ProtoDUNE High Voltage Design

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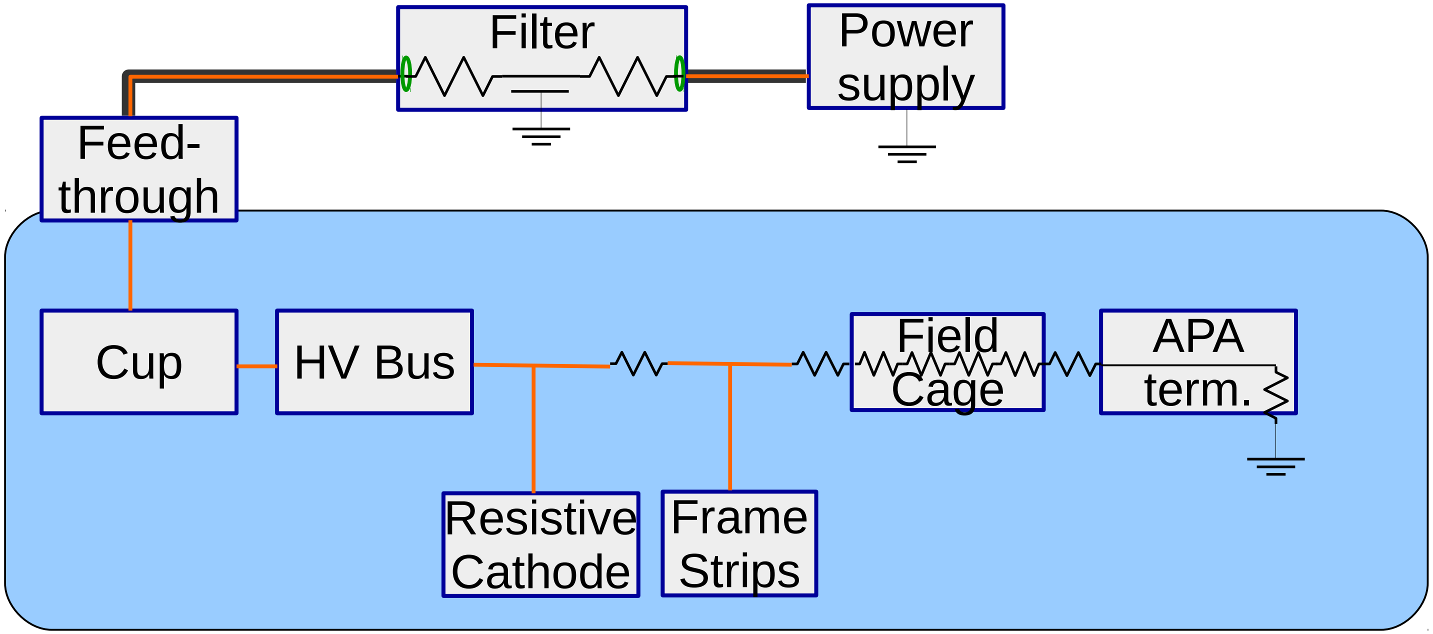
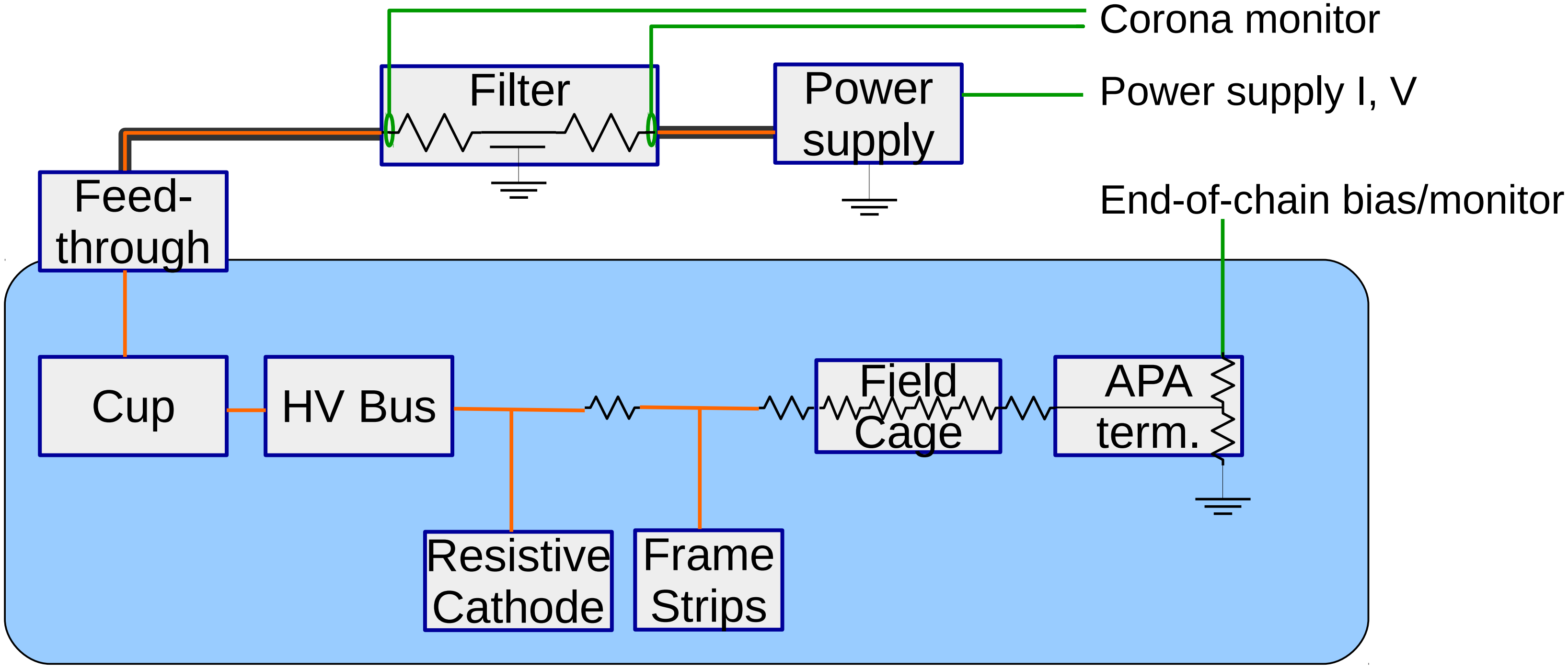
November 9, 2016

