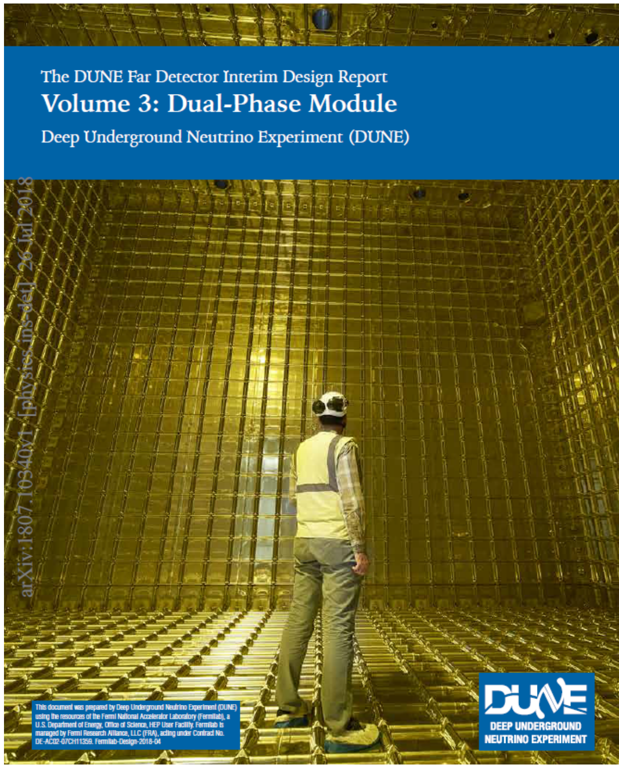
DUNE-DP IDR & TDR Status

Dario Autiero (IPNL Lyon)

LBNC Meeting

December 7, 2018



IDR Volume 3
Dual-Phase Module

https://arxiv.org/abs/1807.10340

280 pages, 8 chapters

1) Design motivations
2) Charge Readout Planes
3) TPC Electronics
4) HV system
5) Photon Detection System
6) Data Acquistion System
7) Slow Controls and Cryogenic Instrumentation
8) Technical Coordination

See presentation given at the LBNC in May → https://docs.dunescience.org/cgi-bin/private/RetrieveFile?docid=8226&filename=Autiero_DP-TP_LBNC.pptx

Editorial team:
D.A. Overview
Charge Readout Planes: Dominique Duchesneau, Edoardo Mazzucato
TPC Electronics: Jaime Dawson, Slavic Galymov
HV System: Francesco Pietropaolo, Jae Yu
Photon Detection System: Burak Bilki, Clara Cuesta
Data Acquisition System: Jim Brooke, Brett Viren
Slow Controls and Cryogenic Instrumentation: Glenn Horton-Smith, Carmen Palormares
Technical Coordination: Steve Kettell

TP Chapters:

1) Design motivations
2) Charge Readout Planes
3) TPC Electronics
4) HV system
5) Photon Detection System
6) Data Acquistion System
7) Slow Controls and Cryogenic Instrumentation
8) Technical Coordination

Consortia:

- CRP consortium (DP):
LEMs, CRP, CRP suspension system

- TPC Electronics (DP):
Cold charge readout electronics, signal chimneys, digital electronics for charge and light readout

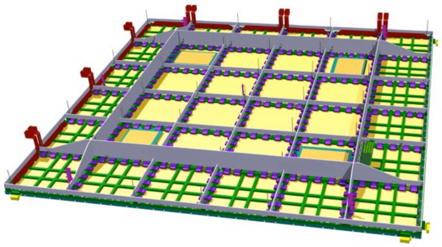
- HV system (Joint):
Field cage, cathode, VHV power supply and feedthrough

- Photon Detection System (DP):
Photomultipliers system, light calibration system

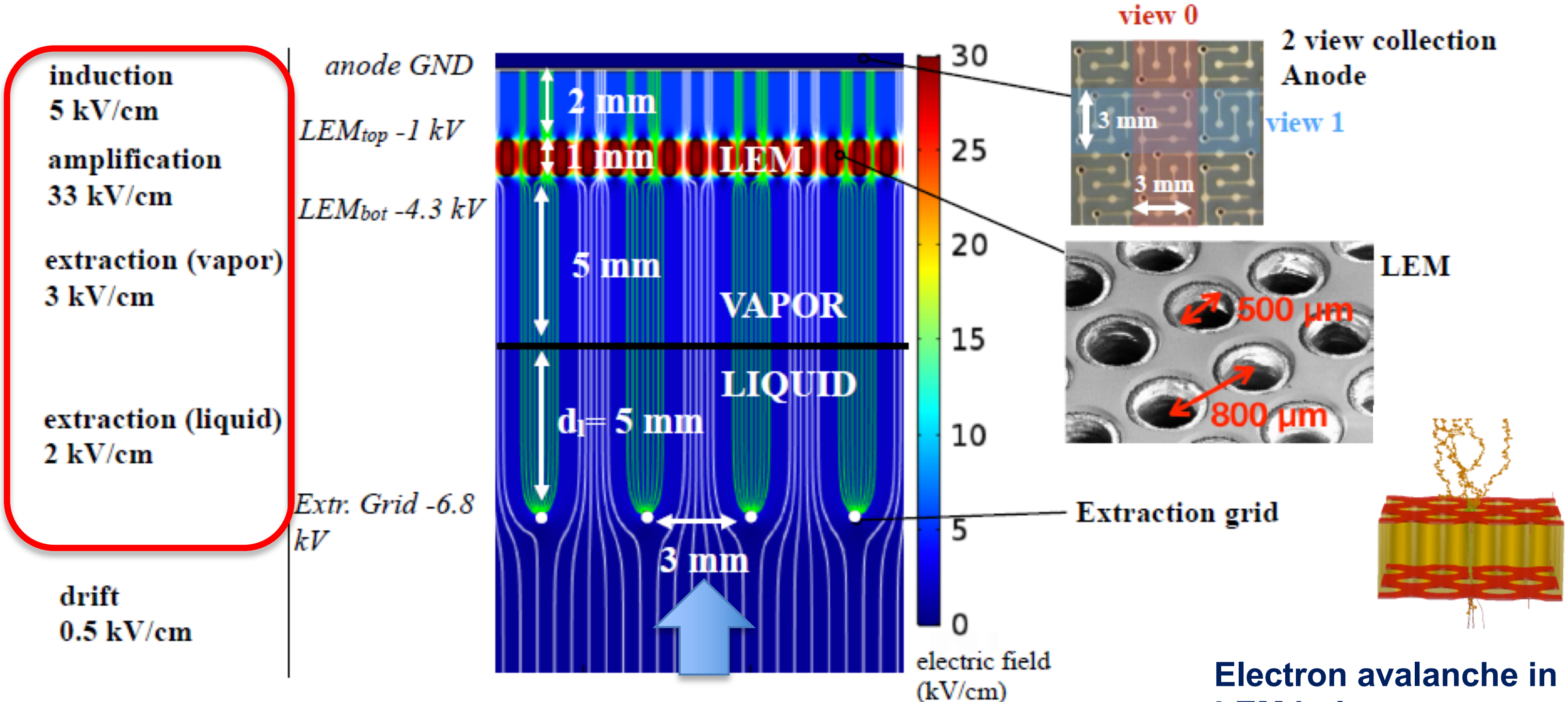
- Data Acquistion System (Joint):
DAQ back-end for trigger and storage

- Slow Controls and Cryogenic Instrumentation (Joint):
Slow control system for LAr, GAr, CRP specific SC + others

Consortia organization and scopes take into account some specific aspects of DP design



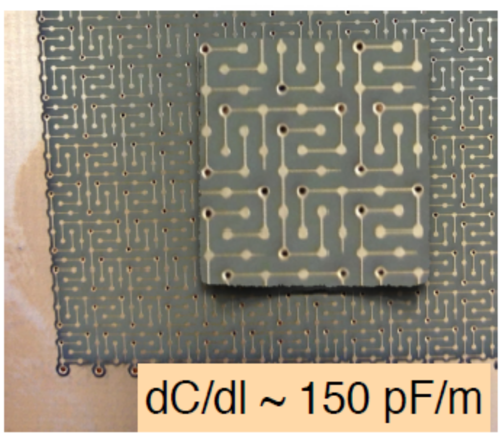
Charge Readout Plane integrating LEM-anode sandwiches

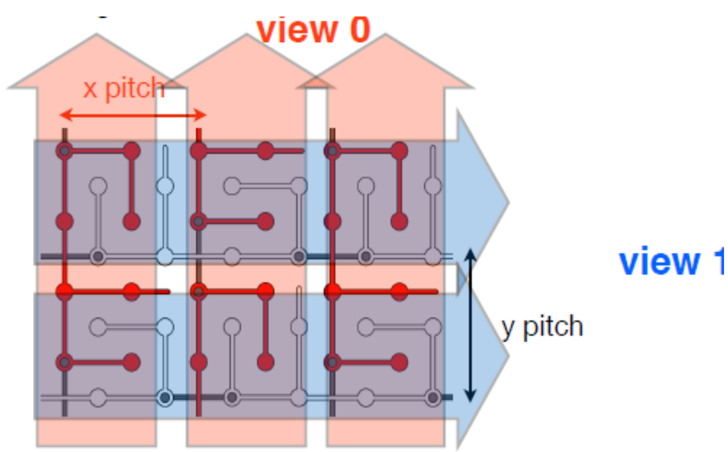


Electron avalanche in LEM hole

50x50 cm^2 LEM

50x50 cm^2 anodes with 2 collection views





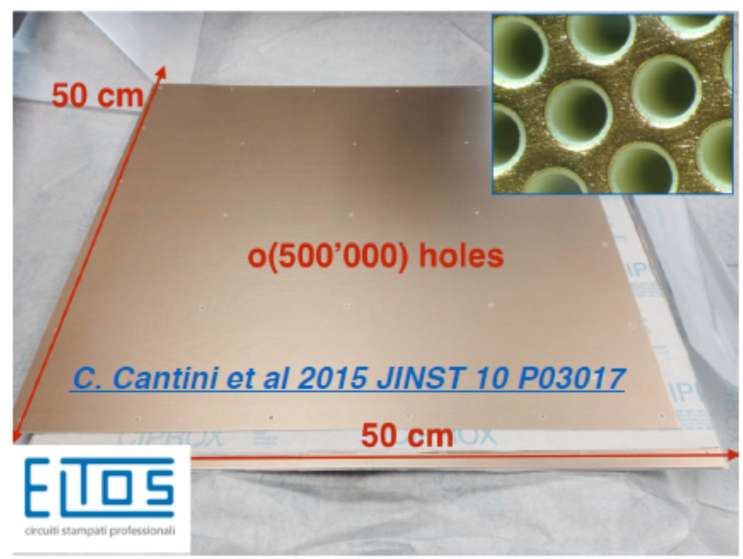
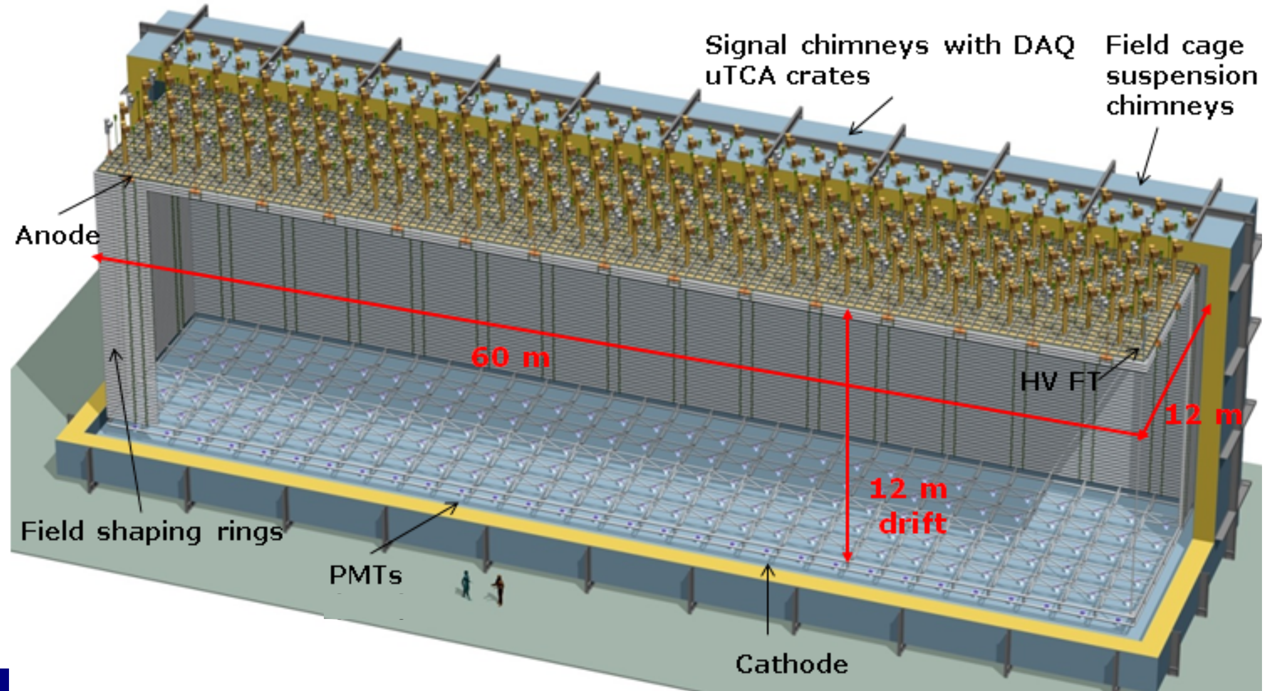


Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

Item	Number or Parameter
Anode plane size	W = 12 m, L = 60 m
CRP unit size	W = 3 m, L = 3 m
CRP units	4 × 20 = 80
LEM-anode sandwiches per CRP unit	36
LEM-anode sandwiches (total)	2880
SFT chimney per CRP unit	3
SFT chimney (total)	240
Charge readout channels / SFT chimney	640
Charge readout channels (total)	153,600
Suspension feedthrough per CRP unit	3
Suspension feedthroughs (total)	240
Slow Control feedthrough per sub-anode	1
Slow Control feedthroughs (total)	80
HV feedthrough	1
HV for vertical drift	600 kV
Voltage degrader resistive chains	4
Cathode modules	80
Field cage rings	197
Field cage modules	288
PMTs (total)	720 (1/m^2)

Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) DUNE Conceptual Design Report, July 2015

Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600

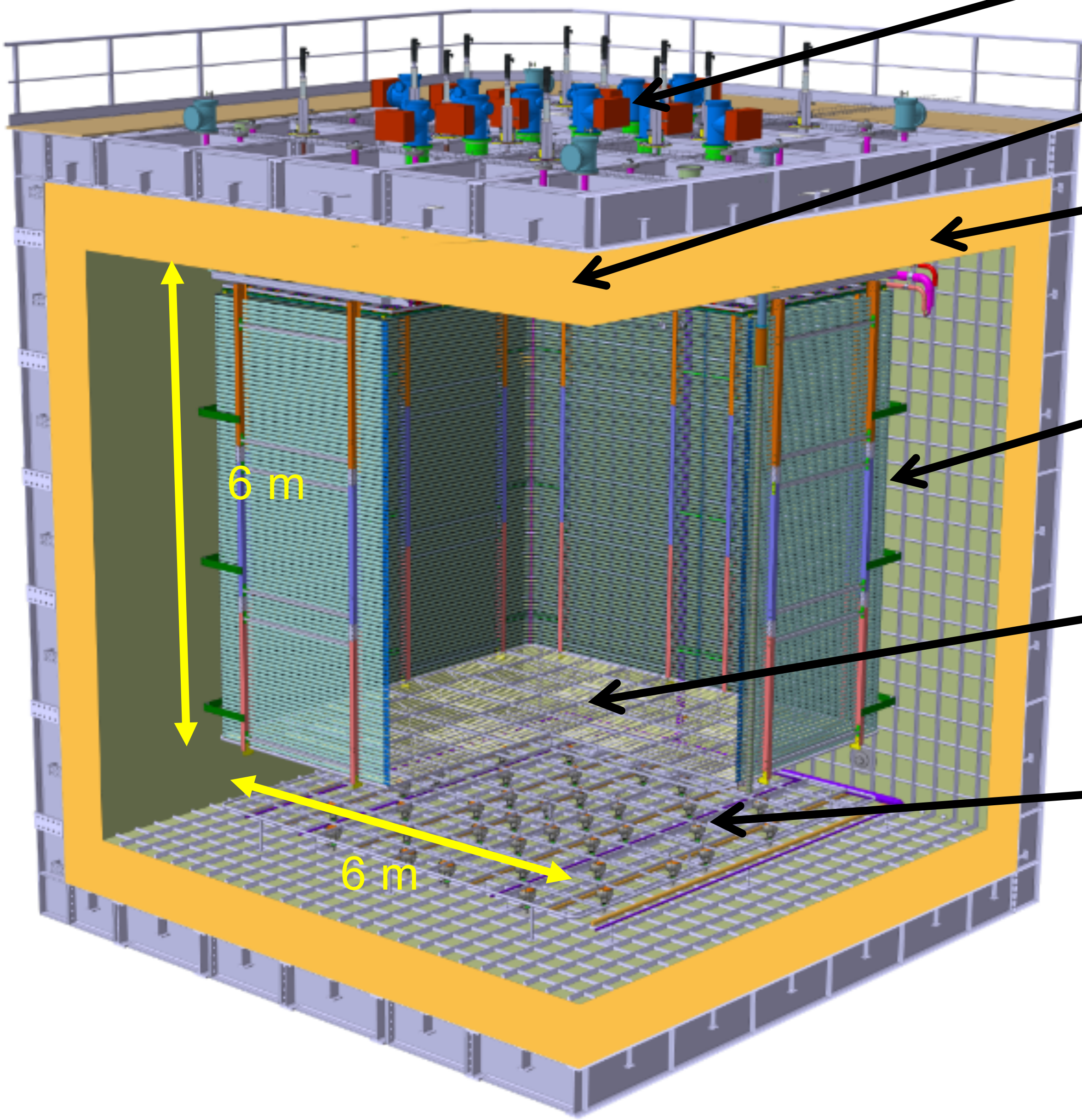


Advantages of dual-phase design:

- Gain in the gas phase → robust and tunable S/N, lower detection threshold, compensation for charge attenuation due to long drift paths
- Finer readout pitch (3.125 mm), implemented in two identical collection views (X,Y) on 3m long strips
- Long drift projective geometry: reduced number of readout channels (153,600 for DP less than half of equivalent SP FD), absence of dead materials in the drift volume
- Fewer construction modules
- Full accessibility and replaceability of cryogenic front-end (FE) electronics during detector operation

Same physics requirements as SP-FD

The DP-FD design described in the IDR is based on ProtoDUNE-DP design



Digital electronics in uTCA crates

Cold FE electronics in SFT "chimneys"

Charge Readout Planes

Field Cage sub-modules (common structural elements with SP)

Cathode modules

36 cryogenic photomultipliers Hamamatsu R5912-02mod with TPB coating

All sub-systems chapters including

- **Design**
- Production and assembly
- QA and QC
- Interfaces
- Installation

Completion of the TDR

DP-TDR Editorial team (mostly the same of the IDR with some small changes):

Summary	Dario Autiero
Charge Readout Planes:	Dominique Duchesneau, Edoardo Mazzucato
TPC Electronics:	Jaime Dawson, Slavic Galymov
HV System:	Francesco Pietropaolo, Jae Yu
Photon Detection System:	Burak Bilki, **Michel Sorel**
Data Acquisition System:	Jim Brooke, **Gerogia Karagiorgi**, Brett Viren
Calibration	**Sowjanya Gollapinni, Kendall Mahn**
Slow Controls and Cryogenic Instrumentation:	Glenn Horton-Smith, Carmen Palormares
Integration and Installaiton:	**Filippo Resnati**

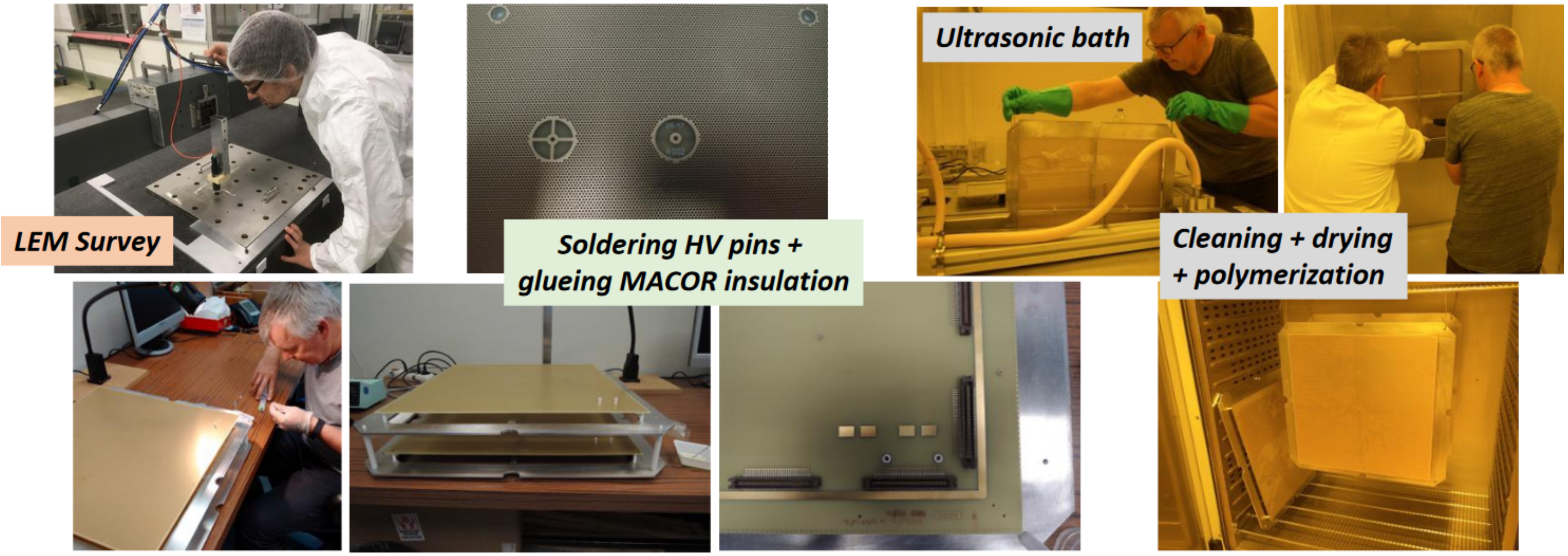
Ongoing work:

1) Completion of editing, evolution from IDR to TDR, additions (costs, installation, etc ..), style standardization, inclusion of the experience of the last 6 months (productions, CRP tests, installation)
2) Return from ProtoDUNE-DP
3) Additional information from consortia activities in progress

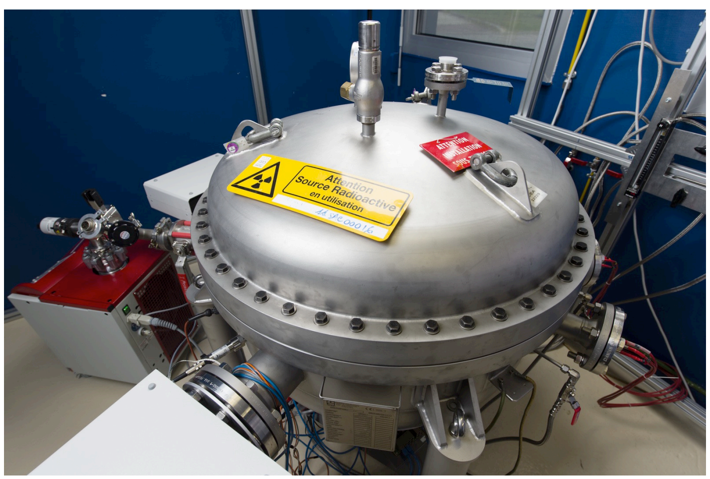
TDR Schedule (DP volume):

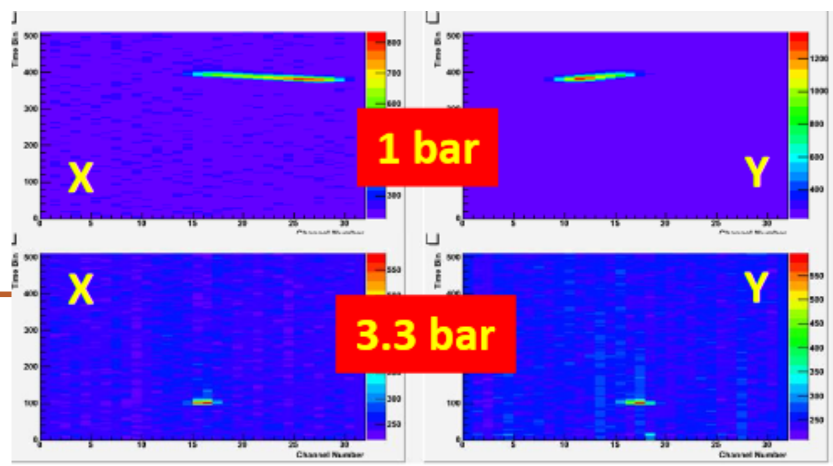
Consortium/task	1st Draft	2^{nd} Draft	LBNC
DP-ELECTRONICS	14/12/18	8/2/19	22/2/19
HV (DP)	1/2/19	1/3/19	29/3/19
DP-PDS	1/3/19	5/4/19	26/4/19
IIC (DP)	5/4/19	10/5/19	31/5/19
DAQ (DP)	5/4/19	10/5/19	31/5/19
CISC (DP)	5/4/19	10/5/19	31/5/19
Calibration (DP)	10/5/19	7/6/19	28/6/19
DP-CRP	10/5/19	7/6/19	28/6/19
Exec. Summary (DP)	10/5/19	7/6/19	28/6/19

LEM production and QA/QC chain



High pressure gas chamber for LEM tests/characterization
→ 3.3 bar gas density conditions as close to LAr surface

