Common Solution Of Three Cosmic Puzzles ?*

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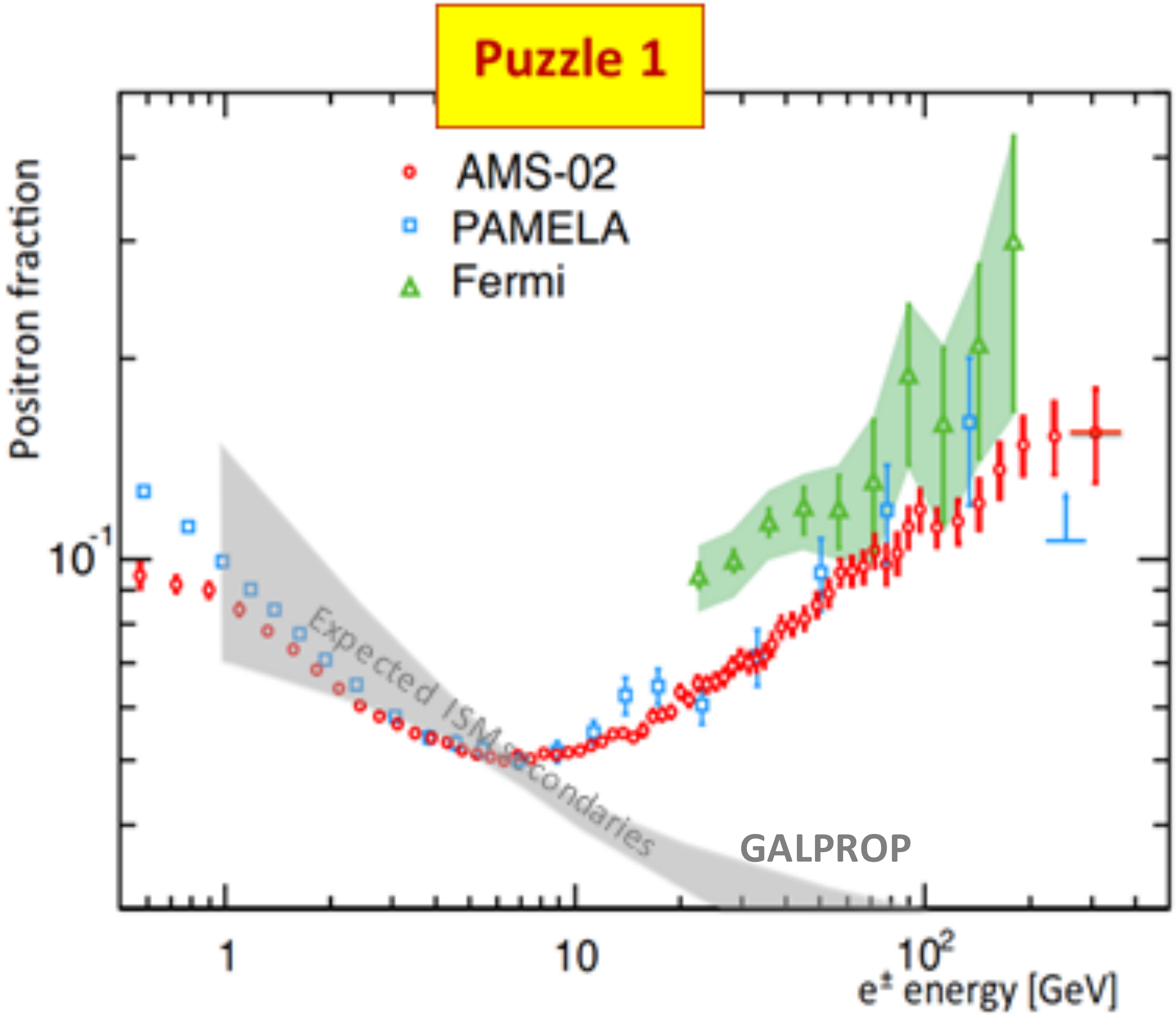
* Origin of :

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

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

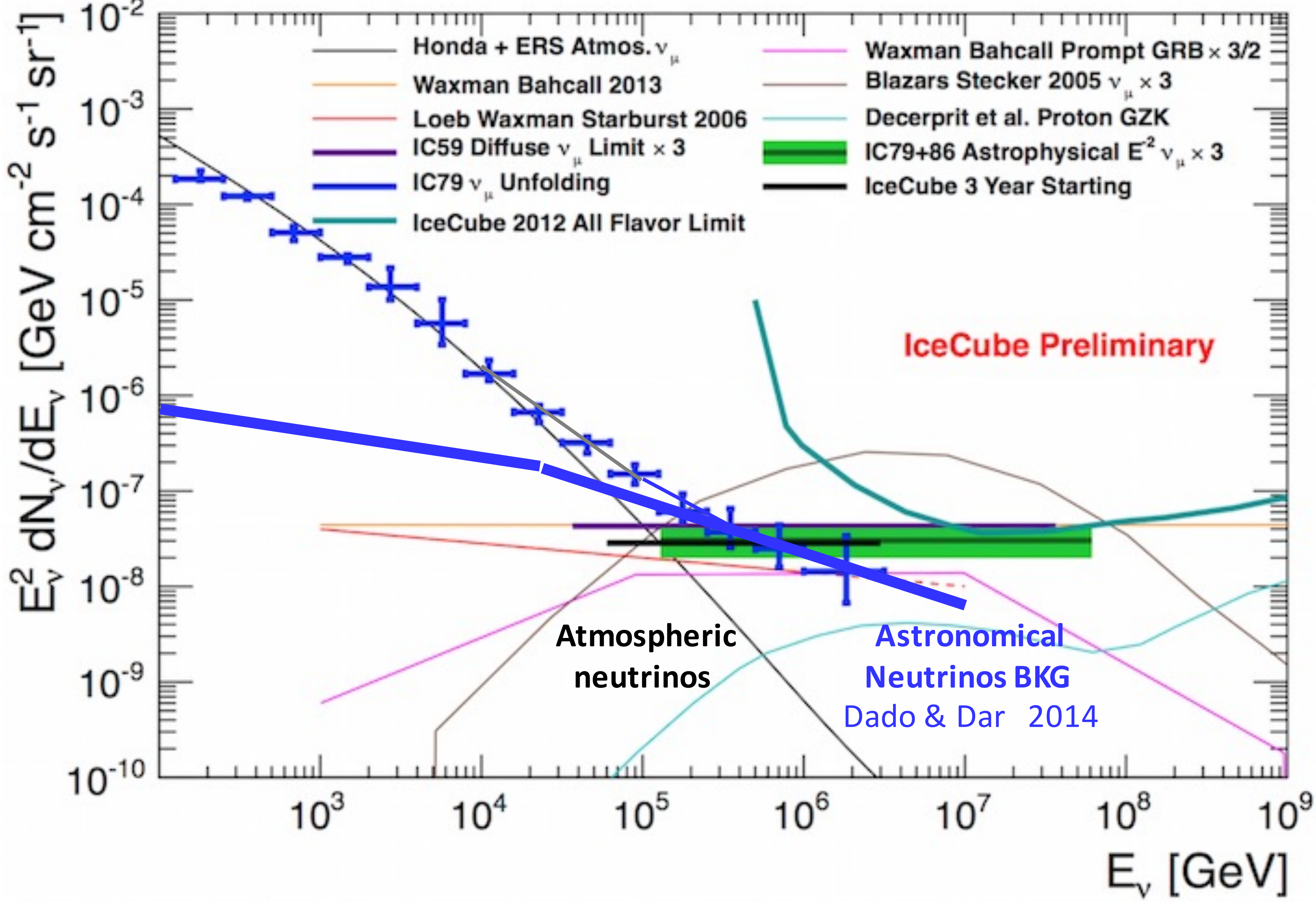
The high energy astronomical neutrinos (IceCube)

