Jožef Stefan Institute
Ljubljana, Slovenia

ATLAS-HGTD hybrid studies

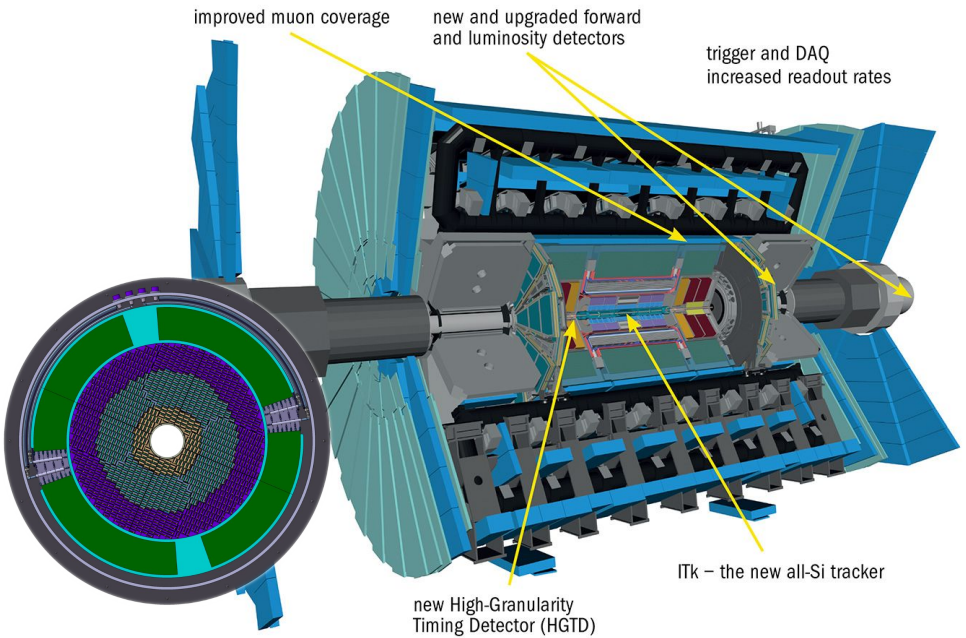
Marko Puklavec, Gregor Kramberger, Theodorus Manuossos (CERN), Bojan Hiti, Brigita Novak

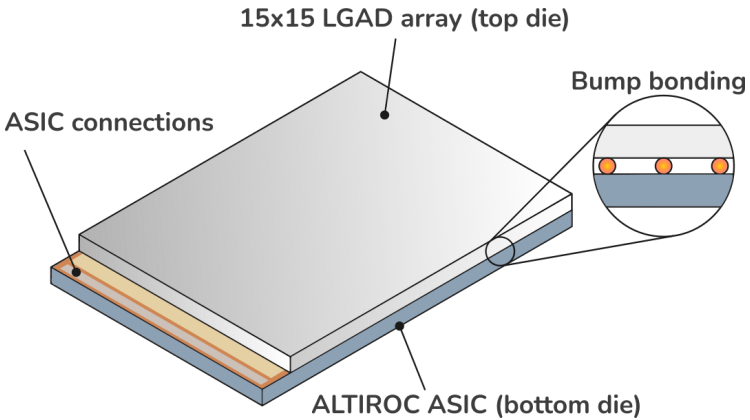
F9 Strategic meeting, Krvavec, 30. September 2026

HGTD hybrid overview

As a part of HL-LHC ATLAS upgrade the new HGTD (High Granularity Timing Detector) will enable 4D track reconstruction.

Building block of HGTD is a hybrid consisting of 15x15 LGAD pixel array and ALTIROC (ATLAS LGAD Time Read Out Chip) ASIC.





225 readout channels with transimpedance amplifiers to read LGAD cells

Provides timing and luminosity measurements

- Internally uses TDC (Time to Digital Converters) to gather Time of Arrival (TOA) and Time over Threshold (ToT) data

ATLAS HGTD hybrid studies motivation

Testing sensor and ASIC behavior after irradiation is *crucial to understanding of behavior at high fluences* near End-Of-Life (EoL) of the detector ($2.5 \cdot 10^{15}$ n_{eq}/cm^2)

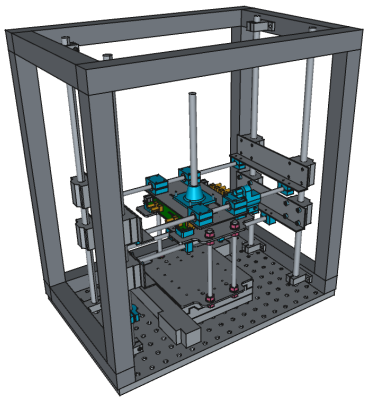
- HGTD hybrids were irradiated at JSI TRIGA reactor to EoL fluences (neutrons)
  - Due to tantalum activation transportation of irradiated samples is difficult **requiring measurements to be performed at JSI**

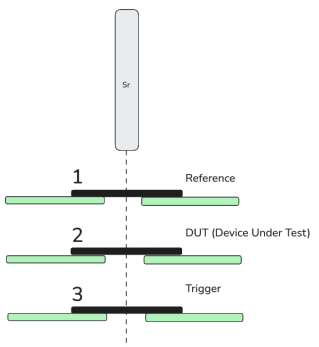
Two main aspects of this work are to evaluate device performance at EoL fluences

