A High Voltage Monolithic Active Pixel Sensor Prototype for the ATLAS Inner Tracker Upgrade

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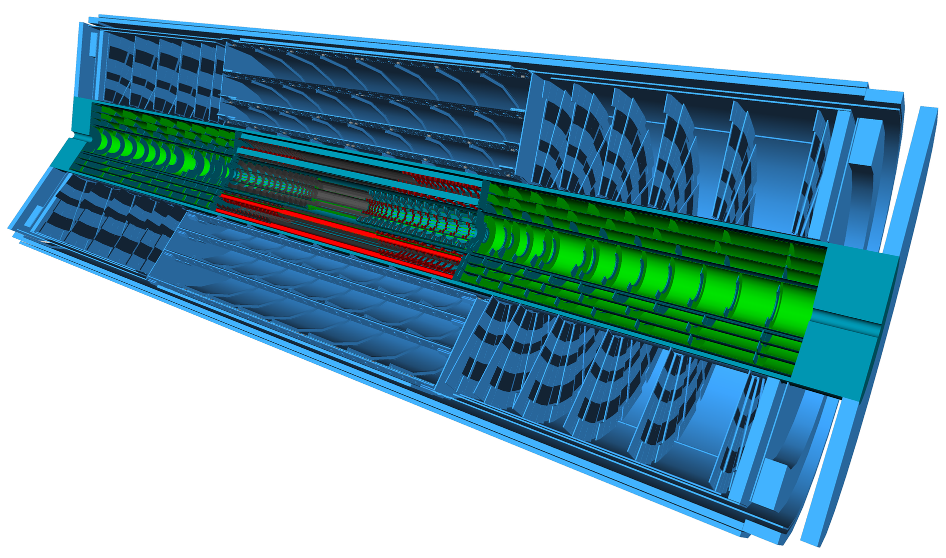
The High-Luminosity LHC

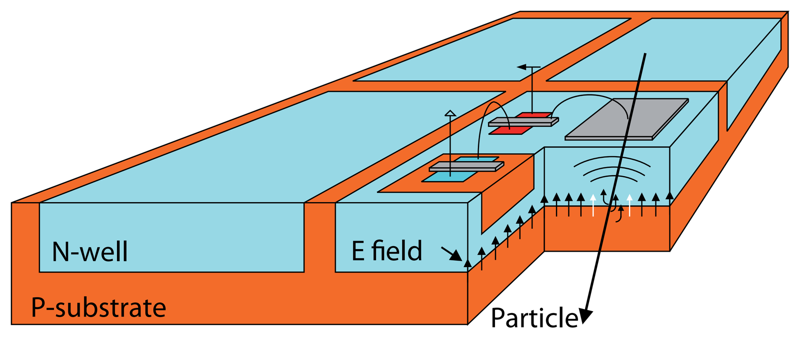
- increase of instantaneous luminosity of LHC to five times the design value to improve discovery potential (installation starts 2024)
- imposes today's most demanding requirements on the detector technologies to be used

The ATLAS Inner Tracker upgrade

- for HL-LHC inner detector of ATLAS experiment will be fully replaced by all silicon Inner Tracker (ITk) (pixels & strips)
- baseline design for pixel detector foresees five all hybrid pixel layers [1]
- ITk will have to deal with higher data rates and radiation damage (compared to current detector) and pileup of ~ 200



HV-MAPS

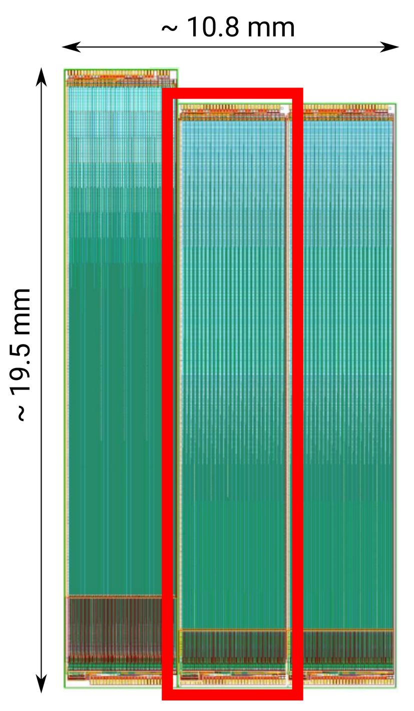


[2]

- can be produced using commercially available HV-CMOS processes
- combine detection volume and full read-out in single chip
- reverse bias of sensor diode with high voltage (ca. 100 V):
  - fast charge collection
  - good intrinsic radiation tolerance

ATLASPix1

- first in series of prototypes to demonstrate suitability of HV-MAPS as an alternative technology for ITk
- specified according to requirements for outermost pixel layer ($r \approx 28$ cm)



