

Performance Studies of an HV-MAPS for the LHCb Mighty Tracker

BTTB 13 Valencia

23.05.2025

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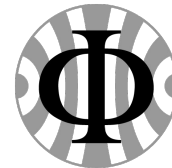
H. Augustin, S. Bachmann, L. Dittmann, D. M. Immig



FSP LHCb
Erforschung von
Universum und Materie



UNIVERSITÄT
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SEIT 1386

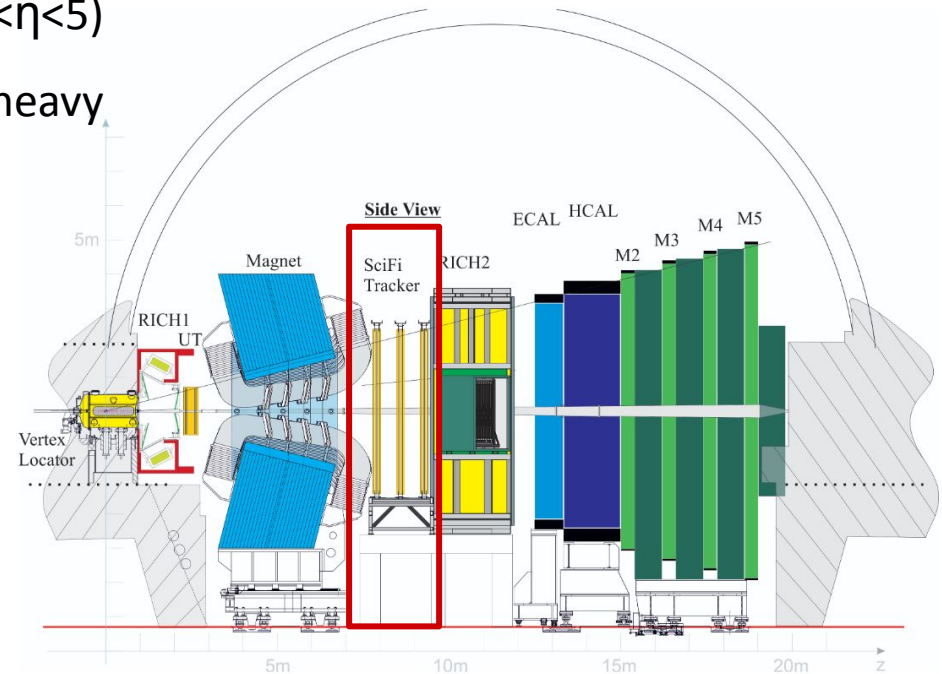


Bundesministerium
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und Forschung

LHCb Experiment

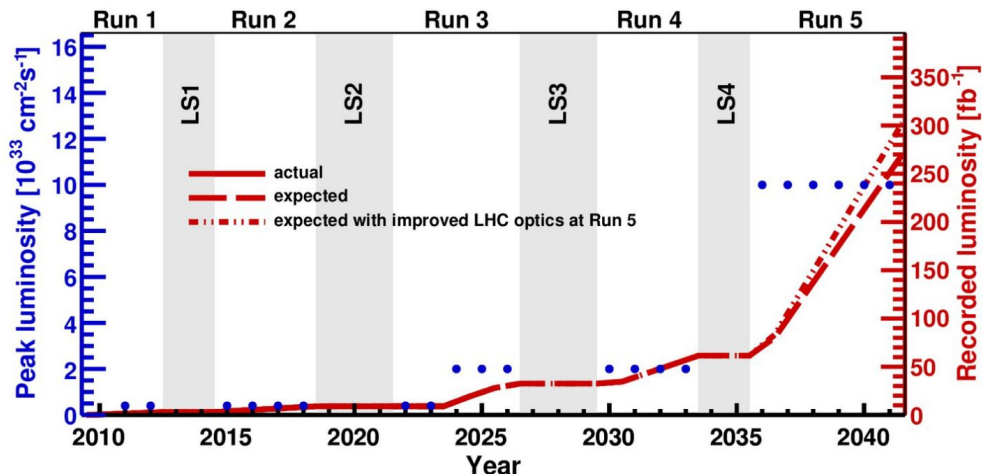
- One of the four large experiment at LHC
- Single-arm forward spectrometer ($2 < \eta < 5$)
- Specialised in CP-Violation and rare heavy flavor decays
- 40 MHz bunch crossing rate
- No hardware trigger!

LHCb Upgrade I

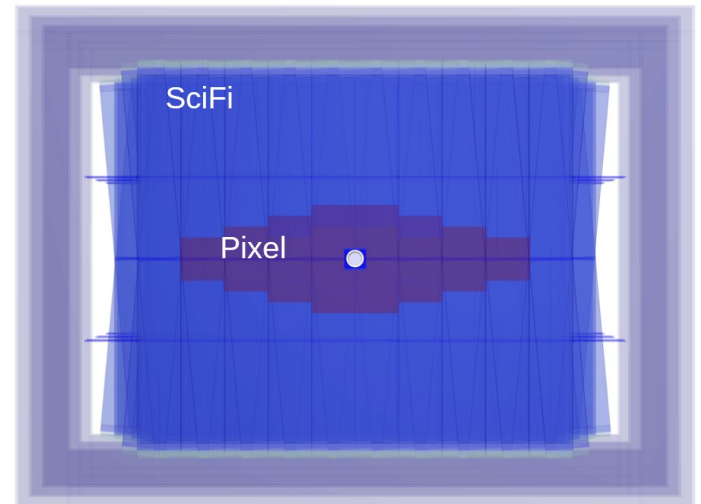


LHCb Upgrade II: Mighty Tracker

- Increased luminosity of $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ necessitates Upgrade II during LS4
 - Highly increased rates (factor 5-6) and radiation level
 - Central tracking region will be instrumented with HV-CMOS Pixel Sensors



