ProtoDUNE DP: a demonstrator of liquid argon dual-phase TPC

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on behalf of DUNE collaboration
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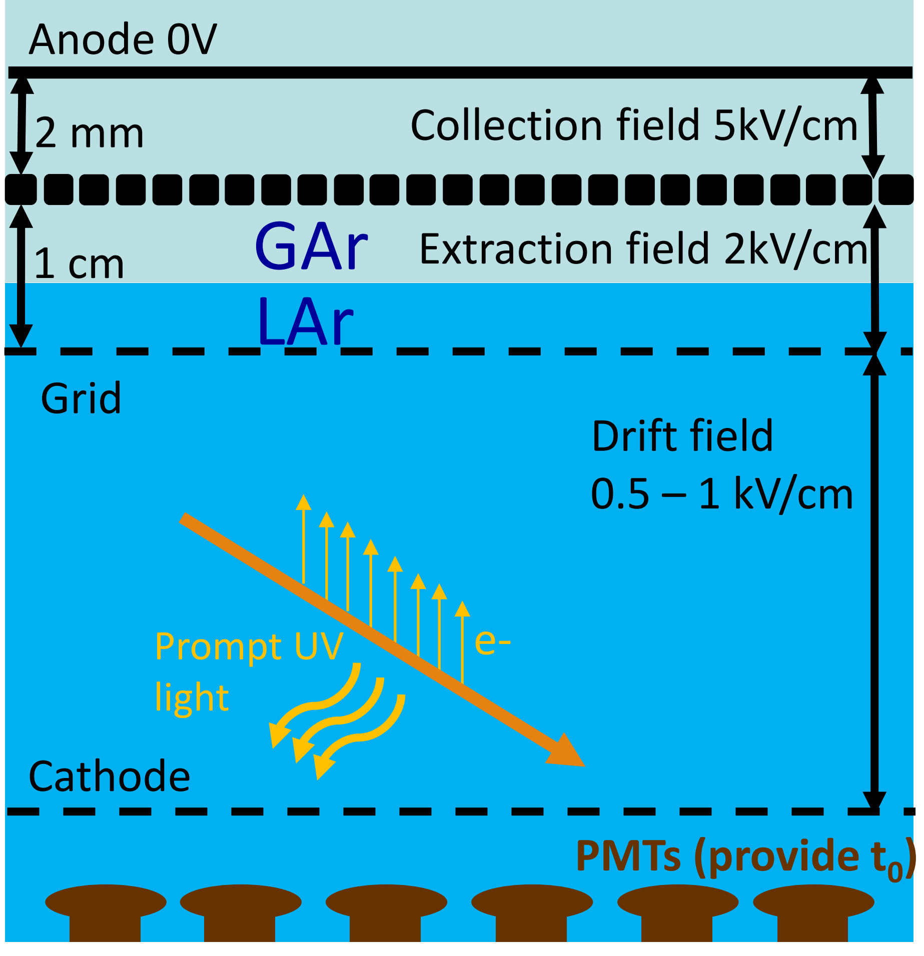
TPC 2016
Dec 5, Paris

LAr TPC with dual-phase charge readout

Concept of double-phase LAr TPC (Not to scale)



Some advantages of LAr TPC design with dual-phase charge readout

- Fine 3mm readout pitch
- Robust S/N with tunable gain due to amplification in LEM
- Only charge collection (no induction planes)
- Can cope with electron diffusion and charge attachment for long drift
- Insensitive to microphonic noise
- No dead material inside the active volume
- Small number of channels
- Accessible electronics

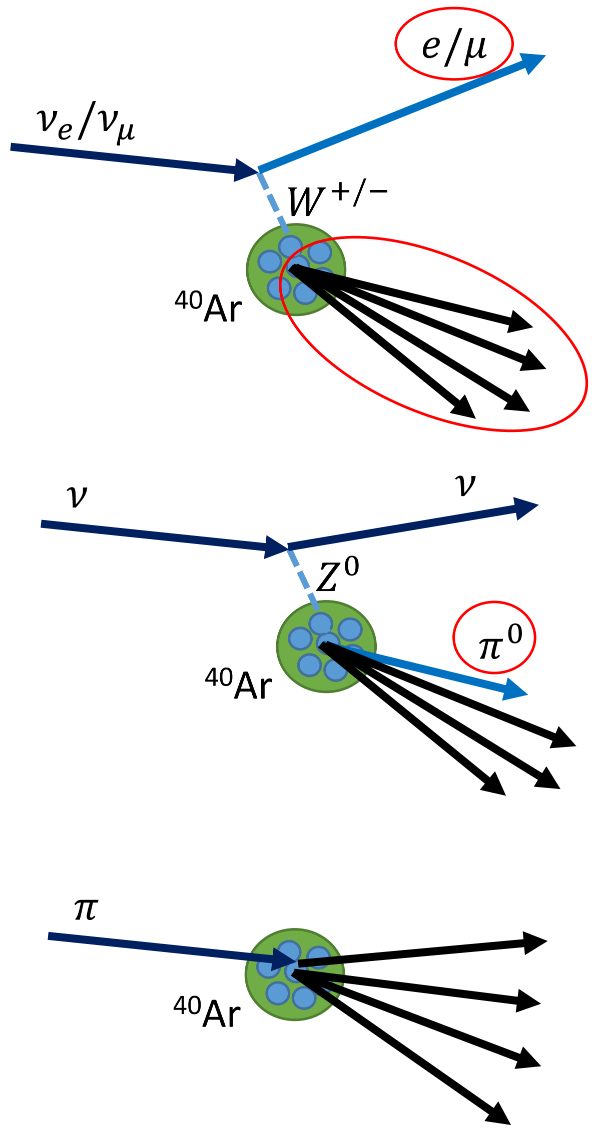
Dual-phase LAr TPC prototype at CERN

Characterize the detector with well defined particle beams

- Development and validation of automatic event reconstruction in LAr ➔ electromagnetic and hadronic showers
- Assessment of PID performance
- Test e/π^0 rejection
- Charged pions and proton cross sections on Ar nuclei (FSI in nuclear environment)

A dataset of ~40^6 interactions covering low 1 – 12 GeV/c region fully contained in the detector

Measure hadron shower development with exceptional granularity of 3x3 mm^2



Dual-phase LAr TPC prototype at CERN

Demonstrate technical feasibility for O(10kton) detectors

- Large surface charge readout in dual-phase scalable to O(10kton) scale detectors
- Charge readout with 3mm pitch in two collection views
- Long drift distances
- High voltage to generate drift field
- Production and QA/QC chains for all detector elements
- Validation of installation sequence in view of underground detector assembly

Conceptual design for **DUNE dual-phase 10kton LAr TPC** is described in DUNE CDR Vol. 4 *arXiv:1601.02984*

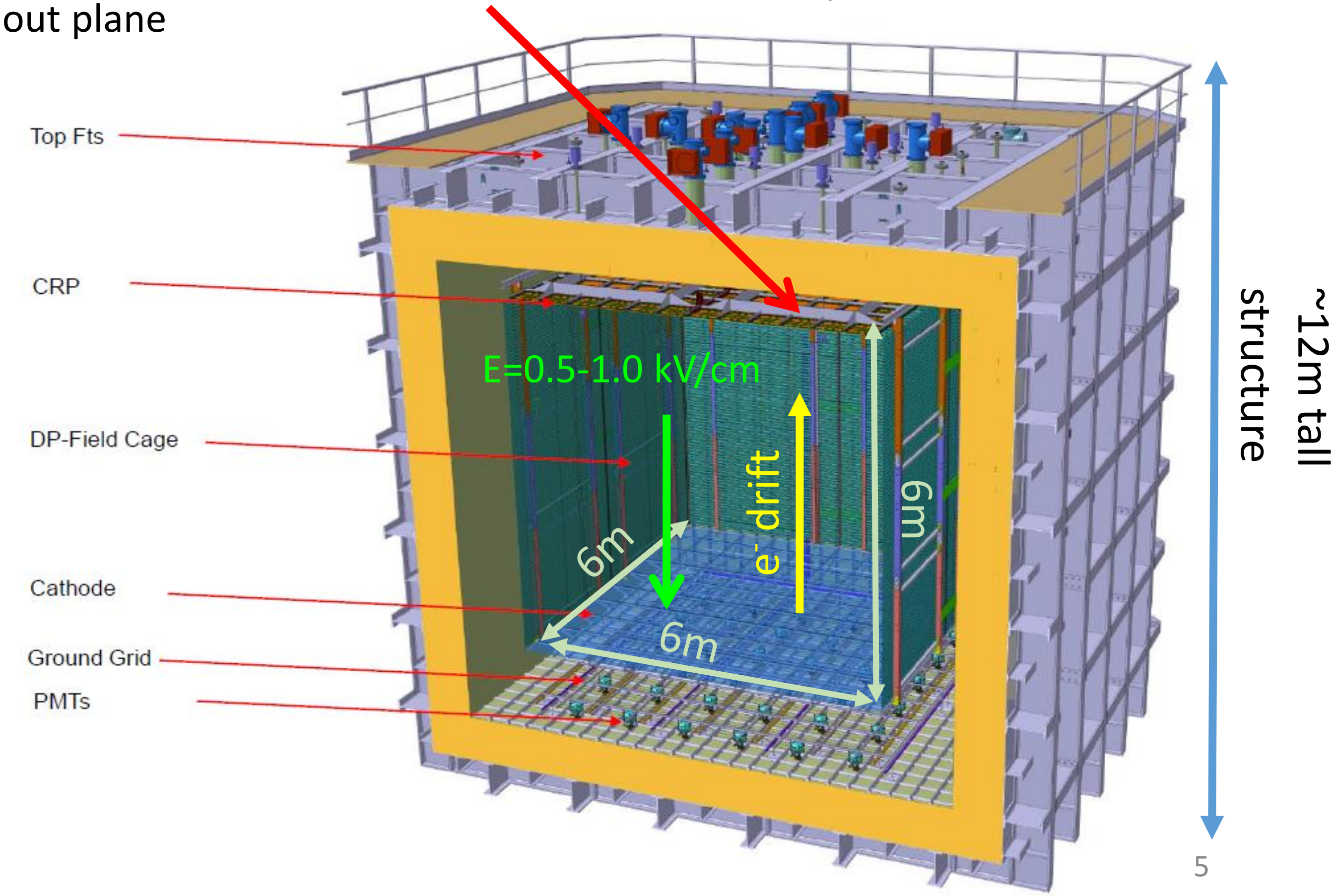
ProtoDUNE dual-phase LAr TPC

- Insulated membrane tank
- Inner volume 8.55 x 8.55 x 7.9 m^3
- Active volume is 6x6x6 m^3
- Total LAr mass ~818 ton (~300 ton active)
- Hanging field cage & readout plane

