Commissioning of GEM Trackers for SBS at JLAB

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Personnel

- **UVa:** K. Gnanvo, S.Jian, N. Liyanage, A. Rathnayake
- **HU:** M. Kohl, M. Rathnayake, T. Gautam
- **INFN:** E.Cisbani, P. Musico, R. Perrino, L. Re
- **And many more @ JLab ....**

Outline

- GEM Trackers for Super Bigbite Spectrometer (SBS)
- Commissioning if the GEMs @ JLab
- Timeline for Installation in Experiments
- New Front Tracker with U-V strip readout

Super Bigbite Spectrometer (SBS) in Hall A @ JLab

Nucleon form factors

- Encode electric and magnetic structure of the nucleon
- Parametrize the properties of the quark and gluon
- Limited neutron measurements in terms the Q^2 range and the precision
- Better access to relatively small G_E
- No recoil polarimetery measurement above Q^2 of 1.5 GeV^2

In High Q^2 range:

→ G_E measurement will sensitive to up and down quark distributions in quark core

→ Insight to the complete set of form factors in the region with small pion cloud contributions

Electromagnetic current density of nucleon:

$$\mathcal{J} = e\bar{N}(p')\left[\gamma^{\mu}F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_{\nu}}{2M}F_2(Q^2)\right]N(p)$$

$$G_E = F_1 - \tau F_2$$
$$G_M = F_1 + F_2$$

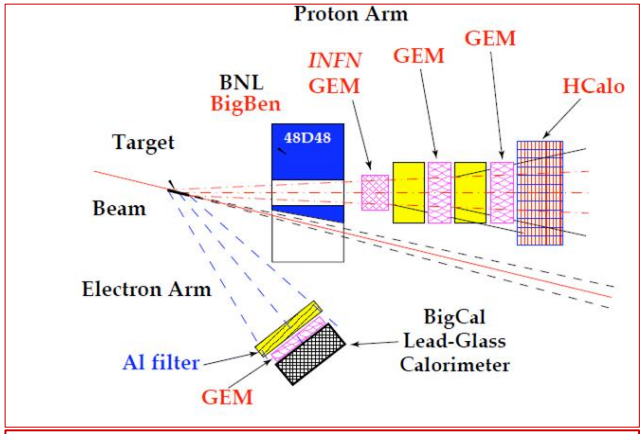
The Super-BigBite Spectrometer (SBS) in Jlab's Hall A will measure the G_E to high Q^2 (>10 GeV^2) using high luminosity + open geometry + GEM detectors

→ Allows for flavor decomposition to distance scales deep inside the nucleon

SBS GEM trackers:

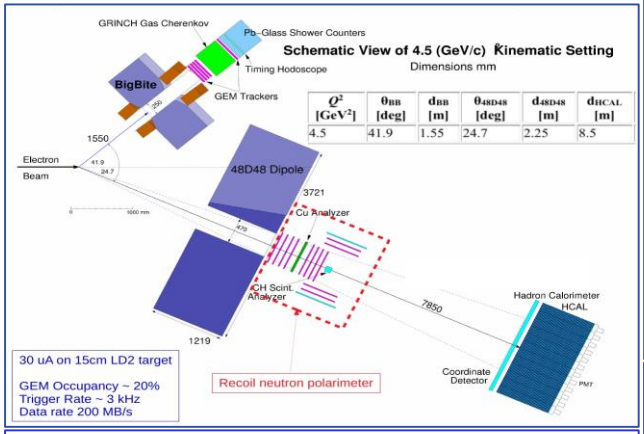
- High counting rate (~ **400 kHz/cm^2**) expected at highest luminosity of **10^{39}** electrons/s-nucleon/cm^2
- Large acceptance & small field integral magnet ⇨ Excellent Spatial resolution **(70 μm)**
- Low cost for large tracking system when compared to silicon trackers and high rate compared to Drift chambers

GEp (5): Proton Form Factor @ high Q^2



E12-07-109: measurement of G^p_E/G^p_M up to Q^2=12 GeV^2 using a target of liquid hydrogen

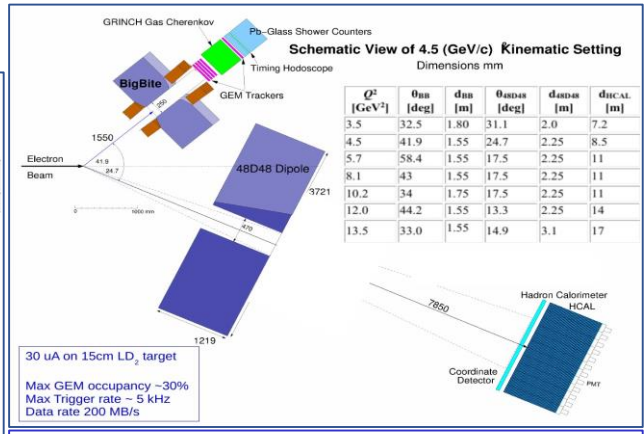
GEn-RP: Neutron Form Factor



Q^2 [GeV^2]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]
4.5	41.9	1.55	24.7	2.25	8.5

E12-17-004: measurement of G^n_E/G^n_M up to Q^2=4.5 GeV^2 polarized deuterium target

GEn & GMn: Neutron Form Factor @ high Q^2



Q^2 [GeV^2]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]
3.5	32.5	1.80	31.1	2.0	7.2
4.5	41.9	1.55	24.7	2.25	8.5
5.7	58.4	1.55	17.5	2.25	11
8.1	43	1.55	17.5	2.25	11
10.2	34	1.75	17.5	2.25	11
12.0	44.2	1.55	13.3	2.25	14
13.5	33.0	1.55	14.9	3.1	17

E12-09-019: measurement of G^n_M/G^p_M up to Q^2=13.5 GeV^2 polarized deuterium target.
E12-09-016: measurement of G^n_E/G^n_M up to Q^2=10 GeV^2 using a polarized ^{3}He target.

SBS GEM Trackers

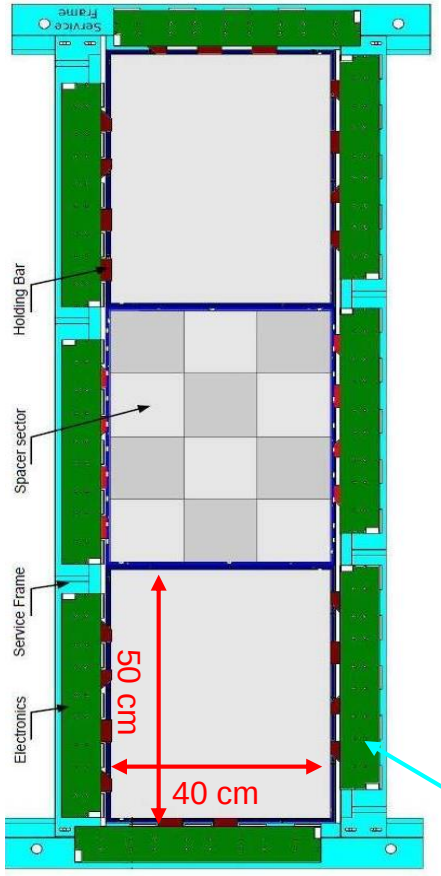
INFN GEMs: Front Trackers GEMs

- Design, Construction and Tests (INFN Catania & Roma)
- 6 GEM Layers active area (150 cm × 40 cm)
- Vertical stack of 3 GEM modules (50 cm × 40 cm)
- Production of 18 modules (+ spares)
- Currently at Jlab for commissioning

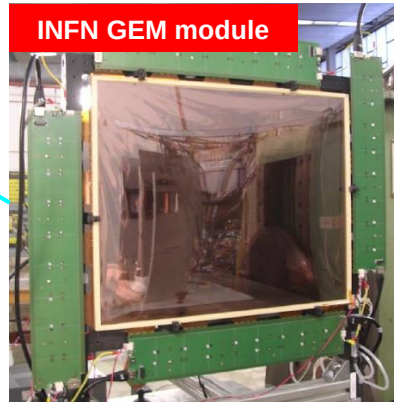
UVa GEMs: Back Trackers GEMs – Proton Recoil Polarimeters

- Design, Construction and Tests @ University of Virginia (UVa)
- Total of 11 × GEM Layers active area (200 cm × 60 cm)
- Vertical stack of 4 × GEM modules (60 cm × 50 cm)
- Production of 44 modules (+ spares)
- Currently at JLab for commissioning

