Neutrino predictions from choked GRBs and comparison with the observed cosmic neutrino flux

Irene Di Palma
On behalf of
Silvia Celli, Antonio Capone, Michela Fasano,
Dafne Guetta and Angela Zegarelli

STVDIVM VRBIS

AMALDI
RESEARCH CENTER

INFN

Outlines

Choked gamma-ray bursts (GRBs): an overview on the source dynamics;

A MC simulation for the photo-meson production of high-energy radiation and neutrinos;

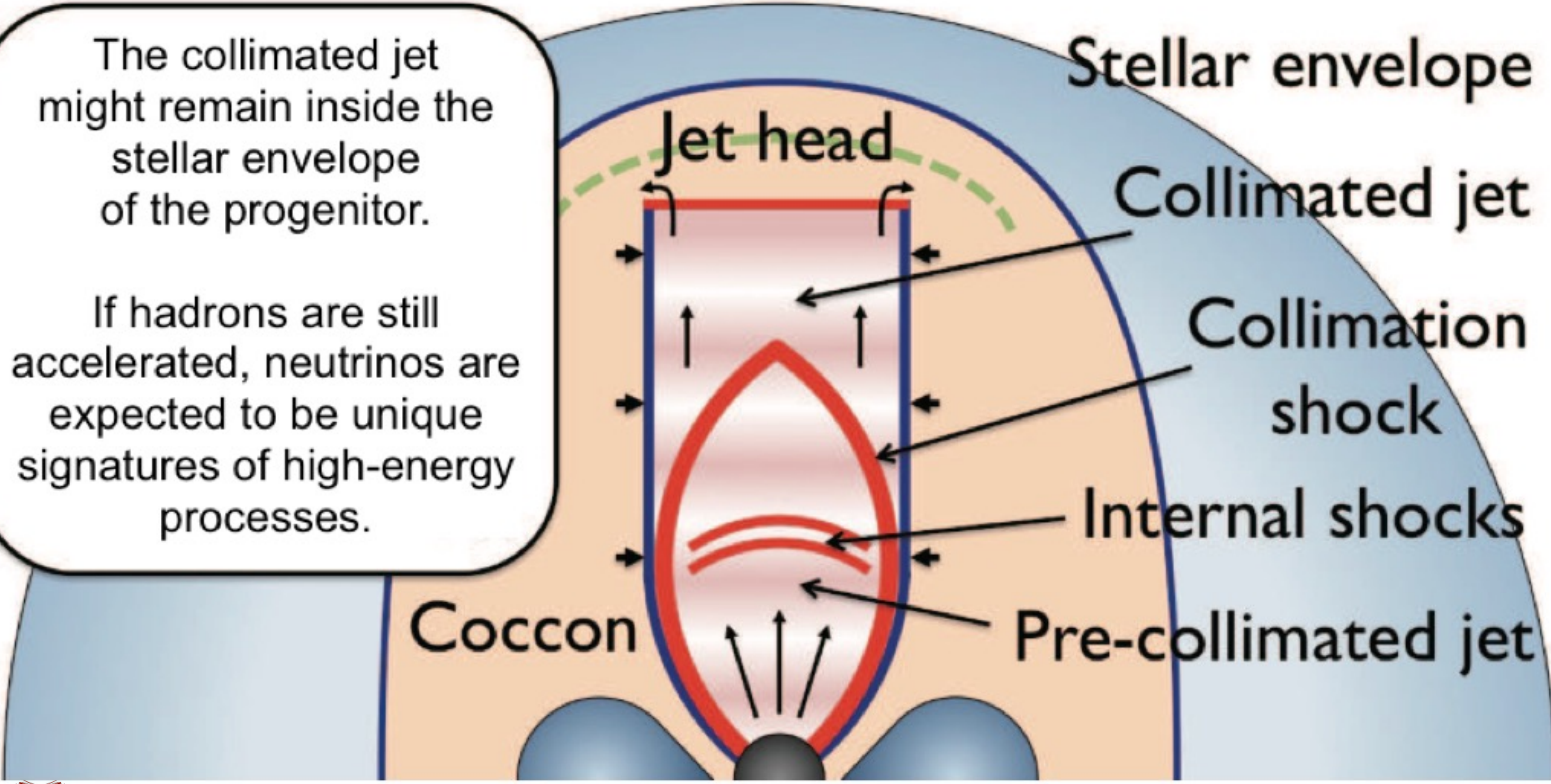
Evaluating the signal event rate expected at Earth in ANTARES, KM3NeT and IceCube;

Choked GRB contribution to the diffuse cosmic neutrino flux.

Fasano, Celli, Guetta, Capone, Zegarelli, Di Palma, (submitted) arXiv:2021:03502

The collimated jet might remain inside the stellar envelope of the progenitor.

If hadrons are still accelerated, neutrinos are expected to be unique signatures of high-energy processes.