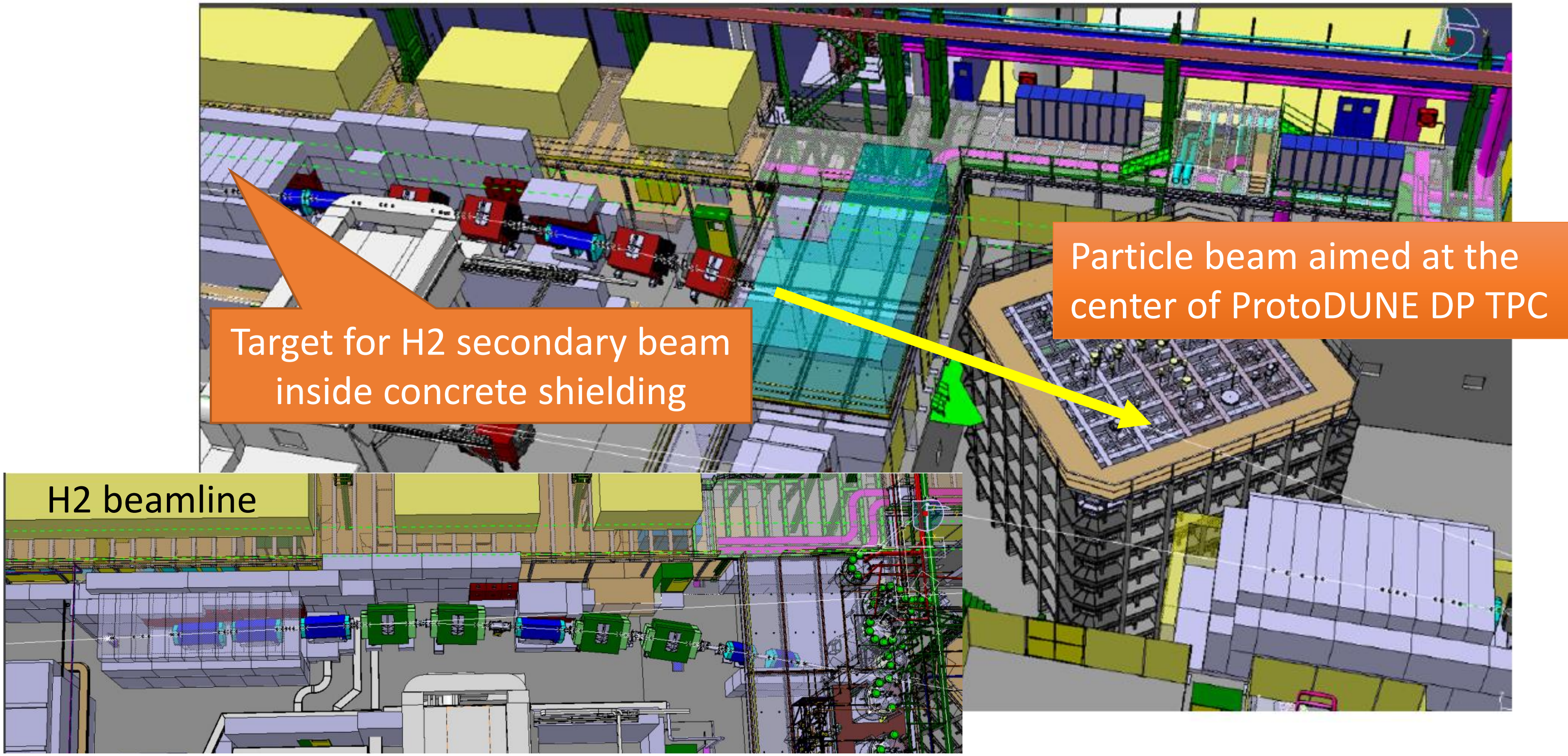
- Readout in gas phase: charge is amplified and collected on a 2D anode
- Charge Readout Plane (CRP) X and Y charge collection strips 3.125 mm pitch, 3 m long →7680 readout channels
- CRP is built from 4 independent 3x3 m^2 units

Drift coordinate 6m or 4ms samped at 2.5 MHz (400 ns), 12 bits
→ 10000 samples per drift window

Total event size 148MB
Data rate 15GB/s (at 100 Hz trigger)
→ DAQ bandwidth on 20 GB/s scale



Test beam at CERN in EHN1 extension

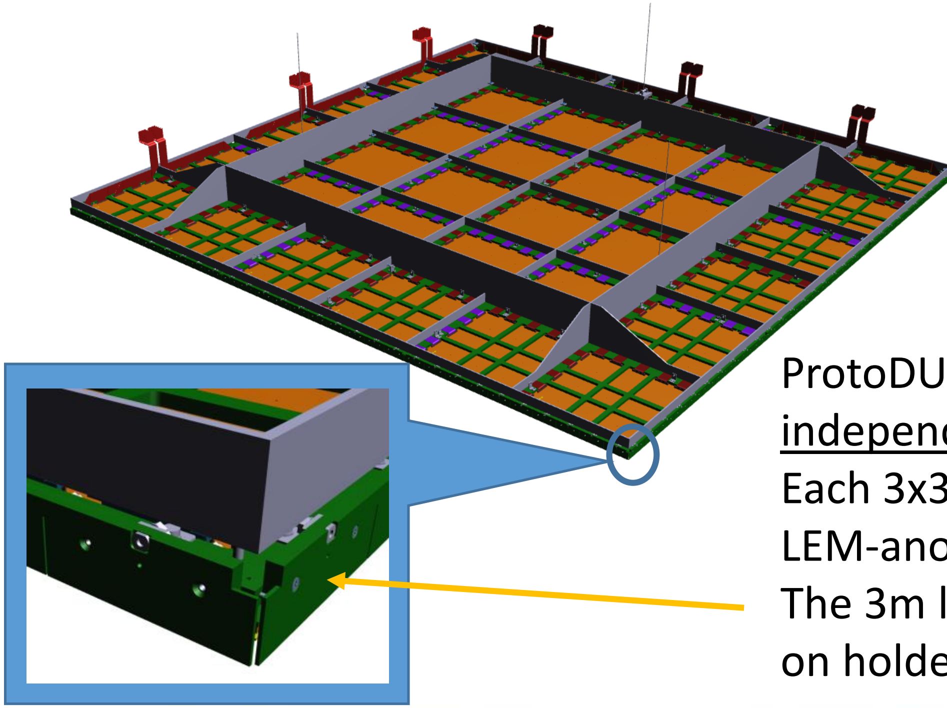


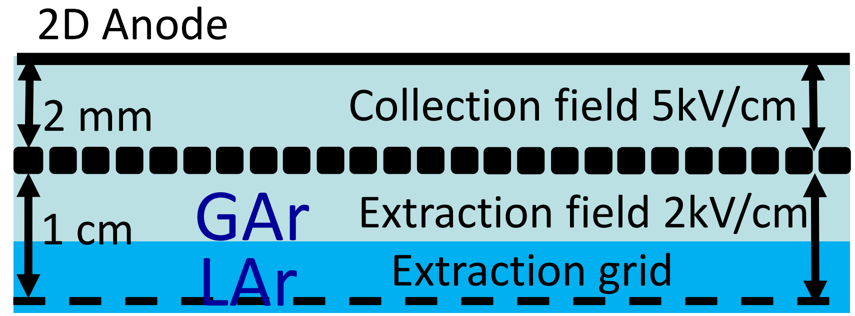
Particle ID system for e/π/p/K over 1—12 GeV/c momentum range

Three fiber monitors for momentum measurements

Trigger rate ~100 Hz to avoid particle overlaps in TPC

Elements of CRP



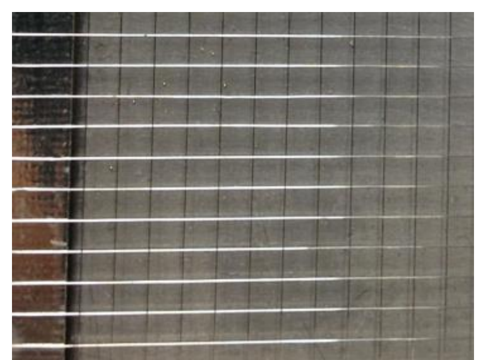


ProtoDUNE 6x6 m^2 CRP is composed of four <u>independent</u> 3x3 m2 units

Each 3x3 m^2 sub-module is built from 50x50 cm^2 LEM-anode sandwiches

The 3m long wires of the extraction grid are mounted on holders attached along the frame circumference

