Performance of SBS/BB Detectors

Xinzhan Bai

University of Virginia

For the SBS Collaboration

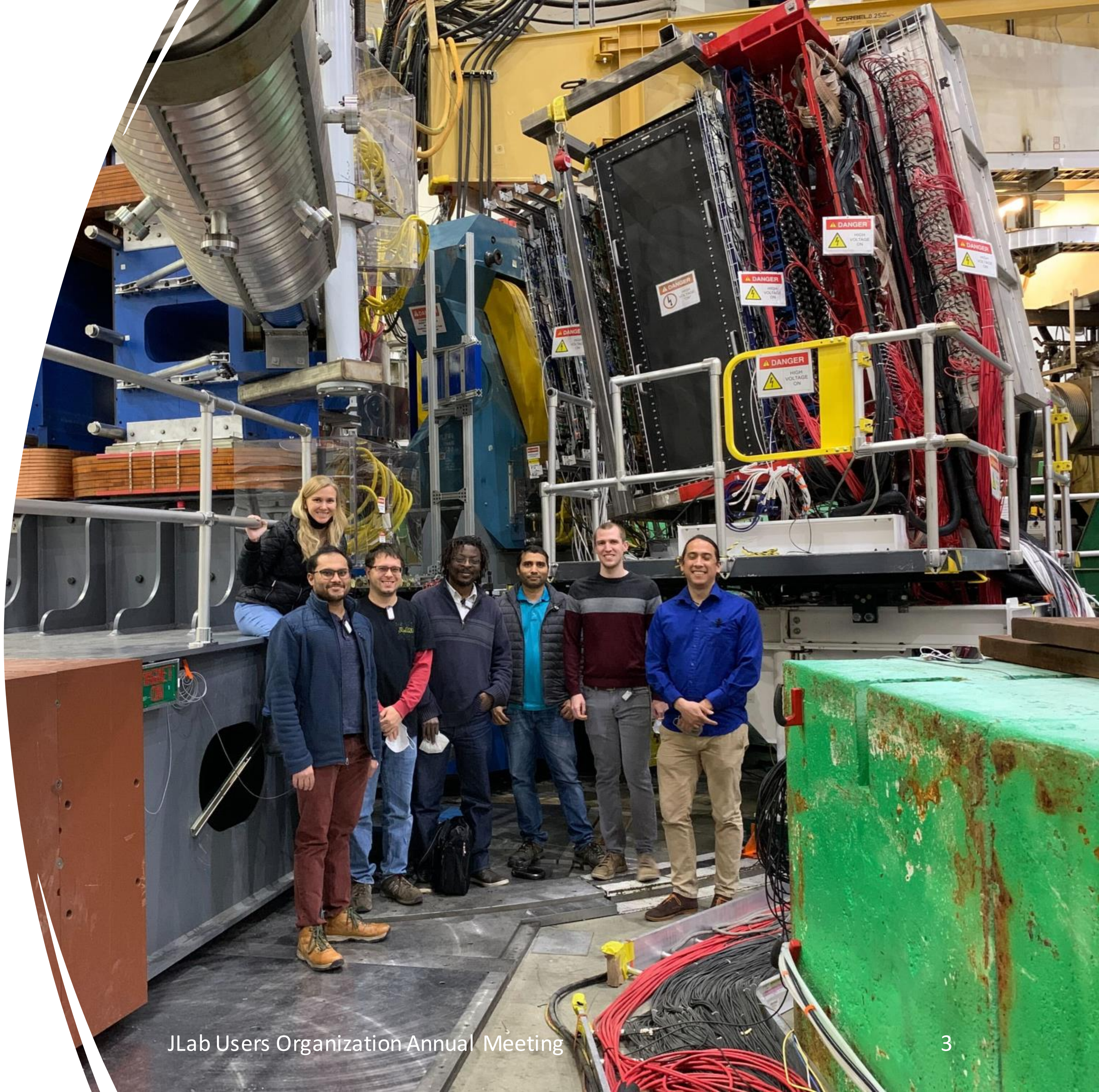
Content

- Bigbite Spectrometer
- GEM Detectors in Bigbite
- Performance of GEM Detectors in Bigbite
- Summary

GEM Group Members in SBS Collaboration

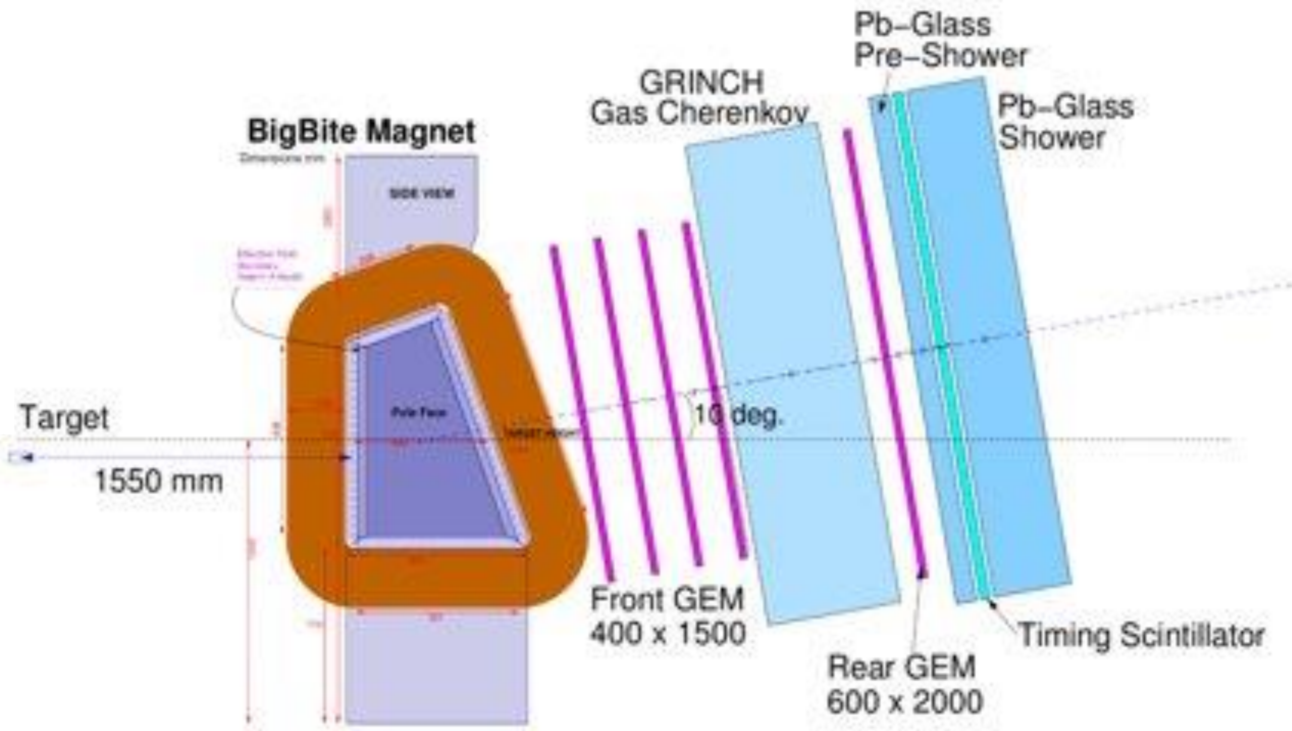
- INFN
  Everisto Cisbani, Paolo Musico
- Jefferson Lab
  Alexandre Camsonne, Kondo Gnanvo, Bryan Moffit, Benjamin Raydo, Brad Sawatzky, Holly Sumila-Vance, Bogdan Wojtsekhowski
- University of Virginia
  Salina Ali, Xinzhan Bai, John Boyd, Bhashitha Thuthimal Dharmasena, Danning Di, Vimukthi Gamage, Sean Jeffas, Siyu Jian, Nilanga Liyanage, John Matter, Huong Nguyen, Anurudda Rathnayake
- William & Marry
  Eziekel Wertz
- University of Connecticut
  Andrew Puckett
- Hampton University
  Sarashowati Dhital, Thir Gautam, Michael Kohl, Malinga Rathnayake, Manju Suresh

