SBS GEM Chambers

Performances of SBS GEMs during GMn

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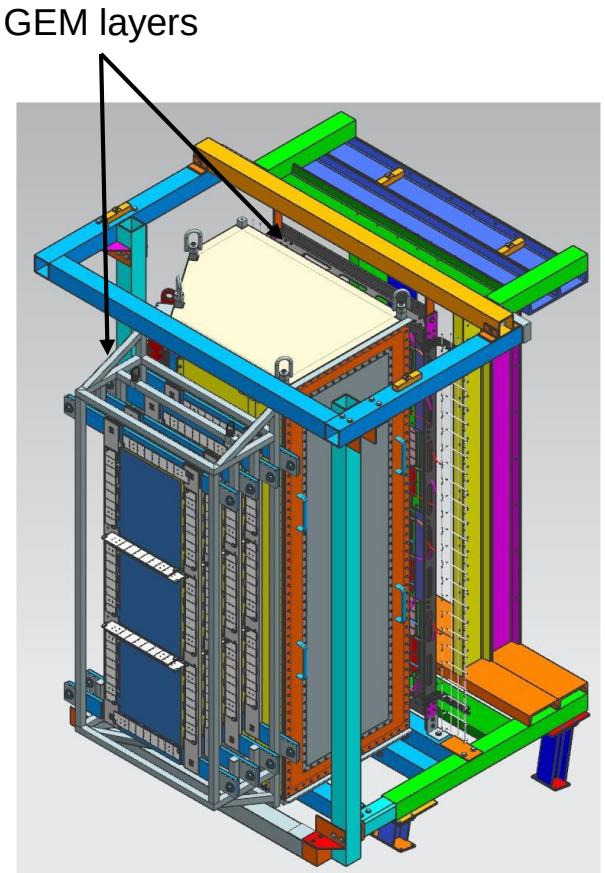
On Behalf of the SBS Collaboration

Hall A Winter Coll. Meeting – February 11, 2022

Outline

- Overview of SBS GEM Chambers
- Performance of SBS GEMs during GMn experiment
- Preparation of SBS GEMs for the upcoming experiments

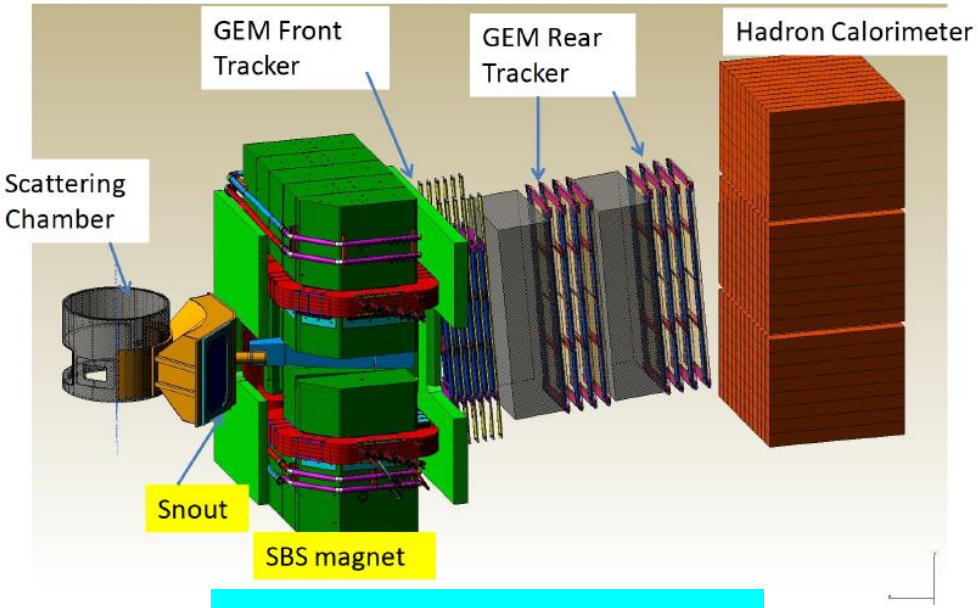
BigBite and SBS GEM Layers



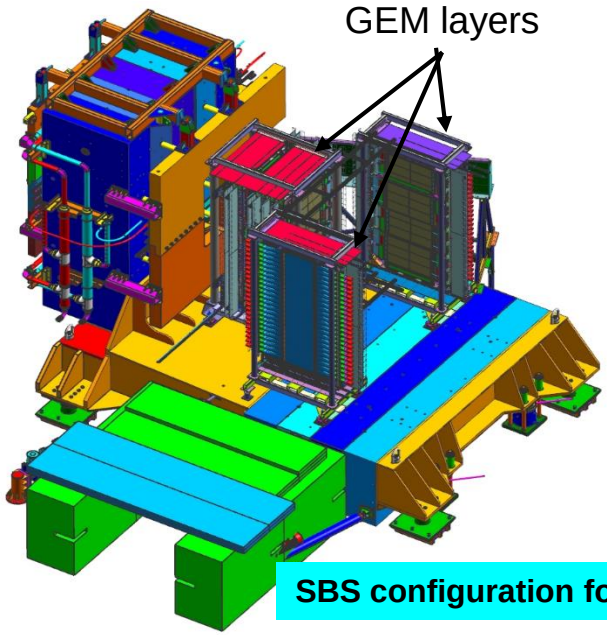
Bigbitre configuration for GMn / GEn

3 GEM layer designs

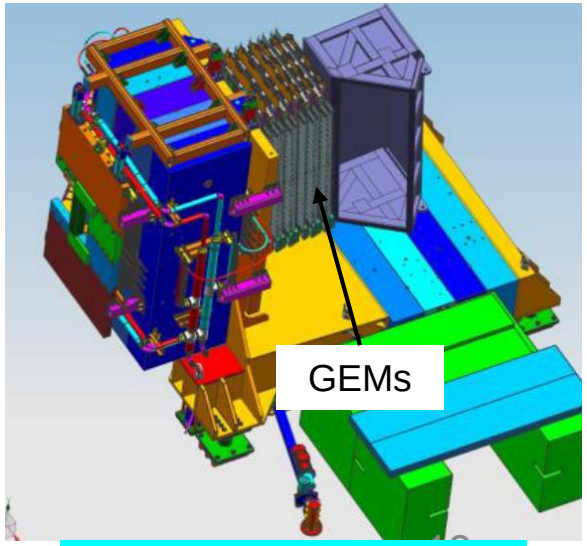
- 11 Back Trackers (X-Y) layers ➔ 200 cm × 60 cm
- 4 Front Tracker (U-V strips) layers ➔ 150 cm × 40 cm
- 6 Front Tracker (X-Y) layers ➔ 150 cm × 40 cm



SBS configuration for GEp(5)



SBS configuration for GEn-RP



SBS configuration for SIDIS

SBS GEM trackers:

- High rate (~ **400 kHz/cm^2**) expected at highest luminosity of **10^{39}** electrons/s-nucleon/cm^2
- Large acceptance & small field integral magnet ⇨ Excellent Spatial resolution **(70 μm)**
- Low cost for large tracking detectors

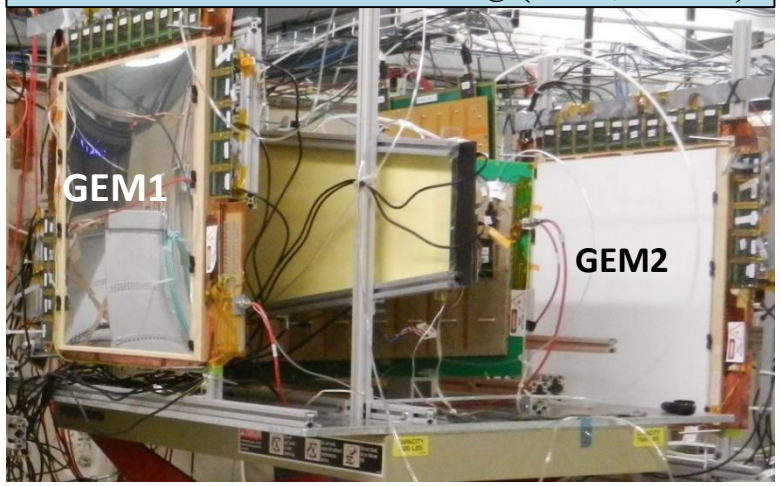
Back Tracker (X-Y strips) GEM Layers

Jefferson Lab
Exploring the Nature of Matter

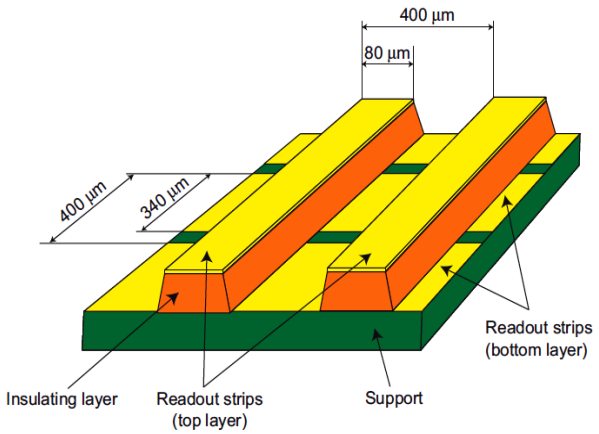
Back Tracker (X-Y strips) GEM layers:

- **50 GEM modules of active area 60 cm × 50 cm fabricated at UVa**
  - COMPASS Triple-GEM design with X-Y strip readout
- 11 layers of active area 200 cm × 60 cm ➔ vertical stack of 4 × modules
- Layer assembly & commissioning at JLab (2019 -)
- Most Back Tracker layers used in SBS spectrometer trackers
- **One layer operated in Bigbite during GMn run (Sept 2021 – Feb 2022)**

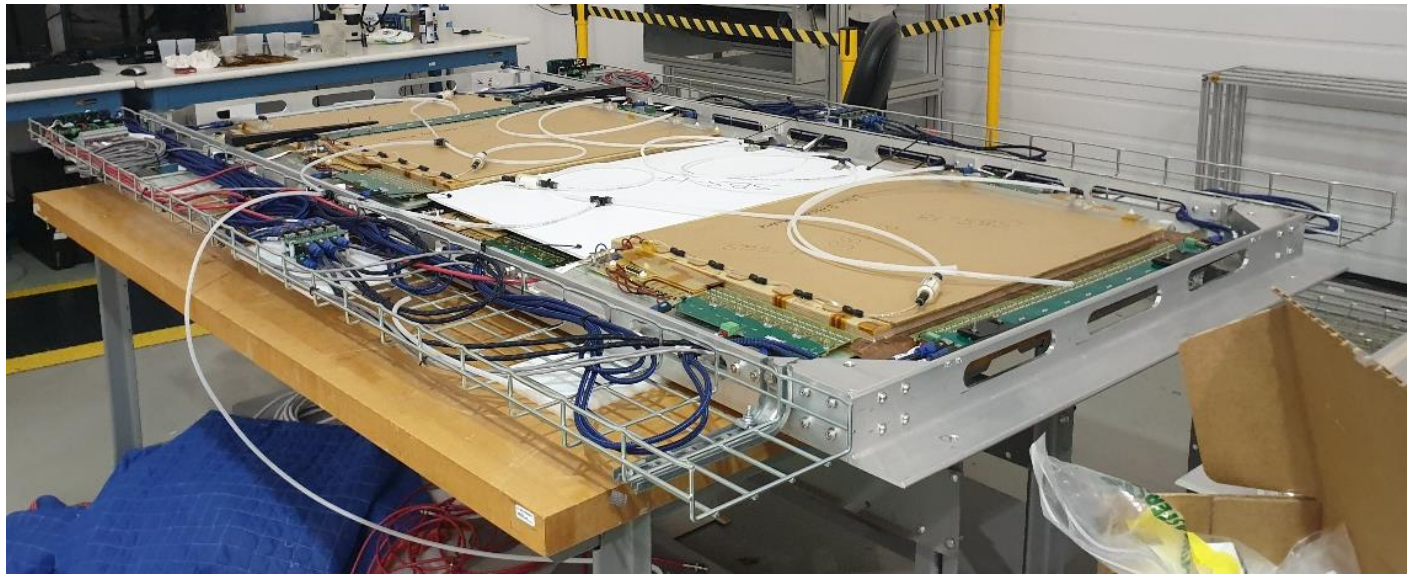
Back Tracker GEMs in Test Beam @ (FNAL, 10/2013)

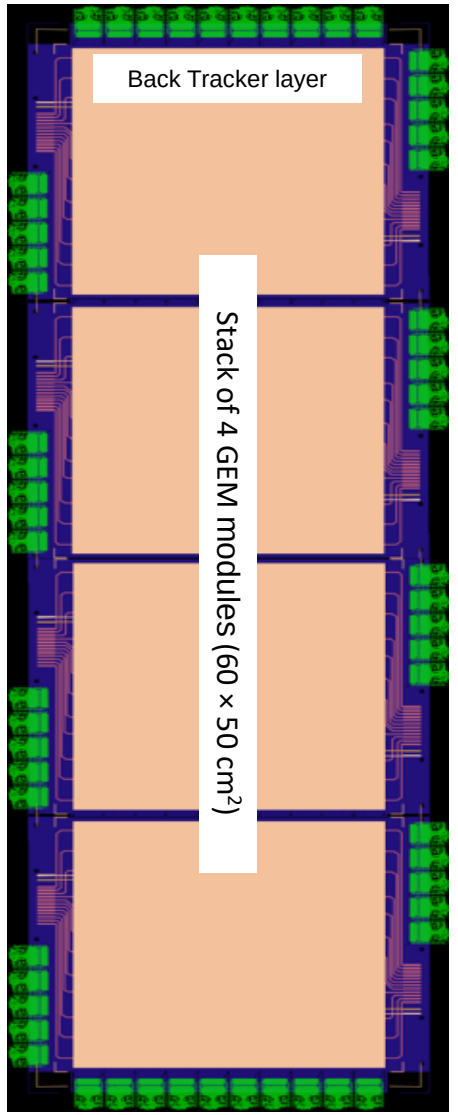


Nucl. Inst. and Meth., A782, 77-86 (2015)



COMPASS X-Y strip readout





Front Tracker (X-Y strips) GEM Layers (INFN)

