SoLID GEM Detectors in US

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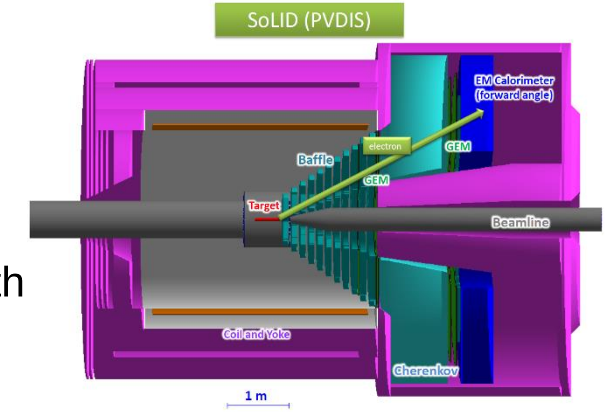
SoLID Collaboration Meeting @ Jlab, 01/13/2016

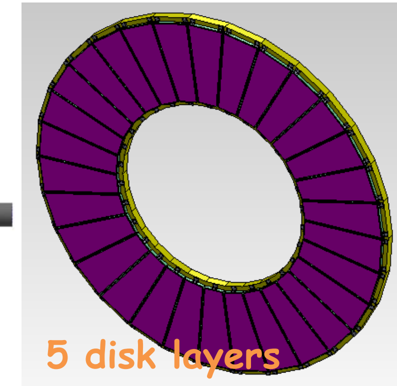
Outline

- ✓ Overview of SoLID GEM Trackers
- ✓ Large area GEM R&D @ UVa
- ✓ Update on APV25 Electronics
- ✓ SoLID GEM-US Pre-R&D

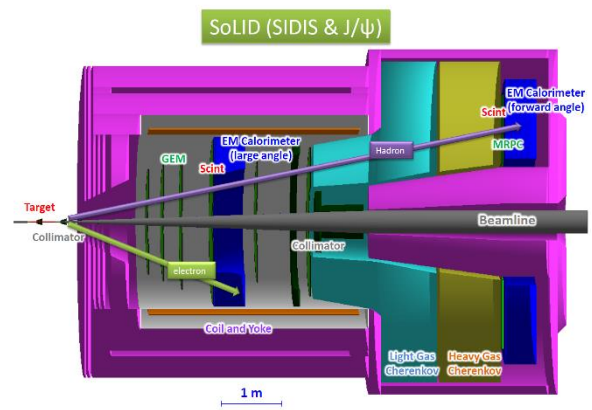
Overview of SoLID GEM Trackers

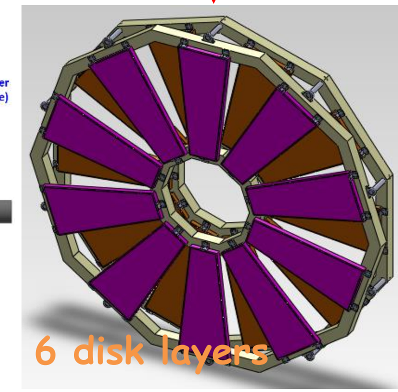
PVDIS





SIDIS





Tracking requirements for PVDIS

- Luminosity ~ 10^{39}/cm^2/s
- Rate: from 100 kHz/cm^2 to 600 kHz/cm^2 (with baffles) from GEANT4 estimation
- Spatial Resolution: ~ 100 μm (σ) in azimuthal direction
- Total area: ~37 m2 total area (30 sectors × 5 planes, each sector covering 12 degree)
- Need radiation and magnetic field tolerant

Idea

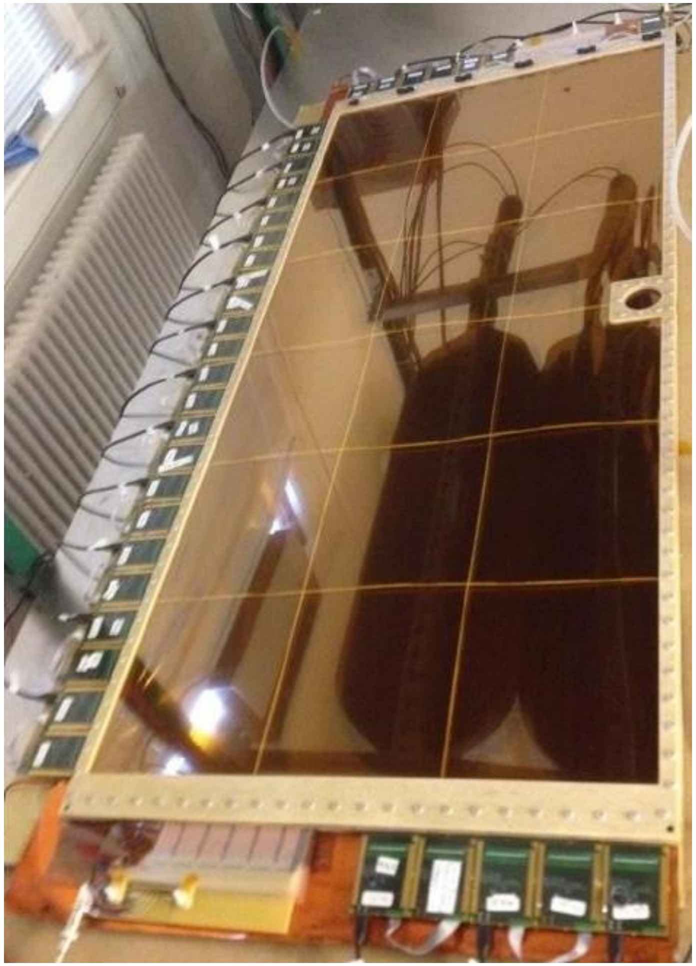
- Use the same set of GEM modules for all 3 configurations (PVDIS, SIDIS and J/ψ)
- All electronics channels from PVDIS would be more than enough for SIDIS and J/ψ

Overview of SoLID GEM Trackers: Large area GEM challenges

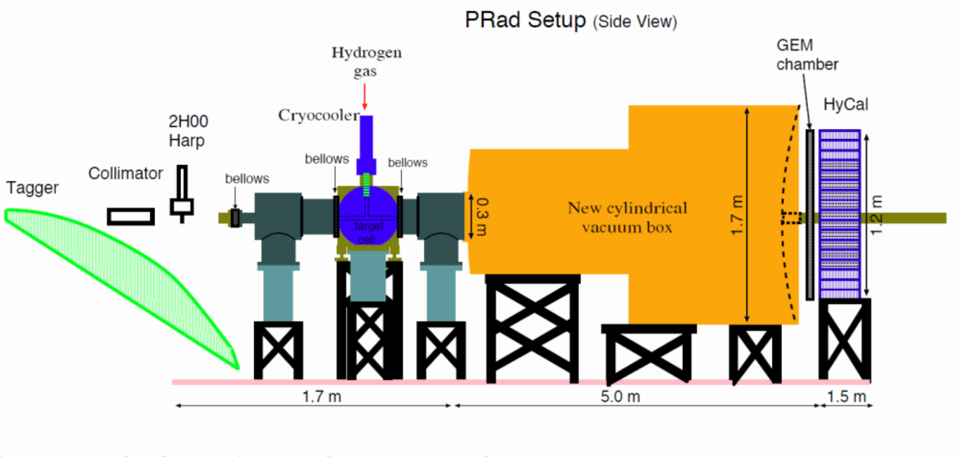
- SoLID needs GEM modules as large as 113 cm × 44 cm for the larger disk of PVDIS
- The biggest challenge used to be the non-availability of large area GEM foils.
  - ✓ Previously limited by double mask technique for etching: hard to the two masks accurately: Max area was limited to ~ 45 cm × 45 cm
  - ✓ New Single Mask technique allows to make GEM foils as large as 200 cm × 55 cm
- The remaining challenge is large production capacity:
  - ✓ If all LHC related large GEM project (CMS, ALICE, TOTEM) gets underway, this will require almost 100 % of CERN production capacity
  - ✓ Currently work going on for large GEM production capabilities in China and in the US.

