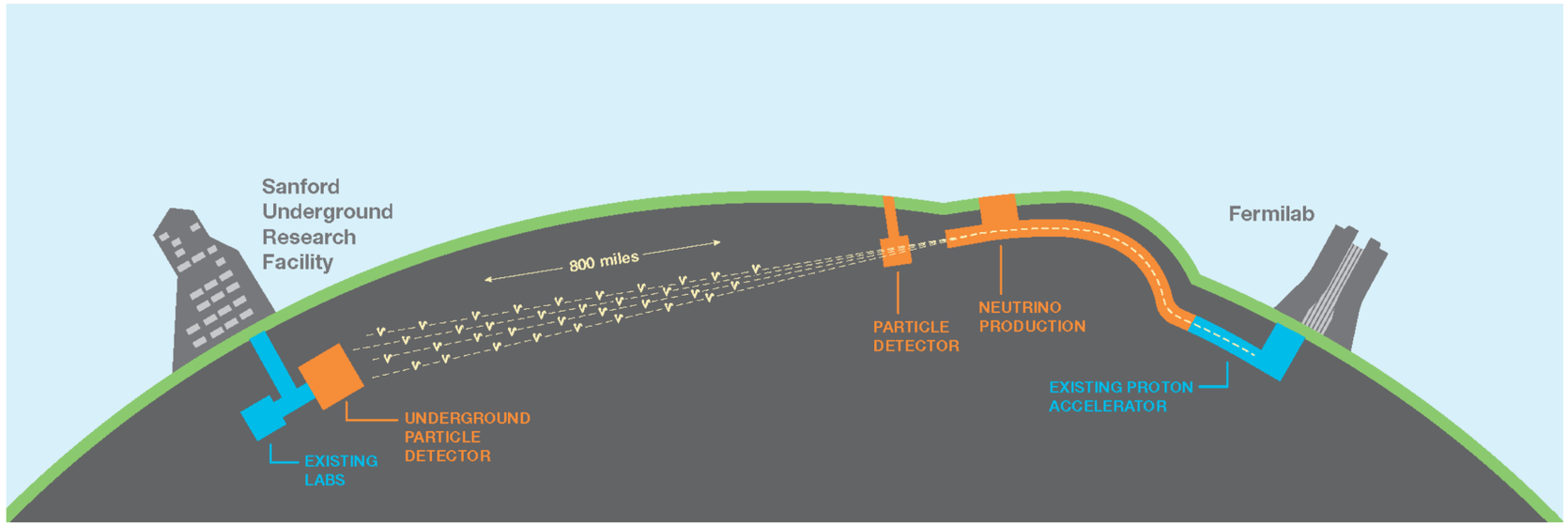


HV system of NP02: status and plans

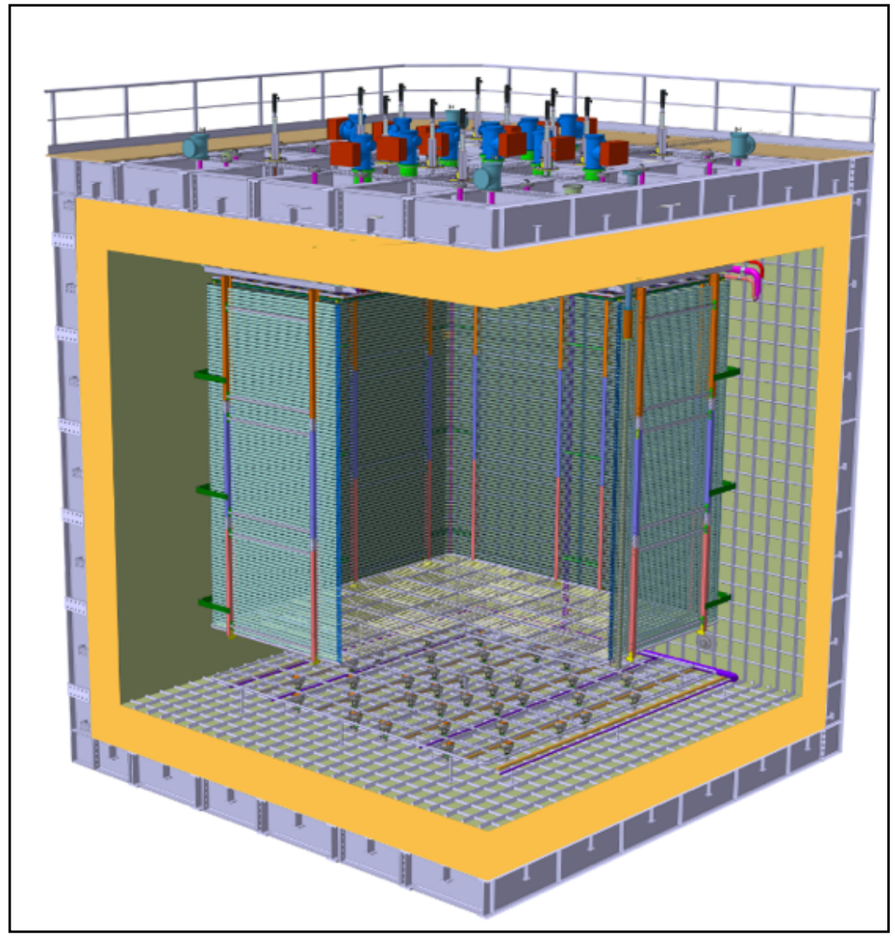
December 5th, 2019

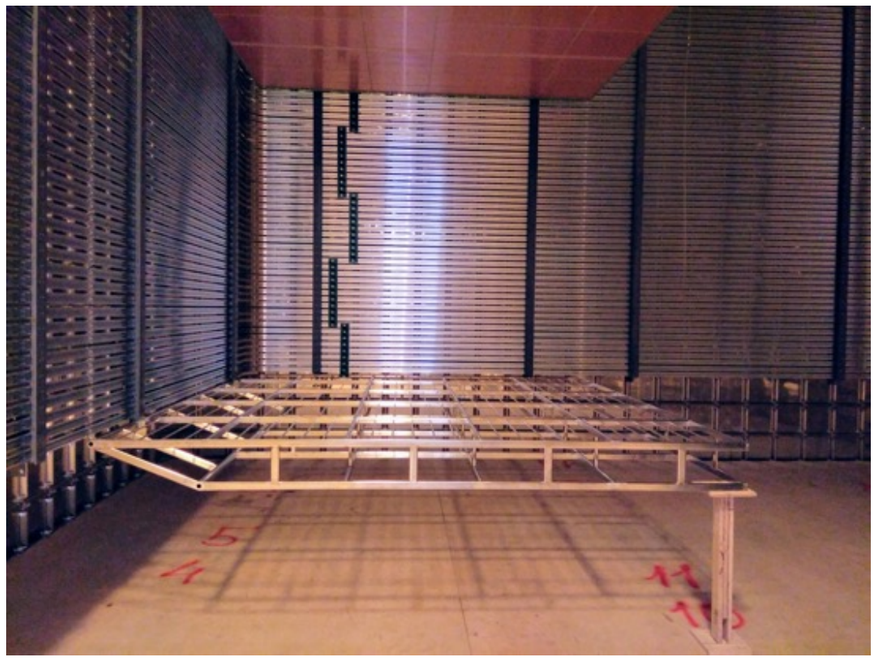
Outline

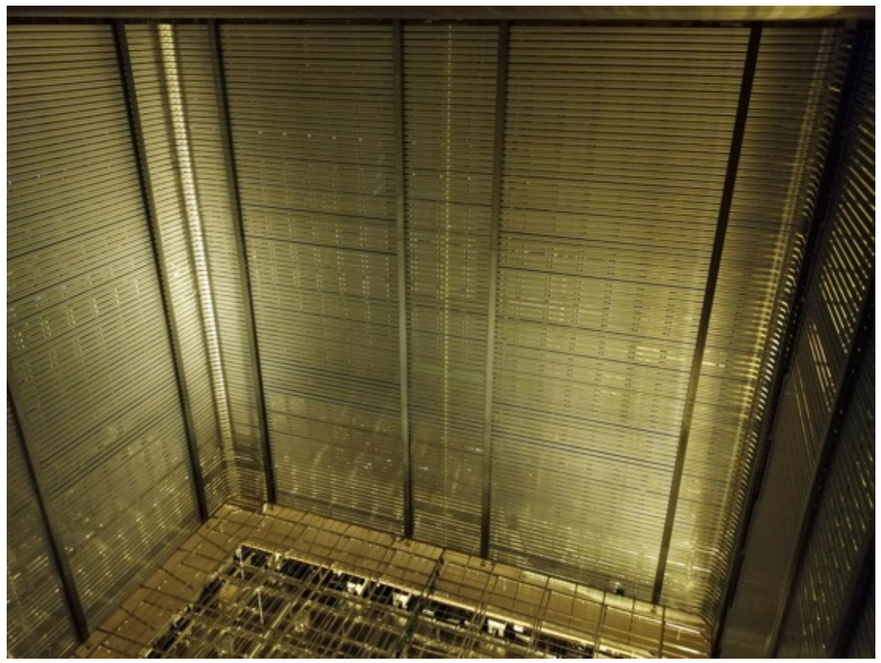
- *The NP02 High Voltage system*
- *Commissioning and present issues*
- *Plans for HV recovery*
- *R&D toward the 600 kV and NP02 phase II*

The NP02 HV system

- Field Cage and cathode hangs off of the ceiling
- Essential to have light yet sturdy structure.
- Based on modular concept as SP.
- The voltage divider boards (2x) are equipped with 2 parallel 2-GOhm resistors in parallel with a series of 4 varistors (clamping voltage 1.8 kV)
- The varistors allow to apply ~7.0 kV before conducting, corresponding to drift E.F. higher then 1.1 kV/cm





