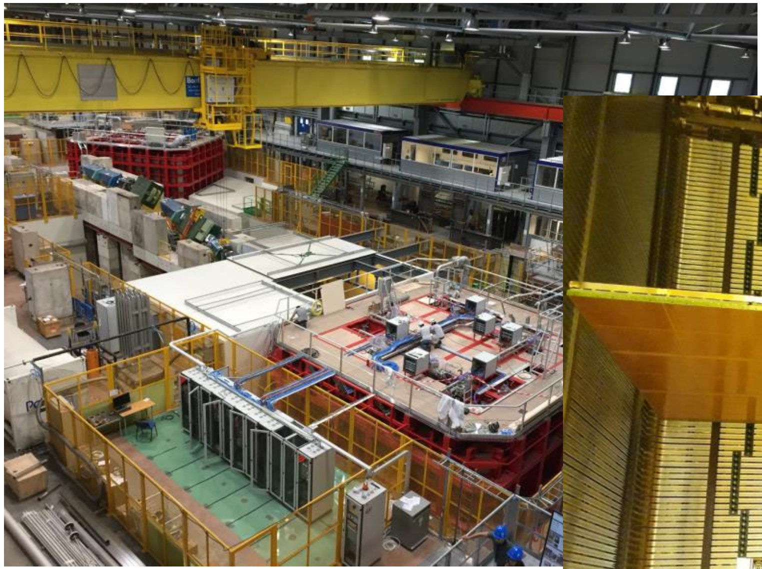
Plans for ProtoDUNE-DP (NP02) after LS2

Dario Autiero

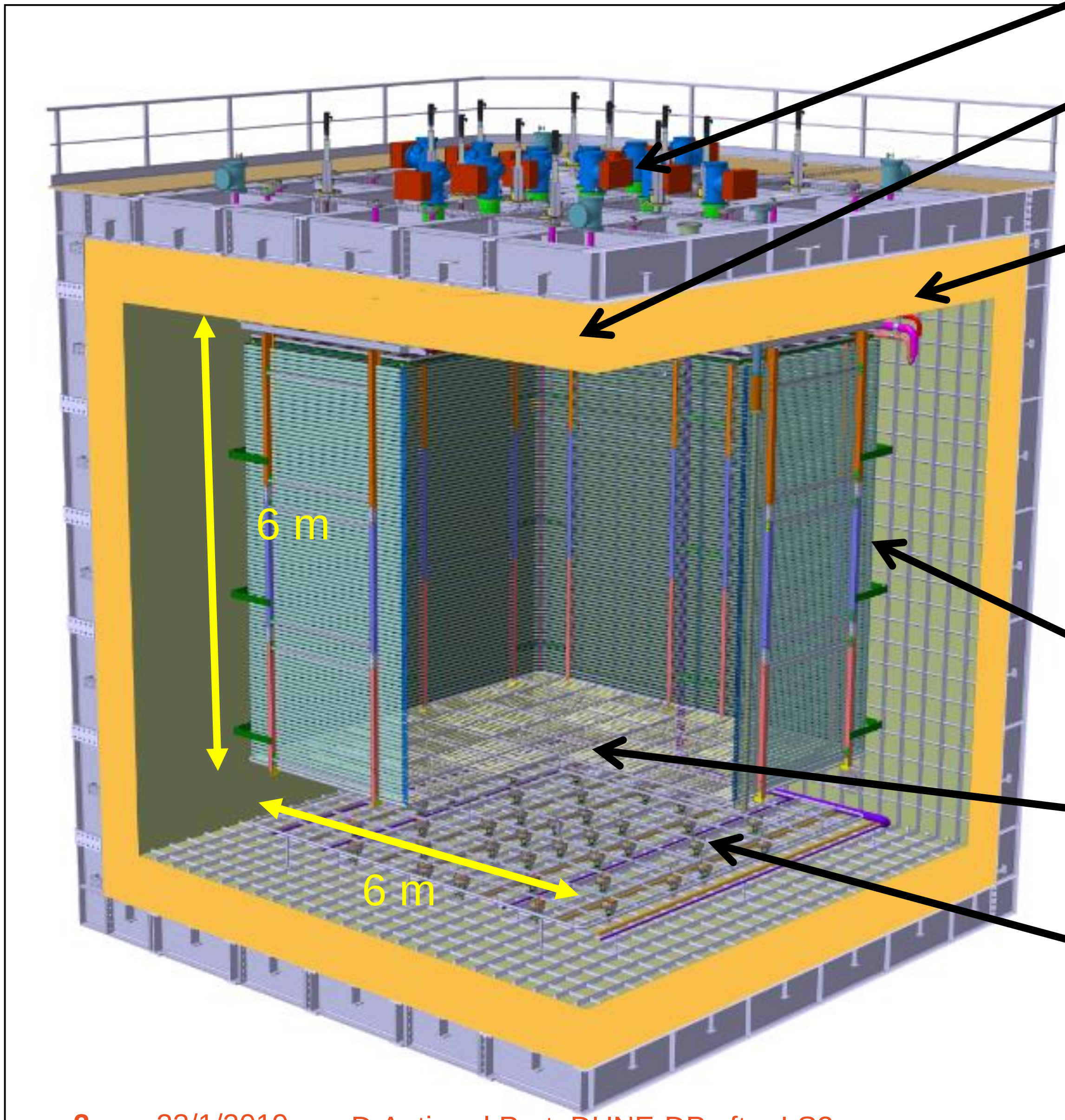
SPSC132

23/1/2019

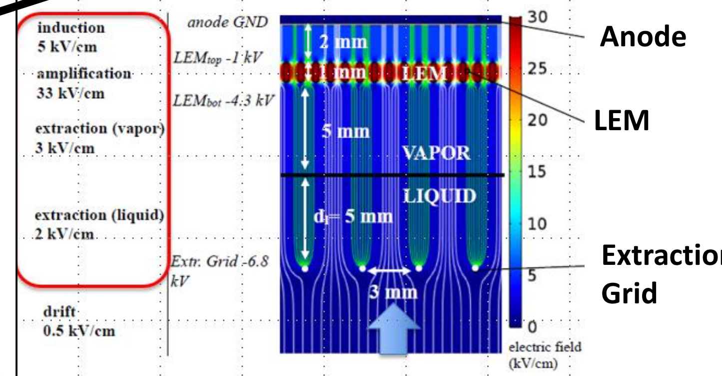


Dual-phase 10 kton design is based on ProtoDUNE dual-phase

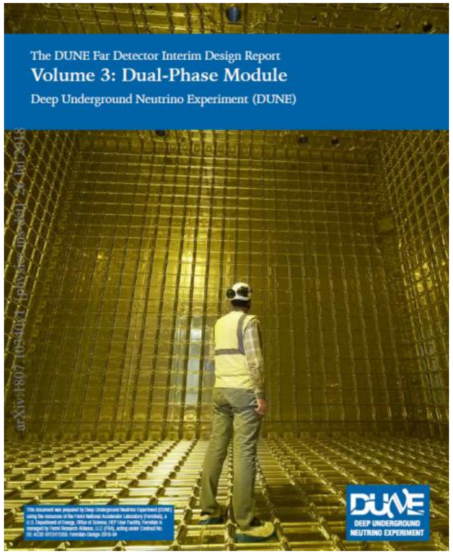
1/20 of active area of a DP 10 kton module: ProtoDUNE-DP 4 CRPs → DUNE 80 CRPs



