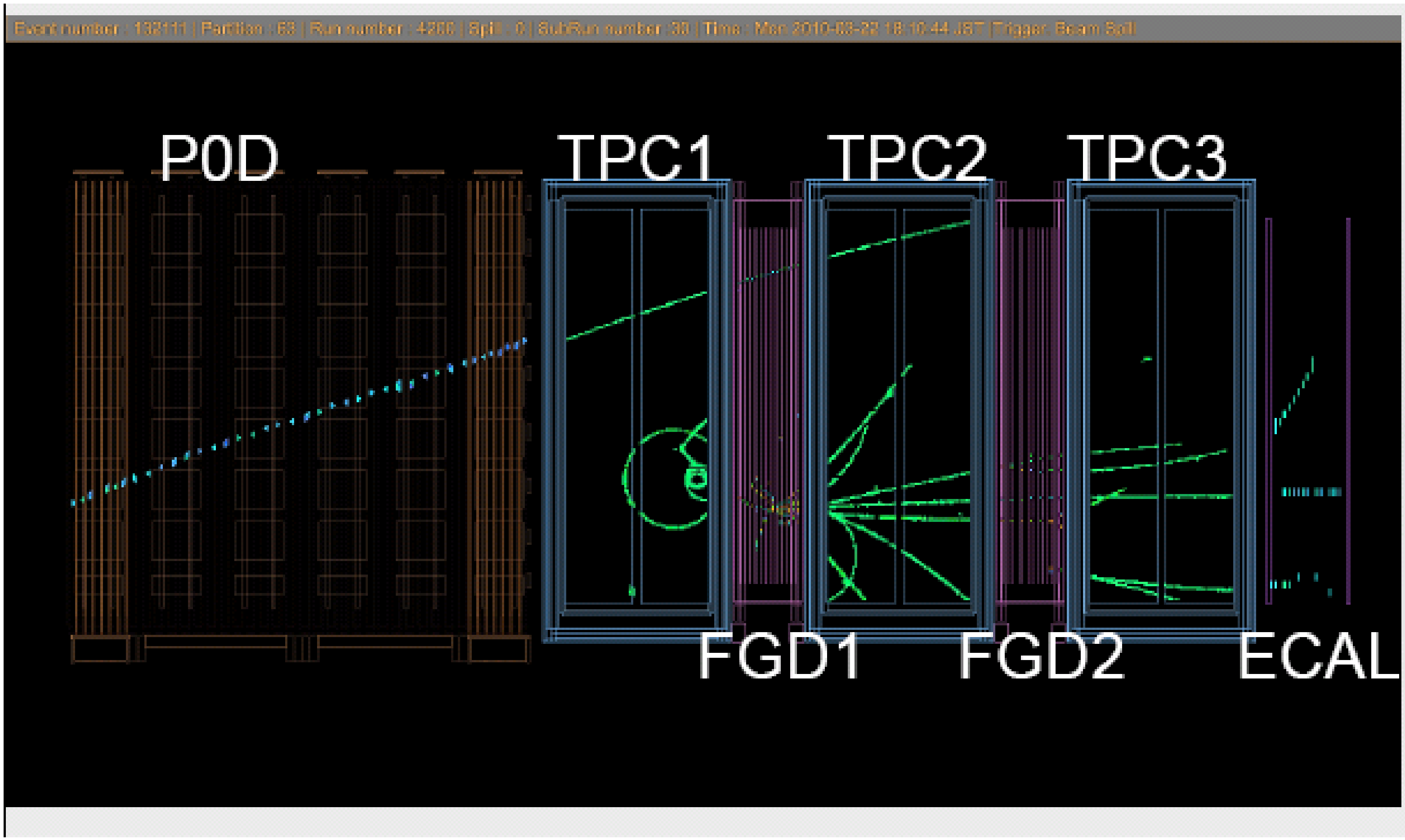
ND 280 upgrades



with help by Jeanne Wilson, Mark Hartz, Leila Haegel, Mark Rayner, and many others

Preamble

ND280 off-axis detector:

1- a magnet (gift of CERN to Japan) refurbished and shipped under the responsibility of ETHZ (A. Rubbia) with funding from the Swiss confederation and from several collaborating countries (France, Germany, Poland, Spain, Japan)

2- a number of detectors P0D, TPC, FGD, TPC, ECAL , SMRD from the whole collaboration

3- a know-how of reconstruction, systematics , etc... still progressing.

4. typical fiducial volume (FGD1) is 1.75x1.75x0.35 = 1.07m^3 ~1 ton.

5. FD/ND flux ~ 0.6-0.8 10^{-6} i.e. statistics at 280 m in 1ton is equivalent to ~1.4 Mton at HyperK location
   ➔ as is, statistics are amply sufficient for HyperK,
   especially since the disappearance is almost complete and appearance is small
   In fact 500kg would be enough.

6. Uncertainty on FD/ND flux is ≤ 2% (T2K, Phys. Rev. D 87, 012001 (2013) and improving.... detector being close to target is probably not a fundamental limitation.

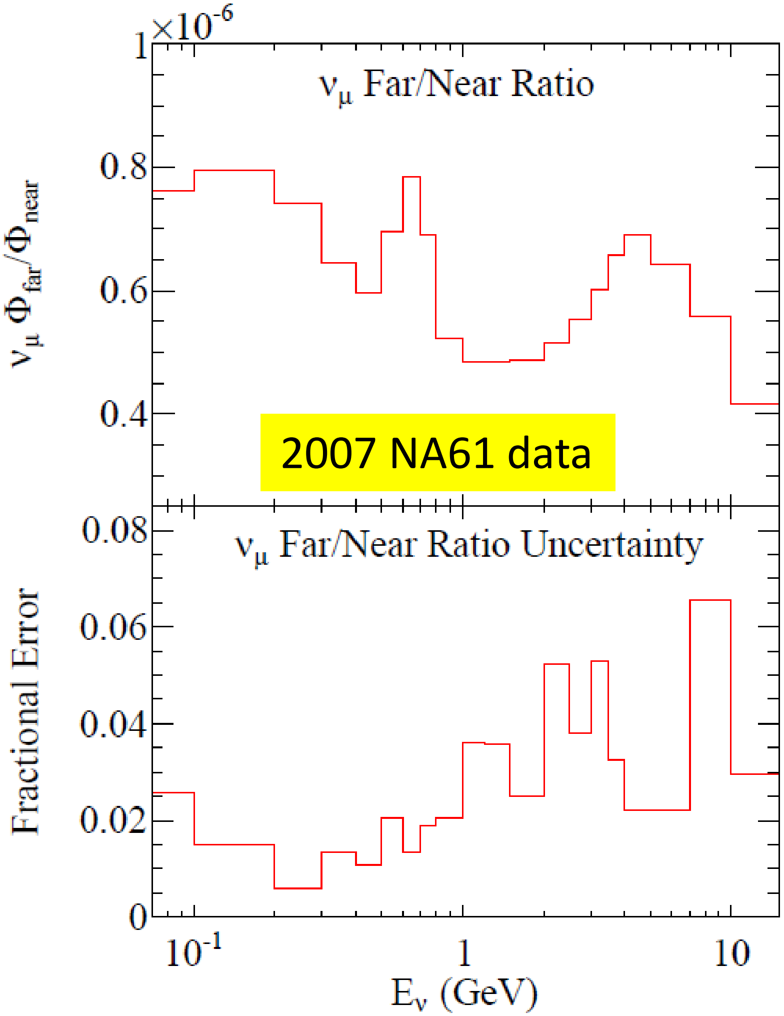


FIG. 45: The far/near ratio for the ν_μ flux prediction (top) and the uncertainty on the ratio (bottom).

preparing 2015 version with 2009 NA61 data

NA61 performance can be further improved, see Silvestro's talk tomorrow

ND280 Detector -> HK

30-3-2015

J R Wilson

Ask those responsible for each Component these Questions:

- 1. What manpower is required to maintain the operation of the detector (including regular maintenance, on call experts and calibration)?
- 2. Would any of the supporting institutes for T2K be able to maintain the operation for Hyper-K? If not, is there potential to donate the hardware to HK at the end of T2K? and who currently owns it?
- 3. Are there any components that would be expected to fail on the timescale of Hyper-K?
- 4. Are there any obvious upgrades that could be made to improve the ease of the detector operation or the performance?
- 5. Can you give an idea of operation costs, including replacement parts etc.?

