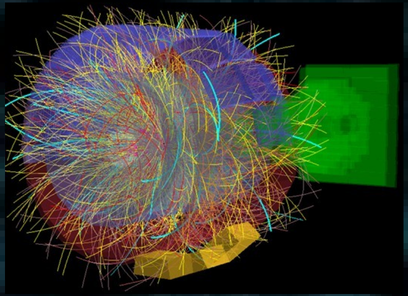
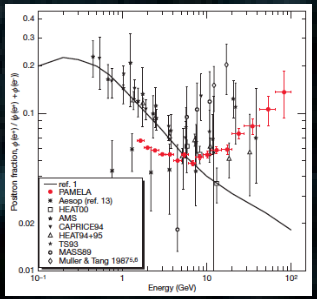
Impact of cross-section uncertainties on the GCR electron/positron fluxes



alice@LHC



@PAMELA

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Nuclear Physics for Galactic Cosmic Rays

LPSC-Grenoble, 3-4 XII 2012

Secondary GCR $e^{+/-}$ production

$$\mathcal{Q}_{\rm sec}(T,\vec{x}) = 4\,\pi \sum_{i,j} \int dT_i \, \frac{d\phi_i(T_i,\vec{x})}{dT_i} \, \frac{d\sigma_{ij\to{\rm sec}}(T_i\to T)}{dT} \, n_j(\vec{x})$$

Low energy (T < 3 GeV)

$$p+p \longrightarrow p+\Delta^+ \longrightarrow \begin{cases} p+n+\pi^+ & (73\%) \\ p+p+\pi^0 & (27\%) \end{cases}$$

$$\pi^\pm \longrightarrow \mu^\pm + \nu_\mu \longrightarrow e^\pm + 2\,\nu_\mu + \nu_e$$

$$K^\pm \longrightarrow \begin{cases} \mu^\pm + \nu_\mu & (63.5\%) \\ \pi^\pm + \pi^0 & (21.2\%) \\ \pi^\pm + \pi^\pm + \pi^\mp & (5.6\%) \end{cases}$$

Higher energy (T > 3 GeV)

$$p+p \longrightarrow \begin{cases} \pi^\pm + X \\ K^\pm + Y \end{cases}$$

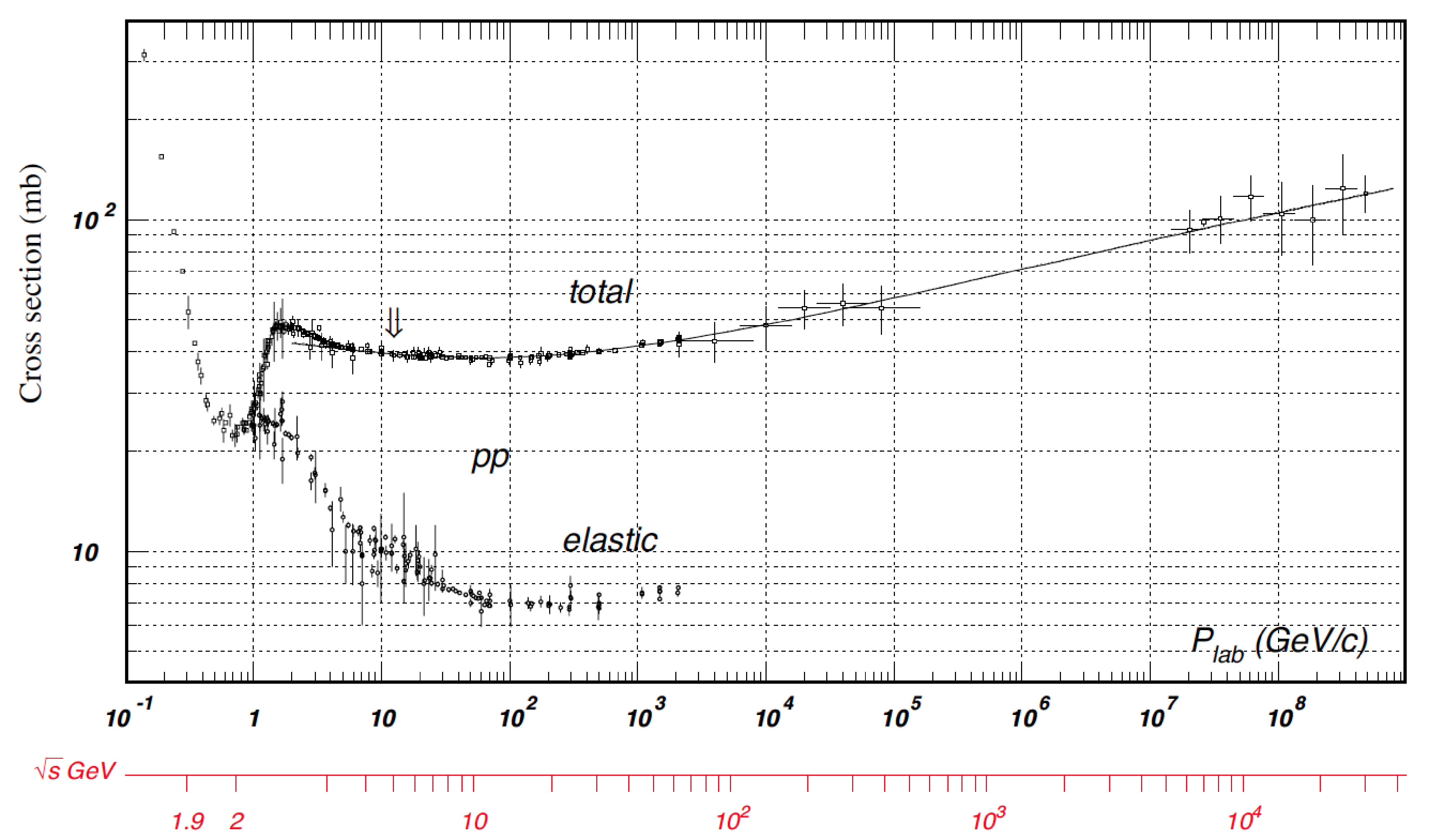
Different approaches:

