PSI Center for Photon Science

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LGAD sensor ASIC design

Response of iLGAD sensors to high intensity photons absorbed within and close to the gain layer

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Introduction

Hybrid X-ray detectors are state-of-the-art for imaging experiments using hard X-rays at synchrotrons and free-electron lasers (FELs), thanks to their high frame rate, large dynamic range and large detection area. However, they have not been used in soft X-ray energy range due to low **Quantum Efficiency (QE)** and **Signal-to-Noise Ratio (SNR)** [1].

To overcome these challenges, two technologies are being developed in collaboration with FBK: a **Thin Entrance Window (TEW)** technology to increase the QE and **Low Gain Avalanche Diode (LGAD)** technology, tailored for photon science, to improve the SNR [2].

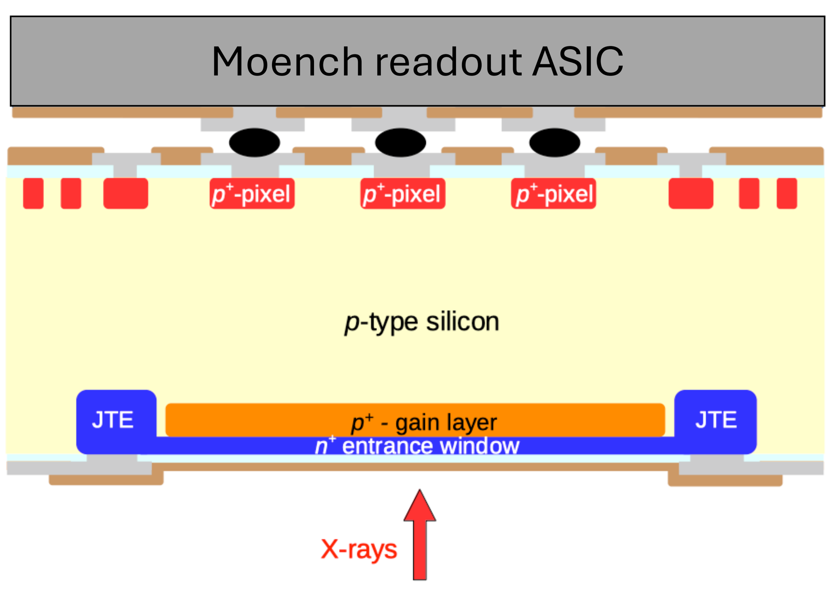
< challenges >	< reasons >	< technologies >
Quantum Efficiency (QE)	Shallow abortion of low-energy photons (100 nm@250 eV)	Thin Entrance Window (TEW) technology
Signal-to-Noise Ratio (SNR)	Small charge created in the silicon sensor (70 e⁻@250 eV)	Gain in the sensor: Low Gain Avalanche Diode (LGAD)

Rewind: Recent developments at PSI

The inverse LGAD (iLGAD) sensors with a TEW optimized for soft X-rays:

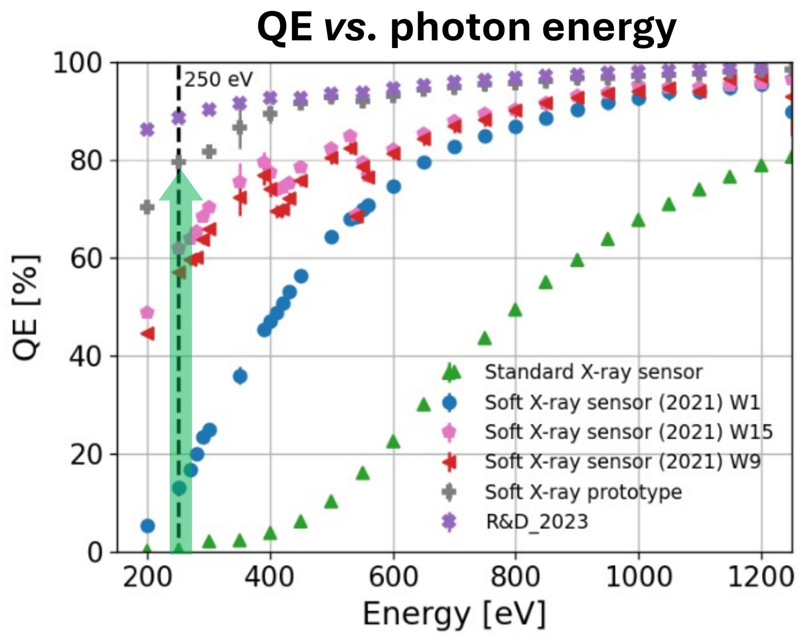
- 100% fill factor → interpolation possible for high spatial resolution [3]
- Gain depends on photon absorption depth → lower gain for < 400 eV

