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T2K

Neutrino Interactions on Lead at T2K

IoP HEPP and APP conference
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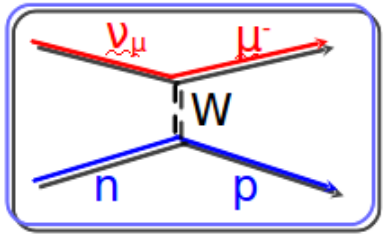
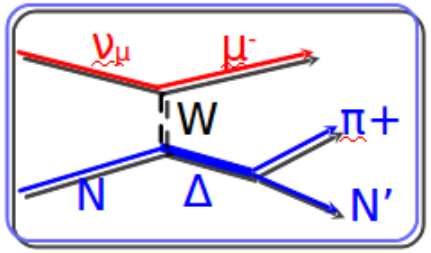
Outline

- Current knowledge of the neutrino interaction cross-section on lead
- A brief look at the Tokai to Kamioka (T2K) experiment
- Selecting neutrino interactions in the electromagnetic calorimeters (ECals) of the ND280 detector
- Initial results
- Current work and future plans

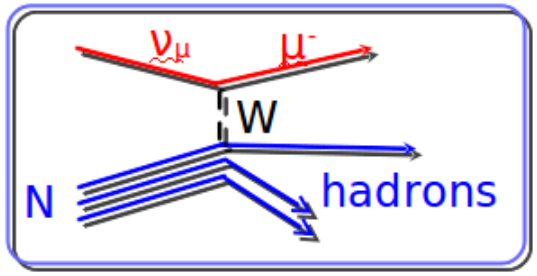
Neutrino Cross Sections



Charged current quasi-elastic (CCQE)

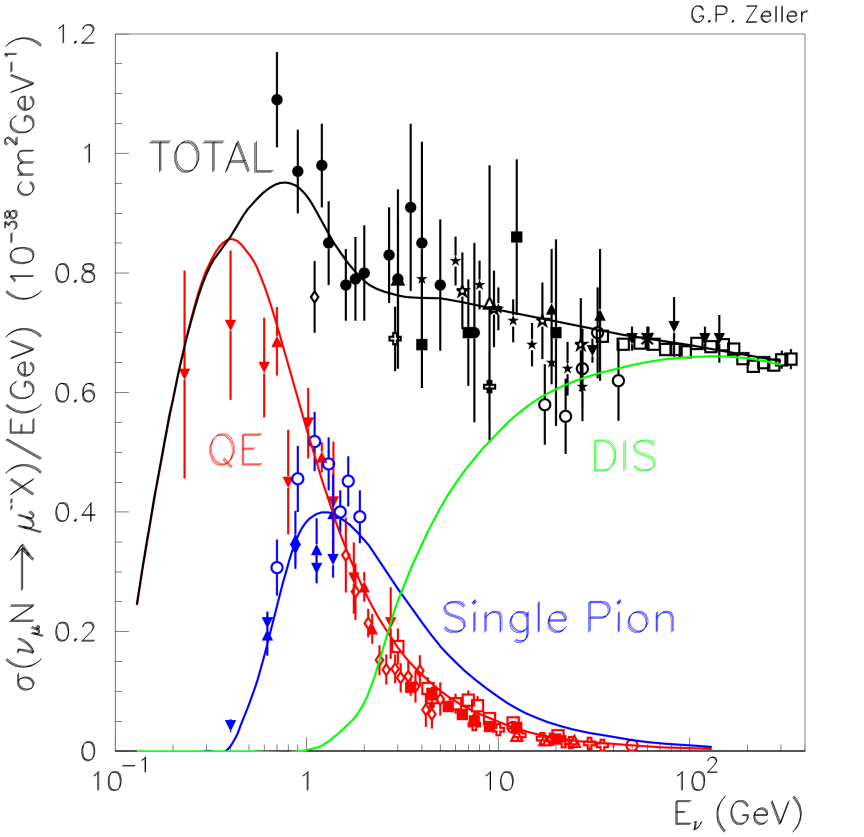


Charged current single pion (CC1π)



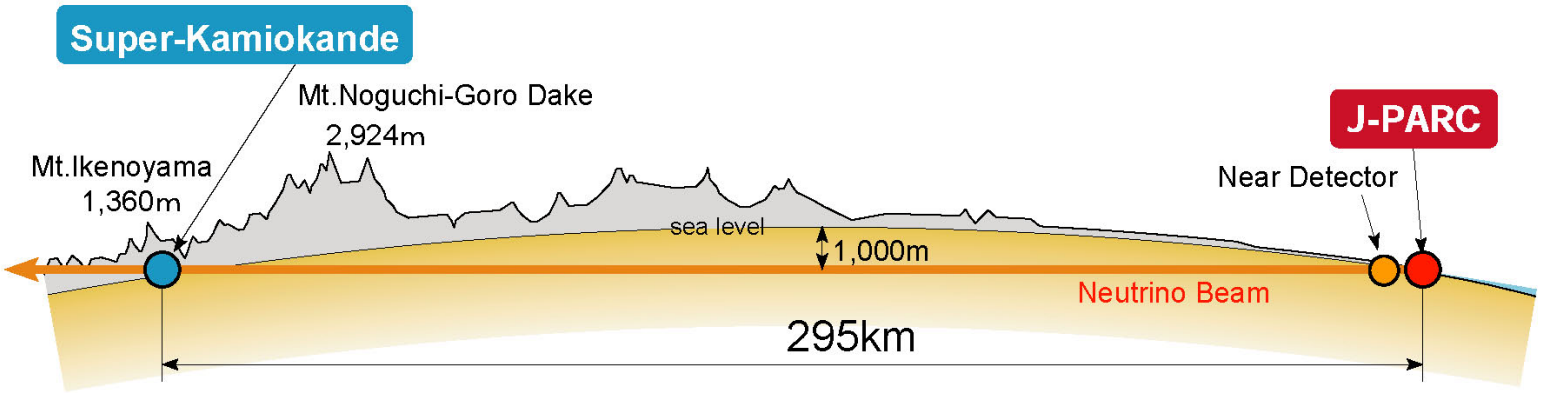
Deep inelastic scattering (DIS)

G.P. Zeller, Proceedings of the Venice 2006: NuInt02



- One measurement on lead from CHORUS experiment at 27 GeV

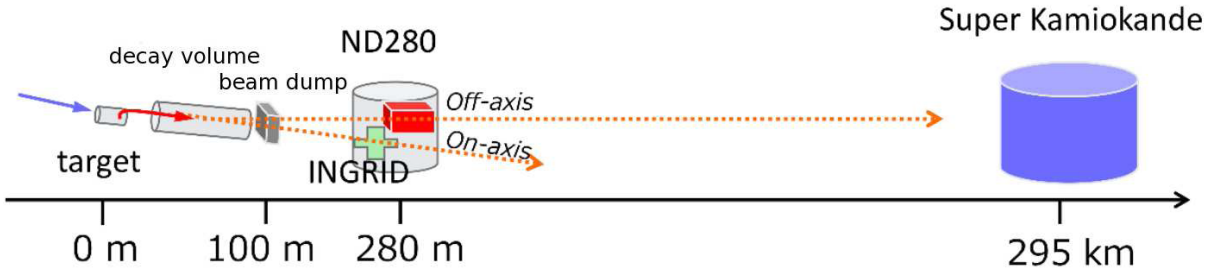
The T2K experiment



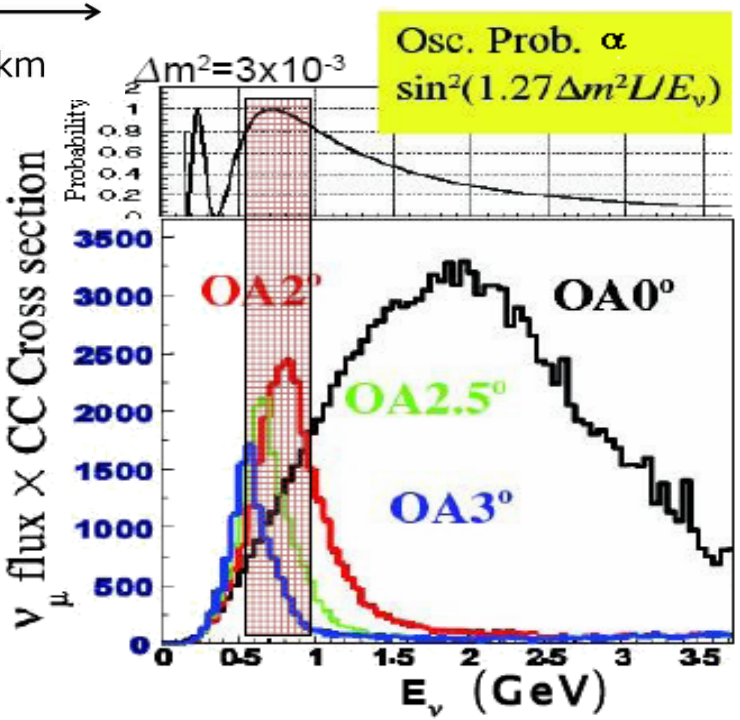
- Long baseline (295km) neutrino oscillation experiment
- Designed to be world's most intense neutrino beam, on the east coast of Japan in Tokai
- Characterised by the near detector suite at 280m, then observed at Super-Kamiokande in Kamioka

