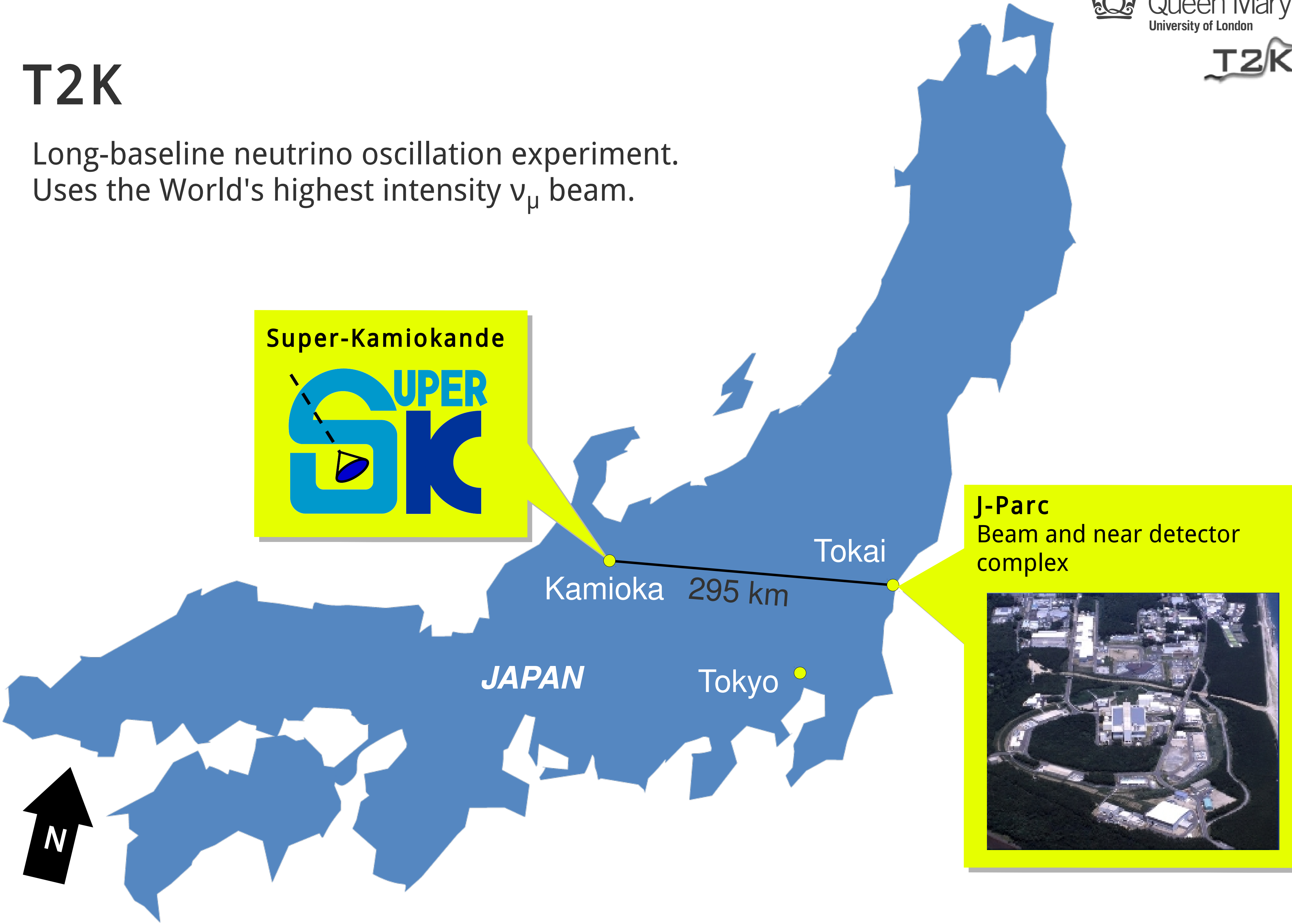
T2K ν_μ Disappearance at Super-Kamiokande

IOP NPPD Conference 4th April '11 - *Alex Hyndman*

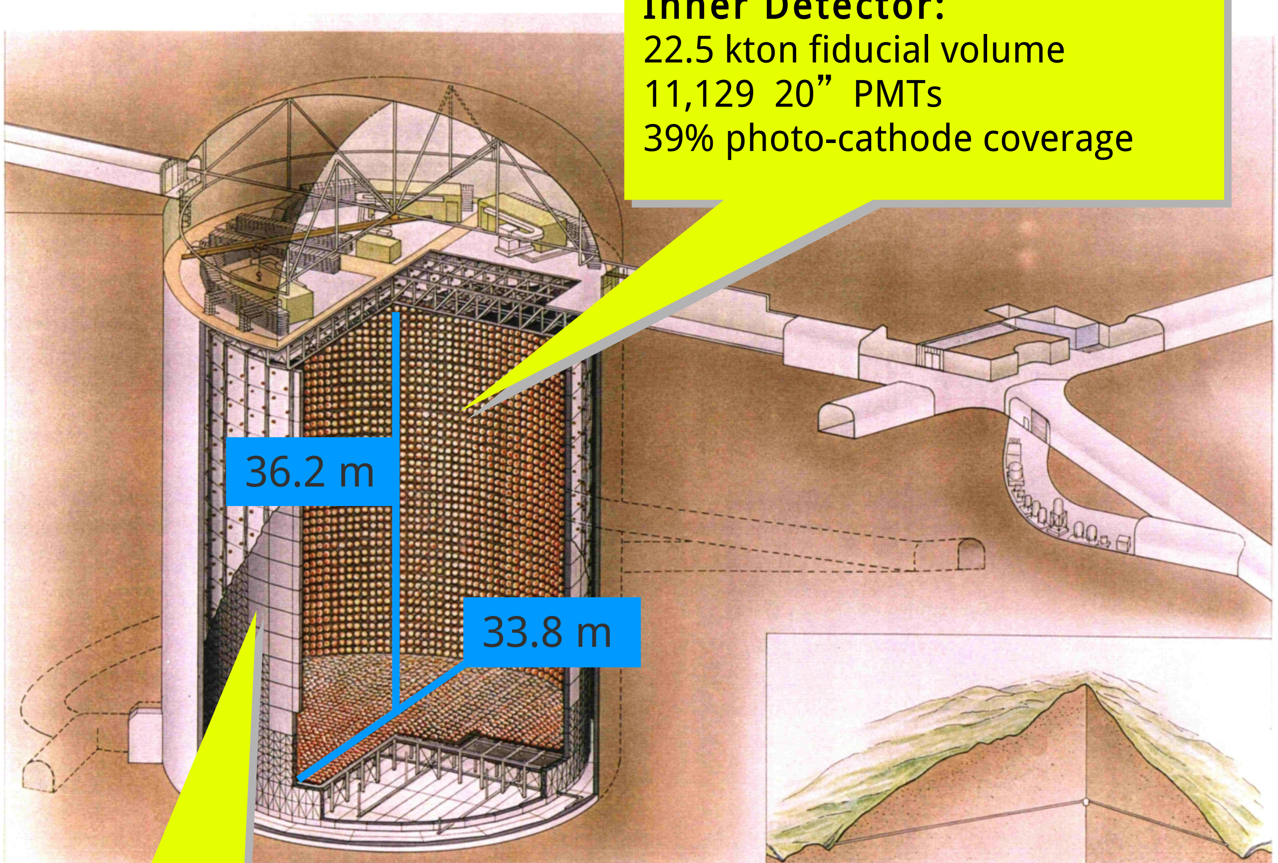
- Neutrino oscillation parameters θ_{23} and Δm^2_{23} are dominant cause of ν_μ disappearance at T2K far detector Super-Kamiokande.
- This talk looks at how we can measure this disappearance and the results from the first period of T2K running.

