Common Solution Of Three Cosmic Puzzles ?*

Arnon Dar

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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 :

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

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

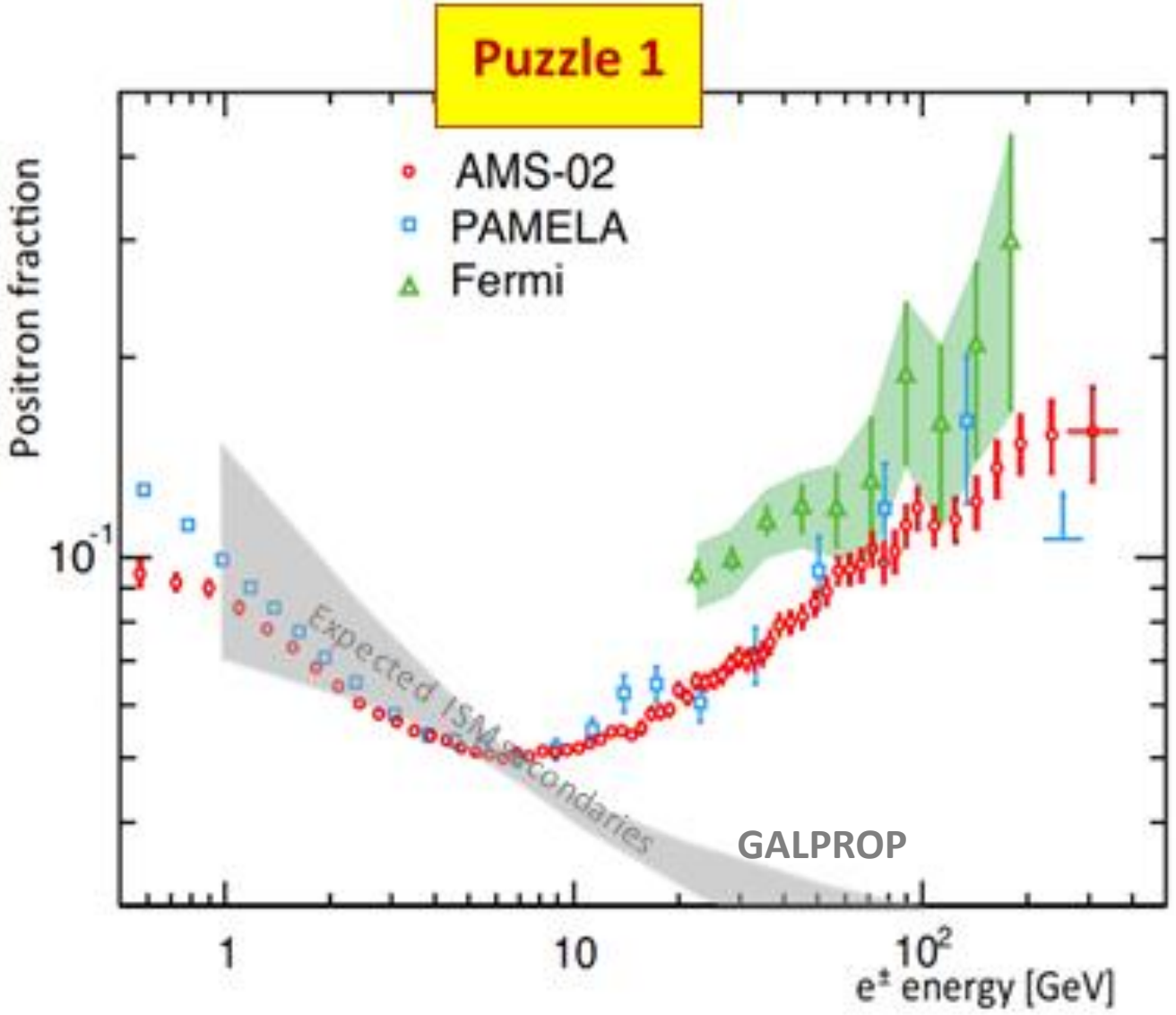
$$pp \to \pi^- X, \quad \pi^- \to \mu^- \bar{\nu}_\mu \to e^- \nu_e \bar{\nu}_e \bar{\nu}_\mu \qquad E_p \cong \langle E_l \rangle / (\langle x_\pi \rangle / 4) \sim 20\, E_l$$

➔ **Unique relations between the cosmic fluxes of γ, ν, 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
$e^{\pm}$ energy [GeV]

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

Model: Steady State Leaky Box Model + Fynman Scaling

$$pp \rightarrow \mu^+ X \qquad \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \qquad \langle E(e^+) \rangle \cong E(\mu^+)/3$$

