GEM Chambers for GEp

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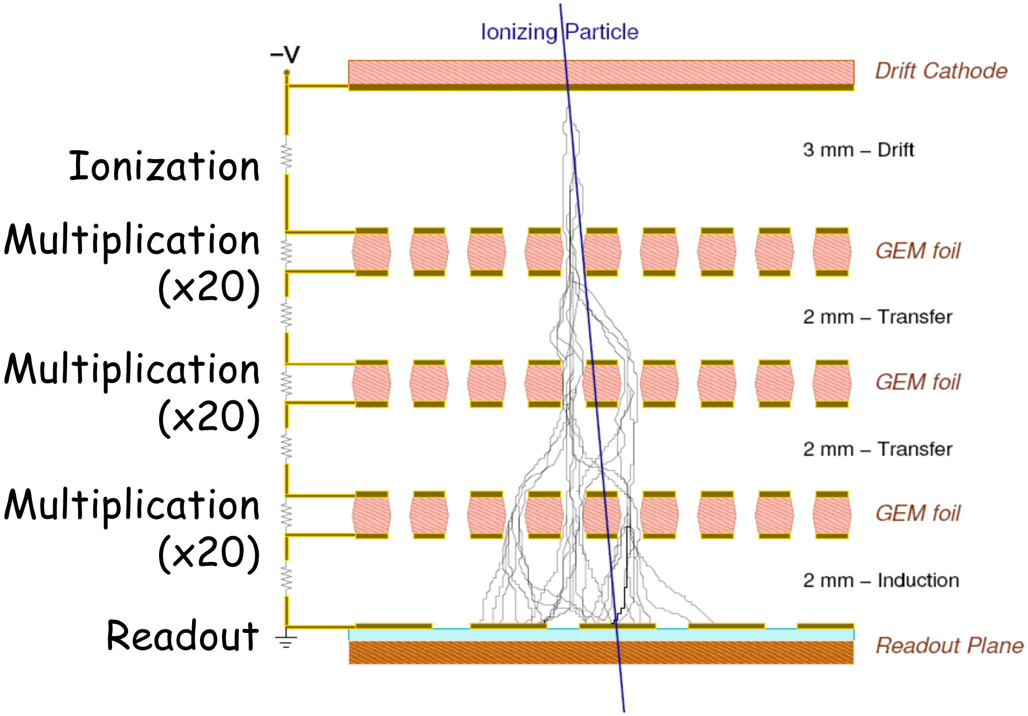
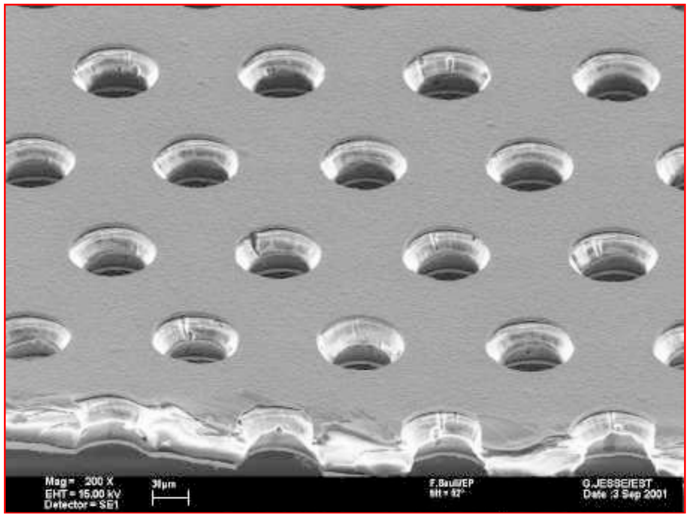
Why GEMs

- SBS 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 etc.



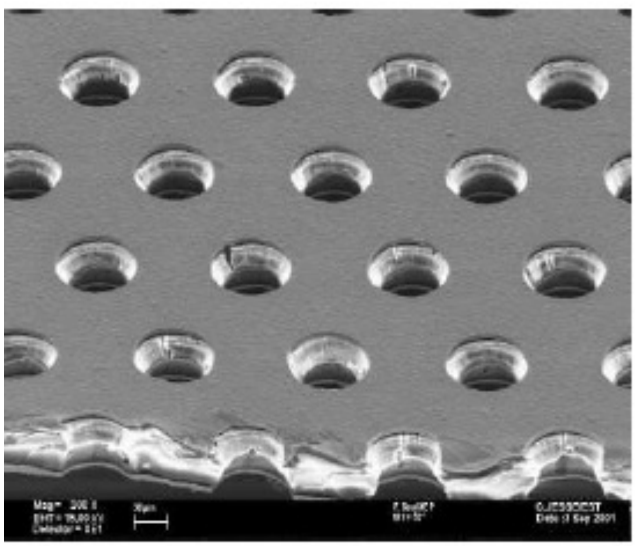
GEM foil: 50 μm Kapton + few μm copper on both sides with 70 μm holes, 140 μm pitch



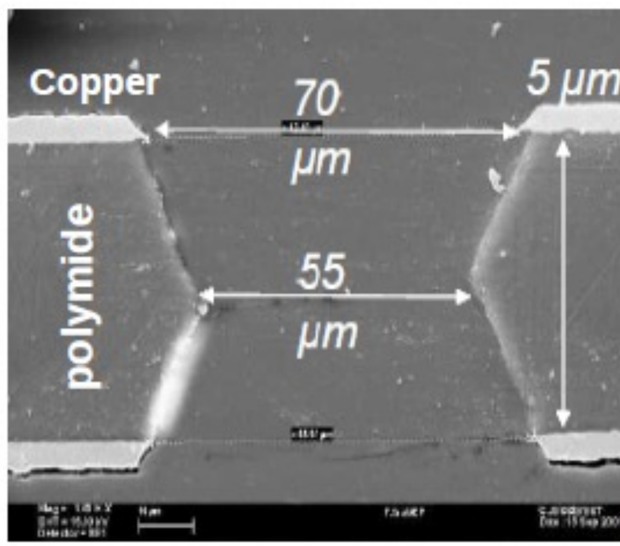
GEM foil: Electron amplification device

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm^2
- Voltage of ~ 350 V across the Cu electrode creates a strong field in the hole leading to amplification
- The ionization pattern is preserved by design with the electric field focusing the charges inside the holes