In collaboration with Shlomo dado

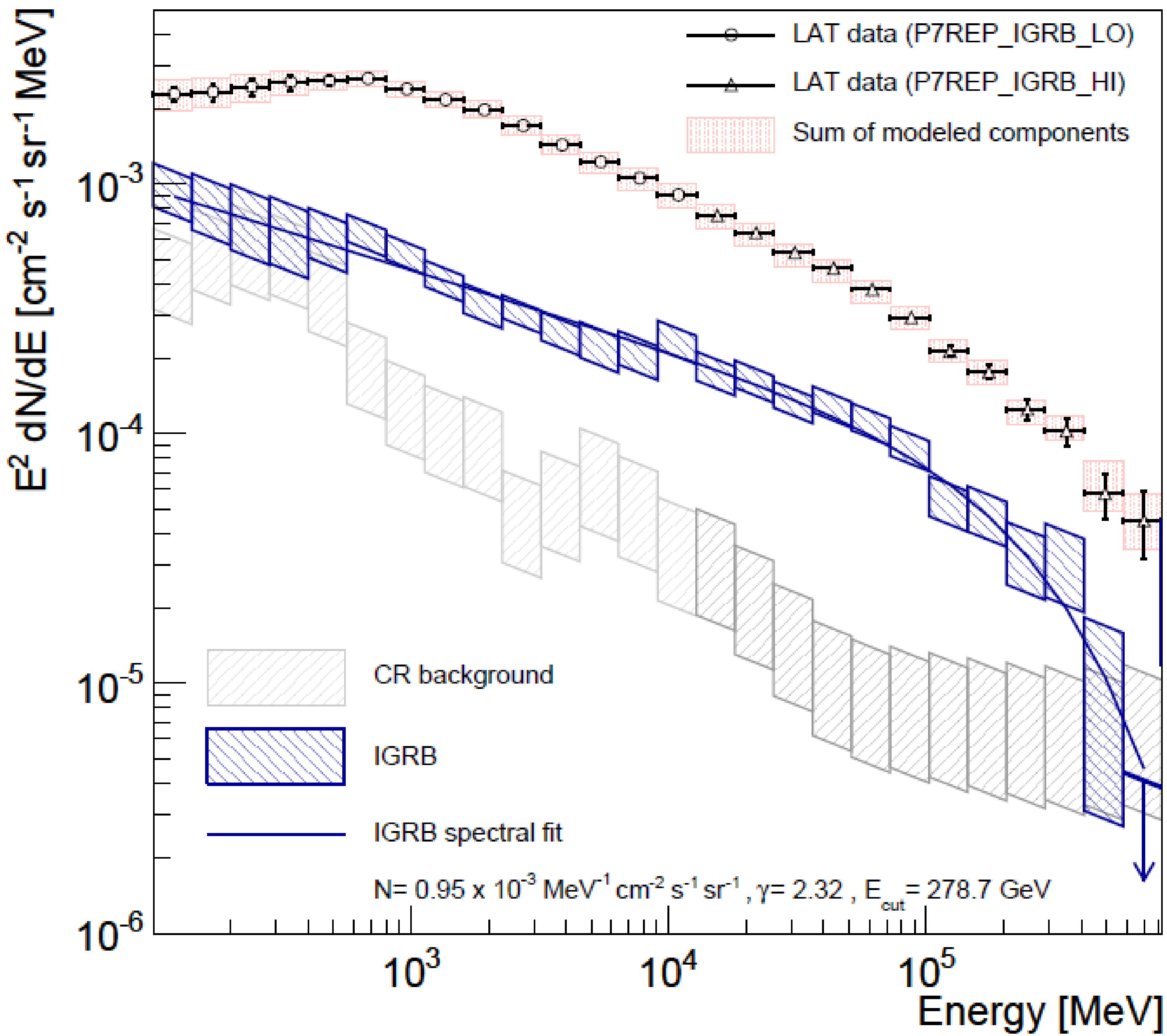

Puzzle 1
AMS-02
PAMELA
Fermi
Positron fraction
10^{-1}
Expected ISM secondaries
GALPROP
1
10
10^2
$e^{\pm}$ energy [GeV]

Puzzle 2

IceCube Astronomical Neutrino Background



The Gamma-ray Background Radiation (GBR)



Hadronic Meson Production by High Energy Cosmic Rays In Source, In the ISM and In the IGM, is Mostly by

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

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

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

➔ **Unique relations between the cosmic fluxes of γ, ν, and e^+**

hadronic meson production may be taken over by photo meson production $p\,\gamma \to \pi X$ 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

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

Model: Steady State Leaky Box Model + Fynman Scaling

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

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

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

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

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

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

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

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

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:

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

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

Porter, Moskalenko and Strong 2006

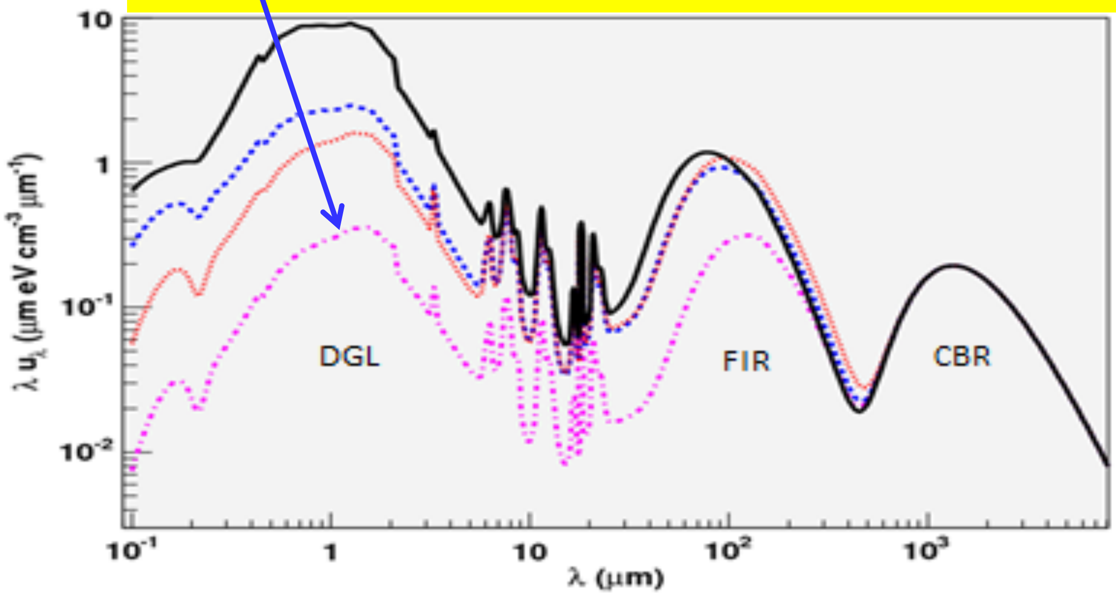
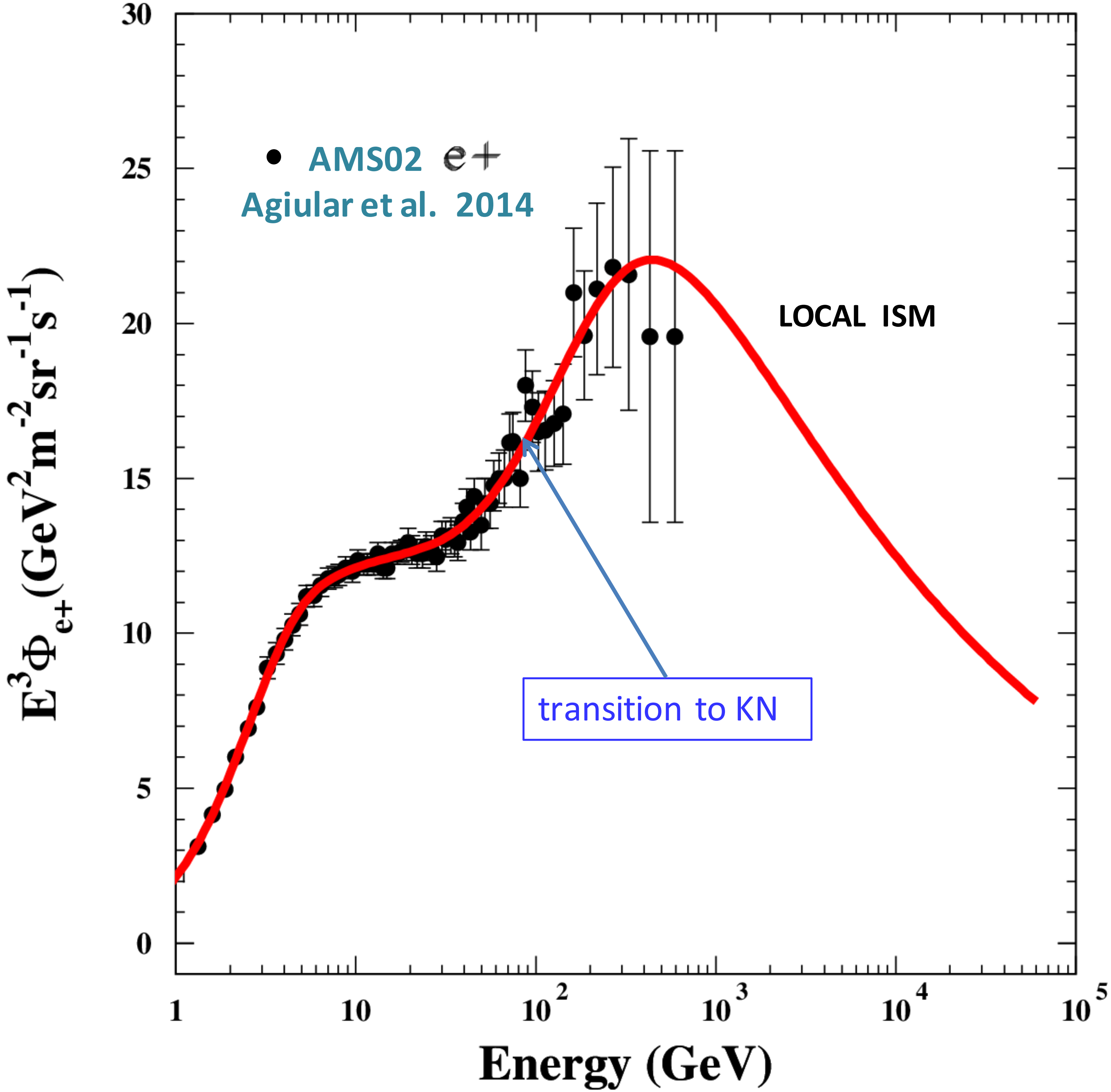
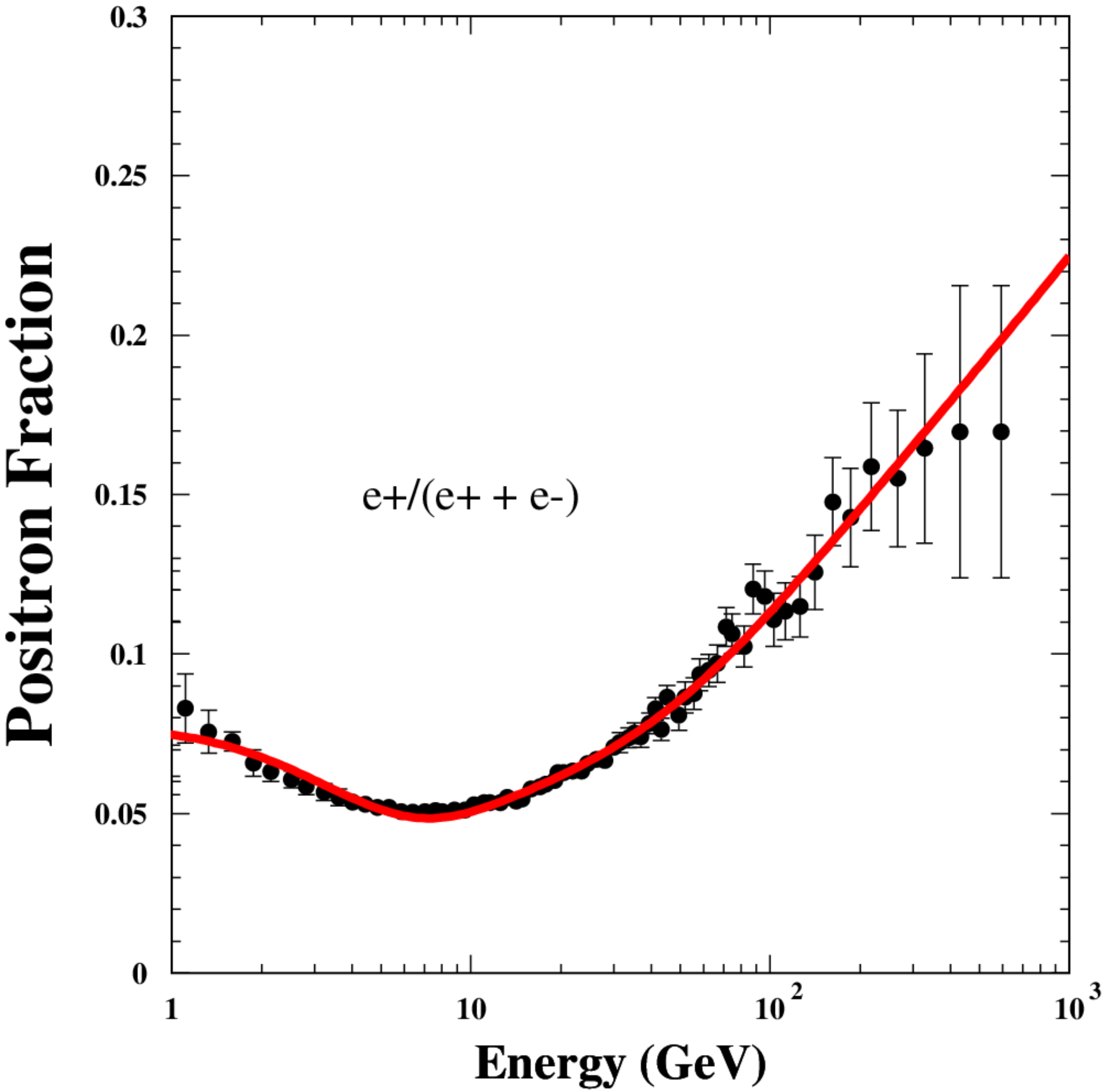


