Department of Physics
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ND Searches for anomalous ν_τ appearance (Updates)

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Introduction

Objectives

- Main objective : study of eventual tau neutrinos that we may have in the DUNE Near detector coming from short baseline oscillations in a sterile neutrino scheme.
  Evaluate the ν_τ appearance sensitivity of DUNE ND in both leptonic and hadronic tau decay channels.

- Event classification : signal and background separation based on kinematic differences. (Kinematic variables similar to those used in NOMAD)

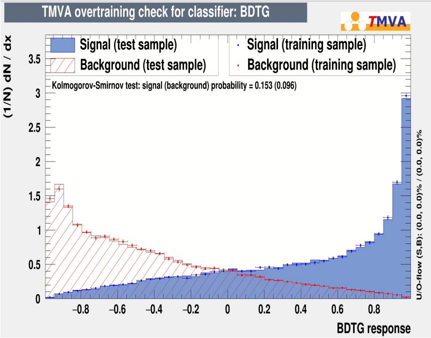
- Simulation : Events were simulated using GENIE and propagated through the Near Detector using EDEP-SIM.

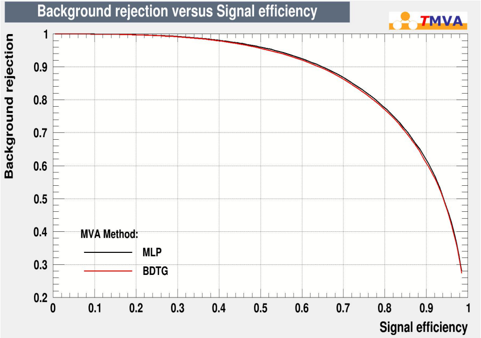
- Beam used : Optimized beam for ν_τ appearance in the DUNE FD.

Electron channel

$\tau \rightarrow e^{-}$ channel

- **TMVA Classification based on TRUE GENIE kinematic variables**





BDTG response (Trained on a flat energy flux)

Electron channel

$\tau \rightarrow e^{-}$ channel

- Sensitivity : based on event counting. All events were normalized such that they would correspond to **1.1e21 P.O.T.** and **67t** fiducial mass.

- $FOM = \frac{signal}{\sqrt{signal + background}}$ (statistics only)

- $FOM = \frac{s}{\sqrt{(s+b) + (0.1*(s+b))^2}}$ (with 10% systematics and select those with FOM ≥ 1.7).

- Event selection : select events with ν_τ BDTG score > 0.995 (region with almost no background for a background sample of 4.5 million events).

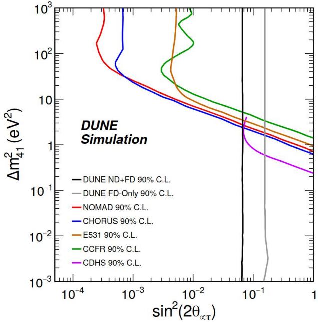


Figure : (For reference) Comparison of exclusion limits from various experiments - DUNE TDR, BSM Chapter

Electron channel
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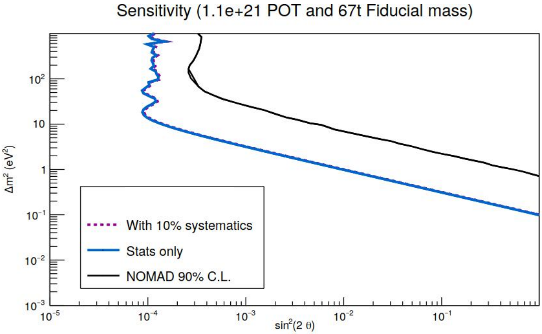

Muon channel

ν_τ CC ($\tau^- \to \mu^-$) and ν_μ CC separation

$\tau \to \mu^-$ channel

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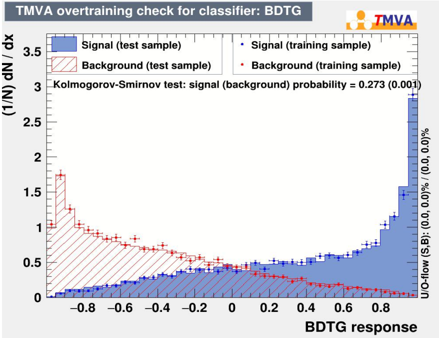

