QA/QC/Test plan

F. Pietropaolo
CERN / INFN Padova

Present and planned QA Program

- Incorporate lessons learned into design (ICARUS, MicroBooNE, 35 ton, ...)

Mechanics

- Perform comprehensive stress analysis from component level to full detector structure
- Fiberglass material mechanical/thermal tests
- Ash River full scale mockup assembly

Electric/HV

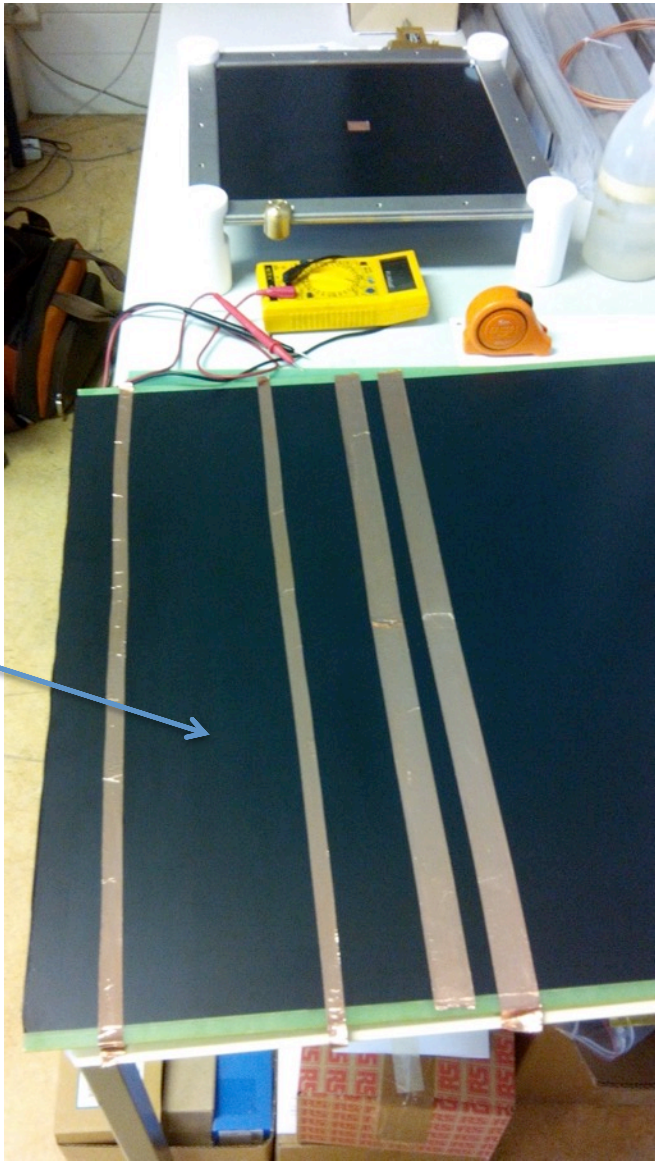
- 2D and 3D electrostatic studies of the electric field in the high field regions of the TPC
- Transient analysis of CPA, FC electrical behavior in a HV discharge
- CPA resistive material selection and thermal/HV tests
- Small scale, full E field, tests of FC concept in 50l LAr-TPC
- Electrodes material HV tests
- FC end cap HV tests
- Divider component and assembly: thermal and electrical tests
- Full voltage HV test in 35ton cryostat

Evaluation of Resistive Materials for CPA

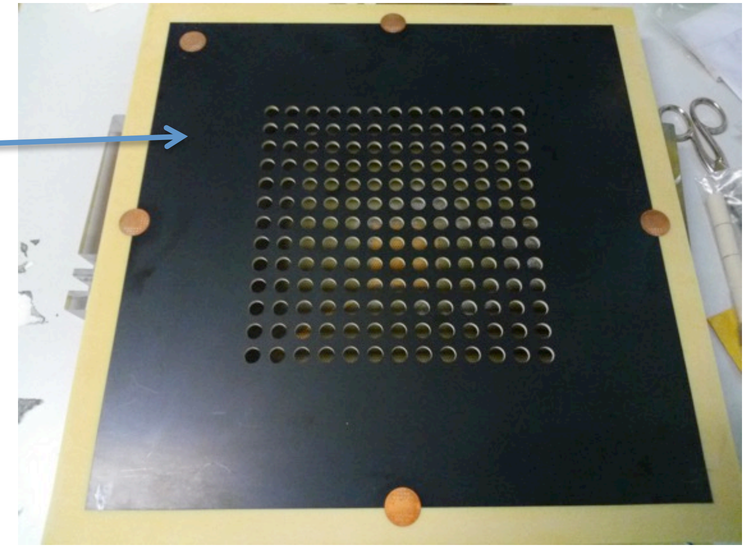
- Investigated materials:
  - NORPLEX, Micarta, phenolic laminate with graphite,
    - Intrinsic bulk resistivity in the required range (few MOhm/cm)
    - Density comparable to LAr
  - FR4 coated with resistive ink (~100kOhm/square) printed with specific patterns to increase average resistivity;
  - FR4 laminated resistive kapton foil Dupont 100XC10E7 (25 μm thickness, graphite loaded, available with resistivity in the 0.5 to 50 MOhm/square range available in 1.2 m wide rolls)
  - Graphite loaded (outer layers) FR4
  - Thin films of Germanium Coated Polyimide (vacuum deposited)
- Kapton on FR4 preferred according to selection criteria:
  - Bonding strength
  - Resistivity uniformity, stability
  - Resistance to sparks, abrasion
  - Cryogenic compatibility
  - Radio-purity (tests at LNGS low counting rate material test facility)

Laminated resistive Kapton foils on FR4

- Standard PCB technique applied at CERN to develop resistive thick-GEM's:
  - Available for dimensions amply larger than 1.2 m x 2.1 m
  - Double sided lamination
- Several large area samples (0.6 x 0.7 mq , 3mm thick) produced for performance evaluation:
  - High resistivity uniformity: 2-3 MOhm/square
    - Small resistivity variation at LAr temperature (+50%)
  - Compatible with standard cleaning with alcohol
  - Long term immersions in LAr (weeks) with several thermal cycle from room to LAr temperatures
    - No delamination observed.
    - No planarity deformation in LAr observed.

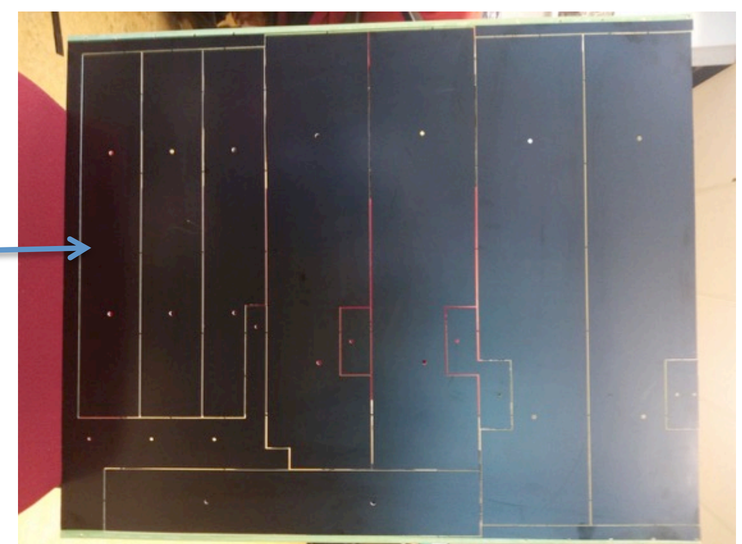


Prototypes for LAr-TPC's



- Resistive cathode planes for the 50-liter LAr-TPC fabricated.
  - Already operated in LAr several times
  - No delamination
  - No electric field distortions observed
  - No LAr purity degradation

- Full size 1.2 m x 2.1 m double sided prototype panel.
  - Industrially produced and machined to be installed in the 35 ton HV test at FNAL
- Resistive strips for CPA frame
  - A first set produced and machined for the 35 ton HV test at FNAL



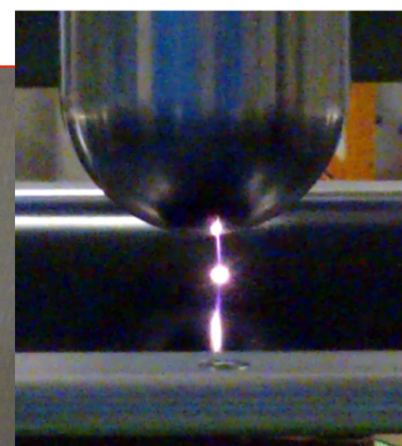
Robustness to sparks

- Dedicated set-up to induce sparks and evaluate resistivity.
  - Resistive material (cathode) kept in position by SS frame.
  - Emispheric anode movable along axis to change distance from cathode plane.
- Sparks induced above 40 kV @ 1cm (in air), Hz rate, long term (minutes)

- Ink print pattern on FR4
  - Sparks develop along direction of less resistivity, following the strip pattern
  - Status after test: degradation with some material evaporation

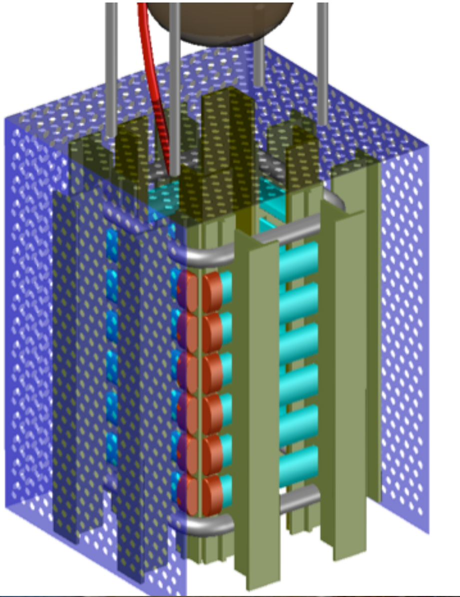
- Resistive Kapton on FR4
  - Sparks are point-like
  - Localized “carbonization’’ on material surface, at the spark position
  - No change in average resistivity





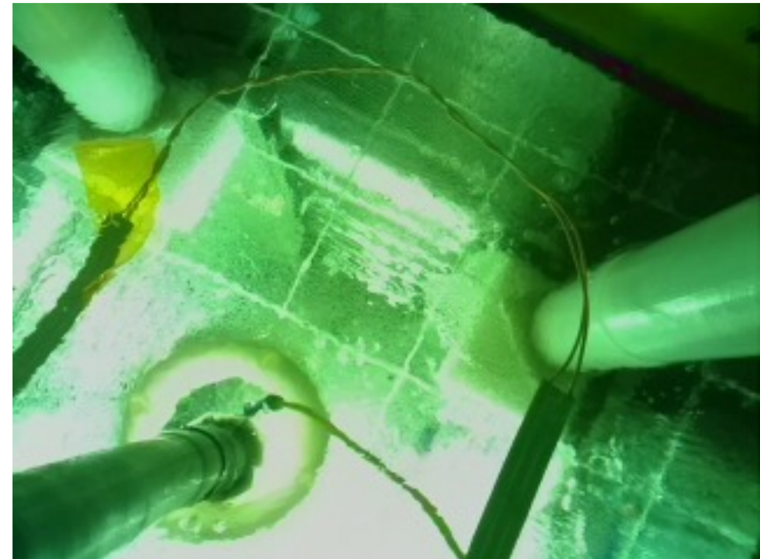

Small field cage test

- To validate the field cage concept in pure LAr
- Designed to fit in the ICARUS 50 liter cryostat (60 cm diameter, 1.1 m height)
- Roll-formed metal profiles with UHMW PE caps
  - Choice of metal (Al, SS) and surface finish
- Pultruded fiberglass I-beams form 4 mini panels
- All profiles are at same potential to simplify HV connection
- Perforated ground planes 66mm away
- Requires 1/3 of FD bias voltage to reach same E field (~ 60 kV)
- Corona-discharge monitor on Power supply cable (based ICARUS scheme)
- Video camera to visually detects light flashes for from arching/discharges and monitor LAr thermal stability (LED illuminated)



