Cosmic Ray e+ at High Energy

Kfir Blum
CERN & Weizmann Institute

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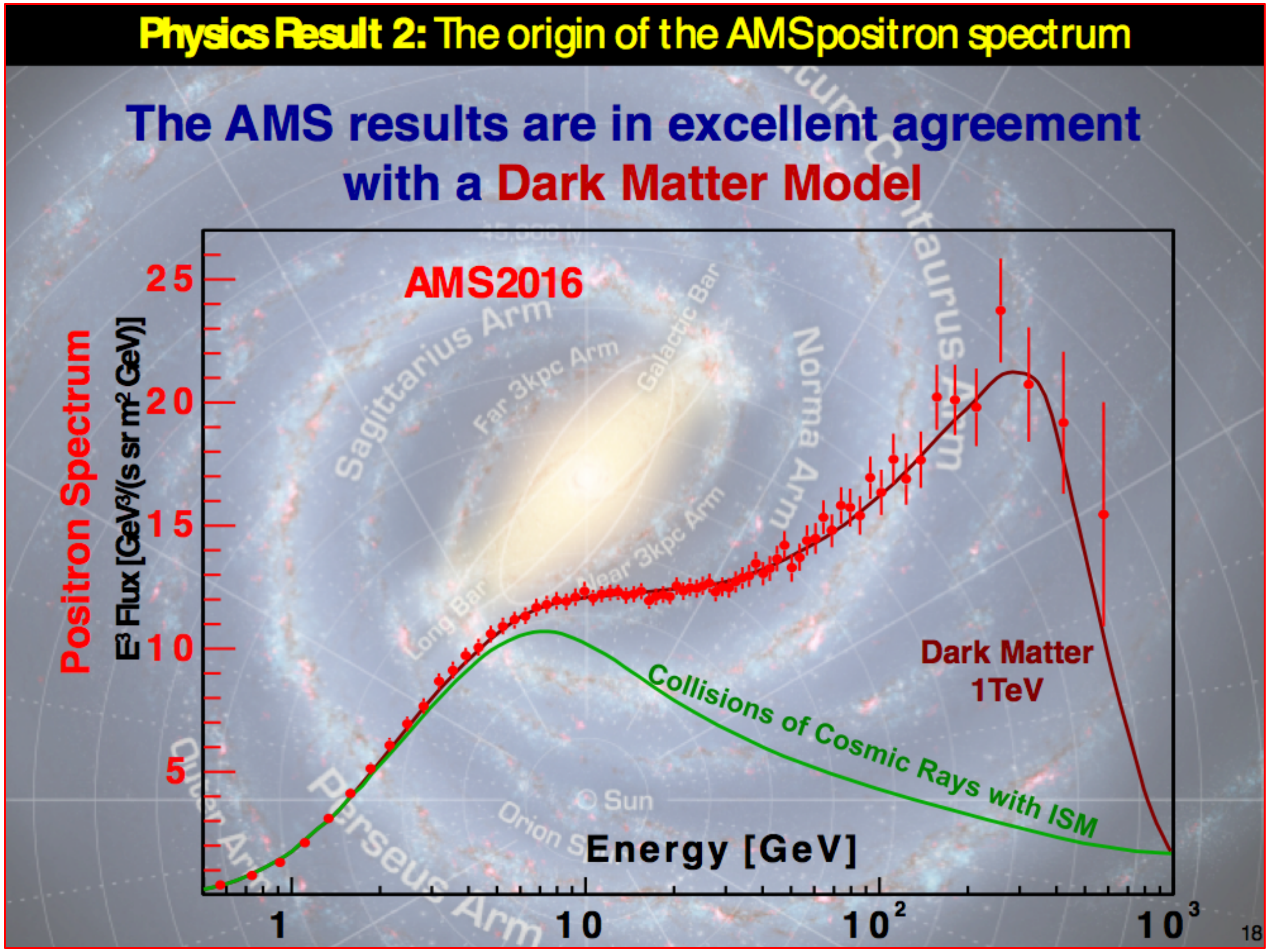
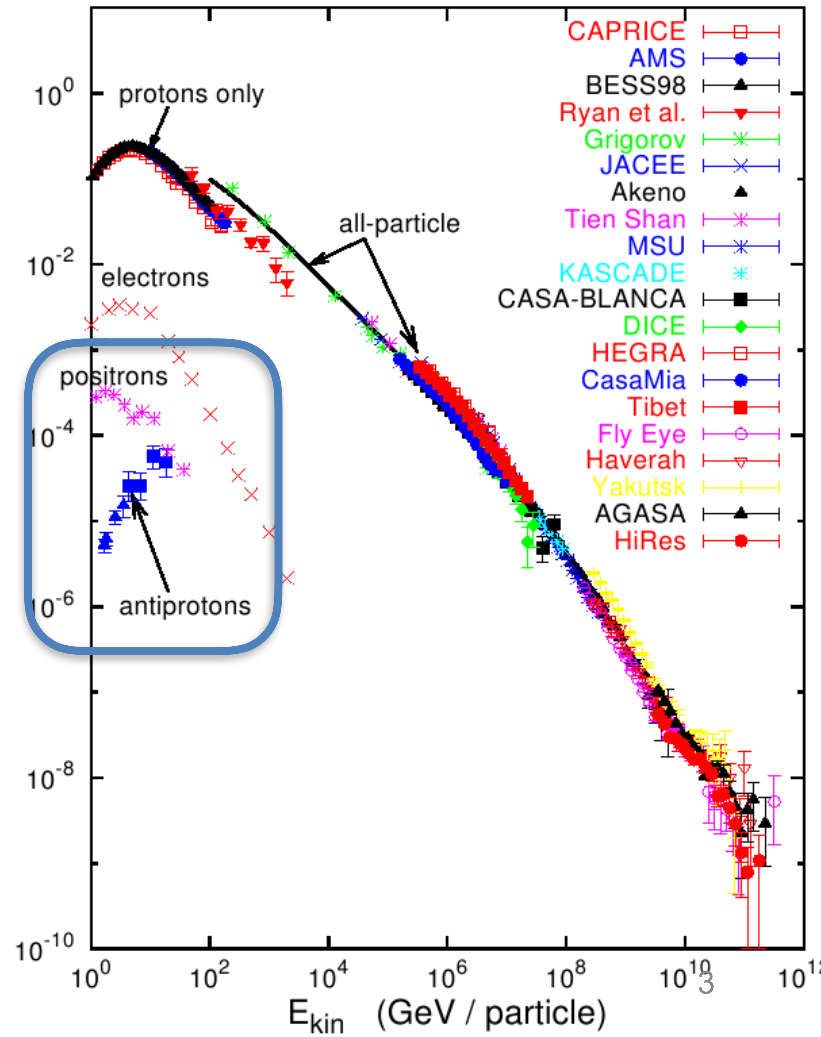


Common belief:
e+ come from either pulsars, or dark matter!

* ***Don't think so.*** Will try to sort this out.

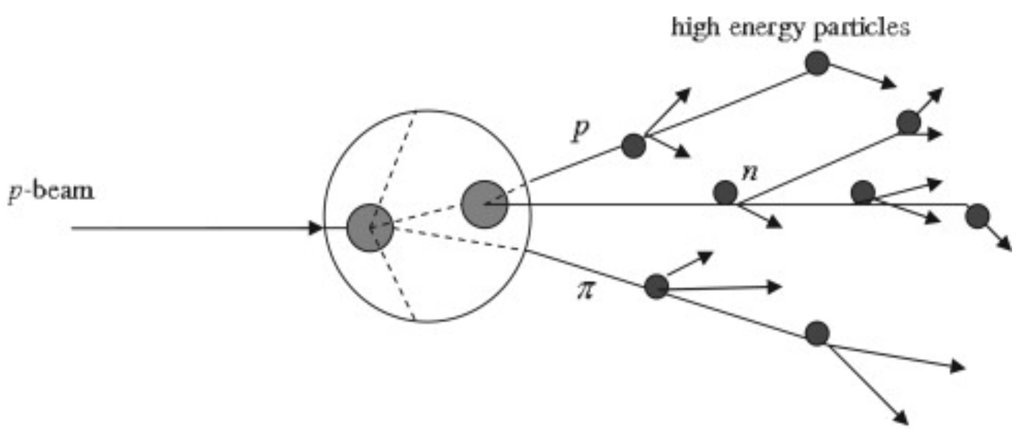
* LHC data: secondary e+ at multi-TeV energy

* DAMPE/HESS/CALET: E > TeV e+- may be all secondary. If so, HECR age is very short (0.1 Myr)



antimatter is produced in collisions of the bulk of the CRs
-- protons and He – with interstellar gas

Need to calculate this background to learn about possible exotic sources

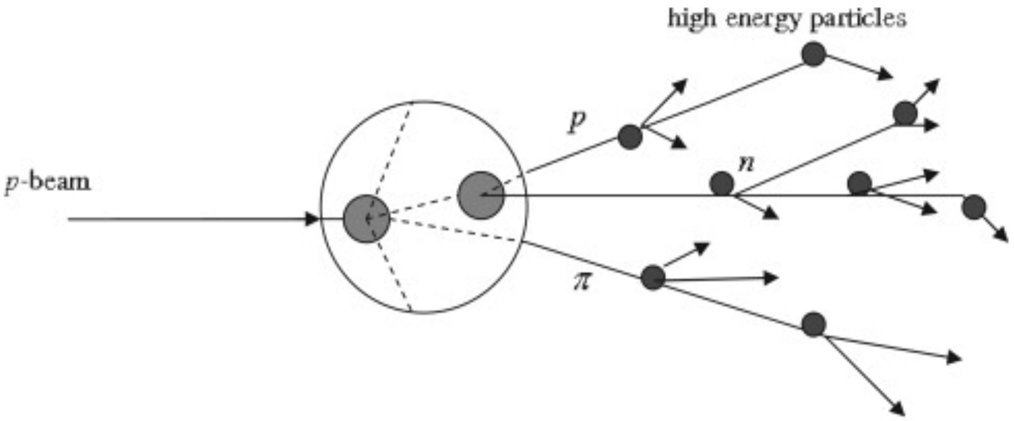


antimatter is produced in collisions of the bulk of the CRs
-- protons and He – with interstellar gas

For secondary CR: particle physics branching fractions

$$\frac{n_a(\mathcal{R})}{n_b(\mathcal{R})} \approx \frac{Q_a(\mathcal{R})}{Q_b(\mathcal{R})}$$

Life is more complicated with e+: **energy loss during propagation.**
Lets calculate anyway, see what happens.

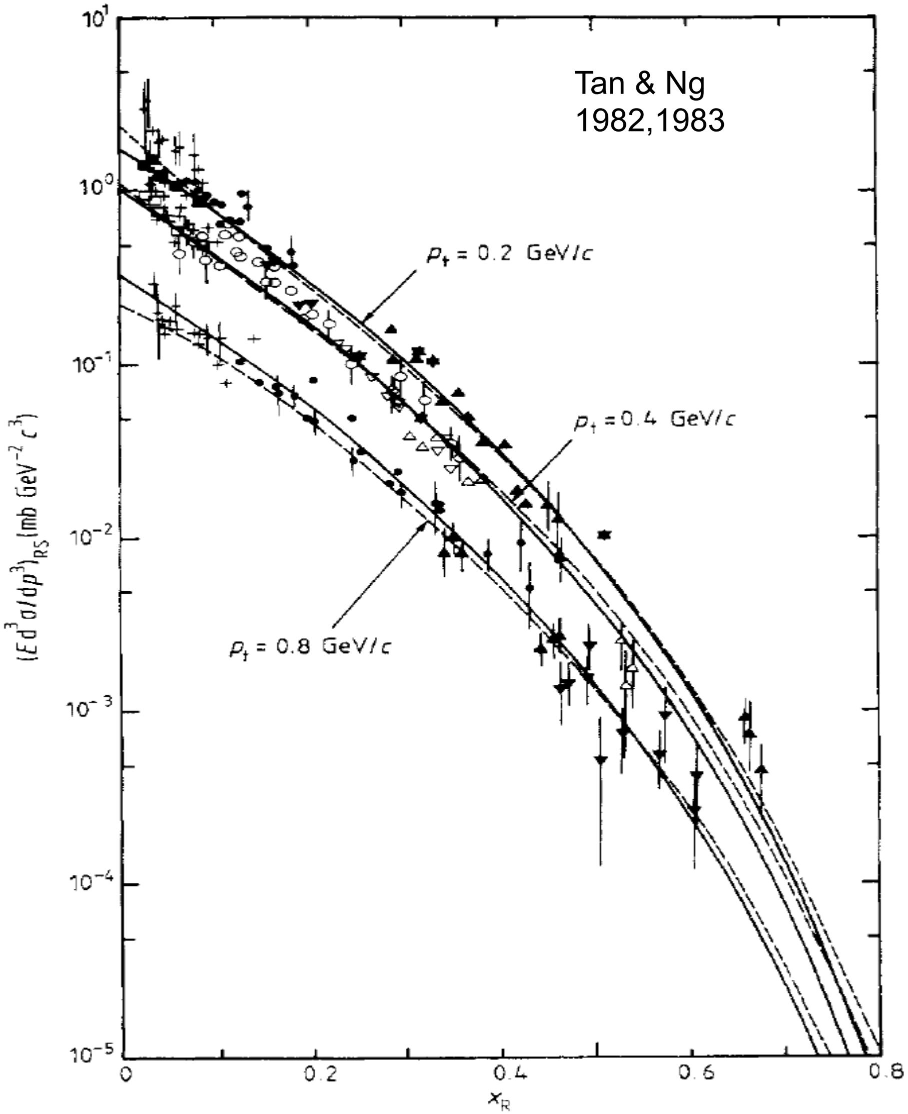


Recipe for a positron pie:

$$\frac{n_a(\mathcal{R})}{n_b(\mathcal{R})} \approx \frac{Q_a(\mathcal{R})}{Q_b(\mathcal{R})} \quad \Rightarrow \quad \boxed{n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\mathrm{B}}(\mathcal{R})}{Q_{\mathrm{B}}(\mathcal{R})} Q_{e^+}(\mathcal{R})}$$

Recipe for a positron pie:

$$n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\mathrm{B}}(\mathcal{R})}{Q_{\mathrm{B}}(\mathcal{R})} Q_{e^+}(\mathcal{R})$$