The T2K experiment

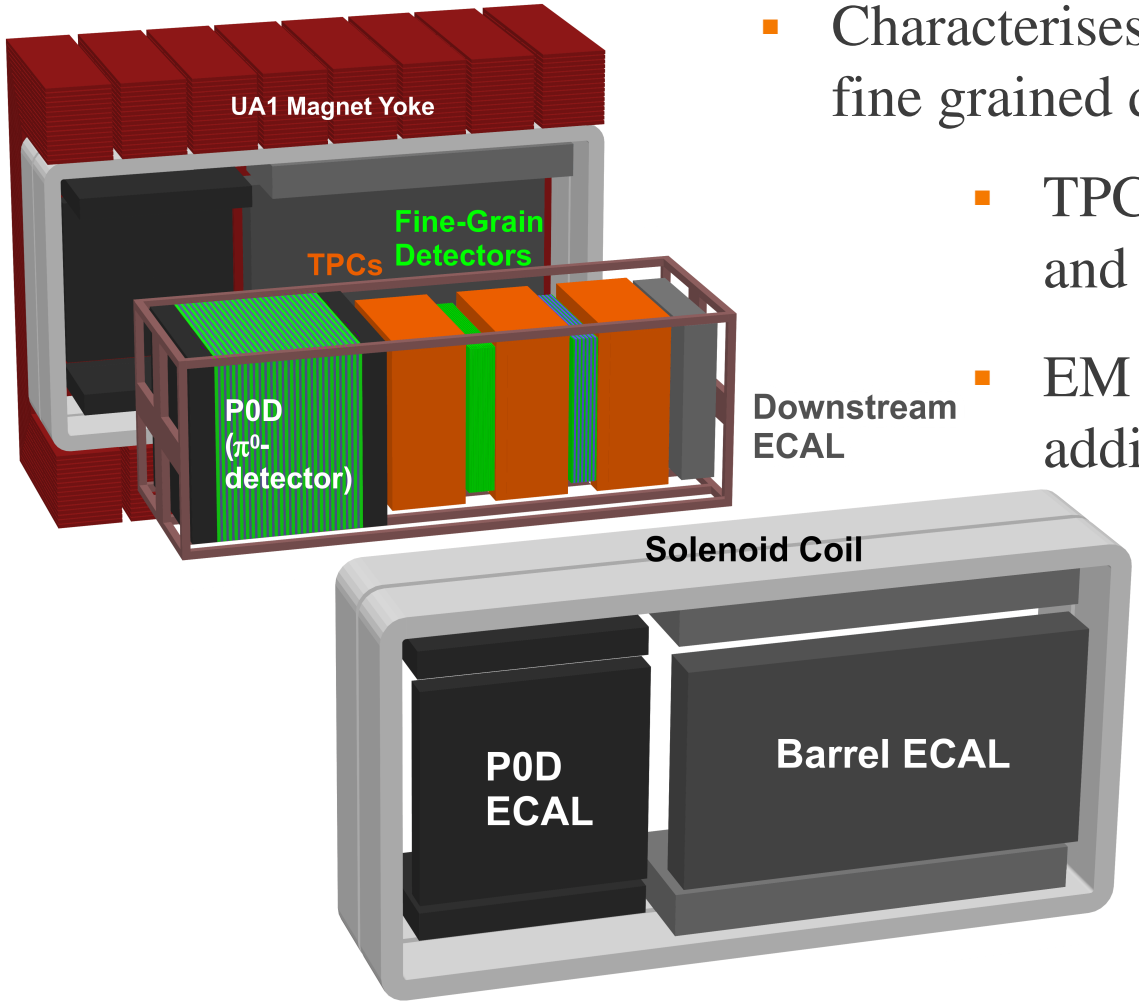
- First off-axis neutrino beam experiment



- Shifts neutrino beam spectrum, reducing the high energy tail and increases the flux at 600 MeV, the peak oscillation energy.



The ND280 detector



- Characterises the neutrino beam, using the fine grained detectors as primary targets
  - TPCs - momentum measurements and PID
  - EM calorimeters - hermiticity and additional PID
- Beam axis passes below and to one side of the ND280

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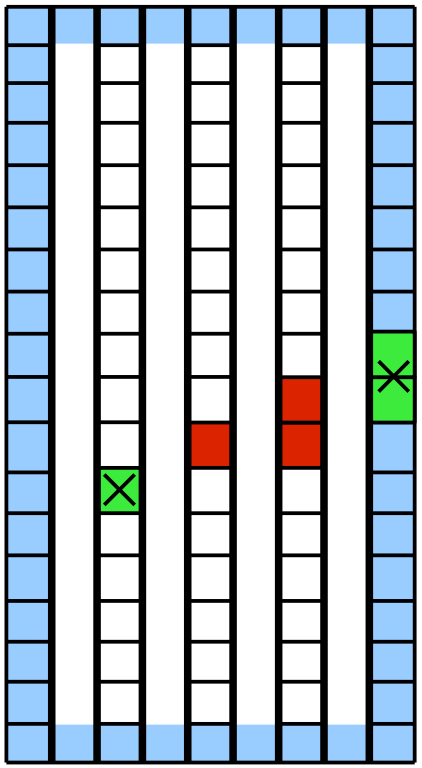
The Electromagnetic Calorimeters

- The electromagnetic calorimeters (ECals) surround the tracker of the ND280
- Formed from layers of plastic scintillator bars, interleaved with lead
- Used for PID and to measure energy of photon showers
- Total ECal mass is approx. 22 times the total FGD mass

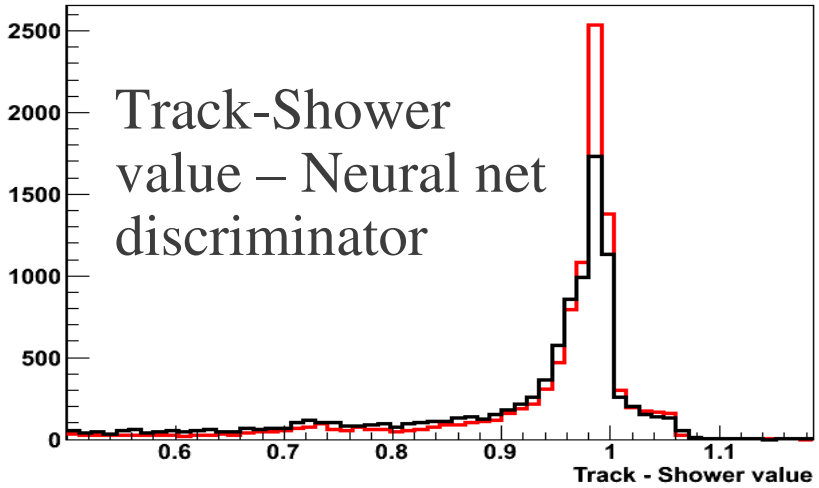
Event selection

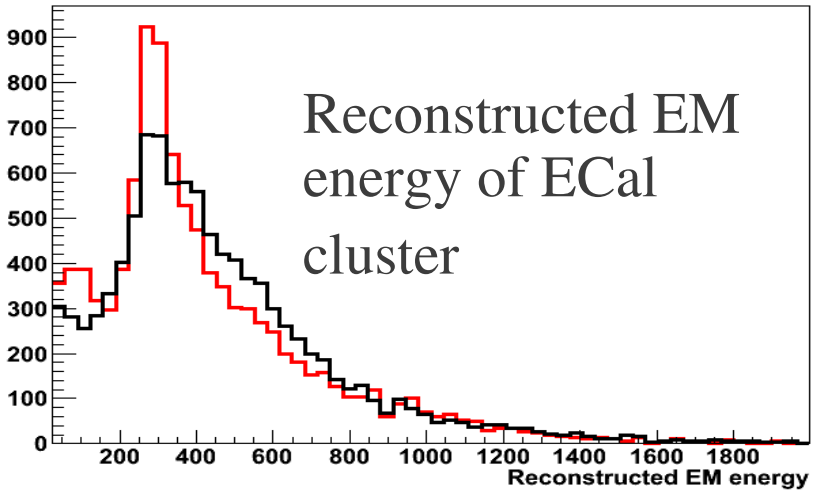
- Selecting clusters in the ECal that pass a pre-selection, shown on the right.
  - Calculate the charge weighted start and end positions of the cluster
  - Require one is inside the ECal fiducial volume (white area)
- Selects particles that are created inside or stop inside an ECal
- A cuts based and a likelihood based analysis were performed
  - Both gave compatible results with a twofold increase in efficiency using the likelihood technique