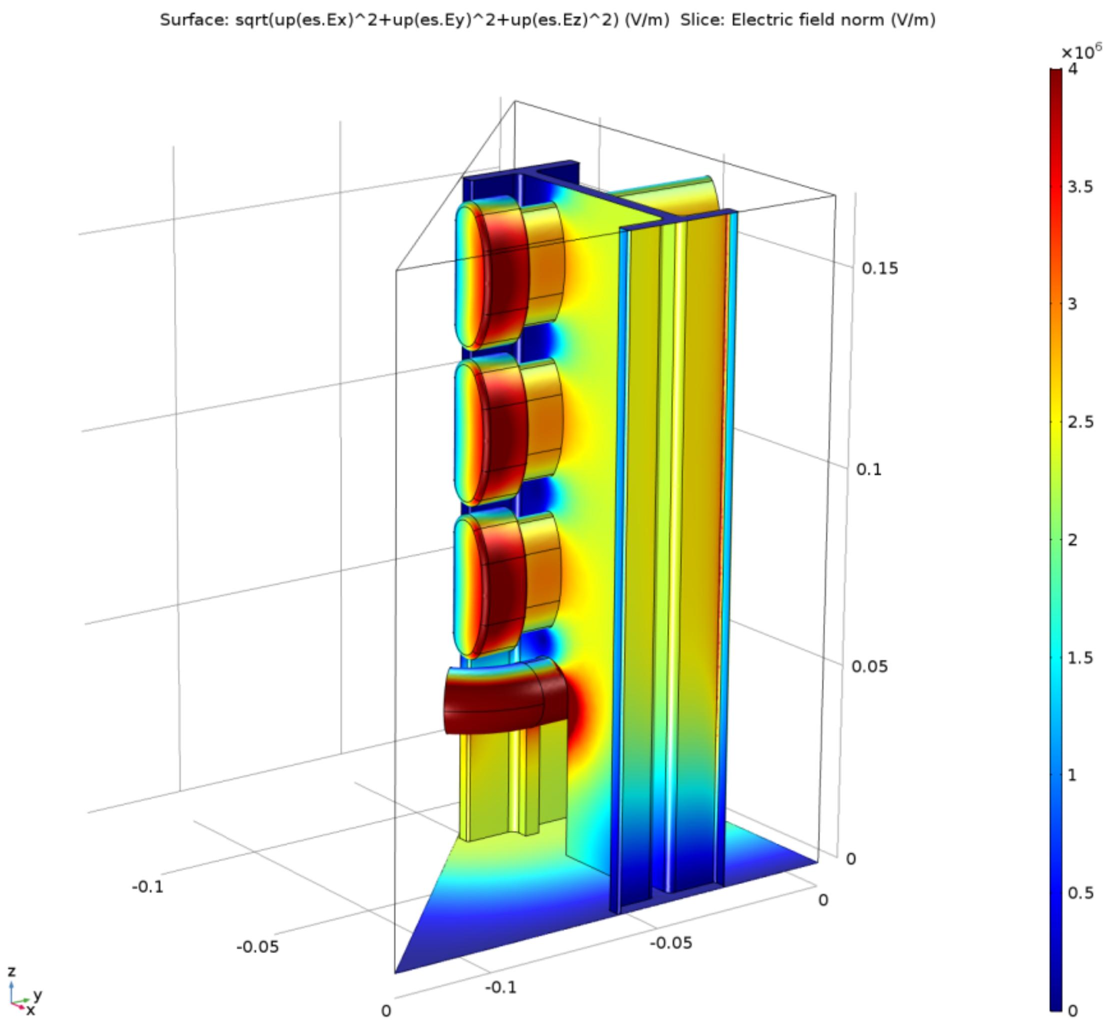
Small field cage in purified LAr

- Aluminum roll formed Profiles
- HV applied in thermalized ultra pure LAr (visual inspection though camera):
  - "slow" ramping up (~5 kV/min at start with step decreasing at higher voltage)
  - Current limitation set to ~ "zero" on PS
- Long tern test
  - HV kept continuously ON for several days.
- Two regimes have been studied:
  - Thermalize LAr (no visible bubble formation): no sparks recorded up to 100 kV.
  - With bubbles appearing to form around the detector elements, few random sparks (one every few hours) appear but only above 80 kV
  - Sparks develop around the HV cable (at hot points) and not between the field cage and the ground plates.



Small Field Cage Tests E field

-100kV on the profiles, 6.6cm to ground plane. Clean argon.

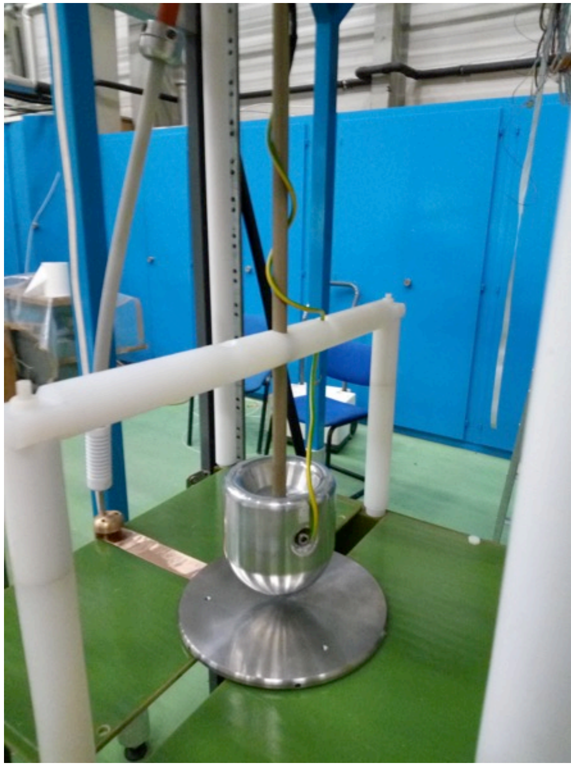


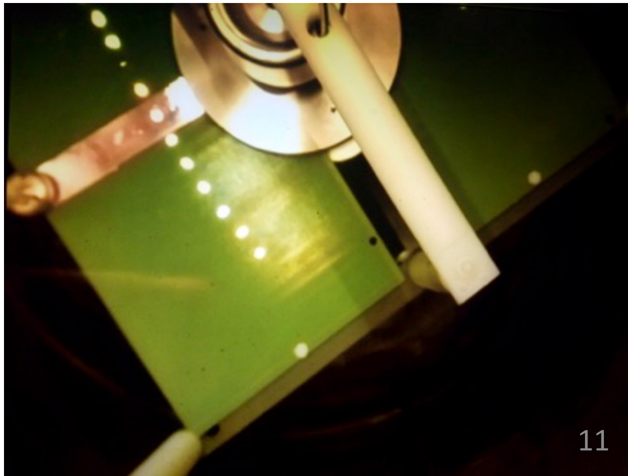
Additional HV tests

- Comparative measurement in commercial LAr with:
  - intentionally scratched surface of one wall of aluminum profiles
    - scratches depth measured to be up to 100 um >> scratches depth (tens of um) due to assembly procedures in the test
  - stainless steel roll-formed profiles installed in one full wall
  - Extruded aluminum profiles installed in other full wall
- Within the tested HV range (100 kV, no bubbles) surface material do not affect the HV performance.

Specific HV test on surface finish

- Material for comparison test:
  - Extruded aluminum (from ICARUS cold body: ~ 5 µm residual roughness)
  - Polished SS (< 1 µm residual roughness)
- Negative HV applied in LAr on flat test surface against grounded polished semi-sphere (4.5 cm radius, 1 µm residual roughness) to minimize edge effects.
- Adjustable gap between electrodes (sub-millimetric regulation)
- Test finding in LAr
  - In stable thermal conditions (without bubble formation), HV values up to 10 kV/mm can be safely applied;
  - linear behavior in gap ranging from 1 mm to 5 mm
  - Long term stability verified (up to 2 days at the 5 mm gap)
  - Instability building up in the 10-11 kV/mm range
  - Strong dependence on LAr thermal condition; evident performance degradation after sparks: several hours thermalisation of the LAr bath required before re-applying HV
  - No apparent dependence on material and surface finish.

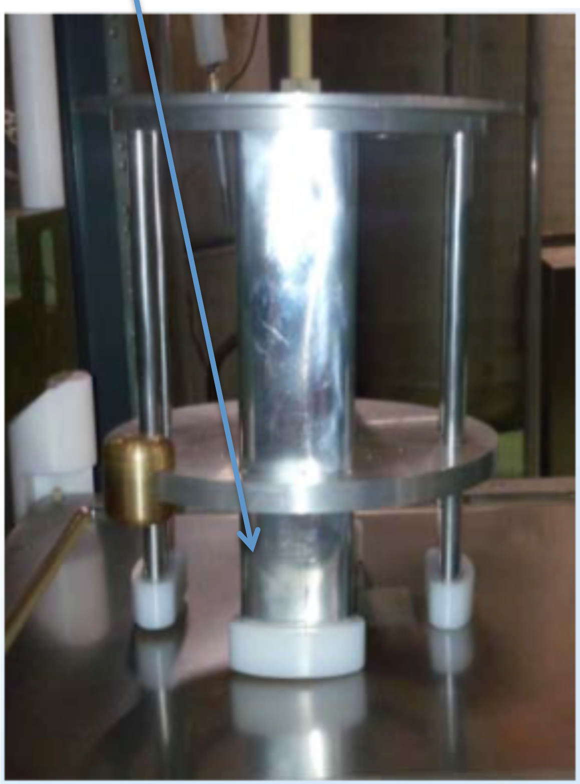


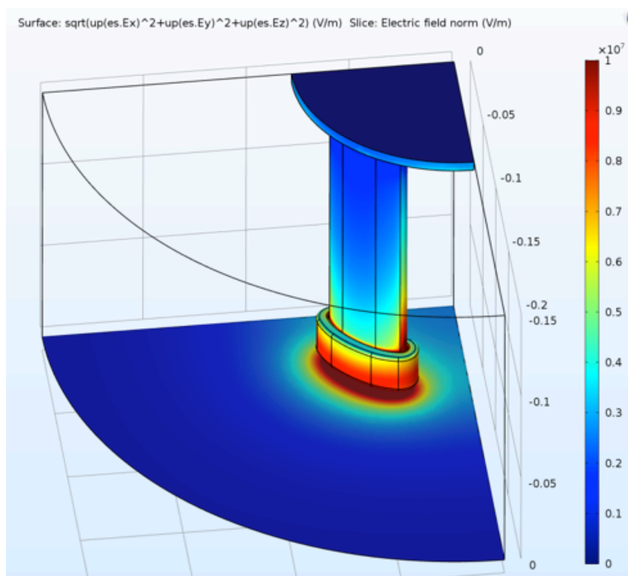


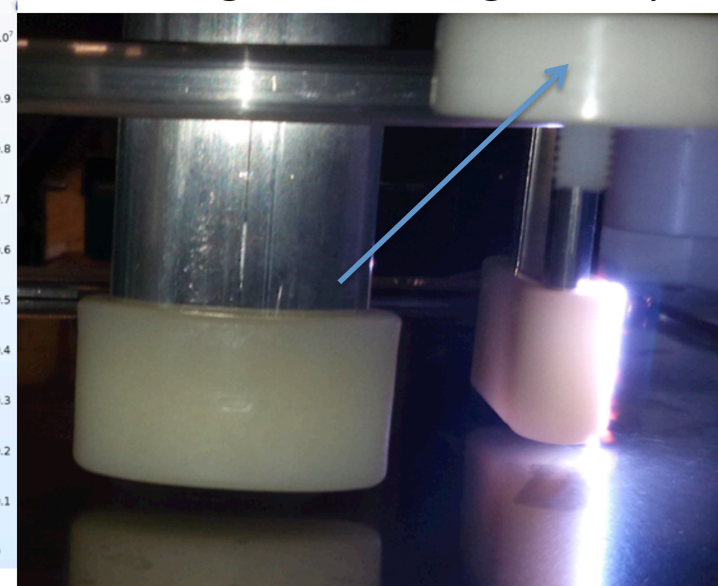
Test of PE endcaps in LAr

- Thermal behaviour: more than 50 endcaps suffered several thermal cycles to Lar temperature:
  - No cracks or mechanical degradation observed
- HV: endcaps (6 mm thick) facing ground plane at 5 mm distance
  - HV applied on profiles
  - Stable up to 150 kV in LAr over several hours provided no bubbles are formed

- IN AIR:
  - Arching for HV>40 kV
  - from metal profile to ground along endcap

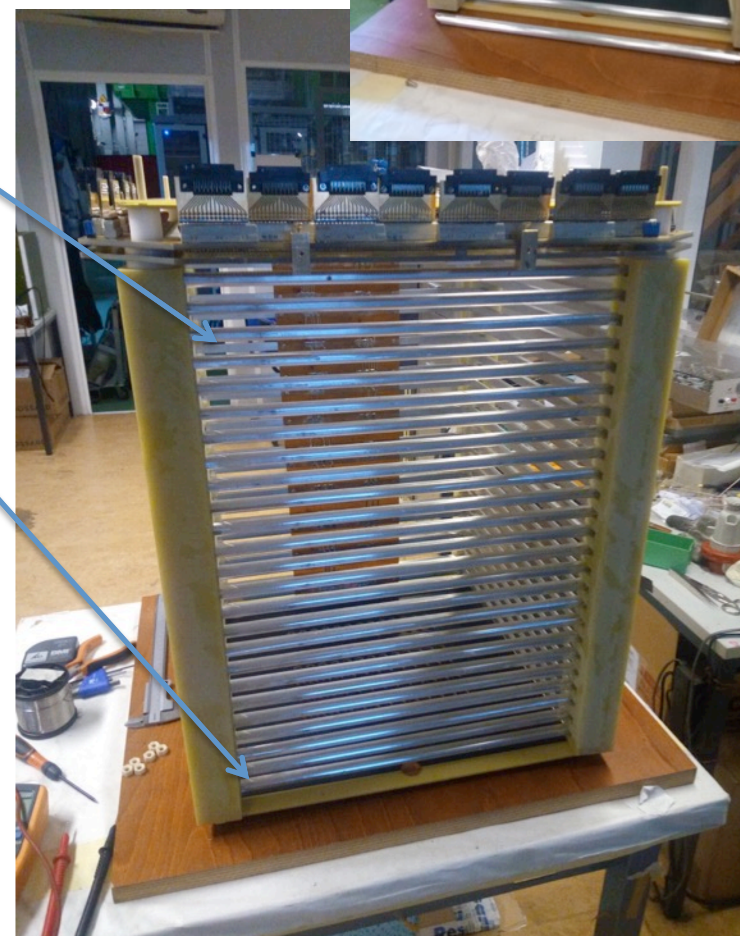






R&D on aluminum field cage

- <u>Malter effect in Liquid Argon?</u>
  - Emission of electrons from Al into LAr due to high e-field built across charged-up oxide layer on Al surface
- Uncoated Aluminum field cage installed in the 50 liter LAr-TPC
  - FR4 spacing column
  - Resistive Cathode
  - Max local E-field on Al surface ~ 26 kV/cm (for Vcath=-25 kV, 500 V/cm drift field) similar to ProtoDUNE SP case
- Long term operation to measure possible effects of electron emission in LAr (charging-up by cosmic rays)
  - HV stability
  - Increase of electronic noise on wires close to FC
  - production of scintillation light