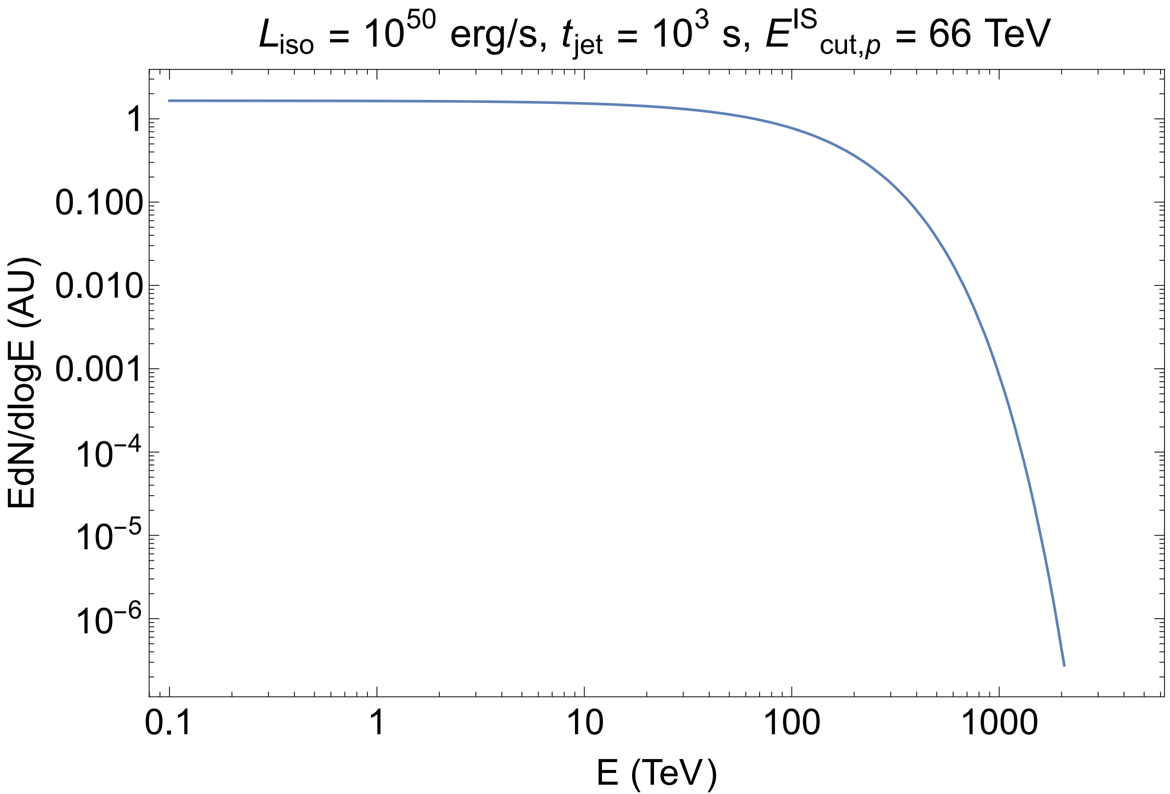
K. Murase & K. Ioca, PRL 111 (2013) 121102

