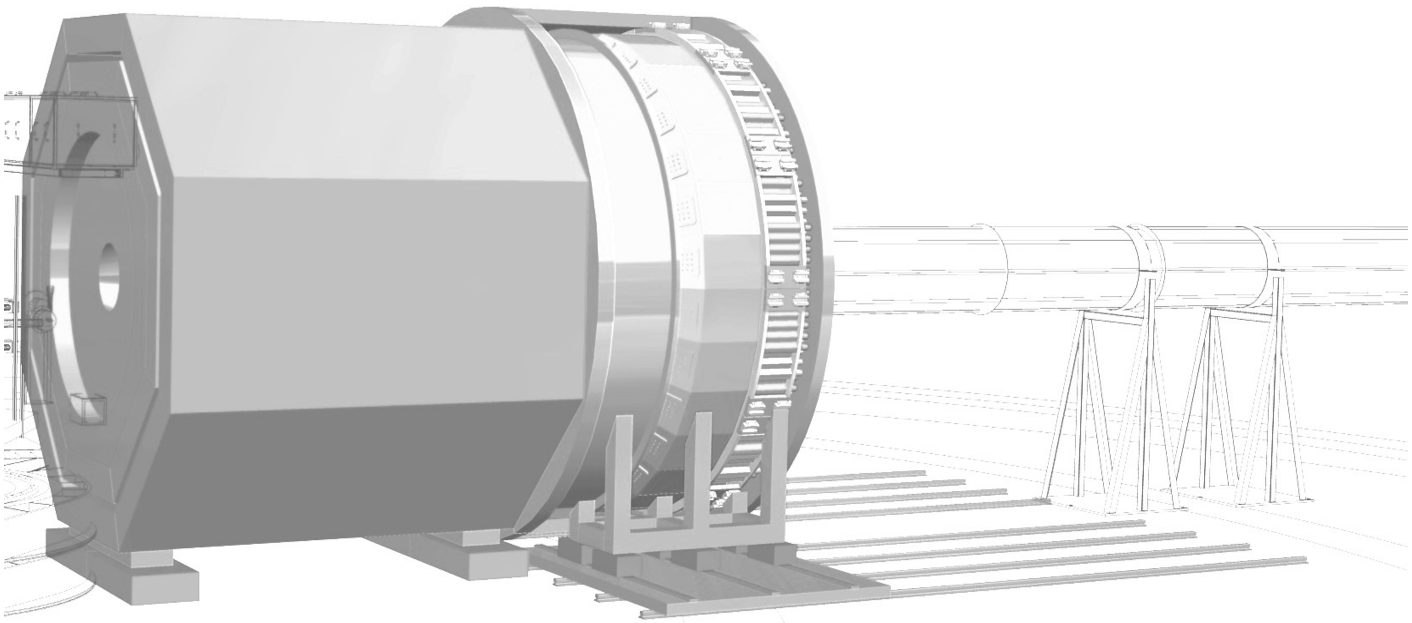
Gas Electron Multiplier (GEM) Tracker



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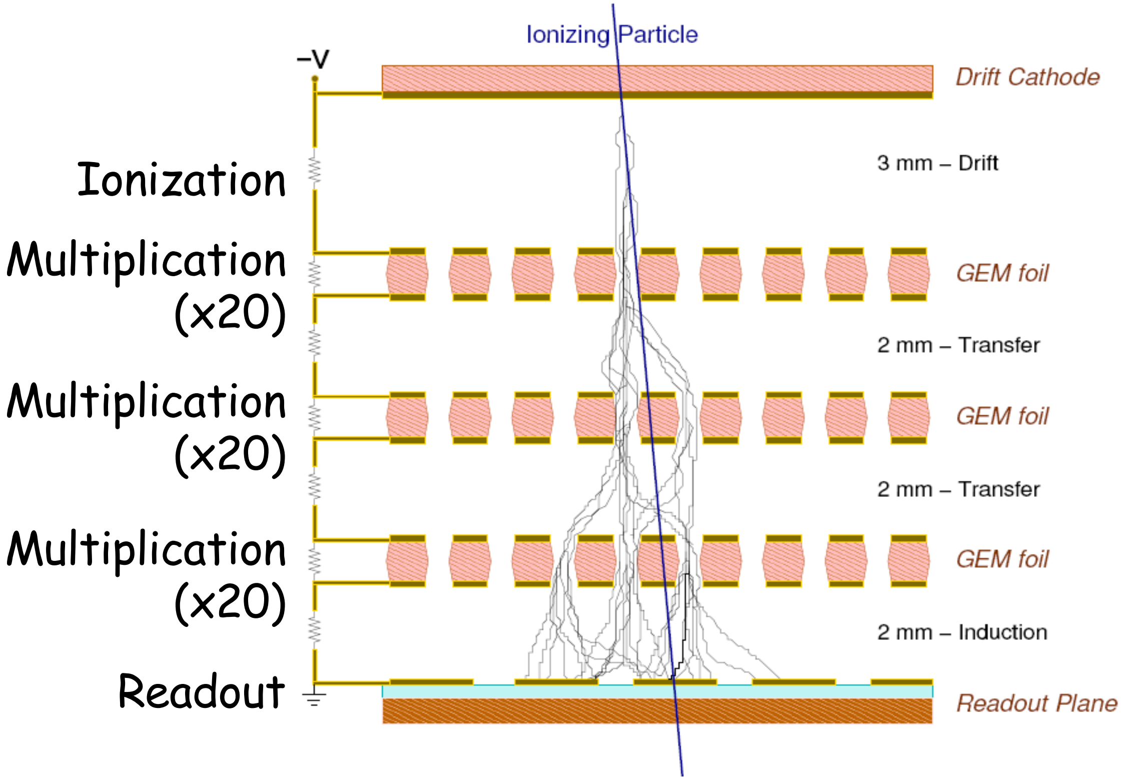
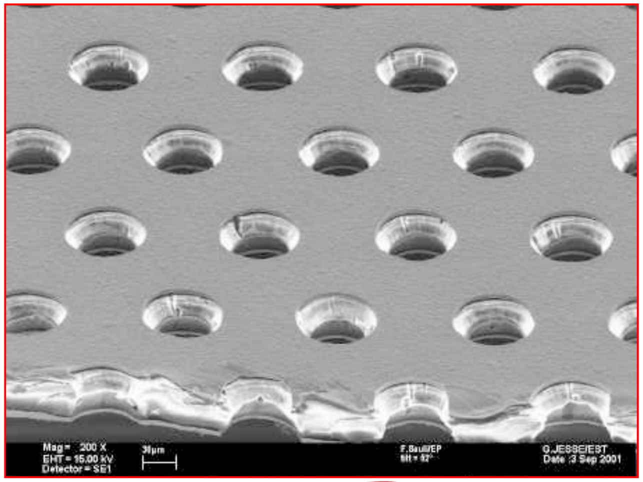
Why GEMs

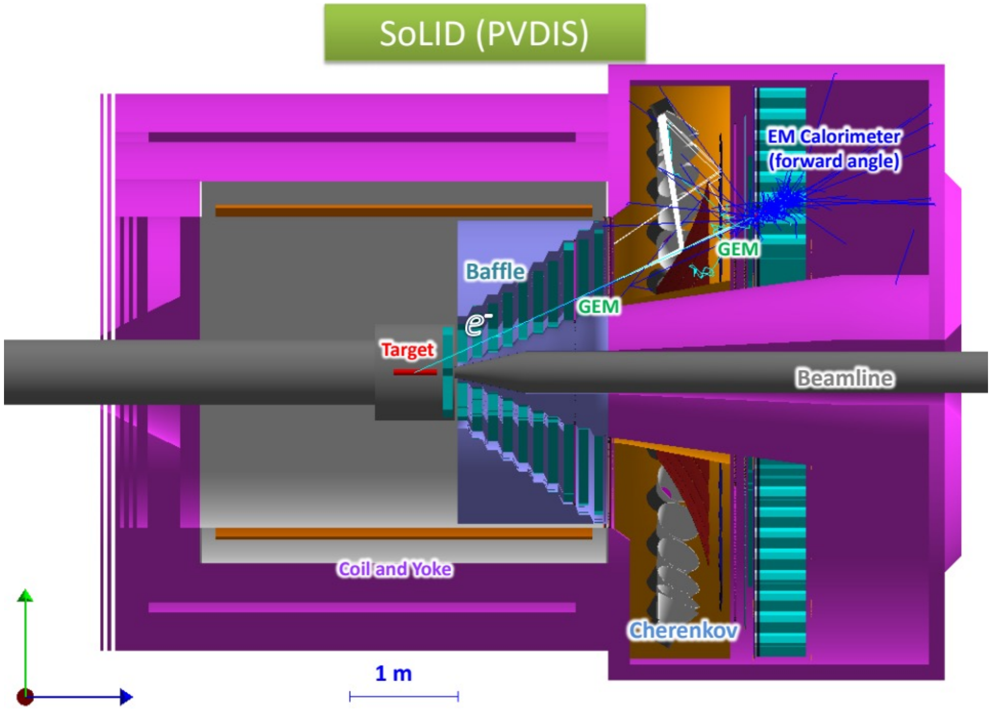
- SoLID concept leads to need for high rate trackers with good position resolution.
- GEMs: cost effective for high resolution tracking under high rates over large areas.
    - Rate capabilities higher than many MHz/cm^2
    - High position resolution (< 75 μm)
    - Ability to cover very large areas (10s – 100s of m^2) at modest cost.
    - Low thickness (~ 0.5% radiation length)
- Used for many experiments around the world: COMPASS, CMS upgrade, ALICE TPC, pRad, SBS etc.