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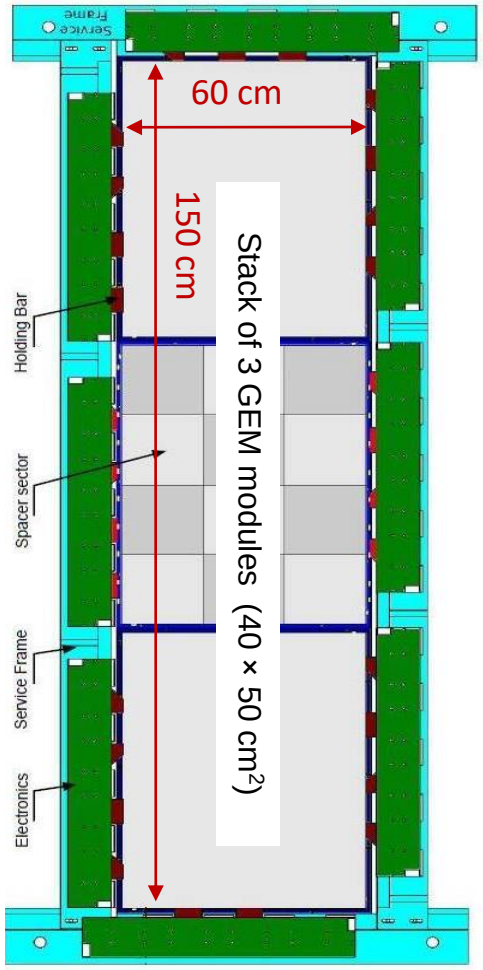
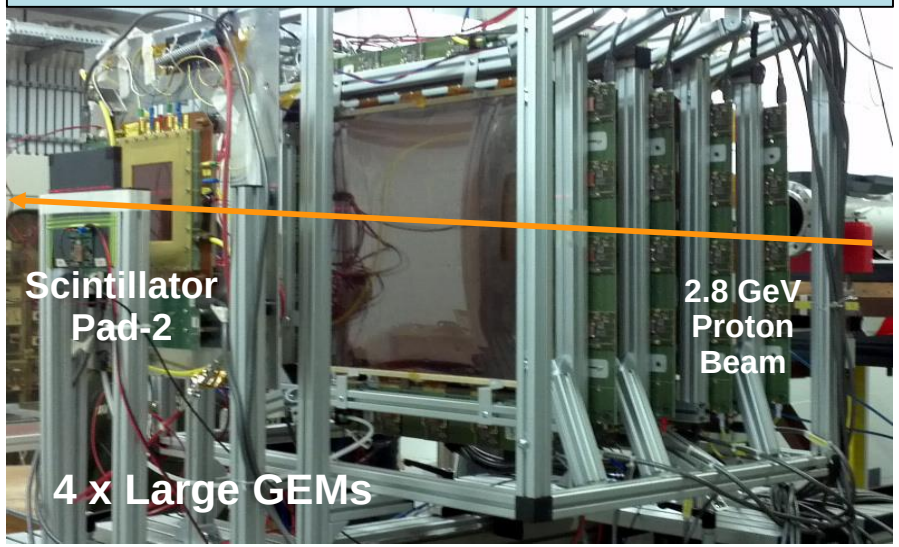
2 INFN GEM layers



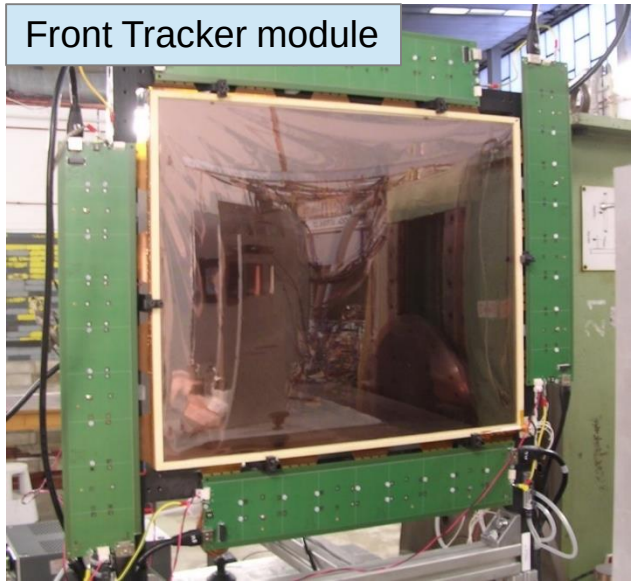
Front Tracker (X-Y strips) GEM layers:

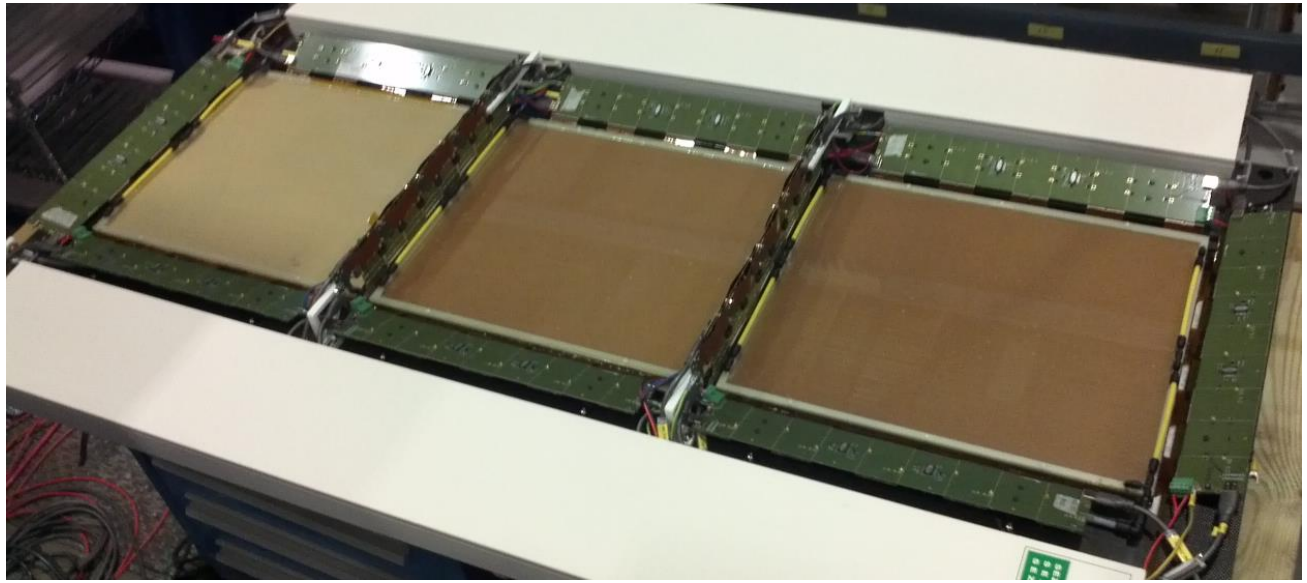
- **24 GEM modules (50 cm × 40 cm) fabricated in INFN Catania / Roma**
  - COMPASS Triple-GEM design with X-Y strip readout
- 6 layers of active area 150 cm × 40 cm ➔ vertical stack of 3 × modules
- Layer assembly & commissioning at JLab (2018 -)
- Front Tracker layers used in both BB & SBS spectrometer
- **Two layers operated in Bigbite for GMn run (Sept 2021 – Dec 2021)**

Front Tracker GEMs in Test Beam @ (Julich COSY, 10/2014)



Front Tracker module





Front Tracker (U-V strips) GEM Layers

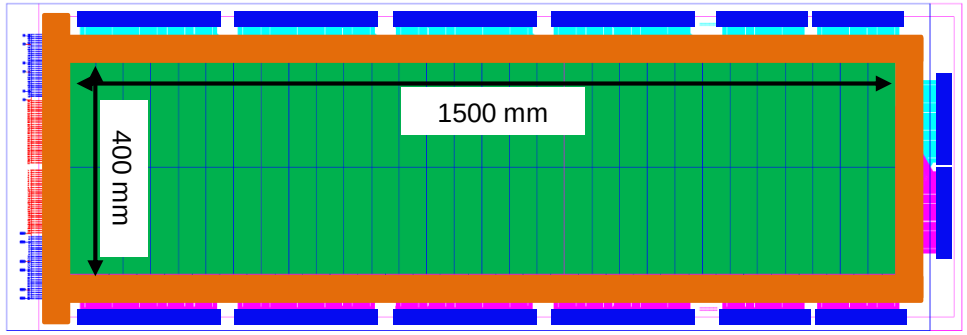
Front Tracker (U-V strips) GEM layers:

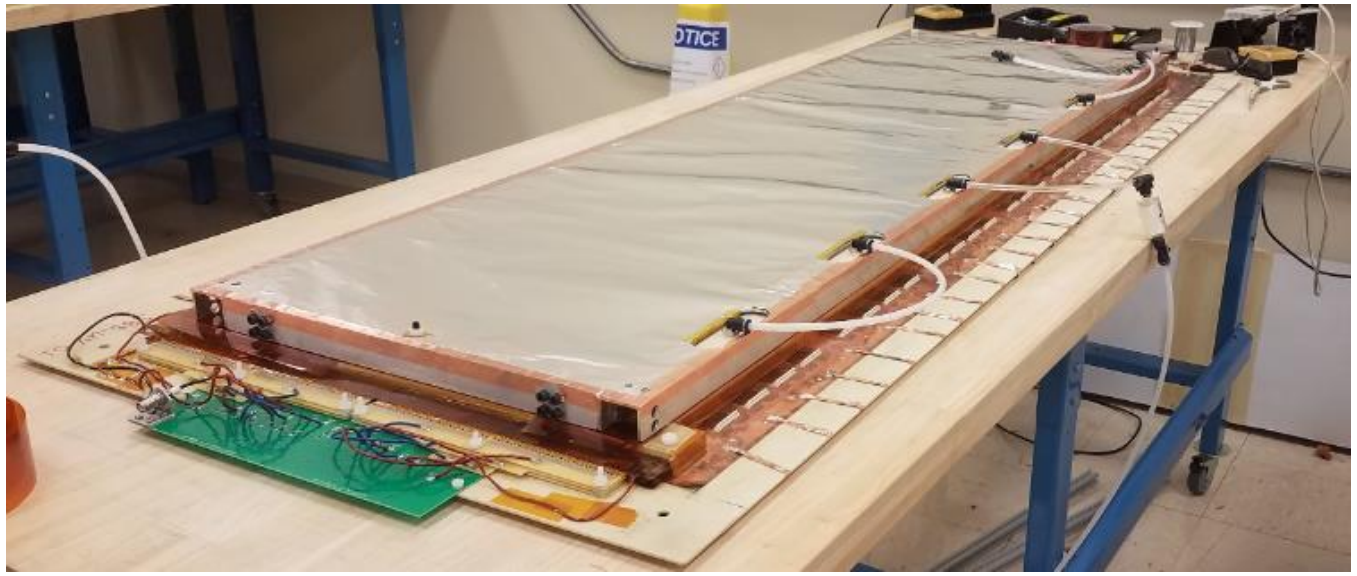
- 4 GEM layers (150 cm × 40 cm) fabricated @ UVa (2020 - 2021)
- Front Tracker layers used in both BB spectrometer
- Two layers operated in Bigbite during GMn run (Sept 2021 – Feb. 2022)
- Two more installed in Bigbite during GMn run (Dec 2021 – Feb. 2022)

GEM foil: HV sectors segmentation on both sides of the foil

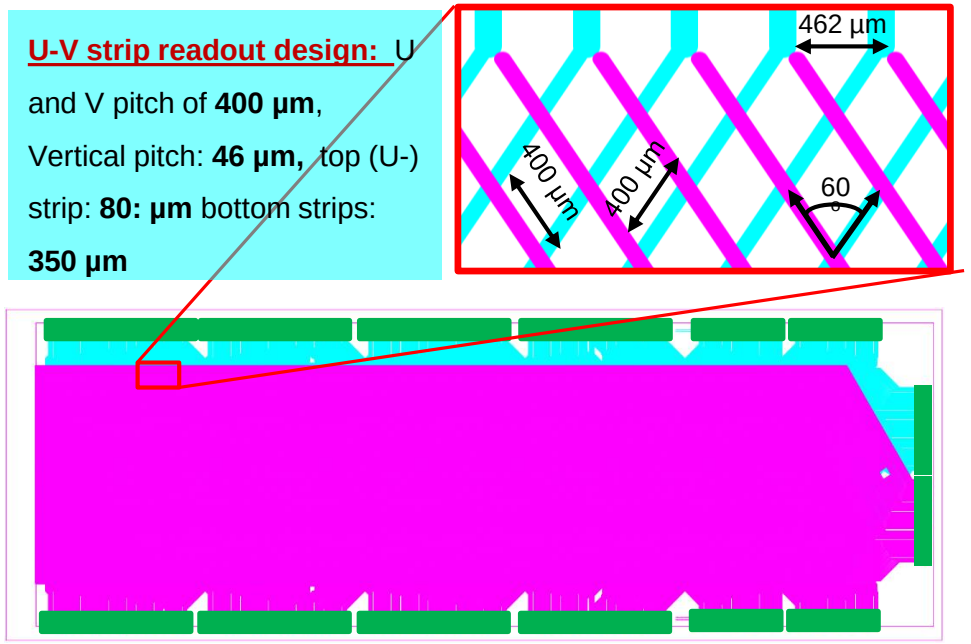
⇨ A short sector does not jeopardize the operation of whole layer

