

# TITUS: An Intermediate Distance Detector for the Tokai-to-Hyper-Kamiokande Neutrino Beam

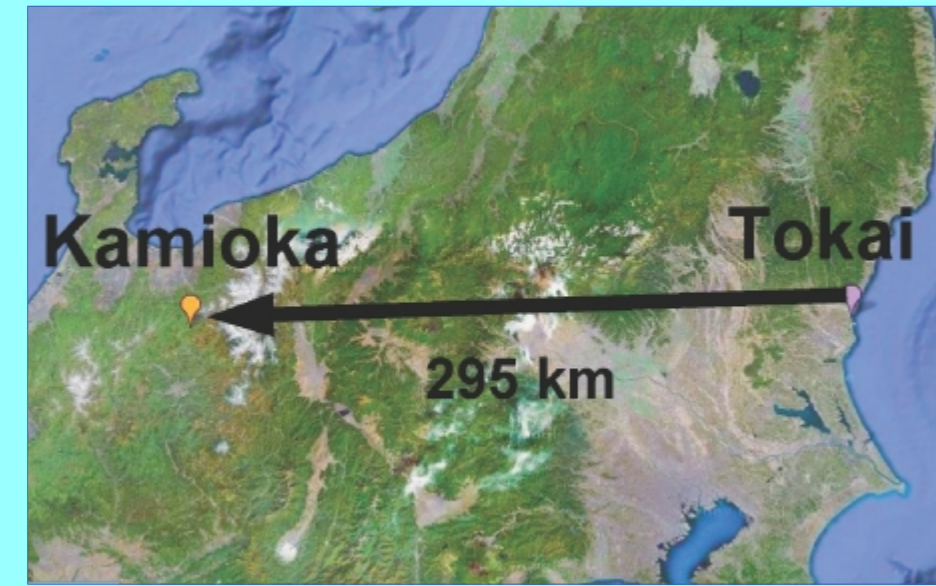
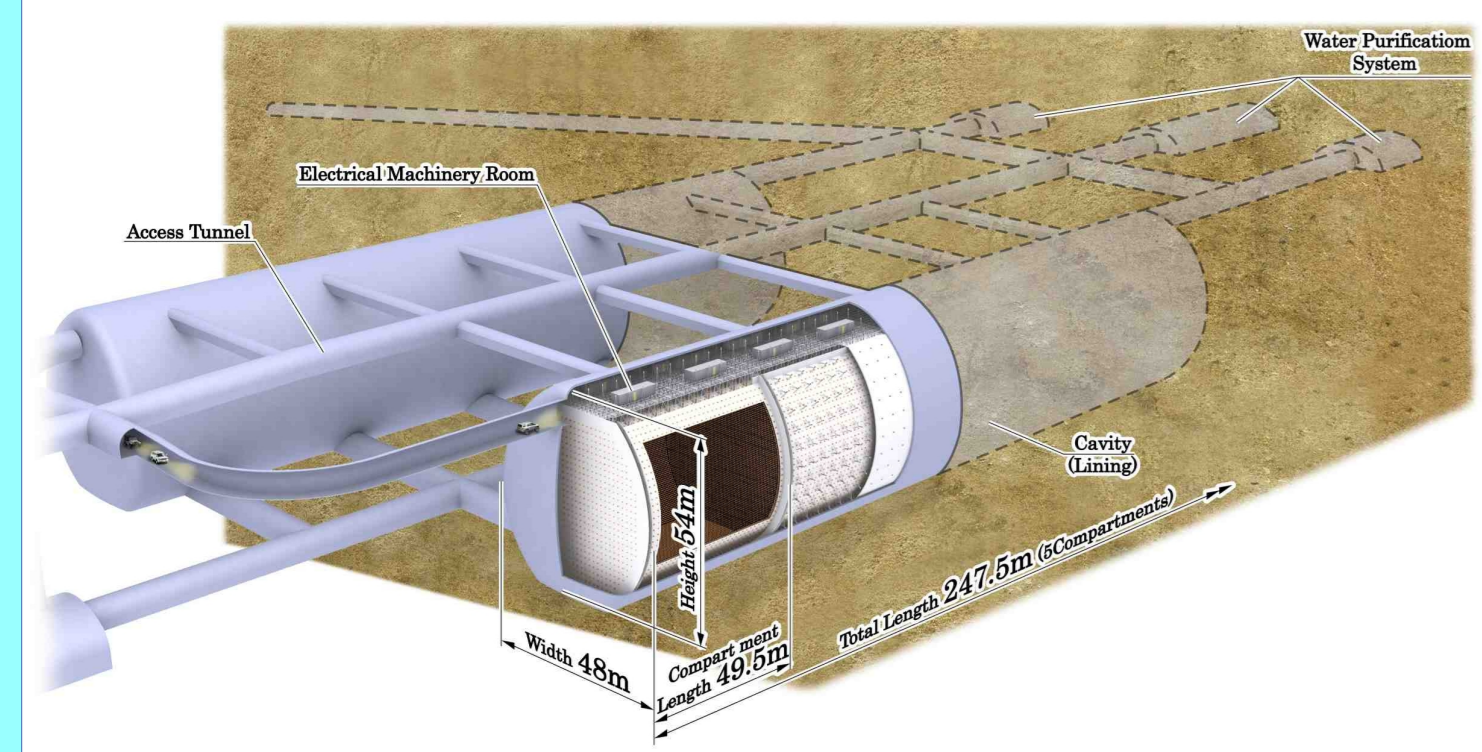


