A New Idea for Relic Neutrino Detection

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Washington University in St. Louis

with V. Brdar, R. Plestid and A. Soni, arXiv: 2205.abcde

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May 10, 2022

Why Relic Neutrinos?

- 'Holy Grail' of Neutrino Physics.
- Detection of cosmic neutrino background (CνB) will provide strong validation of our current cosmological model.
- And provide a window into the first second of creation.
- Indirect evidence for CνB from CMB, BBN and large-scale structure data.
- But direct detection remains a challenge.

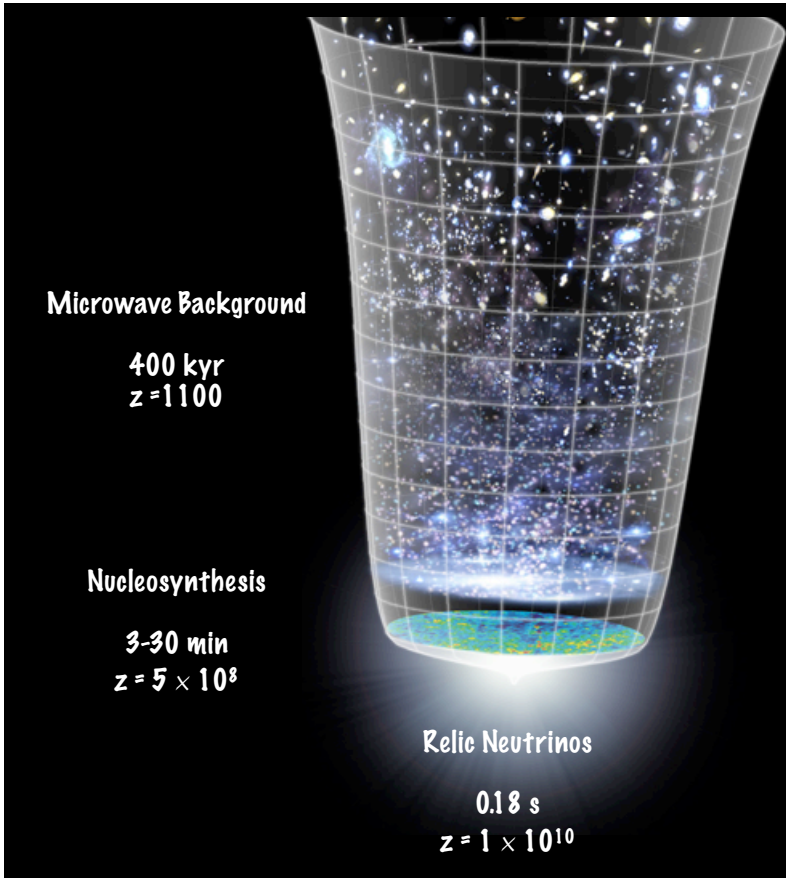

Figure from J. Formaggio

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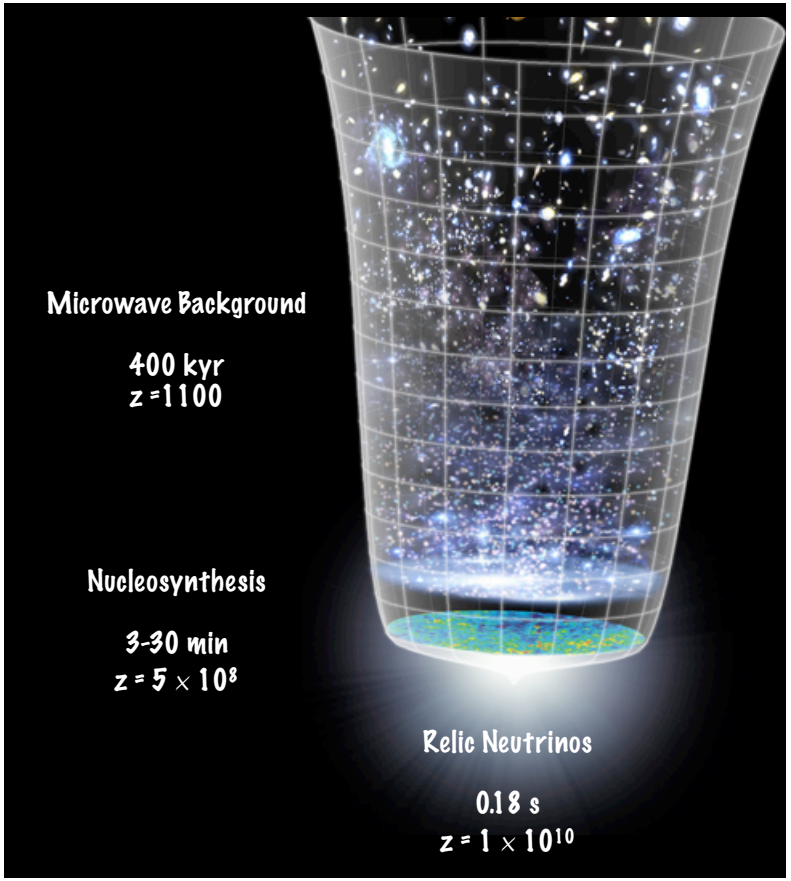

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Why is it so hard?

CνB Characteristics

- CνB inherently connected to CMB: $T_{\nu,0} = \left(\frac{4}{11}\right)^{1/3} T_{\gamma,0} = 1.945\ \mathrm{K} = 1.7 \times 10^{-4}\ \mathrm{eV}$.
- Essentially a fermion gas obeying Fermi-Dirac statistics.
- Number density: $n_\nu = \frac{3}{4}\frac{\zeta(3)}{\pi^2} g T_\nu^3 = \mathbf{56}/\mathrm{cm}^{\mathbf{3}}$ per flavor (and similarly for $\bar{\nu}$).
- Most intense natural neutrino source.

$\nu_i \nu_j \to \nu_i \nu_j$
$\nu_i \bar{\nu}_j \to \nu_i \bar{\nu}_j$
$\nu_i e^- \to \nu_i e^-$
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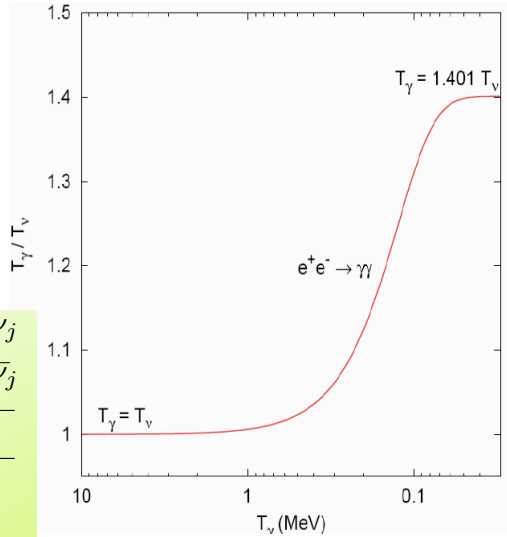
turn off



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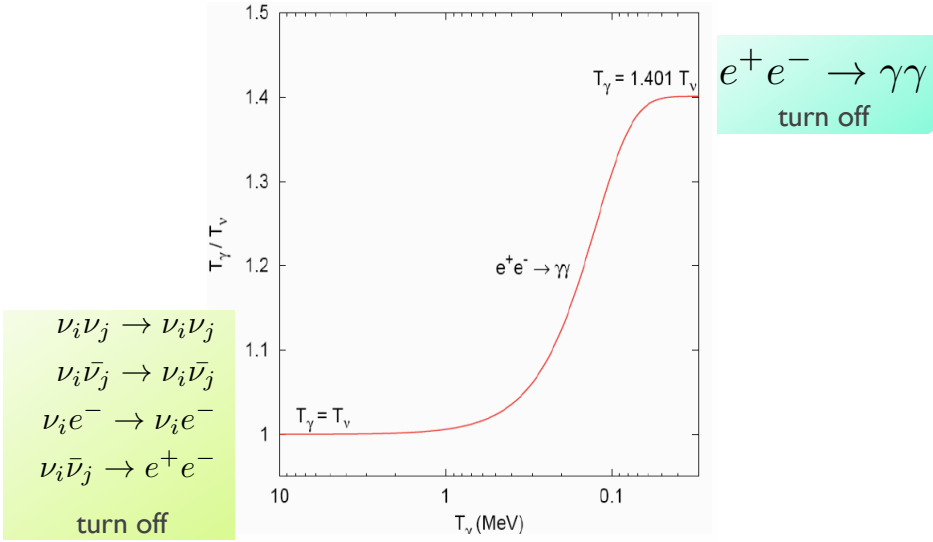