Cross section of iLGAD



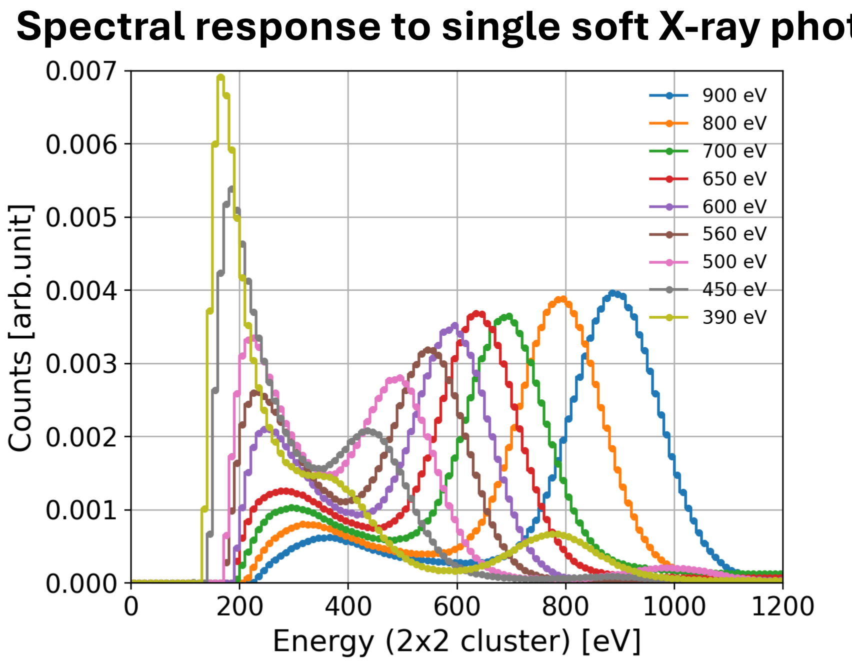
soft X-ray iLGAD sensor @ PSI

QE *vs.* photon energy



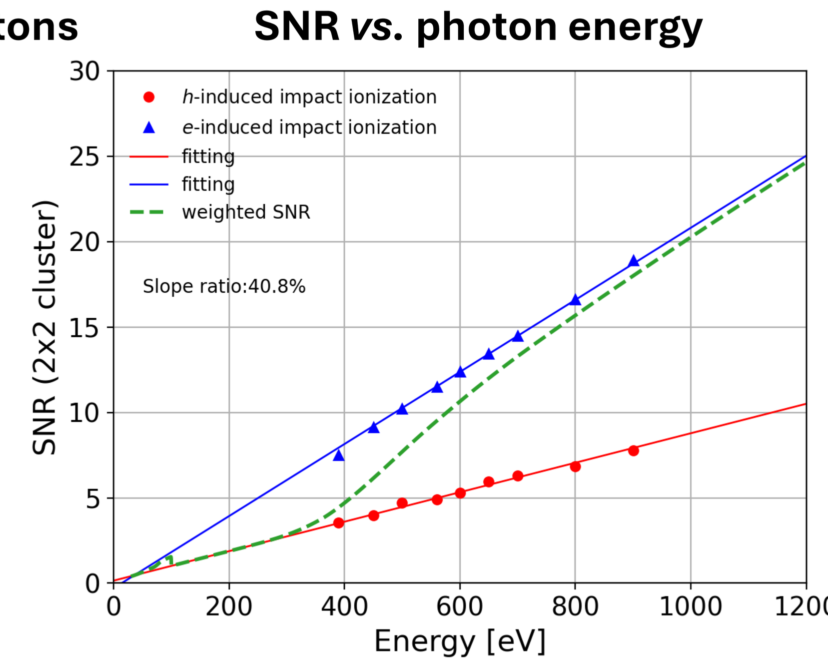
QE > 60-80% at 250 eV [4,5]