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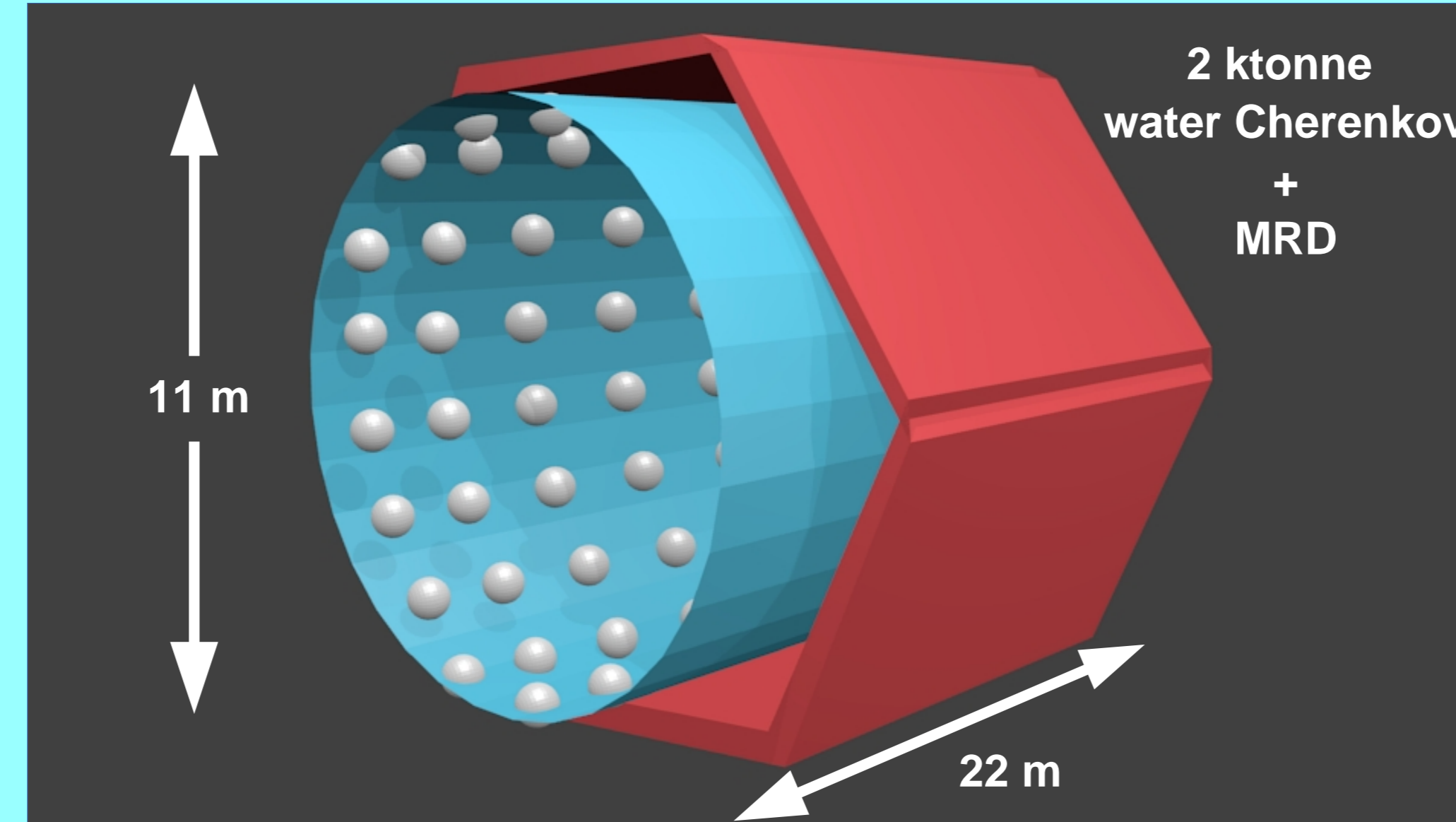
## Hyper-Kamiokande



Hyper-K<sup>[1]</sup> is a next-generation water Cherenkov detector:

- 1 Mtonne total mass (0.56 Mtonne fiducial)
- Rich physics programme includes: atmospheric  $\nu$ , solar  $\nu$ , supernova  $\nu$
- **Can be used as a far detector for the J-PARC neutrino beam**
- See poster (#202) from Hide-Kazu Tanaka for more info on Hyper-K

## TITUS = “Tokai Intermediate Tank with Unoscillated Spectrum”



TITUS is a proposed new near detector for Hyper-K:

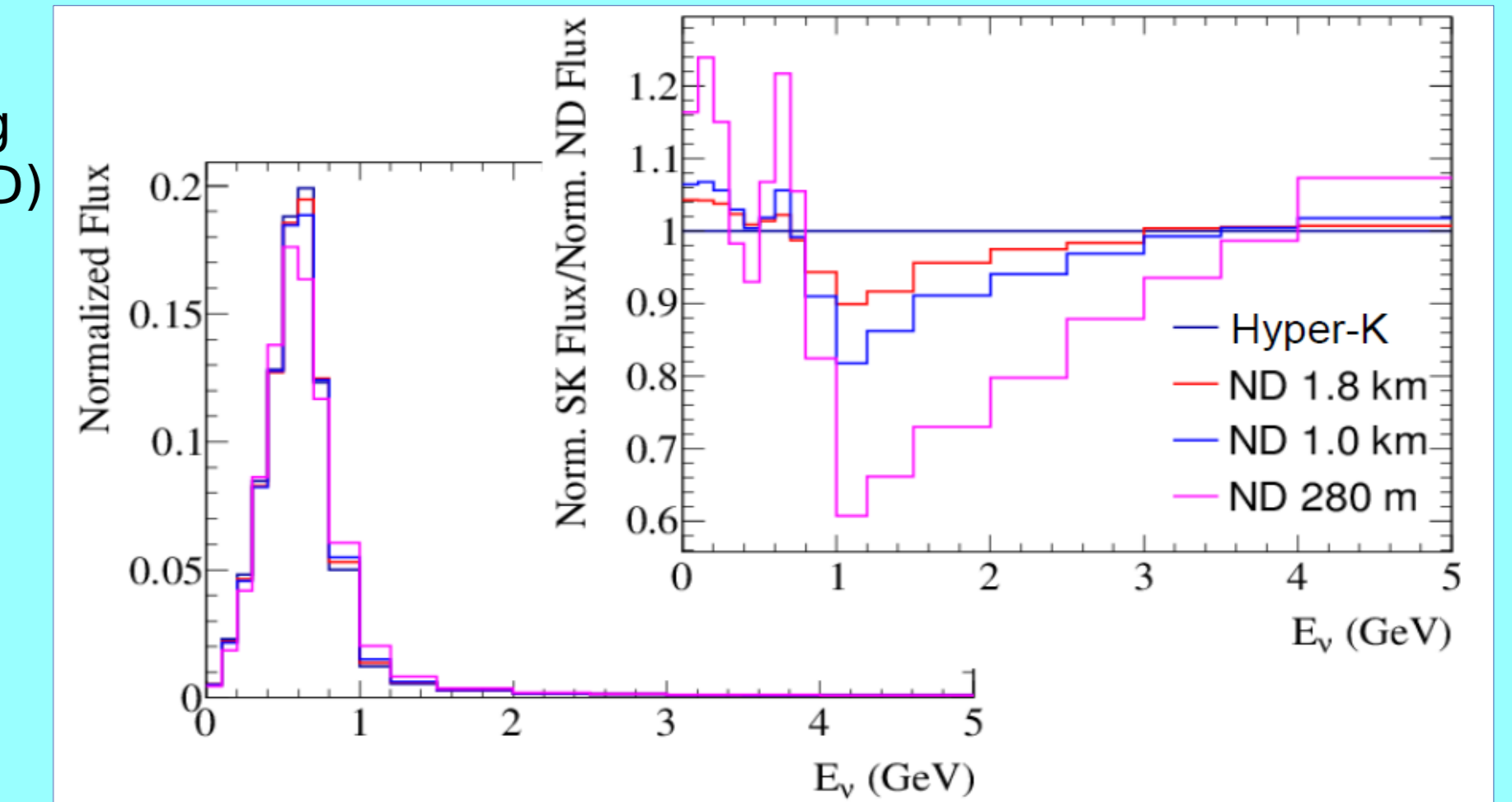
- Approx. 2 km from the J-PARC neutrino beam
- 2 ktonne water Cherenkov, with 0.1% Gd-doping
- Partially enclosed by Muon Range Detector (MRD)

Designed to reduce systematics at Hyper-K:

- Same target nuclei ( $\text{H}_2\text{O}$ )
- Same angle & neutrino energy spectrum
- Many systematics cancel in Far / Near ratio

Gd enhances tagging of  $\nu$  interactions via n capture:

- Neutrino / anti-neutrino discrimination
- Distinguish CCQE from other interaction modes (including Meson Exchange Currents [MEC])
- Final Hyper-K design may also include Gd

