



### Introduction

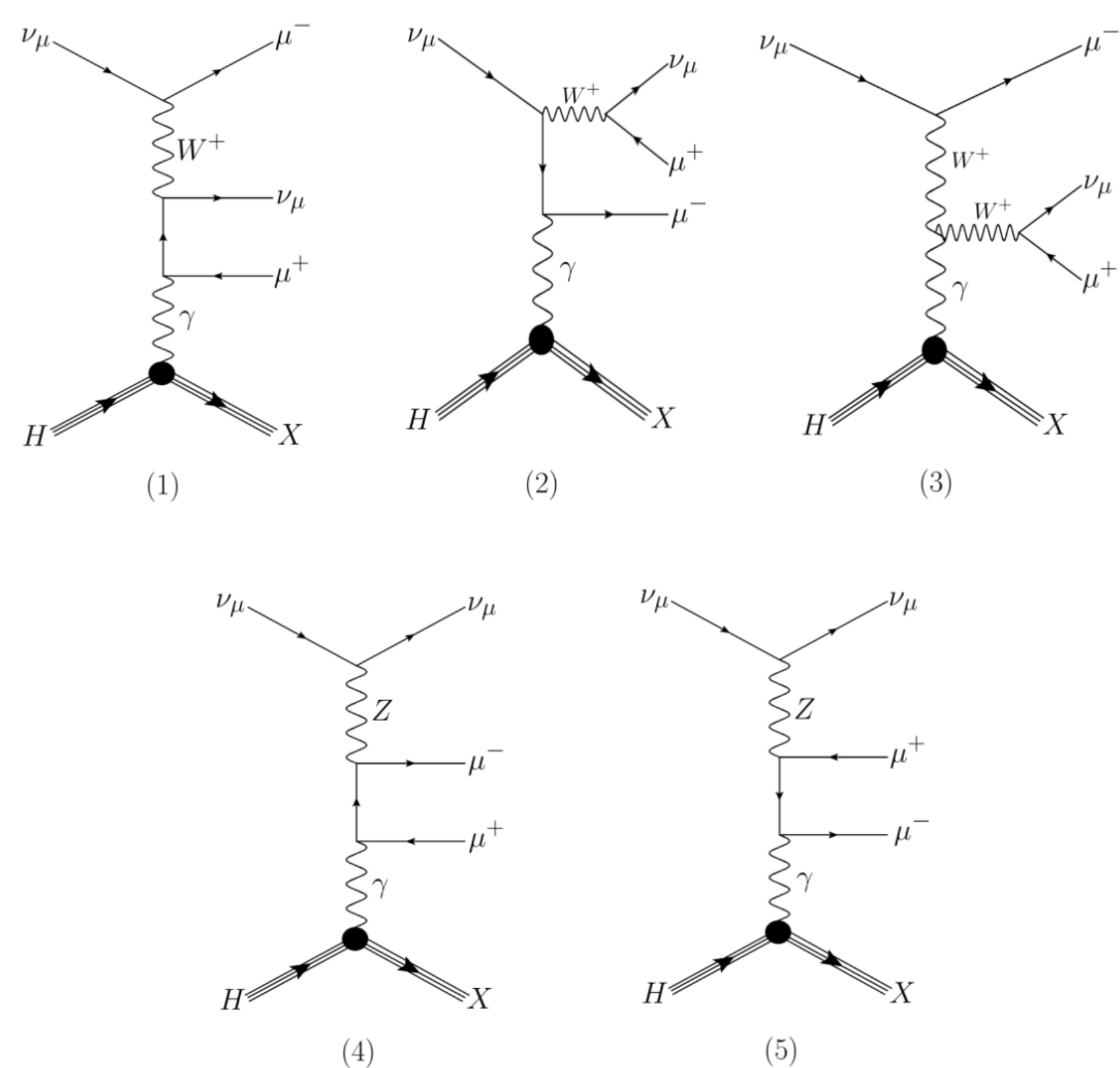


Fig. 1: Neutrino Trident Production Feynman diagrams

- Neutrino trident production (NTP) is a sub-dominant Standard Model process, where an incoming neutrino interacts in the coulomb field of a nucleus as shown in Fig. 1.
- The interaction produces two outgoing charged leptons and neutrino detectors like IceCube can search for two muons from the interaction vertex as the primary event signature.
- Both charged current (CC) and neutral current (NC) interactions contribute to NTP processes.
- High energy neutrinos (above  $\sim 3\text{TeV}$ ) can produce on-shell W boson via the diagrams shown in Fig. 1(2) and 1(3) and enhance the NTP eventrate at the detectors [1].
- Beyond the Standard Model (BSM) physics, such as vector boson  $Z'$  [2] and charged scalar [3] can be probed using the NTP processes.
- Cross-section calculation and event generation for NTP events have been previously focused on accelerator based low energy neutrino interactions [4].
- This poster tries to explore the NTP interaction in the high energy regime ( $10^2 - 10^8\text{GeV}$ ) where increase in the cross-section can lead to the observation of trident events in neutrino telescope detectors like IceCube, Antares.

