Proposal for a Full-Scale Prototype Single-Phase Liquid Argon Time Projection Chamber and Detector Beam Test at CERN

Thomas Kutter, LSU
on behalf of the proposal authors

SPSC Meeting,

CERN, June 23rd 2015

Outline

- Introduction
- DUNE Science
- DUNE Organization
- Prototype detector and beam test
- Schedule and responsibilities
- Summary

Introduction

Within the past 6 months, a new international collaboration (DUNE) has been formed to pursue long-baseline neutrino oscillation physics with deep-underground liquid argon detectors

DUNE collaboration plans to install initial 10 kt fiducial mass liquid argon detector at Sanford Deep Underground Research Facility (SURF) in South Dakota, U.S.A. beginning in 2021

With this goal in mind, the collaboration is taking ownership of previously submitted "Expression of Interest for a Full-Scale Detector Engineering Test and Test Beam Calibration of a Single-Phase LAr TPC" (October 2014) → DUNE Prototype (DUNE-PT)

CERN-SPSC-2014-027 ; SPSC-EOI-011

DUNE-PT Goals

Validate construction techniques and operational performance of full-scale single-phase TPC prototype modules on the time scale needed to begin construction of first underground 10 kt module (late 2019)

Collect and analyze the CERN beam test calibration data necessary for understanding the deep-underground data to be collected with the large-scale detector modules (starting in 2023)

Program Synergies

The DUNE collaboration also recognizes the potential of the dual-phase liquid argon detector technology

The collaboration remains open to adopting this technology for one or more of the three subsequent 10 kt detector modules to be installed at SURF and is therefore also strongly supportive of the previously approved WA105 test program

DUNE plans to take advantage of its overlapping membership with the two test beam efforts to develop synergies and optimize the utilization of program resources

DUNE Primary Science Program

Focus on fundamental open questions in particle physics and astro-particle physics

Consistent with European strategy and P5 recommendations

1) Long-baseline Neutrino Oscillation Physics

- CPV in the leptonic sector
- Mass Hierarchy
- Precision Oscillation Physics (θ_{23} octant, …) & testing the 3-flavor paradigm

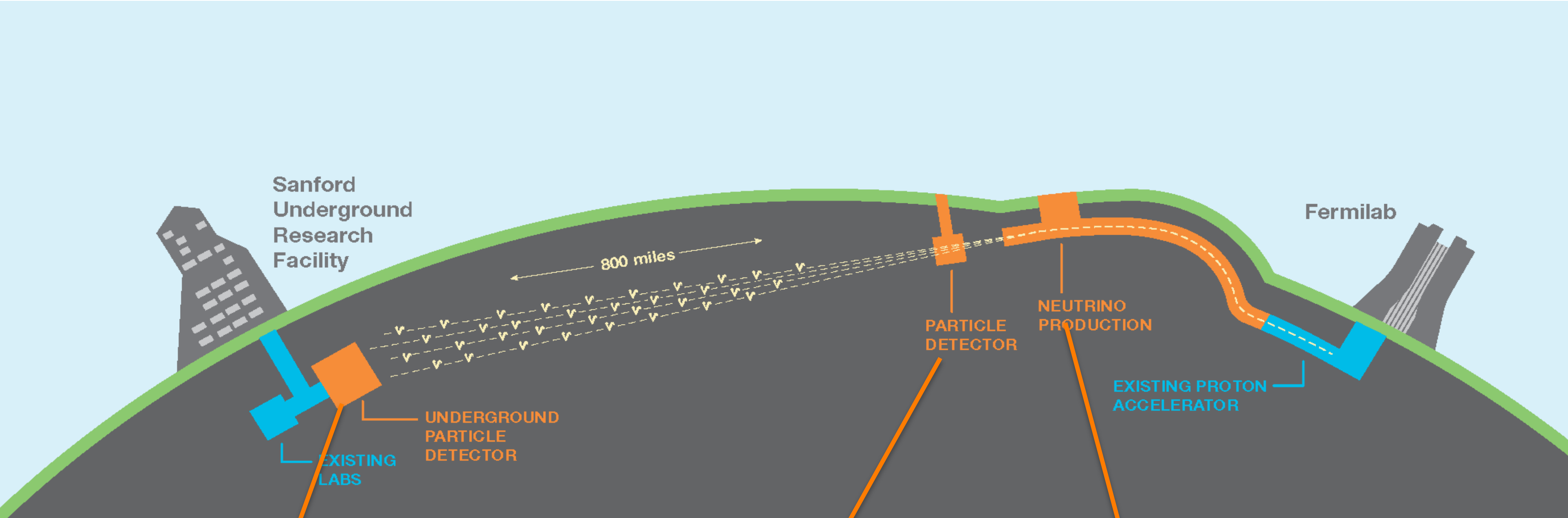
2) Nucleon Decay

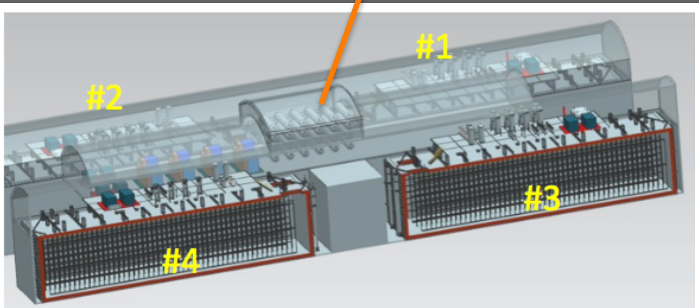
- targeting some SUSY-favored modes, e.g. $p \rightarrow K^+ \nu$

3) Supernova burst physics & astrophysics

- Galactic core collapse super-nova, sensitivity to ν_e

DUNE Experimental Strategy





high precision
near detector

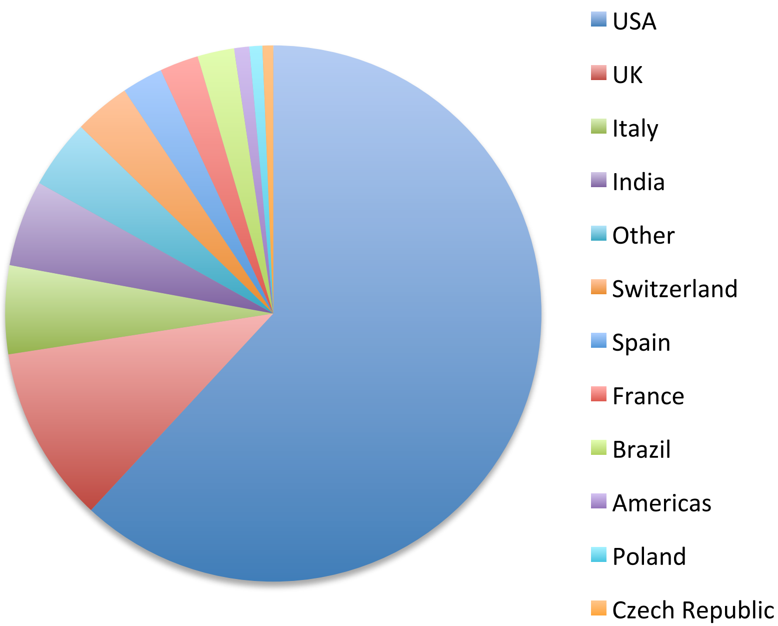
Wide band, high purity ν_μ beam with peak flux
at 2.5 GeV operating at $\sim$1.2 MW and upgradeable

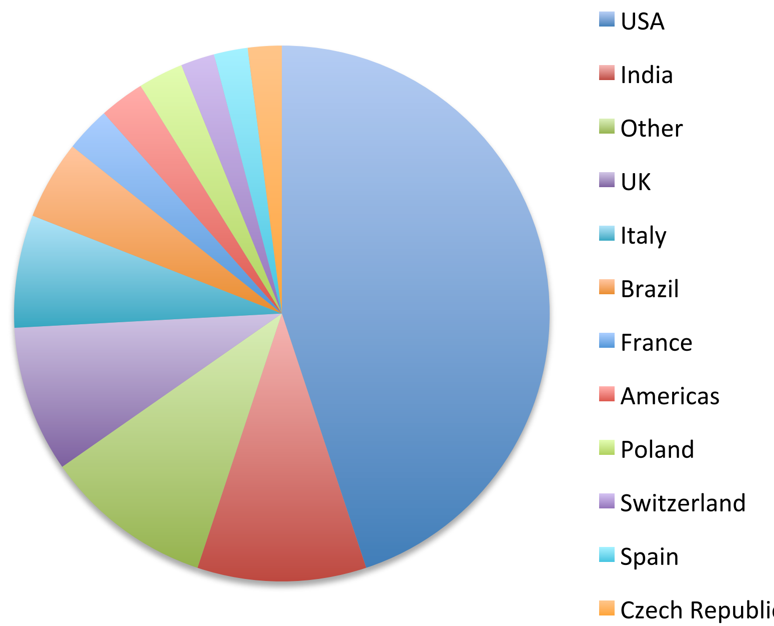
- four identical cryostats deep underground
- staged approach to four independent 10 kt LAr detector modules
- Single-phase and double-phase readout under consideration

DUNE Collaboration

As of today: from

776 Collaborators 144 Institutes





214 of these collaborators from 43 institutes and 7 countries have signed the proposal submitted to the SPSC on June 8th

