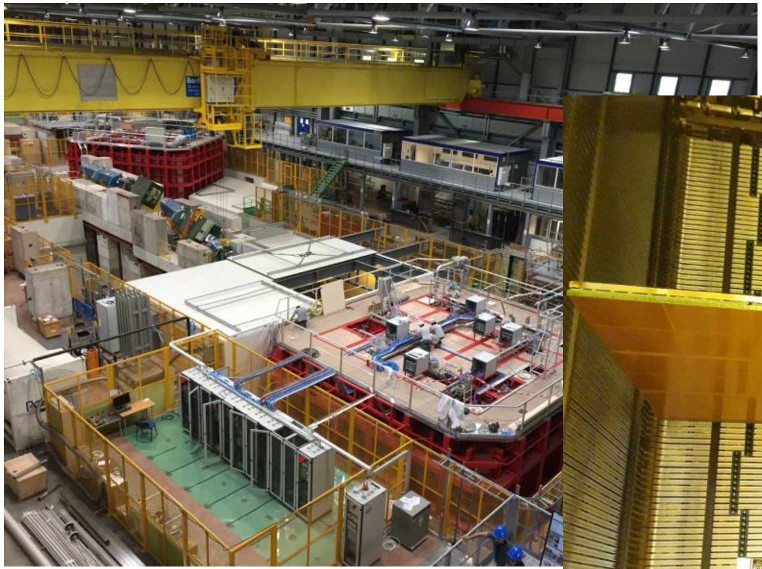
Plans for ProtoDUNE-DP (NP02) after LS2

Dario Autiero

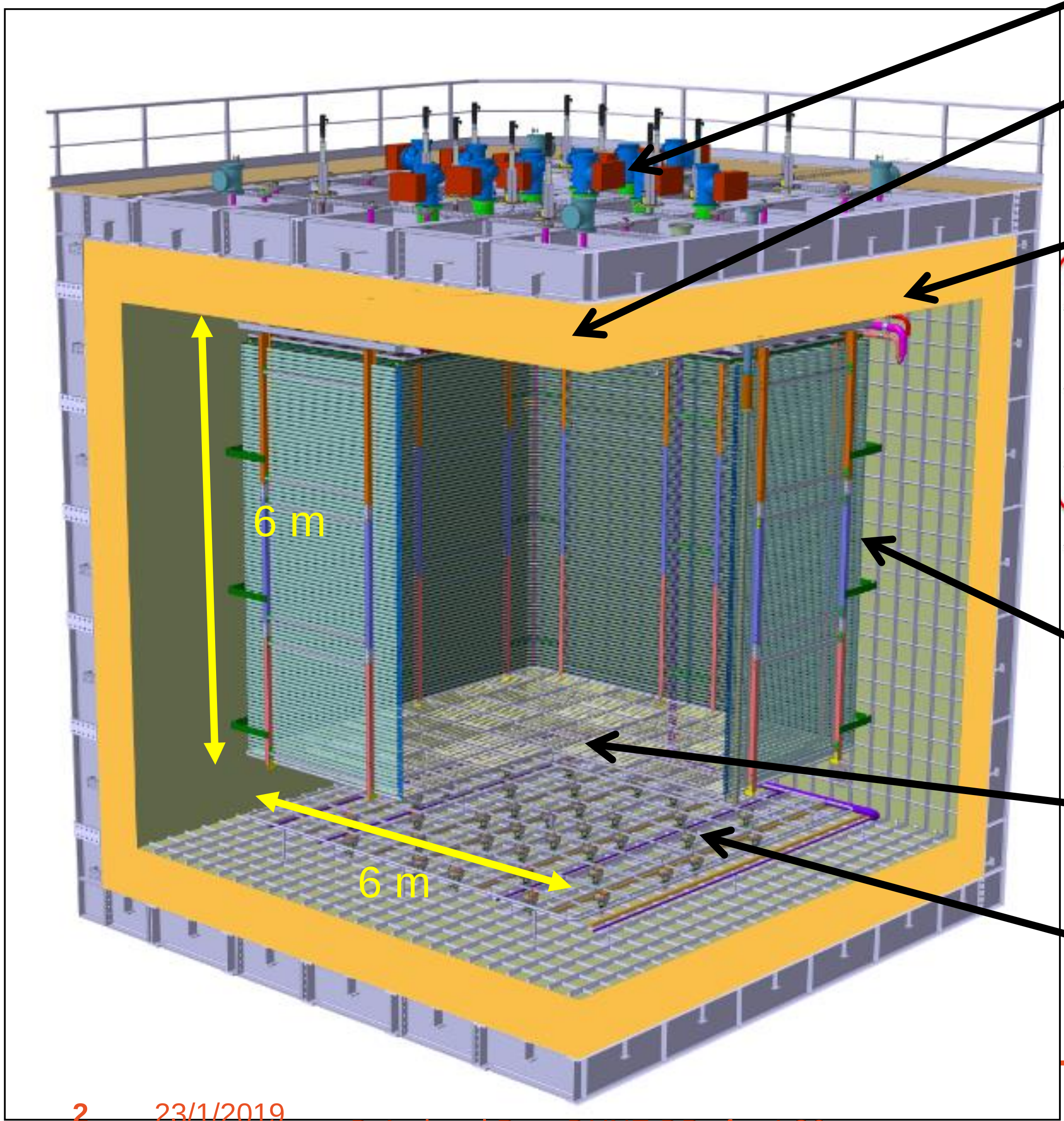
SPSC132

23/1/2019



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

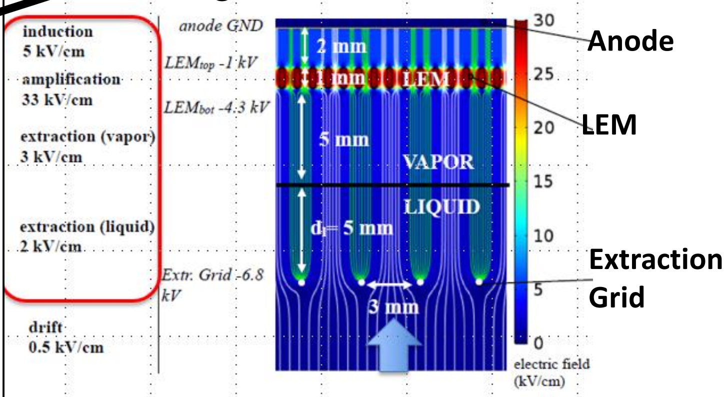
1/20 of active area of a DP 10 kton module: ProtoDUNE-DP 4 CRPs → DUNE 80 CRPs



Digital electronics in uTCA crates

Accessible cold FE electronics in SFT "chimneys"