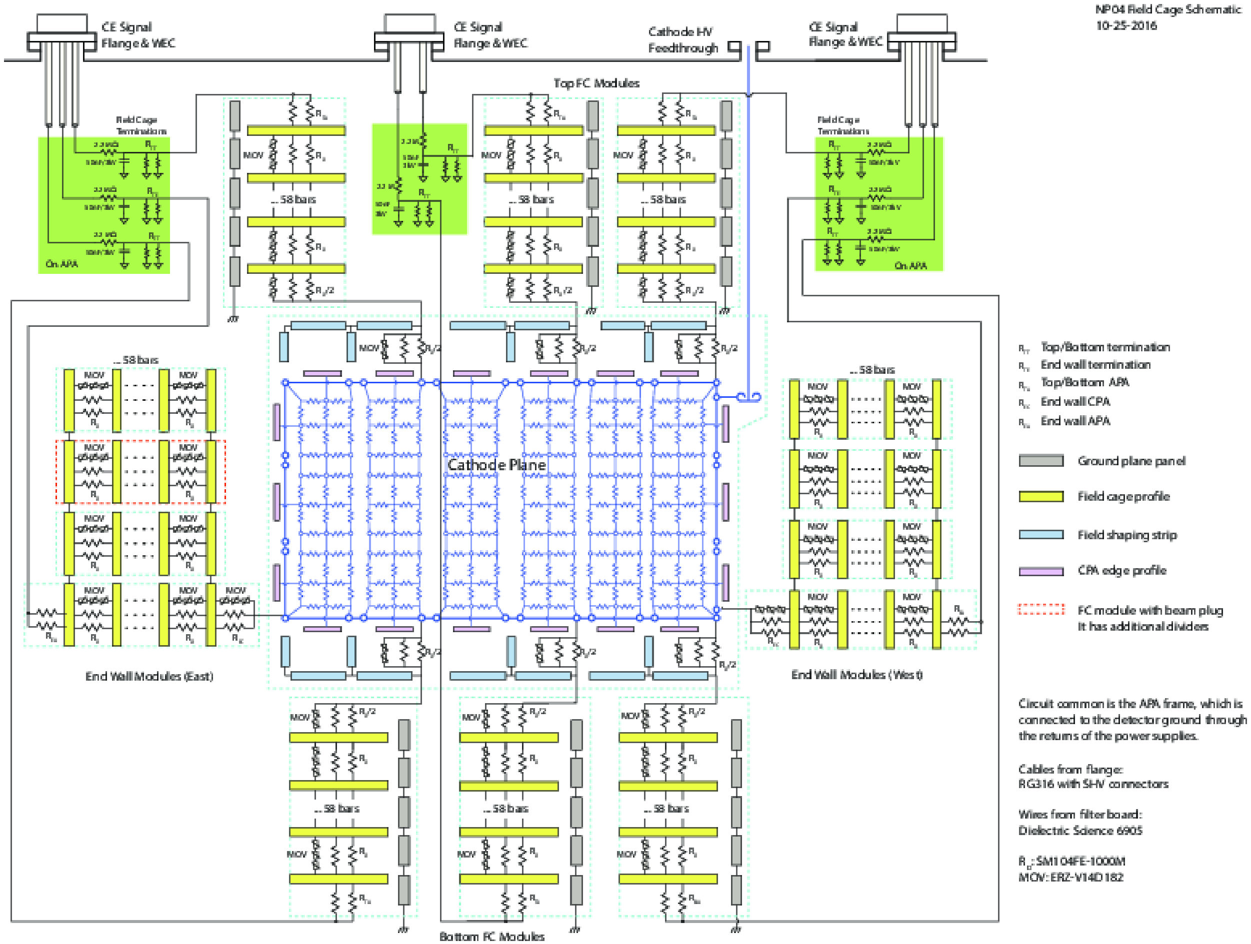
Very Simplified Diagram



Very Simplified Diagram with Diagnostics



Very detailed drawing, with art to show spatial relationships



From Bo Yu, BNL

HV Power Supply – Requirements (from FC/CPA/HV design paper, v25)

- Shutdown on discharge as detected by measured output voltage or current, based on magnitude, duration, or rate.
- Shutdown on discharge detected by various other means (including corona monitors, end-of-chain pickoffs) – implies interface with controls.
- Tolerance: DC voltage within 1% of setting.
- Ripple after HV filter less than 5×10^{-9} required to keep noise on anode wires < 10% equivalent thermal noise.

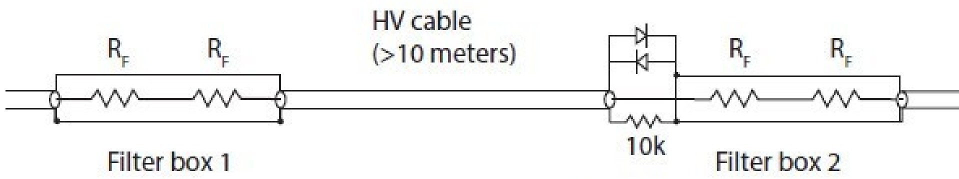
HV Power Supply plan

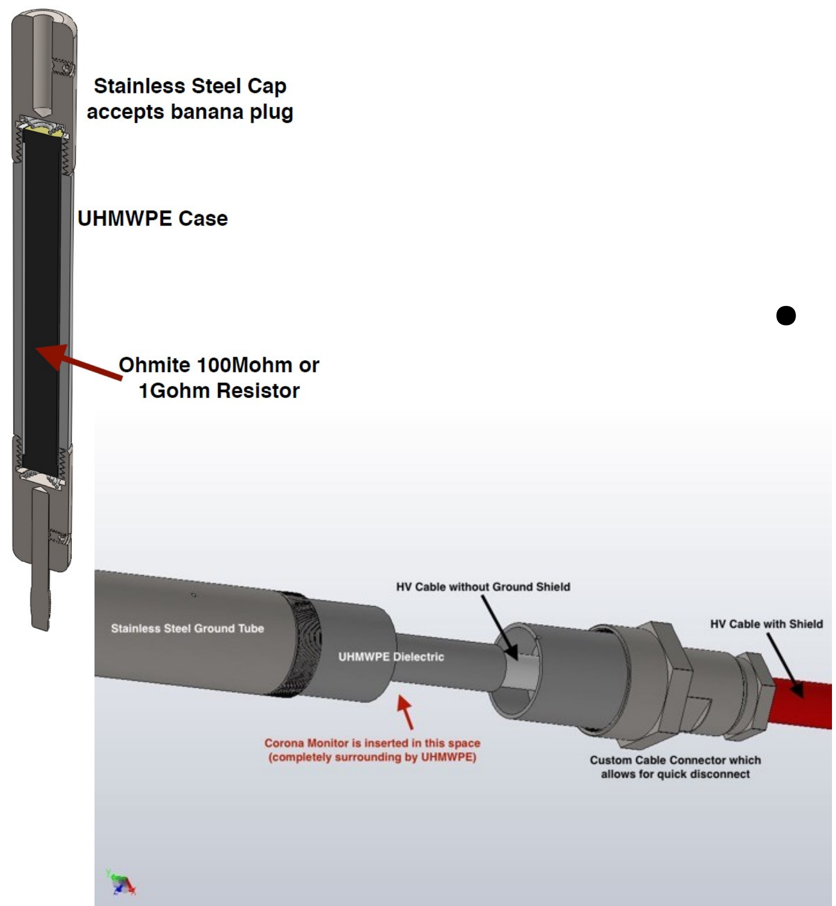
- Heinzinger 300-kV power supply, also planned for dual phase ProtoDUNE.
- Remotely controllable, programmable.
  - Some slow controls software needed for reacting to corona, pickoff monitors.
- CERN, FNAL, UCLA, others have good experience with these supplies.
- Residual ripple less than 10^{-5}
- Factor 2000 additional filtering needed.