T2K

Long-baseline neutrino oscillation experiment.
Uses the World's highest intensity ν_μ beam.



Super-Kamiokande (SK)



50 kton water Cherenkov detector.

Located in a drive-in Zinc mine near Kamioka.

1000 m rock overburden (2700 m.w.e).

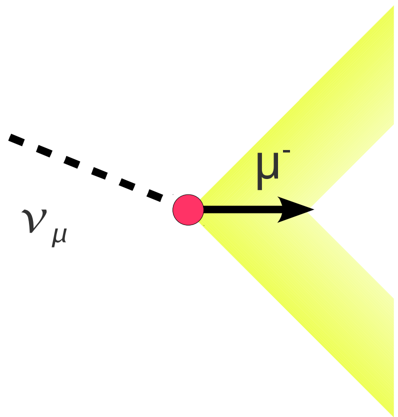
Water filled cavern divided into a cylindrical inner detector (ID) and outer detector (OD).

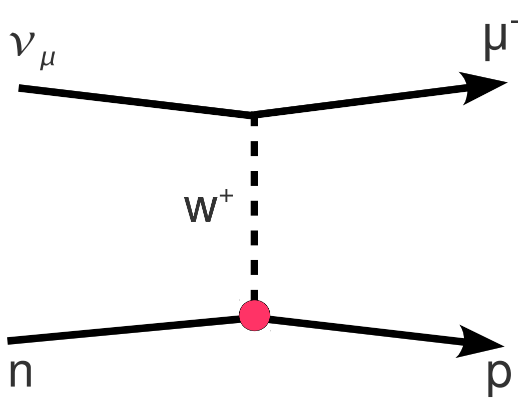
ID & OD optically separated.

Electronics updated in 2006 (SK-IV). Continuous data taking now possible.

SK Events

- SK detects neutrino interactions via Cherenkov radiation produced by outgoing charged particles.



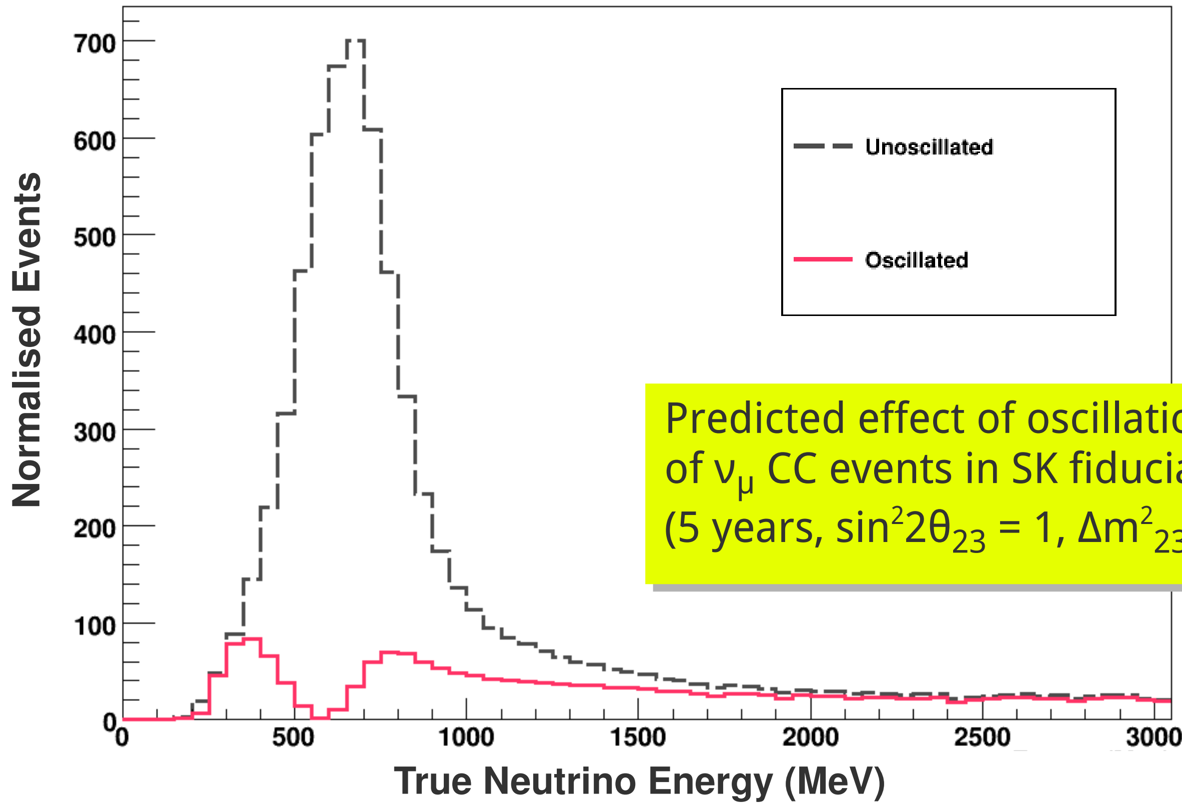


- Timing, hit pattern and energy are recorded and are used to reconstruct the interaction.
- Most important interaction in the T2K energy regime for ν_μ disappearance measurement is charge current quasi-elastic (CCQE) which is taken as our signal.

