# Common Solution Of Three Cosmic Puzzles ?*

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* Origin of :

The high energy cosmic ray positrons (PAMELA, Fermi-LAT, AMS)

The high energy gamma ray background radiation (EGRET, Fermi-LAT)

The high energy astronomical neutrinos (IceCube)

In collaboration with Shlomo dado

**Production of of High Energy Gamma Rays, Neutrinos and Positrons of Energy E<10 PeV, in Source, in the ISM and in the IGM, is mainly by Cosmic Rays of typical energy :**

$$pp \to \pi^0 X, \quad \pi^0 \to 2\gamma \qquad E_p \cong \langle E_\gamma \rangle / (\langle x_\pi \rangle / 2) \sim 10\, E_\gamma$$

$$pp \to \pi^+ X, \quad \pi^+ \to \mu^+ \nu_\mu \to e^+ \nu_e \bar{\nu}_e \nu_\mu \qquad E_p \cong \langle E_l \rangle / (\langle x_\pi \rangle / 4) \sim 20\, E_l$$

$$pp \to \pi^- X, \quad \pi^- \to \mu^- \bar{\nu}_\mu \to e^- \nu_e \bar{\nu}_e \bar{\nu}_\mu \qquad E_p \cong \langle E_l \rangle / (\langle x_\pi \rangle / 4) \sim 20\, E_l$$

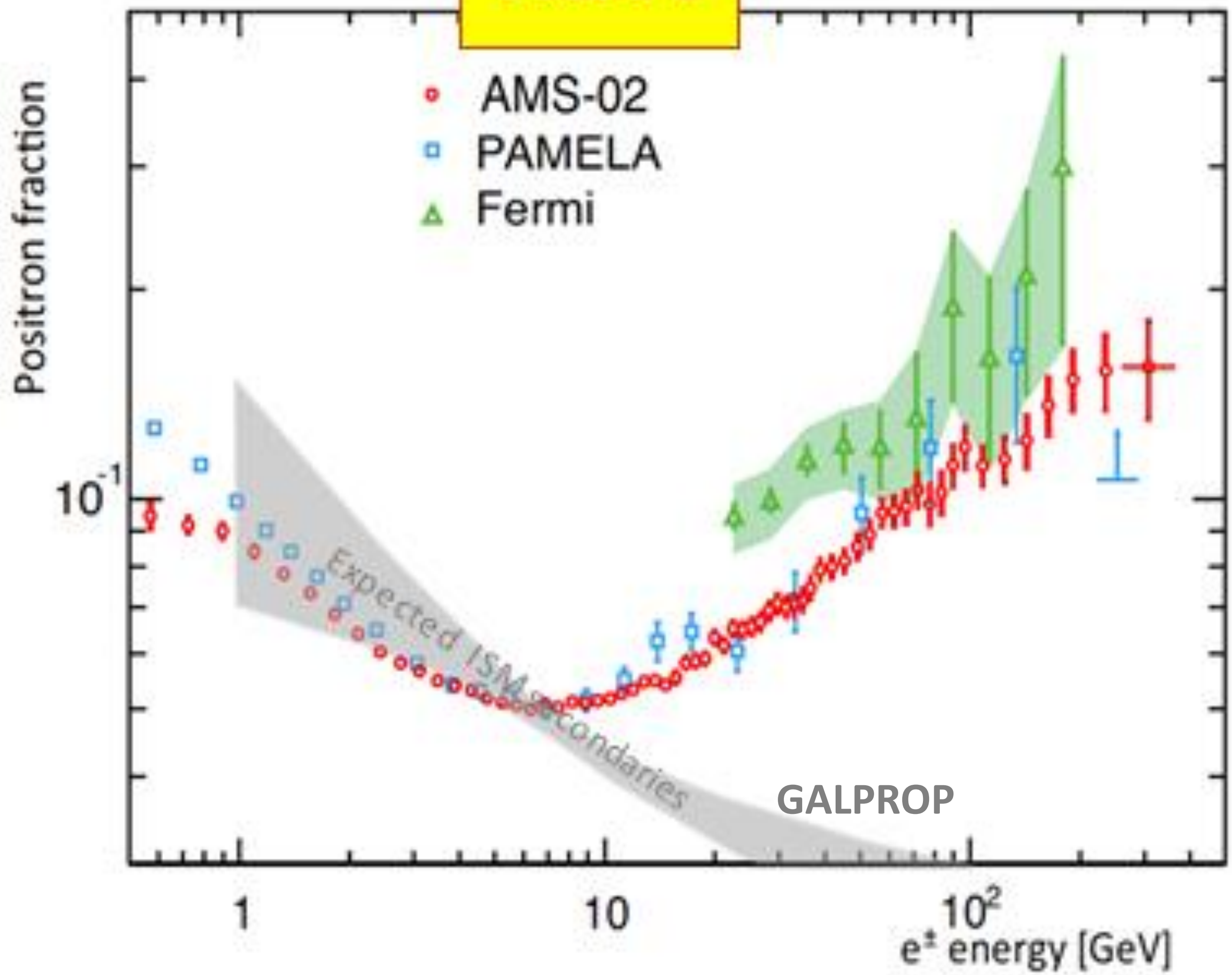
→ **Unique relations between the cosmic fluxes of** $\gamma$, $\nu$, and $e^+$

**hadronic meson production is taken over by photo meson production only at very high energies**

**GZK (1966):** $p + \gamma_{BKG} \to \pi X$

| BKG = | DGL | + | FIR | + | CMB |
|---|---|---|---|---|---|
| **Effective Threshold:** | **25 PeV** | | **4 EeV** | | **40 EeV** |

# Puzzle 1


AMS-02
PAMELA
Fermi
Positron fraction
$10^{-1}$
Expected ISM secondaries
GALPROP
1
10
$10^2$
e± energy [GeV]

# Positron Production In The Local ISM By High Energy Primary Cosmic Ray Nucleons

Model: Steady State Leaky Box Model + Fynman Scaling

$$pp \to \mu^+ X \qquad \mu^+ \to e^+ \nu_e \bar{\nu}_\mu \qquad <E(e^+)> \cong E(\mu^+)/3$$

$$\left[ \frac{d}{dE}\left[b(E)\Phi_{e+}\right] = J_{e+}(E) \right] \qquad b(E) = \frac{dE}{dt}$$

$$\left[ J_{e+}(E) \approx K_{e+}(\beta_j)\, \sigma_{in}(pp)\, c\ n_{ISM}\ \Phi_p(E) \right] \propto E^{-\beta_j}$$

