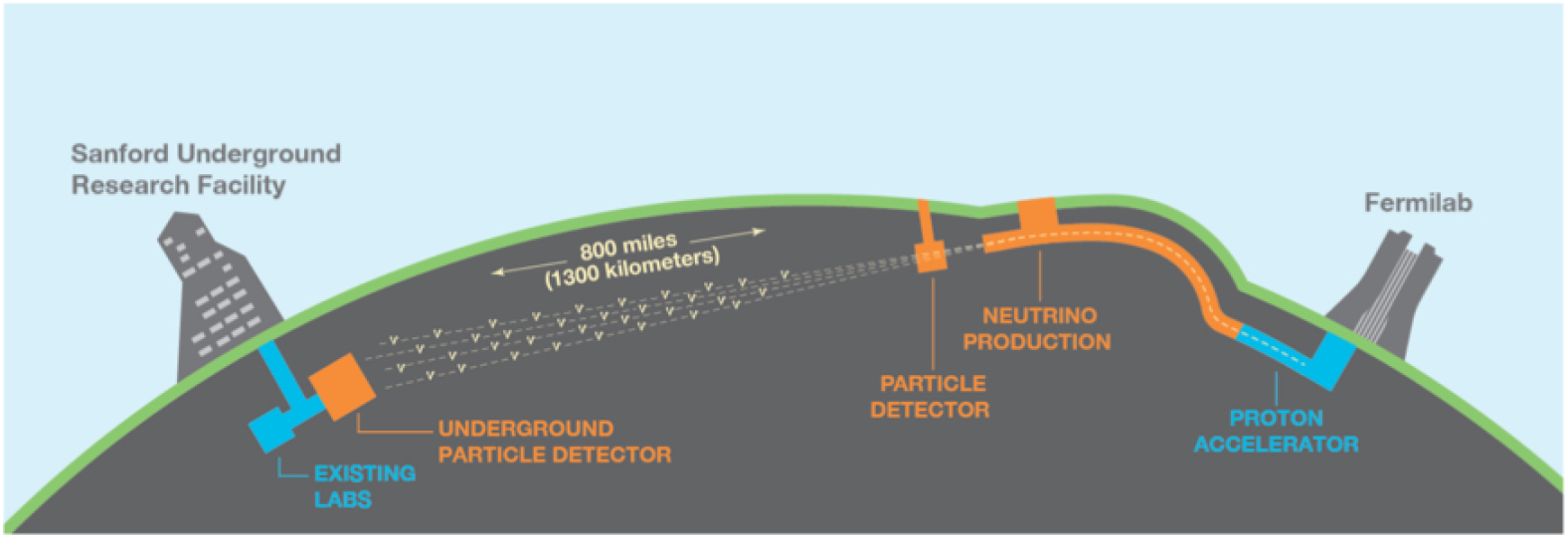
The Dune Near Detector



Albert De Roeck / CERN

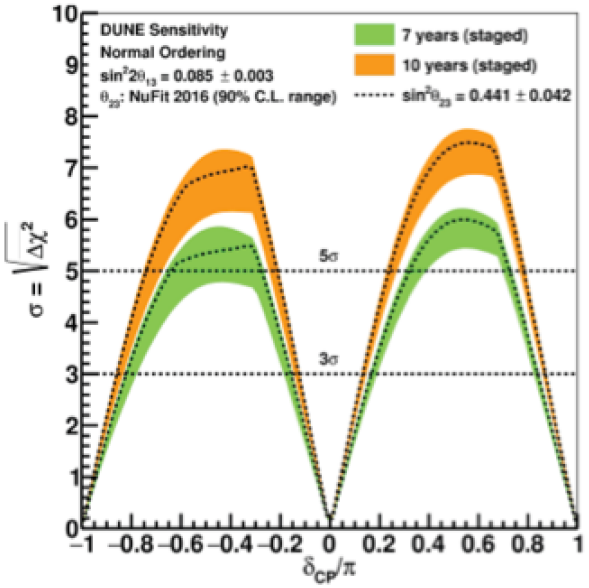
15 August 2018

NUFACT 2018, Blacksburg, Virginia

On behalf of the DUNE Collaboration

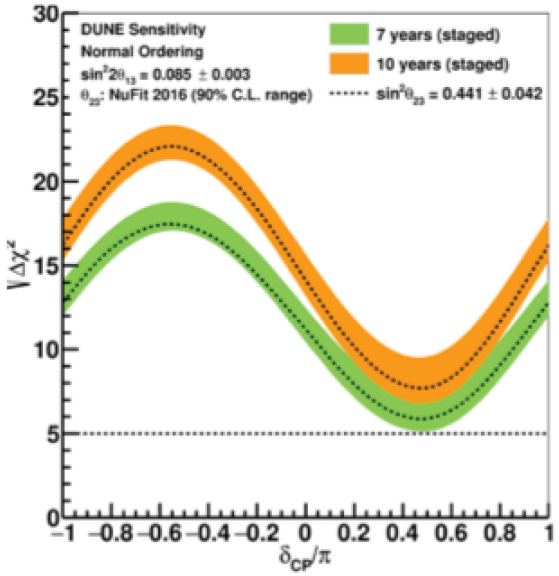
Neutrino oscillations and more

CP Violation



Width of band indicates variation in possible central values of θ_{23}

Mass Ordering



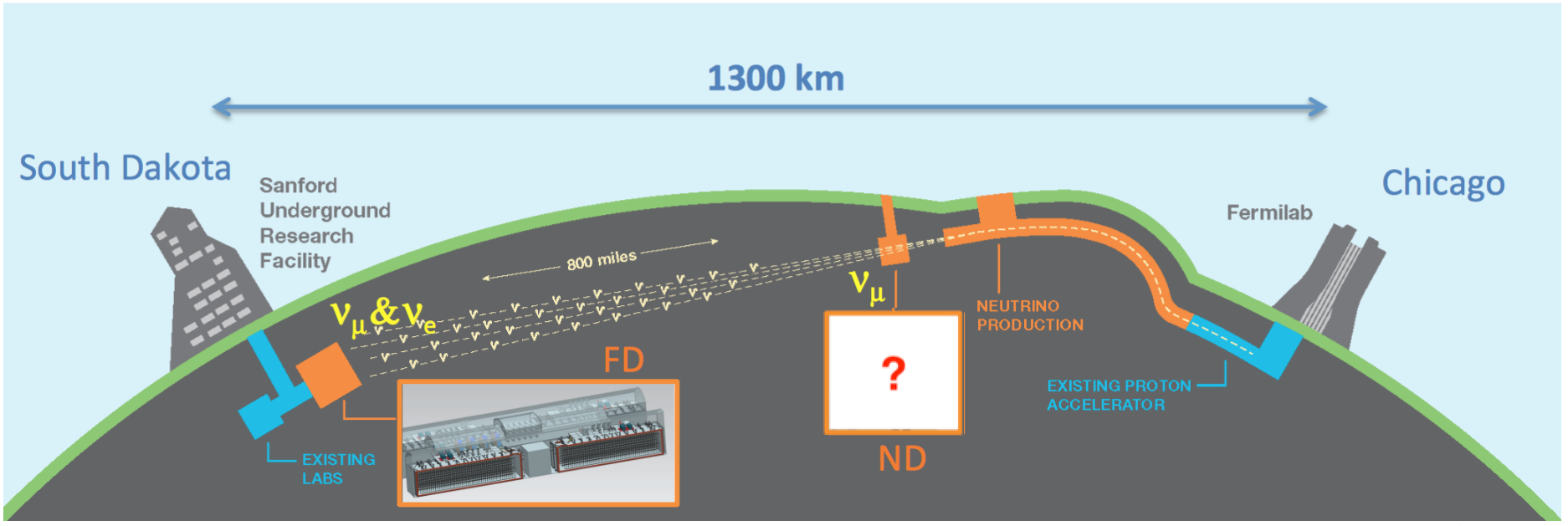
Width of band indicates variation in possible central values of θ_{23}

