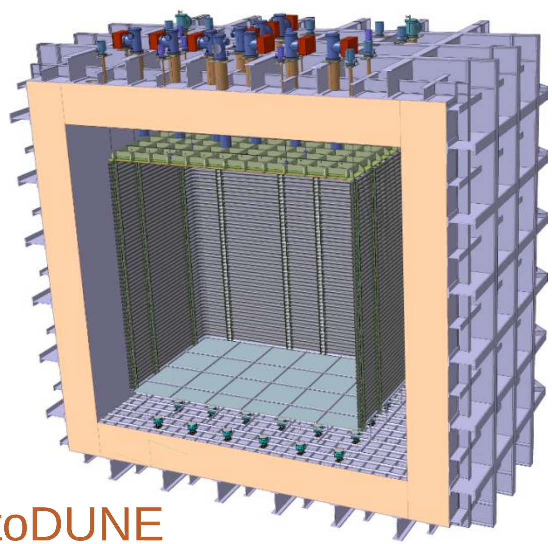
Opportunities with ProtoDUNE-DP

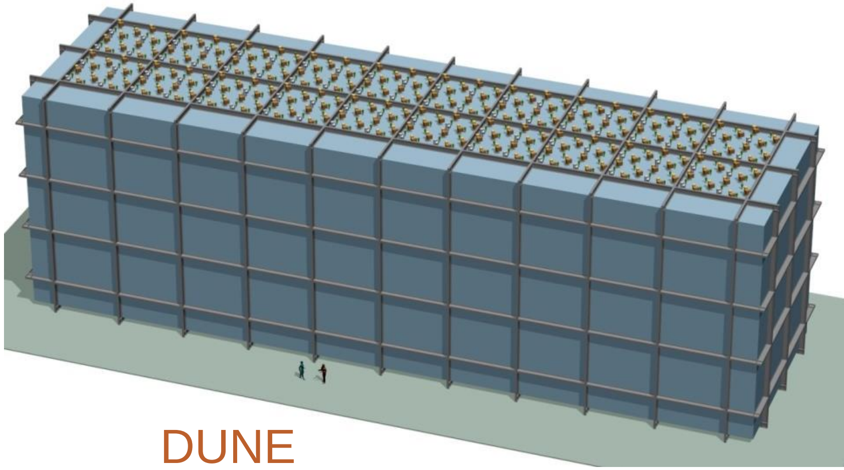
Dario Autiero (IPNL Lyon)

Opportunities with ProtoDUNE-DP

April 8, 2016



WA105
Dual-Phase ProtoDUNE



DUNE

LAGUNA-LBNO Design Study

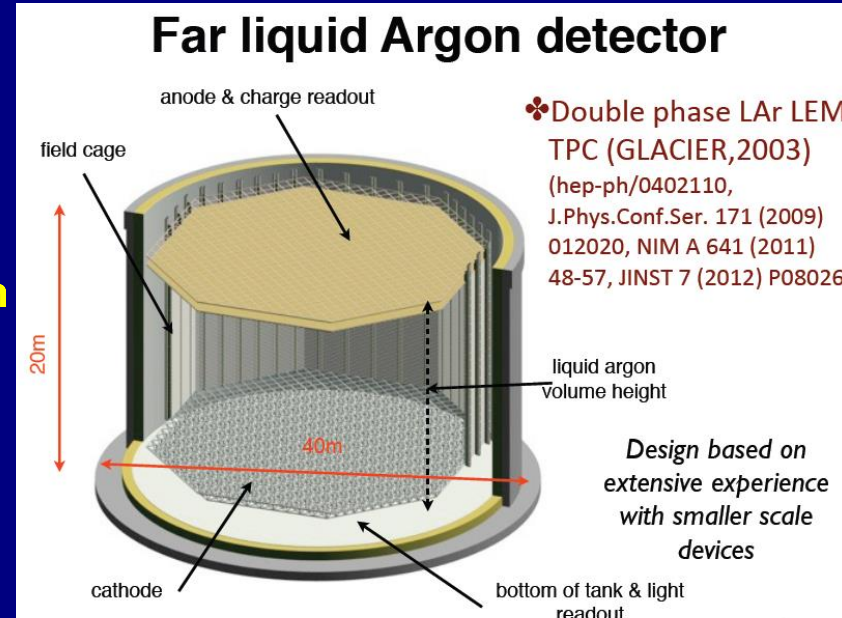
Design study for LBL neutrino experiment
2 EU programs: 2008-2011/2011-2014
~17 Meur investment → Completed by August 2014

→ **Aimed to assess all technical aspects to build an affordable underground detector**
→ **Prototyping activity for double-phase since 2003**

- **LBNO EOI June 2012 (CERN to Pyhasalmi)**

http://cdsweb.cern.ch/record/1457543
224 physicists, 52 institutions
Physics program:

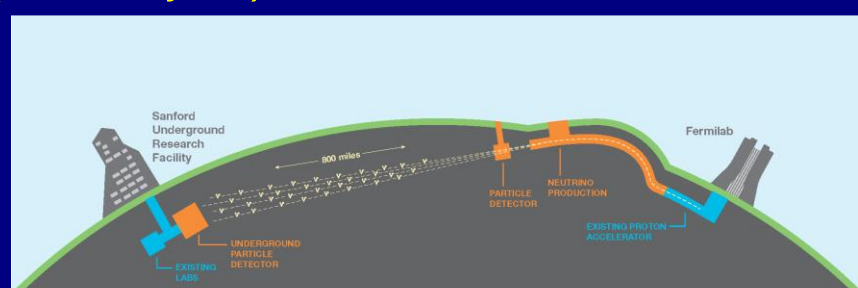
- Determination of neutrino mass hierarchy
- Search for CP violation
- Proton decay
- Atmospheric and supernovae neutrinos



20 kton double phase LAr TPC
(also 50 kton detector designed)

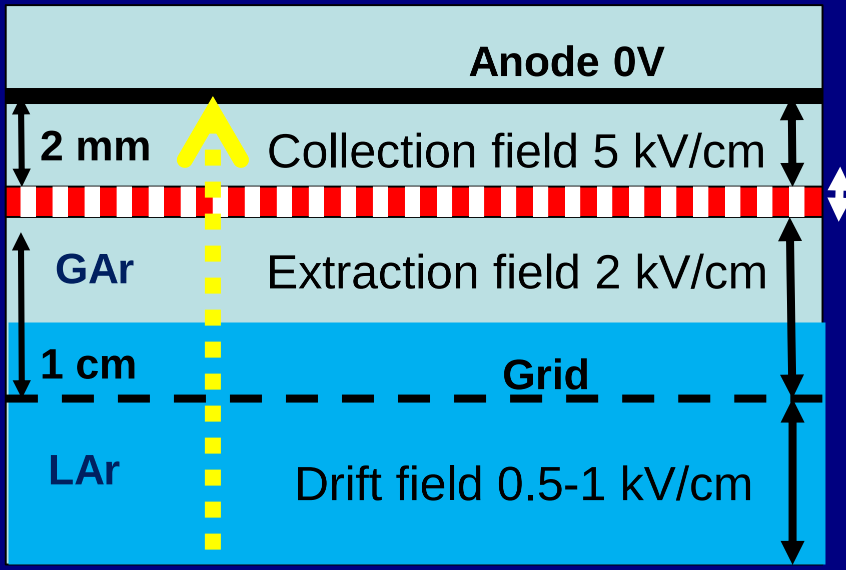
- **ELBNF (now DUNE) LOI, January 2015 (P1062)**

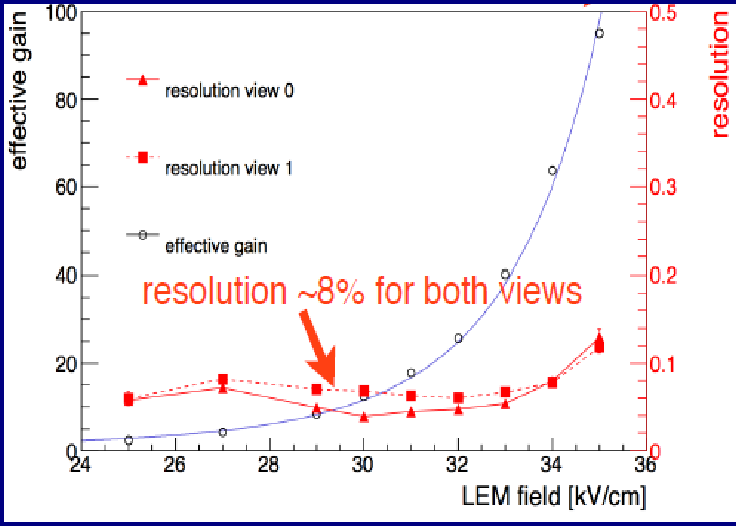
http://www.fnal.gov/directorate/program_planning/Jan2015Public/LOI-LBNF.pdf
503 physicists, 142 institutions
LBL and underground physics (as rec. by P5): 40 kton LAr at Homestake + 1.2(2.4) MW beam

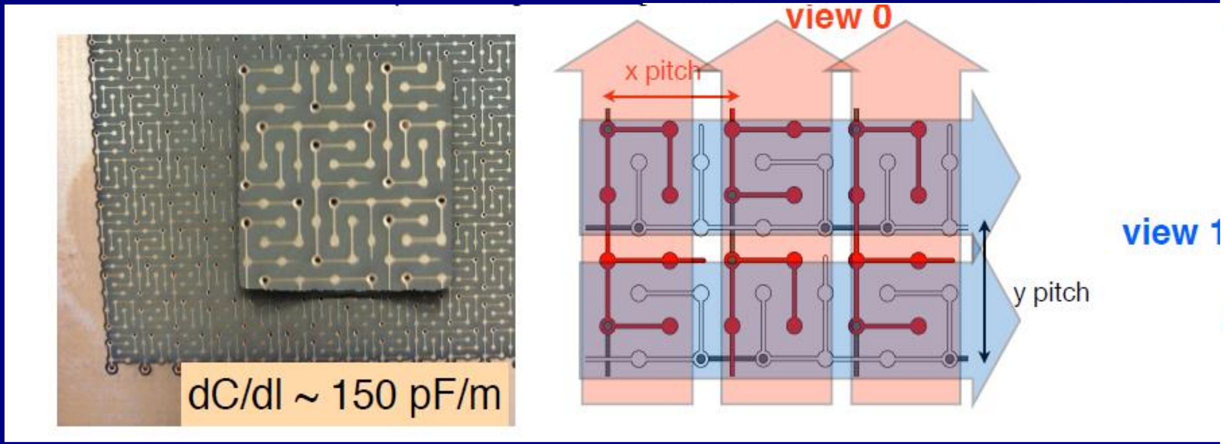


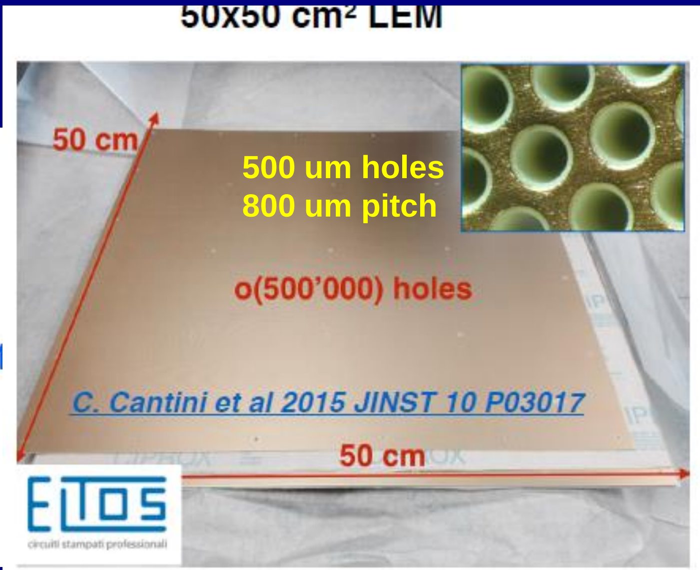
Double-phase readout:

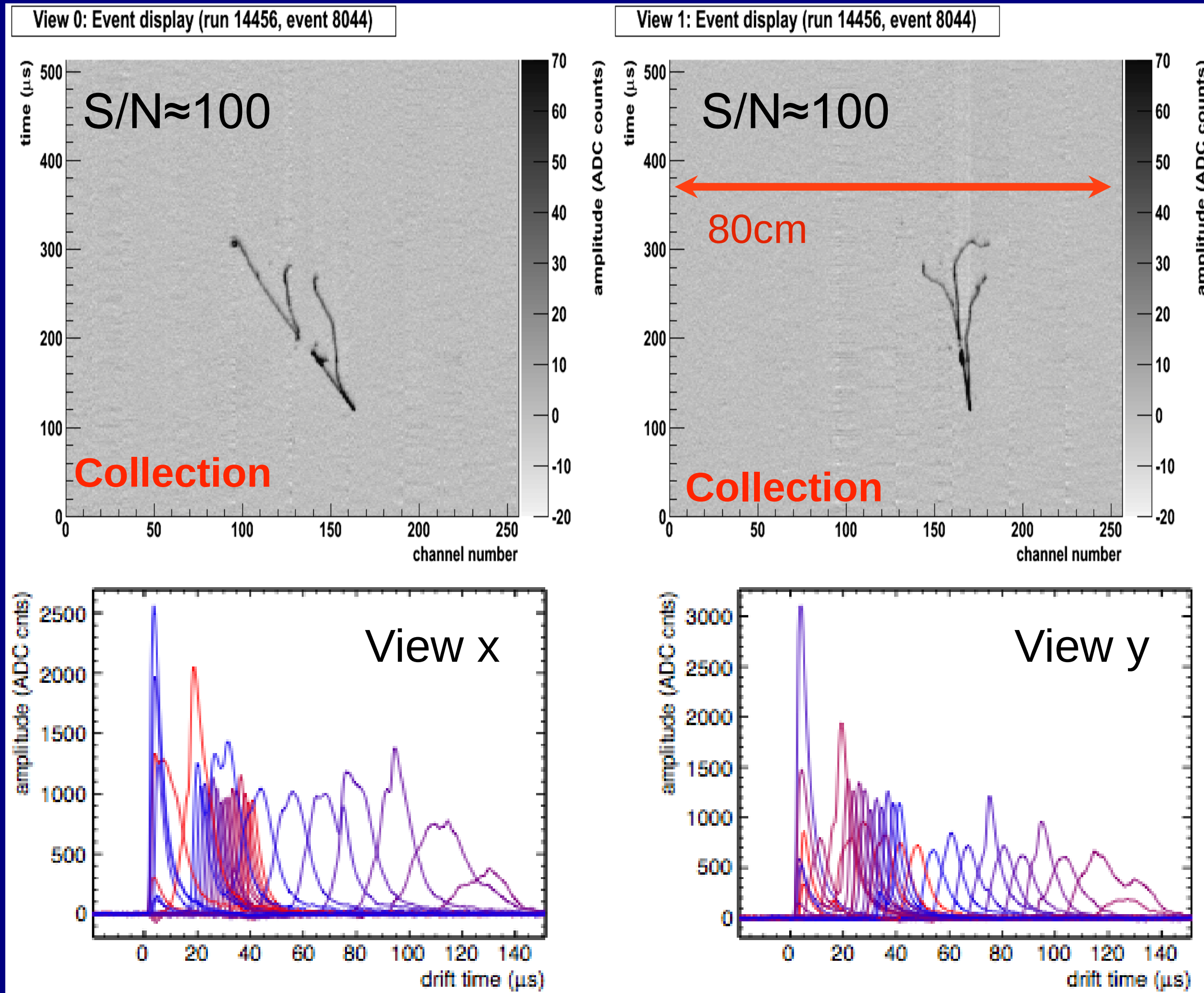
Long drift, high S/N: extraction of electrons from the liquid and multiplication with avalanches in pure argon with micro-pattern detectors like LEM (Large Electron Multipliers)
Tunable gain (~20 minimum), two symmetric collection views, coupling to cold electronics











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

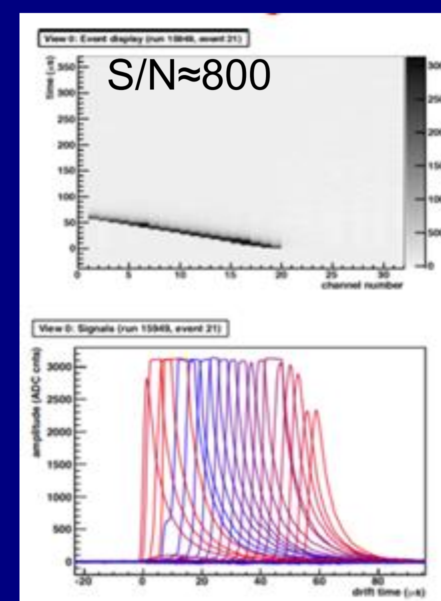
> 15 millions of cosmic events collected in stable conditions S/N~100 for m.i.p. achieved starting from gain ~15

- $3x1x1\ m^3$ setup at CERN starting operations in September 2016
- WA105 $6x6x6\ m^3$ setup will start data taking in 2018

Literature:

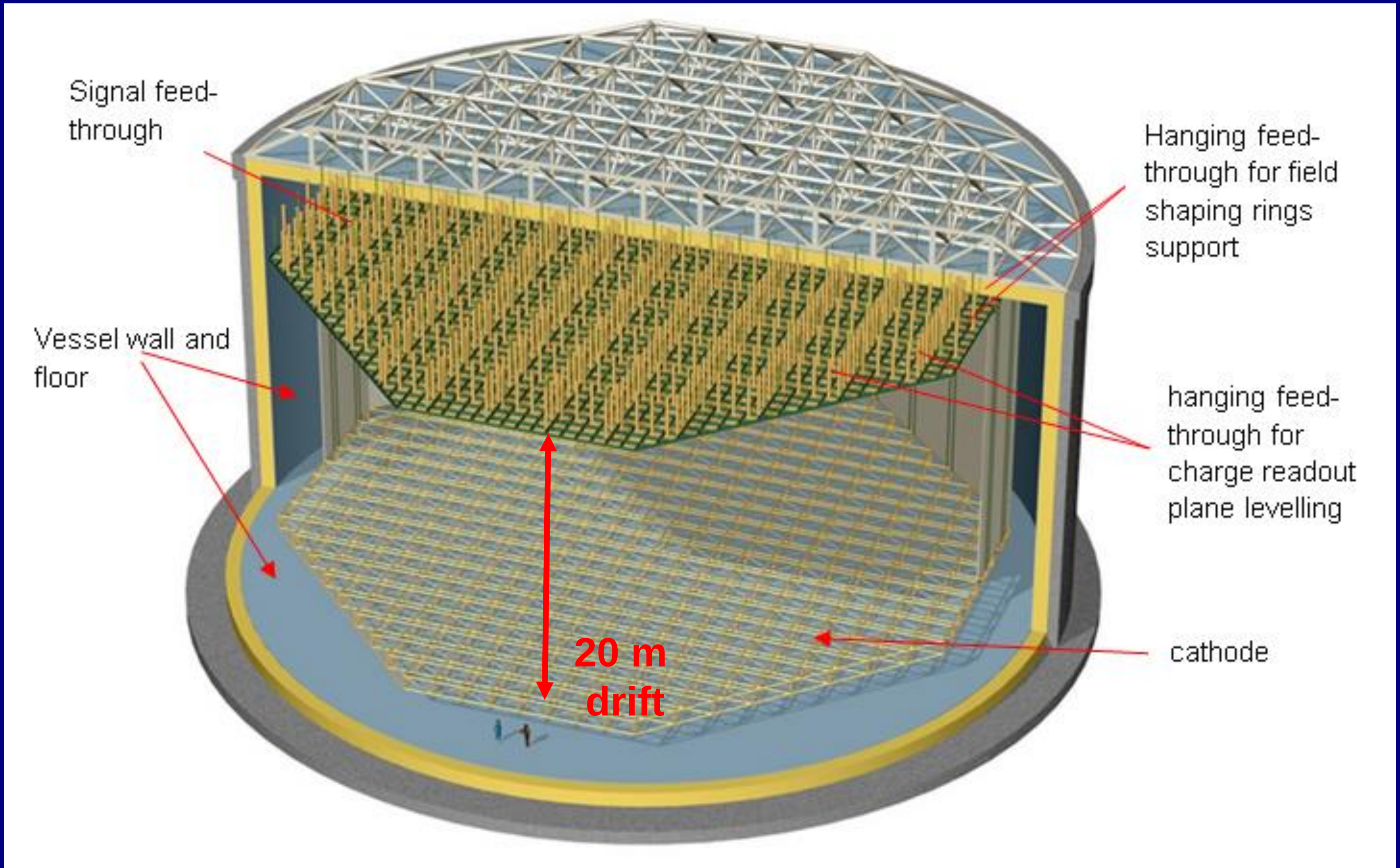
NIM A617 (2010) p188-192
NIM A641 (2011) p 48-57
JINST 7 (2012) P08026
JINST 8 (2013) P04012
JINST 9 (2014) P03017
JINST 10 (2015) P03017

Max achieved gain ~200



LBNO 50 kton

- Drift 20 m
- Cathode span 47 m
- 573444 channels
- Active mass 51.3 kton

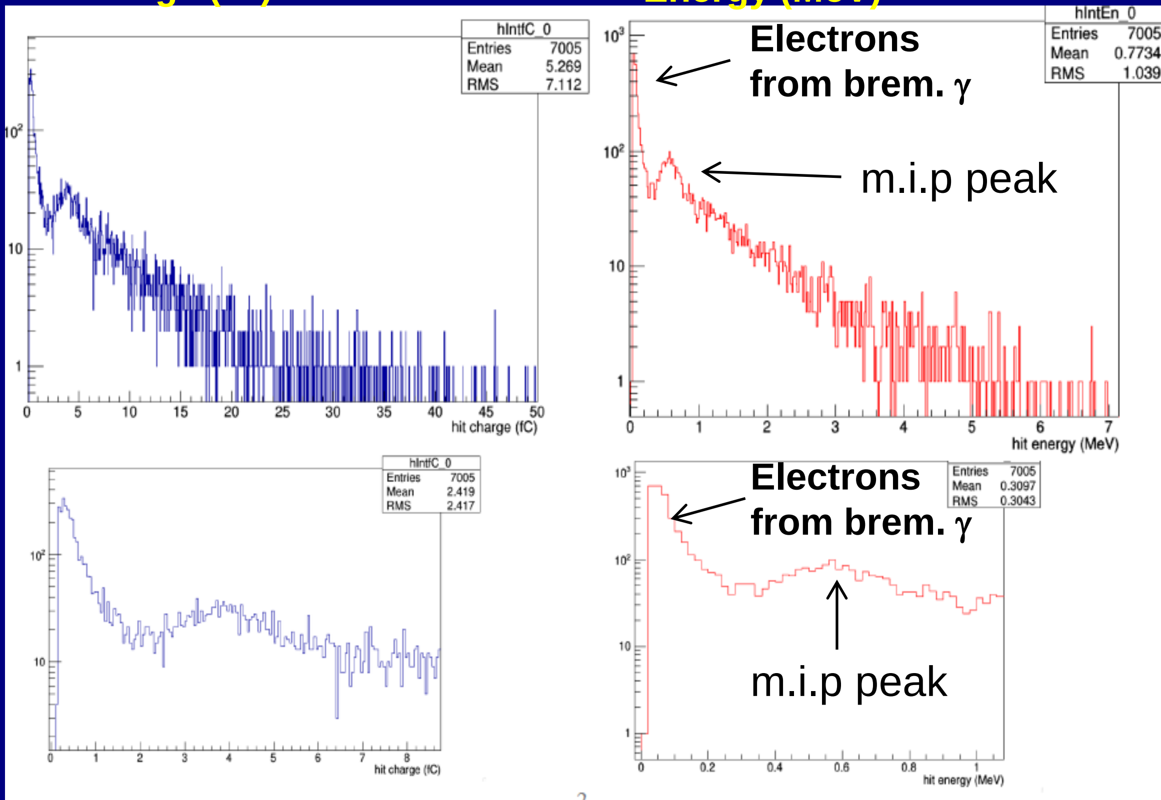


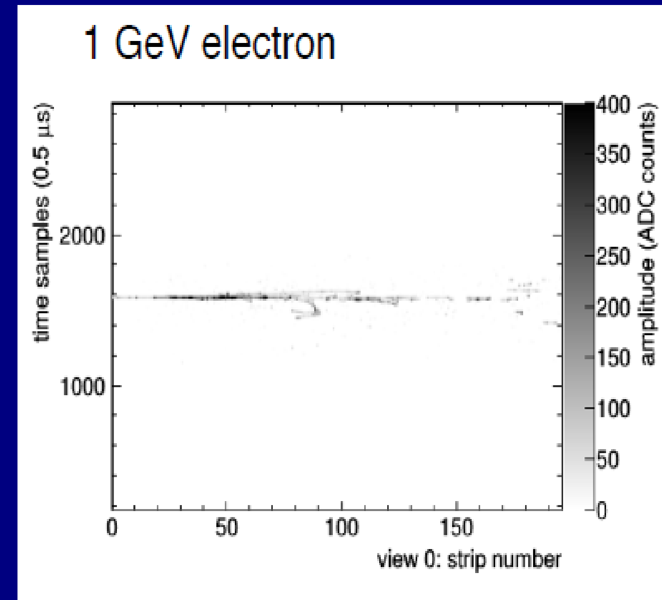
Advantages of double-phase design:

- Anode with 2 collection (X, Y) views (no induction views), no ambiguities
- Strips pitch 3.125 mm, 3 m length
- Tunable gain in gas phase (20-100), high S/N ratio for m.i.p. > 100, <100 KeV threshold, min. purity requirement 3ms → operative margins vs purity, noise
- Long drift projective geometry: reduced number of readout channels
- No materials in the active volume
- Accessible and replaceable cryogenic FE electronics, high bandwidth low cost external uTCA digital electronics

Energy depositions seen at the single wire level for a 1 GeV electron simulated shower (3.125 mm pitch)

Charge (fC) **Energy (MeV)**





→ Many tiny depositions at the single wire level from brem. photons which contribute to the energy reconstruction

→ Importance of operating at low energy thresholds < 100 keV

→ Do not consider only average value of m.i.p. peak for S/N but also under-fluctuations in Landau width

A 10-20 MeV electron from a SNB event will brem. and be split in little per-wire depositions
For SNB is also very important to detect de-excitation gammas of 40K*(40Cl*) for neutrino(anti) tagging → Also pointing to relevance of reconstructing low energy depositions for SNB

Effect of tunable LEM gain (20-100) on S/N and 3σ noise threshold at 6m and 12m distance and for different purity levels

Drift field 0.5 kV/cm, 1300 e- ENC, minimal purity requirement 3 ms (same as for Ref. Design)

3 ms →

	LEM gain 25		LEM gain 50		LEM gain 100	
Distance (m)	S/N	Thresh. (keV)	S/N	Thresh. (keV)	S/N	Thresh. (keV)
6	51	38	103	19	207	9
12	15	133	30	66	59	33

5 ms →

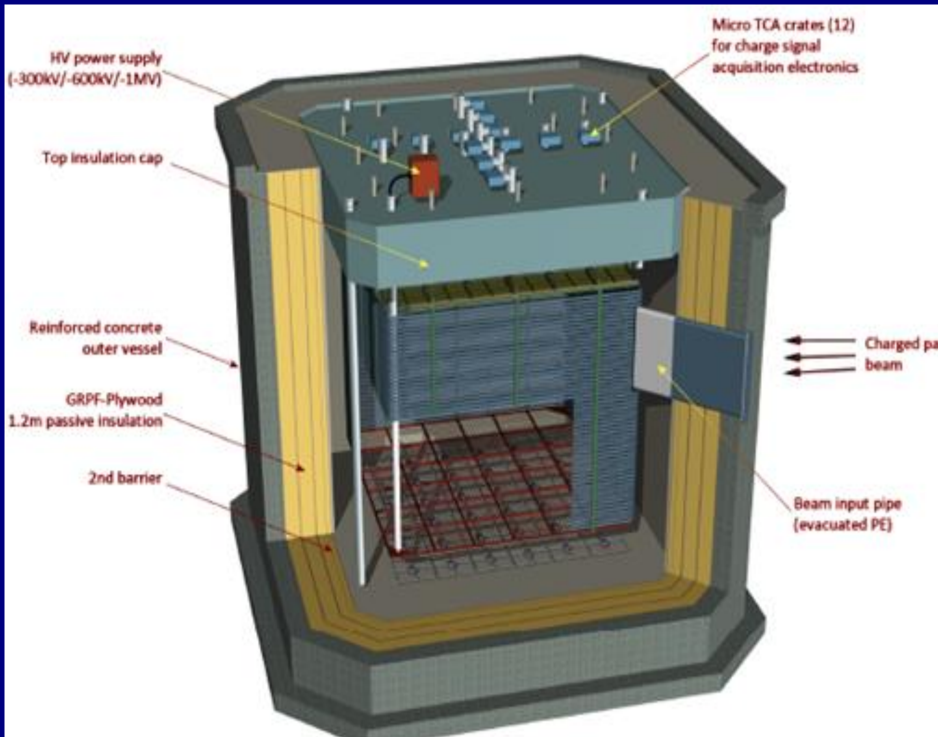
	LEM gain 25		LEM gain 50		LEM gain 100	
Distance (m)	S/N	Thresh. (keV)	S/N	Thresh. (keV)	S/N	Thresh. (keV)
6	85	23	170	12	340	6
12	40	49	80	24	161	12

12 ms →

	LEM gain 25		LEM gain 50		LEM gain 100	
Distance (m)	S/N	Thresh. (keV)	S/N	Thresh. (keV)	S/N	Thresh. (keV)
6	132	15	264	7	528	4
12	96	20	193	10	386	5

The LBNO-DEMO/WA105 experiment at CERN (approved in 2013)

WA105



Liquid argon density	T/m^3	1.38
Liquid argon volume height	m	7.6
Active liquid argon height	m	5.99
Hydrostatic pressure at the bottom	bar	1.03
Inner vessel size (WxLxH)	m^3	8.3 × 8.3 × 8.1
Inner vessel base surface	m^2	67.6
Total liquid argon volume	m^3	509.6
Total liquid argon mass	t	705
Active LAr area	m^2	36
Charge readout module (0.5 x0.5 m^2)		36
N of signal feedthrough		12
N of readout channels		7680
N of PMT		36

→ 1/20 of 20 kton LBNO detector

6x6x6m^3 active volume, 300 ton , 7680 readout channels, LAr TPC (double phase+2-D collection anode): DLAr
Exposure to charged hadrons, muons and electrons beams (0.5-20(10) GeV/c)

Full-scale demonstrator of all innovative LAGUNA-LBNO technologies for a large LAr detector:

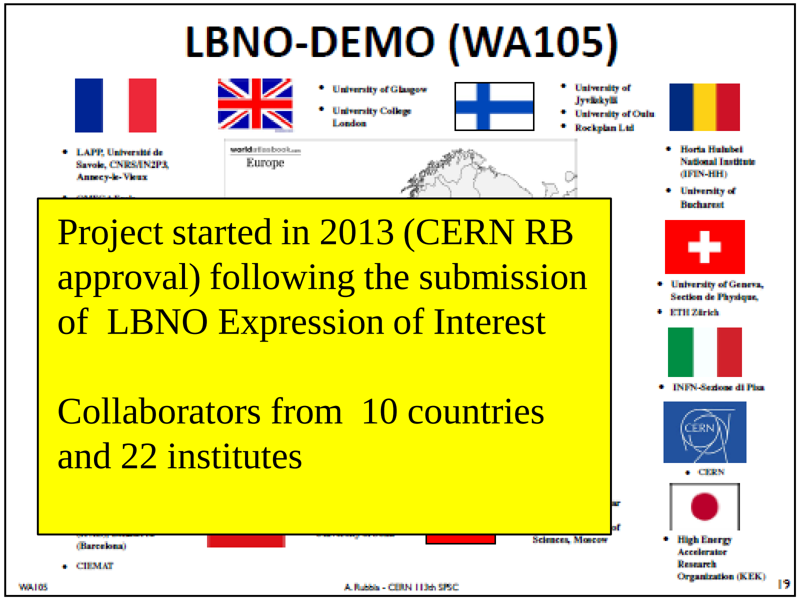
- **LNG tank construction technique (with non evacuated vessel)**
- **Purification system**
- **Long drift**
- **HV system 300-600 KV, large hanging field cage**
- **Large area double-phase charge readout**
- **Accessible FE and cheap readout electronics**
- **Long term stability of UV light readout**

Assess performance in reconstructing hadronic showers (most demanding task in neutrino interactions):

- **Measurements in hadronic and electromagnetic calorimetry and PID performance**
- **Full-scale software development, simulation and reconstruction to be validated and improved**

Installation in the CERN NA EHN1 extension, data taking in 2018
→ Fundamental step for the construction of a large LAr detector

History of Dual-Phase ProtoDUNE / WA105



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-

March

CERN-SPSC-2015-013 / SPSC-SR-158
31/03/2015

Progress report on LBNO-DEMO/WA105 (2015)

The WA105 Collaboration

G. Balik, L. Brunetti, I. De Bonis, P. Del Amo Sanchez, G. Deleglise, C. Drancourt, D. Duchesneau, N. Geffroy, Y. Karyotakis, and H. Pessard
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Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona), Spain

A. Jipa, I. Lazanu, M. Calin, C.A. Ene, T. Esanu, O. Ristea, C. Ristea, S.A. Nae, and L. Nita
Faculty of Physics, University of Bucharest, Bucharest, Romania

P. Bourgeois, F. Duval, I. Efthymiopoulos, U. Kose, G. Maire, D. Mladenov, M. Nessi, and F. Noto
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R. Bayes and F.J.P. Soler
University of Glasgow, Glasgow, United Kingdom

G.A. Nuijten
Rockplan Ltd., Helsinki, Finland

2015 Annual SPSC progress report 31st March 2015
SPSC-SR-158

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

WA105 project MOU fully signed, December 2015

Integration in DUNE project as DP-ProtoDUNE December 2015; EOI call for ProtoDUNEs, January 2016

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

...boration

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

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Yearly progress report on WA105/ProtoDUNE dual

G. Balik, L. Brunetti, A. Chappuis, I. De Bonis, G. Deleglise, C. D...
D. Duchesneau, N. Geffroy, Y. Karyotakis, H. Pessard, and L. Z...
LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux...

