2D charge sharing readout planes for GEM, μRWELL and other detector applications

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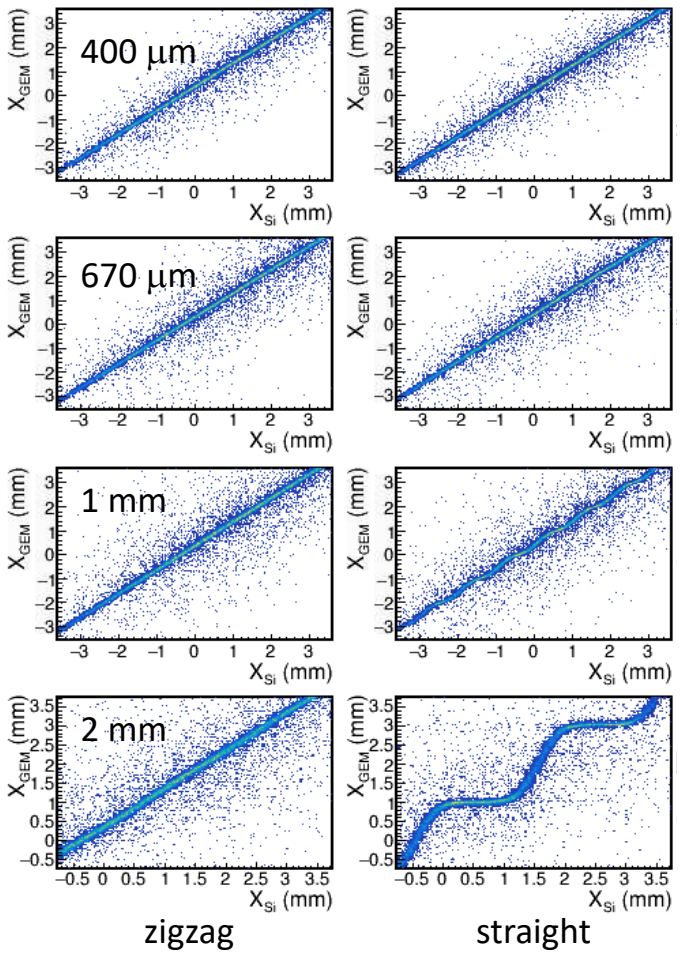
Outline

- 1D zigzag success story overview

- A concept of 1D -> 2D zigzag evolution
- Test stand measurements with the GEM prototype implementation

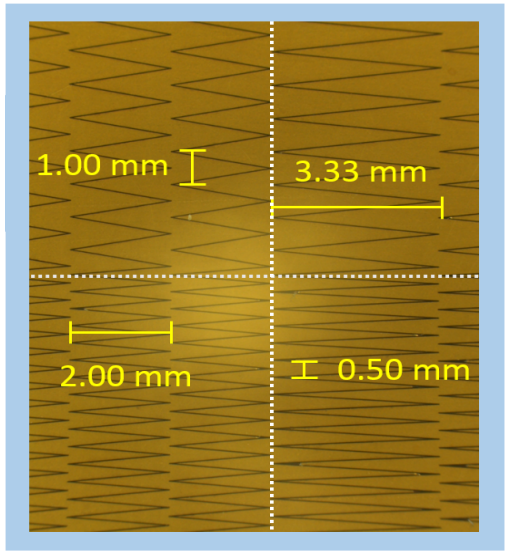
- Other detector options
- Summary & Outlook

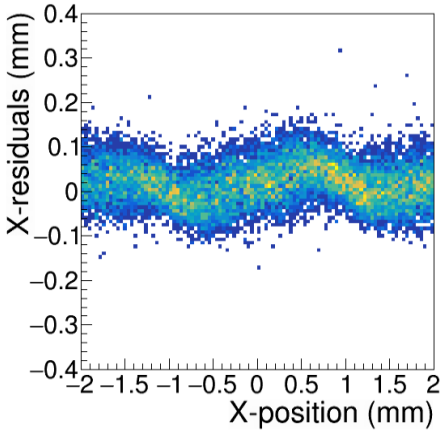
Charge sharing in MPGDs with 1D zigzag electrodes

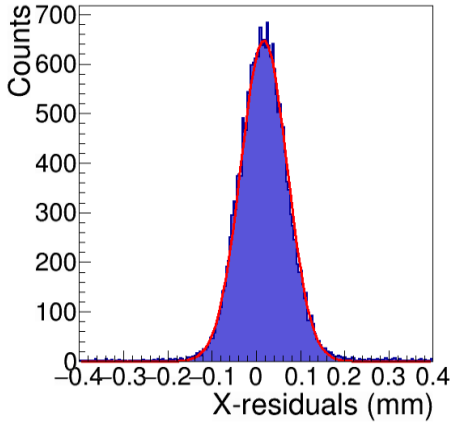


- At a large enough pitch, the straight strips exhibit lack of sensitivity to the primary charge cloud position

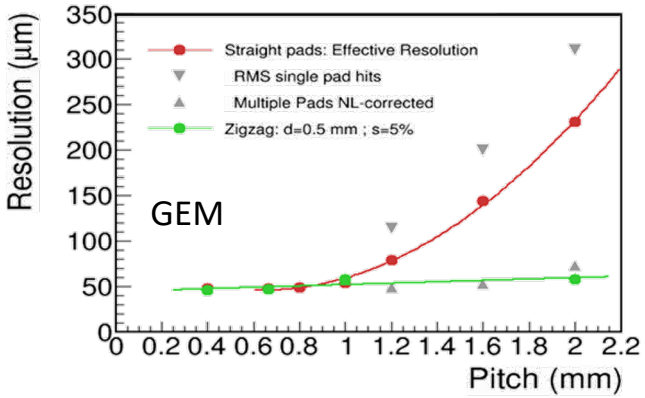
- The solution is using charge-sharing zigzag strips
- Large pitch possible (small channel count) without much of a loss in spatial resolution
- Low differential non-linearity

