Future neutrino-neutrino colliders

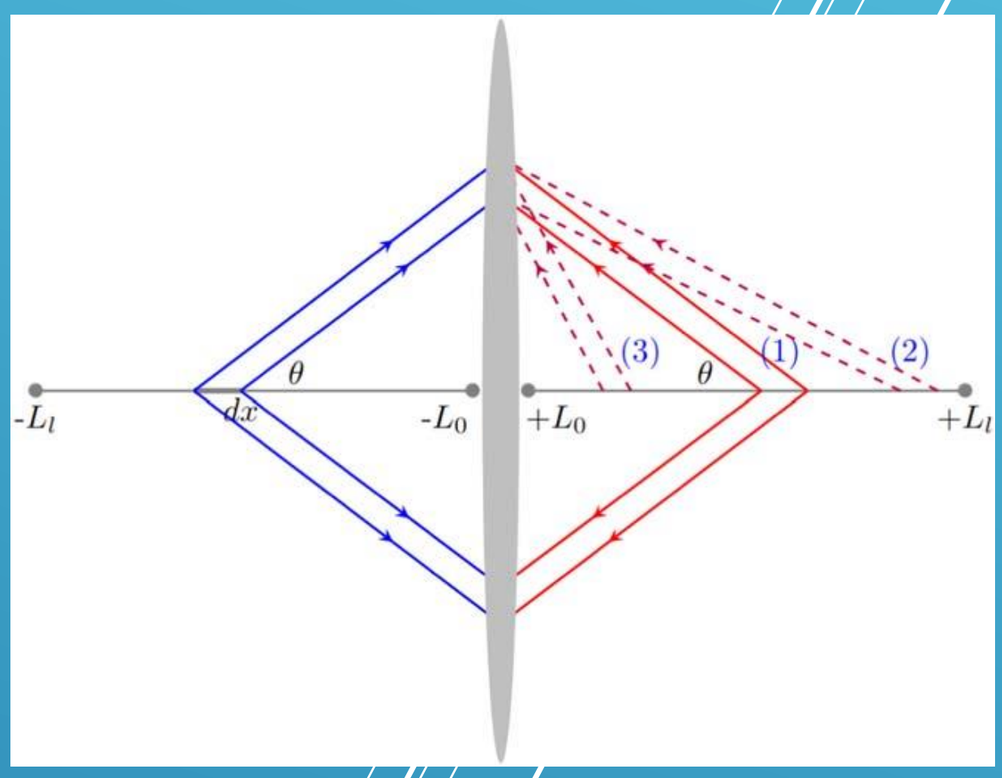
Why colliding neutrinos?

- Neutrinos are among the most abundant but least understood of all particles in the Standard Model (SM) that make up the universe.
- They have tiny but strictly non-zero masses, which is contradictory to the standard model, and current mass upper limits derived from experiments are not satisfactory. The origin of the masses remains mysterious.
- With a suitable neutrino-neutrino collision facility, we should be able to observe and measure the $\nu\nu \to HH$ process which exists in the type-I see-saw model where neutrinos couple with the Higgs boson and acquire a mass.
- Such a device would be generalizable to search for resonances like $\nu\bar{\nu} \to Z$ and even $\nu\bar{\nu} \to X$.

How to produce neutrino beams?

- Collimated muon neutrino beams can be produced in a long straight section along the muon collider ring.
- A high luminosity L could be reached with fair neutrino beams each has $N = 10^{12}$ neutrinos spanning $\sigma_{x,y} \sim 1$ mm transversely at a collision rate of $f = 100$ kHz :

$$L \approx 10^{-2} \frac{N^2 f}{4\pi\sigma_x\sigma_y} \sim 10^{28}\ \mathrm{cm^{-2}s^{-1}}.$$



Physics potential of neutrino-neutrino colliders

- Probing $\nu\bar{\nu} \to X$ resonances. For neutrinos from 200 GeV muon decays, a tiny integrated luminosity of $\sim 10^{-5}\ \mathrm{fb^{-1}}$ is sufficient to observe $\nu_e\bar{\nu}_e \to Z \to \mu^+\mu^-$ in the simulation (Figure 1).
- Probing the Weinberg operator and Majorana neutrinos. For neutrinos from 1 TeV muon decay, analyzing 1 $\mathrm{fb^{-1}}$ of simulated events nearly excludes the SM-Majorana coupling coefficients V_{eN} and $V_{\mu N} \geq 0.01$ at $M_N = 20$ TeV at 95% CL (Figure 2).

