Selection of charged-current muon-neutrino and electron-neutrino interactions in the DUNE far detector

Dominic Brailsford for the DUNE collaboration

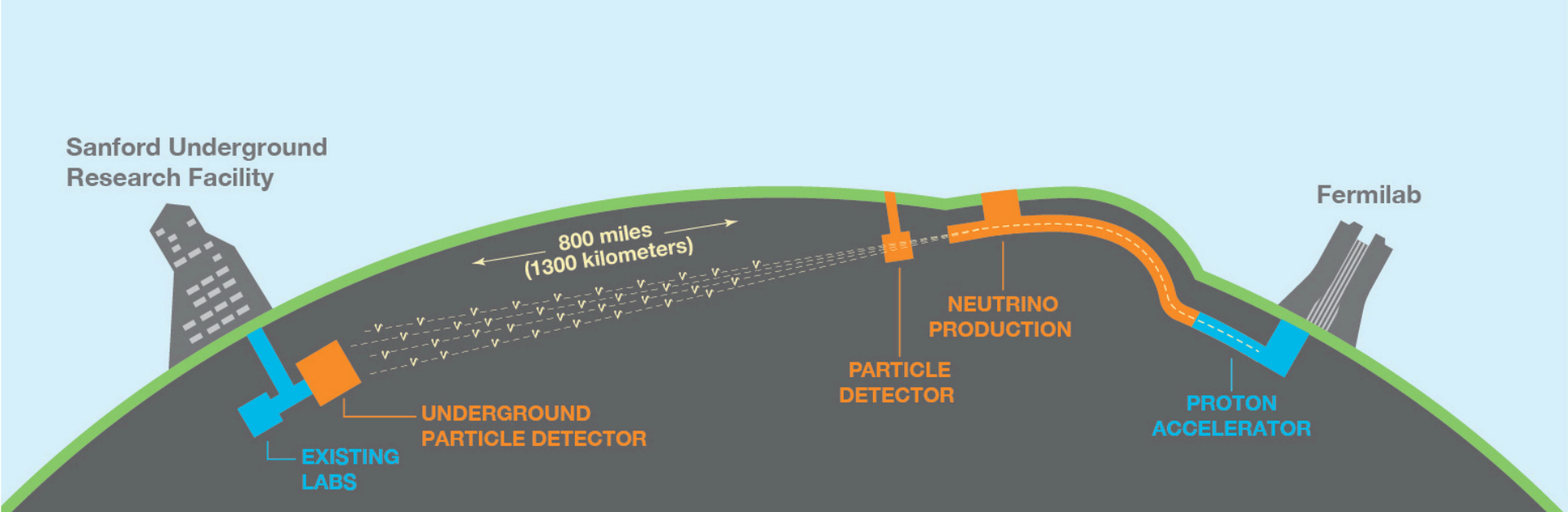
Division of Particles and Fields Conference 2017

03/08/2017

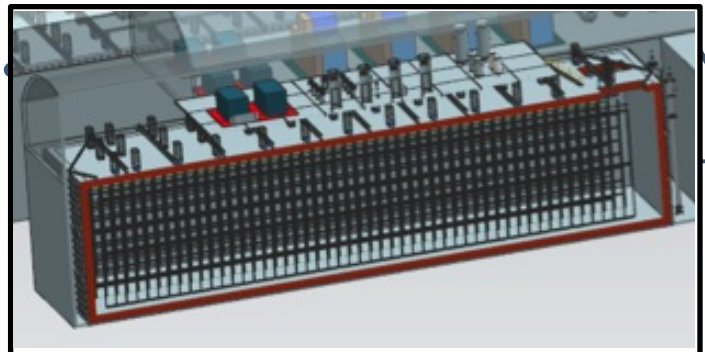
Lancaster University

The what?

- The Deep Underground Neutrino Experiment (DUNE)
  - Future long-baseline neutrino oscillation experiment
  - Consists of two sites 1300 km apart
  - A new MW-scale wideband ν_μ beam with separate ν and $\overline{\nu}$ with mode
  - Will measure both ν_μ disappearance and ν_e appearance

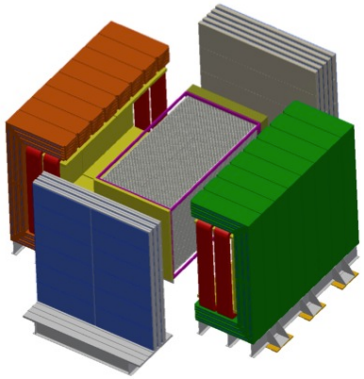


The what?

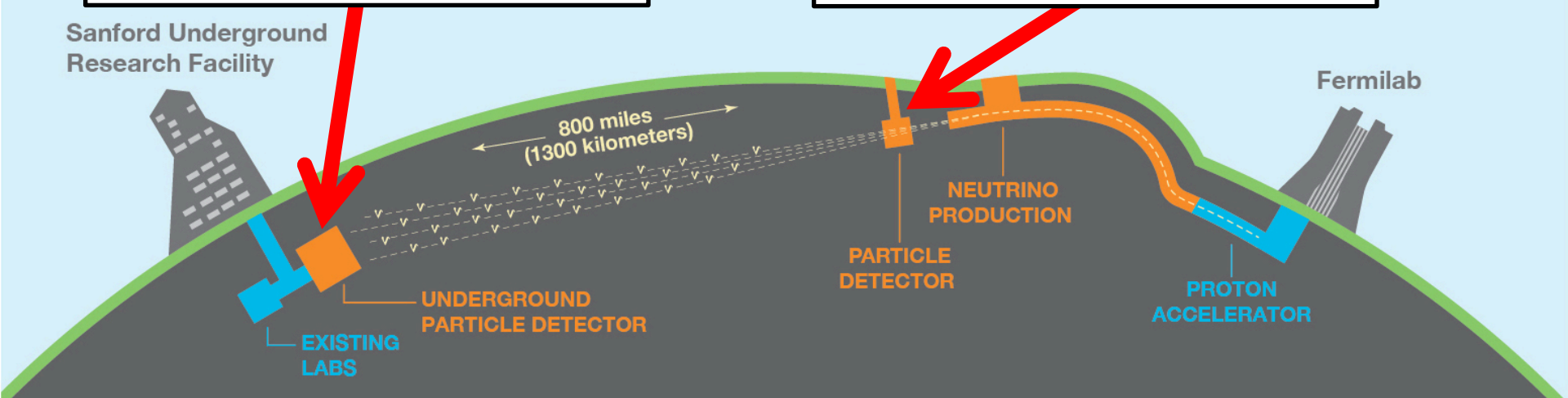


- 4x10 kt **Liquid Argon TPCs** (LArTPC)
- Measures oscillated neutrino rates

Neutrino
trino osc
0 km apa
nd ν_μ bea



- Near detector under design
- Measures un-oscillated neutrino flux



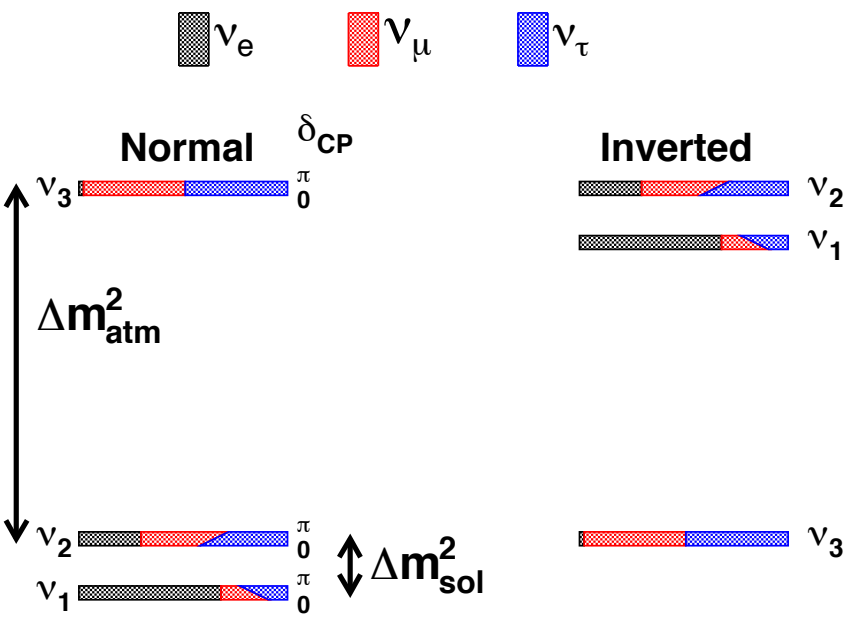
The why?

The PMNS neutrino mixing matrix

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}\ e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

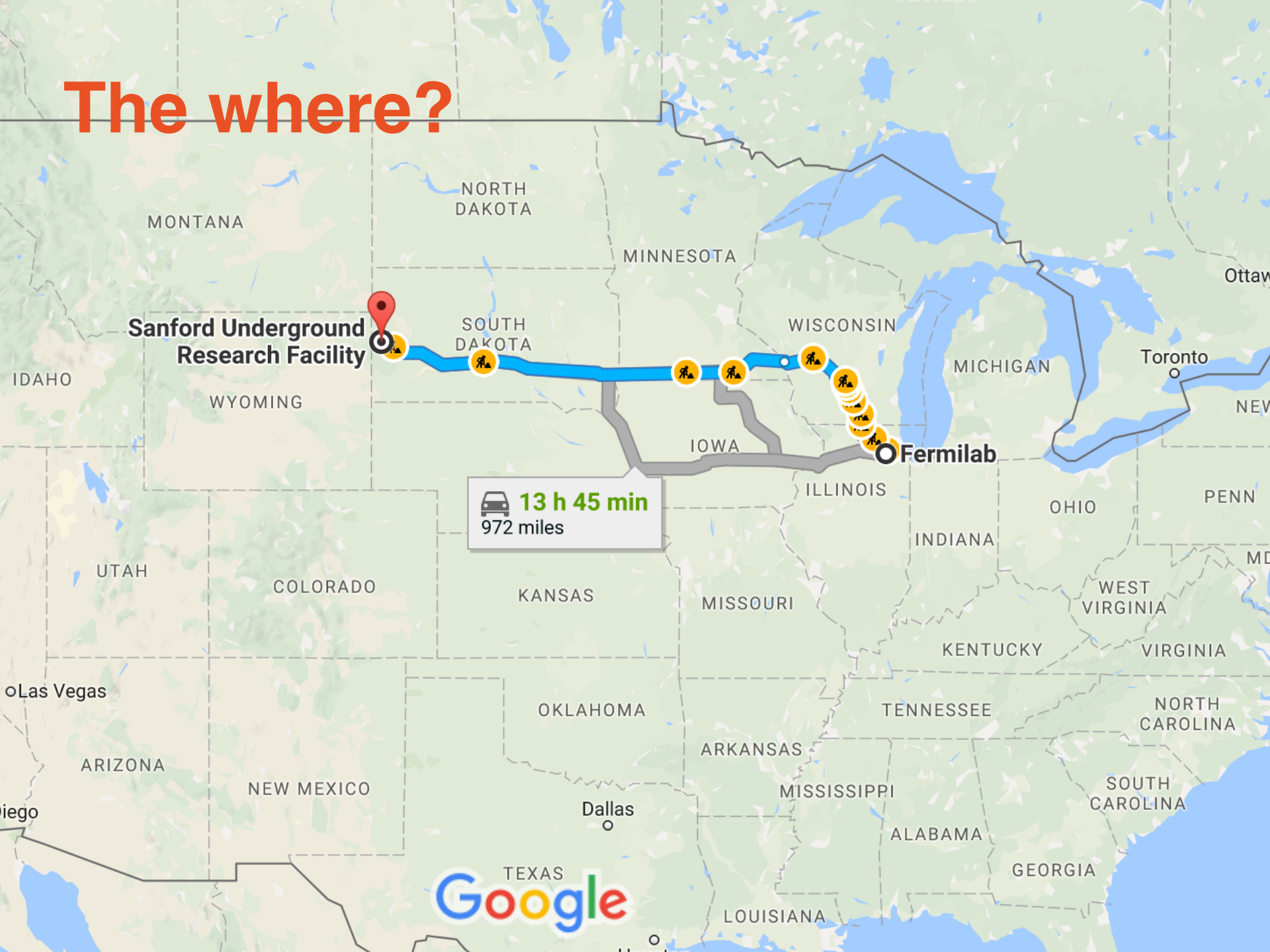
- All mixing angles measured to be non-zero, opening the door to measurements of the CP-violating phase δ

- Questions:
  - Does CP violation occur in the neutrino sector? ($\sin\delta \neq 0$?)
  - Is θ_{23} maximal? ($\theta_{23} = 45^{\circ}$?)
  - What is the neutrino mass ordering?



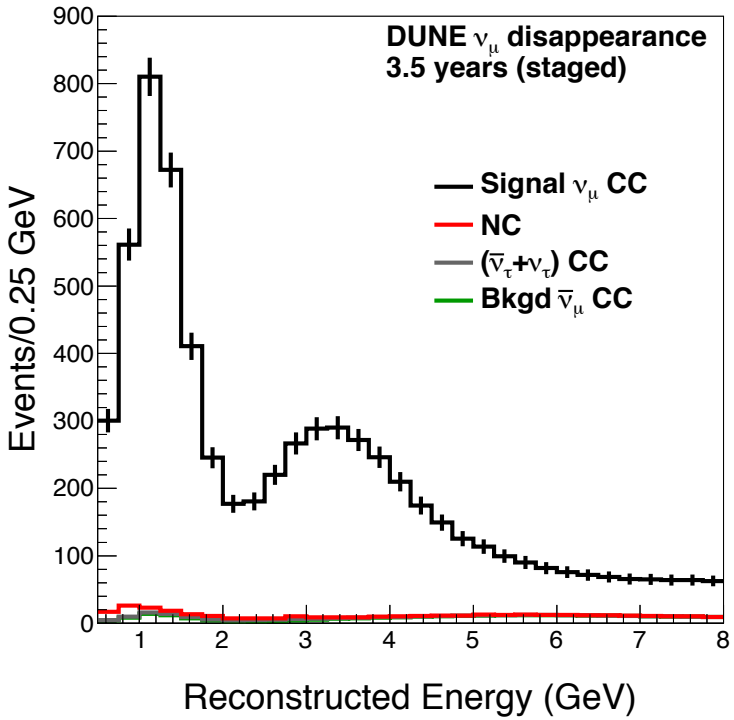
X. Qian and P. Vogel, Progress in Particle and Nuclear Physics 83, 1 (2015)

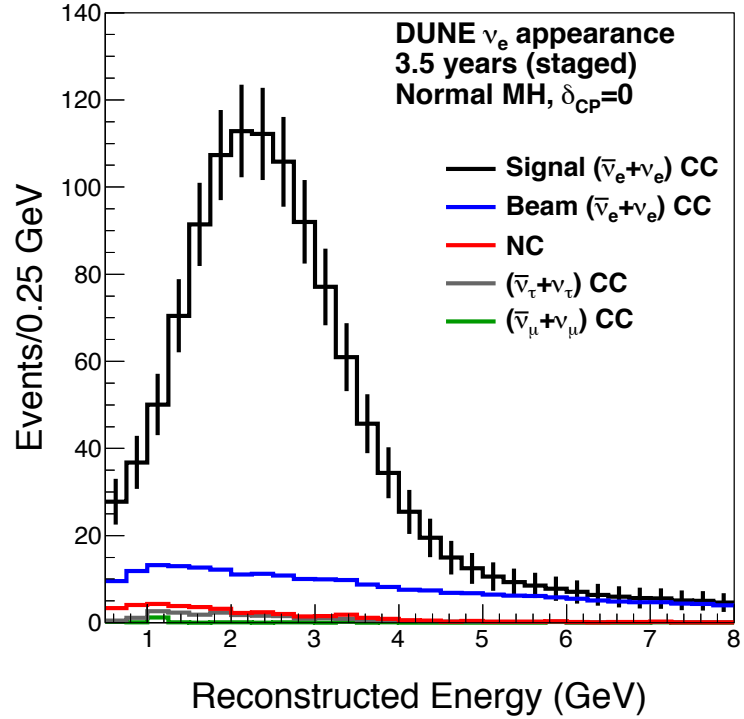
The where?