More details in Sebastien Murphy's talk

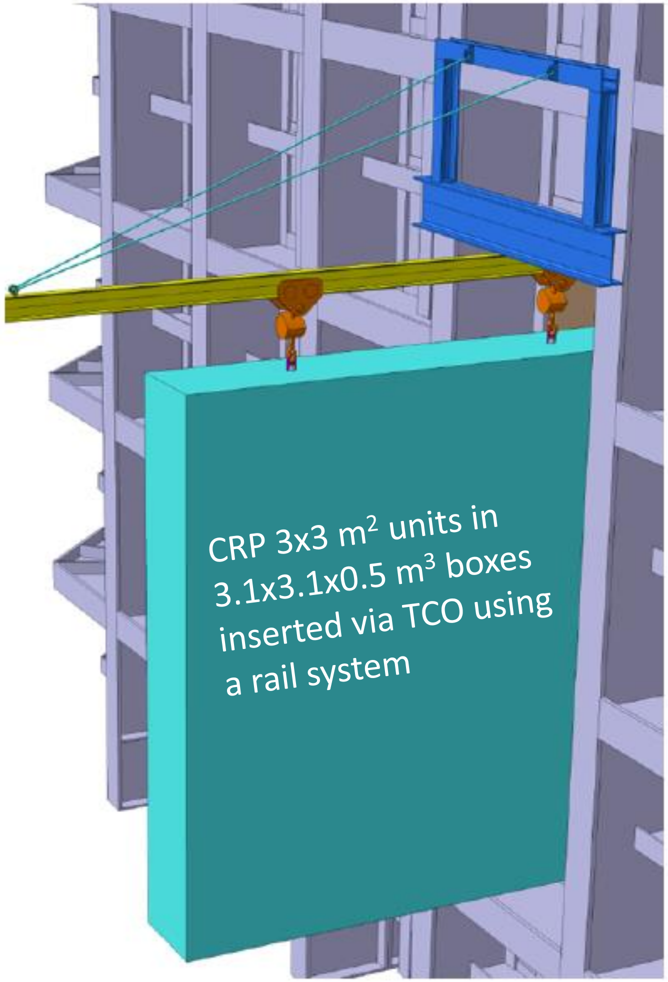


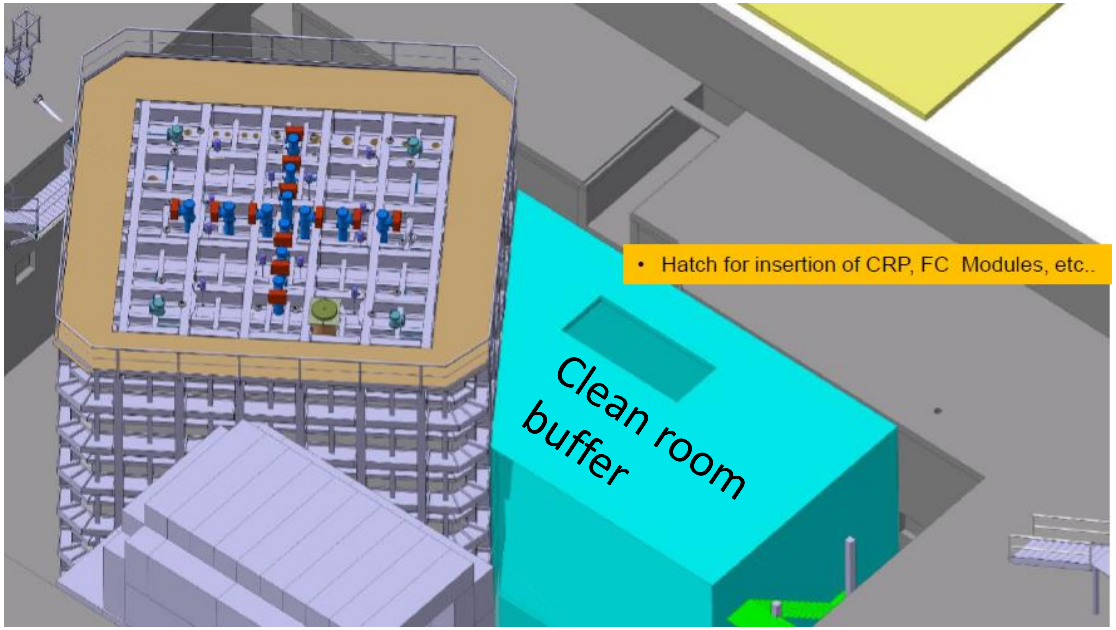
LEM: 500 μm holes, 800 μm pitch, 1mm thick FR4

Multilayer PCB anode. 3.125 mm pitch

Extraction grid: 100 μm stainless still wires

Detector assembly





- Installation sequence same as for 10kt DUNE → prepare for underground detector assembly
- Feedthroughs are installed first
- The material for detector installation is brought to a clean room buffer and then via TCO into the cryostat and TPC is assembled inside the cryostat
- 3x3 m^2 CRPs will be pre-assembled at CERN, packed in a protective case, and then brought in vertically via TCO

TCO = Temporary Construction Opening

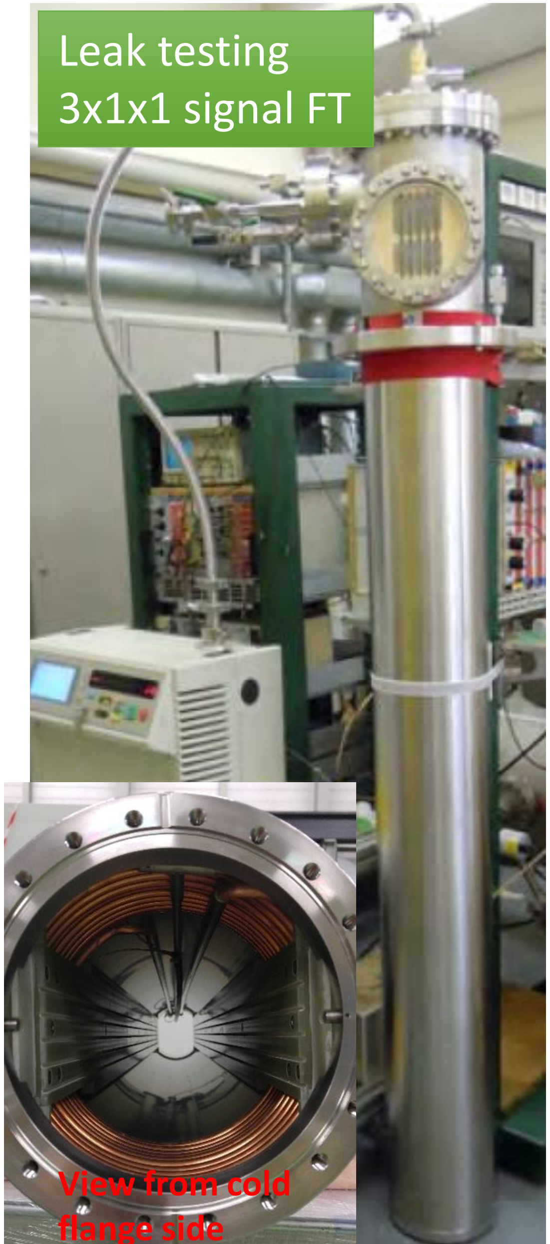
High voltage for drift field

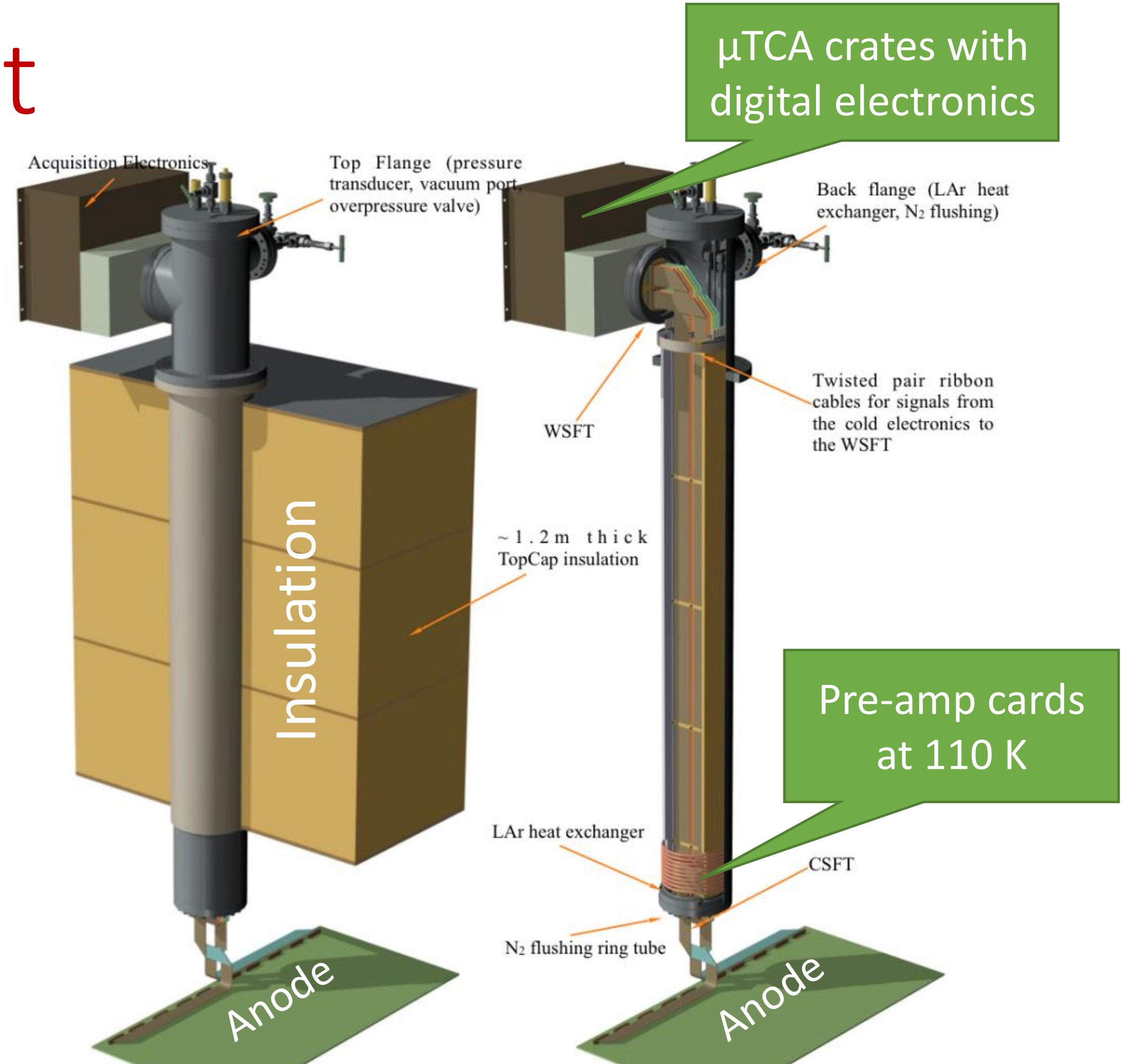
- Nominal required HV on the cathode is 300 kV (E_{drift} = 0.5 kV/cm over 6m)
  - ➔ commercially available (Heinzinger PNChp-series)
- For DUNE 10kt need to go up to 600 kV (E_{drift} = 0.5 kV/cm over 12m)
  - ➔ to be tested in ProtoDUNE DP

HV feedthrough for capable to withstand 300kV operation has been prepared for the 3x1x1 prototype detector at CERN (S. Murphy’s talk)