Spectral response to single soft X-ray photons



Single-photon detection down to 390 eV [6]

SNR *vs.* photon energy

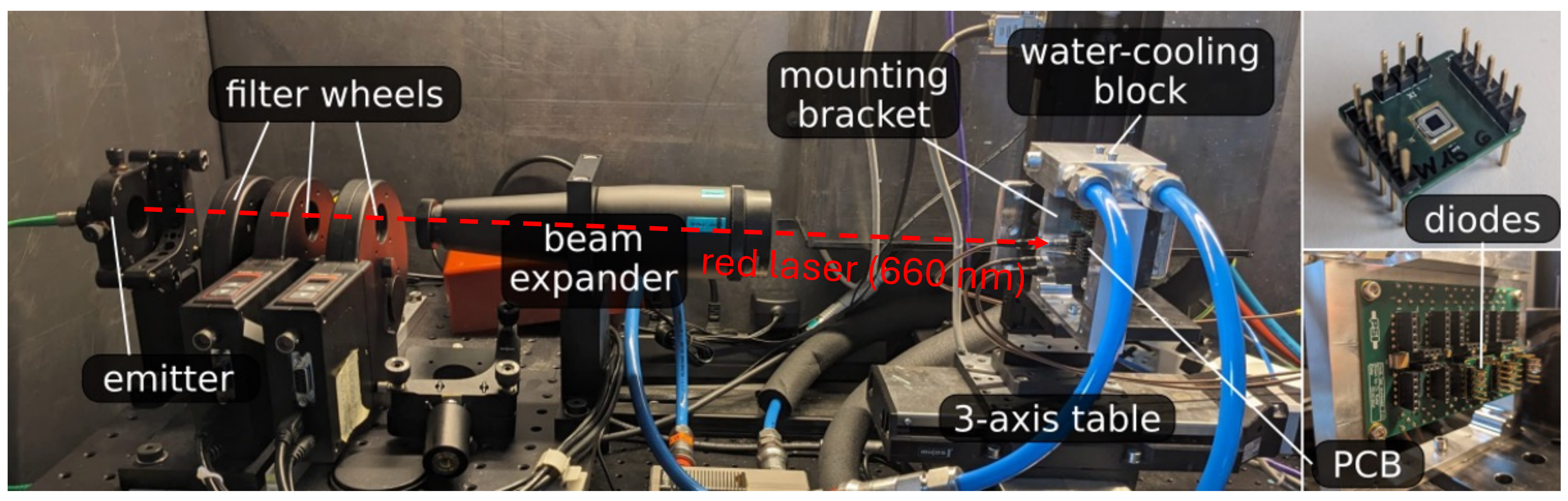


SNR greater than 5 for $E > 390$ eV

Response to high intensity photons

X-ray photons (total energy up to 10^5 keV) arrive on the silicon sensor simultaneously from a single XFEL pulse. A large number of charge carriers are created within and close to the gain layer of the iLGAD sensor, which reduces the electric field in the gain layer and thus causes gain suppression.

