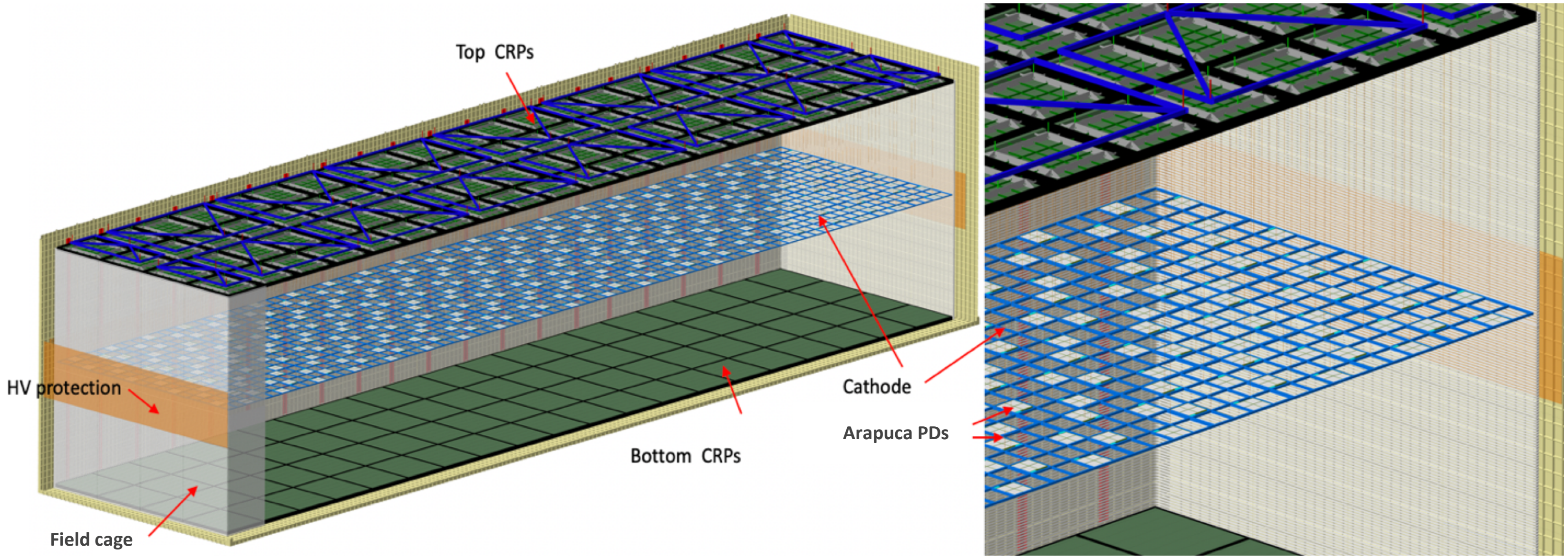
VD demonstrator: HV stability test in 2021



Filippo Resnati
(CERN)

14th June 2021

HV demonstration in NP02

Fundamental:

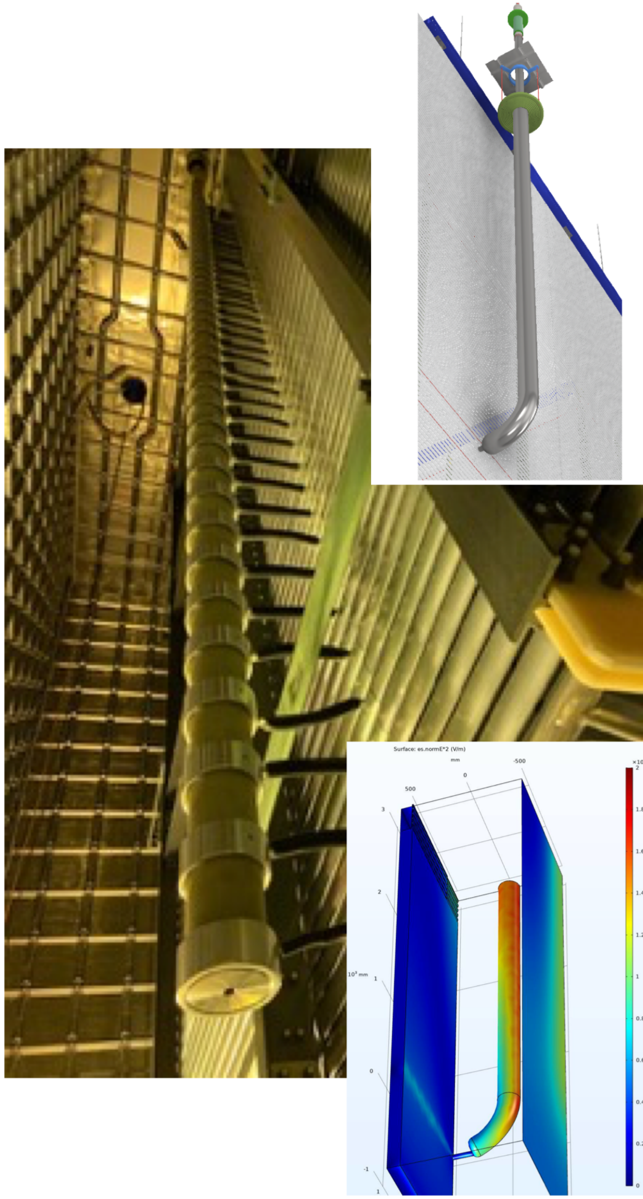
- Stable operation at 300 kV
- New HV extender design
- New HV feedthrough and absence of bubbles
- 6 m drift and long tracks
- Negligible noise induced by HV system on charge electronics
- 70% transparent (portion) field cage (HV operation)
- Absence of FC induced bubbles

Additionally:

- Installation of Arapucas on the cryostat wall behind 70% FC transparent (estimate the light transmission)
- Installation of cathode suspension wires to test in realistic cryogenic and load conditions and evaluate the long-term wire creeping

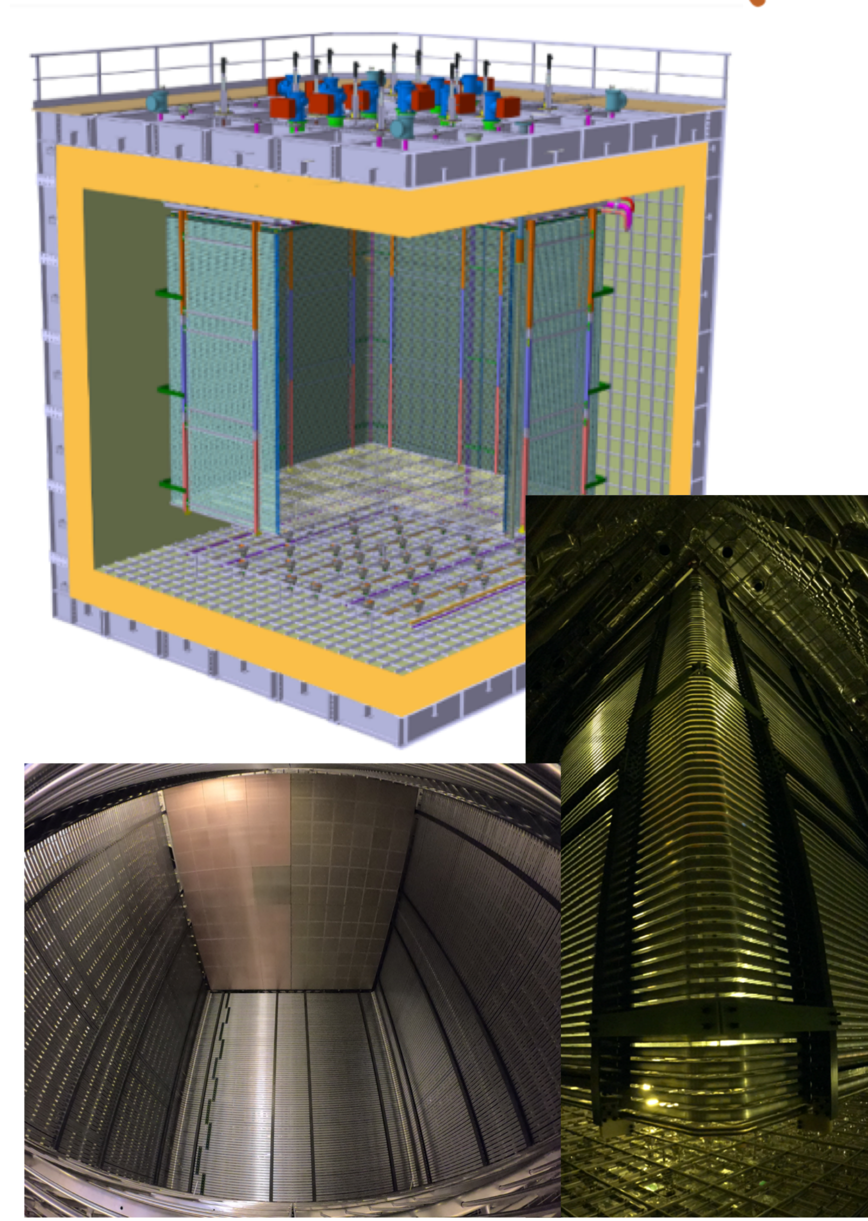
The HV Extender for the VD layout

- The NP02 DP HV distribution had the extender as the main weak element:
  - The NP2 failure was related to manufacturing defects and lack of testing capabilities.
  - the complexity of extender design introduced more uncertainty on the HV performance/stability than the expected advantages on the E-field uniformity.
- The proposed upgrade for the VD layout is based on a highly simplified version of the extender:
  - a simple metallic pipe where the HV discharge protection would be provided by the high dielectric rigidity of the surrounding LAr, designed to stand 350 kV
  - Note that this is the case for the whole field cage where all insulation supports are inside the cage and only metallic element are facing the cryostat membrane, exposed to high E field
  - Test of selected critical parts are on going @ Fermilab;
- ***A full-scale long-term test of the VD-HV distribution layout in the NP02 cryostat is an essential milestone and it is planned to be performed in 2021***