Sanford Underground Research Facility
Fermilab
13 h 45 min
972 miles
MONTANA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
MICHIGAN
IDAHO
WYOMING
IOWA
ILLINOIS
INDIANA
OHIO
UTAH
COLORADO
KANSAS
MISSOURI
WEST VIRGINIA
KENTUCKY
VIRGINIA
Las Vegas
OKLAHOMA
TENNESSEE
NORTH CAROLINA
ARKANSAS
ARIZONA
NEW MEXICO
MISSISSIPPI
SOUTH CAROLINA
Dallas
ALABAMA
GEORGIA
TEXAS
LOUISIANA
Toronto
Google

The measurement necessities

To make measurements of neutrino oscillation parameters we need to identify oscillated neutrinos in the DUNE far detector



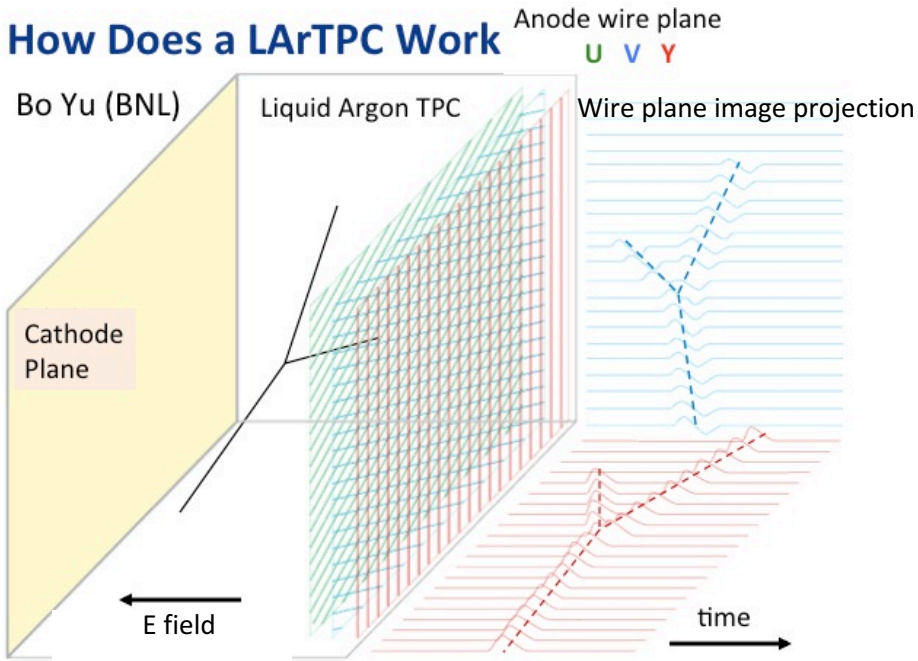


Acquiring such samples requires:

- Fully automated reconstruction
- **Fully automated selections**

Distributions produced using DUNE's 'Fast MC' (truth smearing and parameterised detector efficiency)

Liquid Argon TPC reconstruction



- Charged particles ionise argon
- Ionisation electrons drift in electric field
- Wire planes at anode record current from drifting electrons

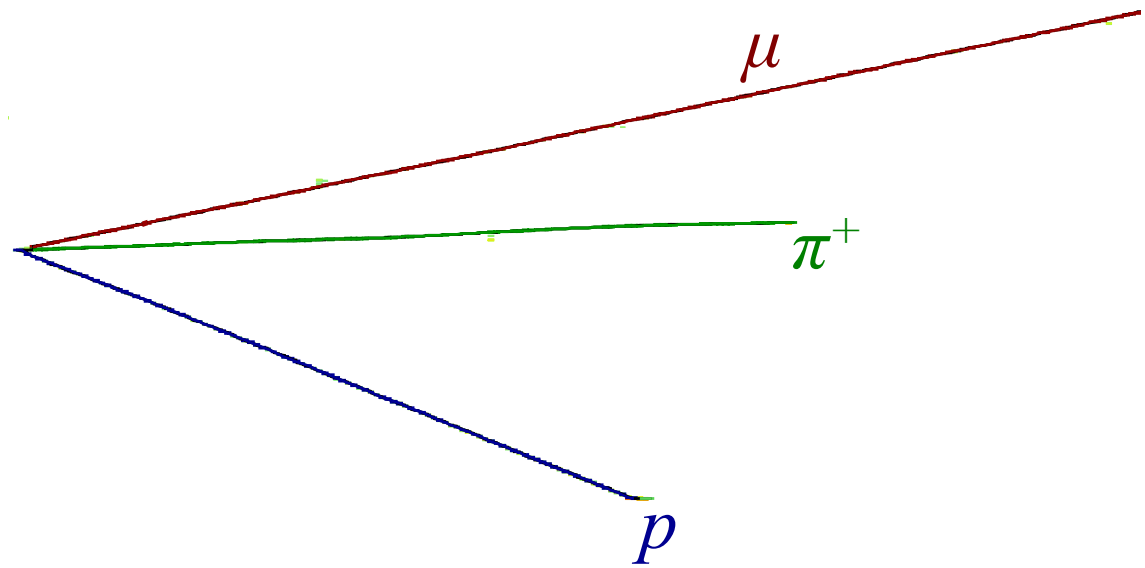
- LArSoft: a fully automated software chain:
  - Physics simulation
  - Detector response simulation
  - Signal processing
  - Hit reconstruction
  - Pattern recognition
  - Track and shower reconstruction
  - Calorimetry

T. Yang, "Automated Reconstruction, Signal Processing and Particle Identification in DUNE," PoS ICHEP 2016, 183 (2016)

The CC ν_μ selection

- Selection is a Multi-Variate Analysis (MVA)
- The selection is split into two parts:
  - Fiducial volume requirement
  - 17-variable Boosted Decision Tree (BDT)
- BDT assesses characteristics of
  - The whole interaction
  - The longest track
- The BDT inputs include…

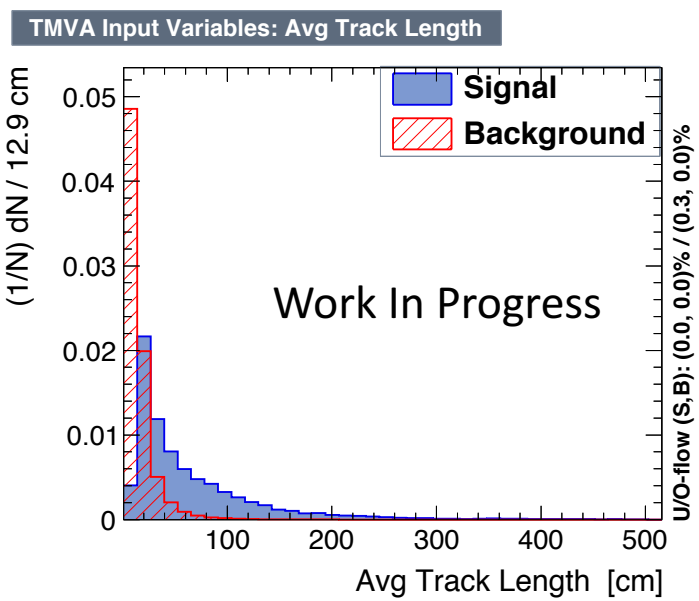
Reconstruction of a simulated CC ν_μ interaction

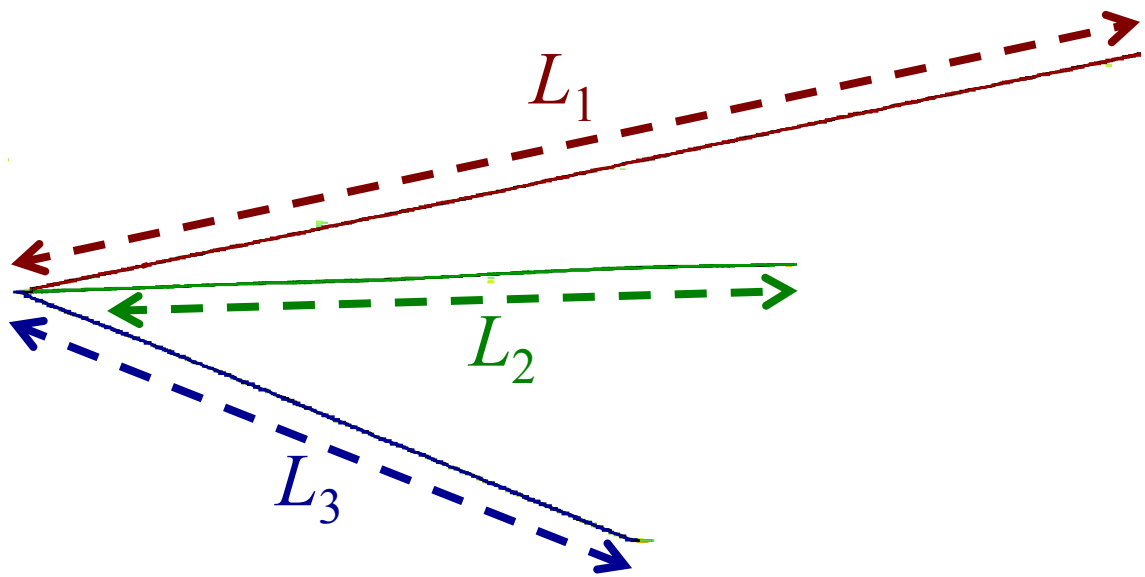


Alternative selection: A. Radovic, "Deep Learning and DUNE", Computing, Analysis Tools and Data Handling, DPF 2017

The CC ν_μ selection

- Average reconstructed track length
  - Arithmetic mean
  - No weighting

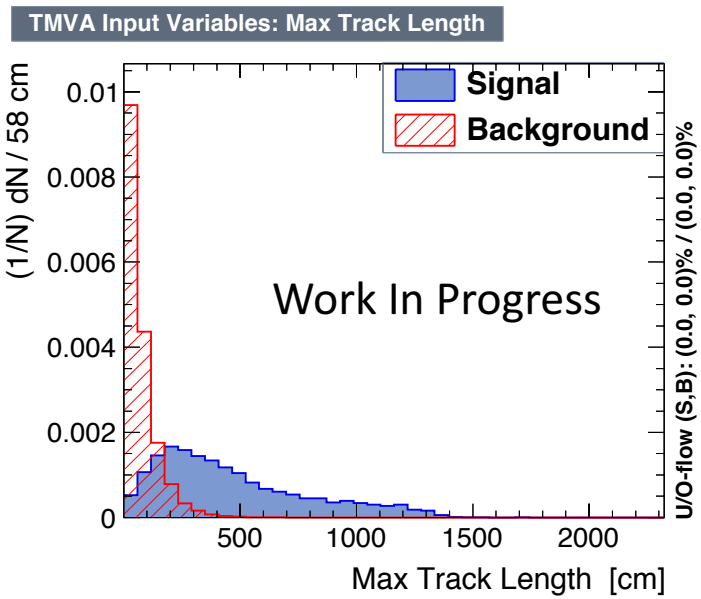


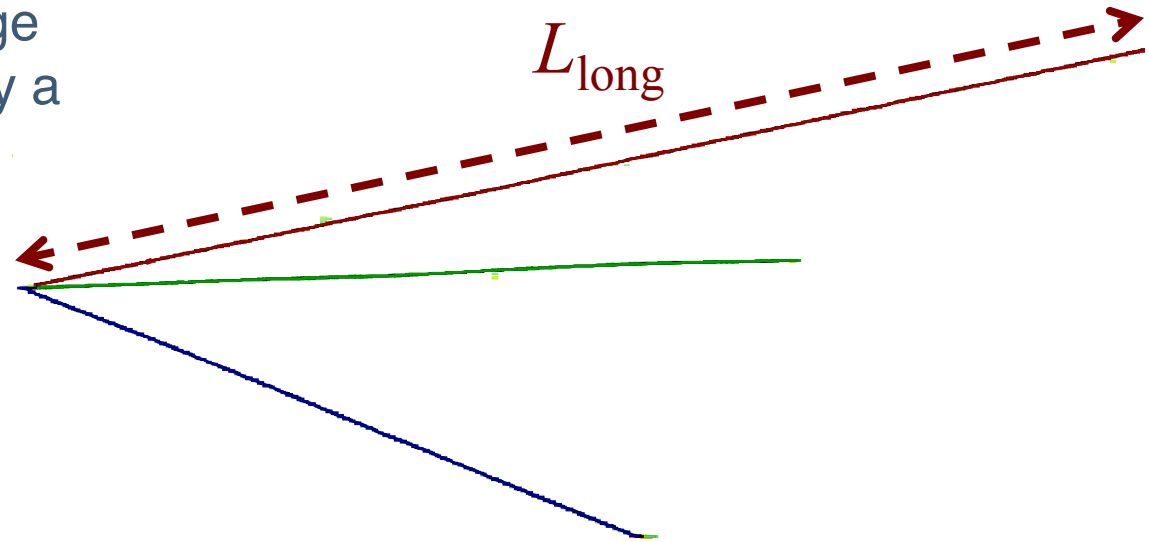


$$L_{\mathrm{av}} = (L_1 + L_2 + L_3)/3$$

The CC ν_μ selection

- The length of the longest track
  - Value tends to be large when track created by a muon