Neutrinos from chocked GRBs

We performed a Monte Carlo simulation of pγ interactions with

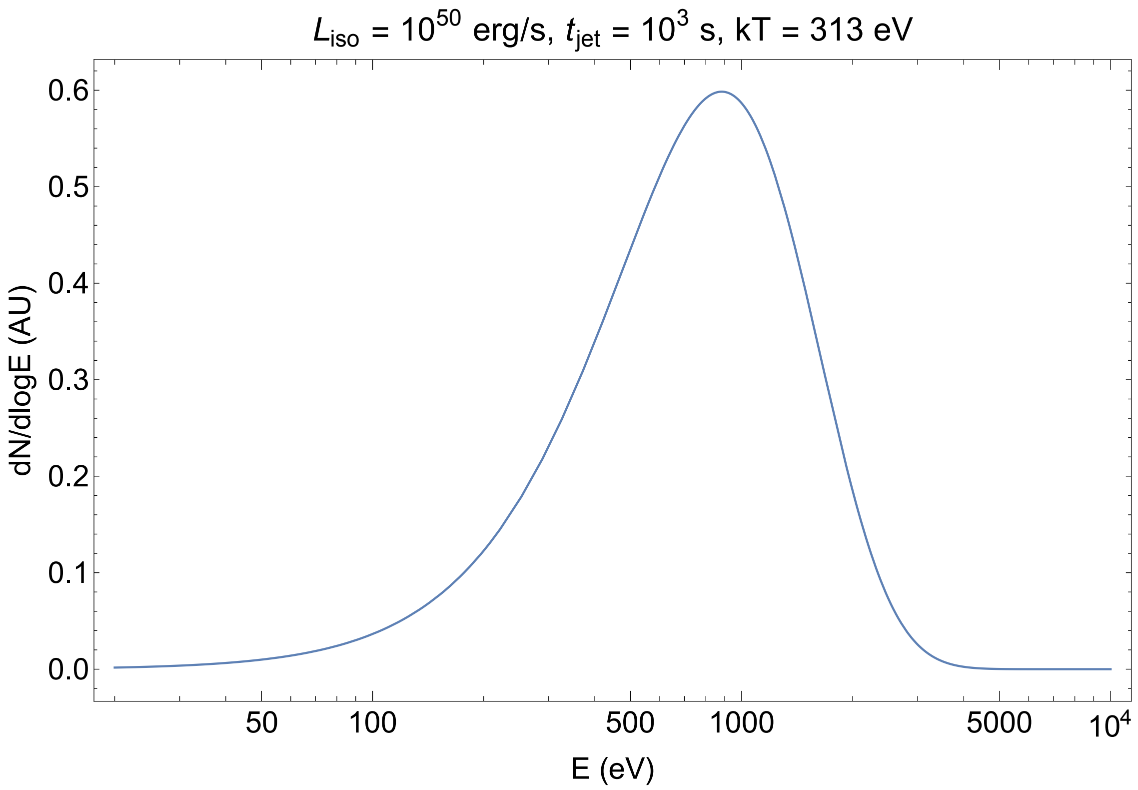
- **accelerated protons:**

$$\frac{dN_p}{dE_p} = k_{\mathrm{MC}}\, E_p^{-2}$$

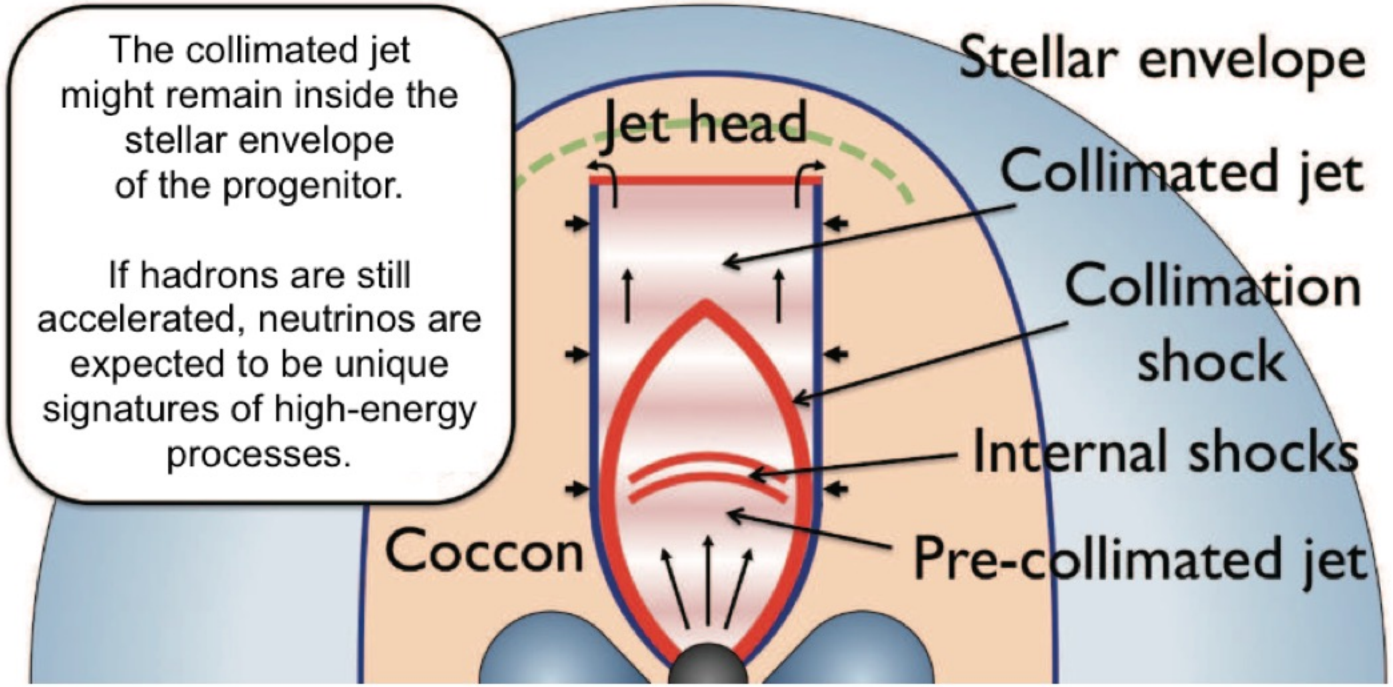


- **target photons:**

$$\frac{dN_\gamma}{dE_\gamma} = \frac{8}{19(kT_\gamma)^3}\frac{E_\gamma^2}{e^{\frac{E_\gamma}{kT_\gamma}}-1}$$



Neutrinos from chocked GRBs



Particle acceleration model from 📕 He et al., ApJ 856 (2018) 119

Thermalised photons in the reverse shock have typical temperature of

$$kT_\gamma \simeq 313\,\mathrm{eV}\ \mathrm{L}_{\mathrm{iso},\,50}^{1/8}\,\epsilon_{\mathrm{e},\,-1}^{1/4}\,\mathrm{t}_{\mathrm{jet},\,3}^{-1/4}\,\rho_{\mathrm{H},-7}^{1/8}$$

Once escaped in the forward shock region, their energy is

$$E_{\gamma,\,\mathrm{IS}}^{\max} = \Gamma_{\mathrm{IR}} E_{\gamma,\,\mathrm{RS}}^{\max} \sim 88.1\,\mathrm{keV}$$

Neutrinos from chocked GRBs

In order to compute the proton path inside the thermal photon gas, it is necessary to invert the path probability distribution:

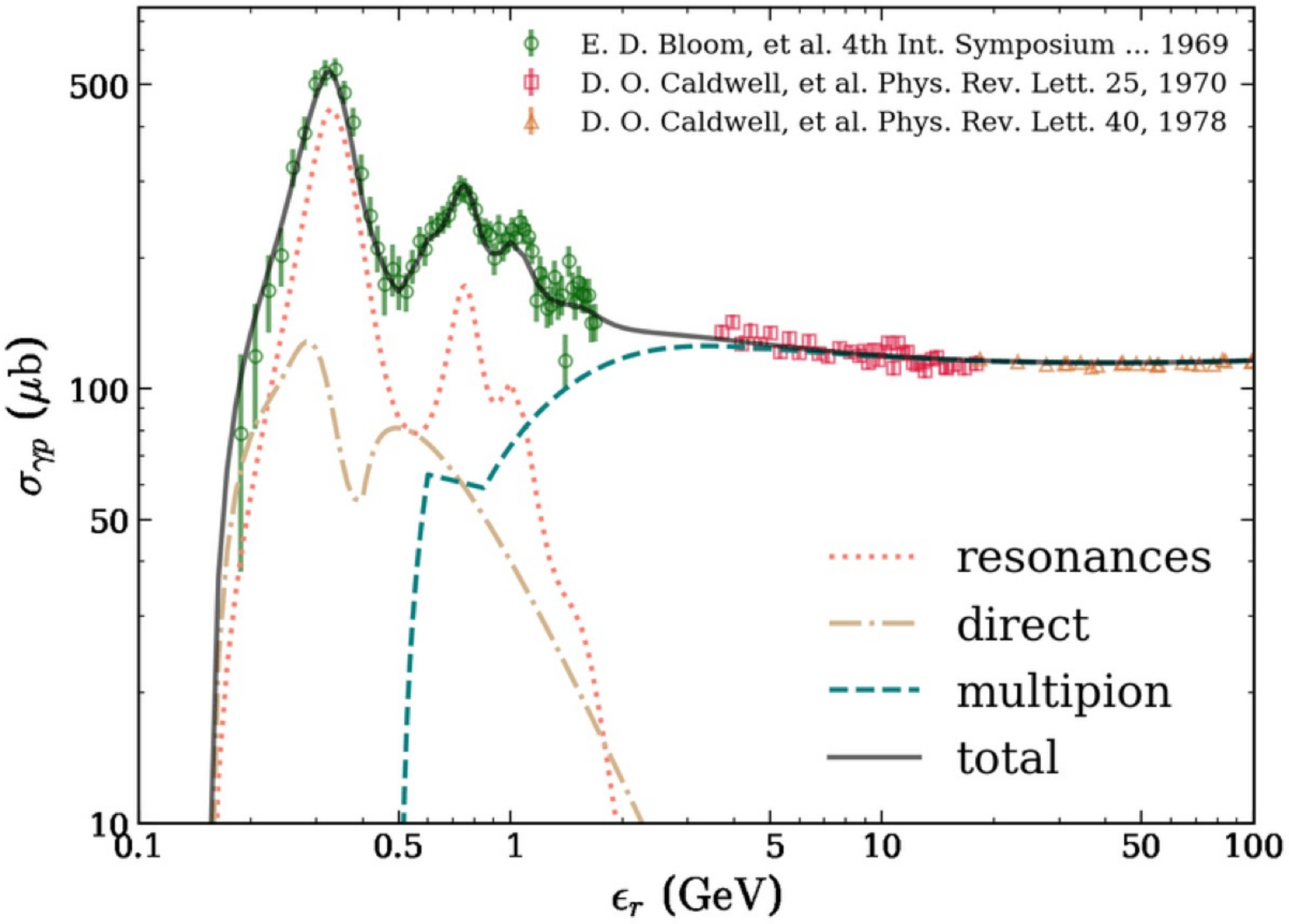
$$dP(x_p) = \frac{1}{\lambda_{p\gamma}} e^{-x_p/\lambda_{p\gamma}} dx_p$$