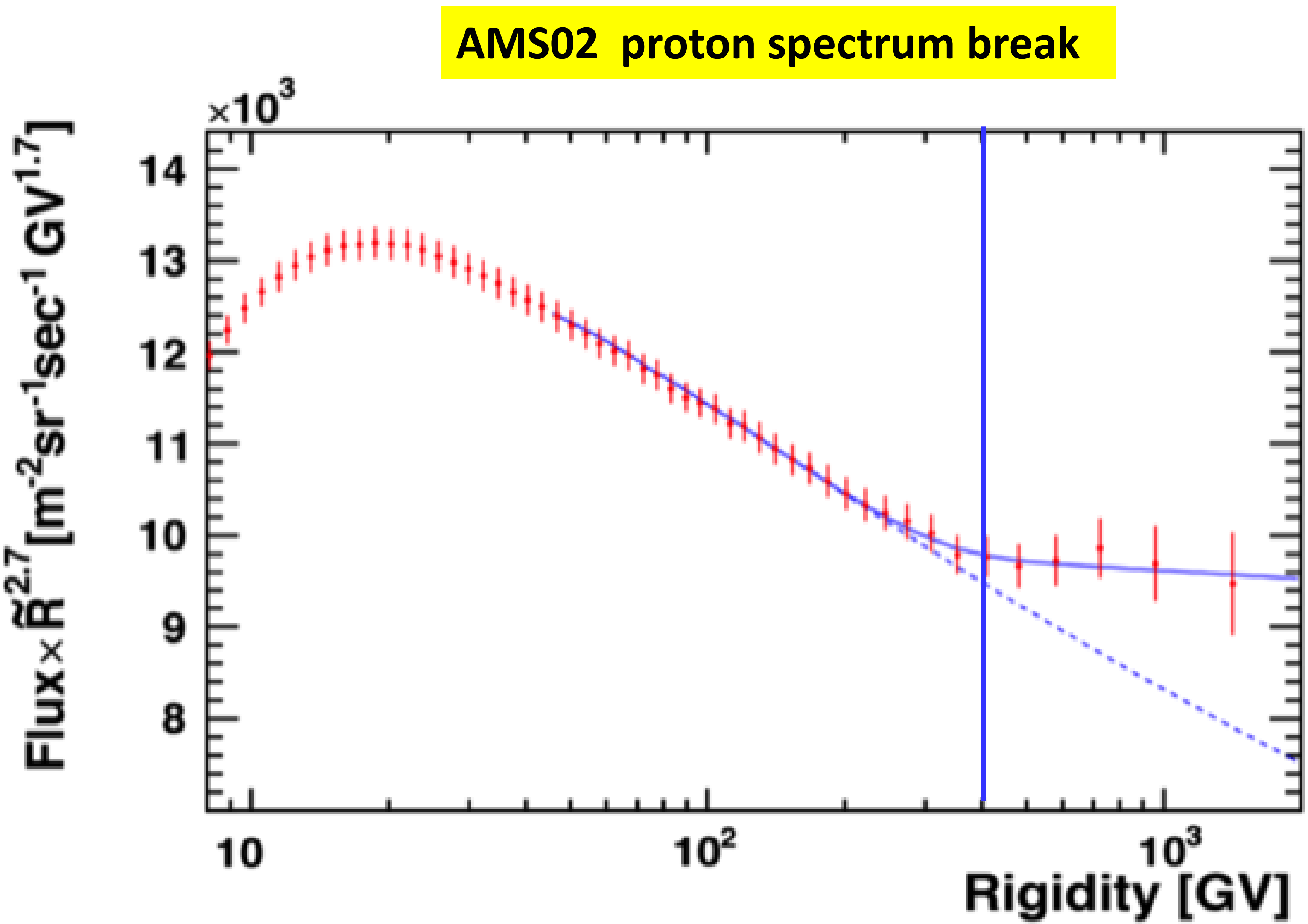
$$\Rightarrow \qquad \Phi_{e+} = \frac{J_{e+}(E)\, \tau_{e+}}{(\beta_j - 1)} \qquad \text{where} \quad \tau_{e+} \equiv E/(dE/dt) = E/b(E)$$

$$\Phi_p(E) \approx 1.8\ (E/GeV)^{-2.7}\ \ [1/GeV\ cm^2\ sr\ s] \quad \text{for} \quad E < PeV \quad (\text{PDG 2014})$$

$$\sigma_{in}(pp) \approx 30\ (E/GeV)^{0.058}\ mb; \qquad \beta_j = 2.64 \to K_{e+}(\beta_j) \approx 7\times 10^{-3}$$

Local $n_{ISM} = 0.9\ cm^{-3}$ (Calberla and Dedes 2008)

$$1/\tau_{e+} = 1/\tau_{rad} + 1/\tau_{esc}$$



AMS02 proton spectrum break
×10^3
14
13
12
11
10
9
8
Flux × R̃^2.7 [m^-2 sr^-1 sec^-1 GV^1.7]
10
10^2
10^3
Rigidity [GV]

**Kolmogorov (1941), … CR Be10 / Be9 ratio → … ,… Lipari(2014):**

$$t_{dif} = \frac{R^2}{2D} \approx 7.5\times10^{14}\left(\frac{R}{4\text{ kpc}}\right)^2\left(\frac{E}{\text{GeV}}\right)^{-1/3}\ \text{s}$$

In the Thomson regime:

$$\tau_{rad} = \frac{3(m_e c^2)^2}{4\sigma_T cUE} \approx 10^{16}\left(\frac{U}{\text{eV/cm}^3}\right)^{-1}\left(\frac{E}{\text{GeV}}\right)^{-1}\ \text{s}$$

