New Results on Capacitive Sharing Large Pad Readout in Test Beam

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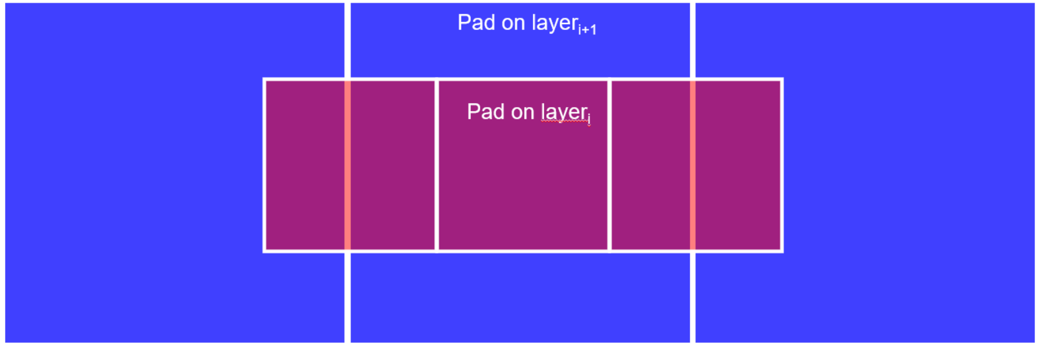
Outline

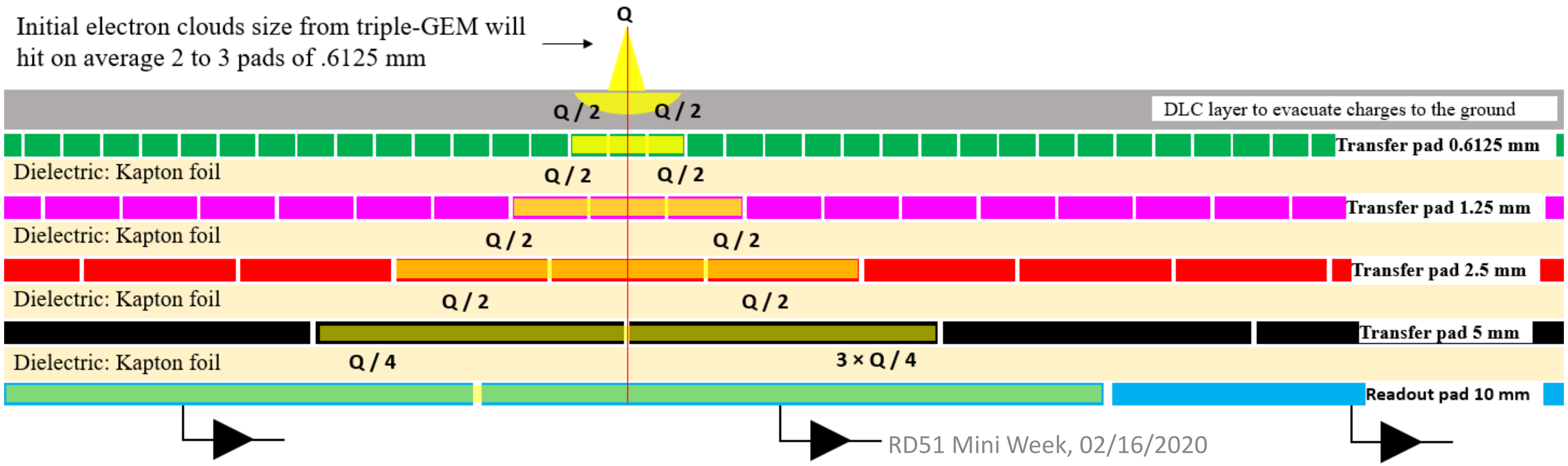
- Principe of Capacitive-Sharing readout & applications
- Preliminary test beam results
- Spatial resolution studies

Principe of Capacitive Sharing readout PCB

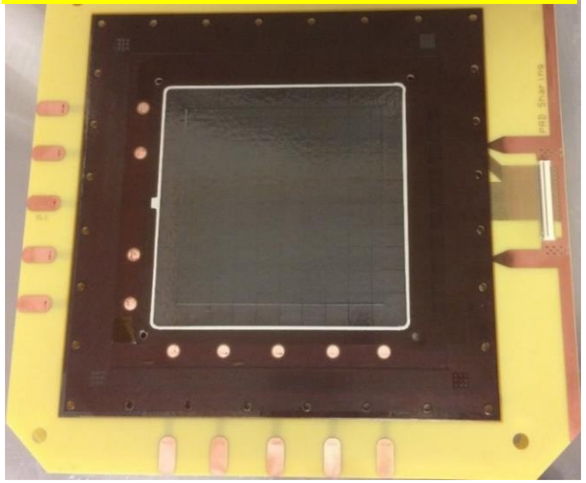
Principle of capacitive-sharing large-pad Readout

- Vertical stack of pad layers ⇨ Charge transfer from layer to layer via capacitive coupling
- The pad size double from a layer (L_i) to the layer (L_{i+1}) below it
- A given pad on L_i is either centered directly with a pad below it on L_{i+1} or at the boundary between two adjacent pads of L_{i+1} as shown on the sketch on the left
- Charges from pad of L_i are either collected by a single pad or two adjacent pads on L_{i+1}
- This spatial arrangement of the pads allows that two neighboring pads with charges of L_i are always transfer charges to 2 neighboring pads of L_{i+1} no mater the size of pads of of L_{i+1}
  - ⇨ Preservation of the position information **i.e.**. spatial resolution
  - ⇨ significant reduction of number of readout channels **i.e.** Low cost
  - ⇨ Flexible readout technology **i.e.** variety of possible applications for MPGD detectors
- Signal readout layer (bottom) could be pad-based,1D, 2D strip, zigzag readout or a different readout scheme depending on the application



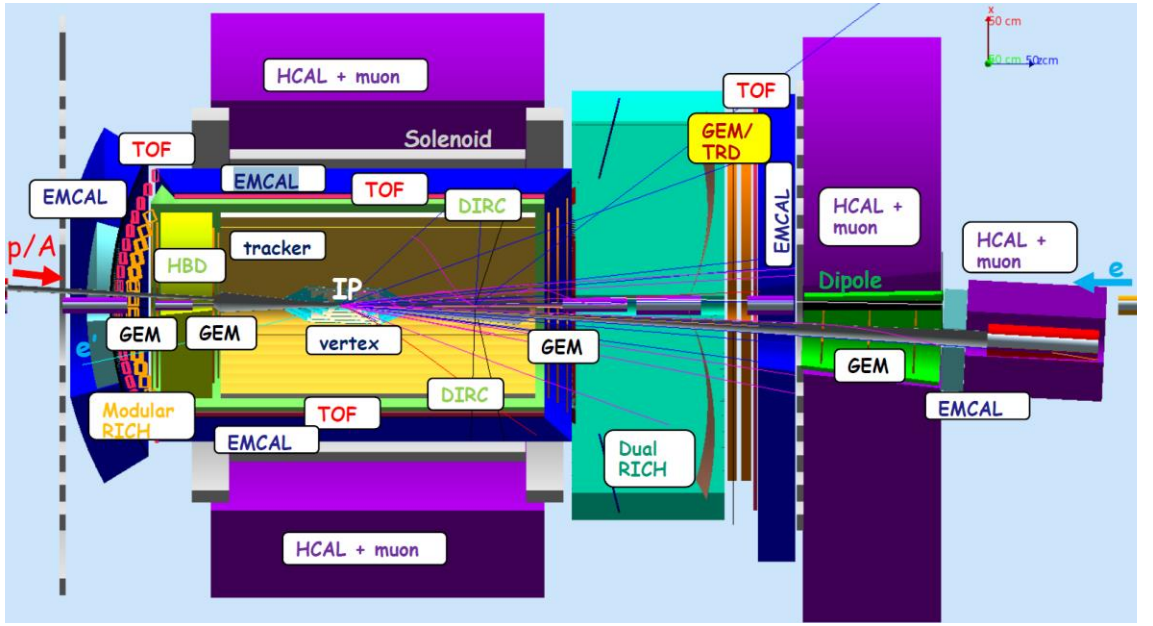


large-pad readout prototype @ UVa



Potential Applications for EIC MPGD-based Tracking & PID Detector Options

EIC Detector Concept (JLEIC) Design



Several MPGD technologies under consideration for EIC tracking and PID

- **Tracking detectors options with MPGDs**
  - ⇨ TPC for central tracking with GEM or hybrid MPGDs readout planes
  - ⇨ Multilayer Cylindrical MPGDs for the EIC barrel tracker
  - ⇨ Planar MPGD disc layers in both electron and hadron end caps
- **PID options with MPGDs**
  - ⇨ Hybrid THGEMs & Micromegas for high momentum RICH in hadron end cap
  - ⇨ Short length GEM-RICH for high momentum RICH in hadron end cap
  - ⇨ GEM-TRD (Transition Radiation Detector) ⇨ both end caps