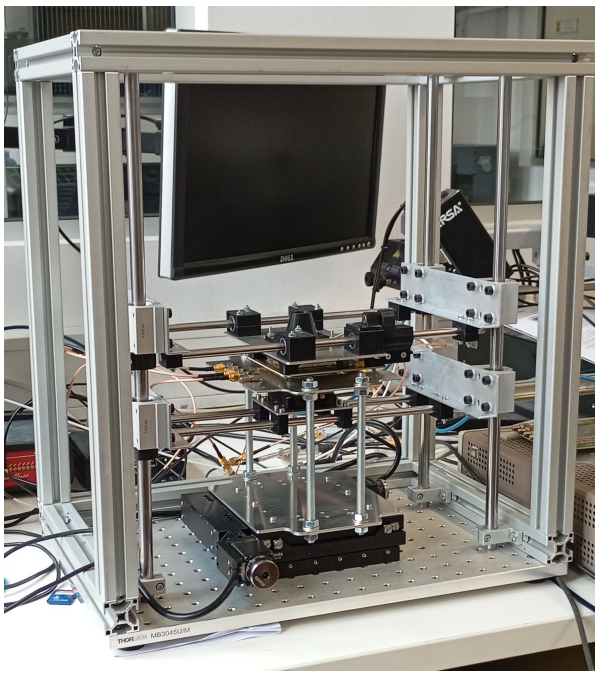
- Verify that performance specifications are met **(70 ps at EoL fluence)**
  - Provide data and models as inputs to simulation (timing and noise performance)
  - Provide insight into device lifetime (replacement interval)
- Verify safety of operation at high voltages **(550 V at EoL fluence)**
  - Could operating at high voltage bias result in destructive sparking between ASIC and sensor dies?

Timing performance measurements

To measure timing performance of HGTD hybrid a new measurement setup has been developed



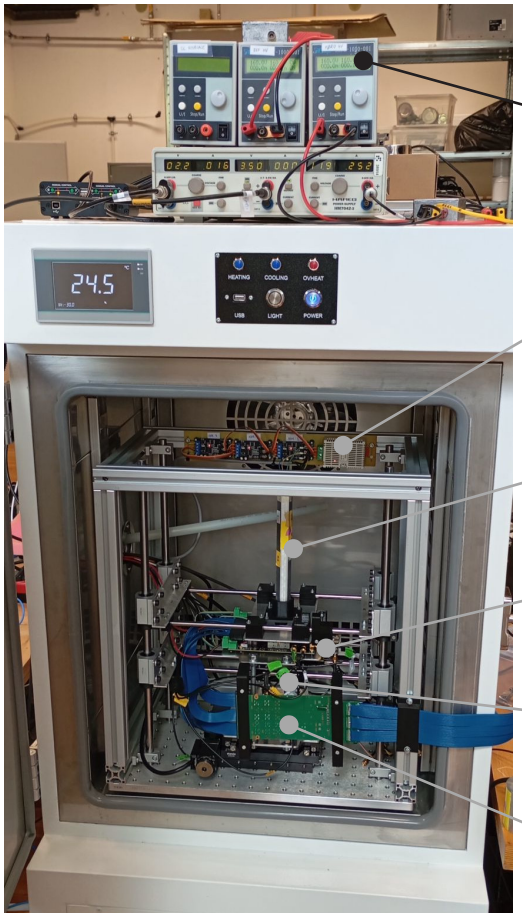


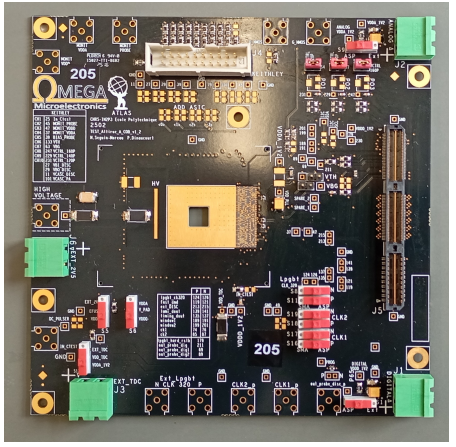


Timing performance is measured using β^- particles from ^{90}Sr source

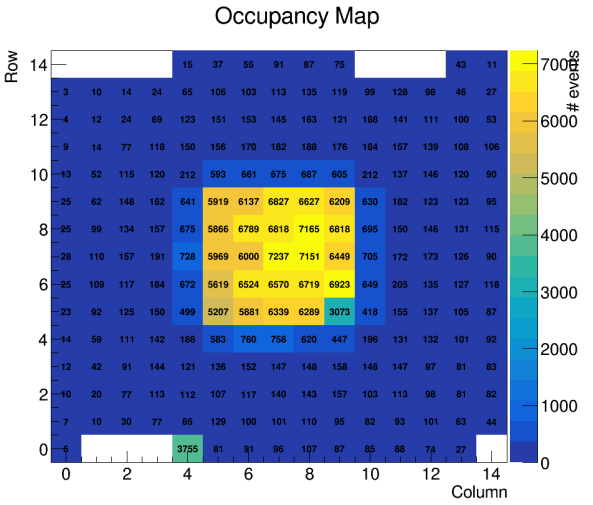
- New setup allows measurements using *3 plane method* (calibration without requiring knowledge of timing resolution of any device - used to characterize reference device)
- Motorized DUT stage and independent movement of reference and trigger planes offers great flexibility
- Mounts for HGTD test boards and other commonly used boards
- Compact dimensions allow use in climate chamber