HV filter and monitor requirements

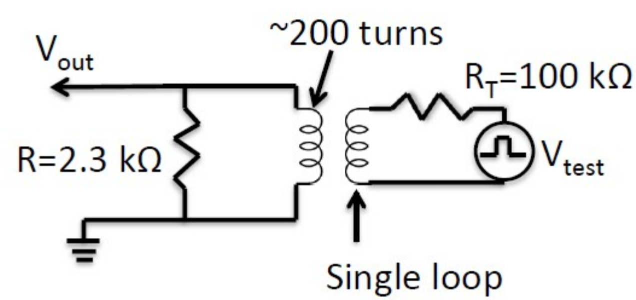
- Provide filtering to required level.
- Withstand up to 150% of design 180 kV. (i.e., 270 kV)
- Voltage drop small enough that max required field (currently specified as 600 V/cm) can be achieved in TPC.
- Monitor transients in filter output.

HV filter and corona monitor





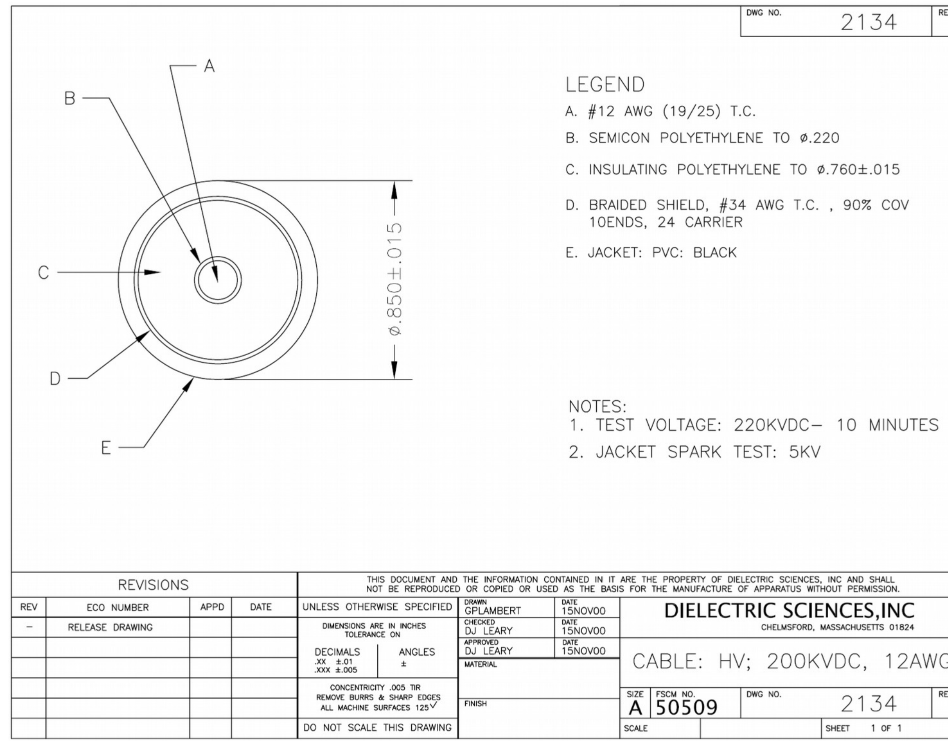
- Resistance in series plus capacitance of cable provides filtering.
- Toroidal transformer senses current spikes



Drawings from A.Renshaw, Houston

HV cables

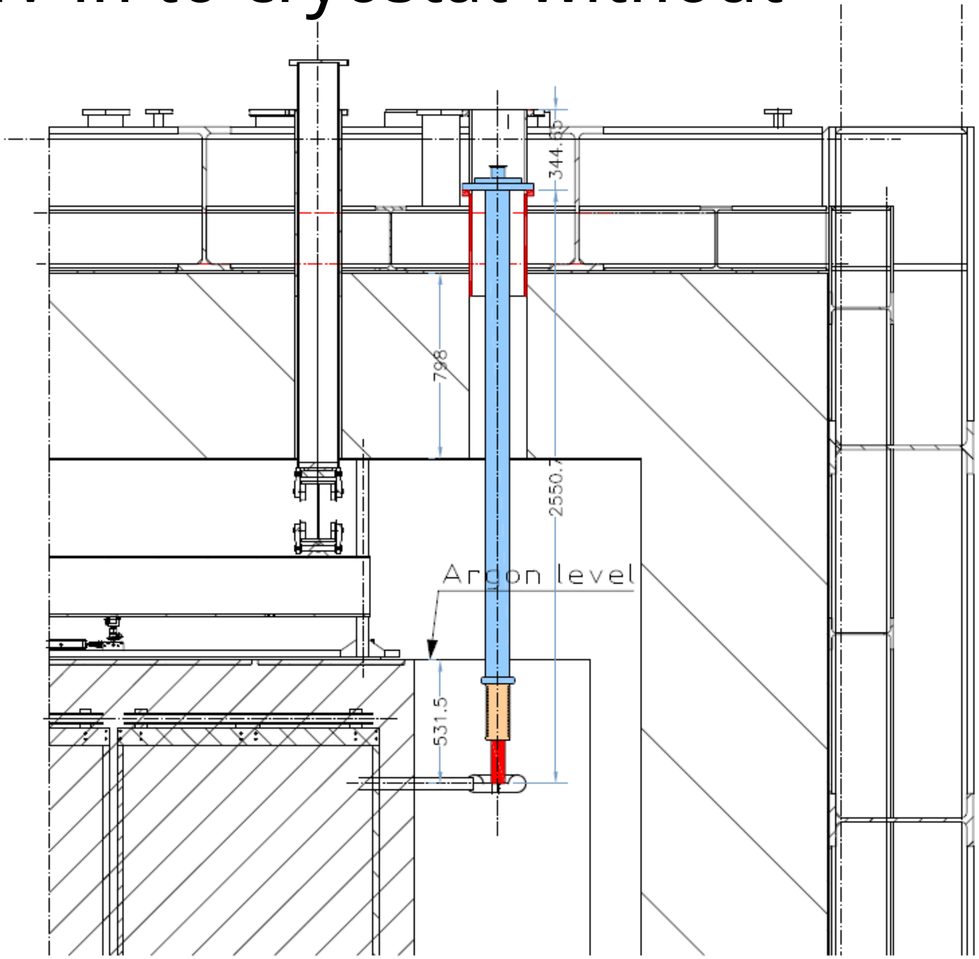
- The power supply comes with a length of suitable cable.
- 200' (60m) of DS2134 cable has been purchased, stored at ANL, for use in HV bus.



DS2134 is nominally rated for 200 kVDC; Heinzinger seems to use identical cable for their 300 kV supplies.

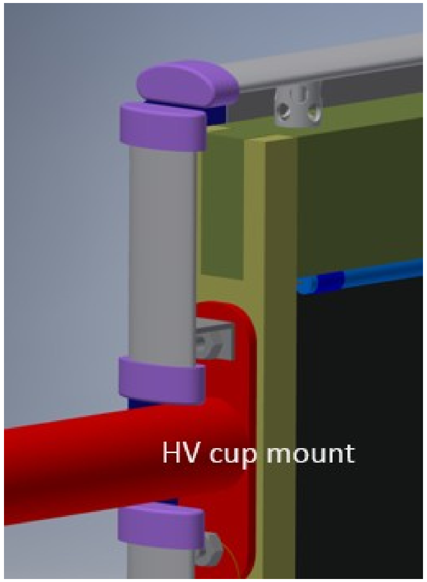
HV feedthrough

- Requirement: bring HV in to cryostat without breakdown at max V.
- Baseline: DP design.
- See Franco's talk for details.



