Overview and Status of the ProtoDUNEs

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Fermilab Neutrino Seminar
May 5, 2016

Outline

- Introduction
- ProtoDUNE goals

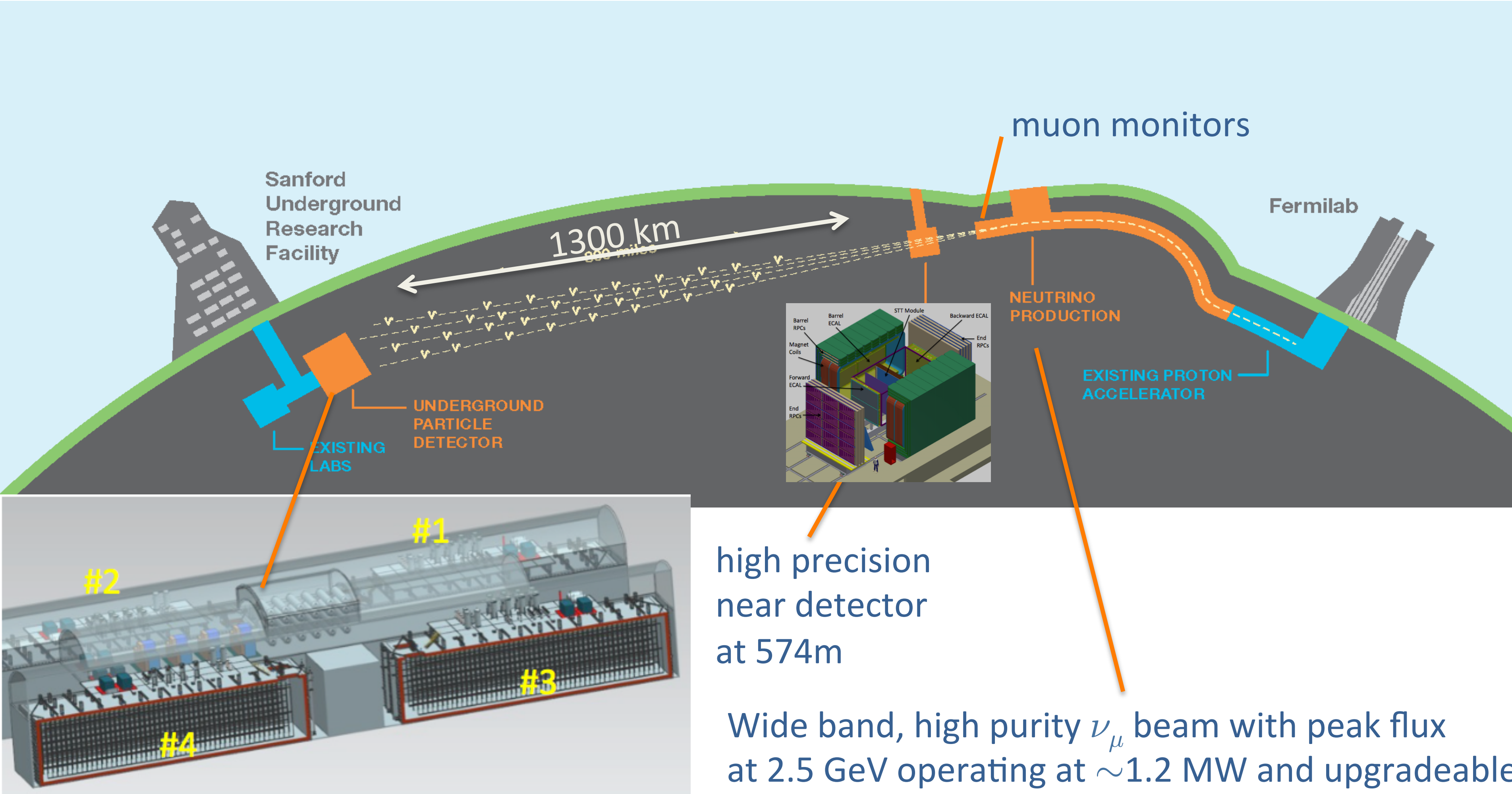
- CERN infrastructure (EHN1 extension)
  - Cryostat + cryogenics
- Detector layout
  - Single phase LAr
  - Dual phase LAr

Common sub-systems

- Measurement program (and calibrations)
- Charged particle beams

- Timeline + organization
- Summary

DUNE Overview

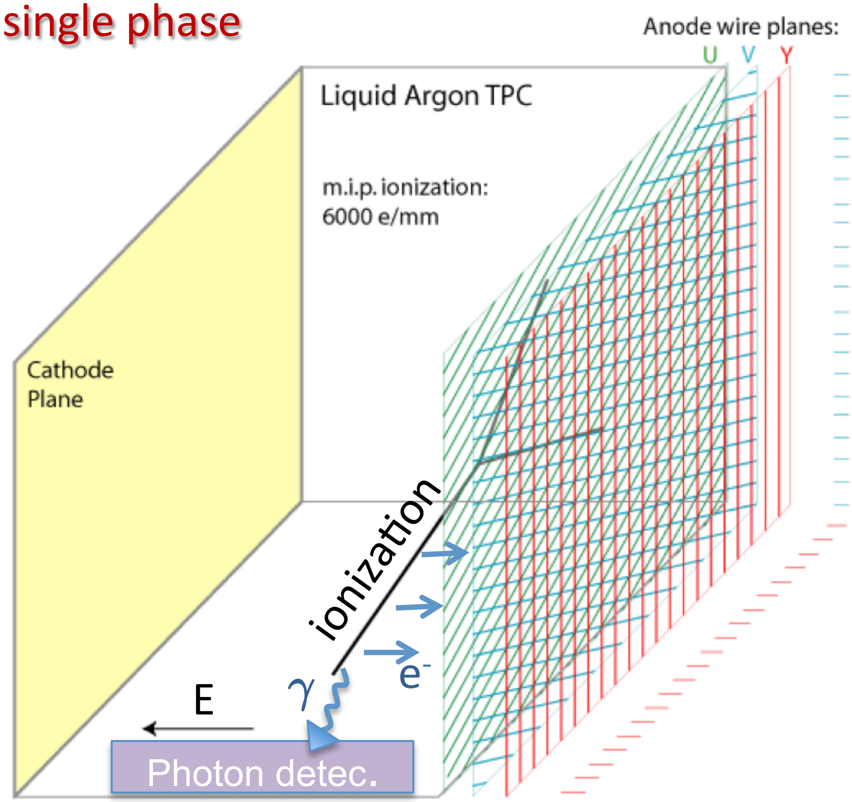


Wide band, high purity ν_μ beam with peak flux at 2.5 GeV operating at $\sim$1.2 MW and upgradeable

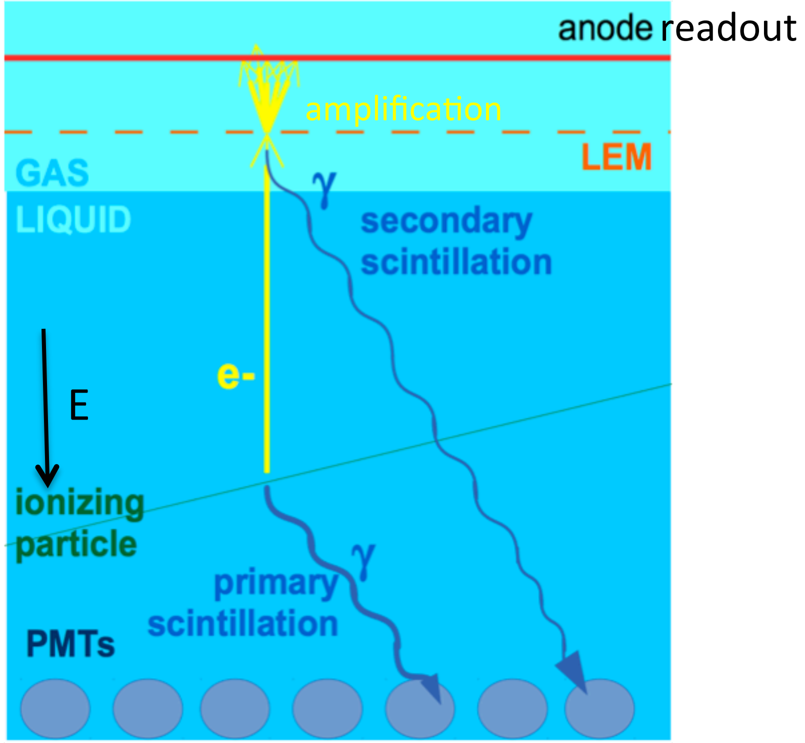
- four identical cryostats deep underground
- staged approach to four independent 10 kt LAr detector modules
- Single-phase and dual-phase readout under consideration

LAr TPC Technologies

single phase



dual phase



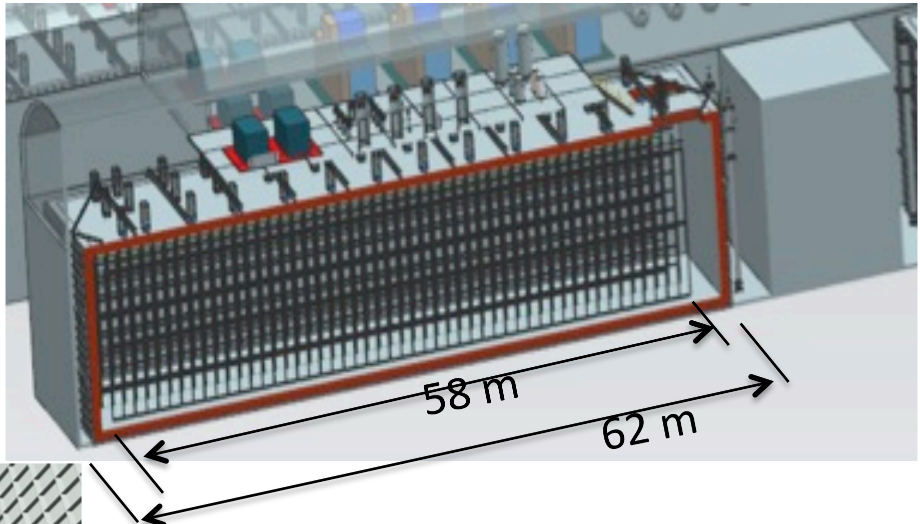
- Ionization: $\sim$ 60,000 e^-/cm for mip (for E $\approx$ 500V/cm)
  → Provides detailed imaging, calorimetric and particle identification (PID)
- Scintillation: $\sim$24,000 γ/MeV (for E $\approx$ 500V/cm)
  → offers event trigger (t_0) information + improved calorimetric information

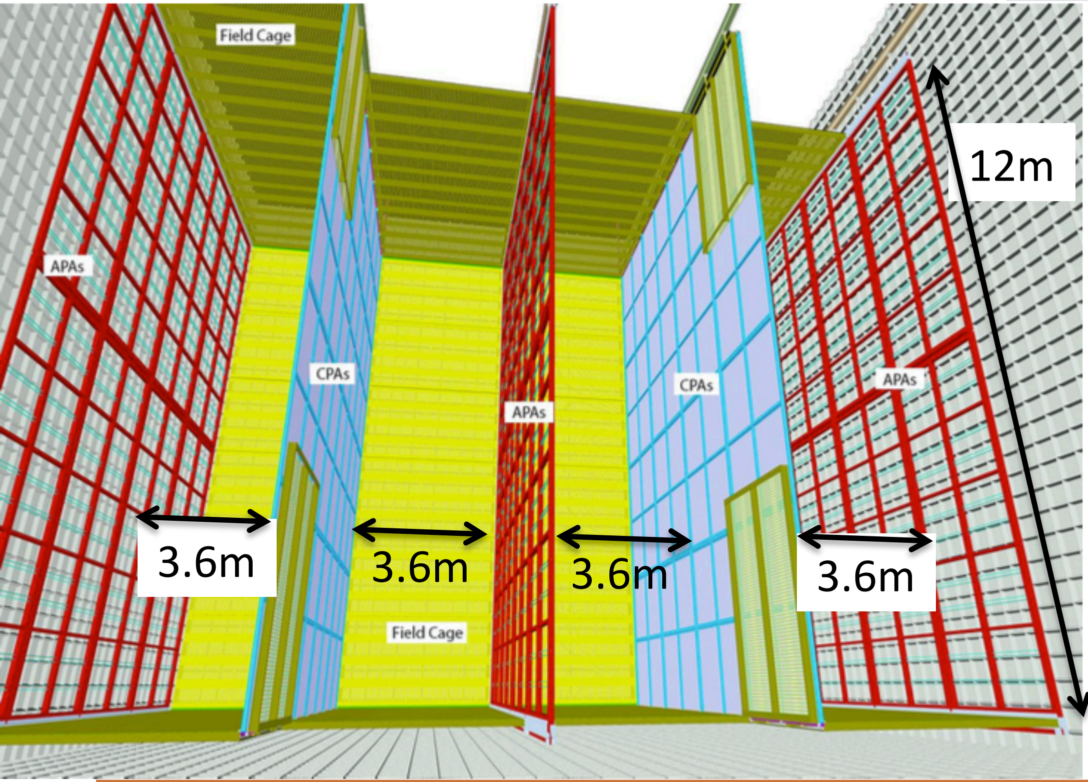
Single-Phase LAr Detector

Readout of

- Ionization charge and
- scintillation light

Detector mass [kt]	
total	17.1
active	13.8
fiducial	11.6





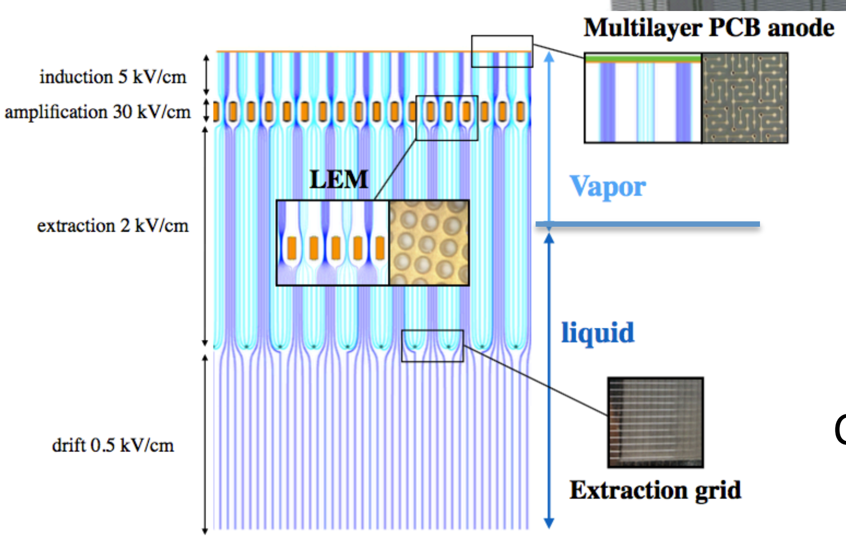
Time Projection Chamber:
wire Anode Planes (APAs)
induction + collection wires
2 cathode planes at -180 kV

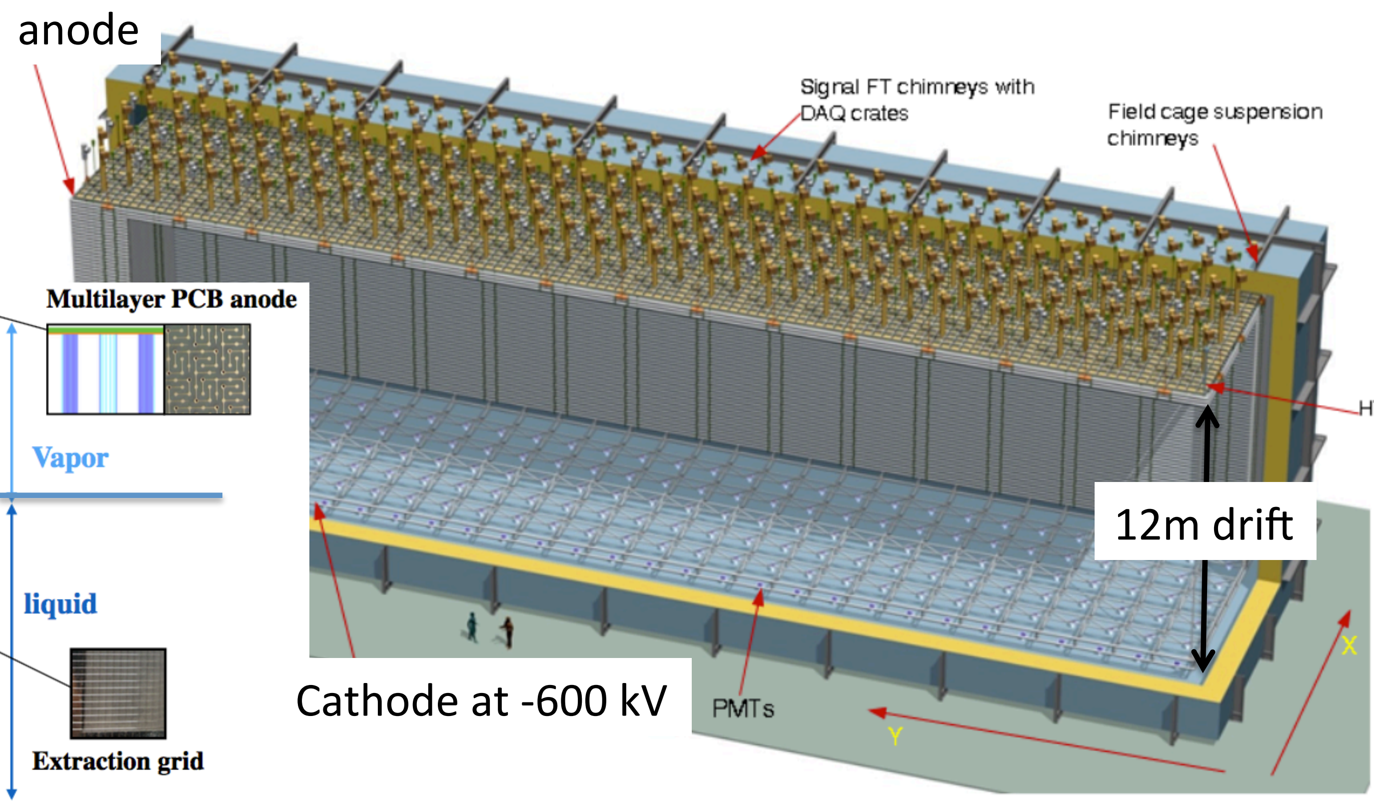
4 drift regions: 3.6m drift each

Photon Detection System
integrated in APAs to measure non-beam event timing

Dual-Phase LAr Detector

Readout of
- Ionization charge
- scintillation light



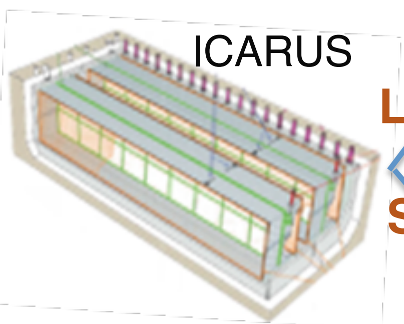


Ionization charge extracted into Ar gas phase
charge amplification via large electron multipliers (LEM) before readout
[2 dimensional charge collection]
→ If demonstrated at large scales, could be used as alternative design for 2nd or subsequent 10 kt far detector modules

LArTPC Development Path

Fermilab SBN and CERN neutrino platform provide a strong **LArTPC** development and prototyping program

Single-Phase



ICARUS

LBL

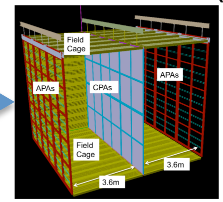
SBL

35-t prototype

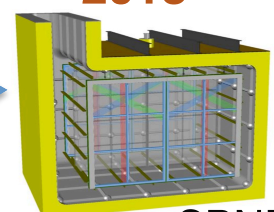
2015

MicroBooNE

protoDUNE (NP04)



