DUNE ND Concepts

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CENF-ND Start-up Meeting

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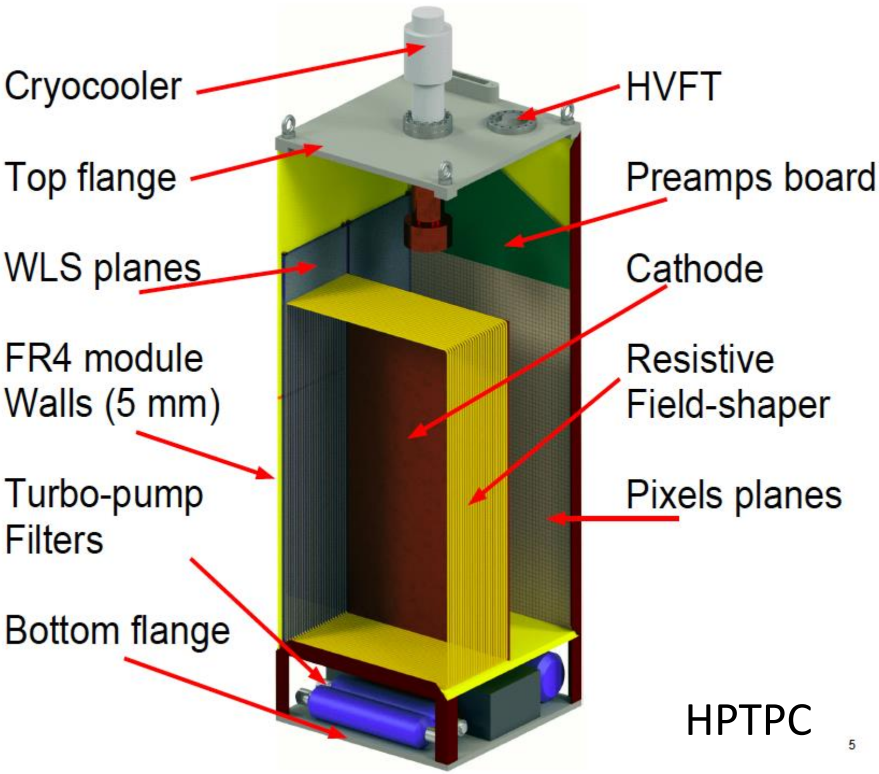
What does the ND need to measure?

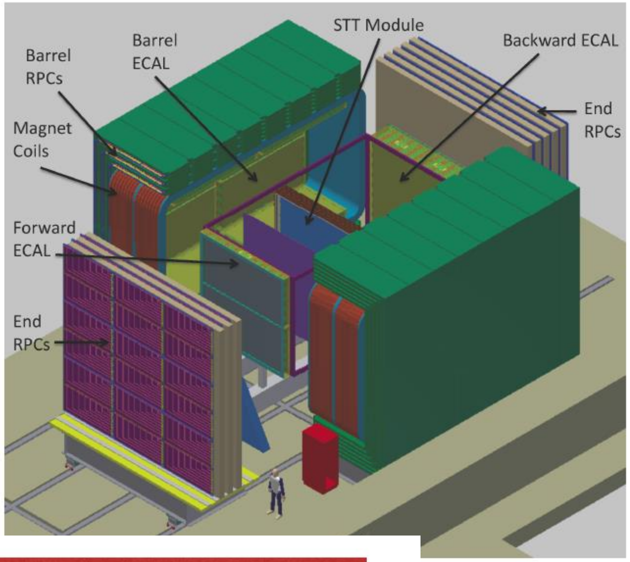
- Constrain systematics in far detector ν_e /anti-ν_e appearance signal
  - CDR level (2%)
- Measurement Strategy
  - Understand detector response and model dependence
    - electron & muon neutrino interactions (LAr TPC)
    - inclusive & exclusive ν_μ CC interactions
      - in Ar and (other materials) in a low-density tracker
  - Understand flux shape
    - low-nu method (little hadronic energy)
  - Understand near-to-far extrapolation
    - ND can help to constrain hadron production & focussing uncertainties
    - measure energy spectrum/flux of all neutrino flavours