Why is large pads with capacitive sharing readout is an option for MPGD technologies for EIC application:

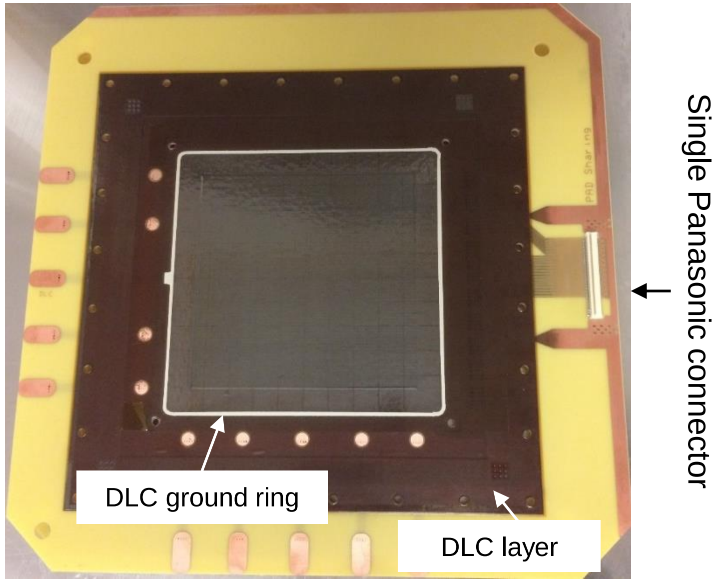
- Moderate particle flux rate expected at the EIC tracking detectors in all eta regions (compared to LHC or fixed target experiment at JLab)
  - ⇨ Pile-up and multiple hit events are less of a concern
- Flexibility of the readout concept: One can design the large-pad readout PCB parameters to address specific detector technology and application
  - ⇨ i.e. pad size for the top and / or bottom pad layers, numbers of layers, pad geometry and thickness … can be detector specific
- The large pads with capacitive sharing readout technique is pretty straight forward: don't anticipate an extensive R&D program to fully validate the concept
  - ⇨ Cost effective solution with low production risk

GEM prototype with capacitive sharing pad readout (1 cm × 1 cm pad size)

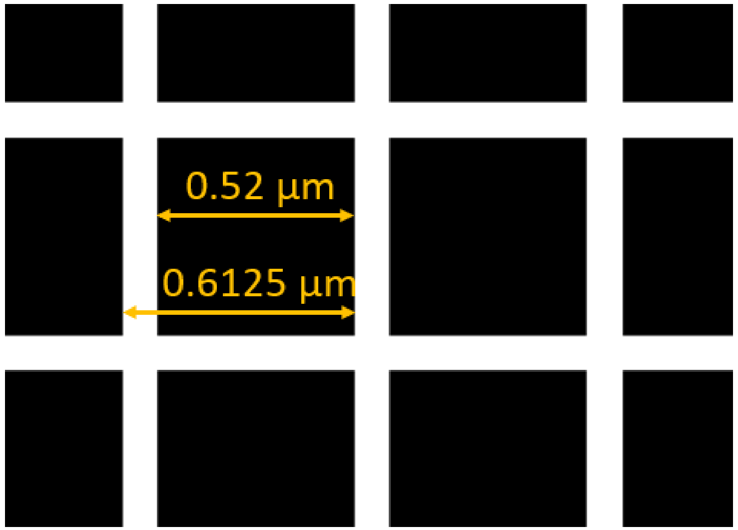
5-layers capacitive-sharing pad readout prototype:

- **Top pad layer** (define basic resolution performances):
  - Pitch: 0.6125 mm × 0.6125 mm (**0.1 mm inter-pad)**
  - Pad size: 0.52 mm × 0.52 mm
- **Bottom pad layer** (readout pad):
  - Pitch: 10 mm × 10 mm (**0.1 mm inter-pad)**
  - Pad size: 9.9 mm × 9.9 mm
- DLC layer with surface resistivity 10 - 20 MΩ
- 100 readout Pads

Bottom Layer: 1 cm × 1 cm pads

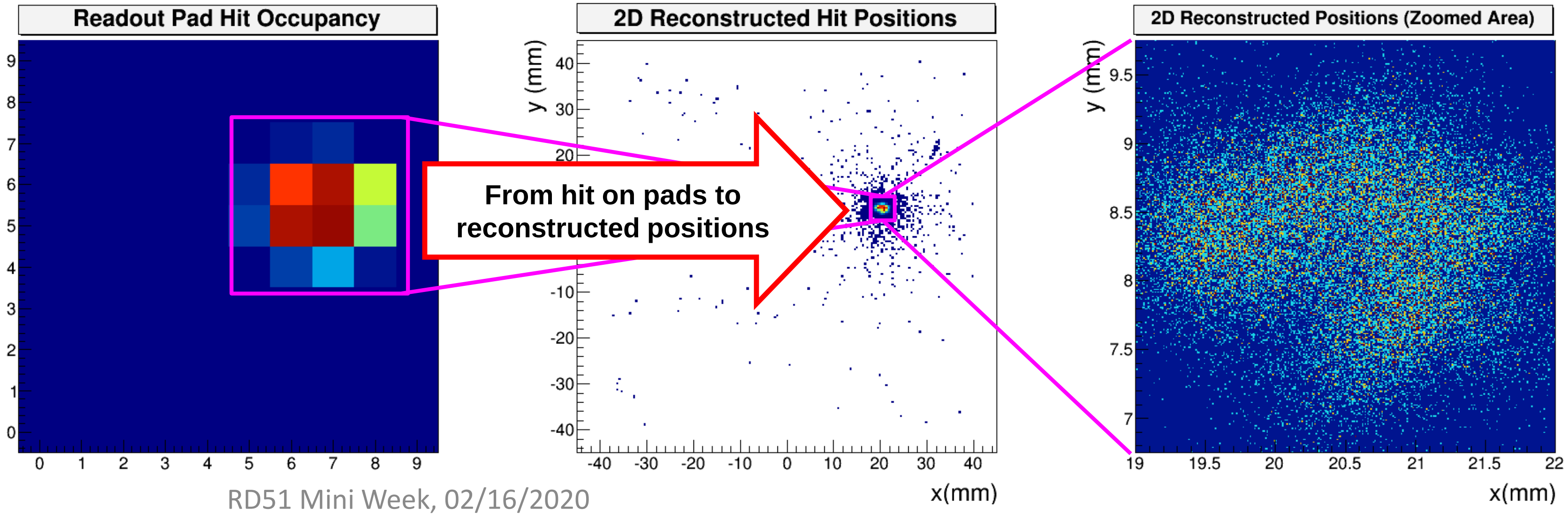


Top Layer : Pad pitch = 0.6125 µm × 1 0.6125 µm



GEM prototype with capacitive-sharing pad in x-ray

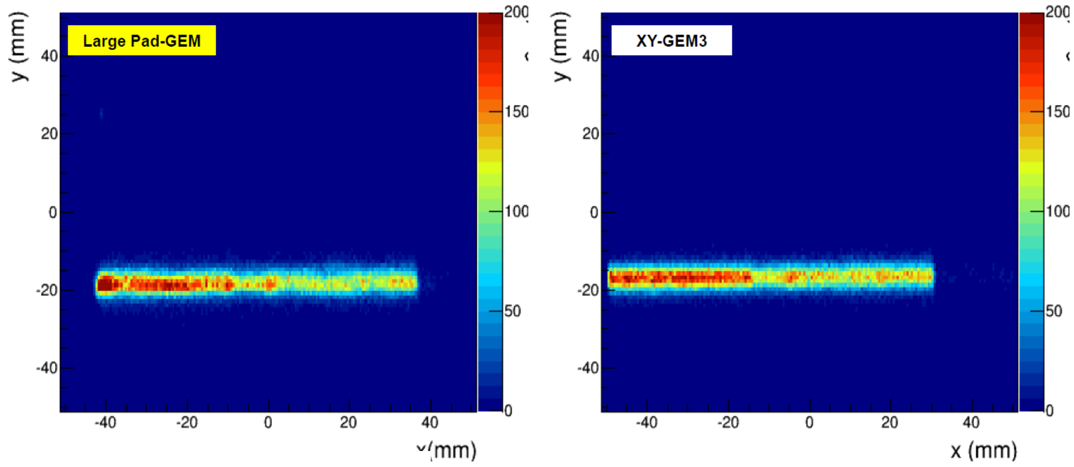
Pad Occupancy & 2D hit reconstruction with x-ray