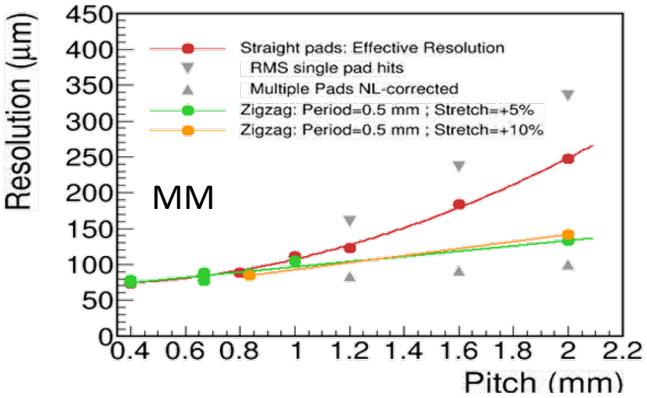


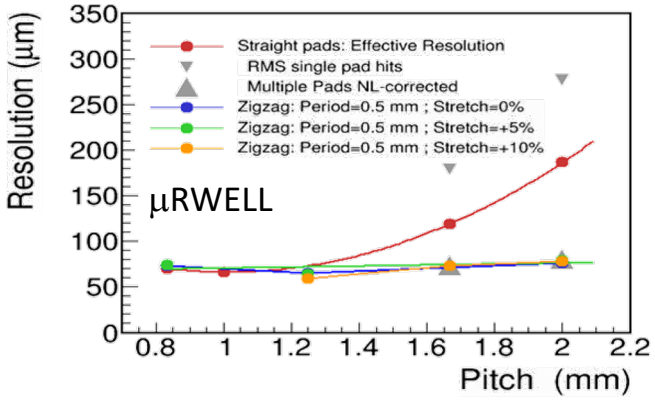




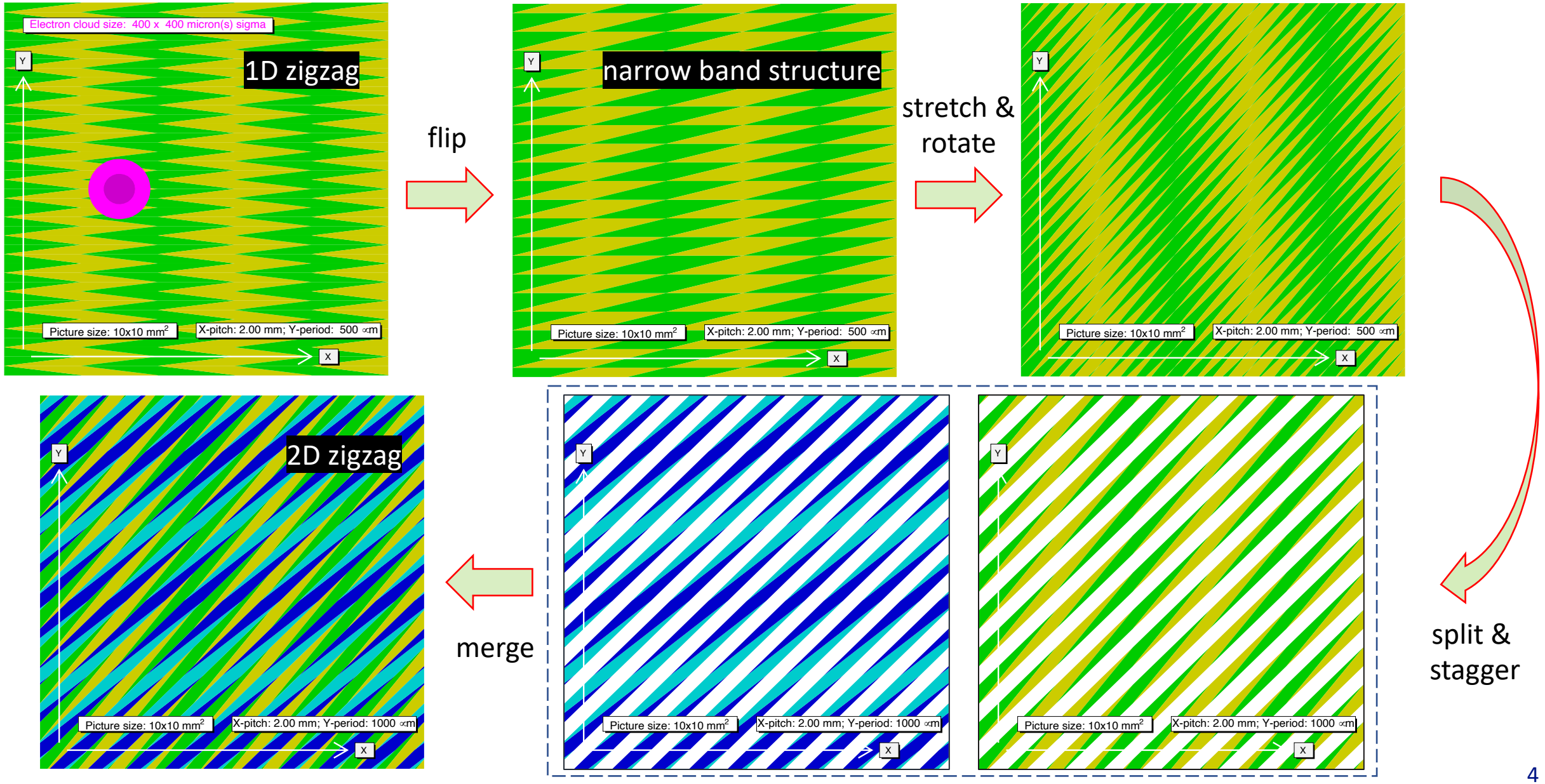
GEM zigzag example: 2 mm pitch & ~50 μm resolution



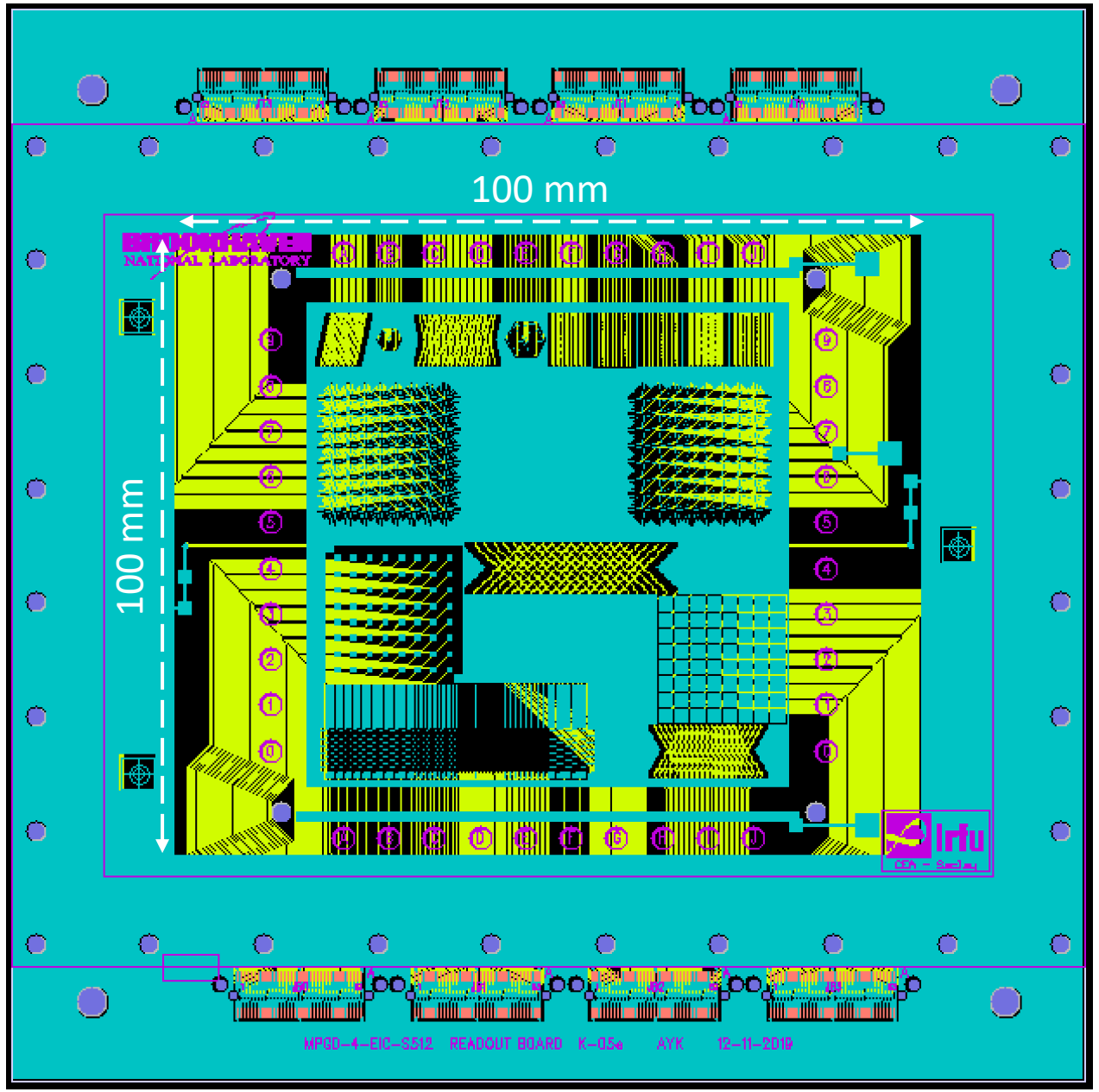




A concept of 1D -> 2D zigzag evolution



The prototype readout board



- Built at CERN
- 100 x 100 mm^2 active area
- Kapton, two-layer design
  - Patterns in the top layer, ~50 μm spacings
  - Interconnect in the bottom layer, with the *chemically etched blind metallized vias*