- DUNE sensitive to many BSM particles and processes
  - Light dark matter
  - Boosted dark matter
  - Sterile neutrinos
  - Non-standard interactions, non-unitary mixing, CPT violation
  - Neutrino trident searches
  - Large extra dimensions
  - Neutrinos from dark matter annihilation in sun
- Active area of research within phenomenology community as well as the DUNE collaboration

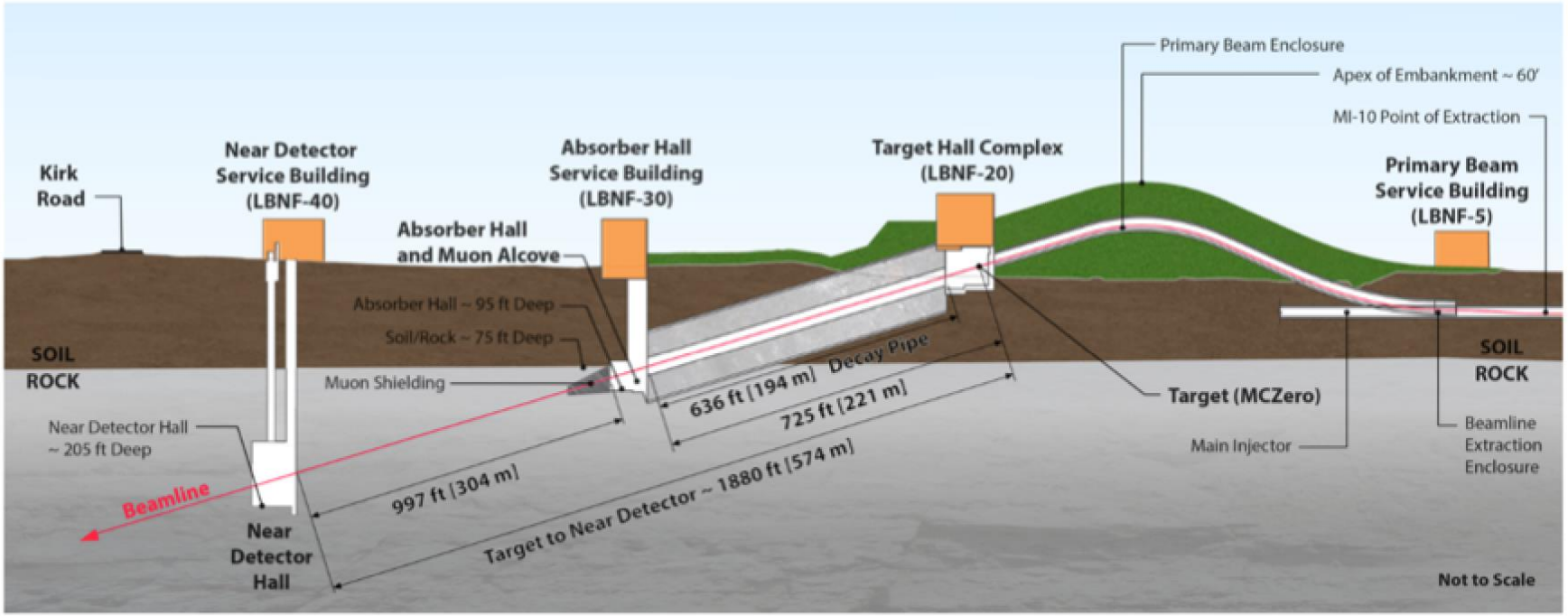
- DUNE is a long-baseline neutrino experiment aiming to determine the neutrino mass hierarchy and CP-violation by measuring ν_μ to ν_e and $\bar{\nu}_\mu$ to $\bar{\nu}_e$ oscillation and to conduct precision measurements of ν_μ & $\bar{\nu}_\mu$ disappearance.

LBNF/DUNE overview

- Muon neutrinos/antineutrinos from high-power proton beam
  - **1.2 MW** from day one; upgradeable to 2.4 MW
- Massive underground Liquid Argon Time Projection Chambers
  - **4 x 17 kton** fiducial mass of > 40 kton
- Near detector to characterize the beam (100s of millions of neutrino interactions)



DUNE Near Detector



- Primary proton beam @ 60-120GeV extracted from Main Injector
- Near Detector located at 574 meters from the target

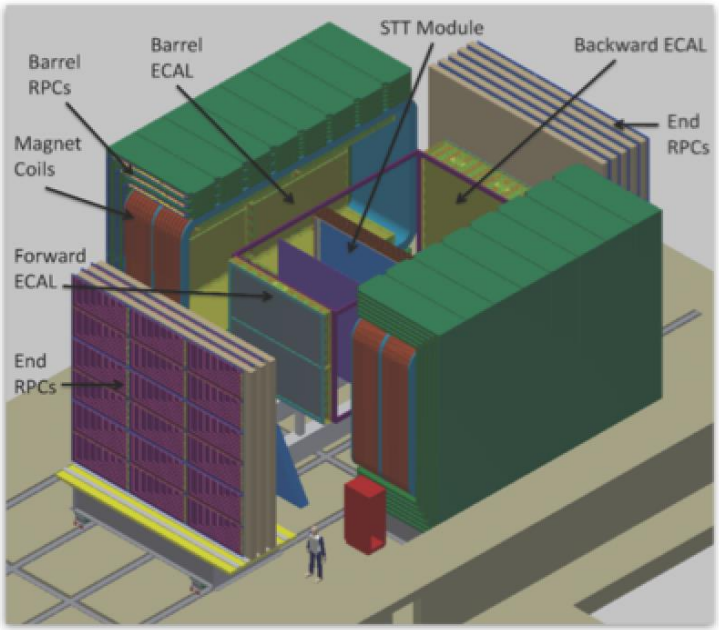
DUNE Near Detector

The ND has a fundamental role for LBL physics, constraining the systematic uncertainties via measurements of the neutrino flux to a few % and relevant interaction cross sections