HV cup

- Requirement: connect end of HVFT to HVBus without breakdown.
- Donut shape to minimize fields.
- Arm needs to be correct length, attachment to frame at correct position to place HV cup at bottom of feedthrough.
  - An “intraface” within the integrated CPA/FC/HV system.

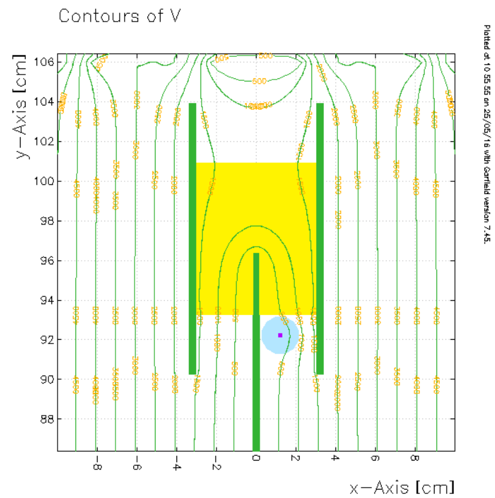


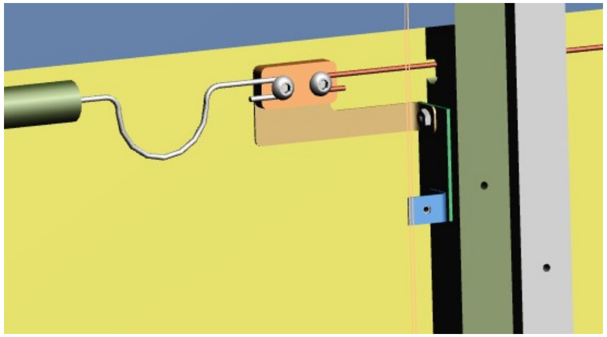
HV Bus Requirements

- Connect all cathode planes to HV cup.
- Low resistance to avoid voltage differences.
- High resistance to cathode except at designed connection points to preserve slow discharge of resistive cathode; must withstand full HV.
- Redundant path in case of a single connection point failure.

HV bus

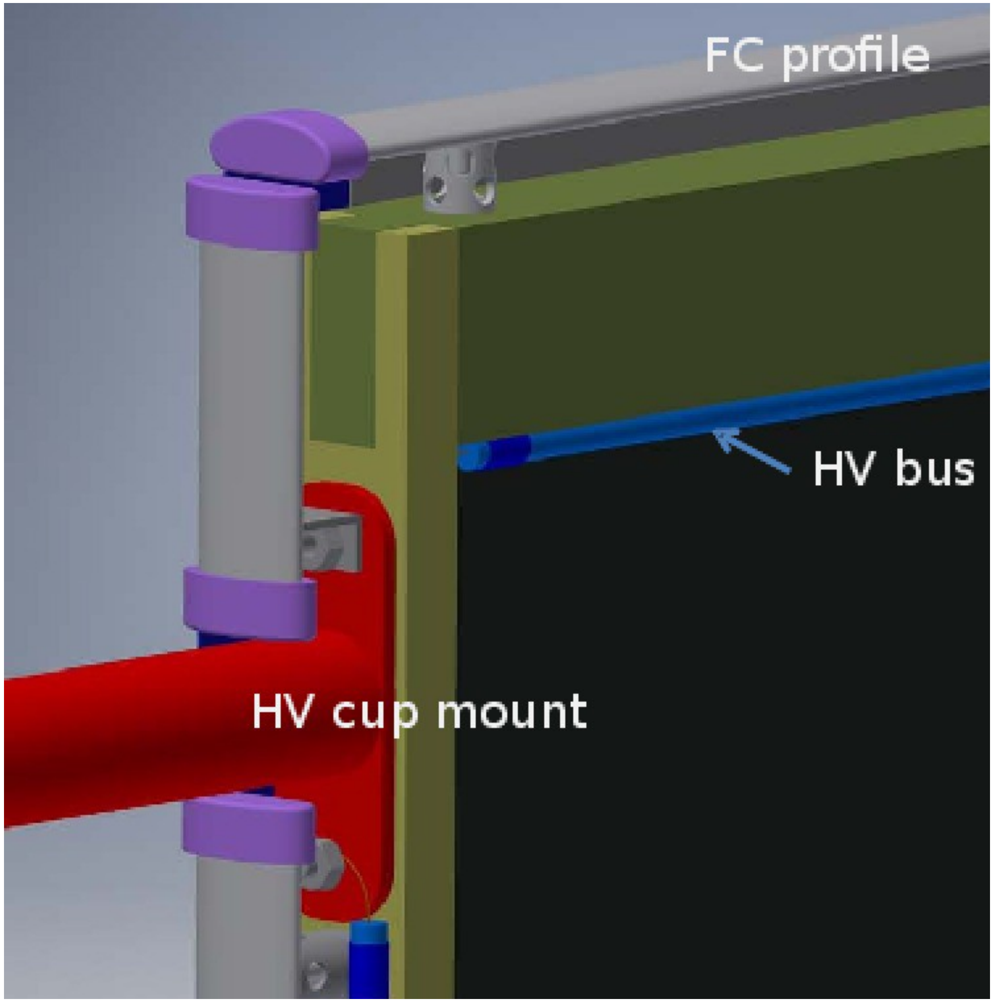
- Use off-the-shelf DS2134 cable without braid.
  - Well-known, well-designed cable
  - Not designed for cryogenic use, but has been used as such, tested.
- Located in the 500 V/cm field between frame strips and cathode.
- Flexible, lower-voltage cable used for connections through frame.





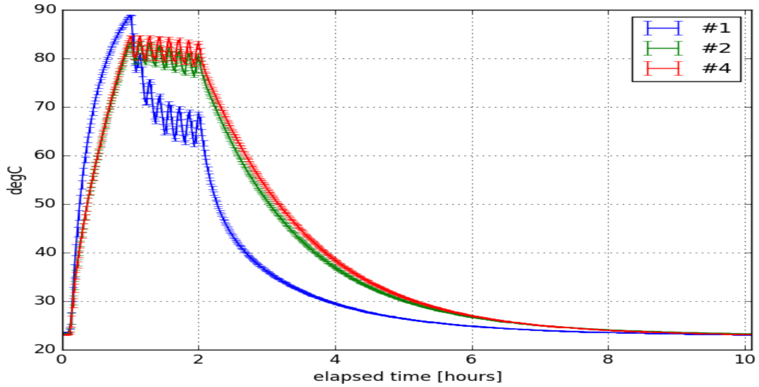
Another view of HV bus

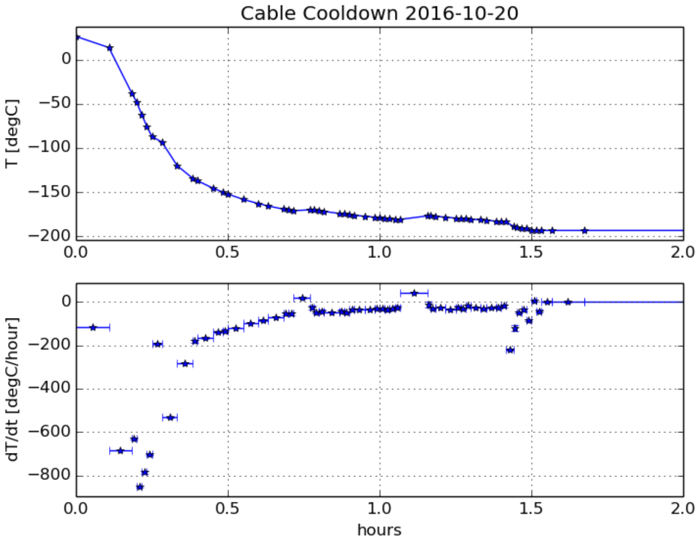
- The CPA frame strips have been hidden in this view.
- HV bus will be installed as part of CPA assembly, before installation of frame strips.