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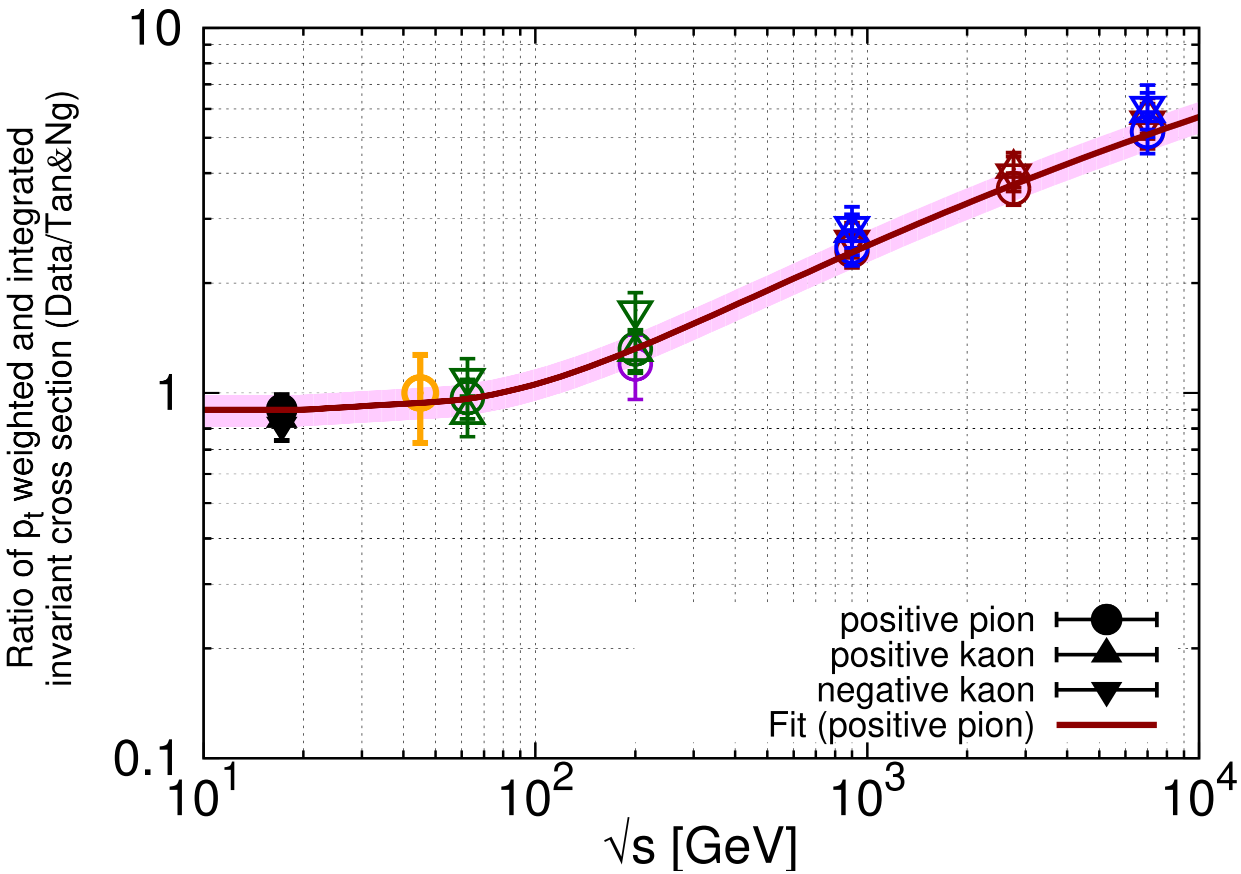
$$n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\rm B}(\mathcal{R})}{Q_{\rm B}(\mathcal{R})} Q_{e^+}(\mathcal{R})$$

KB, Sato, Takimoto, **1709.04953**



Radial scaling violation important for root s > 100 GeV (primary proton > 5 TeV) (e+ >~ 100 GeV)

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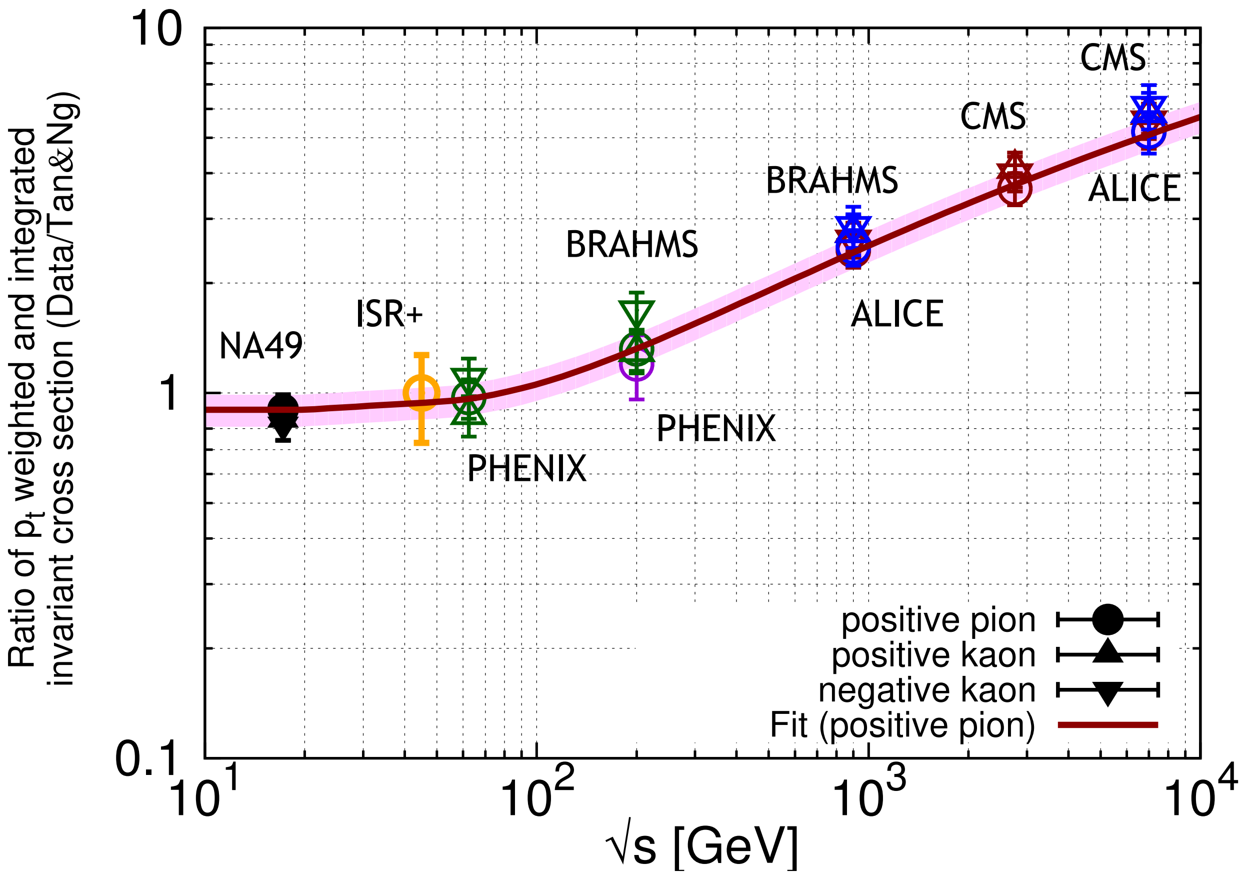

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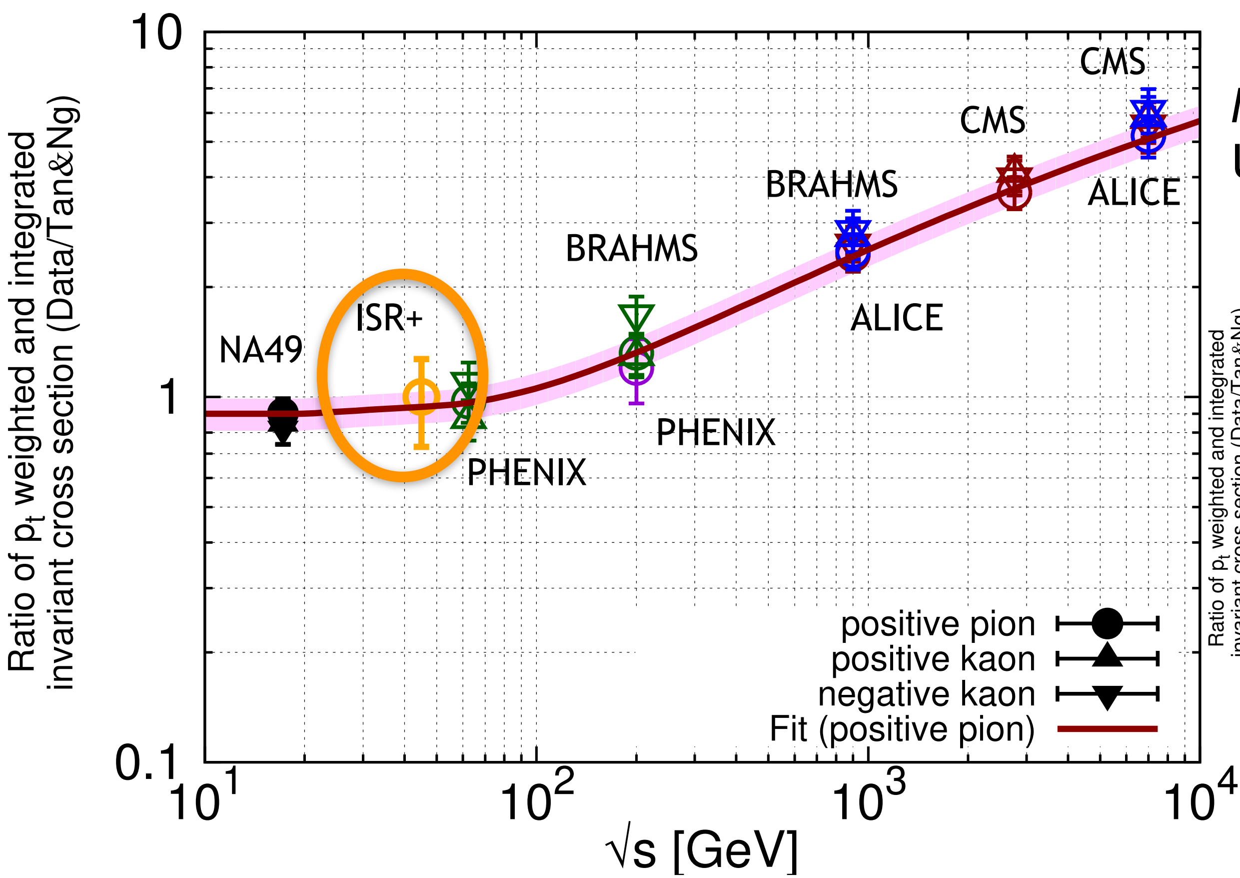
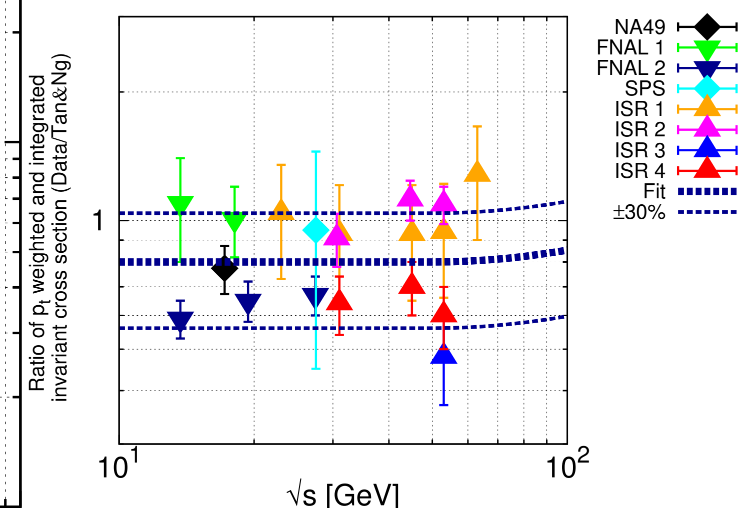


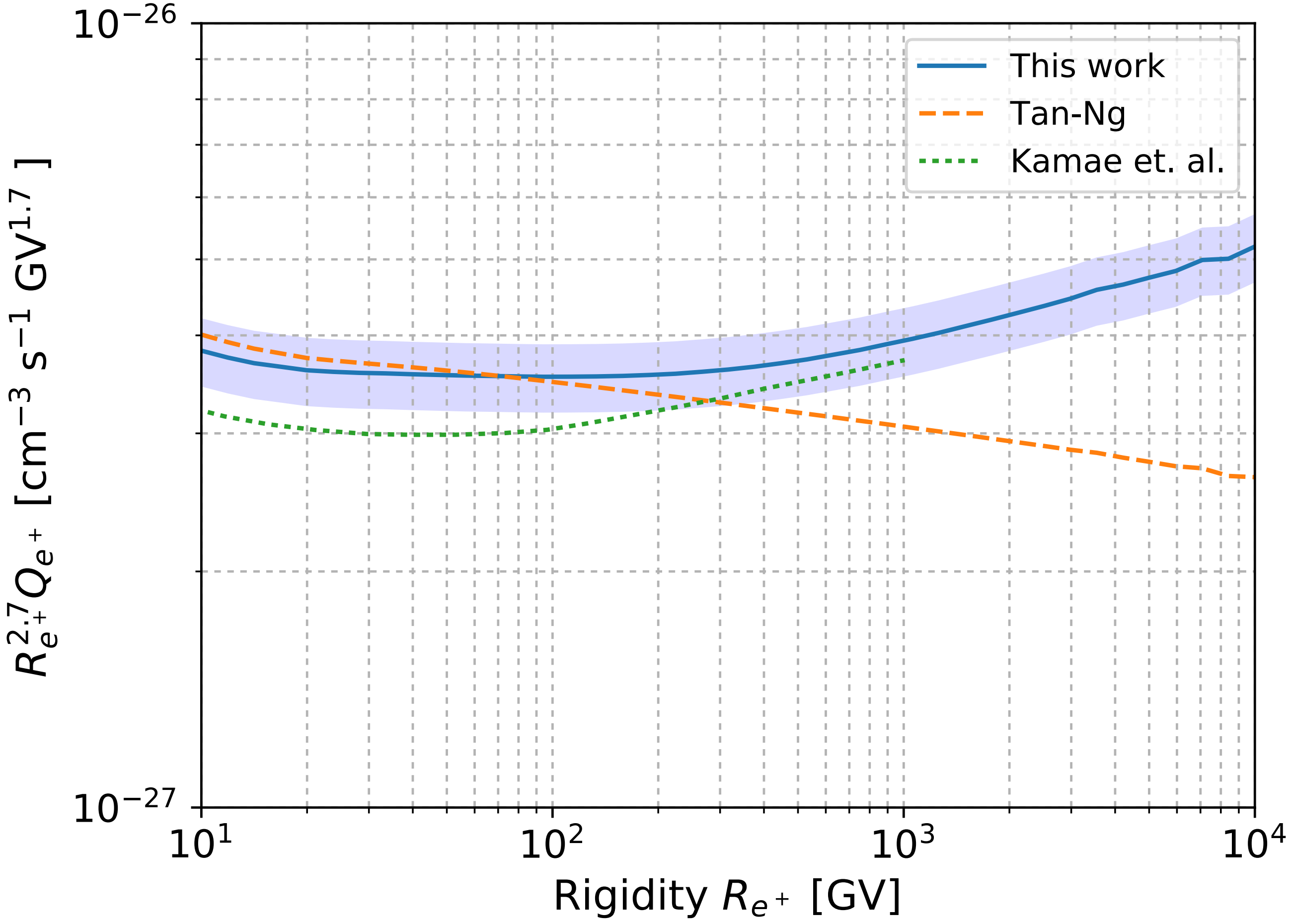
Main O(1) effect under control.
Uncertainties remain O(10%)



Recipe for a positron pie:

Compare with earlier semi-analytical codes, and PYTHIA-based codes

KB, Sato, Takimoto, 1709.04953

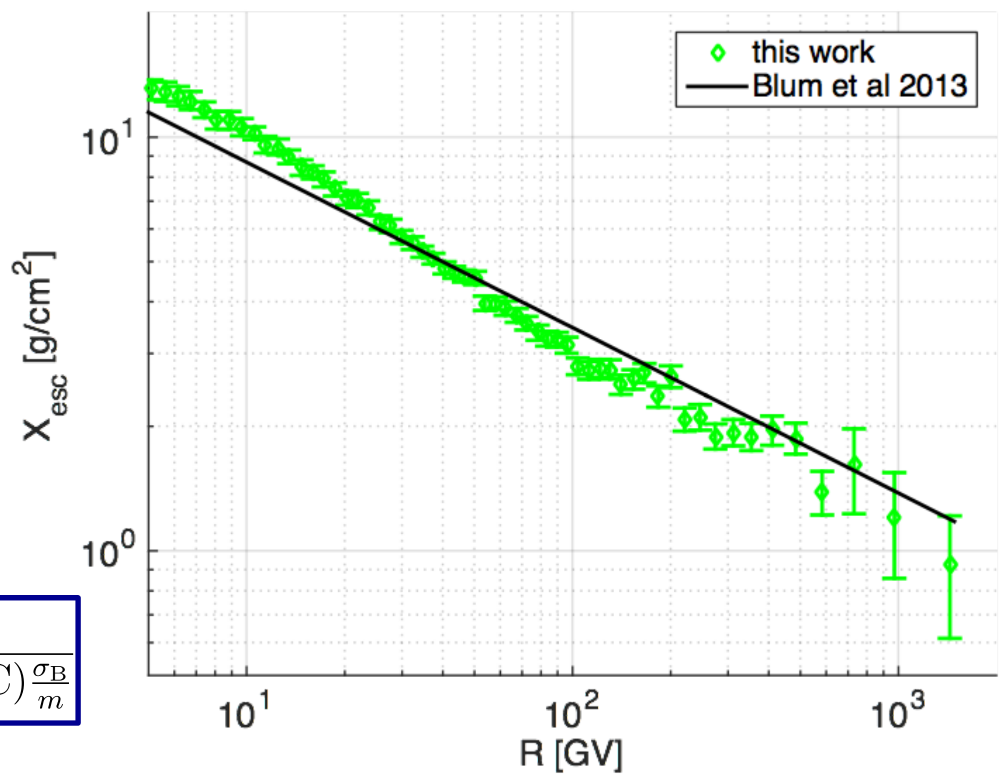


Recipe for a positron pie:

$$\frac{n_a(\mathcal{R})}{n_b(\mathcal{R})} \approx \frac{Q_a(\mathcal{R})}{Q_b(\mathcal{R})}$$

$$n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\rm B}(\mathcal{R})}{Q_{\rm B}(\mathcal{R})} Q_{e^+}(\mathcal{R})$$

$$X_{\rm esc}(\mathcal{R}) = \frac{n_{\rm B}(\mathcal{R})}{Q_{\rm B}(\mathcal{R})}$$

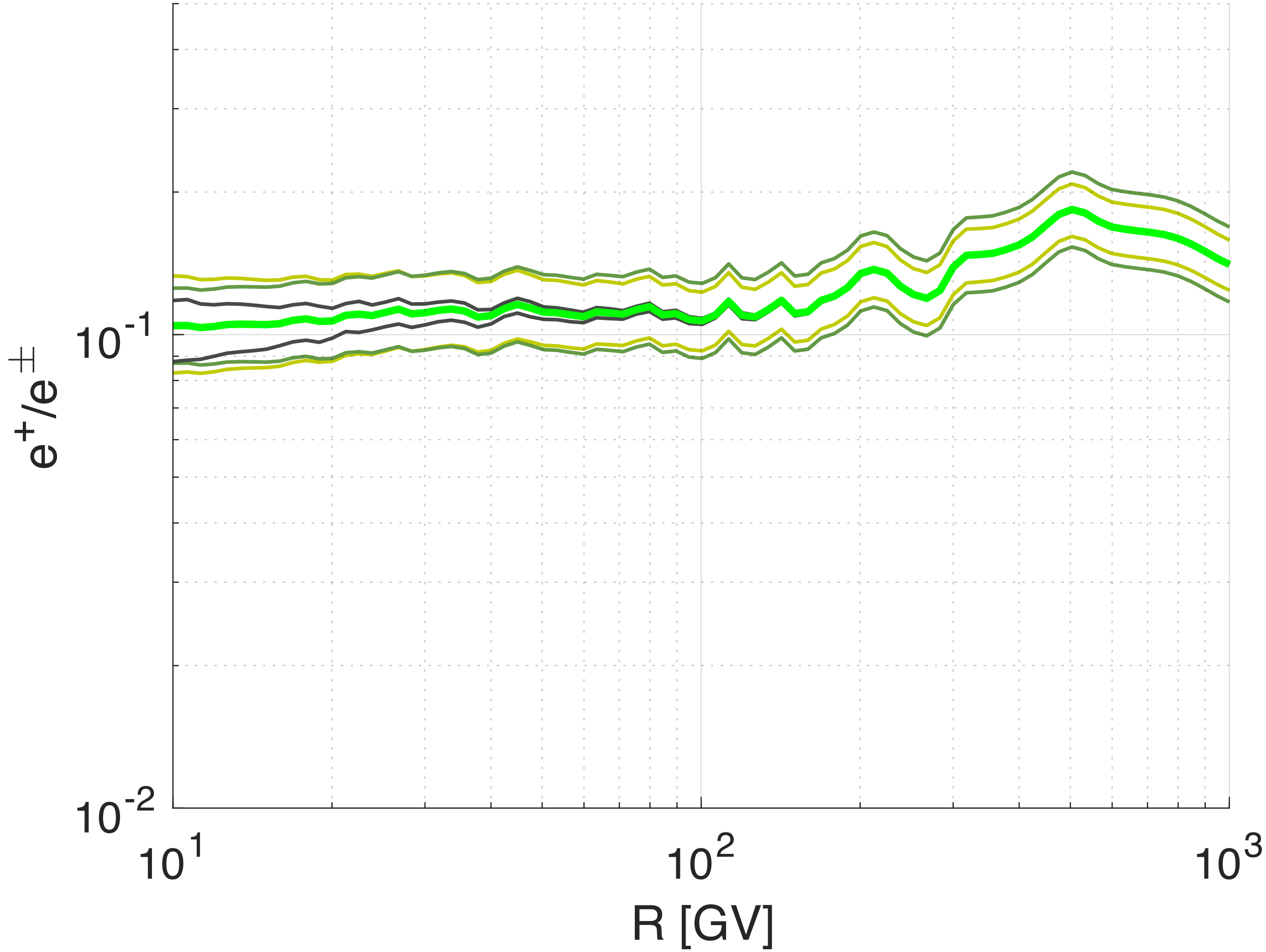


$$X_{\rm esc} = \frac{({\rm B/C})}{\sum_{\rm P=C,N,O,...}({\rm P/C})\frac{\sigma_{\rm P\to B}}{m} - ({\rm B/C})\frac{\sigma_{\rm B}}{m}}$$

result

Secondary *upper bound*
(Based on B/C)

$$n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\mathrm{B}}(\mathcal{R})}{Q_{\mathrm{B}}(\mathcal{R})} Q_{e^+}(\mathcal{R})$$



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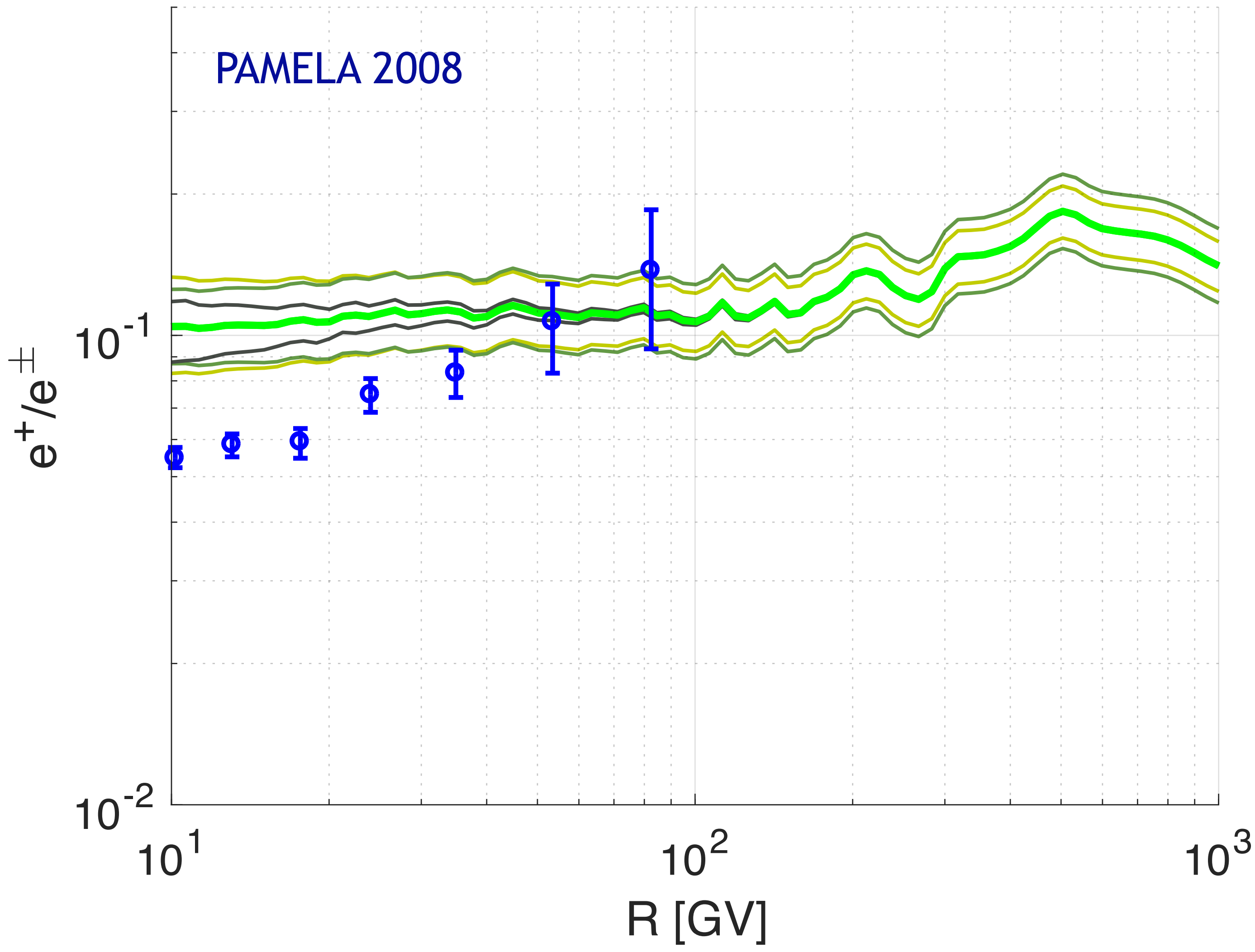

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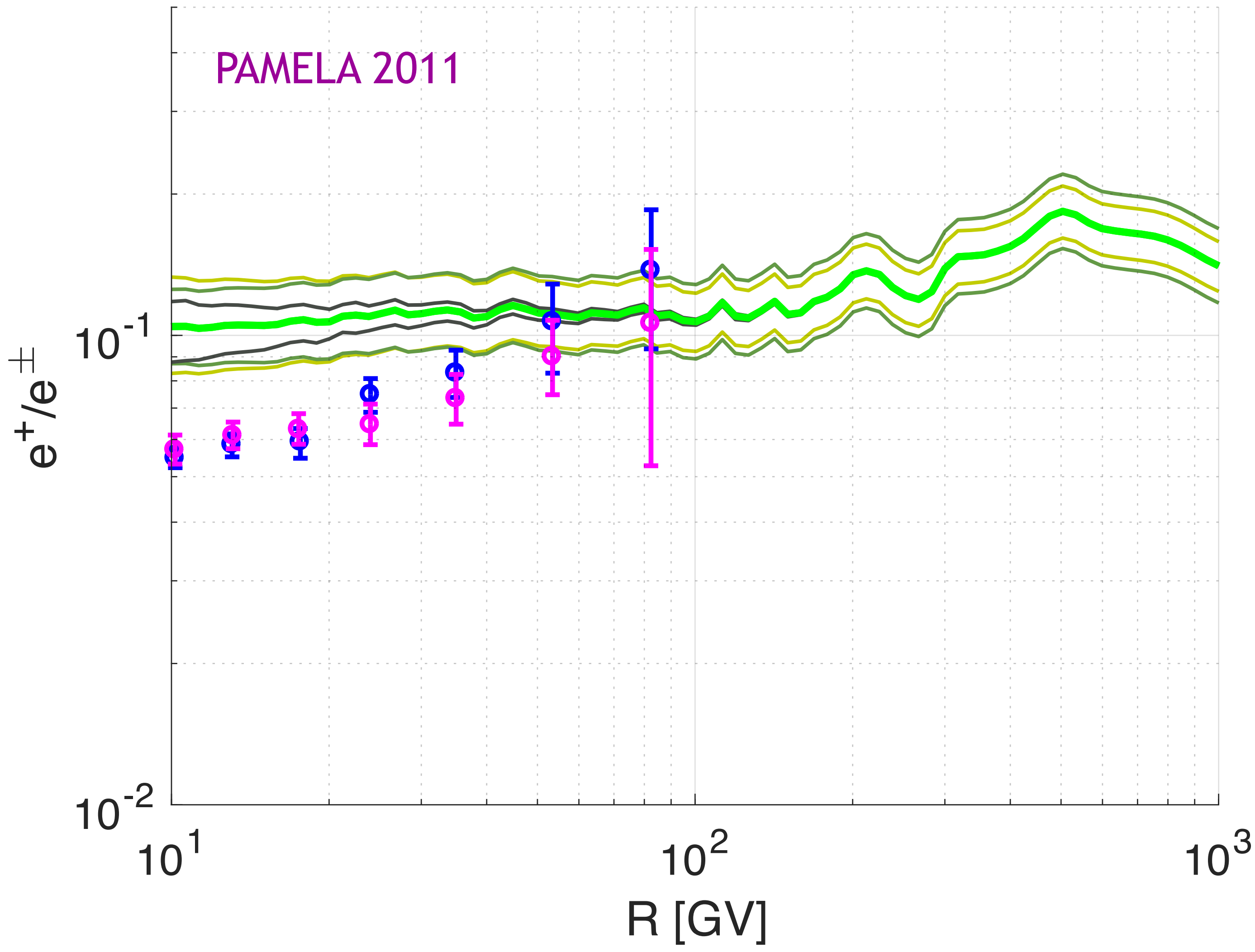

