AIDA 2020

WP8/NA7 Large scale cryogenic liquid detectors

AIDA 2020 Annual Meeting, Paris 6/4/2017

WP8 Report

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Cryogenic Detectors NA

- **Topics and corresponding deliverables: (detector technologies)**
  - ➞ **Task 8.2 Purification and monitoring (Task leader UCL)**
  - ➞ **Task 8.3 Charge readout and double-phase (Task leader IPNL)**
  - ➞ **Task 8.4 Light readout (Task leader Ciemat)**
  - ➞ **Task 8.5 Very high voltage (Task leader ETHZ)**
  - ➞ **Task 8.6 Magnetization (Task leader Glasgow)**
- These 5 topics are identically structured in terms of goals and deliverables, following the guidelines presented above. They corresponds to the frontier developments in the field.
- Collaborating institutes: CIEMAT, CEA, LHEP Bern, ETHZ, Genève, Glasgow, IN2P3 (IPNL, APC, LPNHE, LAPP), UCL; strong connections with the US groups involved in the common project DUNE

→ Worldwide impact on the community working on large cryogenic detectors

Cryogenic detectors Networking Activity:

Basic concept and modus operandi:

- **Benefit from the R&D infrastructure at CERN for WA105** and of other infrastructures available in different laboratories (piggy-back)
- Integrate the hardware available in these infrastructures in a networking activity with dedicated personnel (→main requests to AIDA II in terms of manpower: postdocs contracts)
- Matching funds from other personnel involved in the activities and existing equipment

Goals:

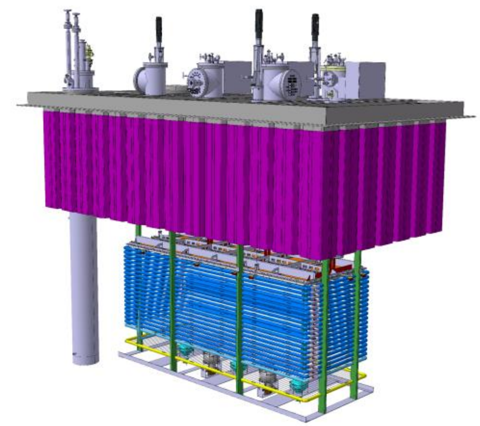
- Networking and exchange among the existing EU expert groups involved in the development of the most innovative experimental techniques
- Reviewing and reporting on some crucial development aspects for large cryogenic detectors.
- Sharing of information and tools (dissemination) in the community and creation of a state of the art common knowledge of the field broadly applicable in future projects

AIDA II support:

- 5 Postdoc contracts of 2 years each for the 5 sub-tasks of WP8 (profiting of ongoing developments on WA105 and R&D on small prototypes present in collaborating laboratories, help in organizing the networking and exchange among the groups and in producing a reporting on some crucial development aspects for the cryogenic detectors).
- Travel money for meetings of the NA

Cryogenic Detectors NA

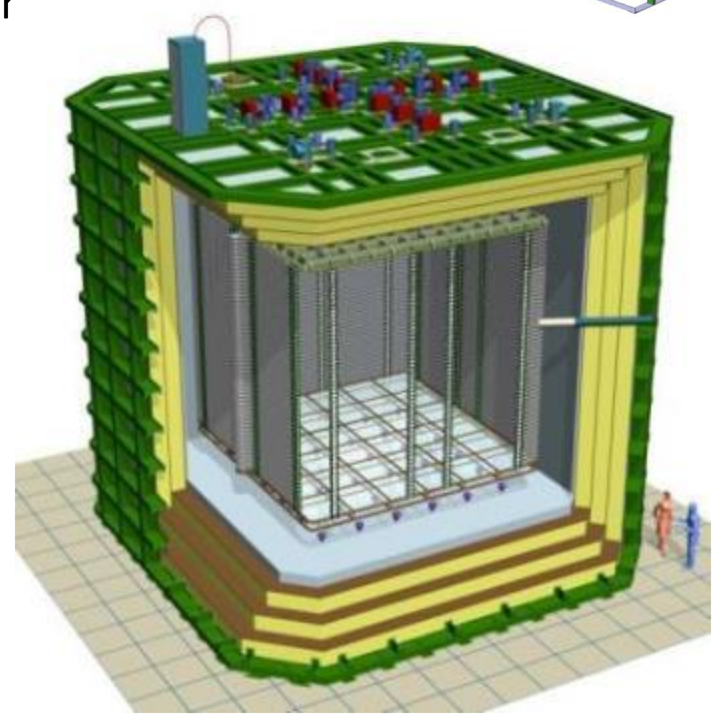
Common infrastructures of the WP8 for the R&D activities at CERN supported by the CERN Neutrino Platform



- 3x1x1 m^3 Dual-phase WA105 Pilot detector

- 6x6x6 m^3 Dual-phase Demonstrator (WA105/NP02/dual-phase ProtoDUNE)

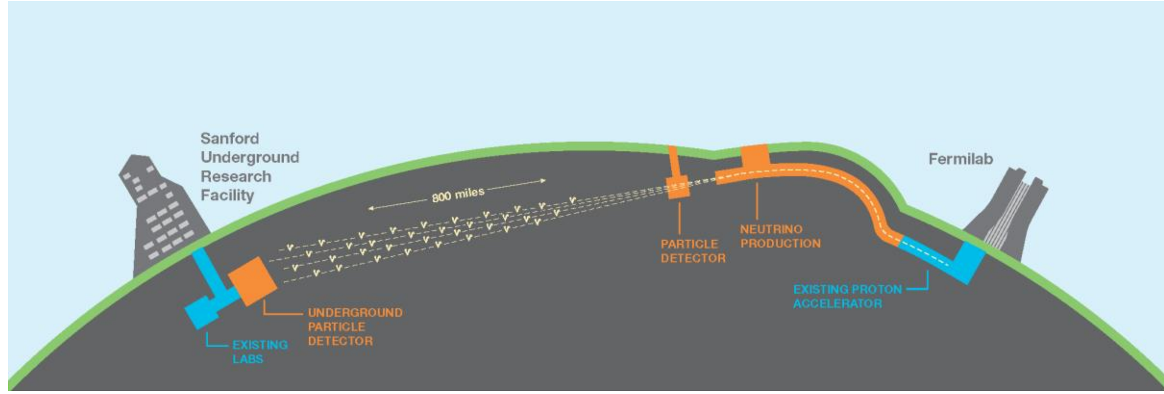
Data taking with charged hadrons and electrons bear 2018



- Baby MIND prototype (NP05)

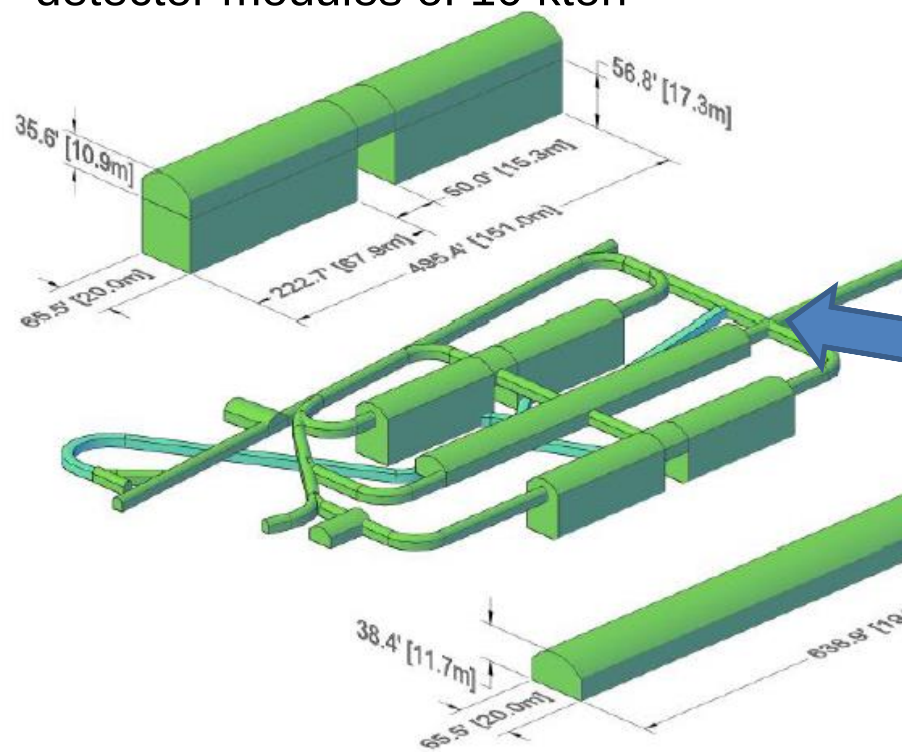
LBNF-DUNE project:

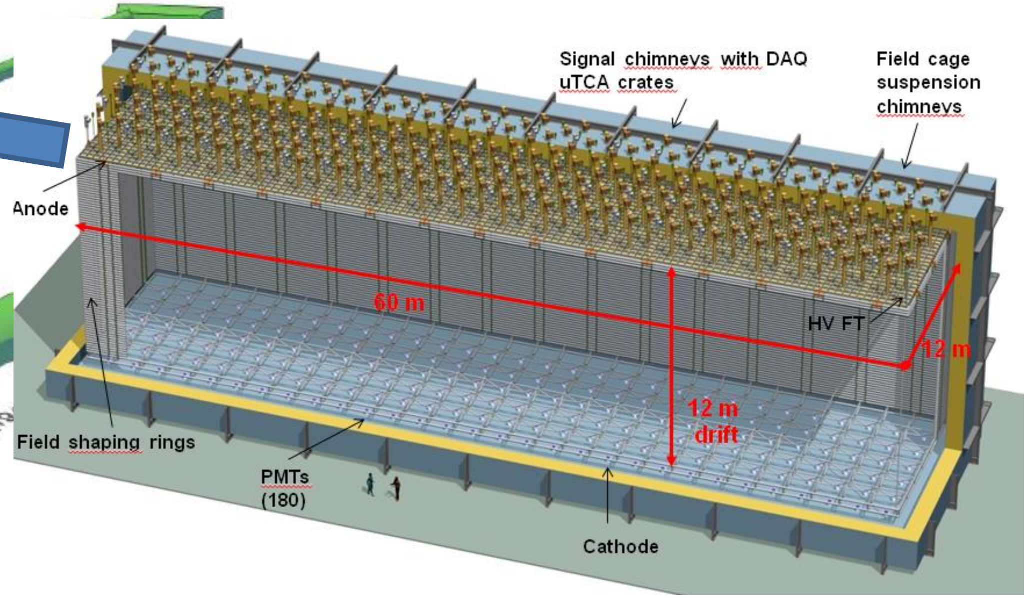
1.2 MW neutrino beam from FNAL to SURF underground laboratory with 40 kton Liquid Argon detector.



4 underground caverns with detector modules of 10 kton

dual-phase 10kton module. Active volume 12x12x60 m^3

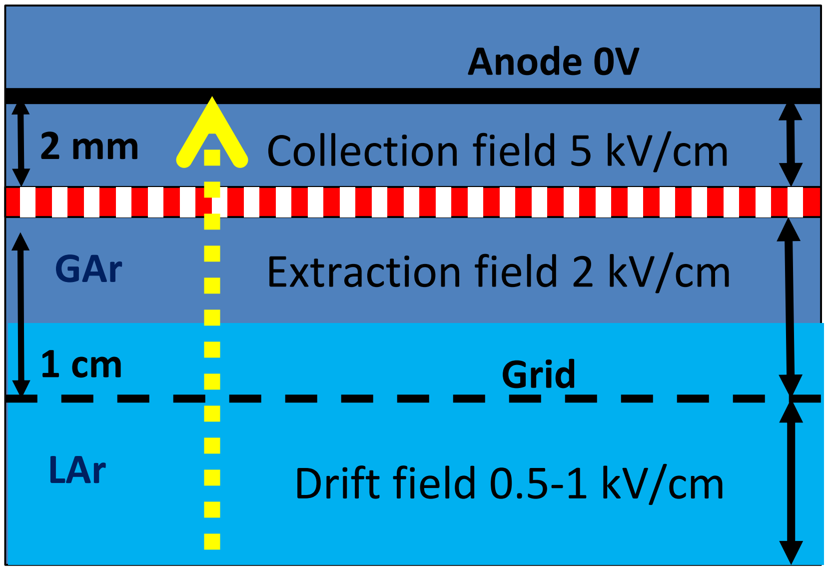




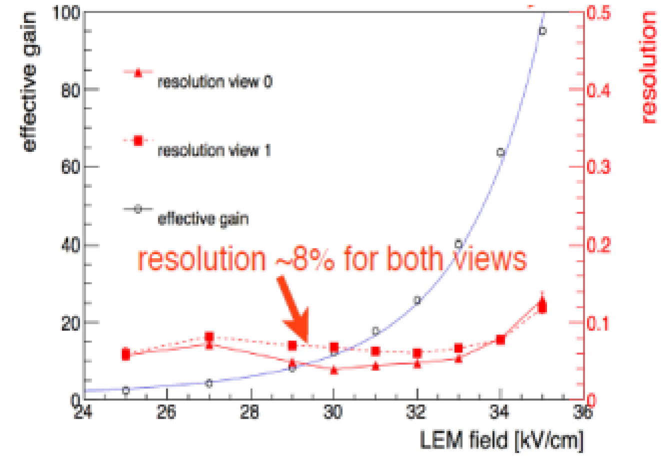
Dual-phase readout (Task 3) :

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)

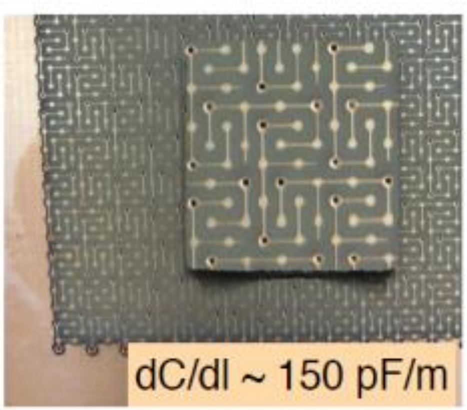
Tunable gain (~20 minimum), two symmetric collection views, coupling to cold electronics