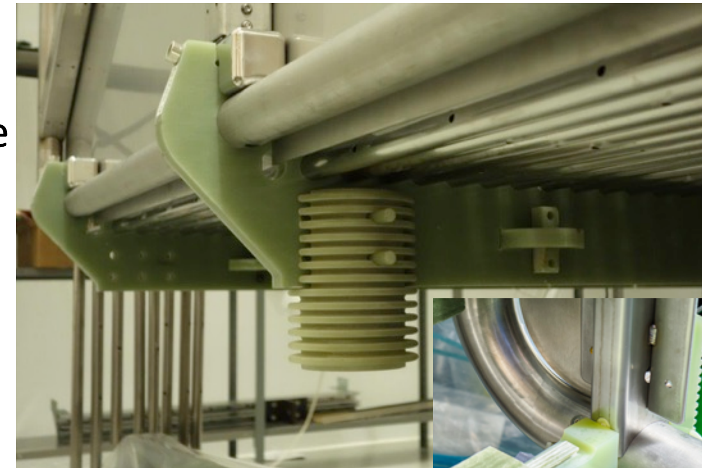


QA Plan: HV

- HV feed-through
  - HV prototype developed by ETH already tested at 300 kV (required 180 kV)
  - Follow/contribute to construction and further tests in collaboration with the DP ETH/CERN group.
- Perform HV test at 35-ton facility at FNAL, including the following:
  - Test ability to hold voltage at full scale;
  - Test expected current and stability of current at all monitoring points;
  - Test mechanical integrity of all components after full cool-down, warm-up cycle;
  - Test discharge mitigation system using induced HV discharges.
  - Study of charging up effects on HV insulators (FRP/G10/FR4) in LAr

Charging-up of insulators

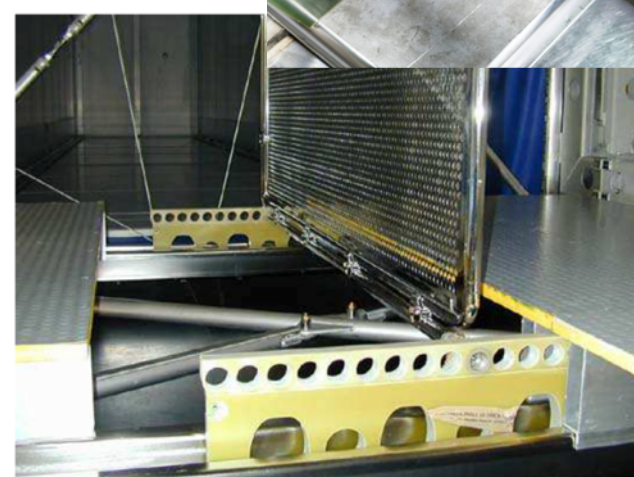
- Charge-up of insulator surfaces occurs when the electric field has a component perpendicular to the surface.
- ICARUS, MicroBooNE, and 35-ton used G10/FR4 in detector supports running from ground to cathode potential over short distances, with field mostly parallel to the edges of the supports:
  - sustained high voltage achieved.
  - for some, not full design voltage, but no indication this is due to charge-up effects due to charge up not observed
- In ProtoDUNE FC thin, flat sections of FRP intercept the electric field running almost perpendicular to the surface.
  - This is a potential concern if the FRP is completely non-conductive.
  - The CERN "small-field-cage" use a similar arrangement without problem (100kV, 6.6 cm).
  - This will be tested in the 35ton test over long term operation (weeks).



MicroBooNE

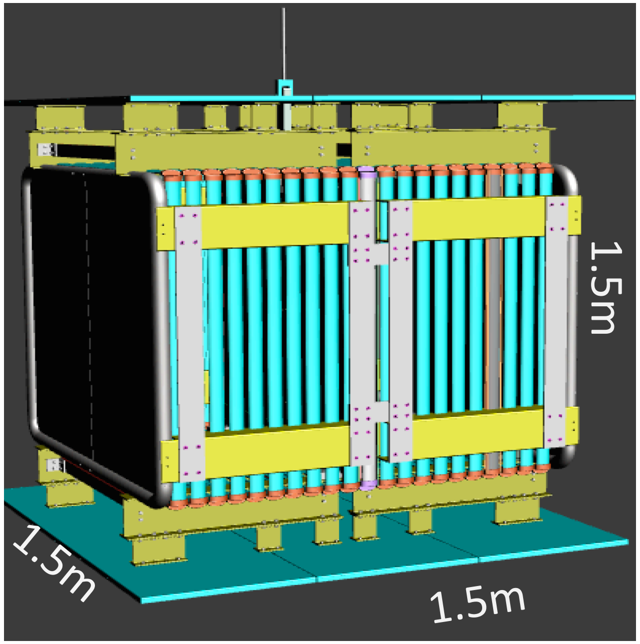
35-ton

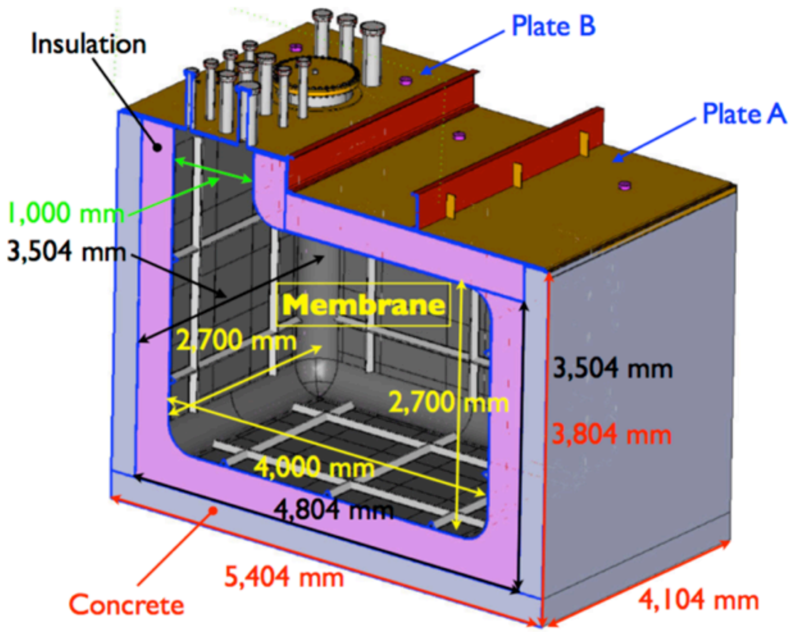
ICARUS
75/150 kV, 15 cm



Proto-DUNE SP FC-CPA-HV Test at FNAL PC4

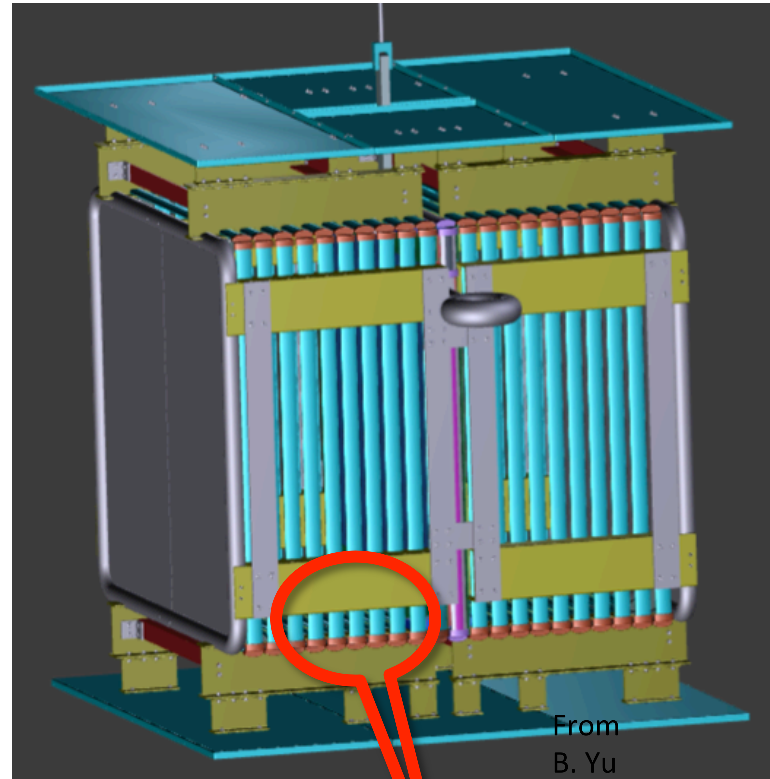
- Motivation
  - Evaluation of the design of ProtoDUNE from a high voltage perspective
  - Design verification
  - Expose any design weaknesses.
- Test performed in ultra-pure LAr in the membrane cryostat of the 35 t facility
  - Cryostat available
  - Cryogenic system available
  - LAr purification system available

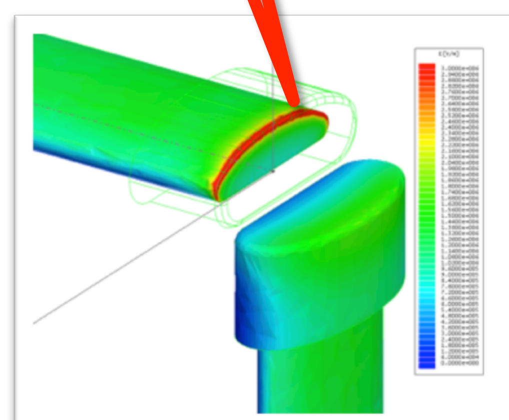


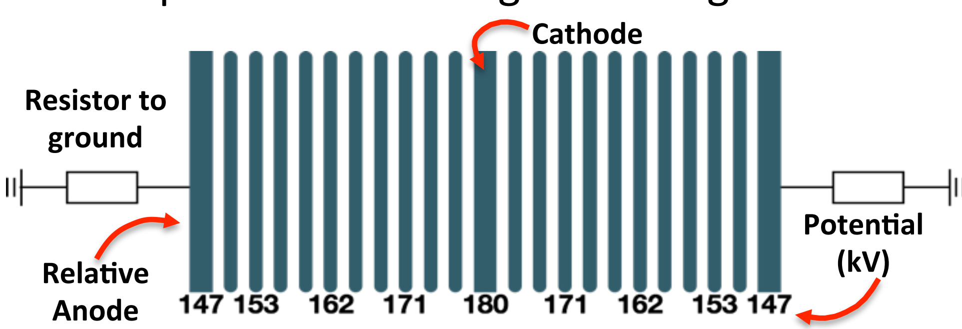


The field cage for the HV test

- The full-sized ProtoDUNE TPC components do not fit in the cryostat
  - However, the test *will be a full-field test*.
  - The device will have the first 10 profiles of the FC and a resistive cathode at their planned voltages.
- Individual components:
  - High field areas → corners near cathode
  - New aspects of the design: FC profiles and FRP beams, resistive plate cathode, ground planes
  - However: dedicated HV feed through (UCLA)
  - NP beam plug in the first phase
- *And* the integration of the pieces
  - Do the pieces of the design work together?

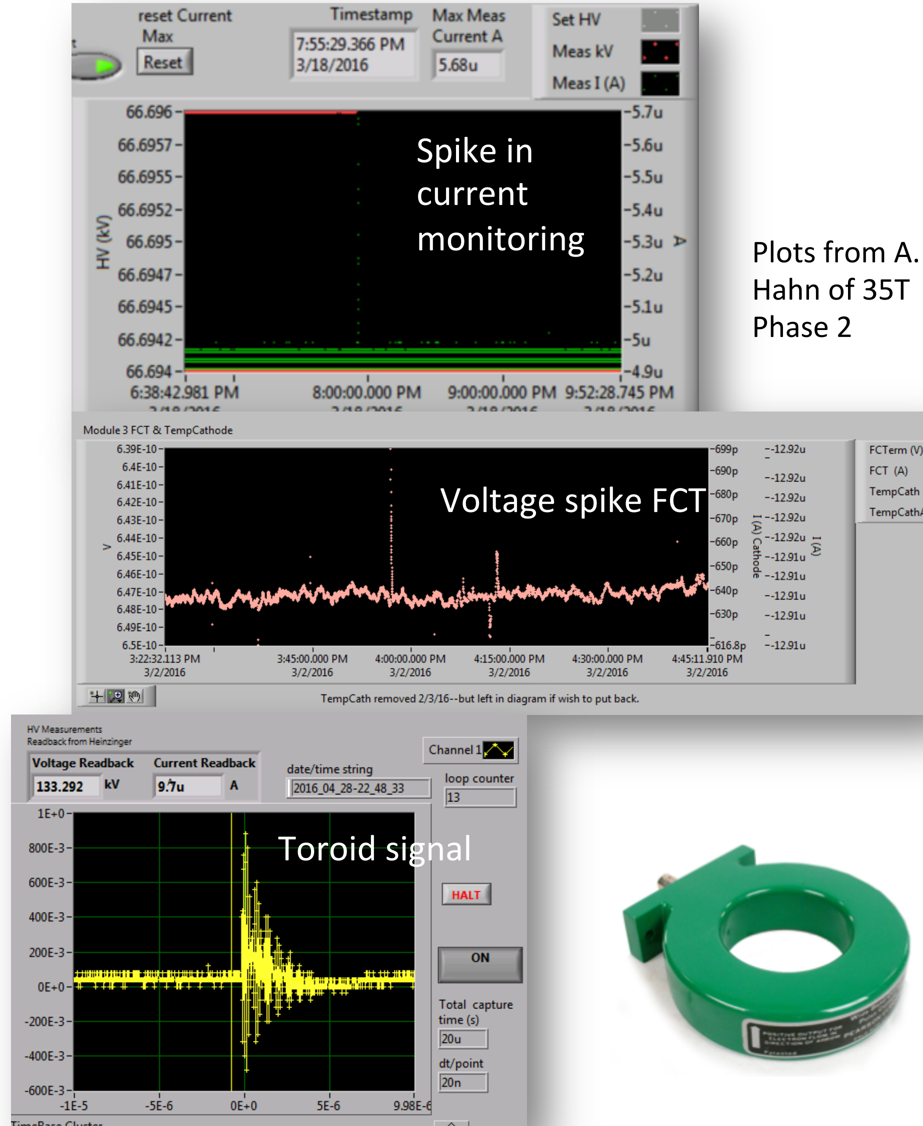






How to Evaluate: Planned Monitoring

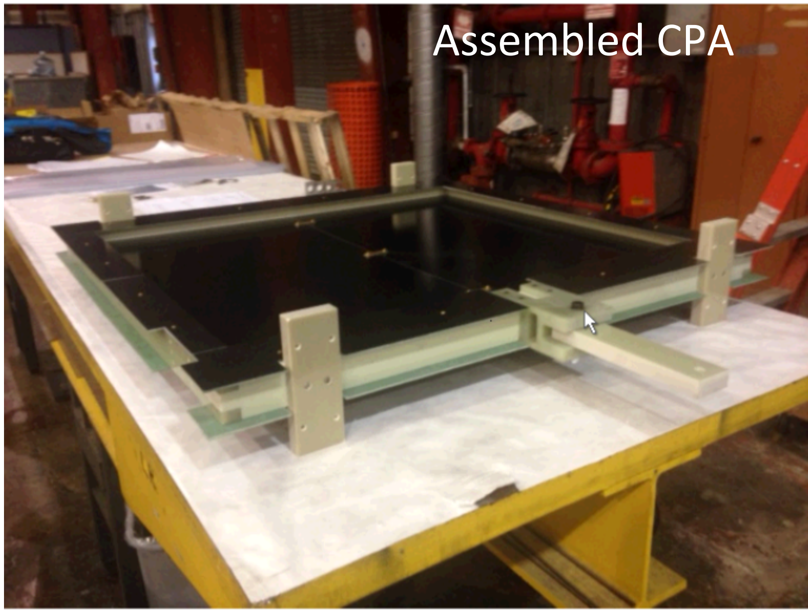
- Current monitoring and logging
  - Monitor the current out of the power supply
- Field cage termination/Pick-off point
  - Monitor the voltage near the end of the resistor network to look for activity in the chain
- Toroid/Corona monitor
  - Sensitive to a change in current flowing through the HV cable just outside of the cryostat
- Cameras
  - William & Mary are working on installing cameras that can help diagnose potential issues.