GEM foil



GEM hole parameters



E Field pattern

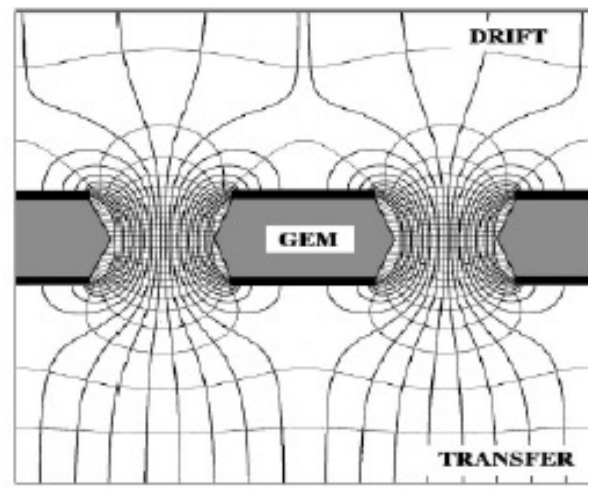


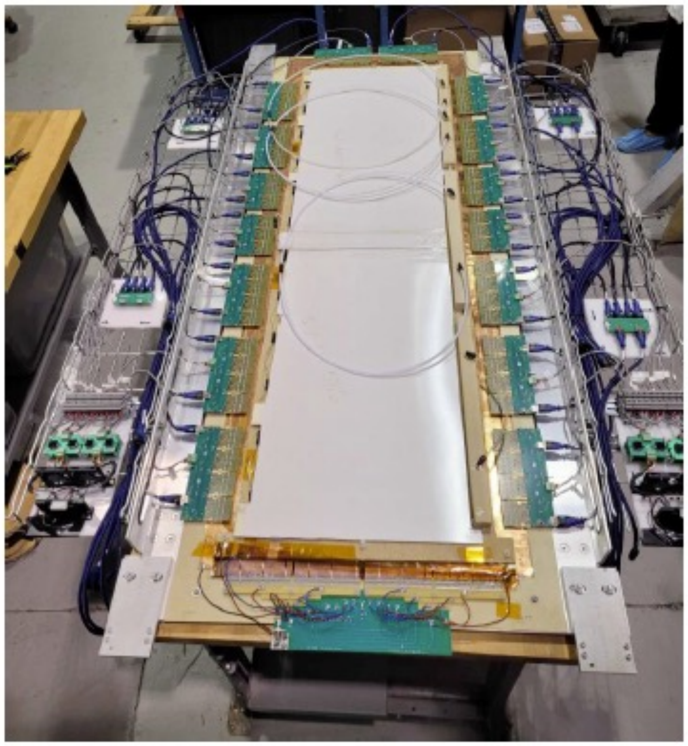
Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

UNIQUE FEATURE

Charge amplification is decoupled from the charge collection ⇨ *Multi-stage amplification*

SBS GEM trackers: gaining GEM operation experience under conditions exceeding SoLID requirements

- 50 cm x 60 cm GEM modules for SBS rear tracker: 48 modules –All installed, 28 have been in beam
- 150 cm x 40 cm large GEM modules for SBS front tracker: 6 modules – all in in beam;



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

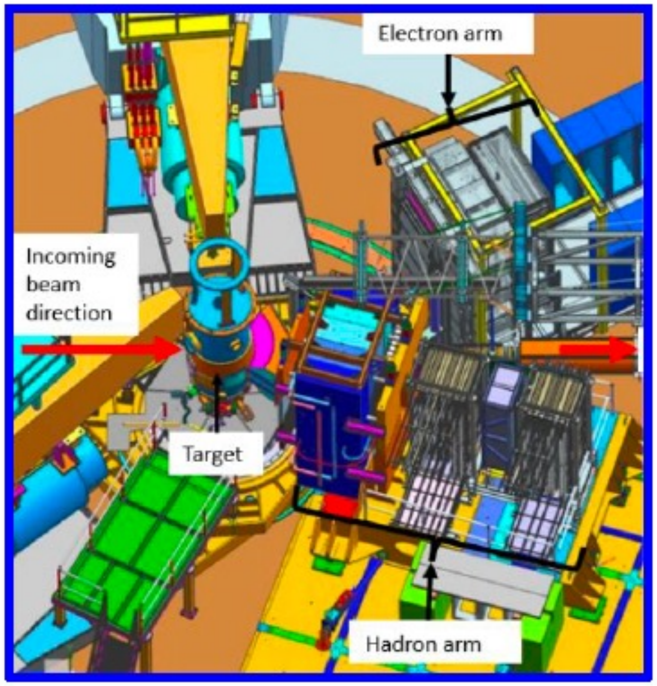
XY (shown)
60 x 200 sq.cm
4 modules

UVa GEM project co-PI Dr. Huong Nguyen and her team built the UV and XW GEMs in record time and in the middle of the pandemic.

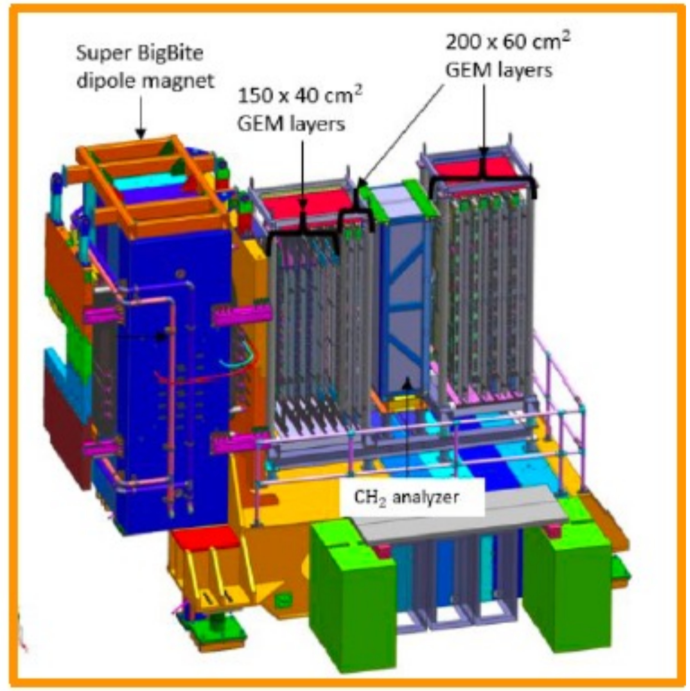
All 6 of these GEMs have performed exceptionally well in beam, exposed to the highest rates.

These are the largest area GEMs in the world.

