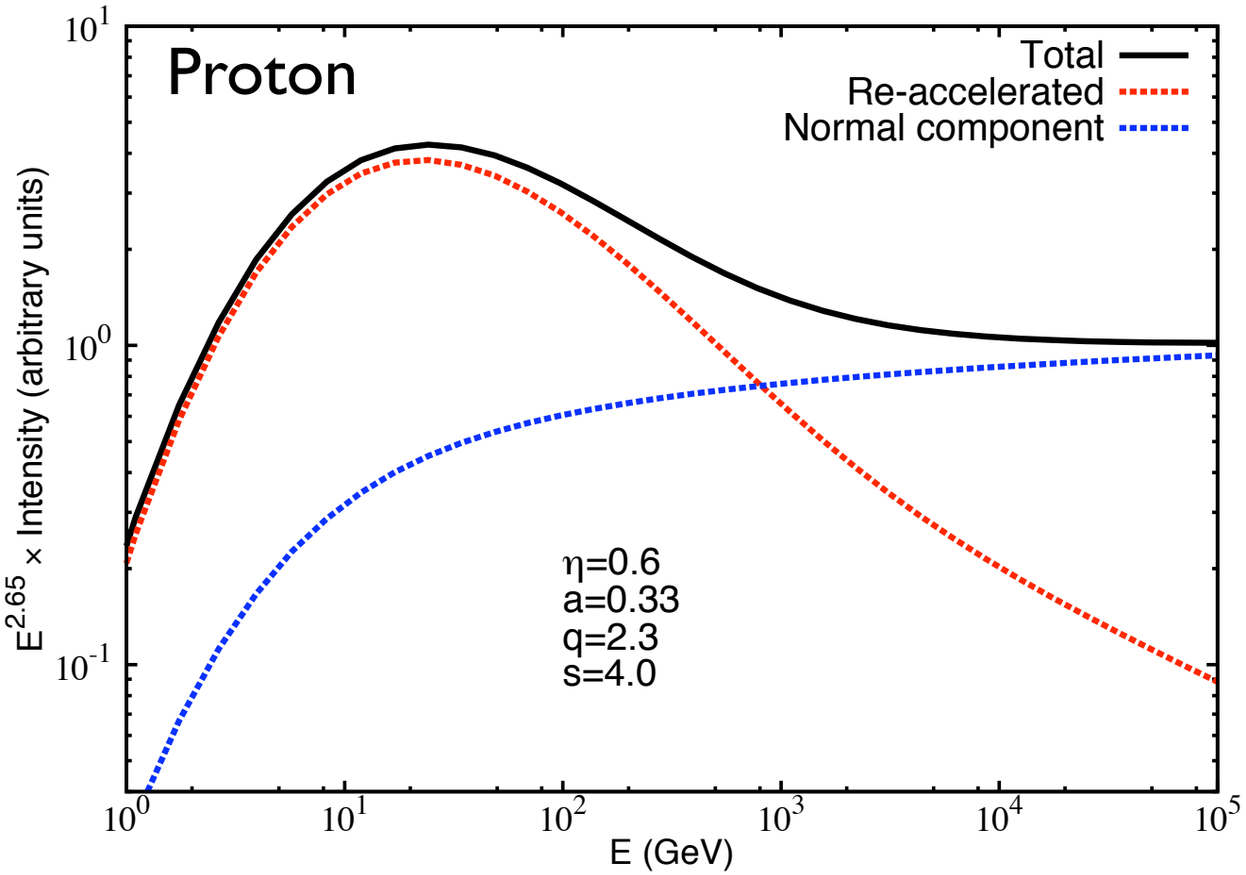
*$N(p)$: Cosmic-ray density; p=> Momentum

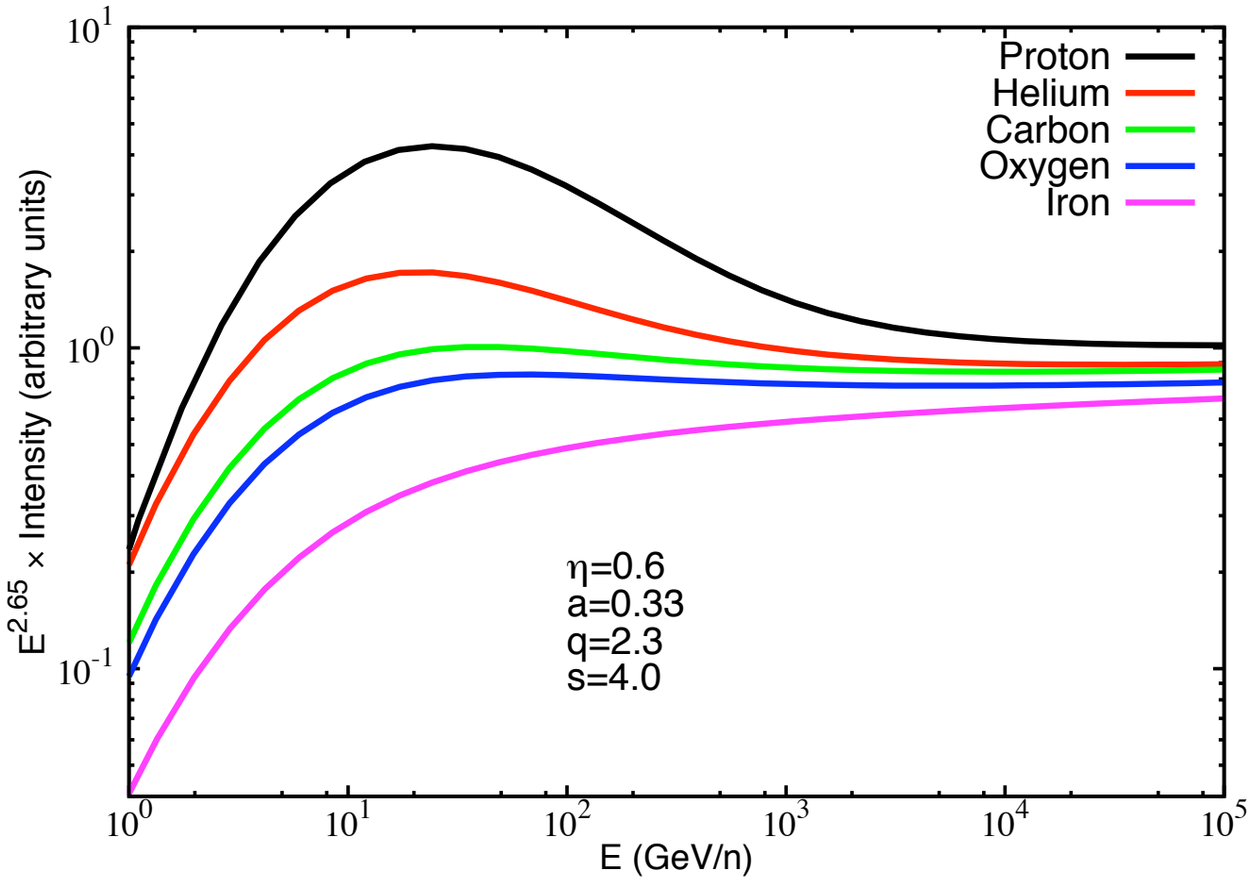
*Propagation parameters: (D_0, ρ_0 a)

*Re-acceleration parameters: (η, s)