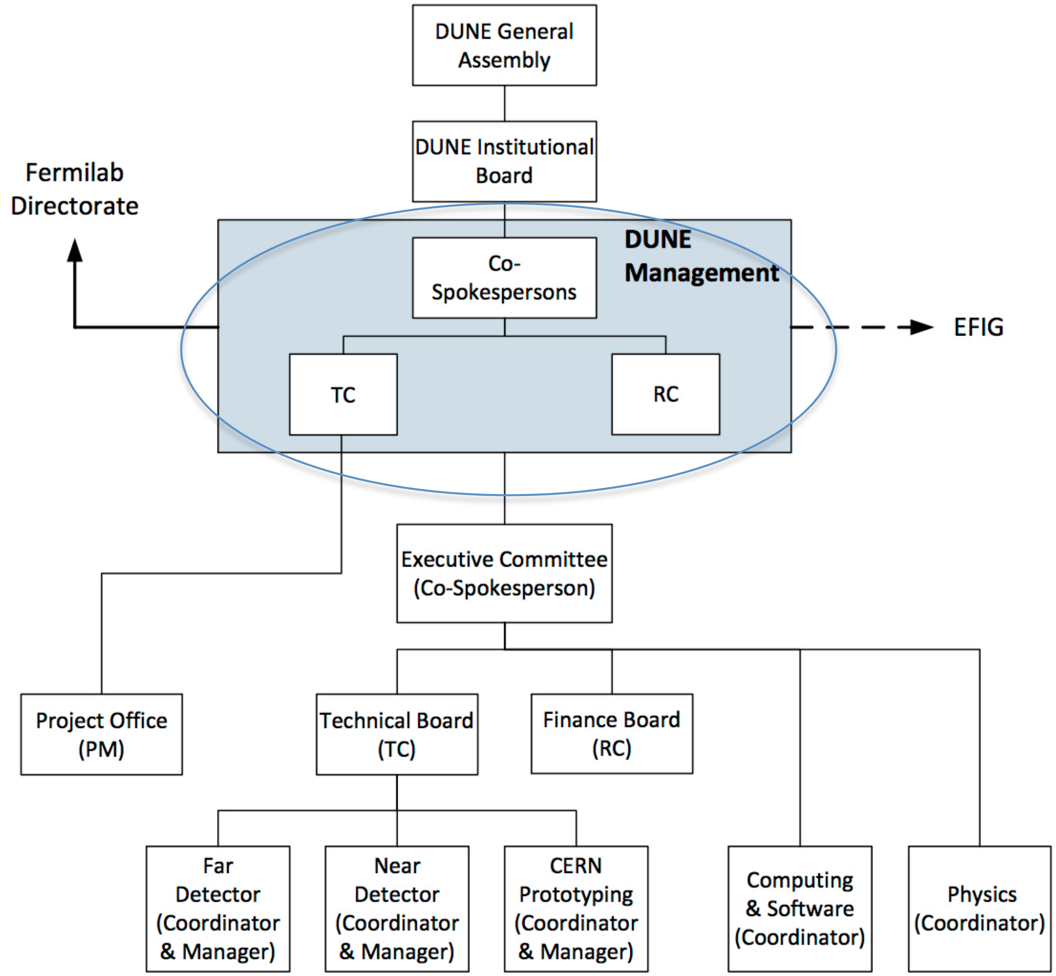
CERN-SPSC-2015-020 ; SPSC-P-351

DUNE Management Structure

DUNE Management assumes responsibility for construction, installation, and operation of the single-phase LAr full-scale prototype

Spokespeople:
Andre Rubbia, ETHZ
Mark Thompson, Cambridge

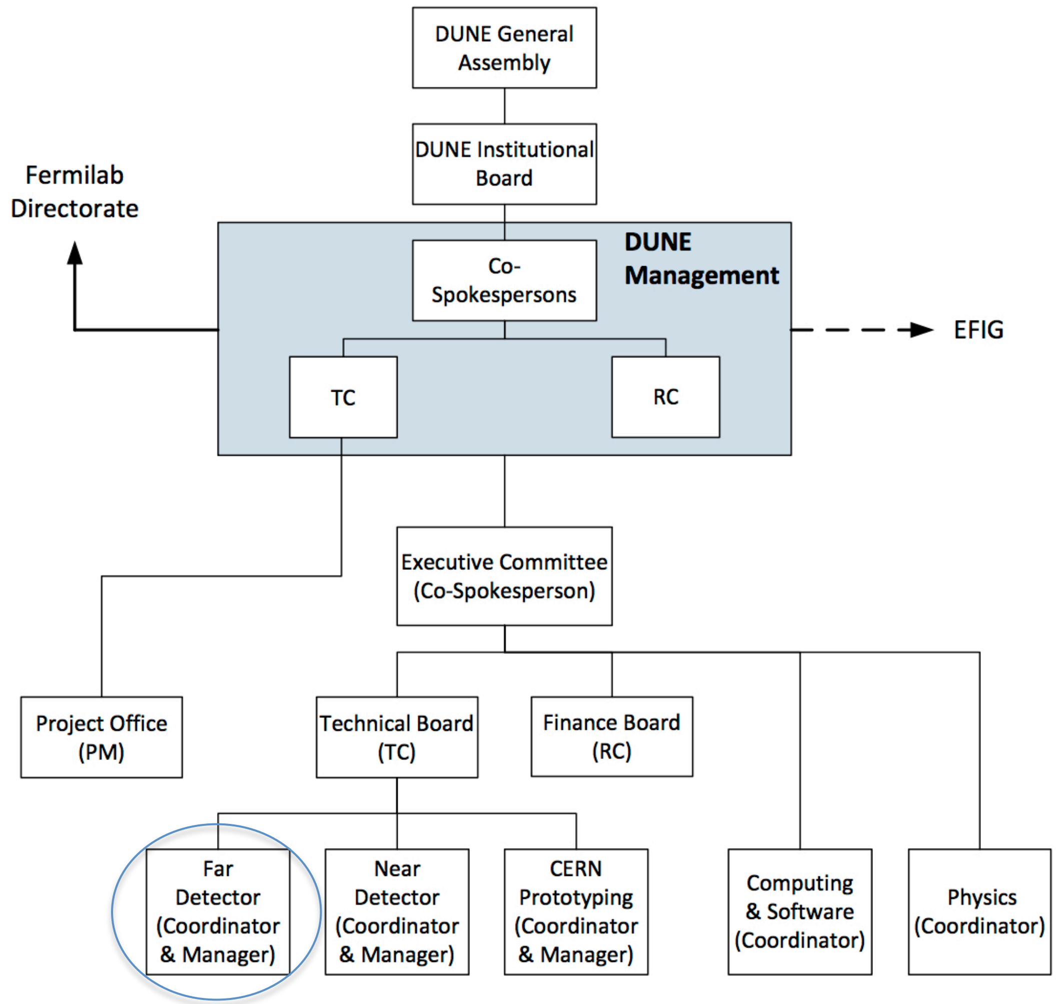
Technical/Resource Coordinators:
Eric James, Fermilab
Chang Kee Jung, Stonybrook



DUNE Management Structure

DUNE Far Detector Organization is responsible for constructing and delivering full-scale prototype detector modules to CERN

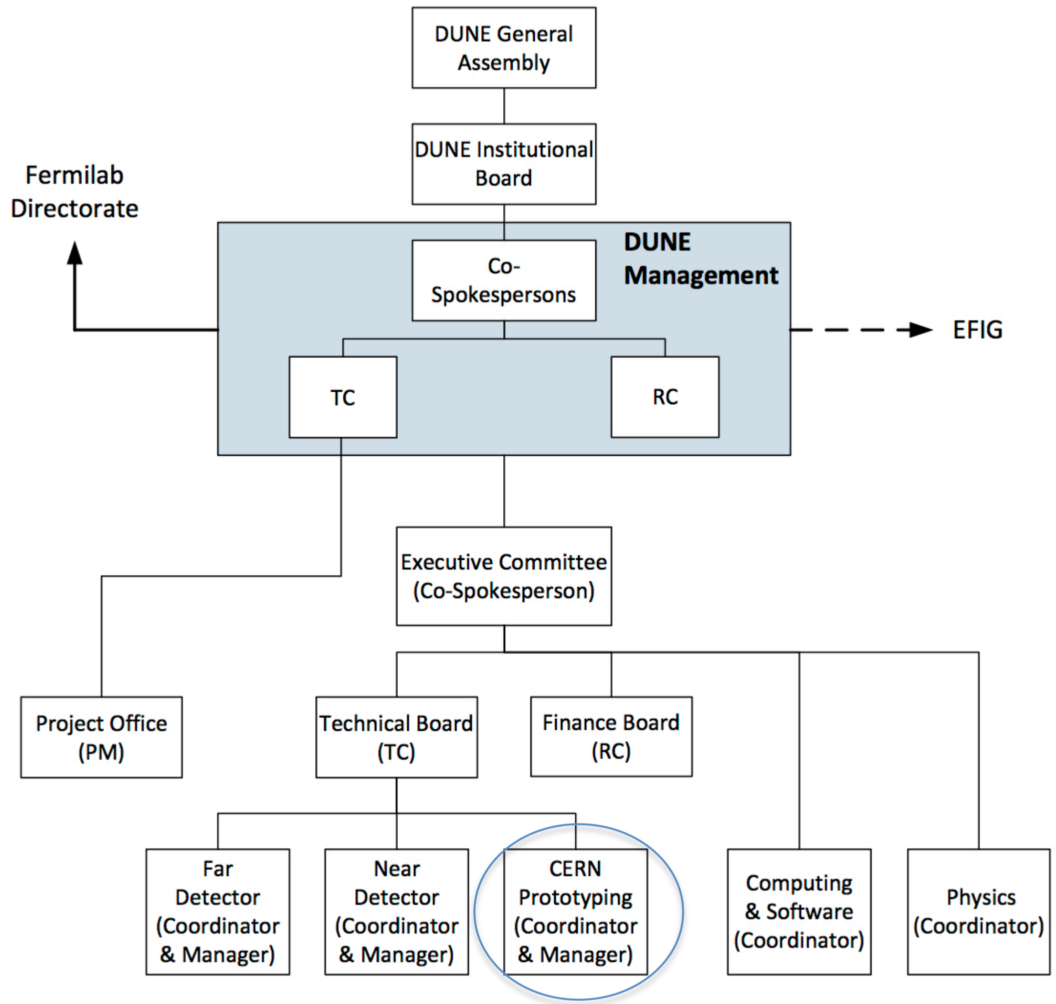
Interim Coordinator/Manager:
James Stewart, BNL