HV FT being tested in LAr dewar

Signal readout



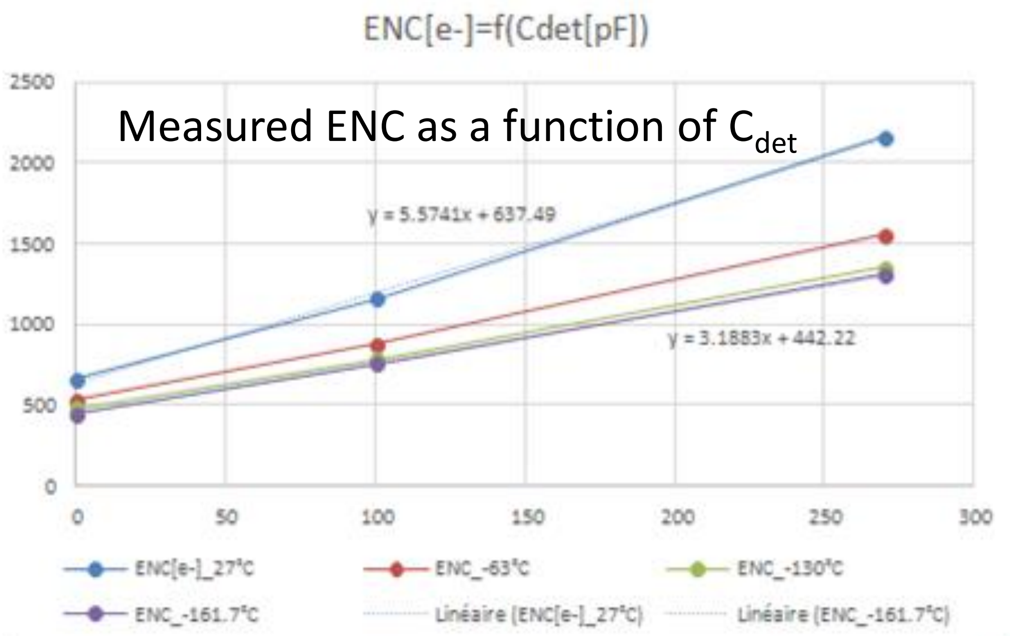


12 signal feed-through chimneys each collecting data from two 3x1 m^2 group of anodes (640 ch / chimney)

Provide access to the FE electronics without opening the main cryostat volume

Cold front-end electronics

- Accessible via chimneys (without opening of the TPC cryostat)
- Shielded from digital electronics
- Preamplifier ASIC:
  - 16 channels
  - Double slope gain with “kink” at 400 fC
  - 1200 fC dynamic range



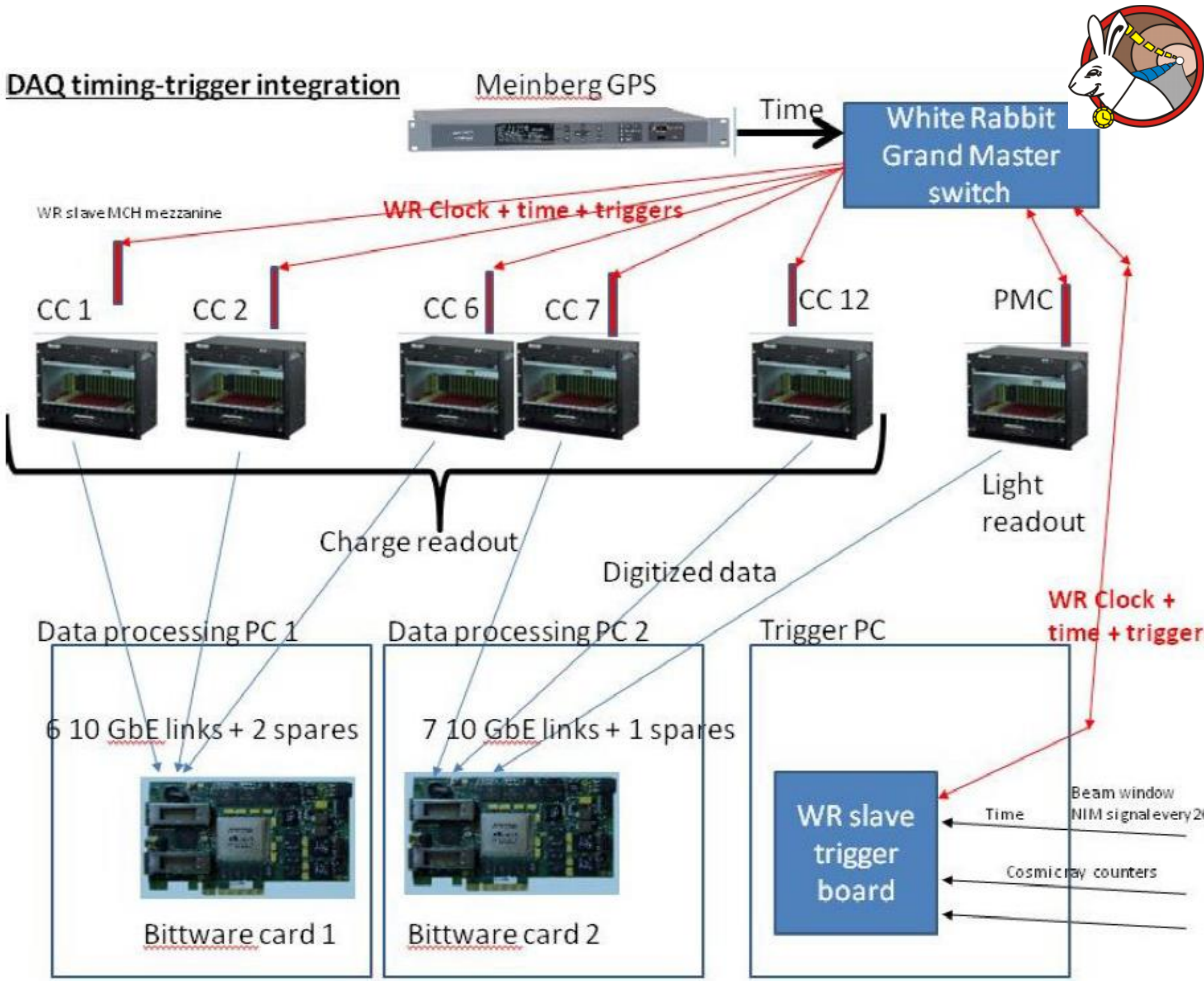
Anode capacitance is 150 pF/m
➔ 450 pF for a 3x3m^2 module:
expected noise = 1600 ENC
For LEM equivalent gain of 20 (10 per each collection view)
S/N ~ 100 for 1MIP signal

Digital electronics and DAQ scheme

Network-based time sync of all DAQ units

Digital electronics for charge readout
- microTCA standard
- 10 cards per crate
- 64 ch per card
- 14bit 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



Digital electronics and DAQ scheme

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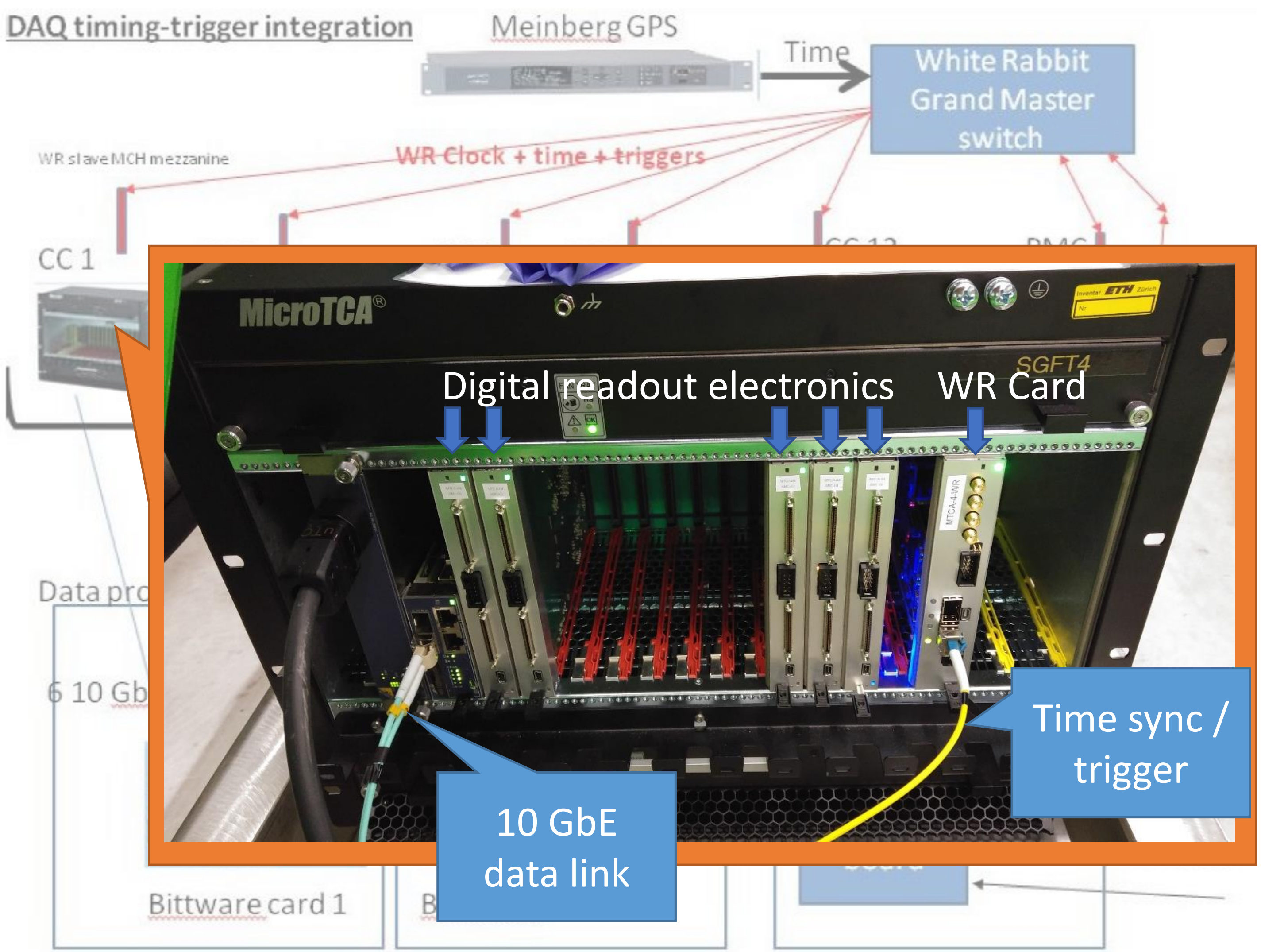
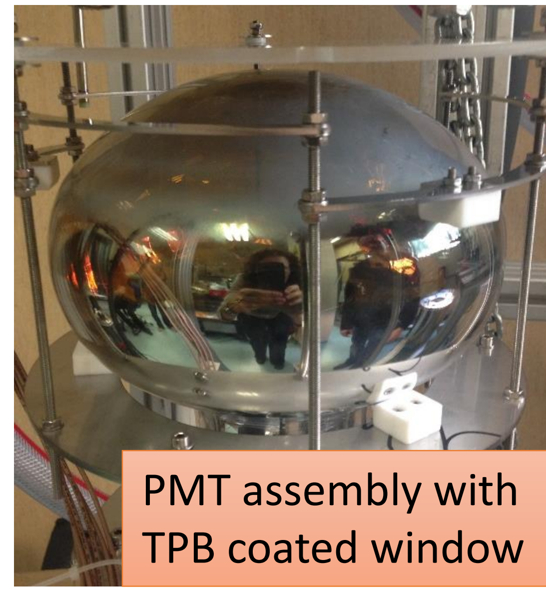