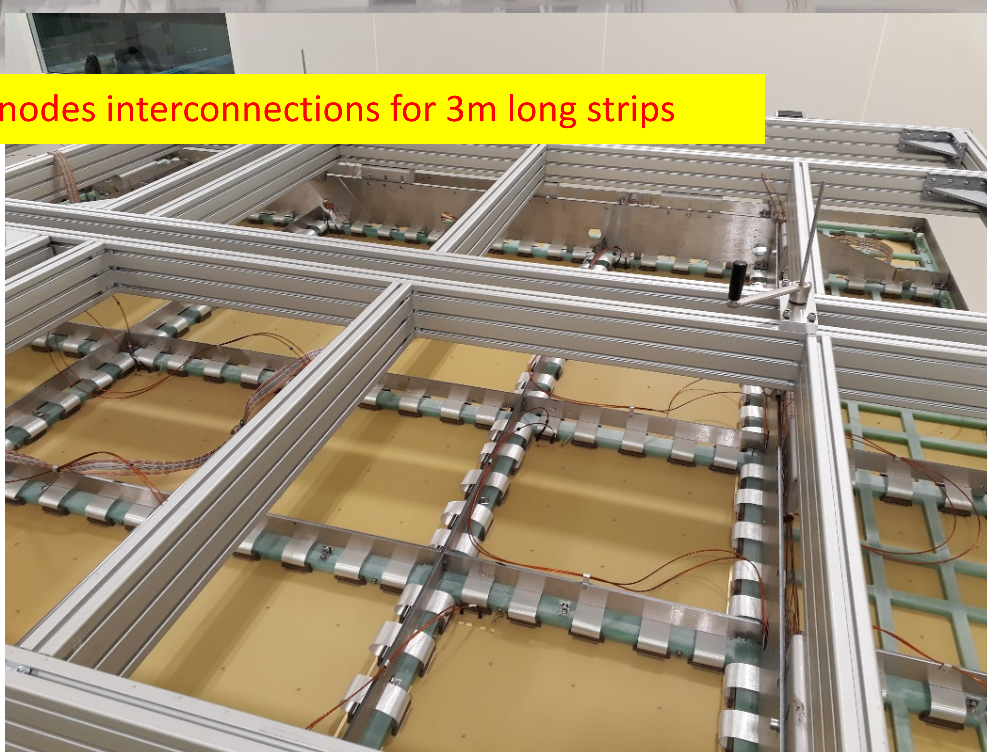




Charge Readout Plane (CRP) with LEM/anodes mounted

CRP cold--box test

Anodes interconnections for 3m long strips



ProtoDUNE-DP accessible cold front-end electronics and uTCA DAQ system 7680 ch

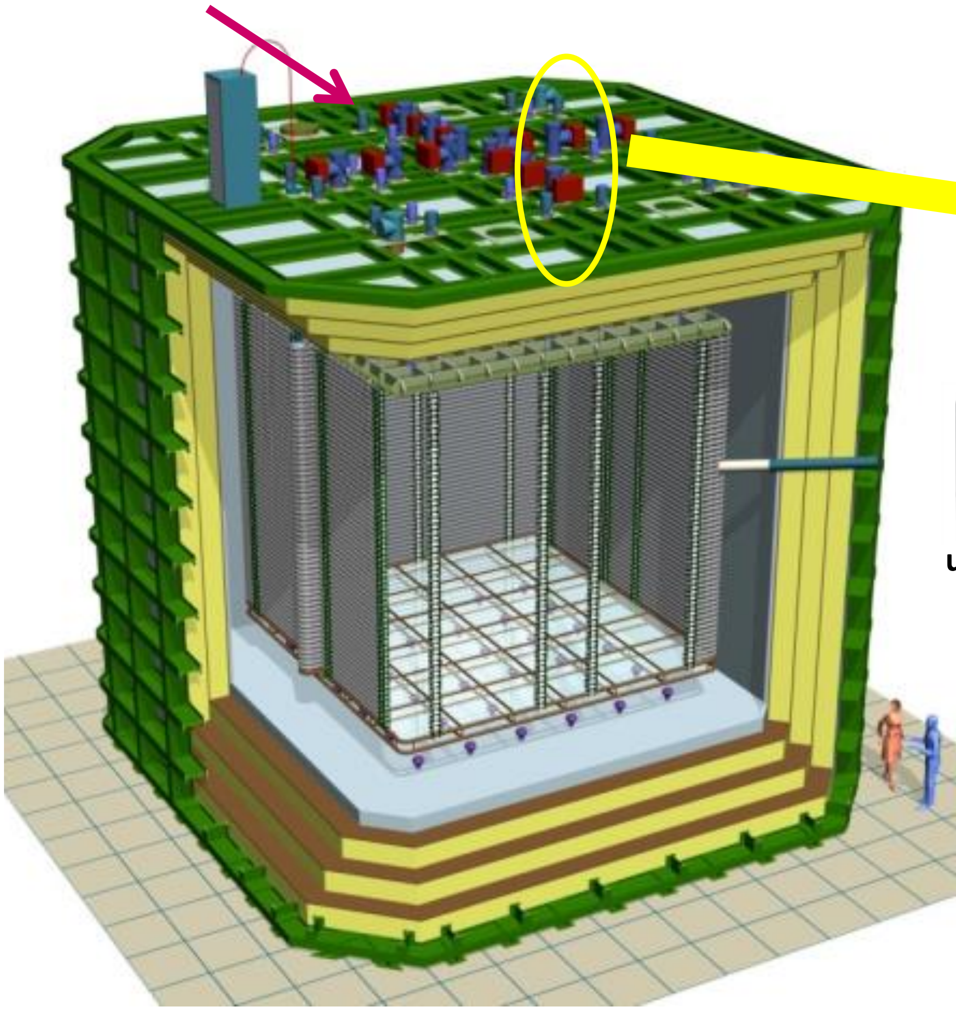
Full accessibility provided by the double-phase charge readout at the top of the detector

- **Digital electronics at warm on the tank deck:**
  - Architecture based on uTCA standard
  - 1 crate/signal chimney, 640 channels/crate

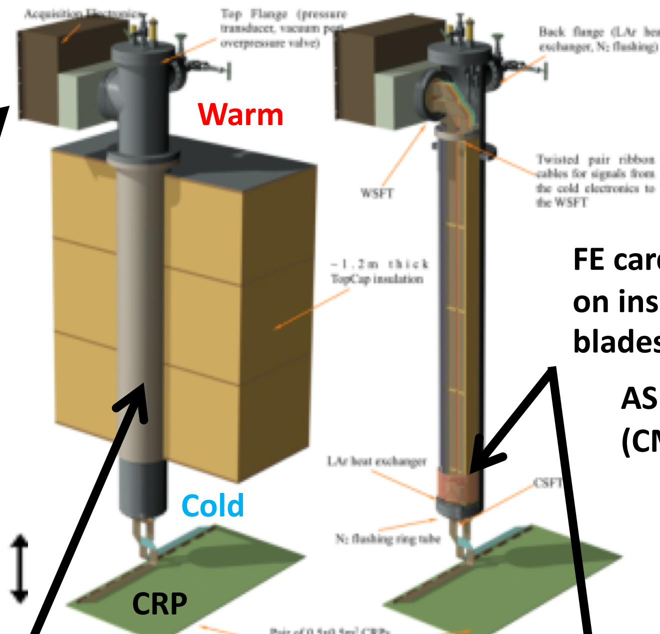
→ 12 uTCA crates, 10 AMC cards/crate, 64 ch/card

- **Cryogenic ASIC amplifiers (CMOS 0.35um) 16ch externally accessible:**
  - Working at 110K at the bottom of the signal chimneys
  - Cards fixed to a plug accessible from outside

→Short cables capacitance, low noise at low T

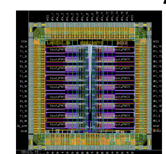


uTCA crate

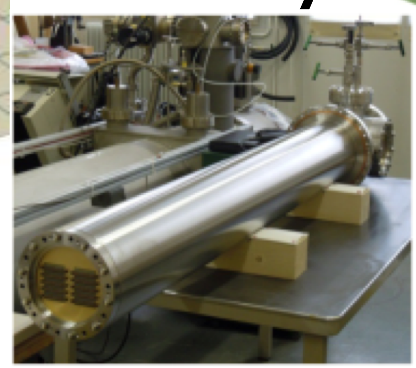


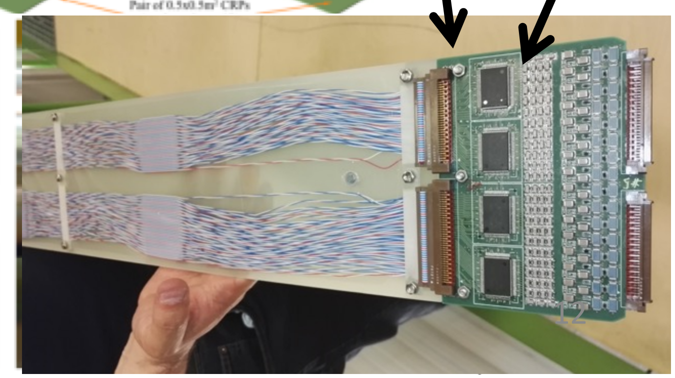
FE cards mounted on insertion blades

ASICs 16 ch. (CMOS 0.35 um)



Signal chimney



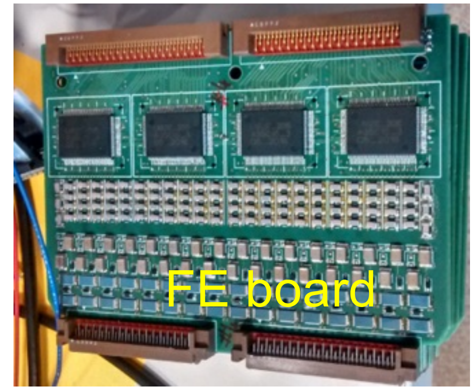


Electronics components chain implemented in ProtoDUNE-DP:

(R&D since 2006, long standing effort aimed at producing low cost analog and digital electronics)

Analog cryogenic FE:

- **Cryogenic ASIC amplifiers DP-V3, 0.35um CMOS (2015)**
- **64 channels FE cards with 4 cryogenic ASIC amplifiers**
- **First batch of 20 cards (1280 channels) operational on the 3x1x1 (fall 2016-spring 2018)**



AMC digitization cards:

uTCA 64 channels AMC digitization cards (2.5 MHz, 12 bits output, 10 GbE connectivity)

- **20 cards operational on the 3x1x1 (fall 2016-Spring 2018)**

White Rabbit timing/trigger distribution system:

- **Full system architecture operational on the 3x1x1 (fall 2016-spring 2018) including uTCA White Rabbit MCH**

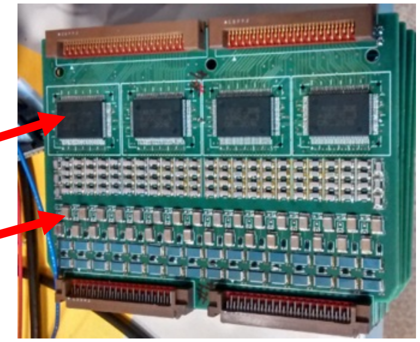
Components for a 10 kton dual-phase module

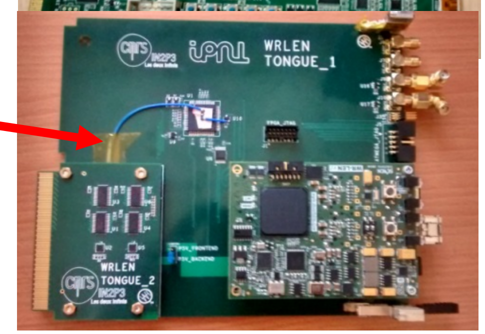
Total number of charge readout channels: 153600
(+light readout channels 720)

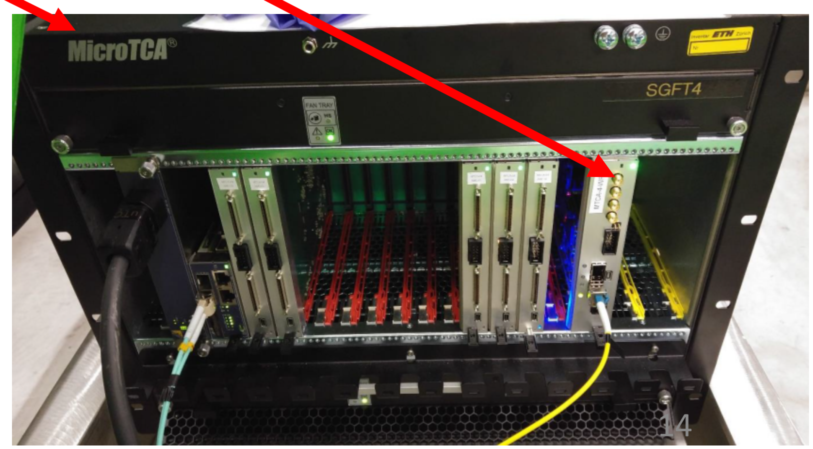
- Cryogenic ASICs (16 ch): 9600
- Cryogenic FE cards (64 ch): 2400

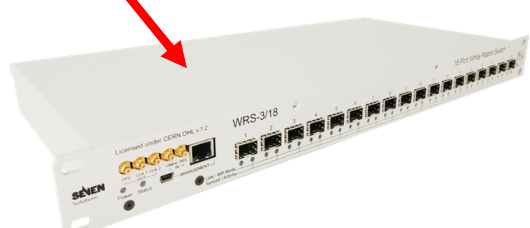
- AMC cards (64 ch): 2400
- uTCA White Rabbit MCH: 240
- uTCA crates (including MCH,PU,FU): 240
- 10 Gbe optical links to backend: 240
- VHDCI cables (32 ch) 4800