T. Gershon [8th Workshop on LHCb Upgrade II](#)



Tai-Hua Lin

MightyPix Specifications

→ Radiation tolerance: $3e14 \text{ n}_{\text{eq}}/\text{cm}^2$, 40 MRad

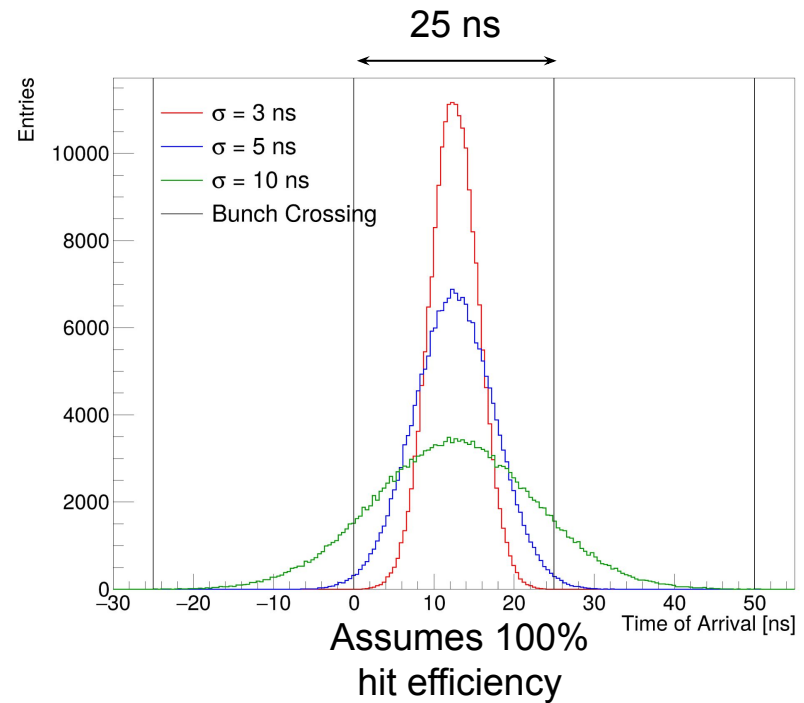
→ Power consumption $< 150 \text{ mW}/\text{cm}^2$

→ Hit rate capability: $34 \text{ MHz}/\text{cm}^2$

→ Noise Rate after irradiation $< 400 \text{ kHz}/\text{cm}^2$

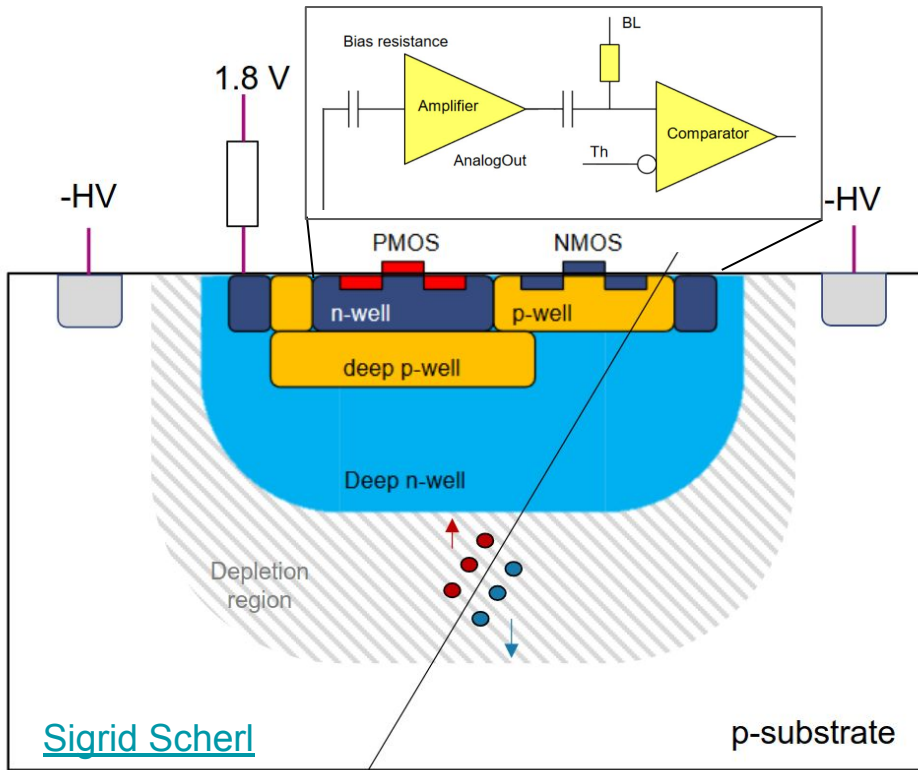
→ **Efficiency & Timing: In-Time efficiency $> 99\%$**

→ needed for correct 25 ns bunch crossing ID!



σ_t [ns]	In-Time efficiency
3	100 %
5	98.9 %
10	79.7 %

High Voltage - Monolithic Active Pixel Sensors (HV-MAPS)



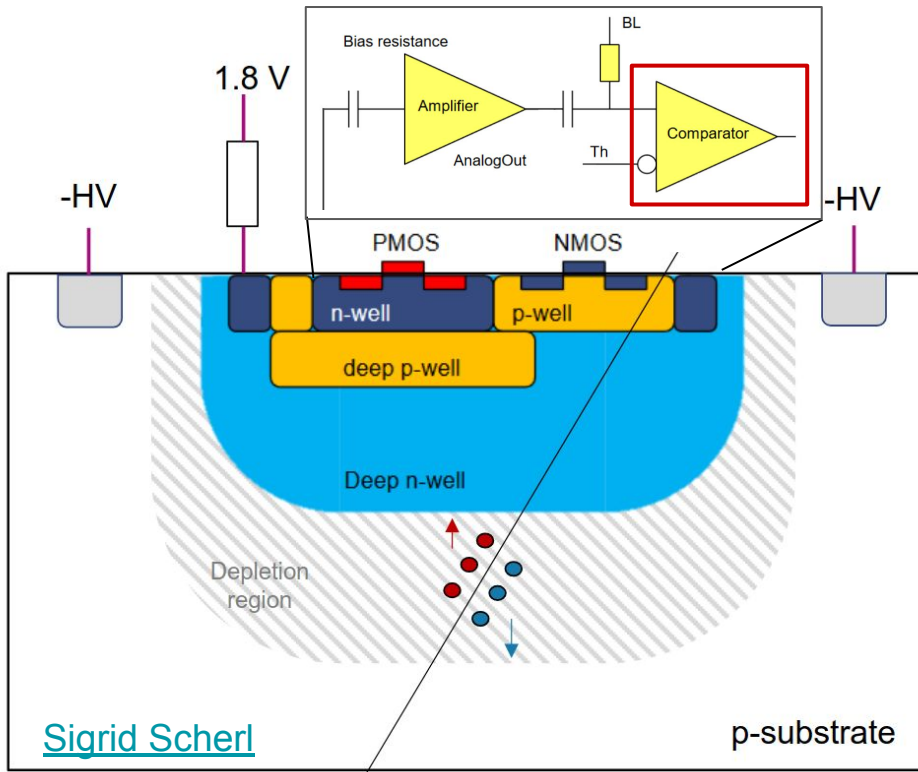
Characteristics:

- **Reverse-biased** diode realised as deep n-well in **p-substrate**

$$\text{Depletion depth} \propto \sqrt{\rho_{\text{substrate}} \cdot U_{\text{ext}}}$$

- Fast charge collection via drift in depleted volume
- Precise time resolution $O(\text{ns})$

High Voltage - Monolithic Active Pixel Sensors (HV-MAPS)



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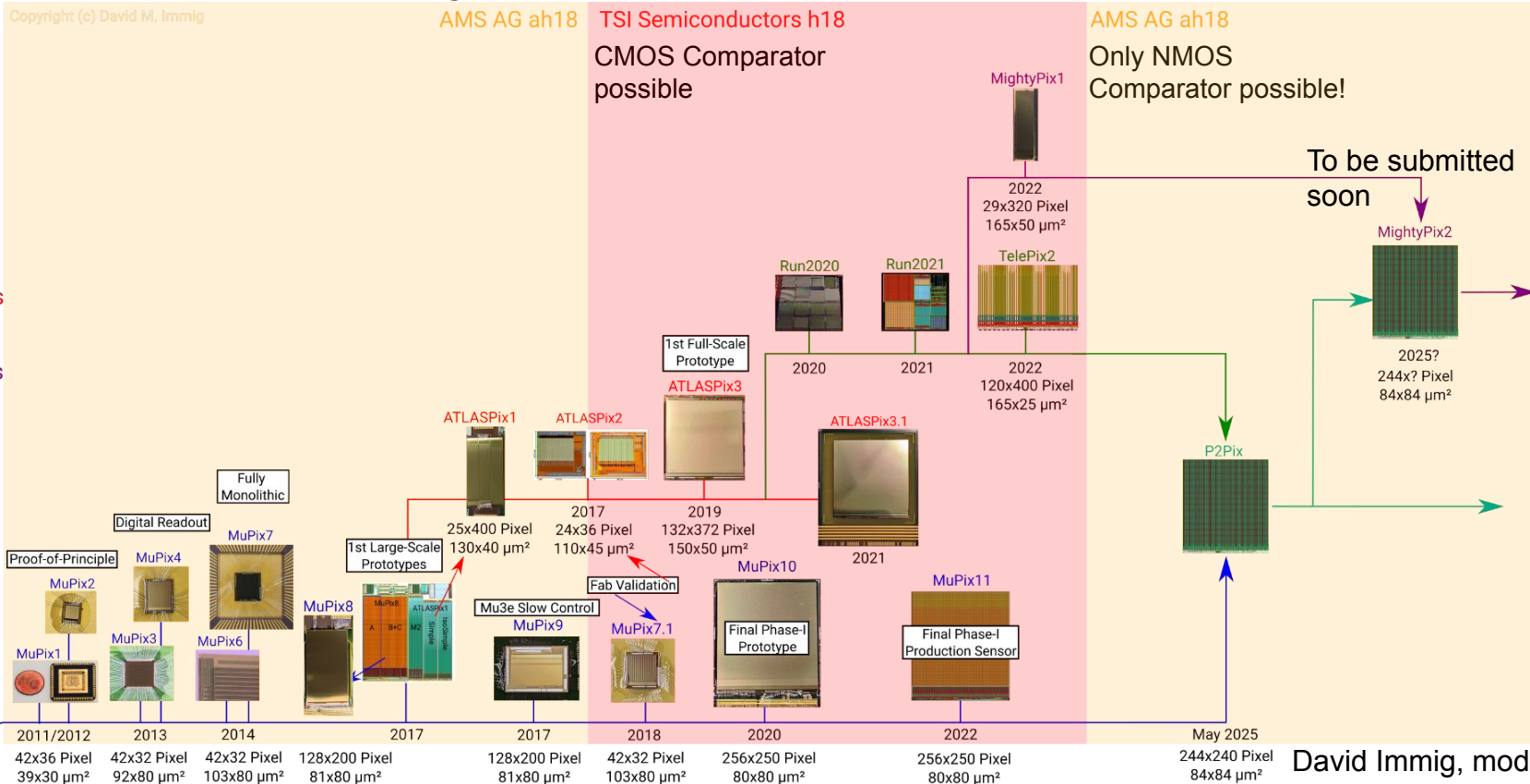
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HV-MAPS Development