→ in the past, semi-empirical models for inclusive pion/kaon production cross section (Delta resonance + non-diffractive processes treated in scaling models)

→ more recently, Monte-Carlo based methods including non-perturbative QCD (scaling violation) + diffractive processes

p-p cross section from RPP2012

PDG: Beringer et al (2012), data available at
http://pdg.lbl.gov/2012/hadronic-xsections/



Some reference works for pion/kaon production models applied to HE astrophysics

<u>Semi-empirical approaches:</u>

Stecker (1970) – neutral pions: Delta (1232 MeV) for $T < 2.2$ GeV; "fireball" process for $T > 2.2$ GeV

Badhwar et al (1977) – charged pions: scaling model

Stephens & Badhwar (1981) – neutral pions: scaling model

Tan & Ng (1983) – charged pions: scaling model

Dermer (1986) – charged and neutral pions: isobaric (à la Stecker) for $T < 3$ GeV, then scaling à la Badhwar et al.

*** **Moskalenko & Strong (1998)**: à la Dermer – reference work for secondary positron predictions (before 2008)

→ no diffractive interactions + no Feynman scaling violation in the non-diffractive inelastic interaction
→ constant inelastic p-p cross section assumed for $T >> 10$ GeV (not supported by more recent data)

<u>Monte-Carlo based approaches:</u>

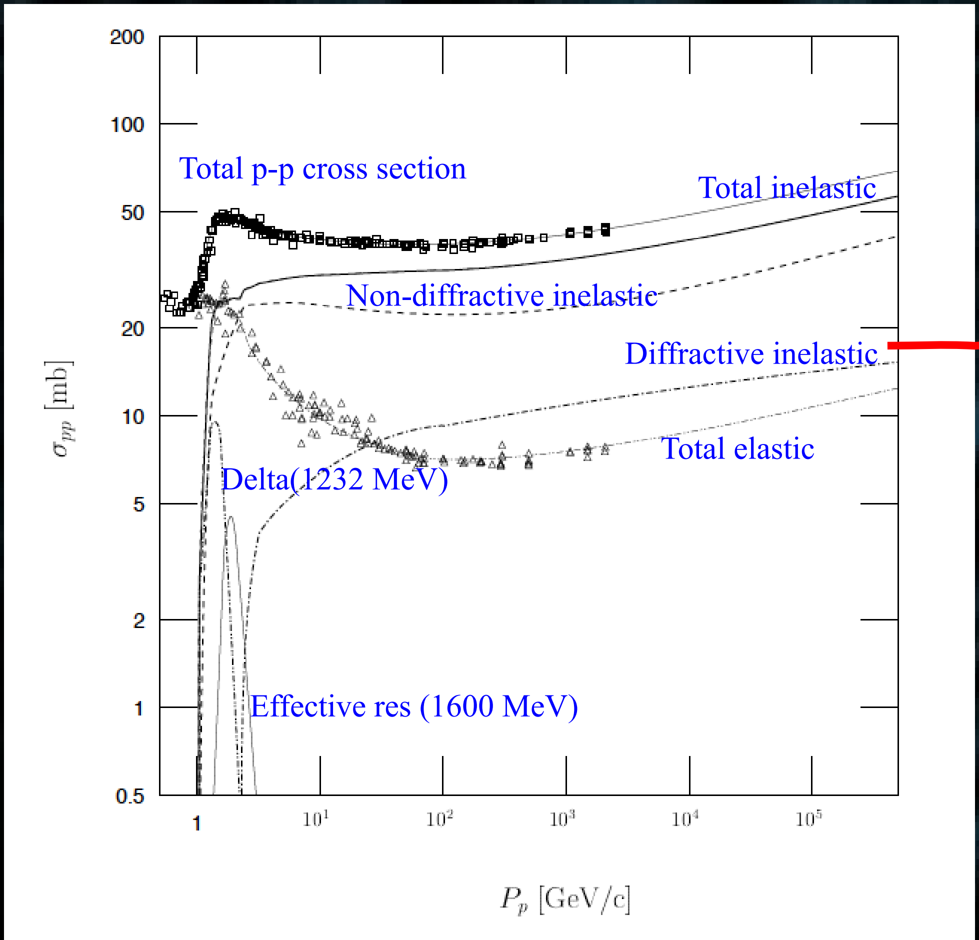
Mori (1997) – neutral pions: Pythia-like (perturbative QCD – Lund model, beyond scaling model, nondiffractive processes only)