ν_μ Oscillation

- The dominant process for the T2K baseline and energy (L/E) is $\nu_\mu \rightarrow \nu_\tau$
- It is sufficient to use a 2 flavour oscillation formula:

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2 2\theta \sin^2 \left(\frac{1.27 \Delta m^2 (eV^2) L(km)}{E(GeV)} \right)$$



Predicted effect of oscillation on the number of ν_μ CC events in SK fiducial volume (5 years, $\sin^2 2\theta_{23} = 1$, $\Delta m^2_{23} = 0.0024$ eV)

Event Selection

- Want to select CCQE events.
- Following cuts applied:

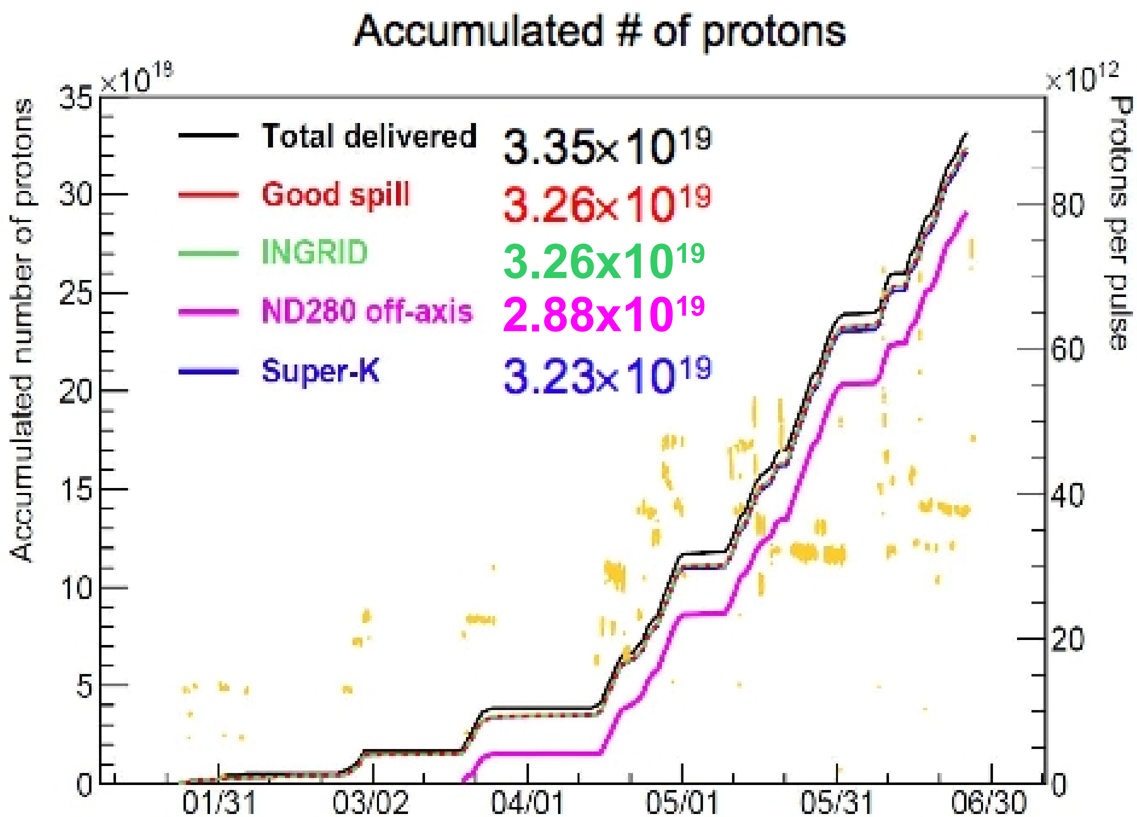
Fully Contained:	only small hit clusters in outer detector
Fiducial Volume:	reconstructed vertex is more than 2 metres from the nearest wall
Visible Energy:	remove low energy events
1 Ring:	only 1 ring reconstructed
μ-like:	ring is μ-like

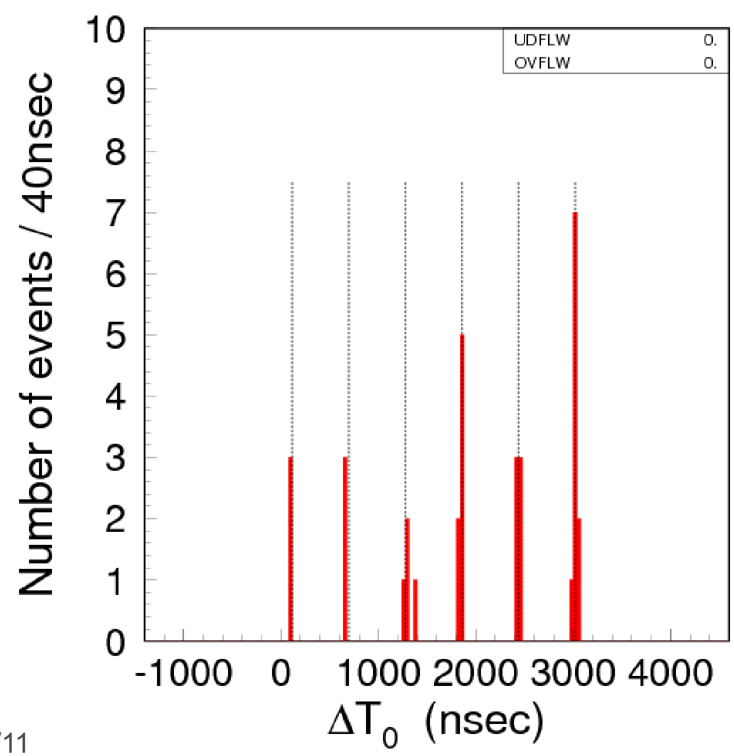
Basic usable event selection. (Fully Contained, Fiducial Volume, Visible Energy)

