Charged Current $1\pi^0$ Interactions in the ND280 Tracker Region of the T2K Experiment

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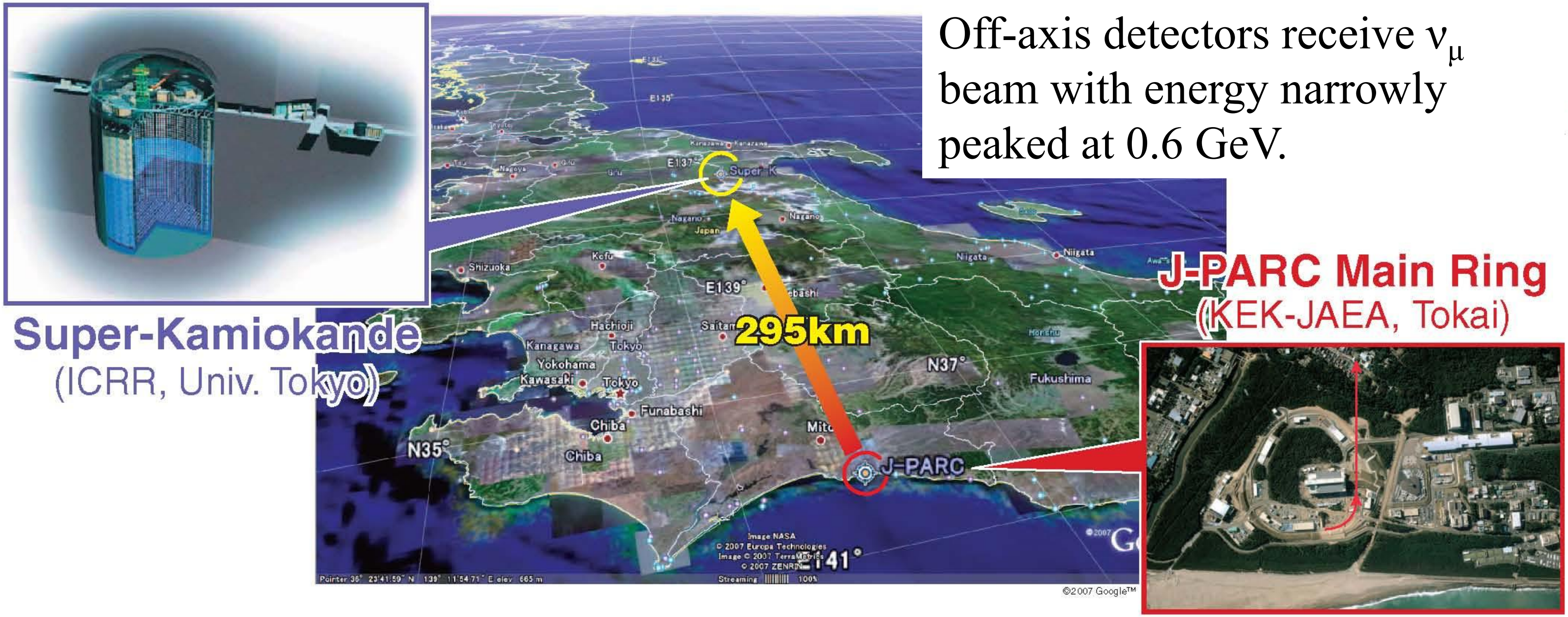
INTRODUCTION TO T2K

Experimental Aims

Off-axis detectors receive ν_μ beam with energy narrowly peaked at 0.6 GeV.

