Status of the DUNE near detector

S. Manly (University of Rochester)*
Representing the DUNE collaboration

NUINT 2017

Toronto, Canada
June 2017

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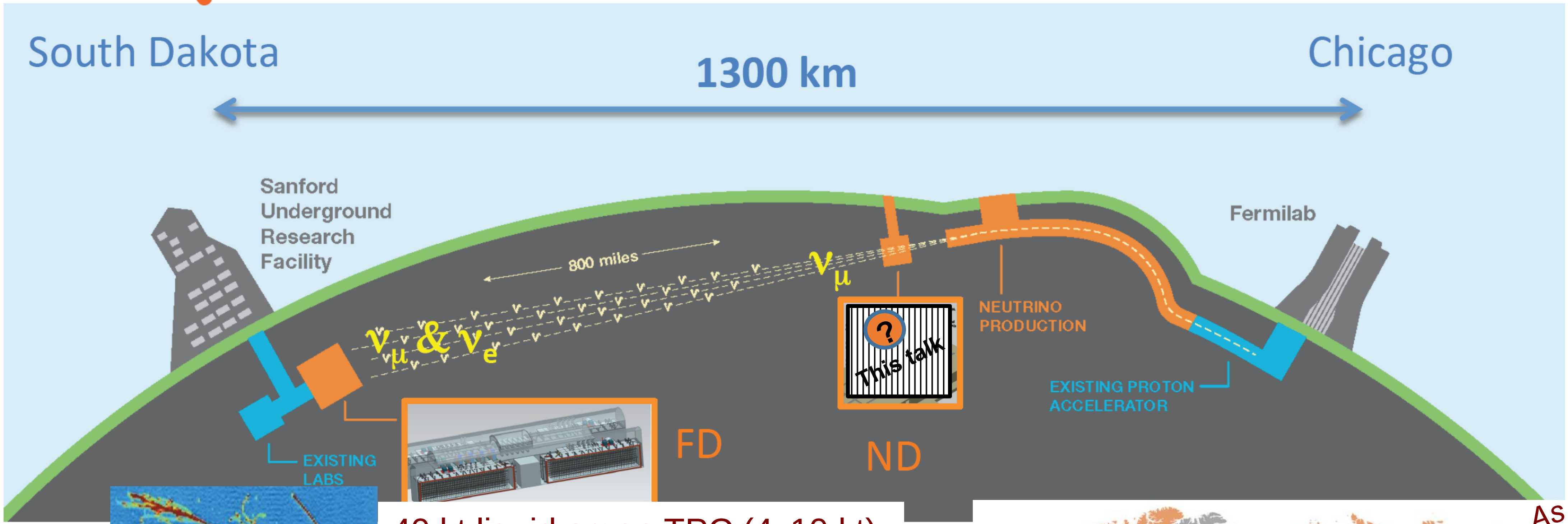
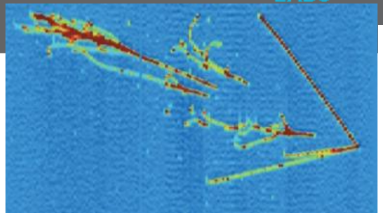
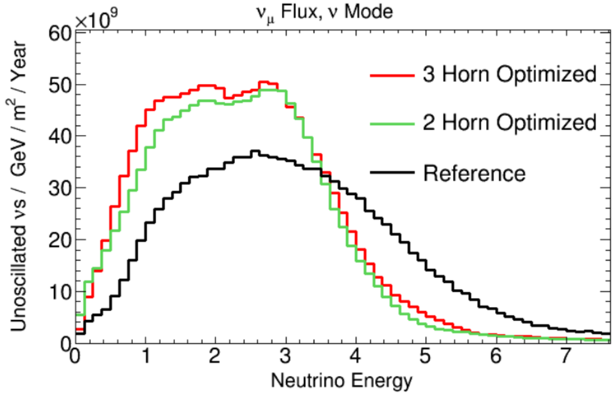
DEEP UNDERGROUND
NEUTRINO EXPERIMENT





40 kt liquid argon TPC (4x10 kt)

- Long baseline neutrino oscillations
- Supernova neutrinos
- Proton decay



Intense wideband beam

As of May 2017:
964 collaborators
164 institutions
30 nations

The near detector is *not* an optional add-on package for DUNE

TABLE XX: Relative uncertainty (1σ) on the predicted rate of ν_μ CC and ν_e CC candidate events.

Source of uncertainty	ν_μ CC	ν_e CC
Flux and common cross sections		
(w/o ND280 constraint)	21.7%	26.0%
(w ND280 constraint)	2.7%	3.2%
Independent cross sections	5.0%	4.7%
SK	4.0%	2.7%
FSI+SI(+PN)	3.0%	2.5%
Total		
(w/o ND280 constraint)	23.5%	26.8%
(w ND280 constraint)	7.7%	6.8%

From a recent T2K oscillation paper – PRD 92, 112003 2015, p. 77

Reduce systematic errors at far detector →

- **detector reconstruction effects**
- **flux*xsec**
- **nuclear effects**

Program to improve xsec errors and constraints

Precision exploration, ready for surprises

Beam monitoring

I wish for a near detector with …

Star light, star bright,
First star I see tonight,
I wish I may,
I wish I might,
Have the near detector I wish tonight.

-anonymous

Reduce systematic errors at far detector → detector reconstruction effects / flux*xsec / nuclear effects

detector reconstruction effects

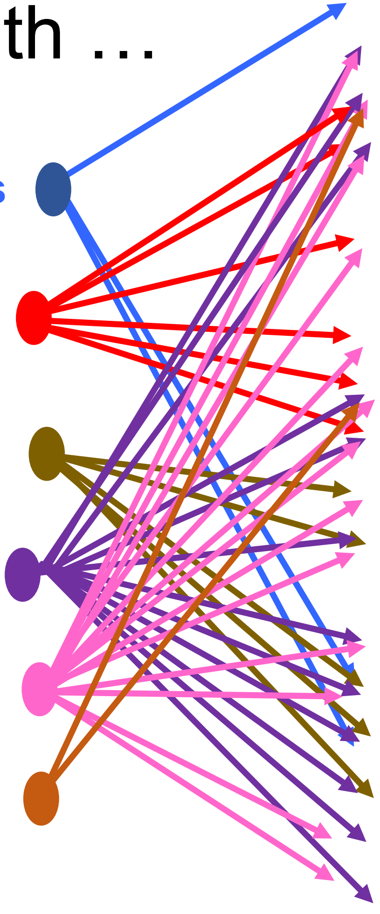
flux*xsec

nuclear effects

Improve xsec errors and constraints

Precision exploration

Beam monitoring



- ❑ LArTPC
- ❑ Low density
- ❑ High(ish) mass for statistics
- ❑ Magnet for charge separation, momentum measurement, PID
- ❑ Small surrounding material to reduce backgrounds
- ❑ Excellent EM energy resolution
- ❑ Excellent momentum resolution
- ❑ Excellent angular resolution
- ❑ Low detection thresholds
- ❑ Good photon and neutron containment
- ❑ Good pizero detection
- ❑ 4 pi coverage
- ❑ Ar target
- ❑ Other nuclear targets
- ❑ Good vertex resolution
- ❑ Good two-track separation

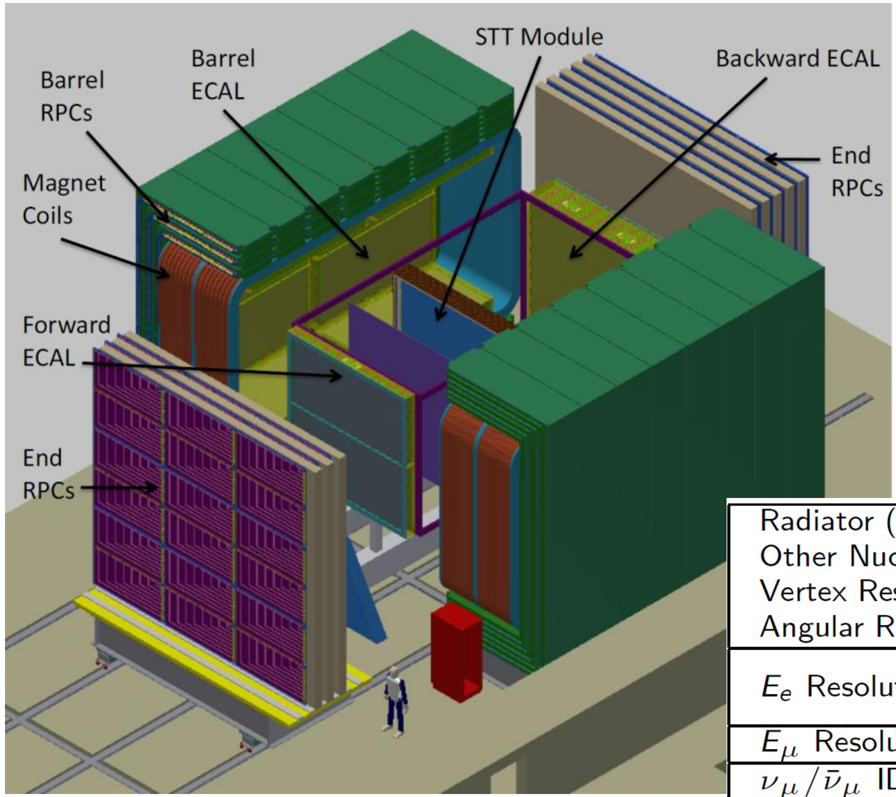
- ➢ Mapping is for illustration only
- ➢ Physics requirements lead to contradictions when translated into near detector characteristics
- ➢ Complex multidimensional parameter space to "optimize"
- ➢ Difficult to accommodate all the needs with a single technology

