Investigating Energetic Heavy Ions in The Solar System with the Juice Mission

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JUpiter ICy moons Explorer (JUICE)

Cosmic Vision
L-class Mission

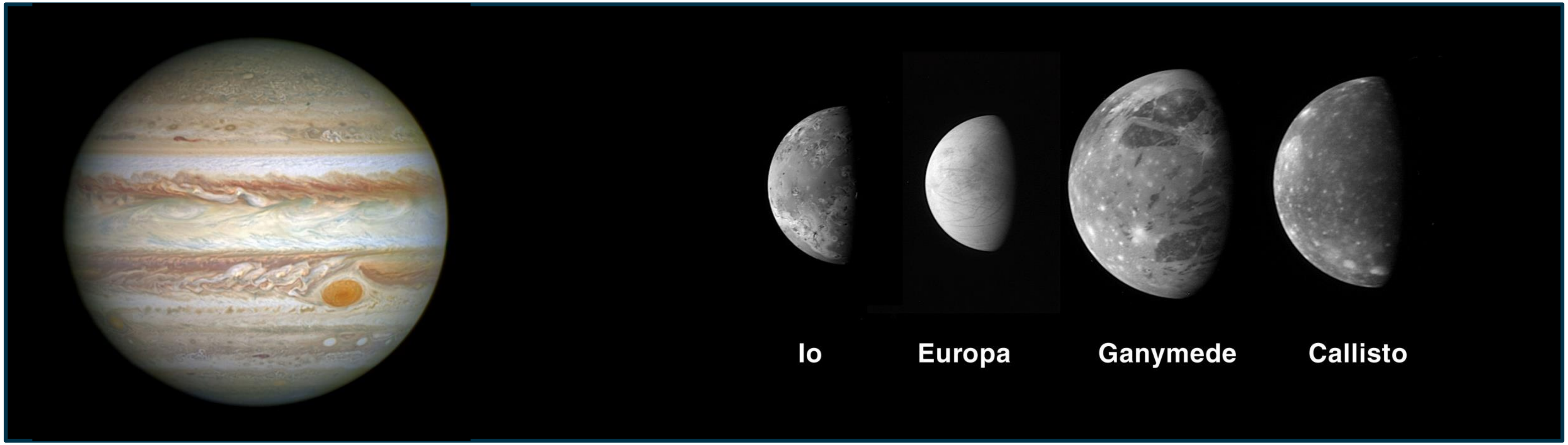
What are the conditions for planet formation and emergence of life?