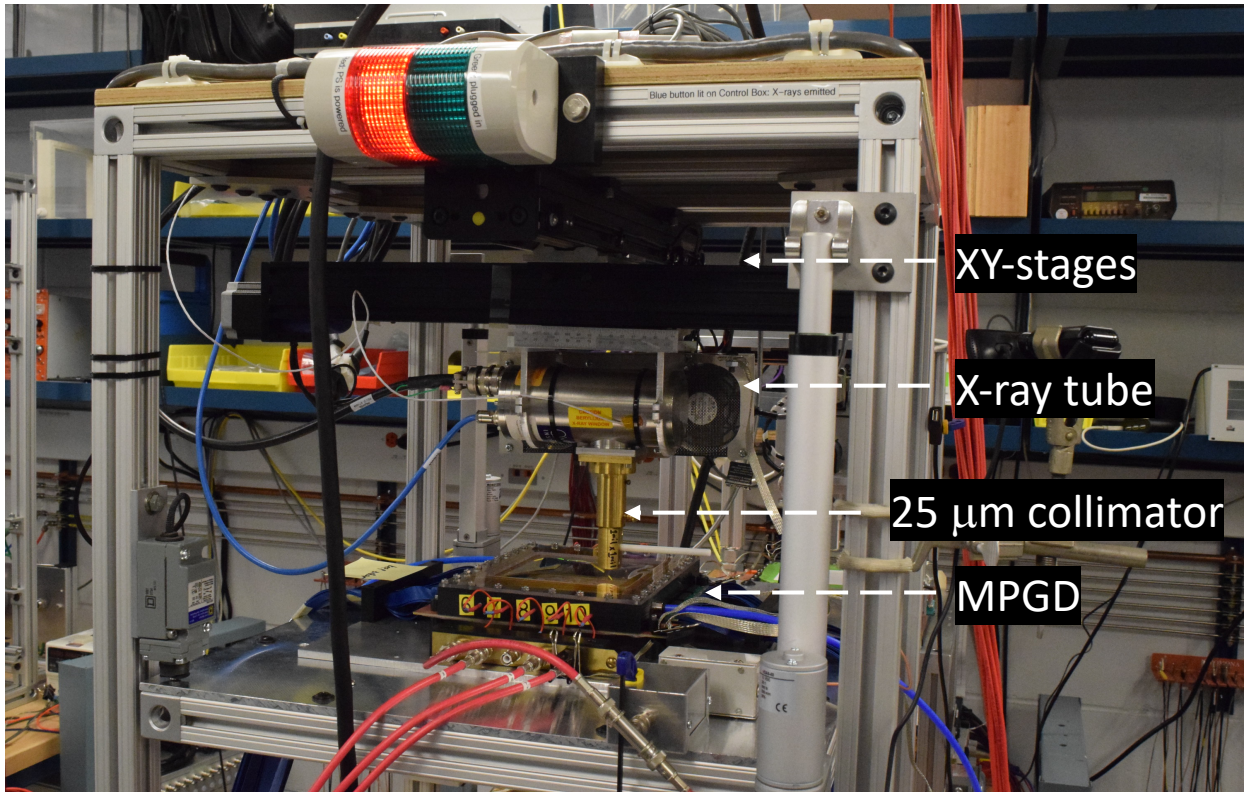
- Multi-pattern design:
  - A full set of “1D zigzag -> diamond (aka 2D zigzag)” evolution patterns
  - A variety of 1.0 mm pitch 2D zigzags at various UV-slopes

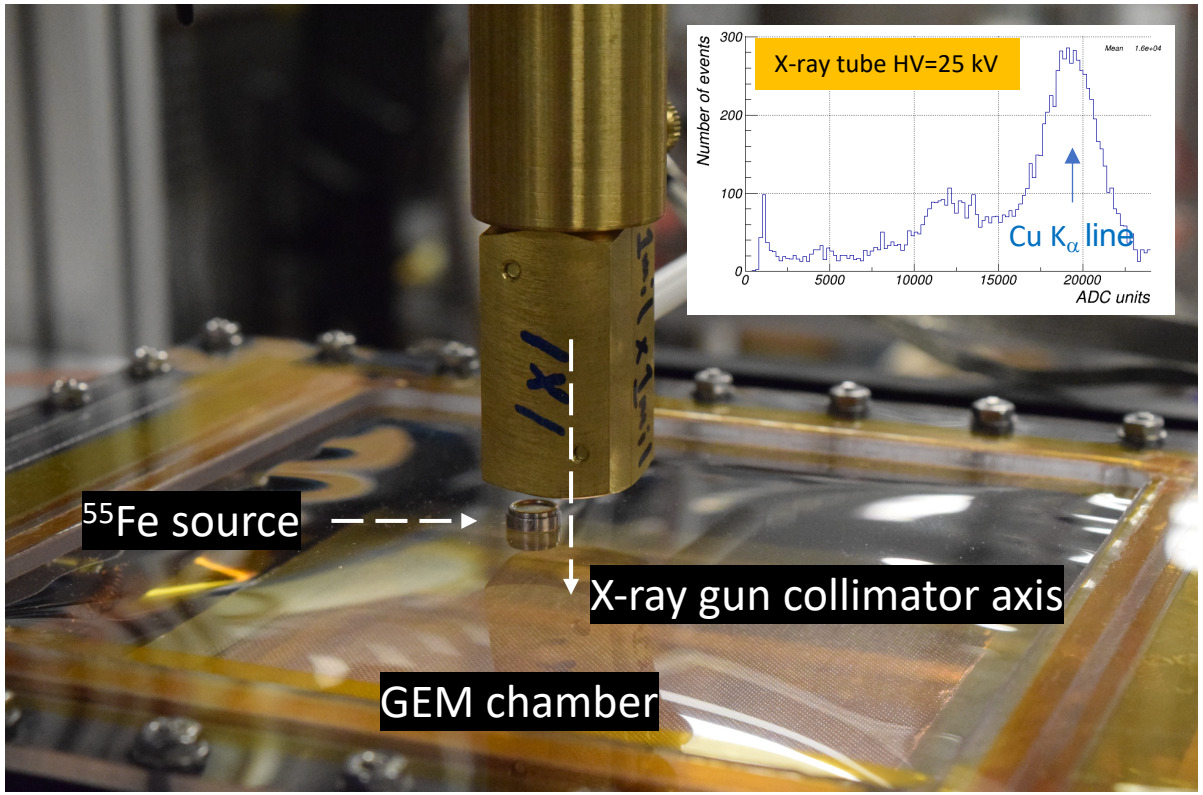
  - *1.0 mm pitch “self-analyzing” patterns*
  - *“COMPASS” 400 μm pitch reference pattern*
  - *1.5 mm pitch 2D zigzag at +/-45^0*

Test setup

- Quadruple GEM chamber
  - Ar(70)/CO_2(30)
  - Gain ~5000
- DREAM readout electronics

Drift	3.0 mm	500 V/cm
Amplification		dV ~ 325 V
Transfer	1.6 mm	3.0 kV/cm
Induction	1.6 mm	3.0 kV/cm





- Either ^{55}Fe or X-ray gun (Cu target, 8.04 keV K_α line) as a primary ionization source

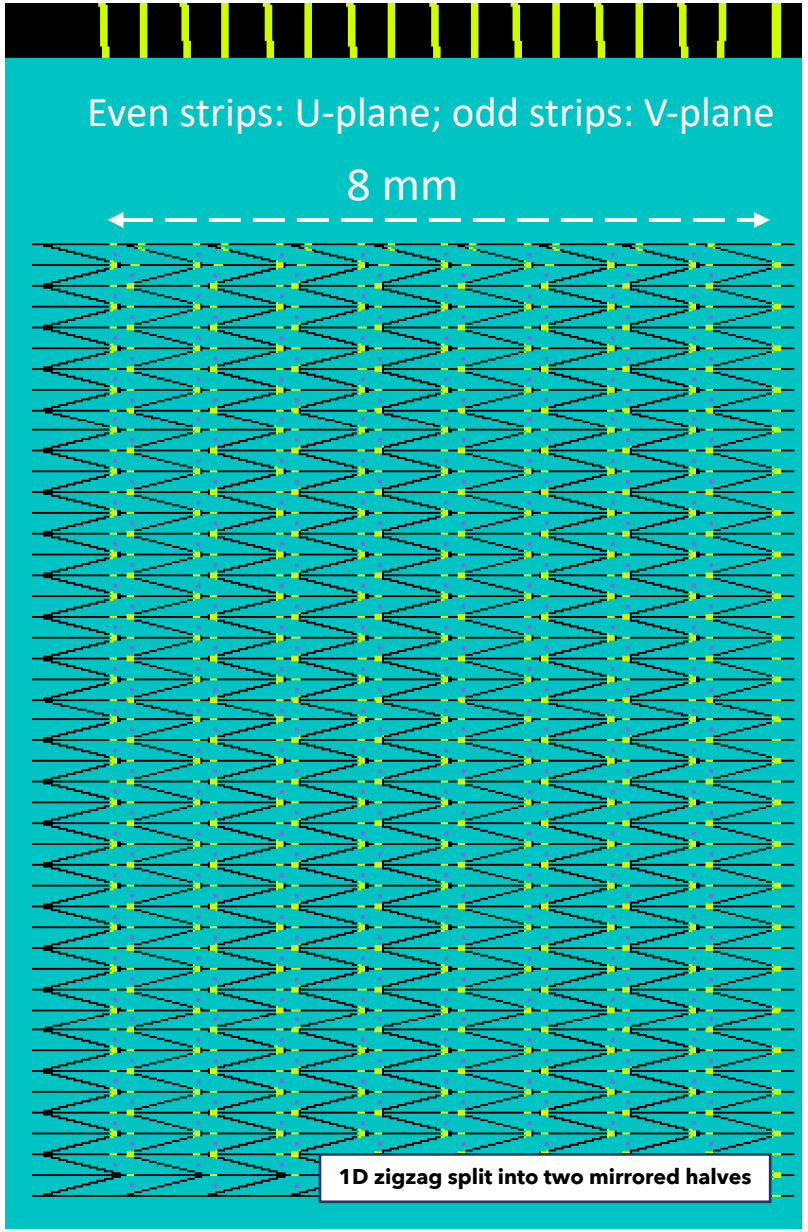
1D pseudo-zigzag self-analyzing patterns with the ^{55}Fe source

