Hyper-Kamiokande

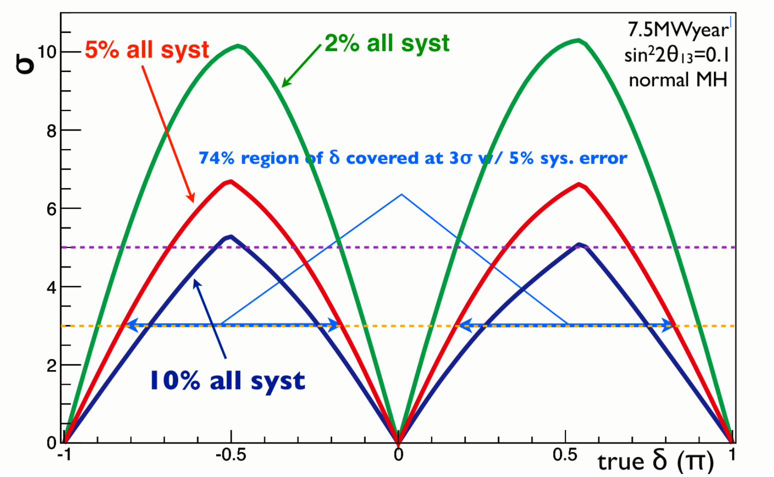
Intermediate Detector

L. Cremonesi, F. Di Lodovico, D. Hadley,
T. Katori, M. Malek, R. Terri, D. Wark,
M. Wascko

4th Hyper-Kamiokande Open Meeting
IPMU, Kashiwa
27-28 January, 2014

Motivations

Decrease error on CPV and extend physics return of HK



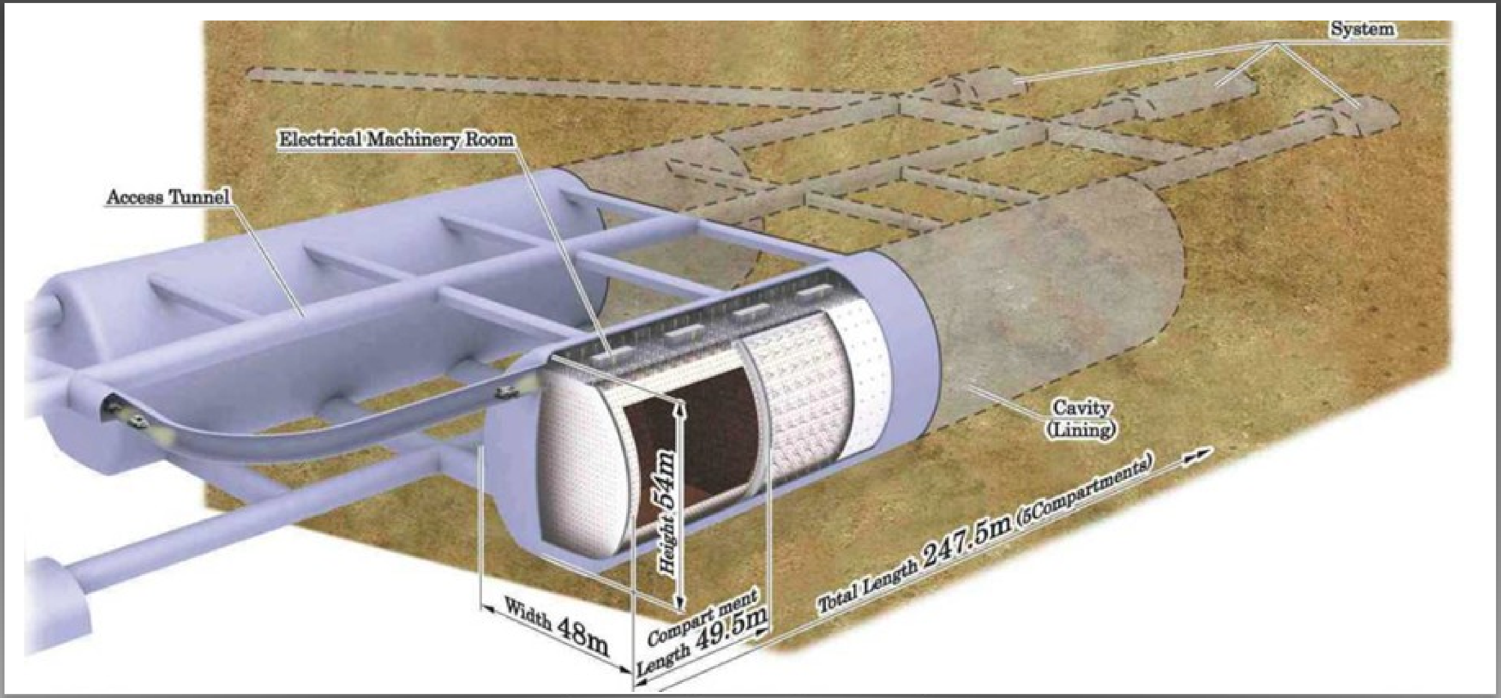
CPV:

- Same beam as at HK (maximize distance from target)
- Same target as HK (use water)

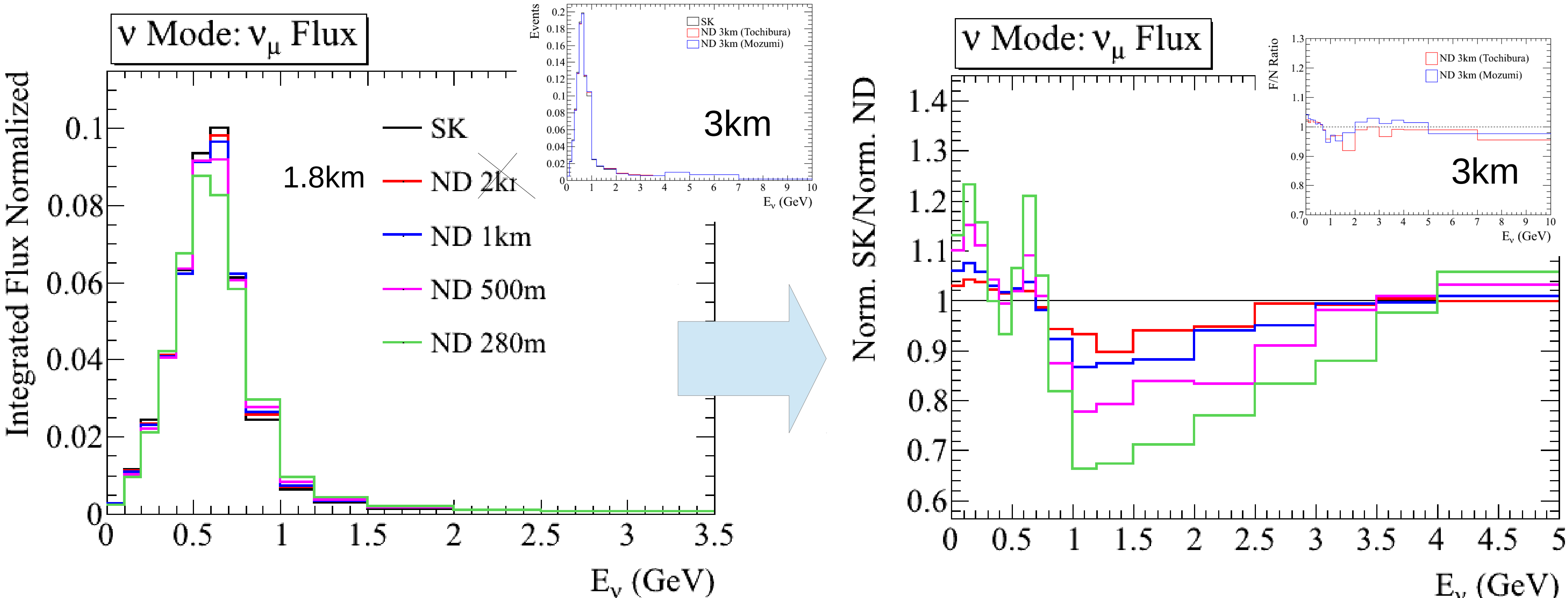
Increasing physics return:

- Improved handling on cross sections
- Neutron tagging (Gd-doping – at least in phases)