and the SBS Collaboration



Bigbite Electron Spectrometer - BB

- A non-focusing, large momentum and angular acceptance spectrometer
- The spectrometer consists of a single dipole magnet and a detection system
- Current detection system includes:
  - 5 layers of GEM detectors (UVa, INFN)
  - GRINCH gas Cerenkov detector (W&M, JMU, NC A&T)
  - A shower and preshower (JLab, UConn, Yerevan)
  - A timing Hodoscope plane (Glasgow U, JLab)
- High background rates due to open configuration
- GEM detectors to handle high rate



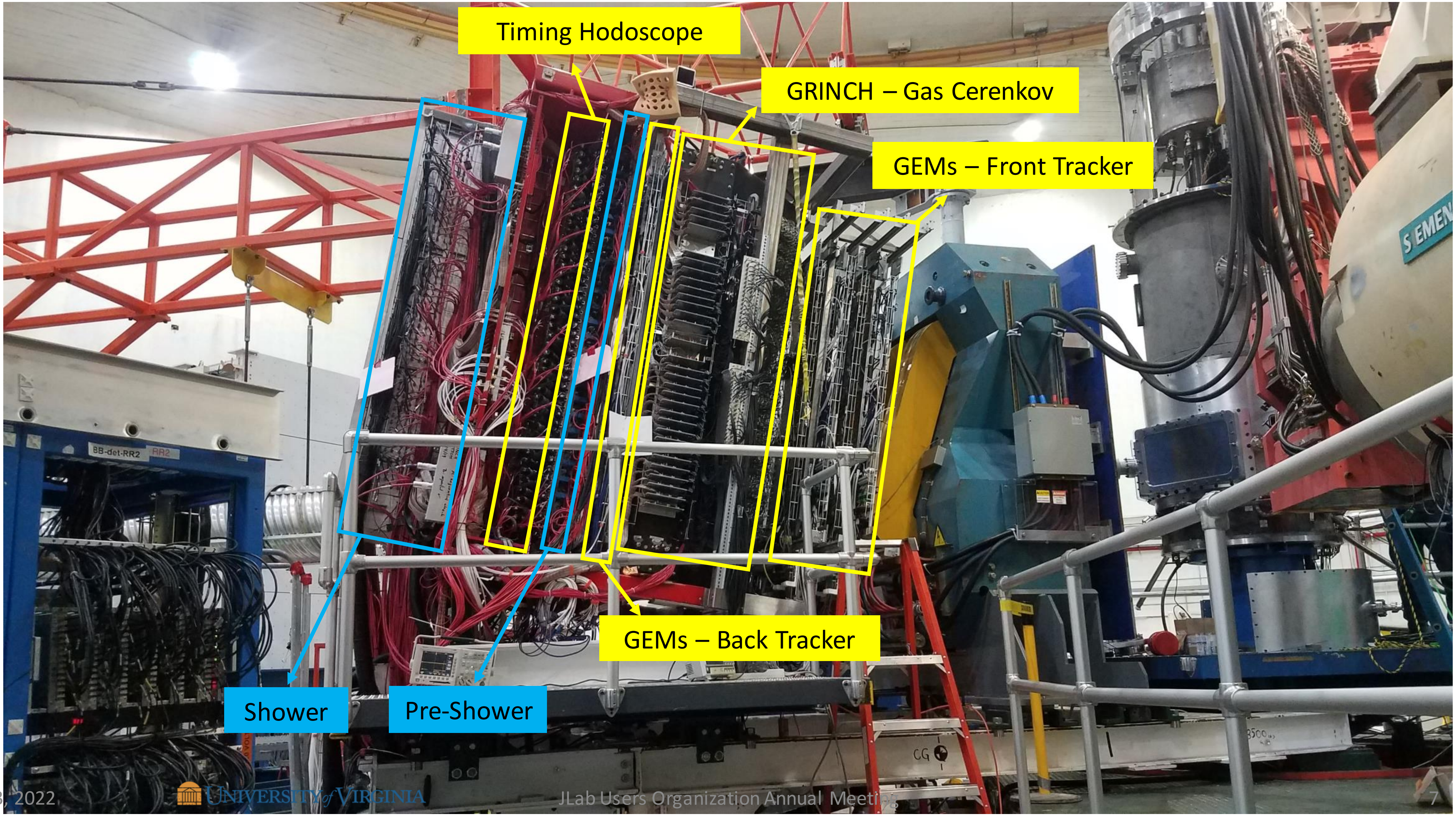
BB Electron Arm

Physics Programs with SBS/BB

- Major measurements of nucleon form factors using SBS/BB Spectrometers
  - GMn (E12-09-019): Precision Measurement of the Neutron Magnetic Form Factor at up to $Q^2 = 18\ (GeV/c)^2$. Data collection **completed February 2022 (see Eric's talk)**
  - nTPE (E12-20-010): Measurement of the Two-Photon Exchange Contribution to the Electron-Neutron Elastic Scattering Cross Section. Data collection **completed February 2022**
  - GEn-II (E12-09-016): Measurement of the Neutron Electromagnetic Form Factor Ratio GEn/GMn at High Q^2. Scheduled **this coming fall**
  - GEn-RP (E12-17-004): Measurement of the Ratio GEn/GMn by the double polarized $^2H(e, e'n)$ Reaction
  - GEp-V (E12-07-109): Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ Using Recoil Polarization Method