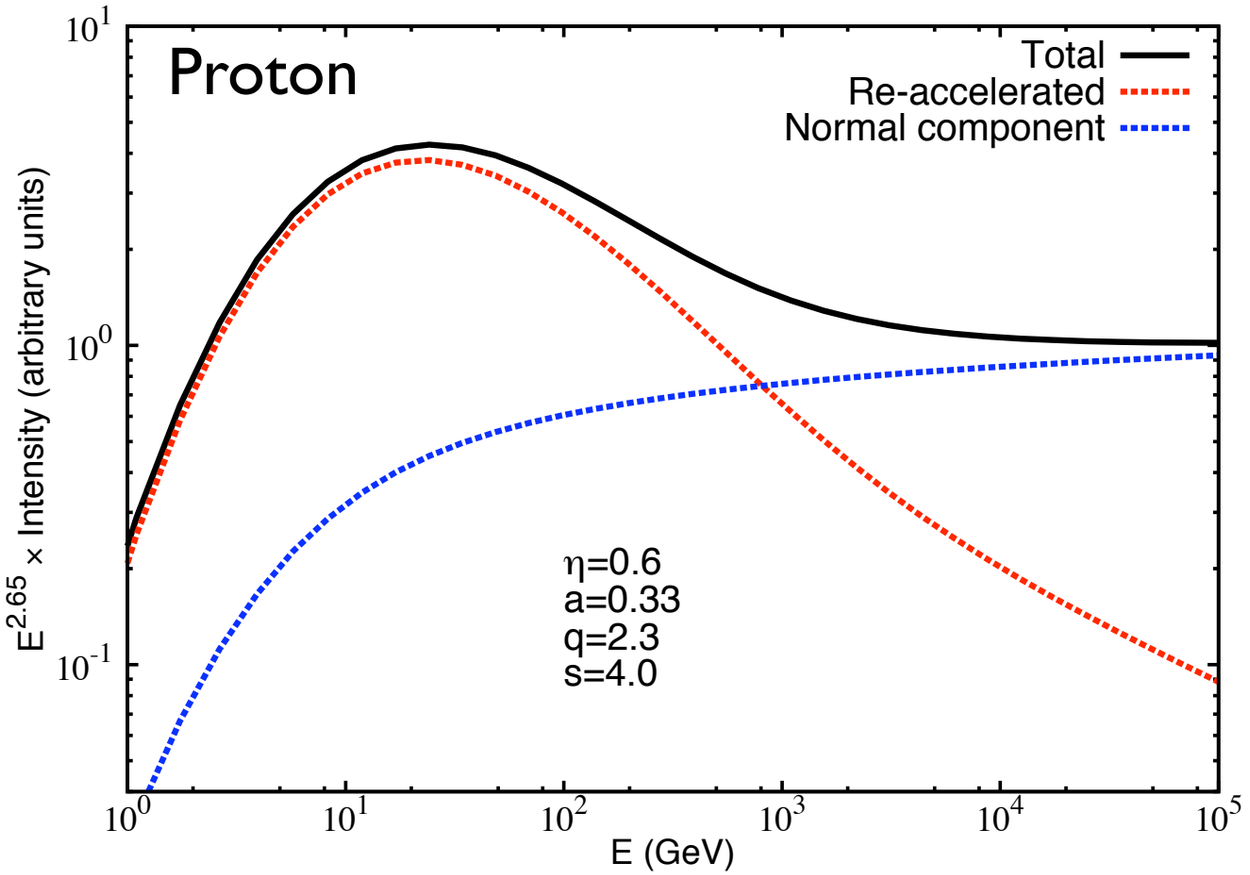
*Source parameters: (q, f)

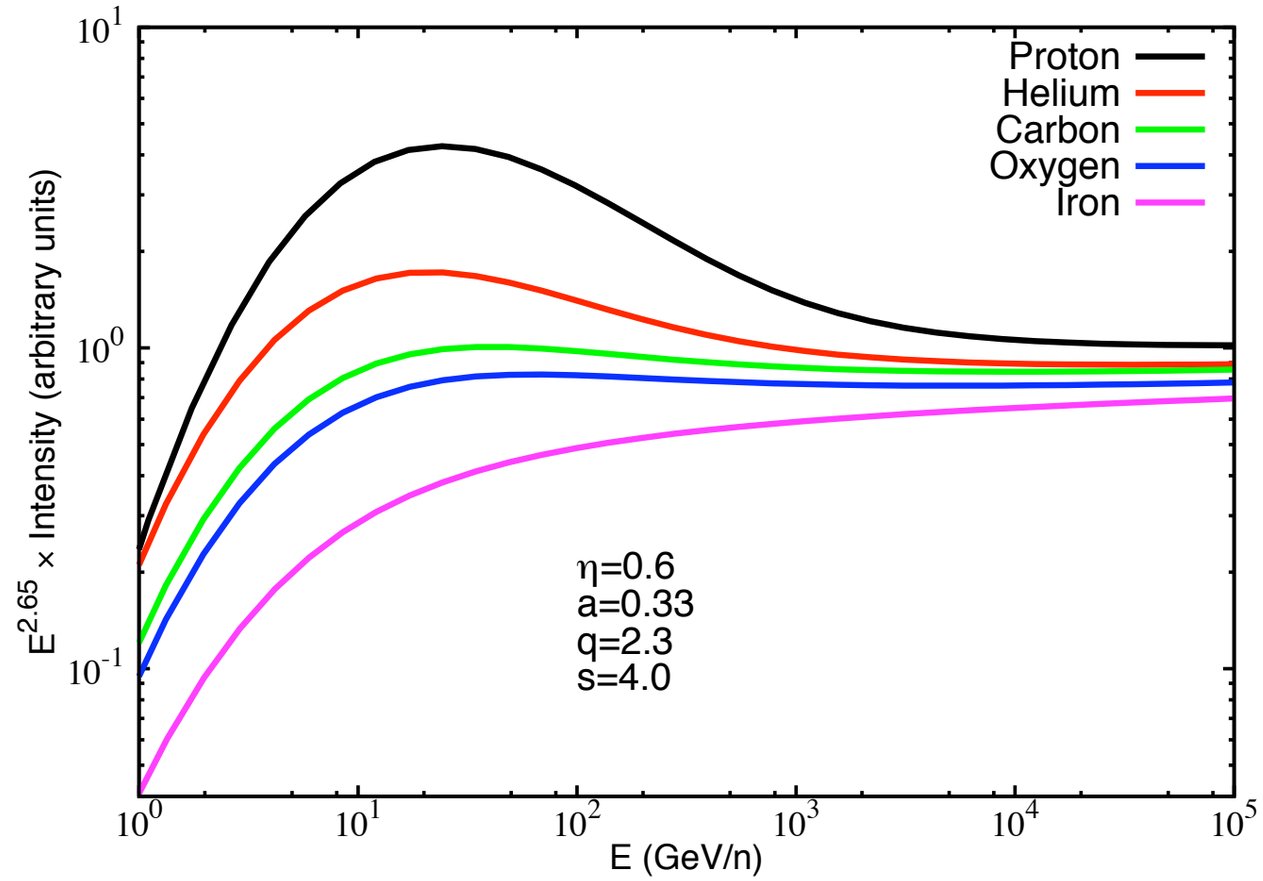
Re-acceleration effect on the cosmic-ray spectrum