It will record the largest sample of neutrino argon interactions ever collected allowing for precision measurements (EWK, QCD)

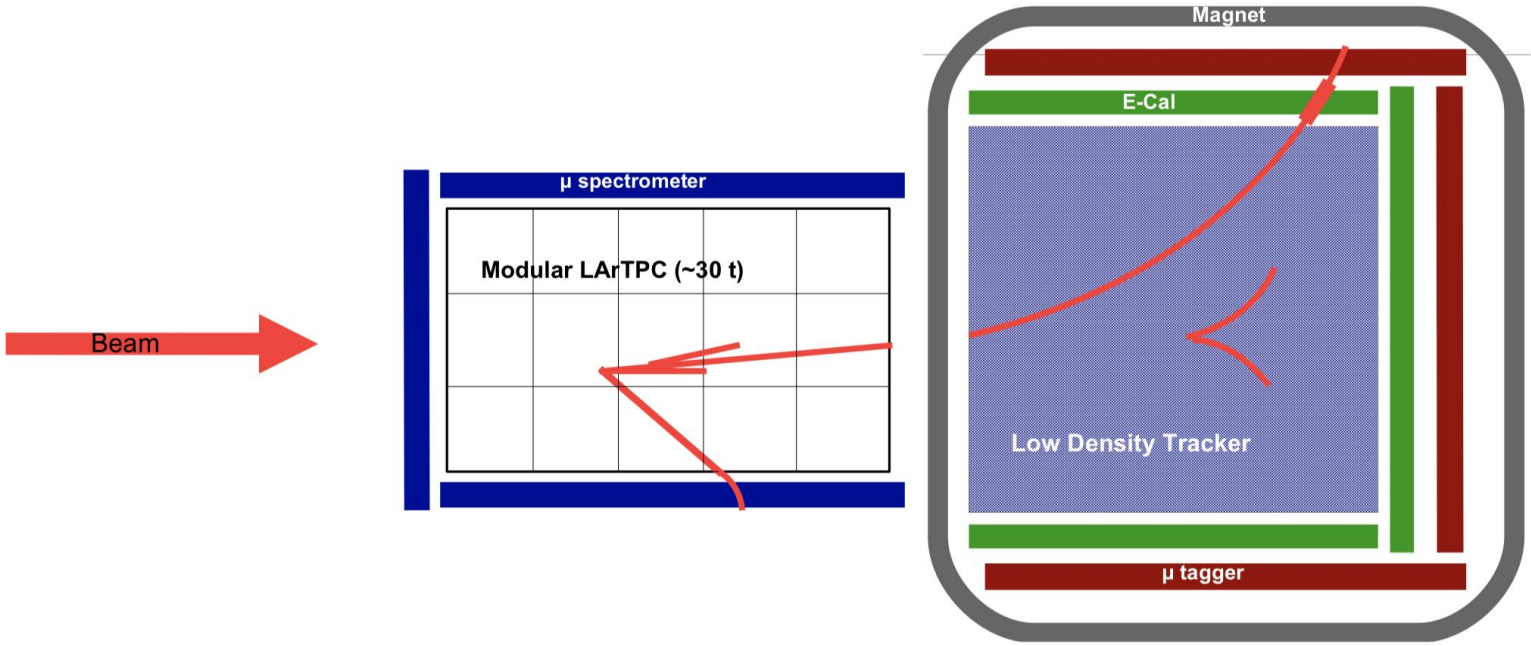
Sensitive to new physics (eg Heavy Neutral Leptons/Sterile neutrinos, light dark matter…)
→ High intensity beam dump experiment.

2015: CDR reference design: Fine Grained Tracker (FGT) in a dipole magnet, with EM Calo, muon system… Tracker bases on straw tubes (NOMAD)
2017: Near Detector design group installed: study new ideas & attracting new collaborators



CDR reference design
arXiv:1601.02984

A Hybrid Near Detector



-A LArTPC upstream has the same nuclear target and similar detector response as the FD.

-A downstream low-density tracker with an excellent tracking resolution, low tracking thresholds, good calorimetry and muon coverage in a magnetic field to provide detailed neutrino interaction information for systematic constraints and serve as a spectrometer for the high energy muons

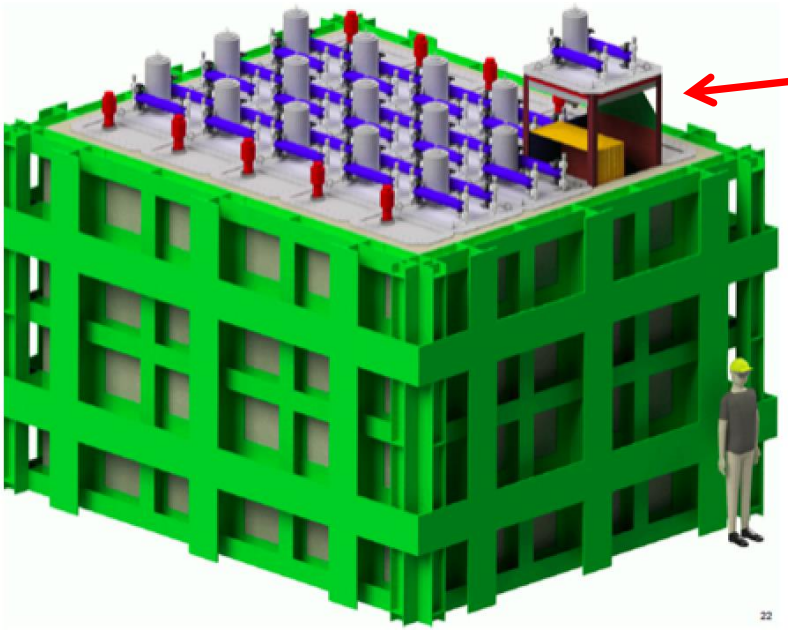
-Movable detectors in the ND hall? -> DUNE-PRISM idea...