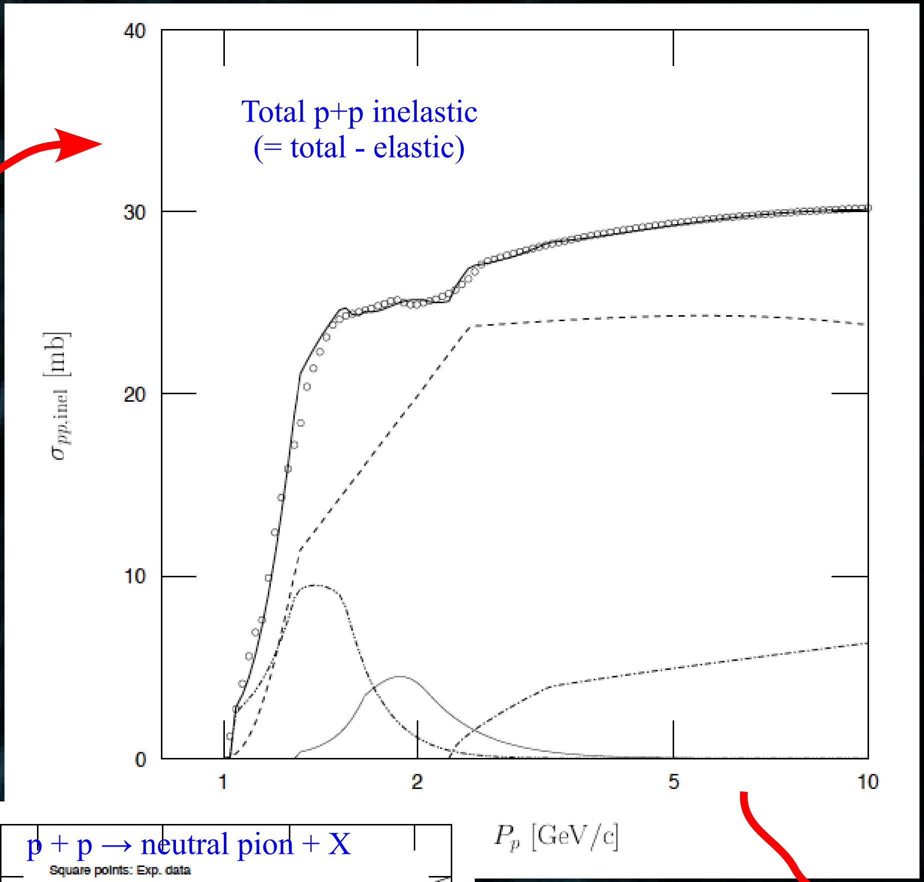
Kelner et al (2006): Based on SIBYLL (Fletcher et al, 1994) and QGSJET (Kalmykov et al, 1997)

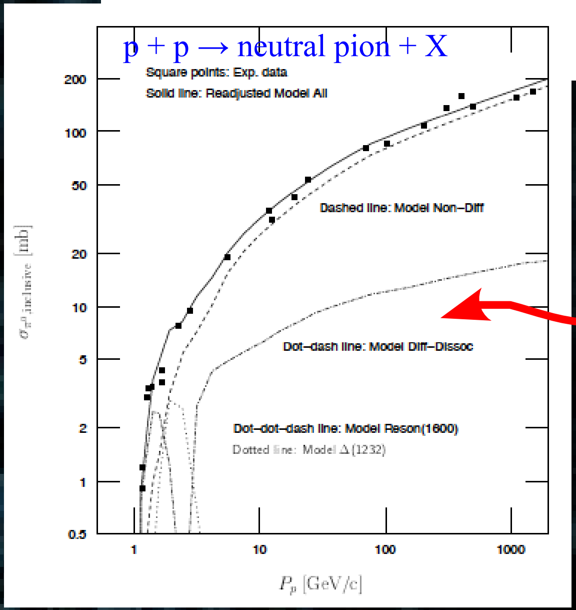
Kamae et al (2006):
→ Delta(1232 MeV) resonance + 1600 MeV effective resonance
→ low energy ($T < 50$ GeV): diffractive by Kamae (Pythia also works), non-diffractive from Blattnig et al (2000)
→ high energy ($T > 50$ GeV) non-diffractive: Pythia 6.2 (Sjöstrand et al, 2001)
→ 0.488 GeV $< T <$ 512 TeV

Kachelriess & Ostapchenko (2012): QGSJET-II + Kamae et al (2006)

Parameterization of Kamae et al (2006)







