Neutral Current Neutrino Interactions at FASERν

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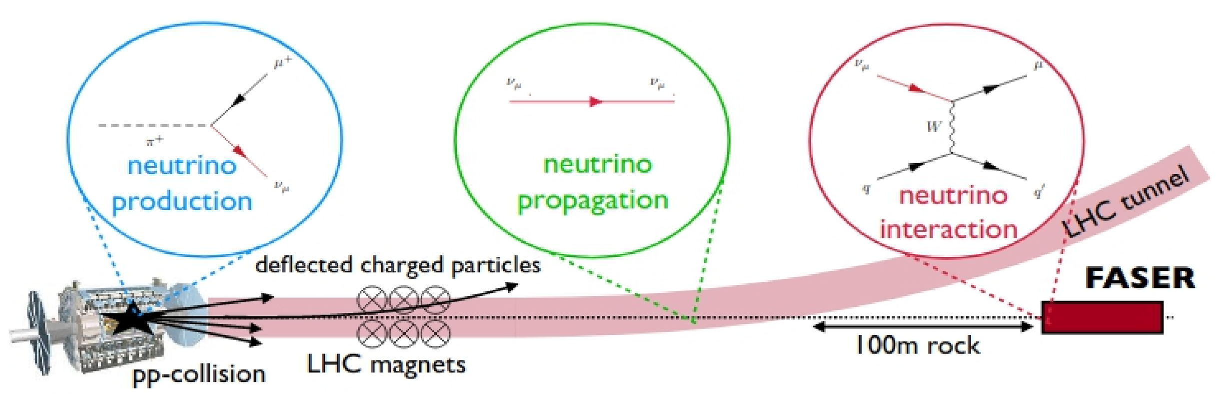
Abstract

- In detecting neutrinos from the Large Hadron Collider, FASERν will record the most energetic laboratory neutrinos ever studied.
- While charged current neutrino scattering events can be cleanly identified by an energetic lepton exiting the interaction vertex, neutral current interactions are more difficult to detect.
- We explore the potential of FASERν to observe neutrino neutral current scattering νN→νN, demonstrating techniques to discriminate neutrino scattering events from neutral hadron backgrounds as well as to estimate the incoming neutrino energy given the deep inelastic scattering final state.
- We find that neural networks trained on kinematic observables allow for the measurement of the neutral current scattering cross-section over neutrino energies from 100 GeV to several TeV.
- Such a measurement can be interpreted as a probe of neutrino non-standard interactions that is complementary to limits from other tests such as oscillations and coherent neutrino-nucleus scattering.

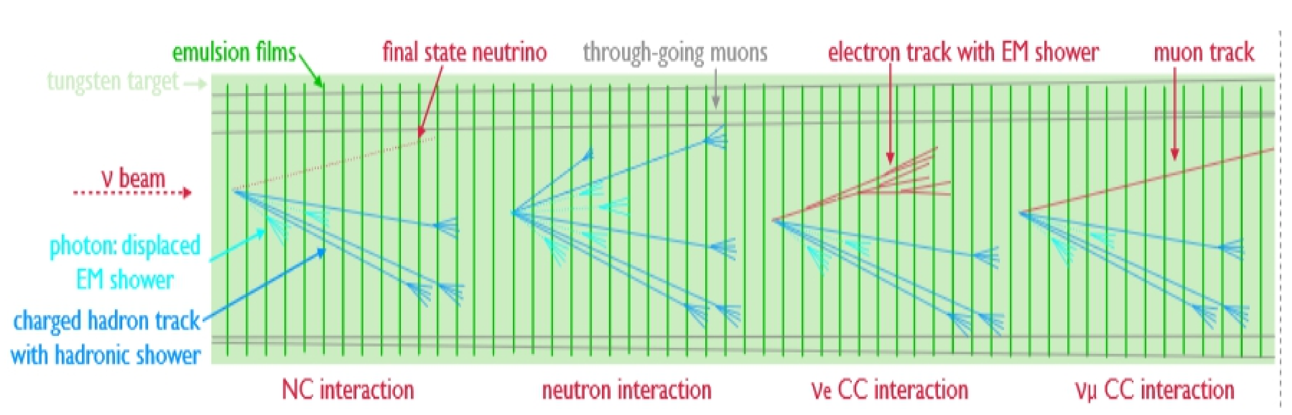
Introduction

- The LHC produces many νs in the far forward (low PT) region from meson decays in the ~ [100GeV–few TeV] range.