- Digital electronics in uTCA crates
- Accessible 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



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

Consortia:

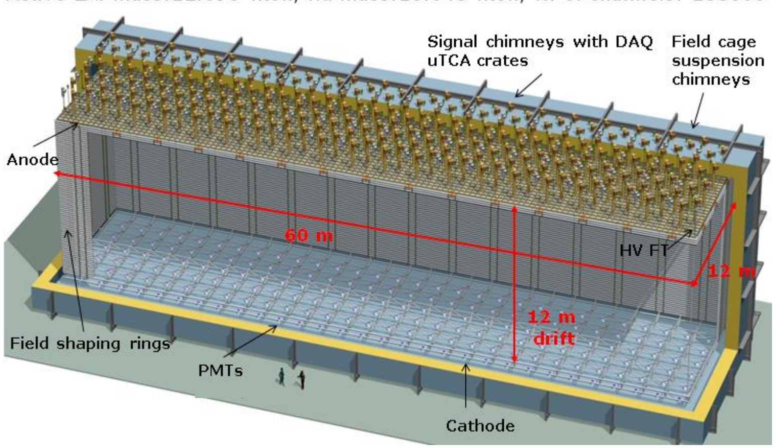
- **CRP consortium (DP):** LEMs, CRP, CRP suspension system
- **TPC Electronics (DP):** Cold charge readout electronics, signal chimneys, digital electronics for charge and light readout
- **HV system (Joint):** Field cage, cathode, VHV power supply and feedthrough
- **Photon Detection System (DP):** 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

Editorial team for the TDR DP Volume:

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 Cryo. Inst.:	**Glenn Horton-Smith, Carmen Palormares**
Integration and Installation:	**Filippo Resnati**

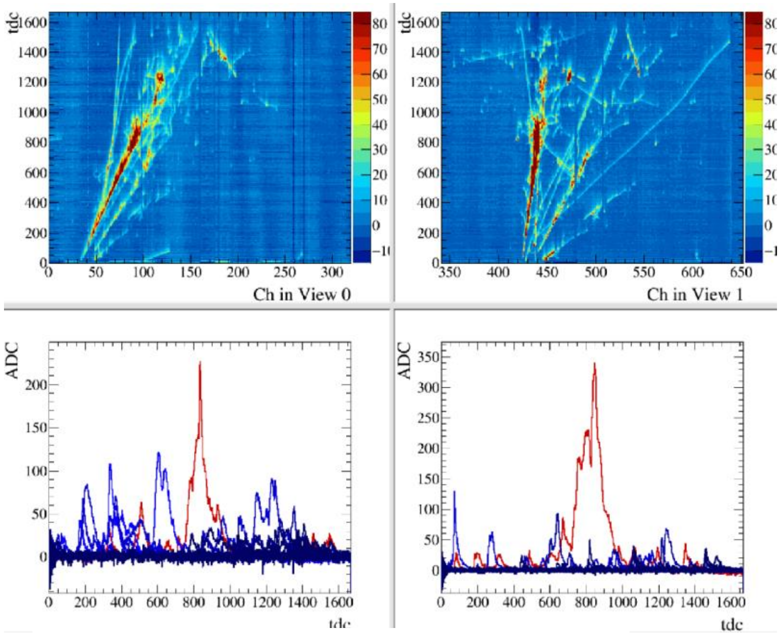
Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) DUNE Conceptual Design Report, July 2015

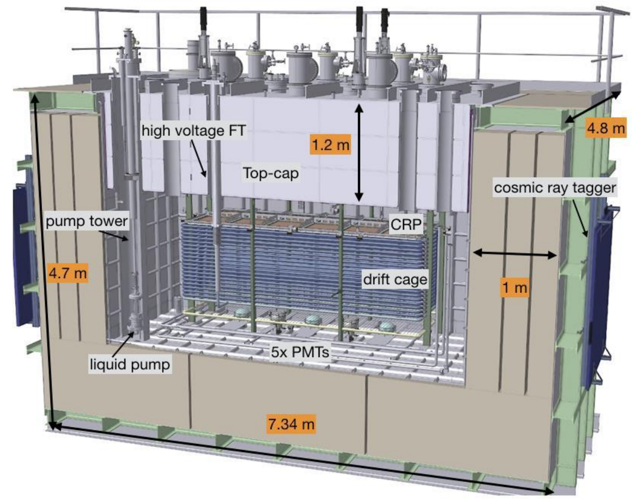
Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600