B. Bourguille, S. Bordoni, T. Lux, and F. Sanchez
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M. Calin, T. Esanu, A. Jipa, I. Lazanu, L. Nita, O. Ristea, and C. Ristea
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CERN, Geneva, Switzerland

K. Loo, J. Maalampi, W.H. Trzaska, and S. Vihonen
Department of Physics, University of Jyväskylä, Finland

2016 Annual SPSC progress report, 7th April 2016
CERN-SPSC-2016-017
SPSC-SR-184

Organization within DUNE of Dual-Phase ProtoDUNE / WA105

Dual-Phase ProtoDUNE Coordinators
Dario Autiero (IPNL Lyon) & Takuya Hasegawa (KEK)

Technical Board (TB, Chair: D. Autiero) which coordinates all the aspects of the detector developments, procurement, construction and installation.

Science Board (SB, Chair: T. Hasegawa) which coordinates the software developments and the preparation of the physics measurements.

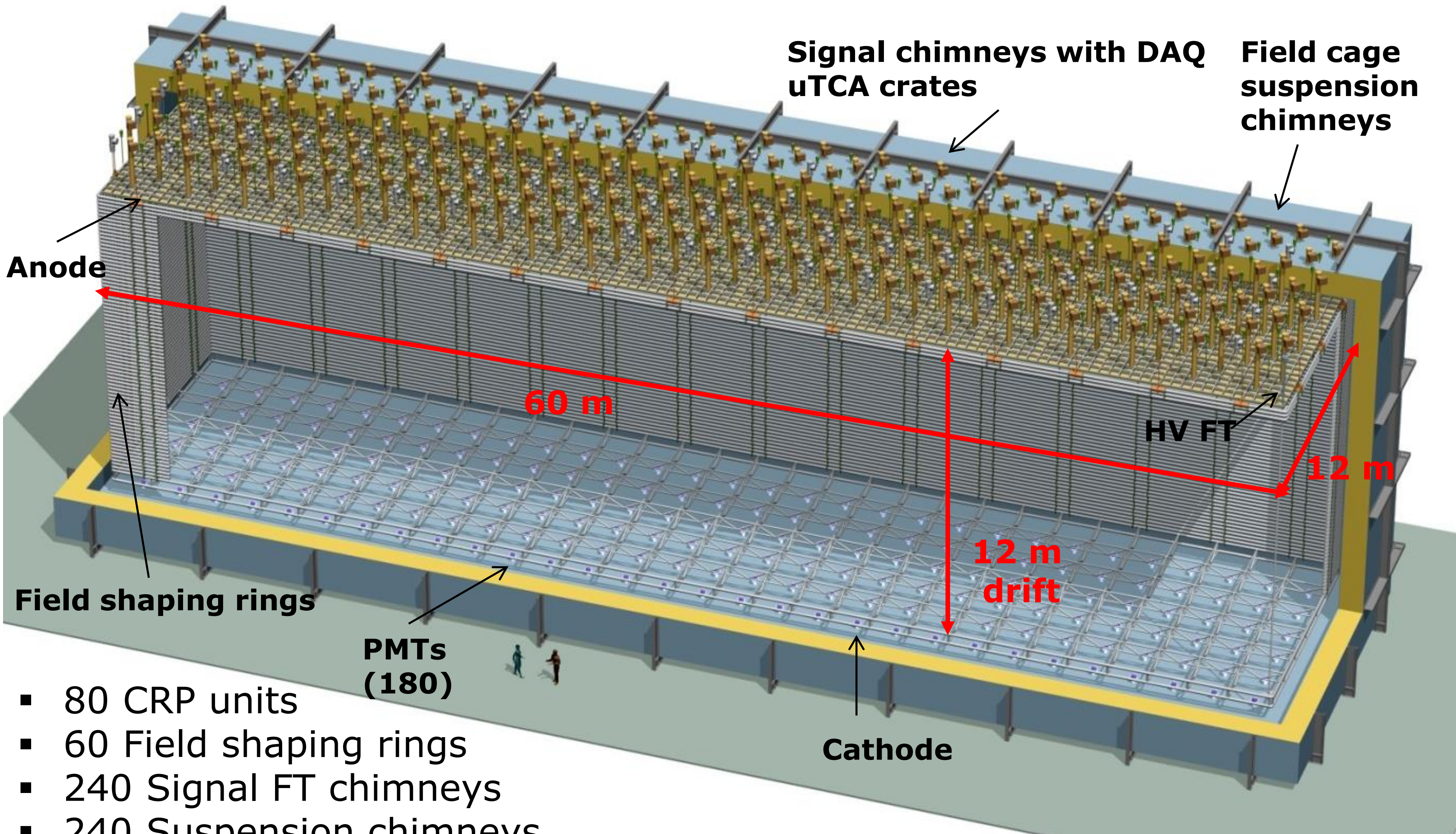
3x1x1 m^3 coordinator (S. Murphy) who coordinates all the aspects of the 3x1x1 m^3 .

with fine structure coordination roles (about 30) are defined as well

The TB, SB, and 3x1x1 m^3 have regular weekly meeting activity

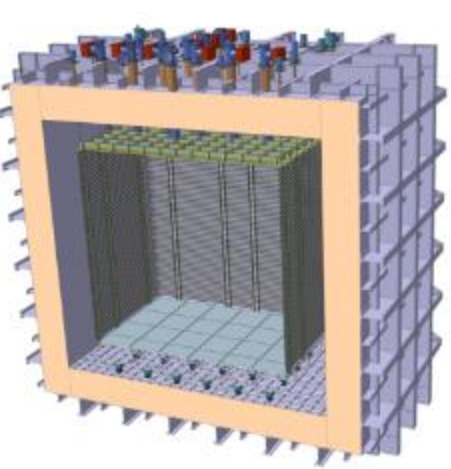
Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) **DUNE Conceptual Design Report, July 2015**

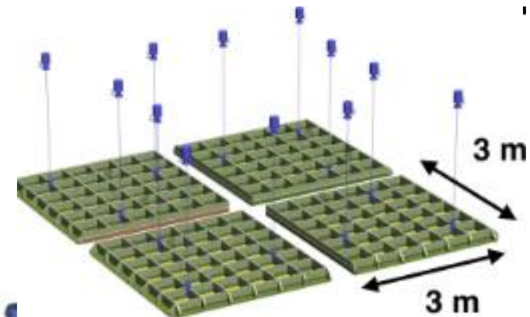
Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600

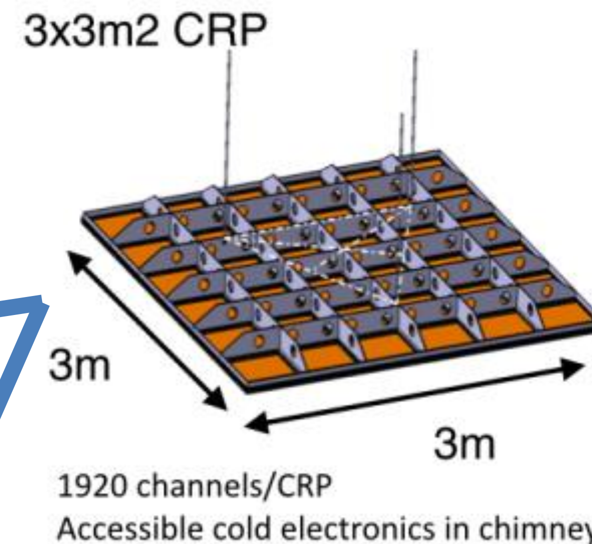


- 80 CRP units
- 60 Field shaping rings
- 240 Signal FT chimneys
- 240 Suspension chimneys
- 180 PMTs

The Dual-Phase ProtoDUNE/WA105 6x6x6 m^3 detector is built out of the same **3x3m^2 Charge Readout Plane units (CRP)** foreseen for the 10 kton Dual-Phase DUNE Far Detector (same QA/QC and installation chains)

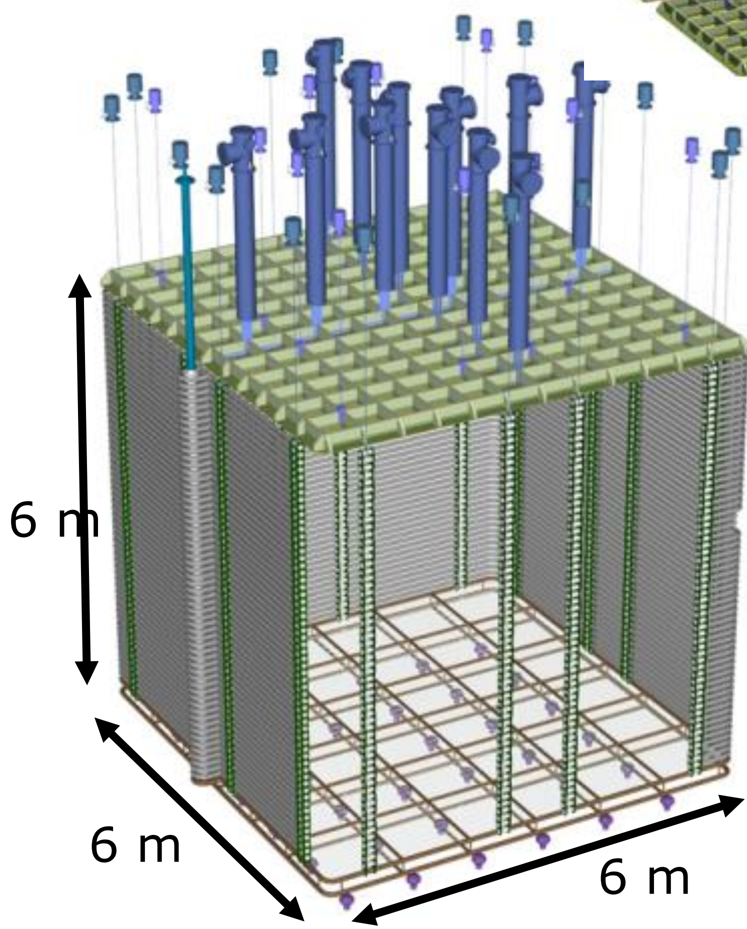


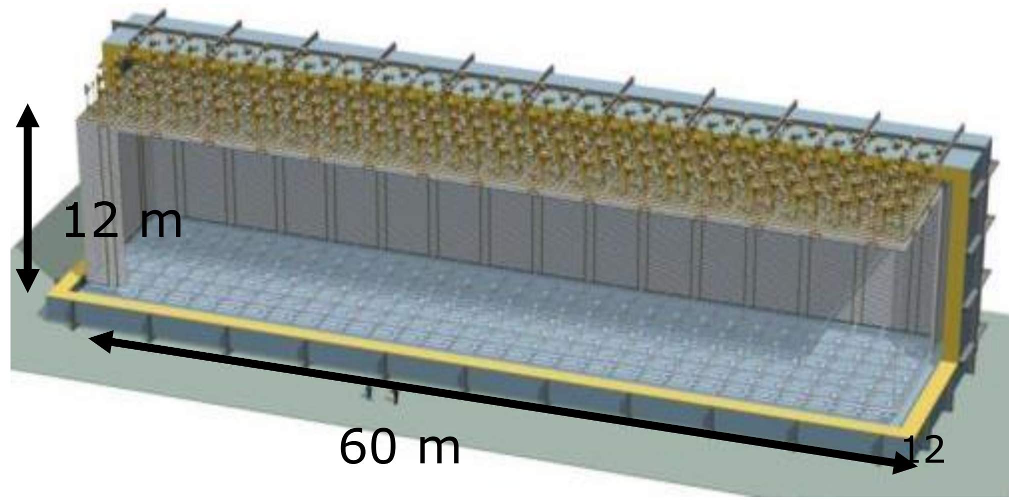




WA105: 4 CRP

10 kton: 80 CRP



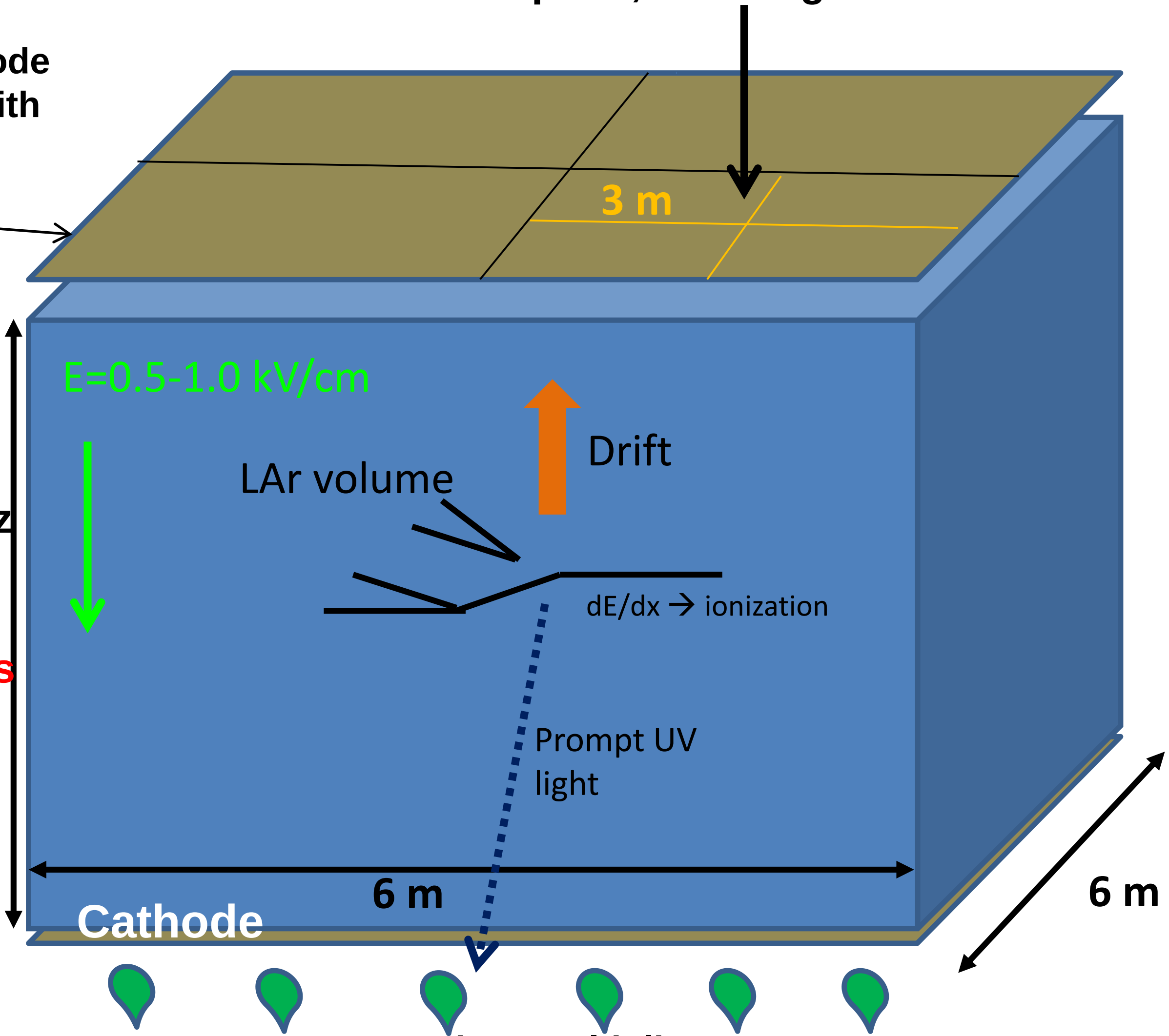


Dual phase liquid argon TPC
$6 \times 6 \times 6\ m^3$ active volume

→ **Event size: drift window of 7680 channels x 10000 samples ⇒ 146.8 MB**

X and Y charge collection strips
3.125 mm pitch, 3 m long **→7680 readout channels**

Segmented anode in gas phase with dual phase amplification



Drift coordinate
6 m = 4 ms
sampling 2.5 MHz (400 ns), 12 bits

→ 10000 samples per drift window

WA105 Accessible cold front-end electronics and uTCA DAQ system 7680 ch

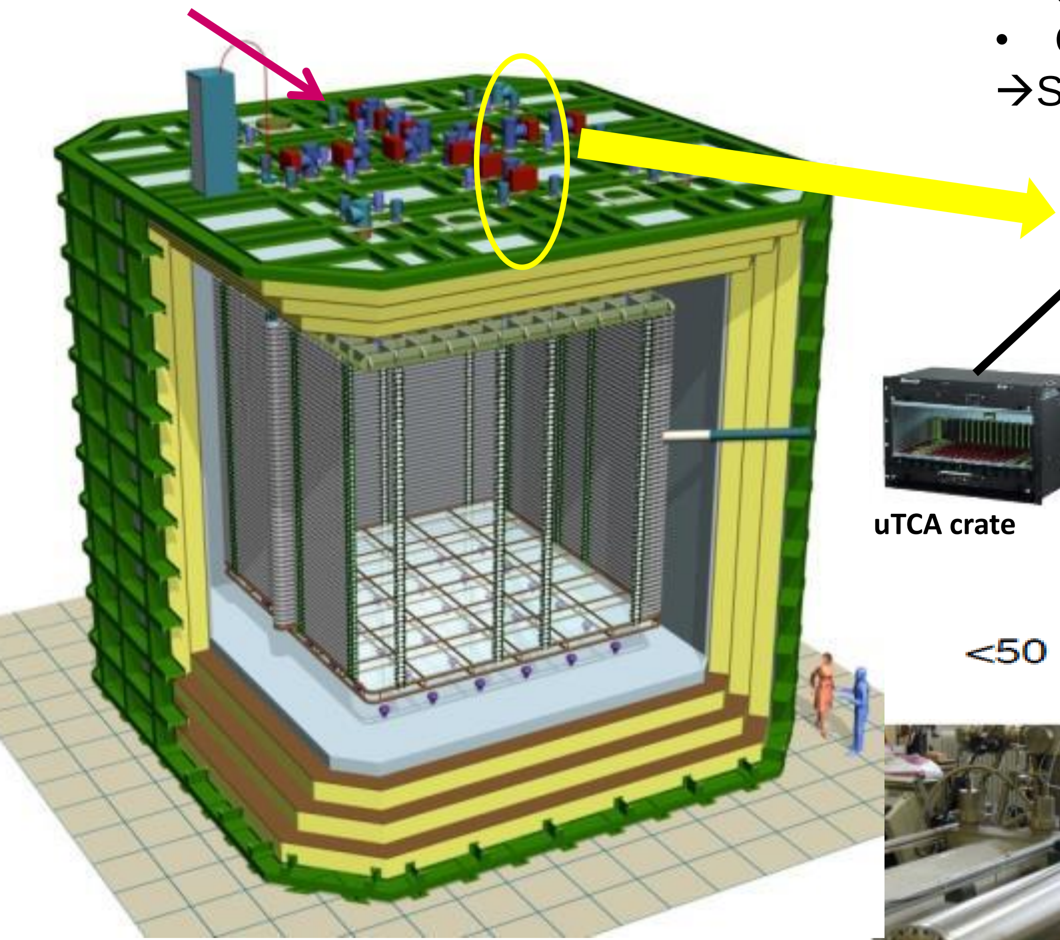
Full accessibility provided by the double-phase charge readout at the top of the detector

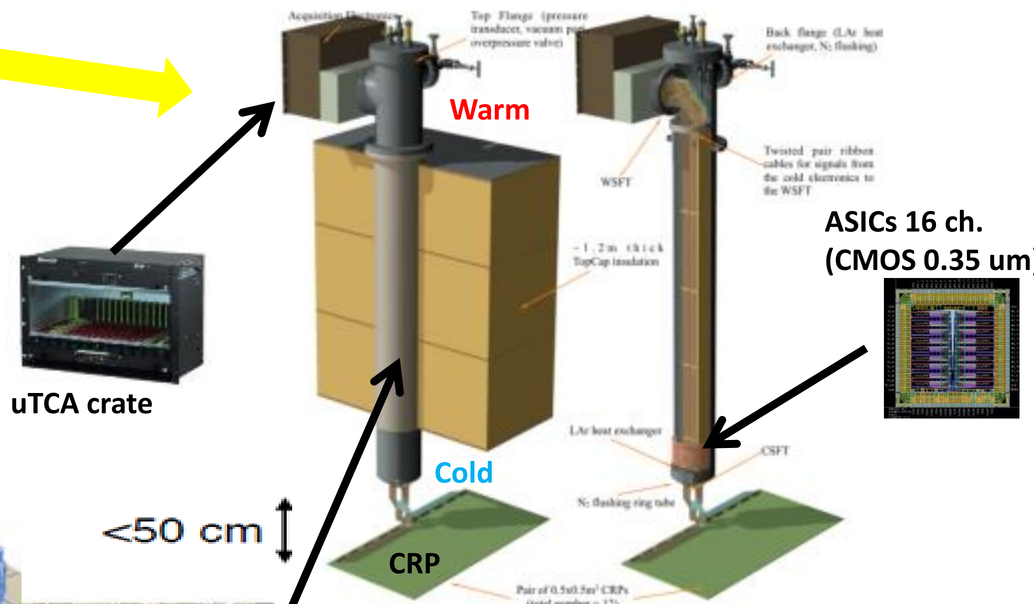
- **Digital electronics at warm on the tank deck:**
  - Architecture based on uTCA standard
  - 1 crate/signal chimney, 640 channels/crate

→ 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





Signal chimney

Progress on WA105 DLAr detector 6x6x6 m^3:

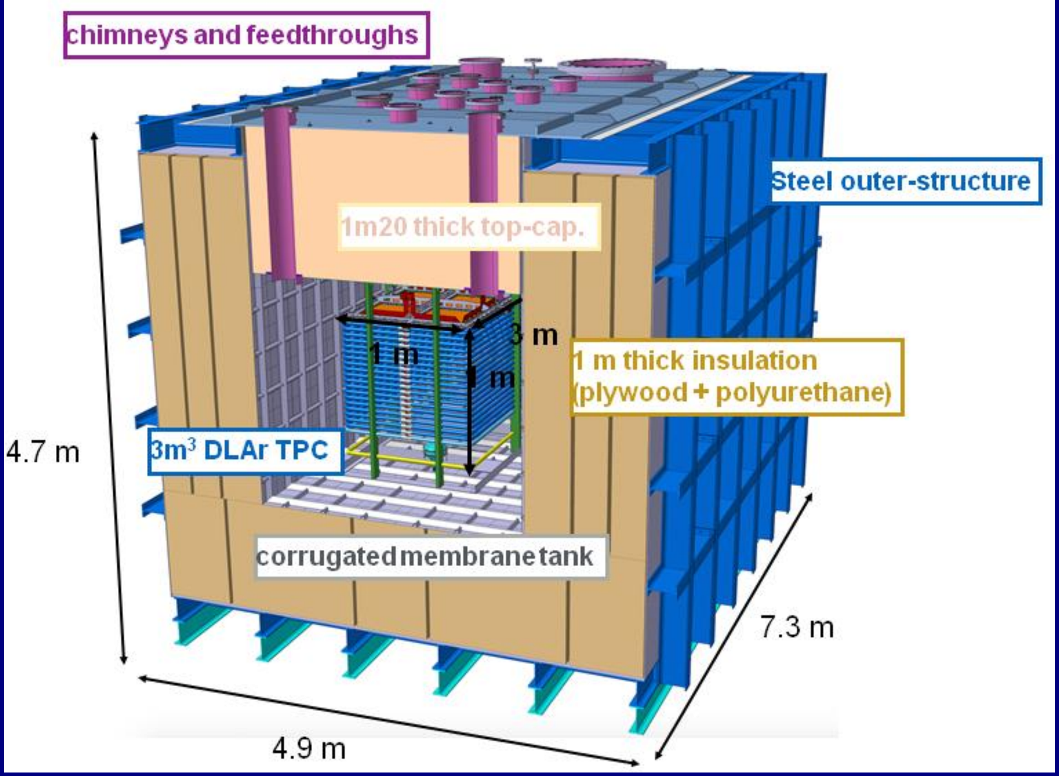
- Membrane vessel design and procurement
- Cryogenics
- Charge Readout Plane (CRP) detectors
- CRP structure and hanging system
- Feedthroughs
- HV and field cage
- Charge readout FE electronics + digital electronics
- Light readout system + electronics
- DAQ and online processing
- Slow Control

→

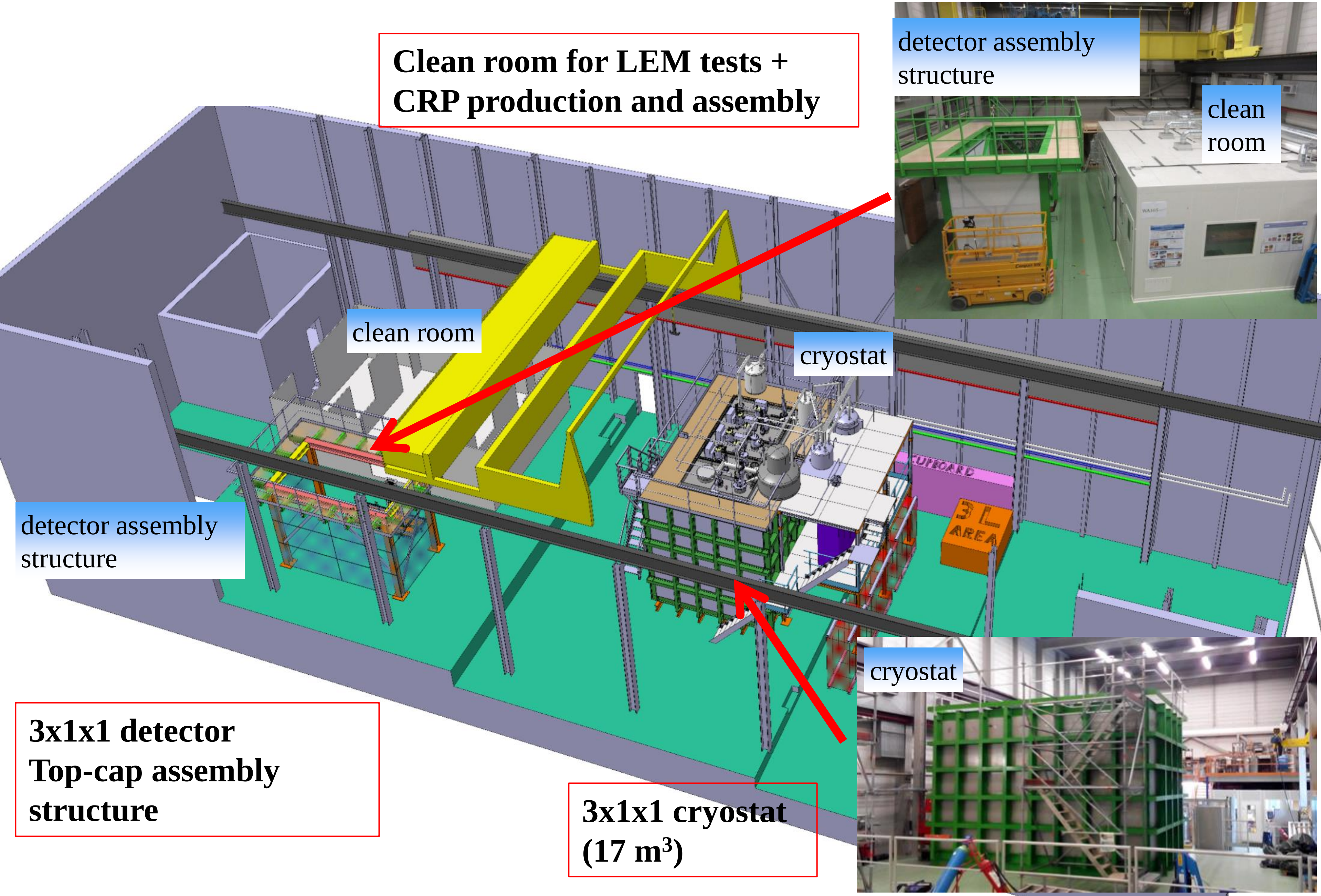
Advanced state of design, prototyping and production preparation

For many items huge benefit from immediate application of a smaller 3x1 prototype LAr-proto (minimal size of RO unit in 6x6x6)

- ✓ Fully engineered versions of many detector components with pre-production and direct implementation (installation details and ancillary services)
- ✓ First overview of the complete system integration: set up full chains for Quality Assessment, construction, installation and commissioning
- ✓ Anticipate legal and practical aspects related to procurement, costs and schedule verification
- ✓ Dedicated weekly meeting to follow up construction progress

