An expanded CCQE cross-section analysis at ND280

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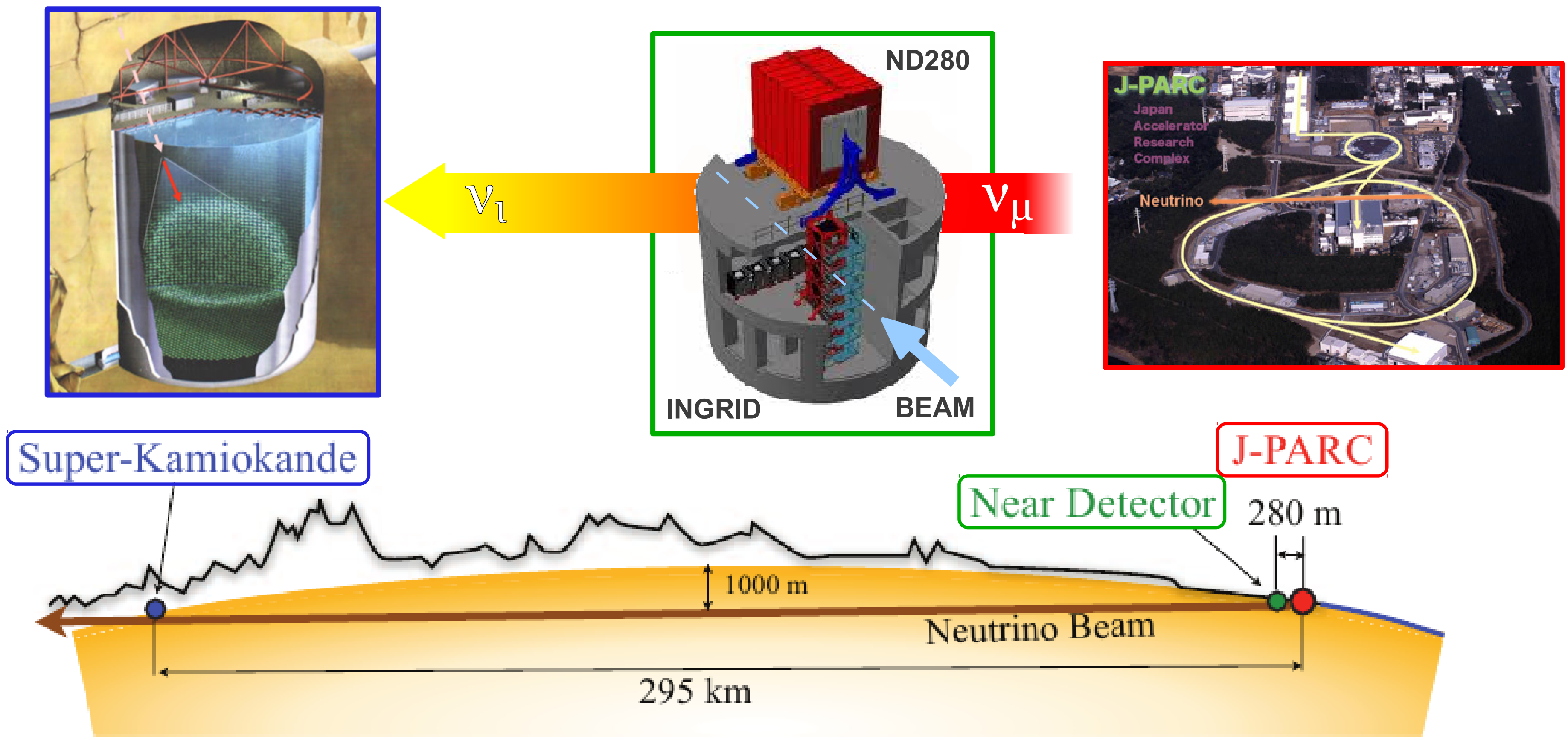
IOP HEPP, 9th April 2013

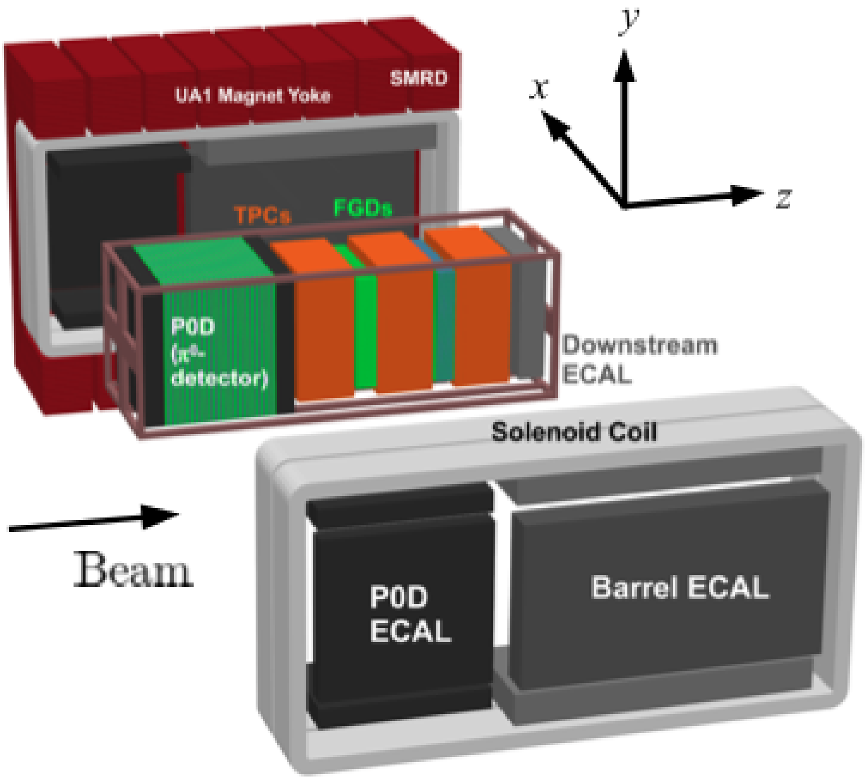
The T2K Experiment



Designed to study neutrino oscillations;

θ_{23}: ν_μ disappearance ($\nu_\mu \rightarrow \nu_\mu$)
θ_{13}: ν_e appearance ($\nu_\mu \rightarrow \nu_e$)

