C-V measurements in (AC-)LGADs

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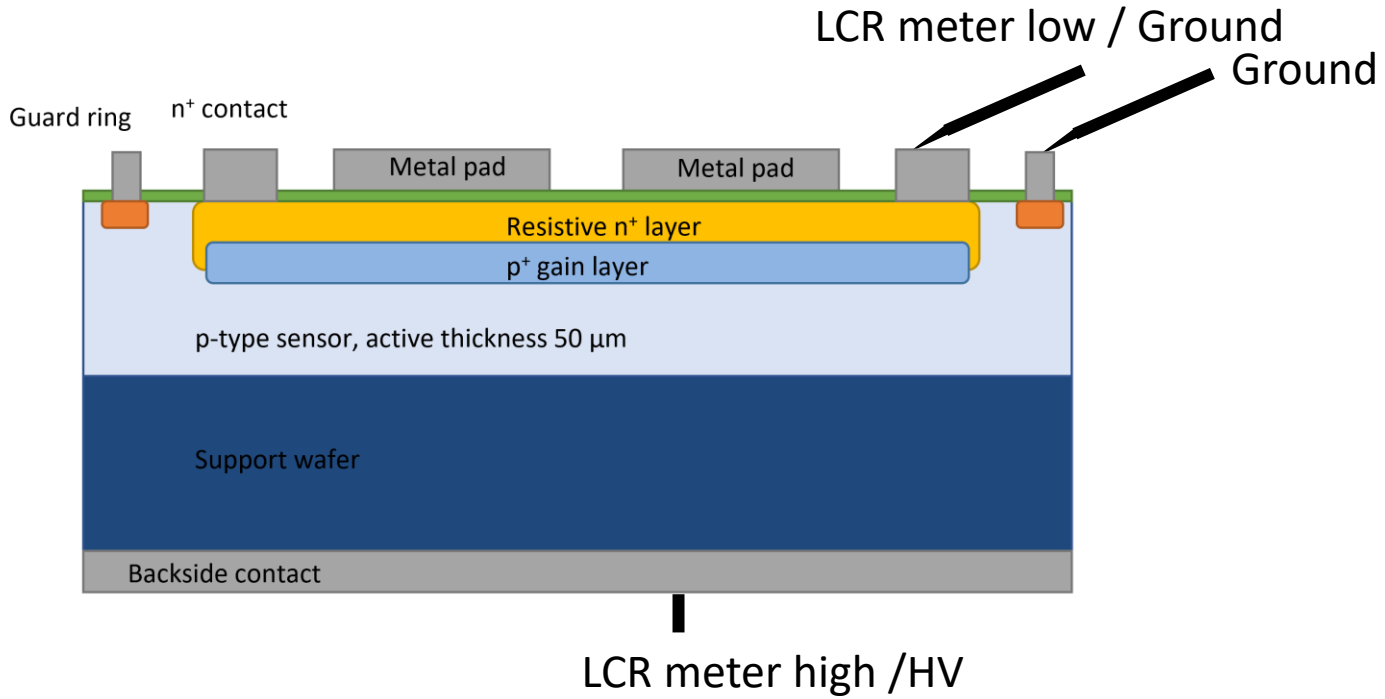
Standard C-V measurement

"Conventional" C-V measurement configuration: sensor backplane to front side electrode

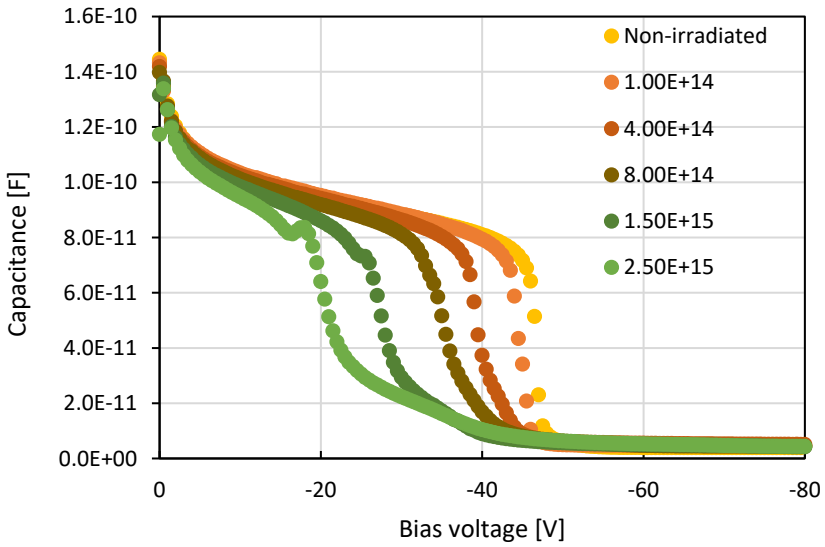
- In AC-LGADs, there is one shared n^+ layer with the DC contact – capacitance measured over the full sensor area
- Depending on area: **pF to 10s of pF**



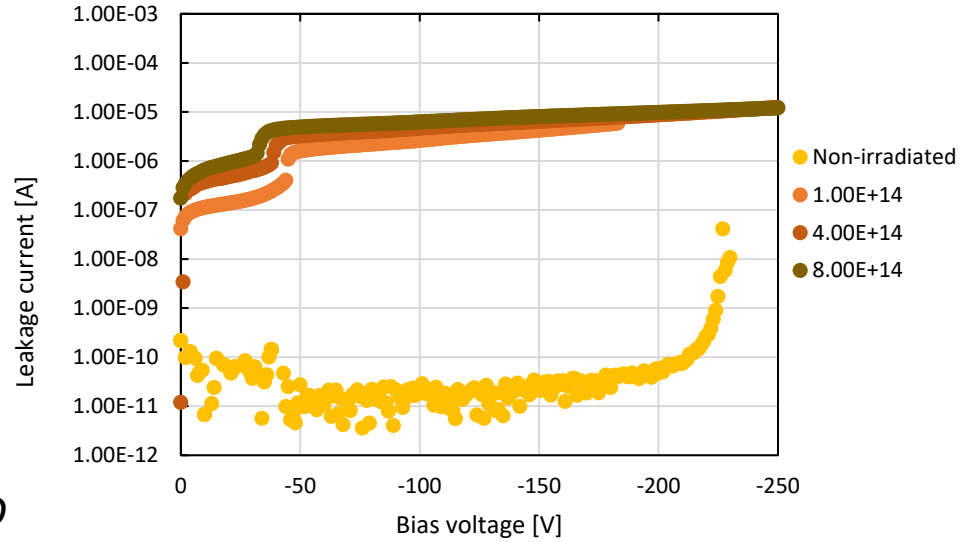
Radiation damage

Irradiation has an impact on the bulk and on the gain layer, just like in other types of LGADs

- Bulk damage: increased leakage current and defect concentration – higher depletion voltage of the bulk volume
- Gain layer: “acceptor removal” – lower depletion voltage



DC-LGAD

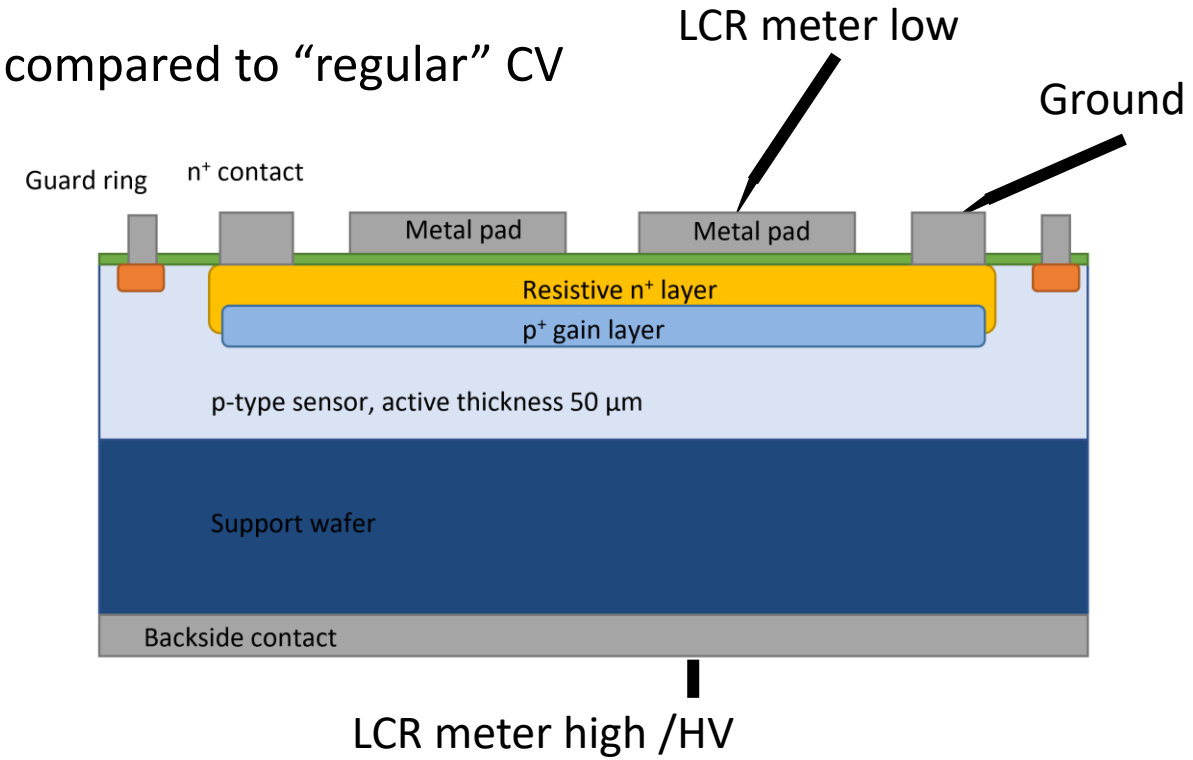


➢ Radiation levels of $\mathcal{O}(10^{14}\ \mathrm{cm}^{-2})$ as predicted for ePIC should not have a significant impact on sensor performance, but increase in leakage current needs to be considered

