Neutral Current Neutrino Interactions at FASERν

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Neutral Current Cross-Section at FASERν

- FASERν will give us a unique opportunity to measure ν cross-section in the $\sim$ [100GeV – few TeV] range. Charged Current (CC) cross-sections were studied earlier.[2]
- Here we present an analysis strategy to identify and reconstruct Neutral Current (NC) interactions and hence constrain neutral current ν cross-sections.

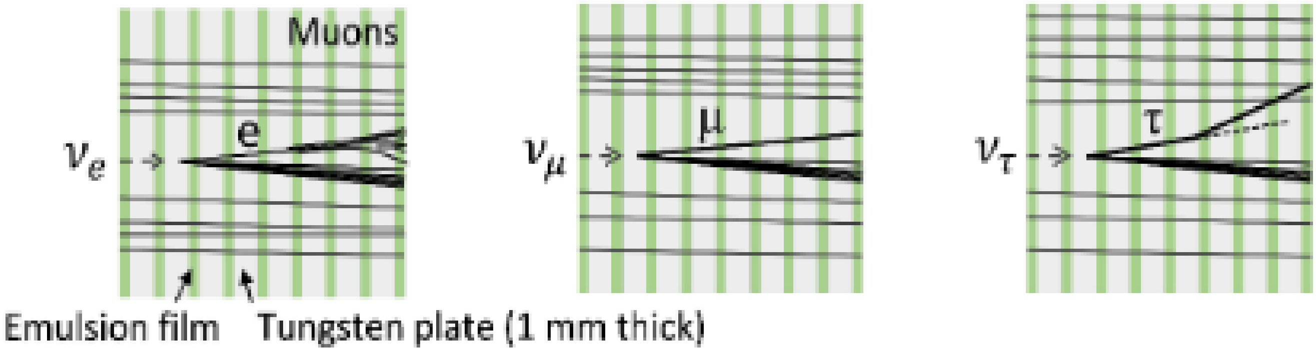
ν NC studies face two main obstacles at FASERν :

- 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 (*one person's treasure is another's background*). This is a less severe problem.
  - Neutral Hadrons (NH), mainly induced by μ's.

[2] arXiv:1908.02310

Backgrounds

CC:

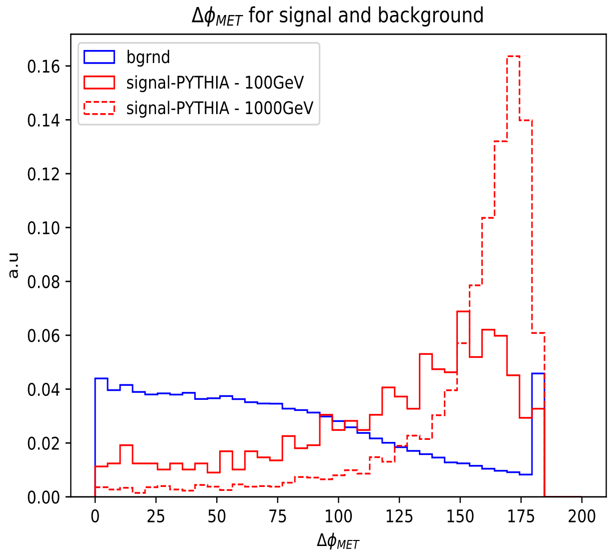


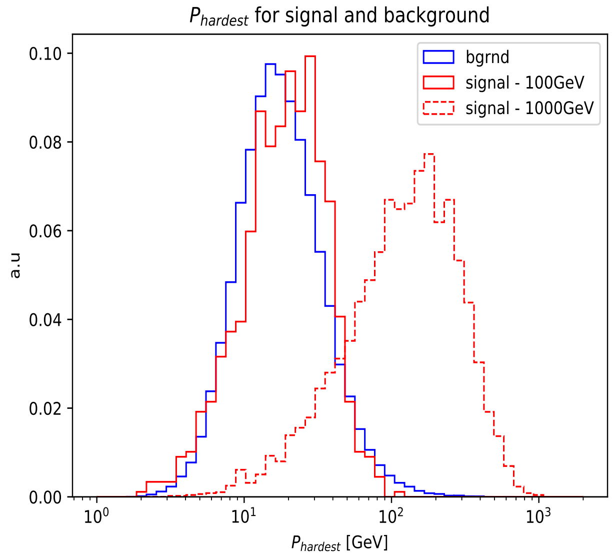
NH: Apart from the ν's we are interested in only, μ's can travel all the way through rock to the FASERν detector. The μ's interact with the rock in front of the detector and within the detector producing NHs. These μ induced NHs are our most dominant background. NH interactions look very similar to our signal events.
NH=$n, \overline{n}, \Lambda, \overline{\Lambda}, K_{L,S}, \pi$

Event Generation and NN training

- *Event Generation:* We use Pythia to simulate ν-W and NH-W collision. Other generators were compared with Pythia and were in agreement.
- *Event Selection:* We select events with ≥ 5 charged tracks, each charged track has energy ≥ 1 GeV, and $\theta < \pi/4$.
- *Detector Simulation:*
  - Track momentum and energy smearing.
  - Identifies each visible track as electron, photon or a normal track.