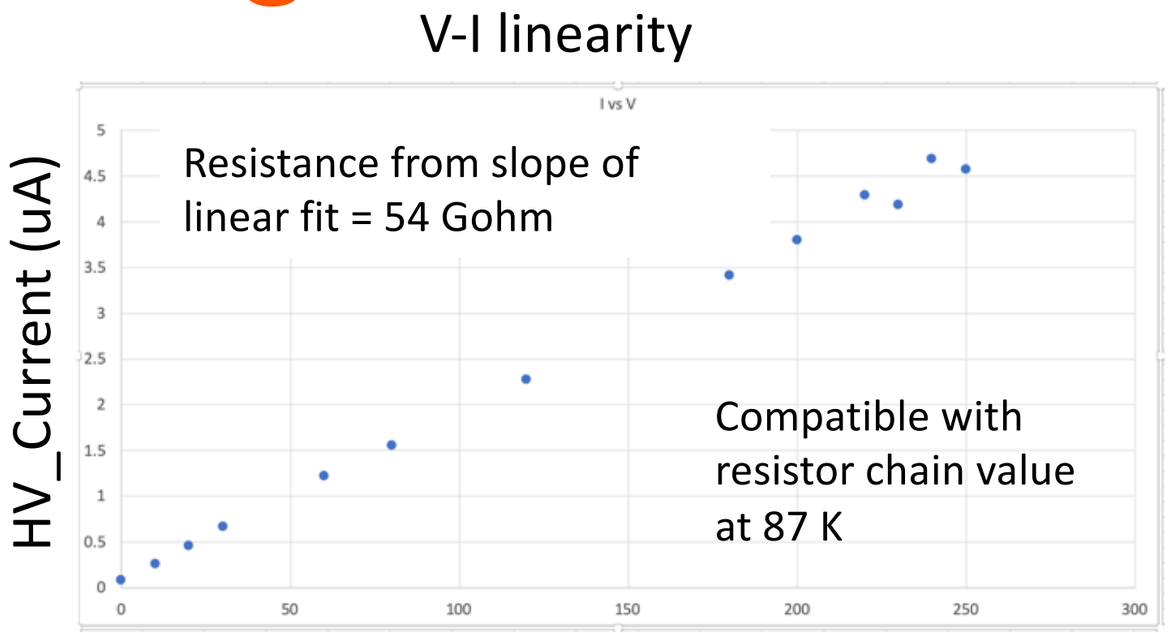


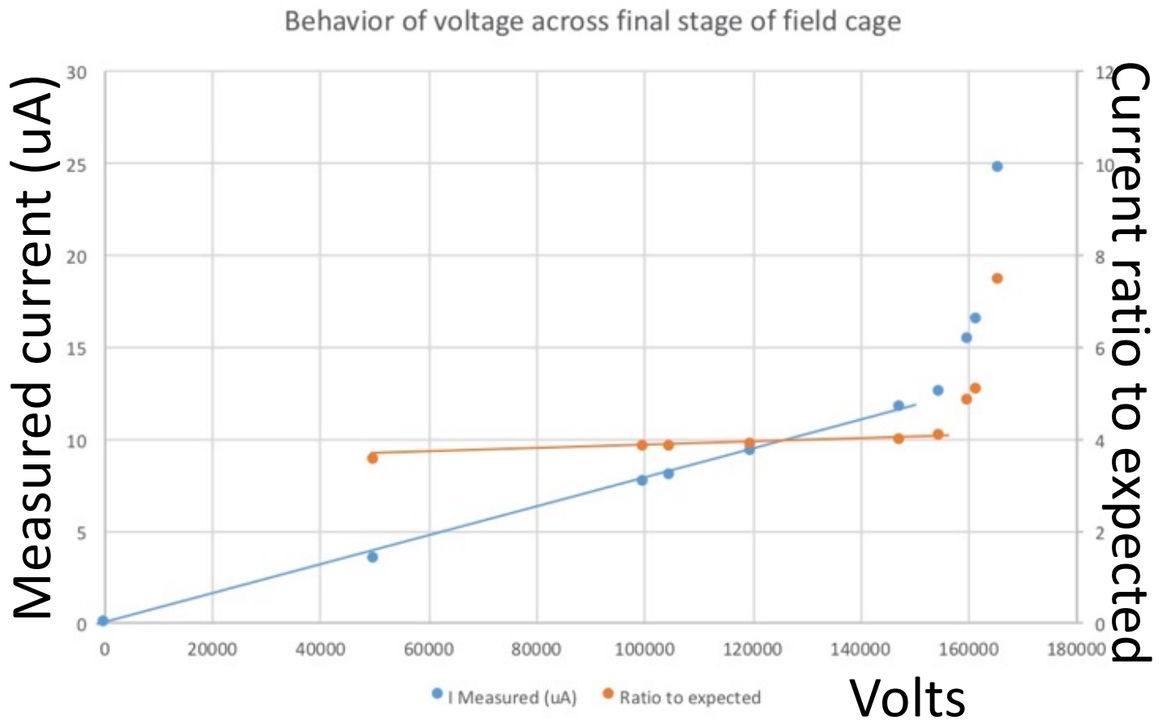
The HV feed-through and extender

- The HV feed-through is the twin of the SP one successfully tested at 300 KV in dedicated test stand
- Commercial 300 kV cable
- HV, 6m long, extender:
  - designed to propagate the drift HV from the tip of the HV feedthrough to the cathode:
  - Insulating tube machined out of G10 thick plate
  - Made in three pieces glued together
  - Metallic rings around the insulator to confine field in G10 insulator, connected to the same height FC profiles

NP02 HV commissioning

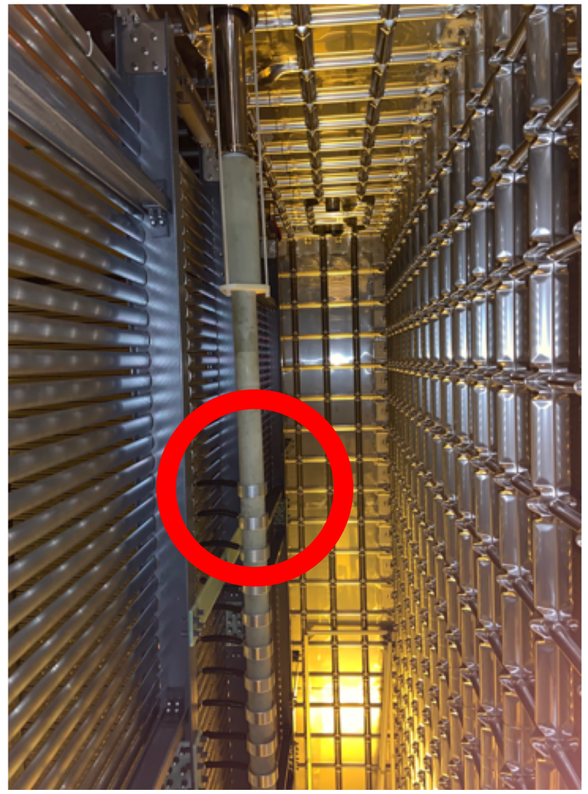
- After completion of the LAr filling in August, HV ramping up started:
  - Two days of stable operation at -60 kV
  - HV = -200 kV reached in steps of 50 kV with a plateau of 15-30 minutes to measure noise on front end electronics
  - A further increase in steps of 10 kV allowed to reach -250 kV
  - After 10-15 minutes at -250 kV, a current trip (> 500 uA) reset the HV-PS voltage to zero
- Behaviour after the HV trip:
  - Current spikes at HV > -10 kV (tenths of Hz rate), visible on front end electronics