DP TDR based on ProtoDUNE-DP design
Completion of TDR editing by June 2019

3x1x1 detector operation June-November 2017



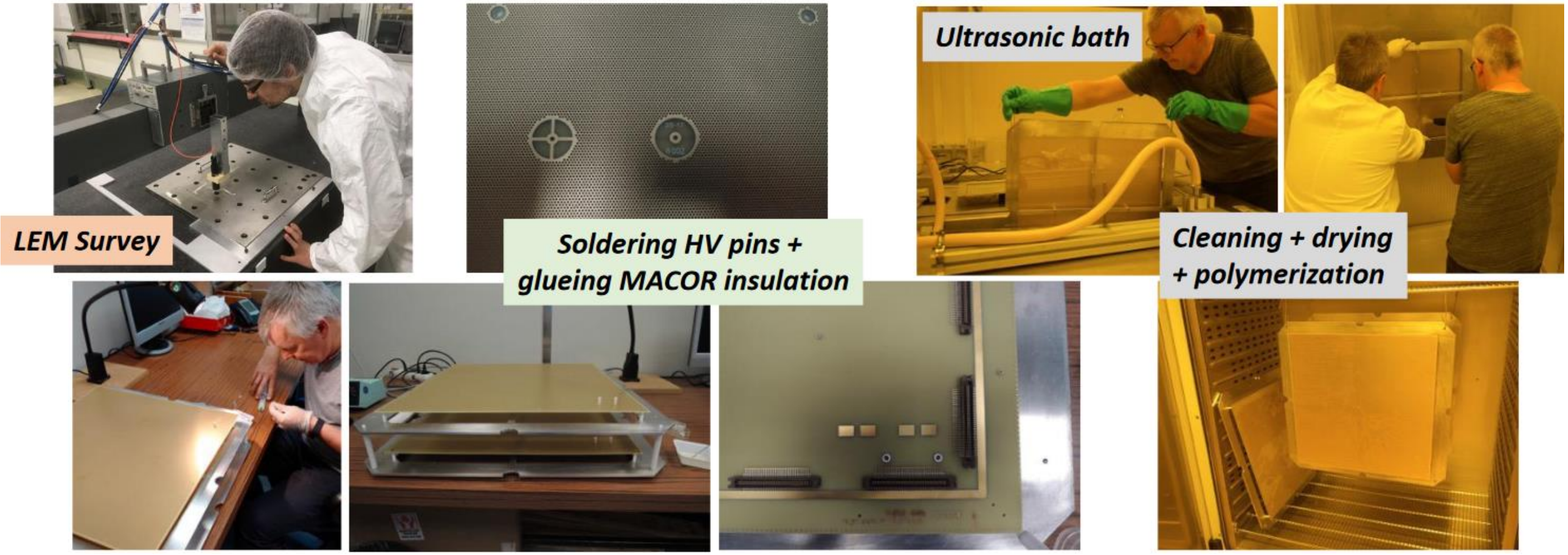


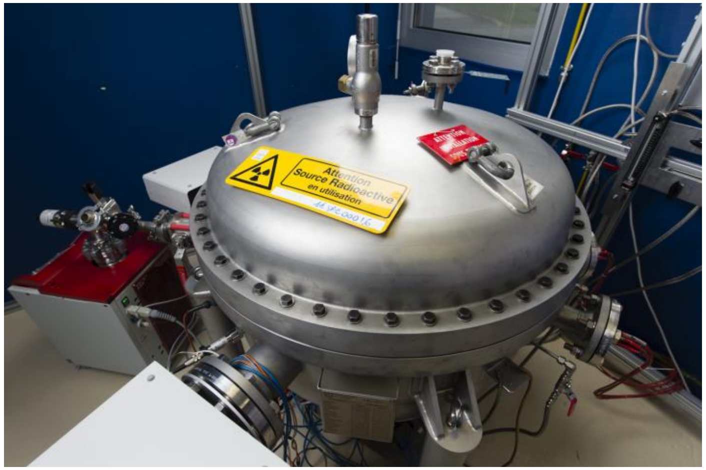
- **Successful in proving the dual-phase concept for a LArTPC at the 3m² readout scale.**
- Detector working point limited by technical HV issues with the **CRP extraction grid limited to 5 kV**
- LEM design also showed limitations, **most of run at 2.8 kV ΔV (effective gain ~3), max ΔV reached 3.1 kV → ProtoDUNE-DP design improved gaining ~300V in max ΔV**
- **CRP design already different for 6x6x6, lessons learned on HV connections**
- Very **useful experience for FE electronics and DAQ operation** → good S/N despite low detector gain
- **62 pages paper** on 3x1x1 published on JINST: https://arxiv.org/abs/1806.03317

A 4 tonne demonstrator for large-scale dual-phase liquid argon time projection chambers

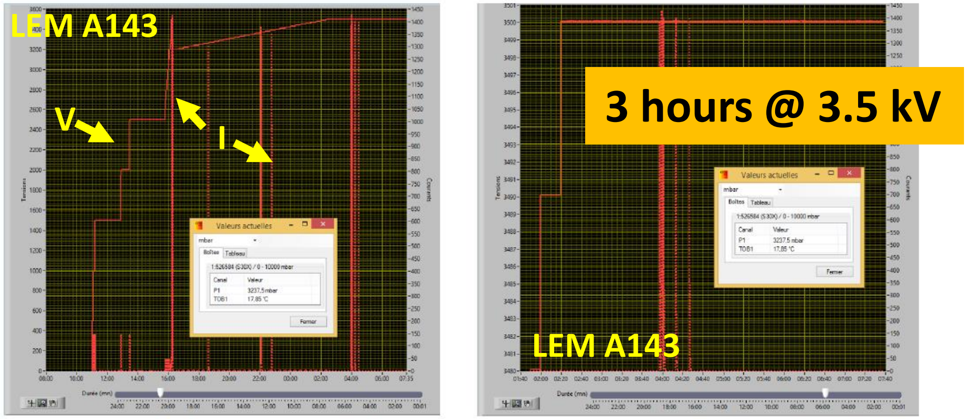
B. Aimard[q], Ch. Alt[g], J. Asaadi[v], M. Auger[b], V. Aushev[p], D. Autiero[s], M.M. Badoi[j], A. Balaceanu[j], G. Balik[q], L. Balleyguier[s], E. Bechetoille[s], D. Belver[d], A.M. Blebea-Apostu[j], S. Bolognesi[k], S. Bordoni[i,1], N. Bourgeois[e], B. Bourguille[i], J. Bremer[e], G. Brown[v], L. Brunetti[h], D. Caiulo[s], M. Calin[c], E. Calvo[d], M. Campanelli[f], K. Cankocak[m], C. Cantini[g], B. Carlus[s], B.M. Cautisanu[j], M. Chalifour[e], A. Chappuis[q], N. Charitonidis[e], A. Chatterjee[v], A. Chiriacescu[c], P. Chiu[g], S. Conforti[t], P. Cotte[k], P. Crivelli[g], C. Cuesta[d], J. Dawson[a], I. De Bonis[q], C. De La Taille[t], A. Delbart[k], D. Desforge[k], S. Di Luise[i], B.S. Dimitru[j], F. Doizon[s], C. Drancourt[q], D. Duchesneau[q], F. Dulucq[t], J. Dumarchez[r], F. Duval[e], S. Emery[k], A. Ereditato[b], T. Esanu[c], A. Falcone[v], K. Fusshoeller[g], A. Gallego-Ros[d], V. Galymov[s], N. Geffroy[q], A. Gendotti[g], M. Gherghel-Lascu[j], C. Giganti[r], I. Gil-Botella[d], C. Girerd[s], M.C. Gomoiu[j], P. Gorodetzky[a], E. Hamada[n], R. Hanni[b], T. Hasegawa[n], A. Holin[f], S. Horikawa[g], M. Ikeno[n], S. Jiménez[d], A. Jipa[c], M. Karolak[k], Y. Karyotakis[q], S. Kasai[o], K. Kasami[n], T. Kishishita[n], I. Kreslo[b], D. Kryn[a], C. Lastoria[d], I. Lazanu[c], G. Lehmann-Miotto[e], N. Lira[v], K. Loo[m], D. Lorca[b], P. Lutz[b], T. Lux[i], J. Maalampi[m], G. Maire[e], M. Maki[n], L. Manenti[f], R.M. Margineanu[j], J. Marteau[s], G. Martin-Chassard[t], H. Mathez[s], E. Mazzucato[k], G. Misitano[m], B. Mitrica[j], D. Mladenov[e], L. Molina Bueno[g], C. Moreno Martínez[i], J.P. Mols[k], T.S. Mosu[j], W. Mu[g], A. Munteanu[j], S. Murphy[g], K. Nakayoshi[n], S. Narita[l], D. Navas-Nicolás[d], K. Negishi[l], M. Nessi[e], M. Niculescu-Oglinzanu[j], L. Nita[c], F. Noto[e], A. Noury[a], Y. Onishchuk[p], C. Palomares[d], M. Parvu[c], T. Patzak[a], Y. Pénichot[k], E. Pennacchio[s], L. Periale[g], H. Pessard[q], F. Pietropaolo[e], Y. Piret[k], B. Popov[r], D. Pugnere[s], B. Radics[g], D. Redondo[d], C. Regenfus[g], A. Remoto[q], F. Resnati[e], Y.A. Rigaut[g], C. Ristea[c], A. Rubbia[g], A. Saftoiu[j], K. Sakashita[n], F. Sanchez[i], C. Santos[a], A. Scarpelli[a], C. Schloesser[g], L. Scotto Lavina[r], K. Sendai[n], F. Sergiampietri[e], S. Shahsavarani[v], M. Shoji[n], J. Sinclair[b], J. Soto-Oton[d], D.L. Stanca[j], D. Stefan[u], P. Stroescu[j], R. Sulej[u], M. Tanaka[n], V. Toboaru[j], A. Tonazzo[a], W. Tromeur[s], W.H. Trzaska[m], T. Uchida[n], F. Vannucci[a], G. Vasseur[k], A. Verdugo[d], T. Viant[g], S. Vihonen[m], S. Vilalte[q], M. Weber[b], S. Wu[g], J. Yu[v], L. Zambelli[q], M. Zito[k]