→ Delta(1232 MeV) resonance + 1600 MeV effective resonance
→ low energy (T < 50 GeV):
  * diffractive by Kamae (Goulianos, 1983) – Pythia includes it now
  * non-diffractive from Blattnig et al (2000)
→ high energy (T > 50 GeV) non-diffractive: Pythia 6.2 (Sjöstrand et al, 2001)

→ validity: 0.488 GeV < T < 512 TeV

Results wrt other parameterizations

Compilation of pion data in e.g. Blattnig et al (2000) and Dermer (1986)

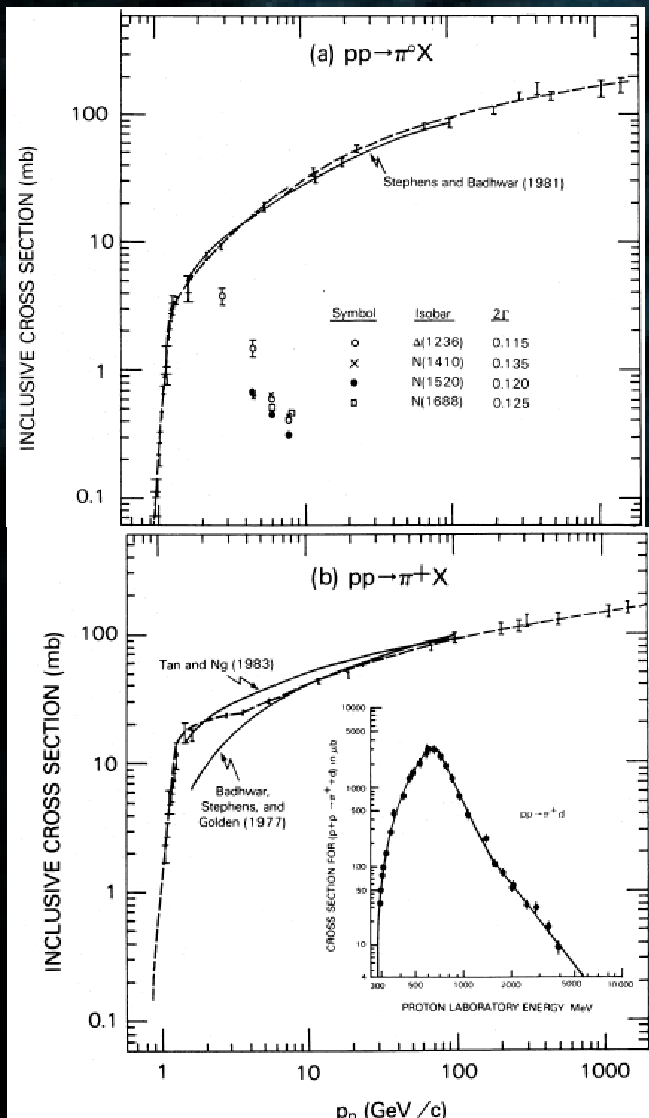
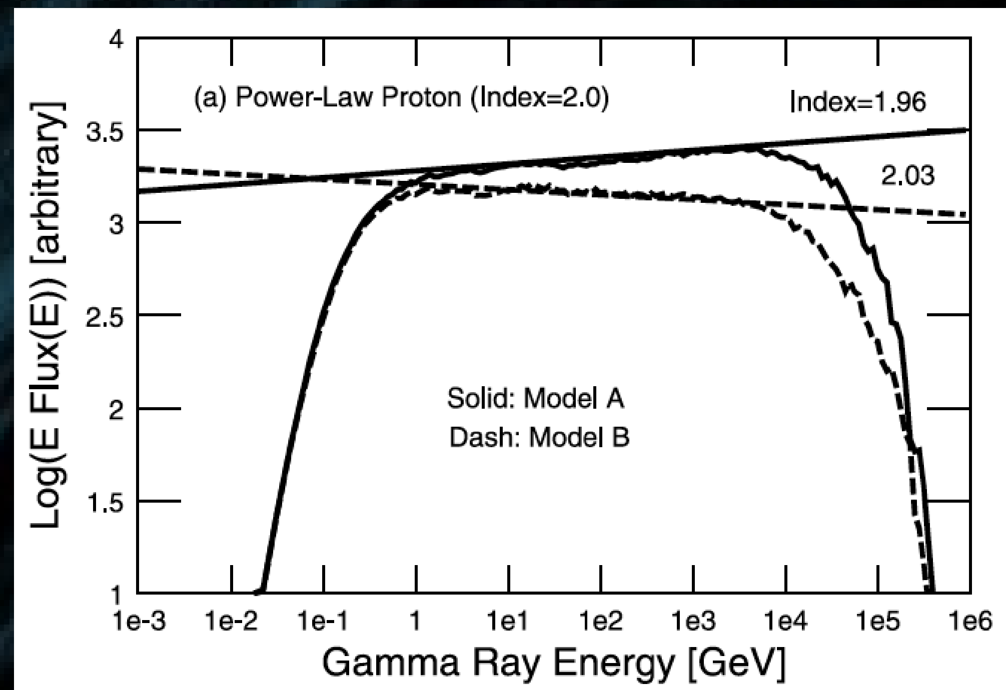