  - Max reachable HV: ~ 168kV,
    - above this value, high current sets up, indicating that varistors start conducting
    - This implies that the HV is actually applied at stage 24 of the divider chain
  - --> SHORT circuit through the extender

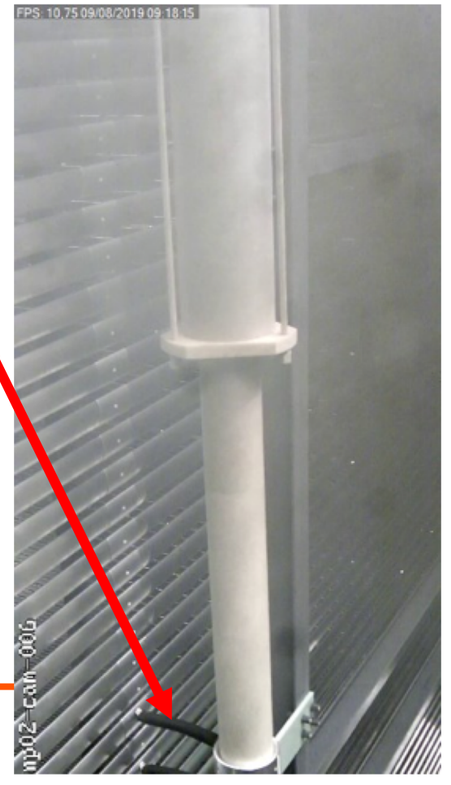




Extender: most likely location of fault

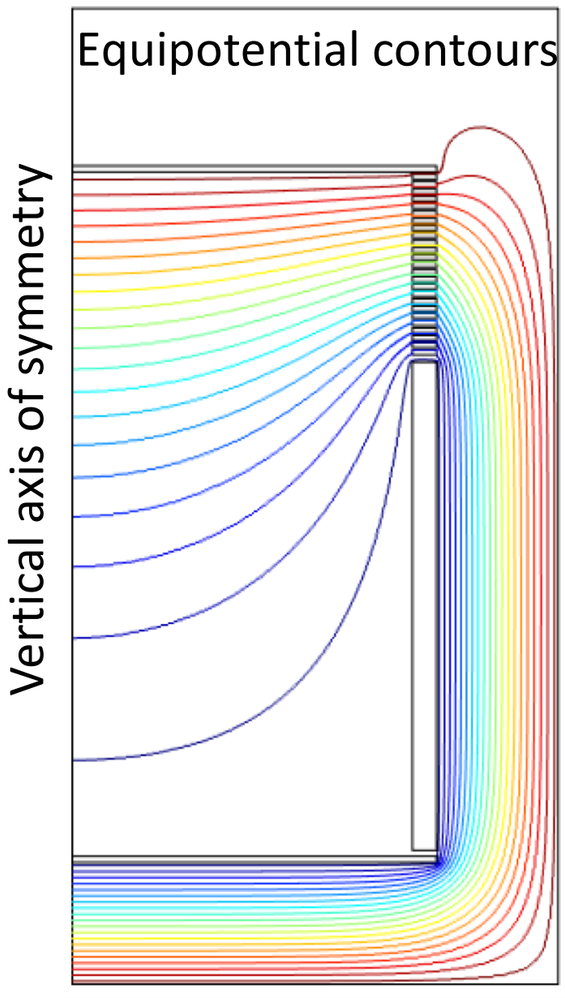
- Issue explained as a short circuit of the inner conductor of the HV extender with the first degrader ring connected to the corresponding field cage ring at about 1/4 of the drift height.
- Fault due to defect in the cylindrical shape of the extender (radial fabric planes are HV weaker)
  - It was not cryogenically and HV tested in a separate test-stand due to its length
  - Possible mitigation: intervene on the HV extender, by removing the first connections to field cage (delicate surgery!!)
- Present operative conditions:
  - Maximum applicable potential with manageable impact on the electronic noise limited to less than 150 kV
  - **Drift field is not uniform but close nominal in the upper 1/4 of the volume for 120 kV, longer drifts are also possible**