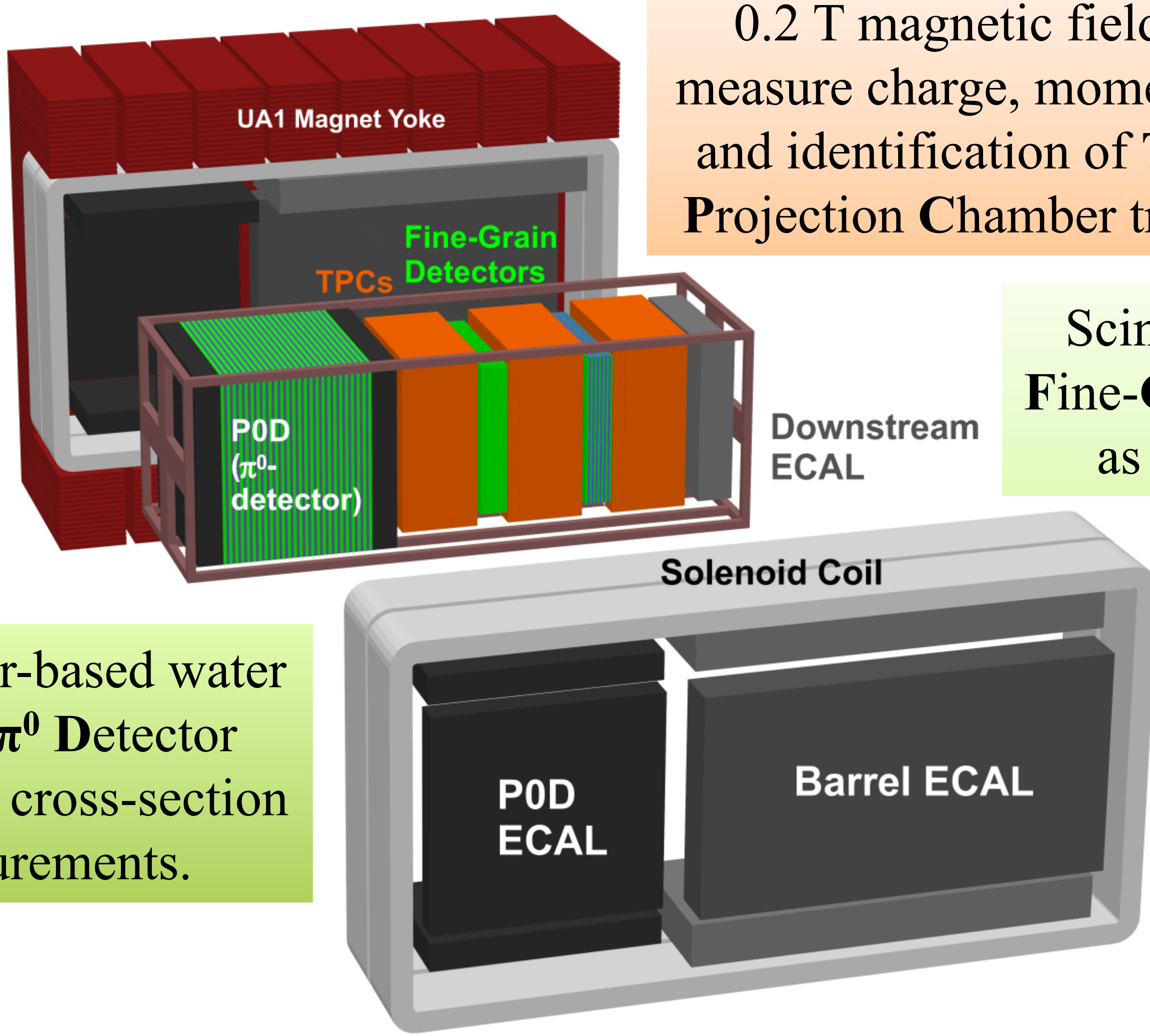


- Neutrino oscillation experiment based in Japan, searching for:

$$\nu_\mu \rightarrow \nu_e \text{ appearance to measure } \theta_{13}$$

$$\nu_\mu \rightarrow \nu_\mu \text{ disappearance to measure } \theta_{23}$$

ND280 Detector



0.2 T magnetic field to measure charge, momentum and identification of **T**ime **P**rojection **C**hamber tracks.

Scintillator-based **F**ine-**G**rain **D**etectors as target mass.

Scintillator-based **E**lectromagnetic **Cal**orimeters, for energy measurements and particle identification.

Scintillator-based water fillable π^0 **D**etector (P0D), for cross-section measurements.

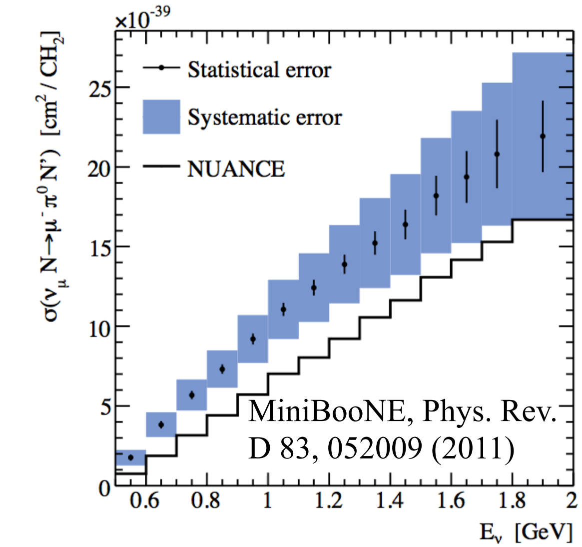
CHARGED CURRENT NEUTRAL PION ANALYSIS

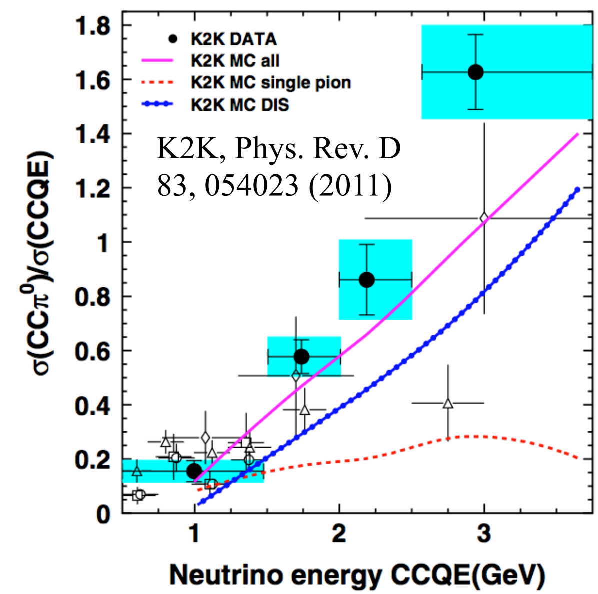
$CC\pi^0$ Interactions

- Developing an analysis to measure the charge exchanging neutrino – nucleus interactions with associated $1\pi^0$ production.