The T2K Experiment

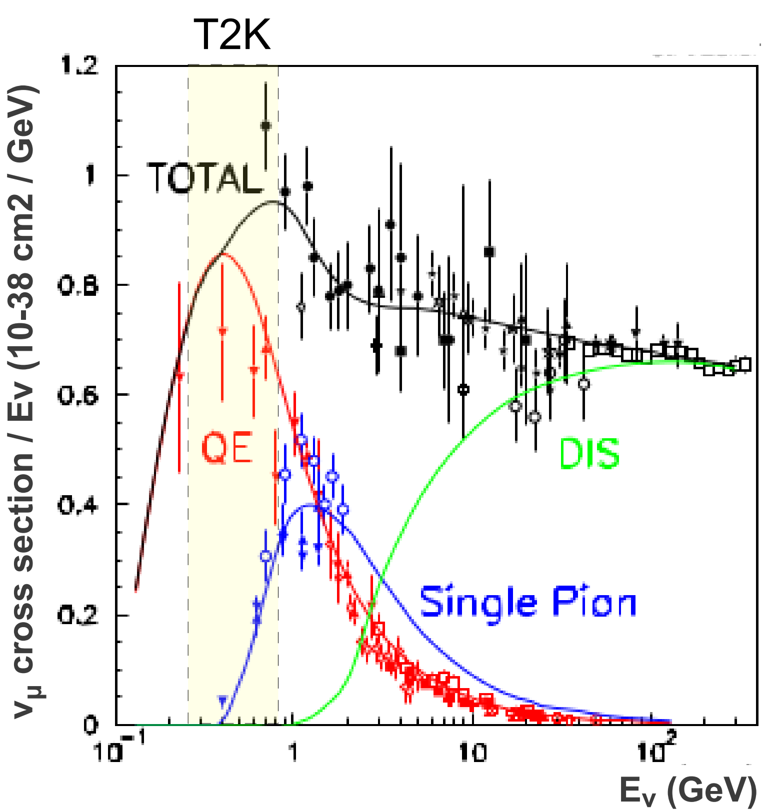


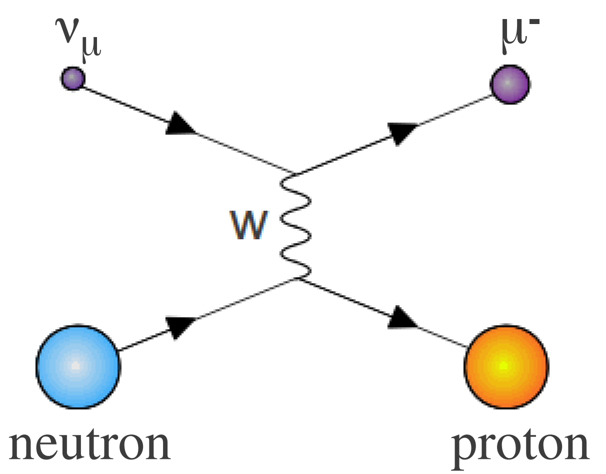
Off-axis near detector: ND280

- Sub-detectors used in this talk;
  - **F**ine **G**rained **D**etectors (**FGD**s)
  - **T**ime **P**rojection **C**hambers (**TPC**s)
  - **E**lectromagnetic **Cal**orimeters (**ECal**s)
  - **S**ide **M**uon **R**ange **D**etector (**SMRD**)
- Magnet from CERN UA1 experiment (0.2 T).
- Multi-purpose detector.

Cross-Sections

- Measured neutrino rate = flux × cross-section.
- Oscillations measured by flux difference between ND280 and Super-K detectors.
- Calculating Flux → accurate cross-sections vital.





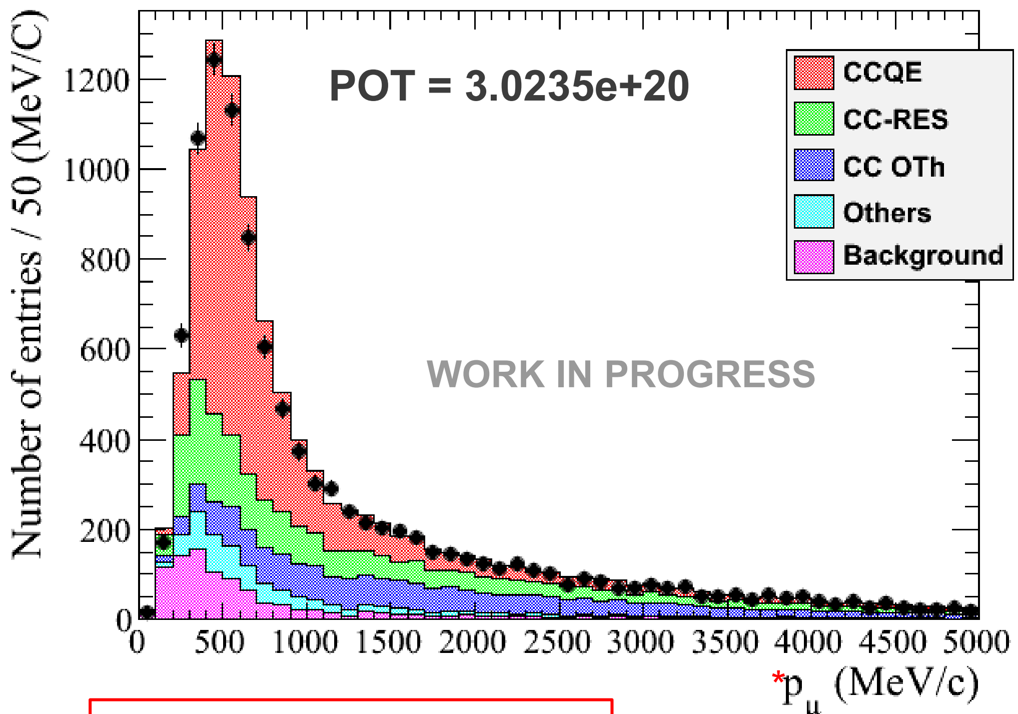
Charged Current Quasi-Elastic (CCQE) interaction