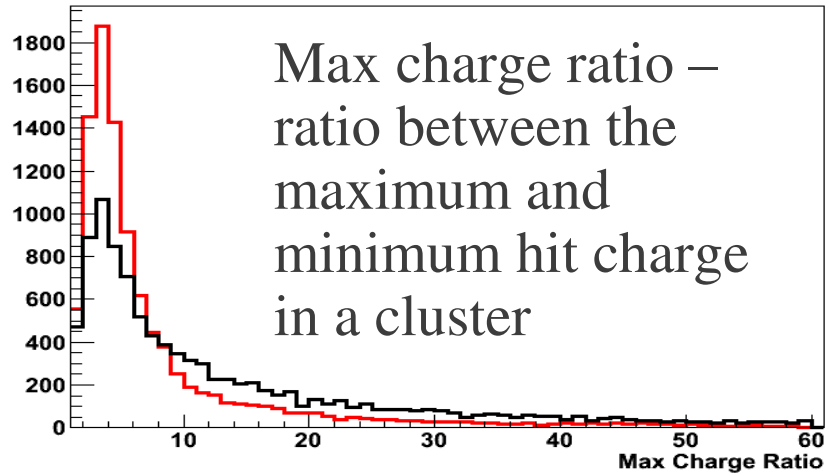


Outside FV = Blue
Hits = Red
Selected Hits = Green

Likelihood Input variables



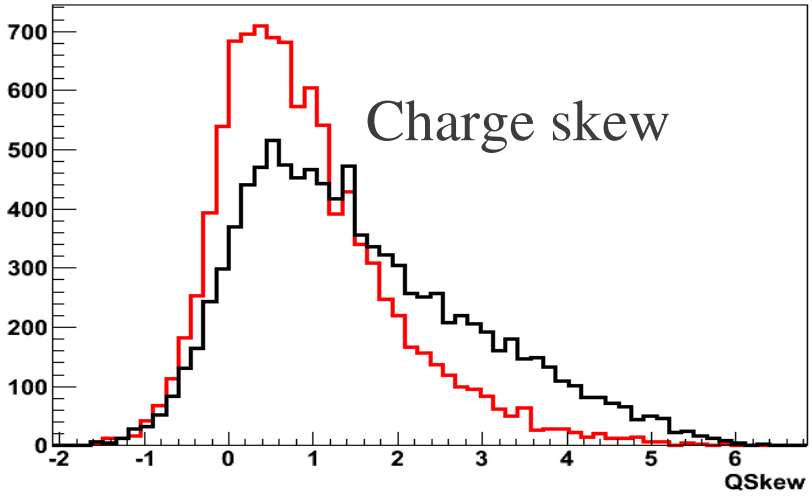


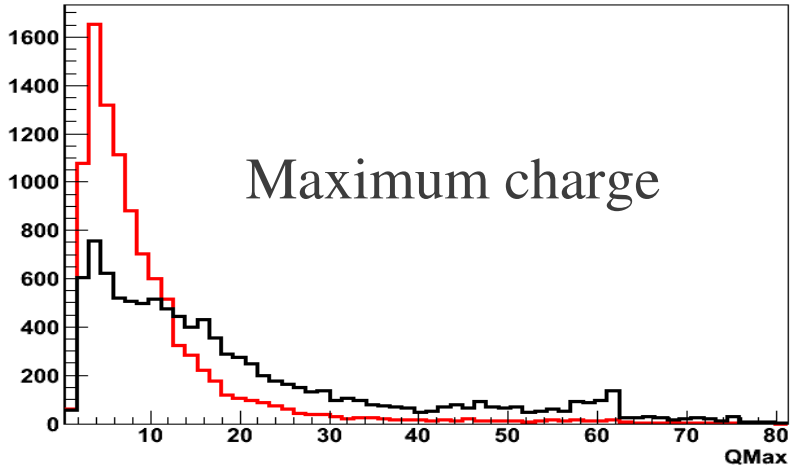


- Red – Background
- Black – Signal

- See some separation

Likelihood Input variables



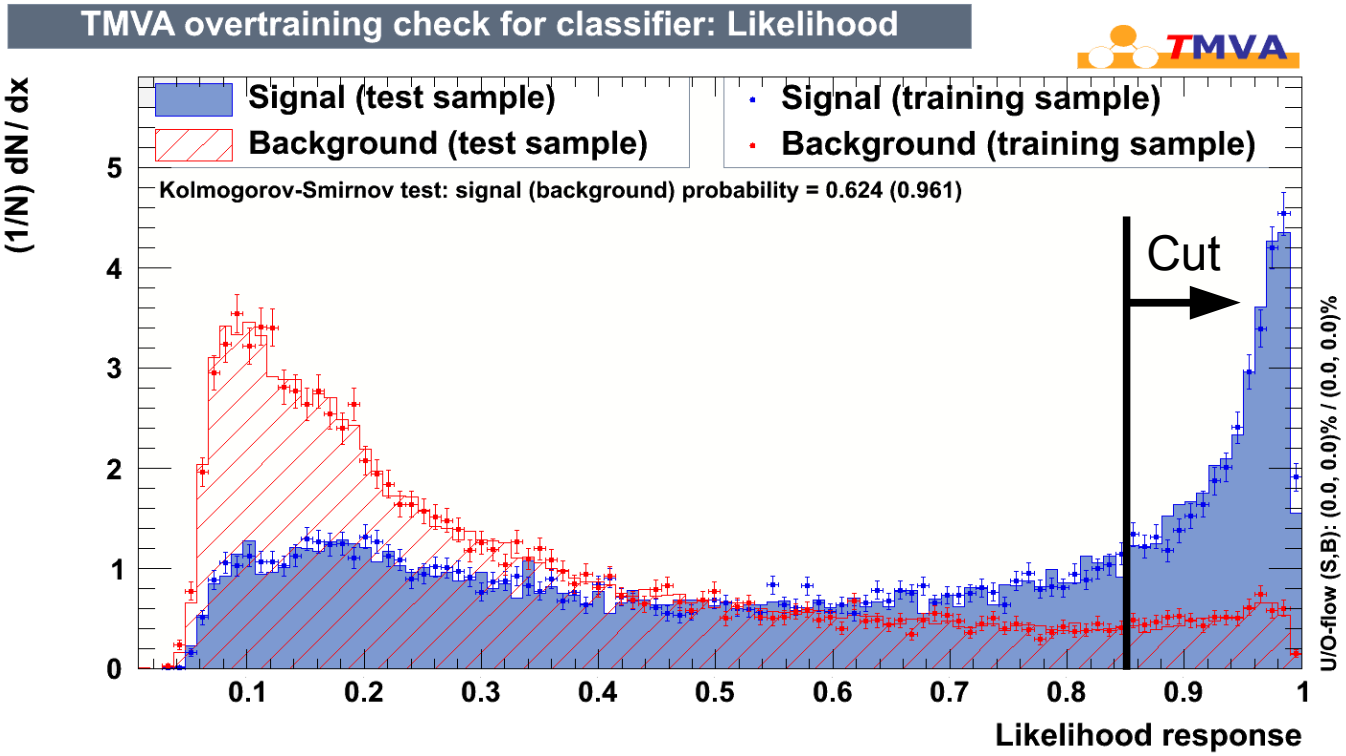


- Red – Background
- Black - Signal

- Charge skew – the skew of the charge distribution within an ECal cluster
- Maximum charge – the maximum hit charge in an ECal cluster

Neutrino event selection

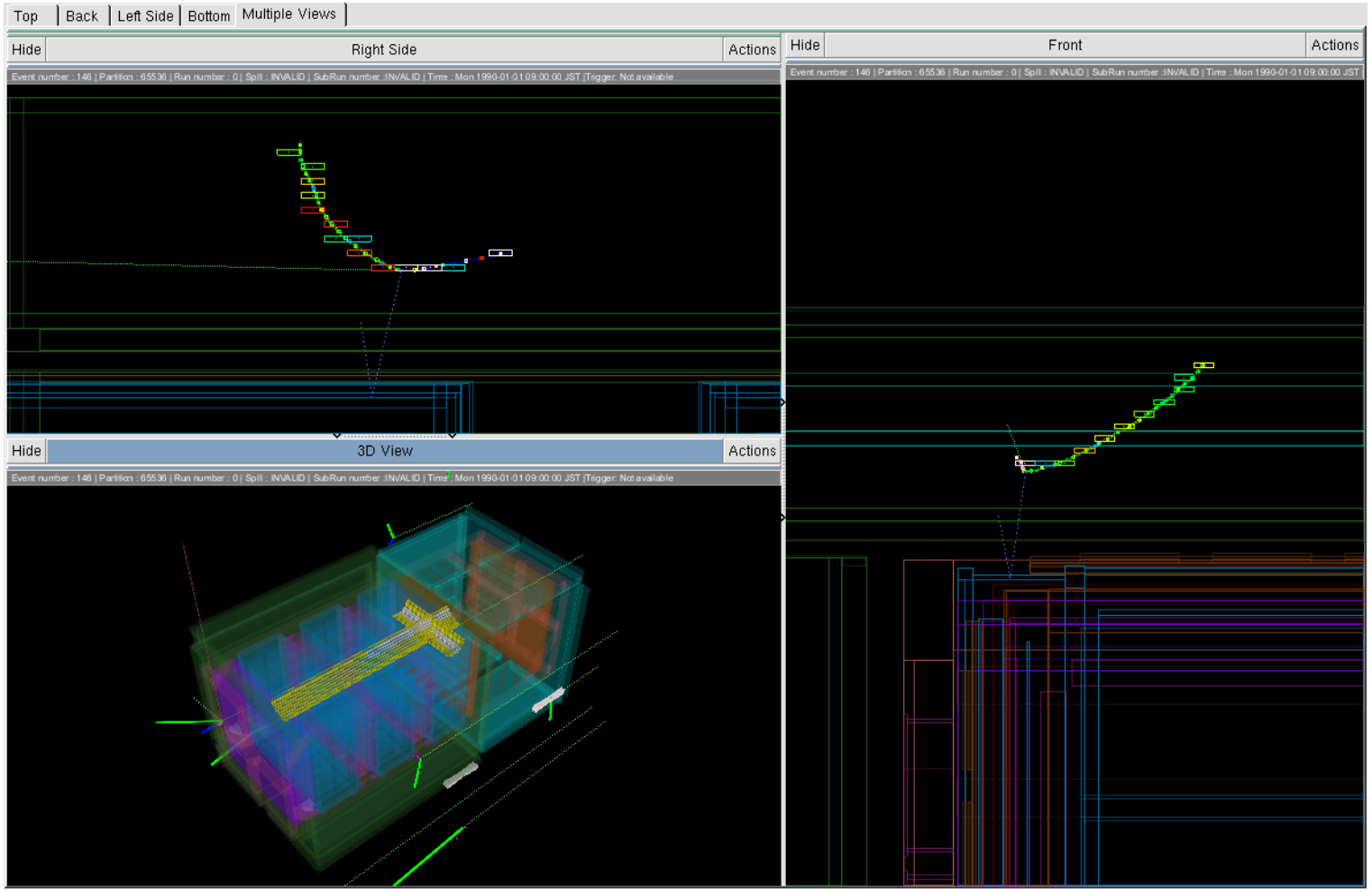
- Applied the likelihood method from ROOT's multi-variate analysis (TMVA) package to full beam spill Monte Carlo