$$\nu_\mu + N \rightarrow \mu^- + N' + \pi^0$$

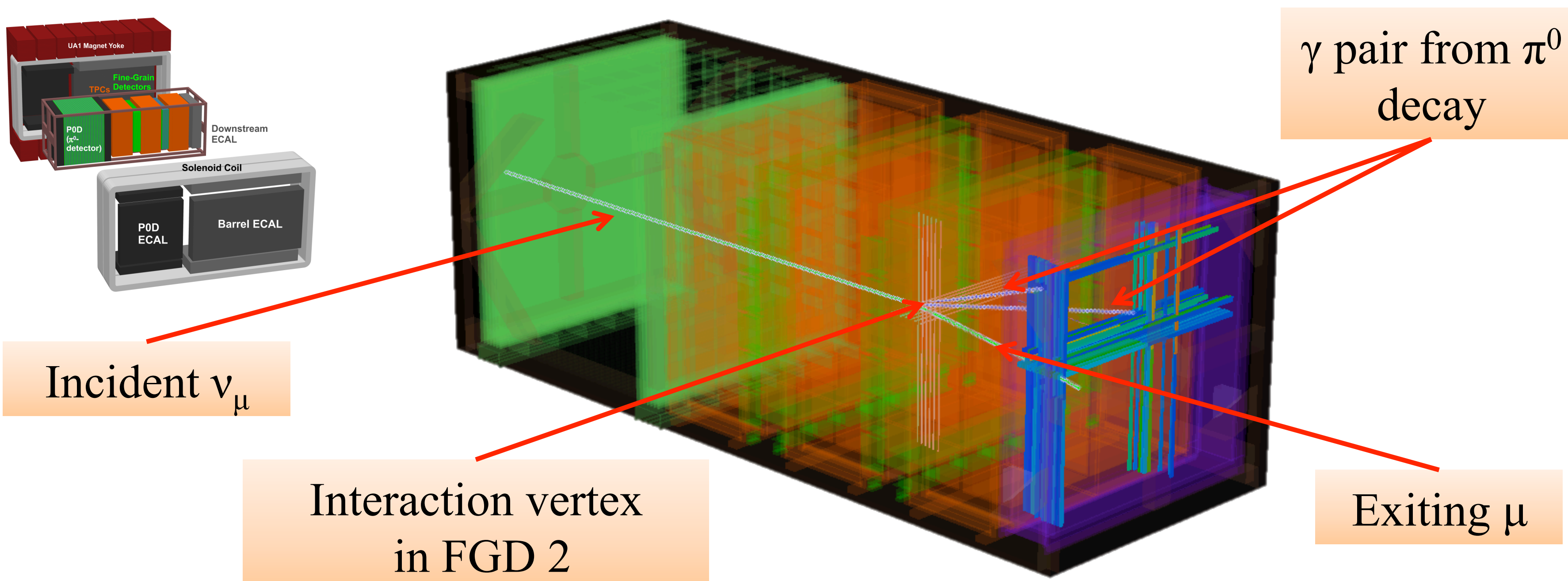
- Measurement of such cross-sections is important for constraining the systematic uncertainty in oscillation analyses at Super-Kamiokande.
  - Previous measurements tend to be at higher energies than T2K.





Event Topology

- μ selected from charged tracks emerging from the fiducial volume of either ND280 Fine-Grain Detector.
- γ pairs from π^0 decay selected by their interaction in the Barrel and Downstream Electromagnetic Calorimeters.