[a] *AstroParticule et Cosmologie (APC), Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Observatoire de Paris, Sorbonne Paris Cité, Paris, France*
[b] *University of Bern, Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics (LHEP), Bern, Switzerland*
[c] *University of Bucharest, Faculty of Physics, Bucharest, Romania*
[d] *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[e] *CERN, Geneva, Switzerland*
[f] *University College London, Dept. of Physics and Astronomy, London, United Kingdom*
[g] *ETH Zurich, Institute for Particle Physics, Zurich, Switzerland*
[h] *Fermilab, Batavia, IL, USA*
[i] *Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona), Spain*
[j] *Horia Hulubei National Institute of R&D for Physics and Nuclear Engineering - IFIN-HH, Magurele, Romania*
[k] *IRFU, CEA Saclay, Gif-sur-Yvette, France*





Fully automated HV training in GAr @3.3 bar up to 3.5kV

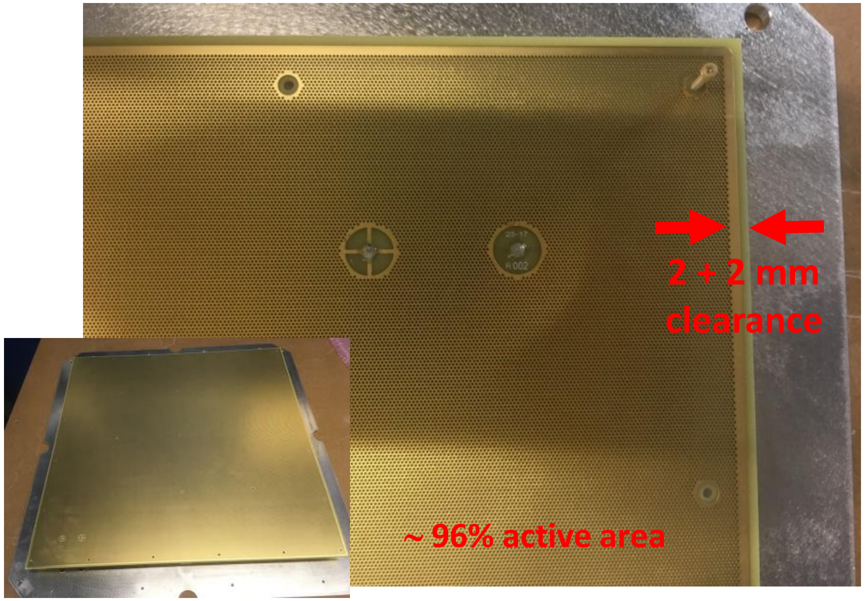


Procurement, preparation and QA/QC chain at Saclay

→ All LEMs individually characterized at at 35kV/cm in a high pressure argon gas chamber 3.3 bar (similar gas density conditions as at cold immediately above LAr level)

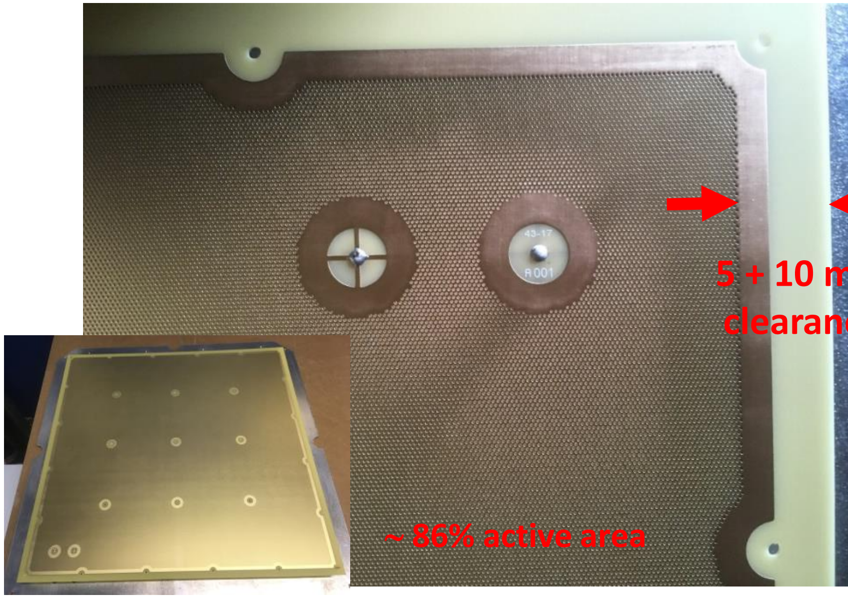
Evolution of LEM design for ProtoDUNE-DP

CFR-34 – 311 prototype



spark rate : ~20/h
(> 45% of sparks near edges or corners)