The LBNF/DUNE CDR reference design

Fine grained tracker (FGT)

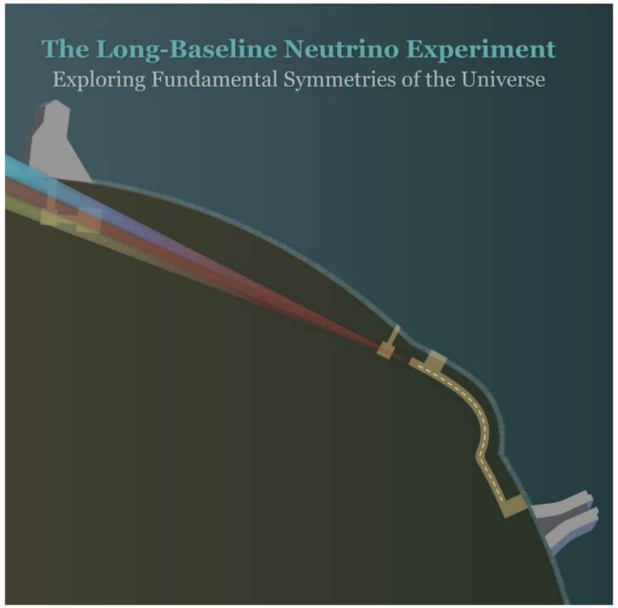
https://arxiv.org/abs/1601.02984

- Straw tube tracker, X_o = 6m
- Low density, excellent resolution
- Transition radiator foils for good electron ID and mass for statistics
- Good particle ID
- 4π coverage
- Ar target in high pressure gas tube layers
- Other nuclear target layers possible
- Charge separation with UA1-like magnet
- B=0.4 T

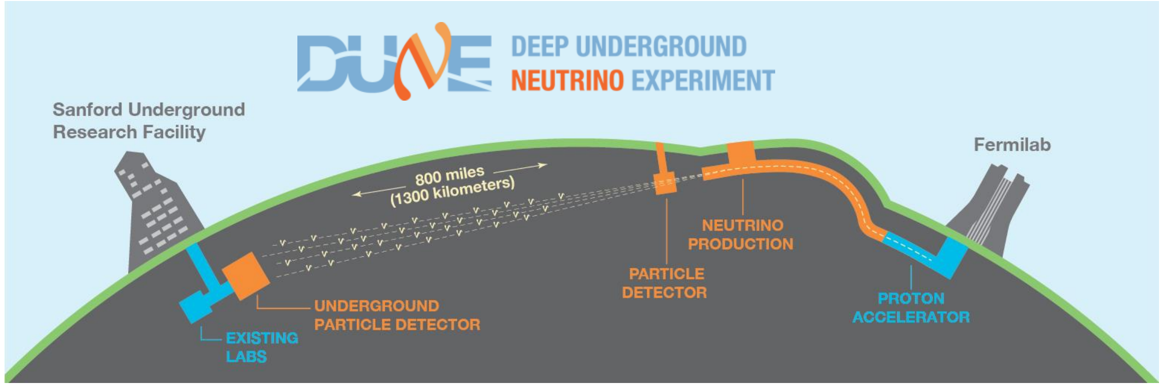


Radiator (Target) Mass Other Nuclear Target Mass Vertex Resolution Angular Resolution	7 tons 1–2 tons 0.1 mm 2 mrad
E_e Resolution	$6\%/\sqrt{E}$ (4% at 3 GeV)
E_μ Resolution	3.5%
$\nu_\mu/\bar{\nu}_\mu$ ID $\nu_e/\bar{\nu}_e$ ID π^- .vs. π^+ ID π^+ .vs. *proton* .vs. K^+	Yes Yes Yes Yes
$NC\pi^0/CCe$ Rejection $NC\gamma/CCe$ Rejection $CC\mu/CCe$ Rejection	0.1% 0.2% 0.01%

The near detector under internationalization and transition from LBNE to DUNE



LBNE → DUNE
Seen as critically important opportunity to grow collaboration



New groups and ideas solicited for near detector effort. DUNE examining ideas, including the reference design, with intent to commit late 2017/early 2018 to a DUNE ND design concept.

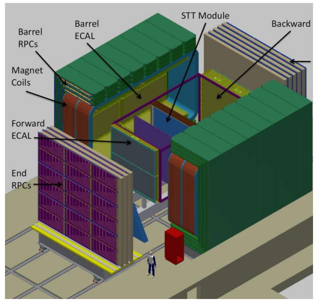
New ideas, interested people/groups and potential resources are still very welcome

2016 - Year of the DUNE near detector task force

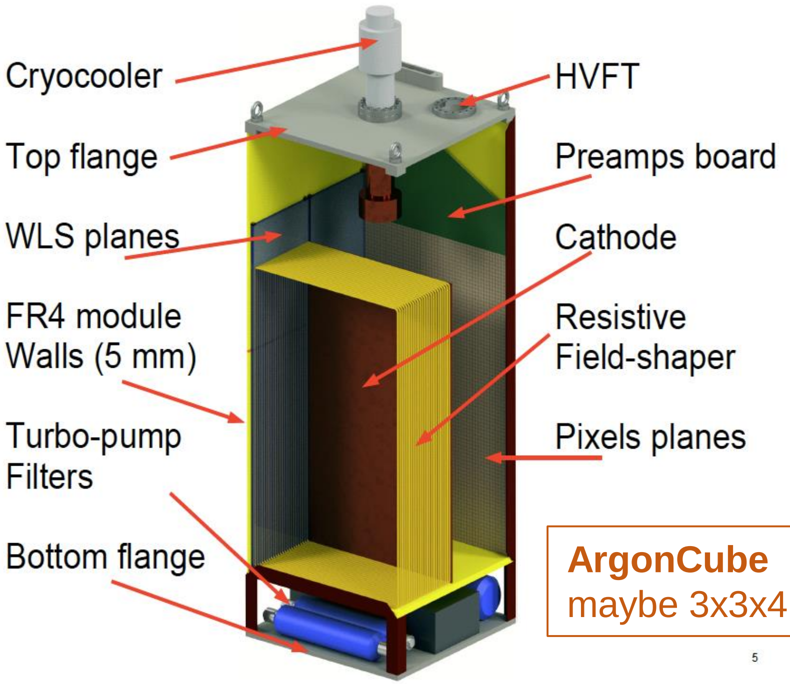
HPGArTPC
maybe 3x3x4 m^3

Summary of charge:

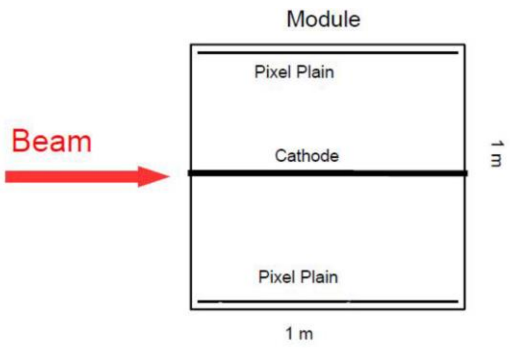
- Develop GEANT4 simulations of reference ND and alternatives
- Perform full end-to-end simulation connecting measurements in ND to far detector systematics
- Evaluate potential benefits of reference ND (STT) as well as LArTPC and HPGArTPC