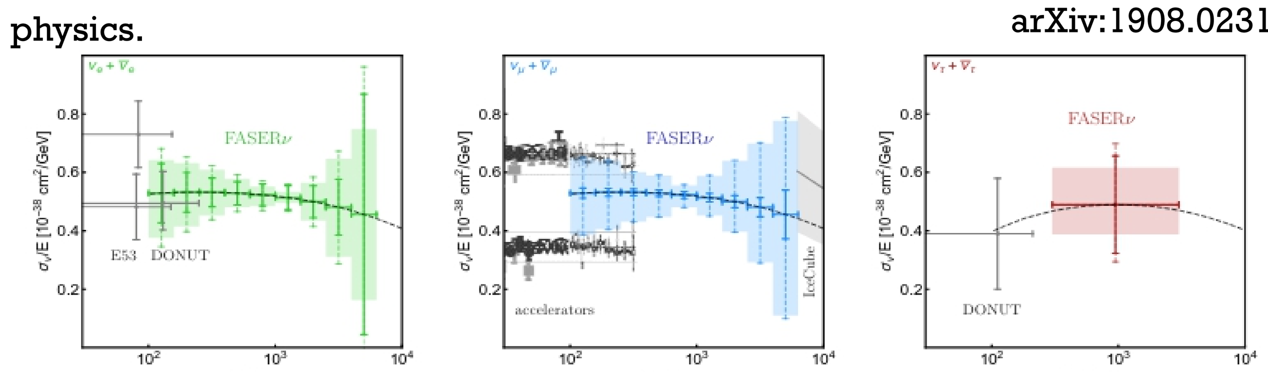


There are 3 event topologies we need to consider:

- Neutrino charged current events (CC), identifiable by the charged lepton in the final state.
- Neutrino neutral current events (NC), this is the **signal** event we are interested in.
- Neutral hadron **backgrounds** (NH), they mimic the NC signal



- Results for the CC study: FASERν probes an important energy gap in neutrino physics. arXiv:1908.0231



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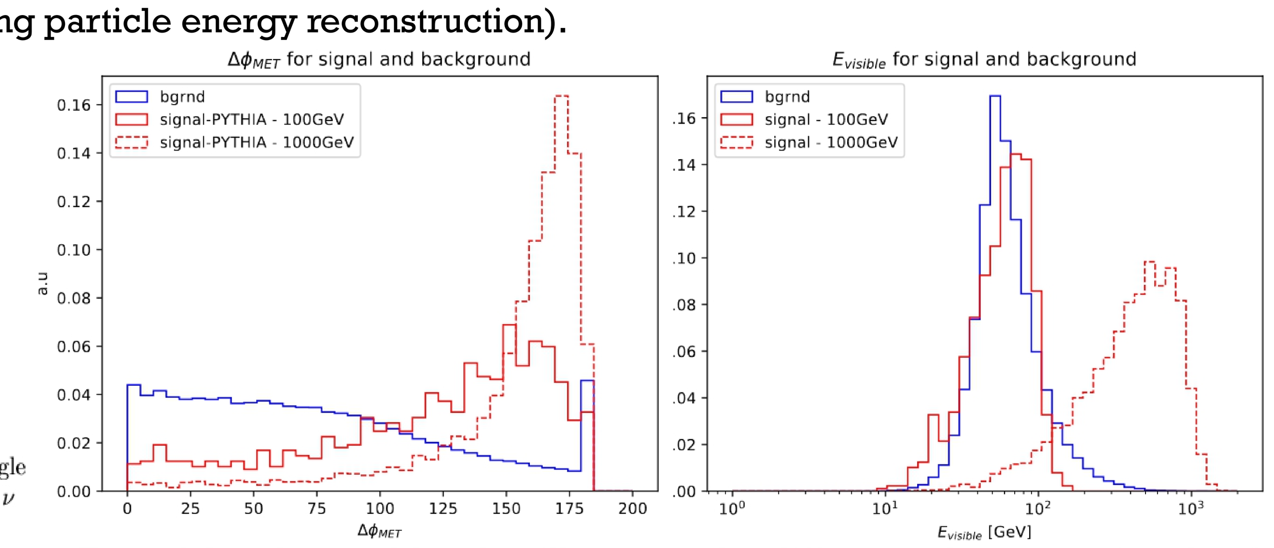
Challenges