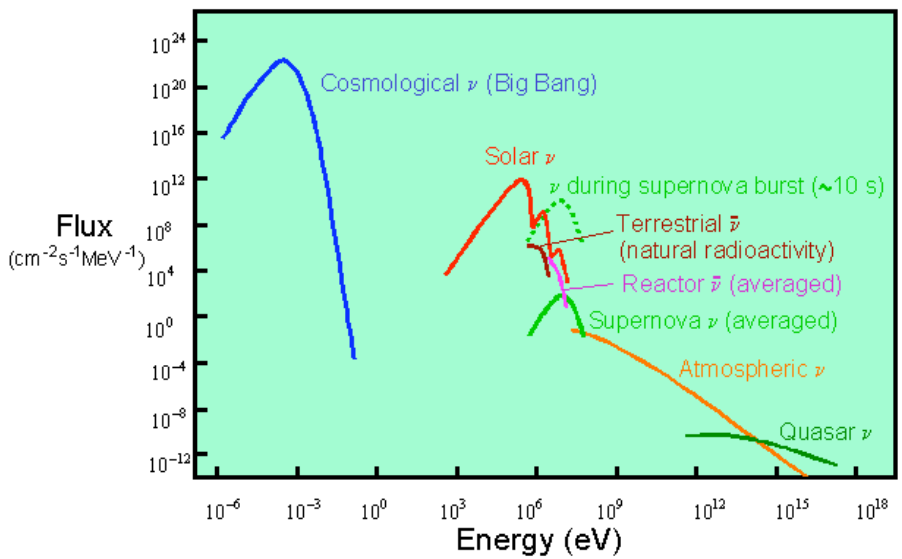

Flux on earth of neutrinos from various sources, in function of energy

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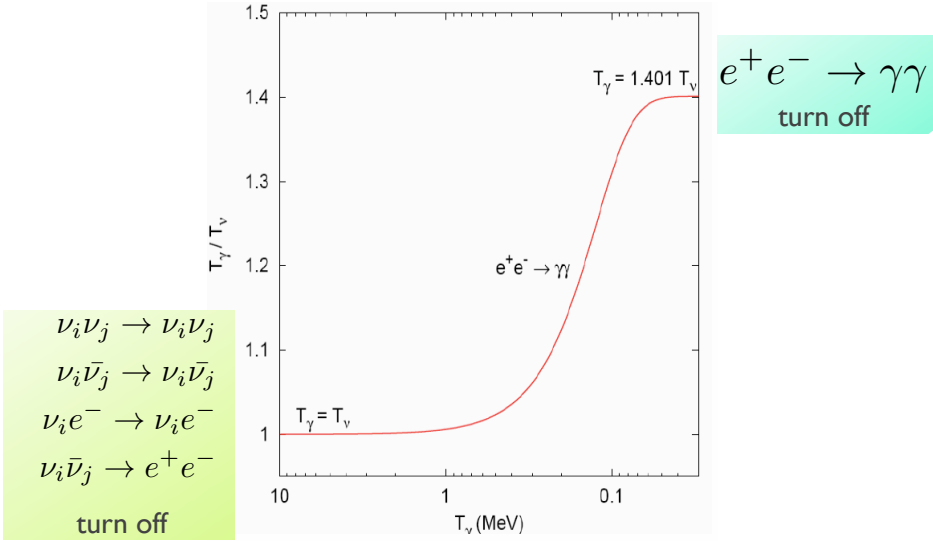

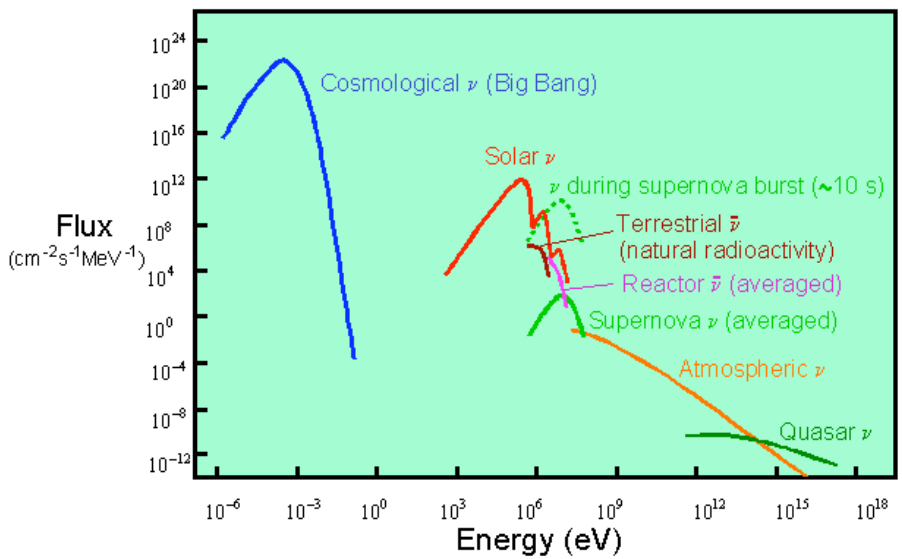

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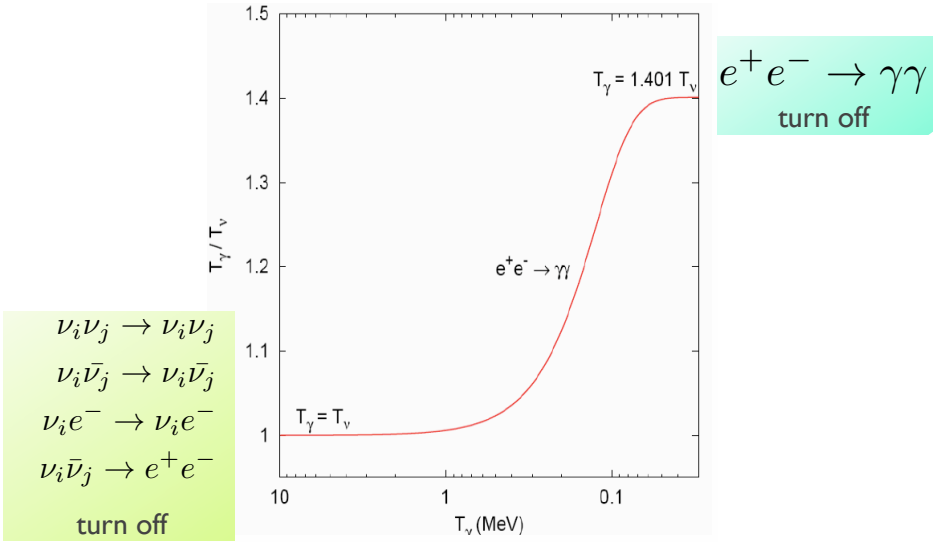
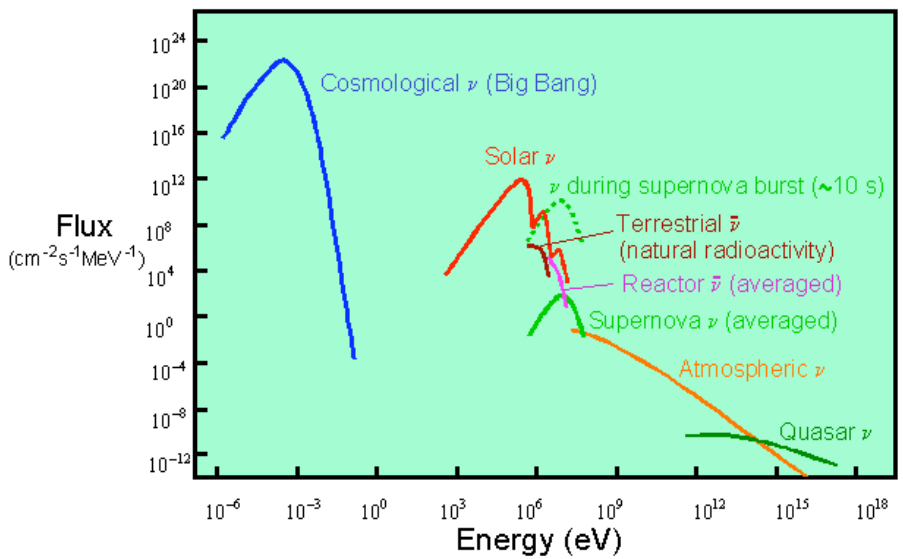
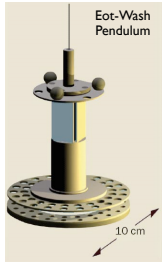