Light readout system

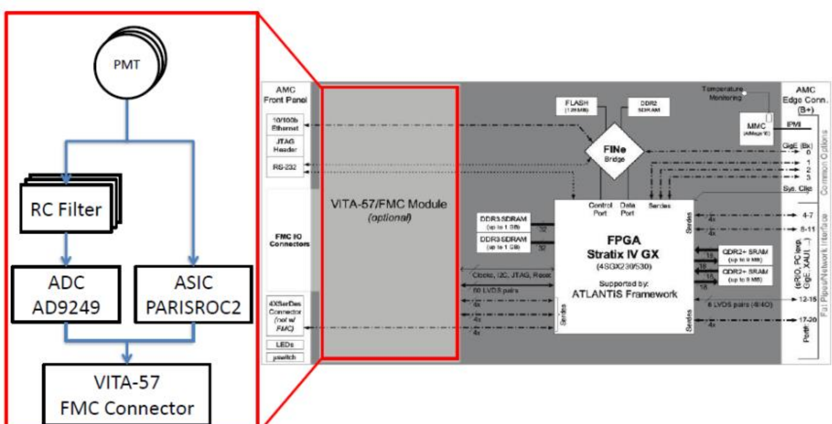
- Primary goal to provide T0 (and for underground operation trigger) for events
- For WA105 (surface operation) critical to tag cosmic ray muon arrival time
- 36 x 8” Hamamatsu R5912mod2 PMTs
- TPB coating to shift 128 nm to visible wavelengths
- Digitized data is written in cyclic memory buffers

  On beam trigger, $\pm$4ms is written out with 400ns time granularity → to reconstruct T_0 of cosmic ray tracks that overlap with the beam event

  Outside of beam trigger, self-triggering mode using PARISROC ASIC → dedicated light signal studies



PMT assembly with TPB coated window



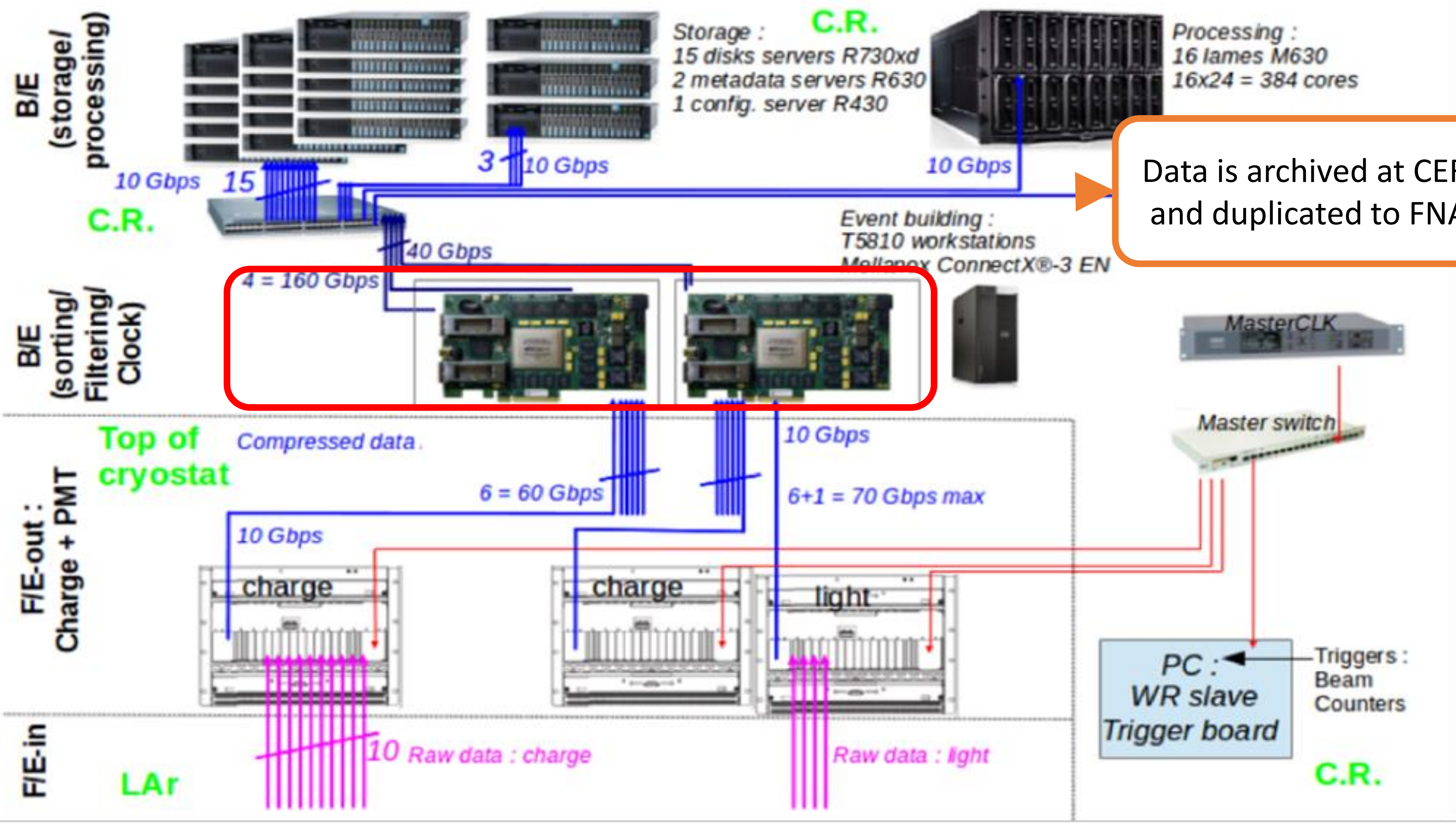
Two modes of acquisition:

- Internal trigger from PARISROC2 ASIC
- External beam trigger

Online storage/computing system

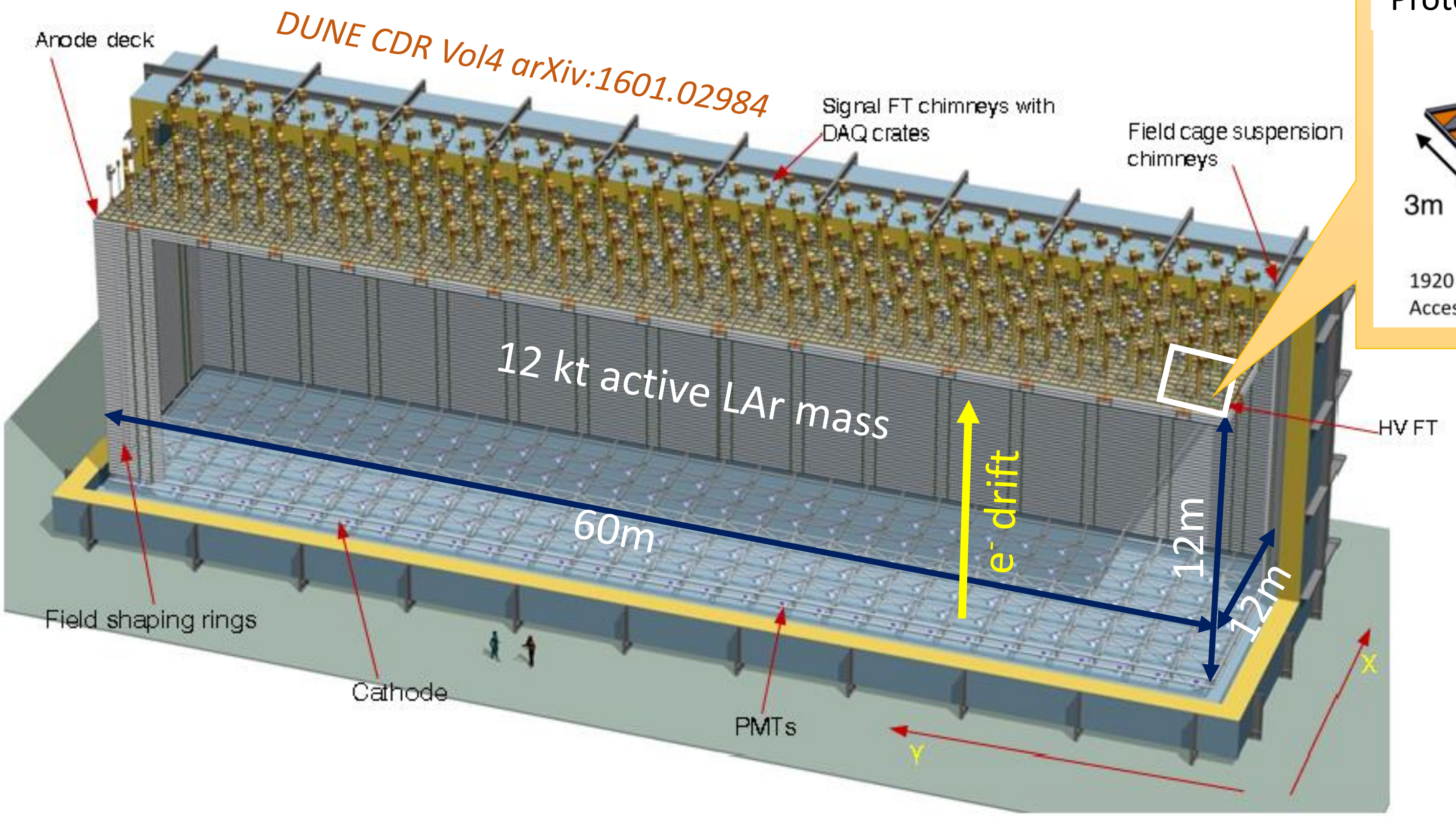
Data is buffered in 1PB local storage system w/ internal 20 GB/s bandwidth
1PB buffer allows running for several days without moving data to CERN storage

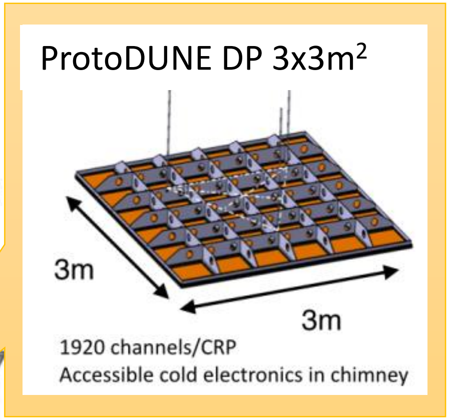
384 core cluster for online analysis:
- Detector performance checks
- Data quality checks
- Data preparation for archiving