NC studies face two main obstacles at FASERν:

- The missing energy in the final state (carried away by the ν) makes event energy reconstruction very difficult. This is a problem shared by all ν NC studies.
- The main background for NC events at FASERν are
- CC events: This is a less severe problem as the charged lepton in the final state can be used to identify and reject these events.
- Neutral Hadrons (NH), mainly induced by μ's. Apart from the ν's, only μ's can travel from the interaction point all the way through rock to the FASERν detector (~500m). The μ's interact with the rock in front of the detector and within the detector producing NHs, our most dominant background. NH interactions look very similar to our NC signal events.

Analysis

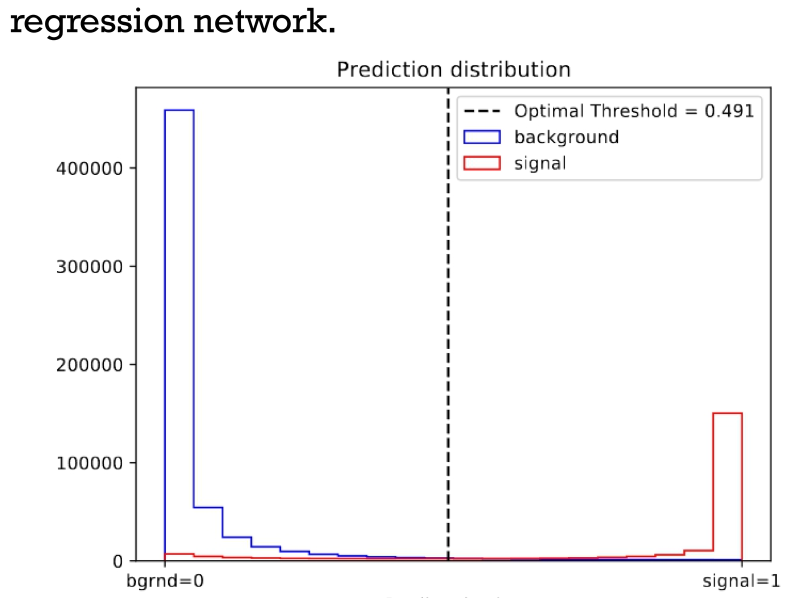
- We use 2 neural network (NN) trained on 9 kinematic observables to perform the classification task (signal vs background) and regression task (incoming particle energy reconstruction).
- Event observables are:
  - **Charged Track Multiplicity:** $n_{ch} \sim \log E_{\rm had}$
  - **Photon Multiplicity:** $n_\gamma \sim 2n_{\pi^0} \sim \log E_{\rm had}$
  - **Visible Hadronic Energy:** $E_{had,v} \sim \sum E_{\rm ch} + \sum E_\gamma$
  - **Momentum of Hardest Track:** $p_{\rm hard} \sim E_{\rm had}$
  - **Inverse Sum of Track Angles:** $\sum |1/\theta_{\rm ch}| \sim E_{\rm had}$
  - **Scalar Cone Angle:** $\tan\theta^S_{\rm cone} = (\sum p_{T,i})/(\sum p_i) \sim H_T/E_{\rm had}$
  - **Vector Cone Angle:** $\tan\theta^V_{\rm cone} = (\sum \vec{p}_{T,i})/(\sum p_i) \sim \vec{p}_T/E_{\rm had}$
  - **Largest Azimuthal Gap:** The largest difference in azimuthal angle between two neighbouring tracks, $\Delta\phi_{\rm max}$ (large for events where a ν recoils all other hadronic activity).
  - **Track-MET-Angle:** The azimuthal angle between the reconstructed missing transverse momentum, $\vec{p}_T$ and the nearest track, $\Delta\phi_{MET}$.



Two of the observables that illustrates the difference between signal at 2 energies (red) and background (blue) .