DAQ and Electronics

1. During running DAQ expert has to be available all the time. -> at least 3 people during any extended running period. This on-call DAQ expert currently has a back-up of real system experts who originally designed, built and commissioned the DAQ/electronics. Calibration -> job of detector experts
2. Most of the hardware (DAQ/electronics) has been donated to KEK and the UK is not expecting to get any of this back. If the UK institutions stay in T2K and continue their involvement in HyperK, we would expect that we would continue supporting the system. However, it is very difficult to say if this also true in 5 years from now. I assume an important question would be if T2K runs until HyperK comes online. This will also depends on the overall decision of the T2K-UK groups and if STFC continue to fund us.
3. We expect all components to fail at some level over the next 5-15 years.
   - The commercial PCs will have to be replaced every ~5 years and it is not clear if the hardware to connect to the backend boards (optical GBit Ethernet) will still be available over the lifetime of the experiment.
   - Uninterruptable power supplies need new batteries every ~3 years.
   - The electronics is already obsolete and it will be impossible to build any new spares.
   - Less than around 1% of TRIPt frontend board have failed over the last years and we do have at least 10% spares. Additionally 5% of the backend board have failed for which we have 20% spares.
   - Could easily imagine failure rate to double -> problems with the backend boards.
   - Power supplies or similar are essentially commercial components for which replacement of similar functionality will always be available.
4. The major source of instability in the system is the optical trigger link. This is something that could be improved changing the firmware of the existing boards, but which would be a major bit of work. We are currently considering doing this. We are also moving into the direction of having remote experts, which may require additional hardware interlocks to be installed.
5. Estimates:
   - Replacement of commercial PC every 5 years: 50-100k£?
   - Replacement batteries every 3 years: 5k£
   - Electricity: no idea

ECals

- Laura will get back to us ~ month

FGDs

1. Manpower:
   - 1 on site expert during beam
   - 1-2 weeks of maintenance per year for the water system and electronics
   - 1 person-hr per week to check the calibration
   - 1 person-week per year of data vs. MC tuning
2. It isn't clear to what extent the Canadian group could continue to support the FGDs into Hyper-K. If they can't, there would be the potential to donate them to whichever institutes could support them.
3. Can't predict how the detector components might age, but there is the possibility of failures with time (electronics, water system).
4. Scott also thought that if an FGD type design was used (and the P0D was removed) it might be better to make a third FGD

TPCs

1. Need 1 on-call expert in JPARC. Normally 2 during the start-up and shut down. Also need experts on the electronics (non TRIPT), but mainly on the gas system. Off-line experts for calibration of the TPC.
2. Need more than 1 institute. Currently 7 institutions and difficult to fill the expert shifts. The donation is something we need to discuss within the group. The only group that has shown interest in HK is the Canandian group, but it might be more in the future.
3. Refurbishing of the gas system is mandatory but also upgrades of the back end readout electronics (DCC). The rate of channel failures is small so will not require big actions both in the MM or the front end electronics.
4. Again the DCC front end might be something to consider to reduce the readout latency and be more robust against high occupancy events.
5. Operation cost is driven by the gas (we operate in open circuit). This is paid at moment from the common fund, not a negligible amount.

P0D

- P0D provides a complementary measurement ofCCinc, NCpi0 etc. where you can do a water subtraction which is foolproof. The measurements w/o a subtraction have difficulties knowing exactly where the vertex originates (in water or Scintillator).
- Also if you measure very accurately neutrino and antineutrino water xsec ratios vs Enu (important for future HyperK/DUNE Physics), we know that the angular distributions of neutrino and antinu are very different due to the antinu helicity, so the backward tracks and vertex migration can be very different.
- One related aspect is if one wishes to continue to use the P0D beyond T2K (after ~2025), it might be useful to consider modest improvements in the medium term. These could include
  1) Better MPPC's
  2) Leak proof bags, turnkey water filling/draining
  3) Water based soluble liq. Scintillator.
- Of course, there are likely degradation issues such as the P0D scintillator light output. We know that MINOS and MINERVA have problems with their light output dropping per year (~5% I think), which can be serious problem over the long term.

SMRDs

1. 1 person is needed for calibration work, 1 should be in Tokai as an expert during the running time.
2. INR is involved in HK, do not see a problem with the SMRD at the HK time.
3. Maybe some MPPC's and and some electronic channels should be replaced.
4. SMRD detectors have good time resolution of 1 ns but electronics we use now allows us to obtain only about 2-3 ns. If better timing will be needed then we have to upgrade the electronics. The second point – we probably need more detectors in the area close to POD and FGD1 where only 2 magnet gaps are filled with detectors.
5. It depends on what should be done. From the installation experience, the driving cost is the labor if all detectors are manufactured and shipped to Tokai. I do not know the operational cost but suggest it is a small fraction of the ND280 operational cost

Magnet

INGRID

Points Raised

- Ease of maintaining experts affected by any gap between T2K and HK running.
- Timeframe is long (-> 2035) expect component failure
  – Electronics spares could become an issue
- Suggestions:
  – 3 FGD running (no P0D)?
  – More SMRD coverage upstream end
  – Faster SMRD timing?

My personal view (Alain)

-- we will run T2K for a factor 9x more statistics
update is wortwhile already for T2K!

-- we will certainly want to keep ND280 for HyperK
information that it provides is quite unique.

-- Also, if we want ND280 to be alive in 2030, **we should update /upgrade it.**

How?

What is missing?

Present systematics in prediction of number of far detector events is presently of order 8.8%.

Neutrino beam mode $\nu_\mu \to \nu_e$ uncertainties:

Error source [%]	$\sin^2 2\theta_{13} = 0.1$	$\sin^2 2\theta_{13} = 0$
Beam flux and near detector	2.9	4.8
(w/o ND280 constraint)	(25.9)	(21.7)
ν interaction (external data)	7.5	6.8
Far detector and FSI+SI+PN	3.5	7.3
Total	8.8	11.1
	signal	**background**

11% uncertainty on 15% background is 1.7% of signal -- small compared with 8.8% on signal (this is dominated by intrinsic beam ν_e)

➔ **In this particular beam, Water Cherenkov is perfectly suited** to do the $\nu_\mu \to \nu_e$ oscillation measurements

(Factor 6 in mass wrt LArg from LBNE study refers to reach in θ_{13} before it was known)

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What are the limitations?

A. Near detector and far detector are different

A quantitative re-projection of these causes of errors is necessary in order to understand better what to improve.

A0. flux at near detector and far detector are different.

The FD/ND ratio is however quite well known

A1. Near dector is scintillator not water

However cross-sections on water are being measured using FGD2 (35% water) , by subtraction from FGD1 with proper weighting, or by identification of events in water

➔ it would be better to have fractionally more water in target.

A2. Near detector has different E_ν resolution and acceptance than far detector.

Acceptance is presently limited to ± 53° (forward) for muons, extrapolation leads to model dependent error. *Needs to be quantified.*

We can now get larger angle muons but momentum and sign determination are unclear.