HV Bus annealing, cool-down tests

- Anneal at 85 degC to remove curvature, internal stress.
- 107 cm of annealed cable cooled to 77 K over 2 hours without damage.



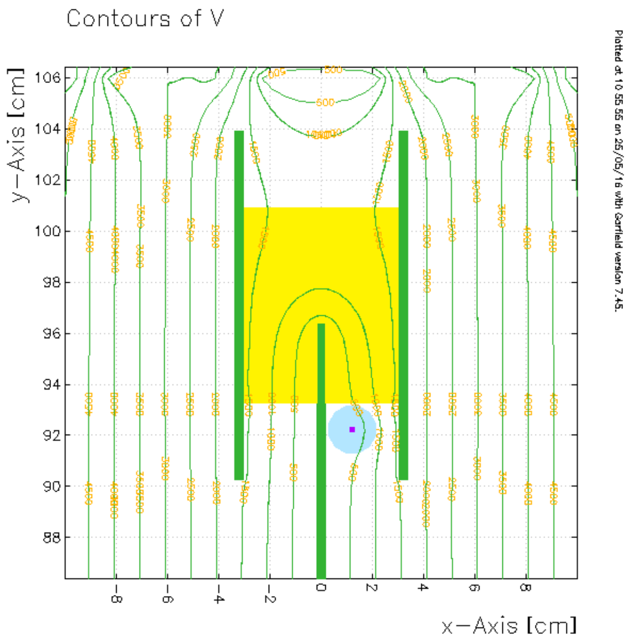


Resistive Cathode Requirements

- Provide uniform surface at required voltage.
- Resistive in order to slow discharge to protect TPC wires from too much current.
- Non-conducting frame to get slowest discharge.
  - The non-conducting frame will cause field distortion unless covered by electrodes at appropriate voltage.

Cathode Frame Strips

- Prevent distortion of field by dielectric constant of non-conducting G10 frame.
- Prevent charge-up of frame by ions drifting in field.
- Also shields TPC drift region from distortion by HV bus, and protects HV bus insulator from charge-up.

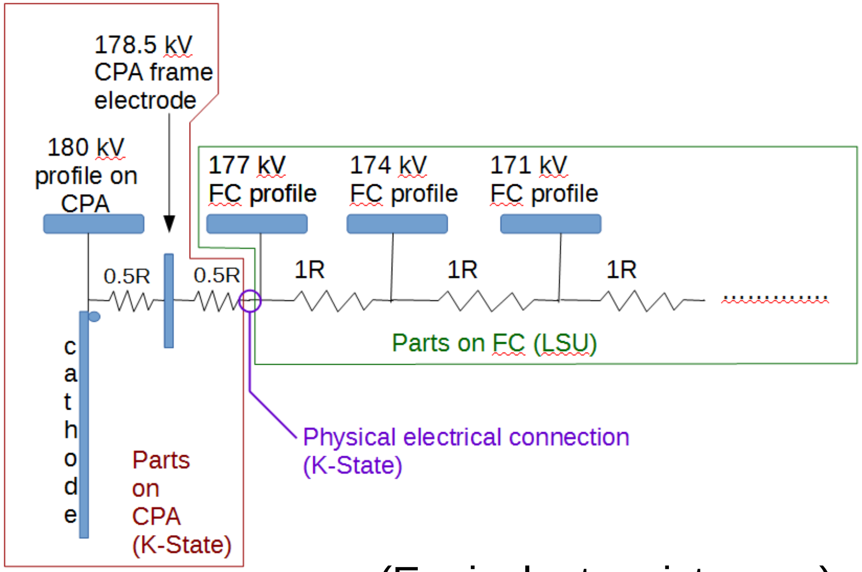


CPA surface and frame strip materials

- The cathode sheets with resistive surface will be provided by CERN.
- Cathode Frame Strips will be made out of the same material.
  - More details on material in QA/QC talk.

Cathode Frame Strip bias

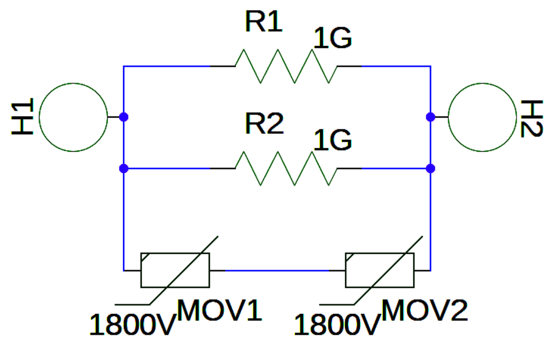
- The field shaping strips on the CPA frame are halfway between cathode and first FC element, half step in voltage.
- Resistors for providing the bias will be mounted on CPA. (plus varistors)
- Install with frame strips.

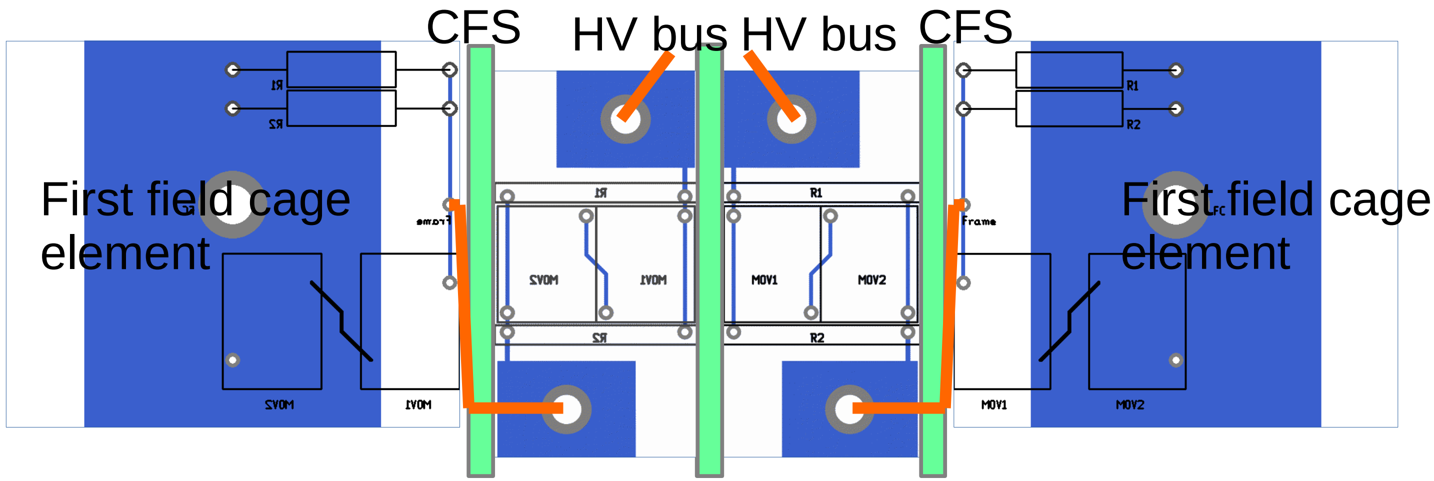


(Equivalent resistances)