Traditional Detector Concepts

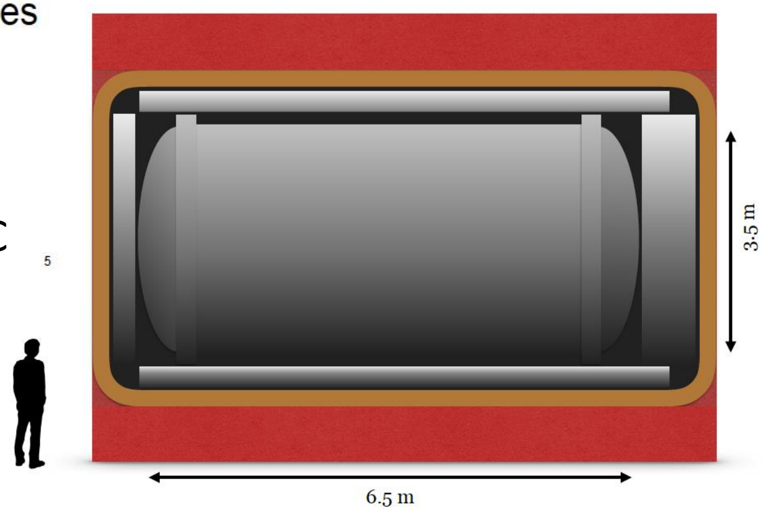
ArgonCube



FGT



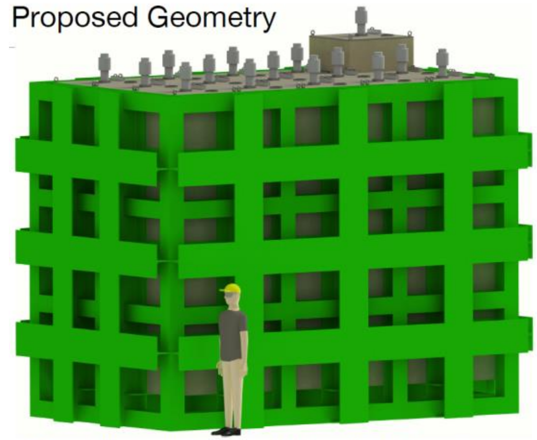
HPTPC



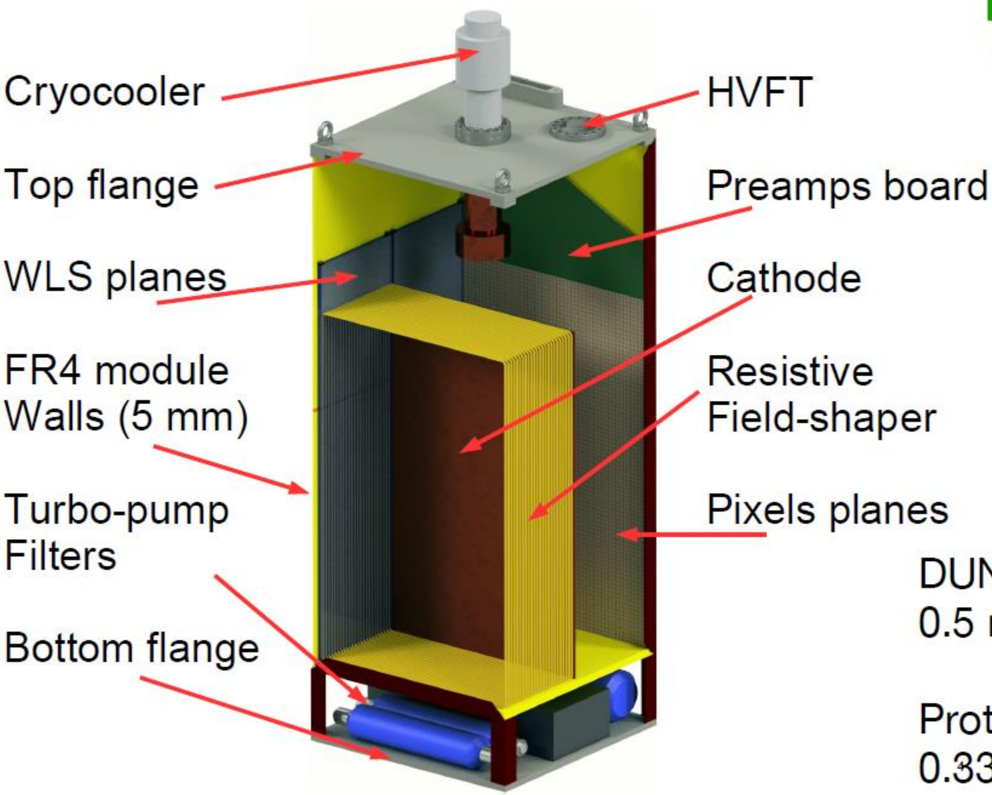
Hybrid Concepts (MPT)

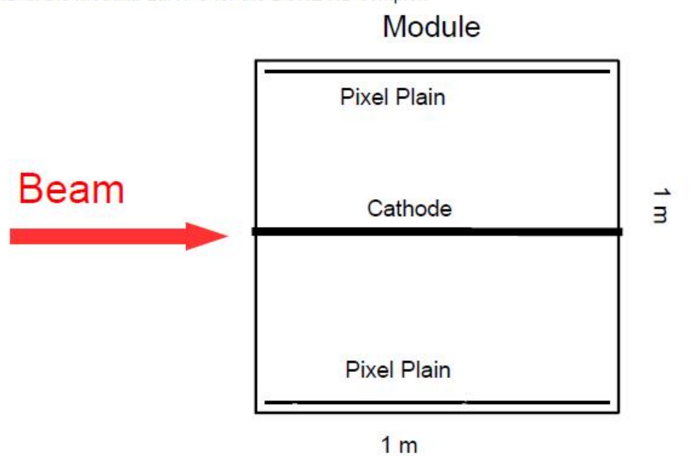
- Measure details of neutrino interactions as much as needed
  Multi-Purpose Tracker
  - Inclusive and exclusive reaction
  - Particle ID
  - Momentum measurements
- Reduce cross section/flux systematics
- Understand relations between visible and neutrino energy
- Several detector options
  - (high pressure) (argon) gas TPC
  - straw-tube tracker
  - (3D) scintillator tracker