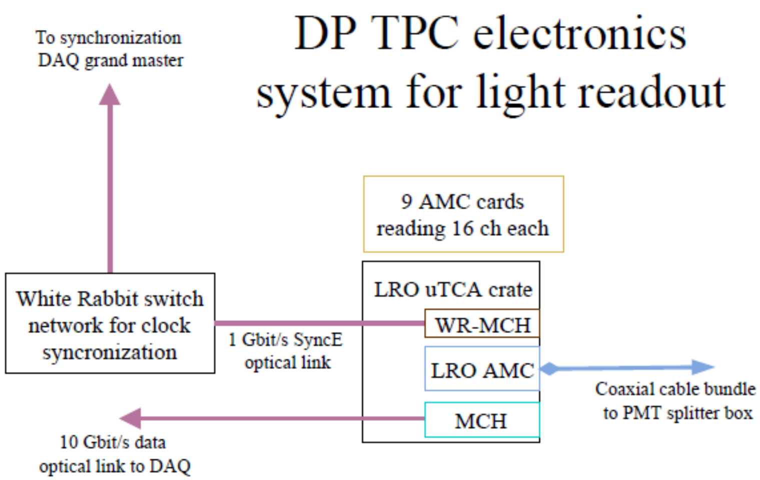
White Rabbit switches (18 ports): 16

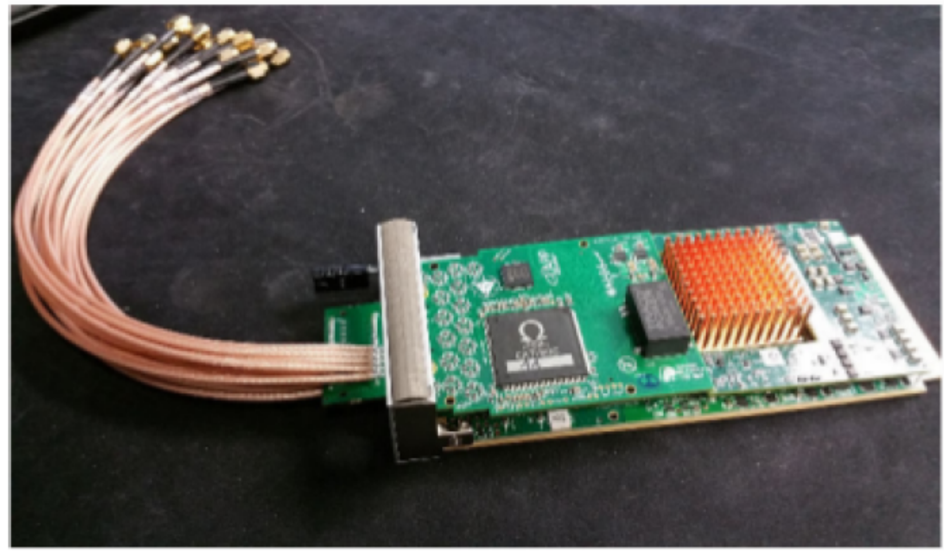










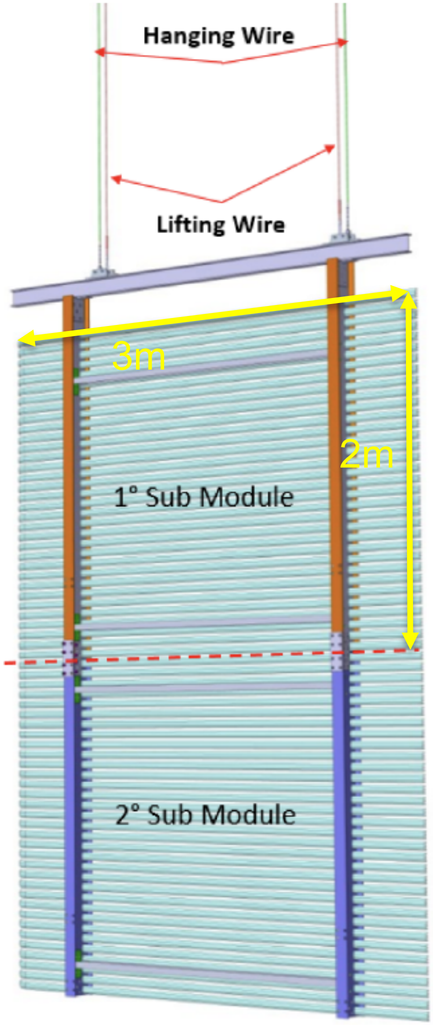


LRO AMC derived from CRO AMC:

- Sharing same uTCA infrastructure, White Rabbit, etc …
- Incorporating Catiroc chip for triggering
- Firmware finalization for NP02, final integration to charge readout design
- Needs for a 10 kton module: 45 AMC cards in 5 uTCA crates

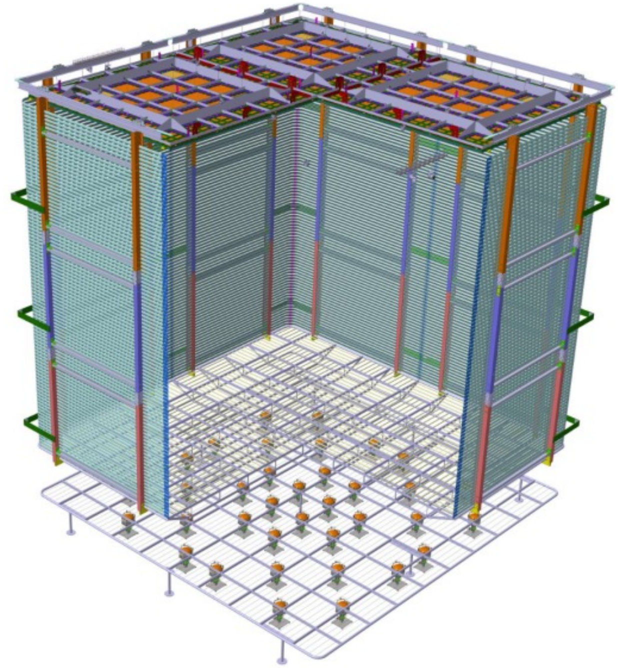
Table 3.6: Main characteristics of CATIROC.

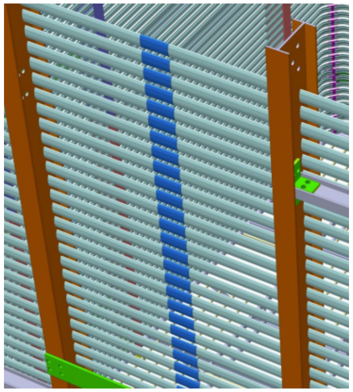
Item	
Number of channels	16
Signal polarity	negative
Timing	Timestamp: 26 bit counter at 40 MHz Fine time: resolution <200 ps
Charge Dynamic Range	160 fC to 100 pC
Trigger	auto-trigger Noise = 5 fC Minimum threshold = 25 fC (5σ)
Digital	10-bit Wilkinson ADC at 160 MHz Read-out frame of 50 bits
Outputs	16 trigger outputs NOR16 16 slow shaper outputs Charge measurement over 10 bits Time measurements over 10 bits
Main Internal Programmable Features	Variable preamplifier gain Variable shaping and gain Common trigger threshold Common gain threshold



NP02 Field cage 3x2 m2 sub-modules with Aluminum profiles and FRP I-beams

Modules for FD-DP:
Hanging chains of 6 submodules rings, continuity among different chains ensured by clips (3 sub-modules in NP02)

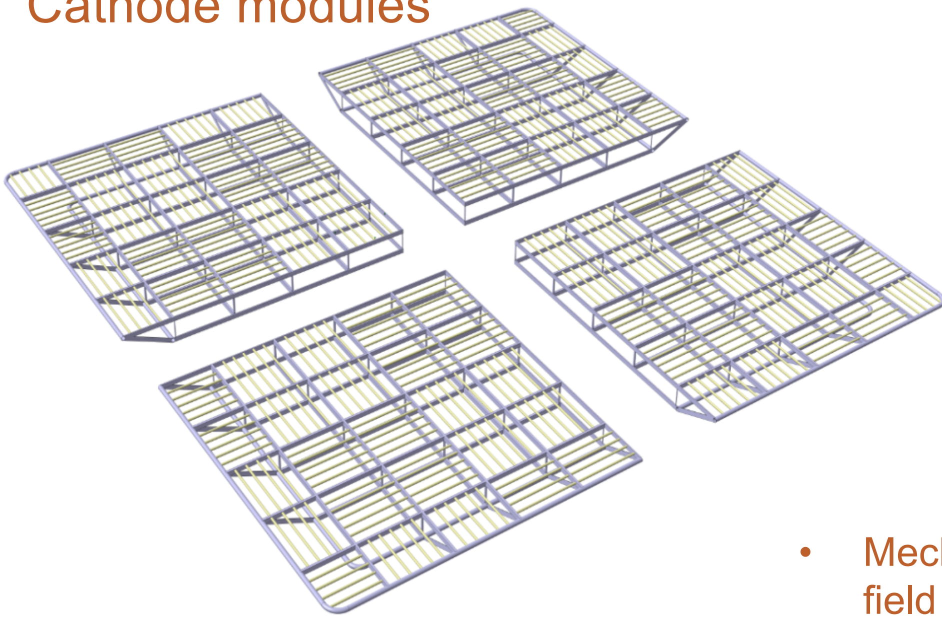


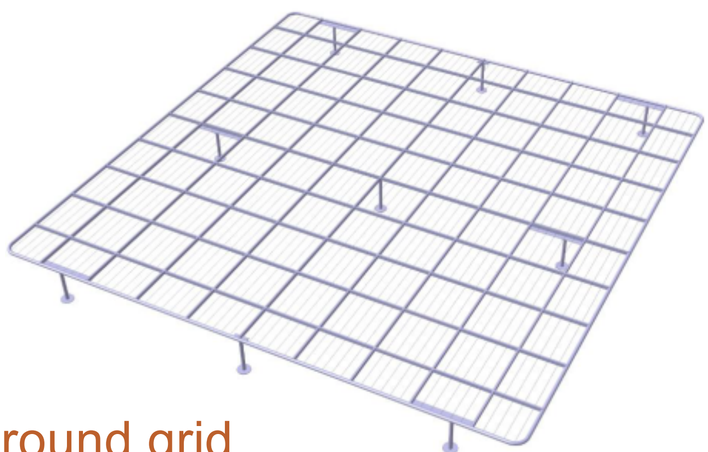


288 modules needed for the field cage of FD-DP (24 submodules in NP02)

Field cage assembly for NP02

Cathode modules





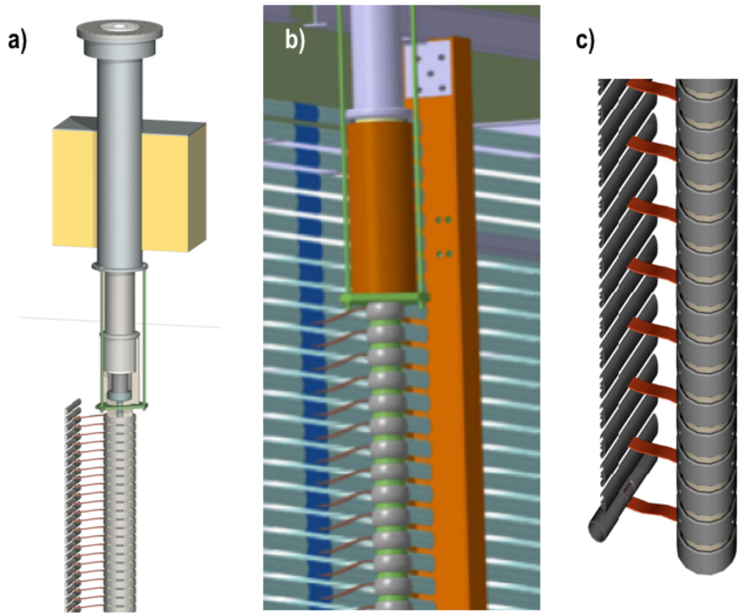
Ground grid

NP02 Cathode plane and ground grid
(grid to protect the photomultipliers from cathode sparking)

→ All in units of 3x3 m^2 similar to CRP modularity

Cathode modules: structure of stainless steel pipes
Electrical segmentation: GOhm resistors interconnecting the cathode modules in order to delay discharges and prevent damages due to storage energy

- Mechanical integration: cathode modules hanging from field cage and connected mechanically together, ground grid with feet laying on membrane floor
- Some mechanical modifications w.r.t. NP02 in order to guarantee the cathode flatness over the longer distance of 12m compared to the 6m of ProtoDUNE-DP.
- The shape of the cathode conductors could also undergo some slight modifications in order to lower the local E field values, based on the ProtoDUNE-DP experience

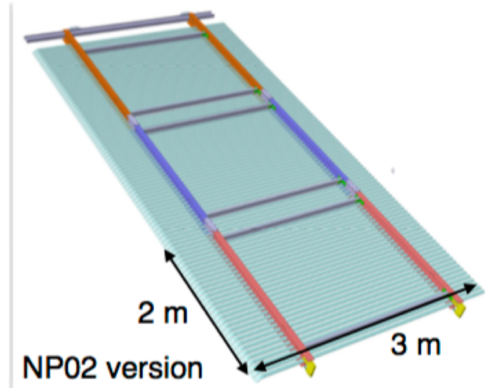


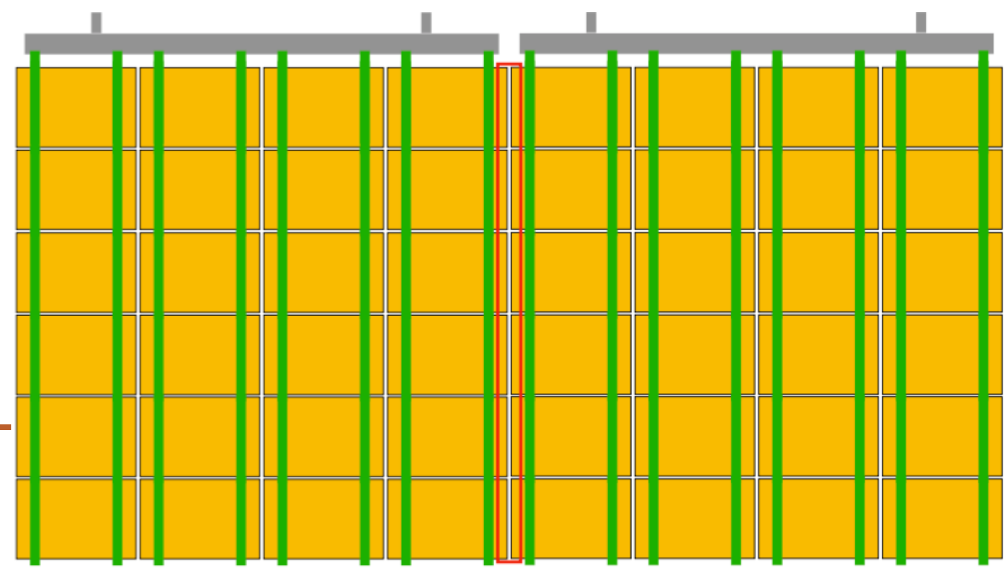
HV feedthrough of NP02 tested at 300 kV

600 kV version:
needs integration of the FT with the power supply (no cabling available at 600 kV) ongoing discussions between the HV consortium and Heinzinger

Field cage optimization for assembly and installation

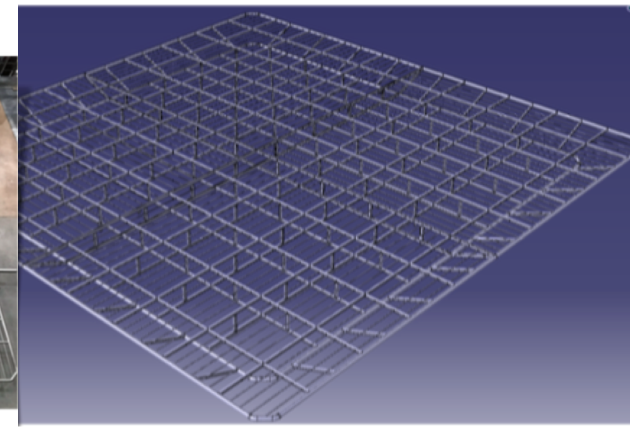
- Long super-modules (12 m wide x 12m high) assembled from 3mx2m sub-modules (à la protoDUNE) constructed inside the cryostat.
- Installation “lift and hang” à la NP02. ➔ lift one row of 4 connected sub-modules (12m x 2m) at a time
- Limit clipping at height to interconnection of super-modules ➔ need to develop method to clip from inside only
- Alternatively leave super modules electrically independent and terminate the profile with insulating/resistive end-caps (single phase style). ➔ May need two rows of HVDB per super module for redundancy
- Row of resistive degrader every super module (1 or 2 depending on the decision above)





Cathode & ground grid:

- Extrapolation from the NP02 concept to DUNE:
  - 12 m x 3m wide super-modules minimising metal components (used only to ensure mechanical strength and longevity).
  - Delivered in pieces and assembled inside the cryostat.
  - Hung from the field cage bridging the long sides.
- Optimisation strategy:
  - Replace the metal grid with resistive surfaces.
  - Studies are ongoing to optimise the design to protect the system from discharges.
  - Two possibilities for the resistive cathode surface:
    - Resistive rods running orthogonal to the supporting structure.
    - Acrylic tiles deposited with transparent resistive polymer and wavelength shifter.
- Ground grid: metal modules laying on the membrane.