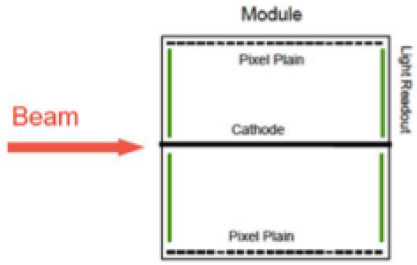
Detector Options being studied

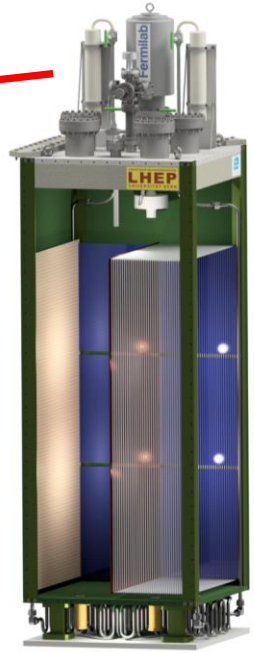
- Highly segmented LAr TPC (LArTPC)
- Straw Tube Tracker (STT)
- High Pressure gaseous TPC (HPgTPC)
- 3 Dimensional Scintillator Tracker (3DST)
- Solenoid (KLOE) or new dipole magnet
- Move the detector(s) (DUNE-PRISM)

LArTPC: ArgonCubes

The LarTPC at the near side should be optically segmented, with a short drift space and 2-dimensional pixelated readout
- Modular structure (0.5m drift distance) to mitigate pile-up!
- ~30 tons of fiducial volume, complemented with muon chambers







Cut-away illustration of an ArgonCube module

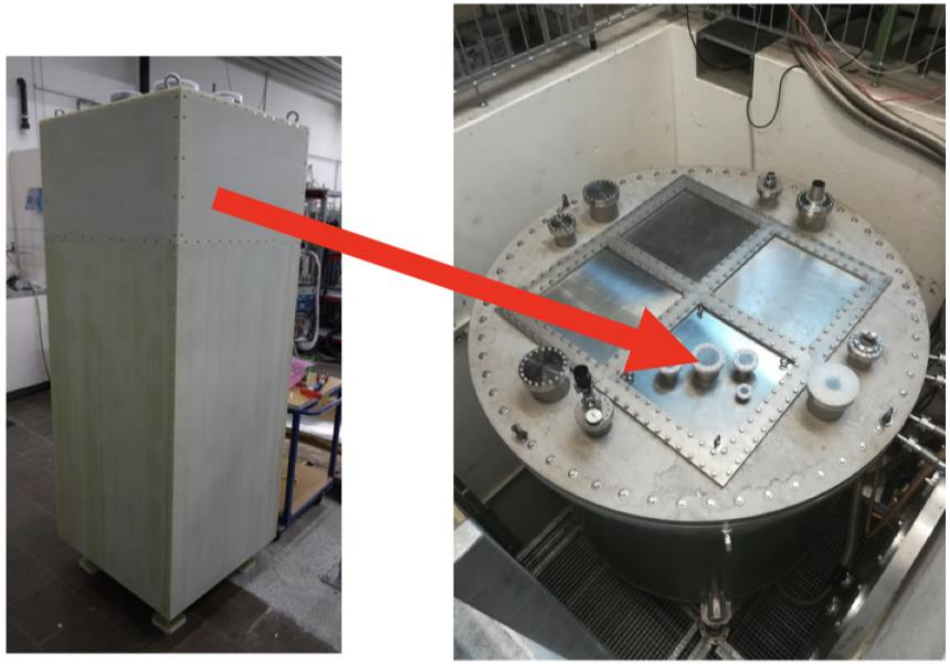
LArTPC

- Useful for
  - Neutrino-electron elastic scattering
  - Low-ν method (E_ν-E_L)
  - Flux integrated event rates on argon
- Needs further studies
  - Exclusive differential event rates
  - Neutrons
    (can see recoil when hitting proton/nucleus, but which event?)
  - Coherent scattering

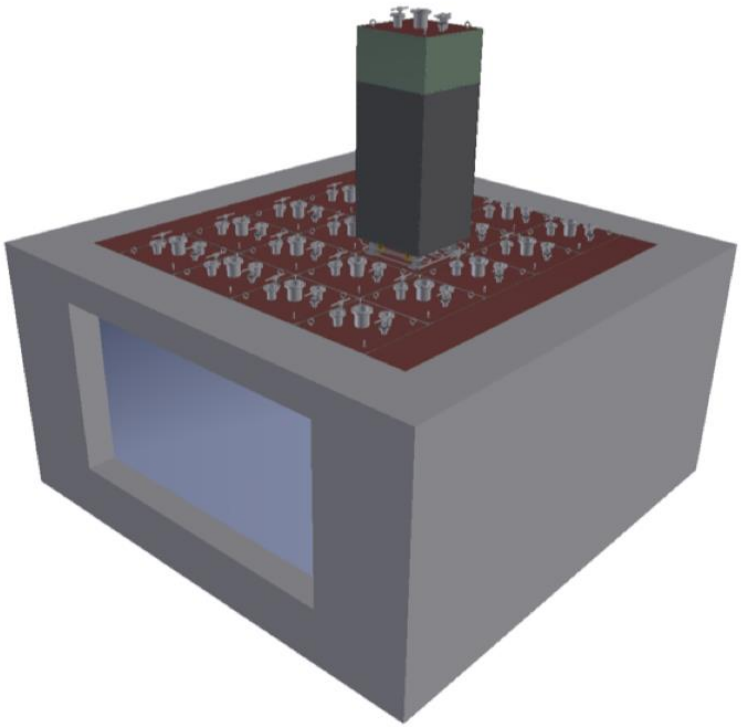
35tons LarTPC & 1.2 MW
-> ~50M ν_μ charged current events /year
and
-> ~15k ν-e events in 5 years

ArgonCube Prototype

ArgonCube 2 x 2 prototype first module deployment due late summer/fall.
Current infrastructure tasks – automation of filling, cooling, filtration...
2D Pixelated readout