⇨ Limit the effect of discharge on the electronics





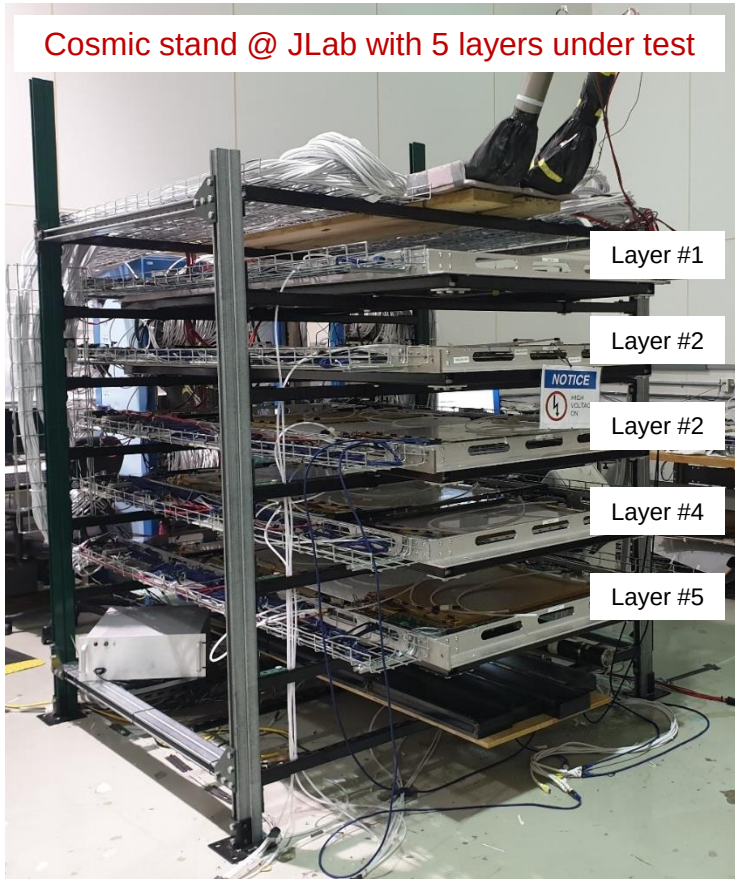
U-V strip readout design: U and V pitch of **400 µm**, Vertical pitch: **46 µm,** top (U-) strip: **80: µm** bottom strips: **350 µm**

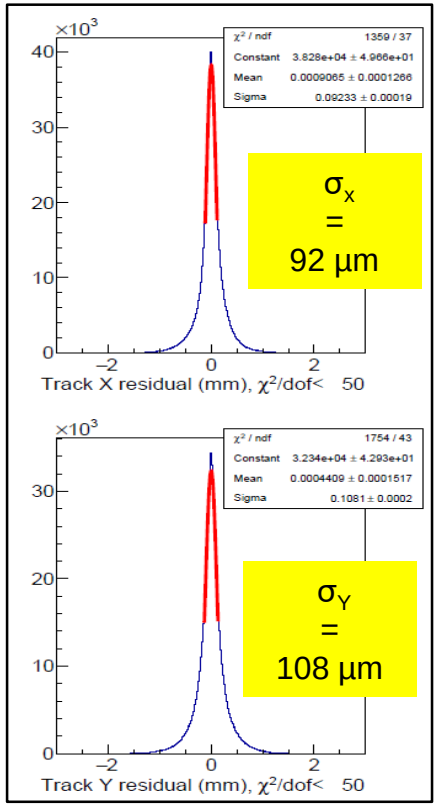


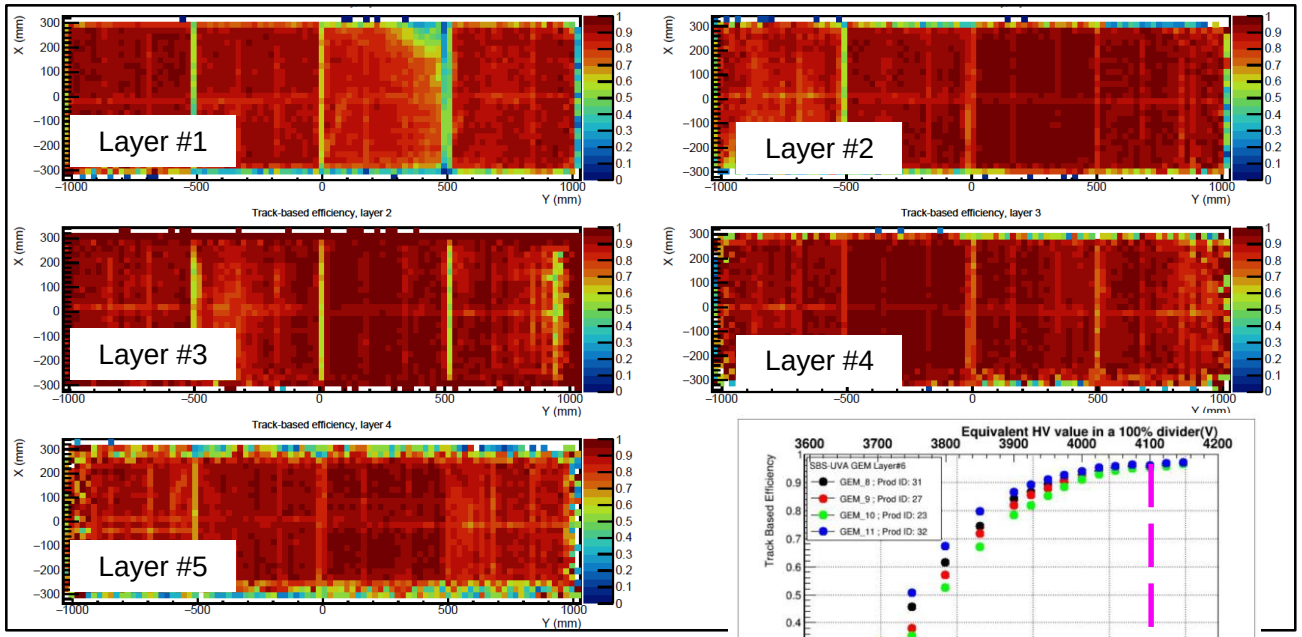
Commissioning of UVa Back Tracker GEMs

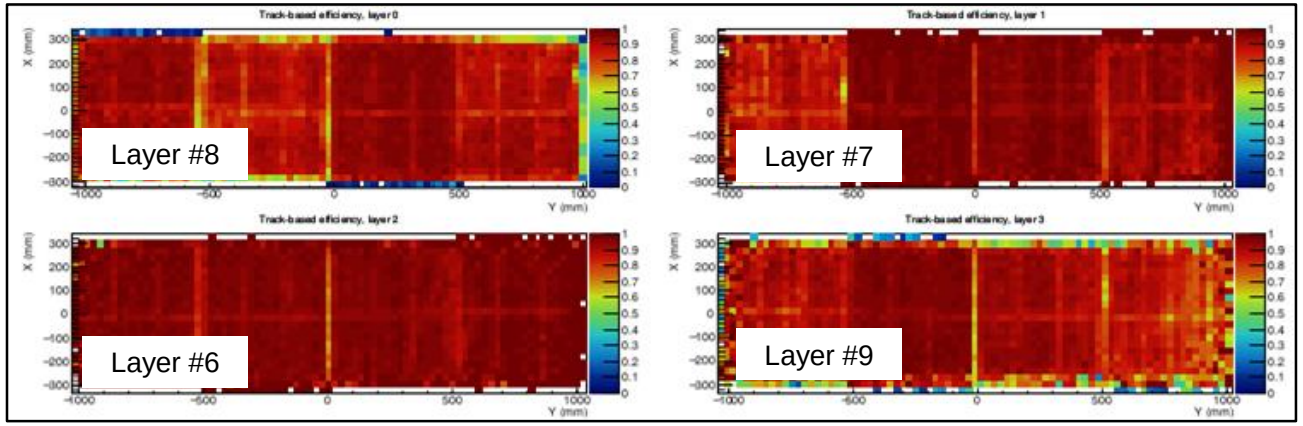
- Assembly of the modules into 11 layers assembly done at JLab
- Commissioning in cosmic at JLab (start 2019, ongoing)
- Good efficiency overall > 95% for most modules
- Spatial resolution with cosmic ~ 100 µm
- **One layer operated in Bigbite during GMn run (Sept 2021 – Feb 2022)**

Cosmic stand @ JLab with 5 layers under test





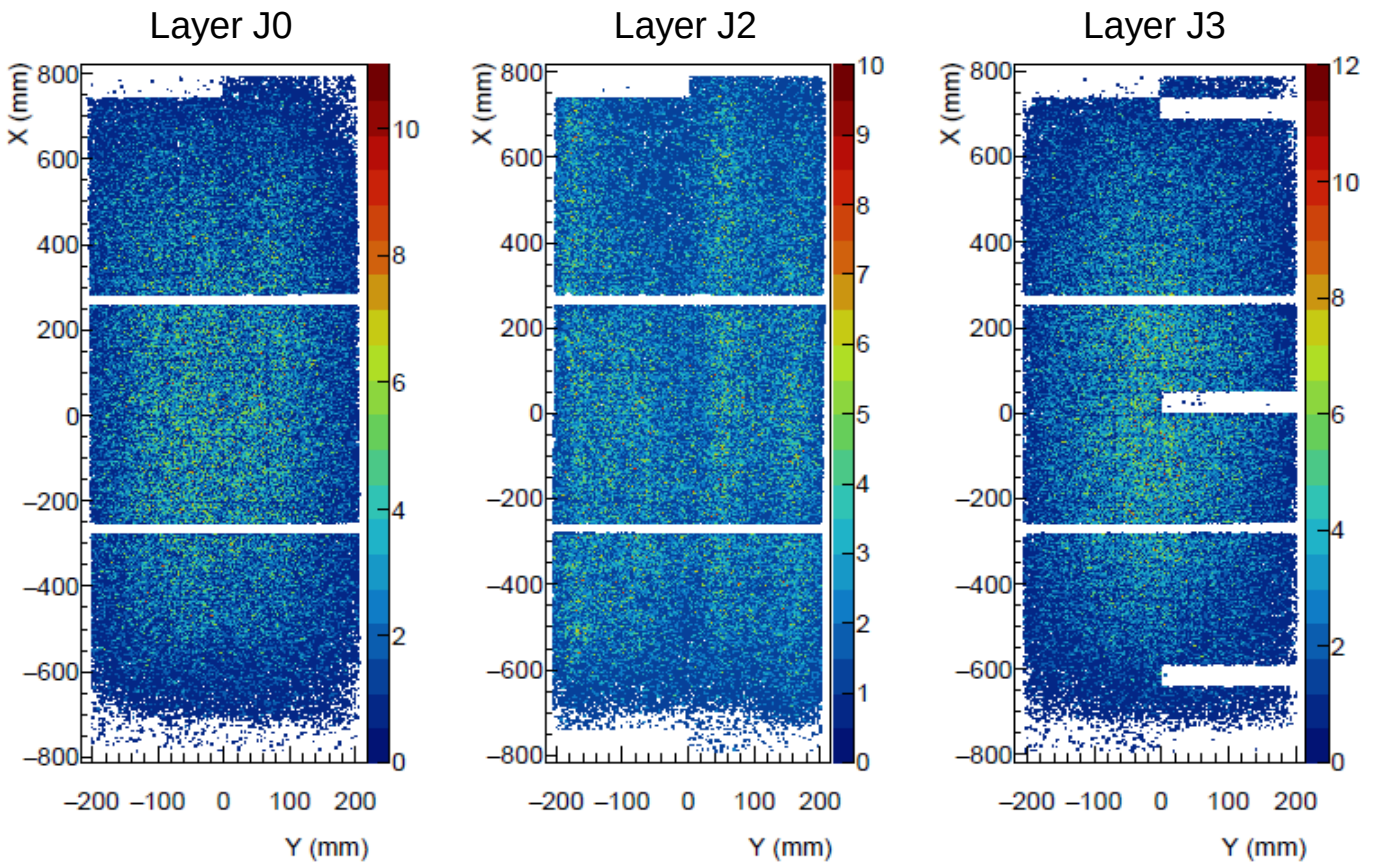




Commissioning of INFN Front Tracker GEMs

- Assembly of the modules into 5 layers assembly done at JLab
- Commissioning in cosmic at JLab (start 2018, ongoing)
- Good efficiency overall > 95% for most modules
- Some issues with a couple of modules under investigations
- **Two layers operated in Bigbite during GMn run (Sept 2021 – Dec 2021)**

INFN GEM cosmic stand in TestLab



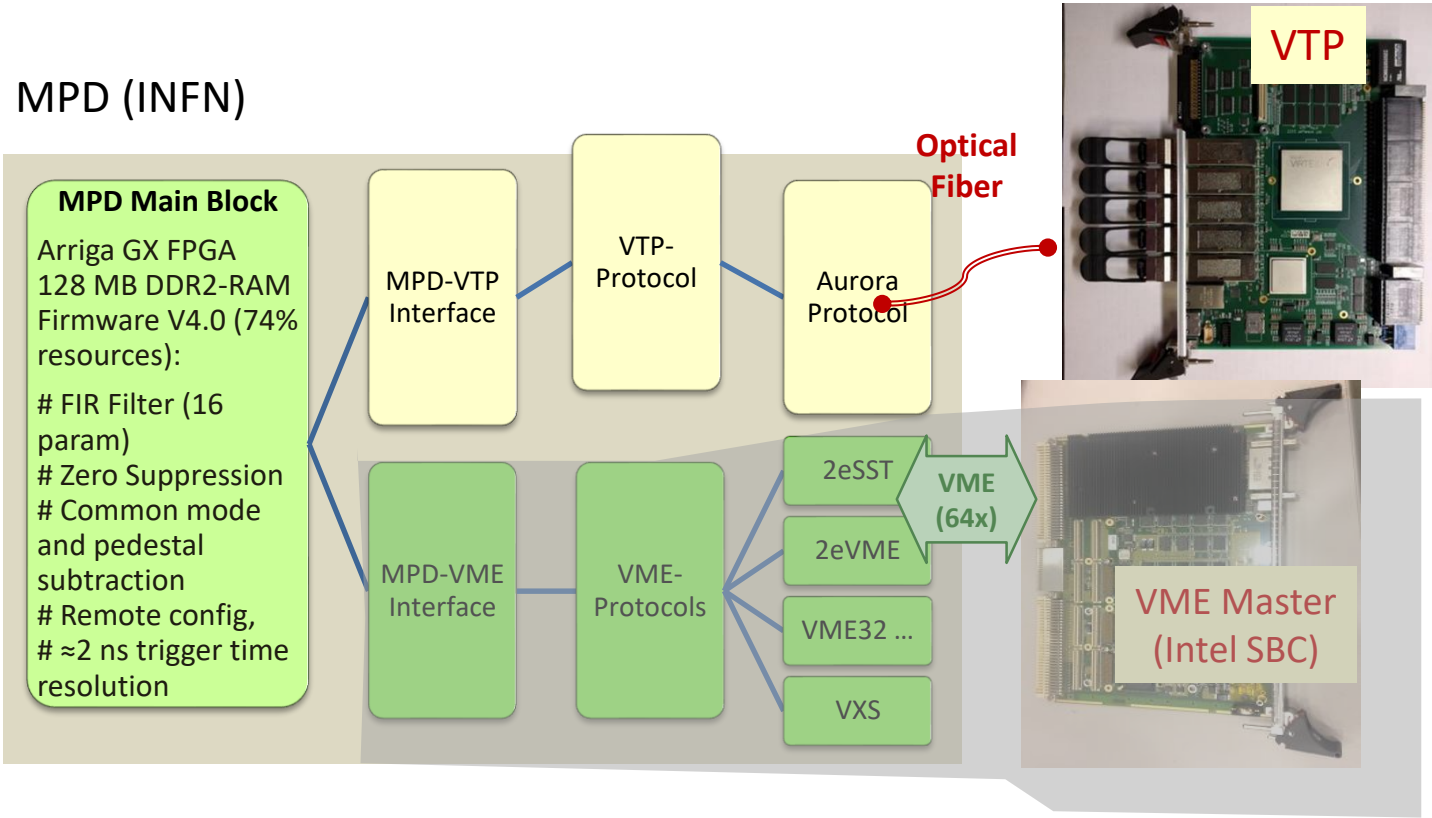
SBS GEM Readout Electronics

- SBS GEM used APV25-based readout electronics,
- The APV25 signals are digitized with the Multi Purpose Digitizer (MPD) readout developed by P. Musico's group INFN Genova
- The system is developed to operate at high trigger rate (!5 kHz) reading out 120k electronic channels
- Online, common mode correction, pedestal subtraction and zero suppression are applied to cope with large data volume