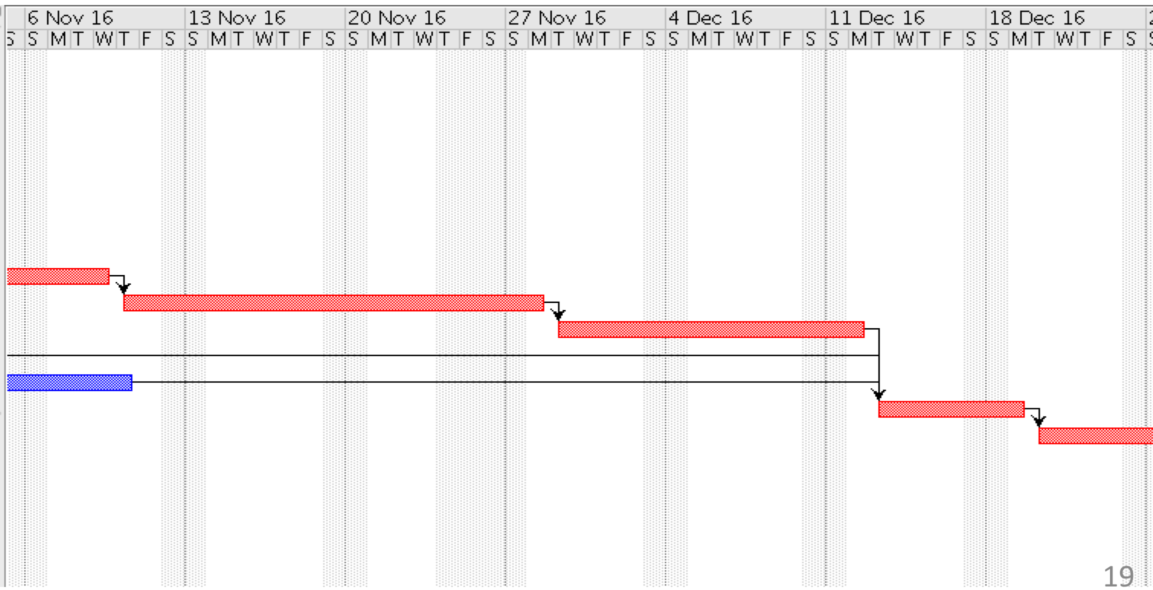
Plots from A. Hahn of 35T Phase 2

Schedule for Stage 1 test

- Completed activities:
  - Design, fabrication and delivery of components to William & Mary
- Now on-going:
  - Clean and preassemble parts
  - Parts delivery to Fermilab
  - Test installed in cryostat
  - Purge, cool down, fill the cryostat
  - Perform test (January 2017)
- In time for Production Readiness Review (February 2017)



		Name	Duration	Start	Finis
1		Complete fabrication drawings	9 days?	7/18/16 ...	7/28/16
2		Deliver resistive panel for CPA	25 days?	7/29/16 ...	9/1/16 5
3		Fabricate CPA	67 days?	7/29/16 ...	10/31/16
4		Fabricate APA	28 days?	7/29/16 ...	9/6/16 5
5		Procure Profiles	39 days?	7/18/16 ...	9/8/16 5
6		Procure plastic caps	15 days?	7/18/16 ...	8/5/16 5
7		Procure ground planes	36 days?	7/18/16 ...	9/5/16 5
8		Procure material/Fabricate Field	61 days?	7/29/16 ...	10/21/16
9		Clean and preassemble parts;	7 days?	11/1/16 ...	11/9/16
10		Ship to FNAL	11 days?	11/10/16...	11/28/16
11		Install in cryostat	10 days?	11/29/16...	12/12/16
12		Electrical Design Review	15 days?	10/17/16...	11/4/16
13		Cryogenic Review	19 days?	10/17/16...	11/10/16
14		ORC	5 days	12/13/16...	12/19/16
15		Purge, recirculation, cool down, f	18 days	12/20/16...	1/12/17
16		Perform test	22 days	1/13/17 ...	2/13/17
17		Warm up	20 days	2/14/17 ...	3/13/17
18		Install phase II	20 days	3/14/17 ...	4/10/17
19		Purge, recirculation, cool down, f	20 days	4/11/17 ...	5/8/17 5
20		Test Phase II	20 days	5/9/17 8:...	6/5/17 5

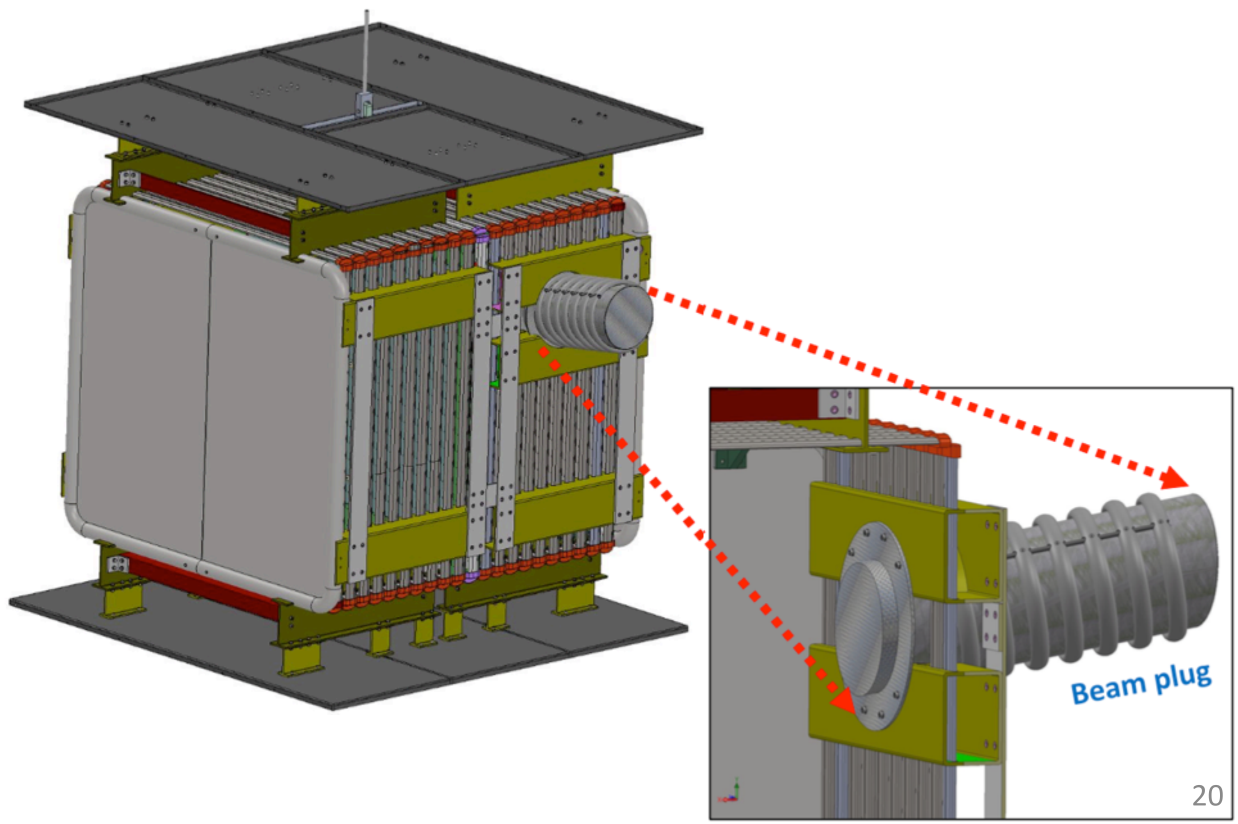


Stage 2 plans (~ Spring 2017)

- In parallel with Stage 1, the beam plug will be tested separately In LAr and at HV in a dedicated set-up
- After completion of stage 1 test, replace one field cage end-wall with one that has beam plug attached

GOAL:

- Verify beam plug does not interfere with the operations of the TPC (i.e. same HV performance with and without the beam plug)



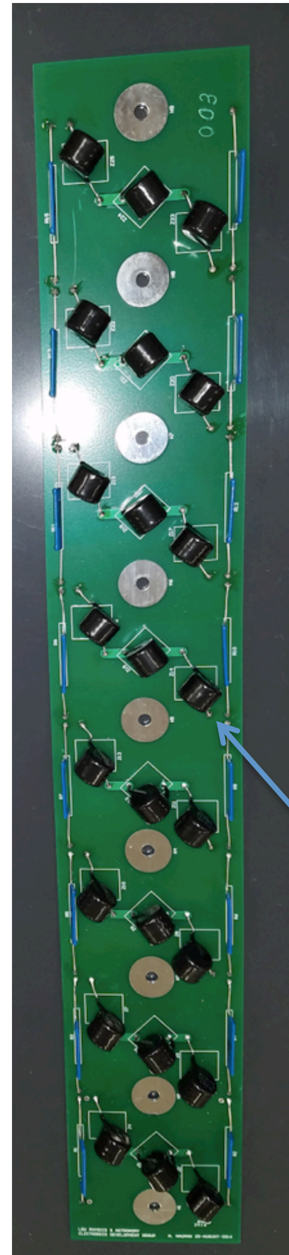
QC Plans

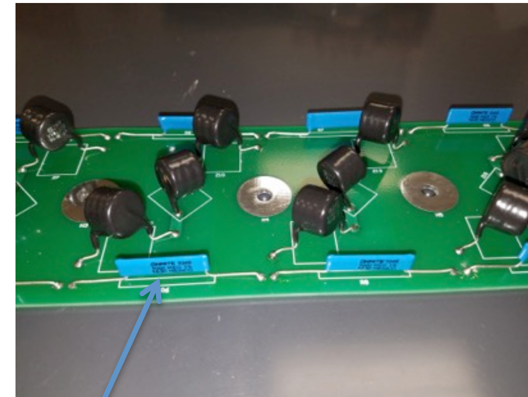
- Full QC plan and procedural documentation is under development and will be finalized for the Production Readiness Review
- Testing and inspections to be performed during production, acceptance at CERN, installation and commissioning are being defined. These will include:
  - Visual Inspection of all the components CPA/FC.
  - Inspection of CPA panels and field strips for scratches or delamination; resistivity sampling on panel surfaces
  - Inspection of all FC profile surfaces and in case of any dents and scratches, -> profile replacement.
  - Check of all the screw connections using a calibrated torque screw driver. These screws will be tightened to a low torque spec and can become loose due to vibrations during shipping. Retightening of screws may be required.
  - Electrical continuity checks between adjacent profiles field cage when resistor divider is mounted.