Efficiency for photons is different? (is it sufficient to estimate correction?)

B. Even if near and far detector were the same:

B1 resolution function $P(E_\nu(rec)-E_\nu)$ contains uncertainties

-- binding energy, Fermi momentum, missing final state etc...

-- this for instance could be extracted from near detector energy distribution

-- this is what nuPRISM tries to do

-- pion interactions in test beam and water Cherenkov could shed light on this issue.

B2 ν_e and ν_μ cross-sections are different due to muon mass interplay with nuclear effects

already knowing response of one species would be great help.

C. of course one way to solve most problems is to have a muon storage ring nuSTORM

-- produces known flux of (μ^+ decay) ν_e and $\bar{\nu}_\mu$ and (μ^- decay) $\bar{\nu}_e$ and ν_μ

-- well known end-point of spectrum provides energy response

e.g. difference between two decay spectra from different muon momentum

gives nearly monochromatic primary beams

-- How to re-design ND280 to improve on these aspects A&B?

Sep 2013
http://www.t2k.org/meet/nd280/meet/NDupgrade/Sep2013/Sep2013-NDWS

Jan 2014
http://www.t2k.org/meet/nd280/meet/NDupgrade/NDWS-Jan14/NDWS

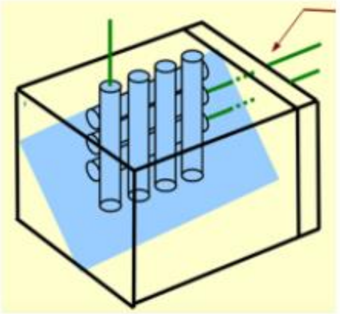
Apr 2014
http://www.t2k.org/ndup/general/meetings/Apr2014/NDup-20140413

Oct 2014
http://www.t2k.org/meet/ndup/general/meetings/20141005/NDup-20141005

Feb 2015
http://www.t2k.org/ndup/general/meetings/20150203/

Instrument P0D water bags
W. Toki

Water-based liquid scintillator
S. Yen
(WBLS is 70% water)



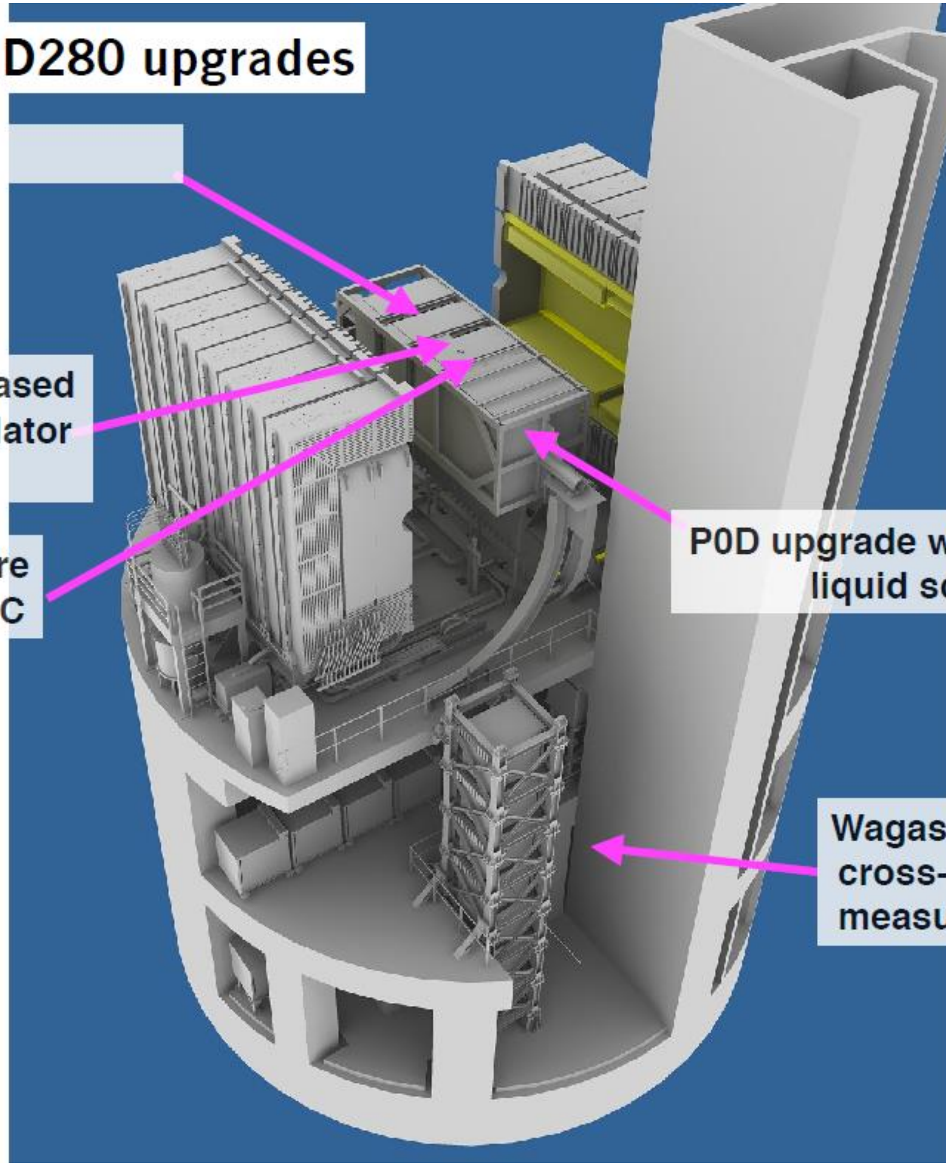
HP-TPC
Sanchéz

nuPRISM
nuPRISM-Lite

Wagasci

Deuterium in FGD2
K. Mahn
- make x-sect meas.
- constrain int. model

Proposed ND280 upgrades



1. IMPROVE WATER TARGETS

2 solutions have been proposed:
-- water based liquid scintillator
-- Wagasci

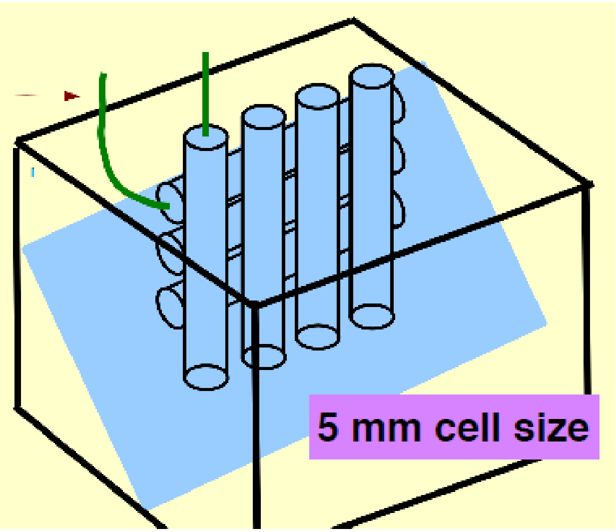
some preference for Wagasci:
-- very robust principle
-- 80% water content
-- scintillator subtraction
empty water
'plastic blocs' section
see Michel Gonin tomorrow
-- missing: 'vertex activity' -- but how important is this?

Straws and WBLS - a better target for ND280?