Physics

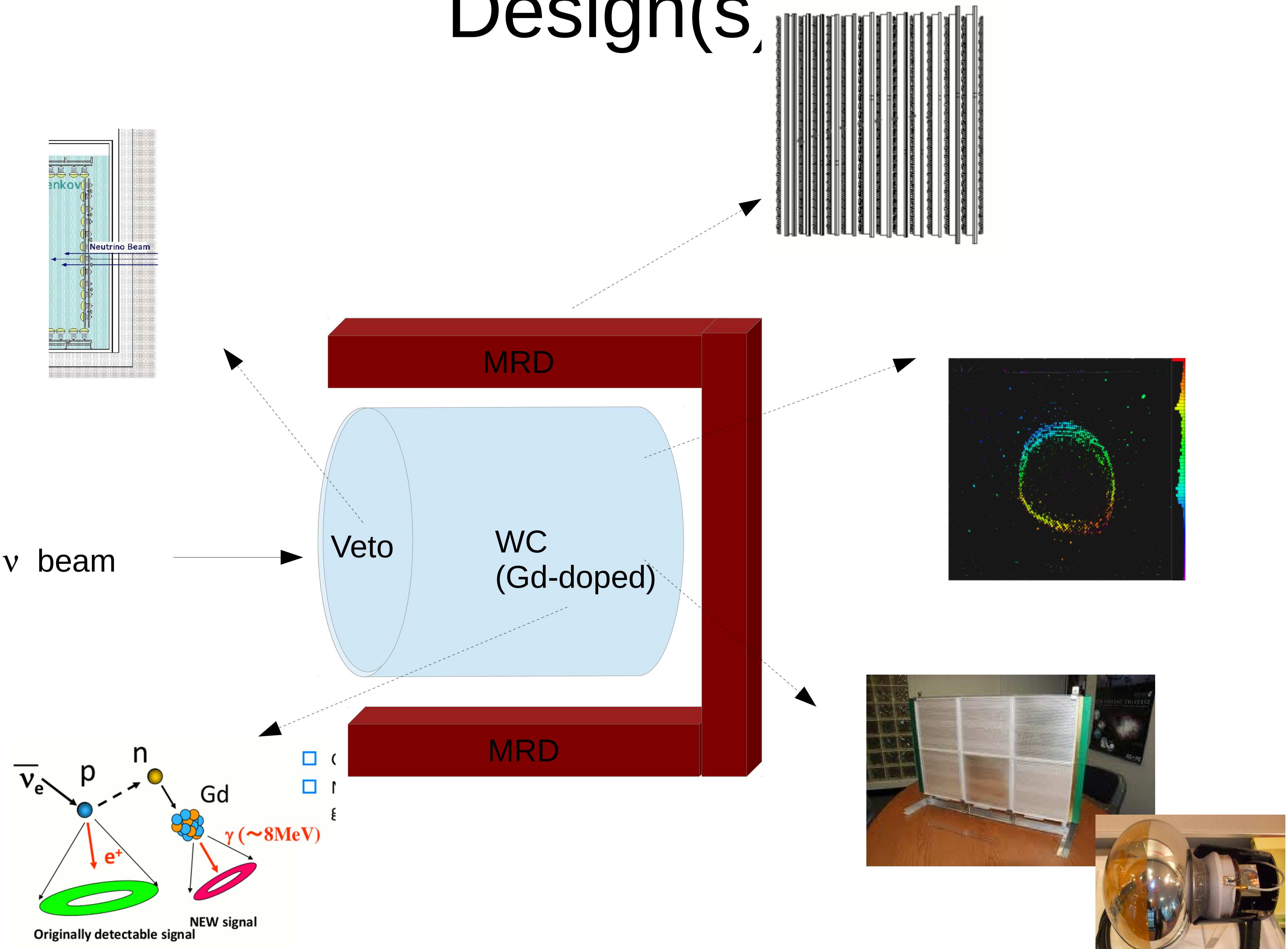

System
Electrical Machinery Room
Access Tunnel
Cavity
(Lining)
Height 54m
Total Length 247.5m (5Compartments)
Width 48m
Compart ment
Length 49.5m

Intermediate Detector



- At 280m: neutrino source not point-like, spectral differences with respect to SK.
- To improve predictions at SK → equalize beam and use same nuclei.
- *Initial look at the global fit (BANFF) used by ND280 to constrain the xsection and flux parameter.*
- *Basic approximations show large improvements at 1.8km.*
- *Planning to use also other techniques (e.g. Far-to-Near ratio) to estimate the effect of the new detector.*

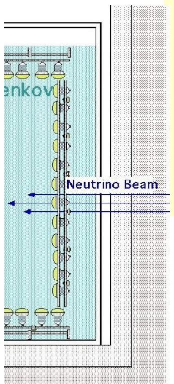
Design(s)

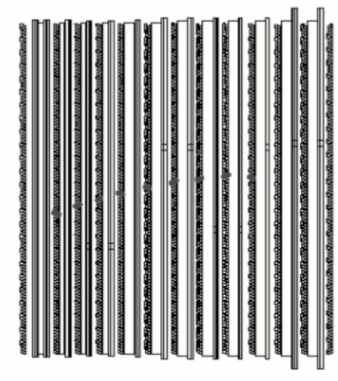


enkov
Neutrino Beam
MRD
Veto
WC
(Gd-doped)
ν beam
MRD
$\bar{\nu}_e$
p
n
Gd
e+
γ (~8MeV)
Originally detectable signal
NEW signal

Design(s)

PMTs facing outwards in the veto region to reject particles that enter or are produced outside the detector

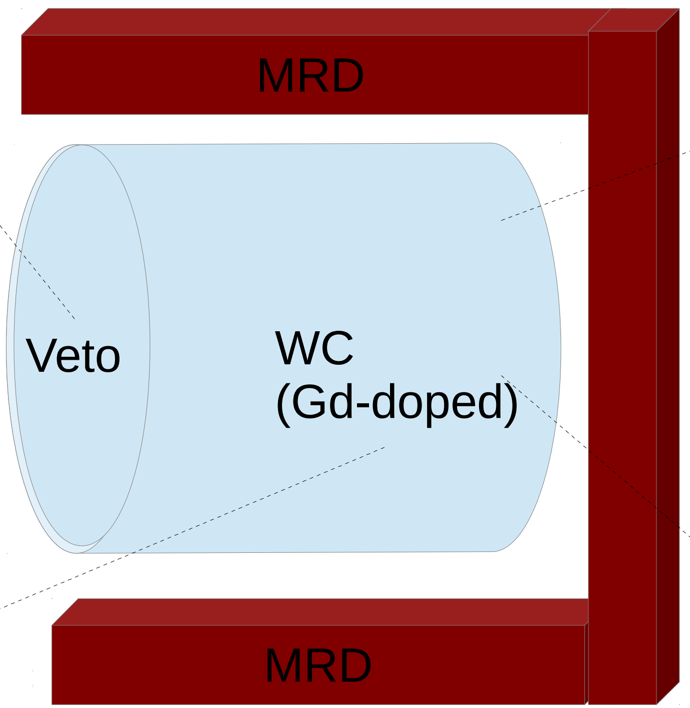


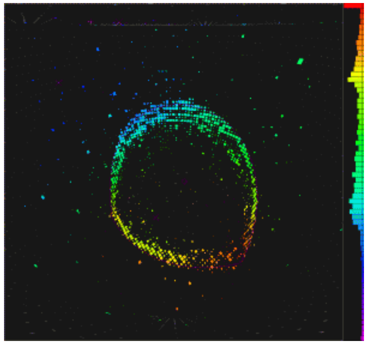


To measure energy, angle and production point of muon from CC interactions. Possibly MIND downstream

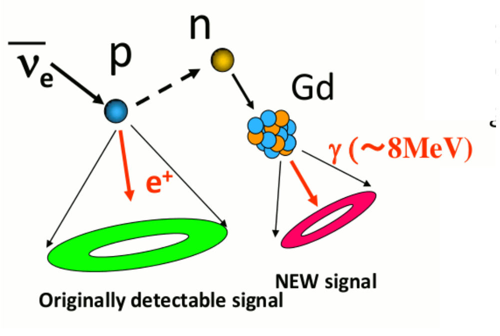
Water-Cherenkov target

ν beam



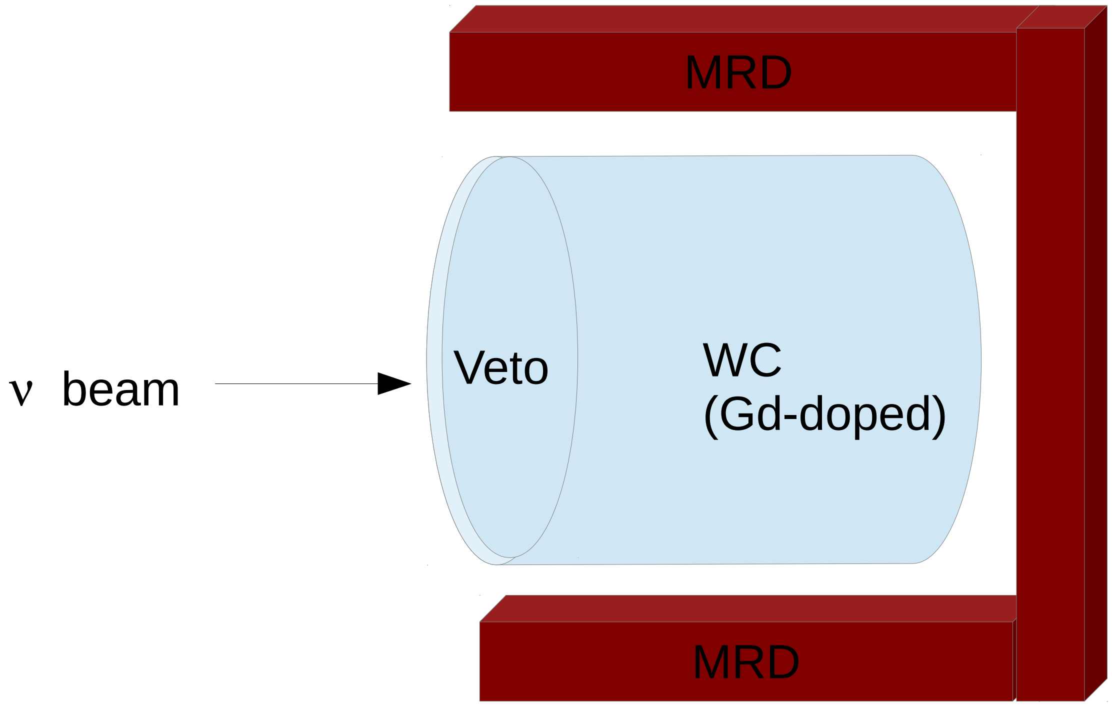


Aim to use LAPPDs (w/ HPD)



Aiming for Gd doped water.

Design(s)

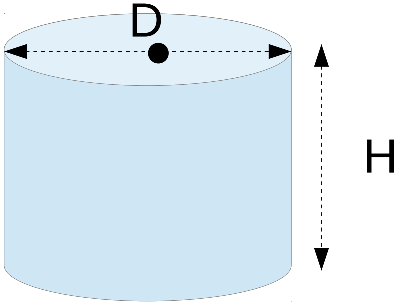


- Currently focusing on optimizing the size of the detector.
- Studying the addtition of the MRD for muon range containment.
- Same angular coverage as HK
- Instrument with LAPPDs with good spacial resolution → possibly looking at an hybrid configuration with PMTs.
- Very useful to have a Gd-doped phase (similar to ANNIE's proposal http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/ANNIE.pdf)

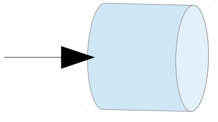
Detector Size

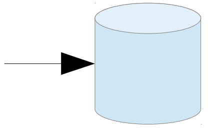
Optimizing detector size using two main criteria: muon containment and pile-up.
Looked at 4 basic detector sizes. We will fine-tune the dimensions soon.

- **1kton** – D: 10.8m H: 10.8m
- **2kton** – D: 11m H: 22m
- **4kton** – D: 22m H: 11m
- **8kton** – D: 22m H: 22m



Looking at both configurations with cylinder axis

along 

or orthogonal 

to the beam.