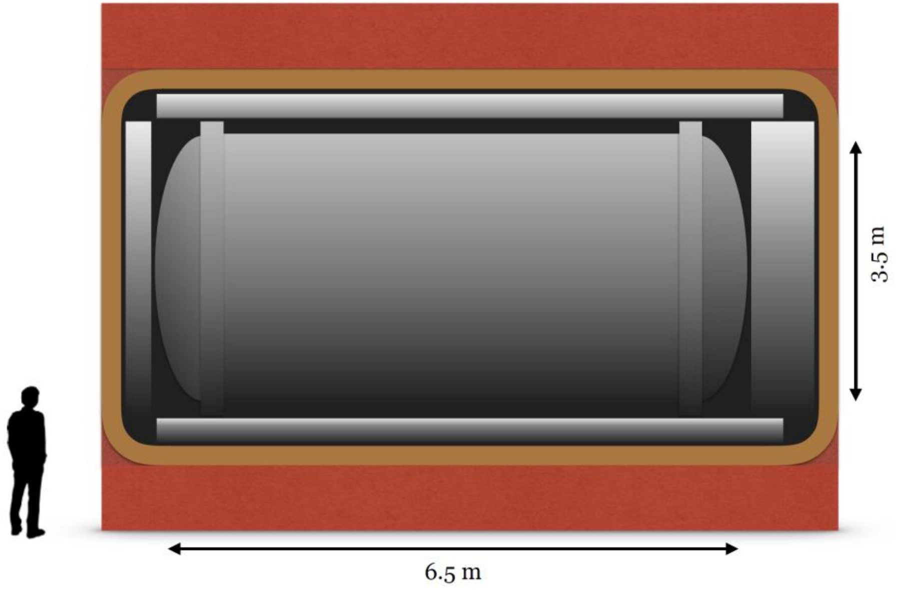


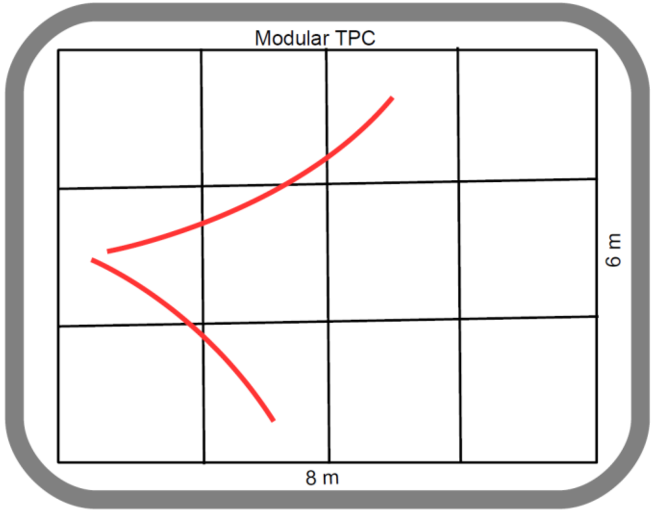
Straw Tube Tracker (STT) shown already



ArgonCube
maybe 3x3x4 m^3







2017 - Near detector design study

Charge:

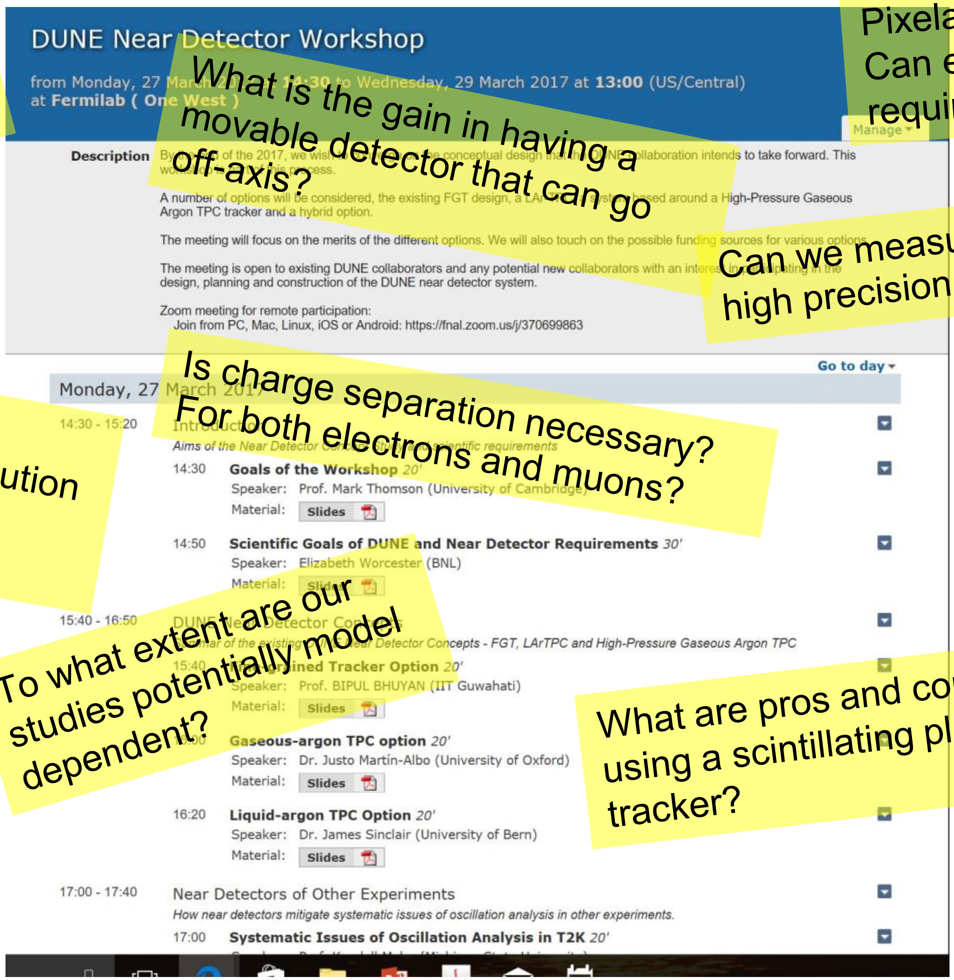
Develop a proposal for a DUNE near detector concept by the end of 2017

- Preserve the momentum/tools generated by the task force
- Generate a concept with collaboration buy-in
  - Technically sound and a plausible path to resources (money, people) sufficient for construction
- Time is short. Supporting physics studies will increase with sophistication as design proceeds toward CDR/TDR.

- beam-ready ND in 2026
- Technical design report by 2020
- conceptual design report by 2019

Near detector design study

Much discussion:
- Workshops on March 27-29 and June 9-10
- Collaboration meetings in January and May



DUNE Near Detector Workshop

from Monday, 27 Mar... to Wednesday, 29 March 2017 at **13:00** (US/Central)
at **Fermilab (One West)**

Manage

Description By ... of the 2017, we wish ... conceptual design ... DUNE collaboration intends to take forward. This ... process.

A number of options will be considered, the existing FGT design, a LAr ... based around a High-Pressure Gaseous Argon TPC tracker and a hybrid option.

The meeting will focus on the merits of the different options. We will also touch on the possible funding sources for various options.

The meeting is open to existing DUNE collaborators and any potential new collaborators with an interest ... in the design, planning and construction of the DUNE near detector system.

Zoom meeting for remote participation:
Join from PC, Mac, Linux, iOS or Android: https://fnal.zoom.us/j/370699863

Go to day

Monday, 27 March 2017

14:30 - 15:20 Introduction
Aims of the Near Detector ... scientific requirements

14:30 **Goals of the Workshop** *20'*
Speaker: Prof. Mark Thomson (University of Cambridge)
Material: Slides

14:50 **Scientific Goals of DUNE and Near Detector Requirements** *30'*
Speaker: Elizabeth Worcester (BNL)
Material: Slides

15:40 - 16:50 DUNE Near Detector Concepts
... of the existing ... Near Detector Concepts - FGT, LArTPC and High-Pressure Gaseous Argon TPC

15:40 **... ined Tracker Option** *20'*
Speaker: Prof. BIPUL BHUYAN (IIT Guwahati)
Material: Slides

16:00 **Gaseous-argon TPC option** *20'*
Speaker: Dr. Justo Martín-Albo (University of Oxford)
Material: Slides

16:20 **Liquid-argon TPC Option** *20'*
Speaker: Dr. James Sinclair (University of Bern)
Material: Slides

17:00 - 17:40 Near Detectors of Other Experiments
How near detectors mitigate systematic issues of oscillation analysis in other experiments.

17:00 **Systematic Issues of Oscillation Analysis in T2K** *20'*

Will backgrounds make it difficult to associate calorimeter clusters to events in HPGasTPC?

To what extent can Ar target layers in FGT be used to cancel nuclear systematics in FD?

What is the gain of better momentum and angular resolution that comes with a low density detector?

Can we separate CC from NC using missing Pt?

What is the gain in having a movable detector that can go off-axis?

Is charge separation necessary? For both electrons and muons?

To what extent are our studies potentially model dependent?

Can a modular LArTPC function in the intense LBNF beam at near hall?

Pixelated readout for LArTPC? Can electronics meet low power requirement?