Experimental set-up for the investigation of gain surppression

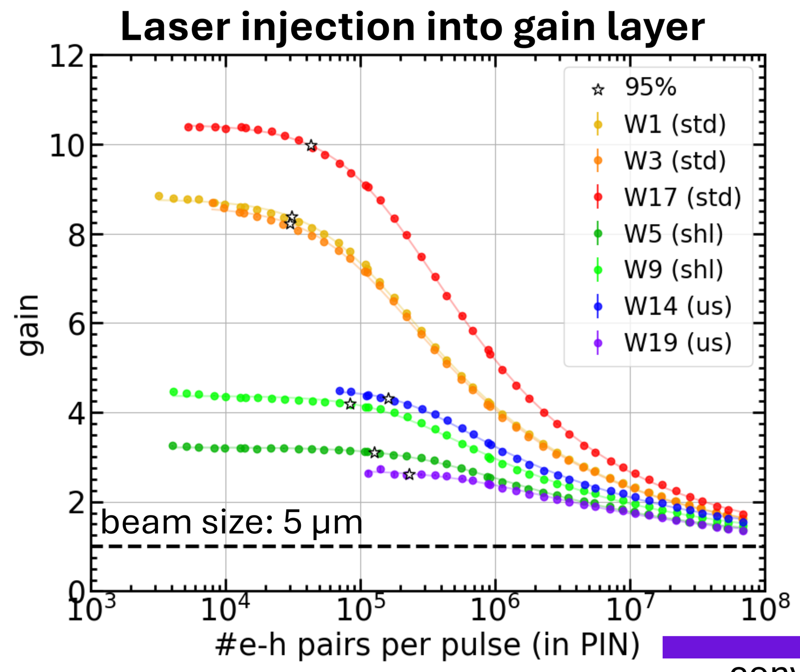


Experimental set-up and measurements:

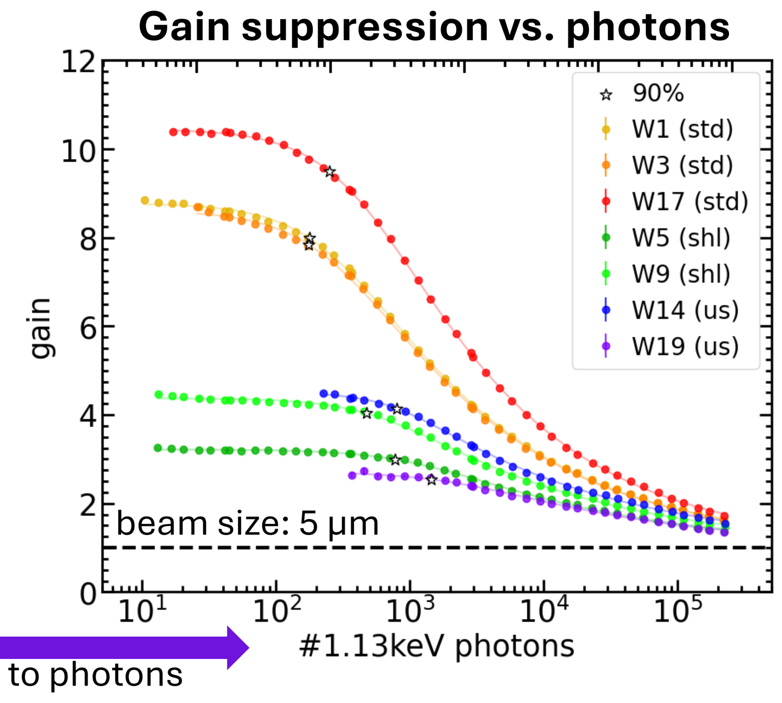
- Pulsed red laser (660 nm) → absorption depth in silicon: 3.88 μm
- Laser intensity was varied using filters
- Photocurrent of iLGAD sensors with 3 different gain designs (standard - std, shallow - shl and ultrashallow - us) and diodes were measured → gain determined as function of *e-h* pairs produced by each pulse