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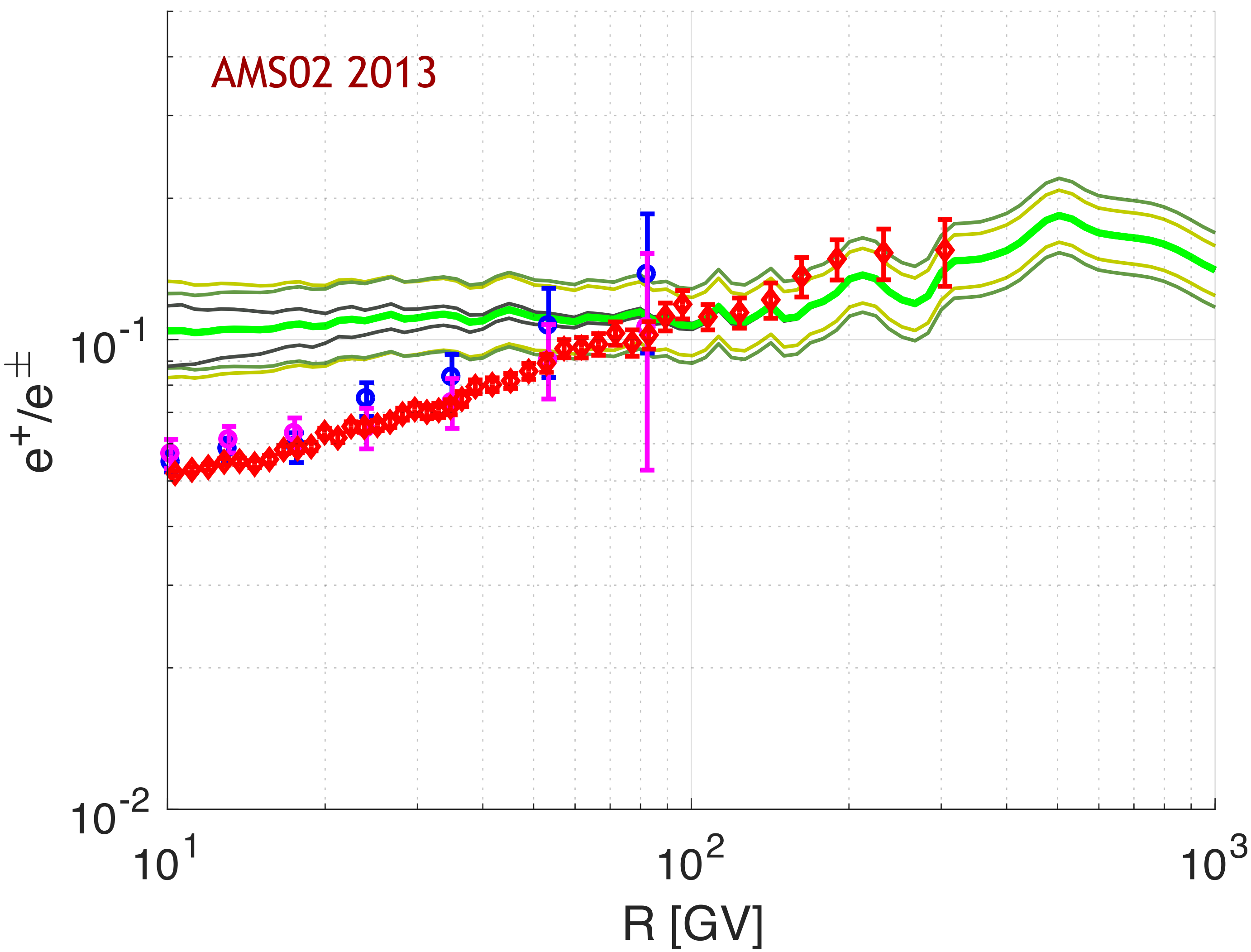

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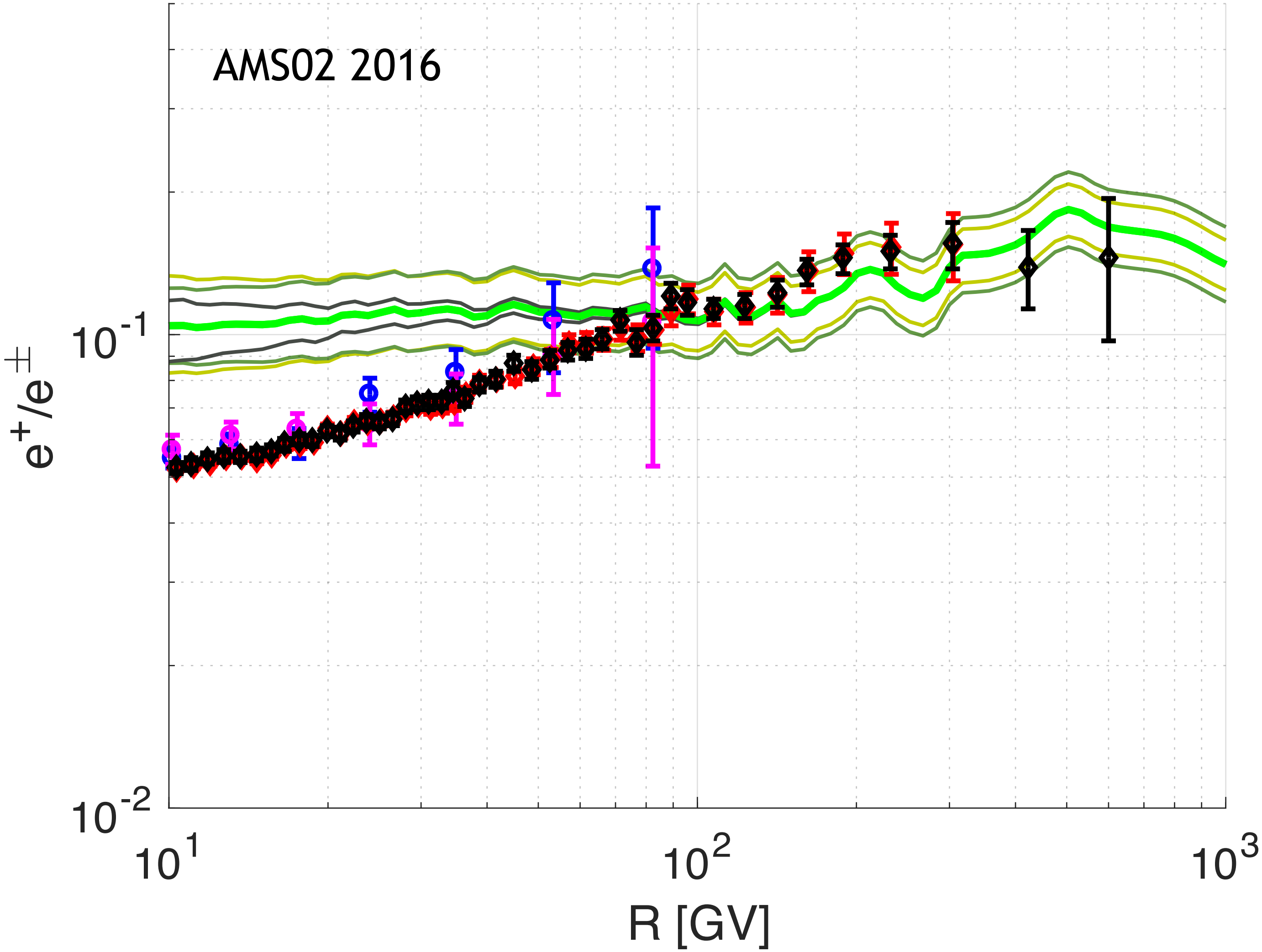
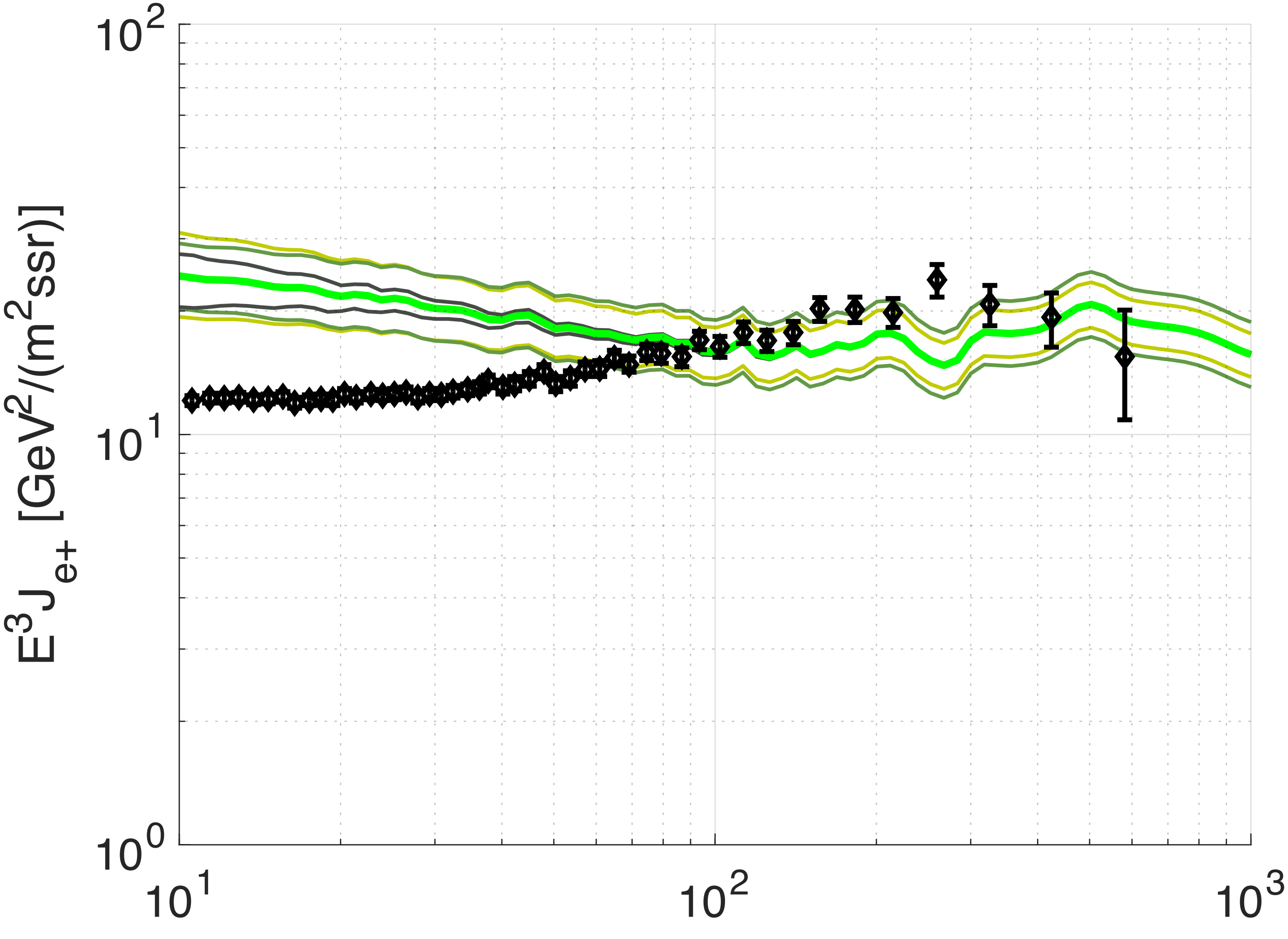
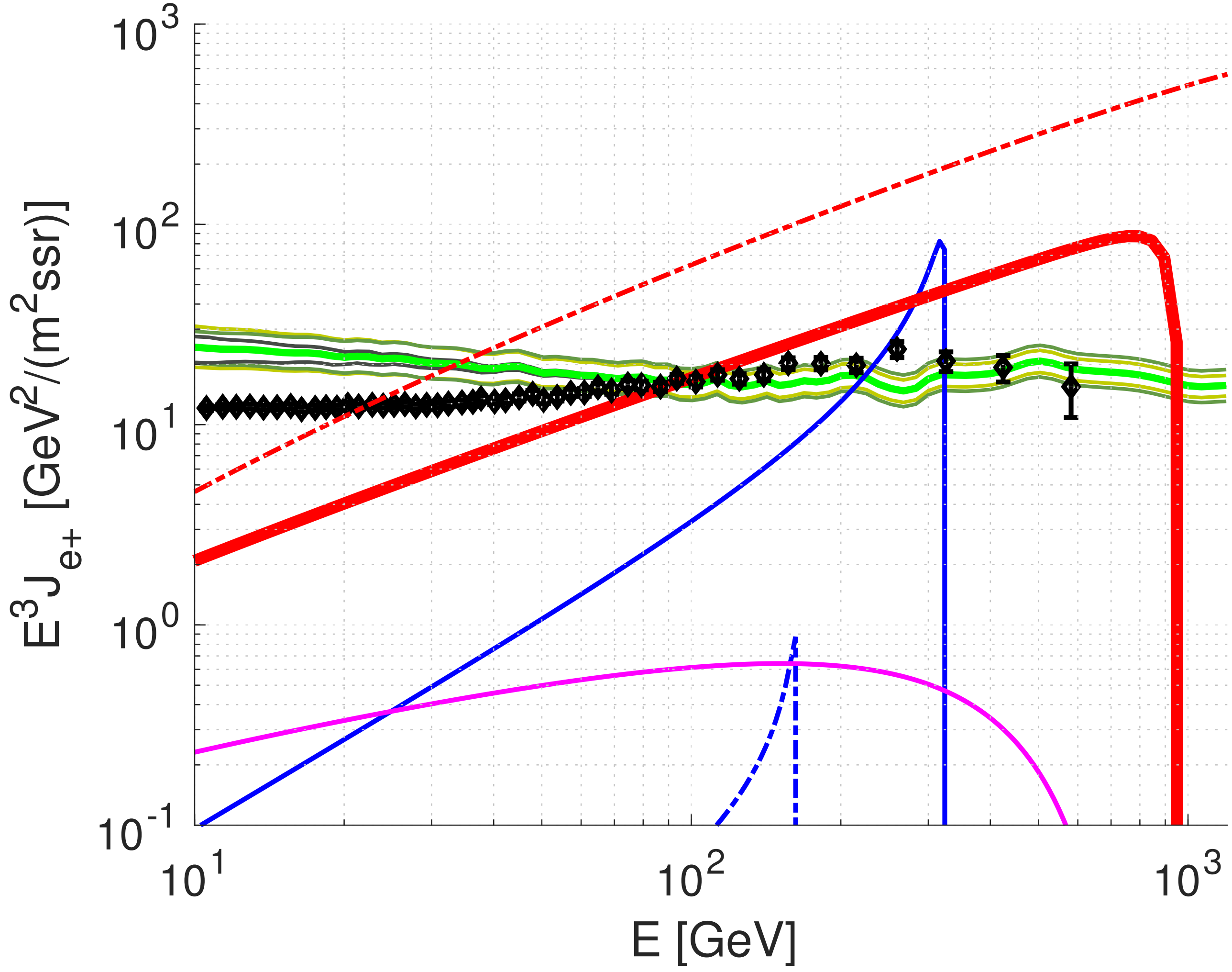




10^2
10^1
10^0
$E^3 J_{e+}$ [GeV^2/(m^{2}ssr)]
10^1
10^2
10^3
E [GeV]

Why would dark matter or pulsars inject ***this*** e+ flux?