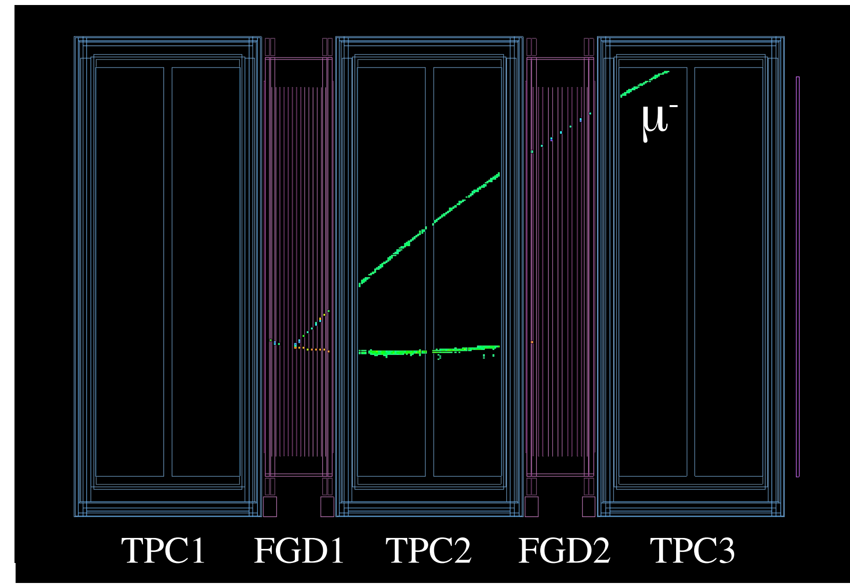
ν_μ cross-section:

- Sparse data in sub-GeV range (T2K).
- CCQE interactions dominate here.
- ND280 selection used to constrain flux & cross sections for both ν_e appearance & ν_μ disappearance.

Standard Selection

Charge Current (CC) ν_μ inclusive selection at ND280





Example ν_μ CC inclusive interaction in ND280

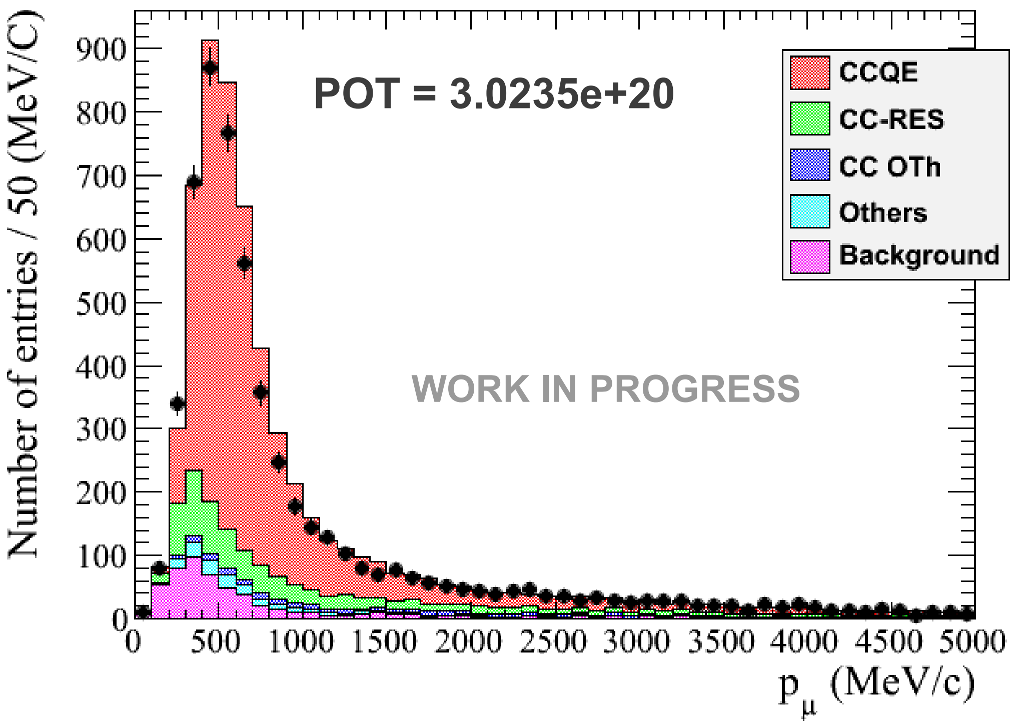
*p_μ = muon momentum

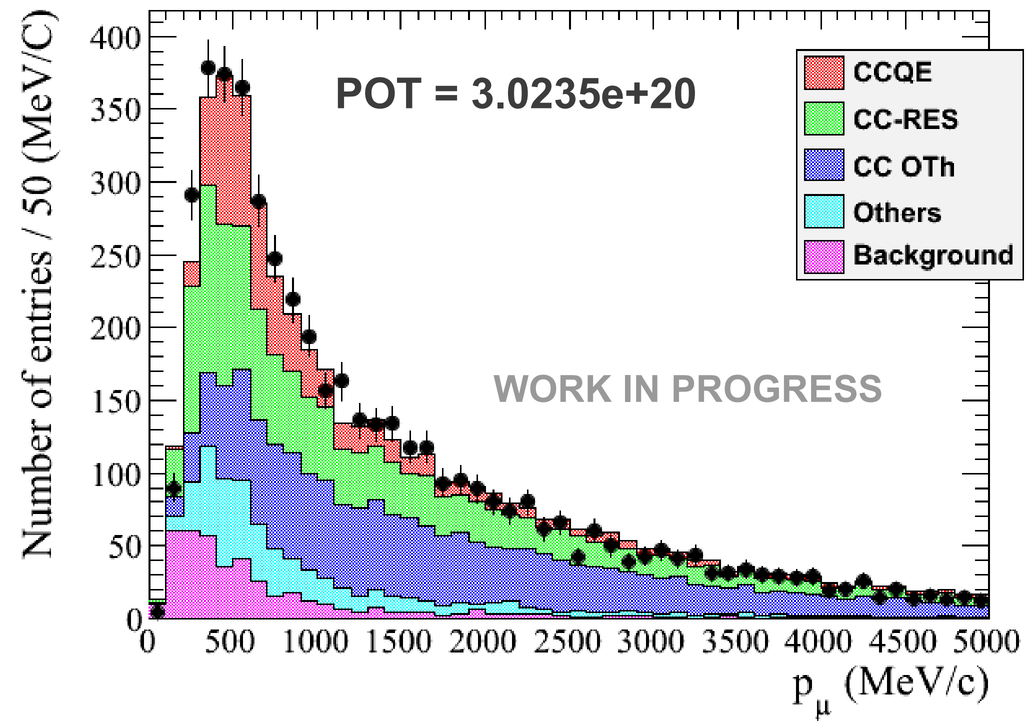
Base selection, looking for signal muon

- Highest momentum negatively charged track in TPC2
- Good TPC2 track quality
- Forward-going with vertex in FGD1 fiducial volume
- Energy loss consistent with muon