- Emergence of habitable worlds around gas giants

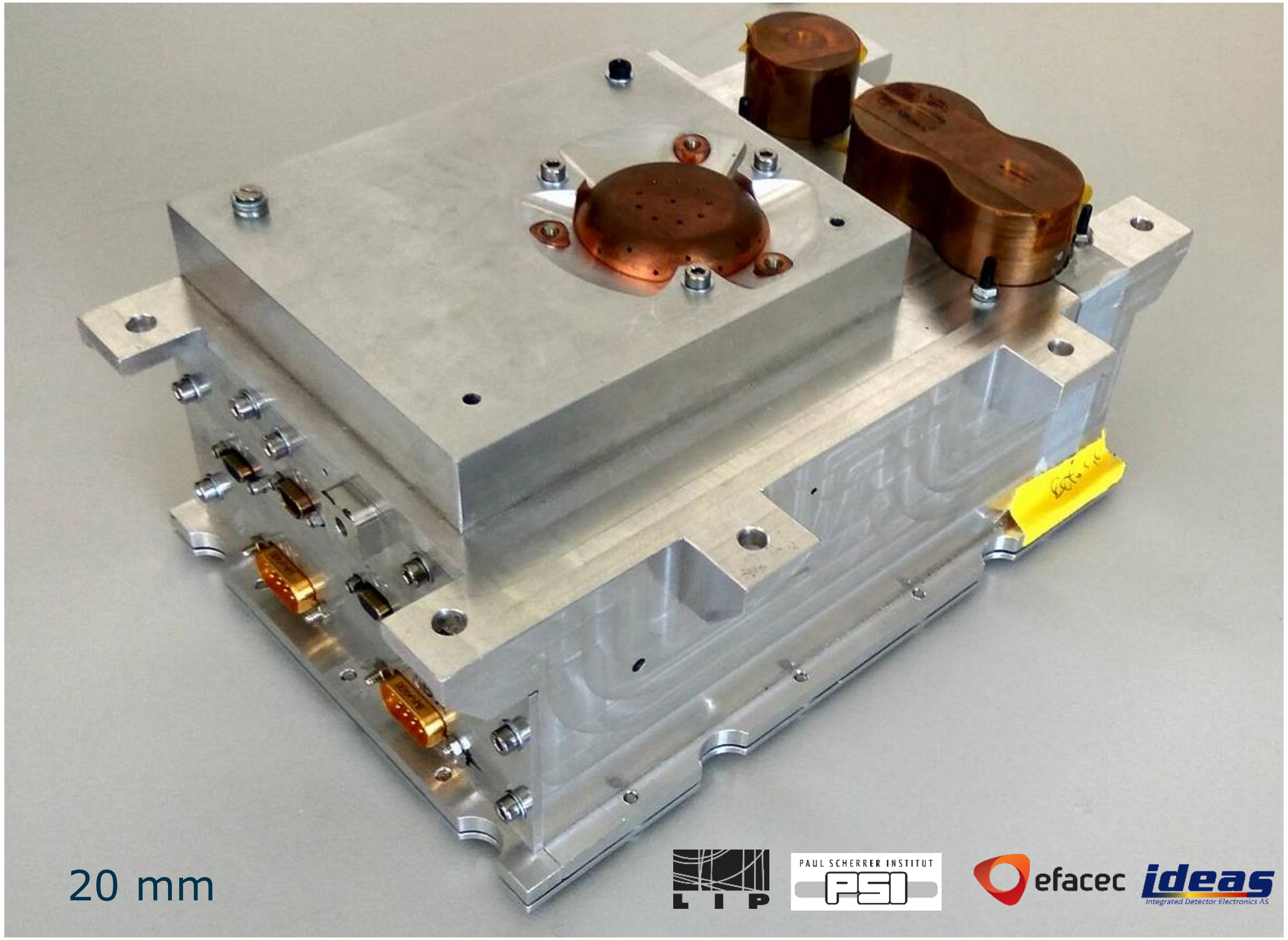
How does the Solar System work?

- Jupiter system as an archetype for gas giants

Launched on 14th April 2023



RADiation hard Electron Monitor (RADEM)



Requirements:

- Measure electron flux
  - Spectral range 300 keV – 40 MeV
  - Peak Flux 10^9 e/cm^2/s
  - Electron Directional Distribution

- Measure proton flux
  - Spectral range 5 MeV– 250 MeV
  - Peak Flux 10^8 p/cm^2/s