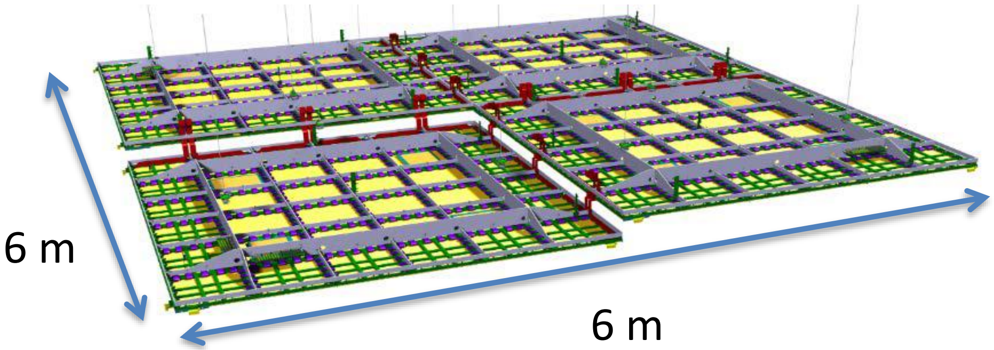
CFR-35 – NP02

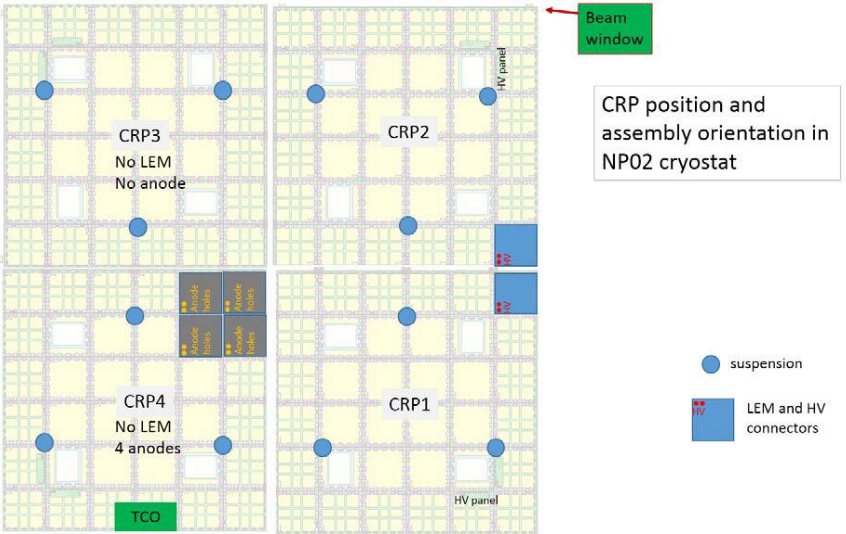


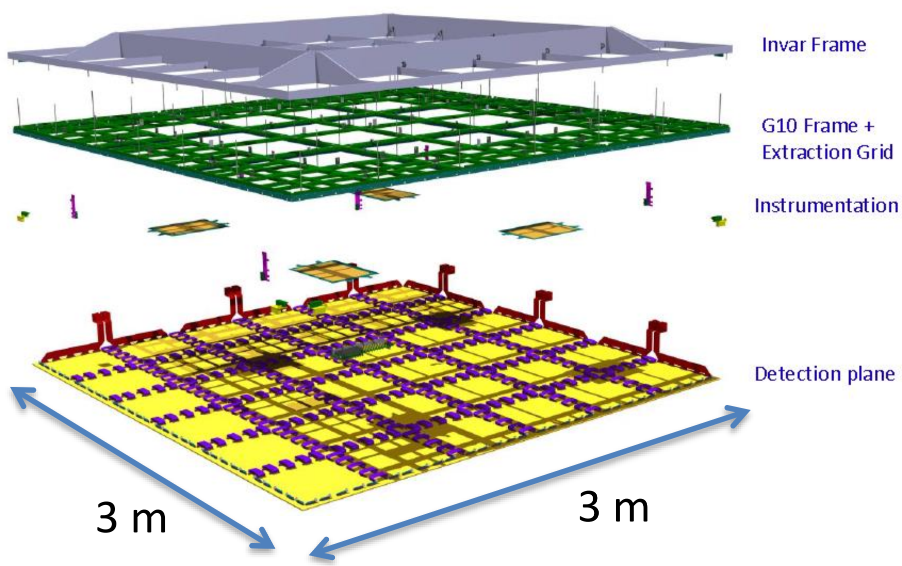
All LEMs tested up to 3.4 – 3.5 kV with
< 1 spark / 20 minutes

→ **Conservative guard ring design allowed increasing by about 300V the max. operating voltage**

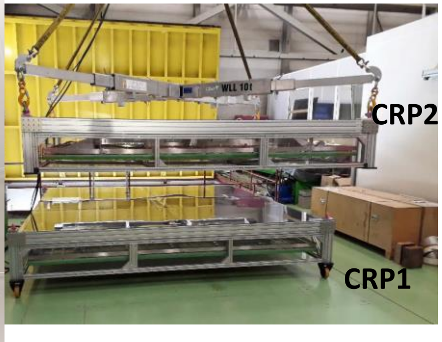
Charge Readout Planes in ProtoDUNE-DP



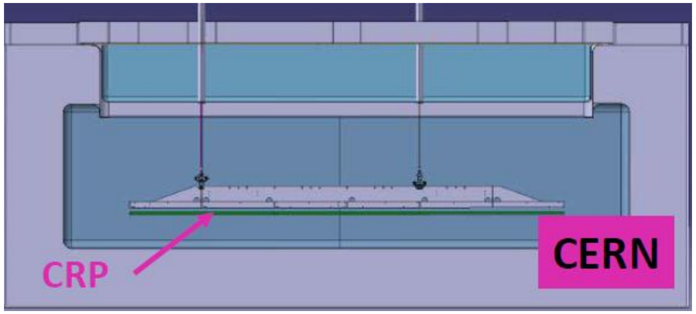




- ➢ **2 CRPs fully instrumented with LEMs and anodes:**
- **CRP#1 built in May-June 2018**
- **CRP#2 built in October 2018**
- ➢ **2 CRPs without LEMs:**
- **CRP#3 built in September 2018**
- **CRP#4 completed in January 2019, single phase-like readout on 4 anodes**



CRP Cold Box test in Hall 182



→ Perform electrical and mechanical tests of each final CRP in nominal thermodynamic conditions:

- Characterization of the HV operation of each LEM
- Characterization of the HV operation of the extraction grid
- CRP planarity test
- Test the tensioning of the extraction grid wires
- Test of the HV contacts and connections (LEM & grid)

First produced Charge Readout Plane inserted in the Cold Box on June 22nd

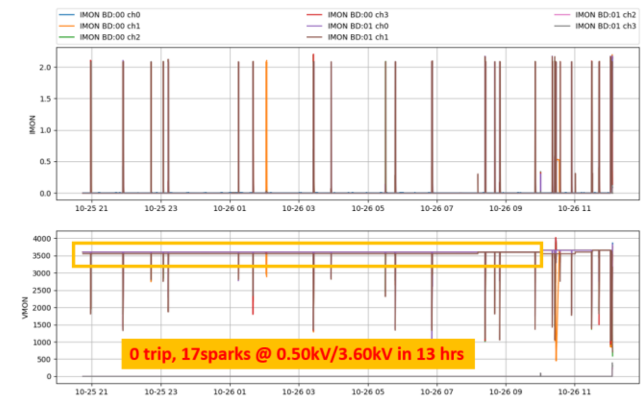
→ First cold-box tests on CRP1 22/6-9/7

- Stable LEM operation during several days at 30kV/cm. Operation voltage over the entire plane could be reached in a few minutes only: low spark rates and fast HV recovery.
- Issues with grid HV: shorts present with a few (6 to 8) LEMs, max voltage limited to 2 kV
- Issues with HV Distribution Box on CRP (HV connectors in gas): max HV reached ~4.2kV

Inspection to CRP at cold and tests at warm showed that wires were becoming loose at cold because of a thermal contraction differential aspect →

- Wires tension at warm increased from 0.6 N to 2N
- Improvements also in grid HV connection and in HV distribution box to LEM: input connectors and also removal insulating glue around resistors for top LEM (breaking some resistors, implemented recently)

CRP1 : V_{TOP} = 0.50kV and V_{BOT} = 3.60kV



→ Second cold-box test on CRP1 27/7-18/8

(wires tension increased and HV connection improved)

- 36 LEMs operated successfully for several days at a ΔV up to 35.5 kV/cm
- Grid was operated at nominal 7.5 kV together with the 36 LEMs turned on over several days.