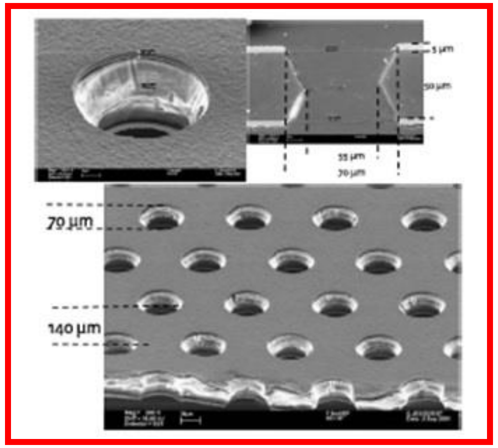
Bigbite Spectrometer in GMn Experiment

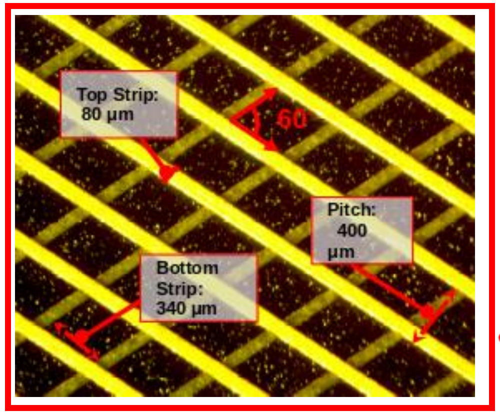
Bigbite Spectrometer in GMn Experiment

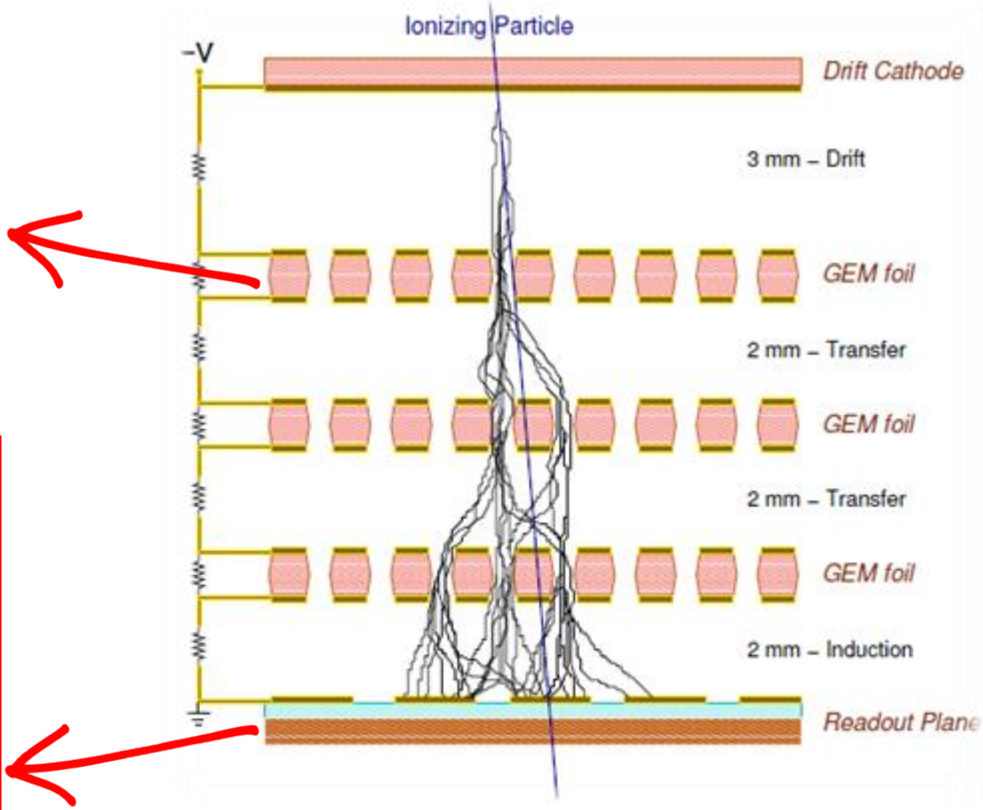


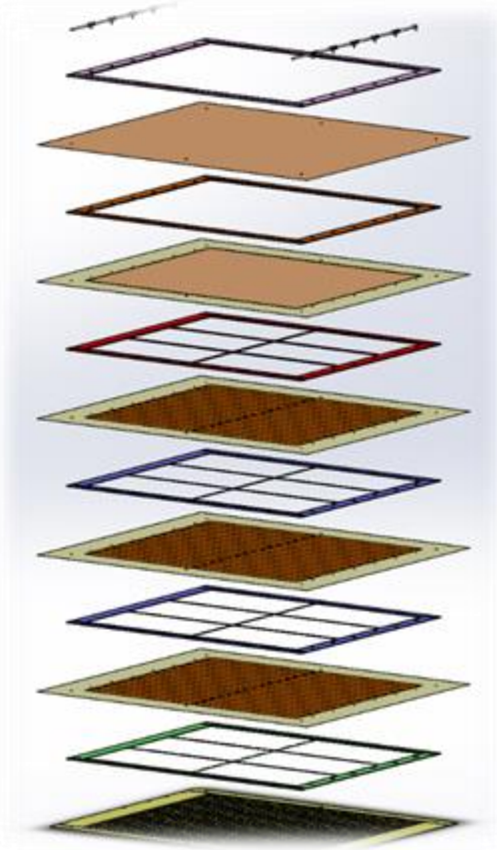
GEM Detector

- GEM (Gas Electron Multiplier) detectors consist of GEM foils and a **2D** readout plane
- Compass triple foil structure
- High Rate (2 MHz/cm^2), high space resolution (70 um)







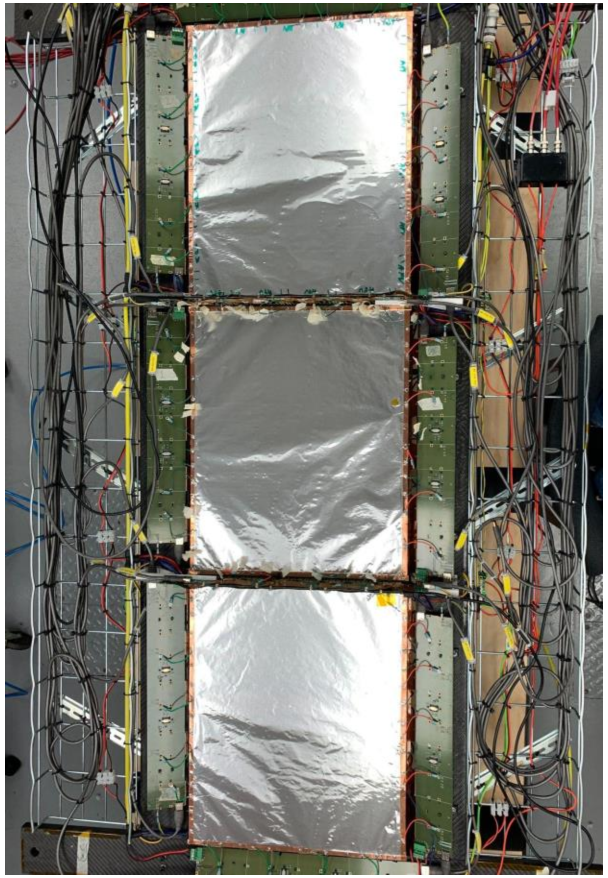


GEM Detectors in Bigbite

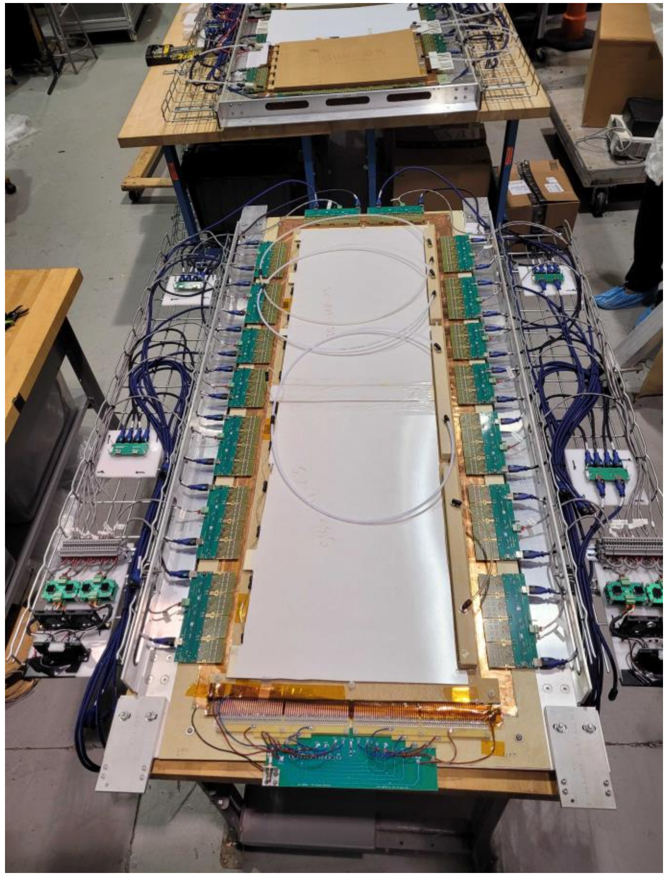
40X150 cm² layers, made of 3 40X50 GEM modules