Setup for GEp-V Experiment



Setup for GEp-V Experiment



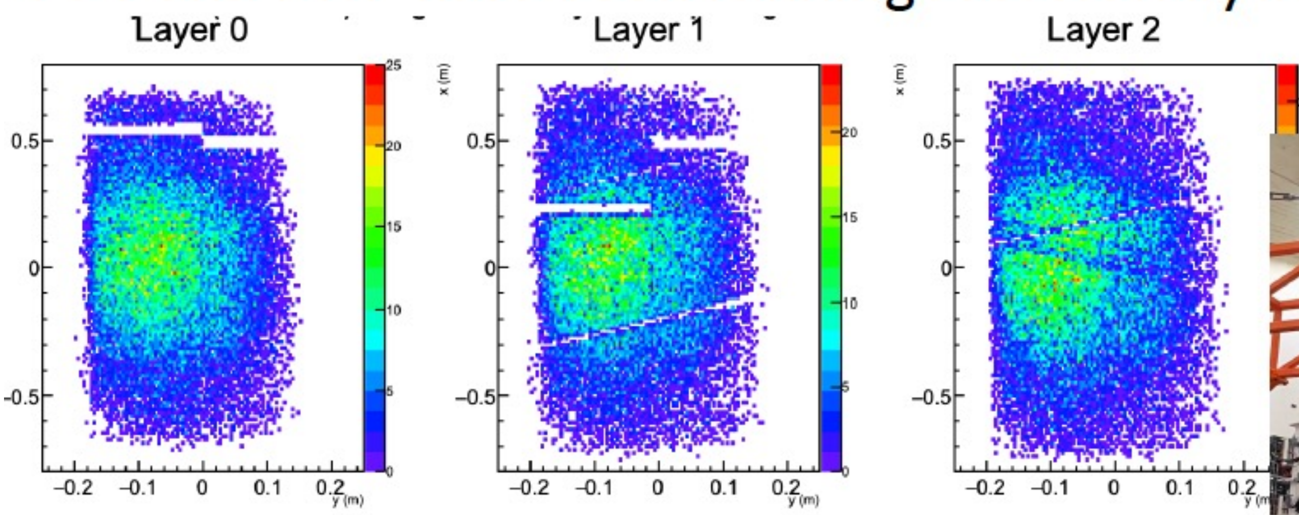
Hadron Spectrometer

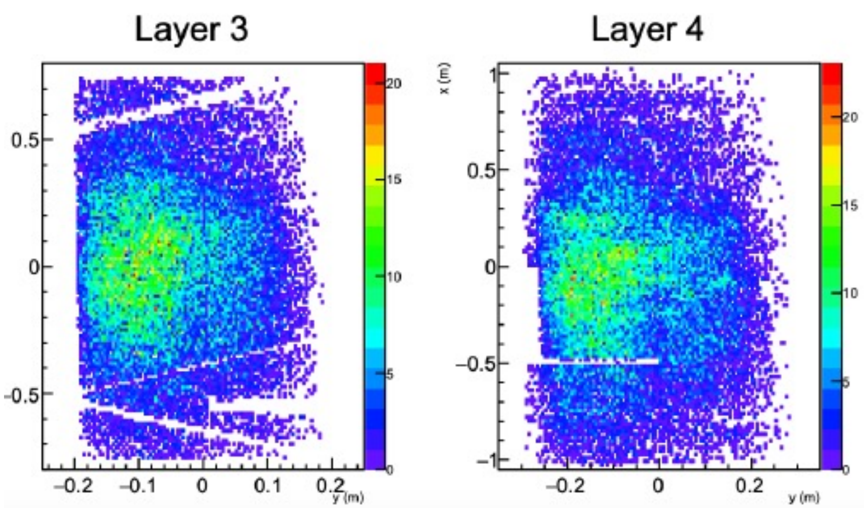
- SBS front tracker
  - 6 layers of 150cm x 40cm GEMs (single module) - 2 XW + 4 UV
  - 2 layers of 200cm x 60cm XY GEMs (four modules put together)
- SBS back tracker
  - 8 layers of 200cm x 60cm XY GEMs (four modules put together)

University of Virginia

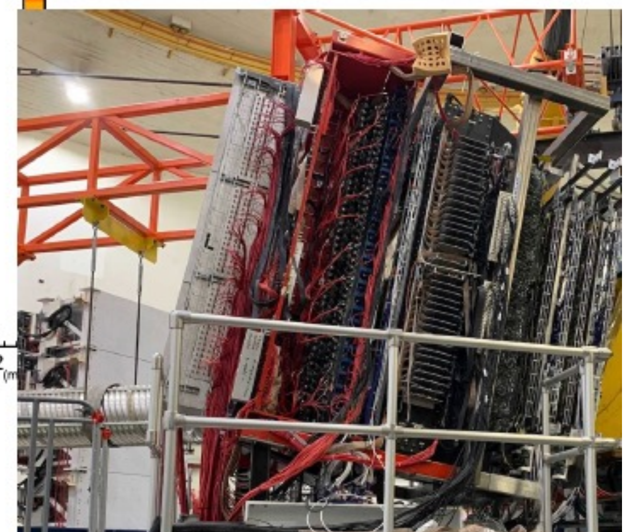
- All 16 GEM layers needed for GEp have been assembled.
- We will have one spare XY layer and about 4 or 5 spare modules
- Important to have these modules tested and ready to go

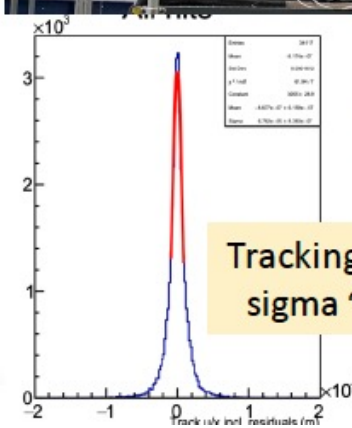
4 UV and 1 XY have been running successfully in BigBite since 2021





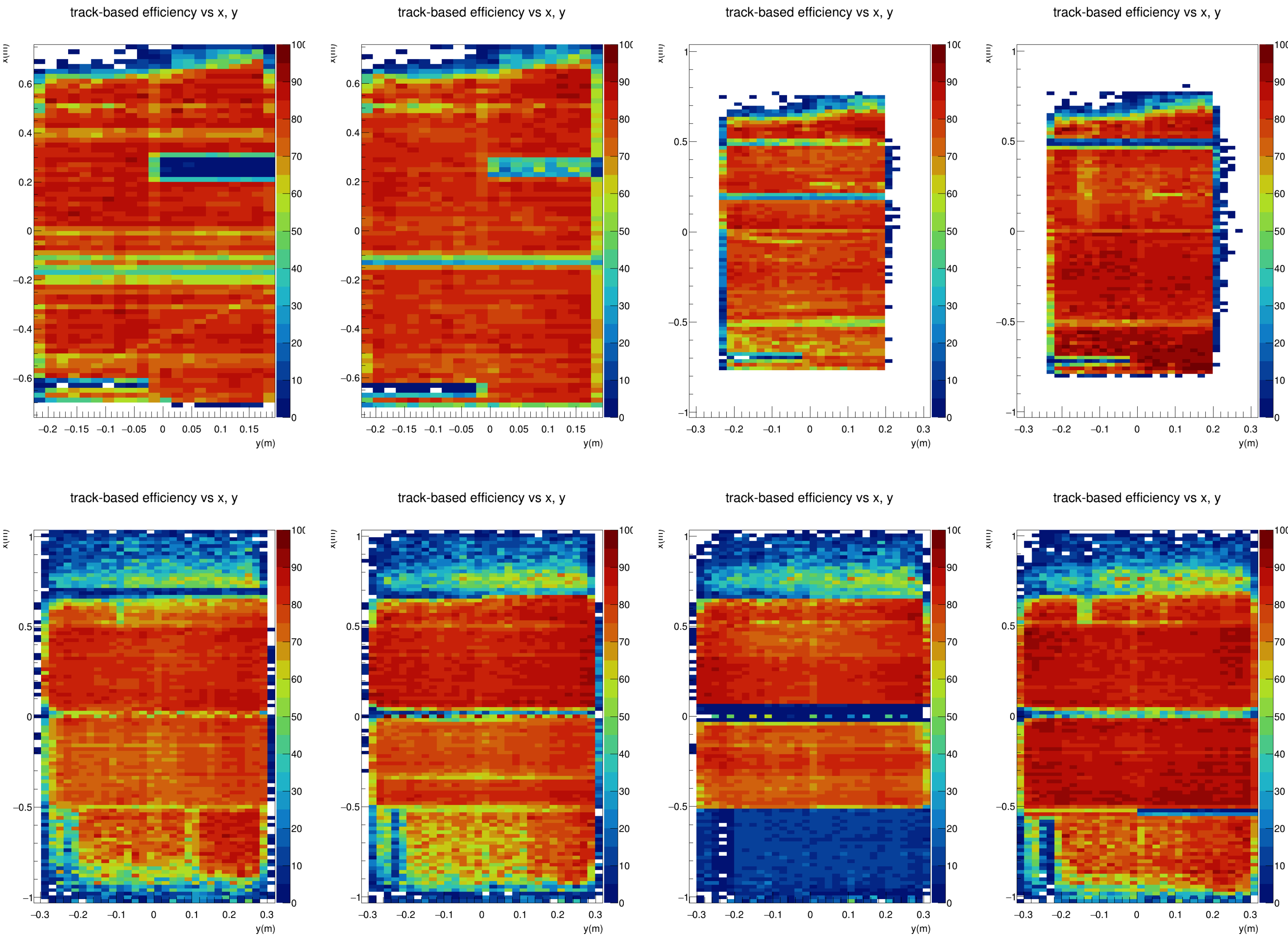
Hit maps with tracking constraints shown per layer