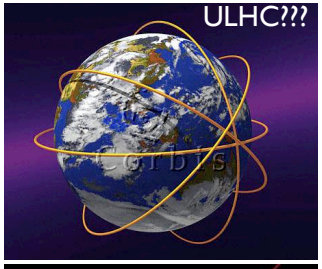
Flux on earth of neutrinos from various sources, in function of energy

Several Ideas on the Table

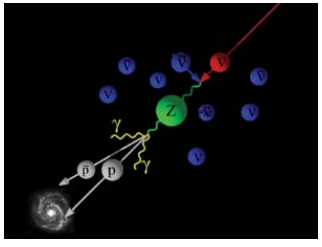
- Mechanical force due to coherent scattering of neutrino wind against a macroscopic object.



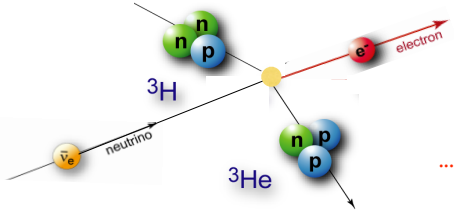
- Scattering on accelerator beam



- Scattering on ultra-high energy neutrinos/cosmic rays

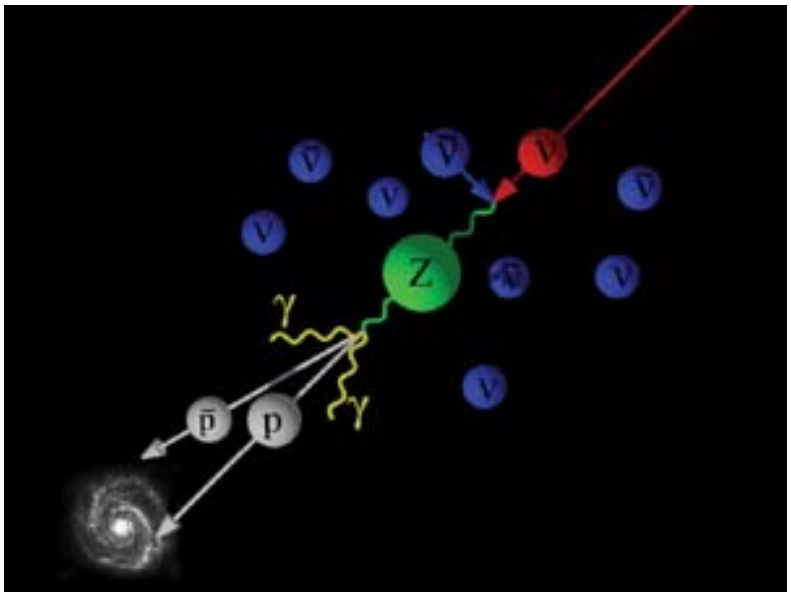


- Neutrino capture on beta nuclei

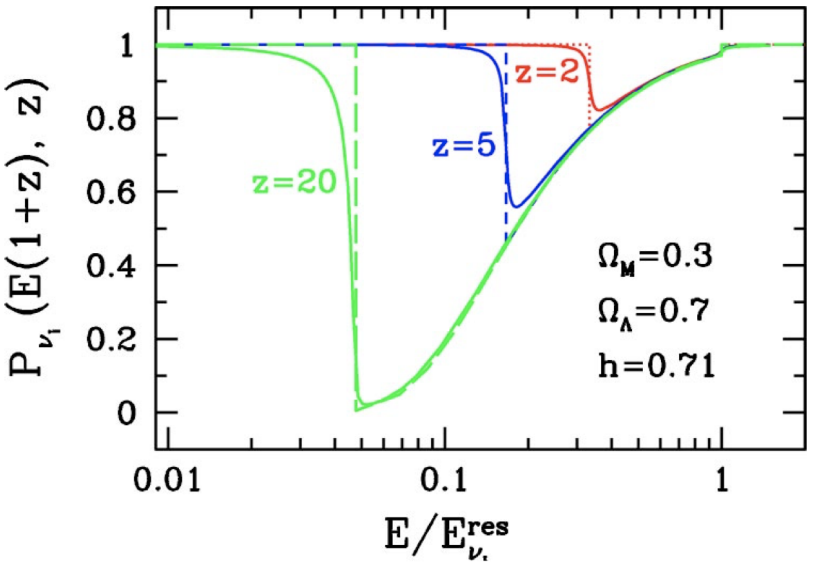


[G. Gelmini (Phys.Scripta '05); C. Yanagisawa (Front. Phys '14); P. Vogel (AIP Conf. Proc. '15)]

Z-burst



[T. Weiler (PRL '82)]



[Eberle, Ringwald, Song, Weiler (PRD '04)]

- Resonant absorption happens at

$$E_\nu^{\rm res} = \frac{m_Z^2}{2m_\nu} = (4.2 \times 10^{22}\ {\rm eV}) \left(\frac{0.1\ {\rm eV}}{m_\nu}\right)$$

Beyond the GZK cut-off!

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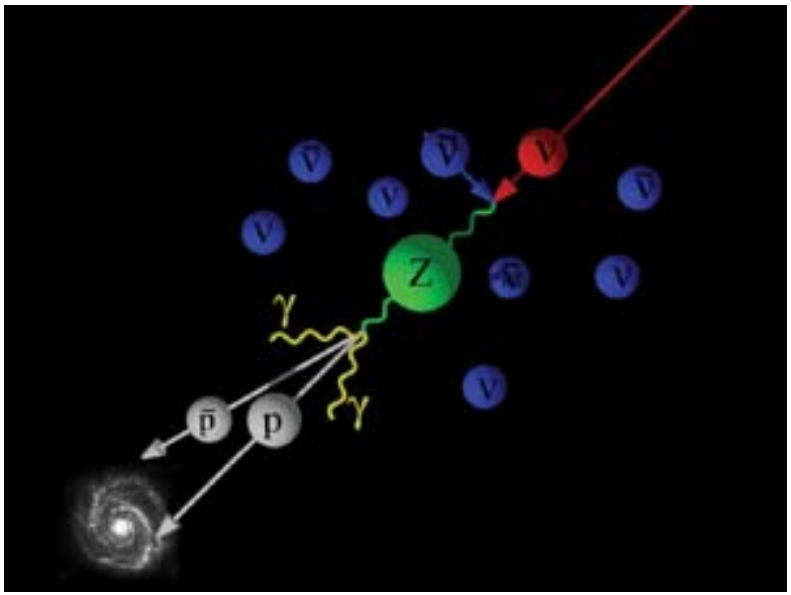