ArgonCube



CAD of the modular LarTPC for the DUNE ND complex

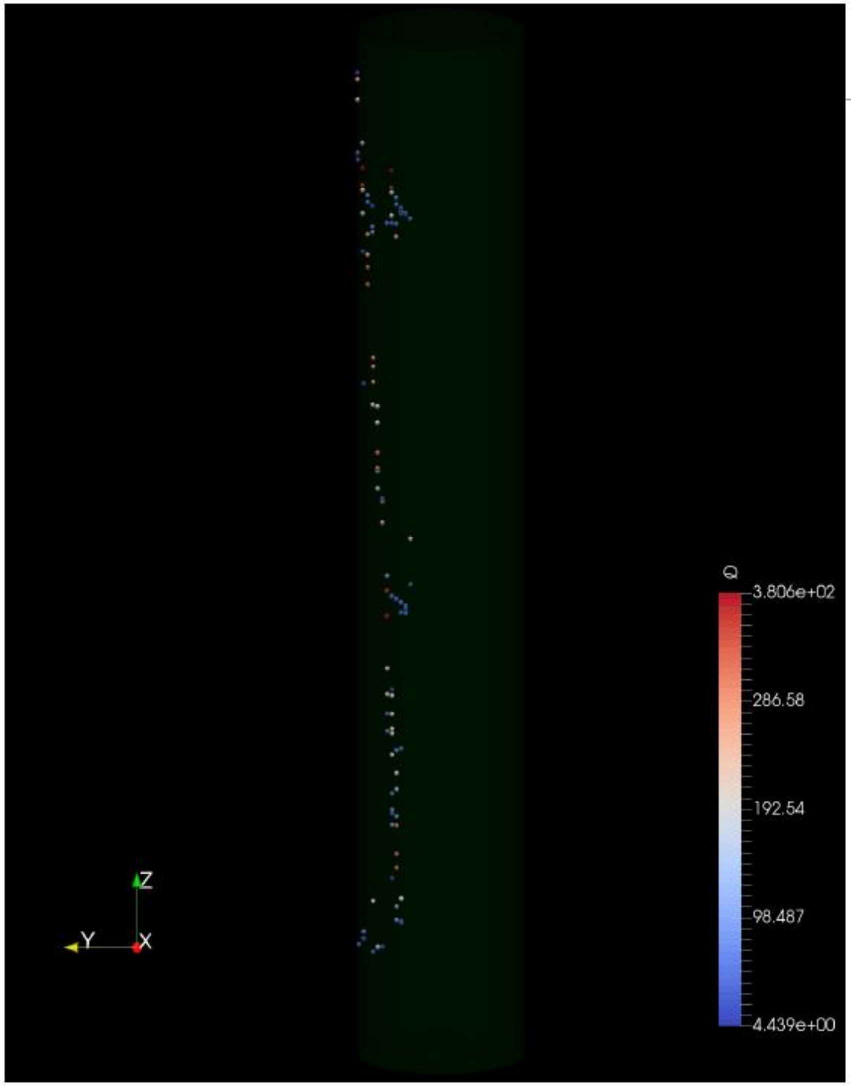


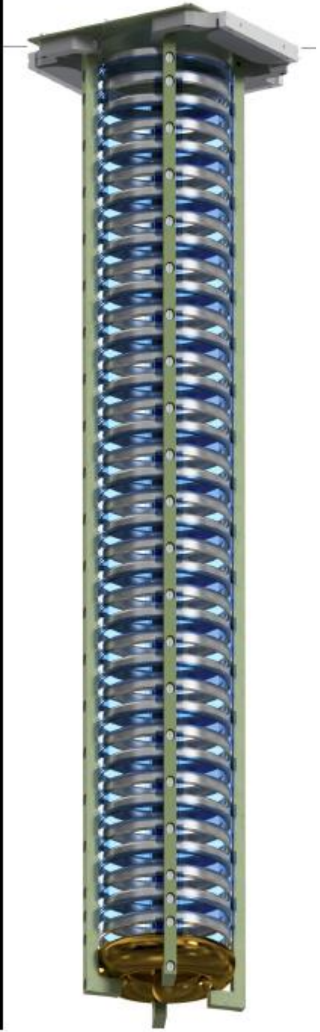


DUNE ND modules: 1.0 x 1.0 x 2.0 m^3.
0.5 m drift length

Prototype modules 0.67 x 0.67 x 1.8 m^3.
0.33 m drift

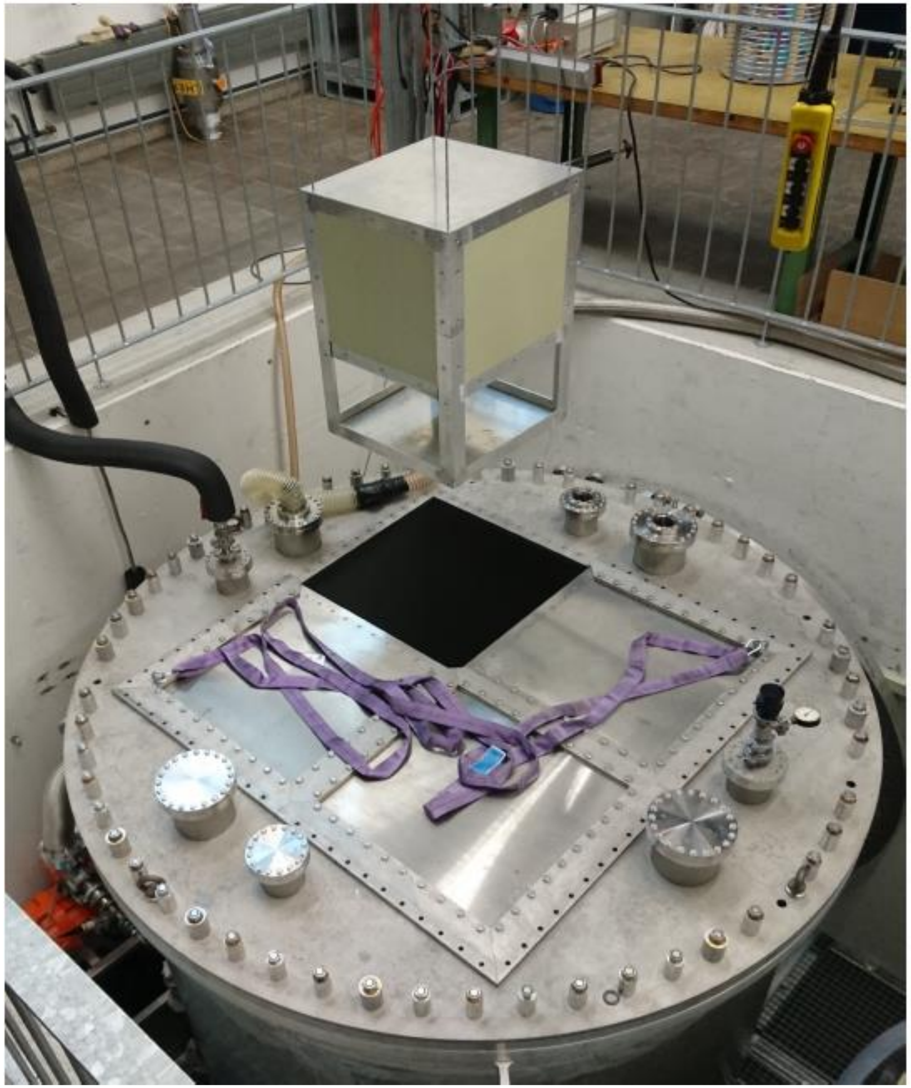
Pixel Readout Events



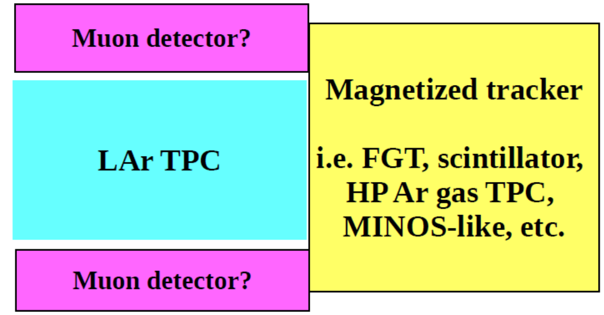


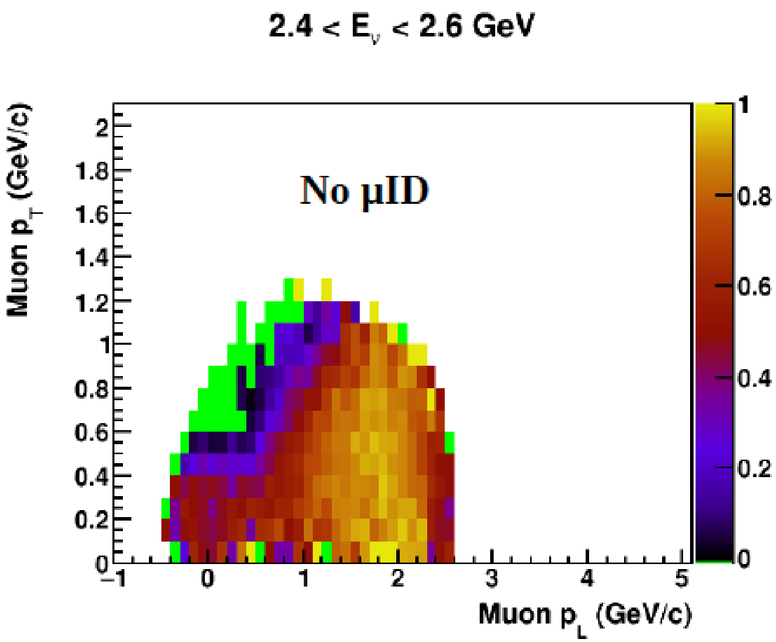
Status and Outlook

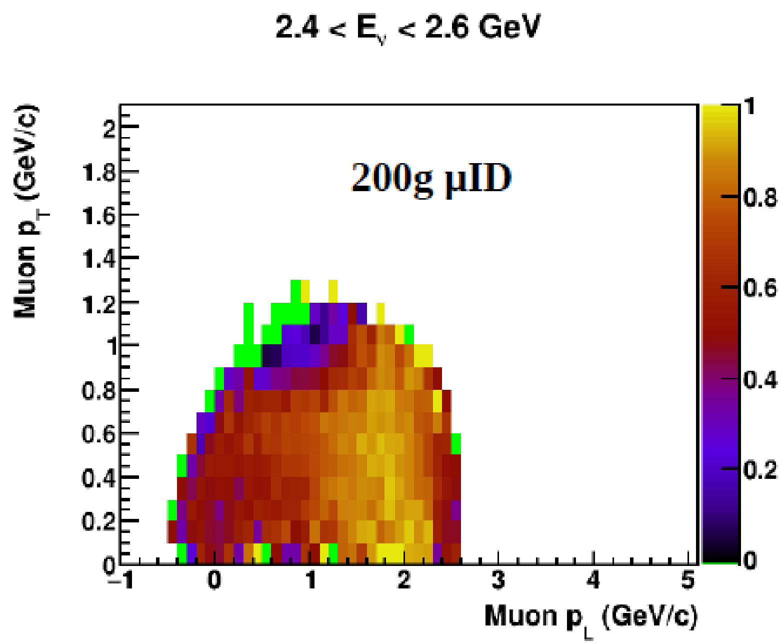