Tracking residual sigma ~ 70 µm

Two XW layers and 6 XY layers were used in the inline trackers during GEn-RP and KLL



SBS GEM trackers: gaining GEM operation experience in conditions approaching GEp

• SBS GEM trackers have been running well for about 18 months months in GMn, nTPE, Gen-II, and GEn-RP experiments.

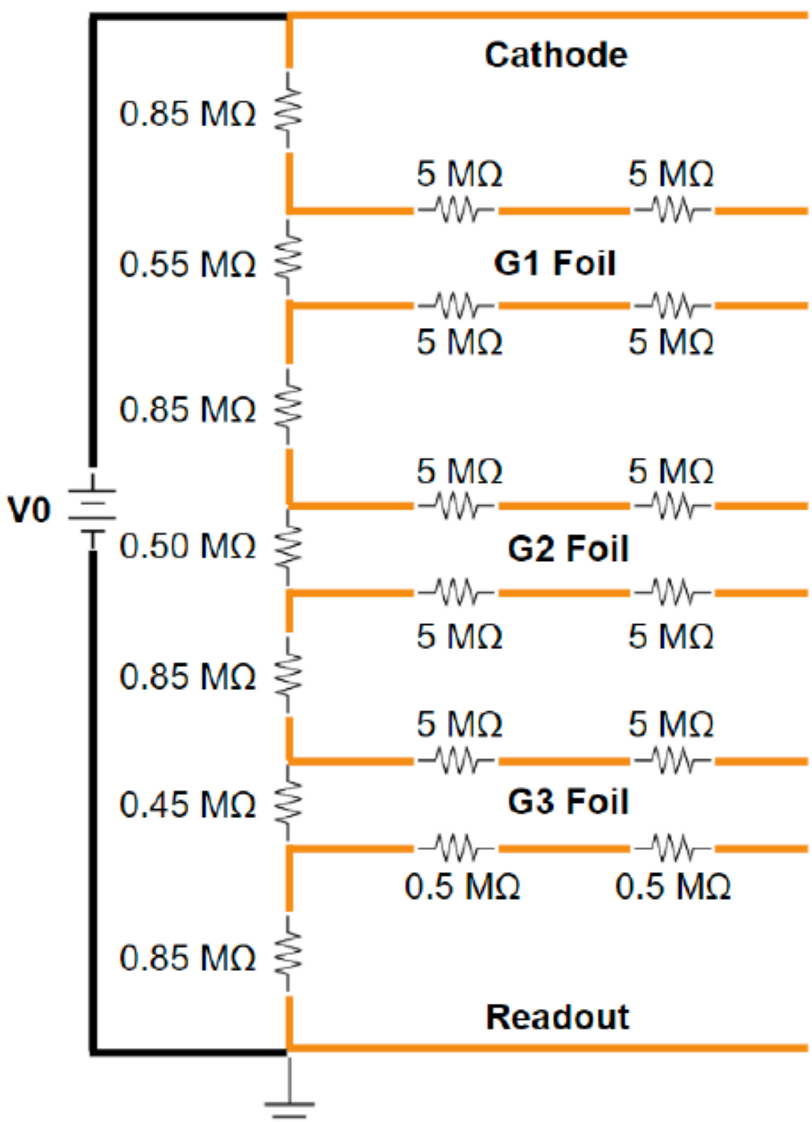
• In GMn and GEn-RP: already ran the BB GEM tracker in unprecedented integrated rates (active area x local rate): stable running with 12 uA beam on 15 cm LD2 target: test runs up to 36 uA on 15 cm LD2: luminosity ~ 3 x $10^{38;}$ within about factor of 3 of GEp luminosity

• GEMs very sensitive to gas mixture: need to pay very close attention, some scary moments at the start of GEn-RP. Gas system calibration done and new filters installed; these will help.

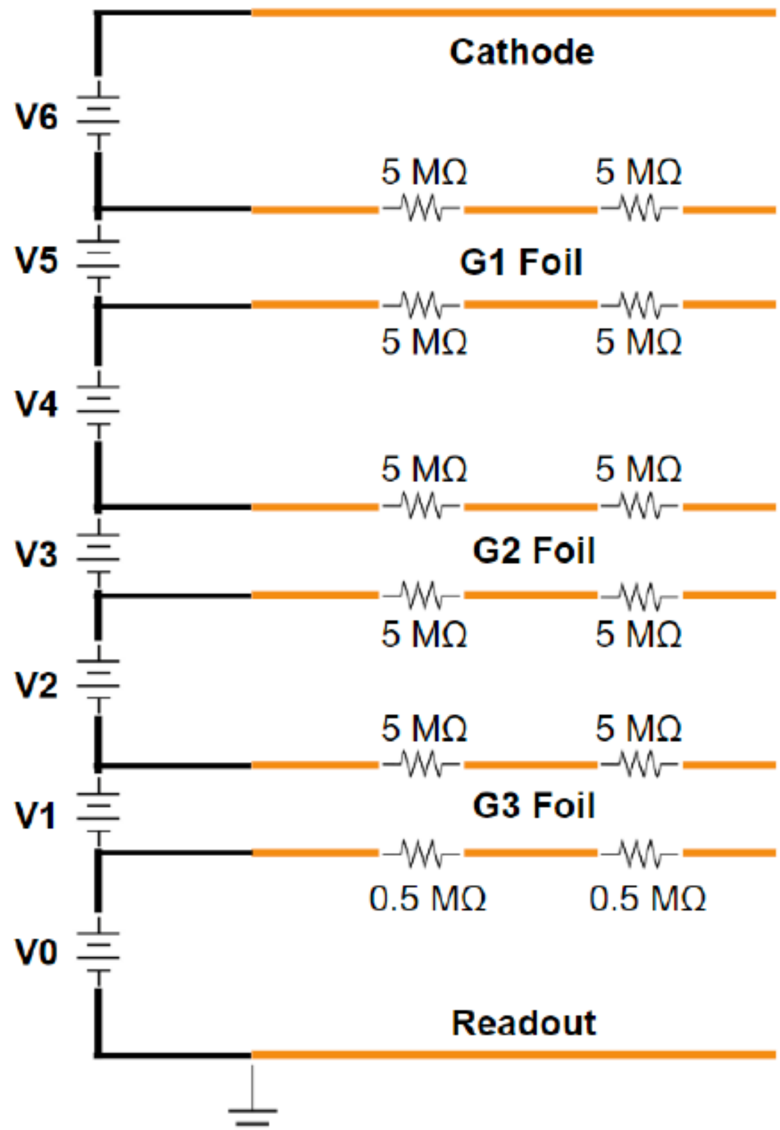
• Main issue identified: gain drop due to low cost resistive high voltage divider: full high voltage upgrade was done before GEn-RP and was highly effective: the gain drop problem effectively gone.