DUNE Management Structure

DUNE CERN Prototyping Organization is responsible for installing, commissioning, and operating detector at CERN

Interim Coordinator:
Thomas Kutter, LSU



CERN Prototyping Coordinator

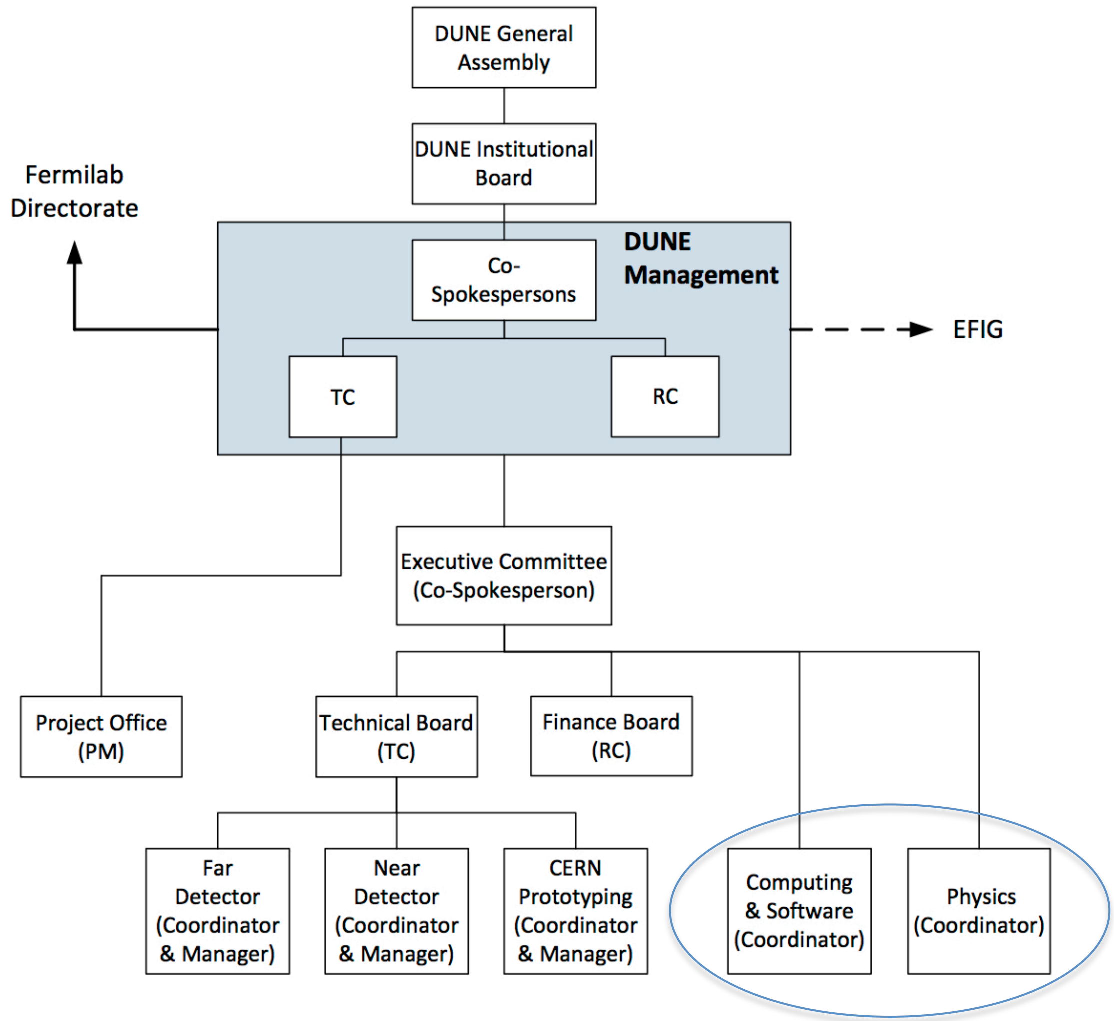
Primary point of contact with CERN SPSC

Interface to CERN neutrino platform and beams division

Responsible for coordination with WA105 effort

DUNE Management Structure

DUNE Physics and Computing & Software organizations will be responsible for simulation, calibration, and analysis efforts associated with CERN prototype



DUNE-PT Funding Resources

Committed funding for the single-phase prototype is available currently through DUNE project funding provided by the U.S. Department of Energy and is sufficient in the short-term for keeping the project on schedule

SPSC endorsement of the proposed program will help to facilitate approvals of submitted and soon-to-be-submitted funding requests from other international partners involved in the effort

The LBNF/DUNE Resources Review Boards (RRB), whose membership includes representatives from each of the contributing funding agencies, will meet in September to further discuss the division of funding responsibilities among the contributing partners

DUNE-PT High Level Goals

CERN prototype:

- Measure and benchmark detector performance of full scale detector components
- Develop manufacturing capabilities at multiple sites
- Test installation procedures and operation of full scale detector components

CERN prototype beam test :

- Assess Detector systematic uncertainties
- Validate and tune MC simulations to data
- Test reconstruction tools and PID
- Evaluate calibration tools and strategy for DUNE far detector
- Also: study pion interactions, muon capture, anti-proton annihilation, …

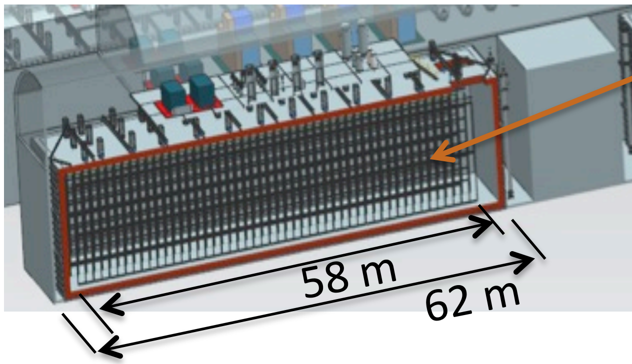
CERN ν-platform:

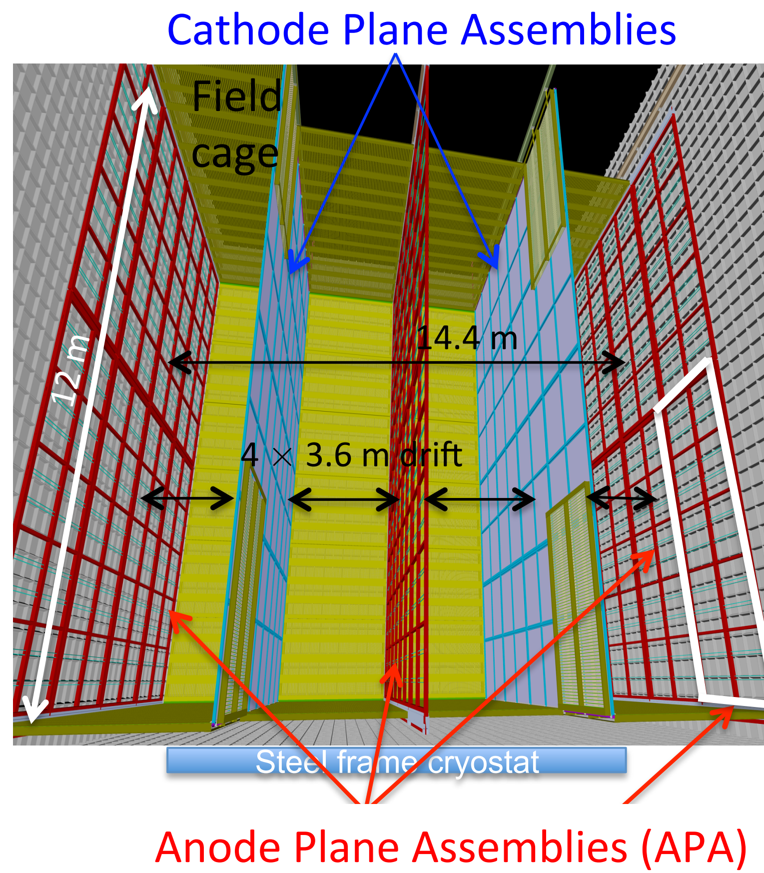
- Validate membrane cryostats and cryogenics system
- Test data handling, distribution and processing
- Compare single and double phase detector technologies