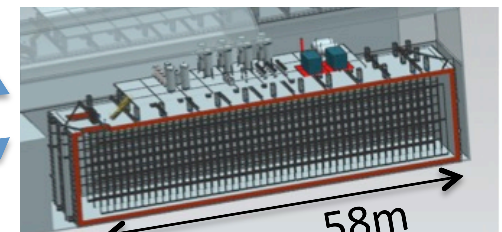
2018



SBND

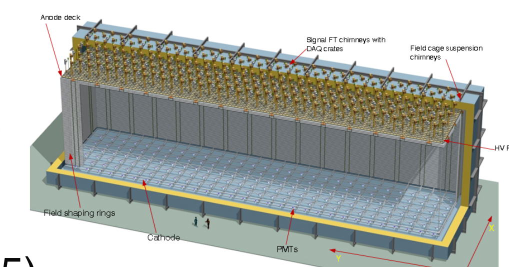
DUNE Reference Design

basis for first 10 kt module



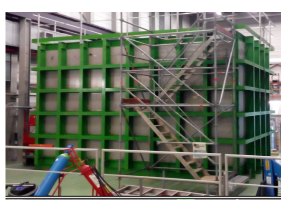
46 times larger than ICARUS

DUNE Alternative Design



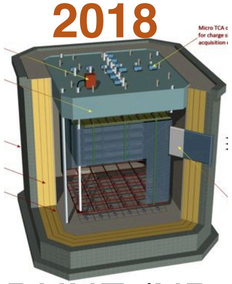
Dual-Phase

2016



WA105: 50-t 1x1x3 m^3

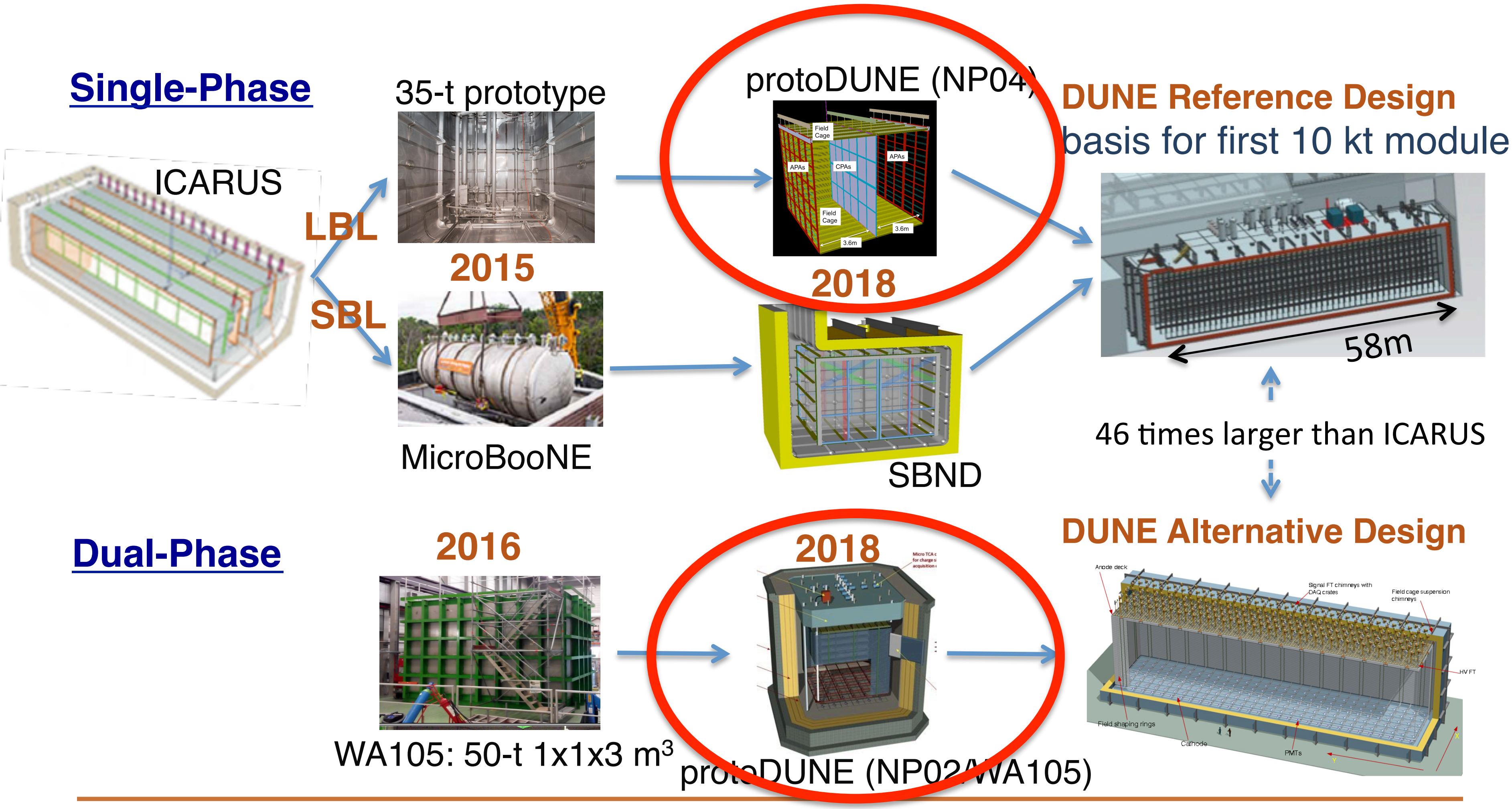
2018



protoDUNE (NP02/WA105)

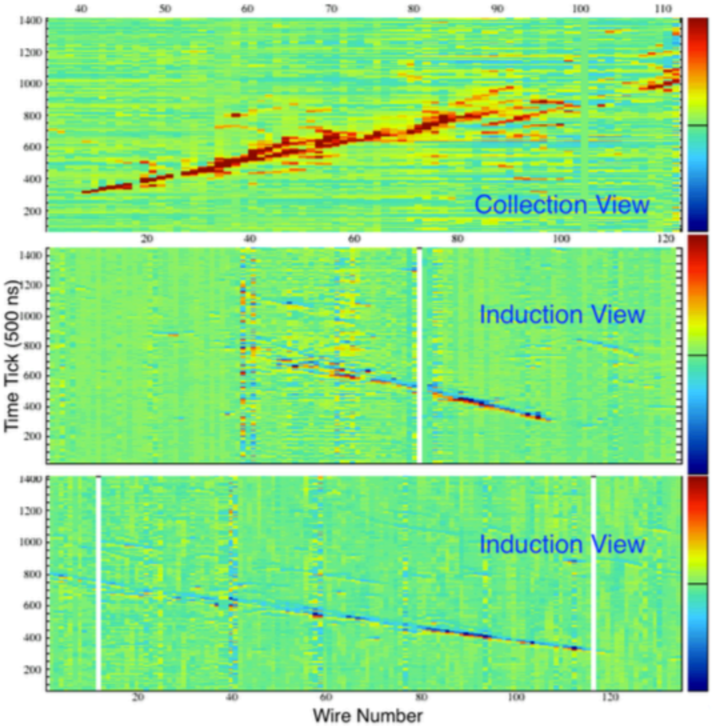
LArTPC Development Path

Fermilab SBN and CERN neutrino platform provide a strong **LArTPC** development and prototyping program

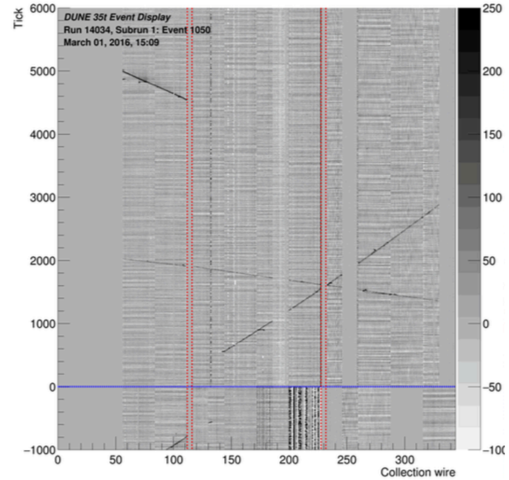


Sample event displays

35 t detector

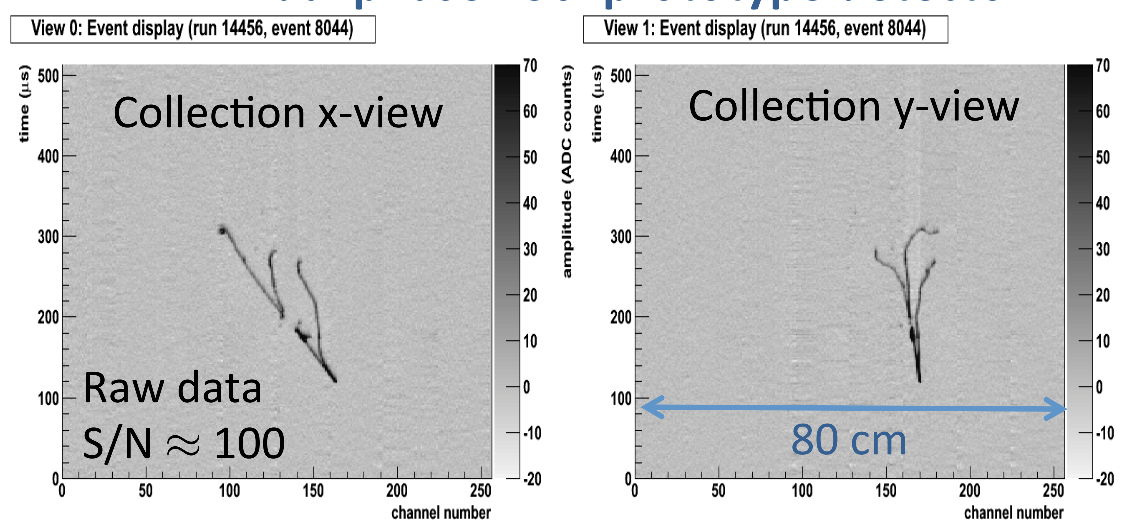


After coherent noise subtraction



Collection view
Raw data

Dual phase 250l prototype detector



→Single and dual phase LAr TPC technologies haven been proven to work at various scales

ProtoDUNE High Level Goals

Detector Engineering:

- Measure and benchmark detector performance of full scale detector components
- Establish manufacturing methods and capabilities at multiple sites
- Demonstrate QA/QC chains for all detector elements
- Develop and assess DAQ strategies, algorithms and data handling
- Validate installation procedures and operation of full scale detector components

Physics Measurements :

- Assess Detector **systematic uncertainties**
- Validate and tune MC simulations to data
- Test reconstruction tools and PID
- Study particle interactions (pion, muon, kaon)
  - muon capture, anti-proton annihilation, …

To be most relevant for DUNE requires charged particle beam to cover energy range and particle types as expected for DUNE ν interactions

Infrastructure and Alternate:

- Validate membrane cryostats and cryogenics system
- Compare single and double phase LAr detector technologies

ProtoDUNE High Level Goals

Detector Engineering: →**informs DUNE TDR and CD-2 review (2019)**

- Measure and benchmark detector performance of full scale detector components
- Establish manufacturing methods and capabilities at multiple sites
- Demonstrate QA/QC chains for all detector elements
- Develop and assess DAQ strategies, algorithms and data handling
- Validate installation procedures and operation of full scale detector components

Physics Measurements : → **help calibrate/improve DUNE detector**

- Assess Detector **systematic uncertainties**
- Validate and tune MC simulations to data
- Test reconstruction tools and PID
- Study particle interactions (pion, muon, kaon)
  - muon capture, anti-proton annihilation, …

To be most relevant for DUNE requires charged particle beam to cover energy range and particle types as expected for DUNE ν interactions

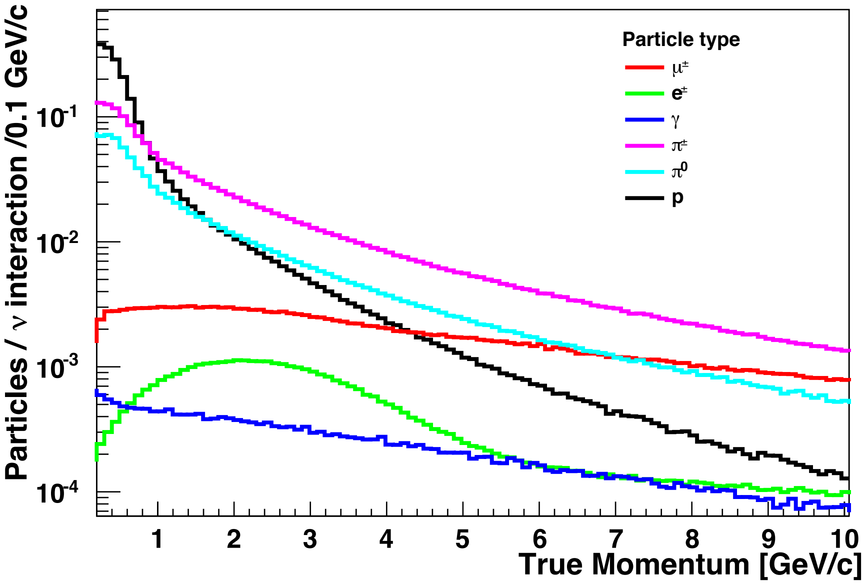
Infrastructure and Alternate: →**informs LAr technology decision**

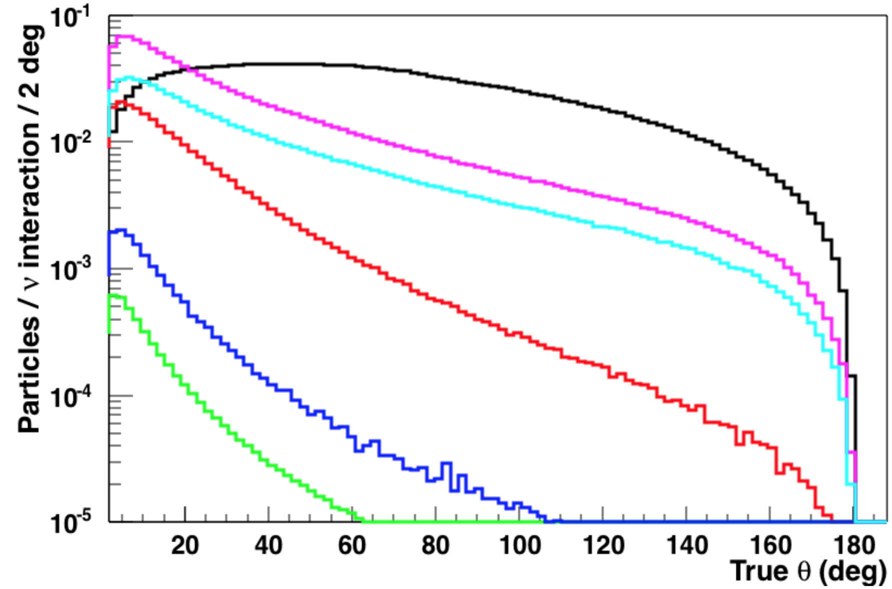
- Validate membrane cryostats and cryogenics system
- Compare single and double phase LAr detector technologies

ProtoDUNE 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 individual charged particles to be studied in CERN beam test

→ Energy ranges of : sub-GeV to several GeV

→ Angular range: few – 40 deg

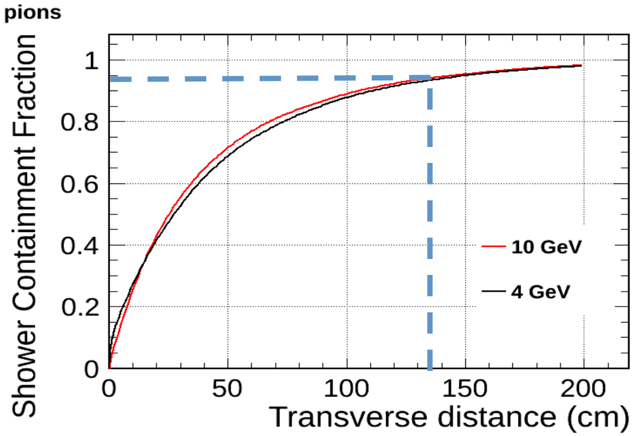
NOTE: particles embedded in showers → study topologies

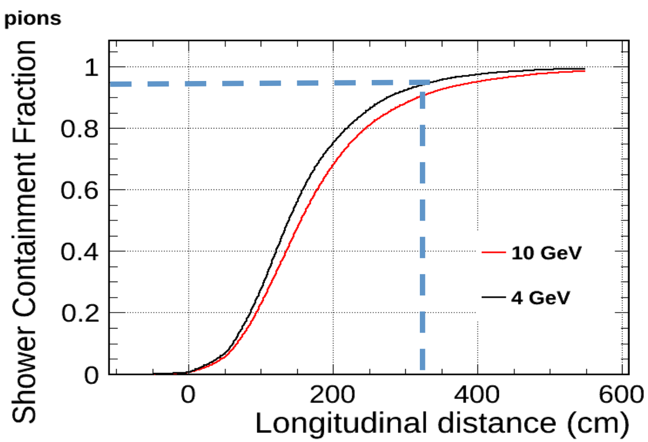
➔ Affects particle containment and detector size

Detector Size/Dimensions

Engineering:
test multiple full-scale components assembled into functional sub-unit

Measurement:
energy bias studies require shower containment

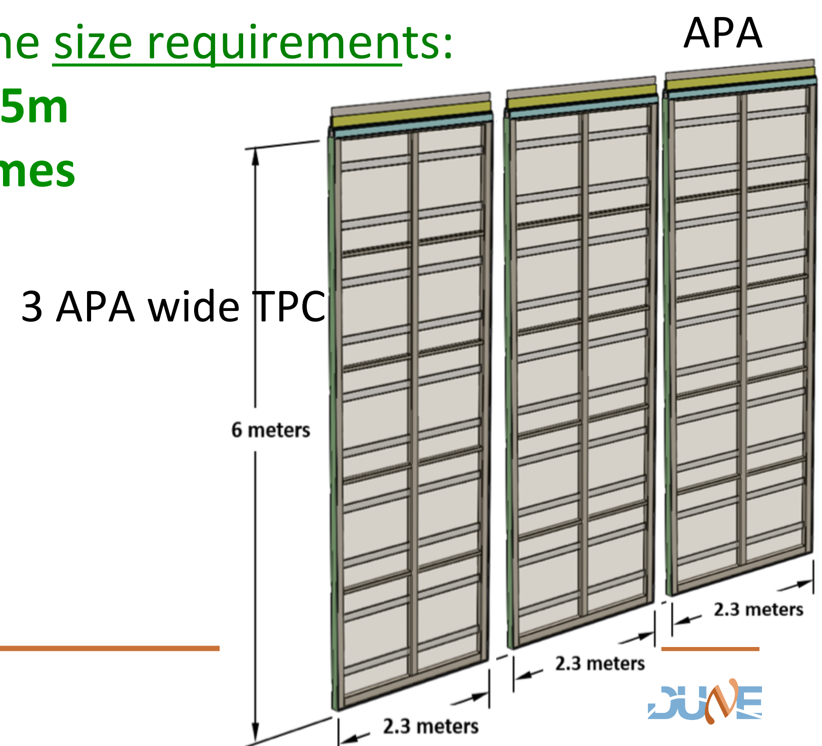




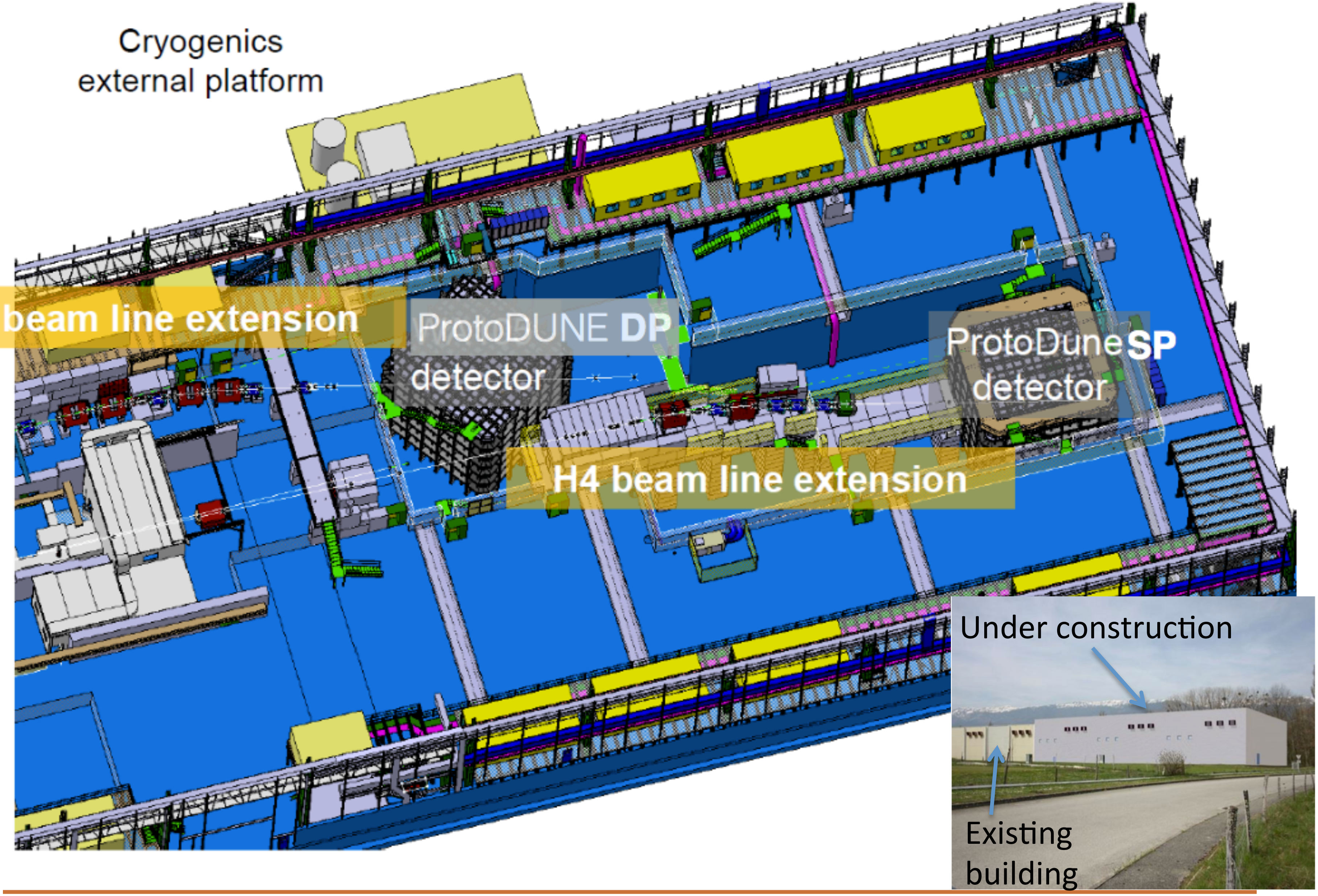
95 % containment envelope
Transverse: 1.4 m
Longitudinal: 3.2 m