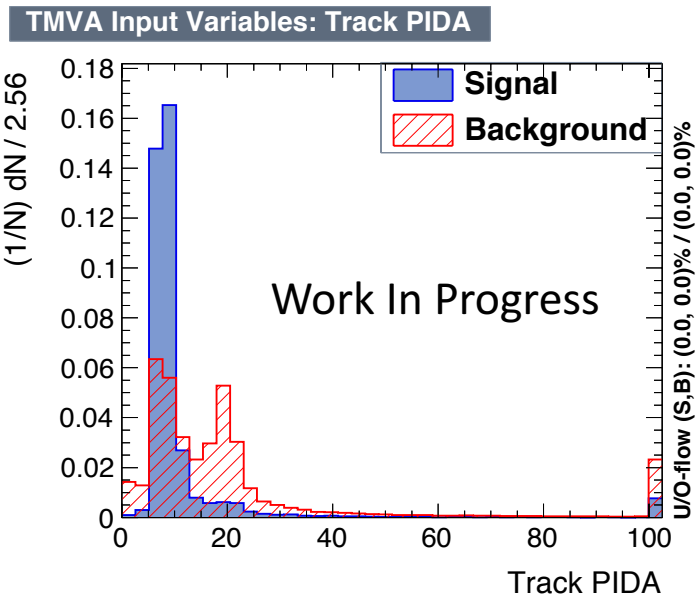


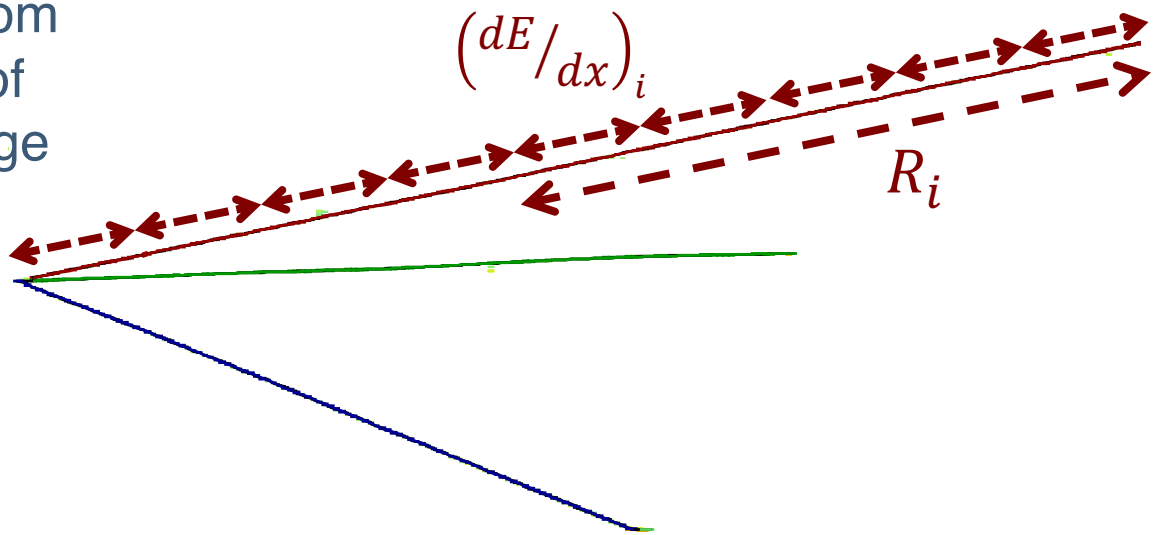


The CC ν_μ selection

- PIDA parameter of longest track
  - Average value of A from all measured values of dE/dx vs. residual range

$$\left(dE/dx\right)_i = A_i R_i^{0.42} \rightarrow A_i = \left(dE/dx\right)_i R_i^{-0.42}$$



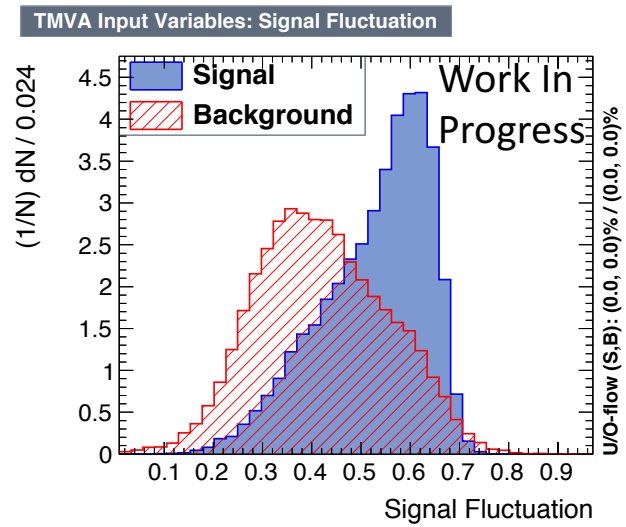


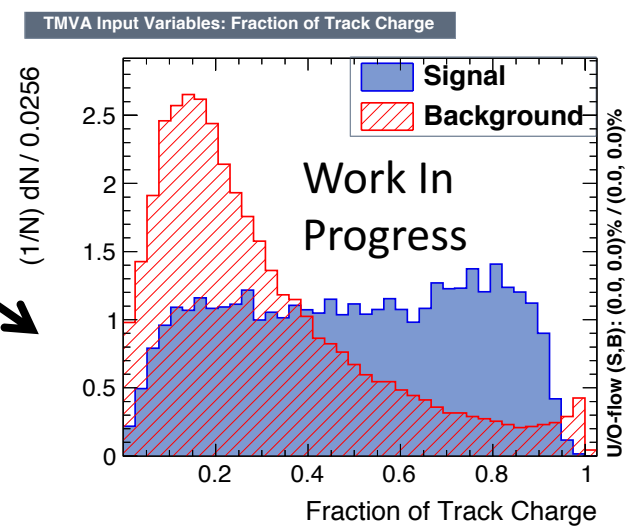
PIDA algorithm developed by B. Baller

ArgoNeuT Collaboration, J. Instrum. 8, P08005 (2013)

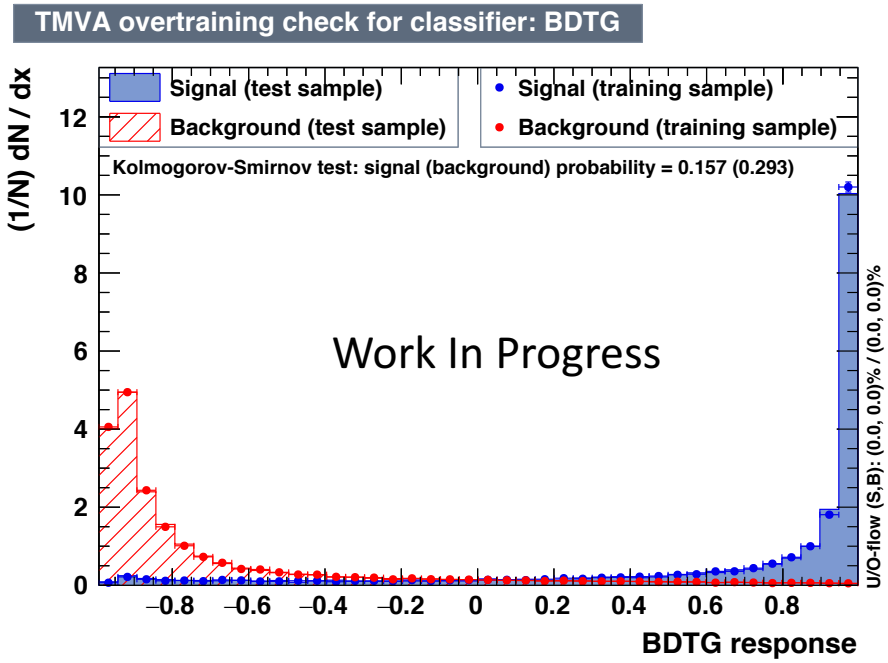
The CC ν_μ selection

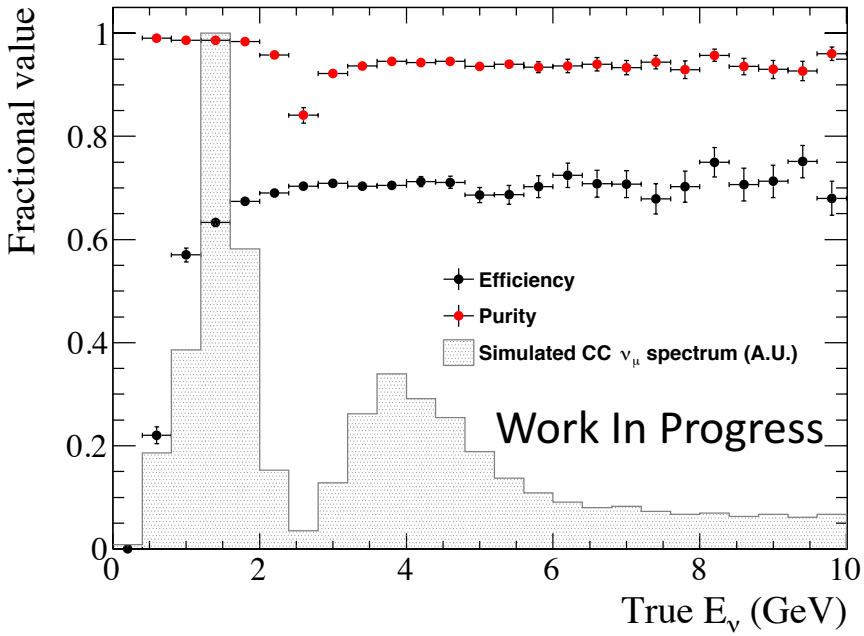
- Number of reconstructed tracks
- Total charge in readout window as measured by the collection plane wires
- dE/dx of longest track
- Ratio of lowest 50% to highest 50% of measured charge
- Fraction of charge within 200 detector clock ticks of longest track
- Fraction of the total measured charge contained on longest track
- Maximum fraction of charge contained on neighboring 5, 10, 50 and 100 wires
- Angle of longest track w.r.t the beam axis
- Longest track's fractional transverse energy





The CC ν_μ selection

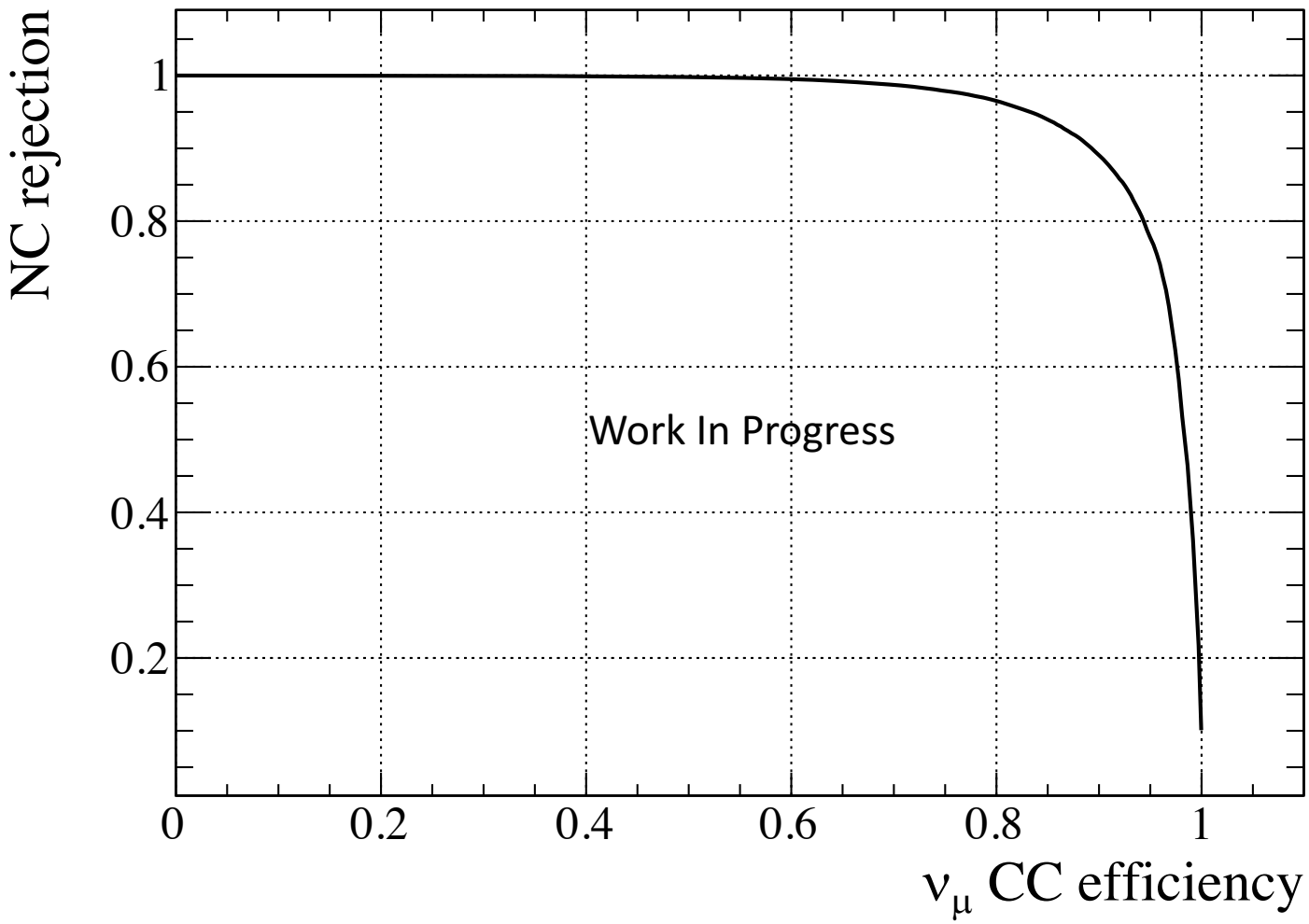




BDT classifier shows excellent separation with no signs of over-training

Efficiency and purity vs. trueneutrino energy when selecting reconstructed event with a BDT response > 0.8

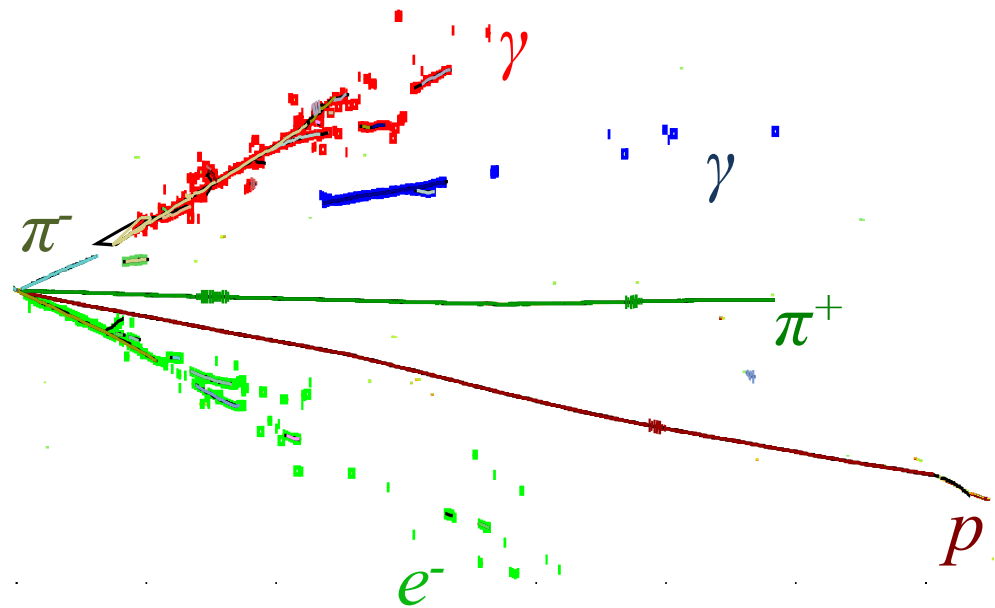
The CC ν_μ selection



The CC ν_e selection

- Selection of CC ν_e is very similar to the CC ν_μ selection
  - Fiducial volume cut followed by BDT
  - BDT uses 30 inputs
    - The same 17 inputs as the CC ν_μ BDT
    - Additional 13 inputs
- BDT assesses characteristics of
  - The whole interaction
  - The longest track
  - **The highest energy shower**
- These additional variables include…

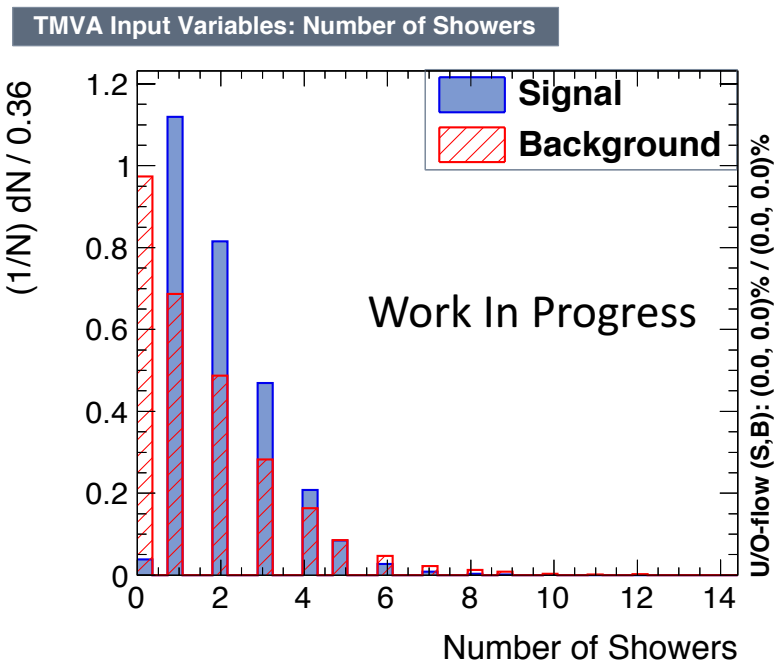
Reconstruction of a simulated CC ν_e interaction