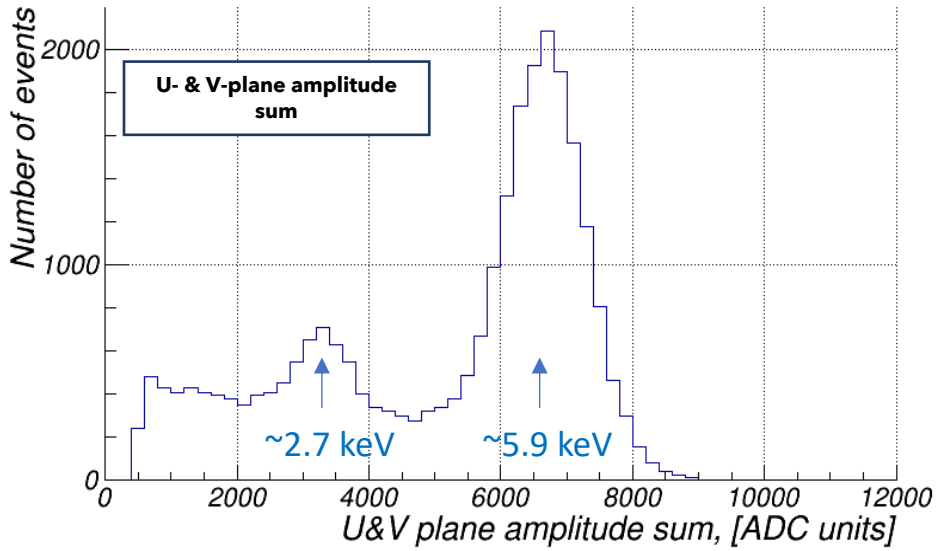
Amplitude measurements

- 1.0 mm pitch
- A single “diamond band” is 250 μm wide

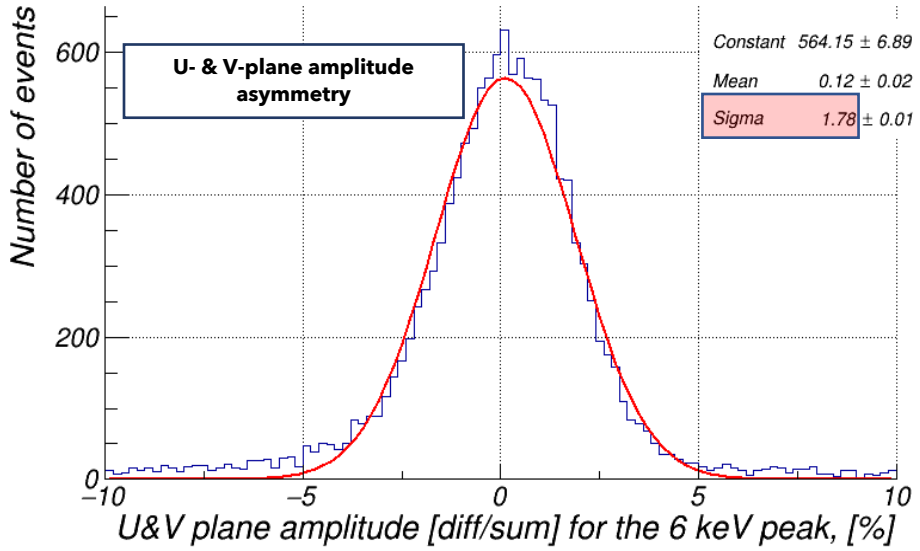
- *Effectively is just a zigzag cut into narrow slices and split between the two independent sets of eight odd & eight even strips (U & V) …*
- *… and measure the same X-coordinate by a pair of 400 μm pitch “planes”*

- Contrary to COMPASS 2D layout, both planes are identical per design and sample the same charge with a measured amplitude difference <2%

