Status and plans of the WA105 experiment

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for WA105 Collaboration

121st Meeting of CERN SPSC

April 2016

Dual-phase TPC prototype at CERN

Characterize the detector with well defined particle beams

- Study PID performance
- Evaluate e/π_0 rejection capabilities
- Calibrate energy scale and evaluate resolution for electronic and hadronic showers
- Validate reconstruction tools

➔Systematics for future neutrino oscillation program

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

Requires:

- **Pions/protons**: reconstruction of secondaries in hadronic interactions, measurements of hadronic shower development, study compensation and energy resolution
- **Electrons**: calibrate energy scale and resolution

Dual-phase TPC prototype at CERN

Demonstrate technical feasibility for O(10kton) detectors

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

WA105 dual-phase LAr TPC

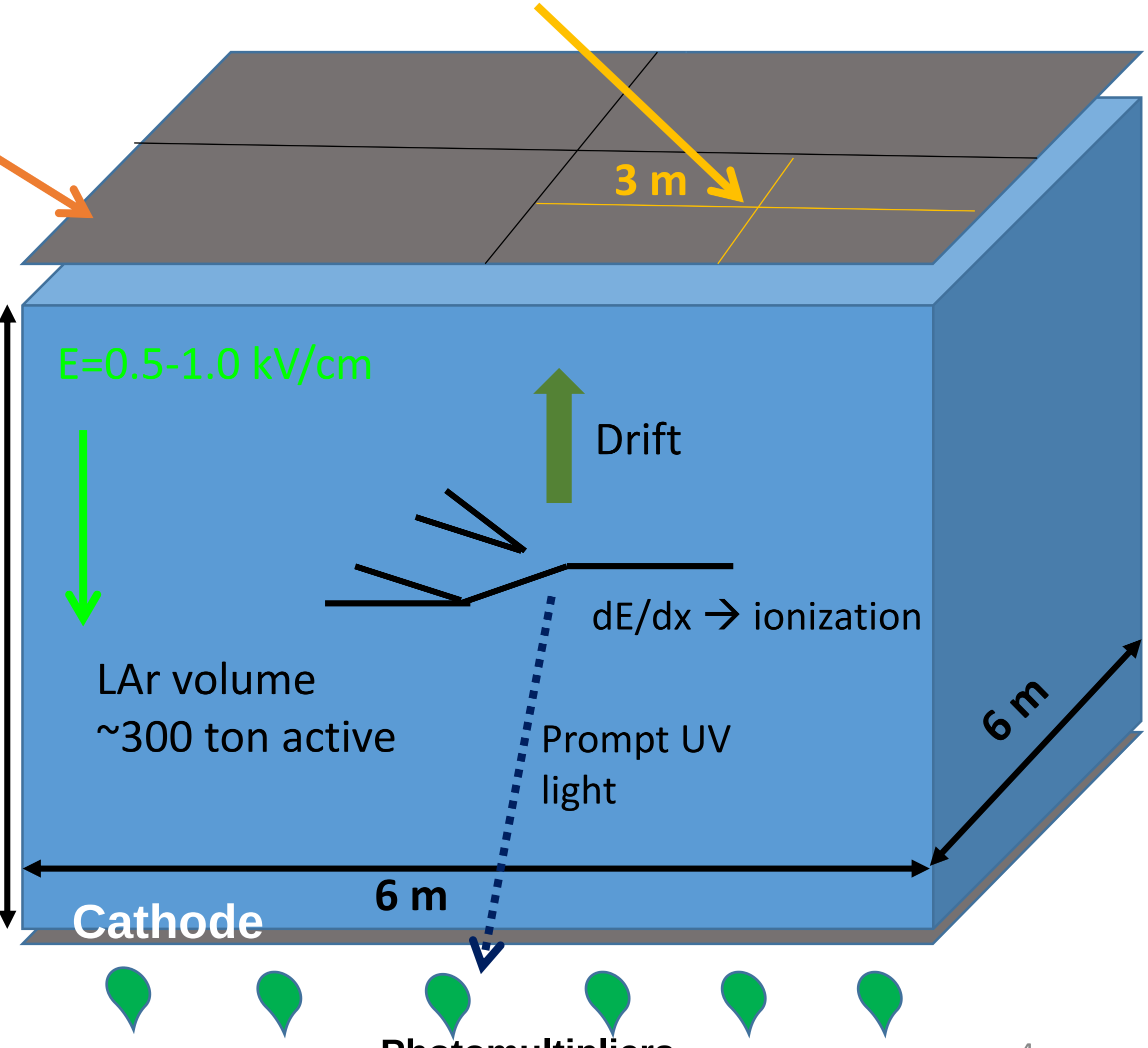
Charge Readout Plane (CRP) X and Y charge collection strips
3.125 mm pitch, 3 m long →7680 readout channels

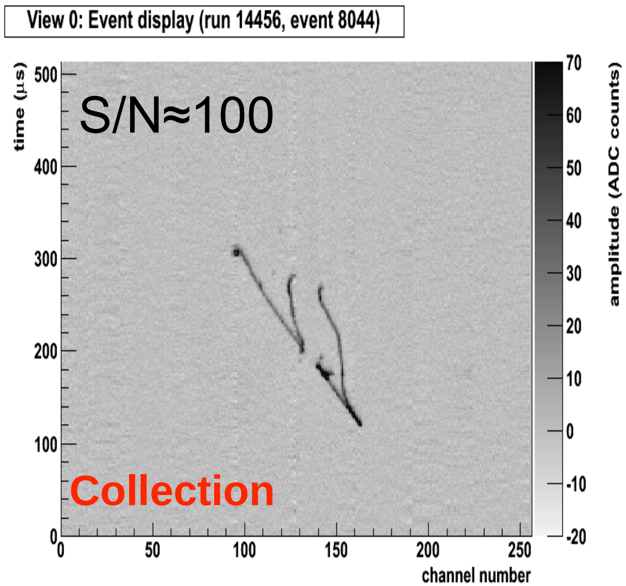
Readout in gas phase:
charge is amplified and
collected on a 2D anode

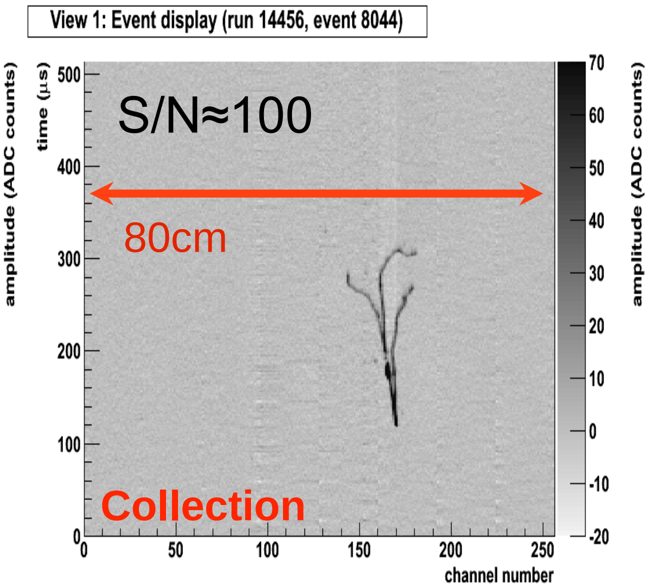
Drift coordinate 6 m = 4 ms
sampling 2.5 MHz (400 ns), 12 bits
→ 10000 samples per drift window

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

Detector is built from 4
independent 3x3 m^2 units
For multi-kton detector, simply
increase the number of CRPs

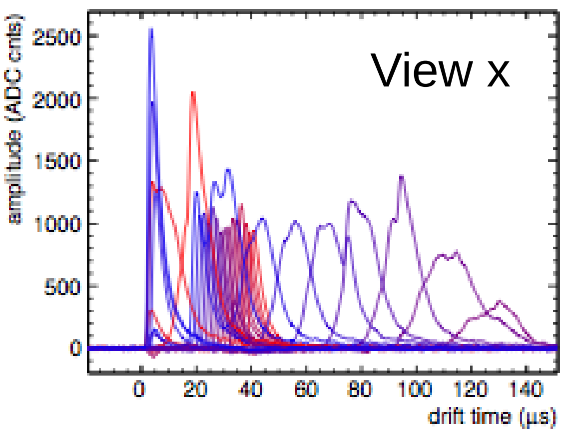


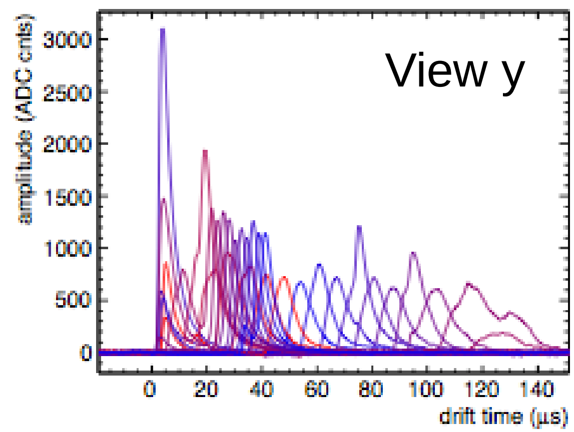




Double-phase prototypes measuring real data events since 6 years with active volumes from 3 to 250 liters

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

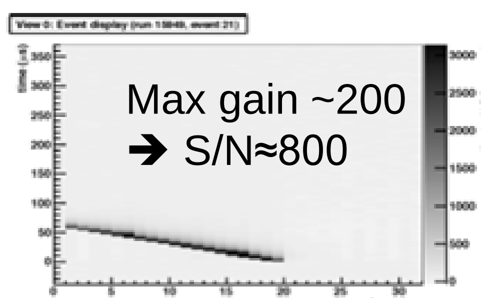


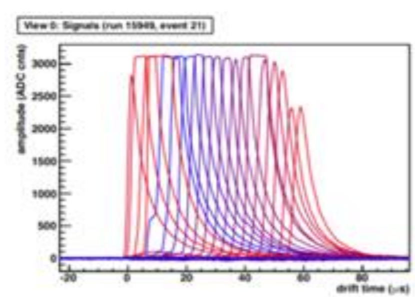


Dual-phase concept advantages:

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

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





History of WA105 / Dual-phase ProtoDUNE

LBNO-DEMO (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

Progress report on LBNO-DEMO/WA105 (2015)

The WA105 Collaboration

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
Positive response (21 institutions submitted EOIs)

- Covering all identified DP-ProtoDUNE subsystems
- In process of bringing together interested institutions

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

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

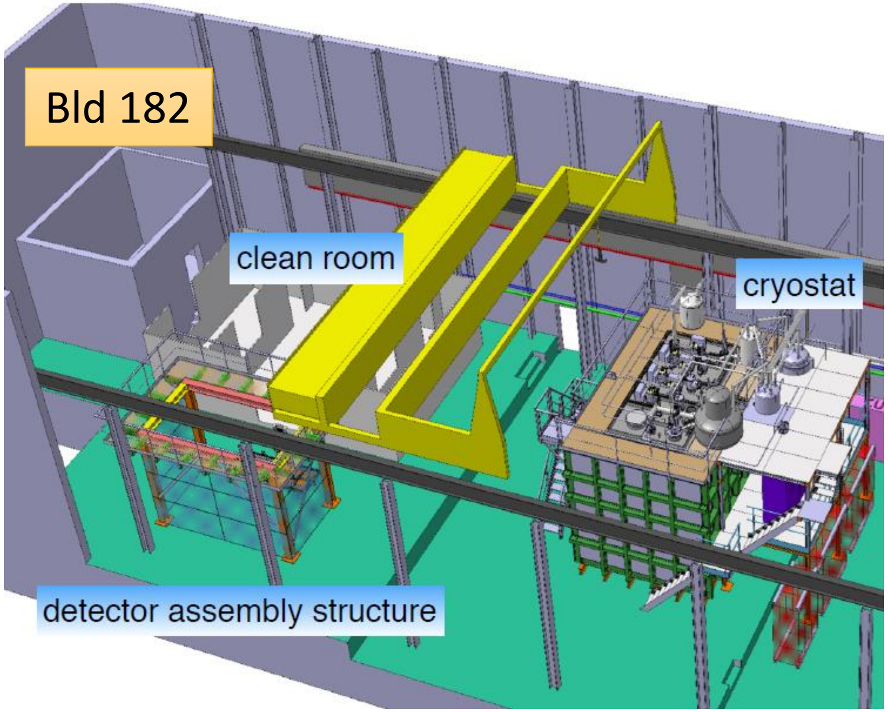
TDR
submitted on 31st March 2014
CERN-SPSC-2014-013
SPSC-TDR-004(2014)

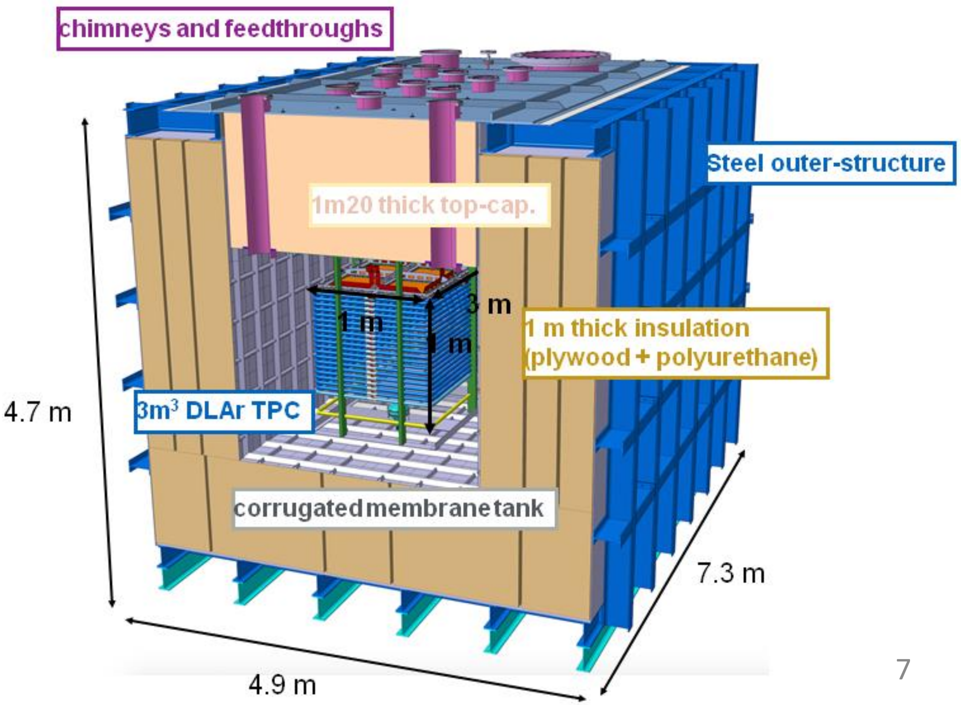
From past SPSC recommendations: *"encouraged CERN and the WA105 collaboration to (...) undertake all efforts to be ready with DLAr in the EHN1 extension for first beam before the start of the Long Shutdown 2."*

LArProto: 3x1x1 m^3 pilot

- 25 ton dual-phase LAr TPC pilot prototype at CERN Bld 182
- Charge readout area = 3x1 m^2, Drift = 1 m
- Significant progress on the pilot in the last year to construct the detector

Starts taking cosmics in September 2016





LArProto: 3x1x1 m^3 pilot

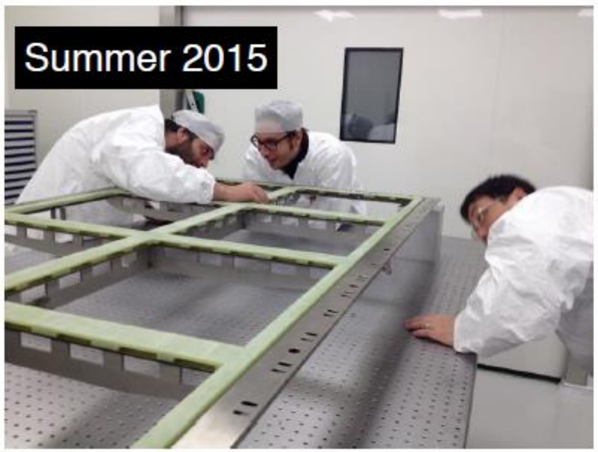
Extremely useful:

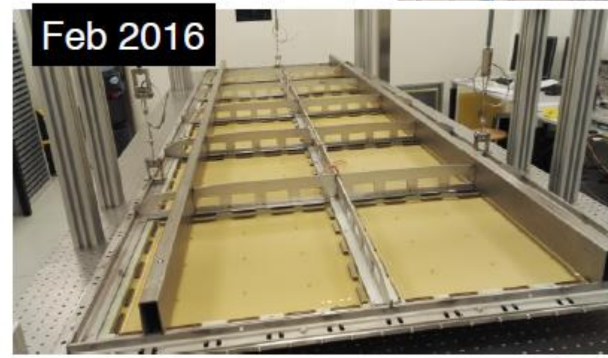
- Routine procedure for mass production, QA/QC tests, and calibration of LEMs
- Cryogenic installation, feedthroughs, thermodynamic condition of the tank, integration, …
- Legal and technical aspects related to cryostat procurement
- Validation of production schedule for 6x6x6 m^3

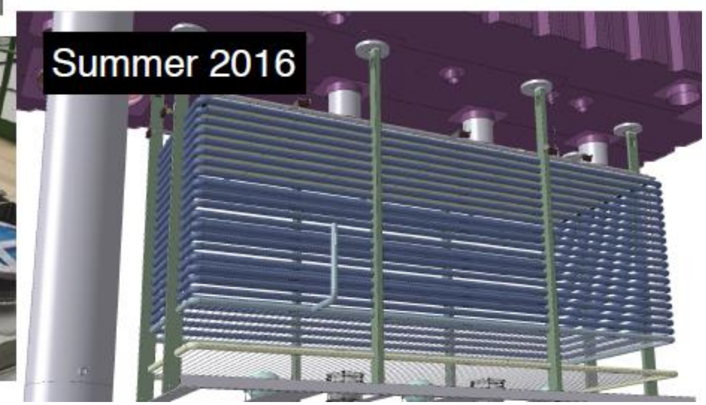
- But due to its size
  - Not a test of very large vessel and field cage structure
  - No large surface charge readout
  - No long drift (purity and diffusion)
  - No very HV generation
  - No event containment or exposure to hadronic beam

Not a demonstrator for a large scale detector and no measurement input for the associated LBL program

Progress LArProto







Chimneys for accessible cold FE

Ongoing feedthrough installations in top cap

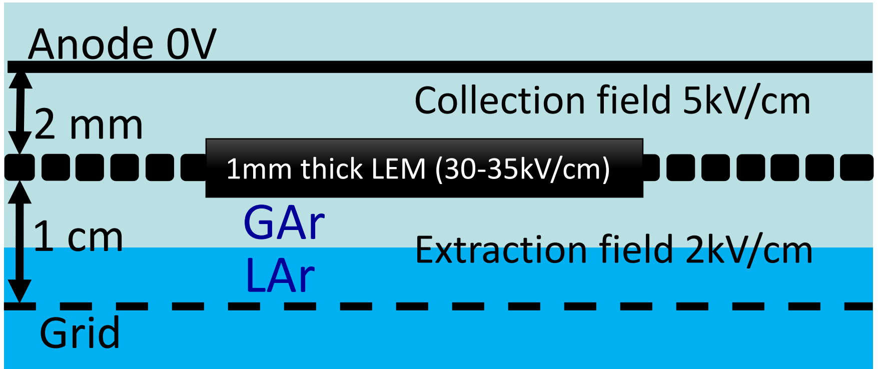
coated PMTs

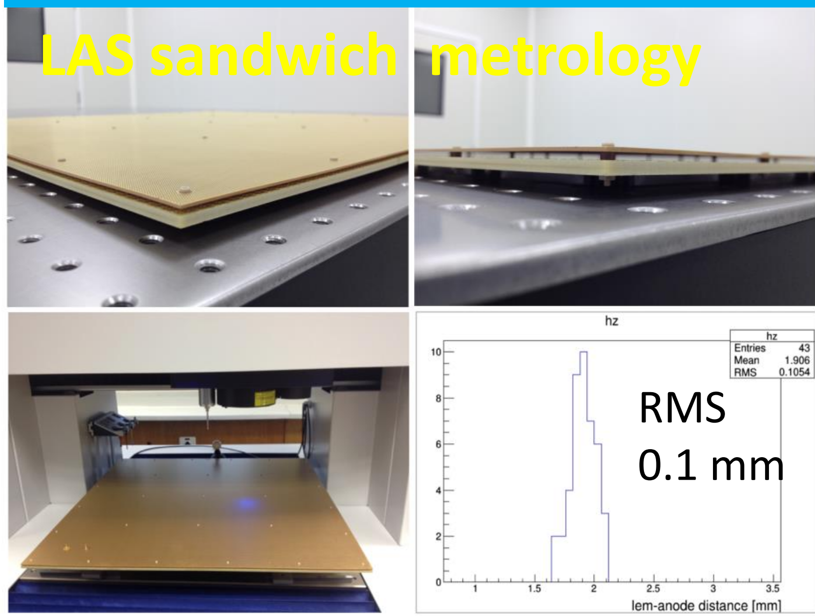
slow control flanges

CRP suspensions

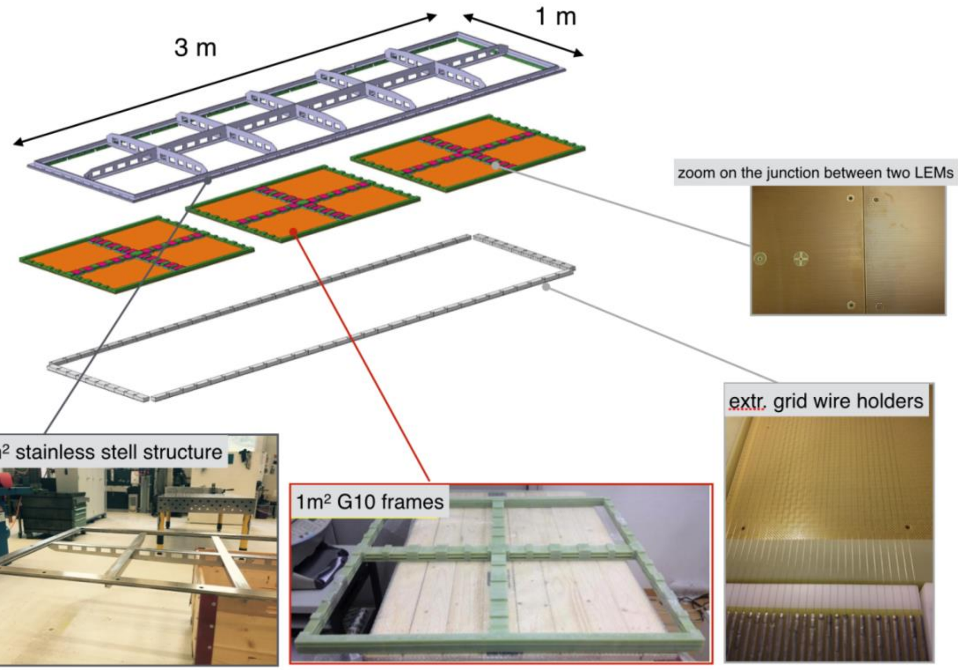
Almost all of the components are now on-site
Ready for detector assembly!