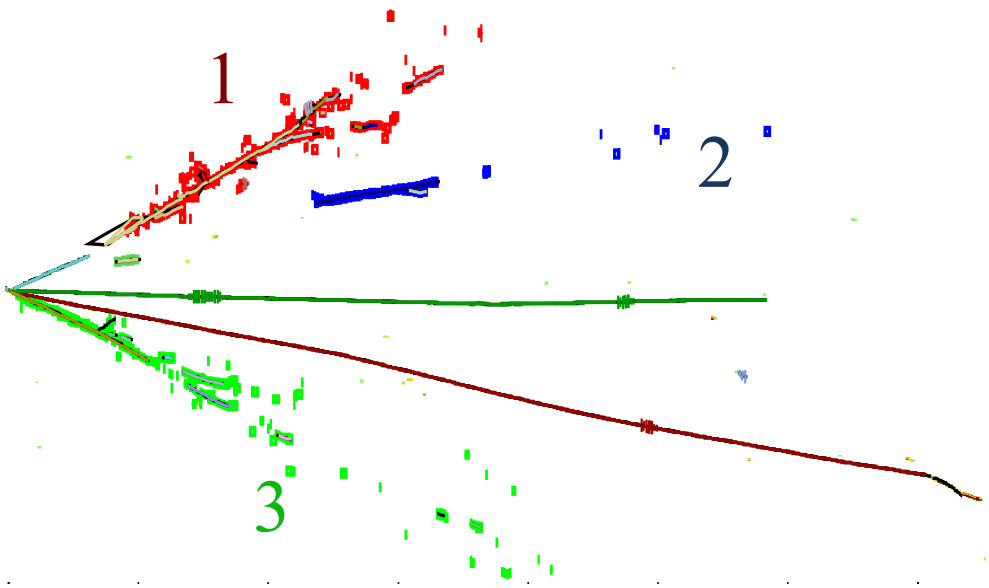


Alternative selection: A. Radovic, "Deep Learning and DUNE", Computing, Analysis Tools and Data Handling, DPF 2017

The CC ν_e selection

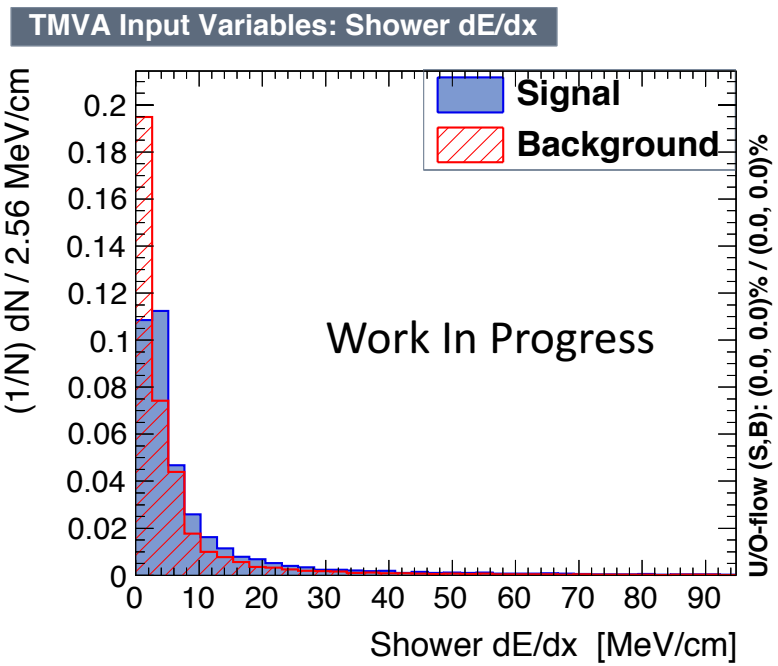
- The number of reconstructed showers

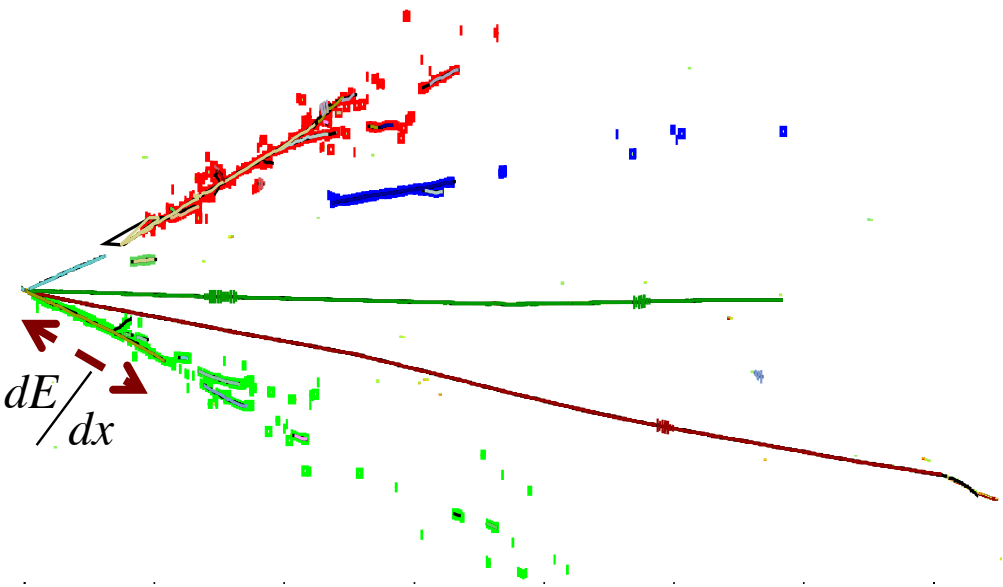




The CC ν_e selection

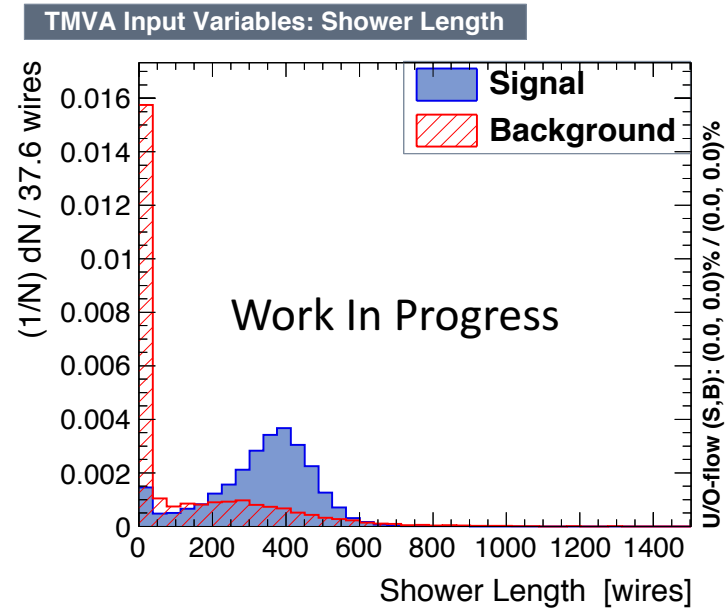
- dE/dx of the shower
  - Calculated using the first 3 cm of the shower

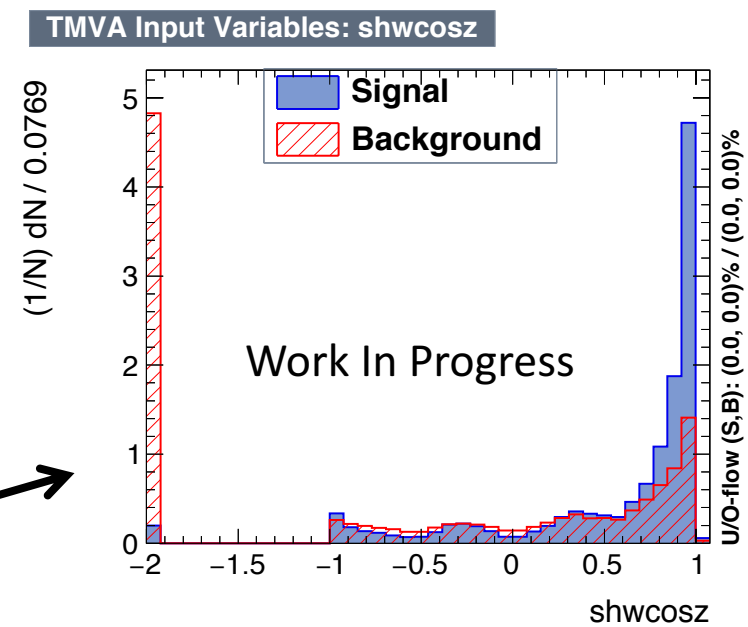




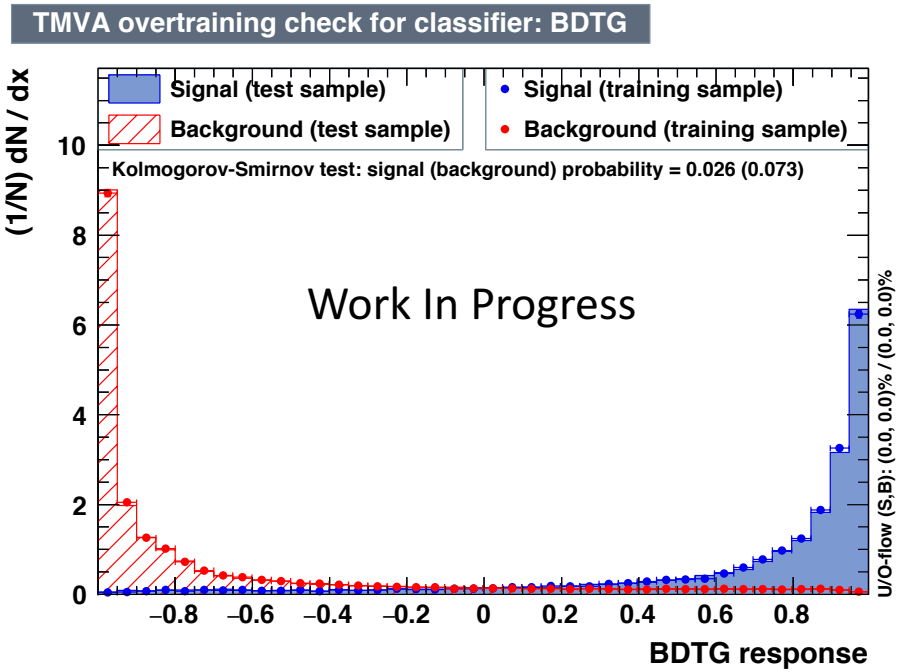
The CC ν_e selection

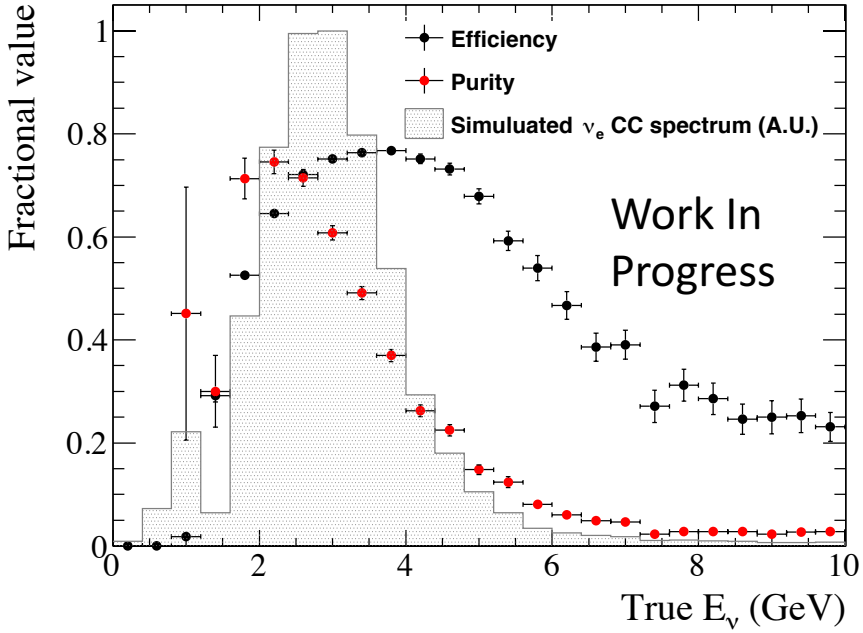
- Total energy of the Highest Energy Shower (HES)
- Fraction of the total measured charged contained in the HES
- Length of the HES
  - Length defined in wires
- Number of reconstructed HES hits per shower hitting wire
- Fractional position along the HES to maximal charge
  - Position defined in wires
- Distance from the HES start point to the neutrino vertex
- Angle of HES w.r.t. the beam axis





