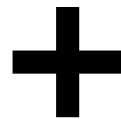


Gamma rays as leptonic portals to energetic neutrinos: a new Monte Carlo approach

Gaetano Di Marco

Rafael Alves Batista

Miguel A. Sánchez-Conde

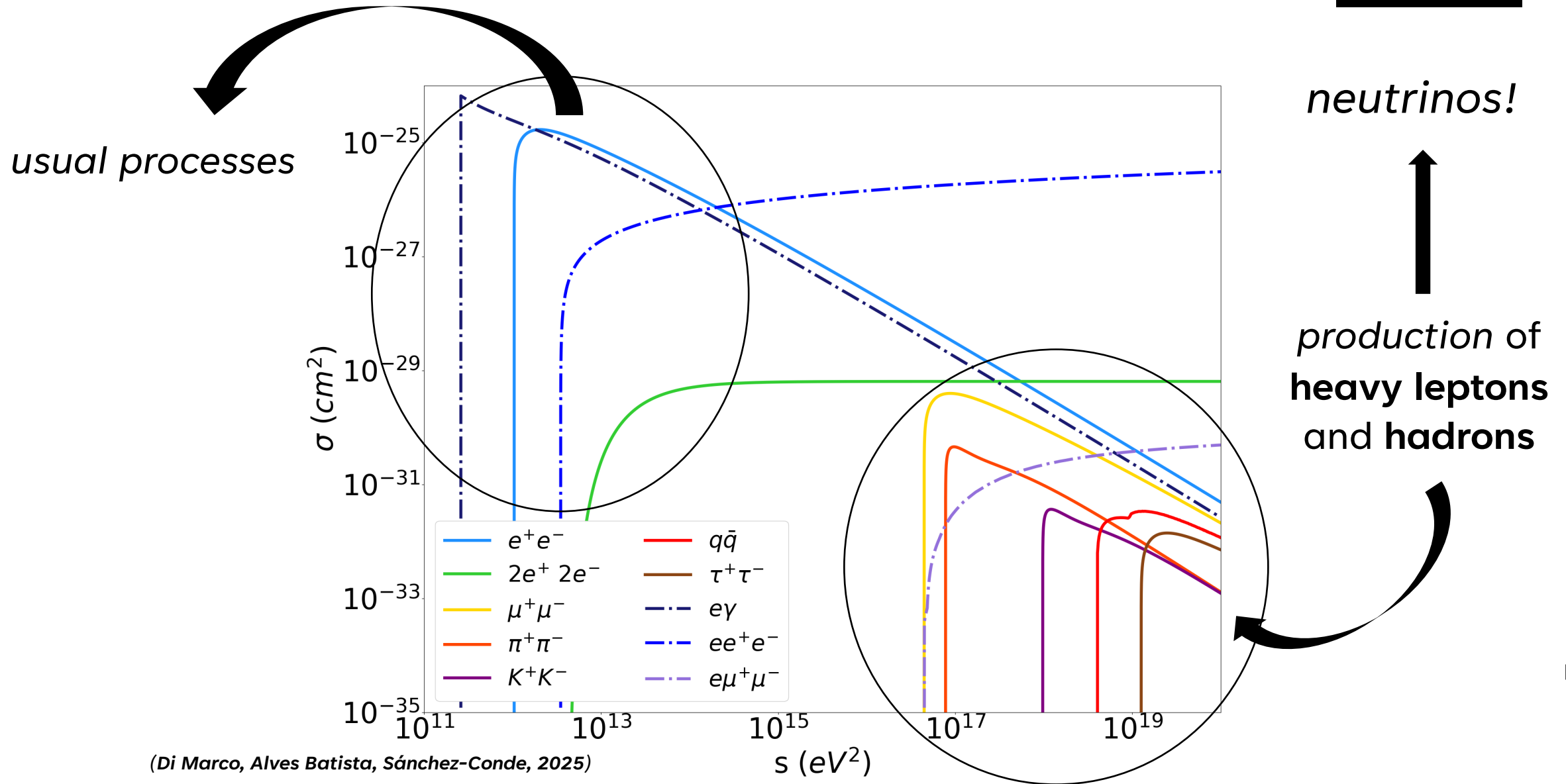


based on arXiv:2507.21867, publ. on
Astroparticle Physics & on
arXiv:26xx.xxxx, the NuPropa code

(J. Lombardi, "Processing landscape")

electromagnetic cascades – cross sections

2



neutrino & γ -ray fluxes – in propagation (usually)

extreme
source?

cosmic rays (p, nuclei, ...)

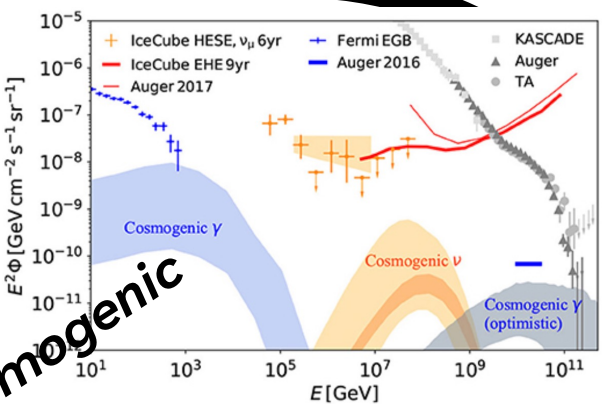


molecular
cloud

gamma rays

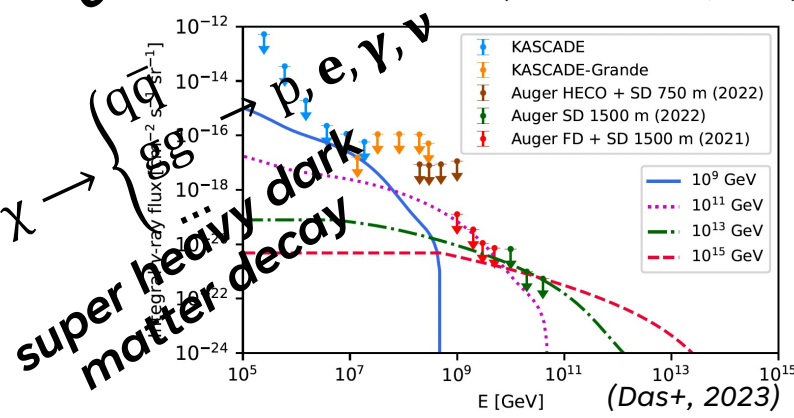
neutrinos

background
photons



cosmogenic

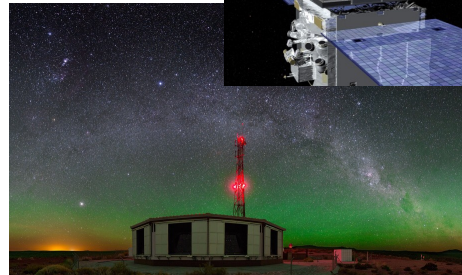
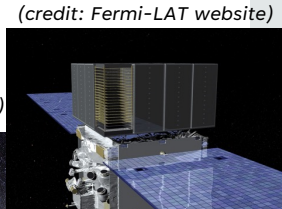
(Alves Batista+, 2019)



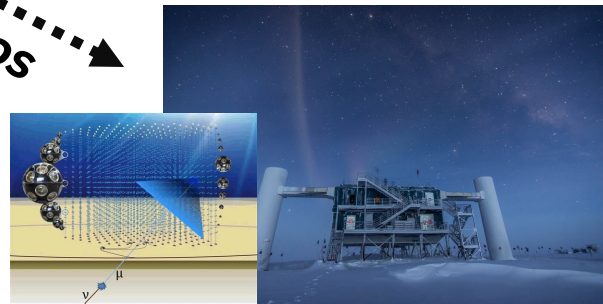
super heavy dark
matter decay

(Das+, 2023)

(credit: Fermi-LAT website)



(credit: IceCube website)