- Cryostat and module material test successfully completed (Oct 2016)
- Lightweight simulation framework summer 2017
- First TPC deployment summer 2017, pending updates to the cryogenic infrastructure.
- Pixel scalability, Light readout & feld shaping studies summer 2017.
- LArPix tests spring 2018.
- Fully instrumented module deployment 2018



LAr Detector



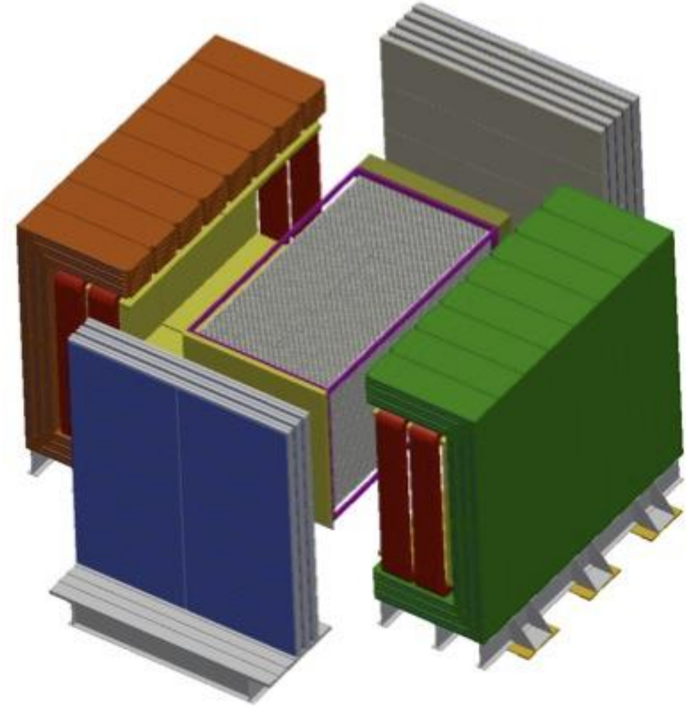




- 3x3x4m detector has really excellent acceptance with μID detector, but very little cross section coverage to be gained