LEM-anode sandwich



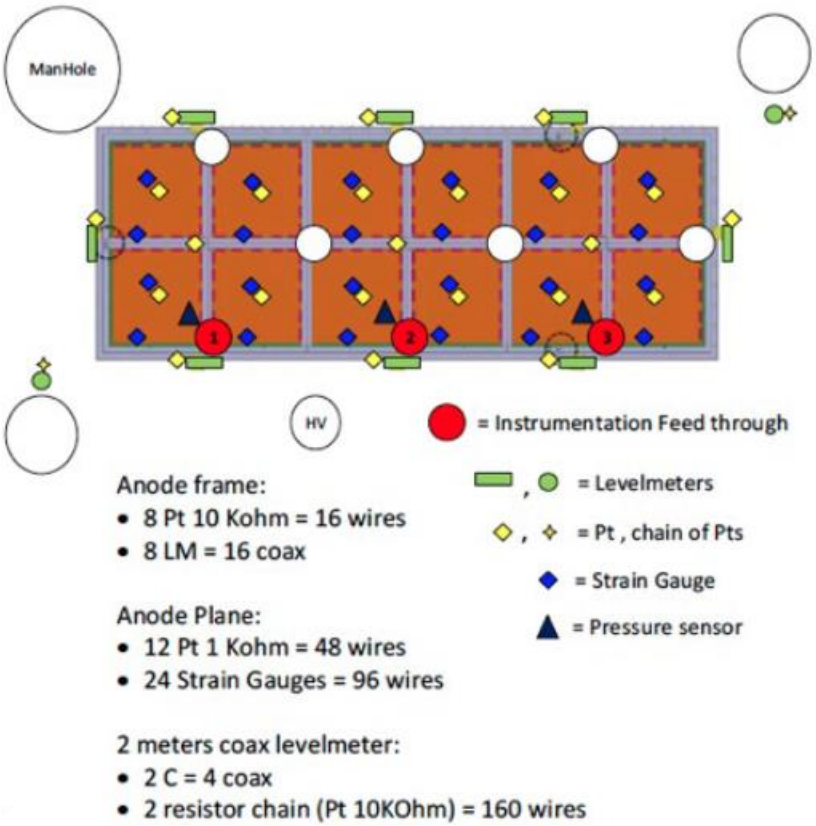


50x50 cm^2 LEM / anodes mounted on a frame

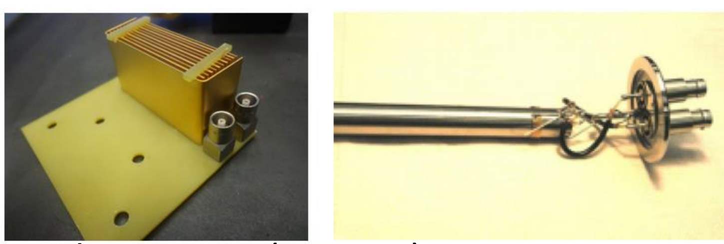


- Clean room infrastructure (ISO-8 class) in Bld. 182
- Full QA chains set up
- Now ready for 6x6x6

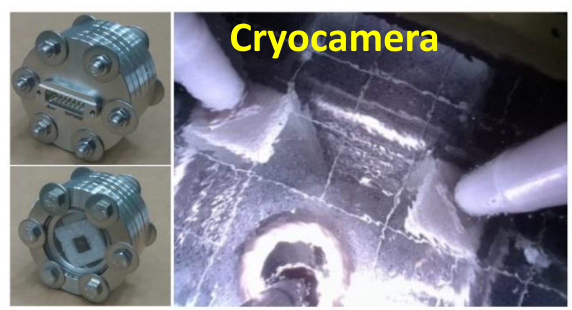
Slow control system

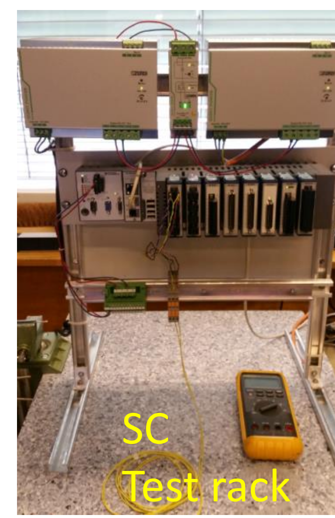


- Extensive network of sensors to completely characterize behavior of CRP
- System designed in collaboration with CERN EP-DT (G. Miotto, N. Bourgeois, G. Maire, S. Ravat, Y. Rigaut)
  - Integrated control of level meters, temperature and pressure sensors, strain gauges, cryocamera
  - Based on National Instruments compactRIO with UNICOS supervisor and single LabView interface
- Easily scalable to the DLAr 6x6x6

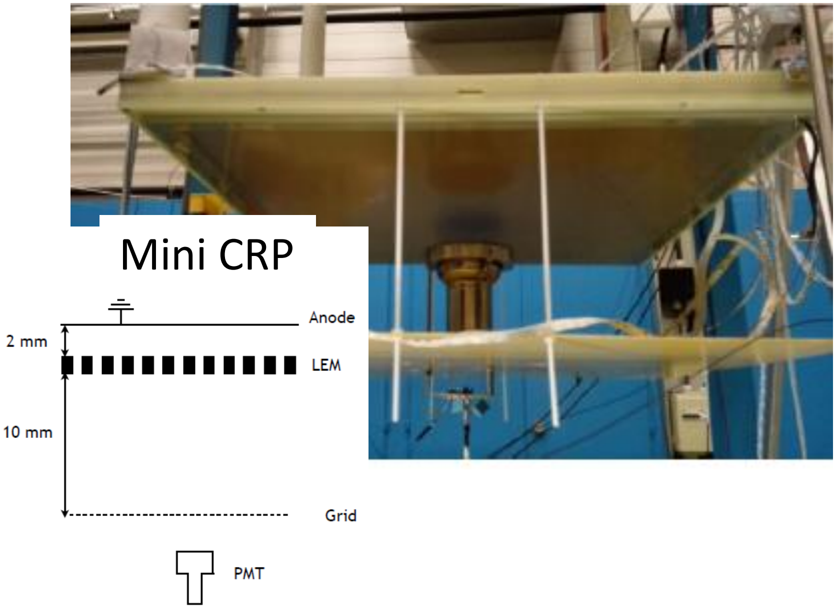


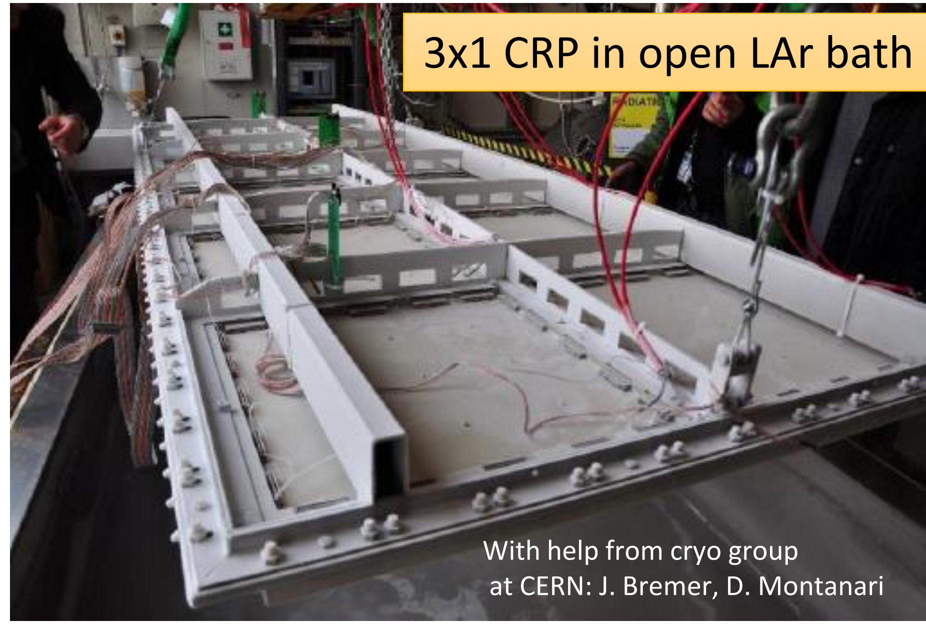
High accuracy (100 um)
and standard (1 mm) level meters





CRP cryogenic tests

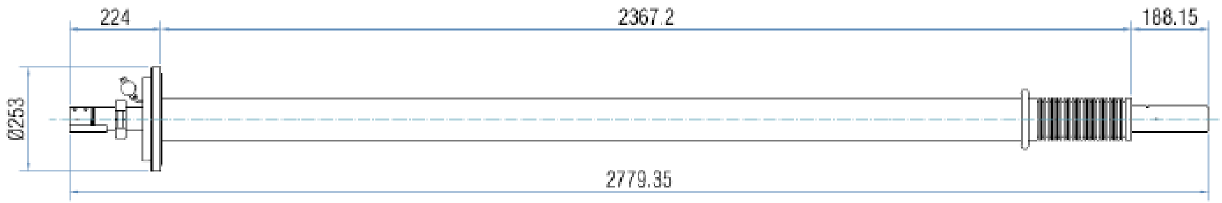




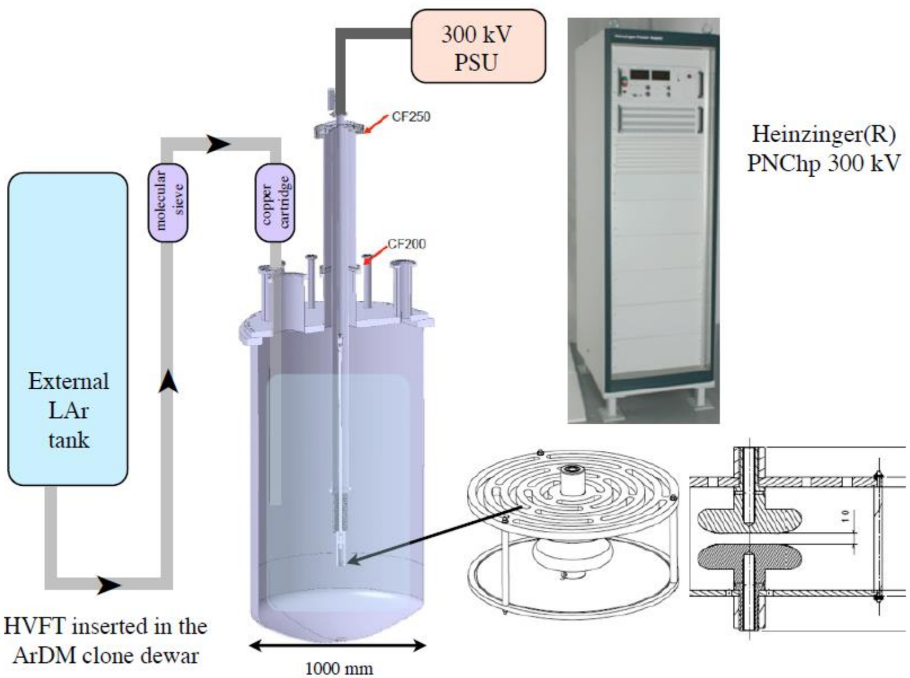
- 50x50 cm^2 LEMs have been successfully tested in pure gas argon at 87K
- The fully assembled CRP mechanical structure has been tested twice in open LAr bath
  - Photogrammetry and strain gauges to measure deformations
- Test of near final configuration (anodes, LEMs, level meters, cameras, …) done in March 2016
  - All instrumentation functioned properly

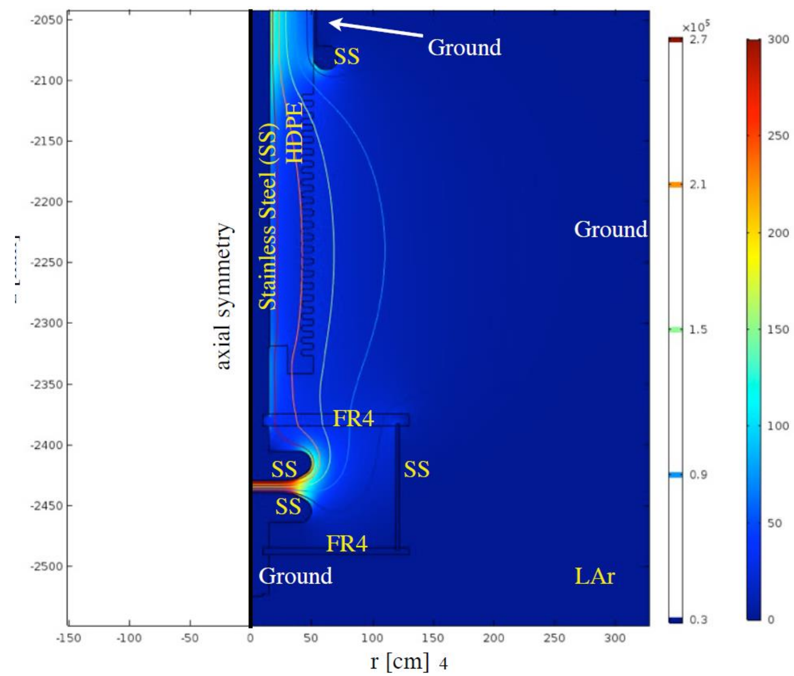
High voltage

- Minimal required HV on the cathode for DLAr is 300 kV → 0.5 kV/cm drift field strength over 6m
- HV feedthrough for LArProto capable to withstand 300kV operation has been designed
- The FT will be tested at CERN with 300kV Heinzinger PS already acquired for WA105



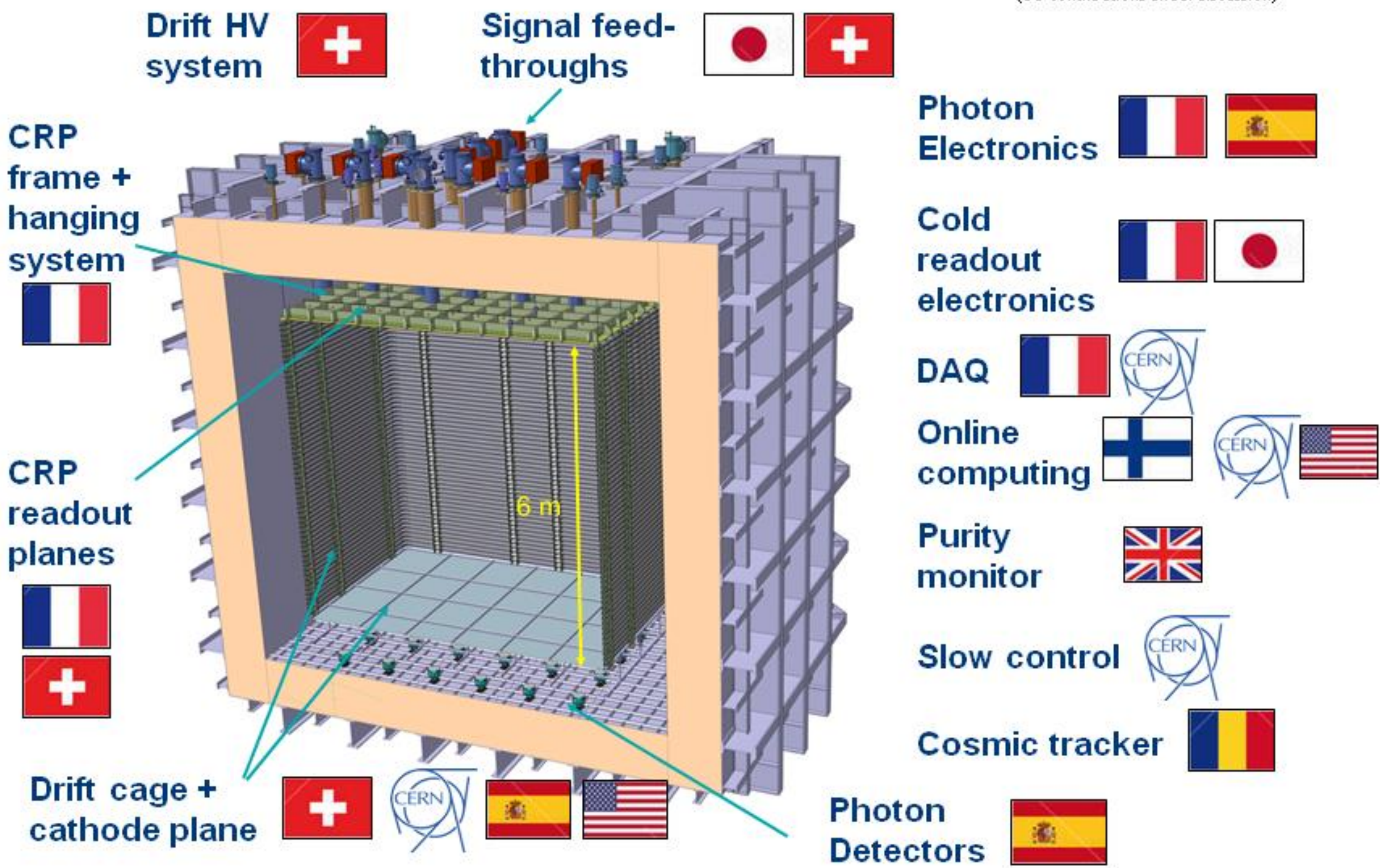
COMSOL simulation of fields around feedthrough



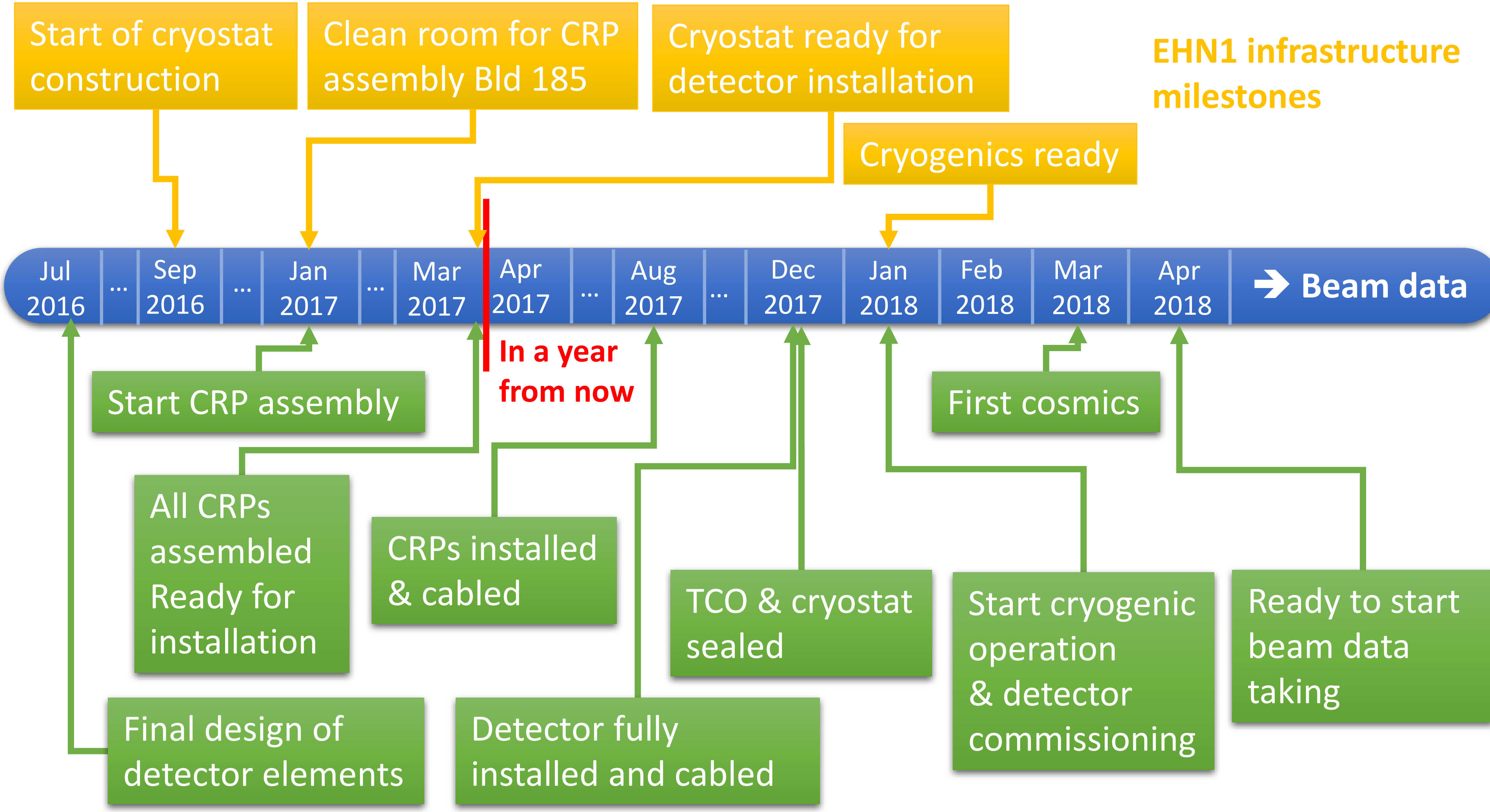


Dual phase protoDUNE - WA105 6x6x6m^3

(US contributions under discussion)

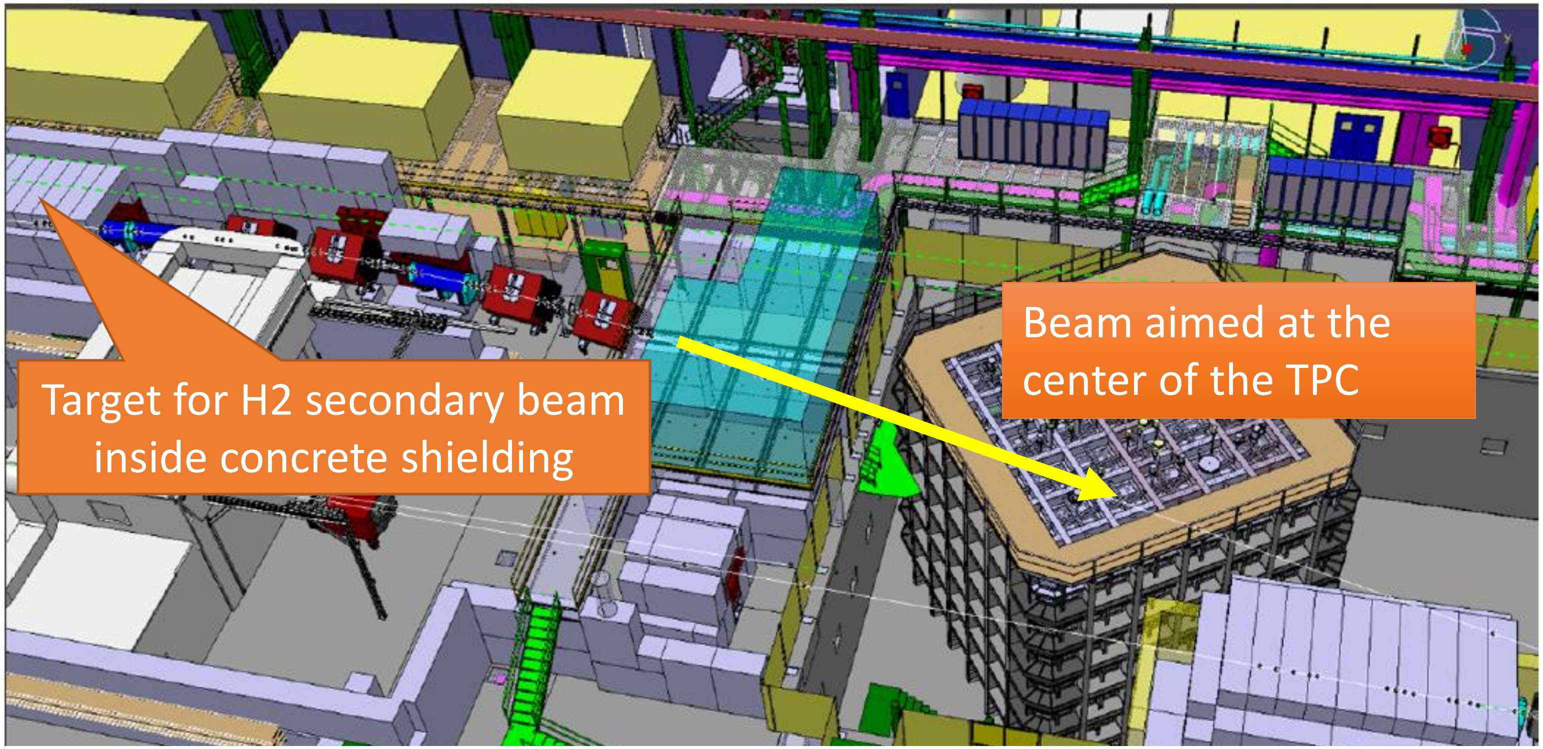


WA105 6x6x6 timeline



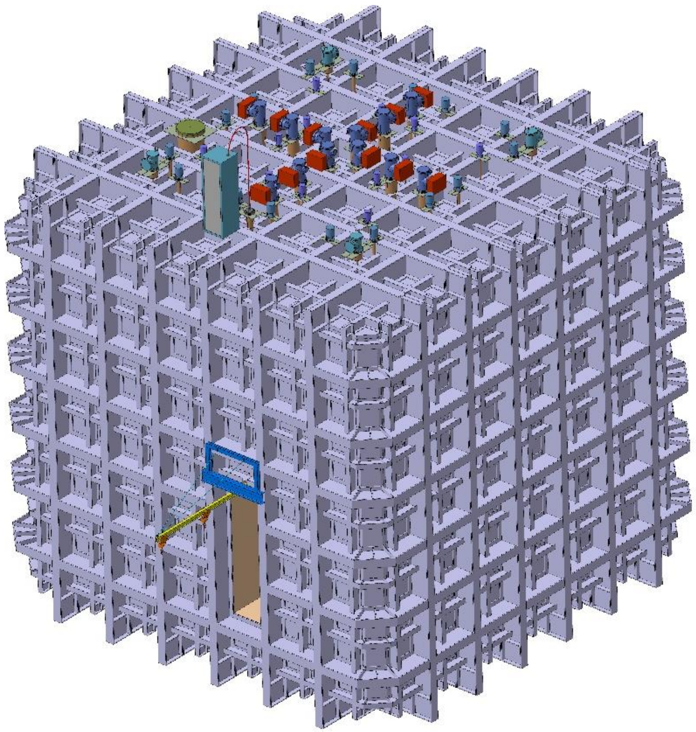
WA105 timeline is fully compatible with EHN1 general schedule
The critical path is defined by availability of infrastructure (clean room in Bld 185, cryostat, cryogenics) provided by Neutrino Platform

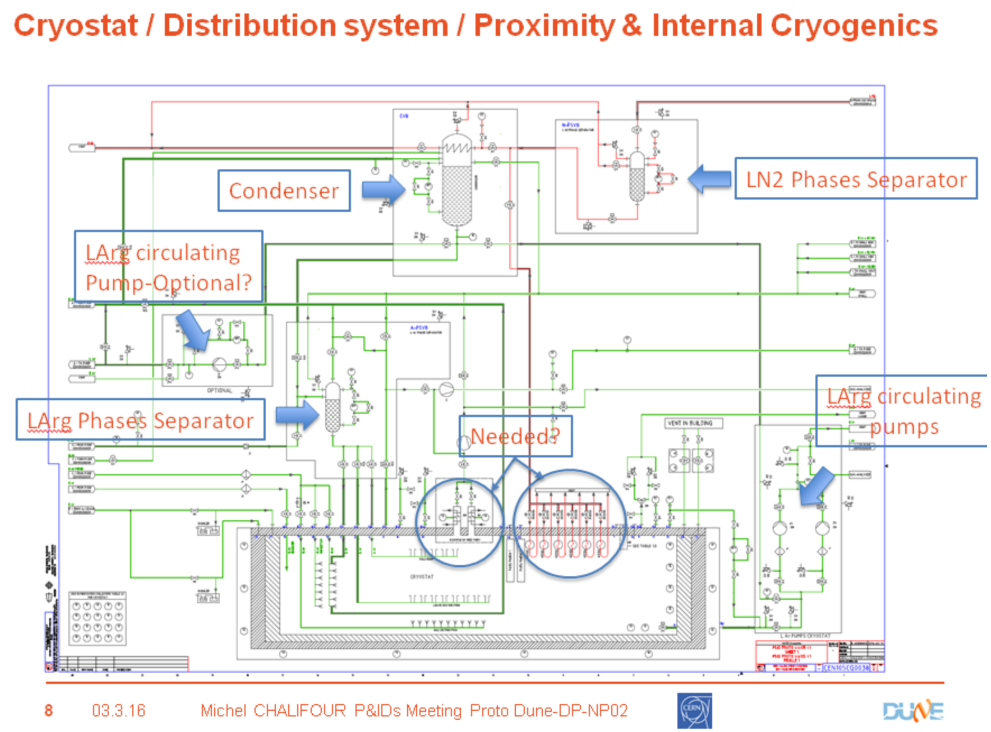
WA105 DLAr in EHN1



- The design of the beamline is almost complete
  - First results of flux simulations from CERN beamline group included in the evaluation of the beam time request
- Efforts to be placed on design of beam instrumentation
  - Particle ID system for π/p/K over all beam momentum range
  - Magnetic spectrometer to reduce momentum bite from 5% to ~1%