Standard Selection

CCQE and CCnQE (CC non-QE) selections at ND280





CCQE (signal)
Only one FGD1-TPC2 track
No Michel electron in FGD1

Split CC inclusive selection

CCnQE (background)
Everything else

Signal and background selections fitted to constrain flux prediction at Super-K.

Expanded Selection

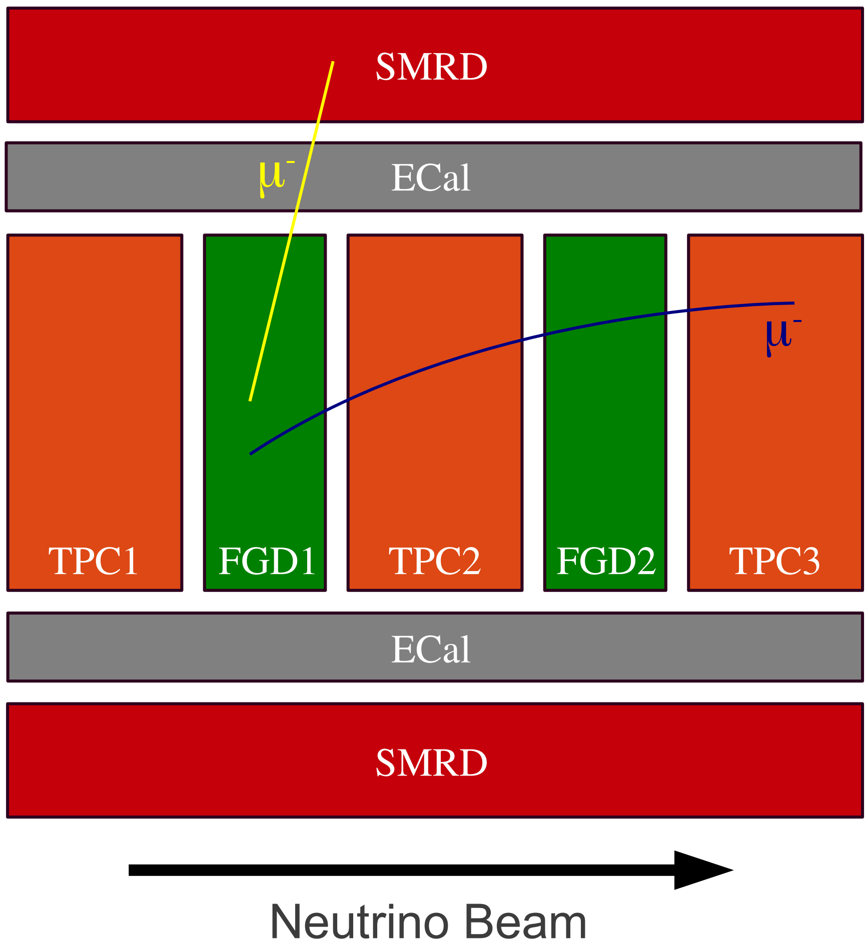
<u>Standard Selection</u>

- Uses FGD & TPC sub-detectors.
- Very forward going TPC dependent selection.

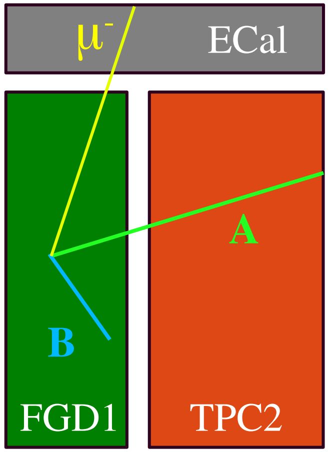
Unused data → can build selection separate from standard.

<u>High Angle Selection</u>

- Look for FGD-ECal going muons not included in standard selection.
  - Recover unused events → more statistics.
  - Higher angle (θ) & lower momentum (p) events → increased phase-space, p-θ.



Expanded Selection



Multi-sample selection

1-Track – 1 FGD1-ECal forward going muon.

2-Track **A** – 1-Track + secondary proton track in TPC2.

2-Track **B** – 1-Track + secondary proton track stopping in FGD1.

If muon traverses TPC2, require it fails standard selection track quality cut → avoid selection overlap.

Selection		Events*	CCQE Purity (%)	CCQE Efficiency (%)
High Angle	1-Track	271	63.63	6.9
	2-Track **A**	89	66.92	2.3
	2-Track **B**	114	77.55	2.9
High Angle		474	67.05	12.1
Standard		1936	71.16	43.7
High Angle + Standard		2410	70.31	55.8