Charge Readout Planes



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

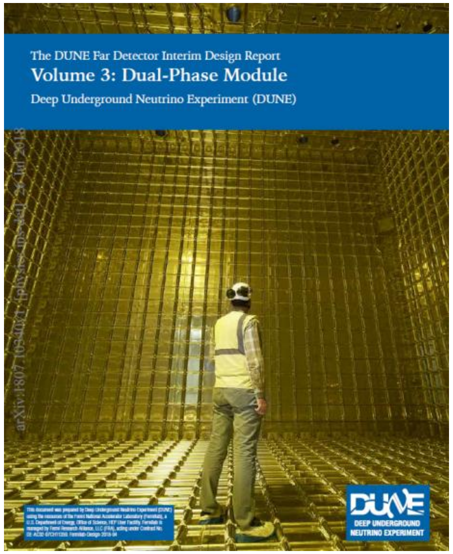
Cathode modules

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

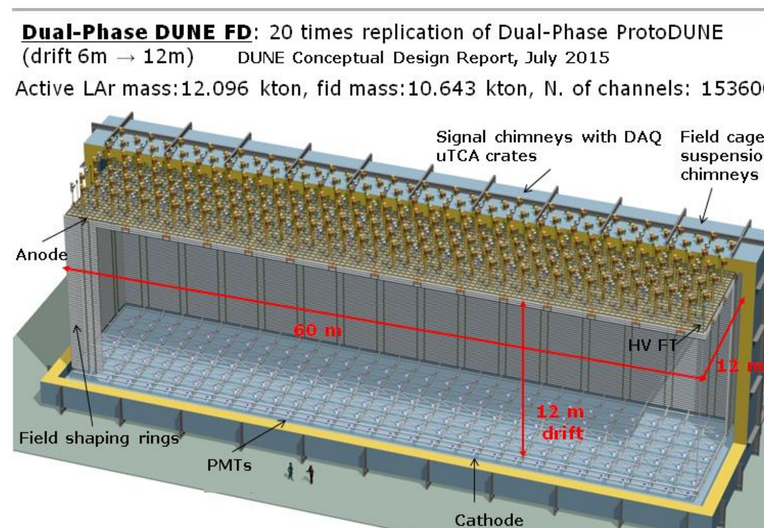


1) Design motivations
2) Charge Readout Planes
3) TPC Electronics
4) HV system
5) Photon Detection System
6) Data Acquistion System
7) Slow Controls and Cryogenic Instrumentation
8) Technical Coordination