  - Determines if the track interacts within the detector.
- *NN training:* We use 2 NN's:
  - Classifier N/W: Distinguishes signal(NC) and background(NH) events.
  - Regression N/W: Estimates the incoming particle energy. Only on identified signal events.

We use a total of 10 observables to characterize an event.
$\Delta\phi_{MET}$ = The azimuthal angle between the reconstructed missing transverse momentum and the nearest track.





Neural Network Results

The trained n/w's predict on a separate data set of signal and background events. First the classifier network classifies events into signal and background. Only the events classified as signal are passed into the regression n/w for energy estimation.

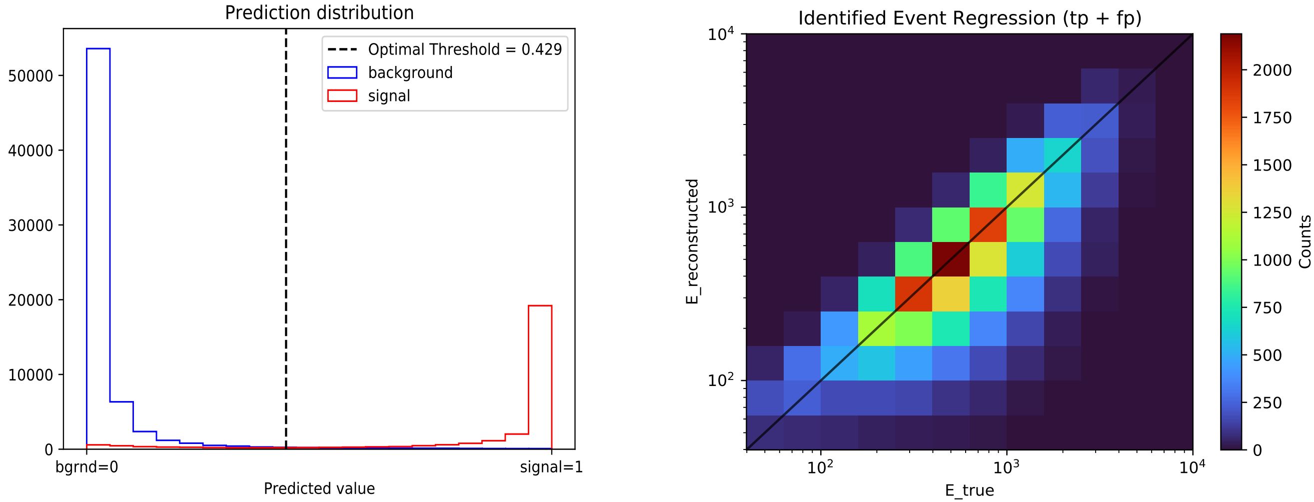
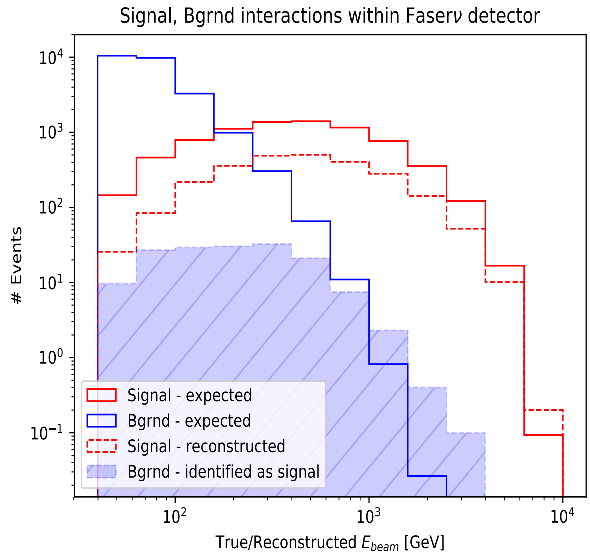
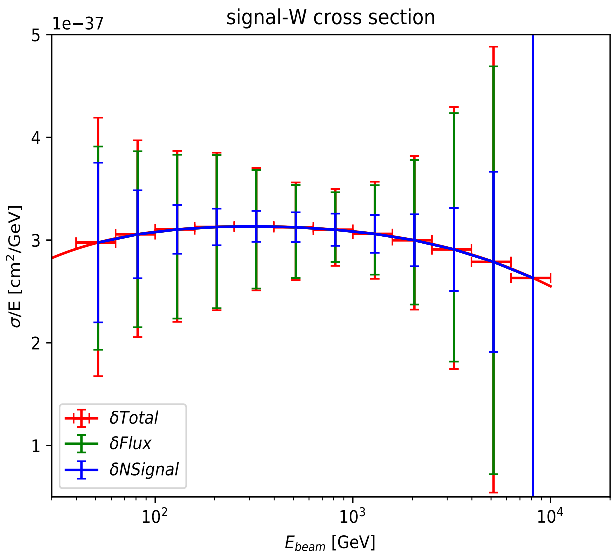