Interface to CERN infrastructure





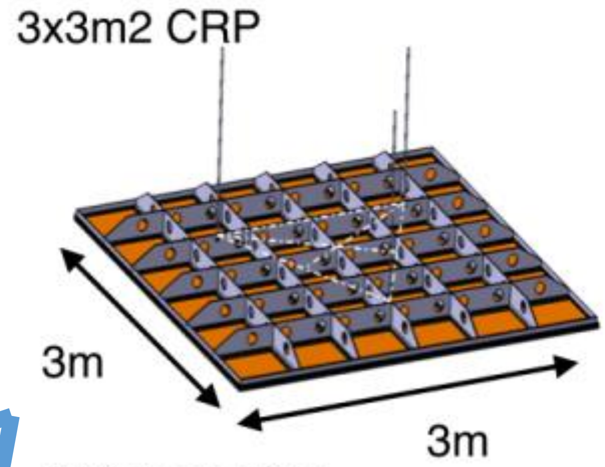
Completed definition of all detector interfaces to cryostat infrastructure

EHN1 Cryogenics:
- Design closure in April 2016
  ➔ Cryo specification meeting 14/04/16
- Contract to be assigned by end of June 2016
- Installation summer 2017

Schedule EHN1:
- Construction of steel structure: July-September 2016
- Assembly of cryogenic insulation: October 2016-April 2017
- Detector assembly inside the cryostat: April-November 2017

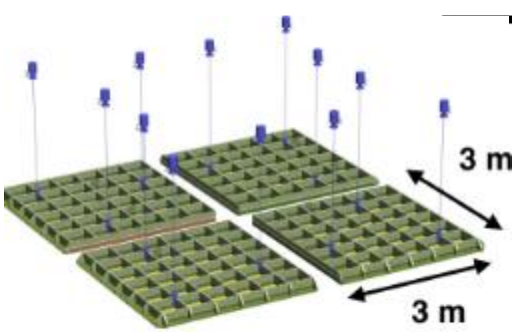
Modular CRP

- CRP is composed of 4 3x3 m^2 readout units built from 50x50 cm^2 LEM and anodes
- Each unit has its own suspension system
- Charge is collected on 3m “strips”
- Identical structure is envisioned for DUNE 10kt



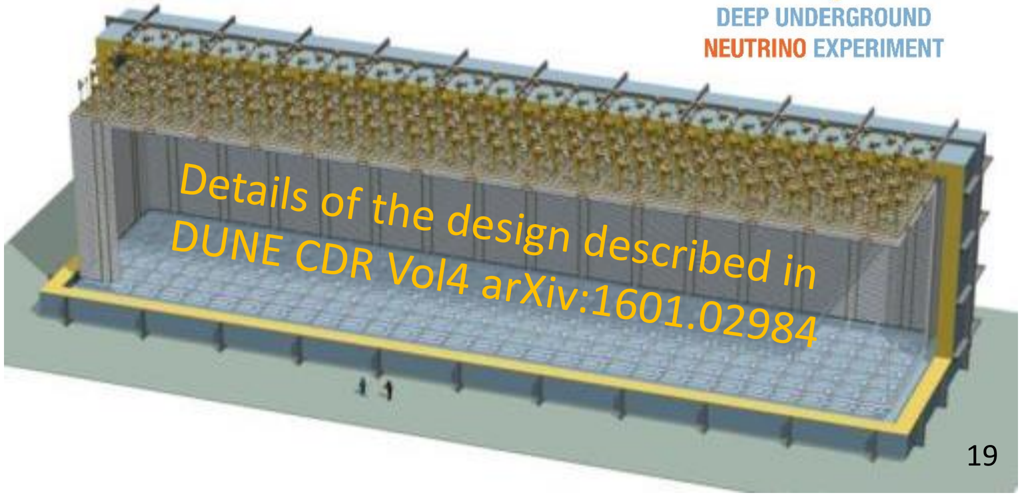
1920 channels/CRP
Accessible cold electronics in chimney

WA105: 4 CRPs



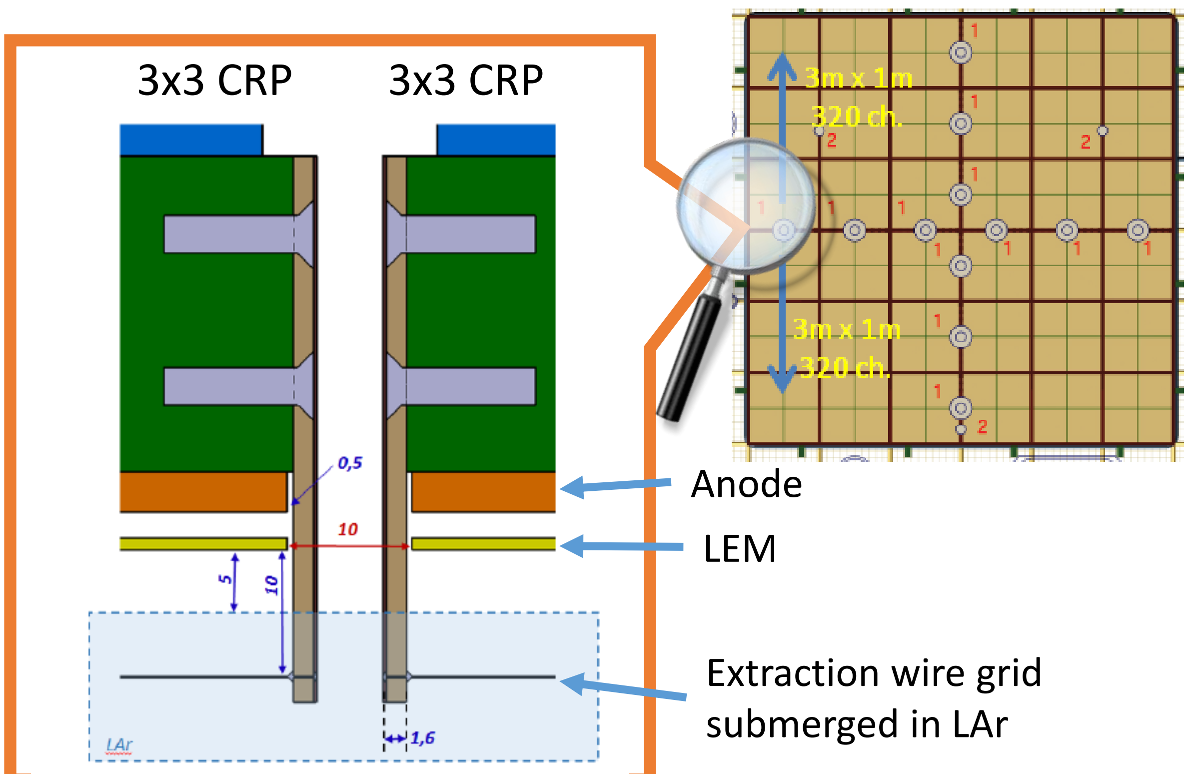
DUNE 10kt: 80 CRPs

DEEP UNDERGROUND NEUTRINO EXPERIMENT



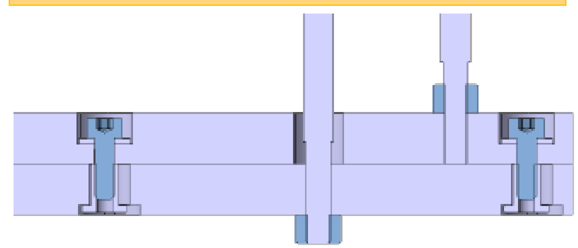
Status of CRP

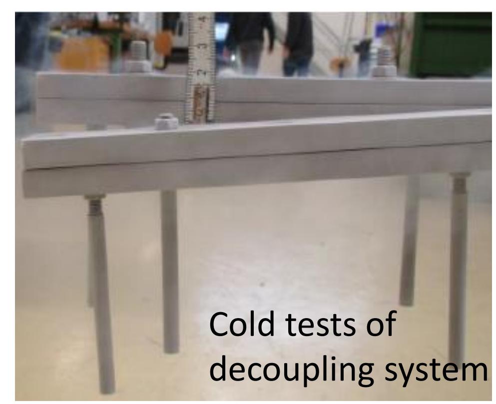
- CRP design is being finalized
  - Extrapolation based on experience from 3x1 CRP design
    - Extraction grid with 3m long wires
    - Photogrammetry measurements and slow control data from cold bath tests
  - Minimize spacing between adjacent CRP modules – presently gap of 10mm (warm)
  - Account for thermal contraction between different elements



Constrain inter-module distance between CRPs <10mm

Decoupled fixation system

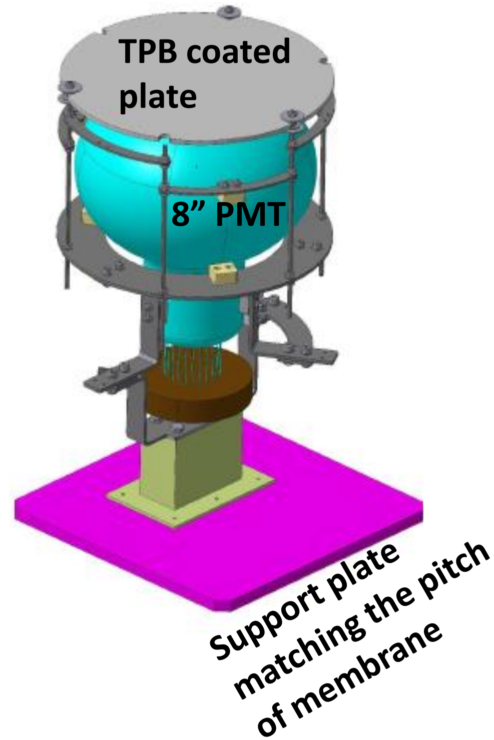


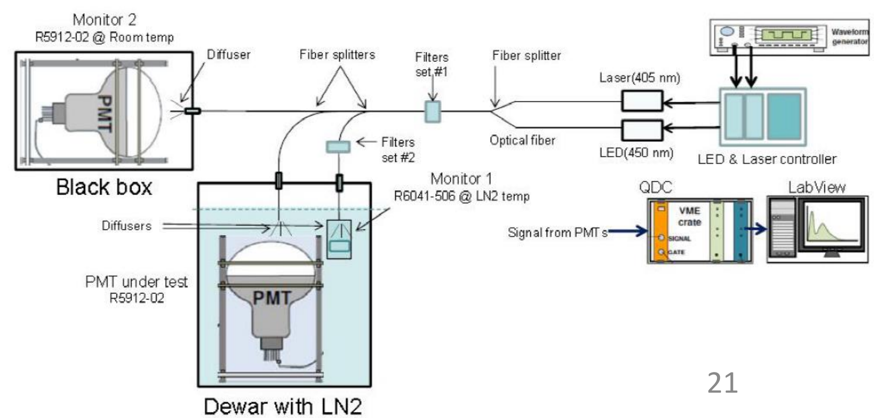


Cold tests of decoupling system

Light readout

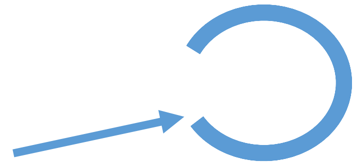
- Scintillation light is detected with a grid of 36 8” Hamamatsu (RD5912mod2) PMTs
- The PMTs are attached SS base plates affixed to cryostat membrane in flat regions between corrugation grooves
  - Support weight is designed to cancel out PMT buoyancy
  - ➔ no net strain on the membrane
- Signal/HV splitter circuit has been developed to allow for a single coaxial cable connection per PMT
  - Minimizes # of cables and feedthroughs
- System for PMT characterization at room and cryogenic temperature has been built (up-to 4 PMTs could be tested simultaneously)
  - Gain – voltage calibration
  - Dark current rates
- PMT procurement from Jun. 2016 – Sep. 2016
- Design of calibration system for DLAr underway





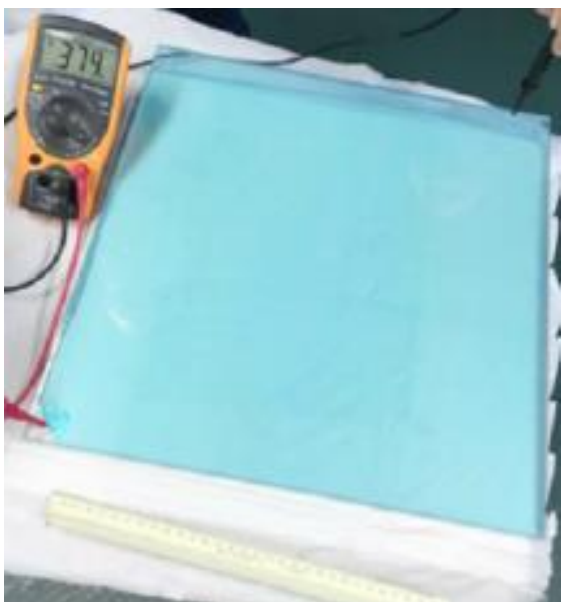
Field cage & cathode

- Baseline design: rings from SS tubes suspended by FR4 pillar chains
- R&D at CERN explored possibility of building field cage out of extruded Al open profiles
  - Light structure
  - Open profile to avoid trapping impurities



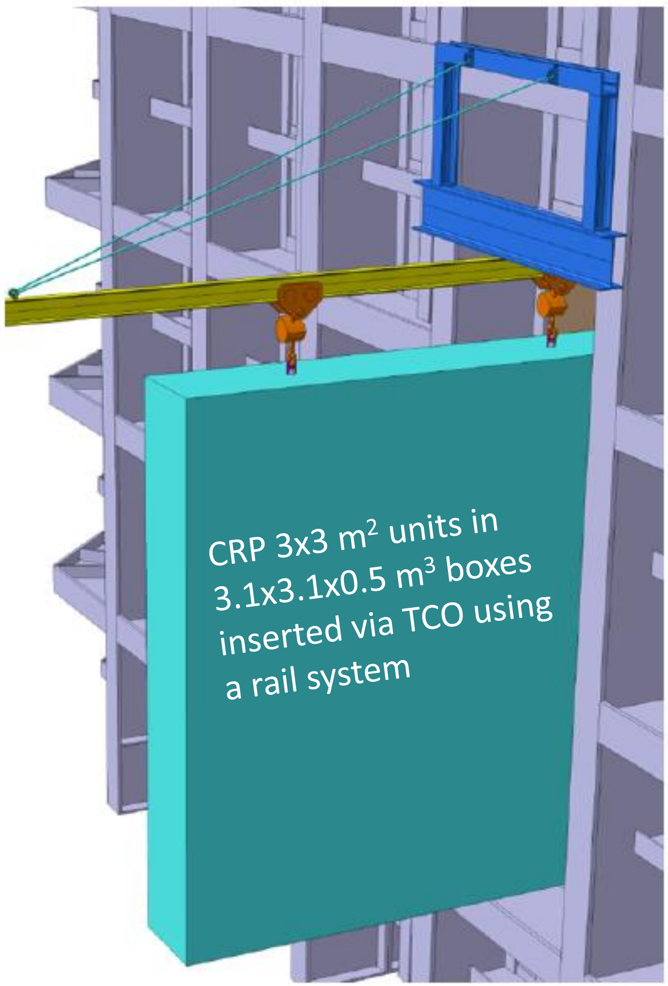
- Successful tests on small scale prototype set up in Bld 182
- Final design is aimed for July 2016

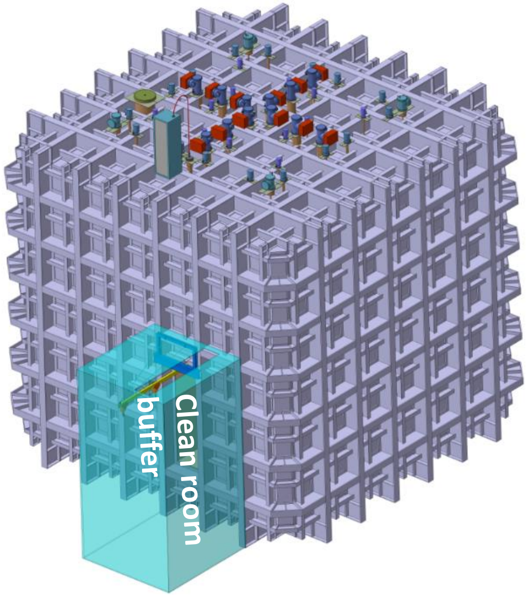
Prototype of field cage w/ open profiles @ CERN

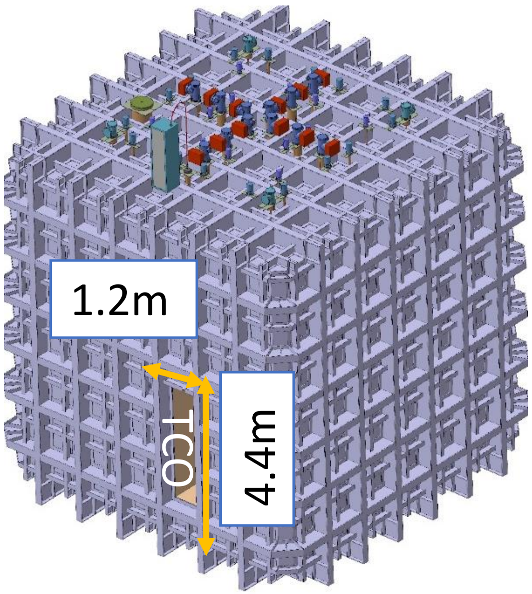


- Transparent cathode built from PMMA plates coated with conductive ITO (Indium Tin Oxide) coating
- TPB coating for VUV shifting
  - Advantage: uncoated PMTs will not be sensitive to light produced below cathode
- Protection against discharges due to possible bubbles from bottom of the tank
- Design of a large PMMA cathode ready by July 2016

Detector installation in EHN1







- First feedthroughs are installed
- The material for detector installation is brought to a clean room buffer and then TCO into the cryostat
- CRPs will be pre-assembled at CERN and then packed in a protective case and then brought in vertically via TCO

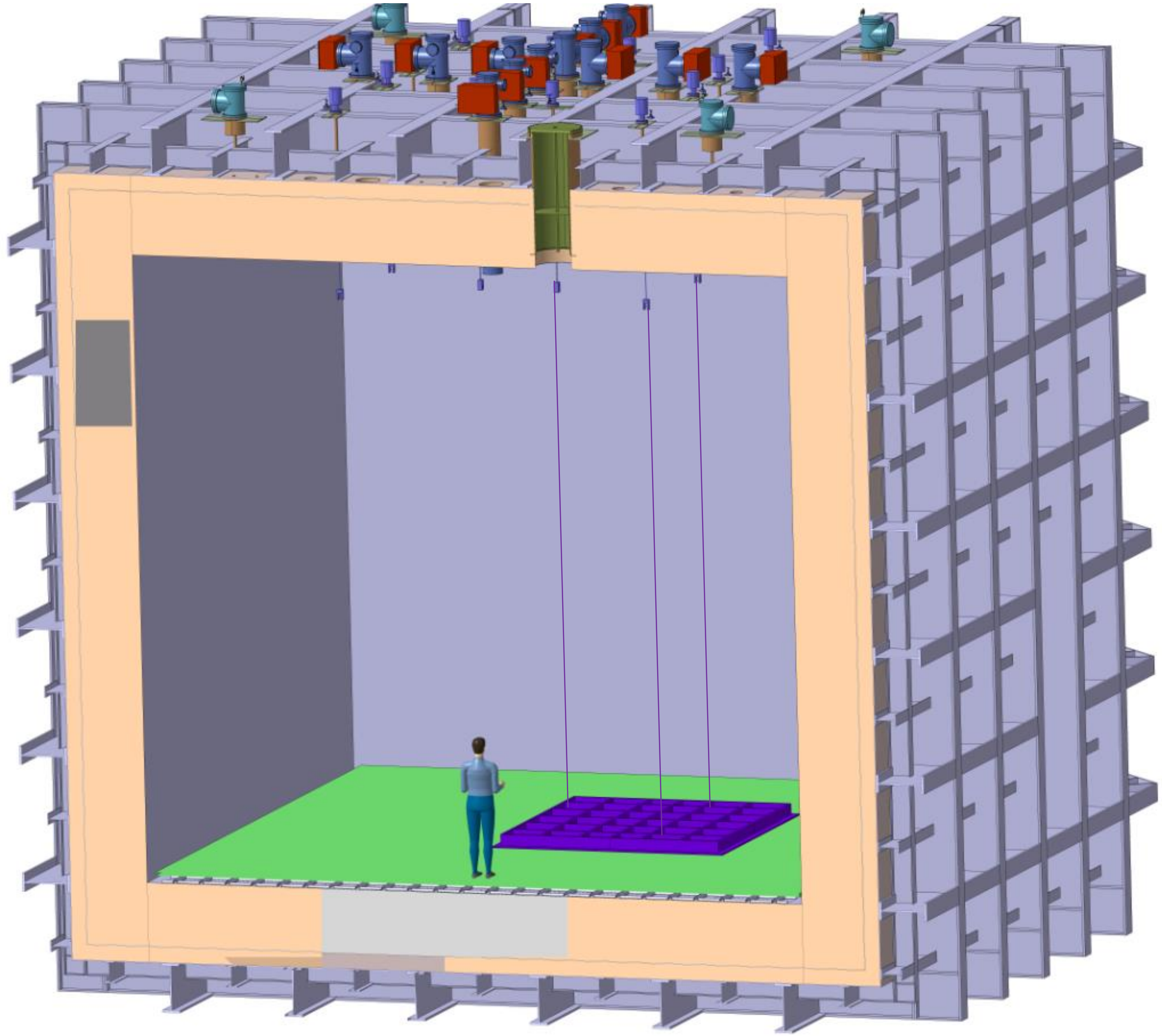
  ➔ Installation sequence same as for 10kt DUNE
- For CRP assembly at CERN a clean room in Bld 185 is requested ➔ Assembly of first CRP to start Jan 2017

TCO = Temporary Construction Opening

CRP 3X3 m²

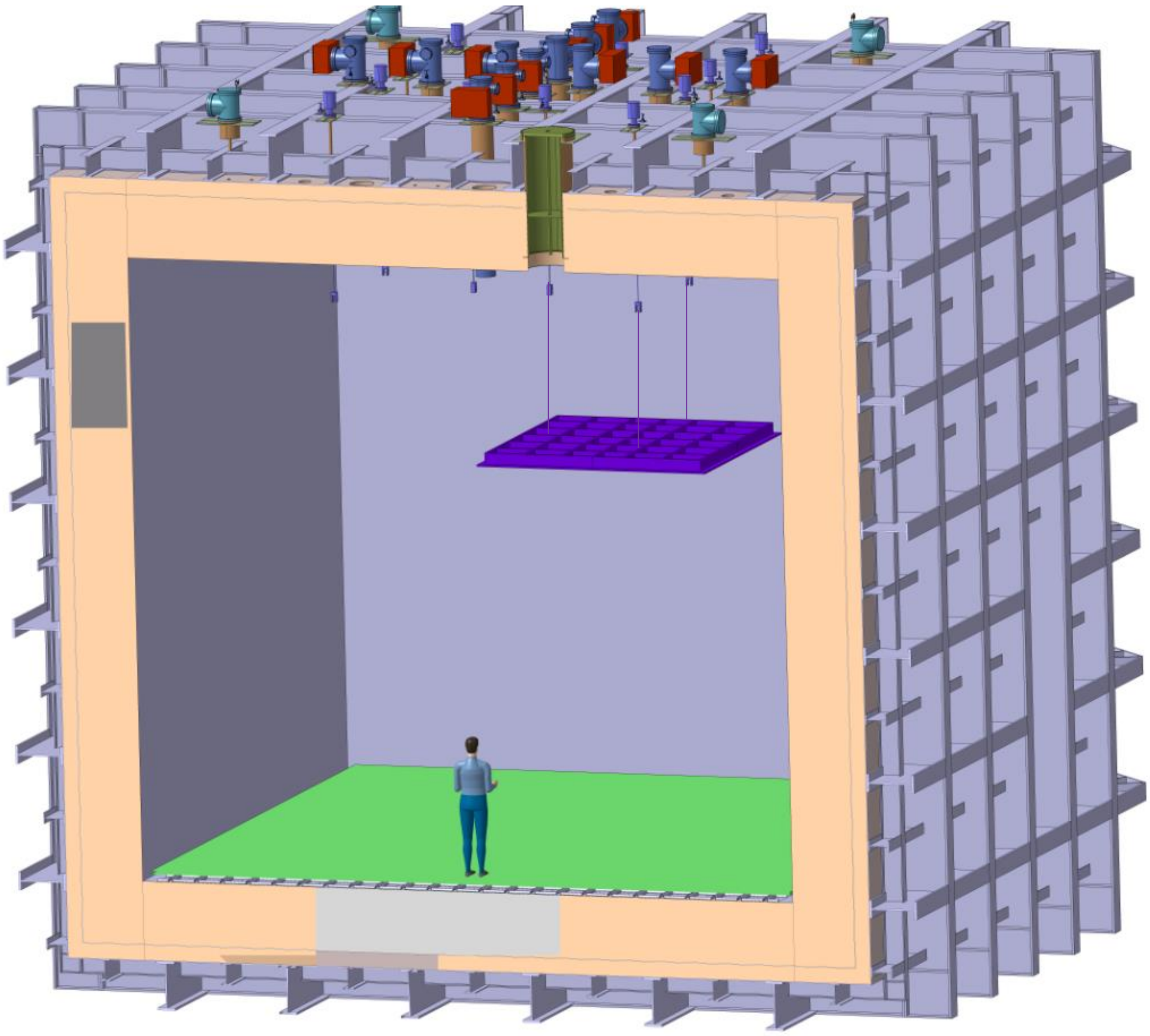
A sequence of frames showing a cut view inside the cryostat will illustrate the assembly procedure