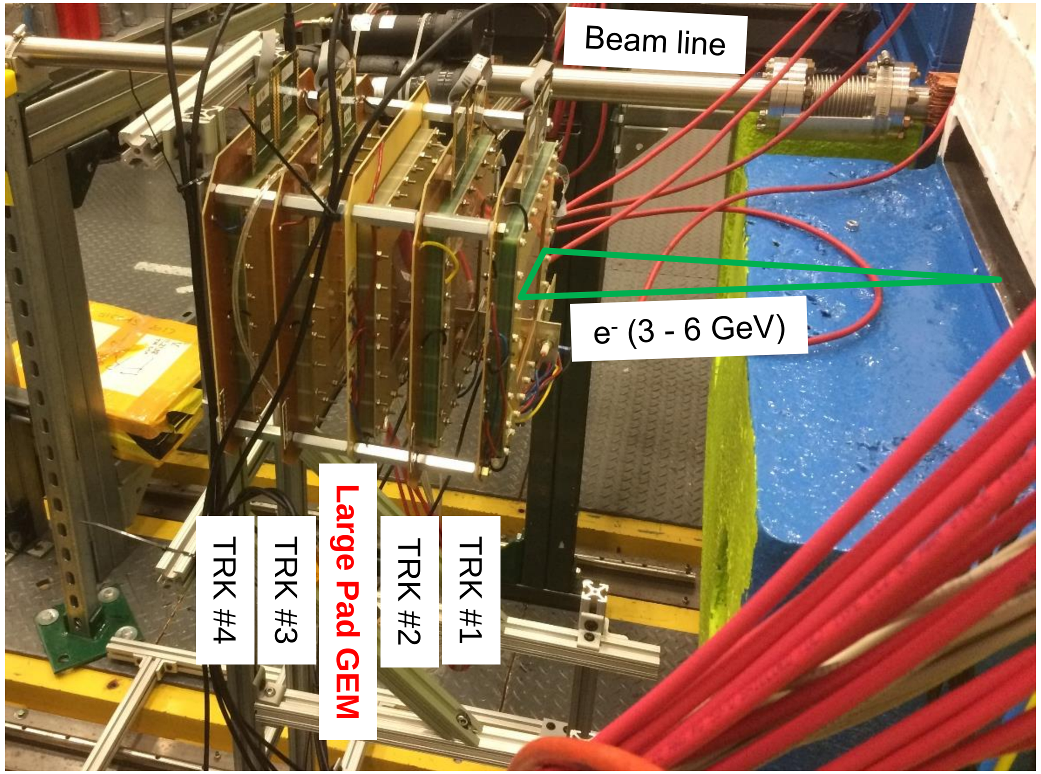


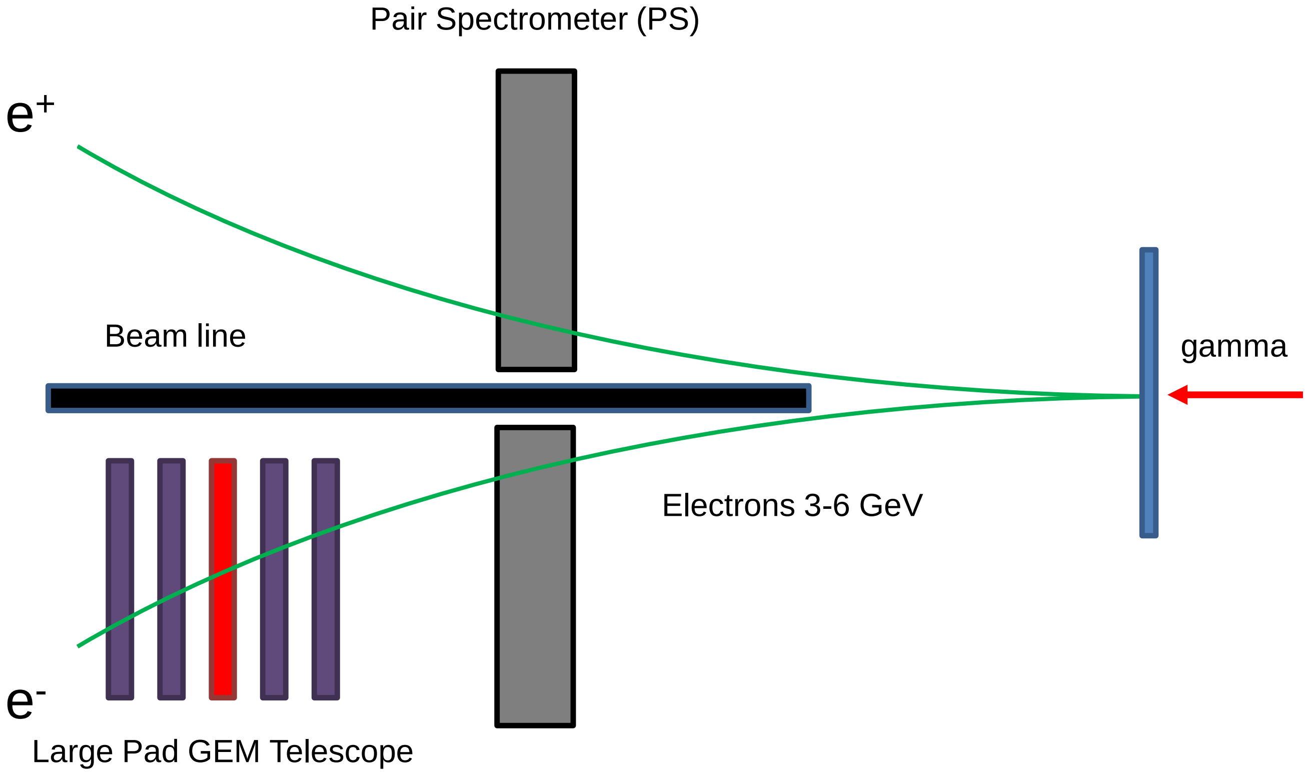
Test Beam in Hall D @ JLab

Test setup in the electron arm of Hall D Pair Spectrometer (PS) @ JLab.

