Status and plans of protoDUNE-SP (NP04)

Christos Touramanis

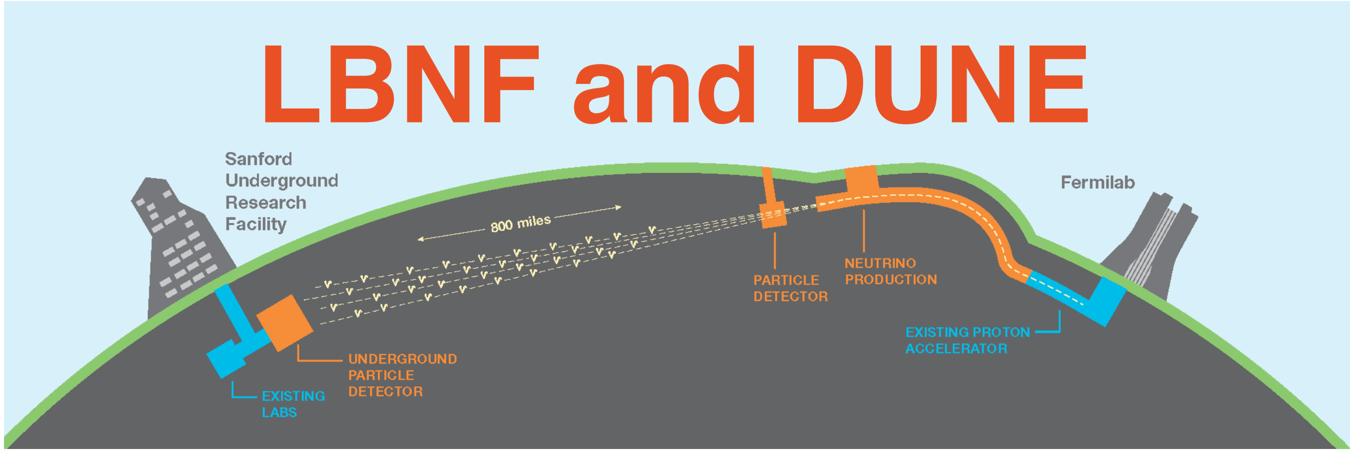
On behalf of the protoDUNE-SP (NP04) collaboration

SPSC-121

CERN, 19 April 2016

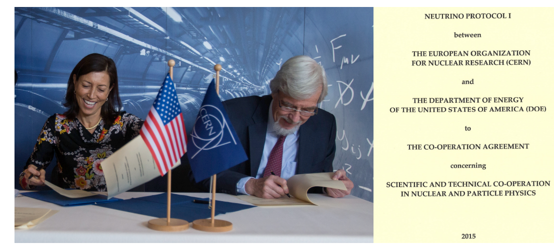
Outline

- Context
  - DUNE
  - protoDUNE-SP
- Update from the 35-ton LAr TPC prototype at Fermilab
- protoDUNE-SP
  - Organisation, management, membership
  - Main areas of activity
  - Schedule
- Conclusions



Long **B**aseline **N**eutrino **F**acility

- Muon neutrinos/ anti-neutrinos from a high-power proton beam
  - 1.2 MW from day one (2026)
  - Upgradable to 2.5 MW
- Near Detector and Far Detector infrastructure, including cryostats and cryogenics

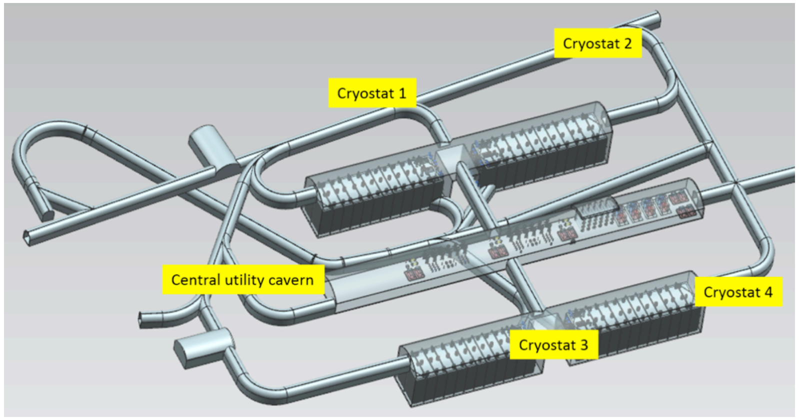


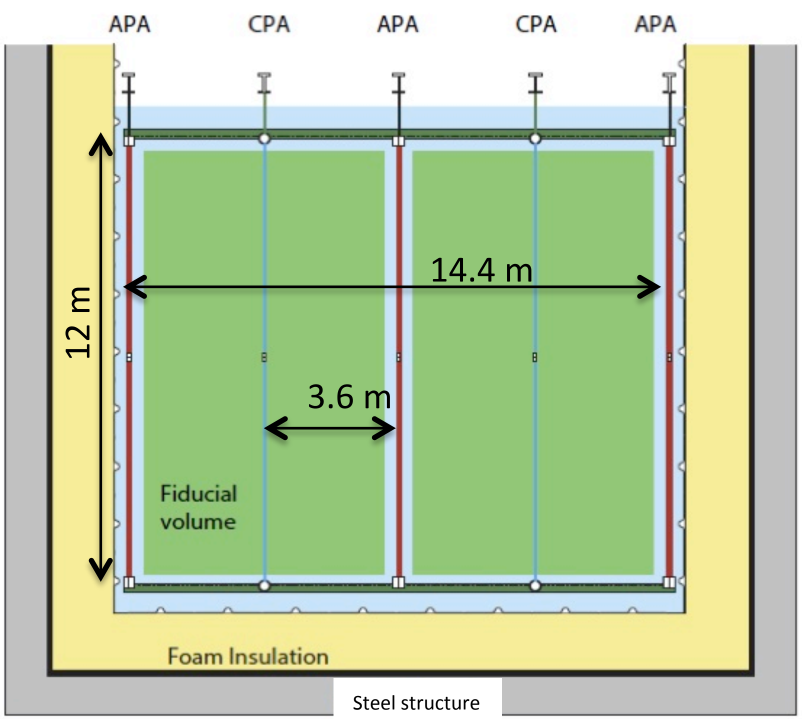
Deep **U**nderground **N**eutrino **E**xperiment (850 collaborators; 146 institutes; 25 countries)

- Near Detector (multiple subsystems considered)
- Far Detector (**L**iquid **Ar**gon **T**ime **P**rojection **C**hambers)
- Planning and execution of the science programme

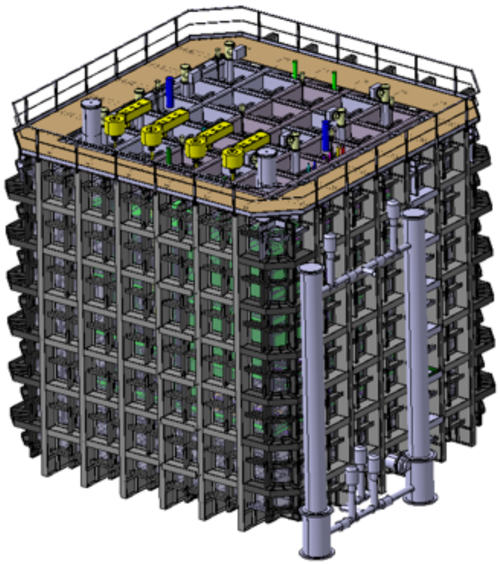
DUNE Far Detector

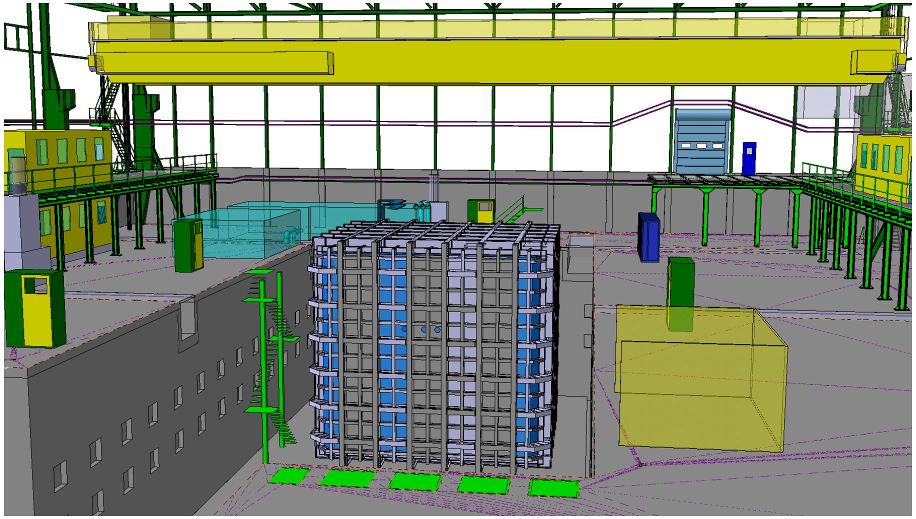
- 1,478m underground at SURF, SD
- 4 identical cryostats
  - 62 x 15 x 14 m^3, 17kt LAr each
  - Membrane technology, external steel support frame
  - Allows for staged construction
- 70kt total LAr, at least 40kt fiducial
- Two TPC technologies considered
  - Singe Phase
  - Dual Phase

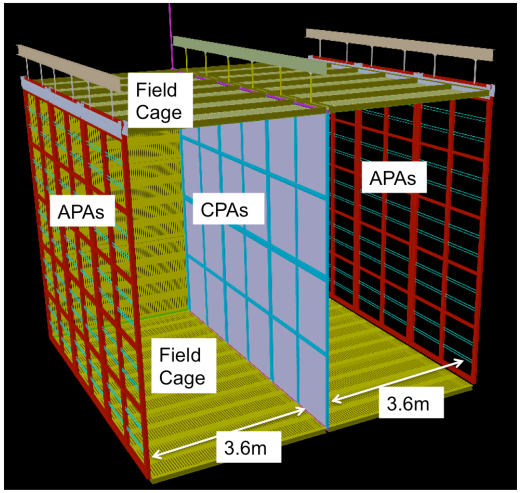


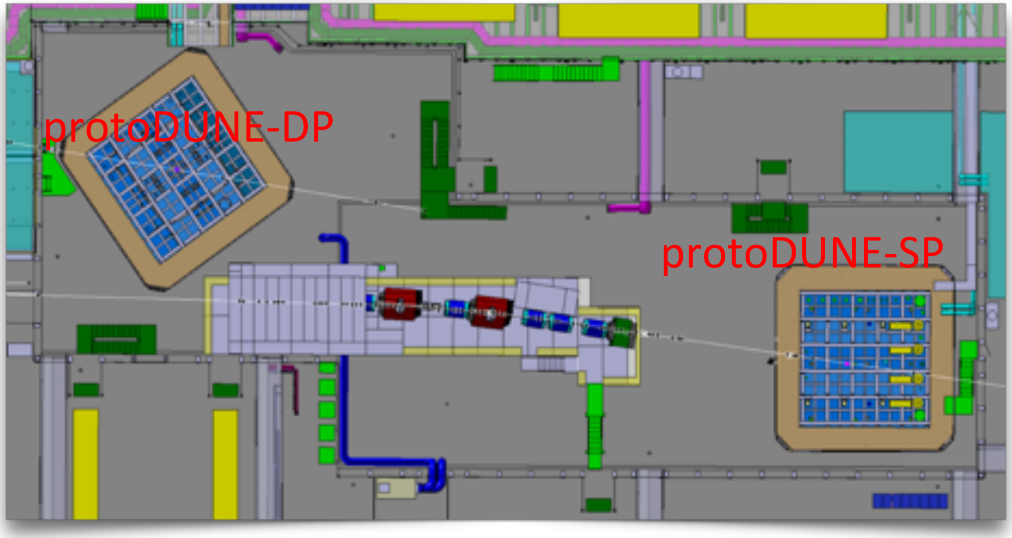


protoDUNE-SP





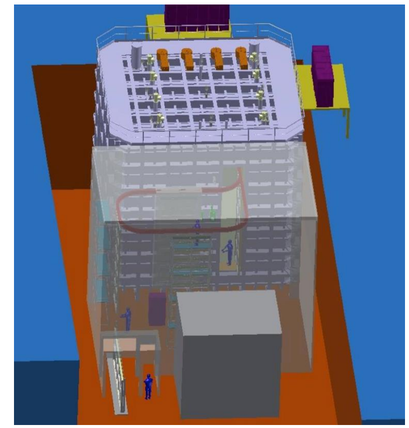




protoDUNE-SP / NP04

The prototype of the DUNE single-phase Far Detector (FD) at the CERN Neutrino Platform (NP).

