HV Discharge Impact on the FD2 PDS

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DUNE FD2 PDS Preliminary Design Review
Ryan Rivera

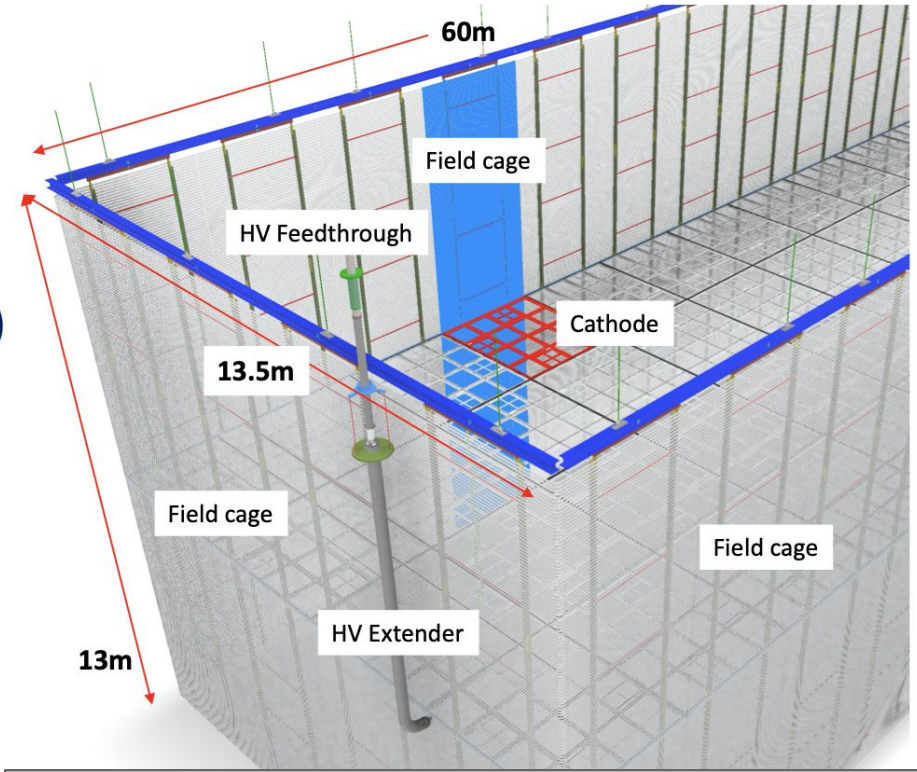
Cathode HV Discharge Impact

- Will cathode discharges happen? (answer: yes)
- Can a discharge impact the cathode-mounted PD modules? (answer: yes)
- Can the impact be minimized? (answer: yes)

- Approach:
  - Two independent simulation studies launched; monthly joint meetings.
    - **BNL**: Sergio Rescia, Veljko Radeka, Bo Yu, Hucheng Chen, et. al.
    - **Fermilab**: Paul Rubinov, Sergey Los, et. al.