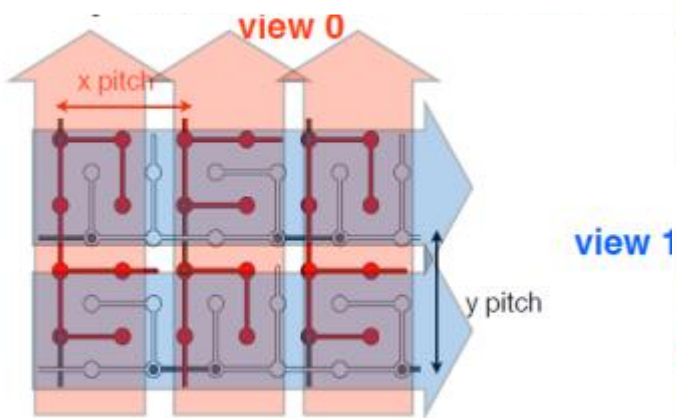


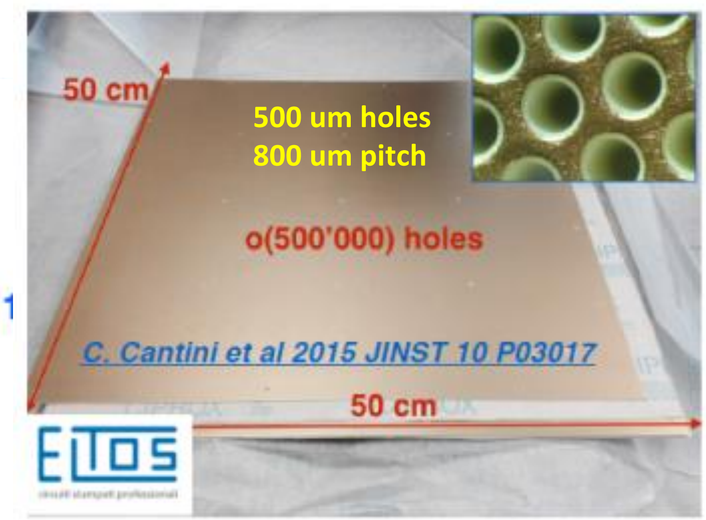
LEM (1mm)
25-35 kV/cm



50x50 cm² LEM

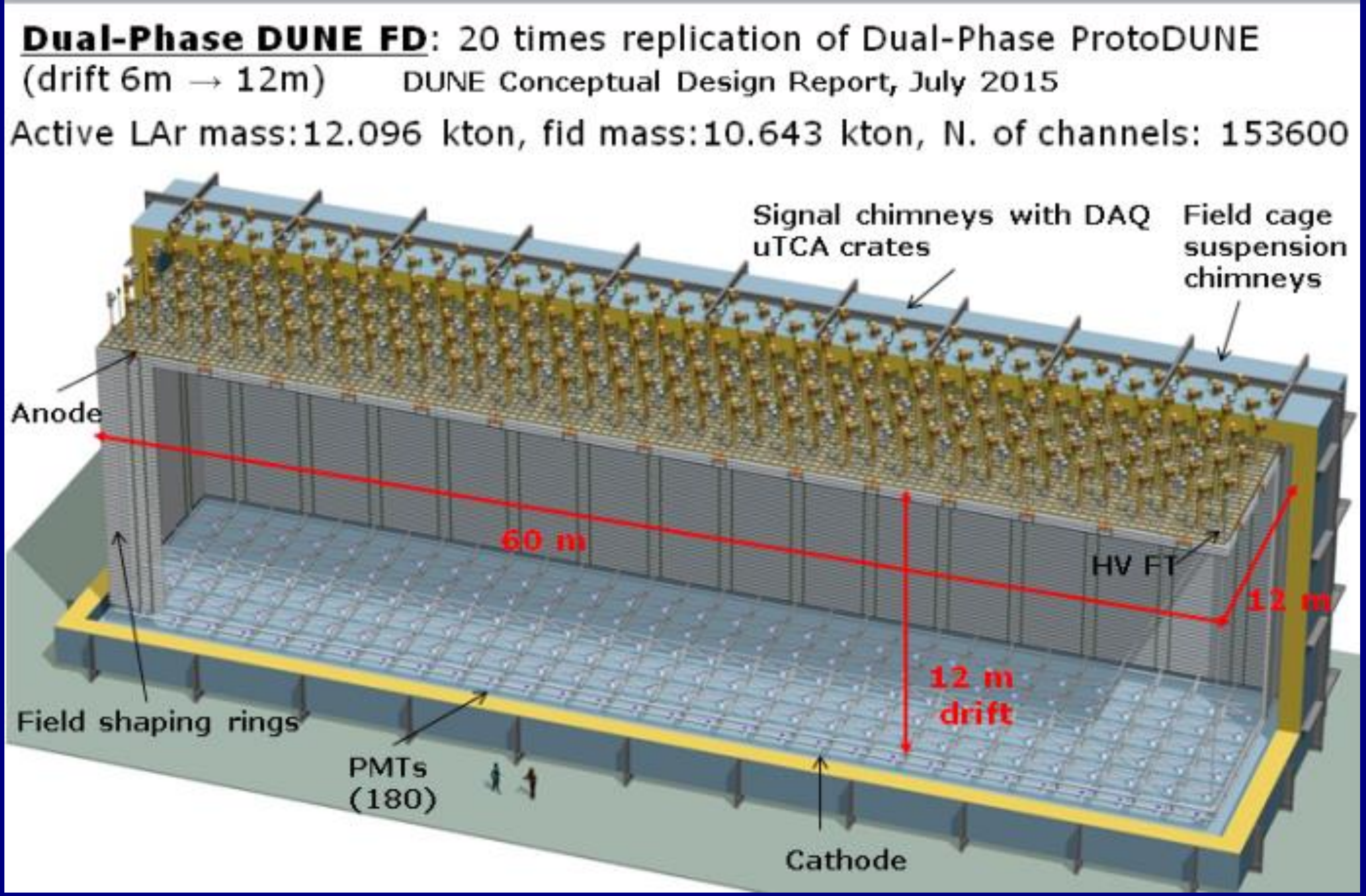






Dual-phase 10 kton FD module

- 80 CRP units
- 60 field shaping rings
- 240 signal FT chimneys
- 240 suspension chimneys
- 180 PMTs
- 153600 readout channels

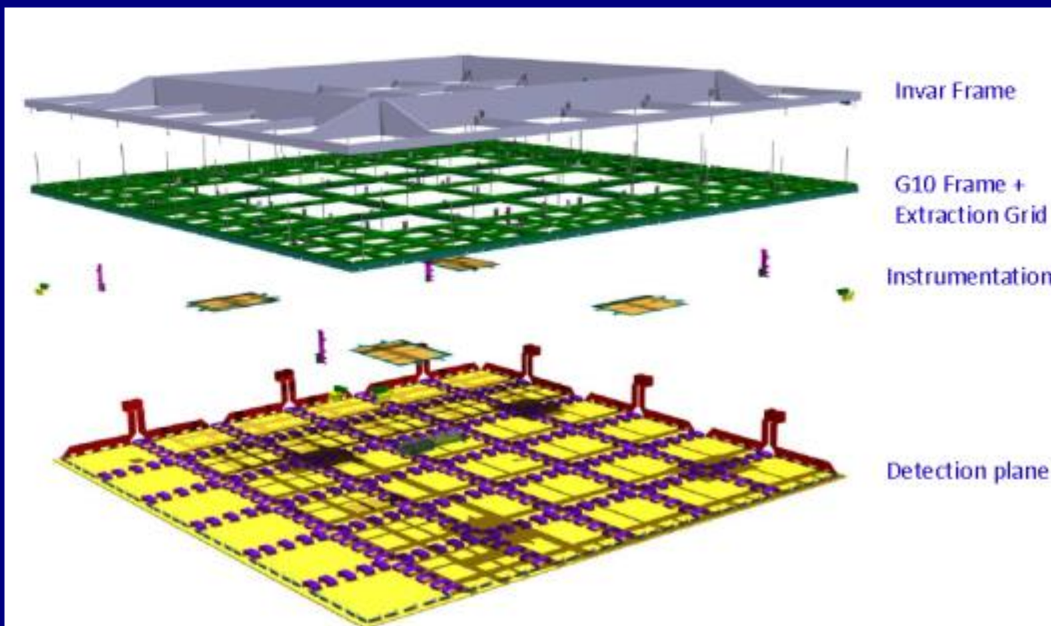


<u>Advantages of double-phase design:</u>

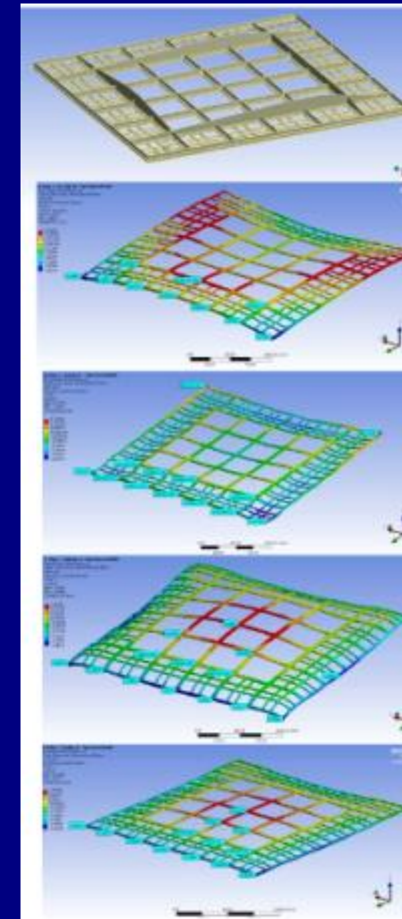
- Anode with 2 collection (X, Y) views (no induction views), no ambiguities
- Strips pitch 3.125 mm, 3 m length
- Tunable gain in gas phase (20-100), high S/N ratio for m.i.p. > 100, <100 KeV threshold, min. purity requirement 3ms → operative margins vs purity, noise
- Long drift projective geometry: 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

3x3 m^2 CRPs integrating the LEM-anode sandwiches (50x50 cm^2) and their suspension feedthroughs

→ Invar frame + decoupling mechanisms in assembly in order to ensure planarity conditions +-0.5 mm (gravity, temperature gradient) over the 3x3 m^2 surface which incorporates composite materials and ensure minimal dead space in between CRPs



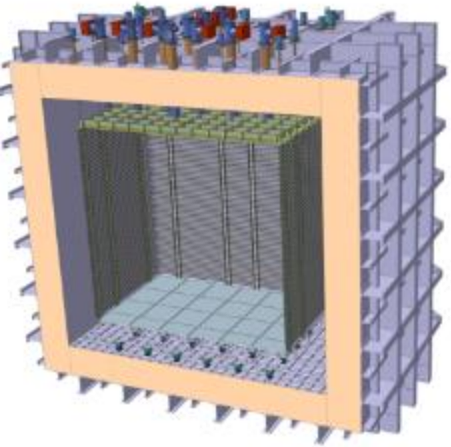
→See talks by B. Aimard (CRPs) and A. Delbart (LEM-anodes production) in DP parallel session

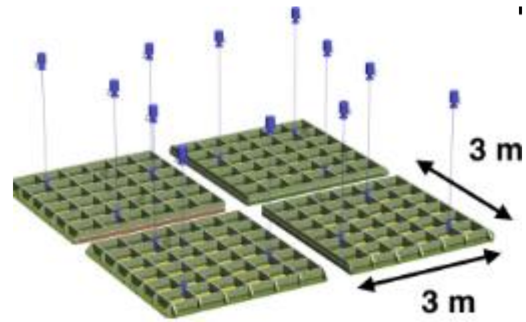


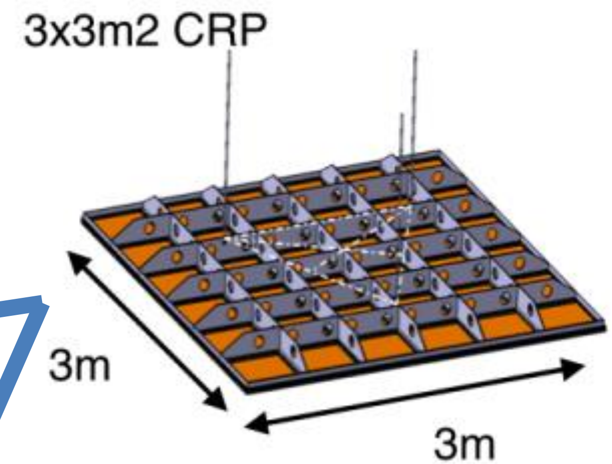
CRP mechanical structure design:

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

The Dual-Phase ProtoDUNE/WA105 6x6x6 m^3 detector is built out of the same **3x3m² Charge Readout Plane units (CRP)** foreseen for the 10 kton Dual-Phase DUNE Far Detector (same QA/QC and installation chains)



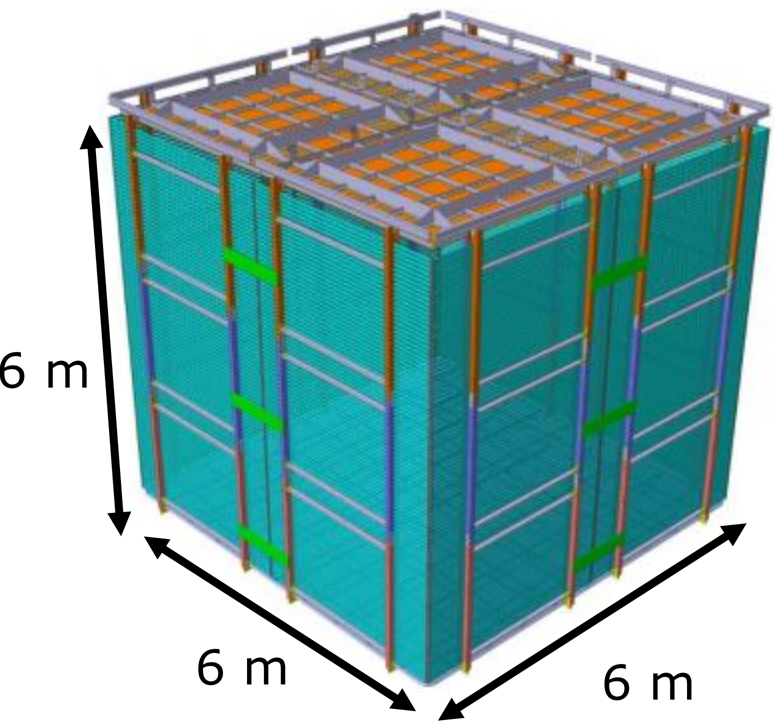


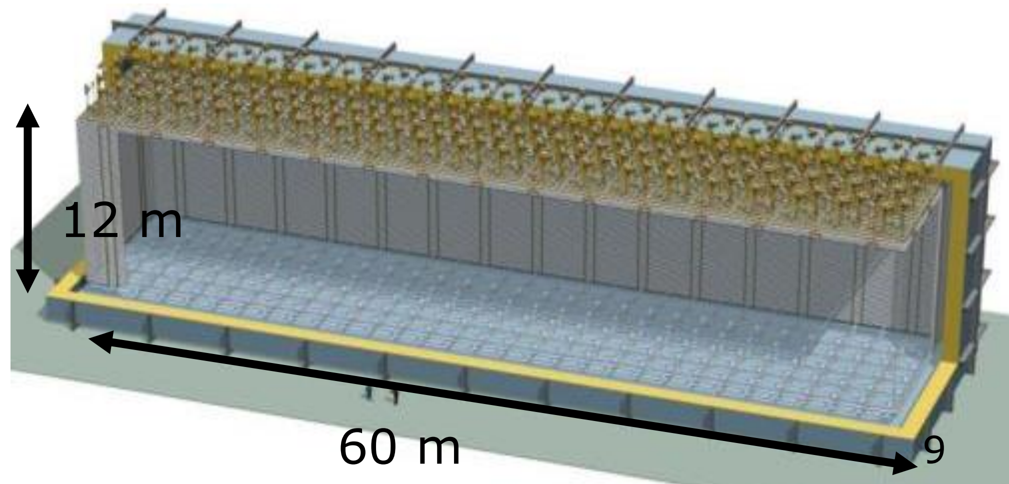


1920 channels/CRP
Accessible cold electronics in chimney

WA105: 4 CRP

10 kton: 80 CRP

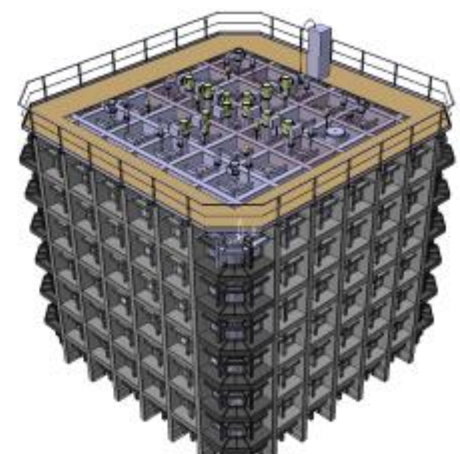




- Extension of North Area completed in 2016. Infrastructure in advanced state of installation. Beam-line construction started

- Cryostat construction completed for the steel exoskeleton, installation of insulation panels started