Data is archived at CERN and duplicated to FNAL

Scalability to full DUNE “10kt” module

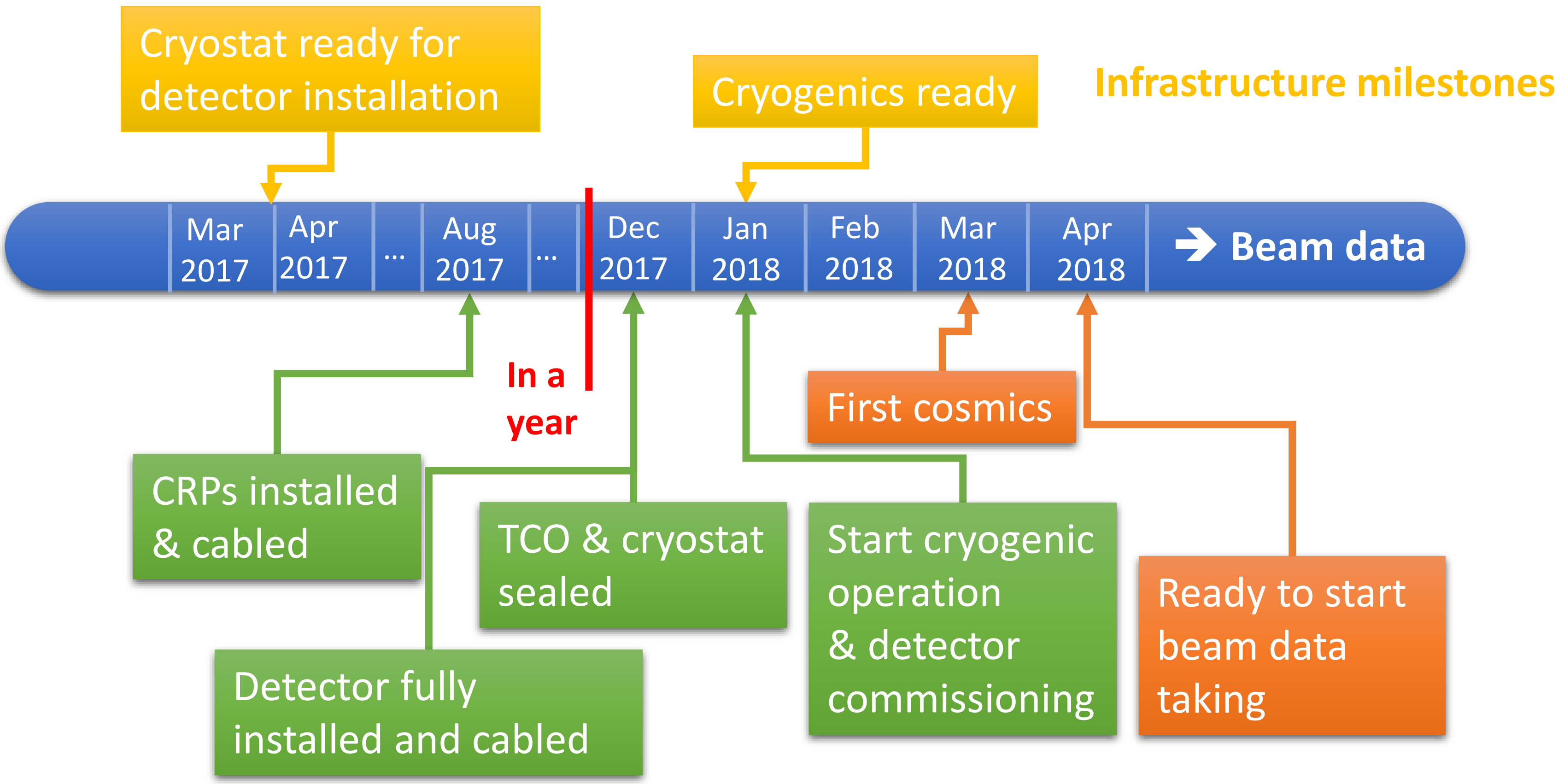




DUNE 10kt DP module to be built from the same components as ProtoDUNE DP

- Prototype CRP 4 x 3x3m^2 → DUNE 10kt 80 x 3x3 m^2 (20 x prototype)
  - Suspension / slow control / charge readout / electronics are the same
- Light readout: 36 → 180 of 8” Hamamatsu PMTs
- Field cage structured from the same units as in the prototype

Timeline



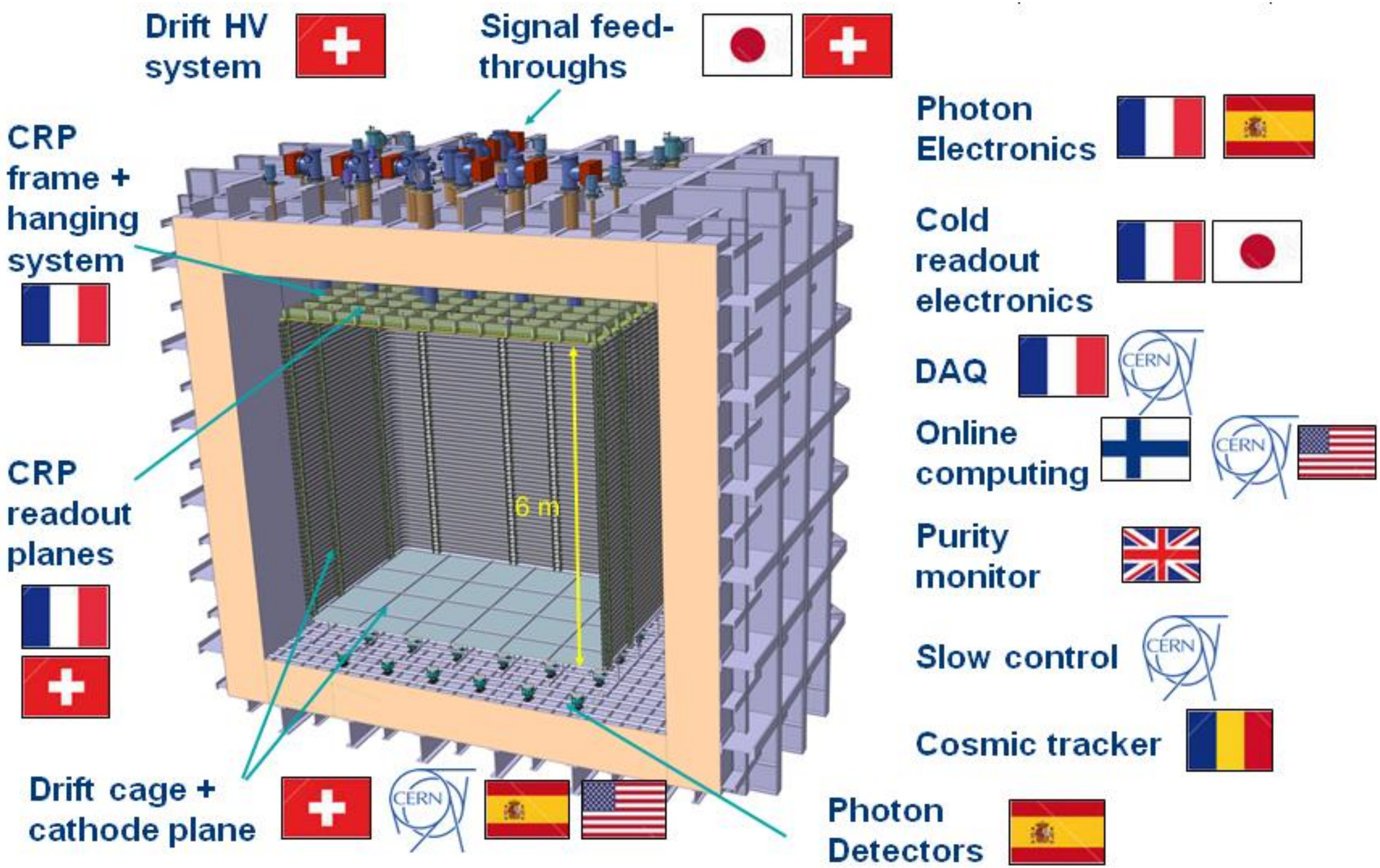
- Critical input on detector performance for DUNE far detector TDR in 2019
- 20-kt (fiducial mass) DUNE far detector ready for beam in 2026
  - Two 10kt modules (DP considered for 2nd module)

Summary

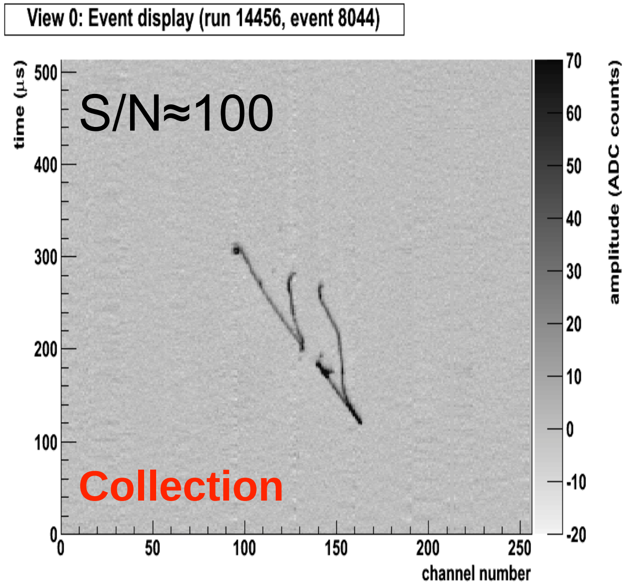
ProtoDUNE DP a double-phase LAr TPC with a ~300 ton fiducial LAr mass