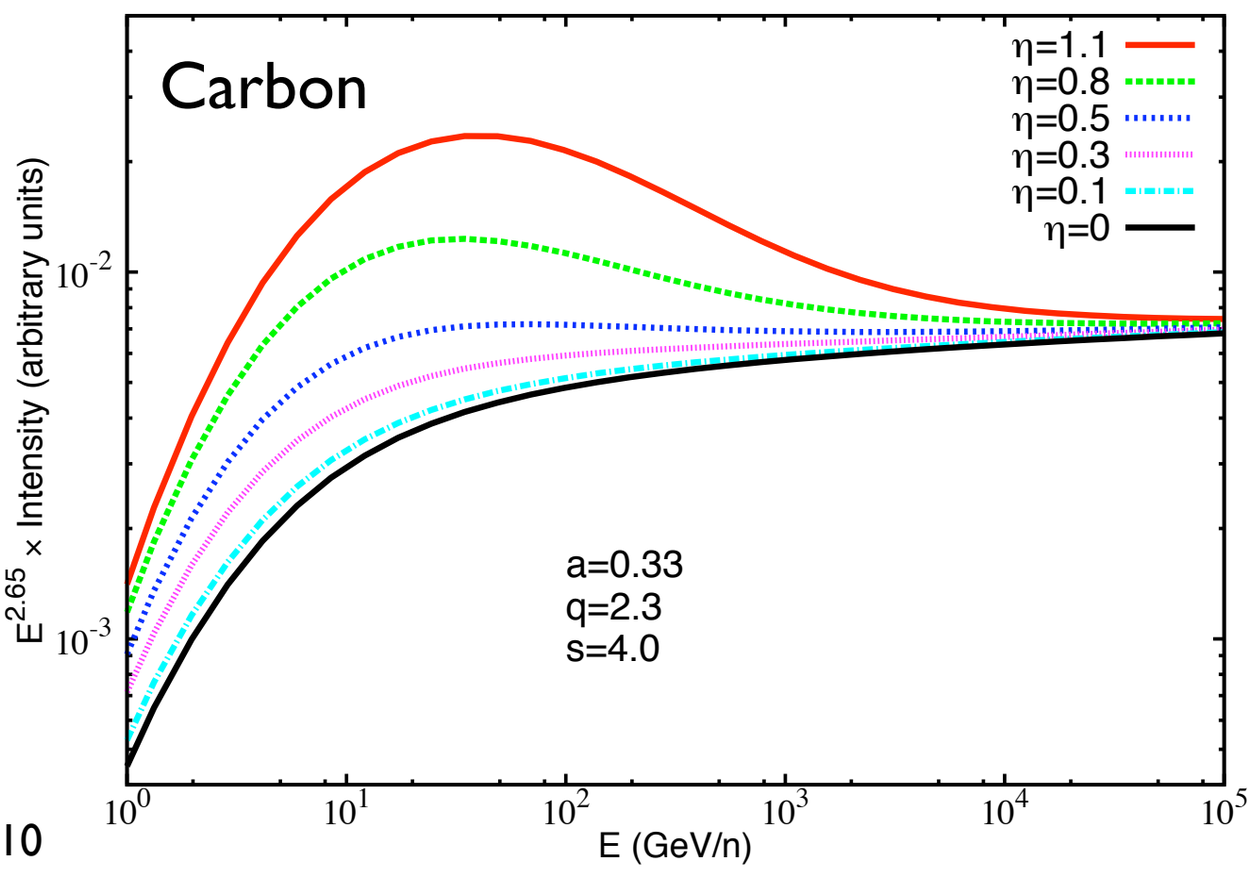


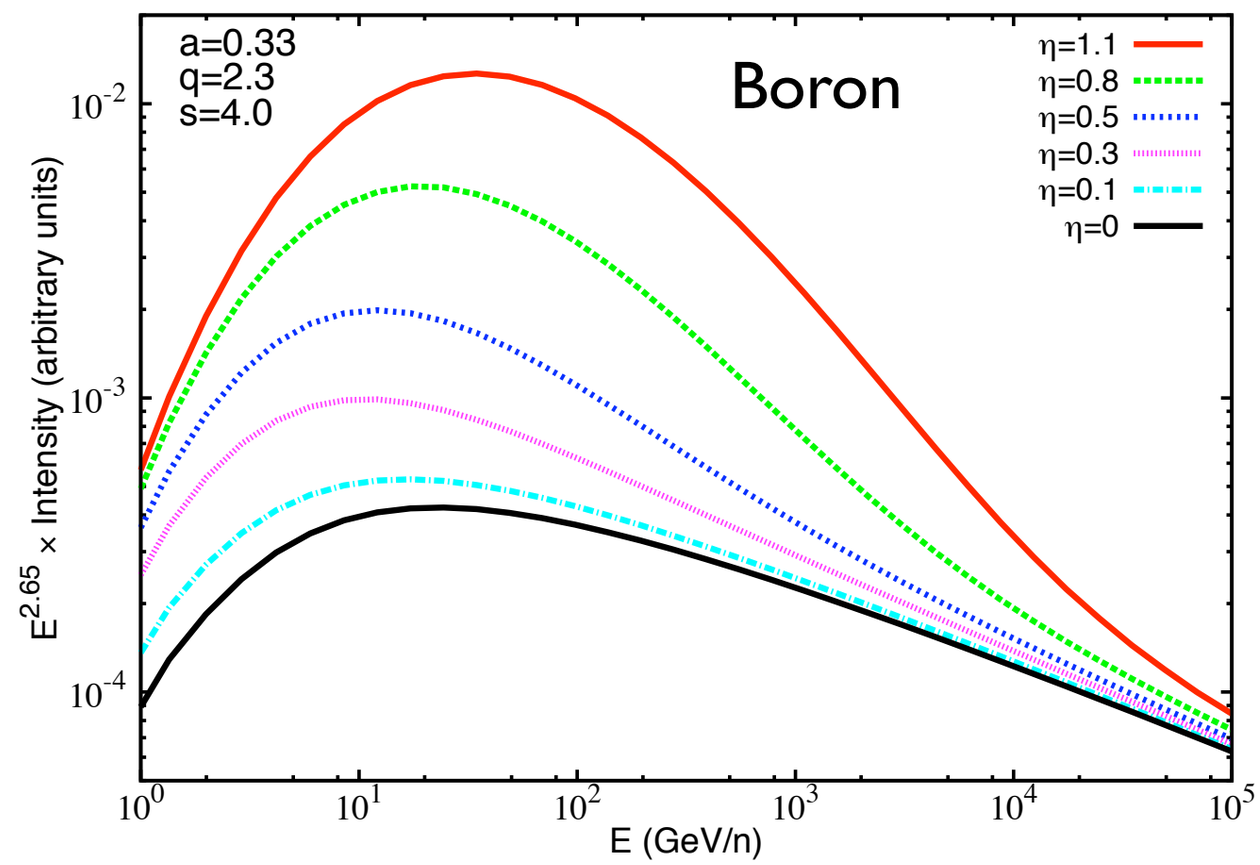


Re-acceleration effect on the cosmic-ray spectrum

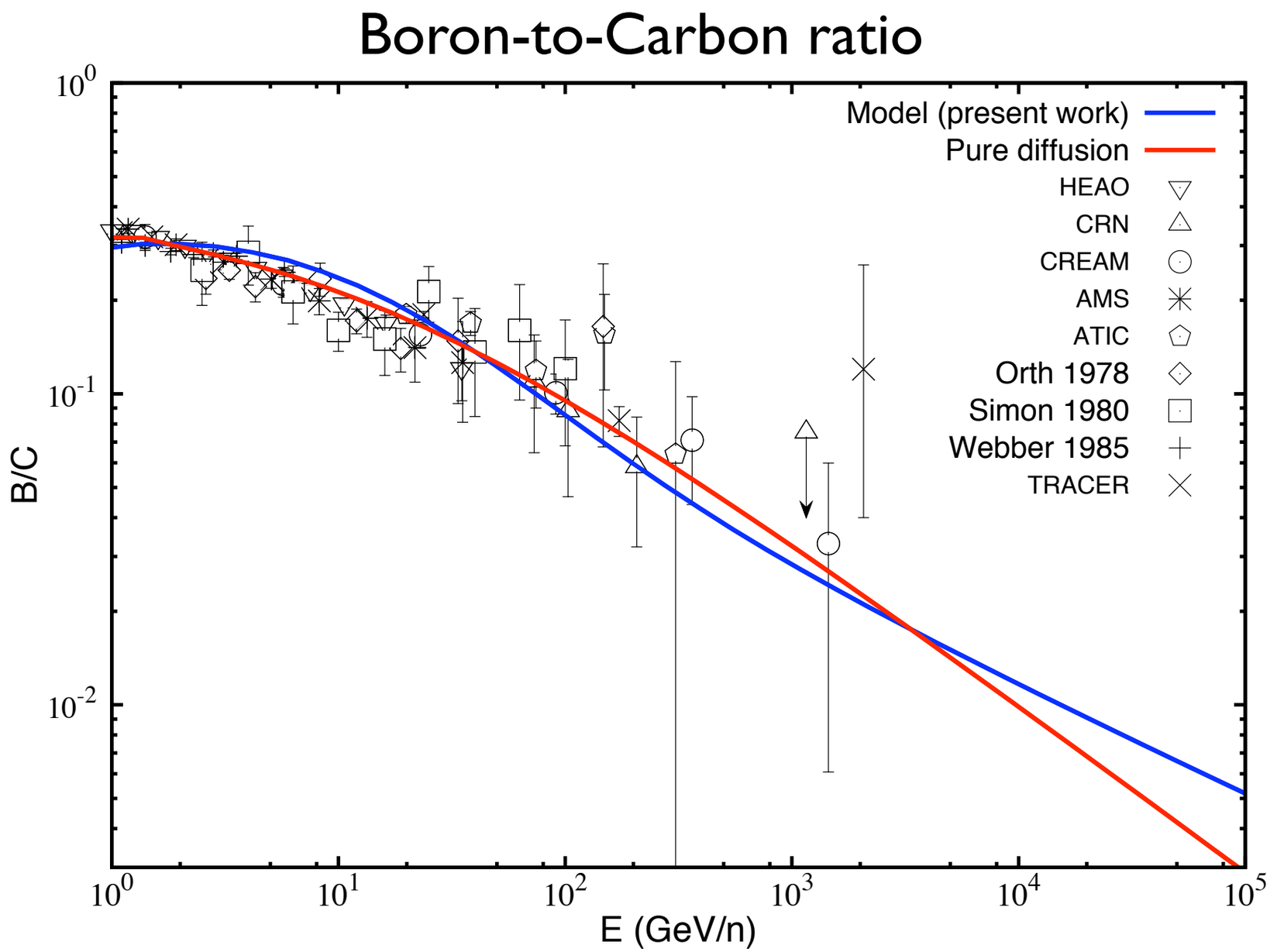








Re-acceleration & propagation parameters



$D_0=9\times10^{28}$ cm^2 s^{-1}