Straw Tube Tracker

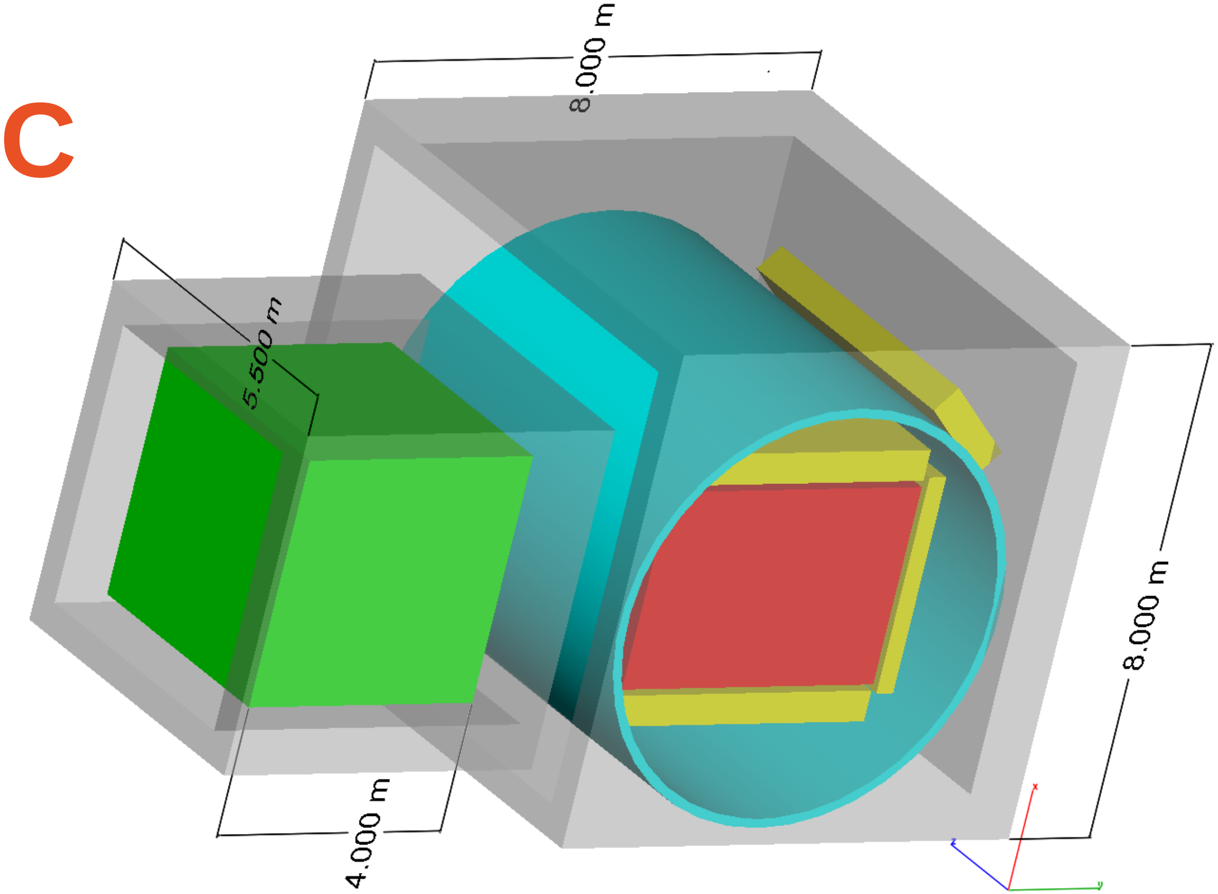
- Function
  - Use as spectrometer for LAr
  - LAr provides in-situ check of STT prediction
  - Two independent neutrino electron measurements



- Statements
  - $3.5 \times 3.5\ m^2$ is absolute minimal transverse dimension
  - 4.5 m is minimum length

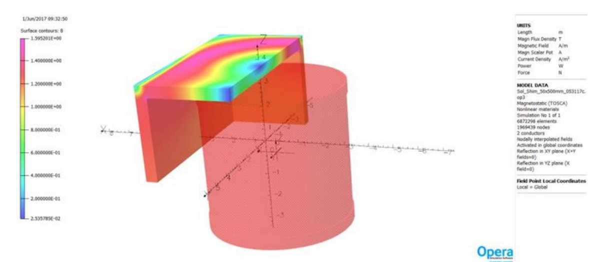
HP GAr TPC

- Magnet (0.5T)
- LAr
- TPC_{hpg}
- EM Cal ($20X_o$)
- Steel ($4\lambda_o$)



LAr:
with 2 X 2 m FV
~ 7 X_o annulus
~ 1.25 λ_o annulus

Magnet is this model is 6.5m diameter and 7 m long
Maximize acceptance for μ from Lar

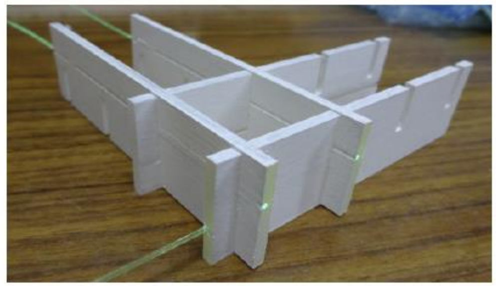


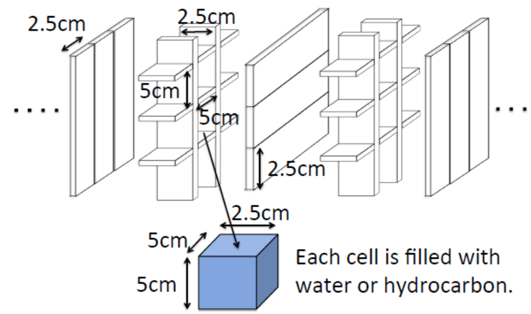
Coil could become pressure vessel

3D Scintillator Tracker

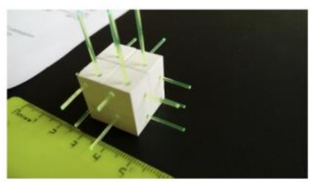
- Several options studied for T2K/ND280 upgrade

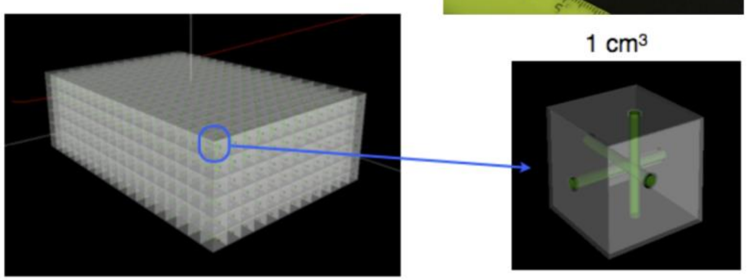
3mm thin scintillator bar made @ Fermi-lab is used.