AC capacitance

Specific to AC-LGADs: measurement from backplane to individual AC metal pad

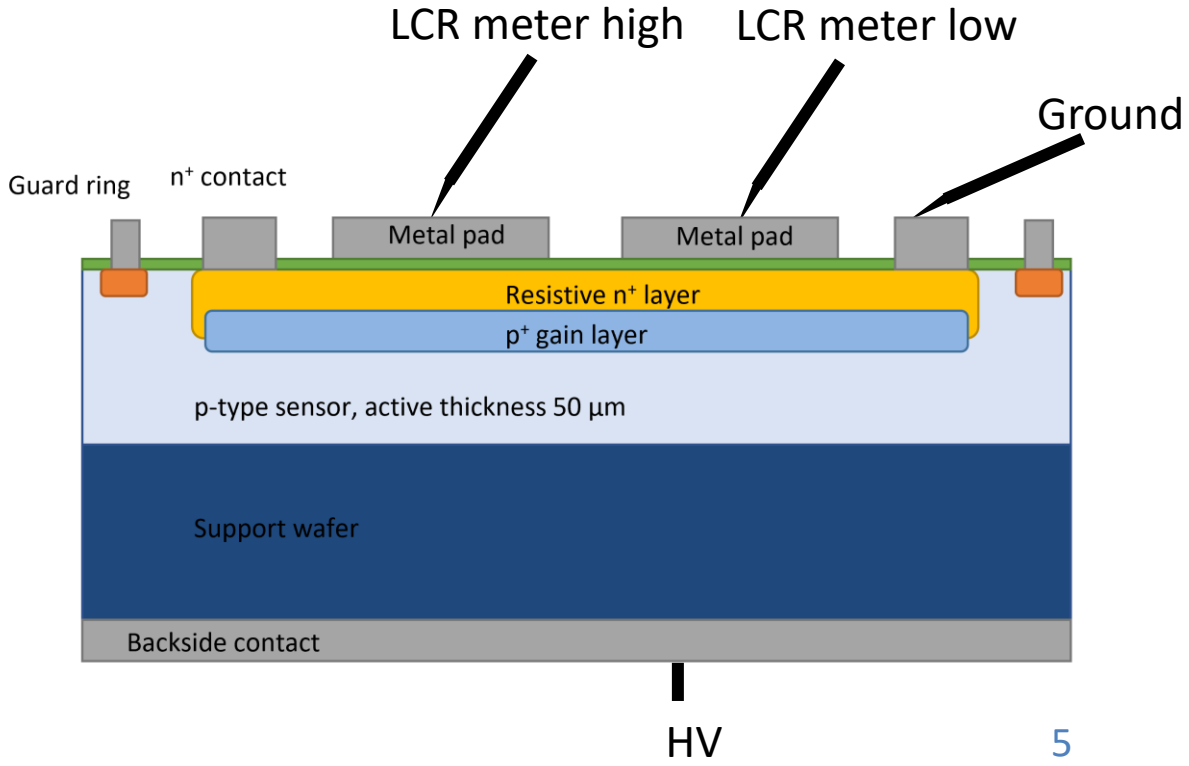
- Depletion visible, frequency dependence before depletion – capacitance component through the bulk
- Pad size affects the final capacitance values, since capacitance is directly proportional to the area
- Values after full depletion are relatively small compared to “regular” CV measurements



Interpad capacitance

Interpad capacitance: between two AC metal pads, sensor biasing from backplane as usual, grounding to the n^+ DC contact

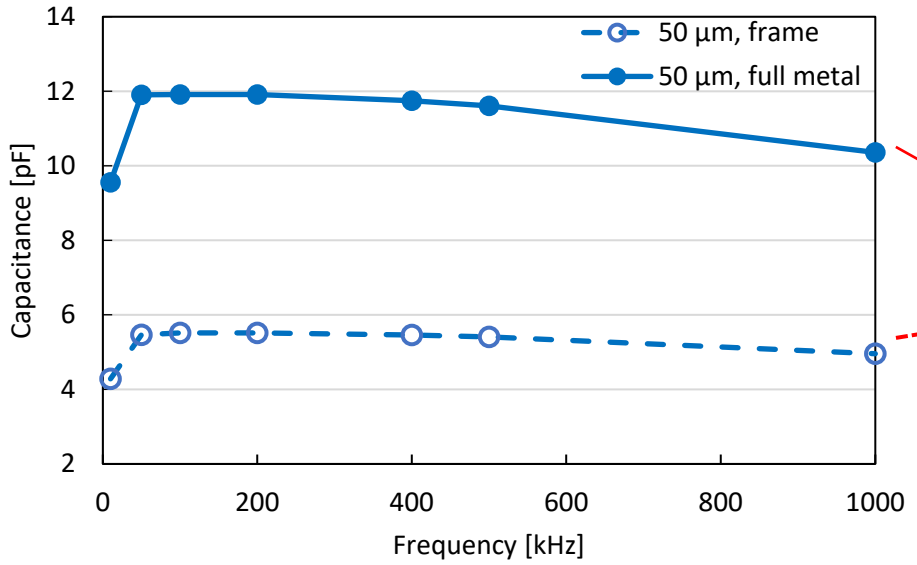
- Depletion visible, frequency dependence before depletion – capacitance component through the bulk
- A factor in the observed higher signal sharing for longer strips

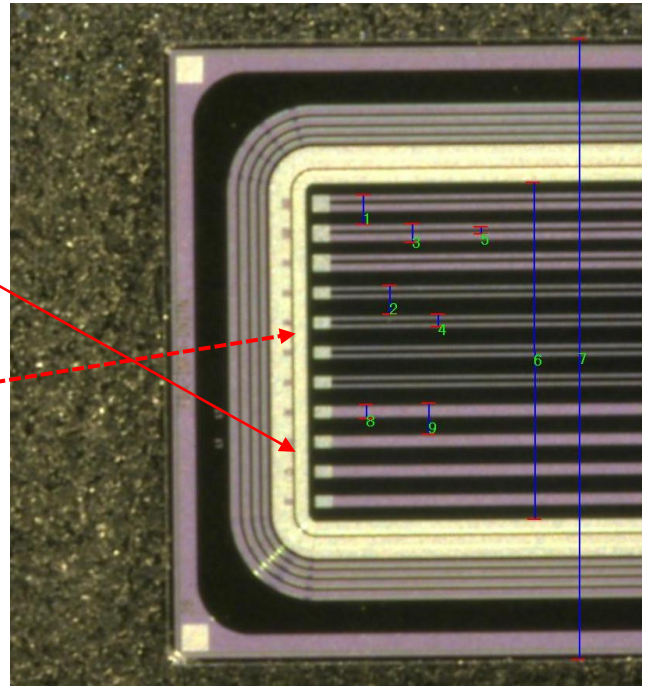


Reducing input capacitance by reducing metal?

E.g. cutting out the metal on strips, leaving a “frame” instead of a fully metallized strip, in FBK RSD2*

- Direct impact on electrode capacitance





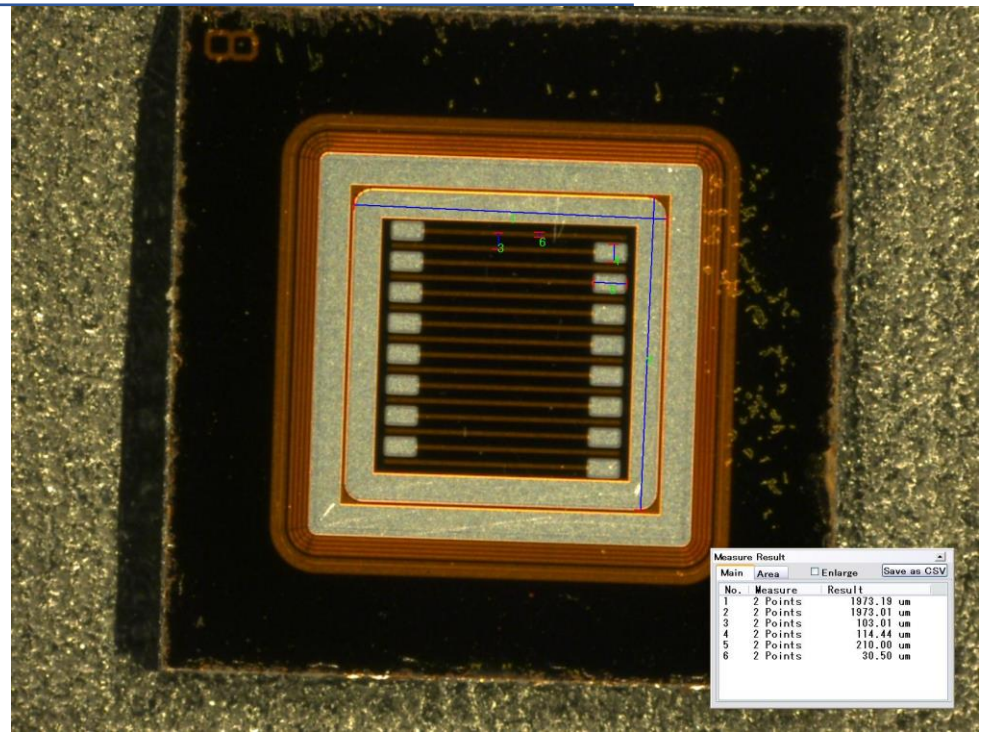
*M. Mandurrino et al, 39th RD50 Workshop, November 2021 (https://indico.cern.ch/event/1074989/contributions/4602006/)

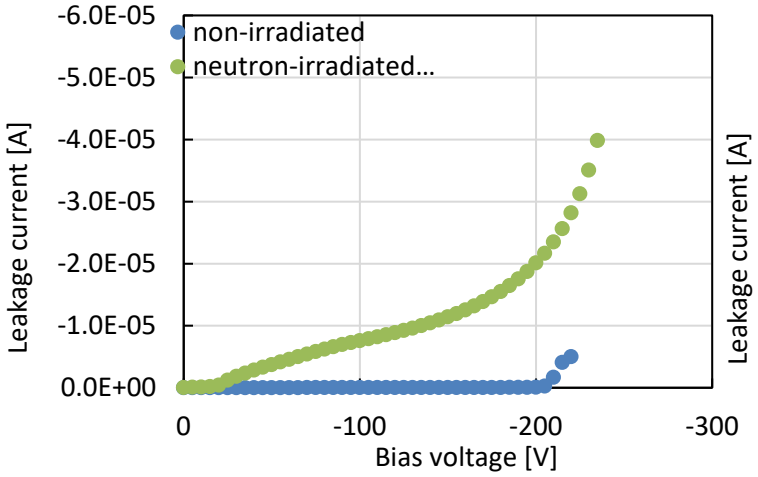
Results on BNL strip AC-LGADs

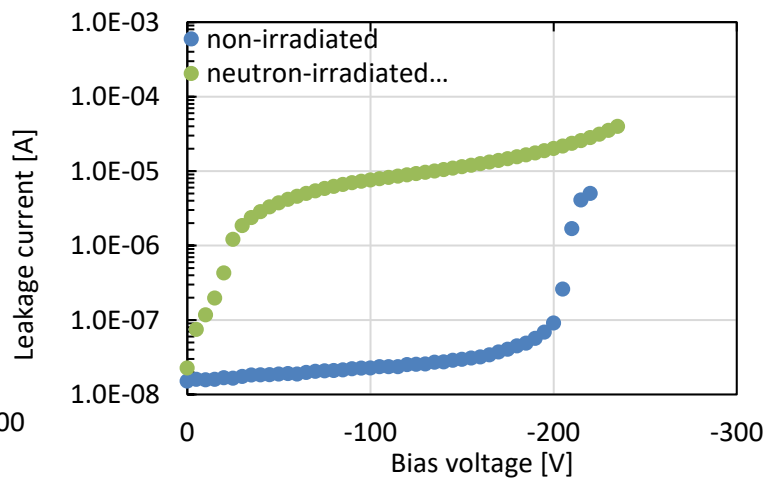
- **Measured at room temperature**
- **Other strips and guard ring floating**
- **In AC and interpad capacitance measurements, n^+ layer goes to ground**

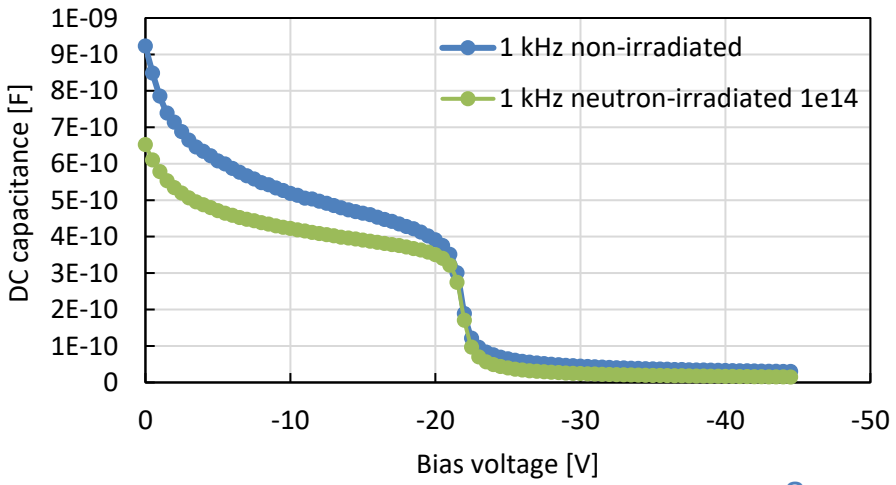
Older BNL strips (2020?)