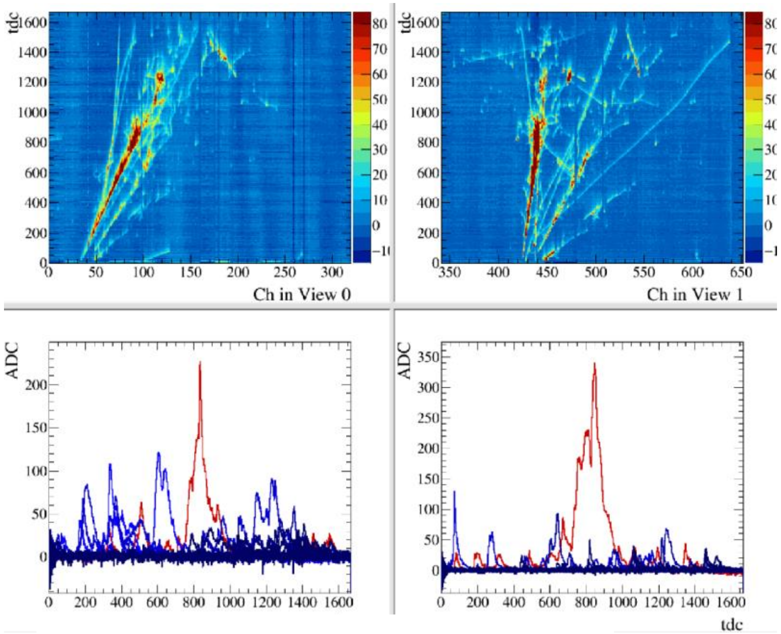
Consortia:

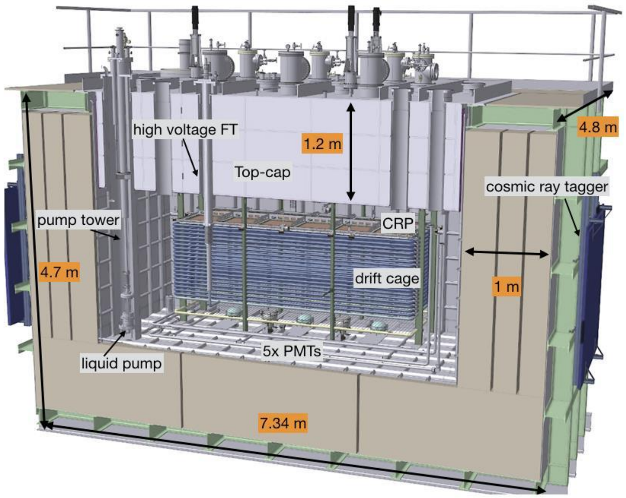
- **CRP consortium (DP):** LEMs, CRP, CRP suspension system
- **TPC Electronics (DP):** Cold charge readout electronics, signal chimneys, digital electronics for charge and light readout
- **HV system (Joint):** Field cage, cathode, VHV power supply and feedthrough
- **Photon Detection System (DP):**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

- **DP TDR editing in progress → based on ProtoDUNE-DP design**
- **Completion of TDR editing foreseen by June 2019**



3x1x1 detector operation June-November 2017





- **Successful in proving the dual-phase concept for a LArTPC at the 3m^2 readout scale.**

- Detector working point limited by technical issues with **CRP extraction grid HV limited to 5 kV**
- LEM design also showed limitations, **most of the run at ΔV = 2.8 kV (effective gain ~3), max ΔV reached 3.1 kV**
- **CRP design already different for ProtoDUNE-DP, 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


arXiv:1806.03317v2 [physics.ins-det] 12 Oct 2018

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]

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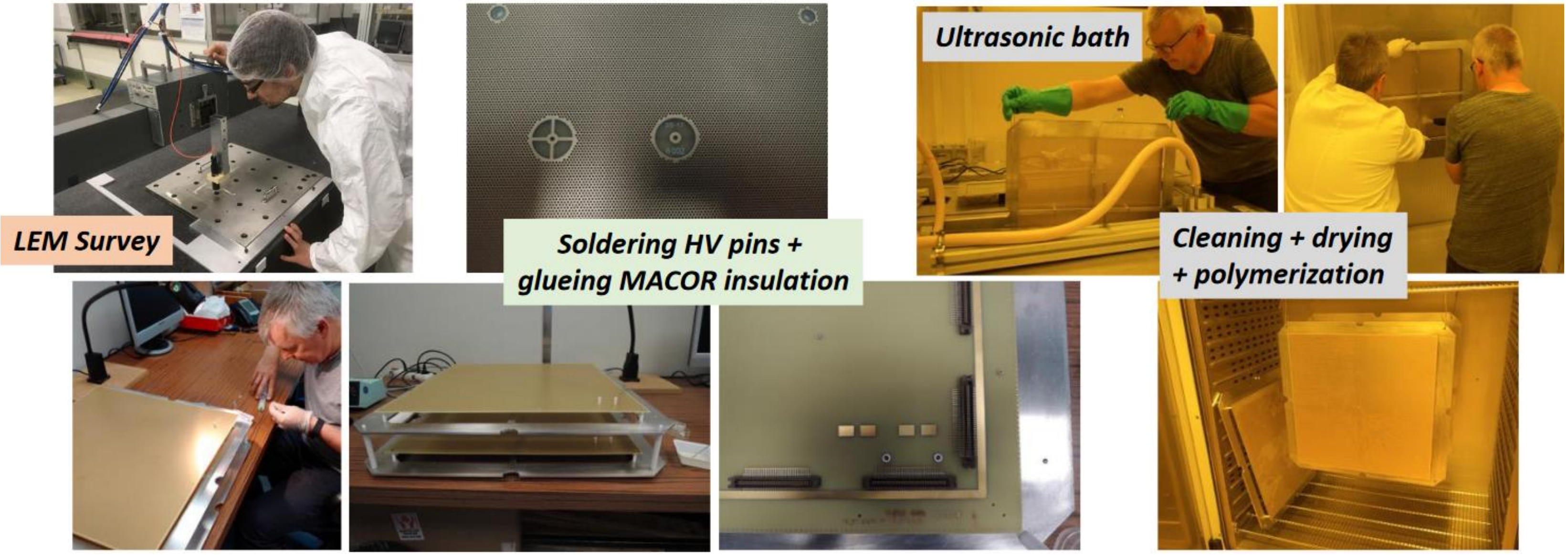
LEMs procurement, preparation and QA/QC chain at Saclay