- First CRP assembled and in position



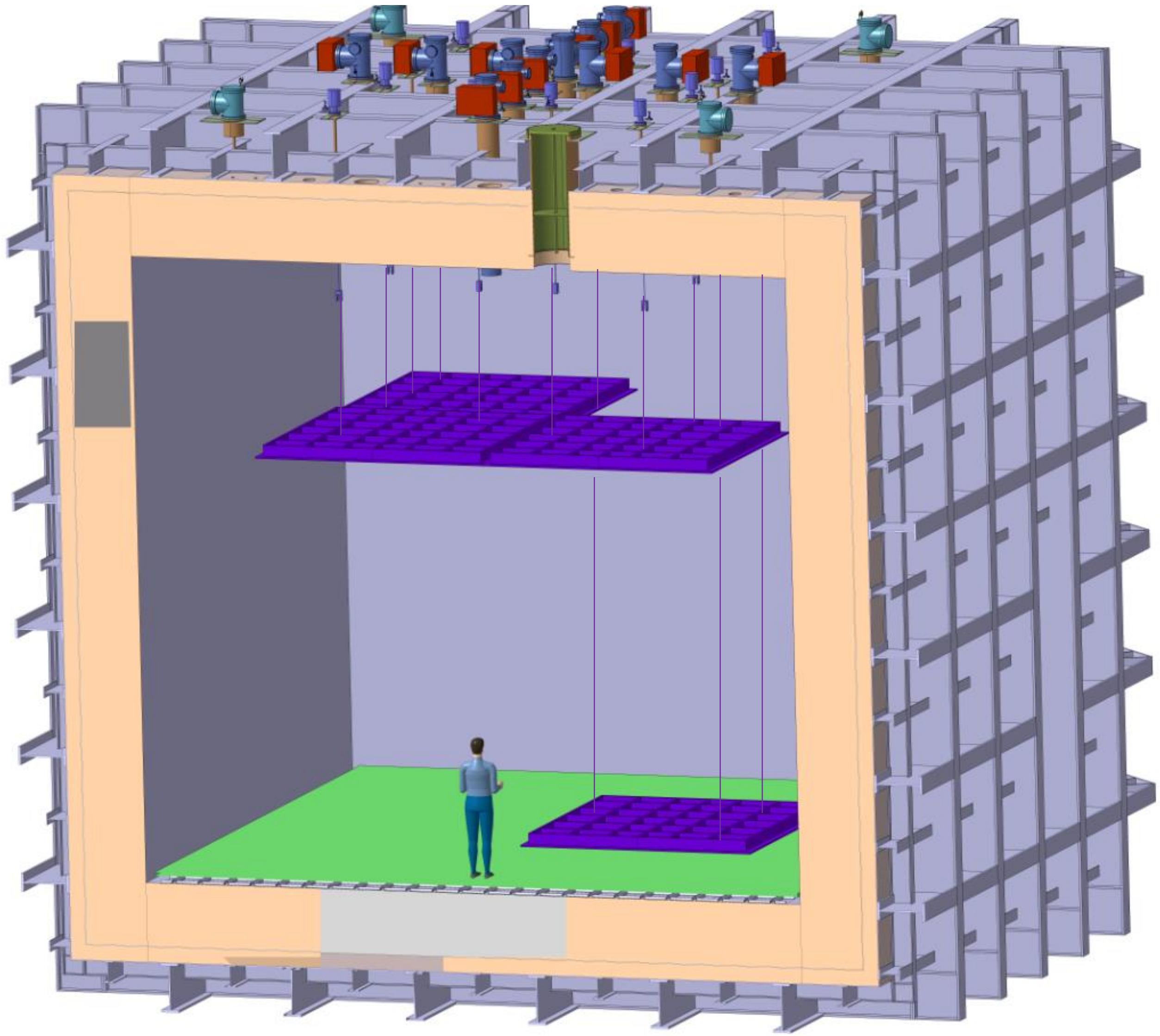
CRP 3X3 m²

- CRP lifted



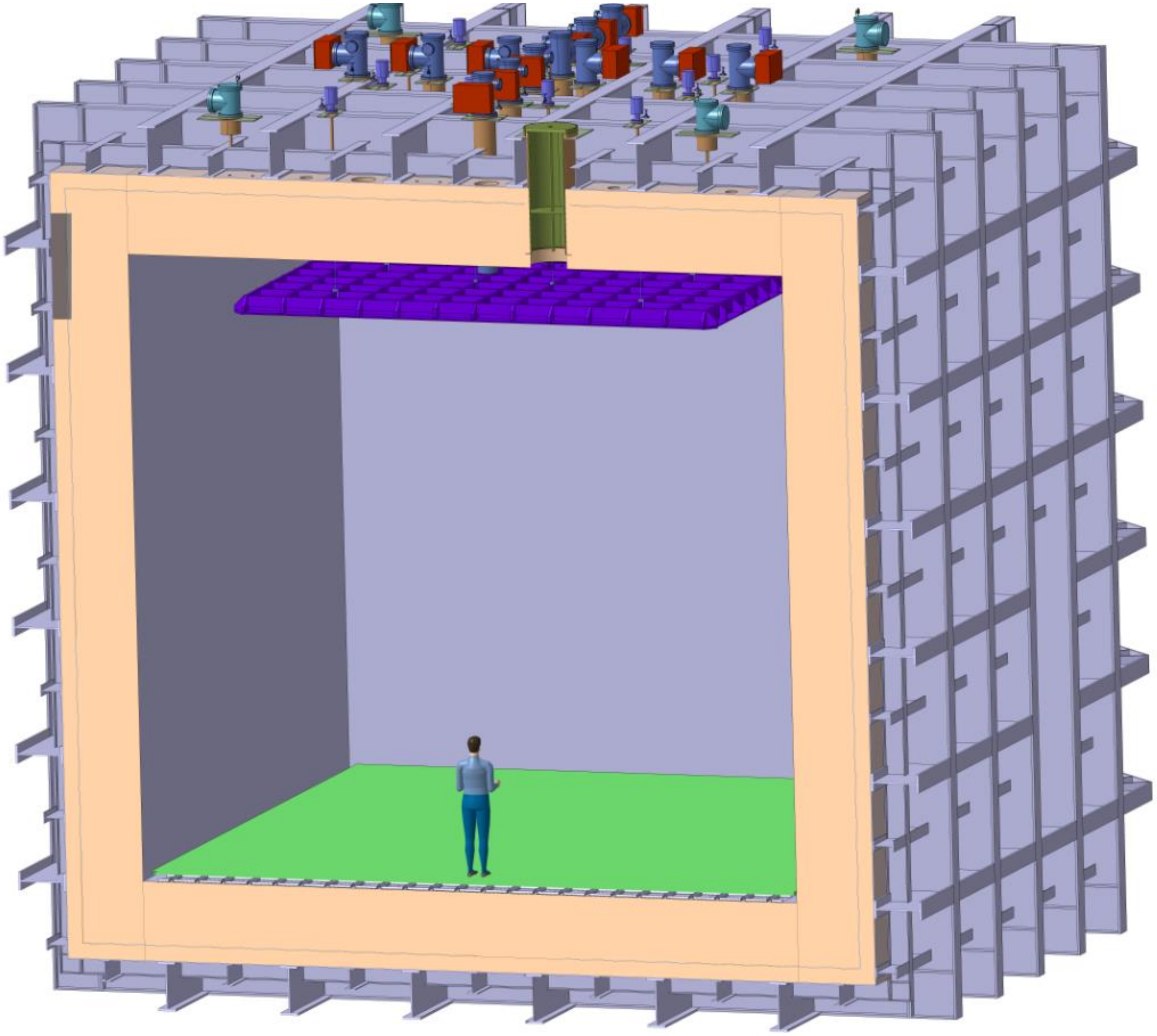
CRP 3X3 m²

- Same Procedure for the other CRPs



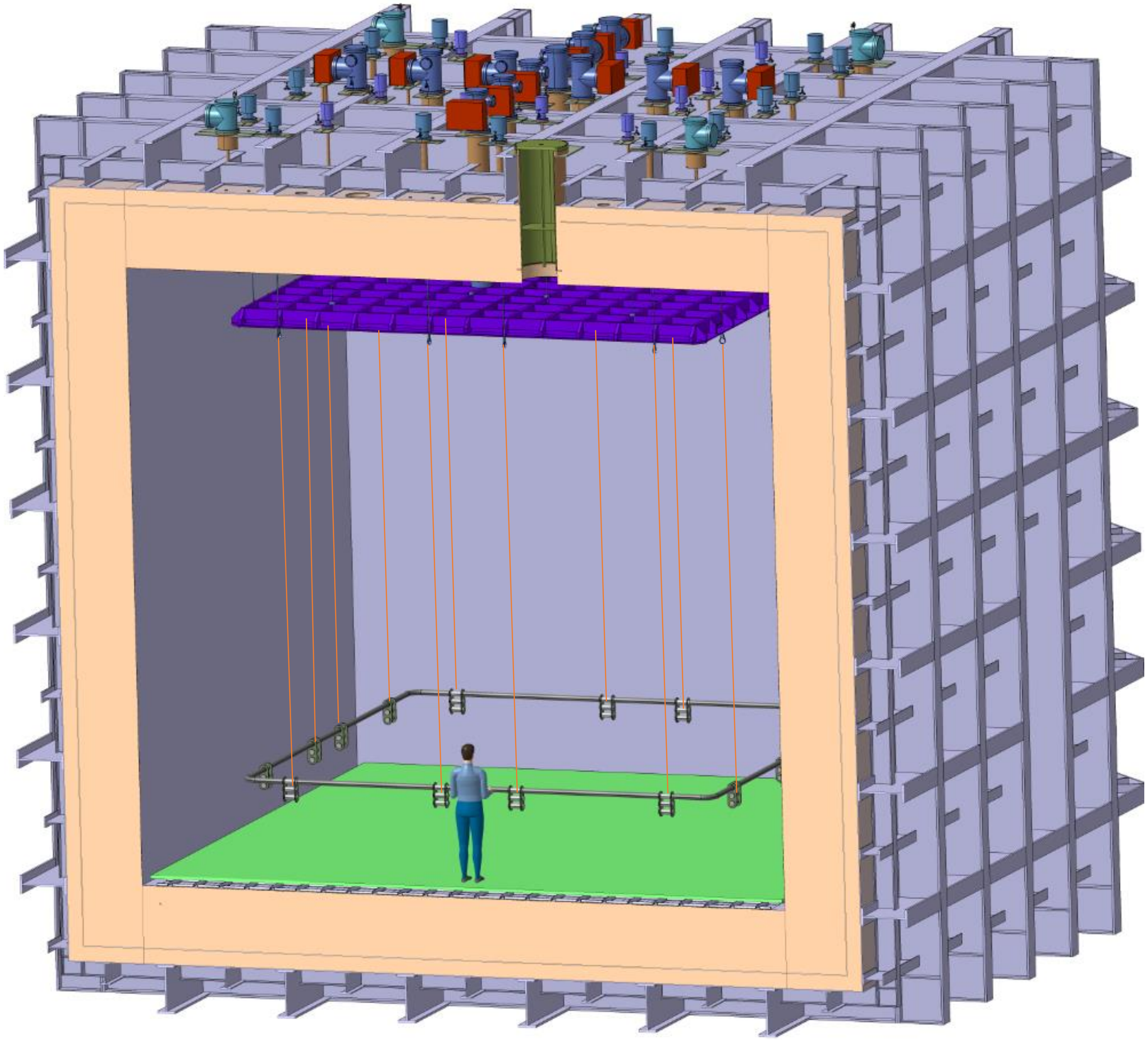
CRP 3X3 m²

- All CRPs fixed on nominal Position



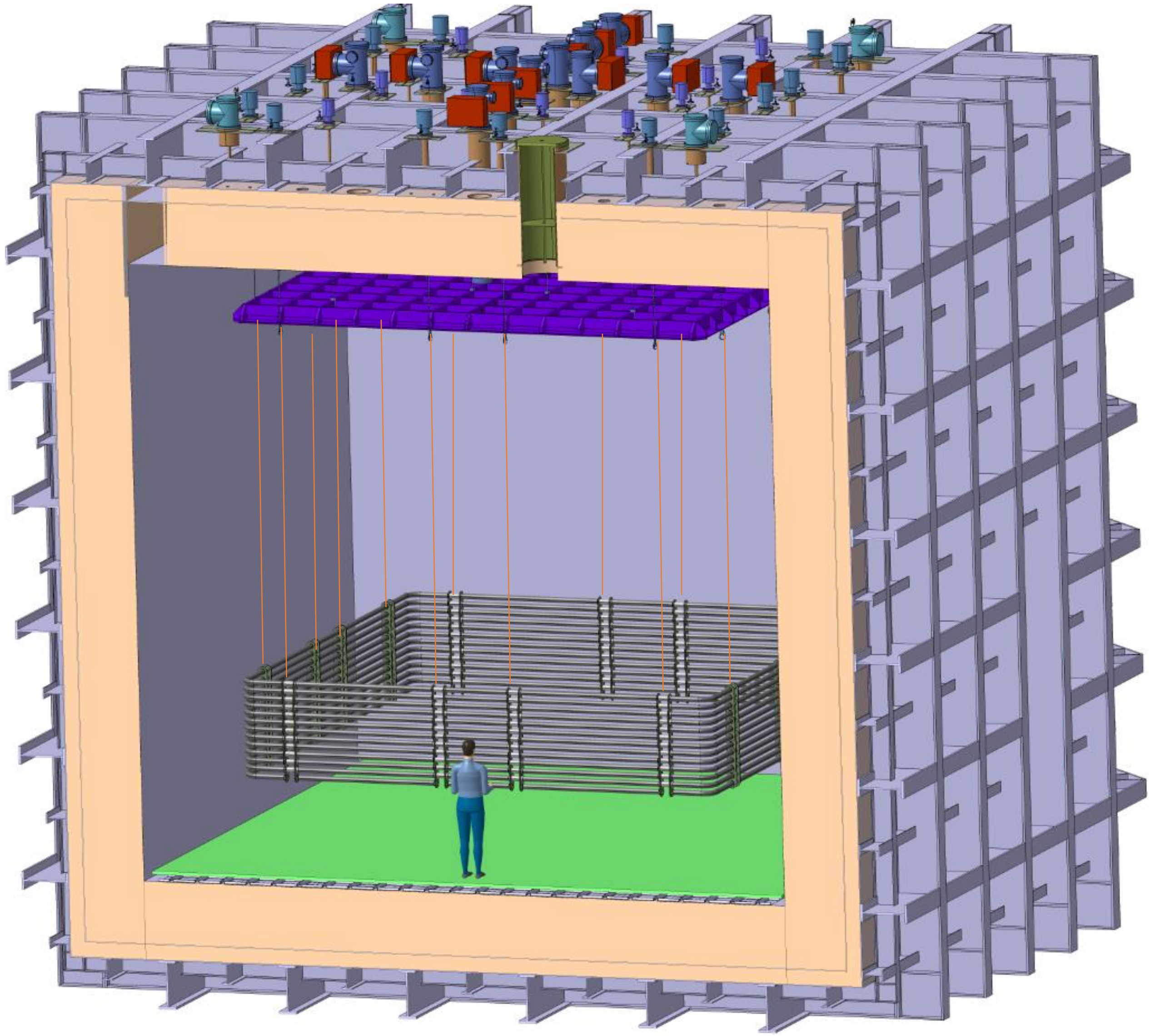
Field Cage

- First Field Shaper Installed



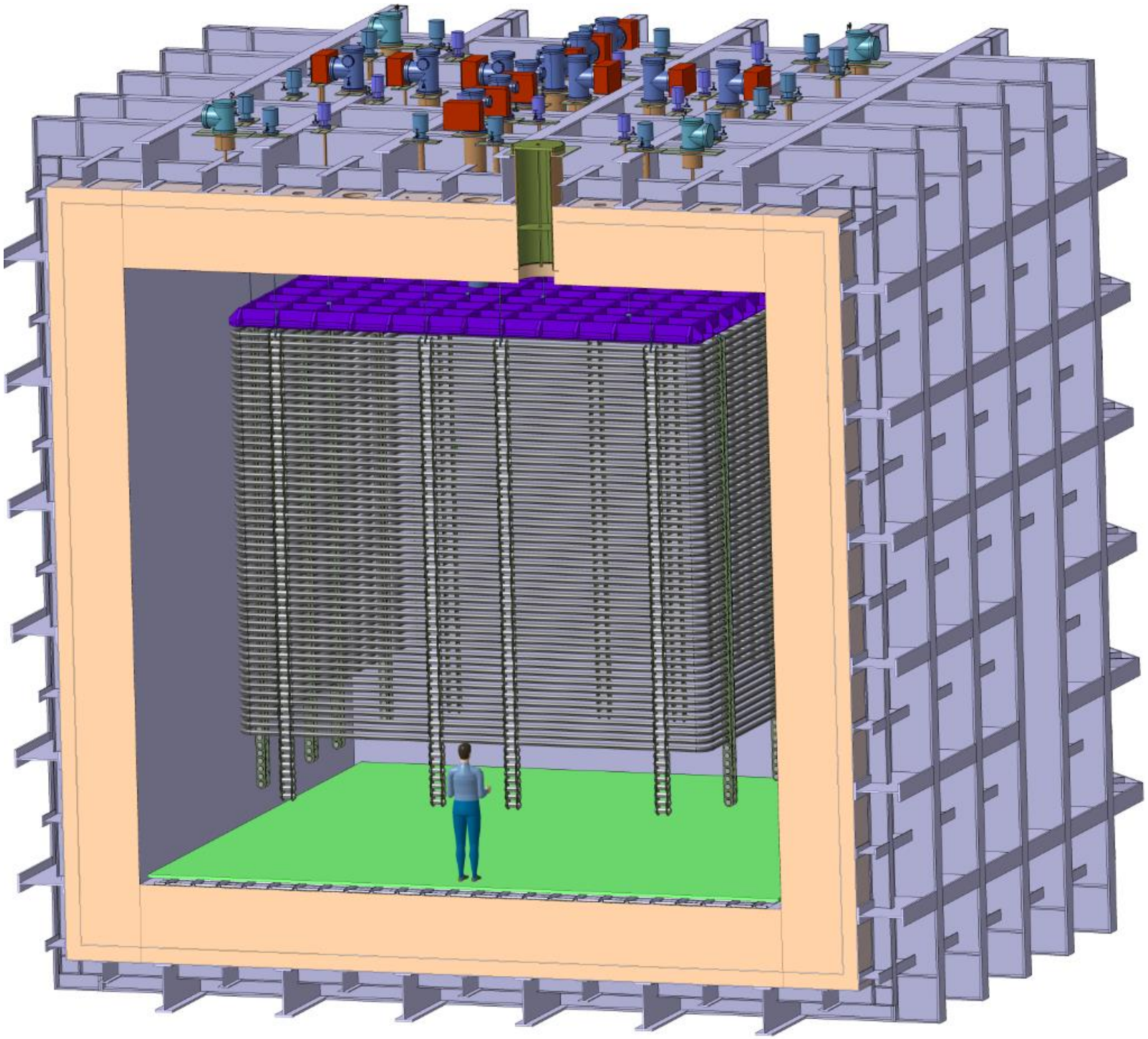
Field Cage

- Drift Cage is lifted as the field shaper are istalled



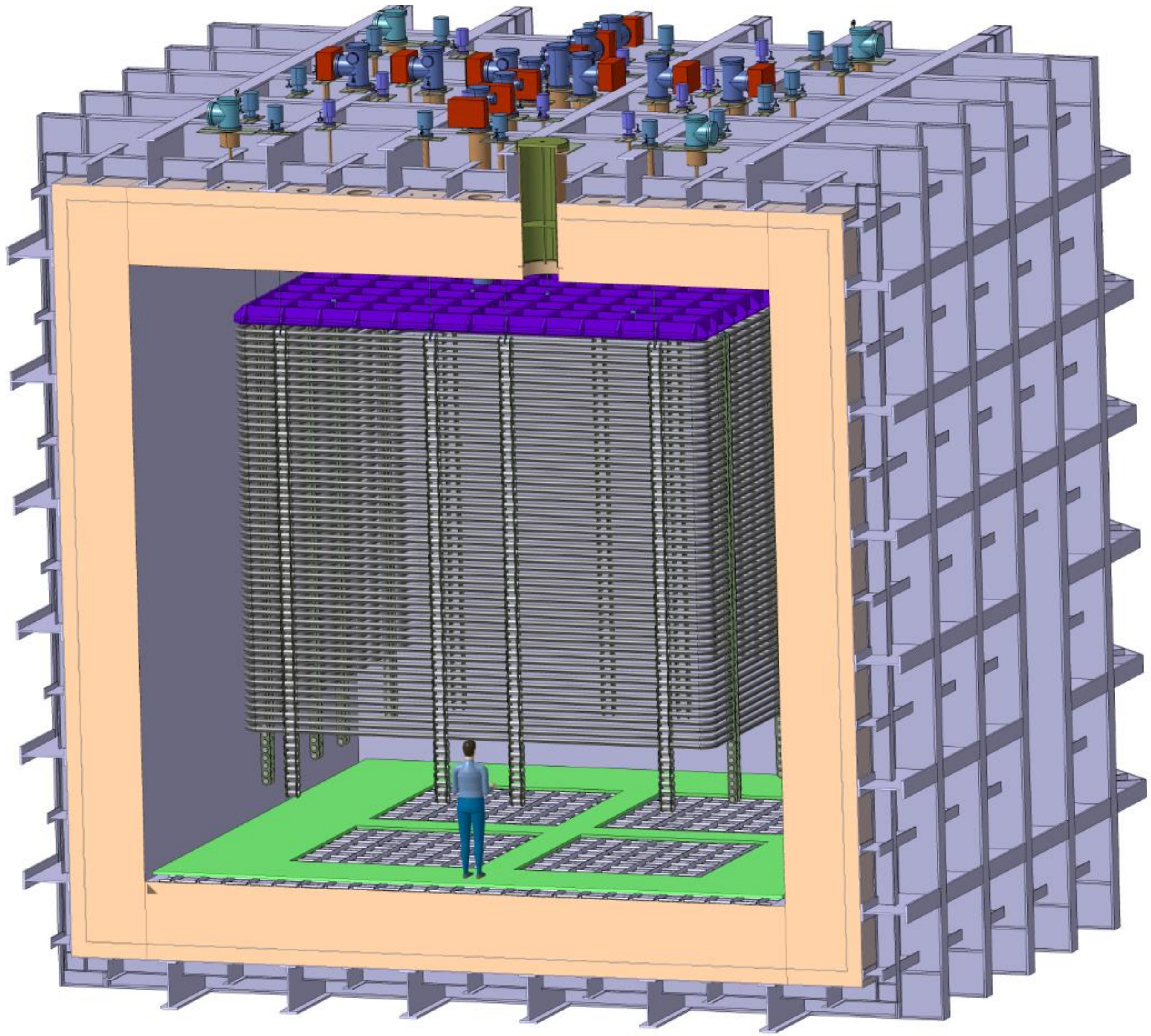
Field Cage

- Last field shapers not yet mounted



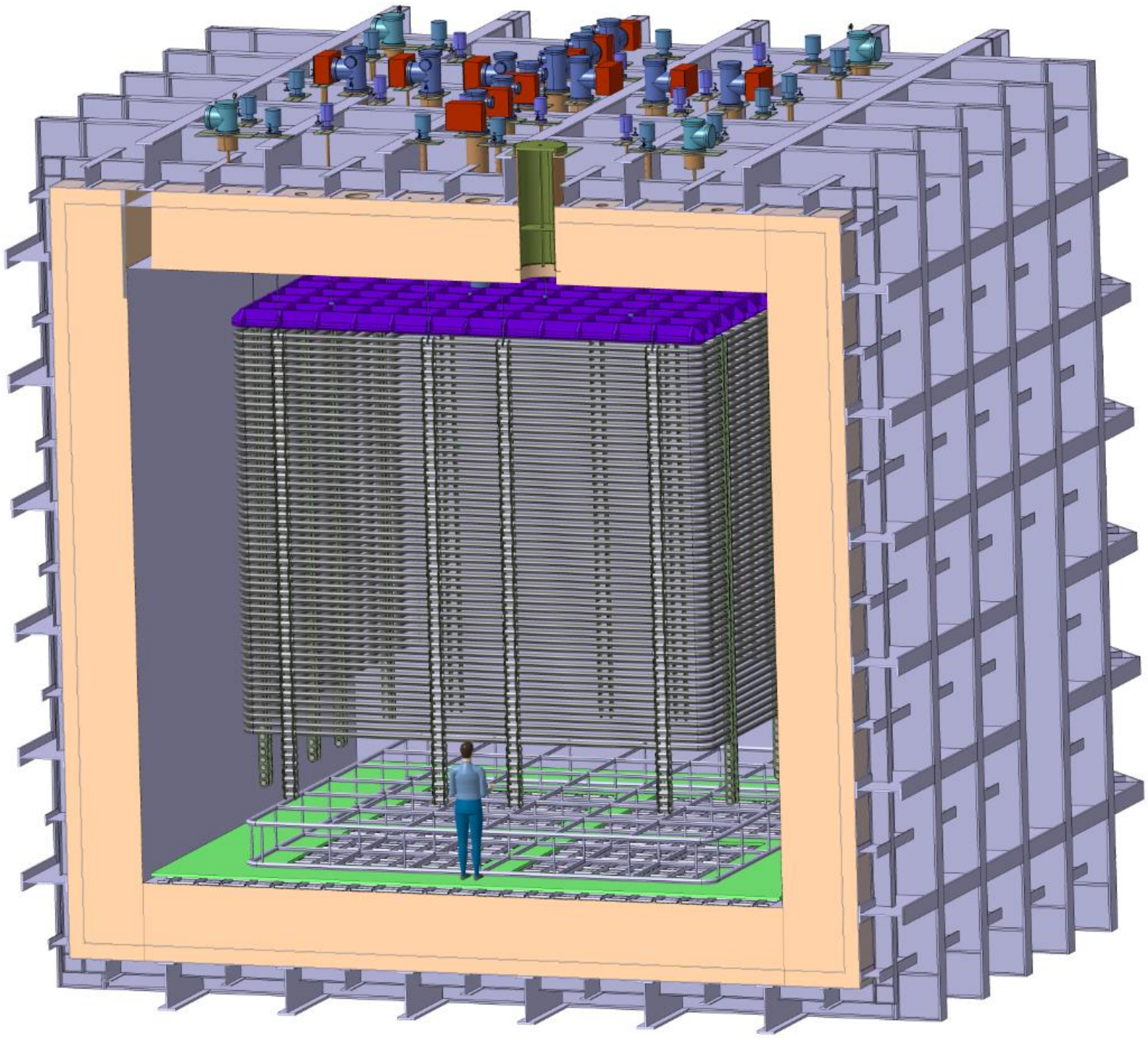
Cathode and PMTs

- Part of the temporary floor is removed



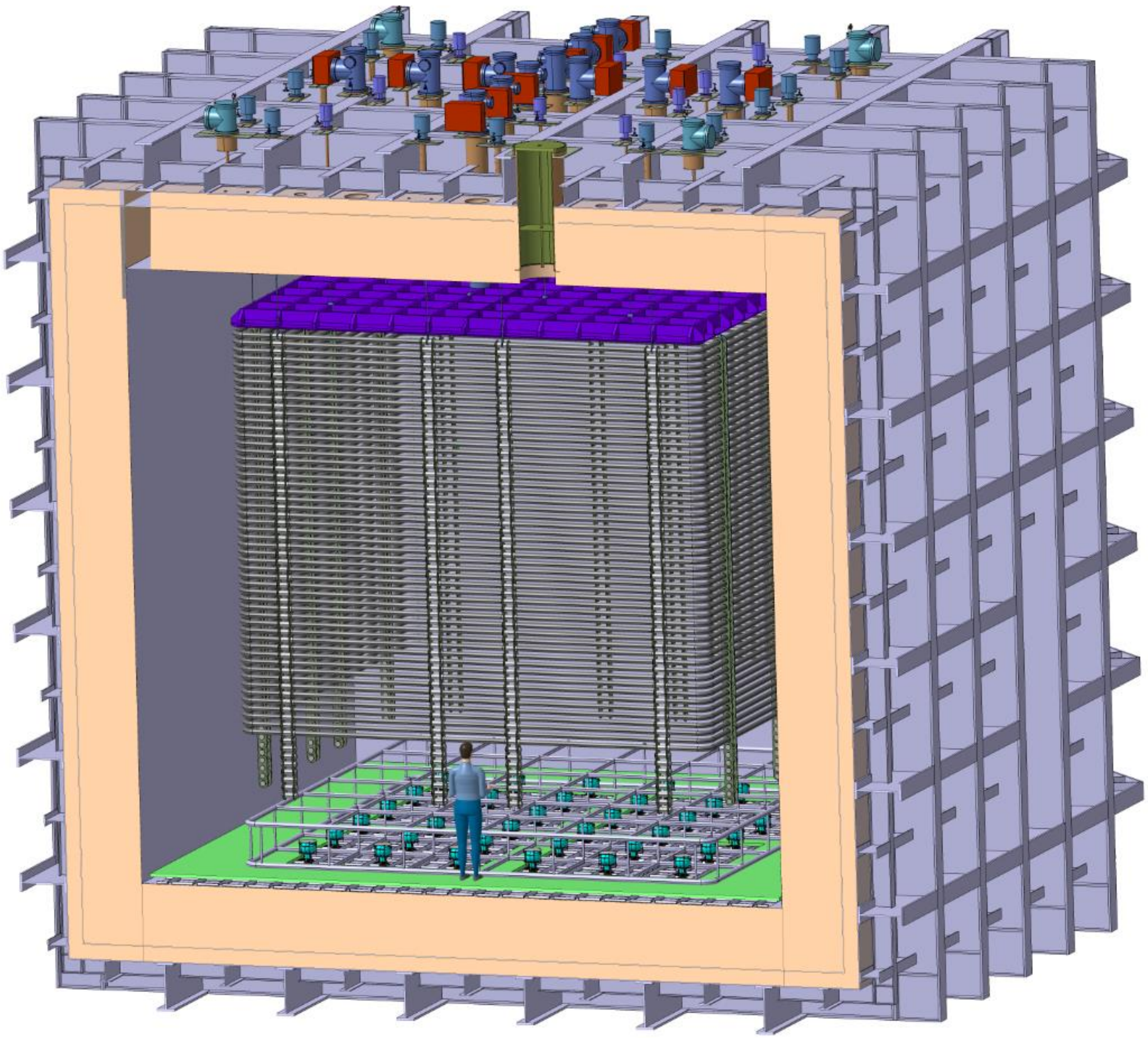
Cathode and PMTs

- Cathode structure assembled on the floor



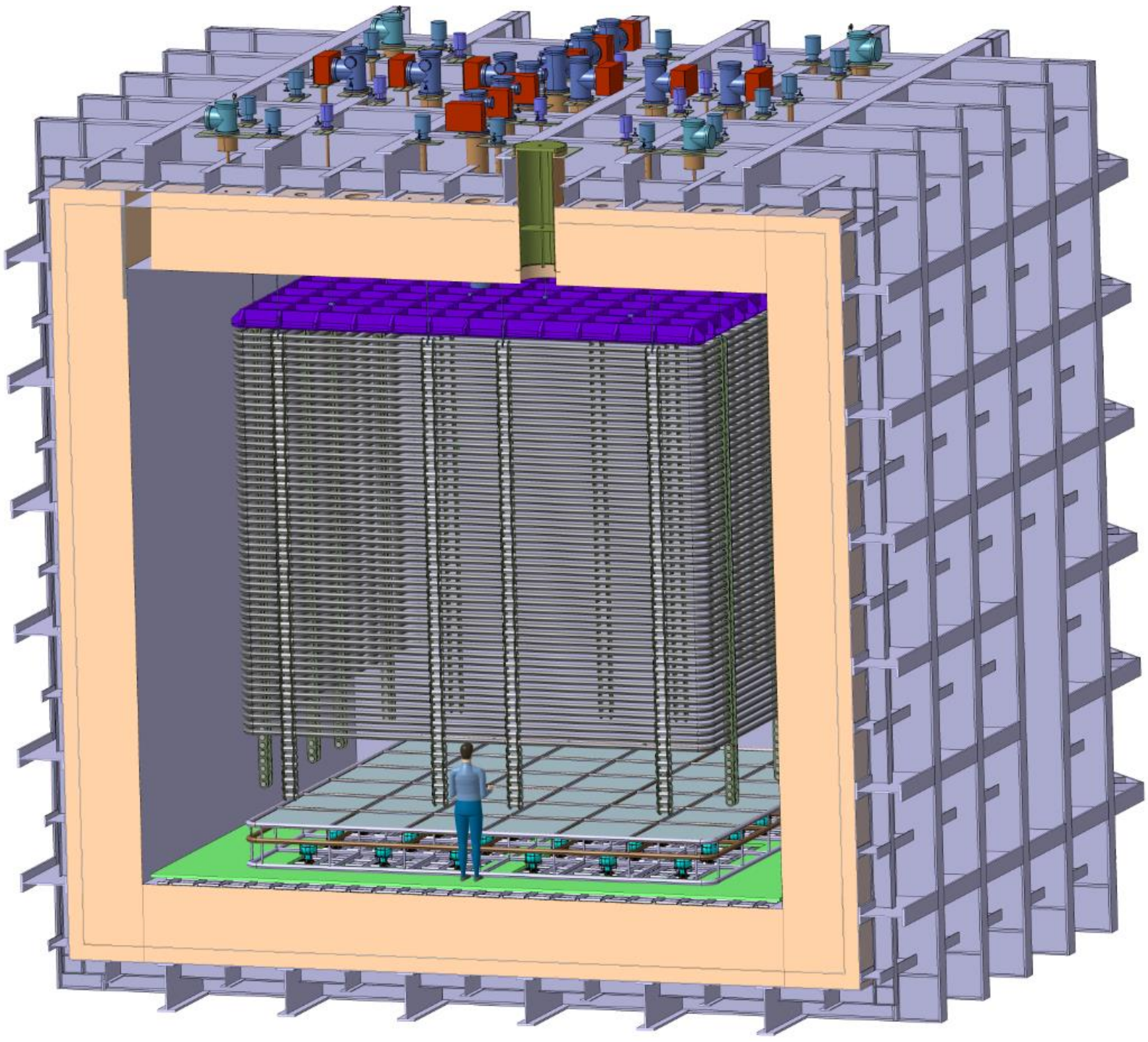
Cathode and PMTs

- PMTs Installation at the structure



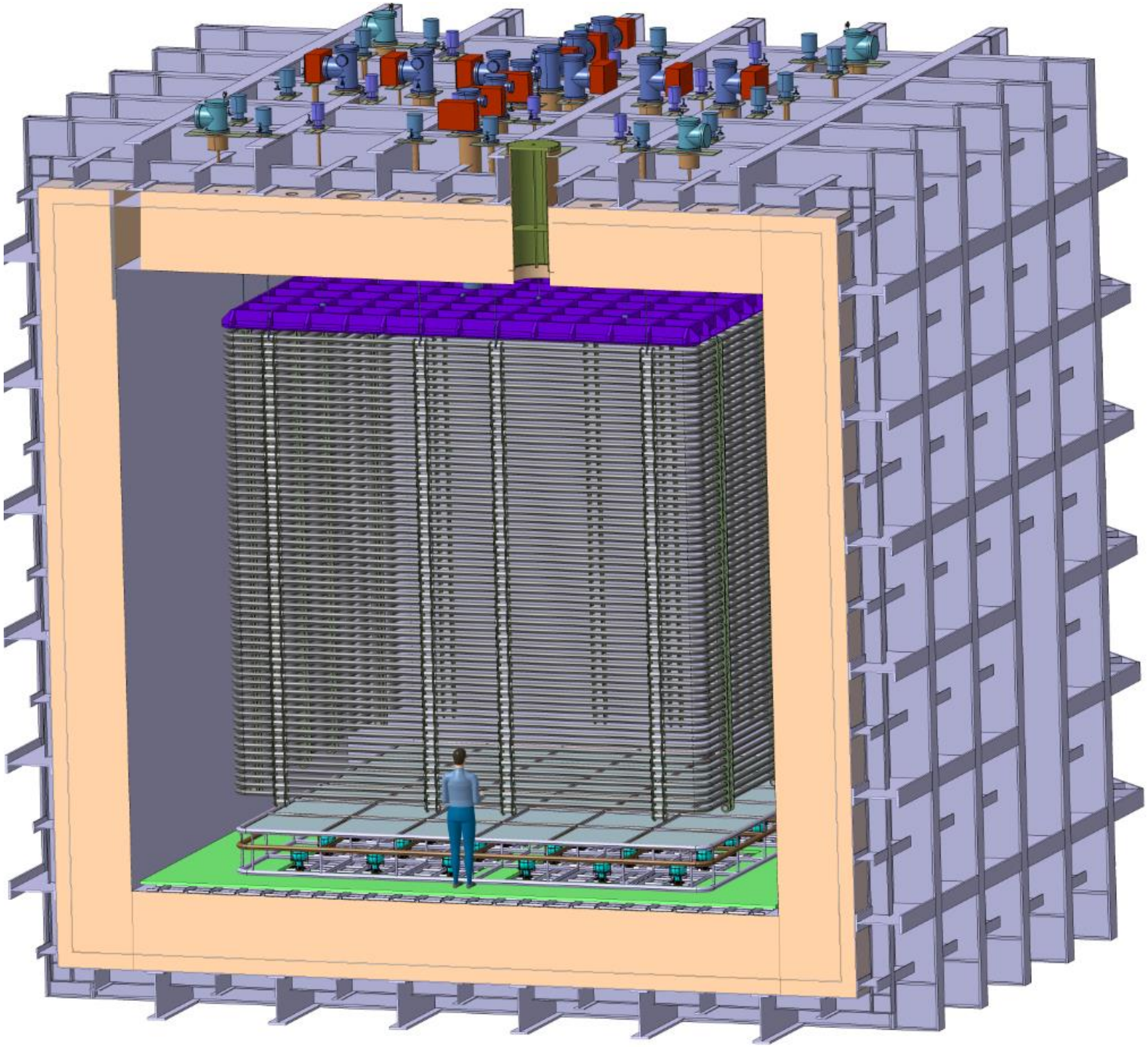
Cathode and PMTs