→ Available for WA105/ProtoDUNE-DP detector installation in June 2017

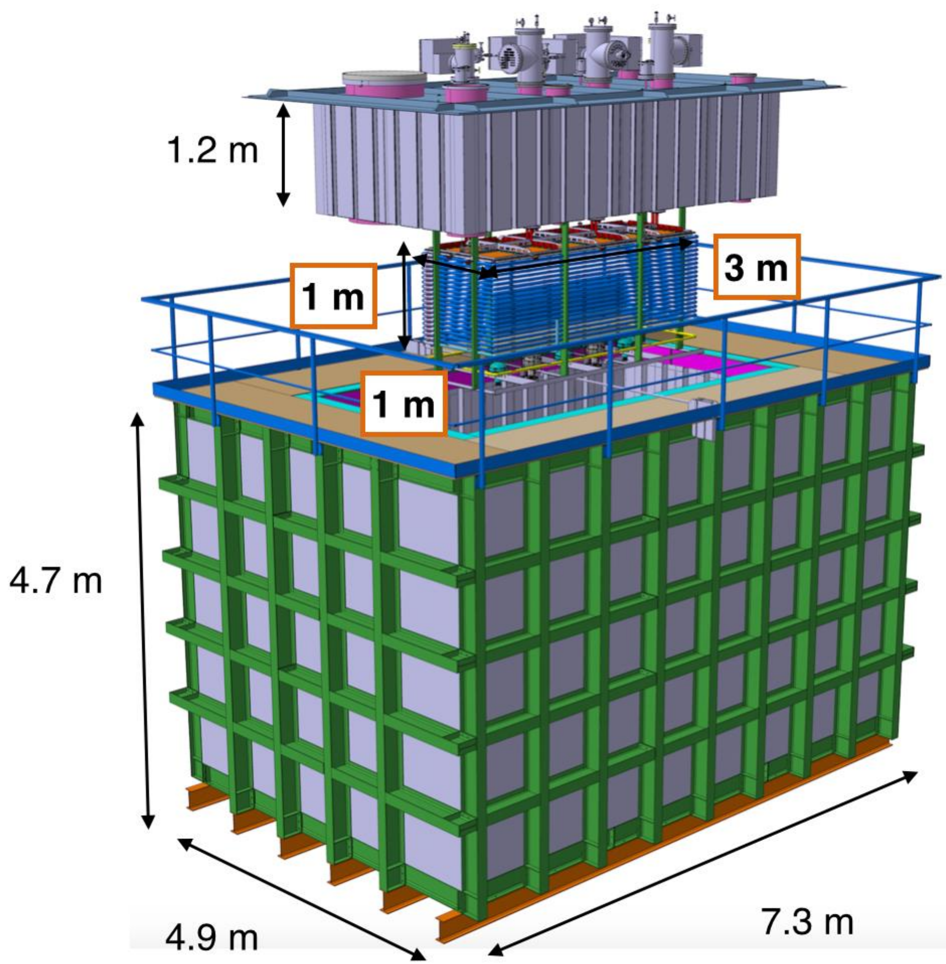


- Detector executive design completed in November 2016. Production/installation activities started. Detector installation inside the cryostat expected to be completed by February, 2018

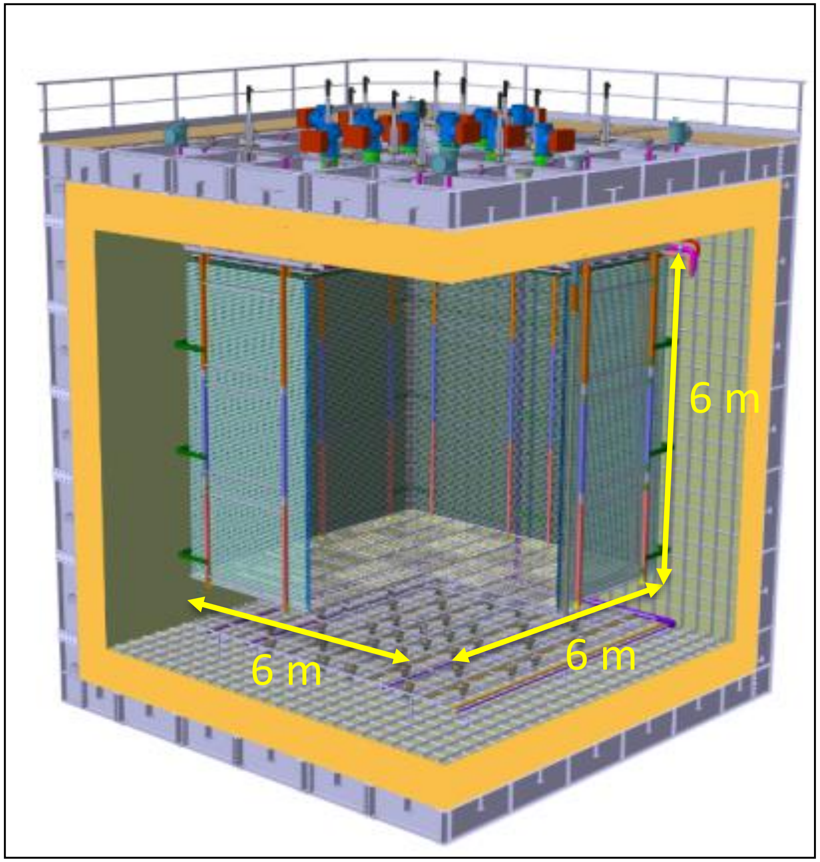
Cryogenic Detectors NA

two detectors closely linked

3x1x1m^3
(3x1x1 m^3 active 24 ton LAr total)



Dual-Phase ProtoDUNE / WA105
(6x6x6 m^3 active 700 ton LAr total)



Cryogenic Detectors NA

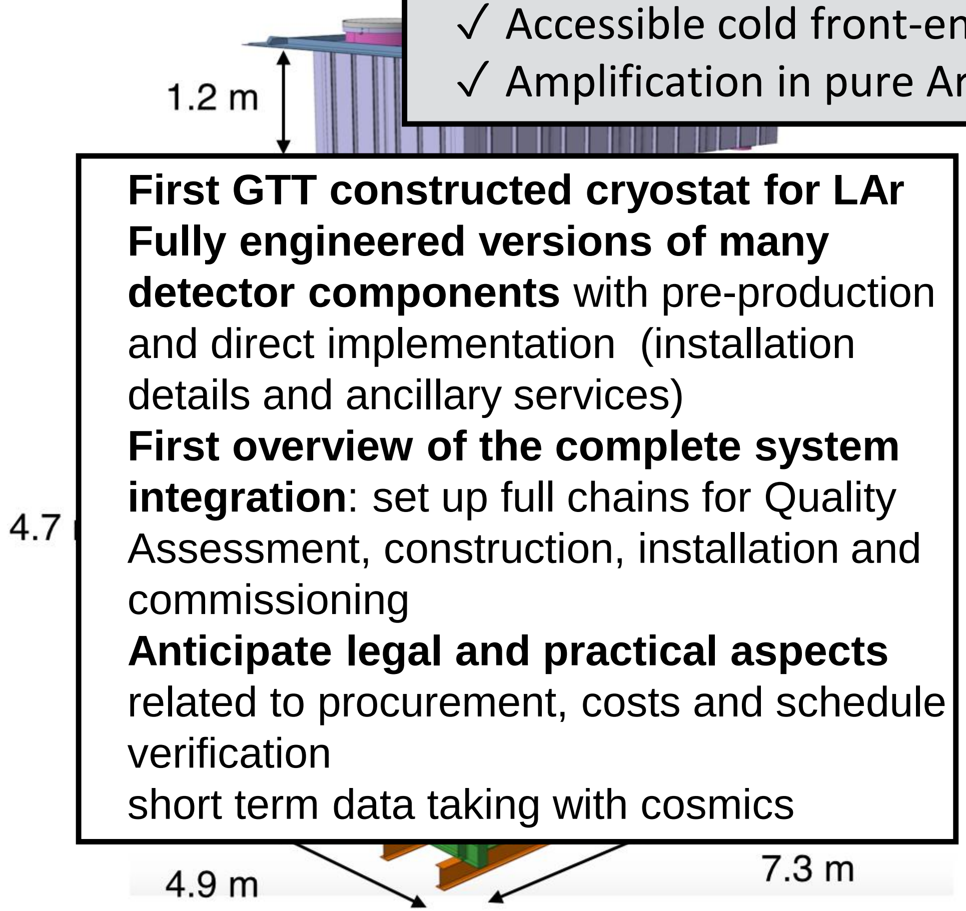
two detectors closely linked

(3x1x1 m^3

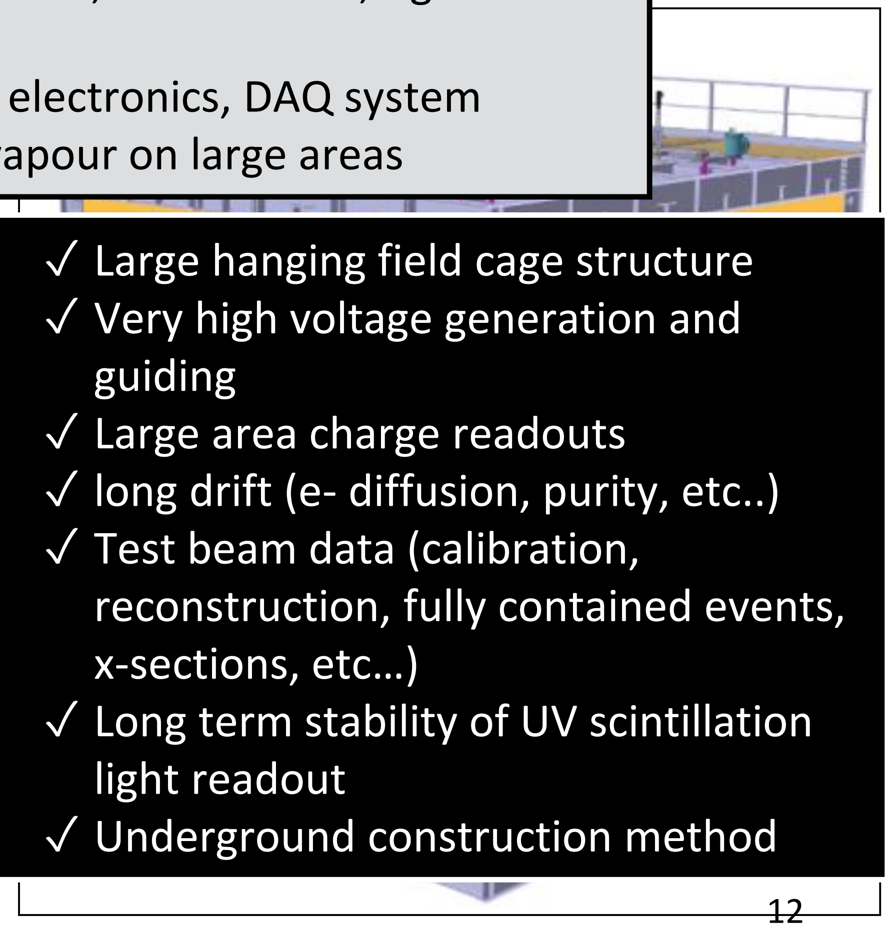
VA105

r total)

- ✓ LEMs and anode: design, purchase, cleaning and QA
- ✓ Chimneys, FT and slow control sensors
- ✓ Membrane tank: legal aspects, construction, tightness and QA methods
- ✓ Accessible cold front-end electronics, DAQ system
- ✓ Amplification in pure Ar vapour on large areas



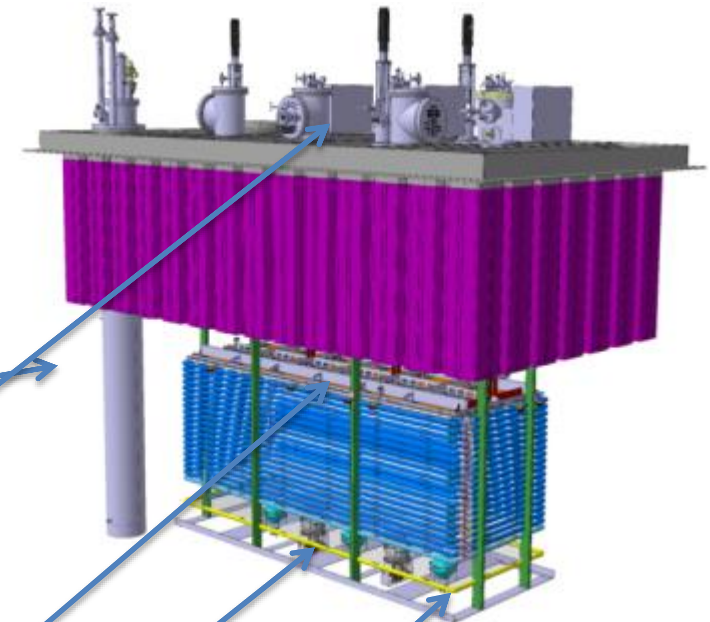
First GTT constructed cryostat for LAr
Fully engineered versions of many detector components with pre-production and direct implementation (installation details and ancillary services)
First overview of the complete system integration: set up full chains for Quality Assessment, construction, installation and commissioning
Anticipate legal and practical aspects related to procurement, costs and schedule verification
short term data taking with cosmics



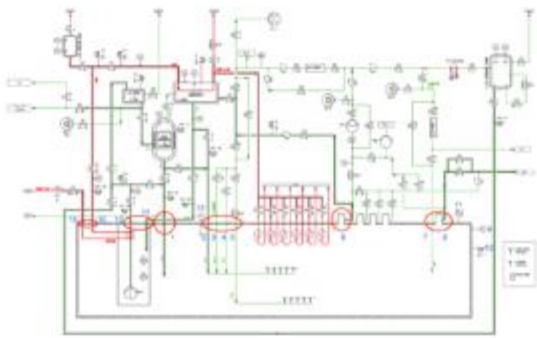
- ✓ Large hanging field cage structure
- ✓ Very high voltage generation and guiding
- ✓ Large area charge readouts
- ✓ long drift (e- diffusion, purity, etc..)
- ✓ Test beam data (calibration, reconstruction, fully contained events, x-sections, etc…)
- ✓ Long term stability of UV scintillation light readout
- ✓ Underground construction method

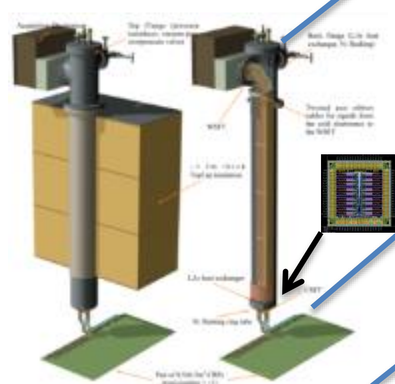
Cryogenic Detectors NA

The finalization of the 3x1x1 has been in 2016 a main playground for the WP8 activities