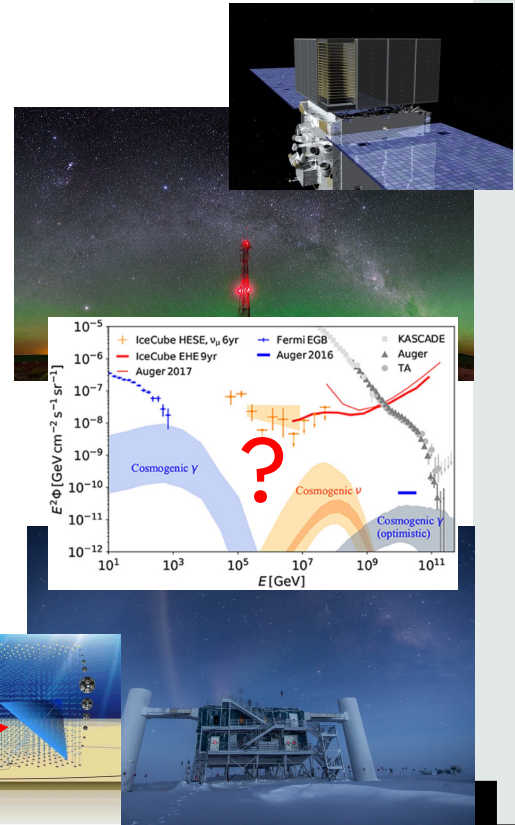
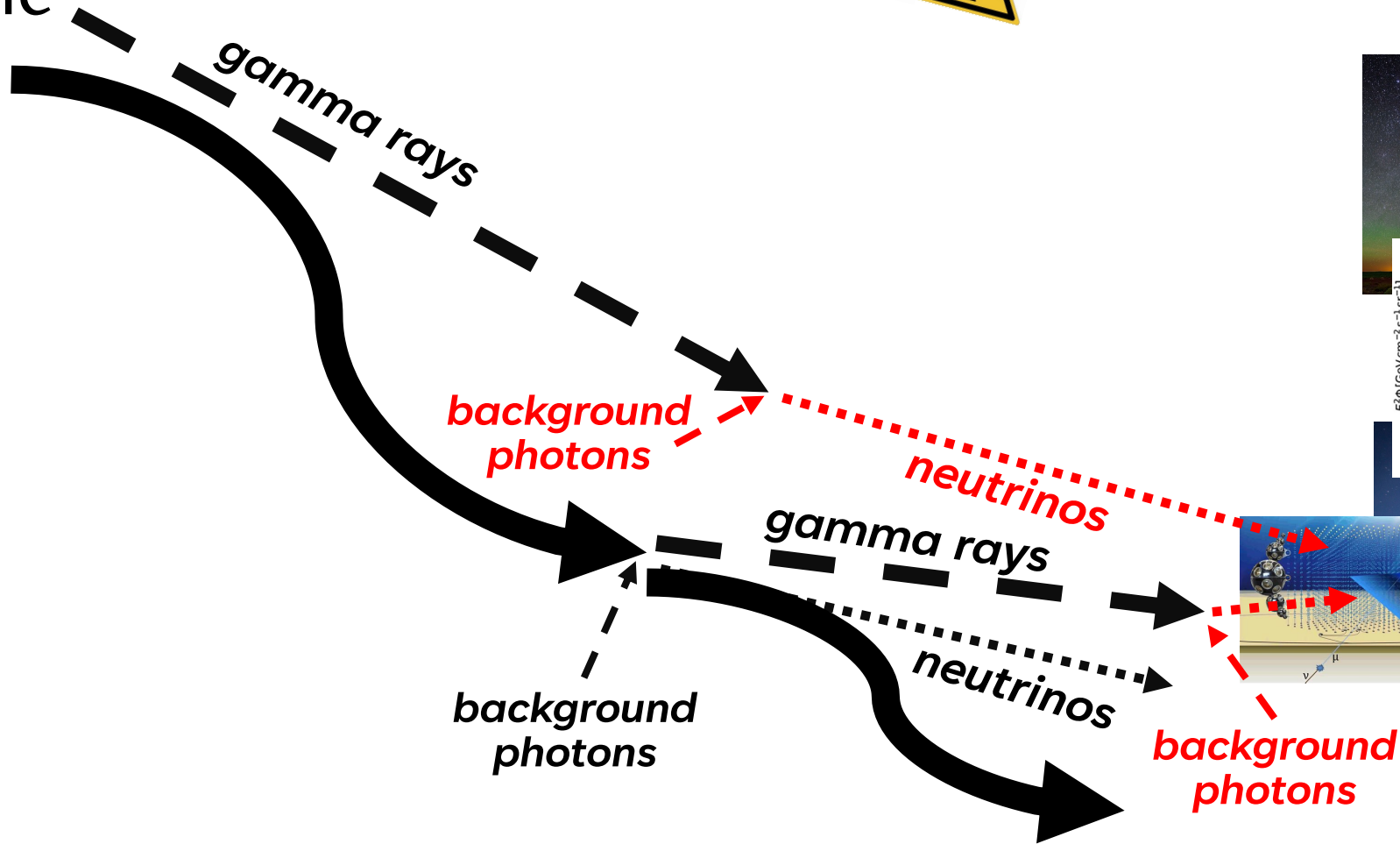
(credit: KM3Net website)



neutrino & γ -ray fluxes – in propagation?

4

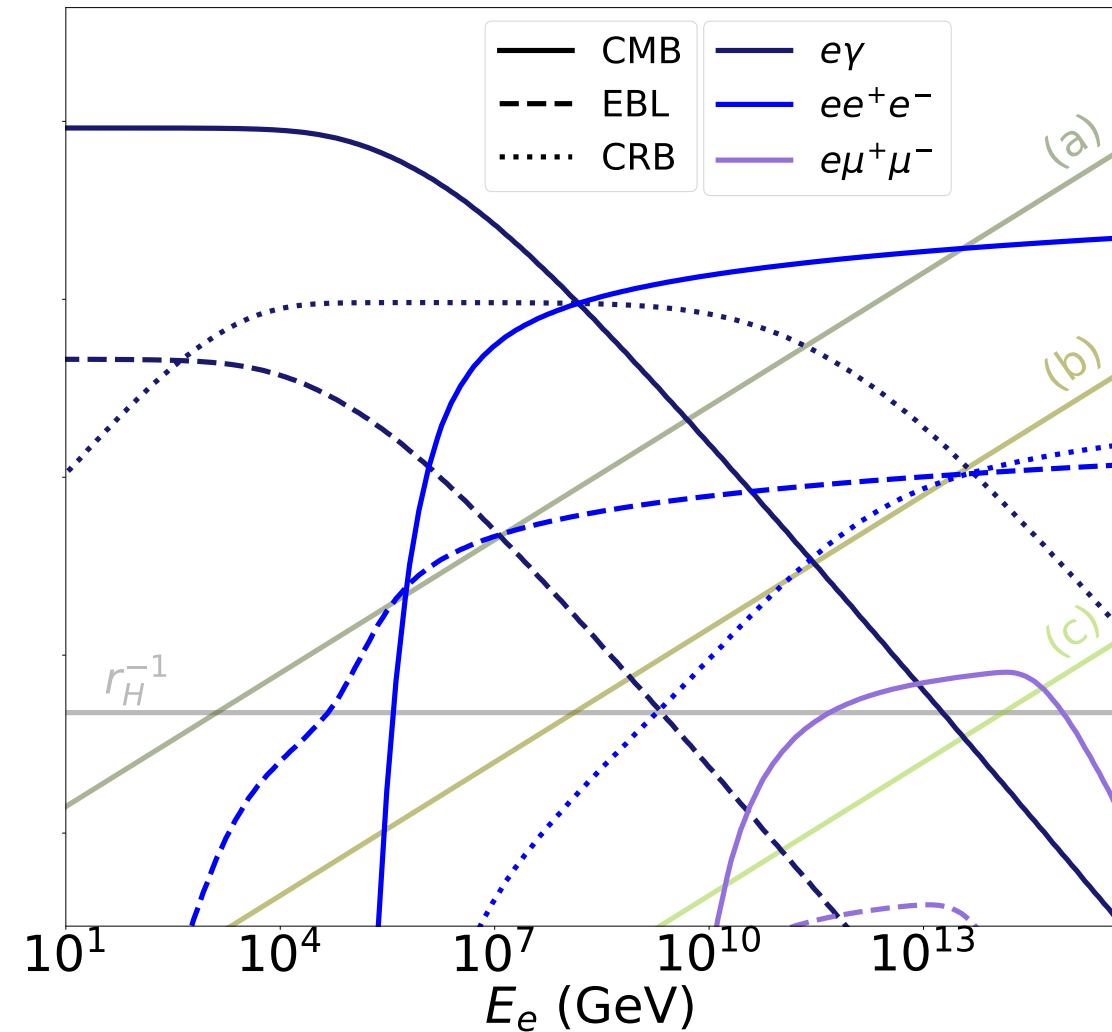
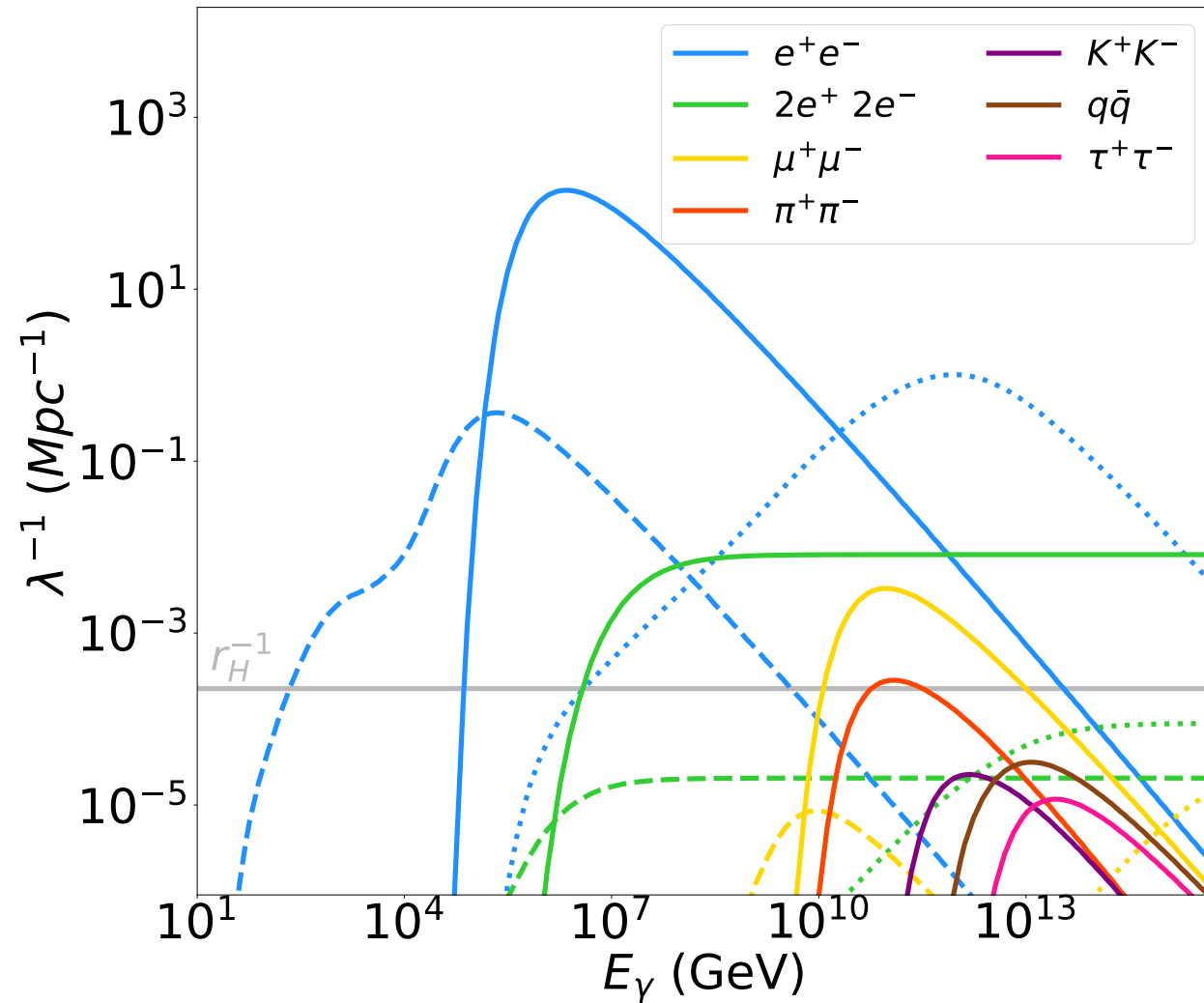
extreme
and/or exotic
source?



electromagnetic cascades – new cosmological rates

5

(Di Marco, Alves Batista, Sánchez-Conde, 2025)



for energies $> 10^{18} \text{ eV}$ muon productions on CMB!

these scenarios in CRPropa

- new decay plug-in:

CRPYTHIAxDecays

(synergy between CRPropa & PYTHIA)

- new interactions:

EMMuonPairProduction

EMChargedPionPairProduction

EMTauonPairProduction

EMElectronMuonPairProduction

MC code to simulate
astroparticle propagation!