For high Charged Current (CC) yield and low Neutral Current. Single μ-like ring corresponds to the outgoing lepton. (1 Ring, μ-like)

Data (Run1)

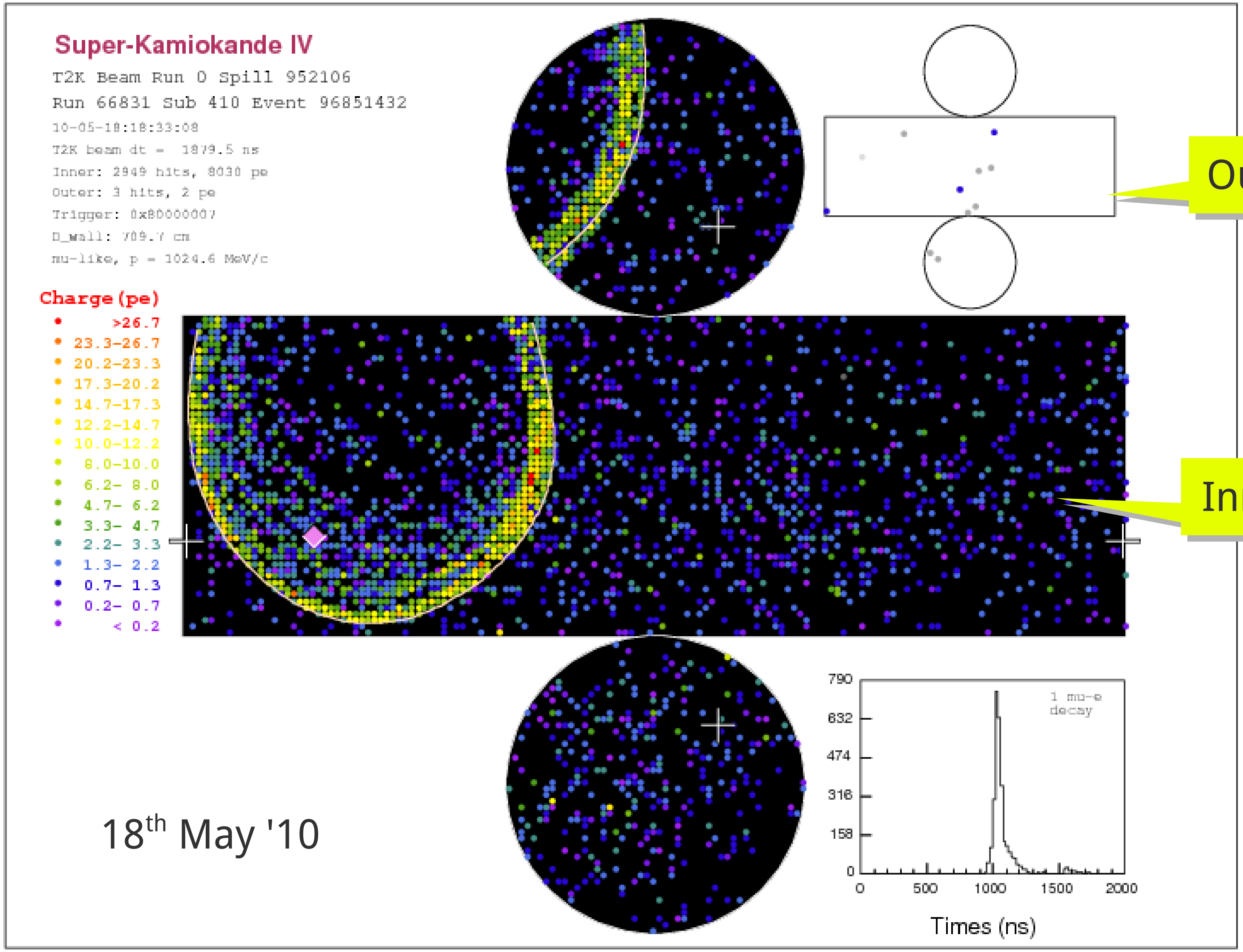
- Run period Jan – Jun 2010
- SK physics efficiency >99%





Bunch timing structure of fully contained events

1st μ-like Single Ring Event



18th May '10

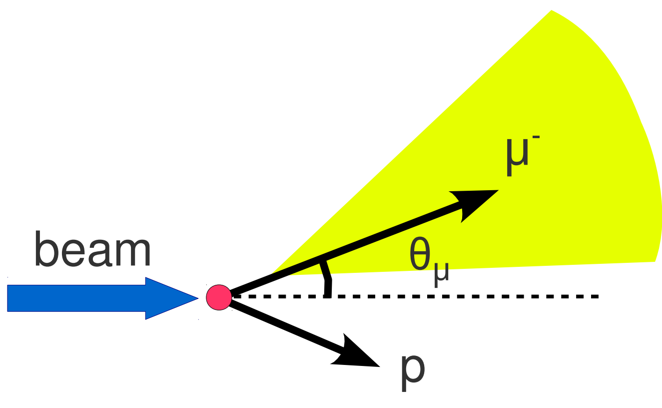
1st Results (Run1)

	Data	MC		BG (12μs window)
		No oscillation	Oscillation $\Delta m^2 = 2.4 \times 10^{-3}$ (eV^2) $\sin^2 2\theta_{23} = 1.0$	
Fully-Contained	33	54.5	24.6	0.0094
Fiducial Volume, Evis > 30MeV	23	36.8	16.7	0.0011
Single-ring μ-like	8	24.6	7.2	-