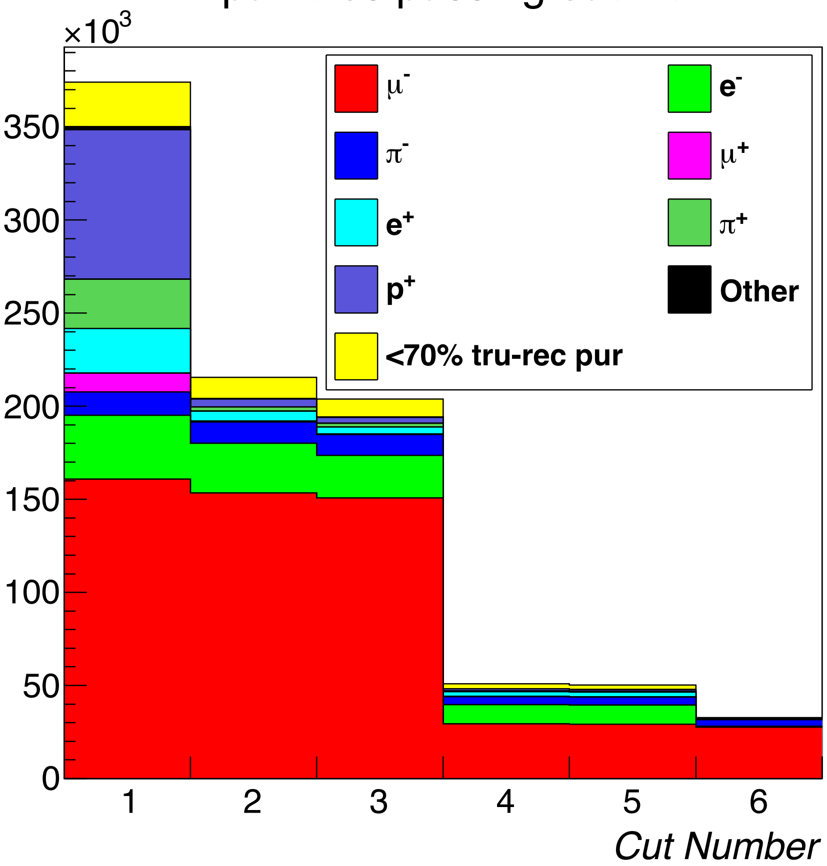


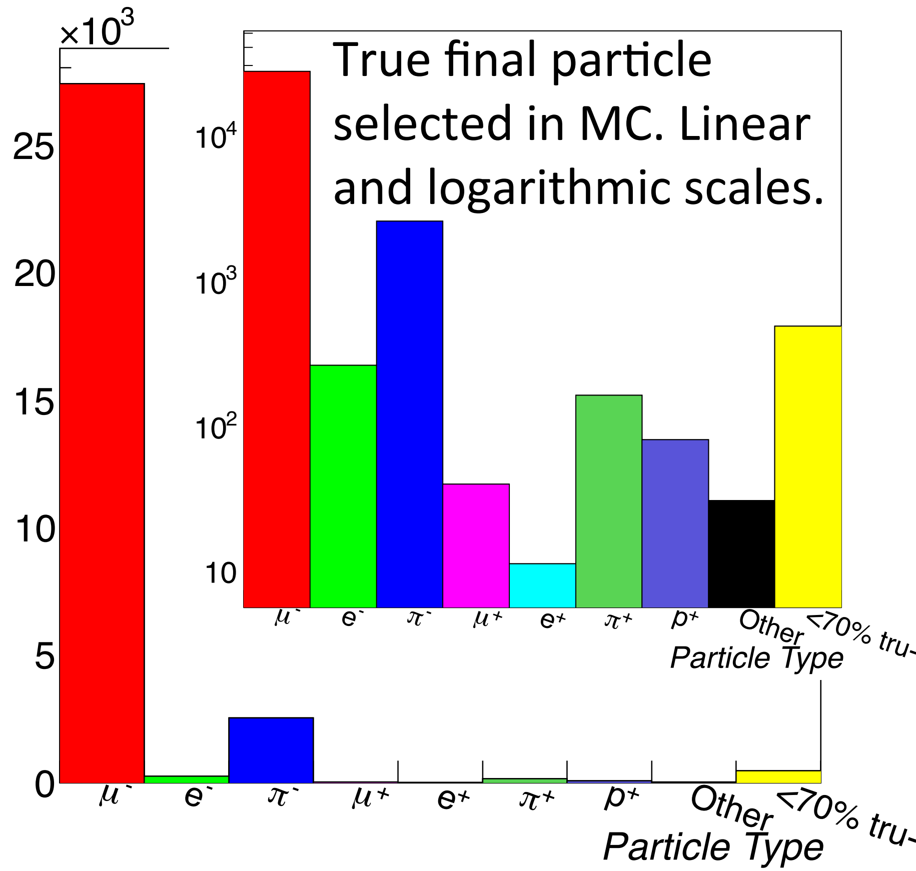
DEVELOPMENT OF THE EVENT SELECTION

Muon Selection

- Based on the official ND280 Tracker muon selection, but with slightly looser cuts optimised for increased statistics.
- Cuts select tracks with:
  - 1: TPC constituent,
  - 2: Negative charge,
  - 3: Sufficient hits for a $\partial E/\partial x$ determination,
  - 4: Vertex in a FGD fiducial volume,
  - 5: Valid $\partial E/\partial x$ based pull in each TPC, and
  - 6: μ-like and not e-like $\partial E/\partial x$ based pulls in a TPC.
- The highest momentum track to pass all cuts is selected as the μ candidate.

Muon Selection





- Background contribution dominated by π^-,
  - Future work will be required to reject events with $\pi^\pm$ in the final state to achieve exclusive $CC1\pi^0$ final state.

Muon Selection

$$Efficiency = \frac{Selected\ Signal + Selected\ Background}{Total\ Signal} \cong 60\%$$

$$Purity = \frac{Selected\ Signal}{Selected\ Signal + Selected\ Background} \cong 90\%$$

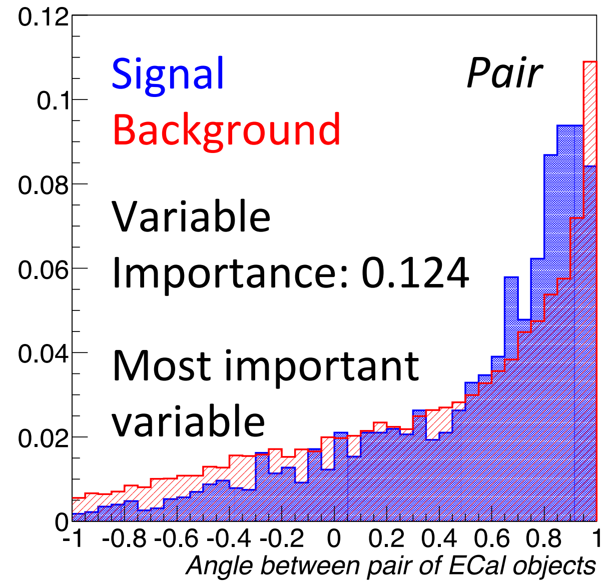
- Additional developments in the official ND280 Tracker muon selection may in time be adapted for use in this analysis.
  - See talk by *T. Duboyski*, Parallel Track 1, afternoon session 09/04, *"An expanded CCQE cross-section analysis at ND280"*.

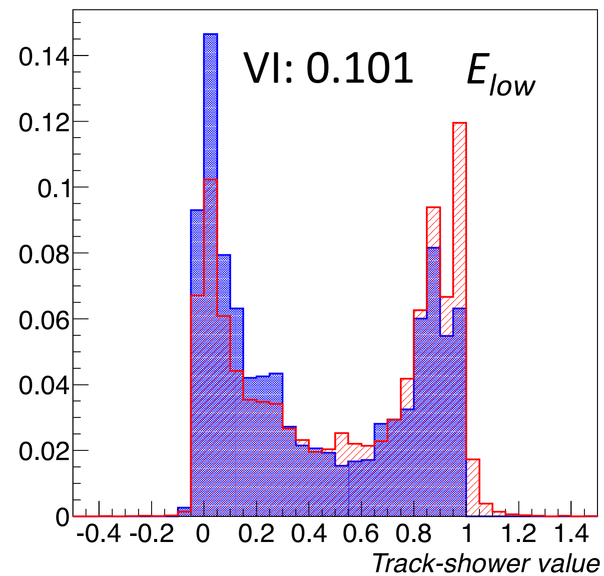
π^0 Selection

- Focus is now on the development of a Multivariate Data Analysis to maximise the power of available discriminating variables.
  - This has shown to be effective in equivalent Neutral Current π^0 analyses,
    - S. Short, IC and P. Guzowski, IC.
  - Machine learning classification system which evaluates the signal to background separation capacity of multiple input variables simultaneously.