Large Area GEM R&D @ UVa: The PRad GEM Trackers

PRad triple-GEM detector (active area: 122 cm × 55 cm)



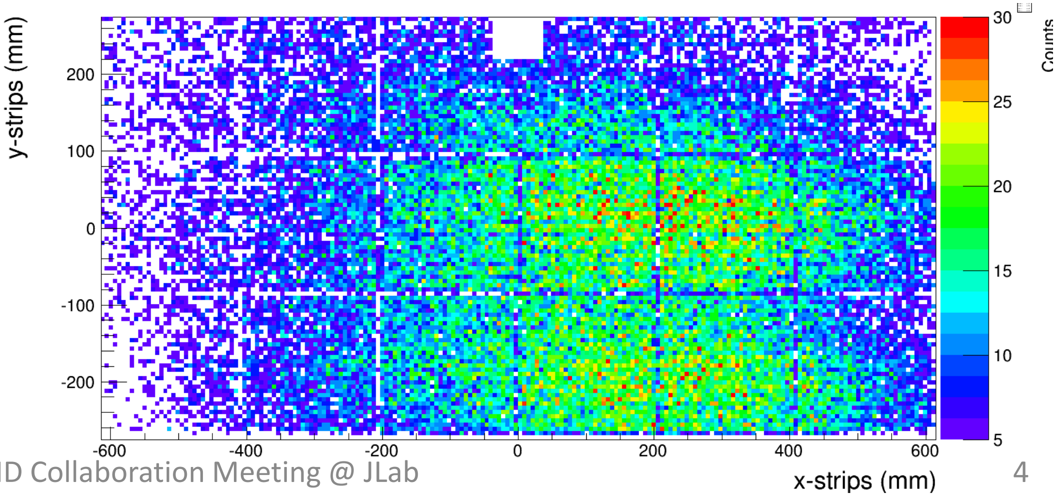
PRad: Proton Radius Experiment in Hall A @ JLab (E12-11-106)



Characteristics of PRad GEM trackers

- ✓ 2 large triple-GEM chambers **(~ 122 cm × 55 cm)**
- ✓ Largest GEM ever built, bigger than the largest SoLID GEM module
- ✓ COMPASS style 2D Cartesian strip readout : long narrow strip (> 130 cm) → **but still low capacitance noise**

Characterization with Cosmics

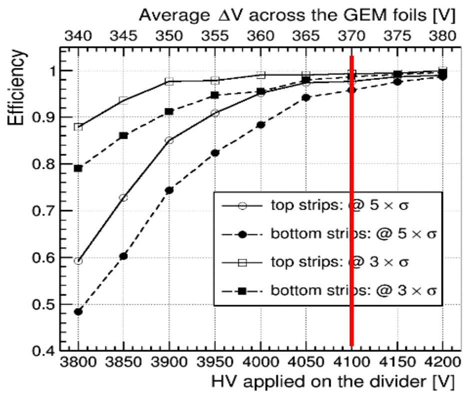


Large Area GEM R&D @ UVa: Performances of U-V strip readout

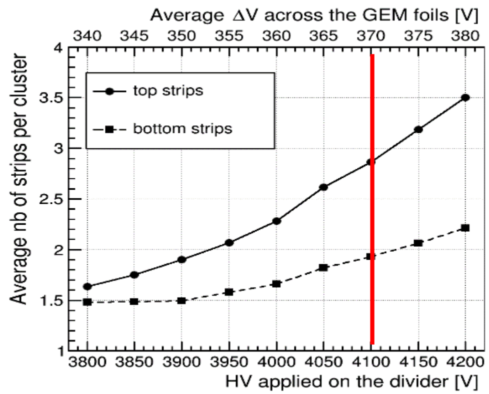
EIC-FT-GEM (SoLID) Prototype I

- Trapezoid shape **1-m long** triple-GEM (3-2-2-2): widths at the inner radius and outer radius equal **to 23 cm and 44 cm** respectively.
- Readout board: flexible 2D U-V strip readouts (COMPASS style) with a **pitch of 550 µm,** top layer (**140 µm, wide U-strips**) run parallel to one radial side of the detector and bottom layer (**490 µm, V-strips**) run parallel to the other side.
- Test beam results published in **NIM A 808 (2016) 83-92**