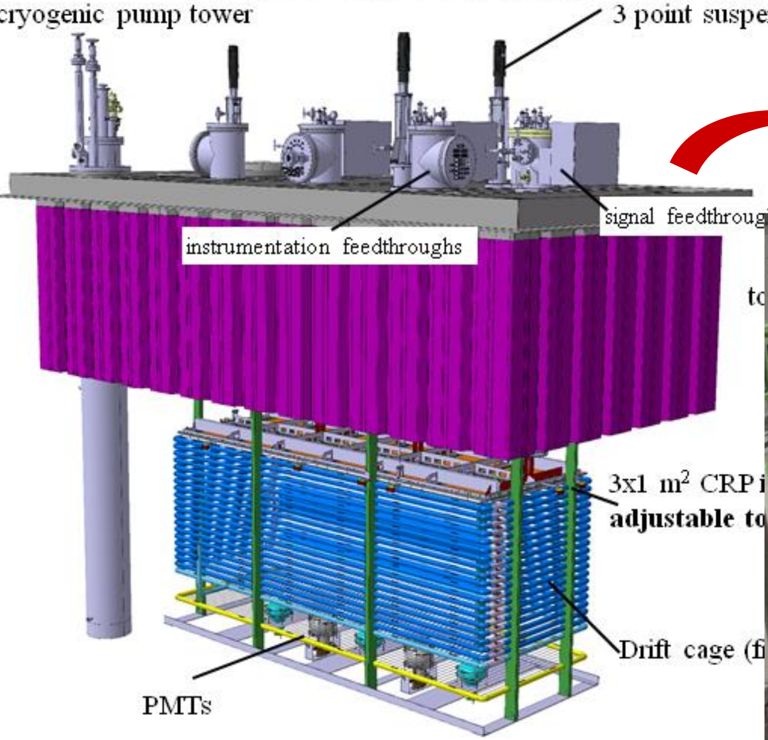


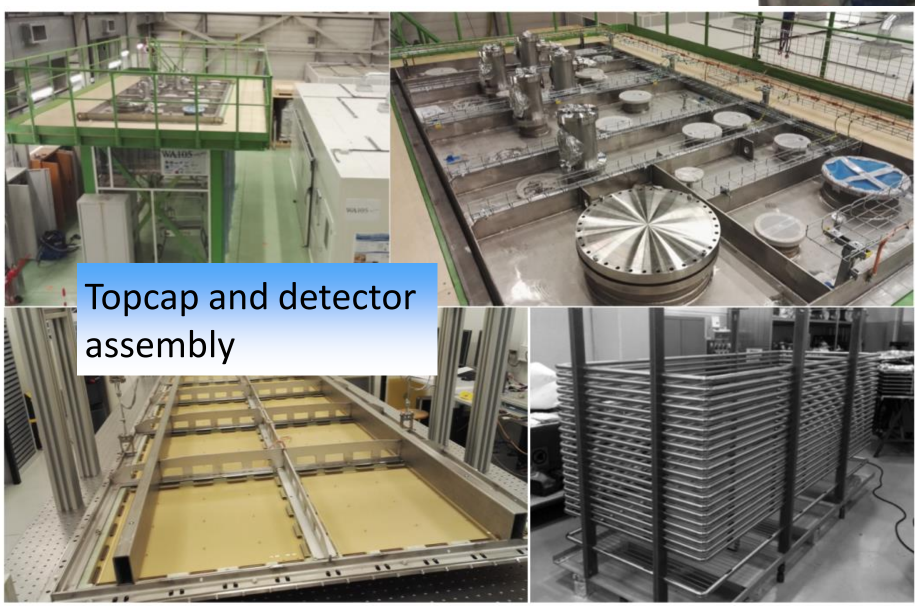
WA105 tests infrastructure in Building 182

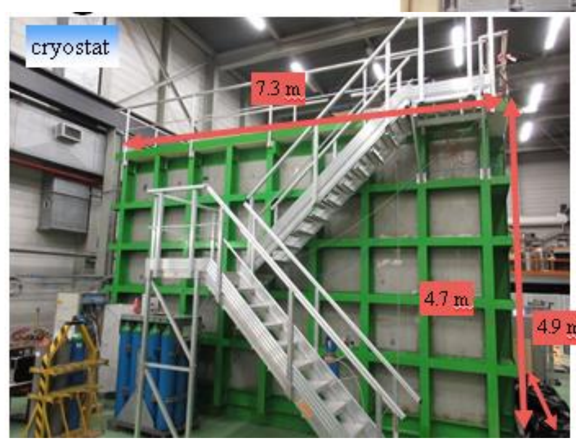


Pilot detector: $3x1x1m^3$

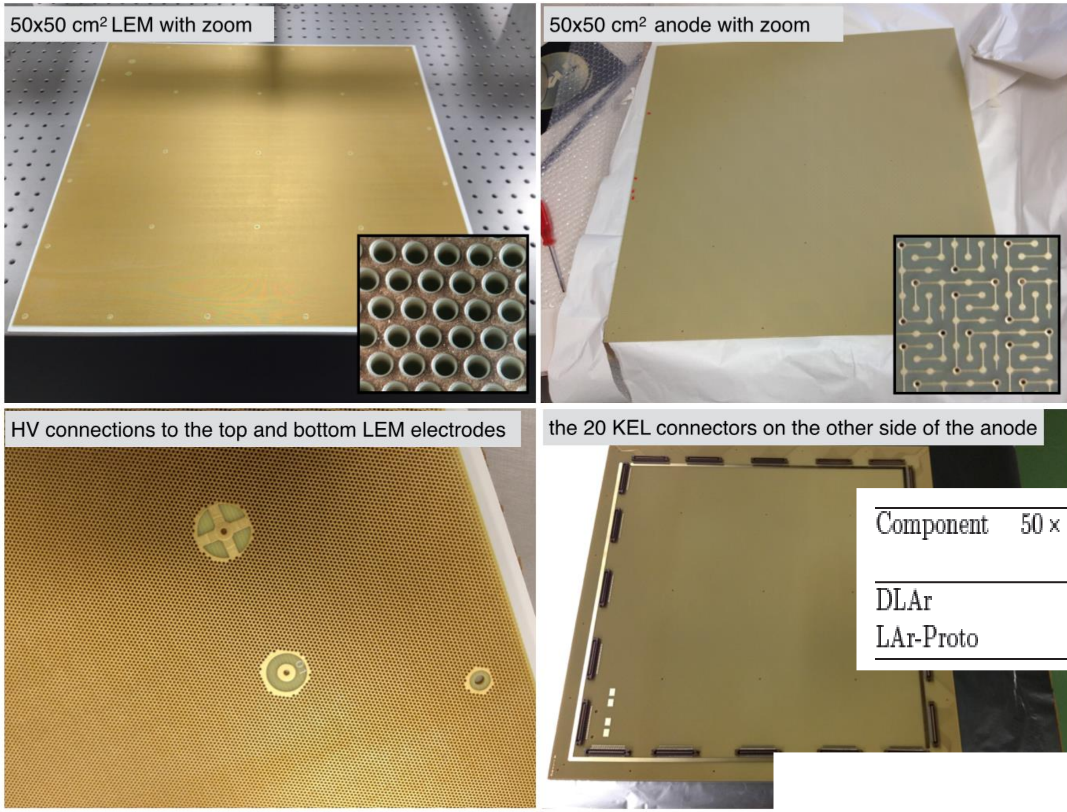
Being assembled now in Bdg 182 !
1280 readout channels

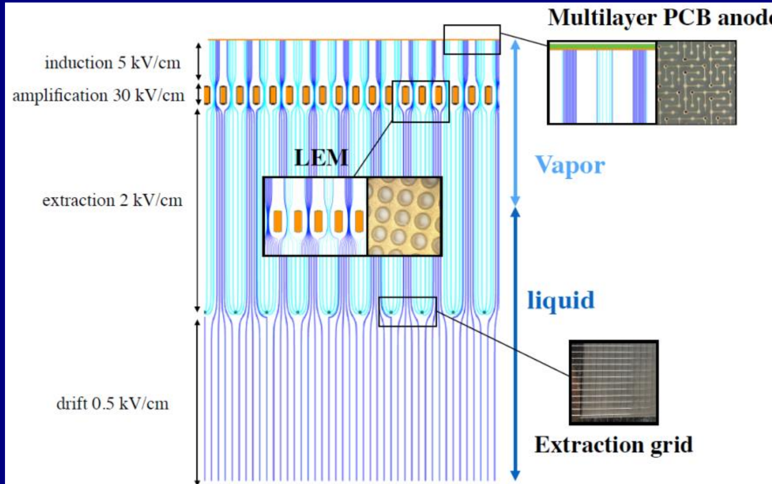






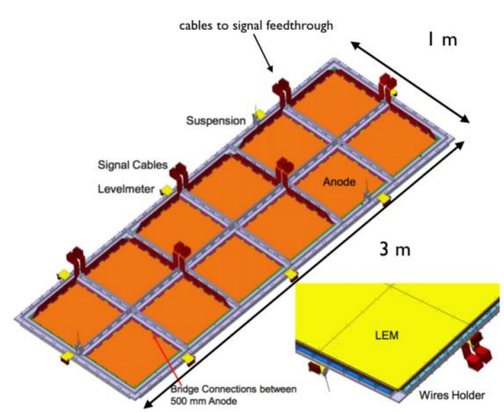
Charge Readout Plane (CRP) 50x50 cm^2 LEM-Anode Sandwich (LAS)

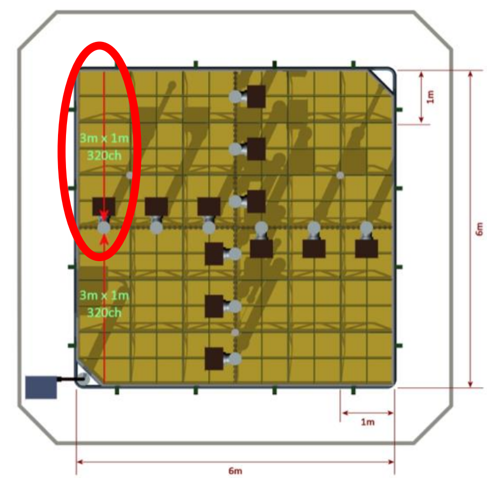




Component	50 × 50 cm^2 Anode panels	50 × 50 cm^2 LEM panels	Signal feddthrough	Suspension feddthrough	readout strip length (m)
DLAr	144	144	12	3	3
LAr-Proto	12	12	6	3	1 or 3

3m readout units in 6x6

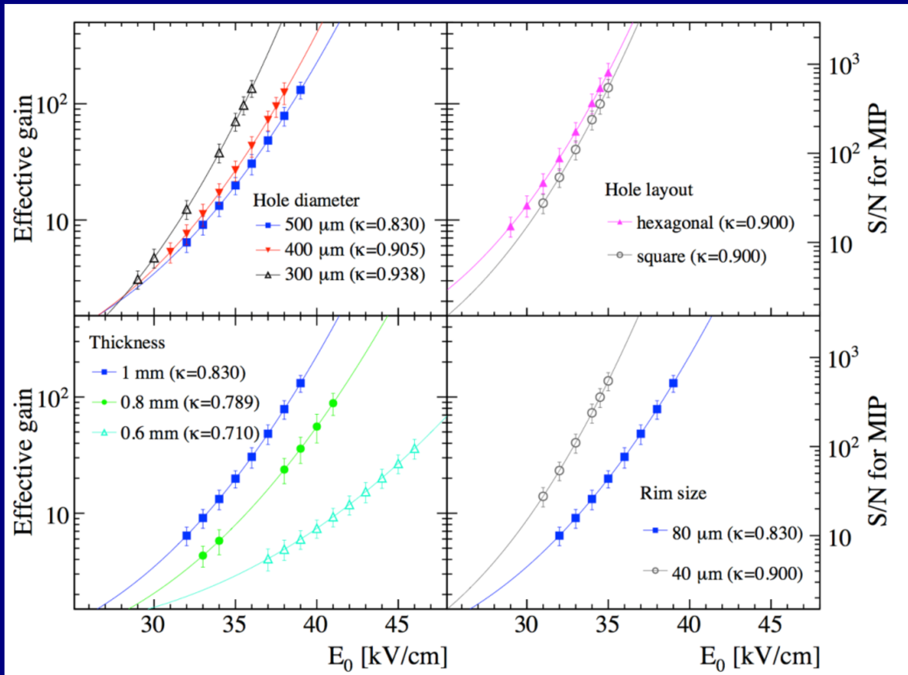




LEM and anodes produced by ELTOS

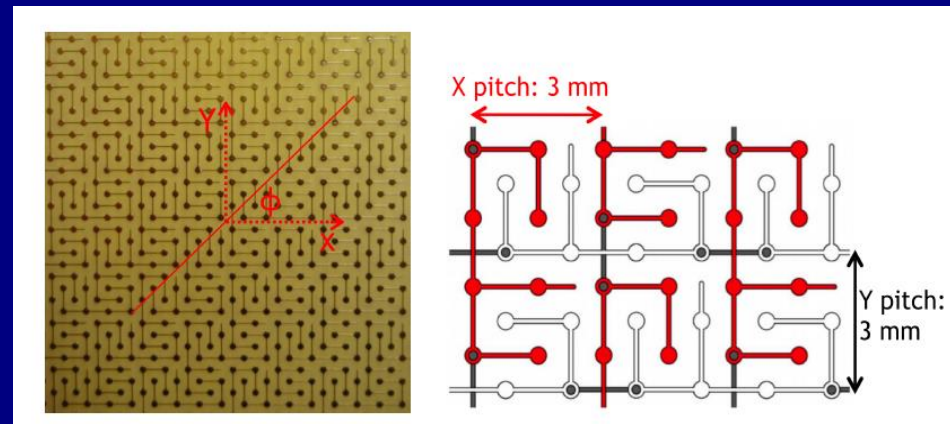
- **LEM: 500 um holes spaced by 800 um, 40 um rim**
- **Anodes: 2D collection views, 3.125 mm pitch, 150 pF/m**

LEM geometry optimization (JINST 10 P03017):

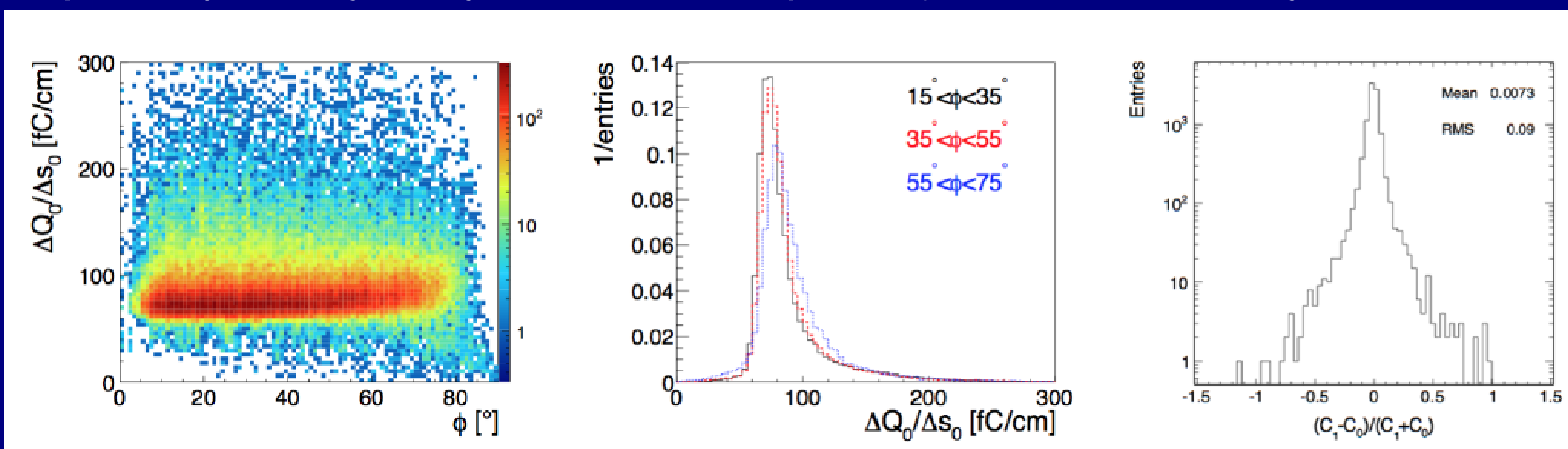


→ Tunable gain by adjusting the LEM HV (up to 200 achieved)

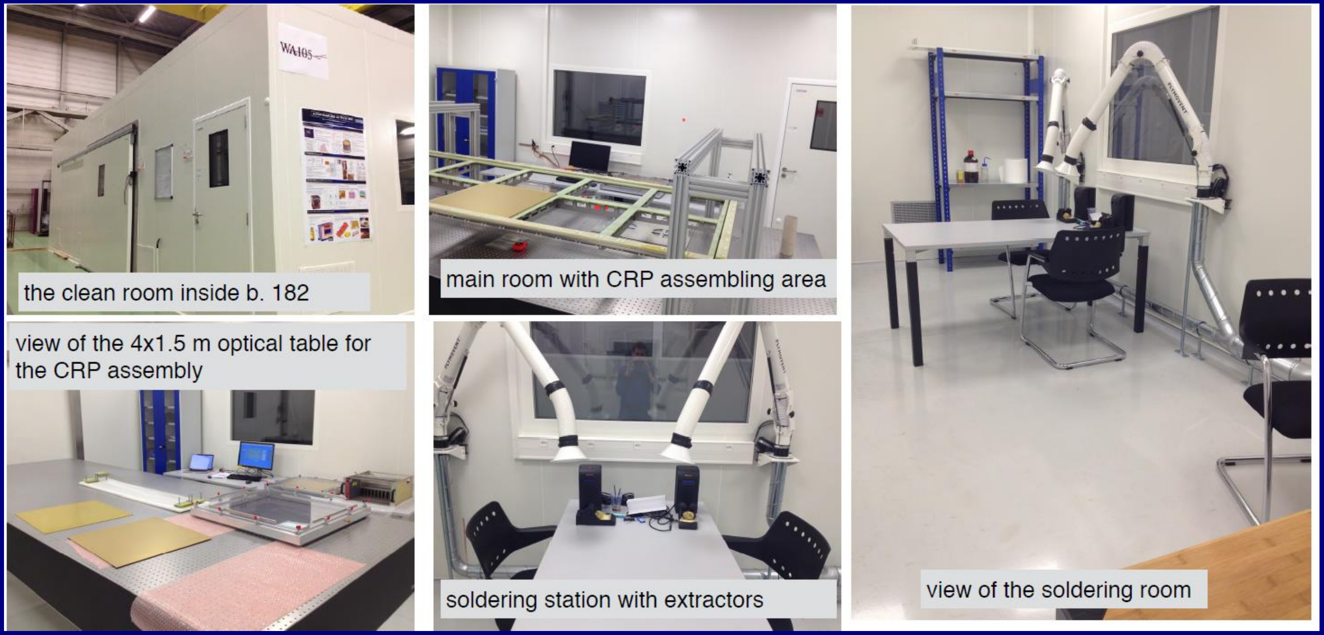
Anode geometry optimization JINST 9 P03017



Anode geometry optimization; 2 collection views, 3.125 mm pitch, 150 pF/m
→ Equal charge sharing among the two views, independency on track azimuthal angle



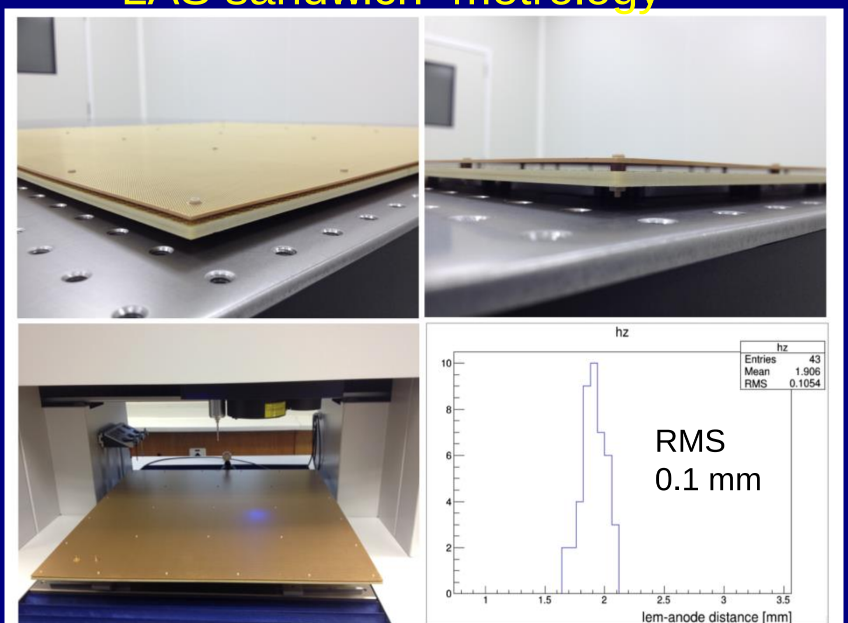
CRP components production and assembly chains:

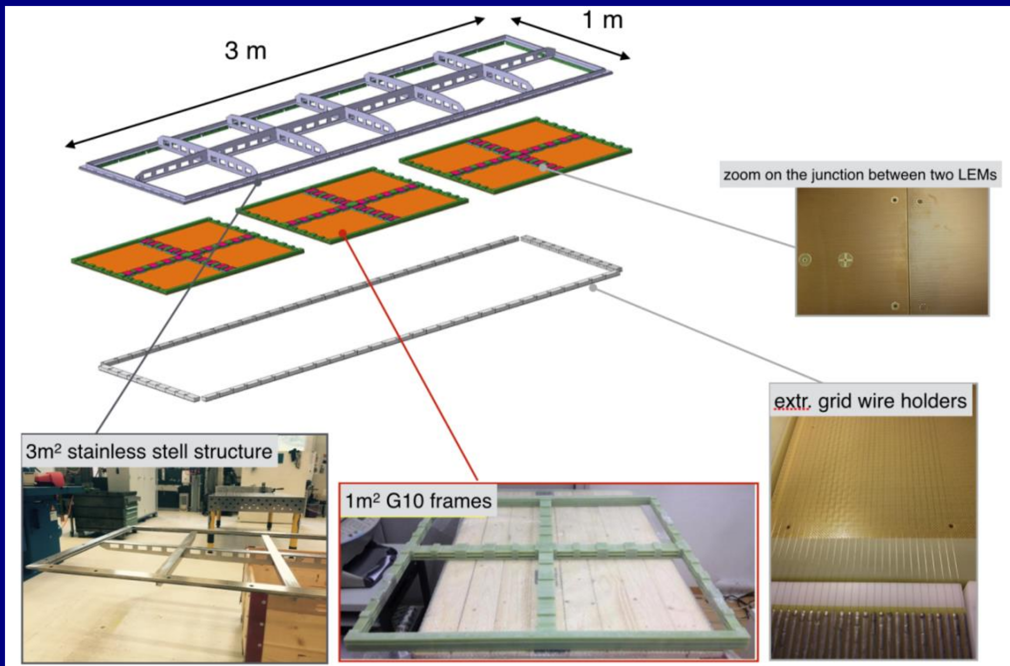


- Clean room ad hoc infrastructure (ISO-8 class) in Bld. 182
- Full production/QA chains set up
- Immediate application for 3x1 setup:

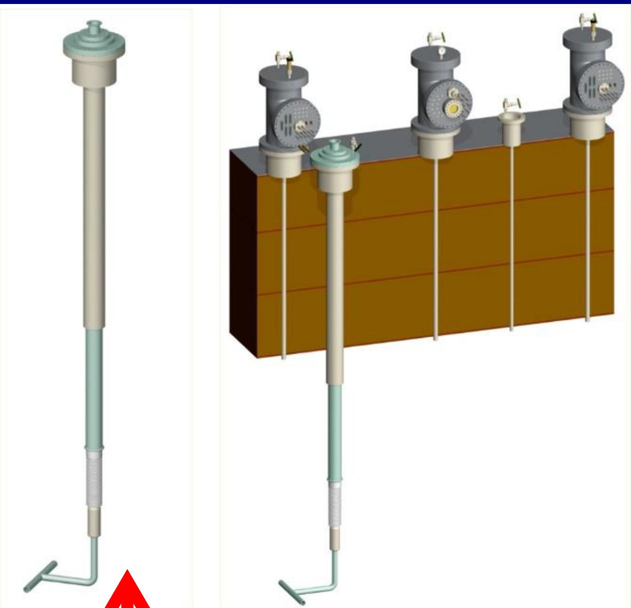
→ 12 LEM/anode 0.5x0.5 m^2 LAS integrated in 3x1 m^2 CRP frame
(pre-production of 20 LAS)

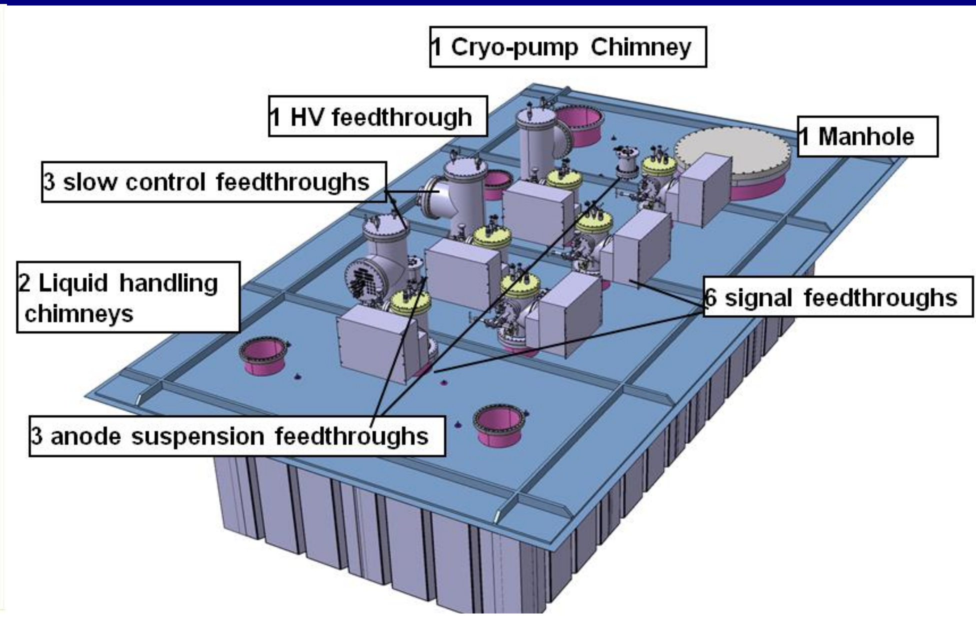
LAS sandwich metrology





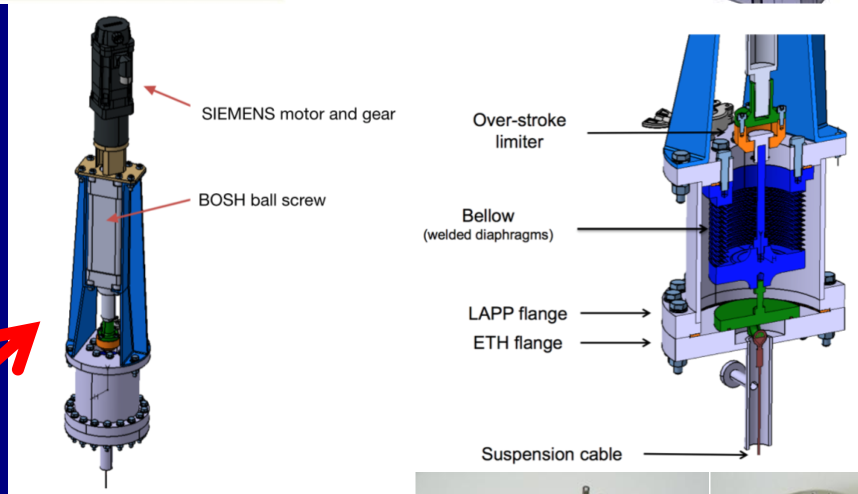
Full design, prototyping and integration of WA105 feedthroughs/chimneys



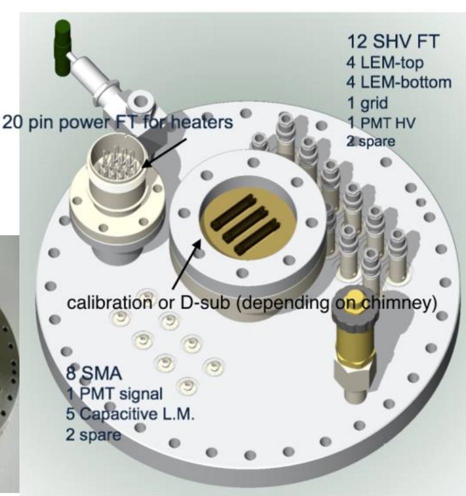


Studied and implemented in 3x1 TopCap

Cathode HV feedthrough

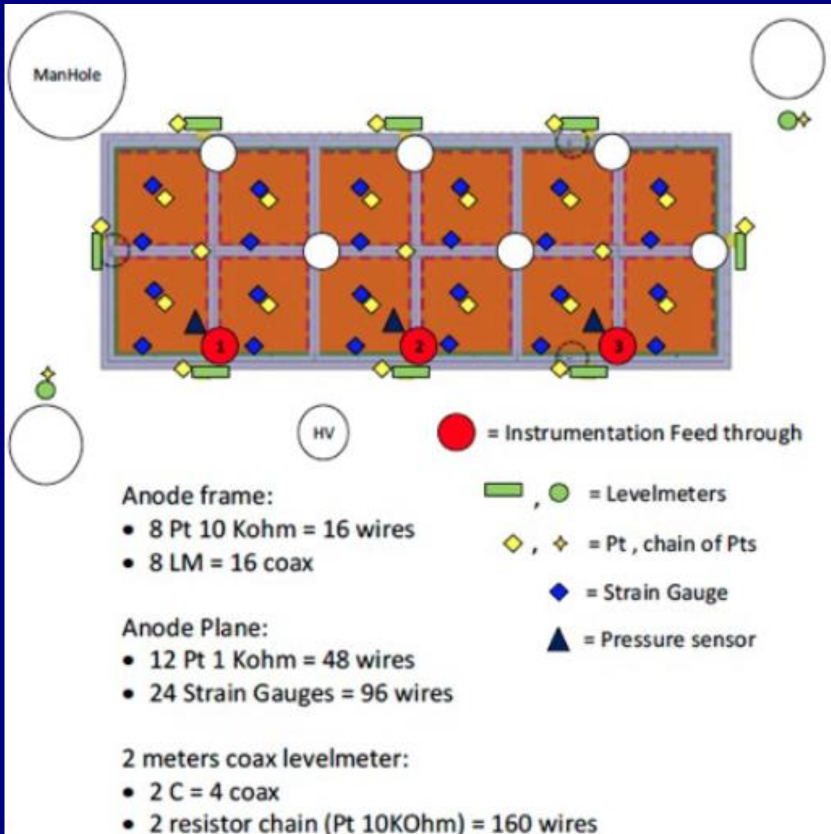


Design of slow control/services feedthroughs



CRP hanging system feedthroughs and motorization system (adjust CRP distance and parallelism to LAr level)

WA105 Slow Control (PCS/DCS/DSS)

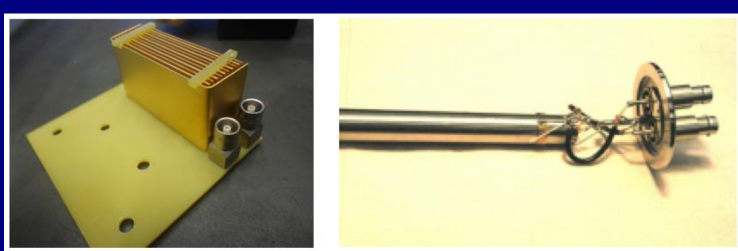


Fully engineered system designed for 3x1 as building block easy to extrapolate to 6x6 in collaboration with CERN PH-DT

→ Based on National Instruments compact RIO modules + UNICOS supervisor + single LabView interface