CRPropa

(Alves Batista+, 2022)

MC event generator
for **high-energy**
physics collisions!



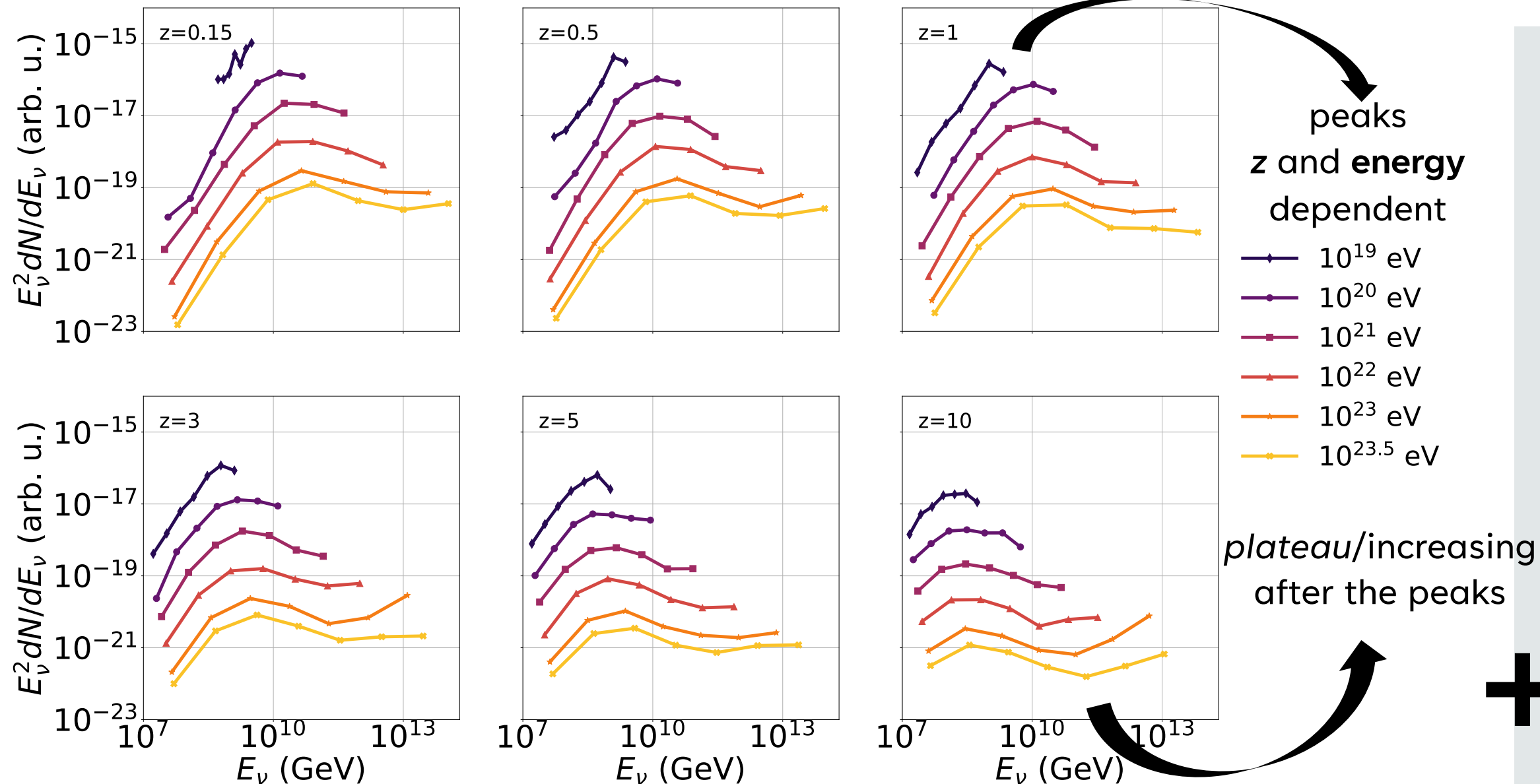
(Bierlich+, 2022)

PYTHIA



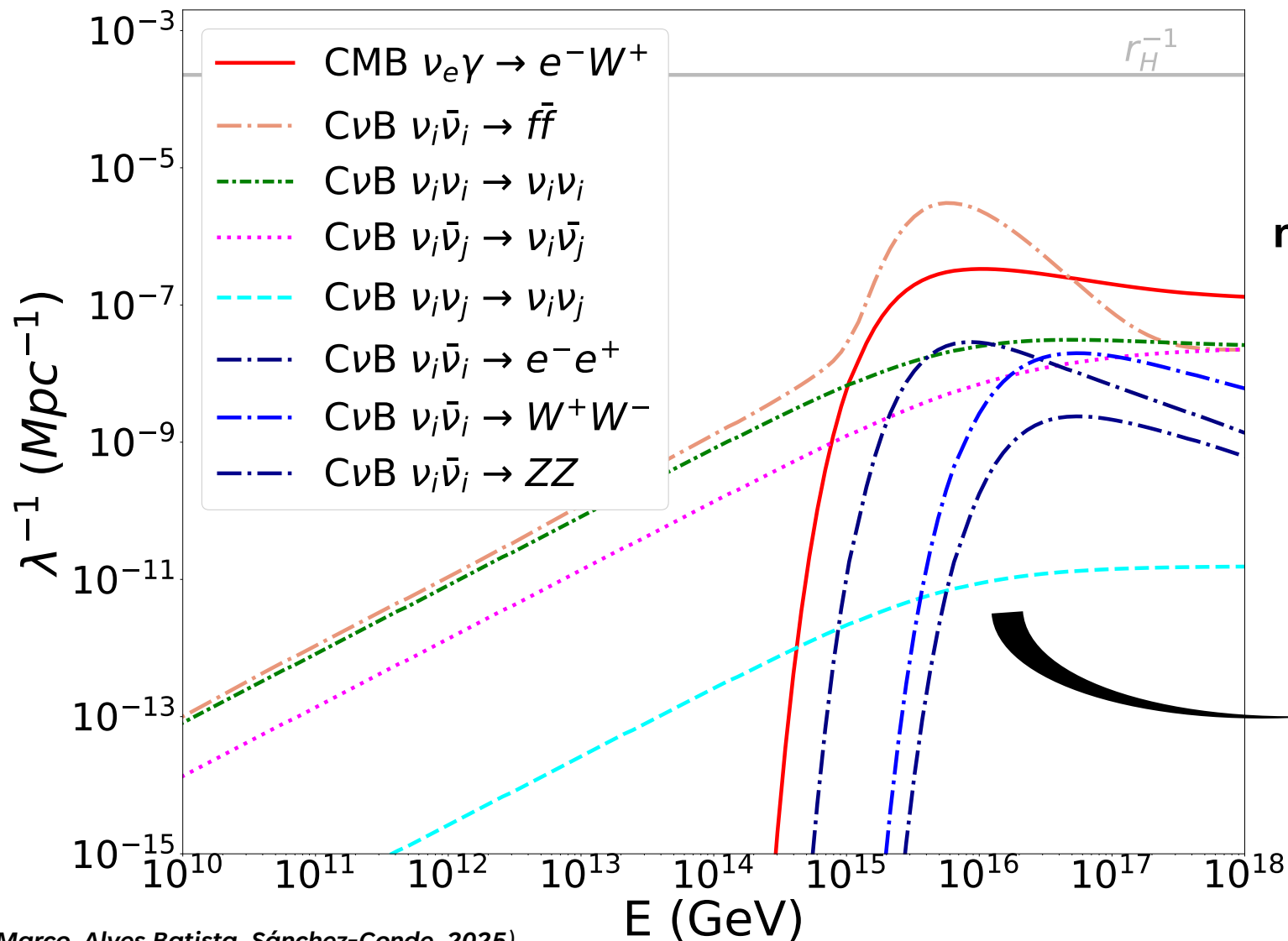
mono sources – emerging ν energy spectra

