Neutrino astrophysics and the multi-messenger approach

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PUCP graduate students seminar
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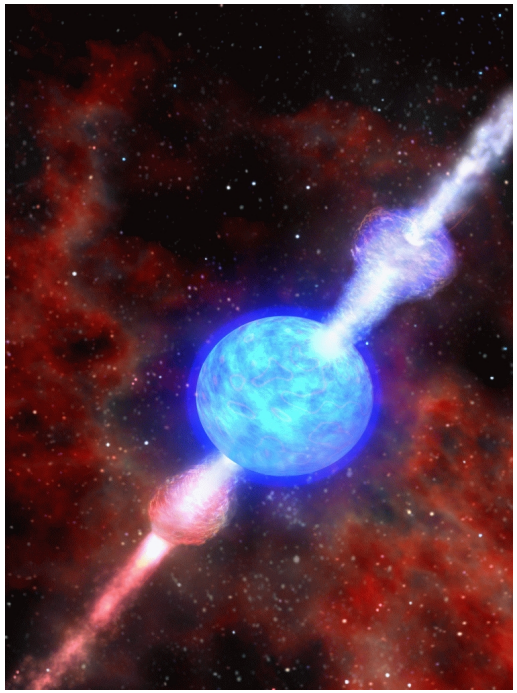
The multi-messenger approach

A self-consistent picture?



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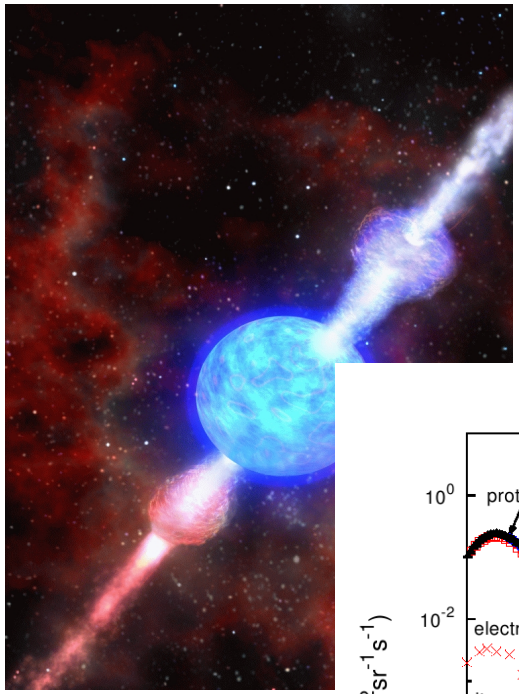

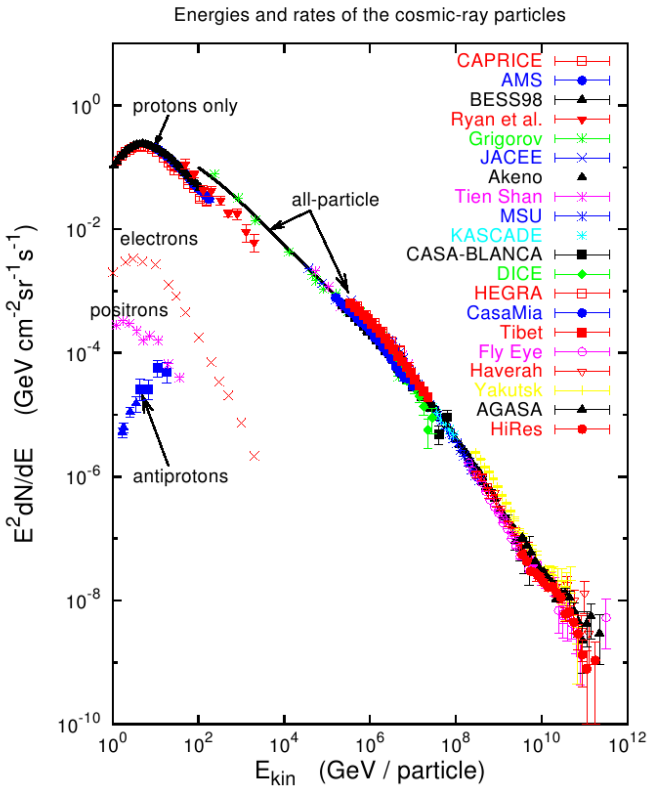

The multi-messenger approach

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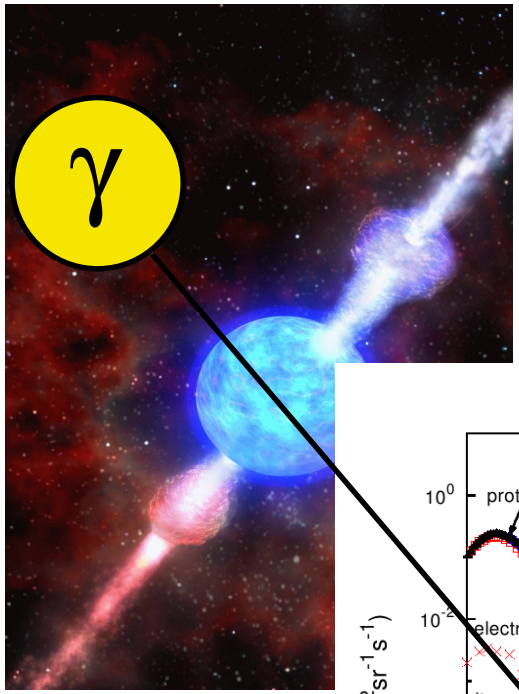