- Achieve reasonable separation between background (red) and signal (blue)

Neutrino event selection

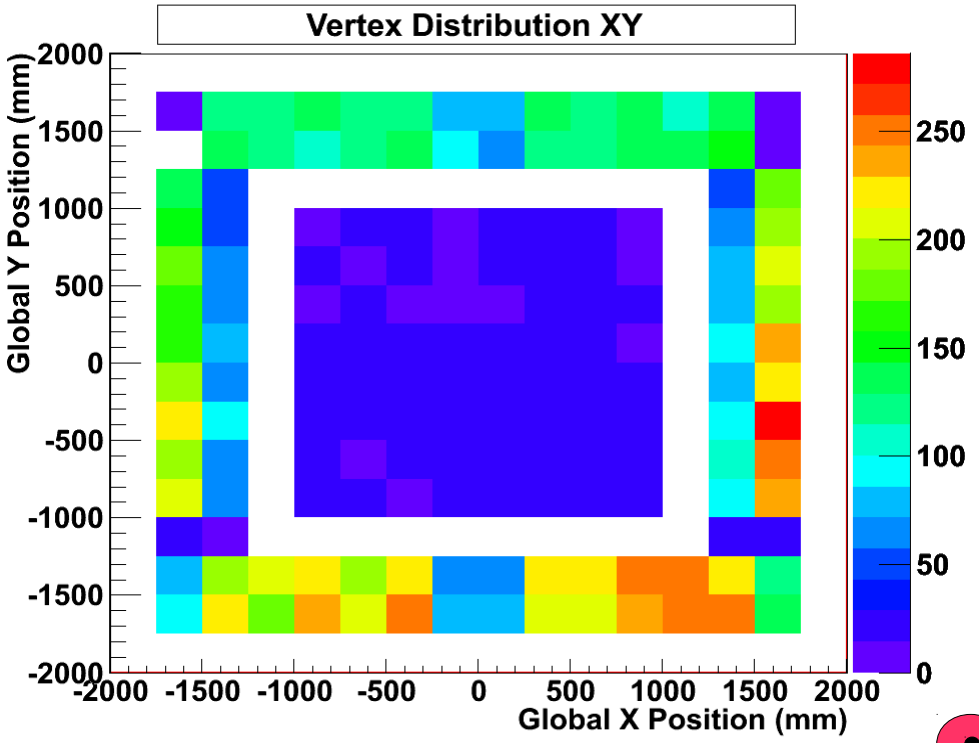
- An MC CCQE event



Neutrino event selection

- Achieve:

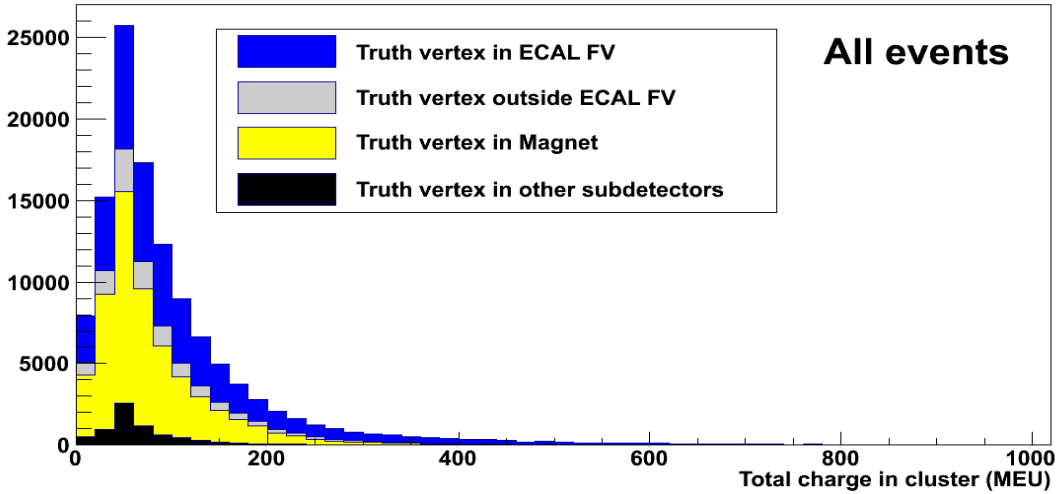
Efficiency / %	Purity / %
12.0	55.3



- Expect 75,000 events in current data set (7.8×10^{19} protons on target, 2% of the planned total data)
- 41,000 true charged current muon neutrino events

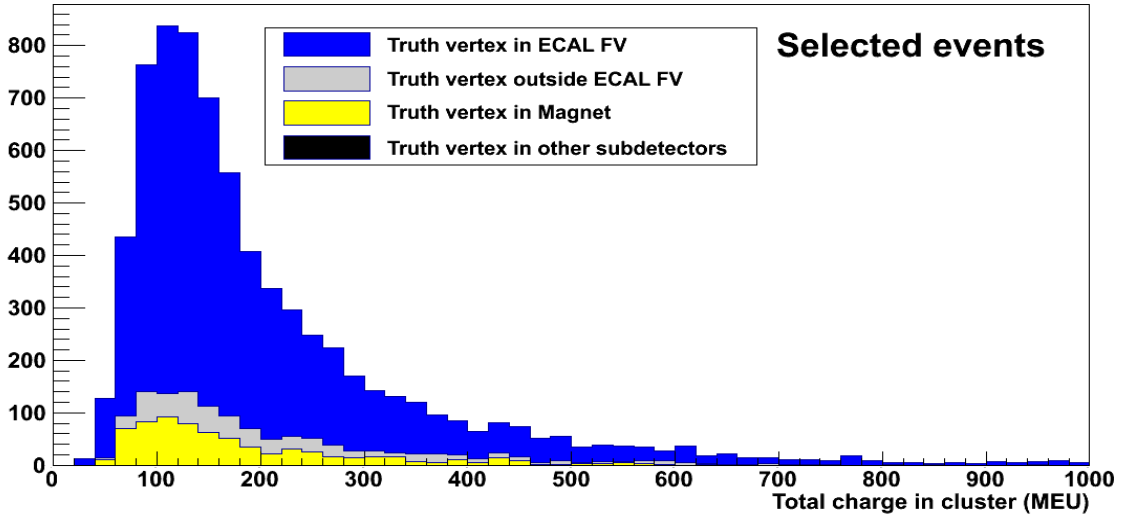
← Beam centre

Event selection

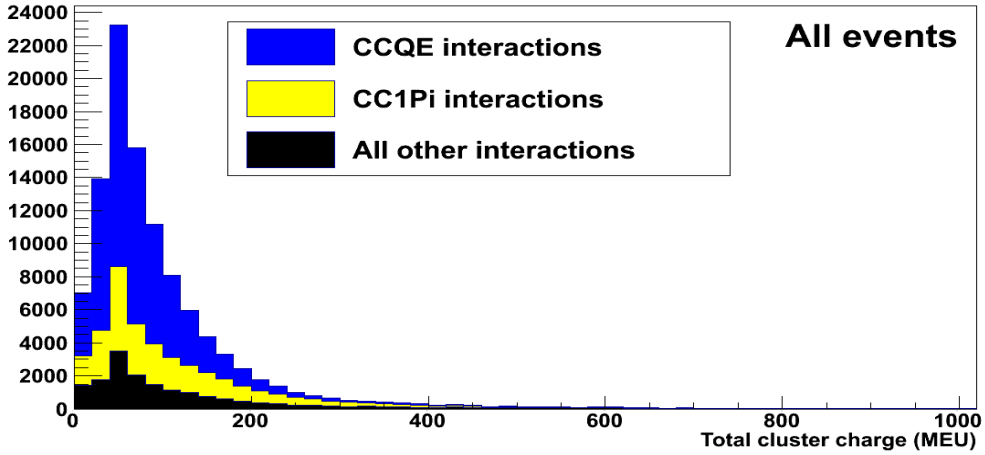


- Plots show true vertex position before (left) and after (below) selection, plotted against the total charge in the cluster

- Main backgrounds – magnet interactions, events from outside the ECal fiducial volume