~99 % containment envelope
Transverse: 2.1 m
Longitudinal: 5.3 m

→ active volume size requirements:
6m × 5m × 5m
→ **2 drift volumes**



CERN Infrastructure



EHN1 Extension Civil Construction Status

14/04/2016

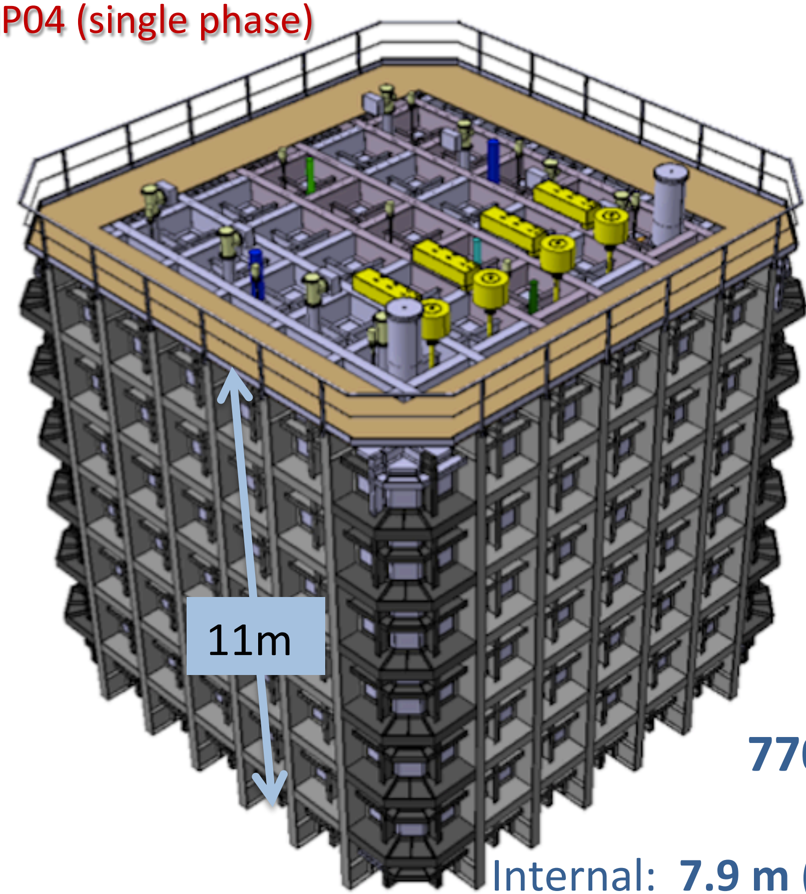
28/04/2016

→ Beneficial occupancy expected 9/2016

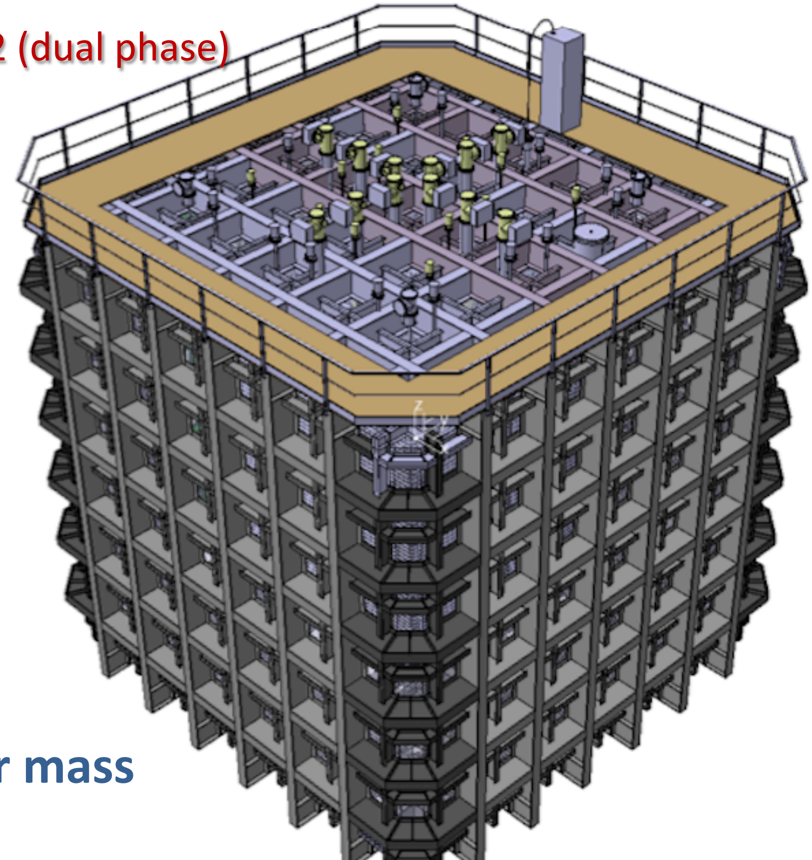
ProtoDUNE Cryostats

Use nearly identical cryostats for single and dual phase protoDUNE

NP04 (single phase)



NP02 (dual phase)



770 t total LAr mass

Internal: **7.9 m (Transv) x 8.5 m (Parallel) x 8.1 m (Height)**

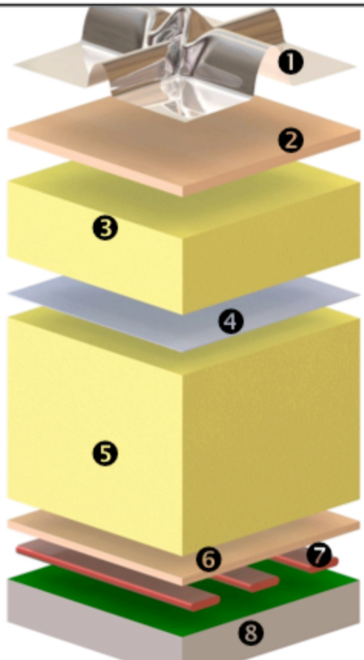
External: **10.8m (Transv) x 11.4 m (Parallel) x 11.0 m (Height).**

→ Costs for both cryostats covered by CERN

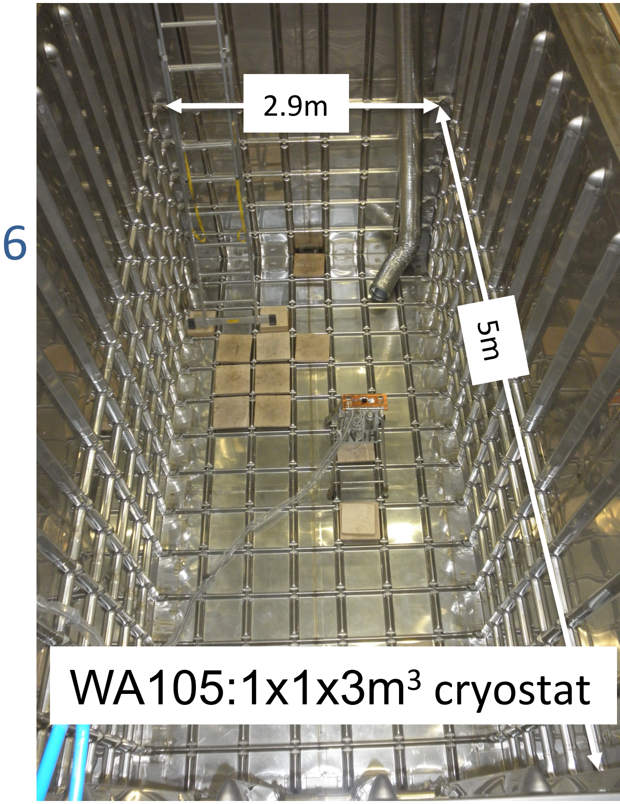
Cryostat Technology

- Outer steel structure (designed by CERN)
  →construction contract in place; delivery summer 2016
- Membrane cryostat (engineering contracted to GTT)
  → tendering for materials in progress

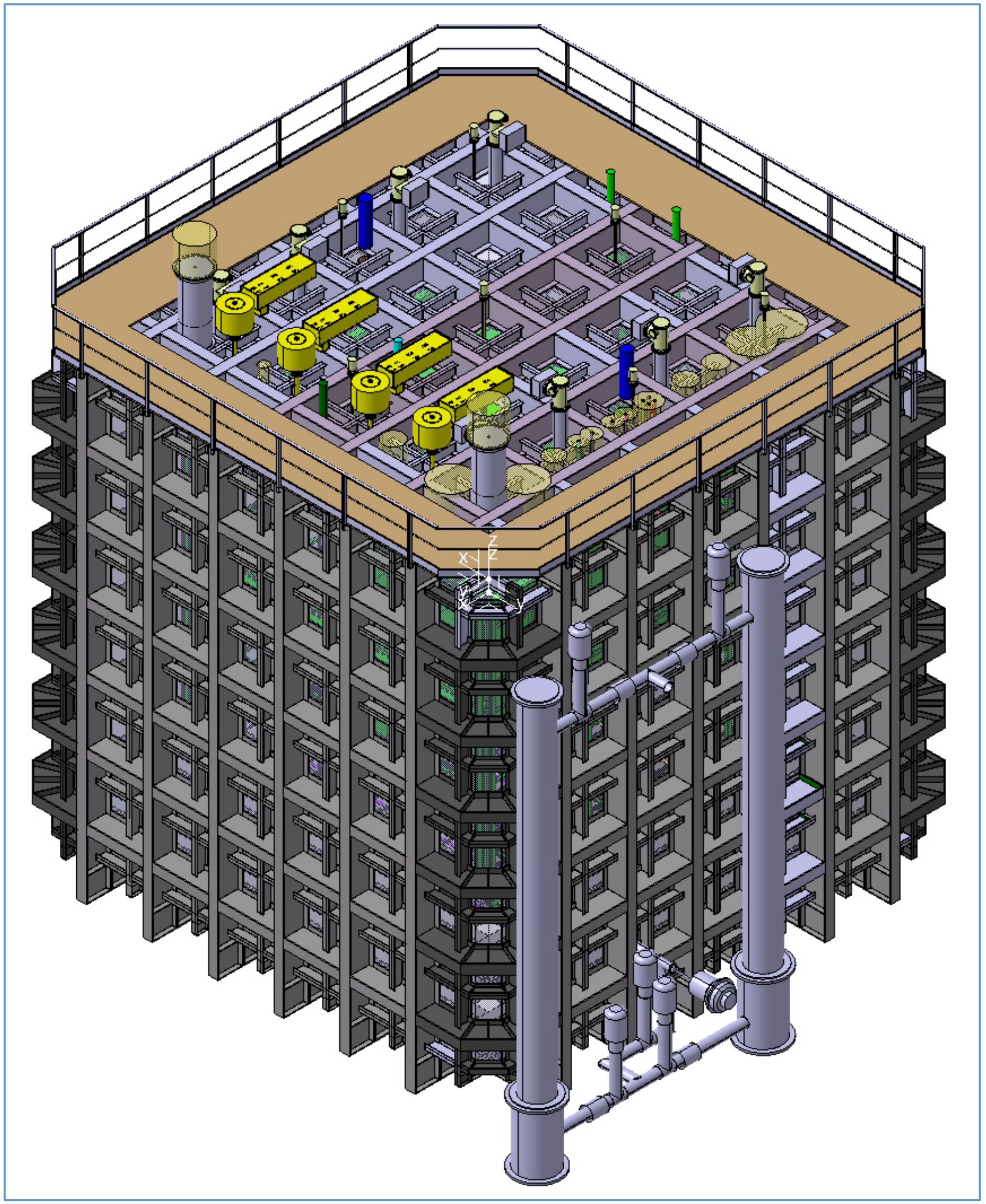
Goal: cryostats ready 3/2017



1. Stainless steel primary membrane
2. Plywood board
3. Reinforced polyurethane foam
4. Secondary barrier
5. Reinforced polyurethane foam
6. Plywood board
7. Bearing mastic
8. Steel structure with moisture barrier



Cryostat with pump towers



EDMS: 1566416

2 pumps for redundancy.

Only 1 running during normal ops.

Cryogenics Modes of Operation

1) Piston Purge

GAr is slowly flown from the bottom of the tank to push the impurities out through the top.

2) Cool down

A mix of GAr and LAr is flown into sprayers to generate a mist of small liquid droplets that are moved around by another set of sprayers flowing GAr only.

3) Filling

Once the cryostat and TPC are cold, LAr is introduced in the cryostat.

4) Normal operations

LAr is continuously purified by means of an external LAr pump (2nd for redundancy only).

Boil-off GAr is recondensed outside of the cryostat and purified before being reintroduced as LAr.

Requirements:

- Electron lifetime > 3ms (SP and DP)
- **no** sources of argon **gas reliquefaction inside** the cryostat
- not to introduce **unwanted noise** into the electronics
- **stable** liquid argon **environment** at a temperature of **88.3 K** $\pm$ **1 K**

5) Emptying

At the end of the operations (or if/when maintenance on the tank is needed), the tank is emptied and the LAr removed.

Cryogenic System Engineering Parameters
(from Detector Requirements)

Mode	Parameter	Value	Notes
1	GAr purge flow rate	88 m^3/hr	From 1.2 m/hr
2	Maximum cool-down rate TPC	40 K/hr 10 K/m	T sensors to be defined and placed by Internal Cryogenics/Detector
2	Maximum Delta T between any two points in the detector	50 K	T sensors to be defined and placed by Internal Cryogenics/Detector
3	LAr filling flow rate (*)	18 l/min	Assuming 2 trucks/day (**)
4	Cryostat static heat leak	3.0 kW	GAr boil-off (18 g/s)
4	Other heat loads (estimate)	5.0 kW	Total estimate is ~ 8 kW
4	LAr circulation (5 days turnover)	72 l/min (19 gpm)	Nominal value (1 pump)
5	Max emptying (w both LAr pumps)	144 l/min (38 gpm)	Limited by size of tank/truck

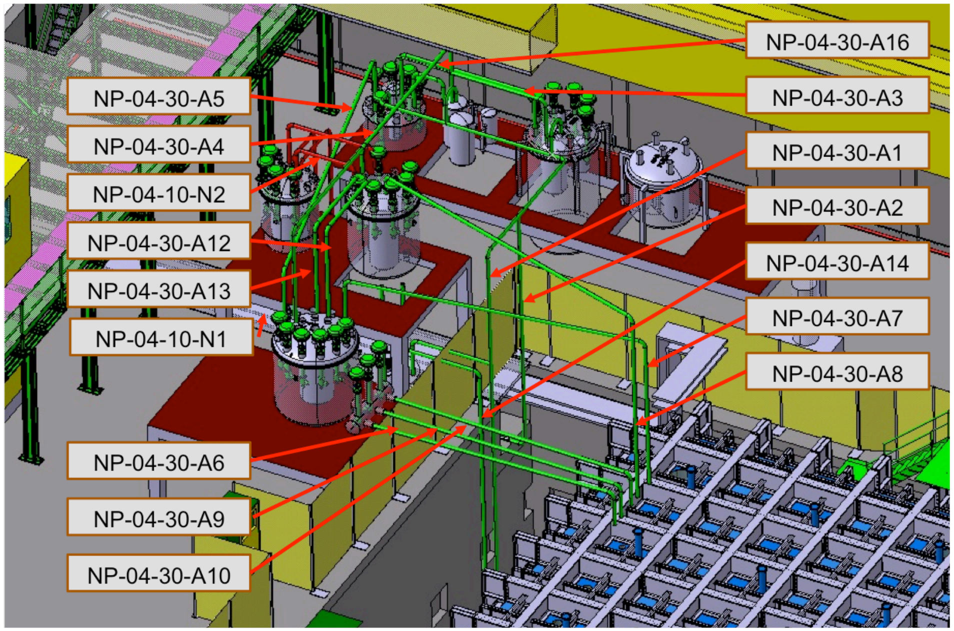
* Value might be limited by the pressure inside the LAr storage dewar.

** We need to contact the supplier to confirm availability of 2 trucks/day of LAr.

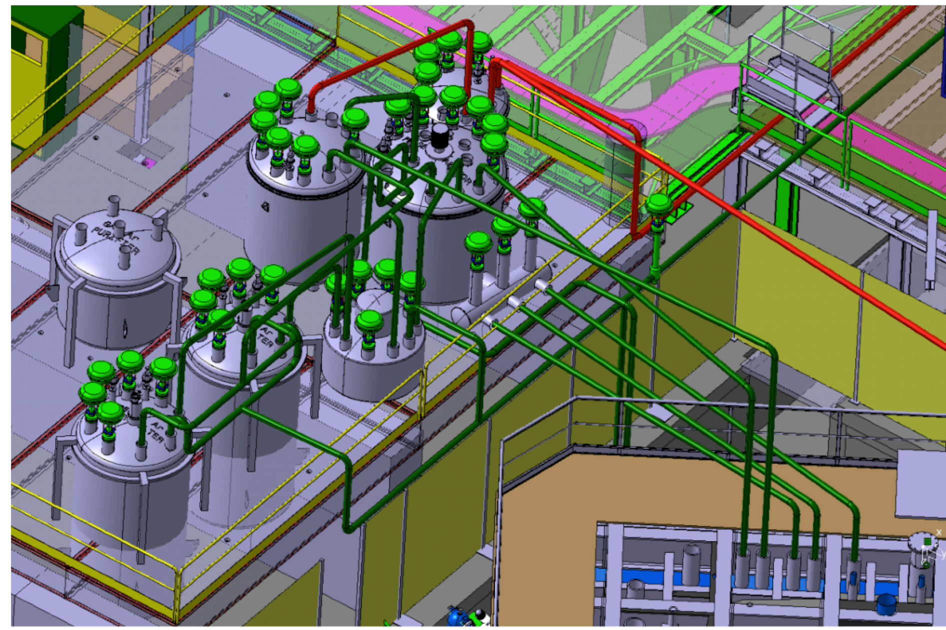
ProtoDUNE Cryogenics

Use nearly identical cryogenics systems for single and dual phase protoDUNE

NP04 (single phase)



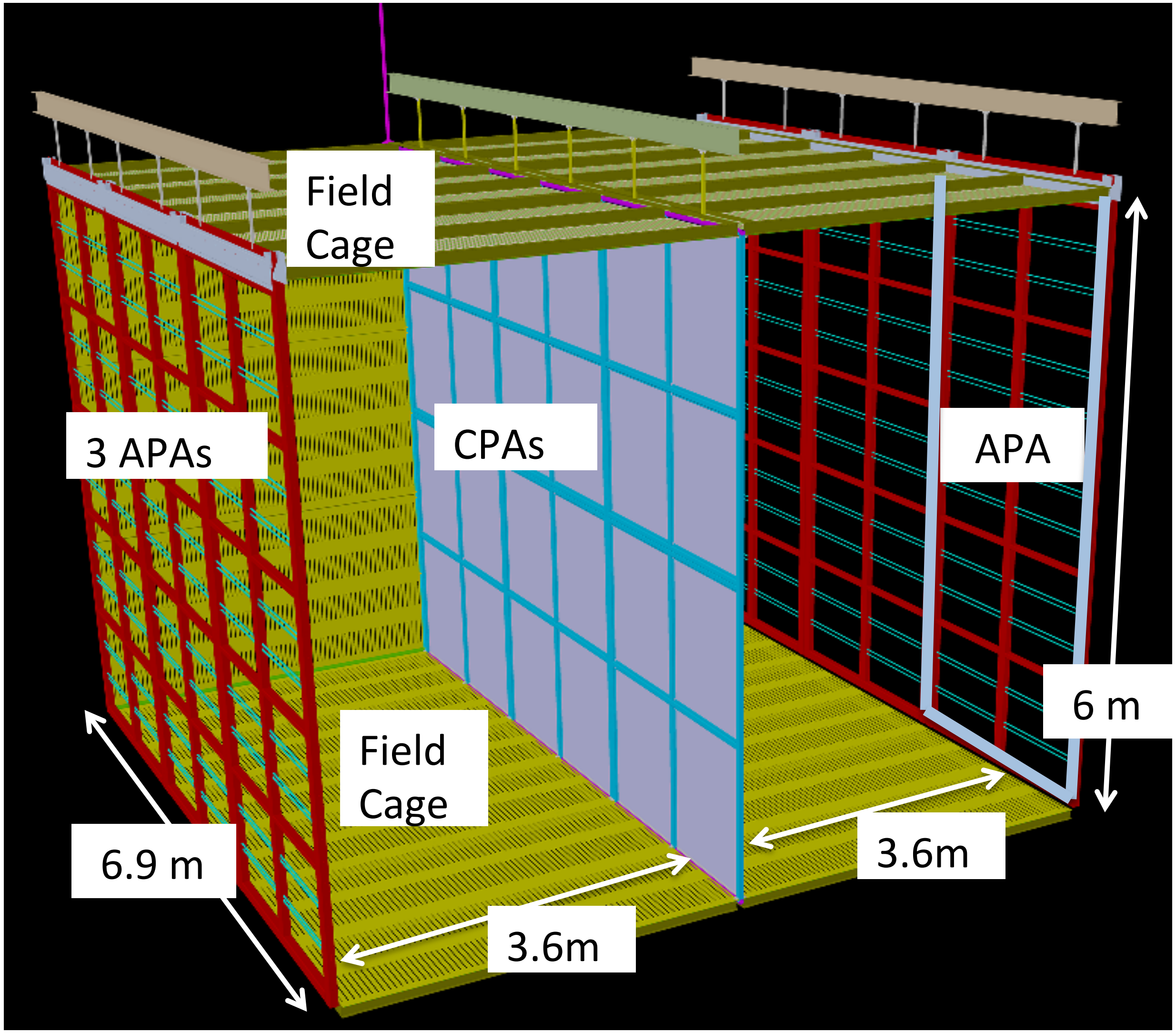
NP02 (dual phase)