- PMMA coated Plates installed at the Cathode



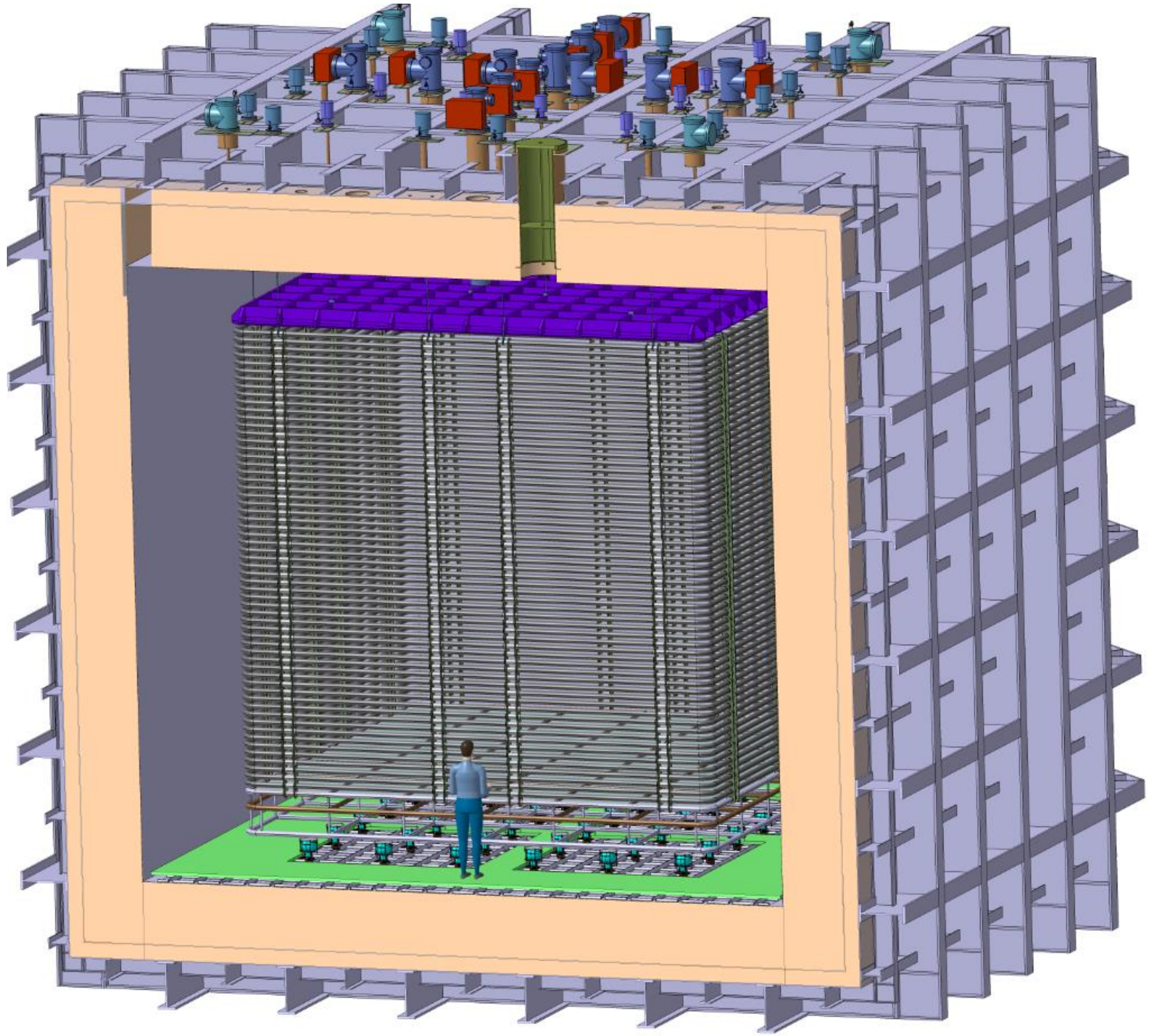
Cathode and PMTs

- Installation of the last field shapers



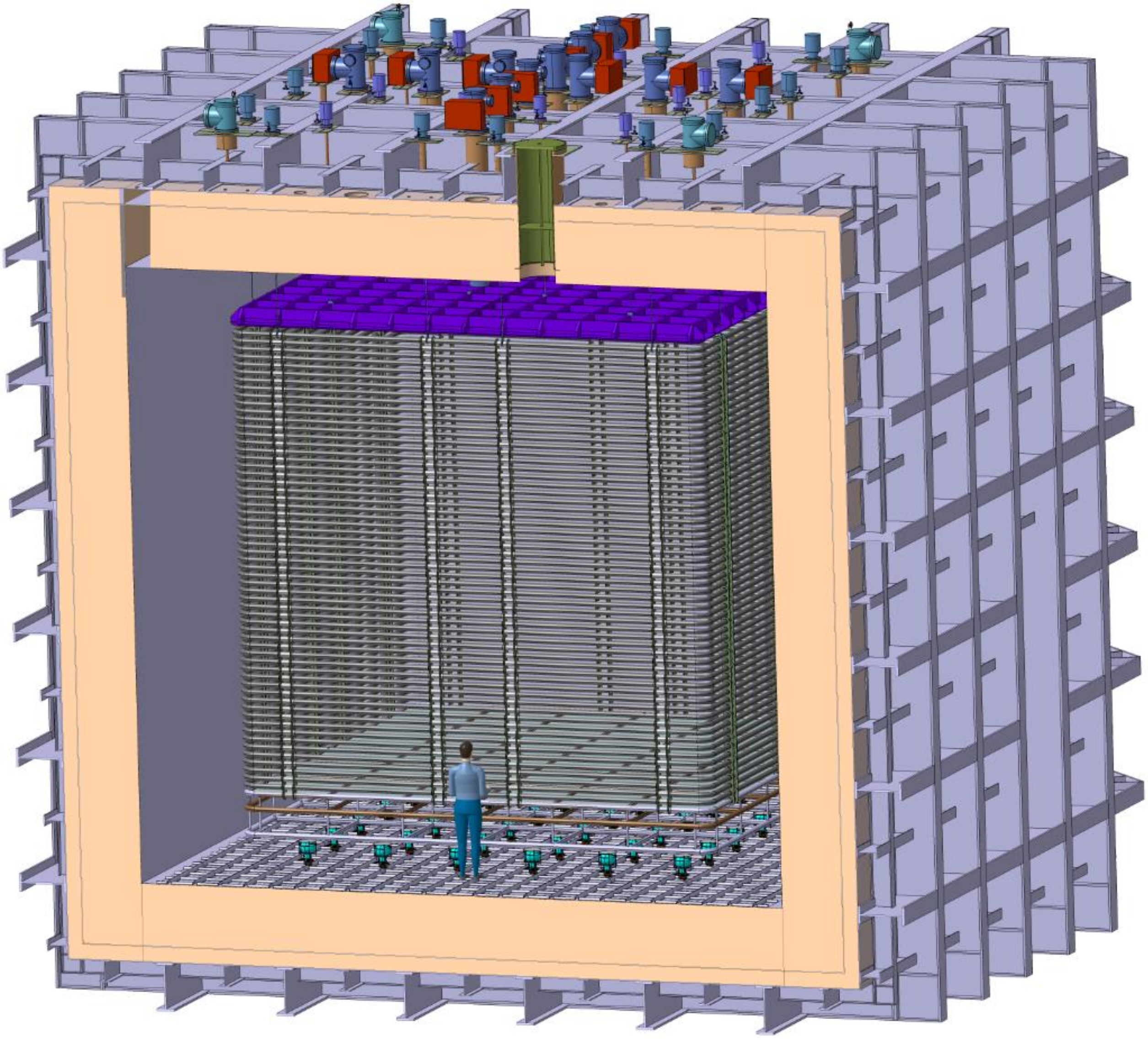
Cathode and PMTs

- Cathode connected to the Drift Cage and Lifted



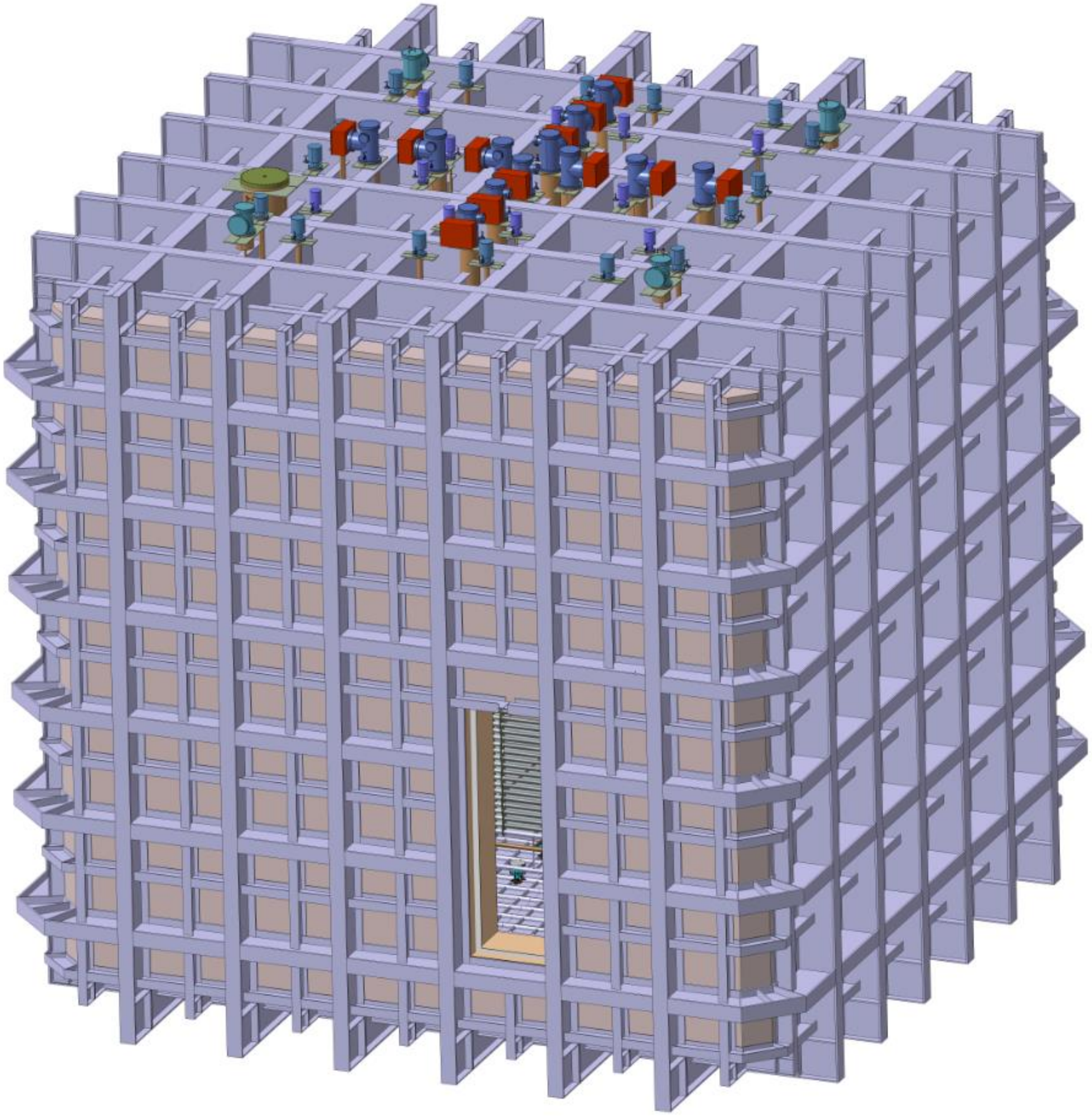
Removal of Temporary Assembly Floor

- Temporary Assembly floor removed



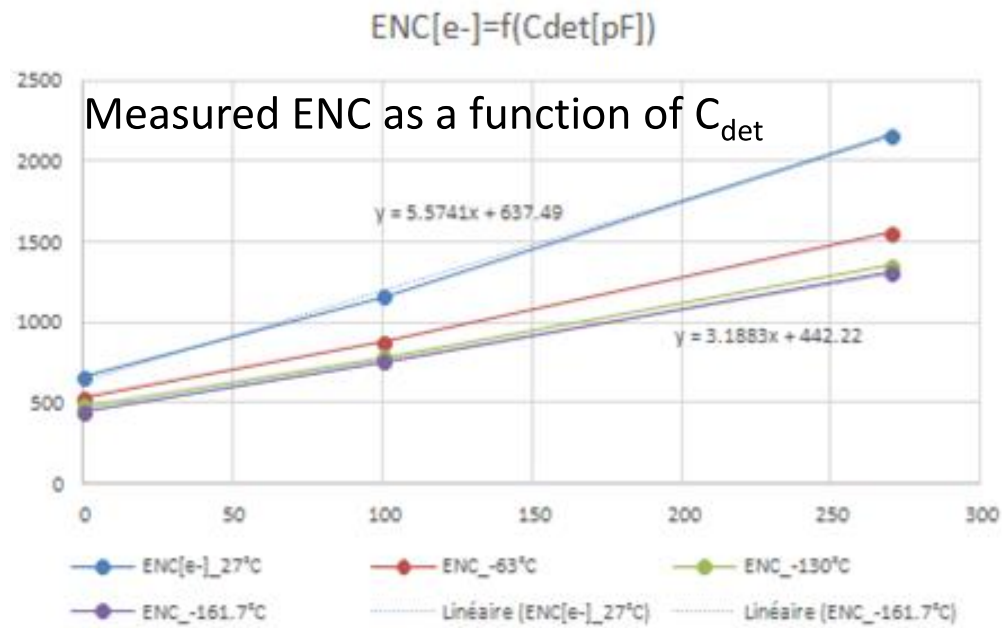
Closure of the TCO

- Membrane and TCO closed



Cold front-end electronics

- Accessible via chimneys (without opening of the TPC cryostat)
- Shielded from digital electronics
- Preamplifier ASIC final version:
    - 16 channels
    - Double slope gain with “kink” at 400 fC
    - 1200 fC dynamic range
- Full production of 700 chips performed in Sep. 2015 (covers fully 7680 ch required for 6x6x6)
- A batch of 25 circuit tested in Jan 2016
- Good performance observed
- Will be available to instrument LArProto



