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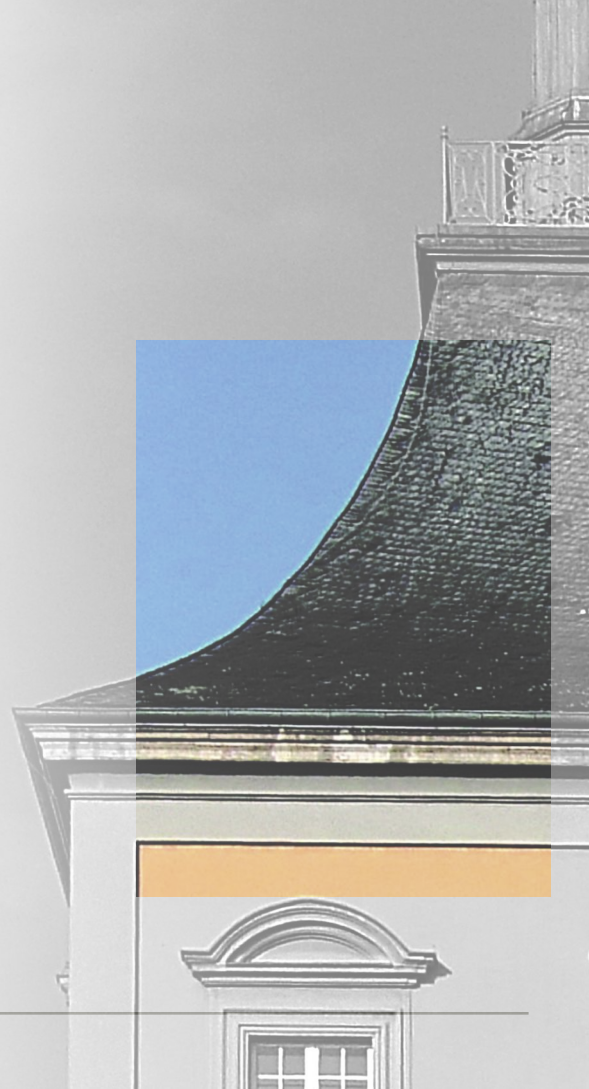
ELMA WORKSHOP

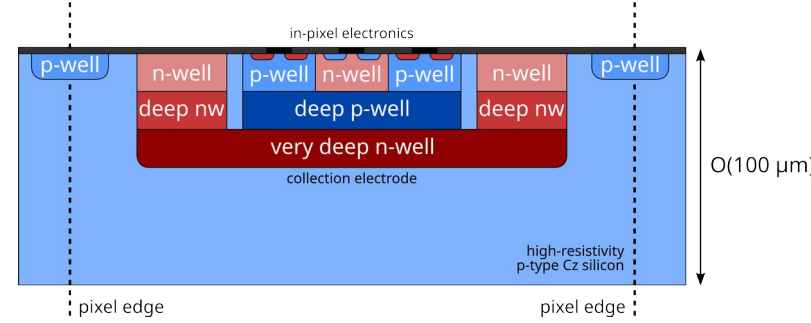
ENERGY RESPONSE OF MONOPIX2 SENSOR SERIES

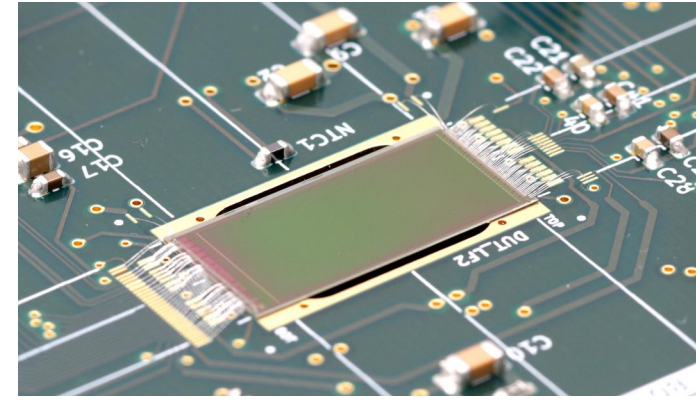
Lars Schall on behalf of the Monopix teams



LF-Monopix2

- 150 nm LFoundry CMOS technology
- Large collection electrode design
- Substrate resistivity >2 kΩcm
- Large scale 1x2 cm² chip
  - 100 µm thick sensor
    - Approx. 6000 e⁻ MIP charge MPV
  - Backside processing and metallization
  - 150x50 µm² pixel pitch
  - 6-bit ToT information @ 40 MHz
  - 4-bit in-pixel threshold tuning
- Fast column drain readout architecture (FE-I3 like)