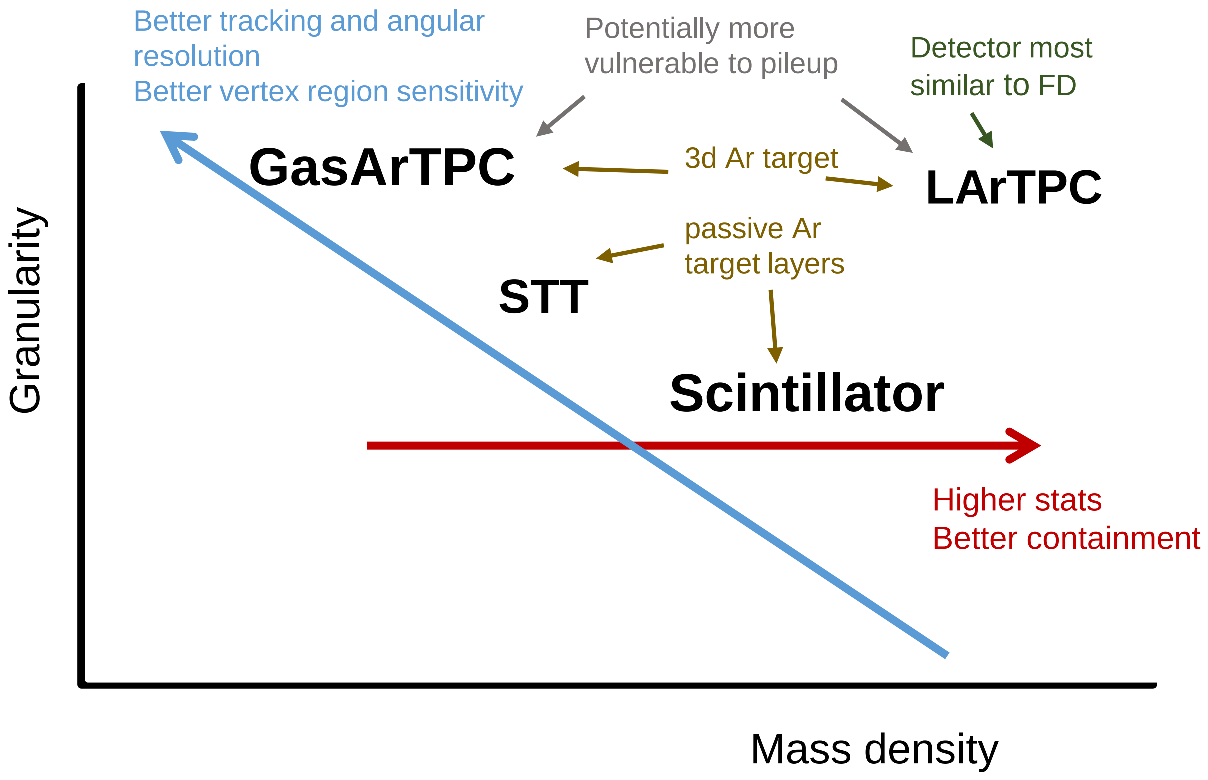
Can we measure neutrino flux spectrum to very high precision using ν-e- scattering?

Is it better to site near hall at 360 meters or 574 meters from target?

What is the effect of beam dispersion on the ν-e- scattering measurement?

What are pros and cons of using a scintillating plastic tracker?

Tracker comparisons along a few relevant axes



Option	X_o	Θ_{rms} @ 1 GeV/c	Δp/p for B=0.4 T
Minerva-like	40 cm	~6 mrad	~10%
Scint. with smaller strips	40 cm	~4 mrad	~10%
LArTPC	14 cm	~4 mrad	~6%
STT	5.5 m	~2 mrad	~3%
GasArTPC	12.6 m	~0.4 mrad	~2%

- All multiple scattering limited for bulk of tracks
- Can get improved dp/p with stronger B
- 3d scintillator detector geometry not included yet in table

A complex problem.

Reasonable people can wind up in very different places …

Angelic spirit of NOvA/MINOS

ND should be just like FD so systematics cancel

Neutrinos are hard. We need both approaches.

Devilish T2K/Nomad sprite

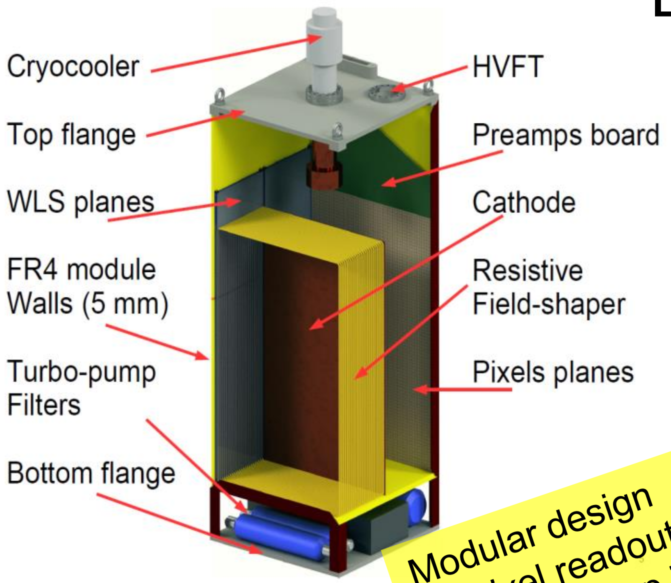
ND should be powerful detector and constrain flux*Xsec with super fit

ND facility:

- Modular LArTPC with pixelized readout
- Magnetized low density tracker
    - probably containing some Ar target mass
    - possibly acting as a magnetic spectrometer for forward tracks from the LArTPC
    - possibly more than one tracking technology
- Probably at 574 m from target
- Exploring
    - Optimal degree of functional integration of different parts
    - use of KLOE magnet & ECAL
    - DUNEprism idea, inclusion of movement off-axis

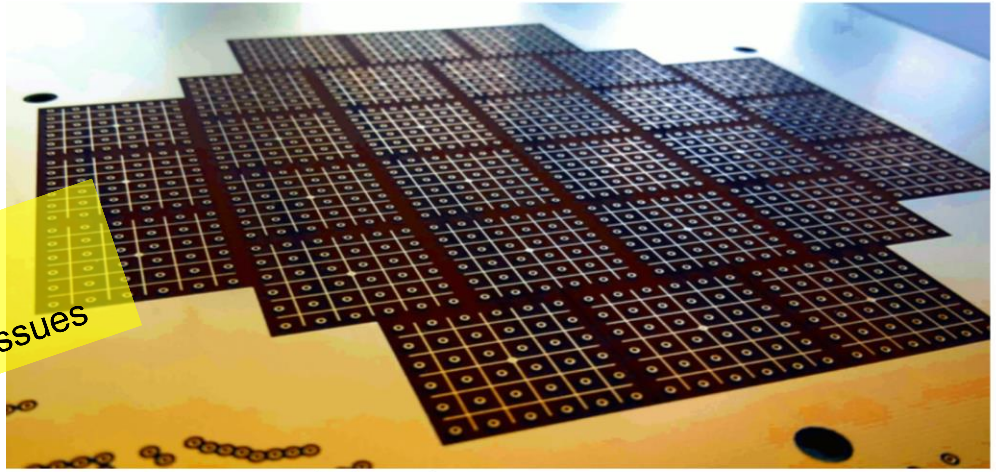
VERSUS

LArTPC option: ArgonCUBE

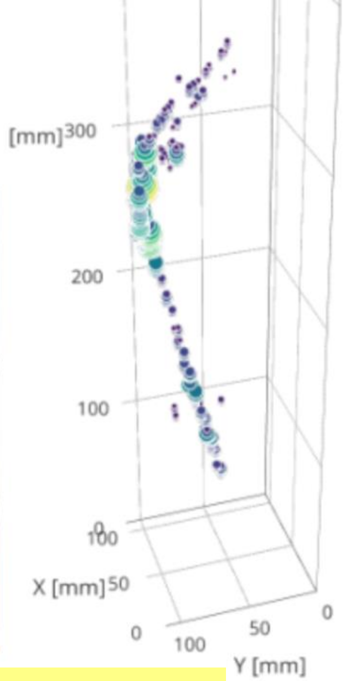


LHEP group at Univ. of Bern / ArgonCUBE:
- Demonstrated pixel sensor in LAr (Summer 2016)
- Need low-power electronics for large-scale feasibility

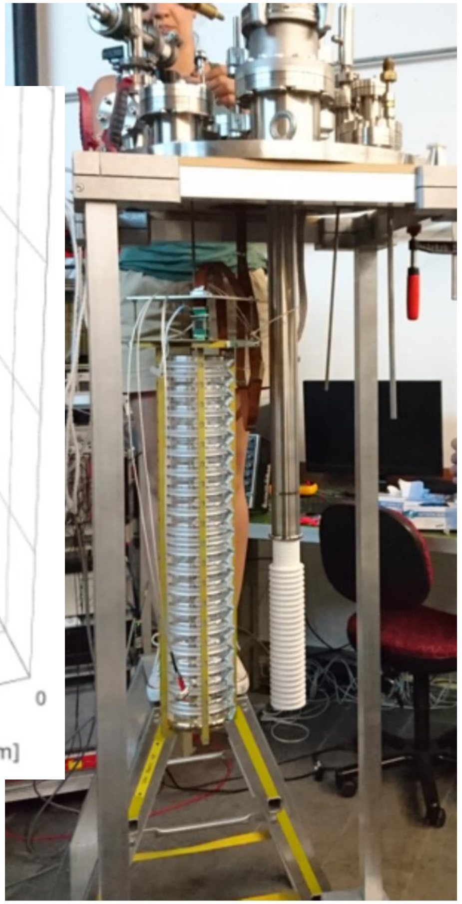
Modular design
2d pixel readout
reduce pile-up issues