FIG. 1.— Interstellar radiation field energy density: solid $R = 0$ kpc, $z = 0$ kpc; dashed line, $R = 3$ kpc, $z = -0.05$ dotted line, $R = 4$ kpc, $z = 0$ kpc; dash-dotted line, $R = 7.5$ $z = 0$ kpc.



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



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

Hadronic production by cosmic ray nucleons yields:

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

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

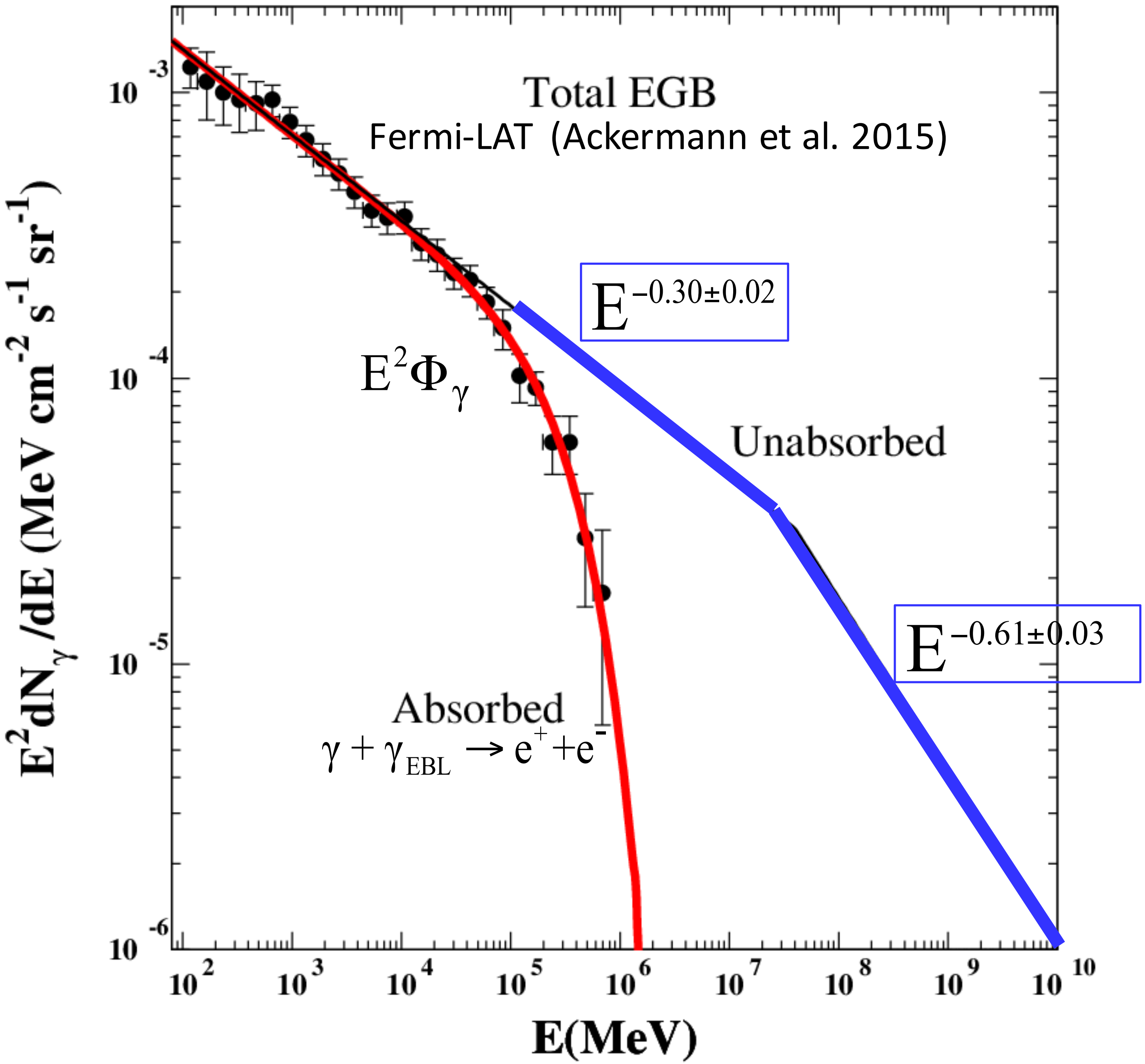
which cannot be tested directly :