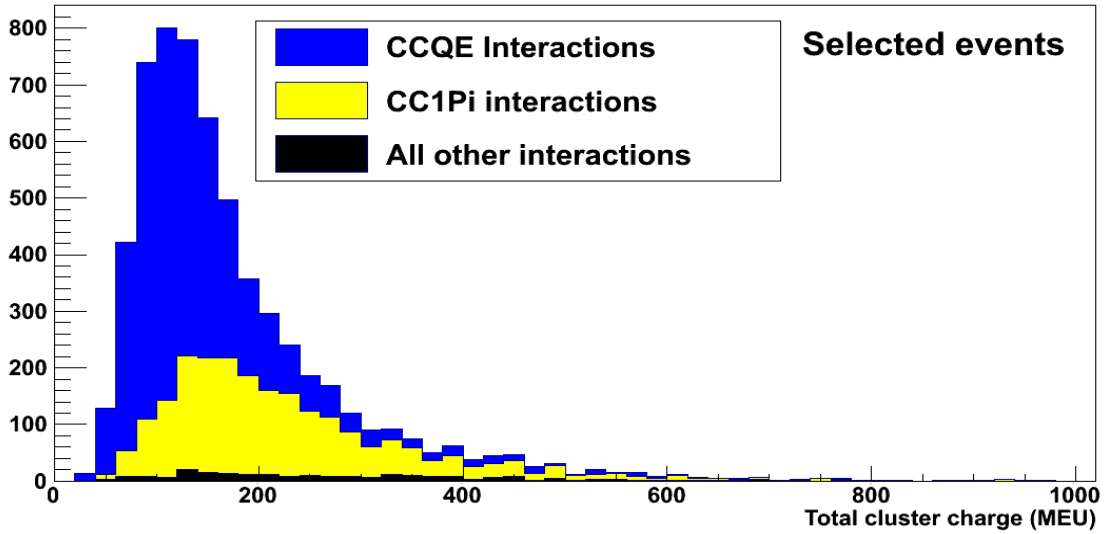


Event selection

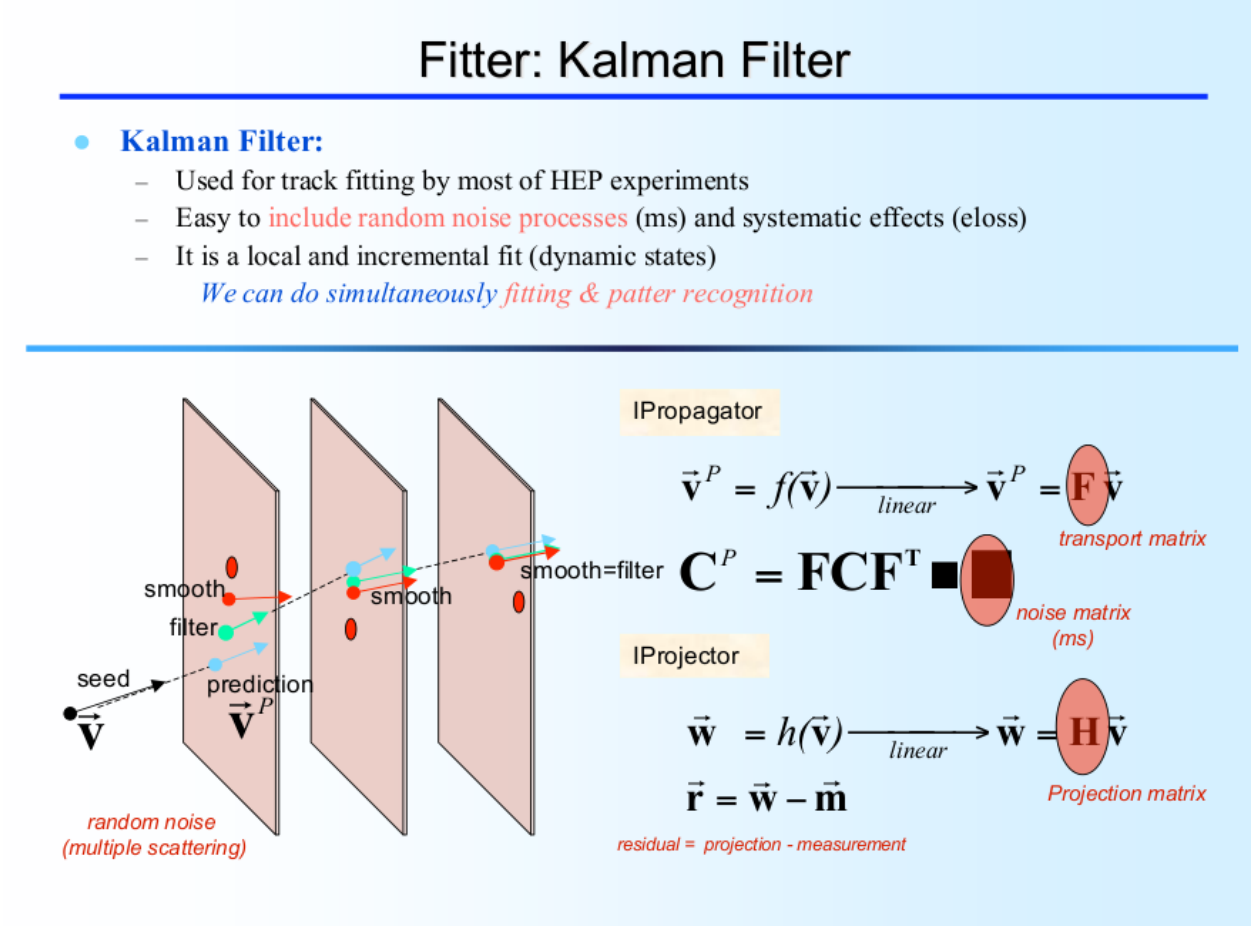


- Plots show neutrino interaction type before (left) and after (below) selection, plotted against the total charge in the cluster

- Tend to select higher energy CCQE or CC1Pi interactions



Current work and future plans

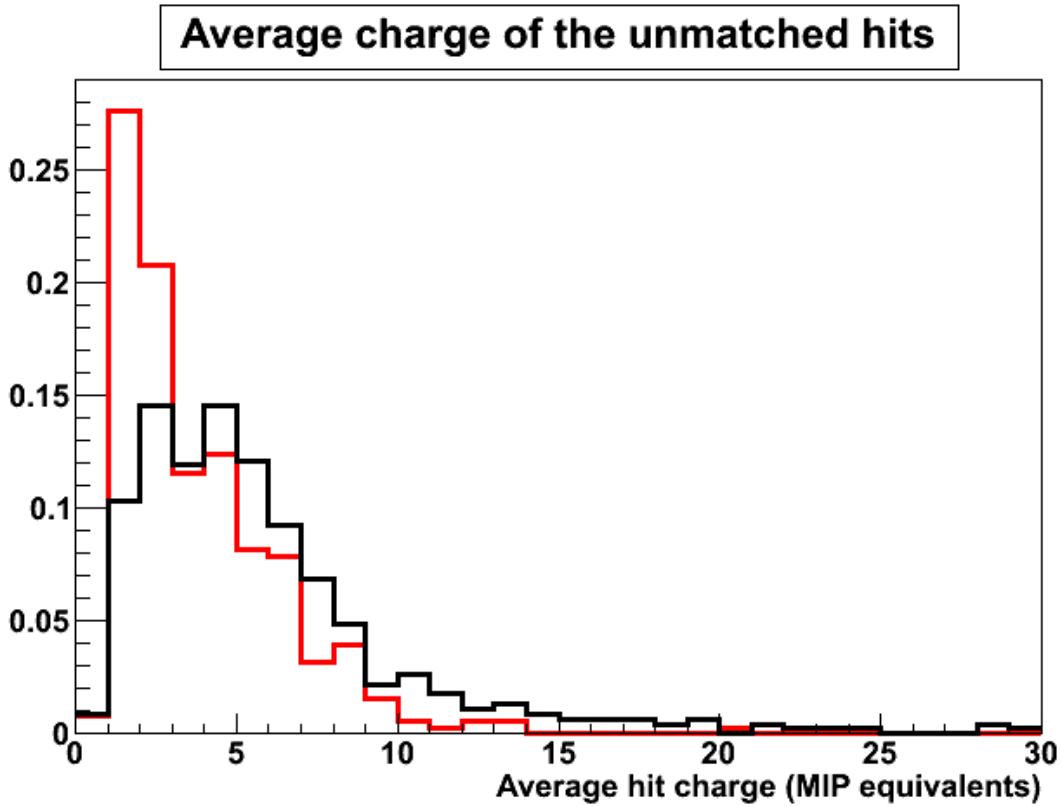


- Focusing on improvements to the ND280 reconstruction
- Applying a Kalman filter to perform track fitting in ECals
- Examining hits that pass or do not pass the filter

Current work

- Kalman filtered hits – plot shows the average charge of hits not included in the track

- Hits from through-going particles (red) have a lower charge than those from tracks starting in the ECal (black)