$$U = U_{DGL} + U_{FIR} + U_{CBR} + B^2/8\pi$$

**Porter, Moskalenko and Strong 2006**

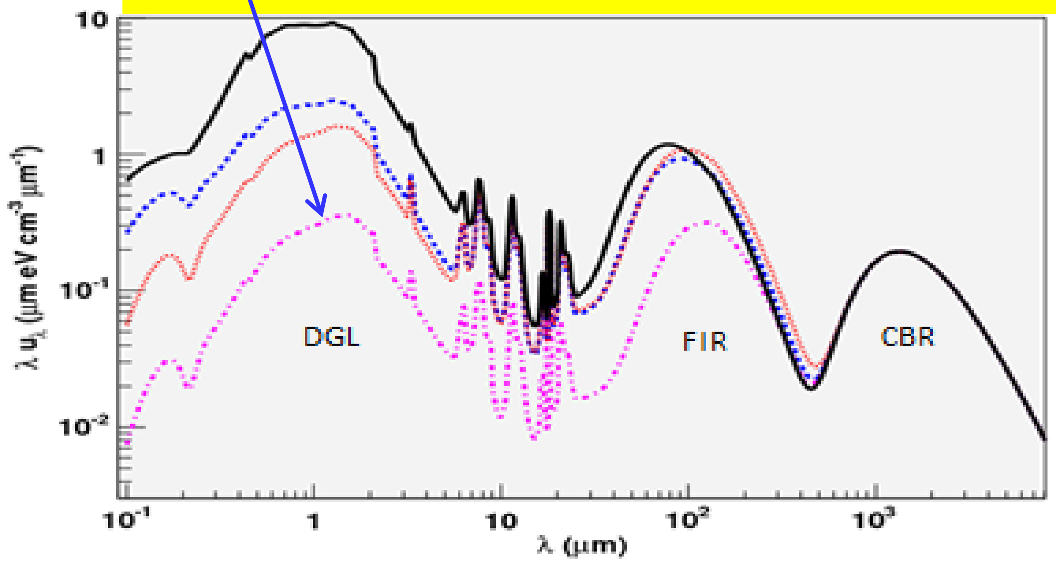
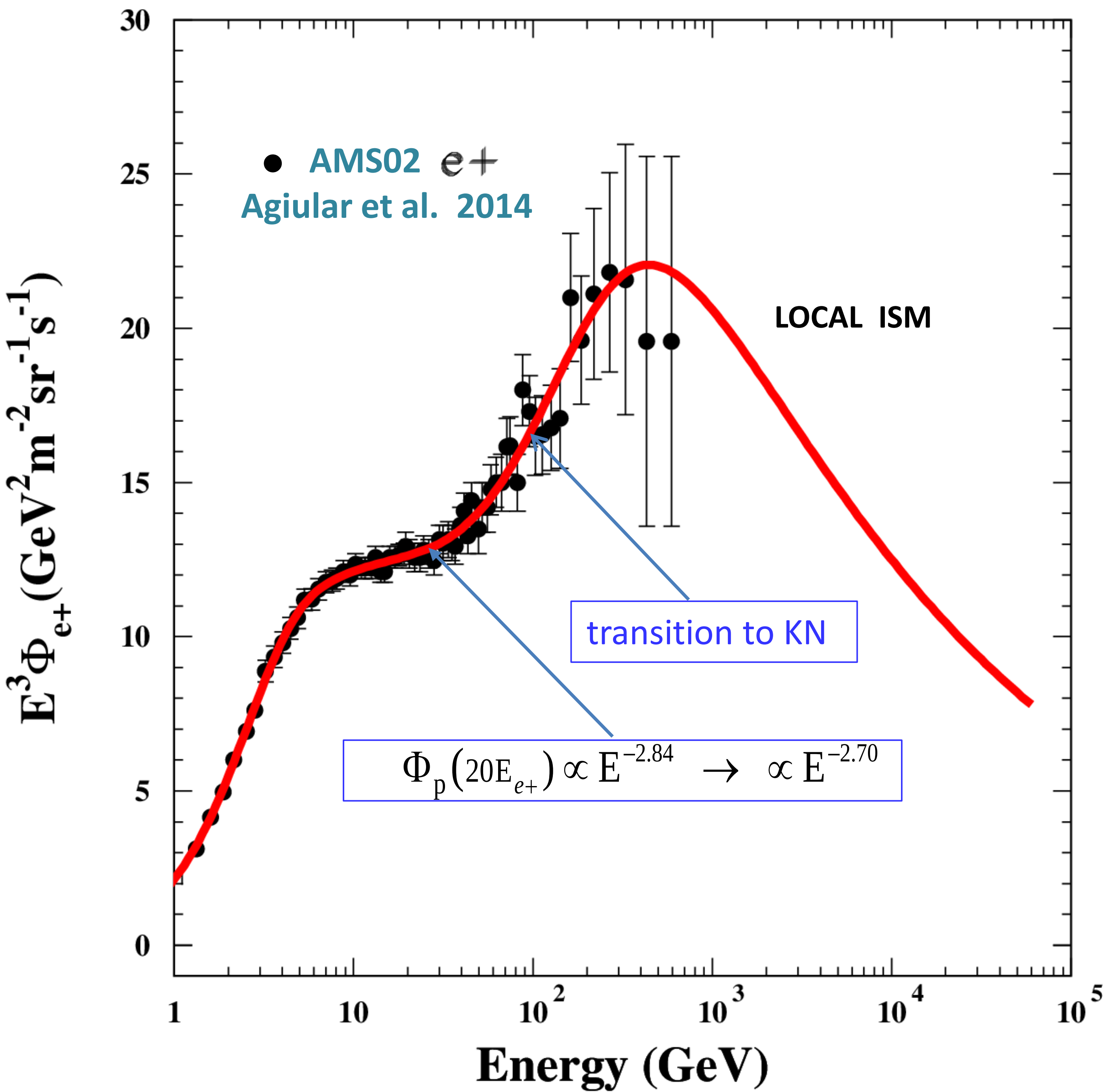