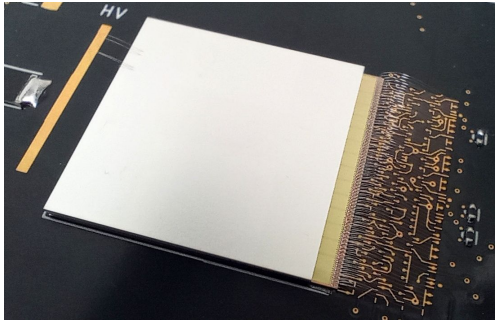
Current HGTD hybrid test setup





HGTD hybrid test board





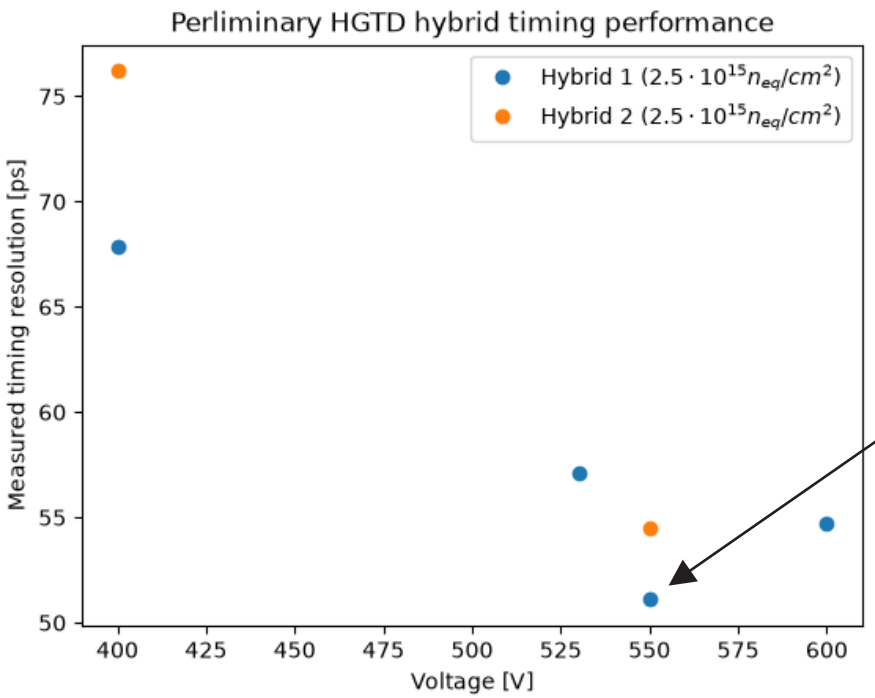
HGTD hybrid wire bonded to test board
(Bojan and Birigita's work, 263 bond wires!)

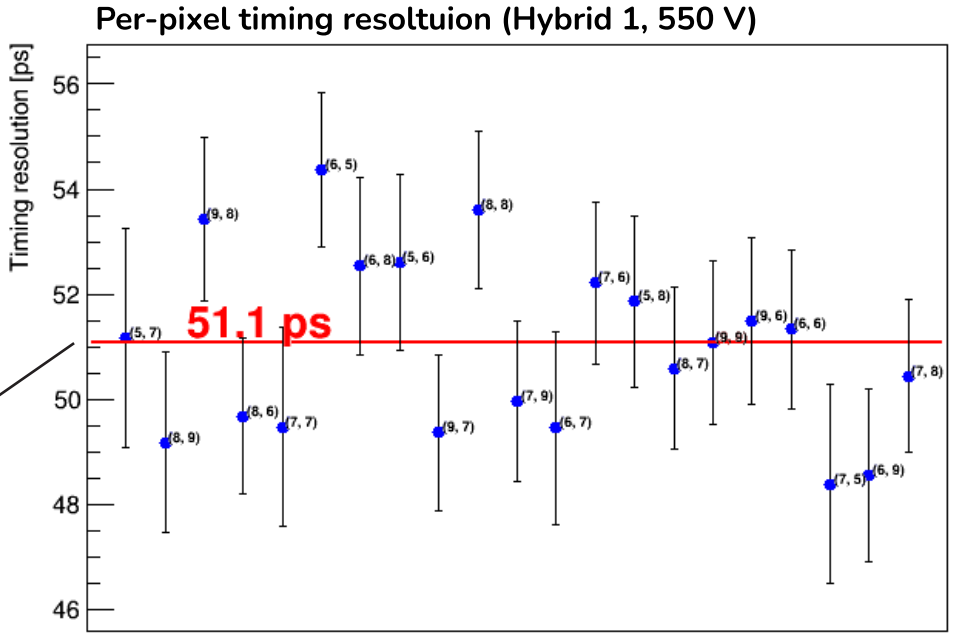
Due to test board geometry limitations only inner 5x5 pixel array can be tested (8 layer 1.6 mm PCB blocks almost all particles coming from source).