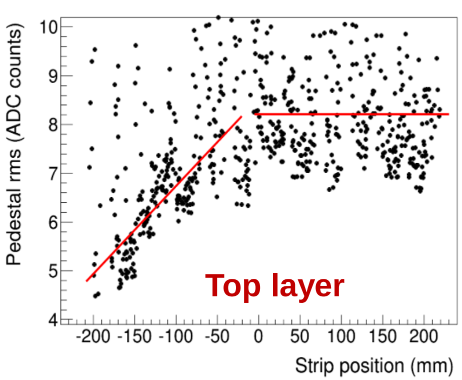
Efficiency vs. HV

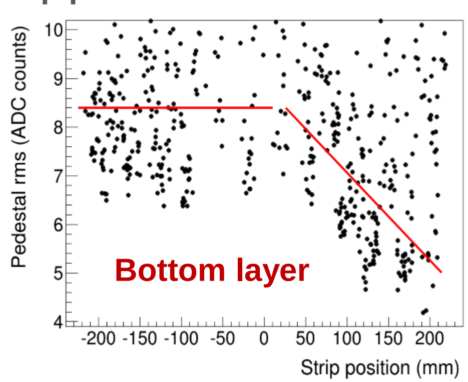


Cluster size vs. HV

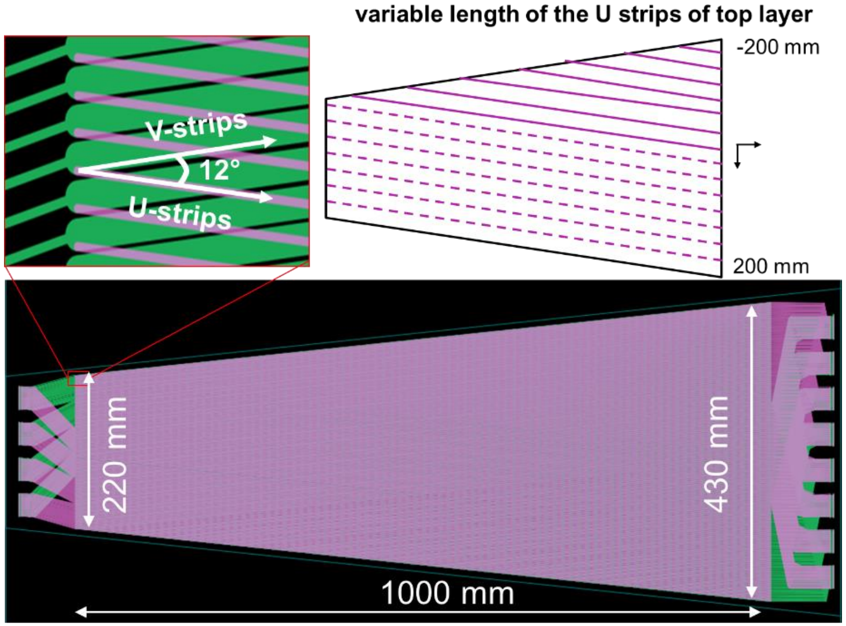


Distribution of the strip pedestal noise

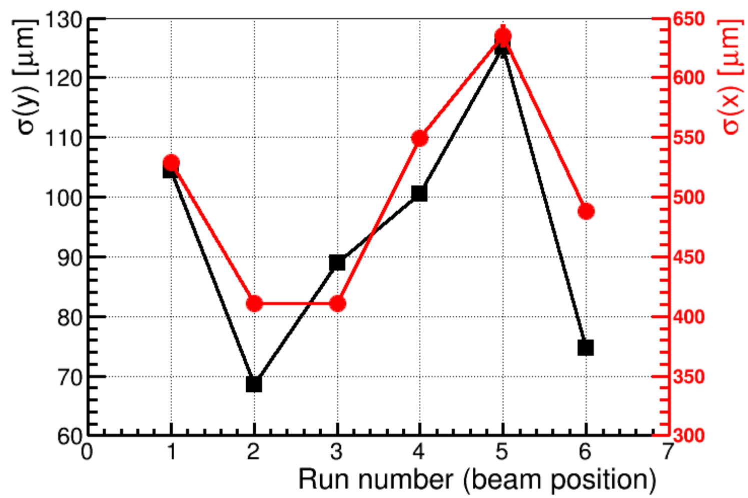




U-V strip Readout of EIC-SoLID GEM Proto I



Position resolution in x (radial) and y (azimuthal) on various locations on the chamber

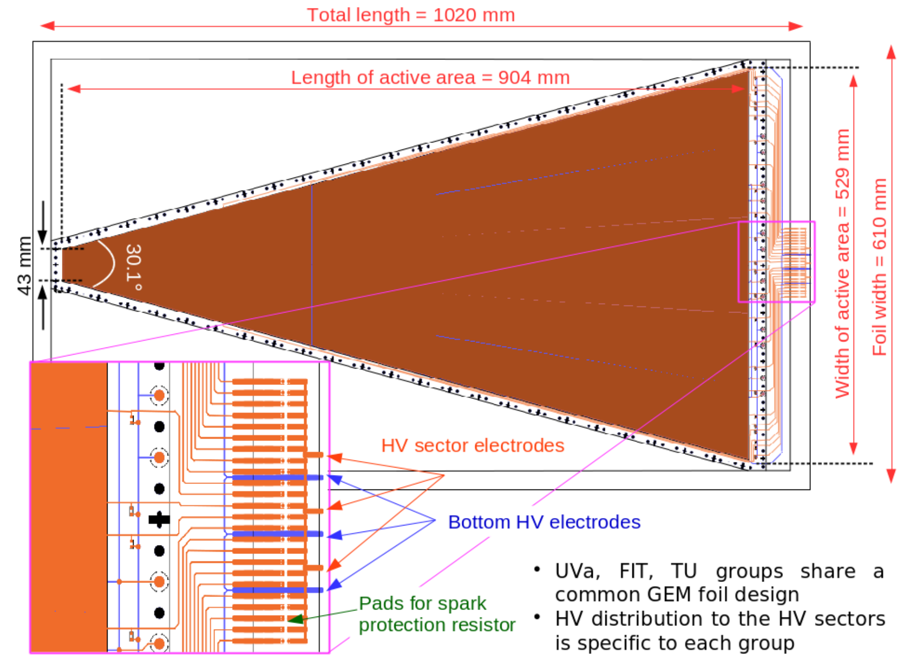


Large Area GEM R&D @ UVa: EIC-FT-GEM Prototype II

Common GEM foil for EIC Forward Tracker R&D:

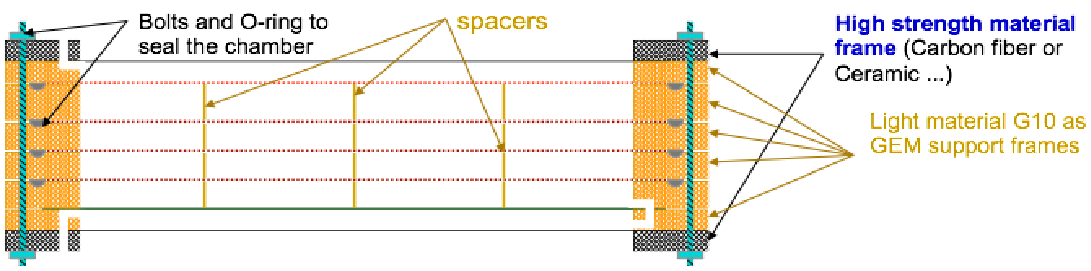
- ✓ Common GEM foil design developed by three groups at UVa, Florida Tech (**M. Hohlmann**), and Temple University (**B. Surrow**).
- ✓ Active area: A trapezoid foil with a length of **903.57 mm,** widths at both ends equal to **43 mm and 529 mm** and an opening angle of **30.1º.**
- ✓ Opening angle of the trapezoid is **30.1 deg**., allows some overlap when making a disk from 12 detectors.
- ✓ All HV sectors connections and gas flow structure are made on the large radius end.
- ✓ Honeycomb support are removed for a low mass detector
- ✓ Share a lot of features with SoLID Trackers GEMs

Common GEM foil for EIC-FT-GEM proto II
(design by A. Zhang @ Florida Tech)



- UVa, FIT, TU groups share a common GEM foil design
- HV distribution to the HV sectors is specific to each group

Novel assembly method for light weight GEM for EIC/SoLID



New assembly method:

- ✓ Ongoing work on the design of proto II of Forward Tracker Detector R&D of EIC
- ✓ Similar assembly technique for the pRad GEM chambers
- ✓ Foils are glued to frames but frames **not glued together** but sealed with O-rings and bolts
- ✓ could be re-opened.

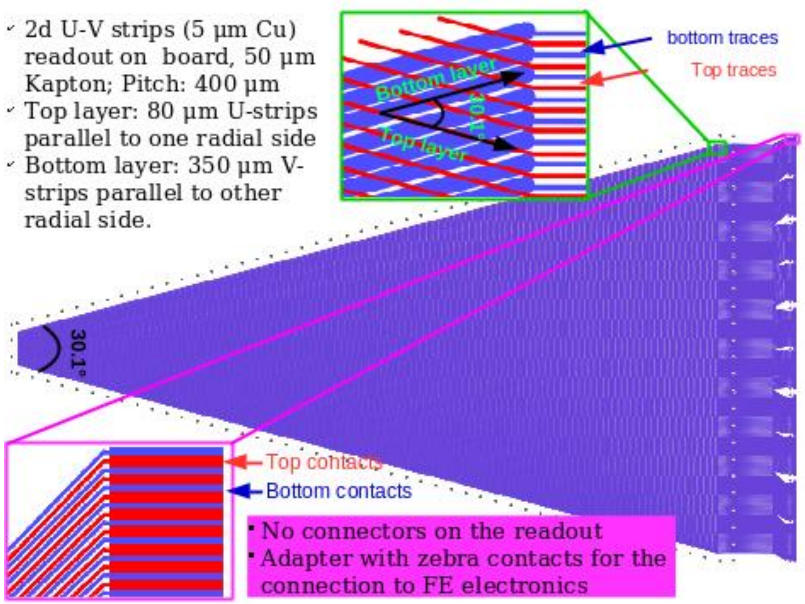
Large Area GEM R&D @ UVa: EIC-FT-GEM Prototype II