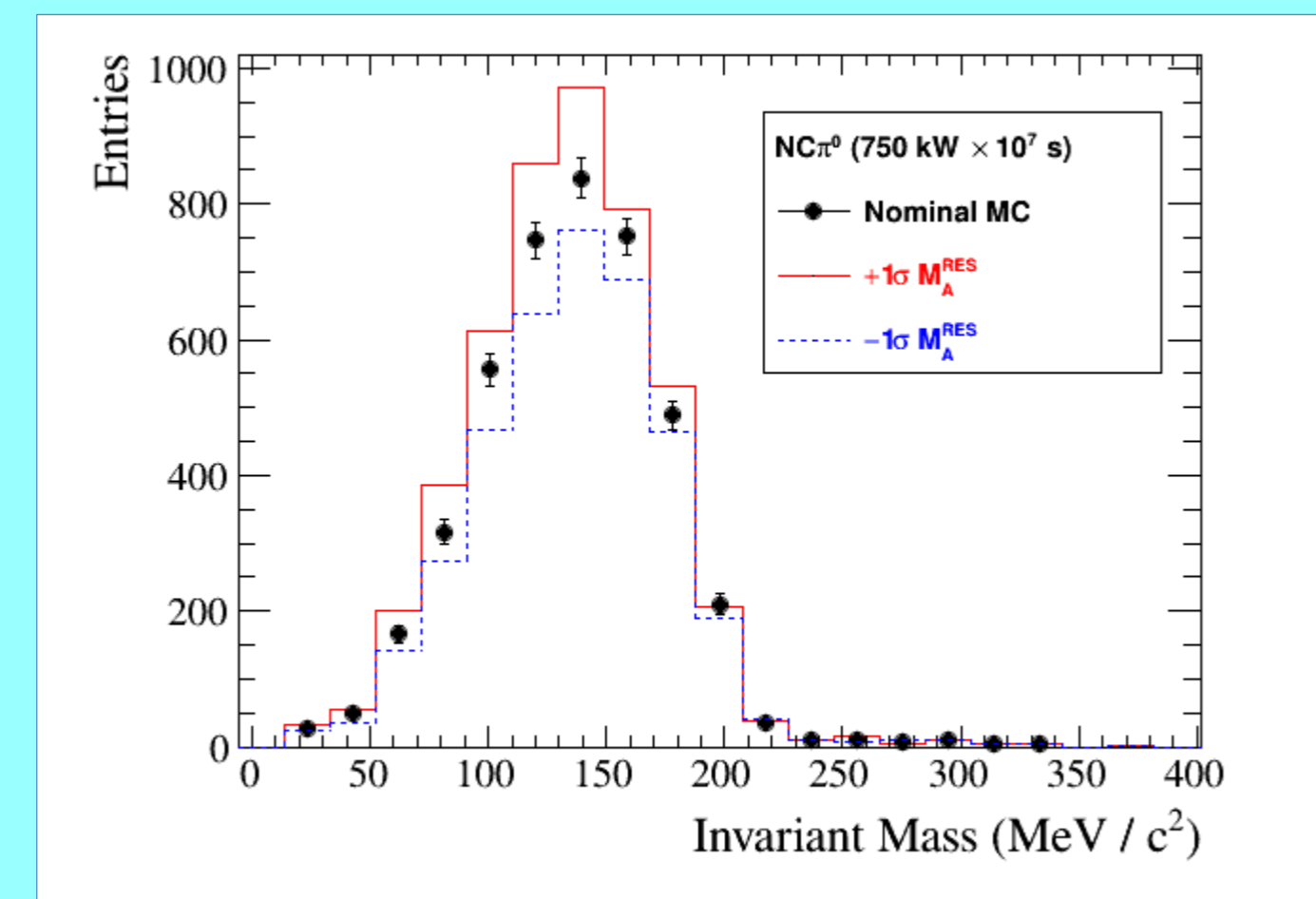


Far-to-Near Ratio For Hyper-K and Near Detector Sites

## Physics Potential

TITUS has a wide physics reach, including the following topics:

- Neutron multiplicity measurements
  - Ability to distinguish CCQE from other neutrino interactions in beam mode
  - Provides important inputs to refine neutrino generator models
  - Improves Hyper-K proton decay search sensitivity
- Measure intrinsic  $\nu_e$  component of neutrino beam
  - Dominant background for  $\nu_e$  appearance oscillation analysis
- Cross-section measurements
  - Inclusive  $\text{NC}\pi^0$  measurement can improve knowledge of  $M_A^{\text{RES}}$  (see figure)
  - $\nu_e$  vs.  $\nu_\mu$  and  $\nu$  vs.  $\bar{\nu}$  and CCQE vs. CC-inclusive
- Supernova neutrino alarm
- Sterile neutrino searches
  - Short-baseline  $\nu_e$  appearance search to test LSND / MiniBooNE anomaly
  - Compare NC rate at  $\sim 2$  km and 280 m to look for active neutrino disappearance



Inclusive  $\text{NC}\pi^0$  Measurement (200 t fiducial mass)