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

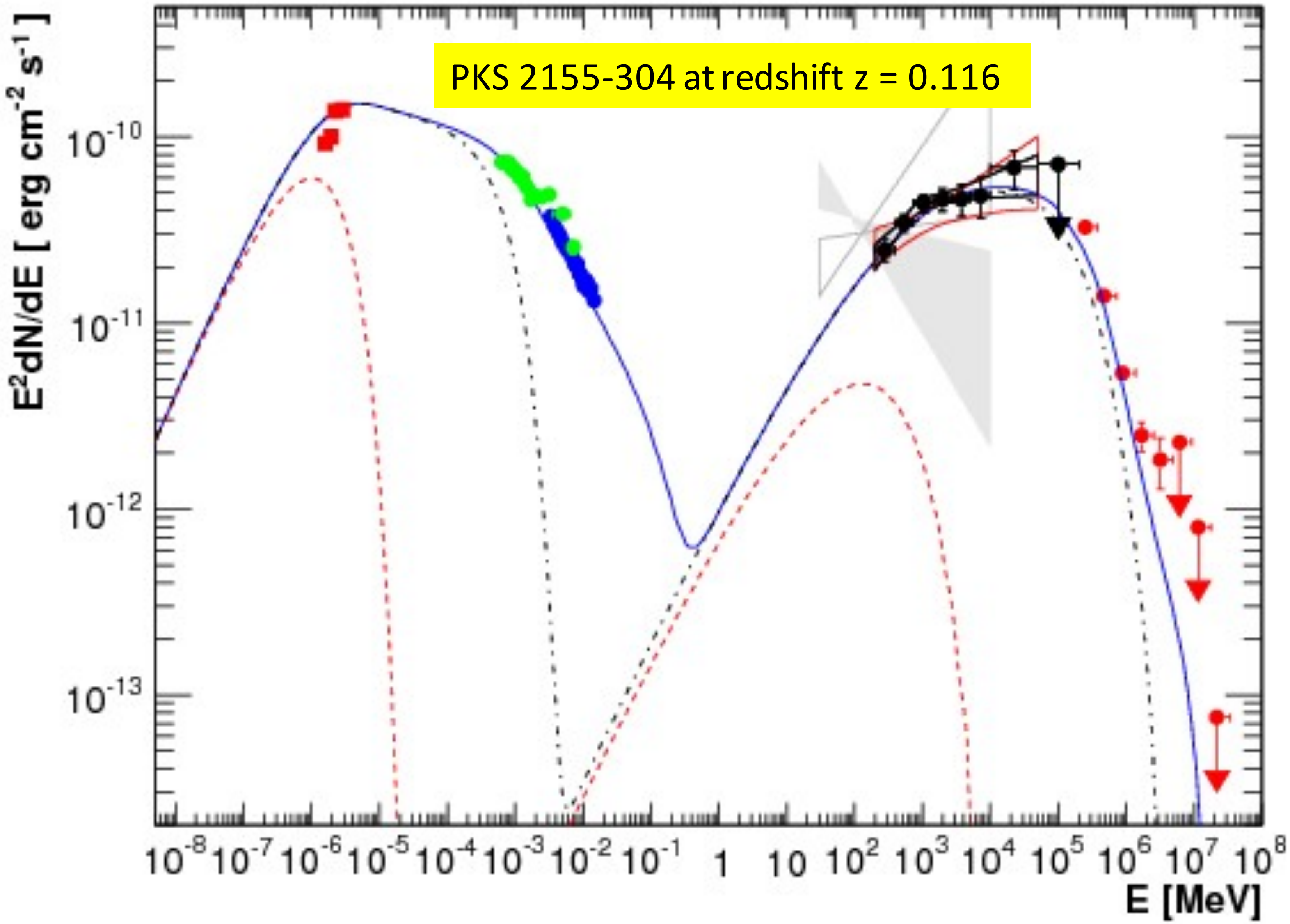
The IceCube $\Phi_\nu(E)$ **observed at E>50 TeV**

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)



Broad-band emission spectrum of PKS 2155-304, with simultaneous measurements in the optical band by the ATOM telescope, in the X-ray band by RXTE and Swift, in the high energy band by Fermi, and at very high energies by H.E.S.S. PKS 2155-304 is one of the brightest and most studied BL Lacs and is often considered the prototype of X-ray selected BL Lacs.



The Extragalactic Neutrino Background (ENB)

Ackermann et al. 2015: Absorbed EGB:

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

Estimated Unabsorbed EGB

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

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

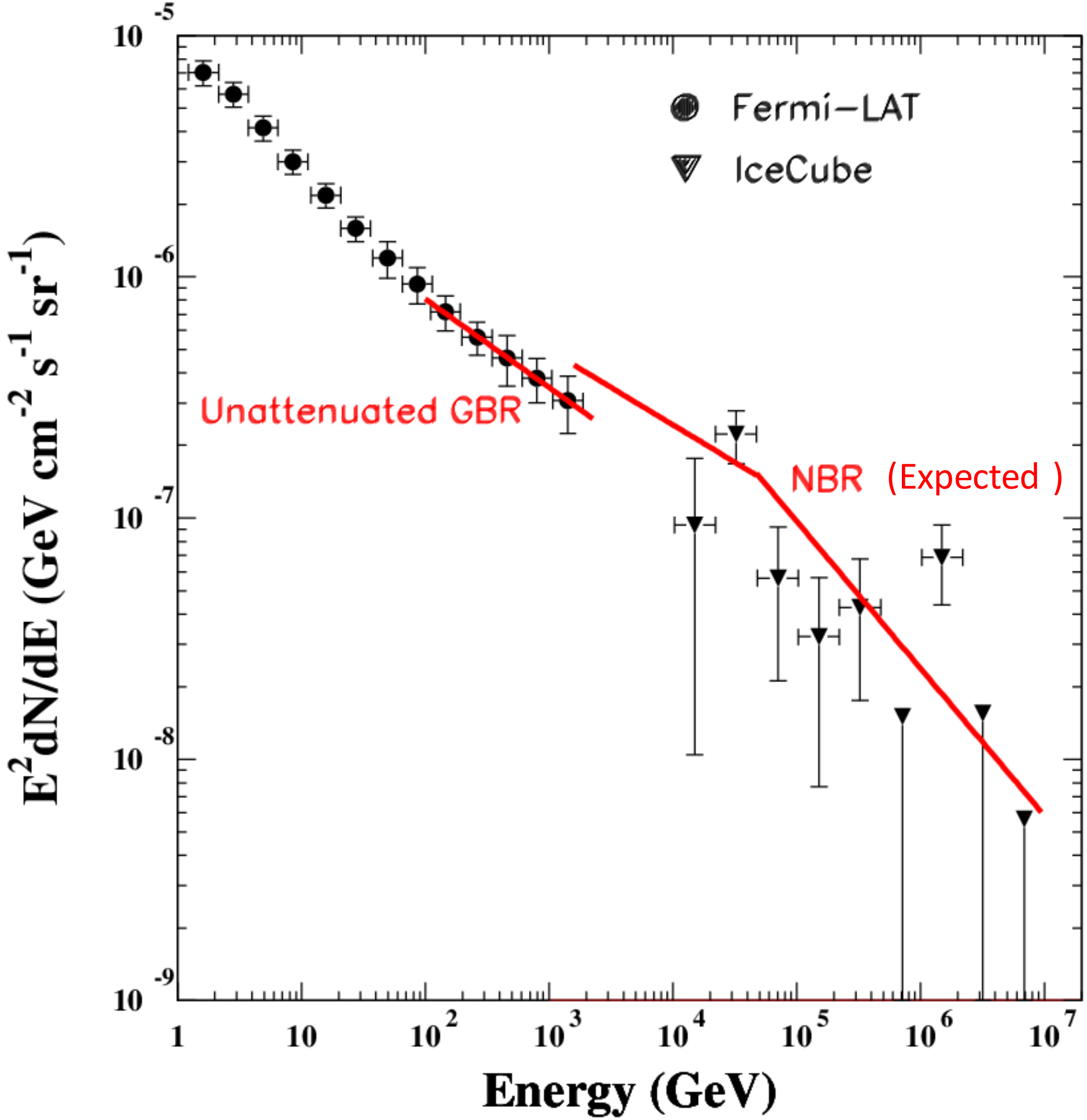
where $\mathrm{fu} = \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ is the flux unit