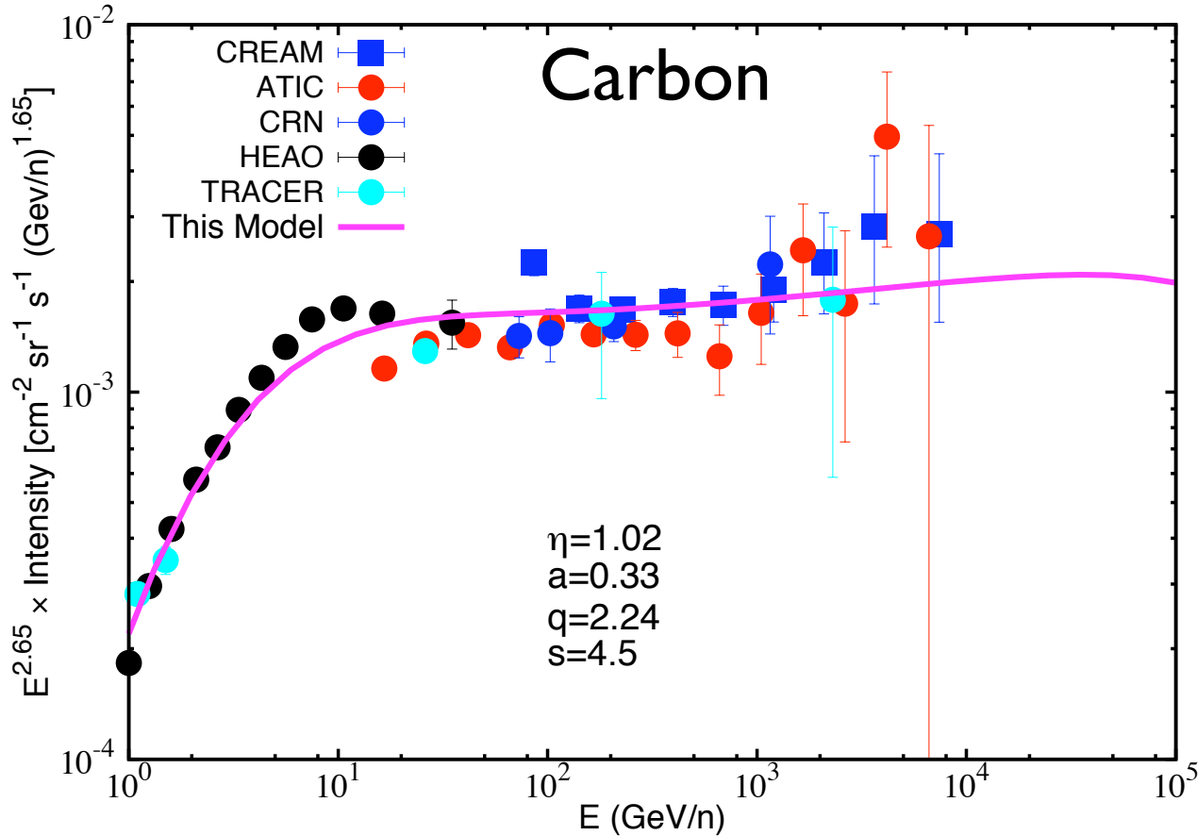
$\rho_0=3$ GV

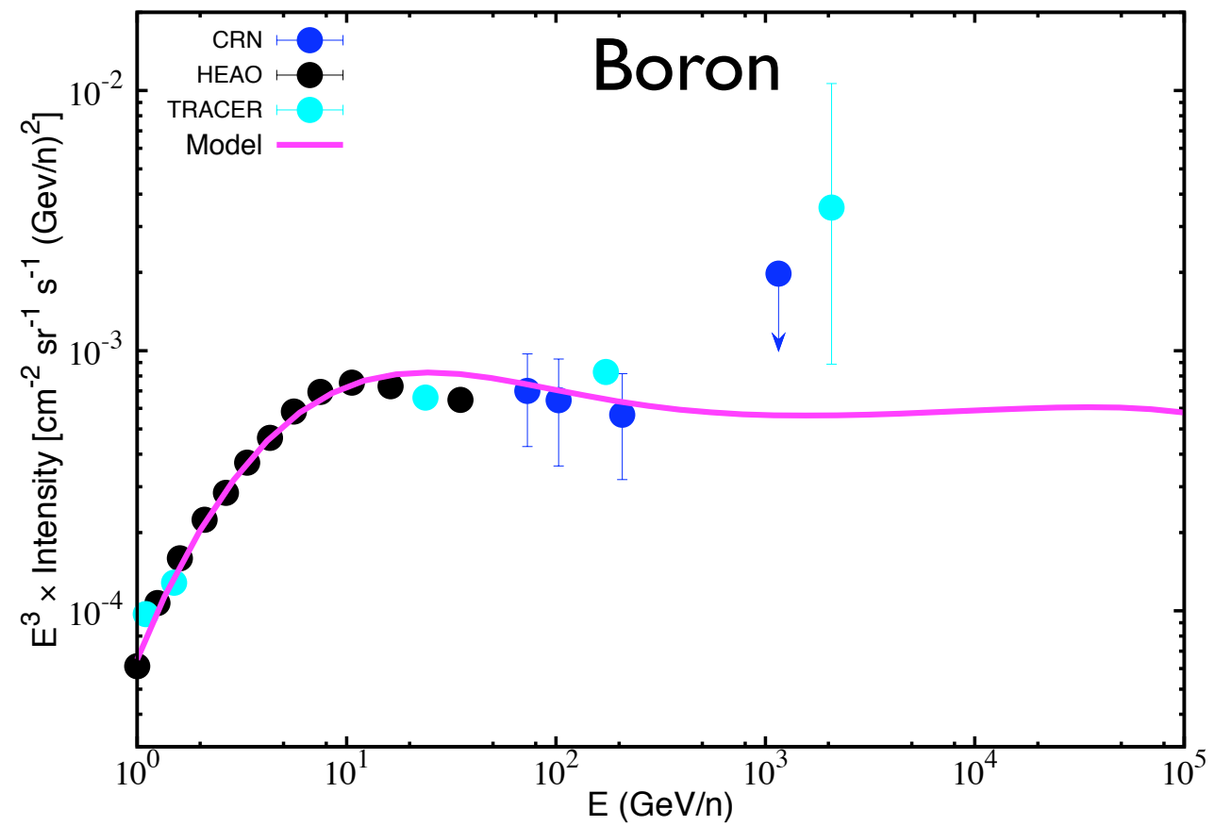
$a=0.33$

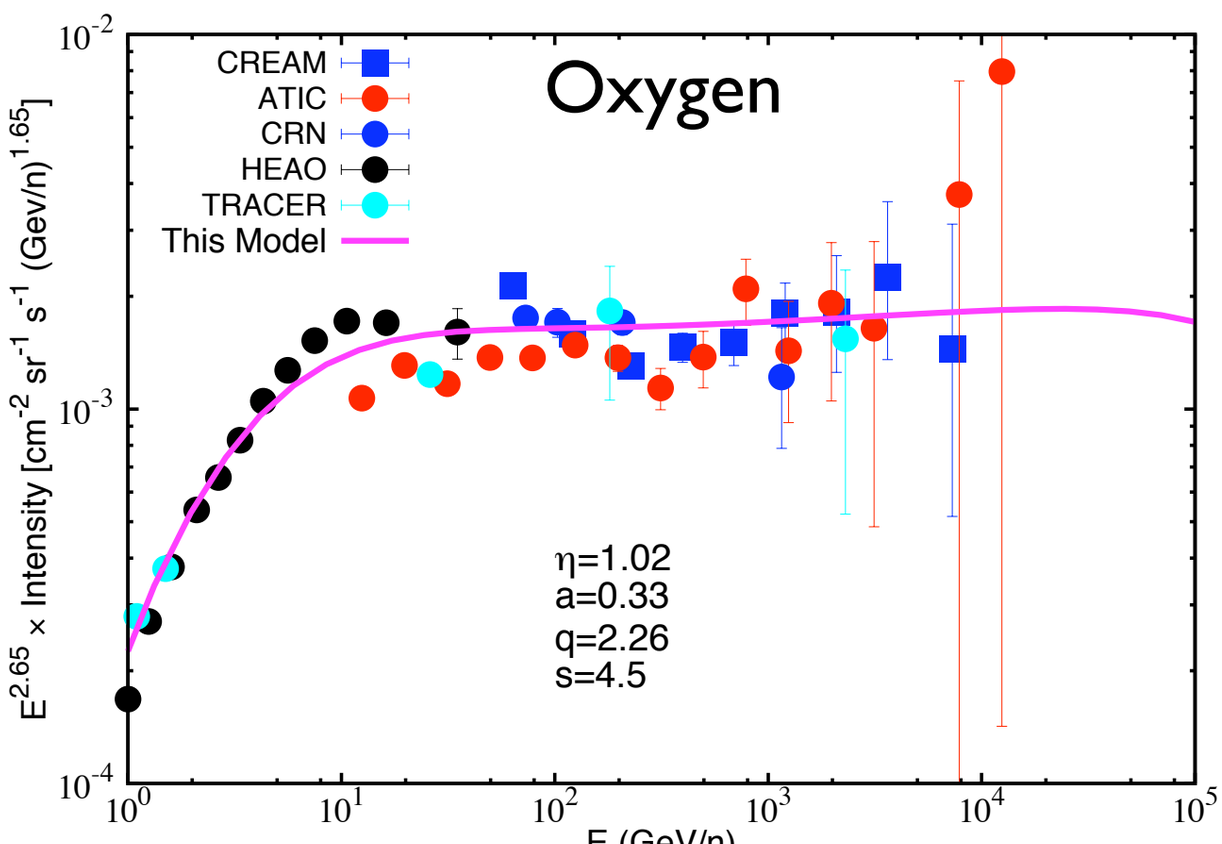
$\eta=1.02$

$s=4.5$

Results: Carbon, Oxygen & Boron spectra





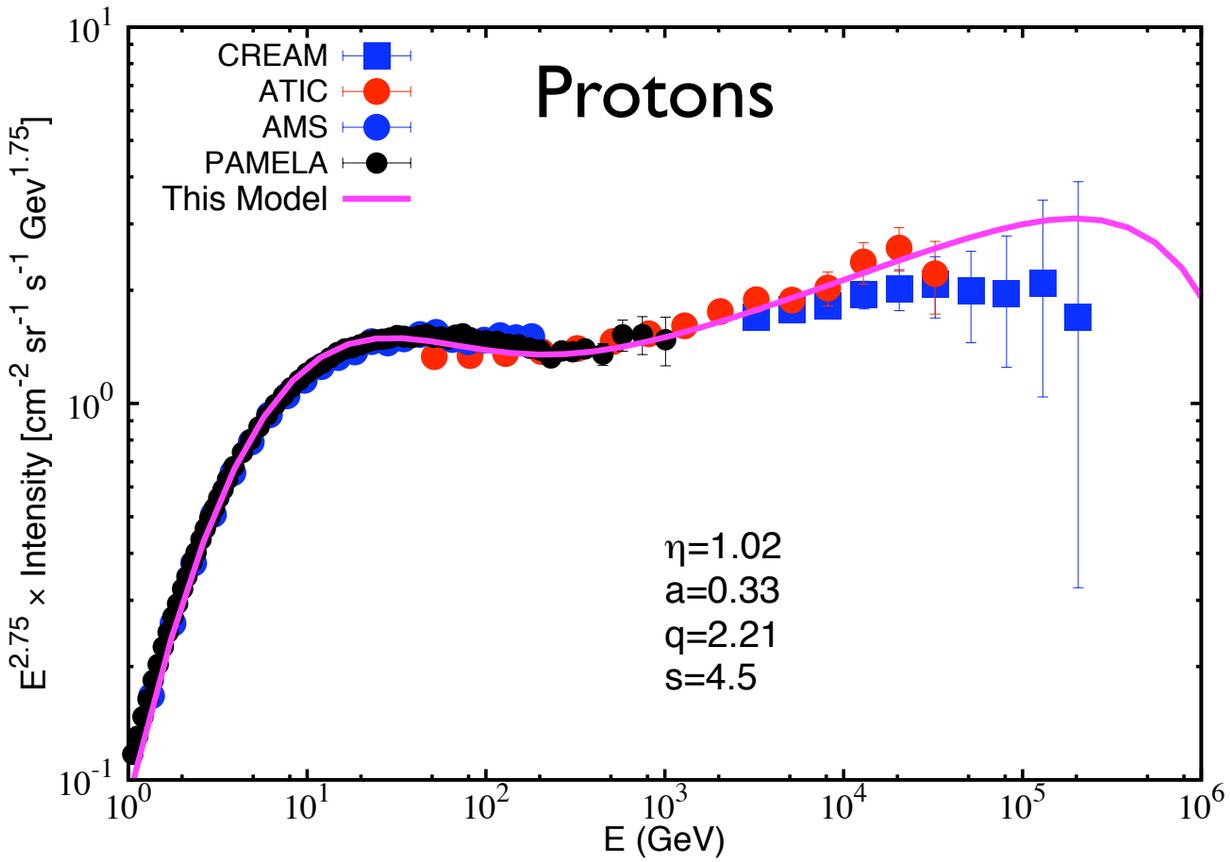