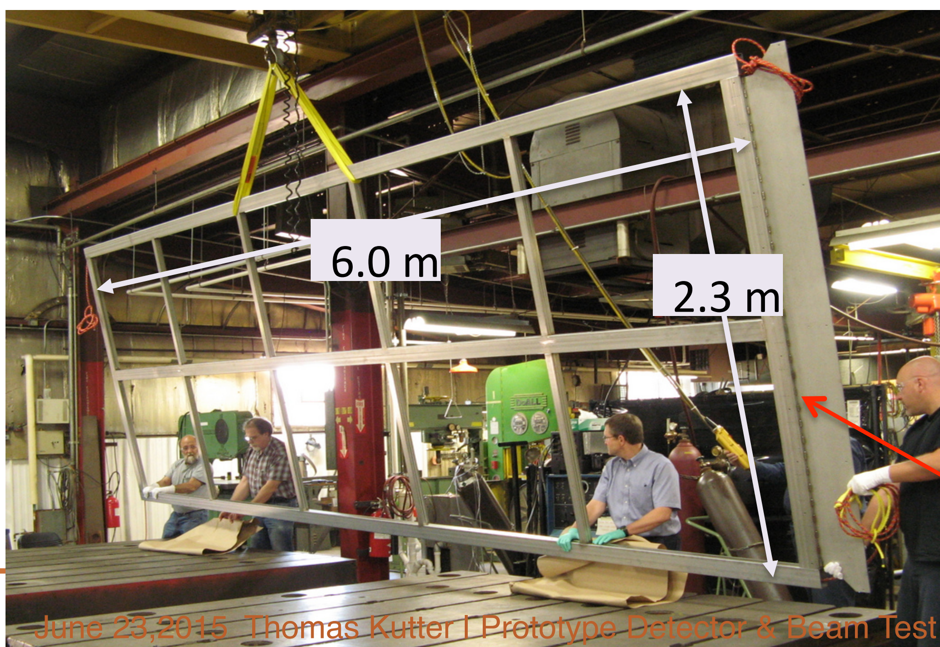
DUNE Single-Phase Far Detector Design

- Single-phase adopted for <u>first DUNE 10 kt module</u>

→ Test full-scale detector components in DUNE-PT



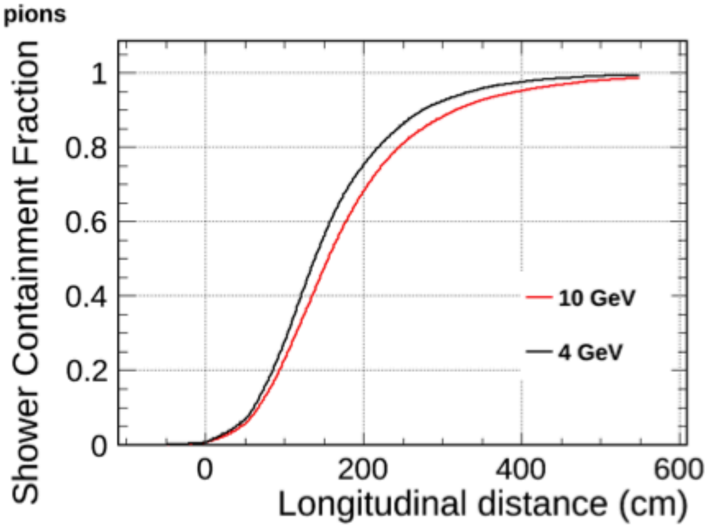


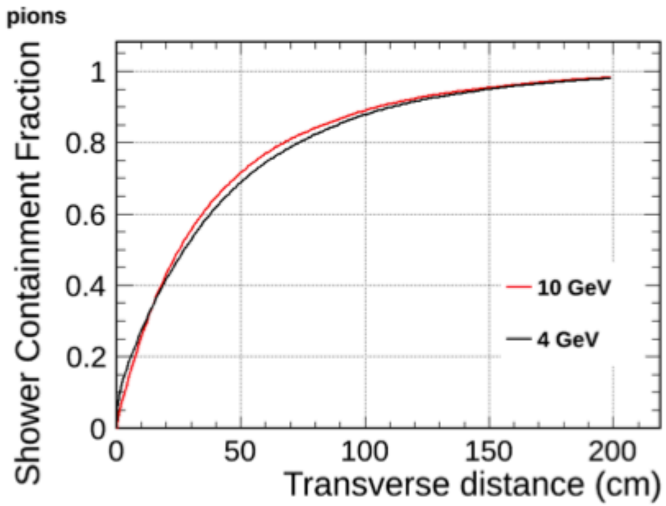


DUNE-PT Detector Layout

Relevant charged particles to be studied in CERN beam test

→ Energy ranges of : sub-GeV to several GeV; Angular range: few – 40°



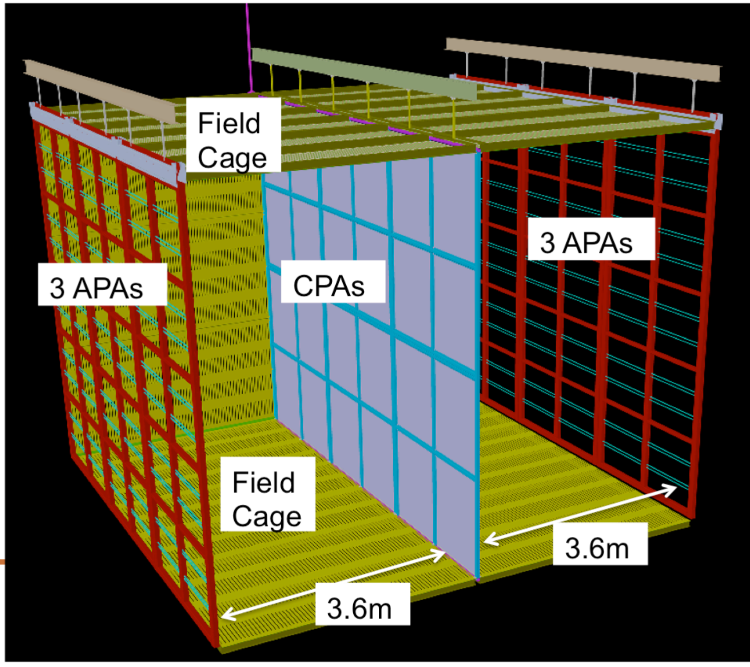


Shower containment

- Detector length of 5 - 6 m seems sufficient
- Detector width and height of ~ 5 m sufficient

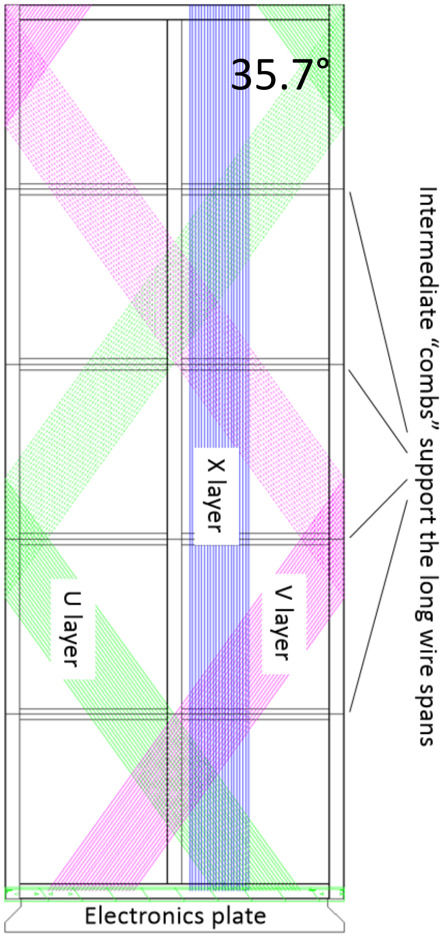
→ active volume size requirements: 6m × 5m × 5m

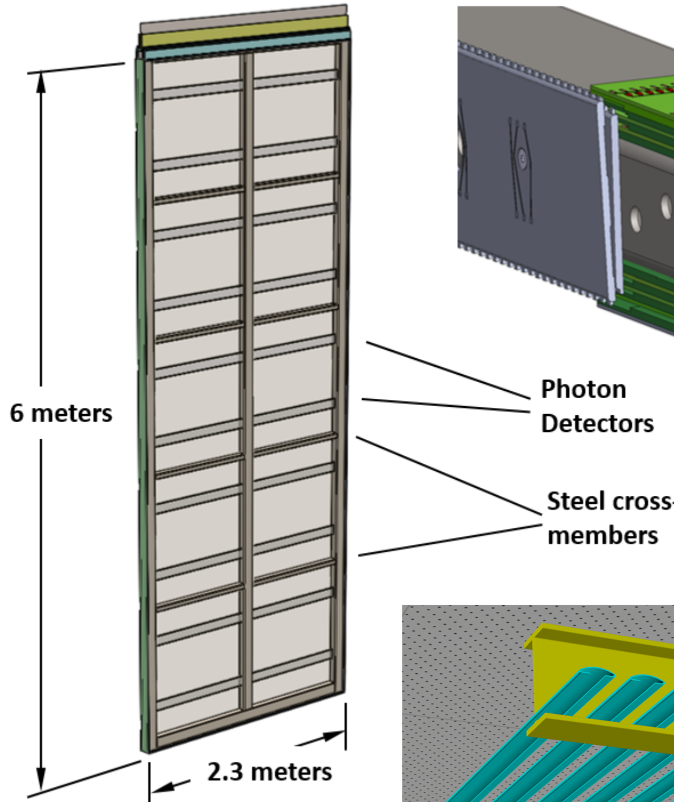
3 APA wide TPC
Drift length same as in far detector