Figure: Results of the (**left**) classifier and (**right**) regression n/w.

Cross-Section Results

O/p of the NN's gives us the number of reconstructed events in each energy bin. This gives us size of statistical uncertainty on ν NC interaction cross-section. The other source of uncertainty is the one on incoming flux.





Other uncertainties: NH flux, simulation.

Future Work - Constraining NSI (an example)

$$\mathcal{L} = -2\sqrt{2}G_F \sum_{f,\alpha,\beta,X} \epsilon^{f,X}_{\alpha,\beta} \left(\overline{\nu}_\alpha \gamma^\mu P_L \nu_\beta\right) \left(\overline{f}\gamma_\mu P_X f\right)$$

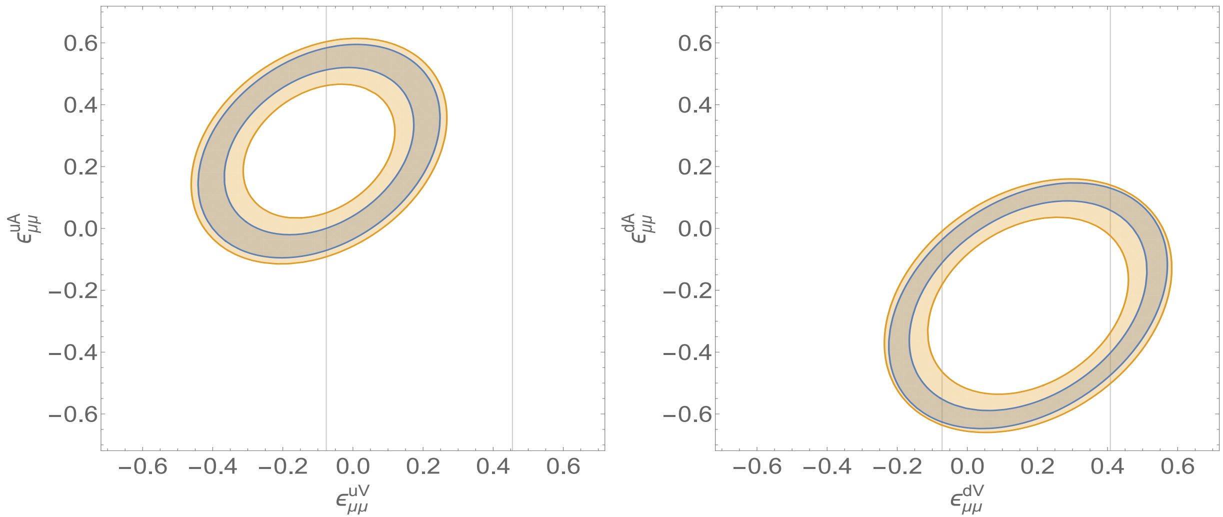


Figure: Comparison of bounds on NSI couplings from CHARM(400GeV)(orange) and FASERν (grey) for (**left:**) up quark and (**right:**) down quark in the Vector-Axial vector coupling plane. Vertical lines are bounds from oscillations and COHERENT that constrain only vector NSI.