8.2 Purification and monitoring: design and test of purification circuit and purity monitors

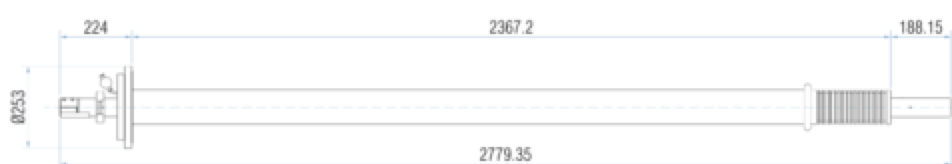




8.3 Charge readout: LEM characterization, electronics design and Charge Readout Plane design

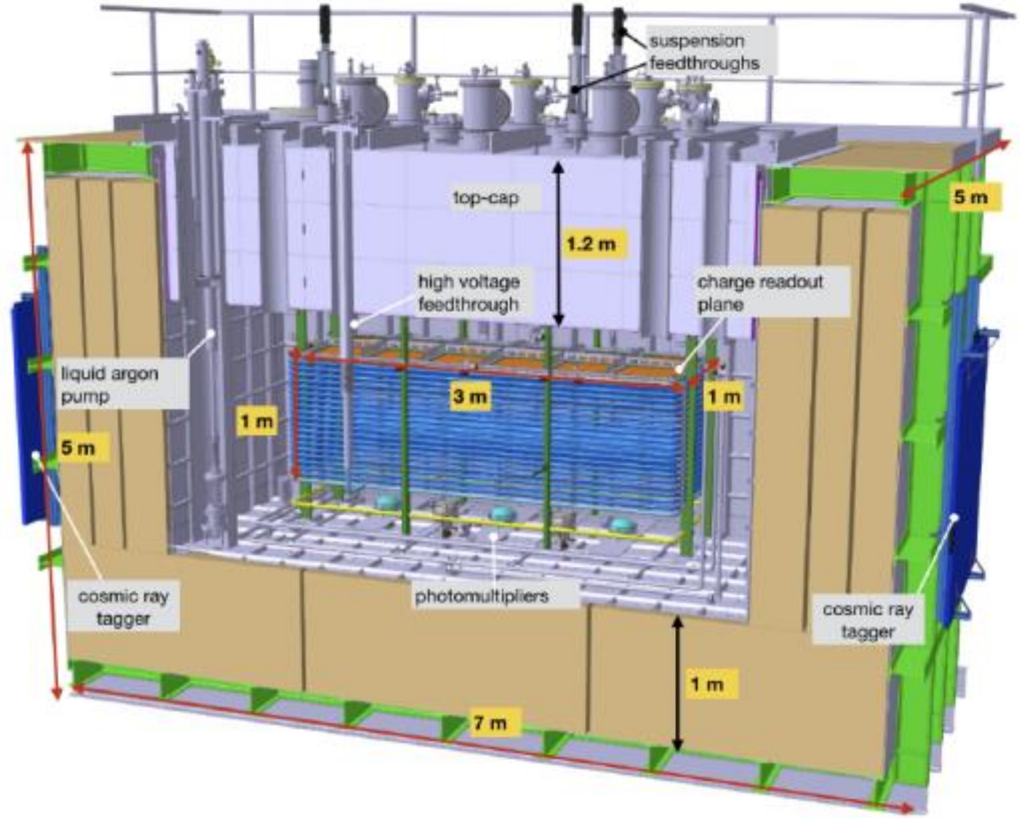
8.4 Light readout: test of different WLS configurations for the PMTs, digitization development

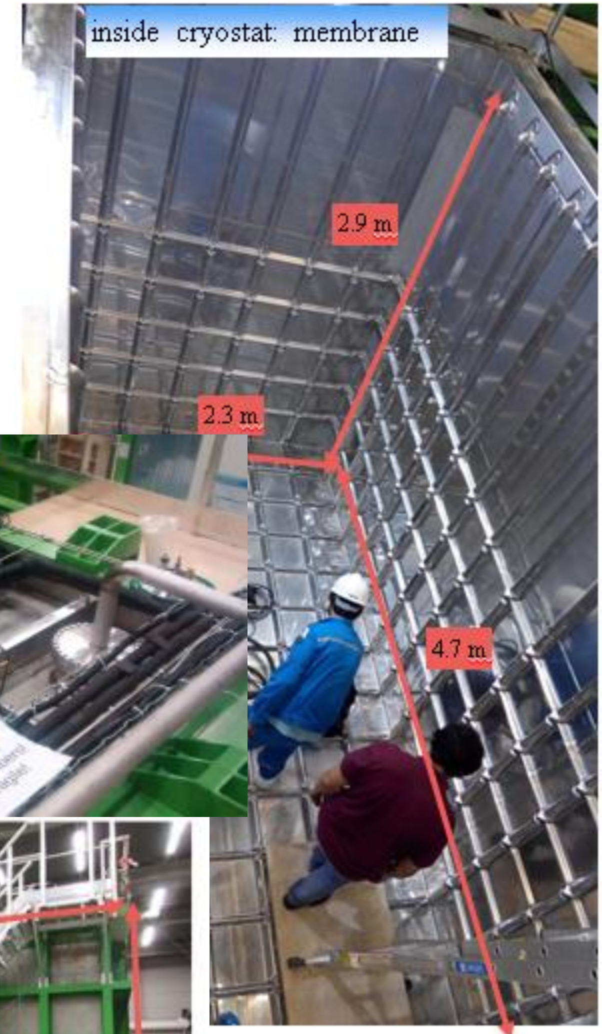
8.5 VHV developments: design and test of Power Supply and HV feedthrough exploitable up to 300 kV

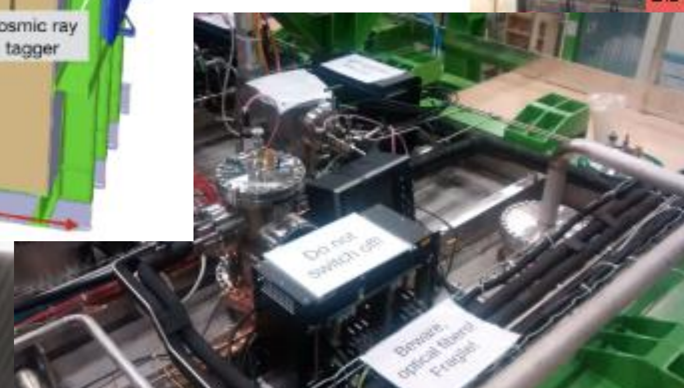


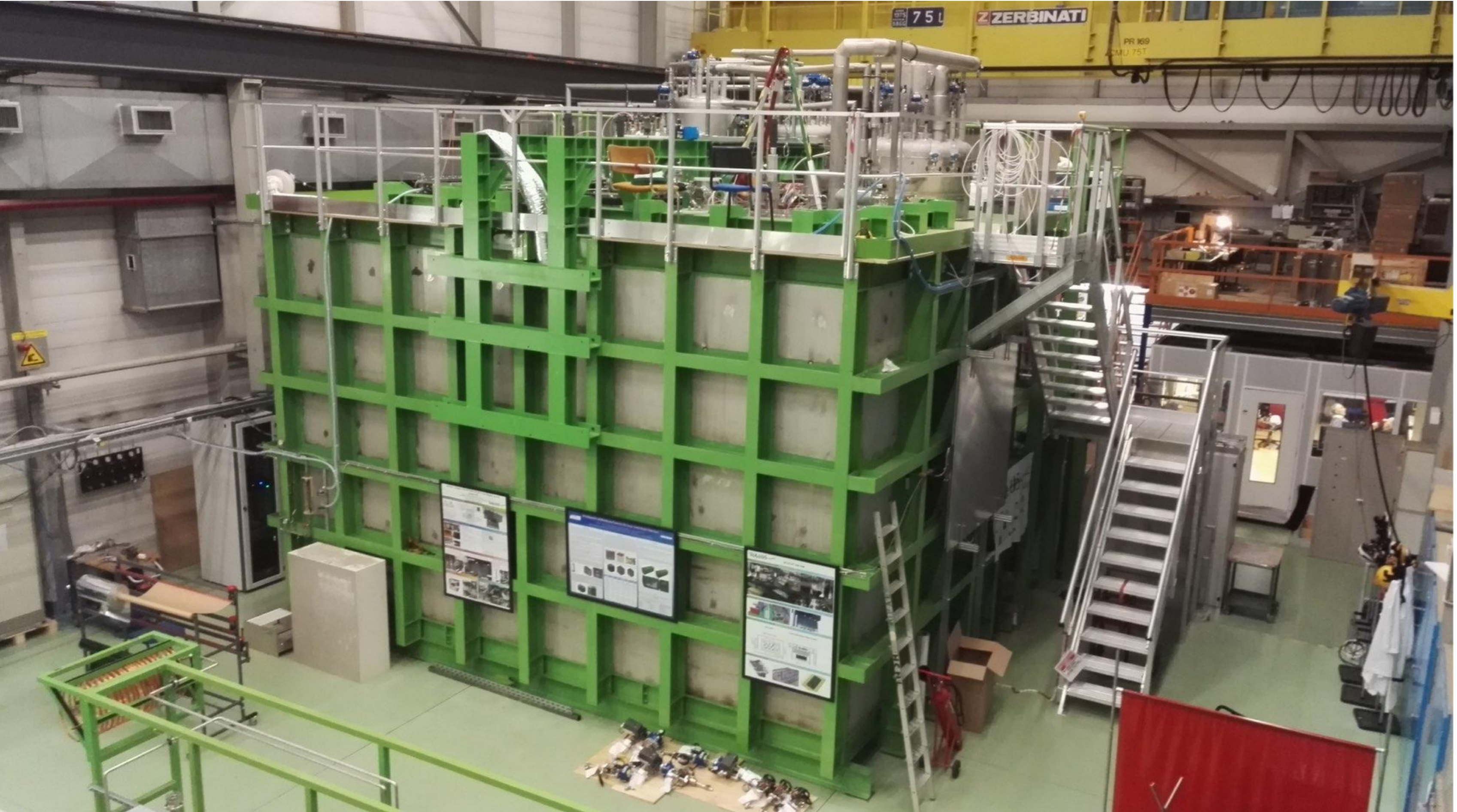
Pilot detector 3x1x1

- Ready since the fall 2016









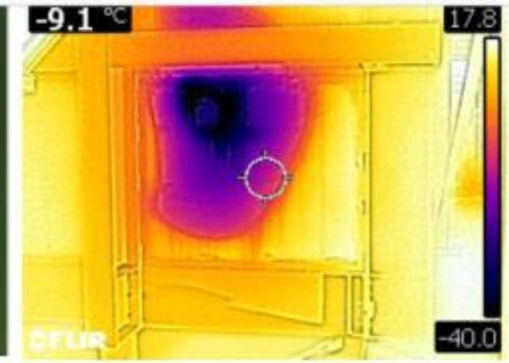
- Delay in the cryogenic system installation and of its commissioning
- The cryostat purge with pure argon was successfully performed by middle of February.
- Cool-down was almost completed on March 3rd in order to start filling with LAr when a cold spot of ice appeared in a corner of the cryostat

→ Cryostat warmed up since March 3rd to investigate, possible leak from corrugate membrane ?

→ Access on 14/3 → No leaks: defect in insulation. Cryostat purging restarted last week

- **January 24th -February 7th : open loop purge, 1.5 ppm 02 reached**
- **February 8th - February 15th : closed loop purge, 80 volumes 0.2 ppm O2 reached**
- **February 15th attempt to cool-down, problems due to the formation of gas pockets on the LN2 line → modification of the LN2 line needed by adding a purging valve at the input of the condenser (1.5 weeks of delay added on the commissioning schedule of the cryogenic system.**

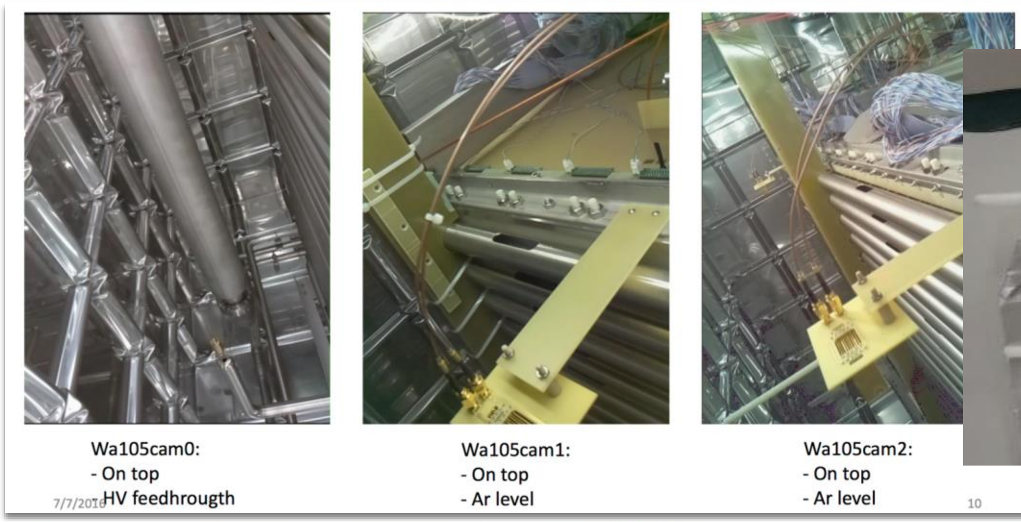
- **Cryostat cool-down started on February 27th - March 3rd**
- **March 3rd observation of a cold spot with ice in a corner of the cryostat exoskeleton → LAr temperature not reached, warming up for inspection**
- **March 14th access possible, visual inspection shown no damages to membrane, March 14th -March 18th several negative leak searches with helium**
- **March 21st , drilling of point corresponding to cold spot on external steel plates showed the presence of an empty corridor without insulation**

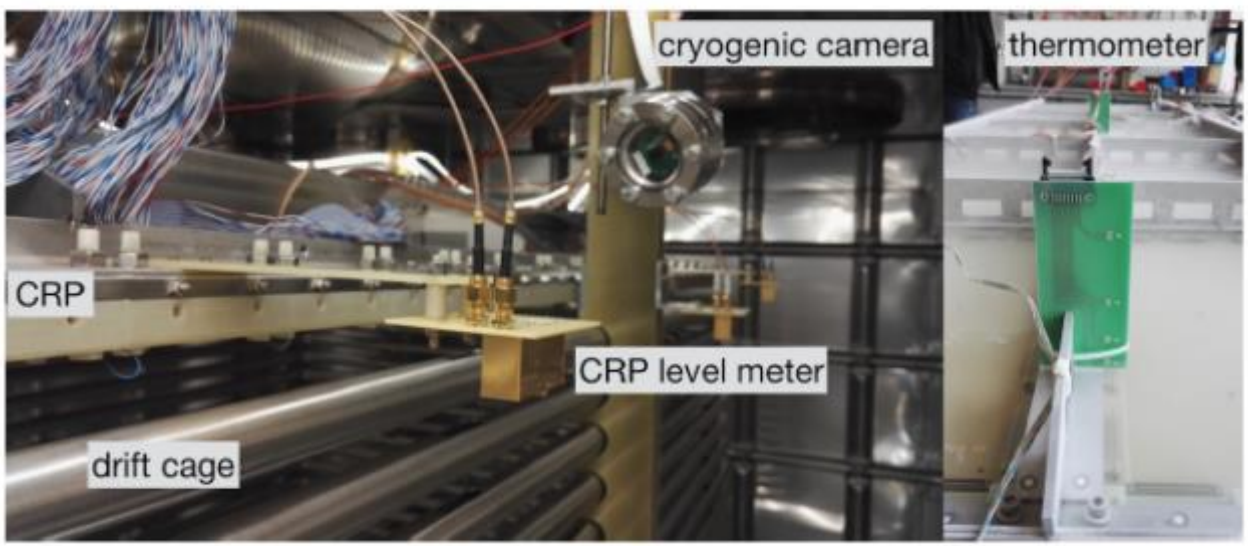


Empty gap of 10x2x95 cm in the Insulation → refilled with foam

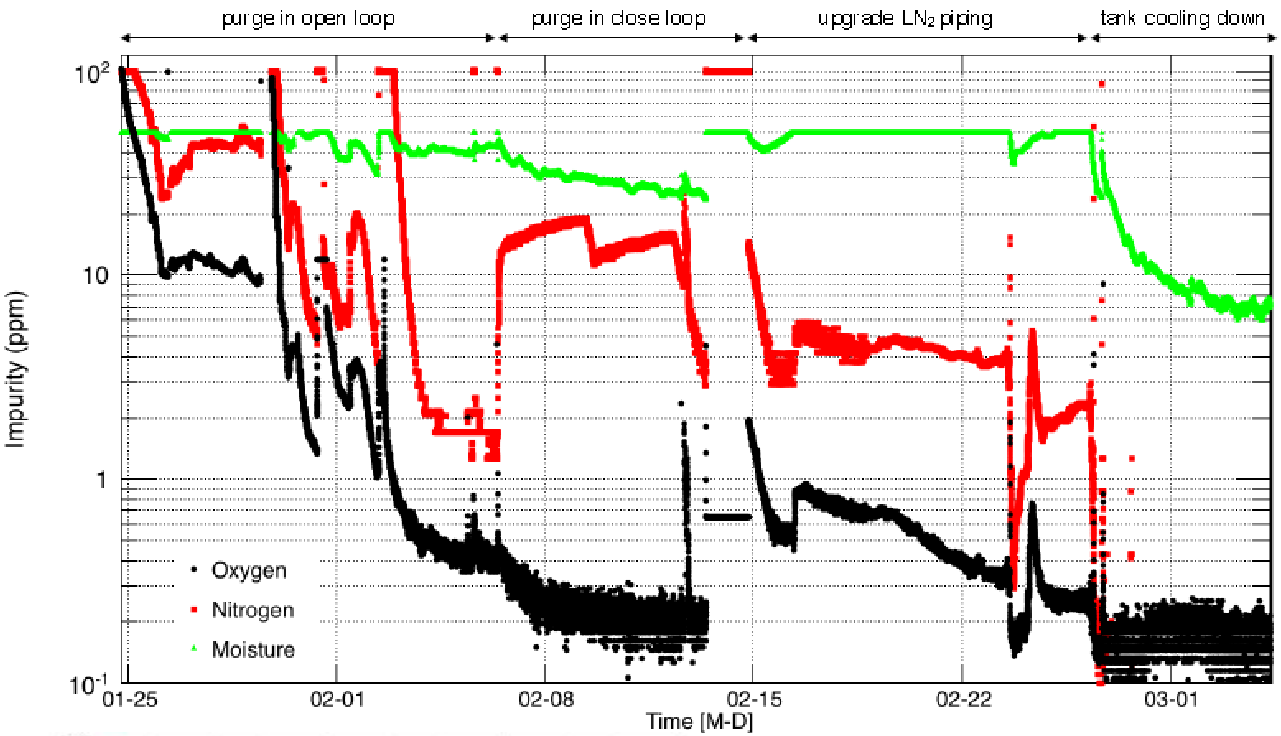
Slow control, cryocameras, level meters, purity monitoring **(Task 2)**