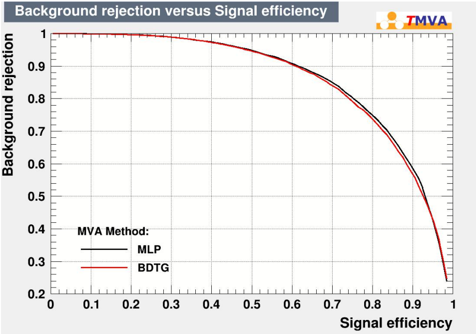

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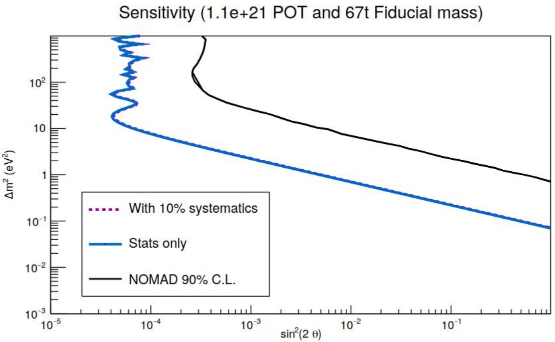


Hadronic channel

$\tau \rightarrow \rho^-$ channel

- **Steps :** develop a ρ selector then develop a classifier that separates NC events from $\nu_\tau(\tau \rightarrow \rho^-)$.

- **ρ classification :** TMVA Classification based on kinematic infomations.

  - Signal (true ρ) : - from ν_τ CC events : $\tau \rightarrow \rho^- + \nu_\tau$; $\rho^- \rightarrow \pi^- + \pi^0$; $\pi^0 \rightarrow 2\gamma$
    - from NC events : $\rho^- \rightarrow \pi^- + \pi^0$ (the ρ is recorded)

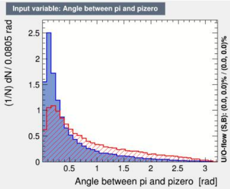
  - Background (false ρ) : any $\pi^\pm + \pi^0$ couple that doesn't come from a true ρ^- from the hadronic system or τ decay.

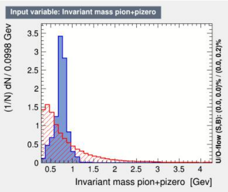
Hadronic channel

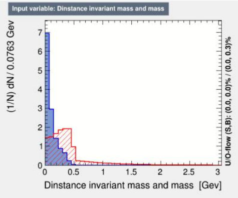
ρ selector

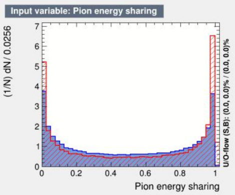
$\tau \rightarrow \rho^-$ channel

- Kinematic variables including :









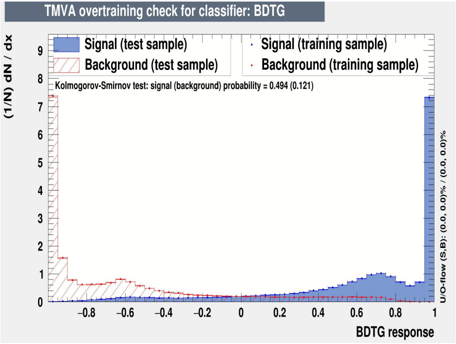
- $$\mathrm{d} = \sqrt{(M_{\pi^0}^{(inv)} - m_{\pi^0})^2 + (M_{\rho}^{(inv)} - m_{\rho})^2}$$

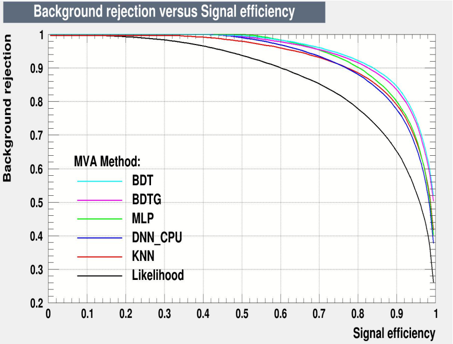
- $$r_{\pi}^{K} = \frac{E_{\pi}^{K}}{E_{\pi}^{K} + E_{\pi^0}^{K}}$$