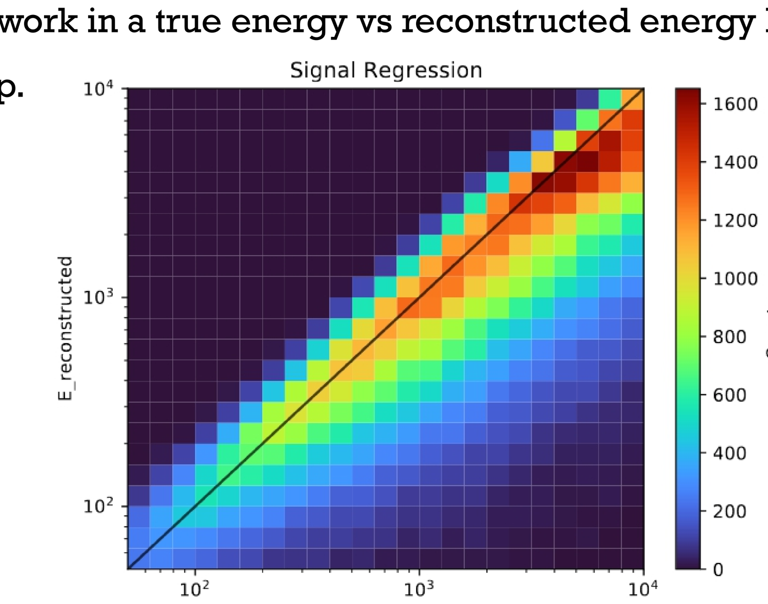
Classifier Network:

- Assigns score to each event, signal =1, background =0.
- Use an optimal threshold to classify events as signal or background.
- Only events classified as signal are fed into the regression network.

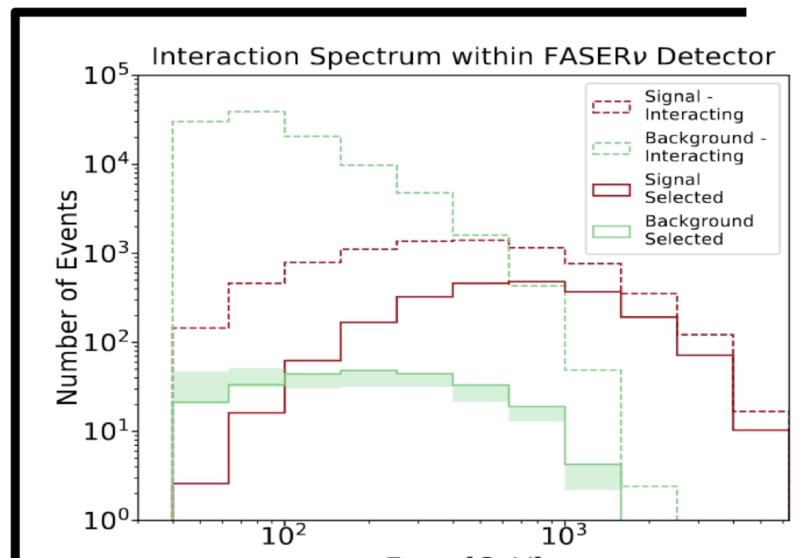


Regression Network:

- Each event classified as signal is fed into the regression network which estimates the incoming particle energy.
- Below we show the performance of the regression network in a true energy vs reconstructed energy heat map.