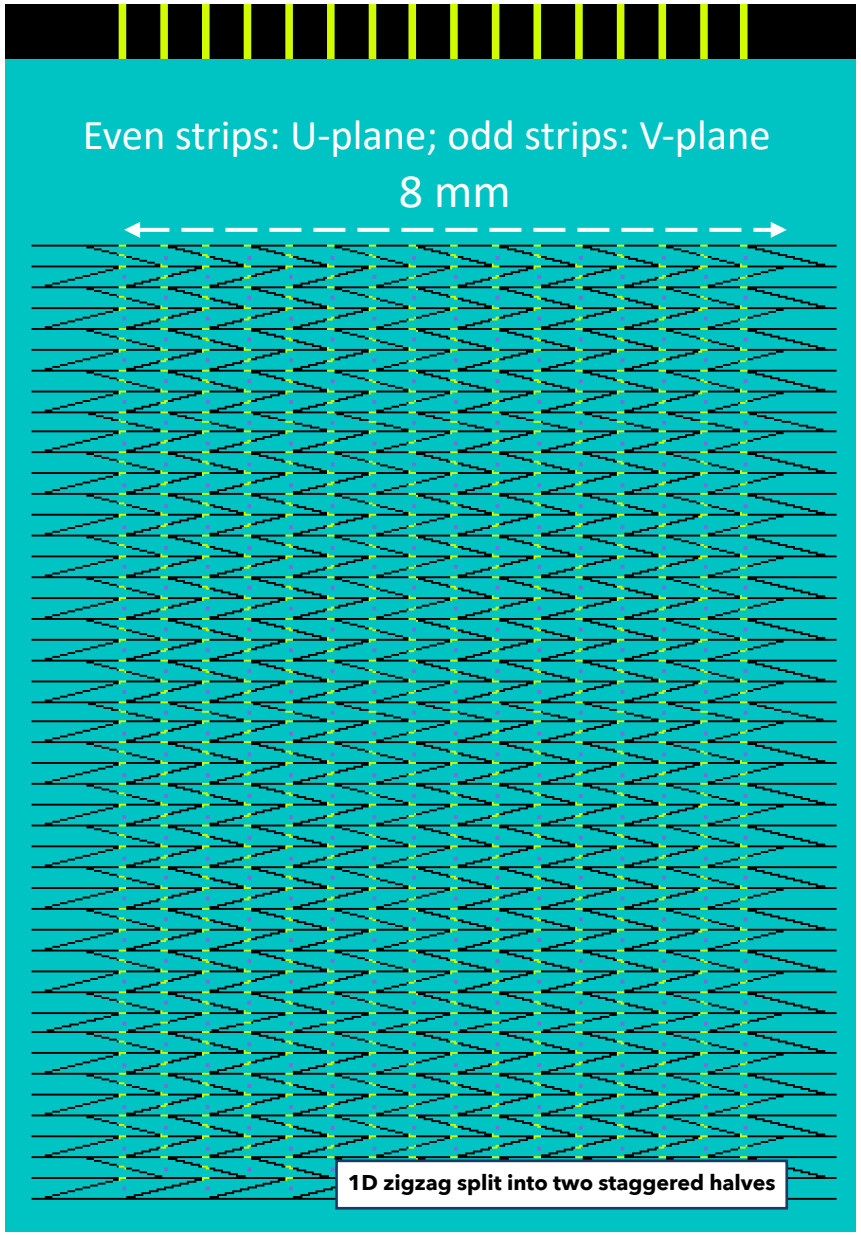




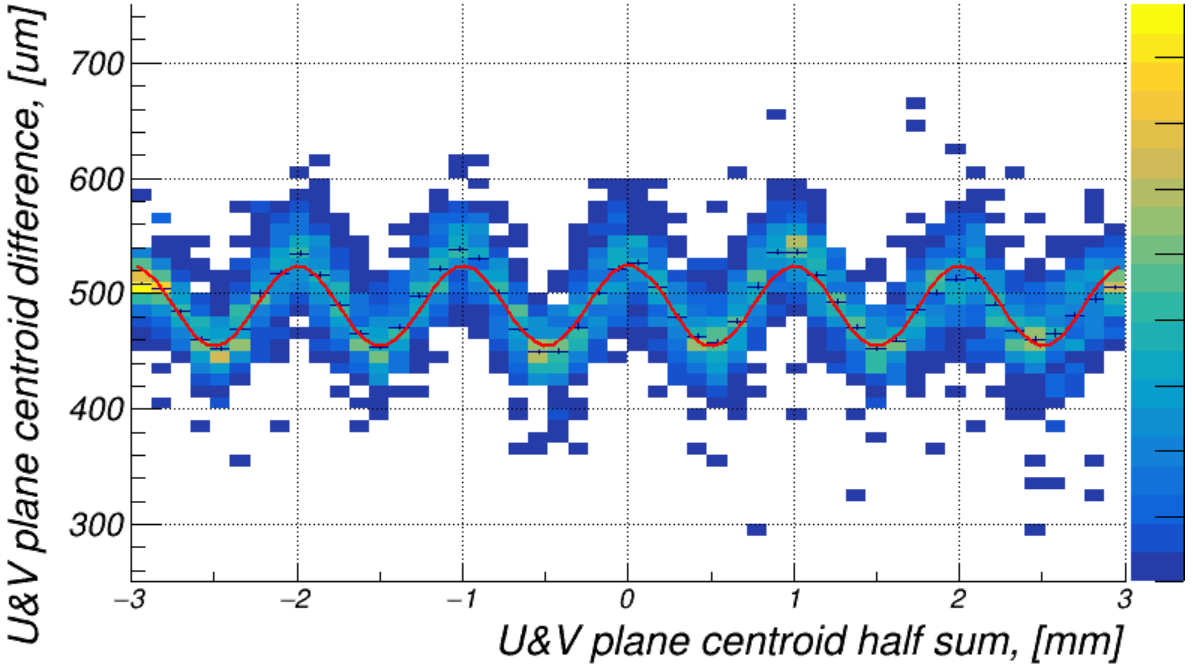
~ 8 x 10 mm² spot flooded by uncollimated ^{55}Fe source



Position measurements



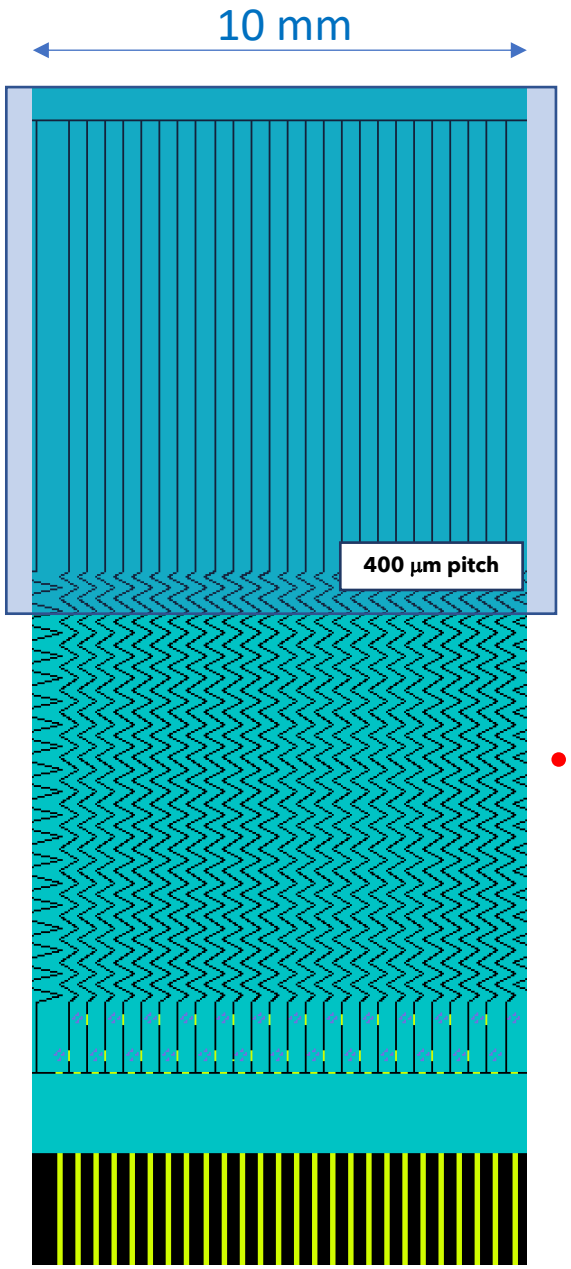
- The pattern is identical to the previous slide, but here the U&V pseudo-planes are staggered by half a pitch (namely by 500 μm)
- Any intrinsic DNL effects are *maximized* for this pattern

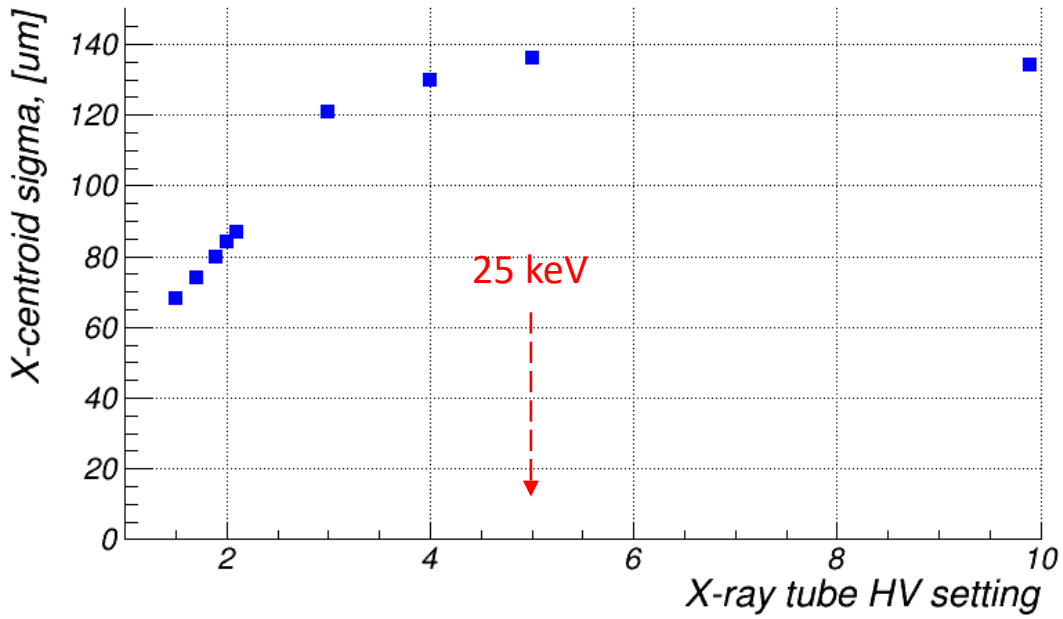


- This 2D plot alone is a good indicator of the position resolution …
- … even that there is a ~40 μm DNL remaining

“COMPASS” 400 μm pitch 1D strips with the collimated to 25 μm X-ray gun

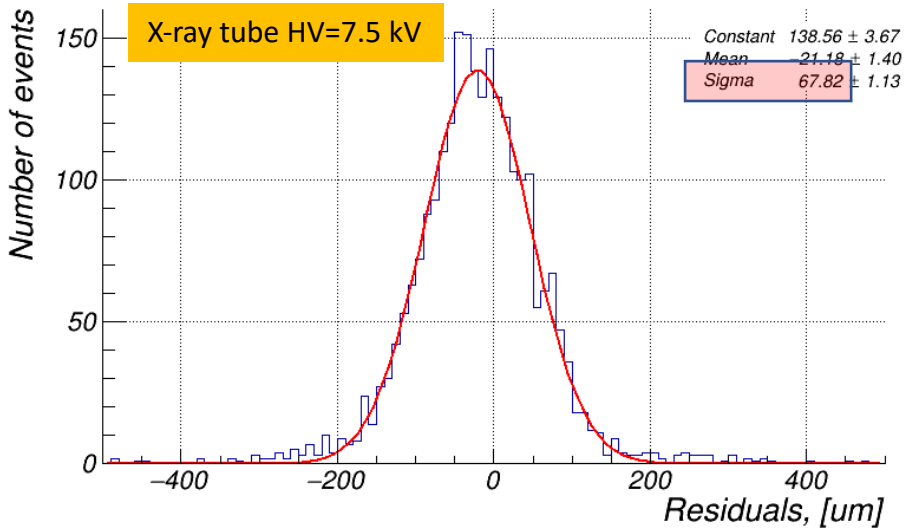
Residual width as a function of X-ray HV setting