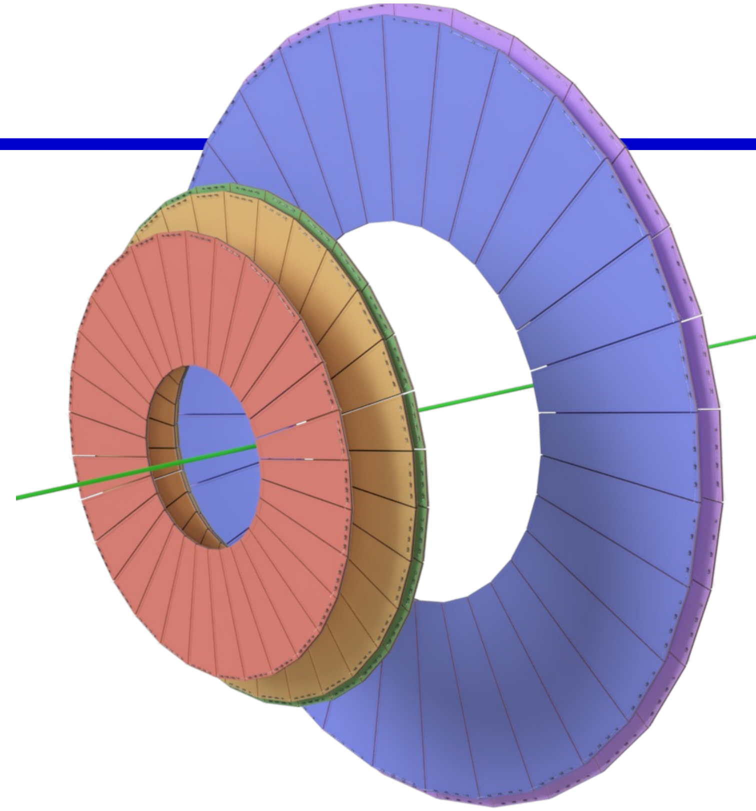


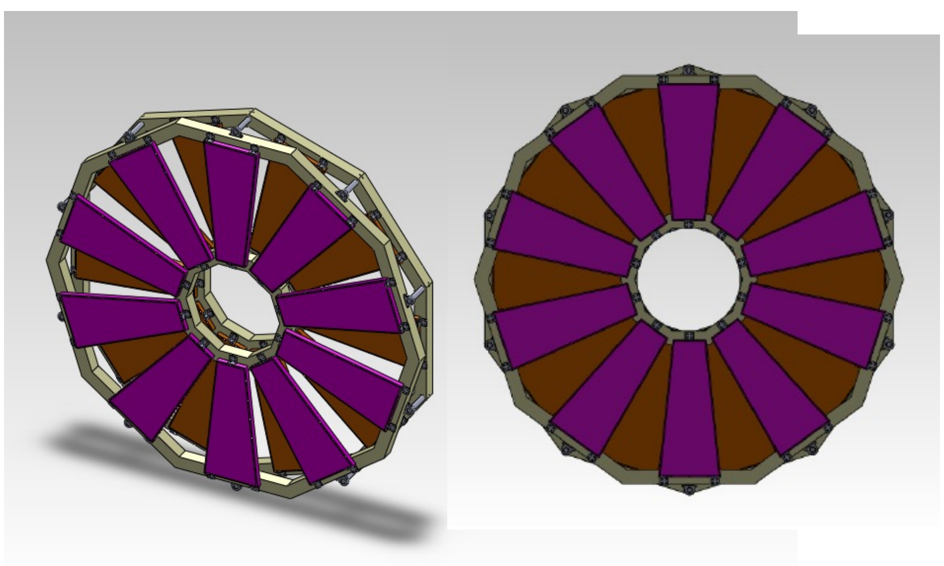
GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch

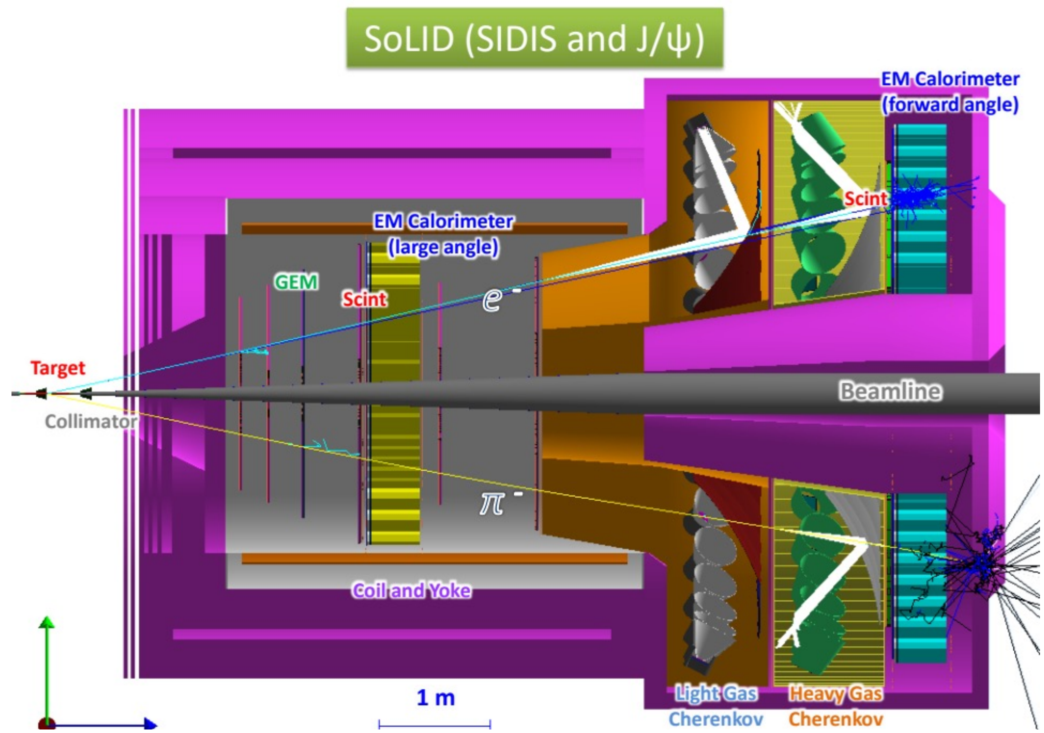


GEM Overview





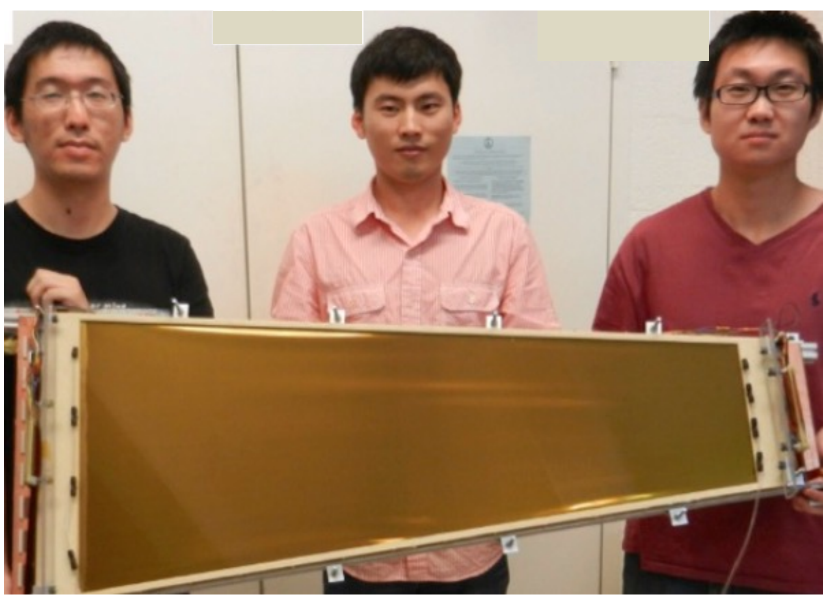


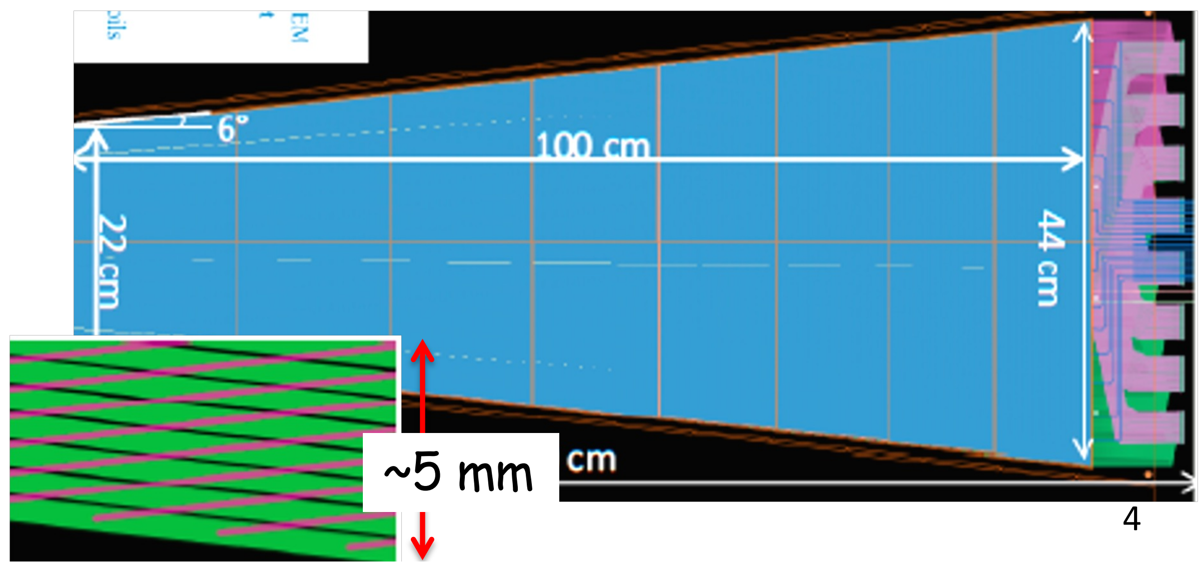


GEM Requirements: for all experiments

- Good position resolution
  - 100 μm (1 mm) in azimuthal (radial) direction.
    - 2D U-V readout with 12-degree stereo angle between strips
    - 400 μm (600 μm) strip pitch for layers 1-3 (5-6)
    - The high occupancy at layer #1: split each readout strip into two channels
    - Total number of channels ~ 215 k (with 15% spares)
- 92 % overall GEM-module efficiency.
- modules with a trapezoidal geometry, with 12^{o} angular width
- All readout electronics located at the outer edge: Given radiation exposure map.
- Side frames need to be very narrow: minimize material thickness in active area (especially for SIDIS, J/Ψ)

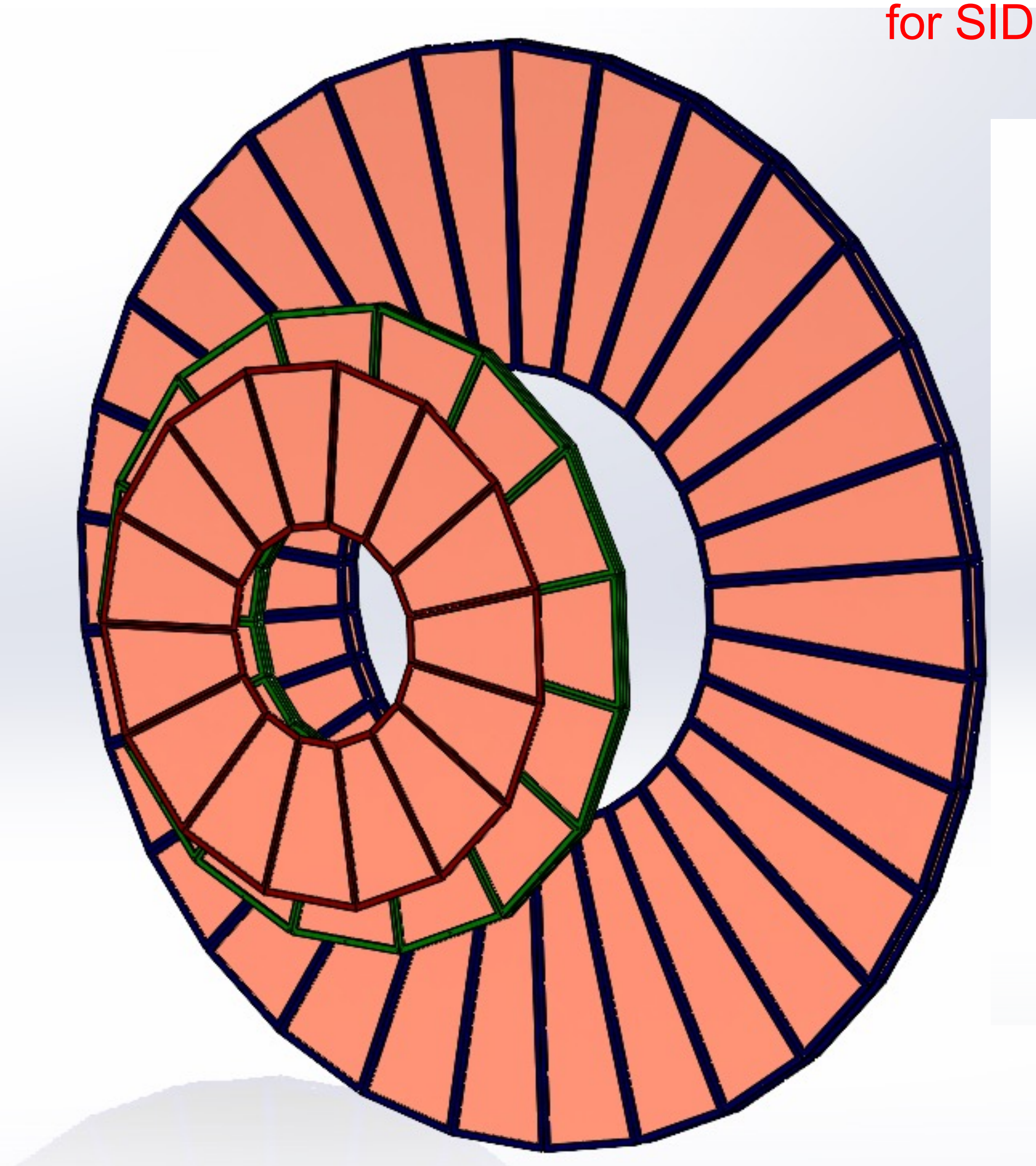
All requirements follow from tracking and neutron/radiation dose simulation to meet SoLID conditions.