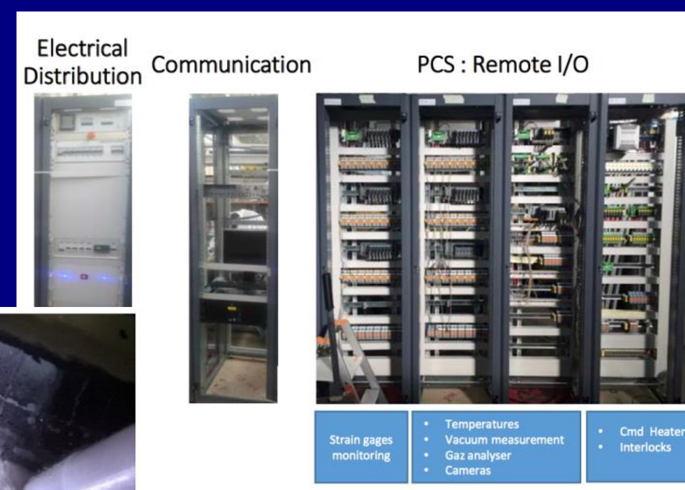
Integrates controls of level meters, temperature and pressure sensors, strain gauges, cryocamera + safety

3x1 CRP sensors instrumentation (highly redundant)

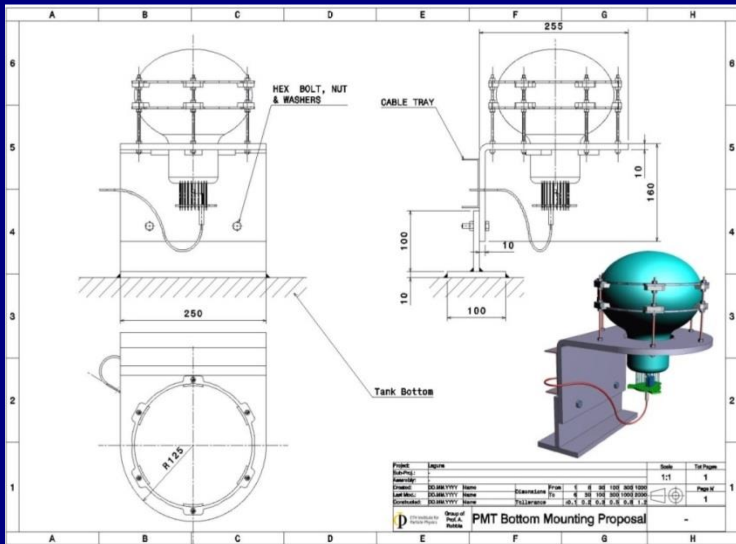


High accuracy (100 um)
and standard (1 mm) level meters

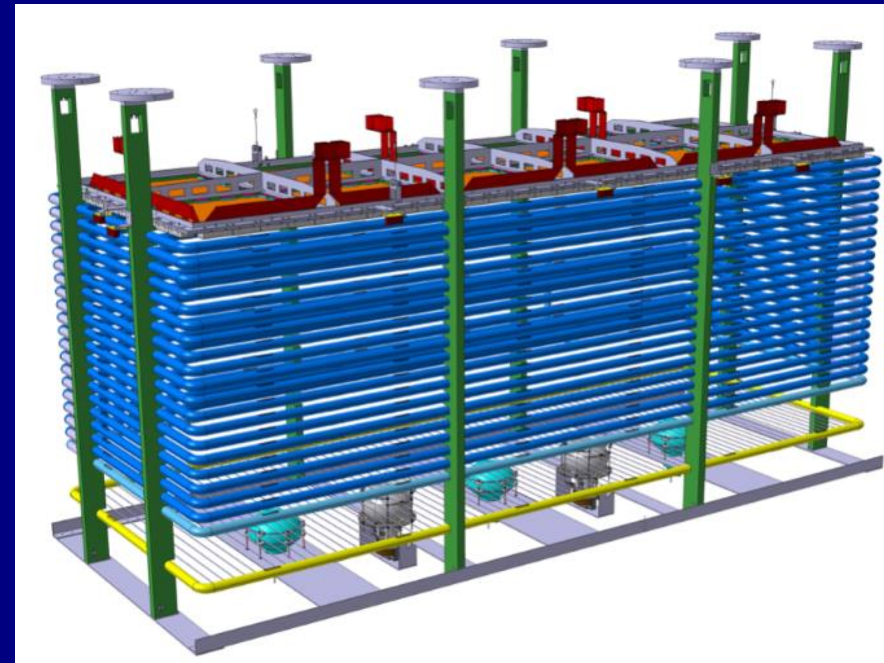
Cryocamera



Light readout



Hamamatsu R5912-02mod PMTs + PMT coating, at the bottom of the tank below cathode, minimal: 1 PMT/4m^2

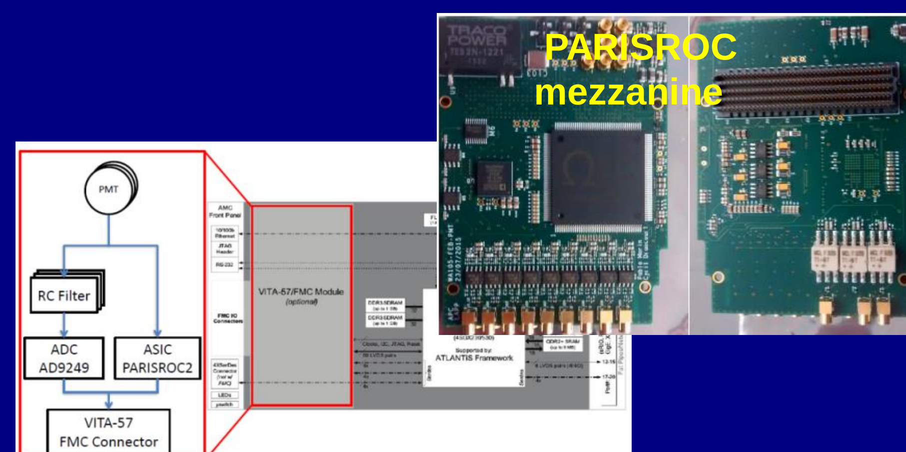


3x1x1: mechanical supports for PMTs + different TPB coating options implemented
Single coax for HV+signals

10 kton ~100% efficiency at 200 MeV
>50% efficiency at 5 MeV (conservative)
Larger efficiency achievable with more PMTs coverage, e.g: 1 PMT/1m^2 as tested in WA105

Development prototype of **uTCA light readout digitization boards** based on Bittware S4AM, 9 channels/card, 36 PMTs in 6x6x6

- Trigger from PARISCROC2 ASIC: →mezzanine card produced



Pilot detector: 3x1x1m^3

Detector parts prepared in previous months, installation in progress

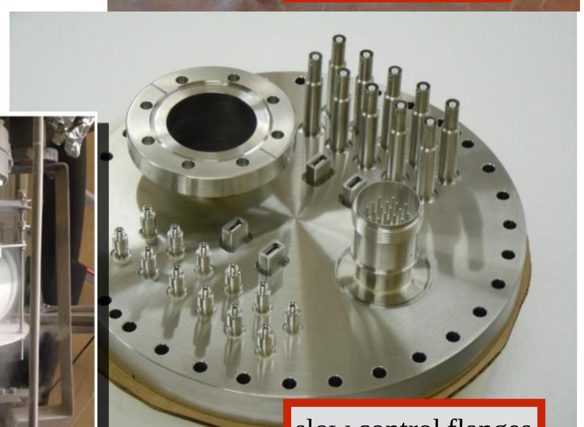
→3x1x1 operational with cryogenics in September 2016


Chimneys for accessible cold FE

CRP suspensions

CRP frame cold bath test

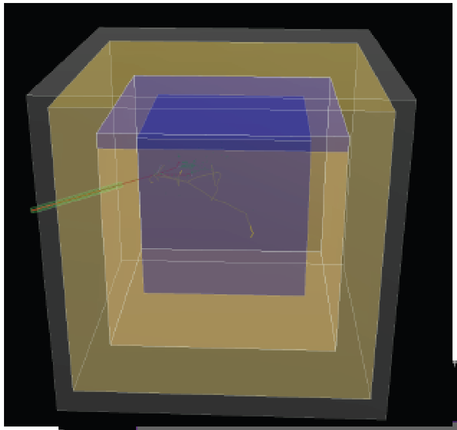
coated PMTs

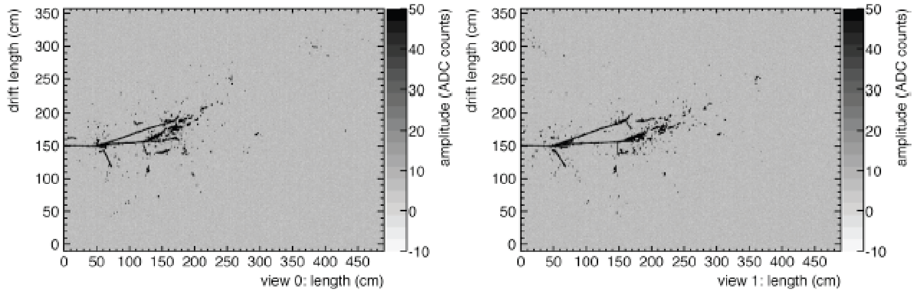


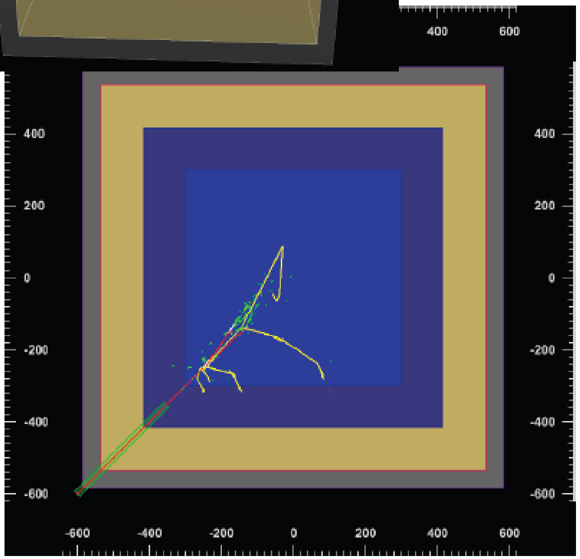
slow control flanges

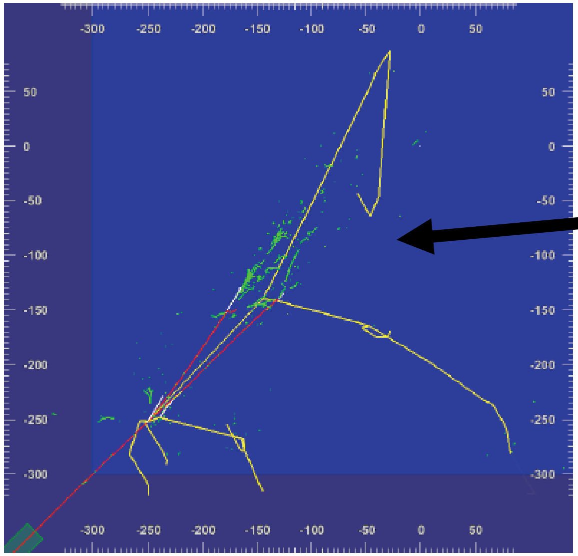
drift cage

5 GeV π+ simulation in 6x6x6m³

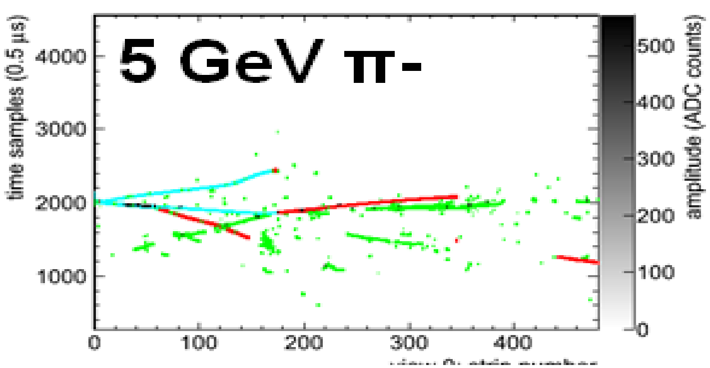


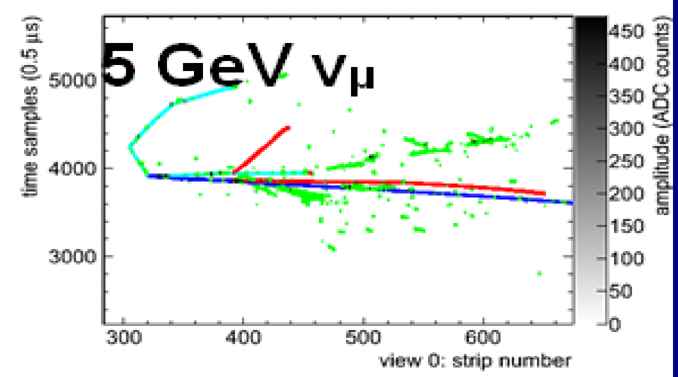






Hadronic showers fully contained in WA105

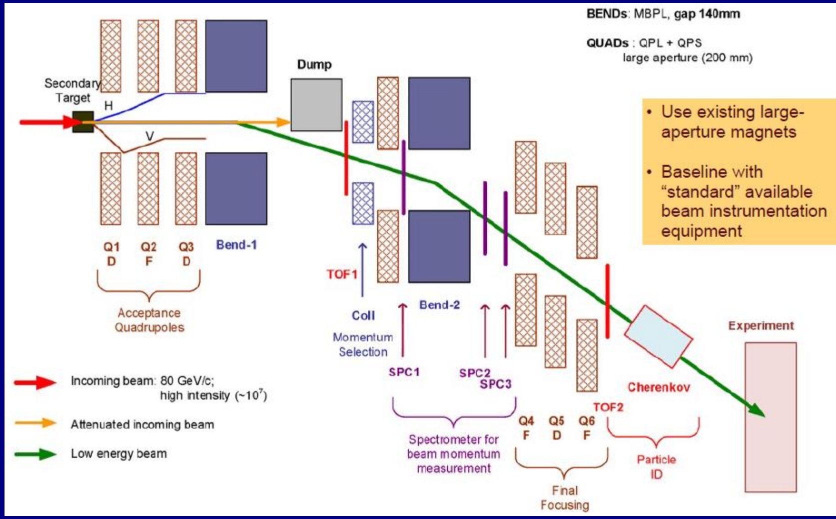




Reconstructed pion and neutrino interactions in DLAr

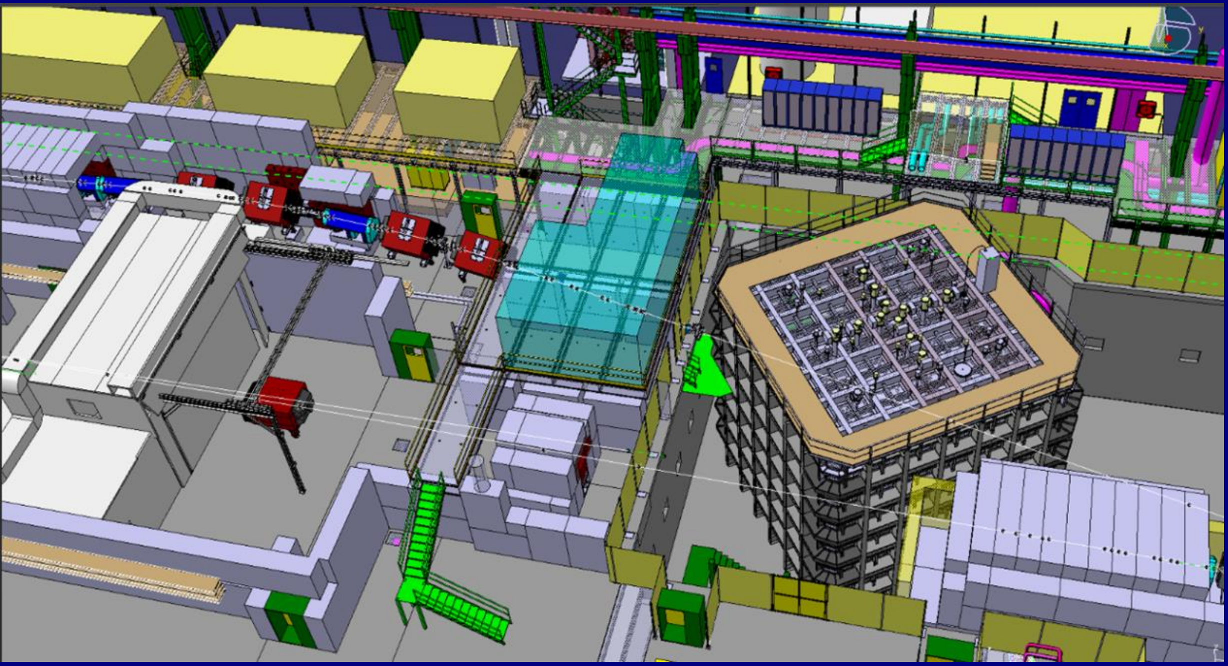
H2-VLE Beamline

Tertiary beam on H2 beamline:
1-12 GeV/c, momentum bite 5% (can be reduced to 1% with integrated spectrometer measurements)



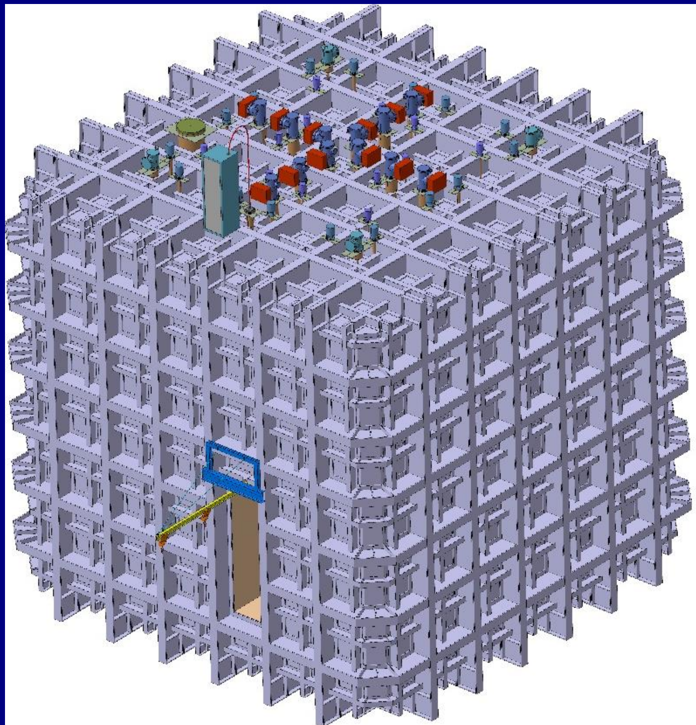
- **Mixed hadrons beam 1-12 GeV/c: pions, kaons, protons + electrons contamination at low energies**
- **Pure electron beams**
- **Parasitic muon halo**

→ O(100 M beam triggers to be acquired in 2018)

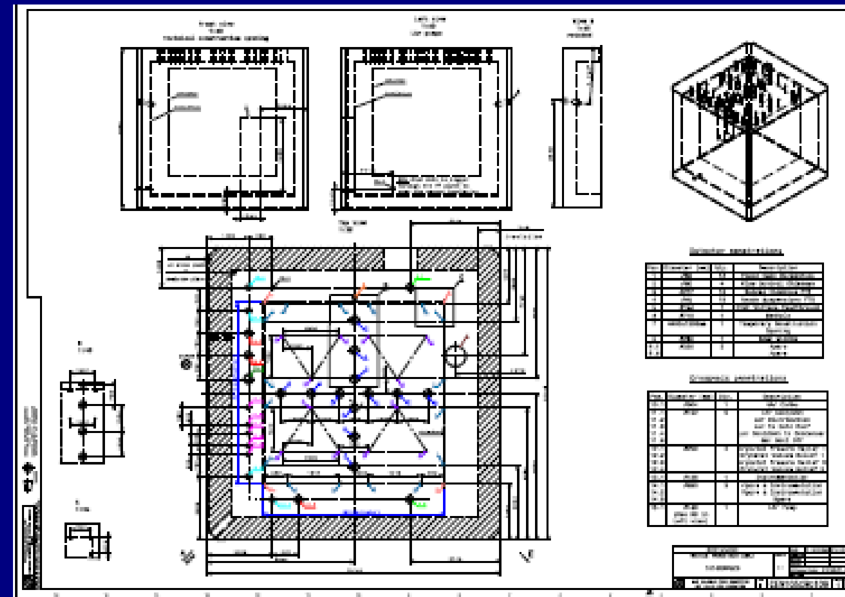


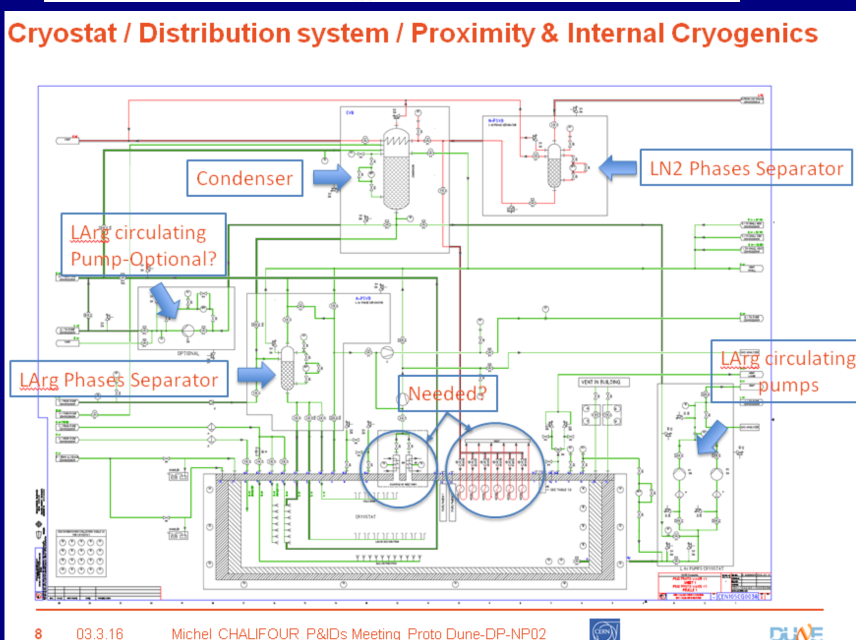
Definition of beam line instrumentation (TOF, triggers, beam profile and spectrometer, Cerenkov → common work also with single-phase group to define and procure the missing hardware. In particular to set up a performant TOF system (~20ps resolution, on 18 m lever arm)

Synergy with SP in definition of beam window/beam plug in non active LAr volume



- **Cryostat: design study with GTT concluded → completed definition of all detector interfaces with WA105**
- **Full engineering study and procurement launched**





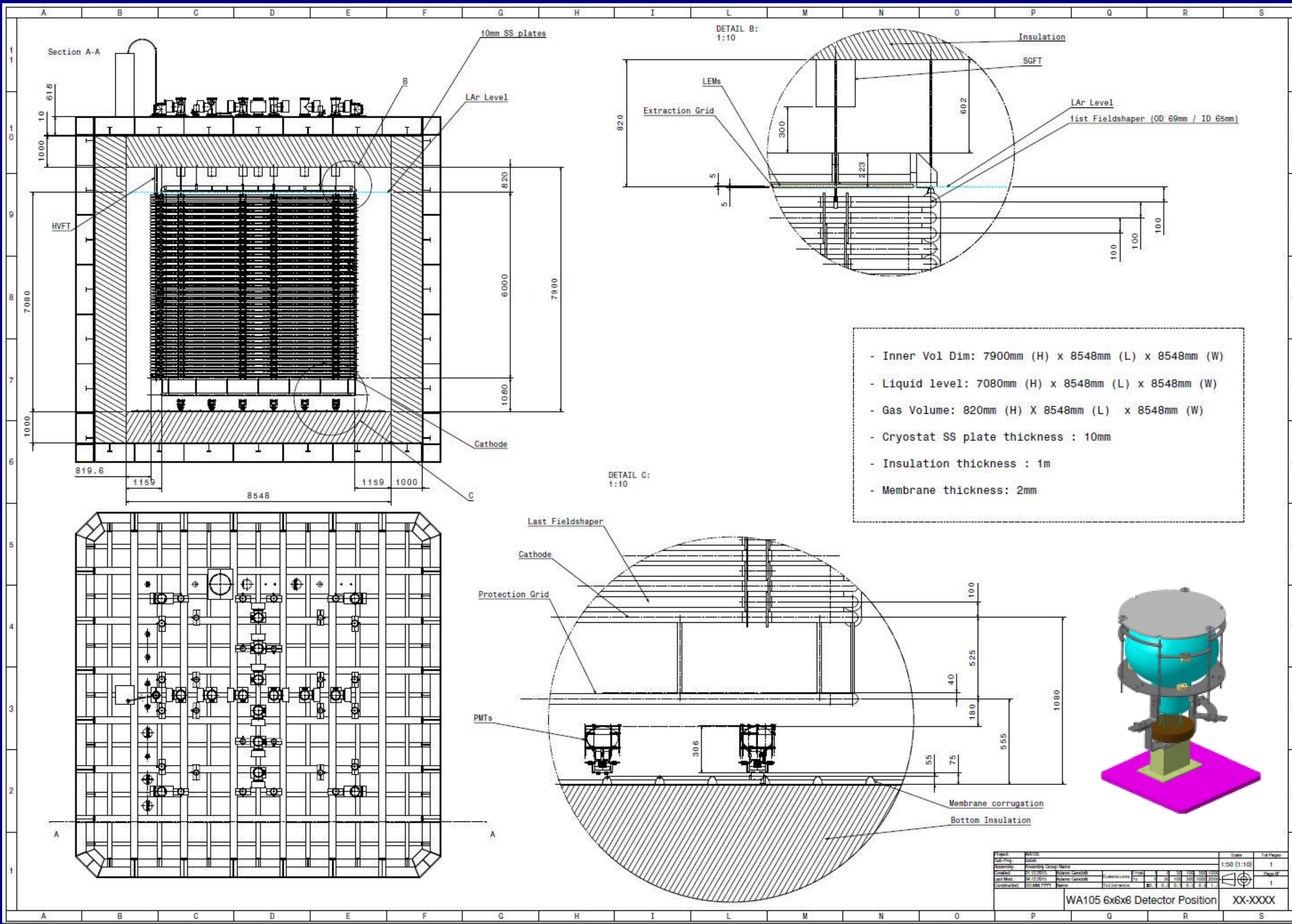
Schedule:

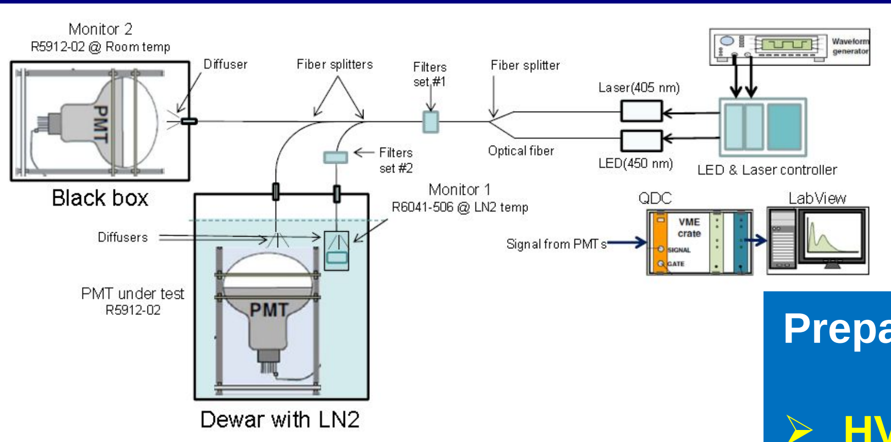
- **Construction of steel structure: July-September 2016**
- **Assembly of cryogenic insulation: October 2016-April 2017**
- **Detector assembly inside the cryostat: April-November 2017**

Cryogenics:

- **Design closure in April 2016**
- **Contract to be assigned by end of June 2016**
- **Installation summer 2017**

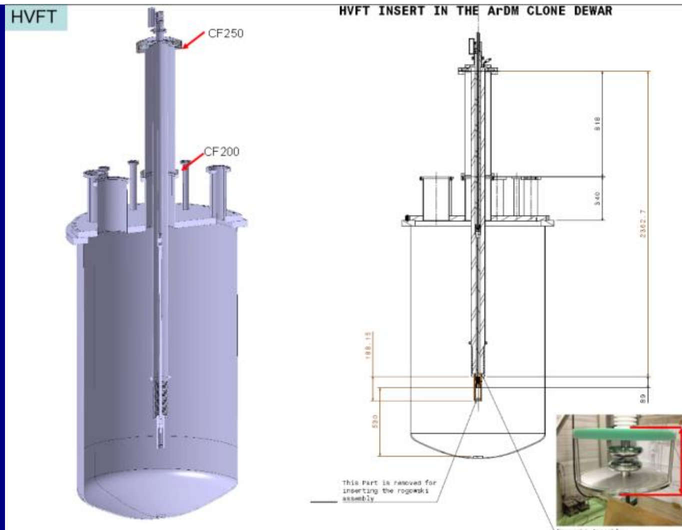
Cryostat-detector integration





Preparation for PMTs procurement:

Test calibration system at warm/cold

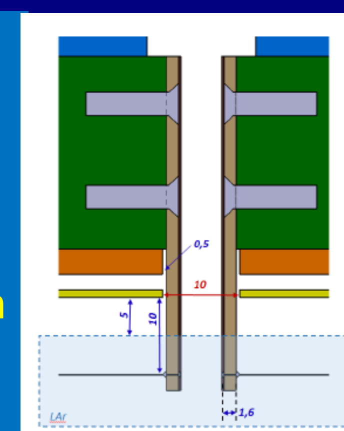


Preparation of cathode HV system:

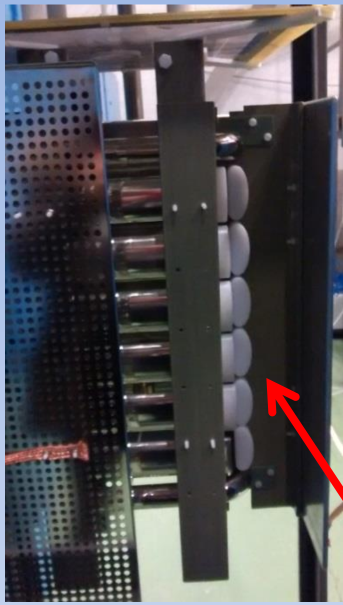
- HV power supply for 300 kV already purchased from Heinzinger
- HV feedthrough to be deployed on 3x1x1 but expected to work up to 300 kV under construction (being tested at CERN up to 300 kV)
- Synergy with SP which can use the same (at 180 kV)

Finalization of CRP mechanical structure design:

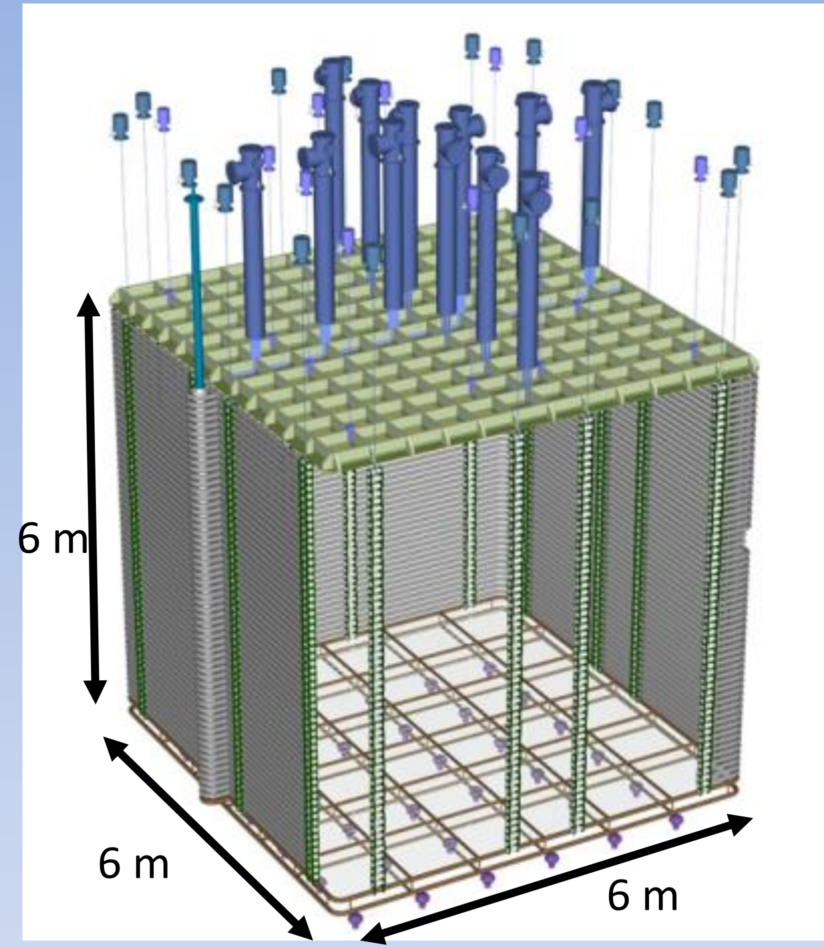
- Cold bath tests + photogrammetry on differential effects in thermal contraction, decoupling mechanism
- Extraction grid wires integration tests



Field cage:



- To be built in collaboration with CERN, interest of UTA in participating to the construction
- Synergy with SP by using similar profiles as foreseen by SP but with a slightly different shape more « closed C » like



Test of SP open profiles in Bdg 182.