### Event Generator

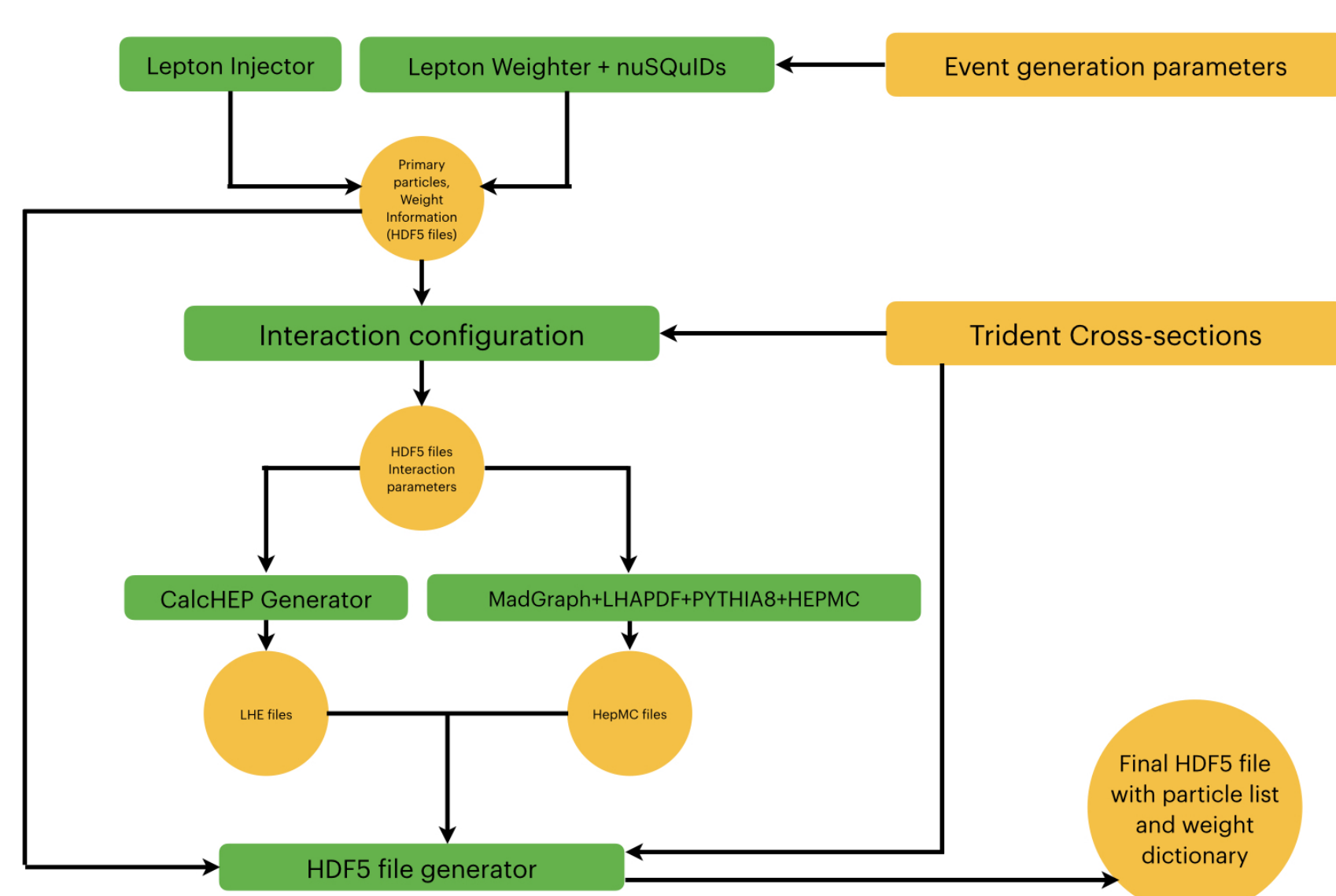


Fig. 2: Flowchart of the trident event generation method. The existing simulation tools used in the generator is noted in [10].

### Event Generation Method

Based on the energy of the exchanged photon, trident interactions probe different nuclear regimes as shown in Fig. 3.