The CC ν_e selection

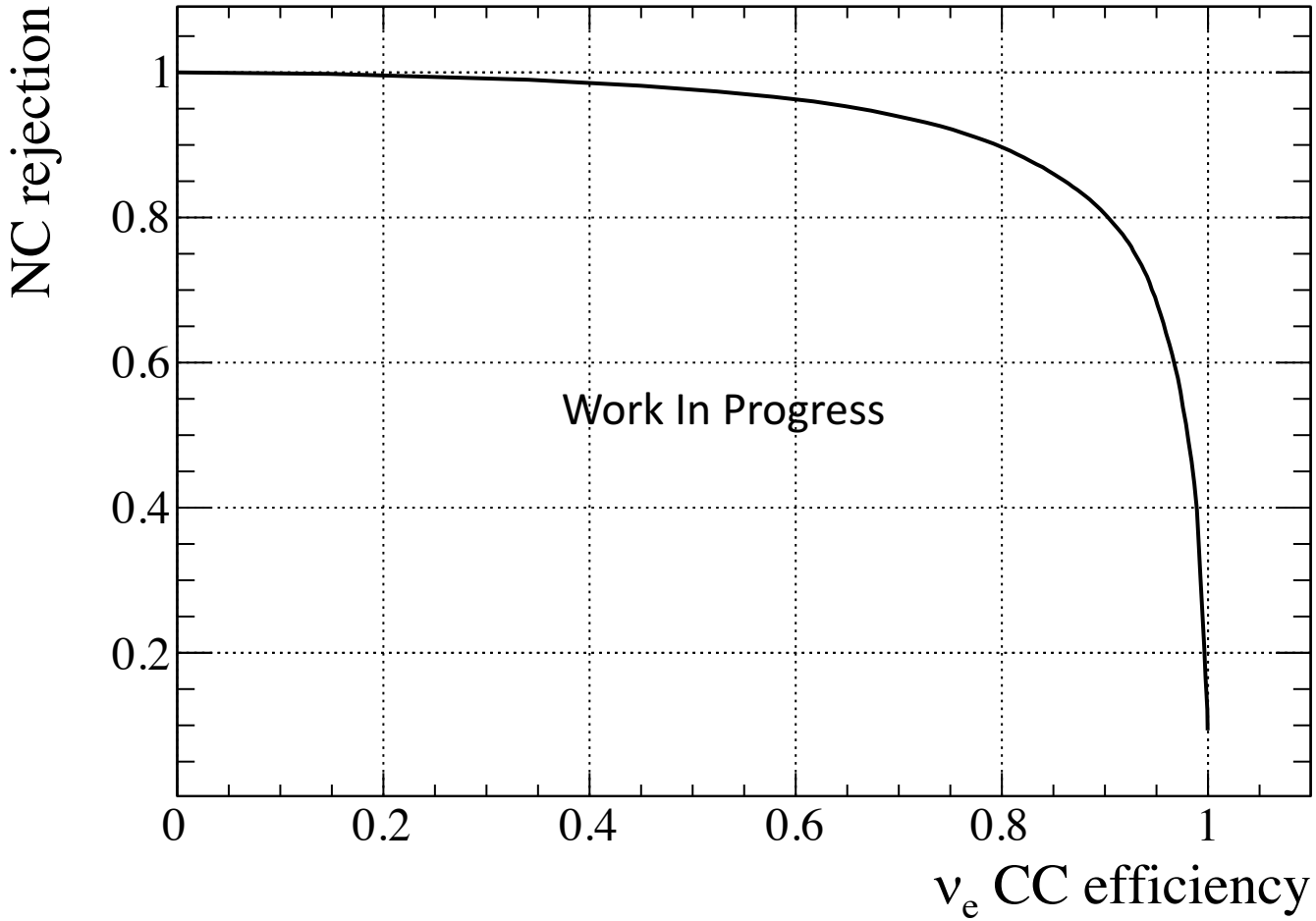




BDT classifier shows excellent separation with no signs of over-training

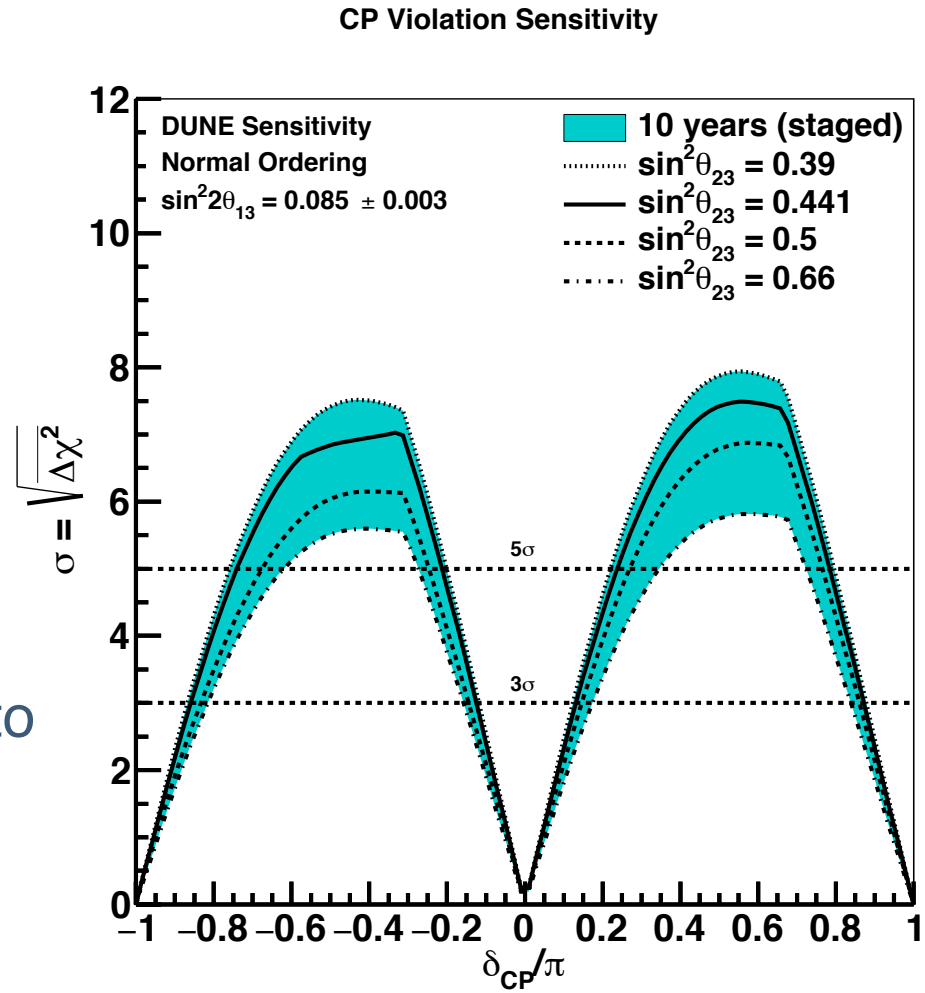
Efficiency and purity vs. simulated neutrino energy when selecting reconstructed event with a BDT response > 0.8

The CC ν_e selection

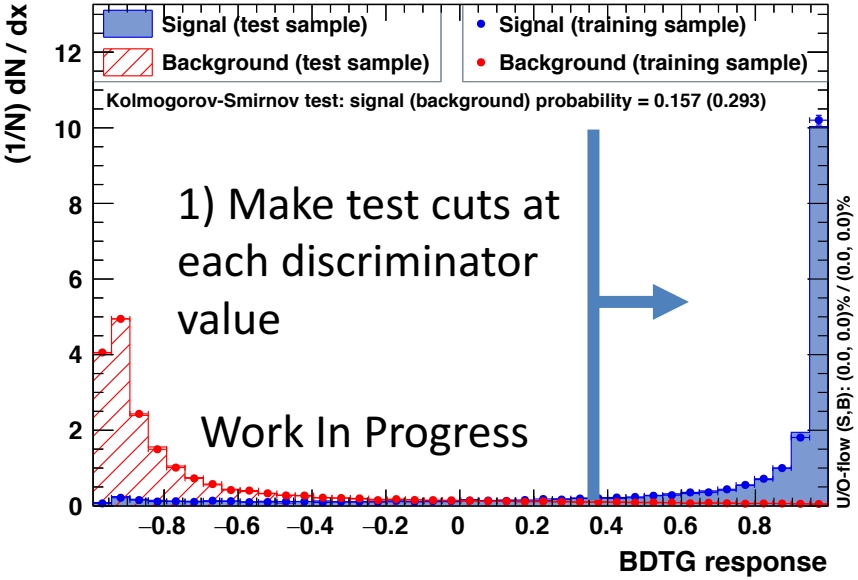


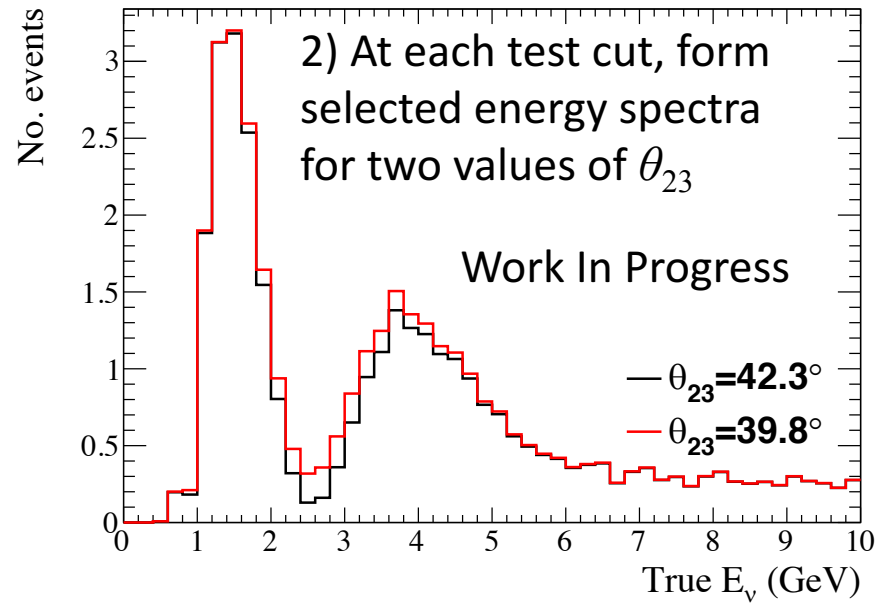
CC ν_μ selection tuning

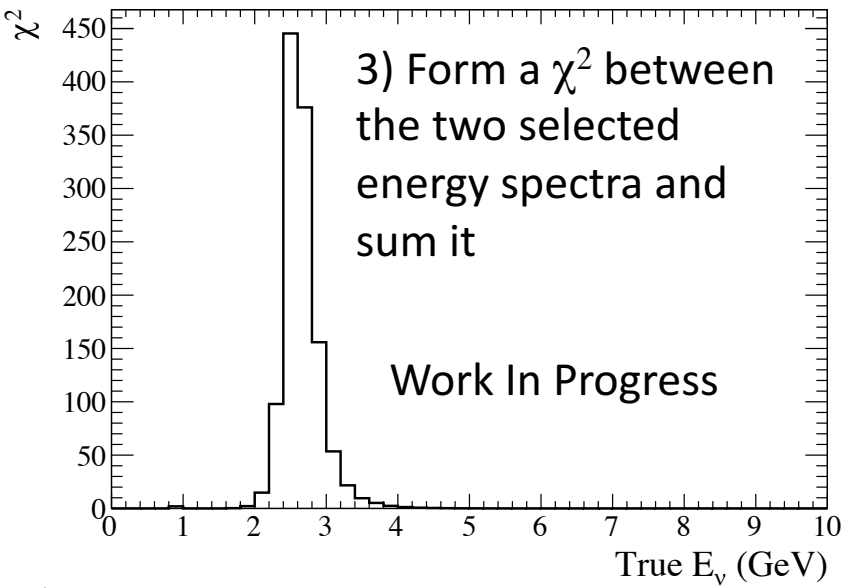
- RHS plot shows DUNE's ability to determine δ_{CP} for different values of θ_{23}
- ν_μ disappearance provides a precision handle on θ_{23}
- The ν_μ selection should be tuned to maximise its sensitivity to θ_{23}
- How is this done?

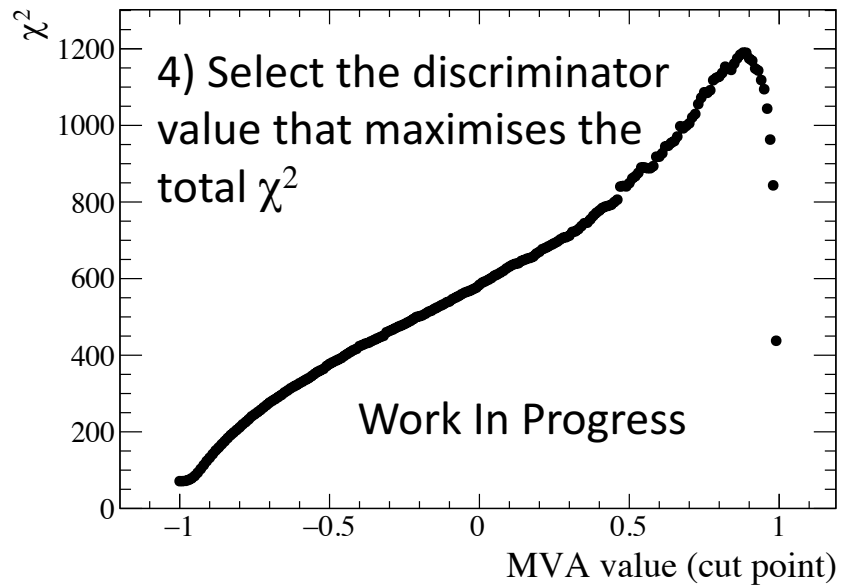


TMVA overtraining check for classifier: BDTG





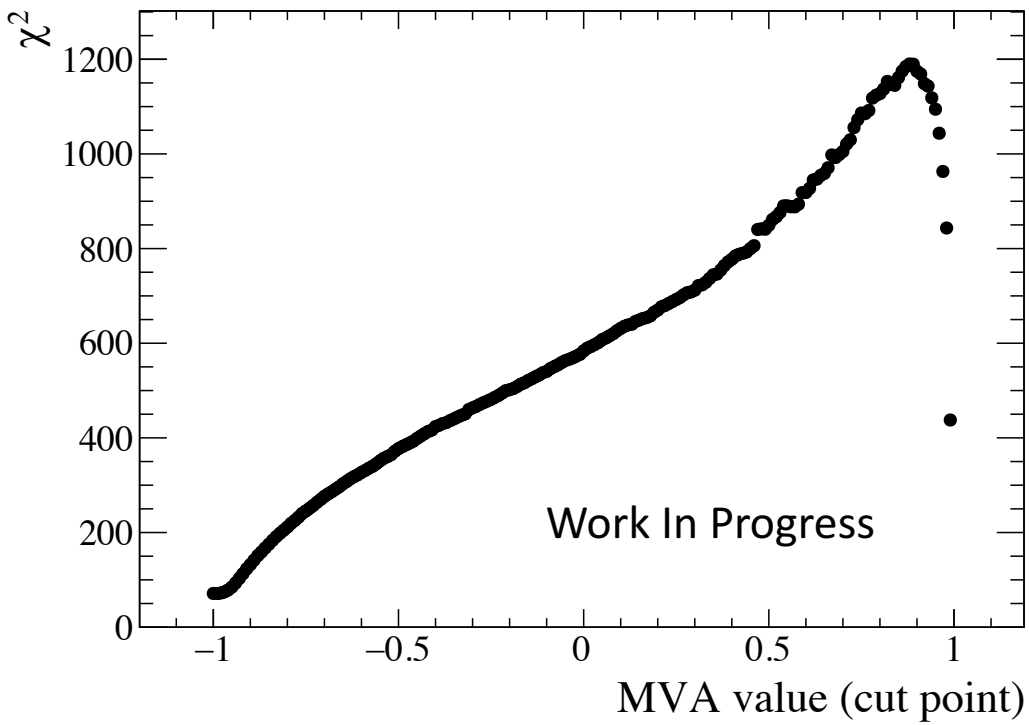




* Inclusion of reconstructed neutrino energy is ongoing

CC ν_μ selection tuning

- RHS plot shows χ^2 distribution for θ_{23}=42.3° and θ_{23}=39.8°
  - NuFit2014 minimum and -1σ value (normal hierarchy)
- Clear maximum in the χ^2 distribution
  - MVA cut point: 0.88
- Further studies for ν_μ and ν_e are ongoing



Summary

- DUNE is a future long-baseline neutrino oscillation experiment that will utilise liquid argon TPC technology
- Selections for DUNE's neutrino oscillation fits are currently being developed
- The core of both selections is a BDT which shows excellent separation between signal and background
- Selection tuning studies are currently taking place