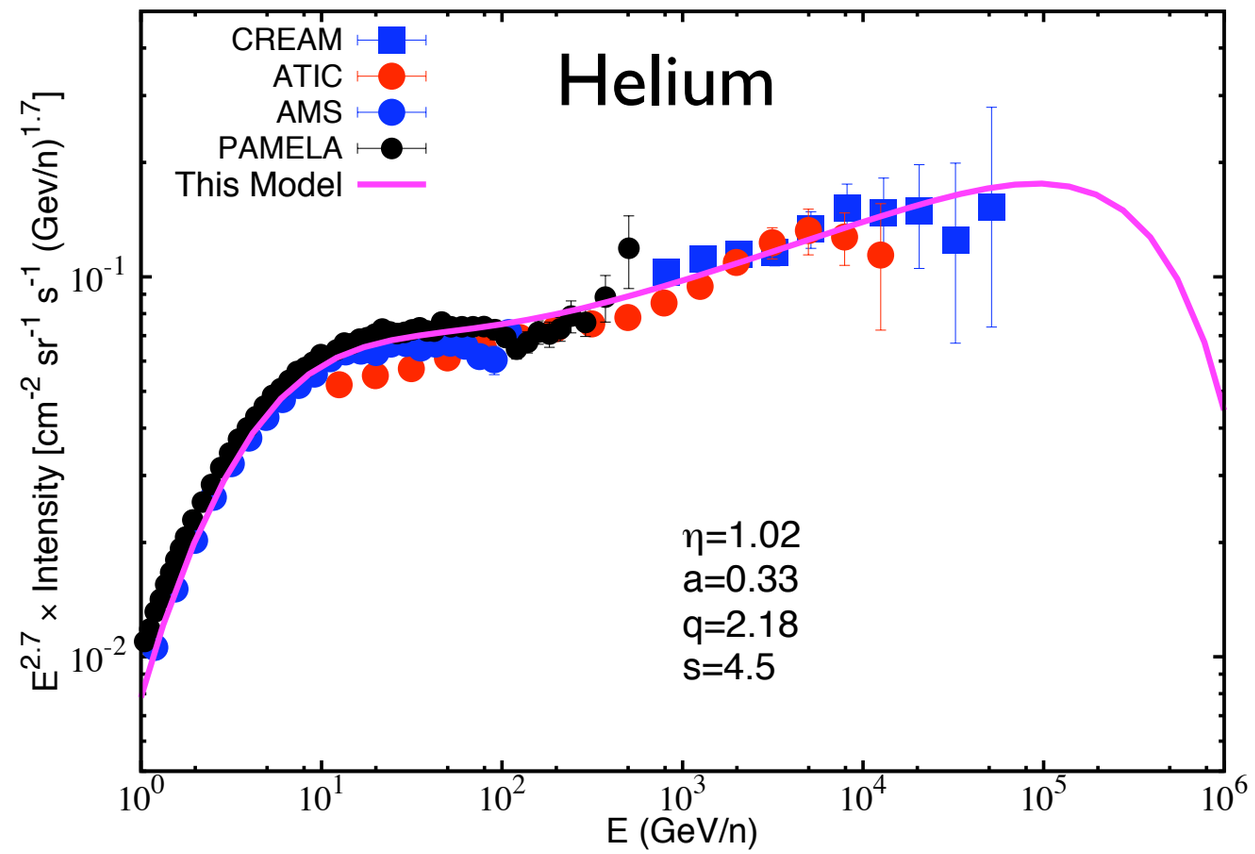
q_C=2.24, f_C=0.024%

q_O=2.26, f_O=0.025%

where f's are in units of 10^{51} ergs

Results: Protons, Helium & Iron spectra

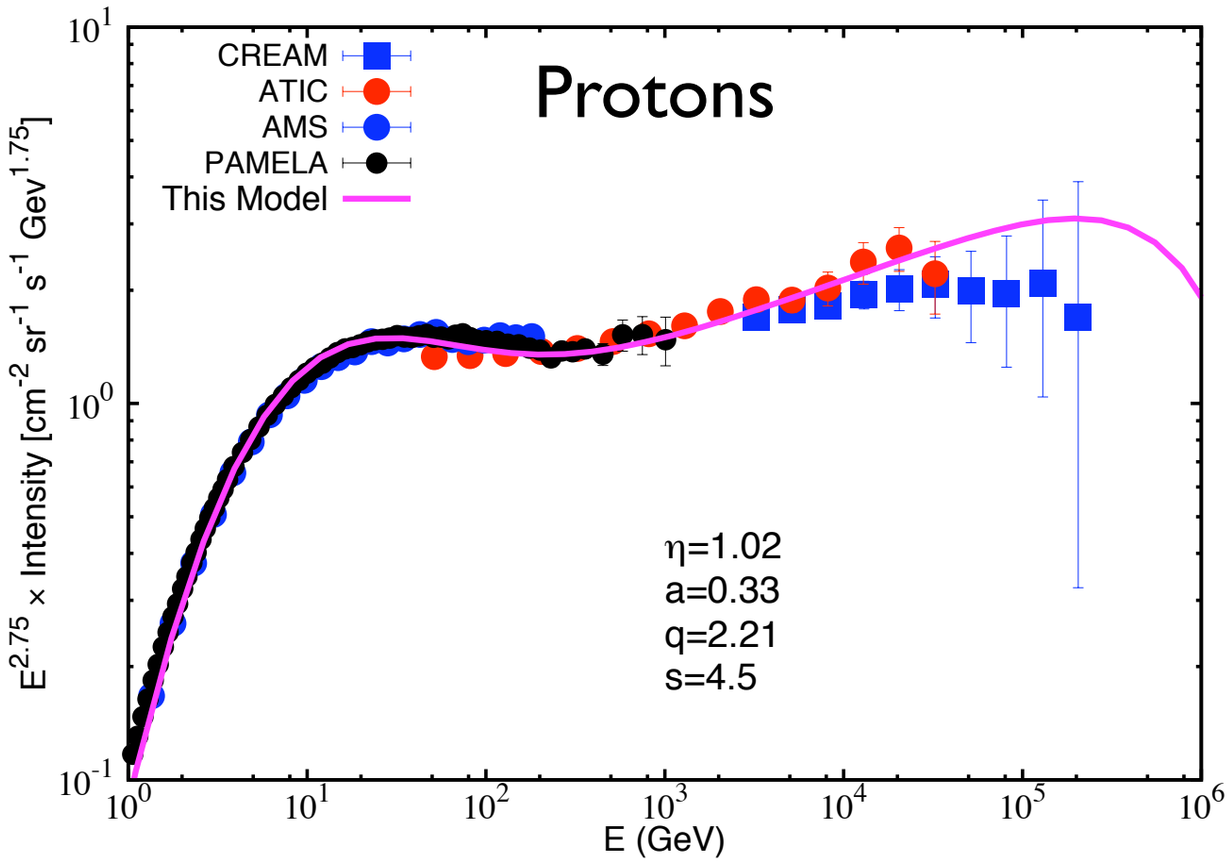


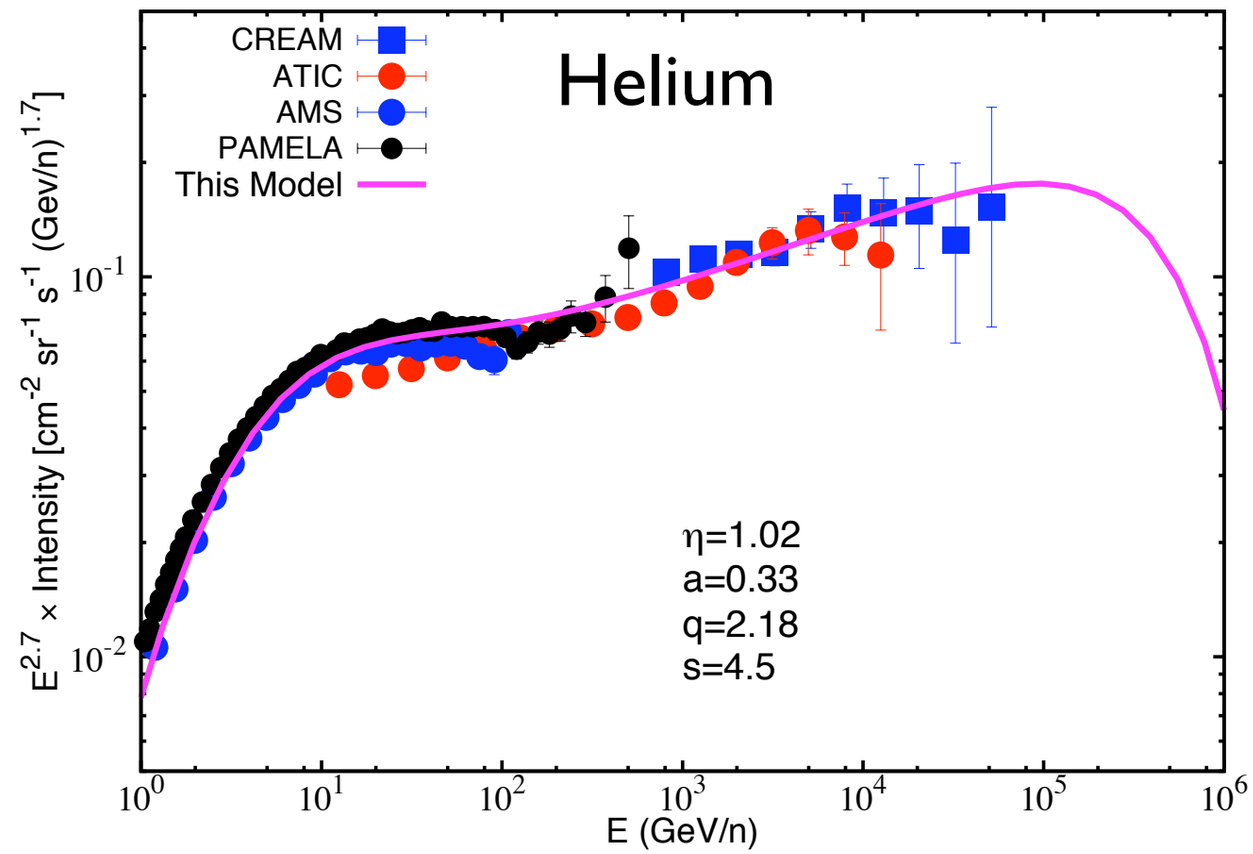


q_P=2.21, f_P=6.95%