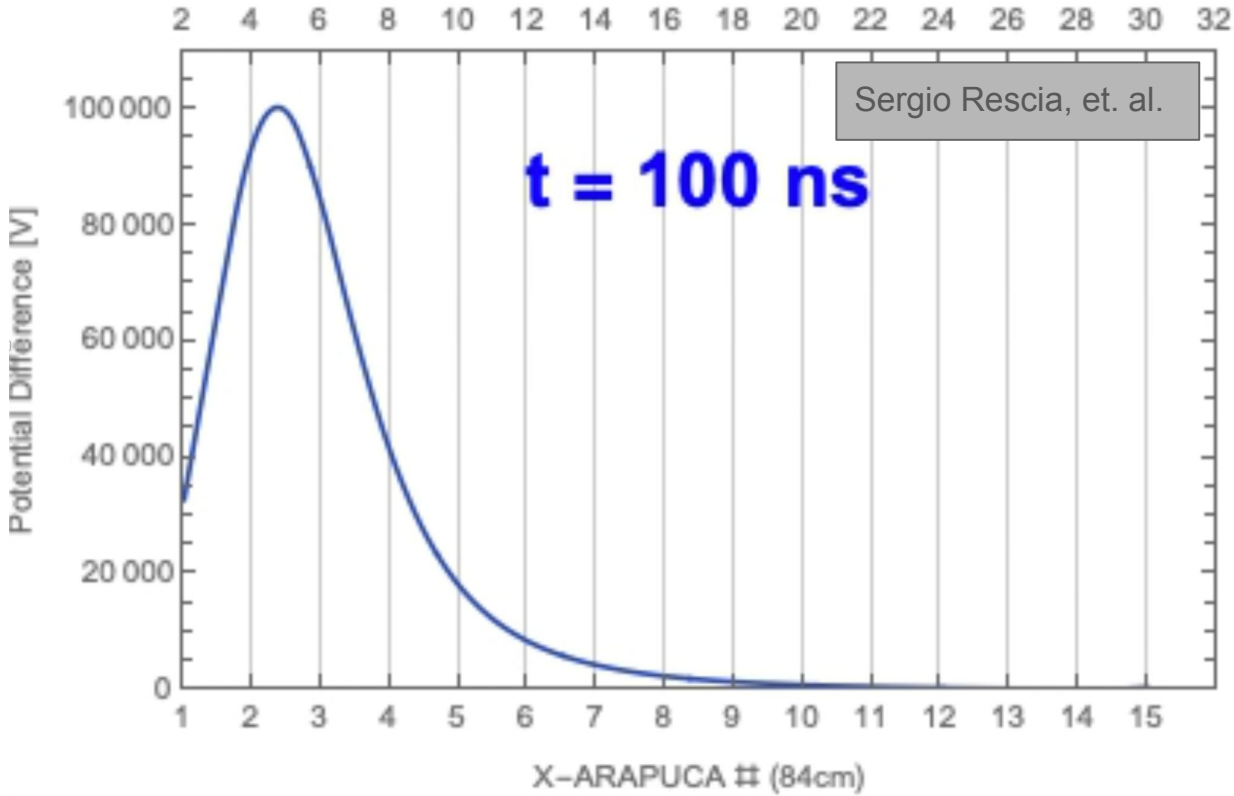
FD2 HV System Components

- TPC sensitive volume: 60m x 13m x 13.5m
- The cathode plane: **60m x 13.5m**
- The field cage is **13m** tall (**6.5m** double sided drift). Each field cage column (with own resistive divider chain) is ~ **3m (3.4m)** wide. The resistance between nodes is 2.5Gohm.
- The anodes (CRPs) are at the top and bottom of the cryostat.
- The nominal cathode voltage is -300kV.