- Clean electron beam (3 to 6 GeV), incoming angle up to 8 degree
- Large Pad GEM + 3 small X-Y CERN standard triple-GEM for tracking
- APV25-SRS readout (DATE + AmoreSRS), trigger rate limited to 400Hz
- Large volume of data for HV scan and for spatial resolution - Mid-September 2020

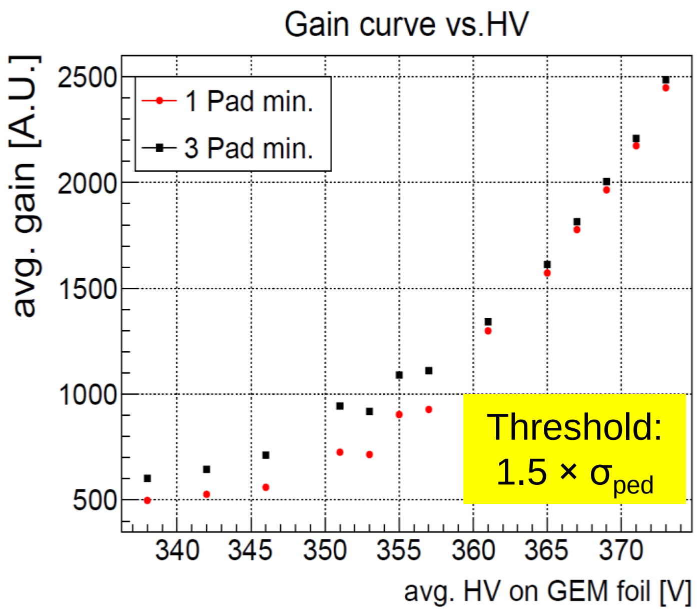


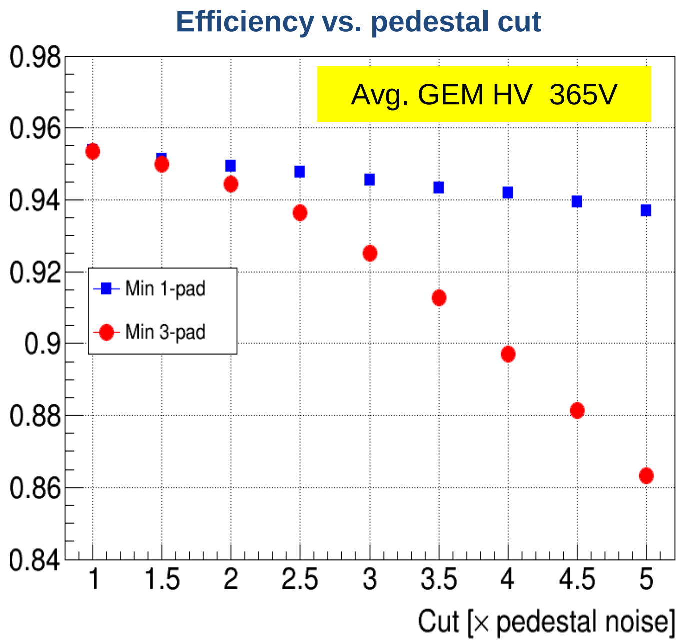


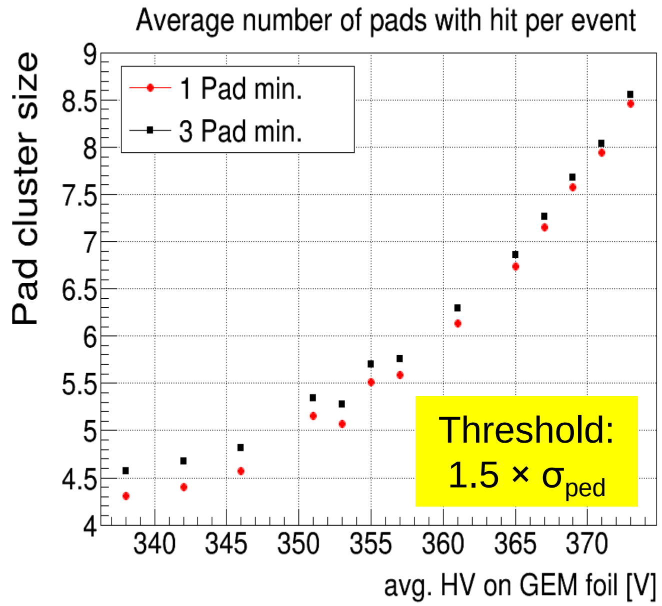


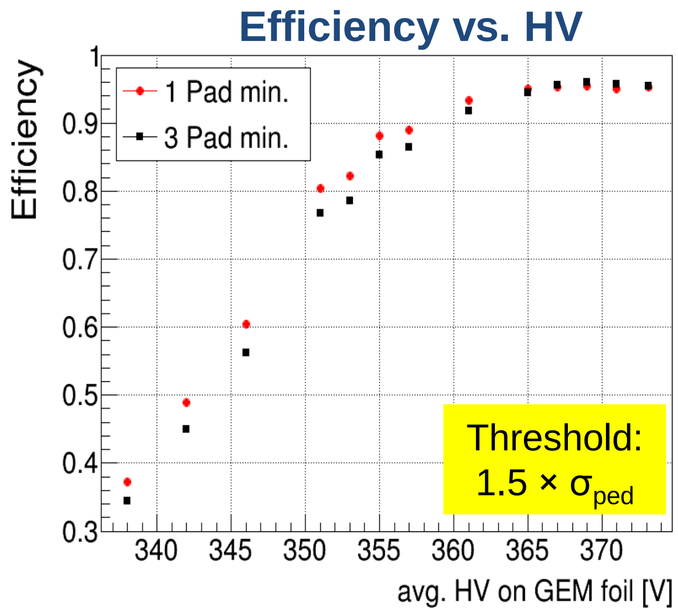
Basic performance of the prototype

- HV scan from with 340 V to 375 V to GEM foils: (COMPASS GEM @ 4100 V = ~372 V)
  - Track based efficiency studies: track from XY GEM trackers define the track
- Full efficiency above 365V for zero suppression threshold =1.5 × σ (pedestal)
  - **1 Pad min.:** all pads above threshold considered in analysis
  - **3 Pad min.:** Only events with at least 3 pads above threshold are considered
- Capacitive sharing performances @ 1.5 × σ pedestal cut
  - Cluster size > 4 pads even at low gain (< 340 V on the GEM foils)
  - Cluster size > 7 pads on average @ GEM voltage > 365V
  - Efficiency drops 10% at 5 × σ pedestal cut with a 3 pad min requirement