Water-based liquid scintillator

Stanley Yen, TRIUMF

Current FGD2
- Dead regions
- Low energy recoil protons produce no signal in passive water



mylar straws painted with reflective paint on the outside, WLS fibres strung inside the straws

Water-Based Liquid Scintillator (WbLS) at Brookhaven National Lab
- WbLS-1 70% water **1000** optical photons/MeV
- WbLS-2 70% water **1500** optical photons/MeV

compared with pure liquid scintillator (BC408) **10,000** photons/MeV

Currently measuring light output using TRIUMF cyclotron

http://www.t2k.org/ndup/ general/meetings/ 20150203/

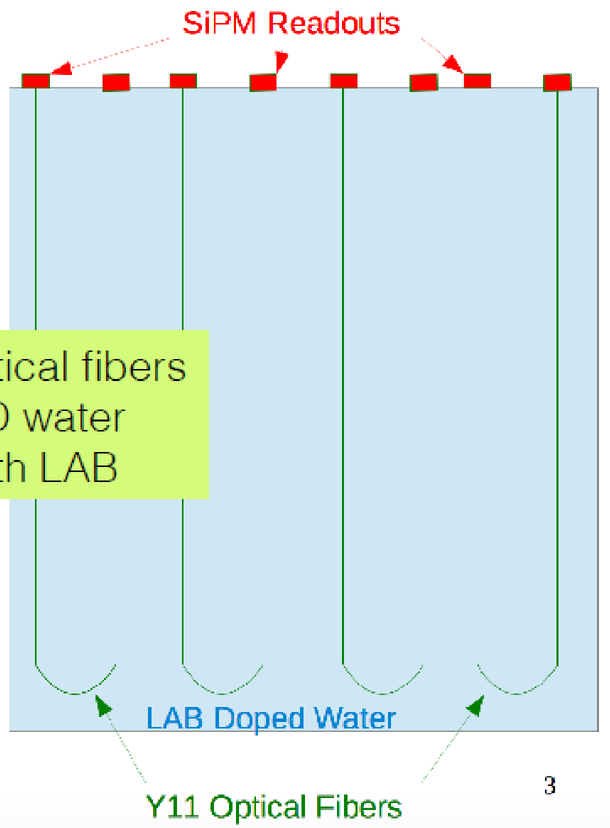
Stop water vertices migrating between p0dules - two methods with WBLS

P0D Water Bag Upgrades

Ryan Wasserman, Norm Buchanan, Walter Toki, Colorado State University

liquid scintillator linear alkylbenzene (LAB)

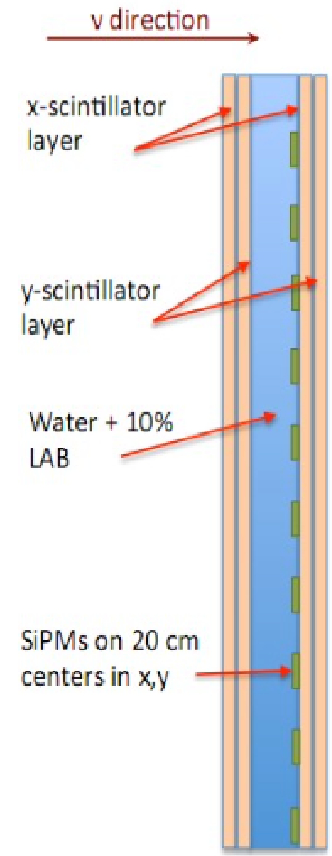
option 1



Curved Y11 optical fibers placed into P0D water bags doped with LAB

option 2

SiPMs and LAB inside P0D water modules



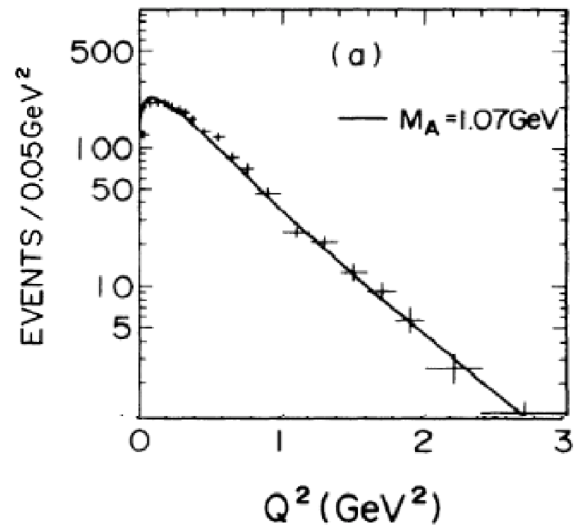
Plans to create a 1m x 1m scale prototype detector in HEP lab at CSU

http://www.t2k.org/meet/ndup/general/meetings/ 20141005/NDup-20141005

Replace FGD2 water with D_2O

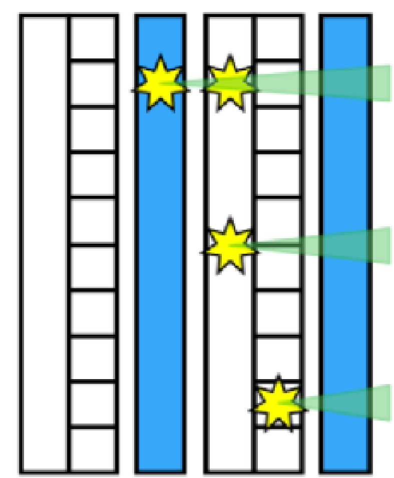
D_2O cross sections with ND280

K. Mahn, Michigan State University



Use neutrino scattering on deuterium to determine 'free neutron'* cross section
*actually a bound state, but an exactly calculable one...

Compare with **BNL** and ANL measurements



- Disentangle axial form factor from nuclear model
- Tune Rein-Seghal model (M_A^{res} etc) using 1π measurement

Extension to Wagasci?

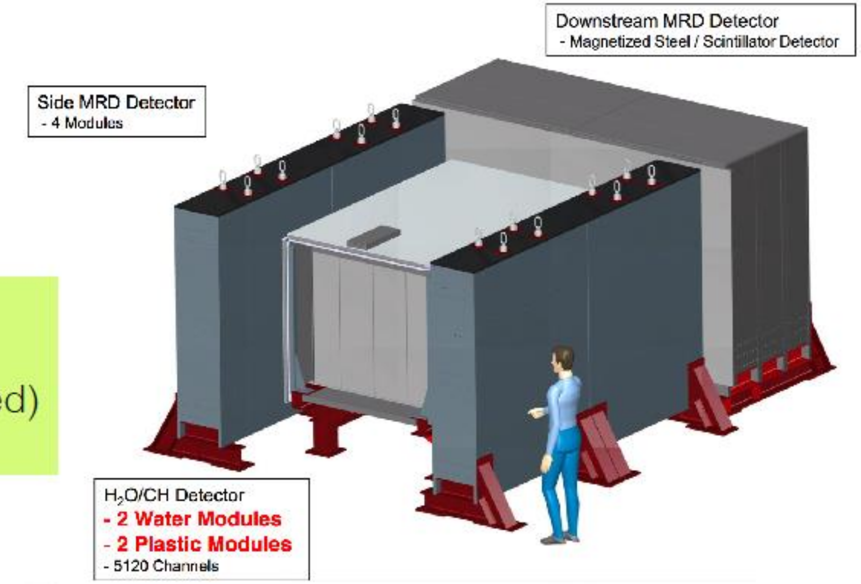
http://www.t2k.org/ndup/ general/meetings/20150203/