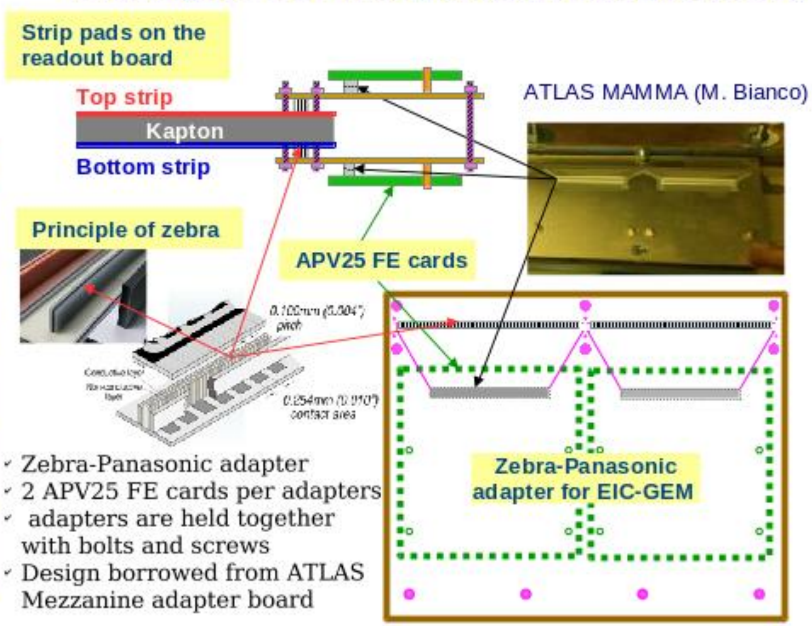
Upgrade of the U-V strip 2D readout board

- ✓ The readout strip pitch is equal to **400 µm** to improve spatial resolution, reduce pedestal noise and strip occupancy
- ✓ but **cluster size will increase** → however provide an easier way to separate photon background from MIPs
- ✓ Larger U-V strip stereo-angle of **30.1º** provide significant improvement of the spatial resolution in the radial direction
- ✓ Electrical contacts between the strips and the FE electronics done with **zebra connectors** on the outer radius side of the detector.
- ✓ With zebra connectors, **no mounted connectors and metallized holes (vias)** on the readout board
  - ✓ Lower production cost and eliminated risk associated with vias short and connector soldering on flexible readout foil

Zebra-Panasonic adapter board

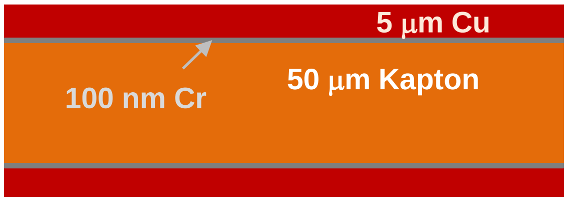
- ✓ Needed to read out the chamber with he existing APV25-SRS Front End Cards, design almost ongoing
- ✓ In the final version, for EIC/SoLID GEM trackers, the zebra strips will be directly on the FE cards

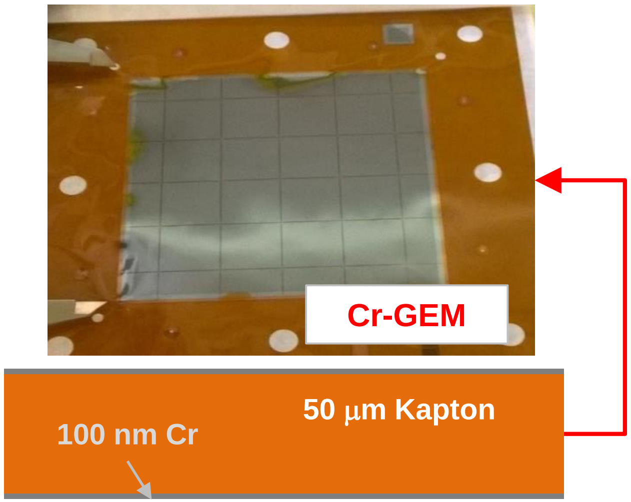




Low-Mass GEM R&D: Chromium GEM foil (Cr-GEM)

Standard GEM





Triple-GEM with standard GEM foil

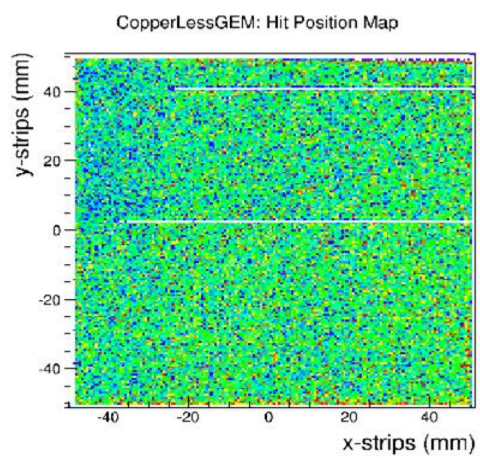
	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	5	8.96	14.3	1	0.0350	0.0045
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	5	8.96	14.3	0.8	0.1678	0.0215
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5	8.96	14.3	0.2	0.0070	0.0009
Copper-350	1	5	8.96	14.3	0.75	0.0262	0.0034
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.471	0.090

Triple-GEM with Cr-GEM foil

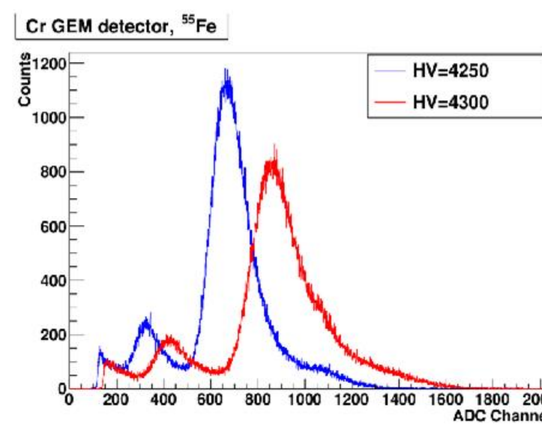
	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0	8.96	14.3	0.2	0.0000	0.0000
Copper-350	1	0	8.96	14.3	0.75	0.0000	0.0000
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO_2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.235	0.060

About 50% reduction in the amount of material in a EIC-FT-GEM with Cr-GEM

Response uniformity



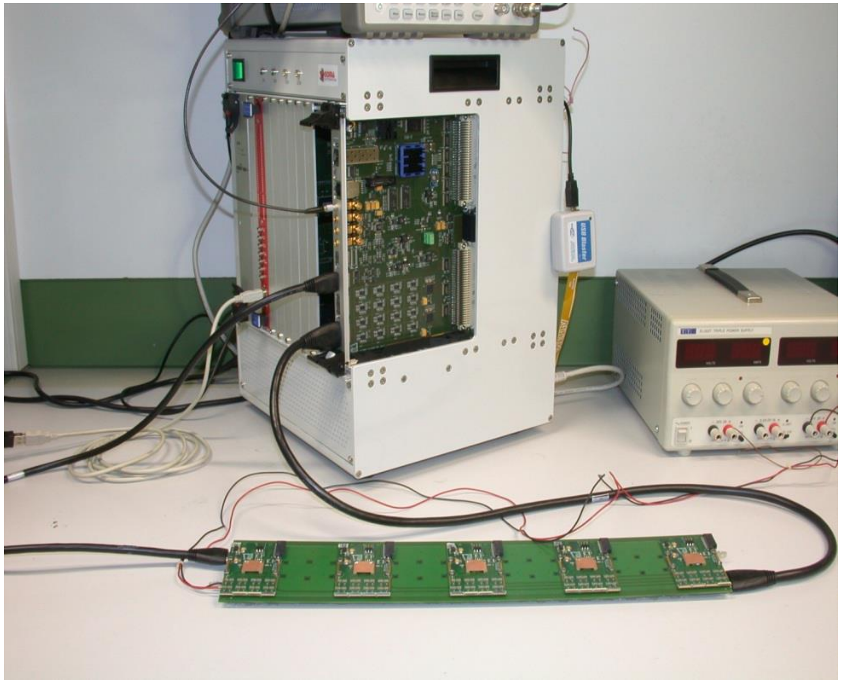
ADC Spectrum with Fe55



Cr-GEM foil:

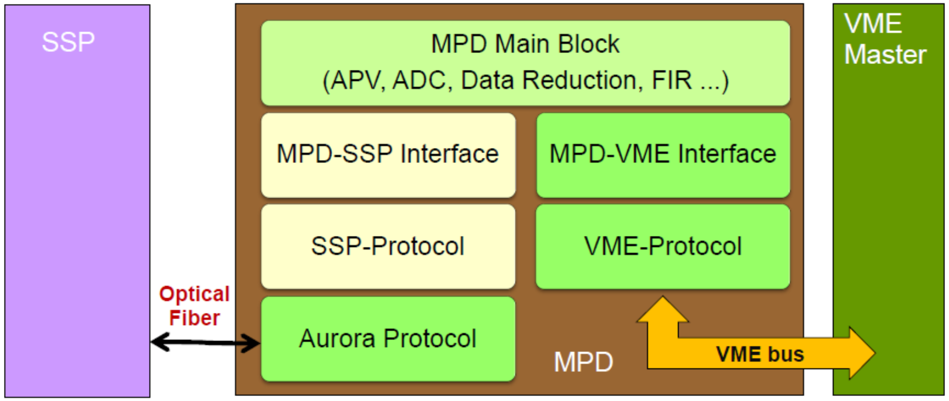
- ✓ Copper (Cu) clad raw material comes with 100 nm Chromium (Cr) layer between Cu and Kapton, 5μm Cu layers removed, leave only 100 nm residual Cr layers as electrodes, **Cr-GEM foils provided CERN PCB workshop**
- ✓ Using Cr-GEM foil lead to almost 50% reduction of the material of an SoLID-like light weight **triple-GEM detector**: this is because the material in a lightweight triple-GEM is dominated by the GEM foils & readout board

Update on APV-25 Electronics: MPD electronics for SBS



Multi Purposed Digitizer (MPD) is a VME64x module

- MPD data transferred may either on the VME bus or via optical fiber
- INFN & JLab currently working on the implementation of the communication between MPD and SSP over optical fiber
- First tested prototype expected by end of Nov/2015
- DAQ: Porting of MPD acquisition code to CODA framework close to be completed

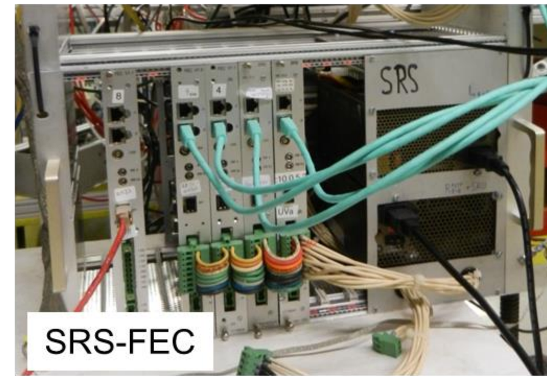


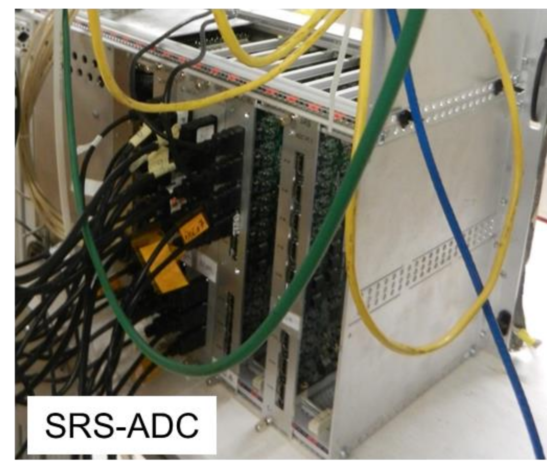
- Integration into CODA DAQ (in good progress, test currently ongoing)
- Test of the full MPD + CODA DAQ with SBS chamber in coming weeks

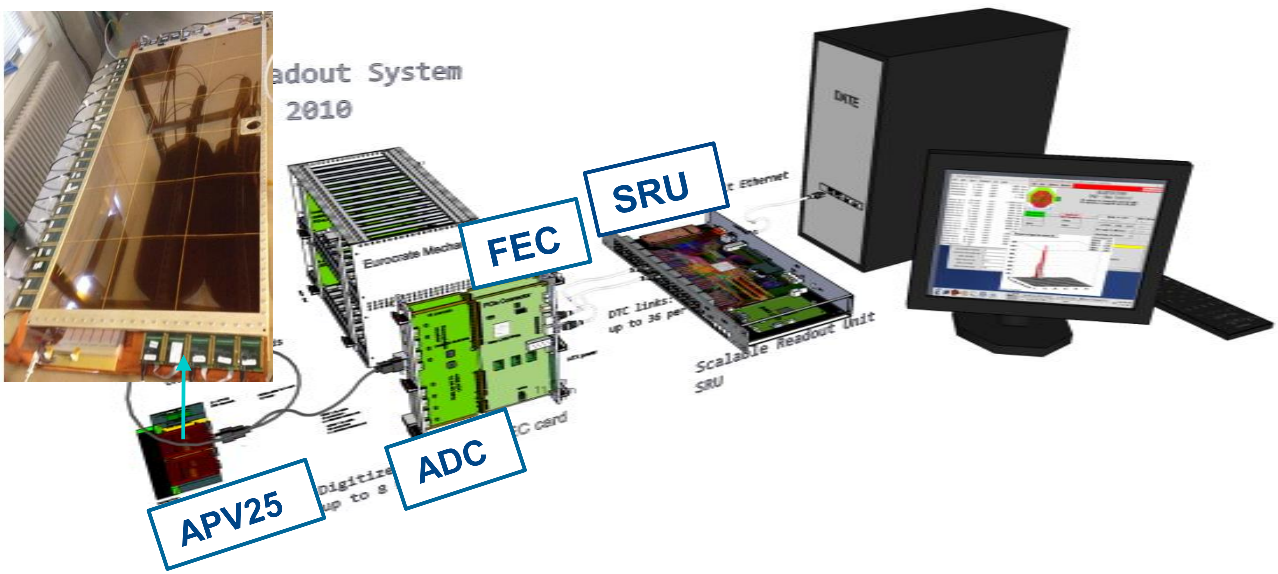
Update on APV-25 Electronics: SRS electronics for PRad

The Scalable Readout System (SRS)

- APV25-based system developed by the international RD51 Coll. based @ CERN
- Front End cards on the chamber host the APV25 chip ⇨ data to ADC via HDMI cables
- ADC cards interfaced with the FPGA board (FEC card) ⇨ FEC data fragment to the SRU
- SRU send the data fragment from many FECs to the DAQ PC through Gb Ethernet







The Need for PRad GEMs readout:

- Peak trigger rate 5 kHz
- 72 APV25-FE cards (9216 channels), 6 (8*) ADC/FECs ⇨ 2 SRU boards
- Implementation of the 10 Gb Optical link for the SRU (done)
- Integration of SRS into CODA DAQ (in good progress, test currently ongoing)

GEM in Experiment at JLab in 2016

- The PRad in Hall B: (April – May 2016)
  - ✓ Two PRad GEMs 120 cm × 55 cm provide 100 μm position accuracy
  - ✓ Readout electronics: APV25 + SRS
- Tritium Experiment in Hall A (Fall 2016)
  - ✓ 4 Experiments with Tritium target with Bigbite Spectrometer @ 11 GeV
  - ✓ Two chambers (150 cm × 60 cm) made of 3 SBS GEM modules each
  - ✓ Readout electronic: APV25 + MPD

SoLID GEM-US Pre-R&D program: Plan for the next 2 years

First year 2016:

- **Study of the performance of GEM in high background rate environment**
  - ✓ Data with x-ray source combine with cosmic (and/ or ^{90}Sr) to provide the input on the GEM efficiency in high rate environment needed for the evaluation of the **tracking efficiency by the tracking reconstruction software group**
  - ✓ Optimization of the design of different GEM modules size needed to equipped all layers in all PVDIS / SIDIS / J/ψ configuration
- **Acquire a few Chinese GEM foils for test and characterization**
  - ✓ Electrical test, Performance comparison with standard CERN foils
- **Readout electronics for SoLID GEMs**
  - ✓ Identify the need for SoLID GEM tracking and specification for the ideal chip
  - ✓ Survey of the candidate chips available on the market other than APV25, DREAM and VMM

Second year 2017:

- **SoLID GEM chambers design & prototyping**
  - ✓ Assembly of a prototype for the most challenging geometry (can even use Chinese GEM foils)
  - ✓ Applied experience learned from the EIC-FT-GEM R&D prototype II
- **Readout electronics for SoLID GEMs**
  - ✓ Acquire a few VMM electronics from RD51 for tests with the SRS DAQ

SoLID GEM-US Pre-R&D program: High rate studies for SBS

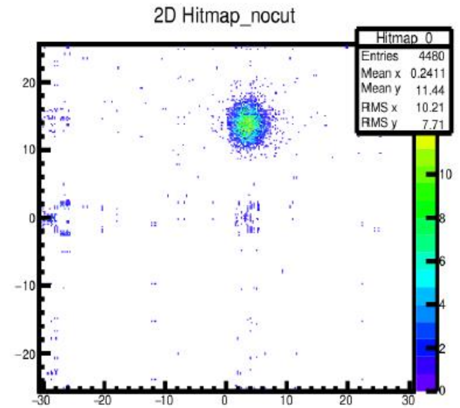
X-ray box setup @ UVa:

- Photon energy range: up to 50 keV
- Angular distribution: uniform within 60º
- Output flux: 24 MHz/cm^2 on the surface of GEM for 20 keV/ and current 5 μA

Charge deposition in GEM:

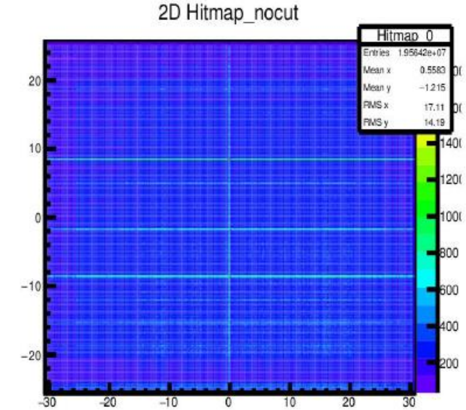
- Conversion rate about 0.5% to electrons for ionization
- up to 3.4*10^{11} electrons/cm^2/s **equivalent to about 7 MHz / cm^2 MIP.**