q_{He}=2.18, f_{He}=0.79%

Results: Protons, Helium & Iron spectra

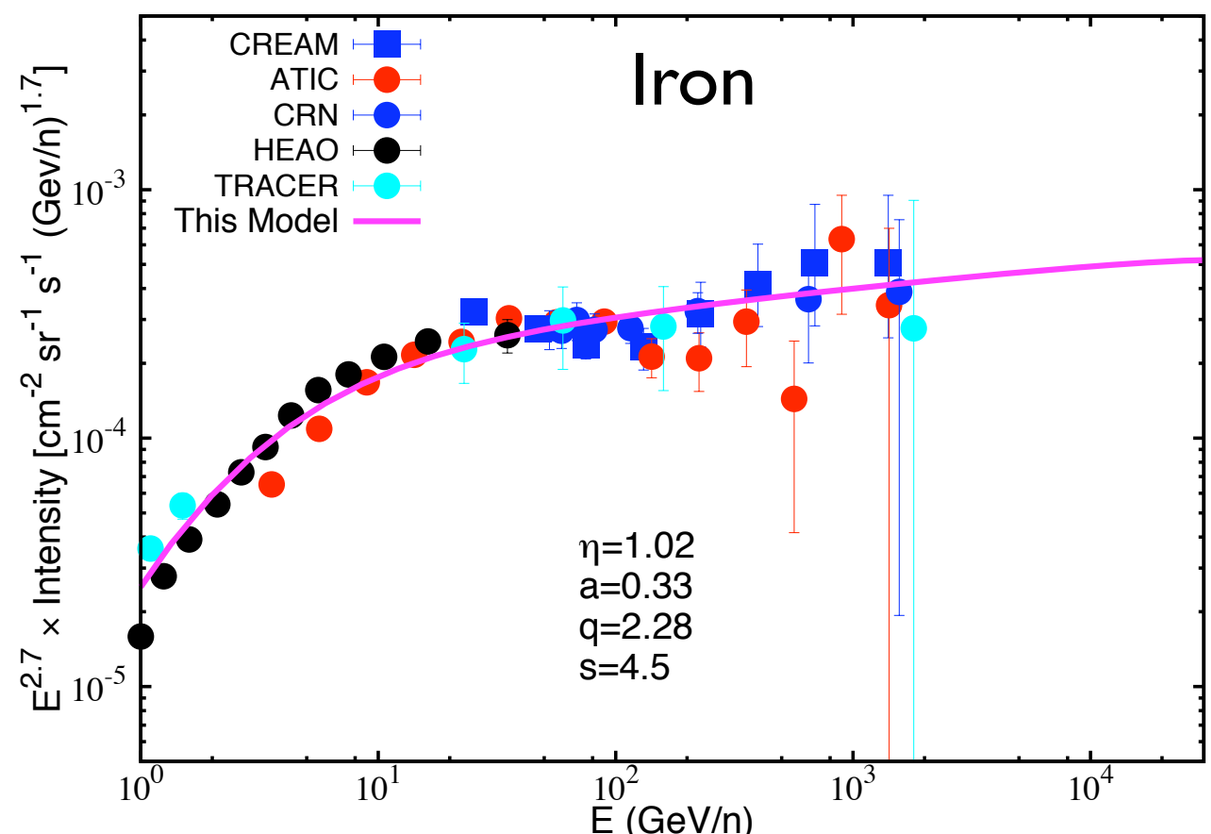




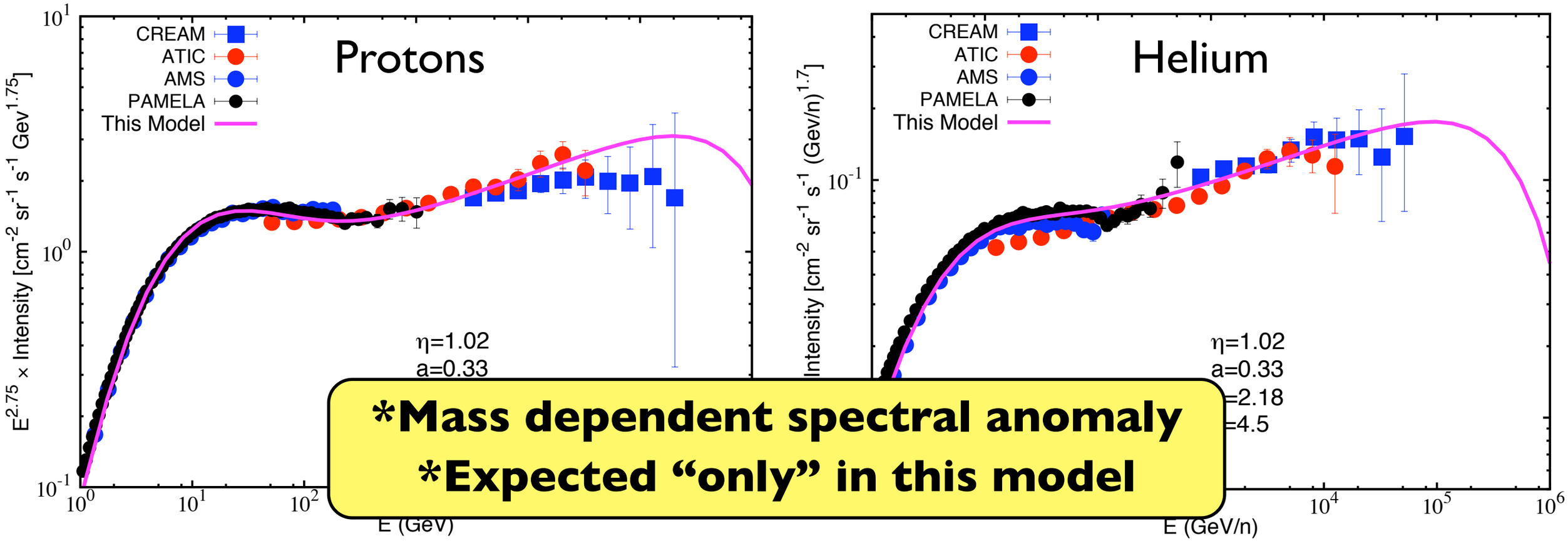
q_P=2.21, f_P=6.95%

q_{He}=2.18, f_{He}=0.79%

q_{Fe}=2.28, f_{Fe}=4.9×10^{-3}%



Results: Protons, Helium & Iron spectra