SBS GEM: HV supply issue

Original low cost resistive divider scheme

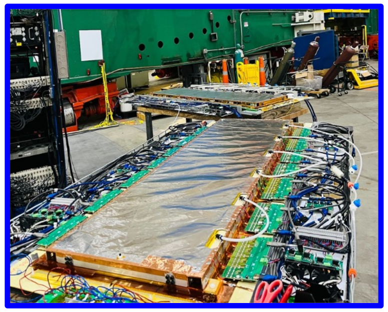


New individual power supply scheme

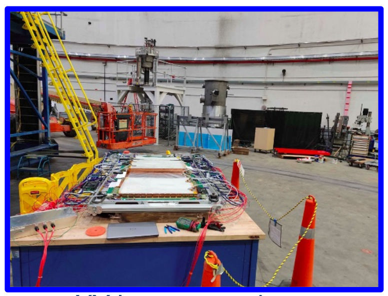


High Voltage Upgrades

- High Voltage upgrade to reduce the gain drop in GEMs in high luminosities
- High power modules which can go up to 3mA(1.5W) per channel are used power up front tracker



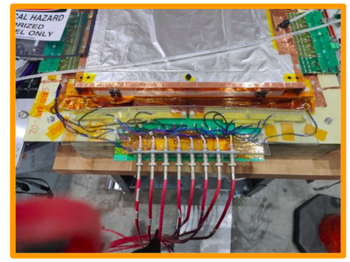
UV layer upgrades

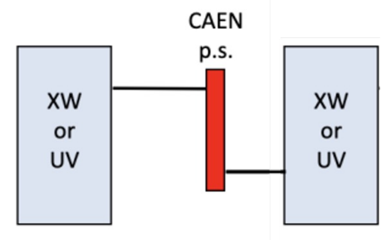


XY layer upgrades

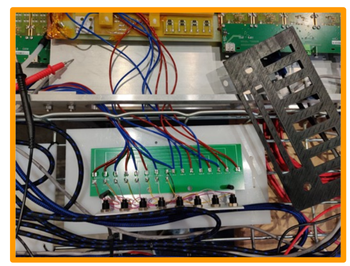
Configuration per GEM type:

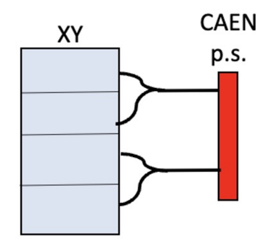
- UV or XW GEMs



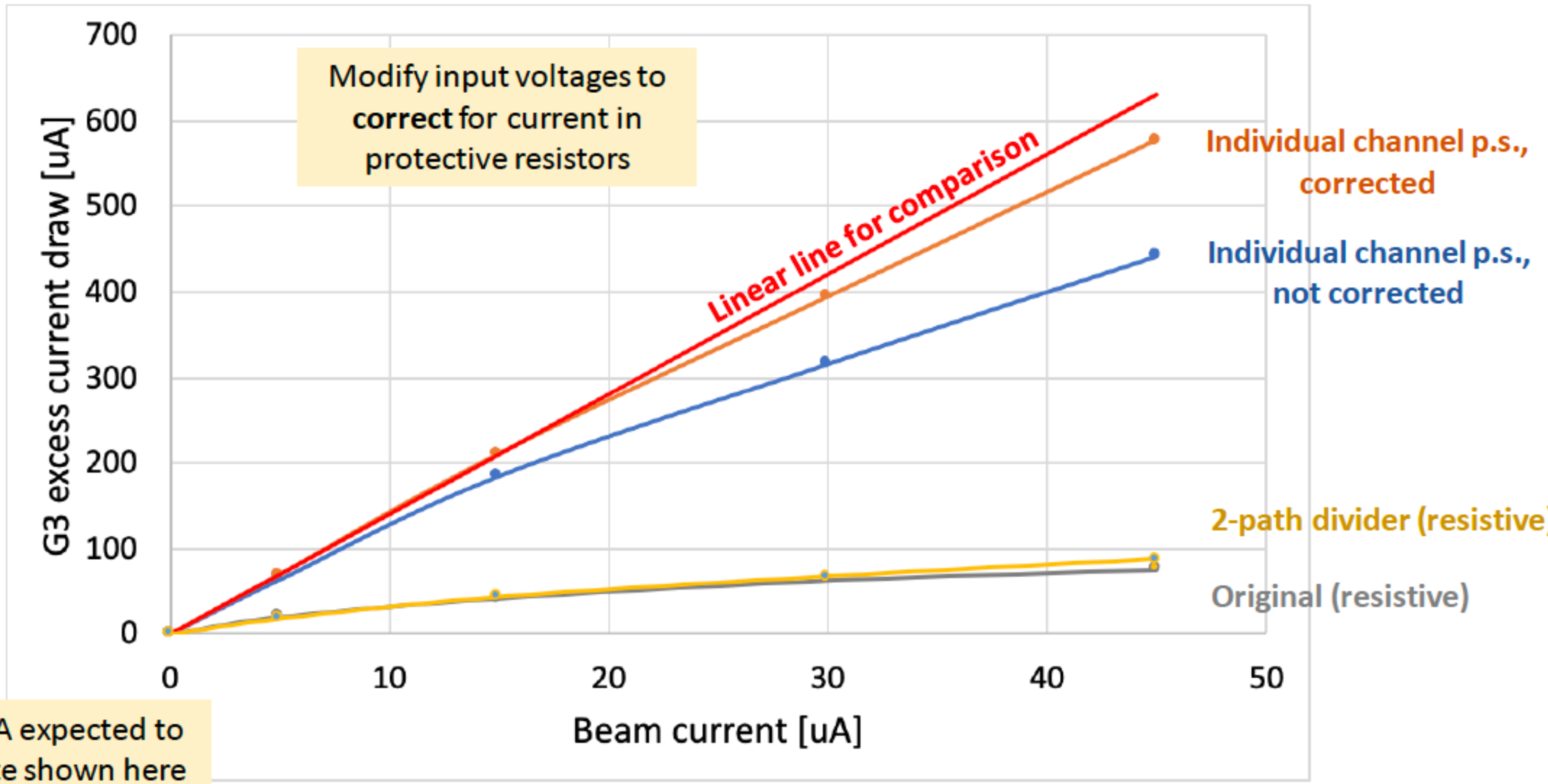


- XY GEMs





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

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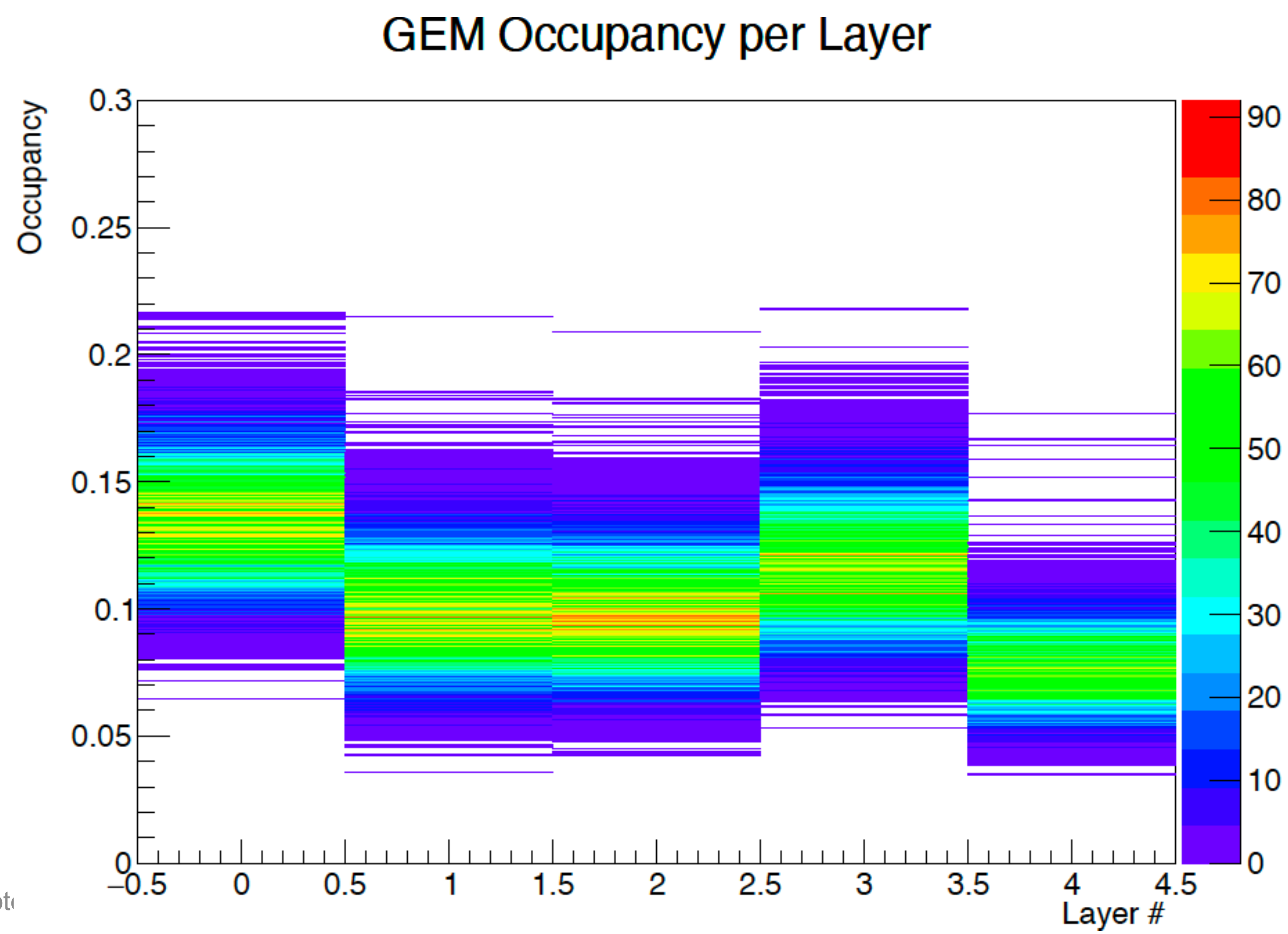
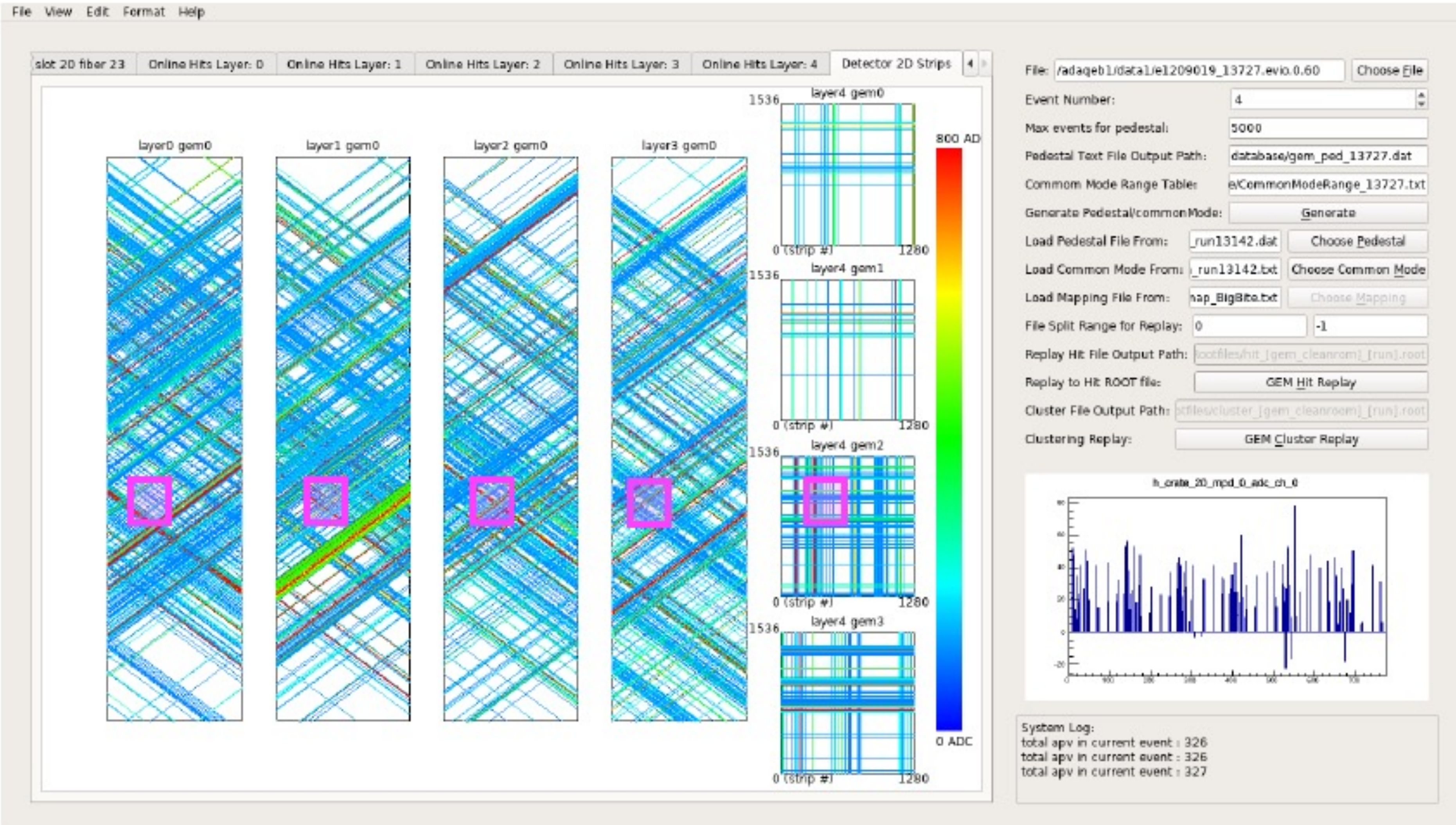
SBS GEM trackers: Important conclusions about long term running under very high exposure conditions