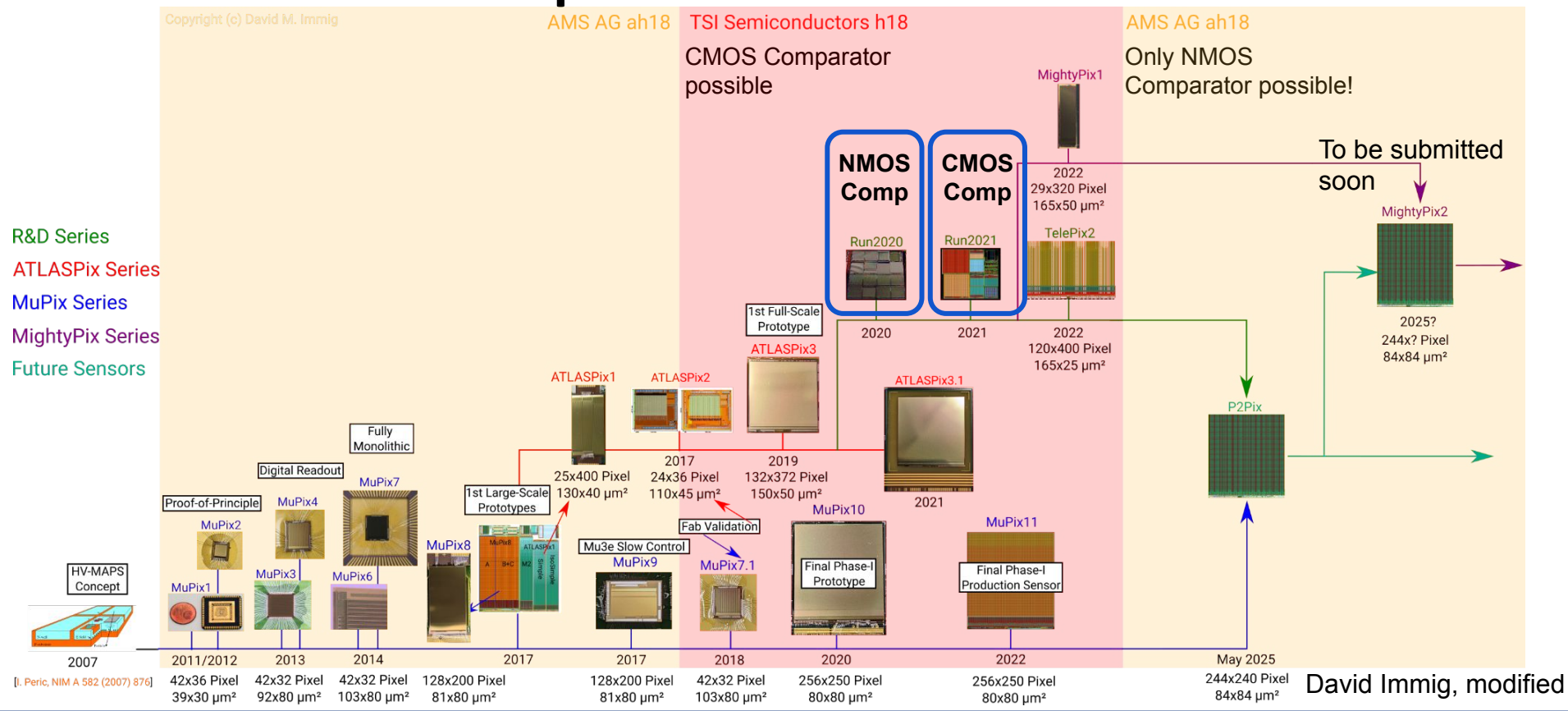
All sensors designed by I. Peric (KIT) et al.



David Immig, modified

HV-MAPS Development

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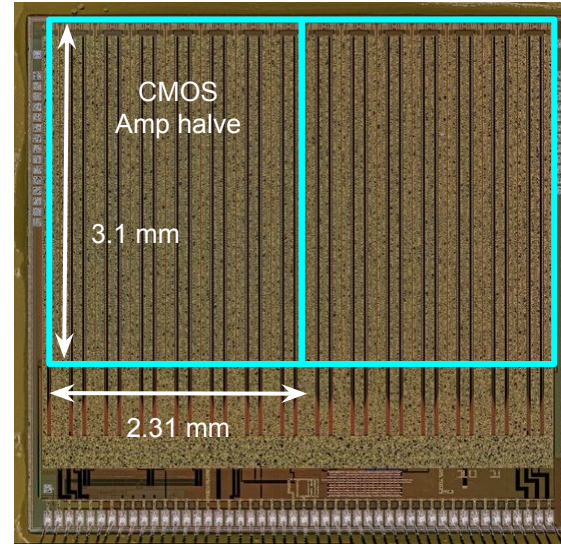


The Run2020 & Run2021 Sensors

See also:
[TelePix1 paper](#)

Run2020

- Chip size $5 \times 5 \text{ mm}^2$
- Pixel size $165 \times 25 \mu\text{m}^2$
- 4 ns time of arrival sampling
- CMOS Amp / NMOS comparator



The Run2020 & Run2021 Sensors

See also:
[TelePix1 paper](#)

Run2020

- Chip size 5x5 mm²
- Pixel size 165x25 μm²
- 4 ns time of arrival sampling
- **CMOS Amp / NMOS comparator**
- Old biasing scheme (~50 μm depleted)

Run2021

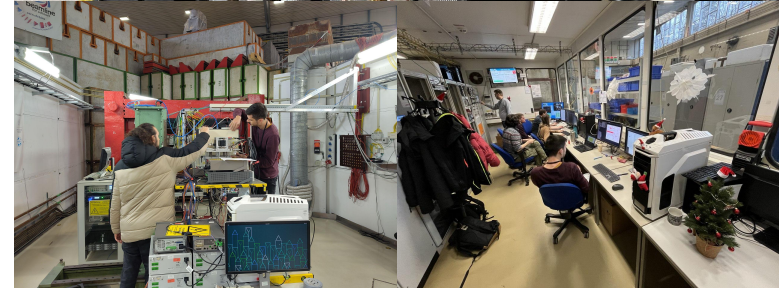
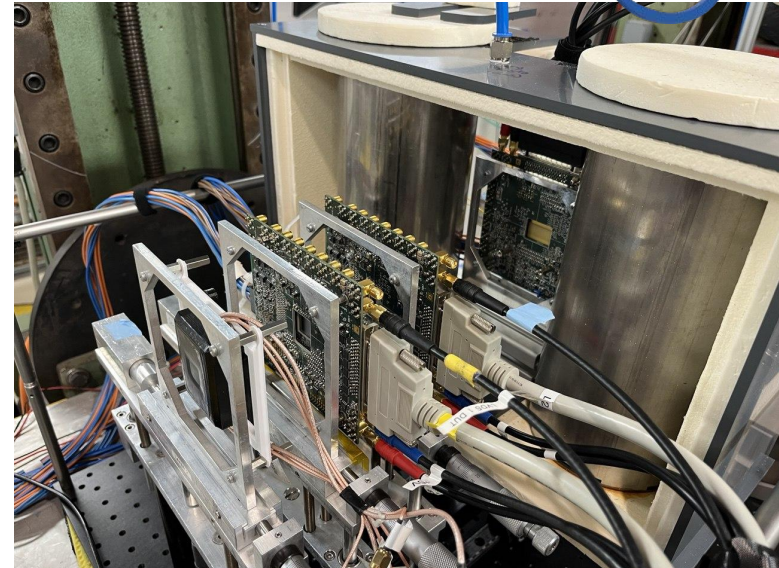
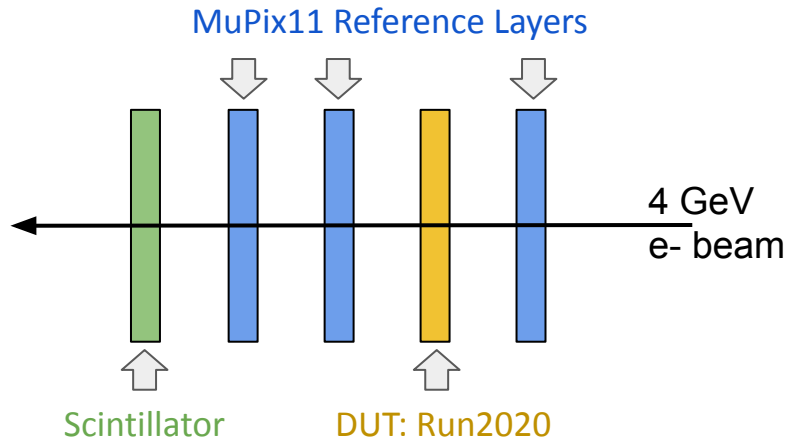
- Chip size 5x5 mm²
- Pixel size 165x25 μm²
- 4 ns time of arrival sampling
- **CMOS Amp / CMOS comparator**
- Larger biasing possible
- Different substrate, comparable resistivity