QC Plans for FC resistor divider (LSU)

- Develop large scale component (resistors, varistors) testing & recording setup
- Perform thermal cycles of all components to accelerate mortality due to fabrication defects
- Perform thermal cycle of the assembled divider board

- Develop test procedure for mounted divider boards

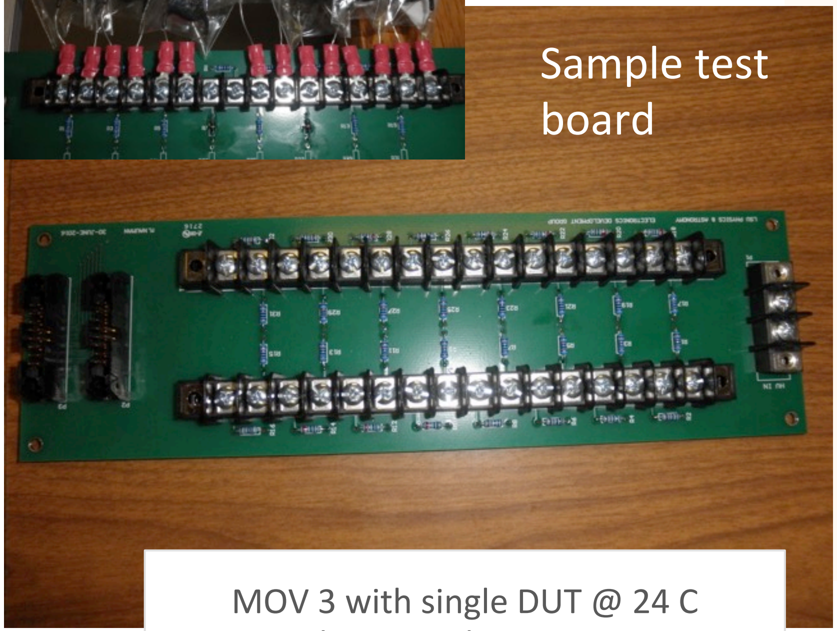


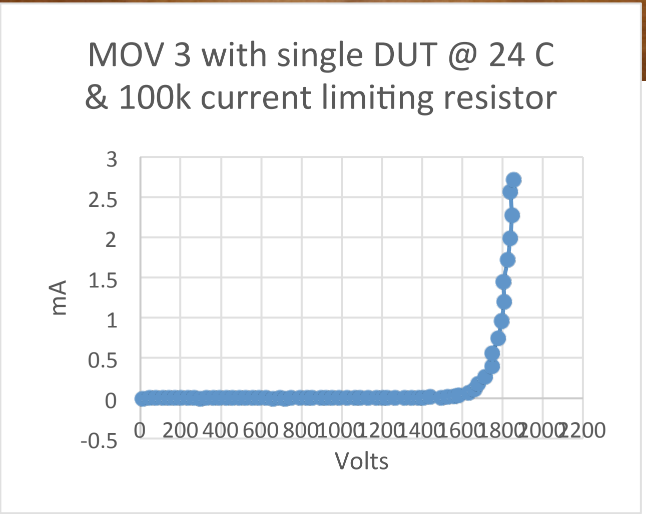


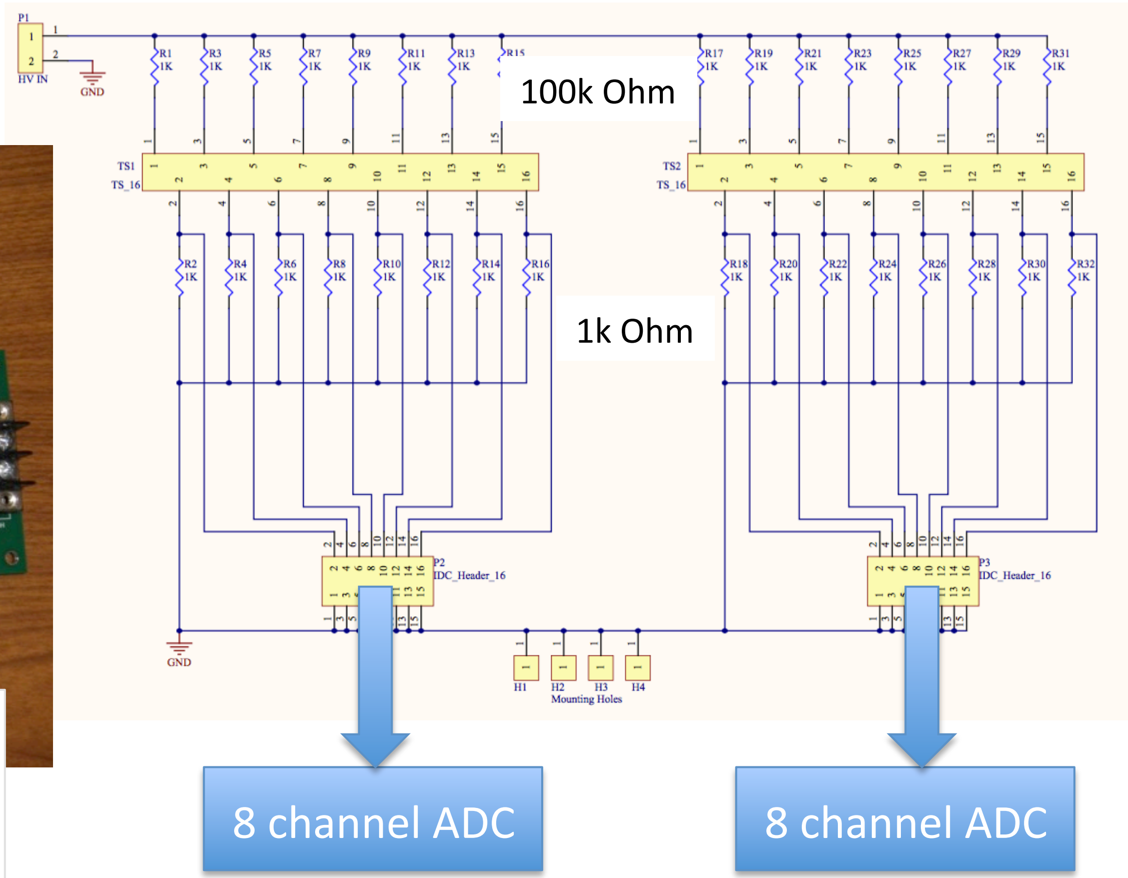
<u>Resistors</u>:
Ohmite Slim-Mox
SM104031007FE
1 G Ohm, 1% tolerance, 1.5 W

<u>Metal Oxide Varistors</u>:
Panasonic
ERZ-V14D182
1800V clamping voltage

Component QC Test Board

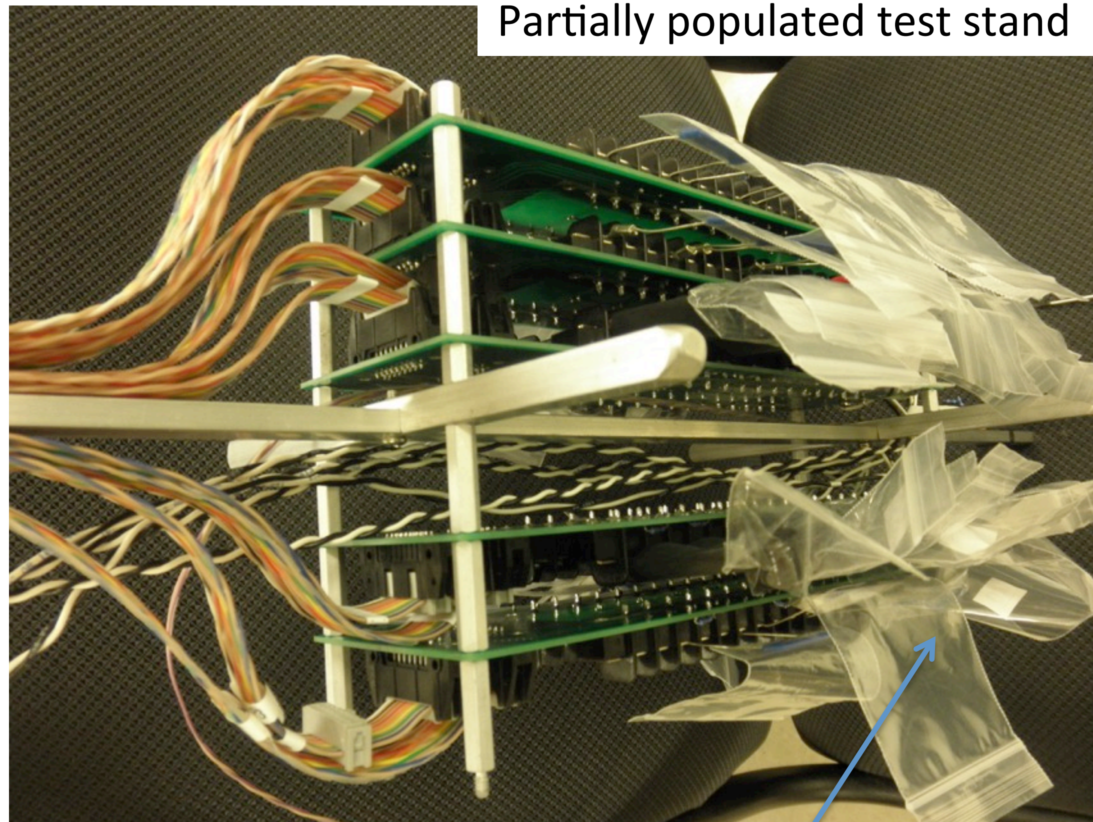






<u>Data logging</u> (and plotting) fully automated

Large Scale Component QC Test Stand



Components are individually bagged and serialized

→ Can stack up to 5 PCBs high
→ Can have 2 stacks on mechanical mount

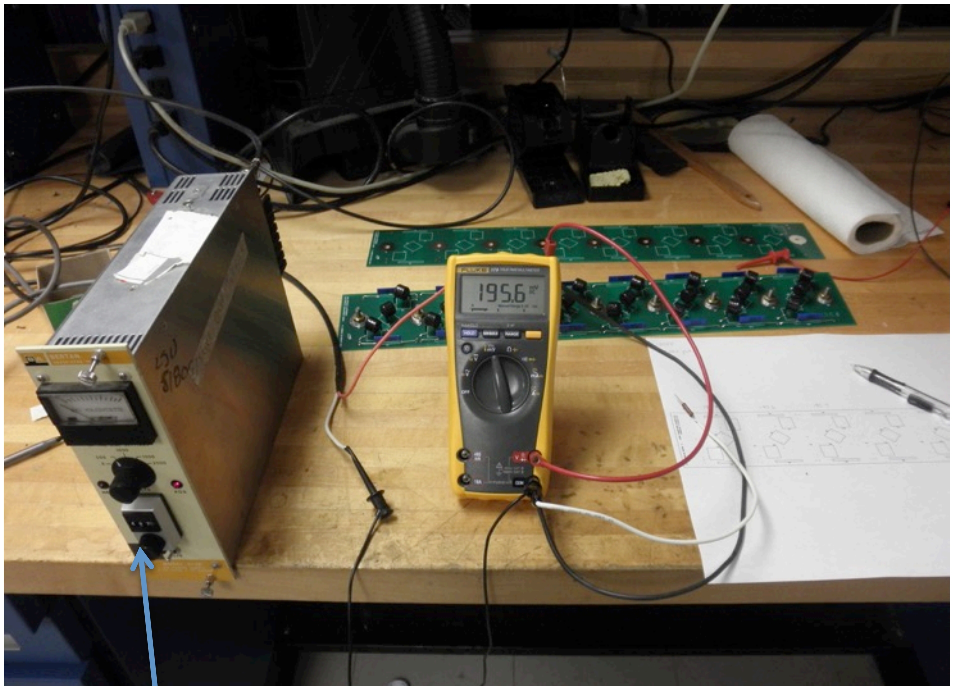
→ 16 MOVs per board
→ Can test up to 160 MOVs per cool down cycle

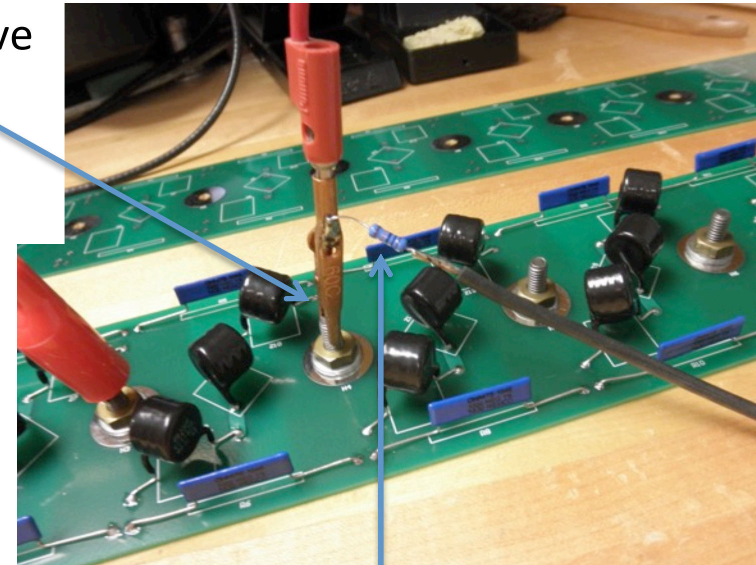
Use very similar setup to test resistors (based on same PCB)
→can test up to 80 resistors per cool down cycle

QC measurement setup (mounted boards)

Insert screws, washers and nuts into divider board to serve as attachment points

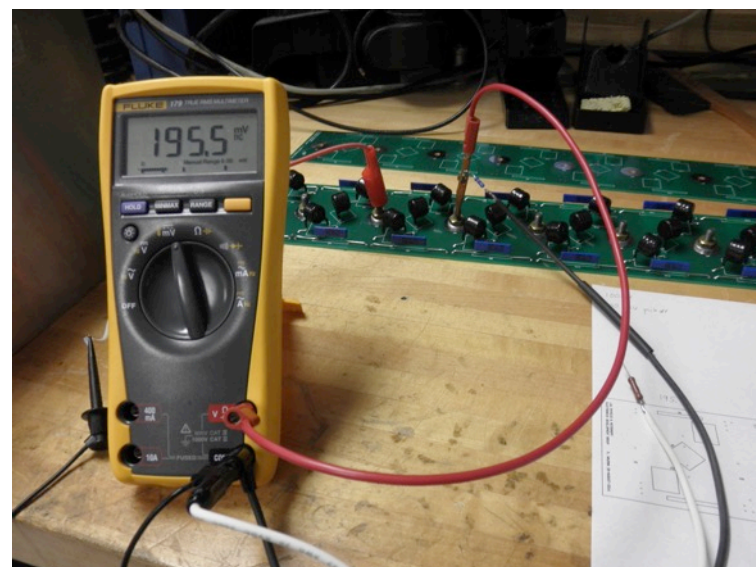
<u>If mounted to profiles</u>, attach alligator clamp directly to profile instead





100kΩ pick-off resistor

HV power supply: used at 1000 V



<u>QC procedure:</u>

Measure voltage drop for each individual stage,
convert to current,
calculate equivalent resistance R_A (nominal: 500 MΩ)

<u>Results:</u> see separate spreadsheet

Sample spreadsheet for resistive divider board

Each test circuit consists of two 1 GΩ resistors in parallel connected to a 100.0 KΩ pickoff resistor.
A DMM with a 10 MΩ input impedance is connected in parallel with the pickoff resistor
The equivalent circuit from above consists of two resistors in series: Ra = 500M and Rb = 99.0099K

A test voltage of 1 kV (Vi) is applied across Ra and Rb.
The current is calculated by dividing the DMM voltage across the pickoff resistor by Rb. (Ic=Vp/Rb)

For the tables below, columns 1-8 are referenced to the first stage at R1/R2 on the left side of the PCB and move sequentially to the right.