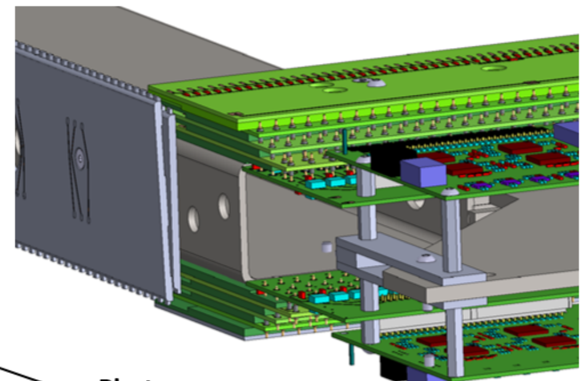


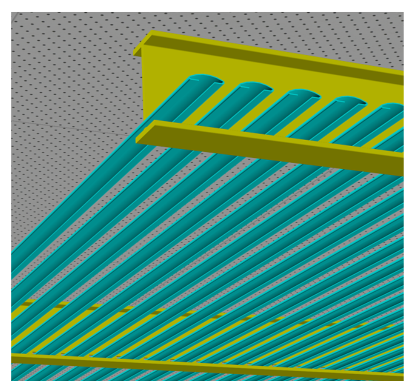
Detector Components

Electronics on one end of the APA frame
10 photon detectors installed in APA module









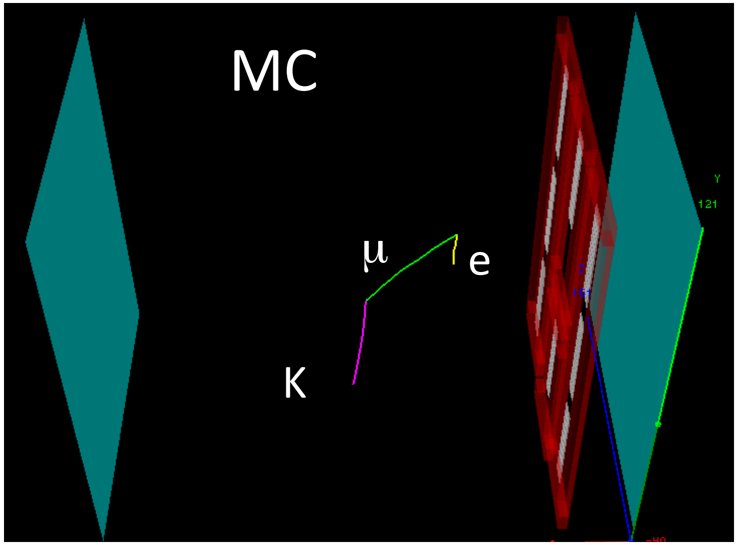
960 X wires @ 4.79mm pitch, vertical
800 U & 800 V wires @ 4.67mm pitch, 35.7°
→ 2560 sense wires/APA module

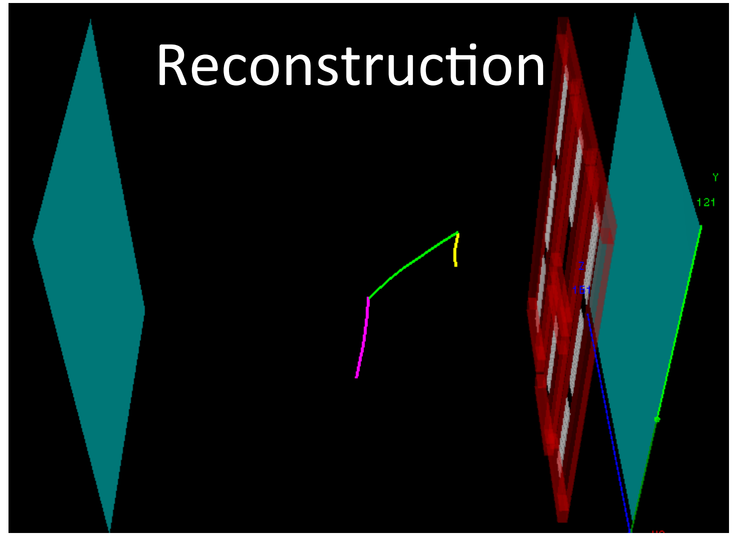
Field cage module

HV feed-through

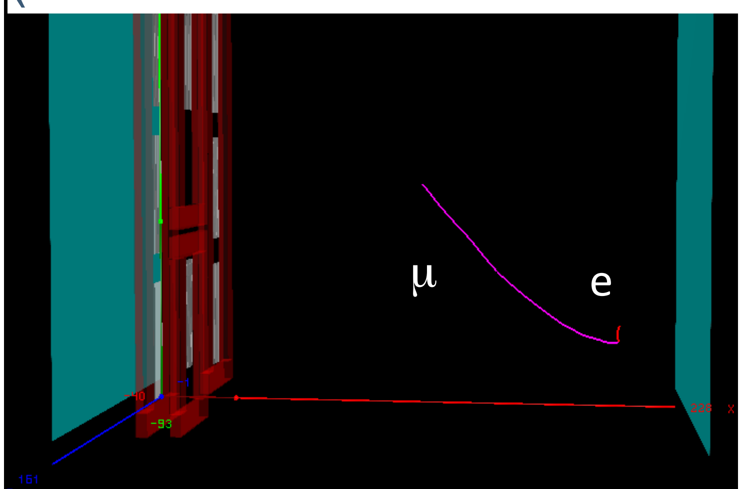
→ Synergies with dual-phase

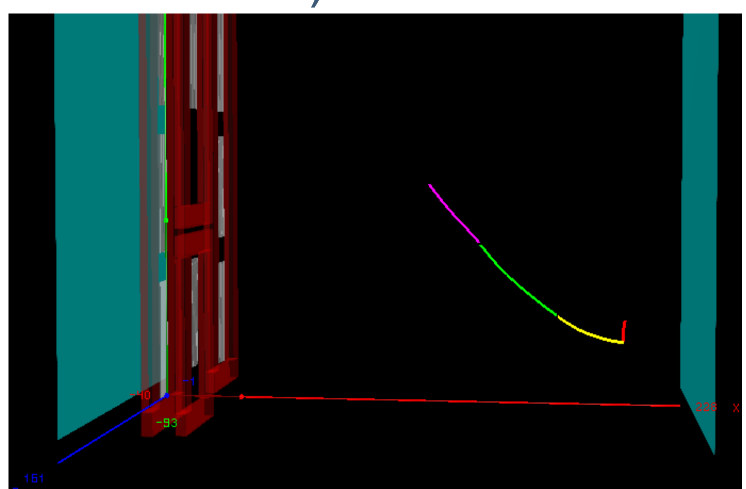
Software Reconstruction Tools





Reconstructed MC events for 35 t detector geometry
(low level of noise included in simulation)





DUNE-PT Performance Studies

Projected detector performance:

- Neutrino energy resolution: 15%/sqrt(E) for ν_e CC; 20%/sqrt(E) for ν_μ CC
- Neutrino energy scale: 2% for ν_μ and ν_e
- Energy resolution: 3%: stop μ; 15% exit μ; ~1%/sqrt(E) electron; 30%/sqrt (E) hadronic system
- Fiducial volume: 1%
- Angular resolution: 1°: e,μ 10° : hadron shower
- interaction model: $\sim$ 2%
- Background processes: $\sim$ 5%