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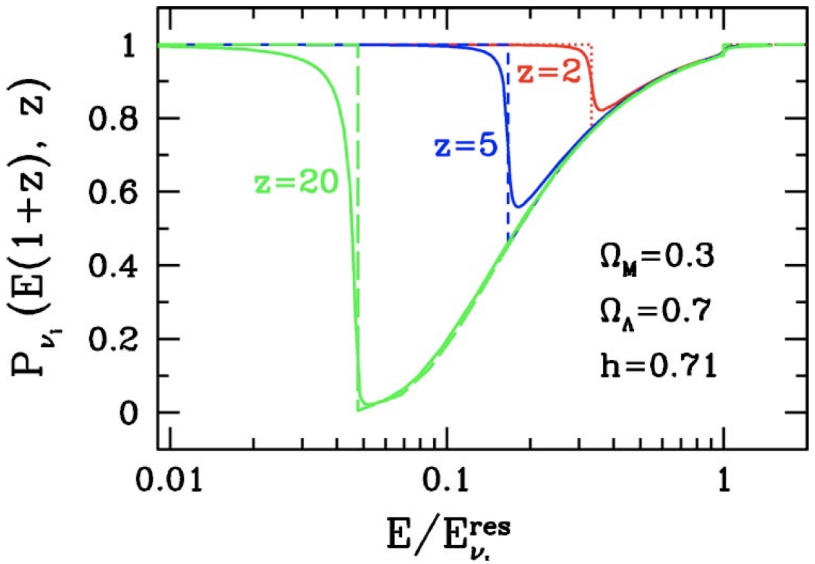

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- But the cross-section is large: $\langle\sigma_{\nu\bar\nu}^{\rm ann}\rangle = 2\pi\sqrt{2}G_F = 40.4\ {\rm nb}$.
- Observable effect, depending on redshift and source energy distribution of the (unknown) super-GZK cosmic ray sources.

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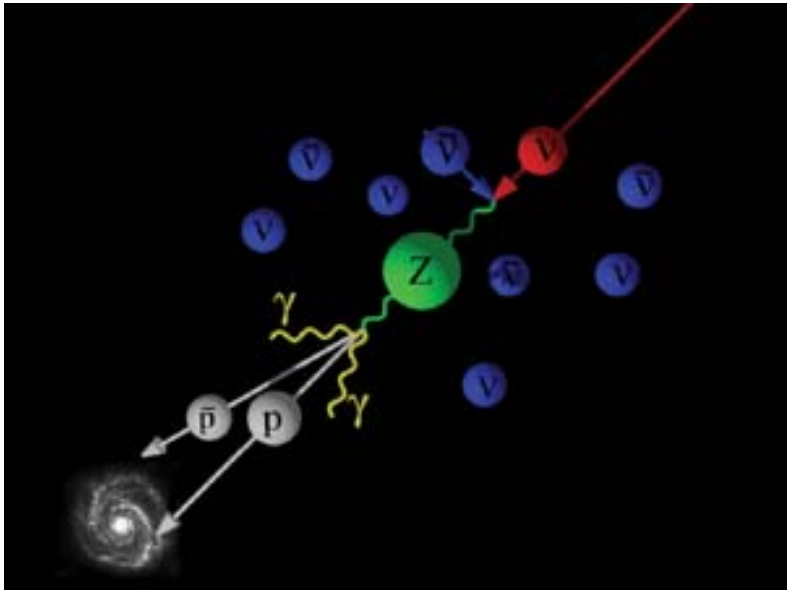

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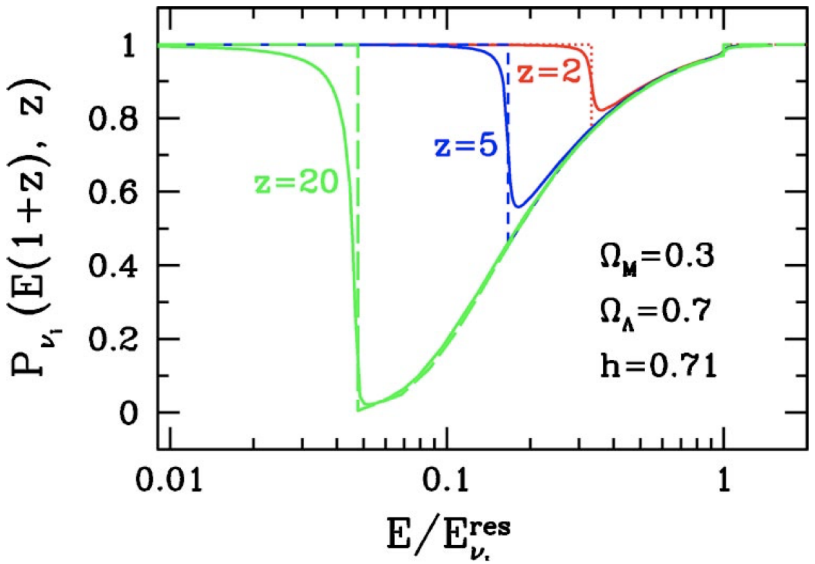

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- Observable effect, depending on redshift and source energy distribution of the (unknown) super-GZK cosmic ray sources.
- Resonance energy can be sub-GZK for secret neutrino interactions with new light mediators. [Ioka, Murase (PTEP '14); Araki, Kaneko, Konishi, Ota, Sato, Shimomura (PRD '15); DiFranzo, Hooper (PRD '15); Cherry, Friedland, Shoemaker (1605.06506); Altmannshofer, Chen, BD, Soni (PLB '16); Esteban, Pandey, Brdar, Beacom (PRD '21)]

New Idea: Use SM Meson Resonances

- Recall vector meson resonances in e^+e^- scattering. [Lee, Zumino (PR '67); Gounaris, Sakurai (PRL '68)]
- Apply it to UHE neutrino scattering off CνB. [Bander, Rubinstein (PRD '95); Paschos, Lalakulich (hep-ph/0206273); BD, Soni (2112.01424)]
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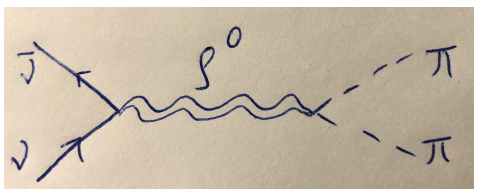

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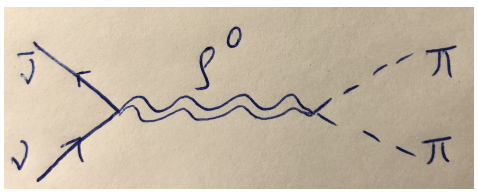

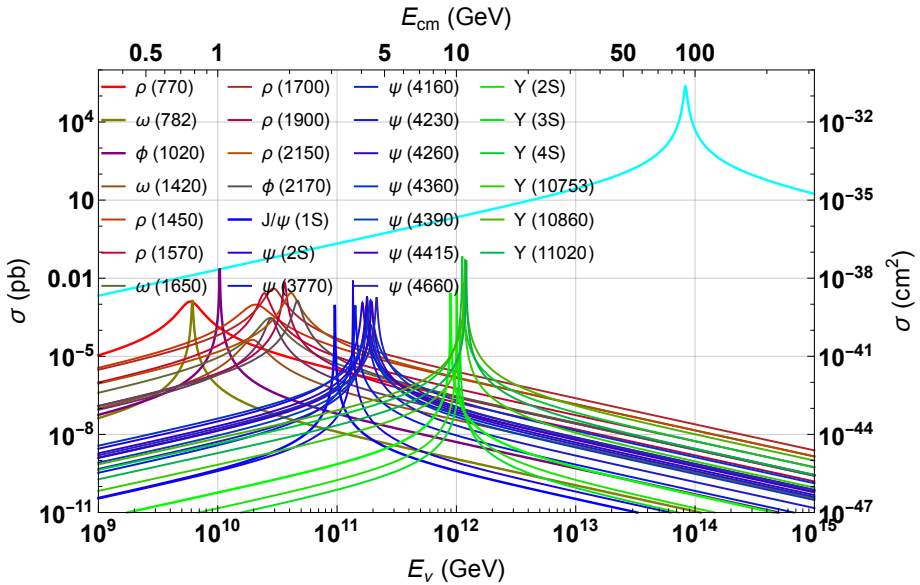

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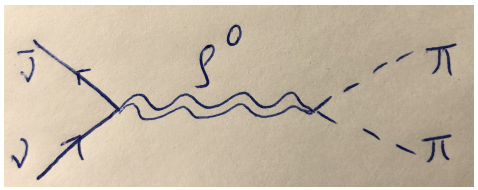