Thank you

Backups

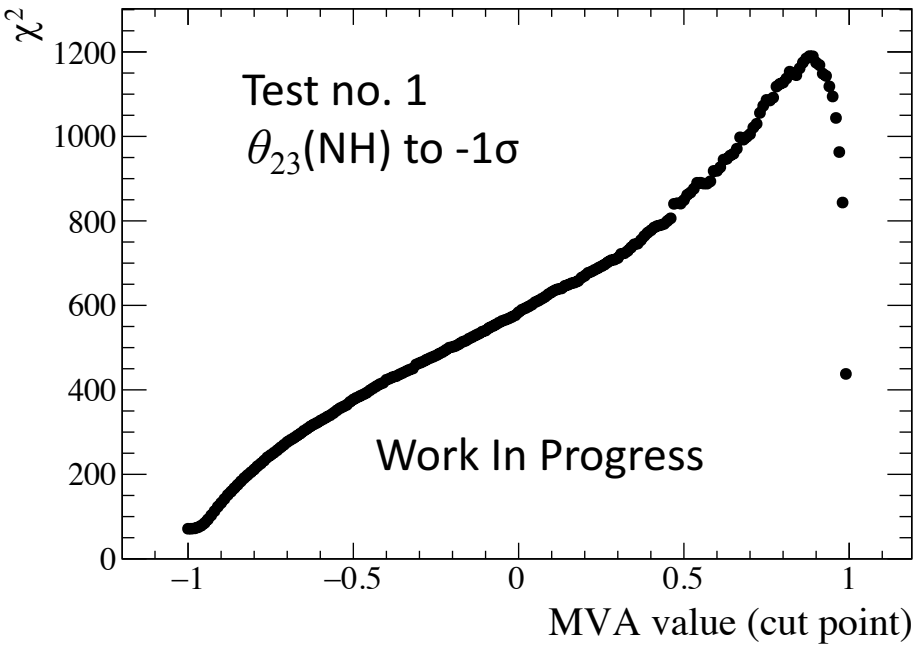
ν_μ selection tuning

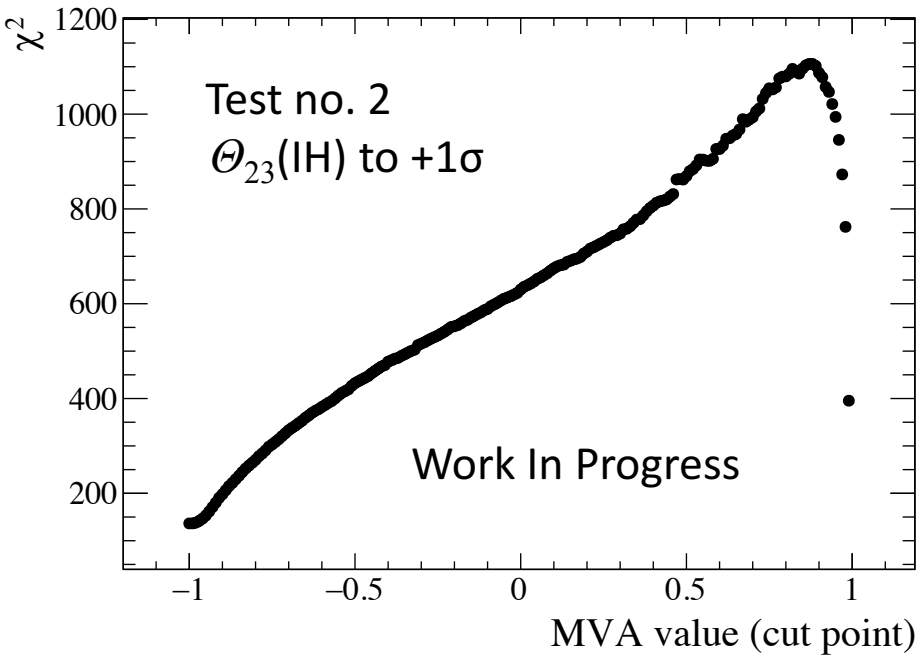
Test no.	θ_{23} A (degrees)	θ_{23} B (degrees)	Why?
1	42.3	39.8	θ_{23}(NH) to -1σ
2	49.5	51.9	θ_{23}(IH) to +1σ
3	45	42.3	Max. mix. to θ_{23}(NH)
4	45	49.5	Max. mix. to θ_{23}(IH)
5	42.3	49.5	θ_{23}(NH) to θ_{23}(IH)

NH: Normal Hierarchy
IH: Inverted Hierarchy

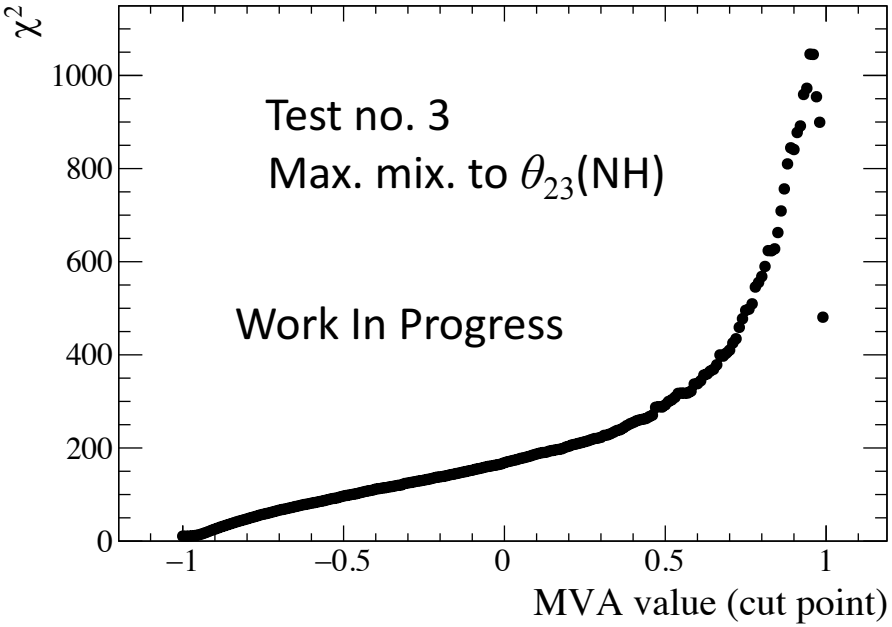
θ_{23} values taken from global fit [REF]

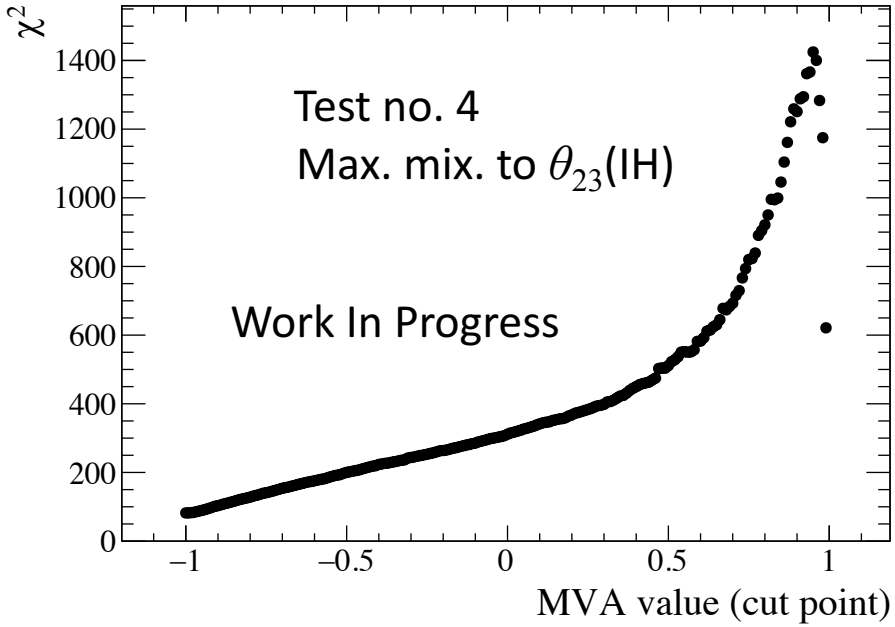
ν_μ selection tuning

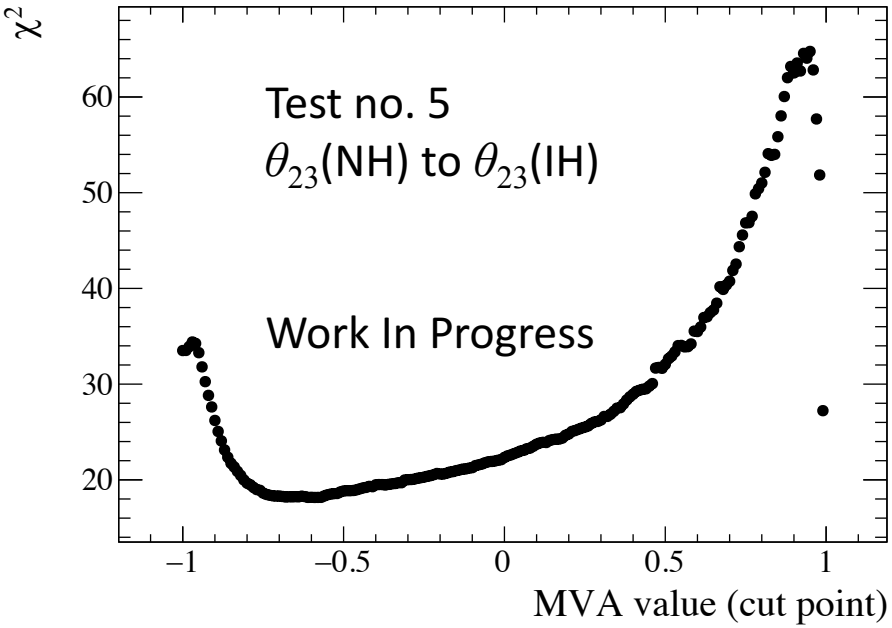




Both tests show well defined maxima with comparable χ^2







- Test 3 and test 4 show similar results
  - Test 4 has a higher max χ^2
- Test 5 shows little sensitivity

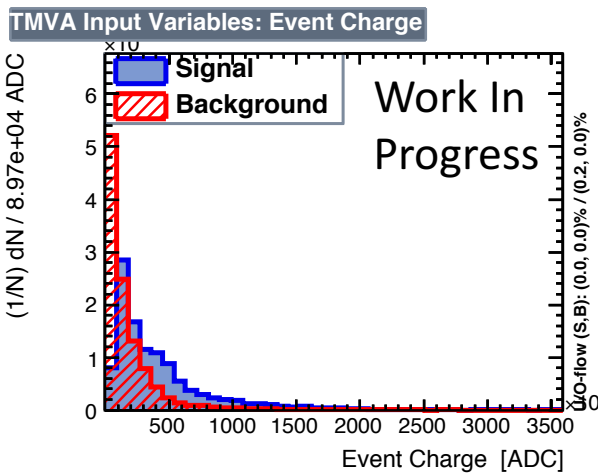
ν_μ selection tuning

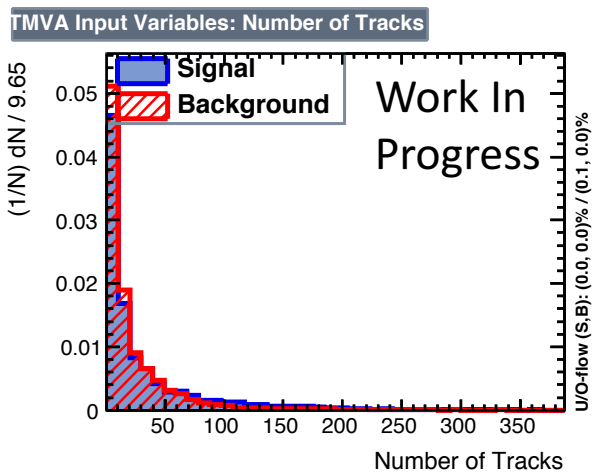
Test no.	θ_{23} A (degrees)	θ_{23} B (degrees)	Why?	MVA val.	Max χ^2
1	42.3	39.8	θ_{23}(NH) to -1σ	0.88	1190.1
2	49.5	51.9	θ_{23}(IH) to +1σ	0.88	1106
3	45	42.3	Max. mix. to θ_{23}(NH)	0.95	1045.87
4	45	49.5	Max. mix. to θ_{23}(IH)	0.95	1424.7
5	42.3	49.5	θ_{23}(NH) to θ_{23}(IH)	0.95	64.8

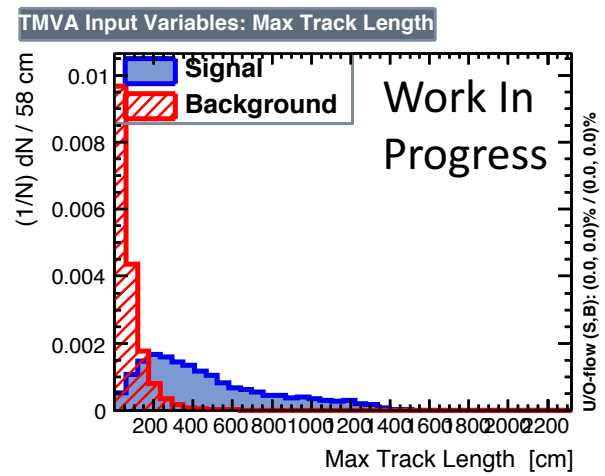
NH: Normal Hierarchy
IH: Inverted Hierarchy

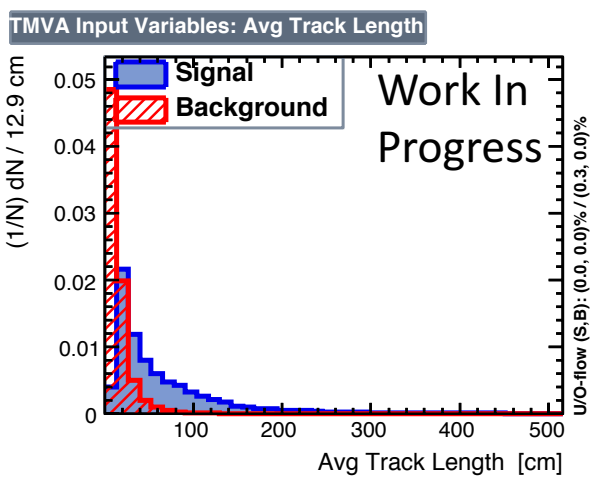
θ_{23} values taken from global fit [REF]