Muon Containment Ratio

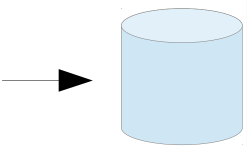
- Eight detector configurations.
- Ratio of contained over total number of muons as a function of neutrino energy.

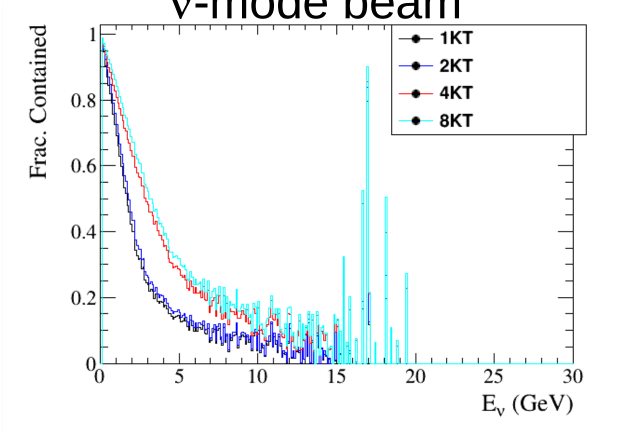
Plots in linear scale

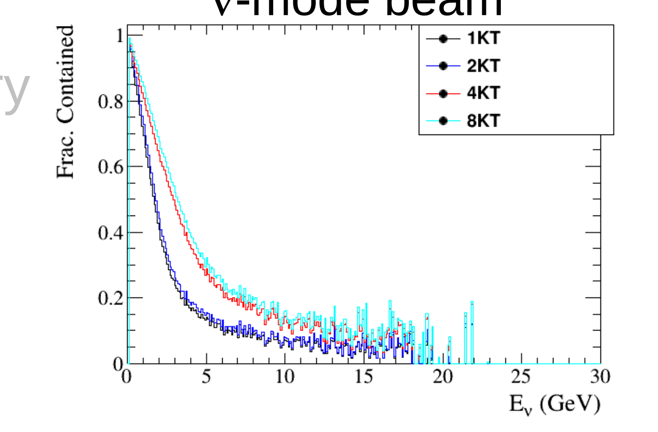
Preliminary

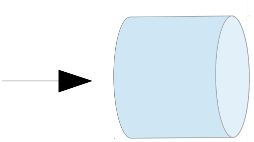
ν-mode beam

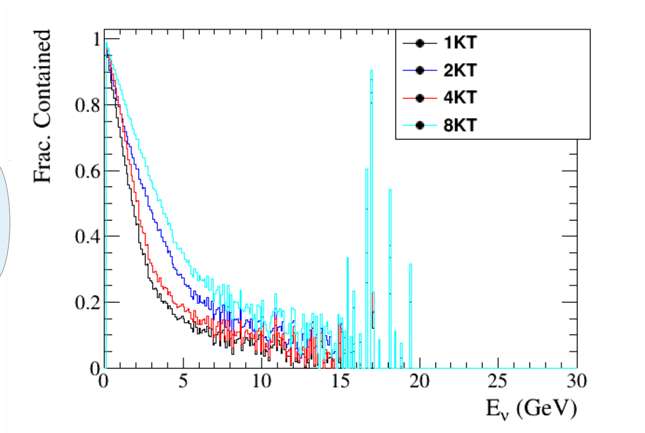
$\bar{\nu}$-mode beam

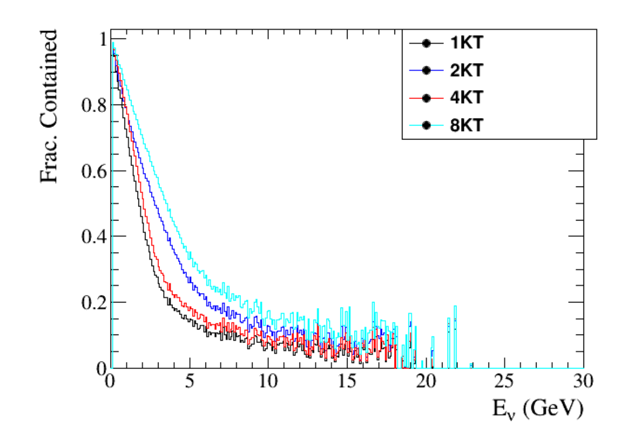












- Preferred configuration axis along the beam line.
- Same considerations for both neutrino and anti-neutrino mode beams.

Muon Containment Ratio

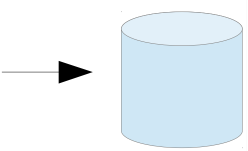
- Eight detector configurations.
- Ratio of contained over total number of muons as a function of neutrino energy.