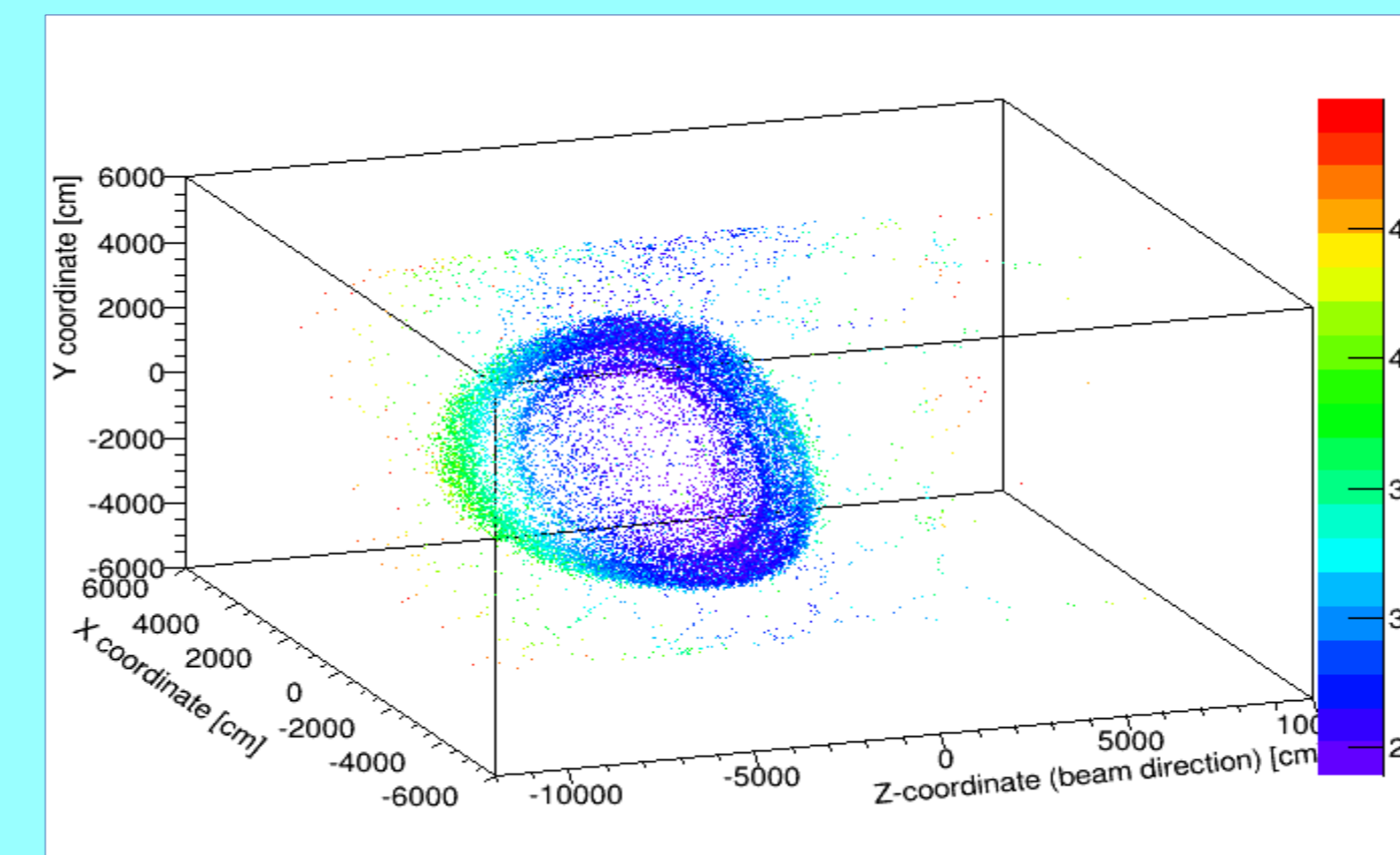
## Water Cherenkov Simulation & Reconstruction

- Neutrino generators:
  - NEUT and GENIE