- 770 t (~ICARUS T600)
- SPSC-P-351 proposal
- NP04 approved by SPSC & Research Board
- CERN-Fermilab MoU signed 12/2015



Management team:

- Coordinators / spokespersons
  - Flavio Cavanna   cavanna@fnal.gov
  - Christos Touramanis   c.touramanis@liv.ac.uk
- Deputy Coordinator
  - Thomas Kutter   kutter@phys.lsu.edu
- Project Manager
  - Maria Chamizo Llatas   maria.chamizo@cern.ch

Goals of protoDUNE-SP

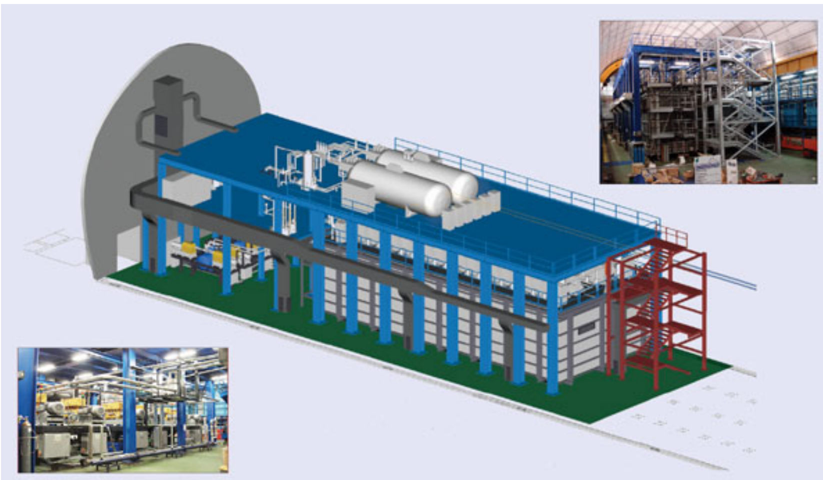
- Demonstrate engineering choices and design
- Establish the construction facilities and methods for full-scale production
- Validate installation plans
- Evaluate cold electronics
- Develop and assess TDAQ strategies and algorithms

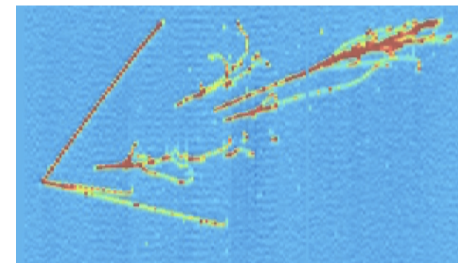
➢ Underpin DUNE TDR and CD-2 review (2019)

- Characterize detector performance with full-scale components
- Assess detector systematics
- Validate / tune MC simulation
- Validate / develop reconstruction and calibration
- Develop and characterize:
  - Particle ID
  - e/γ separation
  - Hadron / em shower energy reconstruction
- Study particle interactions (kaons, pions, muons)

35-ton LAr TPC prototype at Fermilab

Single Phase LAr TPC path





ICARUS (approved 1996)

ArgoNeut (Fermilab, 2008)

Ongoing/ in construction at Fermilab: LArIAT, MicroBooNe, SBND

35-ton (2015) ➔ protoDUNE-SP (2018) ➔ DUNE FD SP (first data 2024)

The 35-ton prototype at Fermilab

Evaluation of DUNE FD technologies:

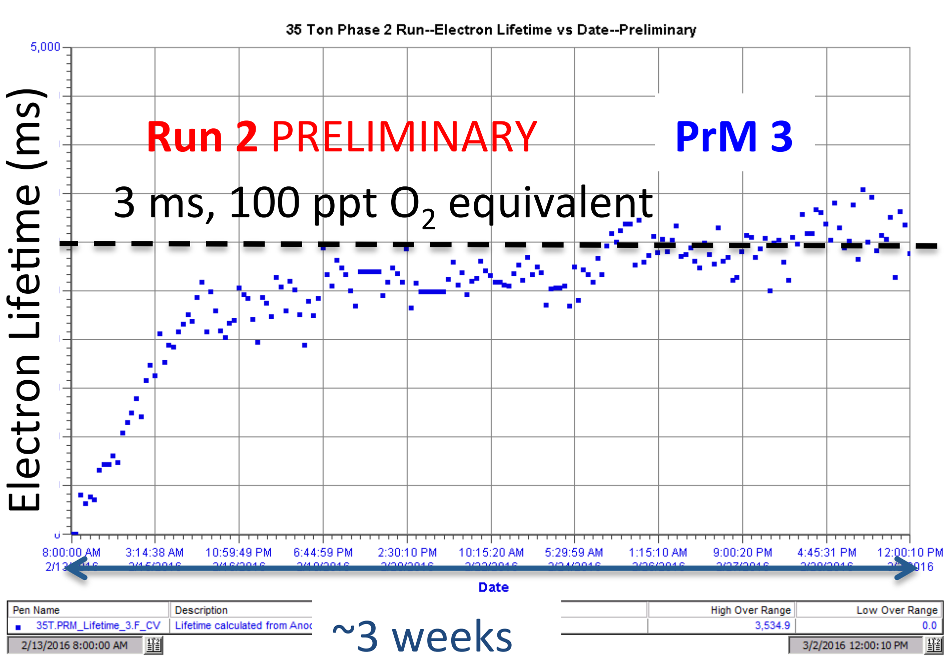
- Membrane Cryostat
- Wrapped wire planes
- Multiple drift volumes
- Cold electronics:
  - FE ASIC (pre-amplifier)
  - ADC ASIC
- Lightguide & SiPM Photon Detectors
- Triggerless DAQ operation (continuous readout) with zero suppression

active volume: 2.5m x 1.5m x 2m

35-ton operations

- 2015: cryostat alone run (purity & temperature sensors)
  - Electron lifetime of 3ms (O_2 contamination ~ 100ppt) achieved and sustained in non-evacuable membrane cryostat
- August/Sept 2015: TPC installation
- Jan/Feb 2016: Detector commissioning (29TB on disk, 400k events)
- 7-19 March 2016: data run
  - 60kV, 250V/cm, half the nominal field
  - 14TB on disk, 200k events
  - March 19th: external pipe failure, end of data run
- From 20th March: HV studies, PD studies
- April 2016: investigation of electronics noise – ongoing

35-ton: purity & electron lifetime



DUNE requirement of 3ms lifetime in a:

- membrane, non-evacuable cryostat
- with a fully instrumented detector

was achieved.

Improvements for protoDUNE-SP:

- Warm plate at the cryostat top eliminated
- Improved flow (location of inlet/outlet of recirculation system)

35-ton: High Voltage system

- The HV distribution system (field cage, cathode, feedthrough) held 60 kV stably over 6 weeks in pure liquid argon.
- No indications of field non-uniformities visible in TPC tracks

- In contaminated argon, it was stable for several days at 90 kV and 120 kV.

35-ton: cold electronics

First deployment of Cold Electronics (still under development):

FE and ADC immersed in LAr

128 channels per Front End Mother Board (FEMB)

- Initially 2% dead channels (production issue, understood), 4% lost during cooldown (same origin, TBC)
- High resonant noise: not all FEMBs read out at all the time

Ongoing test campaign to identify noise sources by experts

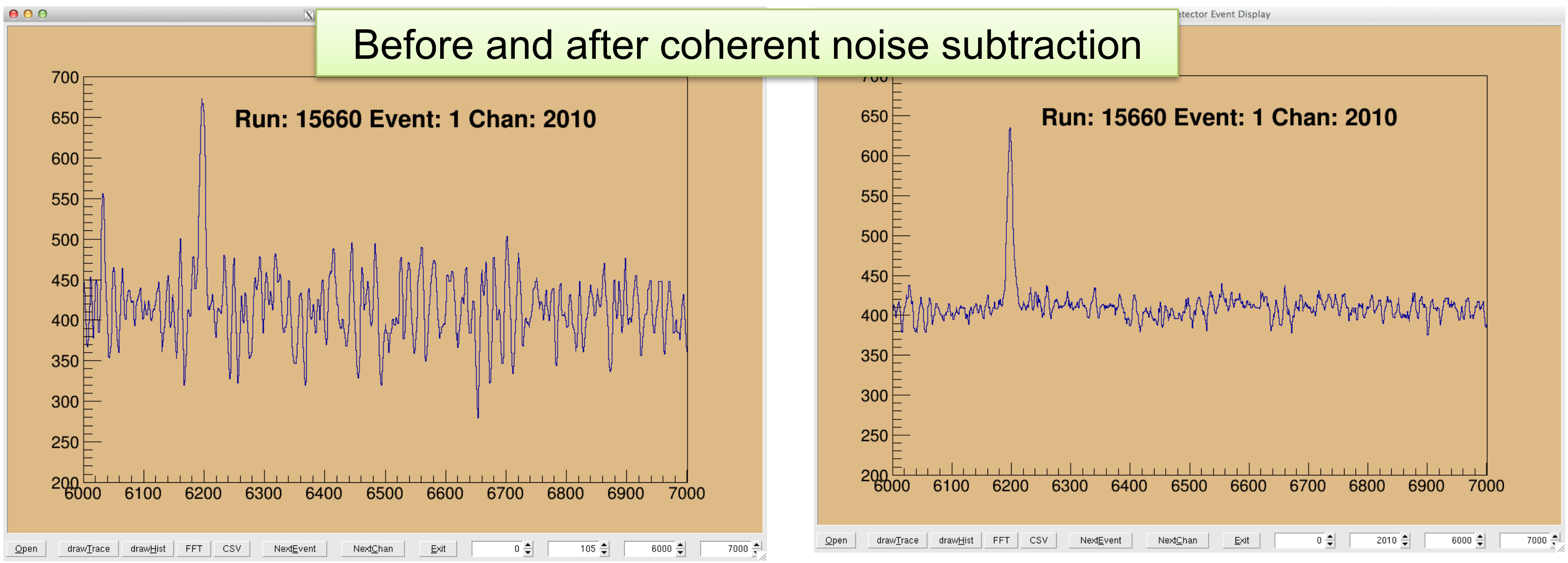
Certain sources identified, action plan includes:

- Joint DUNE – SBND electronics development plan
  - 2 more iterations of the ASIC chips
  - 2 iterations of the CE readout boards
  - Implementation of warm electronics board at feedthrough flange (better grounding, system tests facilitation)
- Multi-stage integration as early as possible at CERN
- Continuous testing during installation built into protoDUNE-SP installation process

35-ton: noise removal in software

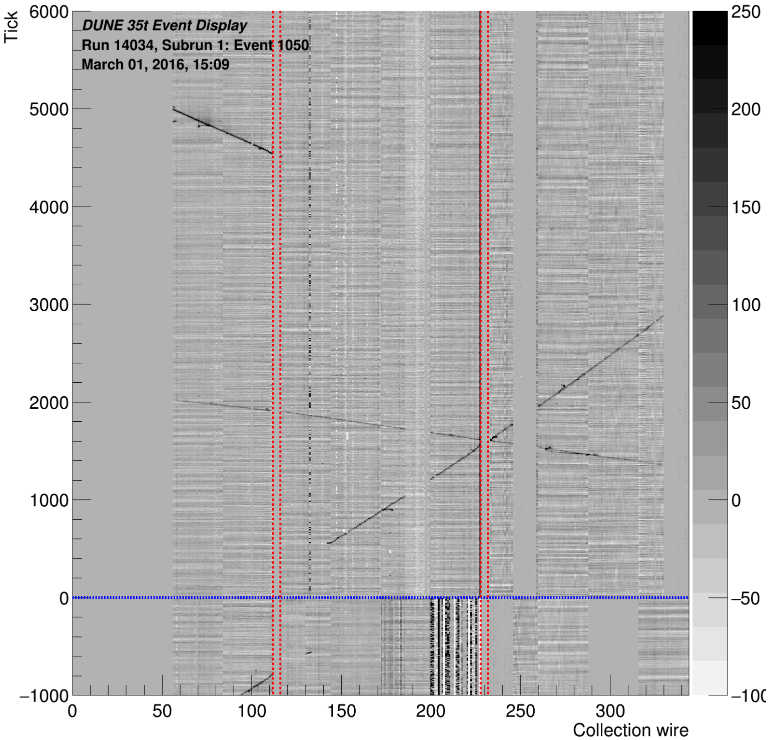
- Coherent noise subtraction using neighbors
- Frequency filtering also being developed

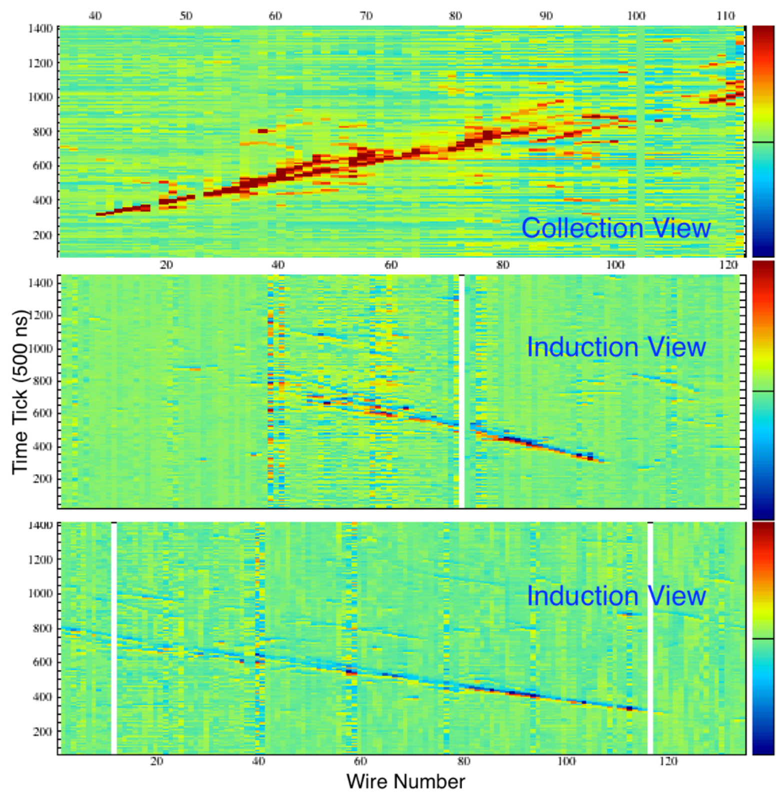
Power filtering will be implemented in next board production



Before and after coherent noise subtraction

35-ton: muon and EM shower





Raw: no noise suppression

After coherent noise subtraction

Collection plane only

35-ton summary

Early prototype for DUNE FD cryostat and TPC solutions:

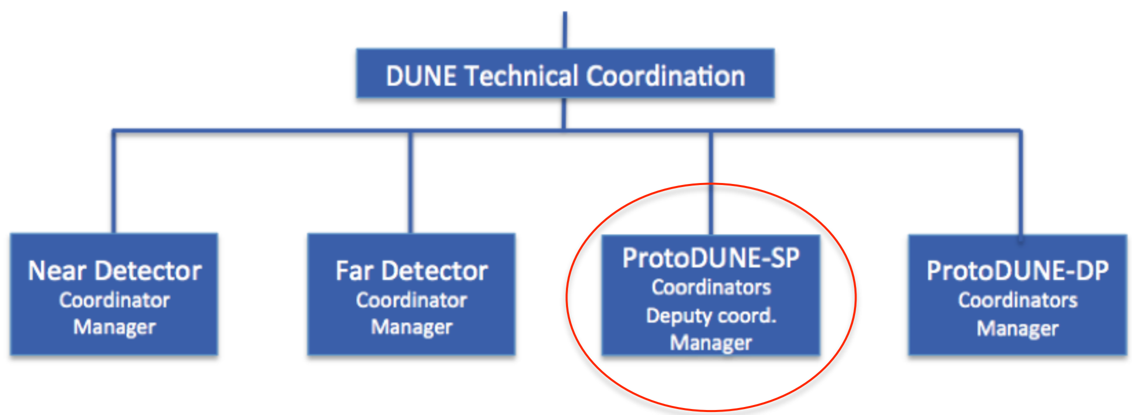
- Membrane cryostat technology proven
- Argon purity / electron lifetime DUNE aim met with a fully-equipped, operational TPC
- HV distribution system demonstrated
- First implementation of Cold Electronics
  - Cosmic muon data collected
  - Full CE system shake-down and problems identification
  - Ongoing remediation plan for protoDUNE-SP

A crucial step in the Single-Phase LAr TPC programme towards the DUNE Far Detector

protoDUNE-SP

protoDUNE-SP management

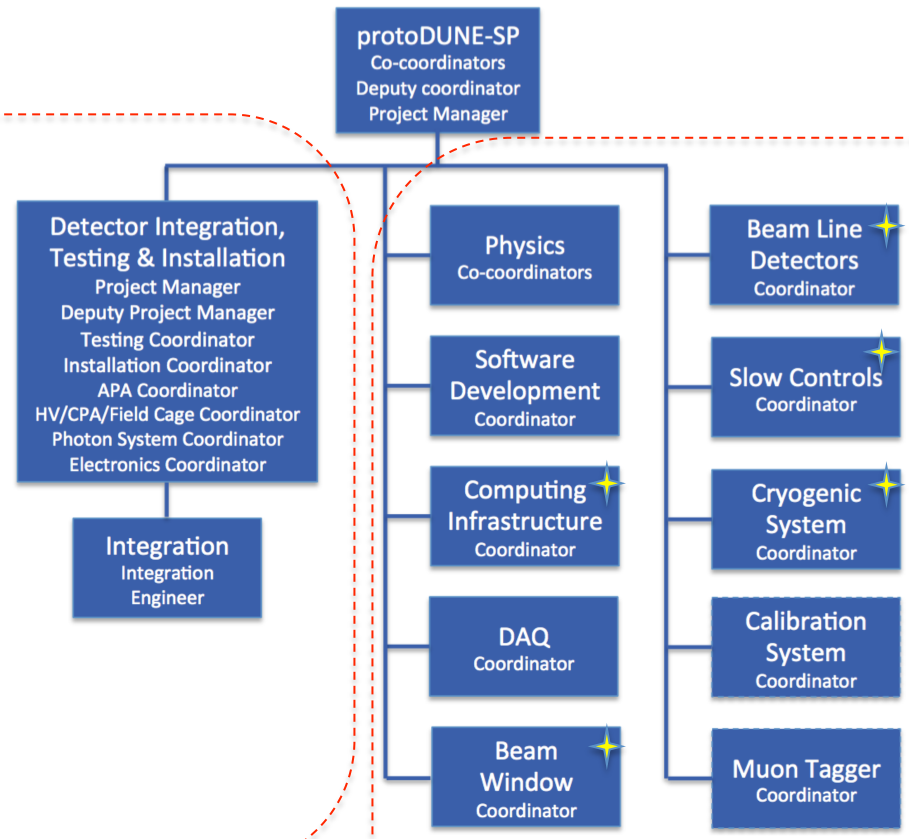
- Embedded within the DUNE collaboration
- Main detector elements (TPC, CE, PDS) are engineering prototypes for the DUNE FD; will be produced by FD organisation
- DUNE Technical Board: main decision-making body (design, construction, installation, commissioning, technology choices)



protoDUNE-SP organisation

DITI interfaces to:

- CERN NP for all infrastructure matters
- DUNE FD WG for detector components
- Members resident at CERN for extended periods as required



protoDUNE-SP teams

- self-organised consortia of groups
- membership from DUNE, based on EOIs
- open to new groups (Europe, Latin America)
- coordinators resident at CERN for extended periods as required

✦ Potential synergy with protoDUNE-DP being explored

protoDUNE-SP membership & responsibilities

From DUNE member institutes:

- Call for EOIs Jan 2016
- 54 EOIs received
- All identified subsystems covered
- New institutes joined protoDUNE-SP

Outreach:

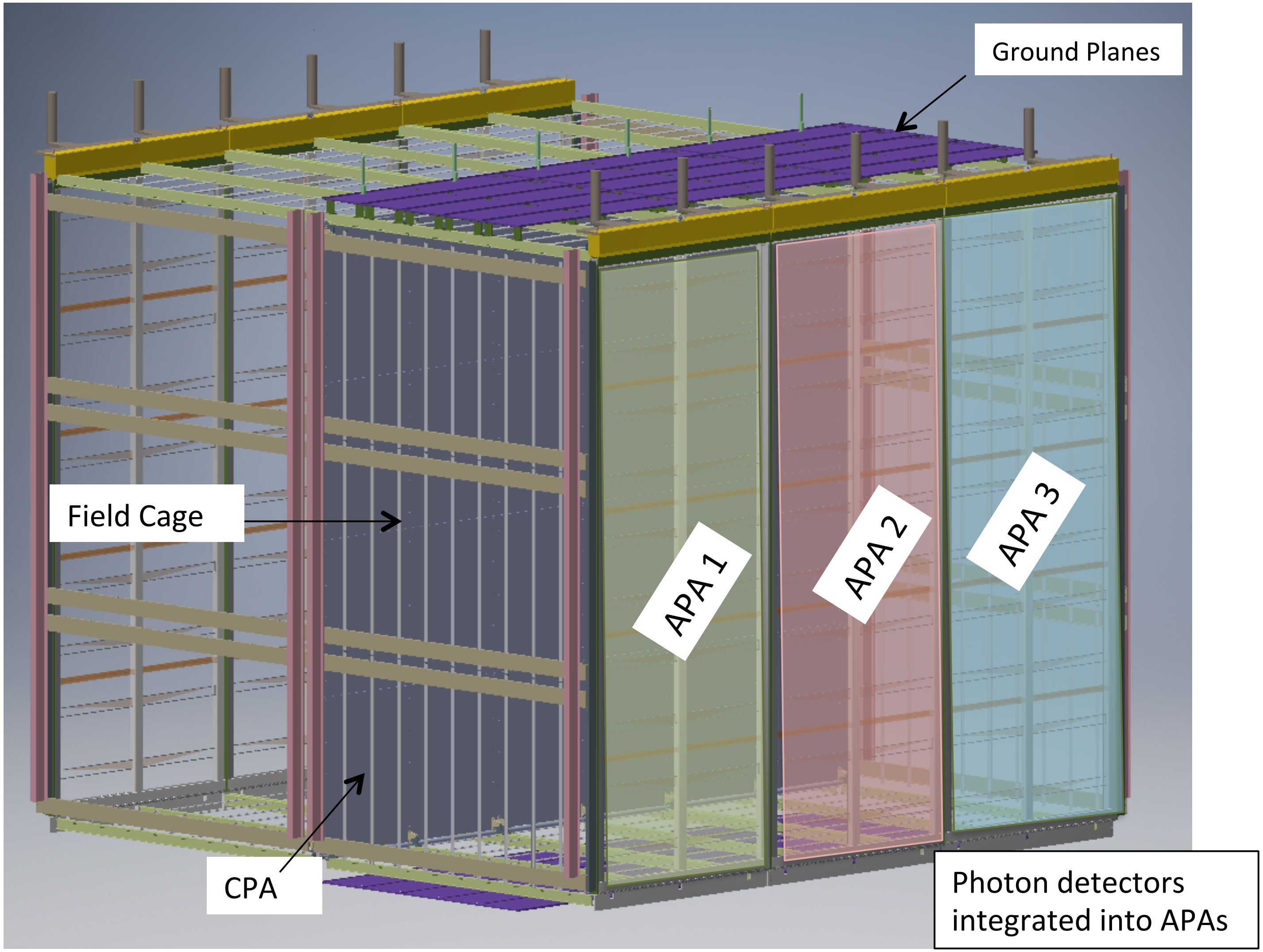
- Event for European institutes, CERN 7-8 April
- 70 attendants, from 13 countries
- Event for Latin American institutes, Fermilab 27-28 April

Goal is to assign responsibilities, confirm leadership of teams by June

EOI results

Description	QTY Institute EOIs
NP04-A APA Planes	12
NP04-B CPA Planes	8
NP04-C HV Distribution	5
NP04-D Field Cages	8
NP04-E Ground Planes	5
NP04-F Cold ASIC chips	6
NP04-G Cold Motherboards	9
NP04-H APA Readout Cables	2
NP04-I Photon Detectors	16
NP04-J PD Readout Cables	3
NP04-K Cryostat Flanges	3
NP04-L Warm APA readout electronics	7
NP04-M PD readout electronics	9
NP04-N Rack Infrastructure	2
NP04-O Back-end DAQ computing	10
NP04-P Run Control Software	2
NP04-Q Slow Controls & Monitoring	5
NP04-R Cryogenic Interfaces & Purity Monitors	2
NP04-S Beam Windows & Beam Interfaces	3
NP04-T TPC Calibration System	9
NP04-U PD Calibration System	4
NP04-V Cosmic Veto System	8
NP04-W Computing Infrastructure	6
NP04-X Detector Installation	9
NP04-Y Detector Integration	9

The TPC

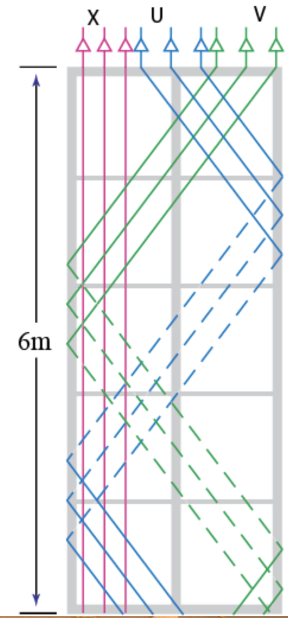

Ground Planes
Field Cage
APA 1
APA 2
APA 3
CPA
Photon detectors integrated into APAs

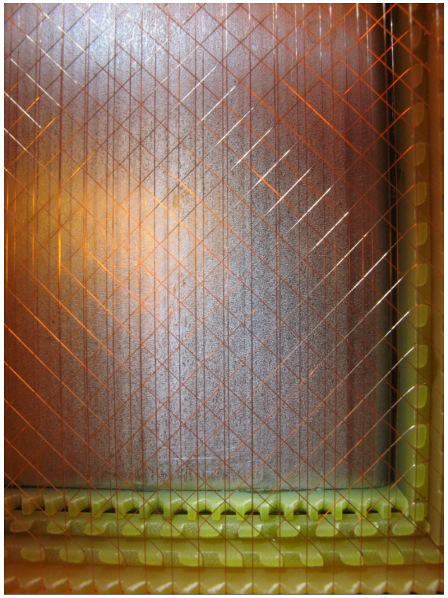
APAs

4 wire planes: Grid plane, collection, U-V induction (wrapped)

960 X wires @ 4.79mm pitch, vertical
800 V wires @ 4.67mm pitch, 35.71° from vertical
800 U wires @ 4.67mm pitch, 35.71° from vertical
960 Grid wires @ 4.5mm pitch, vertical
Wire plane spacing: 4.8mm (3/16”)
2560 sense wires, 3520 wires total
Electronics on one end of the frame

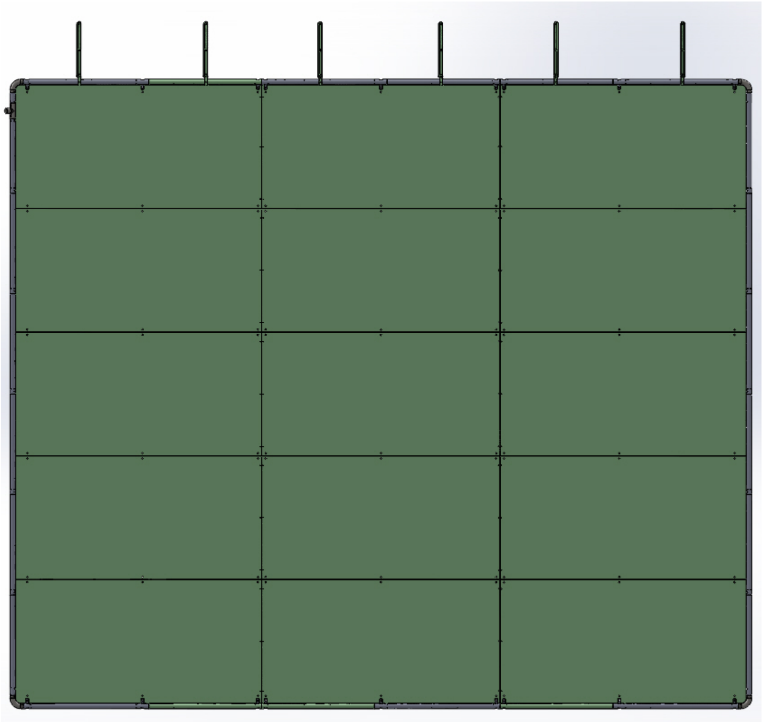
- Construction of 3 APAs at PSL, U.Wisconsin
- Wire winding machine nearing completion
- Construction of 3 APAs at Daresbury, UK (funding confirmation next month) U.Liverpool, U.Manchester

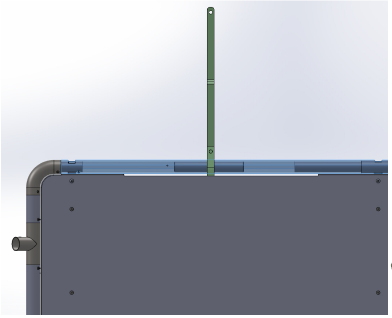


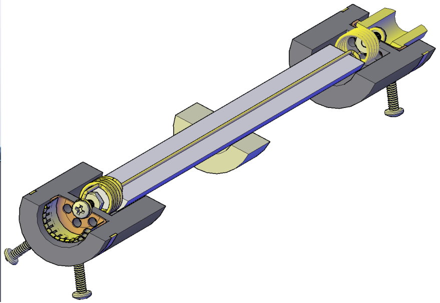


CPAs

- Operate at 180 kV nominal
- New option, under consideration
  - Resistive material instead of steel: coated or bulk-loaded G-10
  - HV buss ensures uniform voltage
- Consortium formed for
  - CPAs
  - Field Cage
  - HV system