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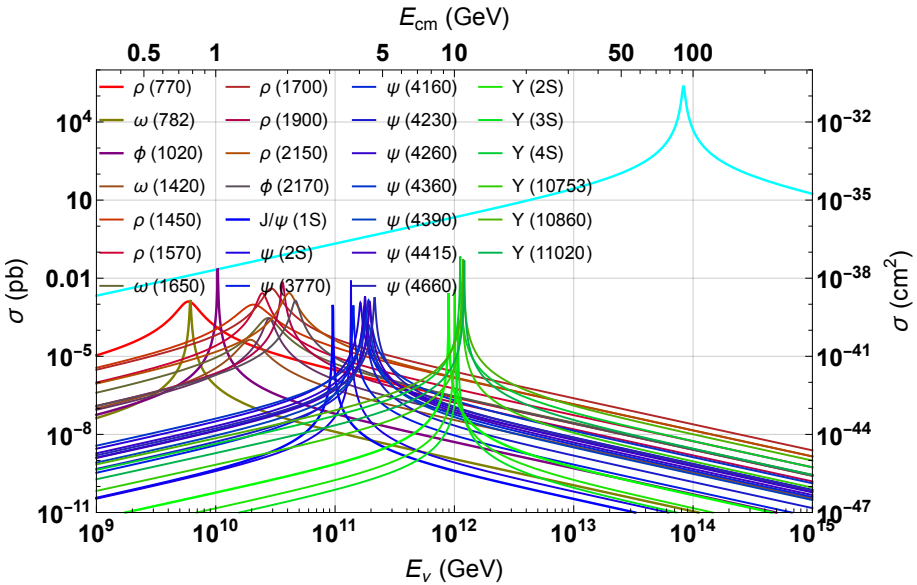

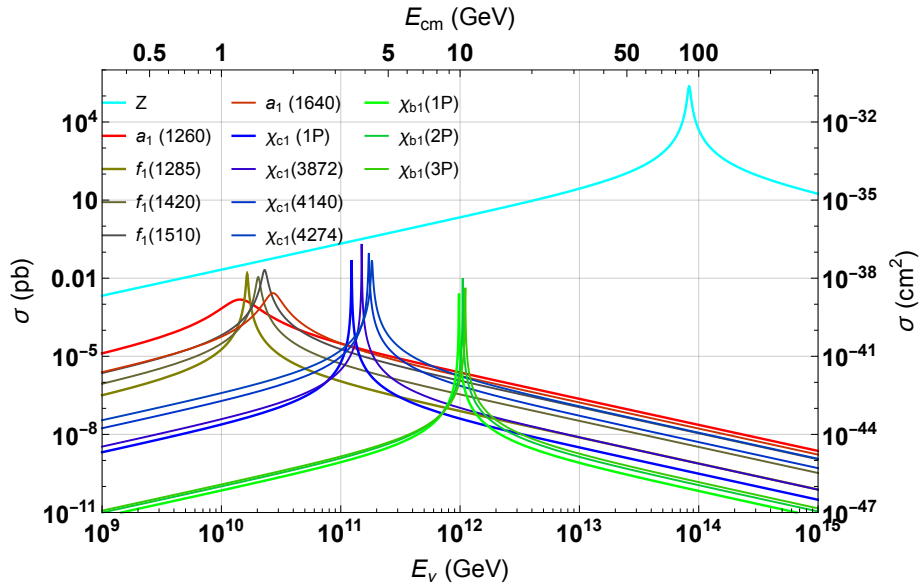

But not enough ☹

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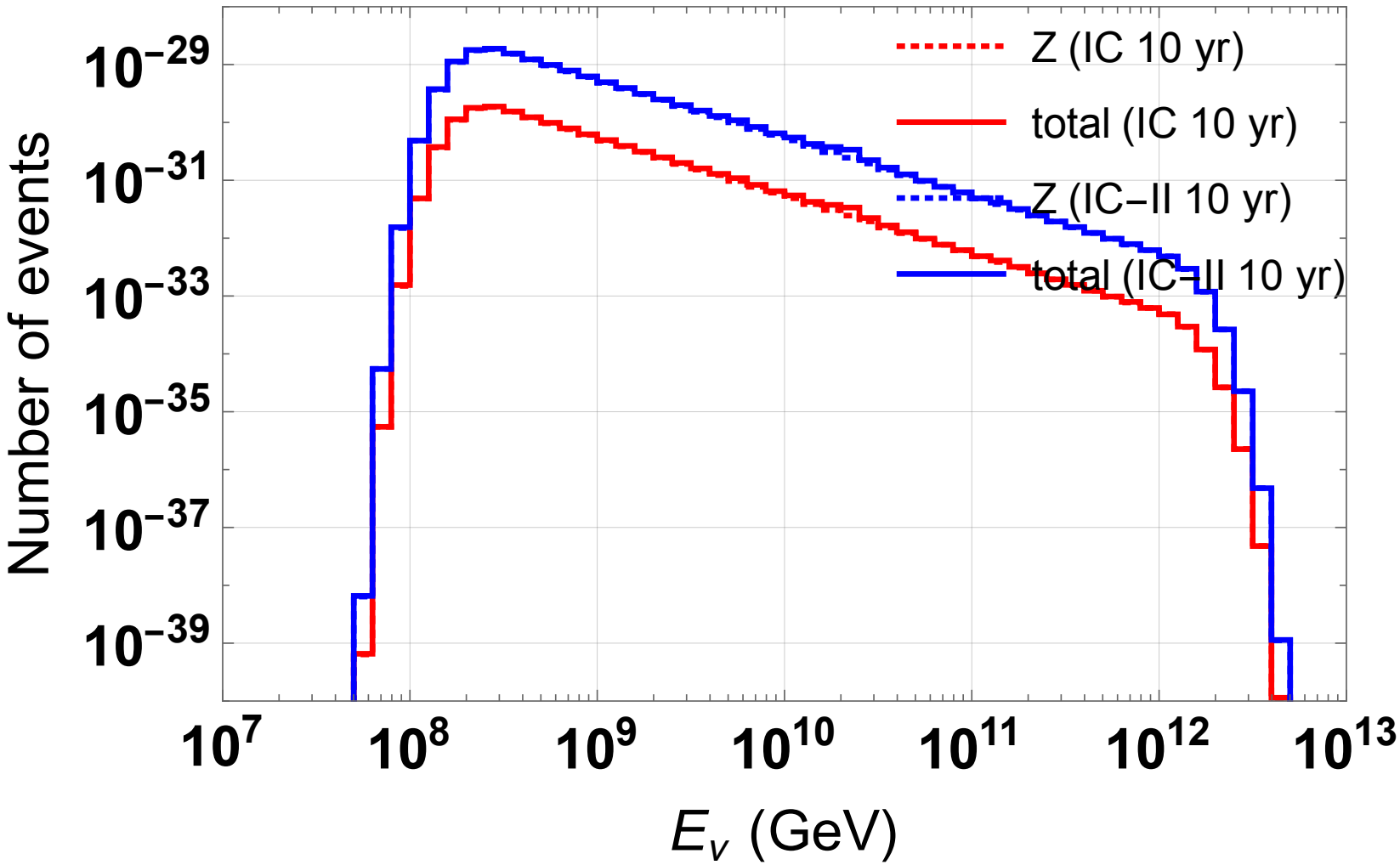