- Non-irradiated and neutron-irradiated to 1e14 cm^{-2}
  - 2-3 orders of magnitude increase in leakage current; very little impact on gain layer and bulk as a whole

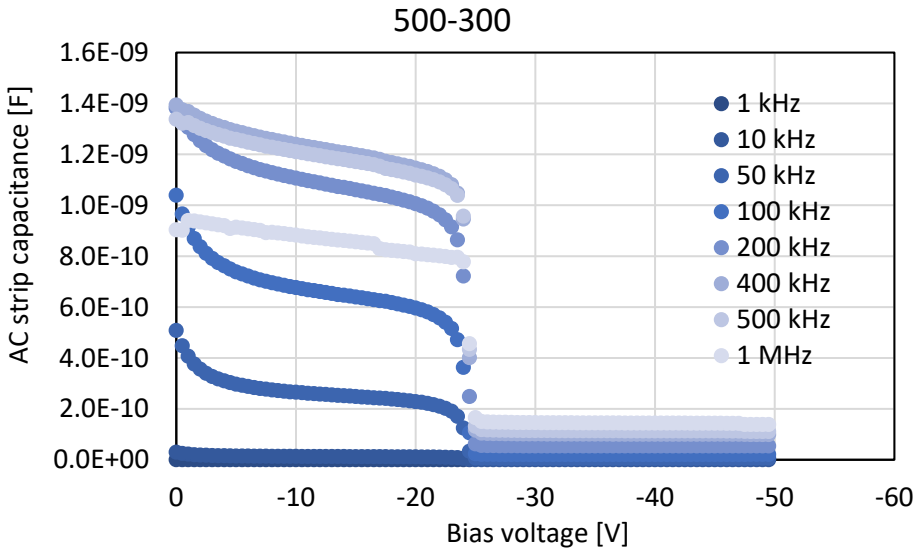


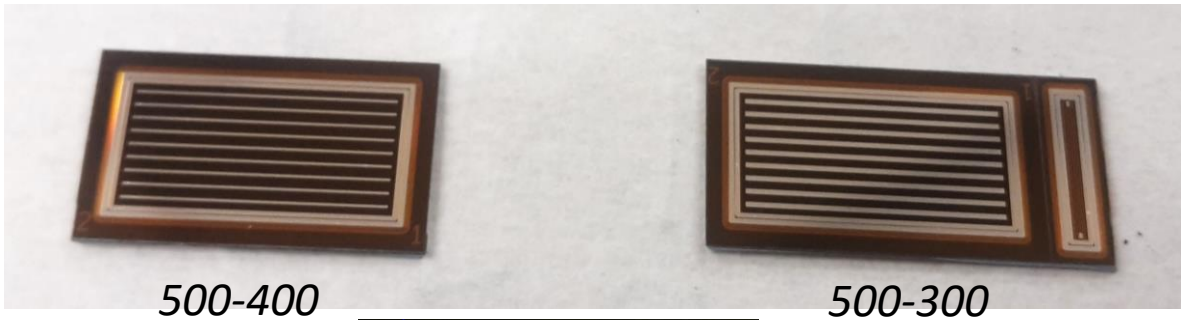


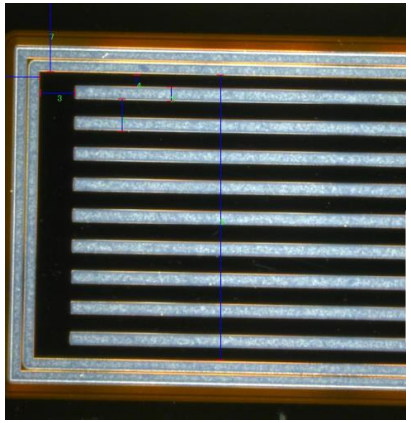


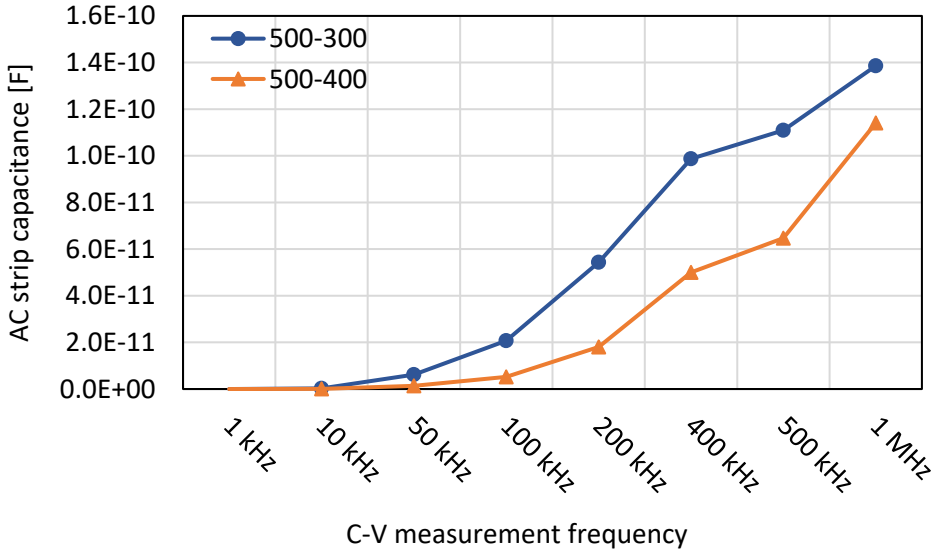


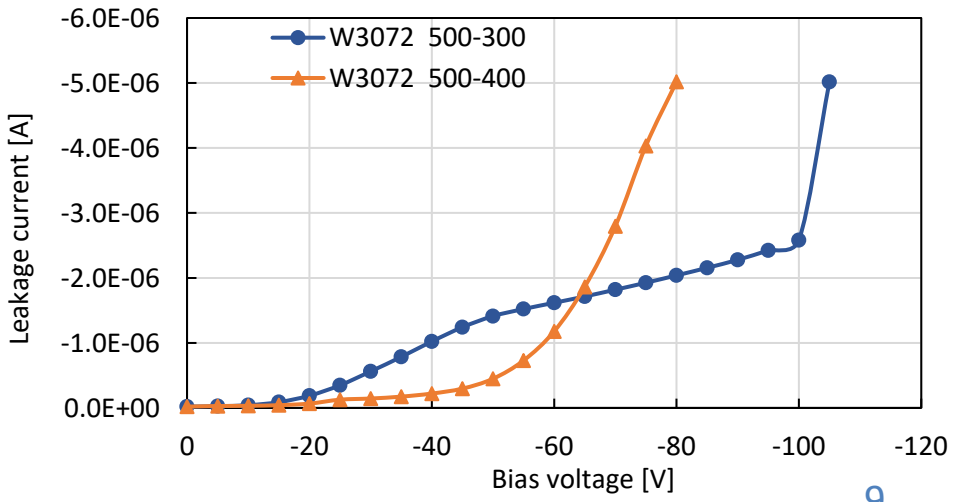
Newer BNL strips: 1 cm, 500 µm pitch, 300 or 400 µm gap











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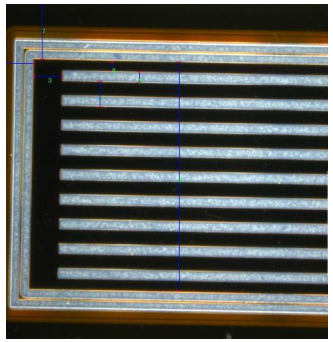
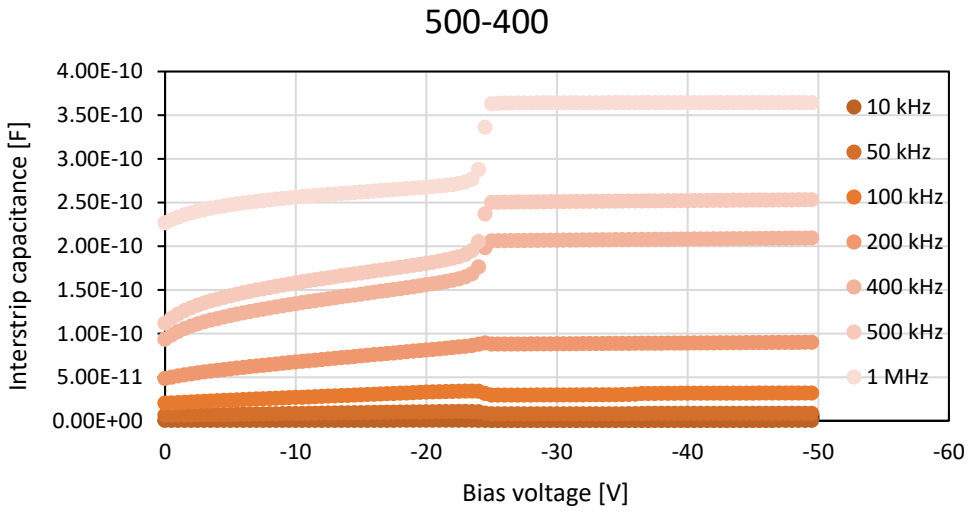
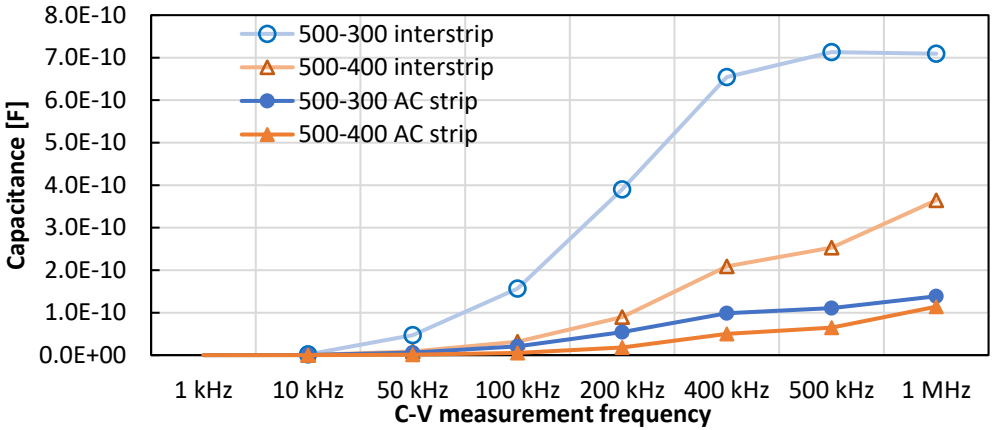
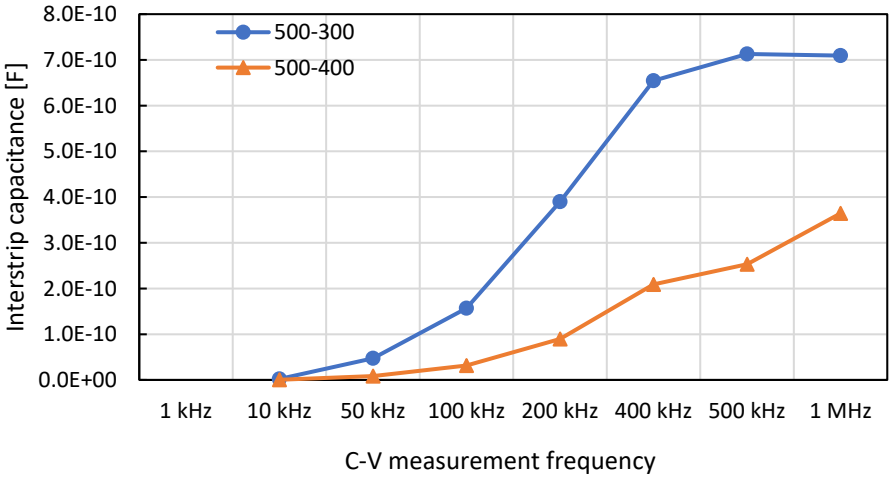
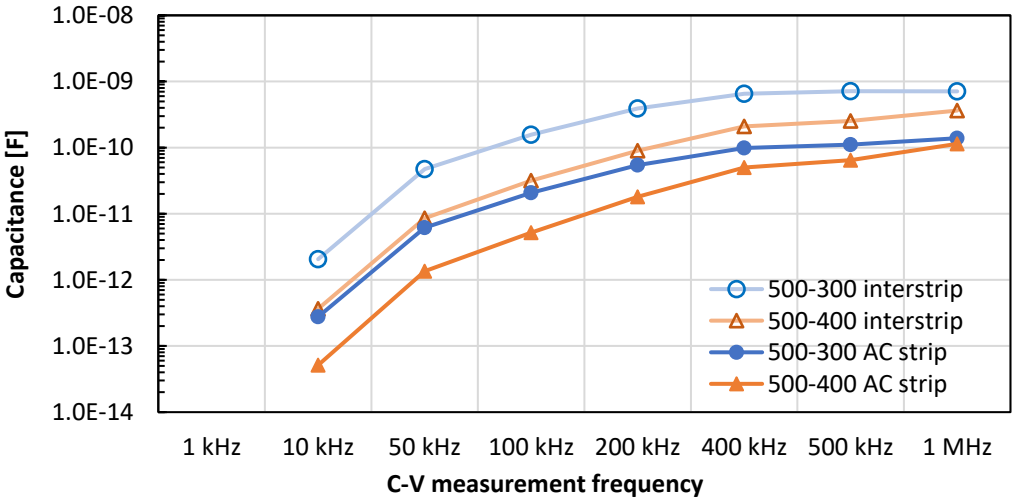