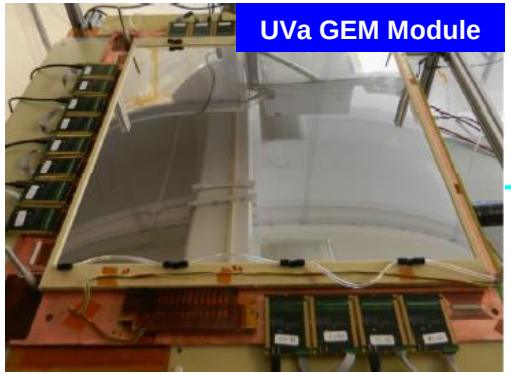
INFN GEM layer



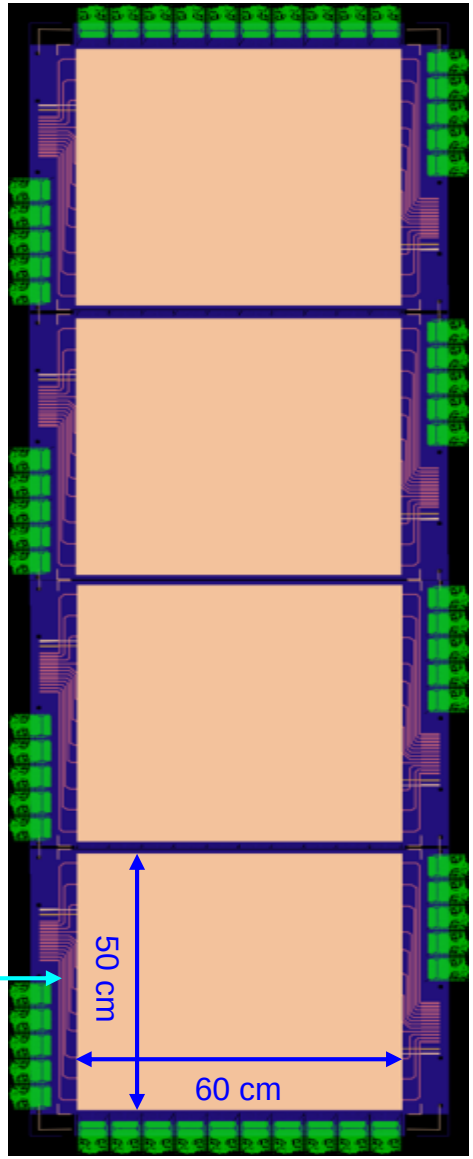
INFN GEM module



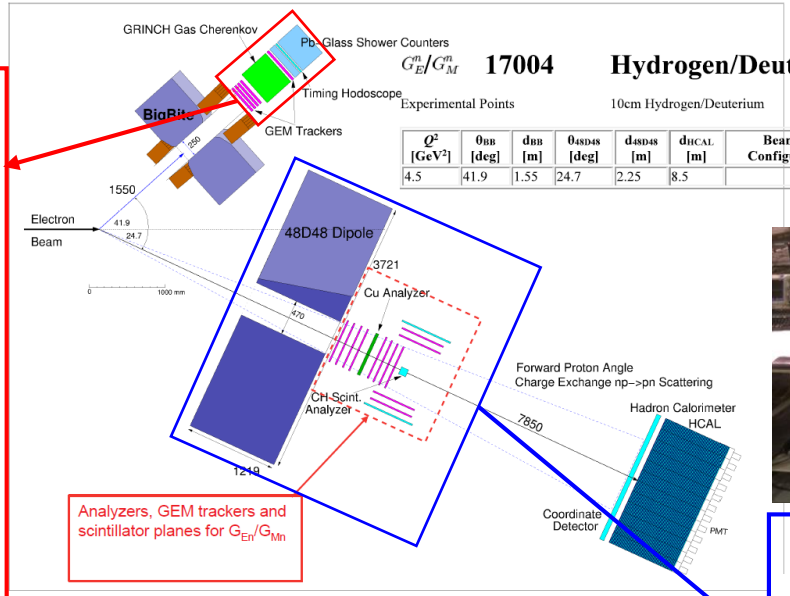
UVa GEM Module



UVa GEM layer



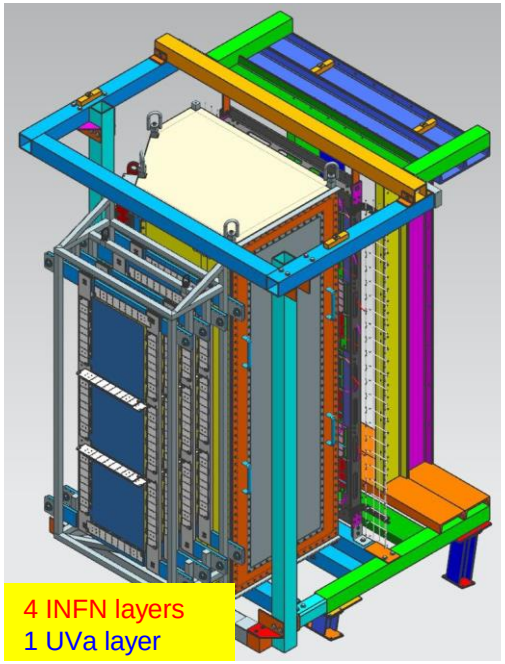
Layout of SBS GEM Trackers for Gen-RP Exp.



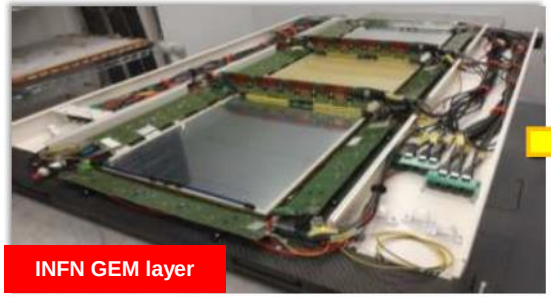
Q^2 [GeV^2]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]	Beam Line Configuration #
4.5	41.9	1.55	24.7	2.25	8.5	3

- GEn-RP scheduled for Spring 2021
- Run in parallel with GMn

BB: Electron arm



4 INFN layers
1 UVa layer



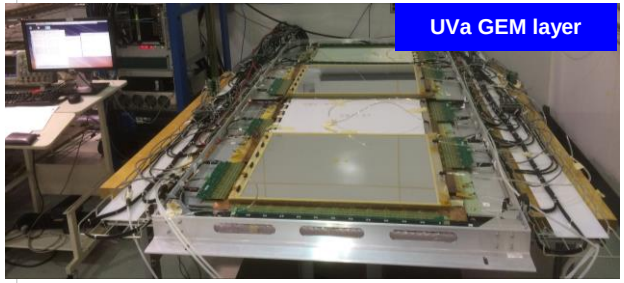
INFN GEM layer

Bigbite Spectrometer (BB): Electron Arm

- 5 GEM layers for the scattered electrons tracking
- 4 INFN layers in front of GRINCH (RICH detector)
- One UVa GEM layer behind the GRINCH

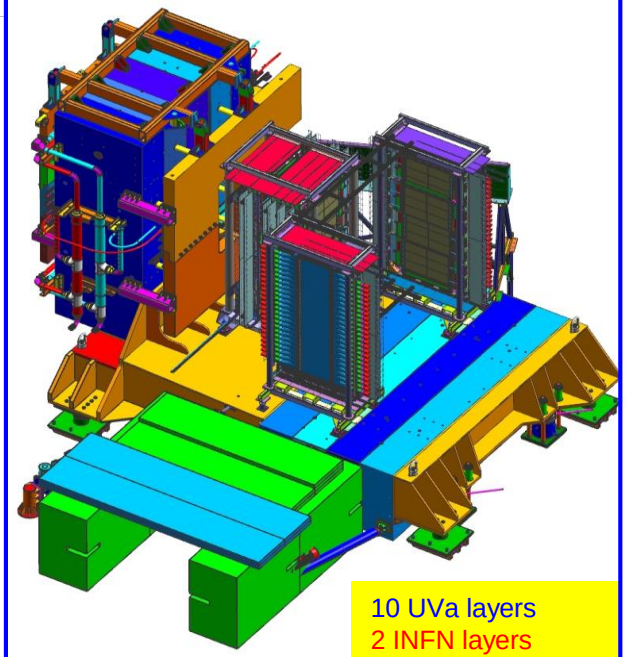
SBS: Proton Arm

- GEM layers for proton polarimetry measurement
- The Charge-Exchange (CE) Polarimeter:
  - 2 INFN + 2 UVa layers, in front of Cu analyzer.
  - 4 UVa layers behind the Cu analyzer.
- The Proton-Recoil (PR) Polarimeter:
  - 2 UVa GEM layers in each arm



UVa GEM layer

SBS: Proton Arm



10 UVa layers
2 INFN layers

SBS GEM Readout Electronics: APV25-MPD

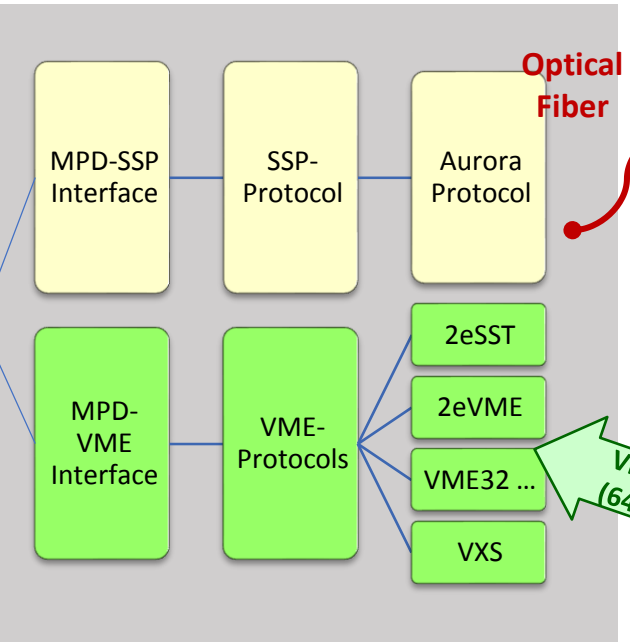
- **128 analog ch / APV25 ASIC**
- **3.4 μs trigger latency** (analog pipeline)
- Capable of sampling signal at 40 MHz
- Multiplexed analog output (**100 kHz readout rate**)

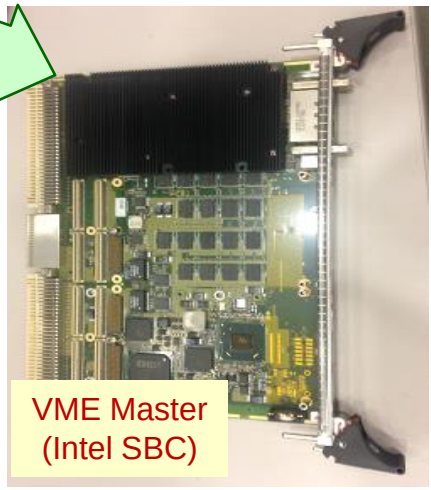
	Channels	APV25	MPDs
Front Tracker	14000	108	8
Rear Tracker	110000	880	70

MPD Main

Arriga GX FPGA
128 MB DDR2-RAM
Firmware V4.0 (74% resources**Block**):

FIR Filter (16 param)
Zero Suppression
Common mode and pedestal subtraction
Remote config,
≈2 ns trigger time resolution