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

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

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

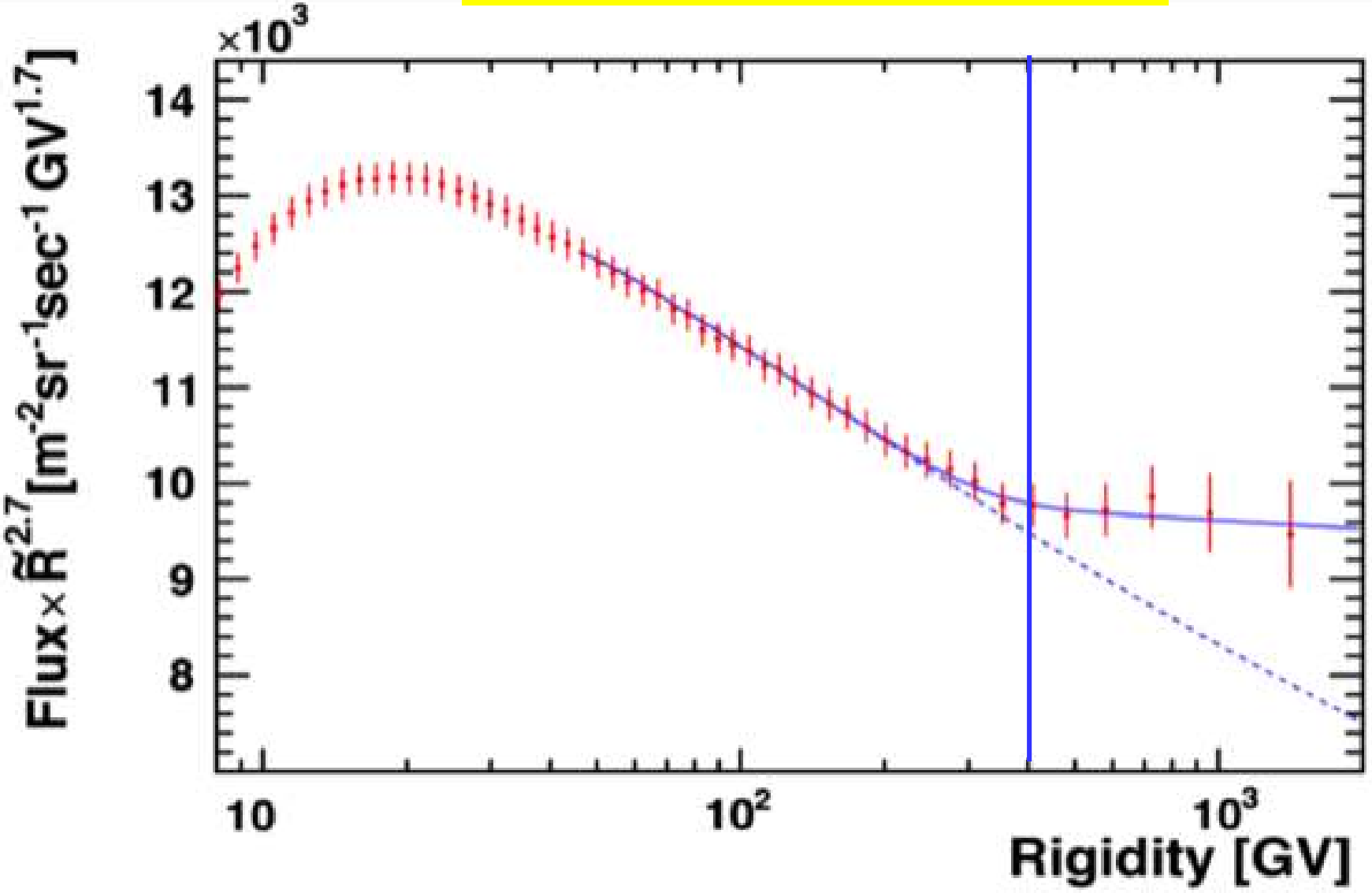
$\Phi_p(E) \approx 1.8\ (E/\mathrm{GeV})^{-2.7}$ [1/GeV cm^2 sr s] for E<PeV (PDG 2014)

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

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

$$\left[1/\tau_{e+} = 1/\tau_{rad} + 1/\tau_{esc} \right]$$

AMS02 proton spectrum break



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

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

In the Thomson regime:

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

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

Porter, Moskalenko and Strong 2006

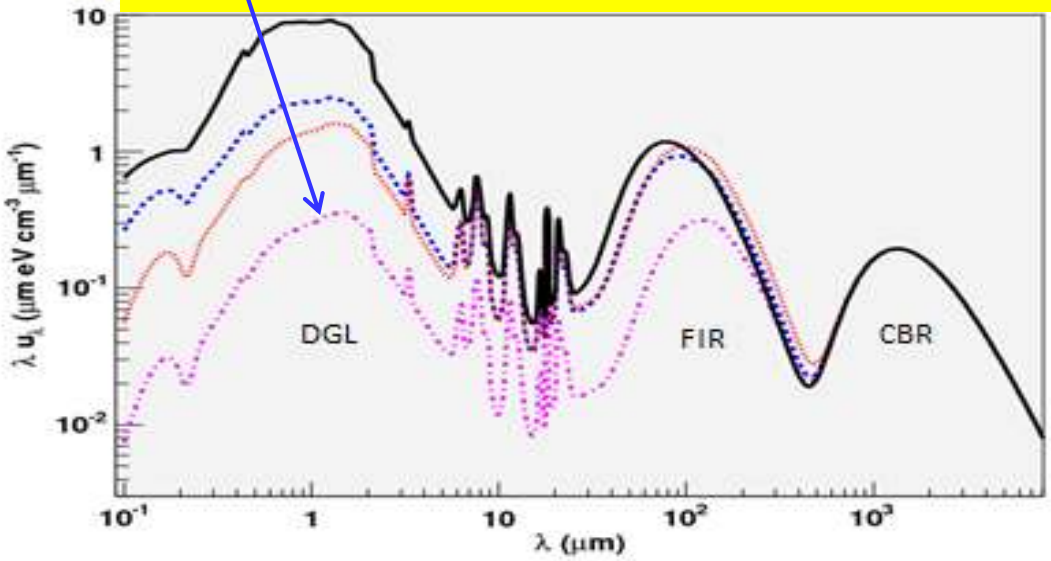
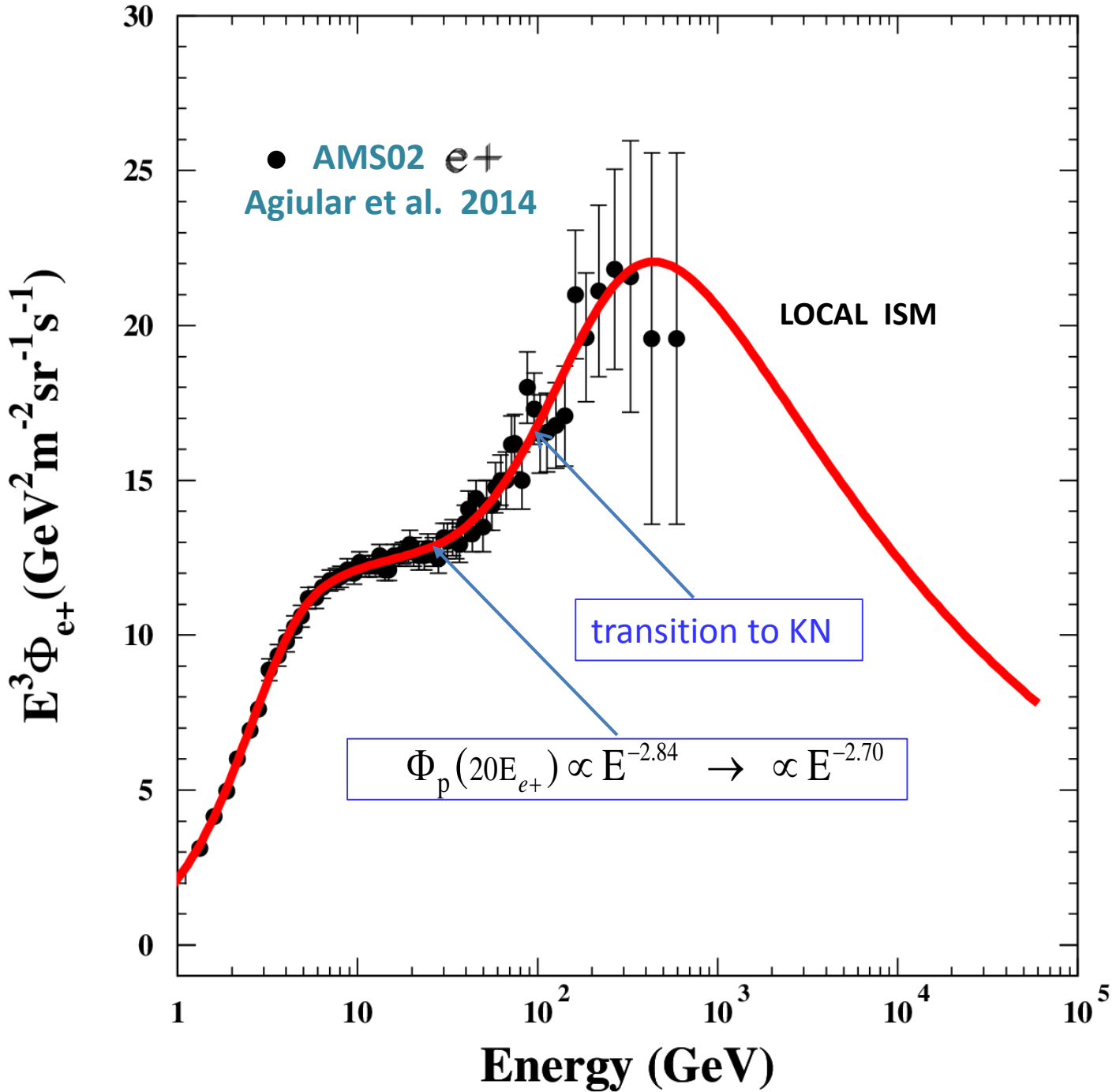
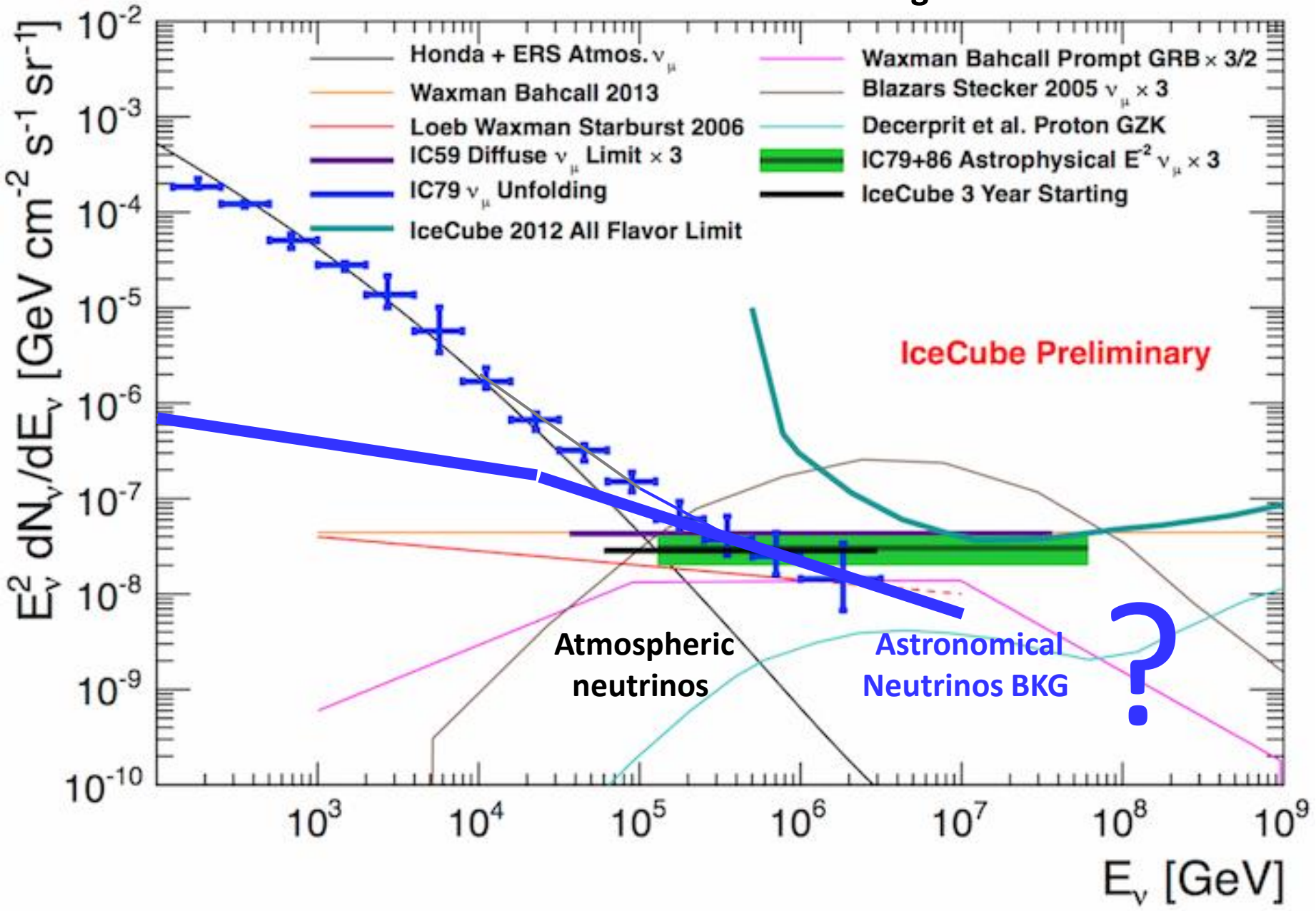