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

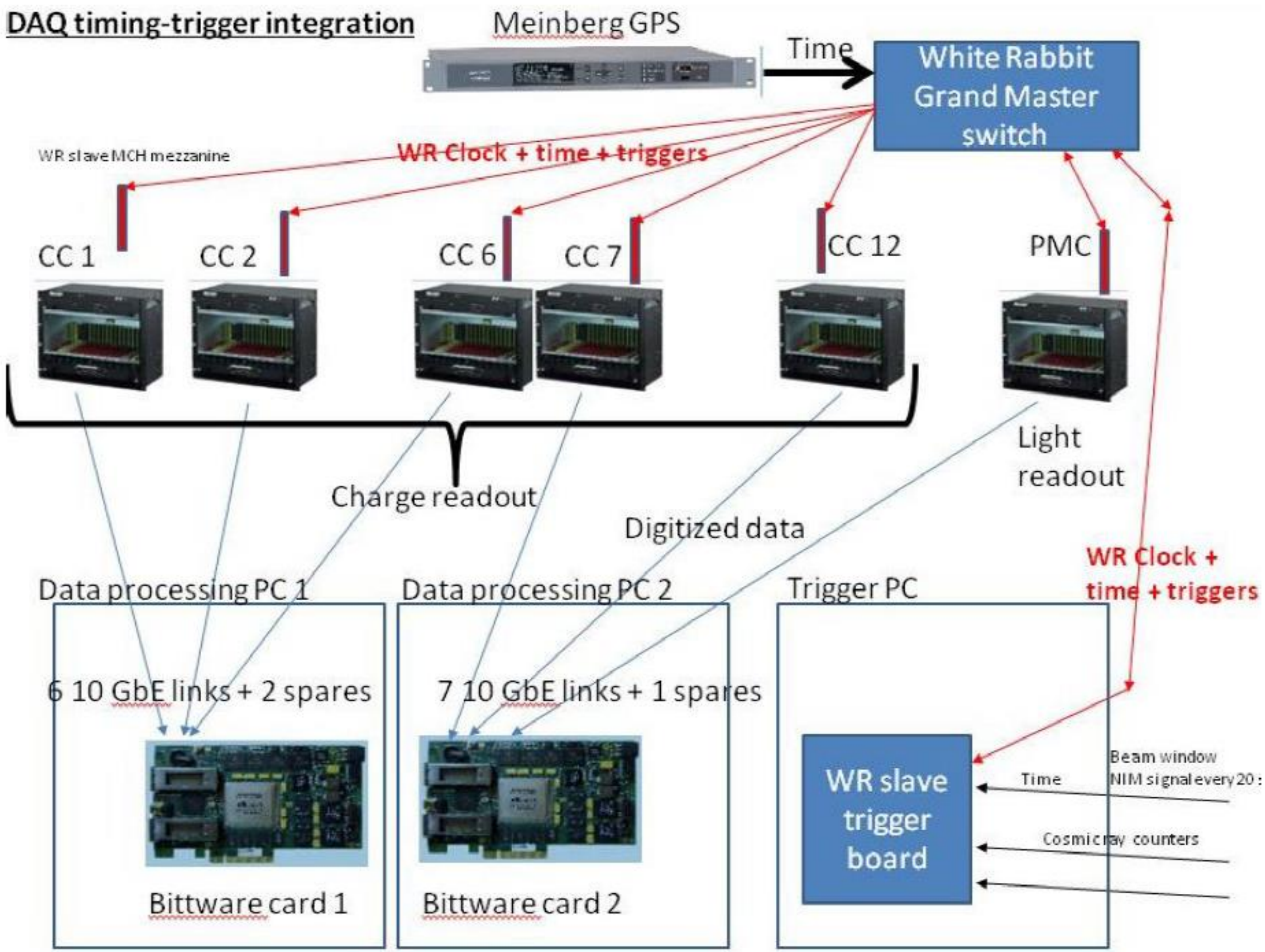
Digital electronics and DAQ scheme

Digital electronics for charge readout

- microTCA standard
- 10 cards per crate
- 64 ch per card
- 12bit resolution
- 2.5 MHz rate

Digital electronics for light readout

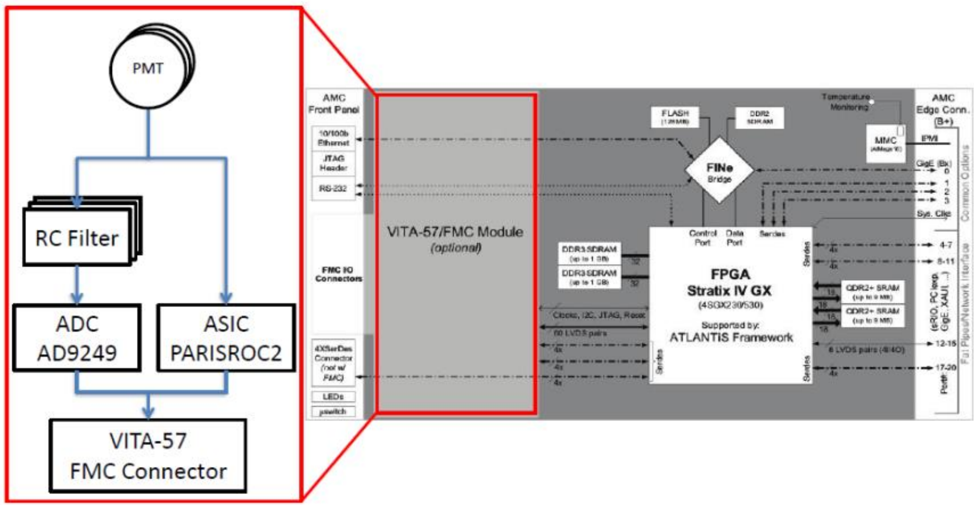
- microTCA standard
- 4 cards in a crate
- 9 ch per card
- 14bit resolution
- 2.5 (max 65) MHz



Charge readout digital electronics status

- The time and trigger distribution based on White Rabbit (WR) standard has been defined
- WR slave cards have been adapted to microTCA format and configured
- All necessary components (ADC, FPGA, memory) evaluated with Bittware microTCA development kit
- Final quantities purchased for DLAr
- Routing and PCB layout is being completed
  - A pre-production batch of 10 cards will be tested in May 2016
- Development of the OpenCL software for the back-end Bittware cards on the event building stations is on-going
- In June 2016 a subset of analog and digital electronics produced for DLAr will be installed in LArProto to provide DAQ for the operation in Sep. 2016

Light readout electronics



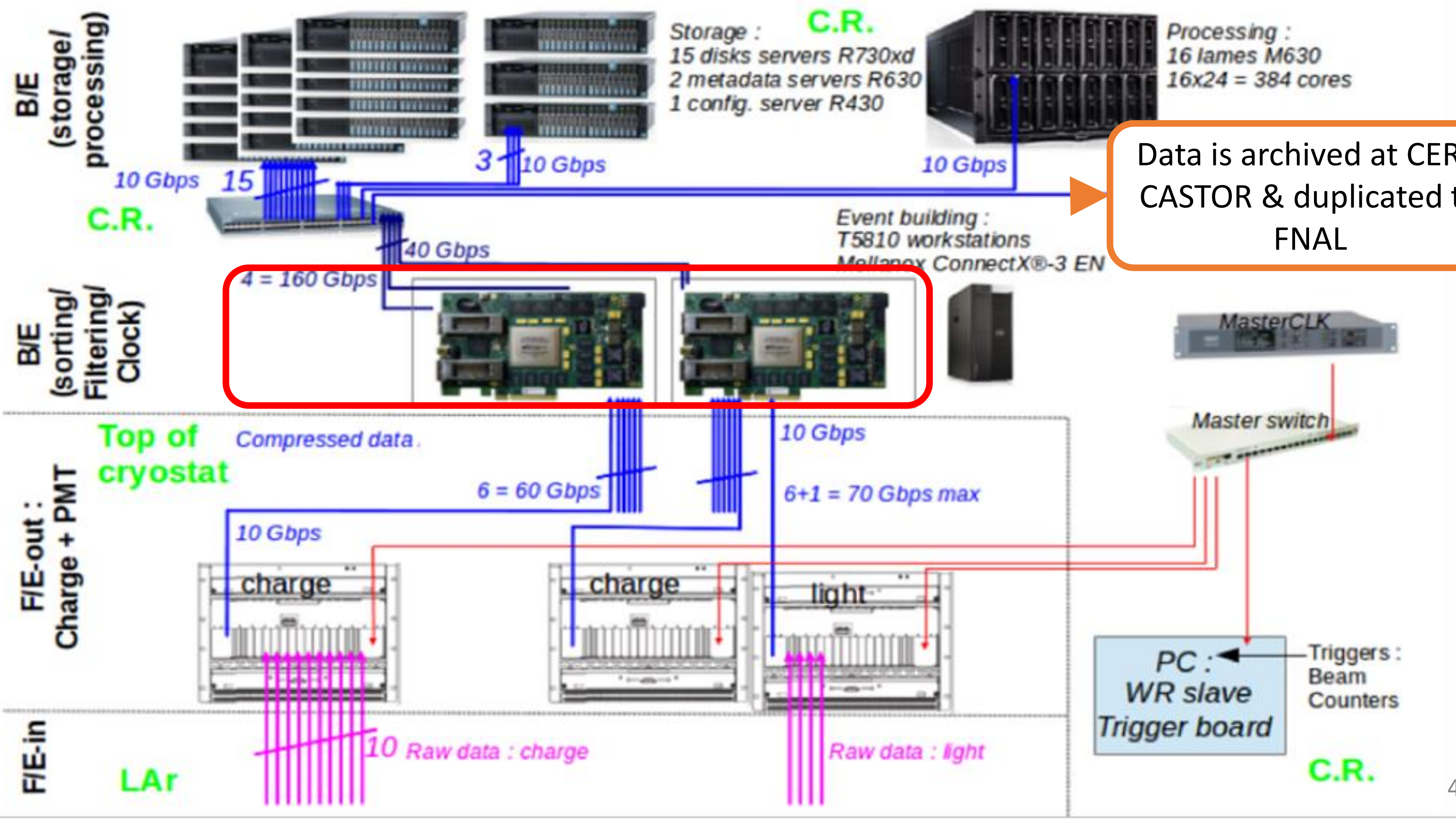
Mezzanine card with PARISROC ASIC

- Integrated into overall WA105 DAQ schemes for the charge readout
  - Timing and trigger distribution via WR
- Front-end cards are based on microTCA standard
- Digitized data is written in cyclic memory buffers
  - On beam trigger, ±4ms is written out with 400ns time granularity → to reconstruct T_0 of cosmic ray tracks that overlap with the beam event
  - Outside of beam trigger, self-triggering mode using PARISROC ASIC → dedicated light signal studies
- The electronics design is being finalized for the DLAr deployment

Overview of DAQ & online storage/computing system

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

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



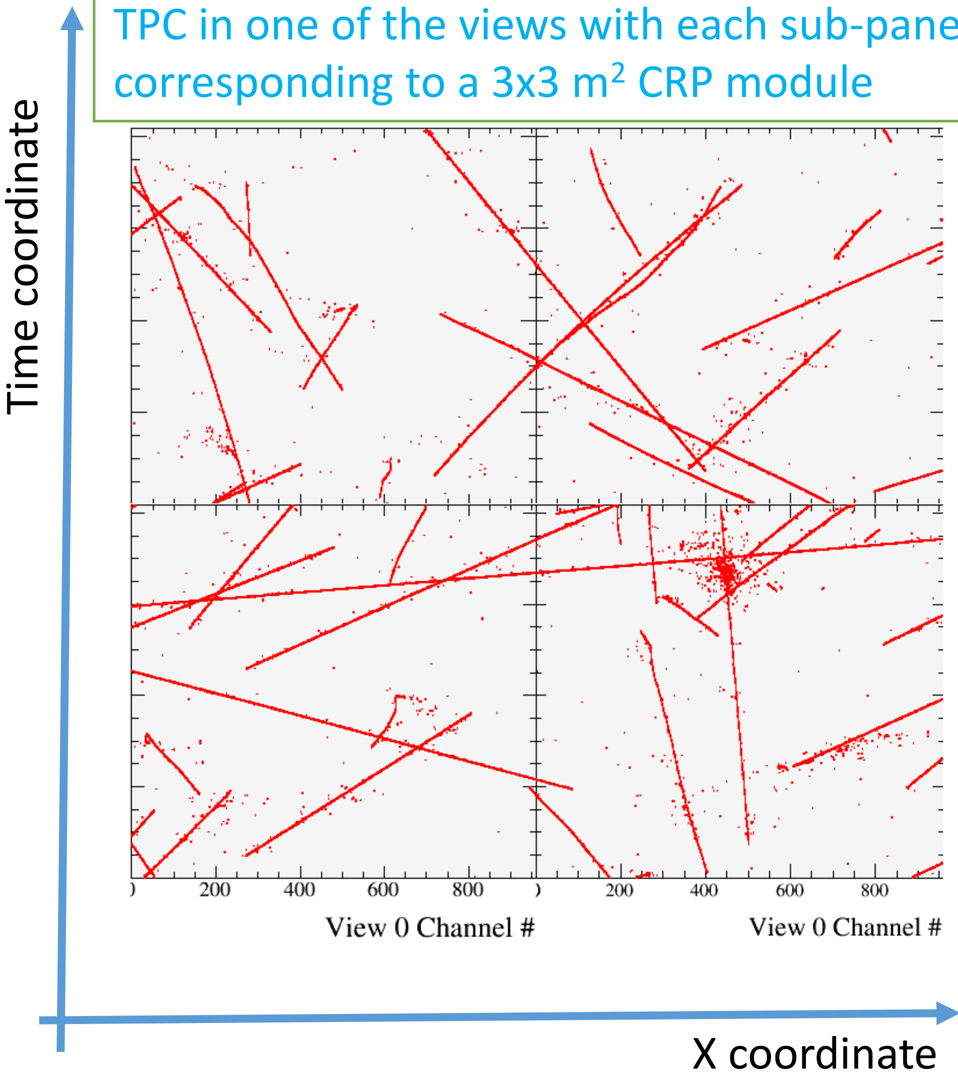
Data is archived at CERN CASTOR & duplicated to FNAL

Online processing tasks

- Complete event building by connecting data streams the two back-end boards
- Combine charge and light readout for fast reconstruction and disentangling of cosmic ray track segments
- Skim cosmic ray sample for useful calibration tracks
- Online data quality checks
- Data filtering and formatting for archiving
- Study online data processing and filtering requirements for future 10kt detector
- A scaled version of storage/online computing system is being setup for LArProto with the help of CERN IT
  - Optimize the storage/analysis/network hardware and software for final system in EHN1
  - Test data transfer and archiving to CERN EOS

Calibration data in DLAr

Example of overlapping cosmics in WA105 TPC in one of the views with each sub-panel corresponding to a 3x3 m^2 CRP module



- Readout window is 4ms
- Expected muons from cosmic ~100 in 8ms time window
  - Could see fragments of cosmics arriving both before ("closer" to anode) and after ("closer" to cathode) beam trigger

Selected sub-sample of these are data for calibration

- LAr purity analysis
- Gain measurement
- Field non-uniformity effects (track distortions)

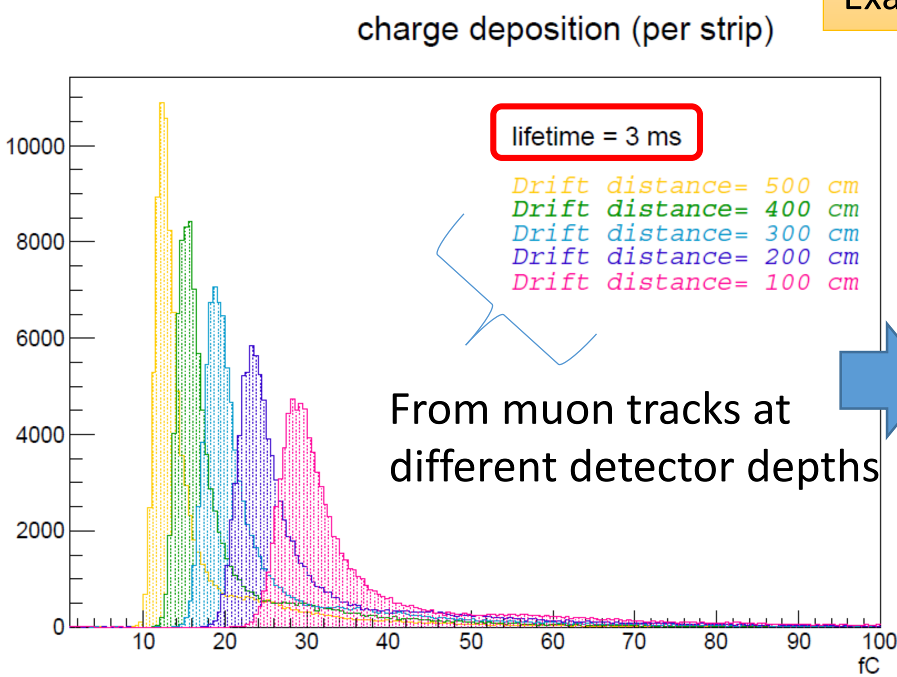
Software developments

Two parallel directions are pursued

- *Implementation of DLAr within LArSoft framework*
  - Profit of the reconstruction tools developed by world-wide community for analysis of beam data
- *WA105 software for simulation and online analysis based on QSCAN*
  - Fast and light-weight, hardware oriented software environment
  - Simulation:
    - Charge quenching effects
    - Electron lifetime attenuation
    - Diffusion effects
    - Response of electronics
  - Many recent developments:
    - Cosmic ray background overlay on the beam events
    - Modelling electric field non-uniformities due to space-charge effects
    - Light simulation from both LAr and GAr (electroluminescence)
  - Simulation tools to meet immediate WA105 needs are in place
  - Development of light-weight reconstruction tools for DLAr online analysis
    - Reconstruction of cosmic ray tracks for fast feedback on the detector operation & data quality
  - QSCAN software ready for use in 3x1x1 analysis

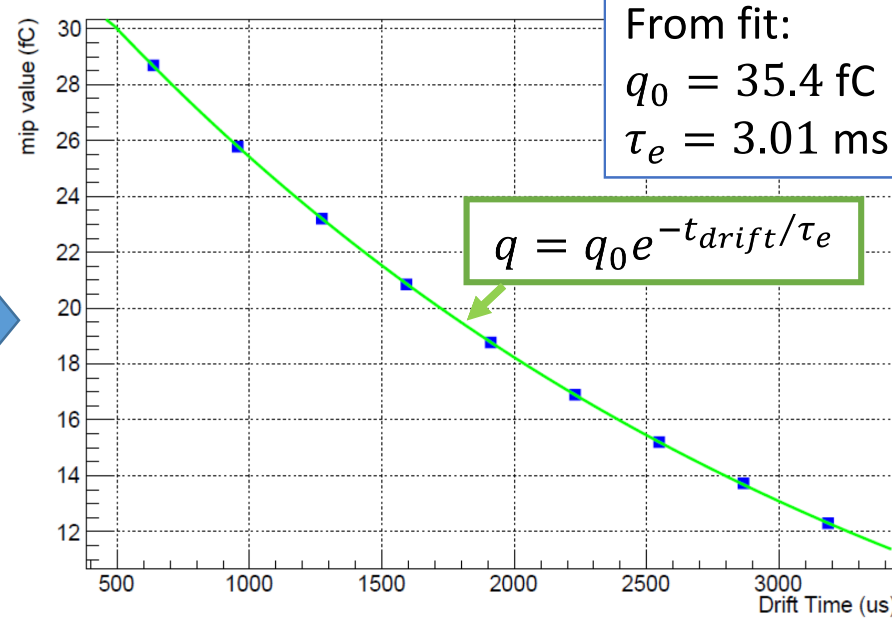
Benchmarking simulation

- Develop automatic procedures to generate sets of benchmark distribution
  - Quickly validation new releases
  - Analysis tools which will be also part of online monitoring tasks
- Time profiling of reconstruction algorithms for online monitoring



From muon tracks at different detector depths

Example: electron lifetime (LAr purity) analysis



From fit:
$q_0 = 35.4$ fC
$\tau_e = 3.01$ ms

$$q = q_0 e^{-t_{drift}/\tau_e}$$

Overall beam particle rates

- Maximum particle rate to avoid too many particle overlaps in TPC:

$$R = 100\ \text{Hz}$$

Assume this could be achieved for any momentum setting of the beamline

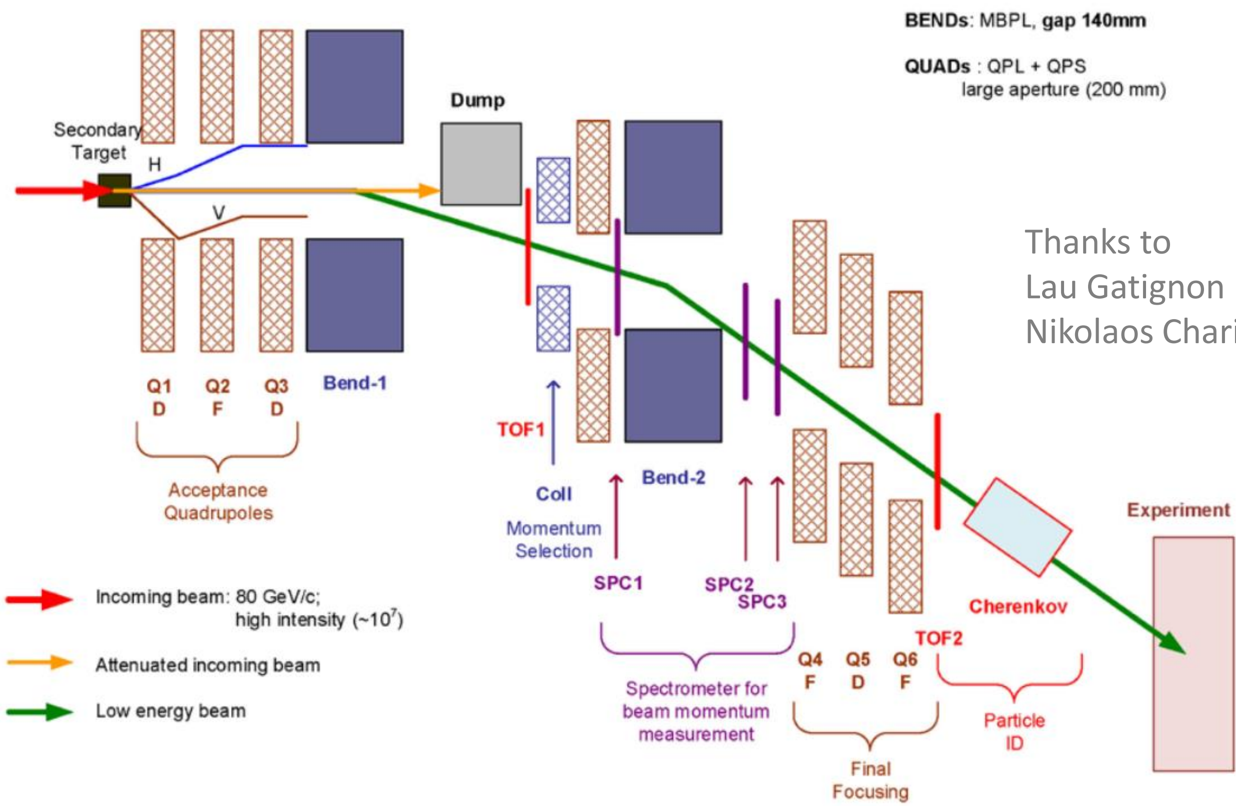
- For SPS spill of *4.8 s* and super-cycle of *2 spills / 50 s* the number of particles expected to be delivered to the detector per super-cycle

$$2 \times 4.8\ s \times 100\ Hz = \sim 1000\ \text{particles / super-cycle}$$

- Assuming 50% running efficiency:

~829k per day

Beamline simulation



Thanks to
Lau Gatignon (CERN)
Nikolaos Charitonidis (CERN)

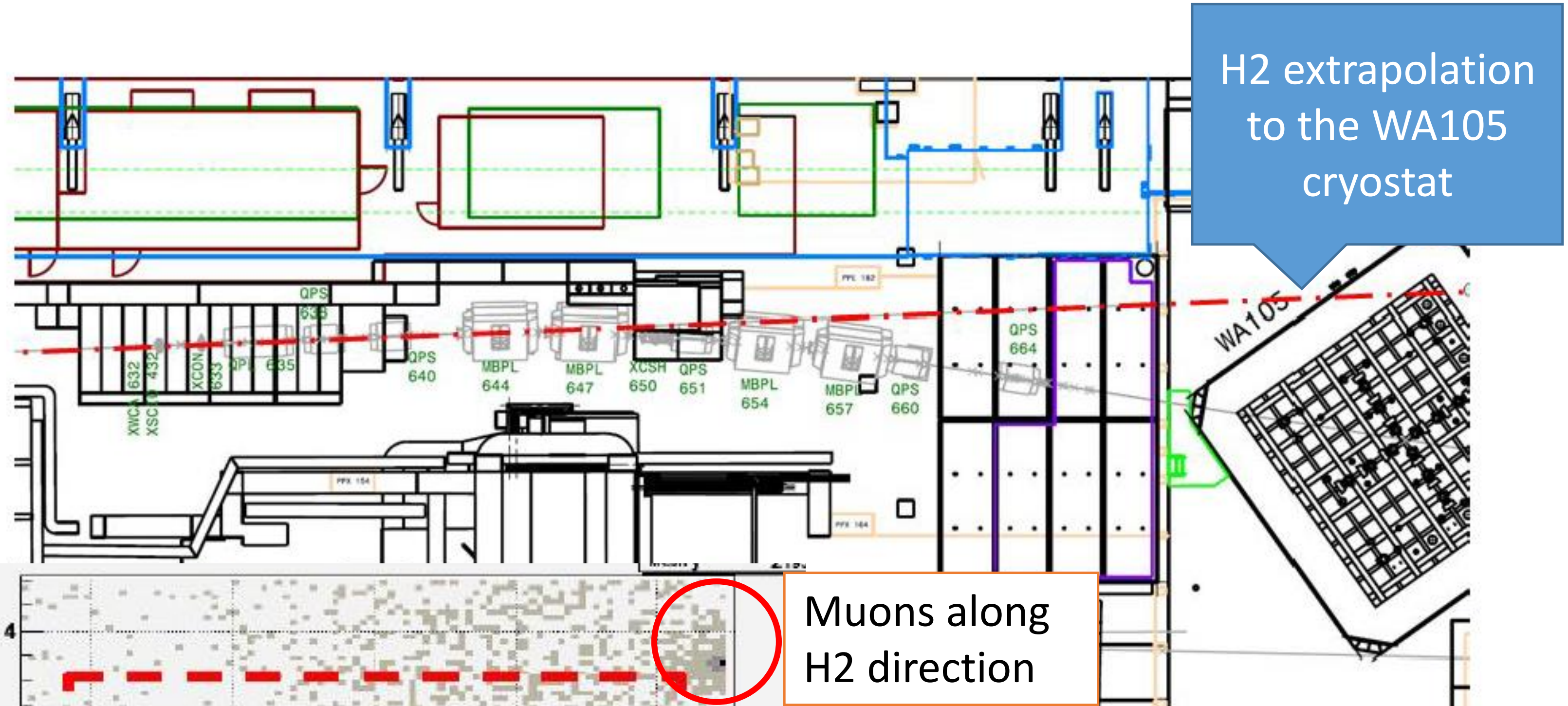
- Simulation of beam optics propagating particles from the target to the detector has been set up with G4Beamline toolkit
- Detailed breakdown of particles rates obtained for different species allows to estimate required running time