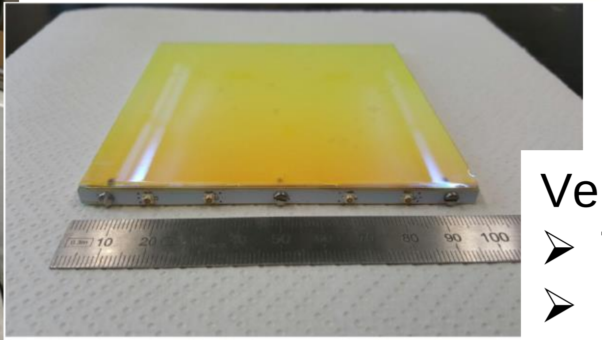


Pixel spacing: 3mm



Pixel readout test

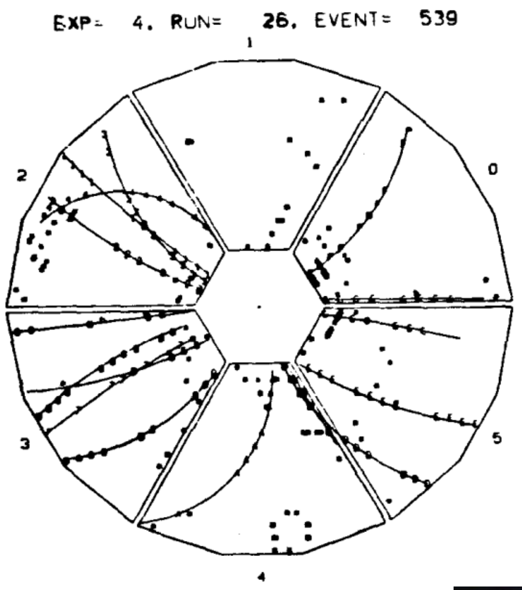




First prototype Dichroic reflector light detector
Bern March 2017

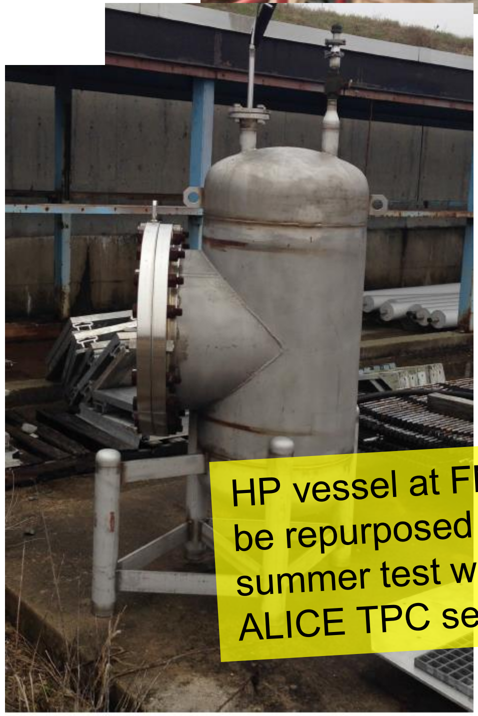
Very active R&D program:
- TPC cryostat test summer 2017
- Low-power electronics in development now, initial tests fall 2017
- Aiming for fall 2017 test in LArIAT test beam setup at FNAL
- Fully instrumented module deployment 2018

HPGasArTPC option

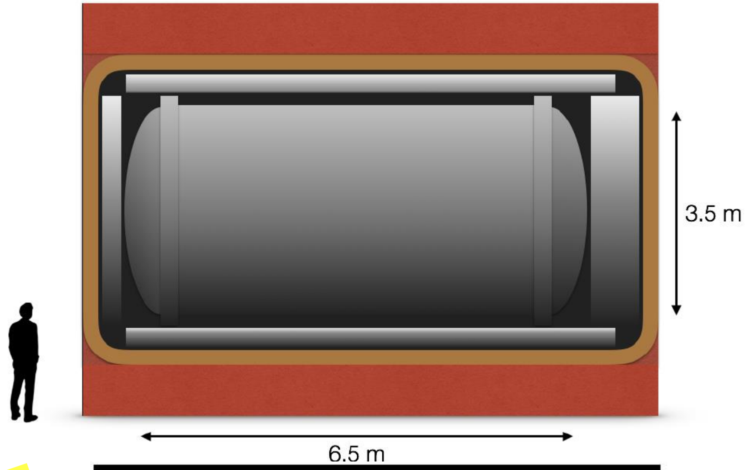


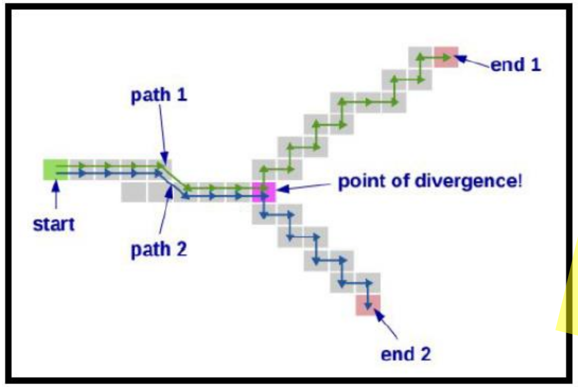
Magnetized HPGasTPC done before at PEP-4 (first cosmics in 1981)

Low pressure prototype vessel at Royal Holloway Univ.



HP vessel at FNAL to be repurposed for summer test with small ALICE TPC segment



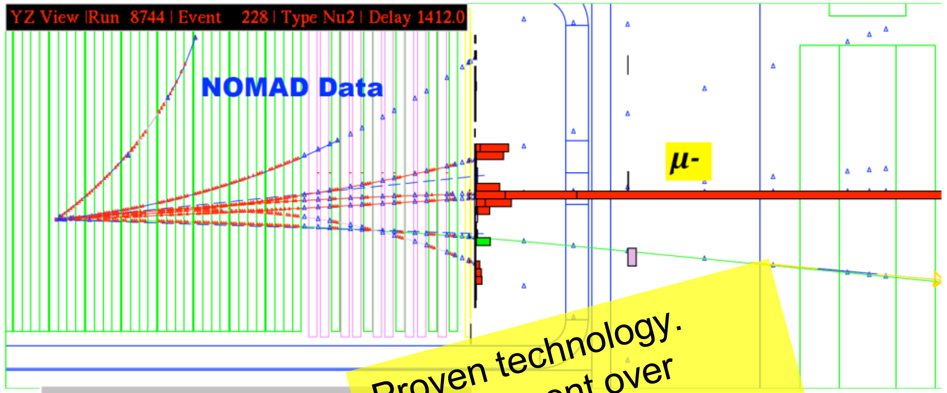


TREx TPC reconstruction software

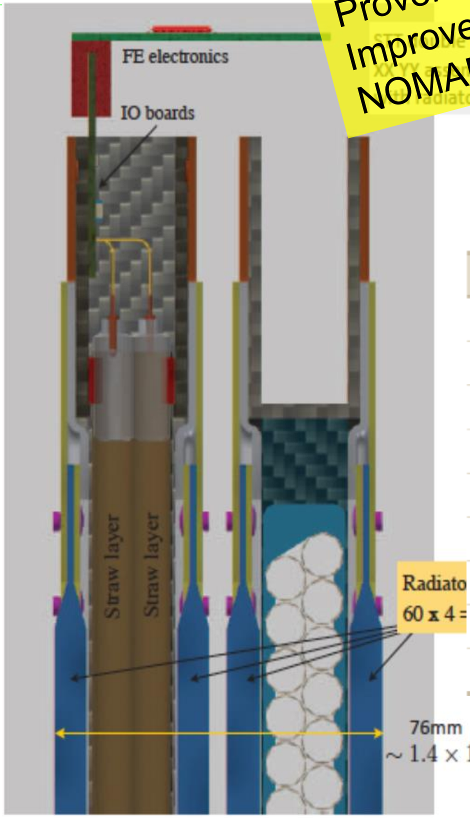
- Excellent resolution and low detection thresholds (soft hadron sensitivity)
- Hardware work in US and UK progressing
- Looking at performance in high intensity beam and complementarity to LArTPC in DUNE ND setting