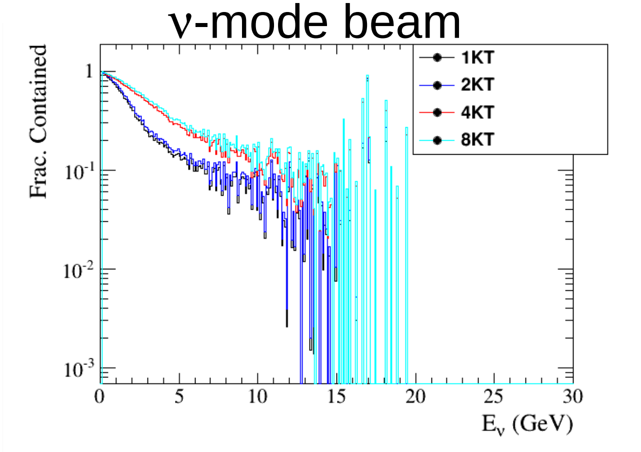
Plots in logarithmic scale

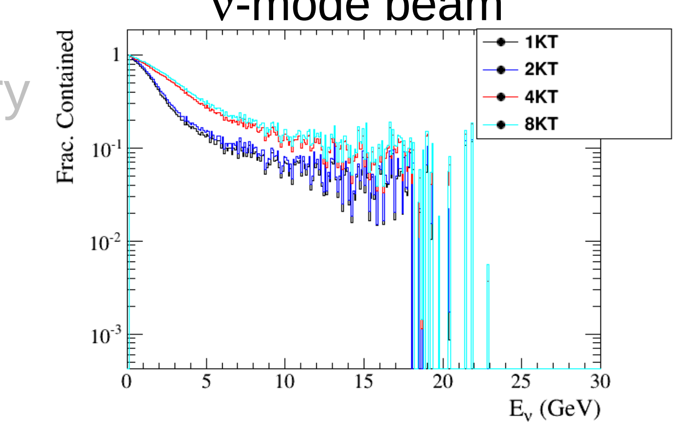
Preliminary

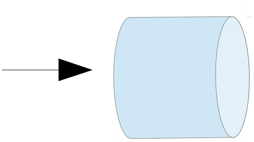
ν-mode beam

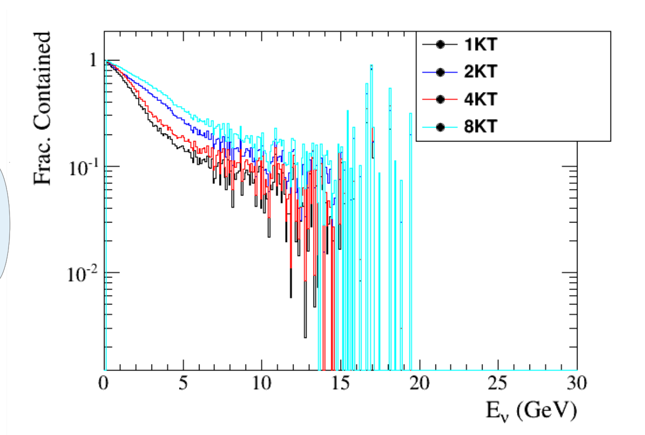
$\bar{\nu}$-mode beam

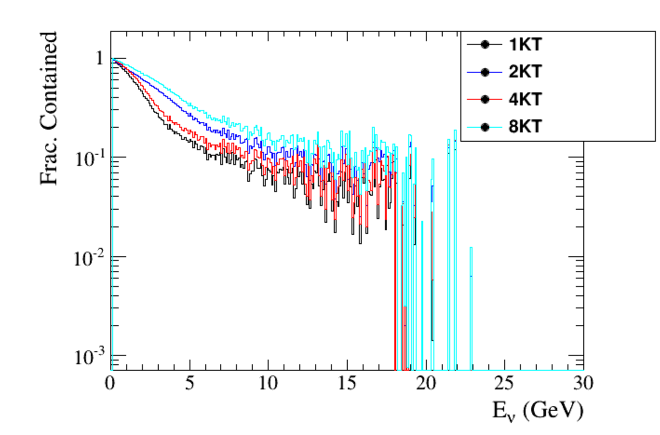








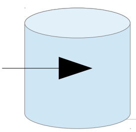




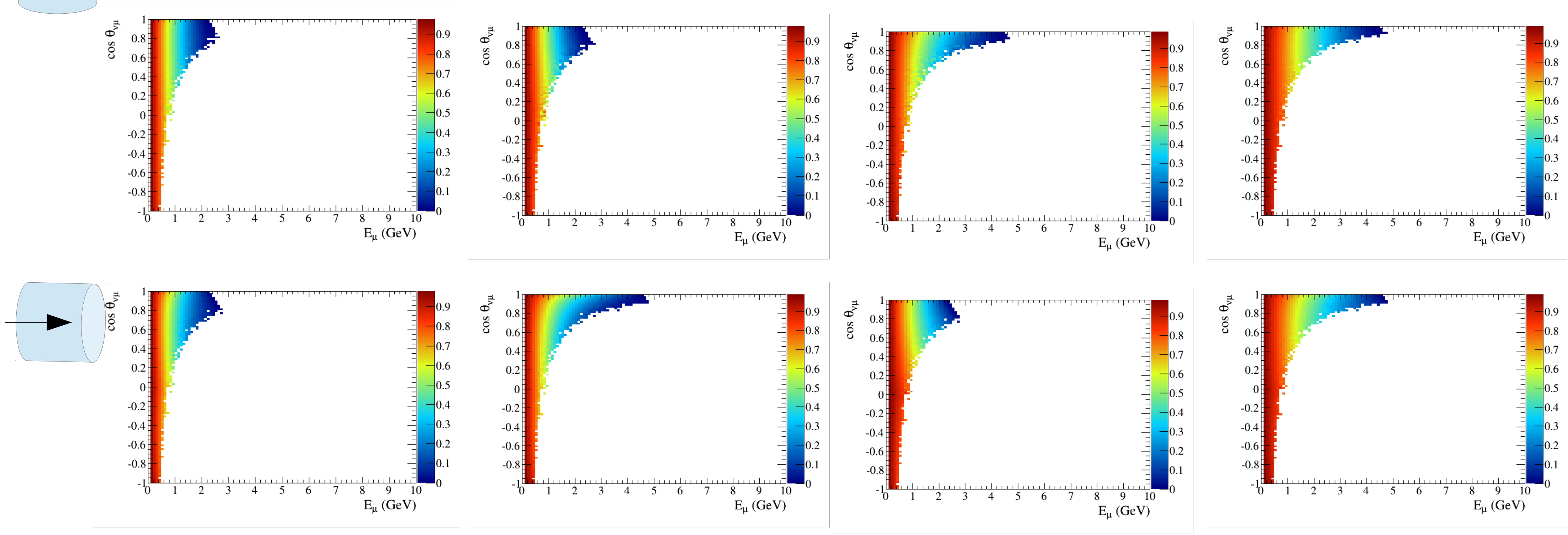
- Preferred configuration axis along the beam line.
- Same considerations for both neutrino and anti-neutrino mode beams.

$(P_\mu, \cos\theta_\mu)$

- Neutrino-mode beam. Eight detector configs.
- P_μ versus θ_μ distributions.



1kton 10.8m(d)x10.8m(z)	2kton 11m(d)x22m(z)	4kton 22m(d)x11m(z)	8kton 22m(d)x22m(z)



- Preferred configuration axis along the beam line and either 2 or 8ktom. We choose 2km
- Similar considerations for anti-neutrino mode beam.

Multiple nu-interaction probabilities

- Calculated the number of interactions in a spill using the J-PARC upgrade proposal (arXiv:1311.5287) => $2e^{14}$ protons per pulse.

- Looked at 4 detector geometries for total # of interactions in a pulse & bunch (8 bunches/pulse) for ν and anti-ν beams.

- In each case, looked at when events are within 10ns defined by randomly throwing Gaussian with width of 25ns (bunch width)

- Study the probability of having at least 2 interactions in either a bunch or pulse (spill) – just use Poisson calculation

Multiple nu-interaction probabilities

1.8km

Detector	Volume (kTon)	+320 kA pulse	-320 kA pulse	+320 kA bunch	-320 kA bunch
1kton	1	8.2%	2.9%	1.1%	0.4%
2kton	2.09	16.3%	5.9%	2.2%	0.7%
4kton	4.18	29.9%	11.4%	4.3%	1.5%
8kton	8.36	50.9%	21.5%	8.5%	3.0%

3.0km

Detector	Volume (kTon)	+320 kA pulse	-320 kA pulse	+320 kA bunch	-320 kA bunch
1kton	1	3.0%	1.0%	0.4%	0.1%
2kton	2.09	6.2%	2.2%	0.8%	0.3%
4kton	4.18	12.0%	4.3%	1.6%	0.5%
8kton	8.36	22.6%	8.4%	3.1%	1.1%

- Use simple $1/r^2$ assumption from 1.8km to 3km
  - Not 100% correct at a couple levels, but should give a reasonable idea

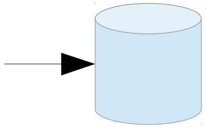
Preliminary

- Smaller volumes give lower event rates => smaller probabilites
- Considering also the muon containment => 2kton detector preferred (dimensions can be further optimized).

NC π^0

- To obtain desired systematic of 2% and fully exploit statistics of T2HK for ν_e appearance, need to better understand π^0 background.

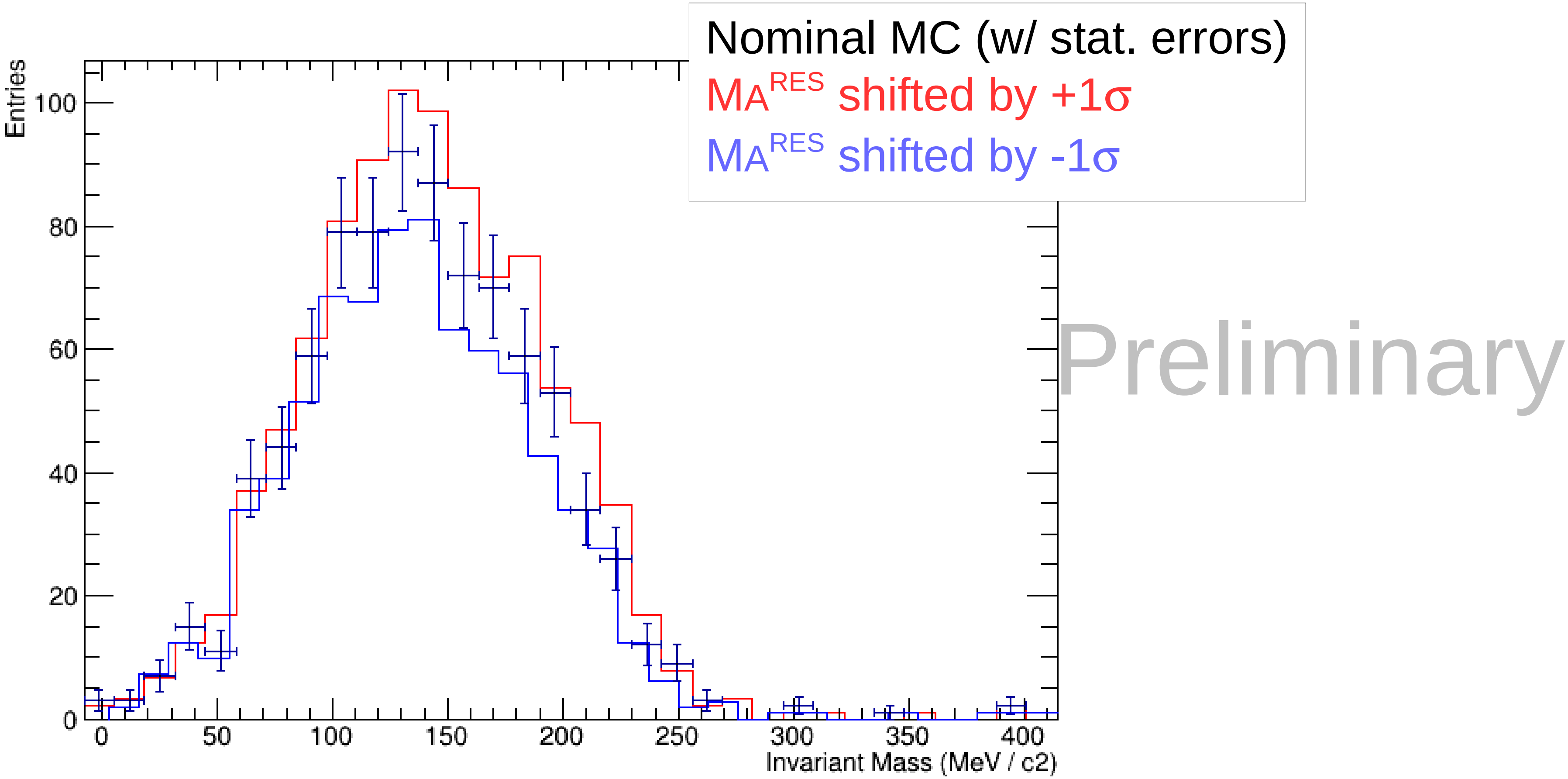
  → Intermediate WC detector is ideally suited to this task!



- Initial study uses:
  - K2K geometry (1 kton, orthogonal to beam)
  - K2K selection cuts:
    - Fully contained
    - 50 t fiducial mass: 4m (D) x 4m (L) at tank centre
    - 2 ring ee-like event

- MC scaled to exposure of one year (750 kW beam x 10^7 sec) or ~1.7 x 10^{21} P.O.T.