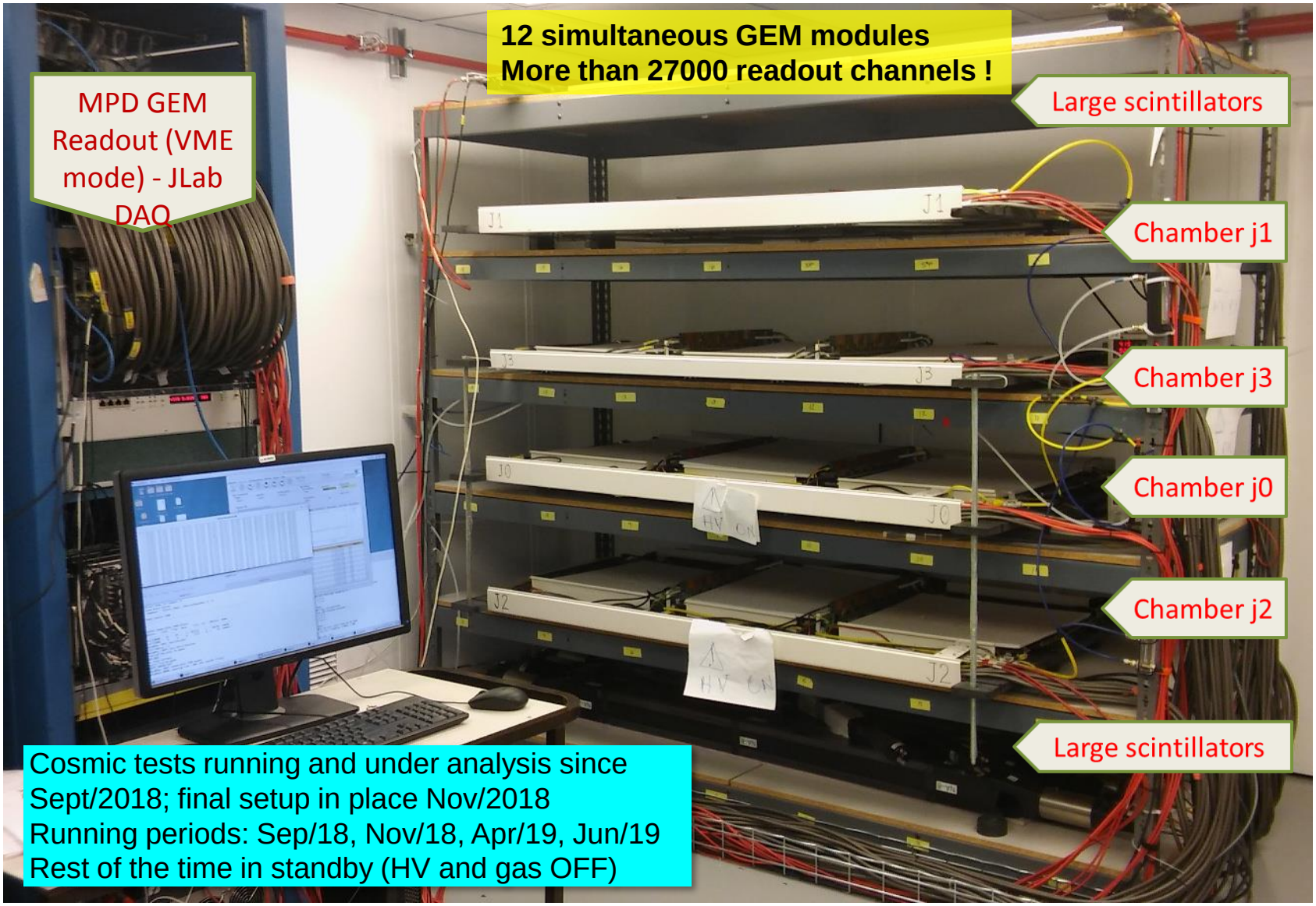


Electronics is up and running (or will be shortly) on

- **Front-GEM cosmic test in VME mode**
- **SSP mode in Rear GEM cosmic test**
- **PREX UVa GEM**

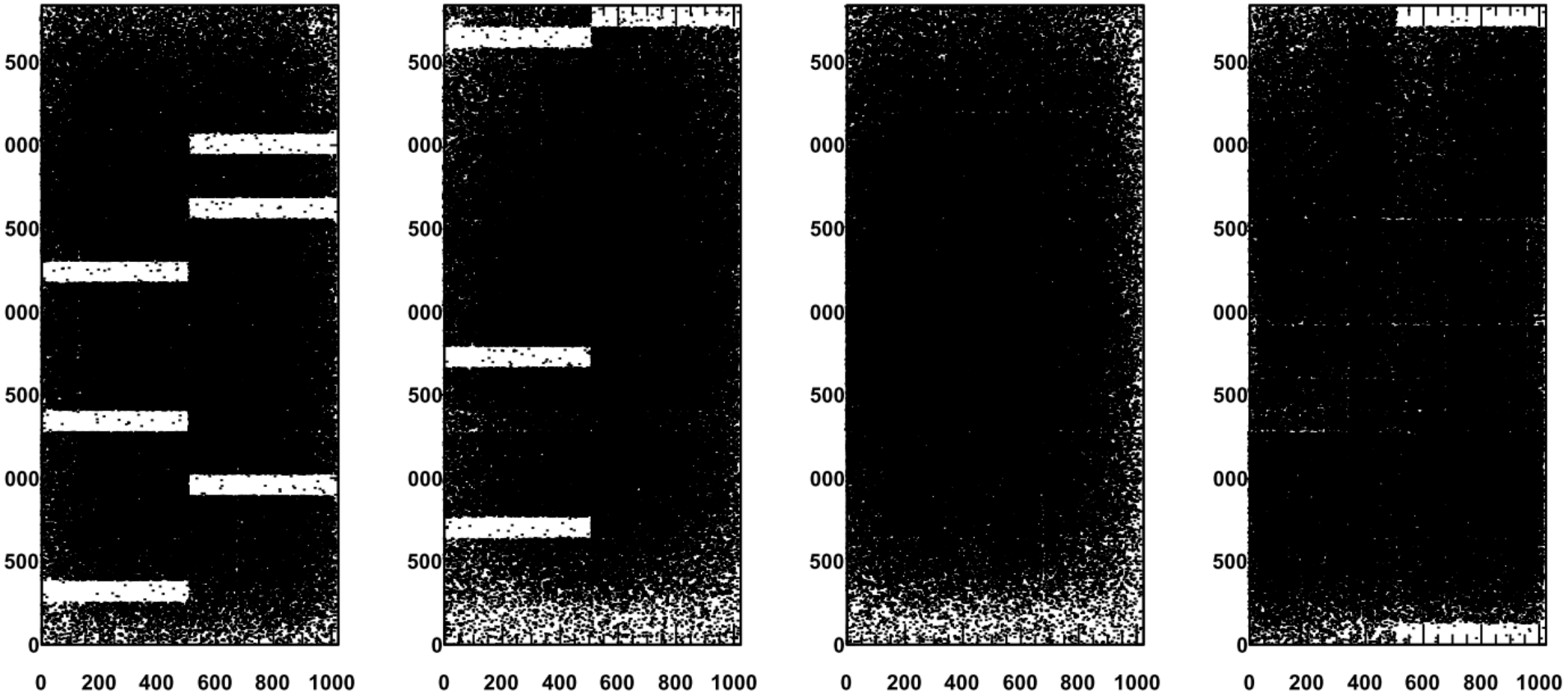
Commissioning of SBS GEMs @ JLab

INFN GEMs: Cosmic Setup @ JLab



INFN GEMs: Cosmic Setup @ JLab

Cosmic Hit Maps / Aug 2019



Gaps between modules NOT included in these plots!

White gaps are shorted GEM sectors

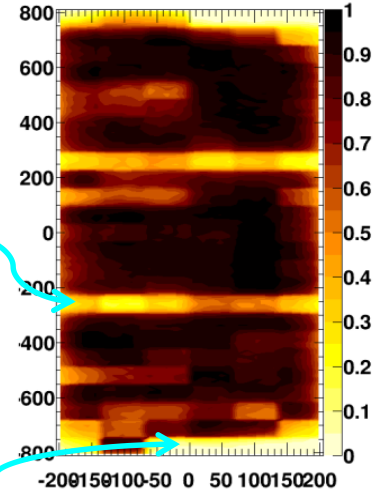
INFN GEMs: Cosmic Setup @ JLab

Track Efficiency:

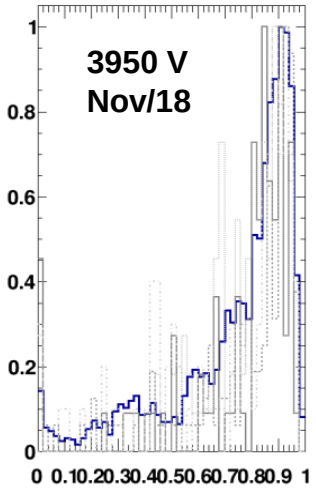
3 hits out of 4 chambers along the simulated track; hit occurrence based on estimated chamber efficiency.