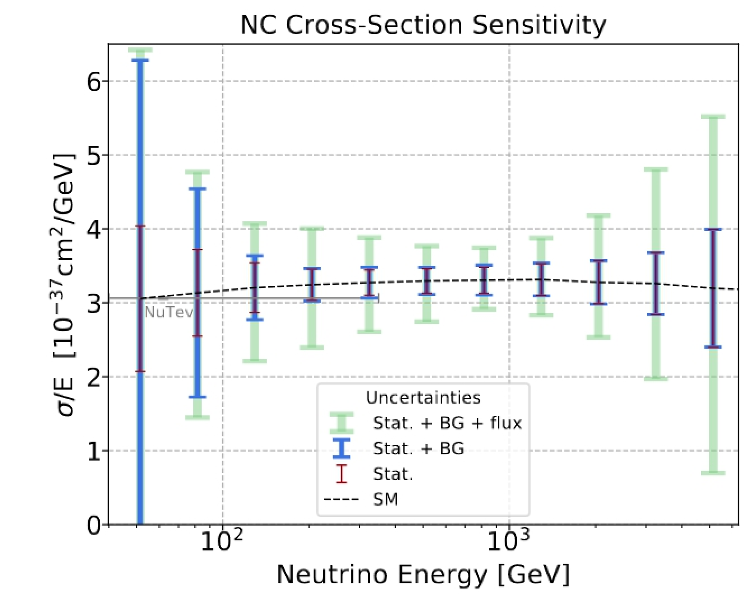
NN Output



- The expected numbers of neutral hadron interactions (green) and NC neutrino interactions(red) with the FASERν detector during LHC Run 3 are shown as dashed lines.
- The solid lines show the spectra for events passing the signal identification and energy estimation NNs.
- The huge suppression of backgrounds (dashed vs solid green line) is a result of the NN analysis.

Cross–Section Sensitivity

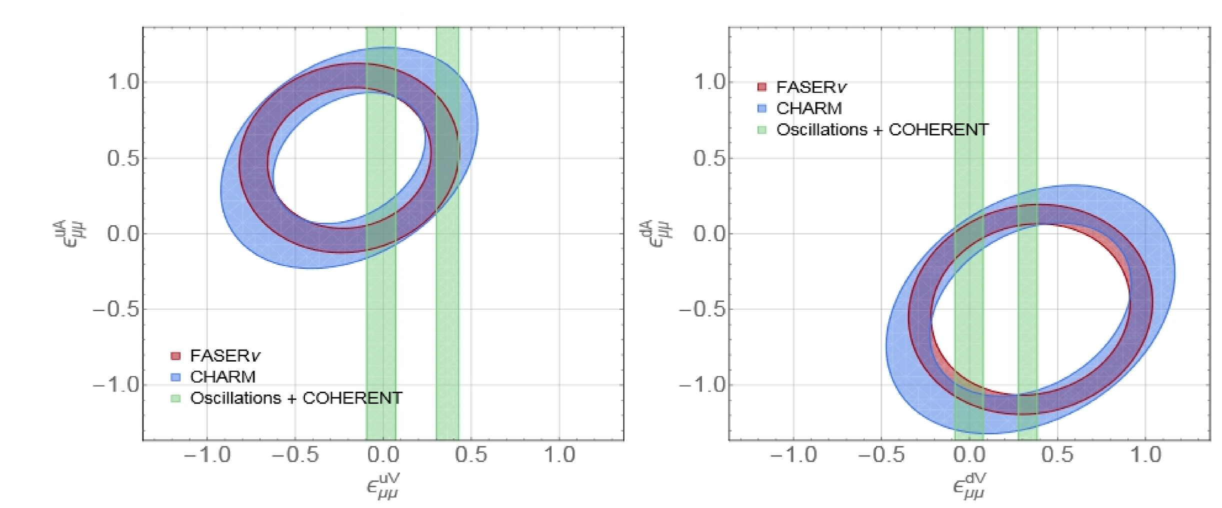
- O/p of the NN's gives us the number of reconstructed events in each energy bin (for a total of ~ 7000 events).
- This gives us the size of the statistical uncertainty on ν NC interaction cross-section.
- The other sources of uncertainty are background uncertainty and incoming ν flux uncertainty (dominant one).



Non-Standard Interactions

$$\mathcal{L} \supset -\sqrt{2}G_F \sum_{f,\alpha,\beta} [\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta][\epsilon^{f,V}_{\alpha\beta} \bar{f}\gamma_\mu f + \epsilon^{f,A}_{\alpha\beta} \bar{f}\gamma_\mu\gamma^5 f]$$

- Neutrino NSI can be written down by the above Lagrangian.
- Neutrino oscillations and neutrino-nucleus scattering probe only the vector couplings.
- High energy experiments (like at FASERν) can probe NSI regardless of the underlying spin structure and hence sensitive to vector and axial couplings.



Conclusions

- There is much physics to be studied in the forward region at LHC.
- FASERν is the dedicated experiment to study collider neutrinos at few GeV to few TeV range, new energy range for neutrino physics.
- We show here a strategy to overcome the usual difficulties with NC studies using NNs.
- FASERν sensitivity to NC interactions are obtained and used to constrain neutrino NSI.

References

•A. Ismail, **R. Mammen Abraham**, and F. Kling, "Neutral current neutrino interactions at FASERν,"Phys. Rev. D103no. 5, (2021) 056014,arXiv:2012.10500 [hep-ph]