where $\lambda_{p\gamma} = 1/(\sigma_{p\gamma} n_\gamma)$ is the interaction length and the photon density in the internal shock frame is:

$$n_{\gamma,\mathrm{IS}} \simeq 1.9 \times 10^{20}\,\mathrm{cm}^{-3}\,\Gamma_2^2\,L_{\mathrm{iso},50}^{-3/8}\,t_{\mathrm{jet},3}^{-1/4}\,\epsilon_{e,-1}^{3/4}\,\rho_{H,-7}^{1/8}$$

Neutrinos from chocked GRBs

We include in the simulation both the region of the Δ^+ resonance, as well as the out-of-resonance region, which appears particularly crucial for neutrino production



$$p + \gamma \to \Delta^+ \to \begin{cases} n + \pi^+ \\ p + \pi^0 \end{cases}$$

$$p + \gamma \to \pi^{A} + \Delta^+ \to \mathcal{N} + \pi^{B}$$

$$p + \gamma \to \pi^0 + \pi^+ + \pi^- + \dots$$

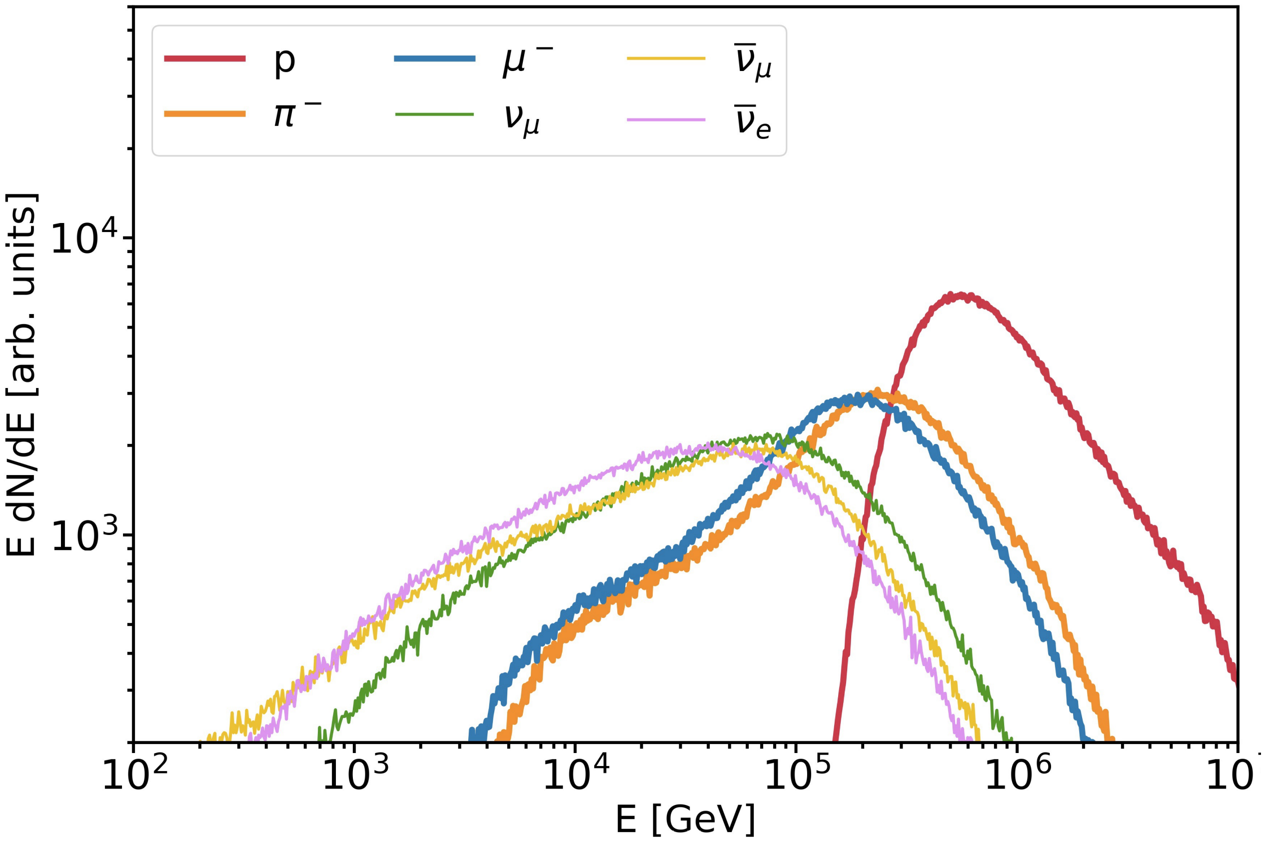
$$\pi^+ \to \mu^+ + \nu_\mu \to e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$

$$\pi^- \to \mu^- + \bar{\nu}_\mu \to e^- + \bar{\nu}_e + \nu_\mu + \bar{\nu}_\mu$$