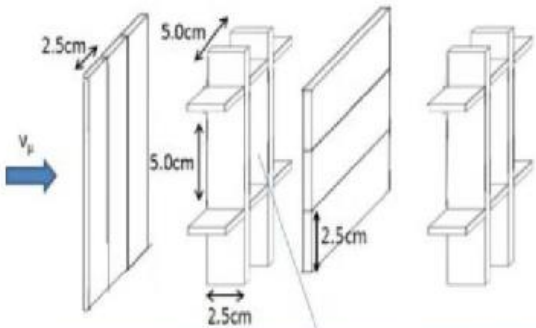
3% precision H_2O / CH x-section ratio

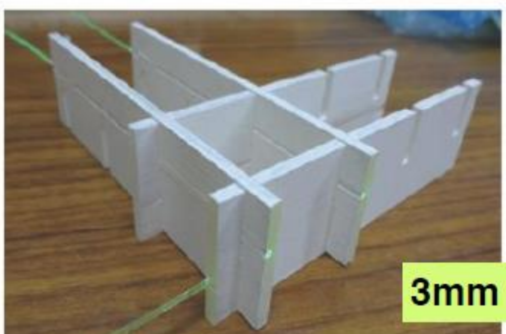
Wagasci

Wagasci collaboration

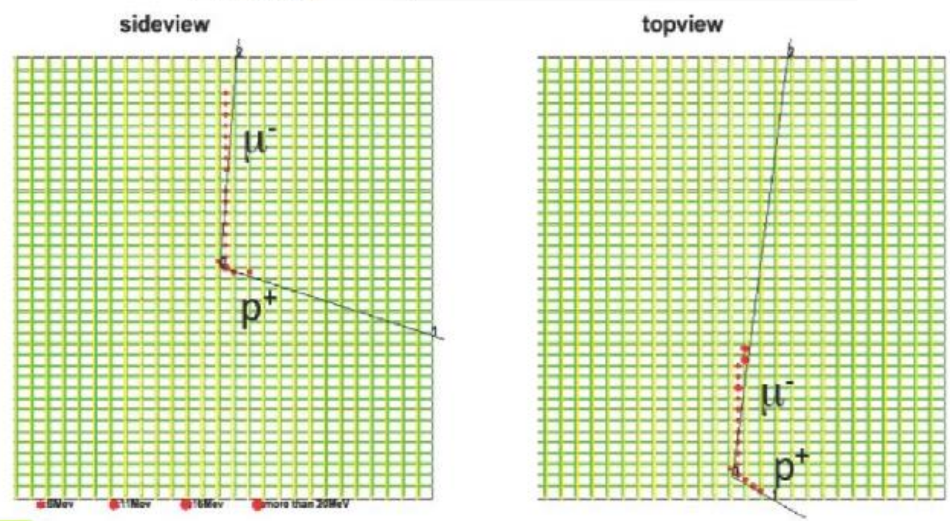
'The B2 experiment'
- 3D scintillator grid filled with water
- Side MRDs and end MRD (magnetized)
- Excellent phase space coverage







3mm thick

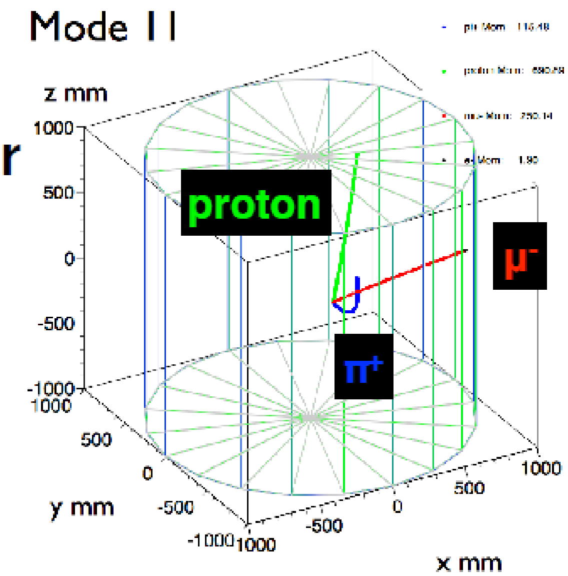


See talk on Tuesday

Low threshold detector to pin down nuclear model

High Pressure Time Projection Chamber

M.Ravonel, F.Sánchez

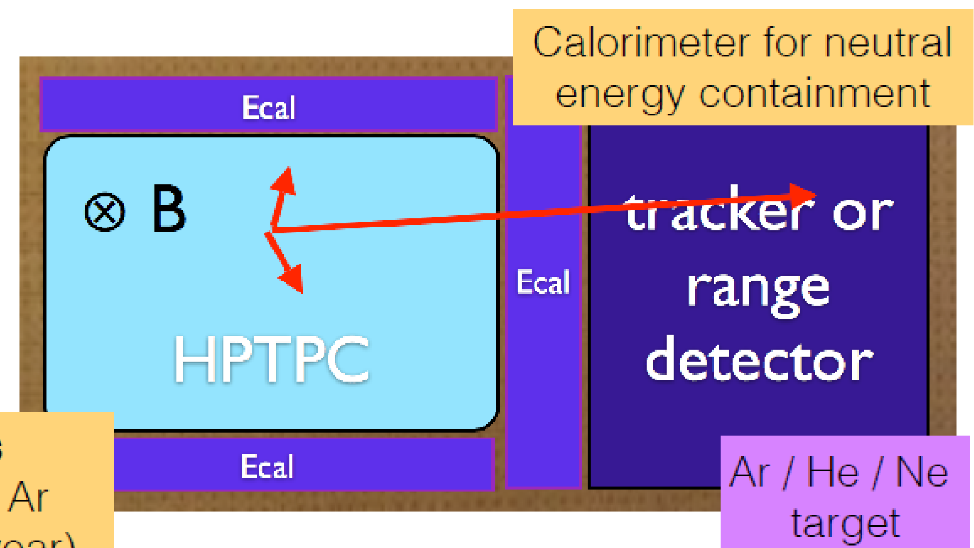


Advantages

- Target = detector.
- 3D reconstruction capabilities
- Possibility to exchange targets
- low density → low thresholds
- excellent PID capabilities
- Almost uniform 4π acceptance

Disadvantages

- low number of interactions → requires high pressure and large volume
- requires in addition a magnet or range detectors to measure momentum



~30,000 CC events in He at 5 bars
A factor x5 for Ne and a factor x10 for Ar
($8m^3$ detector, 4 years, 1.6 x 10^{21} POT/year)

http://www.t2k.org/meet/nd280/meet/NDupgrade/ NDWS-Jan14/NDWS

Improve angular acceptance

-- two solutions were proposed

-- High pressure TPC

very nice vision of vertex

(but what do we learn from that?)

good solution for near detector in case far detector is LArg TPC

(this is why we proposed it for the ND of LBNO!)

still photon and neutron detection needs to be addressed

need pressure vessel around photon detector (→ LBNO prototype)

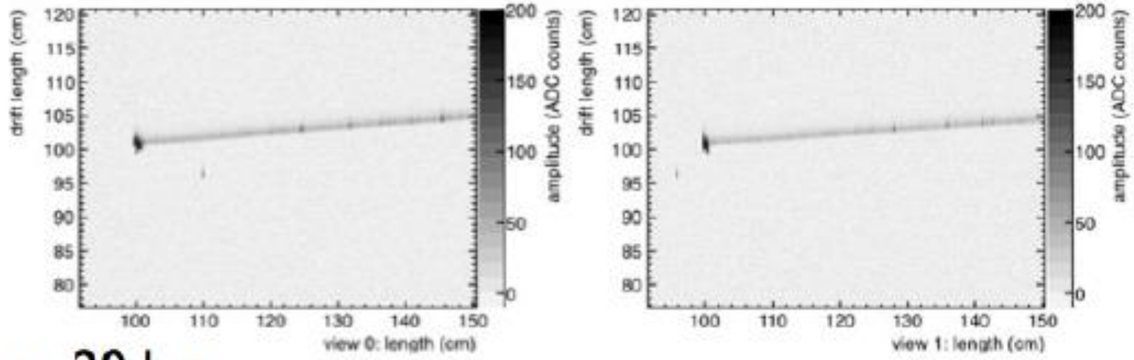
in principle could reconstruct H2O cross-section by combination of gases