Quantities depend on charged particle detector response

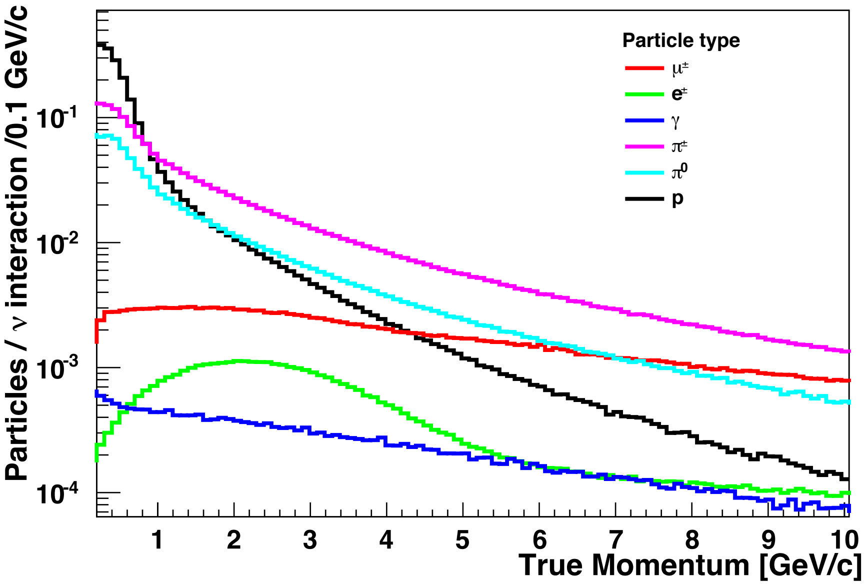
→ To be measured with DUNE-PT

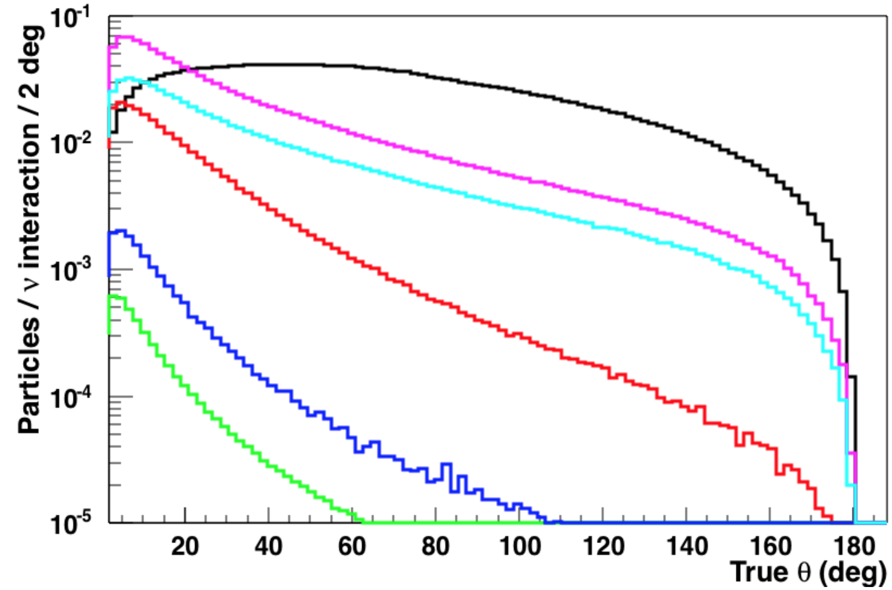
→Collect a calibration data sample applicable to future DUNE data analyses

DUNE-PT Charged Particle Requirements

Expected secondary particle spectra in DUNE far detector; uses ν-beam flux as input

(forward horn current)





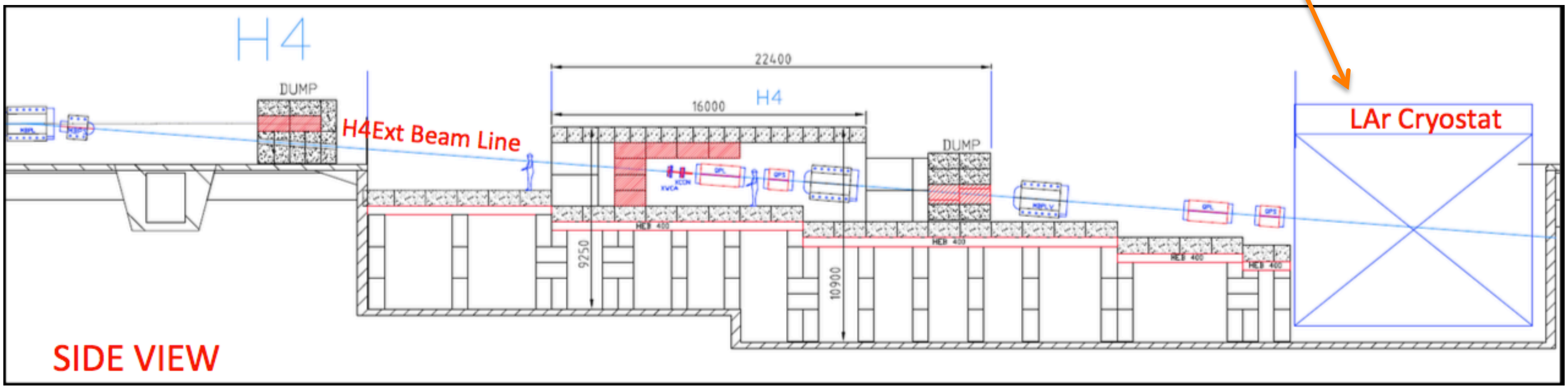
Also looked at atmospheric neutrino flux based on Bartol 3D flux
GENIE to simulate interactions (Ar 40 cross section) and final states

Relevant charged particles to be studied in CERN beam test
→Energy ranges of : sub-GeV to several GeV
→Angular range: few – 40 deg

Beamline

Conceptual Layout in EHN1 Courtesy: Ilias Efthymiopoulos

Cryostat for single-phase detector

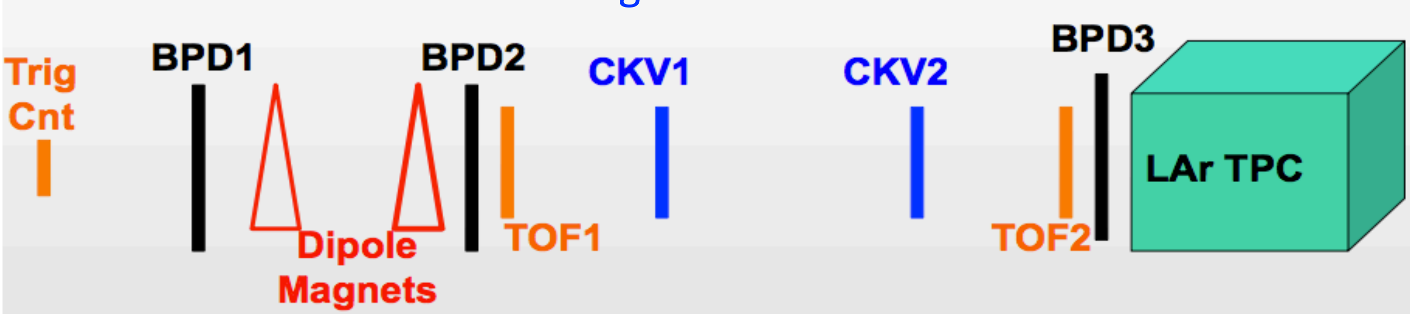


BPD: beam position detectors → tracking

TOF: Time of flight →low momentum PID

CKV: Cherenkov counters → higher momentum PID

Beam instrumentation and Beam optics (work in progress)



Preliminary Run Plan

Estimates for one angular configuration only

Plan to study detector response for multiple beam injection points and directions

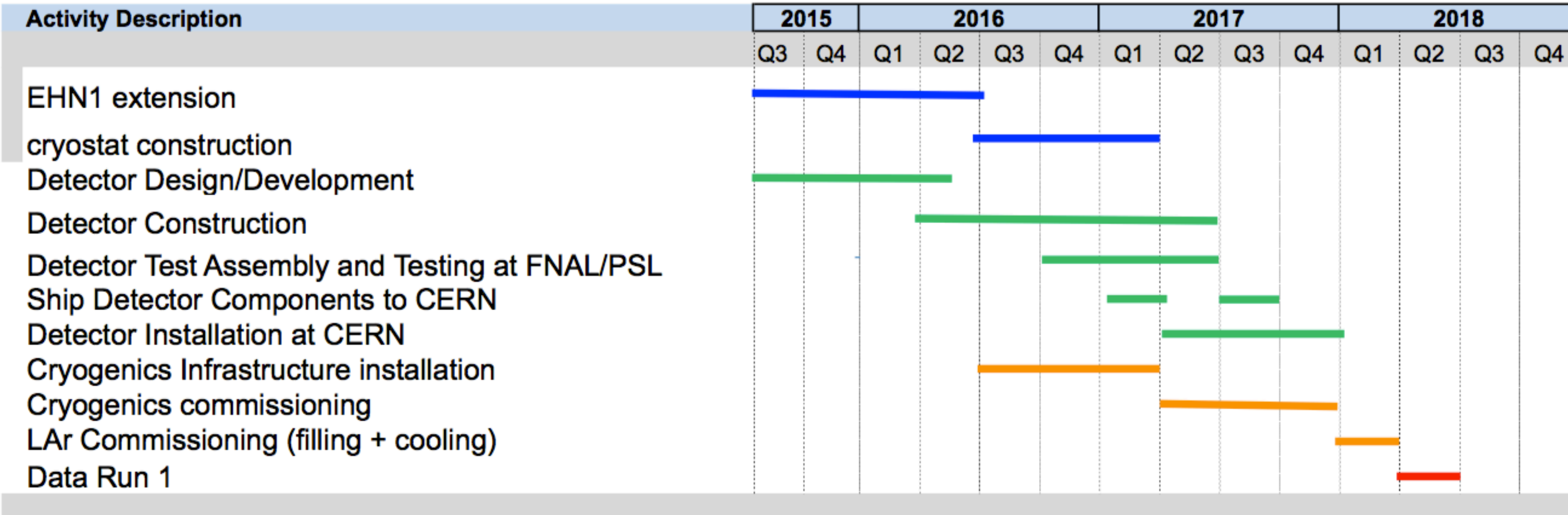
Positive Sample						
P (GeV)	# of Spills	Time (hours)	# of π^+	# of μ^+	# of K^+	# of p
0.2	900	11	**15k**	180k	≈0	160k
0.3	200	3	**15k**	30k	≈0	50k
0.4	150	**2**	22k	18k	≈0	32k
0.5	150	**2**	26k	12k	≈0	38k
0.7	150	**2**	40k	10k	≈0	45k
1	350	4	120k	**10k**	≈0	65k
2	600	8	320k	**10k**	3k	130k
3	500	6	290k	**5k**	7k	70k
5	1800	23	1M	**5k**	5k	270k
7	1200	15	660k	**6k**	3k	120k
Total	6000	76	2.5M	286k	18k	1M