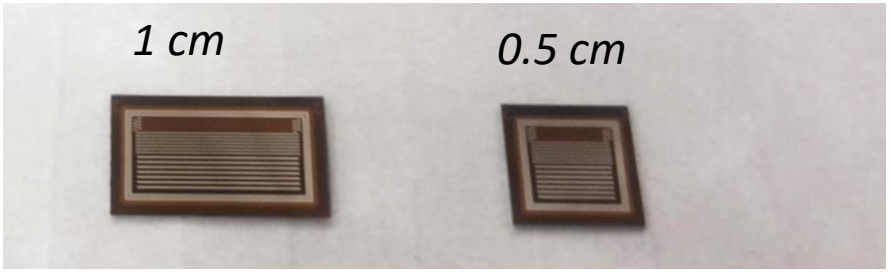


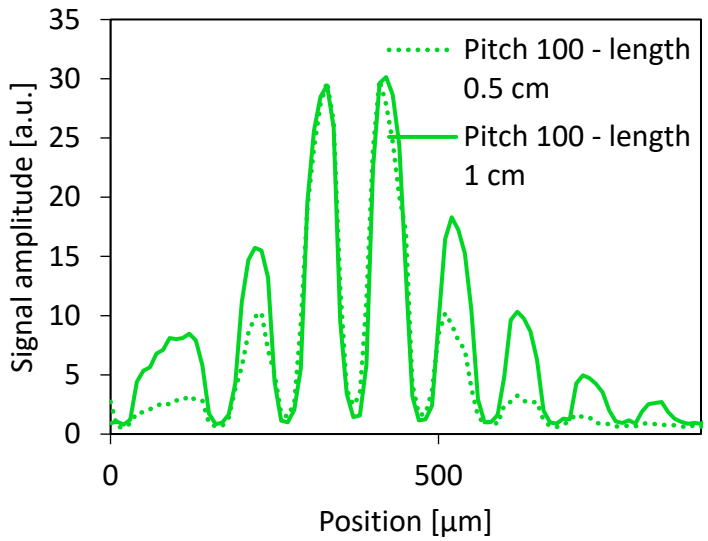


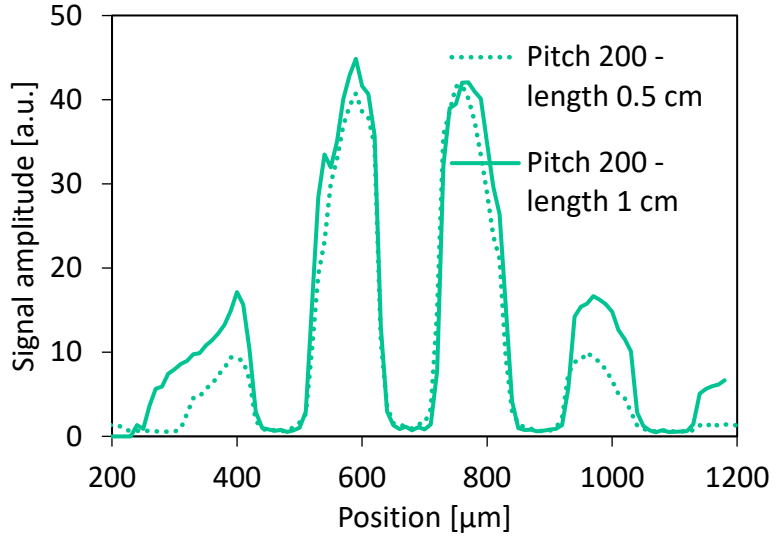


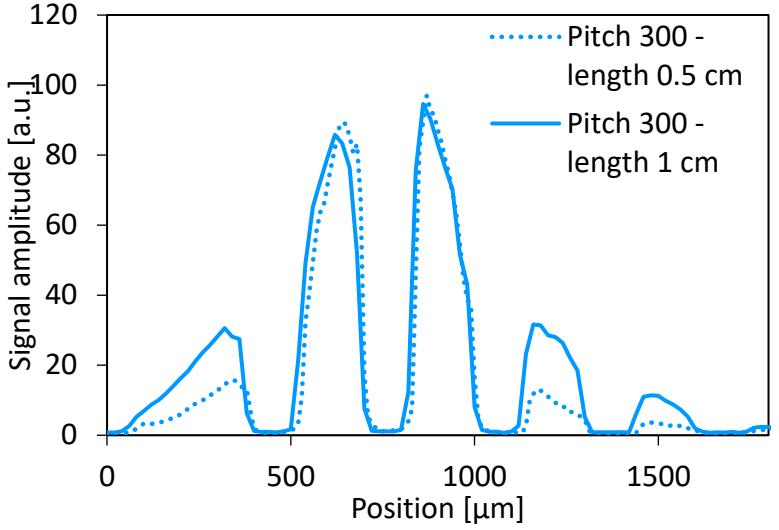
BNL multipitch strips

- More charge sharing in longer strips observed in laser (laser data from BNL earlier production)