Gap between modules

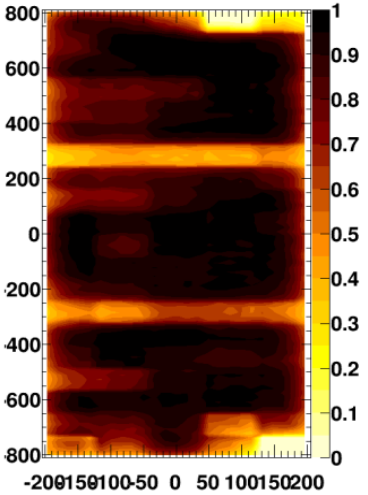
Trigger acceptance

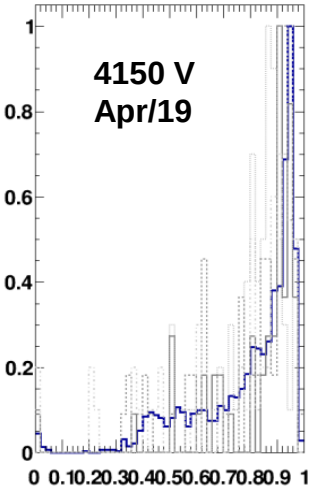


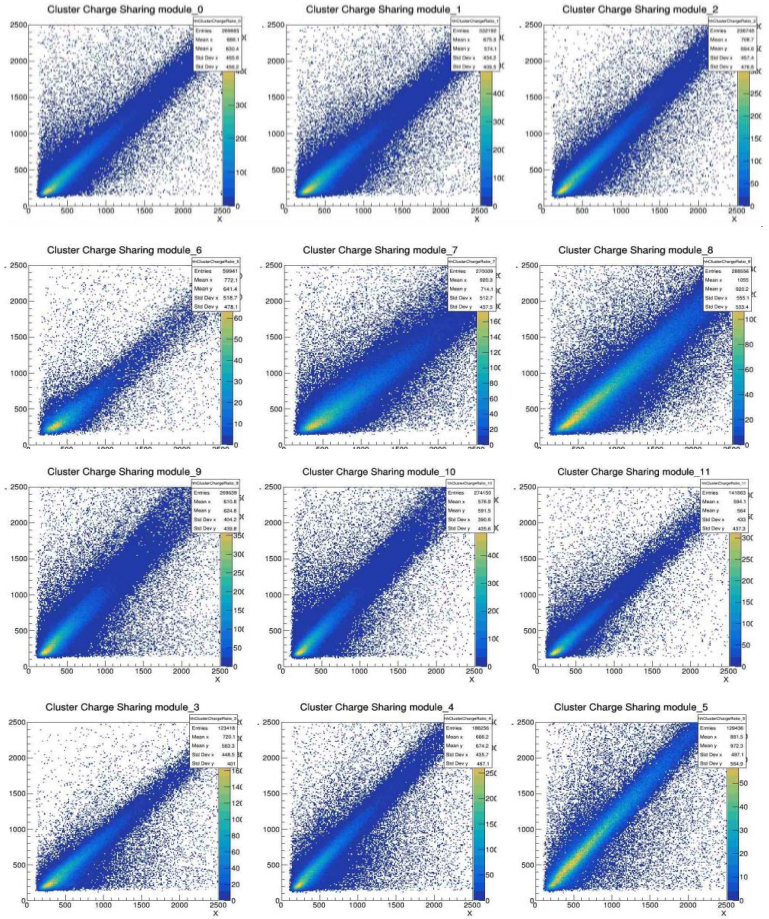
Track Efficiency (polar=10.000000)



Track Efficiency distribution



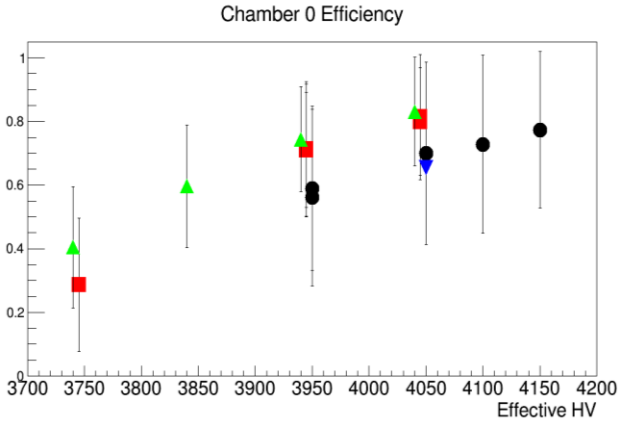


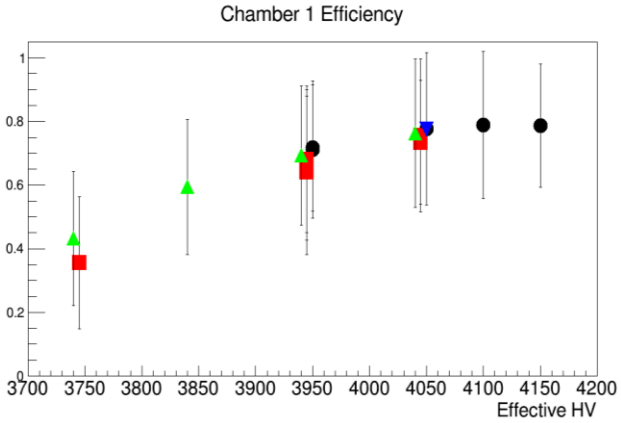


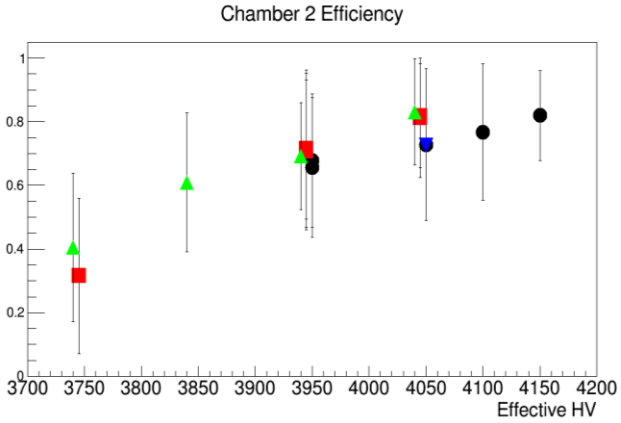
Very good charge sharing looks very reasonable:

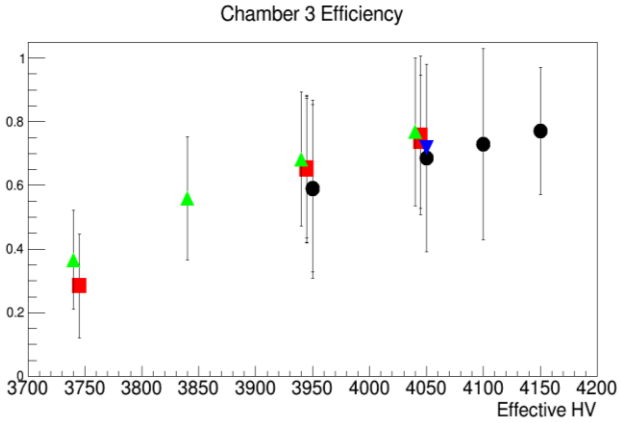
INFN GEMs: Cosmic Setup @ JLab

GEM efficiency vs HV and gas flow









Black Circle: 9 l/h*
Red Square: 18 l/h
Green Triangle: 36 l/h
Blue Triangle: 18 l/h
no alignment

1 chamber volume
~ 12 liters

*) relatively short flushing period

Nov/2018 and Apr/2019 cosmic data

NOTE: Chamber efficiencies include gaps between GEM modules (~5%)!

Effective HV plateau around **4050-4100 V**
Gas flow larger than **18 l/h** (per chamber) to avoid noticeable effects on efficiency

UVa GEMs: Modules production @ UVa

Module 01: ⇨ OK Where: UVa - shelve Tested at: UVa, known fixes	Module 11: ⇨ OK Where: EEL-124 - shelve Tested at: UVa, known fixes	Module 21: ⇨ OK Where: **Hall A - PREX** Tested at: UVa & JLab	Module 31: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 41: ⇨ OK Where: EEL-124 - shelve Tested at: UVa
Module 02: ⇨ OK, 1HV out Where: UVa - shelve Tested at: UVa, known fixes	Module 12: ⇨ OK, 1HV out Where: **Hall A - PREX** Tested at: UVa & JLab	Module 22: ⇨ OK Where: **EEL-124 – Layer#3** Tested at: UVa & JLab	Module 32: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 42: ⇨ OK Where: **EEL-124 – Layer#3** Tested at: UVa & JLab
Module 03: ⇨ OK Where: UVa - shelve Tested at: UVa, known fixes	Module 13: ⇨ OK Where: **EEL-124 – Layer#2** Tested at: UVa & JLab	Module 23: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 33: ⇨ OK Where: **EEL-124 – Layer#1** Tested at: UVa & JLab	Module 43: ⇨ OK Where: EEL-124 - shelve Tested at: UVa
Module 04: ⇨ OK Where: UVa - shelve Tested at: UVa, known fixes	Module 14: ⇨ OK Where: **Hall A - PREX** Tested at: UVa & JLab	Module 24: ⇨ OK Where: UVa - shelve Tested at: UVa	Module 34: ⇨ Stretch issues Where: UVa - shelve Tested at: UVa, require fixes	Module 44: ⇨ FAILED Where: UVa - shelve Tested at: under Investigatio
Module 05: ⇨ Stretch issues Where: UVa - shelve Tested at: UVa, require fixes	Module 15: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 25: ⇨ OK Where: **EEL-124 – Layer#2** Tested at: UVa & JLab	Module 35: ⇨ OK, 1HV out? Where: EEL-124 - shelve Tested at: UVa & JLab	Module 45: ⇨ OK Where: **EEL-124 – Layer#3** Tested at: UVa & JLab
Module 06: ⇨ Stretch issues Where: UVa - shelve Tested at: UVa, require fixes	Module 16: ⇨ OK Where: **EEL-124 – Layer#1** Tested at: UVa & JLab	Module 26: ⇨ OK Where: **Hall A - PREX** Tested at: UVa & JLab	Module 36: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 46: ⇨ OK Where: UVa - shelve Tested at: UVa
Module 07: ⇨ OK Where: EEL-124 - shelve Tests: UVa, known fixes	Module 17: ⇨ OK Where: **EEL-124 – Layer#2** Tested at: UVa & JLab	Module 27: ⇨ OK Where: EEL-124 - shelve Tests: UVa	Module 37: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 47: ⇨ OK Where: **EEL-124 – Layer#1** Tested at: UVa & JLab
Module 08: ⇨ OK Where: EEL-124 - shelve Tested at: UVa, known fixes	Module 18: ⇨ OK Where: **Hall A - PREX** Tested at: UVa & JLab	Module 28: ⇨ OK Where: **Hall A - PREX** Tested at: UVa & JLab	Module 38: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 48: ⇨ OK Where: UVa - shelve Tested at: UVa
Module 09: ⇨ OK Where: EEL-124 - shelve Tested at: UVa, known fixes	Module 19: ⇨ OK Where: **EEL-124 – Layer#1** Tested at: UVa & JLab	Module 29: ⇨ OK Where: **EEL-124 – Layer#3** Tested at: UVa & JLab	Module 39: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 49: ⇨ Under Test Where: UVa - shelve Tested at: under test
Module 10: ⇨ OK Where: EEL-124 - shelve Tested at: UVa, known fixes	Module 20: ⇨ OK Where: **EEL-124 – Layer#2** Tested at: UVa & JLab	Module 30: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 40: ⇨ OK Where: EEL-124 - shelve Tested at: UVa	Module 50: ⇨ Under assbly Where: UVa – clean room Tested at: Not yet