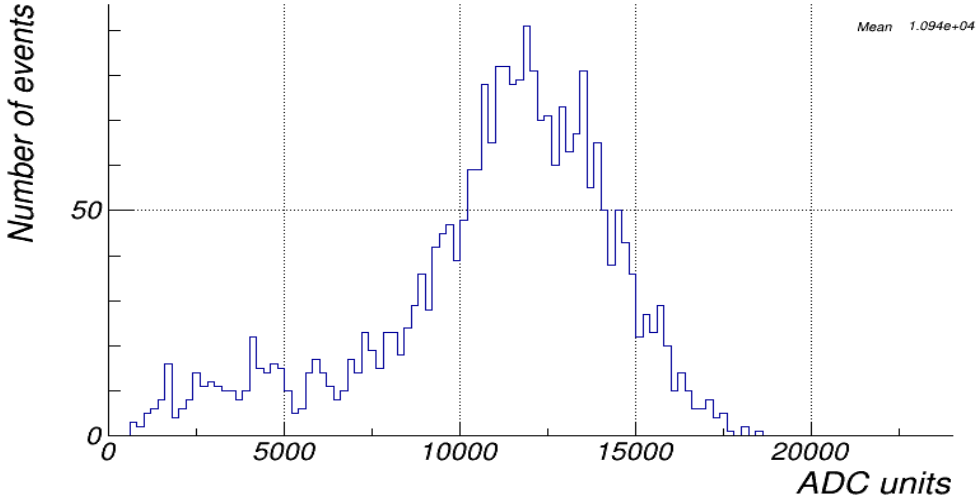


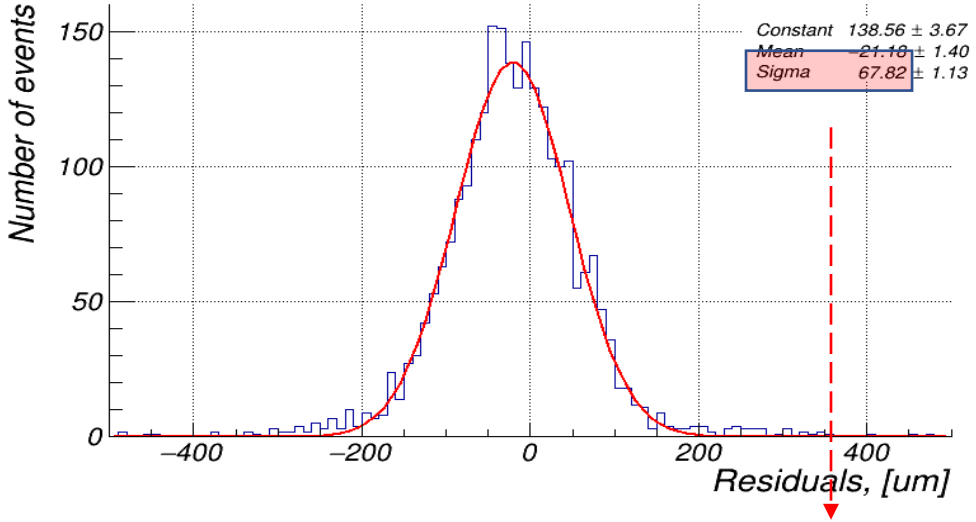
- The expected range of the K_α absorption peak electrons is a few hundred microns …
- ... therefore, need to suppress them by reducing the X-ray tube voltage
- By doing so can bring the residuals down to ~70 μm

- Note: apart from the small contribution from the finite 25 μm collimator size, these ~70 μm obviously include a quadratic sum of the intrinsic COMPASS pattern resolution (perhaps 35-40 μm) and the finite range of the lowest energy secondary X-ray electrons

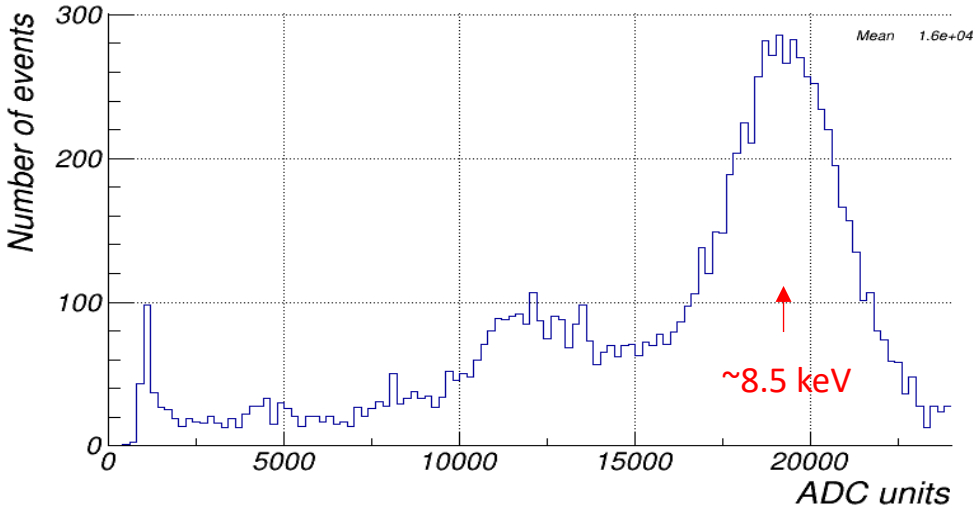


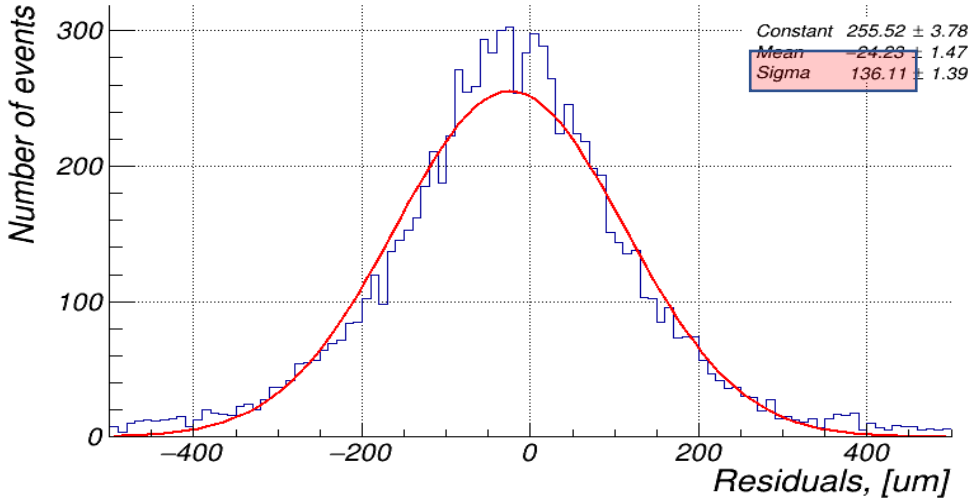
Amplitude spectra and residual distributions





X-ray HV=7.5 kV



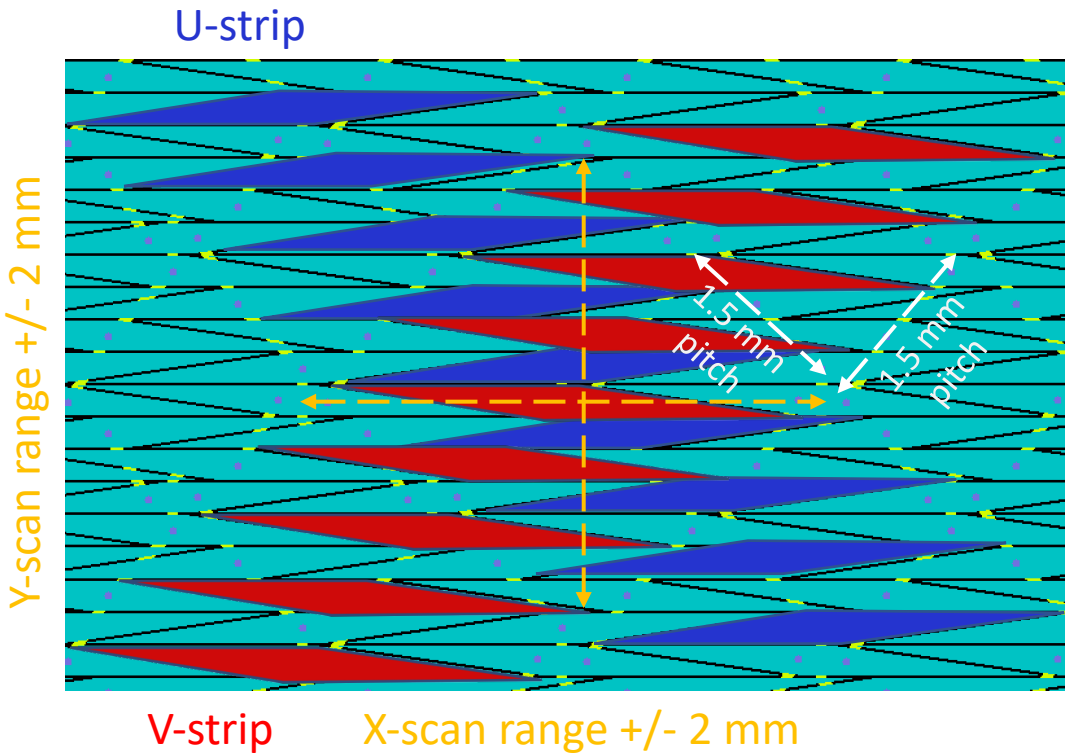


X-ray HV=25 kV

- Also, worth mentioning: the DNL for this 400 μm pitch is small (<10 μm), as expected