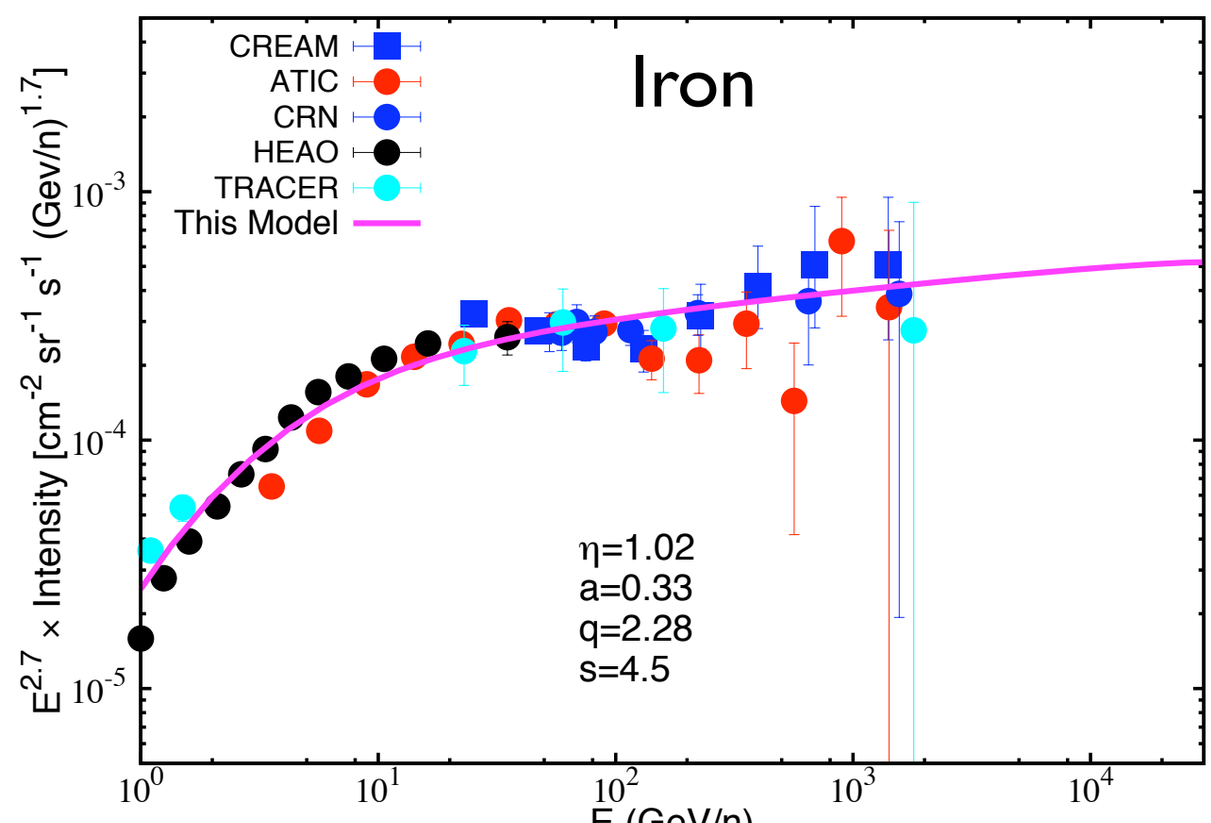
***Mass dependent spectral anomaly**

***Expected "only" in this model**

q_P=2.21, f_P=6.95%

q_{He}=2.18, f_{He}=0.79%

q_{Fe}=2.28, f_{Fe}=4.9×10^{-3}%



Summary

- **The cosmic-ray spectral anomaly at GeV-TeV energies can be due to re-acceleration by weak shocks associated with old supernova remnants in the Galaxy**
- **This model predicts a mass dependent spectral hardening which can be checked by sensitive measurements of heavier species**

Thank you for your attention :)