→ **These sensors allow a direct comparison between NMOS and CMOS comparator!**

Testbeam Setup



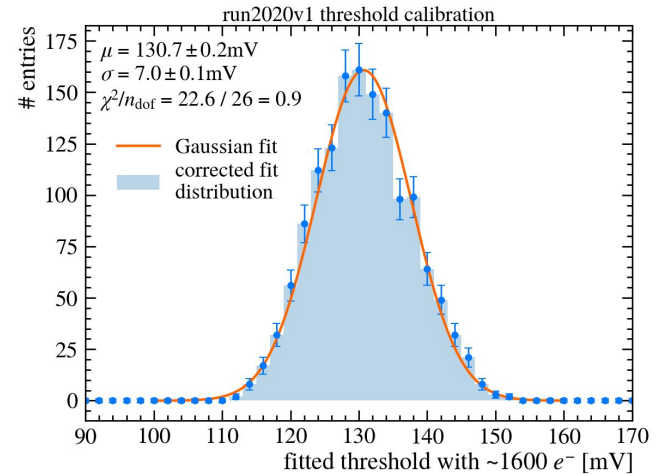
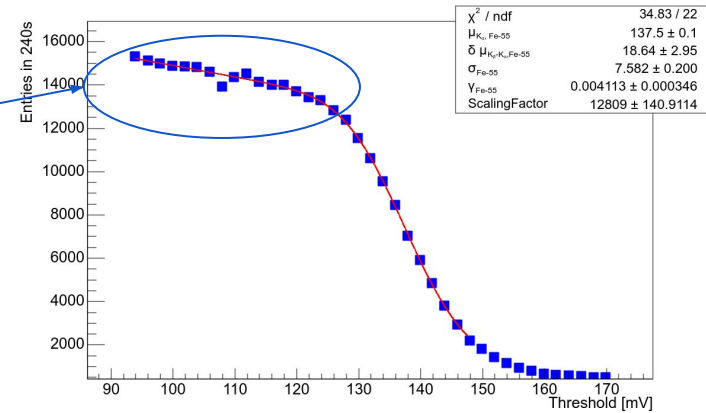
- Testbeam at DESY II: 4 GeV electron beam
- MuPix11 reference telescope + scintillator
- Analysis with Corryvreckan



Threshold Determination

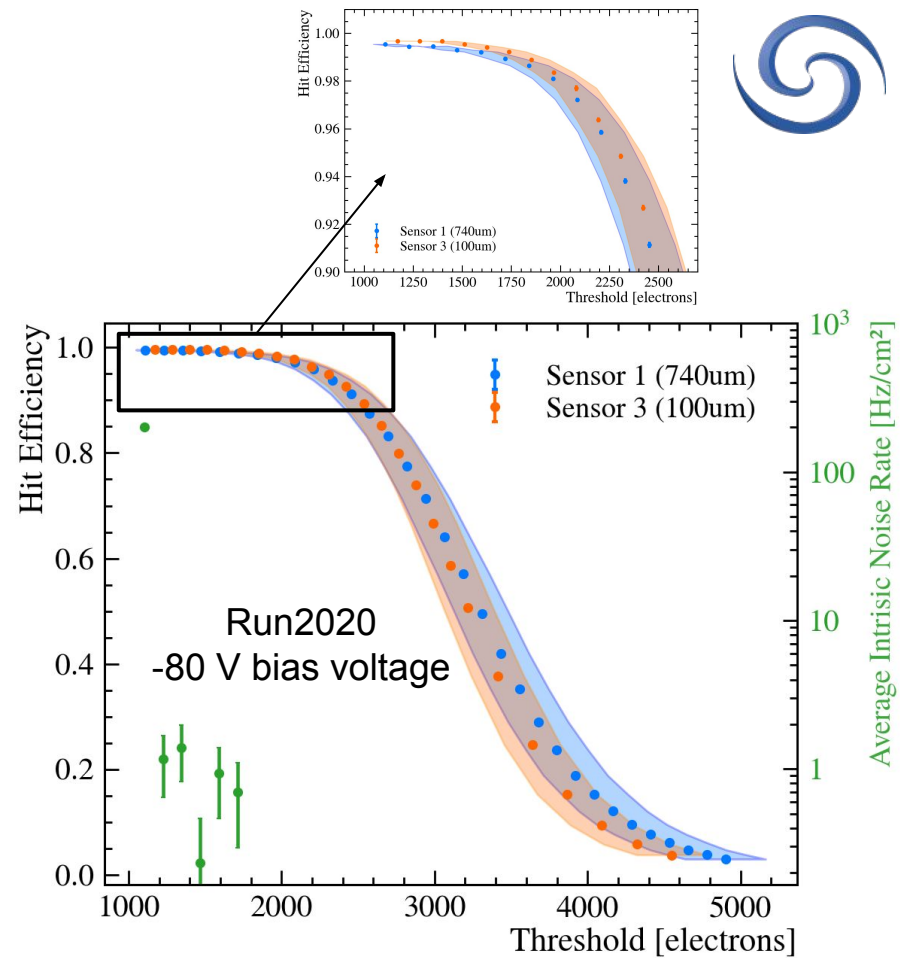
- Threshold in DAC units not comparable (smearing, pixel to pixel variations...)
- Fe-55 as a monochromatic signal
- S-curve yields threshold equivalent to $\sim 1600 e^-$
- Assume linear amplifier behavior