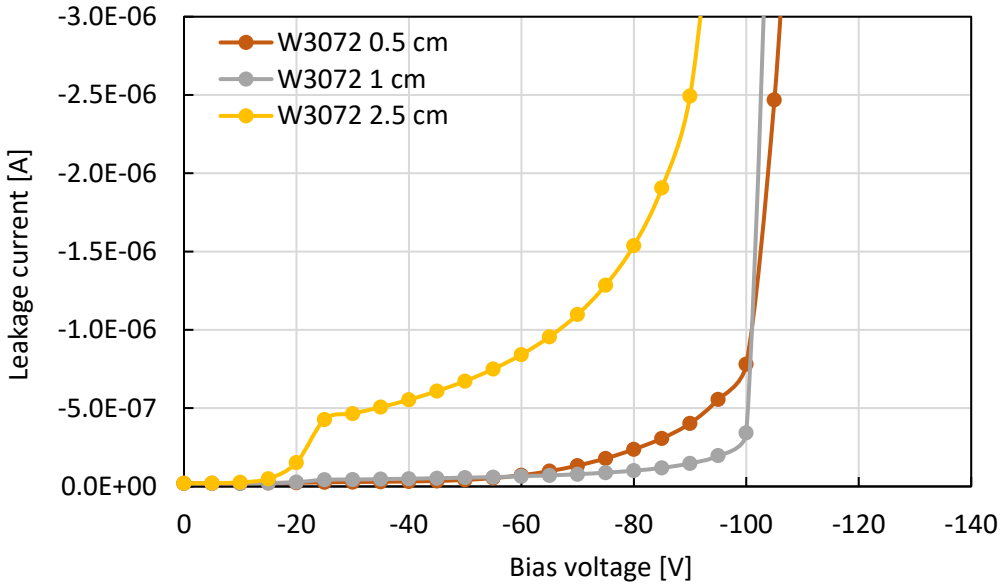


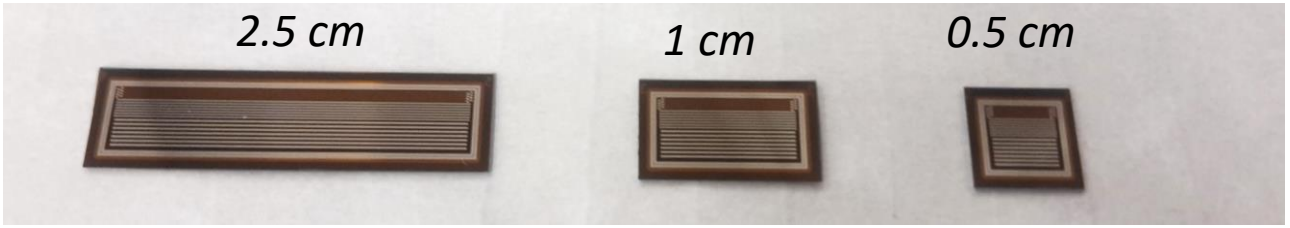


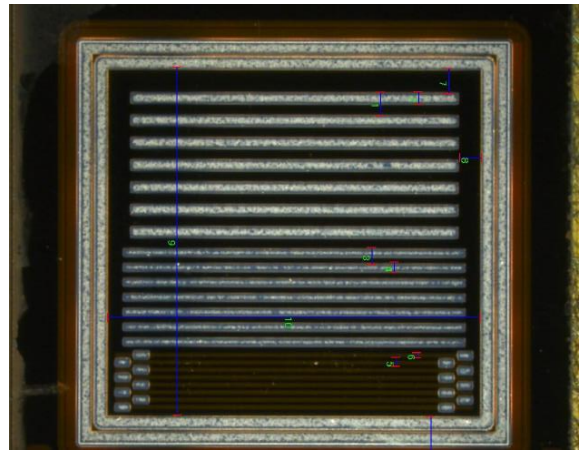


Newer BNL multipitch strips

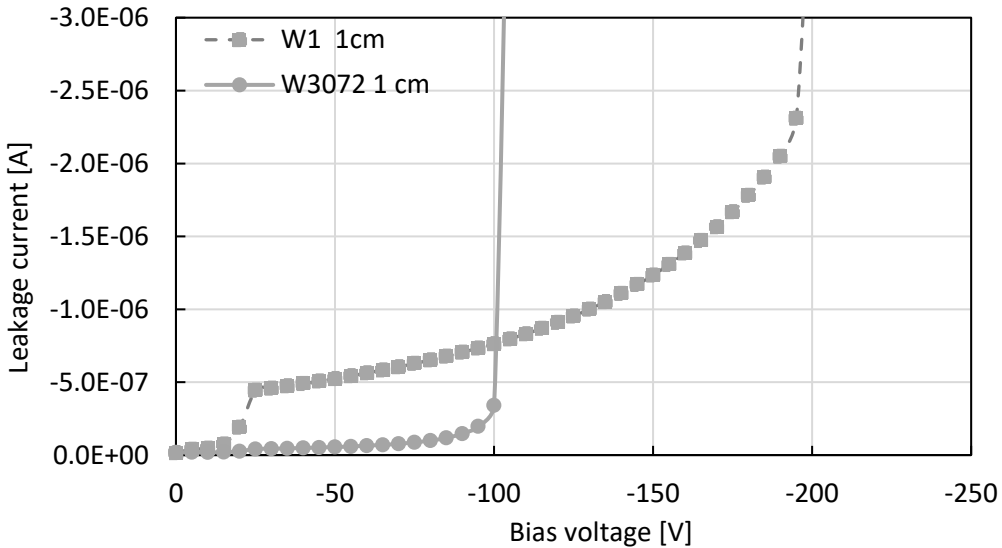
- I-V for different strip lengths



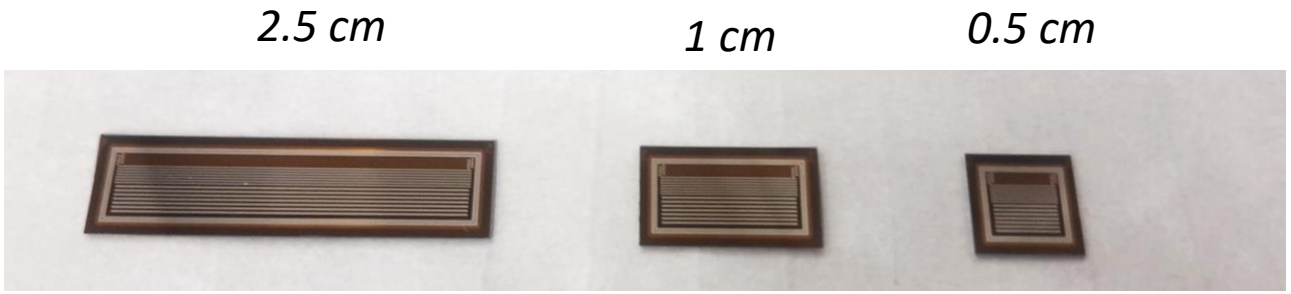


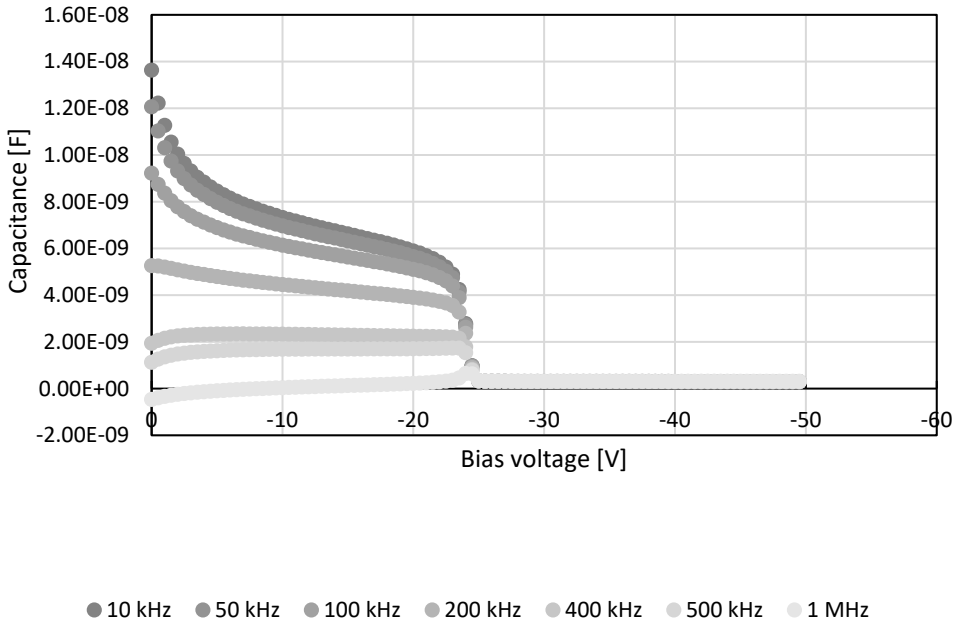


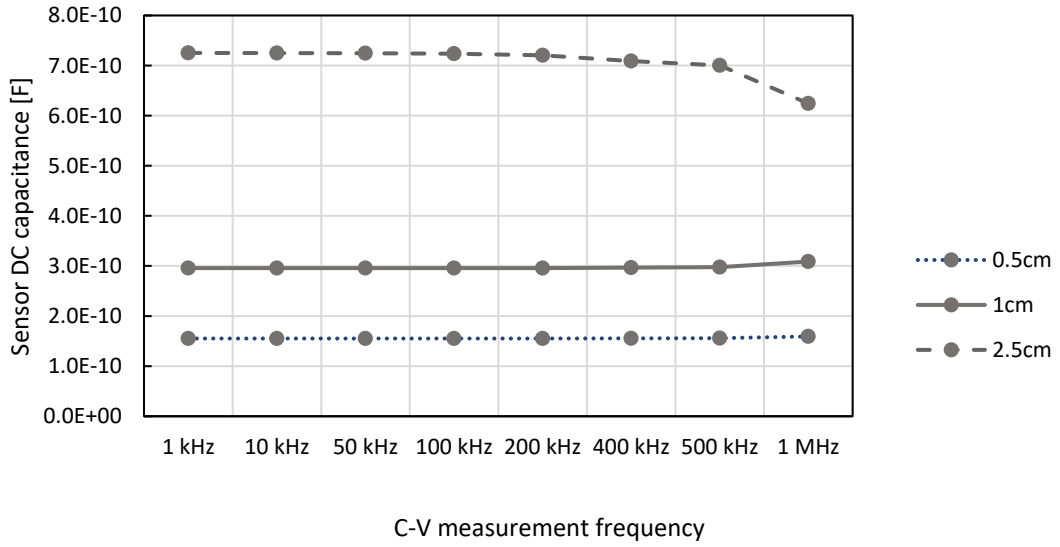
- I-V for newest and older multipitch sensor



Newer BNL multipitch strips: sensor capacitance



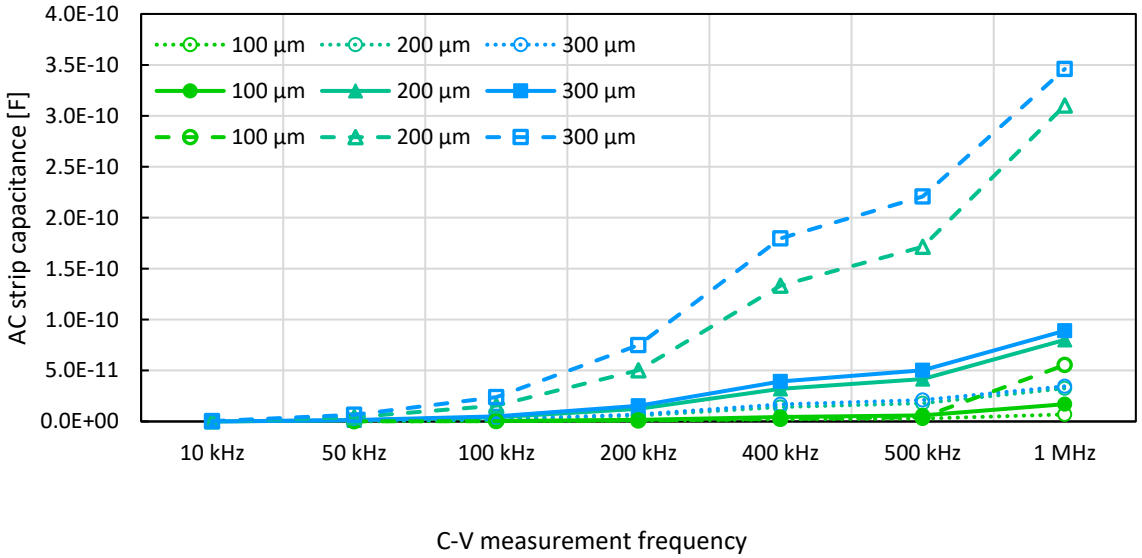


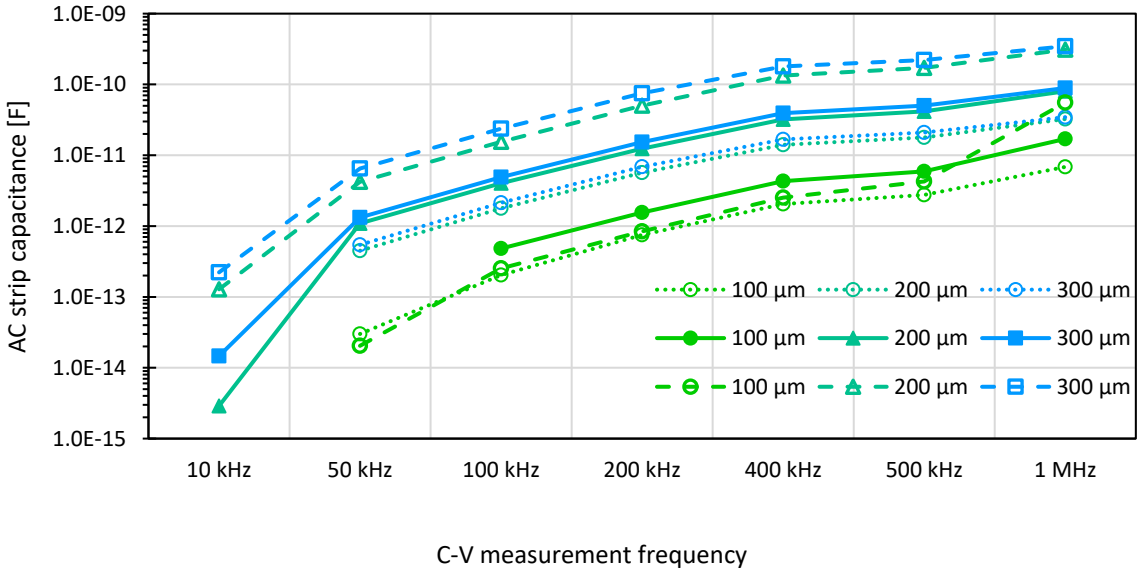


BNL multipitch strip capacitance

Dotted line: 0.5 cm
Solid line: 1 cm
Dashed line: 2.5 cm

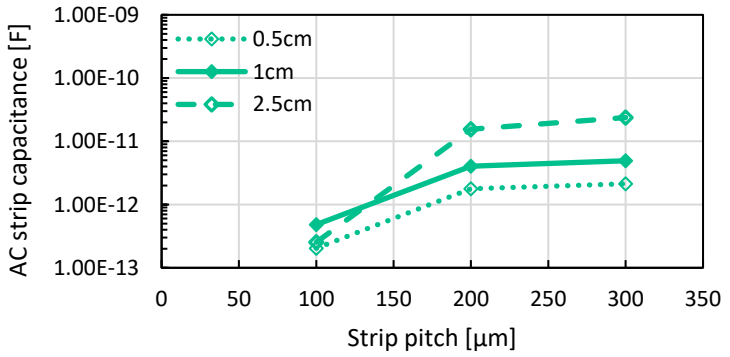
- Higher strip capacitance for:
  - Wider metal
  - Longer strips
- Higher capacitance at high frequency: unusual
  - Compared to DC capacitance of the full sensors