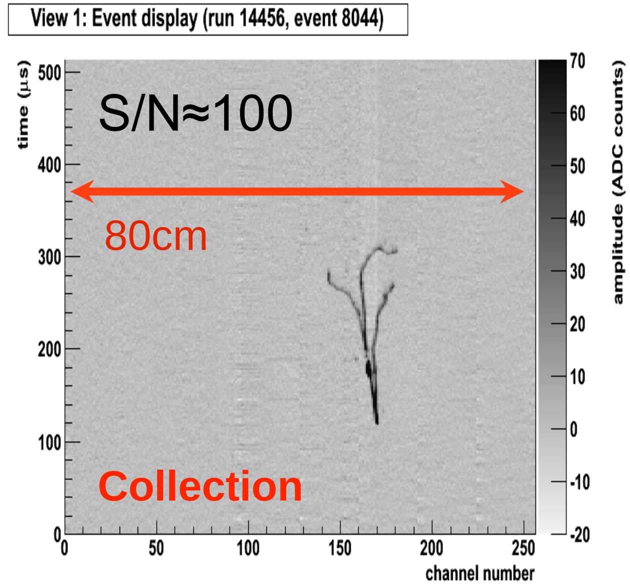
- Offer many advantages compared to single-phase LAr TPC
- Demonstrate double-phase technology for large LAr detector
- Validate the technical design for DUNE 10kt module
- Study detector performance with dedicated charged particle beam
- Start data taking in Spring 2018
- ProtoDUNE DP results to provide critical input to DUNE Far Detector Technical Design Report due in 2019

Thank you for your attention



Extra





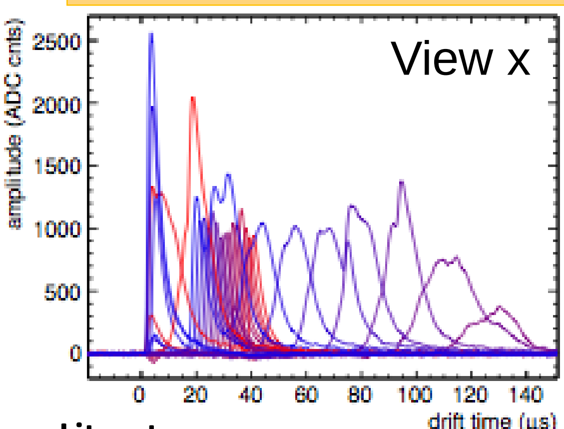
Double-phase prototypes measuring real data events since 6 years with active volumes from 3 to 250 liters

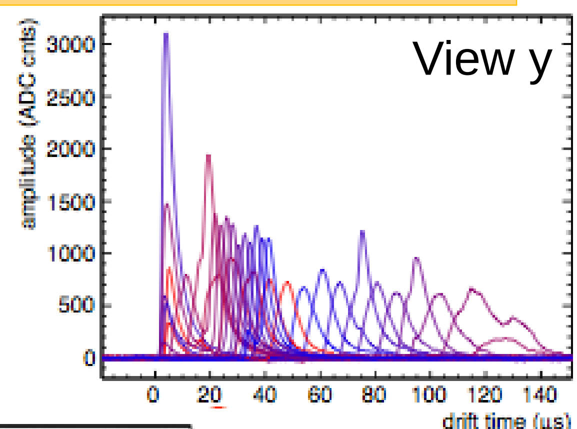
> 15 millions of cosmic events collected in stable conditions S/N~100 for m.i.p. achieved starting from gain ~15

Dual-phase concept advantages:

- 3mm pitch (or less?)
- Robust S/N with tunable gain
- Only charge collection (no induction planes)
- Can cope with electron diffusion & charge attachment for long drift
- Insensitive to microphonic noise

Raw data: no noise subtraction nor post-filtering





Literature:

NIM A617 (2010) p188-192

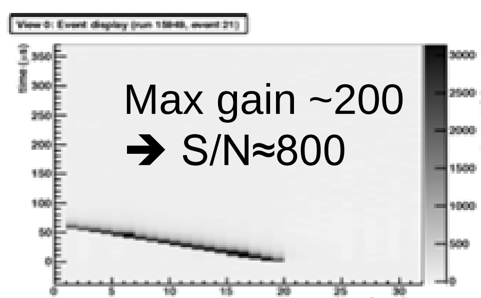
NIM A641 (2011) p 48-57

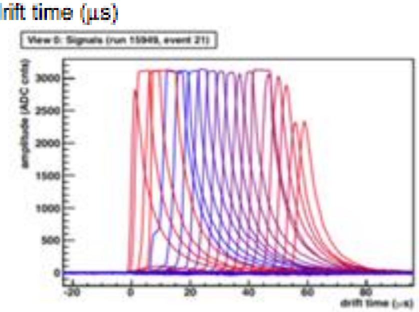
JINST 7 (2012) P08026

JINST 8 (2013) P04012

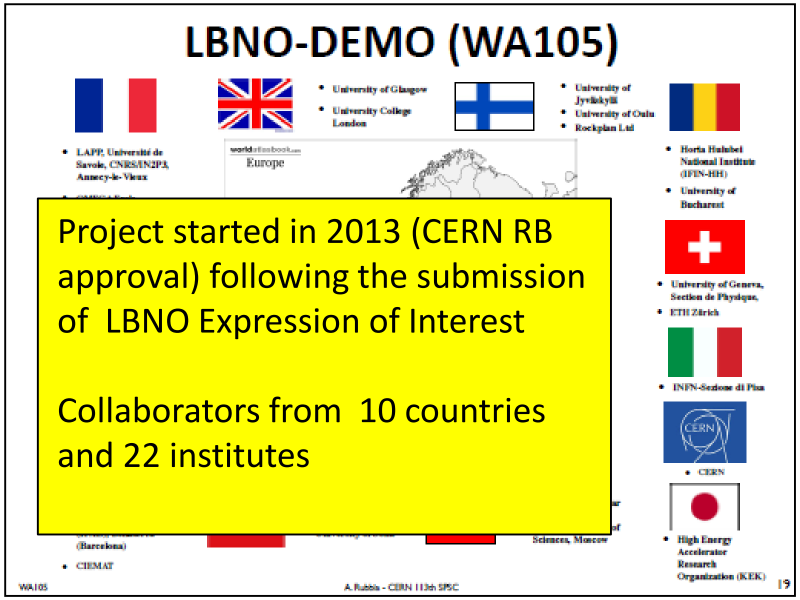
JINST 9 (2014) P03017

JINST 10 (2015) P03017





History of WA105 / Dual-phase ProtoDUNE



Project started in 2013 (CERN RB approval) following the submission of LBNO Expression of Interest

Collaborators from 10 countries and 22 institutes

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SR-XXX
March 31, 2015

Progress report on LBNO-DEMO/WA105 (2015)

The WA105 Collaboration

G. Balik, L. Brunetti, I. De Bonis, P. Del Amo Sanchez, G. Deleglise,
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K. Loo, J. Maalampi, M. Slupecki, and W.H. Trzaska
Department of Physics, University of Jyväskylä, Finland

Dept. of Physics and Astronom

DUNE CDR, July 2015: WA105 and Dual-phase 10 kton design

WA105 project MOU signed w/ CERN, December 2015

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

March 31st, 2014
CERN-SPSC-2014-013
SPSC-TDR-004

Technical Design Report
for large-scale neutrino detectors prototyping
and phased performance assessment
in view of a long-baseline oscillation experiment

...oration

TDR
submitted on 31st March 2014
CERN-SPSC-2014-013
SPSC-TDR-004(2014)

EUROPEAN ORG...

CERN-SR-XXX

Yearly progress report on WA105/ProtoDU...

G. Balik, L. Brunetti, A. Chappuis, I. De Bonis, G. De...
D. Duchesneau, N. Geffroy, Y. Karyotakis, H. Pessa...
LAPP, Université de Savoie, CNRS/IN2P3, Ann...

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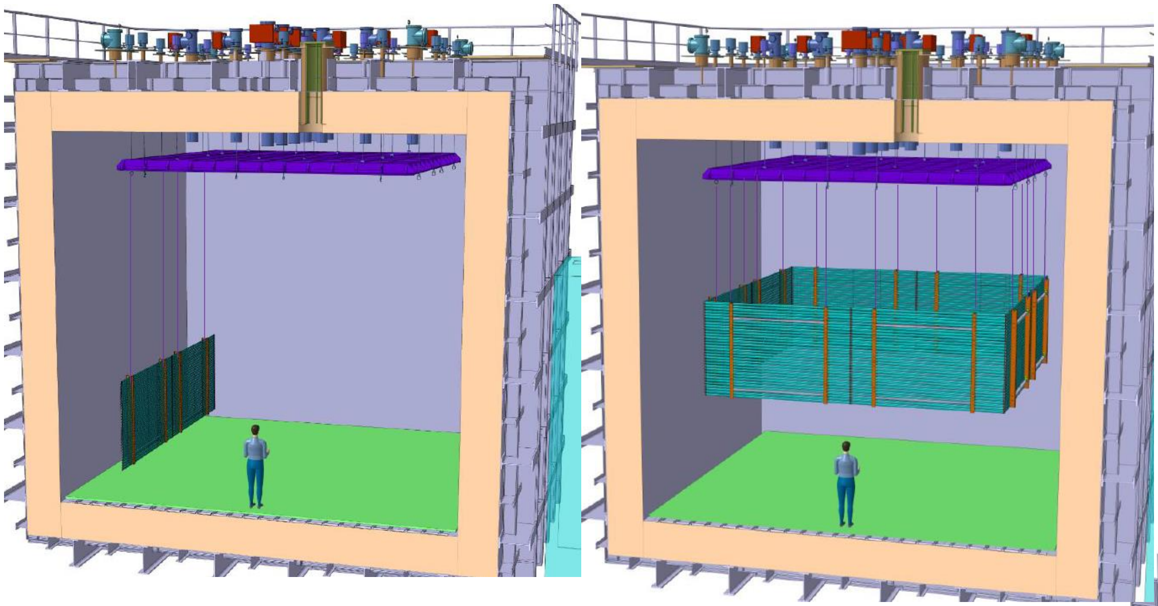
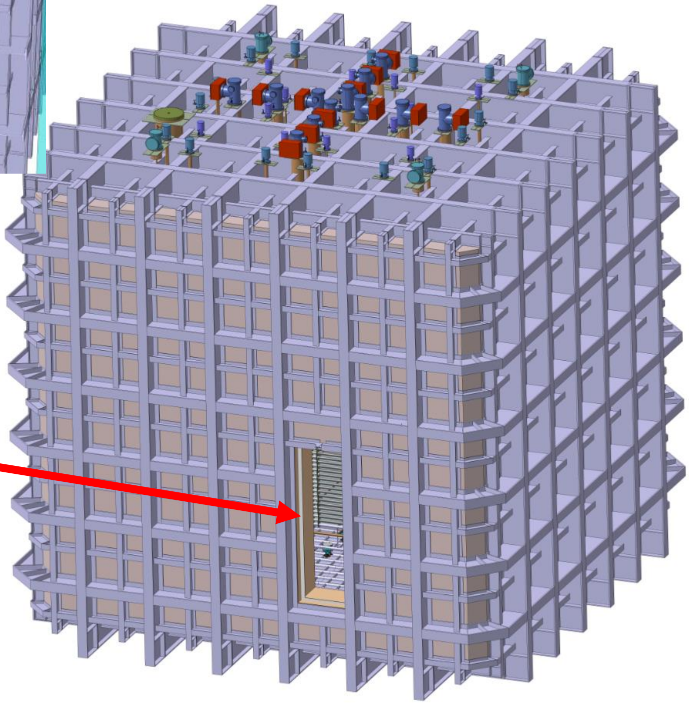
Integration in DUNE project as DP-ProtoDUNE December 2015