Signal (S) = true CCQE

Background (B) = true CCnQE

$$\text{Purity} = \frac{S}{S+B}$$

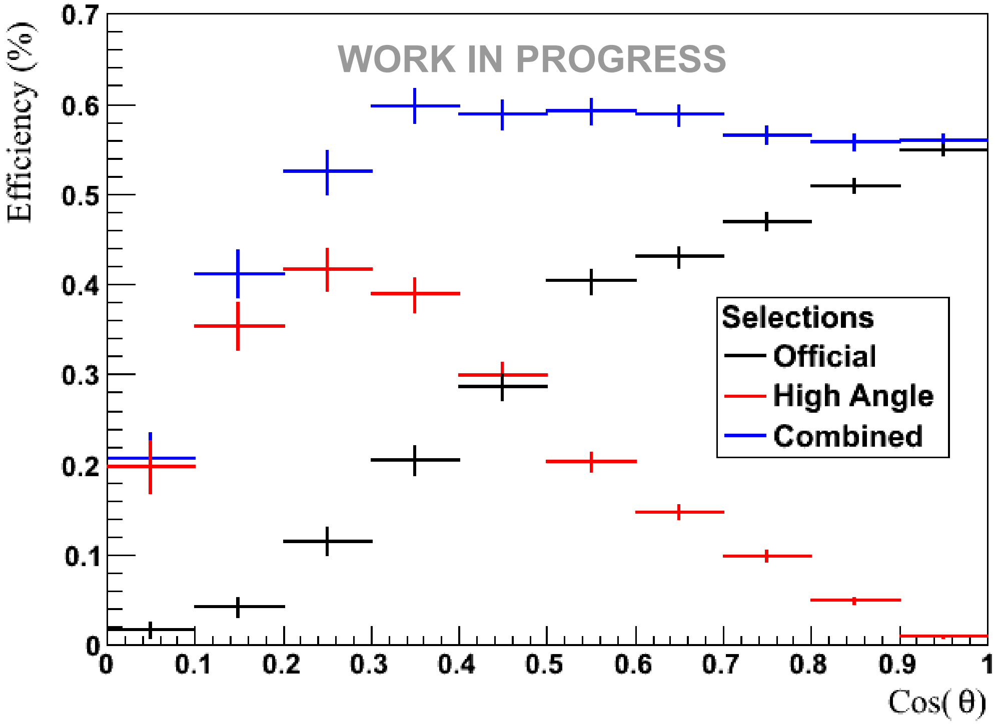
$$\text{Efficiency} = \frac{S\ (\text{post-selection})}{S\ (\text{pre-selection})}$$

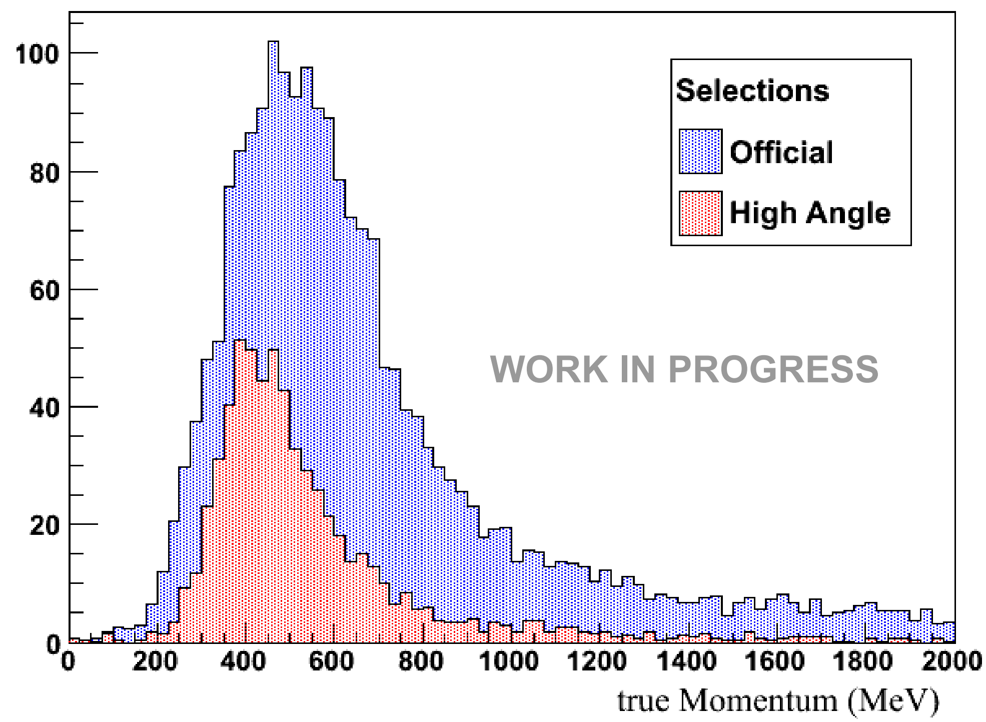
* based on data taken up to March 2012

Combined results

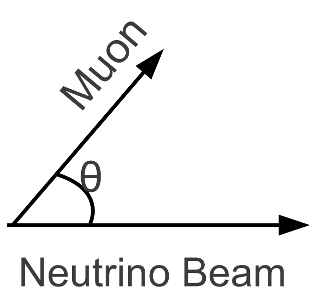
- 12.1% increase in efficiency (~25% gain in statistics).
- Slight decrease in purity → selection not finalised.