- All the “envelopes” for the cryogenic equipment have been put in the models
- For the precise routing, line + valve box diameters etc. awaiting the tender result

- Cryogenic systems will be tendered on “functional specifications”
- Technical Specifications have passed the technical review, will go through an “administrative” review this week, and will be send out before May 15th
- **Goal:** start the installation of cryogenic equipment towards late 2017

Single Phase ProtoDUNE TPC



Detector components are same as for DUNE far detector

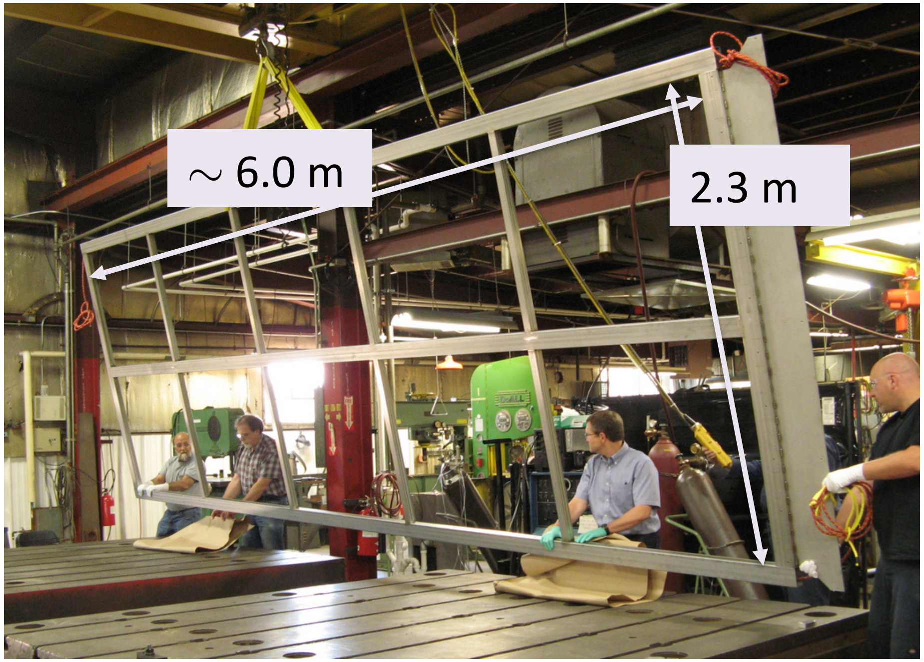
Keep option to reduce drift distance to 2.5m (reduced space charge effects)

Expected cosmics rate: ~ 10 kHz

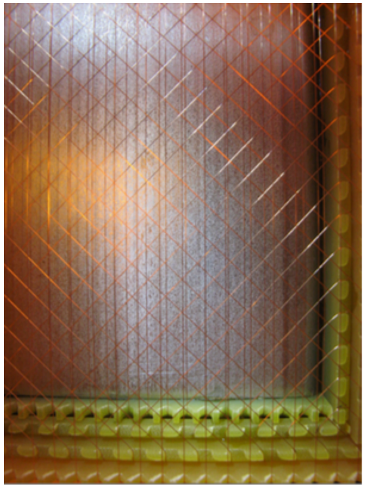
Anode Plane Assemblies (APA)

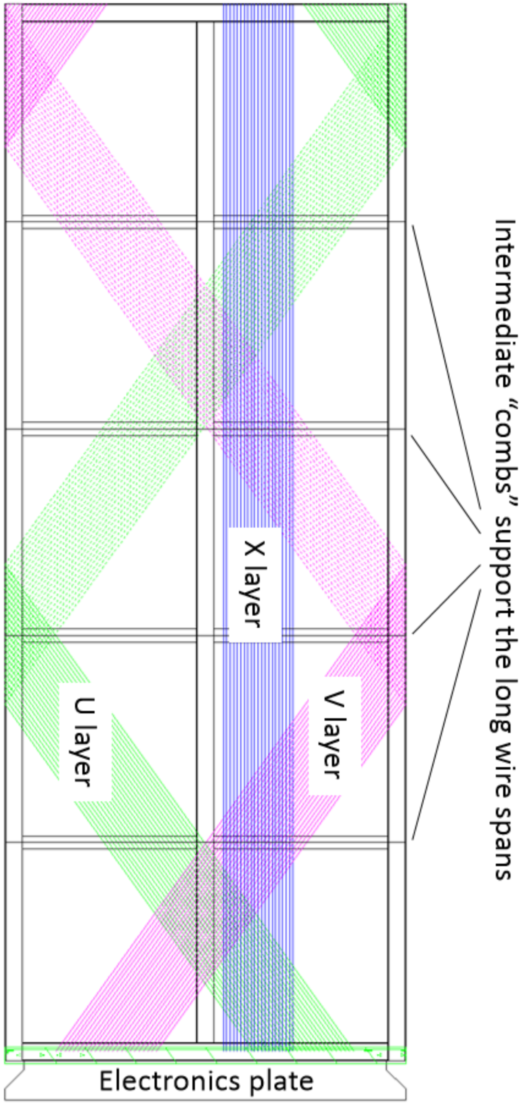
4 wire planes (4.8 mm spacing)

Function	no.	pitch [mm]	orientation	potential [V]
Collection (x)	960	4.79	vertical	820
Induction (V)	800	4.67	35.7° - wrapped	0
Induction (U)	800	4.67	35.7° - wrapped	-370
Grid	960	4.5	vertical	- 665



Wire frame detail
(35t detector)



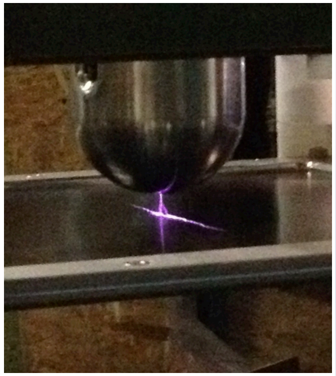


Cathode Plane Assembly (CPA)

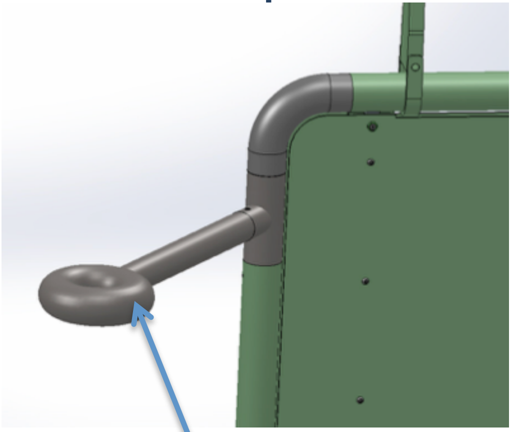
6 interconnected CPA columns (V_{bias} = - 180kV)

- Resistive material (coated or bulk loaded G10)

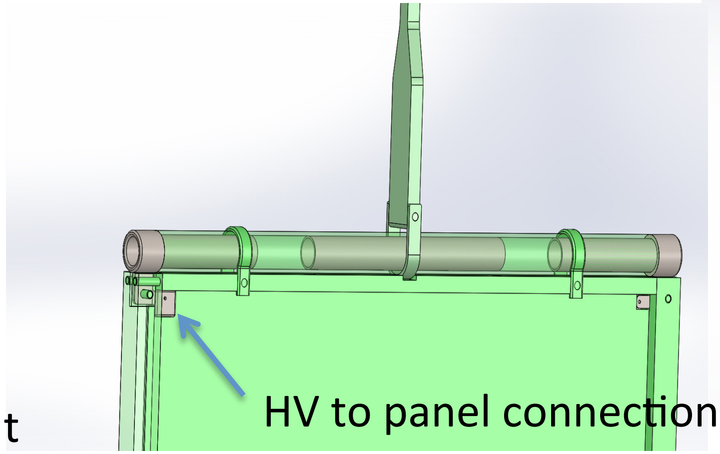
→robustness of variety of materials and coatings to sparks studied in test setup in air and LAr at CERN



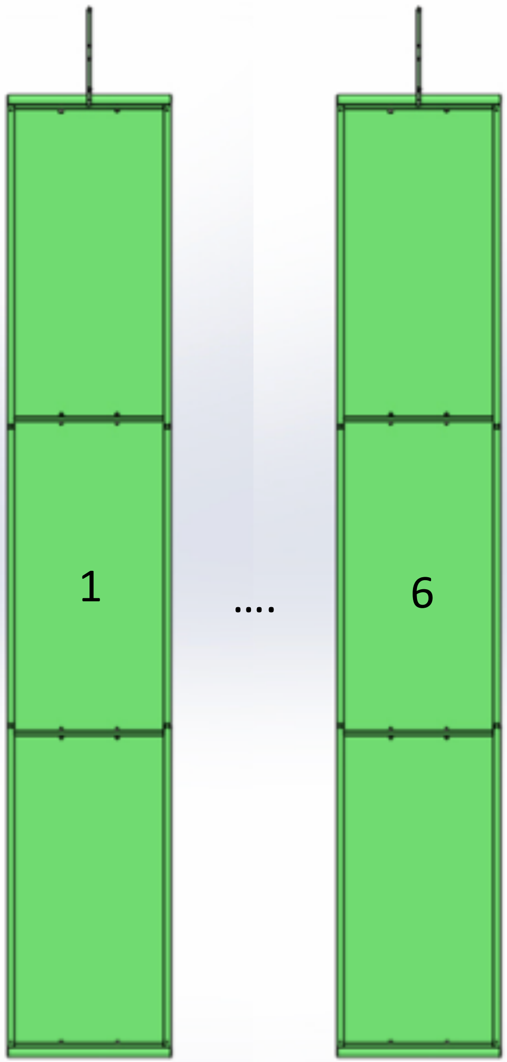
- HV bus provides uniform voltage



Pivoting HV donut



HV to panel connection plate



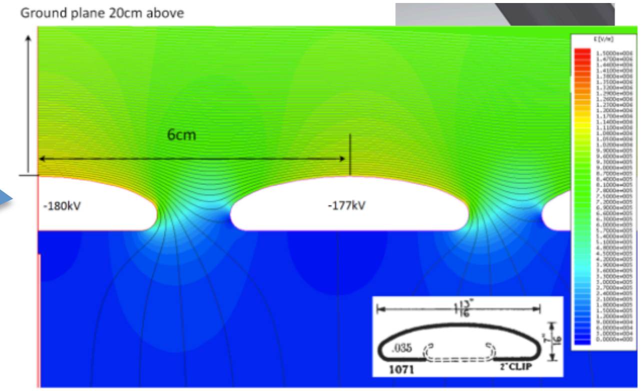
~ 240 lbs each

Field Cage (FC)

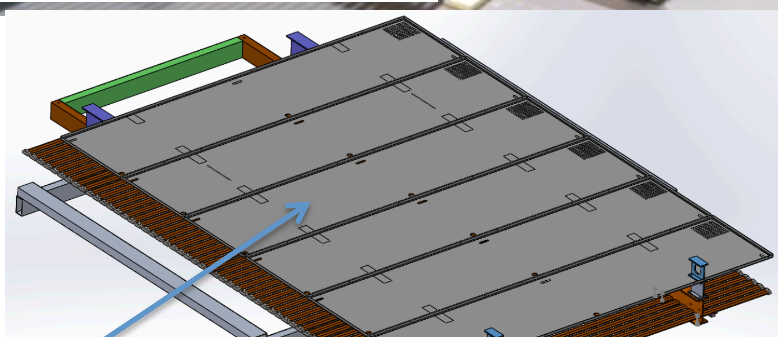
Common to both NP04 and NP02

Constructed from

- roll formed Al or SS profiles and
- Plastic caps to prevent discharge
- 4" I-beams (support)
- Ground planes on top and bottom



Mechanical mock-up



Ground plane (20cm separation)

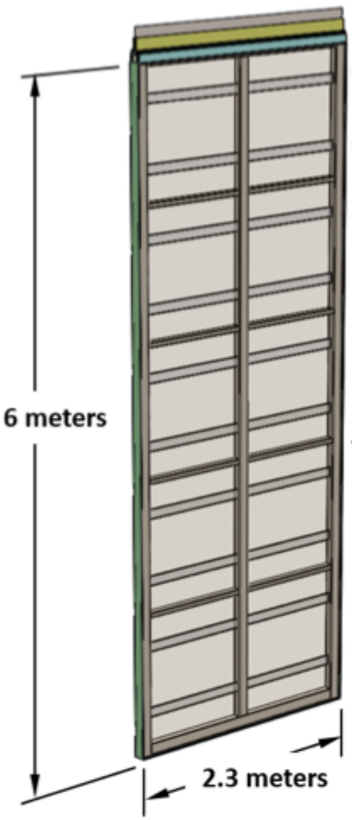
Functional test with Purified LAr:

→NO sparks observed up to 100kV

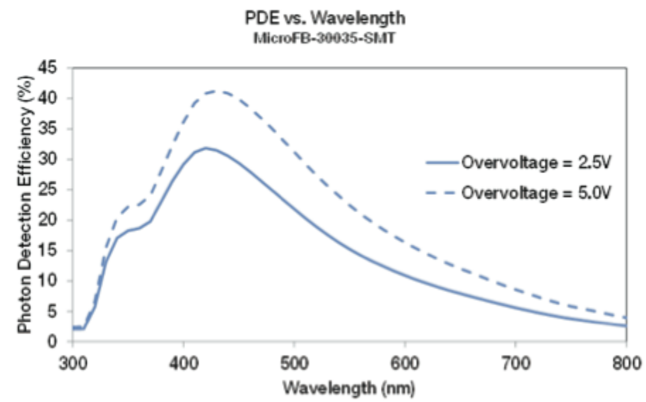
→occasional sparks above 80 kV if bubbles present

Photon Detection System (PDS)

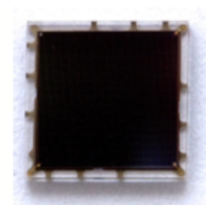
- 10 photon detection panels embedded in each APA
- Wave shifter bars (different variants) read out by multiple SiPMs

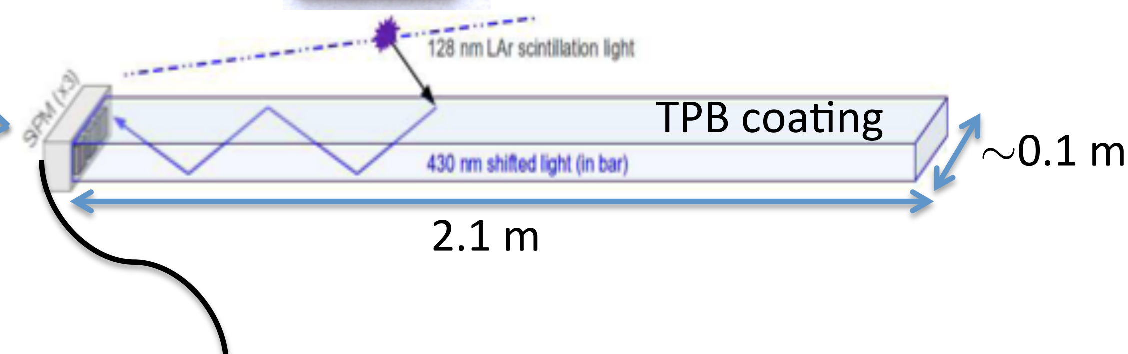


- SensL SiPMs – B/C-series
  - Active area: $6.0 \times 6.0 mm^2$
  - Epoxy front cover
  - 18980 pixels (137×137 array)
  - V_{op} = ~25V (at 88K; V_{br} + 4V)
  - Gain: 4×10^6
  - Dark rate: < 10 Hz



measured at room temp.





Waveforms readout via 150 MHz digitizer and Custom signal processor (warm electronics)

ProtoDUNE NP04 Cold Electronics

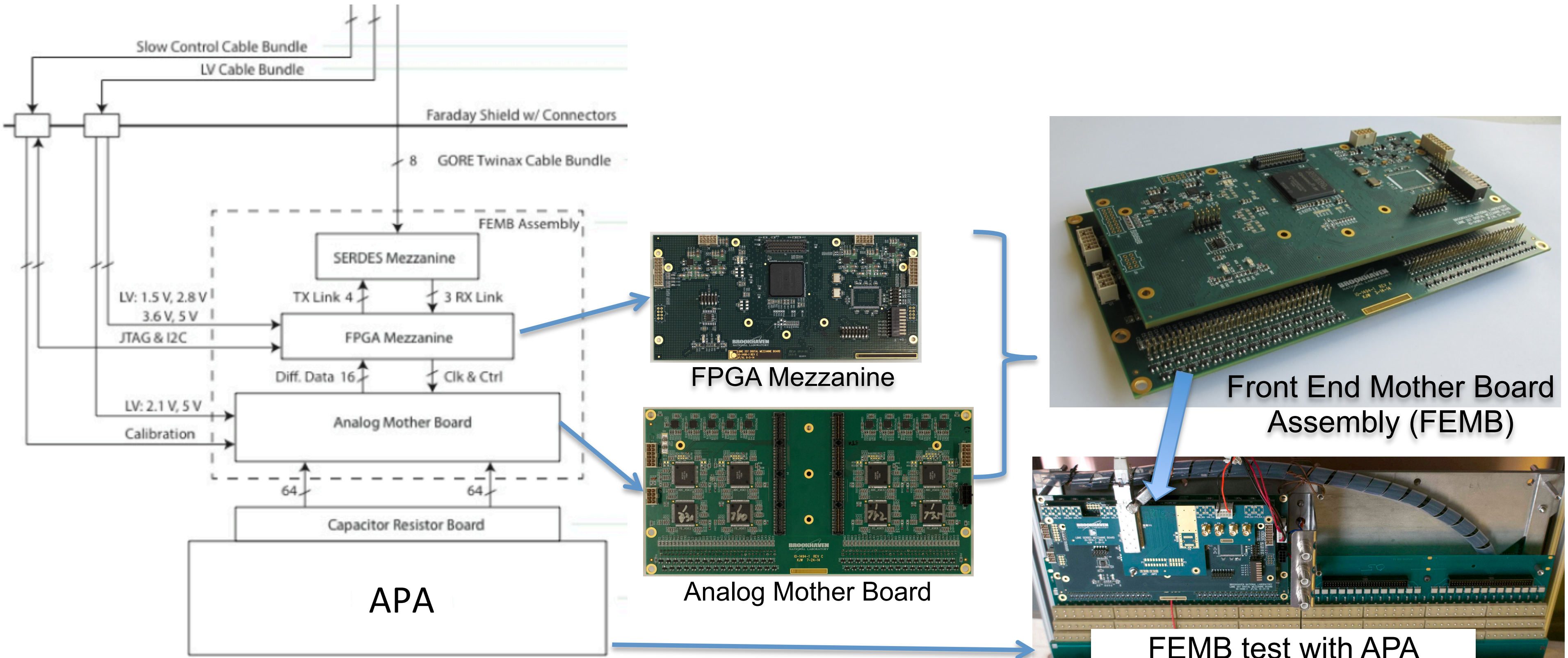
Cold electronics directly attached to APA (2560 wires):

1 APA → 20 FEMB (2560 ch/20 = 128 ch)

- Analog Mother board with 8 FE (16ch) and ADC ASICs (16ch) → 128 wires IN

  → **Multiplexed** to 4 OUTputs: 128 / 8 (ADC ASIC) / 4 (FPGA) = 4 outputs
- 16 ch FE ASIC: Preamplifiers with shaping circuit

→ No zero suppression; no data compression



DAQ

TPC: 6 APA (2560ch. Each) → 15,360 chan.; 2 MHz 12 bit ADC

→ raw pre-trigger rate: 46 GB/s (expect < factor 10 trig. reduction)