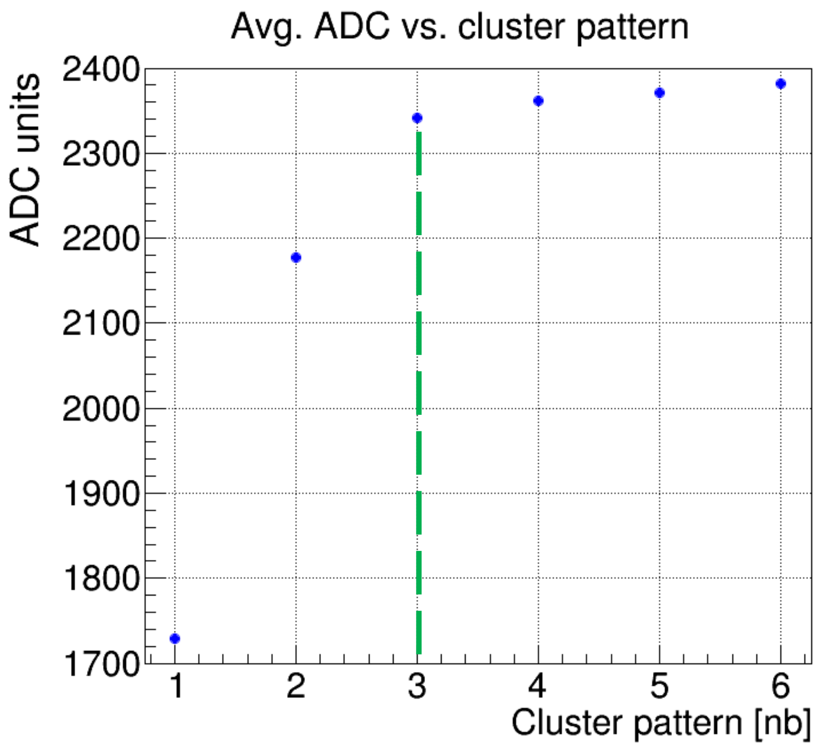


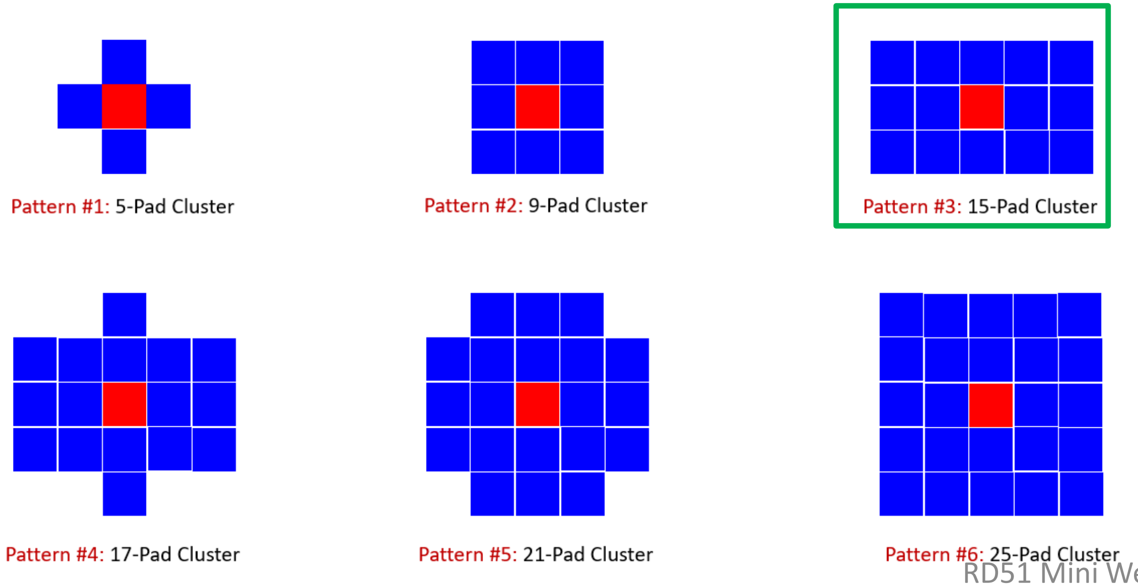




Cluster pattern definition

- ❑ For each event, select the pad with the highest ADC values (shown in red on cartoon below) ➪ this defined the central pad of the cluster
- ❑ Form the cluster by identifying all neighboring pads around the central pad with ADC above pedestal and satisfying the rules defined by the pattern under consideration
  - ➪ For example, for pattern #1, only look for the 4 immediate neighbors of the central pad
- ❑ The number of pads of the pattern is the maximum number of pads per event,
  - ➪ It is not the cluster size
- ❑ We studied 6 patterns as shown on the cartoon of the figure below
  - ➪ Pattern #1 allows up to 5 pads to form a cluster while pattern #6 can go up to 25 pads
- ❑ These studies are performed when applying at (0 × σ) pedestal cut which mean only pads with ADC below pedestal level are removed from the analysis

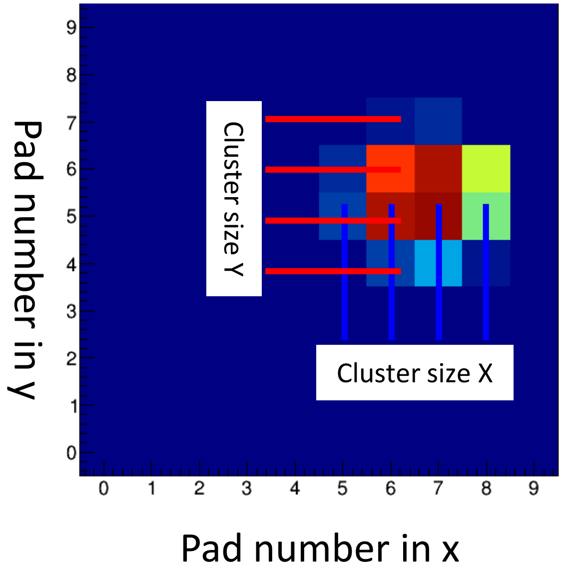


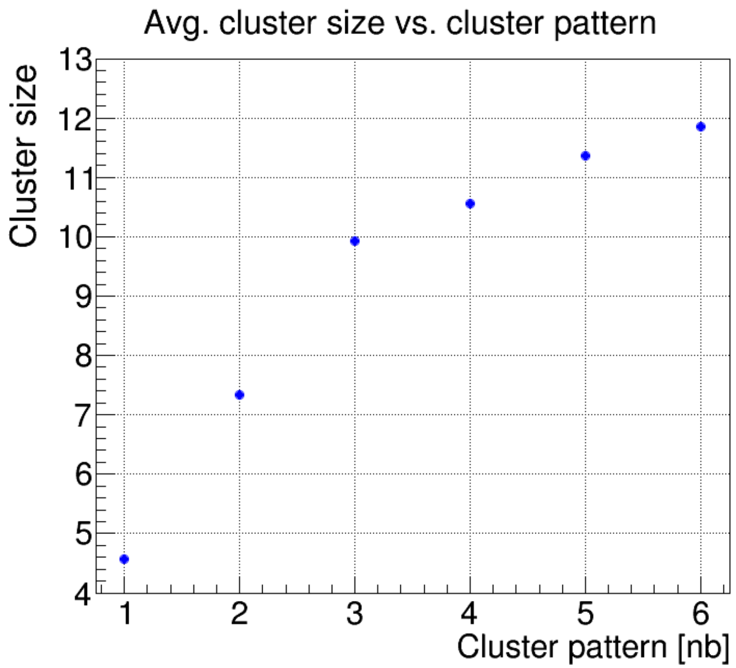


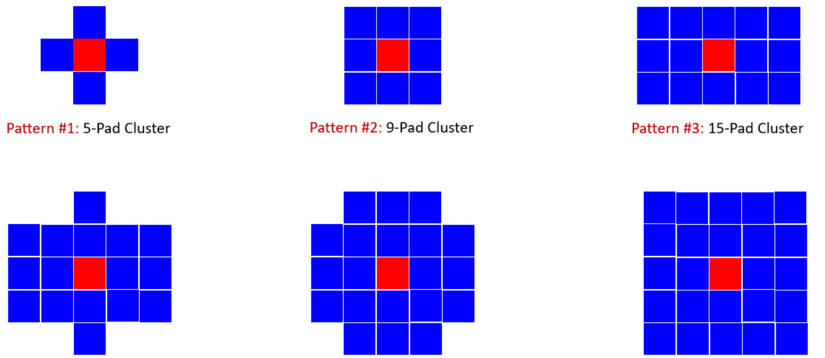
- ❑ Pattern #2 which is symmetric in x and y carries about 92% of the average ADC charges of pattern #3
- ❑ Average cluster ADC vs. cluster pattern shows that starting from pattern #3, the additional pads of pattern #4, #5, #6 have a minor contribution to the total cluster ADC ➪ about 1% of the total ADC
- ❑ So Pattern #3 seems the optimal choice

Cluster size vs. pattern definition

- Average cluster size (2D) i.e. number of pad per events increases with pattern i,.e. maximum allowed pads in the cluster
- However, the increase is not linear: cluster size of pattern #1 is about ~4.5 pads for 5 pads maximum allowed while cluster size for pattern #6 is ~12 for 25 pads allowed.
- The cluster size is also plotted in 1D in x and y defined respectively as number of pad columns and number of pad rows
- Cluster size in x for pattern #3 and #4 is equal ~4.2, the slight increase for pattern #5 and #6 suggests that we are including noisy pads in the selection of the cluster
- Similarly the increase of cluster size in y for pattern #5 and #6 suggests that noisy pads are included in the cluster selection
- we will see the impact later on the spatial resolution studies