Selection Results



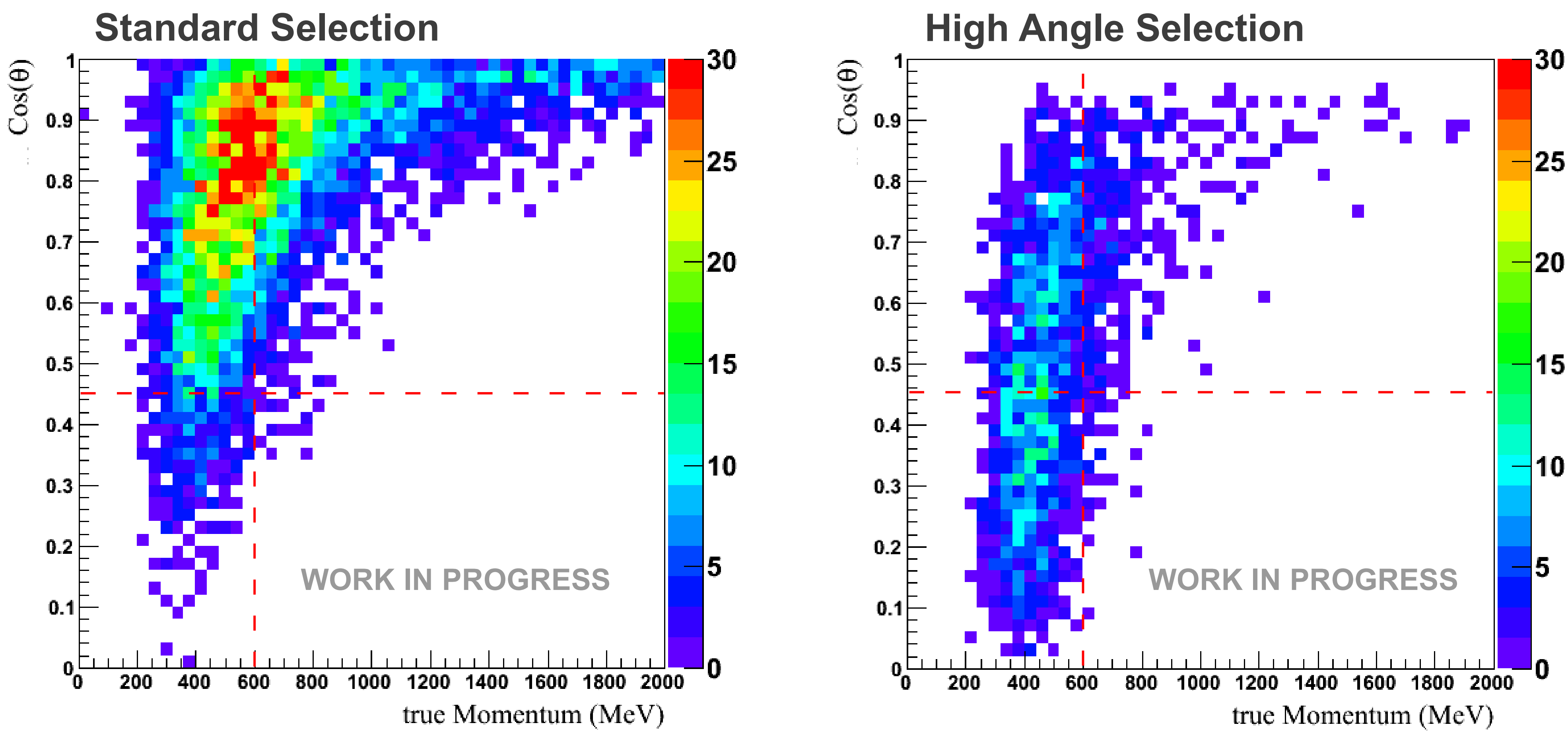


- Early results show good recovery of higher angle events → lower cos(θ).
- Reconstruction issues for very high angle tracks.



- High Angle - momentum
  - Narrower spectrum
  - Lower energy peak
  - Relatively small high energy tail

Expanded Selection



– – – guidelines only, placed to highlight the main differences in selections

→ large gain at low momentum / high angle (bottom left).

Range Momentum

Getting Momentum

Standard Selection

- TPC → good momentum reconstruction through track curvature.

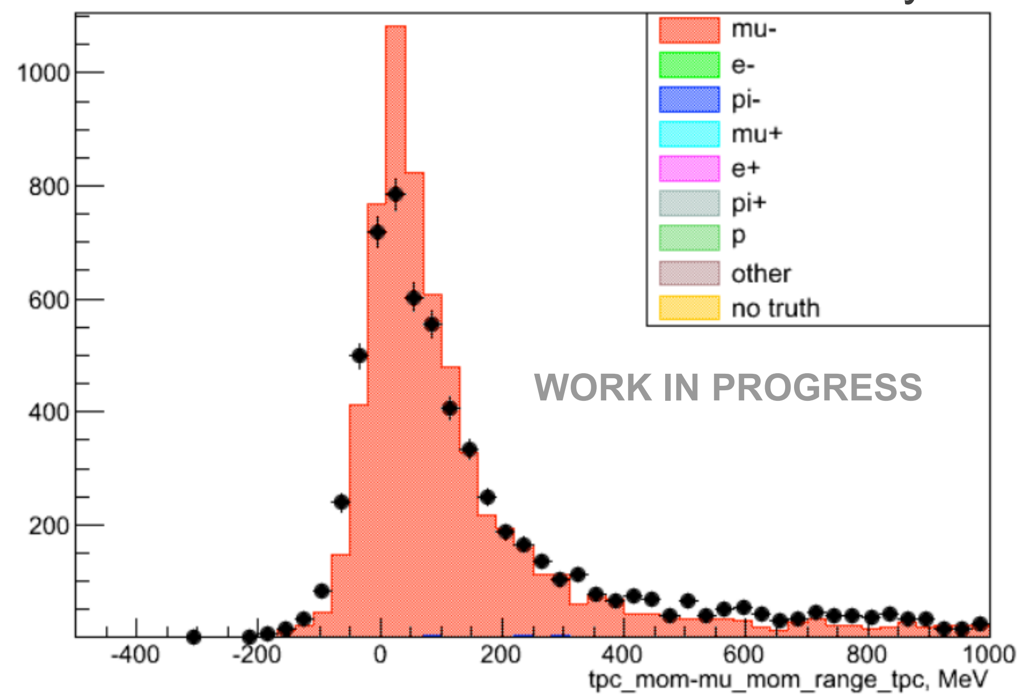
High Angle Selection

- Lack of TPC in most events.
- high angle muons → little to no curvature.
- Have FGD1, ECals (+SMRD) for reconstruction.

Solution:

- For a given particle type stopping in a sub-detector, estimate momentum by range.
- Tuned with Monte-Carlo / data.
- Work in progress - optimisation ongoing.

A.Izmaylov



'TPC momentum – range momentum' for selected muons stopping in the ECal.

Summary

High Angle Selection

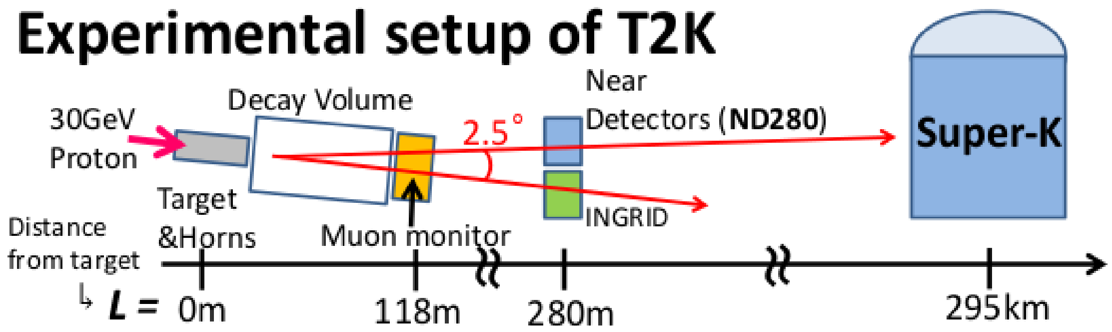
- CCQE FGD-ECal muons → different events to standard selection.
- No TPC → implementing alternative momentum estimate method.
- Adding statistics & new phase-space.