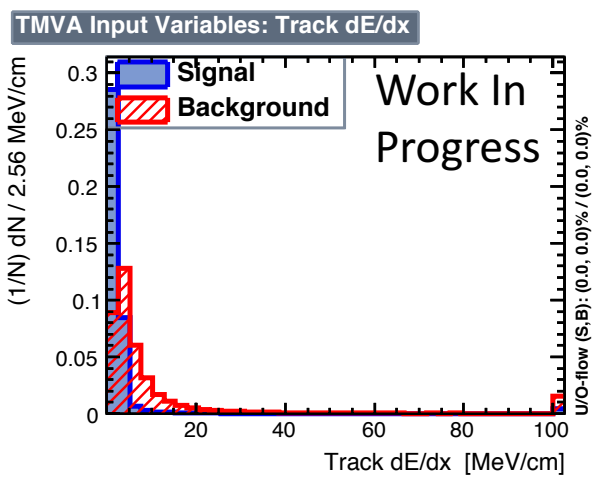
The ν_μ selection

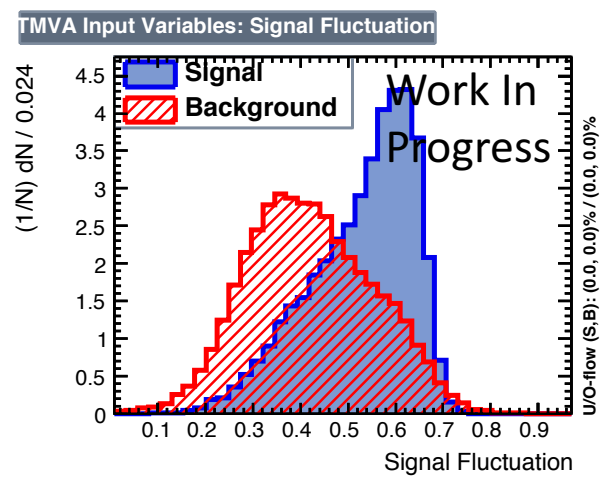












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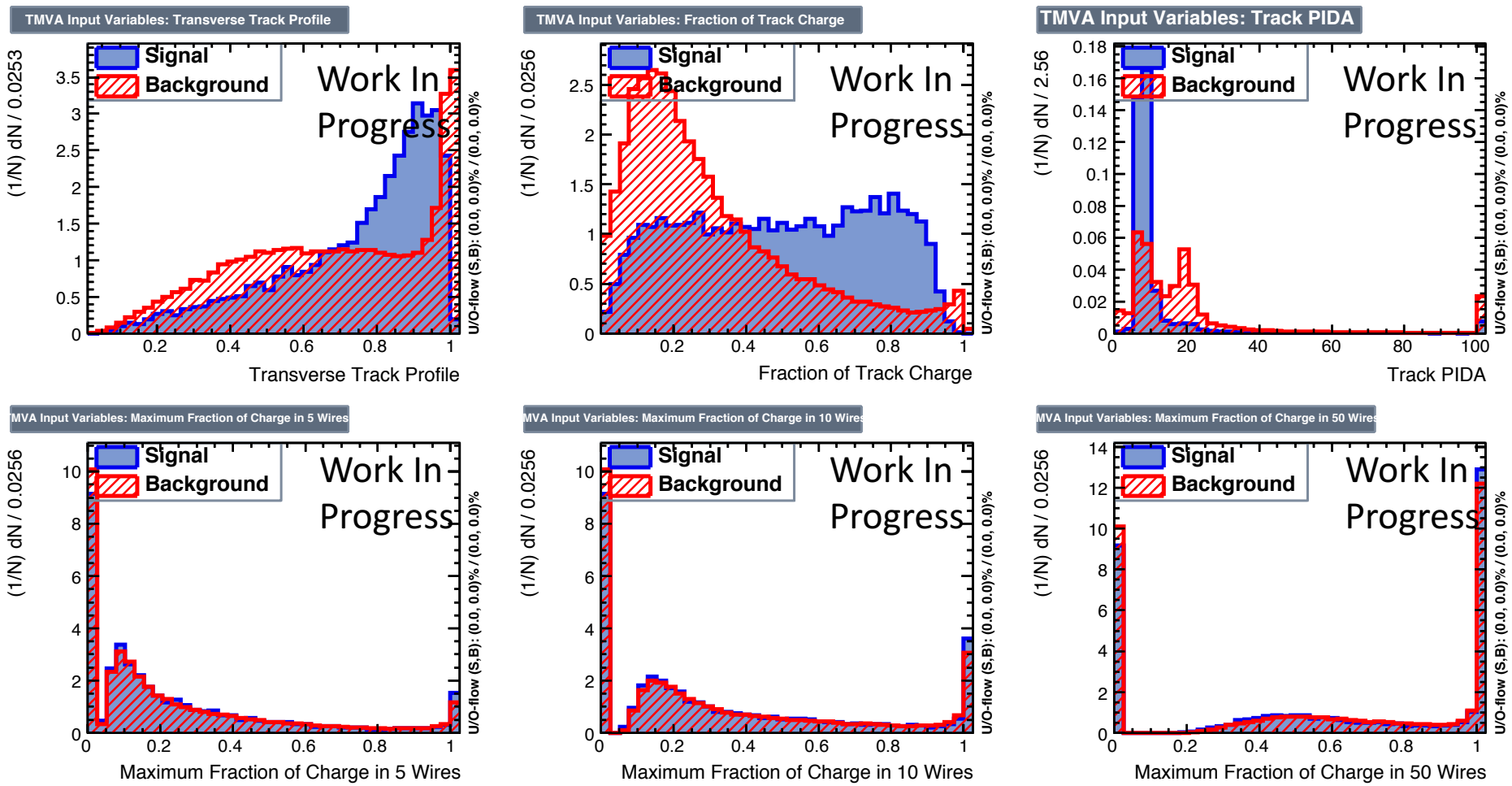

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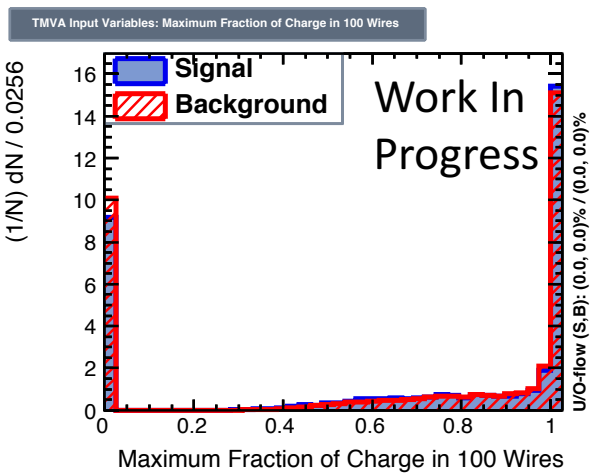

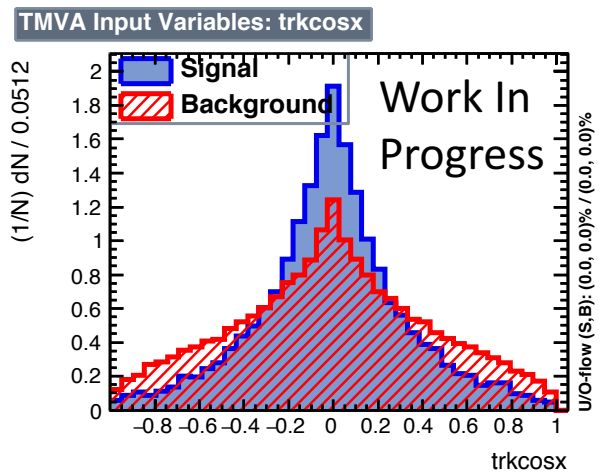

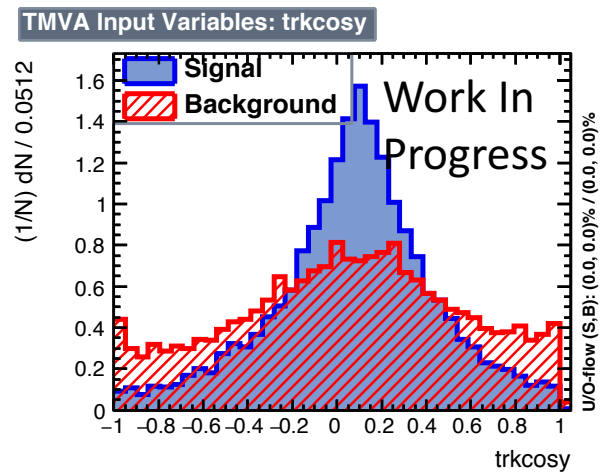

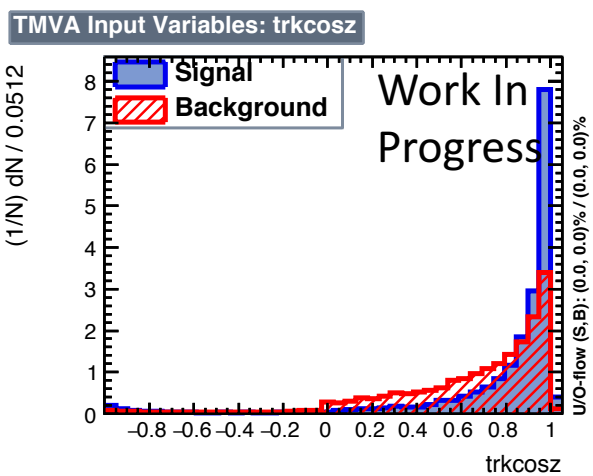

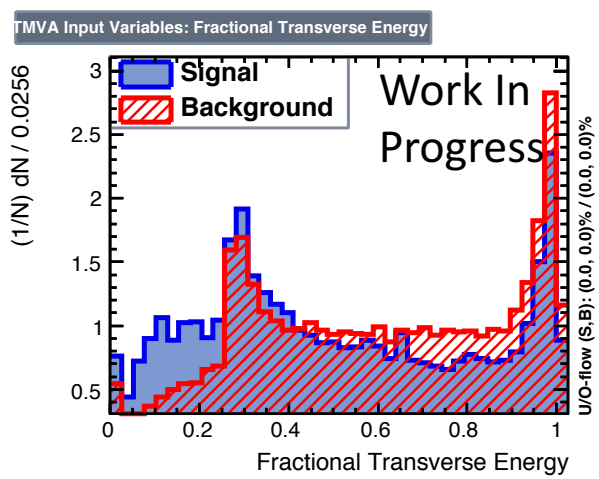

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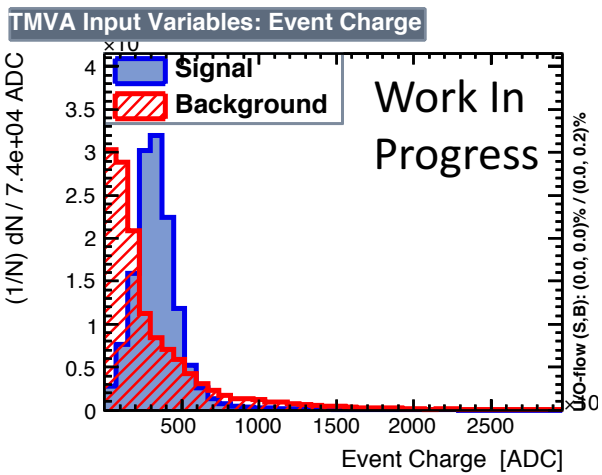

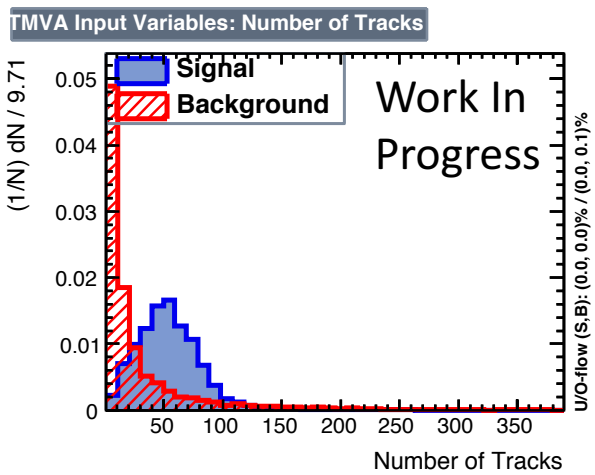

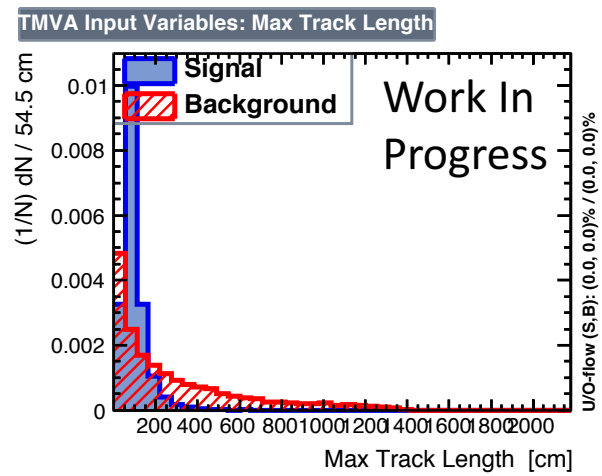

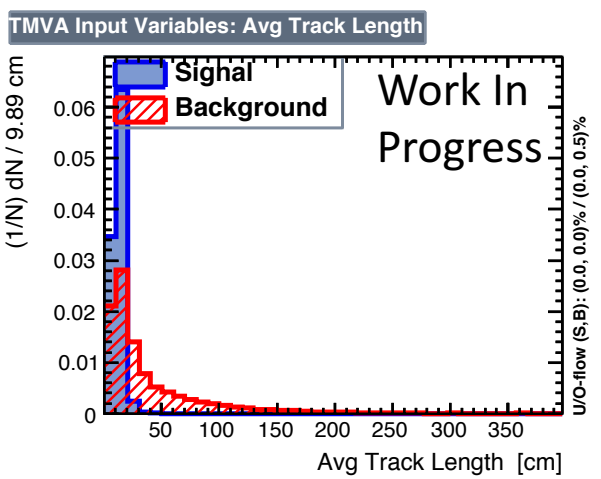

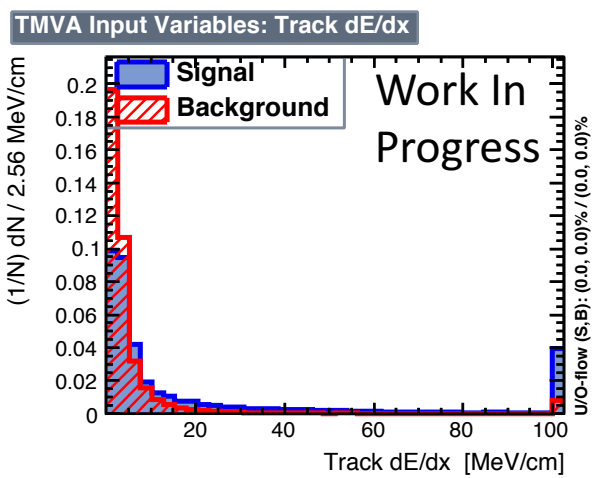

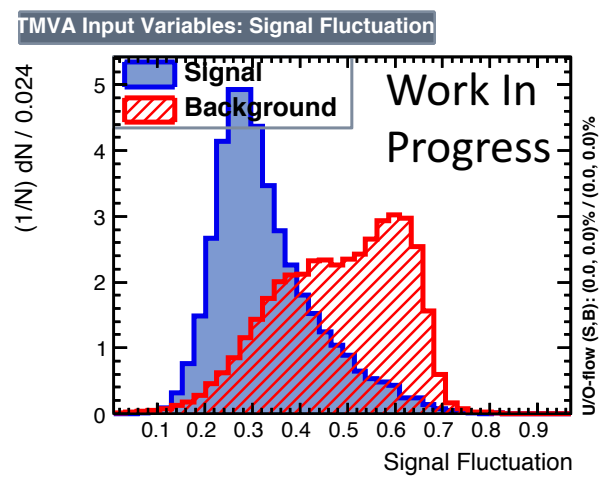

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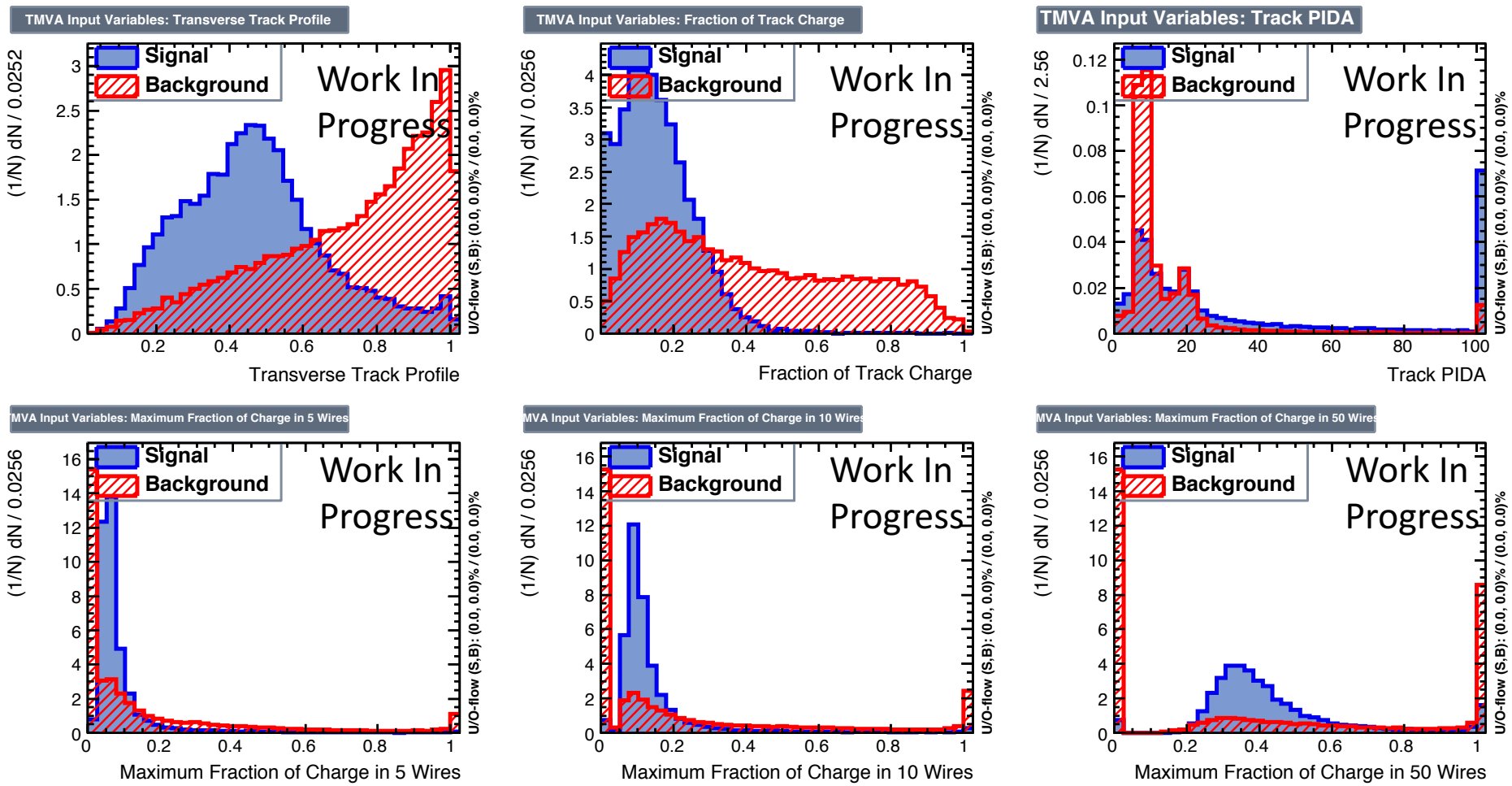