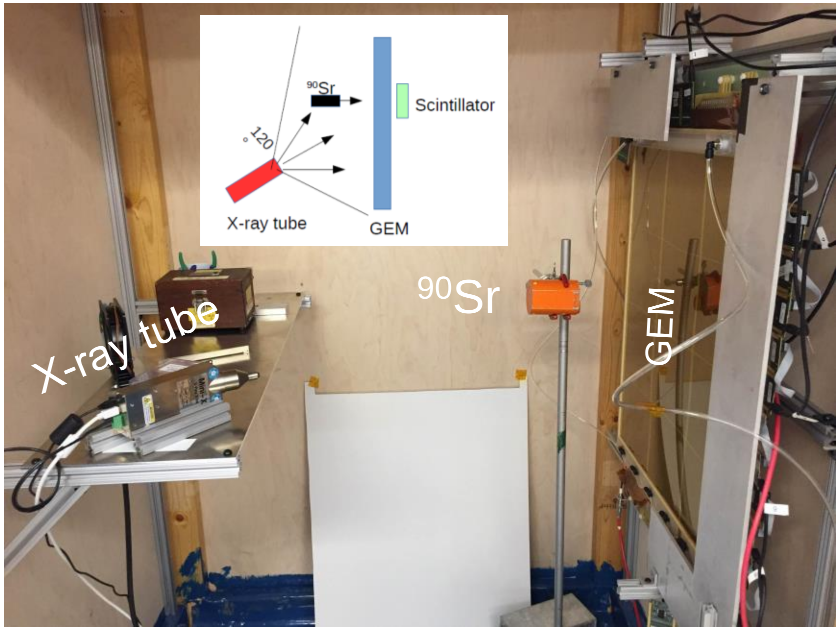
^{90}Sr only, no X-ray



^{90}Sr and X-ray

X-ray settings: 11kV/200uA



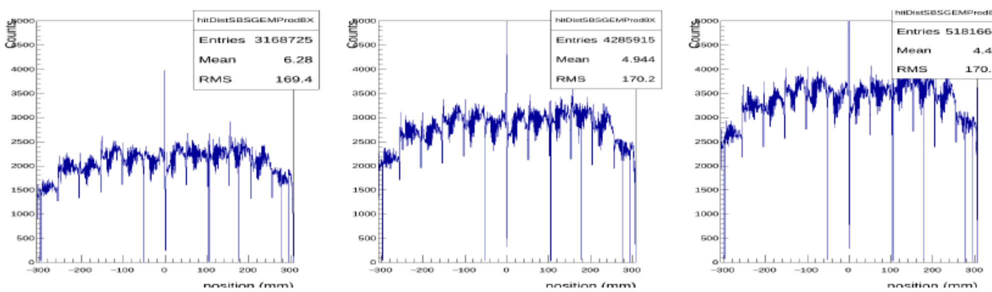


0.22 MHz / cm^2 mips

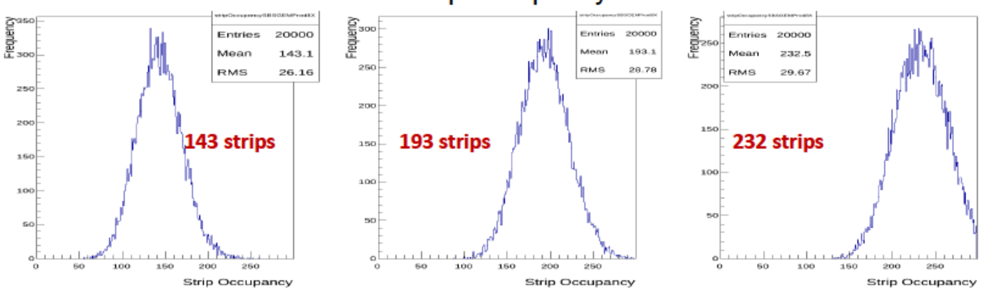
0.33 MHz / cm^2 mips

0.44 MHz / cm^2 mips

Hit distribution

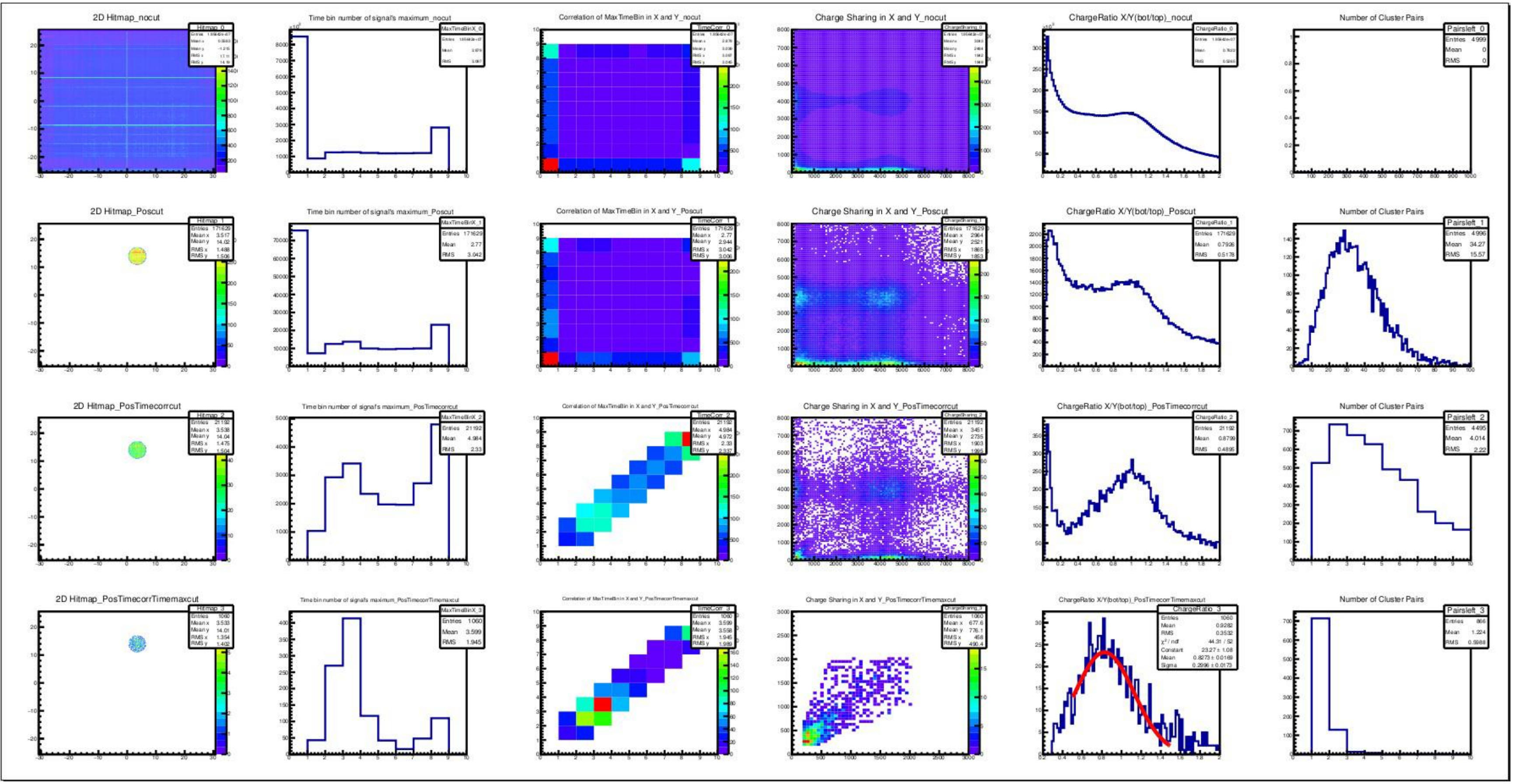


Strip occupancy



SoLID GEM-US Pre-R&D program: High rate studies for SBS

Hit map | Cluster size | APV timing x vs. y correlation | ADC x vs. y correlation | ADC x/y ratio | Cluster multiplicity



No cut

Cut on position

Cut on APV timing correlation

Cut on large ADC value

- These data produced for this study could be used as input for the tracking efficiency for SoLID

SoLID GEM-US Pre-R&D program: BNL VMM chip

- VMM developed at BNL for the ATLAS Muon Upgrage New Small Wheel
- export regulations (ITAR) compliance circuit
- G. Iakovidis MPGD2015 @ Trieste

VMM - ASIC evolution

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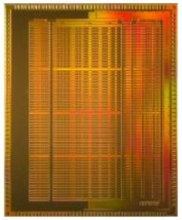
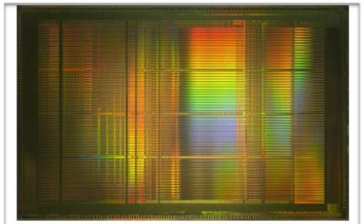
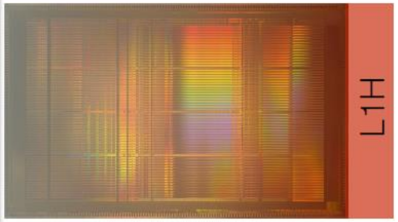


- VMM1 (2012)
- 50 mm²
- 500k MOSFETs
- (8k/ch.)
- mixed-signal
- ...e readout



- VMM2 (2014)
- 115 mm²
- > 5M MOSFETs (>80k/ch.)
- planned deep re-design of VMM1
- higher functionality and complexity
- continuous fully-digital readout



- VMM3 (2015-16)
- 130 mm²
- > 6M MOSFETs
- includes L1 handling and SEU-tolerant logic

...nimo - "VMM2 - An ASIC for the New Small Wheel".TWEPP 2014 - Topical Workshop on Electronics for Particle Physics.
https://indico.cern.ch/event/299180/session/4/contribution/45

...VEN ...ORATORY George Iakovidis - RD51 Collaboration meeting 19/03/2015

VMM2 - Second ASIC prototype in 2014

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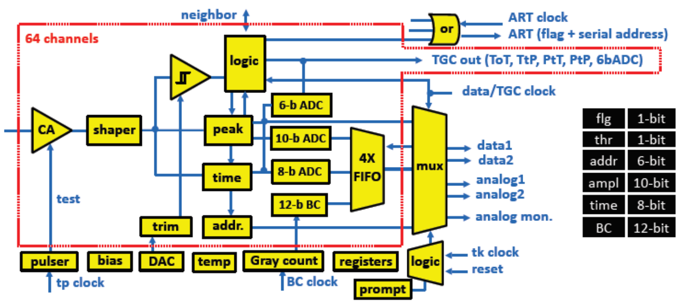
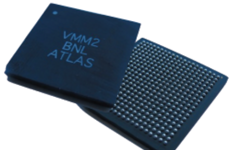


flg	1-bit
thr	1-bit
addr	6-bit
ampl	10-bit
time	8-bit
BC	12-bit



custom 400-pin
21 x 21 mm² BGA

- adjustable discrimination threshold per channel
- trimming range: 15 mV in 1m increments
- sub-hysteresis mode: effective discrimination ~ 2 mV
- neighbour logic: sub-threshold neighbor channels
- polarity: adjustable positive or negative
- gain: adjustable 0.5, 1, 3, 4.5, 6, 9, 12, 16 mV/fC (max charge 2 to 0.06 pC)
- peaking time: adjustable 25, 50, 100, 200 ns
- clock frequency: up to 200 MHz to the 6bit ADC
- 12-bit timestamp: 12-b Gray-code counter on BC provides timing TAC stop (20-b, ~100 μs, sub-ns resolution)
- 4-deep FIFO
- 10-bit, 200 ns , 1.5 mW, for peak amplitude
- 8-bit, 100 ns , 1.5 mW for peak timing (relative to BC)
- 38-bit event data at digital outputs