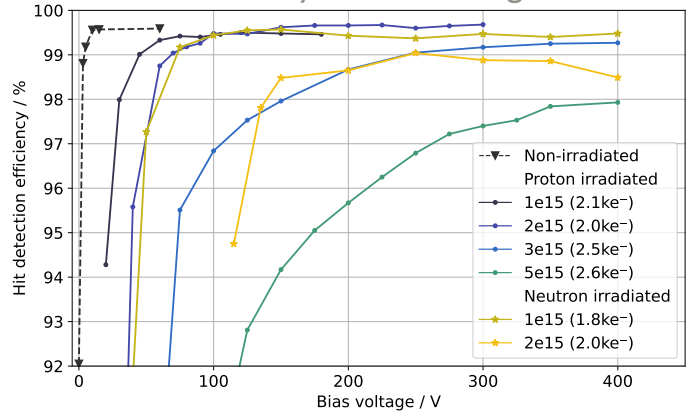




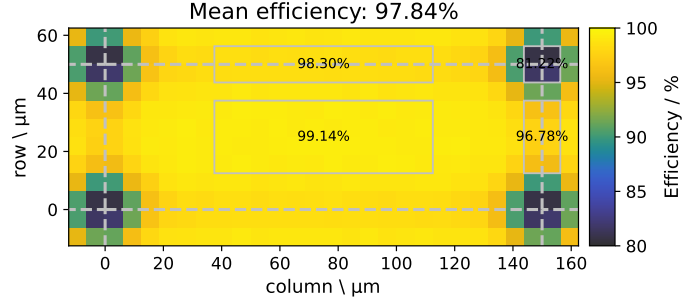
LF-Monopix2 NIEL irradiation

- Electron beam tests at DESY
- NIEL irradiated samples up to 5e15 neq/cm² available
  - Non-irradiated breakdown voltage >460 V
- Reach full depletion and >99% hit-detection efficiency up to 3e15 neq/cm²
- 5e15 neq/cm² still close to 98% mean efficiency
  - Pixel corners around 81%
  - Verified better performance for lower threshold
- This is more than 3 times the initially targeted NIEL fluence!

Efficiency vs bias voltage



Efficiency @ 5e15 neq/cm²

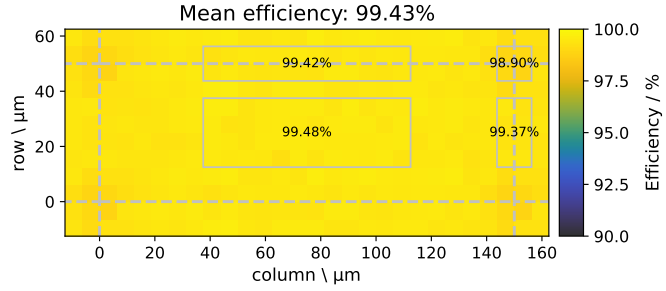


LF-Monopix2 X-ray irradiation

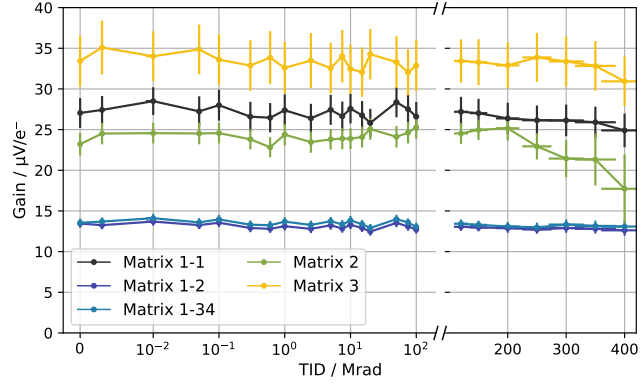
- Tested TID tolerance up to 400 Mrad
  - Fully functional at highest dose
  - Very good efficiency after 400 Mrad
  - Constant gain up to 200 Mrad

TID Fluence [Mrad]	Threshold [e^-]	Threshold Disp. [e^-]	ENC [e^-]
0	2055	91	92
100	1983	108	122
400	1865	142	140