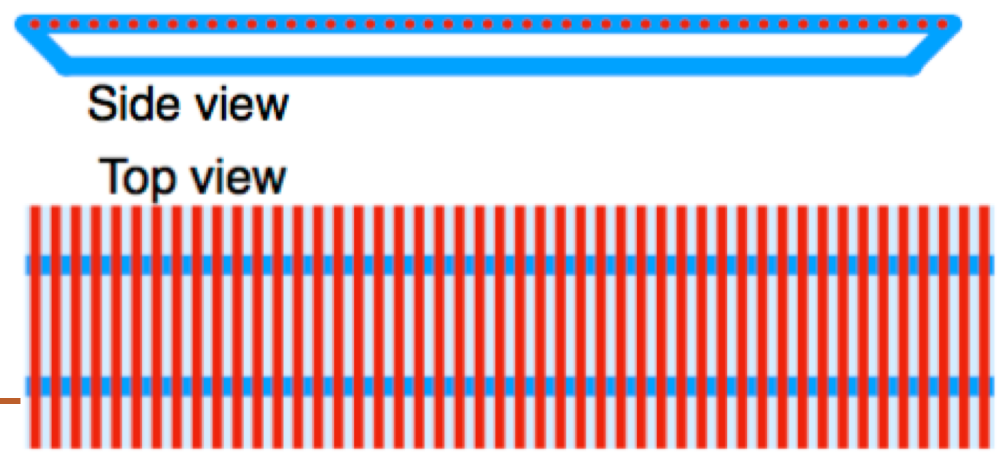
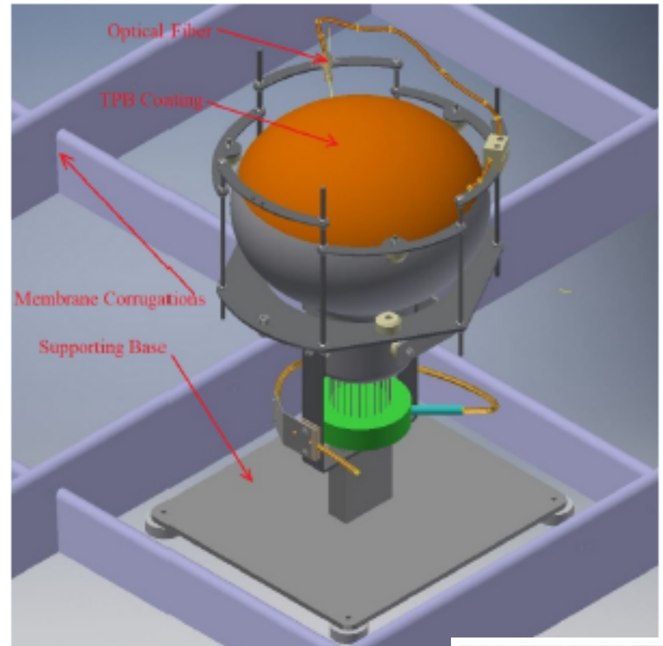


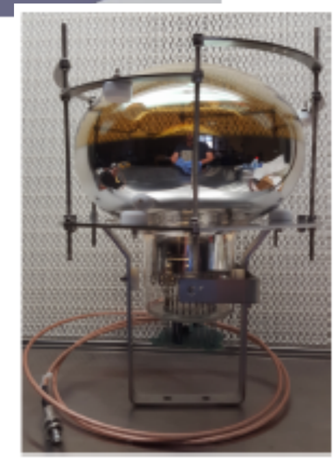
Table 5.1: Summary of tentative requirements for the DP module PDS The table assumes the baseline choice of the R5912-MOD20 PMT manufactured by Hamamatsu Photonics [9].

Feature	Goal	Comment
Optical		
spectral response	127 nm	wavelength shifters are required
light yield	2.5 photoelectron/MeV	for ProtoDUNE-DP, final value depending on simulation results
Electronic		
minimum light signal	SPE	required to perform the PMT gain measurement
gain	$\sim 10^6$-10^9	given by PMT specifications
noise (or signal/noise)	<1 mV	to distinguish SPE from noise, depends on PMT gain
timing resolution	few ns	to distinguish S1 from S2 component
power	< 0.2 W/PMT	used successfully in the WA105 DP demonstrator $3 \times 1 \times 1$ m^3 detector
analog-to-digital converter (ADC) dynamic range	TBD	depending on simulation results, see section 5.4.3
Electrical		
HV range	0–2500V	individual cable per each PMT
HV resolution	1 V	fine tuning of PMT gain
HV noise	<100 mV	extra filtering will be required
HV grounding	isolated	HV outputs shall be floating, crate ground is independent of the return of the HV channels.
PMT placement	isolated	PMT's electrically shielded from the TPC cage
Mechanical		
temperature	cryogenic	PMTs operated in LAr and tested in liquid nitrogen
pressure	2 bar	the argon column will be about 10 m high

5 PMTs operative on 3x1x1 taking data under various conditions



IDR:
Array of 720 TPB coated PMTs Hamatsu R5912-MOD20
(1/m^2 similarly as in NP02) on the cryostat membrane floor



36 PMTs procured and prepared for NP02

Physics requirements

- Converged on same set of physics requirements for SP-PDS and DP-PDS. Photon detector has to provide:
  - Event triggering
  - Event t0 reconstruction
  - Event energy reconstruction

Simulation studies ongoing

to fulfil the DUNE primary physics program. In particular:

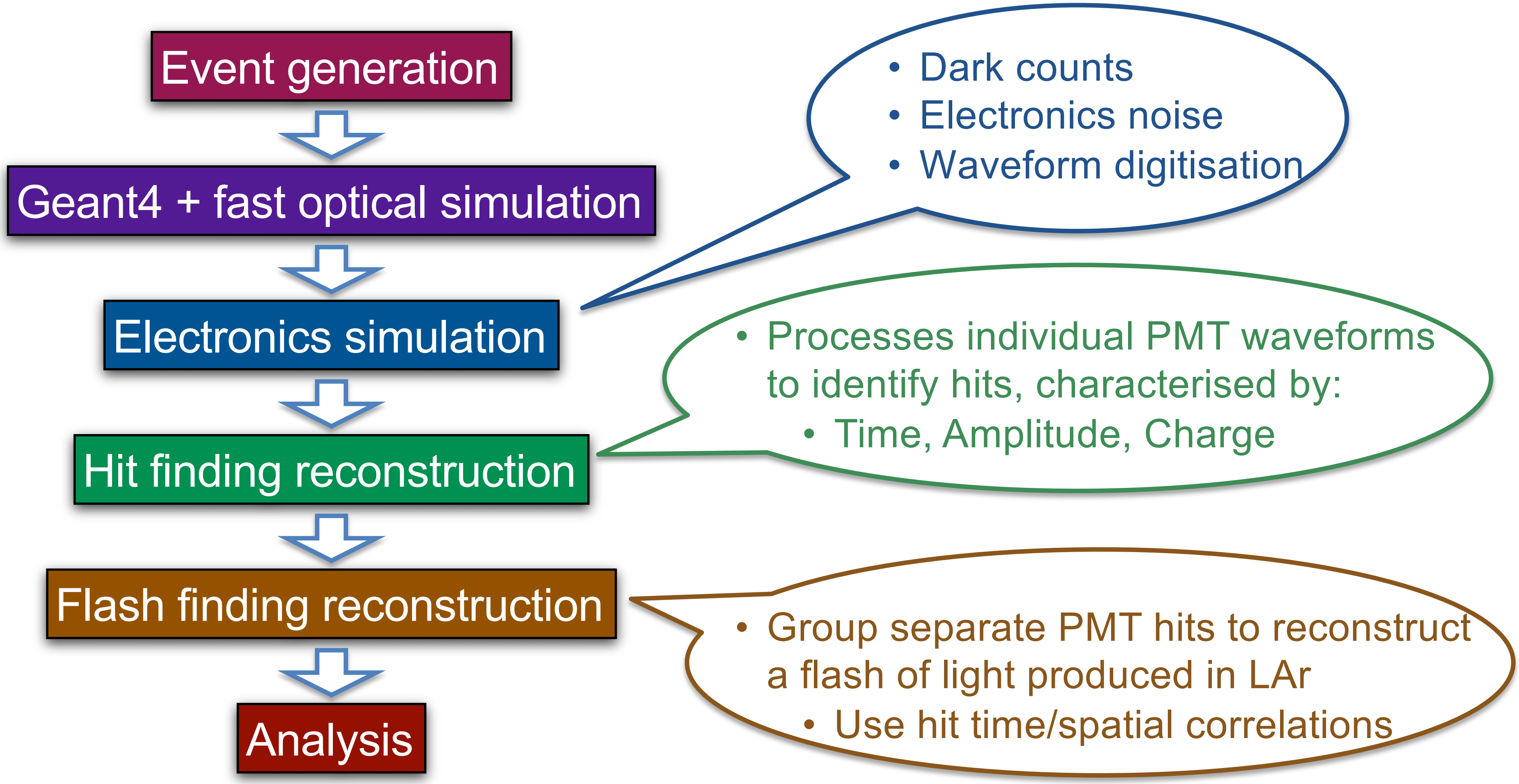
		Supernova Bursts	Nucleon Decays	Atm. Neutrinos	Beam Neutrinos
T0 for	fiducial volume		X	X	
	TPC drift correction	X	X	X	
	sub-ms timing	X			
	Triggering	X	X	X	
	Direct calorimetry	X	X		X
	Position Reconstruction	X	X	X	
	Michel *e* Detection		X	X	X

Requirements

X Additional opportunities

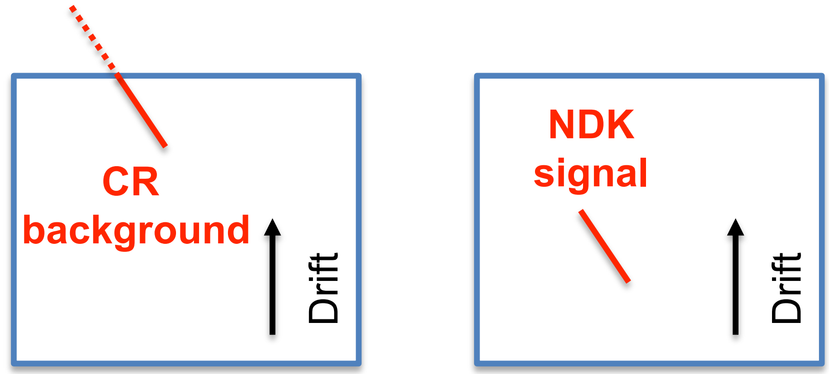
Simulation studies for TDR

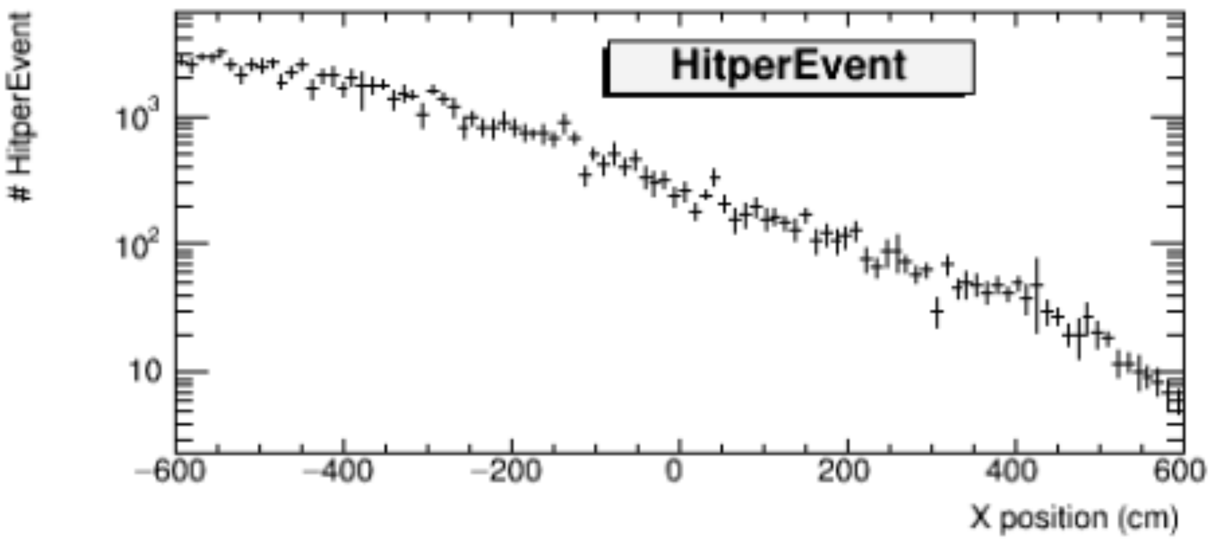
- Developing TDR studies based on full sim/reco chain in LArSoft:



Event t0 reconstruction studies

- **Requirement**: provide t0 for non-beam events, primarily (but not only) to fiducialize proton decay candidate events





- **Now:** understanding no. reconstructed PMT hits in PDK signal events (example: $p \rightarrow \nu K^+$)

- **TDR goal**: flash reconstruction efficiency versus position in FD

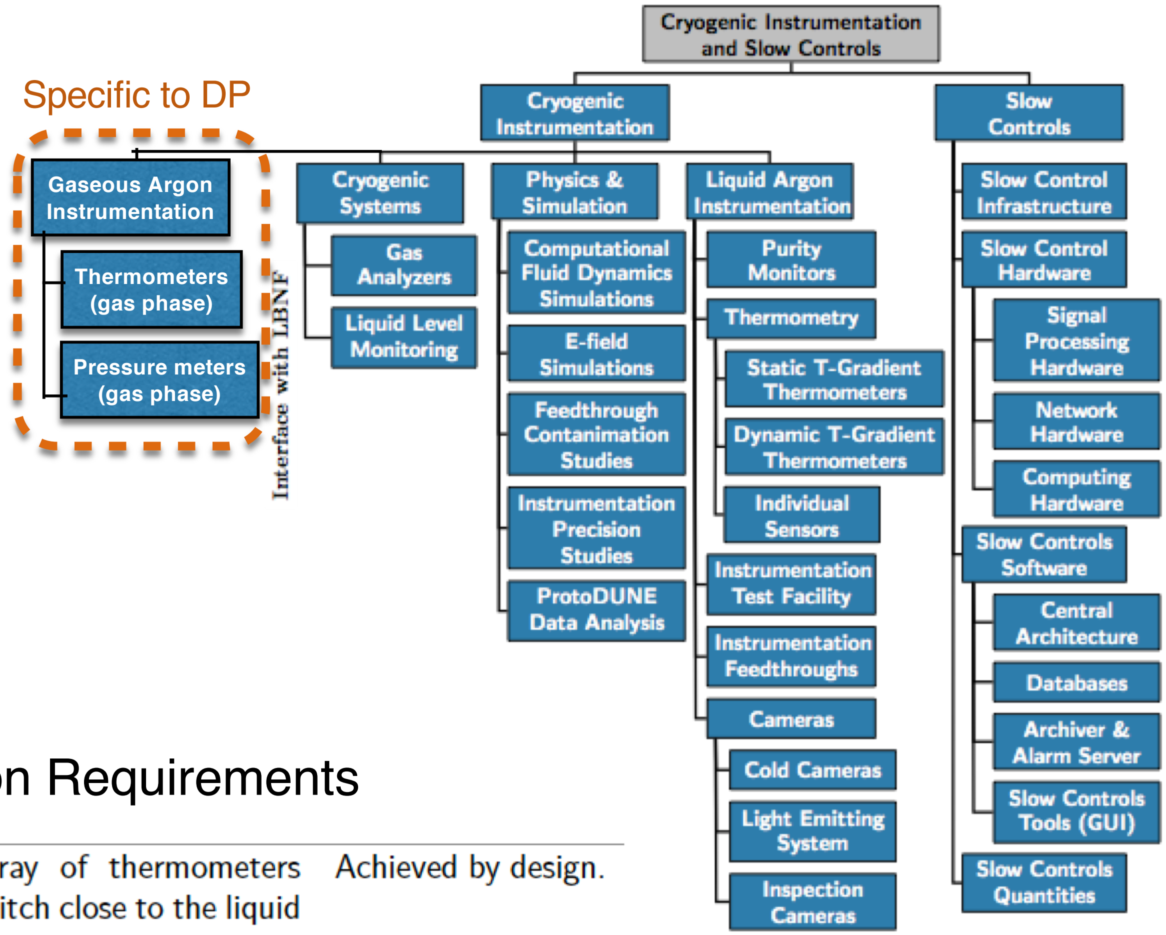
- FE readout (nominal design) or trigger farm (alternative design) hardware and firmware or software development for trigger primitive generation.
- FE computing for hosting of DAQ data receiver (DDR), DAQ primary buffer (primary buffer) and data selector.
- Back-end computing for hosting MTL, EB and the OOB dispatcher processes.
- External trigger logic and its host computing.
- Algorithms to generate trigger commands that perform data selection.
- Timing distribution system.
- DAQ data handling software including that for receiving and building events.
- The online monitoring (OM) of DAQ performance and data content.
- Run control software, configuration database, and user interface
- Rack infrastructure in the central utility cavern (CUC) for readout electronics, FE computing, timing distribution, and data selection.
- Rack infrastructure on surface at SURF for back-end computing.

Common back-end approach for SP/DP

- DAQ: receives data from 245 10 Gbit/s ethernet optical links from uTCA crates
- 240 Charge Readout links: continuous data streaming at 2.5 MHz, no zero skipping, with lossless compression (factor 10) → link occupancy <2 Mbit/s
- 5 Light Readout links
- Back-end defining trigger primitives, global triggers and data persistency in streams (beam, comics, SNb etc on disk). Common developments ongoing for FPGA online processing of data received from optical links. Finalization of data formats and protocols.

CISC-DP Scope

- The scope of CISC for DP is same as SP except for the following:
  - Specific to DP, CISC will provide instrumentation to monitor the temperature and pressure in the gas phase located above the liquid phase.



DP-specific Instrumentation Requirements

Thermometer density gas phase (DP)	$>$ 1/cm (vert.), $\sim$ 1 m (horiz.)	Vertical array of thermometers with finer pitch close to the liquid level to measure the temperature gradient in the gas phase.	Achieved by design.
Pressure meters precision (DP)	$<$1 mbar	To measure the pressure (density) of the gas phase; based on ProtoDUNE-DP design	WA105 DP demonstrator / ProtoDUNE-DP design $<$ 1 mbar

Plans towards the TDR

- The cryostat penetrations for DP cryostat are yet to be defined for instrumentation devices; based on final locations and port design, need to understand cable routing plans.
- For cryogenic instrumentation devices,
  - same designs as SP are envisioned, but may require shielding (e.g. Purity Monitors, Temperature profilers) due to high fields in DP. A preliminary Comsol simulation will be needed to understand location and design of the proper Faraday cage.
  - The base designs are largely tested in ProtoDUNE-SP; plan to test full designs (e.g. including shielding/support structure etc.) for DP in post-LS2 running of ProtoDUNE-DP
  - Need to make a detailed plan with other consortia for support structure installation for some devices. E.g. RTDs can be mounted on PMT or CRP support structures or one can attach them to the ground planes — need to make a decision; 3D models of those structures will be needed to understand this.
  - Need more involvement and feedback from people working on cryogenic instrumentation for ProtoDUNE-DP
- DP-specific Computational Fluid Dynamics (CFD) Simulations planned (done by SDSU group)
  - Model the ProtoDUNE-DP liquid and gas regions with the same precision as the FD.
  - Perform a CFD study to determine the feasibility of a wier for DP; this helps to determine if it can be used to clean the LAr surface before the extraction grid is submerged in the DP module.
- Slow controls performance of the CERN system for ProtoDUNE-DP needs to be understood/evaluated along with assessing what updates/improvements will be needed for FD
- CISC-DP TDR builds largely from the SP draft — first draft due early next year, work underway

Conclusions:

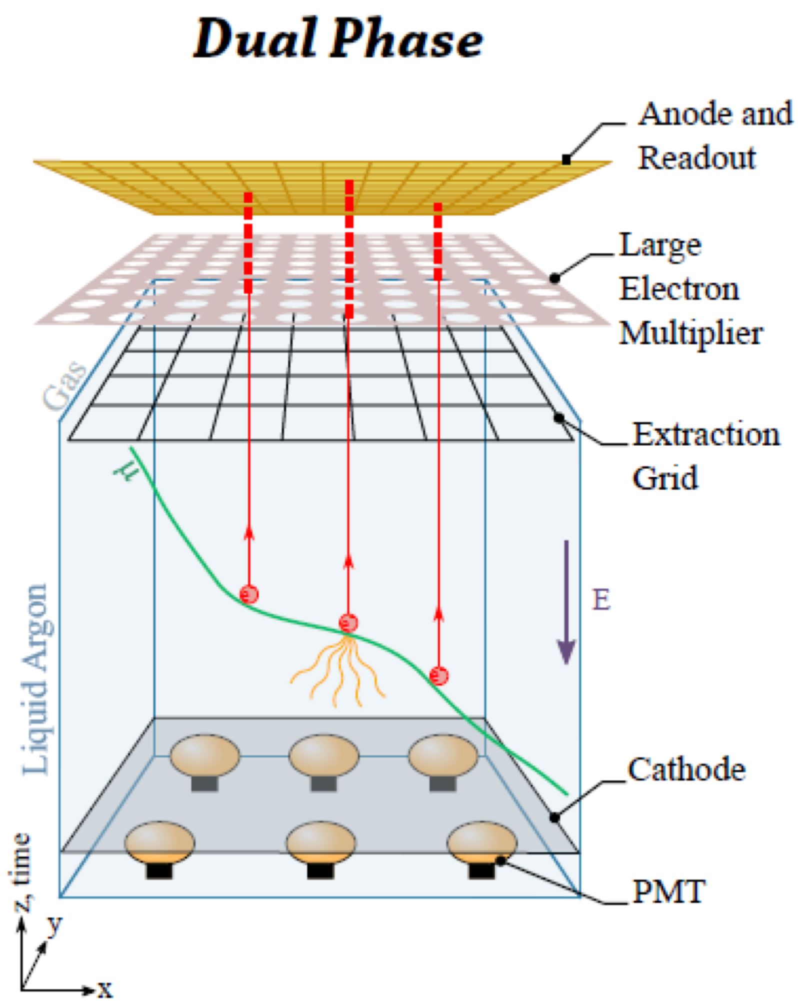
- The DP-IDR describing the dual-phase design being evolved to the TDR level

- The DP far detector design is based on the elements produced for protoDUNE-DP, some structure/electrical modifications are expected for the HV system components. Completion of simulation studies for the light readout system. Charge readout electronics already stable and compatible with common DAQ scheme. CISC specific DP aspects being finalized.

- Looking forward to the return of operation of protoDUNE-DP to be mostly included in the CRP chapter.

- Inclusion of costing (developed) and finalization of installation procedures → technical coordination chapter.

- Many thanks to all the editorial team.



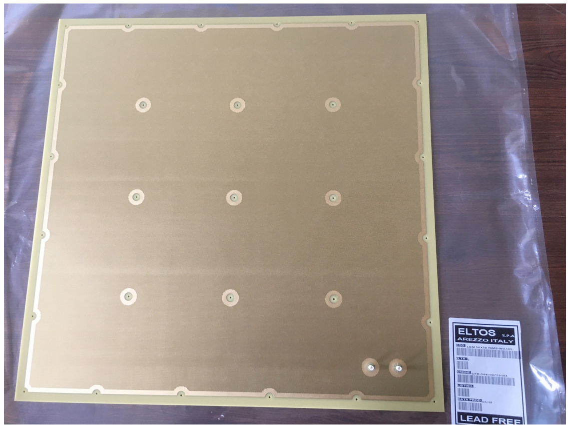
Dual-phase design:

Long drift, high S/N:

- Vertical drift → extraction of electrons from the liquid and multiplication with avalanches in micro-pattern detectors LEM (Large Electron Multipliers) operating in pure argon gas

→ tunable LEM gain ~20 , two symmetric collection views, coupling to cold electronics

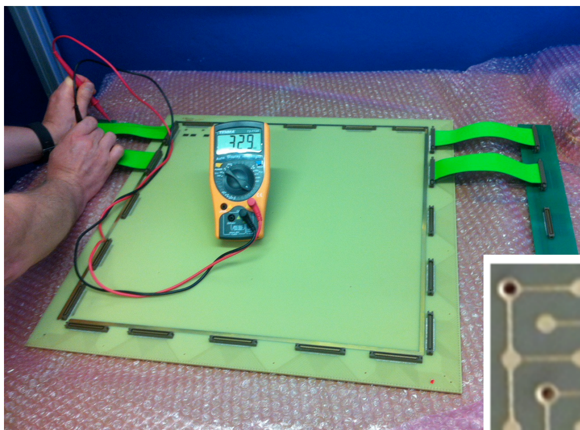
- Light readout performed with an array of cryogenic photomultipliers below the cathode



LEM design
CFR-035 for NP02

Table 2.3: Tolerance values on various LEM parameters

Parameter	Value and tolerance
Dielectric thickness	$1.00^{+0.00}_{-0.05}$ mm
Average total thickness	$1.20^{+0.00}_{-0.06}$ mm
Dimensions	$499.5^{+0.00}_{-0.30}$ mm $\times$ $499.5^{+0.00}_{-0.30}$ mm
Final PCB thickness	$1.10^{+0.02}_{-0.05}$ mm
Active hole diameter	$0.50^{+0.00}_{-0.01}$ mm
Rim size	40 ± 4 μm
Electrical insulation	$>$1 GΩ