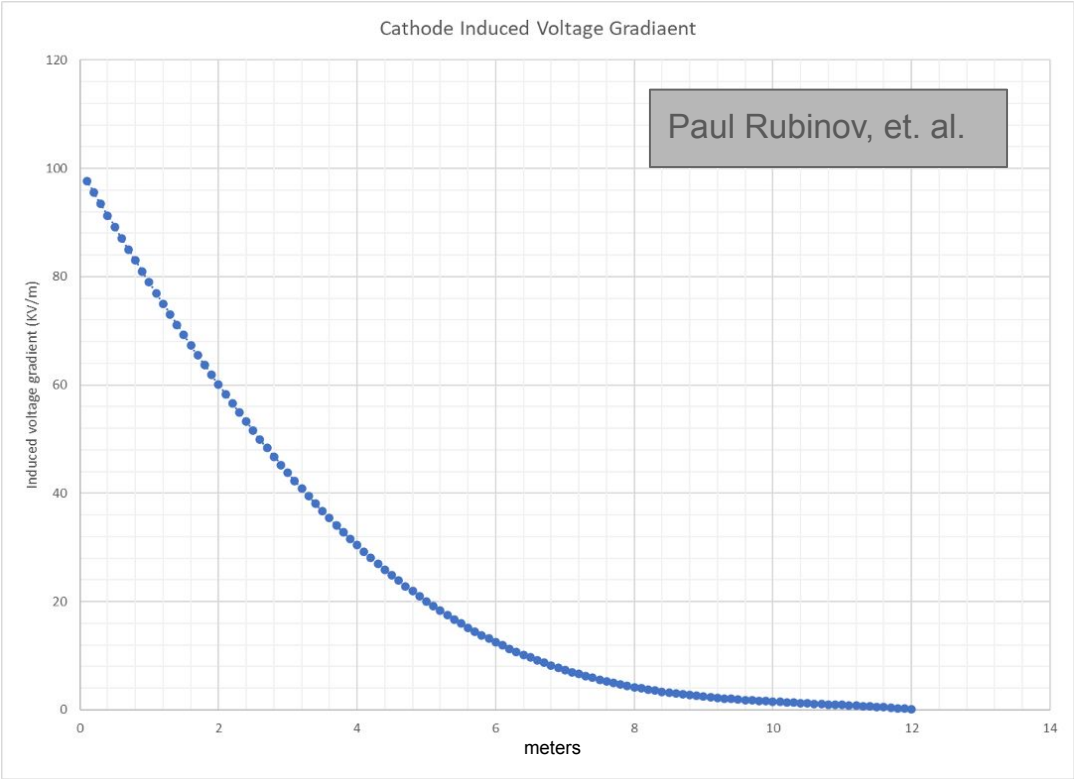


Sergio Rescia, Veljko Radeka, Bo Yu, Hucheng Chen, et. al.