In the near future setup will be upgraded to work with modules (2 hybrids on thinner PCB with less layers) which should allow testing of larger area of the device.

Timing performance measurement results

Measurement campaign is still underway, but preliminary results of few different hybrids have already been captured and analyzed (timing performance measured as difference between value reported by ASIC and value obtained from reference device)

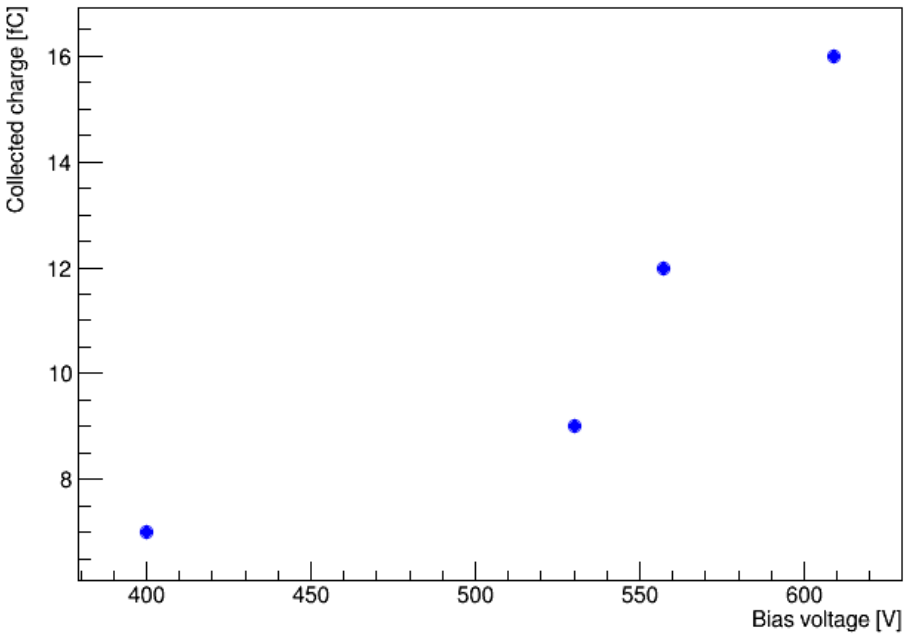




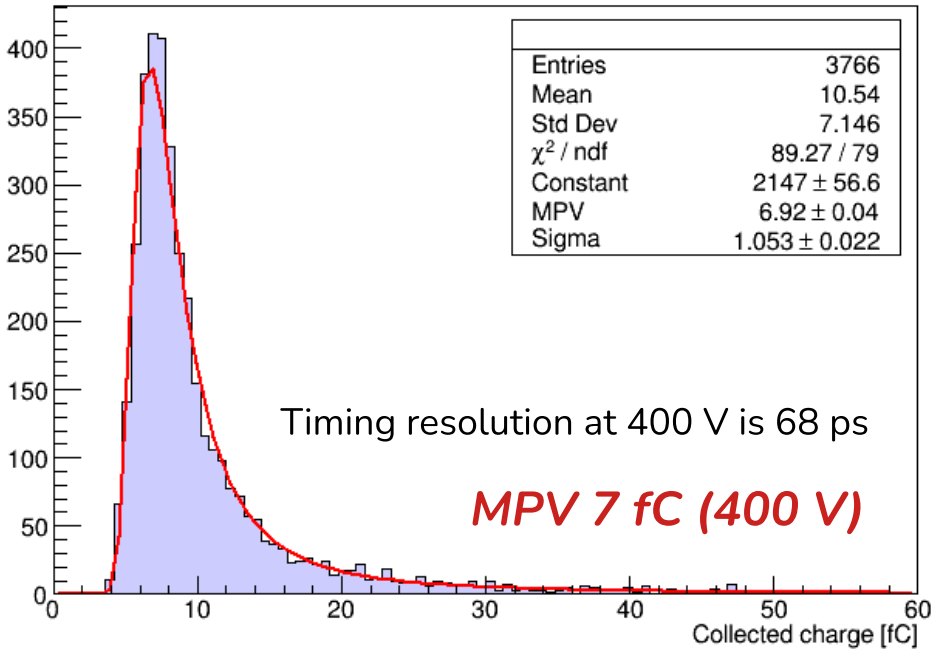
Timing performance measurement results

With calibration of internal transimpedance amplifier collected charge spectrum can be determined.

^{90}Sr collected charge (pixel (8,8))



^{90}Sr collected charge (pixel (8,8), 400 V)



Timing resolution of 68 ps acheved at 400 V still within specifications (70 ps)! Additional 150 V headroom available which corresponds to ~$5 \cdot 10^{14}$ n_{eq}/cm^2. **Expected lifetime of the device up to $3 \cdot 10^{15}$ n_{eq}/cm^2!**