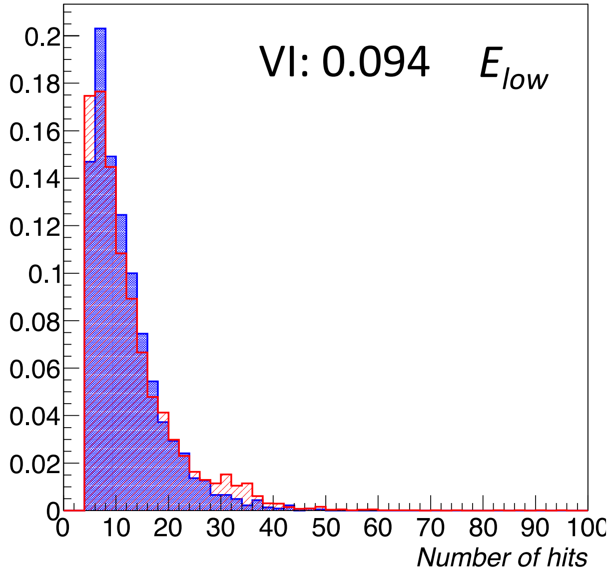
π^0 Selection

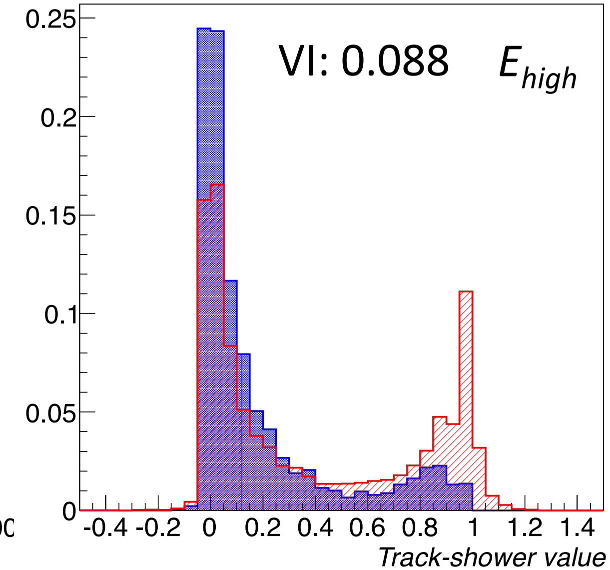
- Variables are defined for the higher and lower energy ECal candidate clusters and between each candidate pair.
  - Currently employing 14 separate input variables.
  - Many additional standard ECal cluster variables are already available.
  - Development of additional analysis specific variables is also underway.
  - With time an appropriate subset of effective input variables will be selected.