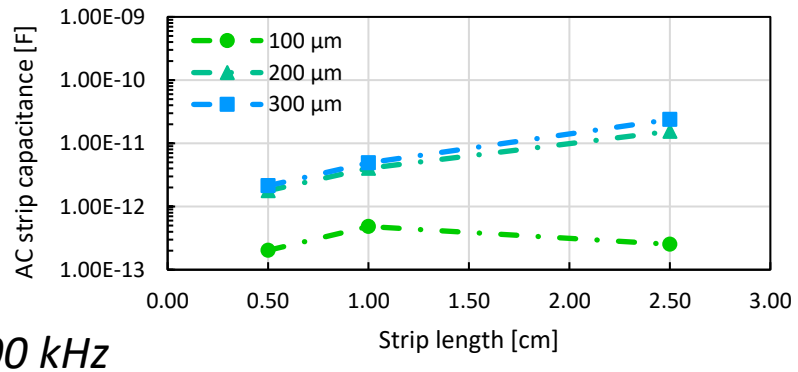




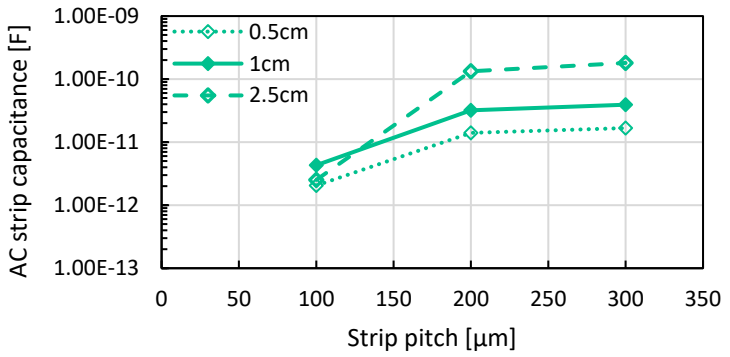
BNL new(est) production: strip length and pitch

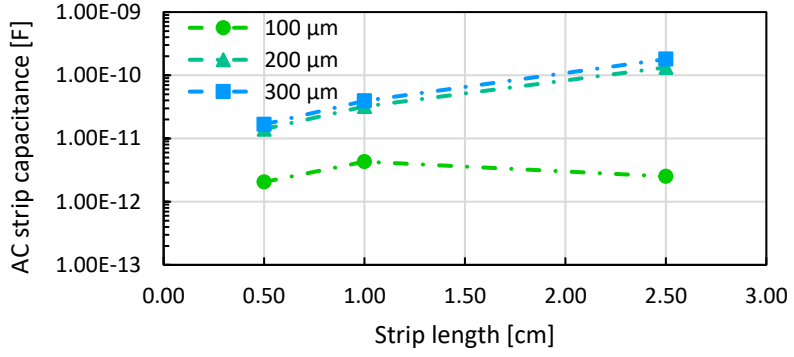
- Strip pitch could also be swapped to strip width



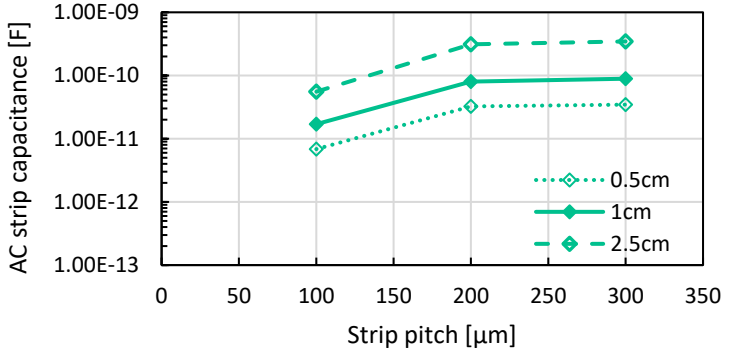


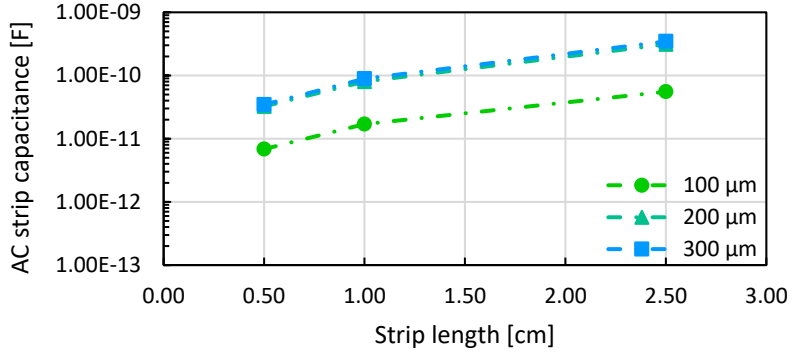
100 kHz





400 kHz

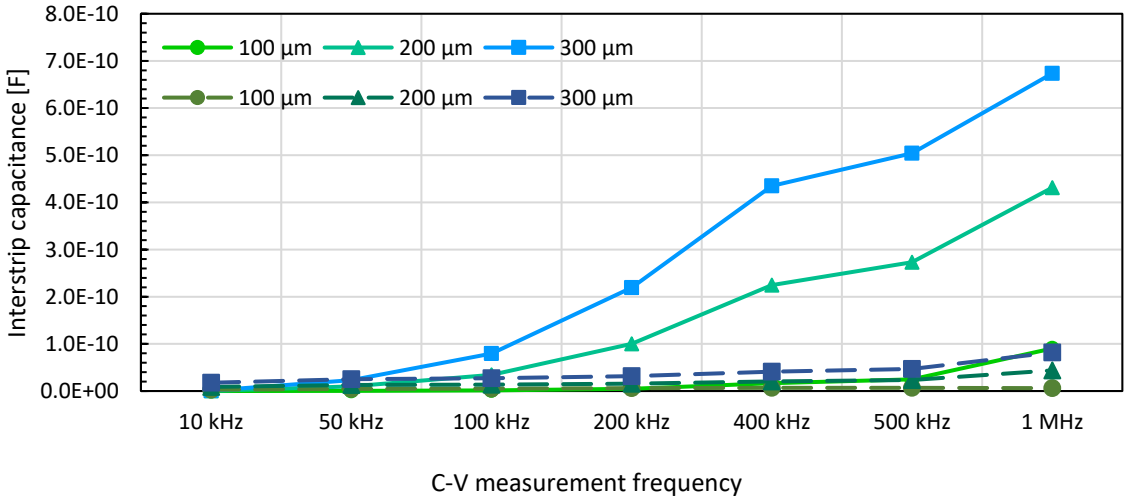




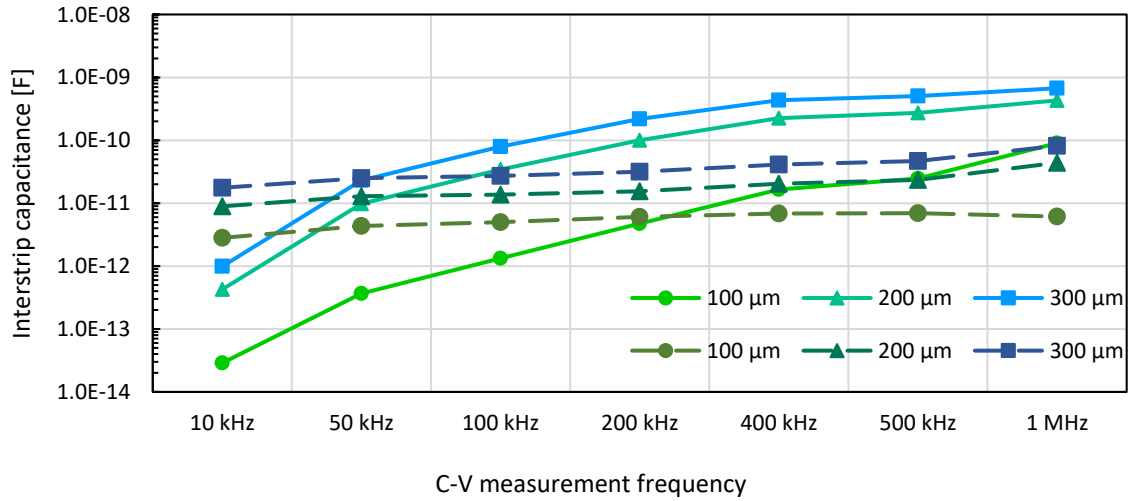
1 MHz

BNL multipitch interstrip capacitance

- Less frequency dependency in older production with identical metal geometry
  - Impact of production
  - Gain layer
  - n^+ doping
  - Bulk



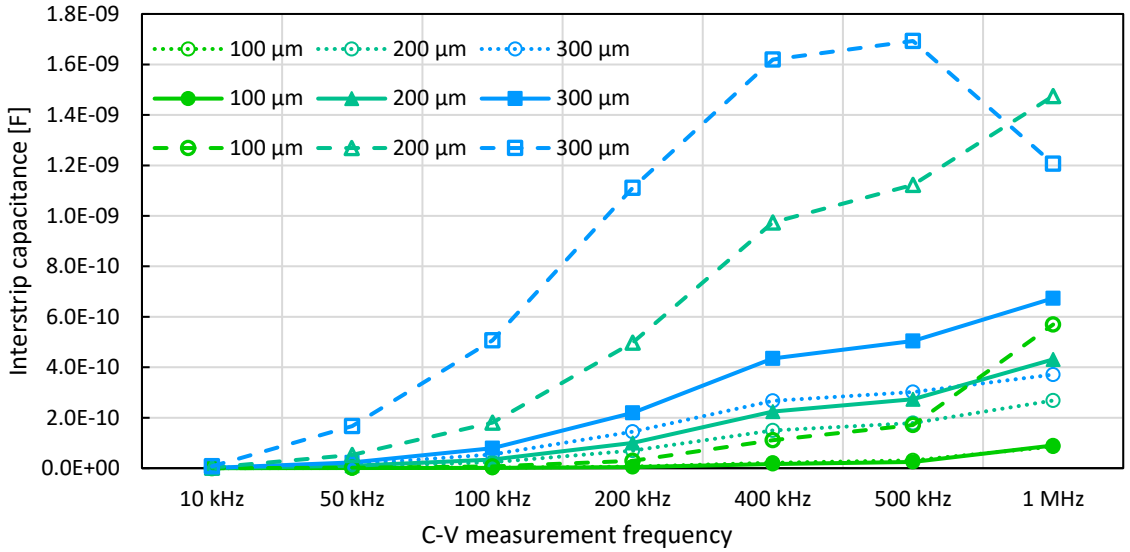
Light colors: W3072 (newest), dark colors: W1 (2021 or early 2022)