1709.06507



Pulsar model: D. Malyshev, I. Cholis, and J. Gelfand, Phys. Rev. **D80**, 063005 (2009)

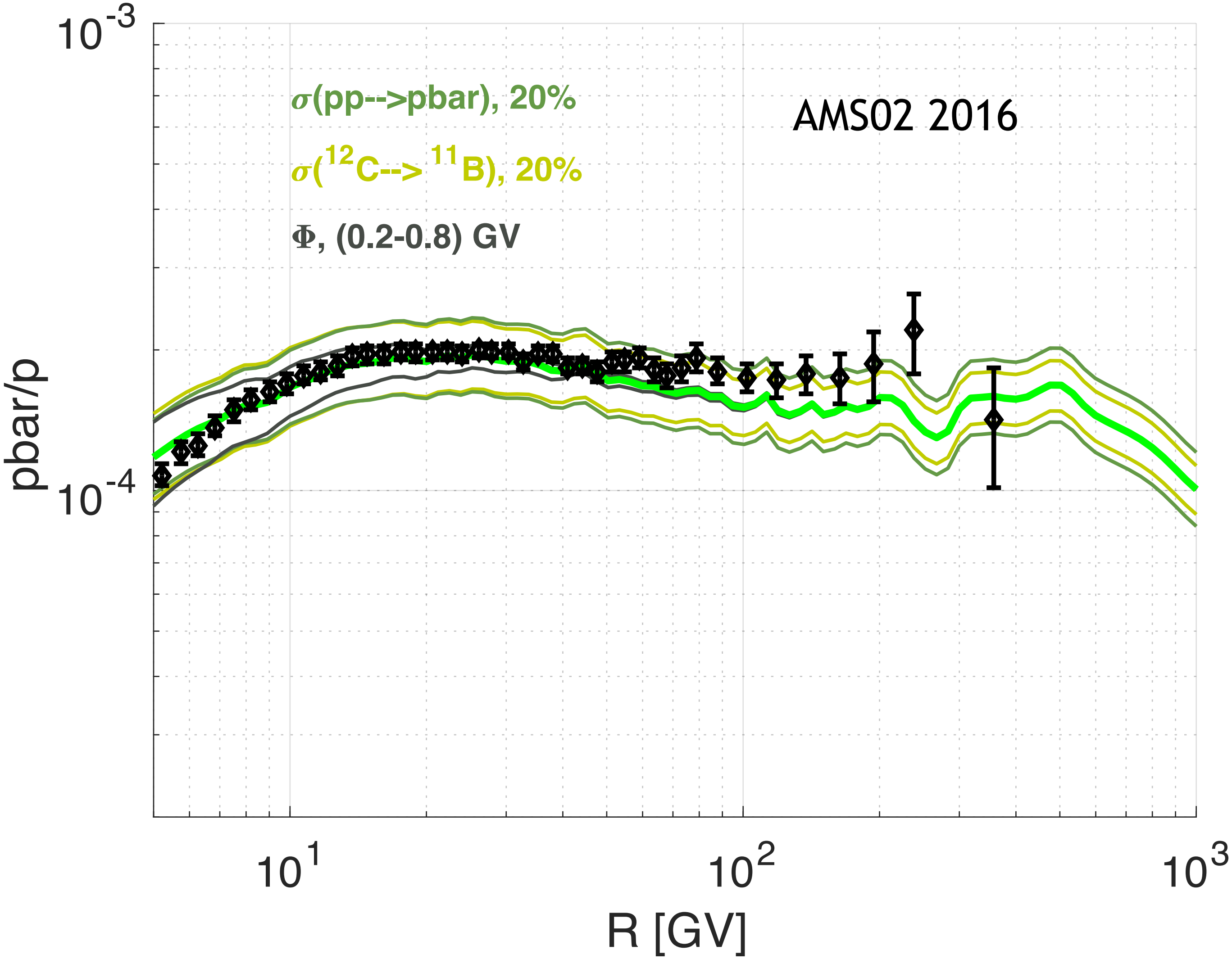
A more robust derivation:

Relate e+ to pbar

Rather than B/C

$$n_{\bar{p}}(\mathcal{R}) \approx \frac{n_{\rm B}(\mathcal{R})}{Q_{\rm B}(\mathcal{R})} Q_{\bar{p}}(\mathcal{R})$$

secondary antiprotons

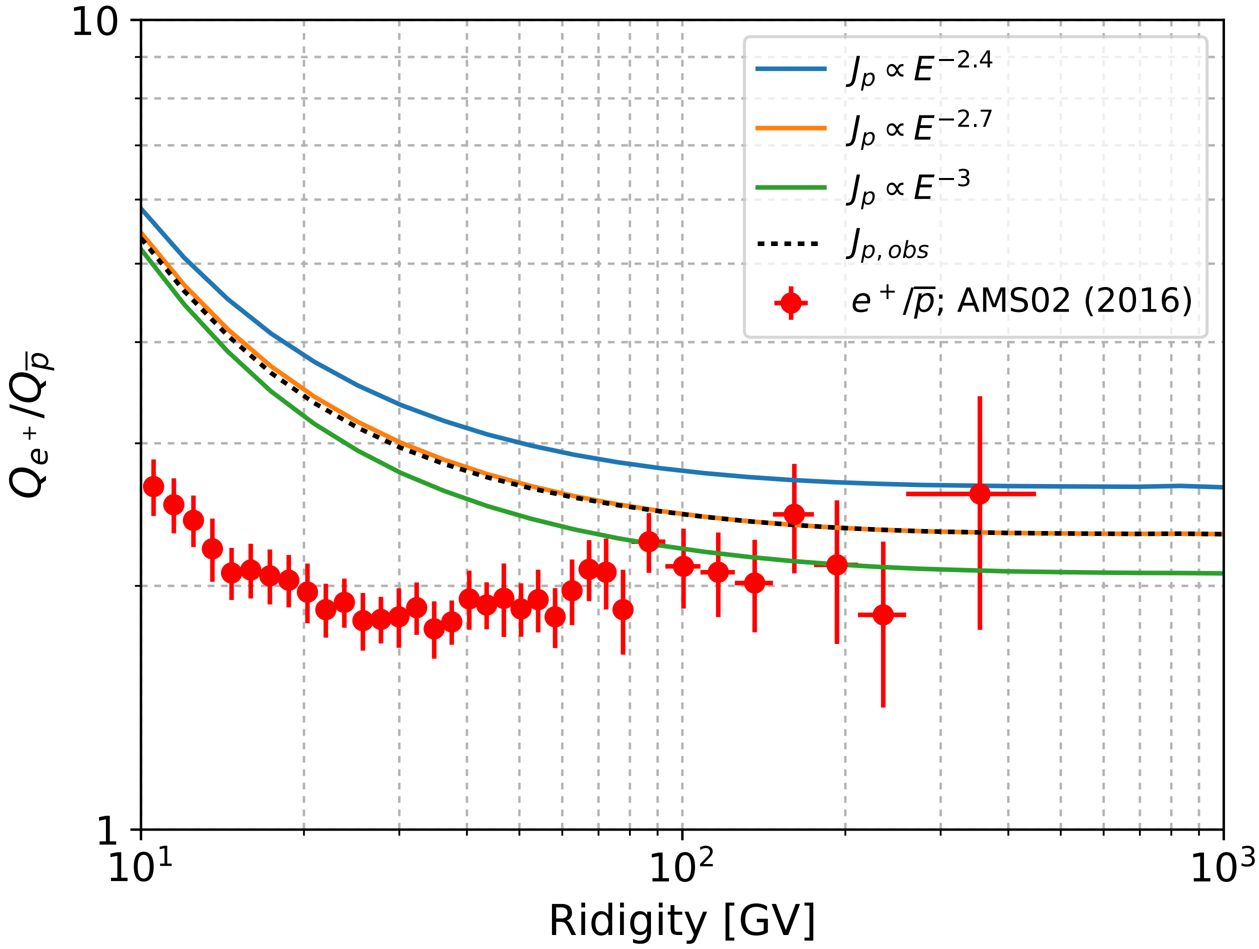


$$\frac{n_{e^+}}{n_{\bar{p}}} = f_{e^+}(\mathcal{R}) \frac{Q_{e^+}(\mathcal{R})}{Q_{\bar{p}}(\mathcal{R})}$$

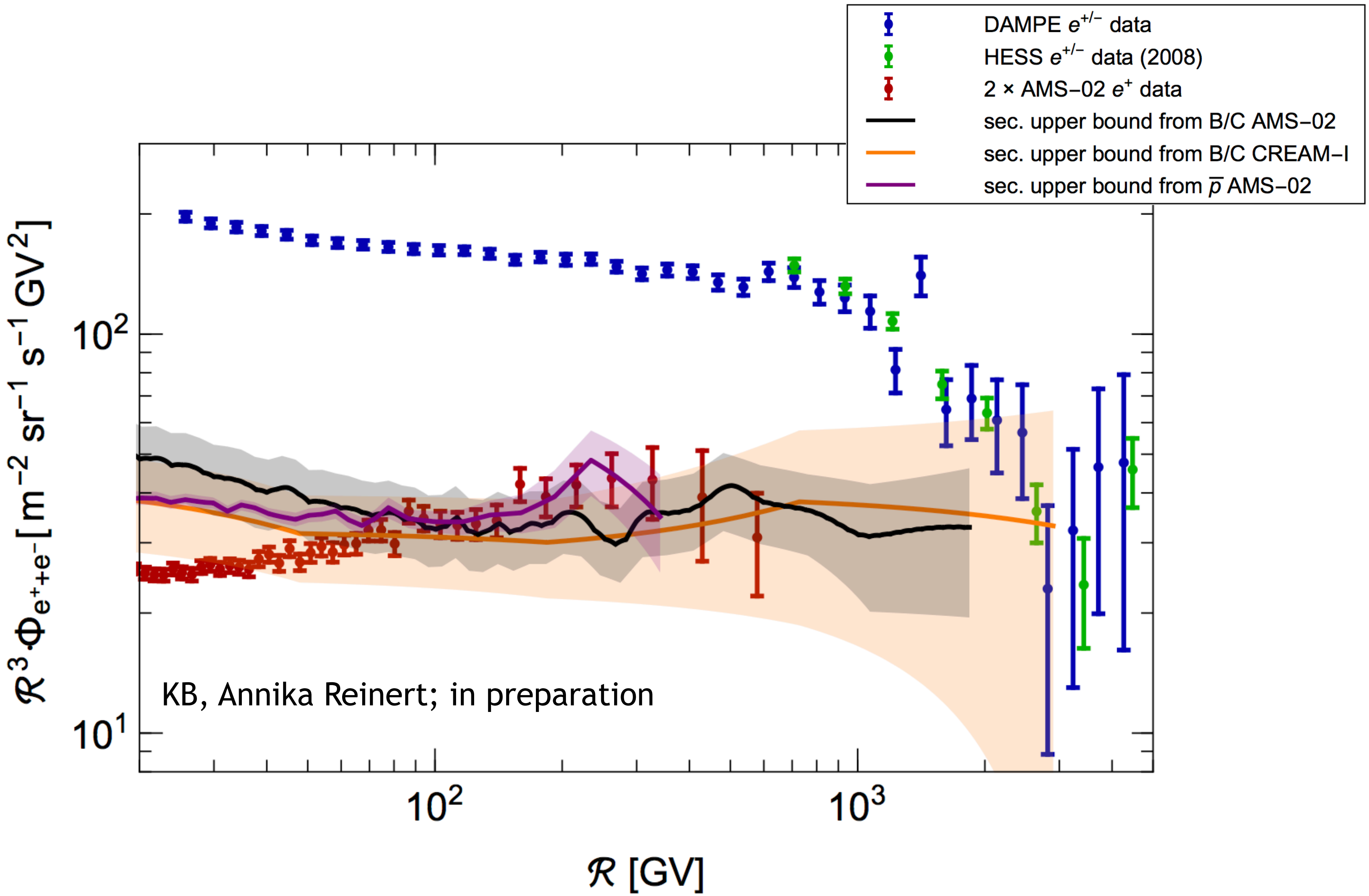
Secondary upper bound

$$f_{e^+}(\mathcal{R}) \leq 1$$

1709.04953



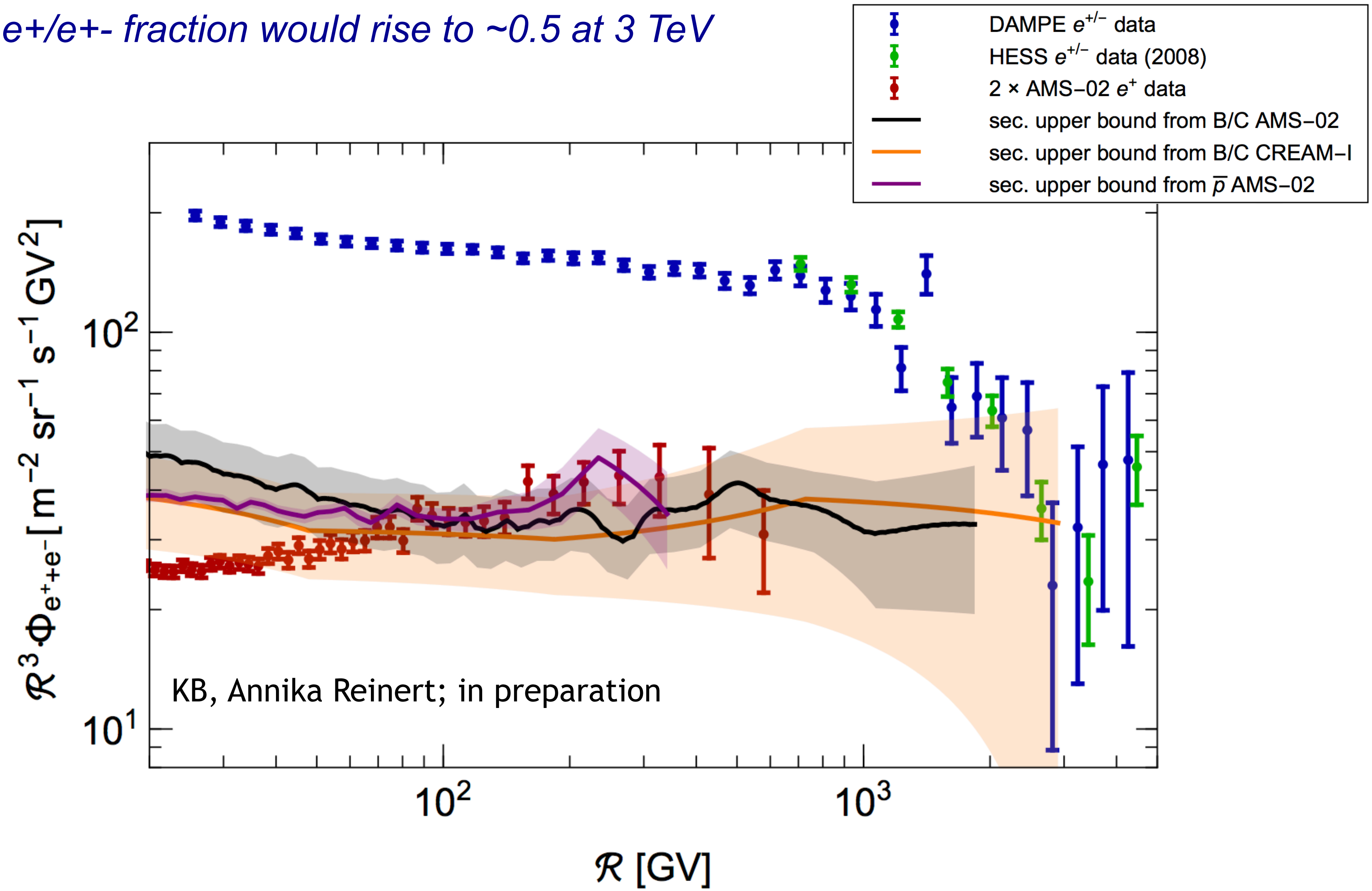
HESS/DAMPE/CALET total e+- flux at E>3 TeV is consistent w/ secondary flux w/ out losses.



HESS/DAMPE/CALET total e+- flux at E>3 TeV is consistent w/ secondary flux w/ out losses.