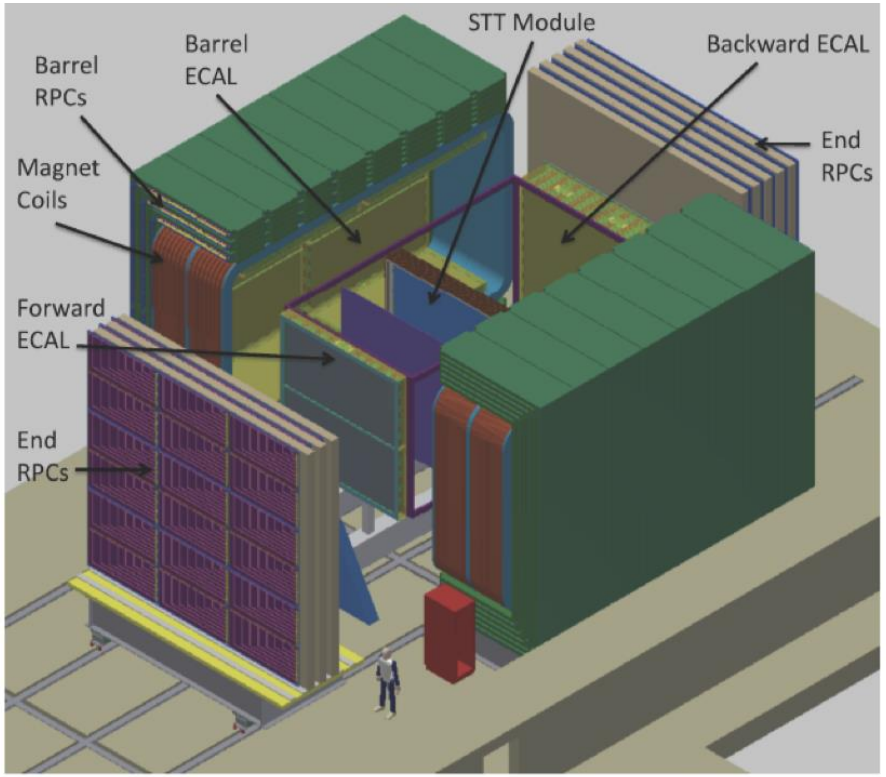
ArgonCube 2x2 prototype in Bern, 1.2 x 1.3 x 1.3 m^3 active



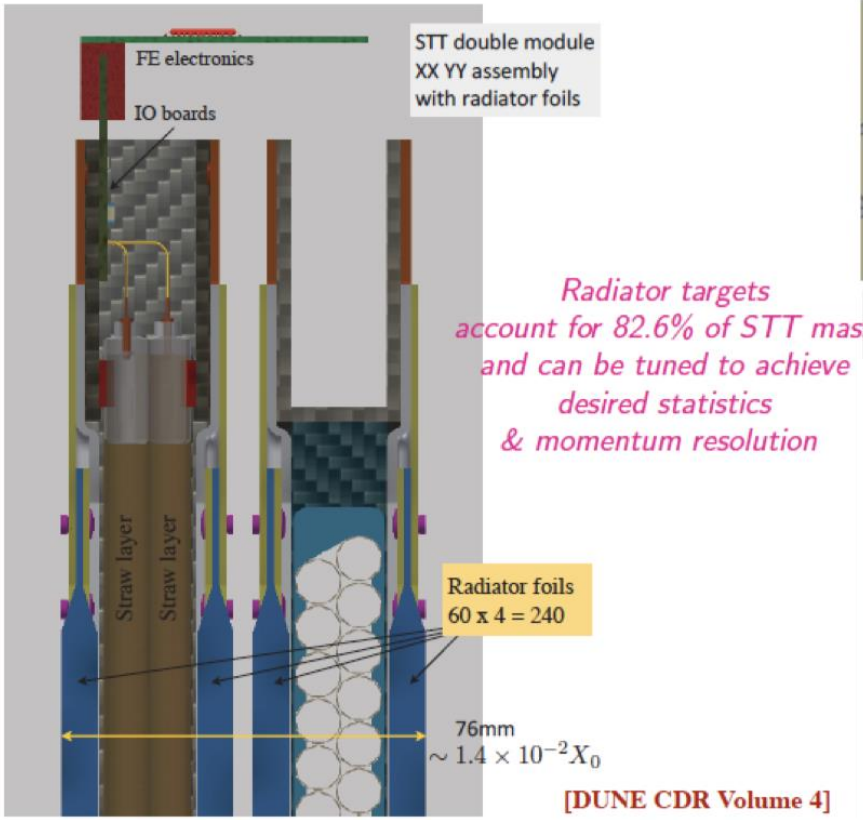
ArgonCube DUNE Near Detector, 3 x 4 x 5 m^3 active

STT Straw Tube Tracker

- The CD1/CD1R detector

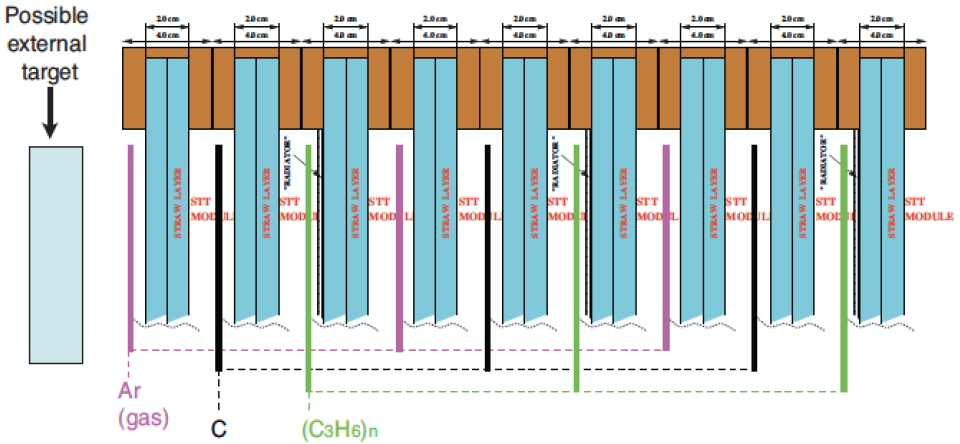


STT module with radiators



Radiator targets account for 82.6% of STT mass and can be tuned to achieve desired statistics & momentum resolution