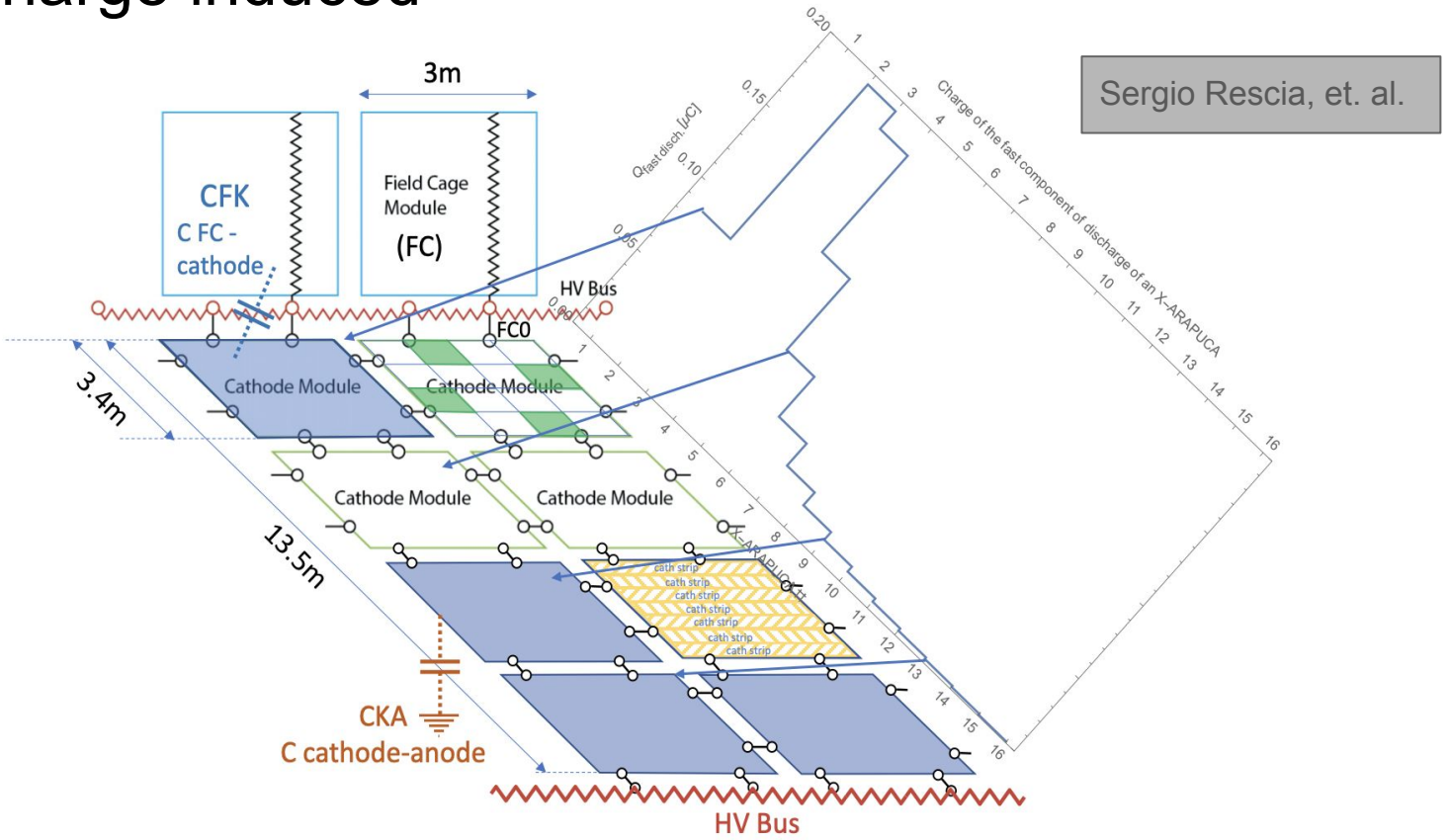
BNL: Voltage Induced on X-ARAPUCA



FNAL: Voltage Induced on X-ARAPUCA



BNL: Charge induced



FNAL: Charge induced

- 1m from Field Cage, the capacitance is about 50pF/m
- The gradient at that point is <100KV/m so ~50KV across PD
- So worst case total charge at an X-ARAPUCA is
  (50KV * 25pF/m) = 1.25 μC per X-ARAPUCA

Paul Rubinov, et. al.

Matching Results

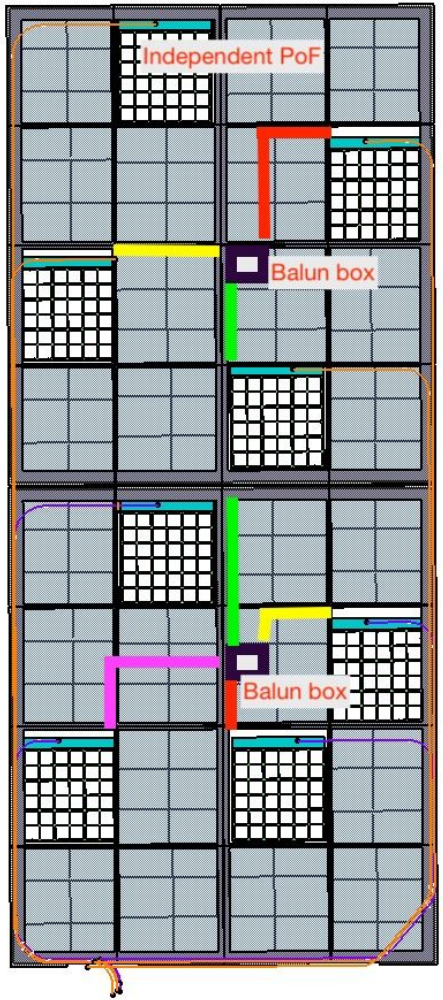
- BNL and FNAL results are same scale
  - The worst case X-ARAPUCA (1m) fast component (10ns) is…
    - 100 KV/m
    - 20-125 A
    - 0.2-1.25 μC

HV Discharge from a Project Perspective

1. During a discharge, there is some risk (worse at the cathode edges) to an X-ARAPUCA with **independent power**, but it is reasonable to expect that a conservatively **shielded design would survive** at any location on the cathode.
2. During a discharge, there is more risk (still worse at the cathode edges) to X-ARAPUCA with **shared/distributed power** and signal, but it is reasonable to expect that a **conservatively shielded design, with conductive conduits and Balun Box break** would survive in the central cathode modules.
3. To converge on a conservatively shielded design, at **test benches** we will **emulate the cathode discharge**, with progressive charge injection approaches, and monitor the system to identify weaknesses in the shielding and to **identify which components are most sensitive**.
4. To converge on a final shielded design, at module-0 we will build two shared/distributed power and signal X-ARAPUCA systems (size 3 and 4), and one independently powered X-ARAPUCA, as shown below, and at the **end of the module-0 run, discharges will be induced** from maximum cathode HV.
5. The **final shielded design** will be demonstrated in a **cold box run after module-0** and in advance of the Production Readiness Review.