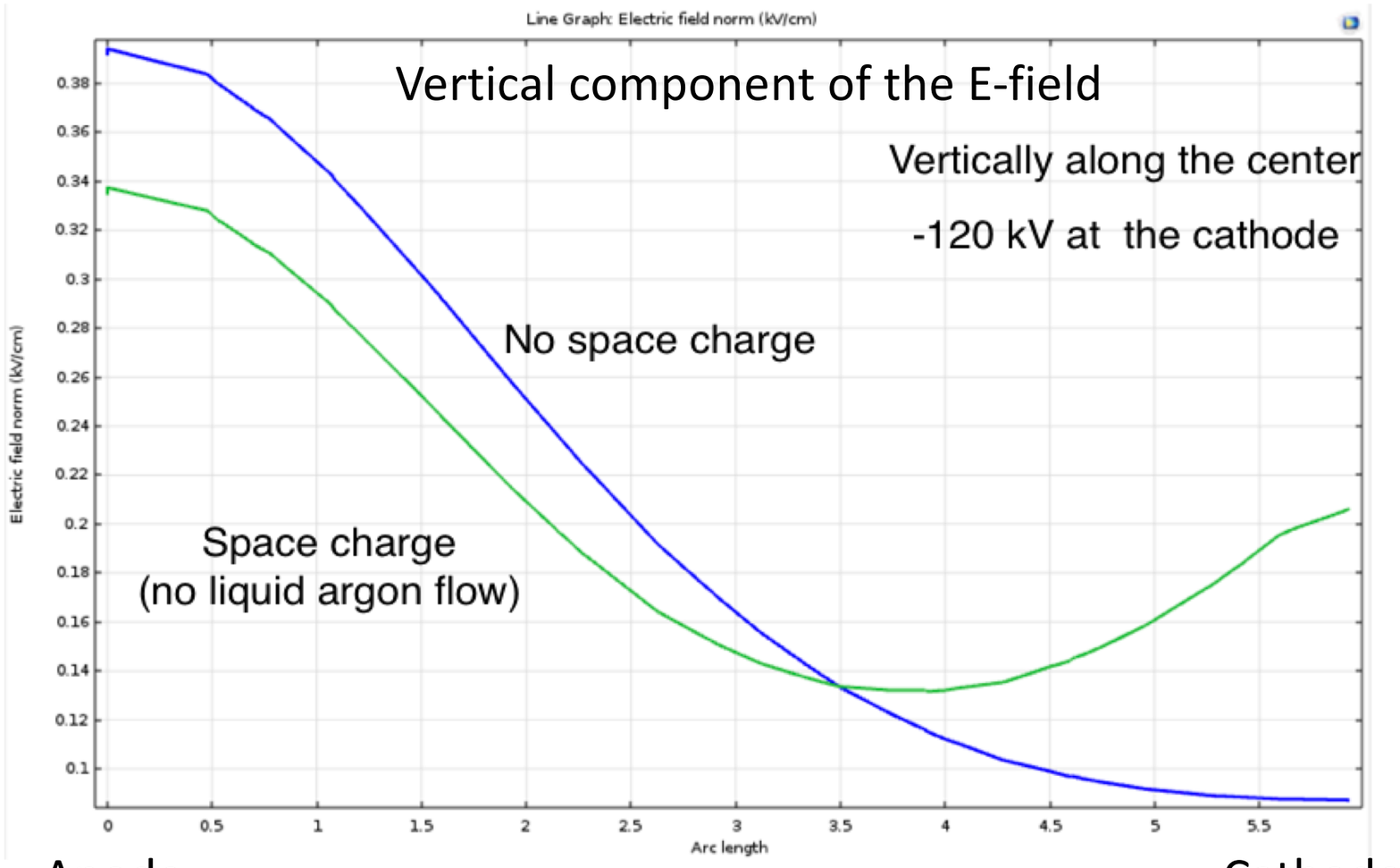




Electric field simulation

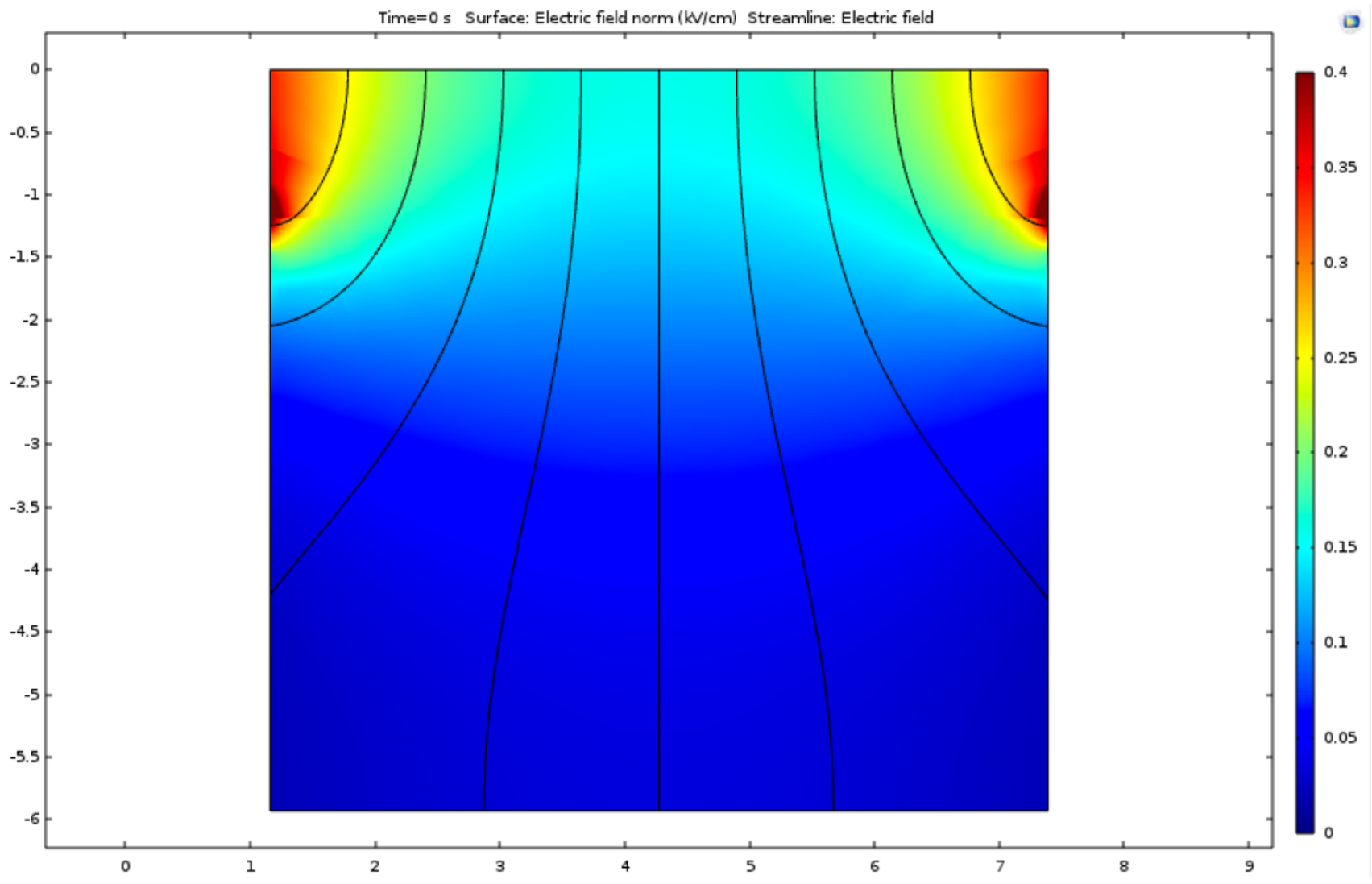
- With present understanding, electric field in the drift volume is calculated with and without space-charge (only the contribution from primary ionization, no from the ion back flow)
- Approx. uniformity in top 1.5 meter allows commissioning of CRP's