If not a coincidence, then at E>3 TeV, age of CR is t<0.1Myr

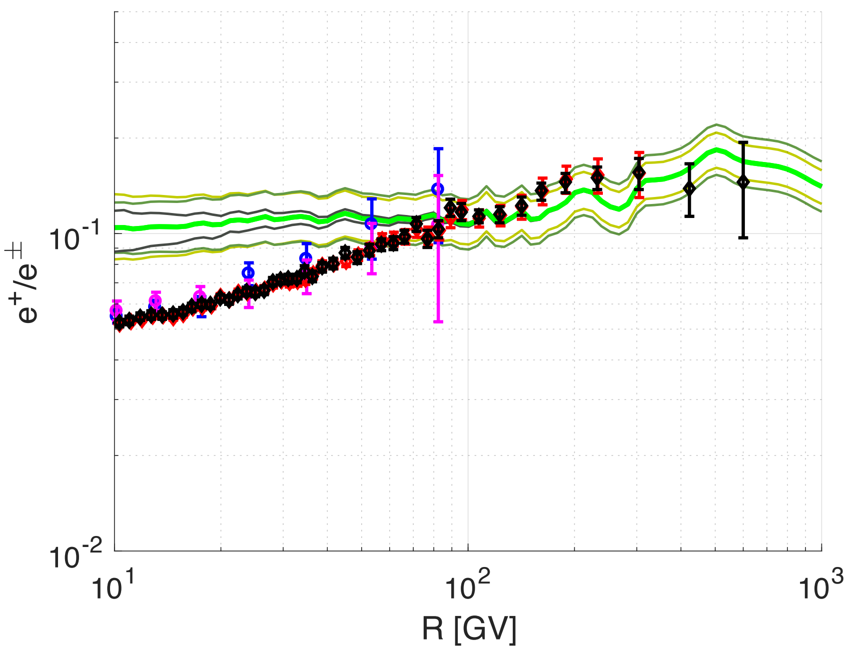
e+/e+- fraction would rise to ~0.5 at 3 TeV

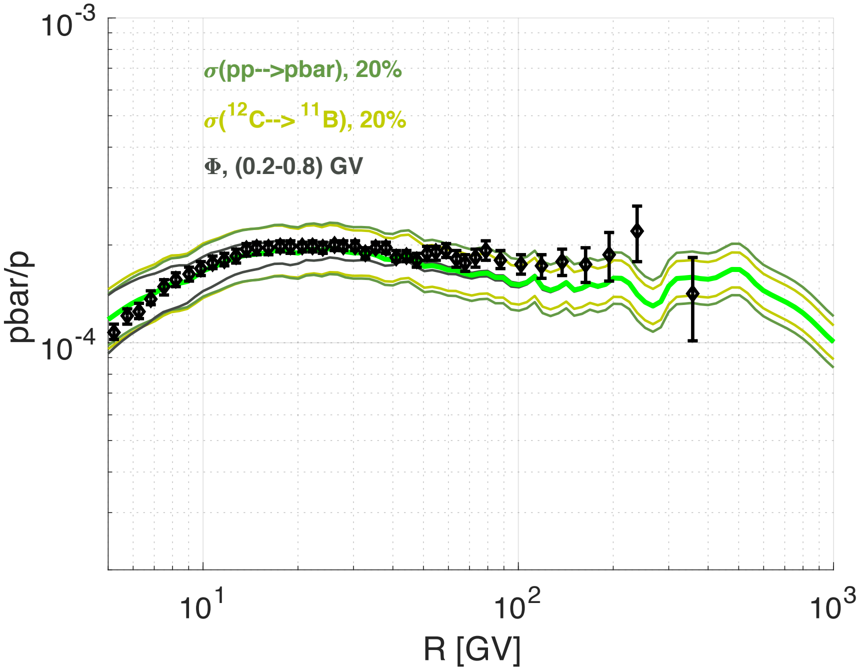


Summary

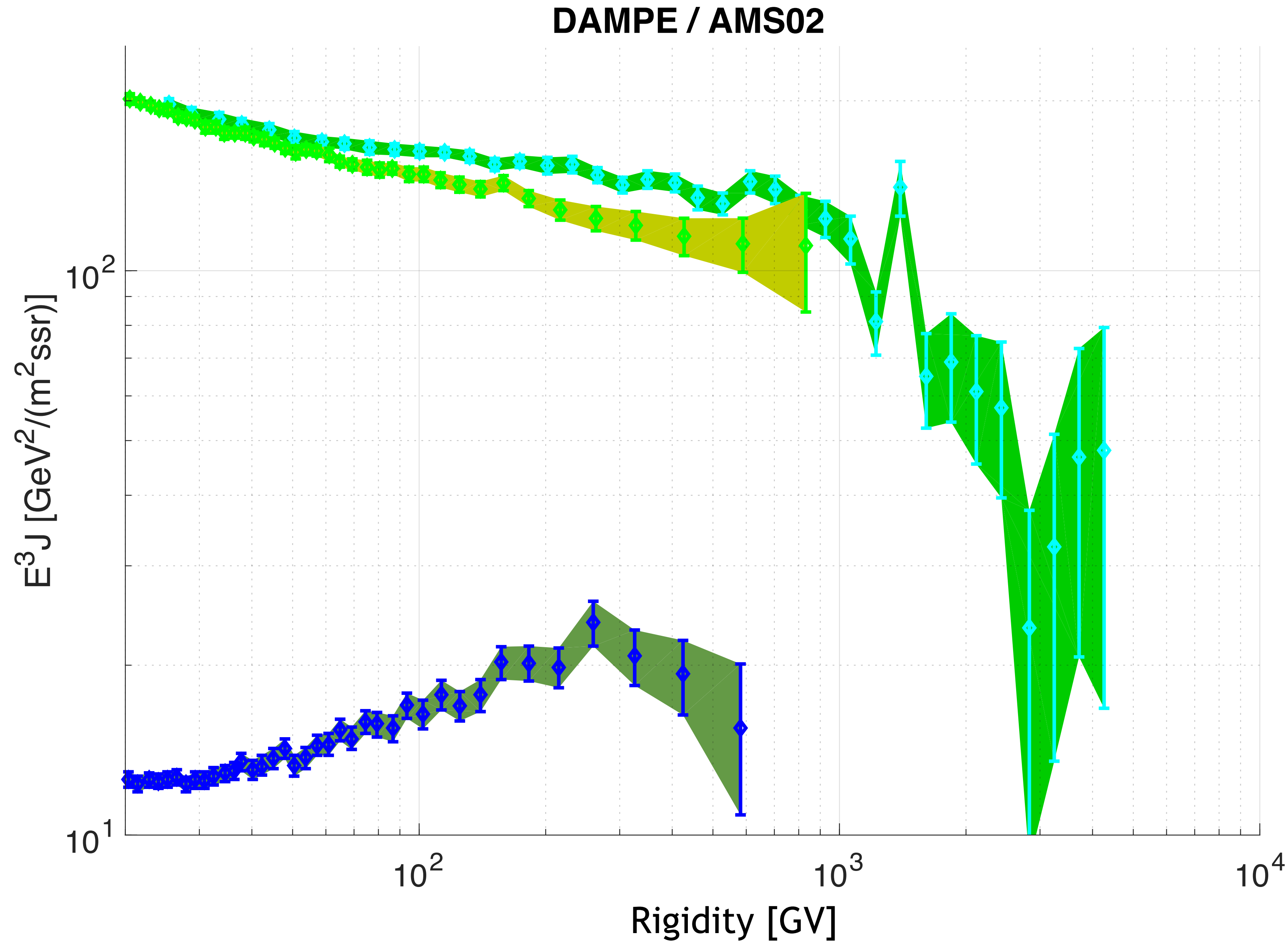
Positrons consistent with secondary.
— CRs more interesting than supposed in simplified diffusion models?

Secondary e+ production cross section: important quantity.
— radial scaling violation affects e+ flux above 100 GeV.
— done from LHC data in: KB, Sato, Takimoto, 1709.04953,
valid to multi-TeV, O(10%) uncertainty.



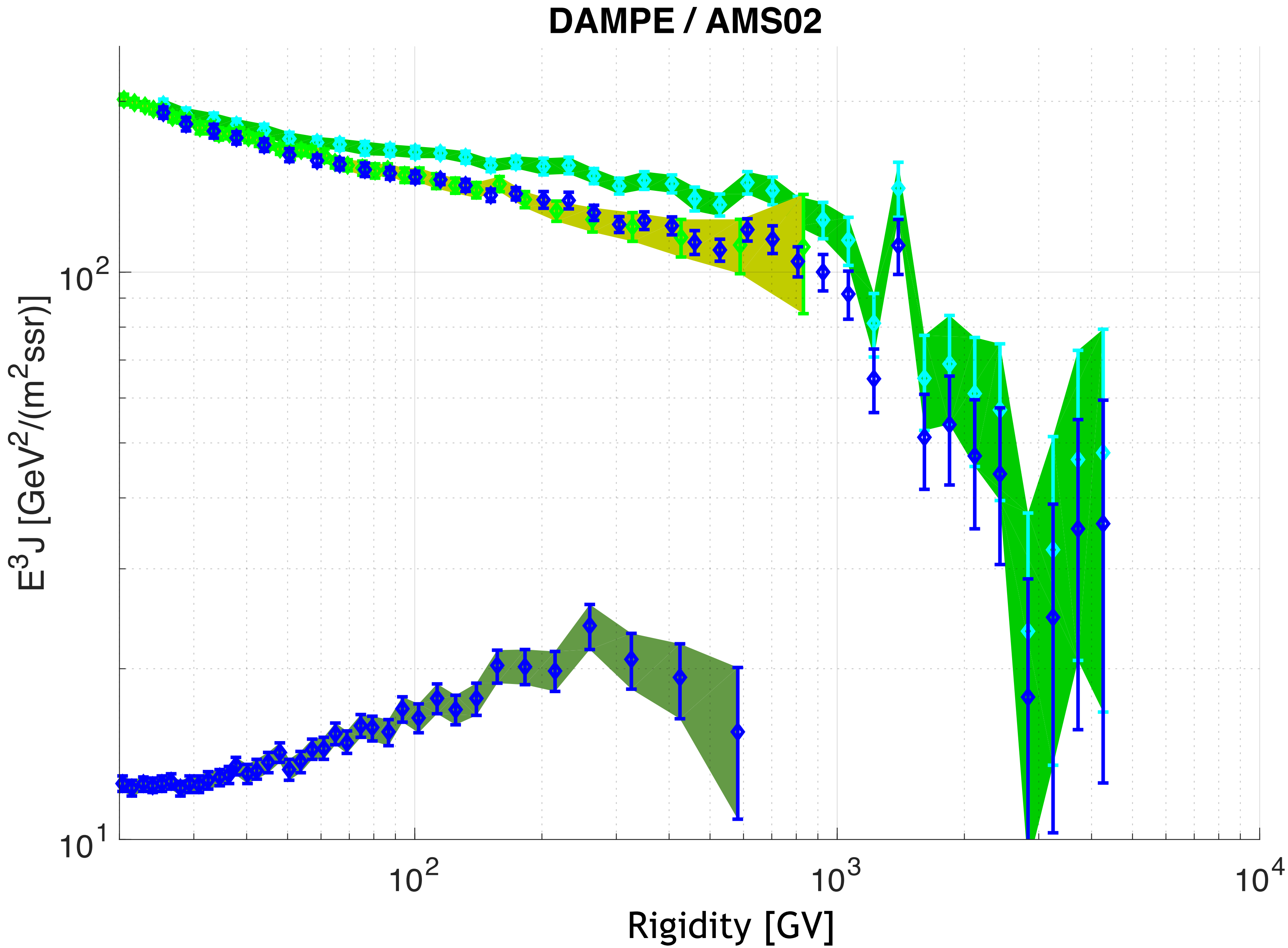


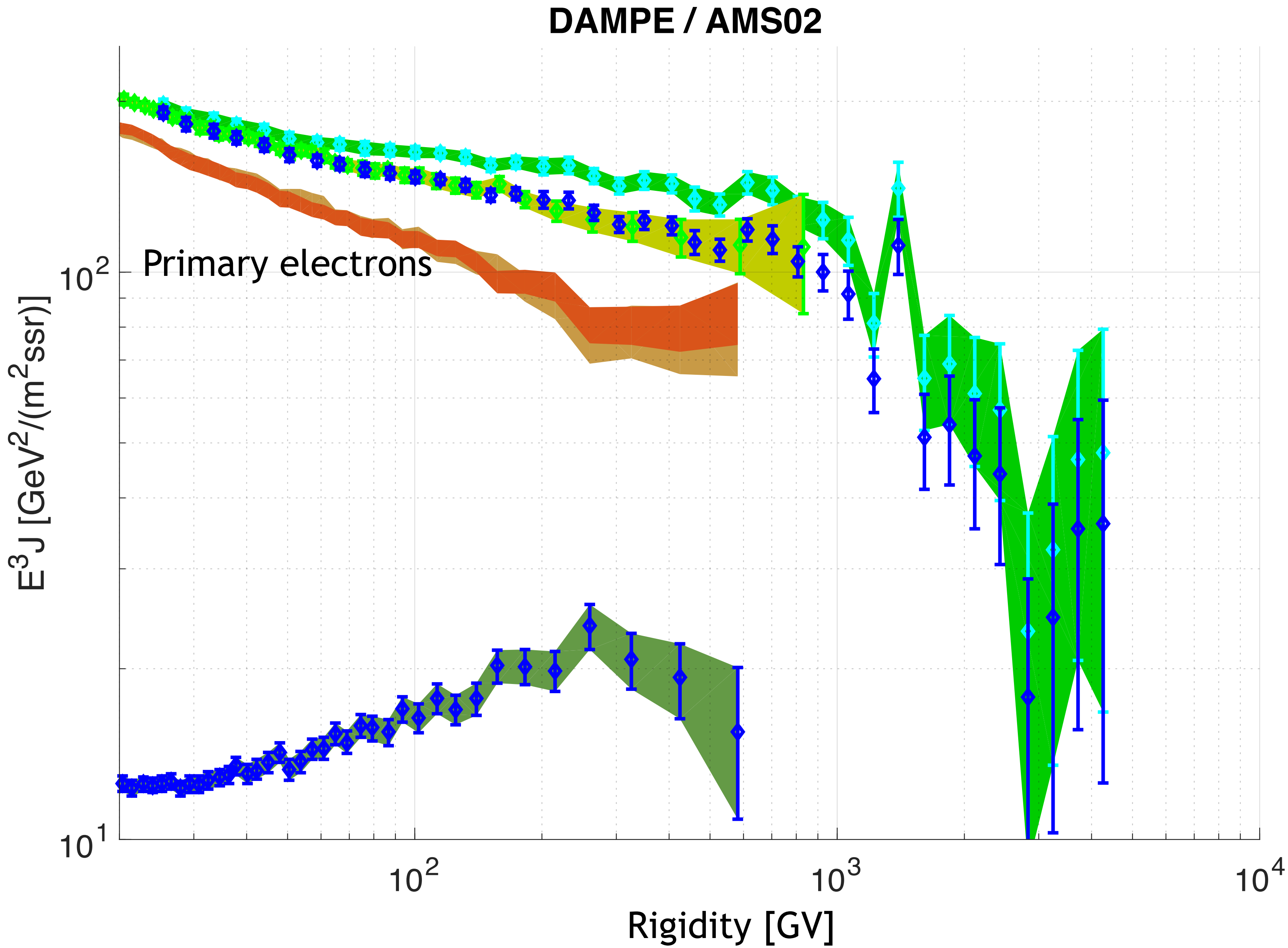
Xtra

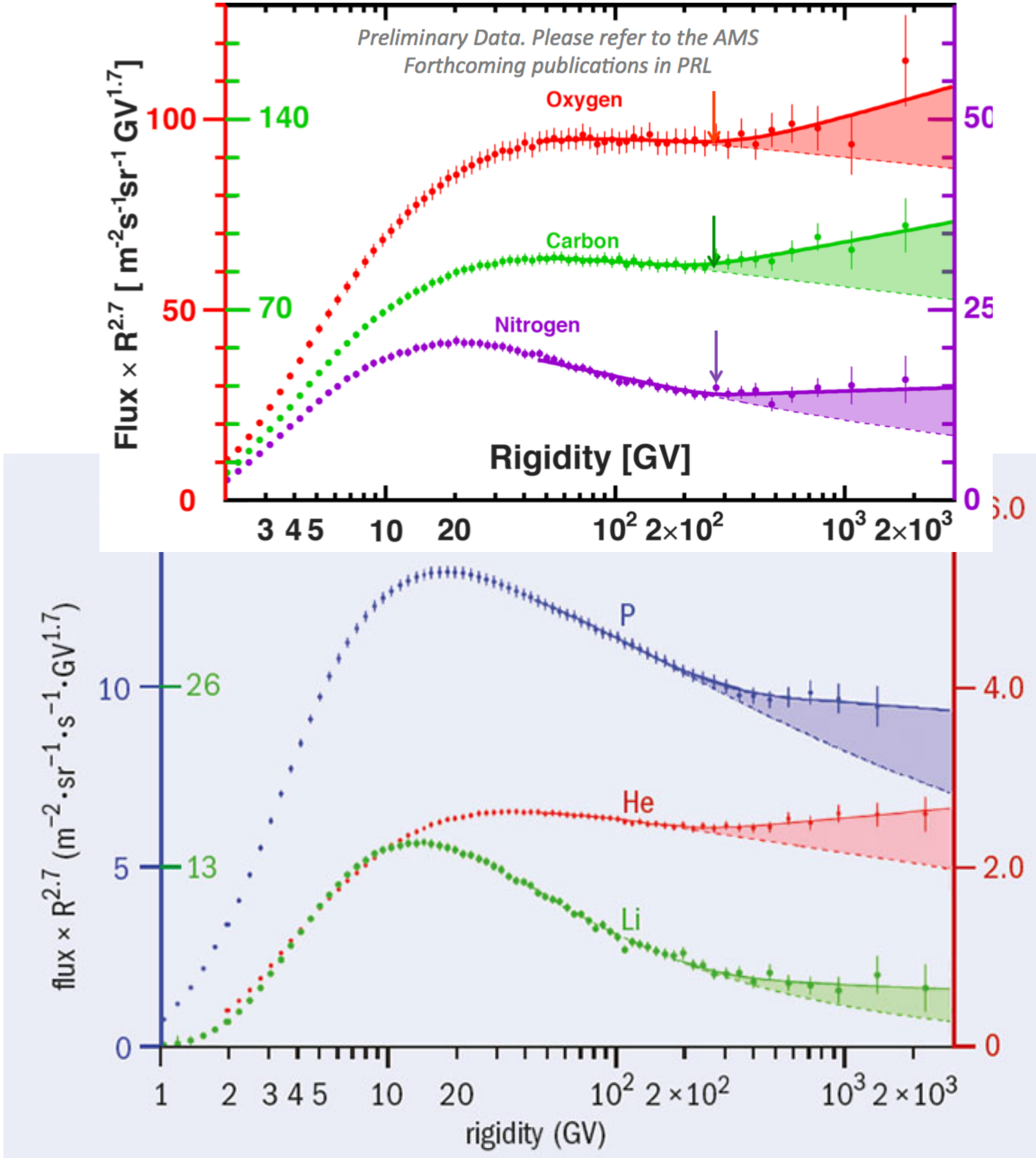


DAMPE / AMS02
E^3 J [GeV^2/(m^2ssr)]
10^2
10^1
10^2
10^3
10^4
Rigidity [GV]