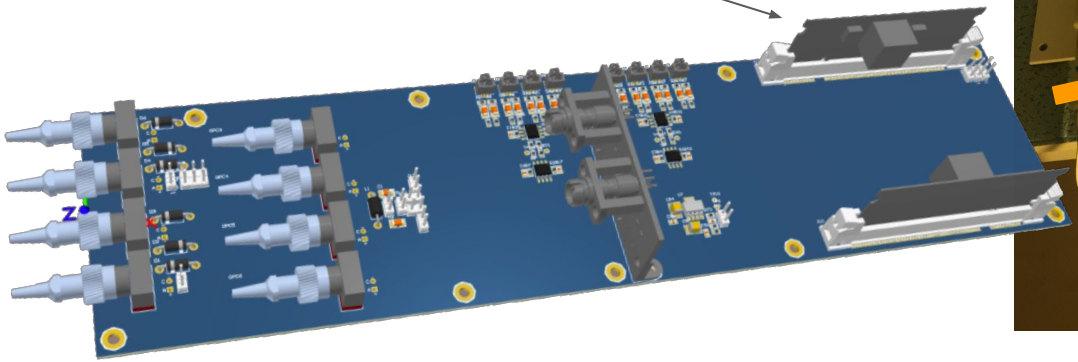
Module-0 cathode topology

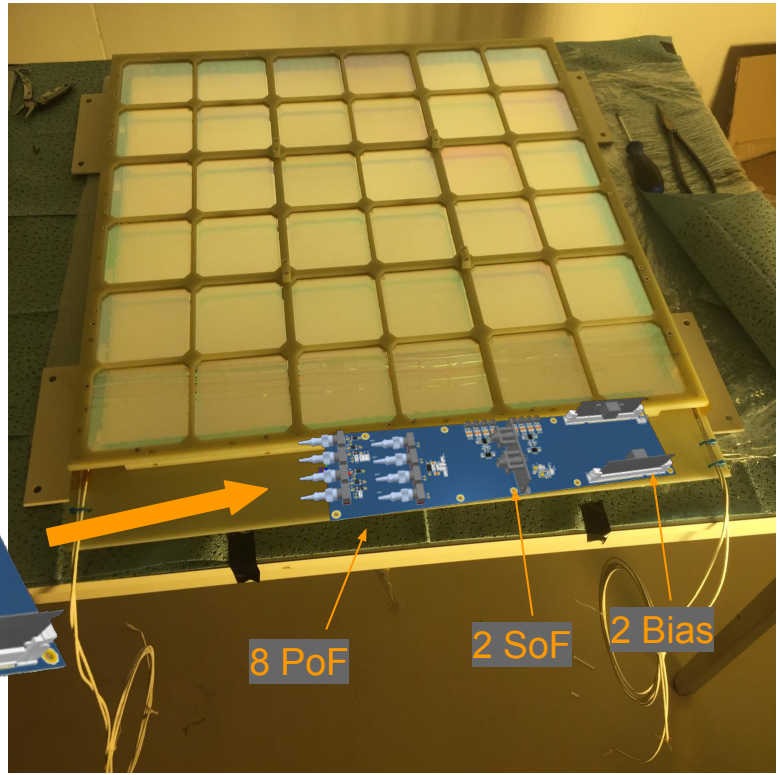
- Two **shared**/distributed power and signal X-ARAPUCA systems (size 3 and 4) connected by Balun box break
- One **independently** powered X-ARAPUCA