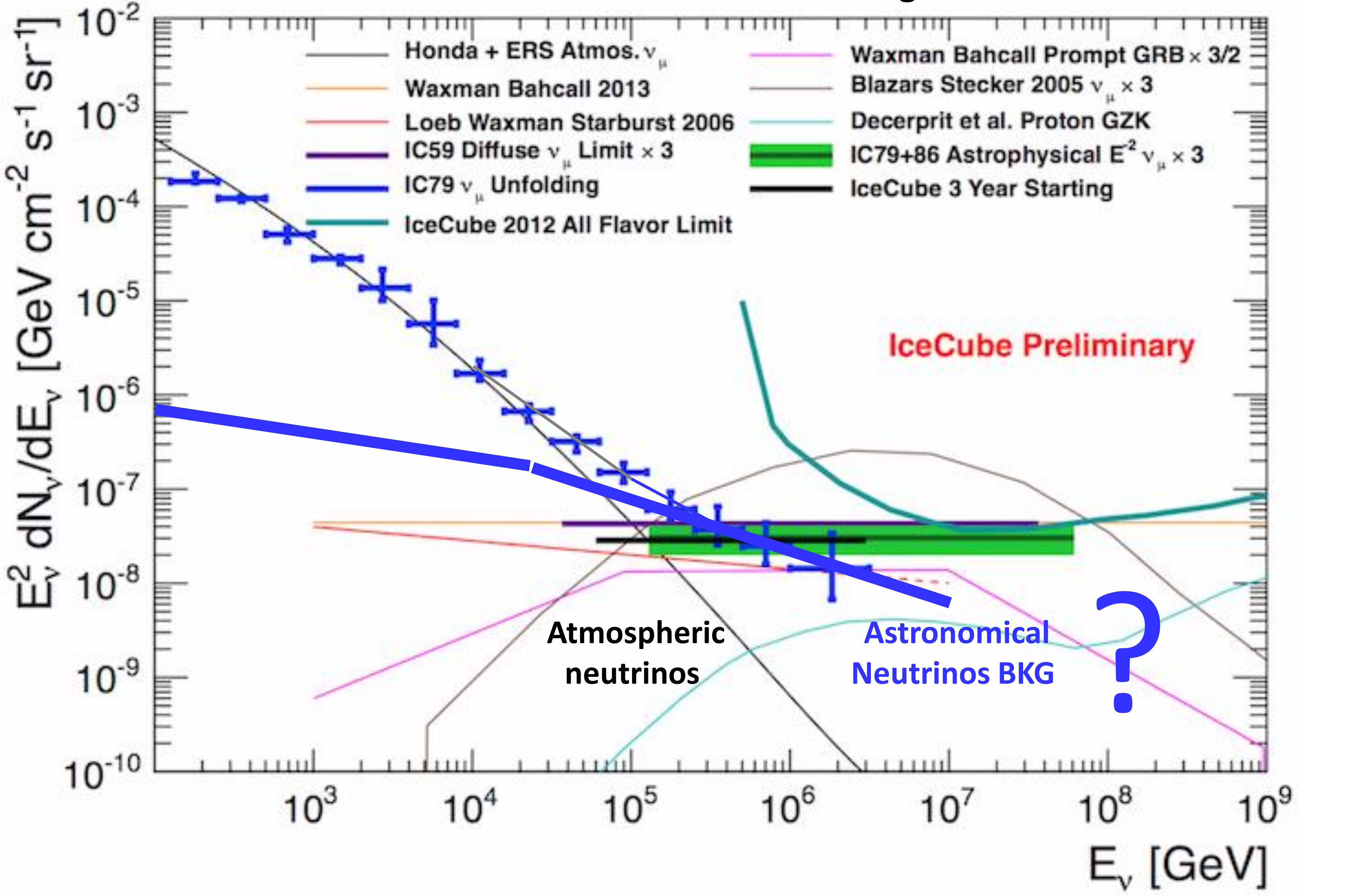

FIG. 1.— Interstellar radiation field energy density: soli
$R = 0$ kpc, $z = 0$ kpc; dashed line, $R = 3$ kpc, $z = -0.05$
dotted line, $R = 4$ kpc, $z = 0$ kpc; dash-dotted line, $R = 7.5$
$z = 0$ kpc.



AMS02 e+
Agiular et al. 2014
LOCAL ISM
transition to KN
$\Phi_p(20E_{e+}) \propto E^{-2.84} \rightarrow \propto E^{-2.70}$
$E^3\Phi_{e+}(GeV^2m^{-2}sr^{-1}s^{-1})$
Energy (GeV)

# Puzzle 2

## IceCube Astronomical Neutrino Background



**Hadronic production by cosmic ray nucleons yields:**

$$\left[\Phi_\nu(E)=(K_\nu/K_\gamma)\,\Phi_\gamma(E)\right]$$

$$K_\nu/K_\gamma \geq (m_{\pi^\pm}/2\,m_{\pi^0})^{\beta_j-1} \qquad (+K\ \text{decay}+\ldots$$

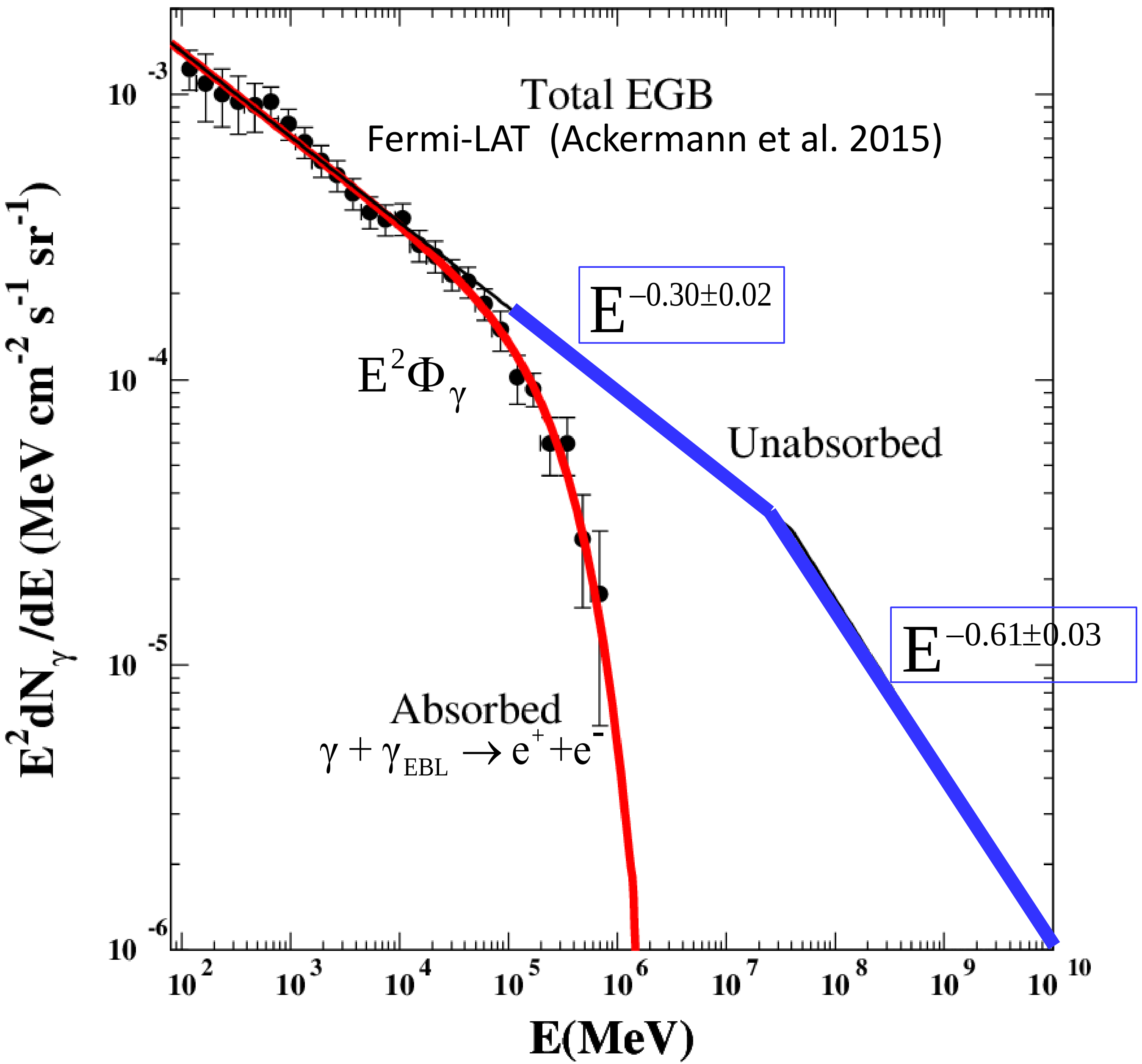
**which cannot be tested directly :**

**The EGB** $\Phi_\gamma(E)$ **observed with Fermi-LAT (at E< 820 GeV ) is attenuated by** $\gamma+\gamma_{BKG}\rightarrow e^+ + e^-$

