Test Beam Analysis of Irradiated Stitched Passive CMOS Strip Sensors

Preliminary summary of results

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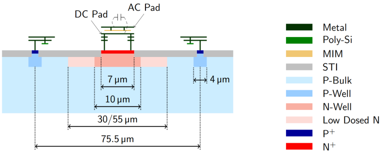
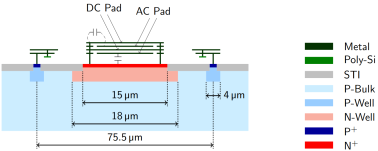
29.11.23

Investigated Sensors

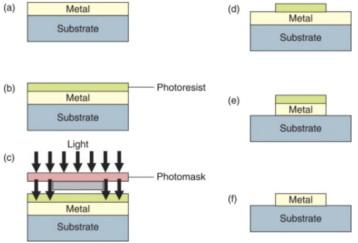
- Passive strip sensors produced by LFoundry in 150 nm process on 3 kΩ cm to 5 kΩ cm substrate with additional backside processing from IZM Berlin
- (150 ± 10) µm thickness, 75.5 µm strip pitch, 40 strips per sensor
- Two different lengths: 4.1 cm & 2.1 cm with either five or three stitches
- Three different designs: Regular, Low Dose 30 & 55
- Sensors irradiated with reactor neutrons to fluences of: $1 \cdot 10^{14} \mathrm{n_{eq}/cm^2}$, $3 \cdot 10^{14} \mathrm{n_{eq}/cm^2}$, $1 \cdot 10^{15} \mathrm{n_{eq}/cm^2}$, $3 \cdot 10^{15} \mathrm{n_{eq}/cm^2}$, $1 \cdot 10^{16} \mathrm{n_{eq}/cm^2}$

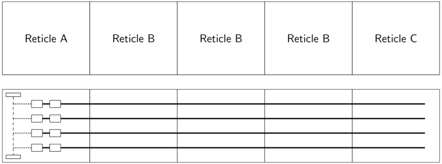




Goal of study: Determine the effects of stitching on the charge collection, spatial resolution and efficiency, check if radiation damage degrades stitches and test overall performance and radiation hardness of sensors

Investigated Sensors
Stitching



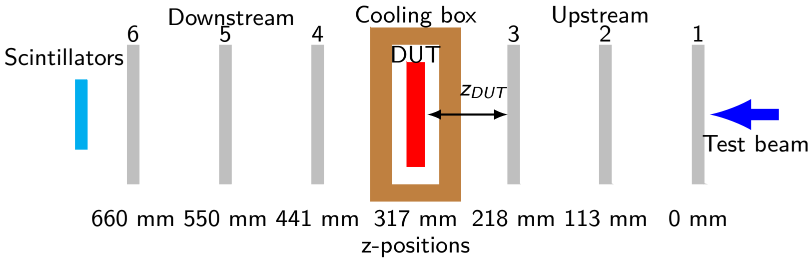


Problem: Area of ITk strip module ~100 cm^2 $\gg$ Typical reticle size of standard industrial processes $\Rightarrow$ Solution: **Stitching**

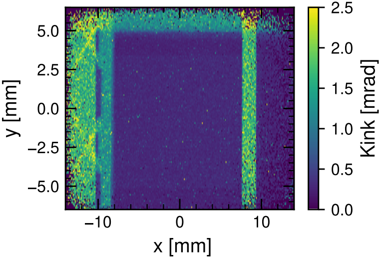
Basic principle of stitching:

1. Divide entire structure into smaller substructures
2. Imprint substructure onto silicon
3. Move mask very precisely to next position
4. Repeat steps 2-3 with same or another mask