Transparent cathode with ITO (Indium-Thin-Oxyde) resistive coating on two sides + PTB deposition at the top side:

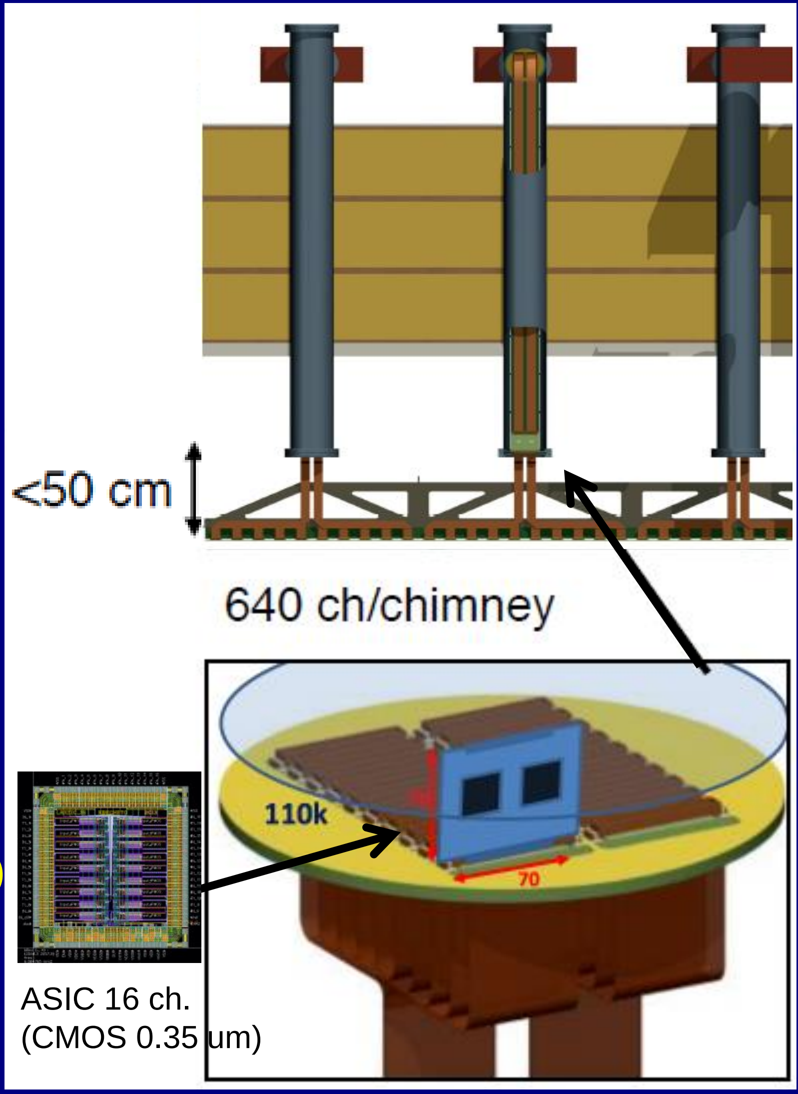
- Well advanced R&D expected to go to executive design by this summer
- Tested ITO coated PMMA plates up to 400x400 mm^2

Cost effective and fully accessible cold front-end electronics and DAQ

Remove long cables and their capacitance, exploit intrinsic noise reduction at low T
→ ongoing R&D since 2006

ASIC (CMOS 0.35 um) 16 ch. amplifiers working at ~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
- Produced at the end of 2015 in 700 units (entire 6x6x6)



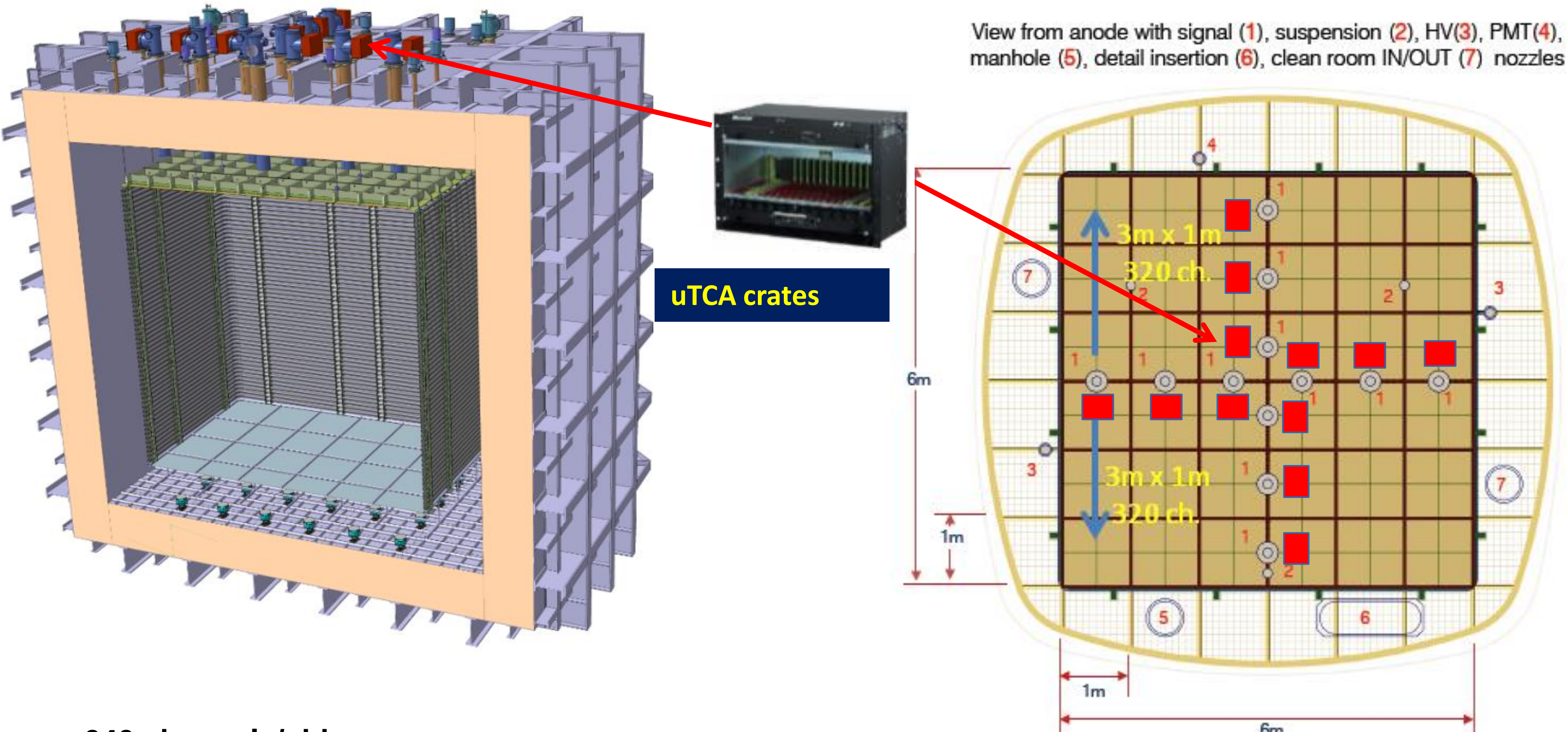
ASIC 16 ch. (CMOS 0.35 um)

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
- Production of uTCA cards started at the end of 2015, pre-batch to be deployed on 3x1x1

→ Large scalability (150k channels for 10kton) at low costs

uTCA charge readout architecture

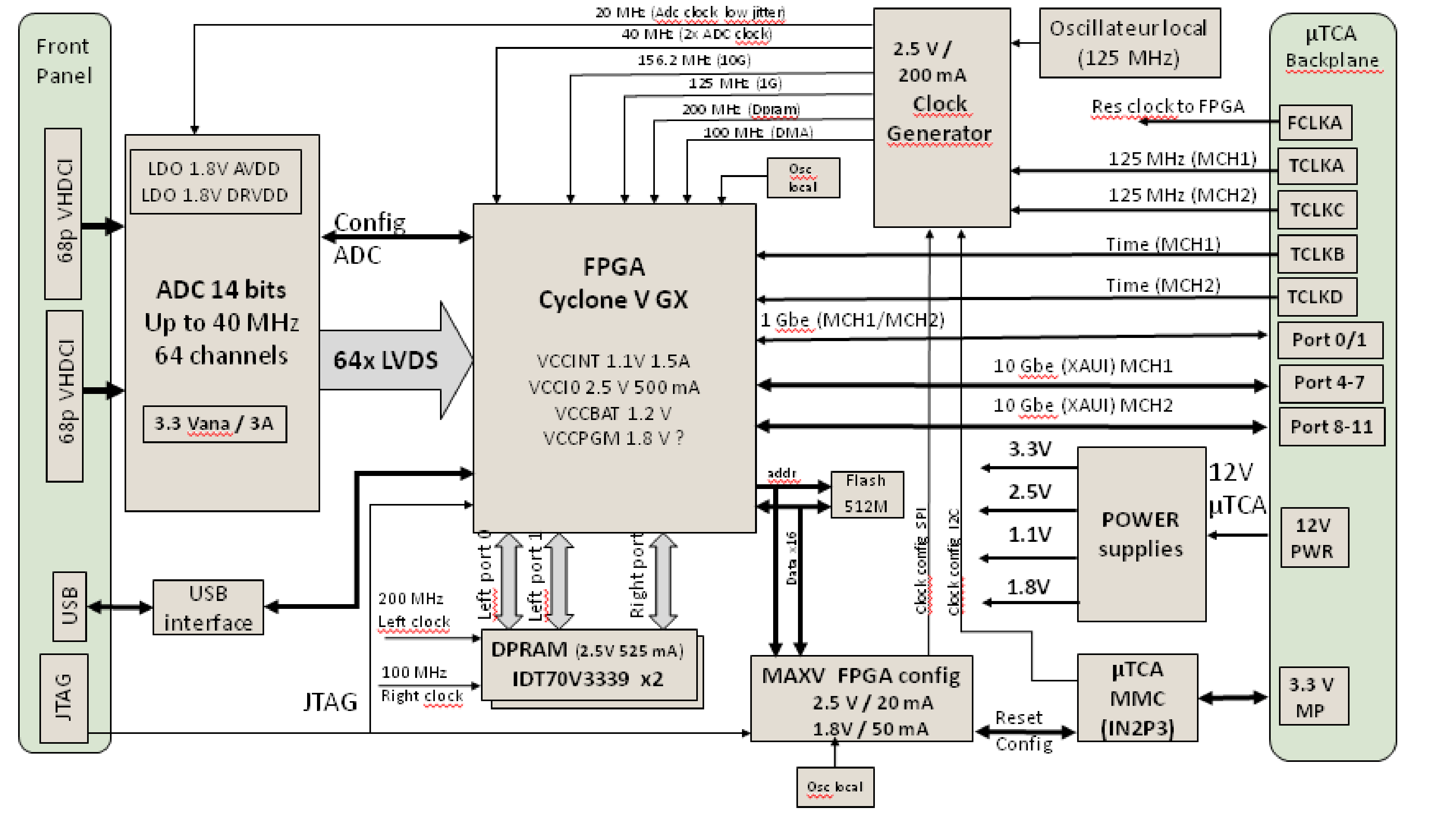


Readout in groups of 640 channels/chimney

top view

- **640 channels/chimney**
- **1 uTCA crate/chimney, 10 Gb/s link**
- **10 AMC digitization boards per uTCA crate, 64 readout channels per AMC board, memory buffer 12228 samples/channel**

→ 12 uTCA crates for charge readout + 1 uTCA crate for light readout



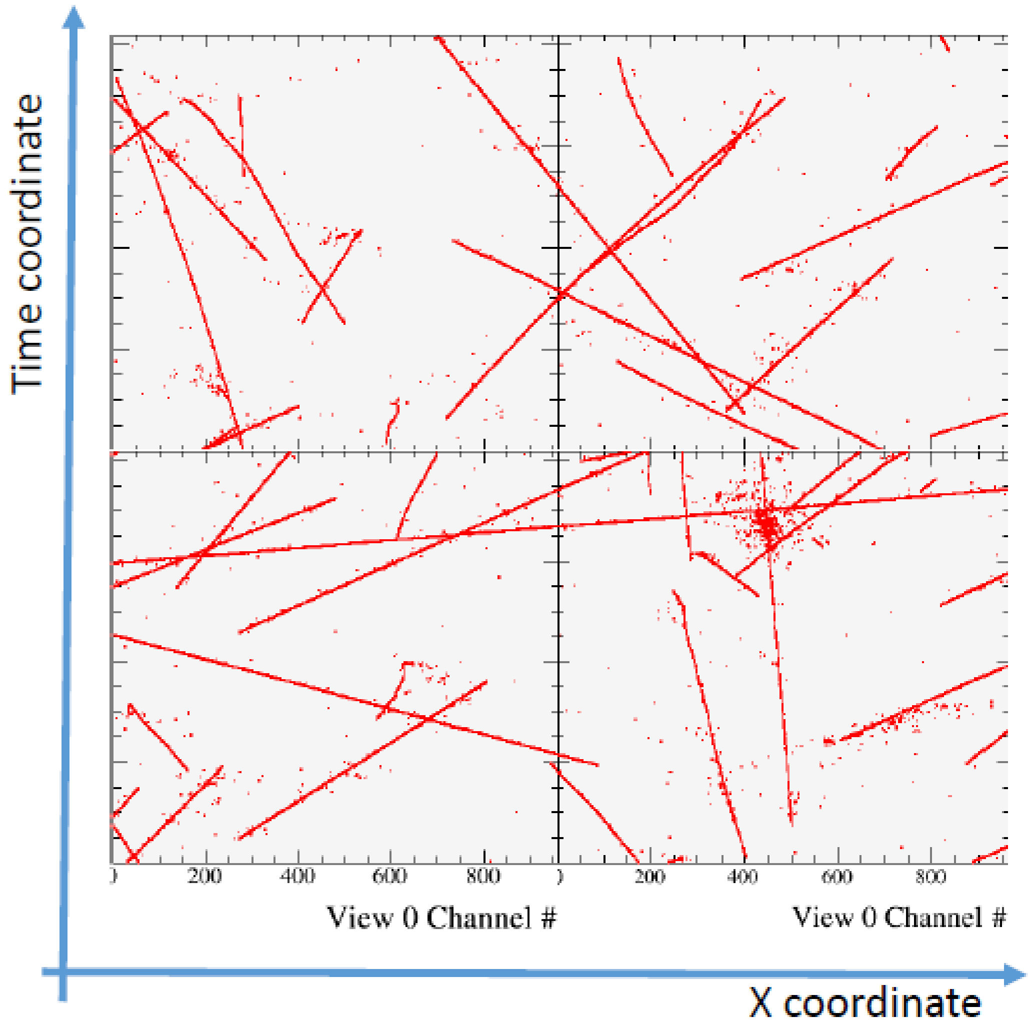
Production of uTCA AMC cards for the 6x6x6 started at the end of 2015, first batch to be deployed on 3x1x1

2015 prototype of the 64 channels AMC digitization card (2.5-25 MHz, 12 bits, 2V, AD5297) hosted on Bittware S4AM, 10 GbE output on uTCA backplane

Typical event signature for ground surface Liquid Ar TPC operation

For each beam trigger we can have on average 70 cosmics overlapped on the drift window after the trigger (these cosmics may have interacted with the detector in the 4 ms before the trigger and in the 4 ms after the trigger → chopped tracks, "belt conveyor" effect

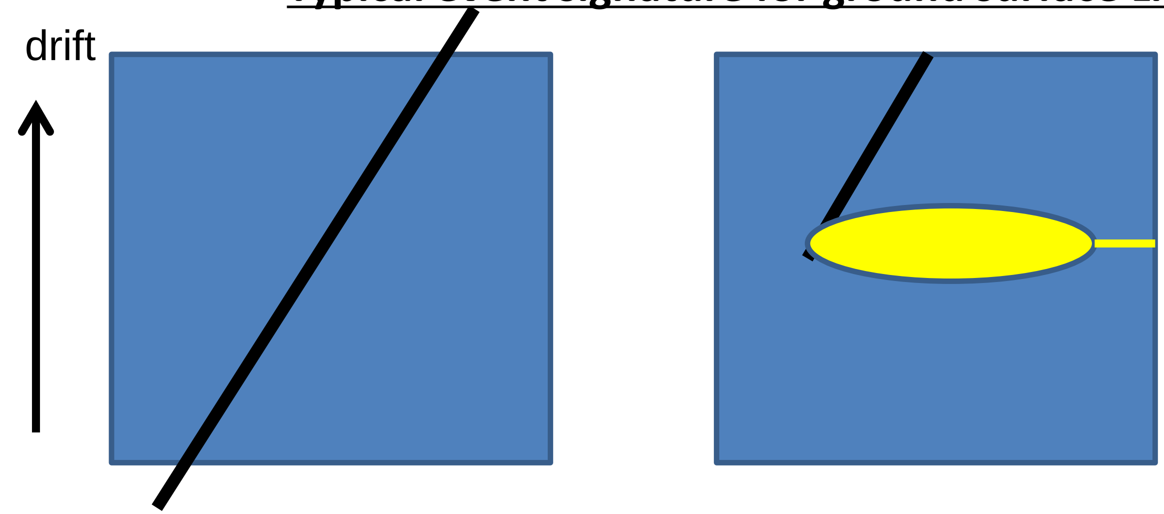
In-spill cosmics in charge data



Example of cosmics only event (in one of the views)

- Red points are reconstructed hits
- TPC is readout in 4 3x3m^2 modules
- After track reconstruction:
  - Attempt to correlate found tracks with light data
  - Remove CR background from beam event
  - Select a subsample of long tracks for calibration purposes

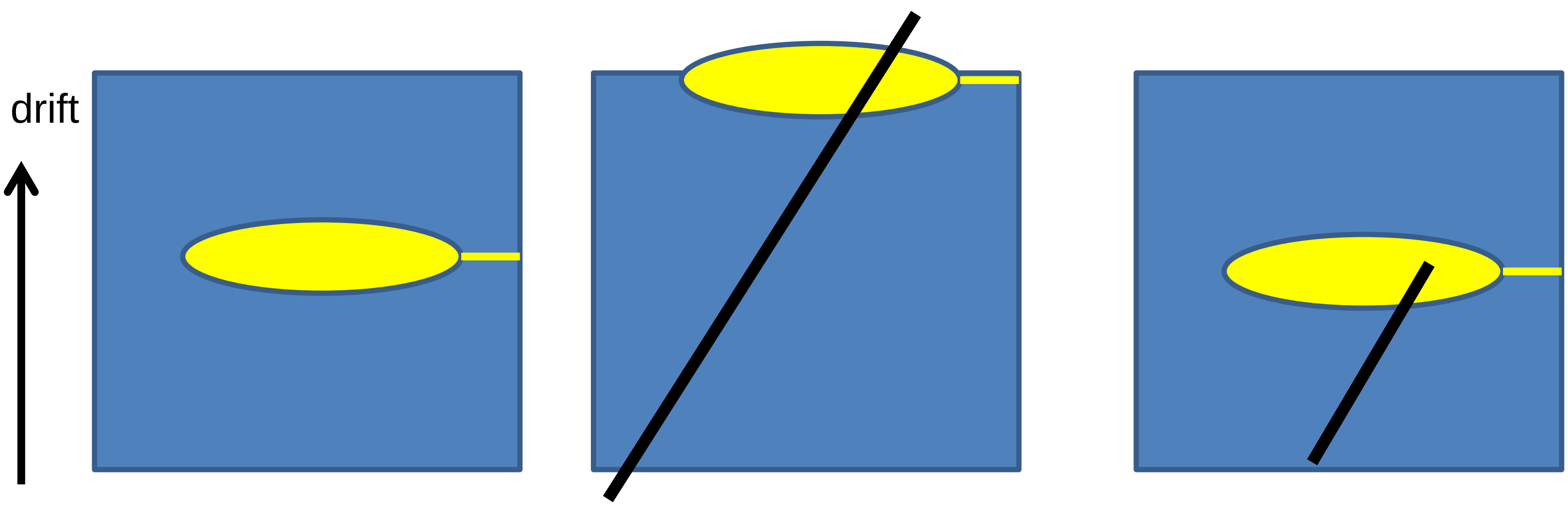
Typical event signature for ground surface Liquid Ar TPC operation



t=beam trigger - 2 ms

t=beam trigger → reconstructed event

The « belt conveyor » effect
+- 4 ms around the beam
trigger time



t=beam trigger

t=beam trigger + 2 ms

reconstructed event

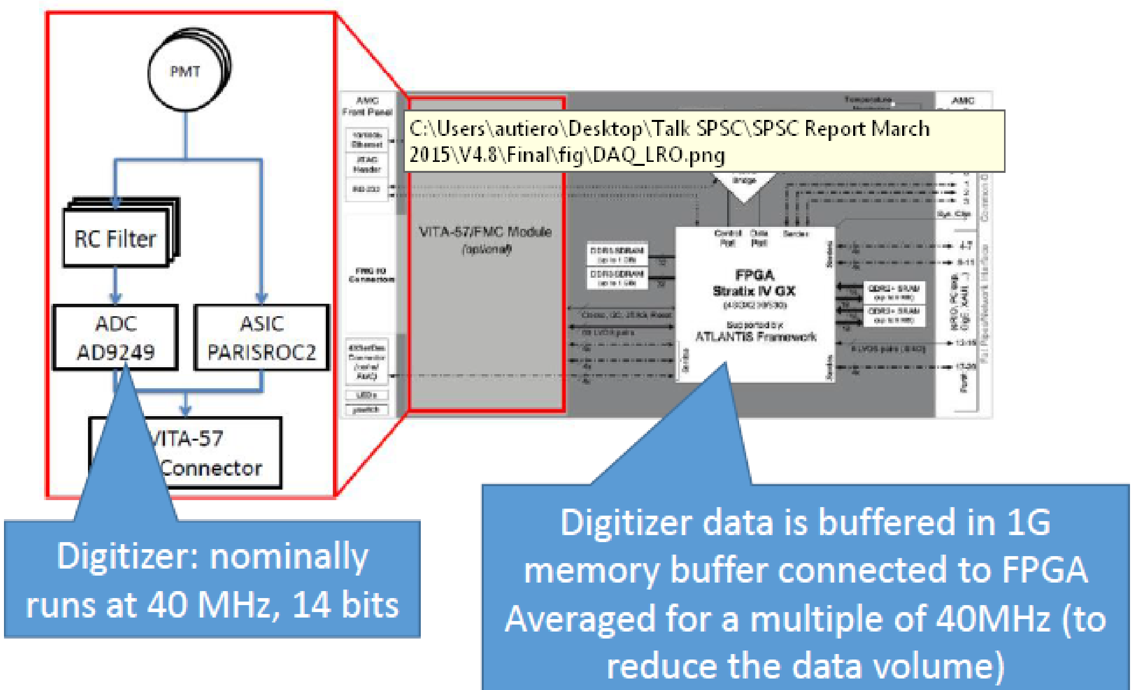
→ During spills it is needed a continuous digitization of the light in the +-4 ms around the trigger time (the light signal is instantaneous and keeps memory of the real arrival time of the cosmics)

→ Sampling can be coarse up to 400 ns just to correlate to charge readout

Light readout electronics

Two modes of acquisition:

- External beam trigger to acquire ±4ms around the spill
- Internal trigger from PARISROC2 ASIC to acquire short time segments

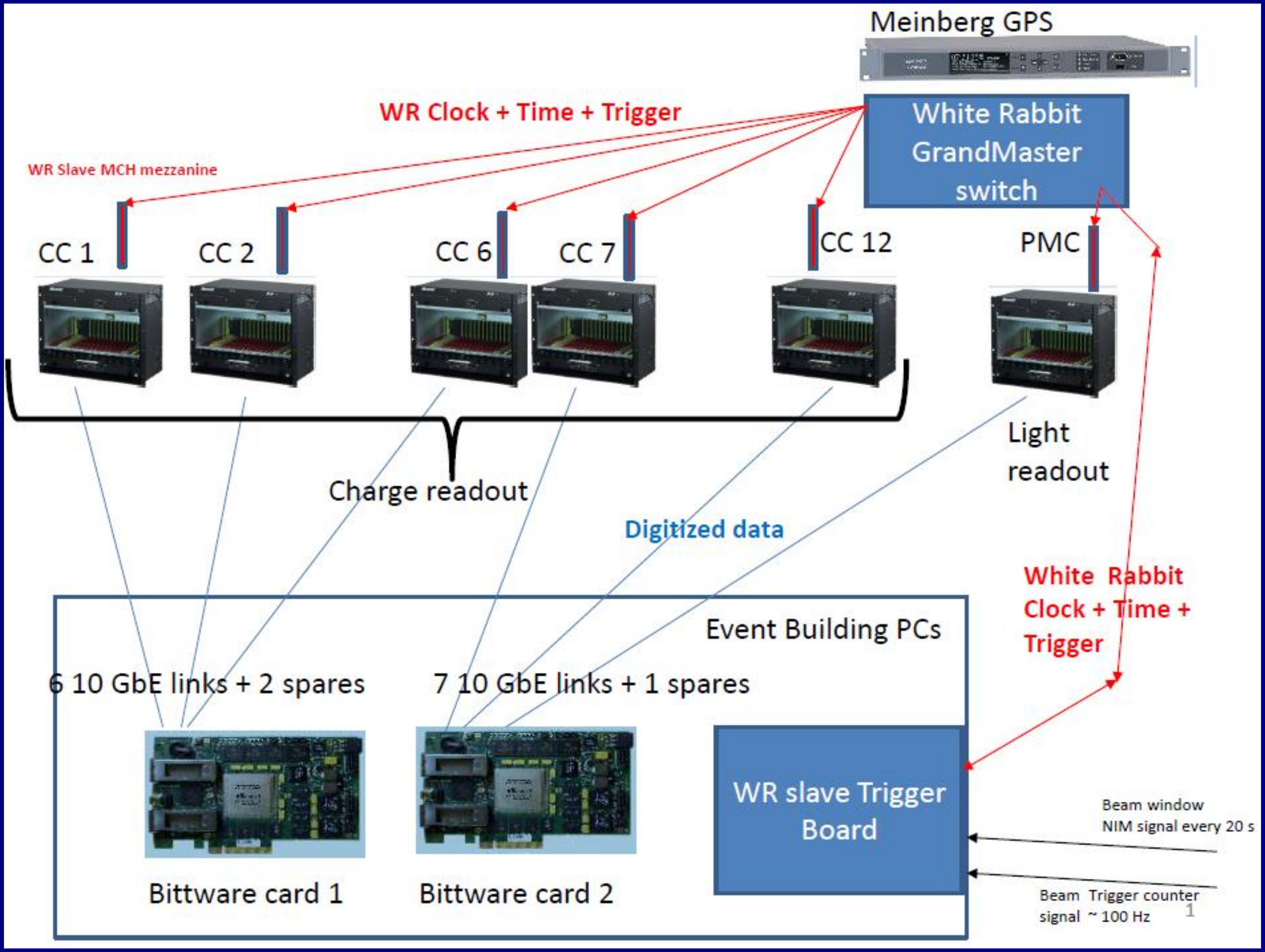


→ Sum 16 samples at 40MHz to get an effective 2.5 MHz sampling like for the charge readout

The LRO card has to know spill/out of spill
Out of spill it can define self-triggering light triggers when "n" PMTs are over a certain threshold and transmit its time-stamp over the WR

Global uTCA DAQ architecture

integrated with « White Rabbit » (WR) Time and Trigger distribution network + White Rabbit slaves nodes in uTCA crates



Data size

- Data are expected to be taken **without zero skipping and exploiting loss-less compression** and the system has been designed to support up to 100 Hz of beam triggers without zero-skipping and no compression
- 7680 channels, 10k samples in a drift windows of 4ms→ 146.8MB/events, No zero skipping
- **Beam rate: 100Hz**
- Data flow= 14.3 GB/s
- Light readout does not change in a significant way this picture (<0.5 GB/s)

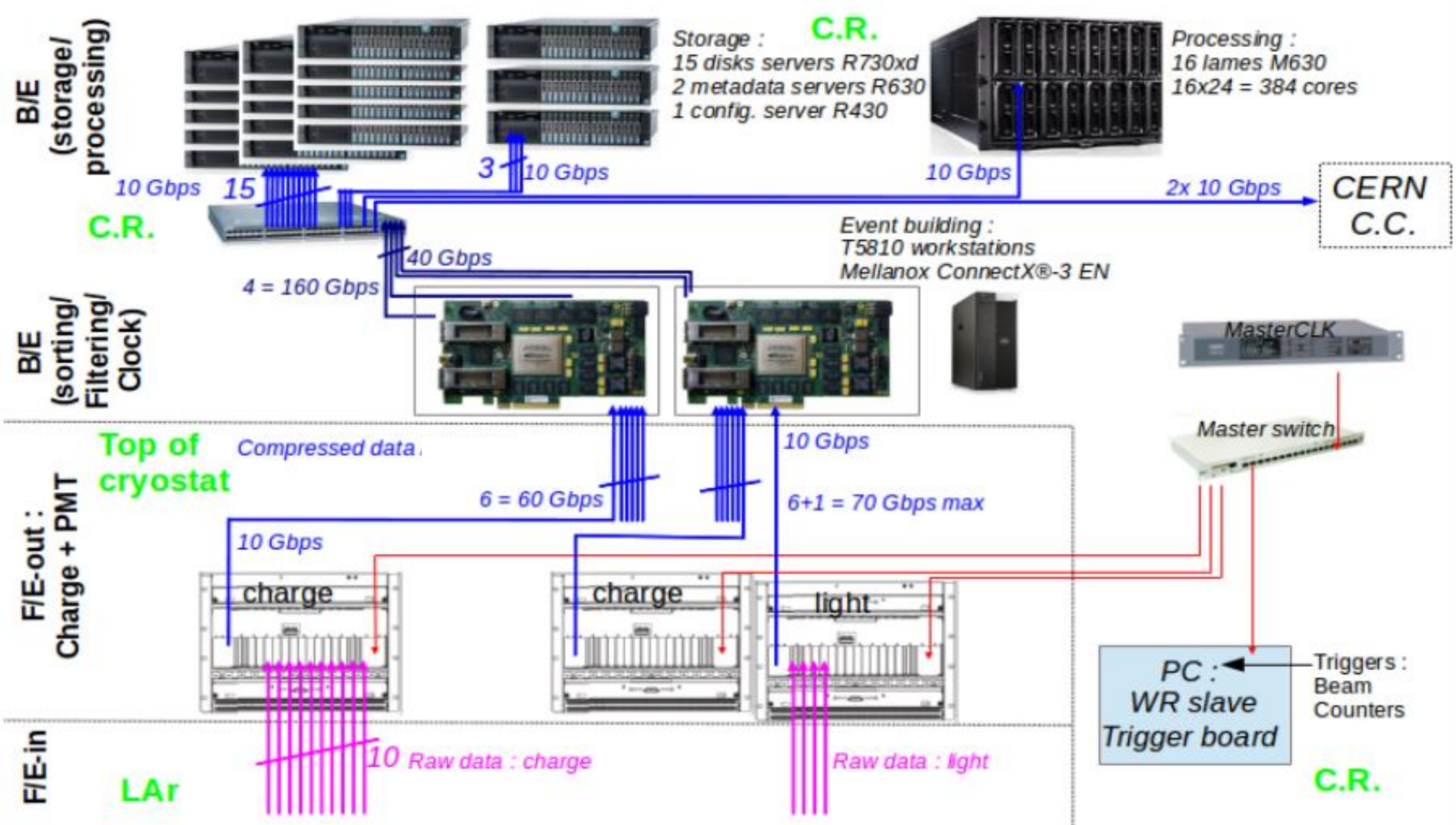
⇩

→ **Integrated local DAQ bandwidth on the "20 GB/s scale"**

Local data buffer ~ 1000TB (no zero skipping, no compression), also used for local processing

Huffman lossless compression can reduce the non-zero-skipped charge readout data volume by at least a factor 10 (S/N for double phase ~100:1, small noise fluctuations in absolute ADC counts)

Online processing and storage facility: internal bandwidth 20 GB/s, 1 PB storage, 384 cores: key element for online analysis (removal of cosmics, purity, gain, events filtering)



Smaller scale test system being prepared for the operation of the 3x1x1 in September

C.R. stands for Counting Room

Offline (downstream the online computing farm) and computing model:

- **MC production and code management actually centralized at CCIN2P3 in Lyon**
- **Massive MC production expected at CCIN2P3 and possible other centers**
- **6x6x6 data production at CERN and Fermilab**

- **Software based on QSCAN (simulation/reconstruction); fast execution and easily adaptable for detector performance analysis, online monitoring and analysis :**

Framework dealing with all the aspects of the detector simulation and reconstruction going from: geometry description, interface to MC transport codes like Geant3/4 via VMC, events generators like Genie, detector response and electronics simulation for both single and dual-phase, simulated and real events reconstruction and event display. Interface to the raw and simulated data formats for various detector setups going from several R&D prototypes to WA105 3x1x1 and 6x6x6 and the 20 and 50 kton detectors considered in the LAGUNA-LBNO design study. Allowing to understand the performance of the detectors under construction like the 3x1X1 and 6x6x6 by also comparing to the result obtained in the last 10 years with different prototypes.