Can included different nuclear targets

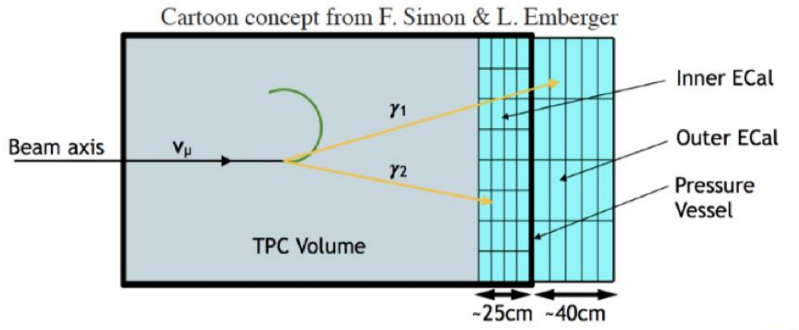


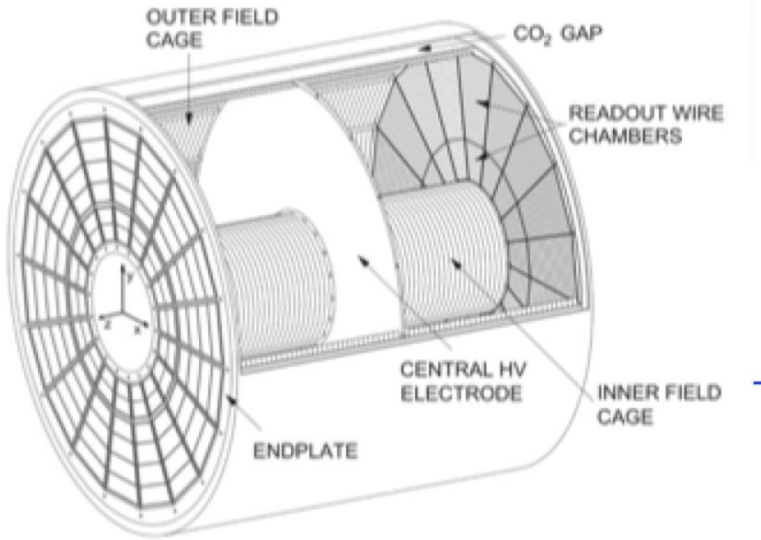
Straw Tube Tracker

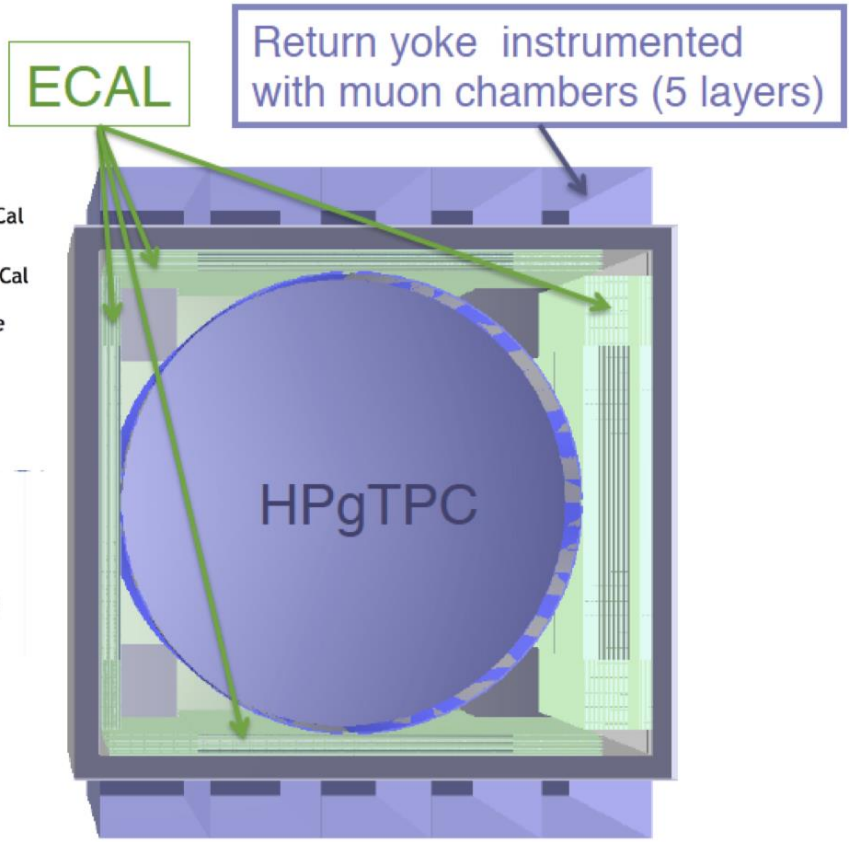
- Useful for
  - Neutrino-electron scattering
  - Low-ν (E_ν -E_L)
  - Measurements on hydrogen in CH_2 radiator (flux, free nucleon cross section)
  - Measurements on several nuclear targets
  - Constrain nuclear modelling uncertainties on C/H/other
- Further work needed
  - Neutron production on CH_2 target (not argon)
  - Argon measurements (needs pressurised 150 bar target)
  - Neutron energy determination

Active mass ~5 ton
Momentum resolution better than 5%
Angular resolution ~ 2mrad
~5k ν-e events in 5 years

High Pressure gas TPC







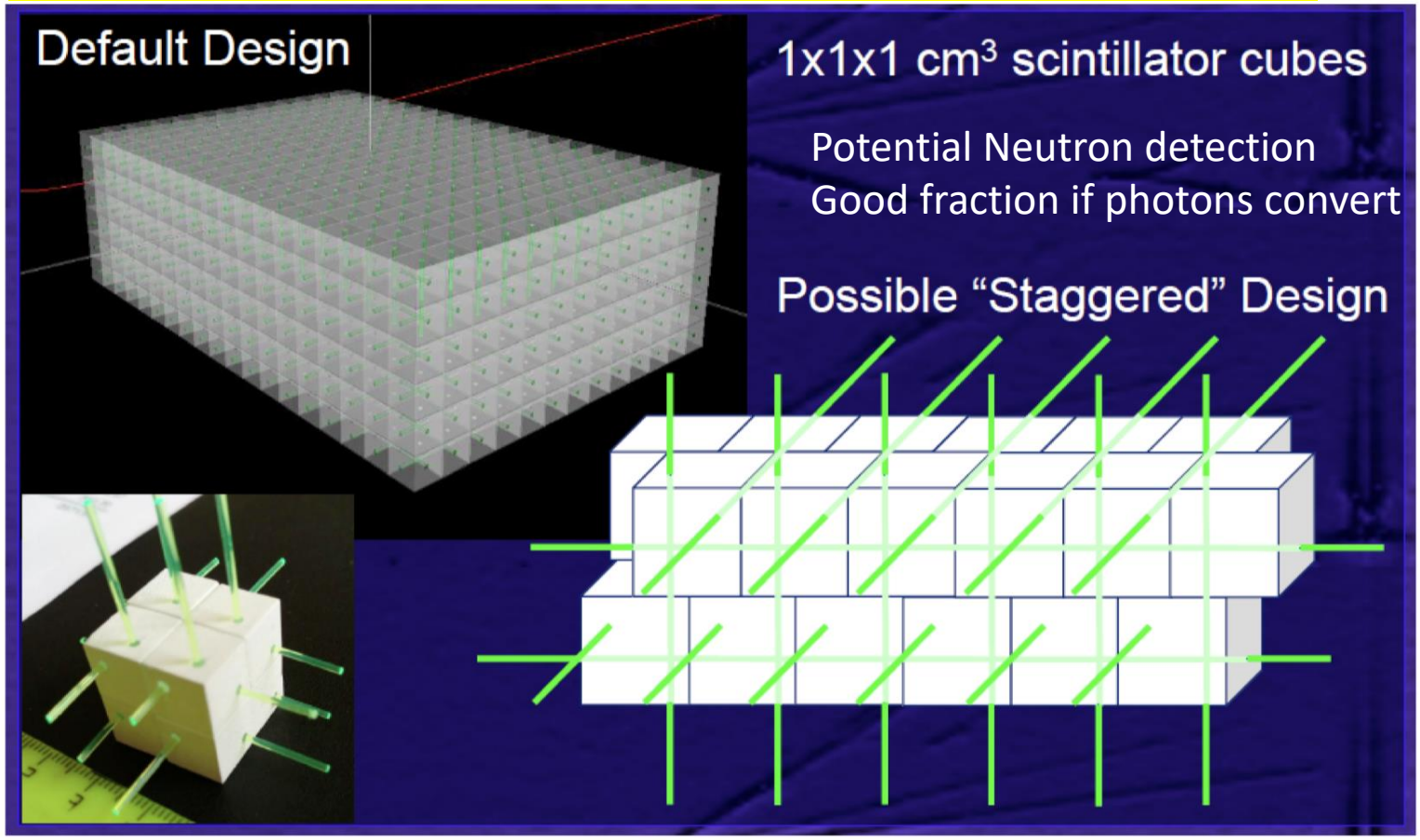
Active mass ~ 1.8 ton
Argon gas as a default/10 bar
Hydrogen/deutrium possible?