7



μ s: emerging ν propagation – interaction rates

8



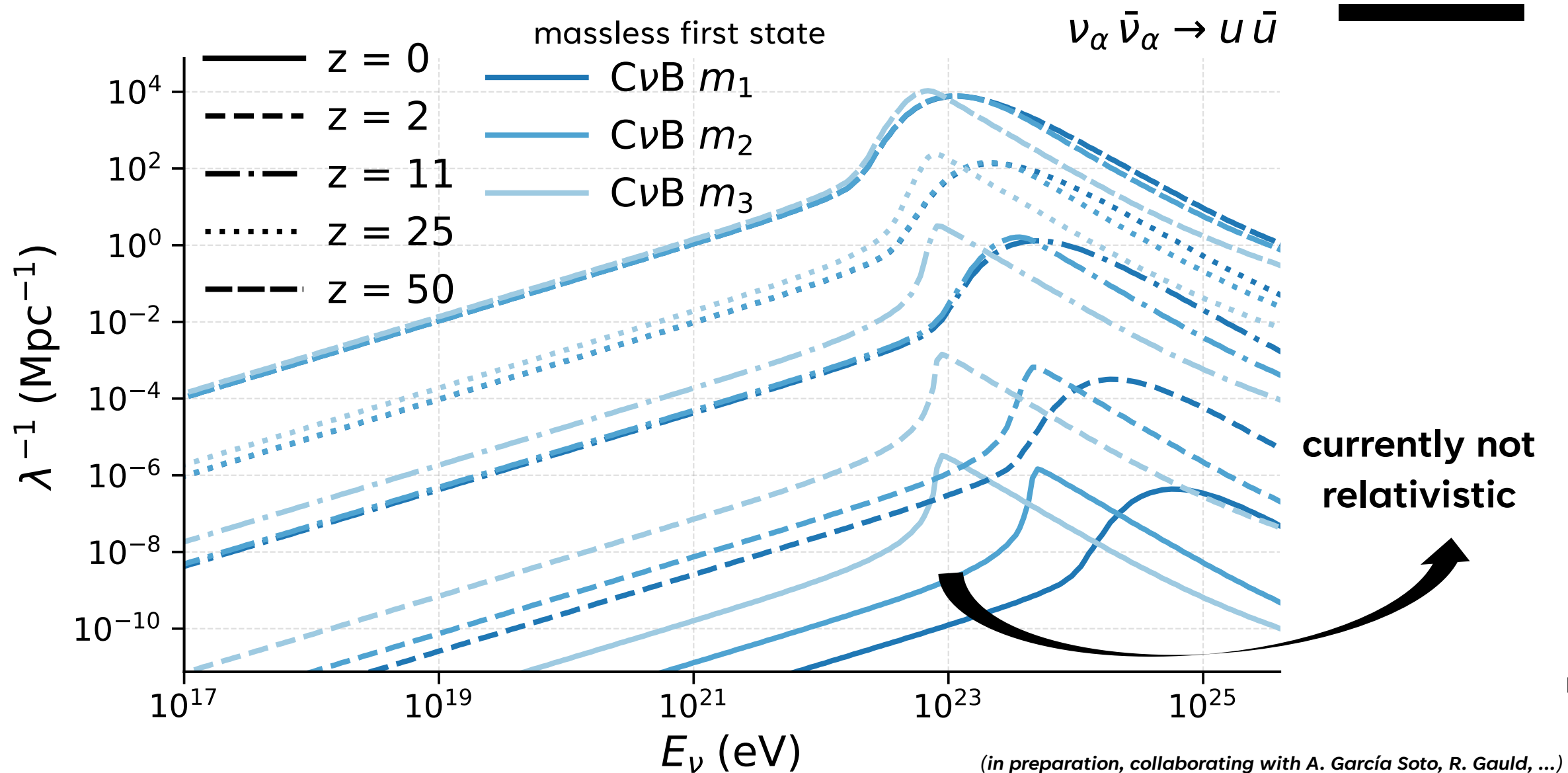
NOT included in this work,
however:
**potential interactions with
neutrino/photons backgrounds**

rates for massless
neutrinos, at $z=0$!



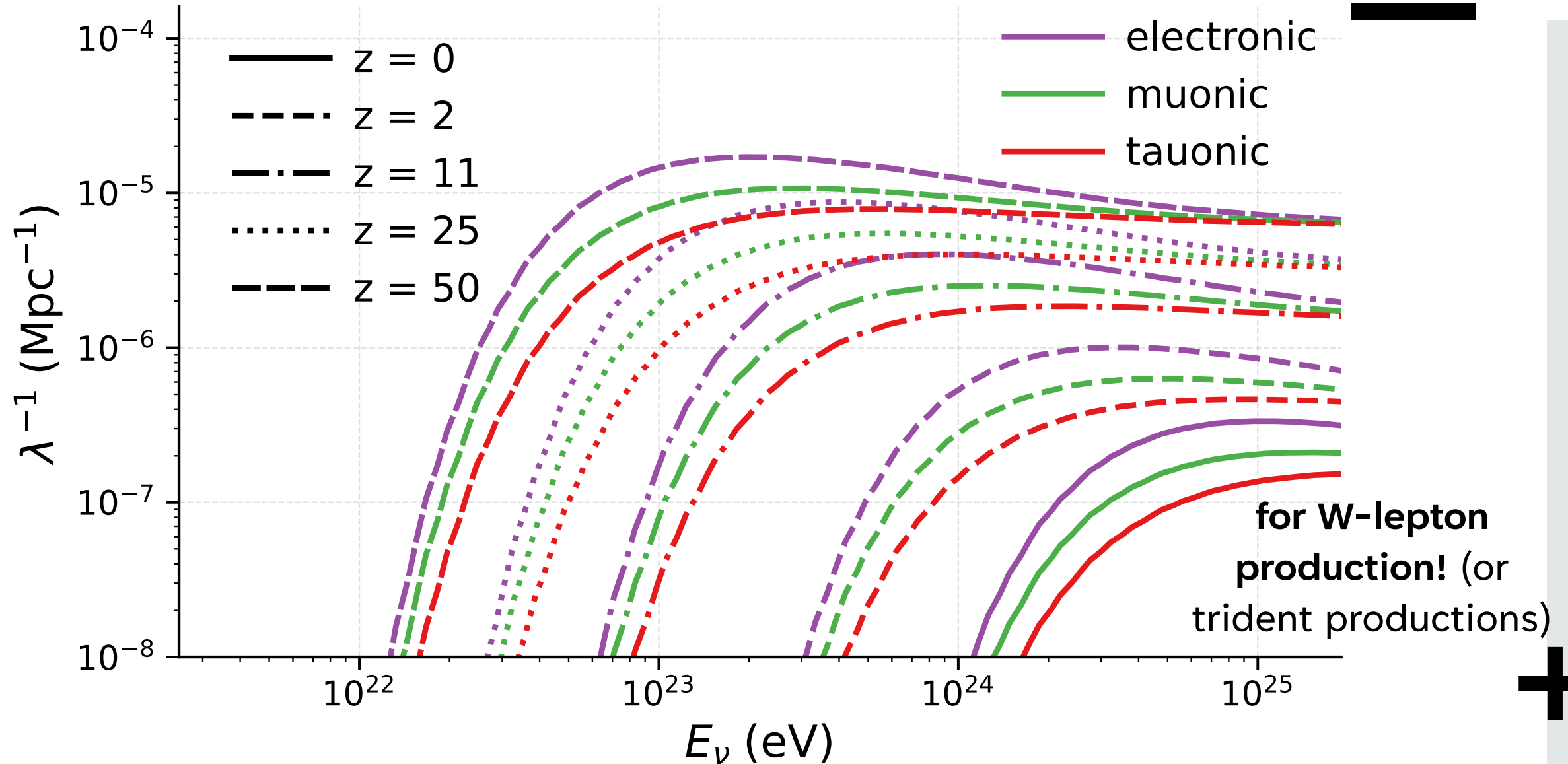
μ s: emerging ν propagation – interaction rates

9



$\bar{\nu}_\mu$: emerging ν propagation – interaction rates

10



p_s : emerging ν propagation – the NuPropa code

11

mounted on **CRPropa framework** to fully-characterize **neutrino propagation effects**:

- several interaction modules:

NeutrinoNeutrinoInteraction
NeutrinoAntineutrinoInteraction
NeutrinoPhotonInteraction

- massive neutrino background:

NeutrinoField

- oscillation facilities:

NeutrinoMixing
NeutrinoOscillation

- treatment of the secondary:

Hadronisation
 (CRPropa & PYTHIA interface)

- the interactions in play in:

Channels
ChannelsBundle

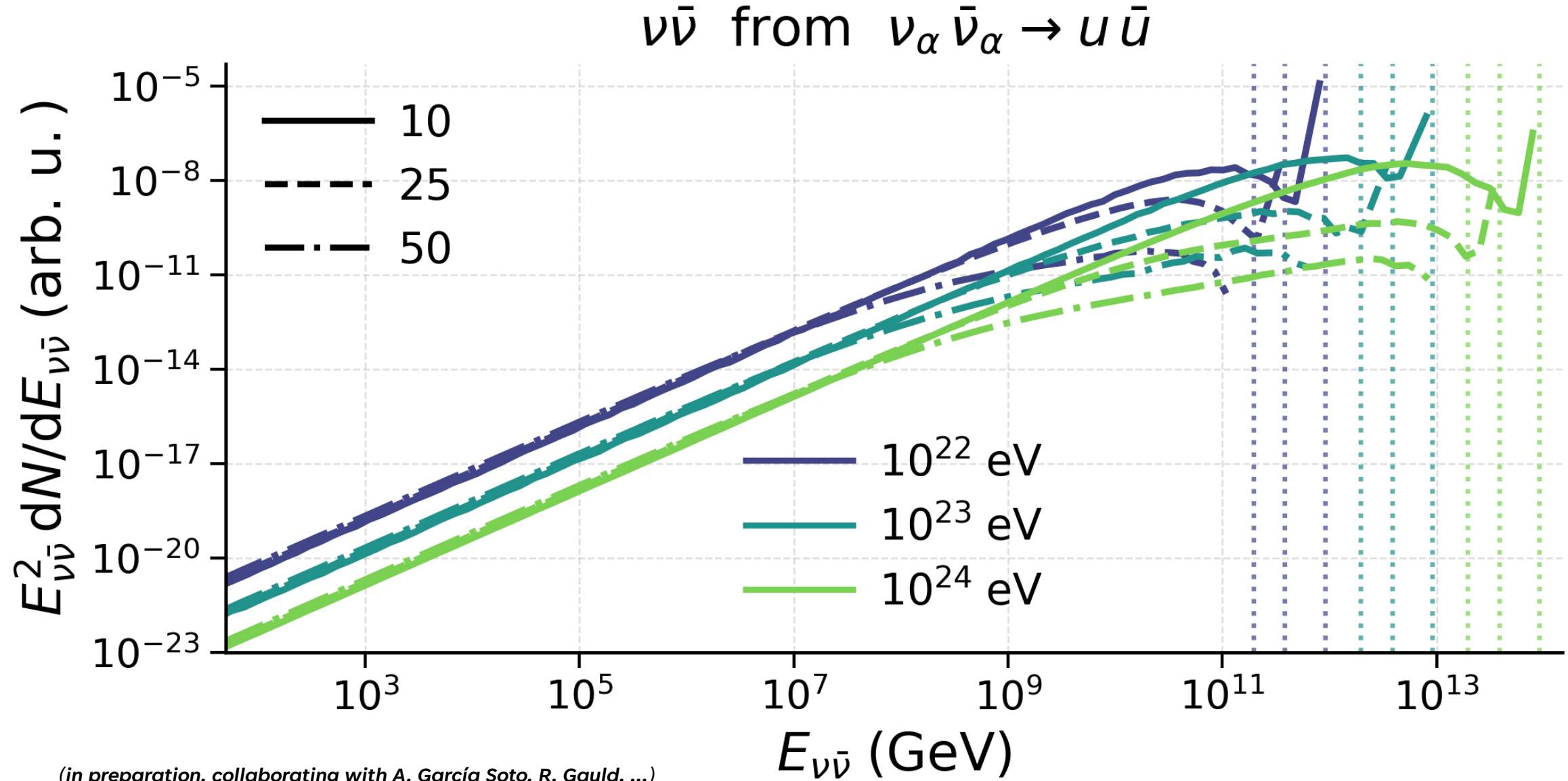
- technical modules:

RelativisticInteraction
PartonicCalculation



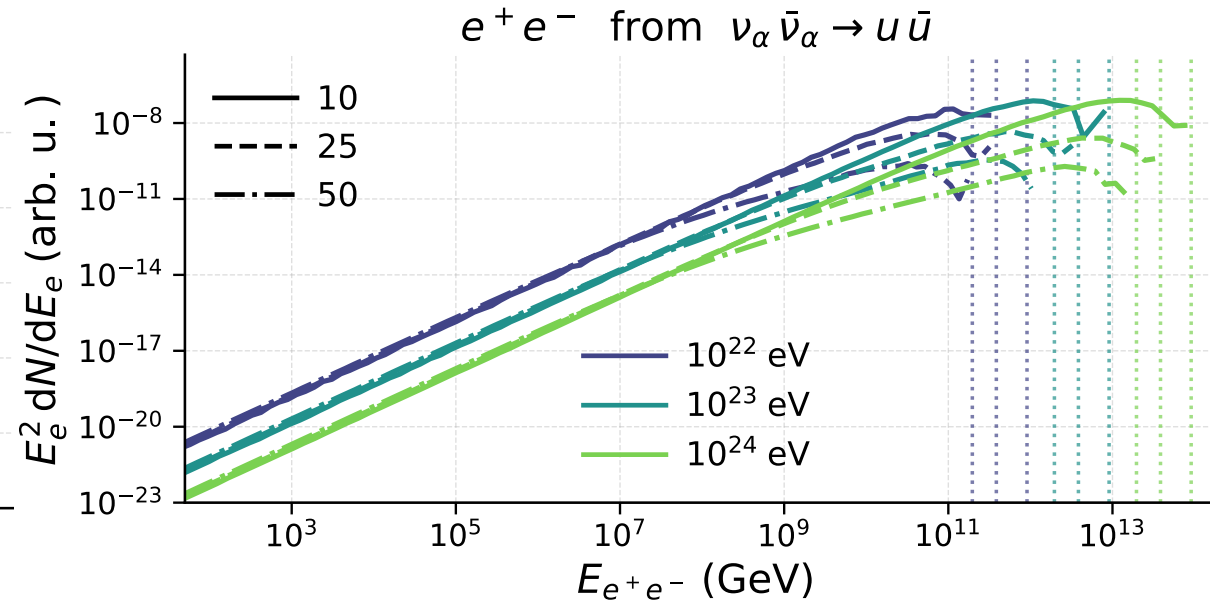
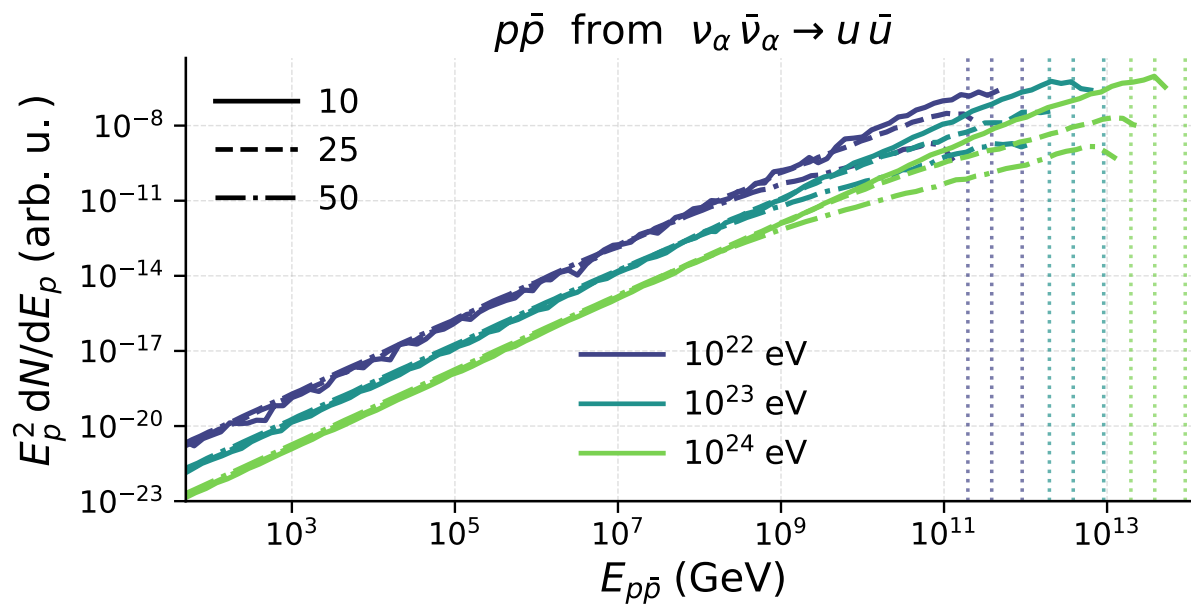
p_s : emerging ν propagation – energy spectra

12

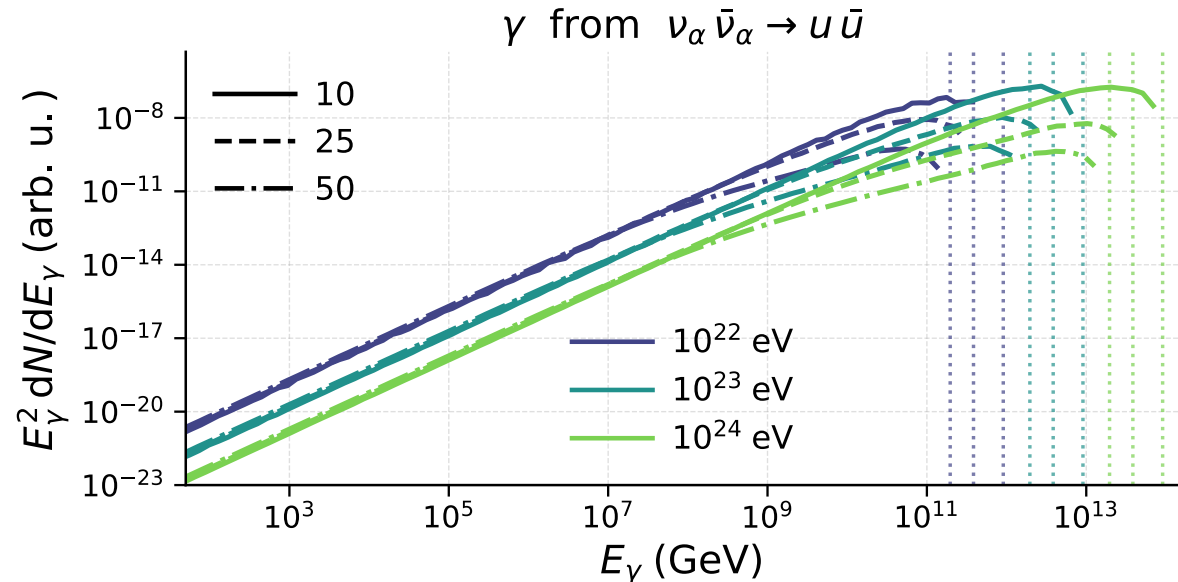


$p\bar{p}$: emerging ν propagation – multimessenger

13



and their propagation could be
further characterised in the same
CRPropa code introducing **magnetic
fields, photons, gases and
processes...**



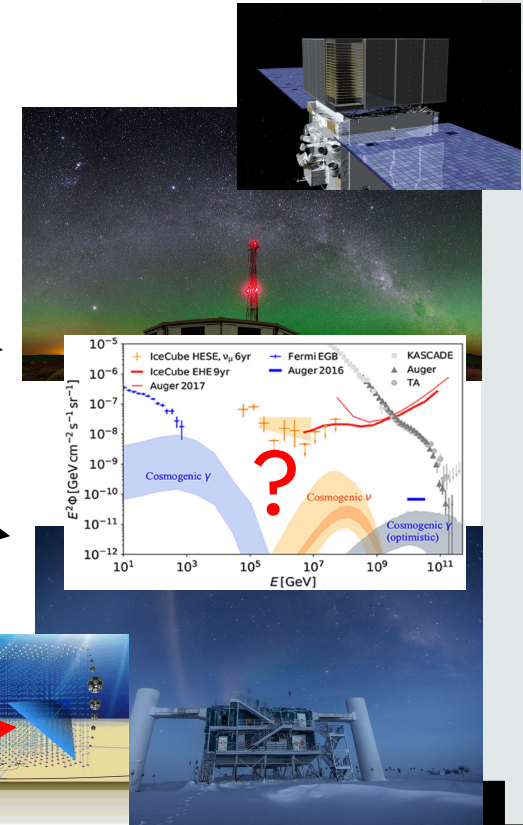
(in preparation, collaborating with A. García Soto, R. Gauld, ...)