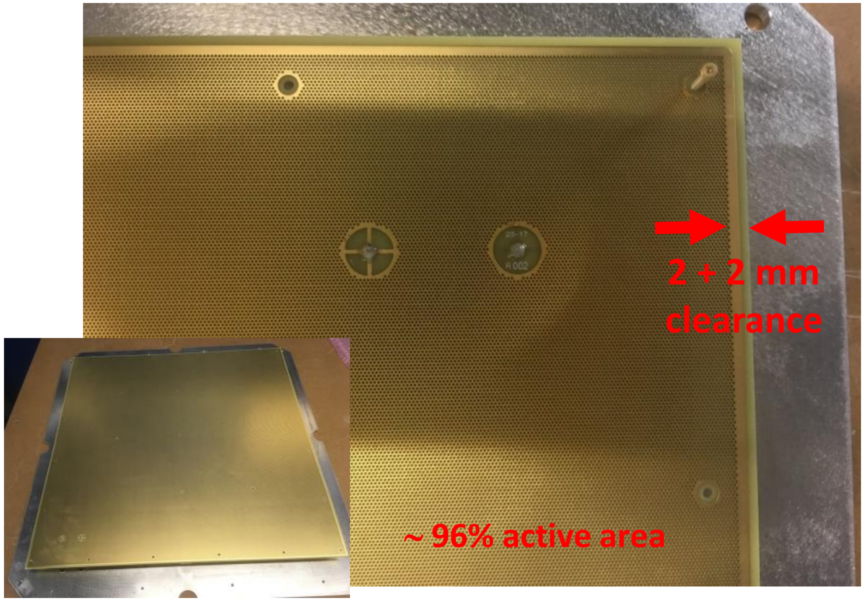


Fully automated HV training in GAr @3.3 bar up to 3.5kV

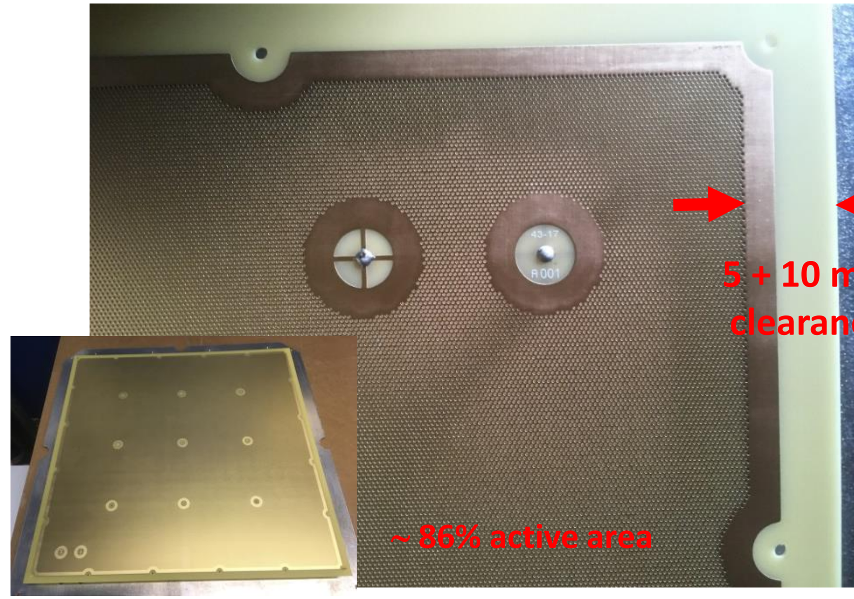
→ **All LEMs individually characterized at at 35kV/cm in a high pressure argon gas chamber 3.3 bar (similar GAr density conditions as at cold, immediately above LAr level)**