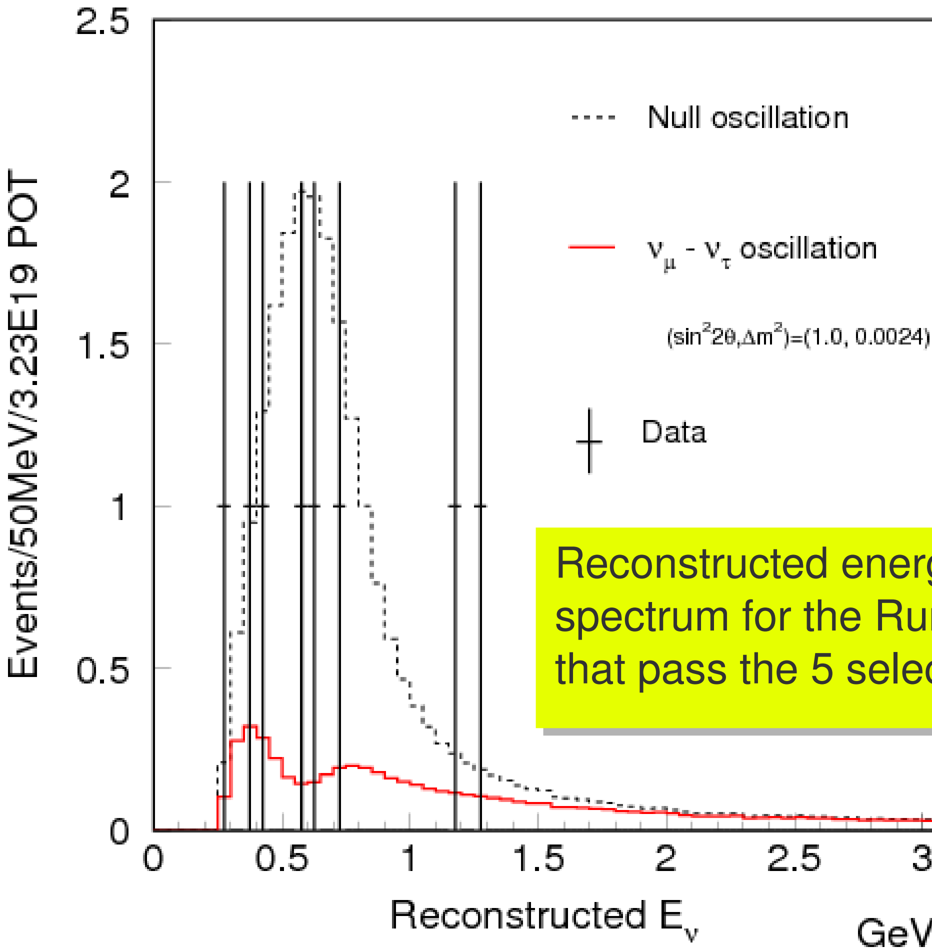
ν_μ selection

Energy Spectrum (Run1)

We can reconstruct the energy of the events assuming a CCQE interaction.



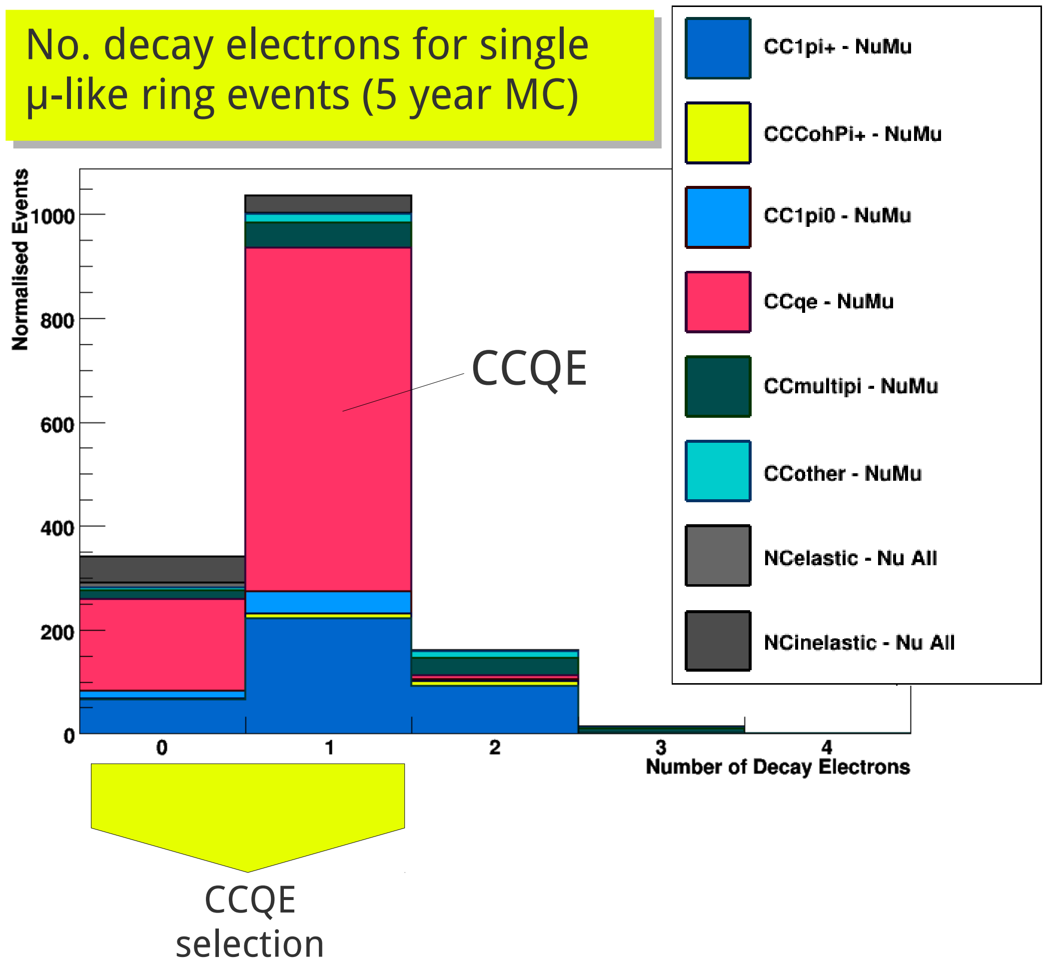
$$E_\nu \approx \frac{2 m_n E_\mu - m_\mu^2}{2(m_n - E_\mu + |\vec{p}_\mu| \cos\theta_{\mu\nu})}$$