PDS: 240 chan.; 150 MHz 14 bit ADC

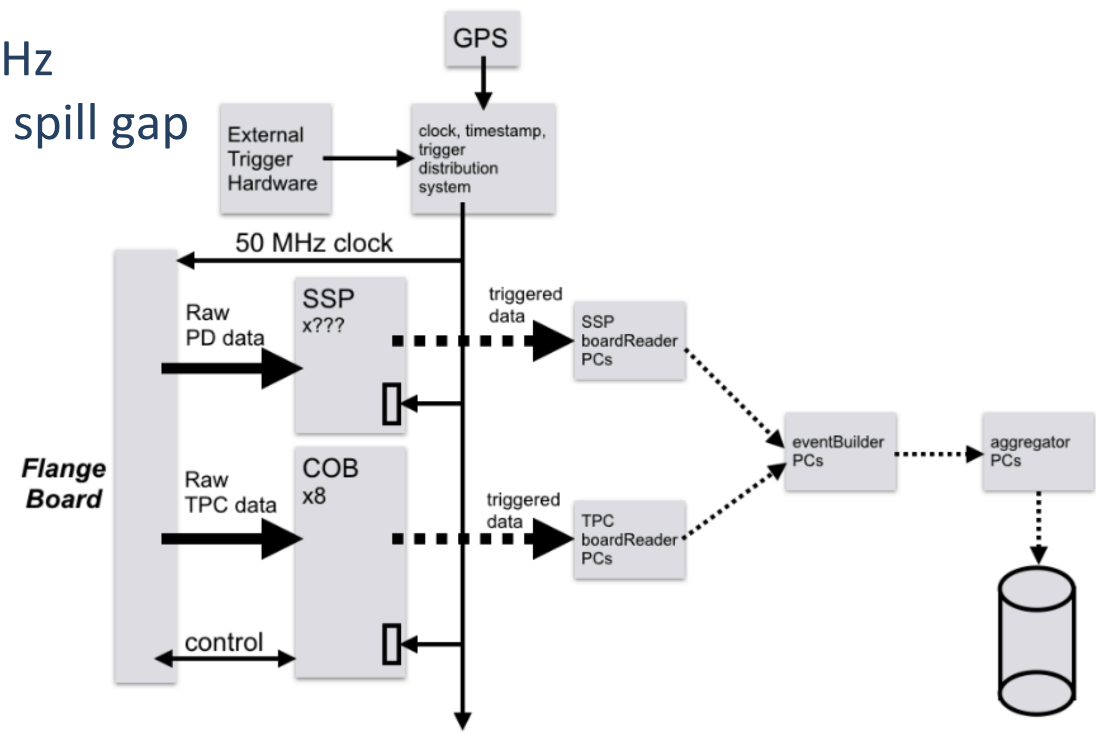
→ 100 Hz triggered data rate: ~ 20 MB/s

Trigger: beam line counters, SPS beam spill; muon tagger

Foresee two data collection modes:

1) Triggered mode up to 50 – 100 Hz
   →drain data to computers during spill gap

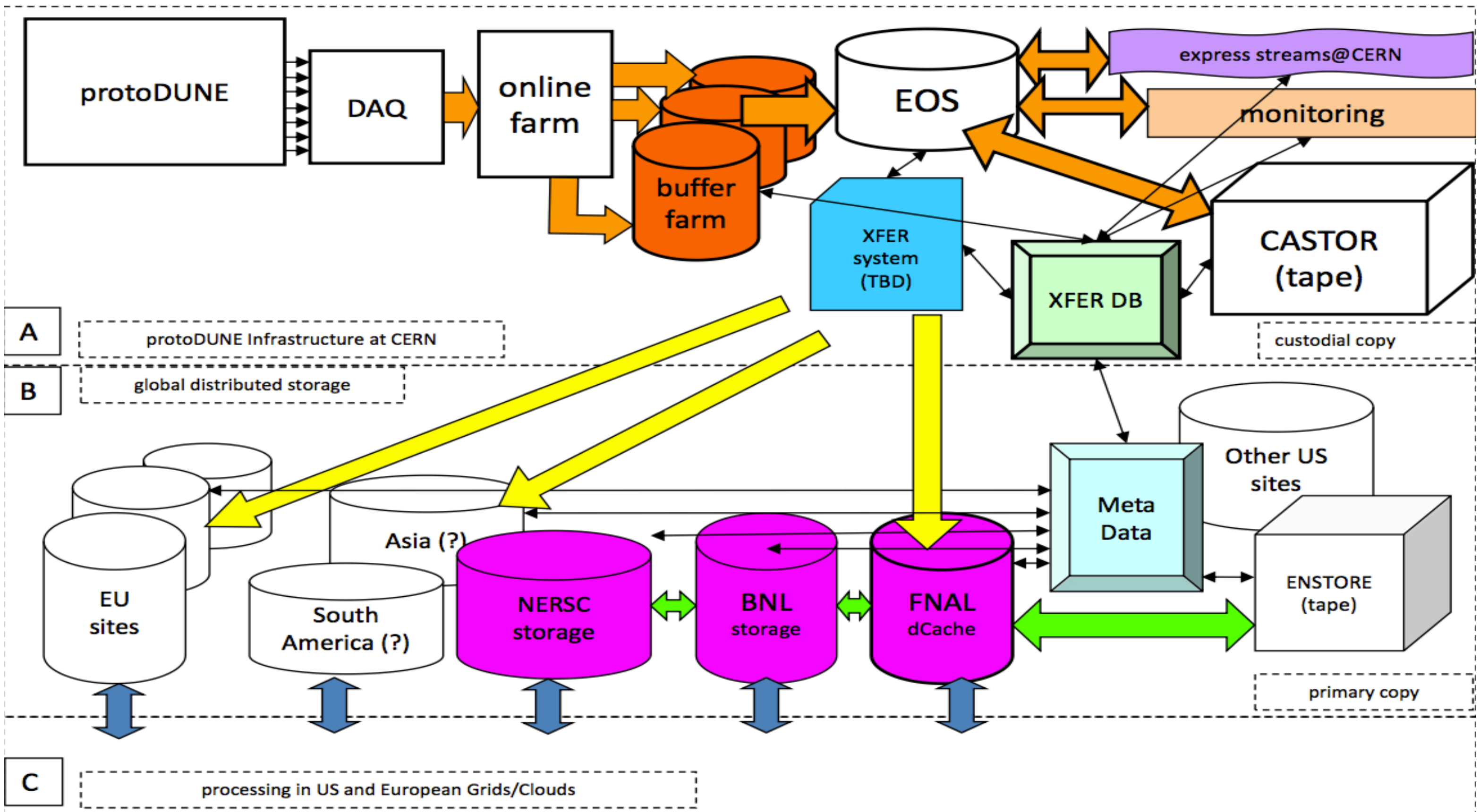
2) Continuous mode
   →perform data filtering on FPGAs and online cluster



Computing

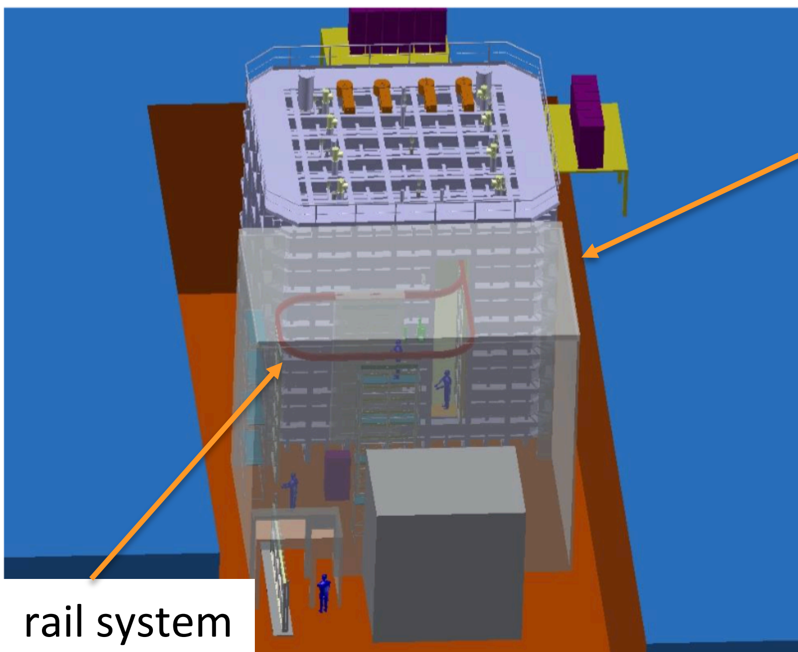
Common to both NP04 and NP02

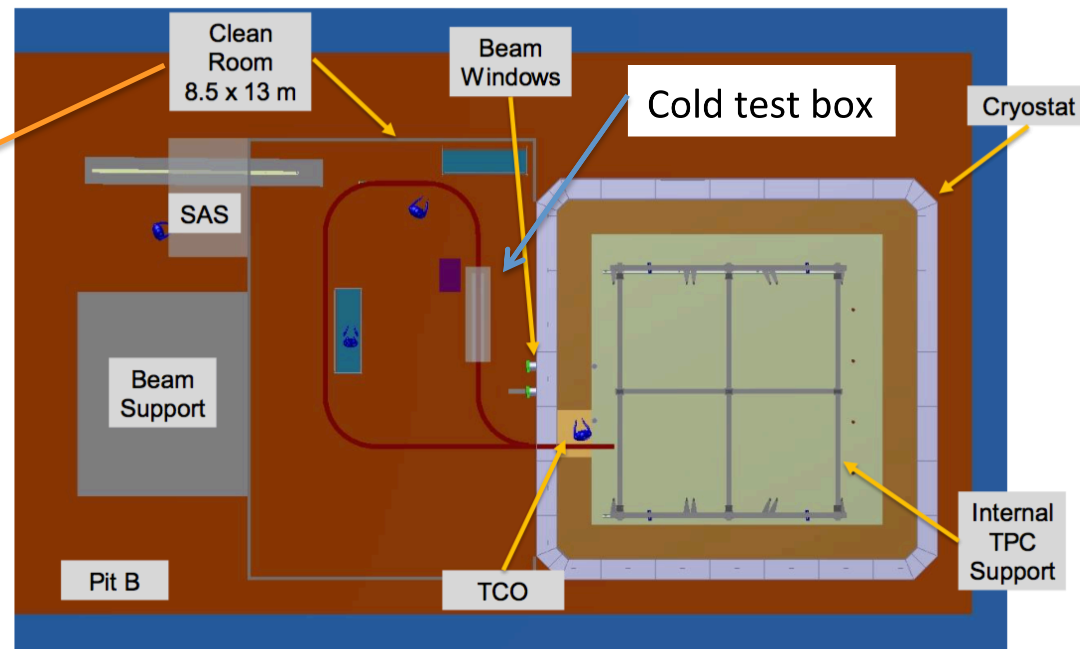
- Transfer raw data from online disk buffer to CERN EOS disk and onwards to tape (CERN: CASTOR; FNAL: ENSTORE) and other end-storage systems
- Collaboration of protoDUNE computing group with CERN-IT and FNAL-SCD



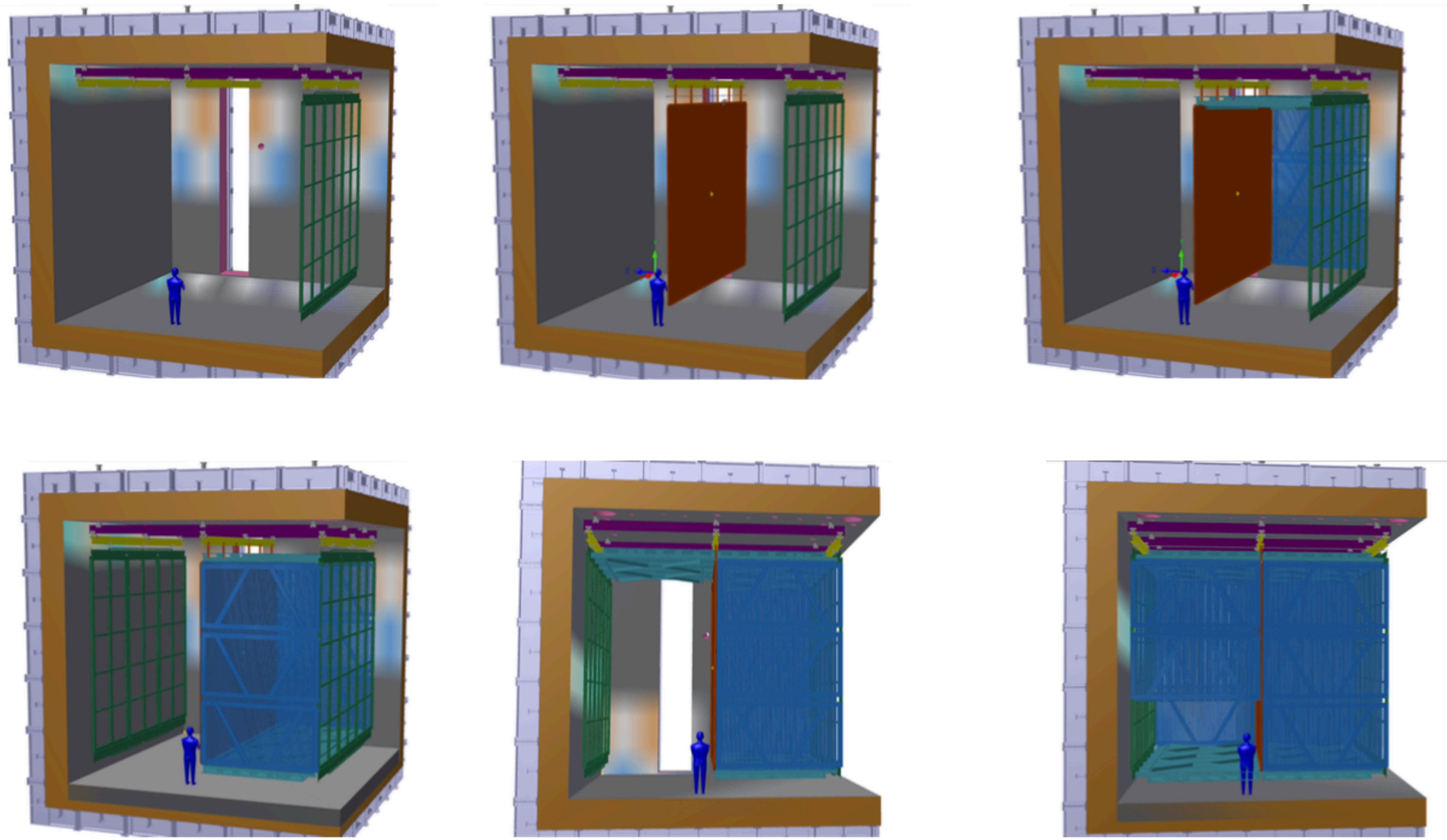
Integration, Testing and Installation

- All detector components arrive at clean room in EHN1
- Integration and tests of APA, CE and PD in clean room
- Perform warm and cold testing (dedicated cold-box)
- Insert APA through TCO into cryostat
- Retest APA once installed in final position



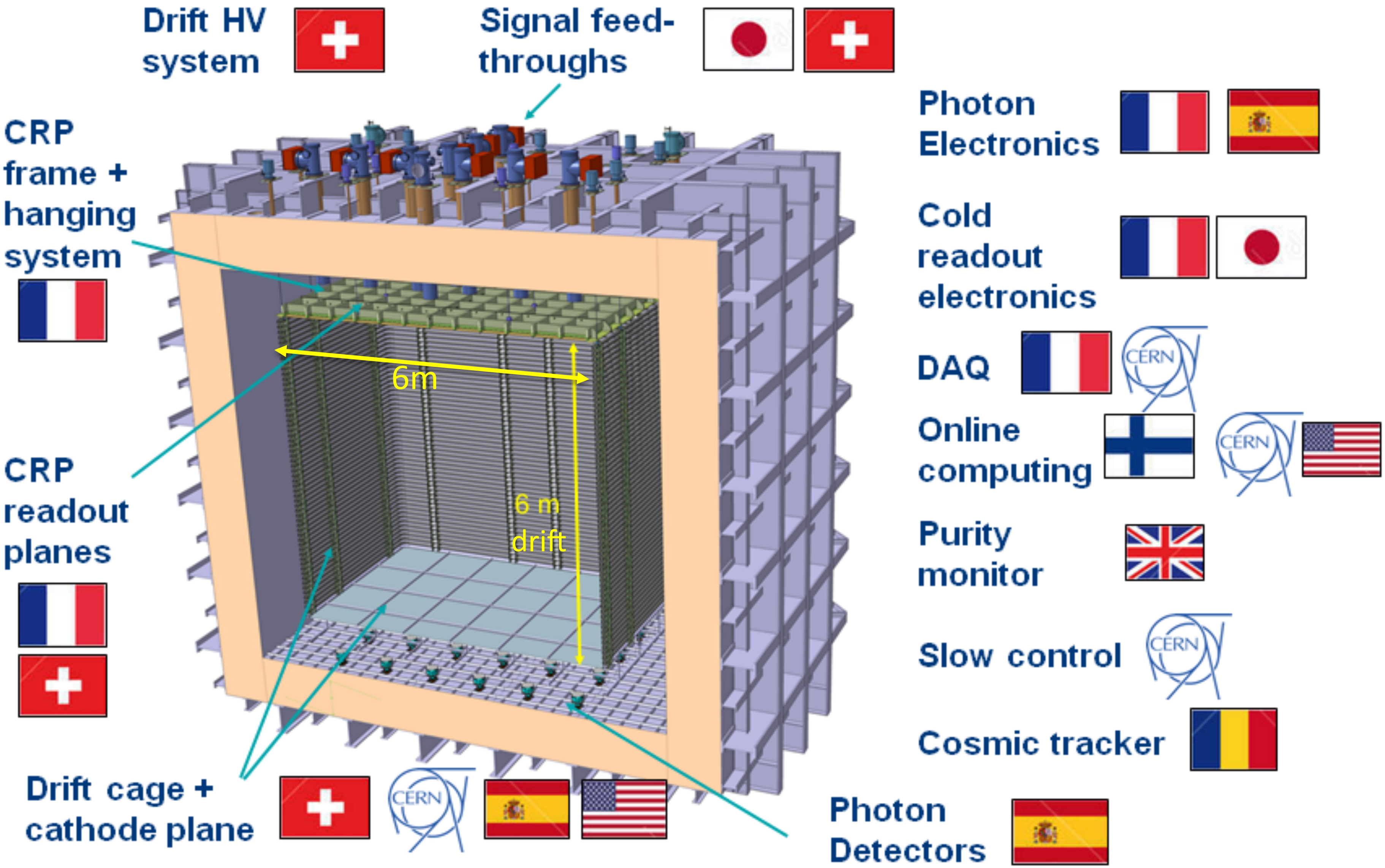


Installation in Cryostat



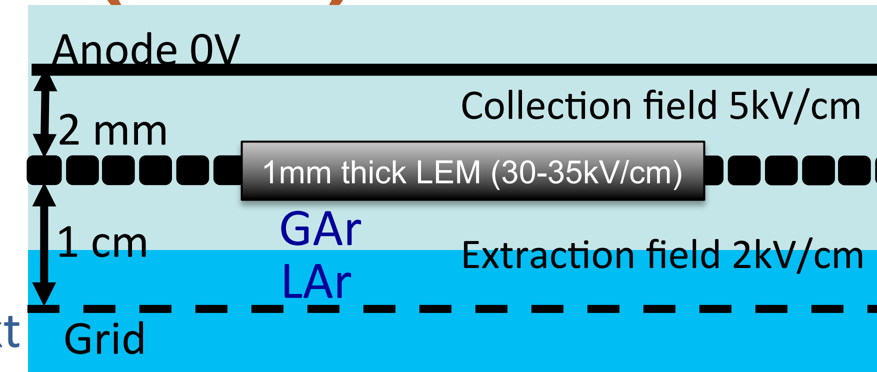
Dual Phase ProtoDUNE TPC

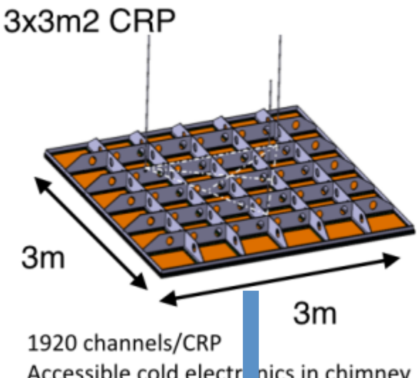
(US contributions under discussion)



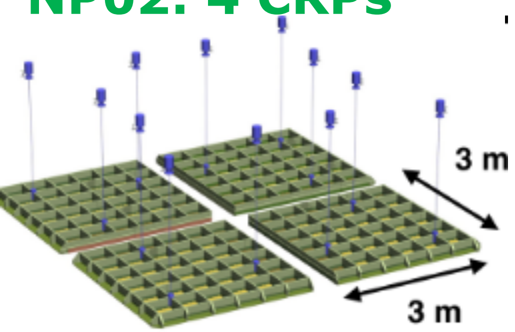
Charge Readout Plane (CRP)