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

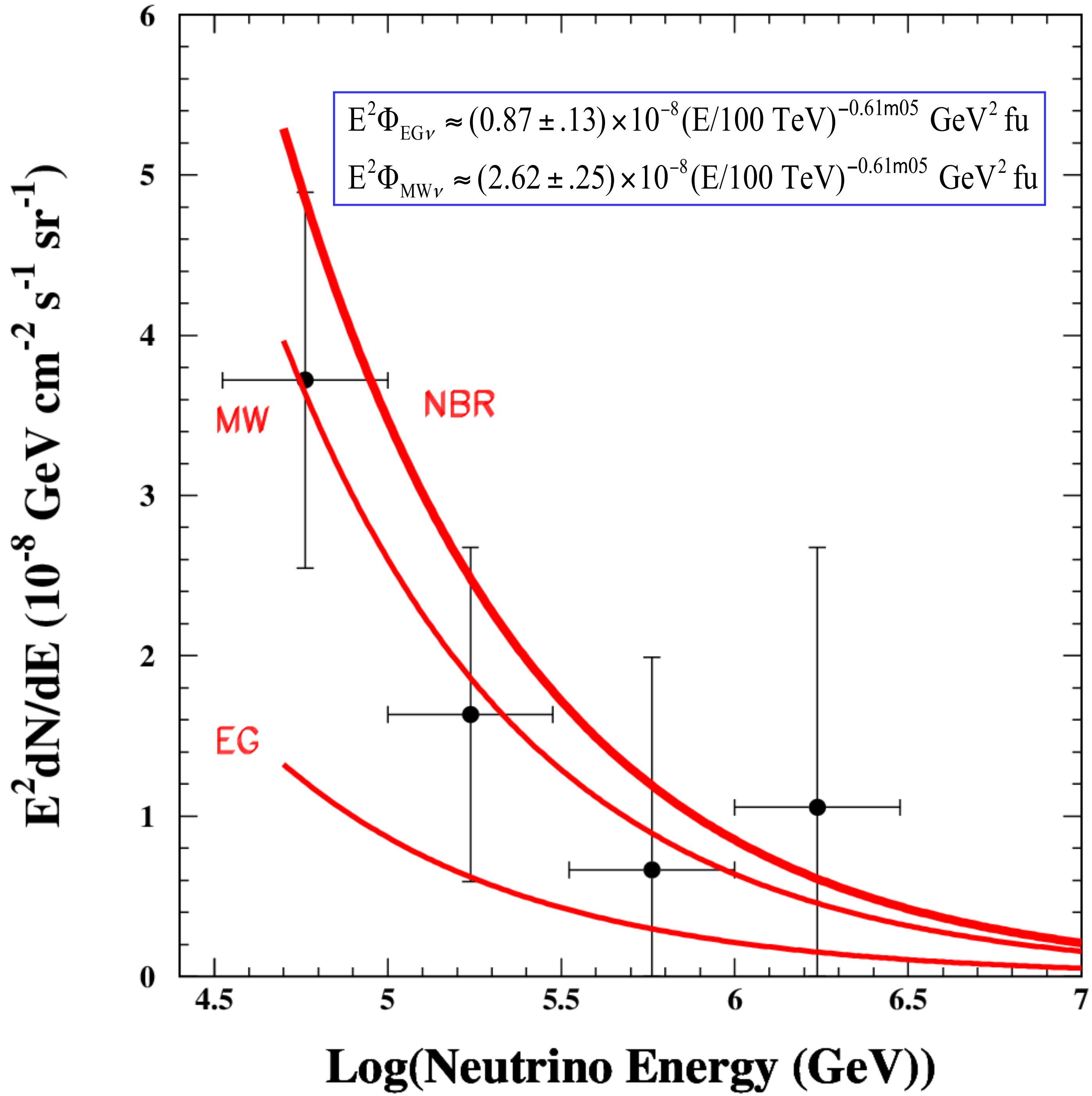
max SFR around 1+z=2.5 ==> knee around 20 TeV,

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

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

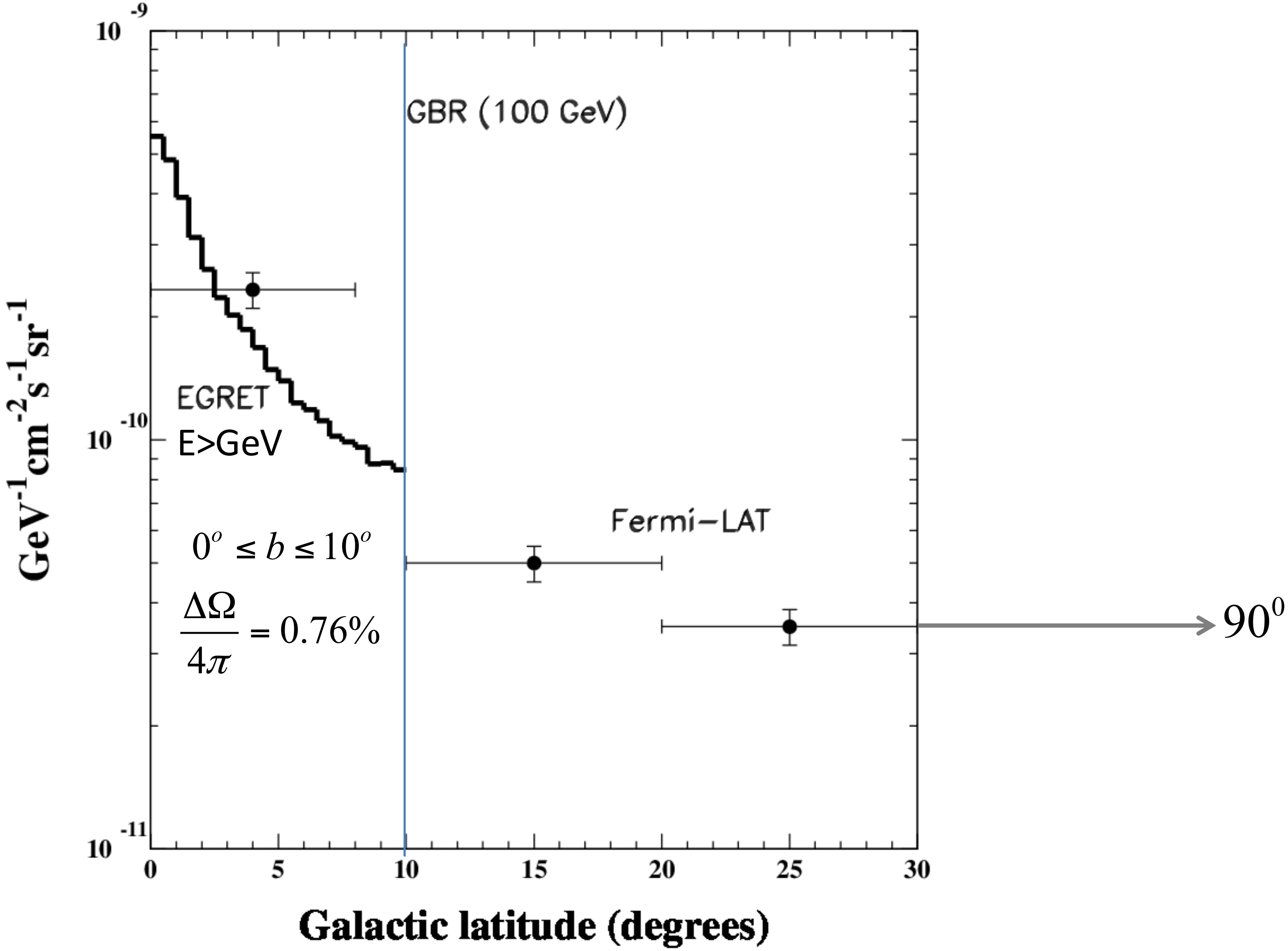


Fermi−LAT
IceCube
Unattenuated GBR
NBR (Expected)
E^2dN/dE (GeV cm^{-2} s^{-1} sr^{-1})
Energy (GeV)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
1
10
10^2
10^3
10^4
10^5
10^6
10^7