Evolution of LEM design for ProtoDUNE-DP from 3x1x1 design

CFR-34 – 311 prototype



CFR-35 – NP02

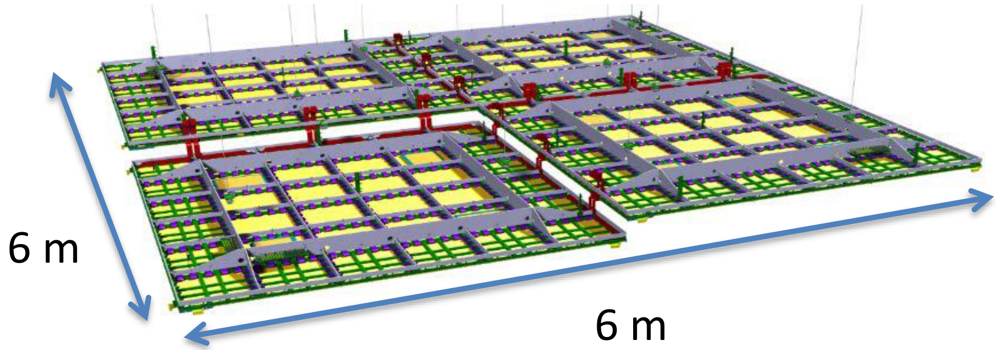


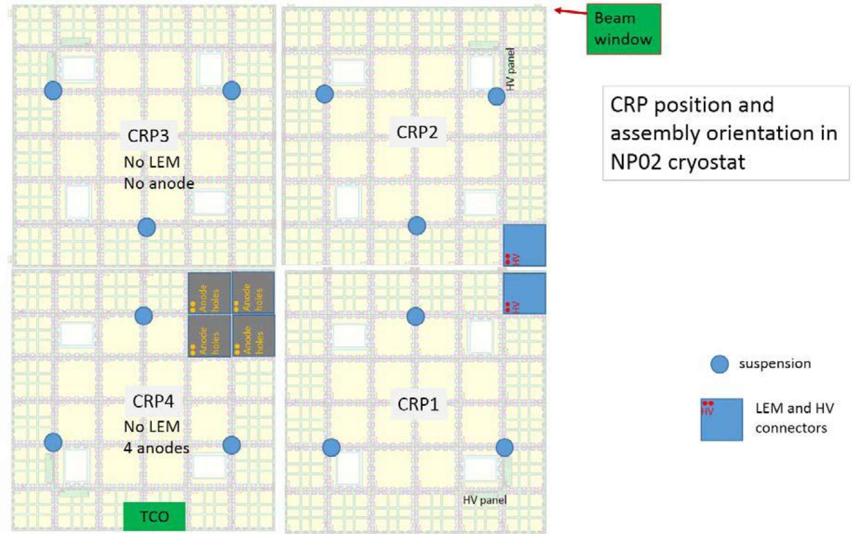
spark rate : ~20/h
(> 45% of sparks near edges or corners)

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

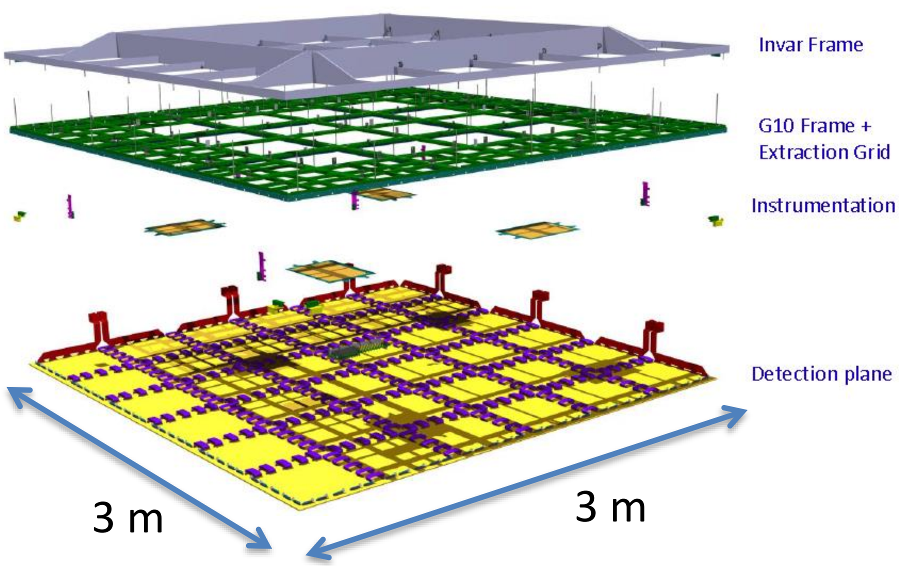
→ **Conservative guard ring design allowed increasing by about 300V the LEM max. operating voltage**