- **128 analog ch / APV25 ASIC**
- **3.4 μs trigger latency** (analog pipeline)
- Capable of sampling signal at 40 MHz
- Multiplexed analog output (**100 kHz readout rate**)

	Channels	APV25	MPDs
UVa GEMs	124,000	968	77
INFN GEMs	14,000	108	8
U/V GEMs	16,000	120	8

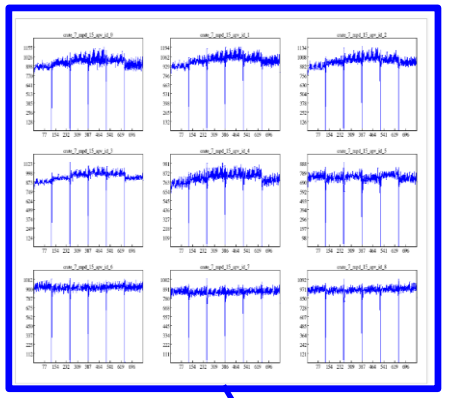
MPD (INFN)



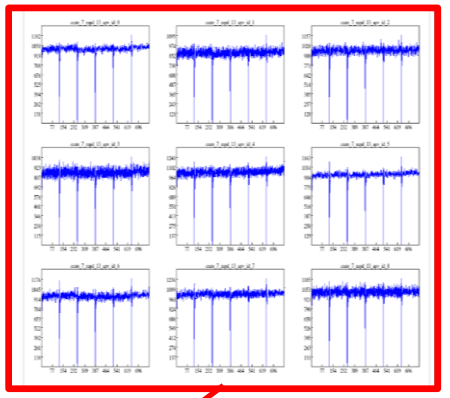
APV25 Common mode mitigation: GEM shielding

- Large APV25 common mode (CM) fluctuation observed when connected to long strips of SBS GEMs and in a noisy environment such as Hall A
- Careful RF shielding of the GEM modules does not fully suppressCM fluctuation but significantly reduce its magnitude by at least a factor 3 ~ 4
- This reduction is critical and sufficient to consider online CM correction, pedestal subtraction and zero suppression during GMn run.
- RF shielding was implemented to all modules for the 3 types of GEM chambers before installation in BB spectrometer

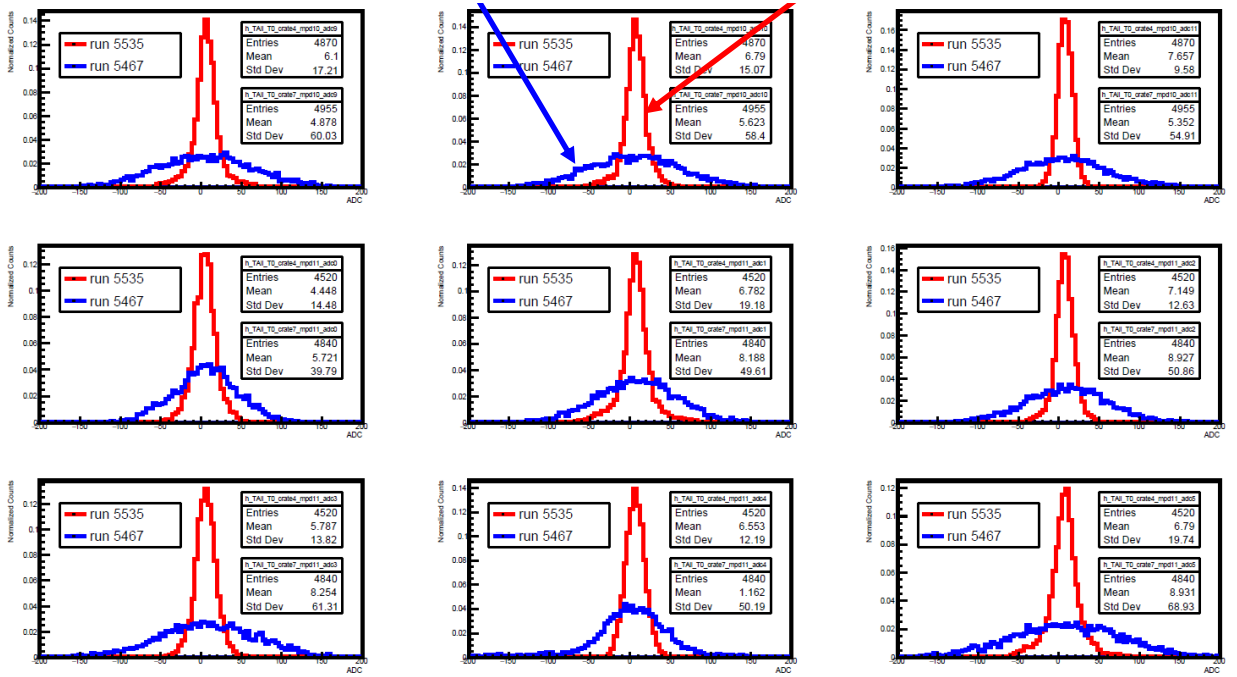
Before shielding



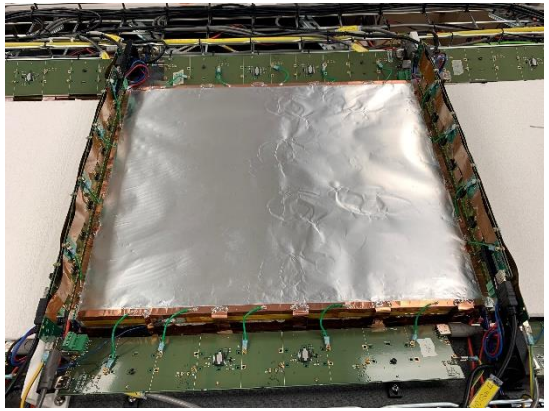
After shielding



Distribution of APV25 CM fluctuation w.r.t first time slice



Shielded INFN GEM module

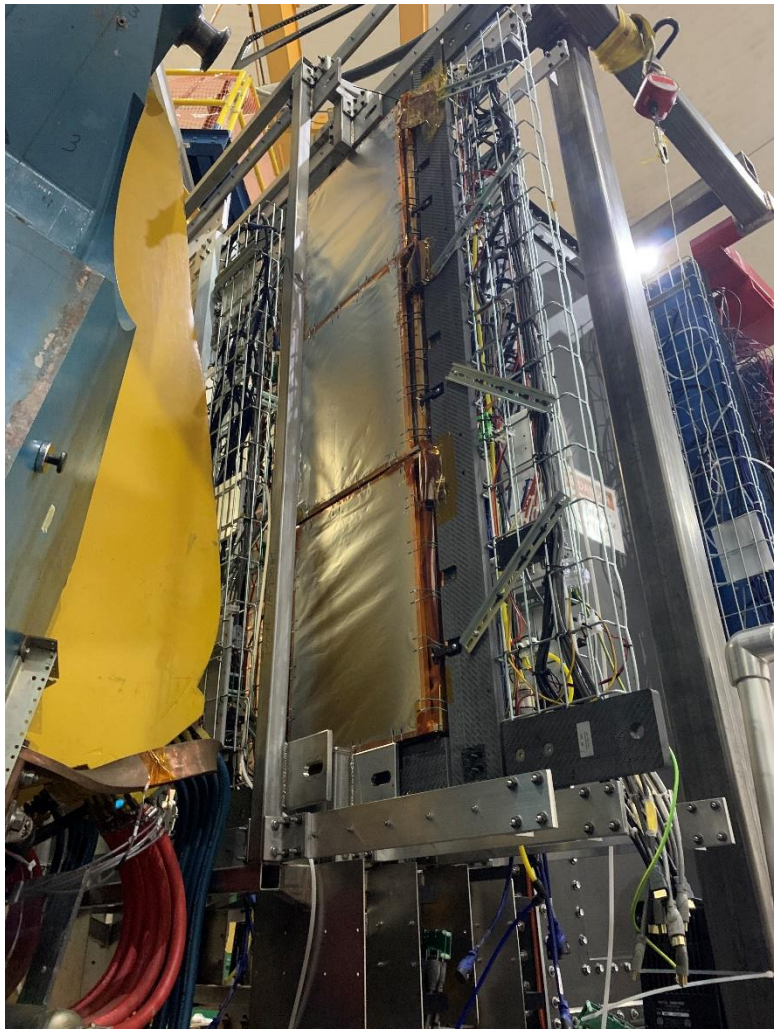


Shielded UVa GEM layer

Outline

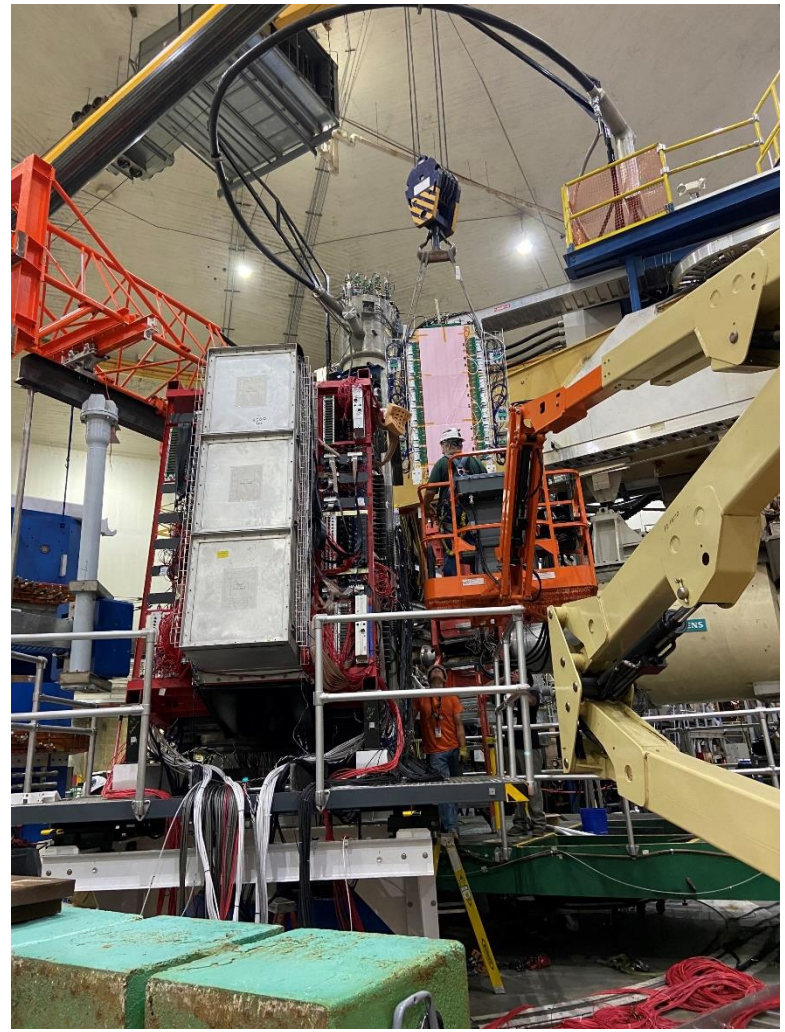
- SBS physics program in Hall A @ JLab & SBS GEM trackers
- Performance of SBS GEMs during GMn experiment
- Preparation for the coming SBS runs