$E^2\Phi_{EG\nu} \approx (0.87 \pm .13) \times 10^{-8} (E/100\ TeV)^{-0.61m05}\ GeV^2\ fu$
$E^2\Phi_{MW\nu} \approx (2.62 \pm .25) \times 10^{-8} (E/100\ TeV)^{-0.61m05}\ GeV^2\ fu$
MW
NBR
EG
$E^2dN/dE\ (10^{-8}\ GeV\ cm^{-2}\ s^{-1}\ sr^{-1})$
Log(Neutrino Energy (GeV))
0
1
2
3
4
5
6
4.5
5
5.5
6
6.5
7

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



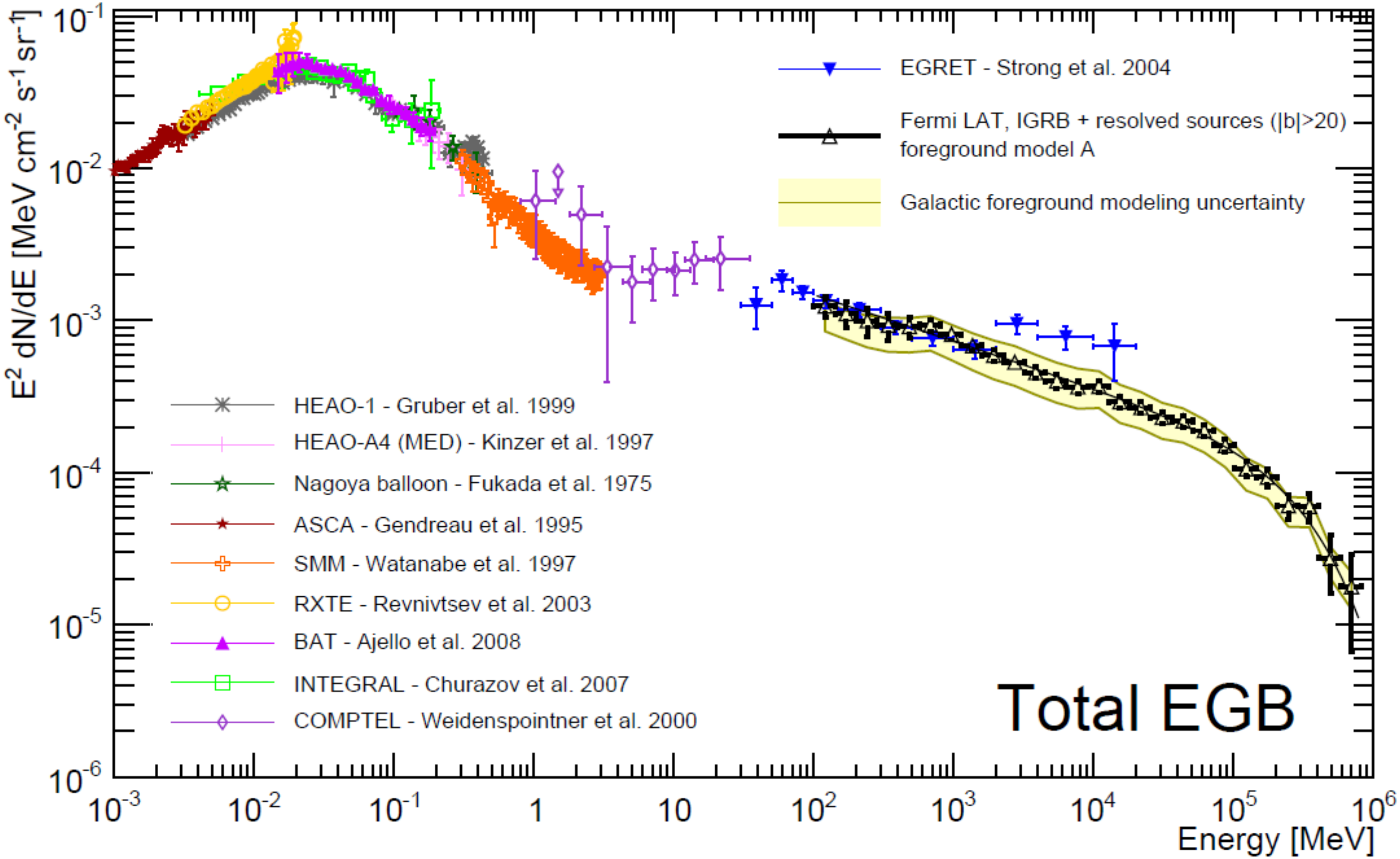
Conclusions

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.