Straw tube tracker option

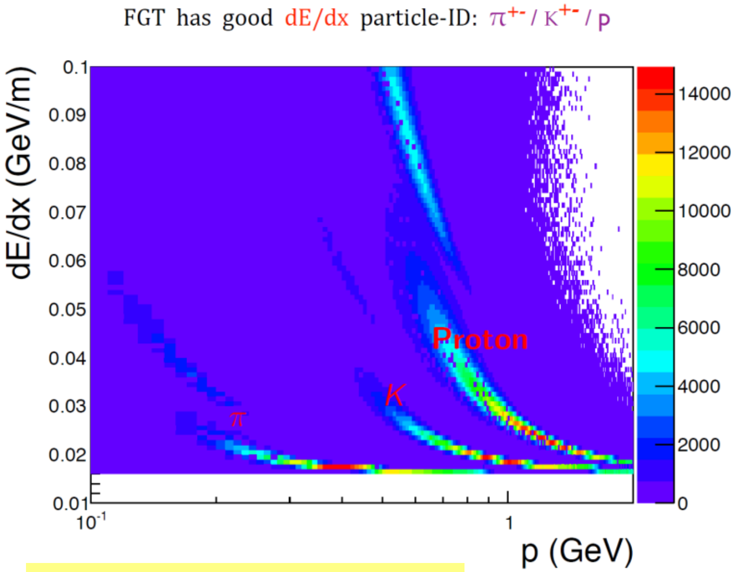
ν_μ-CC Candidate



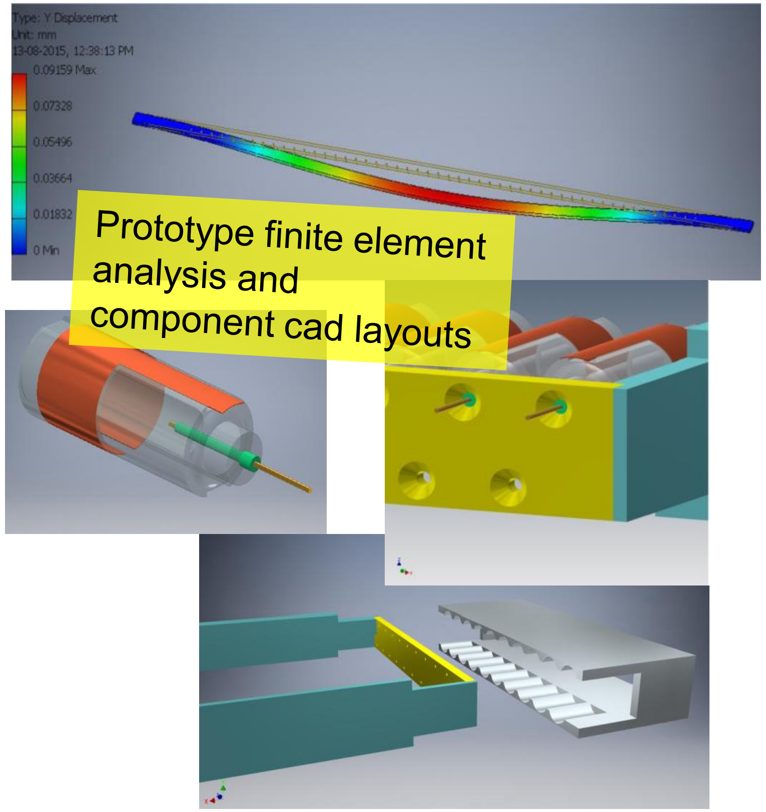
Proven technology.
Improvement over
NOMAD tracker



Performance Metric	Value
Vertex resolution	0.1 mm
Angular resolution	2 mrad
E_e resolution	5%
E_μ resolution	5%
$\nu_\mu/\bar{\nu}_\mu$ ID	Yes
$\nu_e/\bar{\nu}_e$ ID	Yes
$NC\pi^0/CCe$ rejection	0.1%
$NC\gamma/CCe$ rejection	0.2%
$NC\mu/CCe$ rejection	0.01%



Many pre-taskforce and now some taskforce STT performance and physics studies

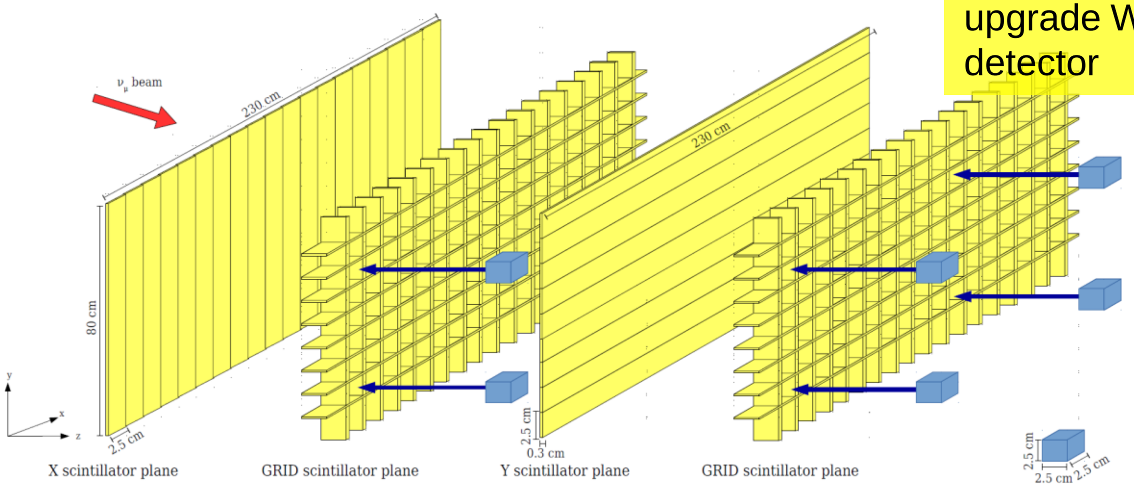


Prototype finite element analysis and component cad layouts

- ➢ STT is tracker in the DUNE reference design
- ➢ Much study of that design, prototypes planned
- ➢ Work slowed in the last year with funding delays
- ➢ No major technical questions need to be resolved for reasonable evaluation of STT as component of DUNE ND

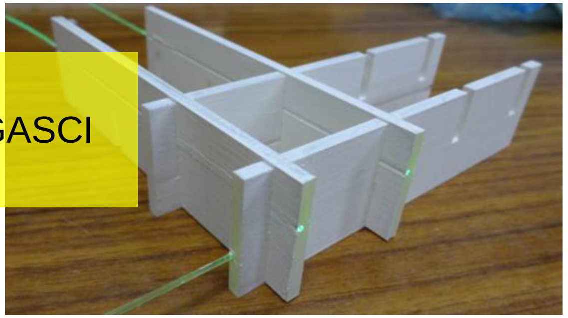
Scintillating plastic tracker option

Proven technology.
In use at T2K and MINERvA

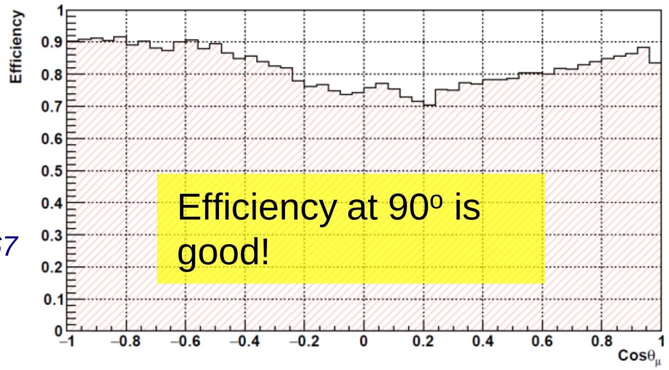


Quilain, Minamino, arXiv: 1610.06367

T2K's ND280 upgrade WAGASCI detector

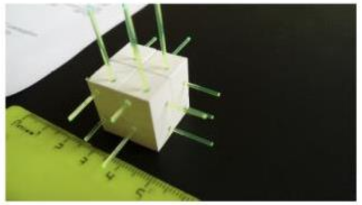


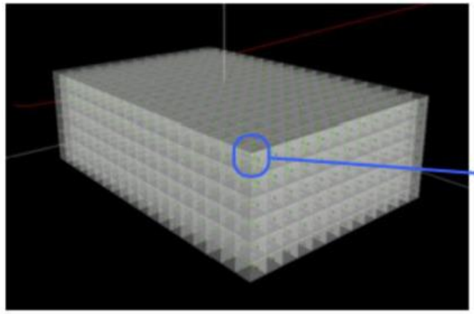
Minamino, NUINT14



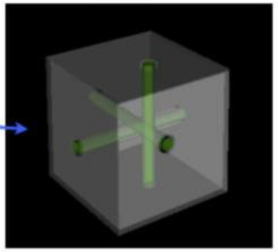
Efficiency at 90º is good!