40X150 cm² layer, made of a single module, no dead area in active area

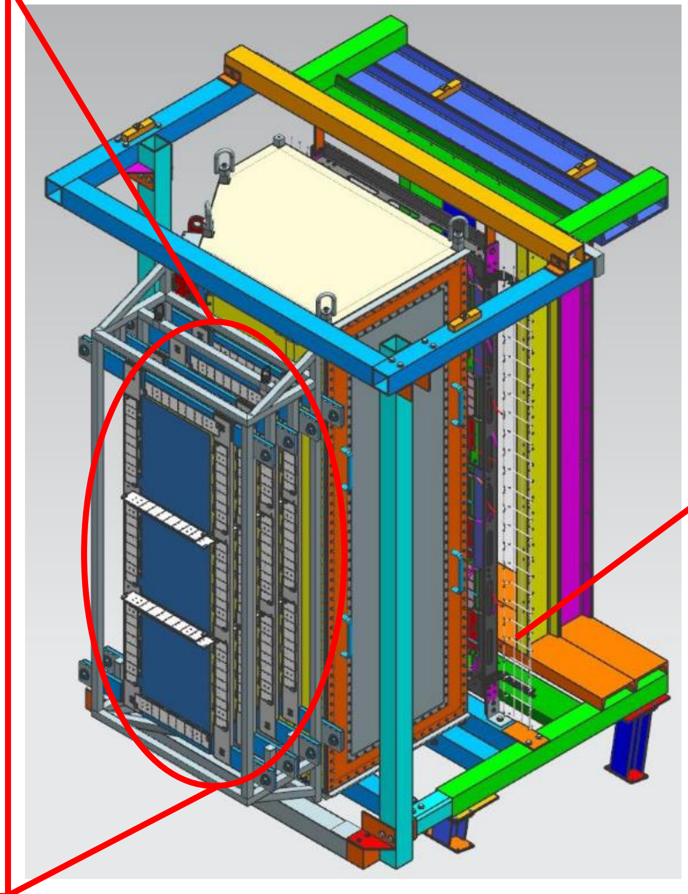
60X200 cm² layers, made of 4 60X50 GEM modules



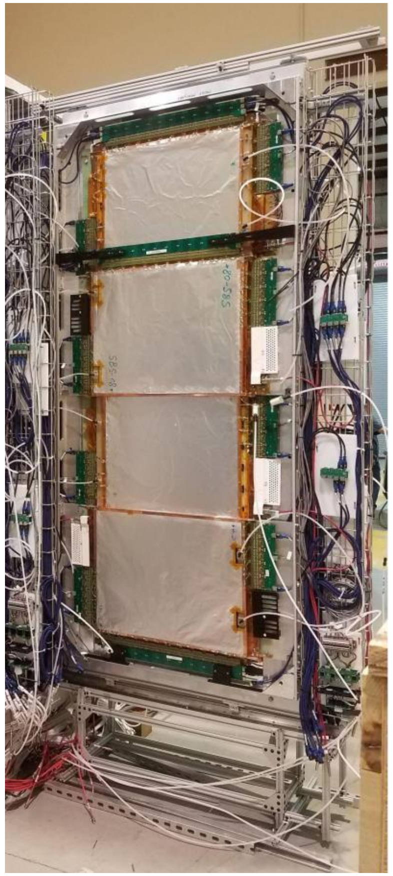
INFN XY



UVa UV



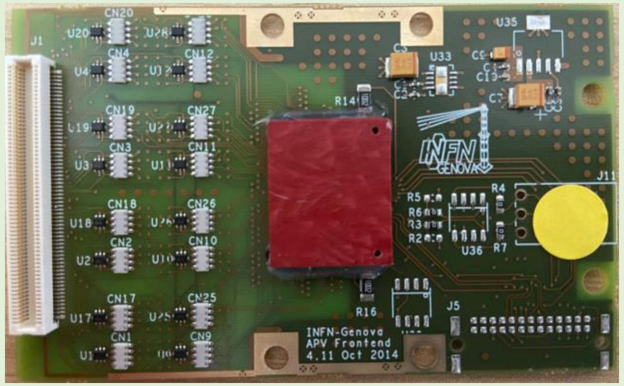
Bigbite Detectors



UVa XY

These layers are among the largest GEM layers ever built

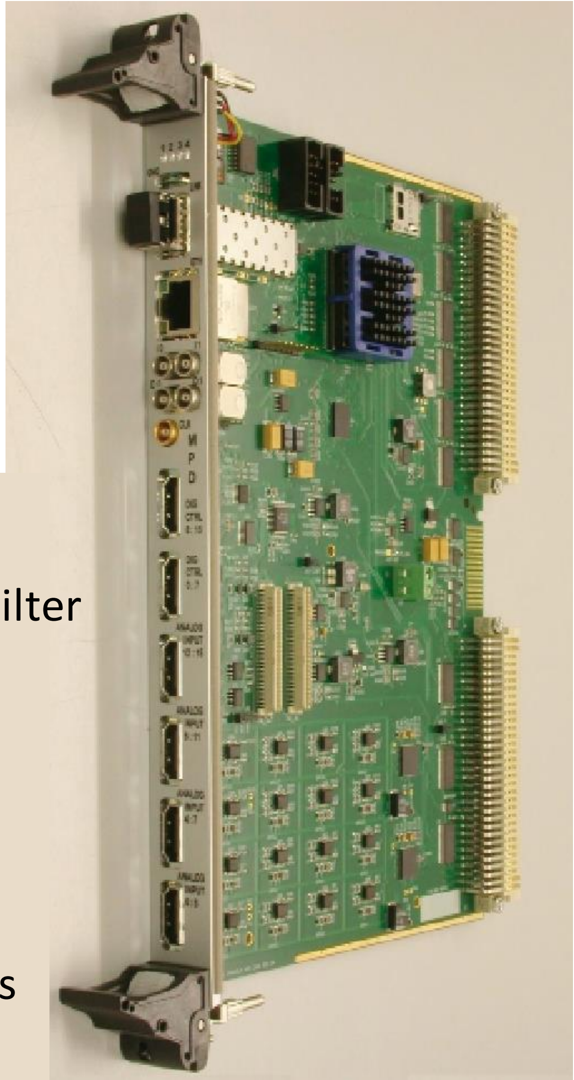
APV/MPD System for Bigbite



- 128 Analog ch / APV25 ASIC
- 3.4 us Trigger Latency (analog pipeline)
- Capable of sampling signal at 40 MHz
- Multiplexed analog output (100 KHz readout rate)

- Total readout channels in Bigbite ~42000
- Physics trigger rate: ~4 KHz
- Up to APV25 cards (2048 ch) on a single MPD (parallel readout)
- Optical fiber link interface (Aurora ~ 2Gb/s peak)
- 250 MHz system clock
- HDMI-A for analog and digital signals