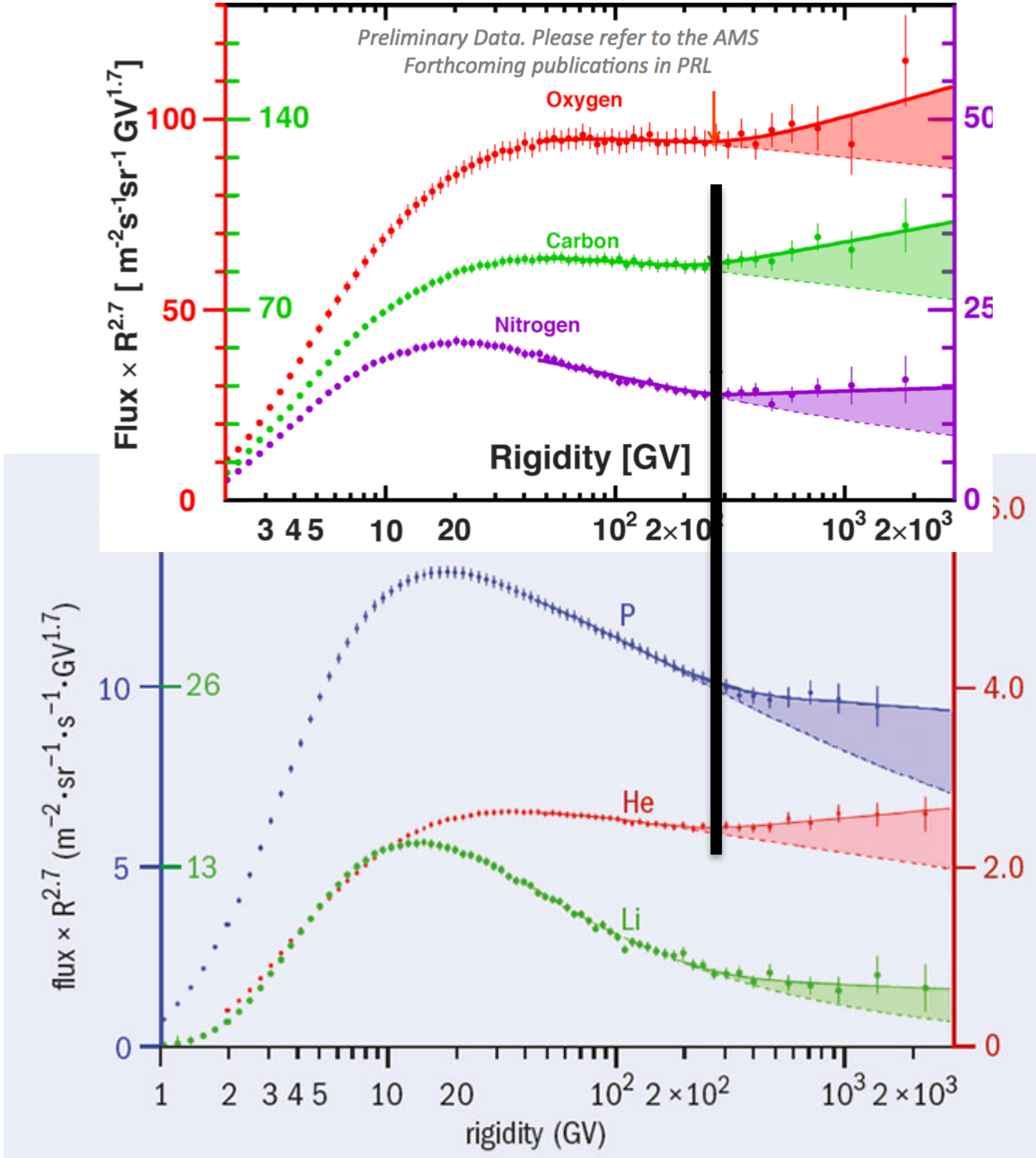
Rescale DAMPE to match AMS02 (sorry China)




DAMPE / AMS02
Primary electrons
$E^3 J$ [GeV^2/(m^{2}ssr)]
Rigidity [GV]
10^1
10^2
10^2
10^3
10^4



Preliminary Data. Please refer to the AMS
Forthcoming publications in PRL
Oxygen
Carbon
Nitrogen
Flux × R^2.7 [m^-2s^-1sr^-1 GV^1.7]
100
140
50
70
0
50
25
0
Rigidity [GV]
3 4 5 10 20 10^2 2×10^2 10^3 2×10^3
P
He
Li
flux × R^2.7 (m^-2·sr^-1·s^-1·GV^1.7)
10
26
5
13
0
4.0
2.0
0
1 2 3 4 5 10 20 10^2 2 × 10^2 10^3 2 × 10^3
rigidity (GV)



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He
Li
flux × R^2.7 (m^-2·sr^-1·s^-1·GV^1.7)
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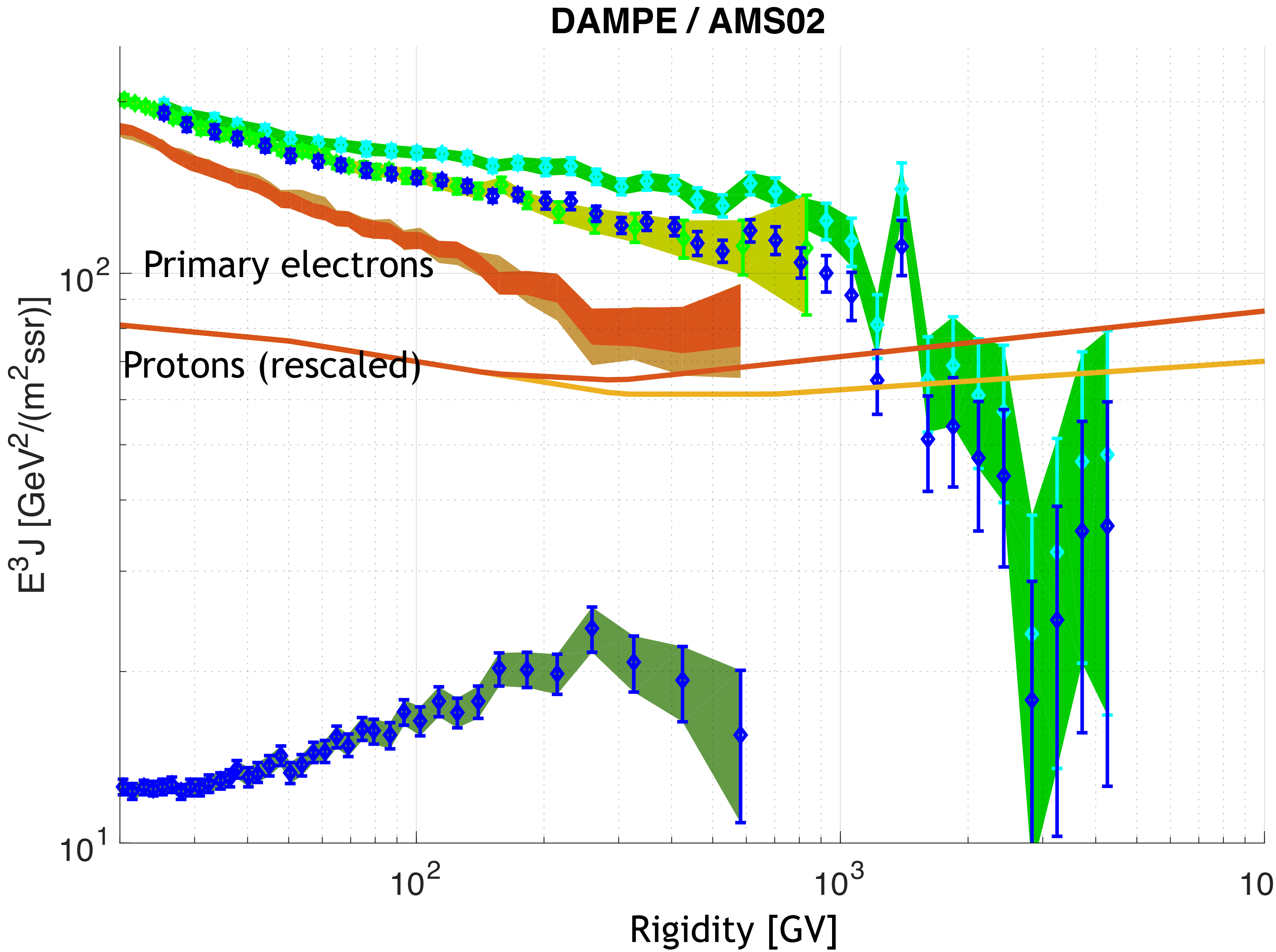
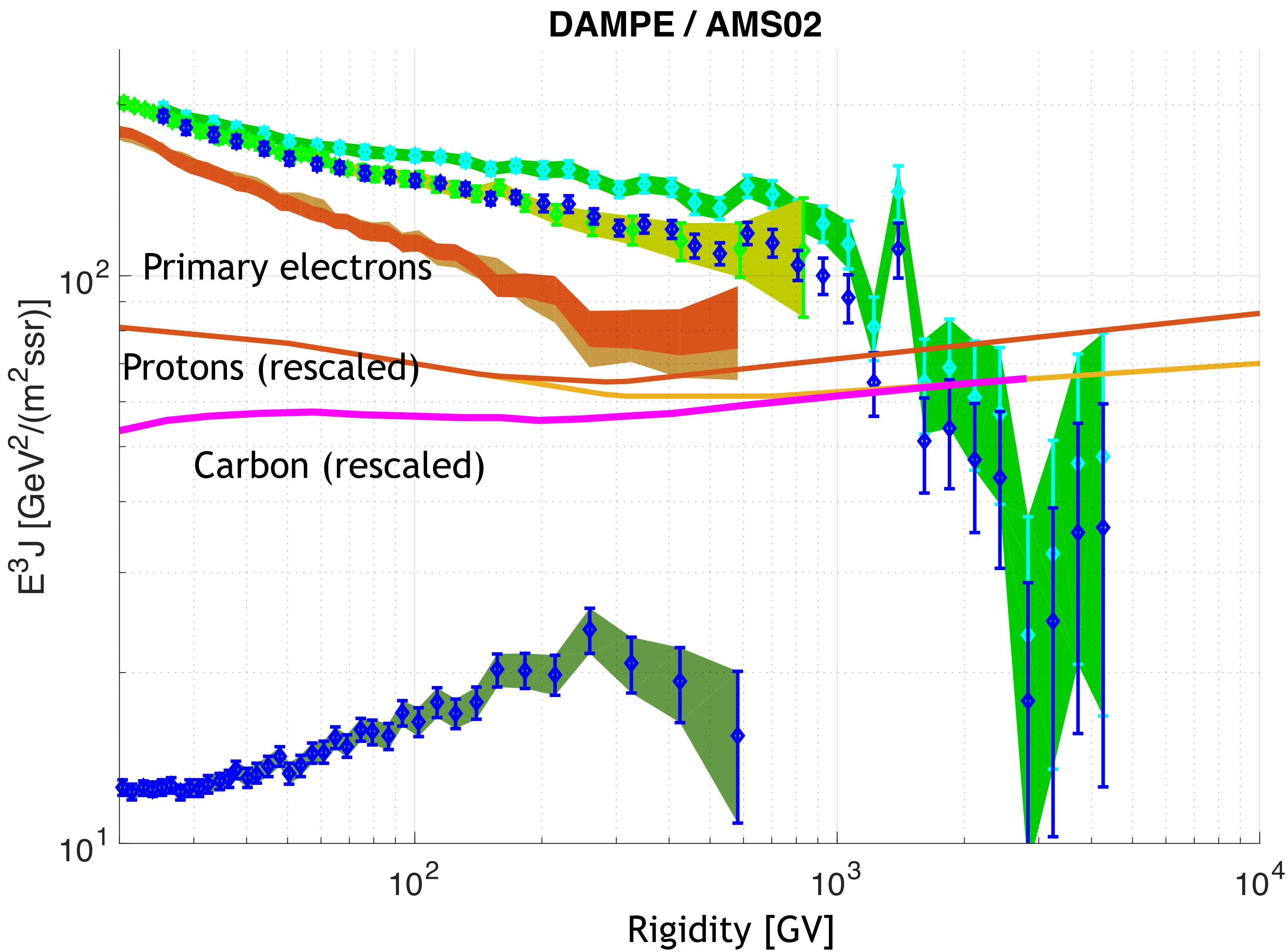
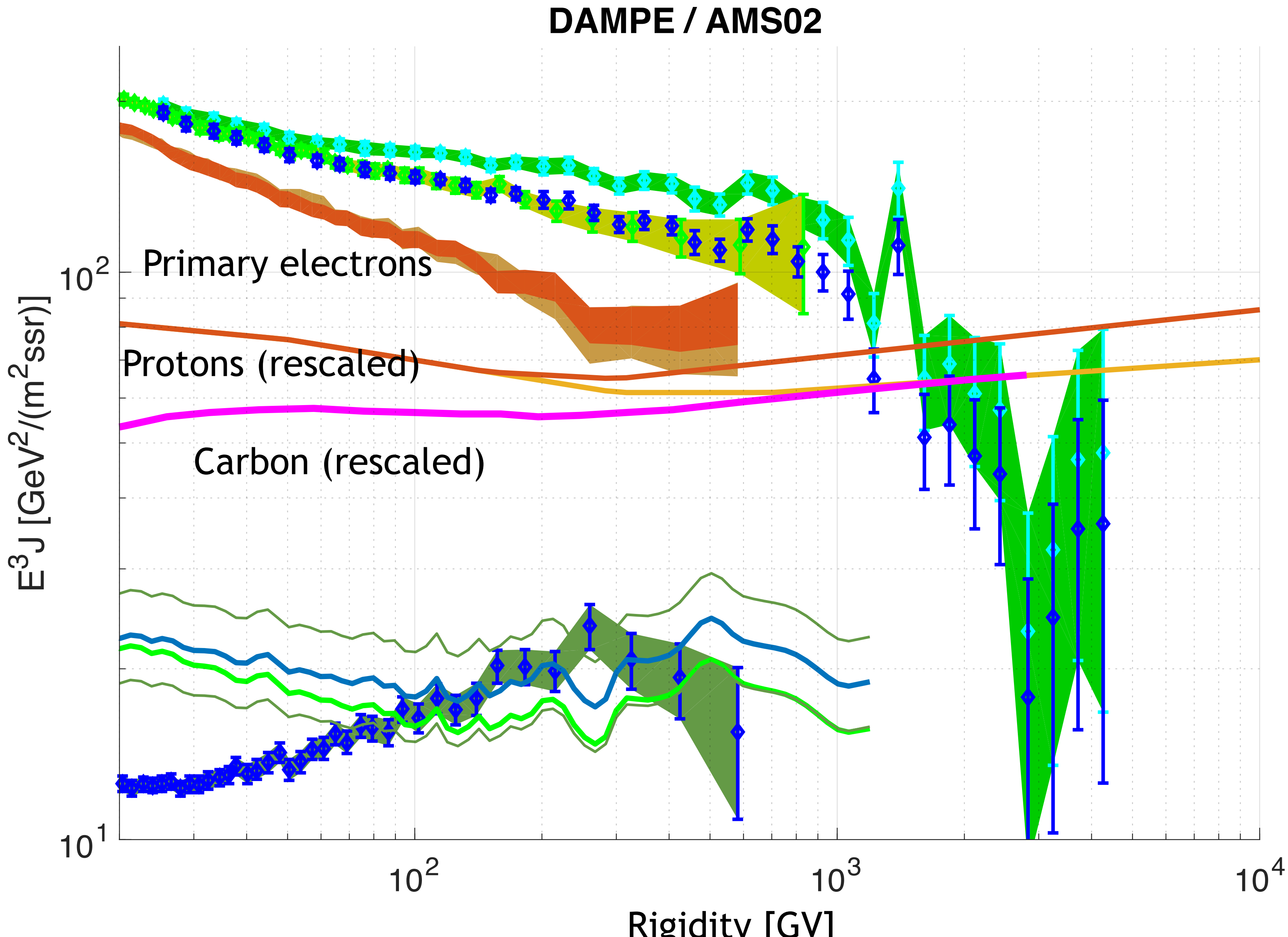
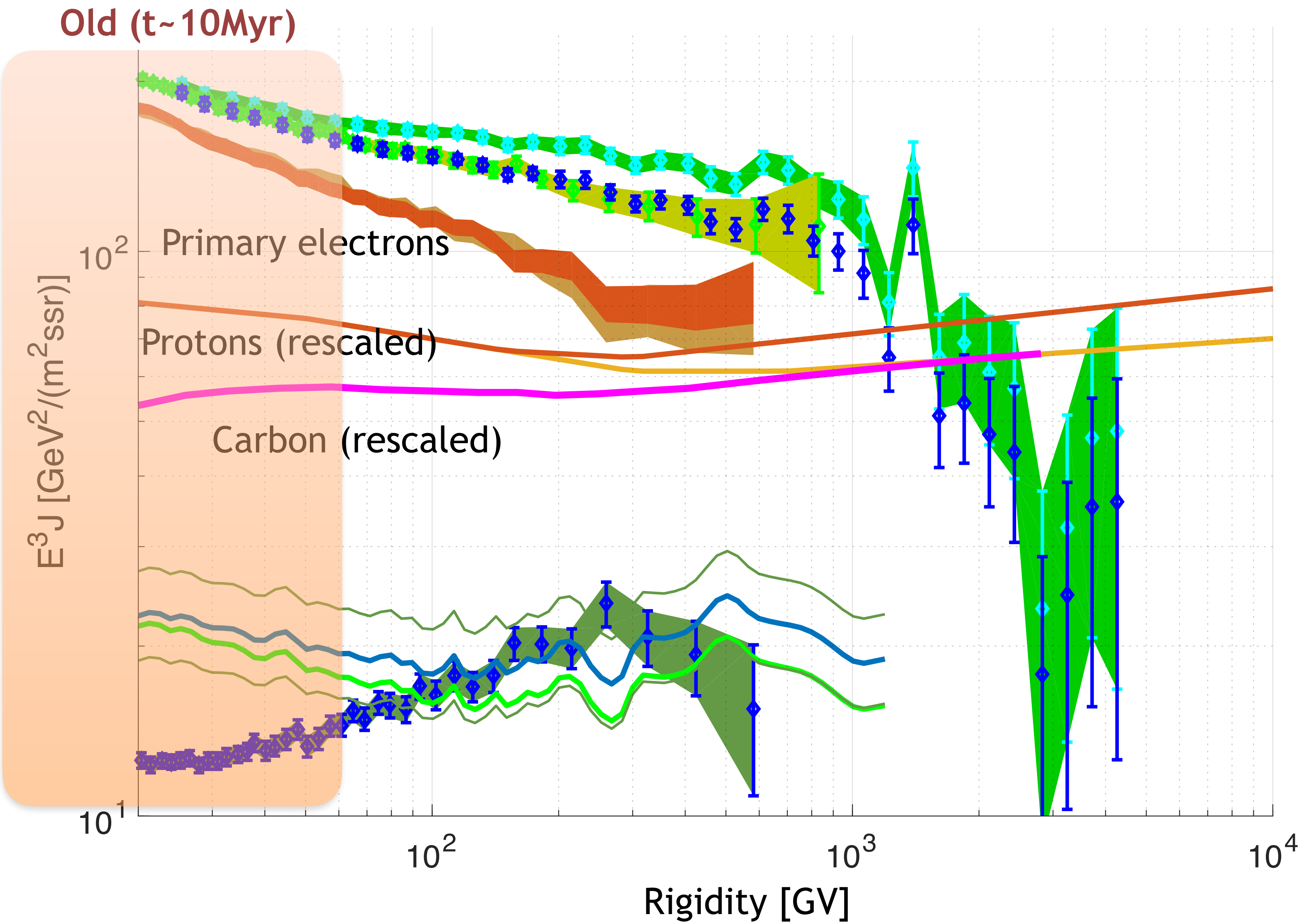
26
5
13
4.0
2.0
1 2 3 4 5 10 20 10^2 2×10^2 10^3 2×10^3
rigidity (GV)