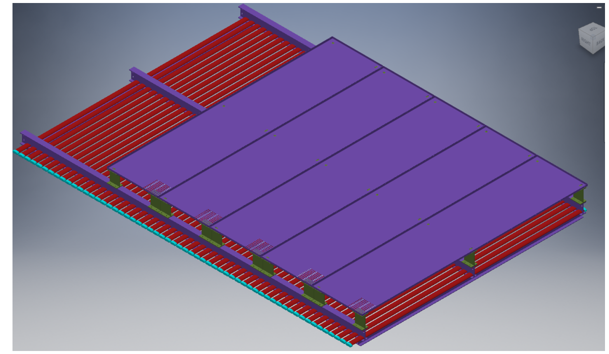


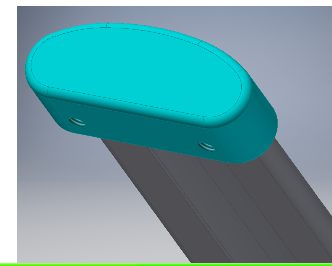


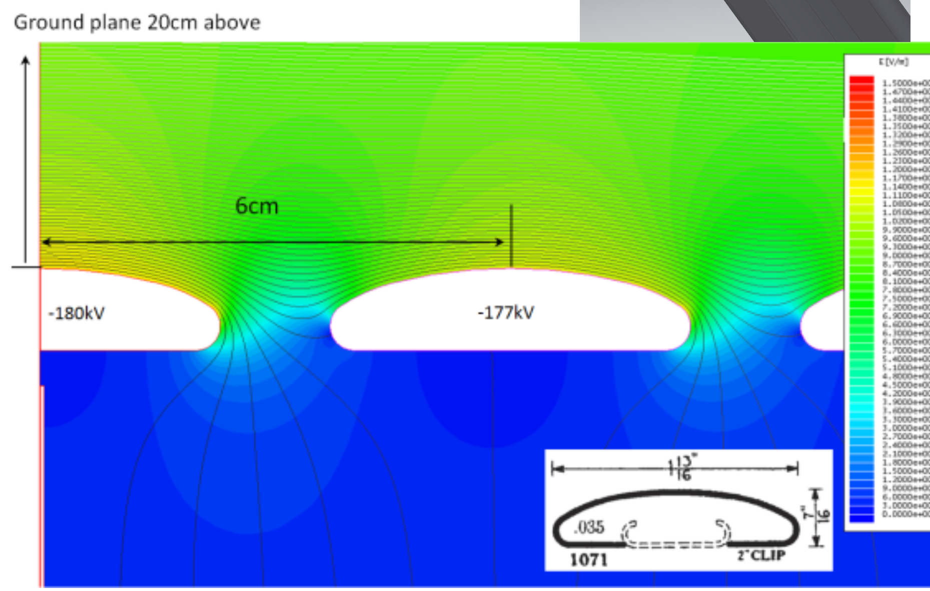


Field Cage

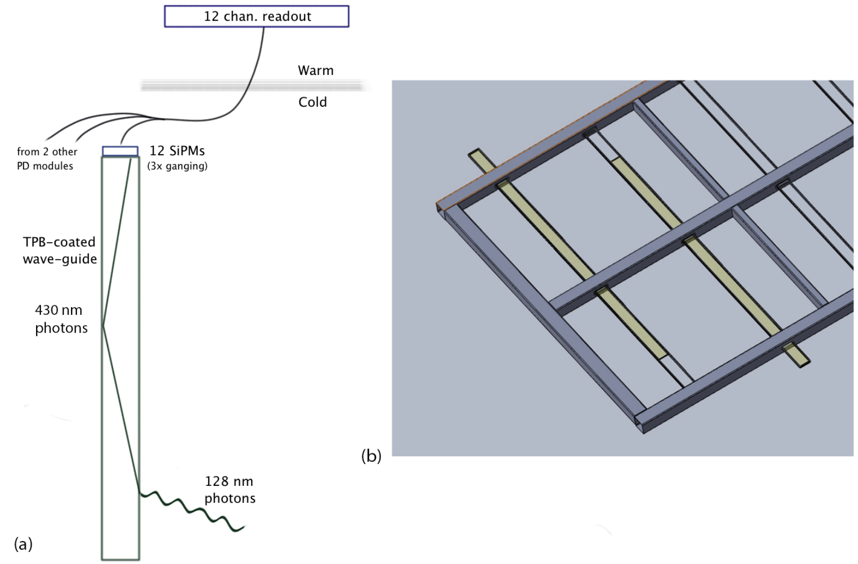
- Field cage will be constructed of roll-formed metal profiles: aluminum or stainless
- 4” Fiberglass I-beam members form the support frame.
- Plastic caps prevent discharge of more than one panel.
- Ground plates mount on top and bottom FC







Photon Detector



Requirements:

- Detect sufficient light to measure efficiently time and intensity of events depositing >200MeV
- Detect sufficient light to measure time of events depositing <200MeV
  - Min. photon yield: 0.1 pe/MeV
  - Photon time resolution: 1 microsec
- Integrated in the TPC modular design; compatible with LAr purity requirements; minimum radioactivity
- Readout system to record continuous waveforms

- wave-length shifter bars couple to ganged SiPMs
- Two variants in development
- Other technologies may be prototyped
- New groups interested

DAQ

6 APAs, 2560 channels each, 2 MHz 12 bit ADCs

Trigger using beam counters & SPS beam spill

DAQ challenging due to large volume of data produced.

- Raw rate pre-trigger TPC: 46GB/s
- Trigger reduction: less than a factor 10

Two modes of protoDUNE-SP data taking foreseen:

1. Triggered mode – from beam counters. Expect to run at about 50Hz which gives 225 events per spill, (max rate (on all the time) would be about 400Hz). Inter-spill gap is sufficient to drain data to computers. Used in first runs.

2. Continuous mode (like far detector), used later. Test data filtering techniques on FPGAs and online cluster.

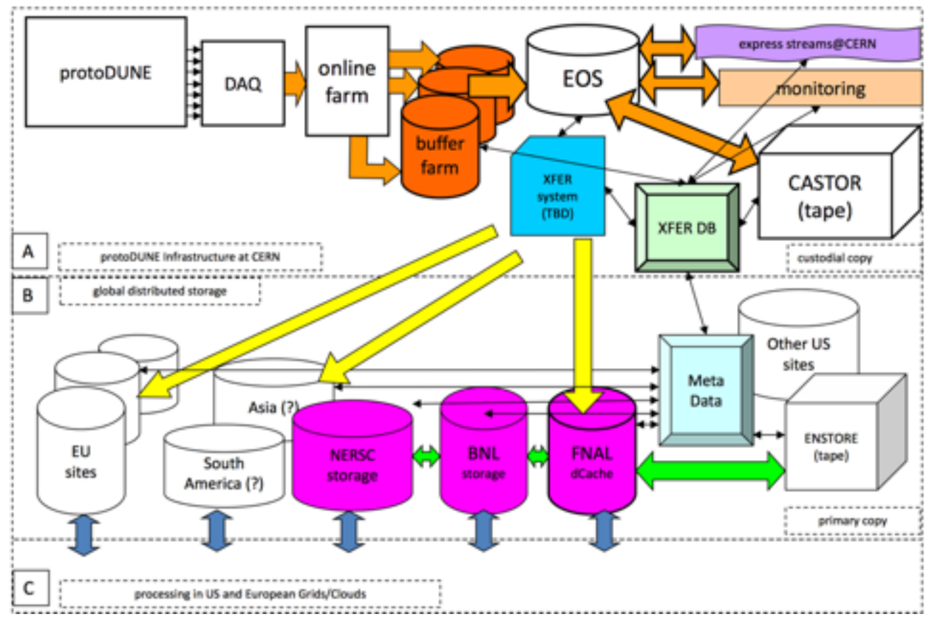
We had a 2-day workshop at CERN in February

Two solutions under development for the back end DAQ based on the RCE (baseline) and FELIX cards

Computing

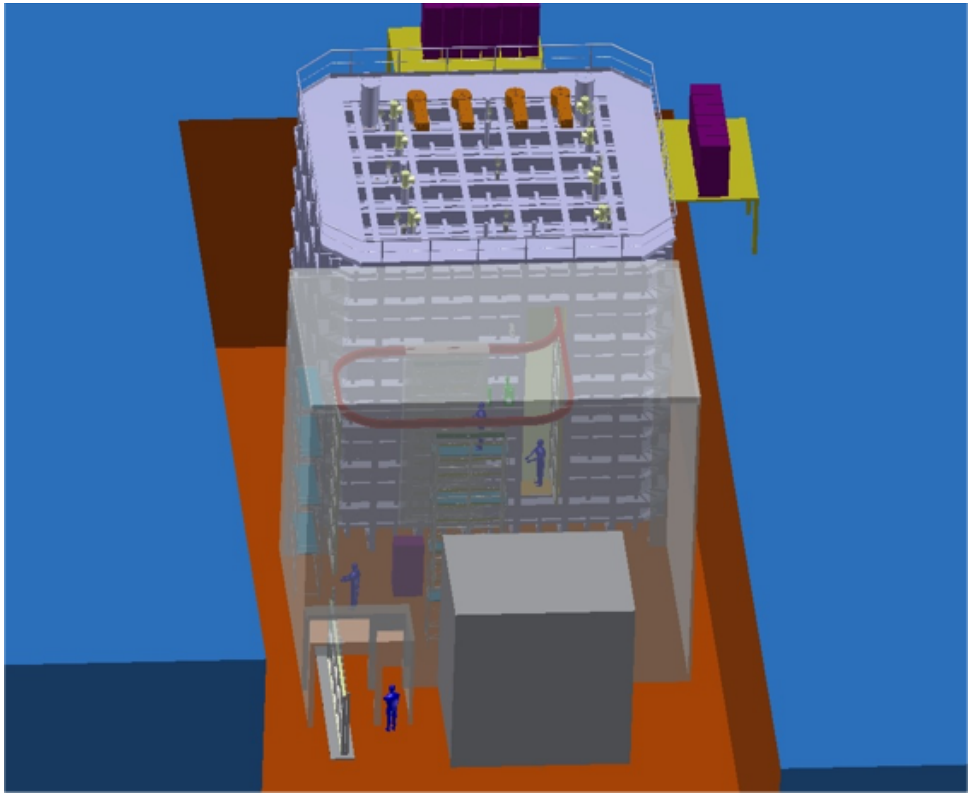
- Collaboration set up between CERN-IT, FNAL-SCD and ProtoDUNE SP & DP
- protoDUNE computing interface group: mandate to define protoDUNE computing model by April 2016 (almost done)
- Transfer raw data files from both online disk buffer farms of the DP and SP detectors to CERN EOS disk and from there to CERN tape (CASTOR), FNAL tape (Enstore) and other end-points.

Conceptual diagram of the raw data flow.
This design is now considered as "standard".