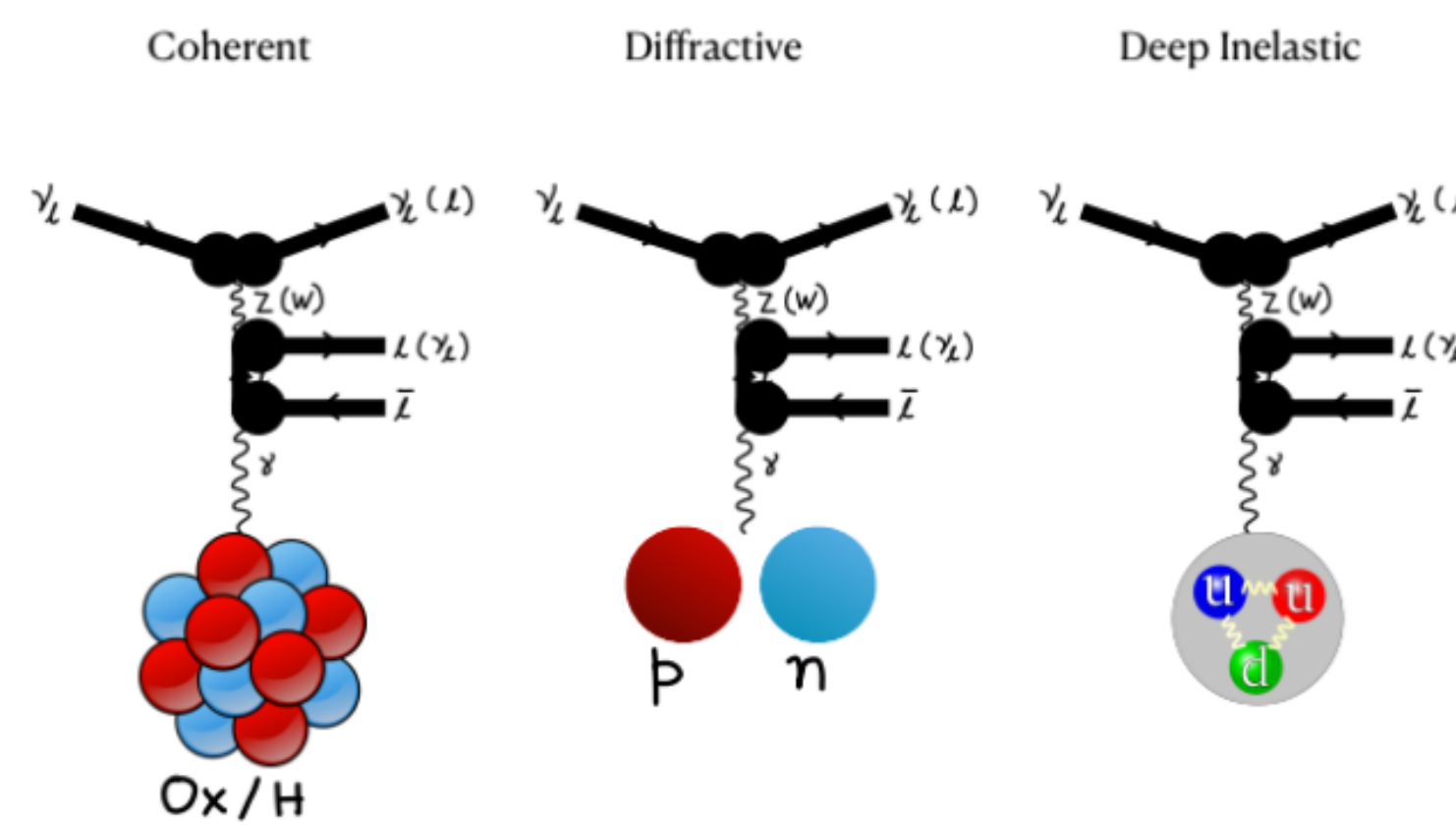


Fig. 3: Schematic diagram of neutrino interaction regimes

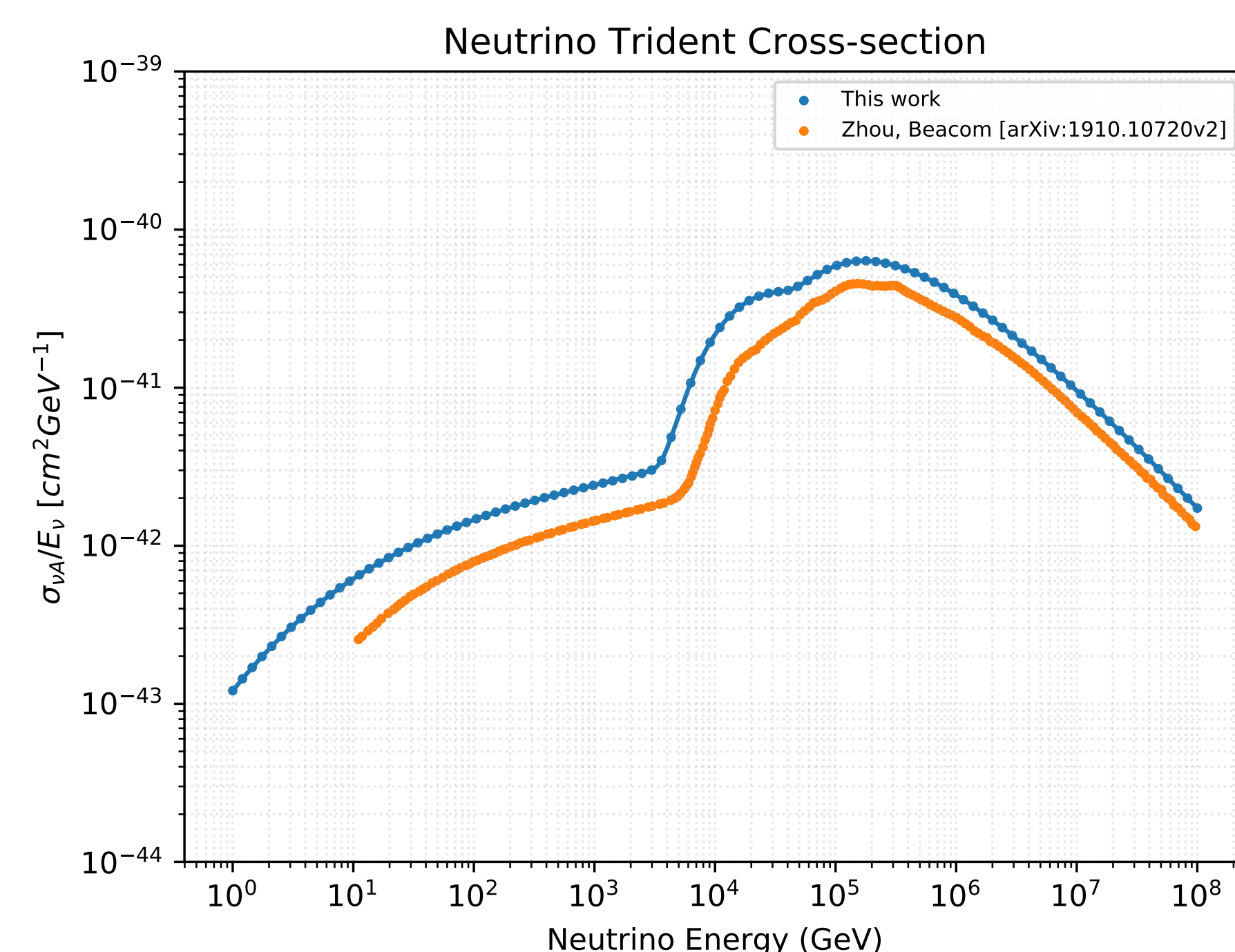


Fig. 4: Comparison of trident total cross section (coherent+diffractive) for muon neutrino interaction.

- Total cross-section for NTP processes using equivalent photon approximation (EPA) method has been calculated in the past and is shown to be overestimated from the exact calculation approximately by a factor of 2 [5], [6], as shown in Fig. 3.
- However, the kinematics of the outgoing particles are not affected by using the approximation method [1]. Therefore, we use the simpler EPA method to generate the differential cross-section of the photon momentum transfer for coherent and diffractive regimes [5].

$$\nu + \gamma \longrightarrow \nu + \mu^- + \mu^+$$

$$\sigma(E_\nu) = \int dQ \sigma_{\gamma\nu}(E_\nu, Q) \int dQ^2 P(s, Q^2) = \frac{Z^2 \alpha}{\pi} \int_{Q_{min}}^{Q_{max}} \frac{dQ}{Q} \sigma_{\gamma\nu}(E_\nu, Q) \int_{Q^2}^{\infty} \frac{dQ'^2}{Q'^2} F^2(Q'^2).$$

$$\frac{d\sigma}{dQ}(E_\nu, Q) = \frac{Z^2 \alpha}{\pi} \frac{\sigma_{EPA}(E_\nu, Q)}{Q} \int_{Q^2}^{\infty} \frac{dQ'^2}{Q'^2} F^2(Q'^2)$$

The differential distribution is then used as probability distribution function to draw samples of photon energies for the interaction generator and produce the outgoing particle kinematics.

### Approximation method validation

- The differential distributions of W boson production have been calculated extensively without using the EPA approximation [7].
- We have generated the same distributions using our event generator [8] and compared the distributions in Fig. 5 and 6 with this more accurate calculation.