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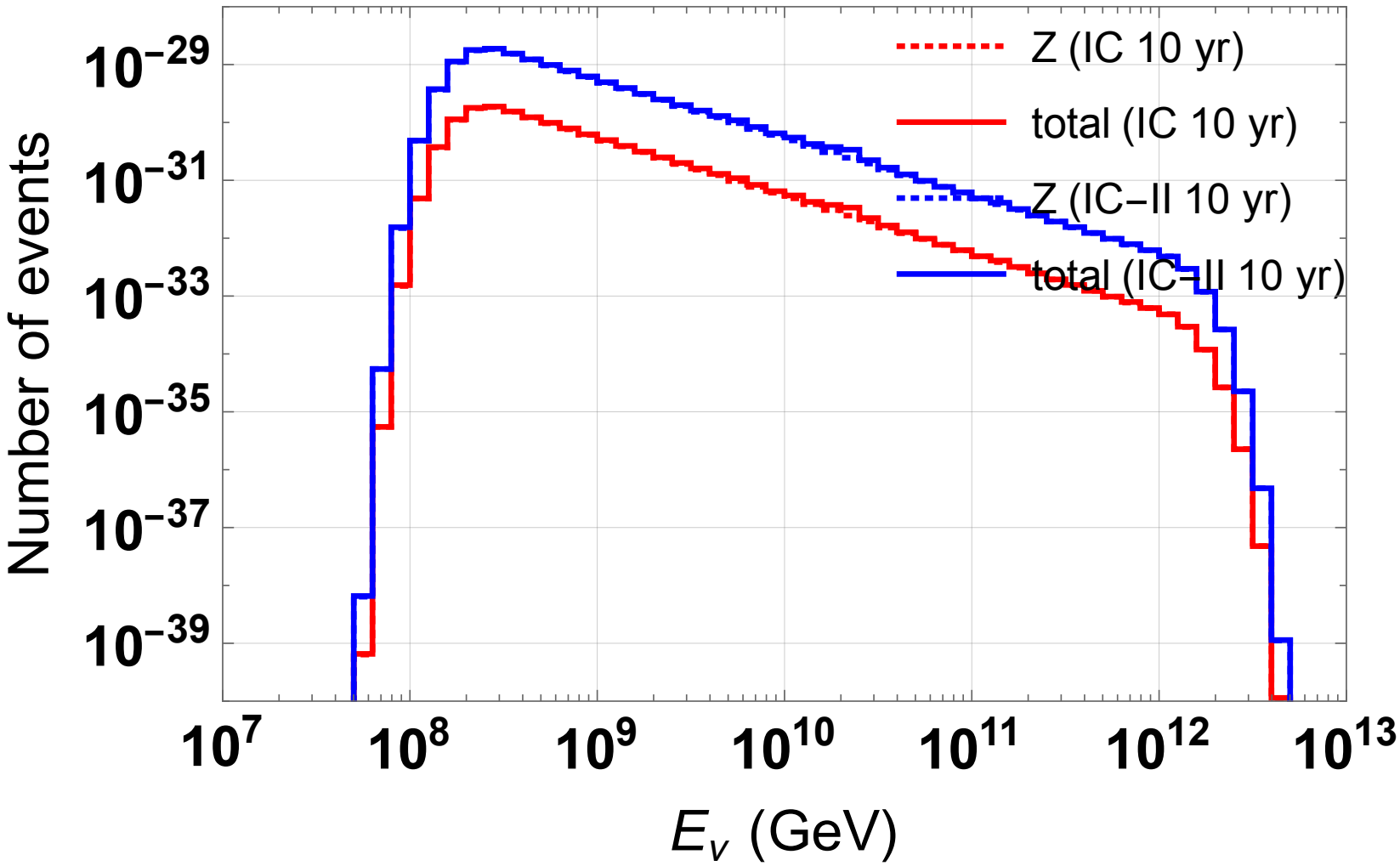
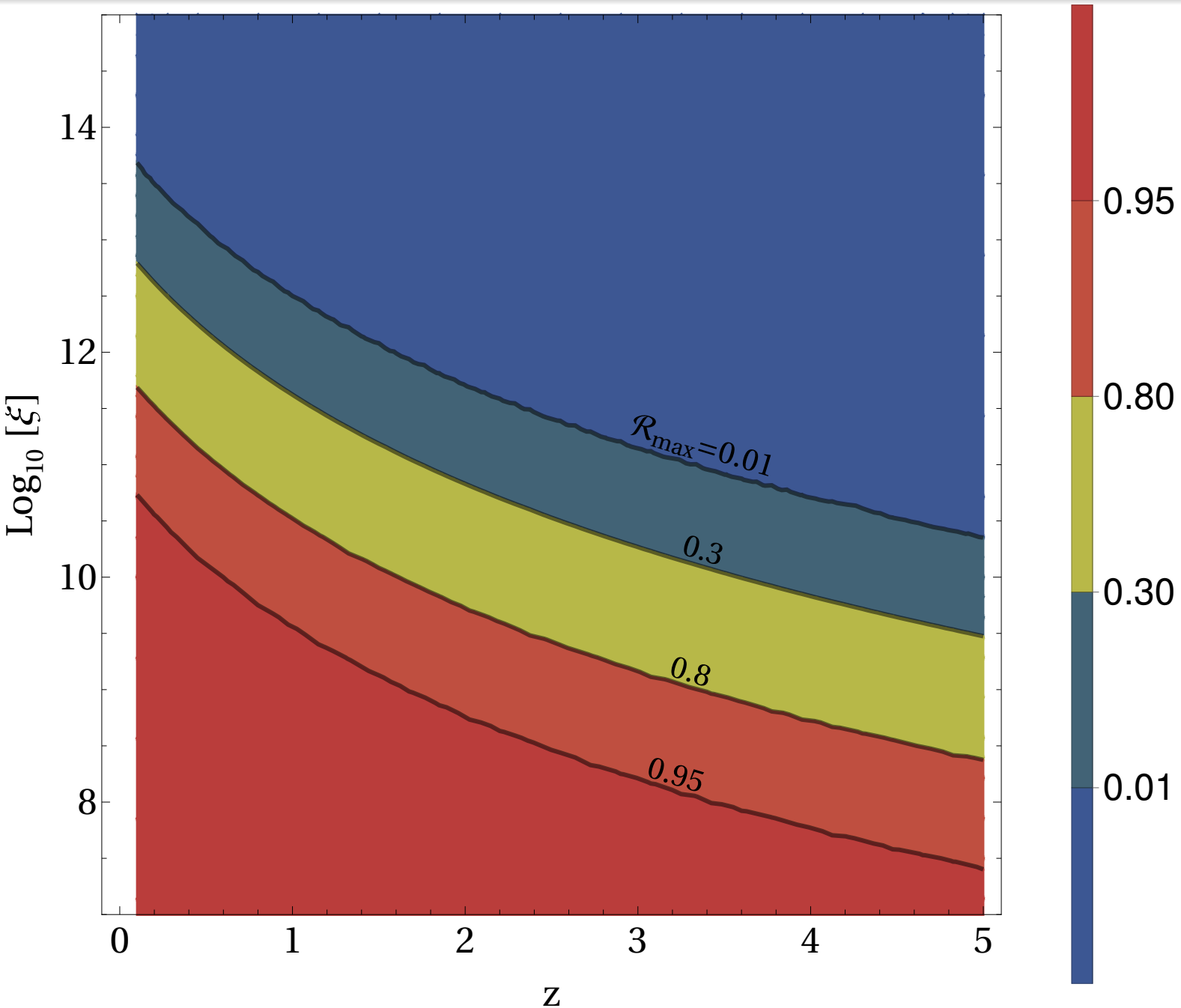
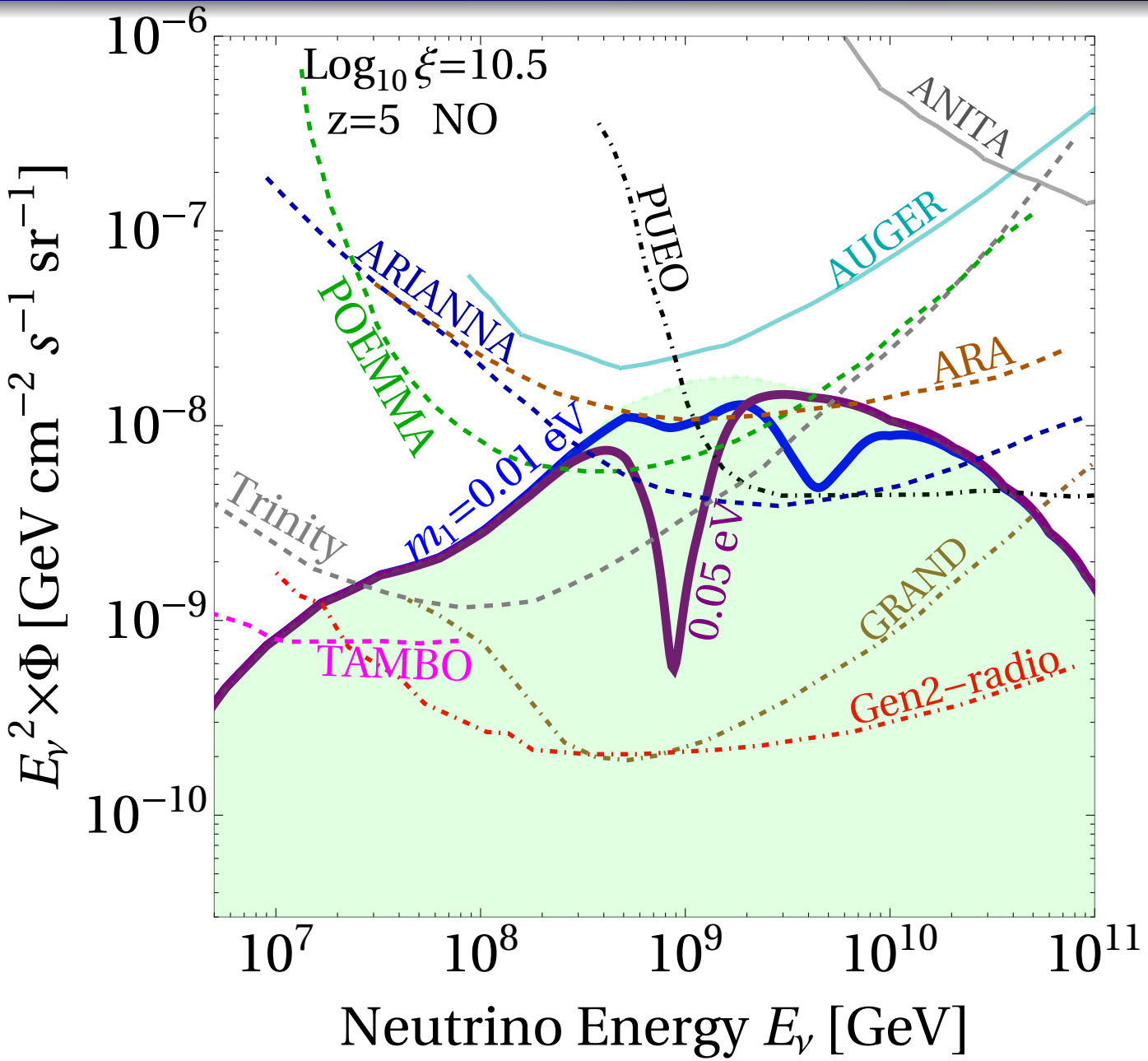