→ CRPs 3 and 4 also tested in Cold Box (CRP4 in January)

→ CRPs cabling inside the cryostat being performed this week

CRP1 and CRP2 LEM HV Test Results (Oct. – Nov./2018)

- Liquid level in CB stable to within ~250µm; T_{LEM} ~ 91°K; $\Delta V_{LEM\text{-}GRID}$ = 3kV

CRP1

V_{TOP} (kV)	V_{BOT} (kV)	E_{LEM} (kV/cm)	Time (h)	Spark Rate (h^{-1})	P_{atm} (mbar)	Estimated G_{eff} (no ch. up)
0.25	3.35	31.0	12	1.3	968 - 972	20
0.50	3.55-3.60	30.5-31.0	13	1.3	962 - 966	24 - 31
0.75	3.70	29.5	42	0.6	943 - 953	20
1.00	3.80	28.0	18	2 trips*	970 - 976	9
1.00	3.85	28.5	12	3 trips	936 - 947	15

*PS TRIP time set too

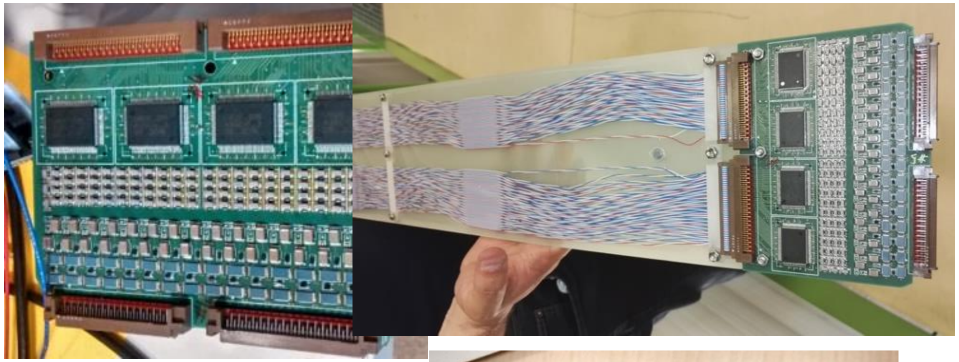
CRP2

V_{TOP} (kV)	V_{BOT} (kV)	E_{LEM} (kV/cm)	Time (h)	Spark Rate (h^{-1})	P_{atm} (mbar)	Estimated G_{eff} (no ch. up)
0.10	3.15 – 3.20	30.5 – 31.0	17	0.8	969 - 973	9 - 11
0.25	3.34	30.9	16	1.3	968 – 970	19
0.50	3.55	30.5	11	0.9	957 – 965	24
0.50	3.555	30.55	42	0.5	962 – 964	25

- **CRP1 and CRP2 operated for several days at different HV settings with all 36 LEMs powered**
- **Effective gain of about 20 or more reached for HV configuration with V_{TOP} ~ 0.5kV**
- **Exceeding by far LEM operation time with the 3x1x1. Stable operation conditions reached with~1 spark/hour per CRP 9m² (typical rate per unit of surface of micro-pattern gas detectors)**

- **Additional operation experience to be gathered in ProtoDUNE-DP in final and better controlled conditions**
- **Possible evolution of LEM design to increase active area or further improve stability can be tested in parallel to ProtoDUNE-DP operation with dedicated cold-box tests**

Charge readout electronics components:



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

Main components ASIC amplifiers, ADCs, FPGAs, IDT memories already procured in 2015-2016. 3x1x1 pre-production batch in 2016.

Analog cryogenic FE:

- Cryogenic ASIC amplifiers DP-V3, 0.35um CMOS → production performed at the beginning of 2016
- 64 channels FE cards with 4 cryogenic ASIC amplifiers
- First batch of 20 cards (1280 channels) operational on the 3x1x1 since the fall 2016
- Production or remaining FE cards for 6x6x6 launched in 2017: batch of 120 cards for 4 CRPs completed and tested

AMC digitization cards:

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

- 20 cards operational on the 3x1x1 since the fall 2016
- Production or remaining AMC cards for 6x6x6 launched in 2017: batch of 120 cards for 4 CRPs completed and tested

White Rabbit timing/trigger distribution system:

- Components produced in 2016 for the entire 6x6x6, full system operational on the 3x1x1 since the fall 2016

- **High bandwidth (20GBytes/s) distributed EOS file system for the online storage facility**

→ Storage servers from CCIN2P3: 20 machines + 5 spares, installed in September 2017 (DELL R510, 72 TB per machine): up to 1.44 PB total disk space for 20 machines, 10 Gbit/s connectivity for each storage server.

- **DAQ back-end/online storage and processing facility network architecture:**

→ Network infrastructure: 40 Gbit/s DAQ switch + 40/10 Gbit/s router procured by CERN: installation completed in January 2018

→ Data challenge in April 2018: transfer rate to CERN central EOS steady 20 Gbit/s (peak 35 Gbit/s) over the 40 Gbit/s link to IT

→ 9 Poweredge R610 service units of the DAQ cluster procured from CCIN2P3, installed in May 2018

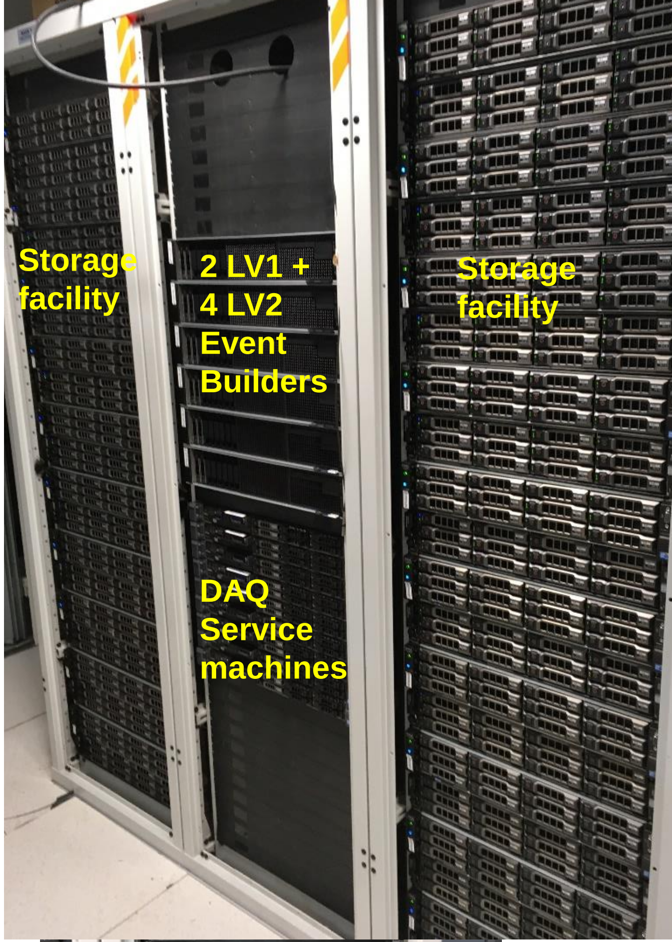
→ DAQ back-end: 2 LV1 event builders + 2 LV2 event builders procured by CERN + 2 LV2 event builders procured by KEK: Installed in August 2018