Very extensive slow control system in 3x1x1 as baseline design for the ProtoDune detectors

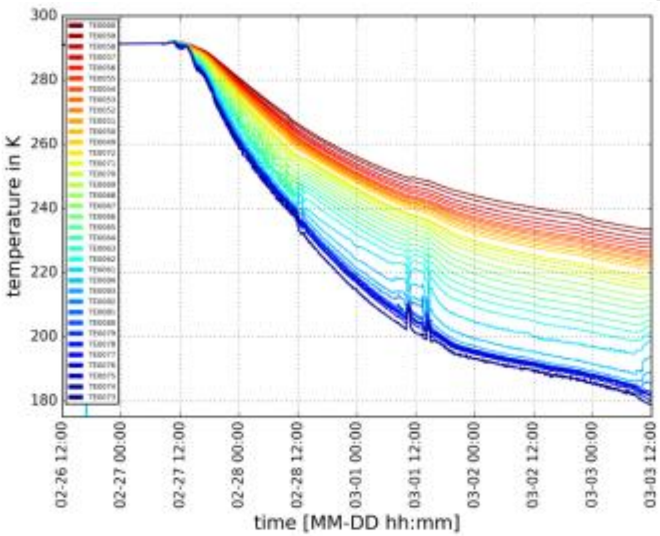




Cryogenic Detectors NA



Purification studies:
Gas impurities evolution during purge and cool-down of 3x1x1

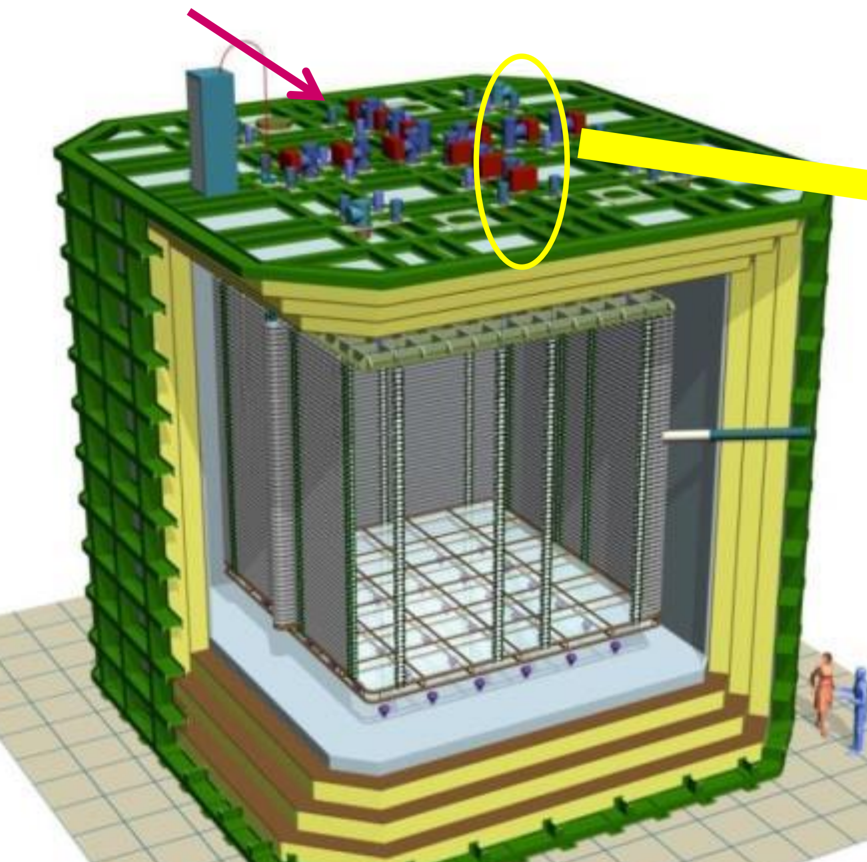


Temperature evolution in the gas at different heights during cool-down of 3x1x1

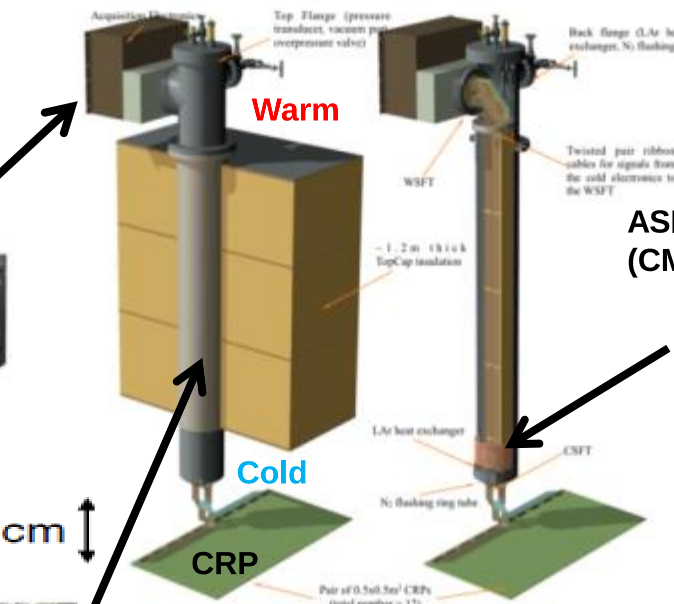
Full accessibility provided by the double-phase charge readout at the top of the detector

- **Digital electronics <u>at warm</u> 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

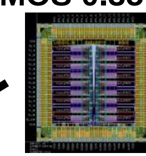
- **Cryogenic ASIC amplifiers (CMOS 0.35um) 16ch <u>externally accessible:</u>**
  - Working at 110K at the bottom of the signal chimneys
  - Cards fixed to a plug accessible from outside
  - →Short cables capacitance, low noise at low T



uTCA crate



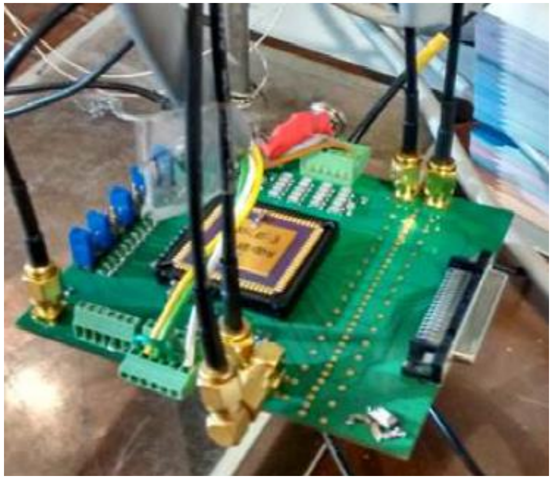
ASICs 16 ch. (CMOS 0.35 um



Signal chimney

<u>Accessible cold front-end electronics and uTCA DAQ system</u>

Cryogenic FE electronics :

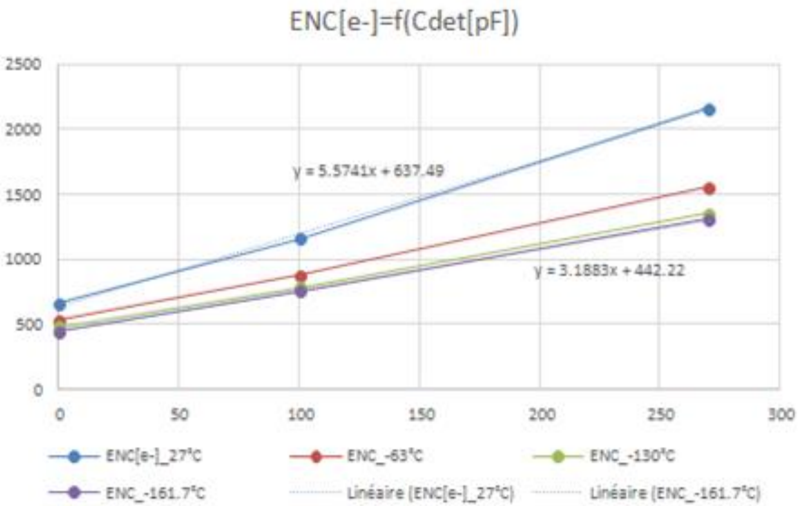


Dual-slope ASICs final version

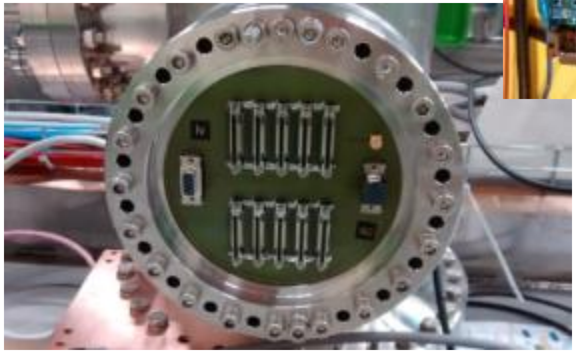
- 16 channels
- Double slope gain with “kink” at 400 fC
- 1200 fC dynamic range

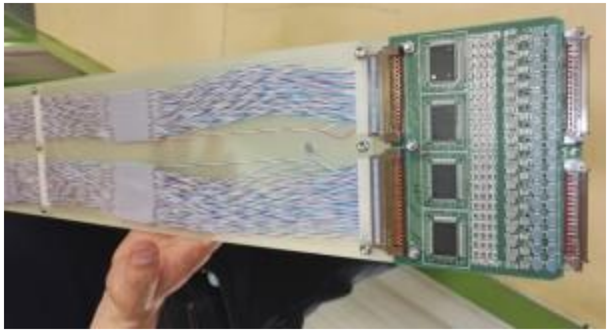
(batch of 25 circuits) tested in January 2016, fully satisfactory. Full production for 6x6x6 produced and purchased (700 chips).

FE-cards designed in 2016 together with chimneys warm flanges PCBs



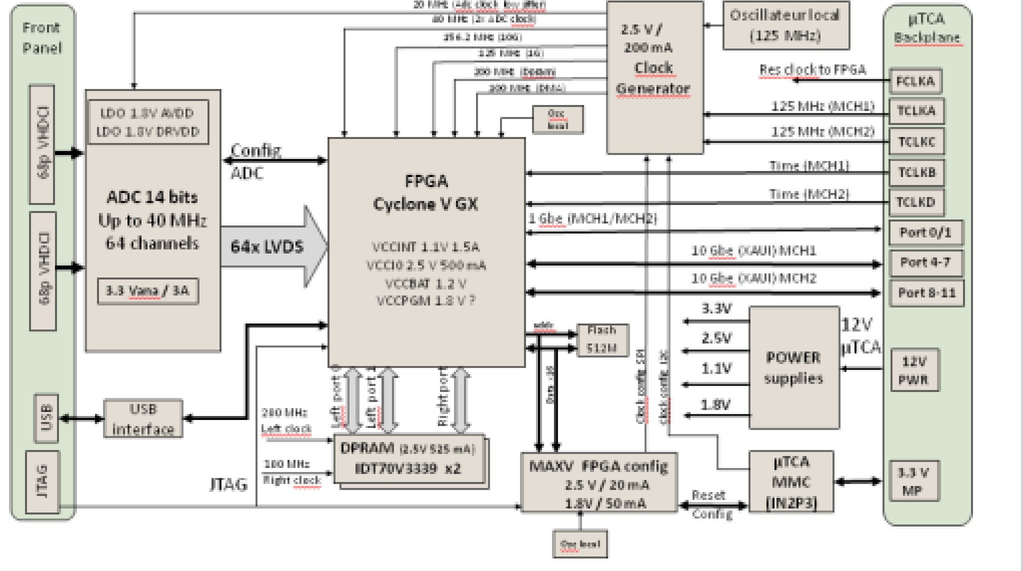
Warm flange PCB





20 FE cards (1280 channels) produced and installed on 3x1x1 pilot detector at CERN

uTCA DAQ system:



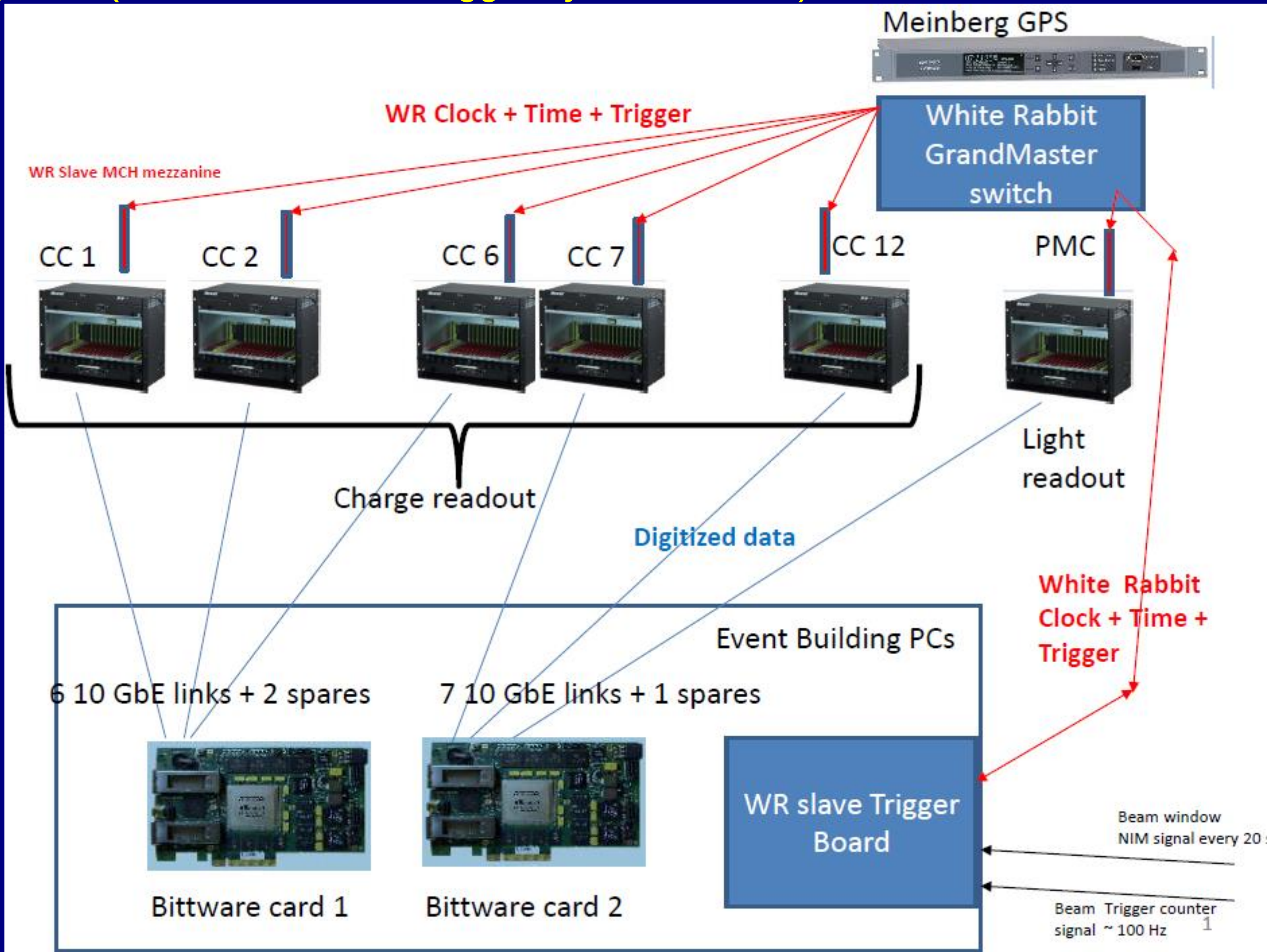
64 channels AMC digitization cards (2.5-25 MHz, 12 bits output, 10 GbE connectivity)

- Demonstrator card with 64 ADC channels built and tested in 2015 for the definition of the final card
- Purchase of main components (ADCs, FPGAs, IDT memories) of the final cards by end of 2015 to equip the entire 6x6x6
  - Final design of digitization PCBs May 2016
  - First assembled cards received in August 2016.

- 20 cards produced by September 2016 to equip the 3x1x1
- Cards production going to be completed with the 2017 budget of remaining 100 FE and uTCA cards for 6x6x6 (main components available)
- The warm flange PCB design is based on an extension of the ones of the 3x1x1

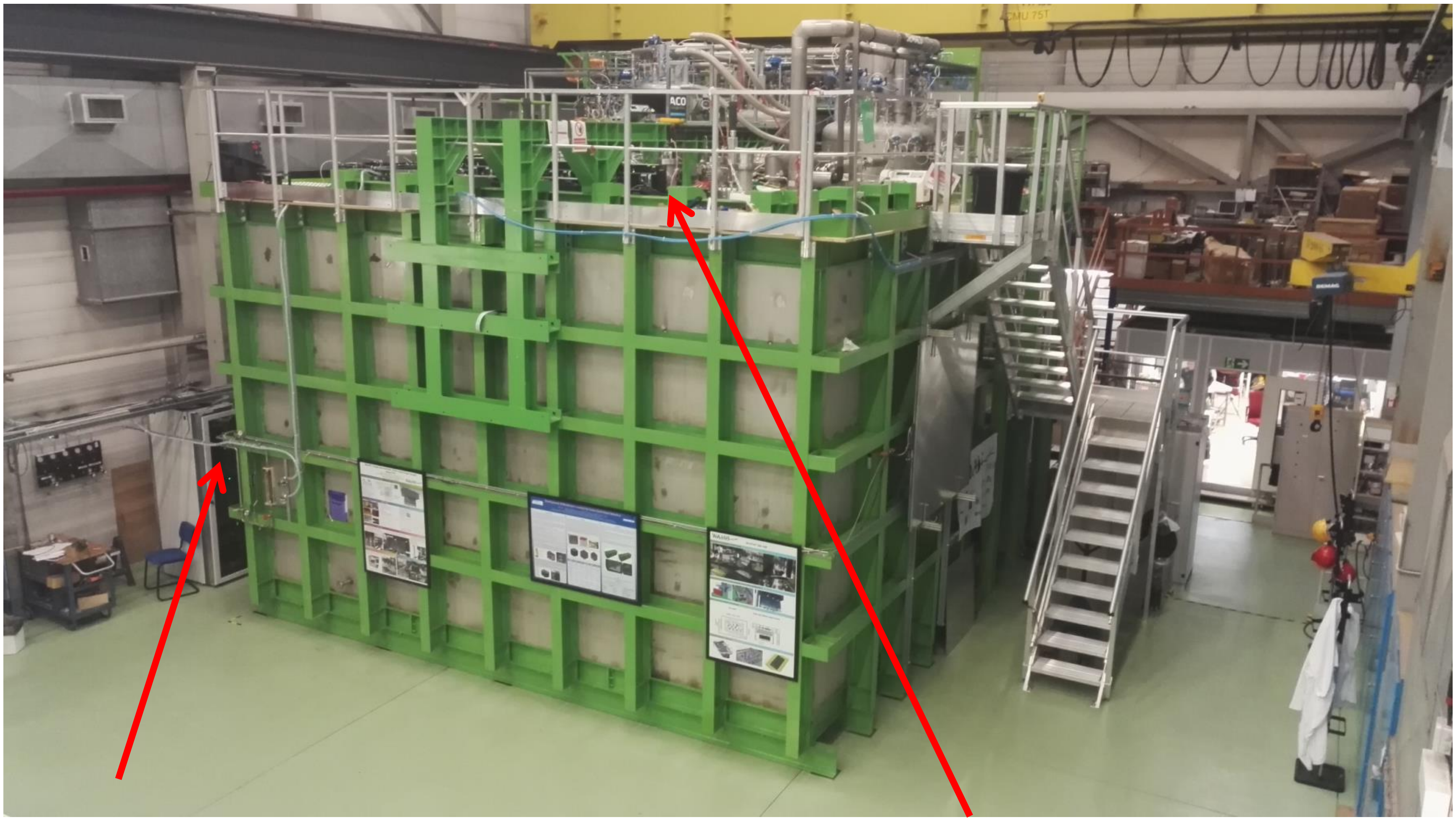
Global uTCA DAQ architecture

integrated with « White Rabbit » (WR) Time and Trigger distribution network
+ White Rabbit slaves nodes in uTCA crates +
WR system (time source, GM, trigger system, slaves)



6x6x6: 12 uTCA crates (120 AMCs, 7680 readout channels)

→ 3x1x1: 4 uTCA crates (20 AMCs, 1280 readout channels)
+ Slow Control



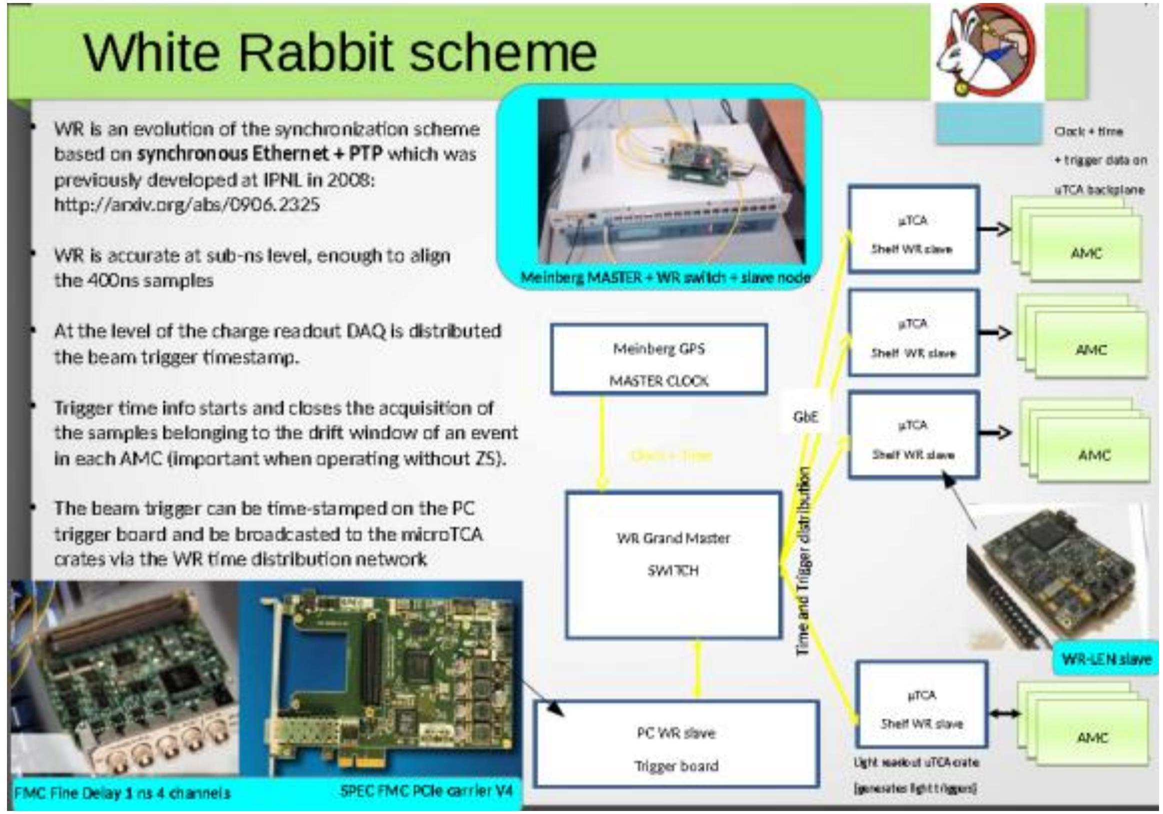
Event builder, network, GPS/White Rabbit GM, WR Trigger PC

Signal Chimneys and uTCA crates

White Rabbit trigger time-stamping PC (SPEC + FMC-DIO)

White Rabbit Grand-Master

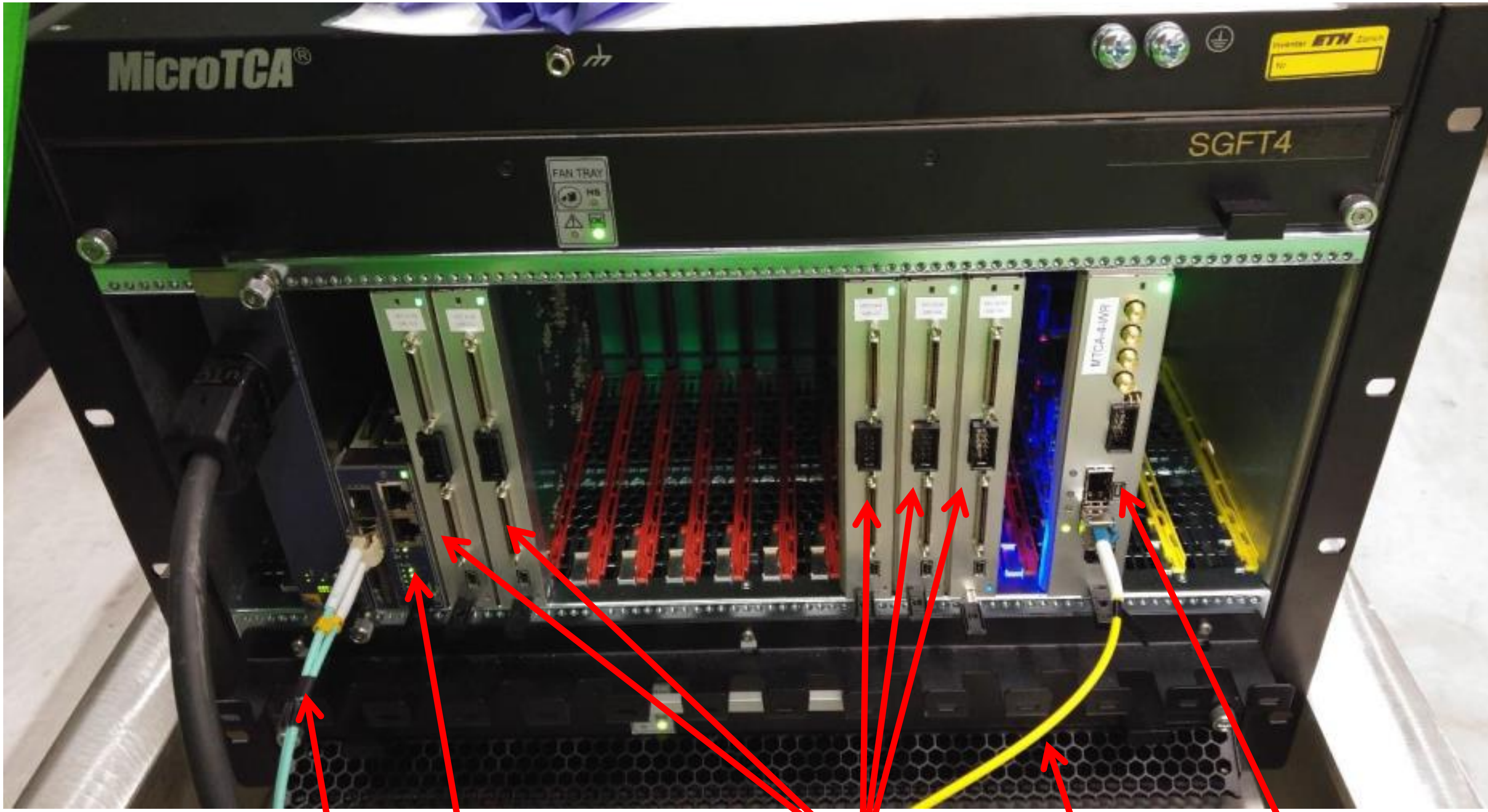
GPS unit



White Rabbit uTCA slave node based on WRLEN developed and produced for entire 6x6x6

Other components of the chain (GPS receiver, WR grandmaster, SPEC+ FMC-DIO + 13 WRLEN) available commercially