FIG. 1.— Interstellar radiation field energy density: soli
$R = 0$ kpc, $z = 0$ kpc; dashed line, $R = 3$ kpc, $z = -0.05$
dotted line, $R = 4$ kpc, $z = 0$ kpc; dash-dotted line, $R = 7.5$
$z = 0$ kpc.


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)
0
5
10
15
20
25
30
1
10
10^2
10^3
10^4
10^5

Puzzle 2

IceCube Astronomical Neutrino Background



Hadronic production by cosmic ray nucleons yields:

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

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

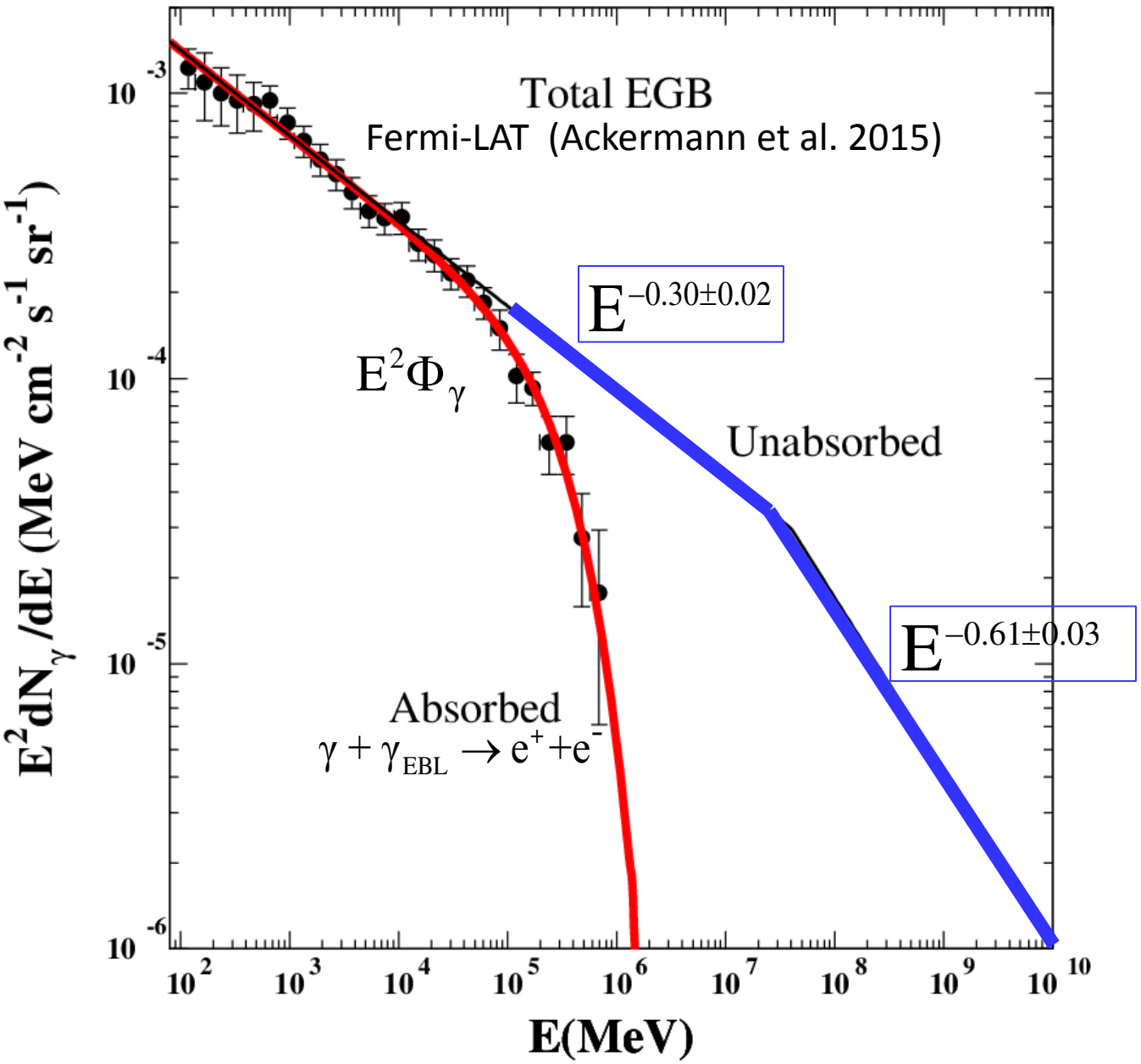
which cannot be tested directly :

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:

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

Estimated Unabsorbed EGB

$$\Rightarrow \text{per } \nu \text{ flavor and } \mathrm{E} < 20 \text{ TeV:}$$

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

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

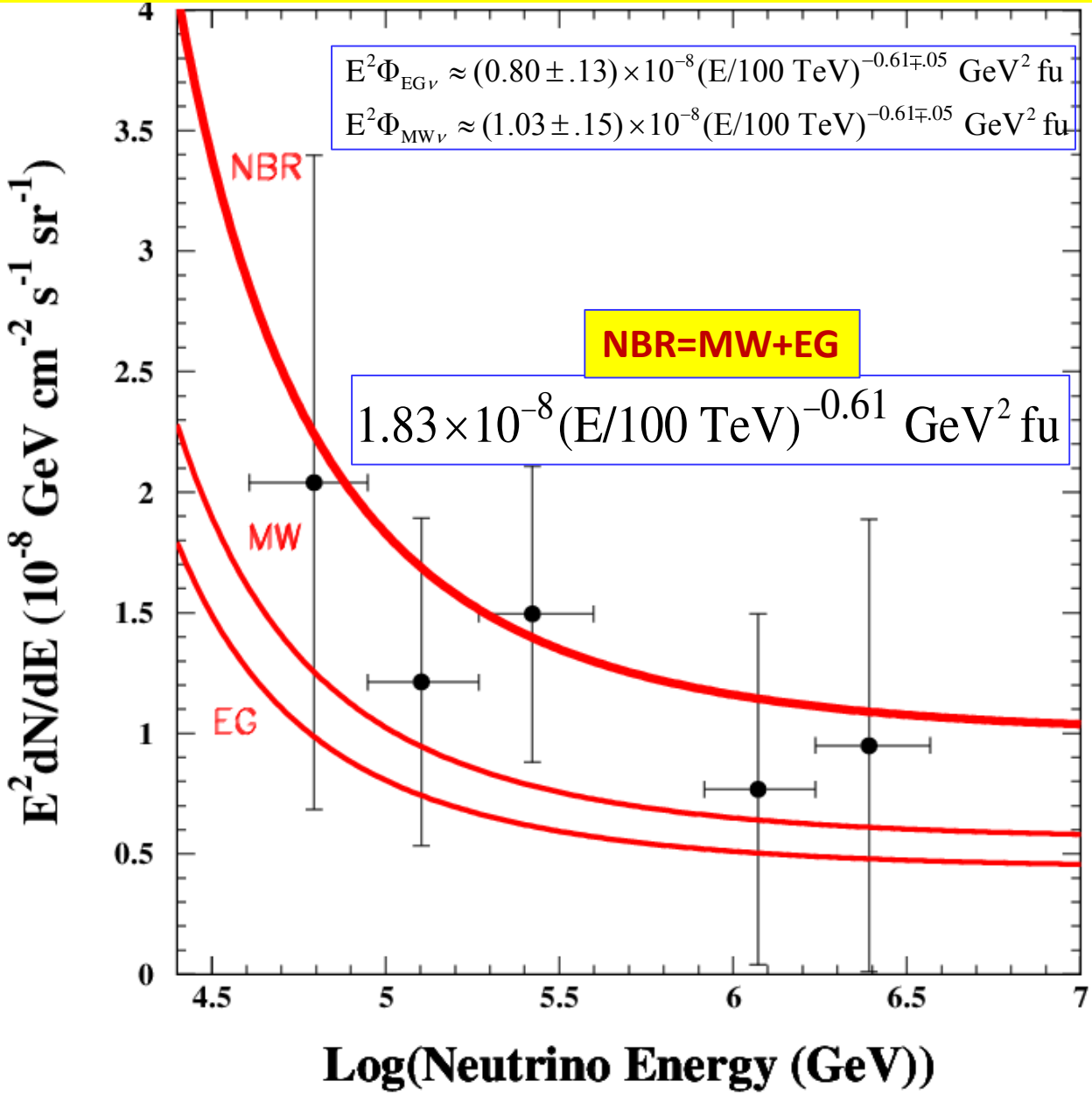
For a universal CR flux, $\Phi_\nu(\mathrm{E}) \propto \Phi_p(20 \langle 1+z \rangle \mathrm{E})$

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

$$\Rightarrow \text{per } \nu \text{ flavor and } \mathrm{E} > 20 \text{ TeV:}$$

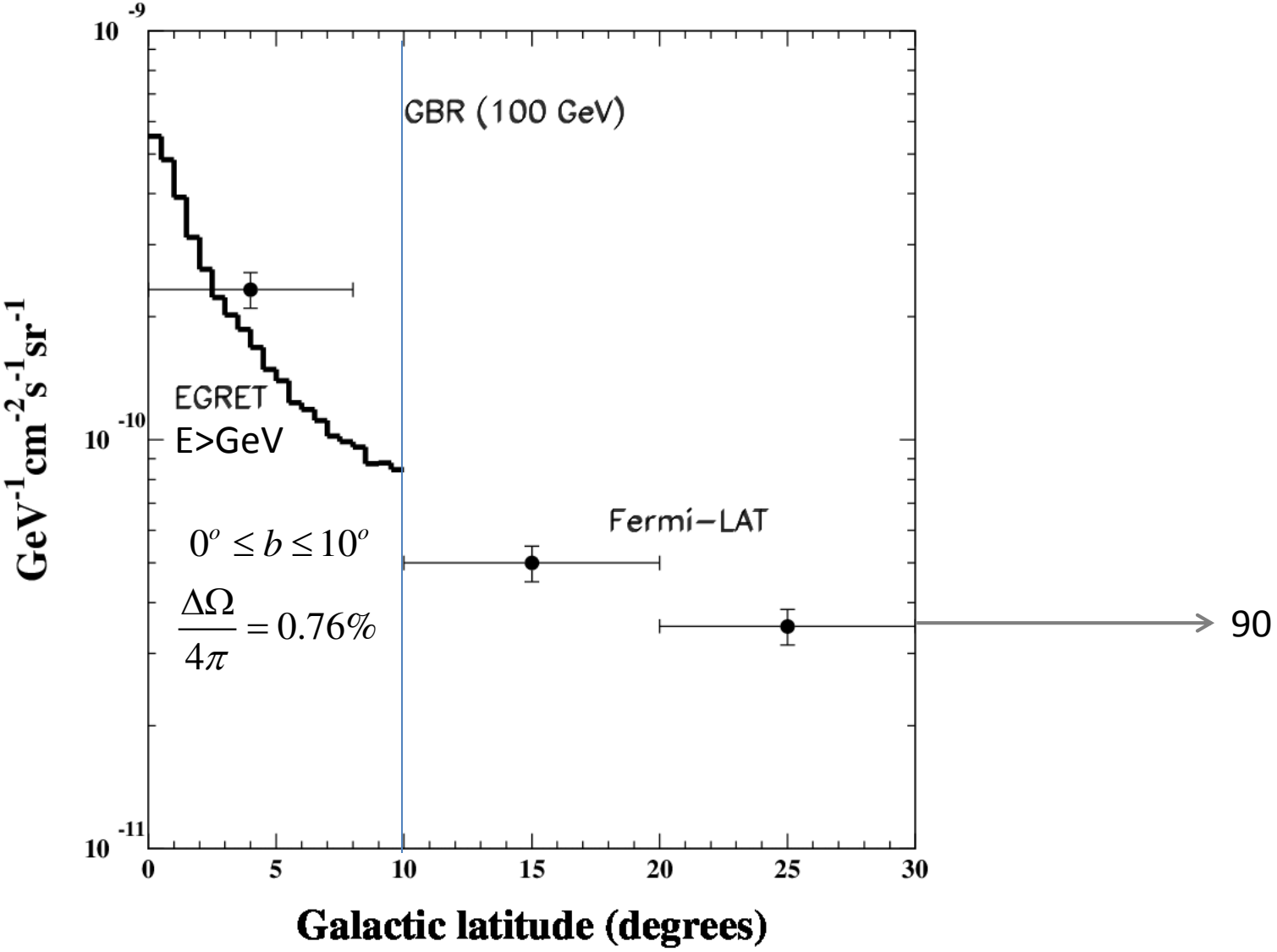
$$\boxed{\mathrm{E}^2\Phi_\nu(\mathrm{EGB}) \approx 0.80\times10^{-8} (\mathrm{E/100\ TeV})^{-0.61} \ \mathrm{GeV}^2\mathrm{fu}}$$