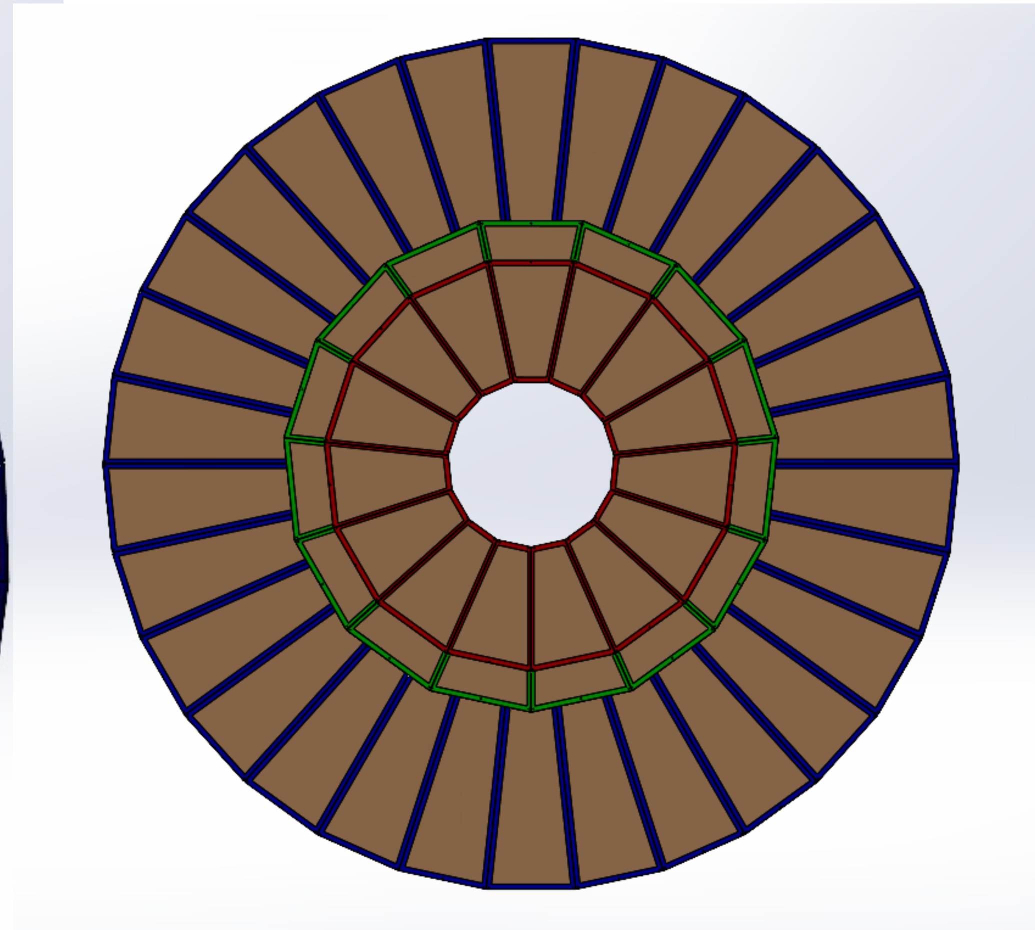




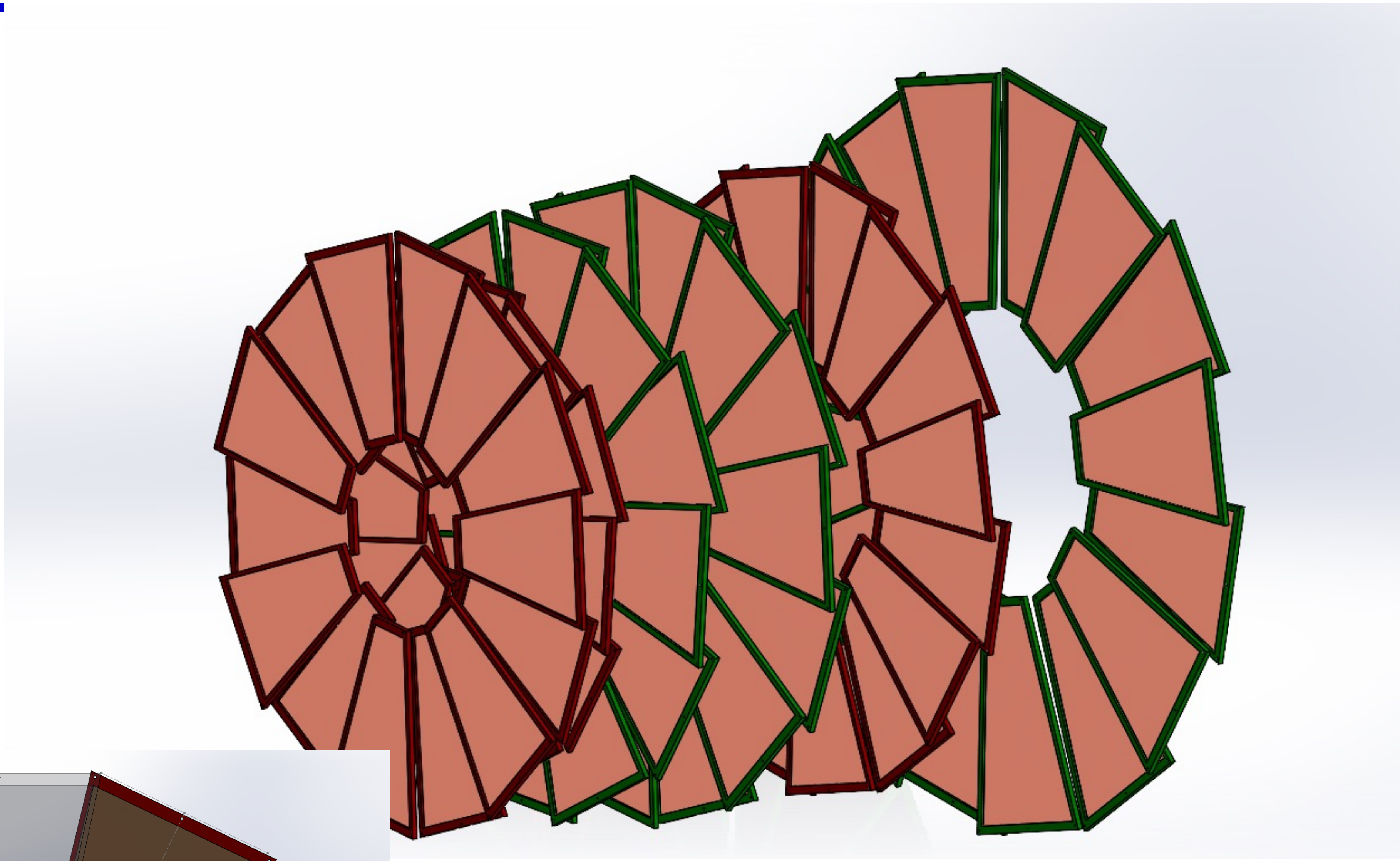
Recently optimized GEM configuration - PVDIS

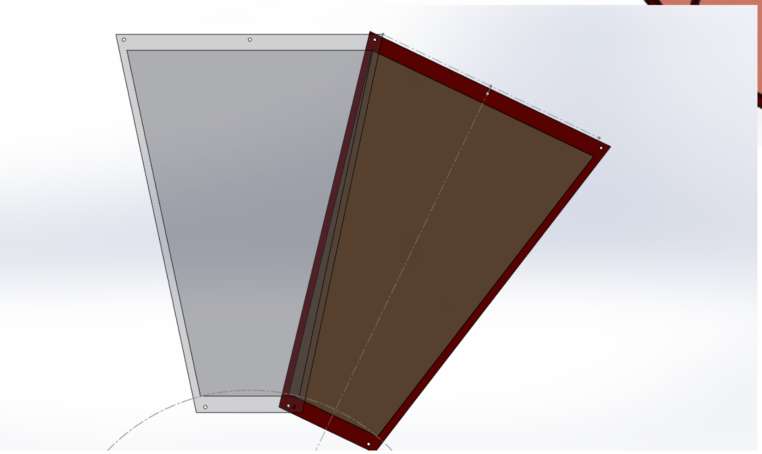
First 3 layers optimized to have only 15 modules:
minimizes the number of frames in the active area for SIDIS





Recently optimized GEM configuration - SIDIS





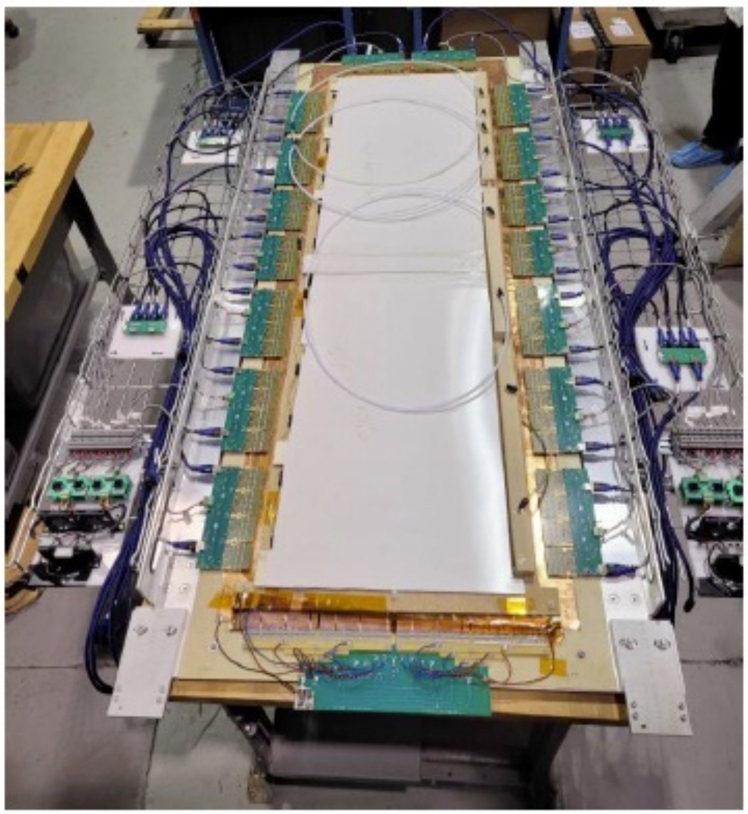
GEM: Proven Technology

The components and fabrication methods to be used for SoLID GEMs were used by the UVa group for the successful fabrication of GEMs for PRad and SBS experiments.