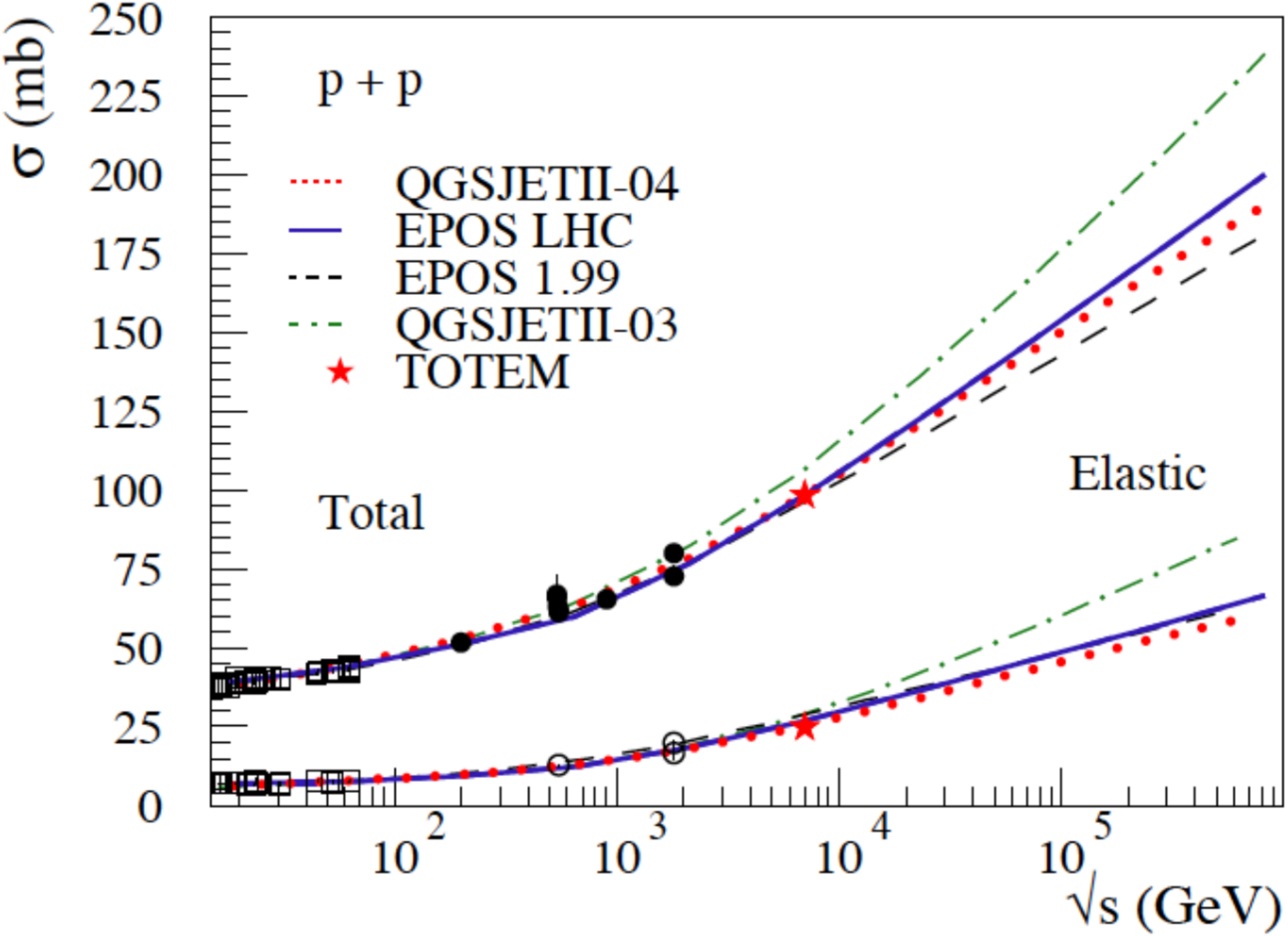
Their observed spectra indicate:

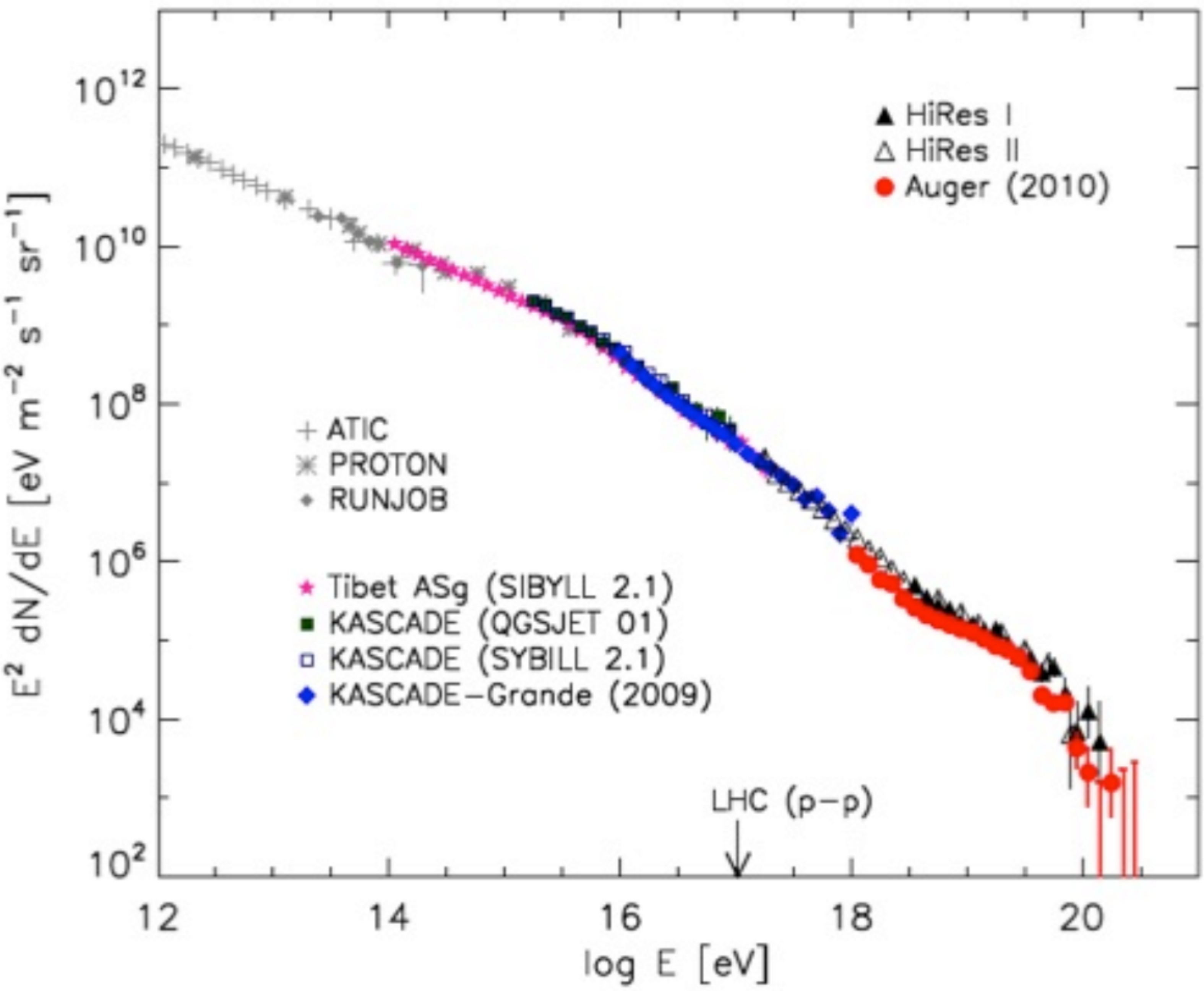
The e^{+}'s observed near Earth are produced in the local ISM.

The high energy γ's and ν's are produced inside/near source (blazars, mostly ultrahigh frequency peaked BL Lac objects).



E2 dN/dE [MeV cm-2 s-1 sr-1]
10-1
10-2
10-3
10-4
10-5
10-6
10-3
10-2
10-1
1
10
102
103
104
105
106
Energy [MeV]
EGRET - Strong et al. 2004
Fermi LAT, IGRB + resolved sources (|b|>20)
foreground model A
Galactic foreground modeling uncertainty
HEAO-1 - Gruber et al. 1999
HEAO-A4 (MED) - Kinzer et al. 1997
Nagoya balloon - Fukada et al. 1975
ASCA - Gendreau et al. 1995
SMM - Watanabe et al. 1997
RXTE - Revnivtsev et al. 2003
BAT - Ajello et al. 2008
INTEGRAL - Churazov et al. 2007
COMPTEL - Weidenspointner et al. 2000
Total EGB


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)



10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
E^2 dN/dE [eV m^{-2} s^{-1} sr^{-1}]
12
14
16
18
20
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)