14

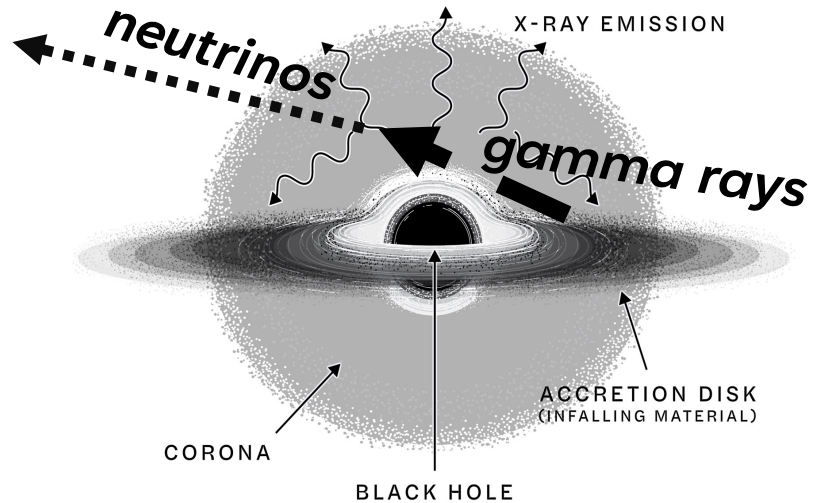
The diagram illustrates the detection of cosmic rays and the resulting particle cascades. It shows the following components and processes:

- cosmic rays**: Represented by a thick black curved arrow entering from the left.
- gamma rays**: Represented by a dashed black line with arrows.
- neutrinos**: Represented by a dotted black line with arrows.
- background photons or gases**: Indicated by a dashed black arrow pointing towards the initial interaction.
- background photons**: Shown as red dashed arrows originating from the initial interaction and pointing towards the detectors.
- neutrinos**: Shown as red dotted arrows originating from the initial interaction and pointing towards the detectors.
- gamma rays**: Shown as black dashed arrows originating from the initial interaction and pointing towards the detectors.
- background neutrinos**: Shown as red dotted arrows pointing towards the detectors.
- Detectors**: Represented by yellow triangular warning symbols (radiation and radioactivity) at the top right, and a detailed view of a detector array at the bottom right.
- Particle Labels**: The bottom right inset shows a particle labeled μ (muon) and another labeled ν (neutrino).



leptonic ν production – in AGN hot corona?

15

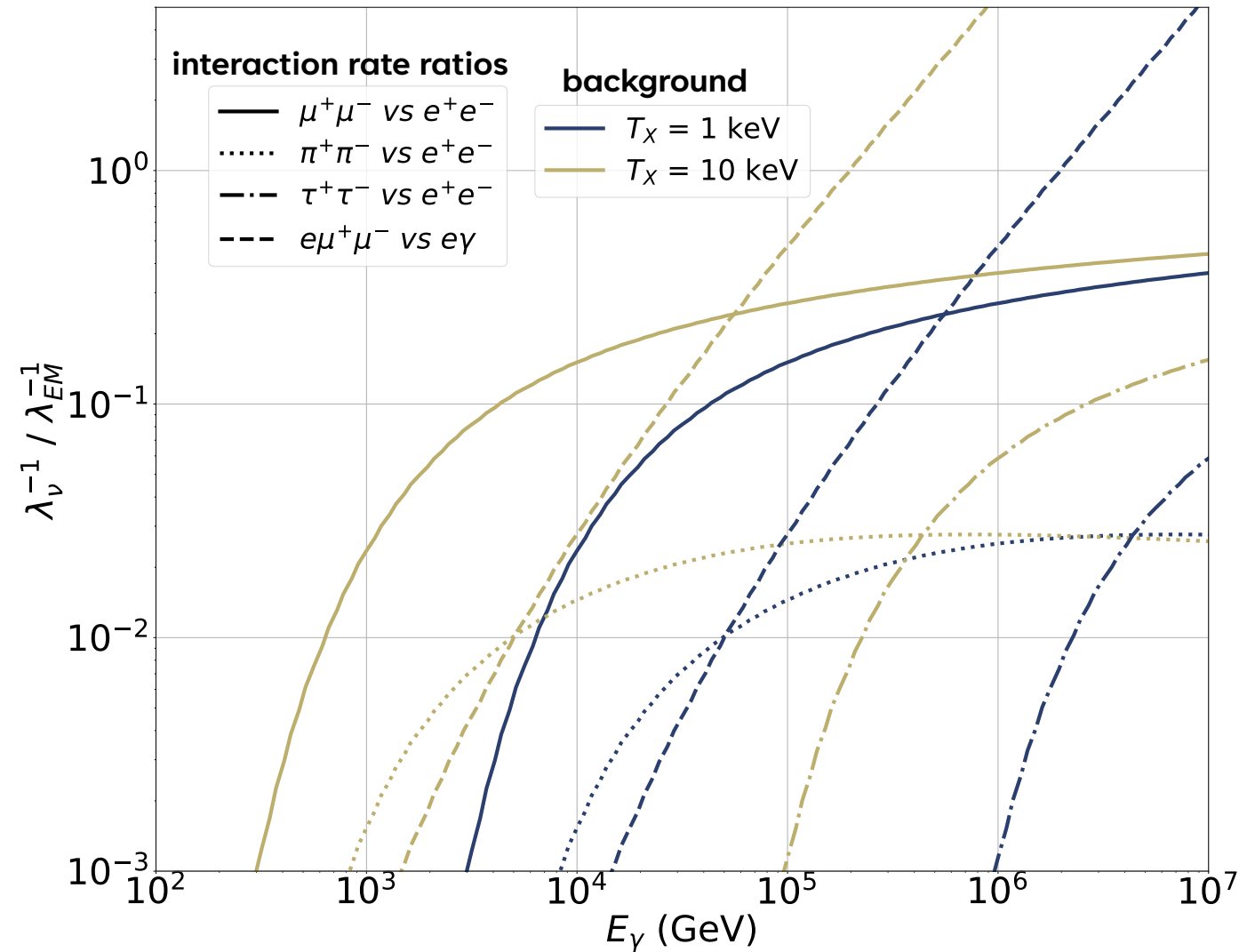
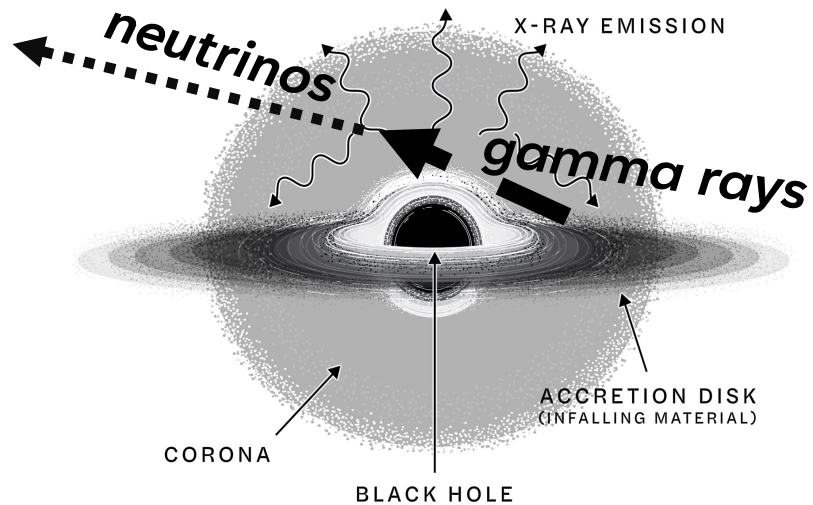


(Halzen, 2023)