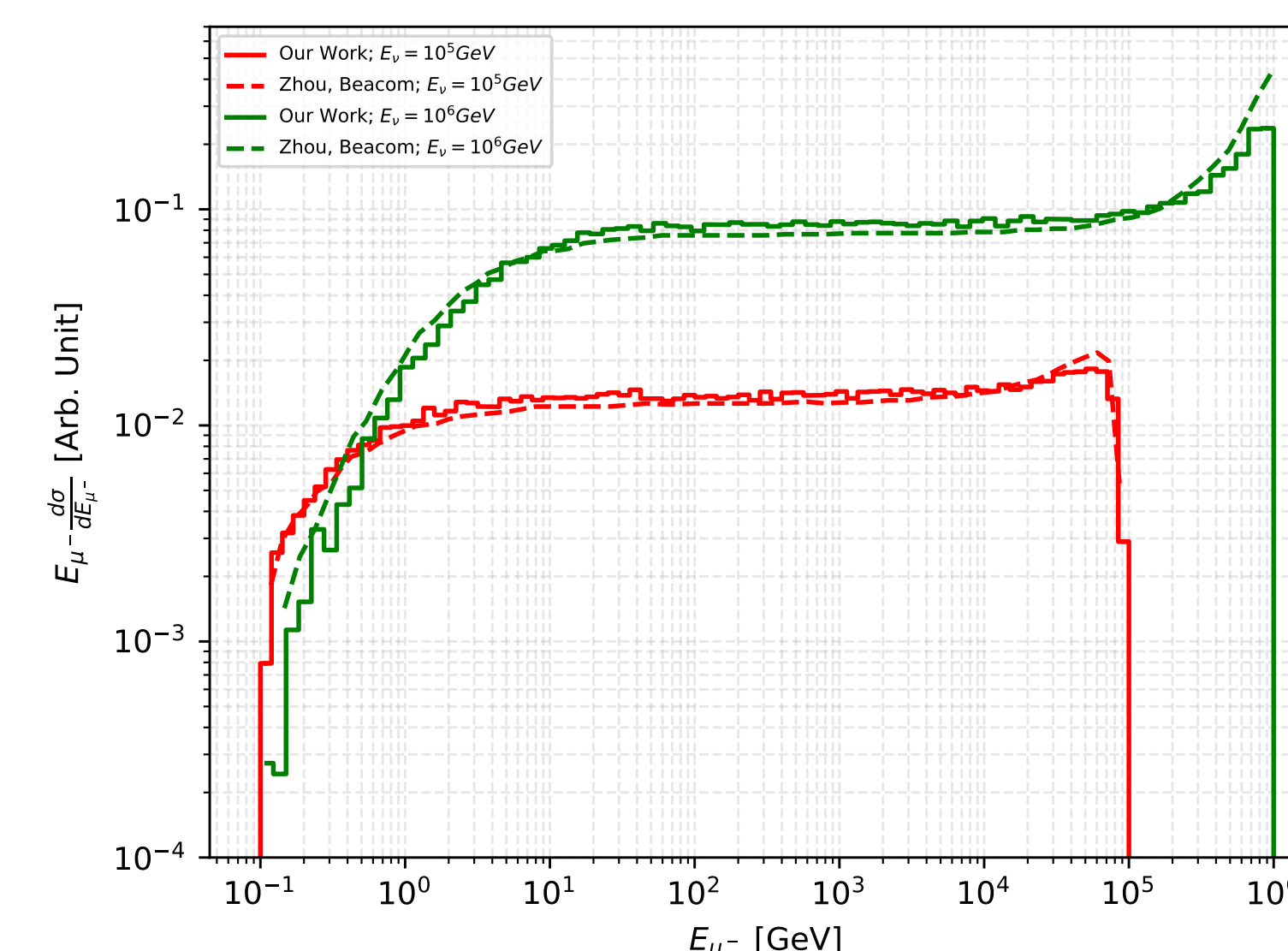


Fig. 5: Differential distributions of the outgoing W boson energy.