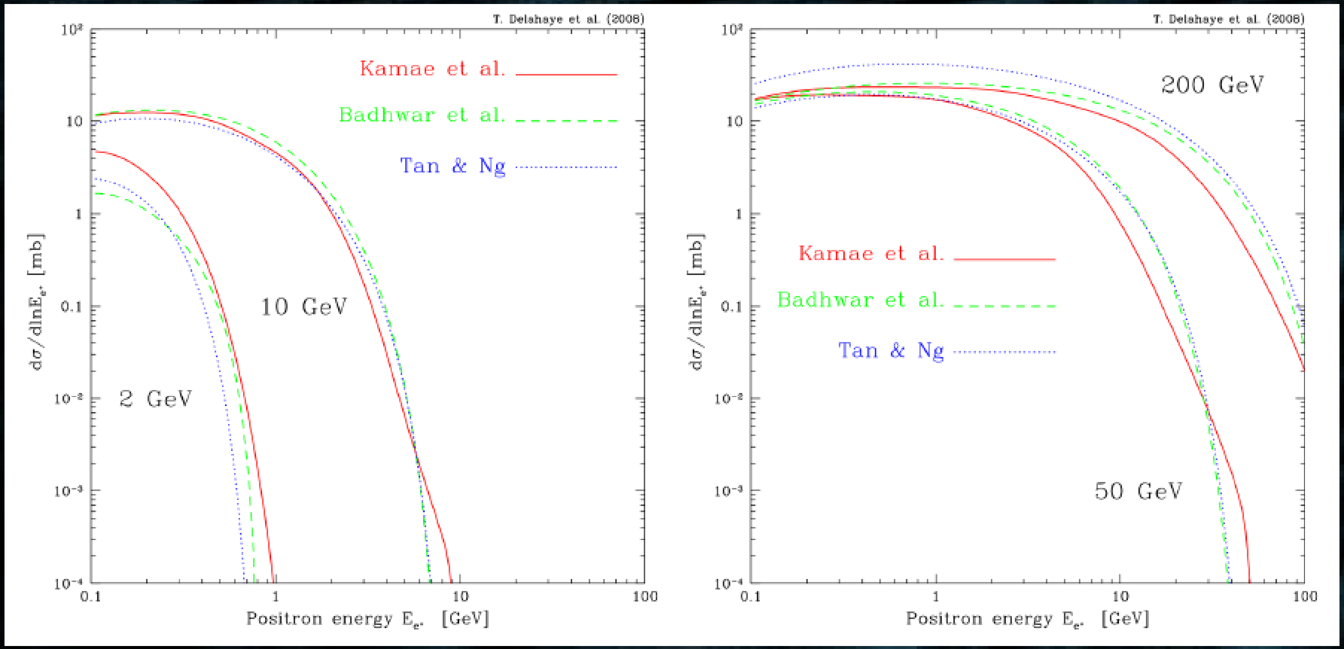
FIG. 2b



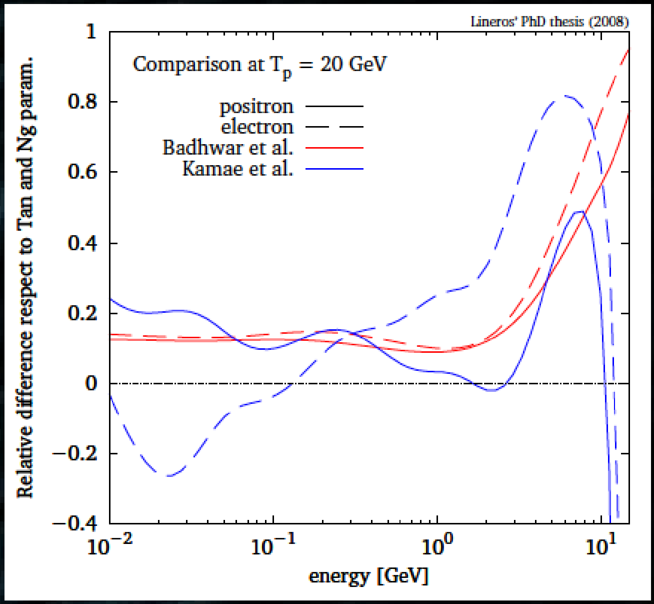
=> Spectral index is found harder, + 0.4
(valid for all pions, neutral and charged)