**The IceCube** $\Phi_\nu(E)$ **observed at E>50 TeV**

But, $\Phi_\nu(E)$ obtained from the observed EGB and GBR at E~100 GeV can be extrapolated to E>20 TeV using $\Phi_\nu(E)\propto\Phi_p(20<1+z>E)$ **at source**

# The Extragalactic Gamma Ray Background (EGB)



# The Extragalactic Neutrino Background (ENB)

**Ackermann et al. 2015: Absorbed EGB:**

$$\Phi_\gamma(\mathrm{EGB}) \approx \left[\left(6.4\times10^{-7}\left(\mathrm{E/GeV}\right)^{-2.30}\right]e^{-\mathrm{E/366\,GeV}}\ \mathrm{fu}$$

**Estimated Unabsorbed EGB**

$\Rightarrow$ per $\nu$ flavor and E< 20 TeV:

$$\Phi_\nu(\mathrm{EGB}) \approx 0.64\,\Phi_\gamma(\mathrm{EGB}) \approx 4.1\times10^{-7}\left(\mathrm{E/GeV}\right)^{-2.30}\ \mathrm{fu}$$

where $\mathrm{fu}=\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ is the flux unit

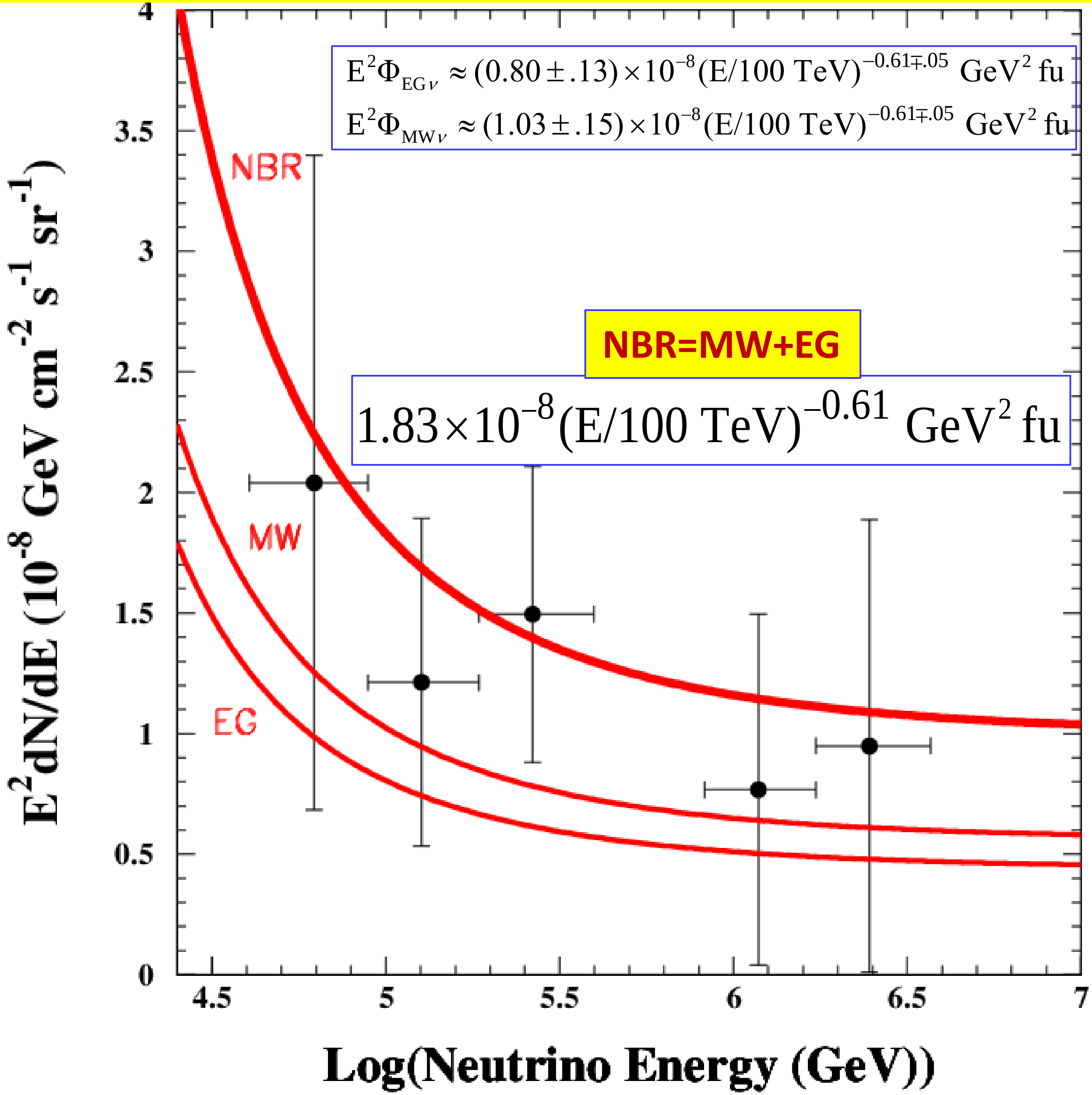
**For a universal CR flux,** $\Phi_\nu(\mathrm{E}) \propto \Phi_p(20 <1+z> \mathrm{E})$

**max SFR/AGN around 1+z=2.5 ==> knee around 20 TeV,**

$\Rightarrow$ per $\nu$ flavor and E> 20 TeV:

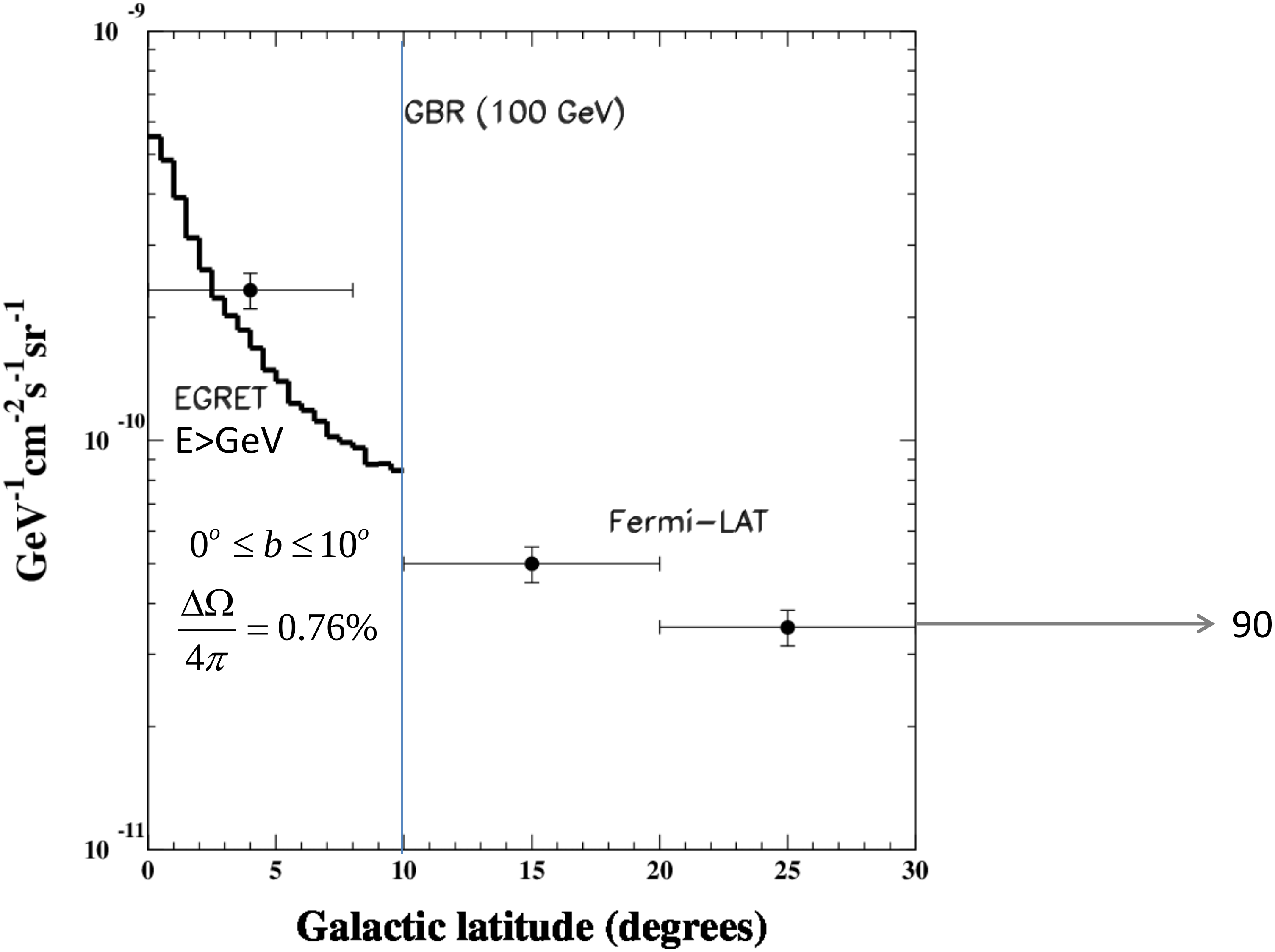
$$\mathrm{E}^2\Phi_\nu(\mathrm{EGB}) \approx 0.80\times10^{-8}\left(\mathrm{E/100\,TeV}\right)^{-0.61}\ \mathrm{GeV}^2\mathrm{fu}$$

# Expected NBR from the measured GBR with Fermi-LAT compared to the NBR measured with IceCube (2014)




$E^2\Phi_{MW\nu}$ From $E^2\Phi_{MW\gamma}$ at 100 GeV (Fermi-LAT) or 1 TeV (H.E.S.S).

**The predicted sky distribution of the neutrino background radiation is the sky distribution of the HE unabsorbed gamma background radiation, i.e., roughly that of the GBR at 100 GeV**