Charge sharing



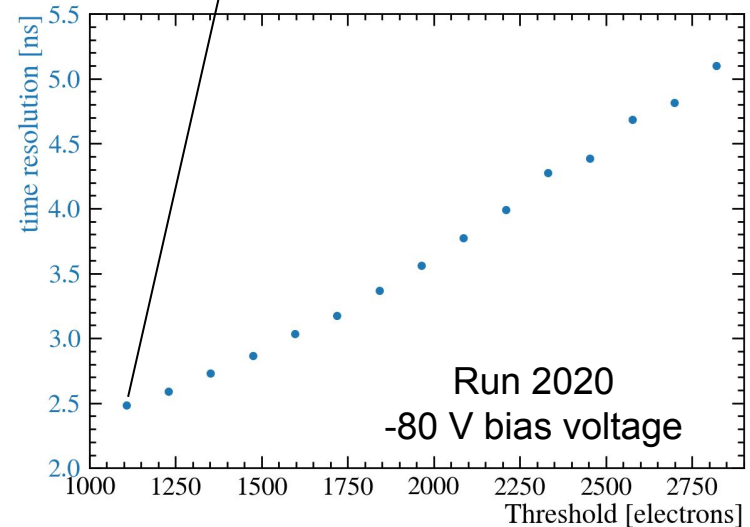
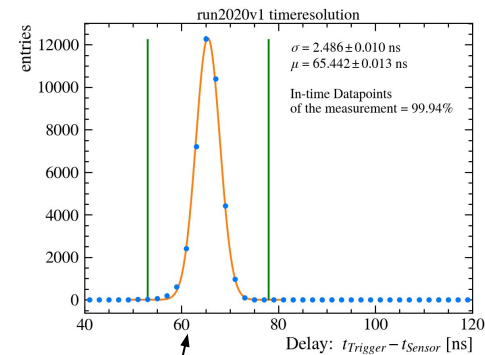
Testbeam Efficiency

- Efficiency plateau > 99%
→ Expected to be longer with larger bias
- Beam off noise measurement
- Comparable results



Testbeam Time Resolution

- System time resolution < 2.5 ns
→ Includes contribution by 4 ns binning and time reference
- With higher threshold time walk deteriorates time resolution

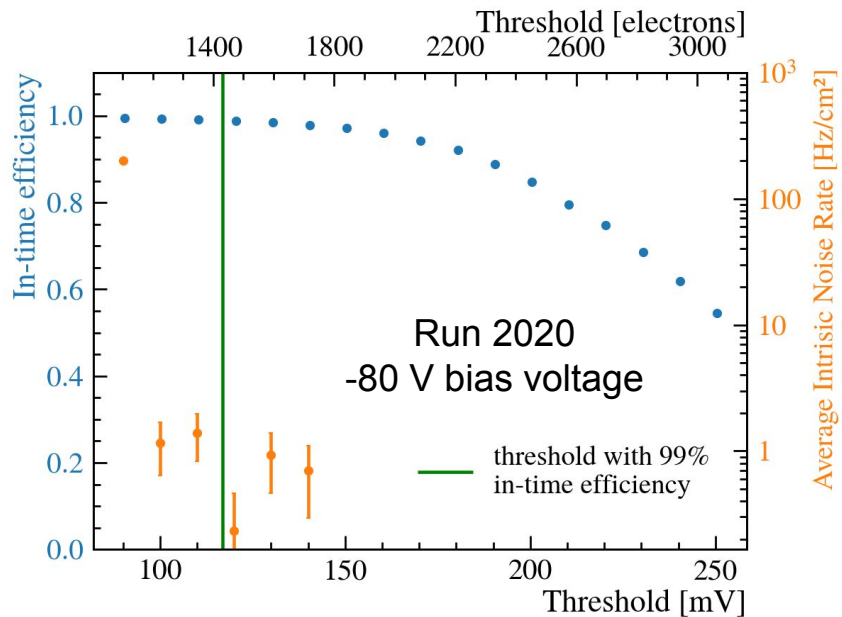




Testbeam In-Time Efficiency

- > 99% in-time efficiency for unirradiated sensor
 - Rather short plateau because of insufficient biasing
 - Will be improved with current biasing scheme!
 - See next talk by [Lucas Dittmann](#)

Specifications fulfilled!

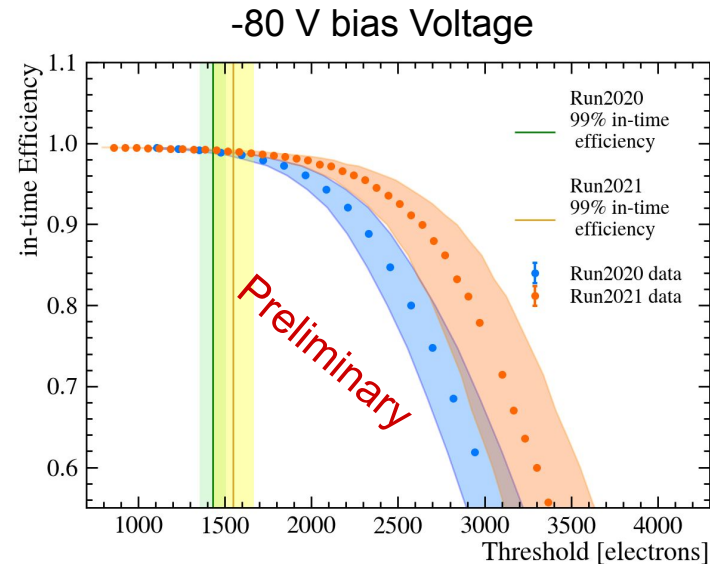
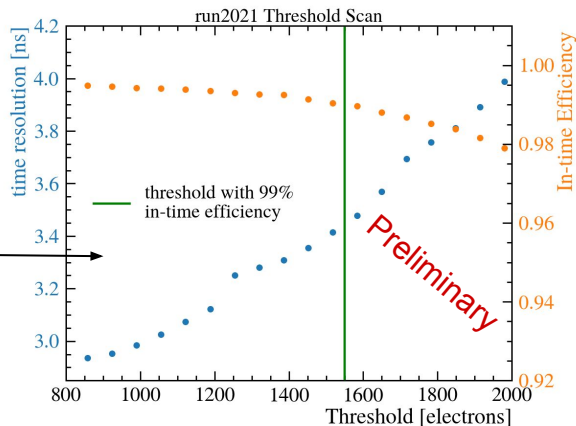