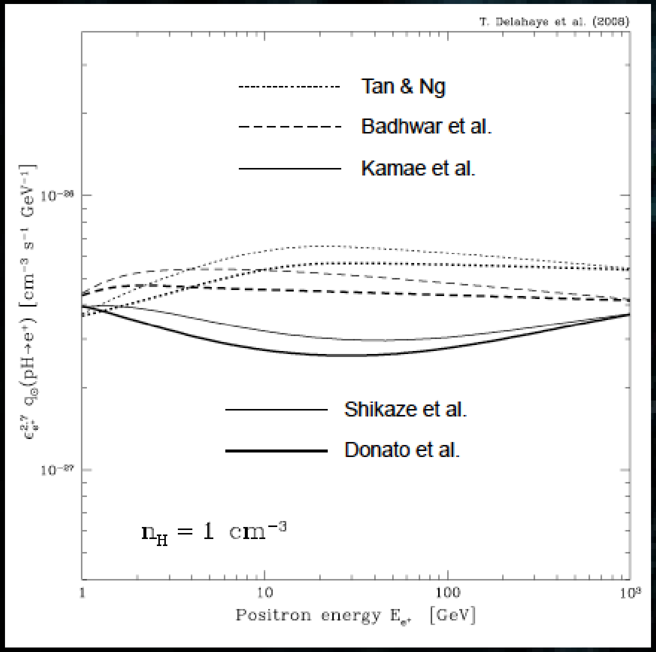
Results on secondary positron production

Delahaye et al (2008)



Lineros' PhD thesis, Delahaye's PhD thesis





Badhwar et al / Tan & Ng / Kamae et al

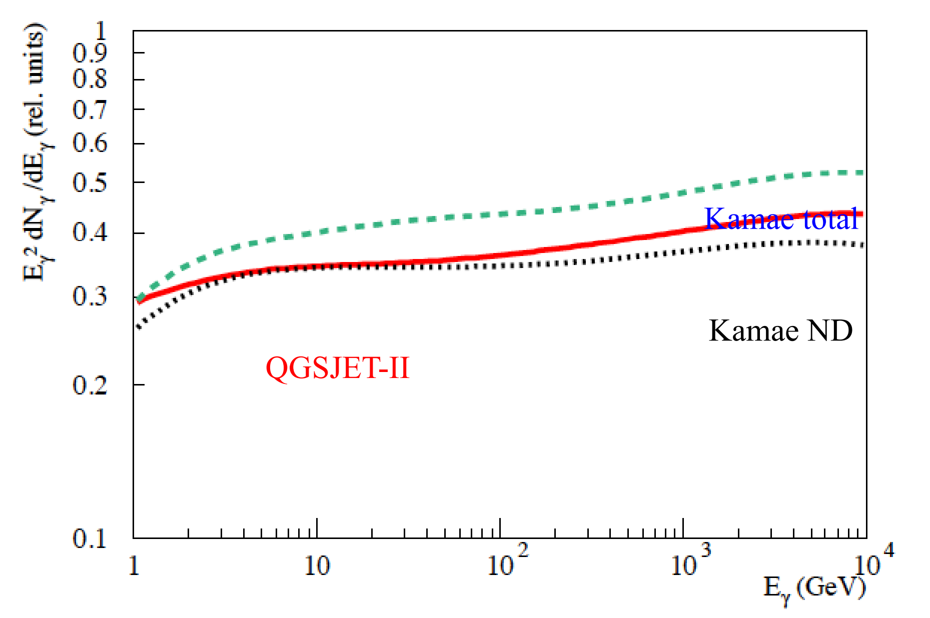
* Factor of 2 difference in amplitude
* Differences in spectral shape
* Most recent model gives lowest flux

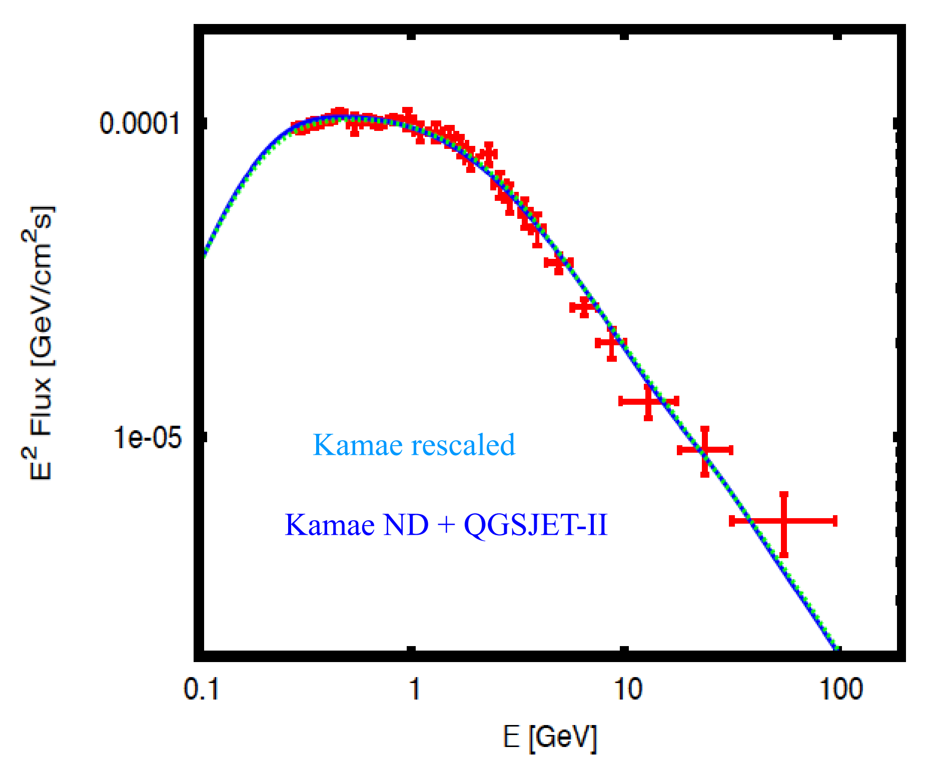
*** Badhwar et al (1977) and Tan & Ng (1983) models are somehow outdated

=> Confidence in Kamae et al (2006) ?