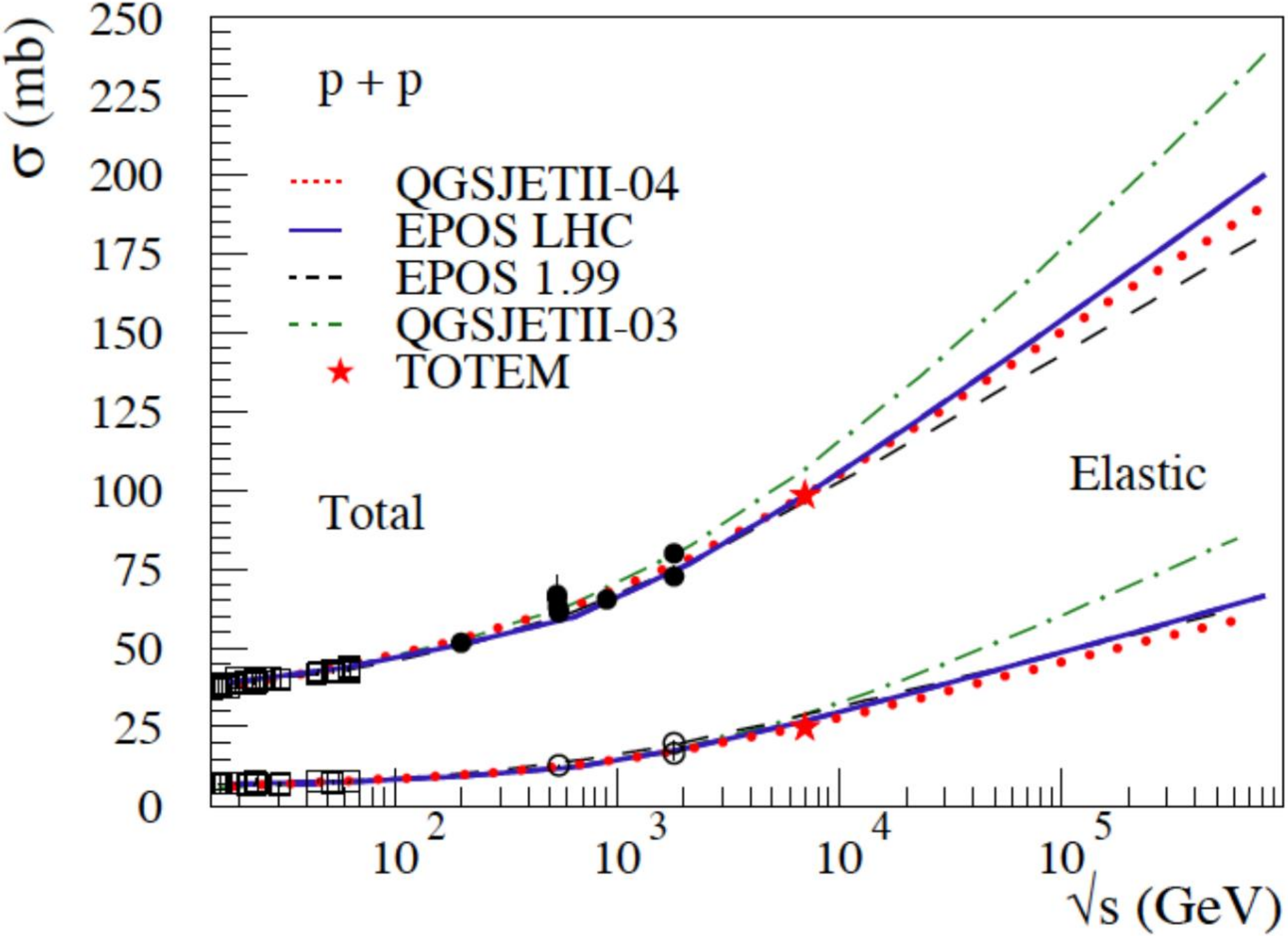
# Conclusions

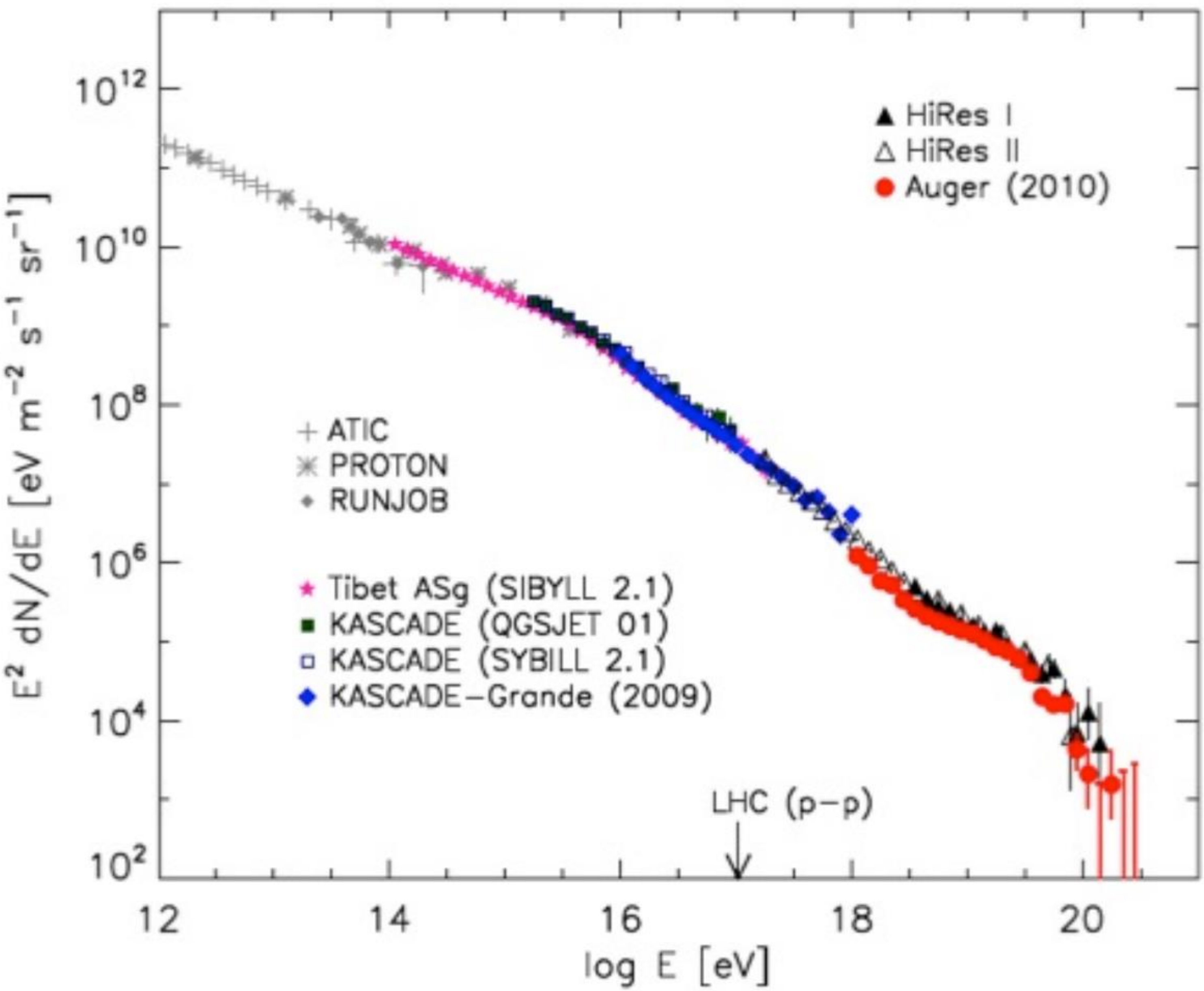
**The observed fluxes, spectra, and sky distributions of the high energy diffuse backgrounds of astronomical** $\gamma$'s and $\nu$'s, and the CR $e^+$'s observed near Earth, **satisfy simple relations, which are expected from their common production in high energy hadronic collisions of cosmic rays in their Galactic and extragalactic sources.**

**Their observed spectra indicate:**

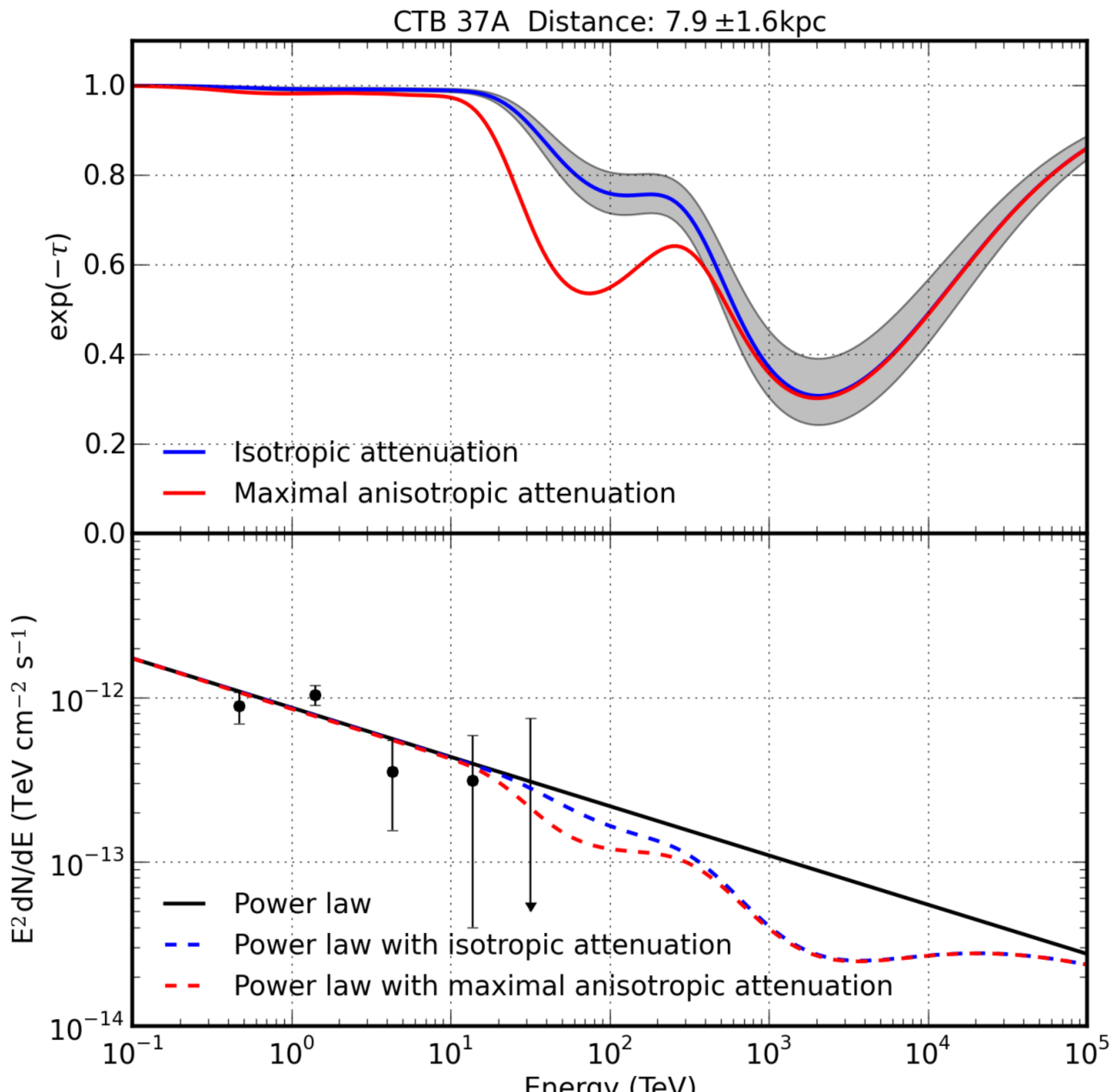
**The** $e^+$'s **observed near Earth are produced in the local ISM.**