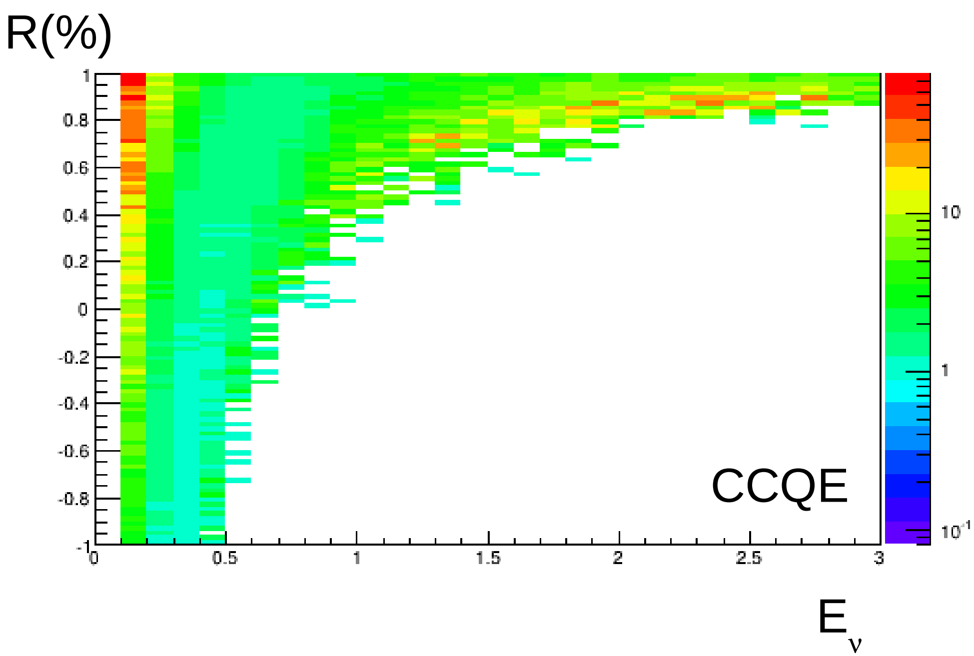
NC π^0

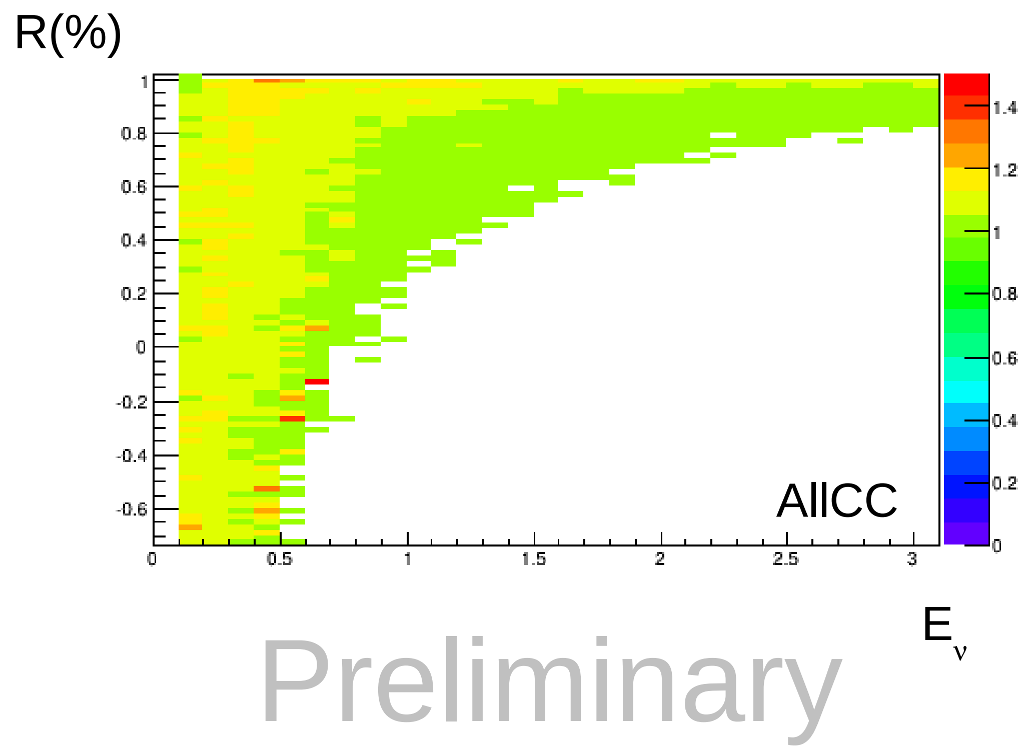


- After about one year, we can constrain uncertainty on NC π^0 rate better than known from error in axial mass
- Need to check other detector sizes & configurations
- Also need to compare with constraint from P0D

MEC

Ratio of ν_μ CC and CCQE interactions w/ & w/out MEC (NEUT)





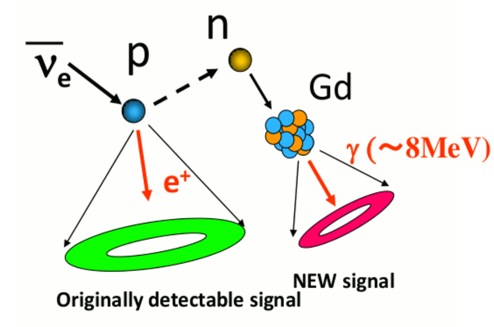
- Looking at ~10-12% effect around 1 GeV relative to the whole CC xsec, with a rapidly changing ratio between 0.5 & 1 GeV
- MEC error cancels in near-to-far ratio. We expect ~a percent error to quick initial tests. We will investigate soon further with reconstructed events at the intermediate detector.

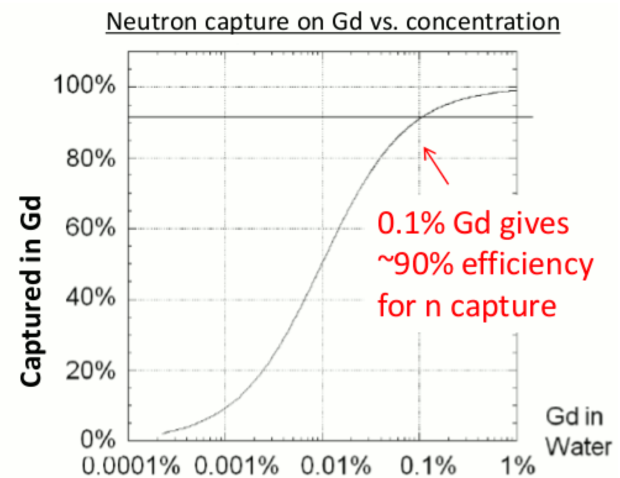
Gd-doping

- Aim to dope the experiment with Gd.

- For 0.1% concentration of Gd 90% of neutrons are captured on Gd rather than thermalized in water.

- We recently started to explore this idea. We will contact soon the EGADS/GADZOOKS!'s experts and also start to work on the the simulation.





- CP-related goals:
  - Use to separate CC versus NC interactions. In neutrino mode, neutron multiplicity is expected to be lower for CC interactions.
  - Separation neutrinos versus anti-neutrino. More neutrons for anti-neutrinos. It's important to measure the neutrino component in an anti-neutrino beam.

Gd-doping

- Xsection physics:
  - Study nuclear models in details. A predicted effect of two-body currents is a high nucleon multeplicity in the final states.

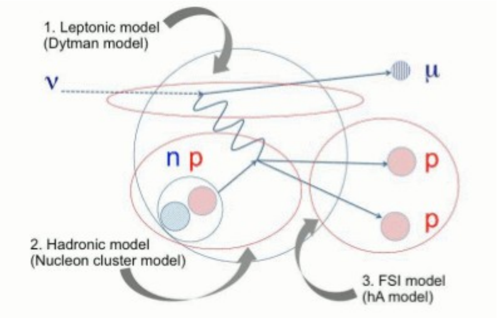


FIGURE 1. Basic strategy of modeling MEC in GENIE.

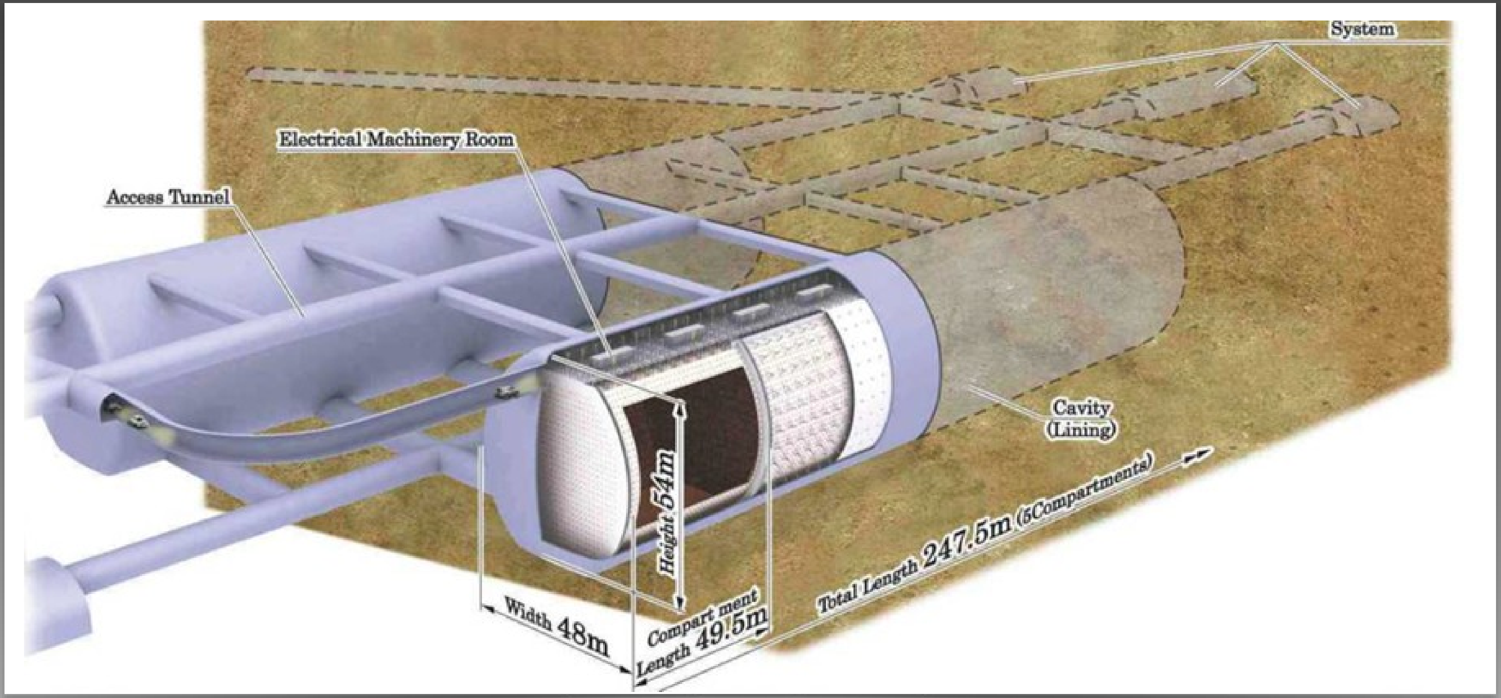
TABLE 1. Comparison of MEC models in neutrino interaction generators.

	GENIE	NuWro	GiBUU
Leptonic model	Dytman model	TEM, np-nh model, and Valencia model	Transverse projector
Hadronic model	nucleon cluster	nucleon cluster	phase space density
initial nucleon momentum	Fermi sea	Fermi sea	Fermi sea
initial nucleon momentum correlation	none	none	none
initial nucleon spatial correlation	none	none	2 nucleons are generated at the same location
initial nucleon pair	n-p:n-n=1:4 isospin ansatz	n-p:n-n=9:1 short range correlation	n-p:n-n=12:5 statistical average
FSI model	hA model	cascade model	BUU transport

T.Katori
arXiv:1304.6014

- "Other" physics:
  - Neutron interaction rate, relevant as a background for proton decay (currently will be investigated by ANNIE, but this detector has a later timescale and larger)
  - SN neutrinos → lower statistics (~500 evts?) than HK, but it is relevant to get an SN alarm in coincidence with HK.