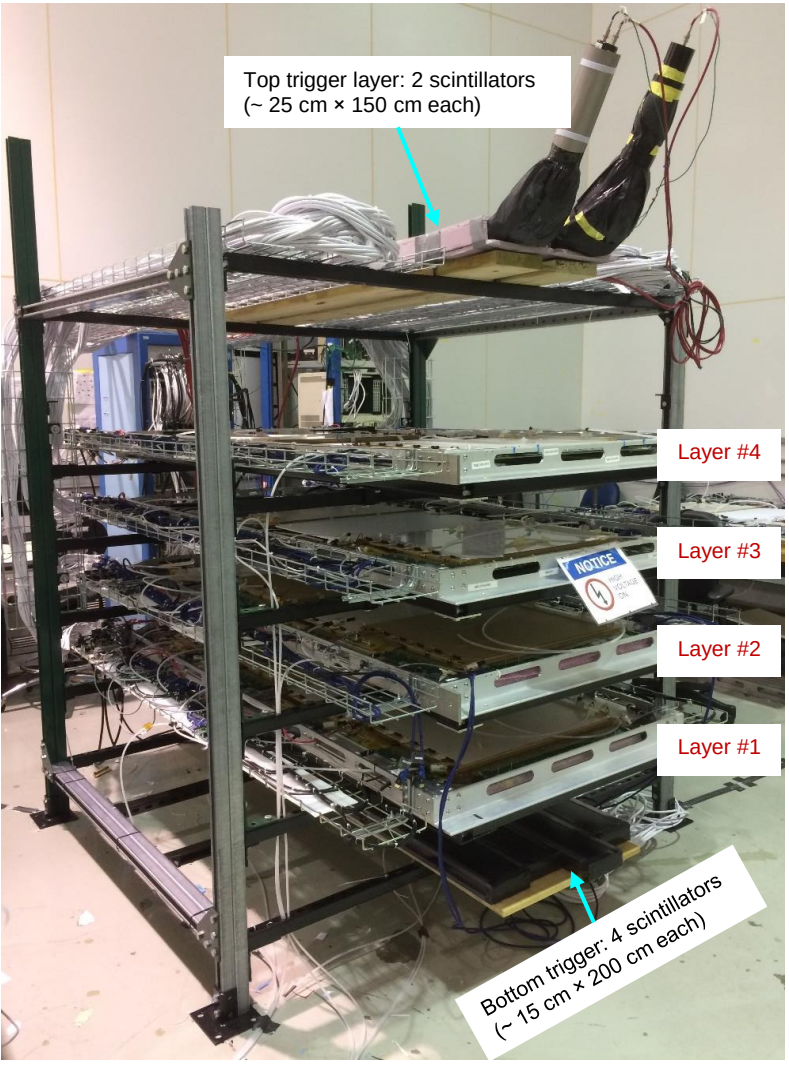
First modules: Require straightforward fixes Under control

4 modules: stretching related HV issues: Under investigation

Modules 49 and 50: Spare modules under construction

UVa GEMs: Cosmic Setup @ JLab

Cosmic stand with 4 UVa GEM layers



Cosmic Stand

- Up to 5 UVa GEM layers to operate on the cosmic stand
- Currently 4 GEM layers installed (16 UVa modules)
- Trigger signal: coincidence between top and bottom layers of scint / PMTs

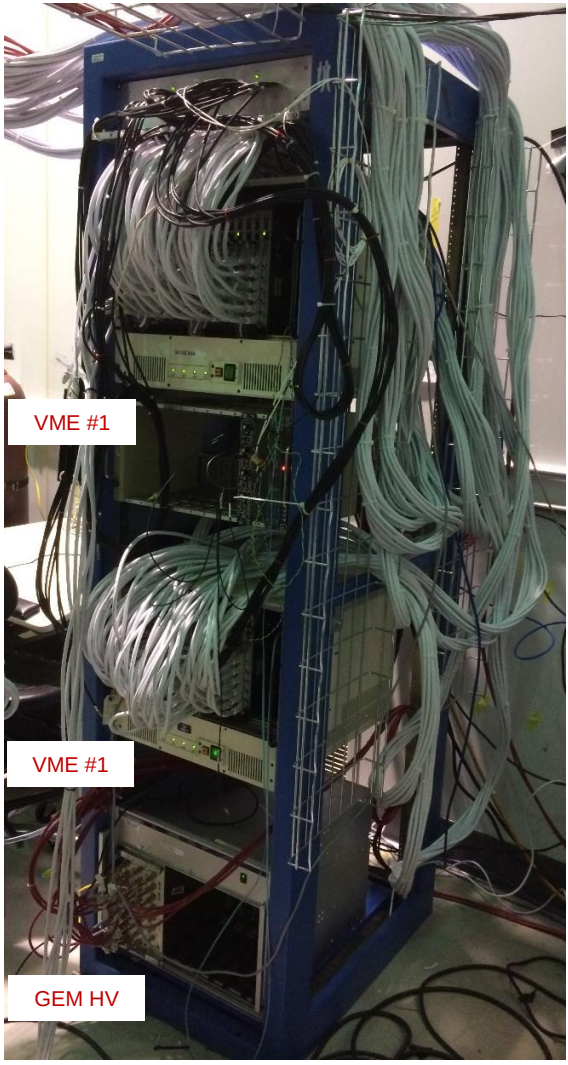
First rack: MPD DAQ & Trigger

- 2 VME crates for the MPD electronics
- reading out 14 MPDs each
- 4 layers in cosmic stand been read out
- Wiener HV PS crates for the GEM
- 3 HV modules 24 channels for 6 layers

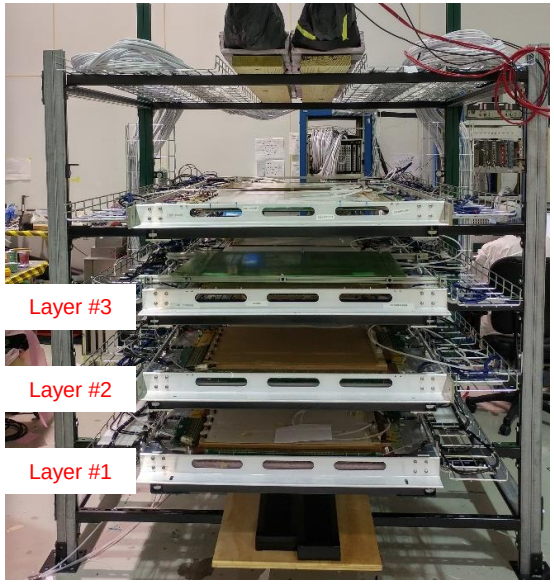
Second rack: MPD DAQ & Trigger

- 3rd VME crates for MPD electronics
- reading out 5th and 6th layers
- 1 VXS crate
- Readout & DAQ in SSP mode
- LeCroy PS crate for the trigger
- NIM crate for the trigger logic

MPD DAQ & GEM HV PS

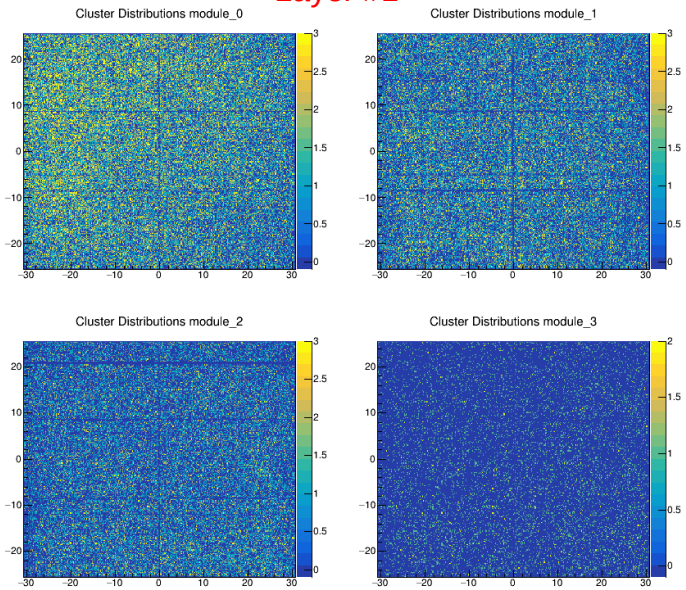


UVa GEMs: Preliminary analysis of cosmic data

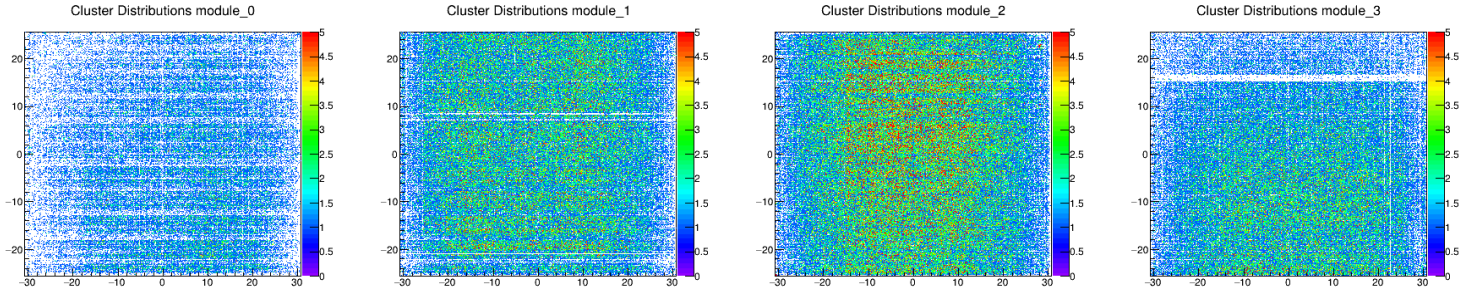


- All 4 layers @ 4050 V on ArCO2 so technically
- First round of cosmic with layer #1, #2 & #3 1.5 M triggers event in 1.5 days
- Preliminary hit map plots below for the 12 modules of layer #1, #2 & #3
- All modules are working very well, no dead
- Few dead area on two modules that are
- Low efficiency in GEM 0 of layer 2 is due to known issue with the chamber GEM module #13 ⇨ need to operate at higher A few of our GEM modules have similar issues due to GEM foil holes parameters we got from CERN ⇨ Not really an issue