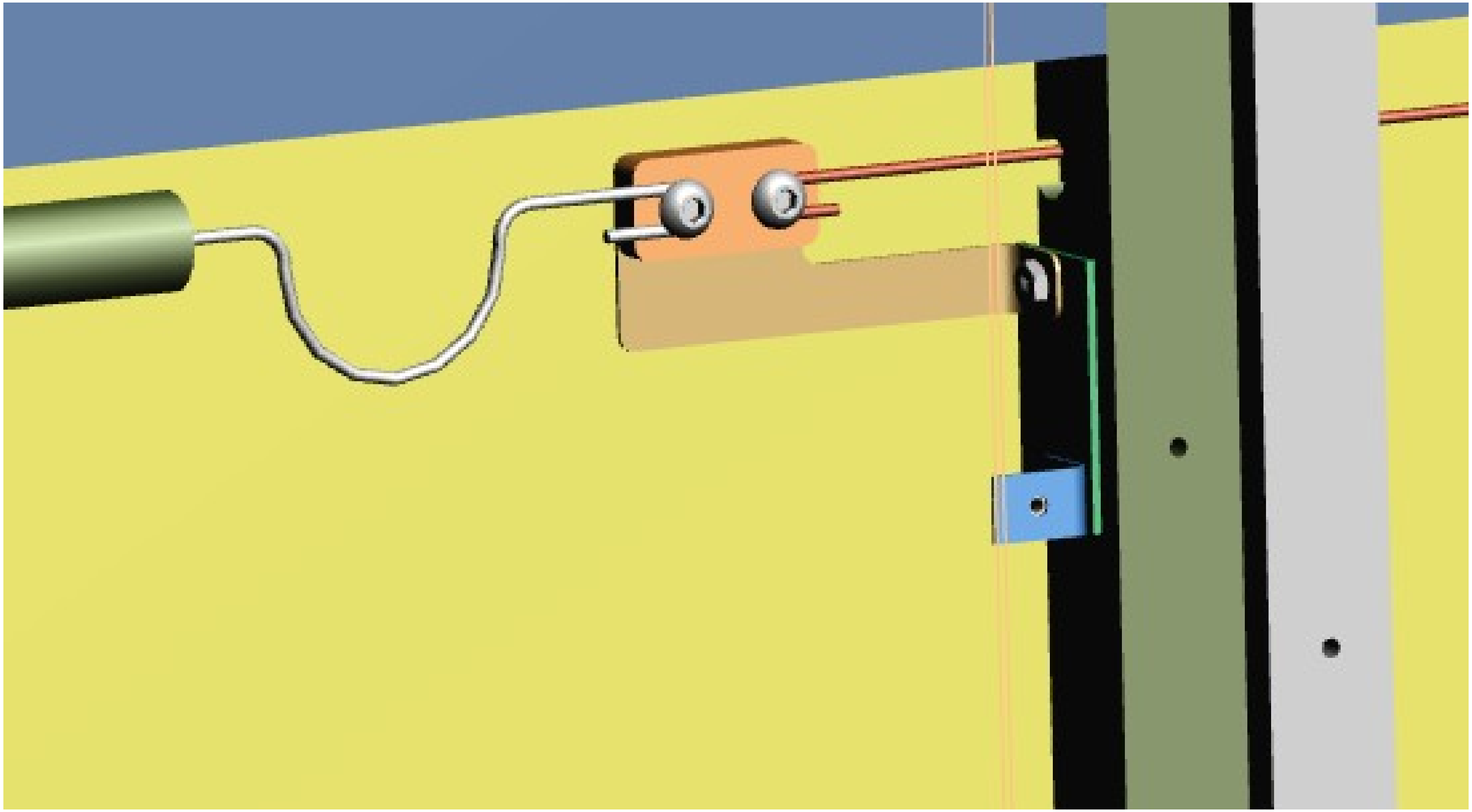
Cathode Frame Strip bias boards

- Two 1 Gohm resistors in parallel with two 1.8 kV varistors in series.
- 2:2 mapping FC:CPA.



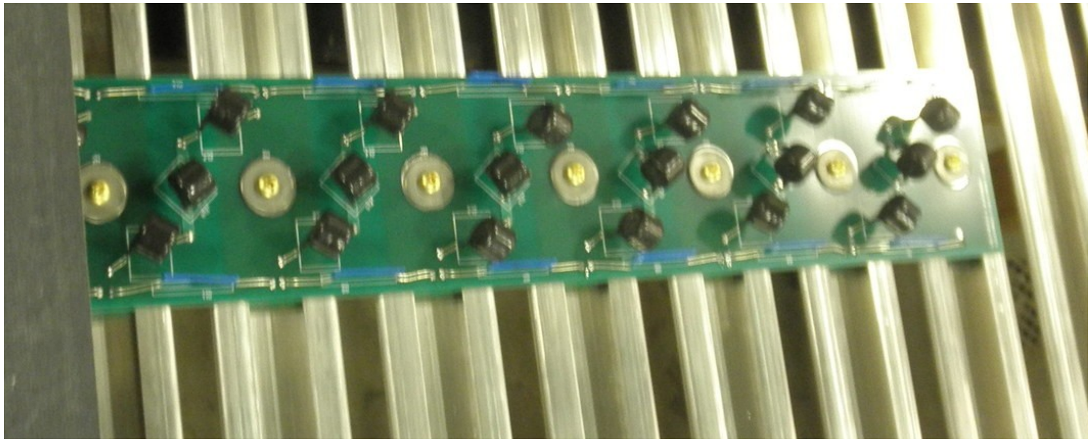


Mounting of CFS bias boards



Field cage resistor boards

- Field cage resistor boards by LSU.
- Installed on the interior side of the FC as part of FC assembly/
  - See field cage talks mechanical talks for installation details.