Testbeam setup

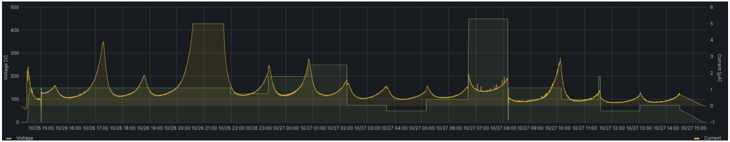


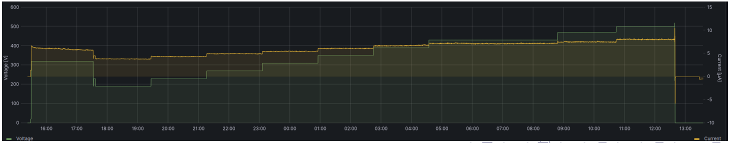
- Three test beam campaigns conducted at the DESY-II test beam
- Beam energy of 3.4 GeV, 4.2 GeV and 4.6 GeV
- ADENIUM telescope with 6 ALPIDE planes, two scintillators in coincidence
- ALPIDE sensors: 1024 x 512 pixels, 29.24 µm x 26.88 µm, total area of 30 mm x 15 mm, thickness of 50 µm
- DUT monitored by ALiBaVa system
- Additional timing plane added in second test beam campaign



- First two testbeams conducted with ITk Testbeam Box with dry ice cooling
- Upgraded to full copper PCB cooled by double-stacked Peltier elements connected to a chiller

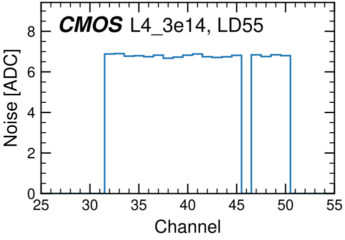
⇒ More stable temperature and automatisation of data taking

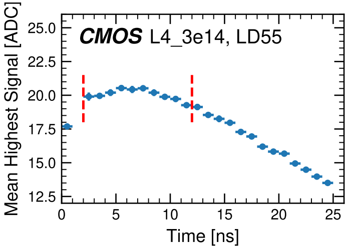


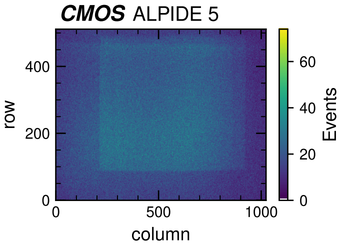


Results of Analysis

ALiBaVa and EUDAQ Eventloader



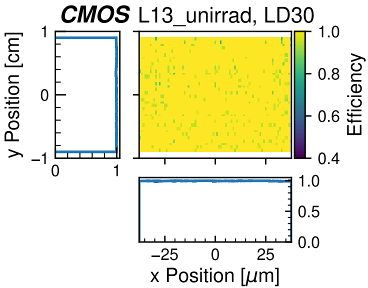


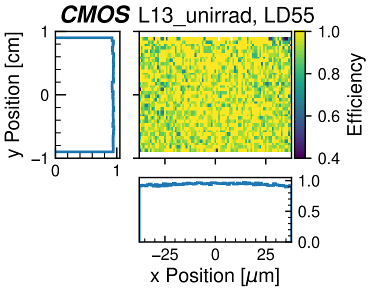


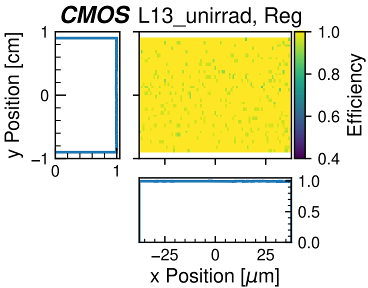
- All sensors shown are beneficially annealed and fully depleted/biased at the maximum save voltage
- Noise at similar level in laboratory
- Noise similar for all designs
- Shape of pulse nicely reconstructed in time profile
- Structure visible in hitmap of ALPIDE planes, due to scintillator overlap