2D zigzag pattern
with the collimated to 25 μm X-ray gun

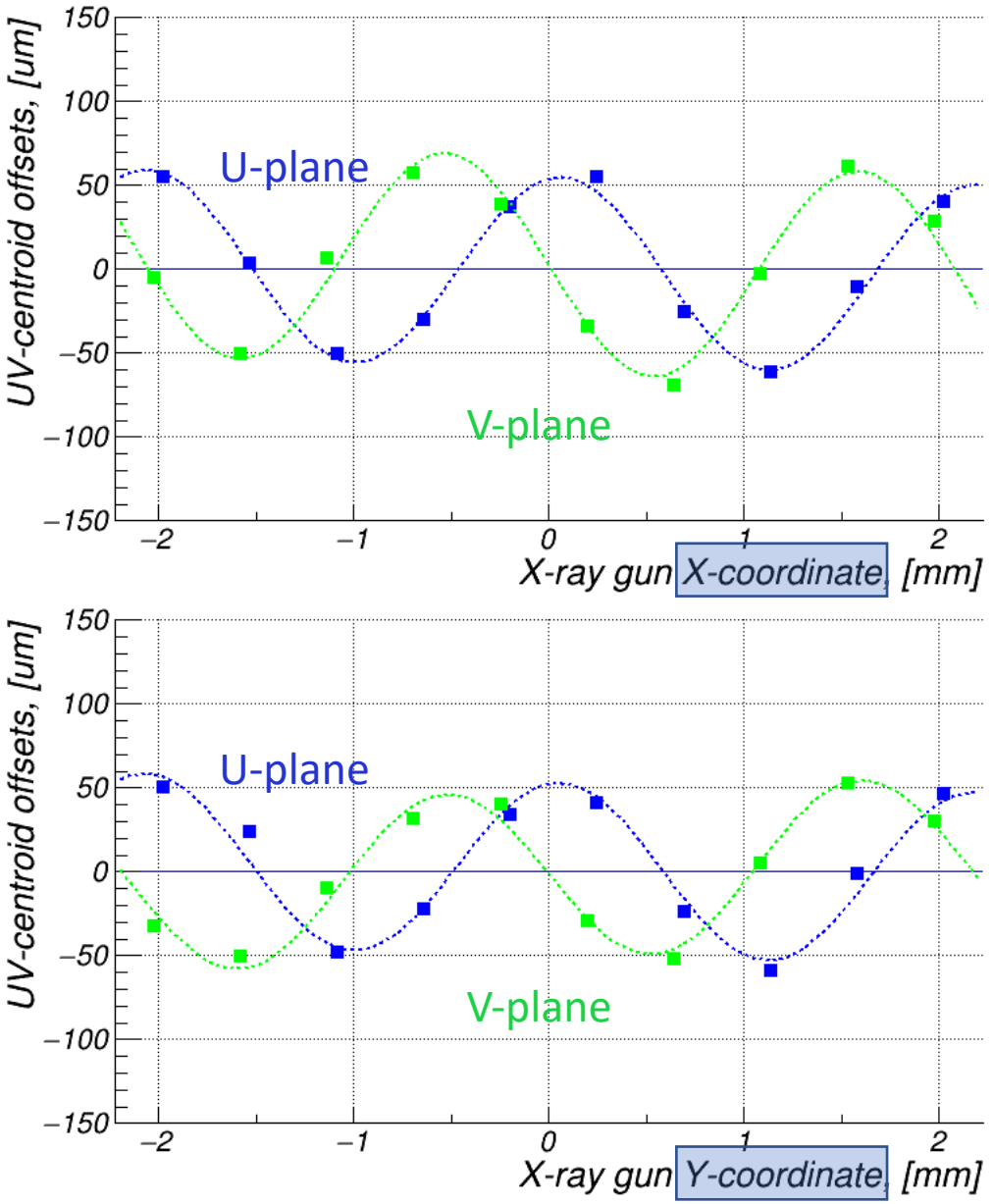
Strip configuration and measured non-linearity



- Stagger the “diamond” segments, which is equivalent to rotating the U- & V-planes
- Measure U- and V-coordinates at once

- Residuals from σ ~ 55 μm to σ ~ 85 μm
- Remaining DNL below ~ 50 μm

X-ray gun setting: tube HV 8.5 kV



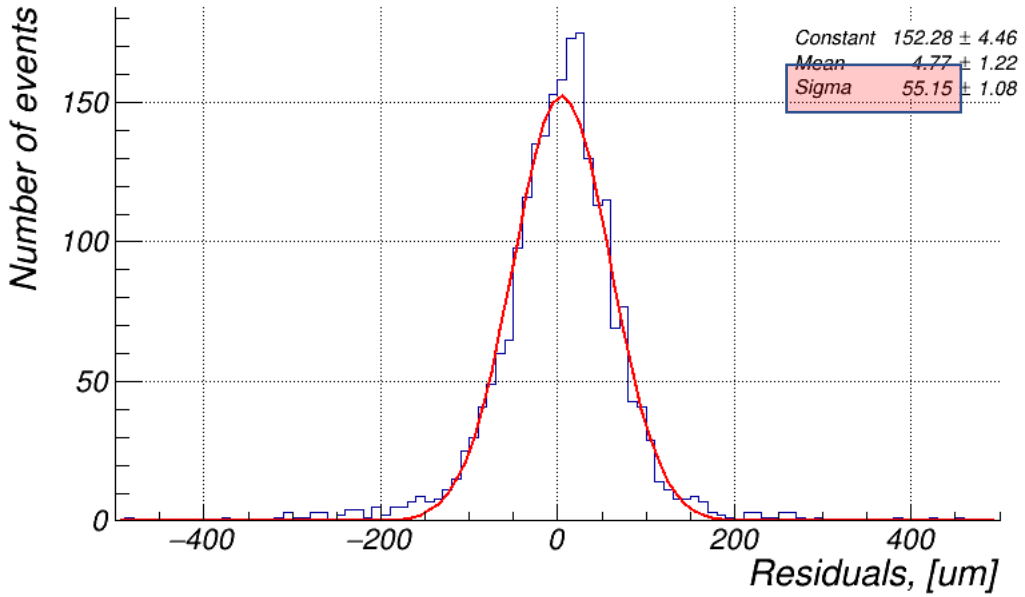
Measured residuals and spatial resolution estimates

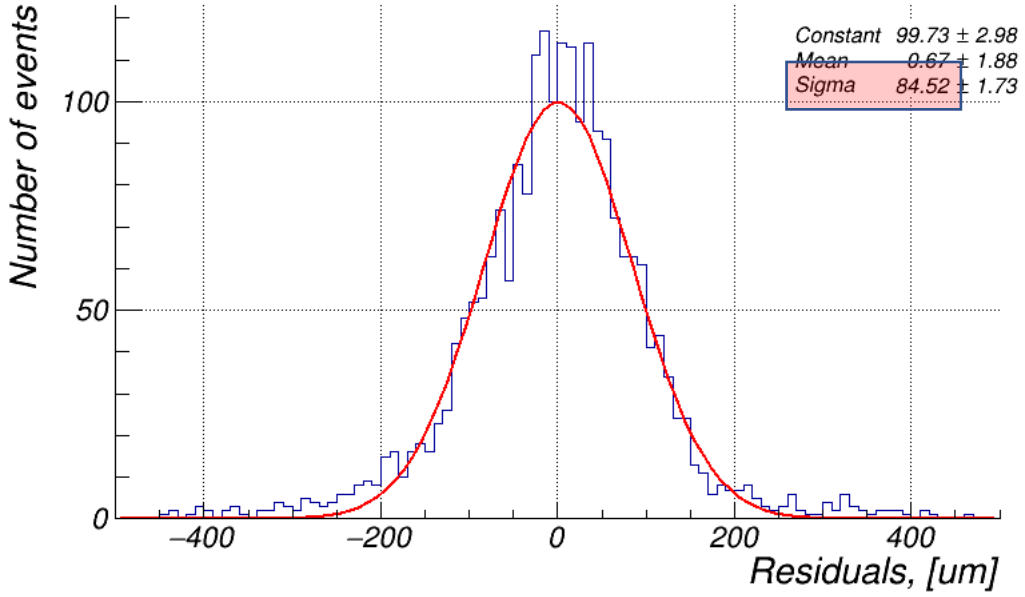
- Horizontal scan data

Taken from the sin() fit, but can be *measured* if needed

Measured residual σ_m, [μm]	Estimated dm/dx derivative	Actual resolution σ_x, [μm]
~75	1.05	~71
~58	0.81	~71
~75	1.12	~67
~82	1.21	~68
~64	0.91	~70