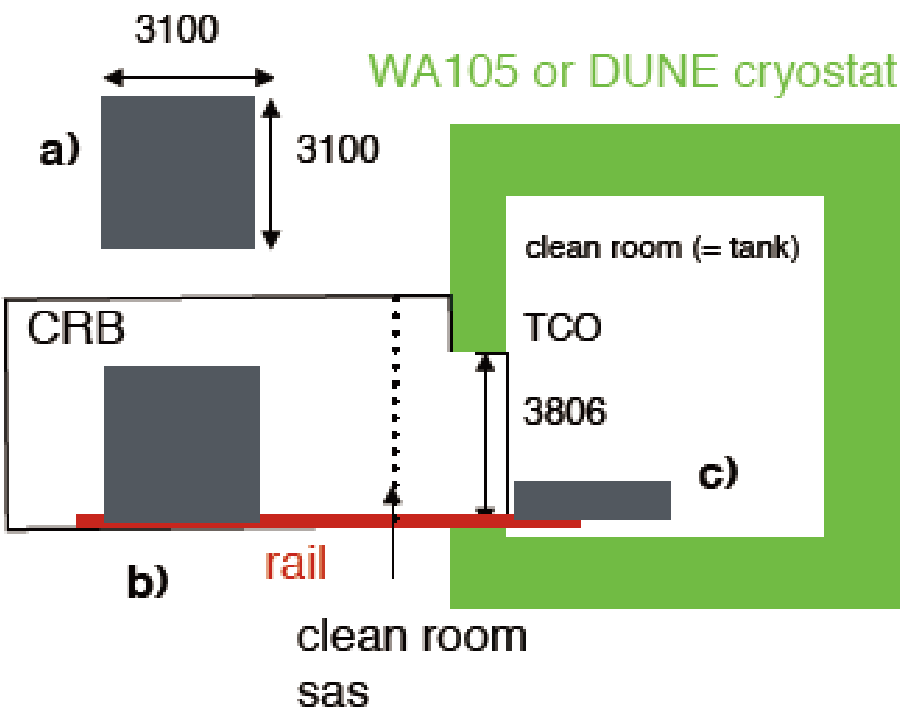
- **3x1x1 simulation analysis and monitoring with QSCAN (September 2016). Developing QSCAN for 6x6x6, needed for detector optimization analysis and online analysis/monitoring**

- **O(100 M) beam triggers expected in 2018 (+ cosmic runs and technical tests). If totally stored in non-zero-skipped, lossless compression format (Huffman factor 10 compression: 15MB/event) → 2.4 PB total data volume**
- **Computing infrastructure (storage/processing) under discussion with CERN IT and Fermilab computing division:**

- **Requested link from online-storage to CERN computing division at 20 Gbps, compatible with 100 Hz non-zero-skipped, Huffman compressed data flow**
- **Existing fast link between CERN and FNAL**

Simple and common installation procedure for Dual-Phase ProtoDUNE / Far Detector

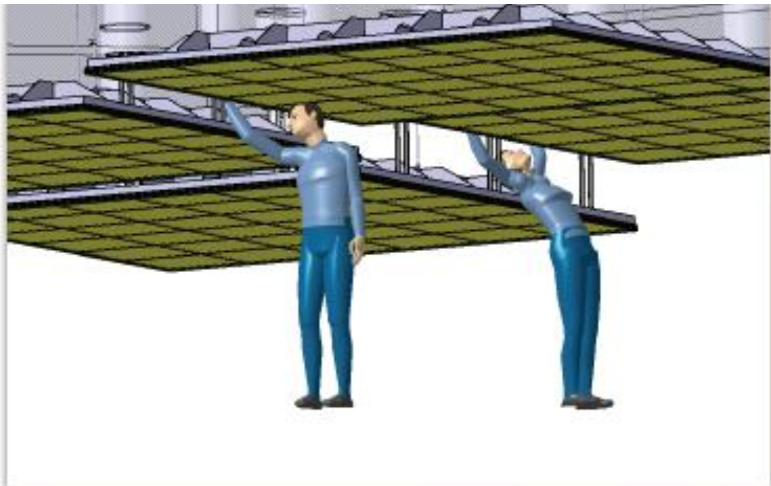
CRP box: 3100x3100x500 that contains the CRP fully assembled.
The box enters the Clean Room Buffer located in the pit through the roof

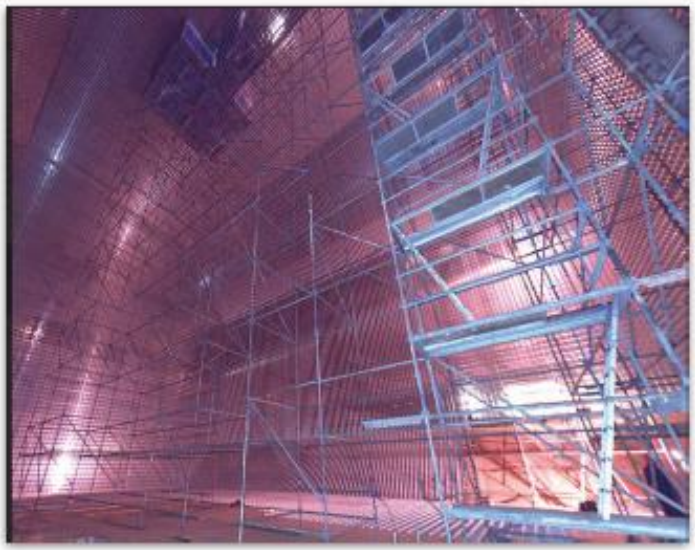


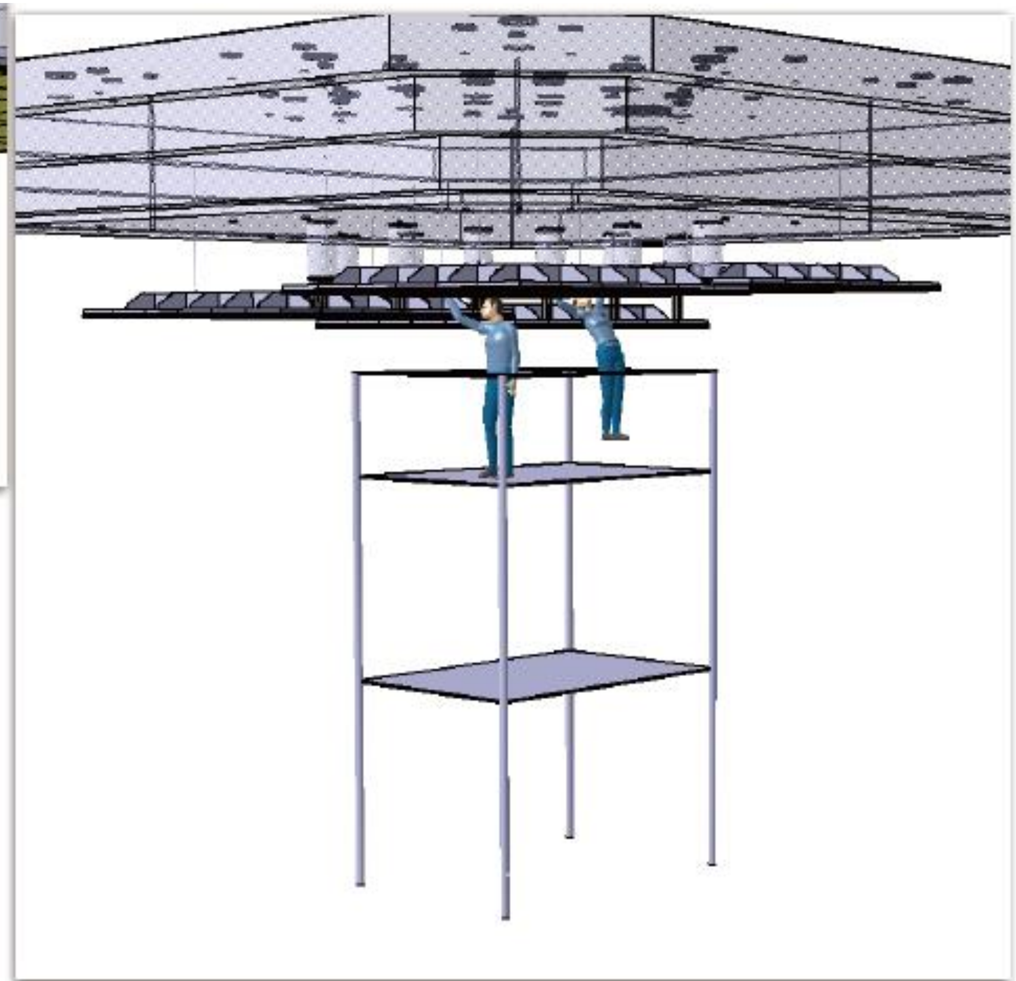
a) insert CRP box into clean room buffer (CRB)
b) fix on rails in CRB and slide into the clean room via the TCO.
c) once inside the tank need a tool to rotate and lay flat to unpack (requires that the rails extend into the tank and a platform inside tank too)

The CRP is delivered and has undergone the full QA/QC chain above ground.

Simple and common installation procedure for Dual-Phase ProtoDUNE / Far Detector

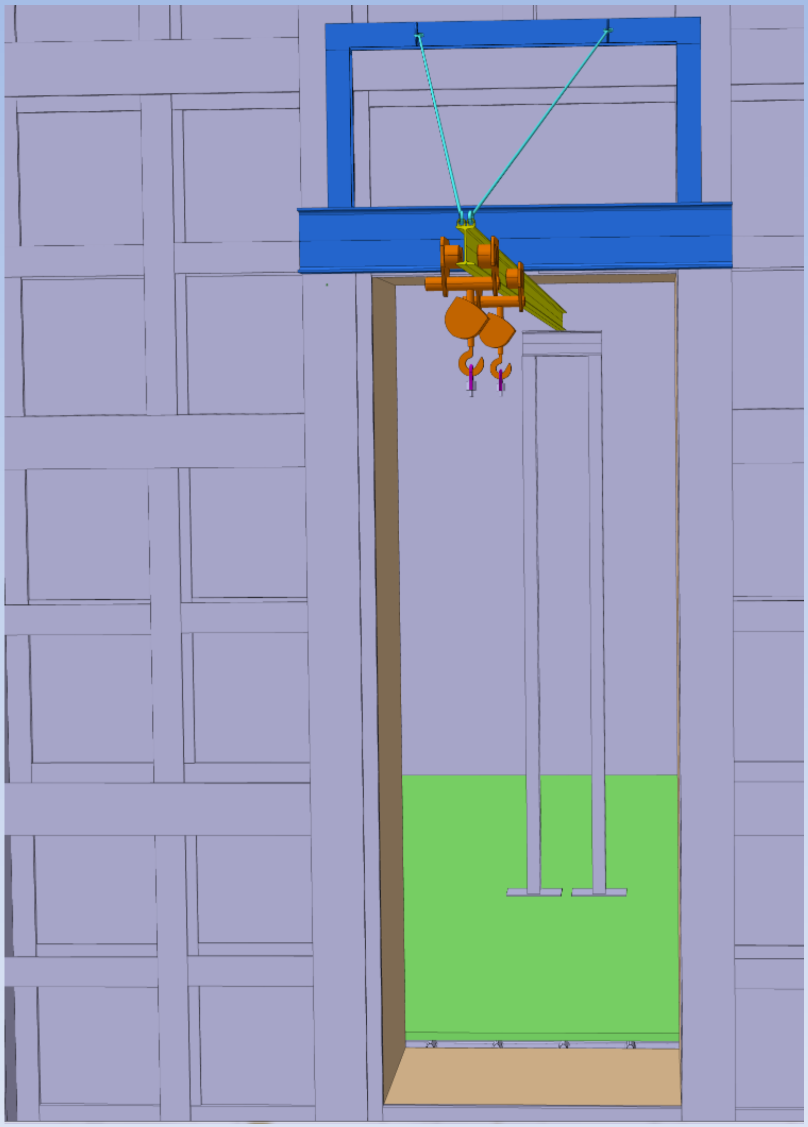


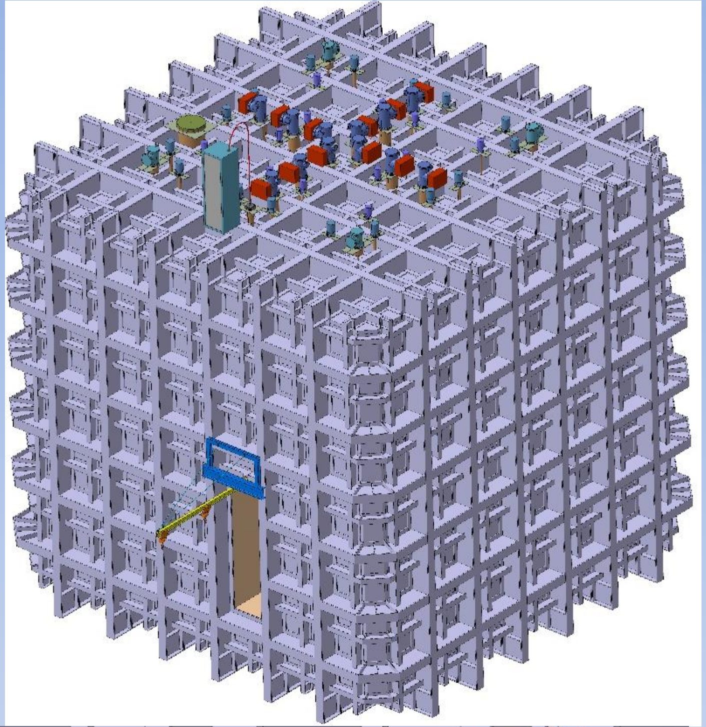


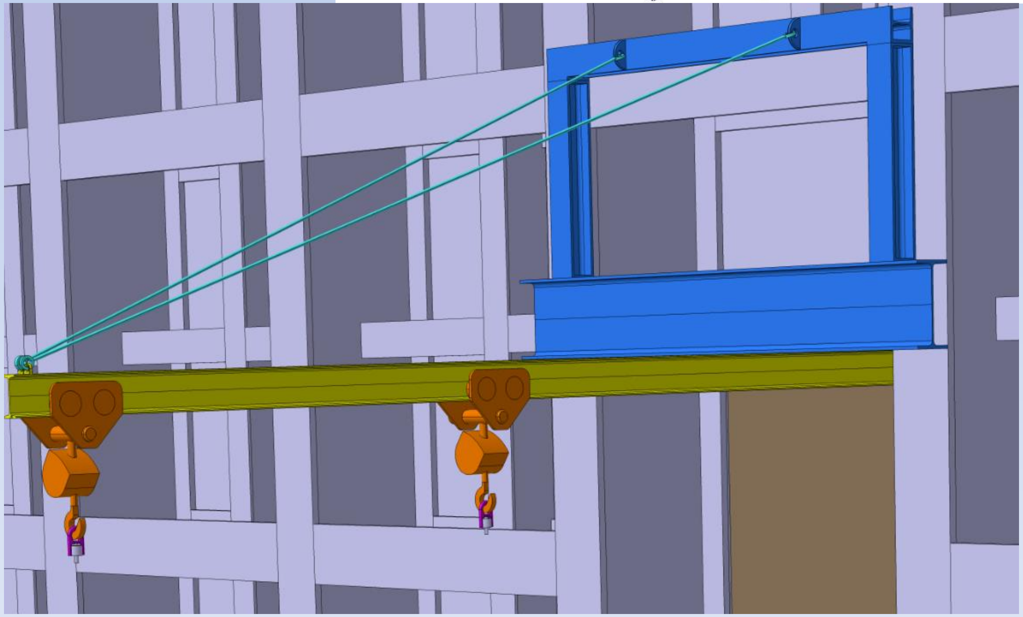


- CRP modules installation in the cryostat: simple procedure that minimises risks.
- Scaffoldings will already be there from the cryostat construction

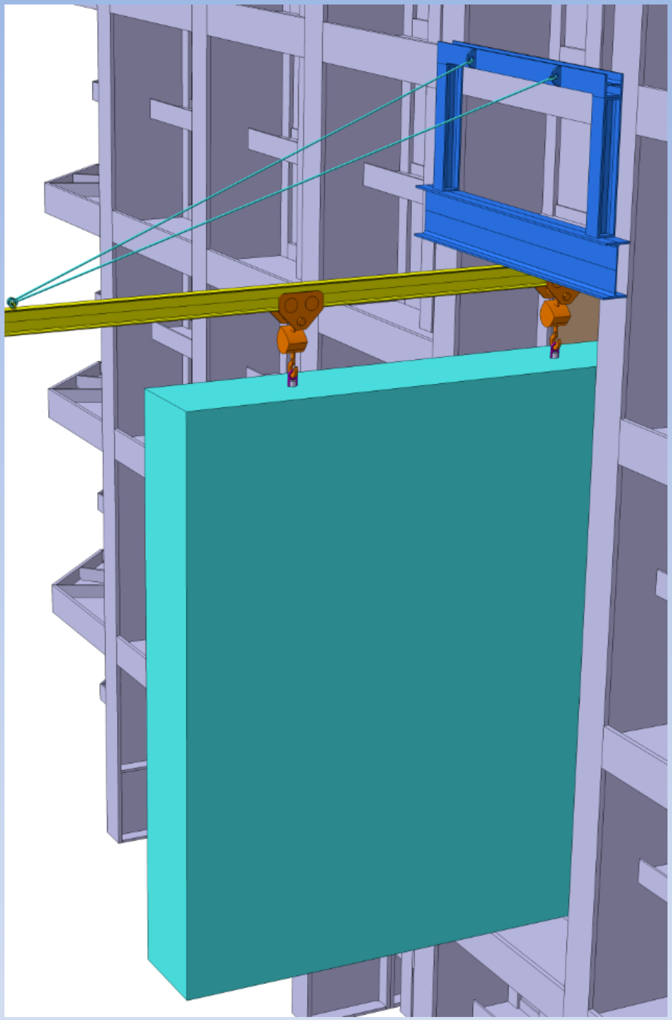
Suspendend Rail for CRP insertion

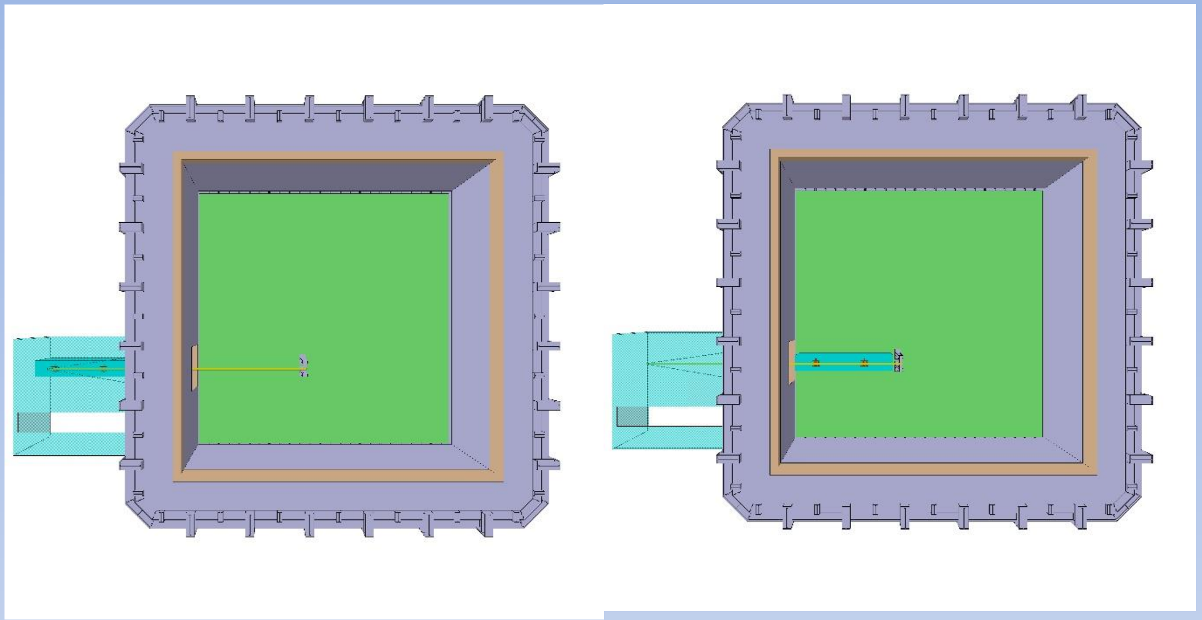




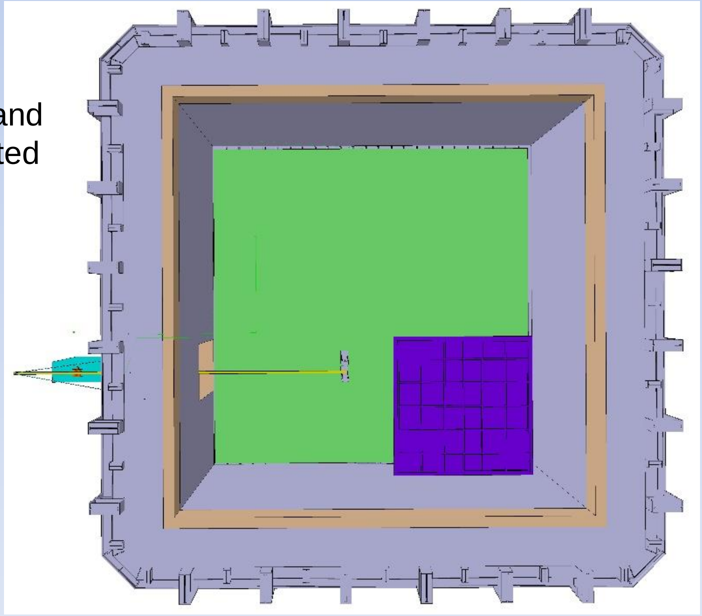


CRP box and CRP 3X3 m² installation





- CRP inside
- Lowered, rotated and unpacked
- Lowered on a «movable table» and placed in Position ready to be lifted



Schedules:

Main milestones

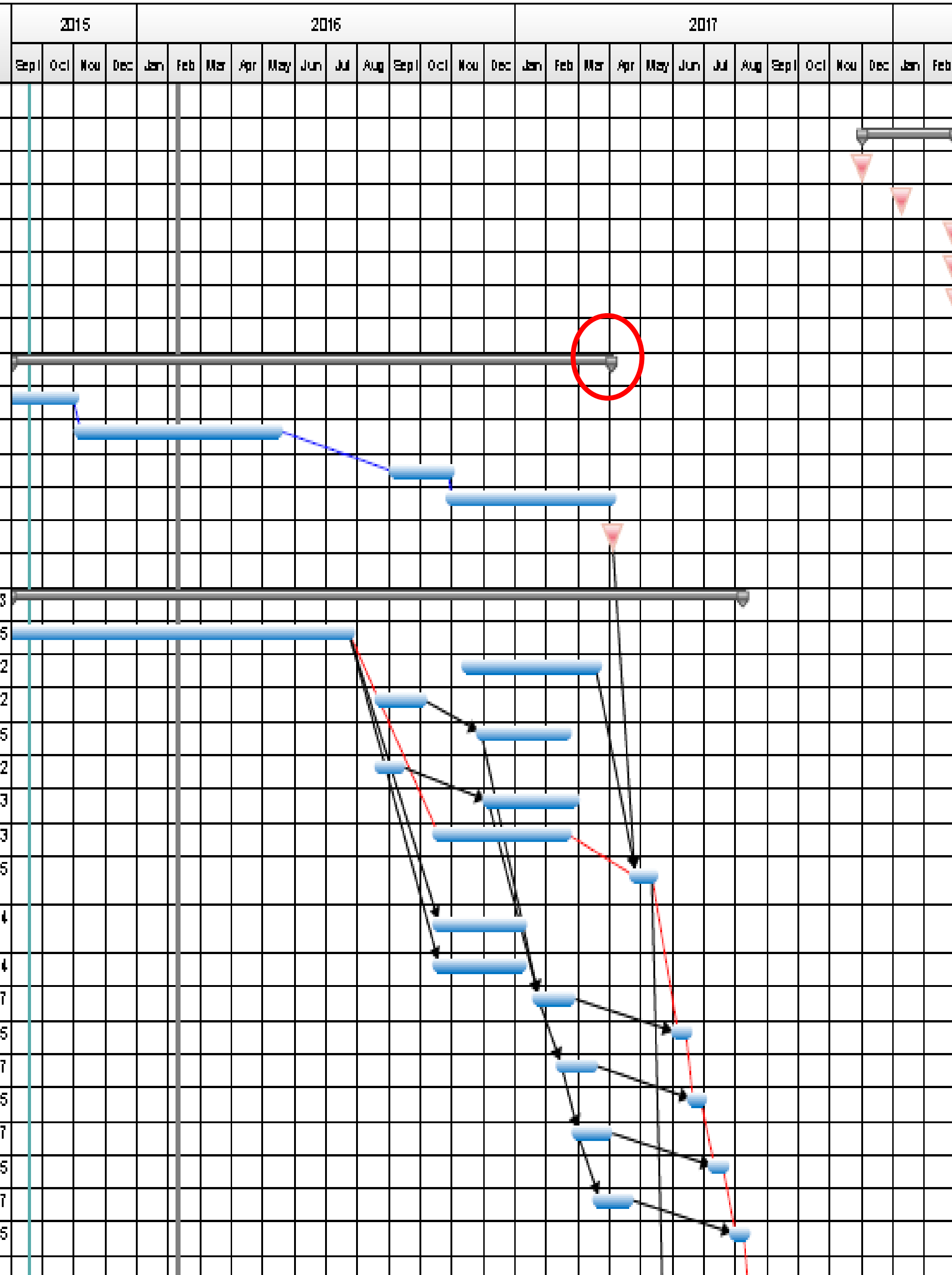
3x1x1 Building 182:

- **February 2016**: start detector installation (arrival at CERN of the Top Cap build by Gabadi which is supporting the detector structure)
- **June 2016**: weld top cap. and seal cryostat
- **July 2016**: perform test in Gas Ar
- **August 2016**: start cryogenic operation
- **September 2016**: start cosmic ray data taking

6x6x6 in the NA EHN1:

- **September 2016**: start cryostat construction
- **April 2017**: start detector installation
- **December 2017**: seal TCO & cryostat
- **January 2018**: start cryogenic operation (cooldown+filling)
- **April 2018**: ready to collect beam data