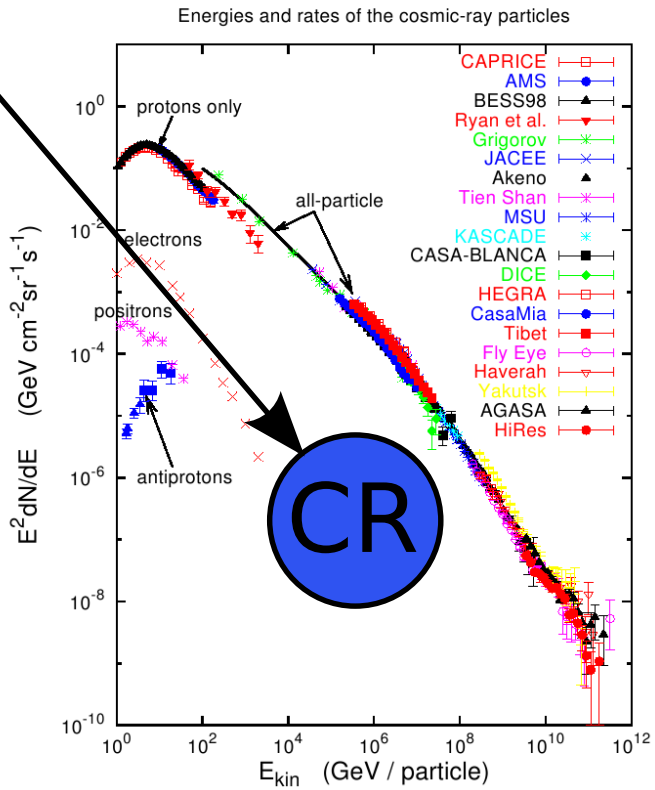

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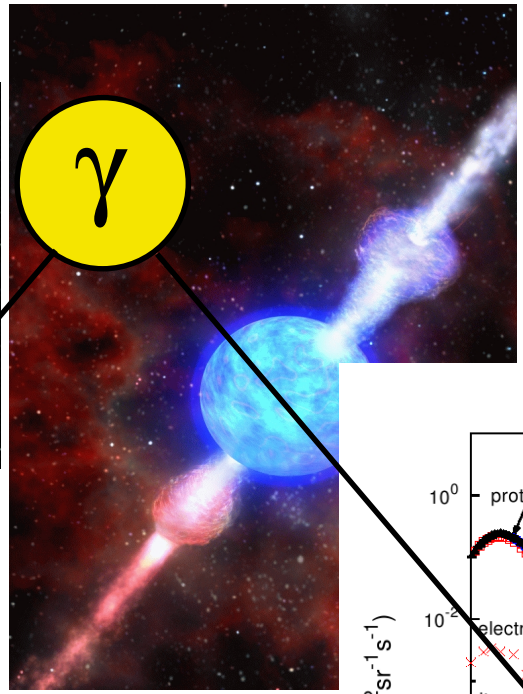
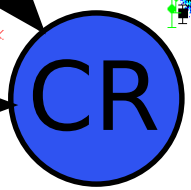
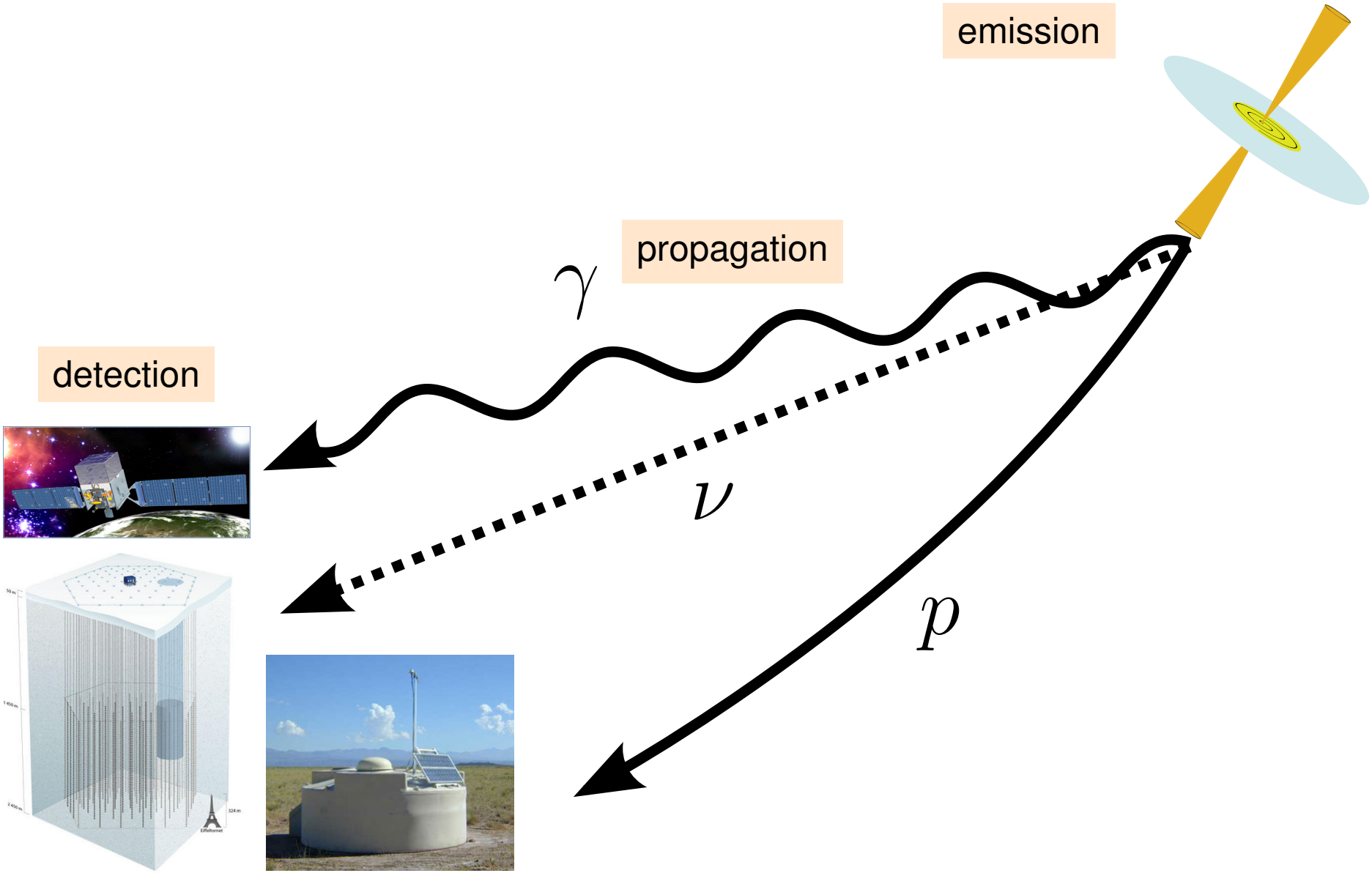


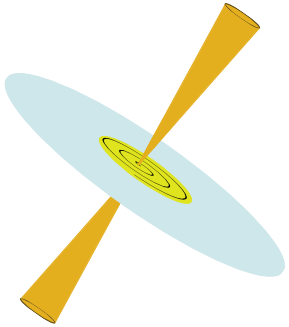


Cosmic-ray, photon, and neutrino propagation

The current working model



emission



- magnetically-confined p's shock-accelerated up to $\sim 10^{21}$ eV
- power-law emission spectrum $\sim E^{-\alpha}$
- best candidates: GRBs (transient), AGN (flaring)
- photohadronic production of UHE γ's and ν's at the source:

$$p + \gamma_b \to \Delta^+(1232) \to \begin{cases} n + \pi^+ & (\text{BR} = 1/3) \\ p + \pi^0 & (\text{BR} = 2/3) \end{cases}$$

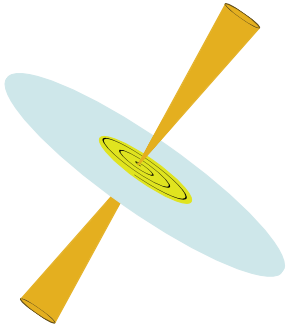
Gamma-rays: $\pi^0 \to \gamma + \gamma$

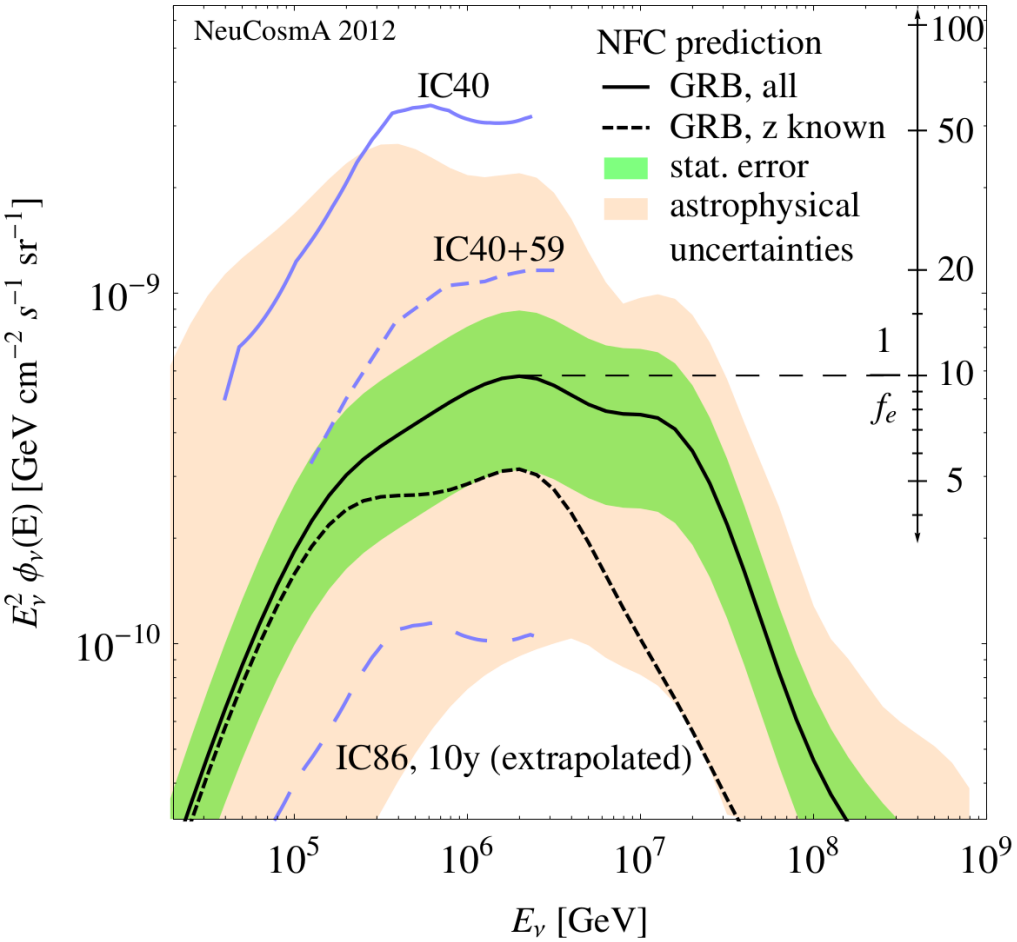
UHE ν's (direct): $\pi^+ \to \mu^+ + \nu_\mu$, $\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$