Installation of the GEM layers in BB Spectrometer



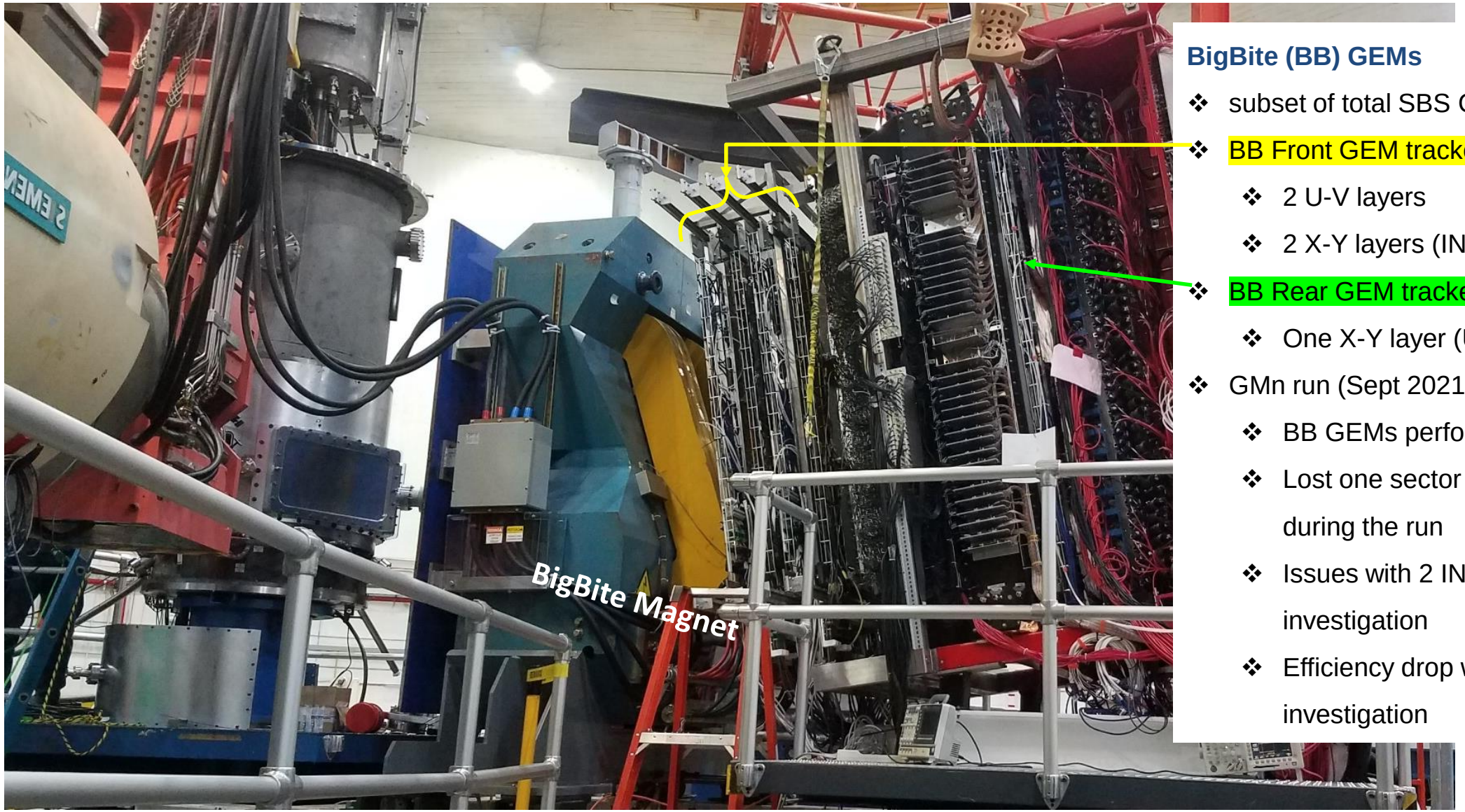
Front Tracker INFN layers **(May 2021)**
Installed in TEDF

Back Tracker layer **(May 2021)**
Installed in TEDF



Front Tracker U-V layers **(July 2021)**
Installed in the Hall

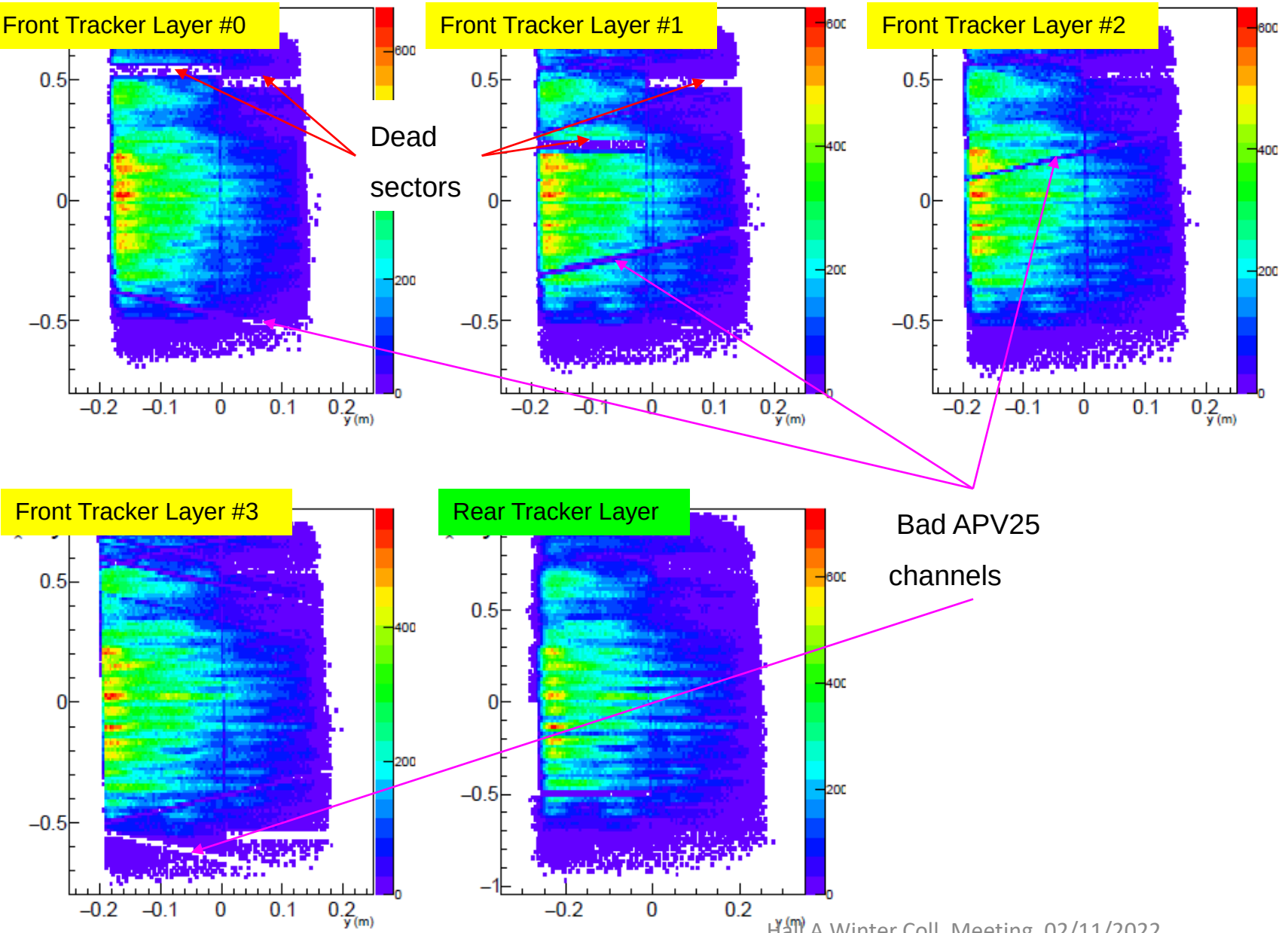
GEM trackers in BigBite Spectrometer



BigBite (BB) GEMs

- subset of total SBS GEM layers (5 out of 17)
- BB Front GEM tracker (150cm × 40cm):
  - 2 U-V layers
  - 2 X-Y layers (INFN)
- BB Rear GEM tracker (200cm × 50cm):
  - One X-Y layer (UVa)
- GMn run (Sept 2021 - Feb 2022)
  - BB GEMs performing very well
  - Lost one sector each in 2 U-V layers during the run
  - Issues with 2 INFN layers under investigation
  - Efficiency drop with high rates ➔ under investigation

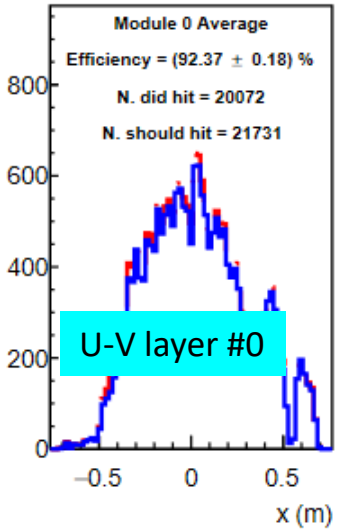
Bigbite GEM Performances: 2D hit maps

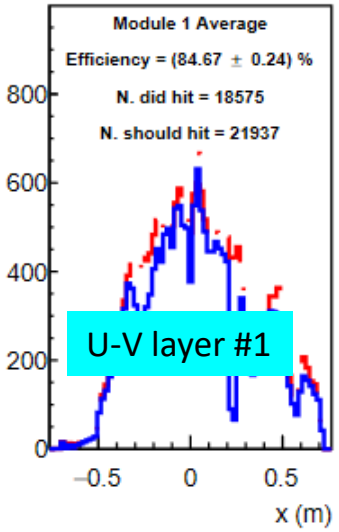


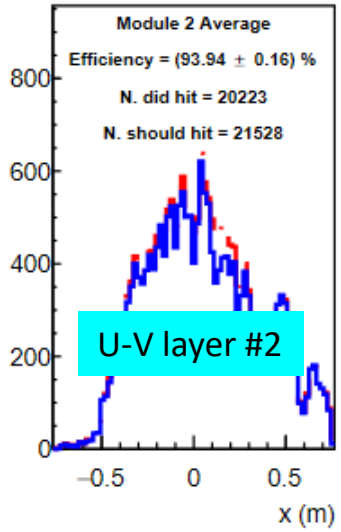
- Hit map in the 5 layers from a large data replay
- Total of 6 dead sectors in all 5 layers ➔ 1 dead sector ~1.5% layer active area
- 2 UV layers have 2 dead HV sector each
- The other 2 have 1 dead sector each
- No dead sector in the 4 back tracker modules
- **Only 2 out of all 6 dead sectors** happen during GMn run ➔ Good sign on the stability of the chambers
- The other 4 occurred during construction of the chambers
- Most of dead sectors were in low acceptance region of the chambers ➔ little impact in GEM efficiency
- Few APVs channels missing ➔ lost of efficiency

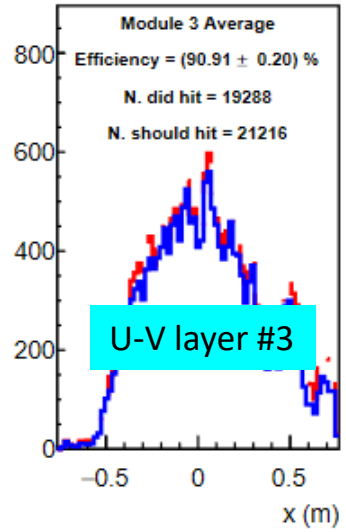
GEMs Efficiencies on LH2 target @ 1 μA electron beam