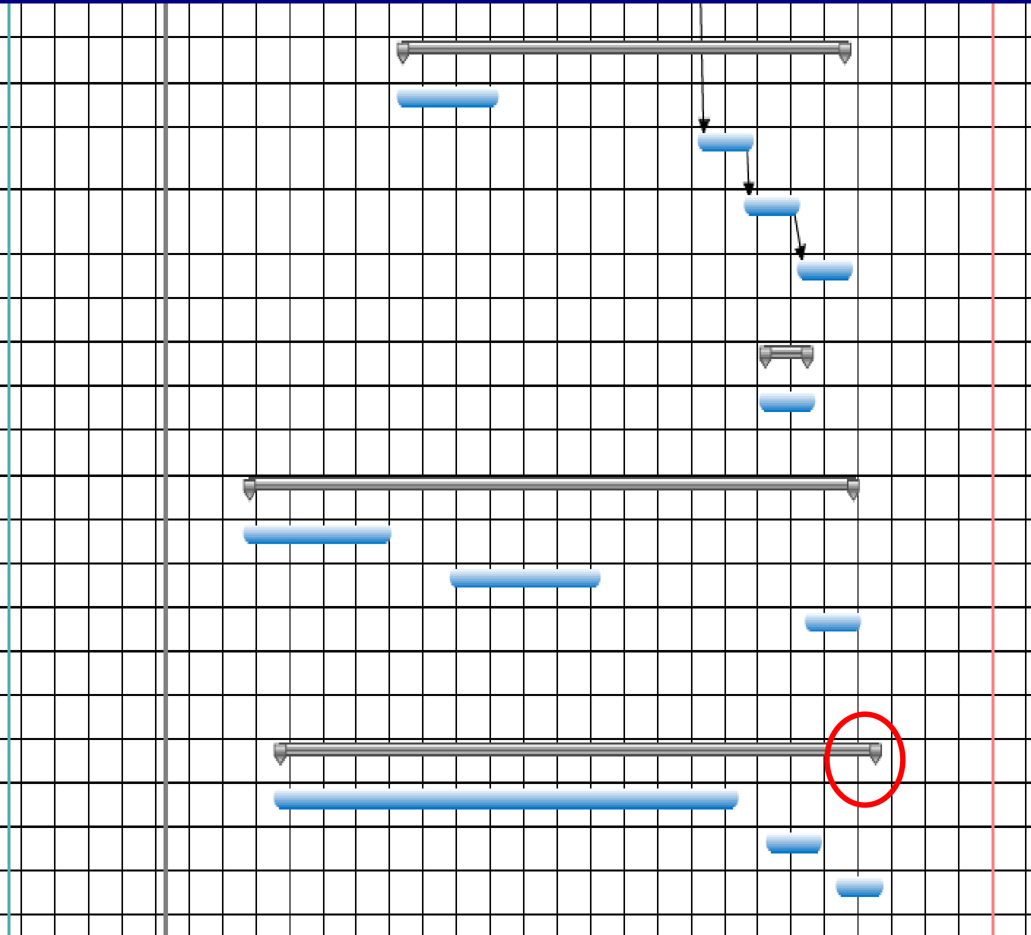
	Activity Name	Duration (Days)	Start Date	Finish Date	Resources Assigned	People
1	WA666 v4 8/2/16 / A R					
2	**Detector Comissioning EHN1**	84.00	12/1/17	3/1/18		
3	*Ready to seal TCO & cryostat*	0.00	12/1/17	12/1/17		
4	*Start of cryogenic operation*	0.00	1/8/18	1/8/18		
5	*LAr purity achieved inside cryostat*	0.00	2/26/18	2/26/18		
6	*Cosmic tracks recorded*	0.00	2/26/18	2/26/18		
7	*Ready for beam*	0.00	3/1/18	3/1/18		
8						
9	**EHN1 cryostat activities**	**414.00**	**9/1/15**	**4/3/17**		
10	*Cold vessel specification*	44.00	9/1/15	10/30/15		
11	*CTT study*	138.00	11/30/15	5/19/16		
12	*Warm vessel assembly*	39.30	9/5/16	10/20/16		
13	*Membrane construction*	110.00	10/31/16	3/31/17		
14	*Cryostat ready for detector installation*	0.00	4/3/17	4/3/17		
15						
16	**Charge readout system**	607.00	8/31/15	8/8/17		83
17	*Design of CRP*	235.00	8/31/15	7/22/16	ETHZ, IRFU, LAPP	5
18	*Signal chimneys + flanges procurement*	90.00	11/14/16	3/17/17	ETHZ	2
19	*LEM procurement market survey*	30.00	8/22/16	9/30/16	ETHZ, IRFU	2
20	*no. 144 LEM procurement*	60.00	11/28/16	2/17/17	ETHZ, IRFU	5
21	*Anode procurement market survey*	15.00	8/22/16	9/9/16	ETHZ, IRFU	2
22	*no. 144 Anode procurement*	60.00	12/5/16	2/24/17	ETHZ, IRFU	3
23	*Procurement CRP hanging system*	90.00	10/17/16	2/17/17	ETHZ, LAPP	3
24	*Installation feedthrough towers in chimneys + CRP hanging systems*	14.00	4/24/17	5/11/17	CERN, ETHZ, KEK	5
25	*Extraction grid preparation (no. 4000 wires)*	60.00	10/17/16	1/6/17	ETHZ, LAPP	4
26	*CRP frames procurement*	60.00	10/17/16	1/6/17	ETHZ, LAPP	4
27	*CRP 3x3 #1 module assembly Bg 185*	21.00	1/23/17	2/20/17	ETHZ, IRFU, LAPP	7
28	*CRP 3x3 #1 module installation*	7.00	6/5/17	6/13/17	ETHZ, IRFU, LAPP	5
29	*CRP 3x3 #2 module assembly Bg 185*	21.00	2/13/17	3/13/17	ETHZ, IRFU, LAPP	7
30	*CRP 3x3 #2 module installation*	7.00	6/19/17	6/27/17	ETHZ, IRFU, LAPP	5
31	*CRP 3x3 #3 module assembly Bg 185*	21.00	2/27/17	3/27/17	ETHZ, IRFU, LAPP	7
32	*CRP 3x3 #3 module installation*	7.00	7/10/17	7/18/17	ETHZ, IRFU, LAPP	5
33	*CRP 3x3 #4 module assembly Bg 185*	21.00	3/20/17	4/17/17	ETHZ, IRFU, LAPP	7
34	*CRP 3x3 #4 module installation*	7.00	7/31/17	8/8/17	ETHZ, IRFU, LAPP	5
35						



	Activity Name	Duration (Days)	Start Date	Finish Date	Resources Assigned	People
36	**Drift cage**	550.00	9/18/15	10/26/17		**25**
37	*PMMA/ITO/TPB R&D*	231.00	9/18/15	8/5/16	ETHZ	2
38	*Field cage and anode design*	120.00	8/22/16	2/3/17	CERN, ETHZ	3
39	*Field cage procurement*	90.00	3/6/17	7/7/17	CERN, ETHZ	3
40	*Cathode procurement*	90.00	3/6/17	7/7/17	CERN, ETHZ	2
41	*Field cage assembly*	21.00	8/28/17	9/25/17	CERN, ETHZ	8
42	*Cathode assembly*	14.00	10/9/17	10/26/17	CERN, ETHZ	7
43						

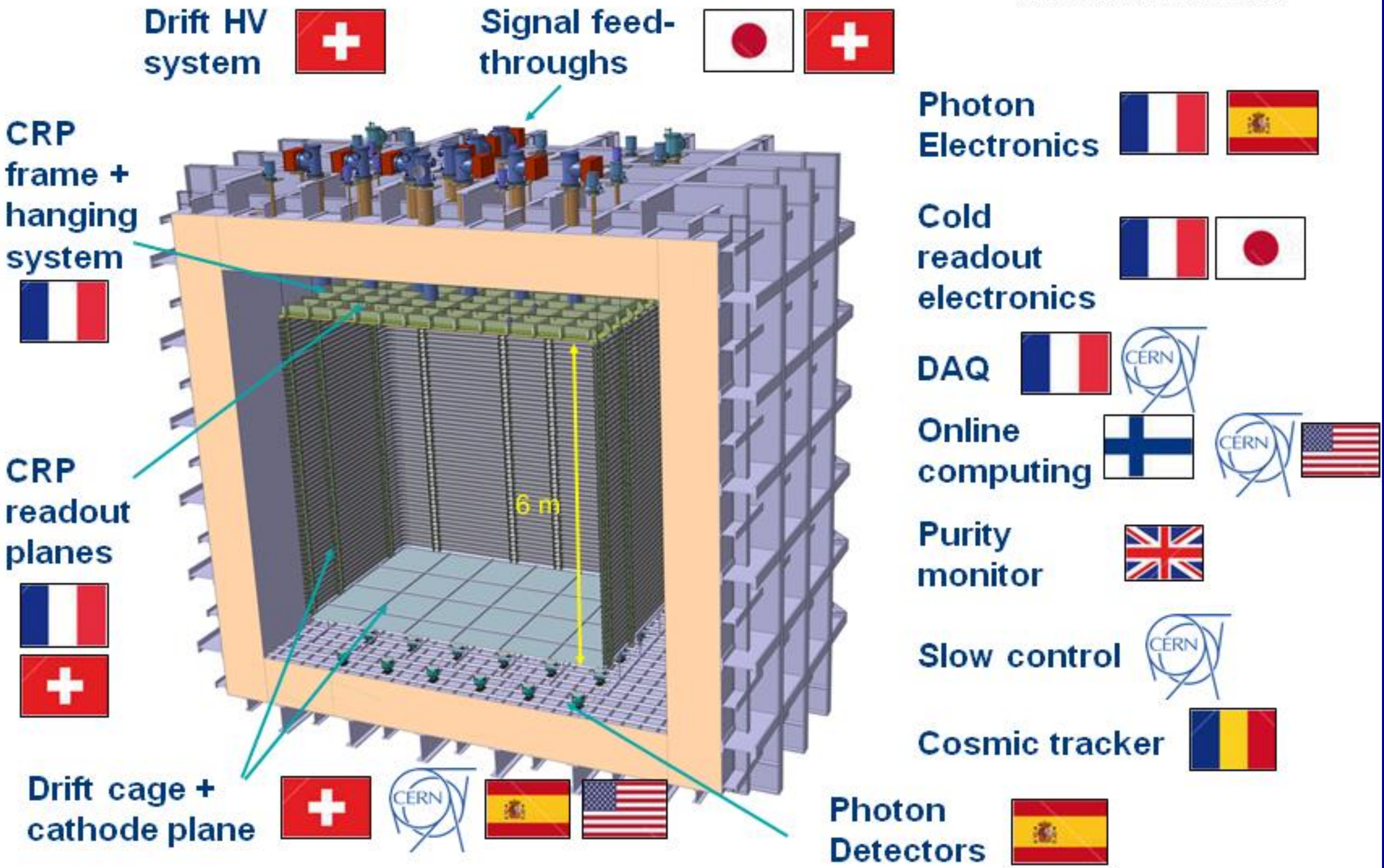
	Activity Name	Duration (Days)	Start Date	Finish Date	Resources Assigned	People
44	**HV system**	557.00	9/1/15	10/18/17		**8**
45	*300 kV power supply*	0.00	9/1/15	9/1/15	CERN, ETHZ	1
46	*HVFT design*	60.00	1/2/17	3/24/17	CERN, ETHZ	2
47	*HVFT procurement*	98.00	4/17/17	8/30/17	CERN, ETHZ	1
48	*Installation on detector*	3.00	10/16/17	10/18/17	CERN, ETHZ	4
49	*600 kV power supply*	0.00	9/18/15	9/18/15	?	
50						
51	**Light readout system**	384.00	6/6/16	11/23/17		**23**
52	*PMT no.36 procurement*	90.00	6/6/16	10/7/16	CIEMAT, IFAE	3
53	*PMT no.36 coating*	40.00	10/24/16	12/16/16	CIEMAT, IFAE	5
54	*PMT base soldering*	18.00	1/2/17	1/25/17	CIEMAT, IFAE	3
55	*PMT testing*	40.00	2/13/17	4/7/17	CIEMAT, IFAE	5
56	*PMT support system*	14.00	10/2/17	10/19/17	CIEMAT, IFAE	3
57	*PMT installation & cabling*	14.00	11/6/17	11/23/17	CIEMAT, ETHZ, IFAE	4

58						
59	**Front-end electronics**	290.00	9/12/16	10/20/17		**23**
60	*micro-TCA no.12 procurement*	60.00	9/12/16	12/2/16	IPNL	4
61	*F/E electronics installation (Insertion of the cards in the chimeneys and cabling)*	30.00	6/12/17	7/21/17	IPNL, KEK	5
62	*micro-TCA installation (Installation of the crates, insertion of the cards ad cabling)*	30.00	7/24/17	9/1/17	APC, IPNL, LAPP	7
63	F/E DAQ Commissioning	30.00	9/11/17	10/20/17	APC, IPNL, LAPP	7
64						
65	**Back-end system+network**	30.00	8/7/17	9/15/17		**5**
66	*computers*	30.00	8/7/17	9/15/17	CERN, IPNL, Jyväskylä	5
67						
68	**Slow control**	395.00	4/25/16	10/27/17		**8**
69	*HV LEM+anodes power supplies*	90.00	4/25/16	8/26/16	ETHZ, KEK	3
70	*SCFT chimneys + flanges procurement*	90.00	10/31/16	3/3/17	ETHZ	1
71	*Cabling & testing*	30.00	9/18/17	10/27/17	CERN, ETHZ	4
72	*Slow control system*					
73						
74	**Purity monitor**	390.00	5/23/16	11/17/17		**10**
75	*Design and construction*	295.00	5/23/16	7/7/17	UCL	3
76	*Installation*	30.00	8/14/17	9/22/17	UCL	4
77	*Comissioning*	25.00	10/16/17	11/17/17	UCL	3
78						



Dual phase protoDUNE - WA105 6x6x6m^3

(US contributions under discussion)



Synergies with single-phase protoDUNE:

- **Beam monitoring detectors – joint Working Group.**
- **Beam window/Beam plug – common development through DUNE FD Working Group**
- **Field cage – common development through DUNE Far Detector Working Group**
- **High Voltage – common development through DUNE Far Detector Working Group**
- **Slow Control/Detector Monitoring – joint Working Group**
- **DAQ with areas of common interest such as DAQ software, Run Control software, data formatting software, and potentially timing distribution hardware**
- **Online Computing focusing on online computing farm, online disk storage, online monitoring, and data transmission to Tier 0 – joint Working Group**
- **Offline Computing - joint effort through DUNE Software & Computing Working Group**
- **Cosmic triggering - joint Working Group**

EOI call within DUNE (January 2016):

New institutes have expressed their interest to work on WA105:
FNAL (Computing and Neutrino Divisions), Czech Republic Institutes, University of Texas Arlington, National Centre for Nuclear Research, Kyiv National University, University of Wisconsin, Maryland, Argonne National Laboratory and DUNE-UK.

The expressions of interest included input for construction, commissioning, operation as well as intellectual contributions to WA105.

→ Additional groups are very welcome, WA105 is not a closed system and there are a lot of opportunities for participation

Conclusions:

- The dual-phase design provides many appealing aspects in improving the detector performance and reducing its construction costs. Long standing efforts have been spent in this direction during the last 10 years and are now culminating in a full scale implementation with the 6x6x6 detector in the NA

- The dual-phase TPC design is a state of the art technique with many innovative and challenging aspects. New groups interested in understanding this technique and in contributing to the 10 kton dual-phase design should consider the opportunity of joining the ProtoDUNE dual-phase efforts

- There is also the opportunity of familiarizing with the variety of techniques employed in dual-phase design with smaller scale prototypes such as the 3x1x1

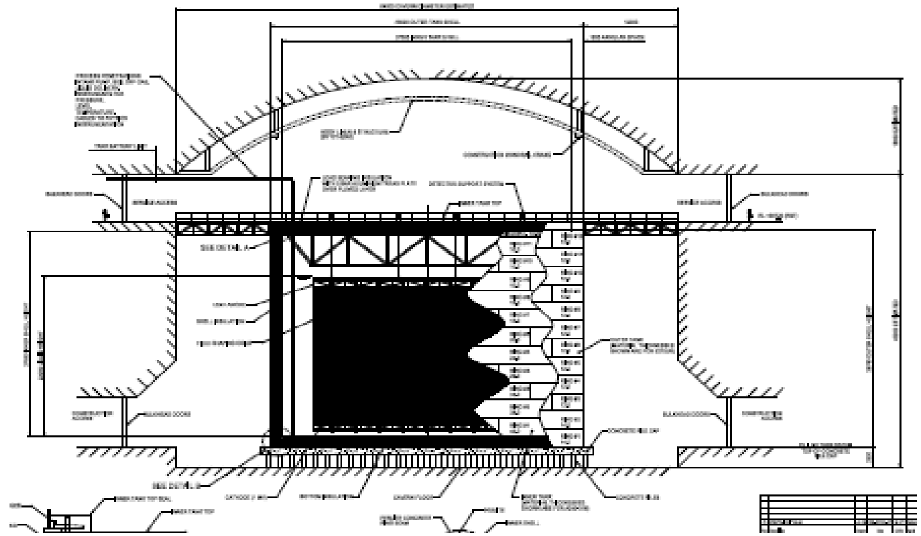
- Despite its advanced design and prototyping state WA105 is <u>an open system</u> to hardware and intellectual contributions → new groups are very welcome to join

- Also the full data analysis of a large data sample of hadronic interactions and the fine studies to improve the far detector systematics will be a challenging and long standing task

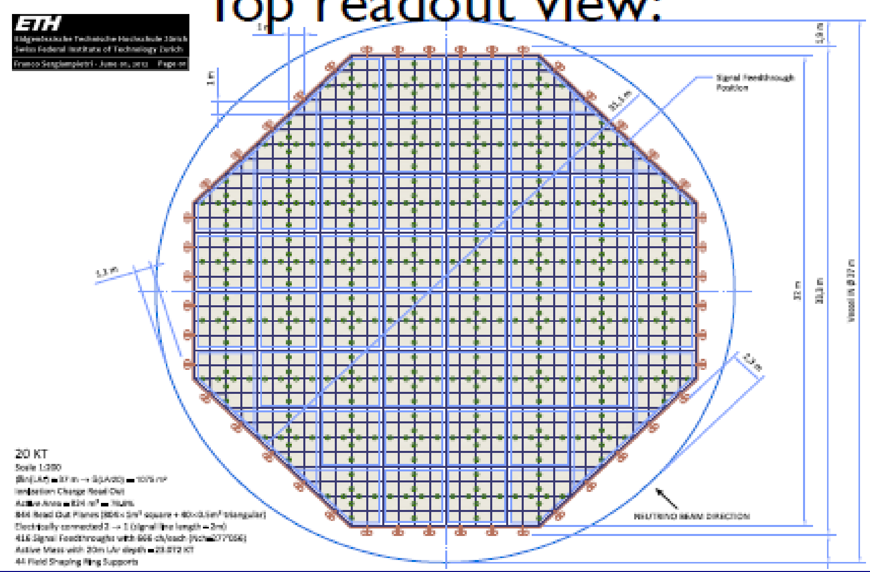
- We are looking forward to the ProtoDUNE DP detector exploitation with the beamline in 2018 !

GLACIER detector design

- ★ Concept unchanged since 2003: Simple, scalable detector design, from one up to 100 kton (hep-ph/0402110)
- ★ Single module non-evacuable cryo-tank based on industrial LNG technology
  - industrial conceptual design (Technodyne, AAE, Ryhal engineering, TGE, GTT)
  - two tank options: 9% Ni-steel or membrane (detailed comparison up to costing of assembly in underground cavern)
  - three volumes: 20, 50 and 100 kton
- ★ Liquid filling, purification, and boiloff recondensation
  - industrial conceptual design for liquid argon process (Sofregaz), 70kW total cooling power @ 87 K
  - purity < 10 ppt O_2 equivalent
- ★ Charge readout (e.g. 20 kton fid.)
  - 23'072 kton active, 824 m^2 active area
  - 844 readout planes, 277'056 channels total
  - 20 m drift
- ★ Light readout (trigger)
  - 804 8" PMT (e.g. Hamamatsu R5912-02MOD) WLS coated placed below cathode
- ★ The concept and the designs are reaching the required level of maturity for submission to SPSC.



Top readout view:



Technical aspects finalized in the LAGUNA-LBNO study as deliverables including detailed costing → August 2014 Affordable underground detector

Table 5.2: Sizes and Dimensions for the 12 kt (15 kt) dual-phase LArTPC

Item	Value(s)	
Active volume width and length	W = 12m	L = 60m
Active volume height	H = 12 m (H = 15 m)	
Active volume/LAr mass	8640 (10800) m^3	12096 (15120) metric ton
Field ring vertical spacing	200 mm	
Field ring tube diameter	140 mm	
Anode plane size	W = 12m	L = 60 m
CRP unit size	W =3m	L = 3 m
HV for vertical drift	600 - 900 kV	
Resistor value	100 MΩ	

DUNE CDR
10 kton double-phase module

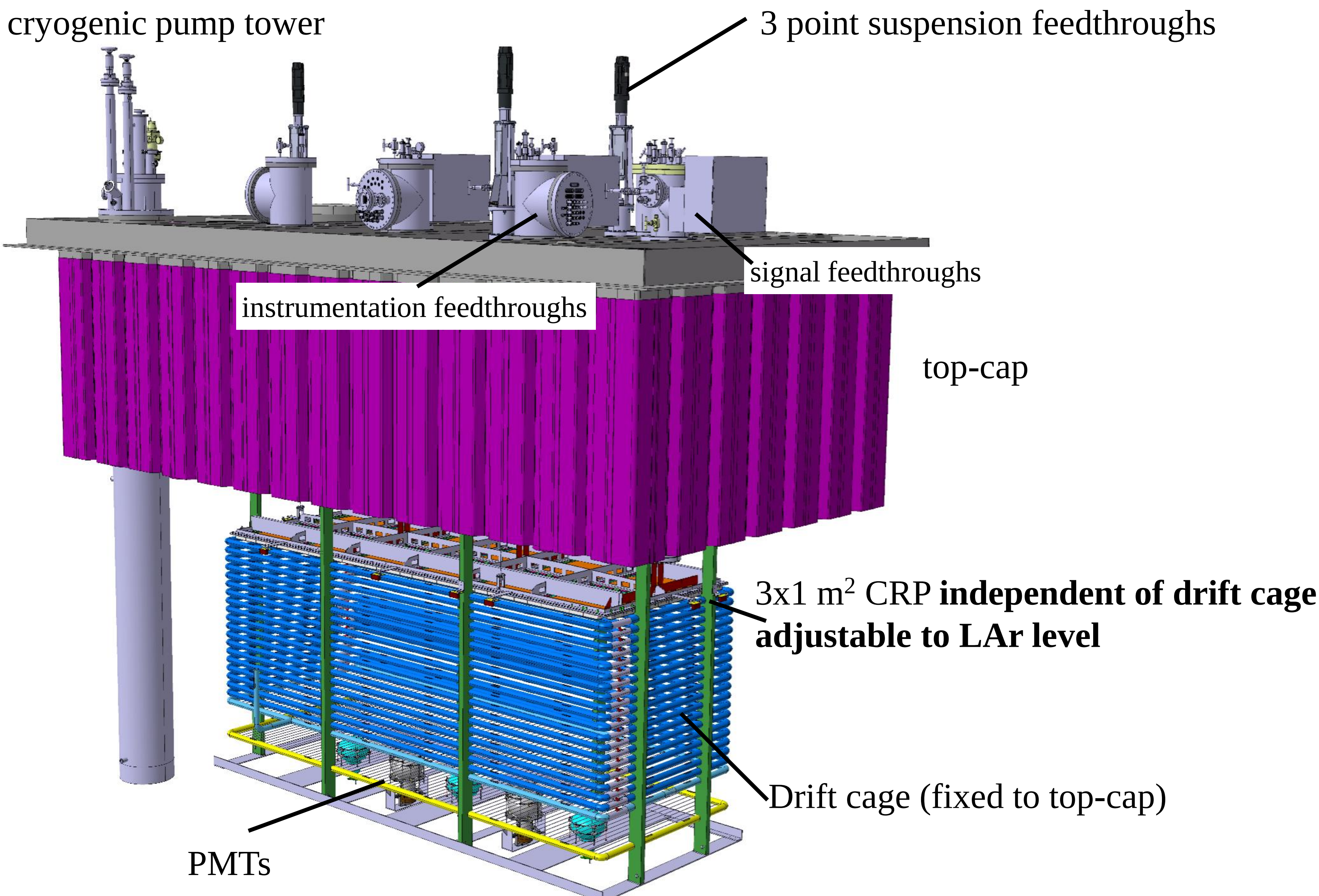
Detector quantities

Table 5.3: Quantities of Items for the 12 kt (15 kt) dual-phase LArTPC

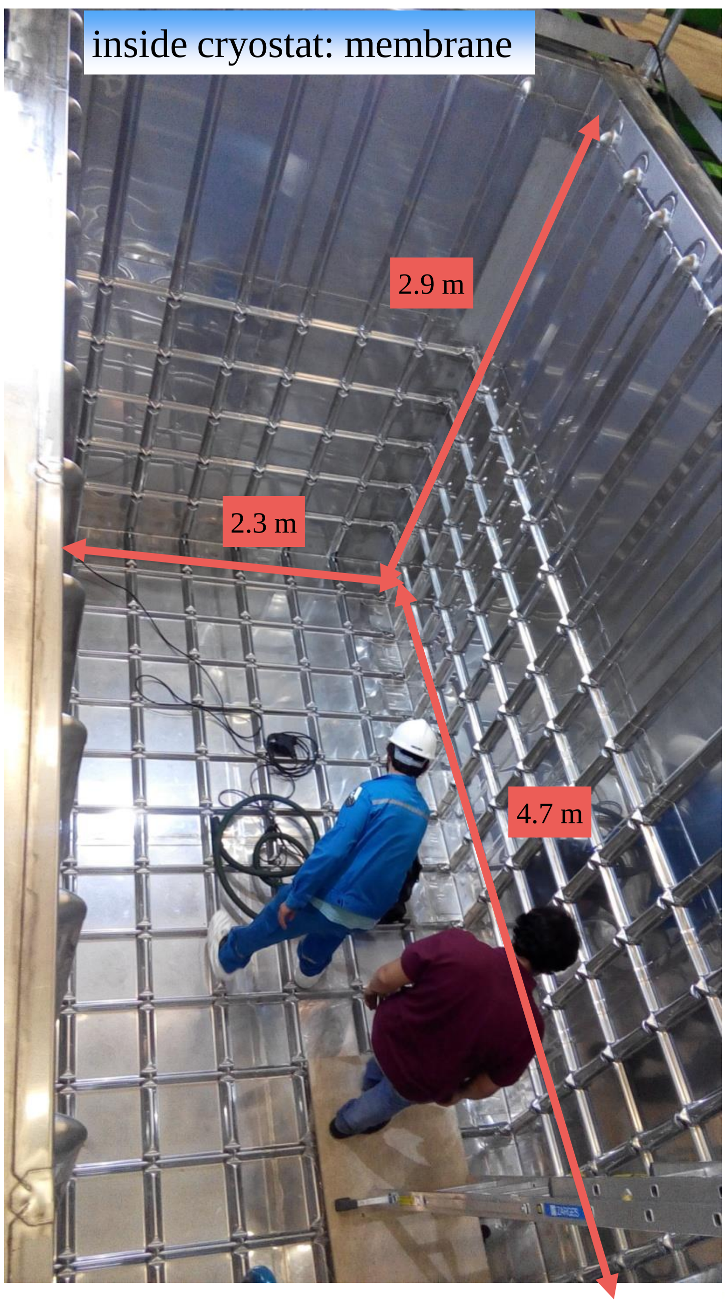
Item	Number
Field rings	60 (75)
CRP units	$4 \times 20 = 80$
LEM/Anode sadwiches per CRP unit	36
LEM/Anode sandwiches (total)	2880
SFT chimneys / CRP unit	3
SFT chimneys (total)	240
Read-out channels / SFT chimney	640
Read-out channels (total)	153600
Suspension FT / CRP unit	3
Suspension FTs (total)	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)

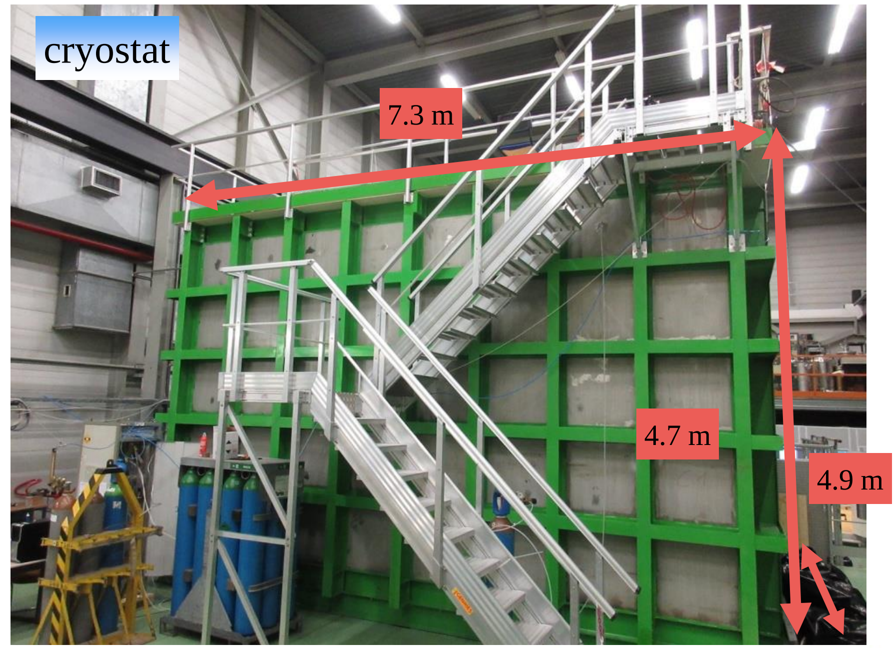
- 80 CRP units
- 60 Field shaping rings
- 240 Signal FT chimneys
- 240 Suspension chimneys
- 180 PMTs

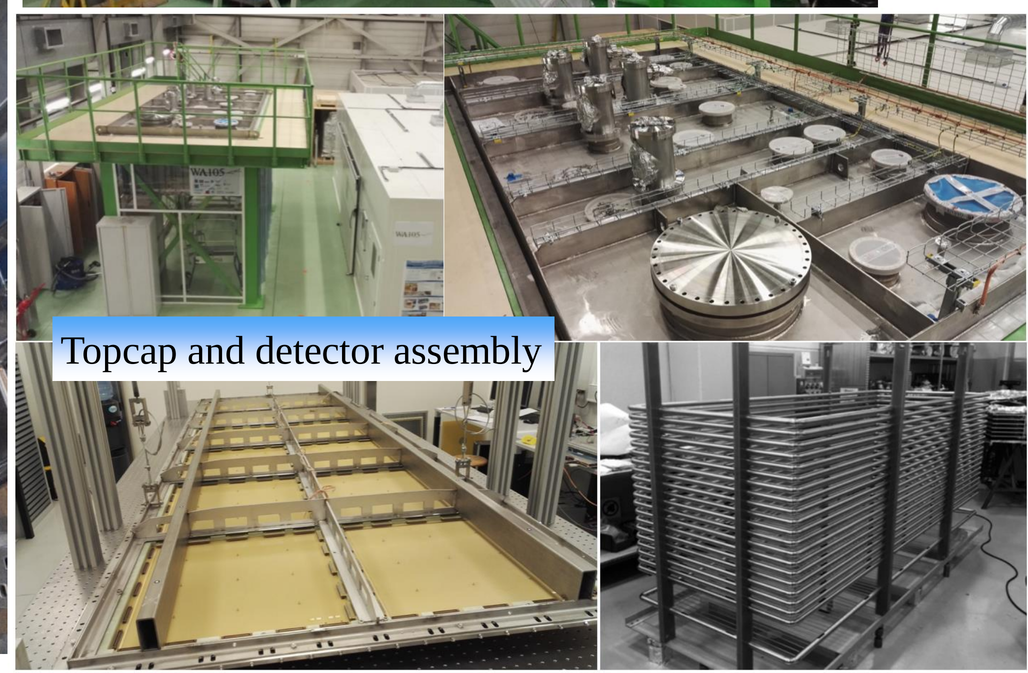
Pilot detector: 3x1x1m^3



3x1x1 cryostat







LEM-Anodes production: assembly chain at CERN for WA105

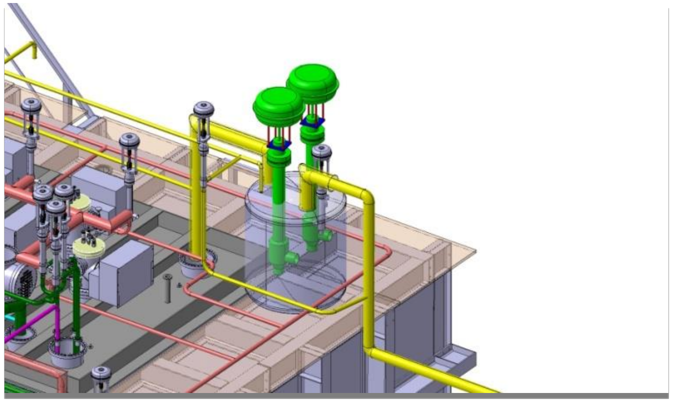
Status of the cryogenic installation

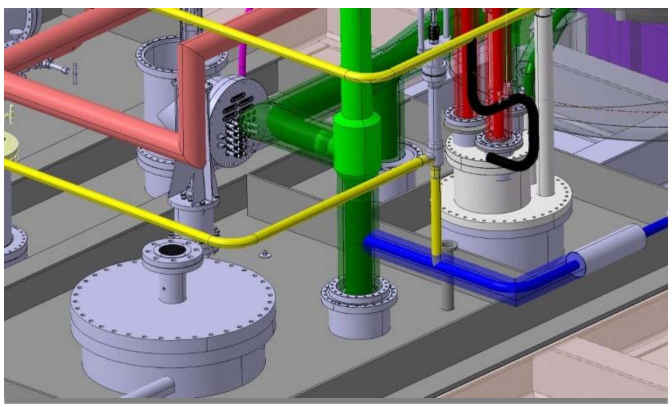
✓Invitation to tender sent to 6 companies in December. Some already answered.