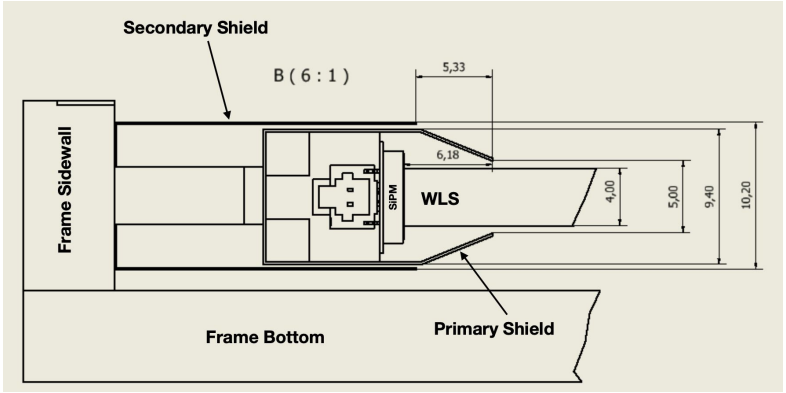
Bias Generation downselect

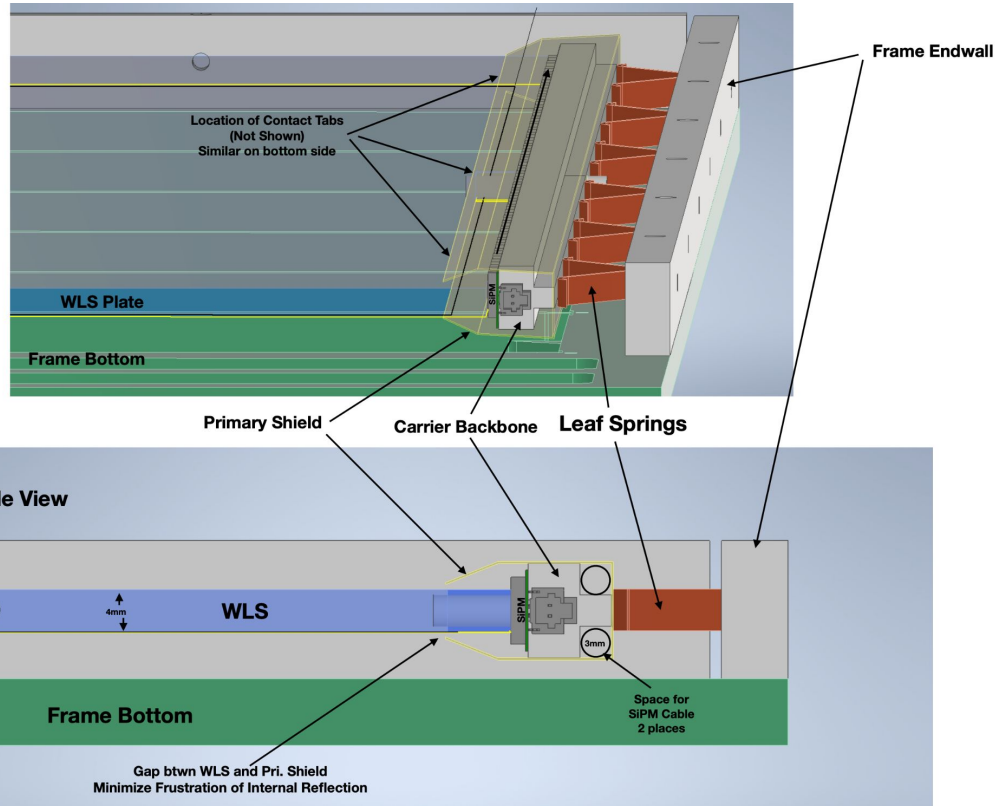
- All bias generation prototypes are targeting July-August ‘22 Cold Box demonstration in daughter card form-factor.





