# Studies of uniformity of 50 µm low-gain avalanche detectors at the Fermilab test beam

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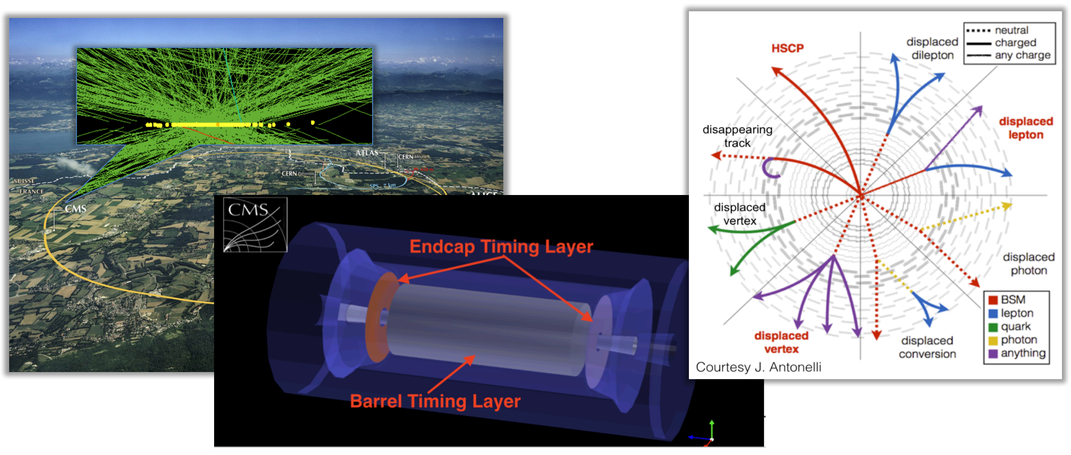
## High Luminosity LHC & Future Colliders

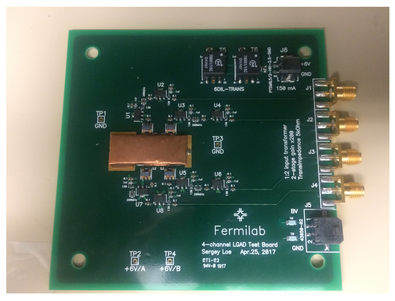
- ***Precision timing is the "Last Great Frontier"* in reconstruction**
  - Pileup reduction: ~200 at HL-LHC, and up to 2,000 at FCC
  - Long-lived particles, displaced vertices, GMSB, many others

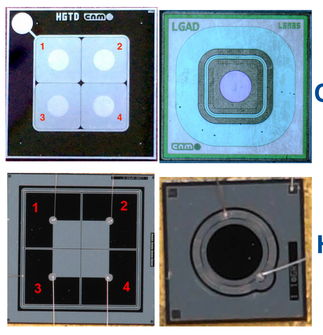



## Timing detector for High Luminosity LHC

- Equip upgraded CMS detector with precision timing MIP detector
  - LGADs in the endcap region: radiation hard, with small pixels
- Key challenges in sensor R&D:
  - Radiation tolerance up to $2\times10^{15}$ $n_{eq}/cm^2$
  - Large area sensors to reduce module multiplicity
  - Maintain uniform gain across irradiated, large sensors
  - Large fill-factor: greater than 95%

**Fast readout board for 4-channel LGAD sensors**

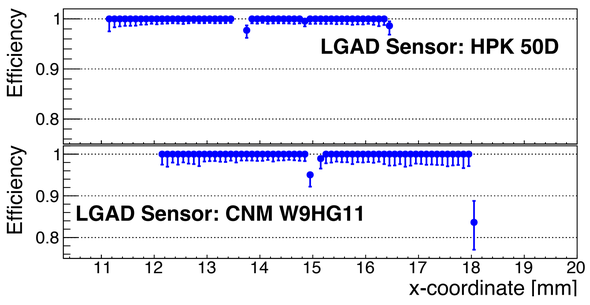




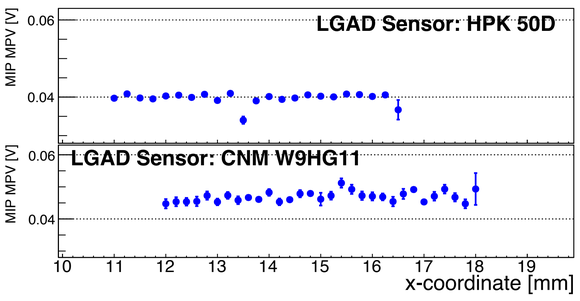
**CNM sensors**

**HPK sensors**

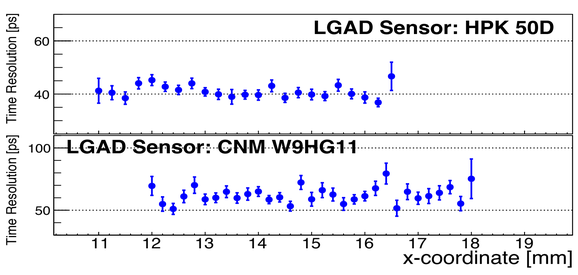
## Sensor uniformity and time resolution



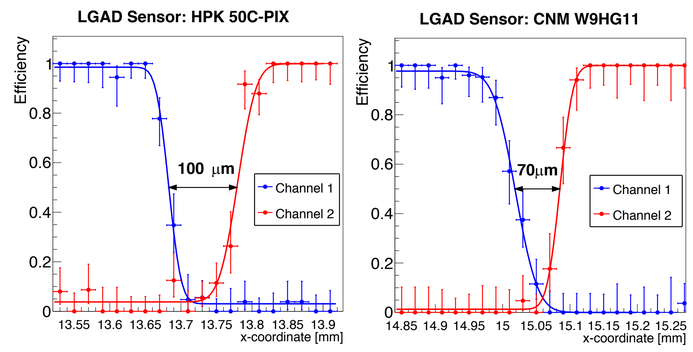

- Signals digitized with CAEN V1742 VME board.
- 100% detection efficiency across the sensor area