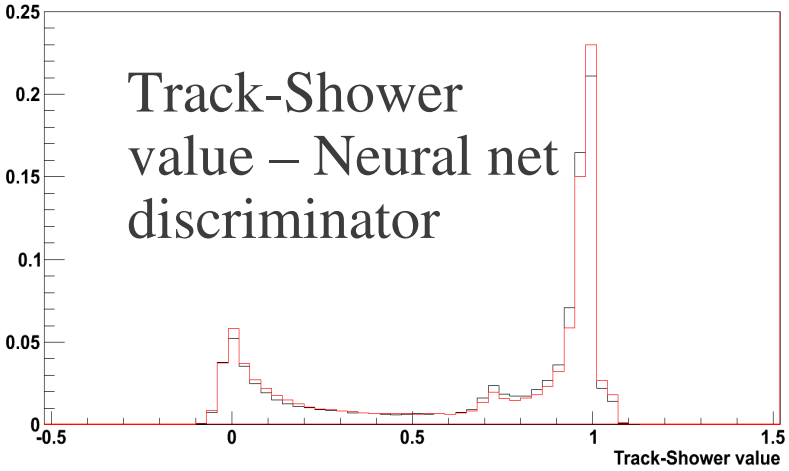


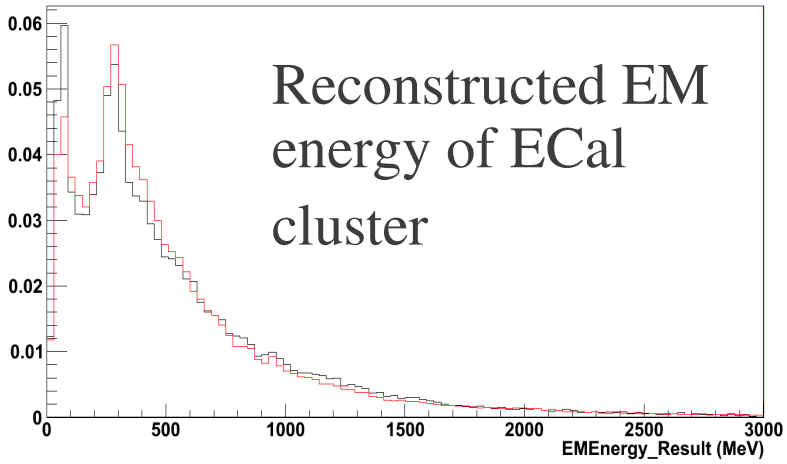
Summary

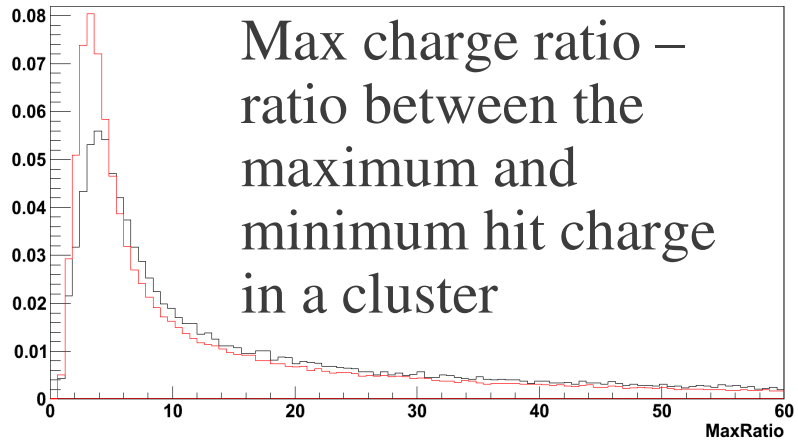
- Working towards a measurement of the absolute charged current cross-section for muon neutrinos on lead
- Achieving 55% initial purity and 12% efficiency is encouraging and will be improved in the future
- This work is being used by current ND280 analyses to understand ECAL backgrounds to the neutrino beam characterisation
- Also benefits the collaboration as a cross-check of the beam flux and could be used to improve the tuning of the current beam Monte Carlo

Backup slides

Data-MC Input variables



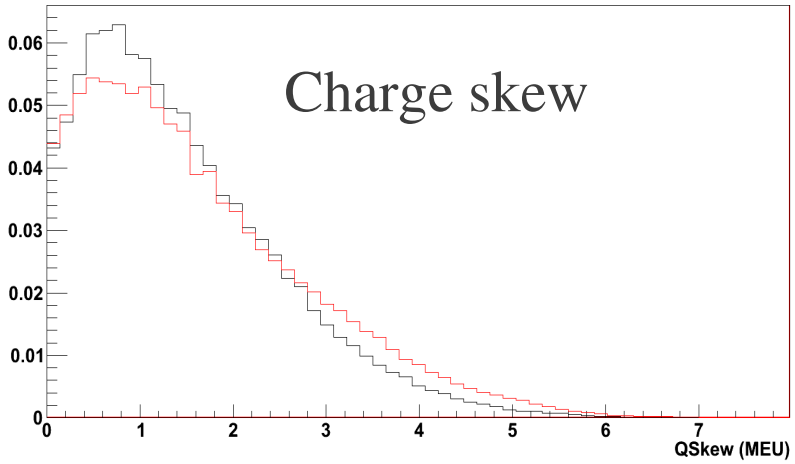


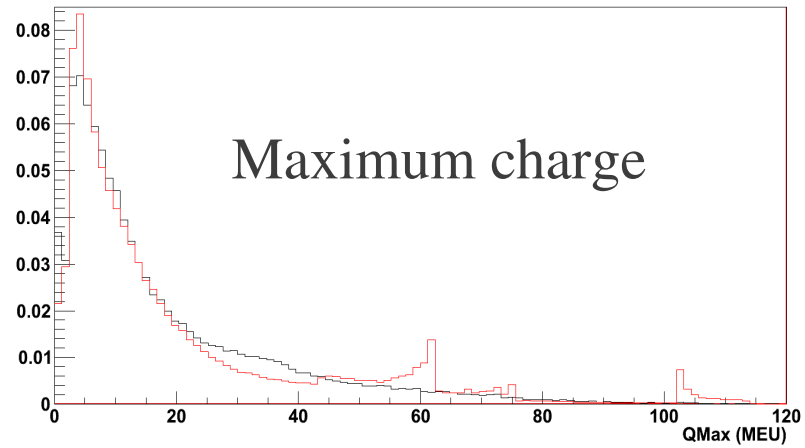


- Red – Monte Carlo
- Black – Data

- See good agreement

Data-MC Input variables



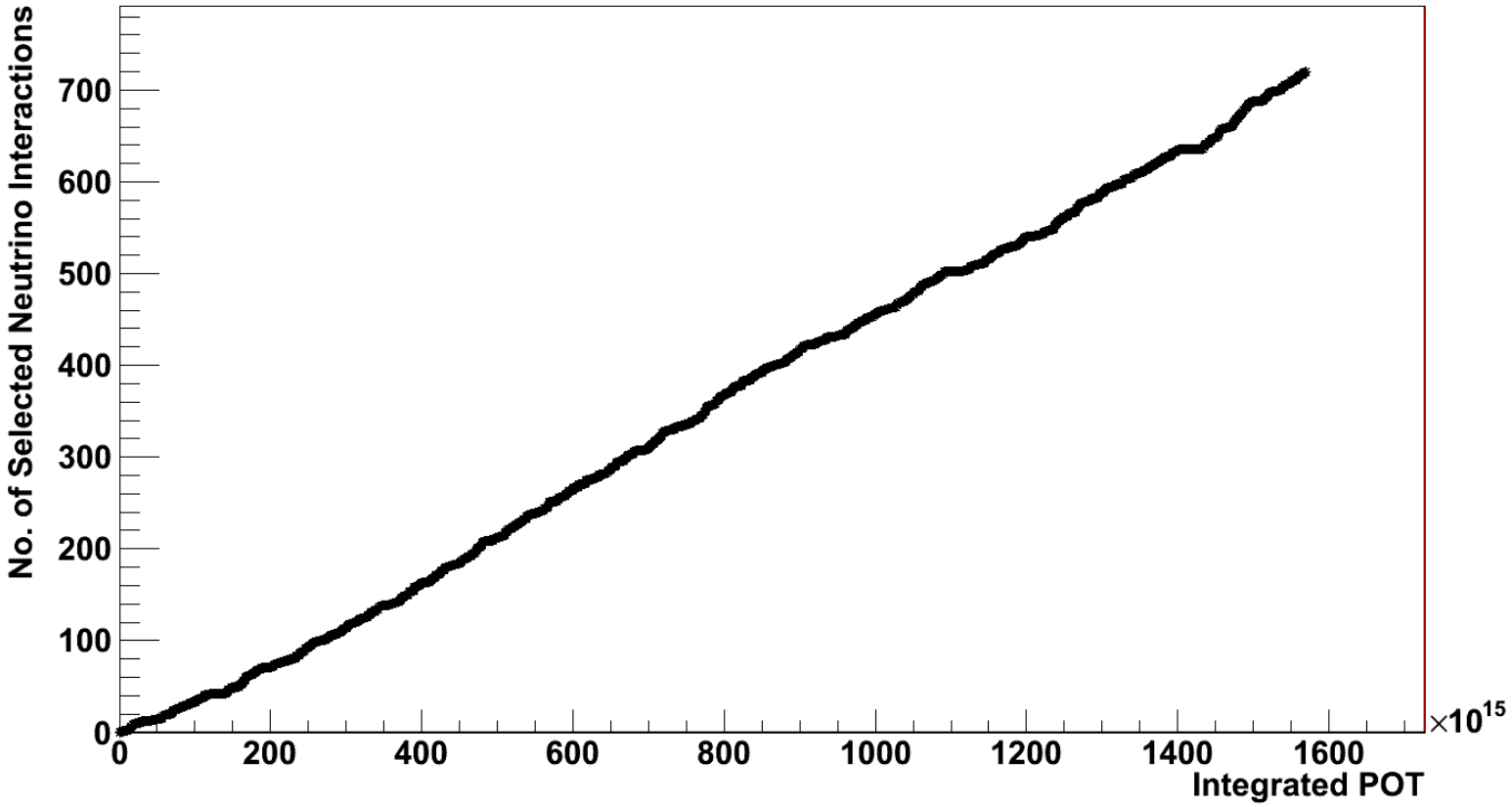


- Red – Monte Carlo
- Black - Data
- Charge skew – the skew of the charge distribution within an ECal cluster
- Maximum charge – the maximum hit charge in an ECal cluster
- See some discrepancy here

Data-MC Comparison

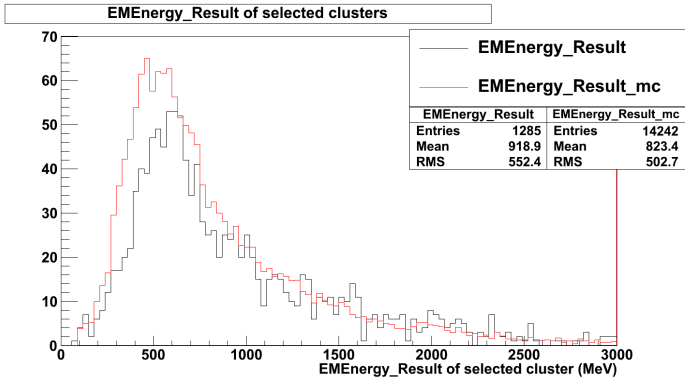
- Applied the selection to a small amount of data (~1.5 x 10^{18} POT) and to both NEUT and GENIE Monte Carlo (~1.5 x 10^{19} POT)
- Took a ratio of Data/MC versus EMEnergyFit_Result and relative off-axis angle
- Also measured the event rate vs POT for data and vs file number for MC
- Data plot follows, for MC see events selected at a constant rate