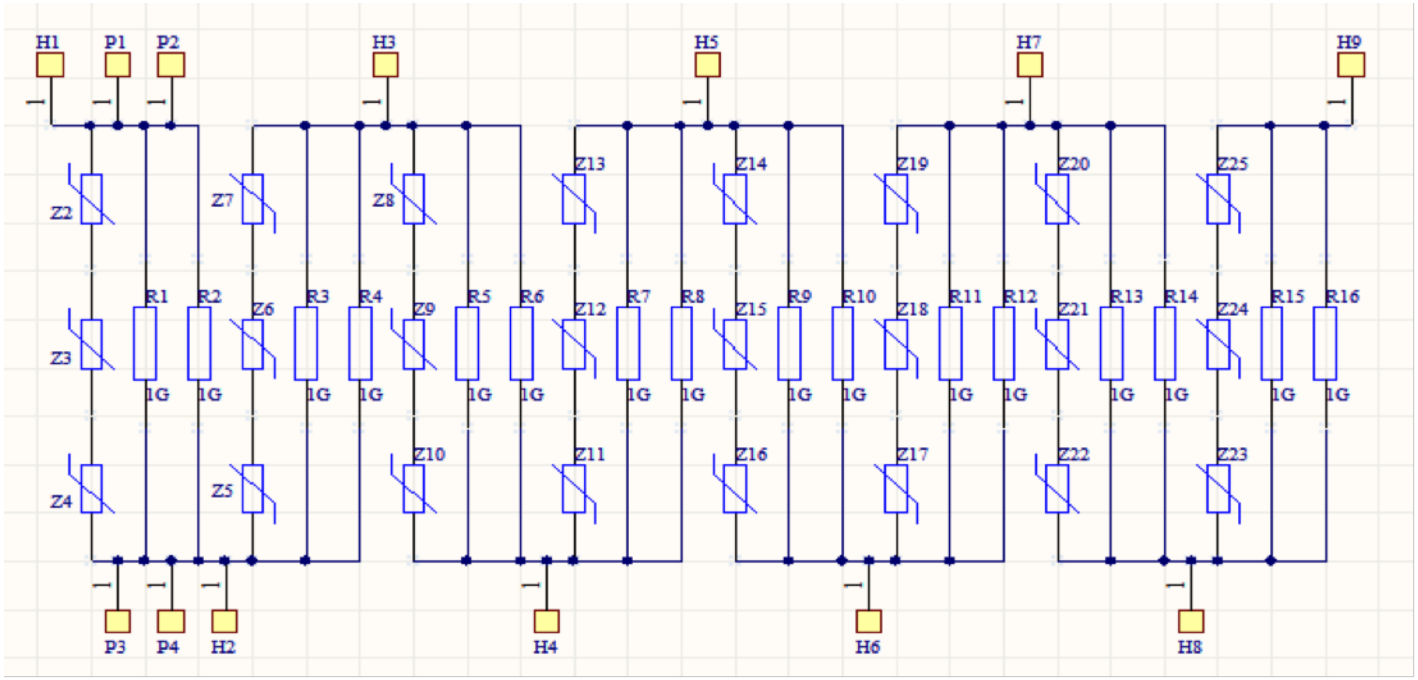


FC divider board schematic

- PCB connects 9 profiles (e.g. 8 steps)
  PCB dimensions: 520 mm length, 80 mm wide

- Profile to PCB connection by means of large Cu pad on side facing profile
  also top side connection by means of washer and M4 brass screw to SS nut

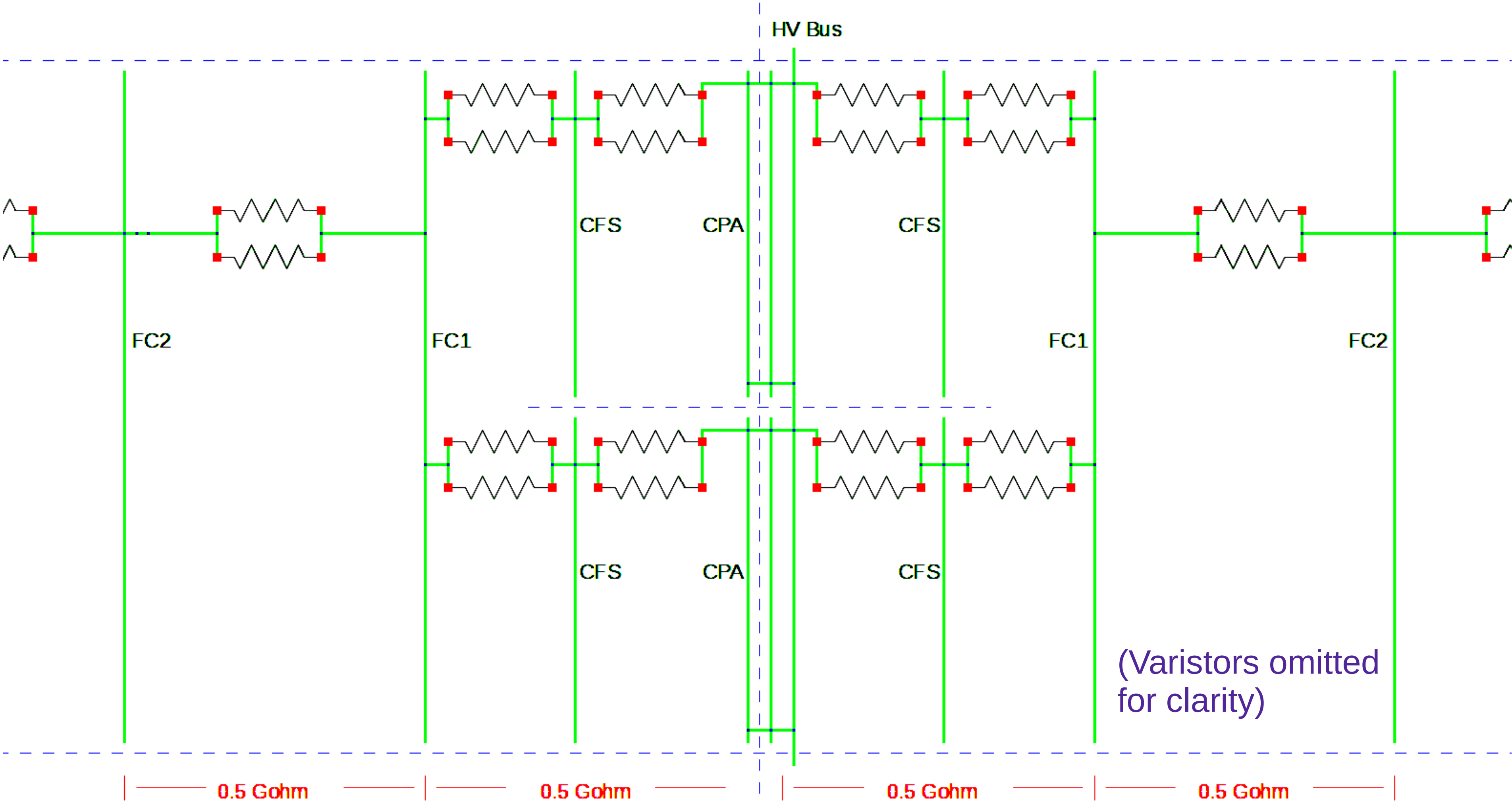
PCB schematic



<u>Components per stage:</u>

- Two 1 GΩ resistors in parallel
- Three varistors in series (nominal clamping voltage: 1800V each)

Two CPAs per Two Field Cages



(Varistors omitted for clarity)

Resistors and MOVs

- **Resistors**: Ohmite Slim-Mox SM104031007FE

  1 G Ohm, 1% tolerance, 1.5 W

  http://www.ohmite.com/cat/res_slimmox.pdf

- **MOVs**: Panasonic ERZ-V14D182

  1800V clamping voltage

https://industrial.panasonic.com/cdbs/www-data/pdf/AWA0000/AWA0000CE2.pdf

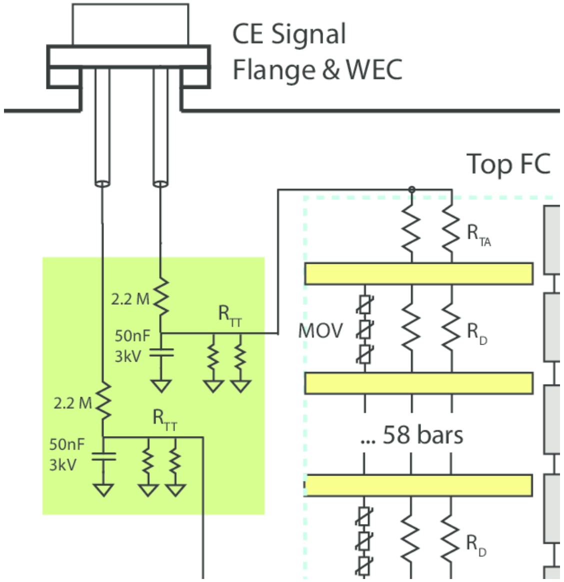
There is an extensive QA/QC operation at LSU – see QA/QC talk tomorrow.