High Pressure gas TPC

- Useful for
  - Low-ν (E_ν -E_L) Very low threshold
  - Coherent scattering (low stat, high resolution)
  - Constrain nuclear modelling uncertainties on argon (low thresholds, excellent resolution, homogeneous acceptance)
- More Study needed
  - neutrino-electron scattering (low statistics)
  - Measurements on hydrogen (flux, free nucleon cross section) needs change of gas (safety!)
  - Neutron production on Ar (important, would need appropriate ECAL)
  - π^0 performance (and neutrons) depends on ECAL

3D-Scintillator Cube Tracker

-A tracker made of small plastic scintillator cubes, 4π coverage
-Similar design as T2K SuperFGD ND upgrade
-Scintillating cubes also used in SoLid (reactor) experiment



3D-Scintillator Cube Tracker

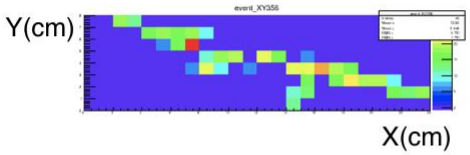
Active mass: ~ 5.7 ton
Fast timing: ~ 1 ns
Momentum resolution: 3-4%
Angular resolution for muons: 12 mrad

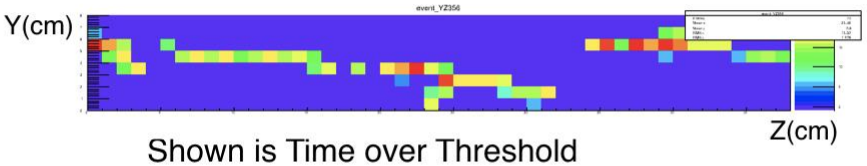
- Useful for
  - Neutron production (and probably energy) on C/H target only
  - Low-ν method (E_ν-E_L)
  - Measurements on hydrogen in CH-scintillator (flux, free nucleon cross section)
  - Constrain nuclear modelling uncertainties on C/H
- Unclear
  - Neutrino-electron scattering (either active target or ECAL)

1.46×10^{21} 80 GeV POT/year
$\rightarrow$ ~ 8 M ν_μ cc events/year
$\rightarrow$ ~ 1000 ν-e events/year

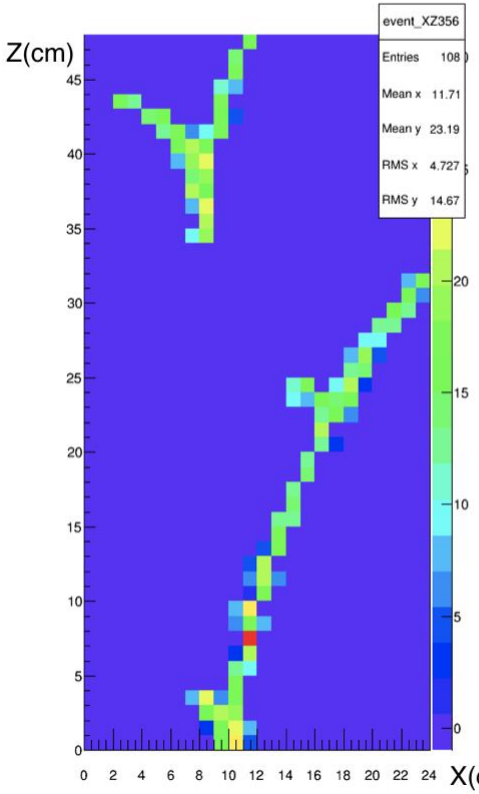
3D-Scintillator Cube Tracker

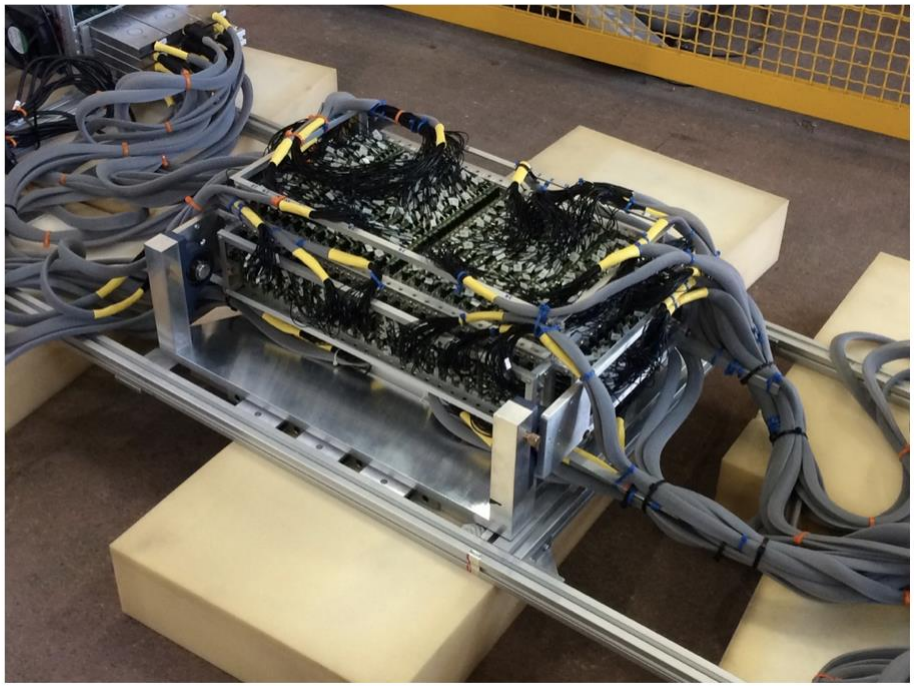
- Test beams in T9 area at CERN. B-field from 0.2T to 0.7T
- Detector size: 24 cm (width) x 8 cm (height) x 48 cm (length)





Shown is Time over Threshold
Signal amplitued calibration is ongoing





Event displays from the test beam at CERN July 2018

A set-up with 10,000 cubes 1,700 read. ch.