Conservative Shielding v1





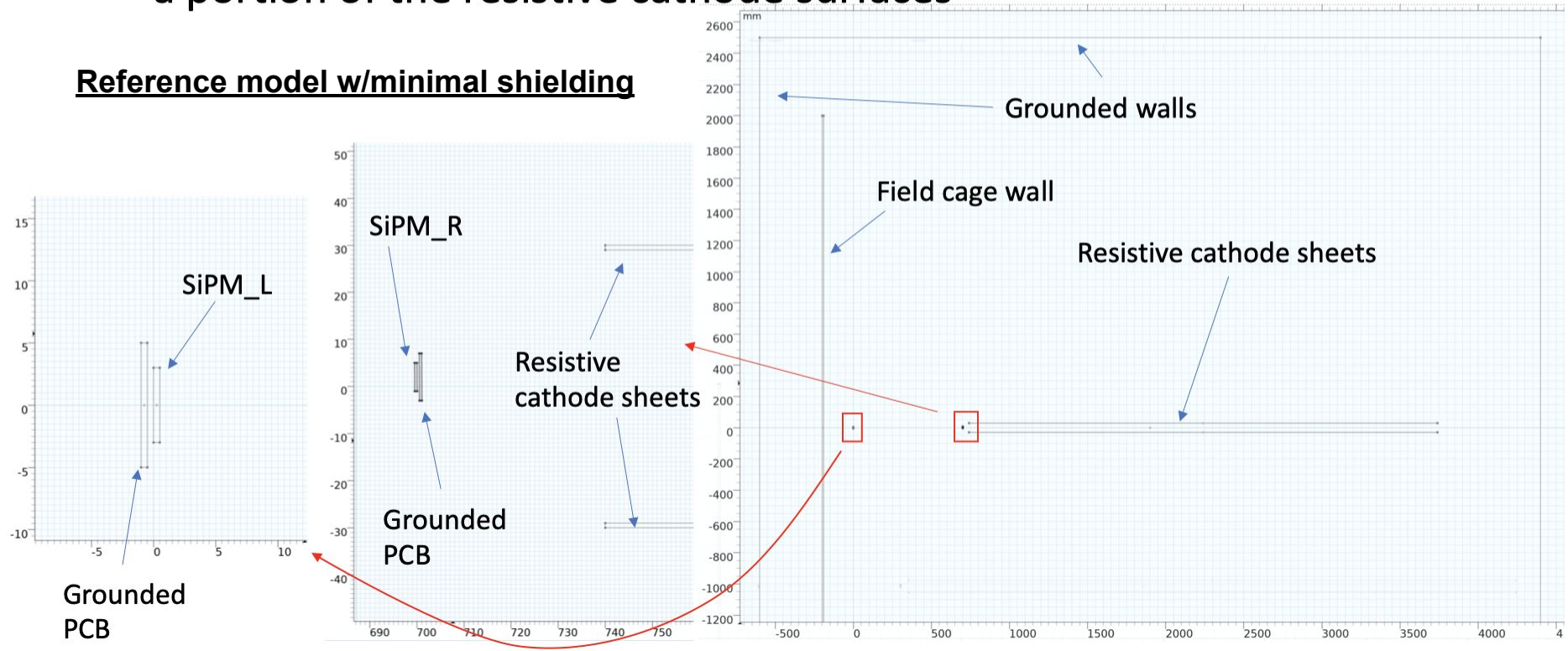
Paul Debbins (Iowa), et. al.

Analysis of Shielding Effect (1 of 4)

Bo Yu, et. al.

- A corner of a TPC with a partial FC wall, two SiPM bands 70cm apart, a portion of the resistive cathode surfaces

Reference model w/minimal shielding



Analysis of Shielding Effect (2 of 4)

Capacitance Matrix (reference model)

Maxwell capacitance (F/m)				
	FC	SiPM_L	SiPM_R	Cathode
FC	2.13E-10	-4.03E-12	-8.86E-13	-1.75E-11
SiPM_L	-4.03E-12	2.08E-10	-5.30E-14	-5.92E-13
SiPM_R	-8.86E-13	-5.30E-14	2.09E-10	-4.87E-12
Cathode	-1.75E-11	-5.92E-13	-4.87E-12	9.04E-11