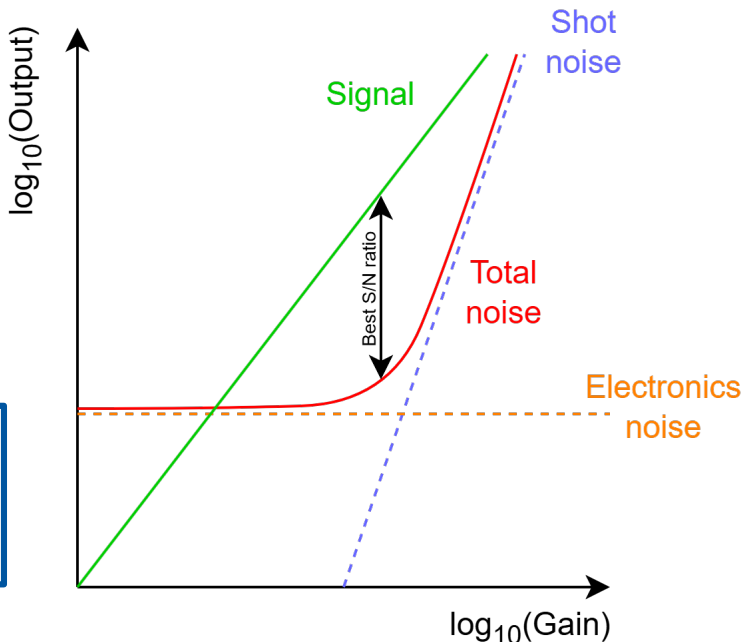
Noise modeling

Irradiation of sensor device results in increase of leakage current, resulting in increase of device noise.

In gain devices main sources of nose are noise from

- Electronics
- Shot noise resulting from thermally generated bulk currents.

To better understand HGTD hybrid behaviour at different operating conditions a new measurement method was developed which allows parametrization of shot noise model



$$\sigma_{\text{shot}} = \sqrt{2\, q\, I_{\text{leak}}\, G_I\, F\, \text{BW}}$$

- q elementary charge
- G_I leakage current gain **n.b.** *(not same as charge gain due to screening)*
- I_{leak} measured leakage current
- F excess noise factor
- **BW** bandwidth

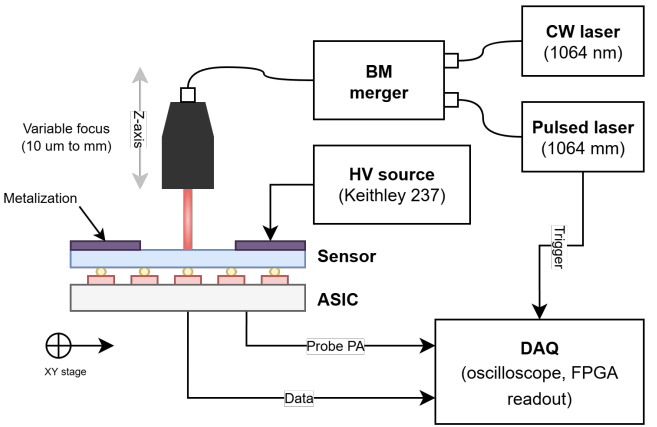
Independent control of leakage current and gain is required!

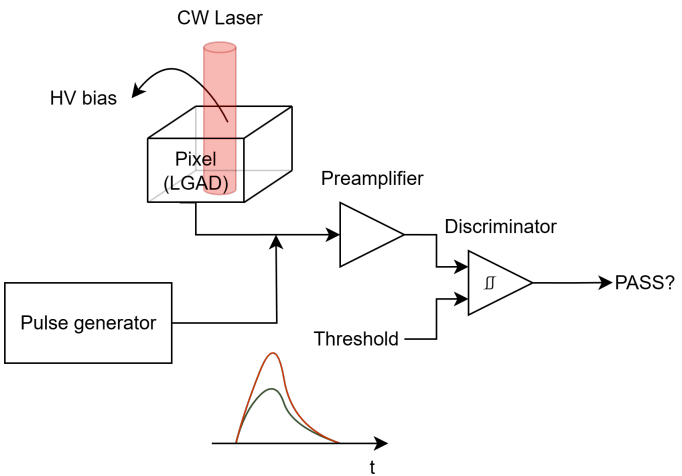
Dual laser based shot noise parametrization method

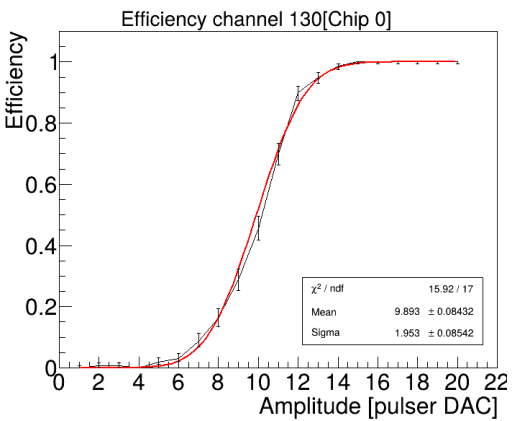
To achieve independent control of gain and leakage current

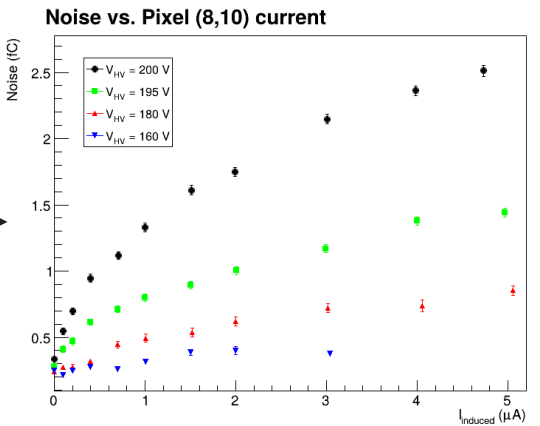
- Continuous wave (CW) laser is used to simulate generation of leakage current in bulk of the sensor
- Independent adjustment of HV bias voltage sets sensor gain