Run2020 & Run2021 Comparison

- Comparison between NMOS (Run2020) and CMOS (Run2021) comparator
- Run2021 is able to reach lower thresholds with similar noise level

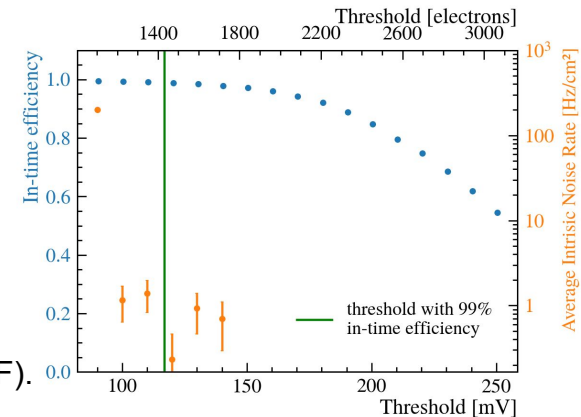
Additional col correction performed for Run2021 for fair comparison



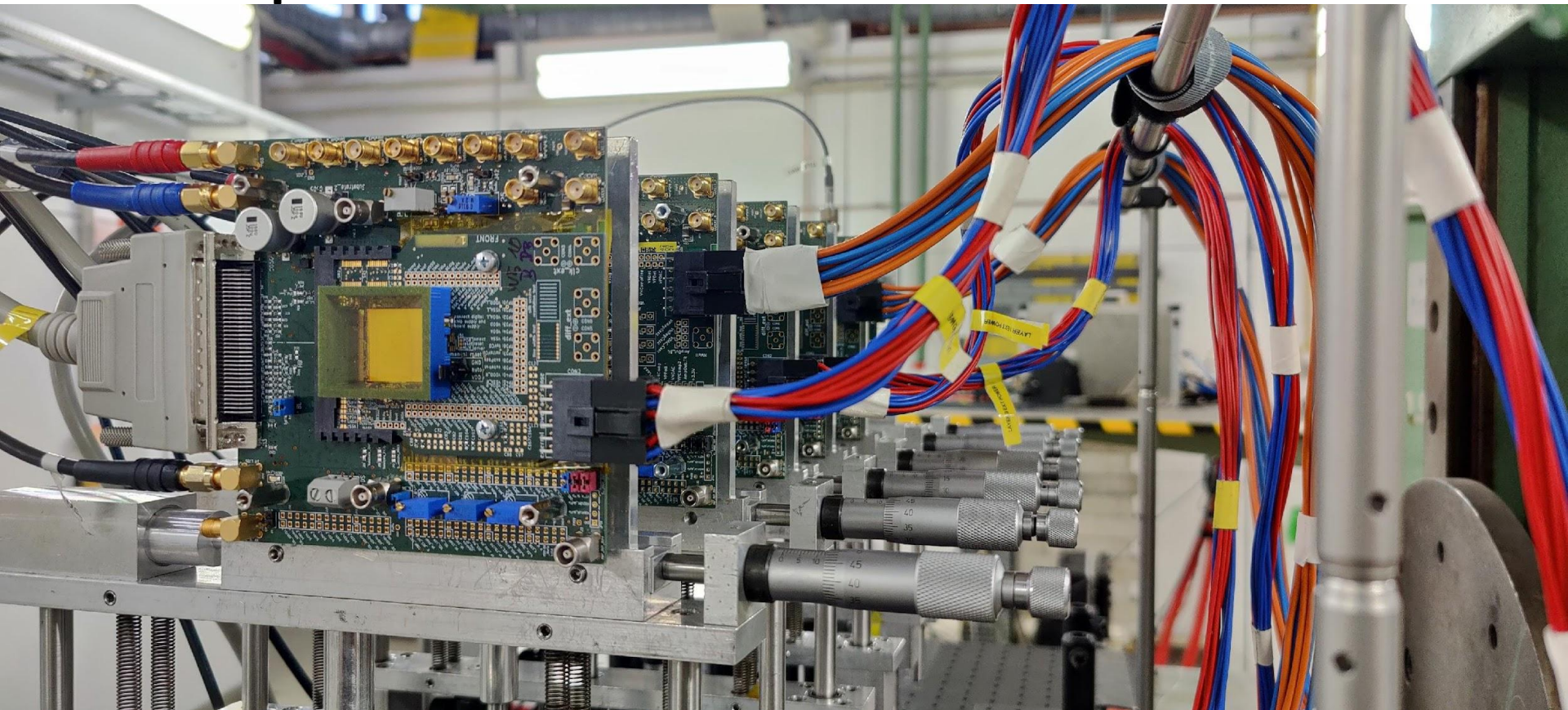
Conclusion

- Unirradiated NMOS Comparator **fulfills** performance requirement of **99% in-time efficiency**
→Efficiency plateau and time resolution are expected to improve with current biasing scheme
- Low noise rate for unirradiated sensor observed
- MightyPix2 will be submitted with AMS soon!