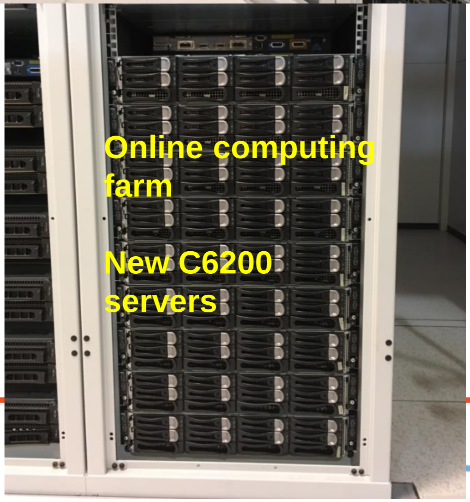
→ Additional 6 uTCA crates needed for 4 CRPs configuration already procured by KEK

- **Online computing farm:**

→ ~1k cores procured by CERN installed in June 2017, 12 racks, 10 Gbit/s connectivity per rack

→ Additional 40 servers Poweredge C6200 from CCINP3 installed in fall 2018 (**more than doubling the computing power of the online farm)**





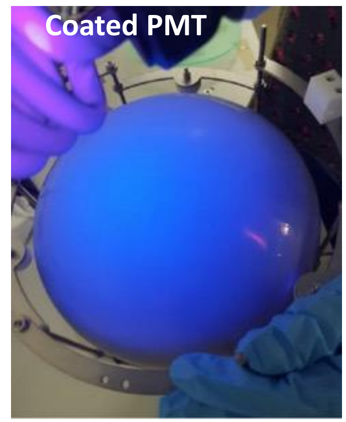
All electronics/DAQ system available for the entire 6x6x6 (4 CRPs operation)

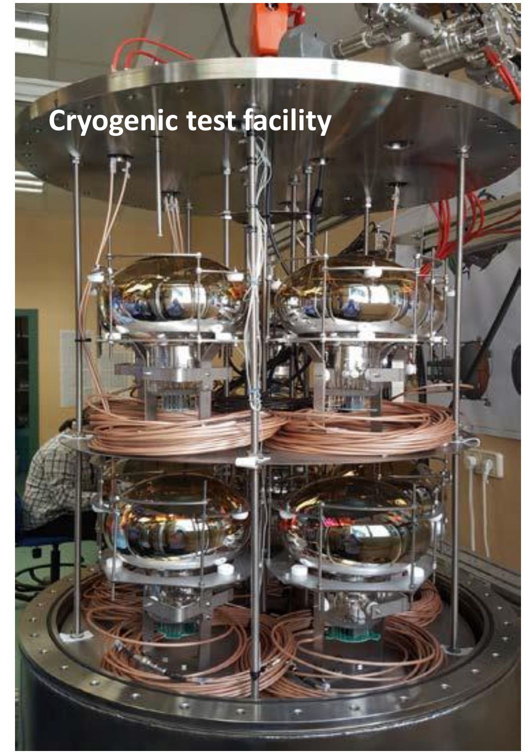
Light Readout System

Full characterization of 36 (+4 spares) 8" Hamamatsu PMTs **completed** at room and cryogenic temperature
→ *arXiv:1806.04571 (submitted to JINST)*

- **Dedicated cryogenic test facility** for testing 10 PMTs at once
- **Final system assembled and validated in LN2** (HV divider, mechanical support and 23 m cables)
- **Database ready** including: **dark current and gain vs HV curves**
- **Extra tests**: PMT light linearity, PMT response vs light frequency, tests at different T regimes
- PMTs **shipped to CERN** (June 2018)
- **TPB coating** performed at CERN during Jul-Aug 2018

➜40 PMTs at CERN ready for installation

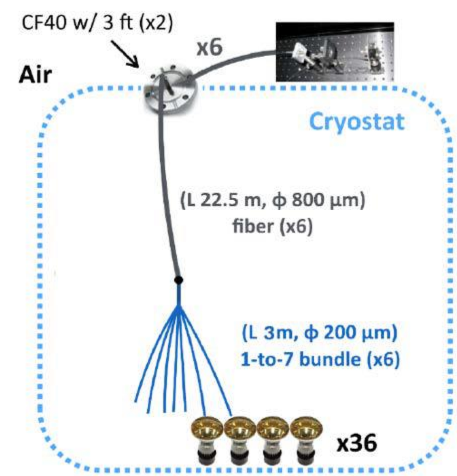




PMT calibration system

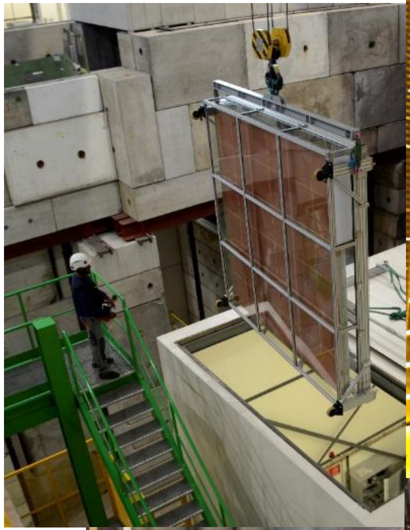
- **Design validated** (black box with 6 LEDs (+1 SiPM) outside the cryostat + 6 fibers into the cryostat divided at the end in 7 fibers arriving to each PMT)
- All final fibers, bundles and optical feedthroughs **procured and tested in LN2**
- Light source components **assembled**

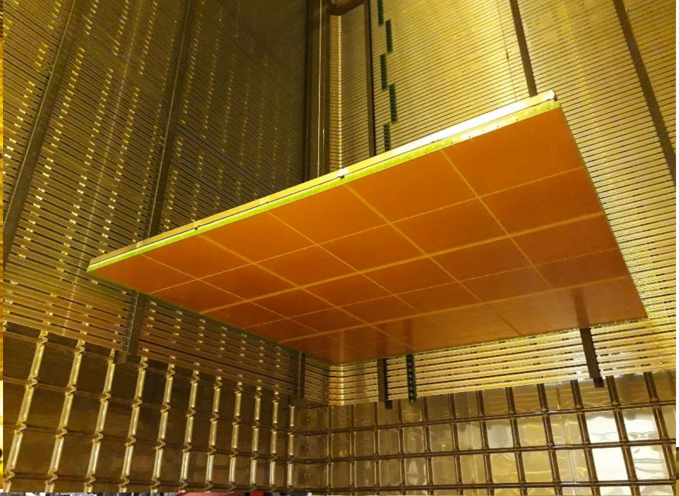
➜Full light calibration system tested in May 2018 and ready for installation