Pattern #1: 5-Pad Cluster

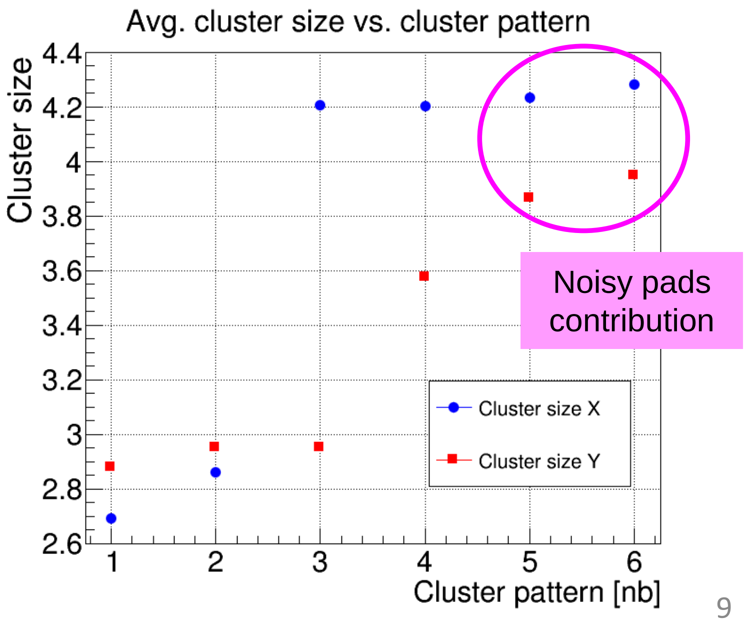
Pattern #2: 9-Pad Cluster

Pattern #3: 15-Pad Cluster

Pattern #4: 17-Pad Cluster

Pattern #5: 21-Pad Cluster

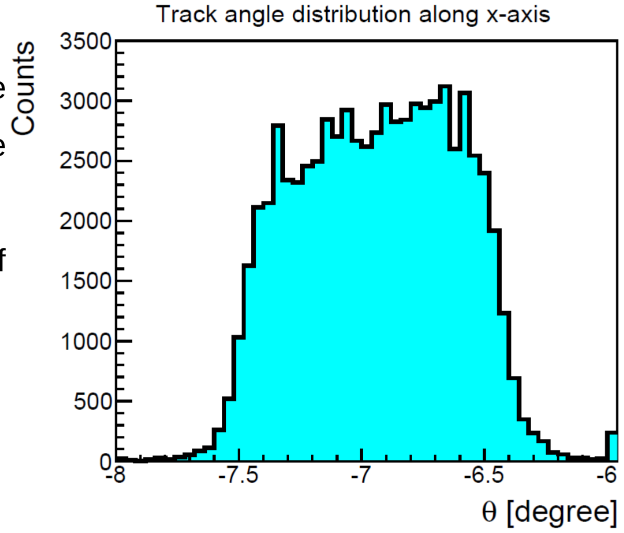
Pattern #6: 25-Pad Cluster

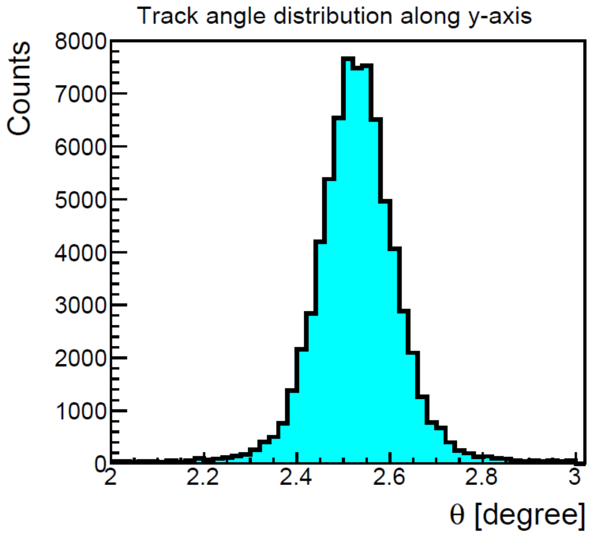


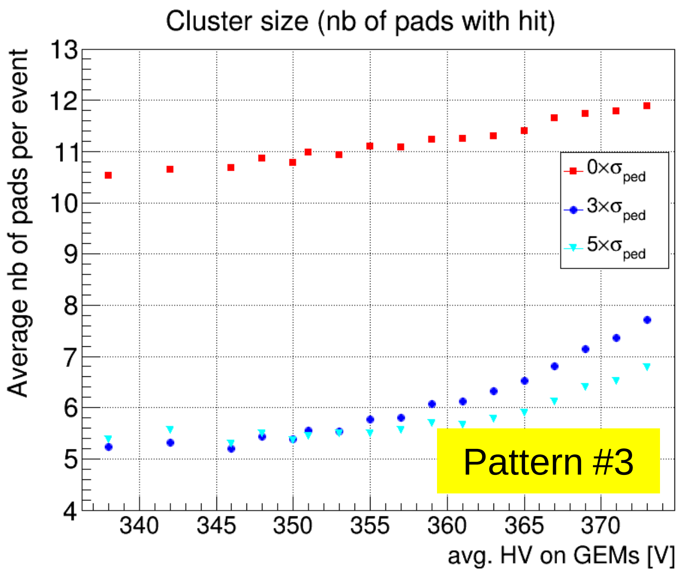
Cluster Size vs. avg. HV on GEMs

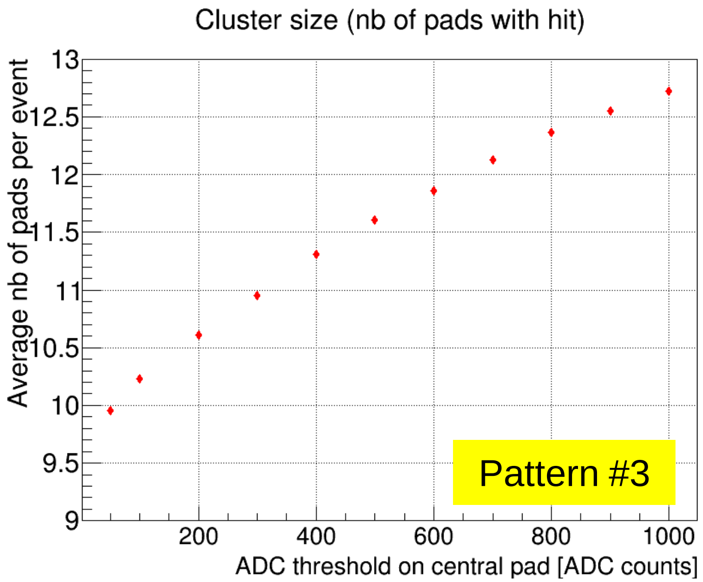
- Strong variation of the cluster size with the HV when pedestal cut is applied
- More moderate variation at (0 × σ)
- When applying a selection based on the minimum ADC requirement on the central pads ➩ Strong dependance of the cluster size on the ADC of the central pad
- This dependance is driven by the cluster size in x direction ➩ because of the larger angle of the tracks in x
- Cluster size is independent of the ADC of central pad in y direction

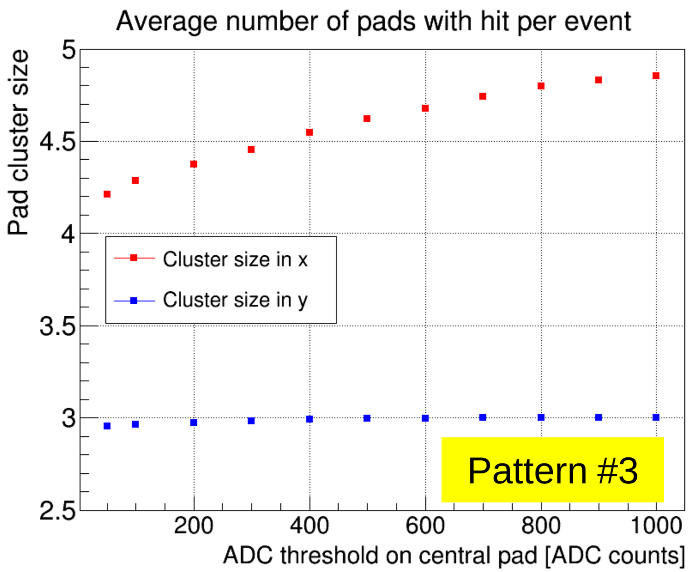
Angular distribution of the tracks in x and y





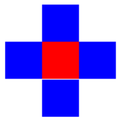


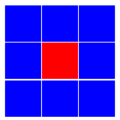


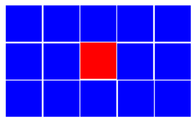


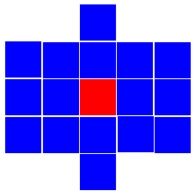
Spatial Resolution vs. cluster pattern

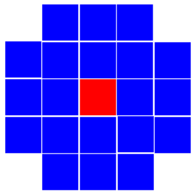
- Spatial resolution as a function of the cluster pattern and cluster size
- In x-direction, strong variation from 900 µm for pattern ➪ #1 to 250 µm or pattern #3 and beyond
- In y-direction, similar behavior but resolution starts degrading again for pattern #4 and beyond ➪ noisy pads and cross-talk pads are included in the cluster formation
- Resolution is very sensitive to noisy pads because even a small ADC contribution large pitch pad readout would lead to impact in the position accuracy