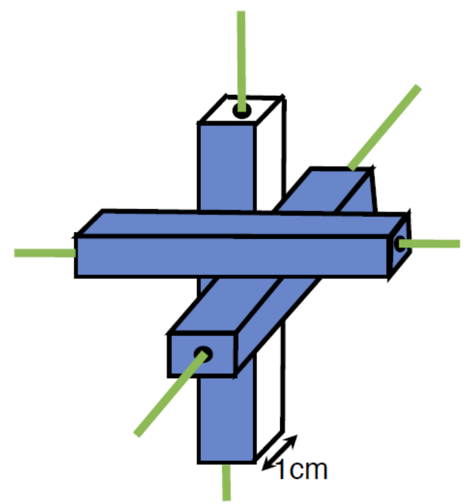




Super FGD

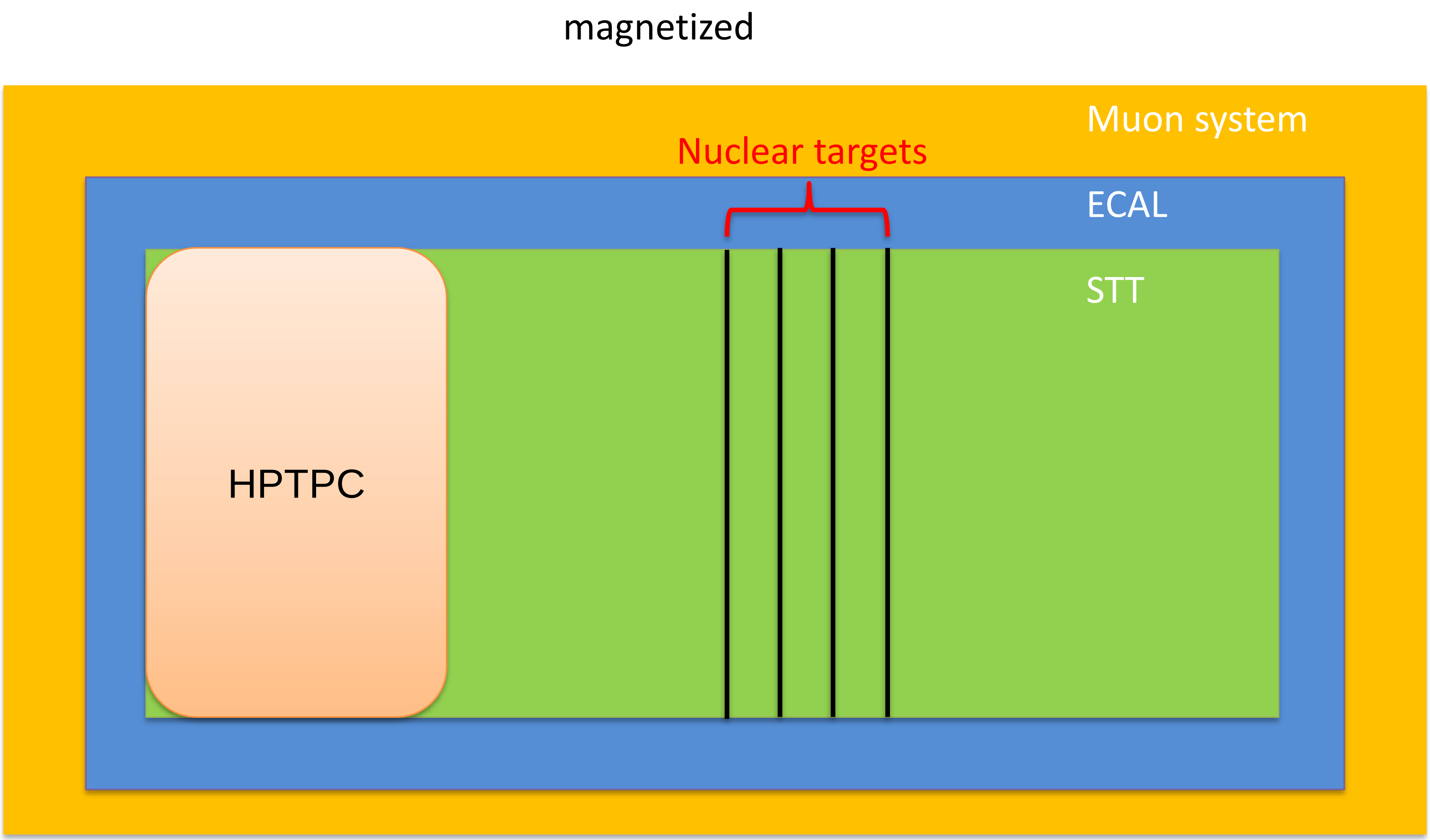




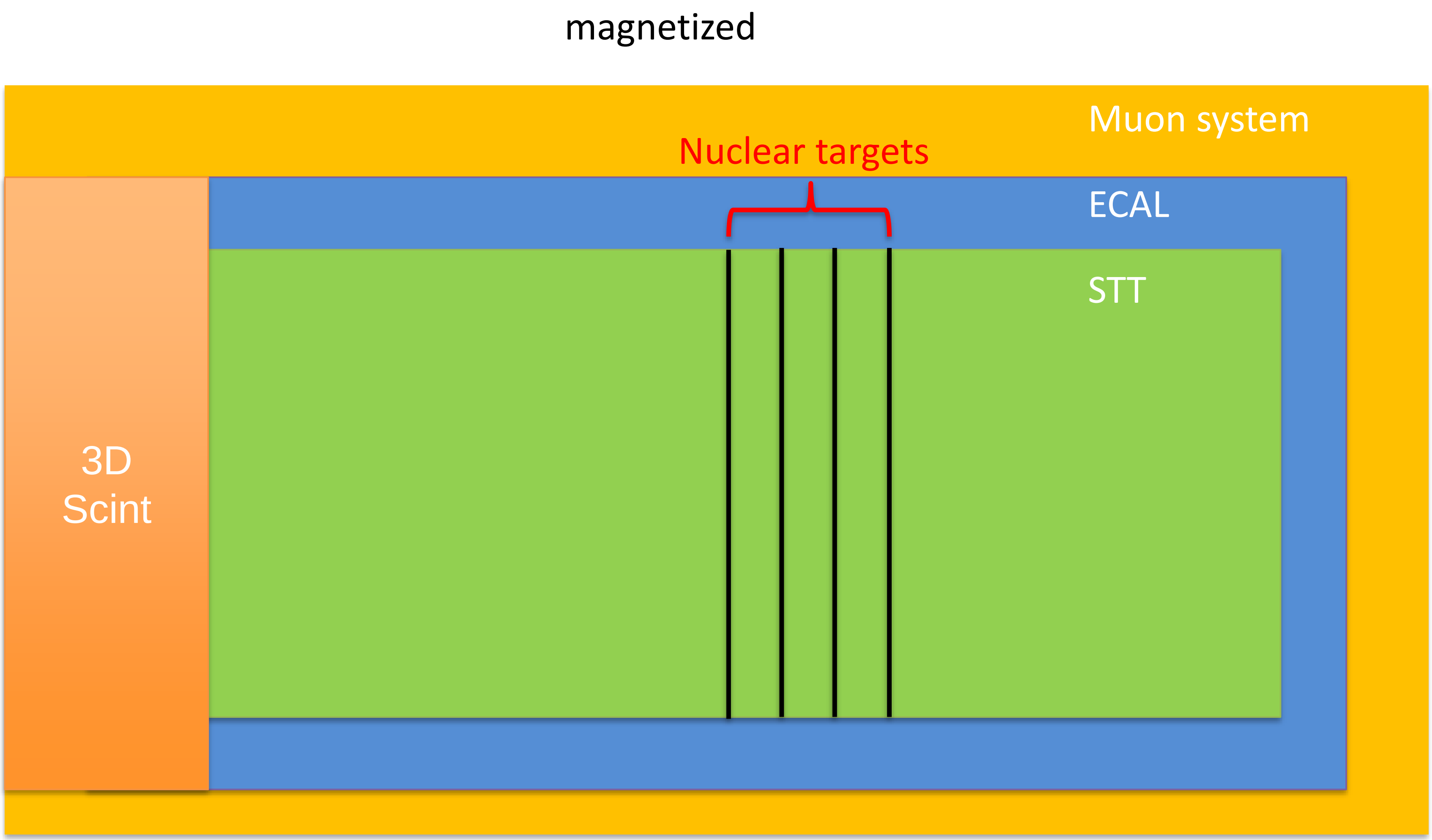


https://indico.cern.ch/event/633840/timetable/
Please check the section “Super-FGD”