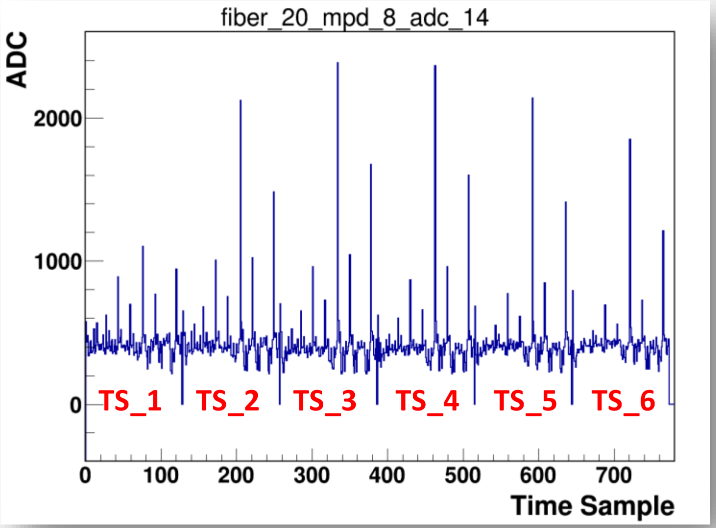
- MPD Firmware
  - FIR (Finite-Impulse-Response) Filter (16 parameters)
  - Online commode and zero suppression
  - 2ns trigger time resolution
  - Remote configuration
  - VME/Optical fiber simultaneous implementation



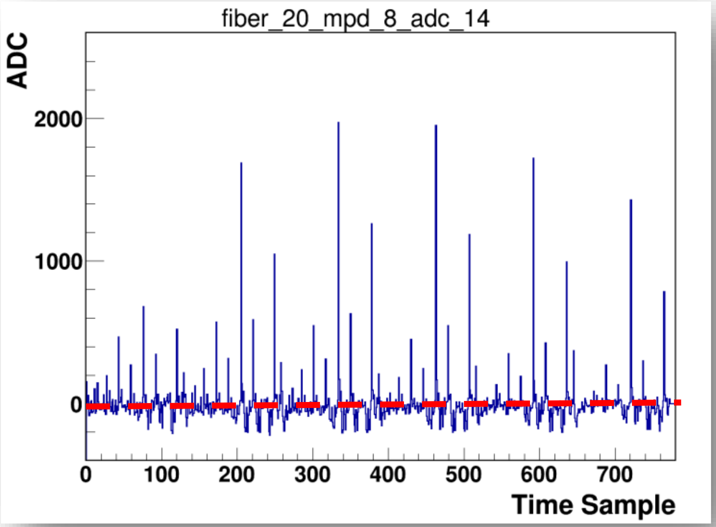
MPD (Paolo, INFN)

Signal and Online Zero Suppression

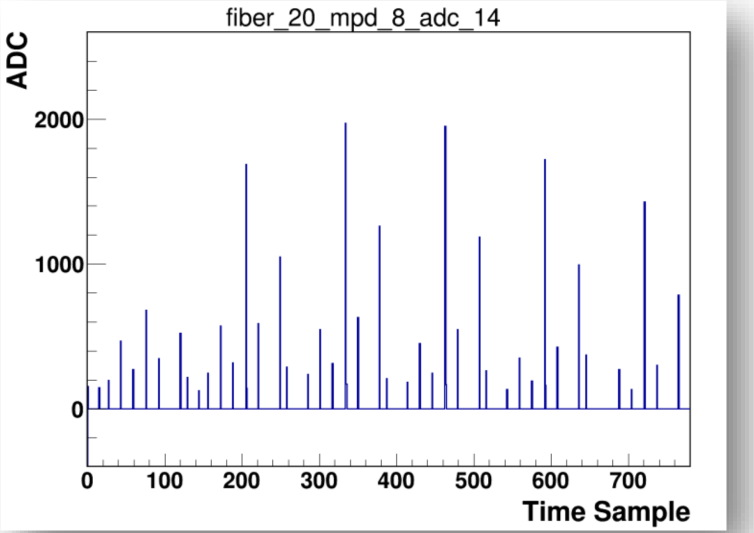
- 25 ns sampling period, 128 channels in each time sample, 6 time samples
- On-board FPGA online zero suppression, a solution to large data volume transfer



Raw Event



Common mode correction, baseline was brough to 0

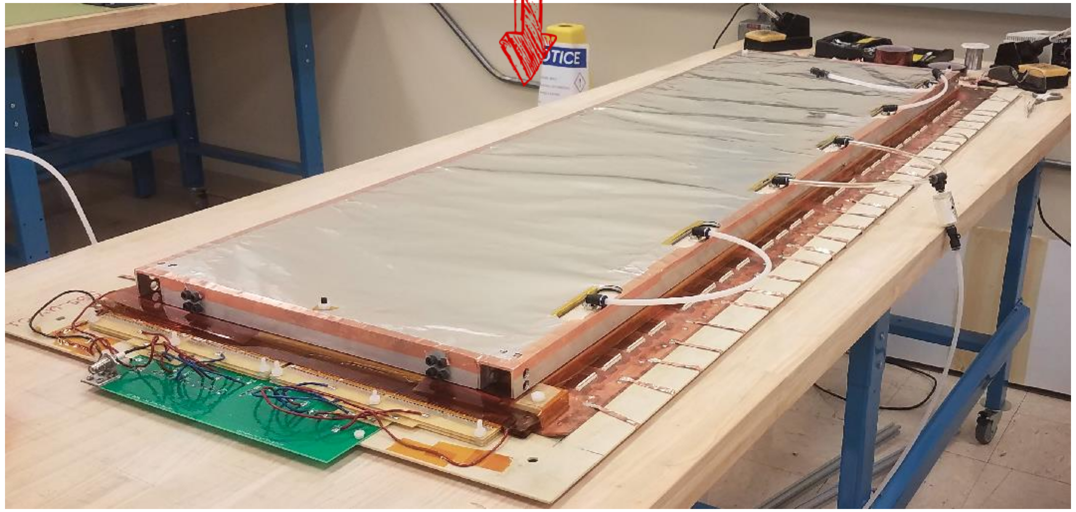


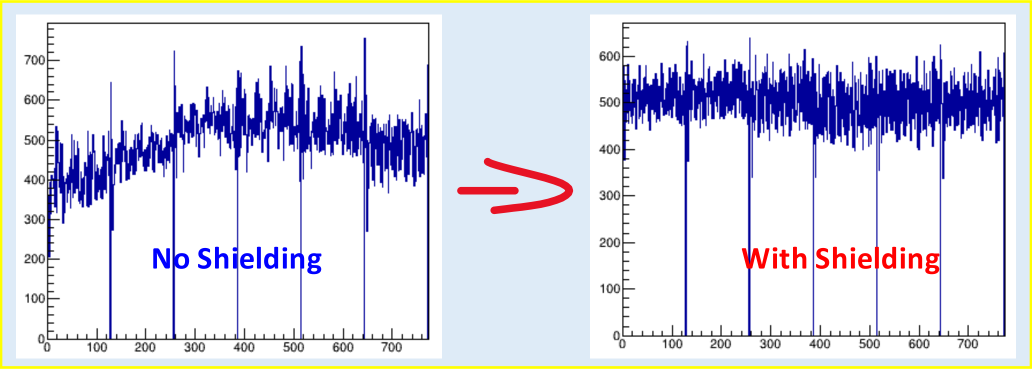
Zero suppression, only channels with hit were saved