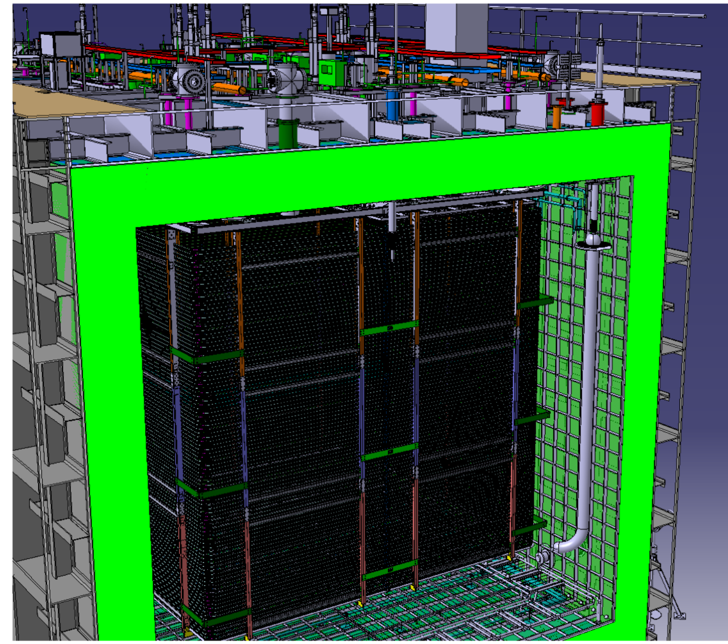
The NP02 detector

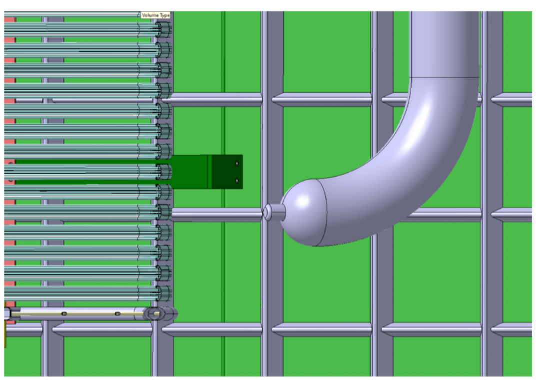
- The HV system of NP02 closely resembles the one of the VD layout:
  - The Field Cage and the Cathode hang from roof for ~6 m drift
  - The FC profiles *shape* & spacing, the bent corners and the resistive divider boards are very similar
  - The CRP structure is decoupled from the FC and hold the anodic (DP) read out units
- A recent inspection confirmed that the whole detector is in good shape (apart from the extender) and can be reactivated as it is:
  - The R/O and biasing
  - The PMTs
  - The monitoring system

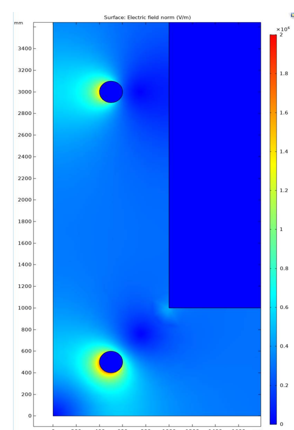


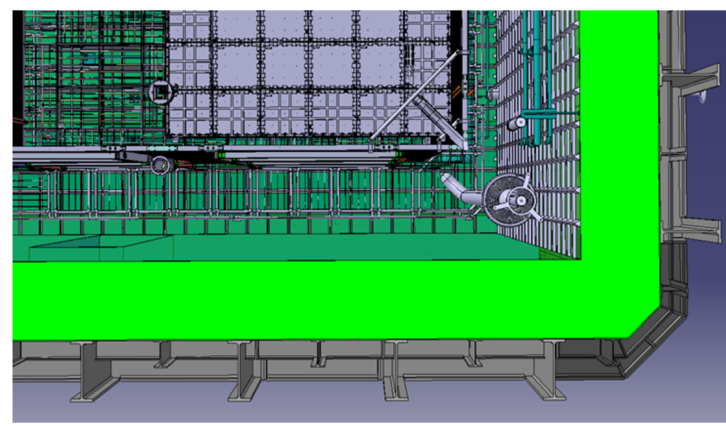
The New extender location in NP02

- Best HVEx position to simulate the distances in the VD case exploits a spare flange along a corner
  - the opening matches to Feed-through requirement.
  - The electric field distribution at the surface of the extender is similar to the case of a location in the straight section
- The elbow will be connected to the cathode via simple spring-loaded wires
  - to avoid that the HVEx push or pull on the FC
  - more than one wire for redundancy
  - no special requirement on precision alignment of FC to HVEx due to week E field region









Installation steps: old extender removal

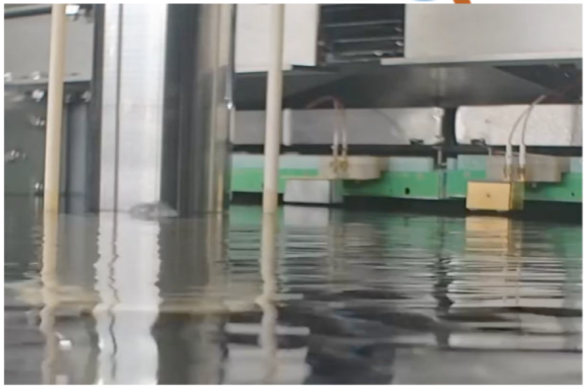
No need to open the TCO. Access of personnel and material will be done through the manhole.

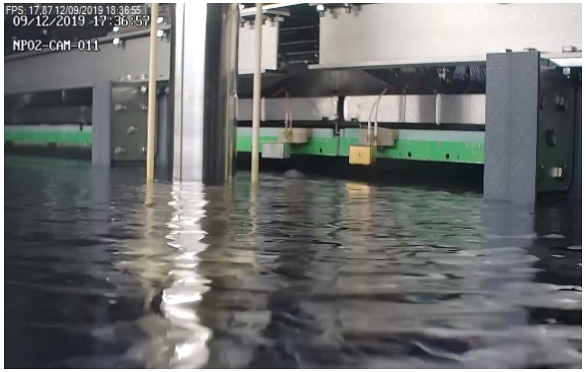
Required steps:

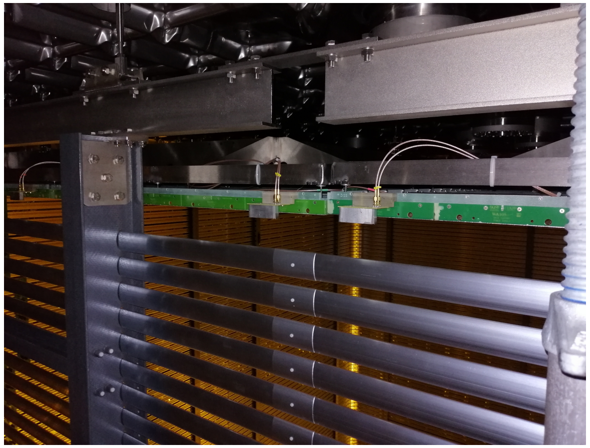
- Access inside the cryostat and remove the periphery ground grid
- Install the false floor below where needed
- Install scaffolding for easy access from the man hole
- Install scaffolding for the access to the extender
- Cut the field cage connections and change/repair the field cage clips
- Remove the extender rings
- Drill holes at the top of the extender for the pin for the sling
- Extract the extender from the HV penetration by means of the overhead crane