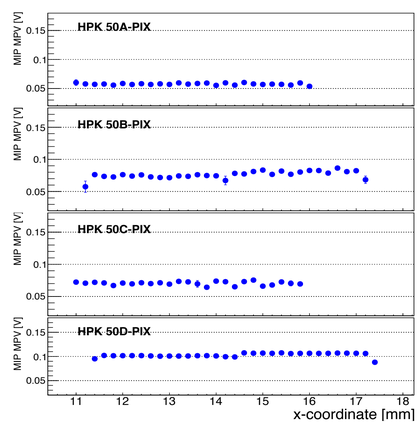

- CNM and HPK sensors show excellent uniformity of signal size over the sensor area.



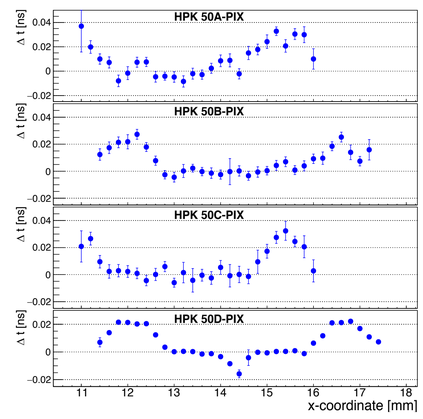

- Time resolution measured with respect to a fast Photek 240 MCP-PMT.
- Uniform time resolution at about 40 ps for the HPK50D, and 60 ps for the CNM.



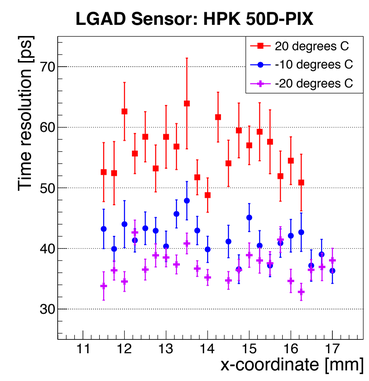

- No-response gap of 110 µm on HPK, and 70 µm on CNM sensors.
- Measured fill factor ~85%
- Ongoing work to achieve fill factor > 95%



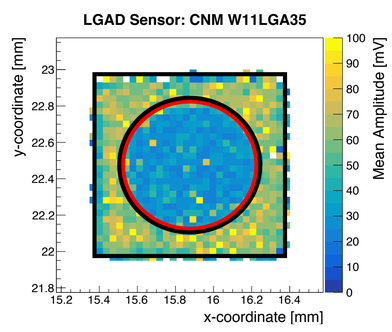

- Four HPK doping profiles studied.
- Δt distribution shows offset of ~20 ps between metallized vs non-metallized areas.
- Work to improve in future iterations.



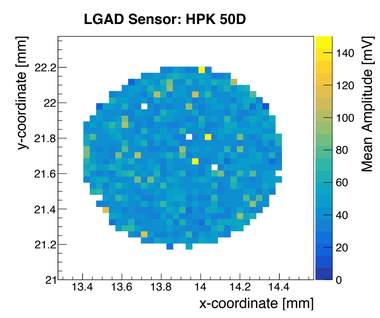

- Uniformity doesn't depend on temperature
- Improved time resolution at lower temperatures.
- Achieved time resolution of about 35 ps achieved for 9 $mm^2$ sensors.

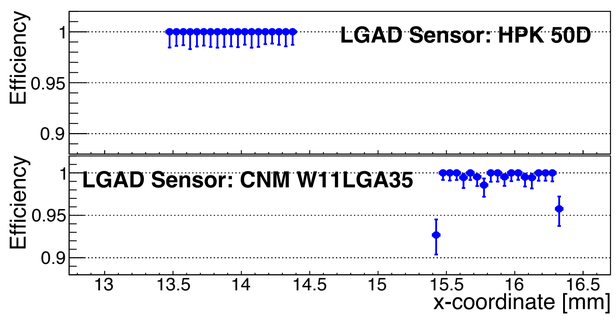


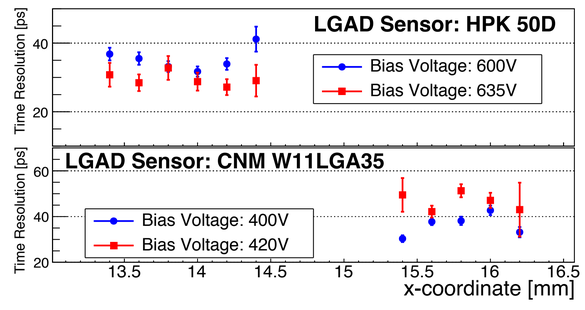

## Tests of irradiated sensors




- Irradiated CNM sensor shows distinct regions with different gains.
- Irradiated HPK sensor has a uniform gain.




**Excellent uniformity of signal across the irradiated HPK sensor area, better than 40 ps time resolution**

## Summary

- The signal size uniformity of measured LGAD sensors before irradiation has a spread of ~2%.
- Efficiency of 100% over the whole surface, and timing resolution of 30-40 ps for pixels with 3x3 $mm^2$ size.
- The "no-response" region between pixels was measured to be about 70 µm for CNM sensors and 110 µm for HPK.
- CNM sensor exhibits a large gain variation over its surface area after a neutron fluence of $6\times10^{14}$ $n_{eq}/cm^2$
- Irradiated CNM and HPK sensors achieve < 40 ps time resolution

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