Front Tracker Layers

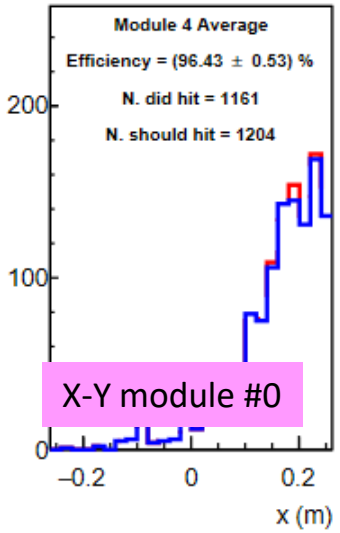


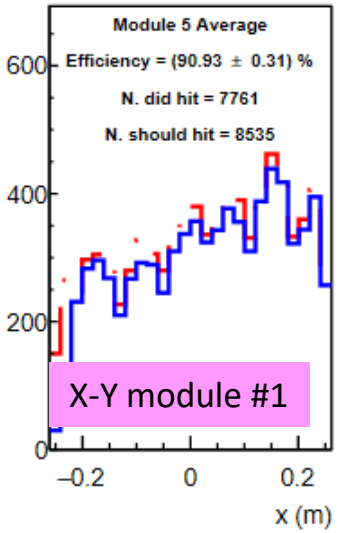


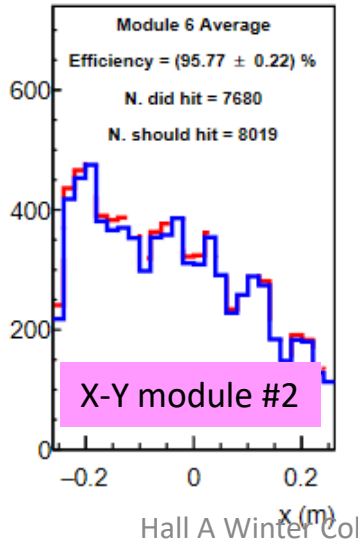


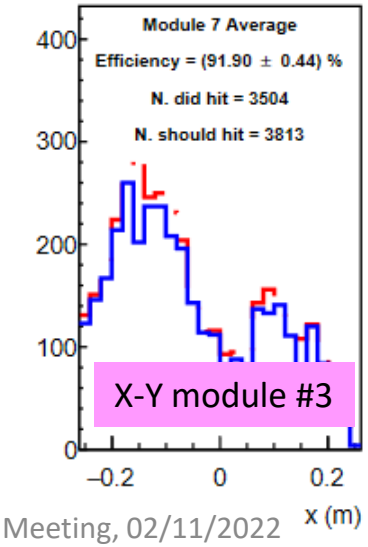


Back Tracker Layer







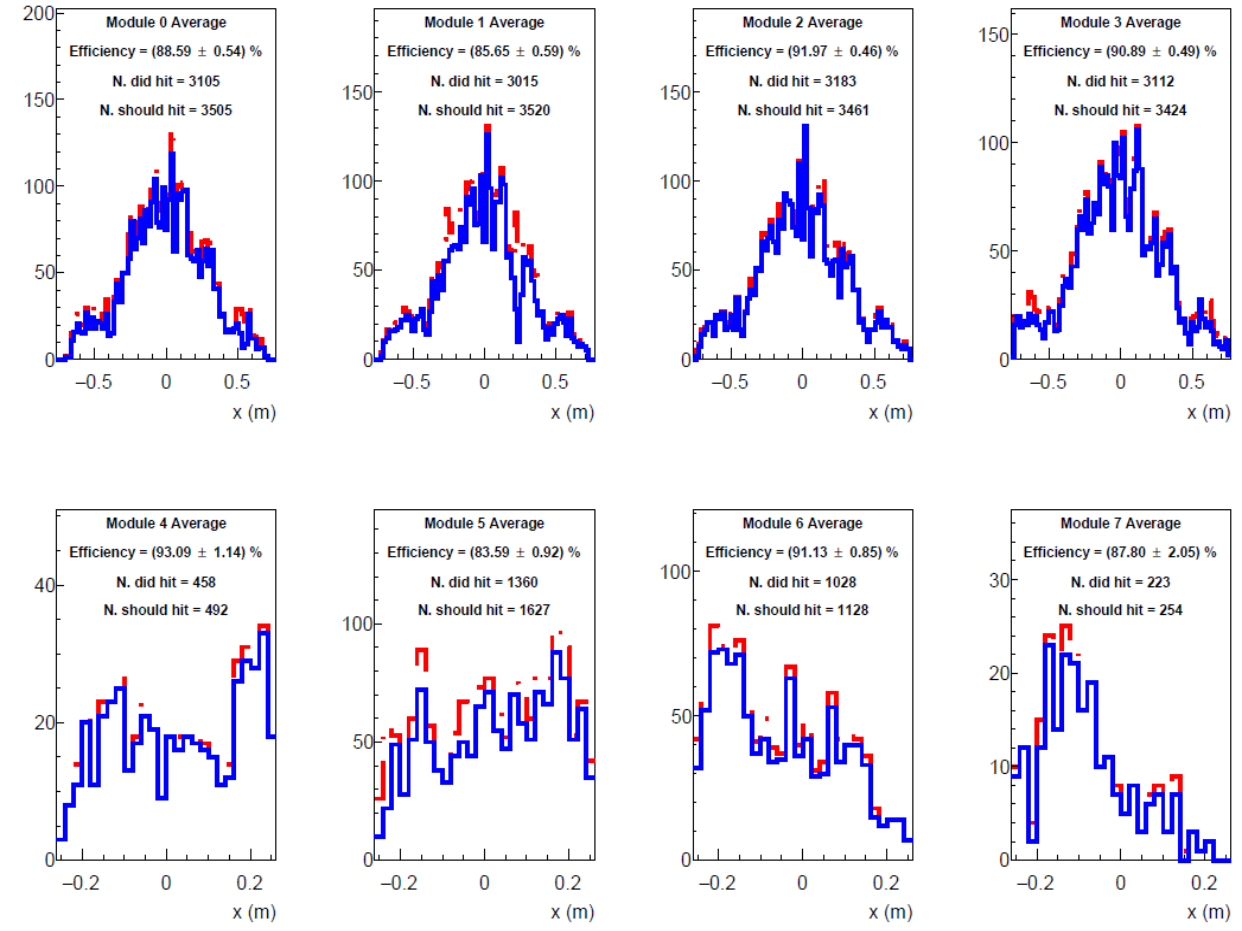


- Overall detector efficiency very high at low beam current 1 μA
- All layer's performances remained steadily stable during the full run
- Efficiency drops with high beam current (see next slides
- Several causes for the efficiency drops under investigation

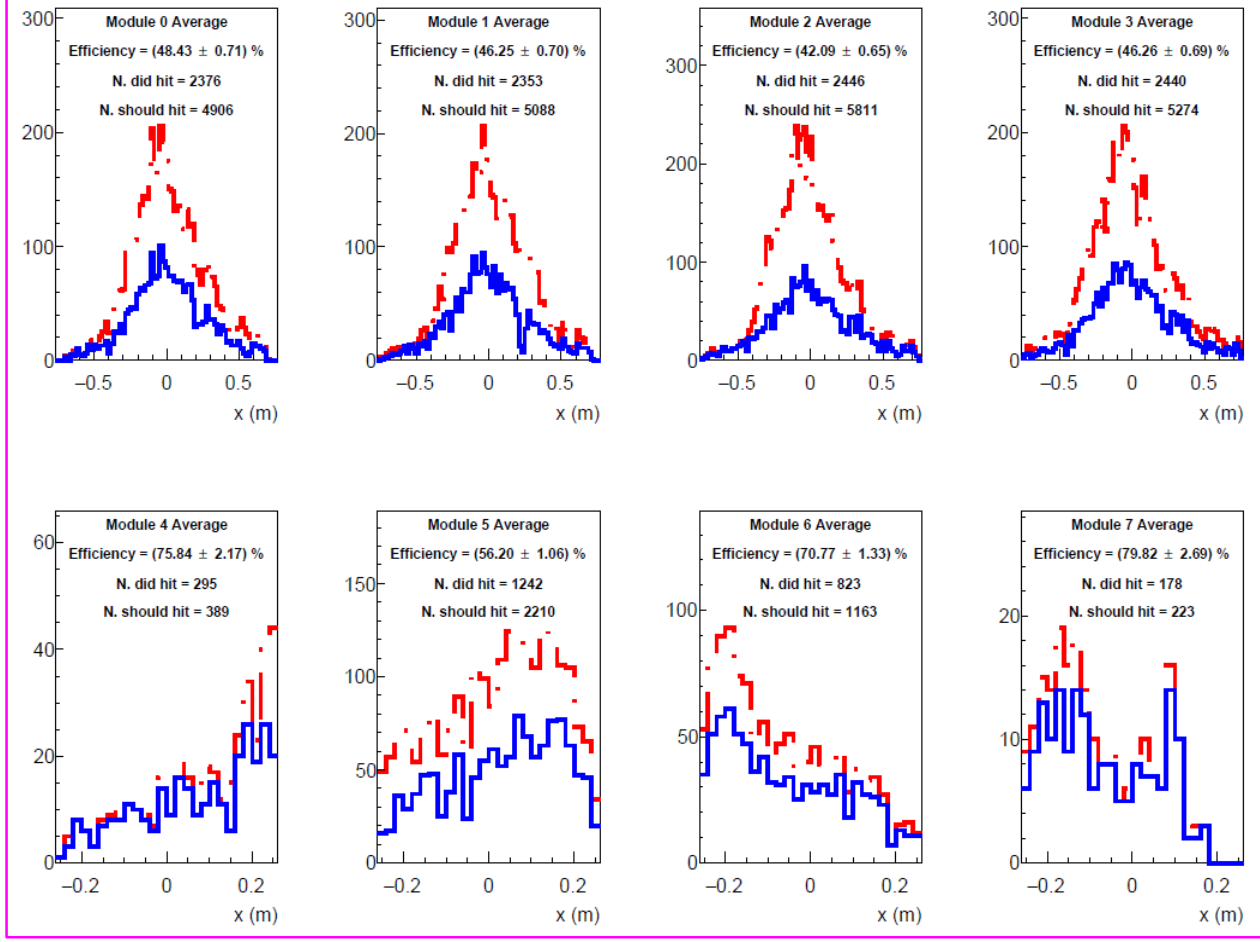
GEM layers Efficiency on LD2 @ 1 μA & 5 μA beam current

- We observe significant drop of the layer efficiency with the beam current increase i.e. particle rate in the chambers
- This was expected to some extent as we are using a standard triple GEM HV divider to power the chambers

Efficiency for 1 μA beam current

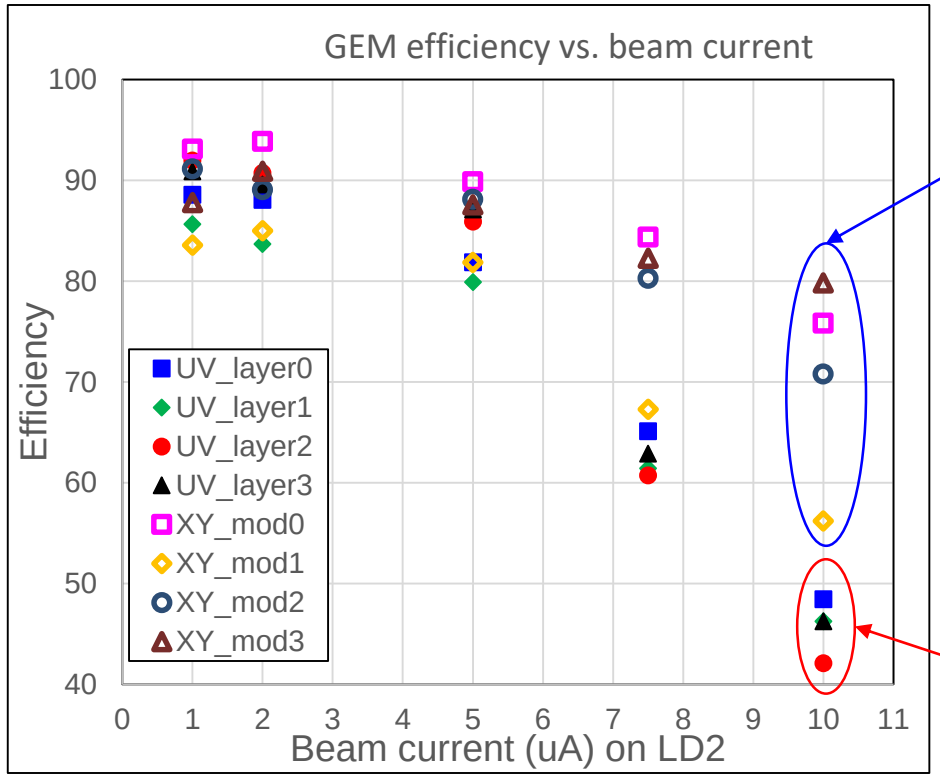


Efficiency for 5 μA beam current



GEM efficiency drop vs. beam current

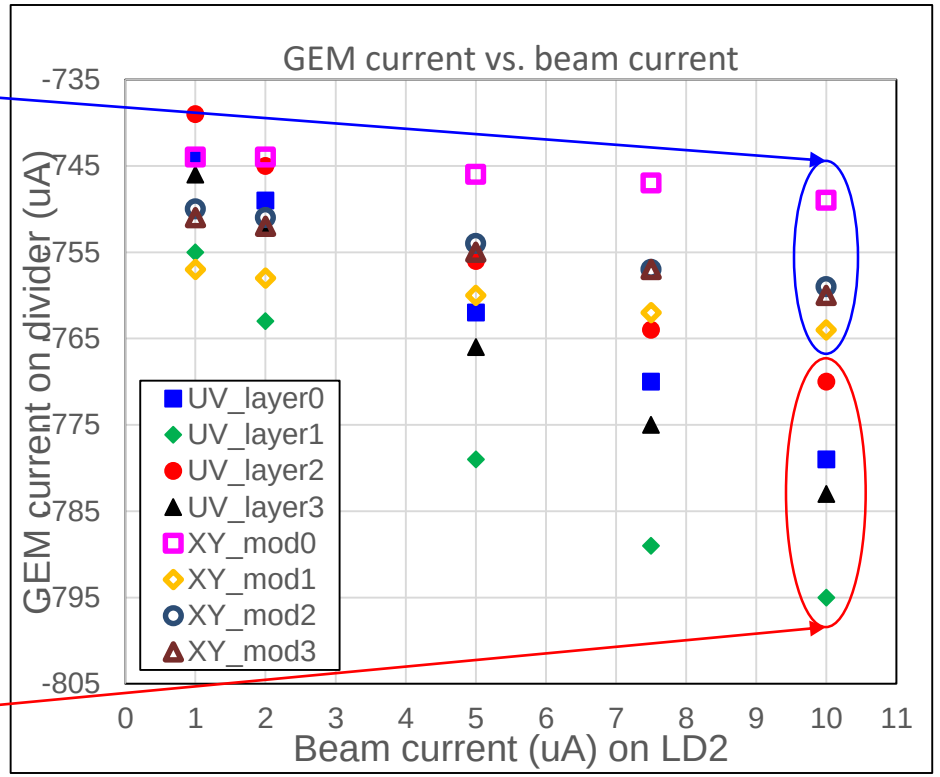
- We observe significant drop of the layer efficiency with the beam current increase i.e. particle rate in the chambers
- This was expected to some extent as we are using a standard triple GEM HV divider to power the chambers
- The current induced in the divider from the huge amount of GEM avalanche charges modifies the resistance of the divider and therefore the HV applied to the GEM foils ➔ resulting in gain drop and subsequently efficiency drop (plots below)
- Correlation between GEM current increases and gain drop is however not perfect ➔ **Another source contributing to efficiency drop**