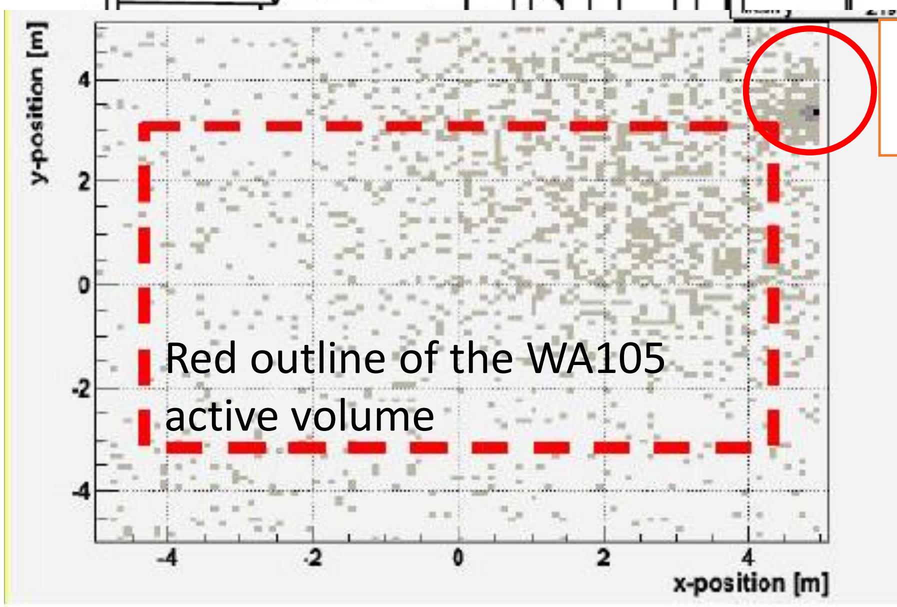
Beam time request

Momentum GeV/c	Surviving π's	Surviving K's	Beam composition $\pi/K/e/p$	π's Stat. (10^6)	Days for π's Stat.	Others $p/K/e$
Positive						
0.4	21%	0.05%	1%/-/22%/13%			
1.0	52%	1%	4%/-/85%/4%	0.5	14	$500k/-/9.8M$
2.0	72%	9%	18%/1e-4(CMS)/68%/7%	1	7	$405k/-/3.8M$
3.0	80%	20%	29%/1e-3(CMS)/56%/7%	2	8	$480k/-/3.8M$
4.0	85%	30%	39%/2%/45%/7%	2	6	$355k/106k/2.3M$
5.0	88%	38%	55%/2%/26%/8%	2	4	$307k/84k/934k$
6.0	90%	44%	56%/4%/21%/10%	1.5	3	$259k/114k/554k$
7.0	91%	50%	67%/6%/10%/10%	1.5	3	$211k/127k/230k$
8.0	92%	54%	61%/6%/13%/11%	1.5	3	$281k/148k/327k$
9.0	93%	58%	67%/6%/10%/10%	1.5	3	$211k/127k/230k$
10.0	94%	61%	69%/6%/10%/9%	1.5	3	$202k/136k/215k$
11.0	94%	64%	70%/6%/7%/10%	1.5	3	$204k/136k/144k$
12.0	95%	67%	68%/8%/5%/14%	1.5	3	$301k/183k/111k$
					~ 59 days	
Negative					~ 59 days	

The running time in each momentum set is calculated based on the number of days needed to collect a desired pion statistics with reasonable rates for other particles acquired in "parasitic" mode taken into account

Muon halo from H2 secondary line





Without dedicated muon shielding would get ~2kHz rate in TPC from muon halo

Need to reduce as much as possible with upstream magnetized shielding

Conclusions

Significant progress has been made last year

➔ On schedule for LArProt (3x1x1) in Fall 2016 and DLAr (6x6x6) operation before LHC LS2

Anticipated overall funding covers adequately construction of 3x1x1 and 6x6x6m^3 detectors

Significant presence at CERN presently focused at 3x1x1m^3 assembly and preparation for operation in September 2016

Entered in the production phase of 6x6x6 DLAr

Request items:

- Mitigation of beam muon halo background
- Clean room for CRP assembly at CERN Bld 185

Overall DLAr detector schedule has been fully integrated with EHN1 schedule

➔ The critical path is set by the availability of the infrastructure from Neutrino Platform

Beam data critical to characterize the performance of the detector and provide physics inputs for future neutrino program

Construction and operation of the 6x6x6m3 prototype will demonstrate our readiness to build a 10kton DUNE FD

Thank you for your attention

Extra

Summary of milestones

LArProto 3x1x1 Building 182:

- **February 2016**: start detector installation (arrival at CERN of the Top Cap build by Gabadi)
- **June 2016**: weld top cap and seal cryostat
- **July 2016**: perform test in gas Ar
- **August 2016**: start cryogenic operation (cooldown+filling)

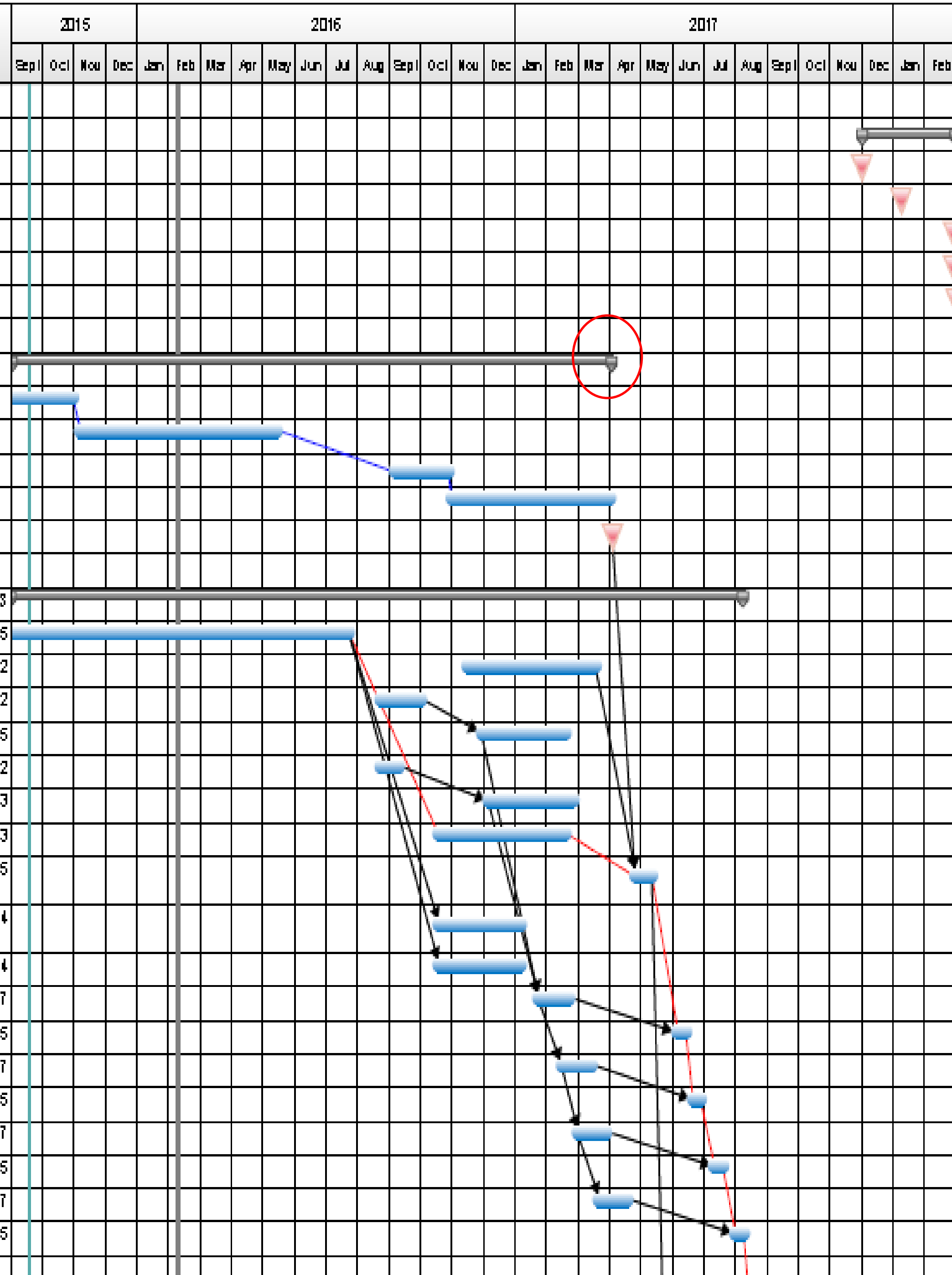
September 2016: start cosmic ray data taking

DLAr 6x6x6 in the NA EHN1:

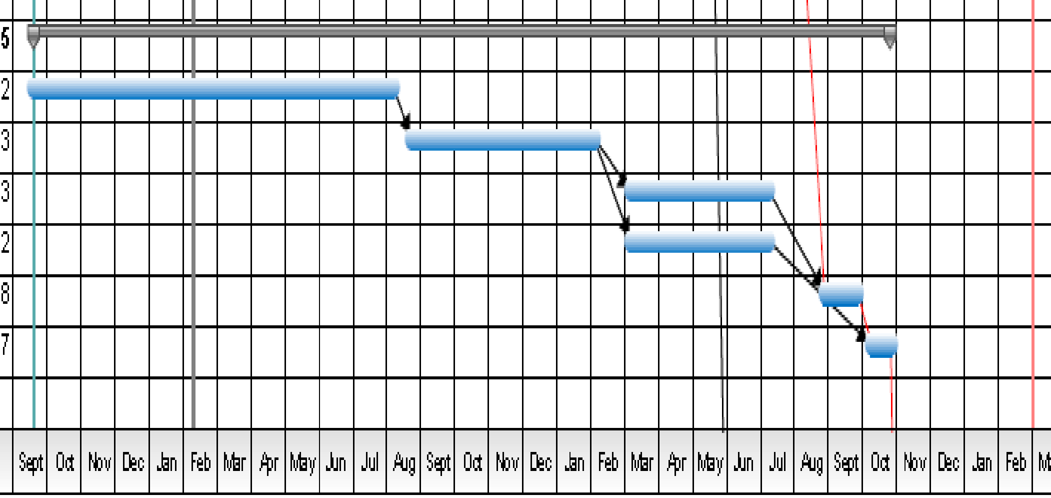
- **September 2016**: start cryostat construction
- **April 2017**: start detector installation
- **December 2017**: seal TCO & cryostat
- **January 2018**: start cryogenic operation (cooldown+filling)

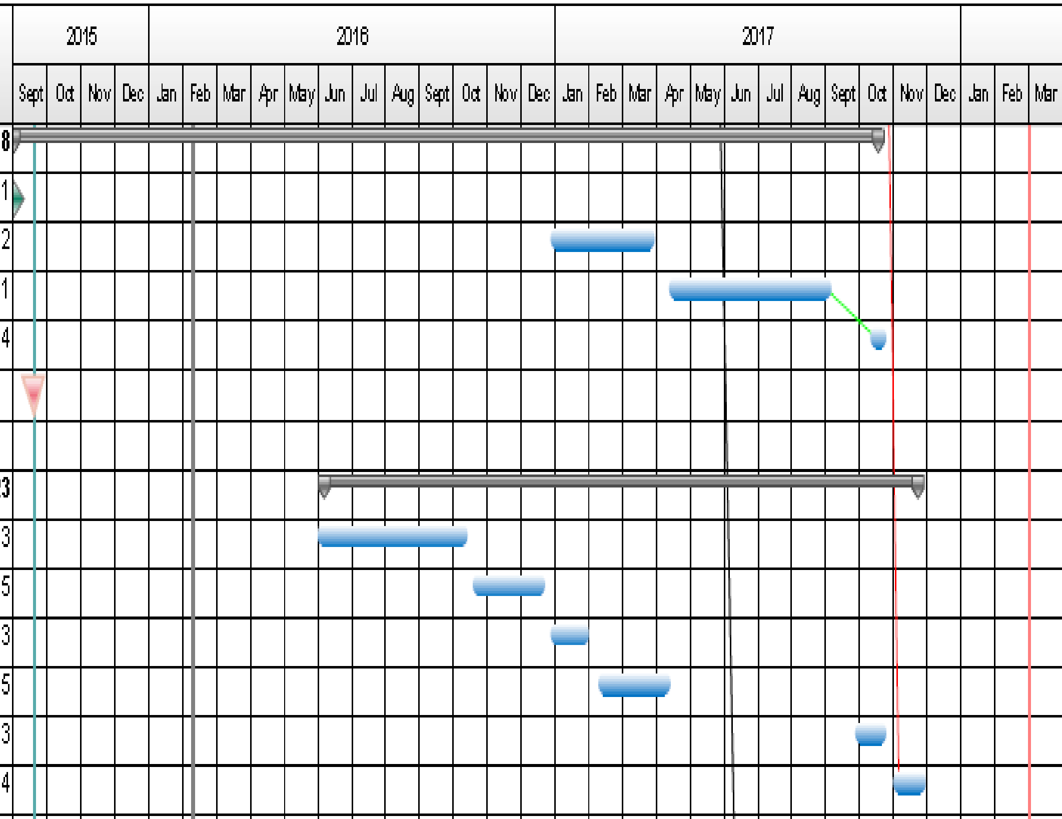
April 2018: be ready to collect beam data

	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*	139.00	11/2/15	5/13/16		
12	*Warm vessel assembly*	39.30	8/5/16	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						

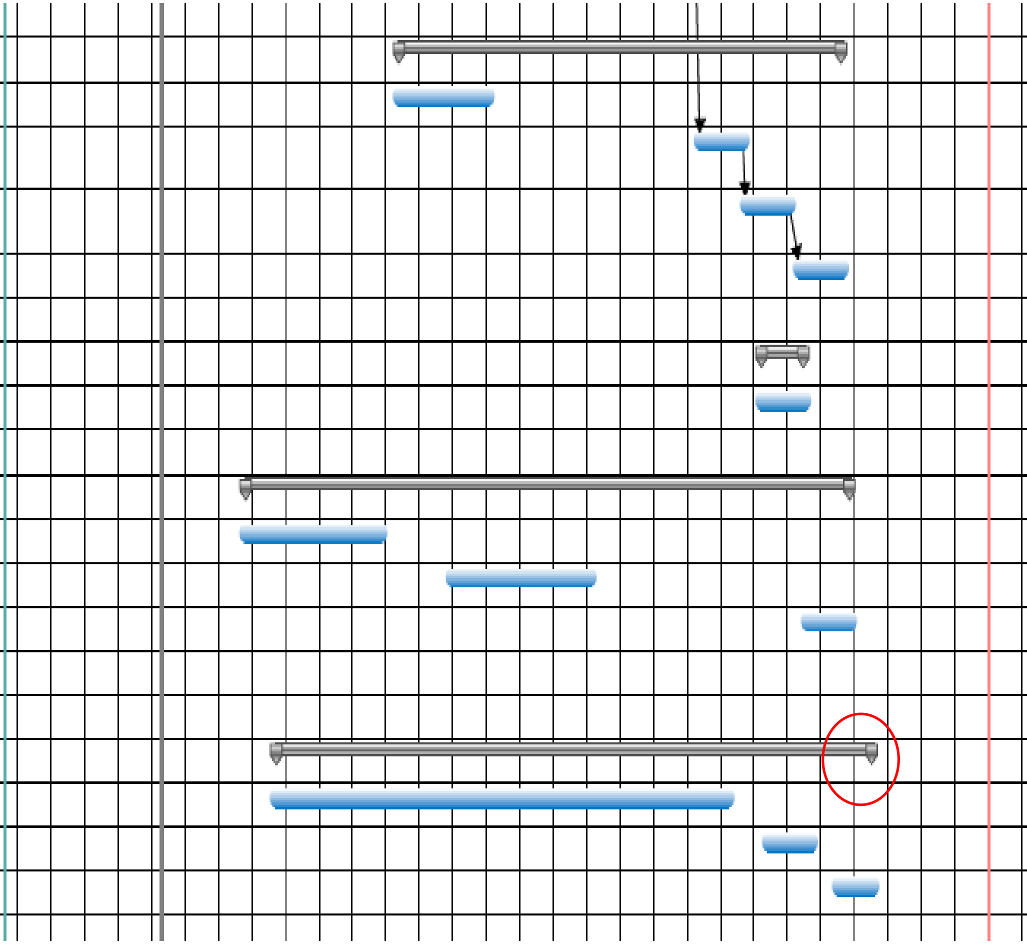


	Activity Name	Duration (Days)	Start Date	Finish Date	Resources Assigned	People
36	**Drift cage**	550.00	9/18/15	10/26/17		**25**
37	*PMMA/ITO/TPB R&D*	231.00	9/18/15	8/5/16	ETHZ	2
38	*Field cage and anode design*	120.00	8/22/16	2/3/17	CERN, ETHZ	3
39	*Field cage procurement*	90.00	3/6/17	7/7/17	CERN,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

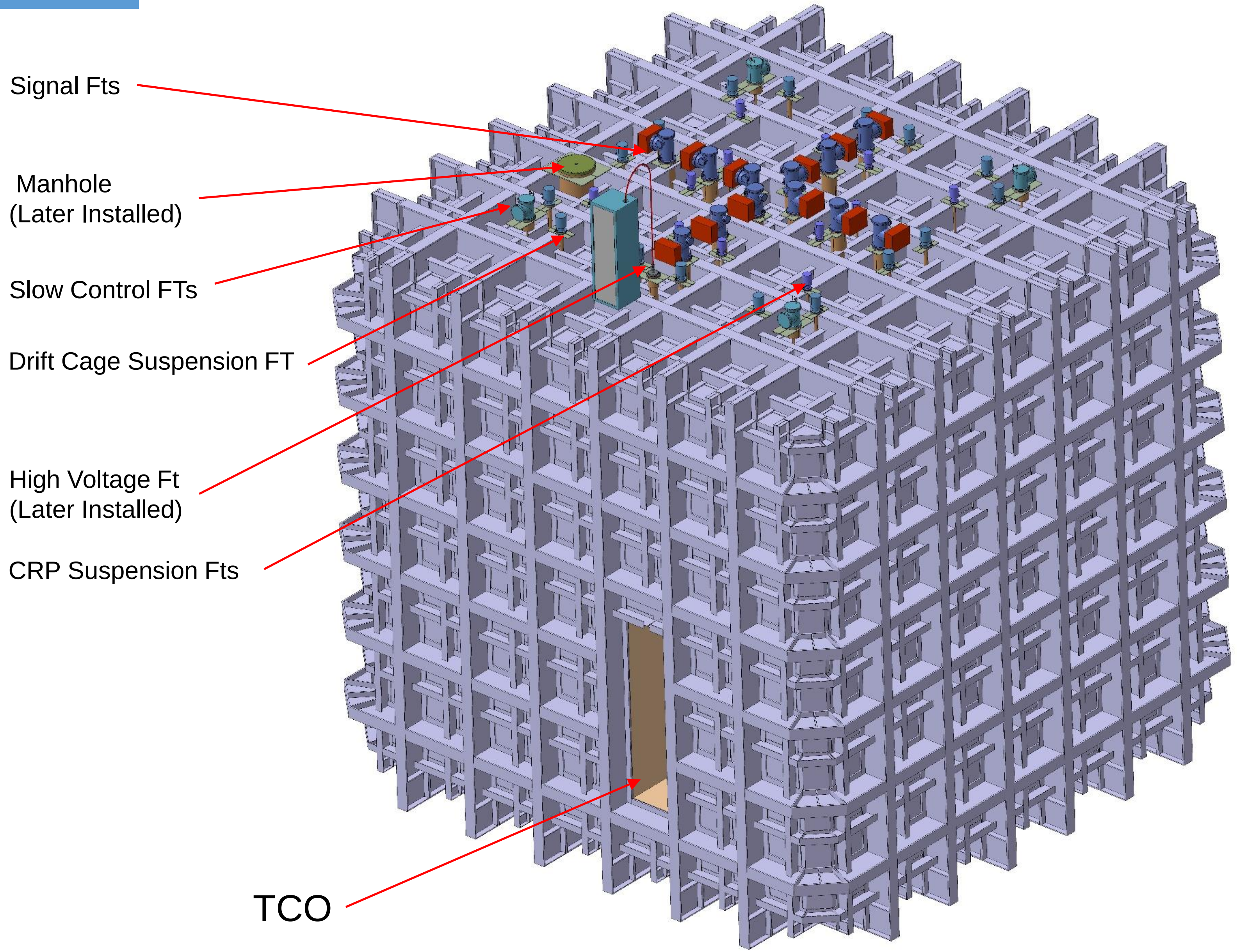




58						
59	**Front-end electronics**	290.00	9/12/16	10/20/17		**23**
60	*micro-TCA no.12 procurement*	60.00	9/12/16	12/2/16	IPNL	4
61	*F/E electronics installation (Insertion of the cards in the chimeneys and cabling)*	30.00	6/12/17	7/21/17	IPNL, KEK	5
62	*micro-TCA installation (Installation of the 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						



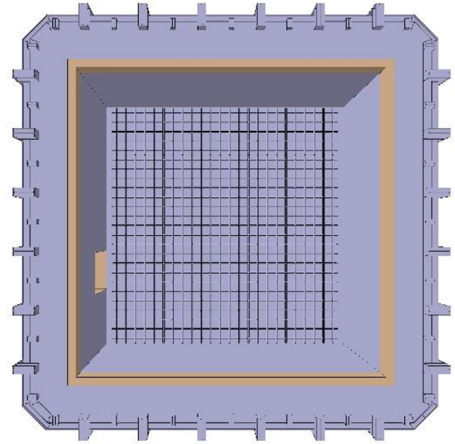
FTs Installation

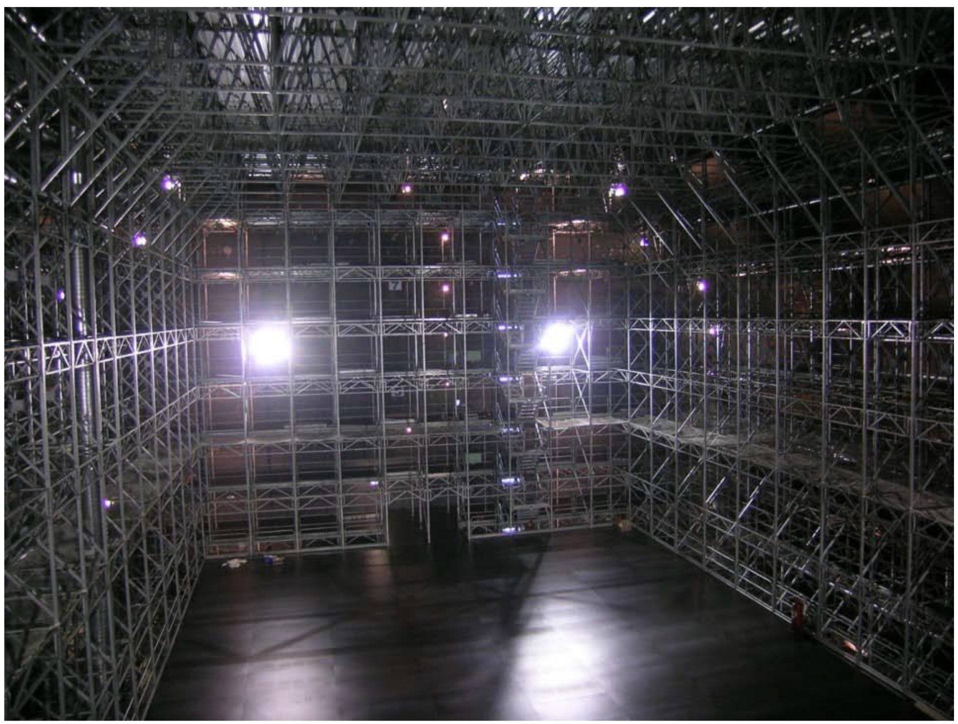


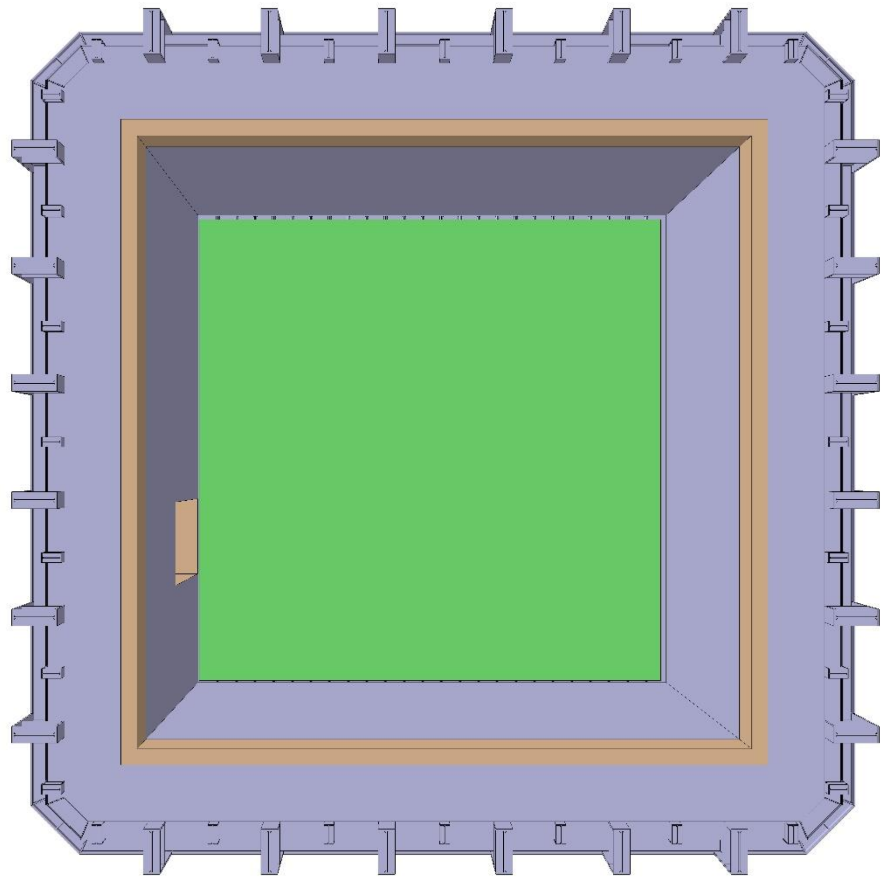
Temporary Construction Floor

WA105

- Cryostat is used as a clean Room
- Field Cage, CRP are installed inside
- Temporary construction floor is needed to protect the bottom membrane