**The high energy** $\gamma$'s and $\nu$'s **are produced inside/near source**

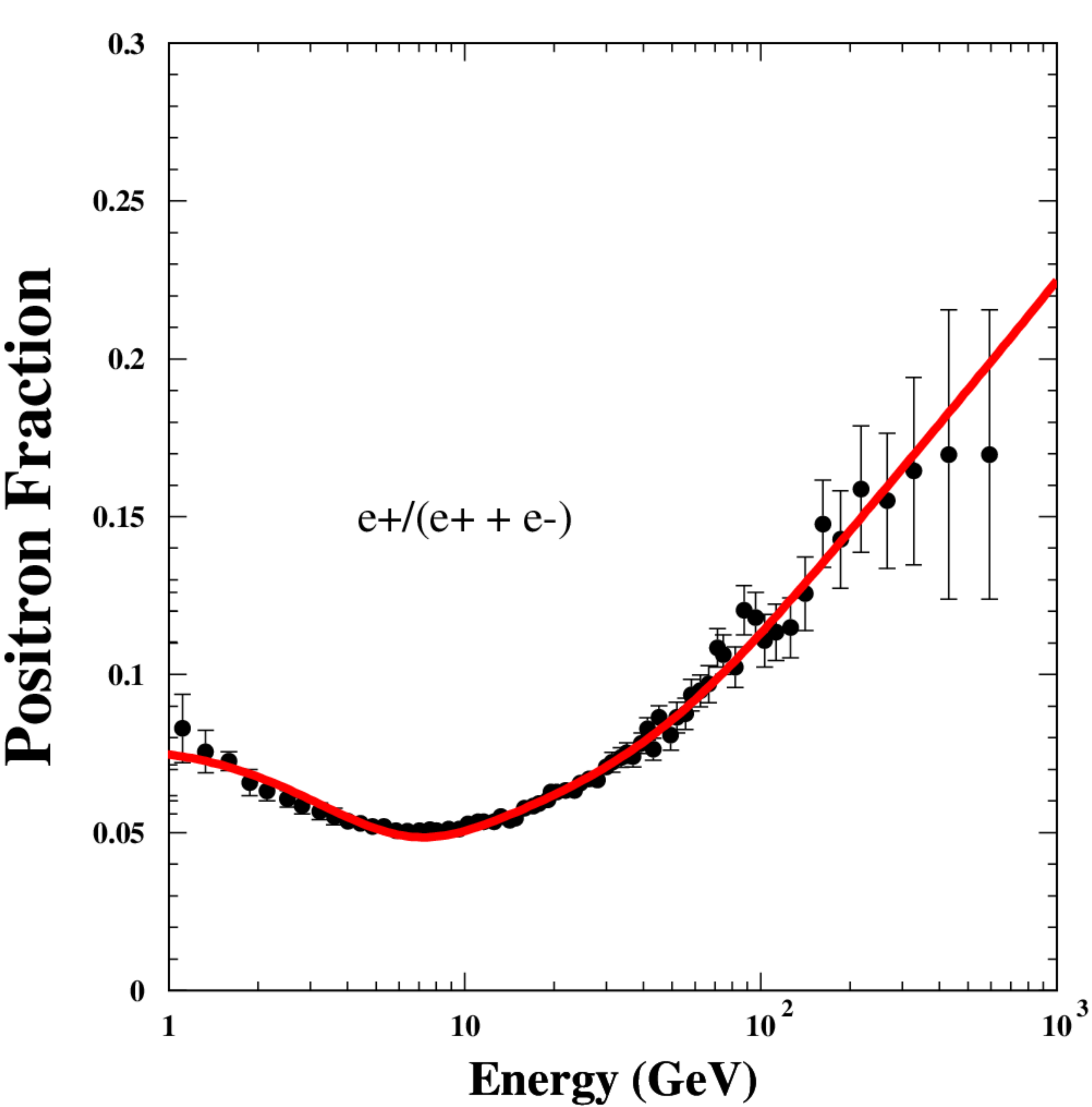

σ (mb)
250
225
200
175
150
125
100
75
50
25
0
p + p
QGSJETII-04
EPOS LHC
EPOS 1.99
QGSJETII-03
TOTEM
Total
Elastic
10^2
10^3
10^4
10^5
√s (GeV)



E² dN/dE [eV m⁻² s⁻¹ sr⁻¹]
log E [eV]
HiRes I
HiRes II
Auger (2010)
ATIC
PROTON
RUNJOB
Tibet ASg (SIBYLL 2.1)
KASCADE (QGSJET 01)
KASCADE (SYBILL 2.1)
KASCADE-Grande (2009)
LHC (p-p)



CTB 37A Distance: 7.9 ±1.6kpc
exp(−τ)
1.0
0.8
0.6
0.4
0.2
0.0
Isotropic attenuation
Maximal anisotropic attenuation
E²dN/dE (TeV cm⁻² s⁻¹)
10⁻¹²
10⁻¹³
10⁻¹⁴
Power law
Power law with isotropic attenuation
Power law with maximal anisotropic attenuation
10⁻¹
10⁰
10¹
10²
10³
10⁴
10⁵
Energy (TeV)



Positron Fraction
e+/(e+ + e-)
Energy (GeV)
0
0.05
0.1
0.15
0.2
0.25
0.3
1
10
10 2
10 3