- **Measure Heavy Ion population**
  - **From Helium to Oxygen**

- Dose determination

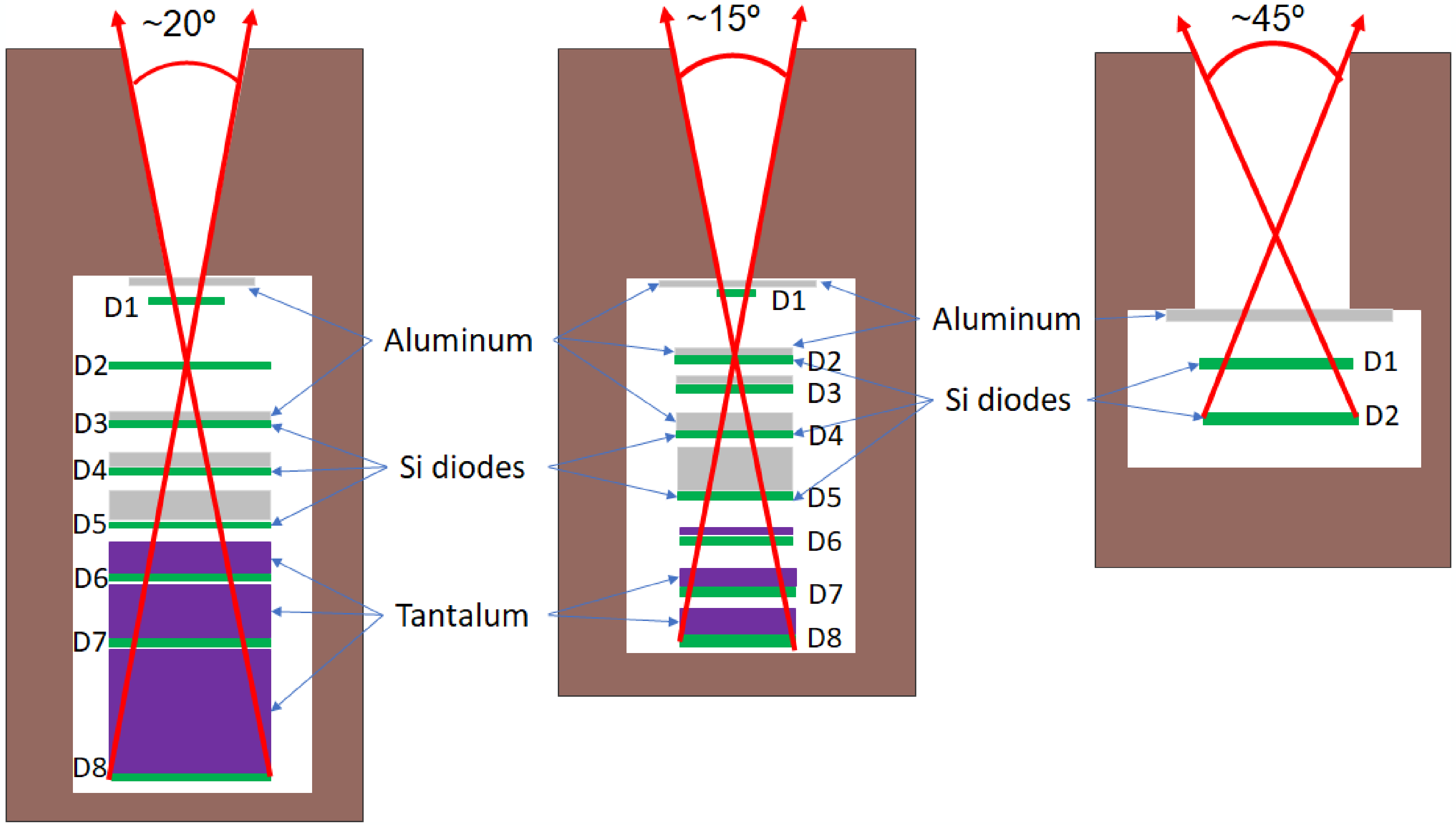
- Low mass (~3 kg currently)
- Low power