Results of Analysis

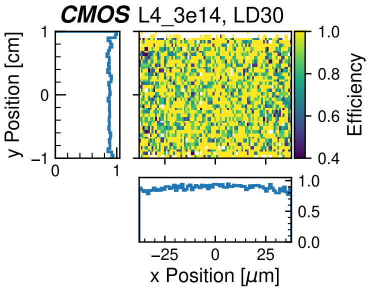
In-strip Efficiency Unirradiated

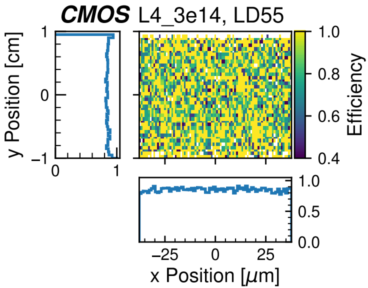


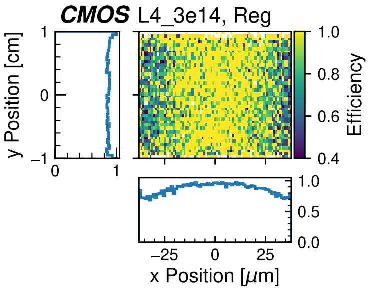




- No change in efficiency along strip length ⇒ Stitching does not influence efficiency
- Slight efficiency decrease towards inter-strip region for LD55, no change for LD30/Regular
- Overall efficiency close to one for LD30/Regular, slightly lower for LD55



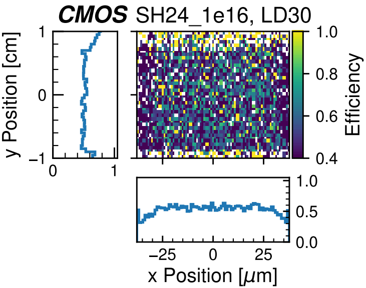


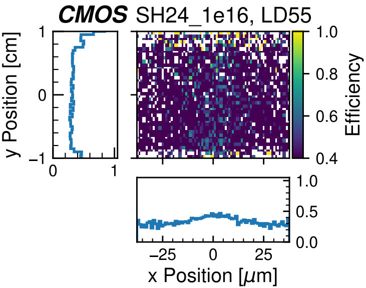


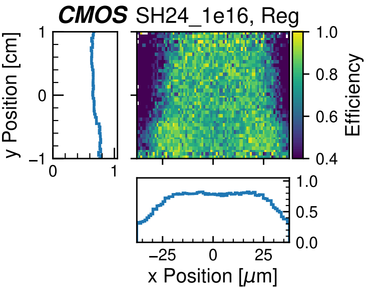
- Overall efficiency significantly lower than for unirradiated sensor
- Large efficiency loss towards inter-strip region for Regular, slight loss for LD30
- No change in efficiency over strip length ⇒ No degradation of stitching with irradiation

Results of Analysis

In-strip Efficiency Irradiated



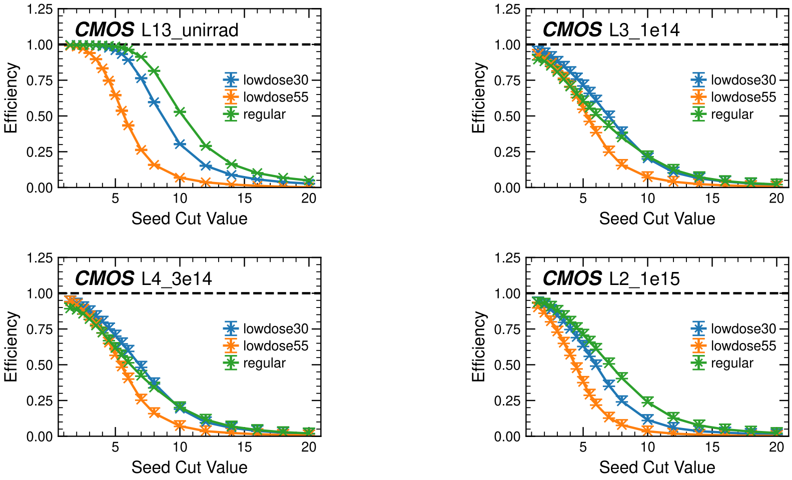




- Similar behaviour to L4_3e14
- Efficiency strongly decreased for all designs
- Asymmetry along strip length for Regular design most probably due to copper PCB + high noise
- Stitching still works at fluence of $1 \cdot 10^{16} \mathrm{n_{eq}}/\mathrm{cm}^2$