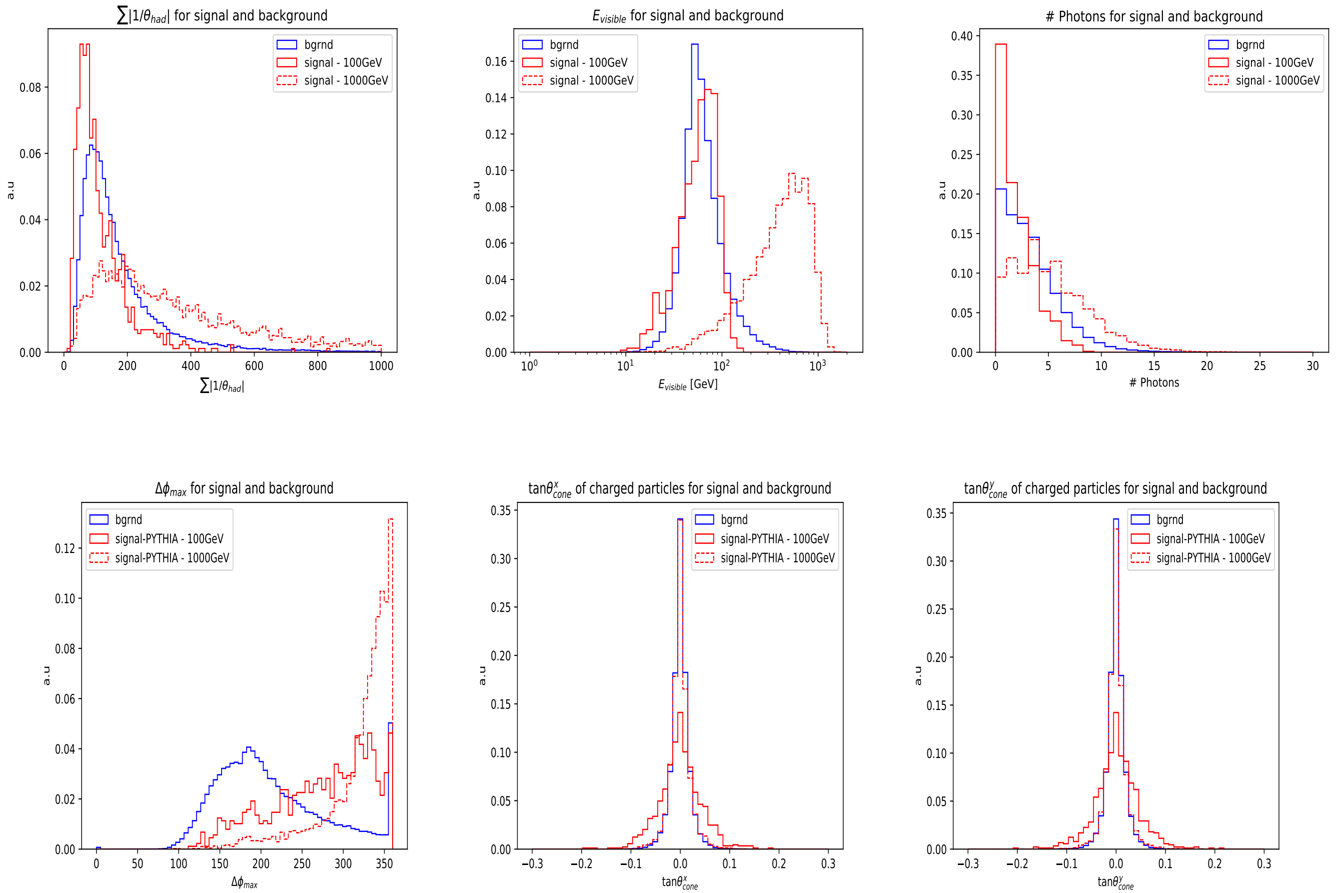
Summary

- FASERν can study CC and NC events at unprobed energies.
- We show here a strategy to overcome the usual difficulties with NC studies using machine learning.
- Both event identification and energy reconstruction were done to constrain ν NC cross-section.
- This sensitivity to NC interactions can be used to do various physics, eg: constraining NSI, light mediators etc.

Backup Slides-Observables

- $n_{ch} \sim \log E_{\text{had}}$
- $n_\gamma \sim n_{\pi^0} \sim \log E_{\text{had}}$
- $\sum E_{\text{ch}} + \sum E_\gamma \sim E_{had}$
- $p_{\text{hard}} \sim E_{\text{had}}$
- $\sum |1/\theta_{\text{had}}| \sim E_{\text{had}}$
- $\tan \theta^S_{\text{cone}} = (\sum p_{T,i})/(\sum p_i) \sim H_T/E_{\text{had}}$
- $\tan \theta^V_{\text{cone}} = (\sum \vec{p}_{T,i})/(\sum p_i) \sim \vec{p}_T/E_{\text{had}}$
- Largest Azimuthal Gap: The largest difference in azimuthal angle between two neighbouring tracks, $\Delta\phi_{\text{max}}$.
- Track-MET-Angle: The azimuthal angle between the reconstructed missing transverse momentum, $\not{\vec{p}}_T$ and the nearest track, $\Delta\phi_{MET}$.