Efficiency @ 400 Mrad



Gain vs TID

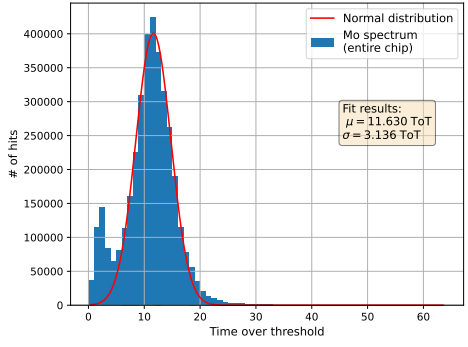


LF-Monopix2 Energy resolution incl. full FE

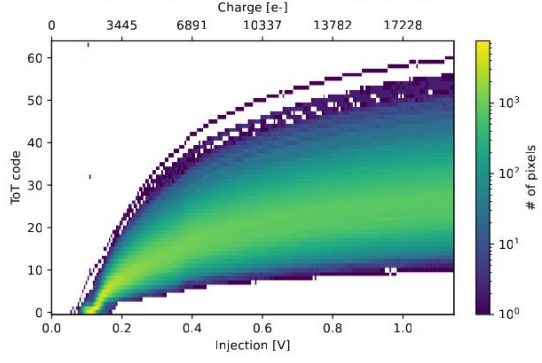
- Source measurements with Mo X-ray source (K_alpha @ 17480 eV)
- Assume linear response across relevant energy range: (4855 – THR) e^- / 11.6 ToT = 244 e^-/ToT
- Relative energy resolution
  - FWHM * 244 e^- / 4855 e^- = 36.6%
- ToT response strongly pixel dependent → Analyze on per pixel basis: 14% = 680 e^-

Dominated by digitization!