Beam plug

- Beam plug requires additional current from HV bus, flows to ground by alternate path.
- Extra resistor boards in parallel with standard circuit upstream of beam plug will provide.
- See Tim's talk for details.

Termination requirements

- Provide the path to ground for each field cage.
- Provide a safe way of monitoring current reaching the end of the field cage.



Monitor/bias at termination

- Connection can be used to monitor current through chain and to apply a bias voltage at end to shape field.
- Resistor to ground needed to ensure “pickoff” does not float to full drift HV at any time.
  - Varistor might be a good idea too.
- Details left to APA group.
  - Interfaces talk by Bo covered the mechanical aspects. Electrical design will affect value needed on last resistors of last FC board.

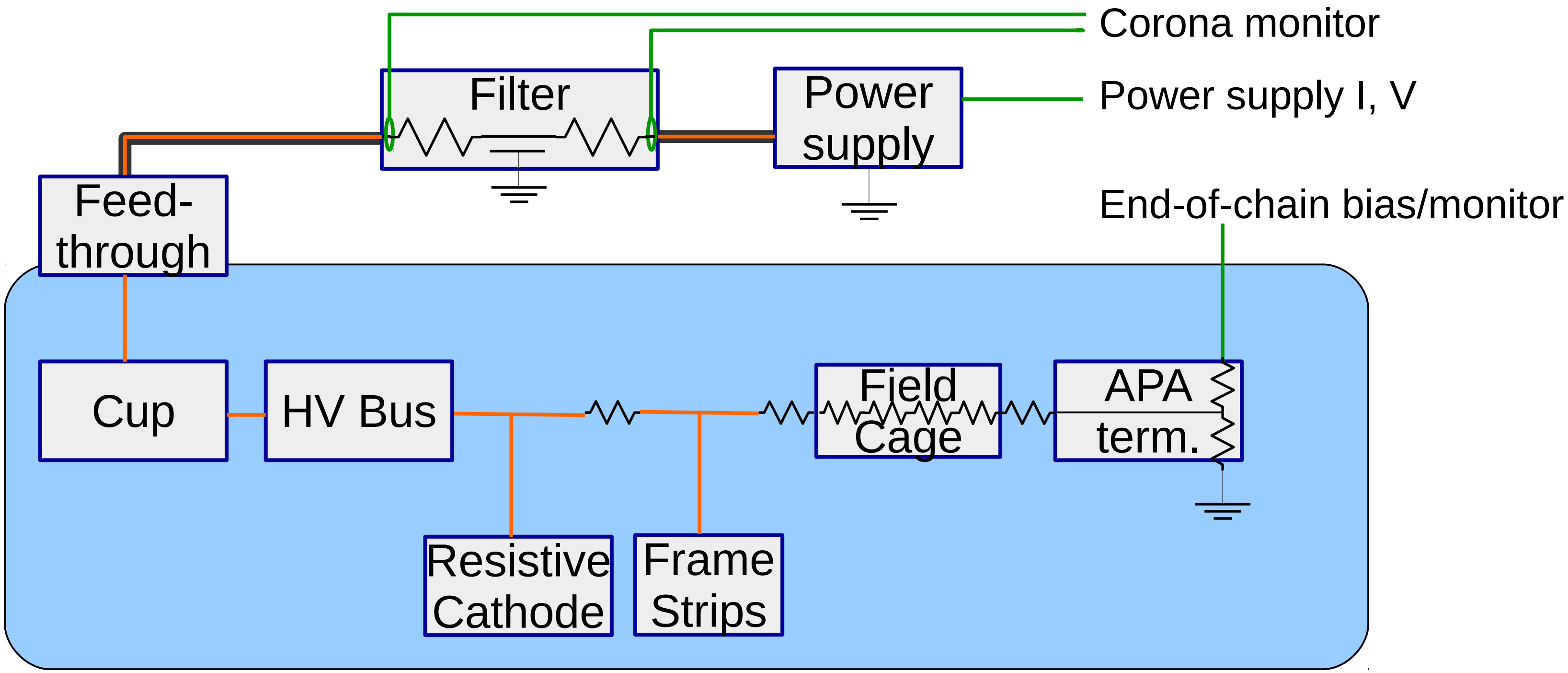
Risks and Hazards

- A section of the design document addresses many HV hazards, comments welcome.
- Risk section is less well developed for HV. Obvious fundamental risks are failure to achieve full high voltage, discharge causing damage, and noise.
  - Finite element sims on all obvious high field points, HV test at PC4 to validate.
  - Varistors to protect against damage to resistors
  - Resistive elements to control rate of change, protect electronics.

Components of complete circuit and who is responsible for them

HV power supply	CERN
HV filter, with monitor	Houston
HV feedthrough	CERN
HV cup	UC Davis
HV bus	Kansas State
CPA surface, frame strips	CERN
Cathode frame strip bias	Kansas State
Field cage resistor boards	LSU
Monitor/bias at termination	APA group

Questions?


Corona monitor
Filter
Power supply
Power supply I, V
Feed-through
End-of-chain bias/monitor
Cup
HV Bus
Field Cage
APA term.
Resistive Cathode
Frame Strips

Extra slides

Charge questions addressed

1. Requirements
2. Risks
5. Intrafaces HV/FC/CPA
6. Drawings (electrical)
7. Grounding, shielding
8. Finish, radii (E-field)
9. HV monitoring, filtering, safety
12. Installation (see also dedicated talk)
13. QA/QC (see also dedicated talk)
14. Resources

Requirements summarized (from FC/CPA/HV design document, v25)

HV-lifetime	1 years
HV-Vtrip-level	10 %
HV-Vtrip-duration	1 s
HV-Vtrip-Maxrate	2 /minute
HV-Vtrip-Autoreset	
HV-monitor-filter	
(HV-monitor-...)	
HV-Edrift-max	600 V/cm
HV-Edrift-min	50 V/cm
HV-Voltage-tolerance	1 %
HV-Frequency-range	100 Hz
HV-Ioperating-max	5 nA
HV-Ileakage-max	1 nA
HV-max-voltage	150 %
HV-max-ccurrent	1 nA
Max wire resistance	10 ohms

How much do I need to talk about...

- Quality Assurance
  - HV bus cable qualification (annealing, testing of 1m lengths in LN2)
  - HV test at PC4
- Quality Control

Some MOV Test Results

Have tested

> ∼ 400 MOVs

∼ 300 resistors

Work in progress