e.g. $0.5\ CO_2 + 13/6{*}CH_4 - 2/3\ C_4H_{10} = H_2O$

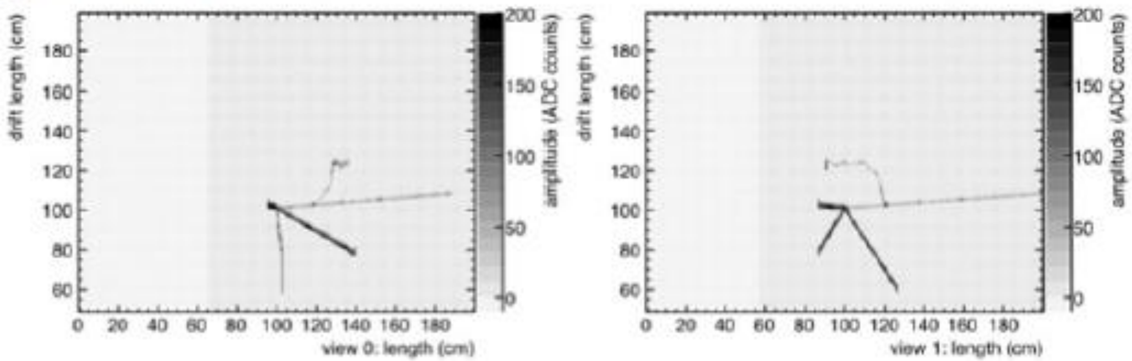
However high P CO_2 captures electrons heavily (capture ↑ more than P)