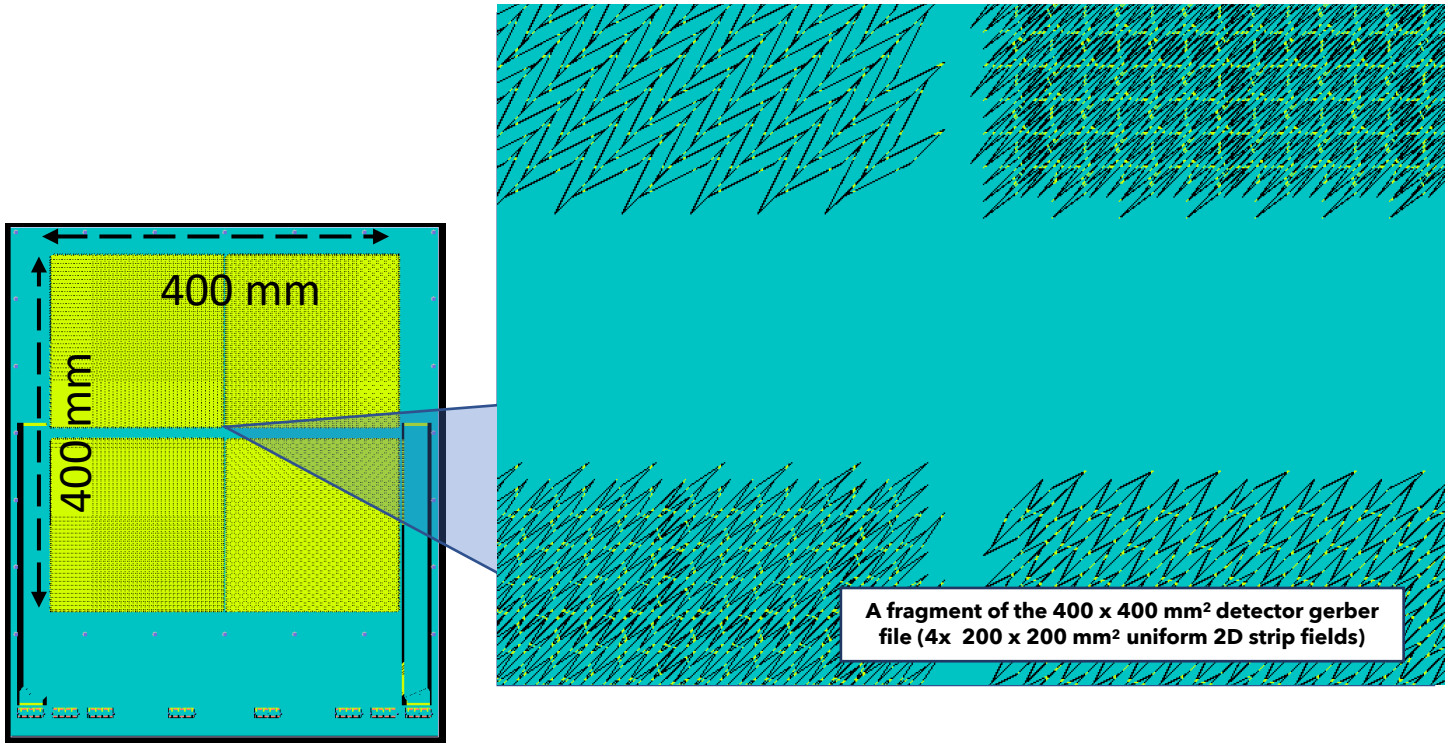
- Perfectly gaussian residuals *of variable width*
- The *actual resolution* is not equal to σ_m, but to $\sigma_x \sim \sigma_m * dx/dm$ …
- … and (see the last column) is roughly constant ~70 μm across the spot acceptance
- (with a substantial contribution of the X-ray secondary electron range)



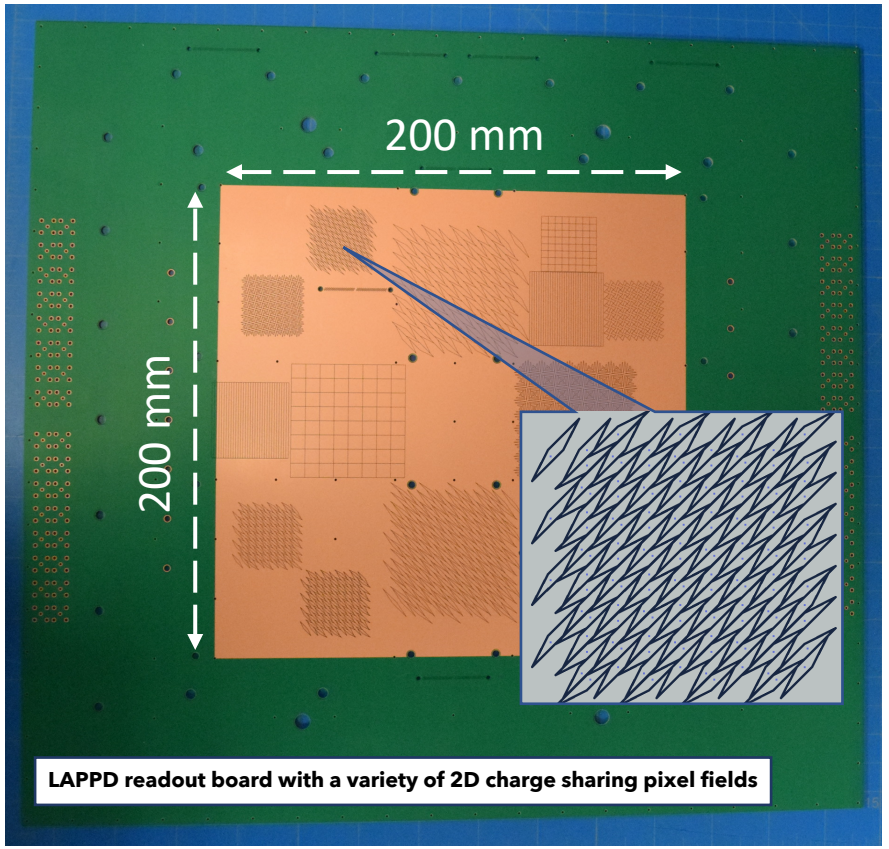


Outlook

- Perform beam test measurements at Fermilab with GEM, μRWELL & micromegas prototypes (June 2021)
- Manufacture a small ~100 x 100 mm^2 GEM detector with a uniform layout (aka EIC 2D readout scheme)
  - 2x 64 channels (X&Y)
  - expected spatial resolution ~50-60 μm
- Demonstrate scalability to ~400 x 400 mm^2, suitable for EIC applications
- Perform bench top and beam test measurements with the capacitively coupled MCP-PMTs and LAPPDs (June 2021)



A fragment of the 400 x 400 mm² detector gerber file (4x 200 x 200 mm² uniform 2D strip fields)



LAPPD readout board with a variety of 2D charge sharing pixel fields

Summary

- A small 2D zigzag charge sharing readout plane prototype was designed, manufactured and benchmarked
- It resembles all the distinguishing features of 1D zigzag, but allows one to measure two (or more) independent coordinates at once:
  - High spatial resolution
  - Low channel count
  - Small differential non-linearity
- Other features of potential interest:
  - Low material budget (if used without a thick PCB substrate)
  - Built-in redundancy (if designed *with more than two* independent planes at once)
  - 2D pixellation with X&Y-resolution independent of the pixel footprint (if one uses strip segments)
- Beam test measurements are starting this week at Fermilab!