DMM voltages (Vp) measured across 100.0 KΩ pickoff resistor. Unit = mV

Board #	V-1	V-2	V-3	V-4	V-5	V-6	V-7	V-8	Measurement
010	196.2	196.1	196.0	196.8	196.5	196.0	196.4	196.1	Bench
010	196.0	195.6	195.6	195.6	196.2	195.6	196.0	***	Profile

Calculated current from above pickoff voltages Ic = Vp*1000/99009.9 Unit = μA

Board #	i-1	i-2	i-3	i-4	i-5	i-6	i-7	i-8	Measurement
010	1.982	1.981	1.980	1.988	1.985	1.980	1.984	1.981	Bench
010	1.980	1.976	1.976	1.976	1.982	1.976	1.980	***	Profile

Calculated resistance from Ic Ra = (Vi - Vp)/Ic Unit=MΩ

Board #	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	Measurement
010	504.5	504.8	505.1	503.0	503.8	505.1	504.0	504.8	Bench
010	505.1	506.1	506.1	506.1	504.5	506.1	505.1	***	Profile

*** - No measurment made due to shorting of profiles at positions 7 and 8 when Al bracket is mounted !

*MOV pos measured from left to right of each goup
*Resistor pos measured from top to bottom on each group

Board Layout

LSU physics & Astronomy	Resistor pos 1 (R1)	Resistor pos 1 (R3)	Resistor pos 1 (R5)	Resistor pos 1 (R7)	Resistor pos 1 (R9)	Resistor pos 1 (R11)	Resistor pos 1 (R13)	Resistor pos 1 (R15)	
	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	MOV pos 3	
	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	MOV pos 2	
	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	MOV pos 1	
	Resistor pos 2 (R2)	Resistor pos 2 (R4)	Resistor pos 2 (R6)	Resistor pos 2 (R8)	Resistor pos 2 (R10)	Resistor pos 2 (R12)	Resistor pos 2 (R14)	Resistor pos 2 (R16)	board #
	group 1 (-1)	group 2 (-2)	group 3 (-3)	group 4 (-4)	group 5 (-5)	group 6 (-6)	group 7 (-7)	group 8 (-8)	

QC Plans for HV bus, frame-biasing

- Inspection of fabricated part of the HV system to make sure they meet the dimensions and tolerances on the fabrication drawings:
  - HV bus cables
  - Inter-CPA connectors
  - Connection points on CPAs, with captive screws
  - Resistor-to-frame and frame-to-FC connectors
- Inspection of each completed HV bus cable segment for curvature or damage.
- Check HV cable post-annealing cooling test.
- Measure HV bus end-to-end and bus-to-CPA continuity and resistance after HV bus installation, compare to design values.
- Measure HV bus to frame continuity and resistance after frame electrode installation, compare to design values.
- HV test at CERN for evaluating side to side and top to bottom resistance for each completed CPA, including HV bus, cup, and frames, but after final assembly and after hanging during installation.

Back-up

Radiological measurements (@ LNGS low counting rate facility)

Sample:	NORPLEX, Micarta, NP 315, phenolic laminate with graphite, black	Current Inc., C770 ESD (Electro-Static Dissipative material), G10/FR4 (glass/epoxy)
weight:	23.0 g	89.0 g
live time:	328991 s	830876 s
detector:	Ge	Ge
Radionuclide concentrations:		
Th-232:		
Ra-228:	(15.2 +- 0.5) Bq/kg <==> (3.74 +- 0.13) E-6 g/g	(54 +- 8) mBq/kg <==> (13 +- 2) E-8 g/g
Th-228:	(15.8 +- 0.5) Bq/kg <==> (3.88 +- 0.13) E-6 g/g	(49 +- 6) mBq/kg <==> (12 +- 2) E-8 g/g
U-238:		
Ra-226:	(9.1 +- 0.3) Bq/kg <==> (7.4 +- 0.2) E-7 g/g	(47 +- 5) mBq/kg <==> (3.8 +- 0.4) E-9 g/g
Pa-234m	(6 +- 3) Bq/kg <==> (5 +- 2) E-7 g/g	< 0.52 Bq/kg <==> < 4.2 E-8 g/g
U-235:	(<0.24) Bq/kg <==> (< 4.2) E-7 g/g	< 6.9 mBq/kg <==> < 1.2 E-8 g/g
K-40:	(7.6 +- 0.6) Bq/kg <==> (2.5 +- 0.2) E-4 g/g	(4.9 +- 0.3) Bq/kg <==> (1.6 +- 0.1) E-4 g/g
Cs-137:	< 50 mBq/kg	< 3.7 mBq/kg

FR4 is preferable: MiCarta is worse by orders of magnitude for most relevant radioactive chains

Polymer Resistive kapton foils

Constructions

100XC10E7 is our standard offering for anti-static applications. It is a one mil film with a nominal surface resistivity of 5 mega ohm/sq. Two grades are available as described in **Table 2**. Custom constructions are also available, and can be produced in thickness from 1 to 5 mil, and with surface resistances from 90 to 10^9 ohms/sq.

The miracles of science™

Table 2
Electrical Properties of Kapton® 100XC10E7 and 100XC10E5 Polyimide Film

Property	Typical Value	Test Method
Film Type 100XC10E7		
Surface Resistivity Aim, mega ohm/sq.	5	ETS 870 electrometer at 100V
Resistivity Range, avg. mega ohm/sq.	.5-50	
Film Type 100XC10E5		
Surface Resistivity Aim, mega ohm/sq.	5	ETS 870 electrometer at 100V
Resistivity Range, mega ohm/sq.	0.1-1000	

Roll width = 1.2 m

Resistivity measurements on sample kapton foils provided by CERN.
Room temperature: 6 MOhm/square
Immersed in LAr: 9 MOhm/square (no change after several days immersion)

Measurements not changing after repeated immersions
Measurements taken with HP-4329A High Resistance Meter
V=100V (cross-checks at 50 V and 250 V)

Resistive ink deposition on FR4

- Developed for resistors on PCB:
- Resistivity range: 100 Ohm/square to 1 MOhm/square
- Desidered average resistivity can be obtained with specific ink patterns (up the hundreds Mohm/square)
- Active area limited by printing machine and oven for curing at 170° (< 0.6x2 mq at CERN PCB workshop)
- A silver paste for soldering electrical contacts and adapted to this ink is also available from the same company (cured at 170° as well)

ESL EUROPE

DEVELOPMENTAL PRODUCT
POLYMER RESISTOR SERIES **D-RS-12100**

DESCRIPTION: ESL D-RS-12100 Series Polymer Resistors are screen-printable, carbon composition, resistive coatings which offer an economical approach for the production of stable resistors in consumer electronic applications. They are designed for the use on FR-4, Kapton, ceramic or other suitable substrates and can be cured either in a box oven or in a near I.R. belt furnace.

PASTE DATA

VISCOSITY: (Brookfield RVT, ABZ Spindle, 10 rpm, 25.5°C ± 0.5°C)	40 ± 15 Pa·s
THINNER:	ESL# 402

PROCESSING DATA

SCREEN MESH/EMULSION:		200/12.5 microns
CURING CONDITIONS:	BOX OVEN:	170°C in a well ventilated oven for 2 hours
	IR BELT FURNACE:	220°C (Used for calibration)
	BELT SPEED:	20 inches / minute (Profile on back of page)
CURED FILM THICKNESS:		12 microns ± 1.5 microns
SHELF LIFE:		6 months
SUBSTRATE:		FR-4 (Used for calibration), Kapton, Ceramic
TERMINATION CONDUCTOR:		1107-S

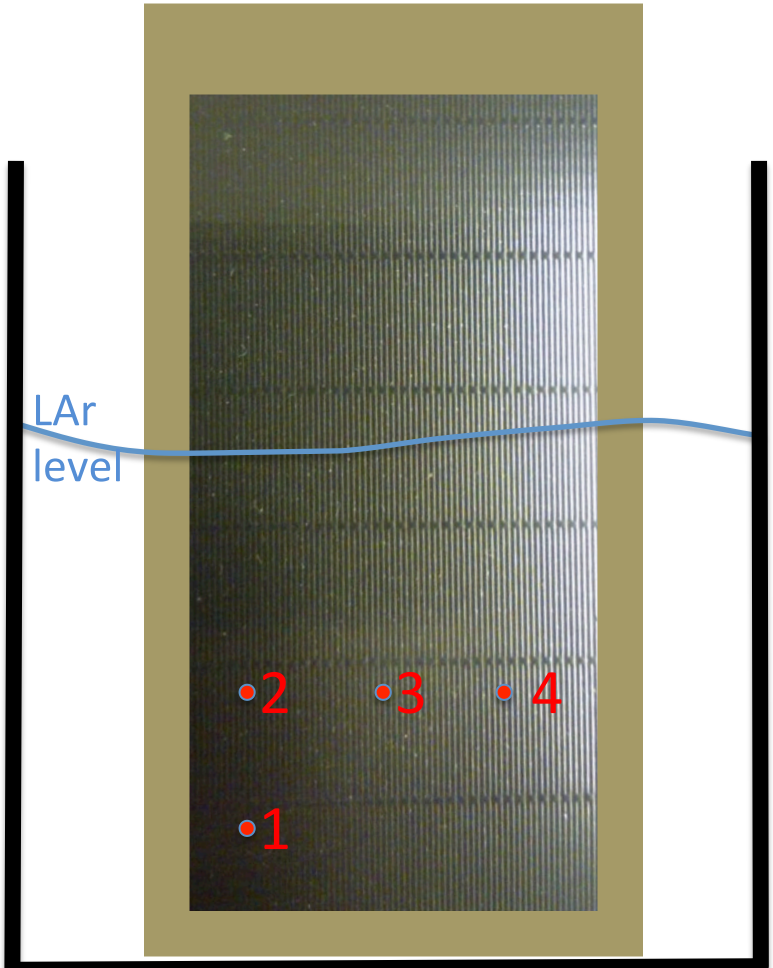
TYPICAL RESISTOR PROPERTIES

	D-RS 12112	D-RS-12113	D-RS-12114	D-RS-12115	D-RS-12116
Resistance[1]	100Ω/SQ.	1 KΩ/Sq.	10 KΩ/Sq.	100 KΩ/Sq.	MΩ/Sq.
CVAR	10 %	6 %	7 %	8 %	10 %
Resistance Tolerance	± 20 %	± 20 %	± 20 %	± 20 %	± 20 %
TCR (RT to +125°C)	+400 ppm/°C	- 200 ppm/°C	-400 ppm/°C	-700 ppm/°C	-1000 ppm/°C
Humidity Test (40°C / 90% R.H.)					
24 hours	-	≤ -1 %	≤ -1 %	≤ +1%	≤ +1.5 %
100 hours	-	≤ +1%	≤ +1%	≤ +1%	≤ +1.5%
1000 hours	-	≤ +1%	≤ +1%	≤ +1%	≤ +1.5%

[1] 10Ω/Sq. under development.

E.S.L. Inc., • 416 Church Road • King of Prussia • Pennsylvania 19406 • Tel: 610-272-8000 • Fax: 610-272-6759
AGMET LTD., • 8 Commercial Road, • Reading, • Berkshire, • England RG2 0QZ • Tel: (0)1734 873139 • Fax: (0)1734 867331
ESL sarl, • Tel: 1-46-31-89-45 • Fax: 1-46-32-21-25 • ELECTRO SCIENCE DEUTSCHLAND • Tel: (0)89-598721 & 598957 • Fax: (0)89-553109

Ink print: resistivity measurements at room and LAr temperatures



average resistivity obtained with parallel strips (~250μm thick ~ 250μm spacing) linked together every ~cm.

Measurements taken with HP-4329A High Resistance Meter		
V=100V (cross-checks at 50 V and 250 V)		
	Room Temp (25°C)	Cold (-180°C, LAr quiet)
1-2	1,5	3,7
1-3	3	6
1-4	6	9.9
2-4	6	10.5
All values are expressed in 10^7 Ohm		

- No variation in resistance values measured at LAr and room temperatures after long term (days) immersion in LAr.
- No visible damage to the screen-print pattern.