Anodes

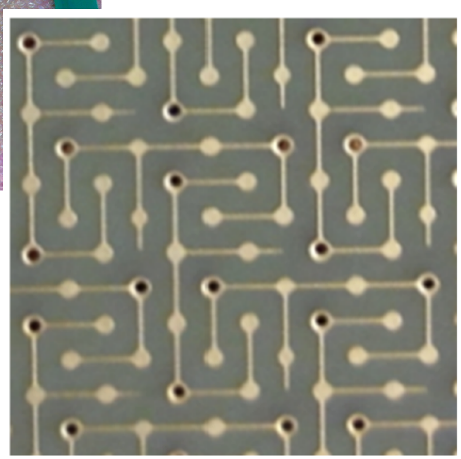


Table 2.4: Specifications for the anode dimensions

Parameter	Value and tolerance
Dimensions	$499.5^{+0.2}_{-0.0}$ mm $\times$ $499.5^{+0.2}_{-0.0}$ mm
PCB thickness	3.5 ± 0.05 mm
PCB sagitta	$<$ 1 mm

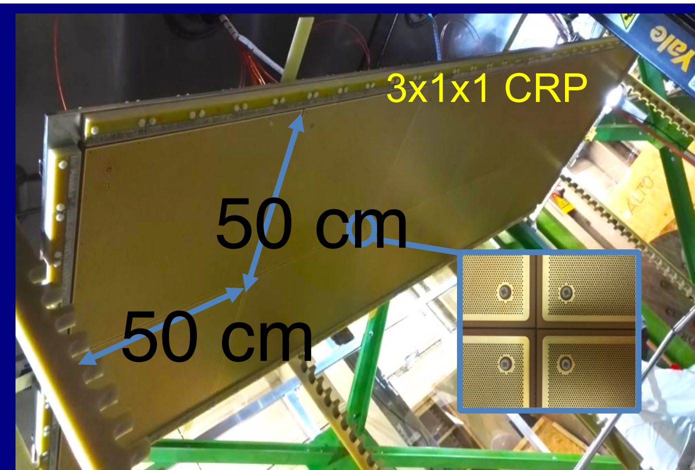
36 LEM-Anode sandwiches per CRP

→ 2880 LEM-Anode sandwiches per FD-DP module

3x3 m^2 CRPs integrating 36 LEM-anode sandwiches (50×50 cm^2) and their suspension feedthroughs.

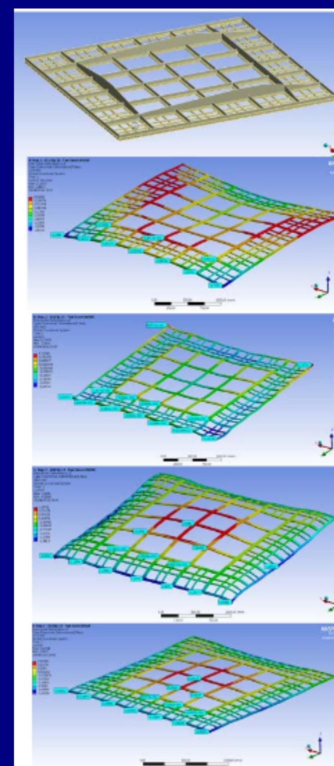
Specifically designed for Protodune-DP, 3x1x1 CRP had different design in stainless steel →

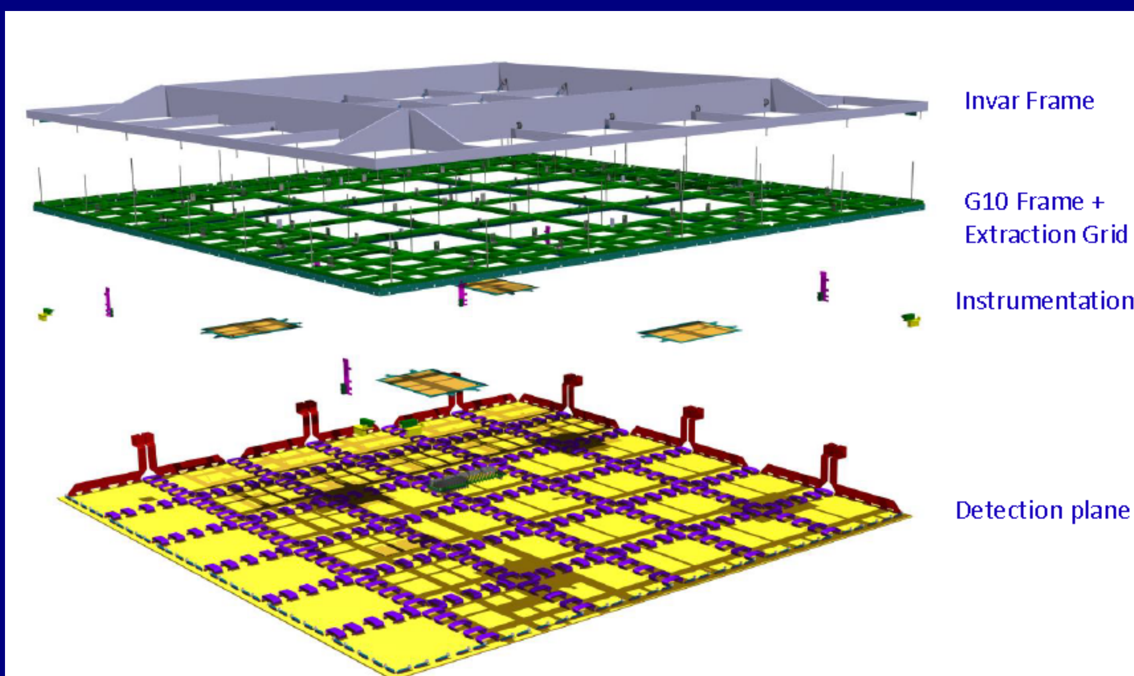
- → ProtoDUNE-DP design based on Invar frame + G10 frame incorporating the LEM. Decoupling mechanisms in between Invar and G10
- Ensure planarity conditions +-0.5 mm (despite gravity and temperature gradient effects) over the 3x3 m^2 surface
- Ensure minimal dead space in between CRPs

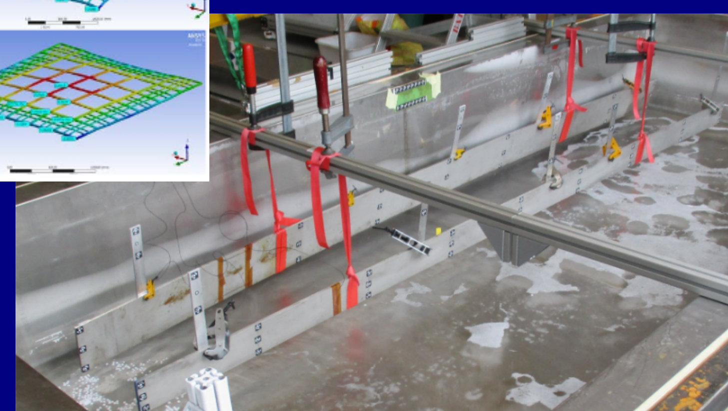


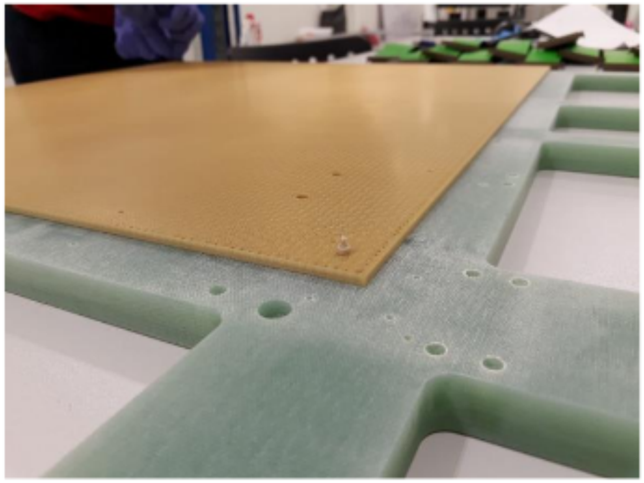
CRP mechanical structure design:

→ Simulations + campaign of cold bath tests with photogrammetry on differential effects in thermal contraction, design of decoupling mechanism









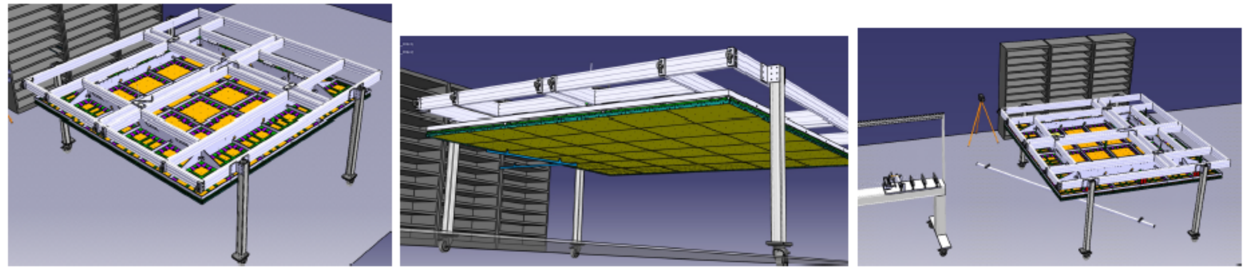
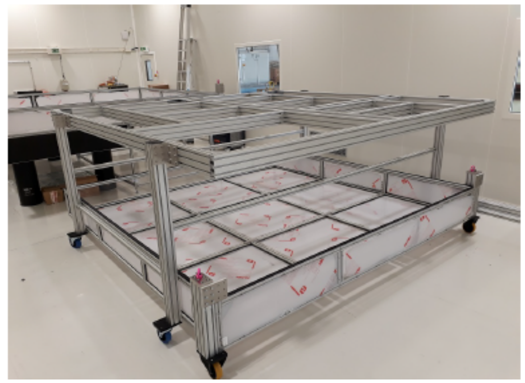
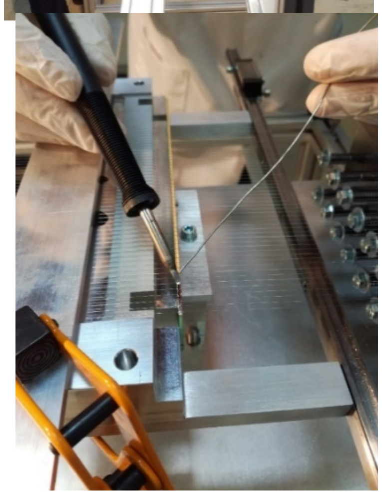


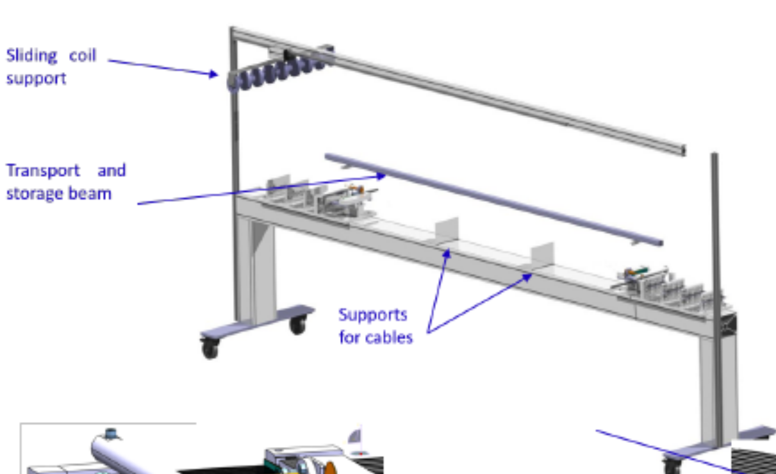
Figure 2.18: Some assembly steps: LEM and anode connection and extraction grid module installation.