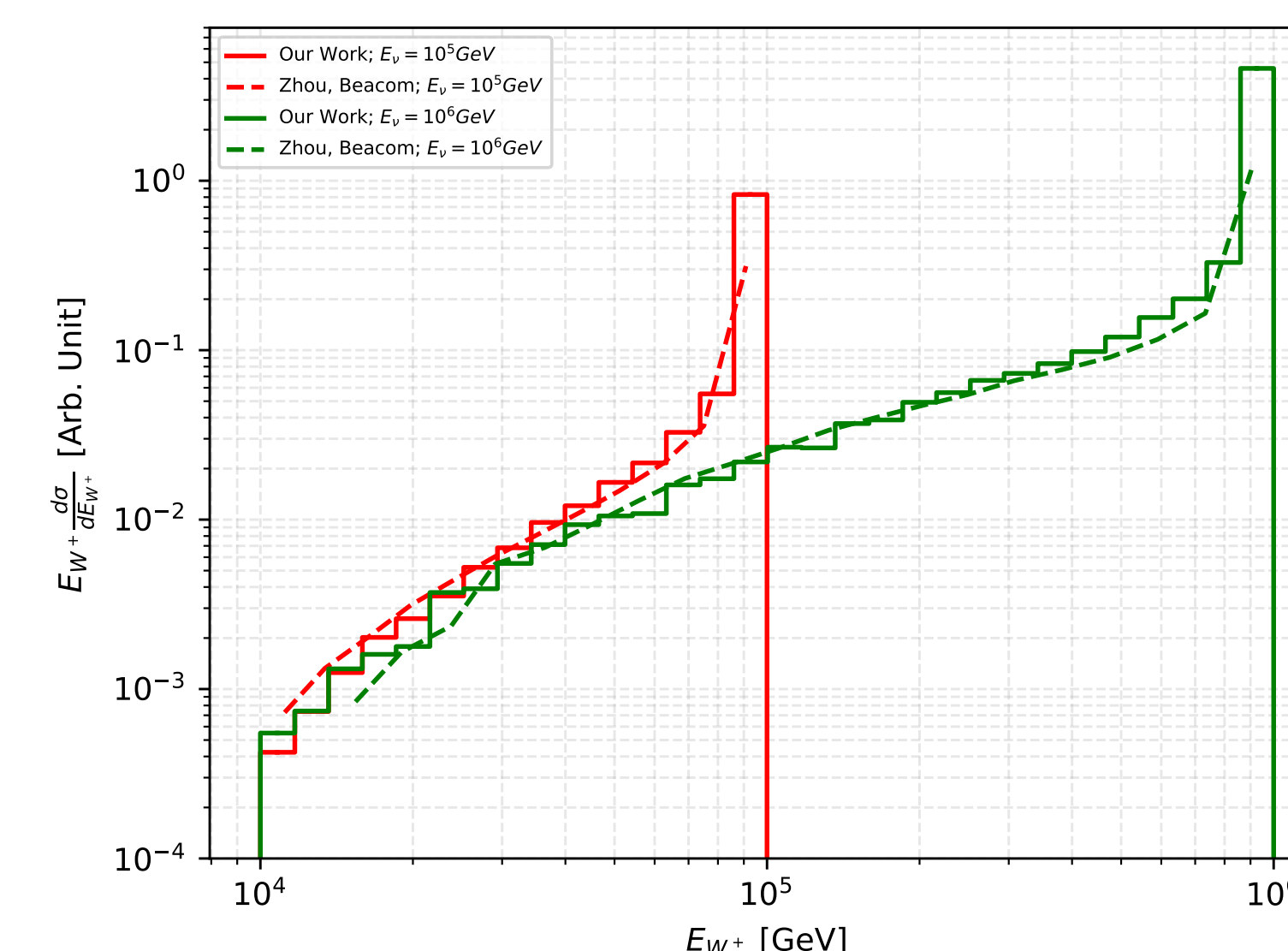


Fig. 6: Differential distributions of the outgoing muon energy.