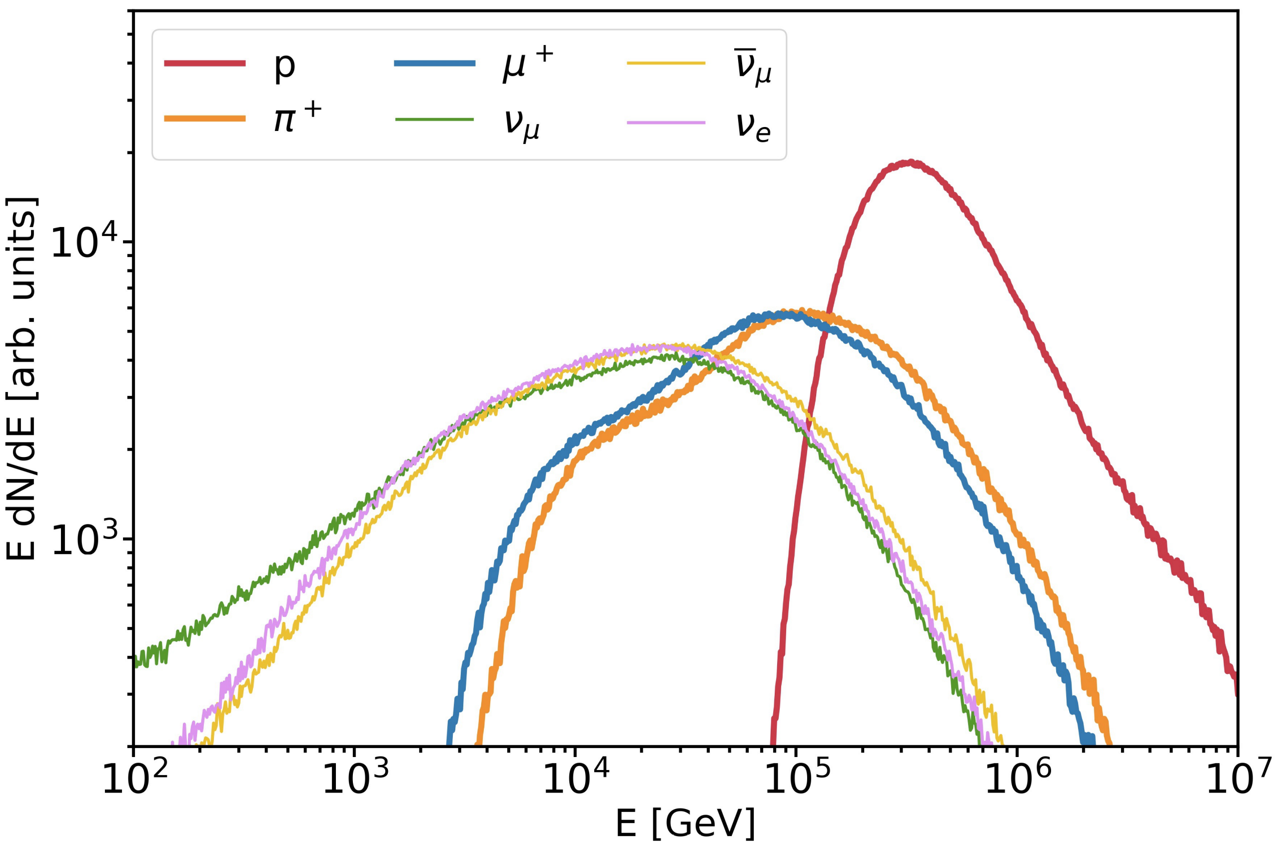
$$\pi^0 \to \gamma + \gamma$$

Neutrinos from chocked GRBs

We obtain the following spectra for emerging particles:



π^- channel

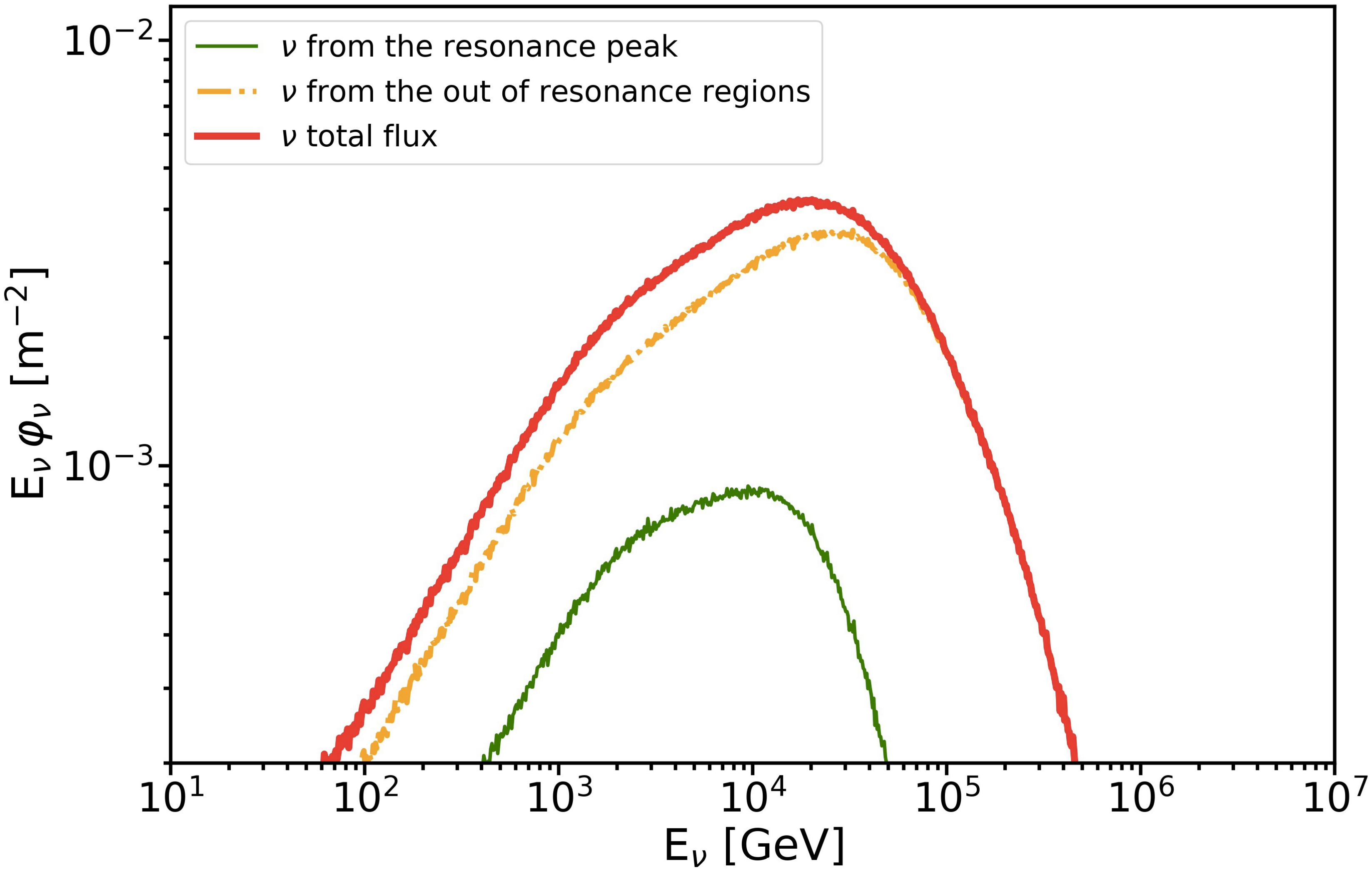


π^+ channel

M. Fasano et al., arXiv:2021:03502

Neutrinos from chocked GRBs

We obtain the following spectra for emerging particles:

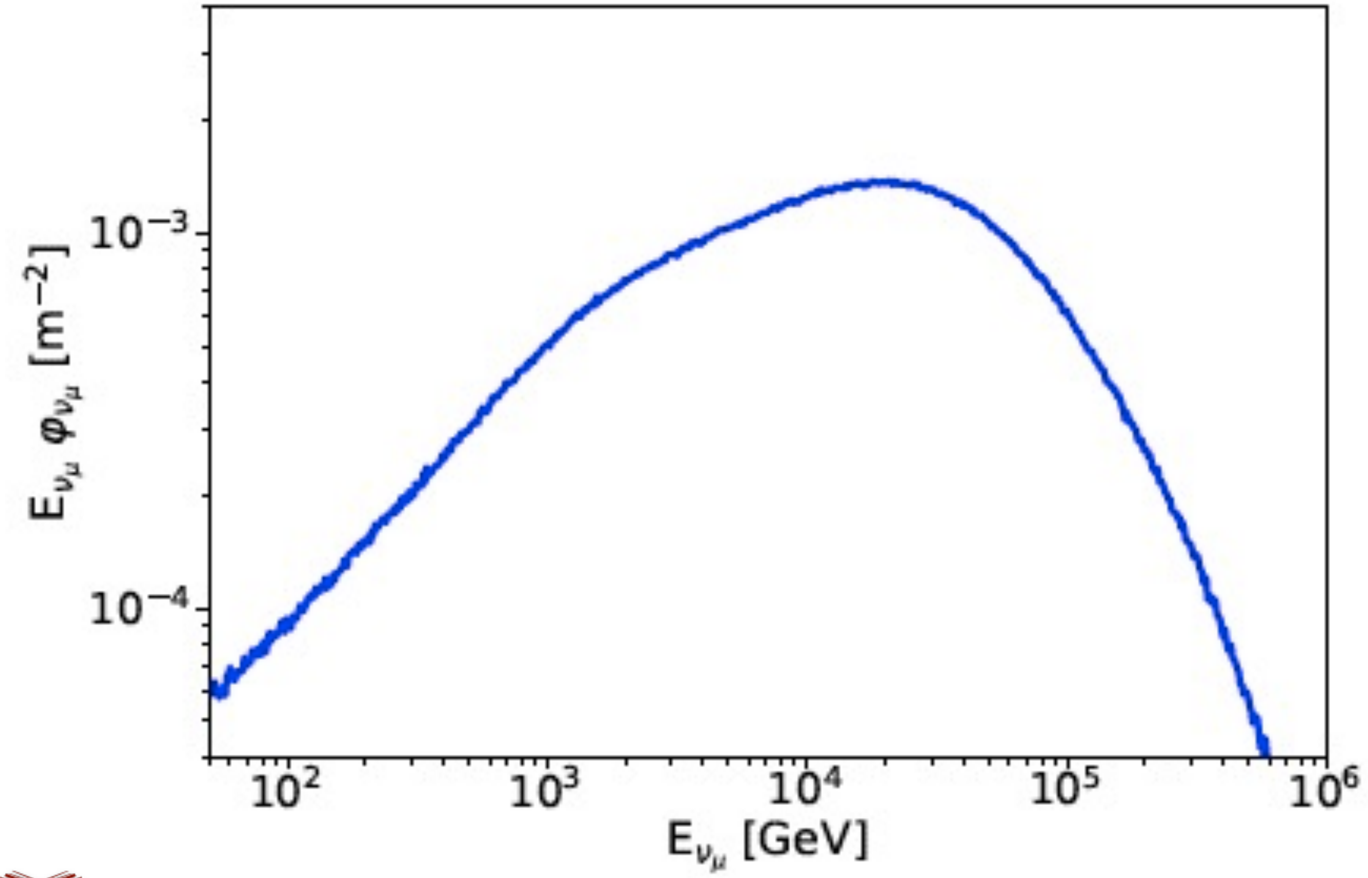


M. Fasano et al., arXiv:2021:03502

Neutrinos from chocked GRBs

1. EXPECTED EVENT RATES

Expected number of muon neutrinos per unit detection area
from a choked GRB with:



$z = 1$

$E_{iso}=10^{53}$ erg

$L_{iso}=10^{50}$ erg/s

$t_{jet}=10^3$ s

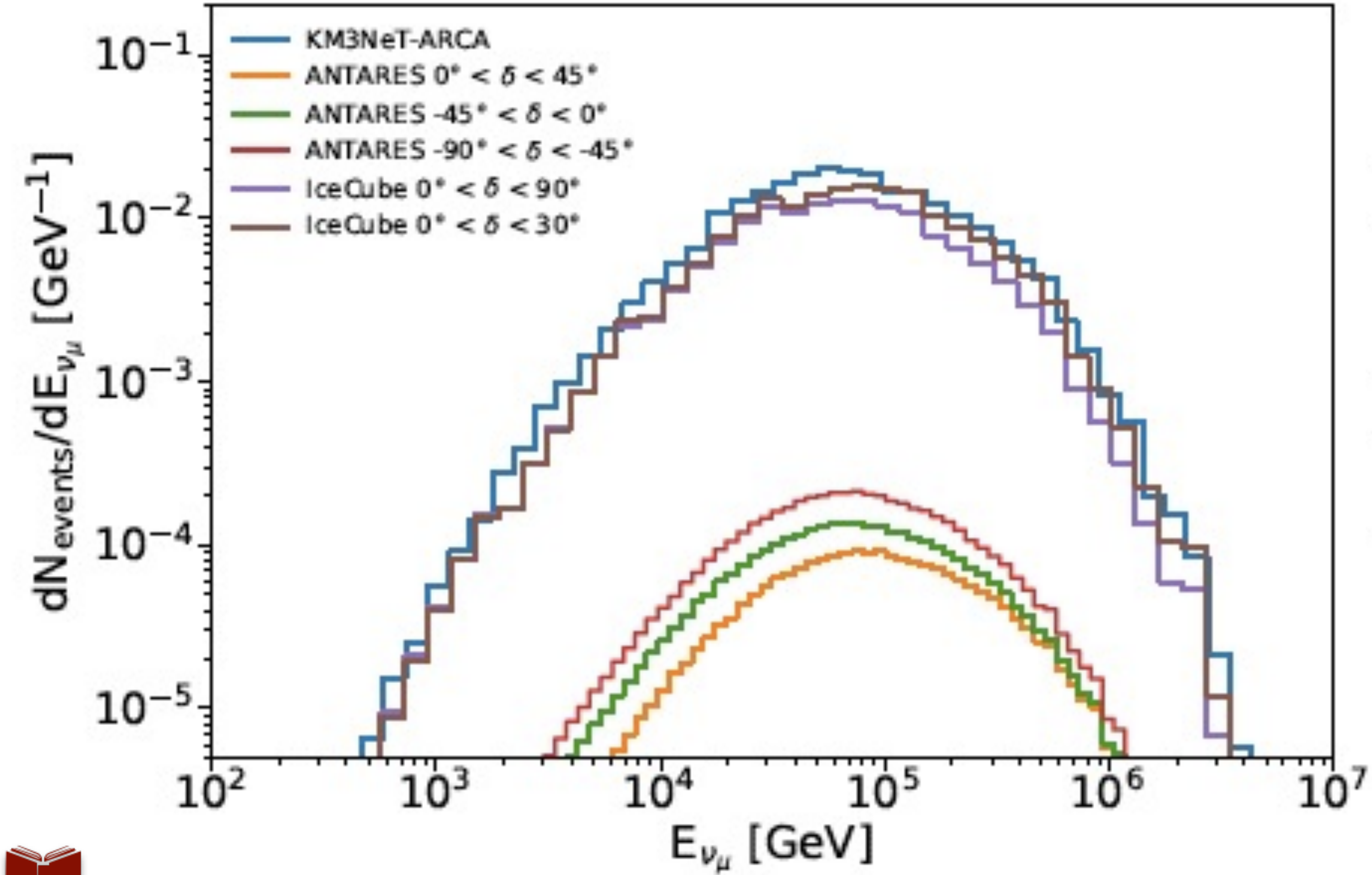
$\Gamma=100$

M. Fasano et al., arXiv:2021:03502

Neutrinos from chocked GRBs

1. EXPECTED EVENT RATES

$$N_{\text{events}}(\delta) = \int \frac{dN_{\text{events}}}{dE_\nu}(E_\nu, \delta)\, dE_\nu = \int A_{\text{eff}}^{\nu}(E_\nu, \delta)\, \Phi_\nu^{\text{Earth}}(E_\nu)\, dE_\nu$$



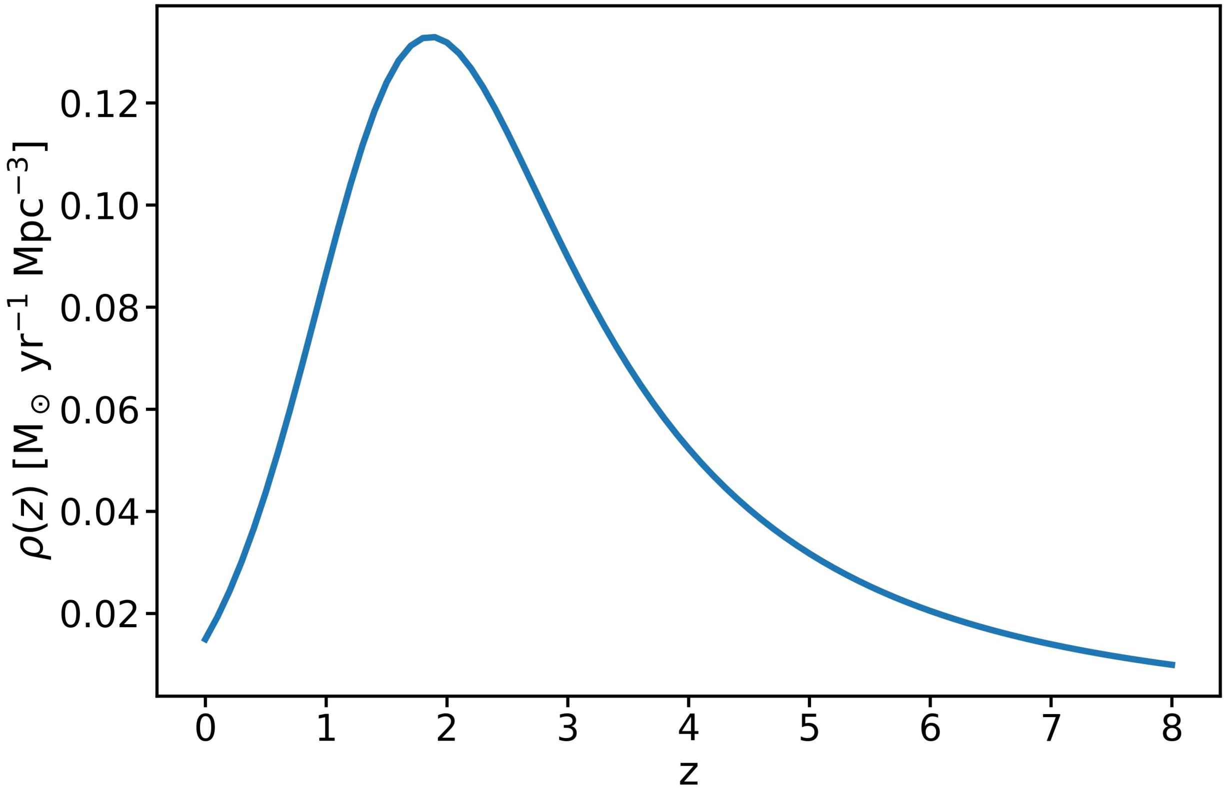
Detector	δ	N_{events}
ANTARES	$0° < \delta < 45°$	2×10^{-3}
	$-45° < \delta < 0°$	3×10^{-3}
	$-90° < \delta < -45°$	5×10^{-3}
KM3NeT-ARCA	Mean δ	2×10^{-1}
IceCube	$0° < \delta < 90°$	1×10^{-1}
	$0° < \delta < 30°$	2×10^{-1}