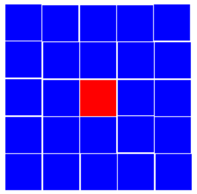

Pattern #1: 5-Pad Cluster

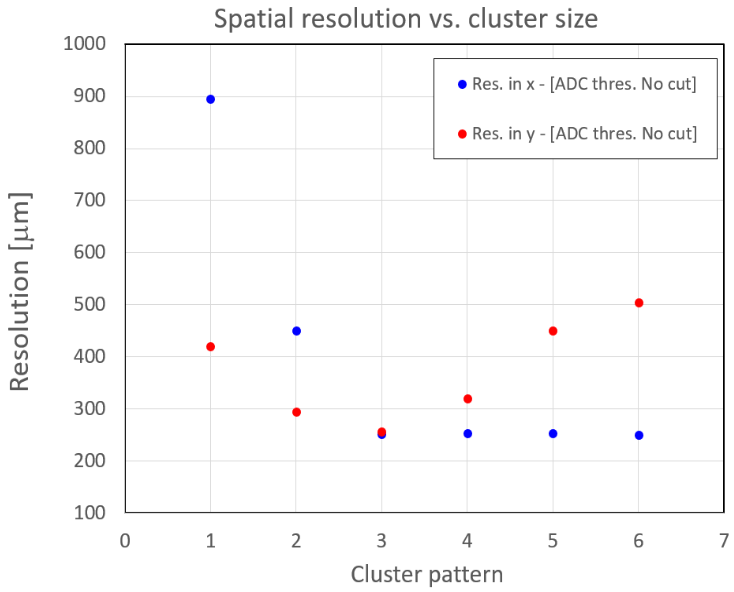

Pattern #2: 9-Pad Cluster

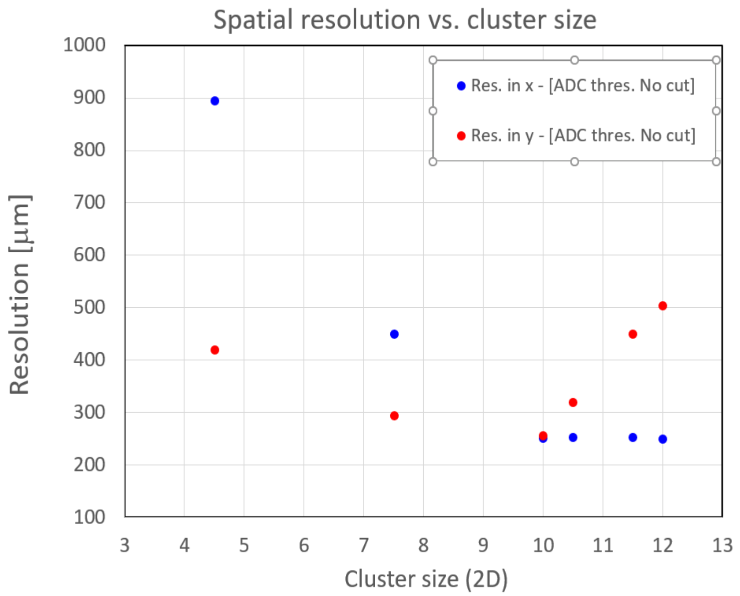

Pattern #3: 15-Pad Cluster

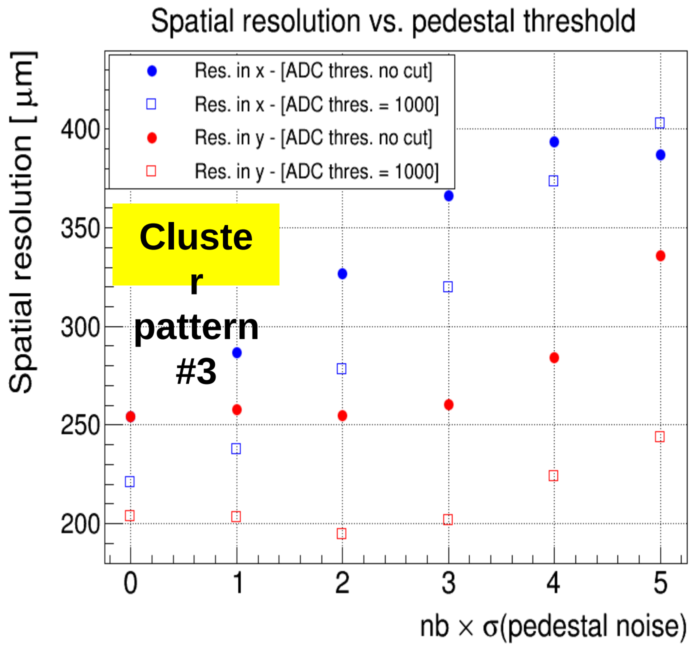

Pattern #4: 17-Pad Cluster


Pattern #5: 21-Pad Cluster


Pattern #6: 25-Pad Cluster

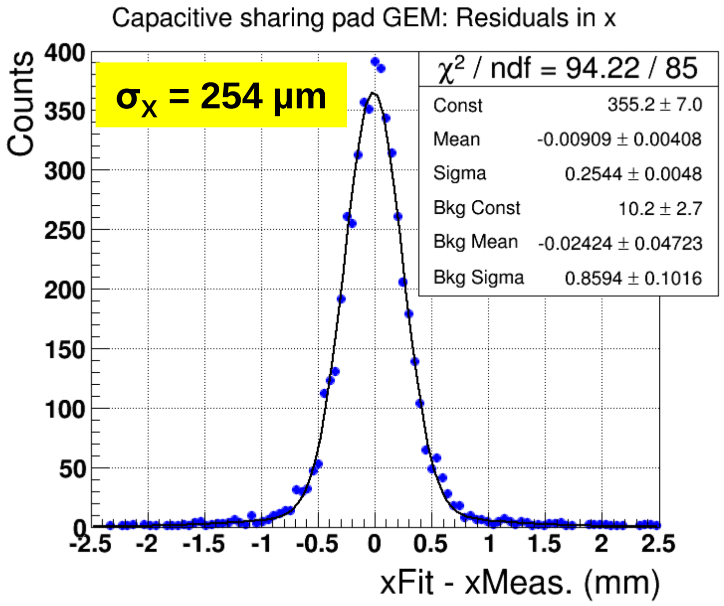


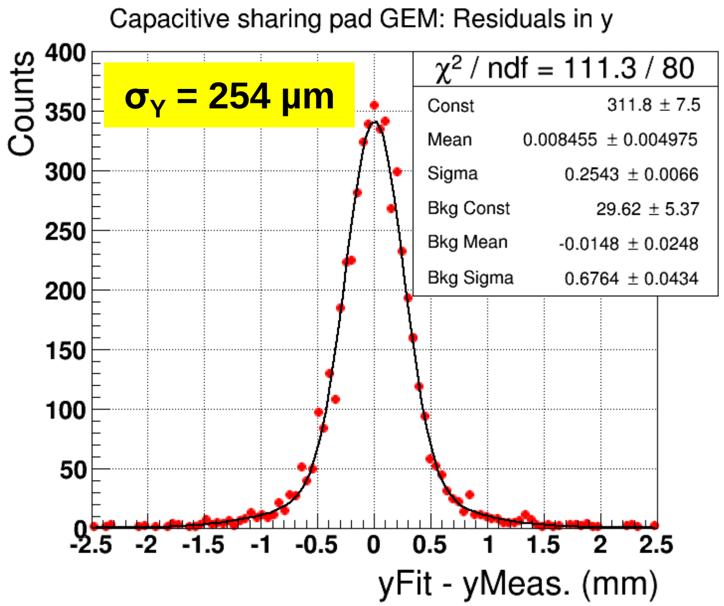


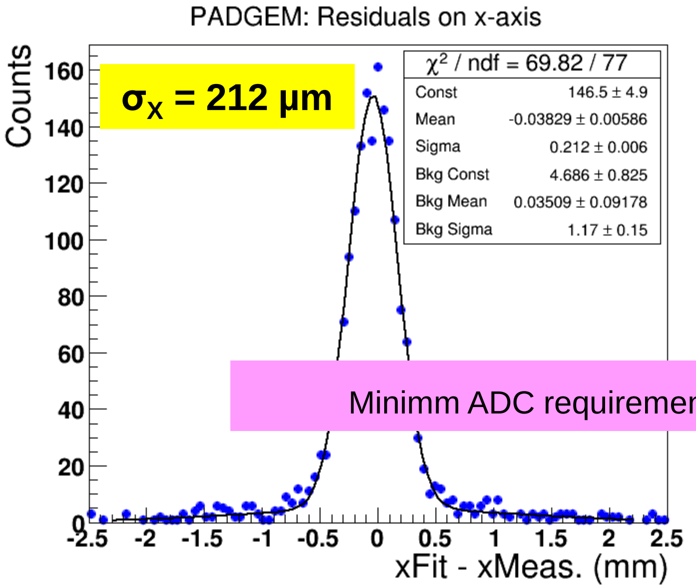


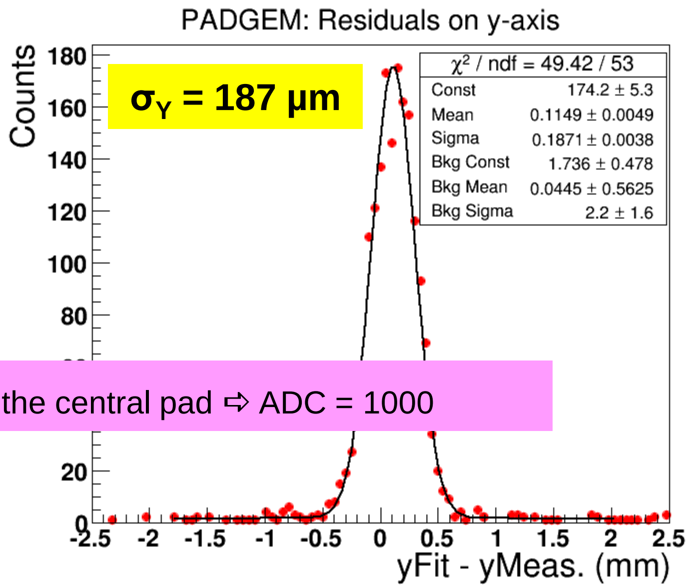
Spatial Resolution

- Spatial resolution of 250 µm achieved in x and y without any cut for 1 cm x 1cm pad readout
- When applying a selection on the minimum ADC on the central pad spatial resolution improves significantly ➪ Performances can be improved with higher detector gain
- Resolution in y is slightly better than in x because of the smaller angle distribution of the tracks









Minimm ADC requirement on the central pad ➪ ADC = 1000

Conclusion

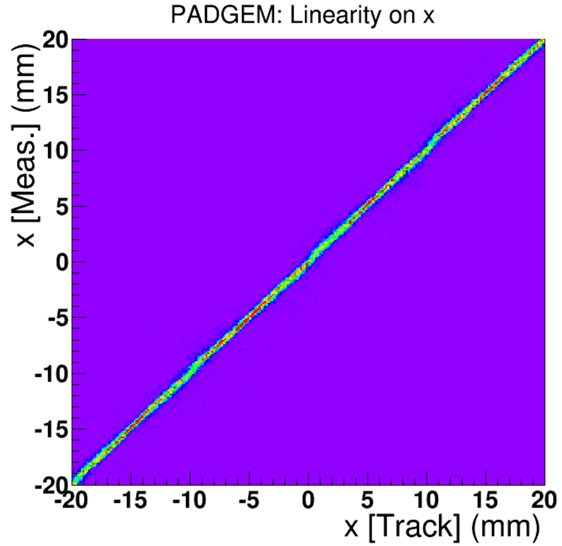
- Very encouraging preliminary results on the performances of the large pad readout with capacitive sharing
- Performances strongly depends on how the cluster of pads is formed