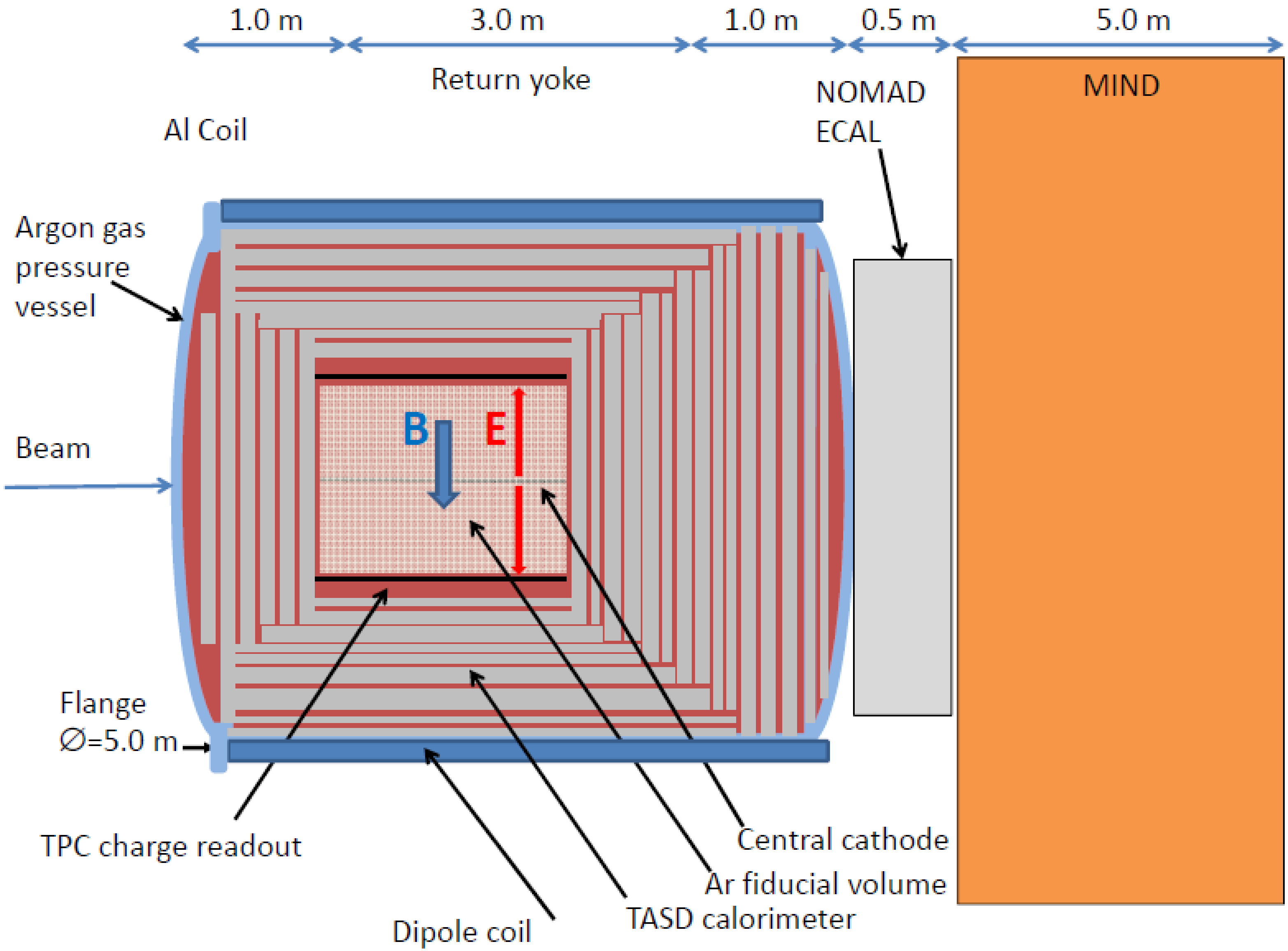
Comparing liquid vs gas argon

liquid Ar



Ar gas 20 bar



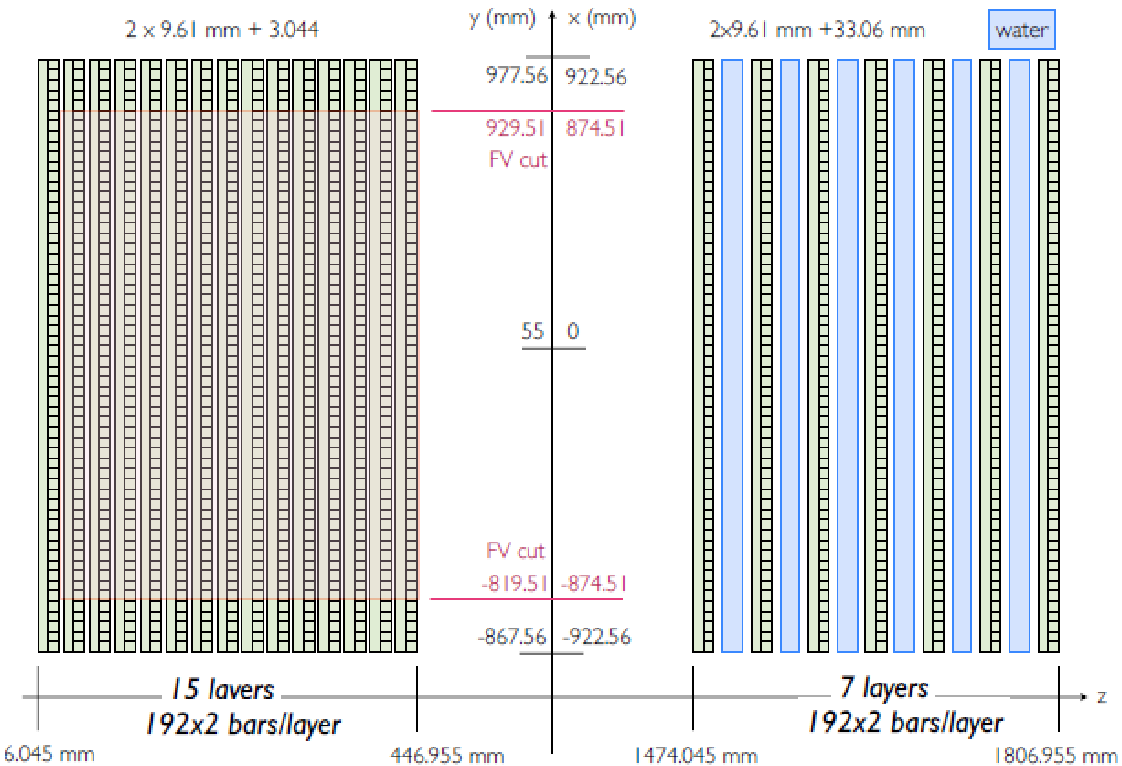


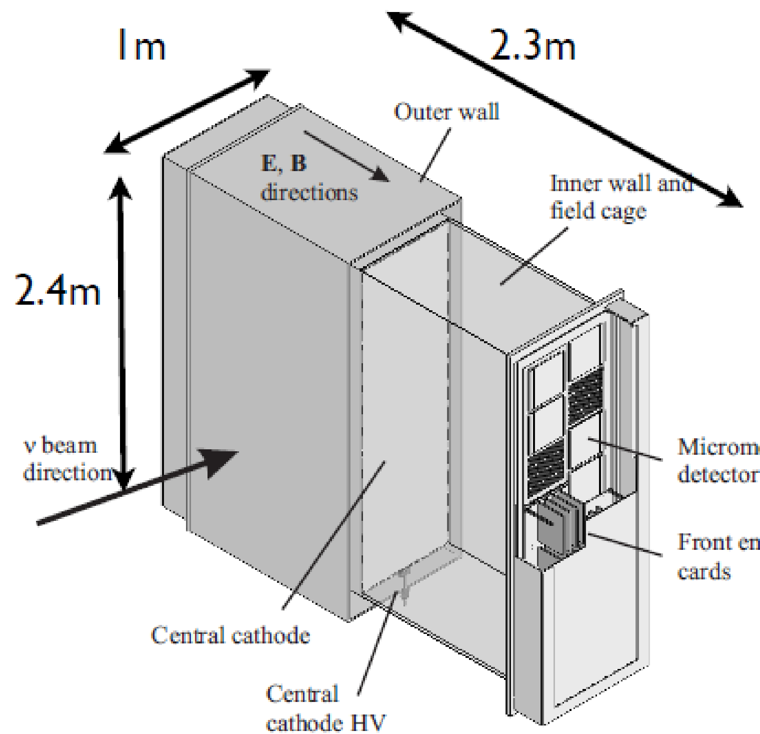
1.0 m
3.0 m
1.0 m
0.5 m
5.0 m
Return yoke
NOMAD
ECAL
MIND
Al Coil
Argon gas
pressure
vessel
B
E
Beam
Flange
∅=5.0 m
TPC charge readout
Central cathode
Ar fiducial volume
TASD calorimeter
Dipole coil

Re-configuration of ND280 to improve angular acceptance

-- use Wagasci for water targets (replacement for FGD)

-- modify geometry to cover uniformly cosθ range





FGDs: $2300\ \mathrm{mm} \times 2400\ \mathrm{mm} \times 365\ \mathrm{mm}$

present configuration

dark blue= TPC drift volume
dark red= TPC micromegas
light blue = FGD

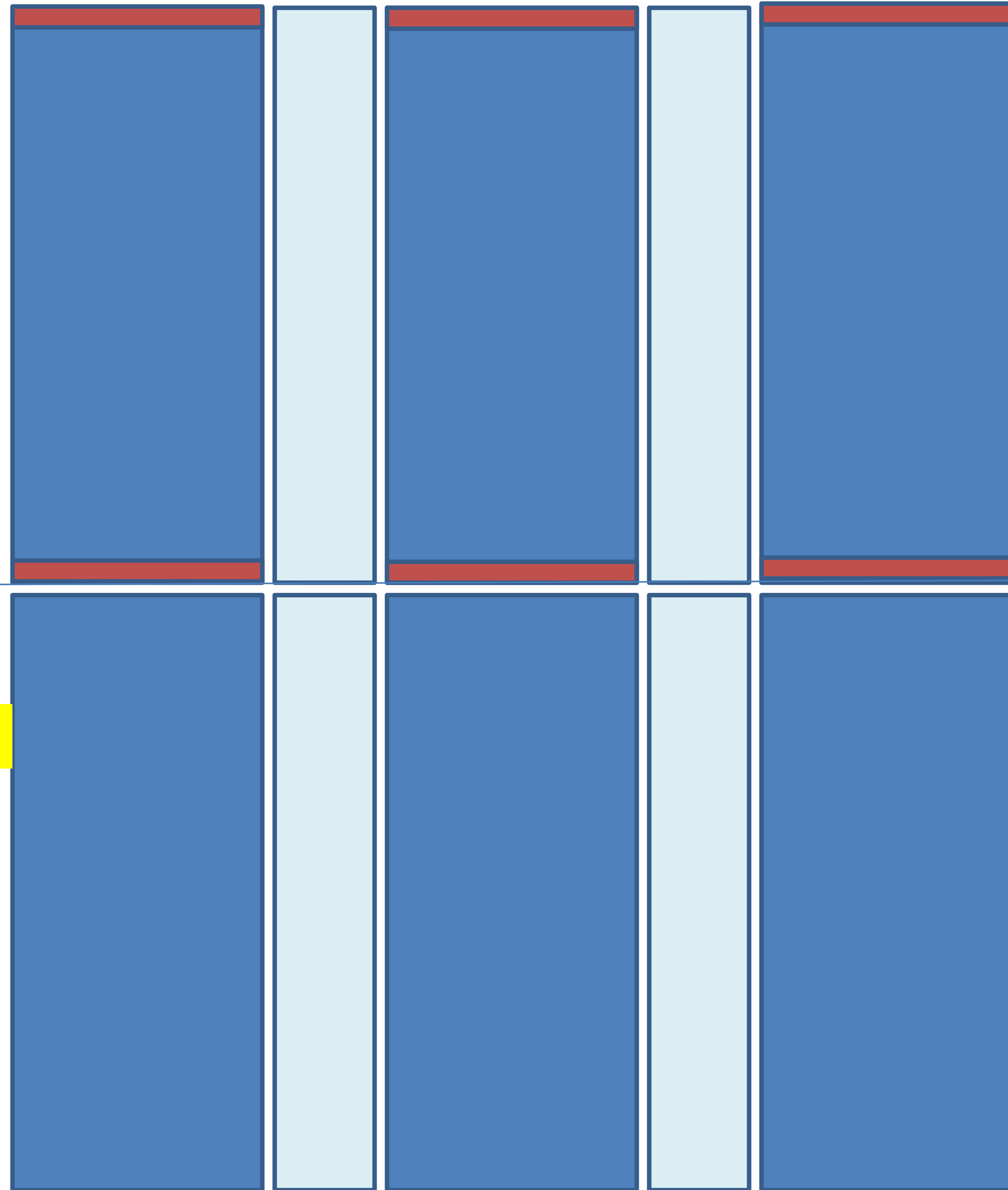
top view:

➔
beam

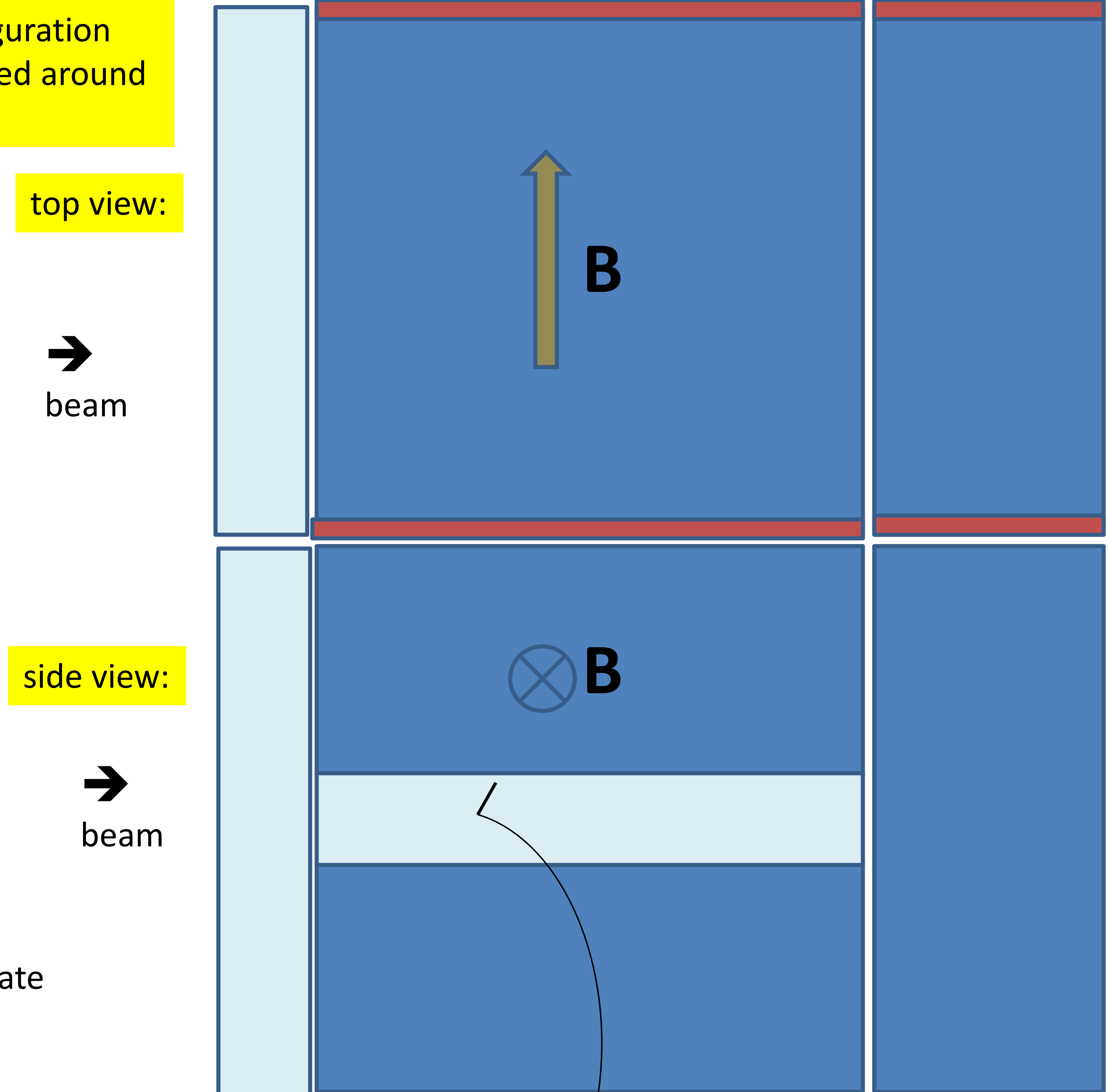
side view:

➔
beam

scale approximate



suggested reconfiguration
TPCs 1 and 2 rotated around
B field axis

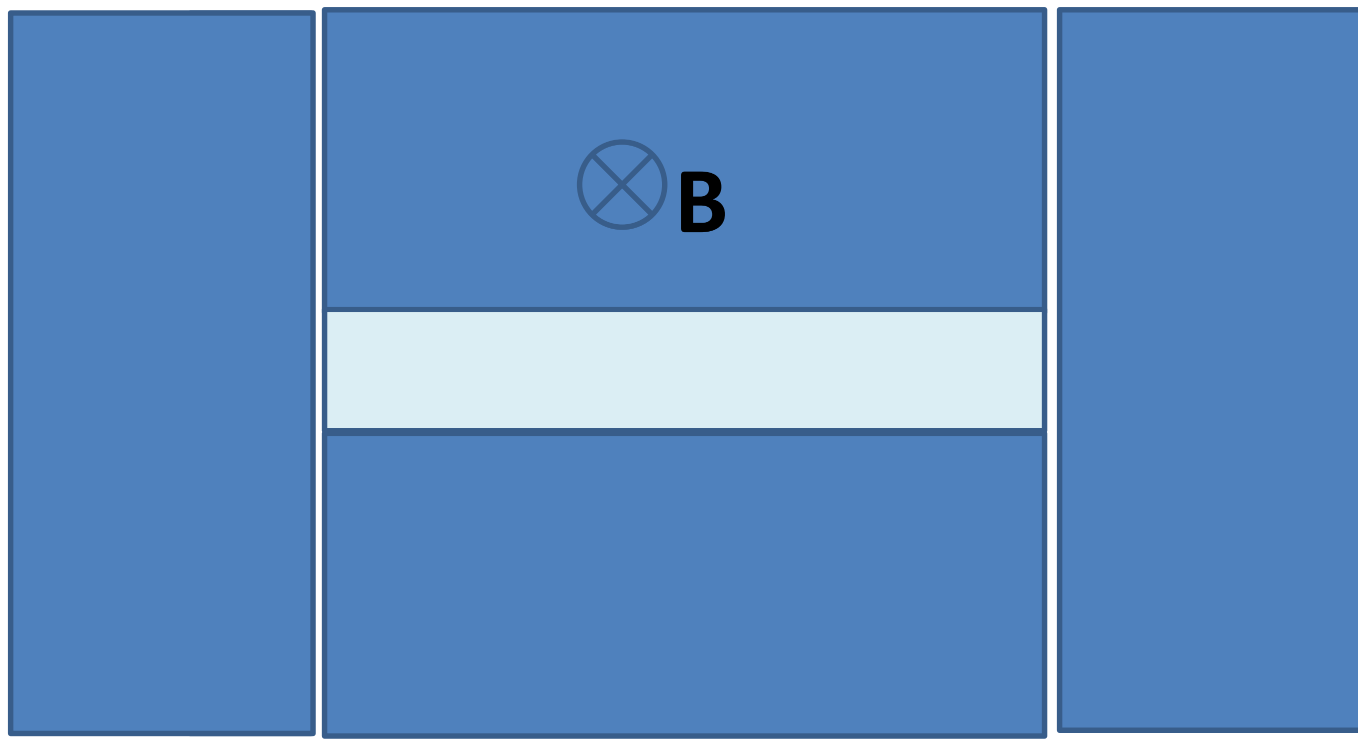


ideally: add a 4th TPC (this was in the plan initially: TPC 0,1,2,3)

side view:

➔ beam

scale approximate



fiducial volume: 2.4x1.7x 0.35 m = 1.4

= 0.6 (plastic) + 0.8 (0.1plastic + 0.7 H_2O) tons

can be increased by improved design of TPC field cage.

CONCLUSIONS

ND280 is a very unique asset of the T2K/HYPERK facility.

MUST keep it and improve it.

This can best be done while still accumulating valuable T2K data

Need T2K-wide effort to optimize this important upgrade

Aim: near detector with water and full cosθ acceptance based on e.g. Wagasci and TPCs

-- are improvements needed/possible to ECAL to complete efficiency to photons?