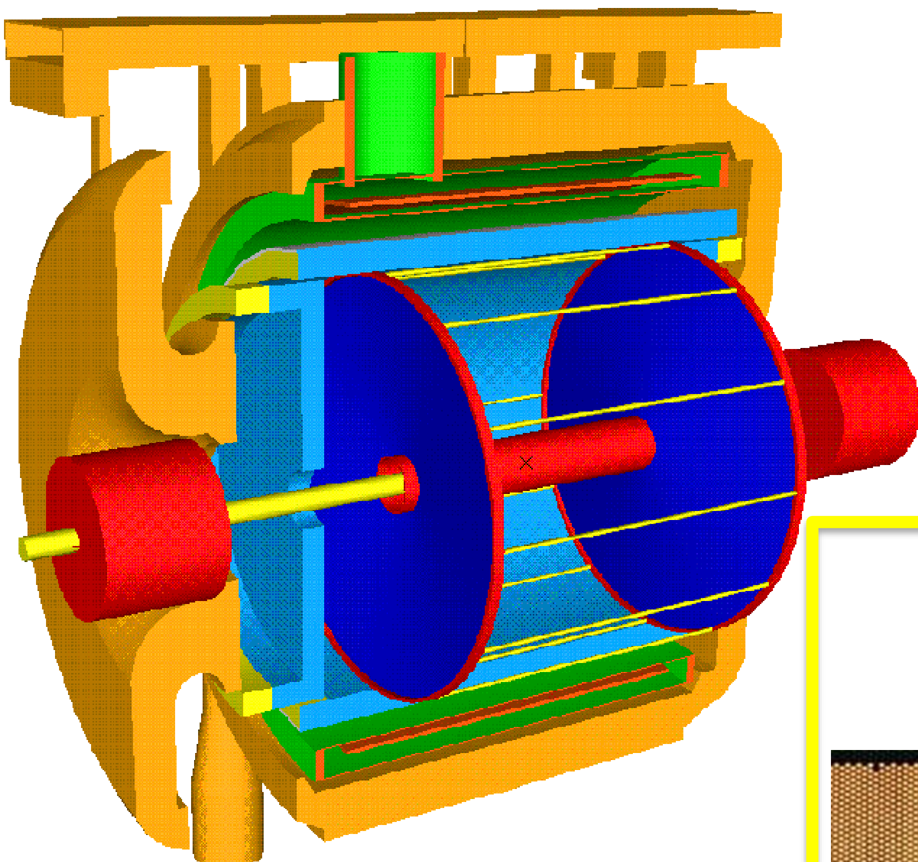
Other Hybrids (I)

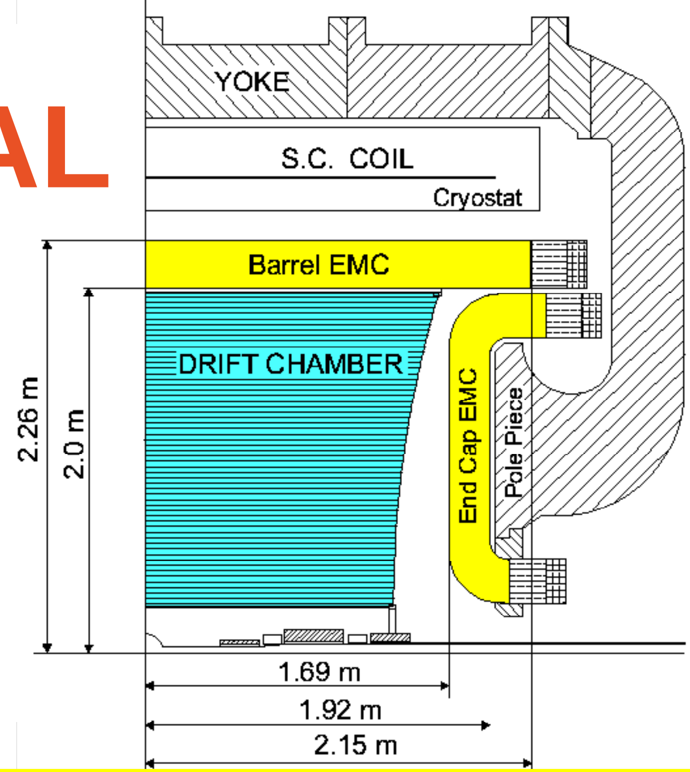


Other Hybrids (II)



KLOE Magnet & ECAL





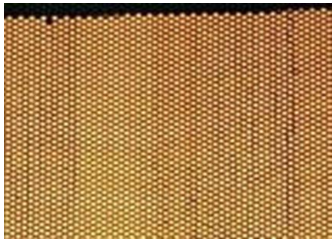
Superconducting coil (5 m bore)