Anode Cathode

Electric field @ 50 kV on Cathode (present operating conditions)

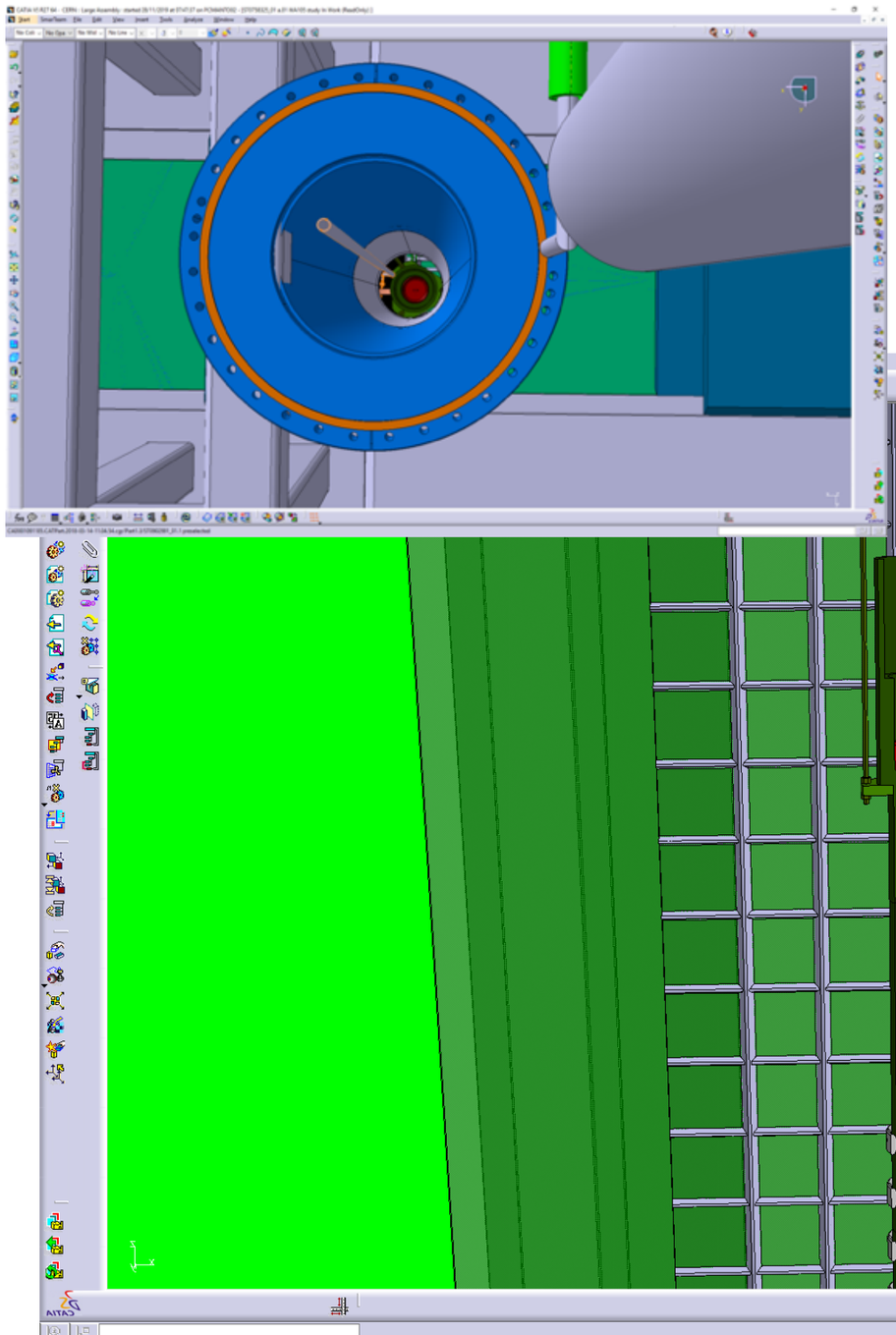


More info on Extender issue:
https://pddpelog.web.cern.ch/elisa/attachment?name=190814_143503_NP02-HV%20report_v3.pdf&fileID=116