Charge Readout Planes in ProtoDUNE-DP

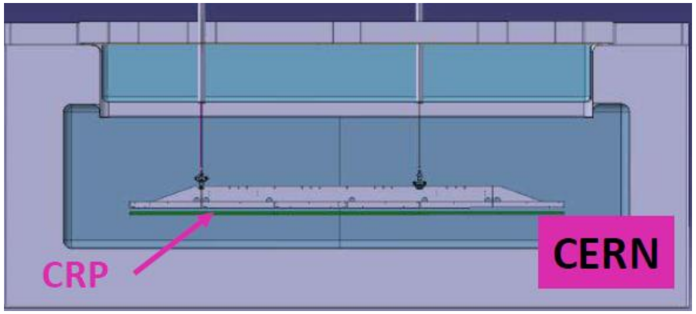




- ➢ **2 CRPs fully instrumented with LEMs and anodes:**
- **CRP#1 built in May-June 2018**
- **CRP#2 built in October 2018**
- ➢ **2 CRPs without LEMs:**
- **CRP#3 built in September 2018**
- **CRP#4 completed in January 2019, single phase-like readout on 4 anodes**



CRP Cold Box test in Hall 182



→ Perform electrical and mechanical tests of each CRP in nominal thermodynamic conditions (Ar purity <100 ppm):

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

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

➢ 1st cold-box tests on CRP1 22/6-9/7

- **Stable LEM operation during several days at 30kV/cm. Fast HV ramping up, low spark rates, fast HV recovery**
- **Grid HV issues: shorts on 6-8 LEMs, max V limited to 2 kV**
- **CRP HV Distribution Box issues: (HV connectors in gas), max V reached ~4.2kV**

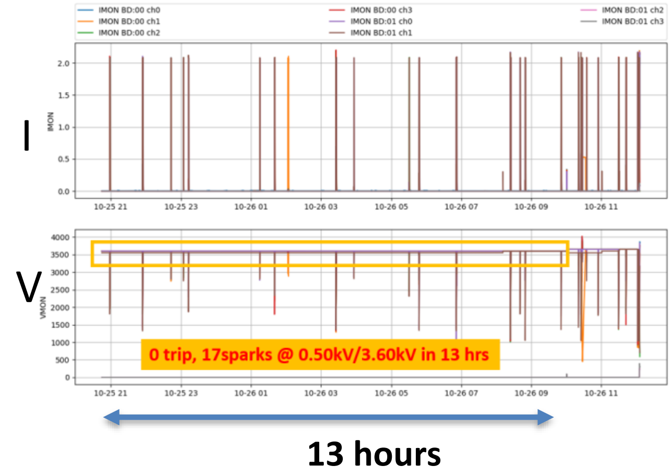
→ **CRP inspection at cold and tests at warm showed that wires getting loose at cold: wires tension increased from 0.6 N to 2N**

→ **Improvements in grid HV connection and in LEMs HV distribution box: change input connectors + removal insulating glue breaking quenching resistors (HV to top LEM faces)**

➢ 2nd cold-box test on CRP1 (after improvements) 27/7-18/8

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

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



➢ 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(2) operated for several days with all 36 LEMs at different HV settings

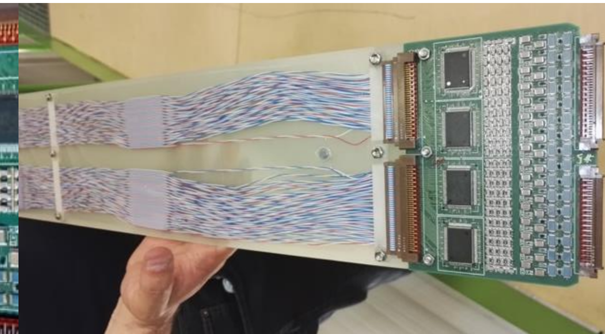
→ Effective gain >20 reached for HV configuration with V_{TOP} ~ 0.5kV (gain 3 on 3x1x1)

- Much larger LEM operation time than in 3x1x1. Stable operation ~1 spark/hour per CRP (9m^2)

- 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 ASICs ADCs, FPGAs, IDT memories already procured in 2015-2016

Analog cryogenic FE:

- **Cryogenic ASIC amplifiers: production performed at the beginning of 2016**
- **FE cards with 4 cryogenic ASIC amplifiers: first batch of 20 cards (1280 channels) operational on 3x1x1 since the fall 2016**

- **Production or remaining FE cards for PD-DP launched in 2017: <u>batch of 120 cards for 4 CRPs completed and tested</u>**

uTCA AMC digitization cards:

first batch of 20 cards operational on 3x1x1 since the fall 2016

- **Production or remaining AMC cards for PD-DP launched in 2017<u>: batch of 120 cards for 4 CRPs completed and tested</u>**

White Rabbit timing/trigger distribution system:

- **Components produced in 2016 for the entire PD-DP, full system operational on the 3x1x1 since the fall 2016**

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

→ 20 storage servers, installed in September 2017 (1.44 PB total disk space, 10 Gbit/s connectivity per server)