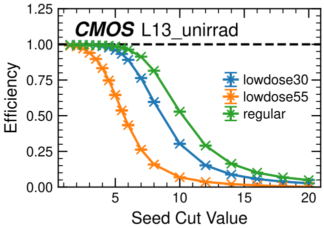
Results of Analysis

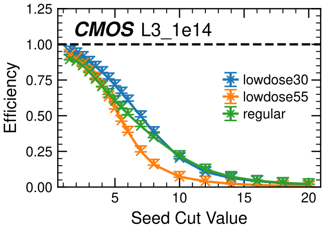
Efficiency

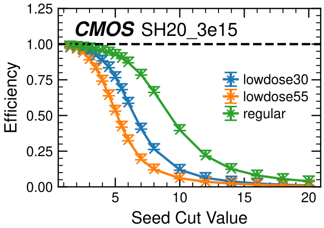


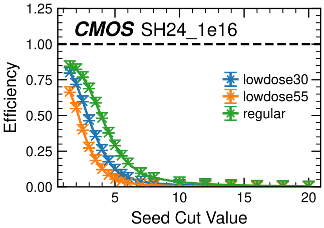
- High efficiency plateau for unirradiated sensor (Regular: 98.5%; LD30: 96.0%, LD55: 64.5% @SC:5) not seen in irradiated sensors
- Efficiency of LD55 design worst, with exception of Regular efficiency at small seed cuts in irradiated sensors (efficiency loss in inter-strip region)

Results of Analysis
Efficiency



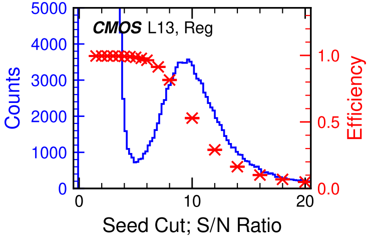


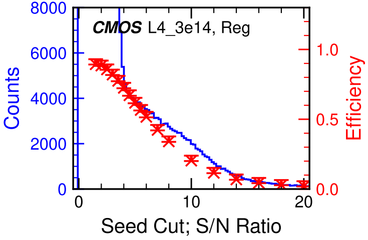




- Strong decrease in efficiency for SH24_1e16 for all three designs
- SH20_3e15 shows higher efficiency than even L3_1e14, ordering of designs similar to L13_unirrad/L2_1e15 ⇒ Behaviour still under investigation

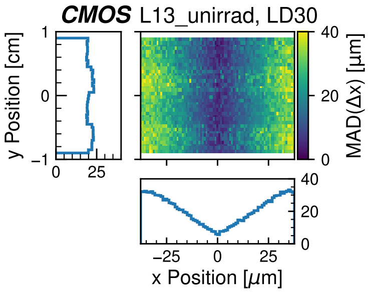
Results of Analysis
Efficiency

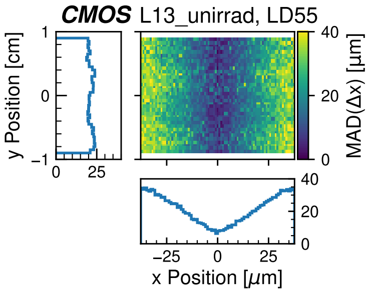


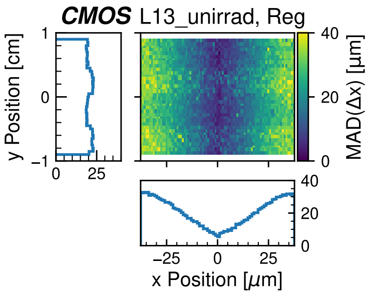


- Clear division between noise (left, cut off Gaussian peak) and signal (right Langaus peak) in unirradiated sensor
- Strong overlap between signal and noise for irradiated sensor