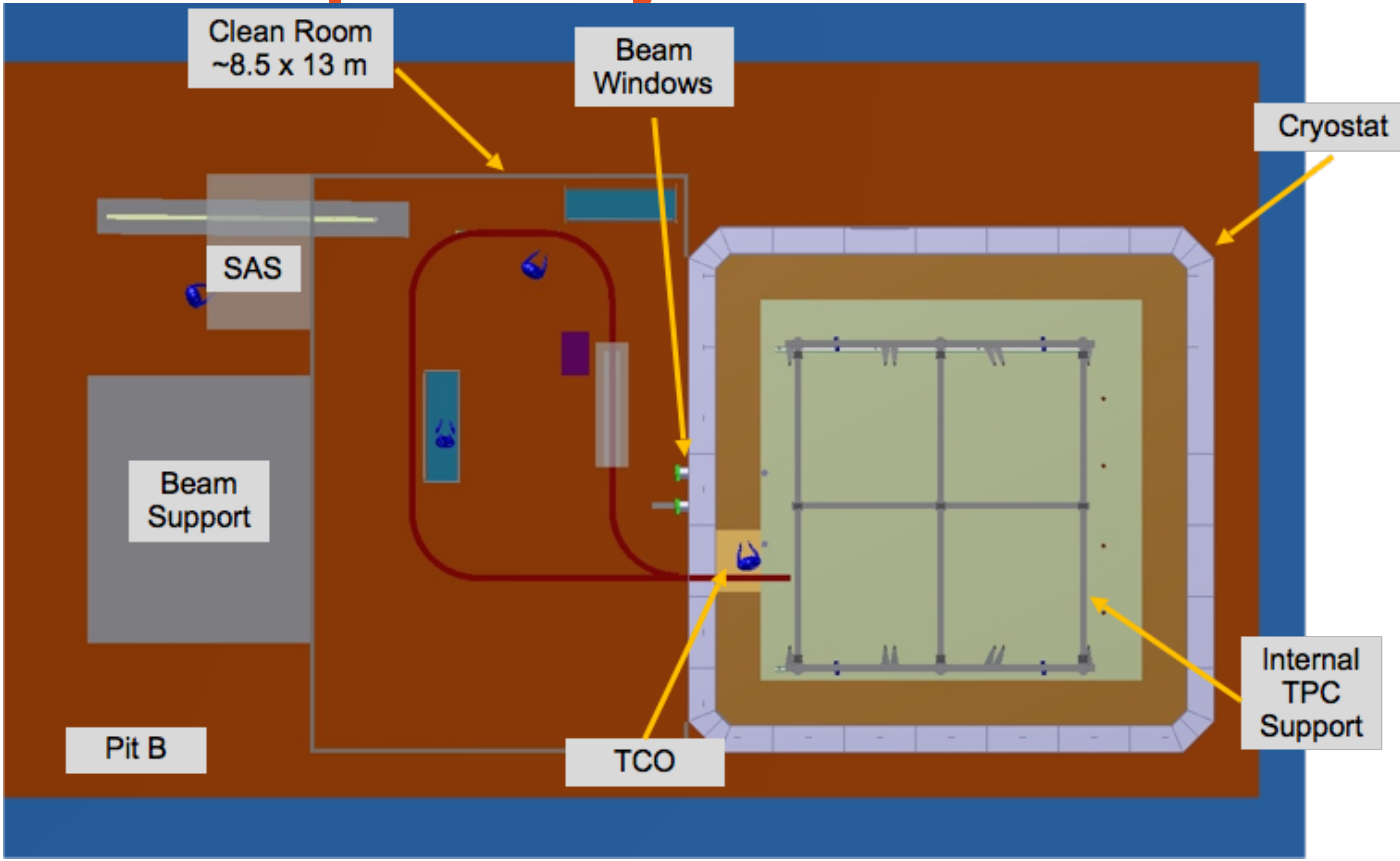


Integration, Testing, Installation

- All detector components will arrive at the clean room in EHN1
- Integration & tests of APA+CE +PD will take place in the clean room
- As soon as one APA is fully equipped and tested it will be inserted inside the cryostat for further tests
- Consecutive test cycles with increasing detector complexity
- Crucial to learn / debug how the detector works from a slice to a full detector
- Construction experts will participate in the installation

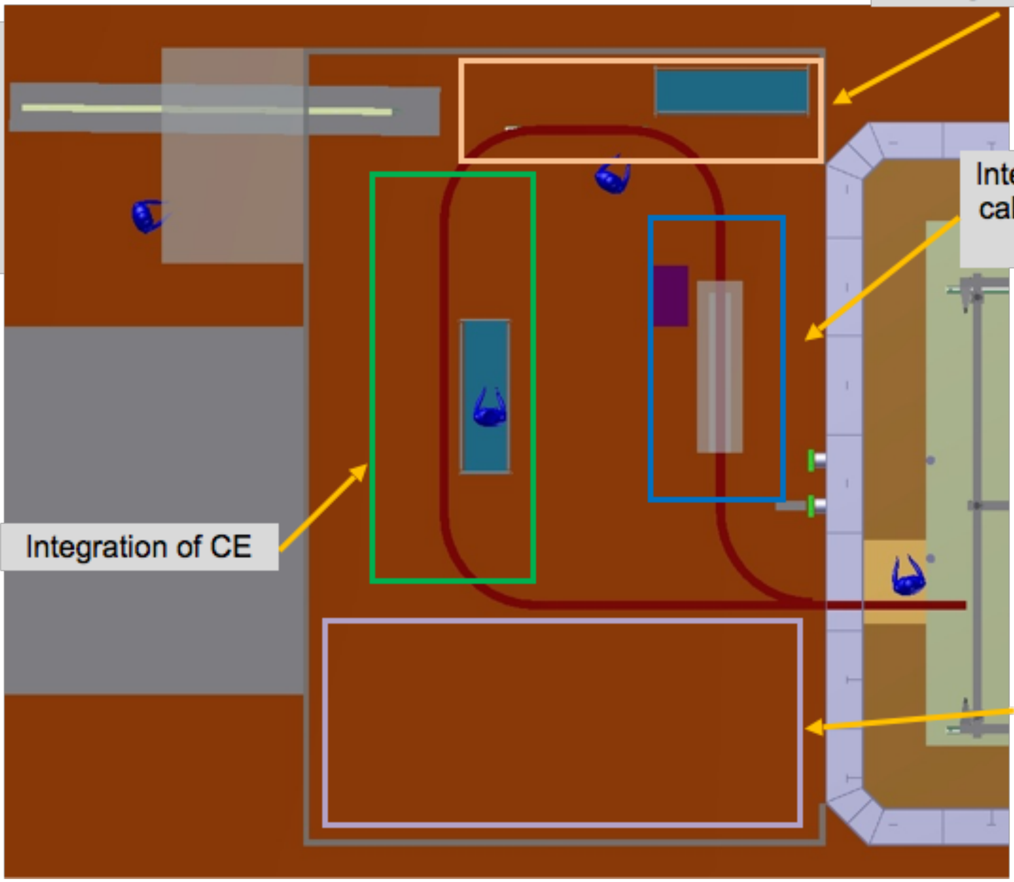


Conceptual layout



Conceptual layout

- SAS comments
- Small parts and tools can arrive via the personnel SAS.
- Large components will be lowered through a vertical SAS to enter inside the clean space.



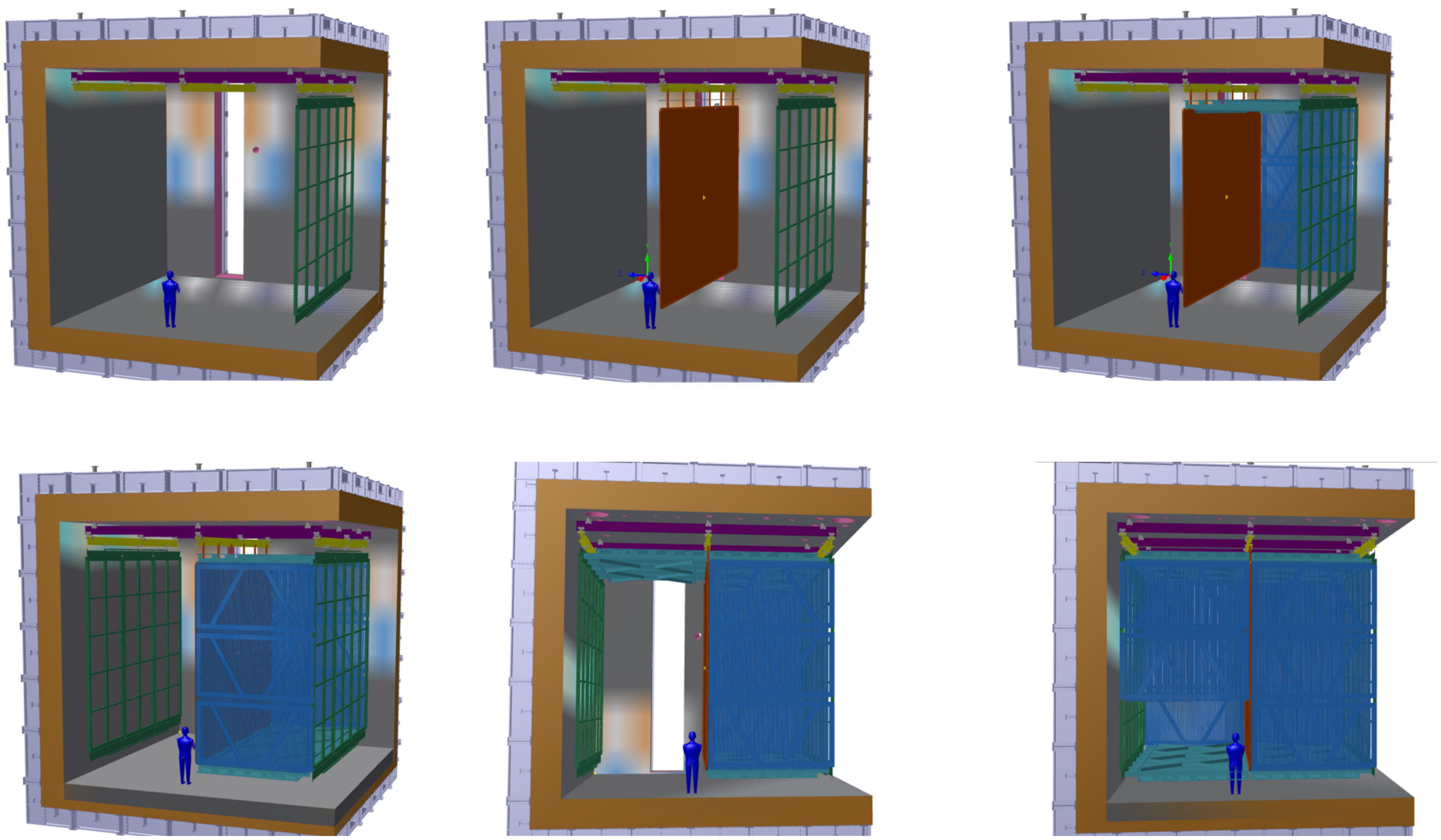
Integrate PD

Integrated cold test box (could be cabled to full chain electronics on top of cryostat)

Integration of CE

CPA, FC, ground plane integration area (~4 x 8.5 m). Leaving this space available allows for APA integration and installation inside the cryostat to happen in parallel.