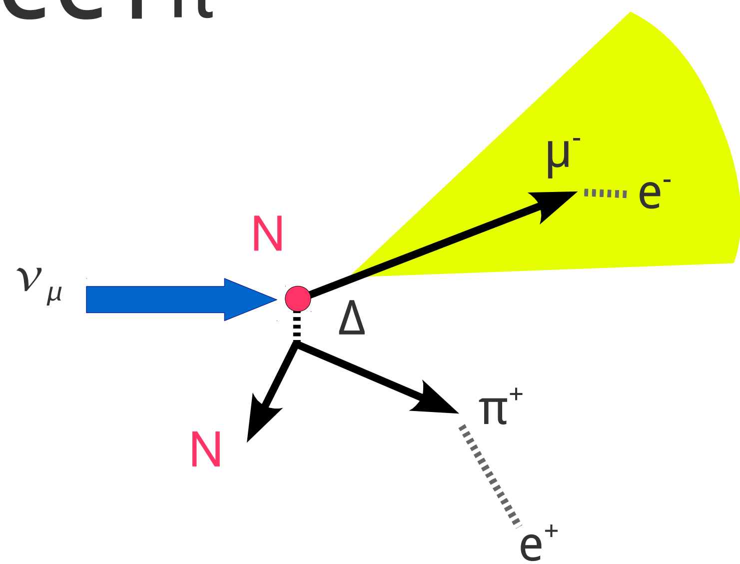
Reconstructed energy spectrum for the Run1 events that pass the 5 selection cuts

Improving the Selection

- As statistics improve, we can apply more rigorous cuts to reduce our backgrounds.
- The following expectations are for the a nominal **5 year** running of T2K (8.33x10^{21} POT).
- First we look for **decay electrons** from the outgoing muon, which produce delayed Cherenkov radiation in the tank.
- A limit of 1 decay electron purifies the CCQE sample (50% → 55%)
- Signal efficiency drop 1% (93% → 92%)

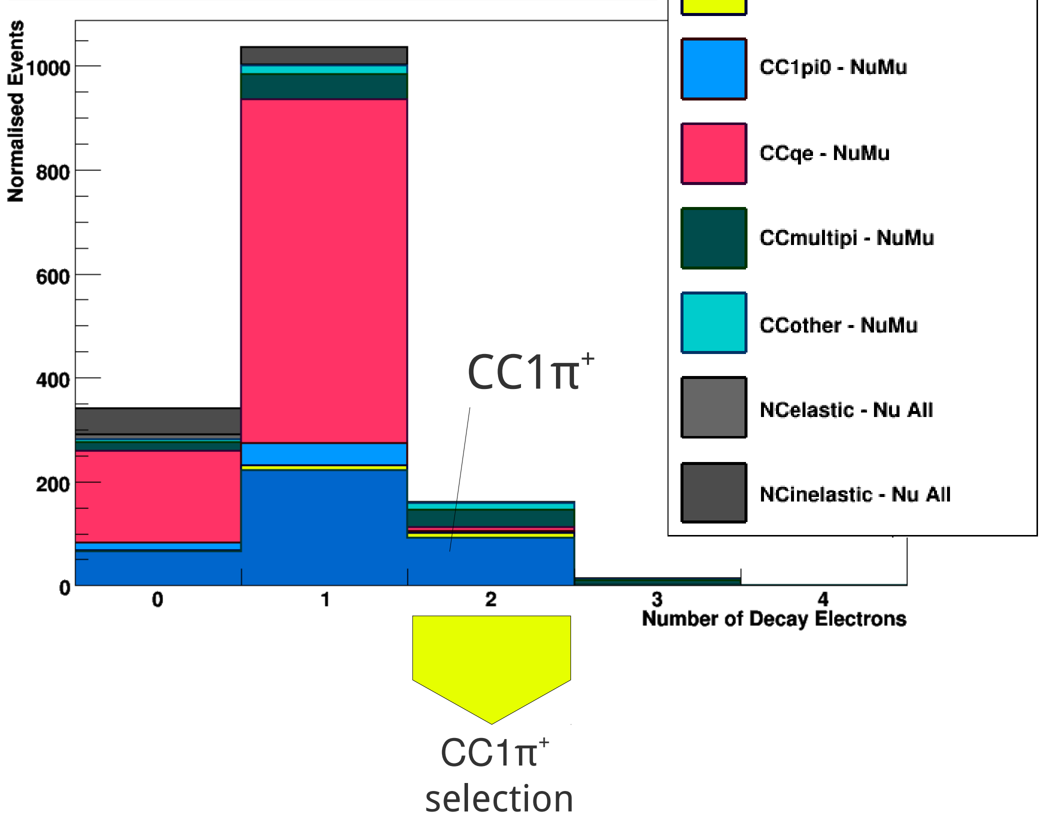


CC1π⁺



- Don't want to lose cut events.
- Events with **2 decay electrons** have a high CC1π⁺ purity.
- Can add these back into the selection if we **reconstruct energy appropriately**.
- Use QE formula but with a recoil delta instead of a proton.