- **Inspired by Thomas Kosc's work on ν_τ analysis in the DUNE FD.**

ρ candidate selector

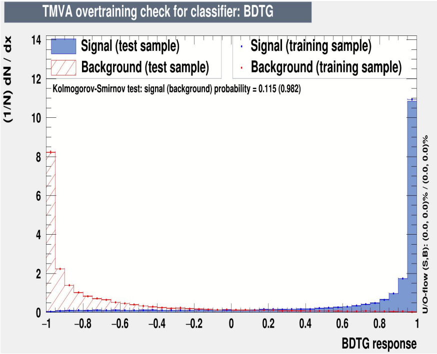
- BDTG response

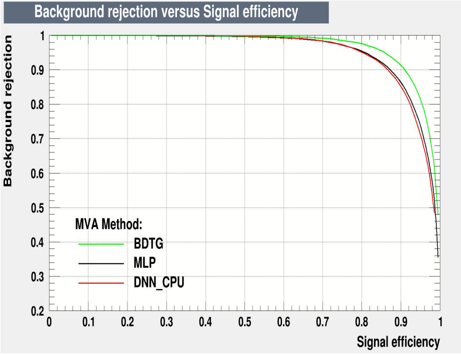




ν_τ CC vs NC

- **TMVA Classification based on TRUE GENIE kinematic variables**





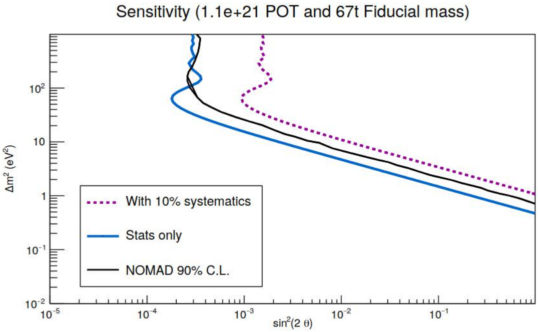
Sensitivity

- Step 1 : get all the events with potential ρ candidates for ν_τCC events and NC events. (Anything that has $\pi^\pm + \pi^0$ or $\pi^\pm + 2\gamma$). Look at all possible ρ system combination.

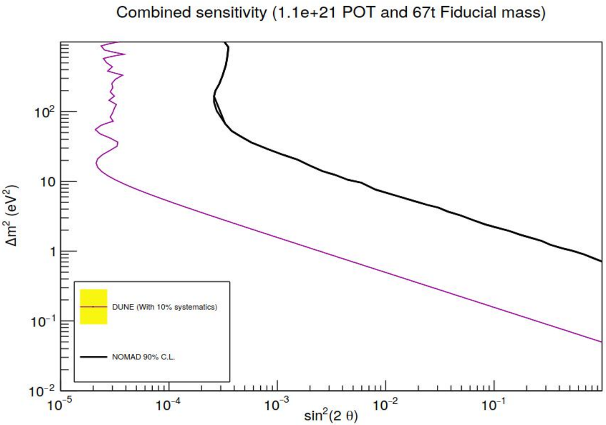
  1^{st} cut : select those with ρ BDTG score > 0.99

- Step 2 : pass through the ν_τCC vs NC selector to get a ν_τ BDTG score.

  2^{nd} cut : select those with ν_τ BDTG score > 0.99



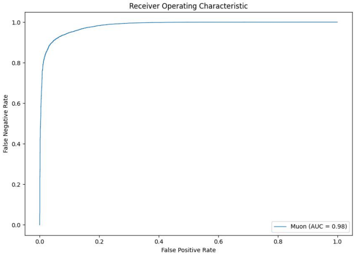
Combined sensitivity



Constraints on NC Backgrounds for leptonic channels

- **Muon / Pion separation** : μ^- loses energy via Multiple Coulomb scattering
  π^- : Coulomb scattering + Hadronic scattering.

- Separation : each information at each point is recorded : scattering angle Θ - dedx, differentiation done using Recurrent Neural Network.



- Area under curve : **0.98**

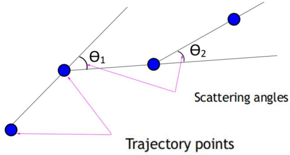
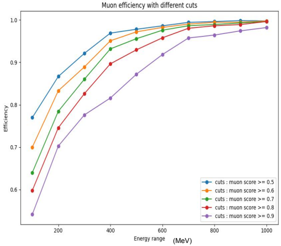


Figure : Scattering angles



- **Current work :** develop an electron/gamma shower classifier.

Conclusion

- Classification based on kinematic variables gives a reasonable output for tau leptonic and hadronic decay channels.

- Sensitivities : based on the true GENIE information studies, DUNE ND's sensitivity to eventual tau neutrino appearance from sterile oscillation is competitive compared to other experiments.

- **Next steps :**
  - Develop an electron/gamma shower classifier
  - Current study is using just the single bin FOM with event counting. Eventually do a proper multi-bin shape analysis
  - Integrate analysis with CAFAna framework being developed by M. Wallbank and evaluate the sensitivities with more realistic systematics

Thank you very much!

Backup

ν_τ CC vs ν_e or ν_μ CC separation kinematic variables

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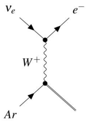


Figure : ν_e CC interaction

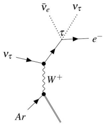


Figure : ν_τ CC ($\tau \to \mu^-$) interaction

- For ν_τ CC : resulting neutrinos from decay take away some momentum $\rightarrow$ Kinematic differences.