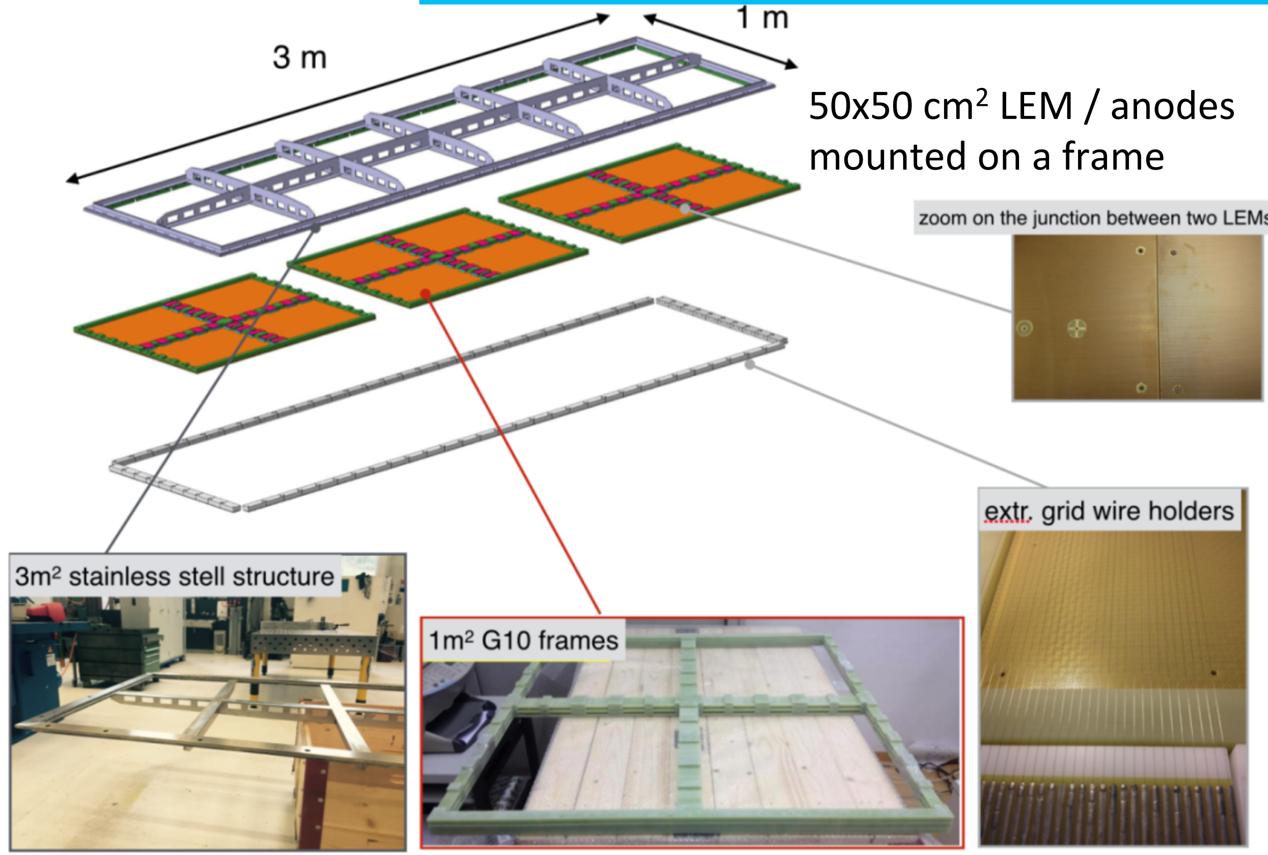
- CRP is composed of 4 3x3 m^2 readout units built from 50x50 cm^2 LEM and anodes
- Each unit has its own suspension system
- Charge is collected on 3m “strips”
- Identical structure envisioned for DUNE 10kt





NP02: 4 CRPs

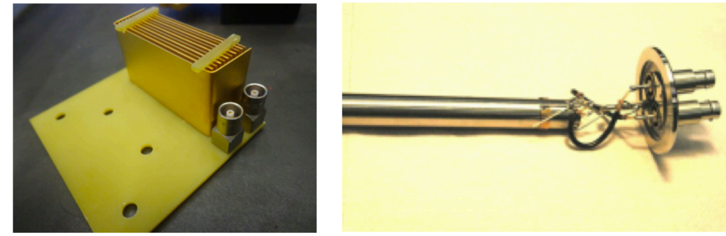




Slow Control System

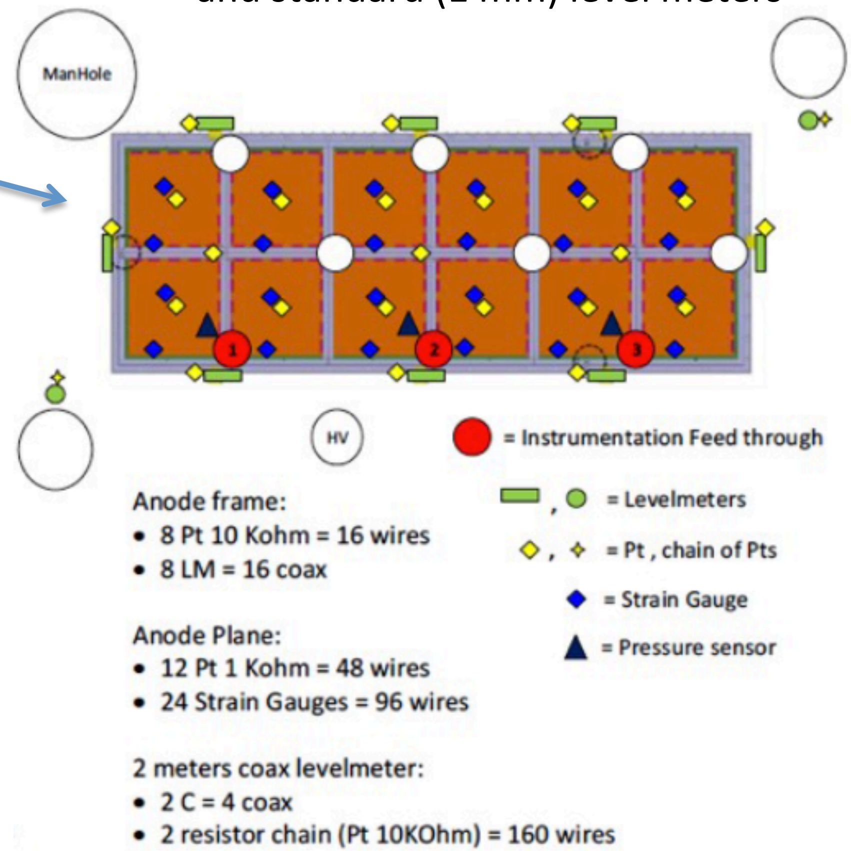
Common to both NP02 and NP04

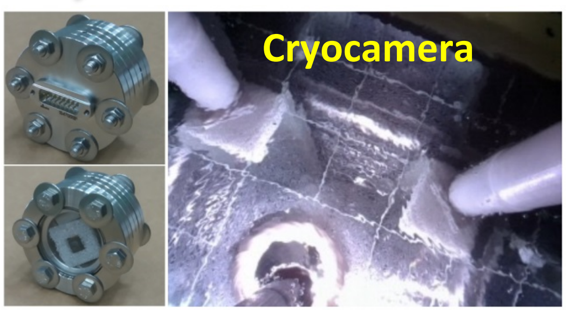
- Integrated control of level meters
- temperature and pressure sensors

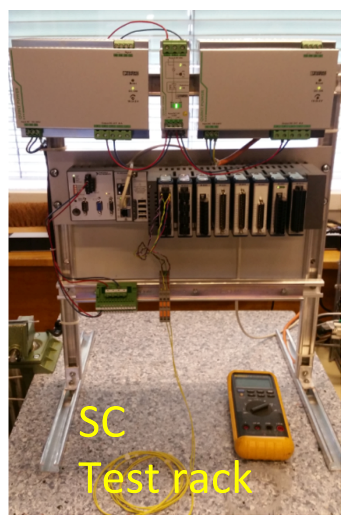


High accuracy (100 um)
and standard (1 mm) level meters

- Extensive network of sensors to completely characterize behavior of CRP
- strain gauges
- Cryocamera



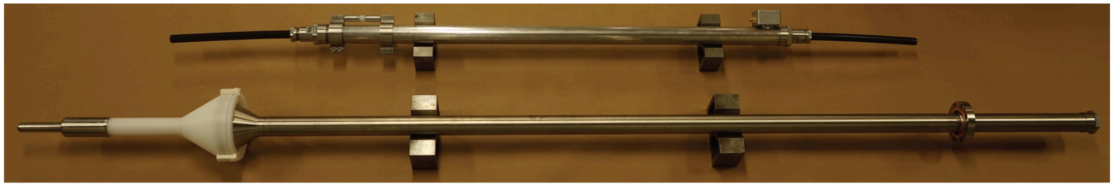




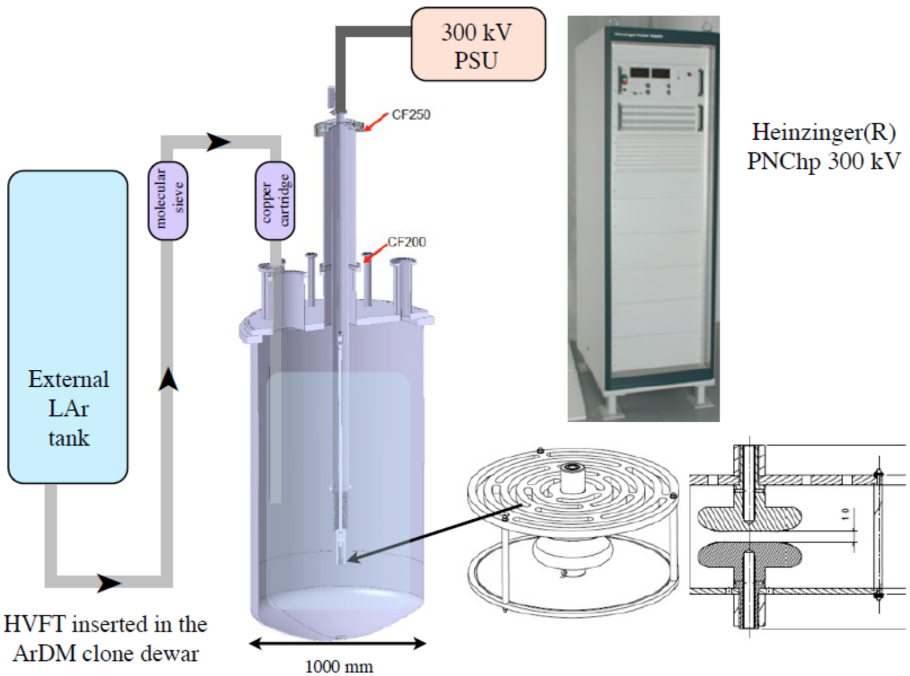
High Voltage

Common to both NP02 and NP04

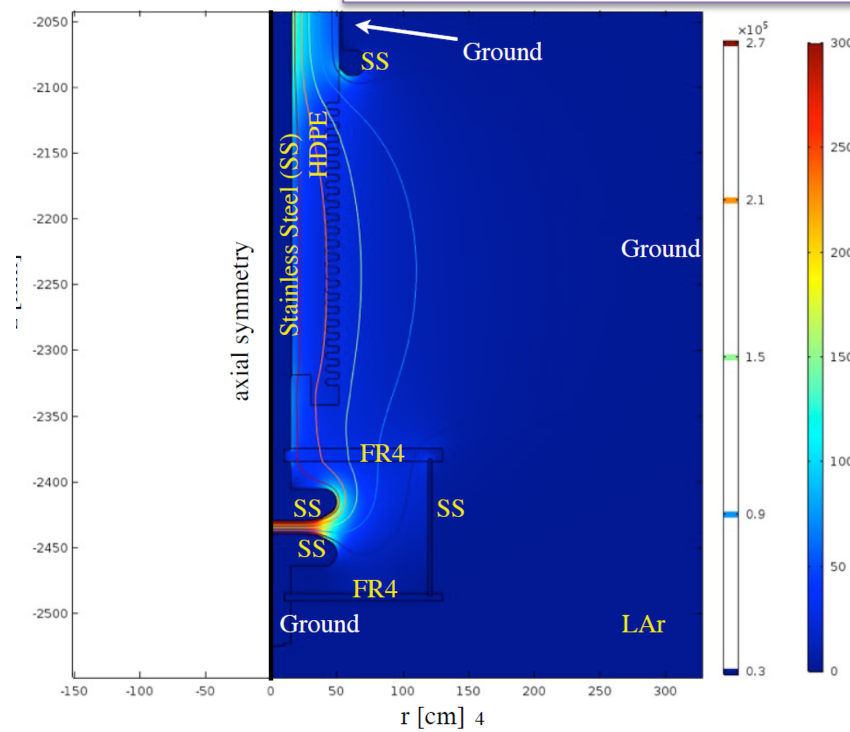
- Required cathode HV for DLAr is 300 kV → 0.5 kV/cm drift field (over 6m)
- HV feedthrough (FT) designed to withstand 300kV operation



- FT test at CERN with 300kV Heinzinger PS (already acquired)

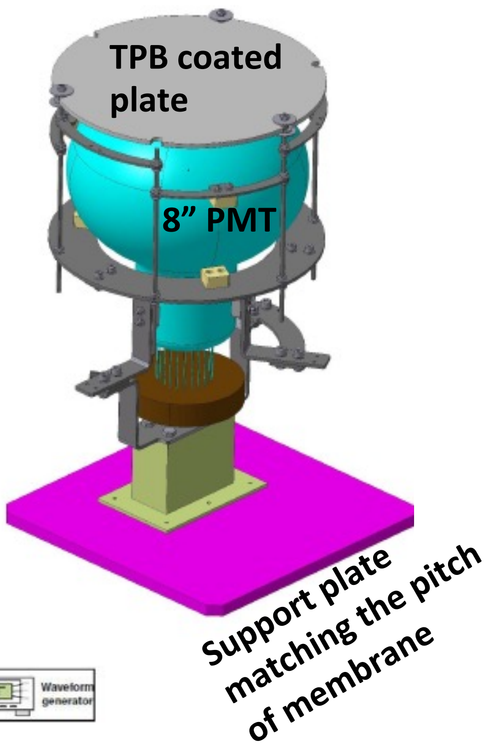


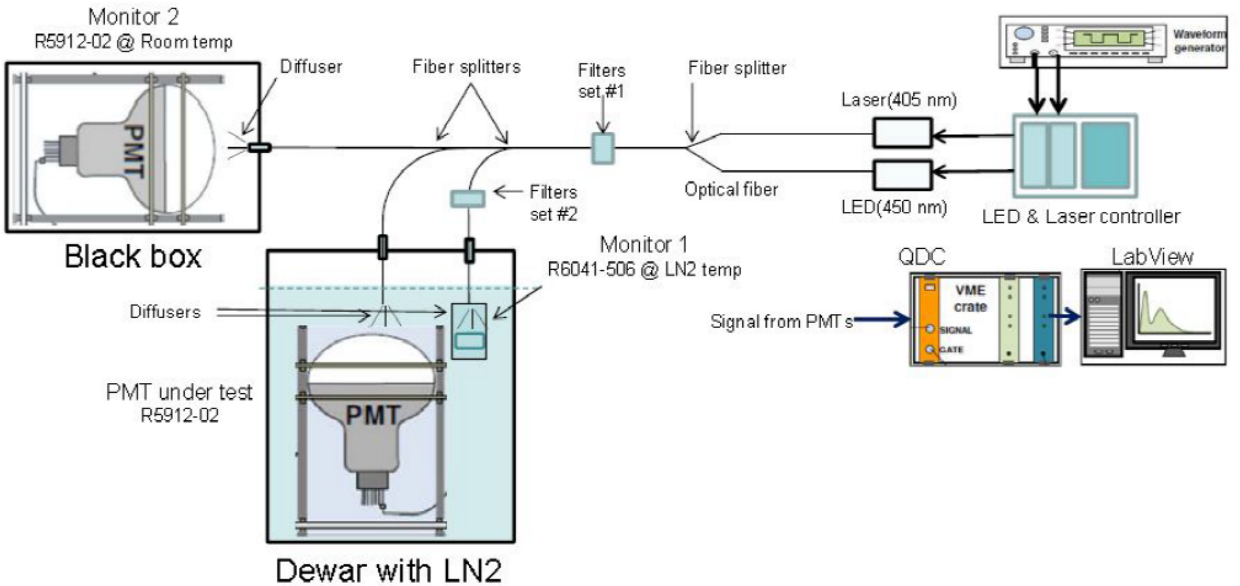
COMSOL simulation of fields around feedthrough



Light Readout System

- grid of 36 8” Hamamatsu (RD5912mod2) PMTs
- The PMTs are attached to SS base plates which fit in flat regions between cryostat membrane corrugation grooves
  - Support weight is designed to cancel out PMT buoyancy
  - ➔ no net strain on the membrane
- Signal/HV splitter circuit has been developed to allow for a single coaxial cable connection per PMT
- System for PMT characterization at room and cryogenic temperature in place: gain, dark current

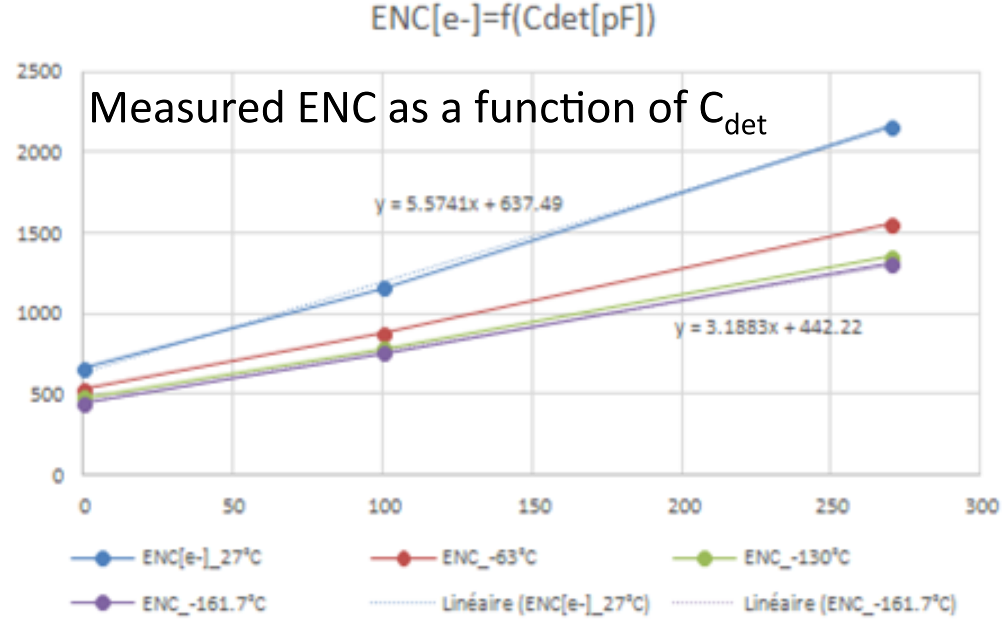




Cold Front End Electronics

- Accessible via chimneys (without opening of the TPC cryostat)
- Shielded from digital electronics
- Preamplifier ASIC final version:
  - 16 channels
  - Double slope gain with "kink" at 400 fC
  - 1200 fC dynamic range
- 7680 ch →produced 700 chips (Sep. 2015) and 25 tested (Jan. 2016)

  → good performance observed



Anode capacitance is 150 pF/m

→ 450 pF for a 3x3m^2 module:

→ expected noise = 1600 ENC

For LEM equivalent gain of 20 (10 per each view)

S/N ~ 100 for 1MIP signal

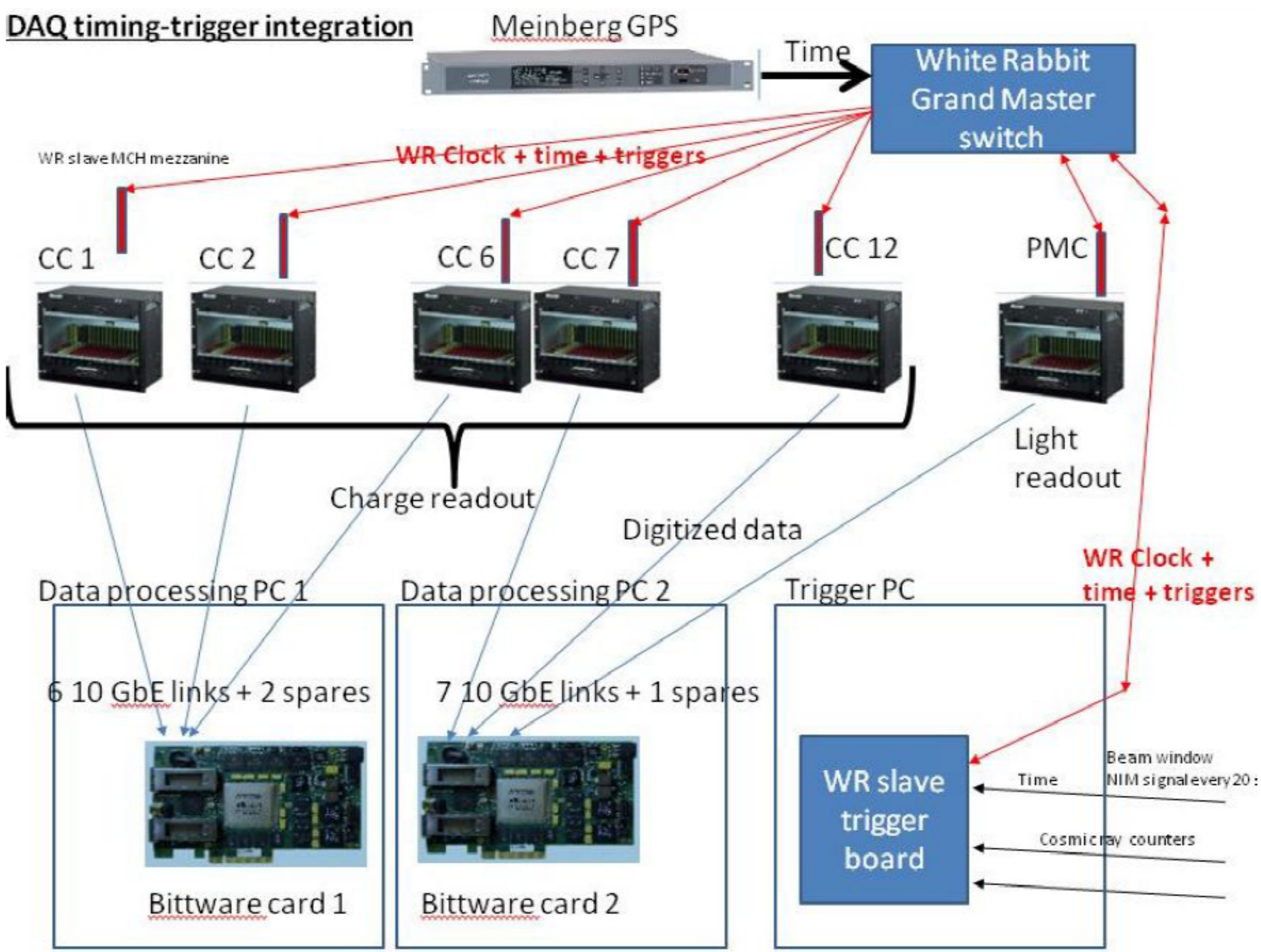
Digital Electronics + DAQ Scheme

Digital electronics for charge readout

- microTCA standard
- 10 cards per crate
- 64 ch per card
- 12bit resolution
- 2.5 MHz rate