Backup Slides-Other Observables



Backup Slides - Comparing various NHs

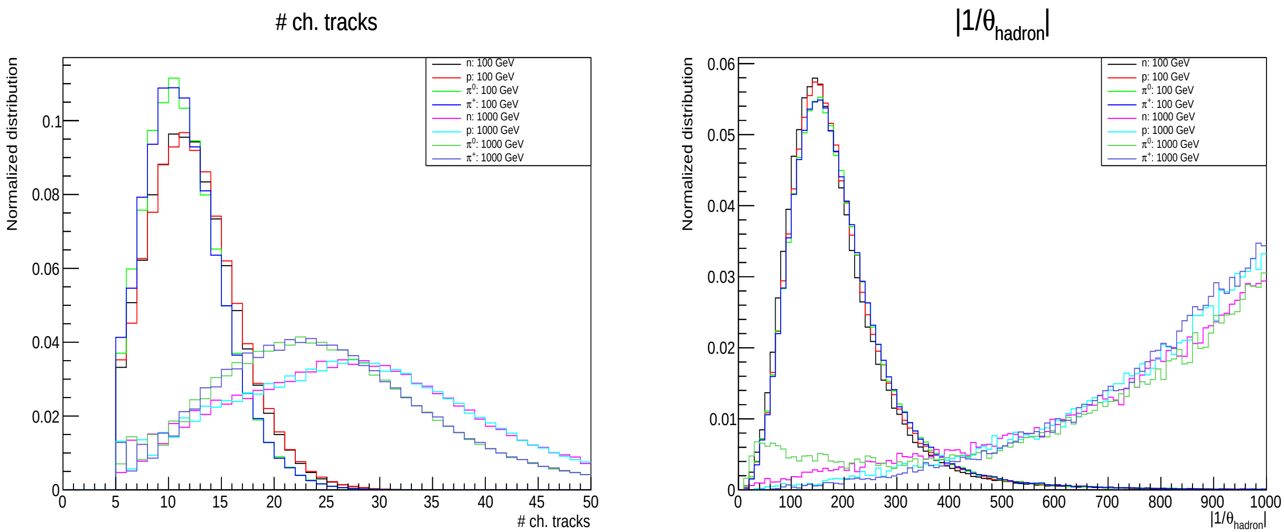
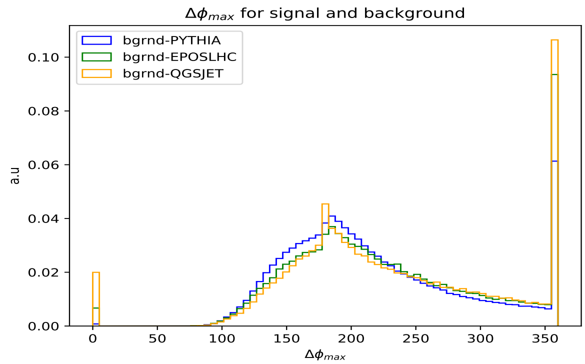
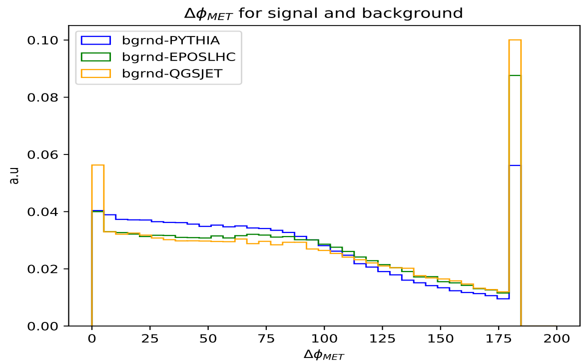
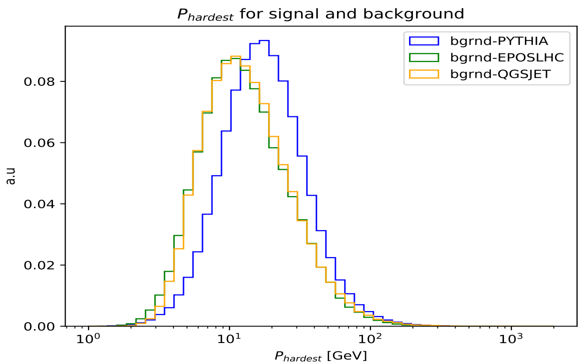


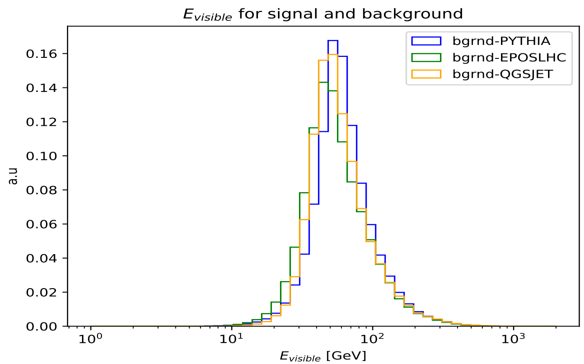
Figure: Comparison of (**left**) charged track multiplicity and (**right**) $\sum |1/\theta_{\mathrm{had}}|$ for n, p, π^0, π^+ at 100,1000 GeV.