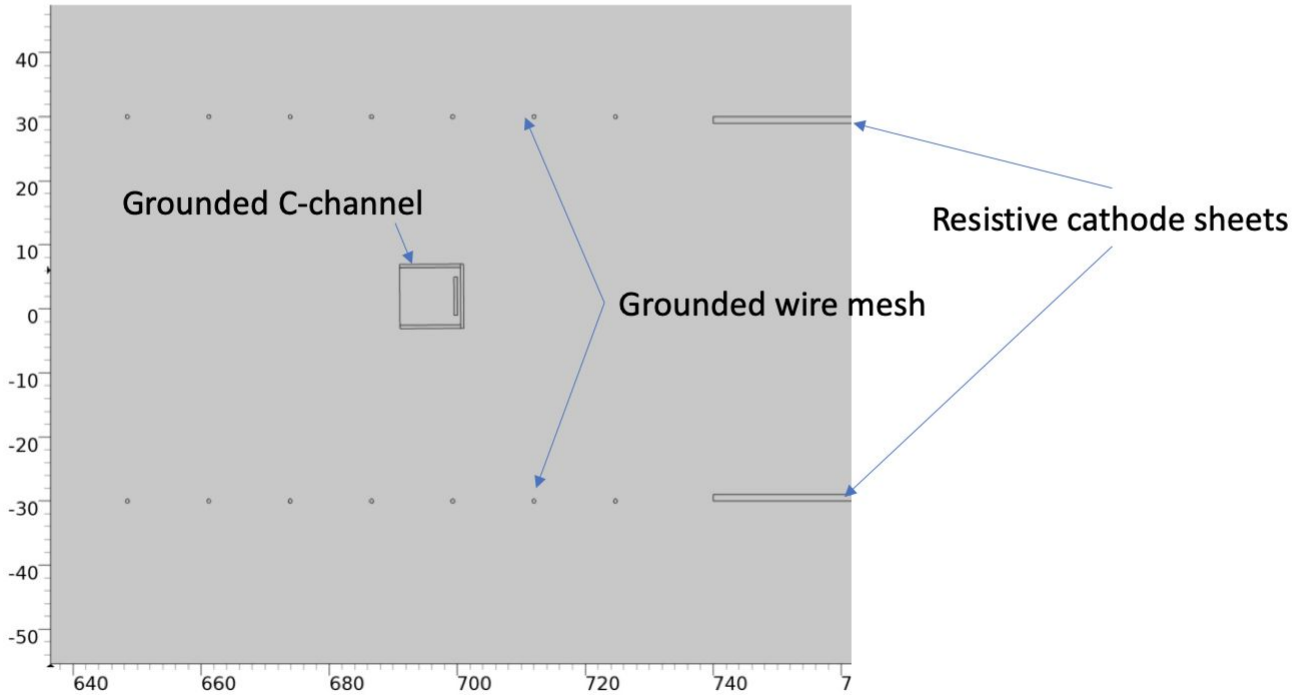
A 300kV swing on FC would inject 1.2uC of charge to 1m long SiPM_L.

A 100kV swing on Cathode would inject 0.5uC of charge to 1m long SiPM_R

As compared to 3nC of charge from SiPMs converting a large event of 2000 photons.

Analysis of Shielding Effect (3 of 4)

- A conductive C-channel (1cmx1cm) is added to shield the SiPM bands



Analysis of Shielding Effect (4 of 4)

Maxwell capacitance (F/m)				
	FC	SiPM_L	SiPM_R	Cathode
FC	2.34E-10	-6.00E-15	-8.02E-16	-1.05E-11
SiPM_L	-6.00E-15	2.24E-10	-3.47E-20	-2.20E-16
SiPM_R	-8.02E-16	-3.47E-20	2.24E-10	-1.49E-14
Cathode	-1.05E-11	-2.20E-16	-1.49E-14	1.19E-10

A 300kV swing on FC would inject 1.8nC of charge to 1m long SiPM_L.

- Reduction by a factor of >600!

A 100kV swing on Cathode would inject 1.5nC of charge to 1m long SiPM_R

- Reduction by a factor of >300!

Conclusion

- Shielding is effective against the HV discharge
  a. Need to balance against cost, weight, and noise induction.
- We have a clear shielding development plan:
  a. Downselections based on test stand and Cold Box demonstrations in ‘22
  b. Large scale demonstration at module-0
     - System integration
     - Induced cathode HV discharges
  c. Final packaging demonstrated in Cold Box in ‘23 in advance of Production Readiness Review