Installation steps: FC modifications

- During operations of NP02, bubbles formation at the LAr surface were observed in steady state cryogenic conditions, originated from
  - the HV feedthrough (gas trapped below the ground donut)
  - From the topmost field cage rings (gas trapped in the C-shaped profiles and escaping from connecting clips).
- Thermodynamic model, confirmed by further cameras observations, indicates that the bubbles are present in the top ~20 cm below the LAr surface.
  - LBNC presentation (2019): https://indico.cern.ch/event/857610/sessions/331374/#20191205
- Plan to mitigate this issue:
  - Cut and remove the three topmost FC rings (requires moving the scaffolding around the field cage)
  - Include gas escape paths in the feed-though design (feature already present in FT under test)

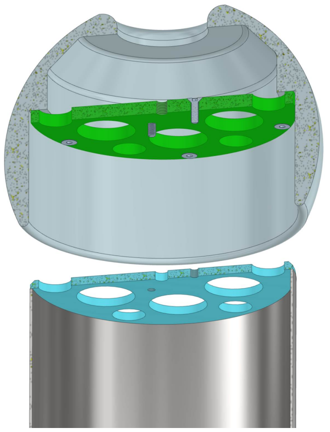


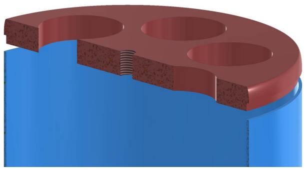


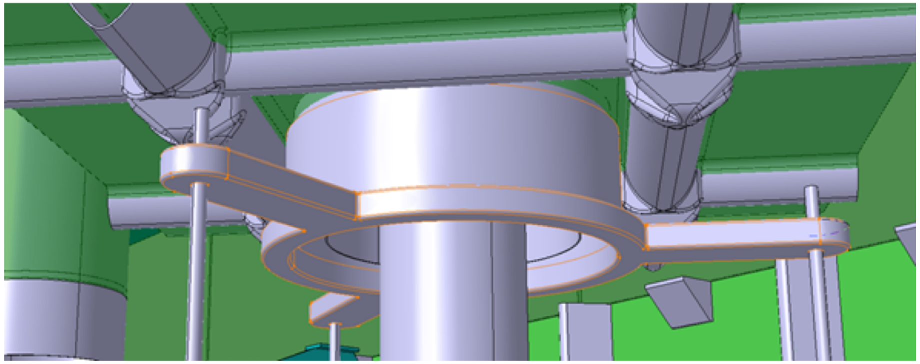


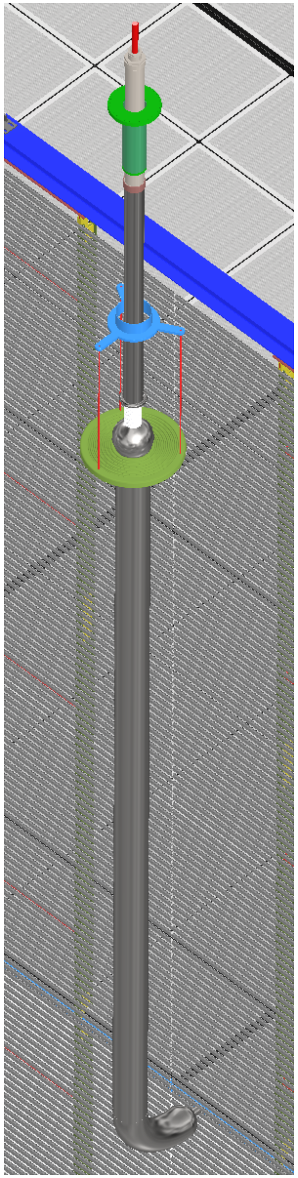
Installation steps: new extender assembly

- Extender head parts and elbow shipped by Fermilab to CERN
- CERN procures passivated tube of proper dimensions (~6 m) and build the stainless steel suspension system
- Assembly of HVEx modular parts, cleaning and surface QC performed at EHN1
- In the cryostat: suspension system welded on the rim of the penetration (similarly to old extender)