DAMPE / AMS02
Primary electrons
Protons (rescaled)
E^3J [GeV^2/(m^{2}ssr)]
Rigidity [GV]
10^1
10^2
10^3
10^4

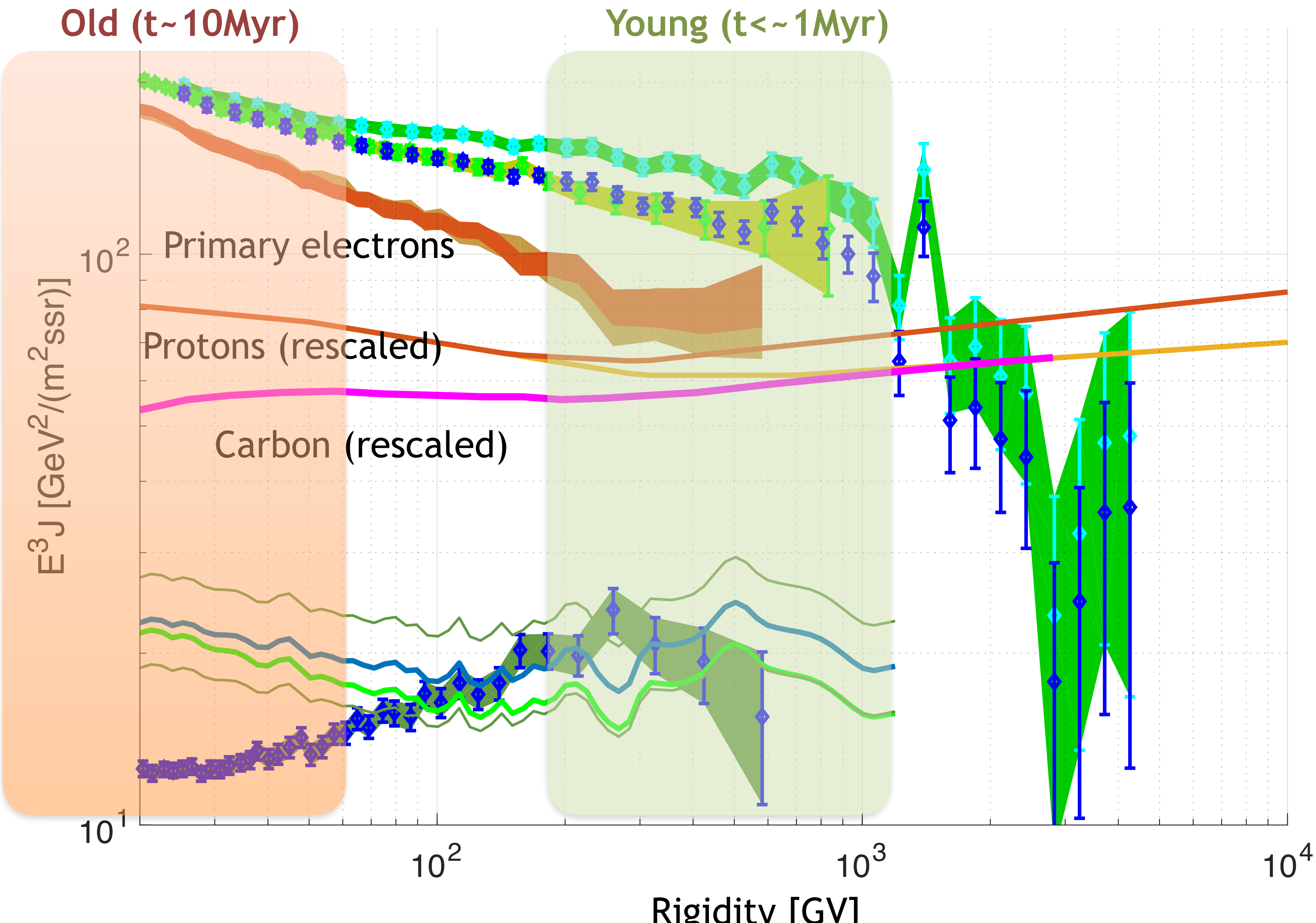


DAMPE / AMS02
Primary electrons
Protons (rescaled)
Carbon (rescaled)
10^2
10^1
10^3
10^4
$E^3 J$ [$GeV^2/(m^2 ssr)$]
Rigidity [GV]

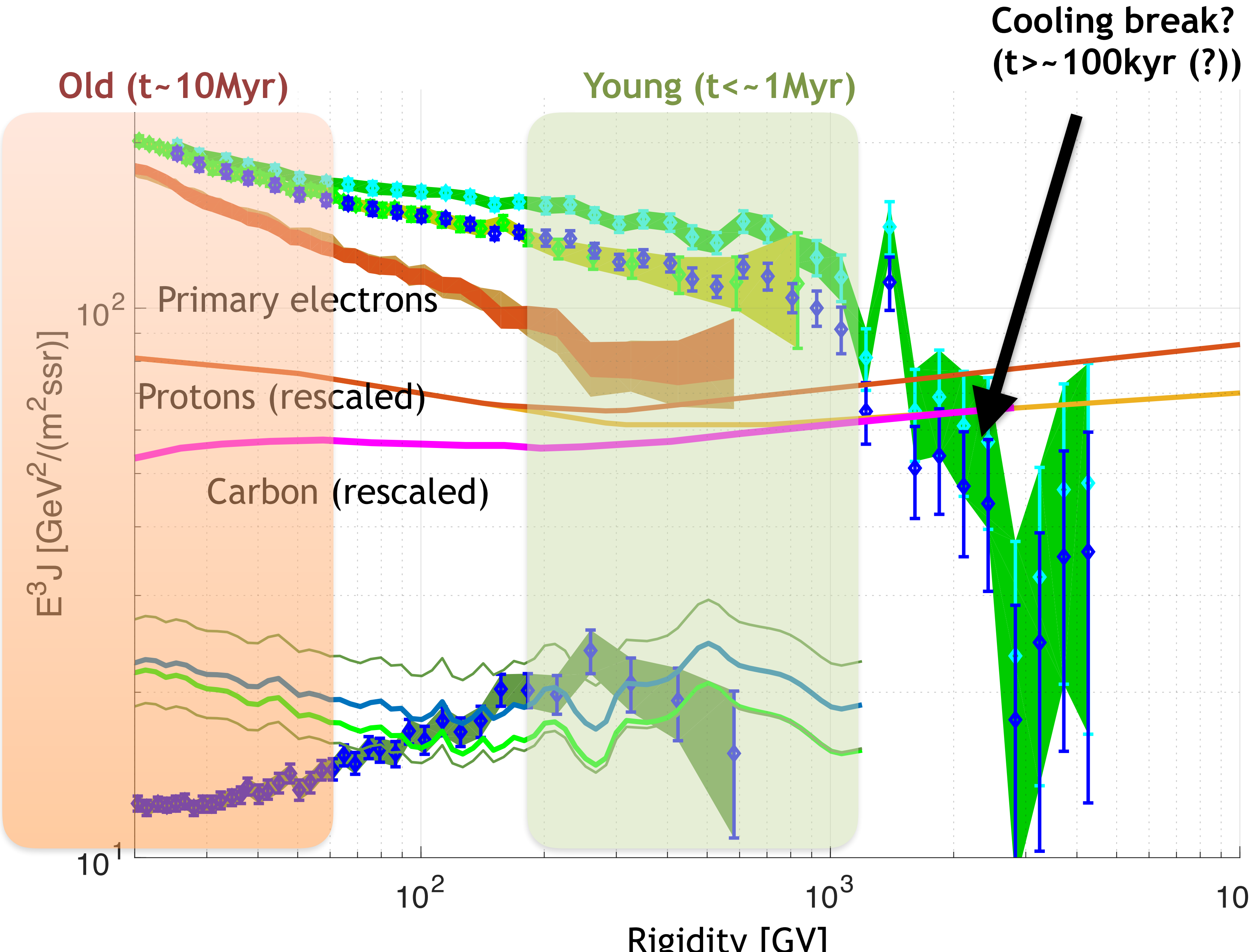

DAMPE / AMS02
Primary electrons
Protons (rescaled)
Carbon (rescaled)
E^3J [GeV^2/(m^2ssr)]
10^2
10^1
10^2
10^3
10^4
Rigidity [GV]



Old (t~10Myr)
Primary electrons
Protons (rescaled)
Carbon (rescaled)
$E^3 J$ [GeV^2/(m^{2}ssr)]
10^2
10^1
10^2
10^3
10^4
Rigidity [GV]



Old (t~10Myr)
Young (t<~1Myr)
Primary electrons
Protons (rescaled)
Carbon (rescaled)
E^3J [GeV^2/(m^{2}ssr)]
Rigidity [GV]



Cooling break?
(t>~100kyr (?))
Old (t~10Myr)
Young (t<~1Myr)
Primary electrons
Protons (rescaled)
Carbon (rescaled)
E^3J [GeV^2/(m^{2}ssr)]
Rigidity [GV]
10^1
10^2
10^2
10^3
10^4