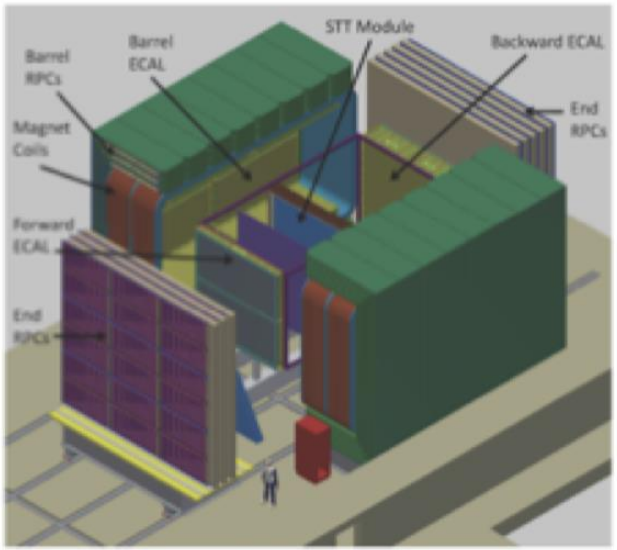
Set-up and event display for an electron + gamma (3-views)

Magnet Choices

- New Dipole or KLOE Solenoid?

Tendency to go for a new dipole, avoiding limitations of existing magnet

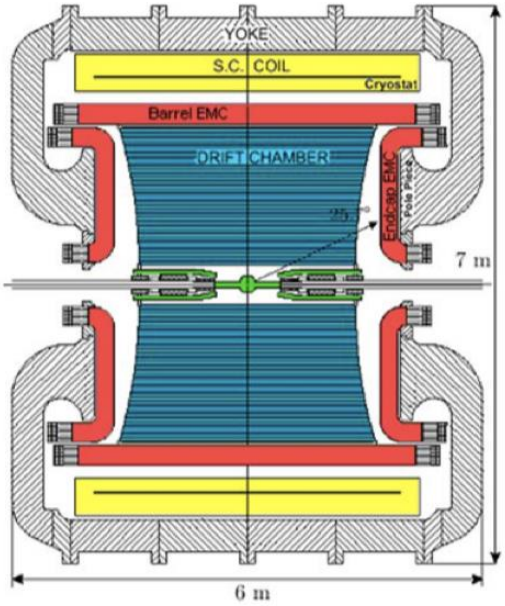
CDR Dipole similar to ND280/NOMAD



Reviewed design exists

Field ~ 0.4T

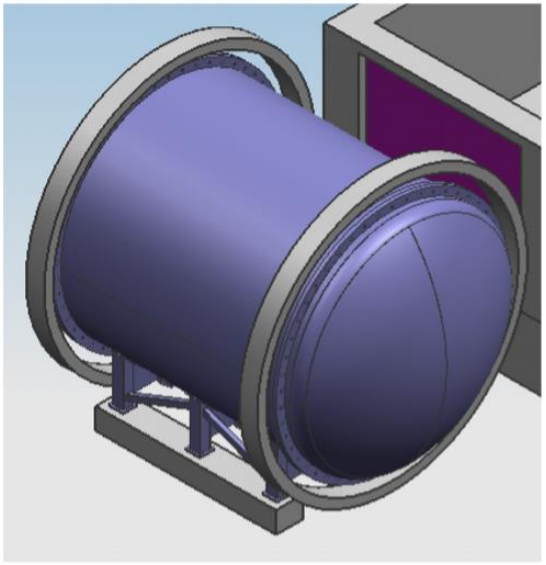
KLOE Solenoid superconducting



magnet exists

Field ~ 0.6T

Helmholtz Coils
Reduced return yoke



idea exists

MPT Choices

1. HPgTPC
2. STT
3. HPTPC & STT
4. HPTPC & 3DST
5. STT & 3DST
6. Dipole(HPTPS & 3DST) & KLOE(STT)

KLOE+STT	Dipole+STT	KLOE+HPgTPC	HPgTPC
6.14×10^6	7.35×10^6	1.16×10^6	2.95×10^6

Number of ν_μ charged current events in the active volume for 1.46×10^{21} 80 GeV protons on target

DUNE-PRISM

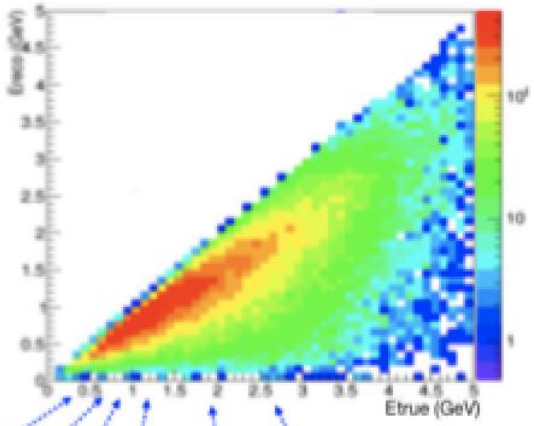
- Alternative approach
  - Vary flux by changing off axis angle
  - Only ever measure product of
    - flux,
    - cross section and
    - detector response
- Move LAr detector along different off-axis angles

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

The experimental floor area must be at least 35m wide x 17m deep.
→ 42.5 m x 17 m would be even better!

DUNE-PRISM

- A major challenge for DUNE is determining the E_{true} -> E_{reco} matrix (i.e. not just the ratio)
  - Energy loss due to neutrons, threshold effects, particle ID (e.g. pion mass), etc.
- Making measurements at a variety of off-axis angles provides an entirely new degree of freedom for constraining E_{true} -> E_{reco}



SUMMARY

- Conceptual design of the DUNE near detector will be finalized soon (~end 2018)
- Choice is for a hybrid solution: A LarTPC plus a Multi-Purpose Tracker.
- Tracker technology being selected. EM-calo/muon system will follow after that.
- Technical details to be completed.
- Option for a DUNE-PRISM kept open
- Near detector also for BSM searches