By injecting pulses into pixel under test a S-curve can be fitted to the resulting data and noise value can be extracted

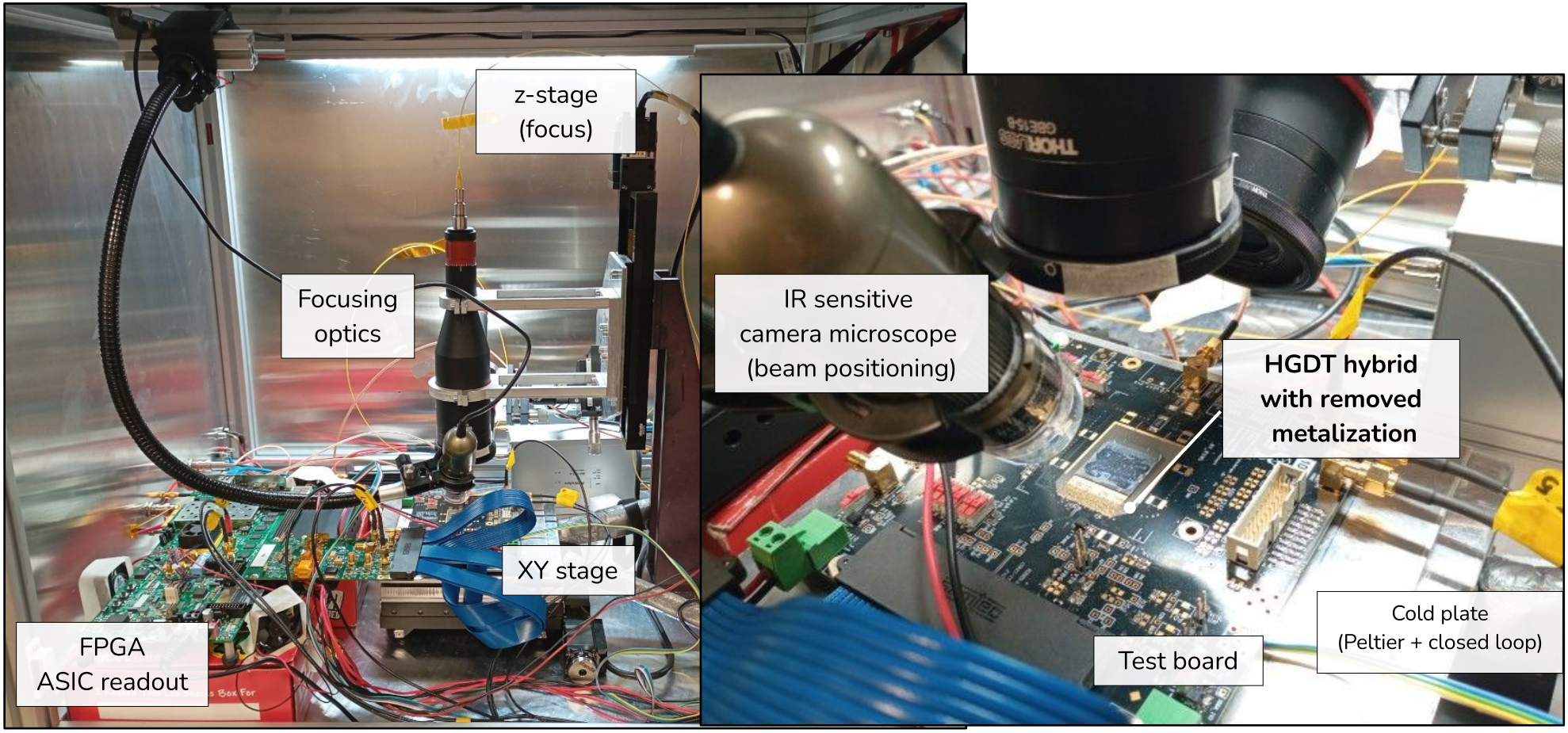




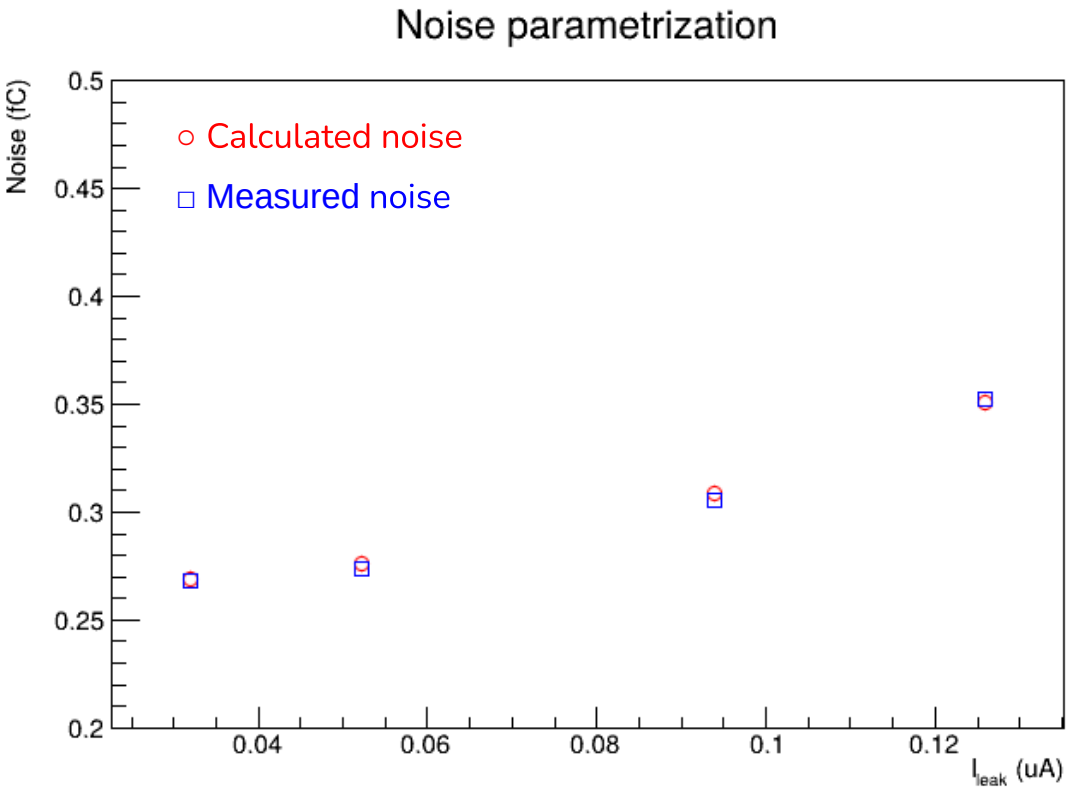




Noise measurements - experimental setup



Noise measurements - HGTD hybrid results



After parametrizing model over space of interest, model was validated using data from pixels without injected leakage current.

Derived model is in good agreement with measured data!

$$\sigma^2 = 0.266^2\,\mathrm{fC}^2 + 0.12\cdot 10^{-3}\,\frac{fC^2}{uA}\cdot F\,G_I\cdot I_{\mathrm{leak}}$$