Detectors

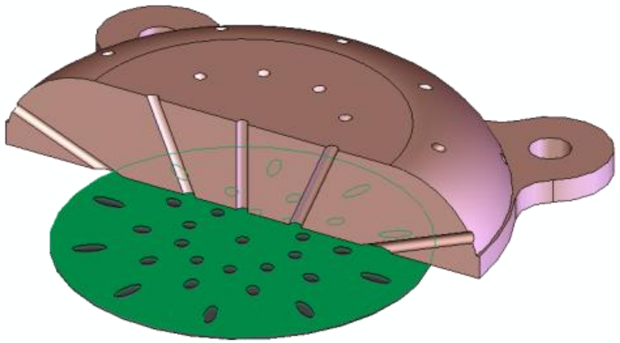
PDH

EDH

HIDH



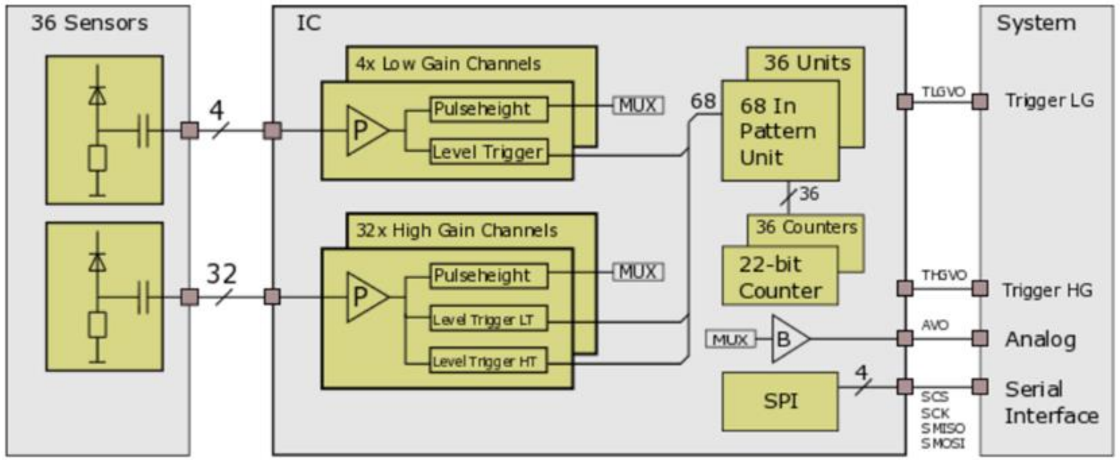
Directional Detector

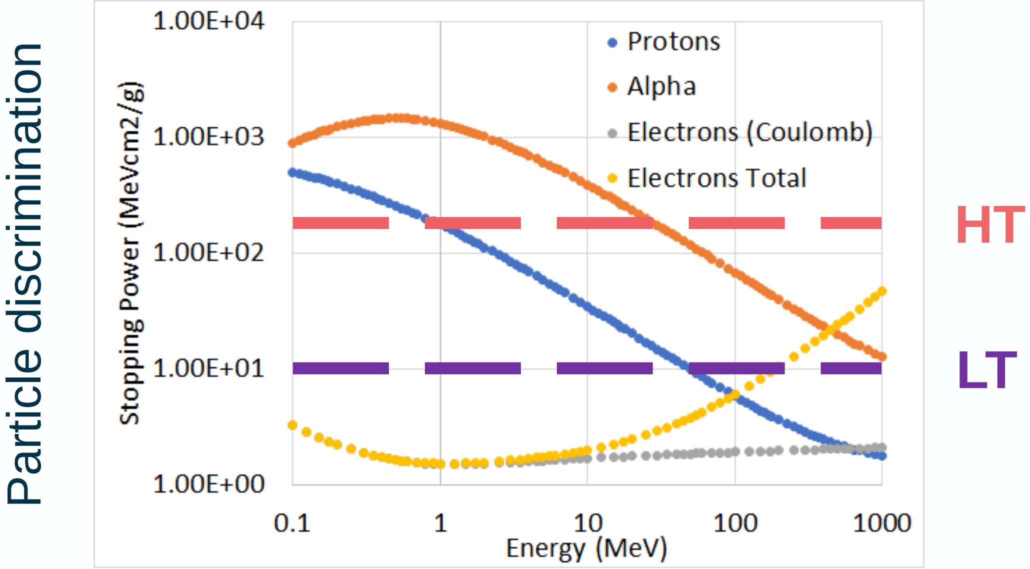


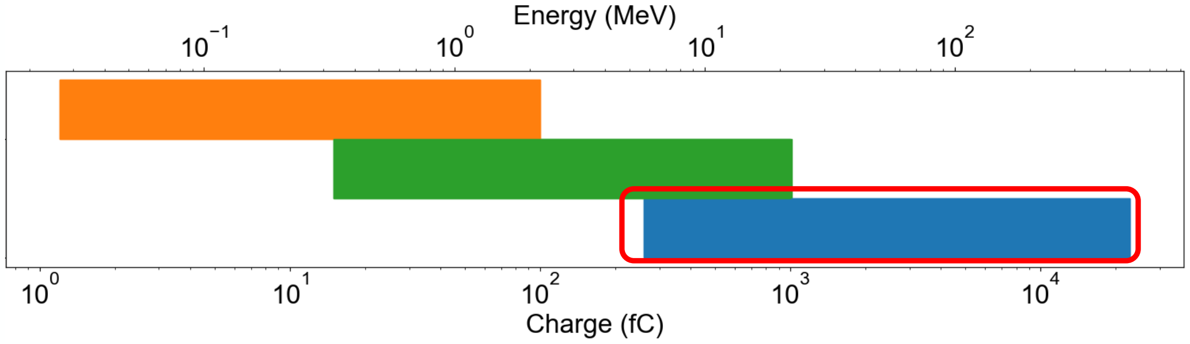
Front-end electronics performed by an IDE3446 ASIC

- ❑ HIDH connected to Low-Gain channels
- ▪ One programmable Threshold
- ▪ Low (LGLT) 10-bit DAC [~0.1-~26 pC]