Caution with Kamae et al (2006)

New analysis by Kachelriess & Ostapchenko (2012) for neutral pion production (QGSJET-II + HERA and LHCdata)





* QGSJET-II valid from T > 10 GeV
* Kamae non-diffractive agrees well with data below 10 GeV
* Kamae diffractive over-simplistic (uniform distribution of energy among produced pions)
=> 20% over-estimate

** Kamae total still OK for the spectral shape, only amplitude in excess

=> Compromise: Kamae ND for T < 10 GeV + QGSJET-II for T > 10 GeV

**** Are diffractive processes included in QGSJET-II?

=> Beware of MC-based statements: all claim to reach 10% precision

Nucleus-nucleus → pions ???

Orth & Buffington (1976)

$$\sigma_{A_1 A_2} = (A_1^{3/8} + A_2^{3/8} - 1)^2 \sigma_{pp}$$

Norbury & Townsend (2007)

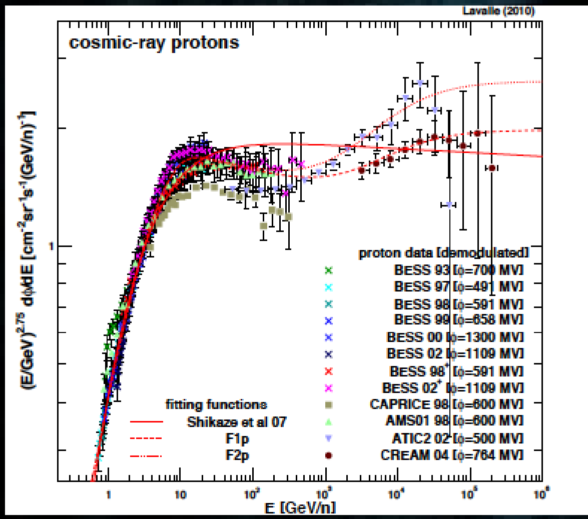
$$\mathrm{Prob(pp)} = \frac{Z_P}{A_P}\frac{Z_T}{A_T} \qquad \mathrm{Prob(nn)} = \frac{A_P - Z_P}{A_P}\frac{A_T - Z_T}{A_T}$$

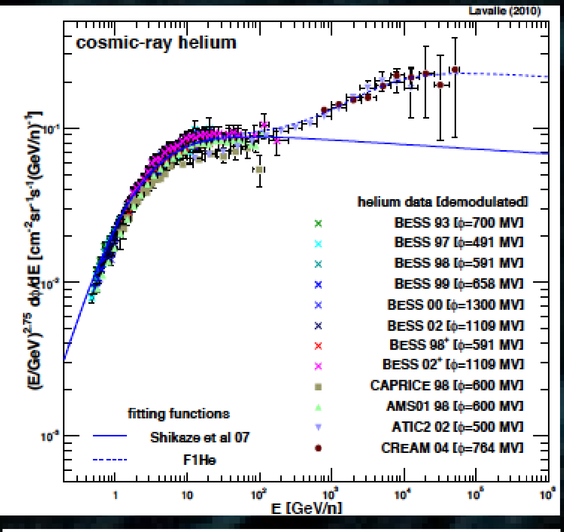
$$\frac{\sigma_{AA\to\pi^+X}}{\sigma_{AA\to\pi^-X}} = \left(\frac{Z_P}{A_P}\frac{Z_T}{A_T}\frac{\sigma_{pp\to\pi^+X}}{\sigma_{pp\to\pi^-X}}\right) + \left(\frac{A_P - Z_P}{A_P}\frac{A_T - Z_T}{A_T}\frac{\sigma_{pp\to\pi^-X}}{\sigma_{pp\to\pi^+X}}\right)$$