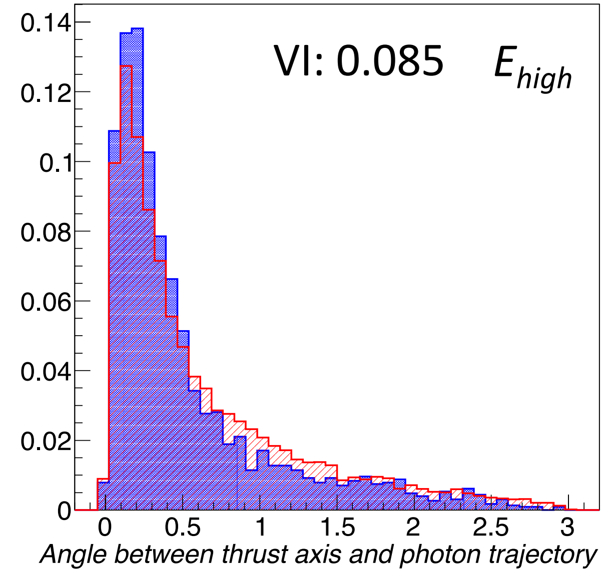


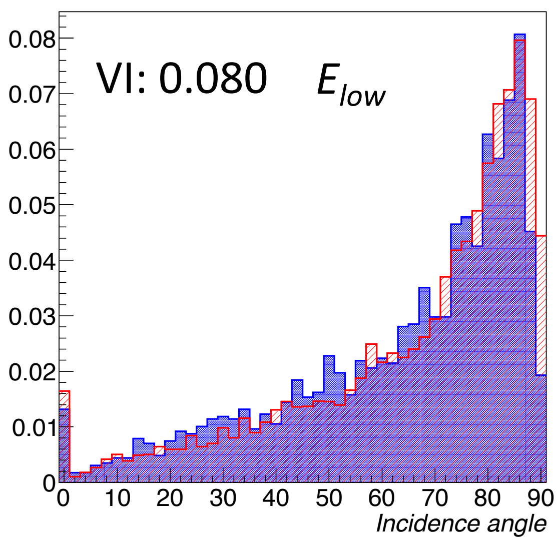


π^0 Selection

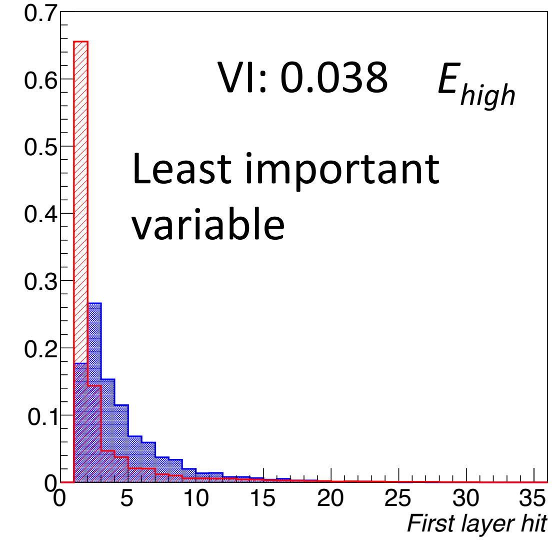






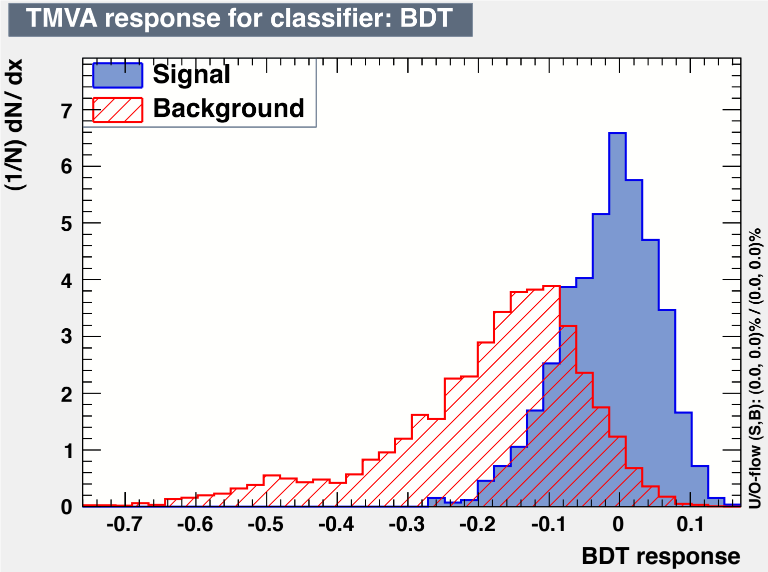


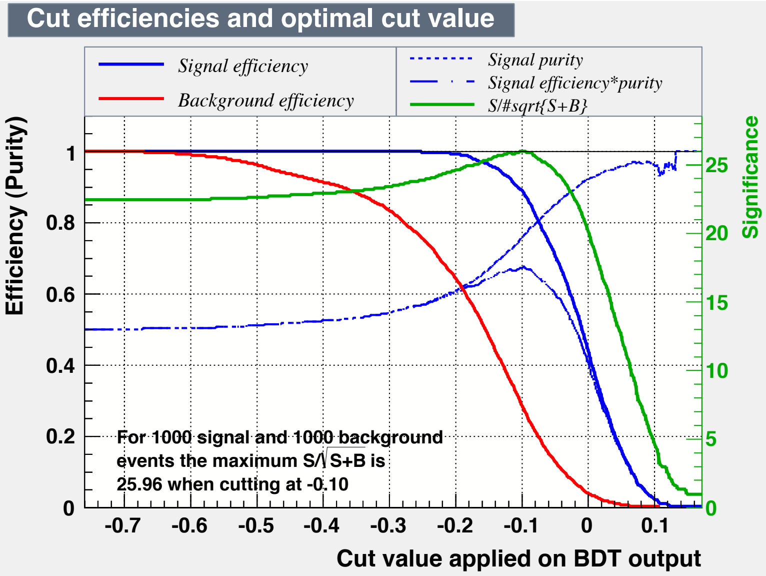
- *First layer hit E_{low}* : 0.075
- *Number of hits E_{high}* : 0.075
- *Thrust to trajectory angle E_{low}* : 0.053
- *Energy asymmetry Pair* : 0.049
- *Last layer hit E_{high}* : 0.048
- *Incidence angle E_{high}* : 0.045
- *Last layer hit E_{low}* : 0.040



π^0 Selection

- Even at this very early stage in the development of a MVA analysis the initial signal to background separation response looks promising.
  - Different MVA techniques have still to be tested.
  - Improved and new input variables can be developed.
  - Further separation of event topologies can be done.
- These should all provide further improvement to the selection.



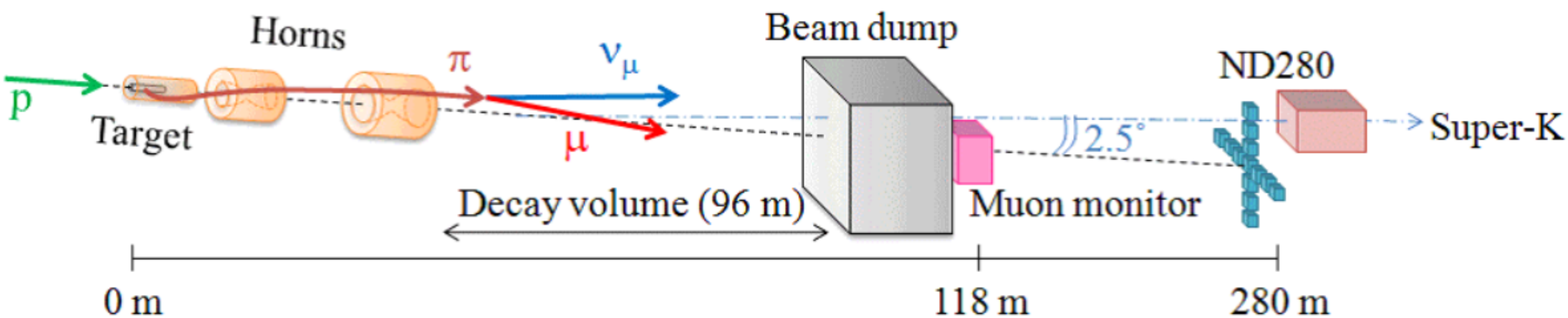


Conclusions

- This CC1π^0 analysis is making good progress in developing an effective event selection:
  - A robust muon selection has already been developed.
  - Consideration of techniques to reject events with associated charged pion production has begun.
  - The decision to move away from a cuts based π^0 decay photon selection has been taken.
  - Initial results with a MVA look promising whilst there is still much scope for improvement.