Germanium Thin film

Parameter (independent of film)	Specified Value
Germanium surface resistivity	$\leq 10^9$ Ω/square (typical 10^7 Ω/square)
Transmittance (Kapton HN only)	$\leq$ 0.20
Solar Absorptance (α) Black Kapton Side	0.93 typical
Normal Emittance (ε_N) Black Kapton Side	0.84 typical
Intermittent temperature range	-250° C to 400° C (-420° F to 750° F)
Continuous temperature range	-250° C to 290° C (-420° F to 550° F)
Outgassing: (ASTM – E595)	TML - WVR $\leq$ 1.0 %; CVCM $\leq$0.1%

Resistivity measurements on a 40x25 cm2 foil provided by Rui.
Room temperature: 4.5 MOhm/square
Immersed in LAr: 70 MOhm/square (no change after several days immersion)

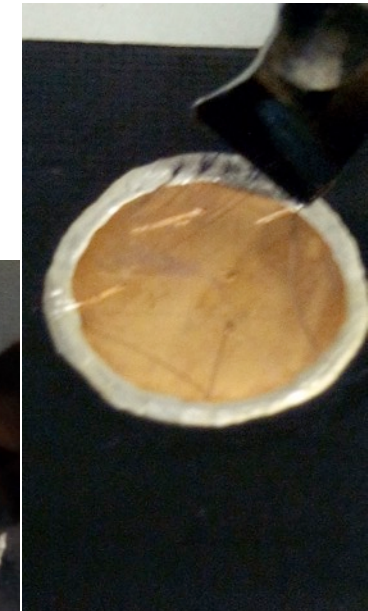
Measurements not changing after repeated immersions
Measurements taken with HP-4329A High Resistance Meter
V=100V (cross-checks at 50 V and 250 V)

Discarded mainly due to the very thin Resistive layer (< 1 um) that can be easily scratched away

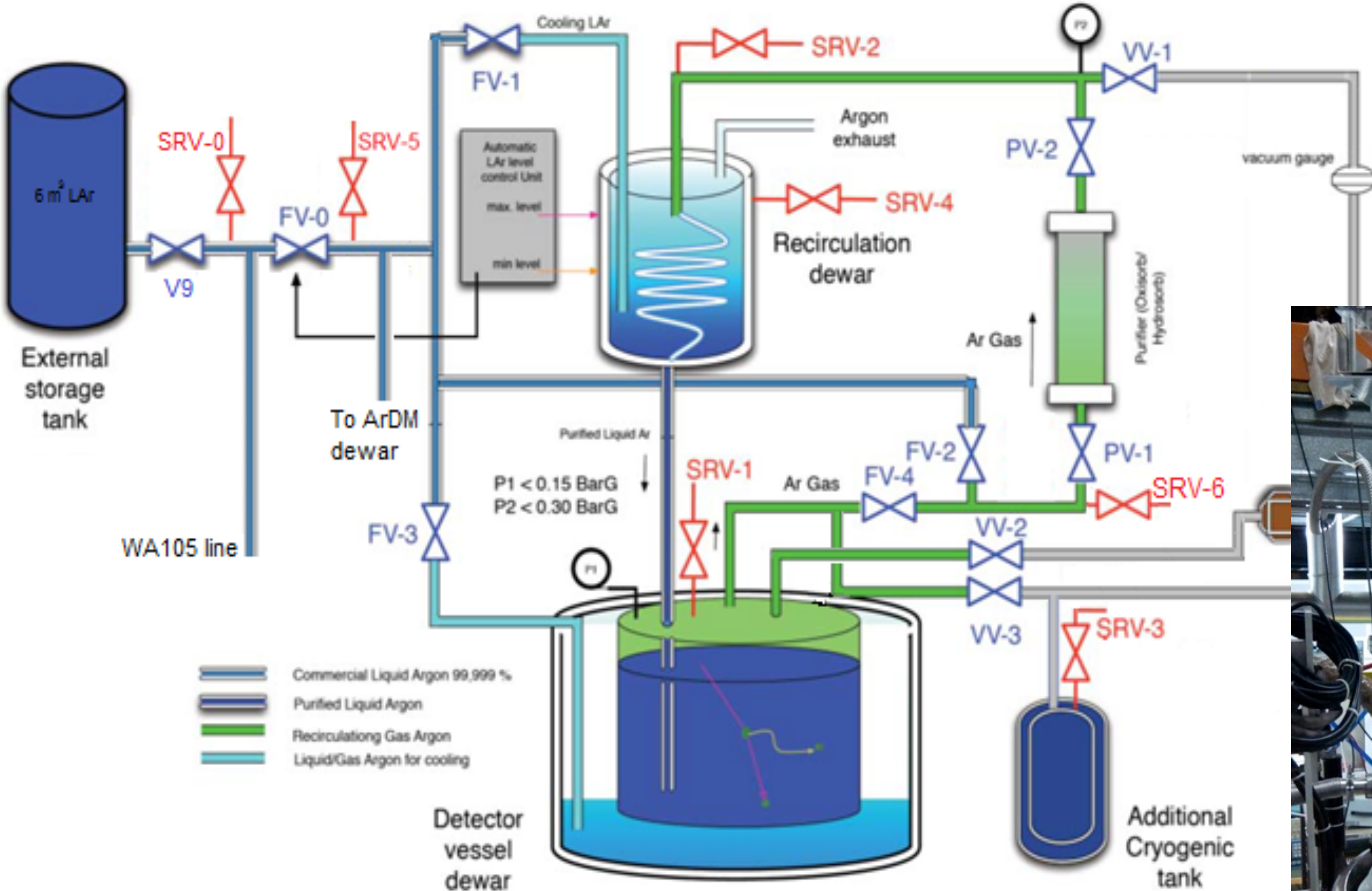
Reliability of silver paste for electrical contacts

- Deposition by painting and curing in oven at 170° (including copper pad)
- High stability at cryogenic temperature
  - No peel-off after many thermal cycles
- Very robust against mechanical scratches

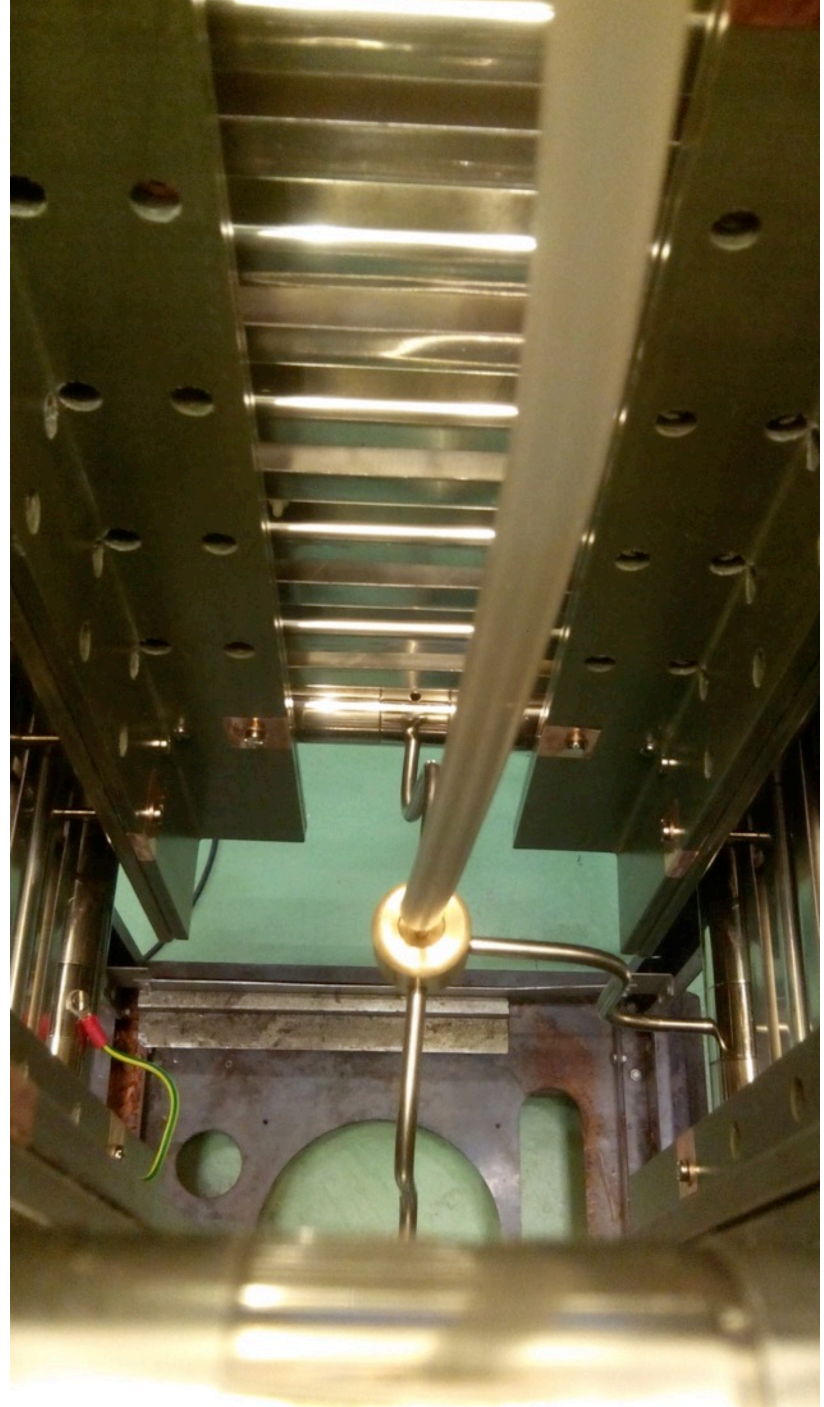
~ 2 cm



The 50 liter LArTPC test set up

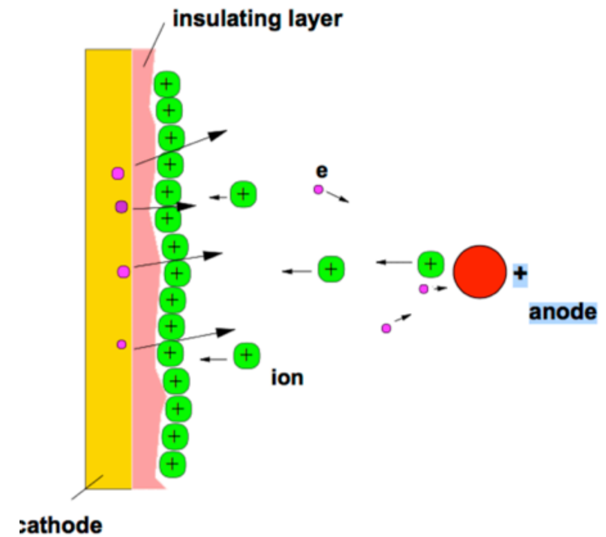


March 7th, 2016



Possible effect of Al surface oxidation

- Alumina oxide is known to build rapidly on Aluminum surface in few nm layers.
- Due to the good insulation properties of Alumina, charging up of its surface could occur producing high electric field through the insulation layer.
- This could result in electron emission through the surface (similar to Malter effect in drift chamber) which in turn could induce noise on FE electronics
- Investigation with the surface treatment experts at CERN, seems to indicate that this effect, if any, should be highly mitigated by density of LAr that strongly reduces the electron mean free path in the liquid, making the electrons stop near the insulator surface contributing to fast ion neutralization.

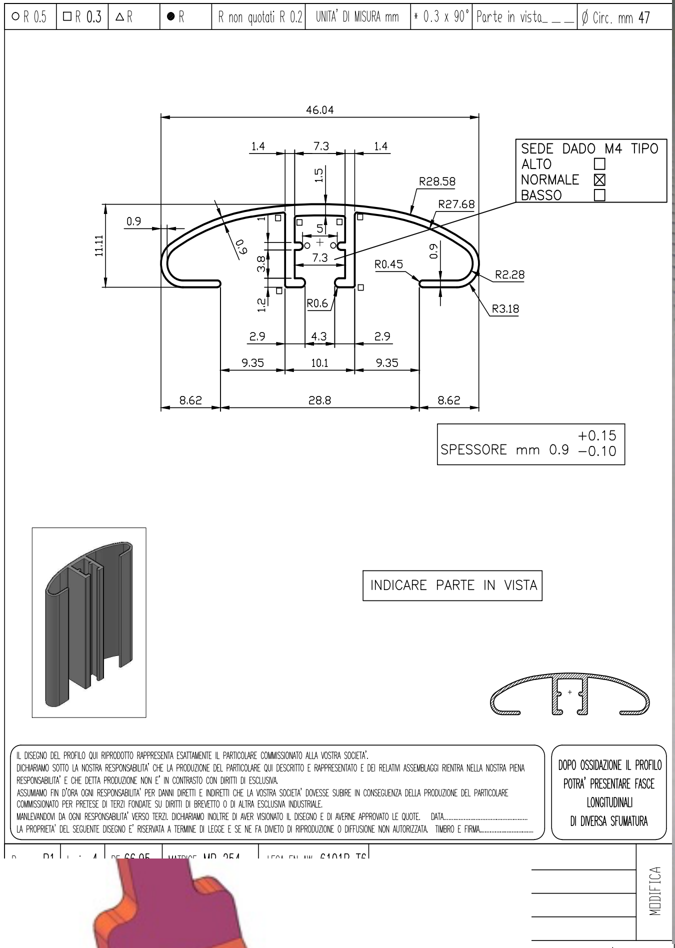


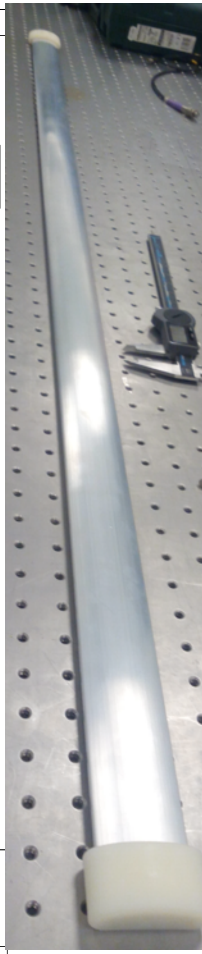
Model of Malter-effect

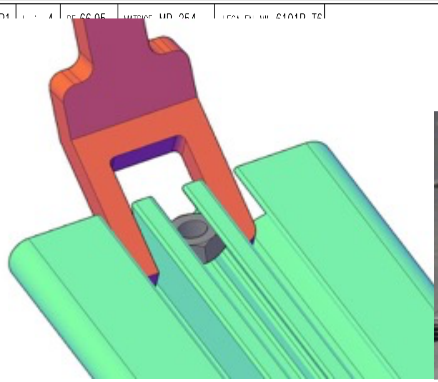
- To test the effect: requires long term exposure of a LAr TPC equipped with Aluminum electrodes.
- Further mitigation of this effect could be however obtained with conductive coating.