These GEMs worked very well in beam with stable performance, high efficiency and good resolution; meeting or exceeding design parameters.

The SBS GEMs produced at UVa

- 50 cm x 60 cm GEM modules for SBS rear tracker: 48 modules –All installed, 28 in beam
- 150 cm x 40 cm large GEM modules for SBS front tracker: 4 modules – all in in beam; two more under construction now



UV (shown)
40 x 150 sq.cm
Single module

XY (shown)
60 x 200 sq.cm
4 modules

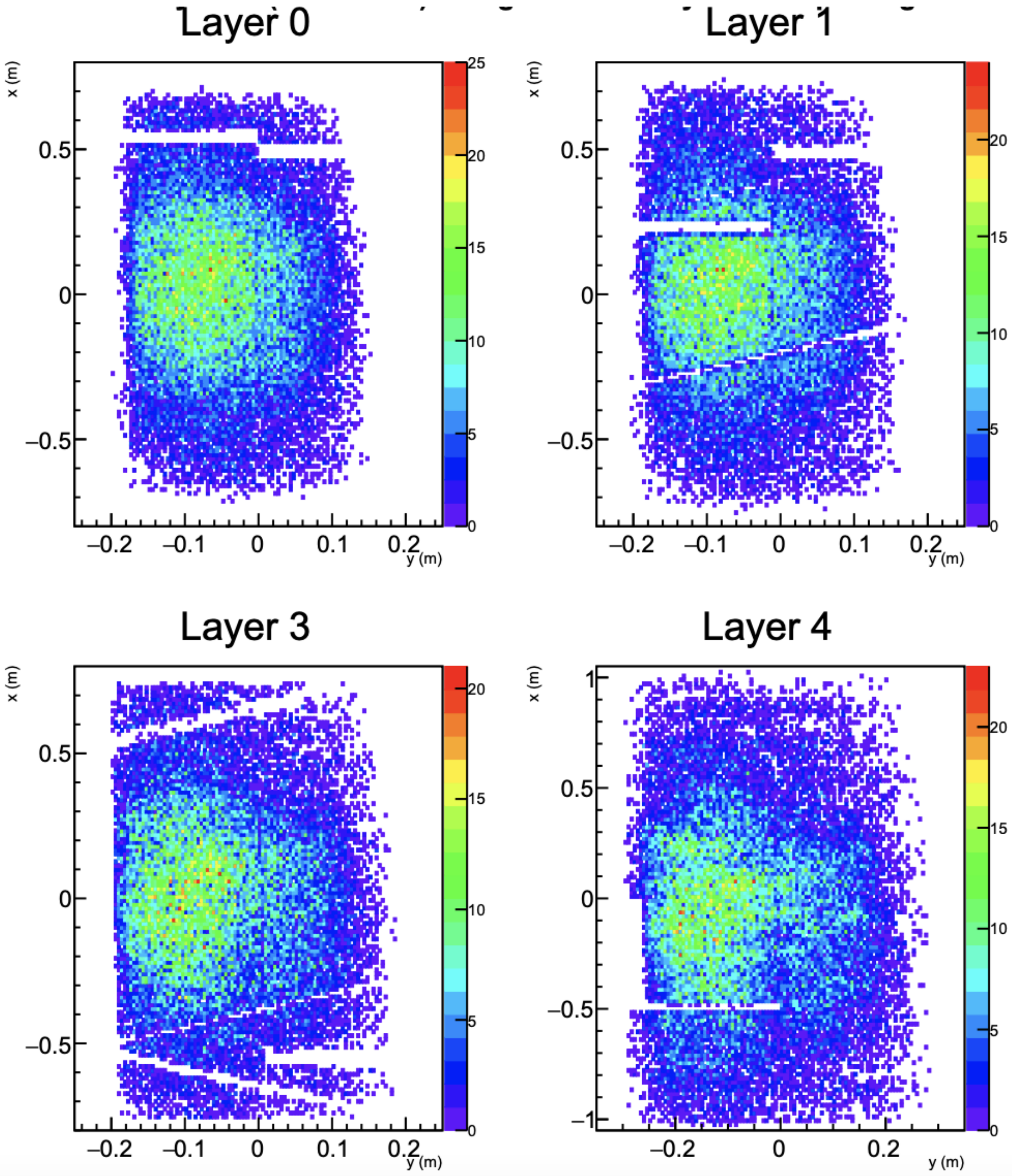
GEM tracker status, issue and possible plans

- For SBS we already ran the GEM tracker in unprecedented integrated rates (active area x local rate): luminosity upto to 0.5×10^{38}

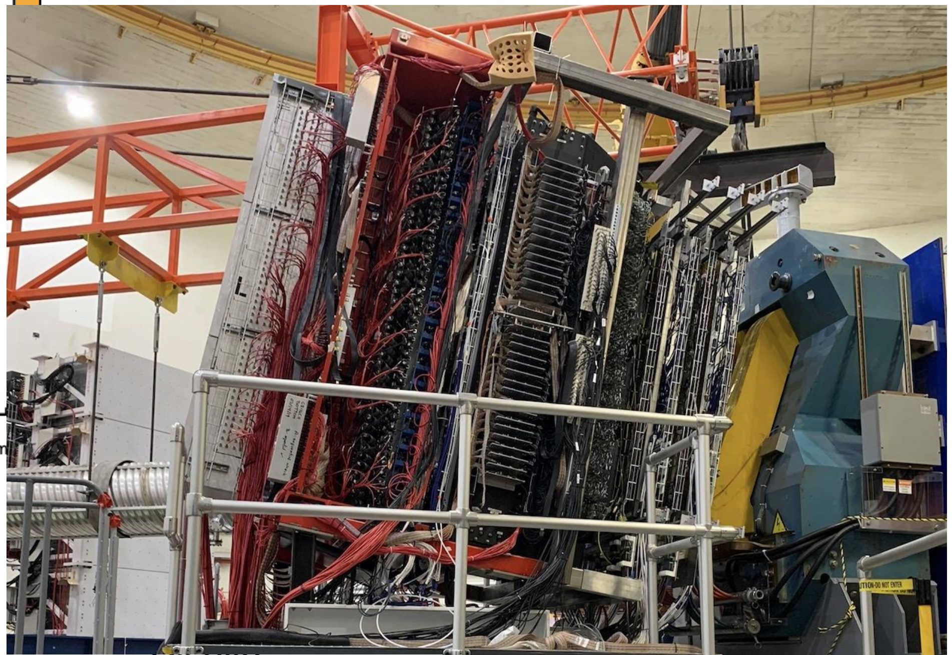
- UVa GEM tracker layers have been working very well:
  - Overall good efficiency
  - Very stable: very few HV trips
  - Noise levels sufficiently low
  - Good gain: signals well above noise
  - Very good resolution: close to what was achieved with comic’s
  - Raw occupancy levels as high as 50%
  - Real time firmware zero suppression has been working very well.
  - Data volumes manageable

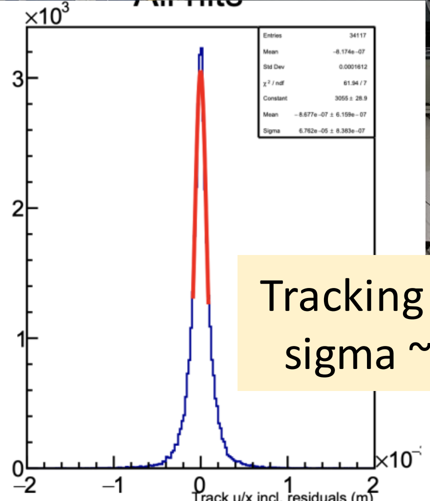
•The observed background hit rates within ~ 40% of the expected; but total ionization in chambers ~ x 2 higher than predicted.

4 UV and 1 XY have been running successfully in BigBite since 2021



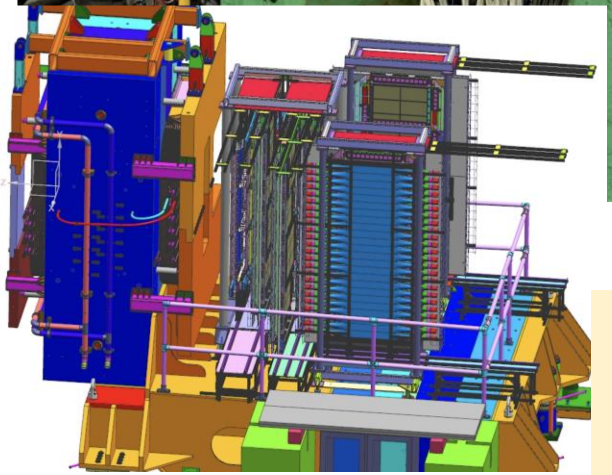
Hit maps with tracking constraints shown per layer