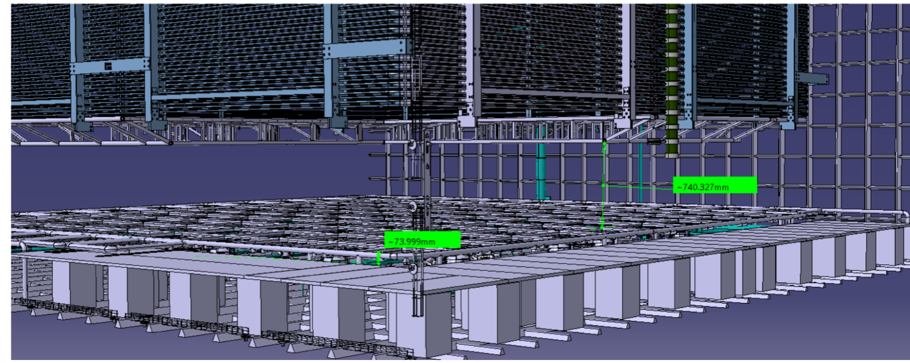


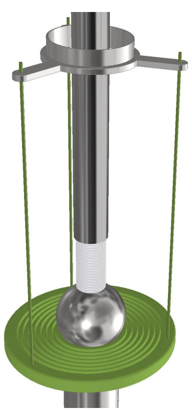


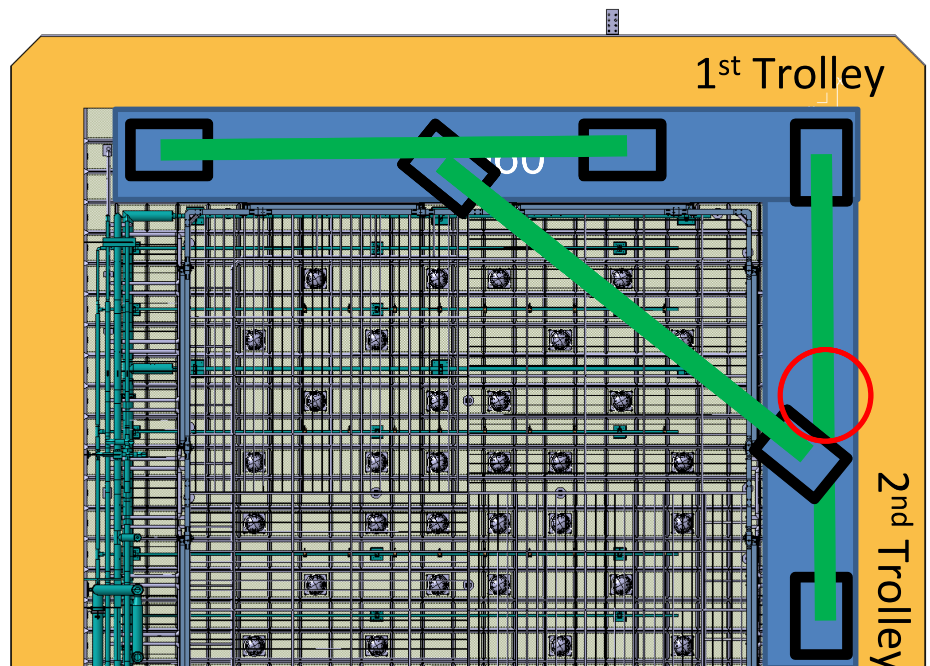


Installation steps: new extender in NP02

- Installation procedure is defined (similarly to old Extender):
  - HVEx inserted vertically through the manhole until reaching the 1st trolley
  - HVEx lowered with the crane, helped by trolley it is pulled towards the correct position
  - the HVEx second extremity placed on the 2nd trolley.
  - rotated and shifted to position
  - Lift the extremity of the HVEx with the crane through the penetration
  - Append the FR4 disc to suspension system with FR4 rods
  - Connect elbow tip to FC with spring wires

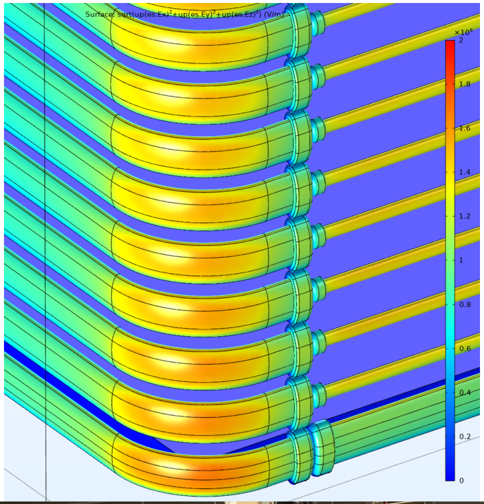






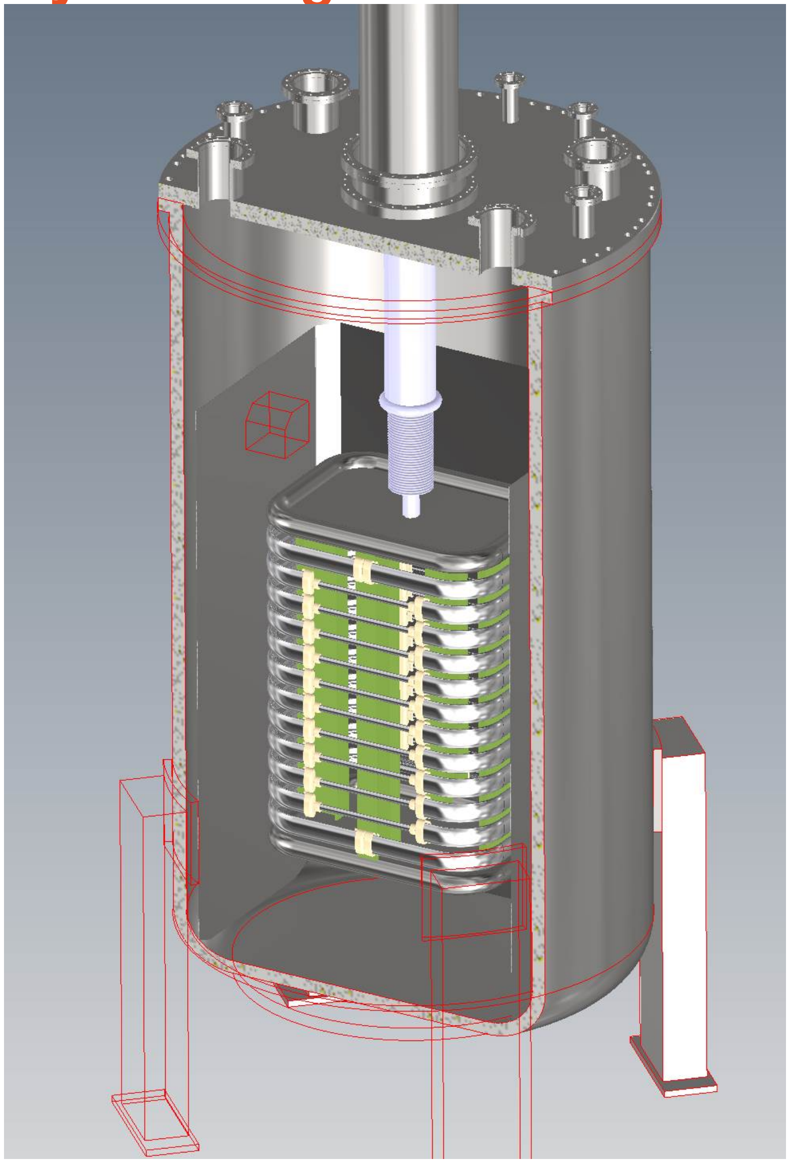
Test of the 70 % transparency field cage.