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

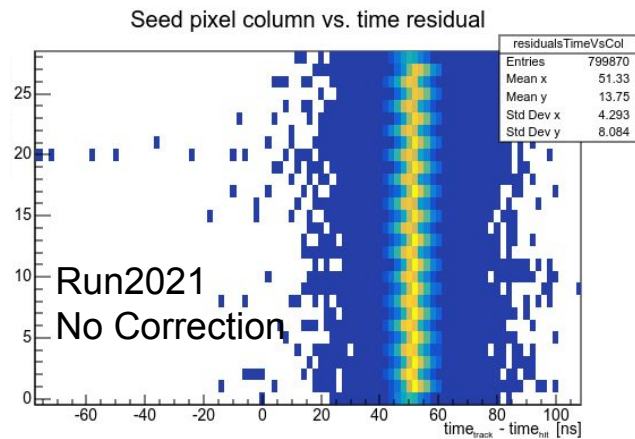
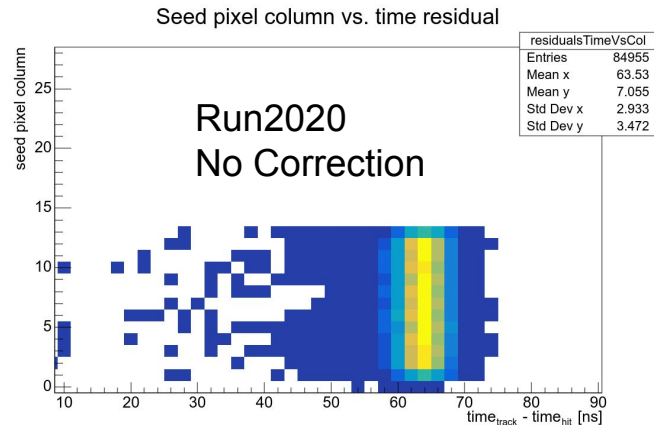
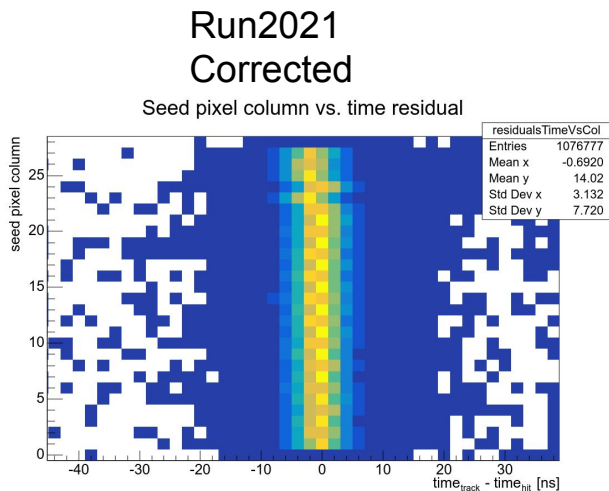
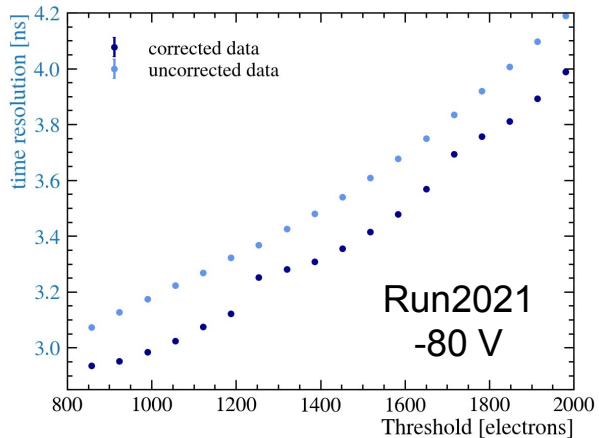


Backup



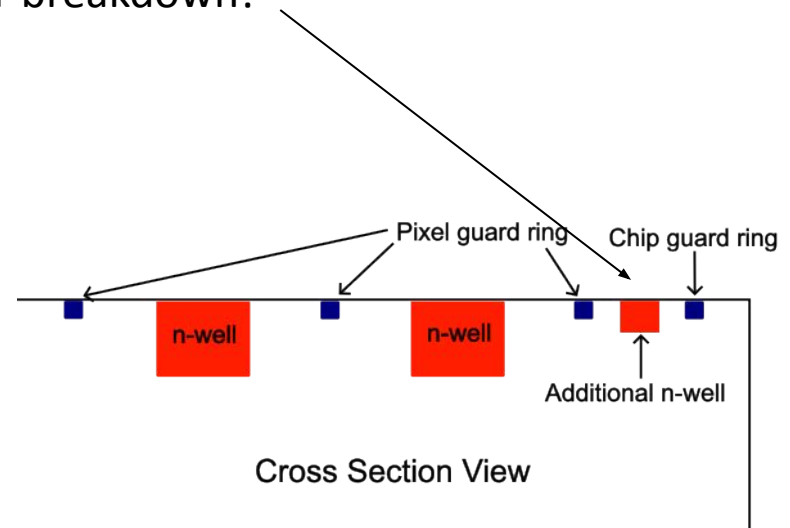
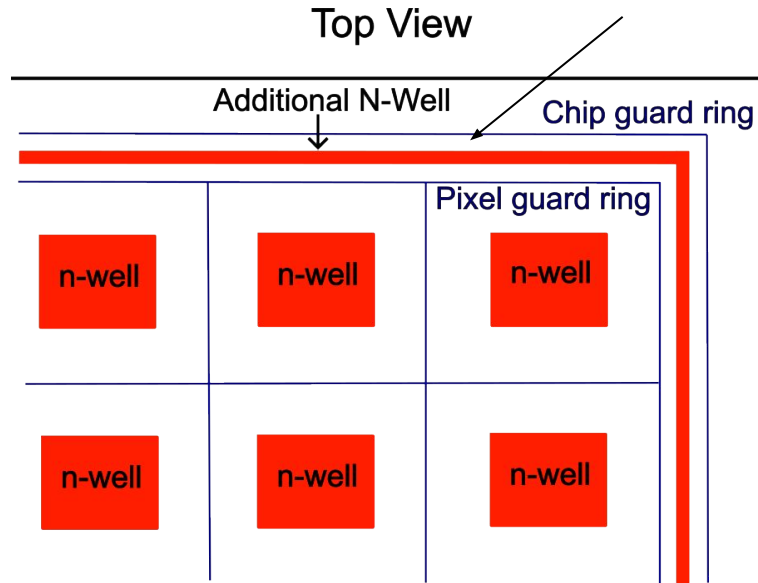
Column Correction Run2021

- Might be due to differing capacitances in the signal lines for odd/ even columns
- Correction is **work in progress**



Biasing Schemes

This additional N-well is missing in the old biasing design, effectively shorting both guard rings. This leads to earlier breakdown!



Berger-Seltzer Formula