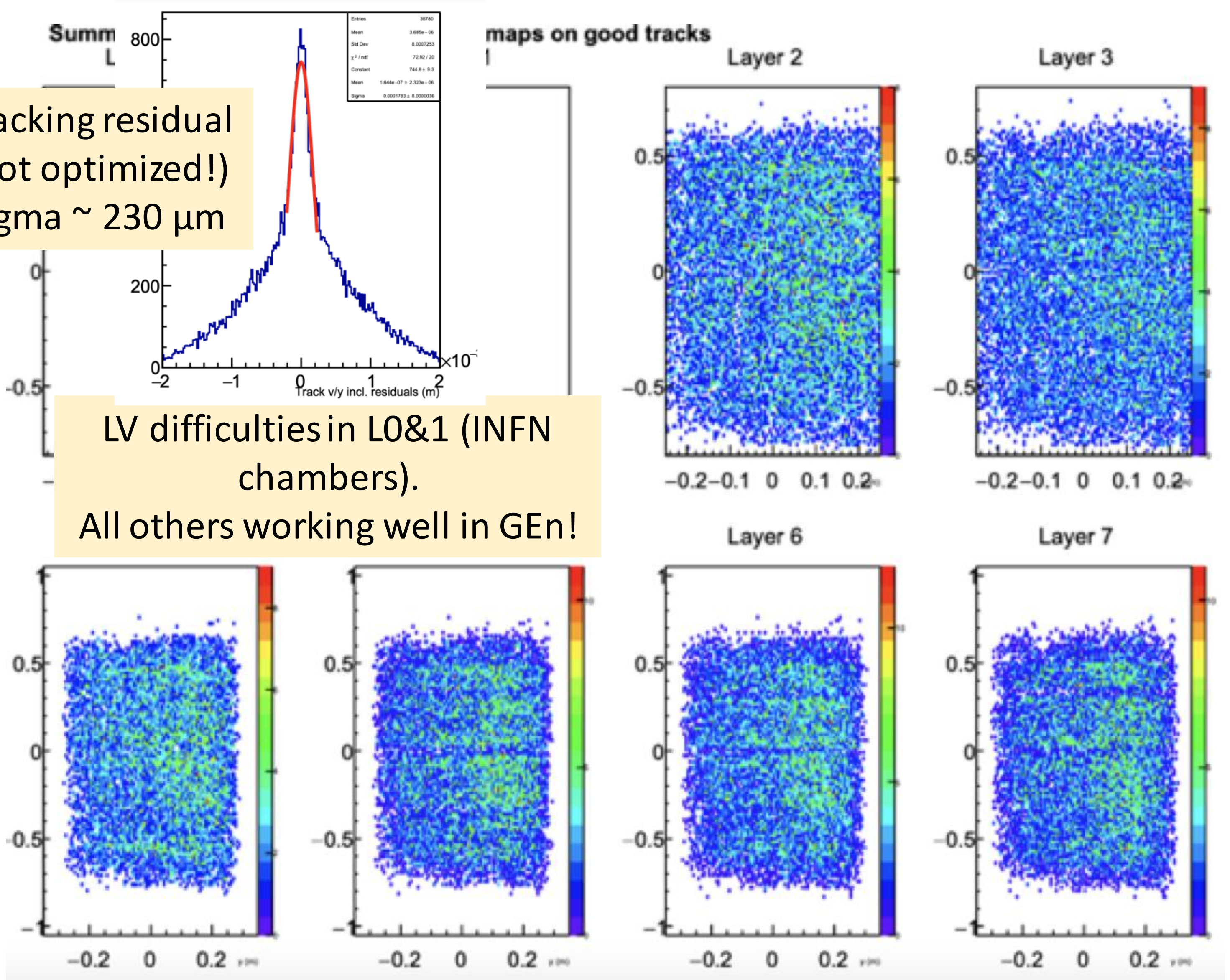




Tracking residual sigma ~ 70 µm

6 XY have been running successfully in SBS since 2022





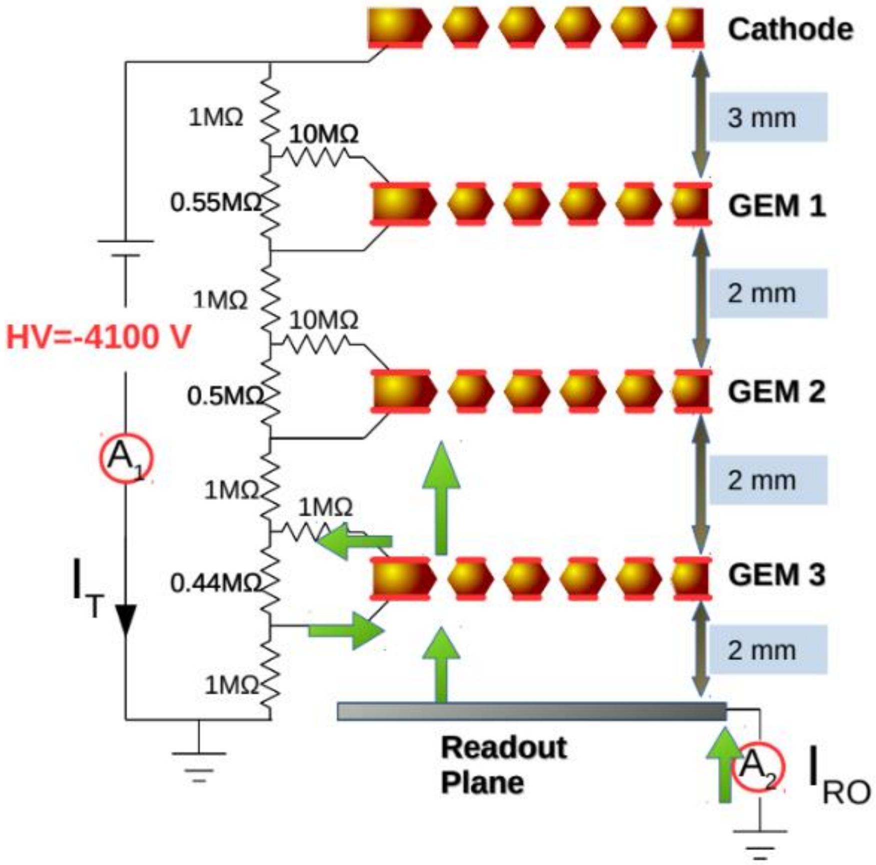
Tracking residual
(not optimized!)
sigma ~ 230 µm

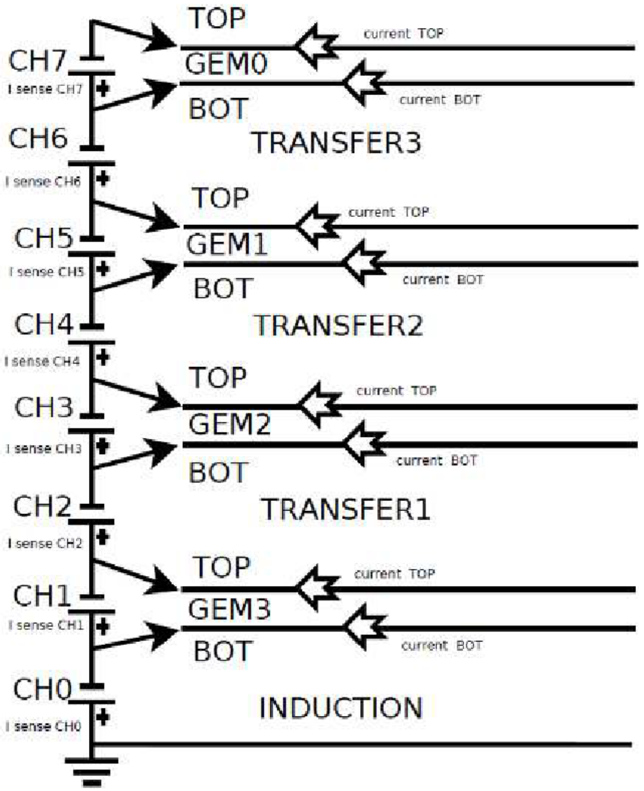
LV difficulties in L0&1 (INFN chambers).
All others working well in GEn!

GEn-RP will run with all layers next spring (prior to GEp)

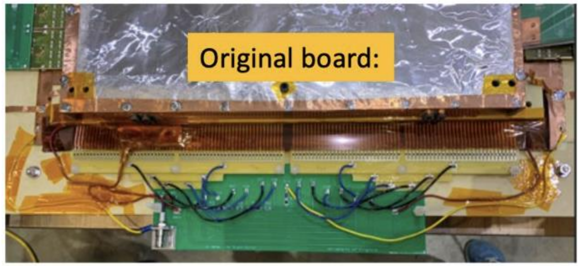
High voltage individual power supply

Current equivalent to Hit rate x Gain x primary electrons x electron charge



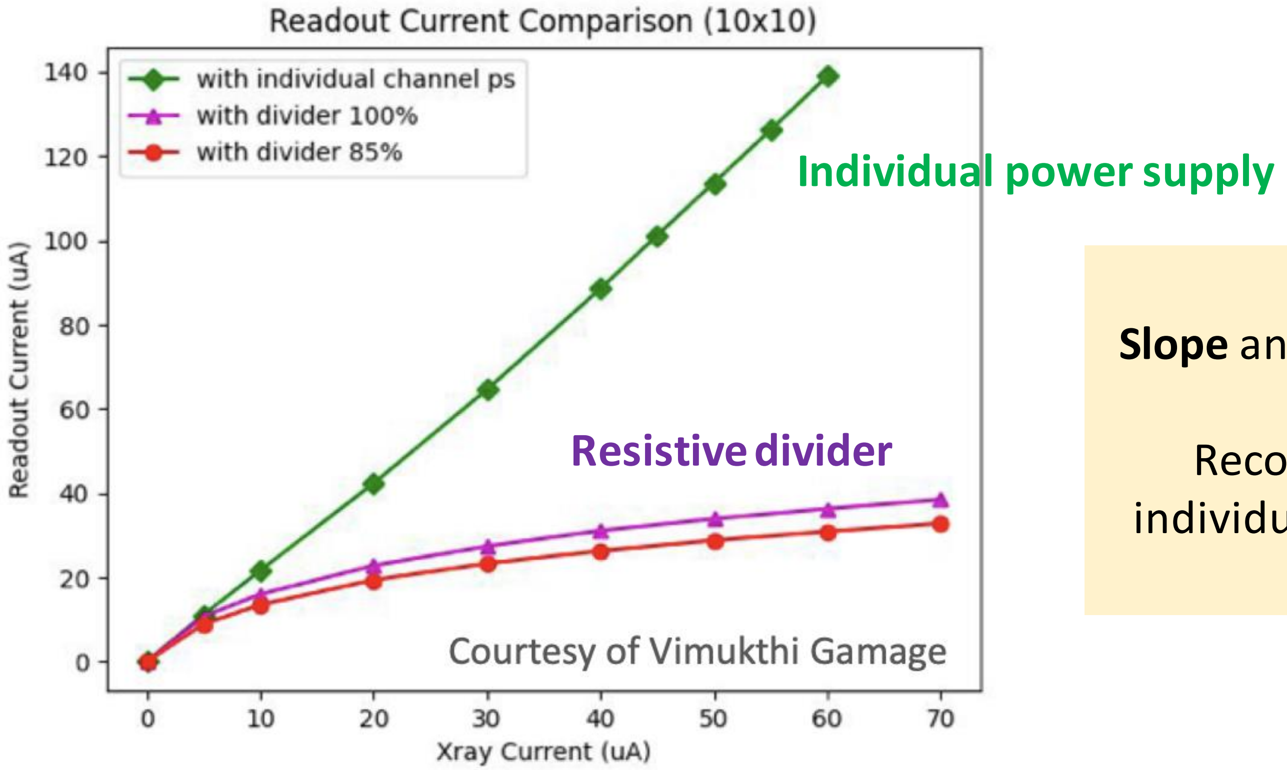


Note: protective resistors not shown here....see backup



High voltage upgrades and lessons learned

- Observed a loss of tracking efficiency that was correlated with occupancy due to the HV divider configuration
- Observed a non-linear increase in the current draw with increased occupancy (replicated in the lab in the red curves below) as related to the divider