- The FC design solution partially implementing thinner FC electrodes seems to be safely complying with the maximum electric field surface requirements (<30 kV).
- A long term HV test at nominal E Field is however important to gain confidence that there are no hidden flaws.
- We plan to perform this test at CERN in the 1 ton Cryostat, where we are testing the HV feed through, adding a mini field cage between the feed though and the ground planes.
- The Cryostat is being equipped with efficient purification / recirculation systems to achieve high purity LAr (safety validation required).
- Monitoring systems (Ground Planes current pick-off, LAr PM, Cameras and temperature/level meters) will be integrated in the new layout.

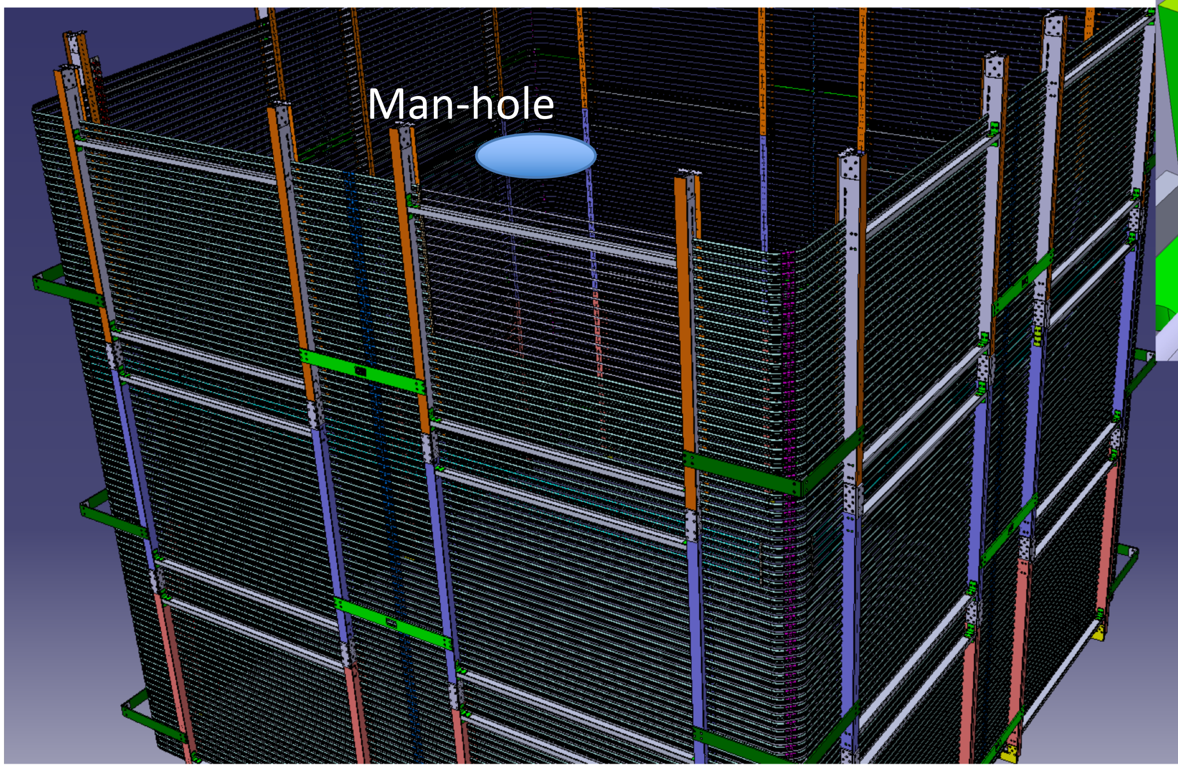


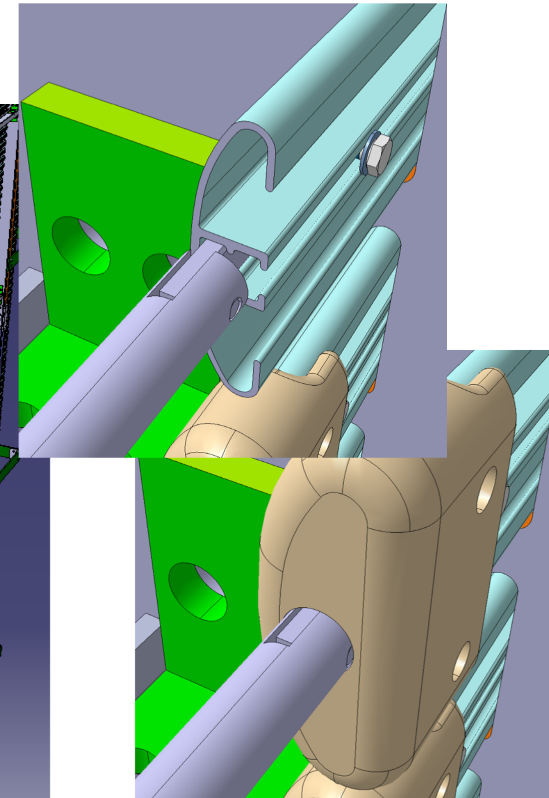
Test stand for the 70 % transparency field cage.