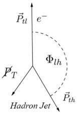


Figure : ν_e CC interaction products in the transverse plane

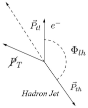
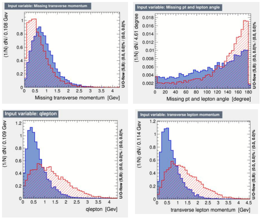


Figure : ν_τ CC ($\tau \to e^-$) interaction products in the transverse plane



- Larger missing transverse momentum $\not{P}_T$ for ν_τ CC.
- Can be applied to other τ decay channels.
- Separation : used ROOT TMVA in which a total of 9 kinematic variables were used (full list in backup slides).

Backup

Muon vs pion separation variables

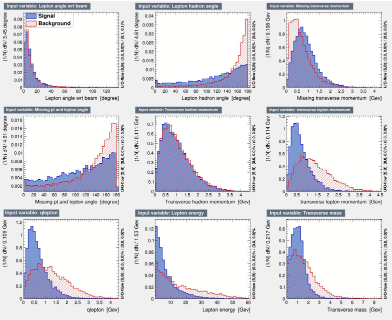


Figure : TMVA Input - CC kinematic variables from events with flat energy distribution (using **GENIE TRUE INFORMATION**)

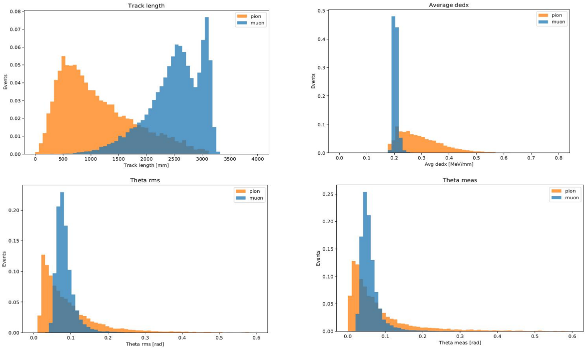
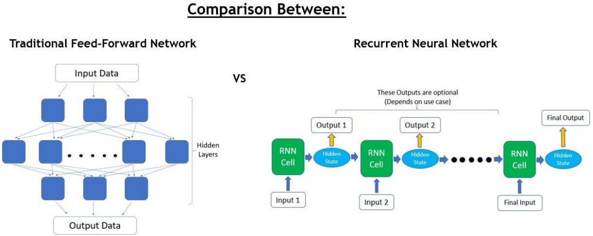


Figure : Sample Muon and Pion separating variables distributions at **700 MeV**

- Recurrent Neural Network: deals with **sequential data**



- Difference : TNN : fixed amount of input data - fixed amount of output. RNN : do not take all inputs at once, take them one at a time in a sequence.
- Non-sequential variables: are handled with traditional neural nets. Those features combined with the features from the Recurrent Neural Network gives the feature for separating pion and muon.

Backup

ρ selection kinematic variables

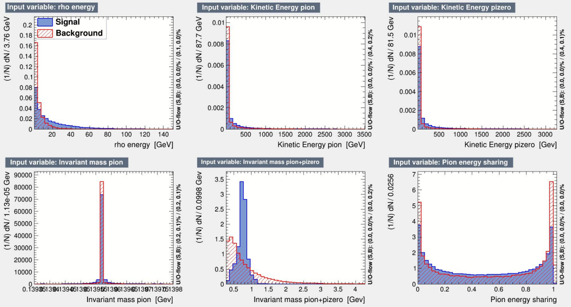
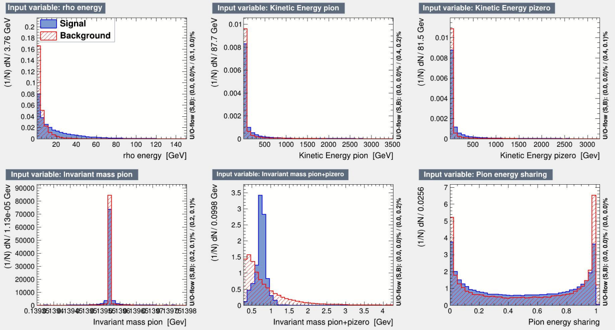


Figure : TMVA Input - rho selection variables

ν_τ CC vs NC separation kinematic variables



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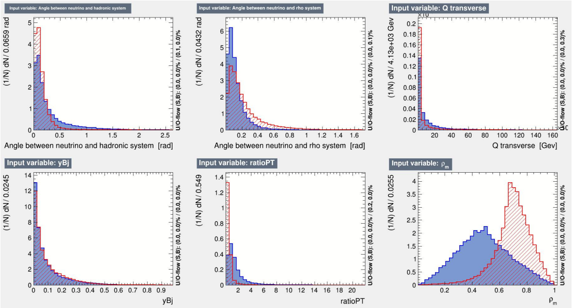

Figure : TMVA Input - NC / nutau CC selection variables (in addition rho selection vars and usual kinematic info)