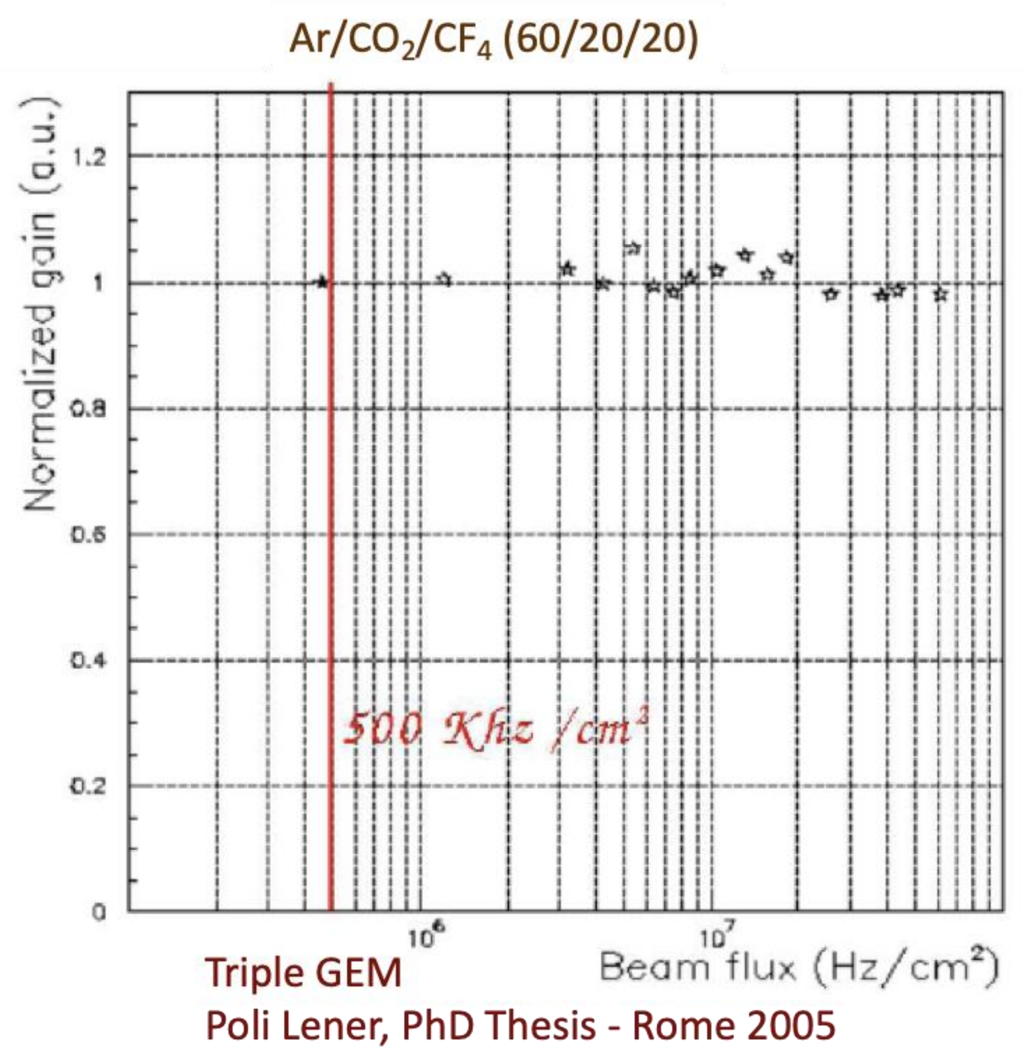


Slope analogous to **gain!**

Recover gain with individual power supply

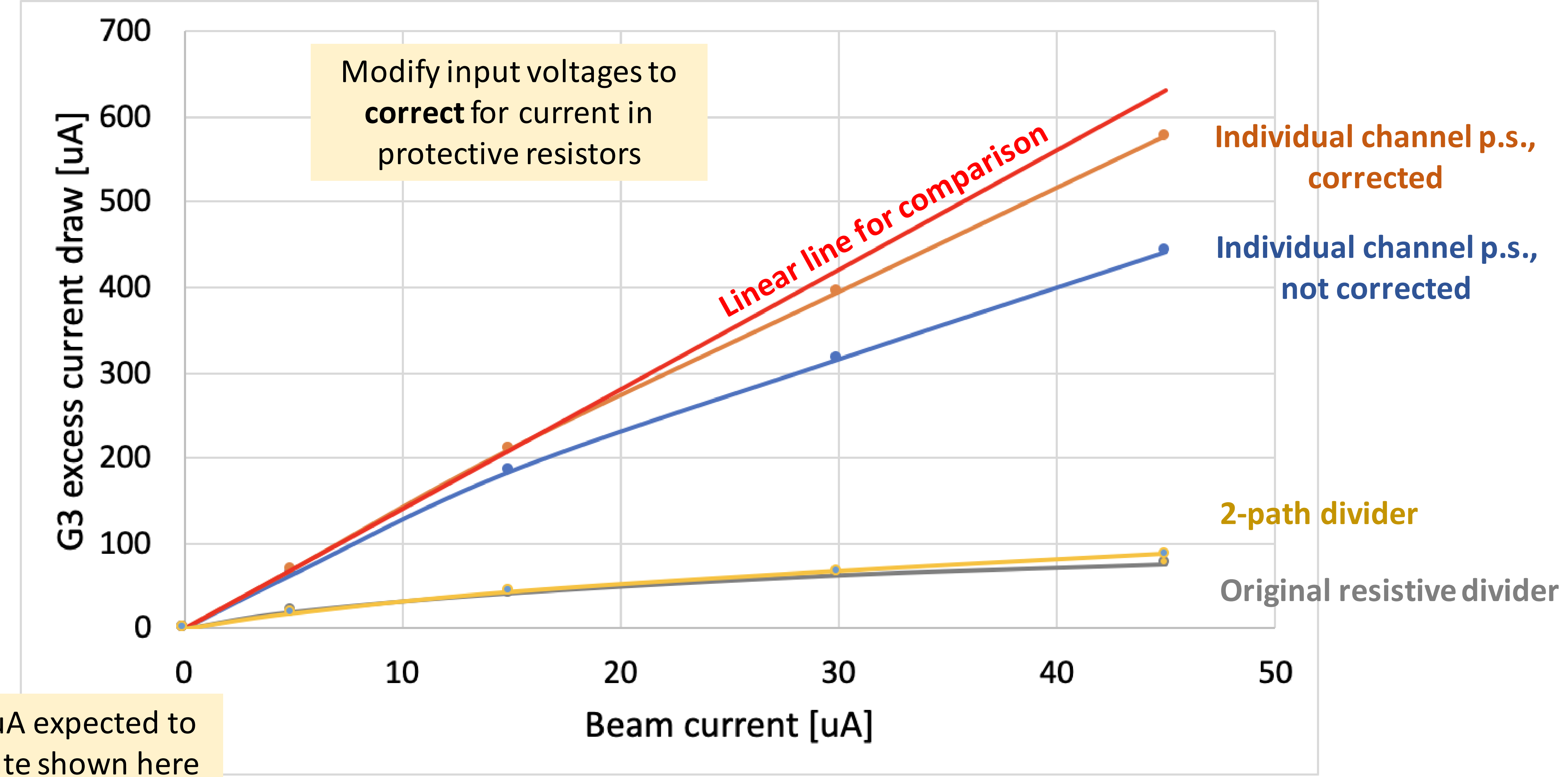
GEMs have high gain in high rate environment

Current equivalent to Hit rate x Gain x primary electrons x electron charge



Gain is stable up to high rate (~100 MHz/sq cm)

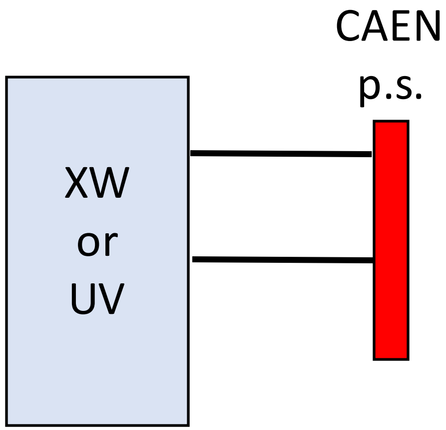
Luminosity scan with different HV divider configurations during GEn (on optics target)

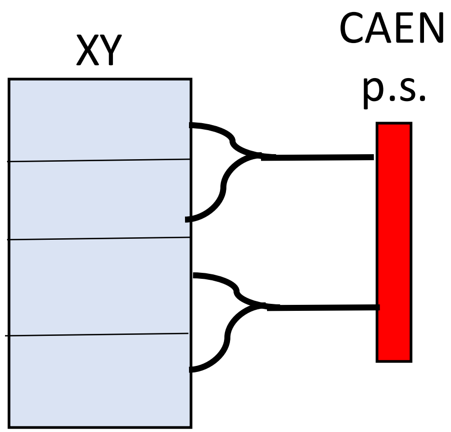


GEp at 50uA expected to increase rate shown here for 45uA by 2.7x

High voltage

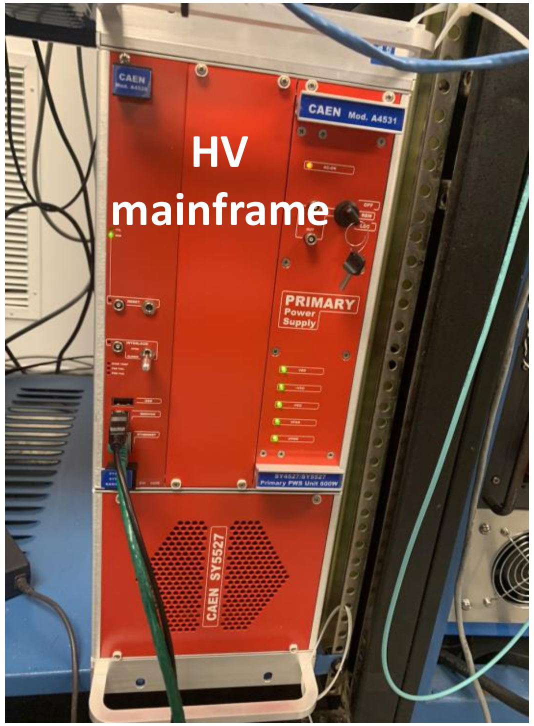
Install parallel-path HV supply on every layer



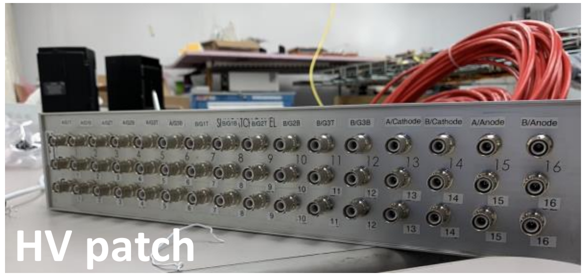


CAEN A1515BTG designed for triple GEMs:

- 2 channels with 7 outputs each
- 1 mA max per output
- Floating ground
- Can trip together



	Need	On hand	To purchase ($100k)
CAEN A1515BTG	16	9	7 (2-INFN, 2-UVa, 3-JLab)
CAEN HV mainframe	4	1	3