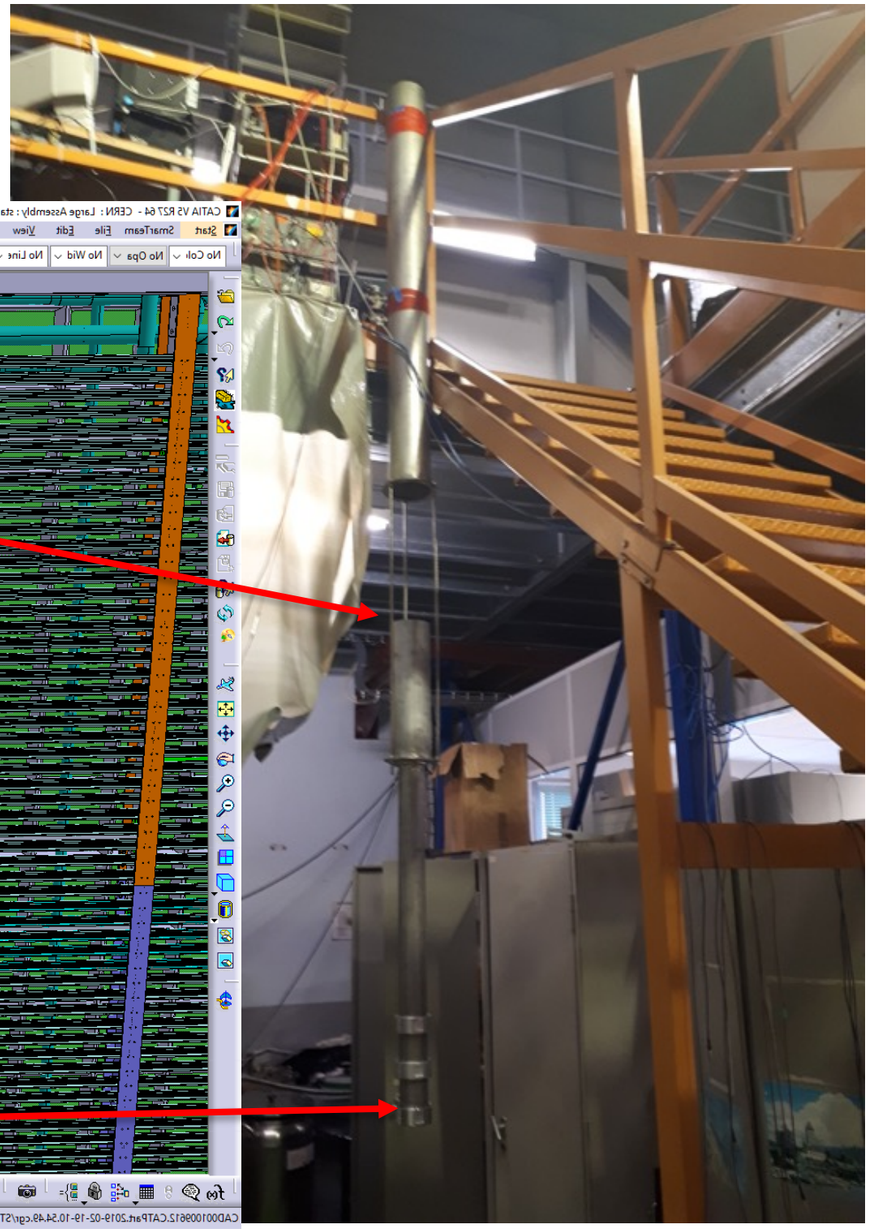
Plan to the next months

- Attempt to mitigate the short circuit in the extender rings and eventually reach the nominal HV value on the Cathode (300 kV)
  - Cut the connection between the faulty rings on the extender and the field cage profiles. Sequence:
    - Remove the HV feed through to gain access to the HV links (~ 2.5 m below the cryostat top surface)
    - Lower the Liquid level to expose the HV links to be cut (the first 2 or 3)
    - Insert special tools (scissors and hooks, camera assisted) mounted on 3m long rod to remotely cut the faulty HV links (both at the side of the extender and on that of the field cage)
    - Recover tool and HV links
  - A mockup is being assembled at CERN to test the whole operation sequence in 1:1 scale.
- If successful, operation on NP02 could be planned for ~ February/March