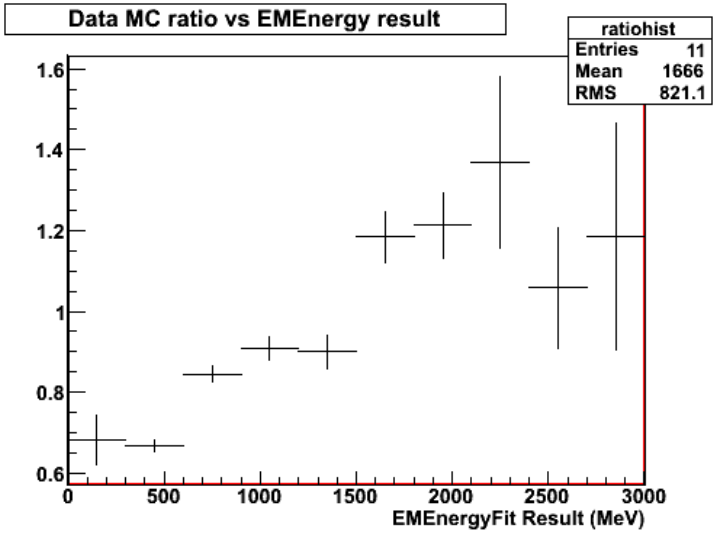
Selected Data events vs POT

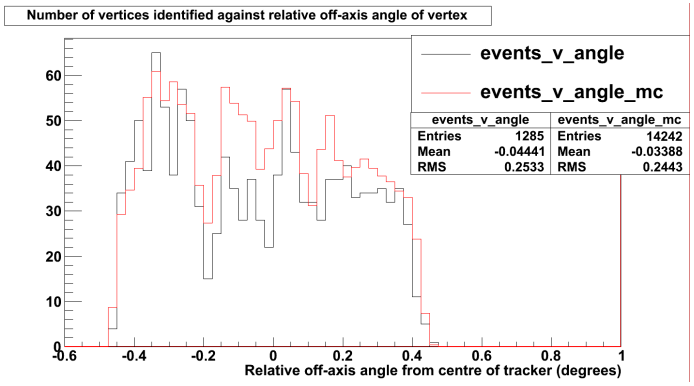


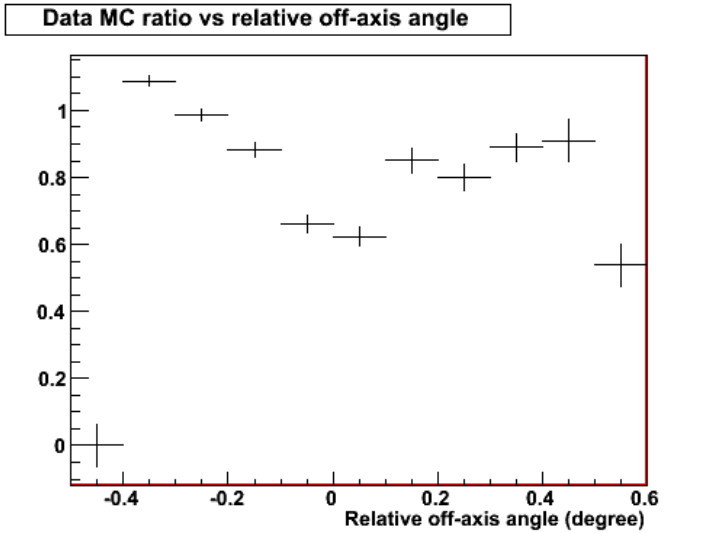
POT normalised Data/MC

- NEUT MC
- POT normalised Data/MC = 0.823 ± 0.180
- Error calculated from spread of ratio with relative off-axis angle
- Stat error = 0.003



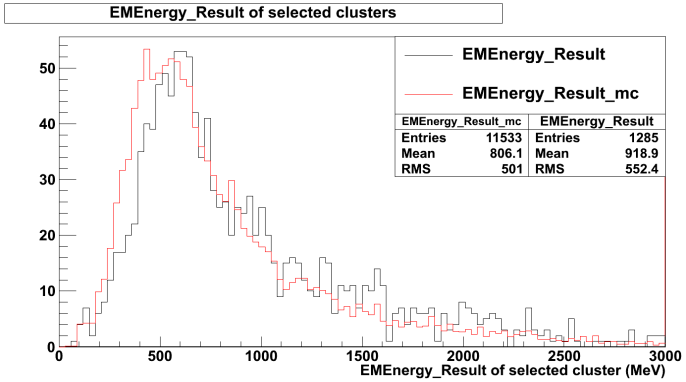


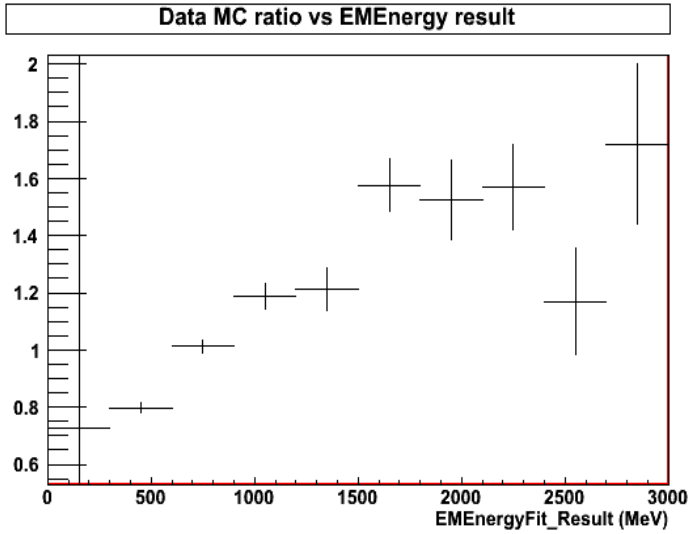


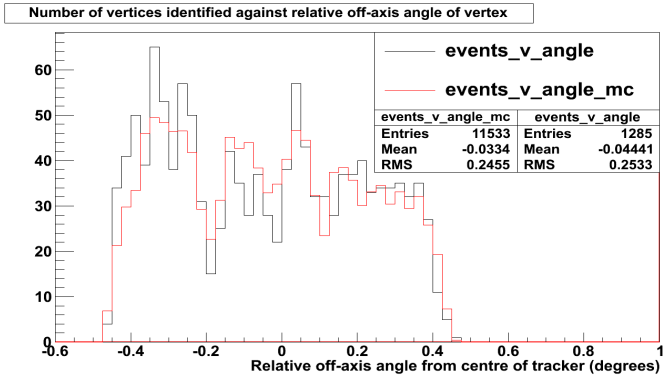


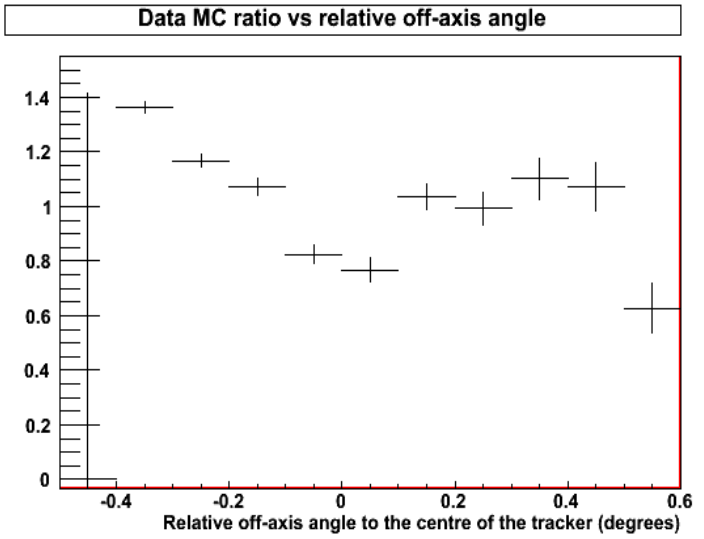
POT normalised Data/MC

- GENIE MC
- POT normalised Data/MC = 1.015 ± 0.202
- Error calculated from spread of ratio with relative off-axis angle
- Stat error = 0.003