### Neutrino Trident Event Properties

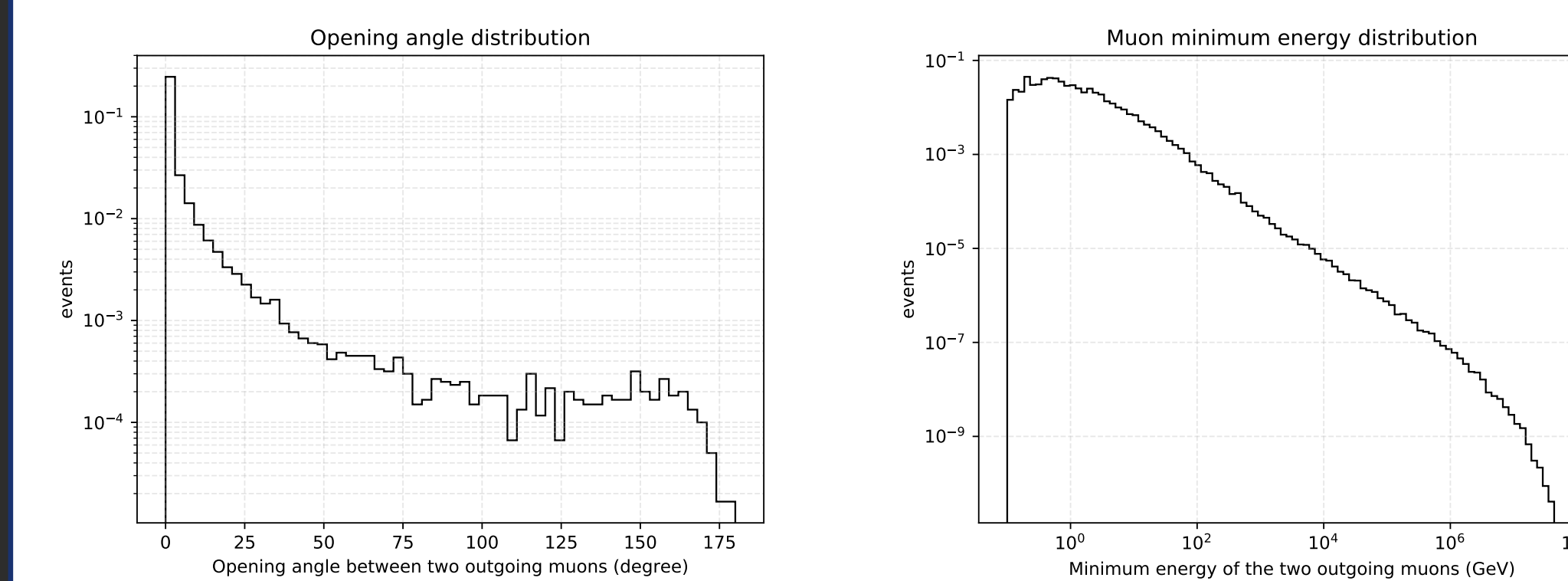


Fig. 7: Kinematical properties of outgoing muons in the trident interaction

Using our general purpose trident generator, we have simulated high energy trident events with the following settings and two of the kinematical distributions is shown in Fig. 7.

Neutrino Energy	$10^2 - 10^8\text{GeV}$
Generation Spectrum	$E^{-1}$
Detector Medium	Ice
Detector Geometry	Cylinder (Radius:500m, Height:1km)

### Event Topology at Neutrino Telescopes

Trident events at high neutrino energies can be observed in neutrino telescope detectors like IceCube, Antares, P-ONE. Typical event topology of a trident event in these detectors is shown in Fig. 8 where two muons are produced and leave a double-track event signature in the detector. Event vertex can be either inside or outside the detector volume.

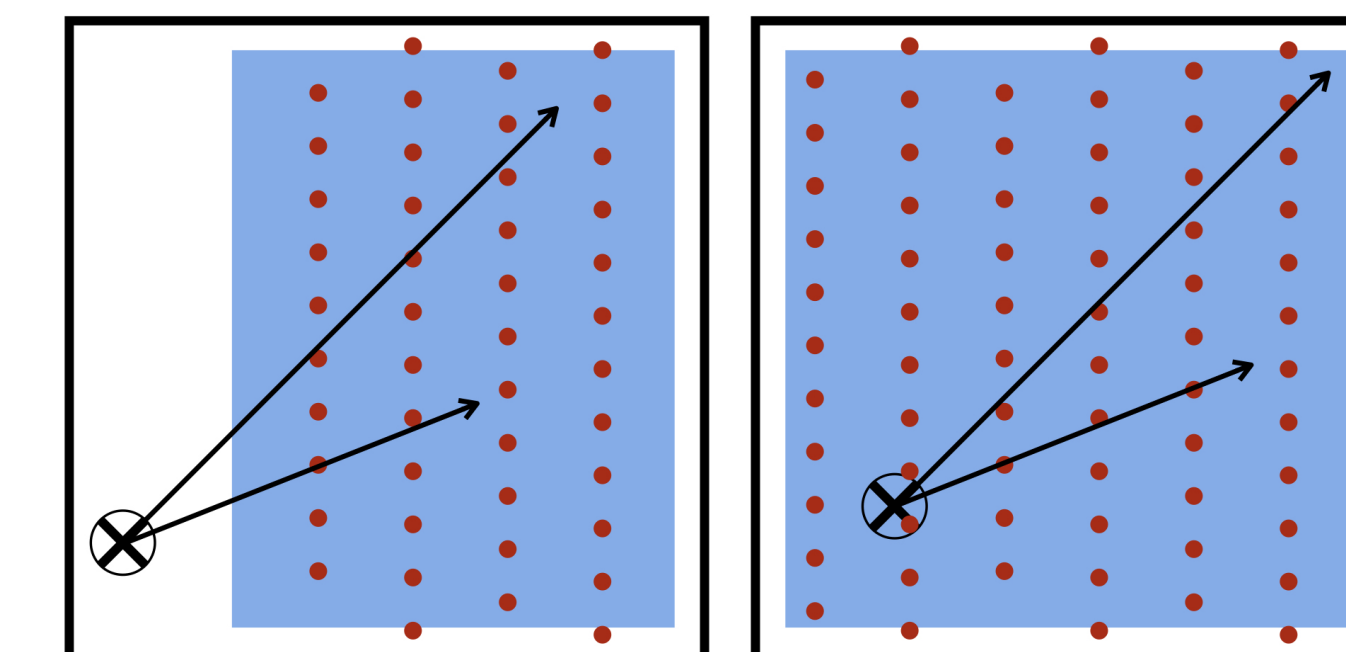


Fig. 8: Trident event topology for neutrino telescope detectors

### Eventrate Prediction at IceCube

Based on the events simulated in a volume of ice comparable to IceCube detector (details shown in the table) we predict the eventrate of SM trident events in Fig. 9. From the positions, directions and lengths (calculated using muon stopping power in ice [9]) of the outgoing muons, we impose a selection criterion on the simulated events which represents an estimate of the double-track detectability in a detector like IceCube.