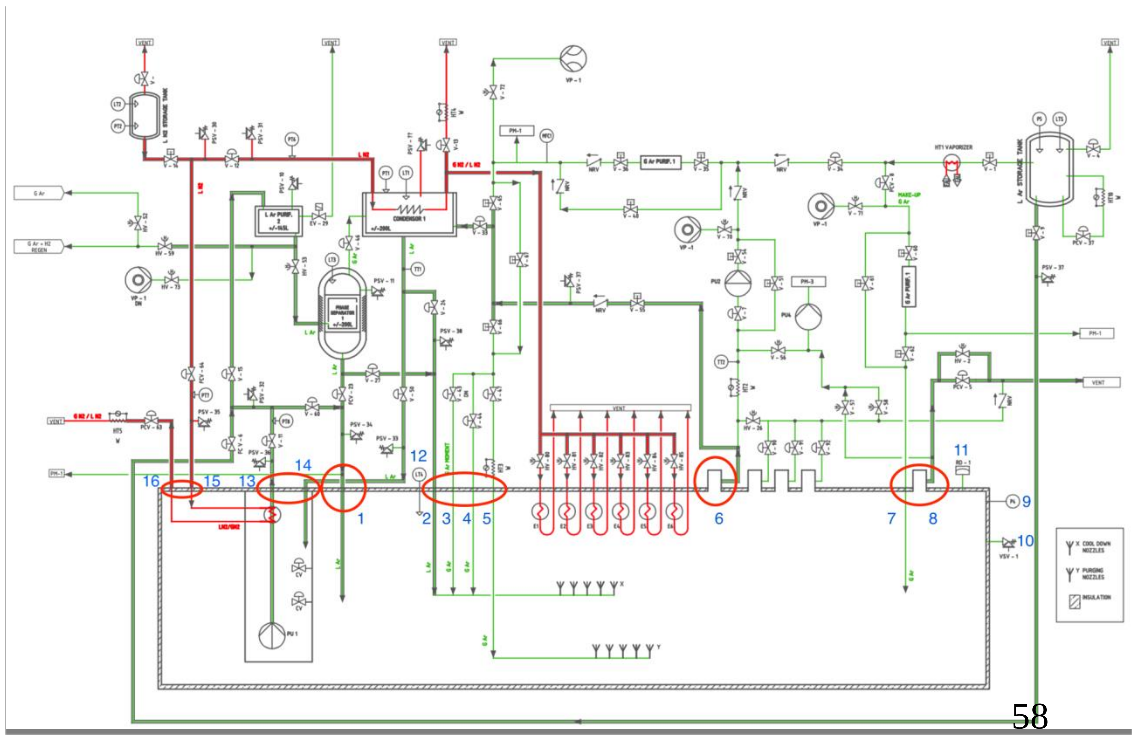
Plan cold operation fall 2016.

✓Ordered and received most of the parts for a "gas only" test.

✓Trace analysers (N_2,O_2, H_2O) all in the lab and tested

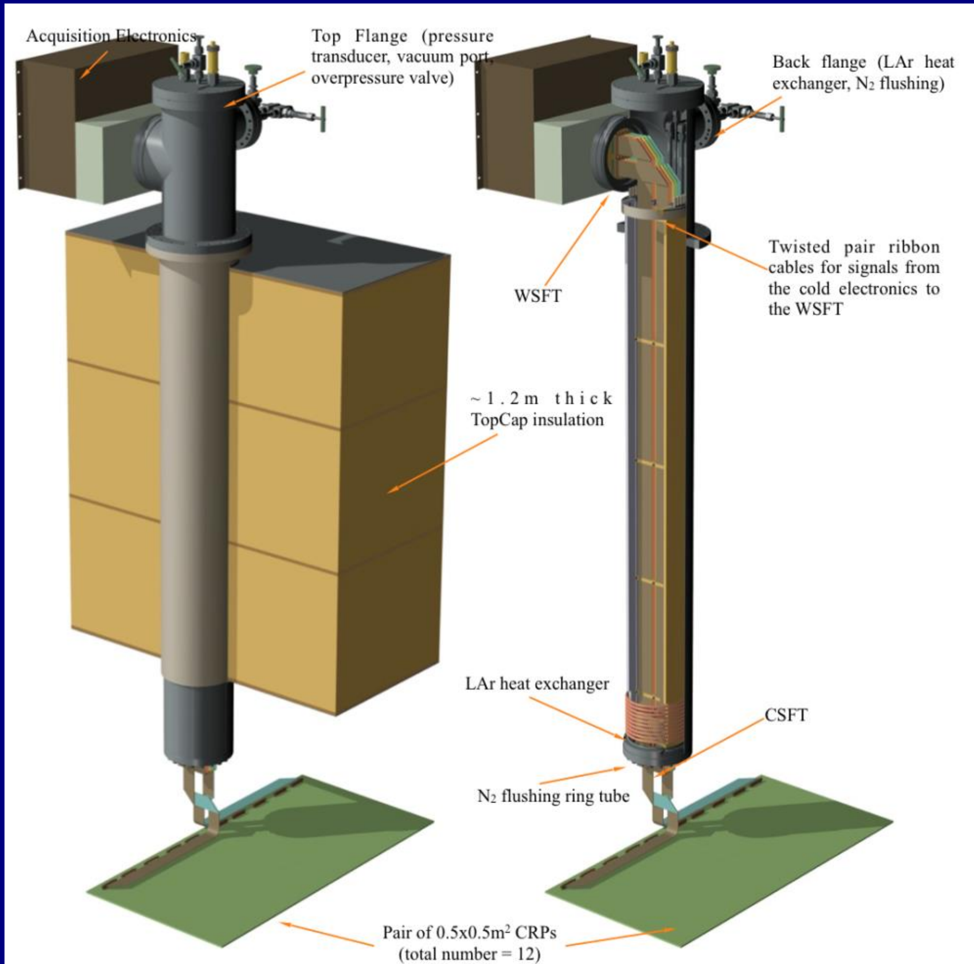


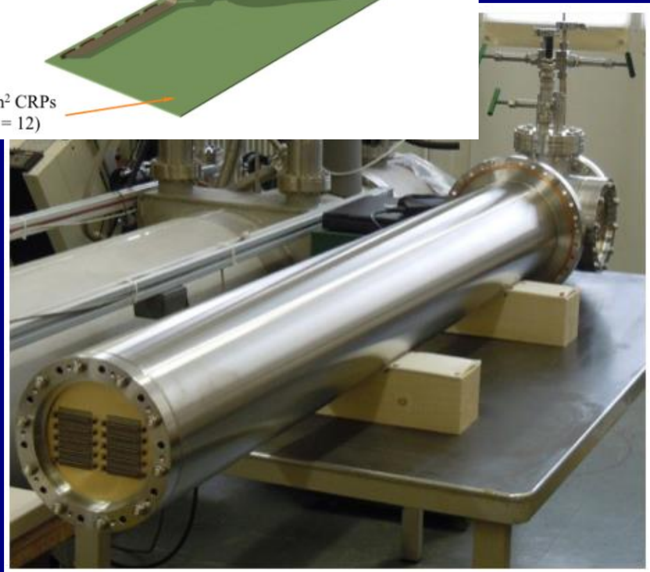


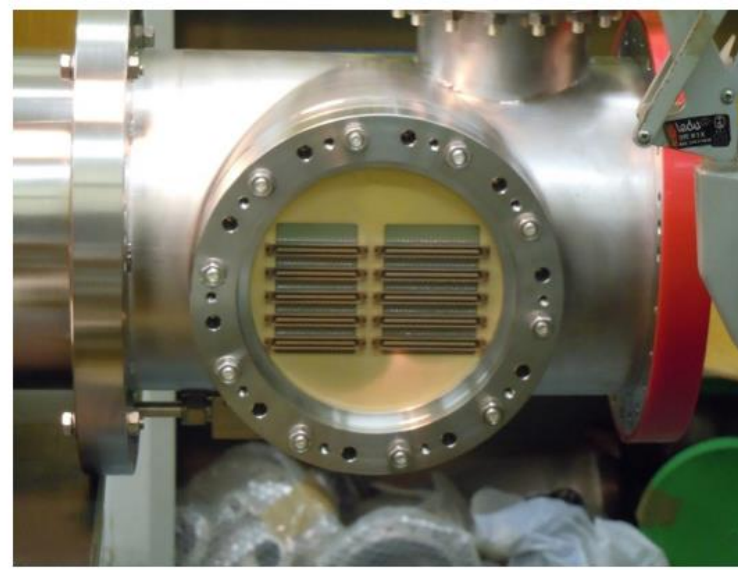


WA105 signal chimneys

- Fully engineered signal chimneys for accessible electronics (mitigate risks on long time scale)
- Inert N2 atmosphere, active cooling around the cards 11.5 W/640 ch + extra heat input from flat cables (6 W)
- Chimneys in pre-production for 3x1x1 prototype at CERN (320 ch.)
- Insertion/extraction of FE cards tested







Online storage and processing

Online storage

- The B/E boards are hosted into Event Building Workstations transferring the data at 40 Gbps to the local storage/processing system (two links per WS)

- A standard 10/40 Gbps switch is used to interconnect all these elements and to send the data to be permanently stored to the CERN EOS/CASTOR system.

- The online storage/processing system fulfills the CERN requirements of a few days equivalent data storage local buffer for the experiment DAQ system.

- The online processing/storage system includes 15 disks servers (Object Storage Servers – OSS, DELL R730xd for the reference design) for a total capacity of the order of 1 PB, 2 redundant MetaData Servers (MDS, DELL R630), 1 configuration server (DELL R430) and 1 processing farm (DELL M1000e with 16 M630 blades leading to 384 cores).

- Final system software configuration under evaluation with data writing/access tests at the CCIN2P3 (LYON computing center), first application of a reduced scale system on 3x1x1

- Software for data transfer at CERN based on IT standards EOS/CASTOR scripts

DELL-based solution : configuration

storage servers :
* 15 R730XD (storage servers) including :
* 16 disks 6To
* 32Go RAM
* 2 disks system RAID 1, 300 Go 10k
* 1 network card Intel X540 double port 10 GB
* 4 years extended guarantee (D+1 intervention)
* 2 processors Intel Xeon E5-2609 v3
* raid H730P
* Rails with management arm
* double power supply

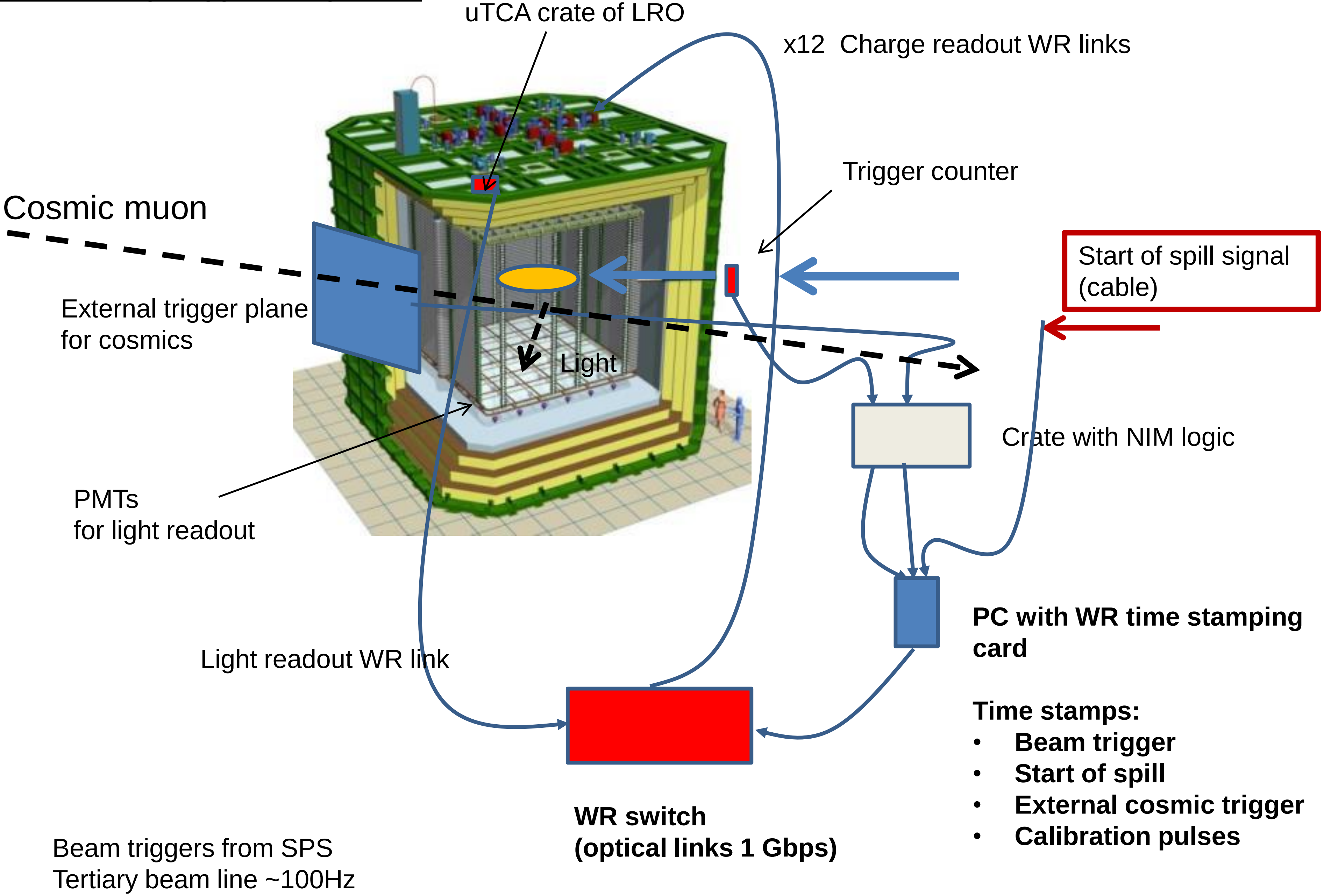
metadata servers (MDS) :
* 2 R630 (metadata servers), including :
* 2 disks 200 Go SSD SAS Mix Use MLC 12Gb/s
* 2 processors Intel Xeon E5-2630 v3
* 32Go DDR4
* RAID H730p
* network : Intel X540 2 ports 10 Gb
* 4 years extended guarantee (D+1 intervention)
* Rails with management arm
* double power supply

configuration server :
* 1 R430 (configuration server)
* 1 processor E5-2603 v3
* RAID H730
* 2 hard disks 500 Go Nearline SAS 6 Gbps 7,2k
* 16 Go DDR4
* Rails with management arm
* double power supply

Offline computing farm: 16*24 = 384 cores
* 1 blade center PowerEdge M1000e with 16 lames M630, each including :
  * 128Go DDR4
  * 2 processors Intel Xeon E5-2670 v3
  * 4 years extended guarantee (D+1 intervention)
  * 2 hard disks 500 Go SATA 7200 Tpm
  * netwok Intel X540 10 Gb

Switch Force10, S4820T (see next slide) :
* 48 x 10GbaseT ports
* 4 x 40G QSFP+ ports
* 1 x AC PSU
* 2 fans

DAQ timing-trigger integration



- White Rabbit developed for the synchronization of CERN accelerators chain offers sub-ns synchronization over ~10 km distance, based on PTP + synchronous ethernet scheme previously developed in 2008 (http://arxiv.org/abs/0906.2325)

- White Rabbit chains can be now set up with commercial components:
  - Network based on Grand Master switch
  - Time tagging cards for external triggers
  - Slave nodes in piggy back configuration to interface to uTCA

- Transmission of synchronization and trigger data over the WR network + clock

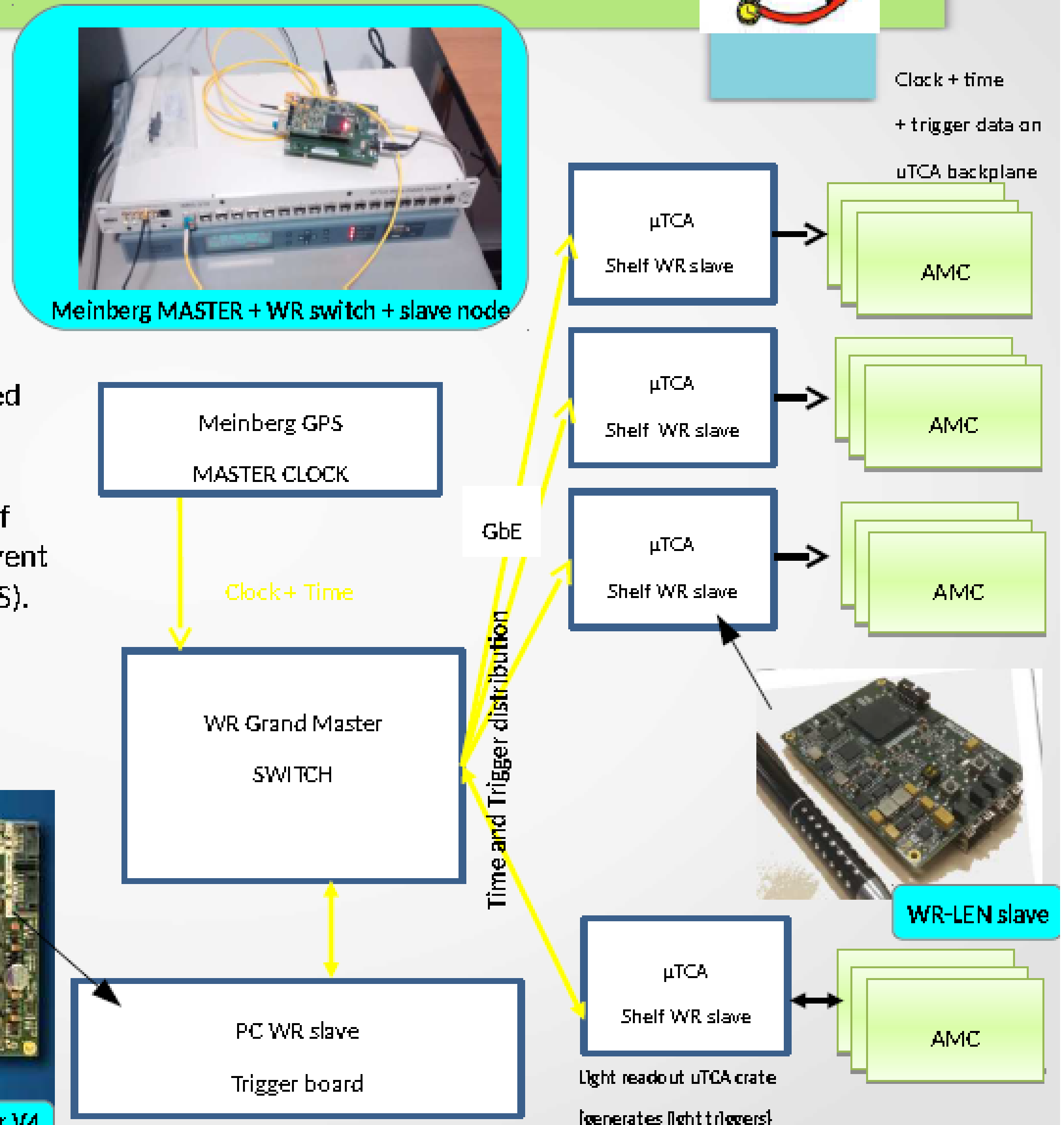
- Slave uTCA nodes propagate clock + sync + trigger planes on the uTCA backplane so that the FE digitization cards are aligned in sampling, know absolute time and can compare it with the one of transmitted triggers

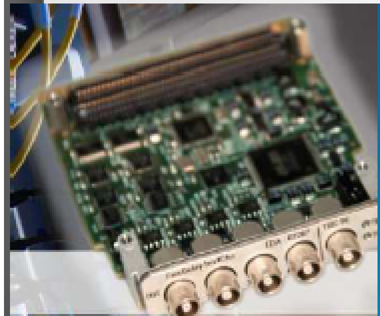
- FE knows spill time and off spill time and can set up different operation modes

- Trigger timestamps may be created by beam counters, cosmic counters, light readout system in uTCA

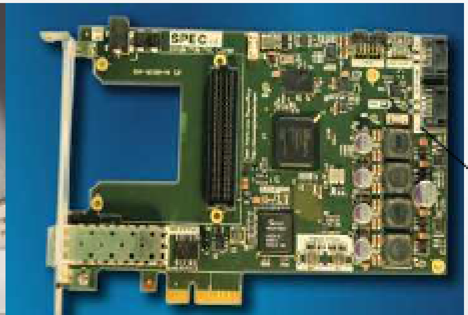
White Rabbit scheme

- WR is an evolution of the synchronization scheme based on **synchronous Ethernet + PTP** which was previously developed at IPNL in 2008: http://arxiv.org/abs/0906.2325
- WR is accurate at sub-ns level, enough to align the 400ns samples
- At the level of the charge readout DAQ is distributed the beam trigger timestamp.
- Trigger time info starts and closes the acquisition of the samples belonging to the drift window of an event in each AMC (important when operating without ZS).
- The beam trigger can be time-stamped on the PC trigger board and be broadcasted to the microTCA crates via the WR time distribution network



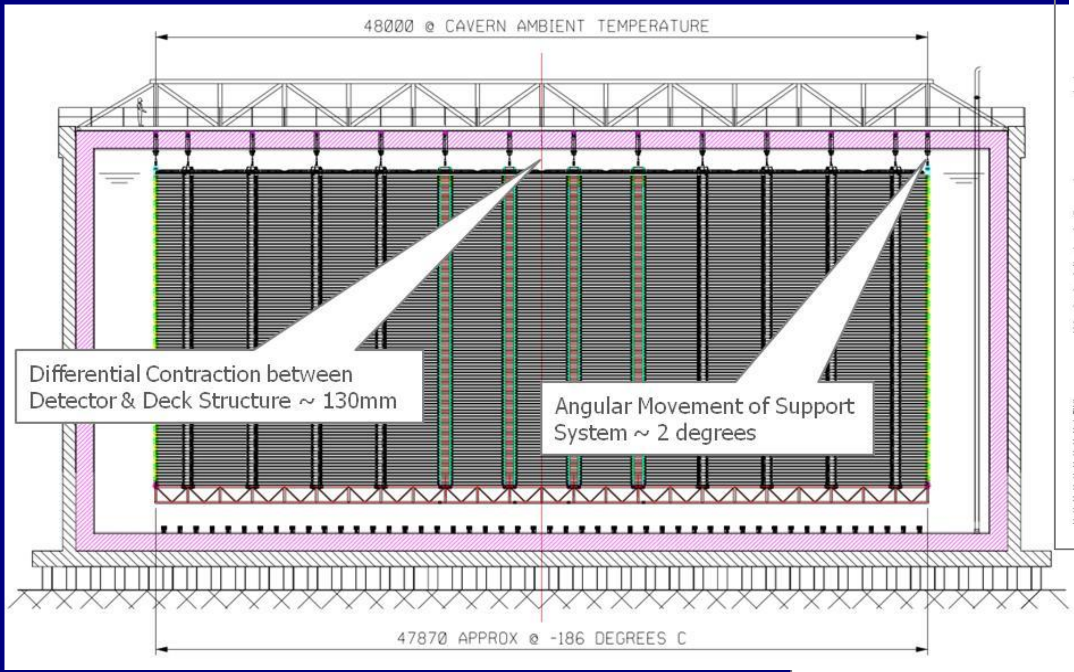


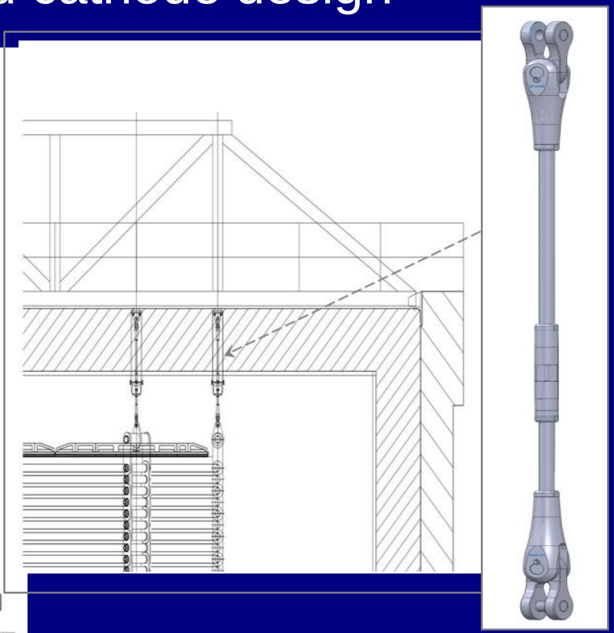
FMC Fine Delay 1 ns 4 channels



SPEC FMC PCIe carrier V4

LBNO suspended field cage (20 m drift) and cathode design

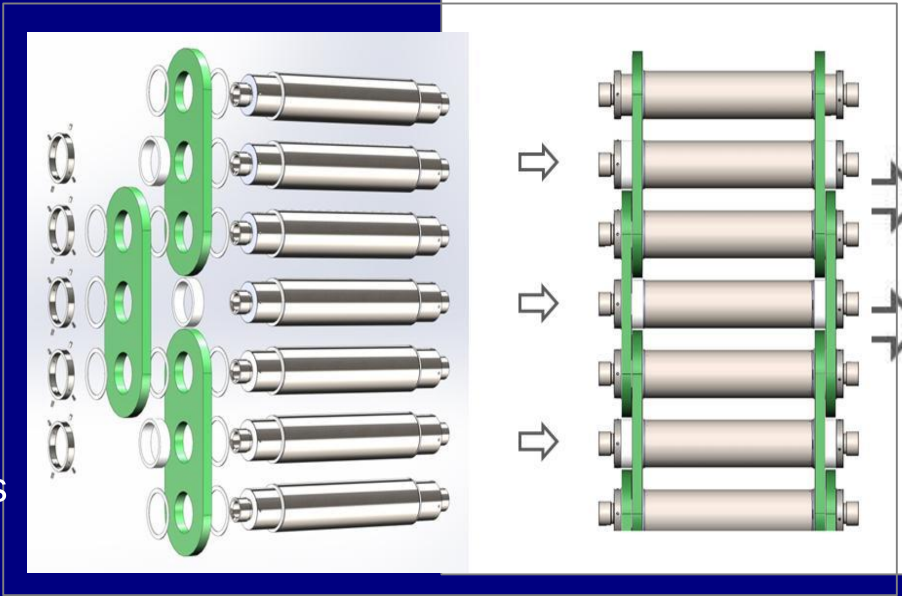


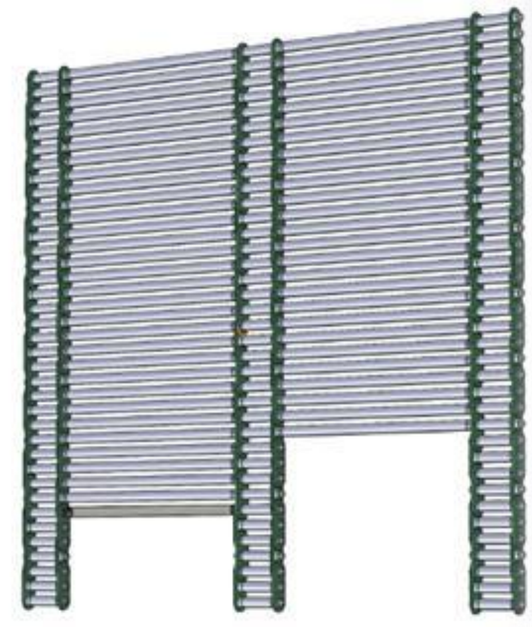


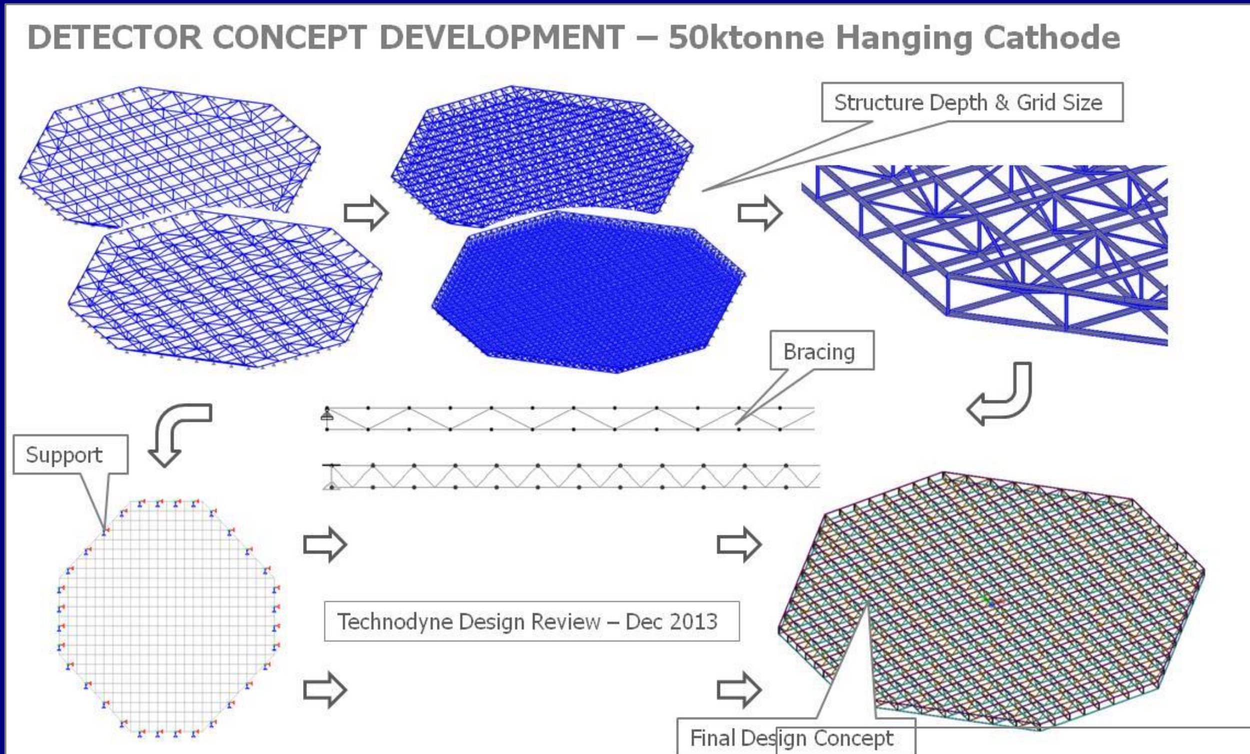
Field cage rings:

Stainless steel pipes 316L 139.7 mm diameter EN 10217-7
200 mm spacing

Hanging columns chains G10CR







50 Kton LBNO cathode design (octagonal structure 48 m span):

Modular elements built of 316L pipes

Max electric field 50 kV/cm

Max sagging over 48 m: 141 mm

→ Simplified structure for DUNE rectangular structure with 12 m minimal span