Installation in the cryostat



protoDUNE-SP team at CERN

DUNE Personnel at CERN for protoDUNE-SP Integration/Installation/Commissioing/Data Taking

	2017												2018											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Managers																								
protoDUNE-SP manager	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Floor Manager	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
Installation coordinator (Jack)			1	1	1	1	1	1	1	1	1	1												
Integration/Test Coordinator					1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Computing Coordinator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Electrical Coordinator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
Safety Coordinator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Detector Experts																								
TPC				2	2	4	4	4	4	4	4	4	2	2	2	2	2	1	1	1	1	1	1	0
TPC HV												2	2	2	2	2	2	2	2	2	2	2	2	0
PD				1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0
Electronics (cold and warm)	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0
DAQ	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1
Trigger				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DQM	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Beam Detectors					1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
Cosmic Muon Tracker*					2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	0
Calibration*					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0
Computing expert	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Slow Control Monitoring	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cryogenics	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
General Assistants																								
Technitians	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1
Run Coordinators (3)																	3	3	3	3	3	3	3	3
Total	21	21	22	26	34	36	36	36	36	36	36	38	32	32	32	32	34	32	31	31	31	31	31	19

	2017	2018	Total
Total personnel at CERN	378	368	746

(person-months)

Draft composition of team at CERN

Expected cover 60% USA, 40% Europe

Funding request submitted to DOE

Timeline

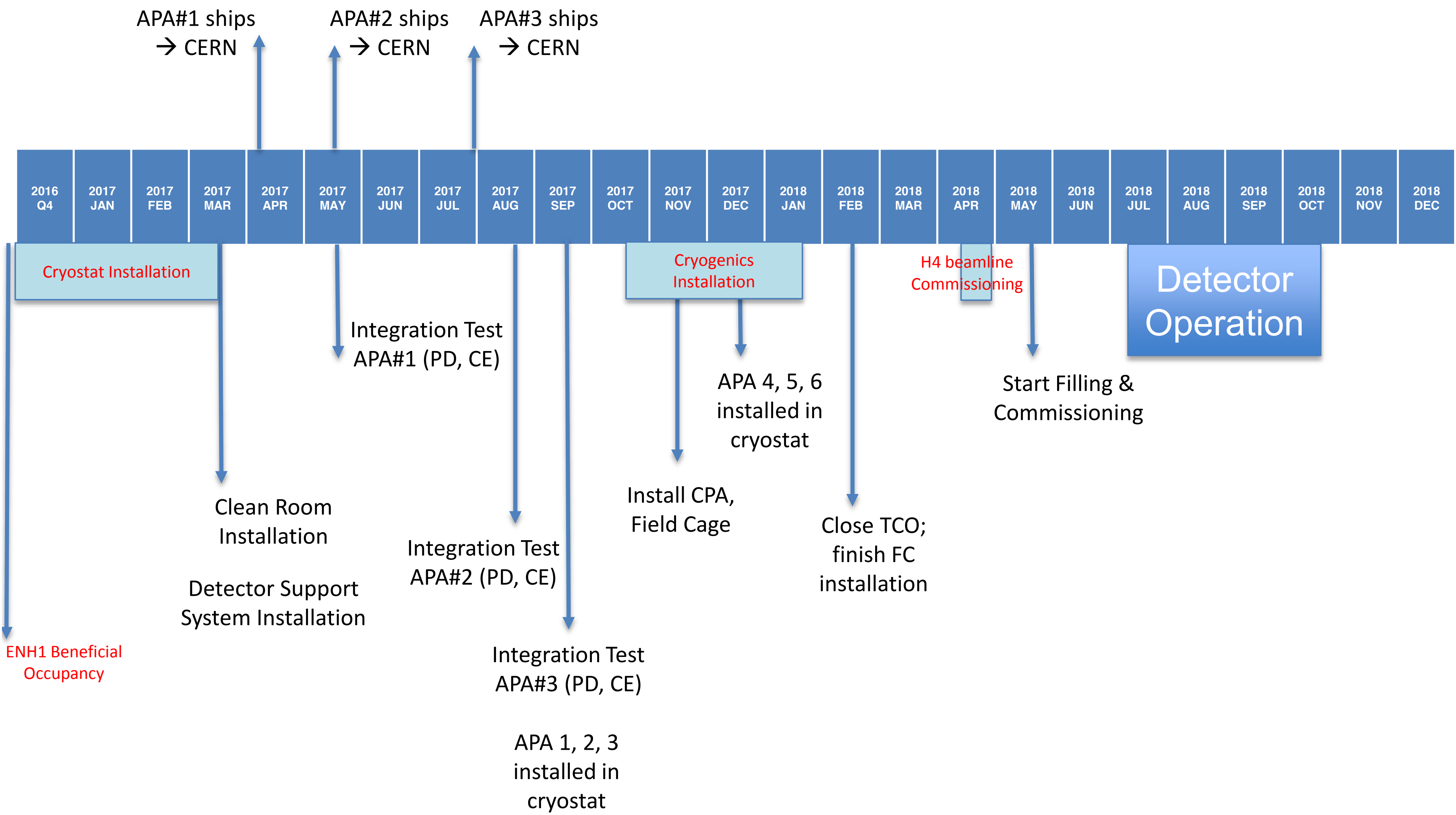
- DUNE TDR for CD-2 Review in 2019
  - protoDUNE-SP outcomes feed into this
- Planned SPS proton run end before LS2: 10/2018

Leading to the protoDUNE-SP schedule at CERN:

- 05/16-12/16 DAQ development - vertical slice operating
- 12/16-03/17 Facilities construction & set up in EHN1
- 05/17-01/18 Acceptance, tests, installation of TPC
- 02/18-04/18 Cryostat close, tests, fill & cool-down
- 05/18-06/18 Detector commissioning
- 07/18-10/18 Beam data taking

compatible with facility, cryogenics and components procurement/ construction schedules

ProtoDUNE-SP Integrated Schedule



Reviews

- Design Review: ensure design quality & sufficiency, review ES&H provisions, examine interfaces, evaluate whether functional objectives are met
- Production Readiness Review: examine manufacturing process & ensure that quality control is in place

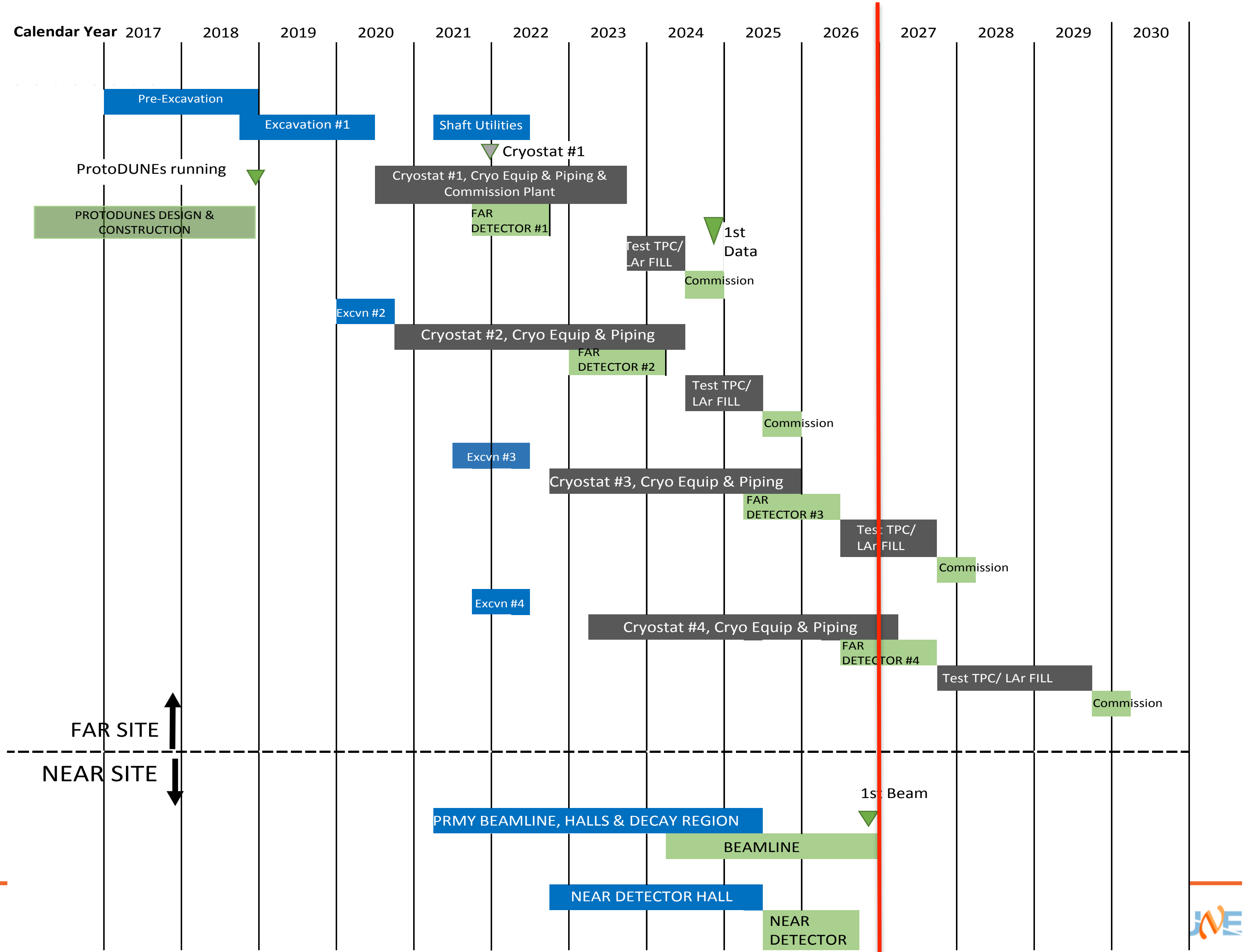
Sub-System	Design Review	Production Readiness
APA	July 2016	Jan 2017
CPA / FC	Oct 2016	Feb 2017
DAQ	Aug 2016	Feb 2017
Cold Electronics	Aug 2016	Feb 2017
Photon	Jul 2016	Feb 2017
Installation	With system	Mar 2017

Summary

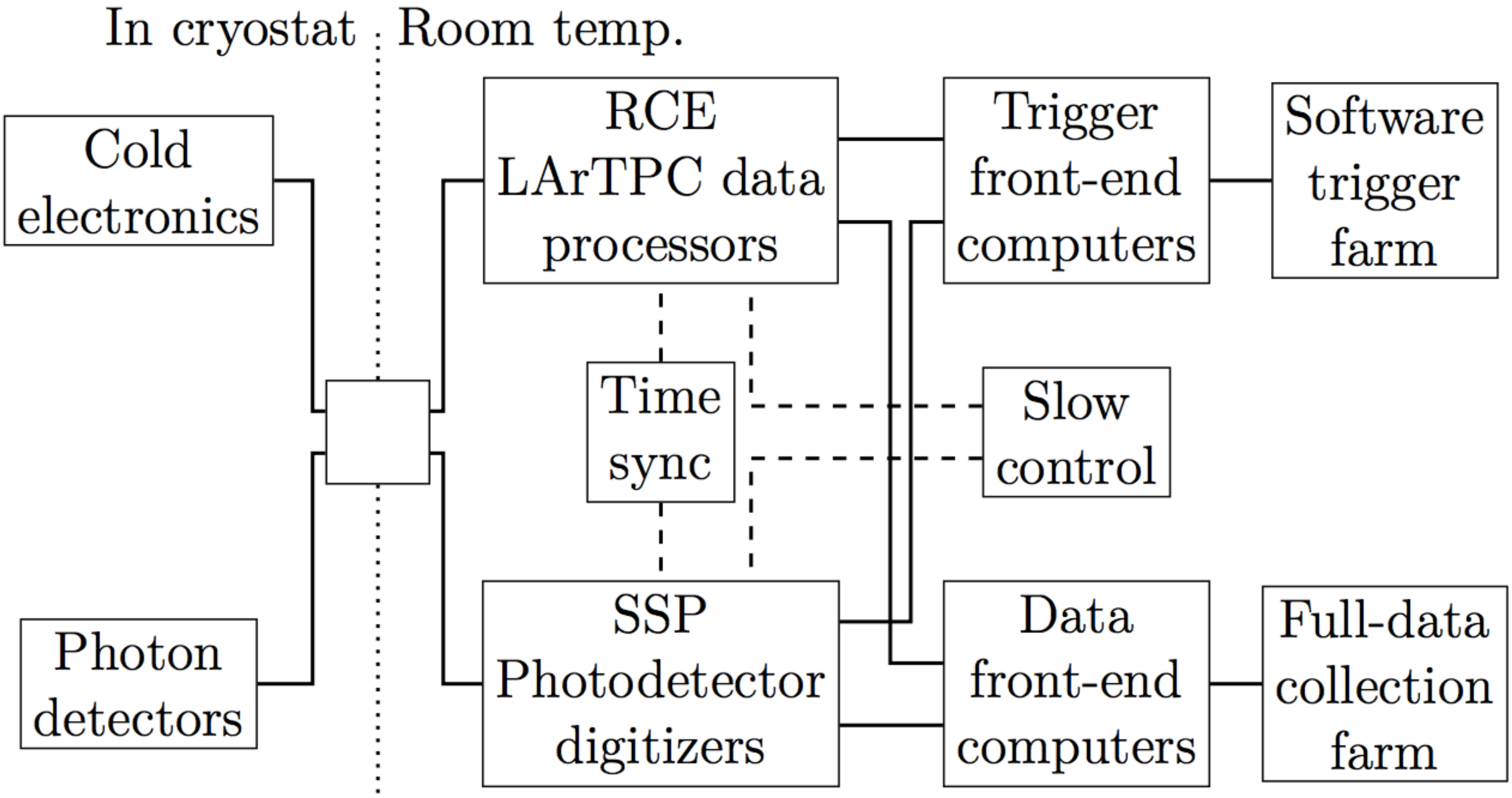
- Significant progress since approval in December 2015
- Management in place, organisation defined
- Membership extended, responsibilities and resources matrix being finalized
- Intense activity in all areas going on in parallel
- Aggressive but realistic schedule aiming for beam operation in 2018, as originally proposed
- TDR will be submitted in Fall 2016 for SPSC-122