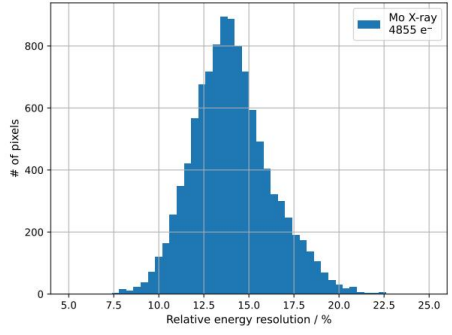
ToT spectrum - full matrix



ToT to charge calibration

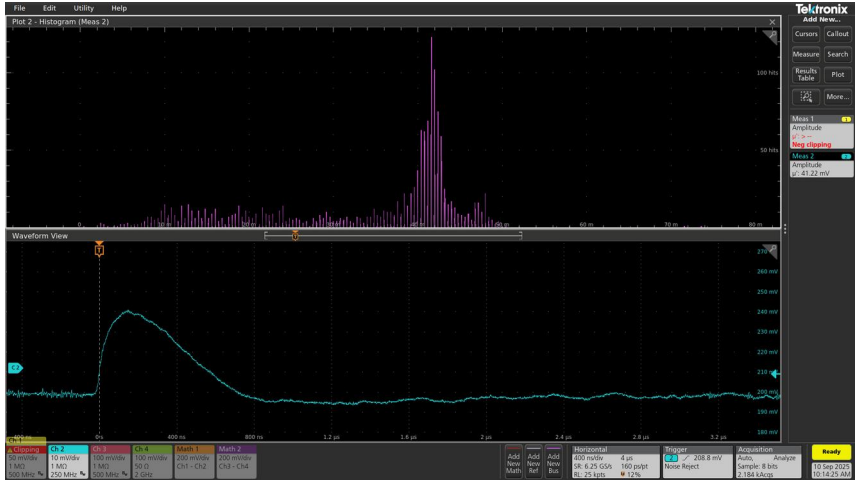


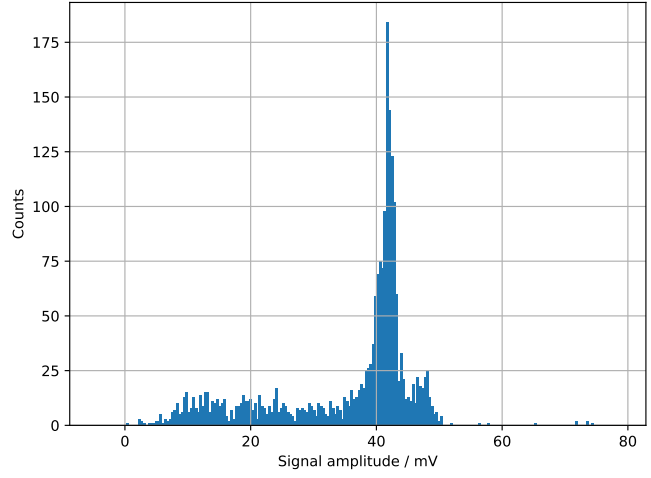
Per pixel analysis



LF-Monopix2 Energy resolution analog

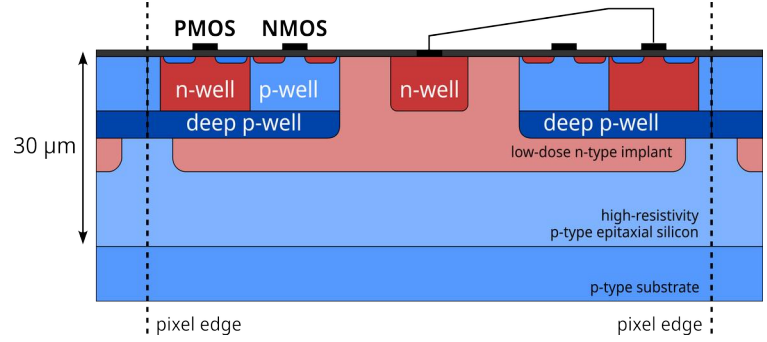
- Single pixel oscilloscope measurement, signal after CSA, little statistics
  - Same Mo x-ray target → See K_alpha and K_beta lines
    - K_alpha1 = 17479 eV, K_alpha2 = 17374 eV, K_beta = 19608 eV
- Relative energy resolution → roughly 2 mV / 42 mV = 4.5%

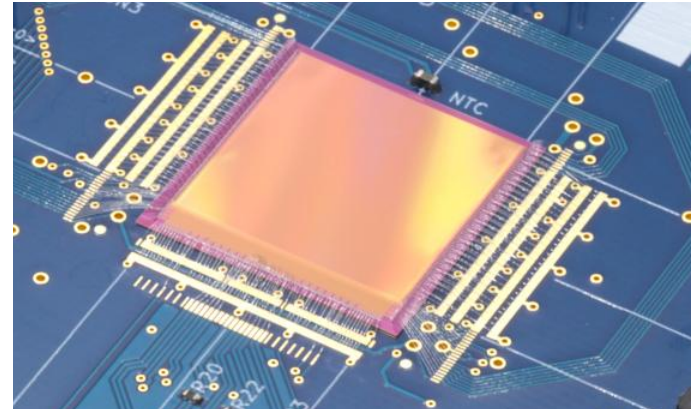




TJ-Monopix2

- 180 nm TowerSemi CMOS technology
- Small collection electrode design
- Substrate resistivity >1 kΩcm
- Large scale 2x2 cm² chip
  - 30 µm Epi layer or 100 µm Cz material
    - 2200 to 3000 e^- MIP charge MPV
  - 33x33 µm² pixel pitch
  - 7-bit ToT information @ 40 MHz
  - 3-bit in-pixel threshold tuning
- Fast column drain readout architecture (FE-I3 like)

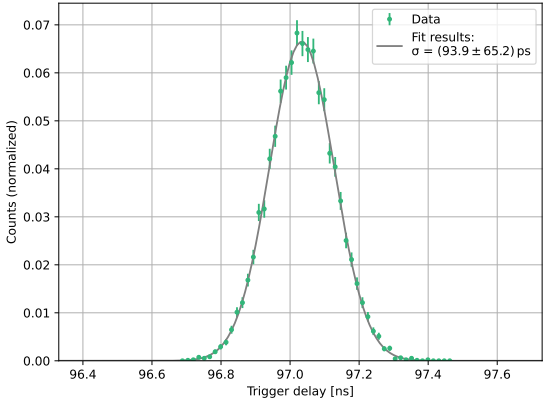




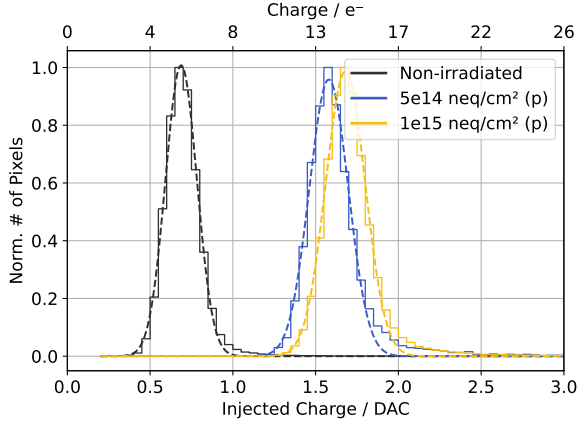
TJ-Monopix2 Beam tests

- Front-end time resolution <100 ps for MIP regime
  - Dominant sensor contribution of 1.5 ns → Long drift distance from pixel corner
- NIEL irradiated up to 1e15 neq/cm² → increase in ENC with fluence, still low
  - Very high hit-detection efficiency >99.5%