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



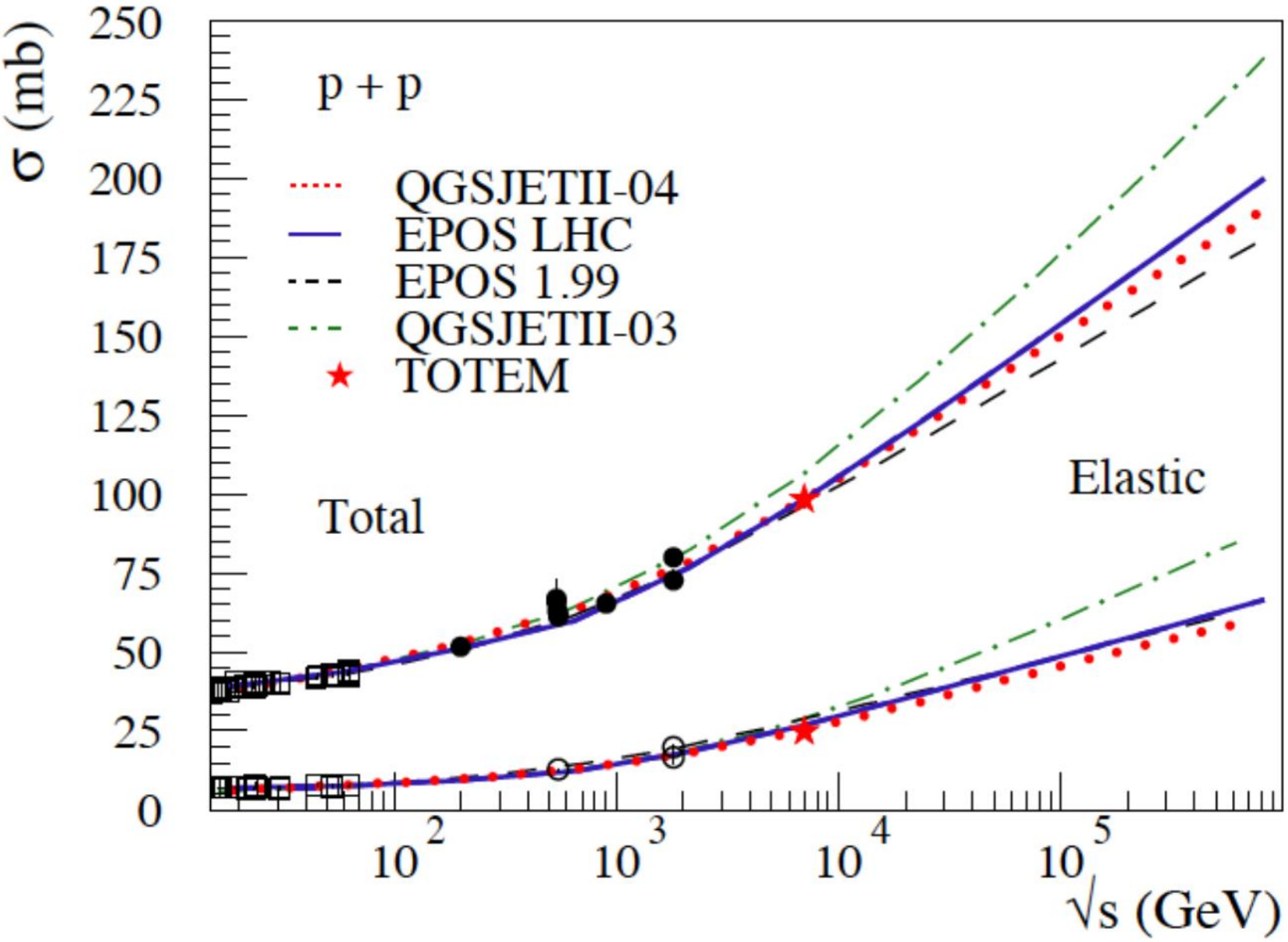
Conclusions

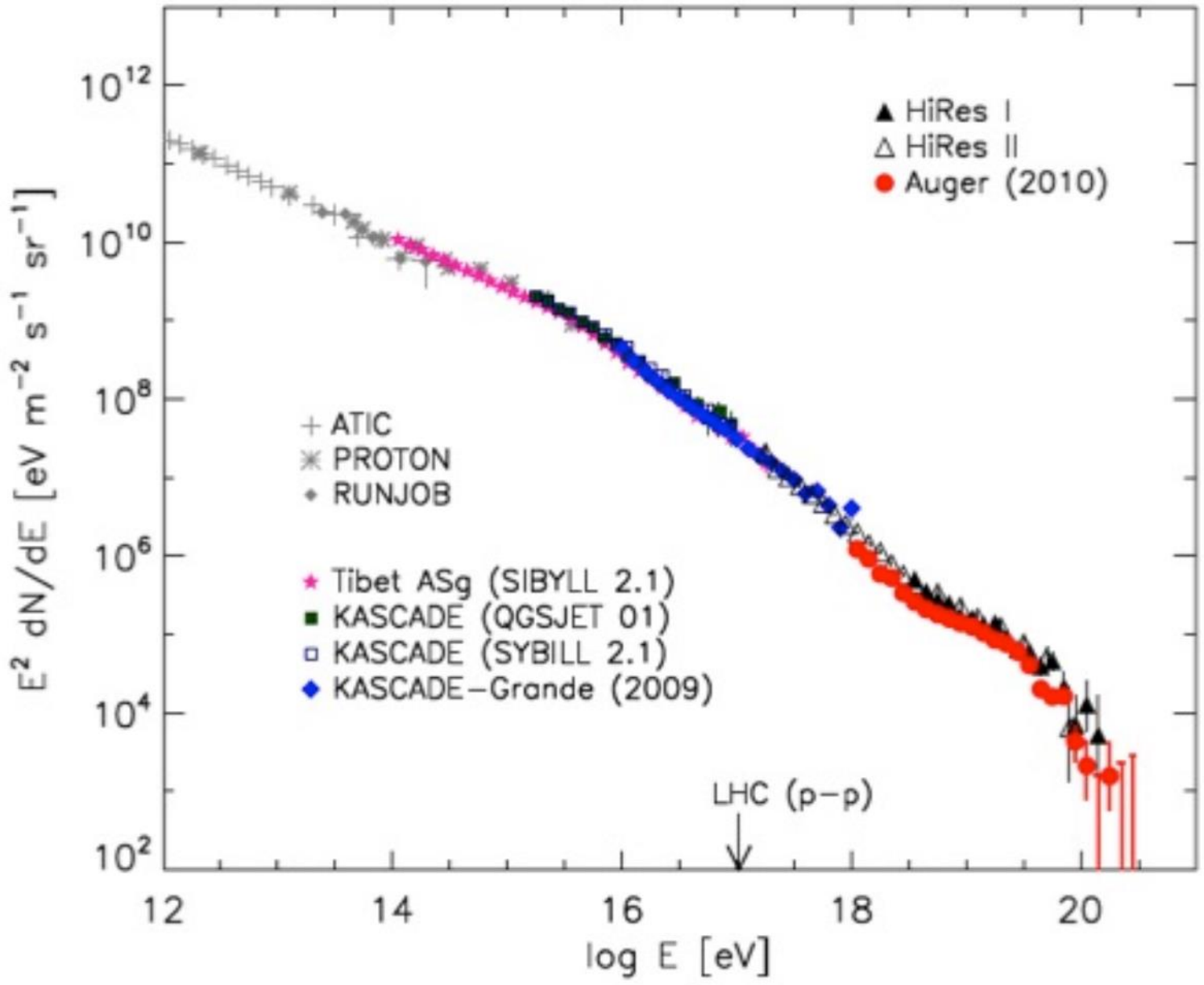
The observed fluxes, spectra, and sky distributions of the high energy diffuse backgrounds of astronomical γ's and ν's, and the CR e^+'s