How a crates was looking like before VHDCI signals cabling to the warm flange



MCH

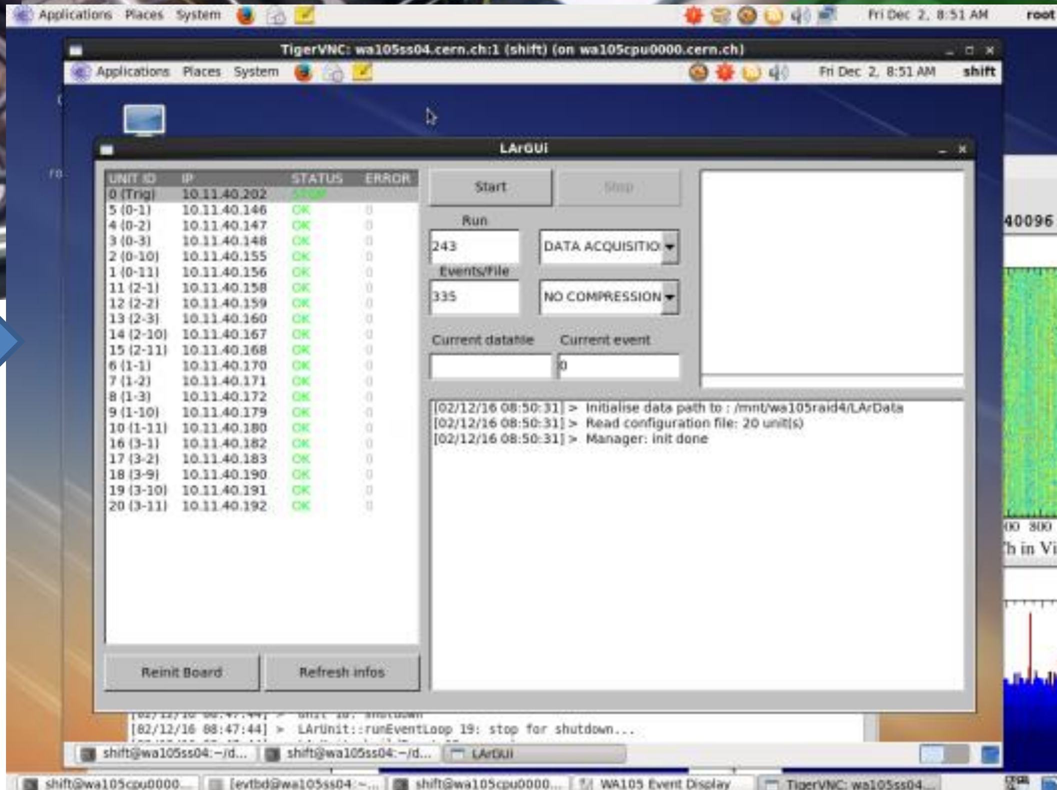
AMC 64 channels digitization cards

WR uTCA slave card node with WRLEN mezzanine

10 Gbit/s data link

White Rabbit optical link

Top cap picture with uTCA crates cabled to signal chimneys



Run control with 20 AMCs

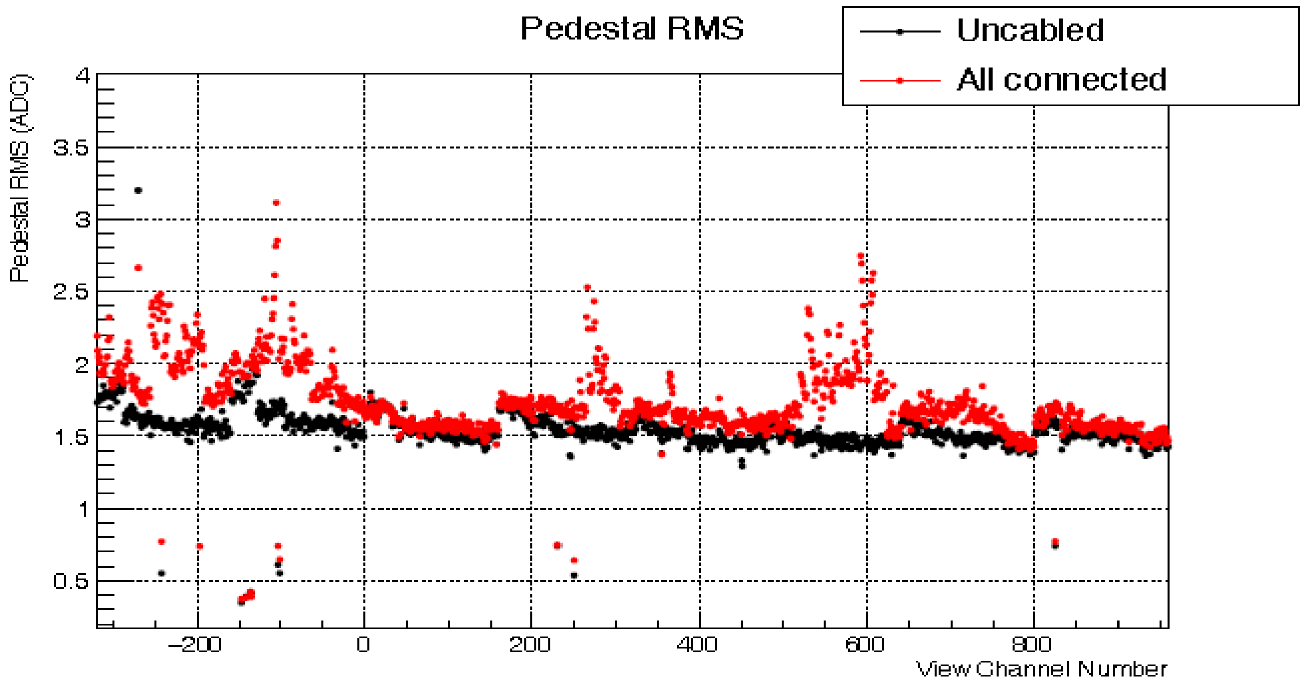
Automatic data processing on online storage/processing farm for purity and gain analysis + data transfer on EOS

Stable system, noise conditions at warm 1.5-1.7 ADC counts RMS

Several campaigns of checking of the grounding conditions/noise measurements since June 2016.

Good noise conditions with some residual small issues related to slow-control/HV grounding and cabling

→ Average RMS noise 1.7 ADC counts (0.82 mV) at warm with all systems active and cabled 1.5 ADC counts with slow control/HV cables disconnected from flanges



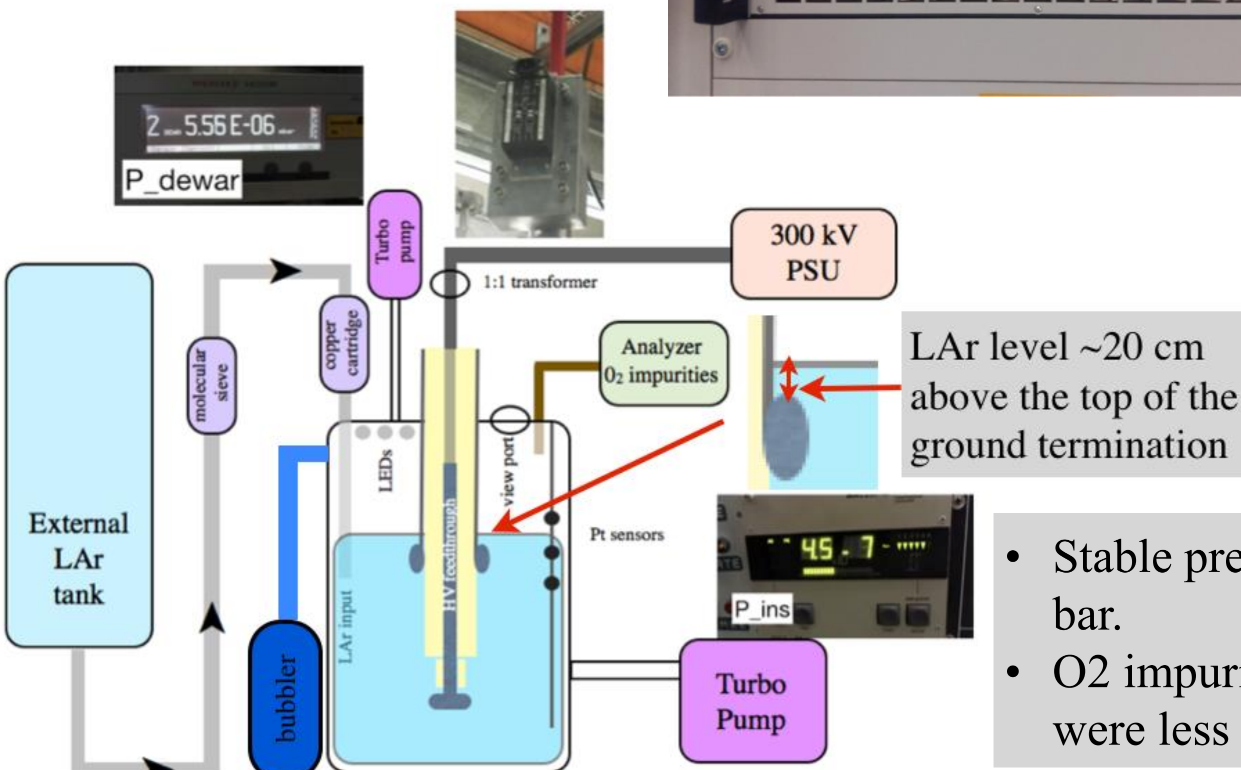
The grounding scheme for the 6x6x6 is more sophisticated with the cryostat, FE electronics and slow control completely insulated from external environment and only referred to cryostat ground.

Task 5 VHV

Major milestone reached in September 2016: test of HV feedthrough in a dedicated Lar test setup at the end of the scale of the Heinzinger PS (about 300 kV)

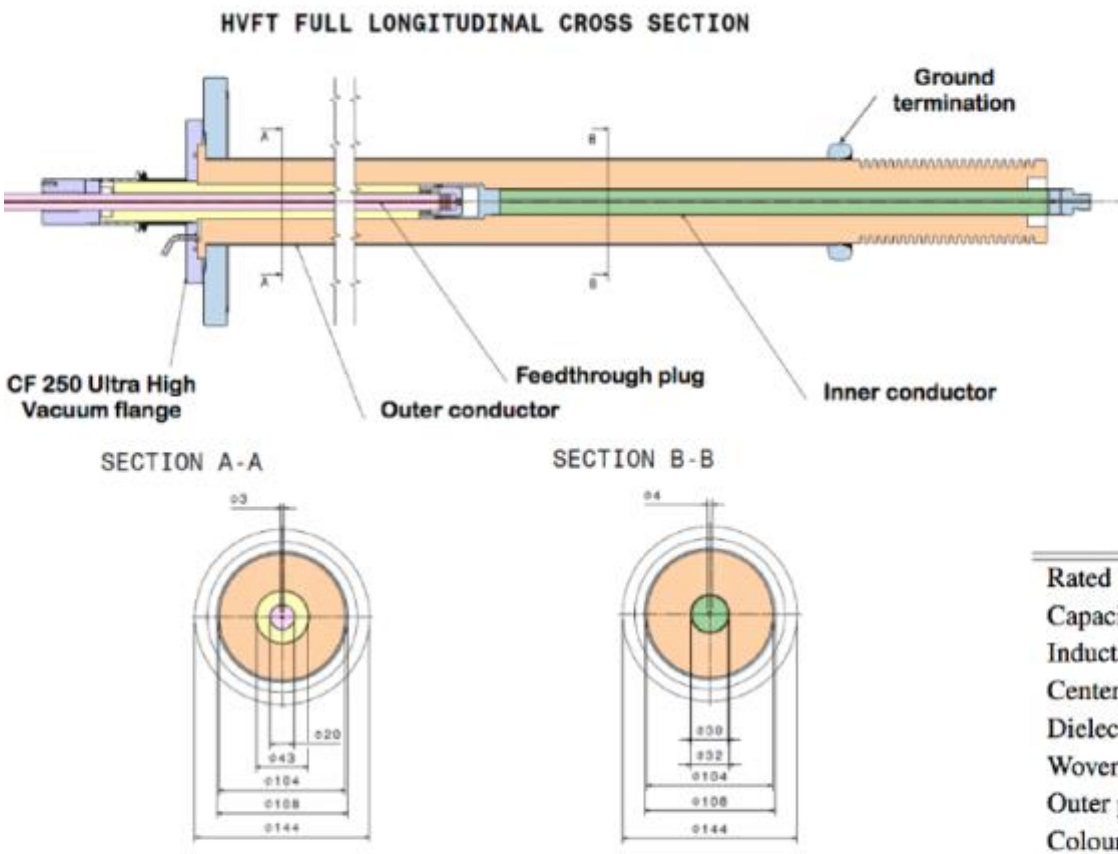
→ HV for nominal drift field of 0.5 kV/cm in the 6x6x6

C. Cantini et al., "**First test of a high voltage feedthrough for liquid Argon TPCs connected to a 300 kV power Supply**",
JINST 12 P03021 arXiv:1611.02085

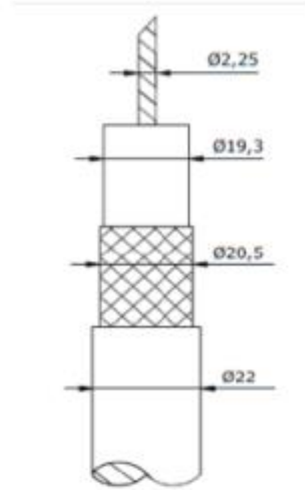


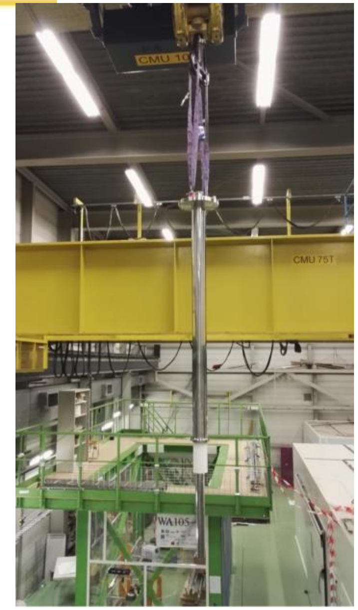
- Stable pressure in the dewar at 1.05 bar.
- O2 impurities measured in the gas were less than 0.1ppm

Transmission: The HVFT and the HV cable



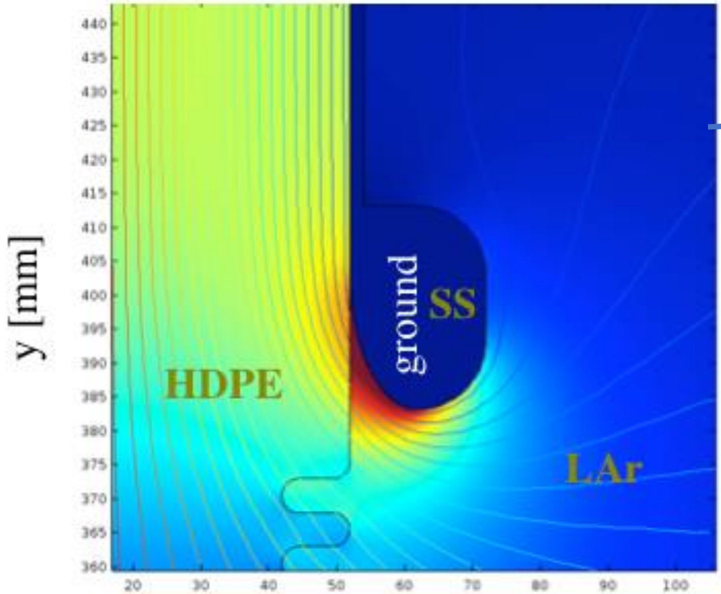
design by Franco Sergiampietri inspired from ICARUS feedthrough