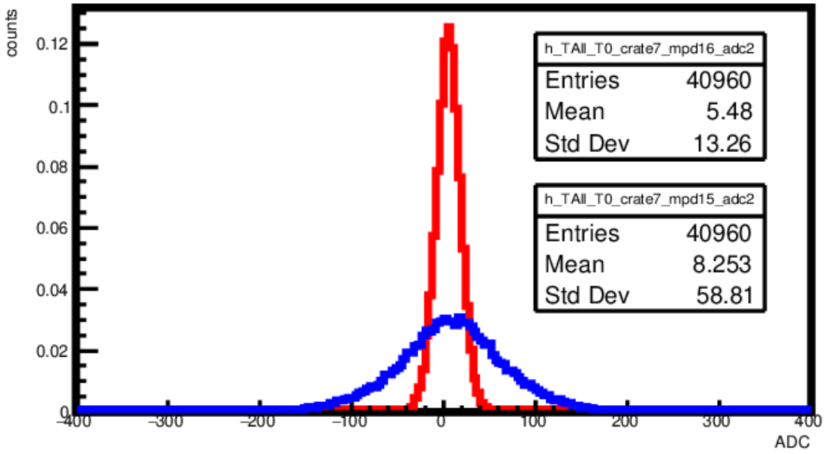
During experiment, noticed negative pulses caused the baseline to shift towards the lower side, no data was lost, we know how to correct this issue offline

Common Mode Noise Reduction

- Applied RF shielding to stabilize common mode fluctuation
- Common mode noise reduction by a factor of around 5



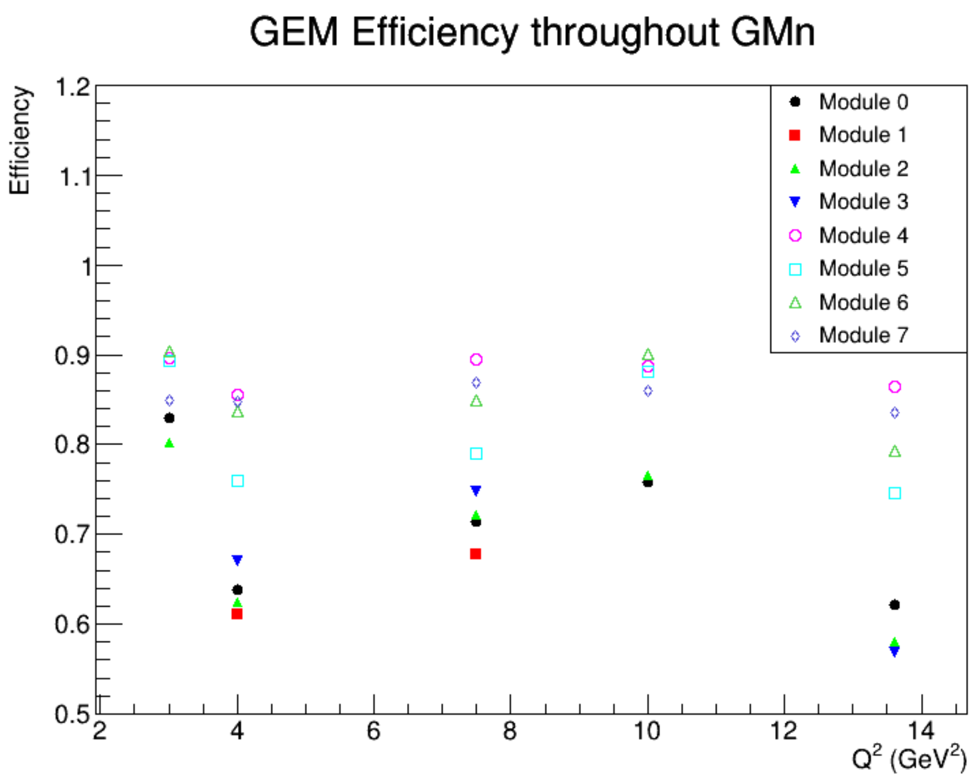


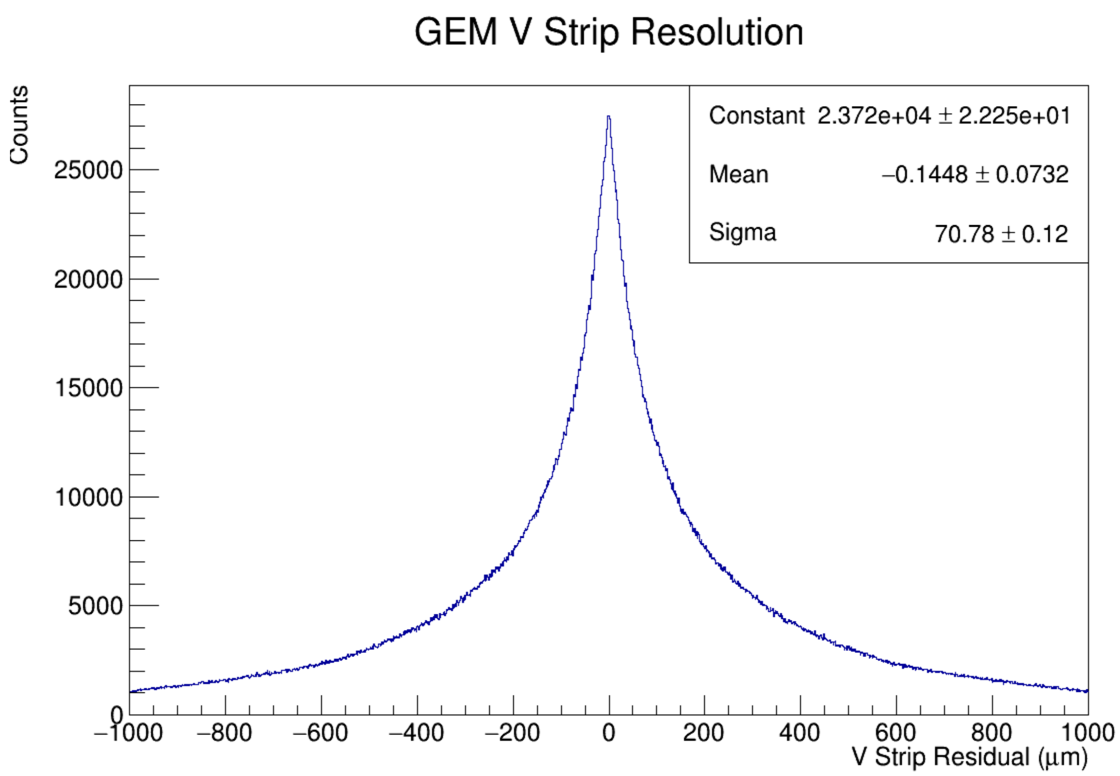


Common mode noise fluctuation

GEM Detector Performance in GMn

- Efficiency varies from module to module due to different rates seen by different modules
- Backtrackers has consistently higher efficiency due to low rates
- Position resolution around 70 um