Super FGD





1 cm³



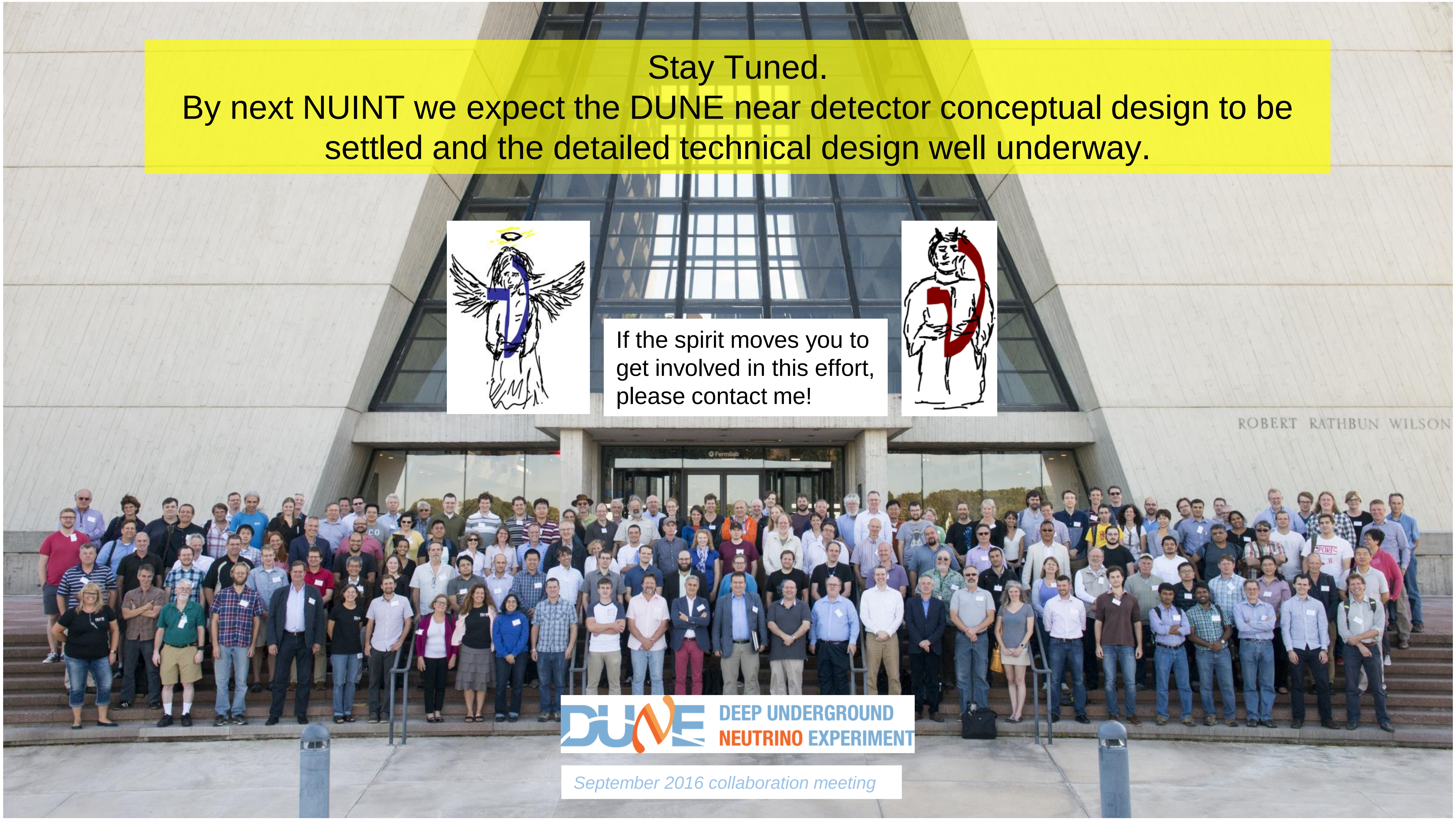
https://indico.cern.ch/event/633840/timetable/

Please check the section "Super-FGD"

- Scintillator tracker is fast
- Mass for containment and statistics
- Resolution suffers with the relatively high density
- 4π coverage with the 3d readout
- Performance/cost ratio likely very good

Stay Tuned.

By next NUINT we expect the DUNE near detector conceptual design to be settled and the detailed technical design well underway.

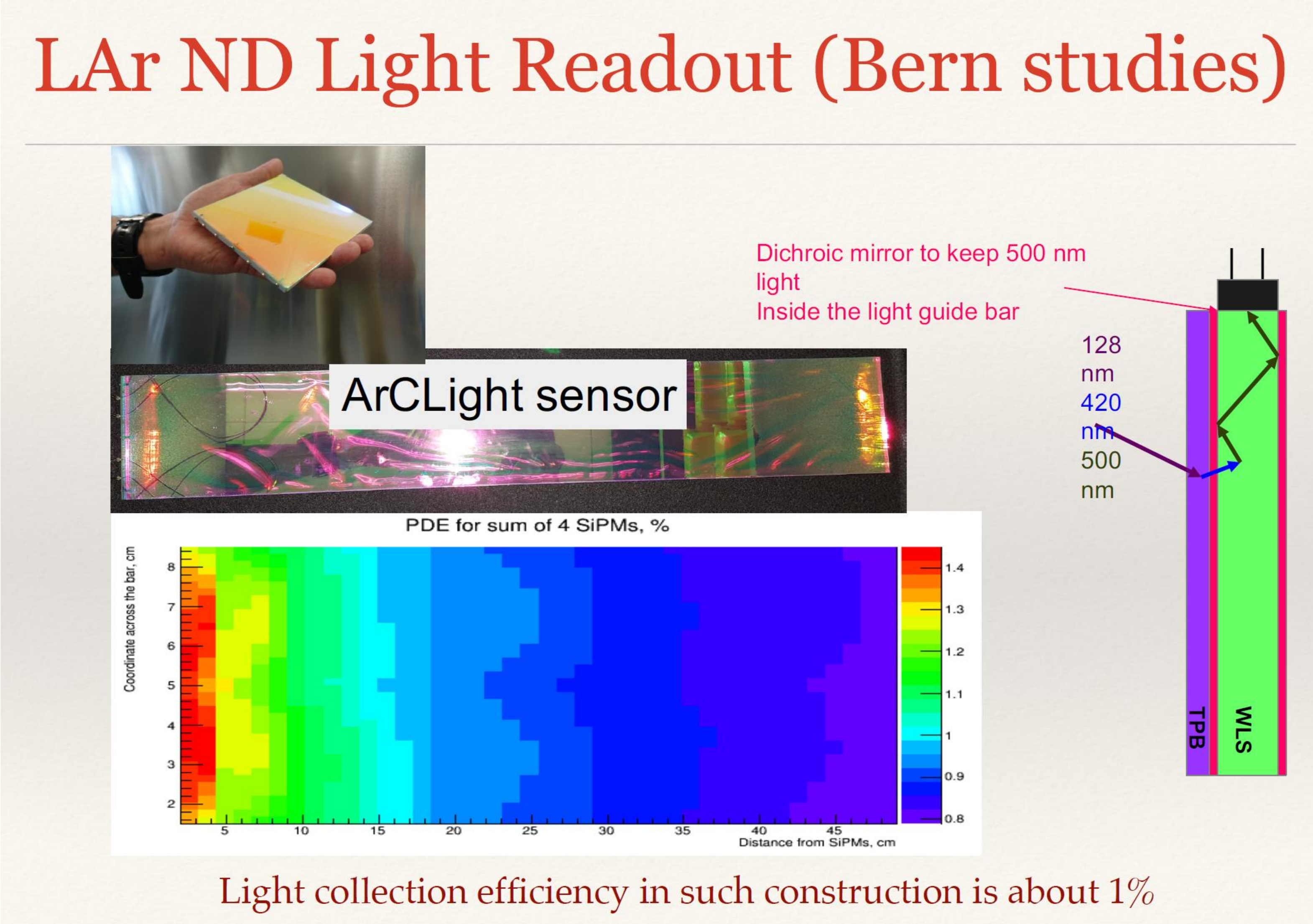


If the spirit moves you to get involved in this effort, please contact me!

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

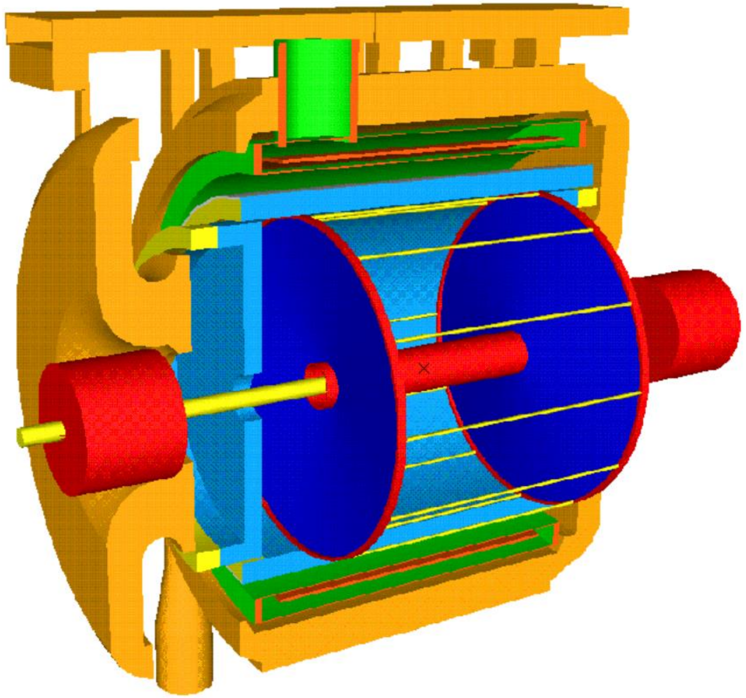
September 2016 collaboration meeting

Shown by A. Selyunin at June DUNE ND workshop



Shown by S. Bertolucci at recent DUNE ND workshop

The KLOE experiment

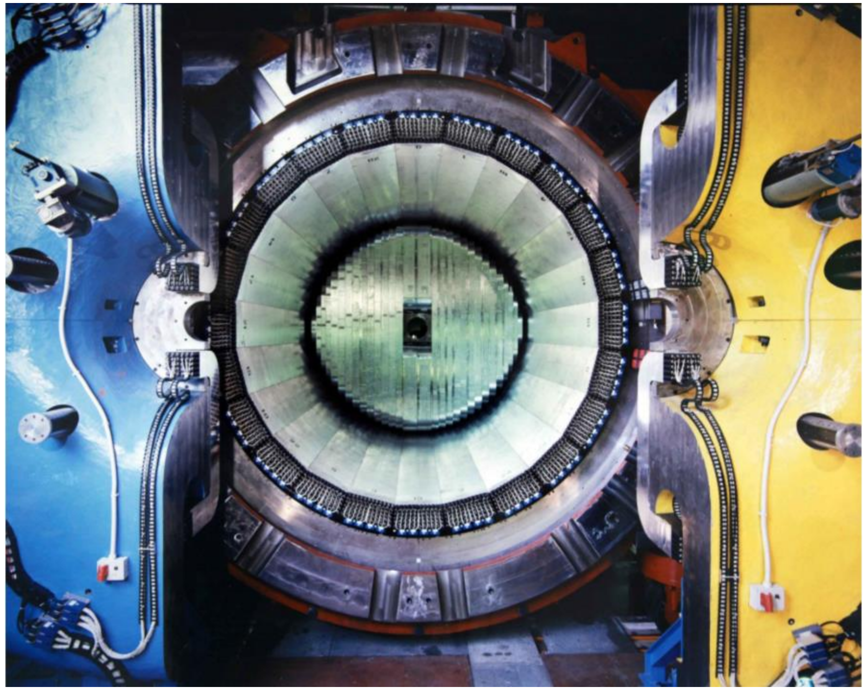


Be beam pipe (0.5 mm thick)
Instrumented permanent magnet quadrupoles (32 PMT's)