- Escaped n's become the UHECRs: $n \to p + e^- + \bar{\nu}_e$
- π^- from additional $p\gamma$ channels (implemented in NeuCosmA code)
- comparison of AGN ν production models:
  ARGÜELLES, MB, GAGO, *JCAP* **1012**, 005 (2010) [1008.1396]

Detailed GRB ν production (fireball model):

emission





HÜMMER, BAERWALD, WINTER, *PRL* **108**, 231101 (2012) [1112.1076]

Cosmic-ray, photon, and neutrino propagation

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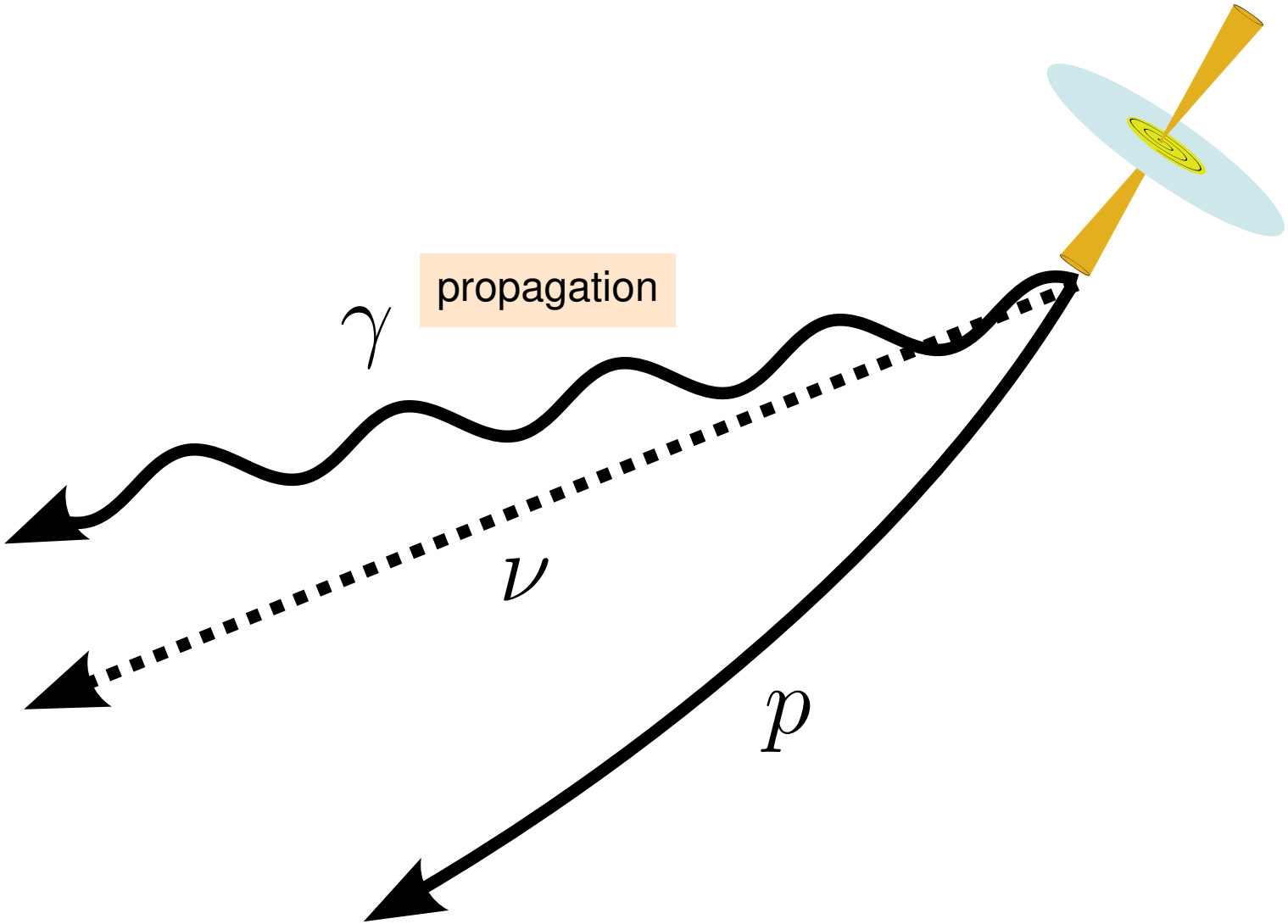
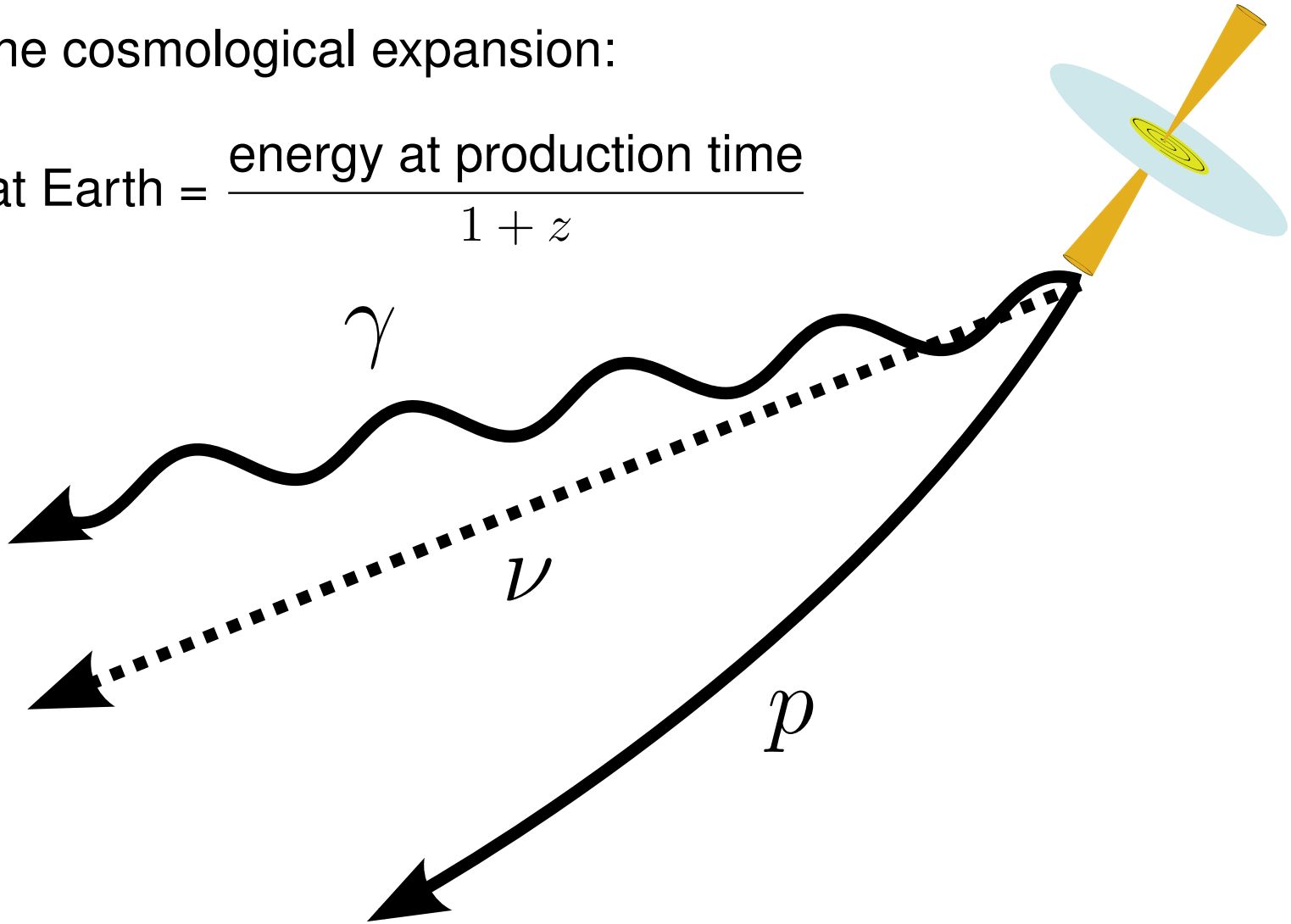
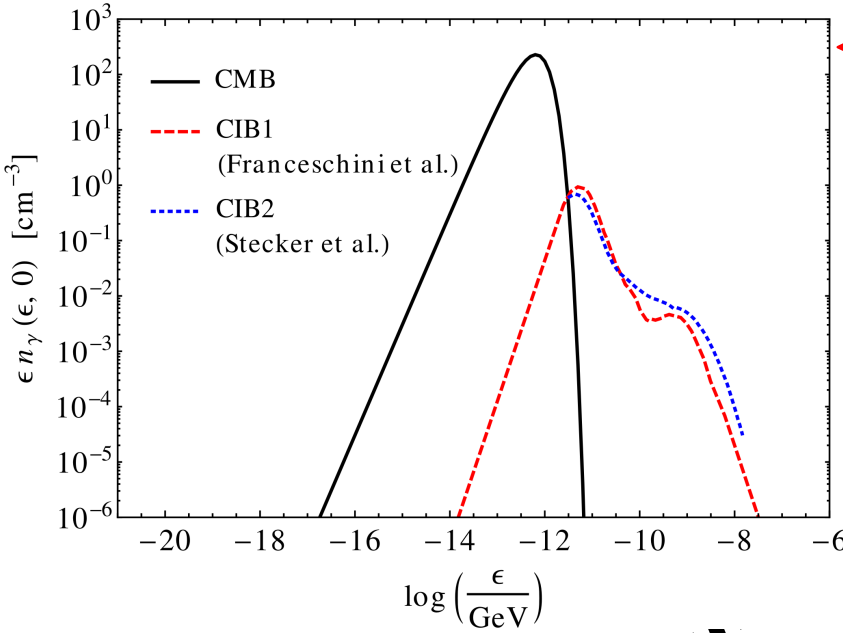