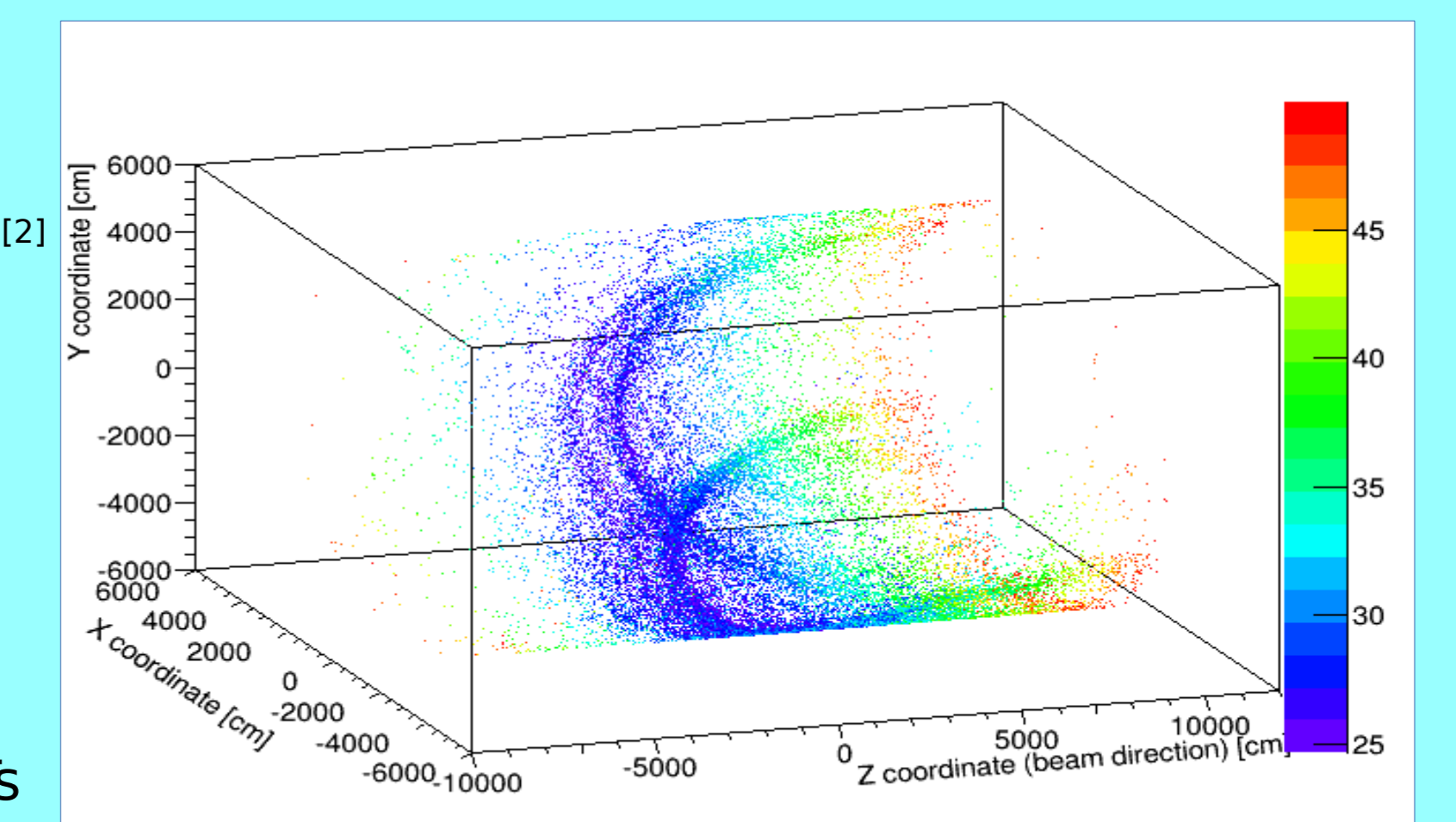
- Detector sim. with WChSandBox<sup>[2]</sup>
  - All results preliminary