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

→ Network infrastructure: 40 Gbit/s DAQ switch + router completed in January 2018. 40 Gbit/s data transfer to IT tested in April 2018

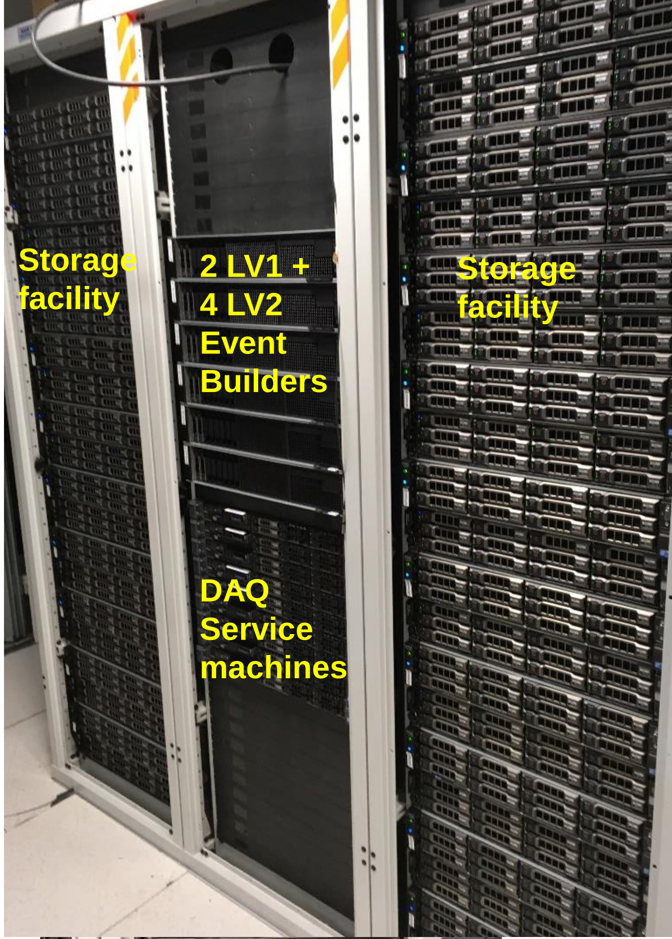
→ 9 DAQ service machines installed in May 2018

→ DAQ back-end: 2 LV1 event builders + 4 LV2 event builders Installed in August 2018

- **Online computing farm:**

→ ~1k cores procured by CERN installed in June 2017

→ 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 ProtoDUNE-DP (4 CRPs operation)

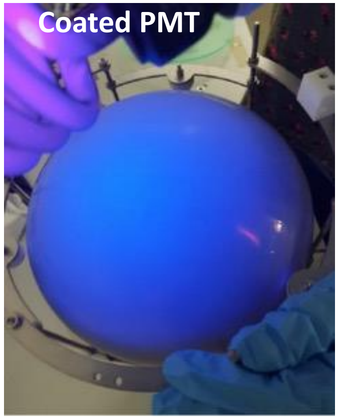
Light Readout System

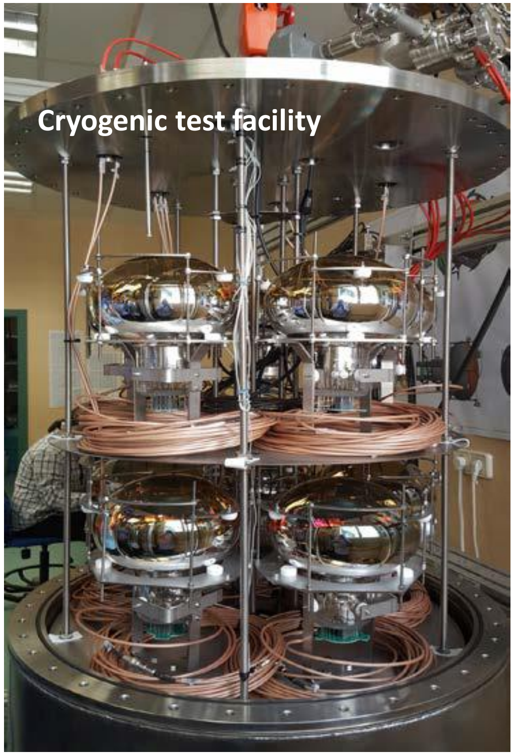
Full characterization of 36 (+4 spares) 8" Hamamatsu PMTs **completed** at room and cryogenic temperature
→ *arXiv:1806.04571 (submitted to JINST)*

•**Dedicated cryogenic test facility → final system assembled and validated in LN2**

•PMTs **shipped to CERN** (June 2018),**TPB coating** performed at CERN during July-Aug 2018