leptonic ν production – rates in corona

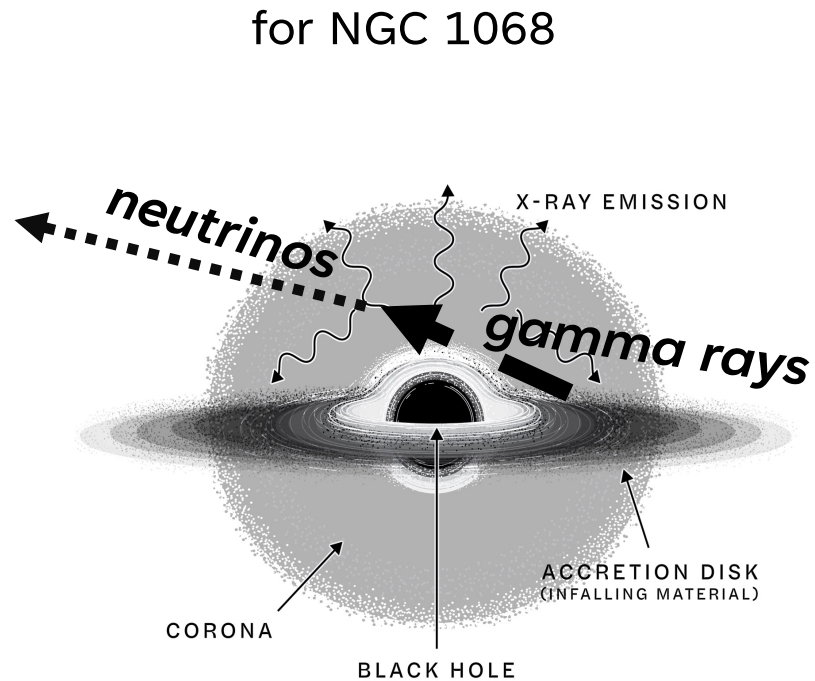
16



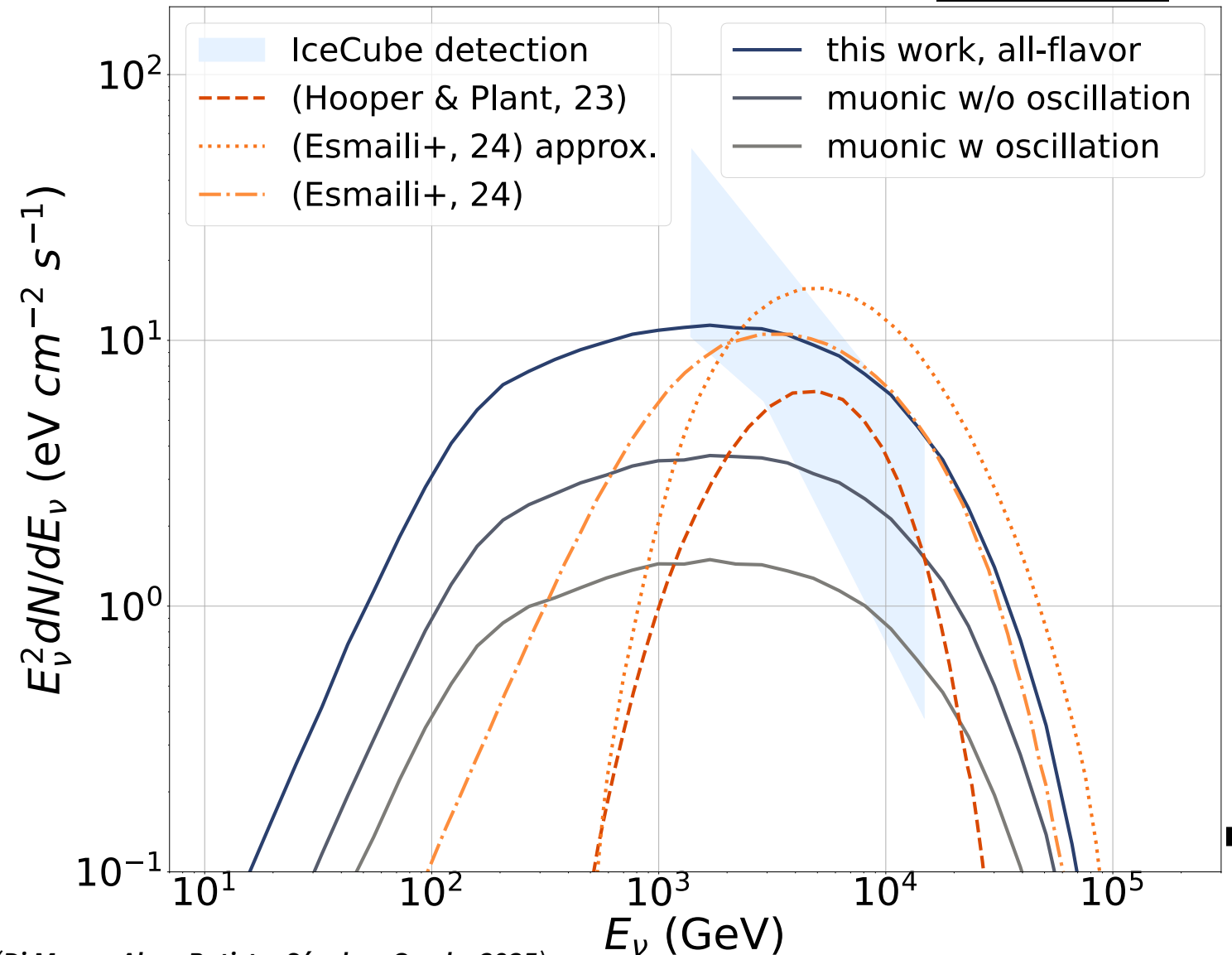
(Di Marco, Alves Batista, Sánchez-Conde, 2025)

leptonic ν production – energy spectra

17



(just by considering **electron** and **muon pair production** processes)

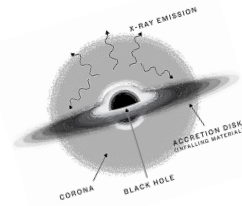


(Di Marco, Alves Batista, Sánchez-Conde, 2025)

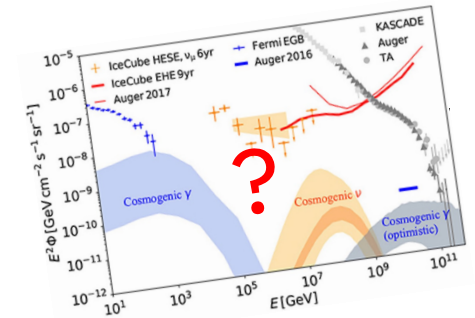


concluding with some prospects

in science:



$$\chi \rightarrow \begin{cases} q\bar{q} \\ gg \\ \dots \end{cases} \rightarrow p, e, \gamma, \nu$$



18

leptonic production of neutrinos and/or neutrino propagation effects their might:

- **alter** expected balance of gamma-ray and neutrino fluxes;
(*cosmogenic?* exotic physics searches, e.g. dark matter?)
- **leptonically produce** neutrino in source, e.g. active galaxies;
- be exploit to characterise the **particle backgrounds**, e.g. overdensities.

in the MC simulation framework:

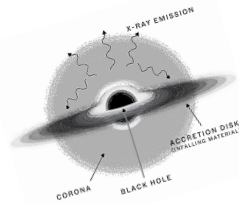
synergy between CRPropa & PYTHIA codes for multimessenger detailed studies, as the **NuPropa plug-in** (soon!) among the possible others.

CRPropa

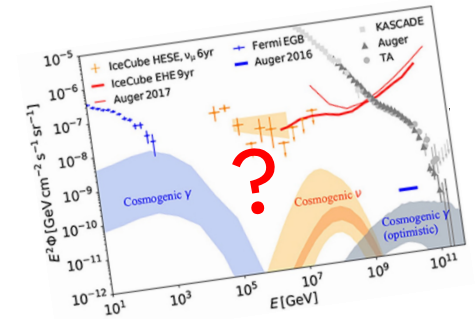


concluding with some prospects

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$$\chi \rightarrow \begin{cases} q\bar{q} \\ gg \\ \dots \end{cases} \rightarrow p, e, \gamma, \nu$$



19

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in the MC simulation framework:

ithank you! ☺

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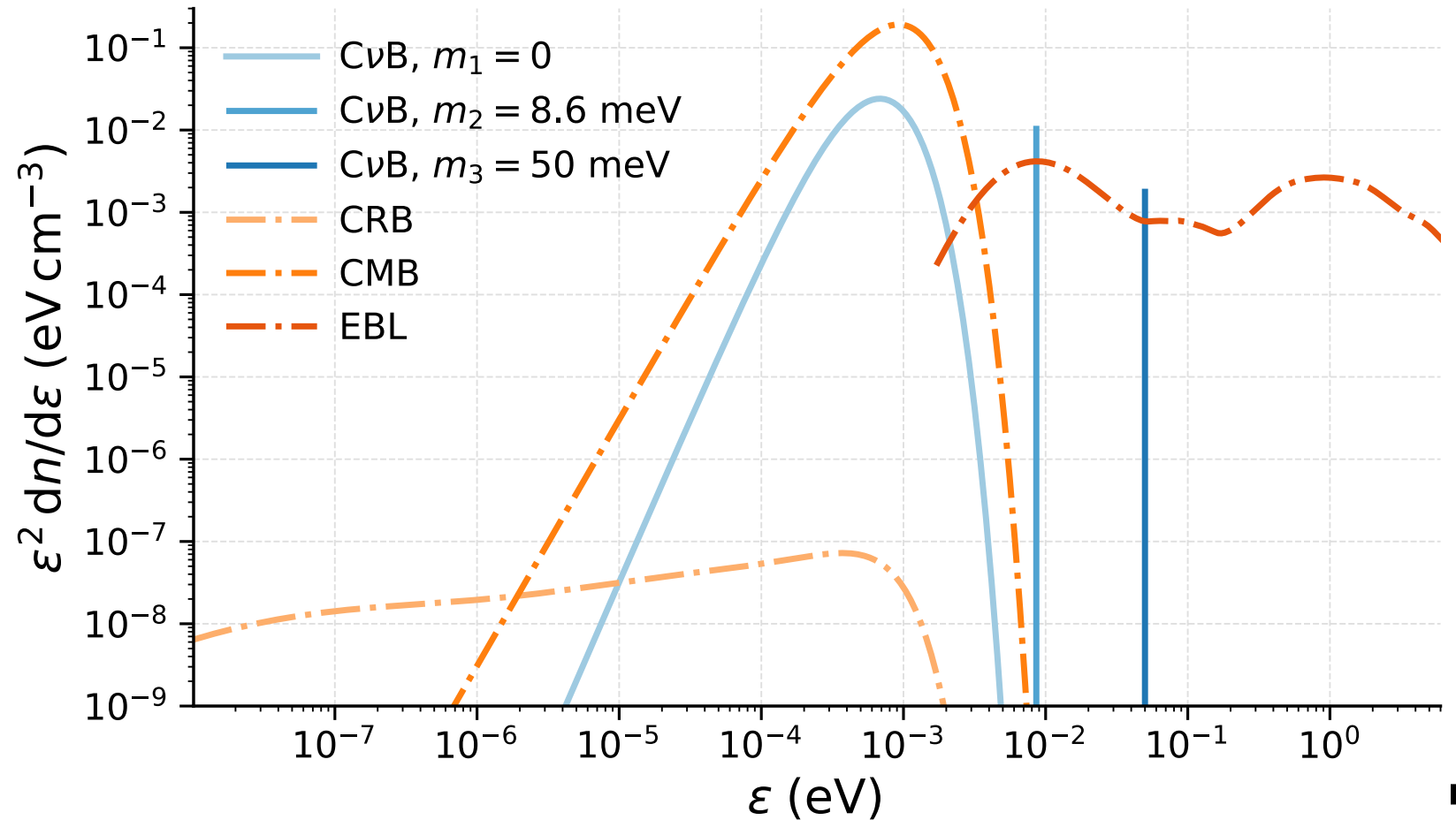
CRPropa ↔