Because of the cosmological expansion:

$$\text{energy at Earth} = \frac{\text{energy at production time}}{1+z}$$



Cosmological photon backgrounds:



◀ they evolve with redshift,
i.e., $n_\gamma\,(\epsilon, z)$

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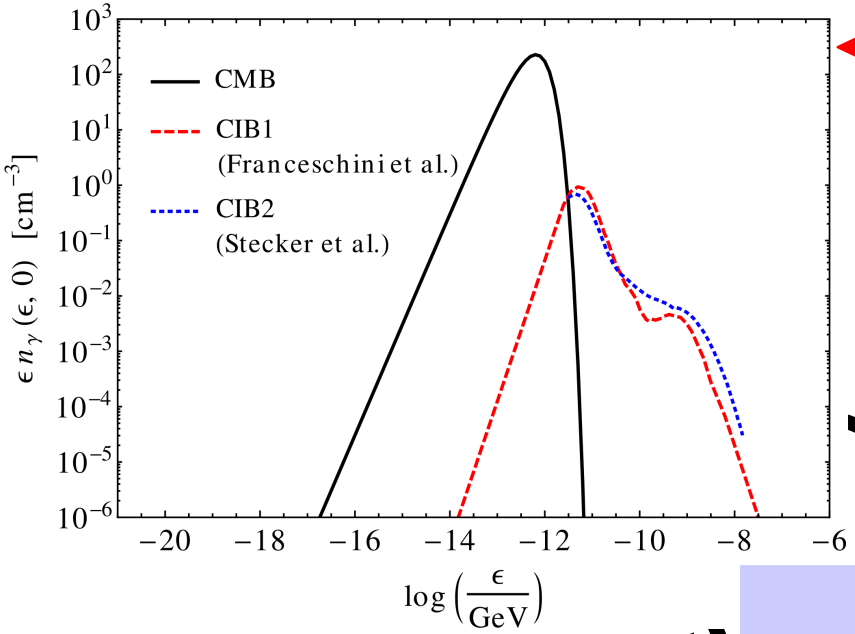

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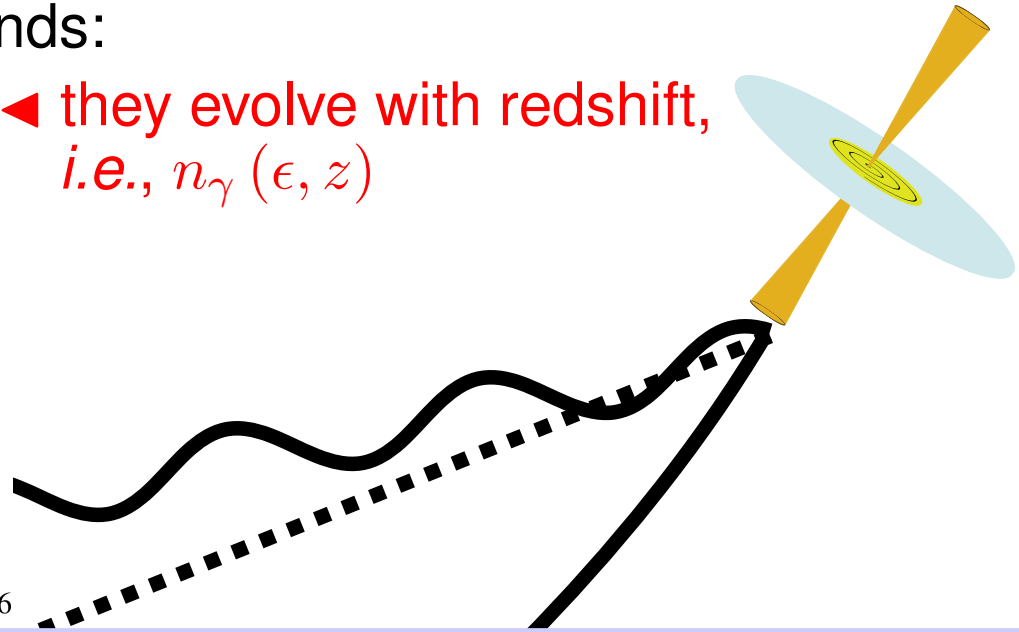


$$p + \gamma_b \to \Delta^+ \to \begin{cases} n + \pi^+ \\ p + \pi^0 \end{cases}$$

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

Cosmogenic ν's: $\pi^+ \to e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$