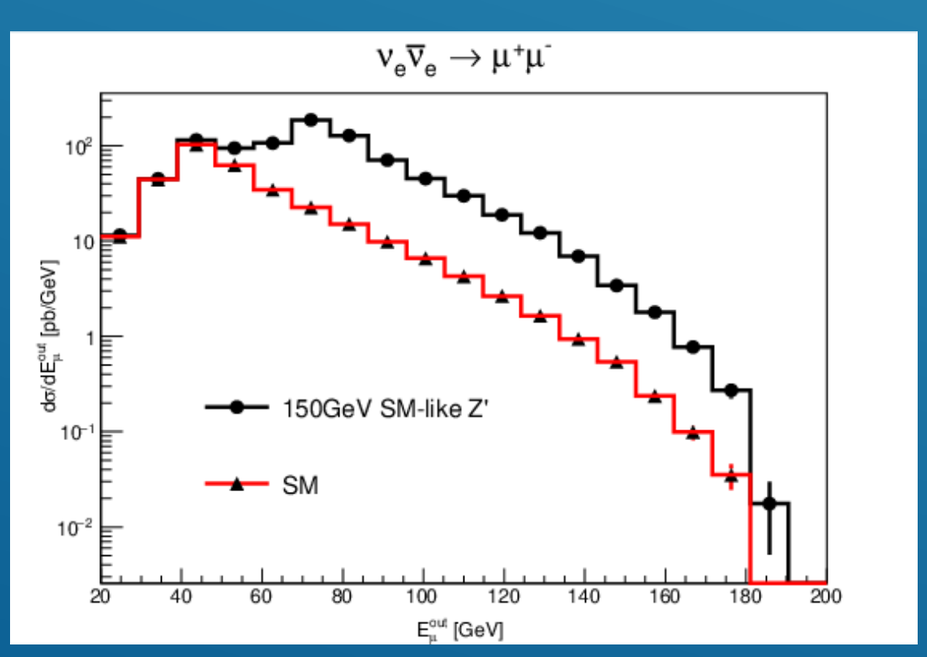


Figure 1. Differential cross sections of $\nu_e\bar{\nu}_e \to X \to \mu^+\mu^-$.

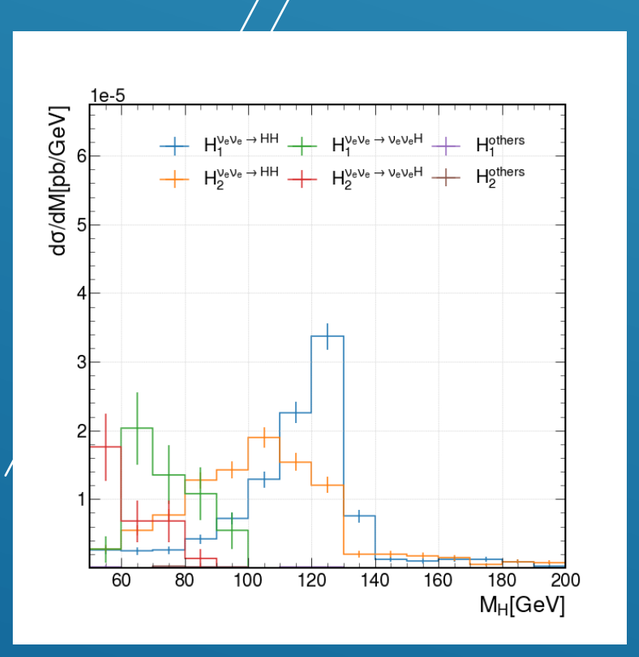


Figure 2. Mass spectrums of $\nu_e\nu_e \to HH$ signals and backgrounds.

Considered background processes:

- $\nu_e\nu_e \to ZZ, ZH$
- $\nu_e\nu_e \to \nu_e\nu_e H$
- $\nu_e\nu_e \to \nu_e\nu_e ZZ, \nu_e\nu_e WW$
- $\nu_e\nu_e \to \nu_e\nu_e ZH, \nu_e\nu_e HH$
- $\nu_e\nu_e \to e^-e^-W^+W^+$

Read more: Sitian Qian *et al* 2024 *J. Phys. G: Nucl. Part. Phys.* **51** 045005