- The mini field cage will include aluminum profiles mimicking the shape of the 70% transparent FC solution.
- The actual layout (electrodes segmentations, distance from the cryostat walls, maximum Voltage) is under optimization:
  - The whole FC will sit at the potential of the HV-FT
  - Ground planes are added at the four sides for an outer E field uniformity similar to the VD
  - With a 10/11 cm FC-GP distance, an actual outer E-field as in VD is reached with 60-70 kV on the HV-FT.
- *A similar test was successfully performed in the CERN 50 liter test stand to gain experience wit the present HD layout.*
- The present plans is to start procuring the required materials as soon as the FC design is ready and validated, in order to perform in early 2022.



70% test in NP02





Mechanical and light transmission test of the field cage:

- 2x2 m^2 portion of highly transparent field cage installed instead of present field cage
- 2x Arapuca from NP04 will installed on the cryostat wall facing the transparent field cage
- The feedthrough for the PD is taken from NP04 and installed on the previous HV feedthrough penetration

Detector commissioning and operation

- LAr contract being awarded. Negotiating the initial date for delivery (earlies 2nd of August):
- 1 week of cleaning, 1 week of purging, 1 week of cooling, 5 weeks to fill.
- Detector completed by the 9th of July (the earliest).
- Nominal LAr purity expected in 3 weeks after filling.
- Detector operation could start late September with HV ramping up.
- CRP R/O operation at various stages of the the HV ramping up can be envisaged to evaluate HV stability, induced noise and LAr purity (through attenuation along muon tracks, and with Purity Monitors).
- When the maximum HV is reached, start long term stability run (several weeks) in steady state conditions:
  - HV monitored, by sensing analogue PS output and FC current termination (20 kHz sampling rate) allowing the detection of current / voltage instability (proven effective in NP04/NP02)
  - CRP R/O (not necessarily always on) to monitor possible induced ripple or spike noise, electric field instability, Argon purity

Goals of the Cold Box test in 2021

Characterize and validate the design and the construction procedures of a full scale charge readout module equipped with electronics.

- mechanical and electrical test of the CRP in cryogenic conditions,

- mechanical test of the cathode module in cryogenic conditions (not final version, metallic mesh instead of resistive mesh),

- characterization of the performance of the perforated anode and the full electronics chain in terms of signal to noise ratio and its stability,

- test the light readout detector concept at large scale and embedded in the cathode,

- test the integrated system as a whole and evaluate the interplay between the powering scheme, the charge electronics and the light detector system.

Upgrade Required

The new requirements for the VD CRP tests imply major upgrades to the mechanics and the cryogenics system of the cold box.

The cold box will be installed at EHN1 to profit from the cryogenics and safety infrastructure already available.

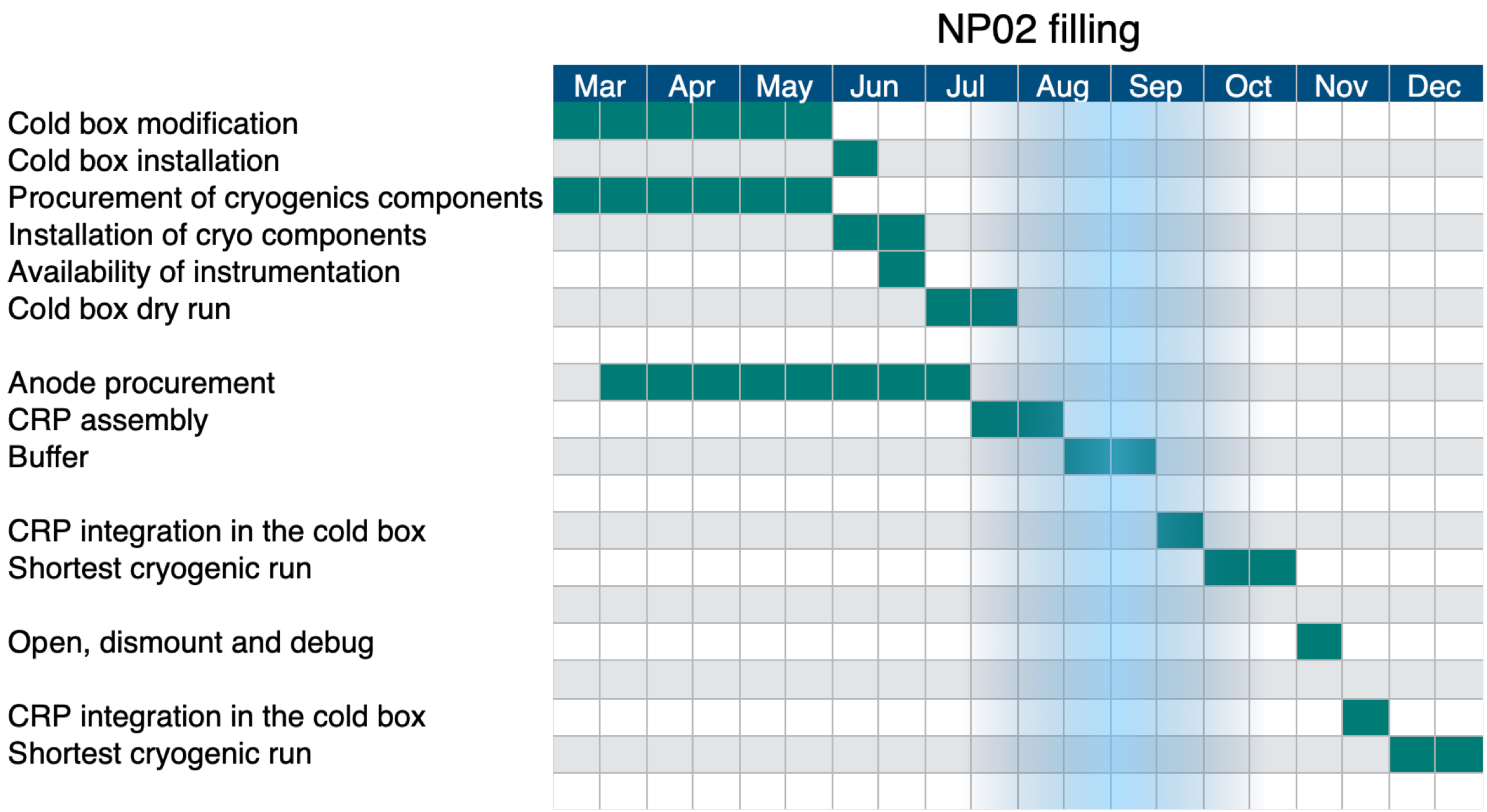
Cold box commissioning starting second half of July, before NP02 filling.