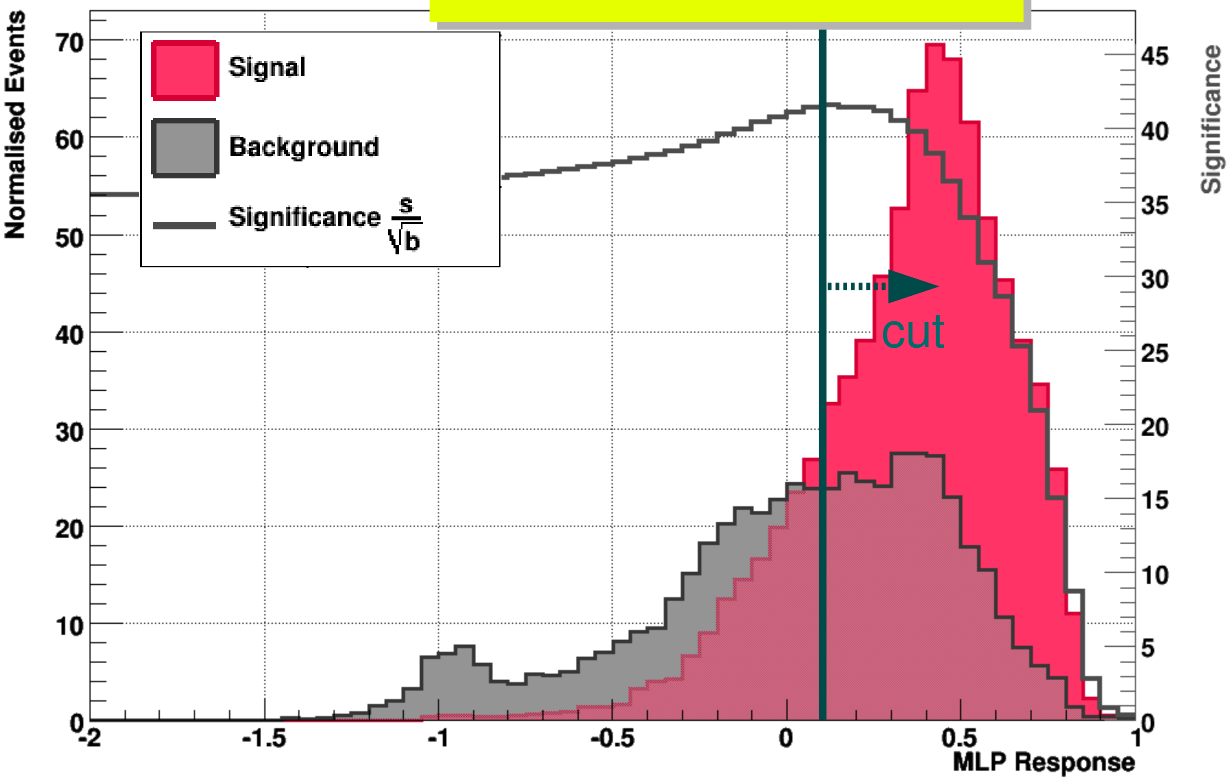
No. decay electrons for single μ-like ring events (5 year MC)



Multi Variate Analysis

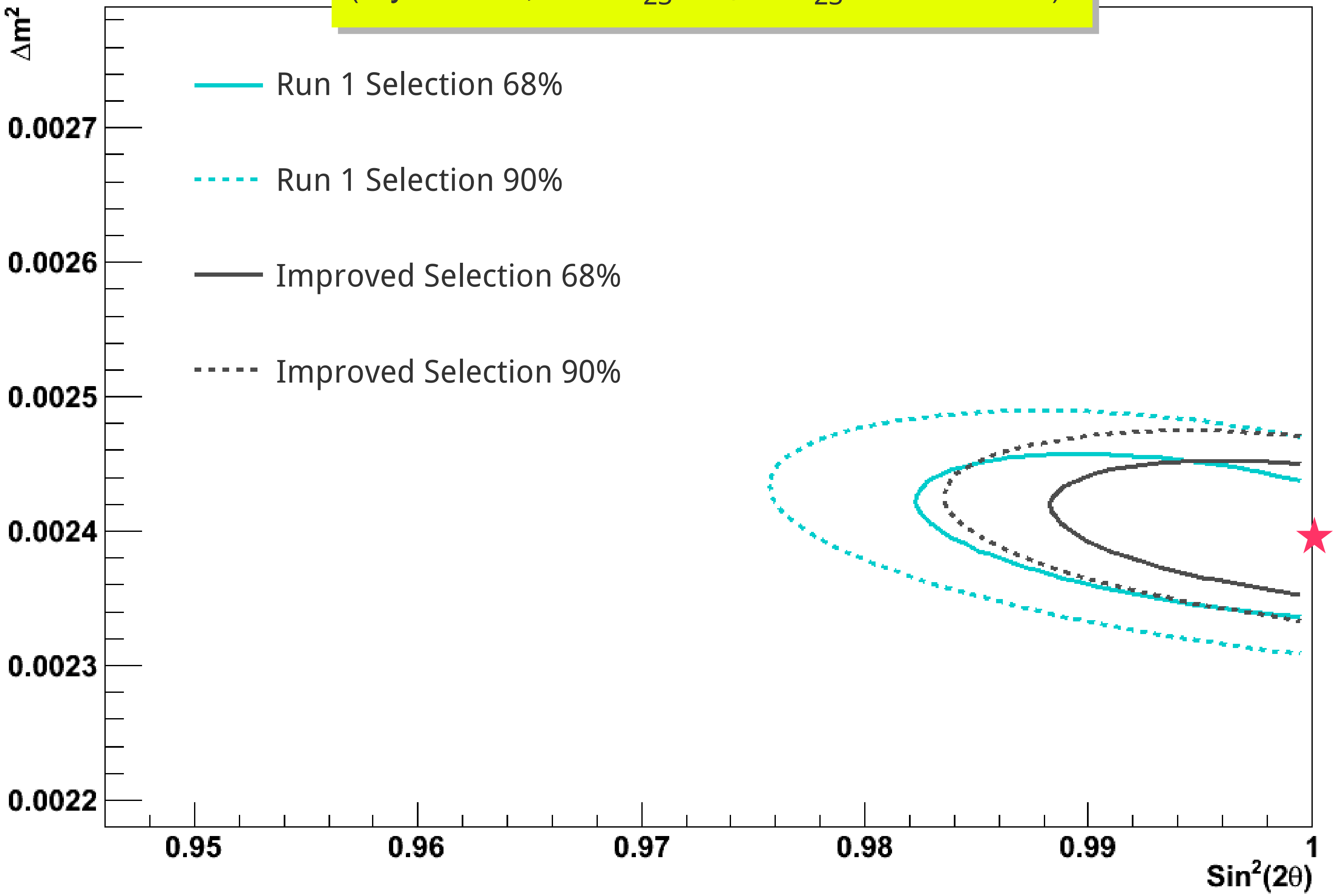
- Additional purification can be achieved with a multi-layer percepton (MLP) **neural network**
- Train on **oscillated MC** events which have passed CCQE linear selection cuts.
- Signal is **CCQE**.
- Training variables include basic likelihoods about the ring and decay electron information.
- With a MVA cut we can increase purity (55% → 72%)
- Signal efficiency drop 18% (92% → 74%)