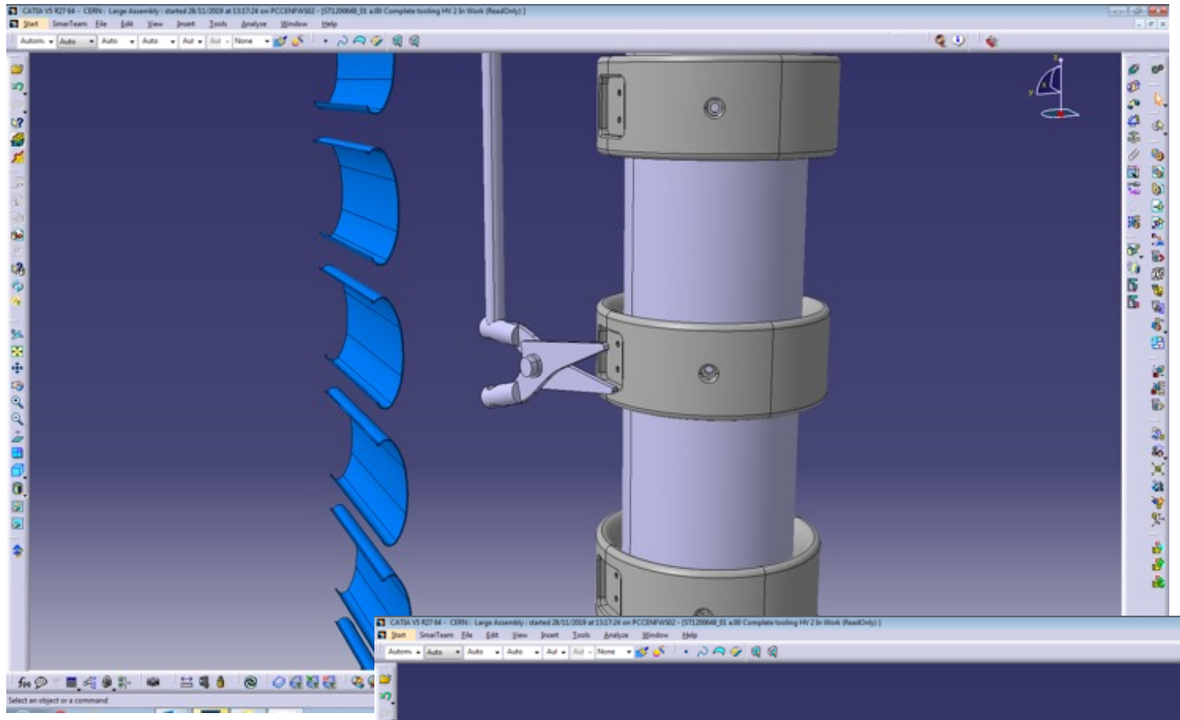
HV links cutting strategy

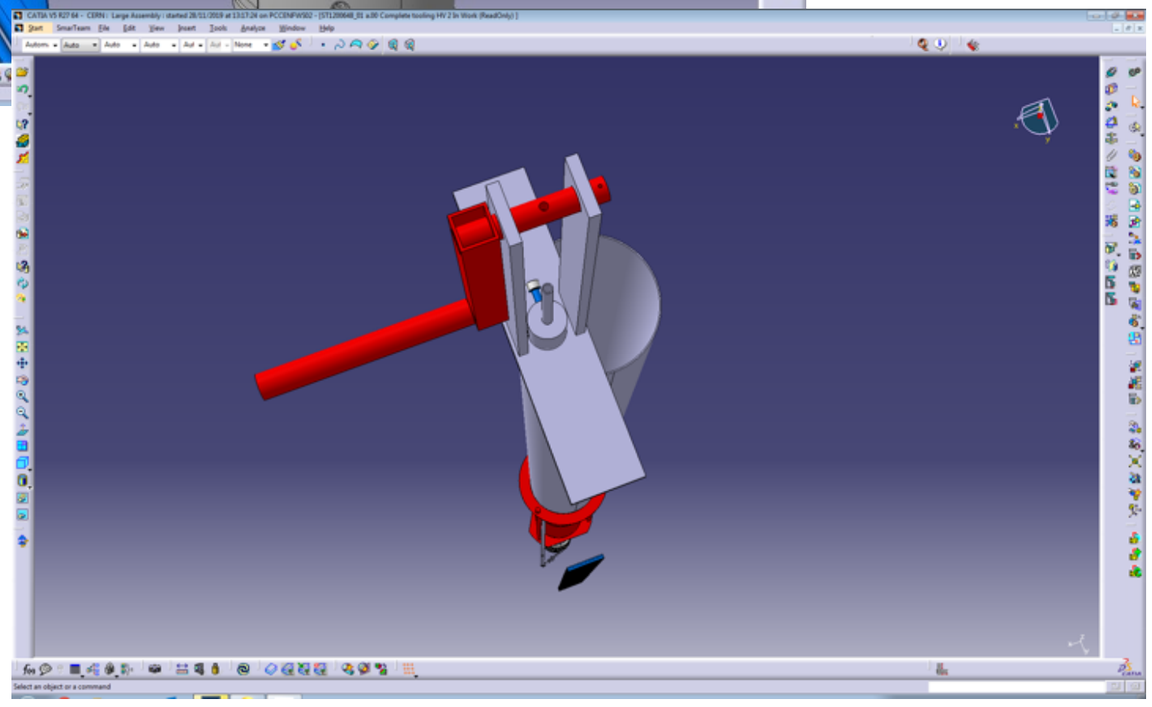


1:1 scale mockup



HV link cutting strategy



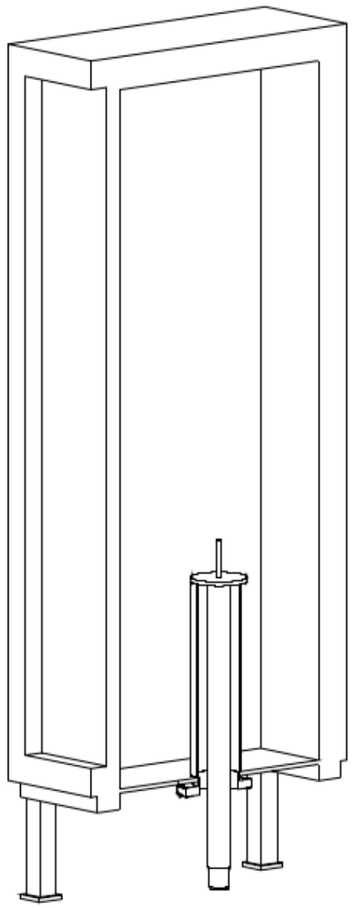


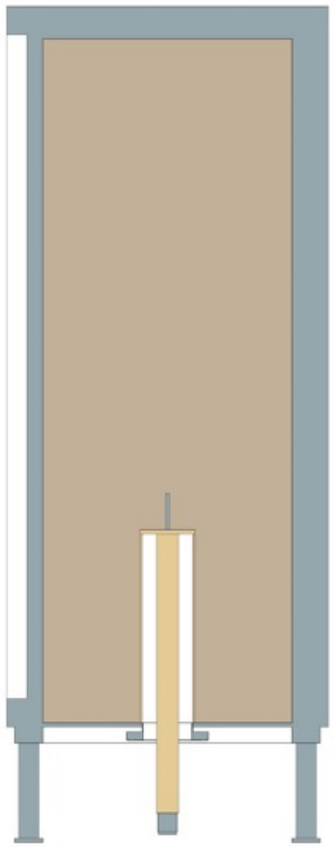
Path toward the 600 kV

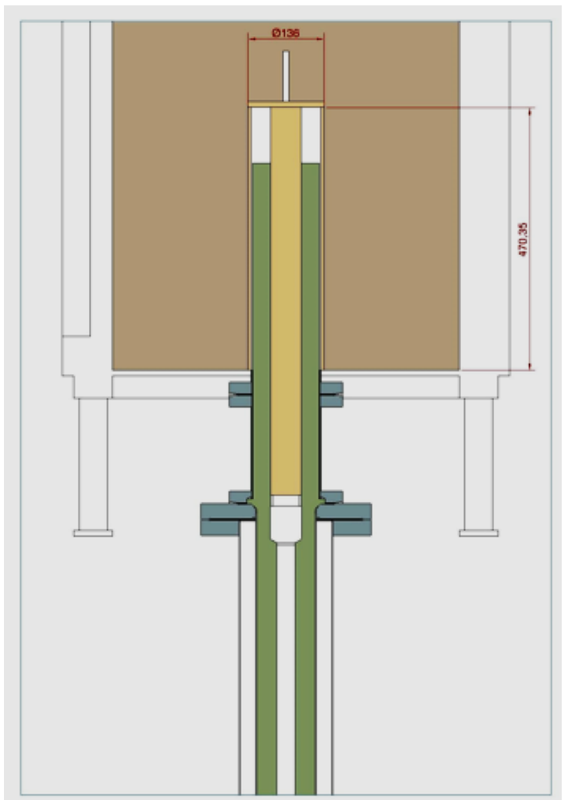
- The joint venture between CERN and Heinzinger for the development of the 600 kV PS delayed but recently contacts have been re-established
  - Base line is Cable-less PS with integrated HV feedthrough
  - Recent Fermilab involvement allows to explore alternative options with US manufacturers of HV-PS (Glassman, Wasik Associates) and cables (Dielectric science, resistive cables also under consideration)
- HV extender: alternative design are being explored
  - Simplified version for ProtoDUNE Phase II:
    - G10 tube (made with wound epoxy/fiber glass layers);; rings replaced by resistive, high dielectric strength shrinkable sheet (Raychem)
    - *Resistive cable directly*
  - Several company already contacted for prototyping (some already provided)
- R&D facilities at CERN and Fermilab required for extensive tests before installation in ProtoDUNE