Drift chamber (4 m ∅ × 3.3 m)
90% helium 10% isobutane
12582/52140 sense/total wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's

Superconducting coil (5 m bore)
$B = 0.6$ T ($\int B\, dl = 2.2$ T·m)

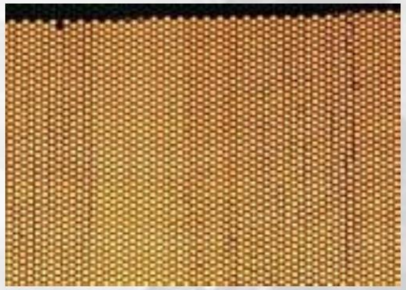


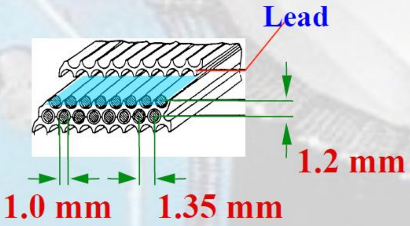
Shown by S. Bertolucci at recent DUNE ND workshop

The KLOE calorimeter

Pb - scintillating fiber sampling calorimeter of the KLOE experiment at DAΦNE (LNF):

- **1 mm diameter sci.-fi. (Kuraray SCSF-81 and Pol.Hi.Tech 0046)**
  - **Core: polystyrene, ρ =1.050 g/cm^3, n=1.6, λ_{peak} ~ 460 nm**
- **0.5 mm groved lead foils**
- **Lead:Fiber:Glue volume ratio = 42:48:10**
- **X_0 = 1.6 cm ρ=5.3 g/cm^3**
- **Calorimeter thickness = 23 cm**
- **Total scintillator thickness ~ 10 cm**



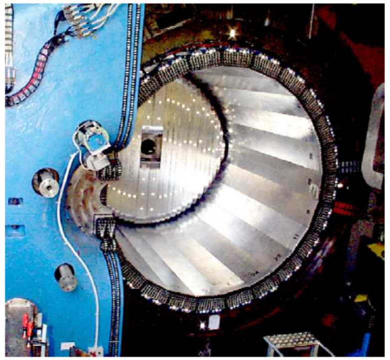


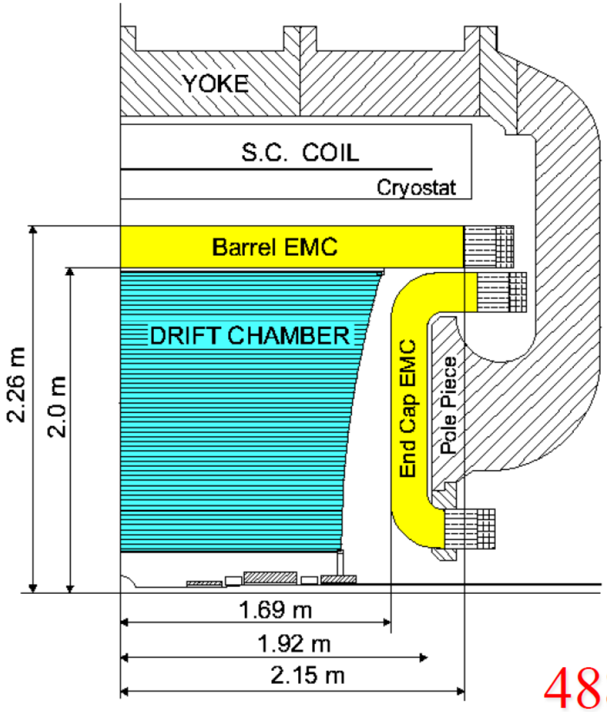
Shown by S. Bertolucci at recent DUNE ND workshop

Electromagnetic calorimeter

24 barrel modules
60 cells (5 layers)
4.3m length

2 × 32 endcap modules
10/15/30 cells



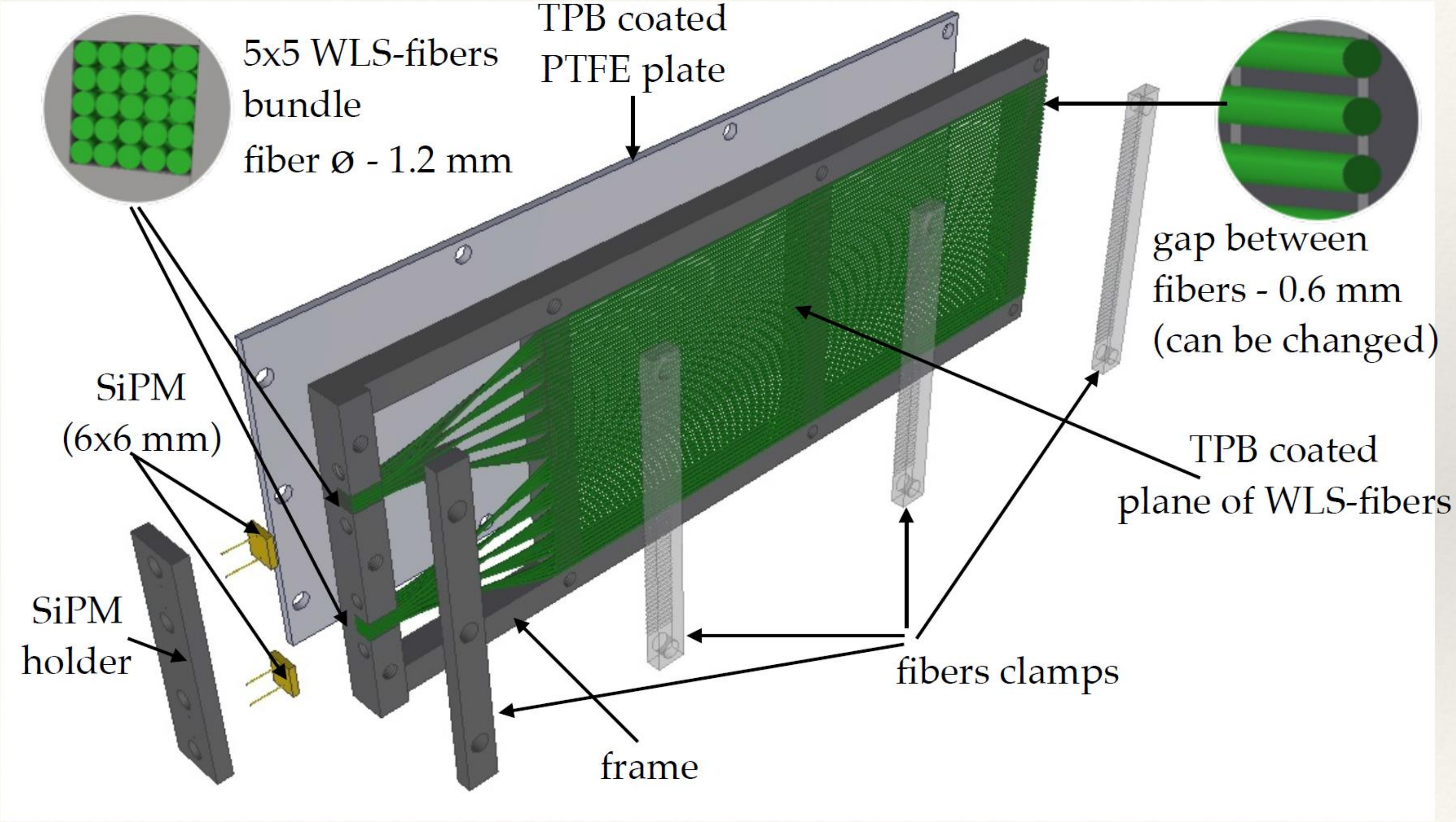


2440 cells total

4880 channels

Shown by A. Selyunin at June DUNE ND workshop

Design of light readout module (Dubna)



module size can be changed optionally
(for the first tests it will have 30 cm length and 11 cm width)