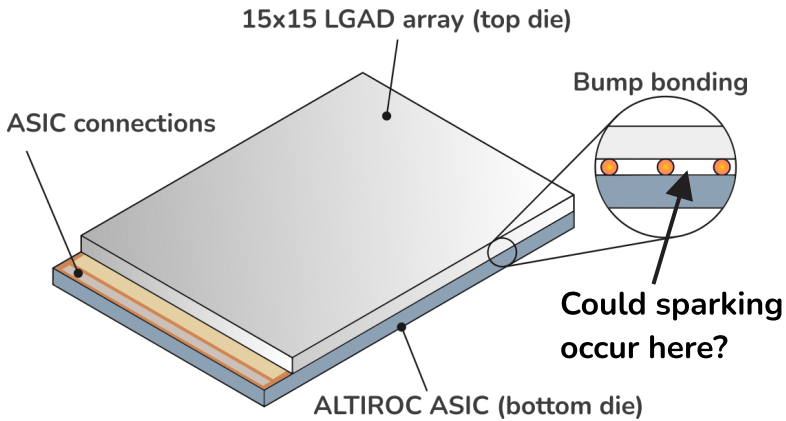
HGTD hybrid sparking tests

HGDT hybrid is projected to operate at voltages of up to 550 V (sensor bias)

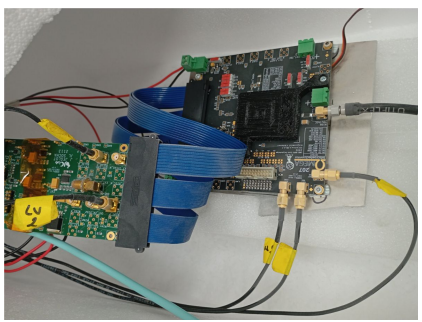
As a result a large potential difference exists between sensor and ASIC dies

- Surface of ASIC is covered with polyamide coating
- A concern was raised whether sparks could occur on dicing edges of two devices (this would require additional steps in production to mitigate)

Goal of these tests is to verify that no sparking occurs between devices (up to and above EoL voltage)



Sensor overlaps ASIC by ~100 um.