Cross-section

- Currently sparse data in sub-GeV range where T2K operates.
- T2K off-axis near detector ND280 can provide new measurements.
- Expanded selection input to fits → better results.

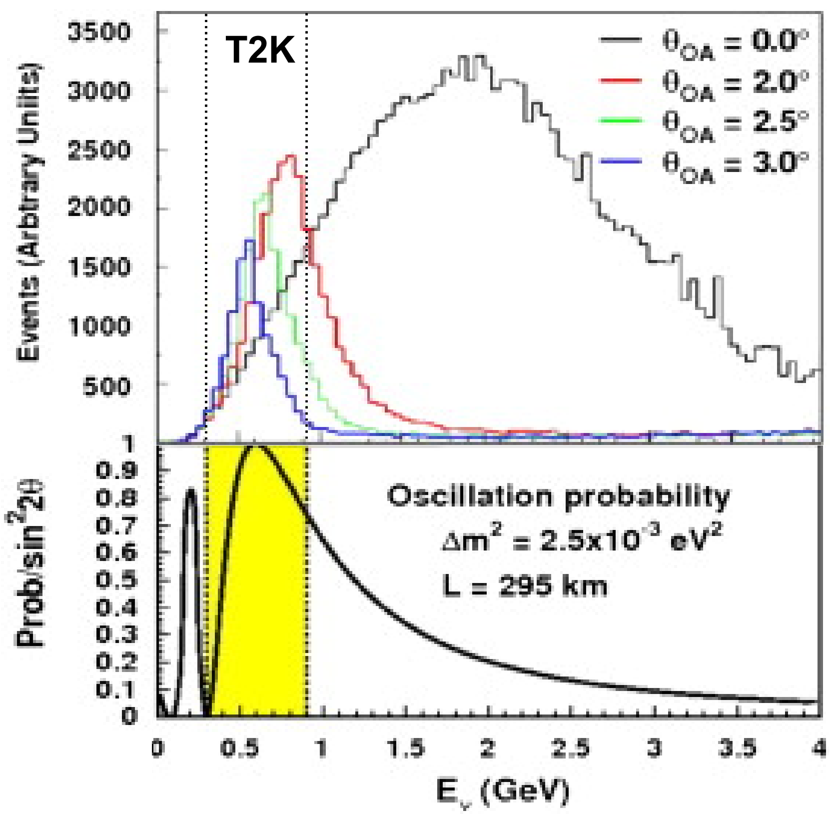
BACKUPS

The T2K Experiment



T2K Neutrino Beam

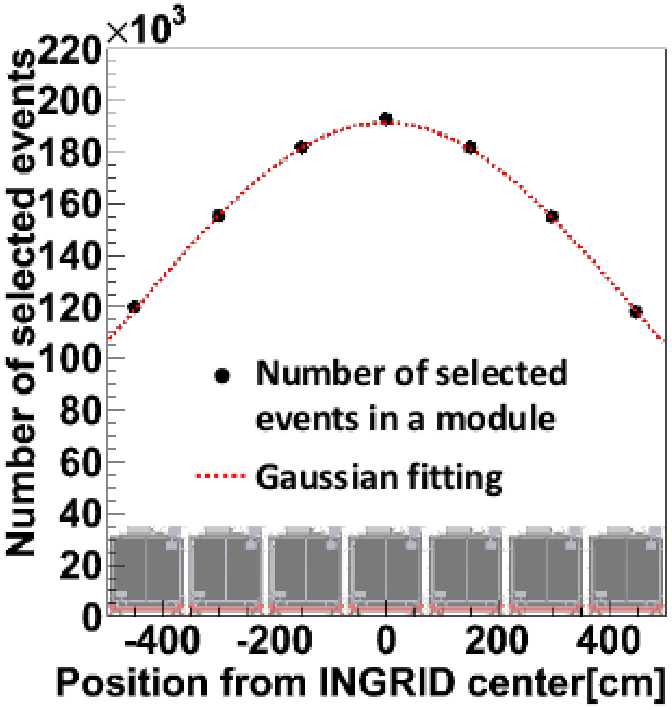
- ν_μ beam produced from 30 GeV protons on graphite target.
- Beam 2.5° off-axis to ND280 and Super-K.
- Creates narrow energy spectrum at second oscillation maximum → maximise sensitivity.
- Suppressed high energy tail → reduced backgrounds.

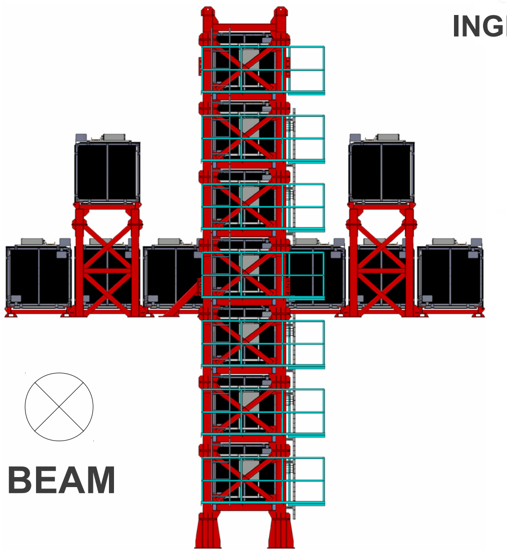


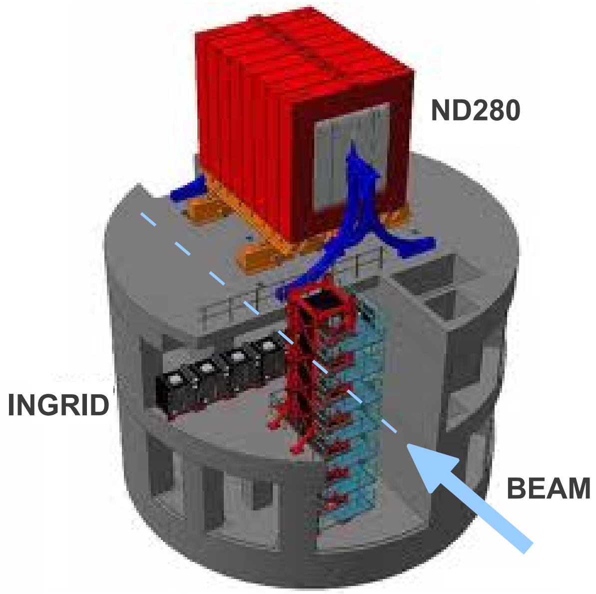
The T2K Experiment

On-axis near detector: INGRID

- Determines ν beam flux, profile and direction.
  - off-axis design requires high precision beam measurement.