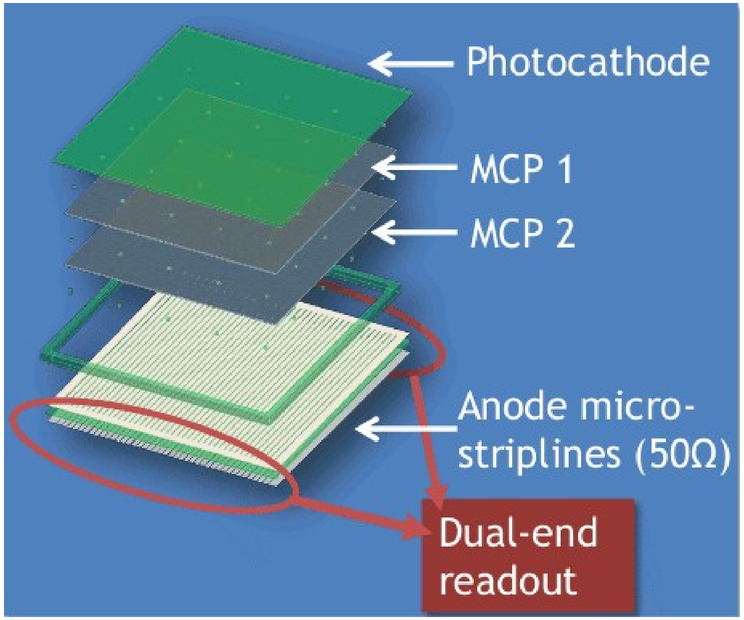
Detector

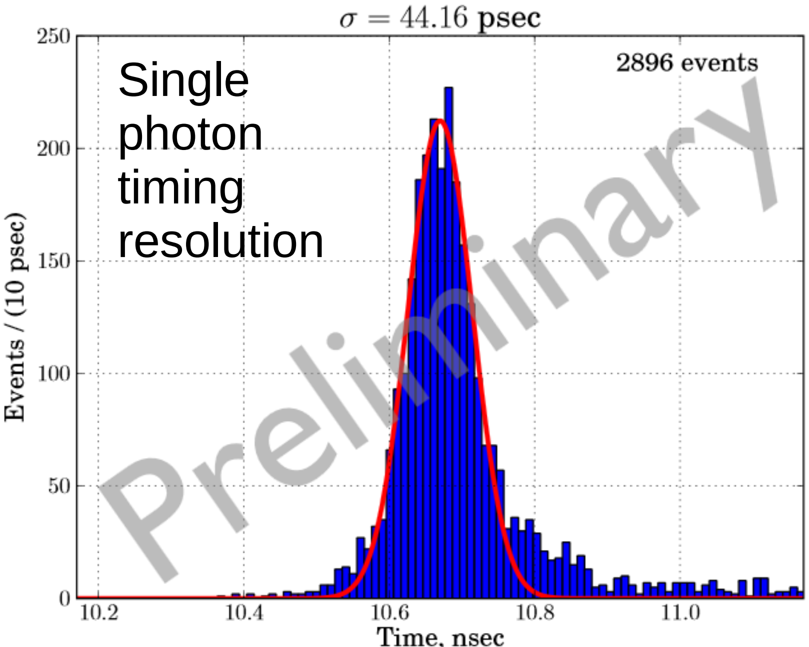

System
Electrical Machinery Room
Access Tunnel
Cavity
(Lining)
Height 54m
Width 48m
Compart ment
Length 49.5m
Total Length 247.5m (5Compartments)

LAPPDs

- Investigating the option of using the LAPPDs (signed ANNIE's proposal). We will discuss this more in details at the next ANNIE collaboration meeting w/ LAPPDs experts.
- Improved timing resolution, currently limited by PMT transit time spread (2-5ns per photon).
- LAPPDs show the benefit of excellent single timing resolution of ~50ps
  - Improved vertex resolution
  - Improved spacial resolution

T.Xin, I. Anghel, M. Wetstein, M. Sanchez

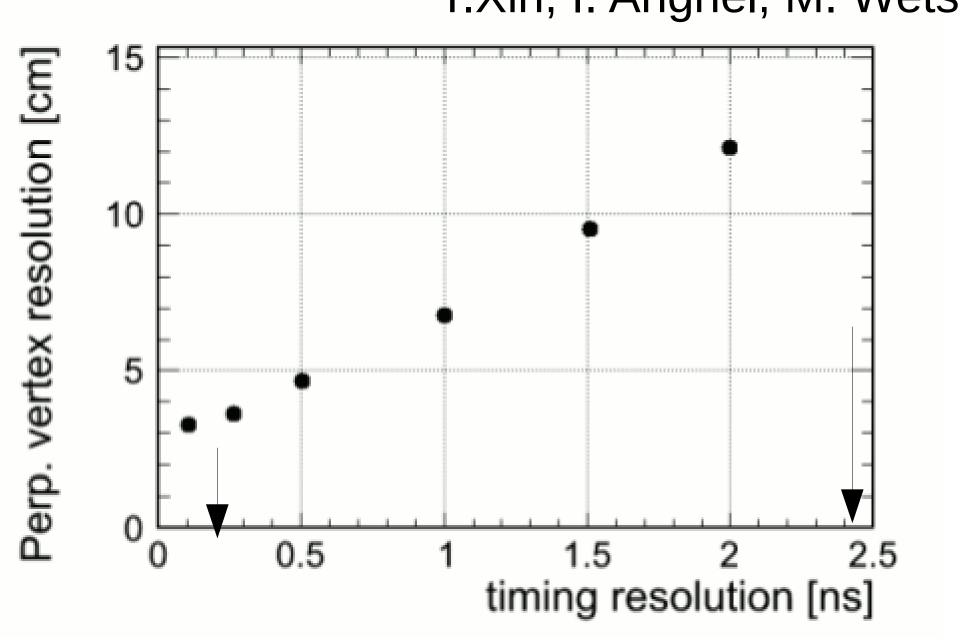


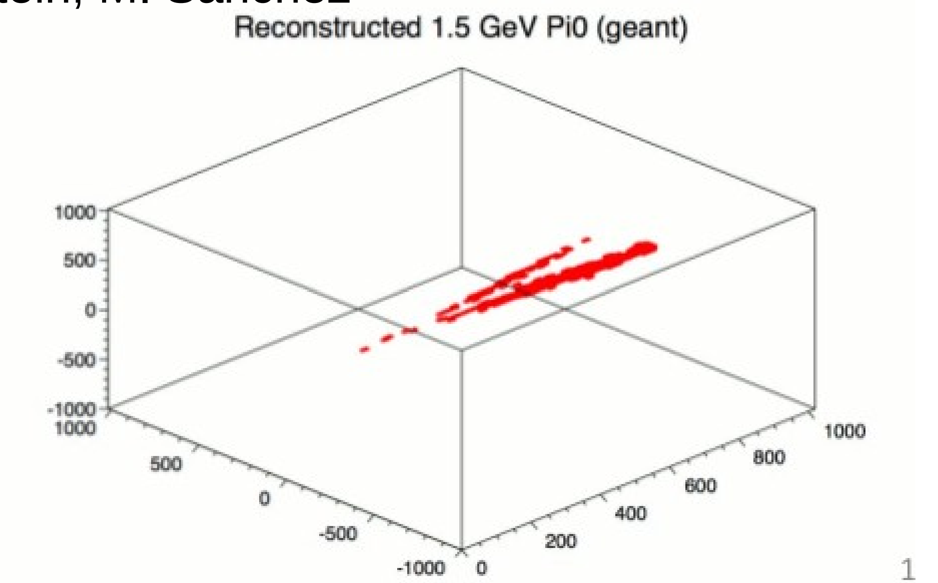


LAPPDs

- Investigating the option of using the LAPPDs (signed ANNIE's proposal). We will discuss this more in details at the next ANNIE collaboration meeting w/ LAPPDs experts.
- Improved timing resolution, currently limited by PMT transit time spread (2-5ns per photon).
- LAPPDs show the benefit of excellent single timing resolution of ~50ps
  - Improved vertex resolution
  - Improved spacial resolution