$$n \to p + e^- + \bar{\nu}_e$$

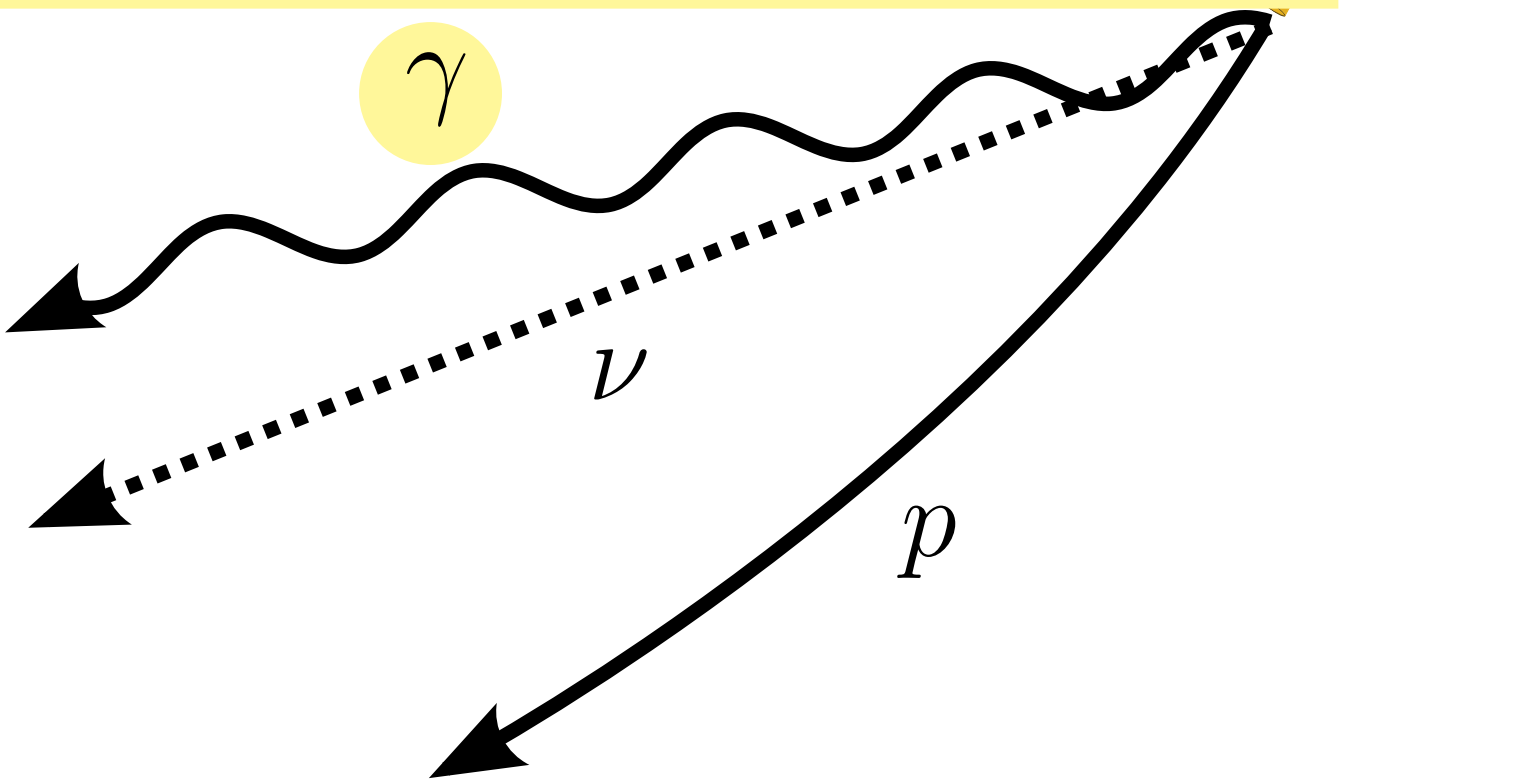
Cosmic-ray, photon, and neutrino propagation

The current working model

γ's and $e^{\pm}$'s dump energy into e.m. cascades through

- pair production, $\gamma + \gamma_b \to e^+ + e^-$
- inverse Compton scattering, $e^{\pm} + \gamma_b \to e^{\pm} + \gamma$

Lower-energy (GeV–TeV) gamma-rays detected by Fermi-LAT



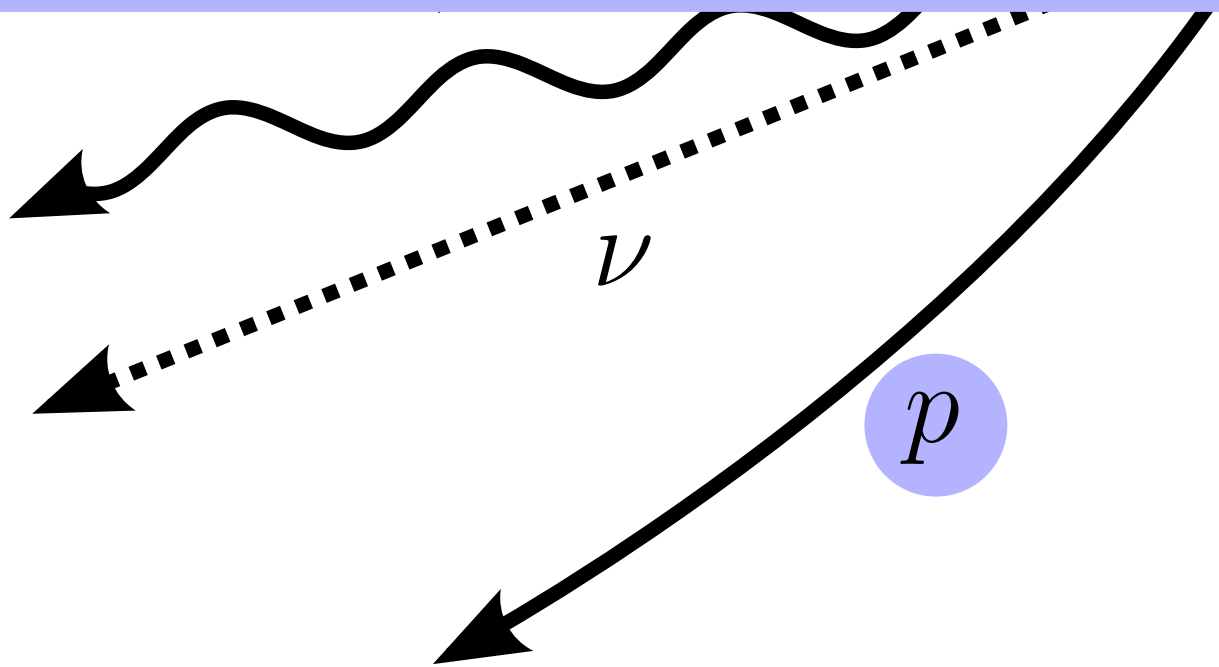
p's are deflected by extragalactic magnetic fields

$\Rightarrow$ except for the most energetic ones, they are **not** expected to point back to the sources } Pierre Auger found weak correlation with known AGN positions

They lose energy through:

- pair production, $p + \gamma_b \rightarrow p + e^+ + e^-$
- photohadronic interactions, $p\gamma_b$

} depend on the redshift evolution of the cosmological γ backgrounds



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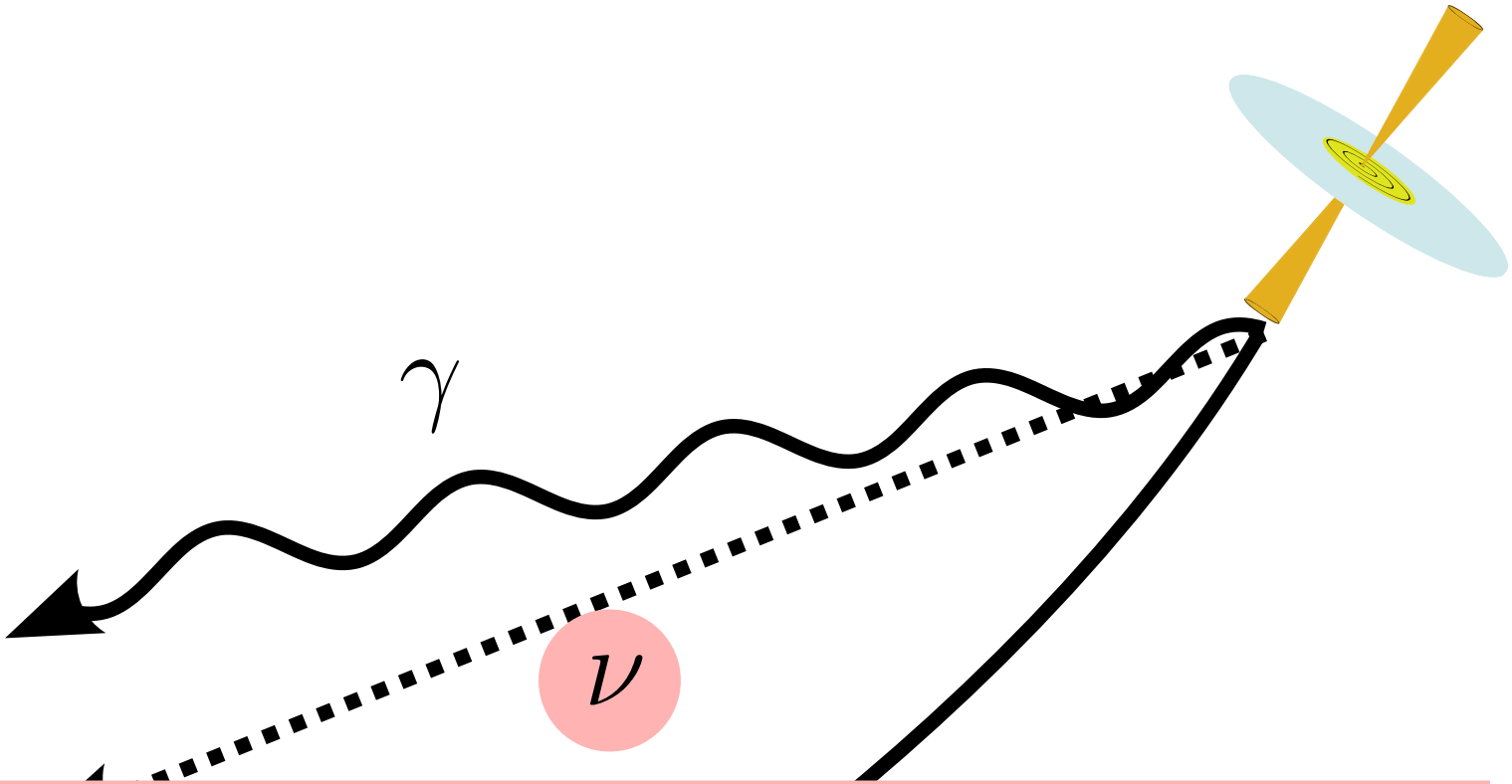