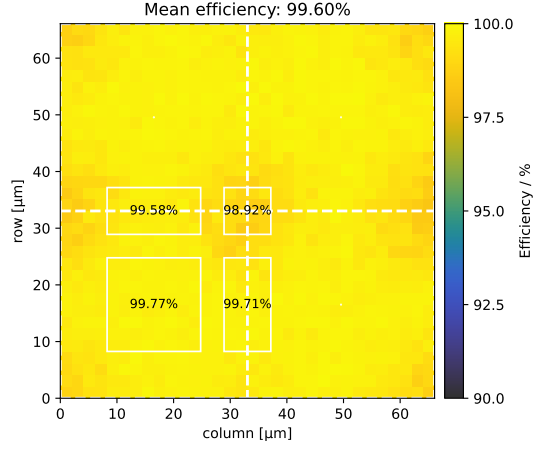
Time resolution of front-end only



ENC distribution



Efficiency @ 1e15 neq/cm²

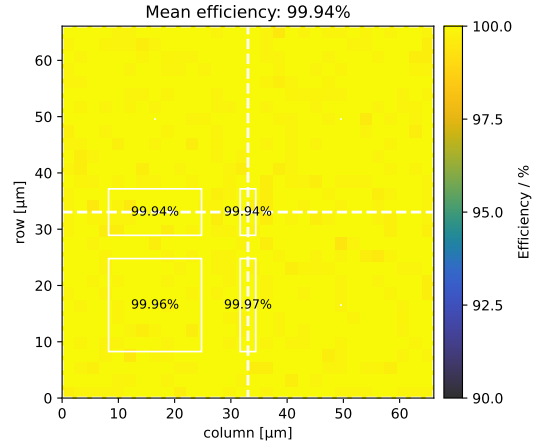


TJ-Monopix2 X-ray Irradiation

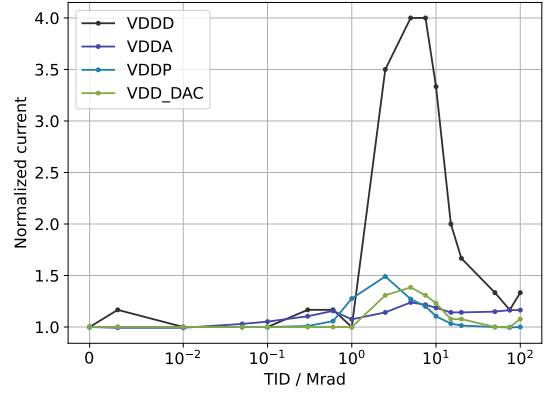
- Irradiated up to 100 Mrad total ionizing dose
  - Peak in power consumption around 1 – 10 Mrad
  - highest relative increase for digital domain
  - Periphery biggest absolute contributor
- Typical threshold reachable after 100 Mrad and annealing
  - Very good hit-detection efficiency

TID Fluence [Mrad]	Threshold [e^-]	Threshold Disp. [e^-]	ENC [e^-]
0	230	5	6
100	245	5	13

Efficiency @ 100 Mrad



Power consumption vs total dose

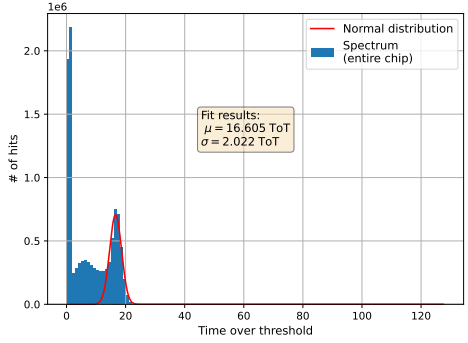


TJ-Monopix2 Energy resolution incl. full FE

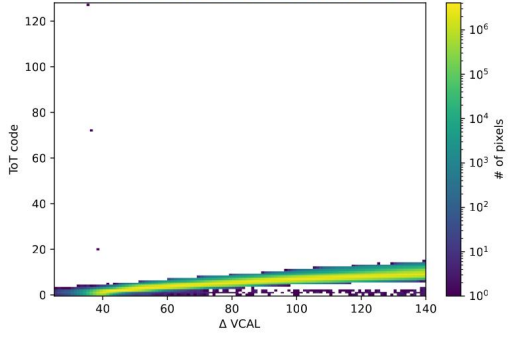
- Fe55 source measurements (K_alpha @ 5890 eV)
- Relative energy resolution of full chip: 25%
  - Per pixel response: around 10%
- Most of 7-bit ToT range is not used, difficult to adjust ToT response
- Limited injection range up to ca. 1600 e⁻ complicates ToT-energy calibration

Dominated by digitization!