$\Rightarrow$ Already for small seed cuts part of signal distribution cut away for irradiated sensor $\Rightarrow$ No plateau and no proper working point (Working point for unirradiated sensor @SC: 5)
$\Rightarrow$ Large efficiency in irradiated sensors at small seed cuts due to noise
$\Rightarrow$ Lower signal and higher noise of LD55 design explains smaller plateau in unirradiated sensor and overall worse efficiency



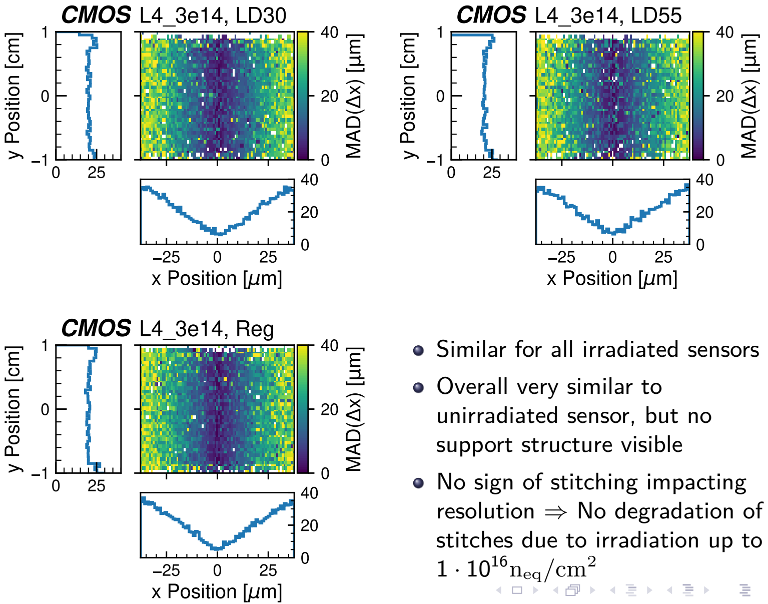




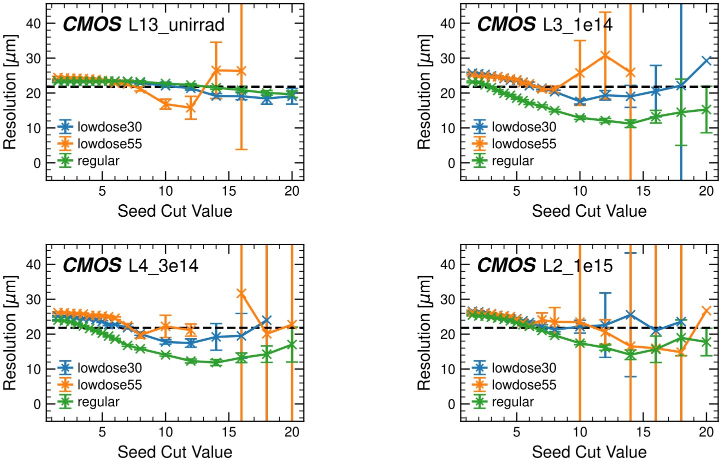
- Mean absolute deviation (MAD) is a proxy for the DUT resolution
- Increasing MAD towards inter-strip region
- Two regions of higher MAD along strip due to Coulomb multiple scattering in sensor support
- No sign of stitching impacting resolution