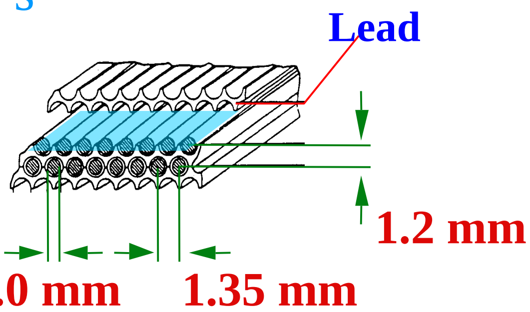
$B = 0.6$ T ($\int B\, dl = 2.2$ T·m)

Electromagnetic calorimeter

Lead/scintillating fibers

4880 PMT's





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DUNE

DUNE Current Status

- Pixelated LAr Detector
  - Not magnetized
  - Size: around **3x3x4** m^3
  - Functionally coupled to MPT
- MPT ⇔ high resolution detector
  - Magnetized (dipole or solenoid?)
  - Straw-Tube Tracker or High Pressure TPC

Major Milestones

Q1/2017: 1st ND design workshop at FNAL	☑
Q2/2017: 2nd ND workshop at FNAL	☑
Q3/2017: narrow down ND options	(on track)
Q4/2017: 3rd ND workshop at CERN	(on track)
Q4/2017: Concept for ND agreed	(Q1/2018)
Including plausible funding model	
Q4/2018: ND CDR	(on track)
Q1/2020: ND TDR available for review in August	(on track)
Q4/2026: ND ready for beam	(on track)

Backup

Why Near Detectors

Overly simplified

Introduction

- Oscillation probabilities

$$P_{\nu_\mu \to \nu_e}(E_\nu) = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{far,no-osc}(E_\nu)} = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}\ (E_\nu)}$$

Well known (1-2%)

- Number of events/energy spectrum

$$\frac{dN_\nu^{det}}{dE_\nu} = \phi_{\nu_\mu}^{det}(E_\nu) * \sigma_{\nu_\mu}^{Ar}\ (E_\nu)$$

- In reality

$$\frac{dN_\nu^{det}}{dE_{rec}} = \int \phi_\nu^{det}(E_\nu) * \sigma_\nu^{target}\ (E_\nu) * D_{\nu_\mu}^{det}(E_\nu, E_{rec})\ dE_\nu$$

- Folding of detector effects
  - Prevents (easy) cancellations of many systematic effects
  - Needs unfolding

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Are there cancellations?

- Oscillation signal

Small theo. uncertainty or measurement

$$\frac{dN^{far}_{\nu_e}}{dE_\nu} \Bigg/ \frac{dN^{near}_{\nu_\mu}}{dE_\nu} = P_{\nu_\mu \to \nu_e}(E_\nu) * \frac{\sigma^{Ar}_{\nu_e}(E_\nu)}{\sigma^{Ar}_{\nu_\mu}(E_\nu)} * F_{far/near}\,(E_\nu)$$

1-2% uncertainty

- Near muon/electron ratio

$$\frac{dN^{near}_{\nu_e}}{dE_\nu} \Bigg/ \frac{dN^{near}_{\nu_\mu}}{dE_\nu} = \frac{\sigma^{Ar}_{\nu_e}(E_\nu)}{\sigma^{Ar}_{\nu_\mu}(E_\nu)} * \frac{\phi^{near}_{\nu_e}(E_\nu)}{\phi^{near}_{\nu_\mu}(E_\nu)}$$

Not so small uncertainty

- Need to know
  - Flux & cross section ratios
  - Far/near extrapolation

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But in Reality

$$\frac{\dfrac{dN_{\nu_e}^{far}}{dE_{rec}}}{\dfrac{dN_{\nu_\mu}^{near}}{dE_{rec}}} = \frac{\int P_{\nu_\mu \to \nu_e}(E_\nu) * \phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}(E_\nu) * \sigma_{\nu_e}^{Ar}(E_\nu) * D_{\nu_e}^{far}(E_\nu, E_{rec})\ dE_\nu}{\int \phi_{\nu_\mu}^{near}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * D_{\nu_\mu}^{near}(E_\nu, E_{rec})\ dE_\nu}$$

- No cancellations
  - Unless you unfold
- Need to understand especially
  - Detector effects in near and far detector
  - Relation of visible to neutrino energy
  - Cross section ratios
  - Near to far flux extrapolation
- Flux normalisation cancels
  - Shape is important

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Event Rates

$$\frac{dN_{\nu_\mu}^{near}}{dE_{rec}} = \int \phi_{\nu_\mu}^{near}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * D_{\nu_\mu}^{near}(E_\nu, E_{rec})\ dE_\nu$$

$$\frac{dN_{\nu_e}^{near}}{dE_{rec}} = \int \phi_{\nu_e}^{near}(E_\nu) * \sigma_{\nu_e}^{Ar}(E_\nu) * D_{\nu_e}^{near}(E_\nu, E_{rec})\ dE_\nu$$

$$\frac{dN_{\nu_\mu}^{far,no-osc}}{dE_{rec}} = \int \phi_{\nu_\mu}^{far}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * D_{\nu_\mu}^{far}(E_\nu, E_{rec})\ dE_\nu$$

$$\phi_{\nu_\mu}^{far,no-osc}(E_\nu) = \phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}(E_\nu)$$

$$\phi_{\nu_e}^{far}(E_\nu) = P_{\nu_\mu \to \nu_e}(E_\nu) * \phi_{\nu_\mu}^{far,no-osc}(E_\nu)$$

$$\frac{dN_{\nu_\mu}^{far}}{dE_{rec}} = \int \phi_{\nu_\mu}^{far}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * D_{\mu}^{far}(E_\nu, E_{rec}) * P_{\nu_\mu \to \nu_\mu}(E_\nu)\ dE_\nu$$

$$\frac{dN_{\nu_e}^{far}}{dE_{rec}} = \int \phi_{\nu_\mu}^{far}(E_\nu) * \sigma_{\nu_e}^{Ar}(E_\nu) * D_{\nu_e}^{far}(E_\nu, E_{rec}) * P_{\nu_\mu \to \nu_e}(E_\nu)\ dE_\nu$$