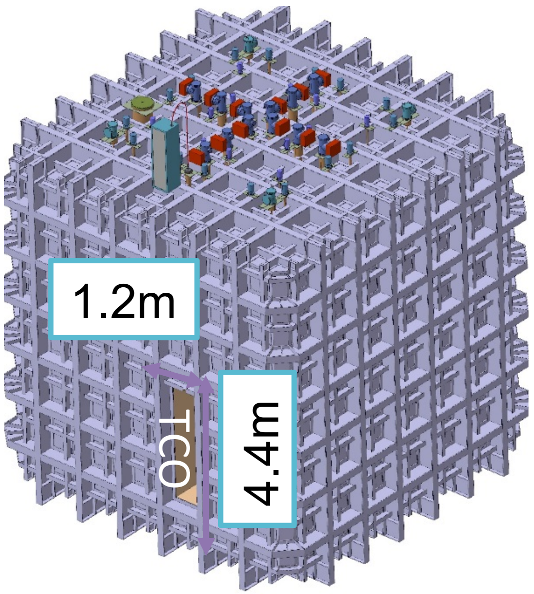
Digital electronics for light readout

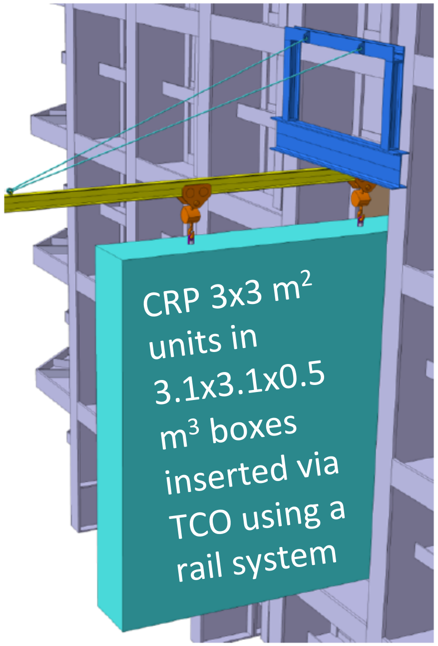
- microTCA standard
- 4 cards in a crate
- 9 ch per card
- 14bit resolution
- 2.5 (max 65) MHz

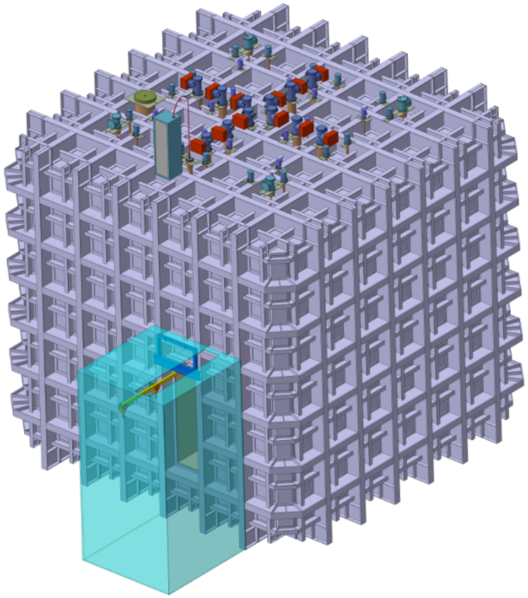


Installation

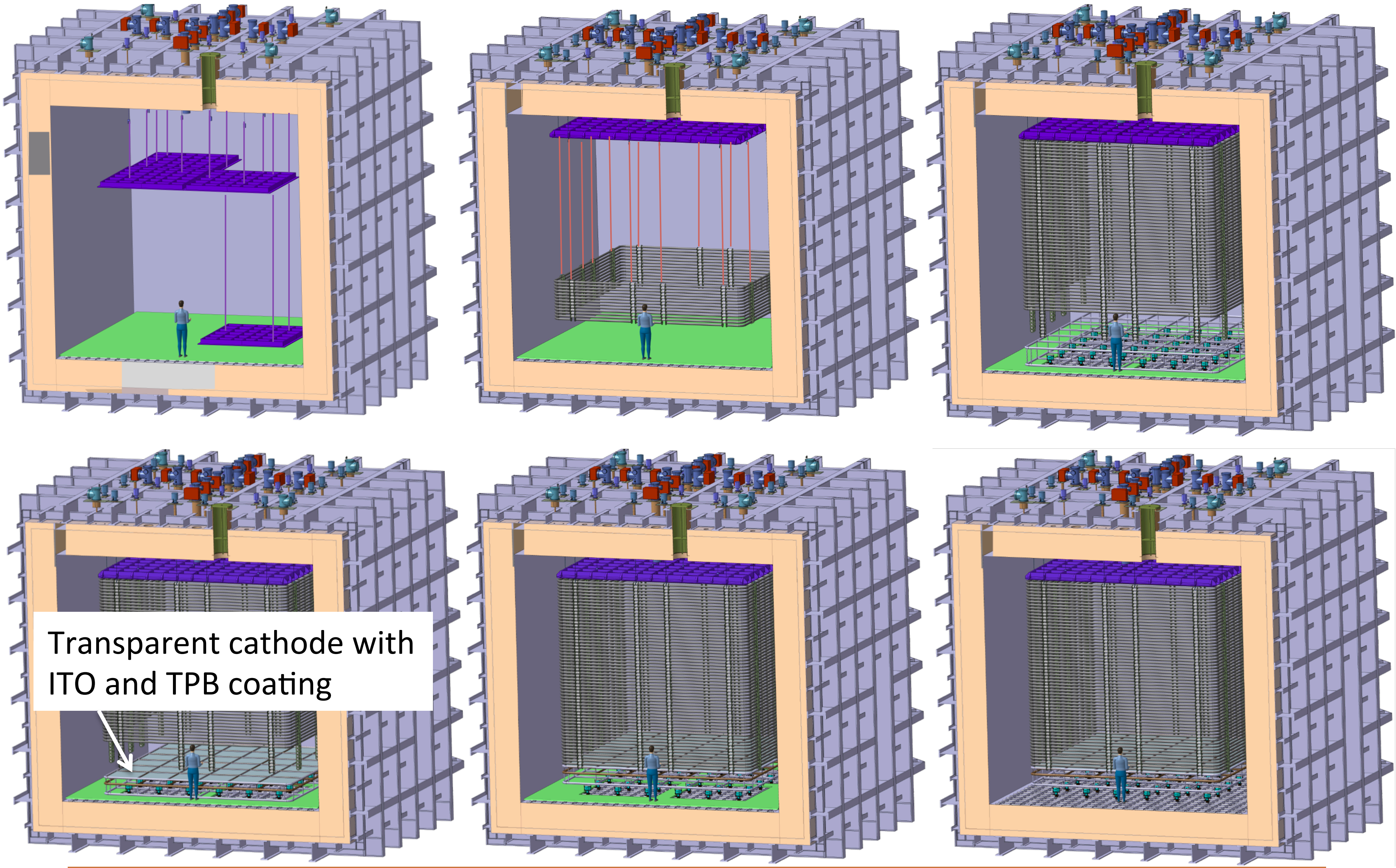
- Feedthroughs are installed first
- The material for detector installation is brought to a clean room buffer and then via TCO into the cryostat
- CRPs will be pre-assembled at CERN, packed in a protective case, and then brought in vertically via TCO
  - ➔ Installation sequence same as for 10kt DUNE







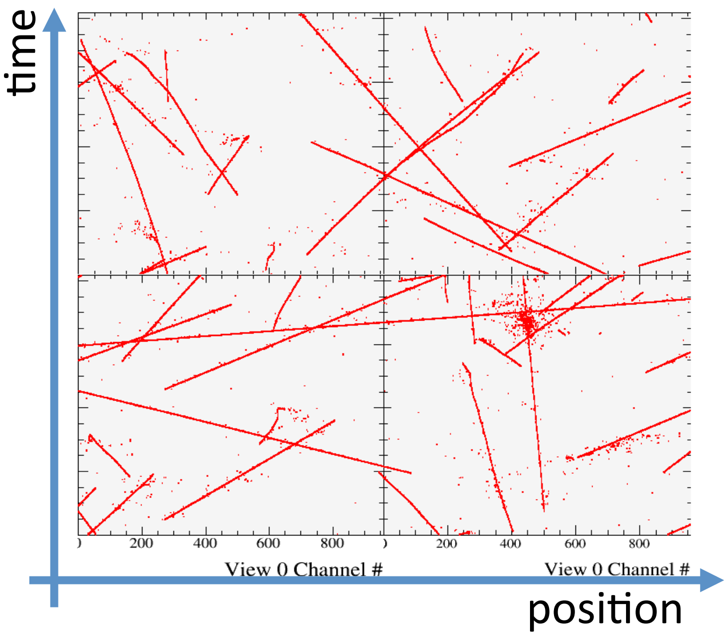
Installation



Calibration + Muon Tagger

Common to NP02 and NP04

Simulated cosmics in NP02 TPC



Selected/tagged sub-sample of cosmics serve for calibration

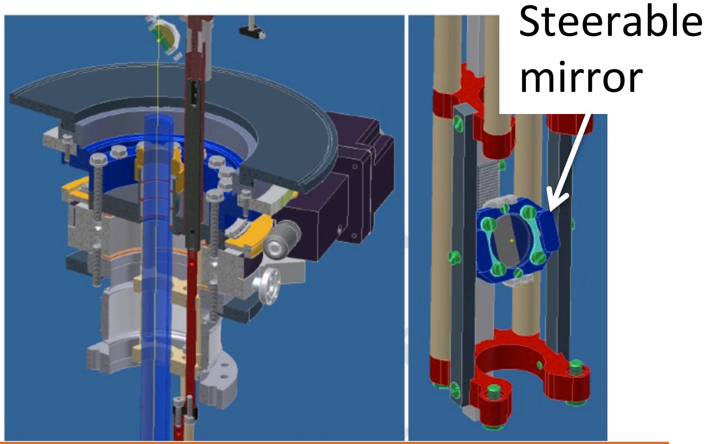
- LAr purity analysis
- Gain measurement
- Map field non-uniformities (track distortions)

→ design for muon tagger under discussion

NP04 also foresees pulsed UV lasers to produce straight ionization tracks
→ Develop and validate calibration strategy for FD

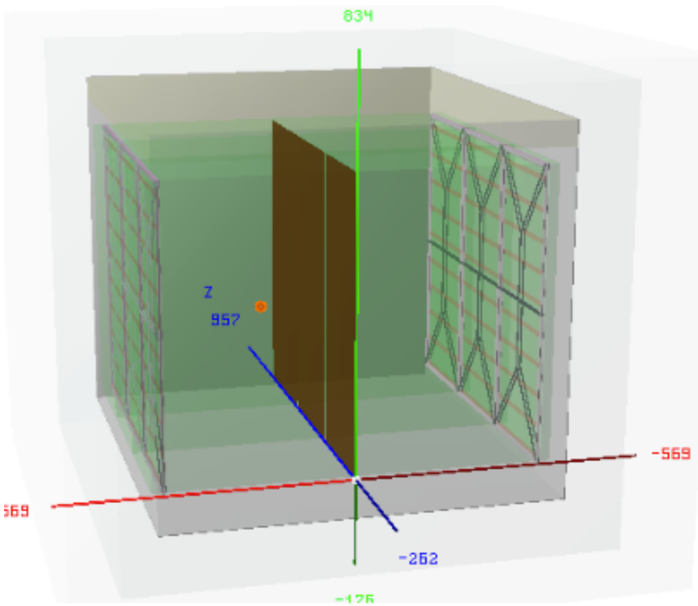
TPC	Drift time [ms]	Readout wind. [ms]	Expec. μ/readout
NP02	3.75	$\sim$ 8	80
NP04	2.25	$\sim$ 6.8	70

Increased readout window to identify track fragments in main event drift time



Software Tools + Simulation Studies

- Use LArSoft framework to benefit from world-wide event reconstruction developments (NP02 and NP04)
- NP02: use QSCAN for fast/lightweight environment



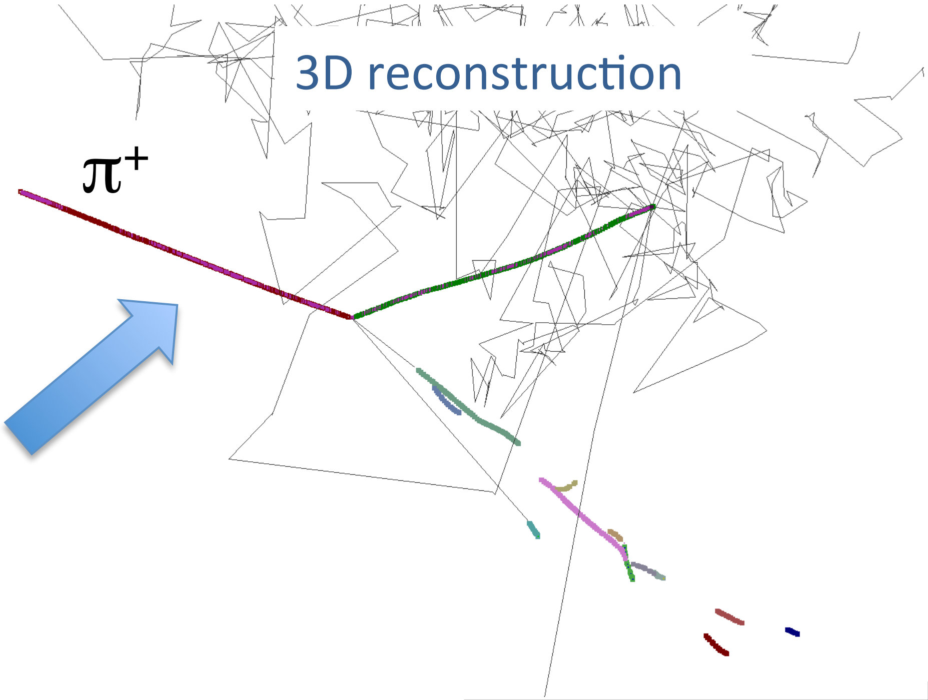
- Cosmic ray background overlays
- Space charge effects
- Diffusion effects
- Electronics response
- …

protoDUNE NP04 geometry
→ Have MC samples MC at hand for further studies

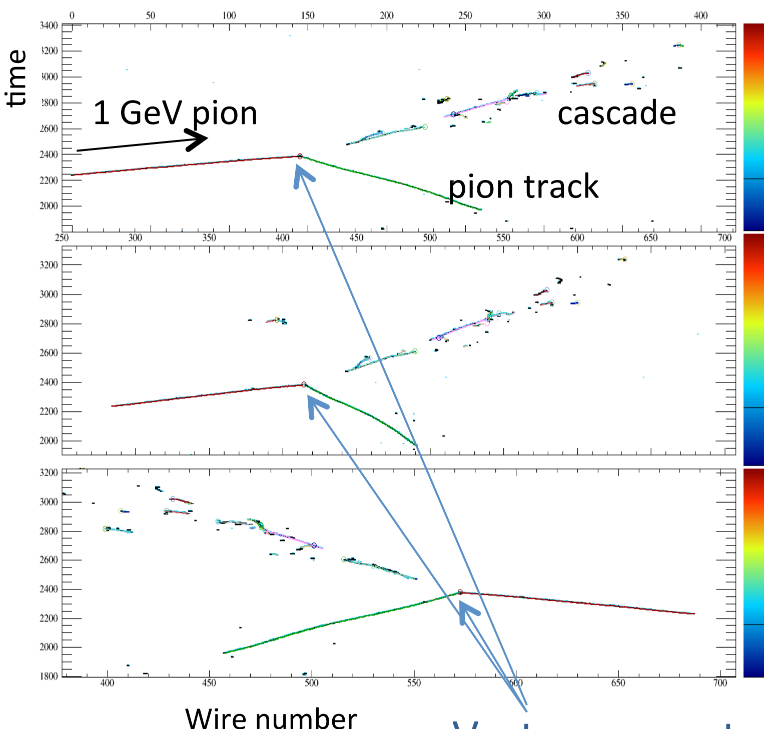
Simulation Studies + Reconstruction

ProtoDUNE NP04 simulated
1 GeV pion event sample

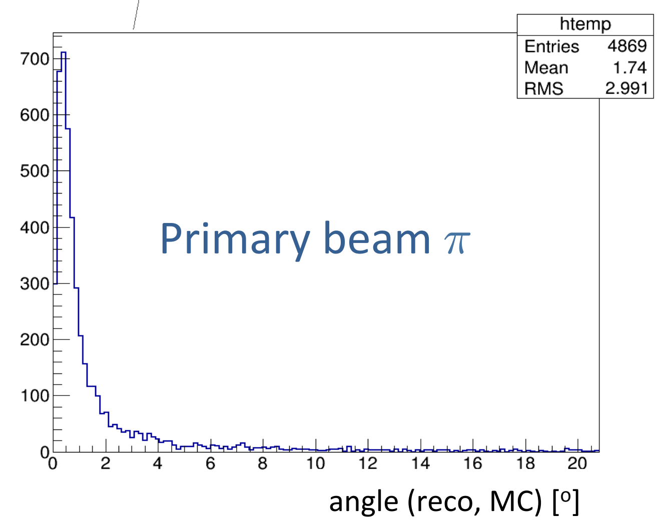
3D reconstruction



2D reconstruction



Vertex reconstruction



Anticipated Measurements (NP04)

Pions/protons:

- Measure calibration constants (energy) and validate reconstruction tools and simulations
- Measure π^+/π^- differences and topological shower differences (< 1 GeV)
- Measure pion interaction cross sections
- Develop PID for stopping pions and protons; μ/π discrimination (≤1 GeV)
- Measure π^0 for NC backgrounds and calibration
- study e-γ separation ($\sim$ 1-2 GeV)

Electrons:

- Study e-γ separation (<2 GeV); need good angular spread
- Calibrate em showers (sub GeV – multi-GeV)

Muons:

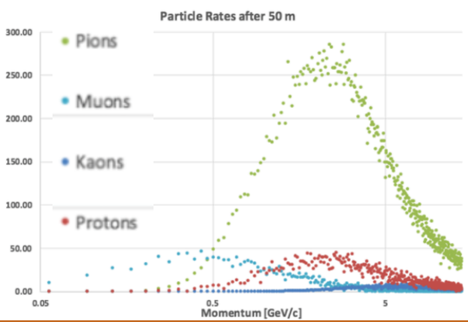
- study Michel electrons, calibrate Bethe-Bloch, study μ^- capture on Ar (≤ 1 GeV)

Not an exhaustive list (work in progress)

Preliminary NP04 Run Plan

Estimates for one angular configuration only

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



NOTE: Table entries based on generic beam line calculation

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

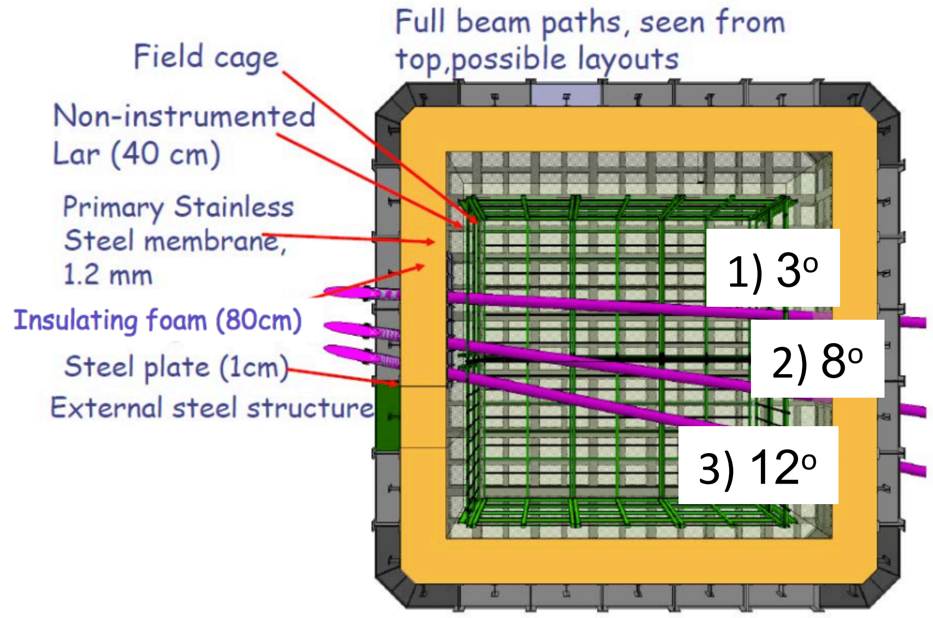
→Total estimated measurement time is of order of several weeks