$$\sigma_{AA\to\pi^+X} \approx (A_P A_T)^{2/3}\sigma_{pp\to\pi^+X}$$

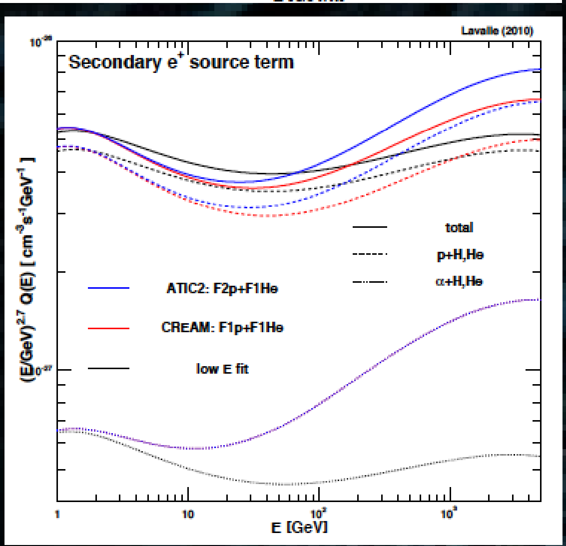
$$\sigma_{AA\to\pi^-X} = \frac{(A_P A_T)^{2/3}\sigma_{pp\to\pi^+X}}{\left(\frac{Z_P}{A_P}\frac{Z_T}{A_T}\frac{\sigma_{pp\to\pi^+X}}{\sigma_{pp\to\pi^-X}}\right) + \left(\frac{A_P - Z_P}{A_P}\frac{A_T - Z_T}{A_T}\frac{\sigma_{pp\to\pi^-X}}{\sigma_{pp\to\pi^+X}}\right)}$$

2/3 → 2.2/3 gives better fits





p+alpha fluxes
+++
H+Helium gas



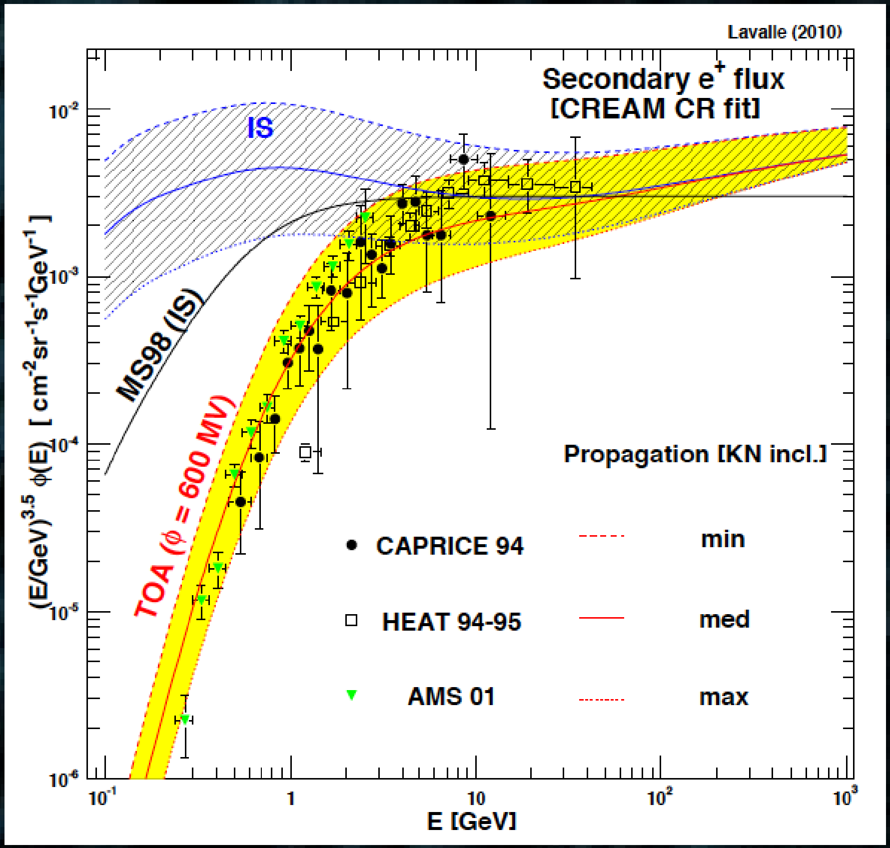
Ex. of proton+Helium:

O&B = 3^(3/4) = 2.28
N & T = 3^(2.2/3) = 2.24

Including CR alpha's and He gas
=> 20% correction

Heavier species < 10% if scaling relation valid

Comparison with transport uncertainties



Conclusions:

* Error on production cross section ~ 20%
(amplitude more affected than spectrum)
* Larger if scaling for nuclei fails < 20%

* to compare with error on ISM and GCR densities

* Transport parameters => factor of 2 unc.

Pion/kaon production and decay to e+/- In Galprop

Manual of Galprop v54
http://galprop.stanford.edu/code.php?option=manual

2.1.6 Secondary positrons and electrons

Secondary positrons and electrons in cosmic rays are the final product of decay of charged pions and kaons which in turn created in collisions of cosmic-ray particles with gas. Pion production in *pp*-collisions is considered following a method developed by Dermer (1986a,b), which combines isobaric (Stecker, 1970) and scaling (Badhwar et al., 1977; Stephens & Badhwar, 1981) models of the reaction. Secondary positron and electron production is computed as described in Moskalenko & Strong (1998), that includes a critical reevaluation of the charged pion and kaon decay calculations. Primary electrons are computed in the same propagation model.

Nota: nHe/nH = 0.11 in Galprop
(We have also taken nHe/nH = 0.11, nH=0.9/cm3, nHe=0.1/cm3)

Alice @ LHC

arXiv:1101.4110