Initial UHE ν flavour fluxes: $\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$

Probability of $\nu_\alpha \to \nu_\beta$ transition: $P_{\alpha\beta}\left(E_0, z\right)$

Flavour oscillations redistribute the fluxes
– at Earth: $\nu_e : \nu_\mu : \nu_\tau \approx 1 : 1 : 1$ (might be changed by exotic physics!)

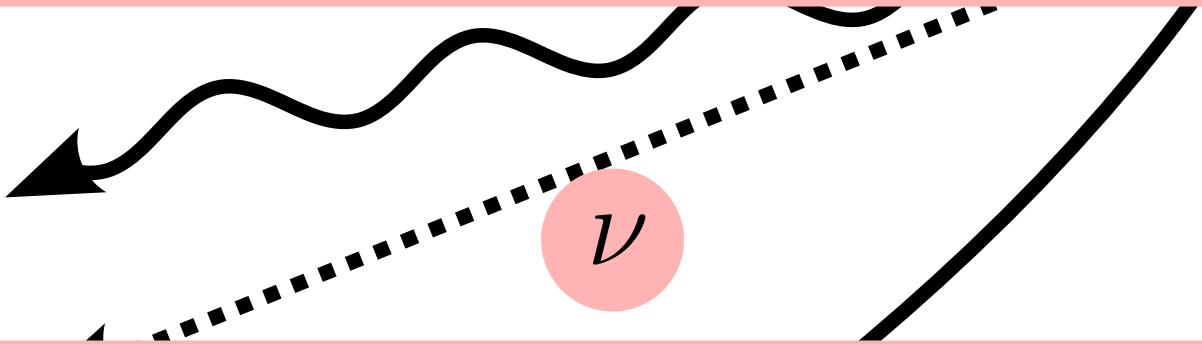
Exotic physics that we have explored:

- CPT and Lorentz invariance violation

BAZO, MB, GAGO, MIRANDA, *Int. J. Mod. Phys.* **A24**, 5819 (2009) [0907.1979]
MB, GAGO, PEÑA-GARAY, *JHEP* **1004**, 066 (2010) [1001.4878]

- neutrino decay

BAERWALD, MB, WINTER, *JCAP* **1210**, 020 (2012) [1208.4600]



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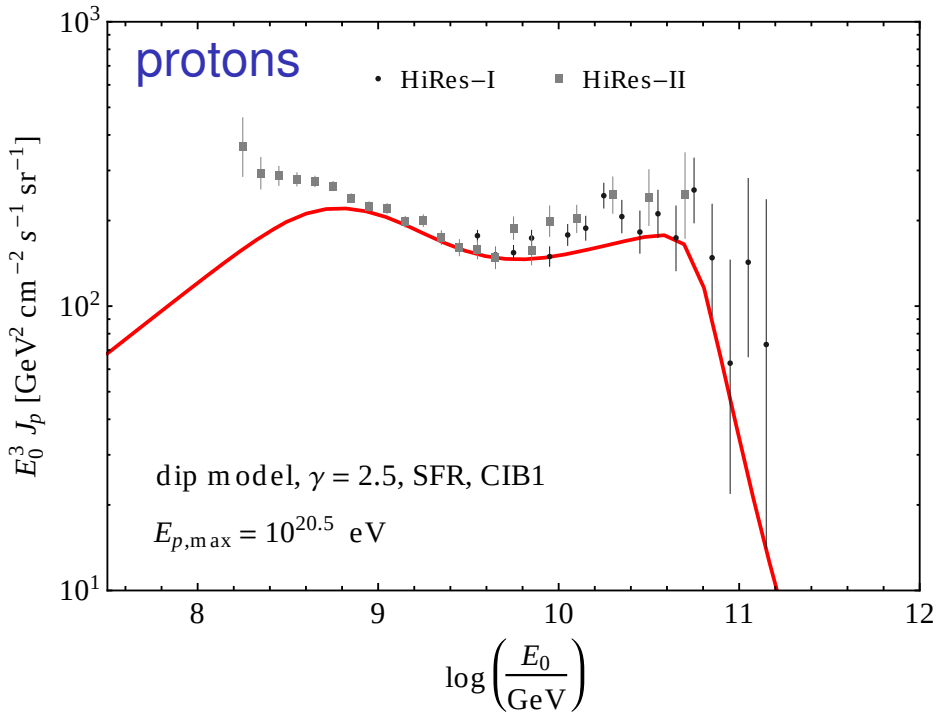
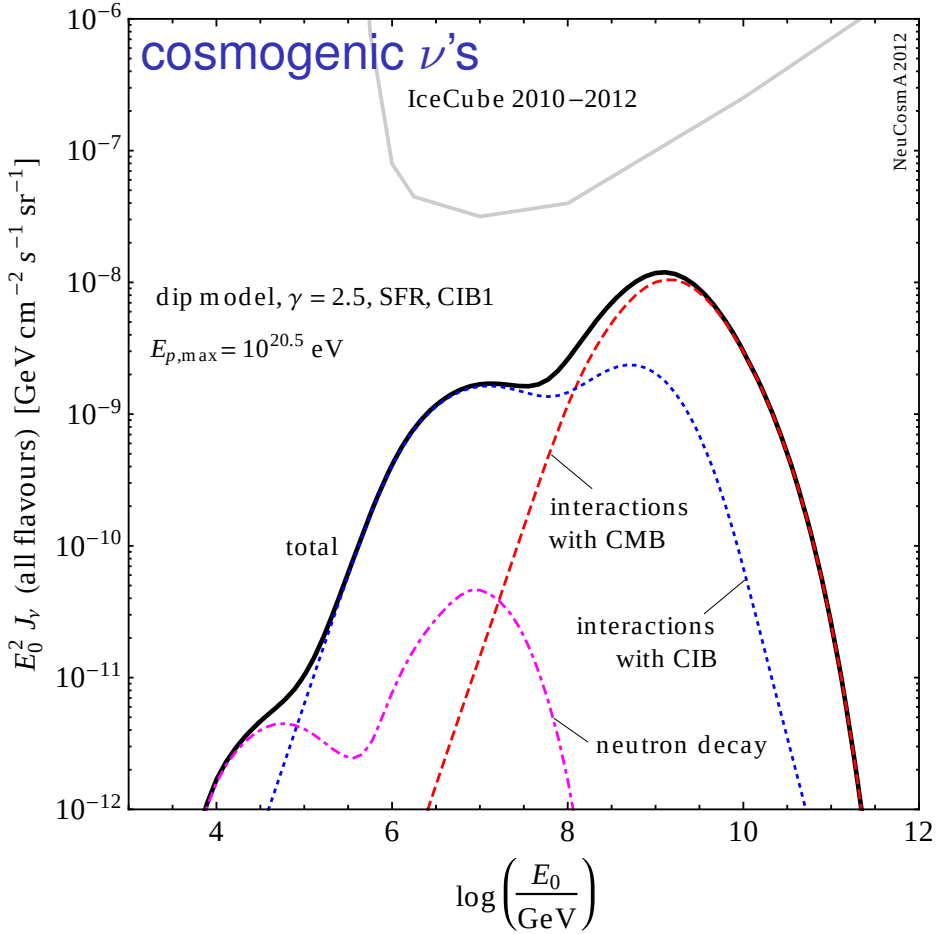
Our code propagates UHE p's, ν's, and γ's to Earth:

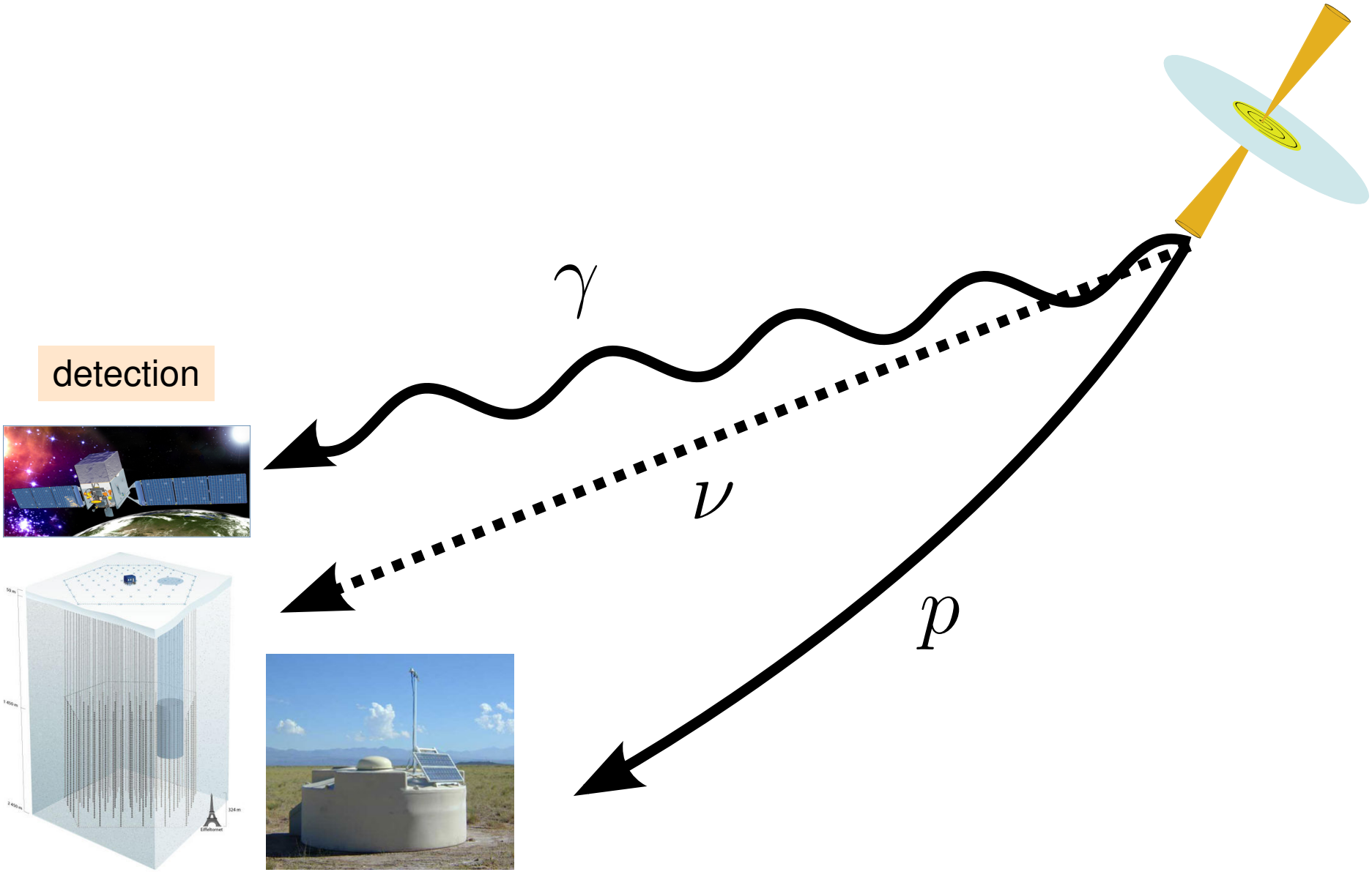


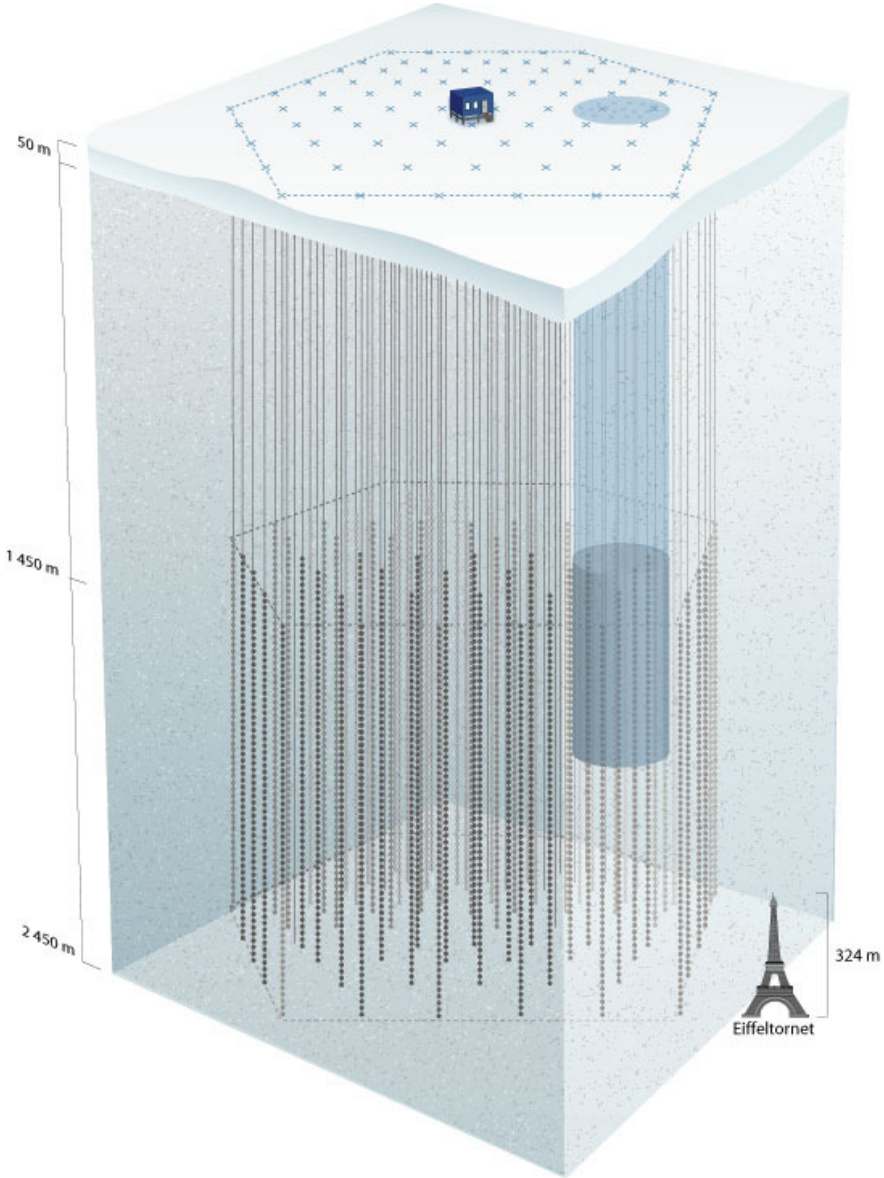


Fast and flexible:
can change emission and propagation parameters

Cosmic-ray, photon, and neutrino propagation

The current working model





IceCube: km^3 in-ice South Pole Čerenkov detector

Exotic physics? SUSY-running of the mixing angles

MB, Gago, Jones, *JHEP* **1105**, 133 (2011) [1012.2728]