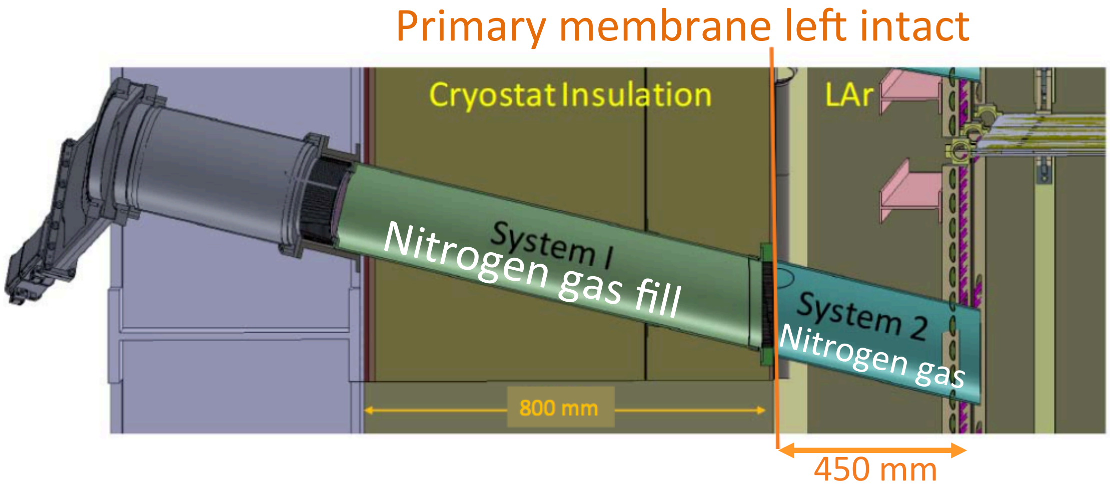
→ desirable to study < 1 GeV/c momentum particles

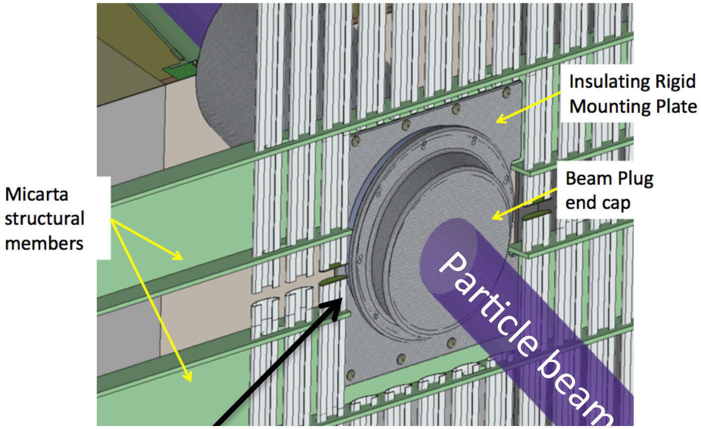
Beam Window

From Fluka/G4 simulations:
→Low E (< 1 GeV) hadrons and electrons require full penetration

Position 1) : Leave foam intact; only cut outer 1cm thick SS; install syst. 2 beam plug
Position 2) : as 1) w/o beam plug
Position 3): Full beam window



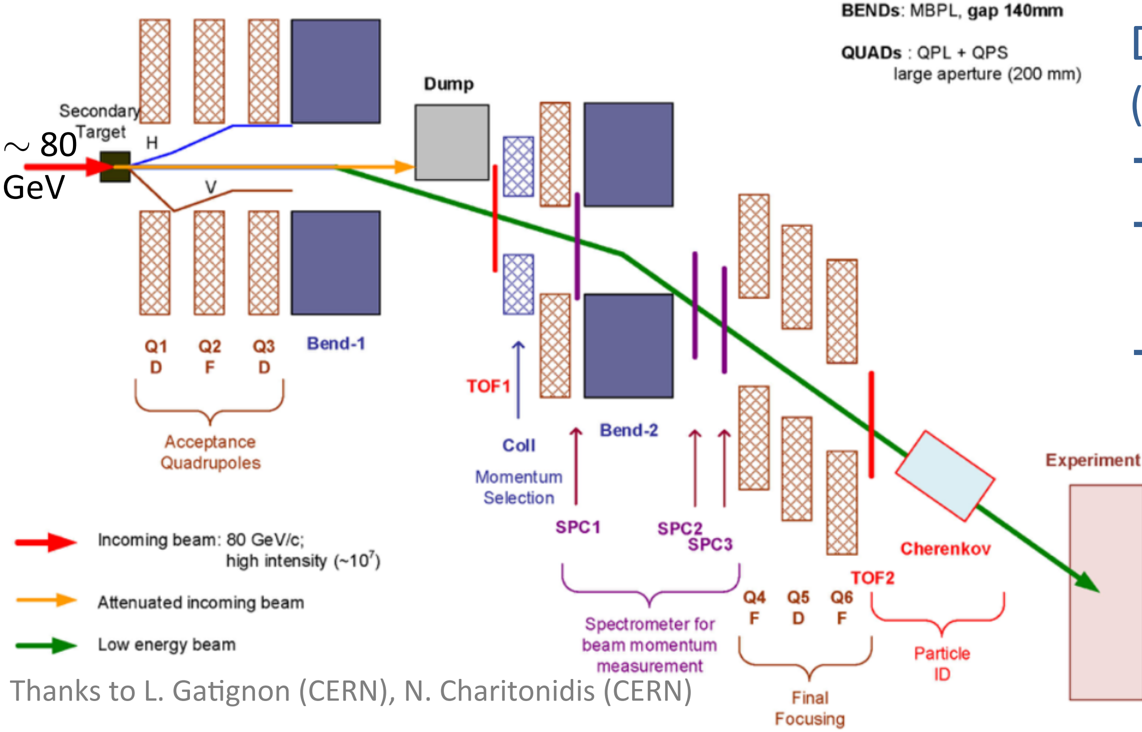




System 2 plug mounted to FC

→ Beam window will be tested in mechanical mock-up at FNAL

Charged Particle Beams



Thanks to L. Gatignon (CERN), N. Charitonidis (CERN)

Default H2/H4 beamline layout
(H4: one extra dipole for sweeping)
→ Mixed hadrons (π, p, K) or
→ Relatively pure electron

→ Required beam instrumentation under discussion

Simulation of H2 beamline completed (H4 in progress)

Maximum particle rate to avoid particle overlaps in TPC $\approx$ 100 Hz

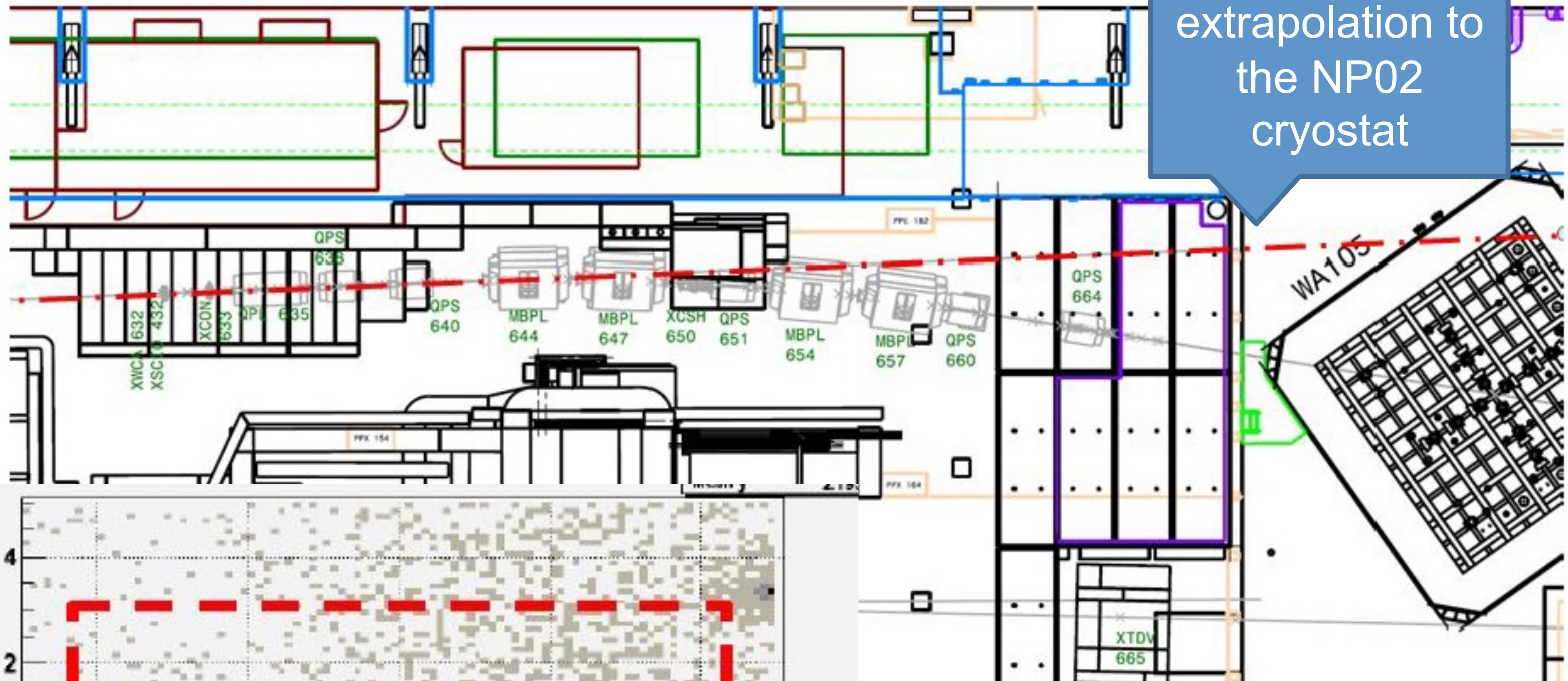
SPS spill of 4.8s and super-cycle of 2 spills/50s
→ $2 \times 4.8\text{s} \times 100$ Hz $\approx$ 1000 pcles/super-cycle
→ With 50% efficiency: $\sim$ 830k pcles/day

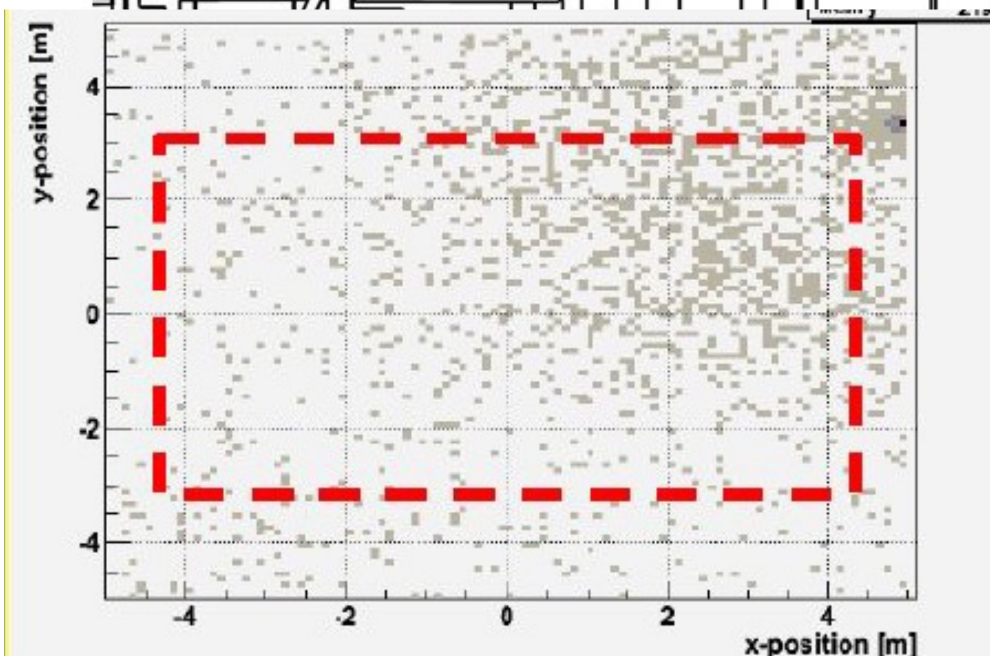
NP02 Beam Time Request

Momentum GeV/c	Surviving π's	Surviving K's	Beam composition $\pi/K/e/p$	π's Stat. (10^6)	Days for π's Stat.	Others $p/K/e$
Positive						
0.4	21%	0.05%	1%/-/22%/13%			
1.0	52%	1%	4%/-/85%/4%	0.5	14	$500k/-/9.8M$
2.0	72%	9%	18%/1e-4(CMS)/68%/7%	1	7	$405k/-/3.8M$
3.0	80%	20%	29%/1e-3(CMS)/56%/7%	2	8	$480k/-/3.8M$
4.0	85%	30%	39%/2%/45%/7%	2	6	$355k/106k/2.3M$
5.0	88%	38%	55%/2%/26%/8%	2	4	$307k/84k/934k$
6.0	90%	44%	56%/4%/21%/10%	1.5	3	$259k/114k/554k$
7.0	91%	50%	67%/6%/10%/10%	1.5	3	$211k/127k/230k$
8.0	92%	54%	61%/6%/13%/11%	1.5	3	$281k/148k/327k$
9.0	93%	58%	67%/6%/10%/10%	1.5	3	$211k/127k/230k$
10.0	94%	61%	69%/6%/10%/9%	1.5	3	$202k/136k/215k$
11.0	94%	64%	70%/6%/7%/10%	1.5	3	$204k/136k/144k$
12.0	95%	67%	68%/8%/5%/14%	1.5	3	$301k/183k/111k$
					~ 59 days	
Negative					~ 59 days	

The running time in each momentum set is calculated based on the number of days needed to collect a desired pion statistics with reasonable rates for other particles acquired in "parasitic" mode taken into account

H2 Muon Halo

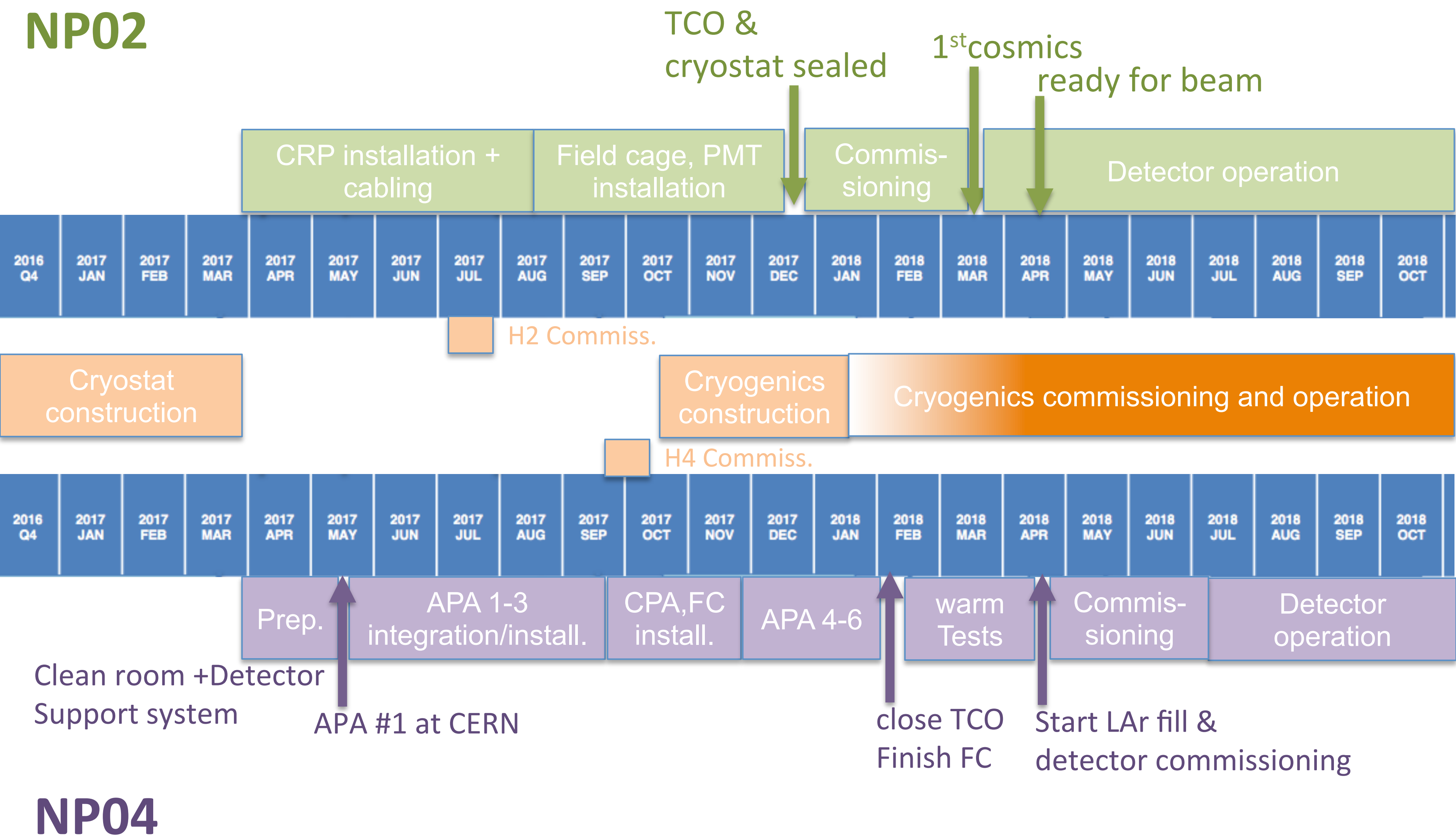




Without dedicated muon shielding would get ~2kHz rate in TPC from muon halo

Need to reduce as much as possible with upstream magnetized shielding

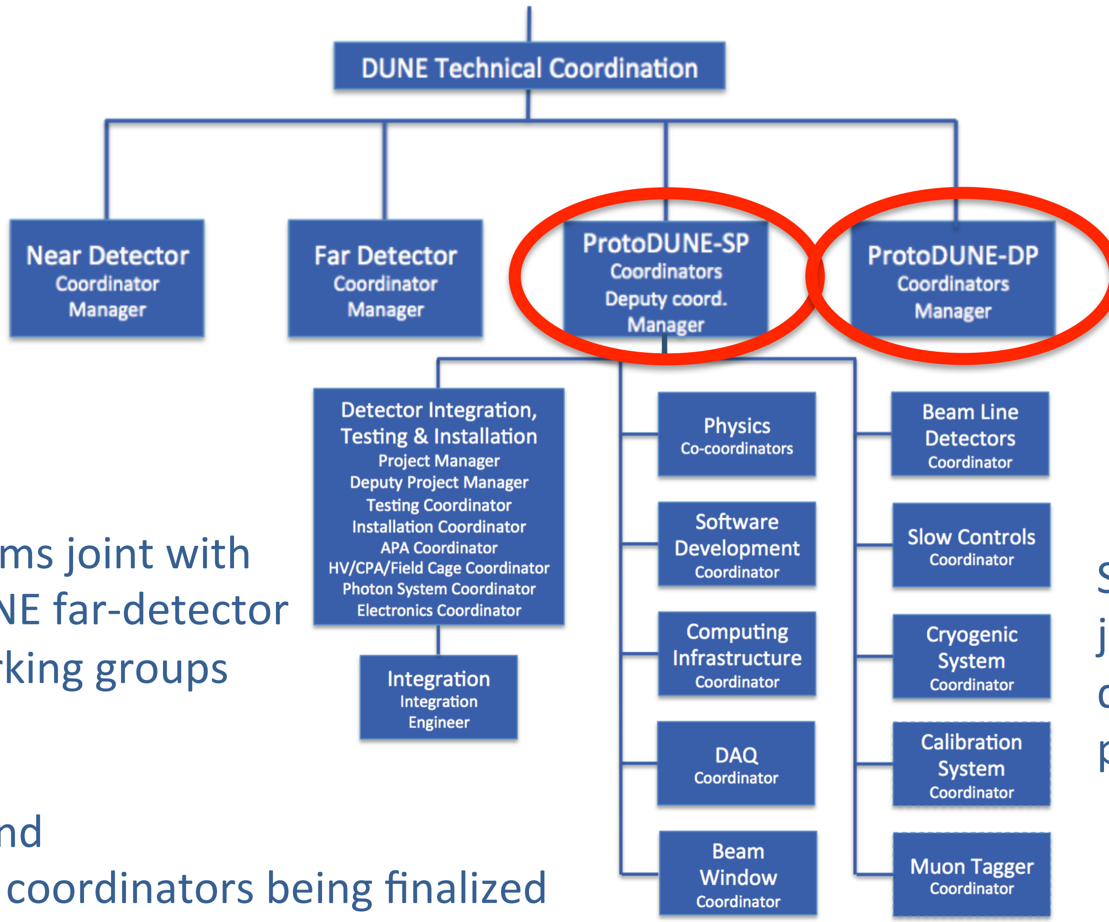
Timeline



Approximate schedule summary from detailed project schedule

Organization

- ProtoDUNEs are embedded within DUNE organization
- DUNE Technical Board is main decision making body:
  design, construction, installation, commissioning, technology choices
- Main single-phase protoDUNE detector elements produced within FD organization



dual-phase protoDUNE organization has similar sub-structure

Teams joint with DUNE far-detector working groups

Some teams joint with dual-phase protoDUNE

Team charges and appointment of coordinators being finalized

Summary

- Provided an overview of the motivation, sub-components and measurements of protoDUNE LAr single and dual phase technologies

→ protoDUNE detectors are an important engineering milestone to
  - → perform full scale component structural tests in LAr
  - validate full scale detector sub-systems (TPC,PDS, electronics) and their integration and installation
  - help to establish multiple production sites and Q/A procedures

→ 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

- Follow aggressive schedule - require close and effective collaboration

→ enhances international collaboration in ν physics