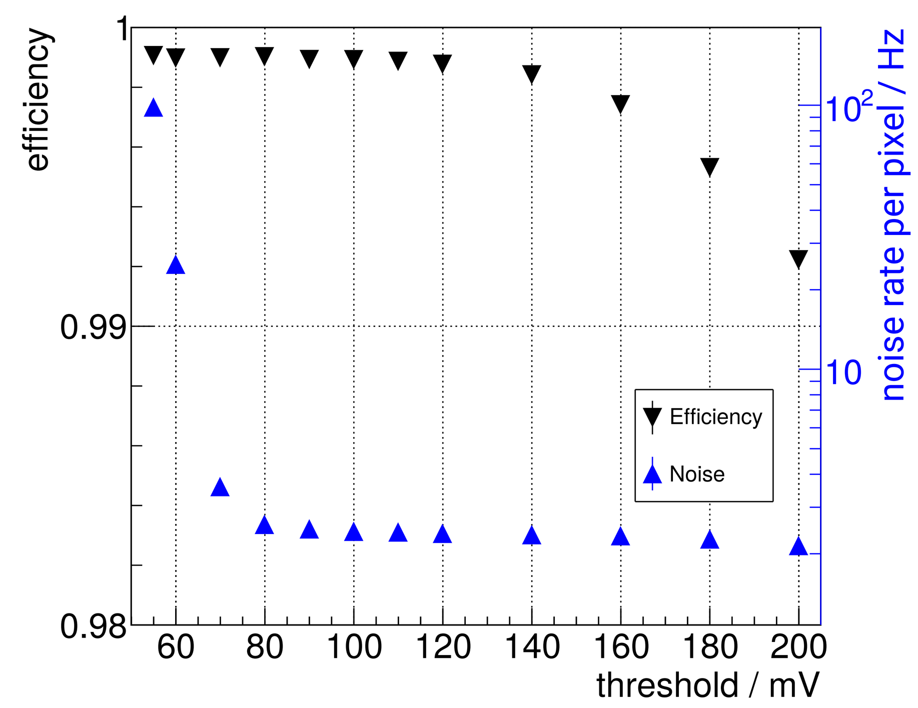
- 25 x 400 pixels
- with size 130 x 40 μm^2
- in-pixel amplifier & comparator
- 10 bit timestamp
- 6 bit ToT
- column drain readout
- 1.6 Gbit/s serial data link
- 200 Ωcm substrate

(reticle comprises three separate sensors, specifications and test results refer only to part marked with red square)

Test results

Efficiency

Efficiency and noise vs threshold for HV = - 80 V:

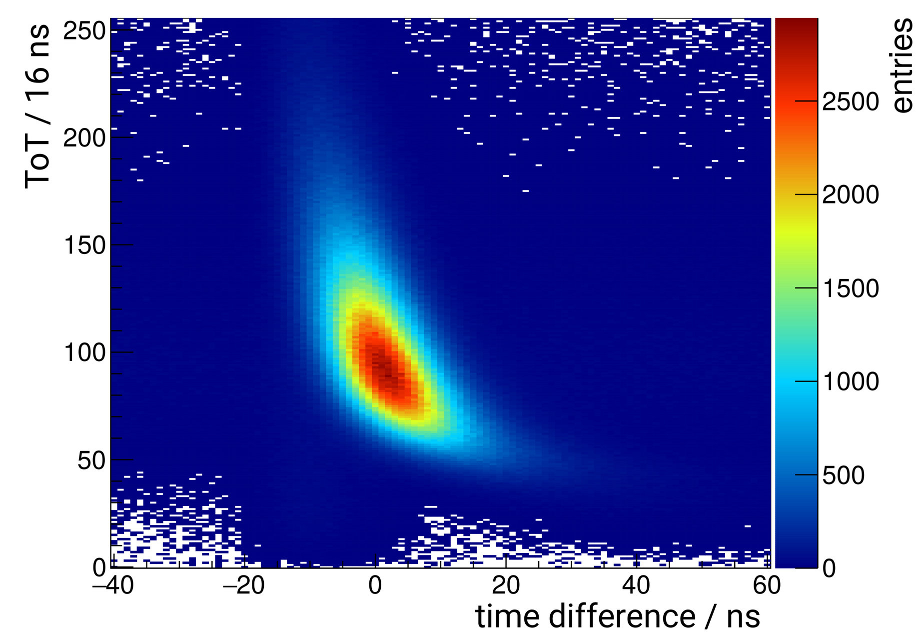


(Threshold of 100 mV $\triangleq$ ca. 1600 e^-)