→40 PMTs at CERN ready for installation





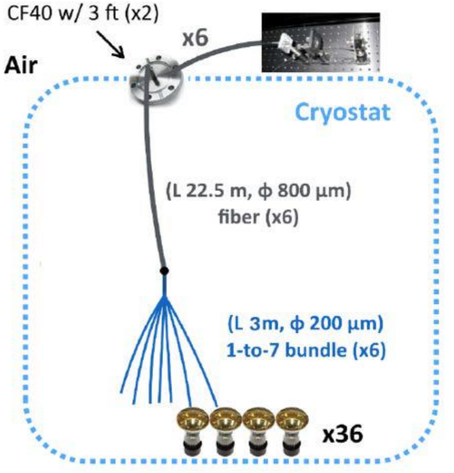
PMT calibration system

•**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)

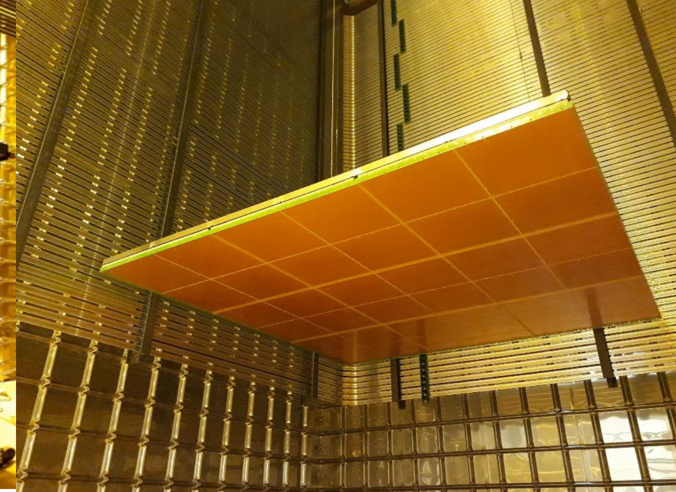
• Components: Light source, fibers, optical feedthroughs **procured**

→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**

ProtoDUNE-DP experience in view of DUNE 10 kton DP FD construction:

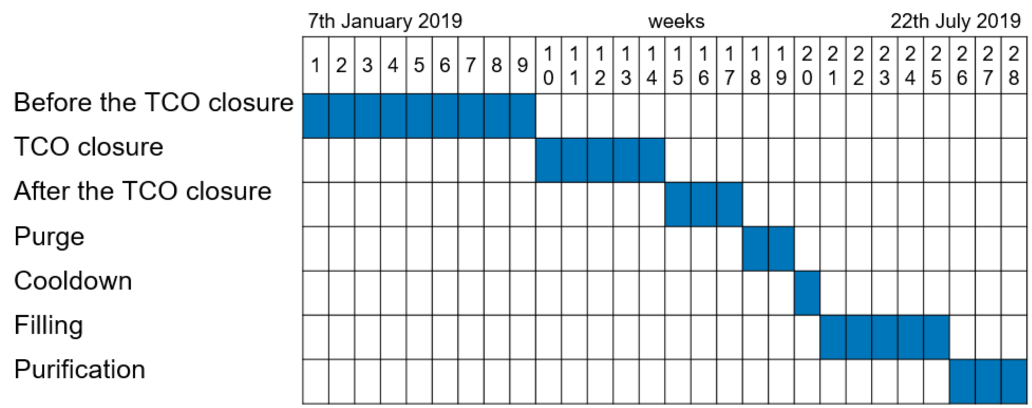
ProtoDUNE-DP construction allowed establishing the fabrication and QA/QC procedures and validating the schedule and integration aspects and costing.

Validations already drawn:

- 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 (field cage design has most of its basic components in common with NP04)
- Slow control system (which has also many elements in common with SP design)
- Cryostat and cryogenics are totally in common with PD-SP and already benefit of what learned with the PD-SP 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 with already known DP-DP design (June 2019)
- Evaluation in DUNE 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, DAQ 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). Program reiterated and refined in 2016 (SPSC-SR-184) 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/$\pi 0$ separation by using $\pi 0$ from secondary hadronic vertices
- Particle identification studies by using particles tagged by the beam instrumentation. Identification of kaons in the beam (DUNE's nucleon decay search)

- Energy scale and energy resolution for electromagnetic and hadronic showers
- Electromagnetic content in hadron-initiated cascades, in particular the $\pi 0$ multiplicity and EM energy fraction as a function of primary hadron incident energy

- Constraining the GEANT4 physics models for interactions of hadrons on argon such as pion charge exchange cross section (understanding the background uncertainty in the DUNE far detector oscillation analysis).
  → large data sample required

- Precision studies of the hadronic cross sections in order to improve the nuclear re-scattering models and the modeling of the neutrino energy reconstruction

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
- Electronics, DAQ, photon detection system are already available for 4 fully instrumented CRPs configuration.
- Expected running until half of 2020, then cryostat access to instrument two additional CRPs, insert the beam plug and implement possible improvements, from accumulated experience, to be further tested.
- Operate with final components/configuration after LS2 in 2021, high statistics data taking with the beam.