M. Fasano et al., arXiv:2021:03502

Neutrinos from chocked GRBs

2. CONTRIBUTION TO THE DIFFUSE NEUTRINO FLUX

We tested the possibility that choked GRBs follow the star formation rate



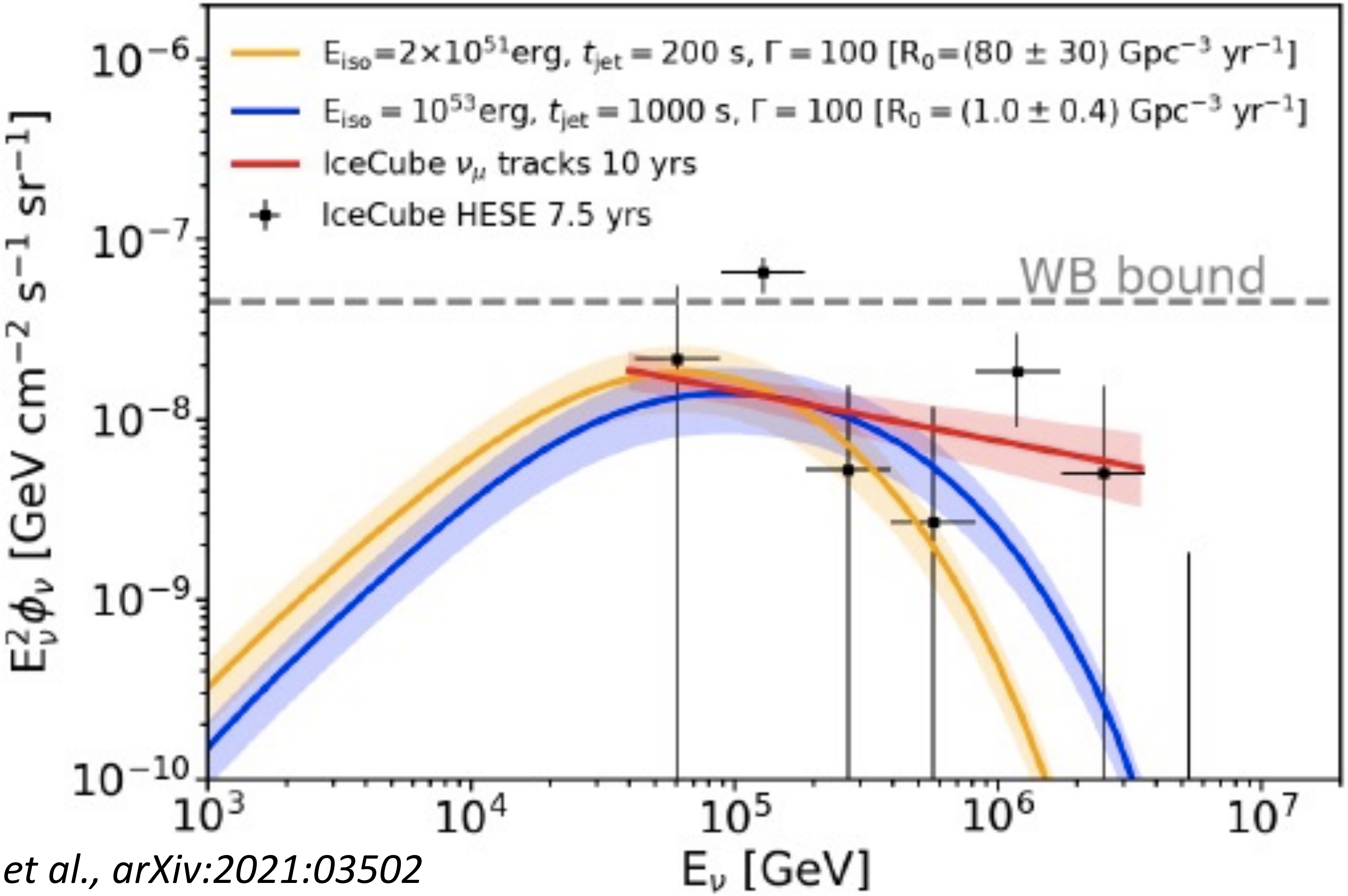
$$\rho(z) = \frac{(1+z)^{2.7}}{1+[(1+z)/2.9]^{5.6}}$$

Madau & Dickinson, Ann. Rev. A&A 52 (2014) 415

$$E_{\nu_\mu}^{\rm obs}\phi_{\nu_\mu}(E_{\nu_\mu}^{\rm obs}) = \frac{c}{4\pi H_0}\int_0^8 E_{\nu_\mu}\frac{dN_{\nu_\mu}}{dE_{\nu_\mu}}((1+z)E_{\nu_\mu}^{\rm obs})\frac{\frac{\Omega}{4\pi}R_0\rho(z)dz}{(1+z)\sqrt{\Omega_\Lambda+\Omega_{\rm M}(1+z)^3}}$$

Neutrinos from chocked GRBs

$$E_{\nu_\mu}^{\rm obs}\phi_{\nu_\mu}(E_{\nu_\mu}^{\rm obs}) = \frac{c}{4\pi H_0}\int_0^8 E_{\nu_\mu}\frac{dN_{\nu_\mu}}{dE_{\nu_\mu}}((1+z)E_{\nu_\mu}^{\rm obs})\frac{\frac{\Omega}{4\pi}R_0\rho(z)dz}{(1+z)\sqrt{\Omega_\Lambda+\Omega_{\rm M}(1+z)^3}}$$



M. Fasano et al., arXiv:2021:03502

Conclusions

- The origin of IC neutrinos remains so far elusive, though overall a major contribution from EG sources appears preferable;

- Upper limits derived in the stacking searches of ANTARES and IceCube disfavor GRBs as major contributors of the cosmic diffuse neutrino flux ($<1\%$);

- Choked GRBs appear a viable alternative, possibly dominating the IC flux if their local rate is of the order of standard GRBs;

- If so, searching for a gamma-ray counterpart would be inconclusive. Lower frequency radiation appears to be better suited for such a search.