BACKUP SLIDES

Beam Production



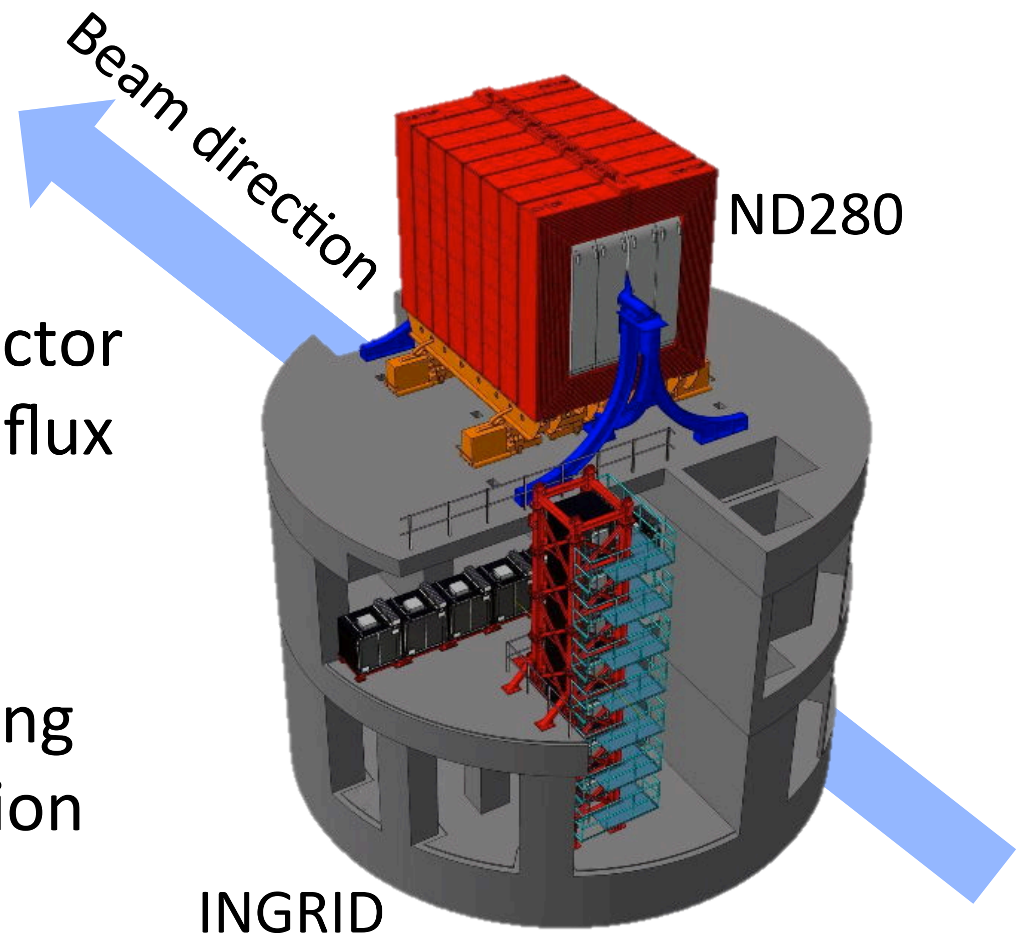
- Accelerated protons are impinged upon a graphite target.
- A flux of π mesons is produced, from which π^+ mesons are focused into a decay volume by magnetic horns.
- Neutrinos are then obtained through the decay:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

- This provides intense neutrino flux with an off-axis energy centred at 0.6 GeV.

Near Detector Complex

- The Near Detector complex house two detectors.
  - INGRID, on-axis detector for measuring beam flux and direction.
  - ND280, 2.5° off-axis detector for measuring beam flux, composition and cross-sections.