cosmological background photons

primordial:
cosmic microwave &
neutrino backgrounds

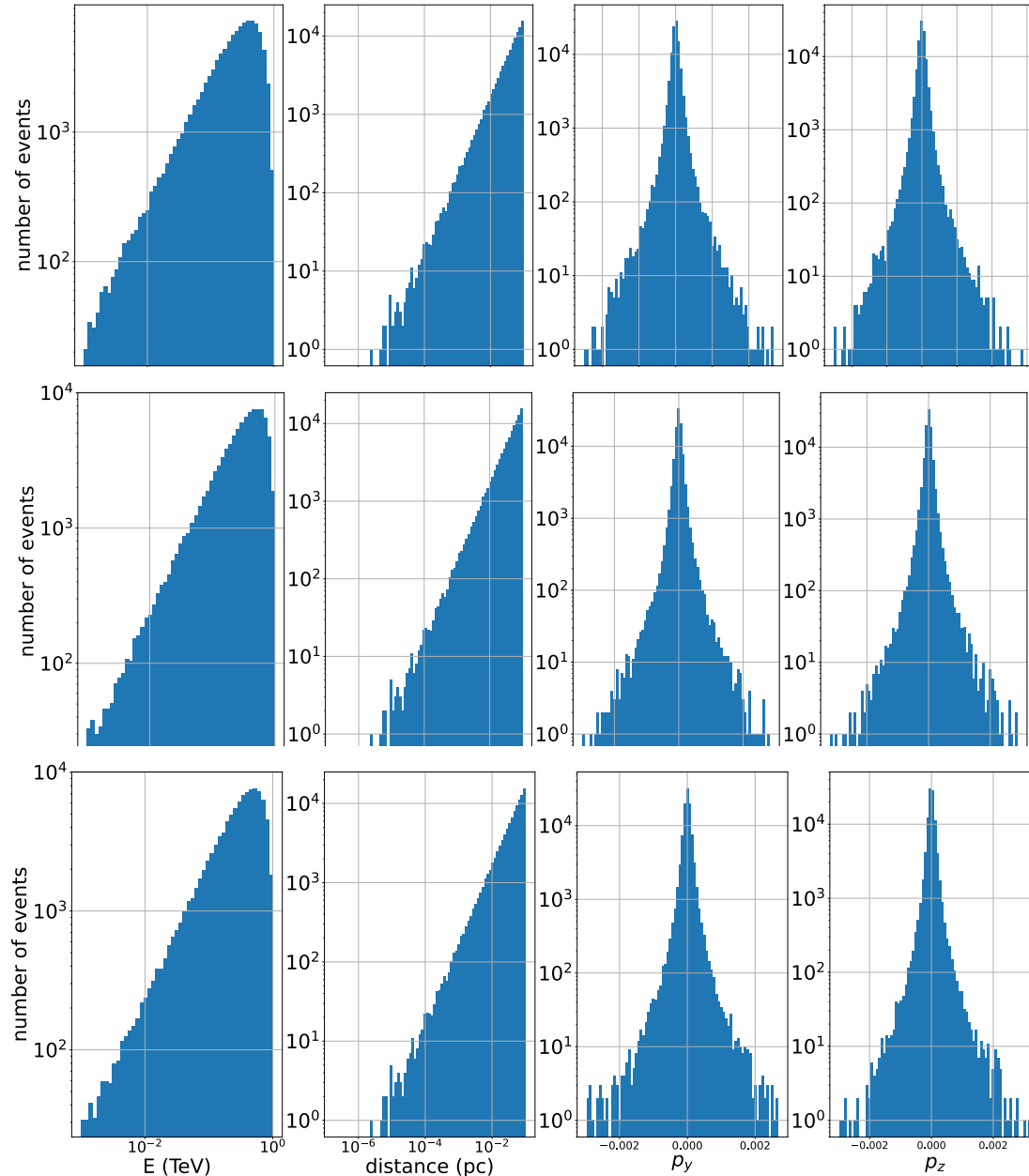
astrophysical:
cosmic radio background,
extragalactic background
light



(in preparation, collaborating with A. García Soto, R. Gauld, ...)

CRPYTHIAxDecays – muon decay

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electrons

- injecting 1e5 muons of **1 TeV** along the x-axis!

electronic
(anti)neutrinos

- angular correction ON

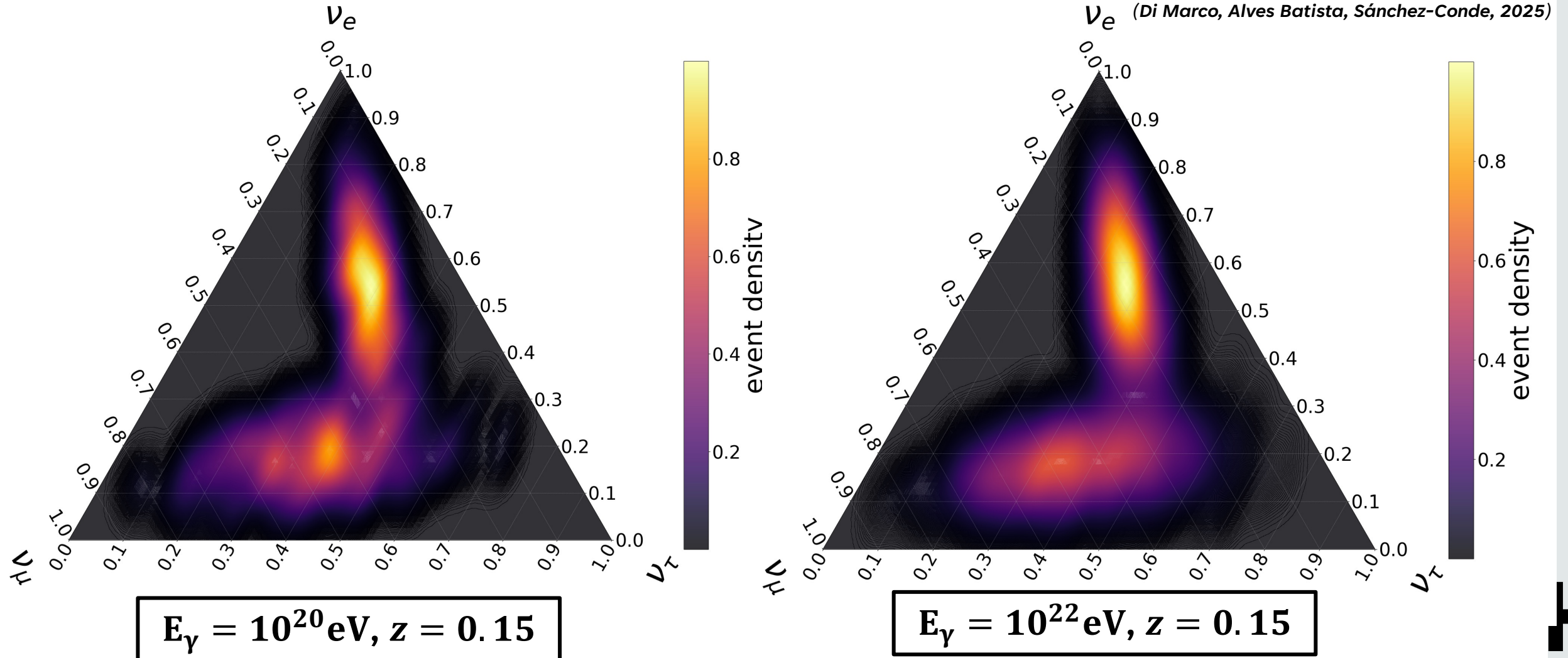
muonic
neutrinos

(Di Marco, Alves Batista, Sánchez-Conde, 2025)



mono sources – flavour probabilities

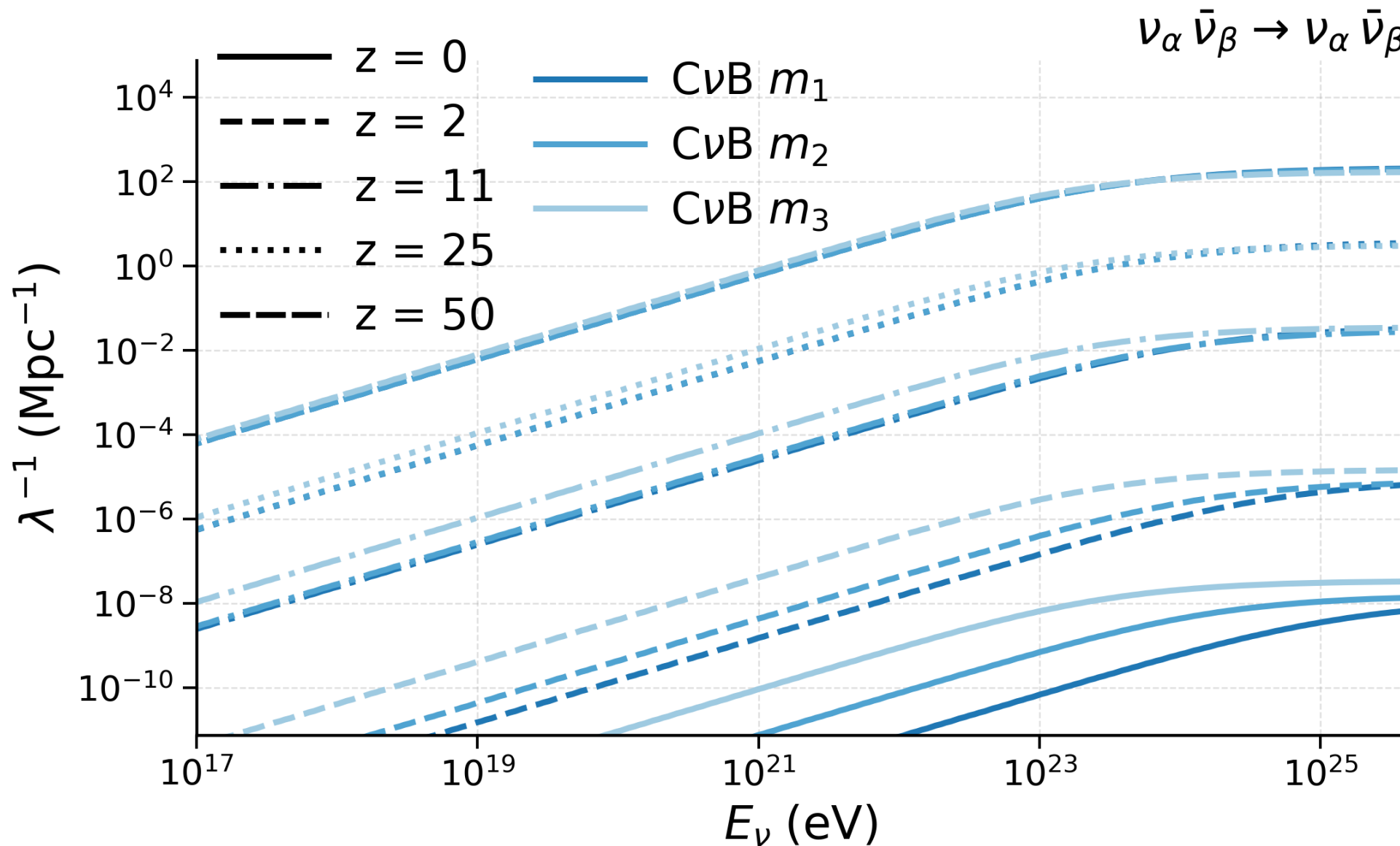
22



plots computed through the [Neurthino](#) code with the last NuFit-6.0 parameters by «propagating probabilities»

μ s: emerging ν propagation – interaction rates

23



(in preparation, collaborating with A. García Soto, R. Gauld, ...)