BROOKHAVEN NATIONAL LABORATORY George Iakovidis - RD51 Collaboration meeting 19/03/2015

Slides from G. Iakovidis (RD51/ & MPGD2105)

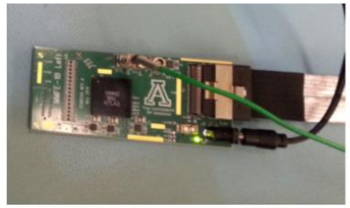
SoLID GEM-US Pre-R&D program: BNL VMM chip

Slides from G. Iakovidis (RD51/ & MPGD2105)

VMM2 - Frontend boards and readouts 9

First wire bonded front end for testing purposes
Four Mini-1 cards were assembled with the first batch of non-planar VMM2 ASICs

Same board with packaged chip



MMFE8- frontend board with 8xVMM2 - final board prototype by next month

Mini-2 - frontend board with 2xVMM2 for the SRS
2xHDMI one for the readout and the other for the trigger signals (ART)
DCARD instead of the ADC card
Same FEC classic card with another firmware
Readout UDP based SRS protocol

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- VMM2 FE card has an SRS version
- Supported by RD51 collaboration as replacement of APV25 chip within the community

Improvements in VMM3 and schedule 17

Function	Circuit	Status
L0 handling logic	Readout	in progress
SLVS IOs	Digital interface	in progress
Latency reduction in analog and digital paths (incl. ck to data)	Shaping amplifier and passive filter	queued
Operation at 2nF input capacitance	Front-end charge amplifier	queued
Simultaneous high-resolution and direct-output operation	Channel and control logic	queued
SEU-tolerant logic	Register, control and reset	queued
Direct input for ADC characterization	ADC or peak detector input node	queued
Configuration	Slow interface	being discussed

task	status
VMM2 design / fabrication	*complete*
BGA package	*complete*
PCB (AZ)	*complete*
VMM2 tests	*in progress*
VMM SEU & L1H circuits	*in progress*
VMM3 design	*in progress*

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- VMM3 expected to be release this year (2016)
- Will be very close to the final version
- Upgrade and bug fix of VMM2
- We plan to acquire a few chips to start test with our current SRS setup

SoLID GEM R&D activities requiring funding at UVa and TU

- Small investments in pre R&D pay big dividends at final R&D and production.
- While a significant progress towards SoLID GEMs accomplished within the EIC R&D program some SoLID specific funding needed.
- Following is a rough estimate for the first year of SoLID GEM pre-R&D
  - UVa $ 20 k :
    - Components and manpower for a Solid prototype design.
  - TU $ 20 k:
    - Design and fabrication costs for SoLID specific GEM foils and chamber components.
  - UVa/TU $ 40 k:
    - Funds to host Chinese collaborators for extended visits.
    - Purchase single mask foils from CIAE and build and characterize prototypes.

From Nilanga's talk @ the previous SoLID Coll. Meeting (Sept. 2015)

Summary / Outlook

Large GEM activities in US (UVa & Temple U)

- Production of Large Area GEM trackers for the SBS in Hall A and PRad in Hall B
- Ongoing intensive GEM R&D for the EIC forward tracking
- Multi-Institute collaboration for development of MPGD technologies
- Effort to promote domestic production of GEM with Tech Etch (B. Surrow, Temple U)
- Progress in the integration of the APV-25 readout electronics into Jlab CODA DAQ
  - Both APV-SRS and APV-MPD Electronics will be used in beam at JLab in 2016

SoLID GEM-US program for a two years pre-R&D

- Finalize the design of SoLID GEM modules for all configuration
- Setup a program to start testing and characterization of Chinese GEM foils
- Construction of full size prototypes of the
- Investigate needs and option for SoLID GEM readout electronics
- Study the currently available candidate such as BNL VMM or Saclay DREAM chip

Back Up

Overview of SoLID GEM Trackers: PVDIS Configuration

- Instrument five locations with GEMs:
- 30 GEM modules at each location: each module with a 12-degree angular width.

Location	Z (cm)	R_{min} (cm)	R_{max} (cm)	Surface (m^2)	# chan
1	157.5	51	118	3.6	24 k
2	185.5	62	136	4.6	30 k
3	190	65	140	4.8	36 k
4	306	111	221	11.5	35 k
5	315	115	228	12.2	38 k
Total				≈ 36.6	≈ 164 k

Largest GEM module size required: 113 cm x (21-44) cm

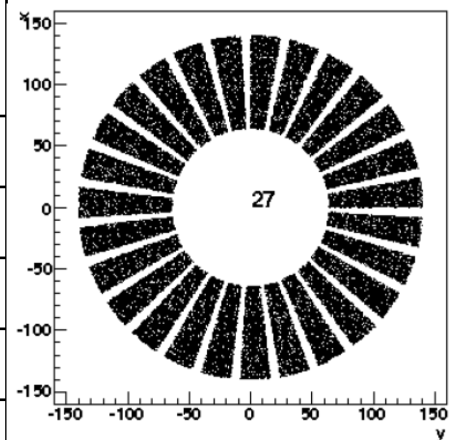
With ~5% spares, we will need about 170 k readout channels.

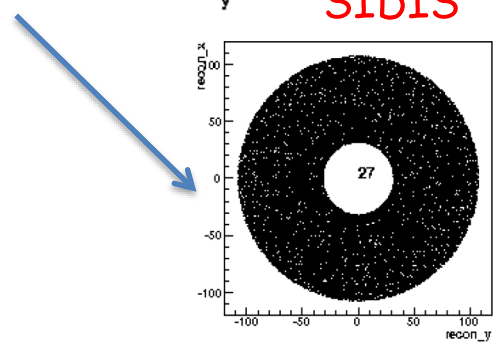
Large number of readout channels; but cost of electronics going down – cost per channel for the RD51 SRS APV-25 based readout is ~ $3.00 + R&D expenses to optimize electronics for SoLID needs.

Overview of SoLID GEM Trackers: SIDIS Configuration

- Six locations instrumented with GEM trackers:
- PVDIS GEMs can be re-arranged to make all layers for SIDIS by moving the modules closer to the axis so that they are overlapping with each other

Plane	Z (cm)	R_I (cm)	R_O (cm)	Active area (m^2)	# of channels
1	-175	36	87	2.0	24 k
2	-150	21	98	2.9	30 k
3	-119	25	112	3.7	33 k
4	-68	32	135	5.4	28 k
5	5	42	100	2.6	20 k
6	92	55	123	3.8	26 k
total:				~20.4	~ 161 k





- The idea of using the same modules for different configurations need to be evaluated
- Might not necessarily be optimal in term of cost production and best design for the experiment

Temple University GEM R&D program

Slides provided by Bernd Surrow

- Major effort on STAR Forward GEM Tracker completed with full installation in fall 2012 - 24 large triple-GEM detectors arranged on disks / 30720 channels (APV25-S1)
- Large group at TU with fully equipped micro-pattern detector laboratory (Detector lab and permanent clear room facility) at new Science Education and Research Center with outstanding resources
- Major funded EIC R&D effort on large triple-GEM detectors focusing on light-weight structures and commercial fabrication of various detector components