Back tracker GEM modules behind GRNCH

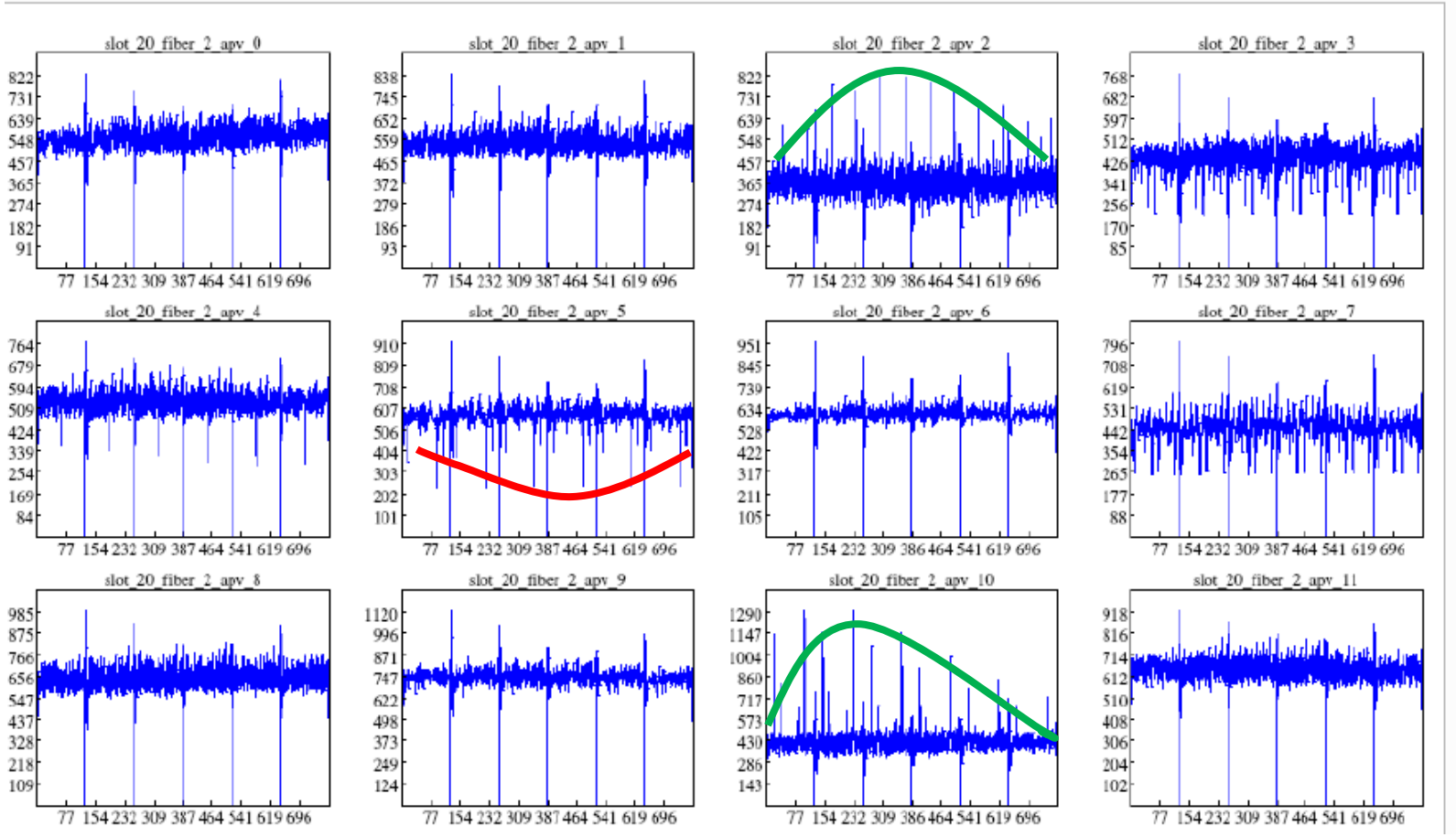
Correlation GEM efficiency & GEM current

Front tracker UV GEMs



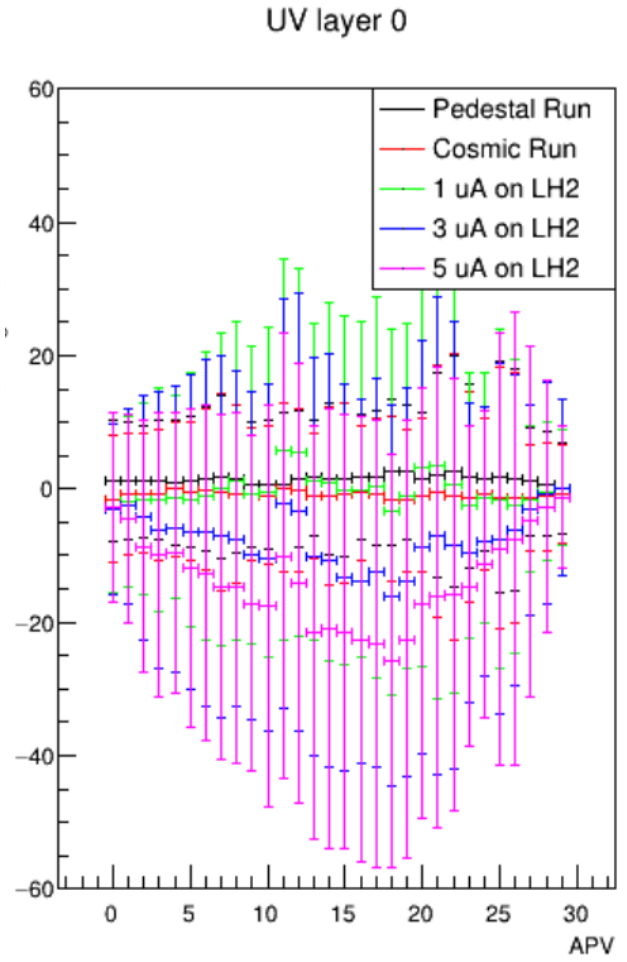
APV25 “negative” pulses:

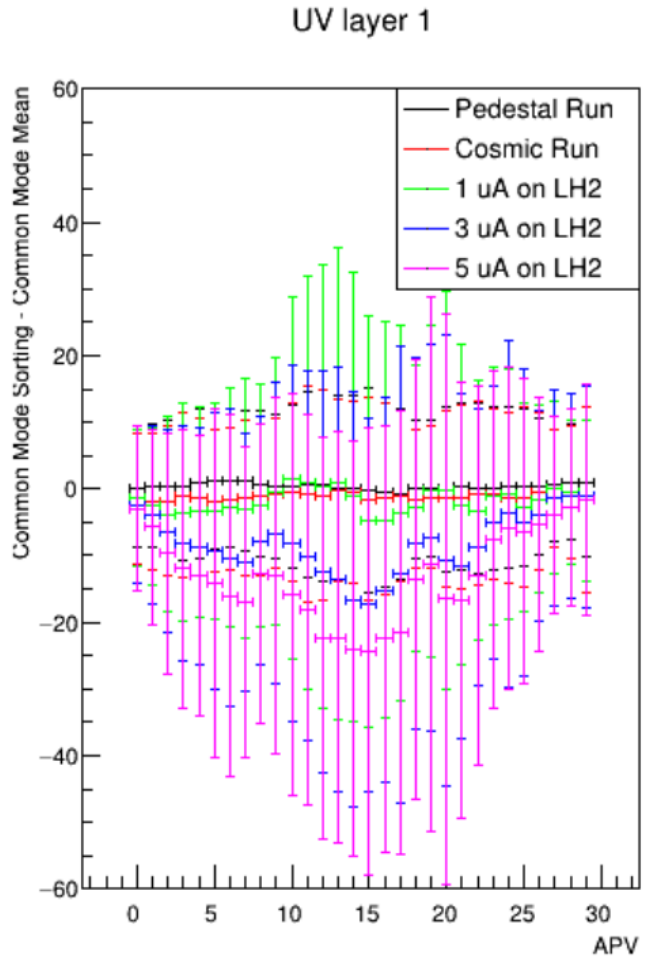
- Observe a lot of “negative” pulse / inversed polarity (red curves) in the APV25 raw data during GMn data taking in the hall
- The rate of these negative APV pulses increases with the particle rate in the chamber
- Such pulses were not observed during the cosmic during commissioning before installation in the hall but are present even with cosmic run in the hall
- Negative impact of the pulses on the efficiency of the chamber is source of concern for the current and future experiments
- We don’t really understand what causes these pulses
- These observation are just preliminary, and the effect is still been investigated



APV25 negative signals issue: Impact on common mode

- Impact of the negative pulse on common mode (CM) correction coefficients could be seen on the plots
- As beam current increases, the deviation of the calculated CM offset values from the nominal CM offset obtained from pedestal run increases ➔ Common correction become less effective, resulting in increase of fake hits and fake tracks rate in the chambers for tracking analysis
- These observations are preliminary, but we already have strong evidence of the impact on the efficiency of the plots
- Luckily, we can relatively easily fix this aspect of the negative pulses for the coming experiments ➔ develop a more robust CM correction method for online zero suppression
- It is even possible to recover from the data already taken for GMn ➔ CM mode offsets values are recorded in the GMn GEM data stream on event-by-event basis





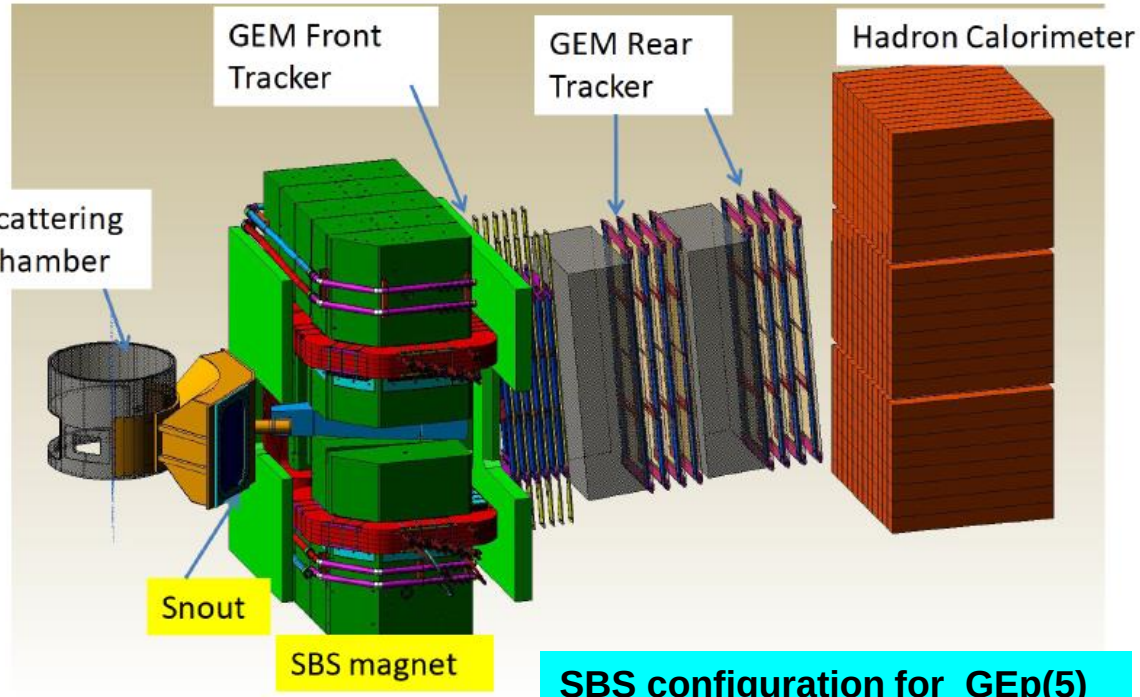
Outline

- SBS physics program in Hall A @ JLab & SBS GEM trackers
- Performance of SBS GEMs during GMn experiment
- Preparation for the coming SBS runs

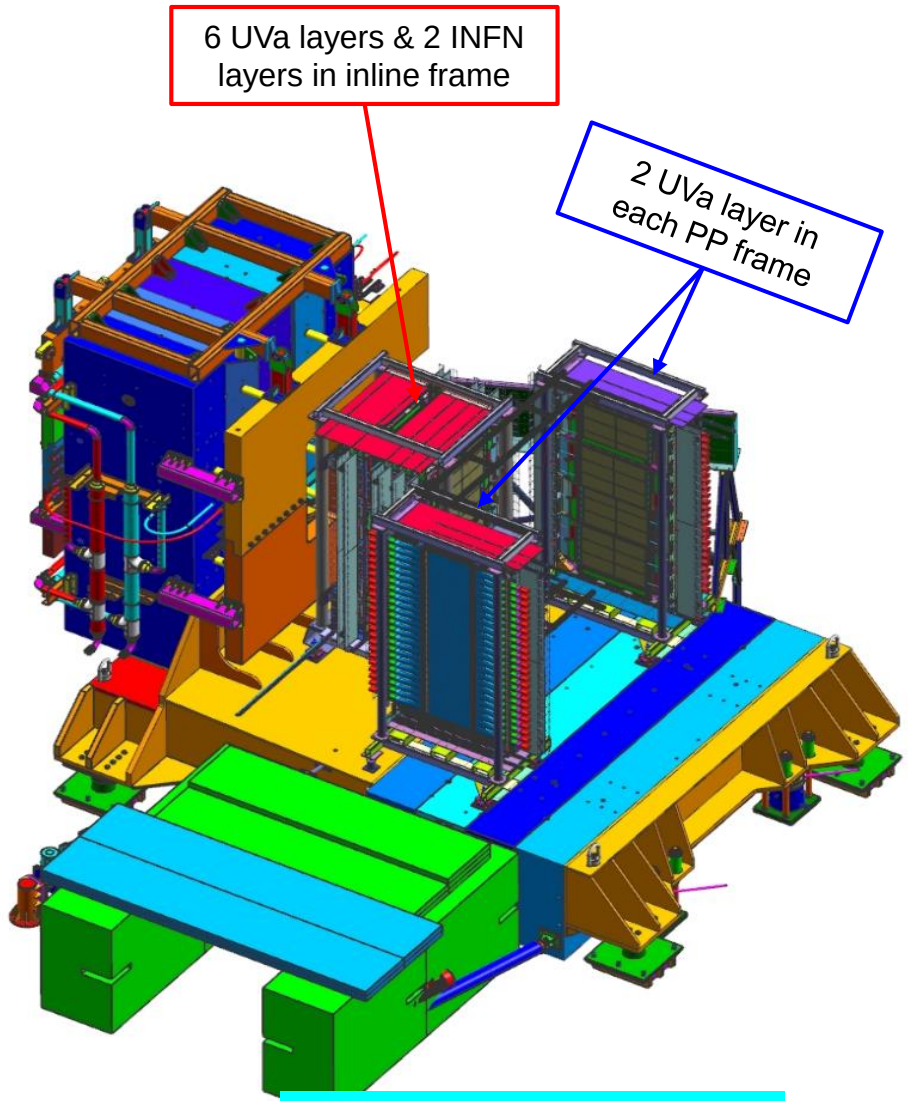
Preparation for upcoming SBS GEn, Gep(5) and GEn-RP

Upcoming GEp 5 (E12-07-109) and GEn-RP (E12-17-004)

- Remaining 12 layers (10 UVa layers + 2 INFN layers) in SBS hadron arm
- Modification on the GEM HV divider and / or HV supply scheme necessary for high-rate environment of GEp (5)
- These additional layers will be installed during SAD for commissioning in beam during **GEn (E12-09-016)** run in fall 2022