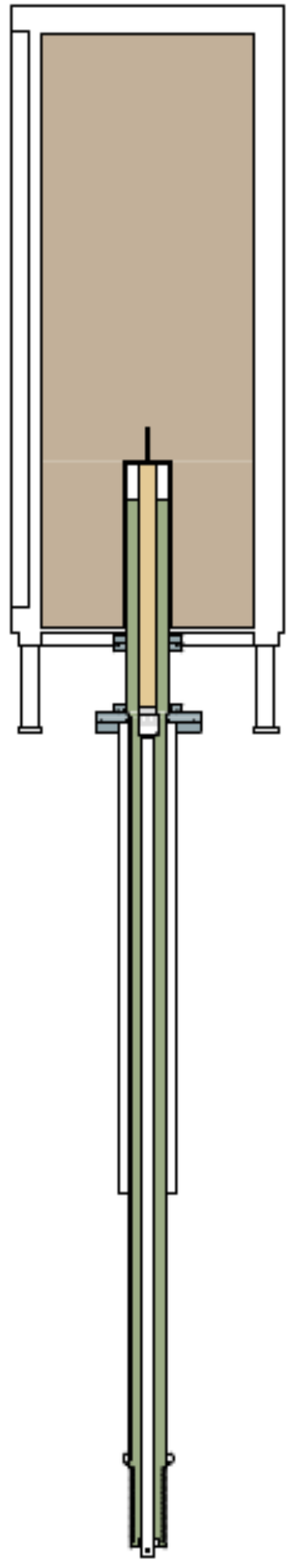
JV with Heinzinger

- Preliminary design aiming at avoiding use of HV cables and reducing number of sockets / connectors discussed.
- No major objections from Heinzinger on feasibility but it requires extensive R&D and engineering
- We are resuming contacts in the present month









R&D on the 600 kV - HV system

- Possible FNAL/US contribution to LArTPC Dual Phase technology

  - 12 m drift / 600 kV Demonstrator *(as proposed at FNAL - PAC Mtg in January 2019)*
  - 600 kV Power Supply with LArTPC grade specs: custom modification of an existing commercial 500 kV - Glassman Power Supply unit (in the picture), with additional dedicated ultra-low ripple filter
  - Design, realization and test of a cold HV feed-through and flange for Membrane Cryostat side penetration - possibly integrated with the HV filter & 600 kV Power Supply Unit

12 m drift / 600 kV Demonstrator

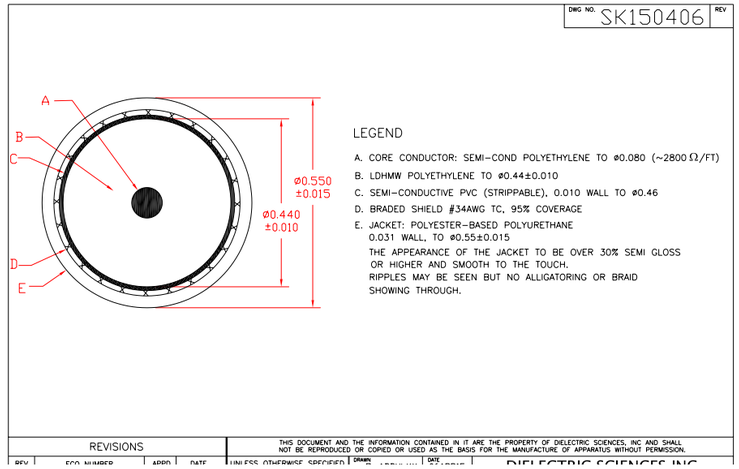
Basic Concepts:

- Large volume LAr vessel @ FNAL: min. dimensions **3ℓ x 3w x 14h m^3 (~180 t of LAr)**
  - full and efficient LAr cryo-recirculation system: min. lifetime $\tau_e \gtrsim$ **10 ms**
  - simplified cryostat (eg DP cold box at CERN, with extended depth)
  - simplified TPC r/o: 1 x 1 m^2, 3 planes SP TPC (eg LArIAT - printed circuit G10 frames)
  - Field Cage with Al profiles
  - Resistive Cathode at the bottom - 12 m drift distance

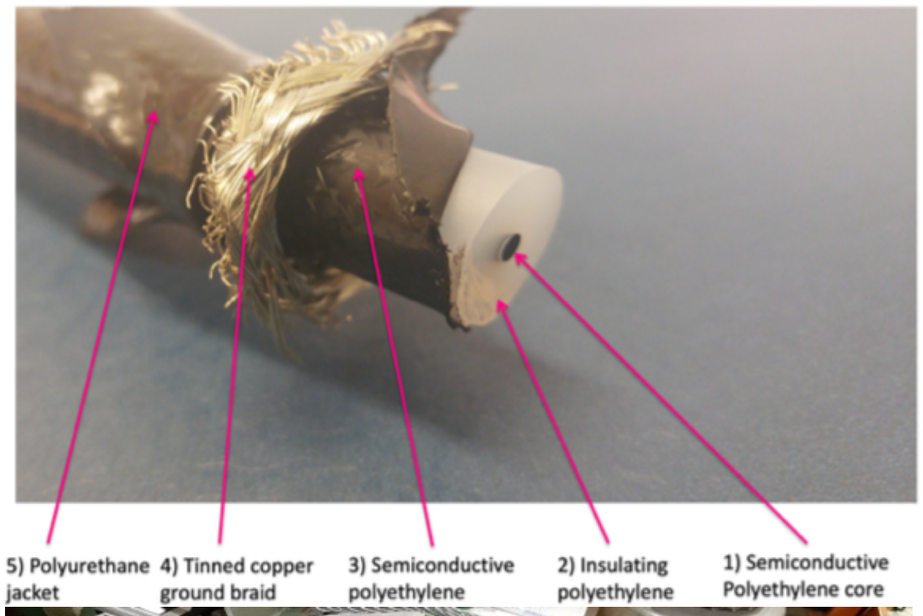
- Different possible lab spaces at FNAL are being identified - suitable to host the 12 m drift / 600 kV Demonstrator
- The need of concrete block shield for cosmic - to reduce Space Charge accumulation - is being evaluated

R&D on resistive cables

- HV Resistive cables are commercially available, coextruded PE with graphite doped inner core and outer layer
  - It allows avoiding the use of externa discrete resistive filters to reduce HV ripple
  - The LZ detector is successfully using a 150 kV cable with 10 kOhm/m inner conductor
- We are investigating the possibility to scale this concept to 300 kV and higher with Dielectric Science (on the basis of their commercial solutions)
- The cable is vacuum tight and cryogenically compatible:
  - a new HV extender designed on this concept is under examination



All-plastic HV cable



R&D on HV extender

- Several options are under evaluation
  - Construct a new G10 tube winding the fiber glass cylindrically (instead of machining out of a G10 thick plate)
  - Use thick mylar layers
    - promising technique under test with a prototype
    - can be made very long and coupled with resistive layers
  - Replace or complement outer rings with resistive “HV stress relief” shrink tube from Raychem, routinely used on HV cable terminations
    - Proven to work also at cryogenic temperature
  - Replace the extender with resistive cable:
    - Appealing, requires R&D