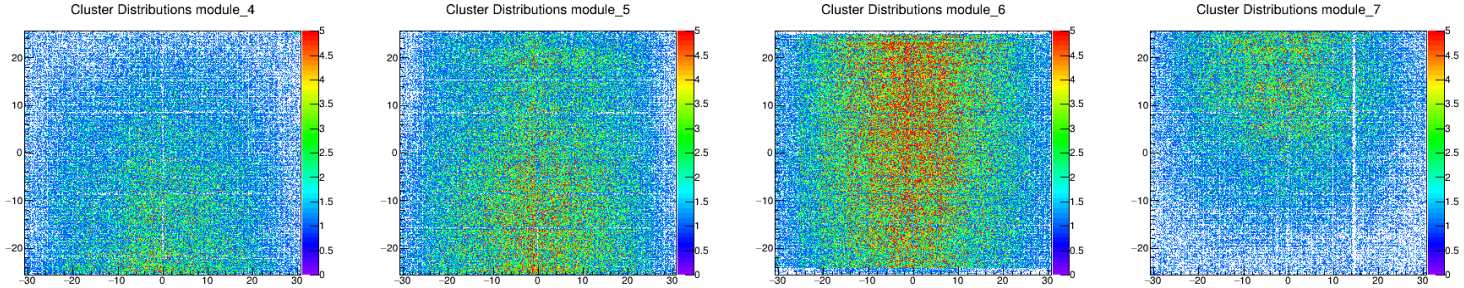
Layer #1



Layer #2

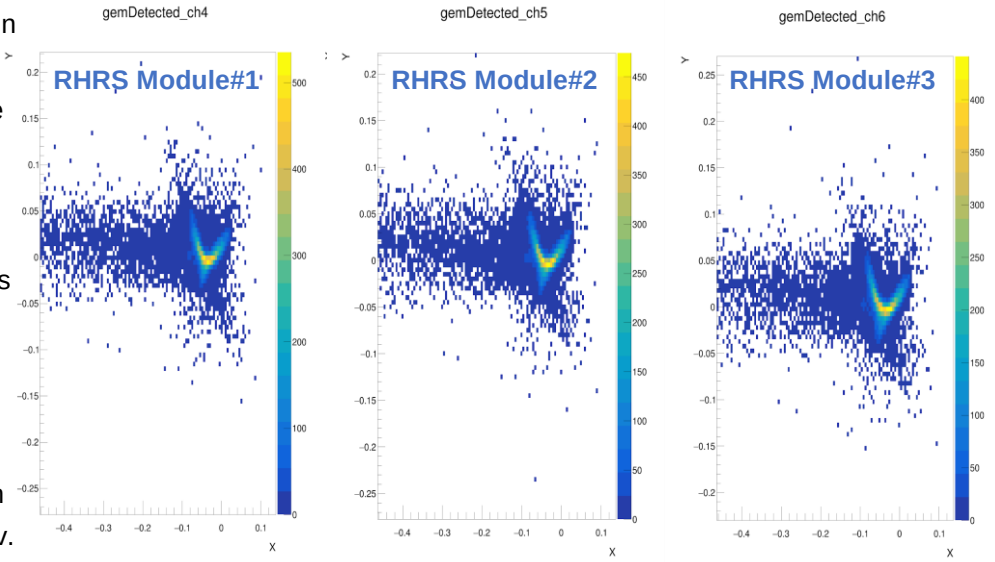


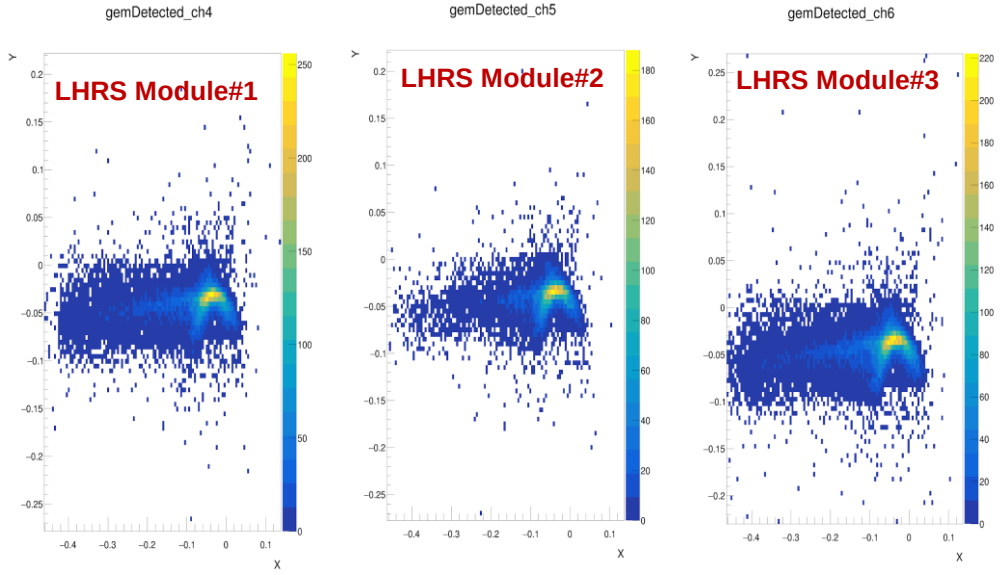
Layer #3



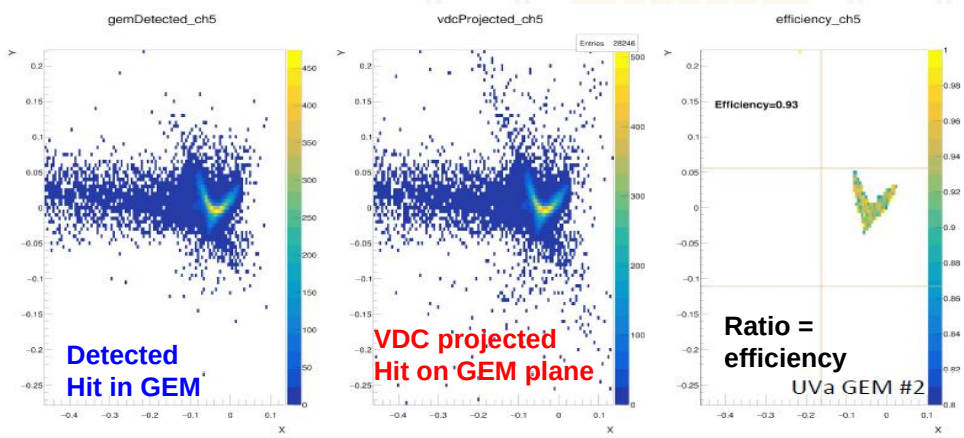
UVa GEMs: PREX experiment in Hall A @ JLab

- Additional 6 of UVa GEM modules currently installed in the Hall A High Resolution Spectrometers (HRS) for the tracking during PREX and CREX experiments (Spring and Fall 2019)
- First round with PREX shows a expected performance for all 6 modules
- First time SBS GEM runs in an experiments
- Commissioning ongoing with the CREX run starting in Nov. 2019





UVa GEMs: Efficiency study with PREX data

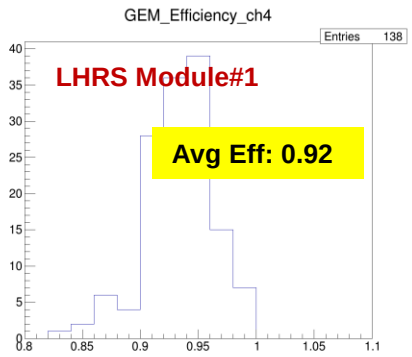


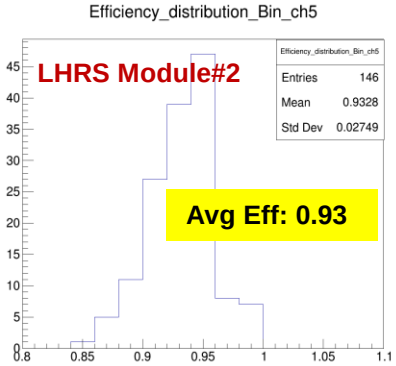
Preliminary analysis

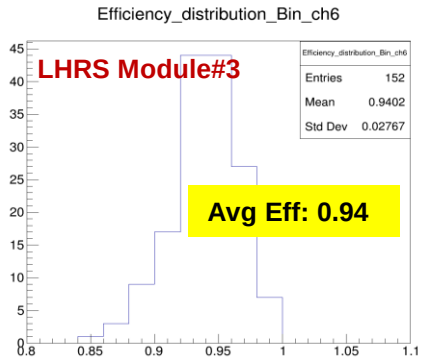
GEM Detected Hit: Project the hit from the vertical drift chamber (VDC) to GEM plane and we search for GEM Hit within 4 cm square area

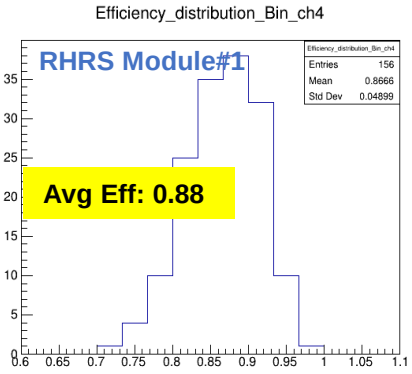
VDC Projected Hit: Project VDC to GEM plane