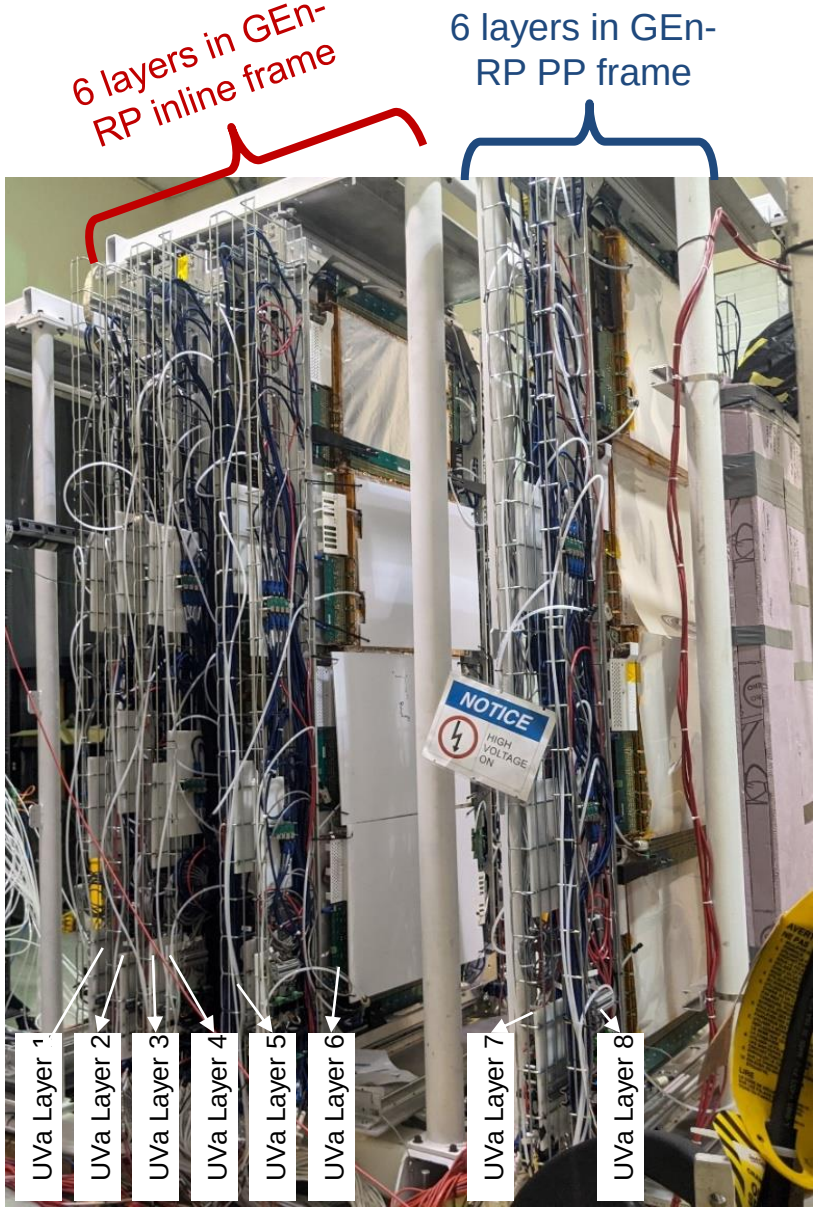


SBS configuration for GEp(5)



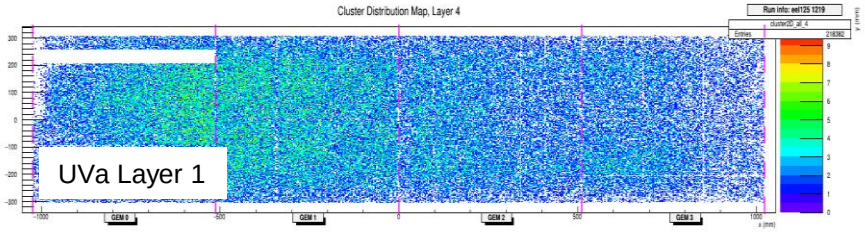
SBS configuration for GEn-RP

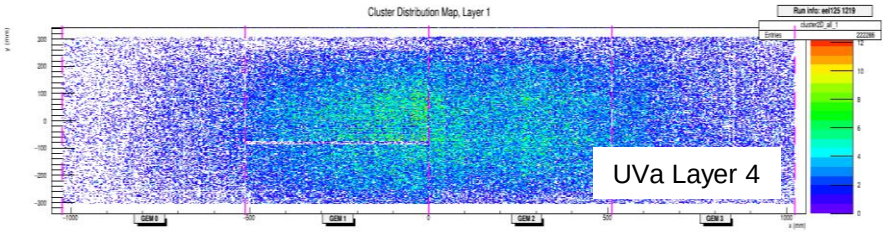
Preparation for upcoming SBS GEn, Gep(5) and GEn-RP

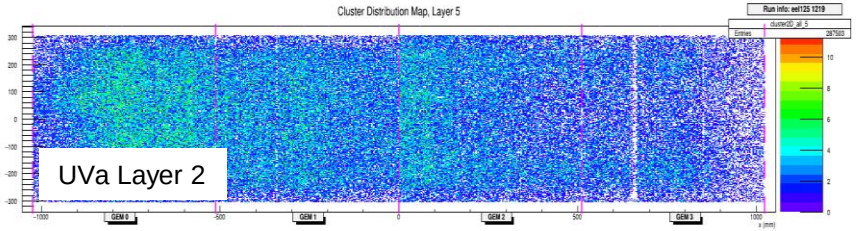


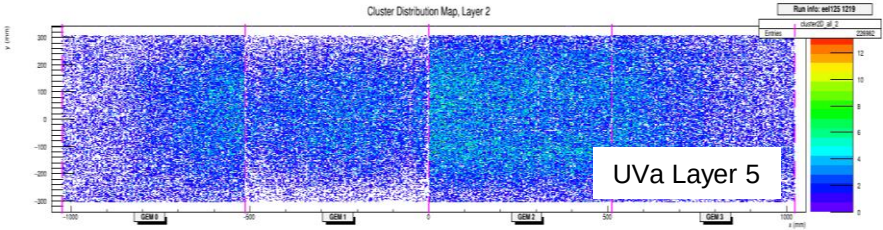
- **Left:** 6 UVa back tracker layers in GEn-RP inline frames & 2 layers in one of GEn-RP PP frame in EEL 125
- **Right:** 2D hit map from cosmic in all 8 layers in GEn-RP frames in EEL 125

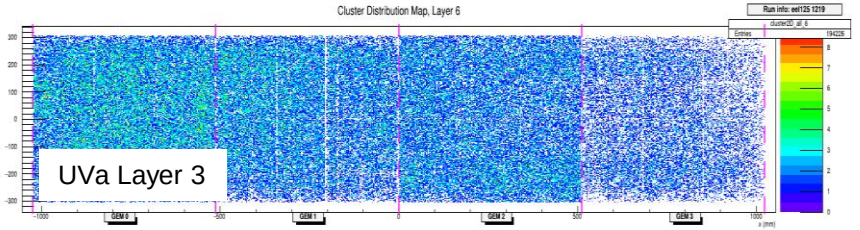
➔ Ongoing debugging of DAQ / readout

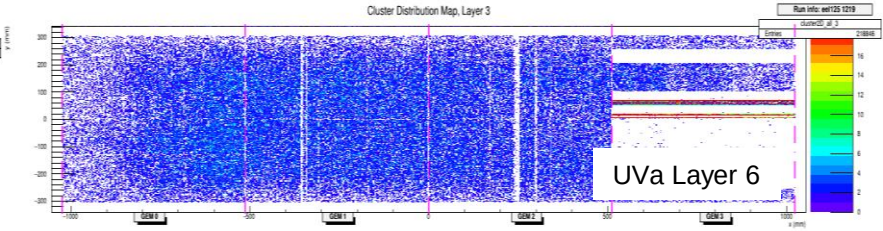


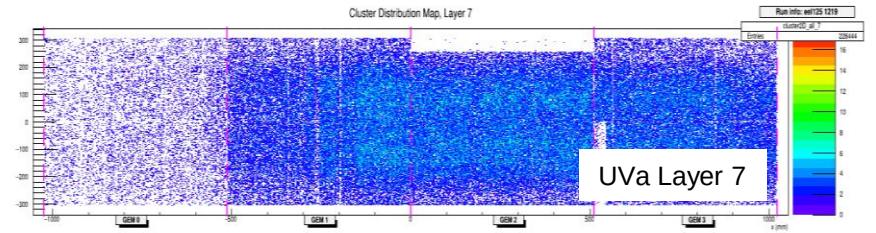


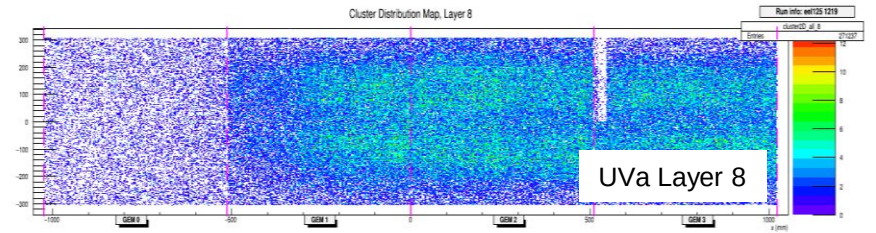








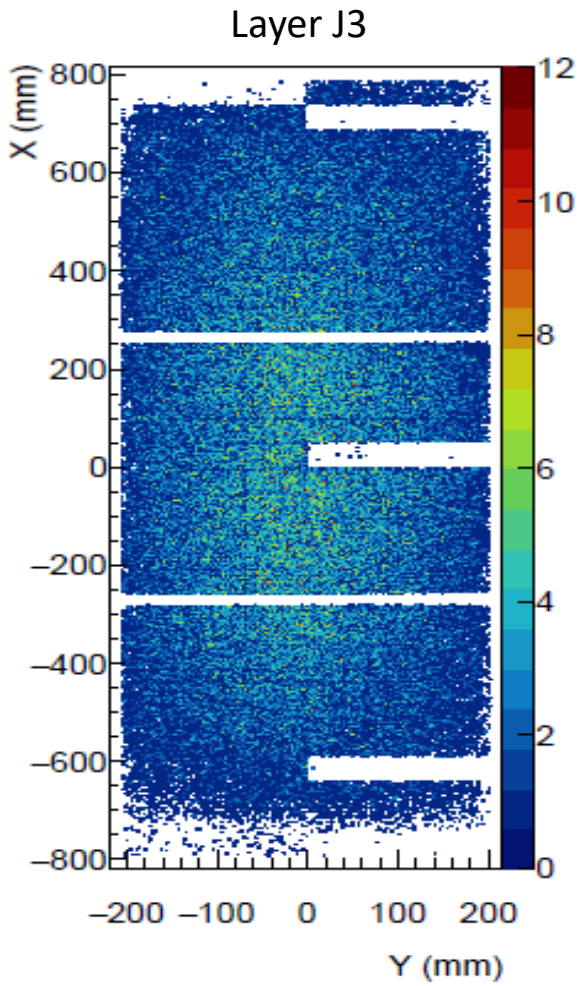




Slide courtesy of J. Boyd

Preparation for upcoming SBS GEn, Gep(5) and GEn-RP

Jefferson Lab
Exploring the Nature of Matter



- **Left:** INFN GEM layers in cosmic stand in Test Lab
- **Right:** XY Hit maps from cosmic data for the 1 INFN GEM layer to go in SBS.
- Note: Layer J1 and J3 are finalized for cosmic test before installation in SBS arm. Layer J4 will require detector debugging, after higher priority tasks completed.

Slide courtesy of E. Wertz

Preparation for upcoming SBS GEn, Gep(5) and GEn-RP

Jefferson Lab
Exploring the Nature of Matter

Upcoming GEp (5) rate and GEM performances :

- **SBS Hadron arm:** Installing shielding next to target to filter out low energy background and reduce rate in GEM by ~ ×4
  - GEM studies with 35 µA on 15 cm LD2 target shows with new divider being developed at UVa (Nilanga's group) to reduce GEM gain drop by ×2 and with a rate reduction through shielding ×4 ➔ SBS Back tracker GEMs will run at full efficiency
- **BB Electron arm:** Bypass HV divider and supply HV to GEM electrodes individually ➔ gain a factor > 8
  - will be implemented only to the 6 Front Tracker GEM layers ➔ To expensive to be considered for all chambers
  - Also combined with rate reduction through shielding ×4, we anticipate that these layers also will operate at full efficiency

APV25 "negative" pulses:

- Develop a more robust common mode correction method for online zero suppression
- Study impact of these issues on GEM performances ➔ Are we losing real hits in the chambers?

DAQ instabilities during GMn run mainly caused by GEM readout problems:

- Take a several of min to restart DAQ after a crash due to GEMs & sometime require several attempts
- GEM electronic for GEp (5) and GEn-RP will be ~4 times larger in number of channels

➔ We would need to investigate ways to make the readout more stable before next run

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Leonardo Re

Ezekiel Wertz

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  - ➔ Fantastic support with installation
- Jack Segal:
  - ➔ Support in Hall A
- Marc McMullen DSG group
  - ➔Develop SBS gas system

Post doc.
Grad students

Summary

- The construction and commissioning of 17 of such large GEM layers were completed by early 2021
  - A subset of these layers were installed in the Bigbite spectrometer
  - successfully operate during the GMn experiment from September 2021 to February 2022.
- GMn gave the first opportunity for in-beam commissioning of SBS GEM layers
  - The chambers performance were stable overall, and preliminary results from data are very encouraging for the future
  - Kudos to all GEM experts who spent de facto week-long “GEM shift” in addition to their normal shift duties, baby-sitting the detectors and running parasitic GEM studies during the experiment
- Lot of lessons learned from this first experience of SBS GEM in experiment
  - SAD will give us the opportunity to implement solutions to the most critical issues we face we the GEMs
- Commissioning of the remaining 12 GEM layers for GEp (5) and GEn-RP is in good shape
  - 8 UVa (X-Y) back tracker layers already installed in GEn-RP frames
  - Remaining 2 already assembled but waiting for electronics before installation in the Gemn-RP frame
  - 2 INFN front tracker layers been tested with cosmic as well
  - The layers will be installed in SBS hadron arm the hall for in-beam commissioning during GEn run this fall

Backup

GEM efficiency vs. Excess GEM current

BigBite (BB) GEMs

- subset of total SBS GEM layers (5 out of 17)
- BB Front GEM tracker (150cm × 40cm):
  - 2 U-V UVa layer (150cm × 40cm)
  - 2 layers of 3 X-Y INFN modules ➔ 50 cm × 40 cm