Negative Sample				
P (GeV)	# of Spills	Time (hours)	# of π^-	# of μ^-
0.2	600	8	**15k**	88k
0.3	200	3	**15k**	30k
0.4	150	**2**	30k	18k
0.5	150	**2**	40k	13k
0.7	150	**2**	50k	12k
1	150	**2**	70k	12k
2	200	3	135k	**6k**
Total	1600	22	350k	180k

Electron Sample			
P (GeV)	# of Spills	Time (hours)	# of electron
0.2,0.3,0.4,0.5,0.7,1,2,3,5,7	150 per bin	2 hours per bin	140k per bin
Total	1500	20	1.4M

→Total estimated measurement time is of order of several weeks

Schedule, Milestones and Goals



- **9/2015 U.S. University funding applications due**
- 2016: TPC Production readiness review
- 2016/17: Engineering Trial Assembly

→ Seek CERN support for cryostat to be ready in early 2017

- 2017: Detector Installation complete

→ Seek CERN support to have cryogenics system completed by end of 2017

- 2018: Commission detector and collect cosmics data

Goal: Collect first beam data in 2018

Responsibilities as of June 2015

item no.	Deliverable	Contributing Institutes
1.	Single-phase LAr detector	
1.1	TPC	BNL, CERN, Lancaster, LBNL, Liverpool Manchester, Princeton, Sheffield, Wisconsin
1.2	Cold electronics	BNL, Fermilab, Penn, SMU
1.3	Photon detection system	ANL, Campinas, CSU, Hawaii, IU, LSU
1.4	DAQ	Cambridge, Duluth, Fermilab, LANL Oxford, SLAC
1.5	HV power supplies & feedthroughs	ETHZ, UCLA
1.6	Installation	CERN, Duke, Fermilab, Minnesota
1.7	Interfaces	BNL, LBNL, CERN, Fermilab
2.	Operation & Scientific Effort	
2.1	Operation	DUNE-PT collaborators
2.2	Software & Simulations	DUNE
2.3	Data analysis	DUNE

CERN: (expected responsibilities)

Cryostat, Cryogenics, infrastructure, beam (instrumentation)

→Seek timely SPSC response to establish MOU

Summary

Science of DUNE is extremely compelling and has been identified as high priority by the particle physics community in the US and Europe

Our proposed prototyping program at the CERN ν-platform enhances US-European and international collaboration in ν physics

CERN prototype detector and beam test

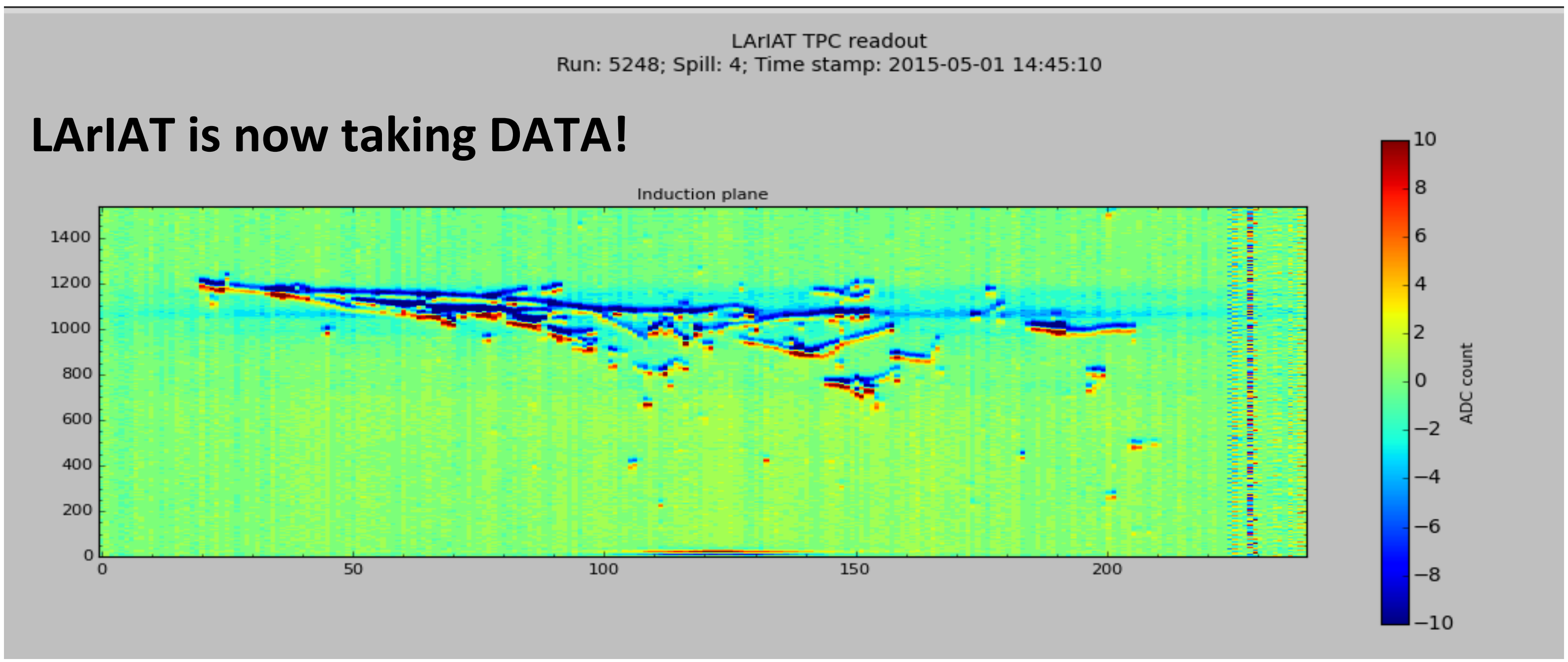
- is a critical engineering milestone to
  - Perform full-scale component structural tests in LAr
  - Test full-scale detector components (TPC, PDS, electronics)
- helps to establish multiple production sites and Q/A procedures
- will measure charged particle response of full scale detector components
  - Validate MC simulations and particle interaction models
  - Measure detector systematics
  - Provide calibration data samples for future DUNE far detector

Additional Slides

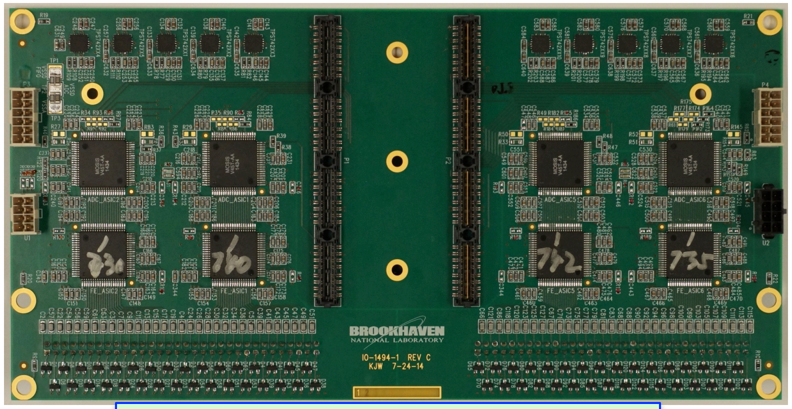
Cold Electronics

- Front end chips have now been used in several LAr single-phase TPCs.
  - Long-Bo, Argon-Tube, LARIAT, ICARUS-50l
  - MicroBooNE and SBN
- DUNE will need to digitize the data in the cold to reduce the cable plant.
- A 12 bit Cold ADC with 8:1 MUX has been fabricated and will be tested in the DUNE prototypes and SB-ND.
- Further multiplexing and control functions require a dedicated ASIC COLDATA chip. Modifications to the existing chips will be needed