- Event display shows photon hits on active area of detector wall

- Photosensor optimisation with:
  - Conventional PMTs
  - High quantum efficiency PMTs
  - LAPPDs<sup>[3]</sup>



Charged Current Quasi-Elastic interaction



Neutral Current  $\pi^0$  interaction

## Neutron Multiplicity

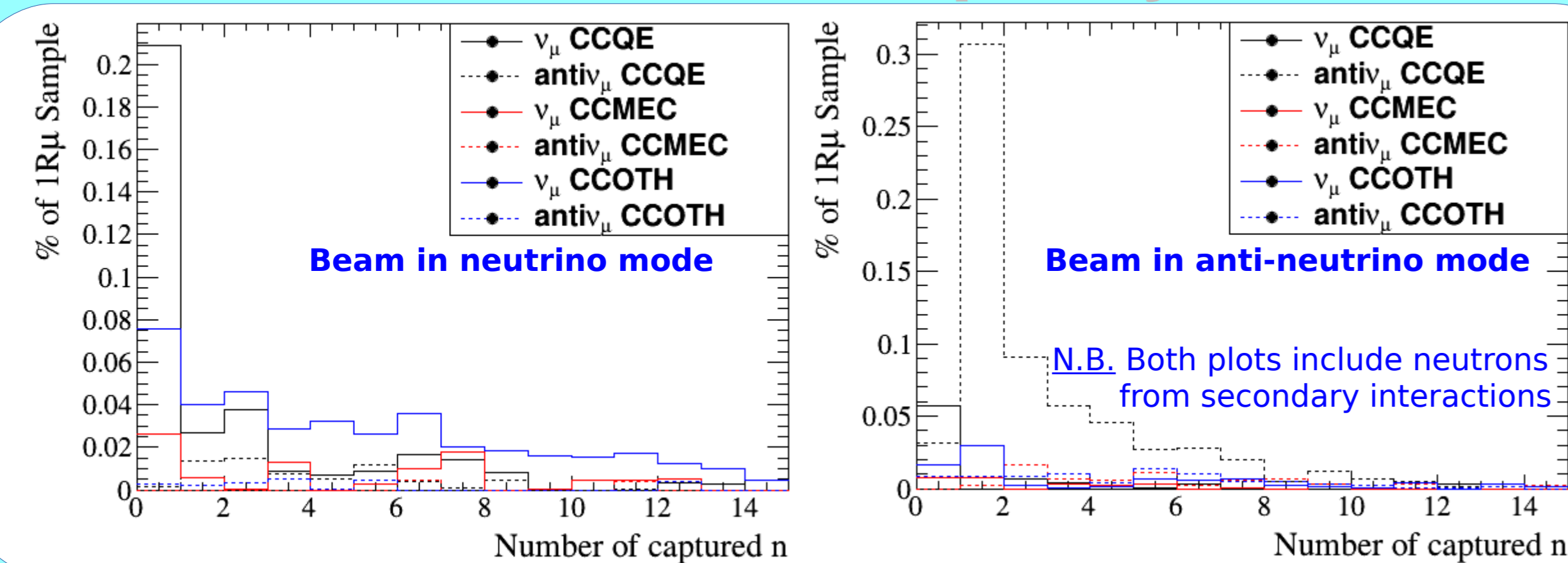
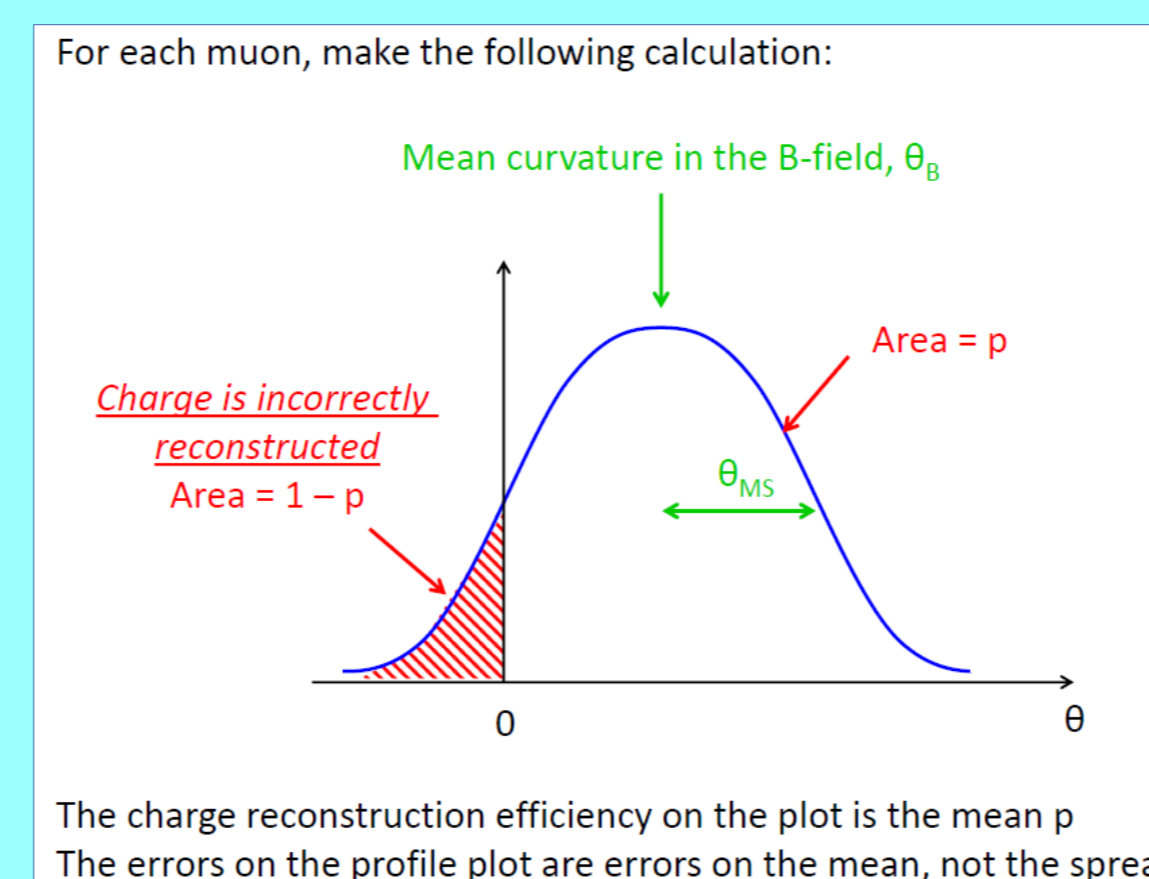