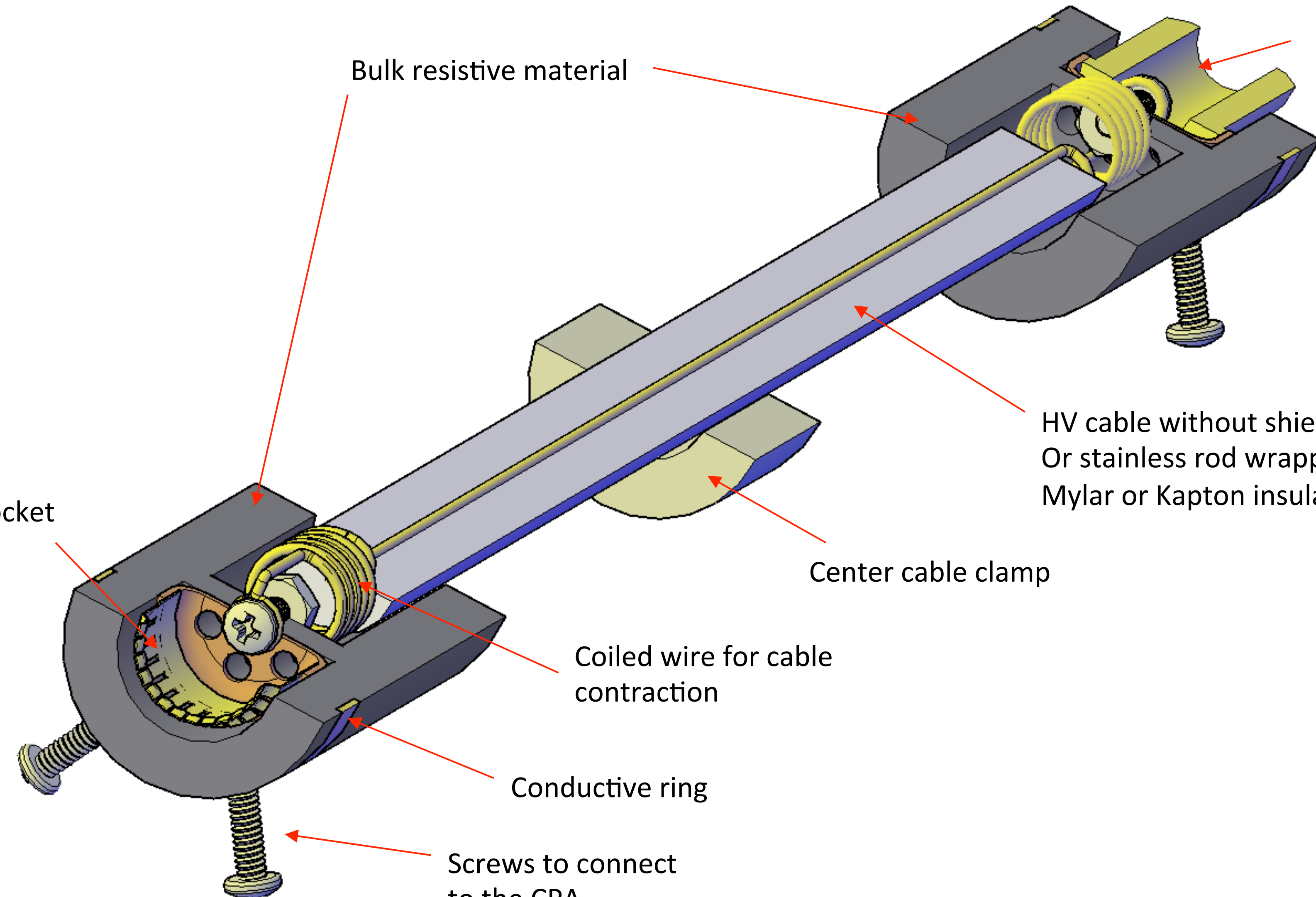
backup

LBNF/DUNE – Construction Timeline



DAQ baseline layout

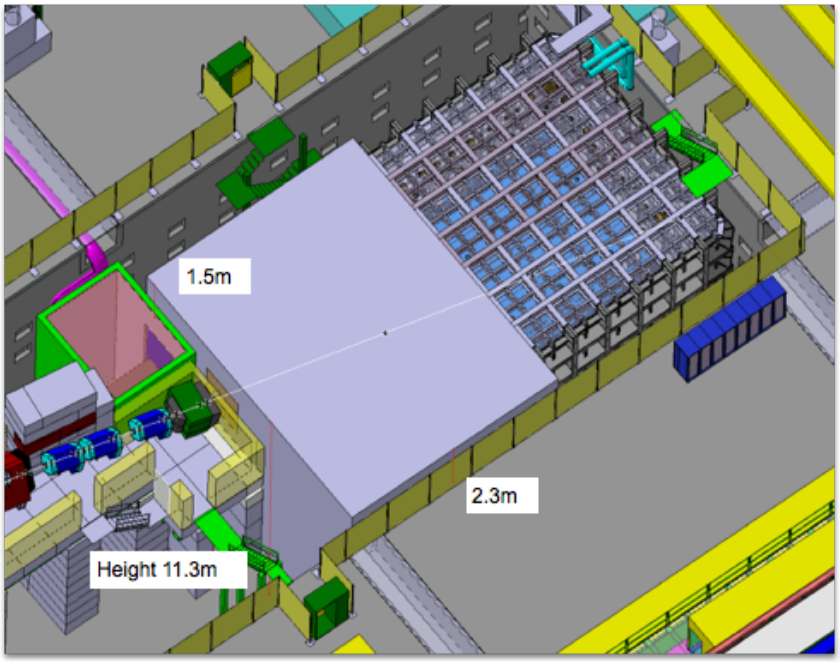


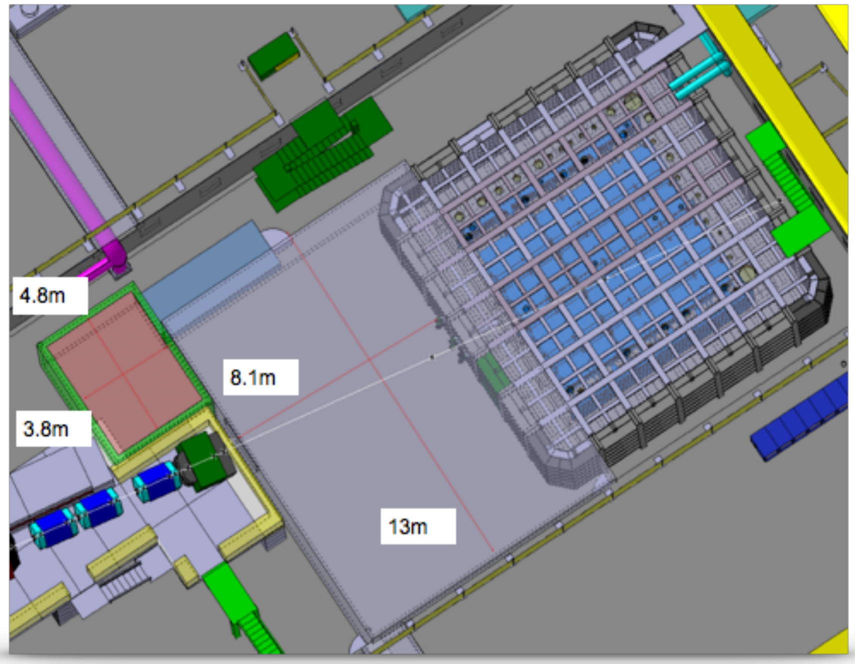

Bulk resistive material
Pin
HV cable without shield
Or stainless rod wrapped in
Mylar or Kapton insulation
Socket
Center cable clamp
Coiled wire for cable
contraction
Conductive ring
Screws to connect
to the CPA

The Clean Room

Interior dimensions

GIROT Sylvain
CLERC Vincent
EN-EAEC
07/03/16





DAQ assumptions and requirements

	Single Phase		Dual Phase	
	ProtoDUNE	One 10kt module	WA105	One 10kt module
#sub detectors	1	1 to 4 modules	1	1 to 4 modules
Data pretrigger per detector GB/s	46	1,152	38	768
Data posttrigger per detector GB/h	O(2000)	O(500)	O(1600)	O(400)
Supernova event size (no compress)		11 TB		8 TB
#channels per APA	2560			
#APA in detector	6	150		
#channels in detector	15360	384,000	7680	153,600
Digitization frequency, #bits, data size	2 MHz, 12bit 12 bit		2.5 MHz 12 bit 16bit	
Drift distance (time)	3.6 m horizontal (2.4ms)		6m vertically (4ms)	
Beam trigger rate	100 Hz	1 Hz	100 Hz	1 Hz
Beam window	4.5 s	10 us	4.5 s	10 us
Time between spills	16.8s	1 s	16.8s	1 s
Other important triggers		continuous		continuous

Raw rate for 10s, no compression

To estimate these numbers: No compression (yet)
Underground: 1 trig/s, 2 drifts, 3% ROI
At EHN1: 50 trigs/s in beam, 1 drift, 30% ROI