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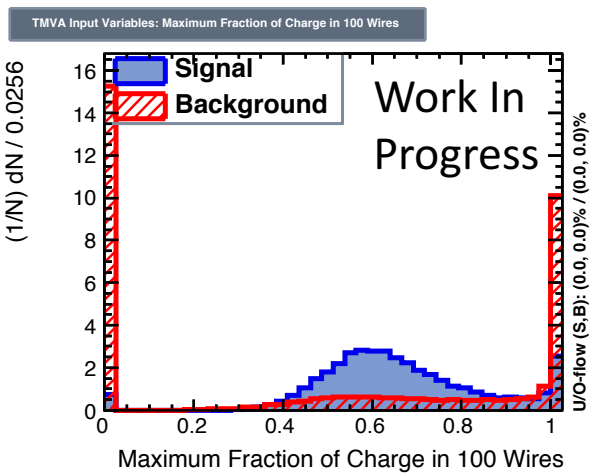

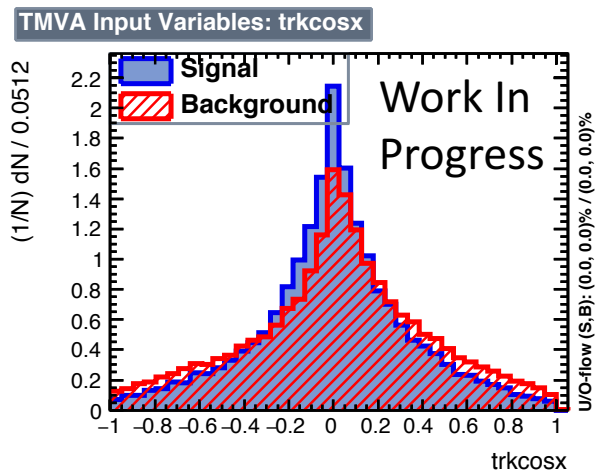

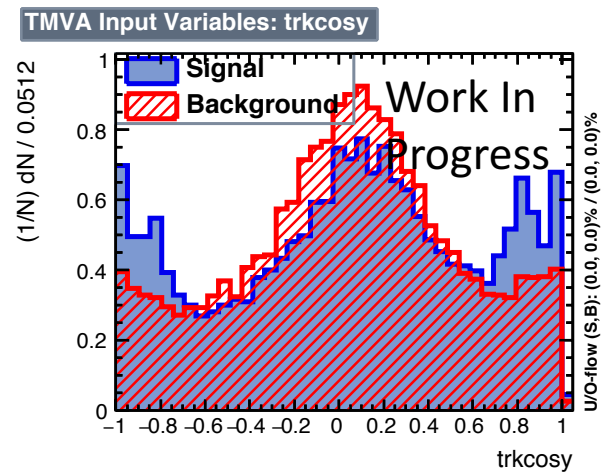

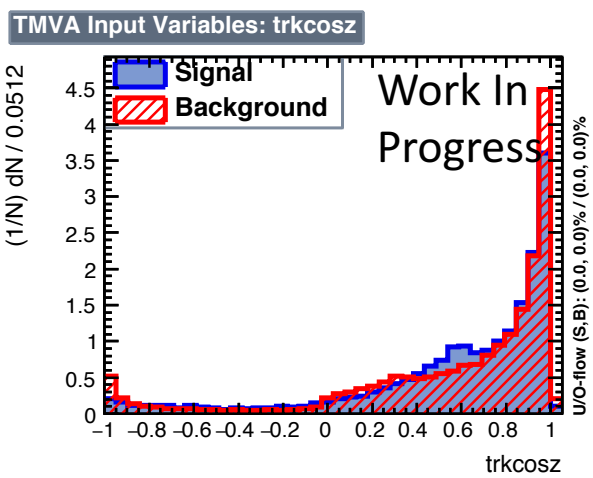

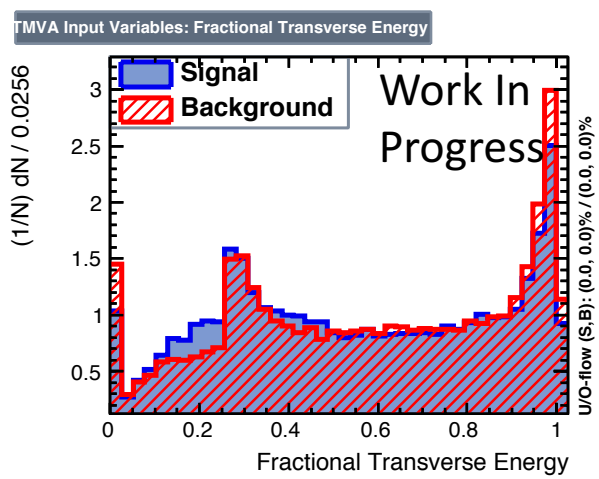

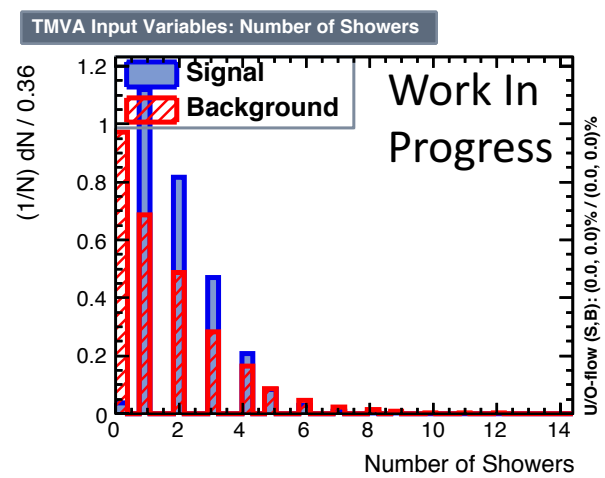

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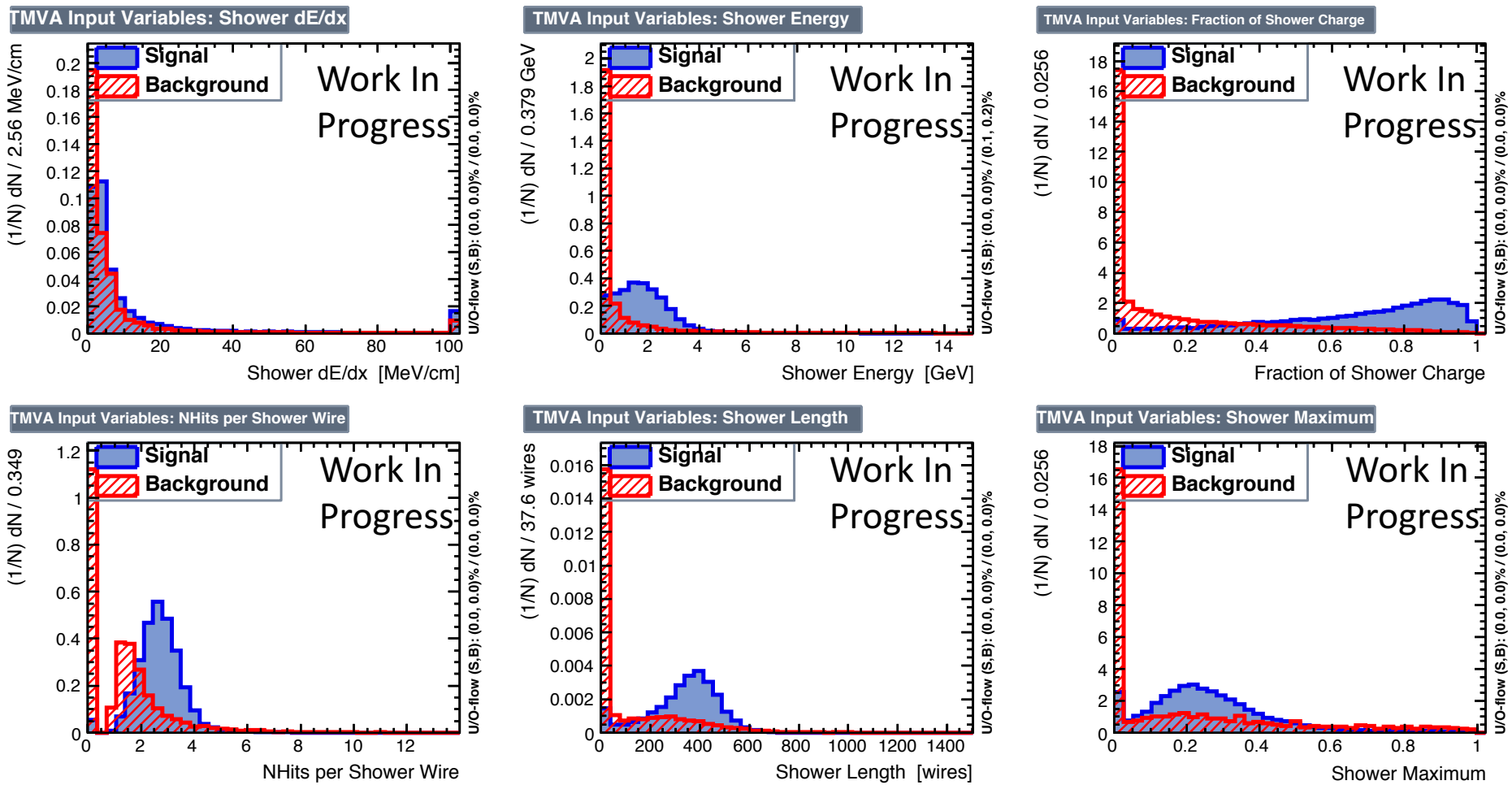

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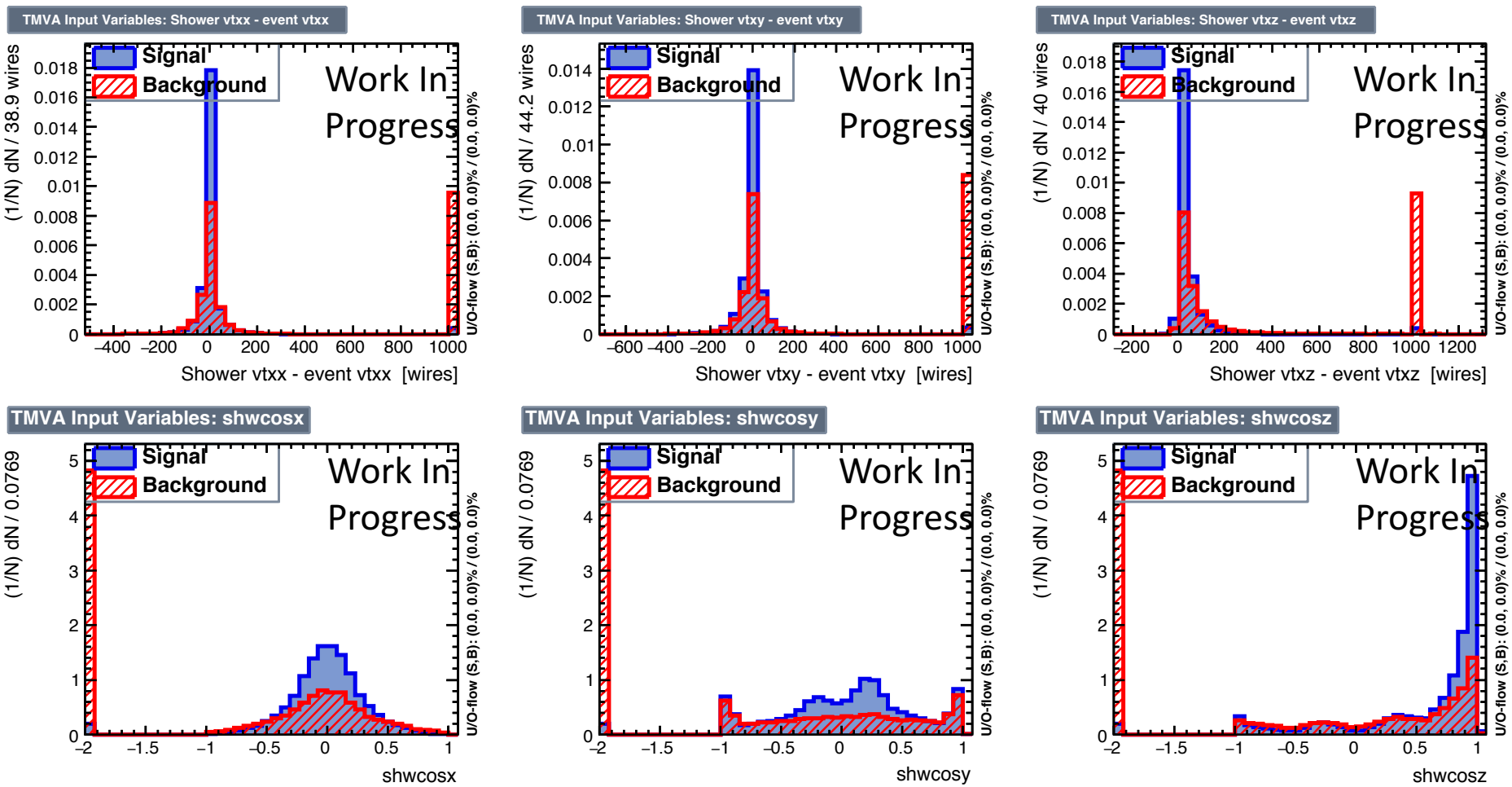

The who?

- Large science collaboration
  - 950+ scientists
  - 164 institutions
  - 30+ countries