Table displays sample purities for various selection criteria (Each row sums to 100%)

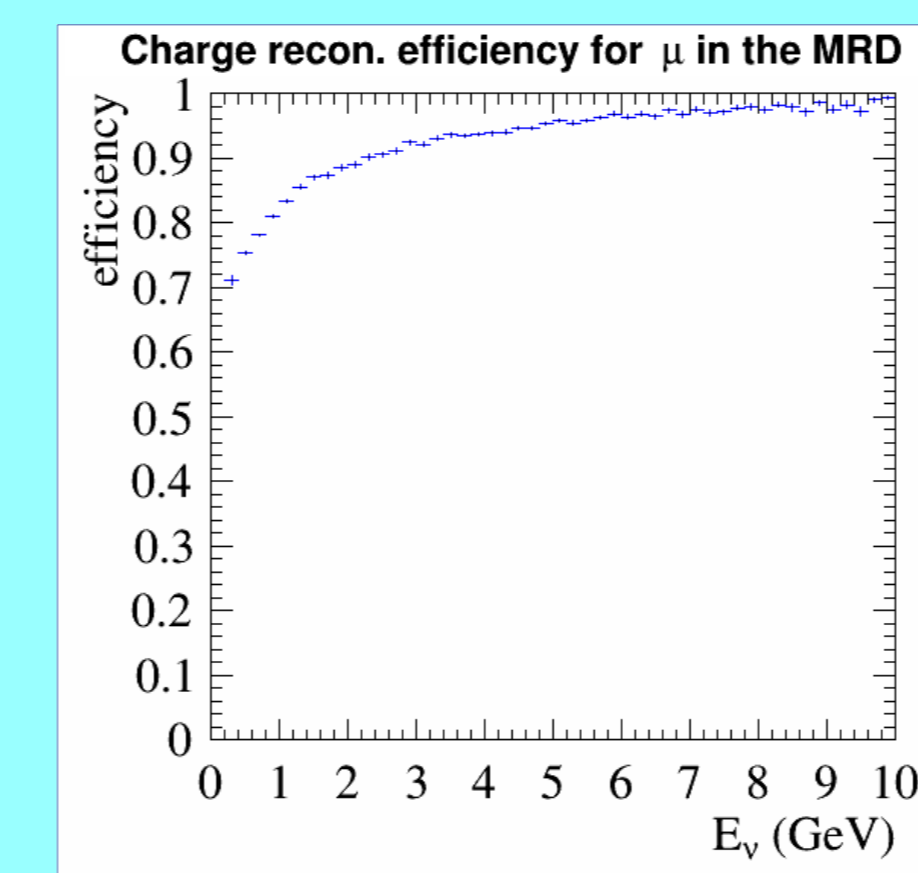
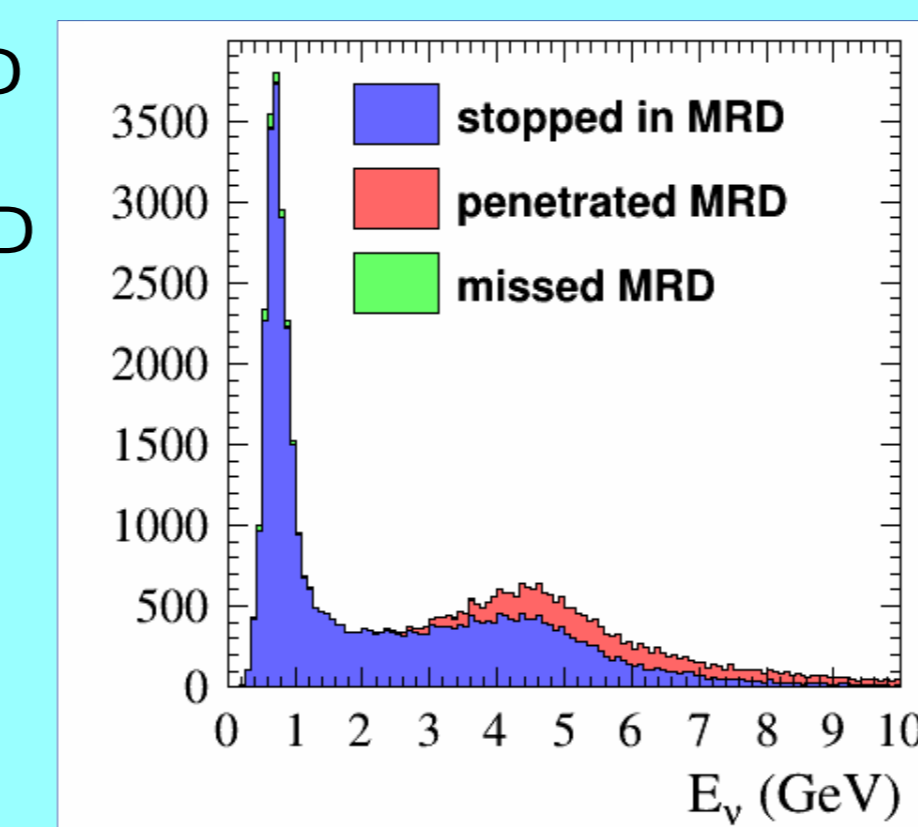
Beam Mode & Selection	CCQE	CC MEC	CC $1\pi$	CC Other	NC	'Wrong-Sign' CC
$\nu_\mu$ all	36%	10%	25%	18%	4%	7%
$\nu_\mu$ with $n = 0$ (CCQE-enhanced)	67%	8%	9%	14%	2%	< 1%
$\nu_\mu$ with $n > 0$ (CCQE-depleted)	22%	10%	32%	20%	6%	10%
$\bar{\nu}_\mu$ all	63%	7%	5%	2%	3%	20%
$\bar{\nu}_\mu$ with $n = 0$	27%	< 1%	< 1%	< 1%	10%	63%
$\bar{\nu}_\mu$ with $n = 1$	88%	< 1%	1%	2%	< 1%	8%
$\bar{\nu}_\mu$ with $n > 1$	57%	13%	8%	2%	2%	18%

## Muon Range Detector

- Muons that escape the water tank enter the MRD
- $\mu$  momentum inferred from range within the MRD
- A 1.5 Tesla magnetic field allows identification of the sign of the  $\mu$  charge:



- Charge-sign measurement can be exploited to obtain  $\mu^+$  vs.  $\mu^-$  discrimination:
- $\mu$  from energetic neutrinos can penetrate MRD
  - Momentum & sign of charge reconstructed from curvature



## Future Work

- Photodetector configuration, optimising hybrid of PMTs and LAPPDs
- Event matching between water tank and MRD to improve  $\nu$  /  $\bar{\nu}$  separation
- Optimisation of  $\text{CC}\pi^0$  selection for maximum exploitation of Gd potential
- Evaluation of uncertainties at detector level and from cross-section models
- Design error matrix for propagation from TITUS to Hyper-Kamiokande
- Oscillation sensitivity studies (e.g.,  $\delta\text{CP}$ , sterile  $\nu$ )

## References

- [1] For more details, please visit: [www.hyperk.org](http://www.hyperk.org)  
Proposal (submitted April 2014) available upon request
- [2] Developed by Matt Wetstein for the ANNIE collaboration (arXiv:1402.6411)
- [3] The Large Area Picosecond Photo-Detector (LAPPD) Collaboration  
For more information, please visit: [psec.uchicago.edu](http://psec.uchicago.edu)
- [4] R. B. Firestone and V. S. Shirley, *Table of Isotopes* (John Wiley, New York, 1996)