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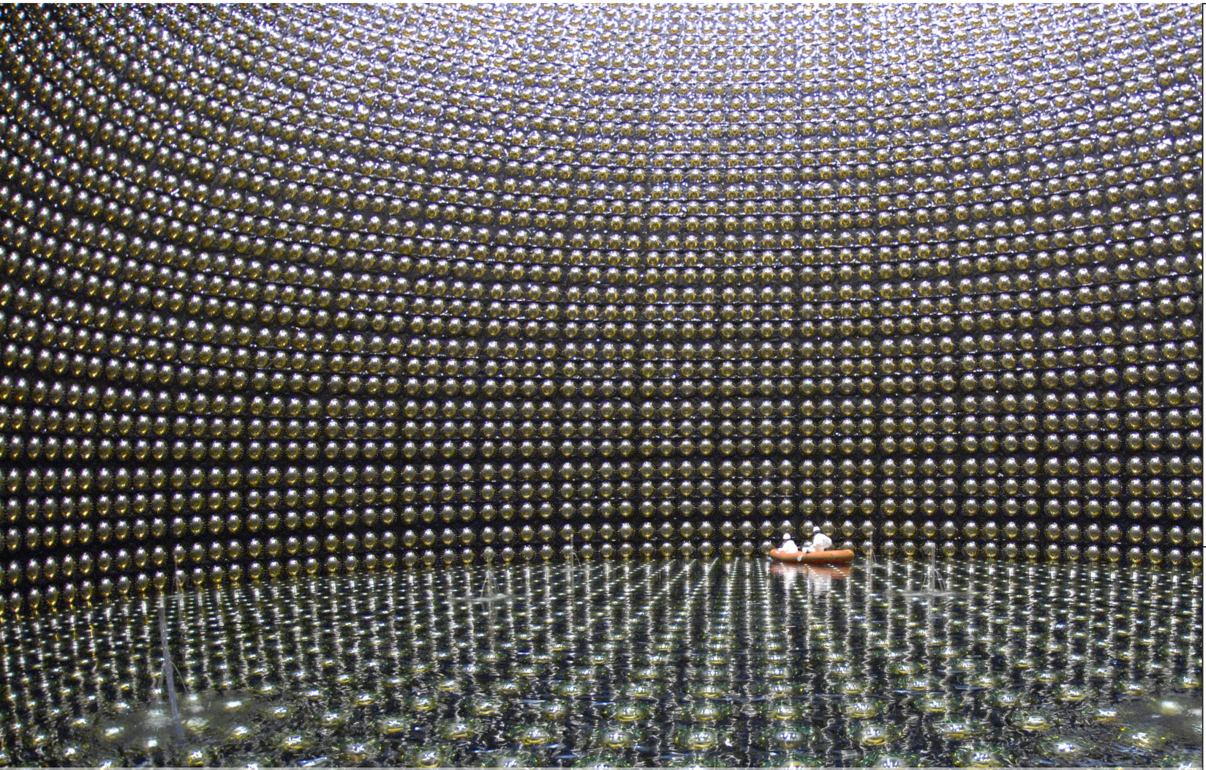
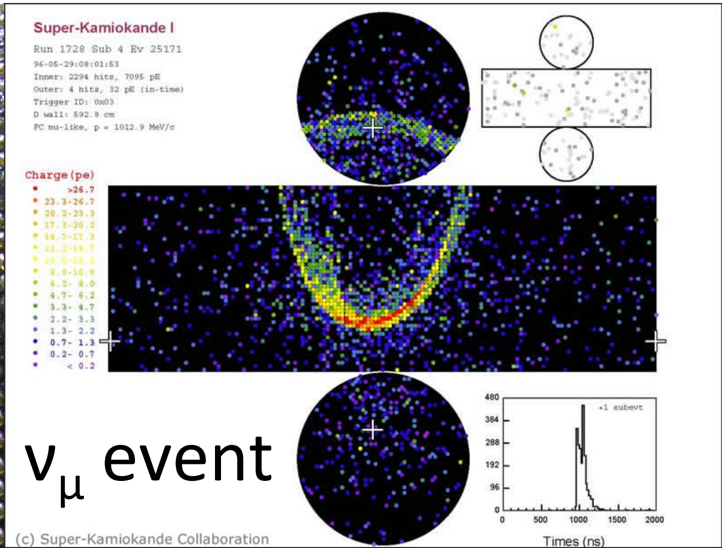
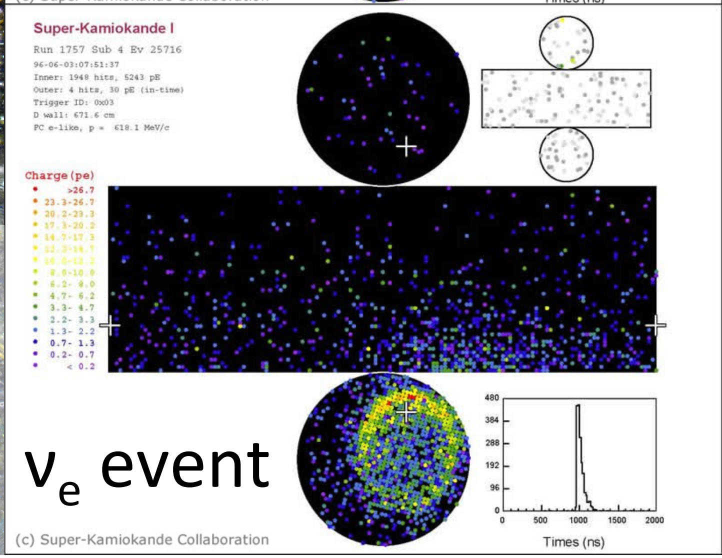
T2K

Super-Kamiokande Detector







- 50 kT (22.5 kT), water Cherenkov detector.
- Particle identification through ring morphology.

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T2K

Boosted Decision Tree

A *decision (regression) tree* (BDT)[29] is a binary tree structured classifier (regressor) similar to the one sketched in Fig. 18. Repeated left/right (yes/no) decisions are taken on one single variable at a time until a stop criterion is fulfilled. The phase space is split this way into many regions that are eventually classified as signal or background, depending on the majority of training events that end up in the final *leaf* node. In case of *regression trees*, each output node represents a specific value of the target variable.[30] The boosting (see Sec. 7) of a decision (regression) tree extends this concept from one tree to several trees which form a *forest*. The trees are derived from the same training ensemble by reweighting events, and are finally combined into a single classifier (regressor) which is given by a (weighted) average of the individual decision (regression) trees. Boosting stabilizes the response of the decision trees with respect to fluctuations in the training sample and is able to considerably enhance the performance w.r.t. a single tree. In the following, we will use the term *decision tree* for both, *decision-* and *regression trees* and we refer to regression trees only if both types are treated differently.

A ranking of the BDT input variables is derived by counting how often the variables are used to split decision tree nodes, and by weighting each split occurrence by the separation gain-squared it has achieved and by the number of events in the node [30]. This measure of the variable importance can be used for a single decision tree as well as for a forest.