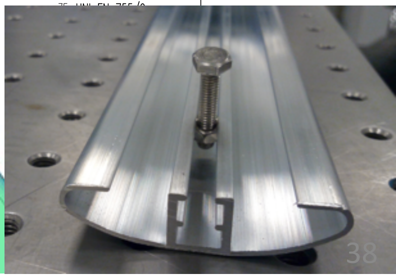
Extruded aluminum profiles for FC

- Production:
  - Optimization of stiffened aluminum extruded profiles; mechanical properties verified (with FEA calculation) at CERN.
  - Same outer shape as roll formed profiles, compatible with standard locking nuts and tooling for mounting
  - Production of prototypes started at selected producers (ALEXIA-Italy, MIFA-Netherland) with different aluminum alloy and with conductive coating (at some cost increase).
  - Prototypes (1.5 m long) verified at CERN.
  - First 100 m available on 11/15th (sufficient for second phase of the 35 ton HV test): 50m with conductive coating (SURTEC).
  - Full production (~3km) for ProtoDune SP available in few weeks time
  - Cost ~ 1 to 2 Euro/m
- Full compatibility between SS roll formed and extruded aluminum profiles; final choice can be made at very last moment



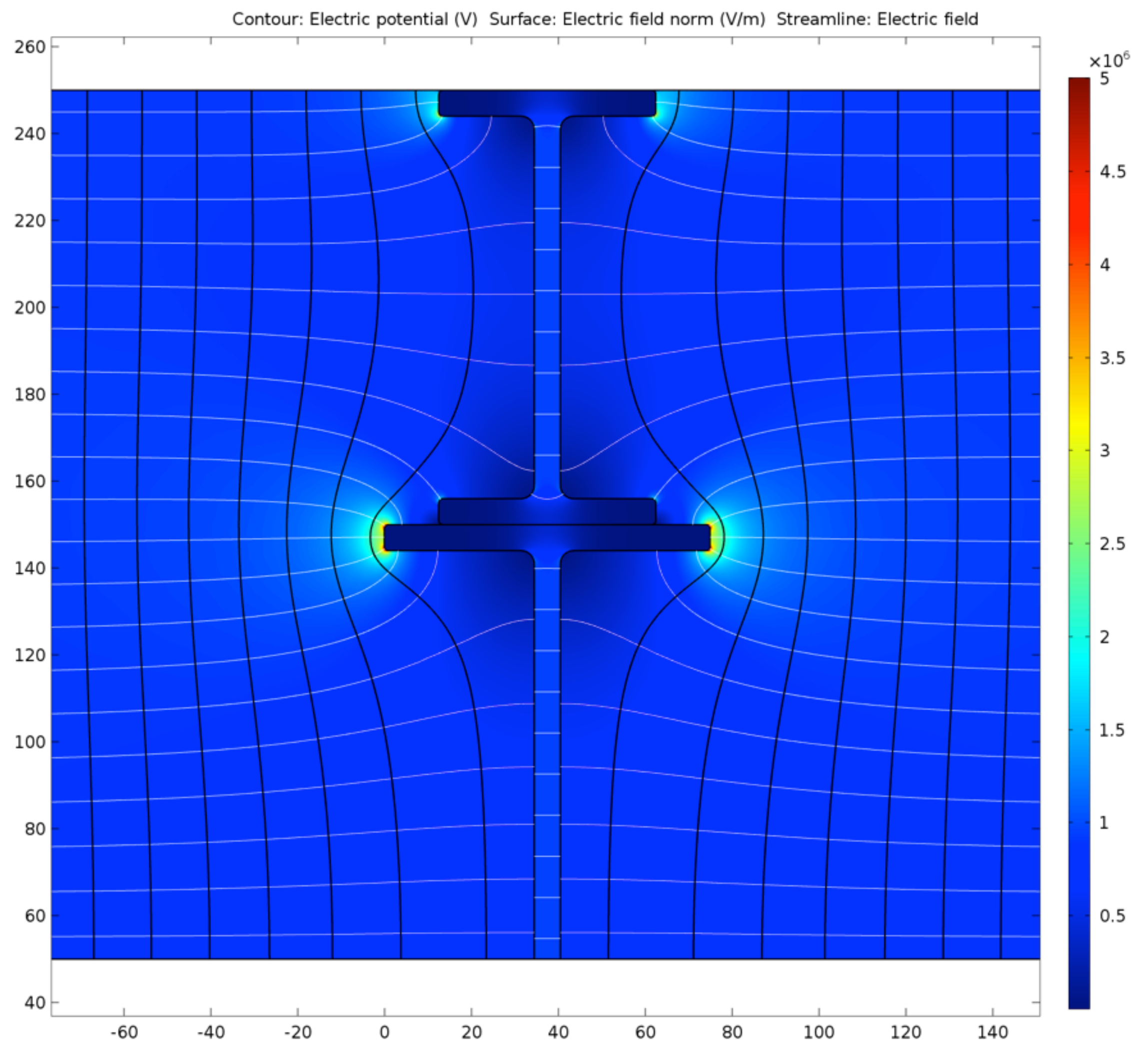






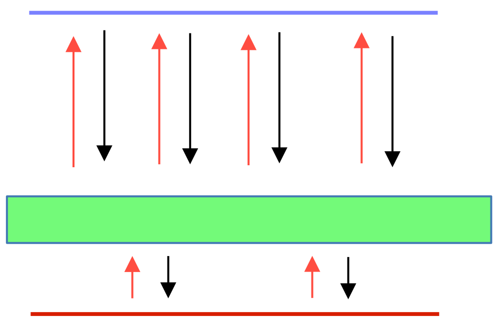
Charge build up

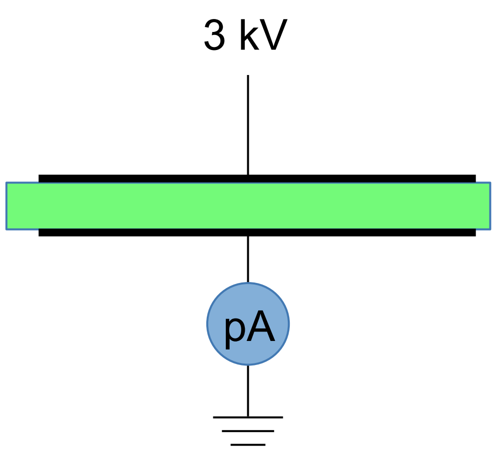
- FEA with "zero perpendicular field" boundary condition on all surfaces of the I-beams except at top and bottom.
- This is the condition when surfaces have charged just enough to repel any further incoming charge.
- White contour lines: V
- Black contour lines: E
- High fields at corners.
- Charge-up rate depends on volume adjacent to surface.



Currents, time constants, and effect of bulk resistance

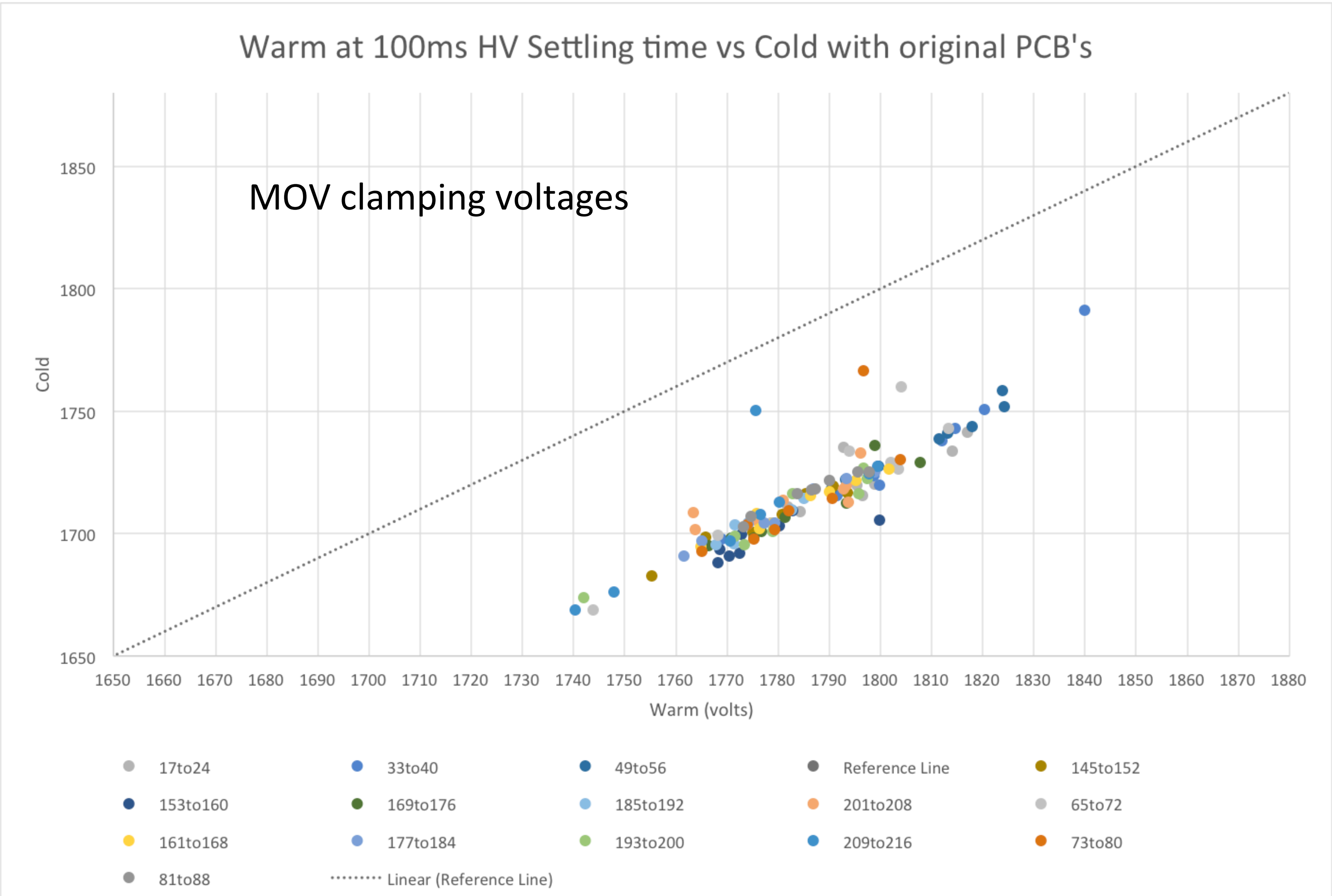
- Charging of two sides can be asymmetric if volume on one side is different from the other.
- E.g., for box beams holding field cages, roughly 20 pA/m^2 on one side, 30 pA/m^2 on the other.
- Approximate analytic calculation gives **~2 day** time constant to charge one side only if no current on other side, **~2 wks** for both sides to charge, for 1/4" thick material.
- **A non-infinite bulk resistance would mitigate charging**: internal $E = J \rho$.
- E.g., if $\rho = 10^{18}$ ohm-cm, then
- $E < (30 \text{ pA/m}^2)(10^{16} \text{ ohm-m}) = 3000$ V/cm.
- Attempted to measure resistivity of 12" x 12" x 1/4" FRP plates at K-State at E = 4.7 kV/cm. Saw long, increasing time constants of hours then days, slow "self-recharge" after applied voltage zeroed or reversed. Done in air at room temp.
- **Need test at full HV and E scale, in LAr.**





Some MOV Test Results

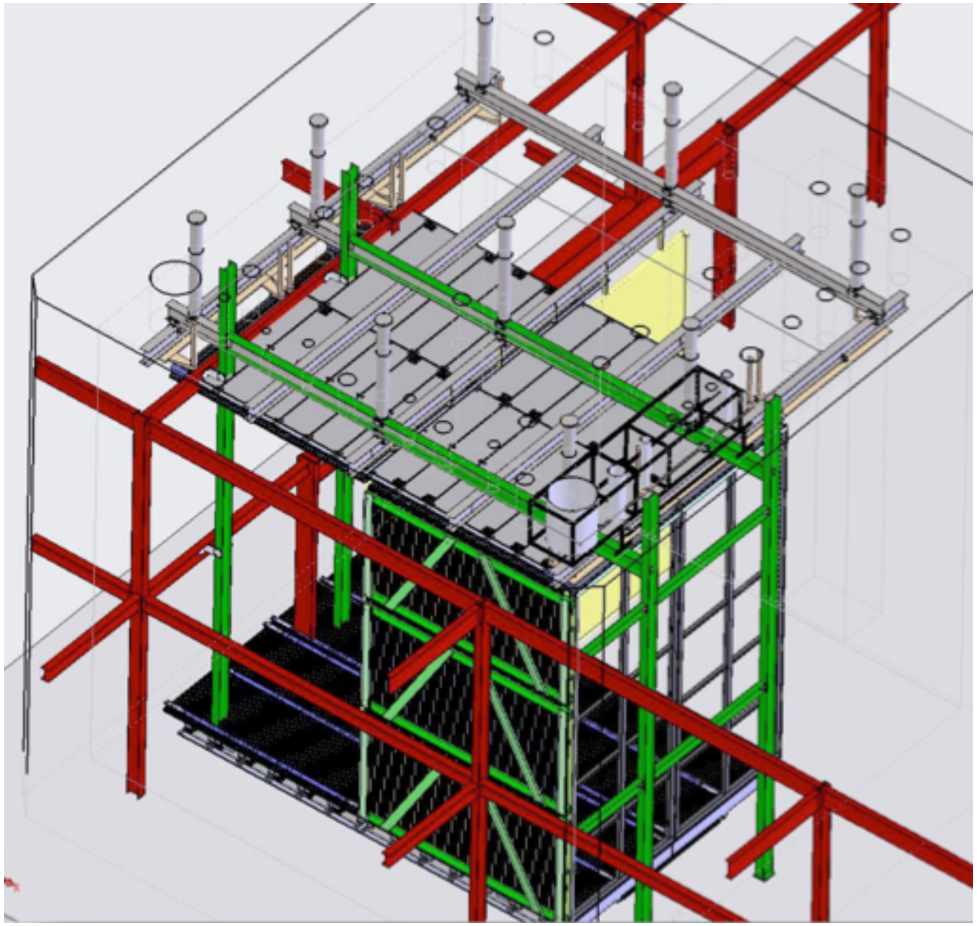
Work in progress



Mechanical mock-up in Ash River

- Full scale ProtoDUNE-SP components (FC, CPA, support structures)
- Tests of interfaces and handling
- Test of assembly procedures

Presently underway



Ash River Installation components

- One APA frame (no wires)
- 4 CPA columns (without resistive lamination)
  - FR4 Frames completed with FR4 panels
- 4 Top/Bottom FC Panels:
  - 2 Panels with latest design (No splice joint and latest modifications)
  - 2 panels older version with stainless hardware just for mockup.
- 4 End-wall Panels:
  - Top panel with hangers
  - Panel with beam plug mockup.
  - 2 Regular End wall panels.
- Most panels fully populated with field shaping profiles
- Few end caps missing.
- Additional weight on the panels to make up for missing weight due to missing ground planes (replaced by plywood) .

Ash River present Achievements

- Phase 1 of the ProtoDUNE Trial Assembly
  - Hanging the first CPA
  - Getting elevations in TPC correct
  - Moving the first CPA Pair
  - Hanging the first Field Cage
  - Rotating the FC
  - Packaging for shipping