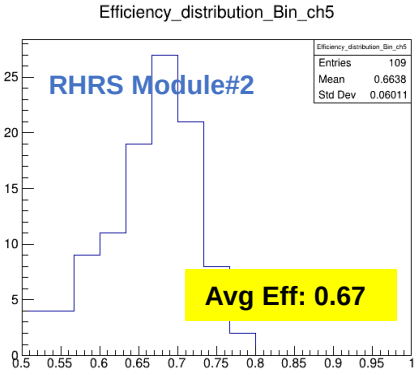
- If the total number of projected events in a give bin is smaller than 30, that bin is rejected from the calculation
- background caused by cosmic
- fake hit caused by VDC ghost hit combinations at high rates(U-V wire signature of VDCs clearly visible)
- Efficiency is calculated for each 1 cm^2 bin
- GEM High voltage: 4050
- Lower efficiency for RHRS Module#1 & #2 expected ⇨ issue with the GEM foil batch

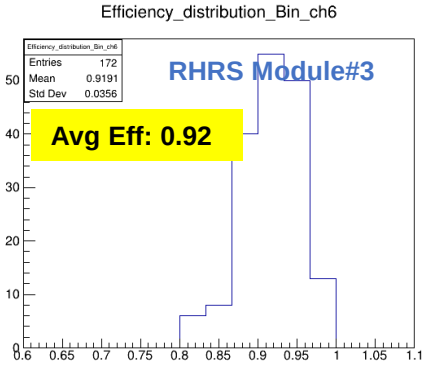






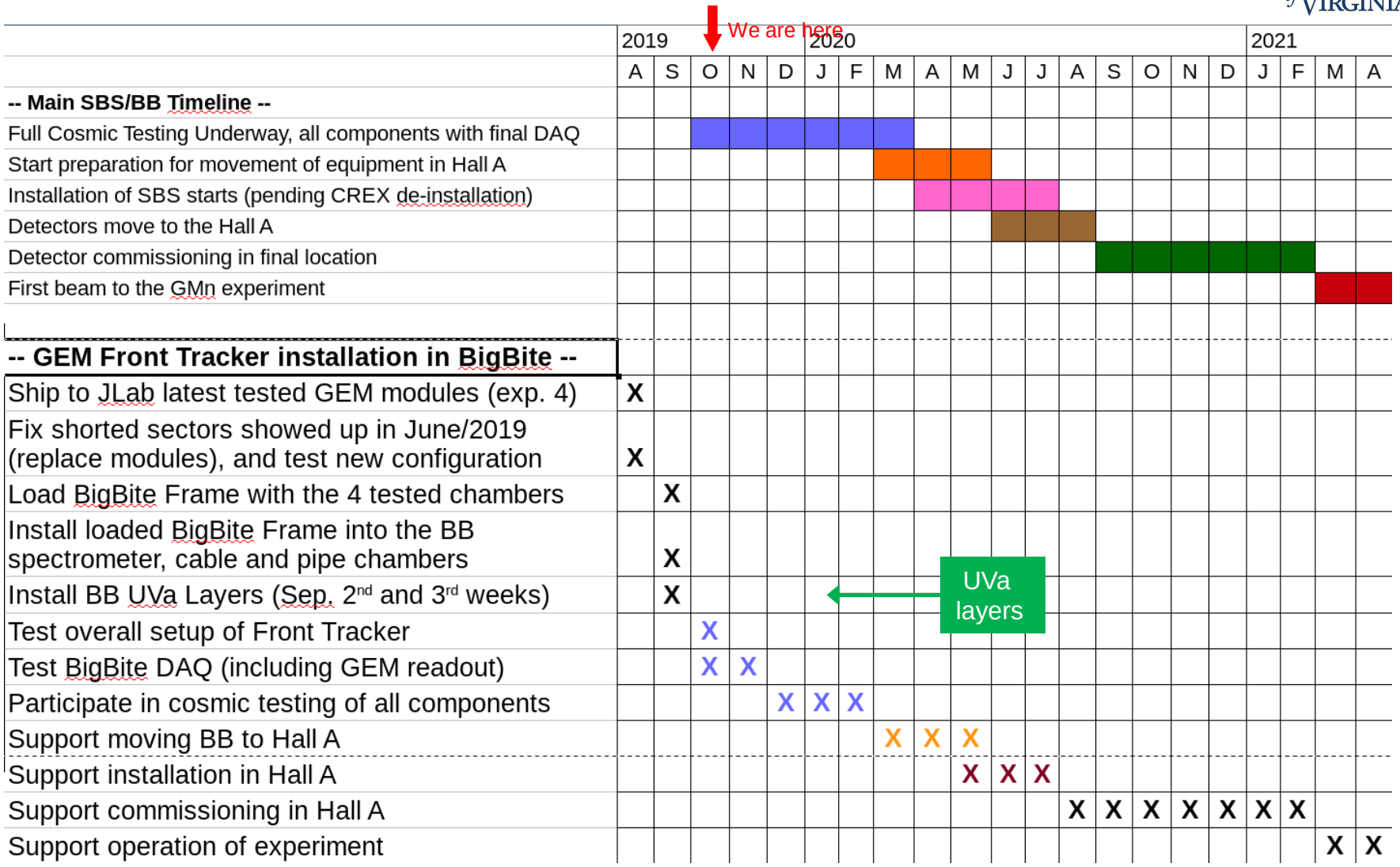






Timeline for Installation into the Spectrometers

Installation of GEM layers into BB spectrometer



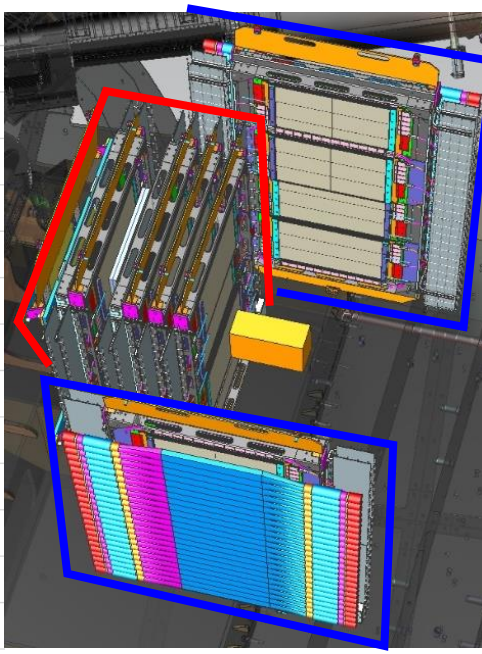
- Ideally UVa GEM for BB can be installed in Sept week #2 or #3 ⇨ Pretty straight forward,
- If well coordinated with Doug and Jessie's crew …, one week is more than enough for the installation in BB

Installation of GEM layers into SBS spectrometer

To Do List (next 12 Months)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Manpower
layer #1, #2 and #3 on cosmic stand	Current status												
Layer #3: Assembly / Cosmic Tests	Assemble	Test											KG, AR, MR, TG (NL & MK)
Layer #4: Assembly / Cosmic Tests		Ass.	Test										KG, AR, MR, TG (NL & MK)
Layer #4 in BB			BB										KG, AR, MR, TG (NL & MK)
Layer #5: Assembly / Cosmic Tests			Ass.	Test									KG, AR, MR, TG (NL & MK)
Layer #3 & #5 in Gen-RP Ch. Ex Pol.					Ch. Ex.								KG, AR, MR, TG (NL & MK)
Layer #6: Assembly / Cosmic Tests				Ass.	Test								KG, AR, MR, TG (NL & MK)
Layer #7: Assembly / Cosmic Tests					Ass.	Test							KG, AR, MR, TG (NL & MK)
Layer #6 & #7 in Gen-RP Ch. Ex Pol.							Ch. Ex.						KG, AR, MR, TG (NL & MK)
Layer #8: Assembly / Cosmic Tests						Ass.	Test						KG, AR, MR, TG (NL & MK)
Layer #9: Assembly / Cosmic Tests							Ass.	Test					KG, AR, MR, TG (NL & MK)
Layer #8 & #9 in Gen-RP Ch. Ex Pol.									Ch. Ex.				KG, AR, MR, TG (NL & MK)
Layer #10: Assembly / Cosmic Tests								Ass.	Tes				KG, AR, MR, TG (NL & MK)
Layer #11: Assembly / Cosmic Tests									Ass.	Test			KG, AR, MR, TG (NL & MK)
Layer #8 & #9 in Gen-RP Proton Pol.											PP		KG, AR, MR, TG (NL & MK)
Layer #1: Re-Assembly / Cosmic Tests										Ass.	Test		KG, AR, MR, TG (NL & MK)
Layer #2: Re-Assembly / Cosmic Tests											Ass.	Test	KG, AR, MR, TG (NL & MK)
Layer #8 & #9 in Gen-RP Proton Pol.												PP	KG, AR, MR, TG (NL & MK)

We are here

INFN layers



- INFN layers for in Ch. Ex frame (anytime between January and June 2020)
- Likely, first layer in February 2020
- Second INFN layer, if available for in Ch. Ex frame (after April 2020)

New SBS Front Tracker GEM with U-V strip readout

New SBS FT GEMs: U-V strips readout

Motivation:

⇨ The U-V GEM modules to complement the INFN Front Tracker GEM Layers which use COMPASS 2D cartesian strip readouts.

⇨ The addition of U-V geometry enhances and complements the X-Y strips and will help with tracking in the high rate environment.