Simulation shows back tracker receives 40% of the rate of the front tracker

HV supply schemes to reduce gain drop

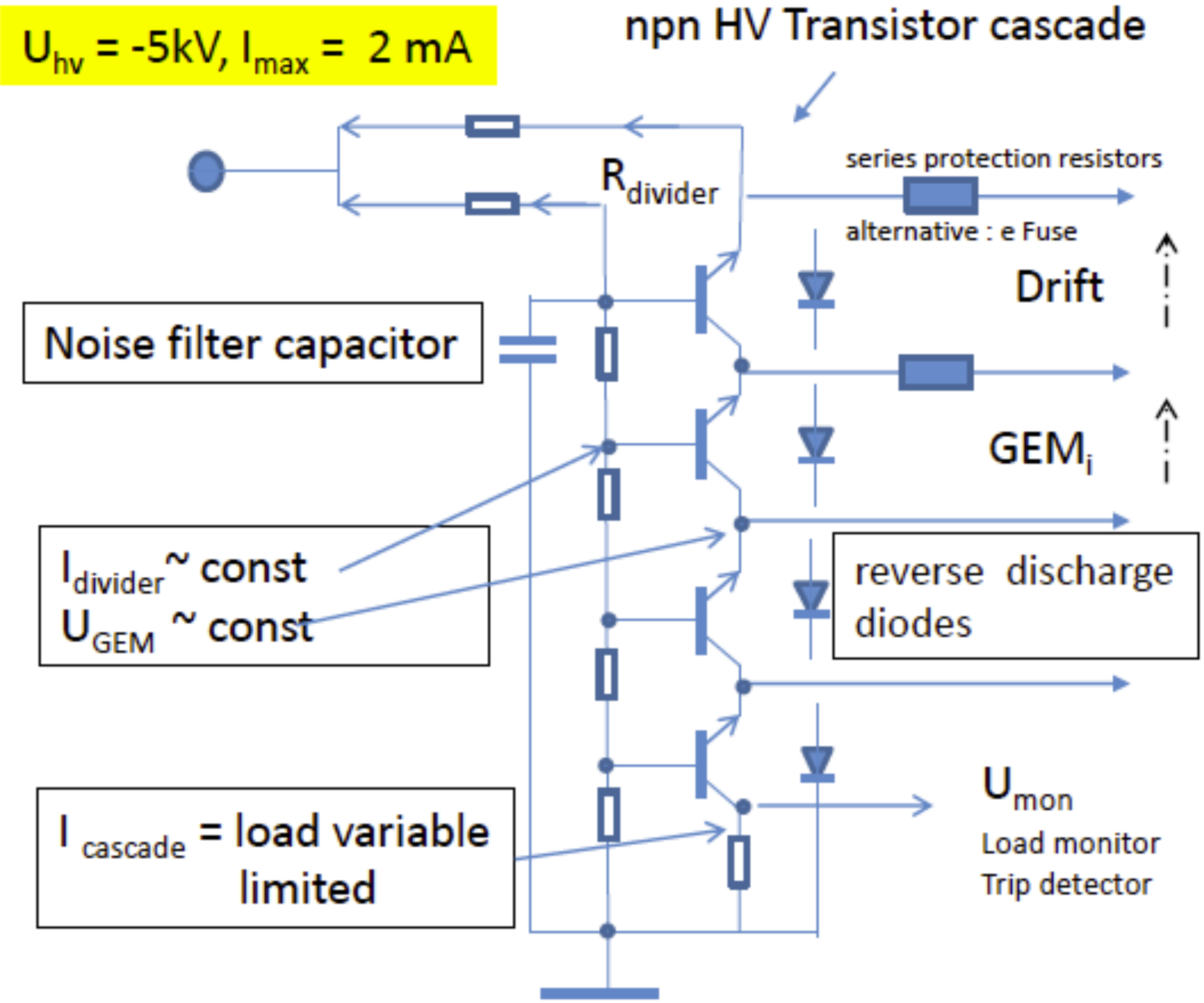
- **Use individual power channels for each electrode. Reduce the problem by a factor of 4-8 or more**
  - Expensive: cost about $ 700 per GEM ~ $ 1 M for SoLID
  - Tested extensively at Uva with X-ray illumination
  - Then implement on one BB UV chamber for beam testing during Gen-II
  - This method just adopted for all SBS GEMs: total cost was ~ $ 250 k: SoLID can reuse some these supplies to bring down cost.

- **Build an active divider**
  - We are working with a CERN GEM electronics group to build this
  - ~ 1-2 year project.
  - Cheaper, but need to make sure no extra noise.
  - No other GEM group made this work yet
  - Need support from Jlab electronics group

10

AVD basic principle npn:

max 600V between stages

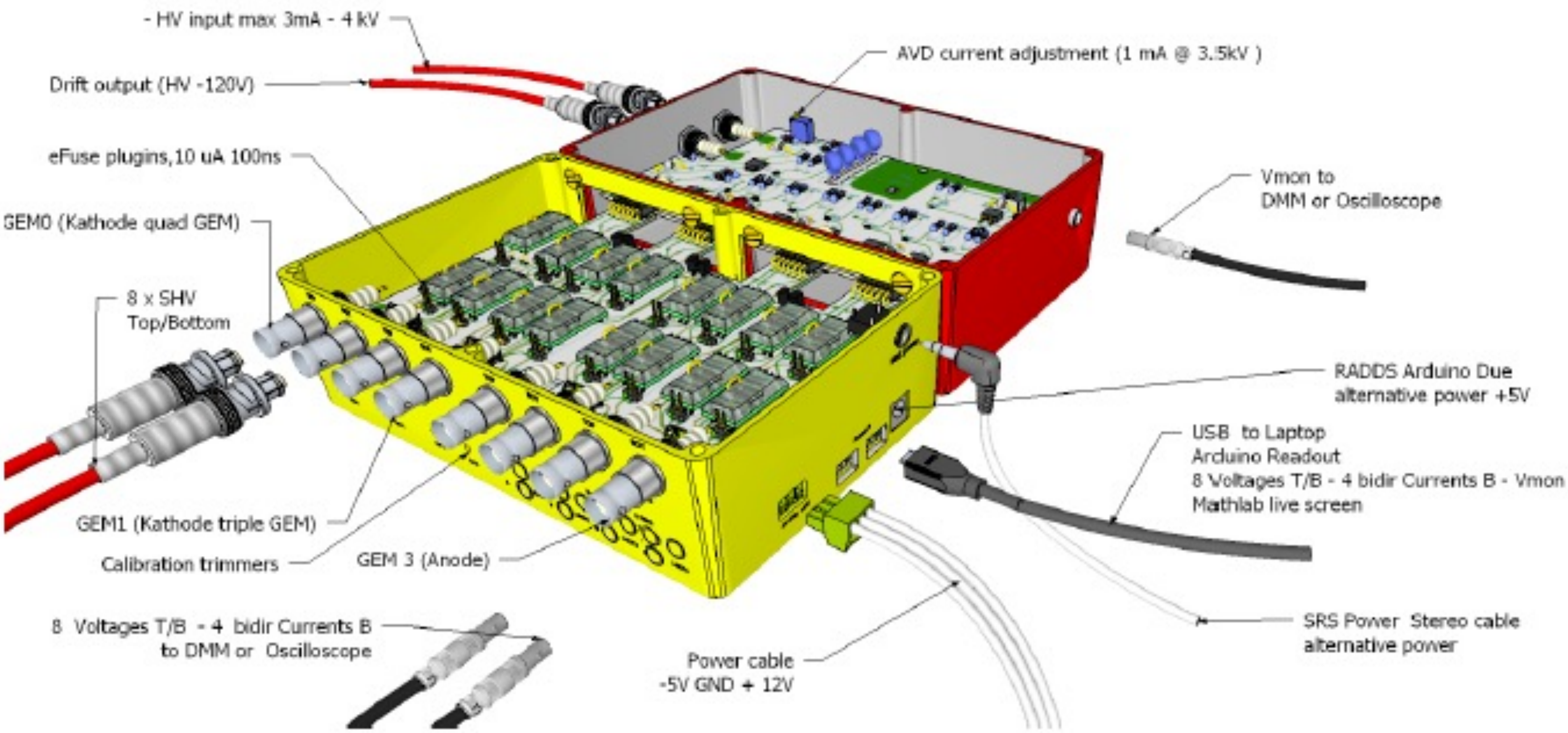


Principle:

- GEM Voltages follow Voltages of resistor divider by ~ 0.8 V but at low output impedance (=> constant voltage)
- load dependent currents flow Through transitor cascade, current load through $R_{divider}$ divided by gain of the transistors (~ 100)
- Regulation max 600 V for Drift and GEM_i
- Primary filter capacitor decoupled From discharge into detector
- Dynamic currents available as U_{mon} for load monitoring and HV trip of all load-induced currents.
- U_{mon} available as very fast trip signal for primary HV supply
- Reverse diodes discharge detector at ramp down

Advantage npn: voltages follow closely $R_{divider}$ U_{EB} variation +/- 0.2V @ T=const
Disadvantage npn: I_{EB} forward currents O(5uA) reflect up 5% load into $R_{divider}$

AVD$_{2015}$ Prototype Implementation



2016: put all (including external HV module) into a single box

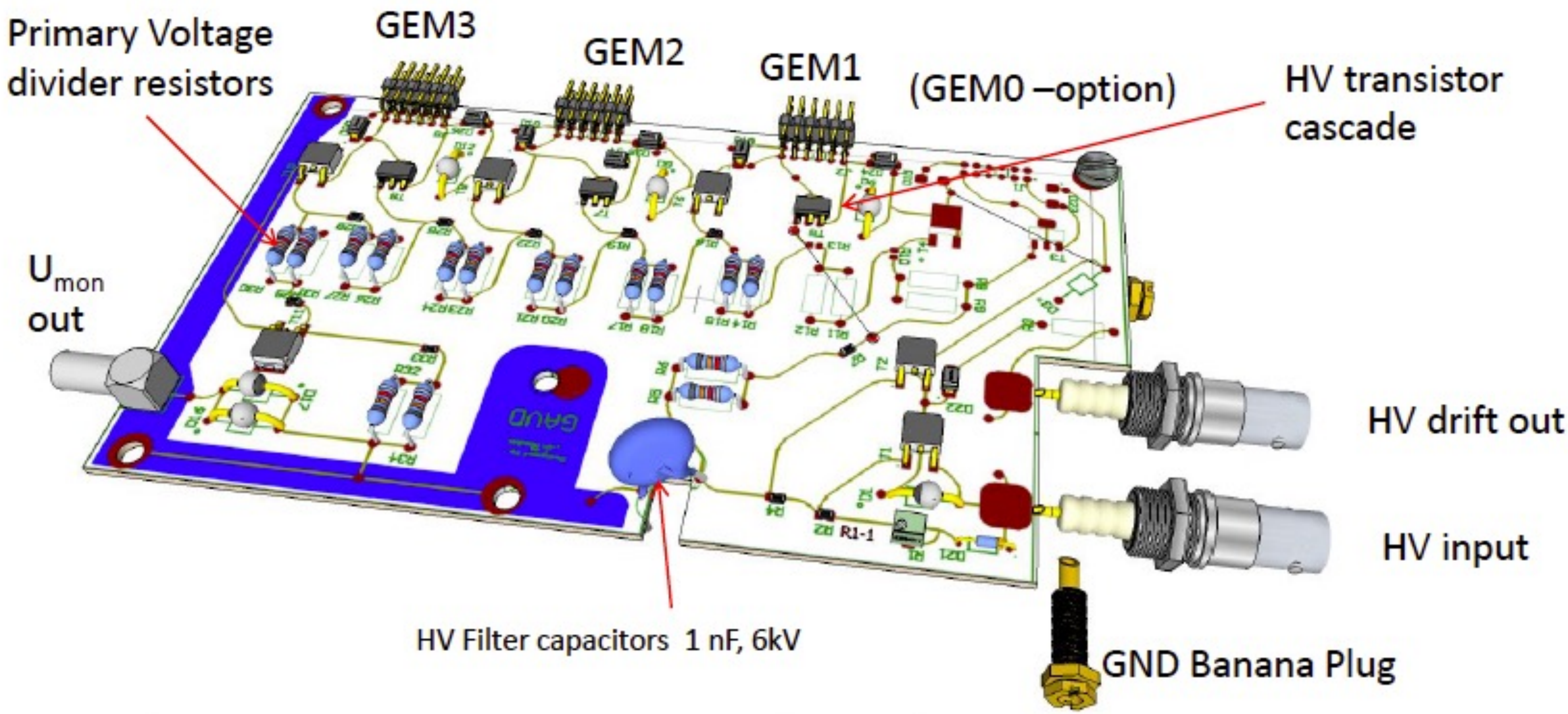
was successful but quite bulky

AVD$_{2015}$ board

(single layer, ceramic)