Installation under completion:

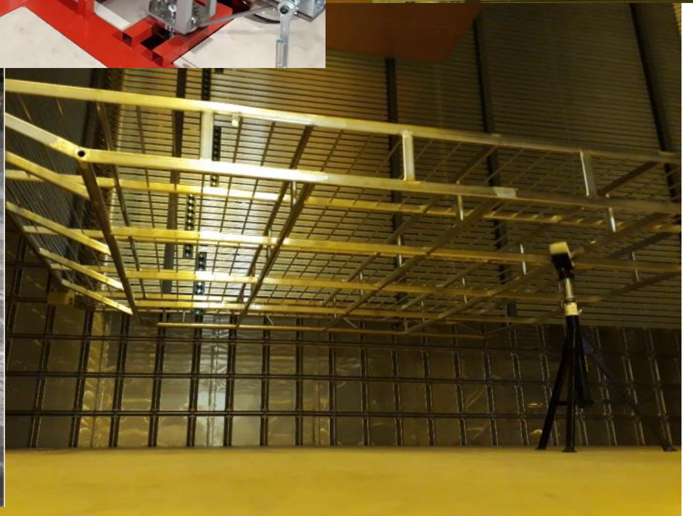
CRPs Installation →





Signal Chimneys →

Cathode →



→ **Completion of 4 CRPs installation in January 2019**

NP02 experience in view of DUNE 10 kton DP FD construction:

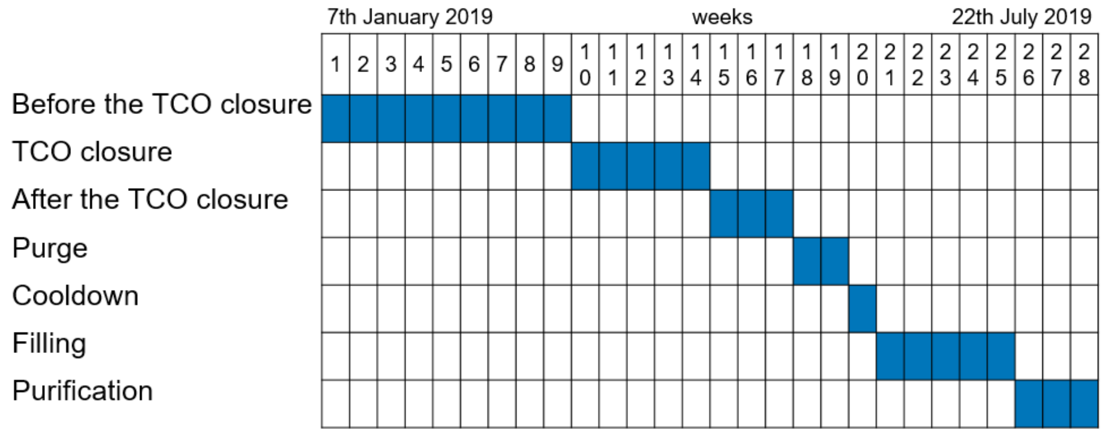
NP02 allowed establishing the fabrication and QA/QC procedures and validating the schedule and integration aspects and costing. Some immediate validations can be drawn regarding:

- LEMs production and testing procedures
- CRPs modular design, production tooling and methods and cold box testing
- Electronics production, testing and operation (already performed with the 3x1x1 prototype)
- Photon-detection system production, WLS coating, testing and operation (already performed with the 3x1x1 prototype)
- Field cage and cathode modular design, production and integration (the field cage design has also most of its basic components in common with NP04)
- The slow control system, which has also many elements in common with SP design

Aspects concerning the cryostat and cryogenics are totally in common with NP04 and already benefit of what learned with the NP04 cryogenic operation.

Planning:

- Completion of CRPs Installation: January 2019. Overall activities before TCO closure (including finalization of cathode installation, ground grid, HV FT, PMTs): 45 days
- TCO closure: 5 weeks
- Activities inside the cryostat after TCO closure: 15 days
- Start of purge: week18, end of filling: week 25 → start of CRPs operation



- Completion of TDR (June 2019)
- Evaluation of ProtoDUNE-DP detector basic performance with cosmic rays (fall 2019)

- Long term stability running: 2019-summer 2020
- Access in 2020 to prepare to post LS2 activities: **instrumentation of other 2 CRPs, installation of beam-plug** + possible improvements based on ProtoDUNE-DP running experience/parallel tests. Additional improvements (as foreseen for SP): cryo instrumentation, trigger as in 10 kton, calibration systems
- High statistics beam data taking in 2021 for about 6 months beam time

Motivations for large statistics beam data taking

already mentioned since WA105 (ProtoDUNE-DP) TDR (SPSC-TDR-004). This program was reiterated and refined in the 2016 (SPSC-SR-184) and 2017 (SPSC-SR-206) SPSC reports

→ Proposed beam-based program, including 120 days of beam data, yielding the collection of 175 million beam triggers including both beam polarities and various momenta bins

In-depth understanding of detector response and valuable data for FD analysis and systematics: data useful for calibration and enabling precision studies of the hadronic cross sections to improve the nuclear re-scattering models and the modeling of the neutrino energy reconstruction.

→ Assessment of several issues directly relevant to DUNE physics analyses:

- **Electron identification and electron/π0 separation by using π0 from secondary hadronic vertices**
- **Particle identification studies by using particles tagged by the beam instrumentation. Identification of kaons in the beam, providing useful information to DUNE's nucleon decay search**
- **Energy scale and energy resolution for electromagnetic and hadronic showers**
- **Electromagnetic content in hadron-initiated cascades, in particular the π0 multiplicity and EM energy fraction as a function of primary hadron incident energy; (more general interest in hadronic showers modelization**
- **Constraining the GEANT4 physics models for interactions of hadrons in argon. The pion charge exchange cross section is very important for understanding the background uncertainty in the DUNE far detector oscillation analysis. The branching ratio of this process is small (approximately 10% at 1 GeV) → large data sample required to measure this cross section precisely**
- **Precision studies of the hadronic cross sections in order to improve the nuclear re-scattering models and the modeling of the neutrino energy reconstruction**
- **Recombination for different particle species and angle dependence**

Conclusions:

- Useful experience accumulated during the last six months with the cold box tests → large improvements with respect to 3x1x1 prototype running experience
- Installation of ProtoDUNE-DP close to completion: 4 CRPs tested in cold bath, installation finalized by the end of January, remaining components ready for installation. End of filling foreseen for week 25 (23/6)
- Looking forward to the validation of the DP detector operation with cosmic rays
- Expected running until half of 2020, then access to instrument two CRPs, beam plug and possible improvements from accumulated experience to be tested (electronics, DAQ, photon detection system already available for 4 fully instrumented CRPs configuration).
- High statistics data taking after LS2 in 2021 with 6 months of beam statistics (originally foreseen in the WA105 TDR and following SPSC documents). Physics program useful for FD analysis and systematics

Details of ProtoDUNE dual-phase back-end architecture