Plot courtesy of Sean Jeffas

Tracking Algorithm

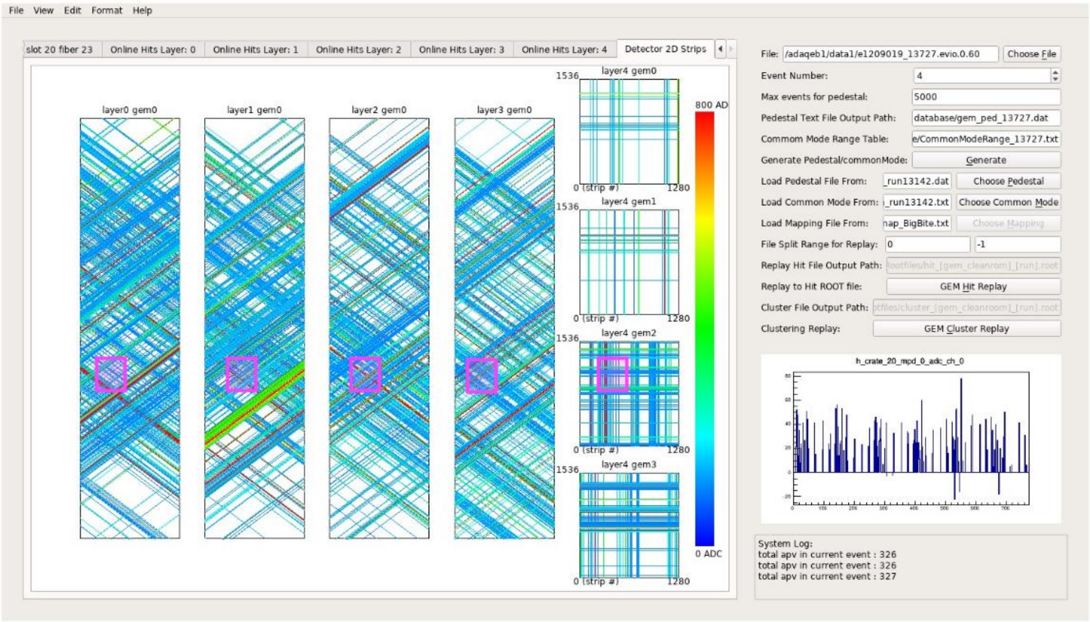
- 5 GEM layers out of electromagnetic field, high rate, large quantity of combinations

Tracking algorithm in a nutshell:

- Perform 1D clustering of strips along each dimension in each GEM chamber
- Form all possible 2D combinations within calorimeter-defined region
- Divide each tracking layer into a uniform 2D rectangular grid, accumulate a list of 2D hit candidates in each grid bin (bin size 1 x 1 cm^2)
- Loop all possible combinations from hits in outermost layers (within search region)
- Form straight-line projection
- Loop all possible combinations from each inner layer (minimum 3 layers)
- Find the hit combination with best X^2/ndf

Tracking algorithm credit goes to **Prof. Andrew Puckett and Dr. Weizhi Xiong**

What we're up against, II (run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$)



- This is the same event as previous slide, but requiring max ADC sample on a strip greater than 100, a typical offline threshold for cluster maxima that is higher than online threshold

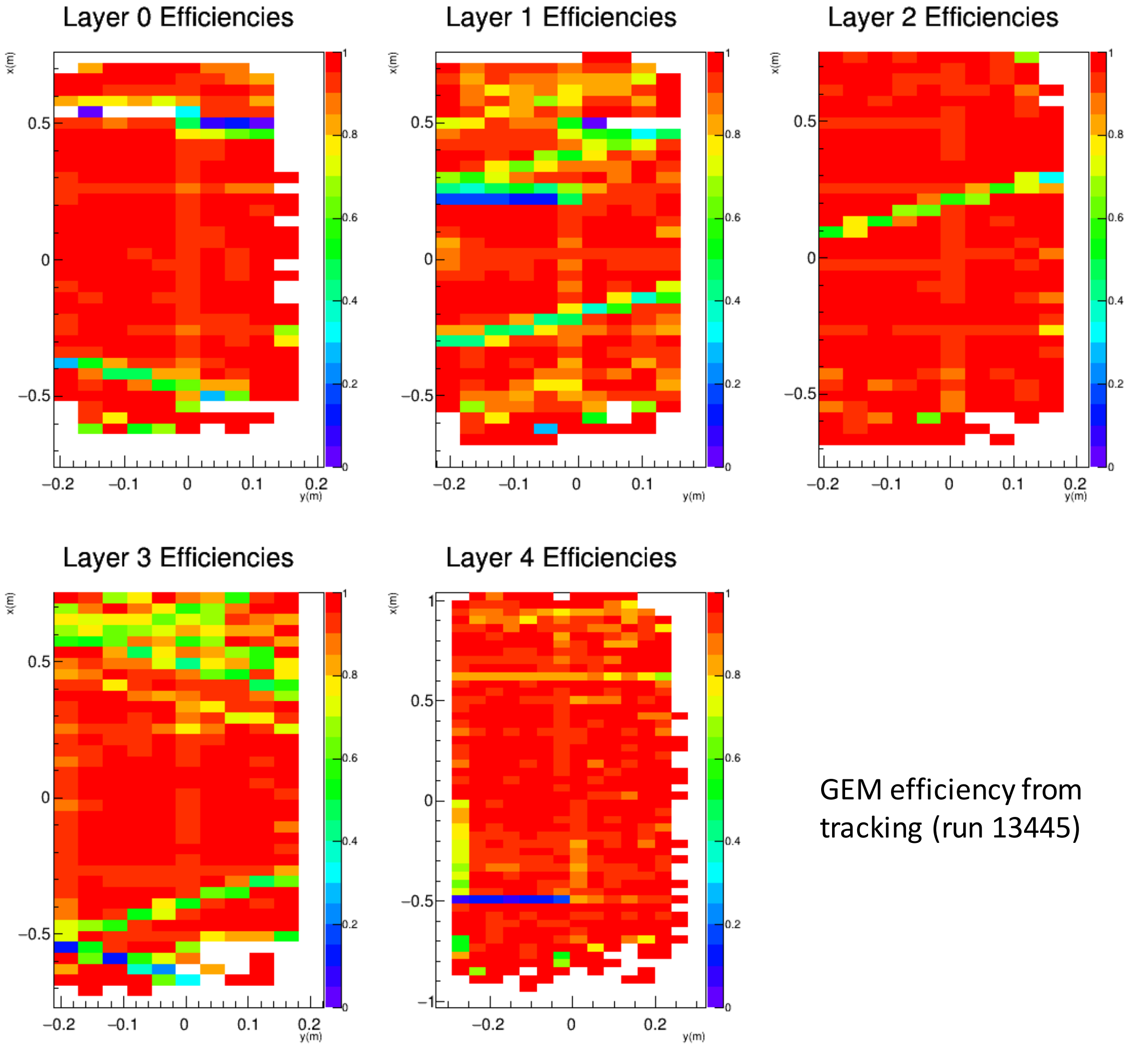
= approximate size of calorimeter-constrained track search region at each layer

UCONN 2/11/22 Hall A Winter Meeting 2022 9

Slide courtesy of Prof. Andrew Puckett

Tracking Performance

- **Average > 90% under low occupancy, > 60% under high occupancy in GMn**
- Low efficiency area due to dead channels on GEM detectors and APV chips
- While occupancy increases, efficiency drops
  - GEM gain drop due to high voltage system design
  - Larger number of possible 2D combinations, more fake tracks
  - More noise hits due to negative signals, common mode sagging towards the lower side under high occupancy – offline correction developed (Sean Jeffas from UVa)
- We took a set of high beam current (high occupancy) runs to study this effect, the analysis work is in progress, further improvements will be made in future