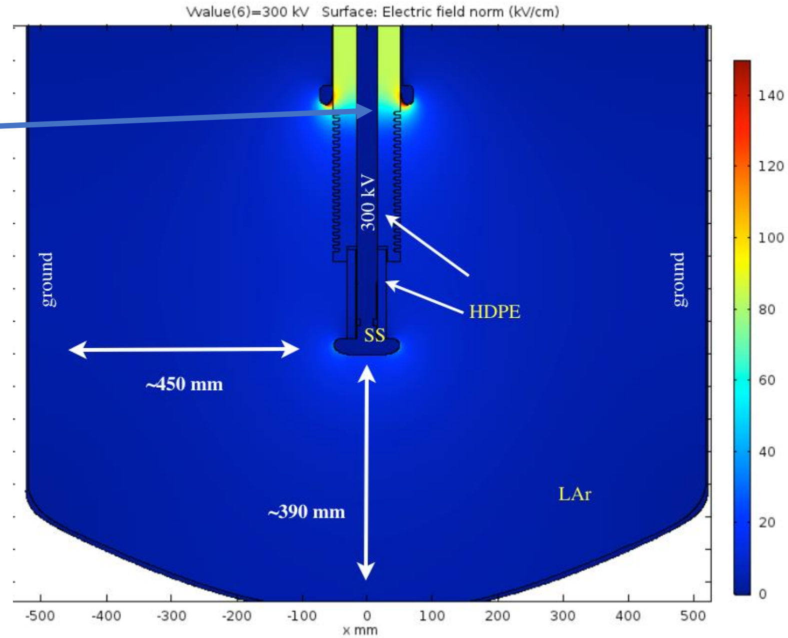


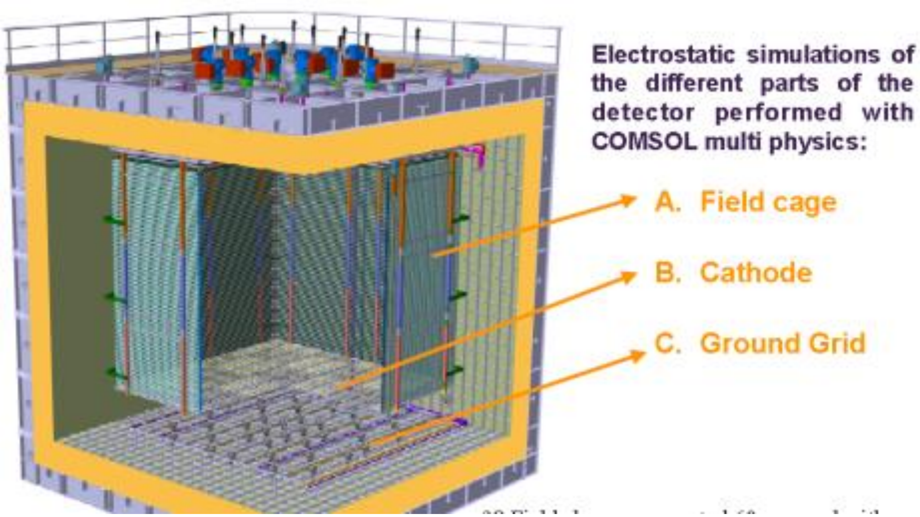


Rated voltage	300 kV
Capacitance	101 pF/m
Inductance	0.3 μH/m
Center Core	Copper
Dielectric insulator	Polyethylene
Woven copper shield	CuSn
Outer plastic jacket	PVC
Colour	red
Minimum bending radius	440 mm
Temperature resistance up to	60°C

- **HV feedthrough and PS operational on 3x1x1**



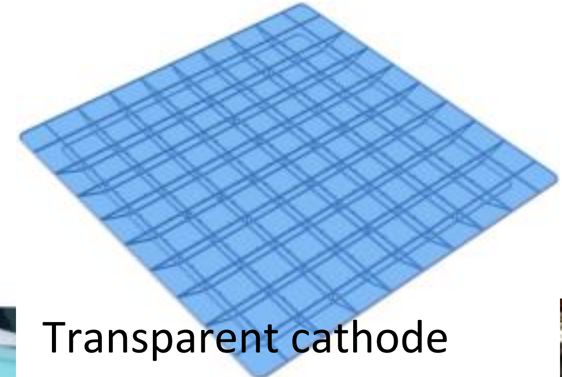




- **Simulations of the operation at 300 kV achieved in the test setup showing the highest field values reached around the FT neck where the ground conductor ends**

- **Completion of electrostatic simulation for entire feedthrough, field-cage, cathode system of 6x6x6 max local field <30 kV/cm**

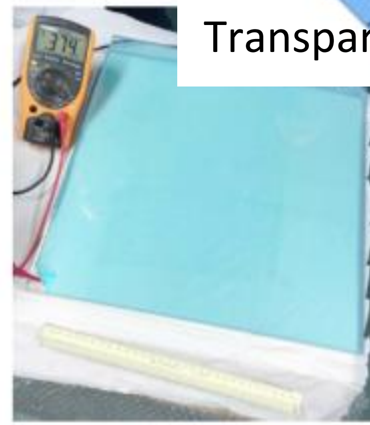
Light readout (Task 5)

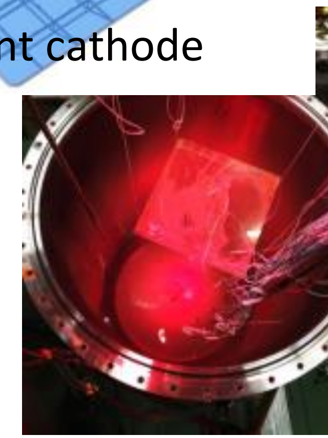


<u>Transparent cathode with ITO</u> (Indium-Tin-Oxyde) **<u>resistive coating</u>** on two sides of PMMA plates + TPB deposition at the top side:

- R&D and conceptual design for plates integration in cathode structure completed
- Infrastructure set up for TPB evaporation coating
- Tested ITO coated PMMA plates up to 850x600 mm^2 (produced by industry) → chosen size 650x650x10 mm^3

Transparent cathode

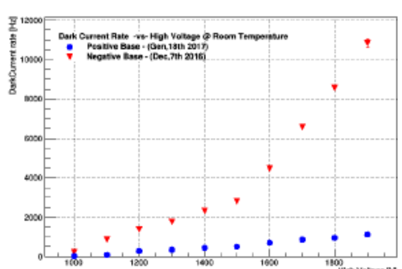


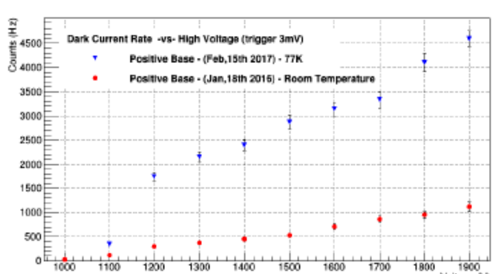


Integration and test of different PMT solutions (coating, signal+HV distribution in a single cable) in 3x1x1, development of PMT readout electronics for 6x6x6

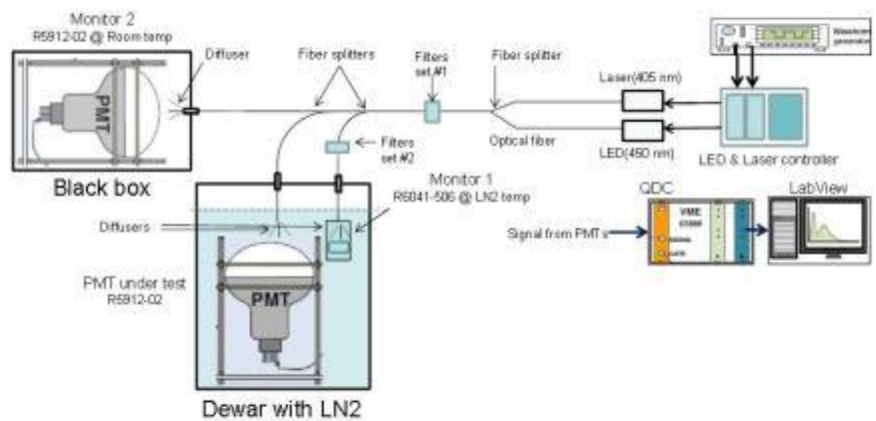
Integration and test of calibration system (laser+fibers)

Dark current (DC)





PMTs characterization chain



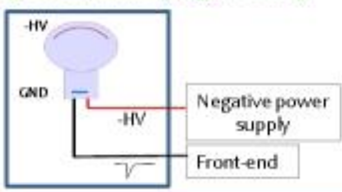
Light system at the 3x1x1 m³ prototype

5 PMTs

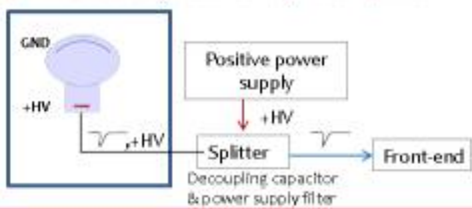
Different options being tested

- 2 options for the HV supply and cabling being tested:

A) 2 cable base (negative HV)

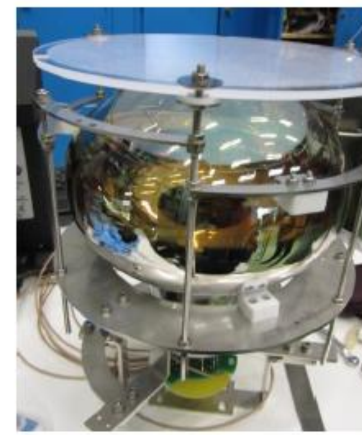


B) 1 cable base (positive HV) + ext. splitter



Main difference: The splitter in the PB decreases the effective voltage by a small per cent, but reduces the number of cables.

TPB evaporated on PMT



TPB evaporated on plate

- 2 options for wavelength-shifter being tested:
  a) 3 TPB coated PMTs
  b) 2 PMTs + TPB coated plate

Cryogenic Detectors NA

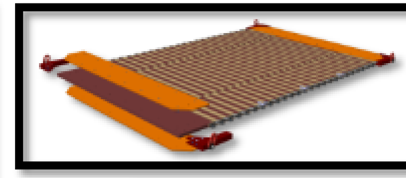
Task 6 Magnetization: Baby MIND

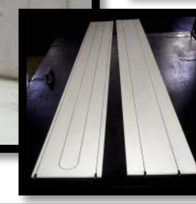
The Baby MIND collaboration is going to **perform beam tests on the Baby MIND spectrometer at the CERN PS-T9 beam line in May and June 2017.**

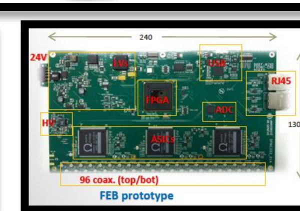
Construction of the 33 Baby MIND novel magnet modules was completed on schedule at the end of February 2017 by CERN. This brought to an end a production phase started in September 2016 with ARMCO steel, following first prototyping activities in March 2016 on standard construction steel. A paper on the magnet design is under preparation, close to being finalised. The design will also be presented at a Magnet Technology conference, MT25, in Amsterdam in August 2017.

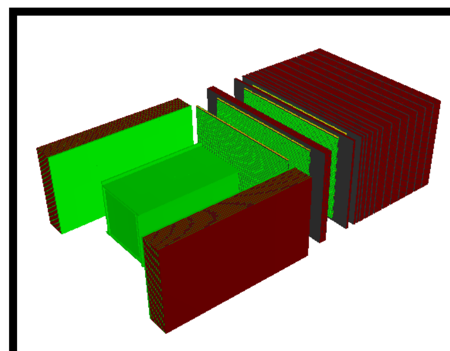
Scintillator bars delivered to CERN from INR in November 2016, well ahead of the initial plans which foresaw delivery Q3 2017. Of the 18 custom scintillator modules required for the test, 9 have been assembled, and integrated onto magnet modules. **Assembly of the remaining 9 modules will proceed as planned in April 2017.**

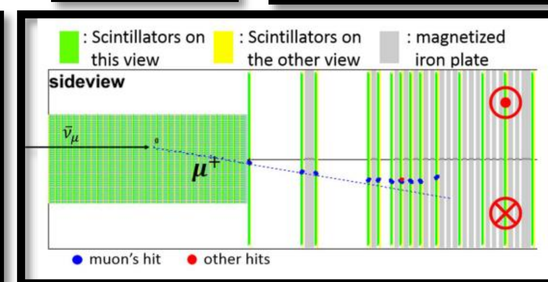

Magnet proto.



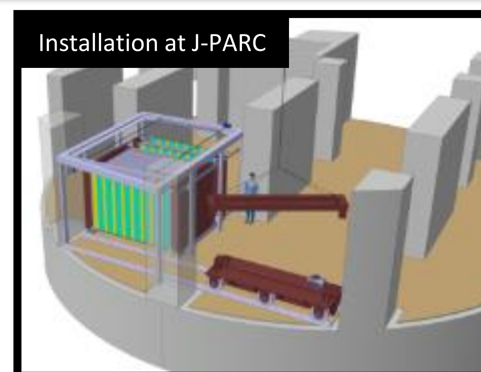






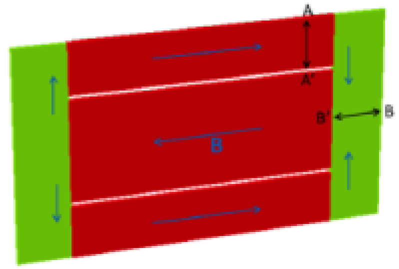


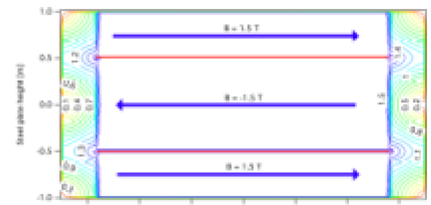

Installation at T9


Installation at J-PARC

Magnet module concept

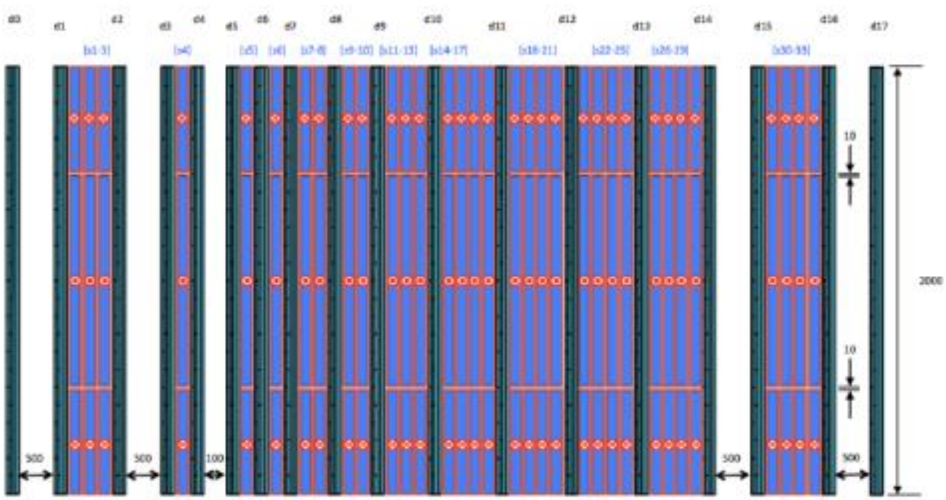
- Design principles:
  - Individually magnetized iron (ARMCO) plates.
  - Two-slit design.
  - Well defined B-field lines in central zone: $B = B_x$.
  - Contained stray fields.
  - Modularity and flexibility.
- Dimensions:
  - $3500 \times 2000 \times 30 mm^3$.
  - 10 mm wide slits (water jet).
  - 10 mm-thick flux return plates $\times 4$.
  - Aluminium coil: 50 mm wide $\times$ 4 mm thick: half-turns.
- Test measurements.
  - Field > 1.5 T for coil current ~ 140 A
  - Power for all 33 modules: 12 kW





Baby MIND layout

- Magnet module thickness: 50 mm (30 mm Fe) (envelope: 60 mm).
- Detector module thickness: 38 mm (31 mm CH).



Magnet module assembly: all 33 modules complete

Conclusions:

- The AIDA2020 groups involved in WP8 are intensively working on the hardware activities related to Baby MIND, the exploitation of the 3x1x1, the construction of the 6x6x6 and the design of the 10 kton detectors. These activities have now a strong connection with the USA community

- These WP8 activities are in an advanced state with already a set of remarkable achievements for all the tasks, which will be useful to the entire community. The topics reviewed by the WP8 tasks are <u>essential ingredients</u> concerning the state of the art technologies. The AIDA2020 involvement will contribute to a wide dissemination of all this experience

- 3x1x1 detector operation delayed by cryogenic system installation and commissioning → looking forward to data taking which will be exploited by many activities of WP8.

- 6x6x6 design being completed by the end of November 2016, cryostat construction in advanced state, preparation for detector installation started

- ***The R&D activities connected to WP8 already achieved several interesting results and gathered a considerable amount of knowledge of general interest for the community. We should now focus on the dissemination and make all that available via the WEB (WP8 wiki), as originally foreseen. This is a fundamental aspect of the deliverables.***

Cryogenic Detectors NA