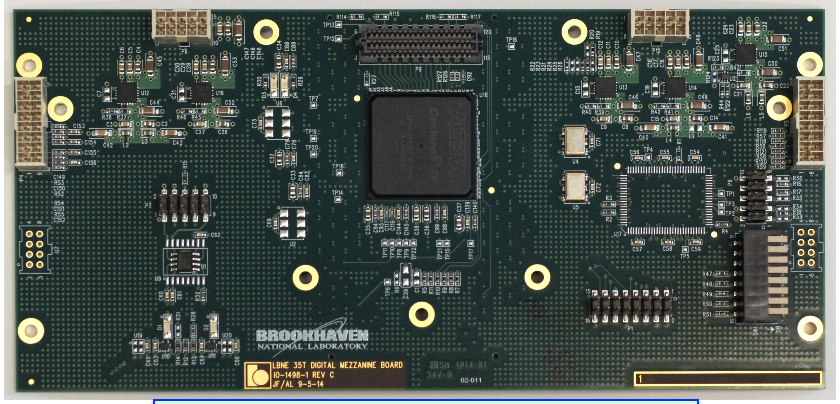
Developed at BNL



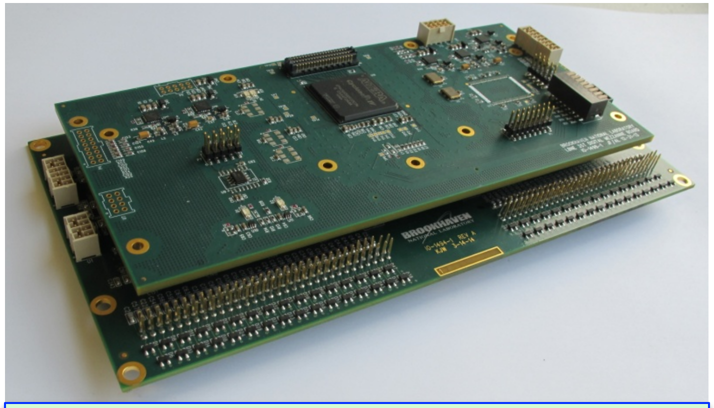
DUNE 35 Ton Cold Electronics



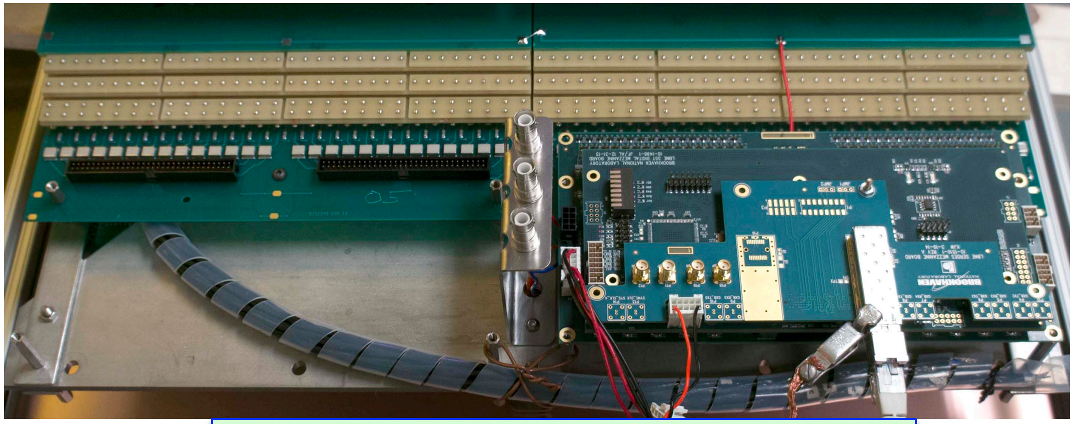
Analog Mother Board



FPGA Mezzanine



Front End Mother Board Assembly



FEMB test with APA

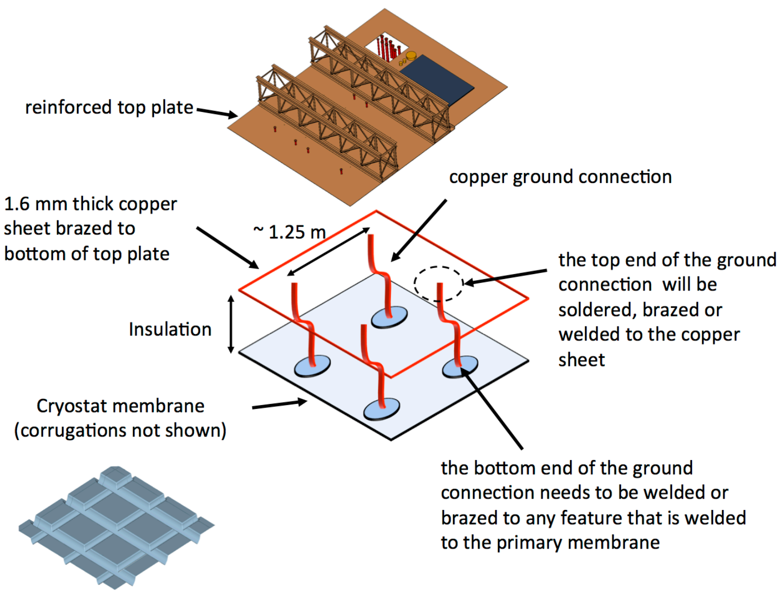
Cryostat and Cryogenics

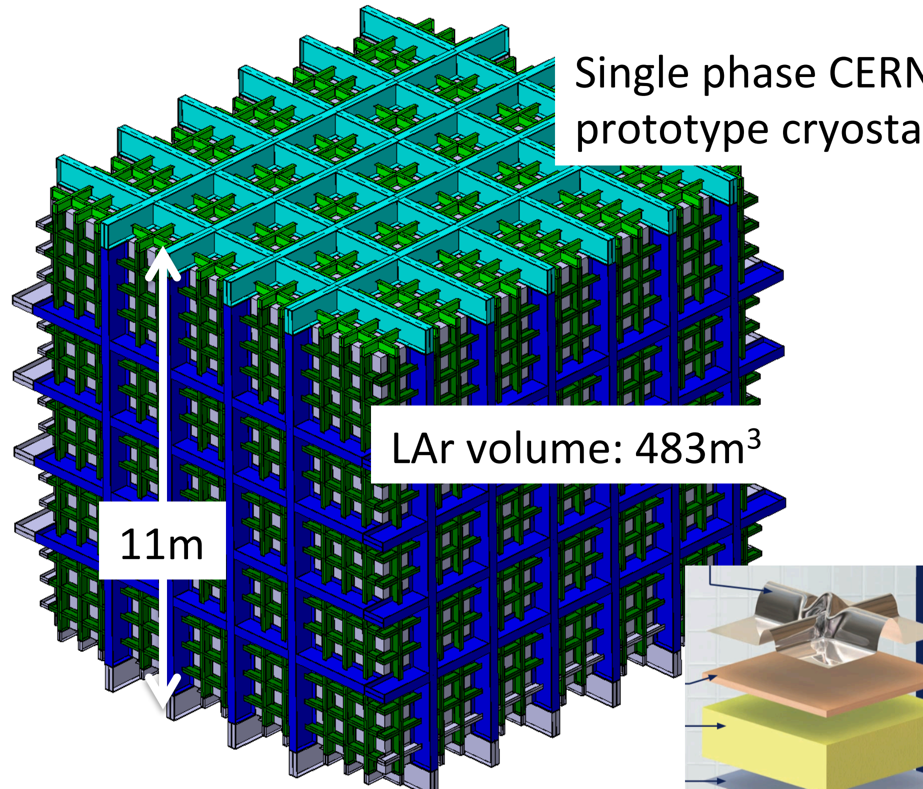
<u>joint CERN-Fermilab cryo-engineering team:</u>

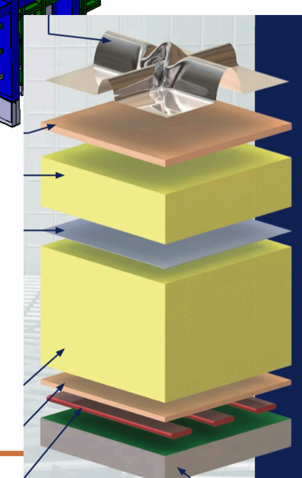
- Designed novel cryostat (similar to 1x1x3m^3, WA105, SBND, DUNE far detector)
- Developed cryogenics system

Tests:

- Verify Ar contamination levels and mitigation scheme
- Check grounding and isolation strategy





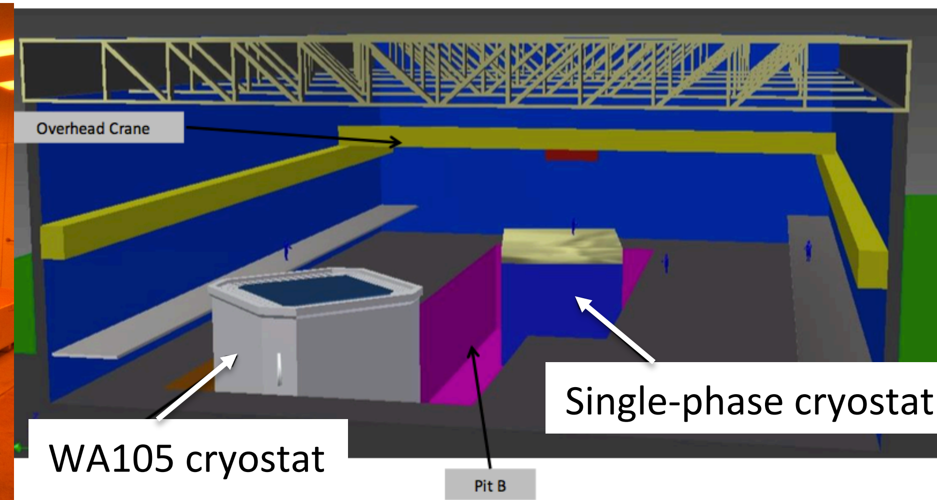


GTT membrane

Installation and Integration

35t detector trial assembly (9/2014)

CERN EHN1



- Trial assemblies are valuable milestones

- First time to install full-scale TPC inside a cryostat

→ Opportunity to evaluate clearances and integration of full-scale TPC components