T.Xin, I. Anghel, M. Wetstein, M. Sanchez



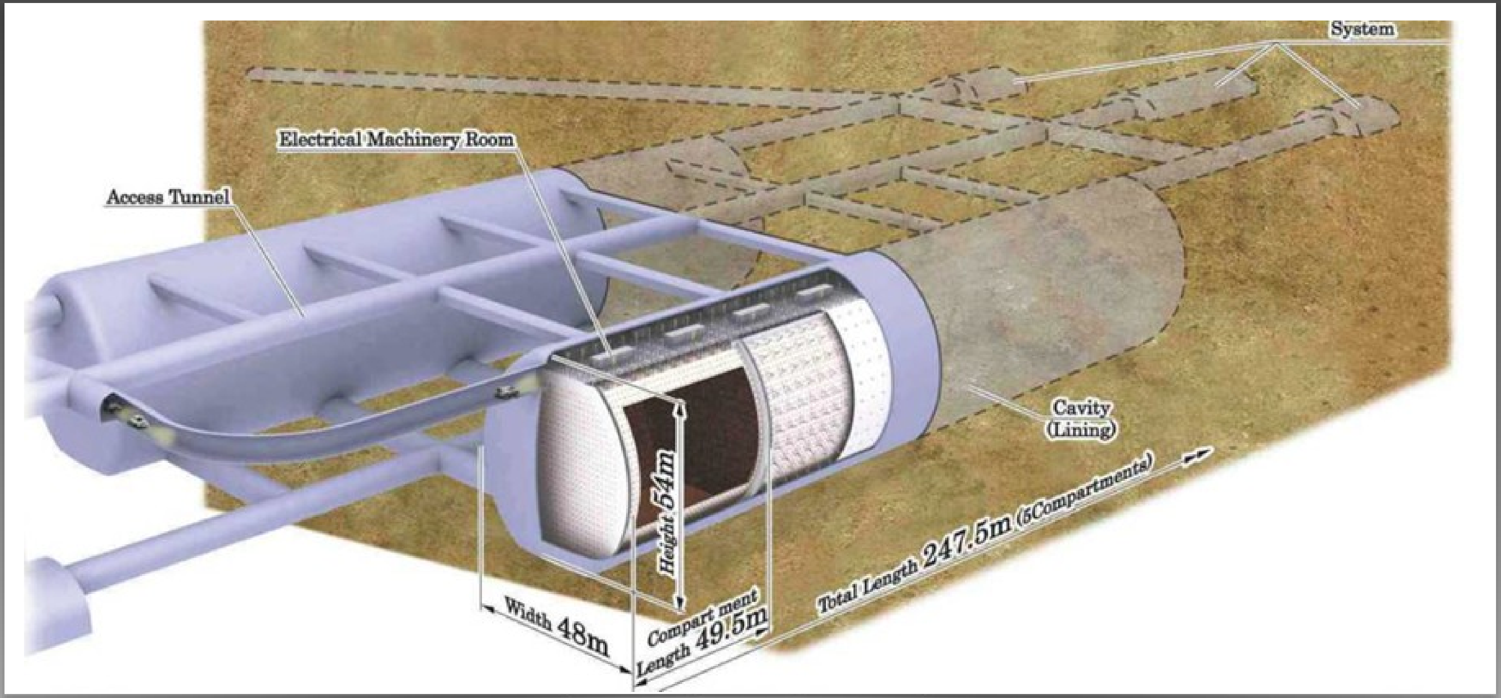


Summary of Areas of Interest

DAQ	extremely successful performance in T2K. New ideas being investigated (see talk at this open meeting).
Calibration	huge expertise.
Photosensors	Interested in the usage of LAPPDs.
Software/Computing	working on computing model.

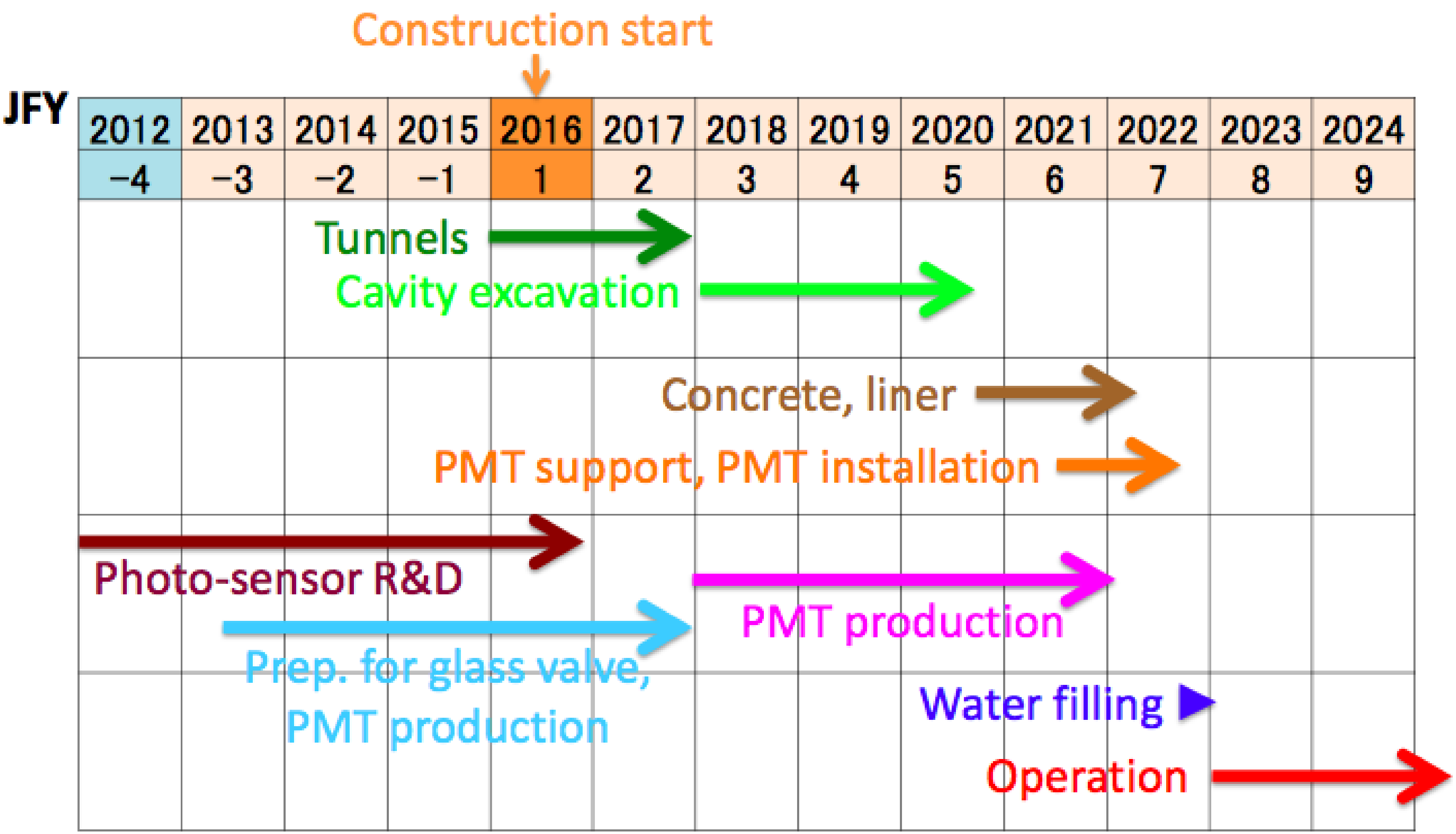
- Interest from other Countries is very welcome.
  - We will contact EGADS/GADZOOKS!'s, LAPPDs/ANNIE's experts.
- Intermediate Detector meetings happening ~weekly on Monday mornings GMT from the end of 2013.
- Please let me know if you want to contribute.

Schedule & Costs



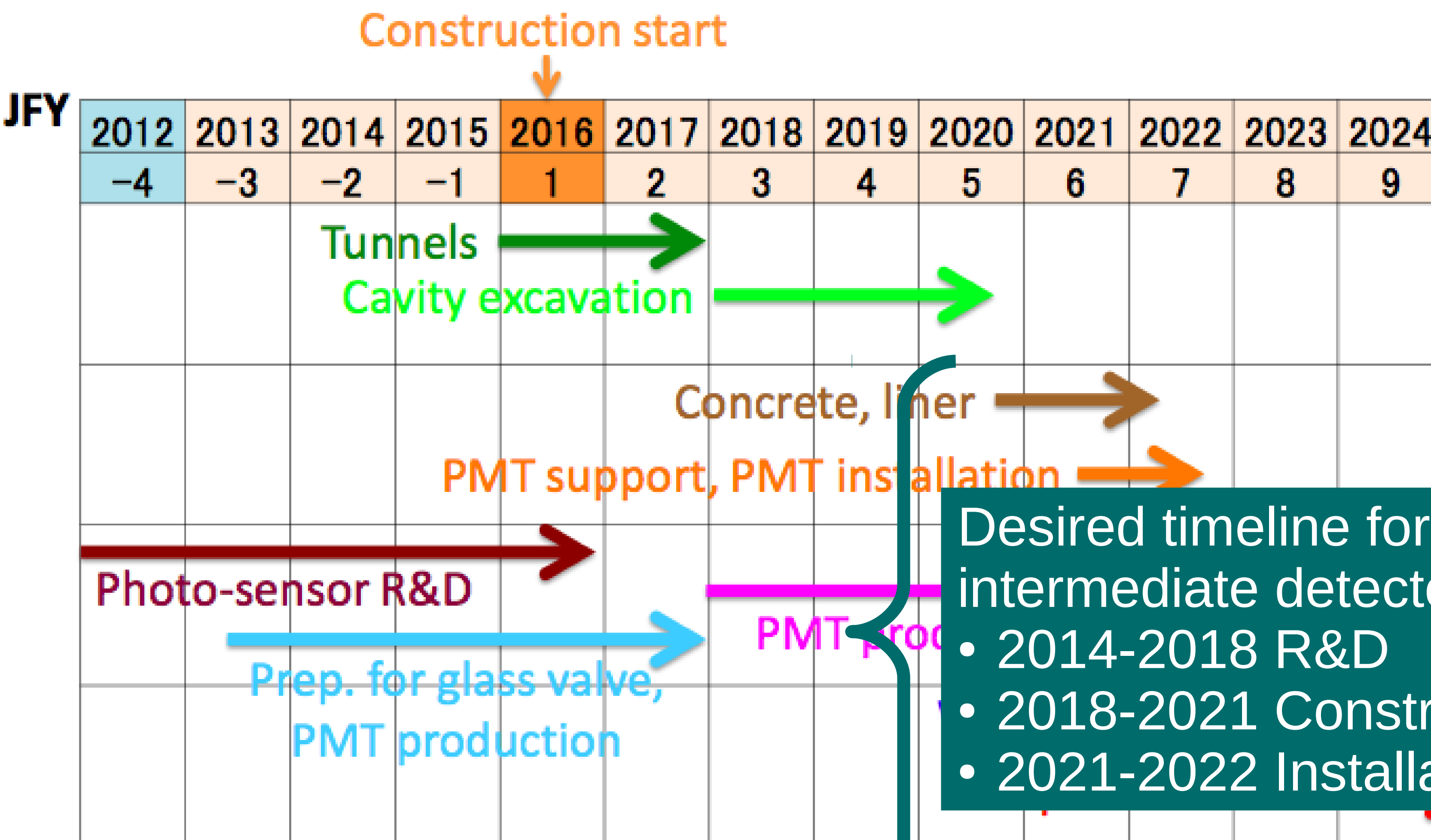
Overall Project Schedule

- Overall HK construction: ~7 years
- Assuming full funding starting in 2016.



Overall Project Schedule

- Overall HK construction: ~7 years
- Assuming full funding starting in 2016.