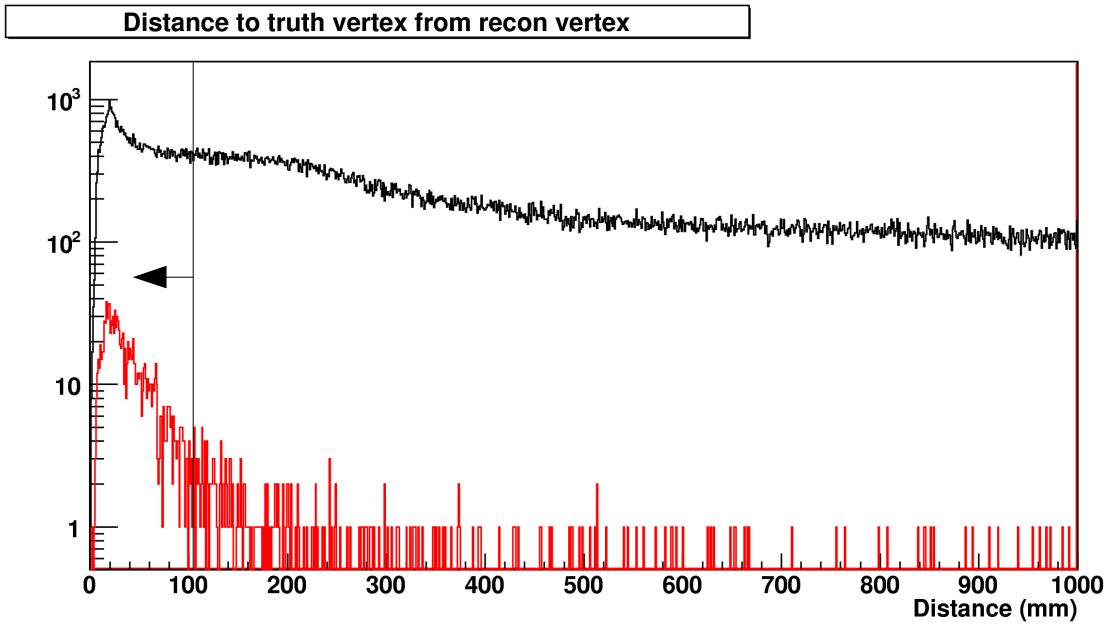
Truth Matching

- Initially performed using the oaUtility methods
- Tested oaUtility truth matching using muon particle gun MC, with muons generated within each ECal module
- Truth matching succeeded for 97.3% of trajectories.

Truth Matching

- Additionally, associated a reconstructed cluster to a truth trajectory if the start of the cluster was within 100mm of the trajectory

- Label a cluster as a true neutrino interaction if its start point is within 100mm of the truth vertex



- Red – Separation between true vertex and start of reconstructed cluster for correctly identified vertices
- Black – Separation for all reconstructed clusters and true vertices

Cut based selection

- Select event if it passes these cuts:
  - AMR < 150 or 270 < AMR
    - AMR - The ratio of the major to minor eigenvalues from PCA result of the cluster – capped at 300
  - 14 < Max hit charge
  - 8 < Max charge ratio
    - The ratio of the maximum hit charge to the minimum hit charge
- Achieve:

Efficiency / %	Purity / %
5.7	51.4

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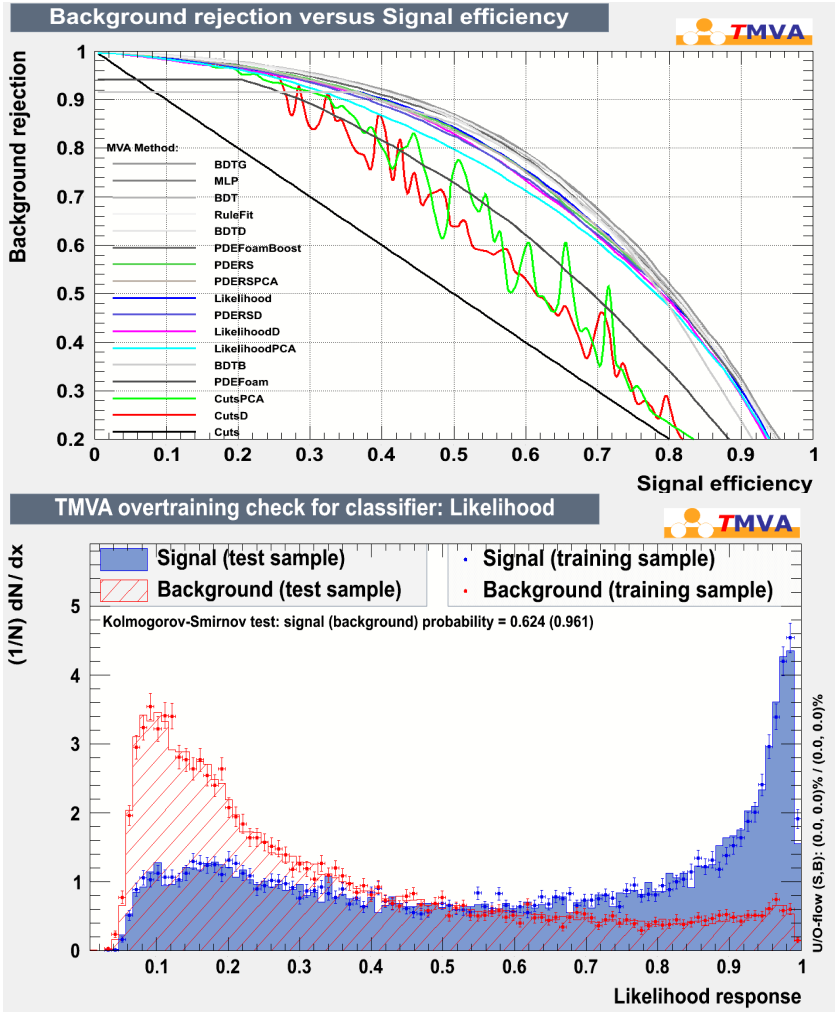
TMVA Selection



- See no large difference between methods
- Likelihood easiest to understand
- See some separation of signal (blue) and background (red)

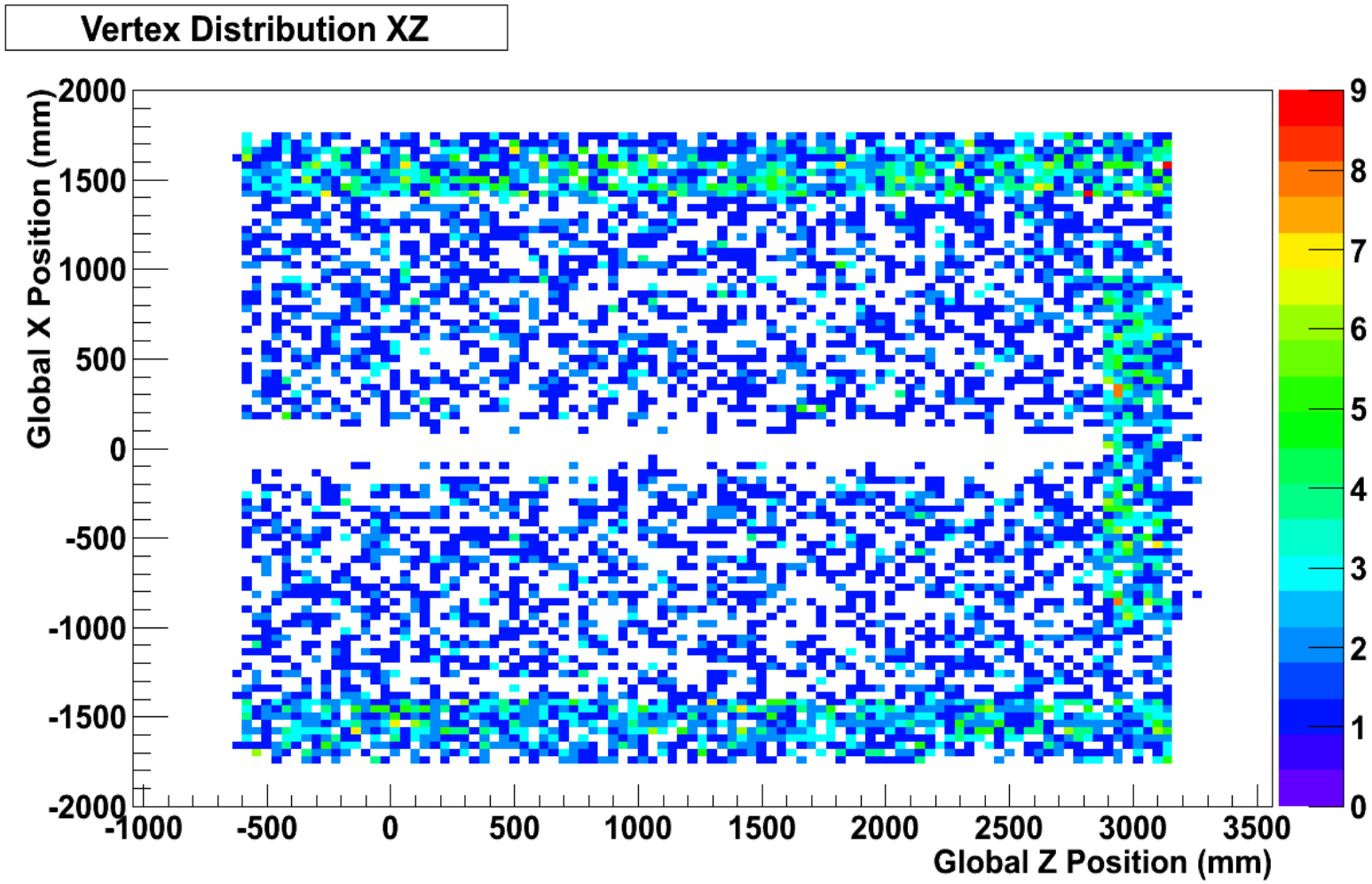
An ECal veto

- Find 1388 interactions with a truth vertex in the FGD scintillator and a cluster in the ECal, from 118661 total events with an ECal cluster.
- Imposing MVA selection:

Cut Value	0.2	0.5	0.85
No. of selected FGD vertices	184	81	21

- 0.85 cut would remove ~12,000 events with ECal clusters
- No selection applied to these FGD vertices, don't know if they would pass nue selection

XZ distribution - MC



YZ distribution - MC