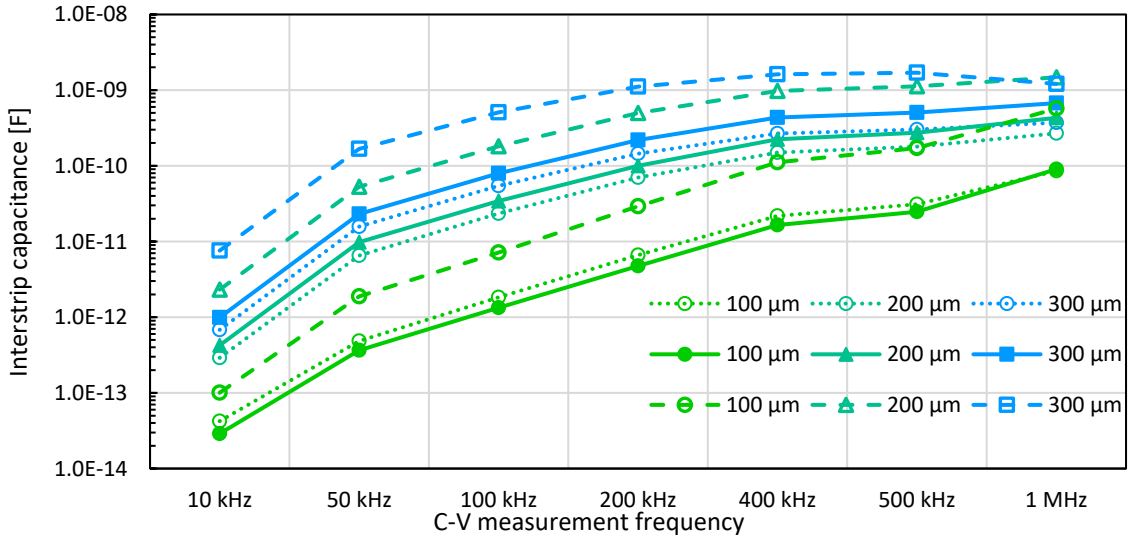


BNL new(est) production: strip length

Dotted line: 0.5 cm
Solid line: 1 cm
Dashed line: 2.5 cm

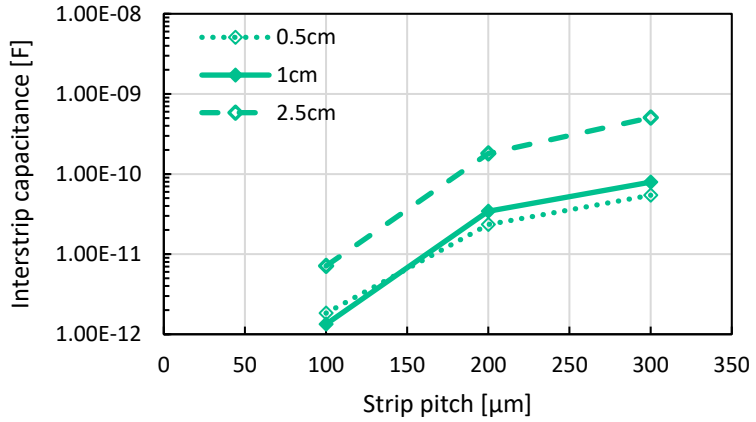
- Higher interpad capacitance for:
  - Larger pitch = wider metal
  - Longer strips

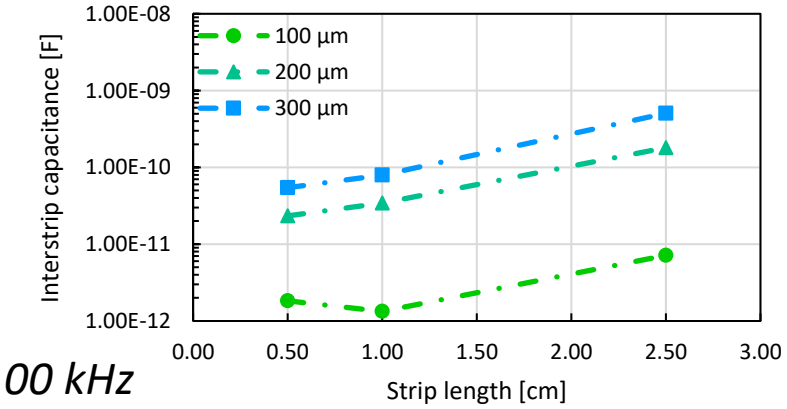




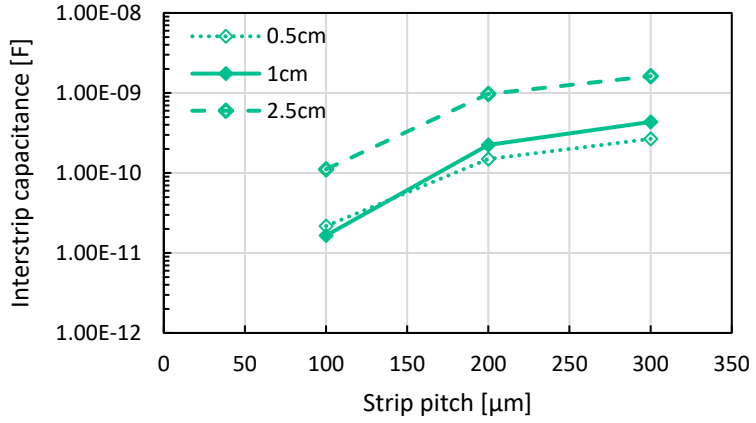
BNL new(est) production: strip length and pitch

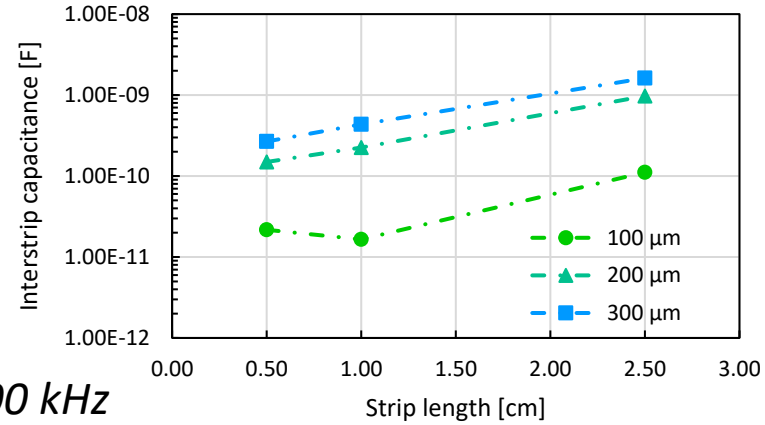
- Strip pitch could also be swapped to strip width



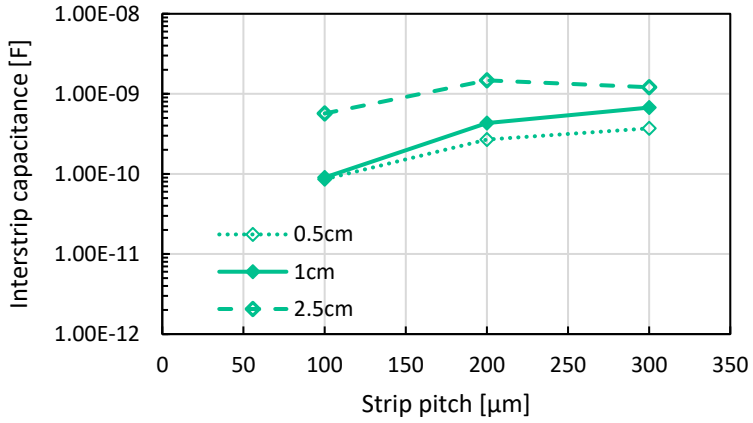


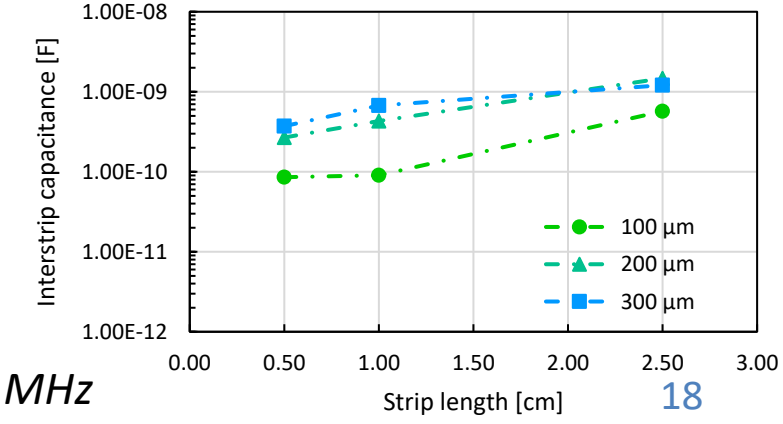
100 kHz





400 kHz

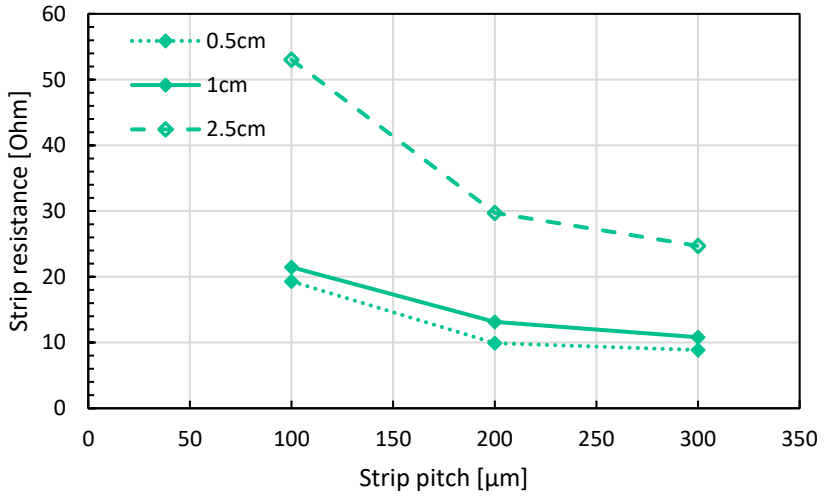


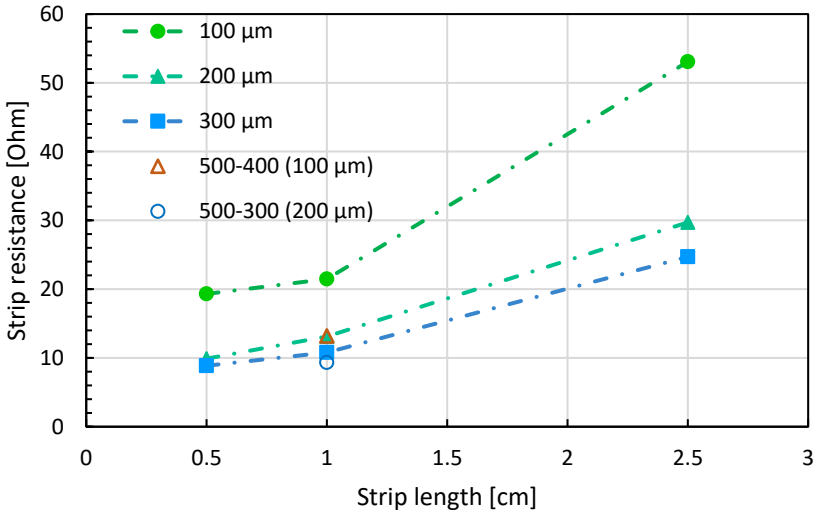


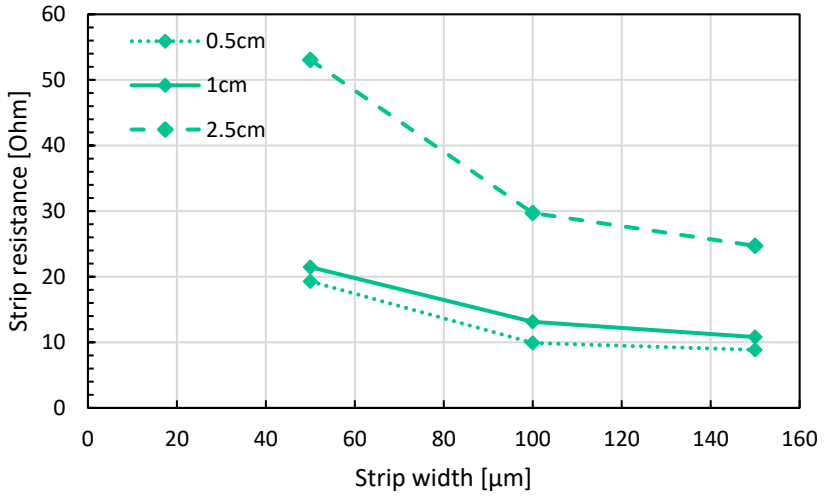
1 MHz

BNL new(est) production: strip resistance

- Higher resistance for:
  - Narrower strip
  - Longer strip
- Not linearly proportional