- Neutrino sources: Atmospheric muon neutrino and antineutrino flux (Honda 2006 model) and diffuse astrophysical neutrino flux.
- Selection criterion: Both muons enter the detector volume and highest track separation is  $> 20m$ .
- A total of 41 events is predicted to satisfy the selection criterion as double-track trident events in 10 years of IceCube data.

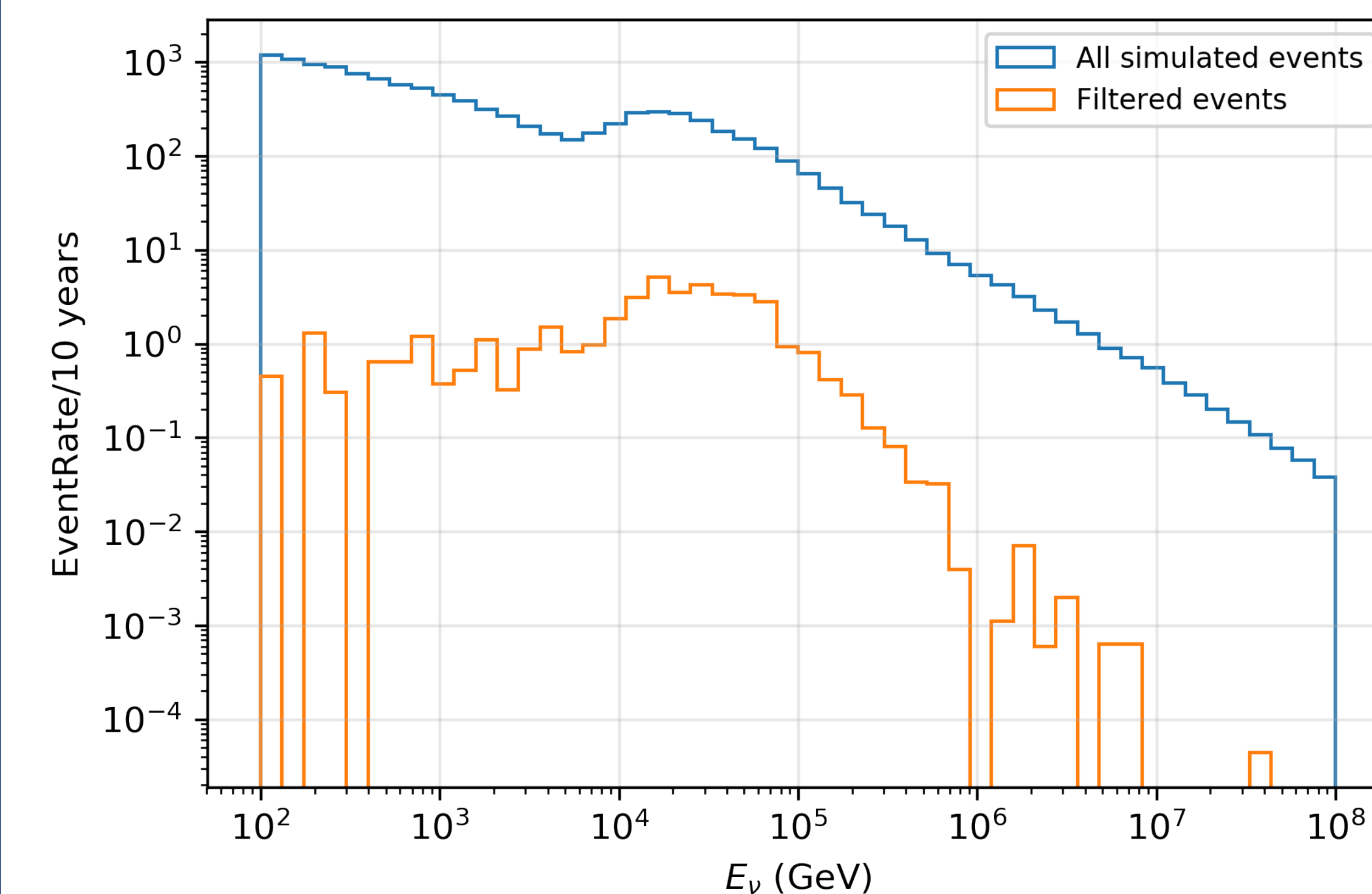


Fig. 9: Expected trident eventrate in icecube from atmospheric and diffuse muon neutrino and antineutrino flux.

### Conclusion

- The detection of NTP events in neutrino telescope detectors can be used as a probe for BSM physics search at CM energies that can exceed LHC.
- High energy SM NTP interactions should be observable in the current detectors like IceCube, Antares.
- Significant increase in the statistics of observed trident events is expected in future experiments like IceCube-Gen2, KM3Net, P-ONE.
- A general purpose trident generator is now available for use in any high energy neutrino detector for developing trident event search analysis.

### References

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