Desired timeline for intermediate detector
- 2014-2018 R&D
- 2018-2021 Construction
- 2021-2022 Installation

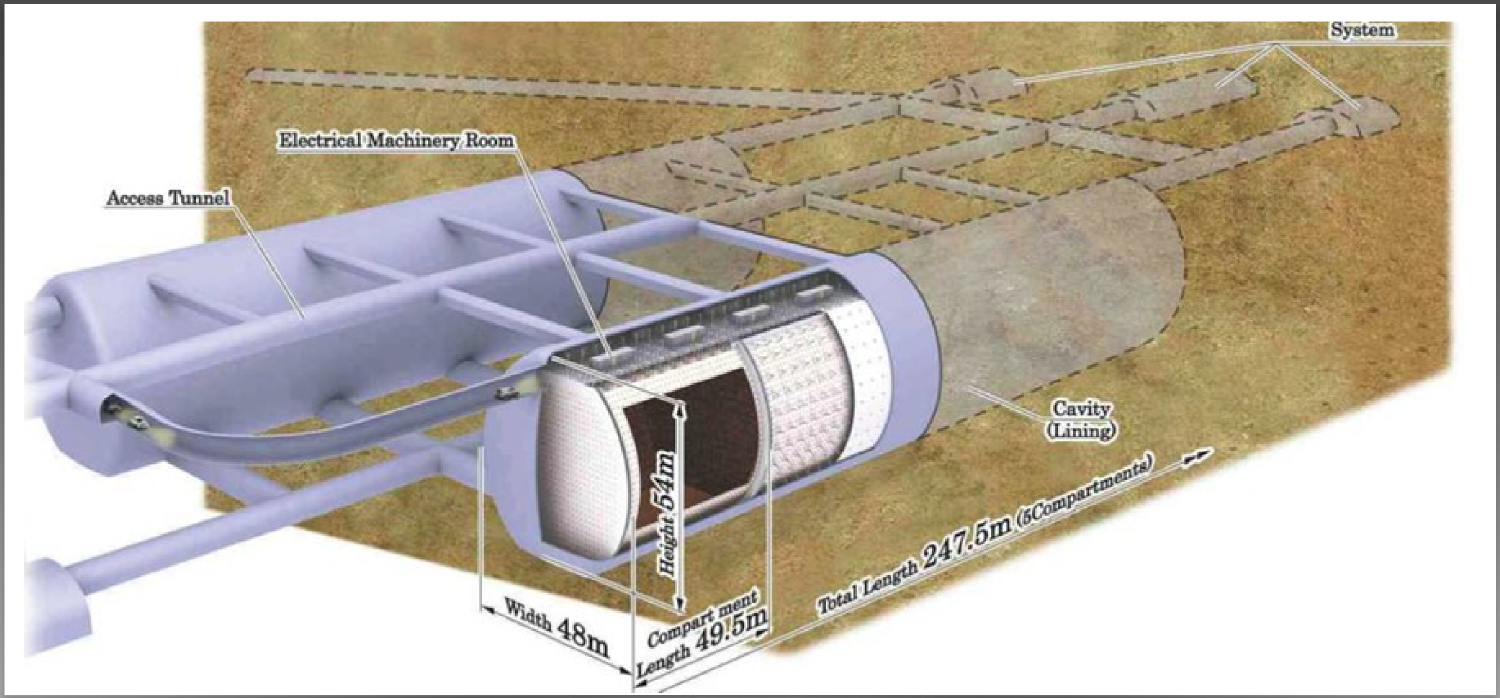
Short Term Timescale

- All needed studies have started.
- We will move to use reconstructed events next month.
- We will use expertise from EGADS/GADZOOKS!'s, LAPPDs/ANNIE's experts
- February:
  - BANFF and F/N studies → input to sensitivity studies
  - Use reconstructed events to finalize results on muon range/pile-up/MEC/NCπ^0
  - Initial studies w/ Gd-doped detector.
- March:
  - Continue above studies
  - Cost estimates

Overall Cost Estimate

- We are starting to estimate the costs.
- We aim to re-use estisting vessels and water systems if possible (eg HK WC 1kton prototype → can we build a 2kton instead as prototype? etc)
- Similarly for the MRD (eg SciBooNE → ANNIE MRD).
- We can also limit the usage of the LAPPDs and partially use HPDs or other PMTs.
- 2006 civil construction cost at 2km: ~$11.2M (T. Kajita), but included also LAr detector→ the length of this detector will be less, so the costs will be smaller.

Summary

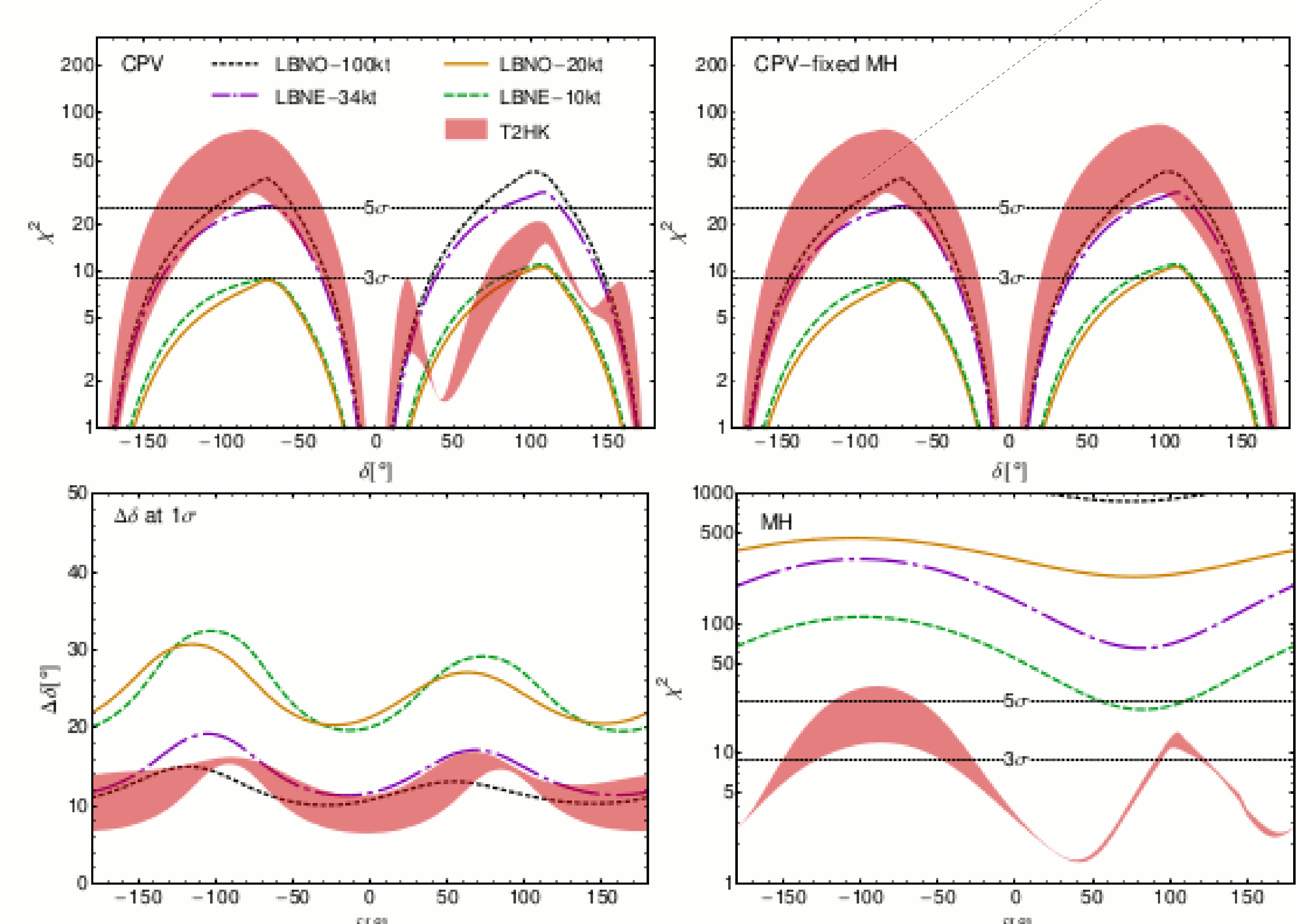

System
Electrical Machinery Room
Access Tunnel
Cavity
(Lining)
Height 54m
Width 48m
Compart ment
Length 49.5m
Total Length 247.5m (5Compartments)

Summary

- A new intermediate detector can
  - **Reduce CPV error w/ flux and target as at Hyper-K.**
    - Very promising initial results.
  - **Can measure NCπ^0 and ν_e/ν_μ**
    - Good constraint on NCπ^0 just after 1y.
  - **Gd-doping can augment the physics portfolio**
    - CP physics (CC/NC separation, ν/anti-ν sepation)
    - Xsection: help to understand the multinucleon models
    - Proton decay: measure neutron rate
    - SN: add a coincidence detector.
- From initial studies on muon range and pile-up, we aim for a 2kton 11mx22m detector with MRD to be further optimized.
- Preferred location between 2-3km.
- Will continue address all the aspects more in details for the LoI

Summary

We can improve it!



Input to strategy group for the update of the EU strategy
http://cds.cern.ch/record/1628377/files/Briefing_book.pdf(2013). Beam power: LBNE 700kW 10years, T2HK 1.66 MW 5 years, LBNO 800kW 10 years).

Backup Slides

Multiple nu-interaction probabilities

1.8km

Detector	Volume (kTon)	+320 kA pulse	-320 kA pulse	+320 kA bunch	-320 kA bunch
1kT	1	31.5%	12.1%	4.6%	1.6%
Half SK	8.36	95.7%	66.0%	32.7%	12.6%
Mid1	4.18	79.4%	41.7%	17.9%	6.5%
Mid2	2.09	54.7%	23.6%	9.4%	3.3%

3.0km

Detector	Volume (kTon)	+320 kA pulse	-320 kA pulse	+320 kA bunch	-320 kA bunch
1kT	1	12.7%	4.5%	1.7%	0.6%
Half SK	8.36	68.0%	32.2%	13.3%	4.7%
Mid1	4.18	43.4%	17.6%	6.9%	2.4%
Mid2	2.09	24.8%	9.3%	3.5%	1.2%

- Without applying the 10ns cut
- Same conclusions