Neural network response (MC, 5 years)



Sensitivity

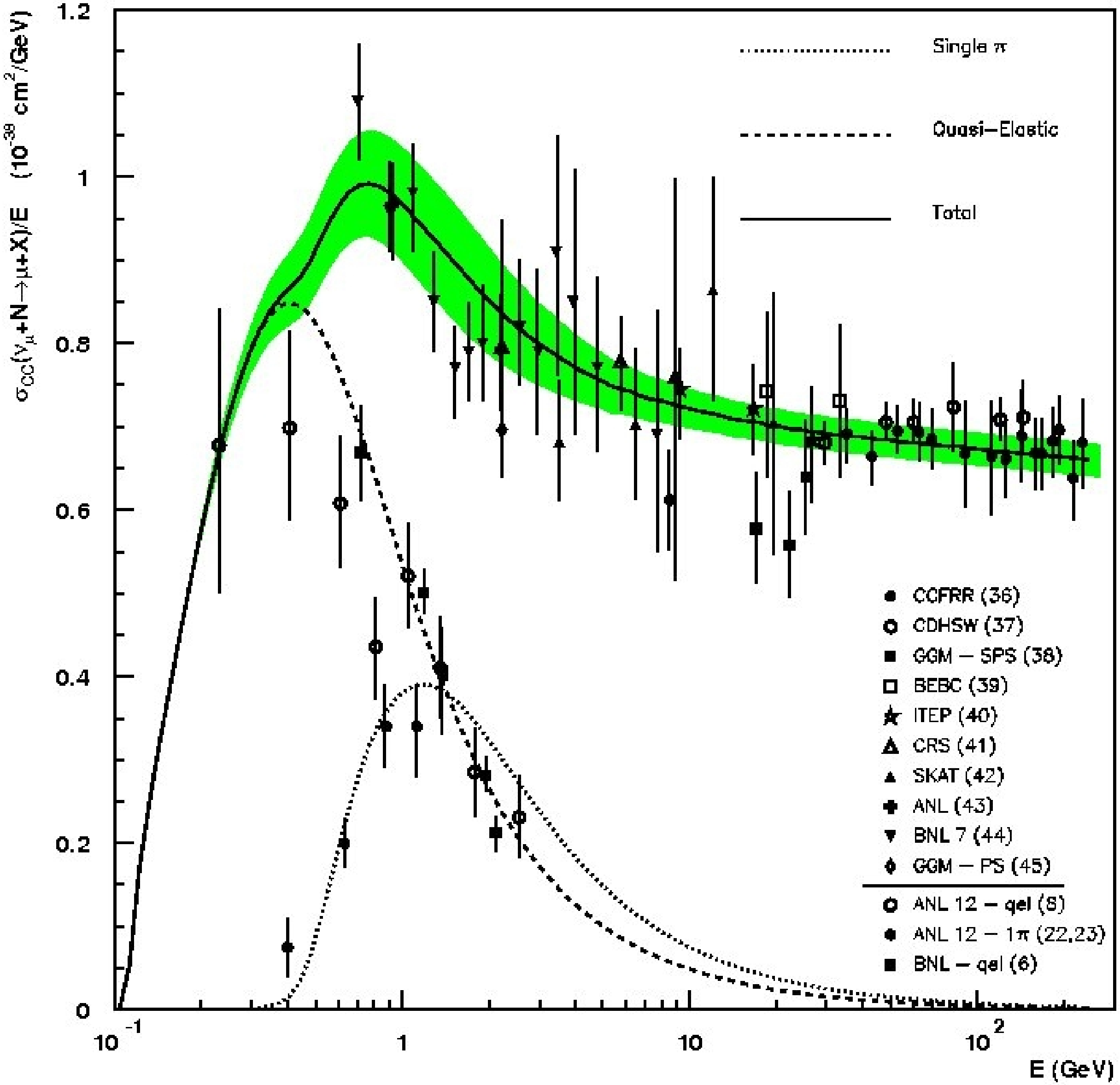
Oscillation sensitivity using chi-squared map
(5 year MC, $\sin^2 2\theta_{23} = 1$, $\Delta m^2_{23} = 0.0024\ eV^2$)



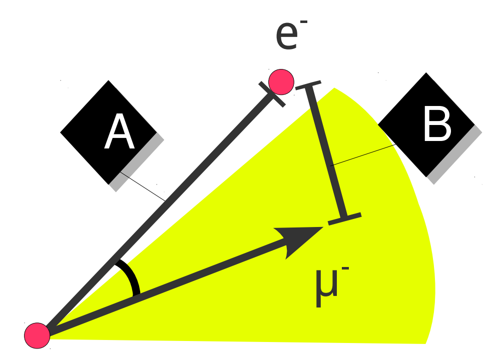
Conclusion

- SK is the far detector for T2K.
- So far seen 8 ν_μ disappearance signal events (3.23×10^{19} POT).
- This is inconsistent with no oscillation.
- Shown 3 long term ways to improve sensitivity to oscillation parameters:
  - 0 or 1 decay electron cut
  - Additional CC1π^+ sample (2 decay electrons)
  - MVA cut

CC ν_μ Interaction Cross-Section



MVA Training Variables



1) **PID likelihood**
2) **Cosine of ring direction with beam**
3) **Ring counting likelihood**
4) **Reconstructed ring momentum**
5) **Decay electron hits**
6) **Decay electron hit times**
7) A Distance of the decay electron vertex from the interaction vertex
8) B Distance of the decay electron vertex from the reconstructed stopping point of the muon
9) **Decay electron type** integer: 0 = no electron, 1 = <0.6μs decay time, 2 = well reconstructed electron

Individual Sensitivities