Any hope?

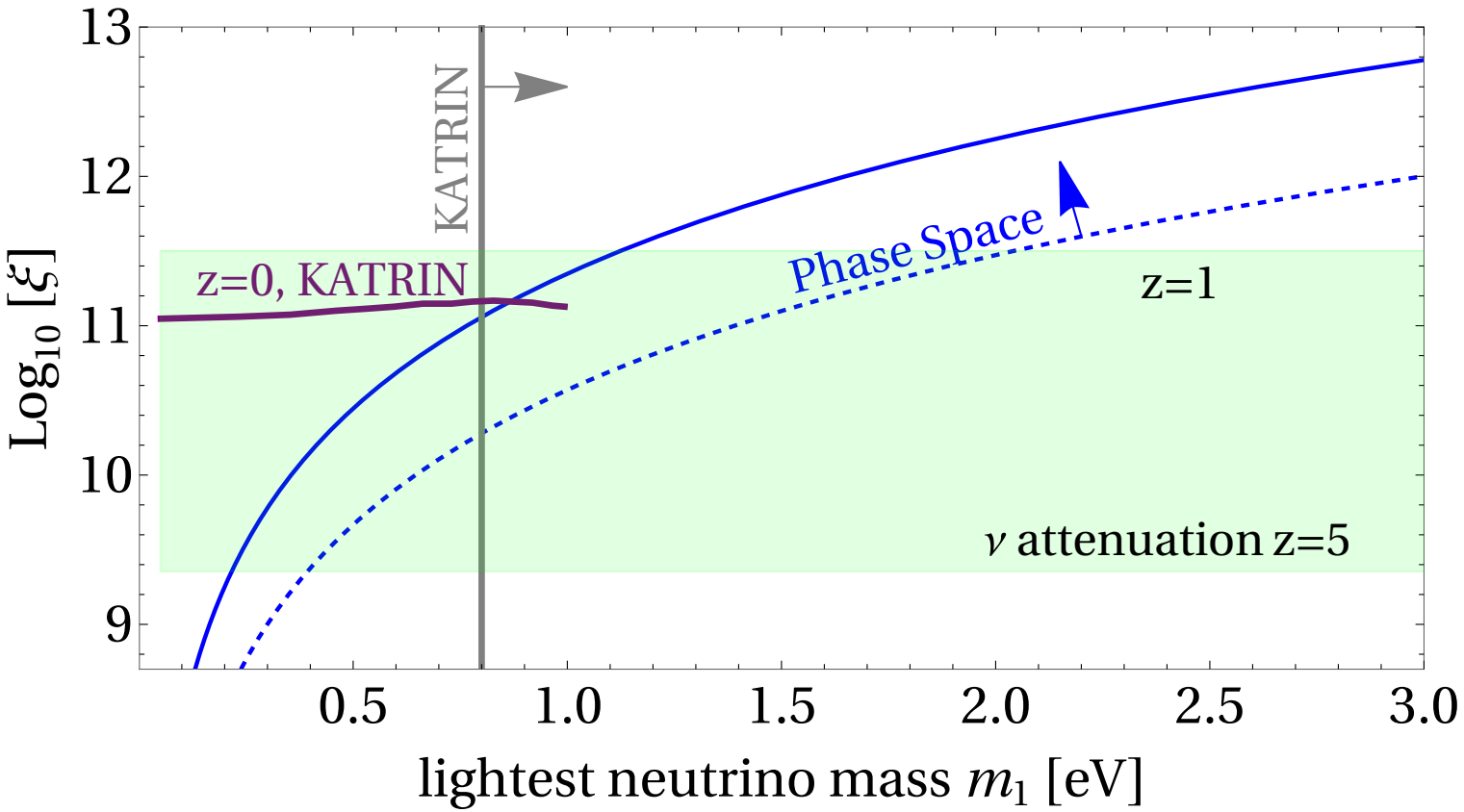
Attenuation due to Overdensity



Observable Effect in GZK Neutrino Flux



Complementary to KATRIN



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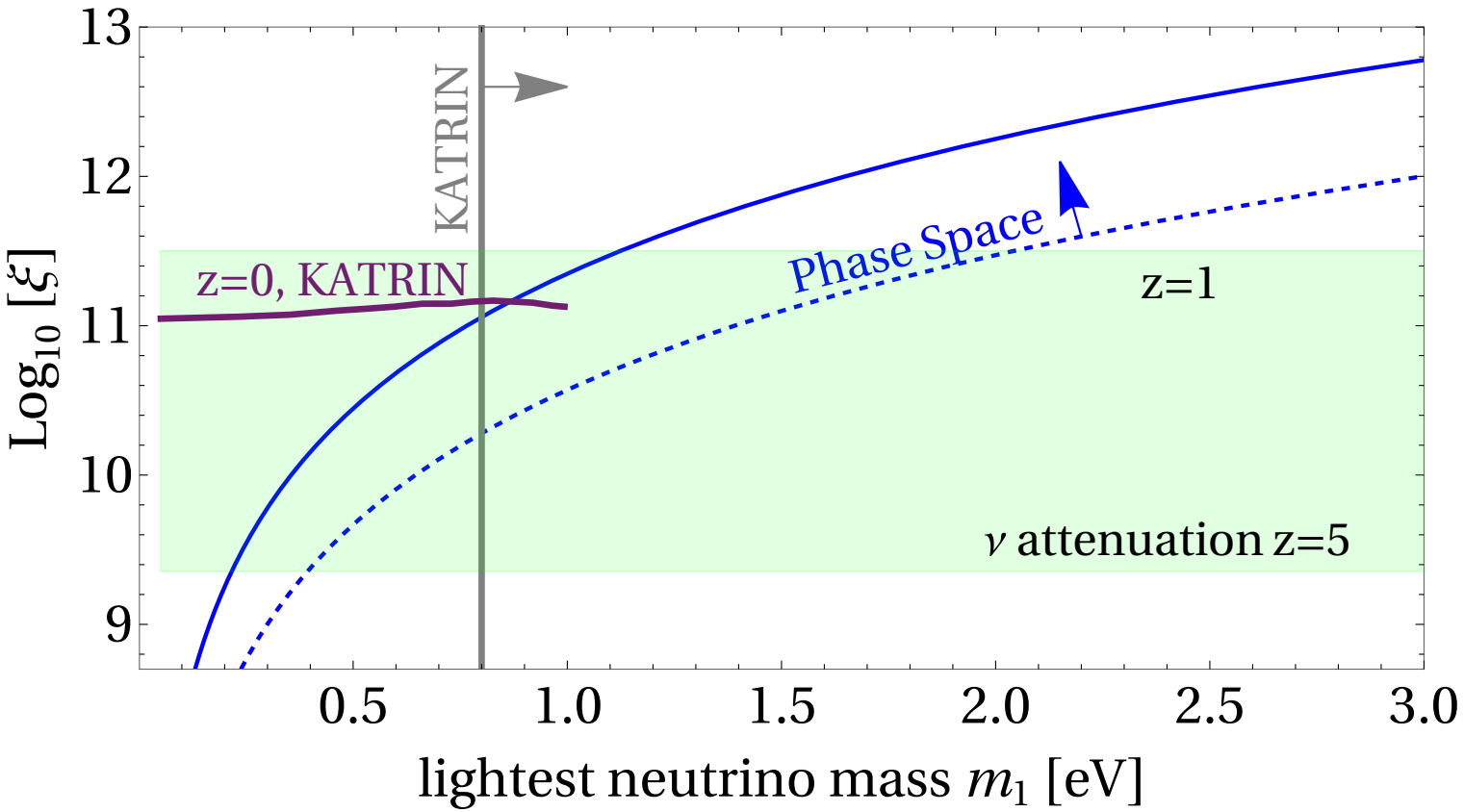

What are we asking for?

- Large overdensity $\xi \equiv \frac{n_\nu}{n_{\nu,0}} \gtrsim 10^{10}$.
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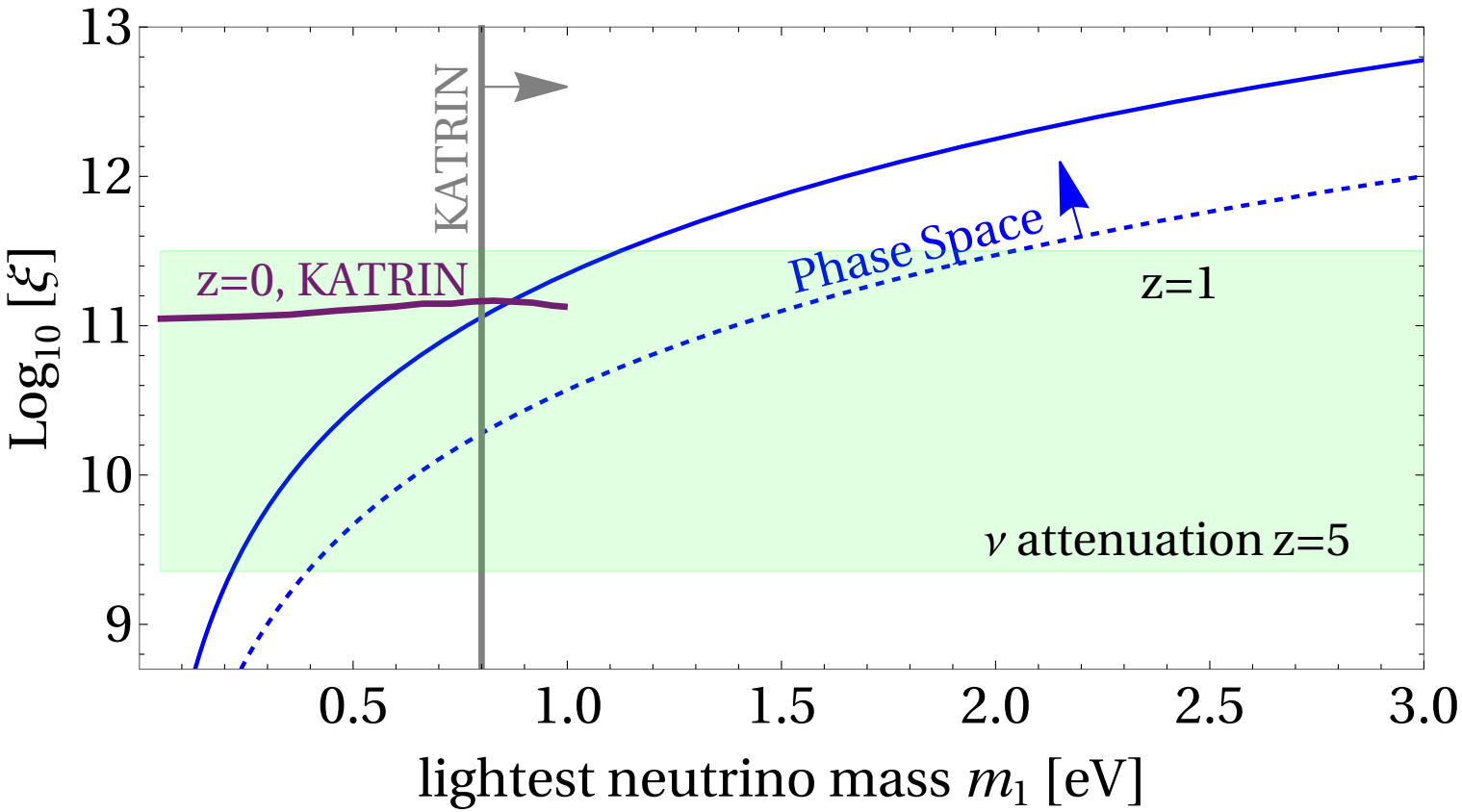

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Both are possible, but 

Conclusion

- Detection of CνB is an important unsolved problem in neutrino physics.
- A new idea for CνB detection due to resonant scattering off GZK neutrinos via vector (axial-vector) mesons.
- Works if there is a large overdensity of CνB along the line-of-sight.
- Can probe overdensity at higher redshifts, unlike KATRIN which is only sensitive to local overdensity.

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