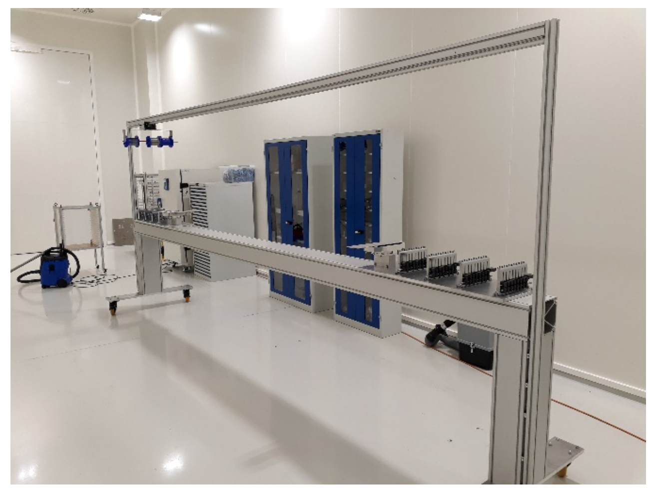


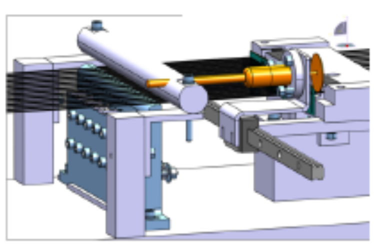
CRP assembly tooling

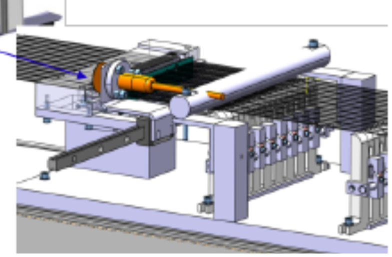


Grid mounting tooling

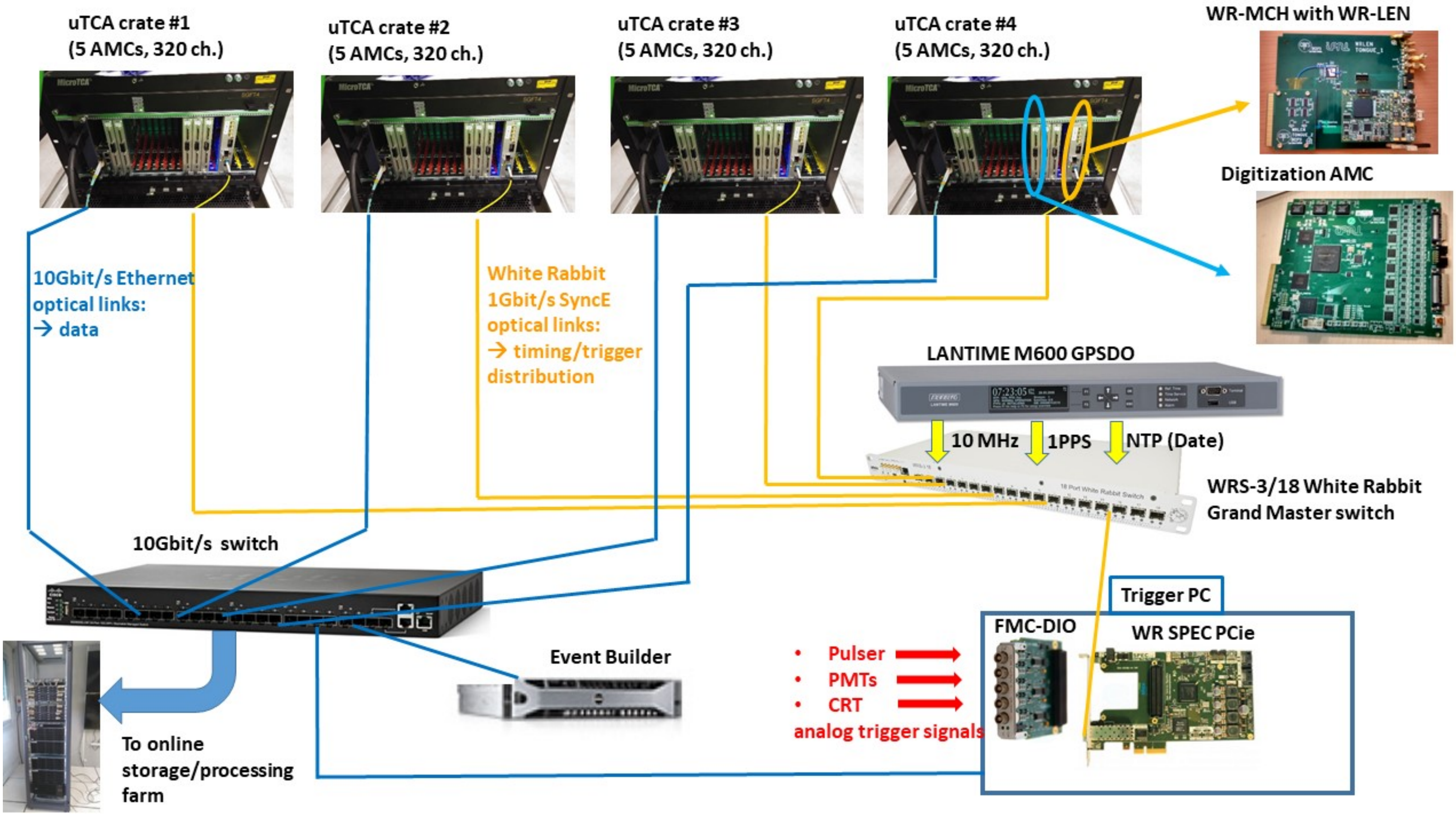






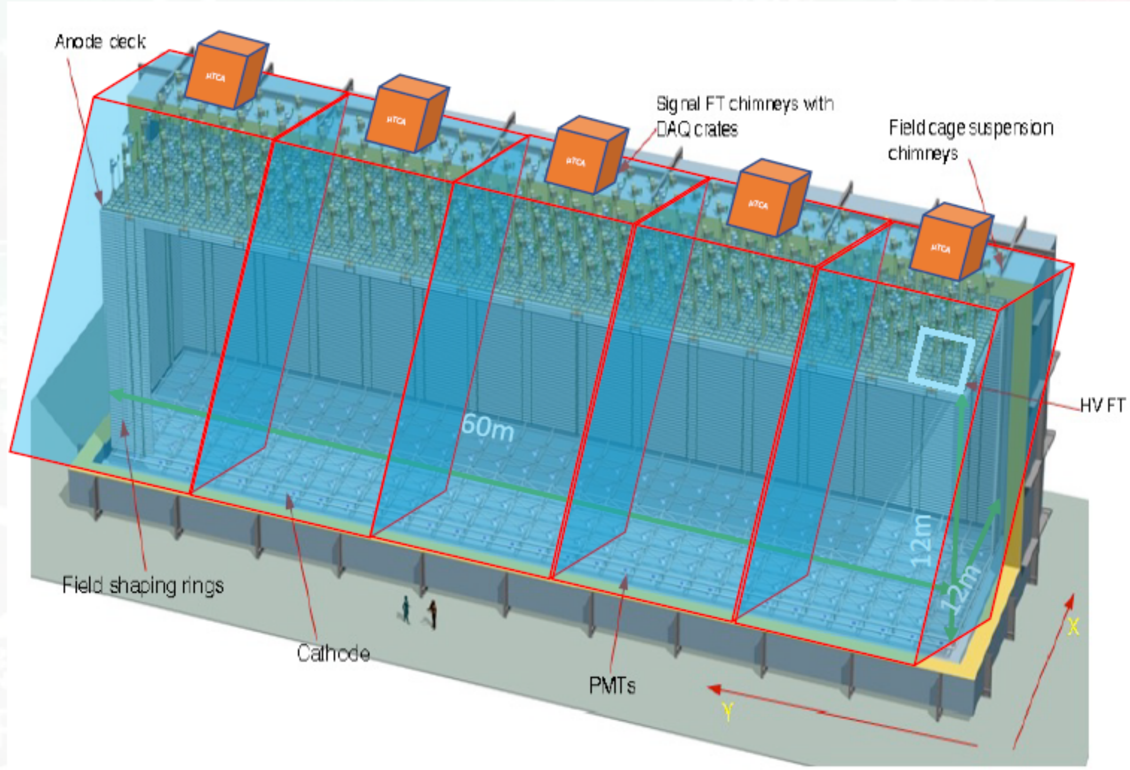


DAQ system of 3x1x1



Optimized version 1: 720 PMTs (1 PMT/ m^2)

Item	Details	Quantity
PMTs		720
FE-Cards	16 channels	45
	Components	
	printed cirquid	45
	PCB masques	1
	Mounting of components	
	Cabels SMA	720
	Catyroc	45
	ADC	45
micro-TCA crate		5
	MCH	5
	Power Module	5
	XAUI (x4)	5
	Uplink SFP+	5
	Uplink SFP+850	5
White Rabbit		5
	SPEC Card	5
	FMC DIO	5
	SFP (x2)	5



45 FE Cards + 5 Crates + 5 WR units

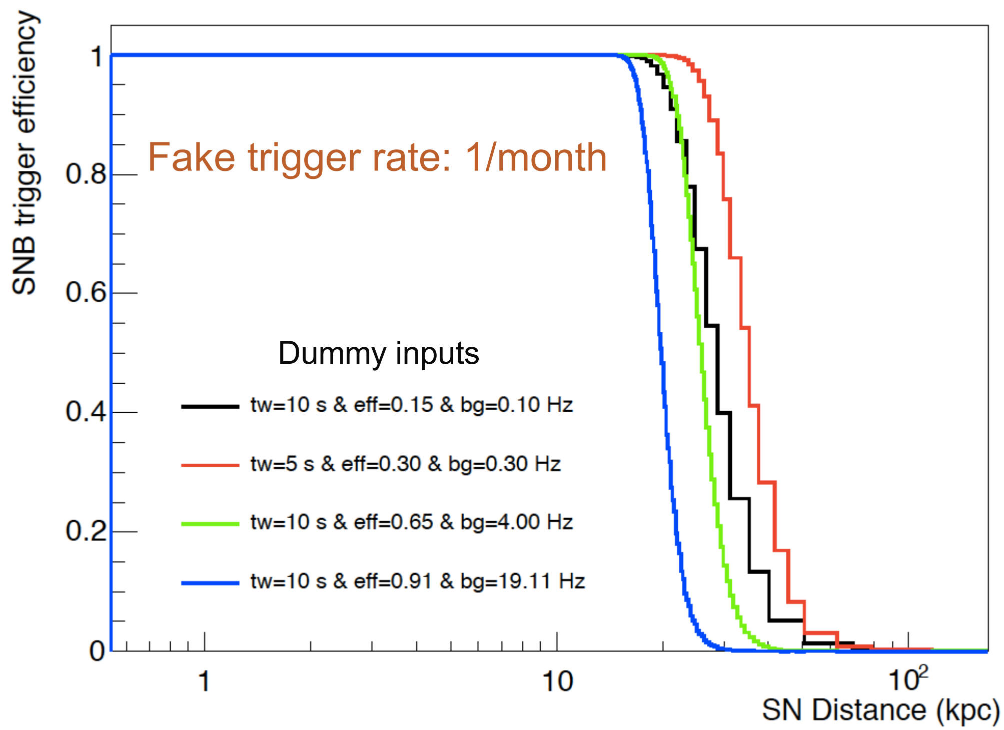
The distribution of the cards and number of crates to be optimized wrt to cable length and signal attenuation

First idea: cut detector in 5 12 m long segments
(5 x 12 m) long x 12 m wide -> 5 crates on top of the detector

Light Readout system (assuming similar photodetectors coverage as in ProtoDUNE-DP)

Event triggering studies

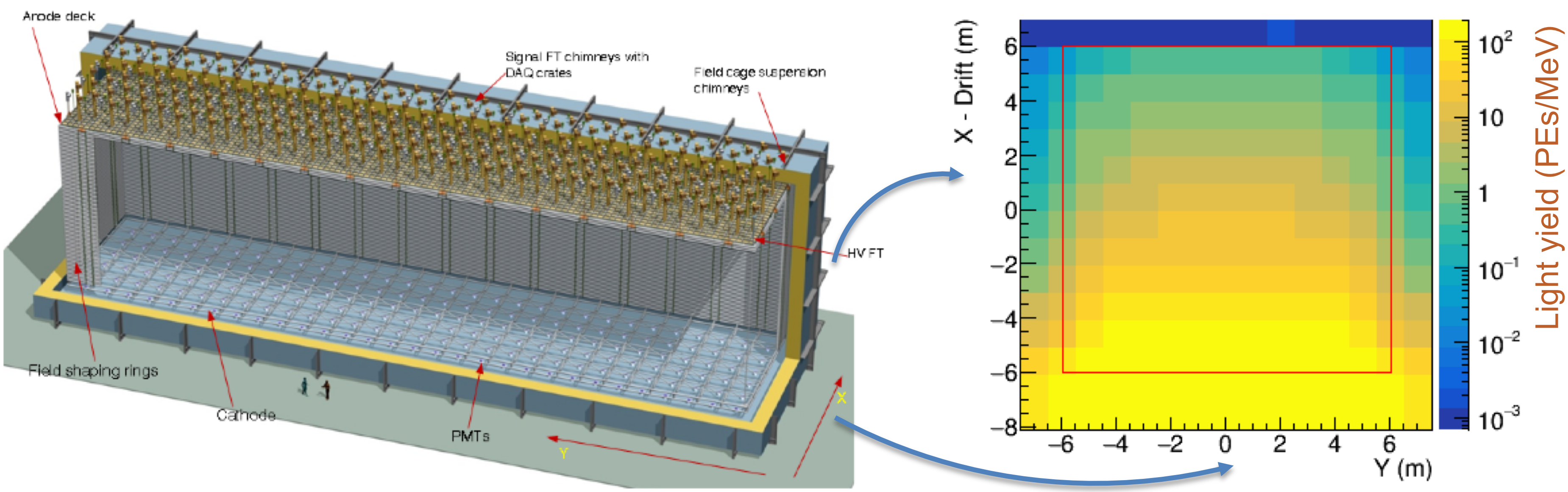
- **Requirement:** provide efficient triggering for galactic SN bursts
- **Now:** understanding how SNB trigger efficiency depends on representative values for SNν efficiency and background rate. Ongoing work to estimate those.



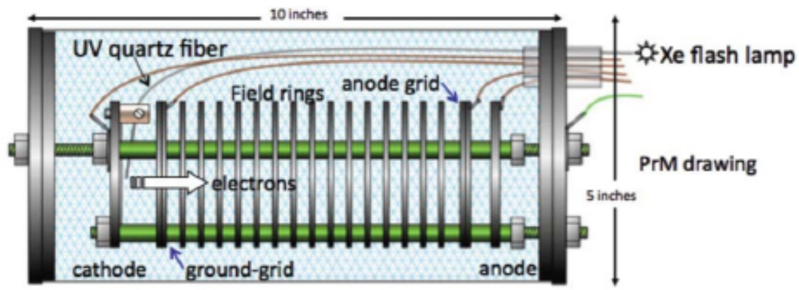
- **TDR goal:** SN burst triggering efficiency versus SN distance

Event energy reconstruction studies

- **Requirement:** provide PDS-based energy measurement based on total detected light yield, for beam and SN neutrinos
- **Now:** understanding how to correct for spatial dependence of PDS response



- **TDR goal:** PDS-based neutrino energy resolution for beam and SN ν_e CC interactions in TPC active volume



Similar needs as for SP:

- LAr cryogenic instrumentation
- Purity monitors
- Cryocameras
- Gas analysers

Specific DP controls:

- Gas temperature and pressure controls
- CRP controls:
- ➢ CRP temperature probes (36/CRP)
- ➢ CRP high accuracy level meters, capacitive grid-LEM measurements, distance meters
- ➢ Control of CRP step motors
- ➢ CRP anodes calibration
- ➢ LEM HV 41 channels/CRP, grid HV 1 channel/CRP
- PDS HV controls