GEM efficiency from tracking (run 13445)

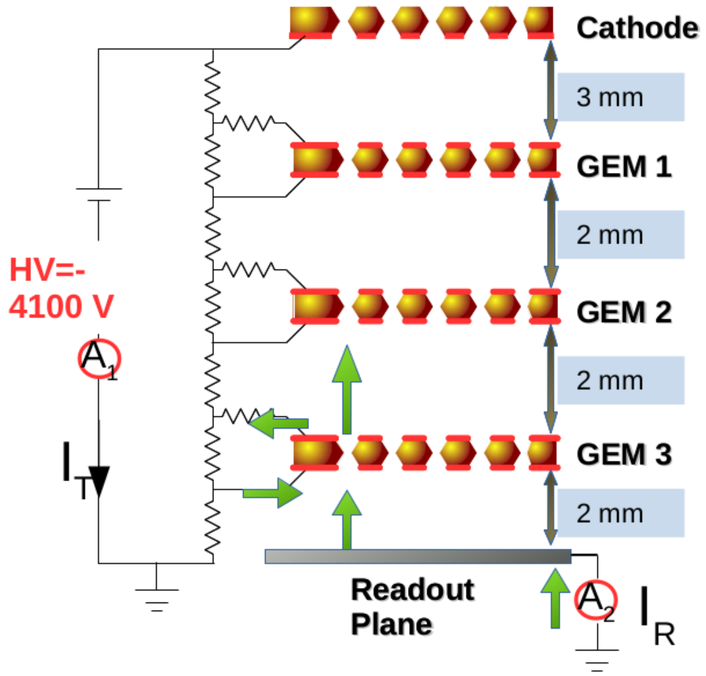
Estimated Rates in GMn

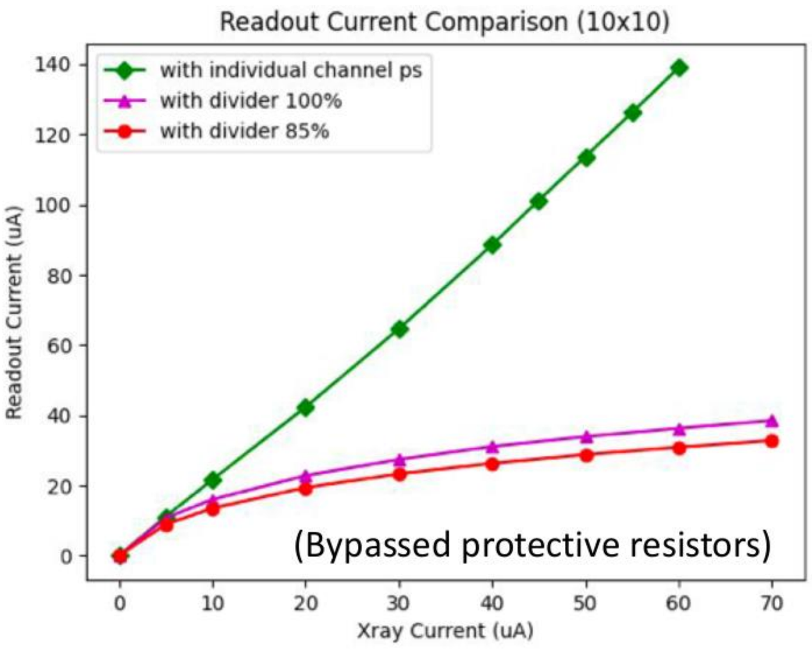
- Background comes from: beamline structure, target window...
- A majority background rate comes from low energy photons, less than 1% conversion rate, can be rejected by tracking
- Estimated from GEM gain factor measurement, not precise
- Rates are about a factor of 2 – 3 times higher than expected

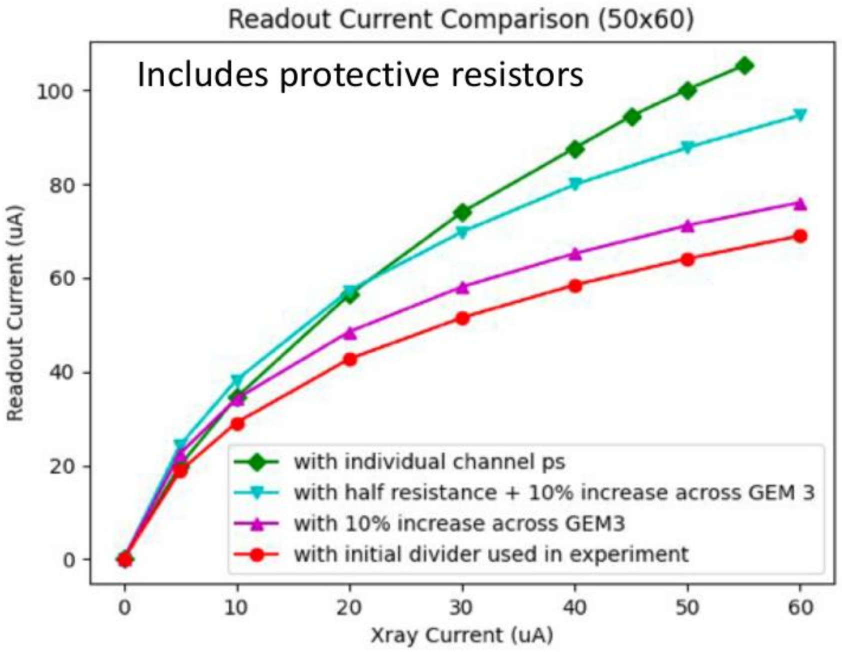
SBS Period	Target	E_beam (GeV)	Beam Current (uA)	BB Angle (Deg)	BB Distance (m)	Q^2 $(GeV/c)^2$	Extrapolated I_excess	Rate
SBS-4	LD2	3.728	1.75/3.75/7/10	36	1.8	3.0	(R. 28) E. 28	**159.6 KHz/cm²**
SBS-7	LH2	7.906	1/2/4/8/10	40	1.85	9.8	(R. 38) E. 40	**228 KHz/cm²**
SBS-8	LH2	5.965	1/2/3/4/5/8	26.5	2.0	4.5	(R. 40) E. 48	**273.6 KHz/cm²**
SBS-11	LD2	9.91	2/4/8/10/11/12	42	1.55	13.5	(R. 71) E. 105	**598.5 KHz/cm²**
SBS-14	LD2	5.965	1/2/7.5/8/10	46.5	1.85	7.4	(R. 42) E. 49	**279.3 KHz/cm²**

Further Improvement for High Rate

- Under high rate, the large current flowing through GEM detector will change the HV distribution on each GEM foils
- A HV drop on 3rd GEM foil was observed
- Increased the HV distributor resistor for GEM3 by 10% before GMn
- A new solution using a parallel HV unit to provide HV for each GEM foil separately







Summary

- First GEM operation in high-rate experiment at Jefferson Lab
- Very stable performance during GMn run – low noise, good efficiency, high resolution
- Large system (more than 40,000 channels in GMn), online zero suppression algorithm worked successfully
- Gained lots of experience, further improvements already implemented for the coming GEn-II run
- 10 times higher luminosity, 3 times higher total channels expected in the GEp-V and GEn-RP experiments
  - ❑ GEp-V will be detecting protons, a shielding can be added close to target to filter out electromagnetic backgrounds without affecting protons, the actual rates can go up by a factor of 3, instead of 10