Backup Slides - Background Observables: Pythia vs EPOSLHC vs QGSJET

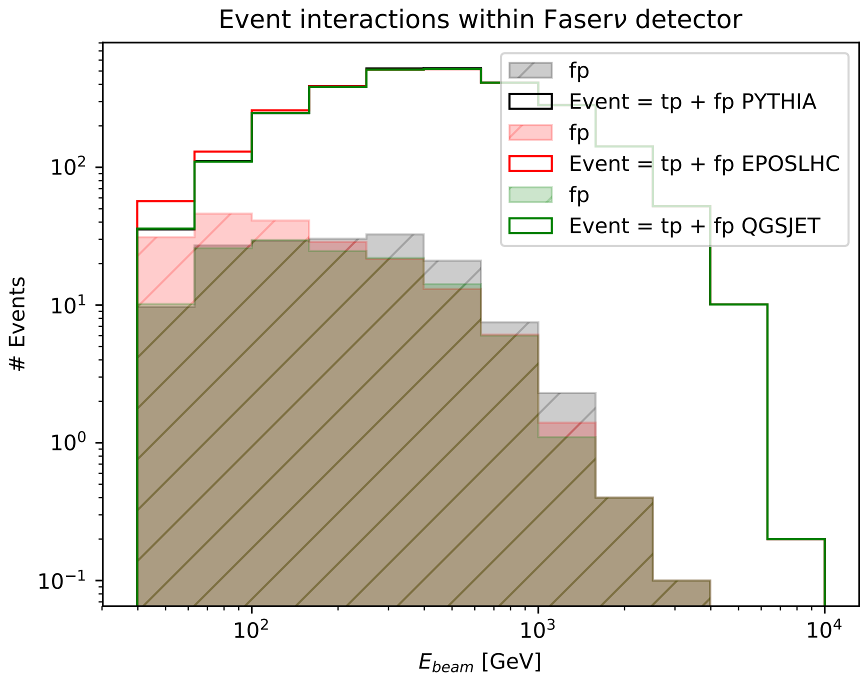








Backup Slides - Prediction with Different Backgrounds: Pythia vs EPOSLHC vs QGSJET



Backup Slides - Neural Network Results

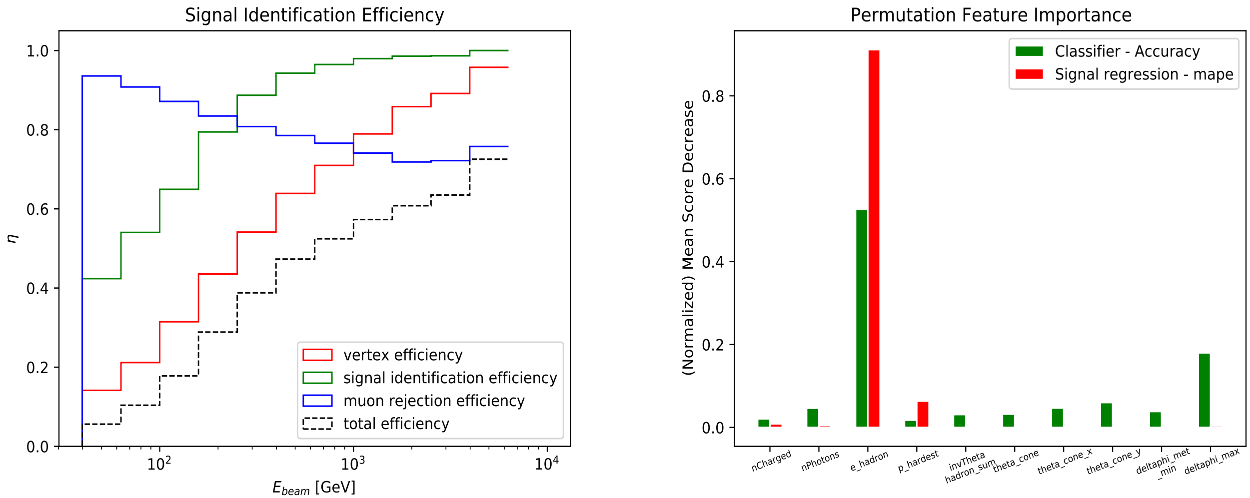


Figure: (**Left**) Signal identification efficiency and (**right**) feature importance.