- The GEM tracker layers have been working very well:
  - stable operation: some occasional HV trips, manageable.
  - Robust under harsh conditions. So far only 2 out of the 32 detectors in beam had to swapped out due to suspected short in a couple of sectors (out of 30 in the detector).
  - No radiation damage observed
  - No detector aging effects observed
  - Noise levels sufficiently low
  - Good gain: signals well above noise
  - Very good resolution: ~ 70-80 um
  - Real time firmware zero suppression has been working reasonably very well: going to get an upgrade soon.
  - Data volumes have been manageable; but will get more demanding with GEp new component additions will help
  - We really need to do real time readout selection of GEM regions based on HCal hit locations

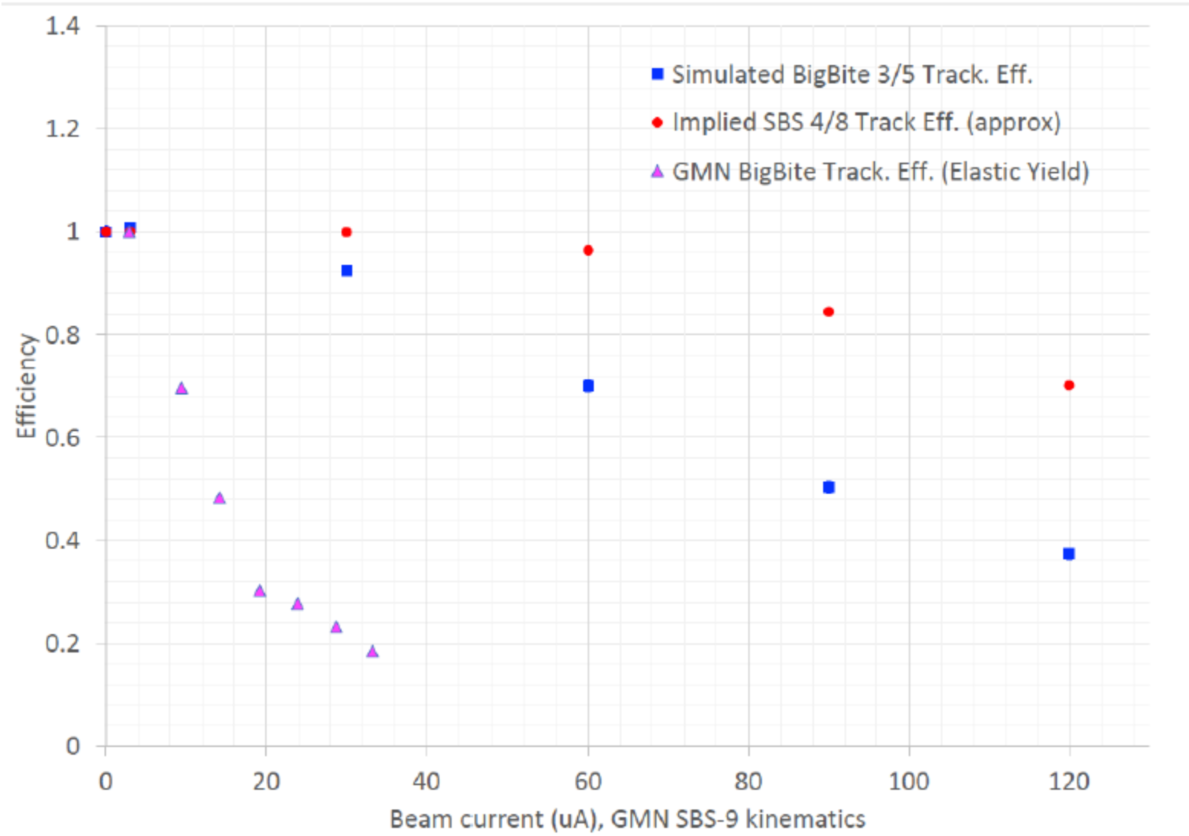
Gen-II run 2551 -
45 uA on polarized
3He target



run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$



GEM Reconstruction Efficiency at High Rate

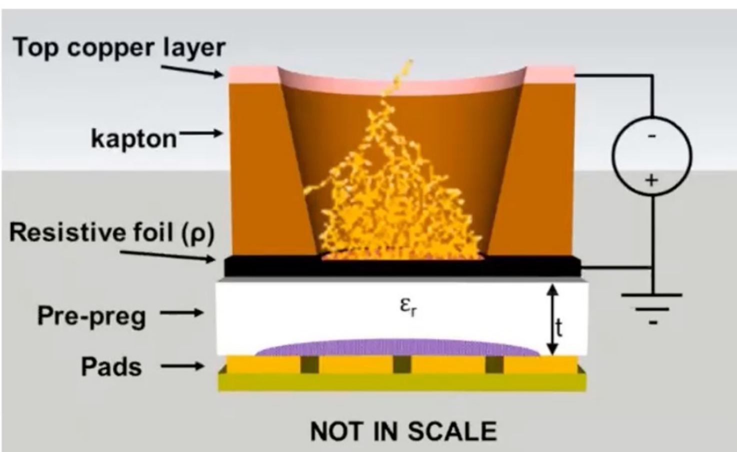


- *g4sbs* reproduces observed BigBite GEM rate/occupancy at "low" beam current (3 uA)
- "High current" study done at end of GMN went up to 34.5 uA on LH2, LD2 in previous slide's kinematics.
- Elastic yield drops rapidly with current (effect of GEM gain/efficiency drop → Holly's talk)
- **Simulated BigBite tracking efficiency** shows much slower drop-off (without any fine-tuning or optimization)
- **GEP-equivalent** beam current for this configuration is ~120 (50) μA for Front Tracker (Back Tracker)
- Implied 4/8 efficiency for SBS FT in GEP is ~70%, consistent with assumption in PAC47 uncertainty projections (rough, preliminary)

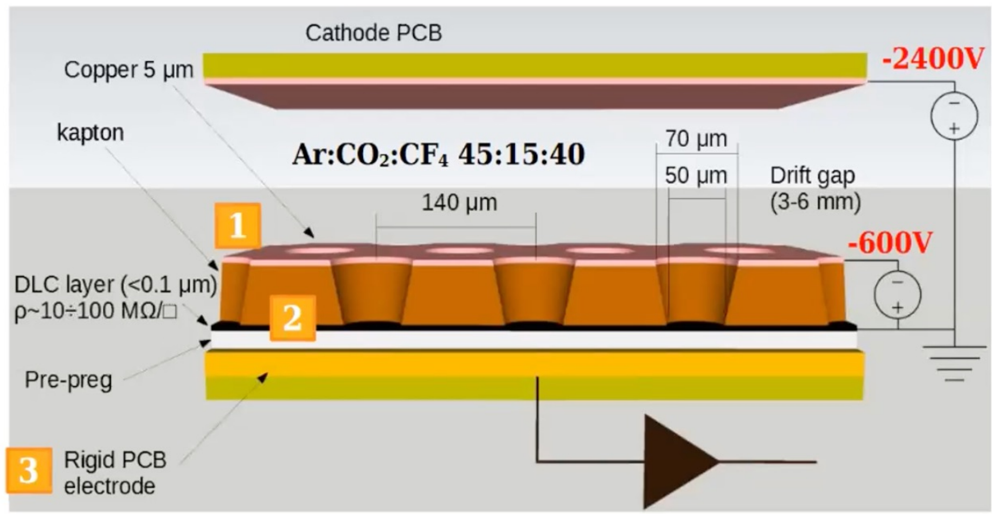
A new possibility for SoLID tracking: u-Rwell. Large area detectors with rate capabilities up to 10 MHz/cm² have been developed for LHCb.