observed near Earth, **satisfy simple relations, which are expected from their common production in high energy hadronic collisions of cosmic rays in their Galactic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

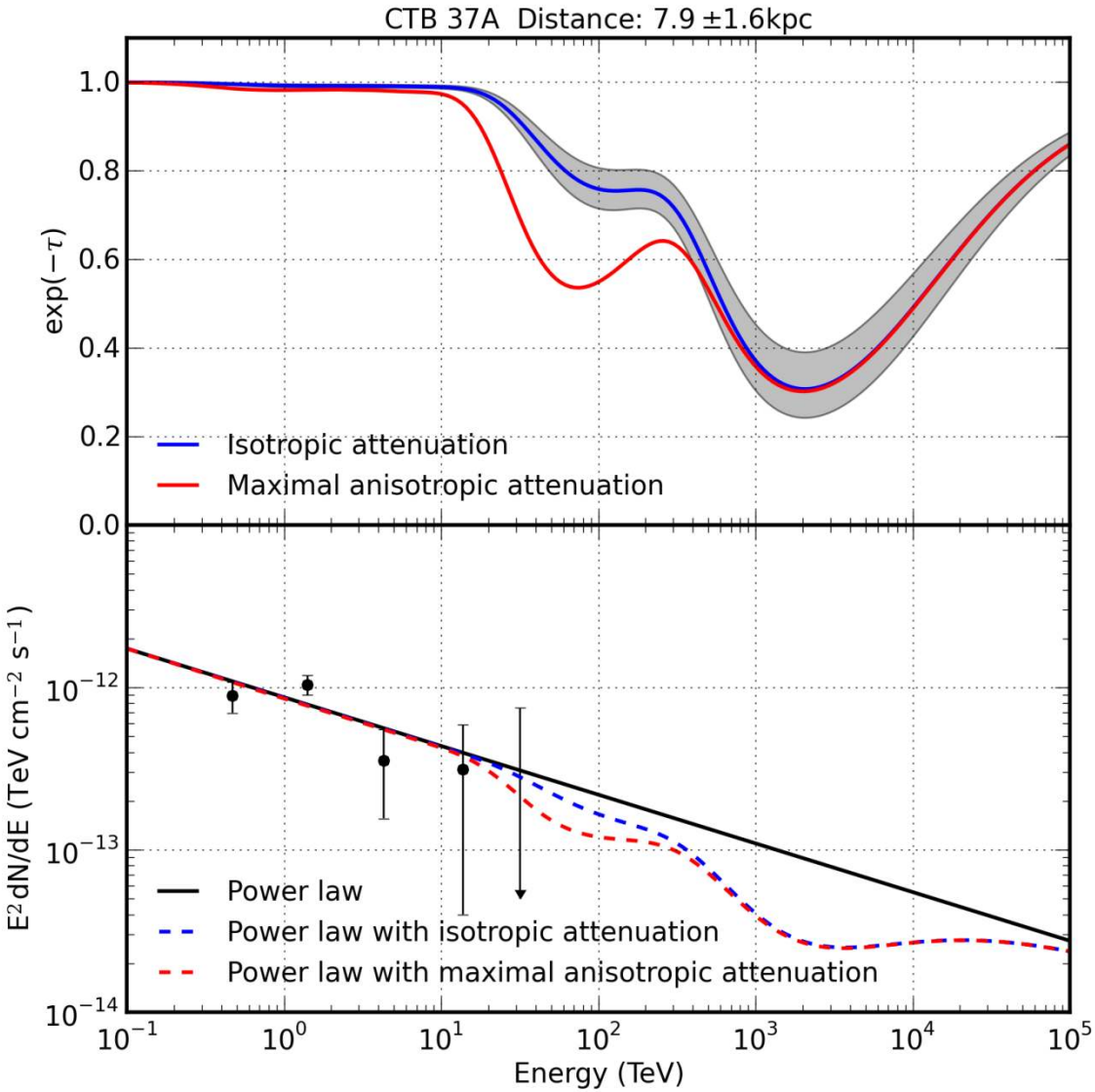
Their observed spectra indicate:

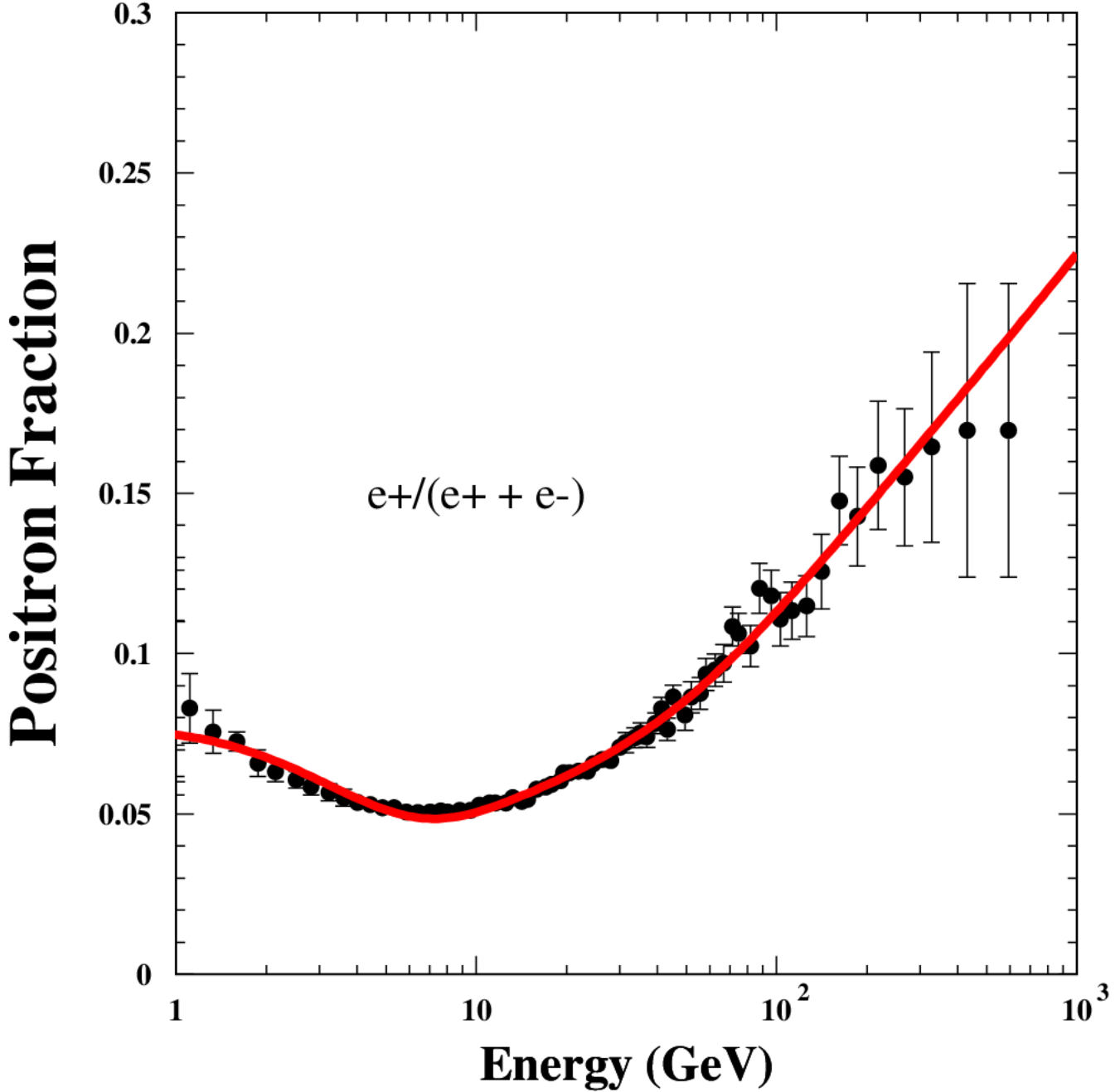
The e^+'s **observed near Earth are produced in the local ISM.**

The high energy γ's and ν'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)


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)
E² dN/dE [eV m⁻² s⁻¹ sr⁻¹]
log E [eV]
10¹²
10¹⁰
10⁸
10⁶
10⁴
10²
12
14
16
18
20


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
E² dN/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
0.3
0.25
0.2
0.15
0.1
0.05
0
e+/(e+ + e-)
1
10
10 2
10 3
Energy (GeV)