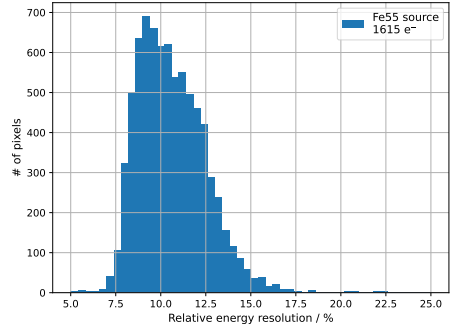
ToT spectrum - full matrix



ToT to charge calibration

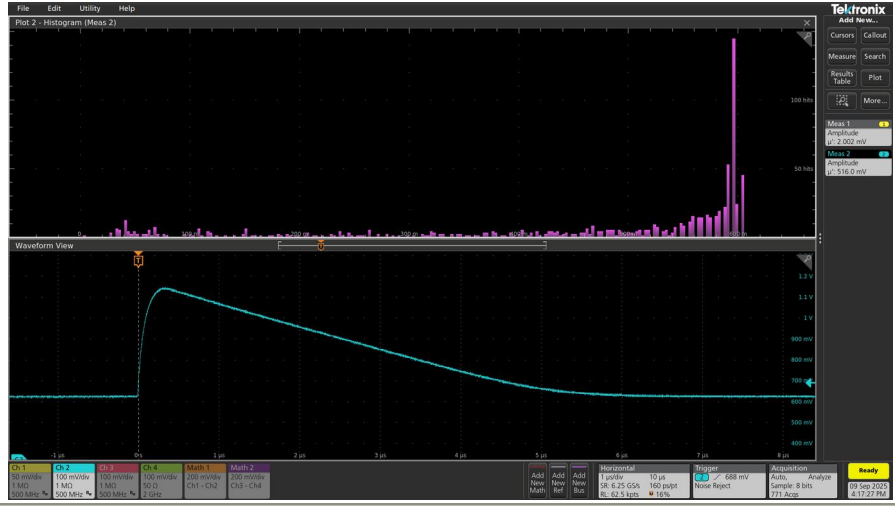


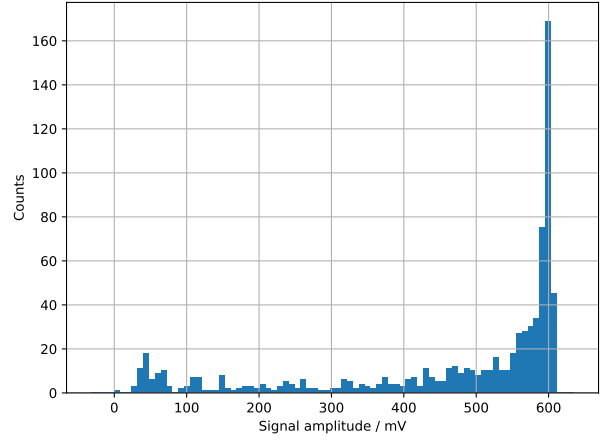
Per pixel analysis



TJ-Monopix2 Energy resolution analog

- Very limited statistics from only one analog test pixel available
  - Signal after pre-amplifier measured with oscilloscope (Fe55 source)
  - Initial sensor signal also available as test pixel, but not yet measured
- Relative energy resolution → less than 15 mV / 600 mV = 2.5%





Conclusion

- Both Monopix2 chips are not optimized for dE/dx measurements
  - No possibility to tune ToT response and large deviations between pixels
- LF-Monopix2:
  - 14% rel. energy resolution of full readout chain
  - Roughly 4.5% rel. energy resolution for pre-amplifier output signal
  - Dynamic range: 2 ke^- to >10 ke^- (upper limit not tested)
- TJ-Monopix2:
  - Around 10% rel. energy resolution of full readout chain
  - Less than 2.5% rel. energy resolution for pre-amplifier output signal
  - Limited dynamic range of 250e^- up to 3 ke^-

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Thank you for your attention!

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)

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