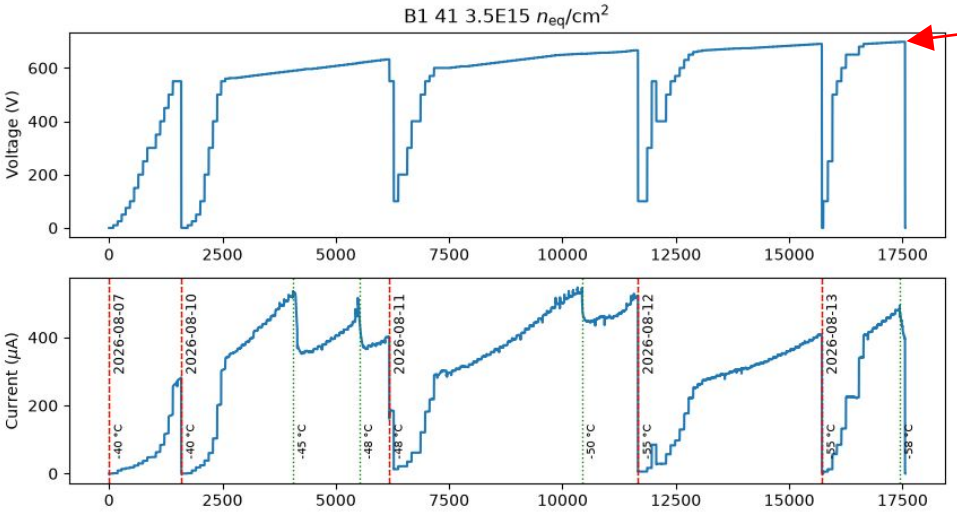
Several testing campaigns with different hybrid devices

- Non destructive testing up to 600 V ($2.5 \cdot 10^{15}$ n_{eq}/cm^2)
- Destructive testing until failure **($3.5 \cdot 10^{15}$ n_{eq}/cm^2)**

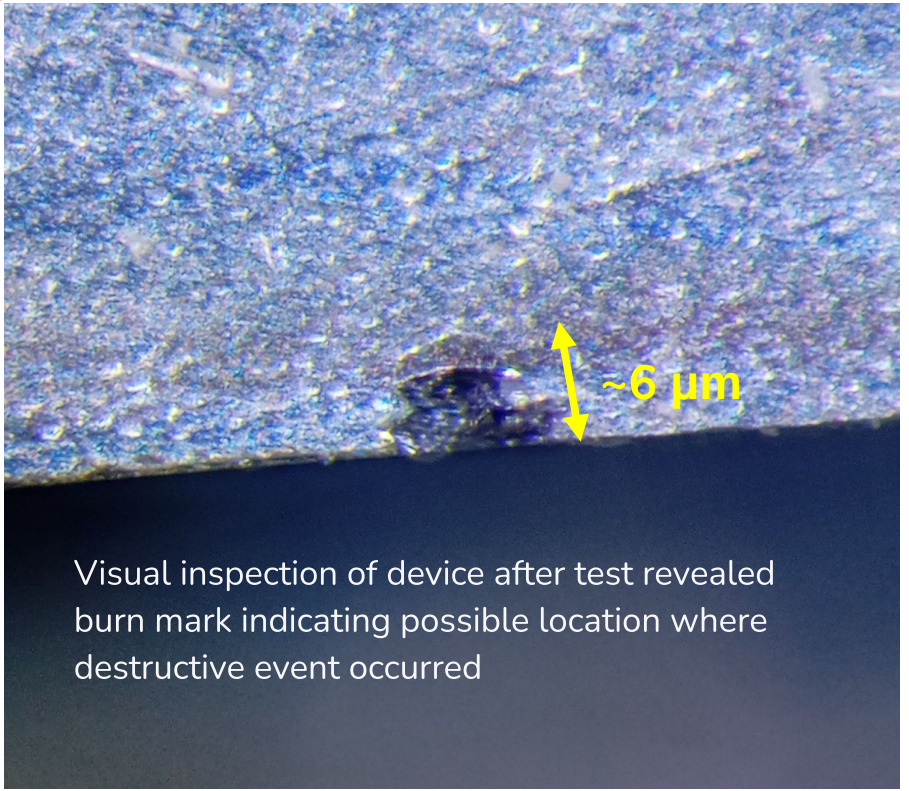
Tests so far did not reveal any solid evidence that would indicate sparking issues, but more tests are underway.

HGTD hybrid destructive testing

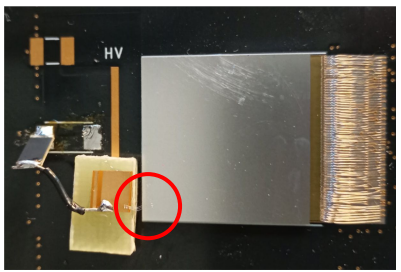
Test performed over several days until destructive event occurs. Important: **hybrid still fully operational at 50% more fluence than specified** (EoL).

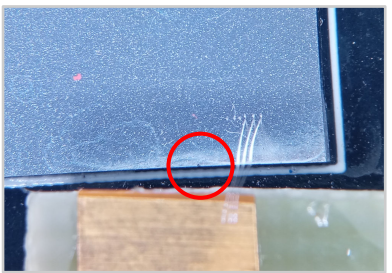


Failure at 698 V!



Visual inspection of device after test revealed burn mark indicating possible location where destructive event occurred





Research work timeline and outlook

Preliminary timing performance results indicate performance and expected lifetime of the hybrid is better than specified (operation possible up to $3 \cdot 10^{15}$ n_{eq}/cm^2 with 70 ps timing resolution)

- More statistics is required, tests with additional hybrids in the near future (20 hybrid devices)
- Upgrade setup to test HGTD modules (2 hybrids on same PCB - same as in actual detector)

Developed noise parametrization is an important input to detector simulation

Sparking tests so far did not reveal any sufficient evidence that sparking is occurring at high sensor bias voltages, but additional tests are planned

Work and results presented so far is an important input to better our understanding of how HGTD will perform over its lifetime