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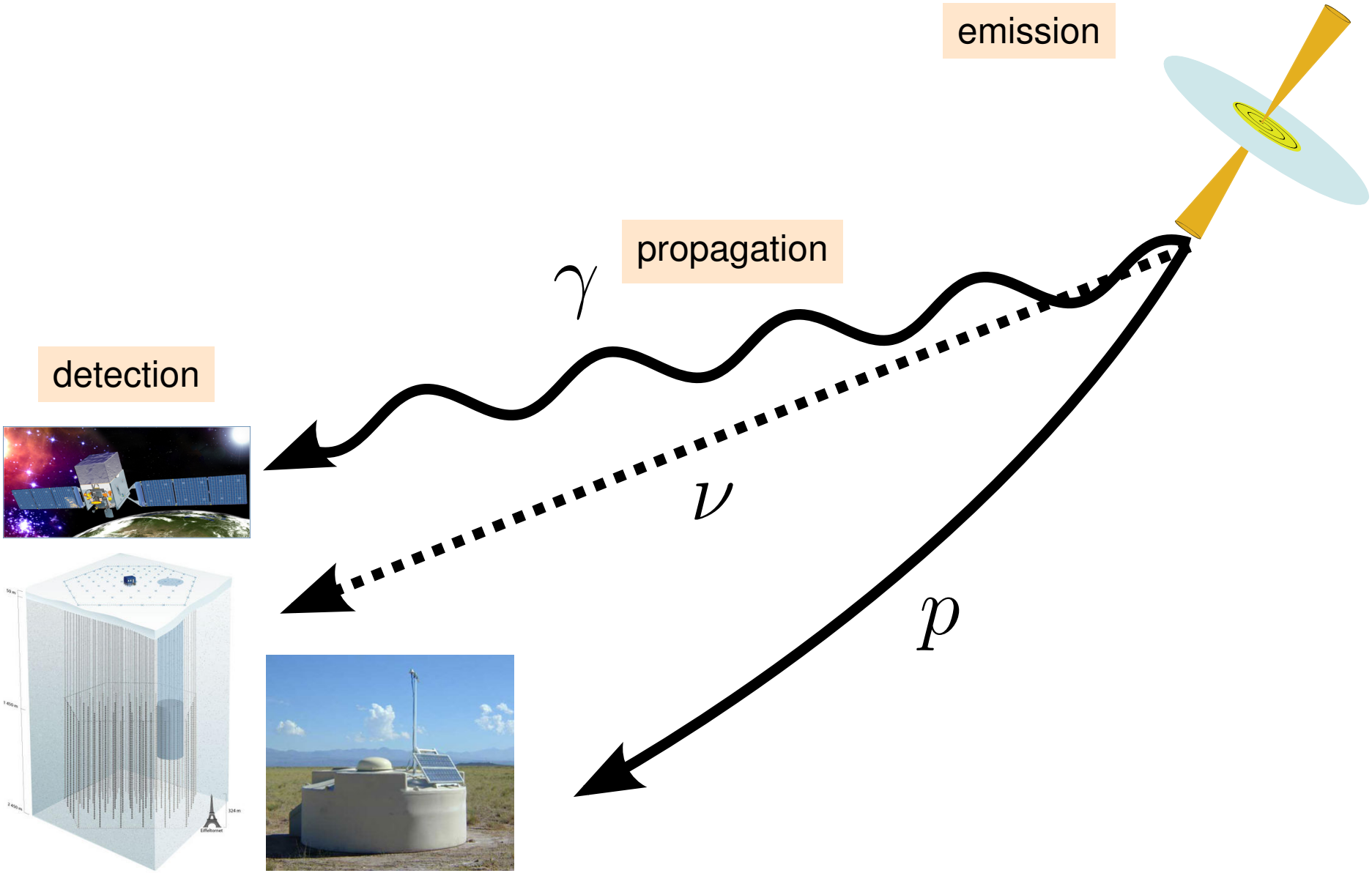

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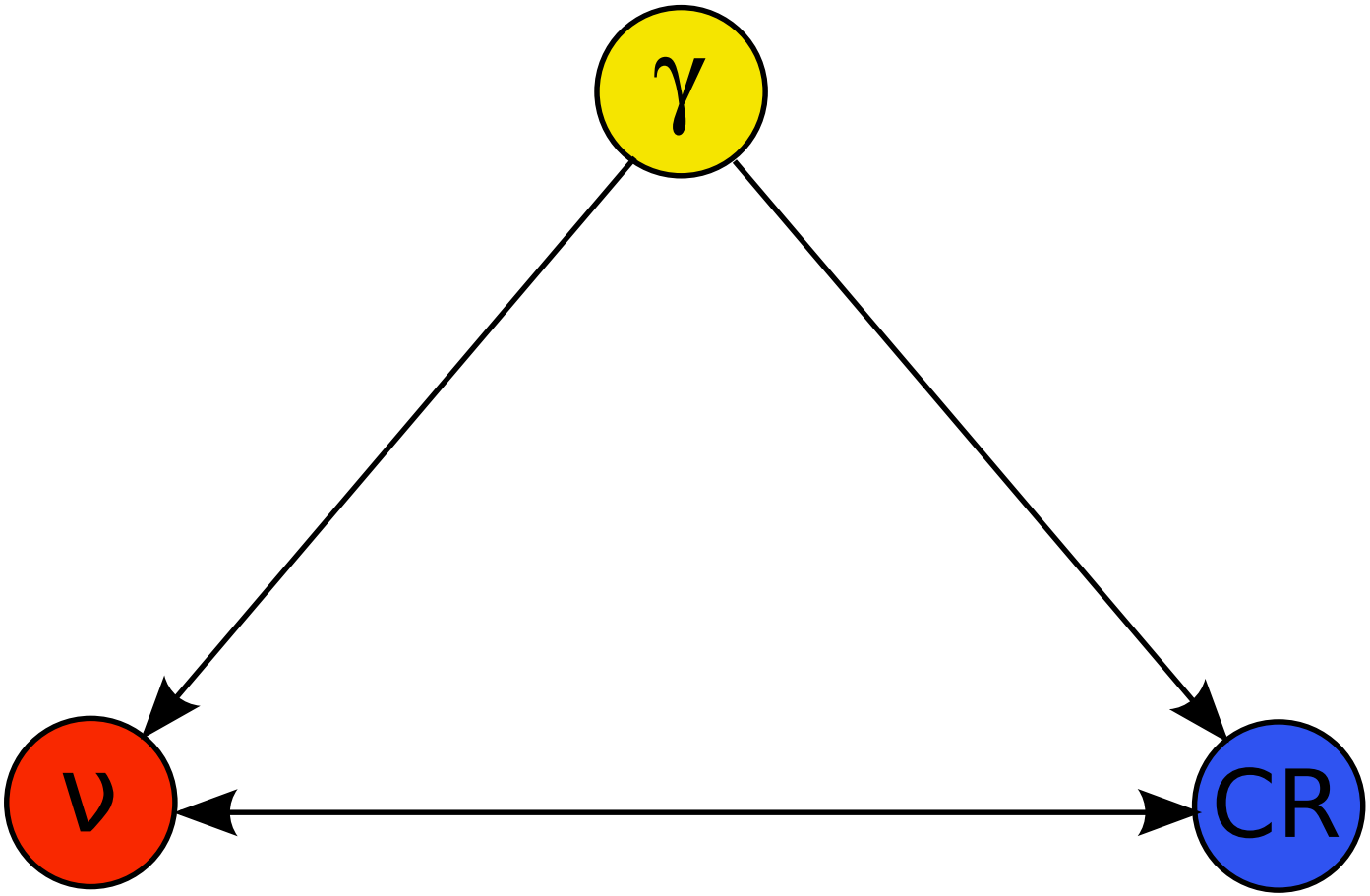

Ongoing work

Emission

- more realistic model of p escape in GRBs (also, γ's and ν's) [Baerwald, Spector, MB, Waxman, Winter]

Propagation

- effect on cosmogenic ν's of enhancing the high-z EBL [Evoli, MB, Sigl, Winter]
- a systematic study of the CR production and propagation parameter space [MB, Winter]
- novel scenarios of UHE ν decoherence [Argüelles, Baerwald, MB, Gago, Mehta, Winter]

Detection

- improved stacked and diffuse UHE CR and ν predictions [Ahlers, Baerwald, MB, Halzen, Winter]