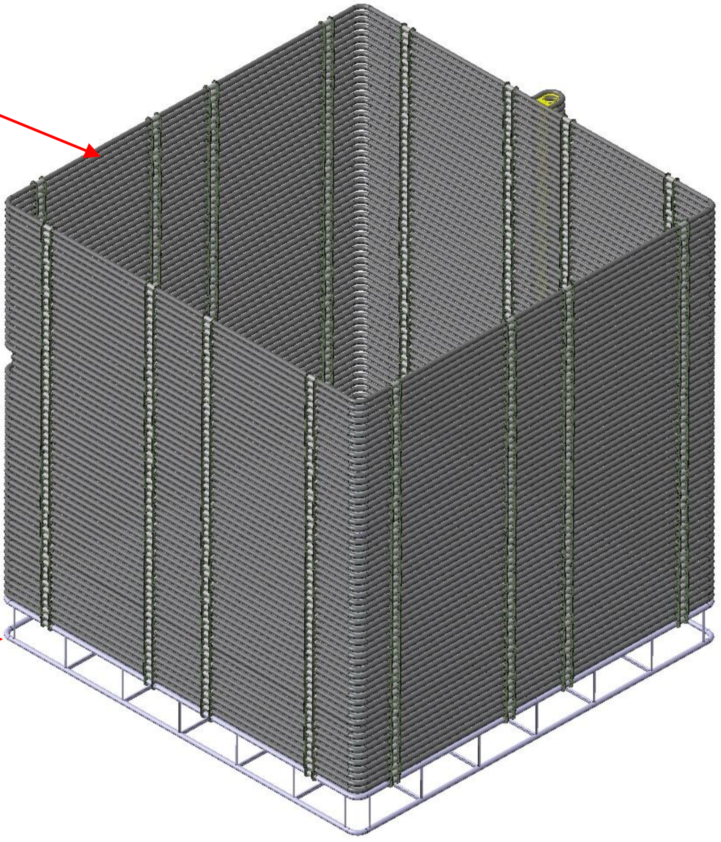


Field Cage

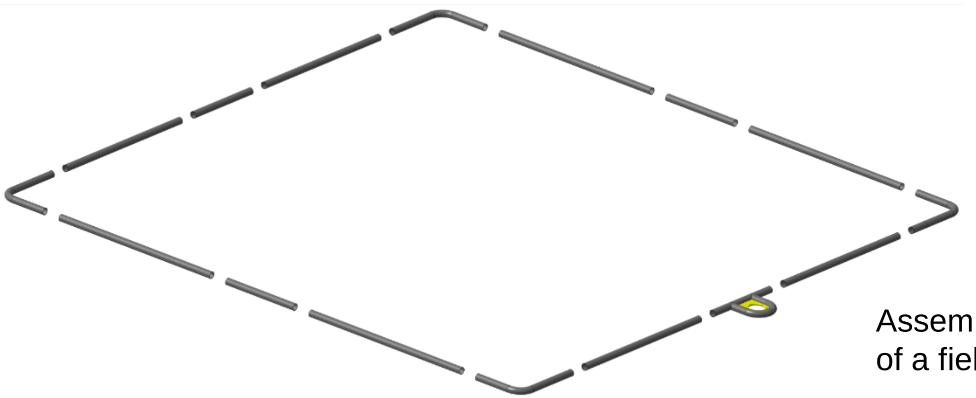
WA105

- Field Cage and Cathode structure is made of relatively small part (mainly pipes) that will be assembled inside the Cryostat
- Assembly procedure was already studied with an external Engineering Company (Technodyne for Laguna LBNO study)

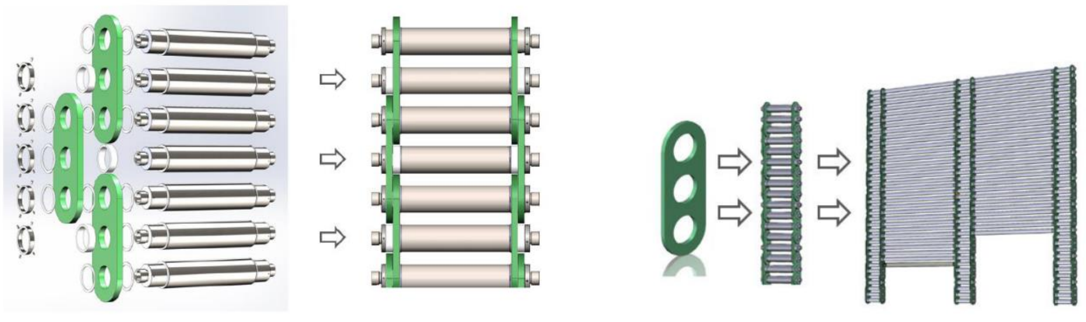
Field Shapers



Cathode Structure

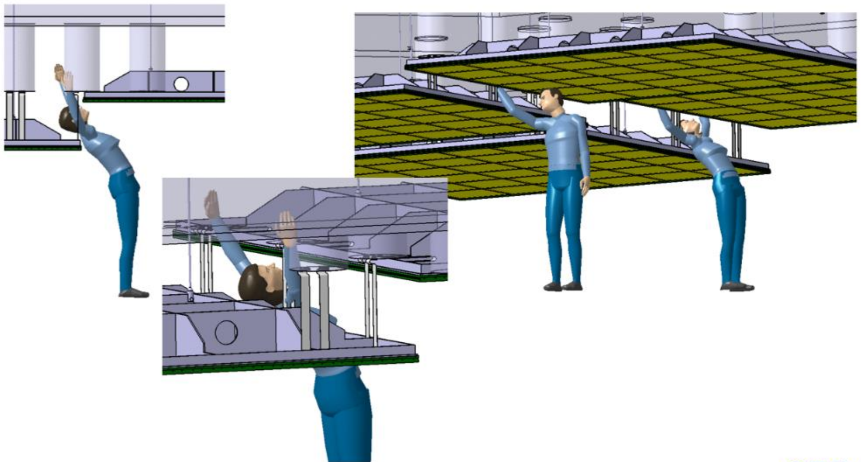


Assembly Parts
of a field Shaper

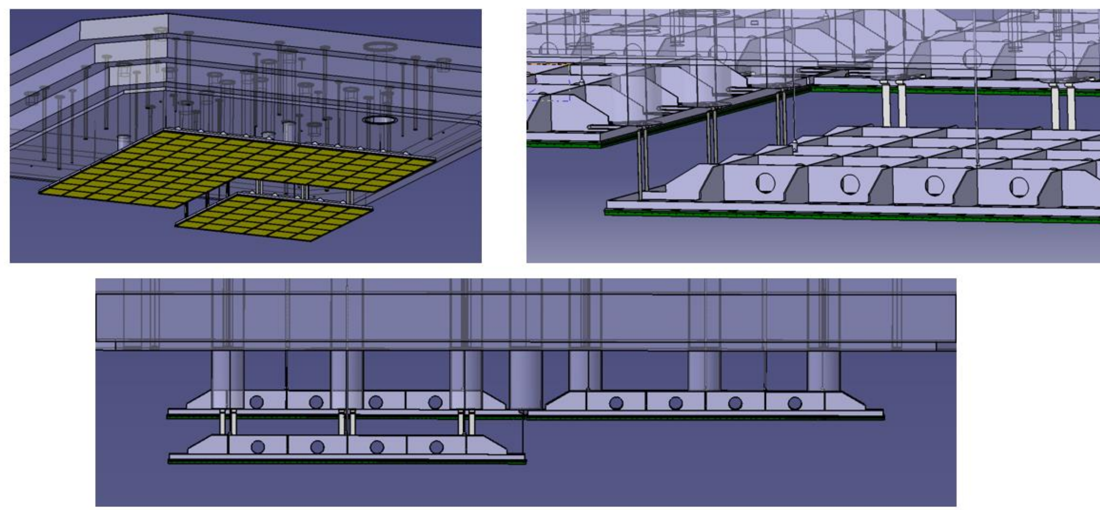


CRP 3X3 m²

CRP Assembly



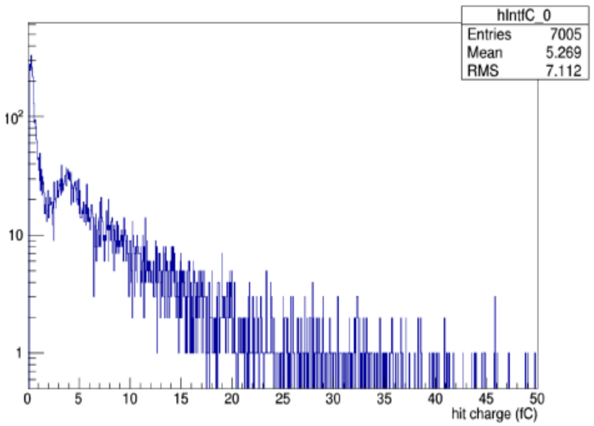
CRP Assembly : Scenario – last step

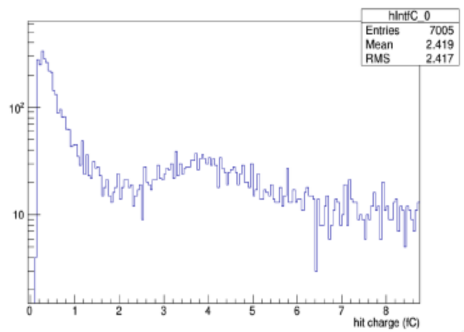


No problem to connect, even last module.

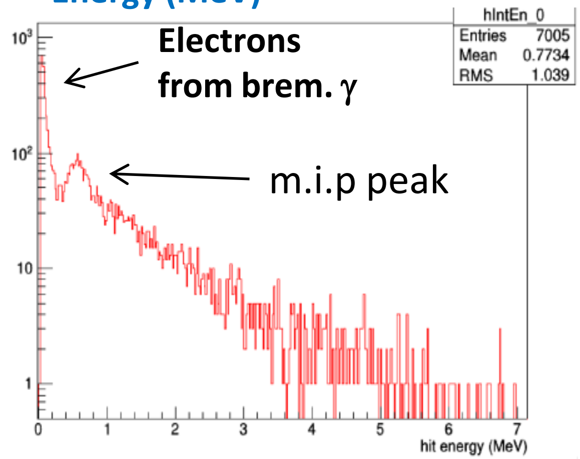
- Installation Scenario has been studied by LAPP group

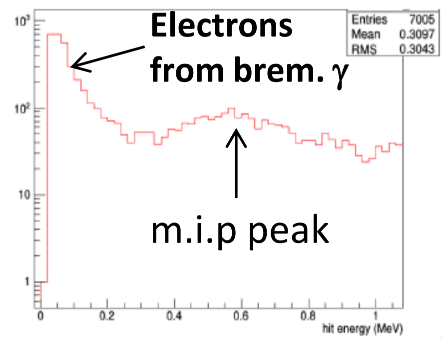
Charge (fC)



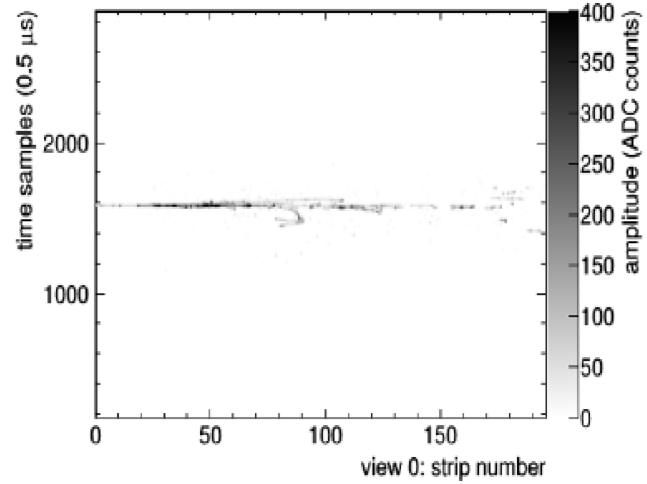


Energy (MeV)





1 GeV electron



→ 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 SP)

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

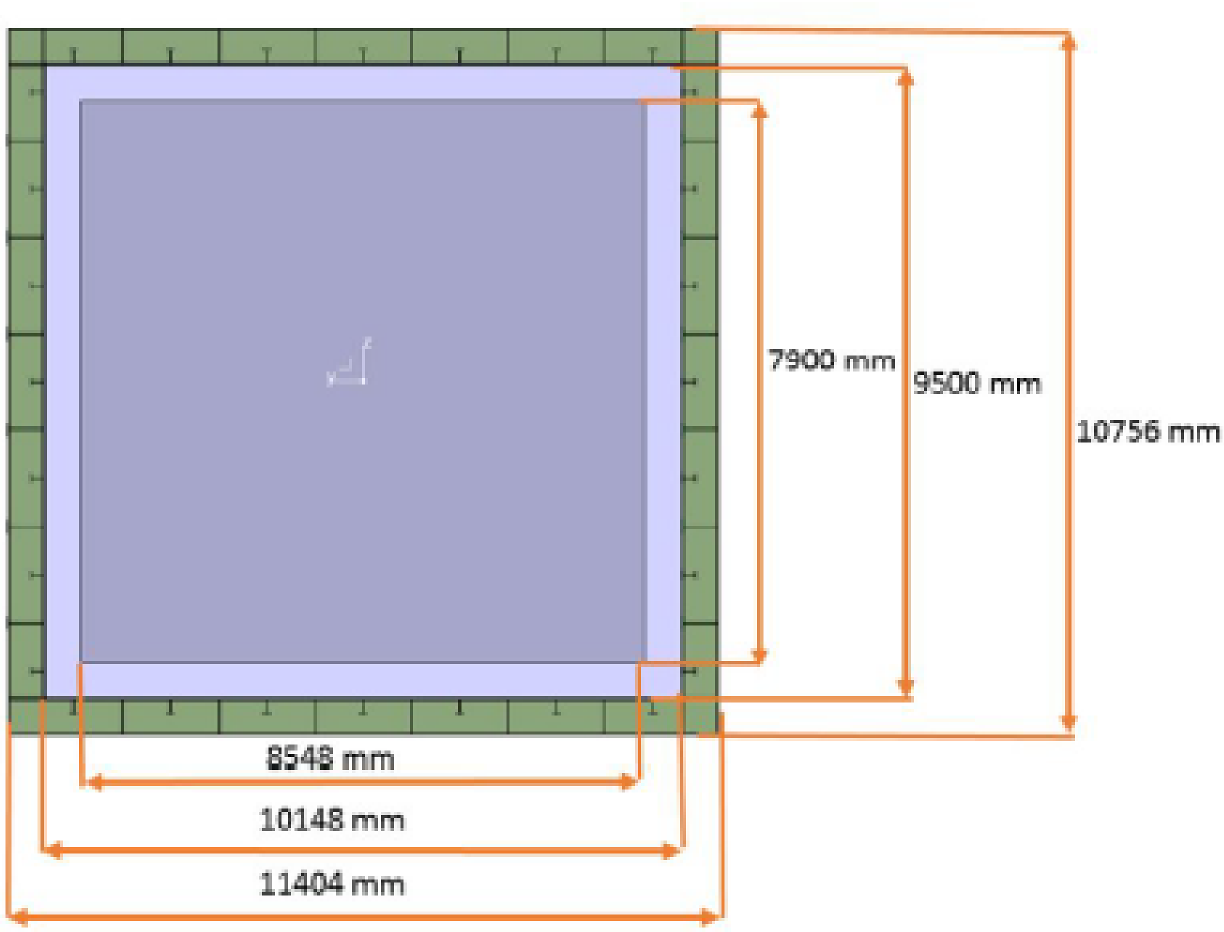
5 ms →

	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

Cryostat dimensions



Cryogenic system specifications

- GAr purge flow rate, $88m^3/hr$
- Maximum cool-down rate, $40K/hr$
- Maximal temperature difference between any two points in the detector, $50K$
- LAr filling rate, 18 l/minute
- Cryostat static heat flow, 3.0 kW
- Other heat loads, 5 kW
- LAr circulation (5 days turnover), $72l/min, 19gpm$
- Emptying (with both LAr pumps), $144l/min, 38gpm$

Operating pressure between 950 and 1100 mbar
Local heat input 5 W/m^2

NP02

CERN
ETHZ
IFAE and CIEMAT
IFIN - HH
IN2P3 (APC, ipnl, lapp, omega)
IRFU/CEA
KEK
University College of London
University Jyväskylä

NP02-C CRP hanging system/movement

Czech Republic Institutes

NP02-E Purity Monitoring

The DUNE-UK Collaboration

NP02-I Charge readout cold analog ASIC

Institut de Physique Nucleaire de Lyon (IPNL)
University of Texas Arlington

NP02-J Charge readout digital FE and timing distribution system

Institut de Physique Nucleaire de Lyon (IPNL)

NP02-L Photomultipliers, WLS coating, and mechanical integration

CIEMAT-Madrid and IFAEBarcelona (Spain)
Czech Republic Institutes
Kyiv National University
University of Wisconsin

NP02-M Light readout cabling

CIEMAT-Madrid and IFAEBarcelona (Spain)

NP02-N Light readout digitization system

University of Texas Arlington

NP02-Q DAQ and Online Data Processing and Storage Facility

Fermilab Scientific Computing Division
Institut de Physique Nucleaire de Lyon (IPNL)

NP02-R Run control software

Institut de Physique Nucleaire de Lyon (IPNL)
Maryland

NP02-S Slow control system, sensors, and cabling

Maryland

NP02-V Large area trigger counters

Czech Republic Institutes

NP02-W Computing Infrastructure

Argonne National Laboratory
Fermilab Scientific Computing Division
University of Texas Arlington

NP02-X Detector Integration

Kyiv National University

NP02-Y Engineering and Management

University of Texas Arlington

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):

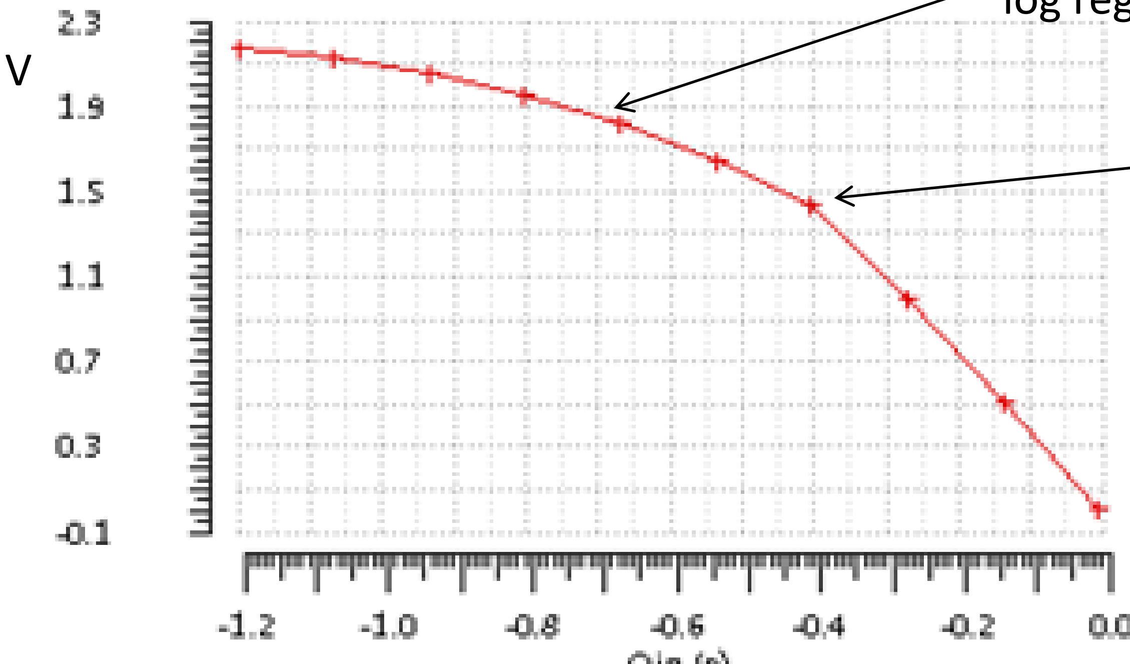
New institutes have expressed their interest to work on WA105:
FNAL (Computing and Neutrino Divisions), Czech Republic Institutes, University of Texas Arlington, National Centre for Nuclear Research, Kyiv National University, University of Wisconsin, Maryland, Argonne National Laboratory and DUNE-UK.

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

WA105 cold electronics

To increase dynamic range of the front-end electronics up-to 1200 fC the cryogenic amplifier have a double-slope feature:

- High gain up-to 400 fC (~13 mip with LEM gain of 10 per collection view)
- Smaller slope for high energy depositions

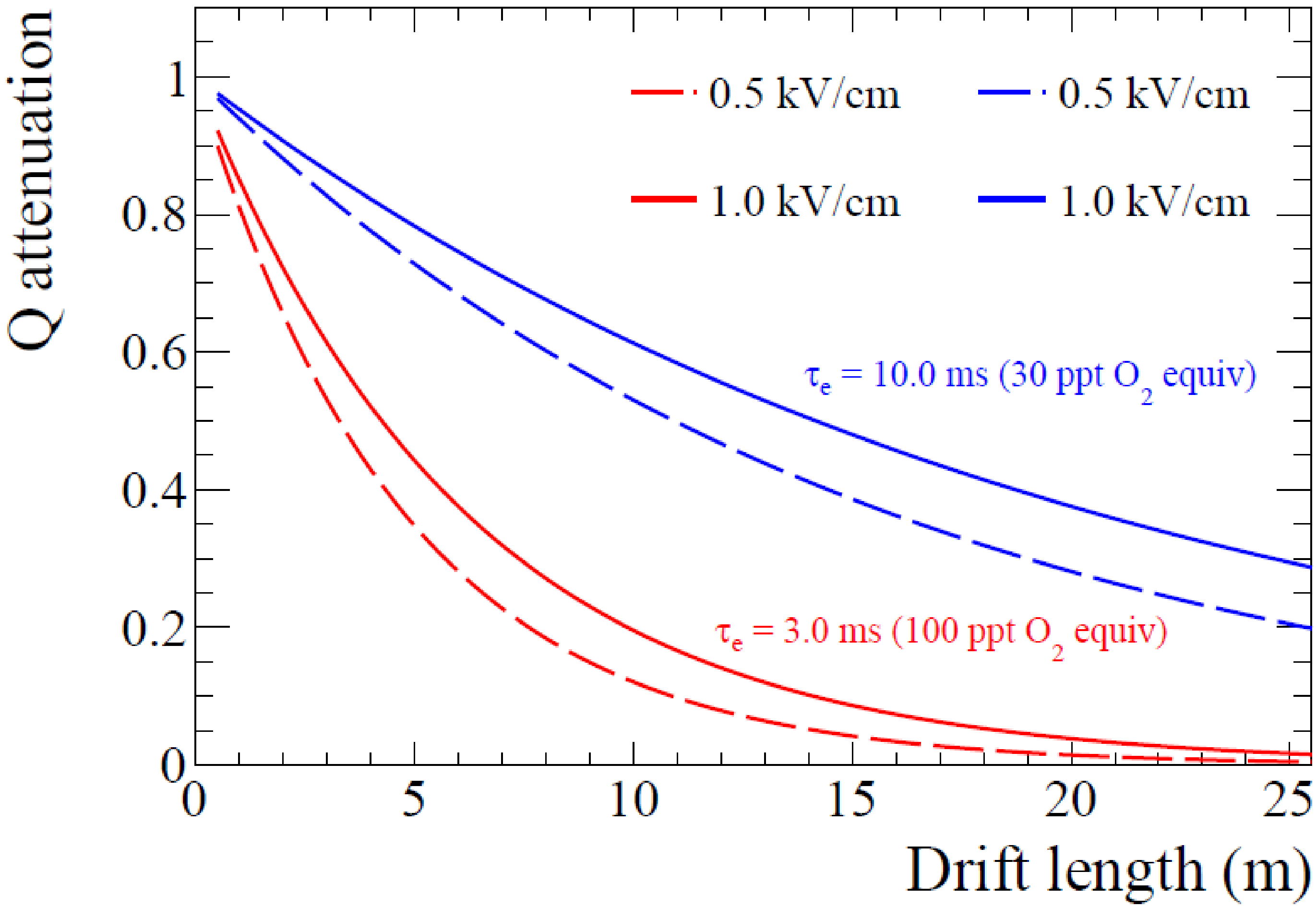


~log regime up to 1200 fC

Kink at 400 fC
~13 mip with LEM
effective gain = 20

pC

Charge loss



Q attenuation
Drift length (m)
0.5 kV/cm
0.5 kV/cm
1.0 kV/cm
1.0 kV/cm
τ_e = 10.0 ms (30 ppt O_2 equiv)
τ_e = 3.0 ms (100 ppt O_2 equiv)
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25