- With capacitive sharing, the dependence of the position resolution with the angle is sensitive
- Spatial resolution of 250 um is easily achieved with 1 cm x 1 cm pad readout without any cut applied to the data
- Resolution can be vastly improves with increasing the detector gain
- Resolution is very sensitive to noisy or cross talk pads
    - capacitive sharing readout board should be optimized to minimize the occurrence of noisy and cross talk pads
- Just received a new capacitive sharing readout boards with different characteristics to study further the performances of this concept

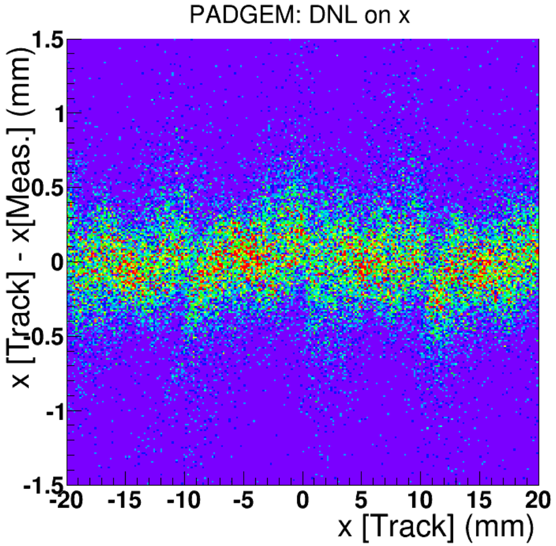
BACKUP

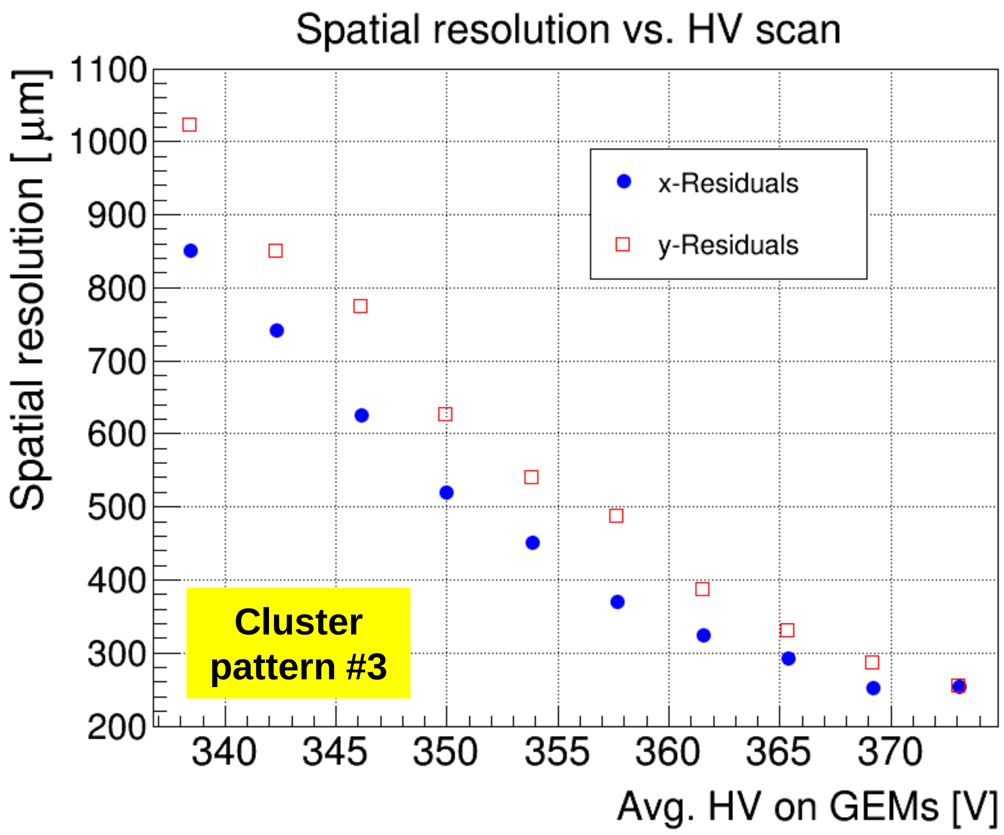
Spatial Resolution vs. Pedestal cut

Parasitic setup in the electron arm of Hall D Pair Spectrometer (PS) @ JLab.

- Clean electron beam (3 to 6 GeV), incoming angle up to 8 degree
- Large Pad GEM + 3 small X-Y CERN standard triple-GEM for tracking
- APV25-SRS readout (DATE + AmoreSRS), trigger rate limited to 400Hz
- Large volume of data for HV scan and for spatial resolution - Mid-September 2020







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