Detector assembly



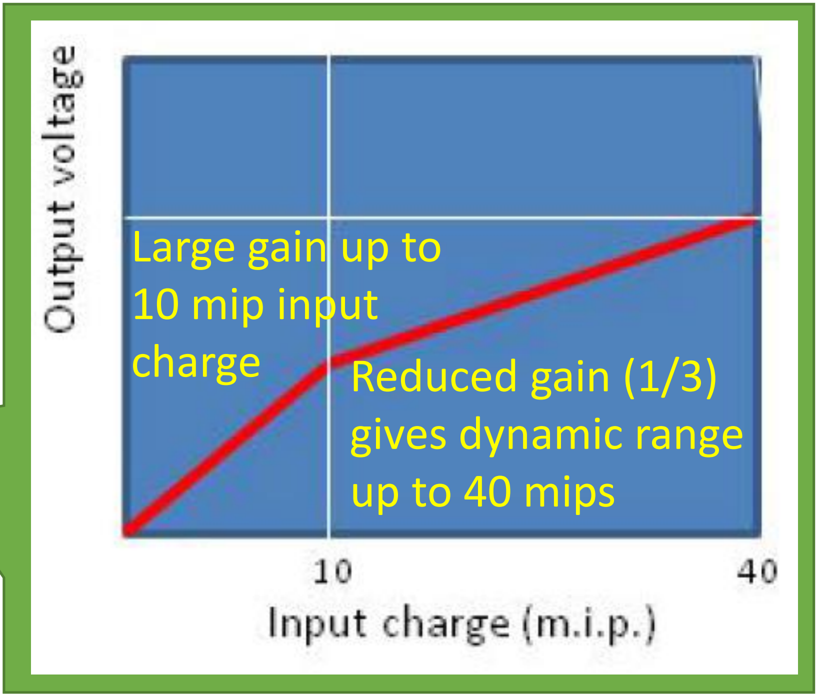


- The detector is assembled inside the cryostat tank
- Once finished membrane and TCO are closed
- Remaining personnel exit via “manhole” – a large feedthrough on the top

Front-end and digital electronics

16 channel ASIC with CMOS-based pre-amplifiers

- Low noise due to ambient temperature of 110 K and proximity to anode(short cables)
- Power consumption 18mW/ch
- Large dynamic range up to 40 mip using double slope structure of the gain
- R&D since 2006



Digital electronics in warm zone on the tank deck

- DAQ system based on micro-TCA standards
- Readout frequency 2.5MHz
- Total time window of 4000 usec ← covers completely 6 m of drift

Scalability to large detectors (150k ch for 10 kton) at low cost

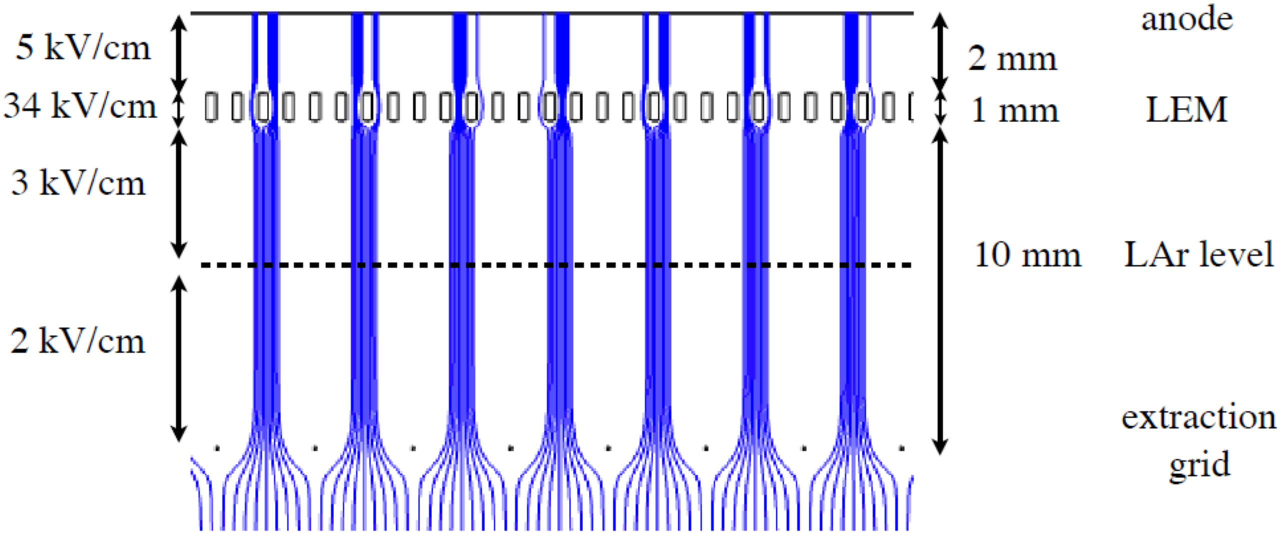
DUNE double-phase LAr TPC fact sheet

Parameter	Requirement	Achieved Elsewhere	Expected Performance
Gas phase gain	20	200	20-100
Electron Lifetime	3 ms	$>$ 3 ms 35-t prototype	$>$ 5 ms
Minimal S/N after 12 m drift	9:1	$>$ 100:1	12:1-60:1

Item	Value(s)	
Active volume width and length	W = 12 m	L = 60 m
Active volume height	H = 12 m (H = 15 m)	
Active volume/LAr mass	8,640 (10,800) m^3	12,096 (15,120) metric ton
Field ring vertical spacing	200 mm	
Field ring tube diameter	140 mm	
Anode plane size	W = 12 m	L = 60 m
CRP unit size	W = 3 m	L = 3 m
HV for vertical drift	600–900 kV	
Resistor value	100 MΩ	

Item	Number
Field rings	60 (75)
CRP units	$4 \times 20 = 80$
LEM/Anode sadwiches per CRP unit	36
LEM/Anode sandwiches (total)	2,880
SFT chimneys / CRP unit	3
SFT chimneys (total)	240
Readout channels / SFT chimney	640
Readout channels (total)	153,600
Suspension FT / CRP unit	3
Suspension FTs (total)	240
Slow Control FT / sub-anode	1
Slow Control FTs (total)	80
HV feedthrough	1
Voltage degrader resistive chains	4
Resistors (total)	240 (300)
PMTs (total)	180 (1/4 m^2)

CRP alignment requirements



Tolerances are calculated to keep gain stability <5%

	[mm]	electric field [kV/cm]	tolerance [mm]
anode-LEM	2	5	0.1
LEM	1	34	0.01
LEM-grid	10	2	1
liquid level	5 (from grid)	-	1

ASIC (CMOS 0.35 um) 16 ch amplifiers working ~110 K to profit from minimal noise conditions:

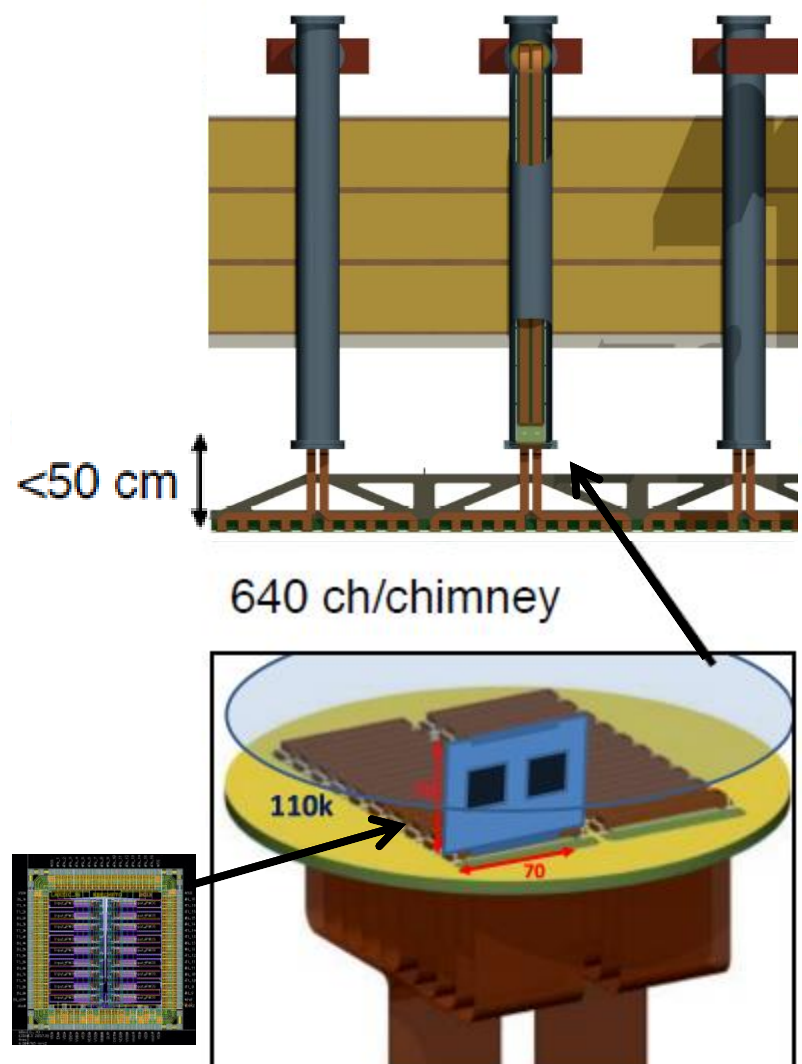
- FE electronics inside chimneys, cards fixed to a plug accessible from outside
- Distance cards-CRP<50 cm
- Dynamic range 40 mips, (1200 fC)

(LEM gain =20)

- 1300 e- ENC @250 pF, 100 keV sensitivity
- Single and double-slope versions
- Power consumption <18 mW/ch

DAQ in warm zone on the tank deck:

- architecture based on uTCA standard
- local processors replaced by virtual processors emulated in low cost FPGAs (NIOS)
- integration of the time distribution chain (improved PTP)
- Bittware S5-PCIe-HQ 10 Gbe backend with OPENCL and high computing power in FPGAs



ASIC 16 ch.
(CMOS 0.35 um)