- efficiency of 99.9 % was measured at noise rate of 2 Hz per pixel

Timewalk

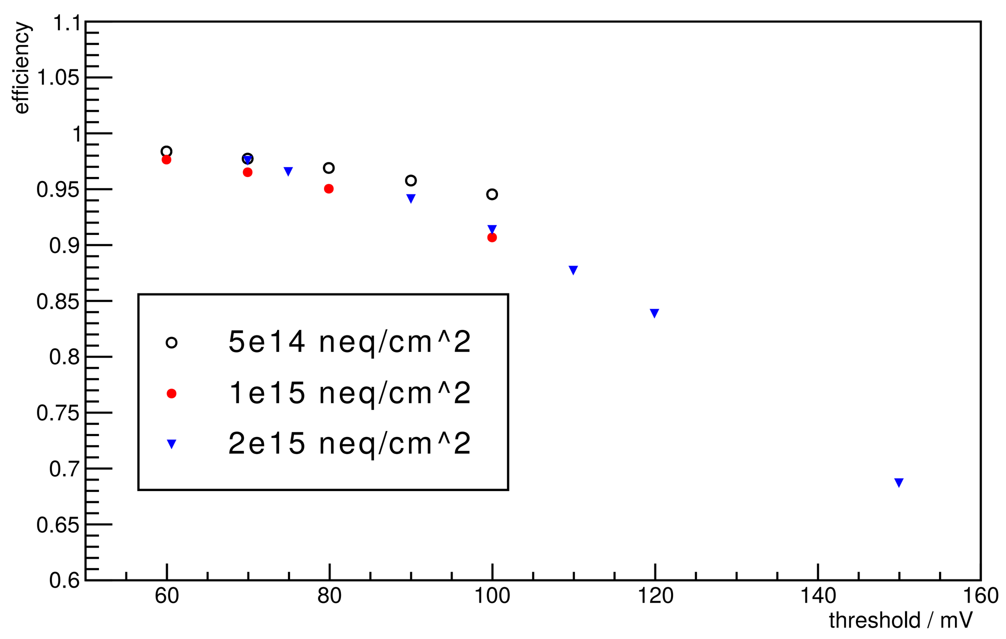
Correlation of time difference (timestamp - reference time) and time over threshold (ToT):



- measured here at large threshold to enhance the effect for illustration
- ToT can be used to correct time resolution offline for timewalk

Radiation hardness

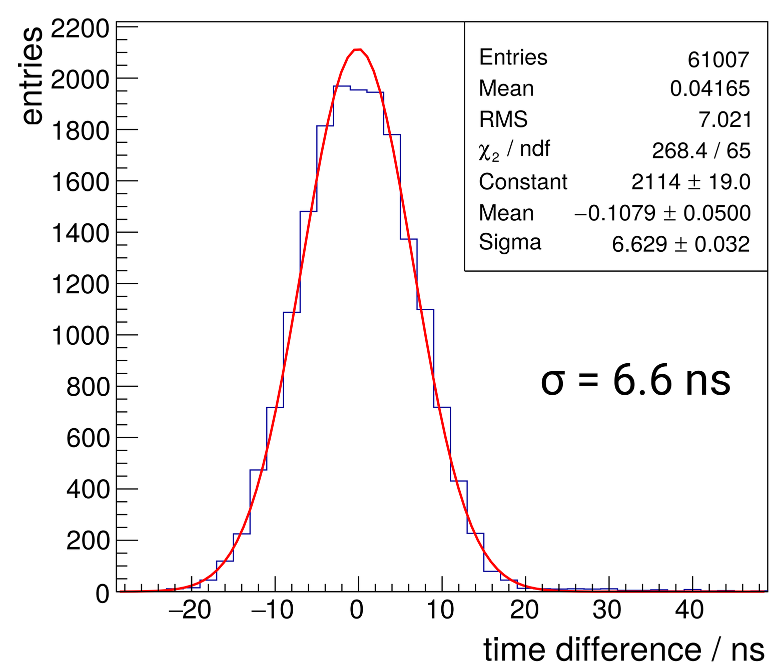
Efficiency vs threshold (HV = - 60 V) after irradiation with different neutron fluences:



- sensor temperature was ca. 5 °C
- no threshold tuning for individual pixels applied
- after irradiation with neutron fluence of 1e15 neq/cm^2: efficiency = 99.5 % (at 40 Hz noise per pixel, HV = - 80 V)

Time resolution

Gaussian fit to the distribution of the time difference (HV = - 60 V, threshold = 50 mV):



- earliest timestamp of clusters matched to reference track
- $\sigma = 6.6$ ns
- result includes timestamp binning contribution of $16\,\mathrm{ns}/\sqrt{12}$

Conclusion

- efficiency unirradiated: 99.9 %
- efficiency after irradiation with neutron fluence of 1e15 neq/cm^2: 99.5 % at allowed noise level
- time resolution unirradiated: $\sigma = 6.6$ ns
- 97 % in-time efficiency could be achieved by doubling timestamp sampling frequency (taking result for unirradiated sensor)
- ATLASPix3 submitted in March 2019, features module ready design

References

[1] ATLAS Collaboration. *Technical Design Report for the ATLAS Inner Tracker Pixel Detector*, CERN-LHCC-2017-021, ATLAS-TDR-030, **2017**.

[2] I. Perić. *A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology*, Nucl. Instrum. Methods Phys. Res. A, 582, 3, 876-885, **2007**.