Results of Analysis

In-strip resolution Irradiated

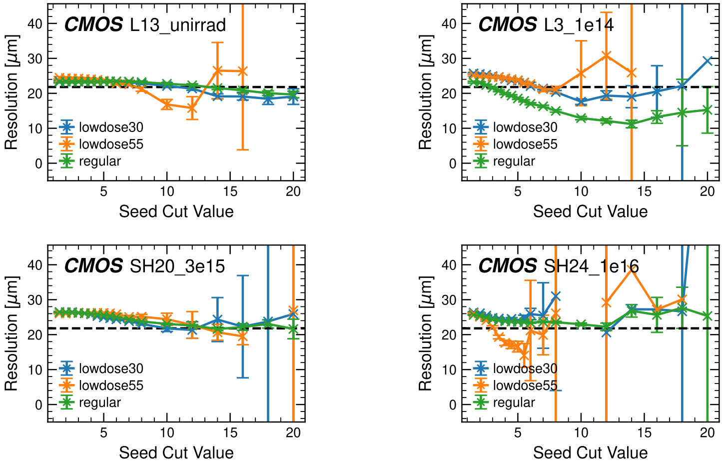


- Similar for all irradiated sensors
- Overall very similar to unirradiated sensor, but no support structure visible
- No sign of stitching impacting resolution ⇒ No degradation of stitches due to irradiation up to $1 \cdot 10^{16} \mathrm{n_{eq}/cm^2}$



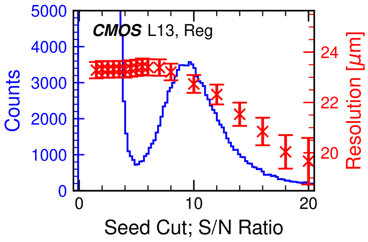
- Regular best, LD55 design worst resolution; Irradiation decreases resolution value for Regular, increases for LD30/55 design
- Too large resolution of unirradiated sensor due to sensor support material distorting residual distribution

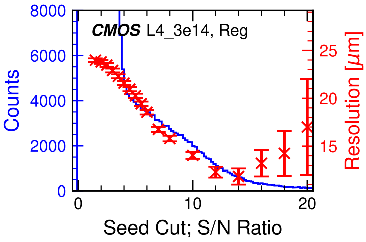
Results of Analysis
Resolution



- Resolution values for SH20_3e15 and SH24_1e16 too large because scattering in copper PCB not yet taken into account
- SH20_3e15 behaves again more similar to unirradiated sensor

Results of Analysis
Resolution





⇒ Cutting away parts of signal distribution leads to smaller resolution values

Bad separation between noise and signal in irradiated sensors leads to

- No proper working plateau
- Association of noise clusters to tracks causes worse resolution for small seed cuts

Stronger seed cut dependence of unirradiated LD55 design and bad statistics for irradiated LD55 design due to generally smaller collected charge

Summary and Outlook

- Stitching does not negatively impact the resolution and efficiency of a CMOS sensor and does not degrade up to a fluence of $1 \cdot 10^{16} \mathrm{n_{eq}/cm^2}$
- The Regular design shows the best performance (except the loss of efficiency towards the inter-strip region), the Low Dose 55 design the worst $\Rightarrow$ For future submission the LD55 design should not be considered further
- Regular design still works (although not well) after fluence of $1 \cdot 10^{16} \mathrm{n_{eq}/cm^2}$
- Still a lot to look at: Charge collection in the test beam, performance at different voltages, studies of the bond pad region, characteristics of proton irradiated samples

Thanks for your attention!

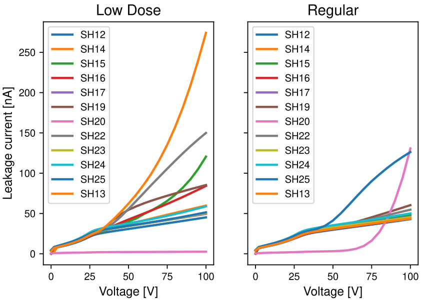
This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511 (EURO-LABS).