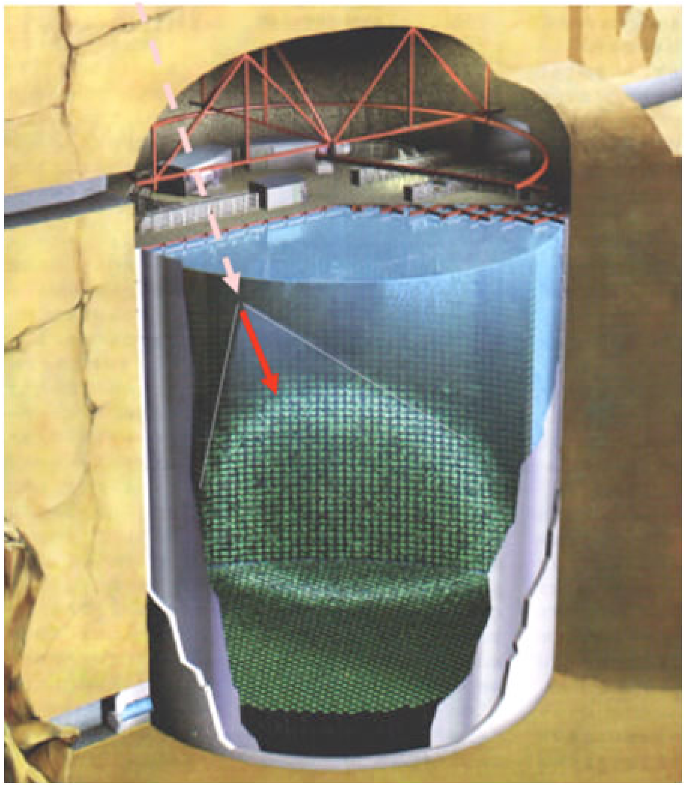


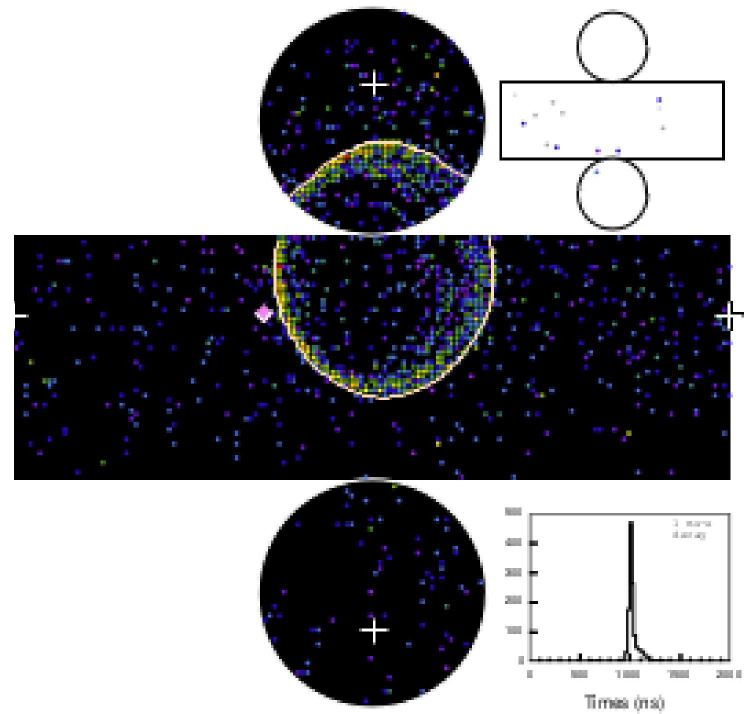




The T2K Experiment

Off-axis far detector: Super-K





- A 22.5 kton fiducial mass Cherenkov detector.
- Determines ν_μ or ν_e events from ring shape topology.

Cross-Sections

- Uncertainties on cross-section parameters propagate to final results → improve models & decrease uncertainties with new data (new phase-space).
- E.g. CCQE cross-section → large uncertainty on parameter axial mass, m_A.

Experiment	Target	Energy Range (GeV)	m_A $(GeV/c)^2$	Reference
World Average	Deuterium	0.7-20	1.02 ± 0.03	arXiv:0708.1946 [hep-ex]
MiniBooNE	Carbon	few-GeV	1.35 ± 0.17	arXiv:1007.4730 [hep-ex]
MINOS	Carbon	few-GeV	1.19 ± 0.17	M. Dorman, AIP Conf. Proc.1189(2009) 133
NOMAD	Carbon	4 - 100	1.05 ± 0.06	arXiv:0812.4543 [hep-ex]
K2K SciFi	Oxygen	few-GeV	1.20 ± 0.12	arXiv:hep-ex/0603034
K2K SciBar	Carbon	few-GeV	1.14 ± 0.10	arXiv:1107.3400 [hep-ex]

Axial mass (m_A) measurements from previous accelerator experiments.

- Inconsistent results & sparse low energy data → large uncertainty.
- T2K provides new input;
  - Low energy range (off-axis design)
  - Multiple target materials (ND280)

Systematics

What needs evaluating

- Efficiency - selection needs finalising.
- Momentum Resolution - momentum-by-range.
- Angular Reconstruction - especially at very high angles.
- Alignment/matching between detectors - potentially 4 detectors for a given track (FGD-TPC-ECal-SMRD).
- Particle Identification (PID) - new variables (FGD, ECal).
- Magnetic Field Effects - expect minimal for this selection.

Overlap with official selection

- Michel Election Tagging.
- Backgrounds - cosmic rays, naturally higher angle events.
- Out-of-fiducial volume backgrounds - variety of sources.