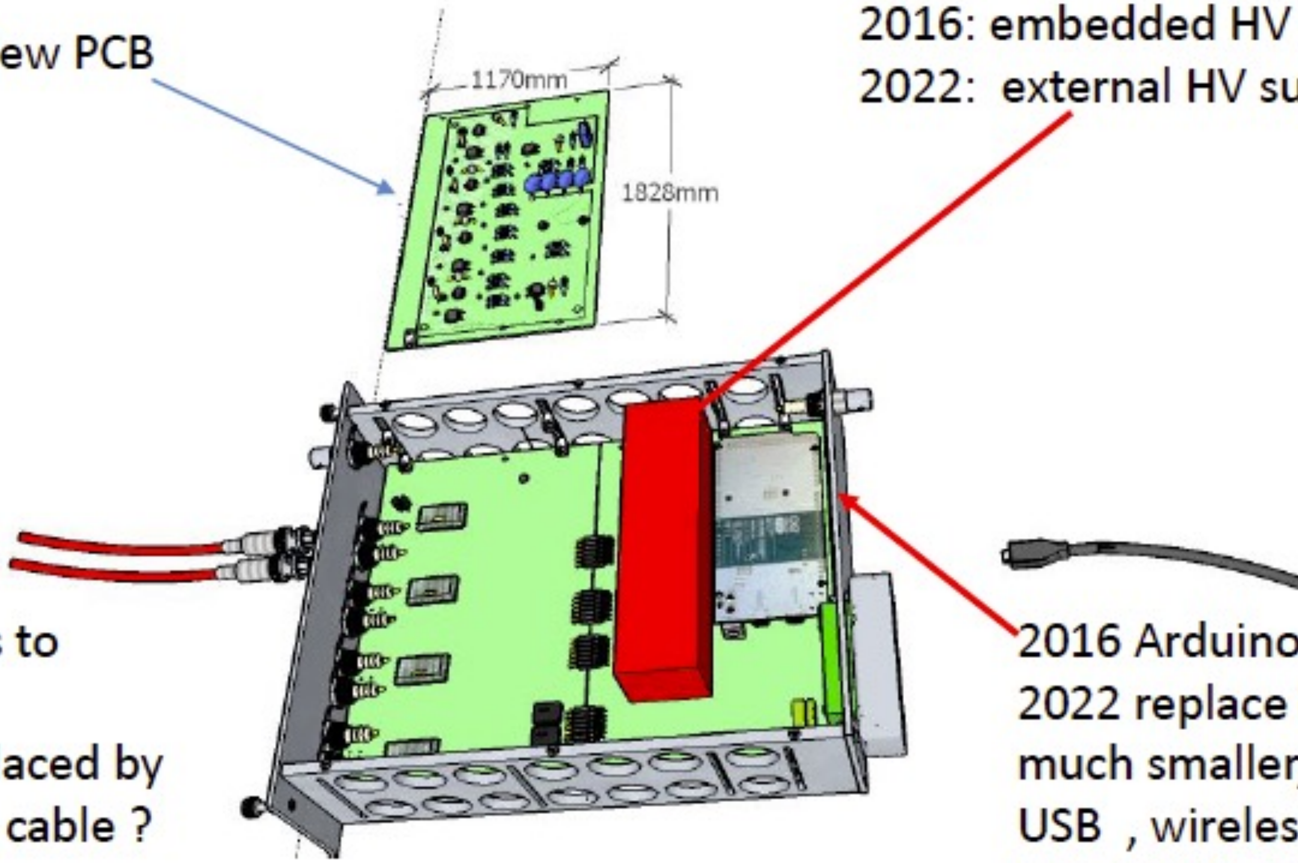
⇒ make some component and connector updates

⇒ fit into NIM module PCB size



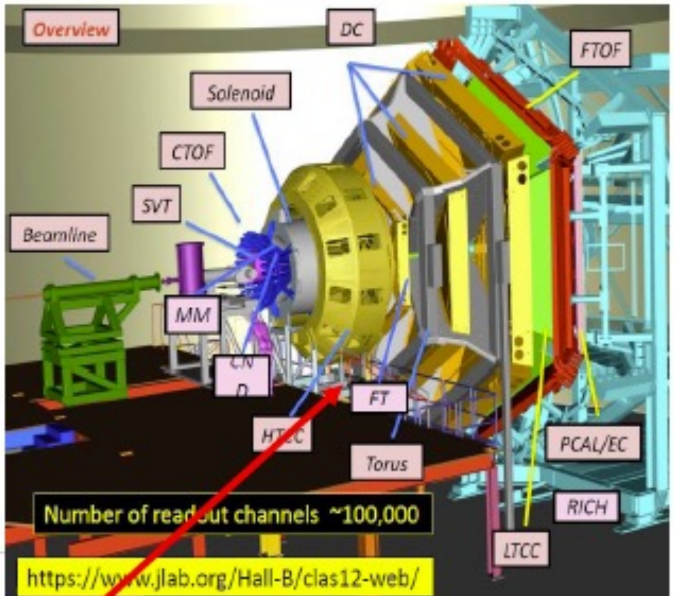
2022 re-boxing of AVD:

fit in NIM module (shown status 2017)

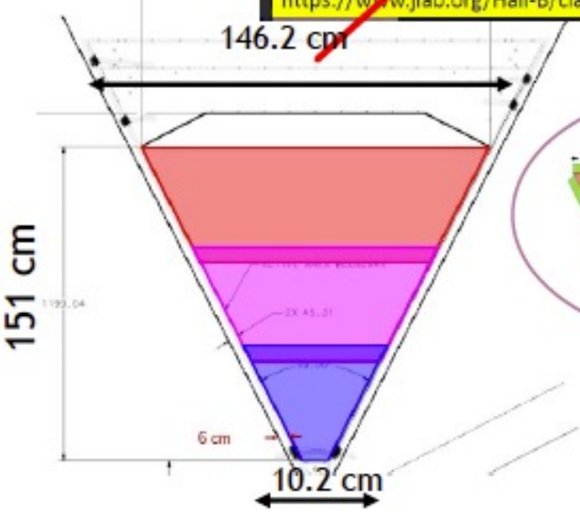


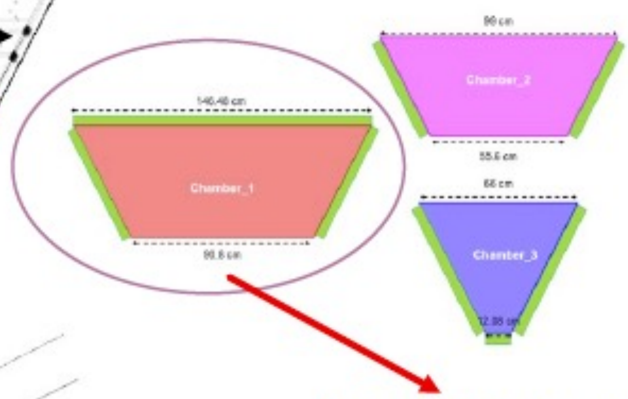
Full size prototype of µRWELL detector

Hall B of JLab: Upgrade of CLAS12 Forward Tracker with “µRWELL” detectors

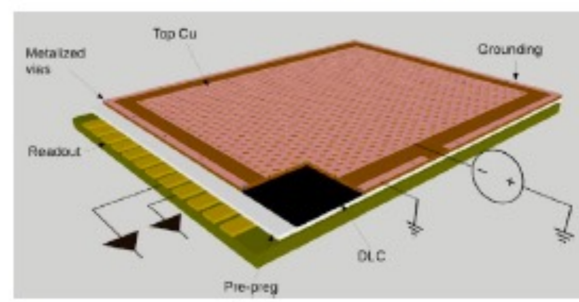


- Goal for upgrade: achieve higher luminosity $2\,x\,10^{35}\,cm^{-2}\,s^{-1}$ than current running conditions $0.7x\,10^{34}\,cm^{-2}\,s^{-1}$ per nucleon
- Limiting factor is forward tracker (FT)
- Introduce uRWELL technology in FT detectors
  - Low-material budget detector; “low mass”

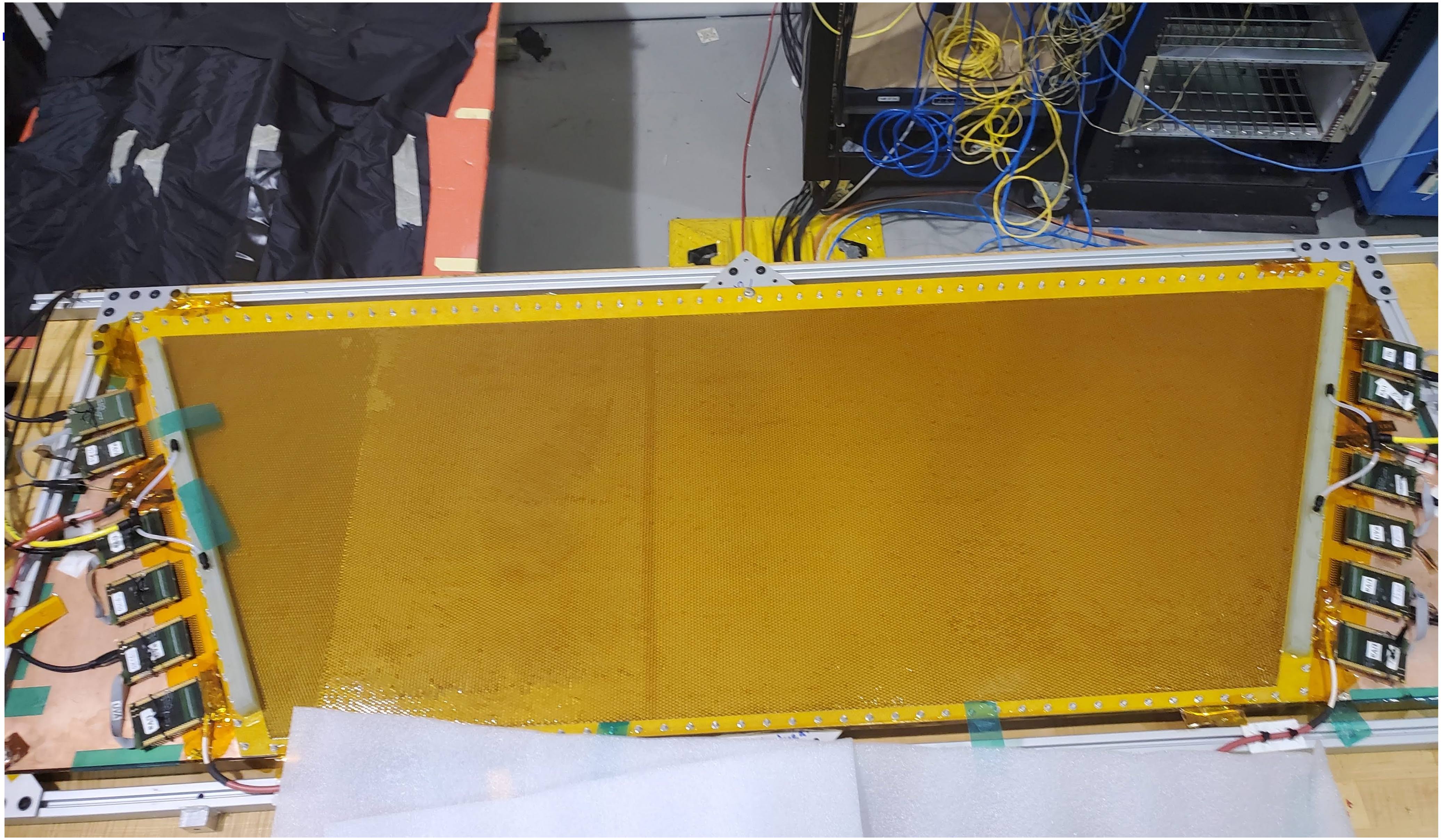




µRWELL technology



Design 146.2 cm x 101.2 cm Chamber 1 prototype at UVa/JLab



Large area uRwell prototype under testing at Jlab

GEM R&D needed before production

- Engineering designs for all sizes
- Several (3-4) prototypes of different sizes at Uva
- 1-2 large uRwell prototypes to establish the concept for the two large wheels.
- 2-3 prototypes at each of the partner institutions (MIT, SBU ?)
- One pre-production prototype for each size