A CRP equipped with both top and bottom electronics will be tested in TPC mode from October till the end of the year.

Additional tests of CRP equipped uniquely with top and bottom electronics or different strip layout will be planned for 2022.

Cold box modification

Time line


NP02 filling
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Cold box modification
Cold box installation
Procurement of cryogenics components
Installation of cryo components
Availability of instrumentation
Cold box dry run
Anode procurement
CRP assembly
Buffer
CRP integration in the cold box
Shortest cryogenic run
Open, dismount and debug
CRP integration in the cold box
Shortest cryogenic run

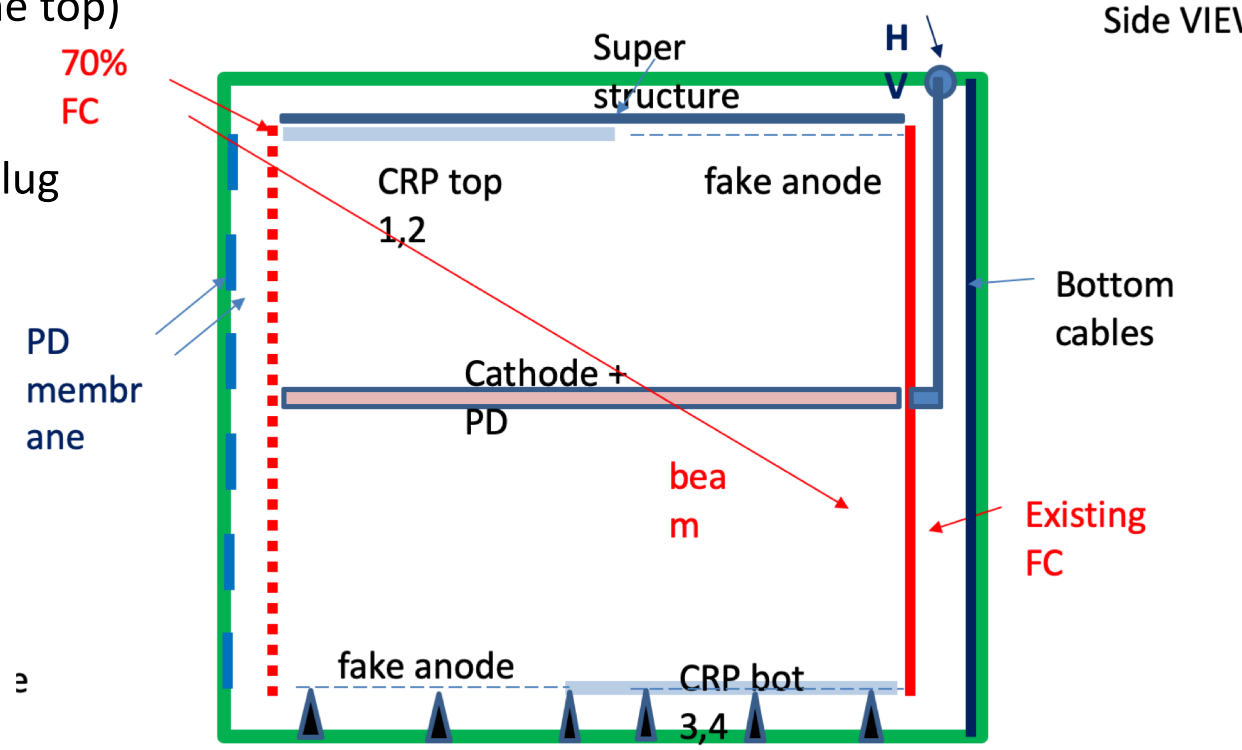
After the NP02 and cold box tests

Open points related to HV system still to be demonstrated after the 2021 tests:

- Voltages beyond 300 kV
- Full size transparent field cage
- Cathode hanging system
- Full size cathode with resistive mesh
- Symmetric drift

Module 0 proposal

2 Bottom CRPs in real conditions (supports, cable length 27m)
Cathode as in final VD including supports
70% FC at cryostat distance equivalent as foreseen at FD
PDs on wall where 70% FC and on the cathode
SUPER structure to support top CRPs (6x6 m2)
Shorter HV extender
Drift length 3.2 m (or more on the top)
HV= 300 KV ~ 1KV/cm
Vertical cable trays as in DUNE
Beam test and therefore beam plug



Summary

- The plan for a full scale validation of the VD HV system, with special focus on the HV Extender, is well defined and moslty on schedule.
- The NP02 detector will be fully operated, to ensure that the FC and the HV distribution performed according to requirement in terms of maximum voltage, voltage stability, induced noise in R/O system.
- It successful, a major milestone toward the realization of a 6 m drift LAR TPC will be reached.
- The cathode design and the integration of the light readout at HV will be partially tested during the the cold box tests.
- R&D to demonstrate the HV reliability of the high transparency FC concept is being set up.

BACKUP