The µ-RWELL – Principle of Operation

The µ-RWELL is a Micro Pattern Gaseous Detector (MPGD) composed of only two elements: the µ-RWELL_PCB and the cathode. **The core is the µ-RWELL_PCB**, realized by coupling three different elements:



Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.



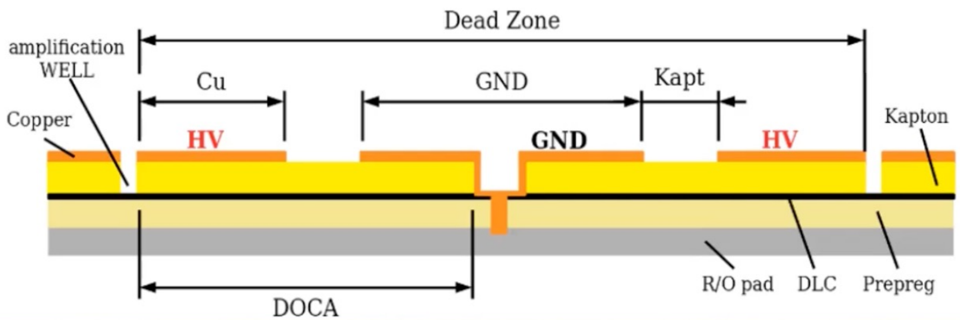
1. a **WELL** patterned kapton foil acting as **amplification stage** (GEM-like)
2. a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity ~ 50÷100 MΩ/□
3. a standard readout PCB

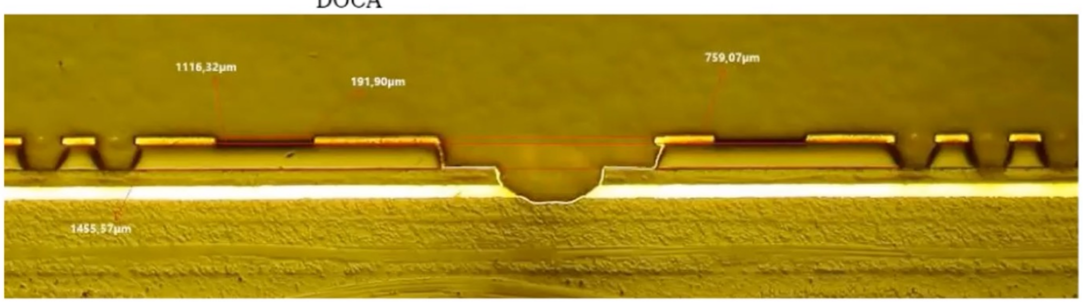
G. Bencivenni et al., 2015 *JINST* **10** P02008

New development by Giovanni Bencivenni's group at Frascatti in collaboration with Rui De Oliveira at CERN

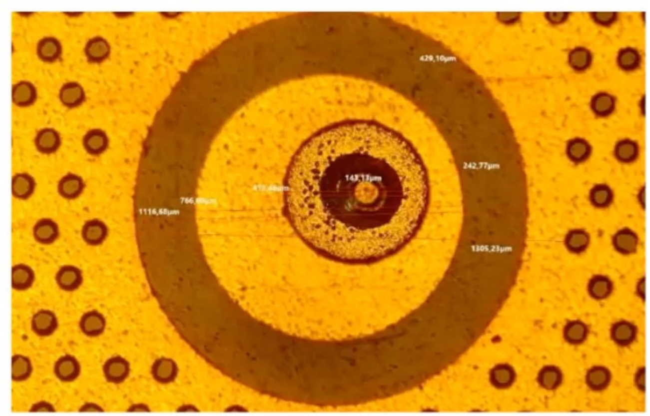
The PEP-dot µ-RWELL

DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.1 (2%)	0.6	0.25	0.7





- The most recent high rate layout
  - **P**atterning-**E**tching-**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%

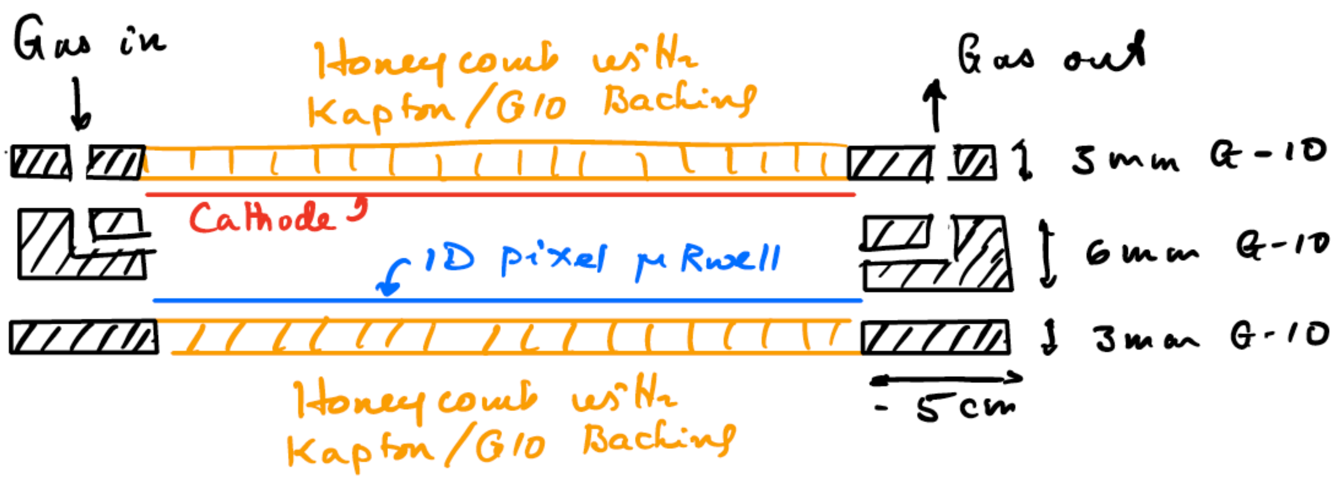


• Gianni Bencevinni's group at Frascati has shown that the improved uRwell could operate at hit rates up to 10 MHz/cm^2; my colleague Huong Nguyen has visited his lab and formed collaborative connections with his group; Dr. Bencevinni has graciously agreed to collaborate with us on this new development to build 3 pixel chamber layers to supplement SBS tracking.

•Having three pixel chambers separated by some distance and requiring .AND. between hits on all 3 can clean up most of the random hits and select mostly the high energy tracks.

•Given the catchment area for these pixels, the occupancy level would be about 1/6th of that of any proposed UV chamber; so in the worst case the occupancy would be around 10%; and the .AND. condition would lower this down to about 10^{-3}

•All this would ensure that we have a pretty narrow (about a factor of 100 smaller in area than right now), very clean search area for hits on the strip chambers.



- Detailed CAD design completed for the pixel chambers
- Bencevinni visiting our group soon; will work out the uRwell layout details
- Have the quotes for the components, hopefully the orders will go out next month
- Plan is to get the chambers ready by March