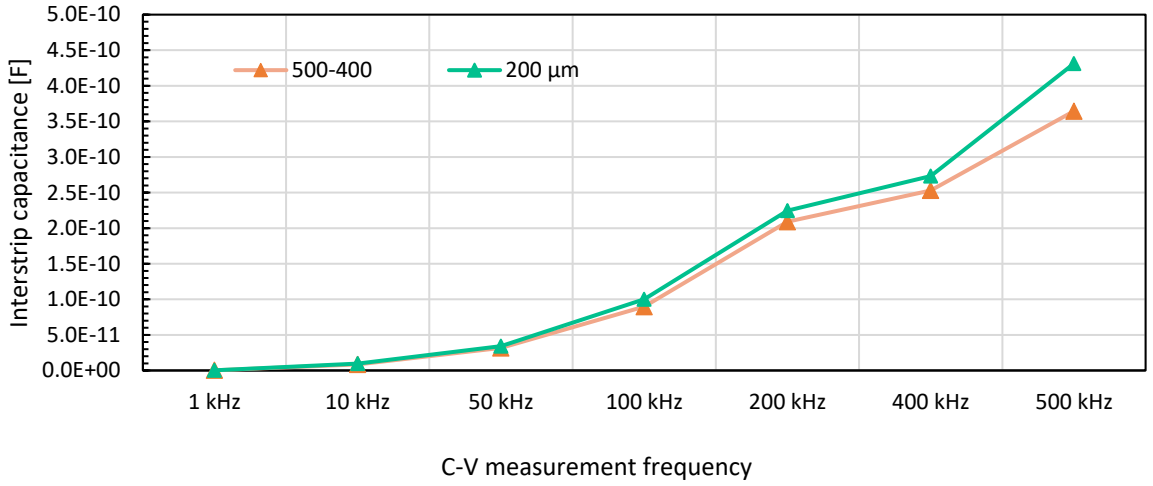




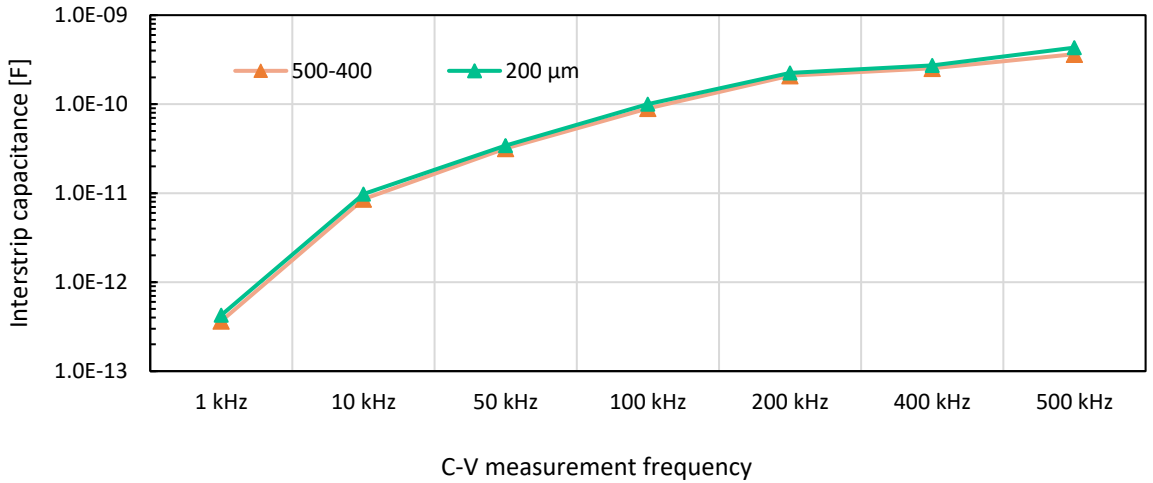


BNL new(est) production: strip pitch and gap

- 100 µm strip metal width, but 500 vs 200 µm pitch and 400 vs 100 µm gap
- Smaller interstrip capacitance for wider pitch and gap, but effect small compared to strip length and width
- Supports theory that interstrip capacitance is governed by the strip area and the sensor (bulk, backplane, and/or n^+), not the physical distance between strips



1 cm length, 100 µm strip metal width



Newer BNL strips

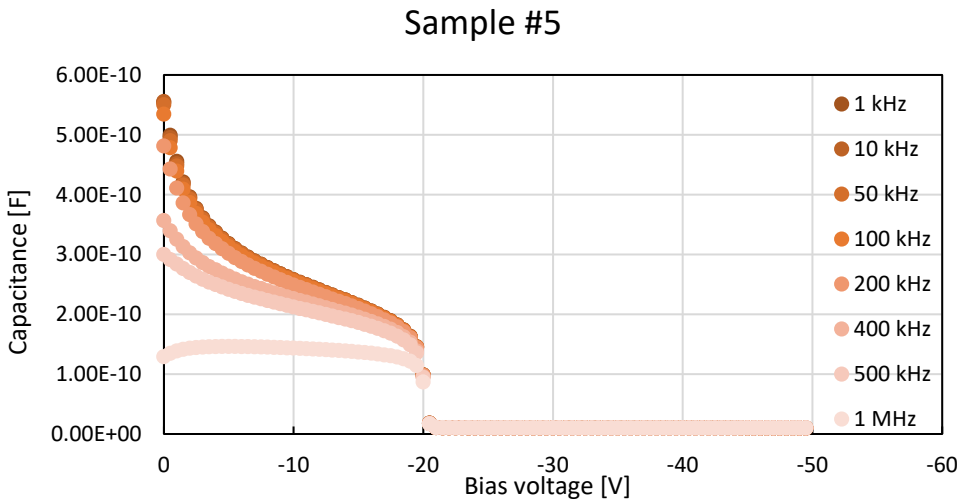
- Multipitch sensors, IV
  - Relatively low breakdown voltage for some samples; lower leakage current levels than W1, but lower breakdown voltage
  - Higher current for larger sensors
- 500 µm strips, 300 / 400 µm gaps
  - AC capacitance is lower for 100 µm metal: expected

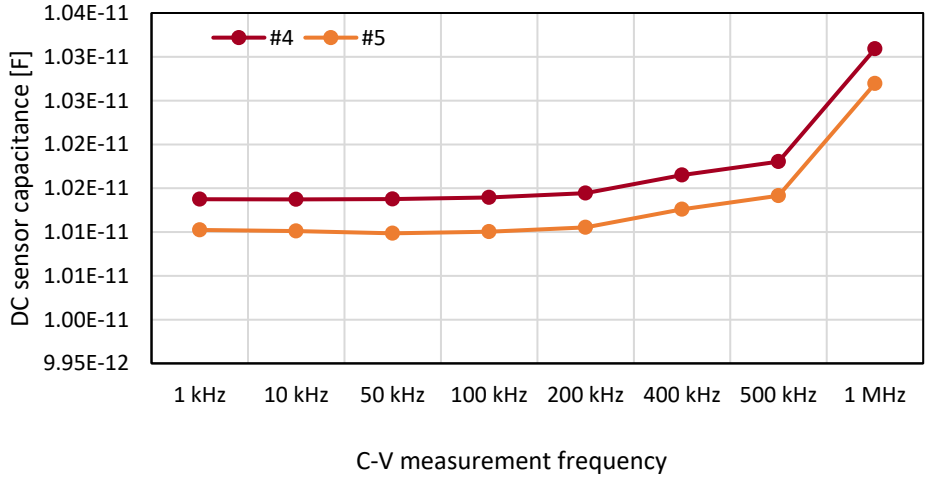
- **Interstrip capacitances are higher than AC strip capacitances; depend on strip length and pitch/width**
- **Strong dependency of AC and interstrip capacitance on frequency even after full depletion – unusual compared sensors from other vendors!** Not in line with physical mobility of charge carriers in bulk, which is observed more regularly in the DC configuration
- **Impact of pitch and distance on interpad capacitance actually appears to be quite small – strip width and length more important**

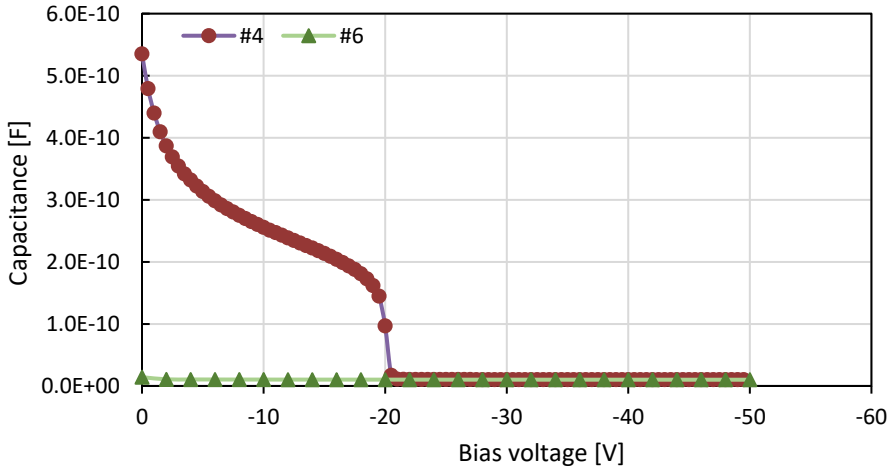
- W.I.P. on more variations with even narrower strips, and also bulk thickness (20 vs 50 µm)

20 µm DC-LGADs

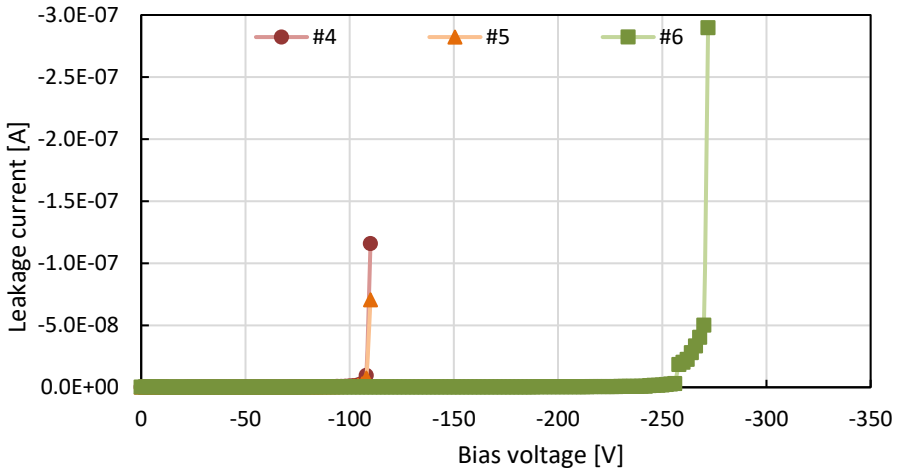
- Final capacitance for 1 mm pad: ca. 10 pF, compared to 4 pF for 50 µm







#6 is a PiN :)



20 µm and 50 µm AC-LGADs

- Strips with 500 µm width and 100 / 50 (?) µm metal width (500-400, 500-450)
- On 20 µm and 50 µm wafers
- *C-V measurements to come…*