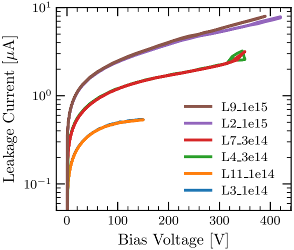
The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

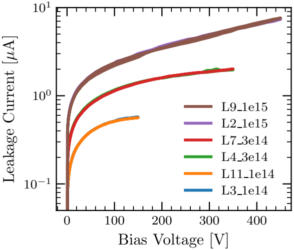
Spyridon Argyropoulos, Jan-Hendrik Arling, Marta Baselga, Naomi Davis, Leena Diehl, Ingrid-Maria Gregor, Marc Hauser, Fabian Hügging, Michael Karagounis, Kevin Kröninger, Fabian Lex, Ulrich Parzefall, Arturo Rodriguez, Birkan Sari, Surabhi Sharma, Simon Spannagel, Dennis Sperlich, Niels Sorgenfrei, Jens Weingarten, Iveta Zatocilova

Backup

IV measurements



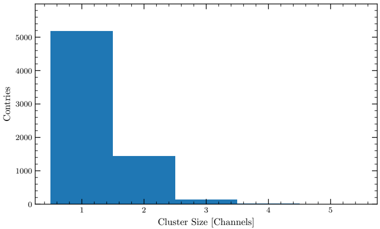


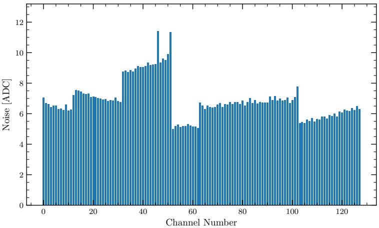


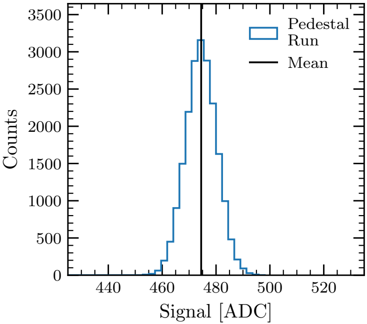
Voltages used in measurements

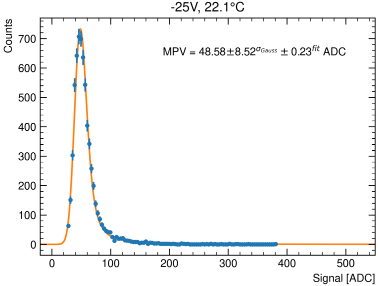
- L13_unirrad: 70 V (fully depleted)
- L3_1e14: 130 V (fully depleted)
- L4_3e14: 250 V (fully depleted)
- L2_1e15: 450 V (fully depleted)
- SH20_3e15: 500 V (maximum save voltage)
- SH24_1e16: 500 V (maximum save voltage)

Backup
Beta measurements



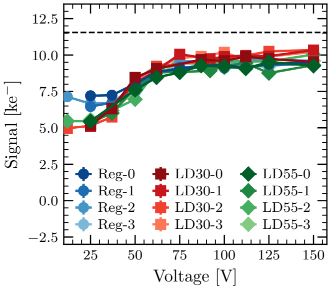


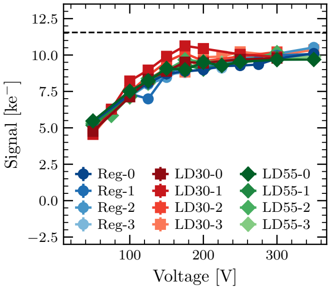


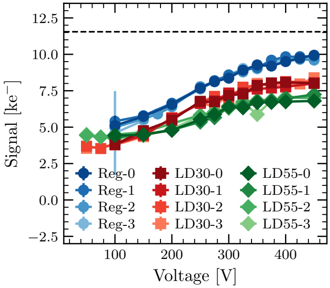


Backup

Beta measurements







- Top left: L3_1e14
- Top right: L4_3e14
- Bottom left: L2_1e15

Backup

Fake rate vs. S/N ratio