Results and conclusions

Laser injection into gain layer

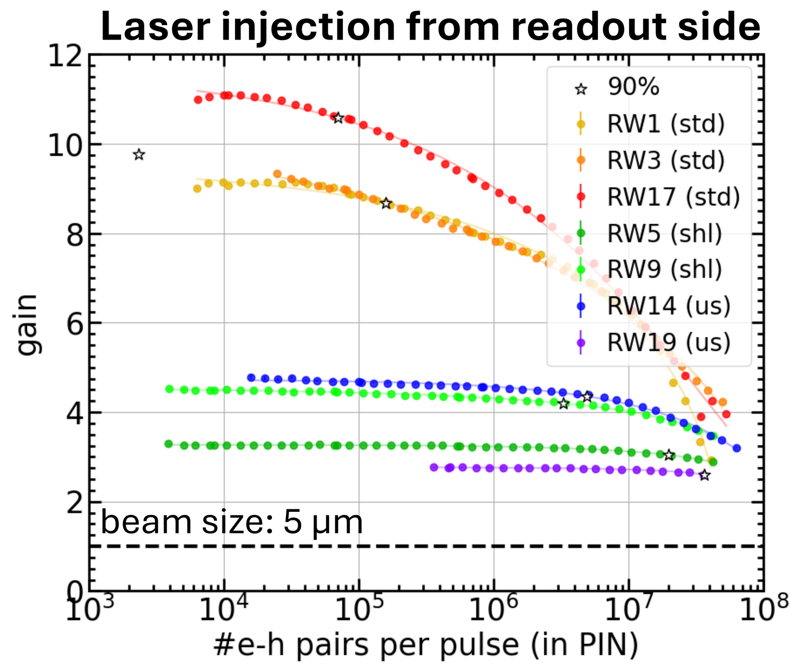


Gain suppression vs. photons

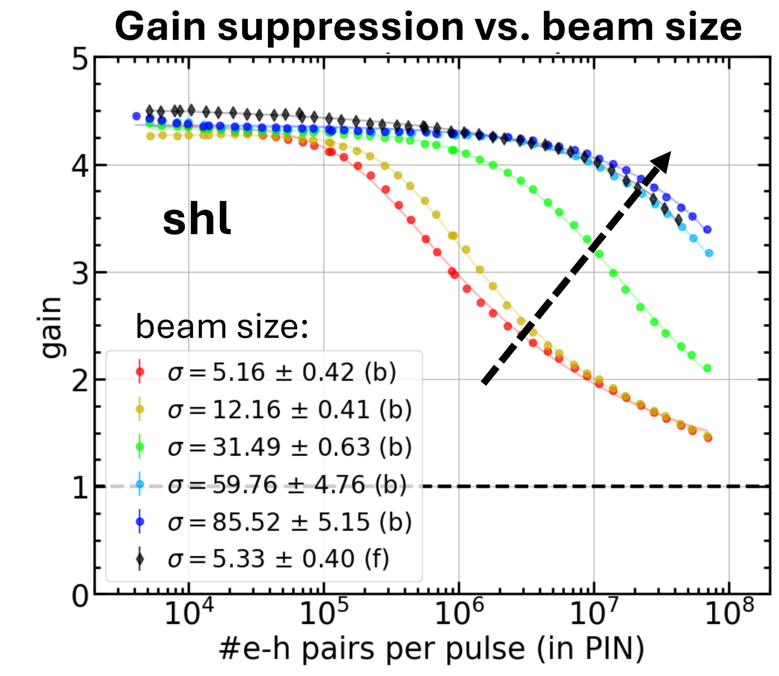


convert to photons

Laser injection from readout side



Gain suppression vs. beam size



Gain suppression depends on [7]:

- Intensity (total number of e-h pairs produced per pulse)
- Beam size → initial charge distribution
- Gain layer design → shallow/ultrashallow gain layer is preferred
- Charge density when carriers reach the gain layer by drift/diffusion

Implications for photon science:

- Non-linear detector response at high X-rays intensity
- Calibration procedures need to be implemented for FEL applications

References

[1] Andrae et al., *JSR* **26**, 1226 (2019).
[2] Zhang et al., *JINST* **17**, C11011 (2022).
[3] Hinger et al., *Front. Phys.* **12**, 1352134 (2024).
[4] Carulla et al., *JINST* **18**, C01073 (2023).
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[7] Frank, ETHZ semester thesis (unpublished)