⇨ 3 large U-V GEM chambers to be built by summer 2020

Key Features: active area: 150 × 40 cm^2, U-V strips readout (60º) stereo angle

⇨ New GEM foil technology allows for this new FT U-V GEM layer to be **one single large module**

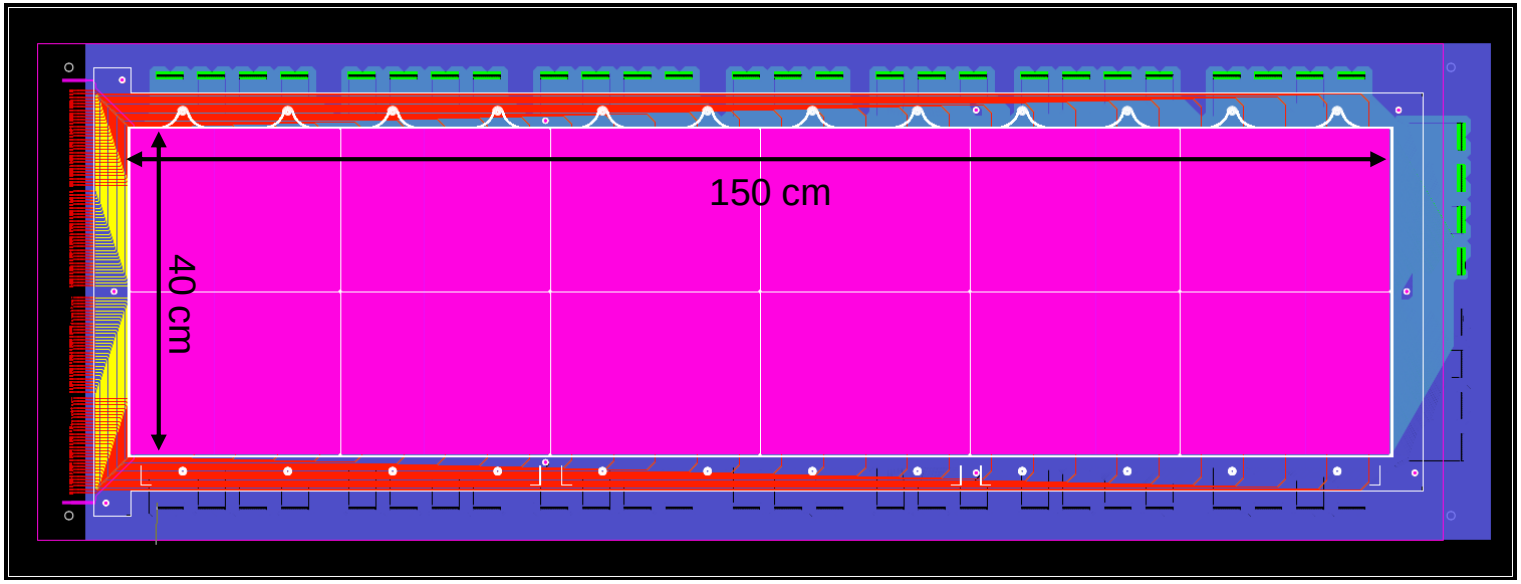
⇨ **No dead area** from support frames or electronics (Other than for the frame spacers and HV sector boundaries)

⇨ The INFN-built MPD readouts for these GEMs will be the same as for all SBS GEMs

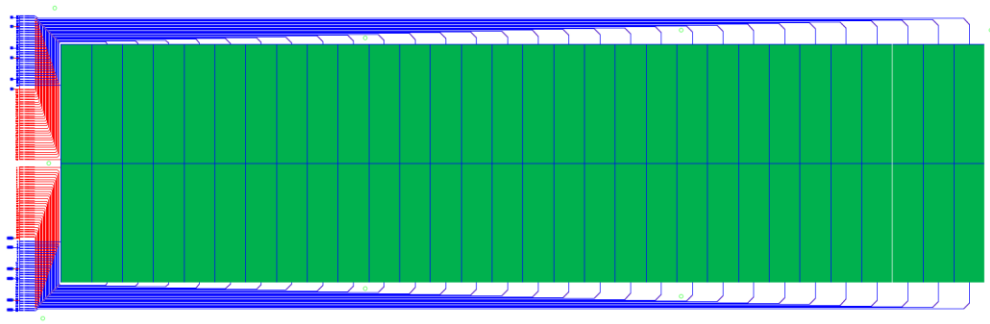
Our Experience: UVa has a successful track record with large area GEMs and U-V readout

⇨ Large GEM with PRad Experiment (June 2016 in Hall B), similar size ⇨ but PRad **more far challenging** to build

⇨ U-V strip readouts with large U-V GEM prototypes for the EIC Forward GEM Trackers Detector R&D



New SBS FT GEMs with U-V strips readout: Design



GEM foil:

⇨ Segmentation on both side unlike previous large GEM chambers

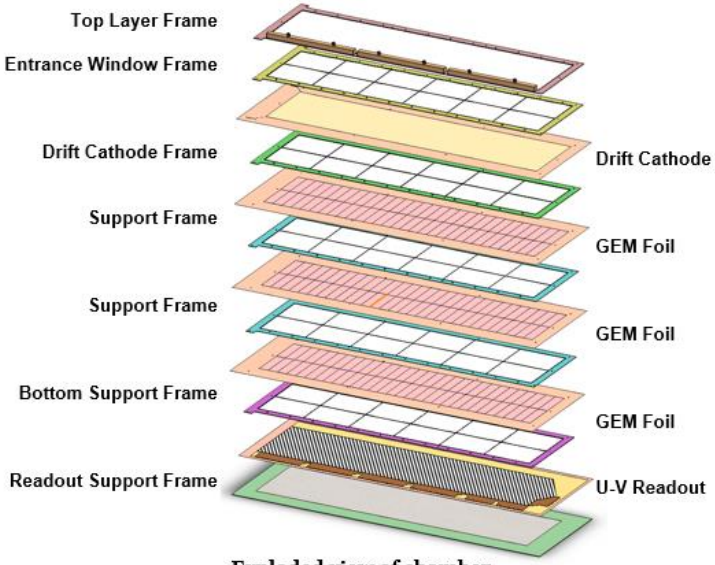
⇨ A short sector during operation **would not make the whole layer inoperable** ⇨ but only dead sector

⇨ Limited voltage drop in the divider at high particle rate

GEM support frame design:

⇨ 500 μm spacer grid to provide uniform gap while minimizes dead area.

⇨ Designed with a wide outer frame for added rigidity and support when fully assembled.



Exploded view of chamber

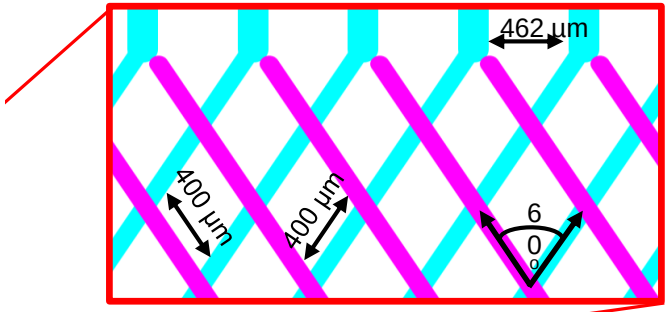
U-V strip readout design:

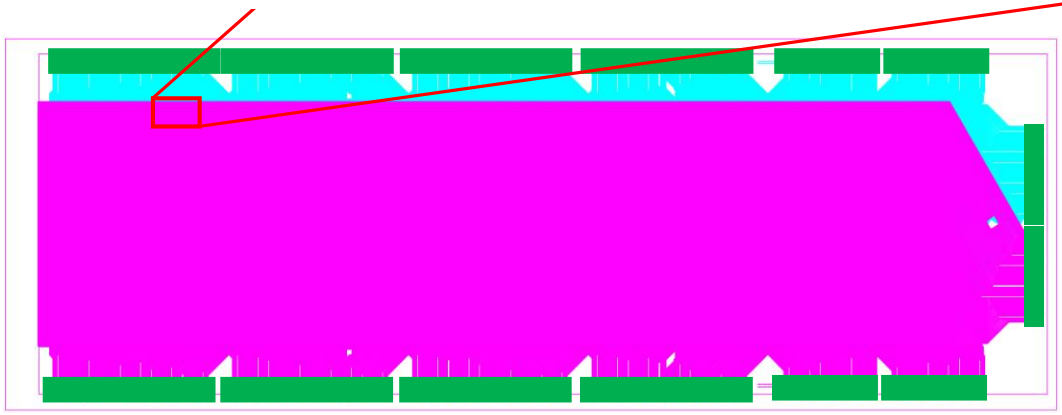
⇨ U and V pitch of **400 μm**, Vertical pitch: **462 μm**

⇨ top (U-) strip: **80: μm**

⇨ bottom strips: **350 μm**

⇨ About 7k e- channels per layer





FT GEMs with U-V readout: Production Timeline

UNIVERSITY of VIRGINIA

⇨ GEM and Readout foils (CERN)

- Design of GEM foil and R/O almost completed
- To do: Finalize the design ⇨ few more details to hash out and check compatibility with support frames design
- Green light CERN for production (**min ~ 6 Months expected**)

⇨ GEM frames (RESARM Belgium)

- Communication with RESARM ⇨ No problem fabricating frame of this size
- To do: Finalize the frame design and check compatibility with GEM foils
- Green light CERN for production (**min ~ 3 Months expected**)

⇨ Timeline of the two U-V GEM chambers assembly at UVa

- Foil Stretcher (Tooling and Clean Room Equipment): **(12/2019)**
- 3 chambers Fabrication: **(end 06/2020)**
- Testing & delivery to JLab: **(end 07/2020)**

Summary

⇨ **Large volume GEM production for SBS in Hall A @ JLab**

- 18 Front Trackers GEM modules for 6 SBS GEM layers (INFN GEM layers) built in Catania and characterized in Rome
- 44 (+ 6 spares) Back Tracker GEM modules for 11 SBS GEM layers (UVa GEMs) built and characterized at UVa
- Production almost completed in both sites

⇨ **Ongoing commissioning of the GEM layers**

- SBS GEM Modules shipped to JLab and assembly into layers ongoing
- Commissioning of the GEM layers with two cosmic setup
- Installation of the first GEM layers into BB and SBS Spectrometers is scheduled to start soon

⇨ **Construction at UVa of new U-V GEM Front Tracker GEM for SBS**

- New large SBS Front Tracker GEM with U-V strip readout
- Design phase almost completed and Production of GEM foils and readout layers at CERN started