- ❑ Other sensors connected to High-Gain channels
- ❑ Two Programmable Thresholds:
- ▪ Low (HGLT) 10-bit DAC [~0.1-~100 fC]
- ▪ High (HGHT) 10-bit DAC [~10-~1000 fC]





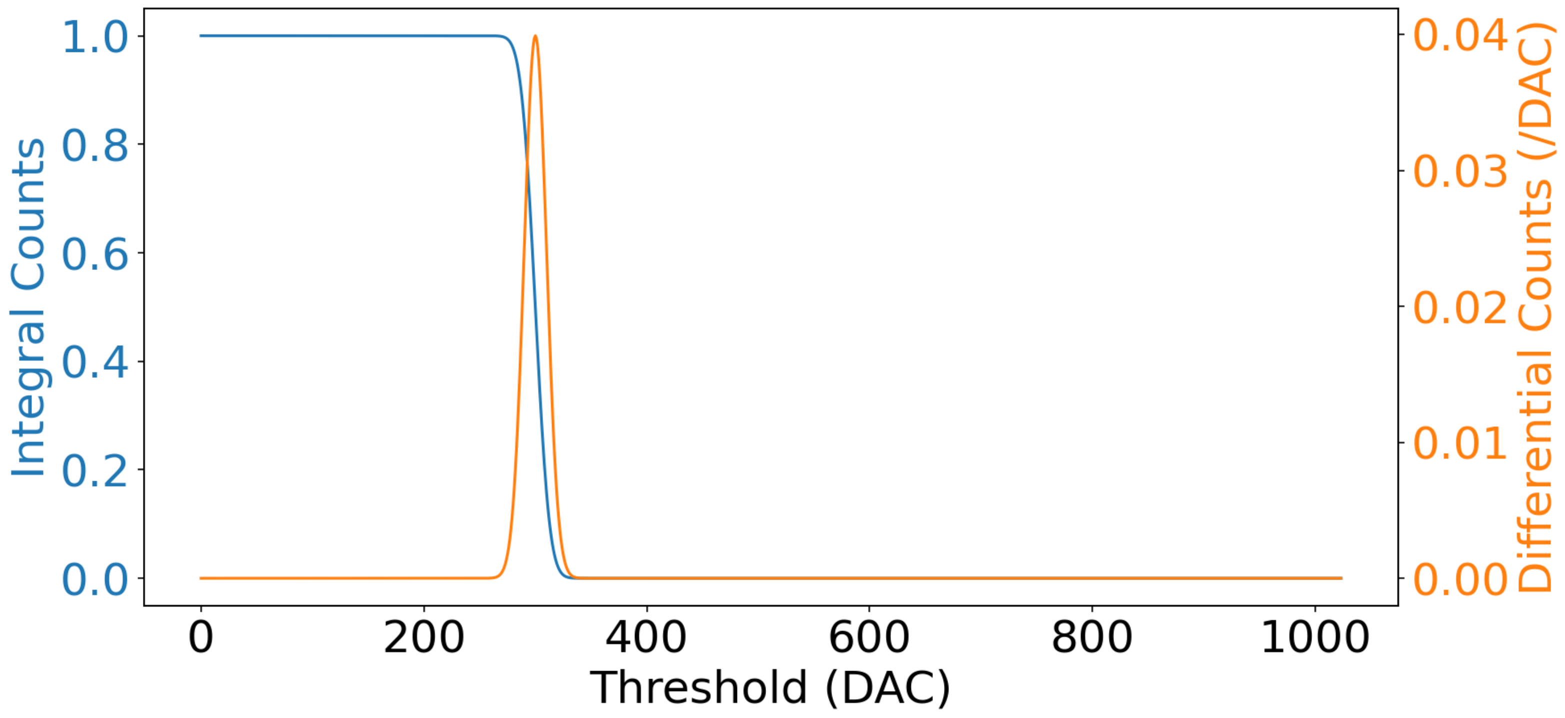


- Global gain adjustable (10-bit DAC)
- Coincidence time adjustable (10-bit DAC)
- Temperature dependence

Heavy Ion Detector Head (HIDH)

Signal Processing

Pulse height analysis is not performed
Differentiating DAC scans can overcome this limitation
Not feasible in flight



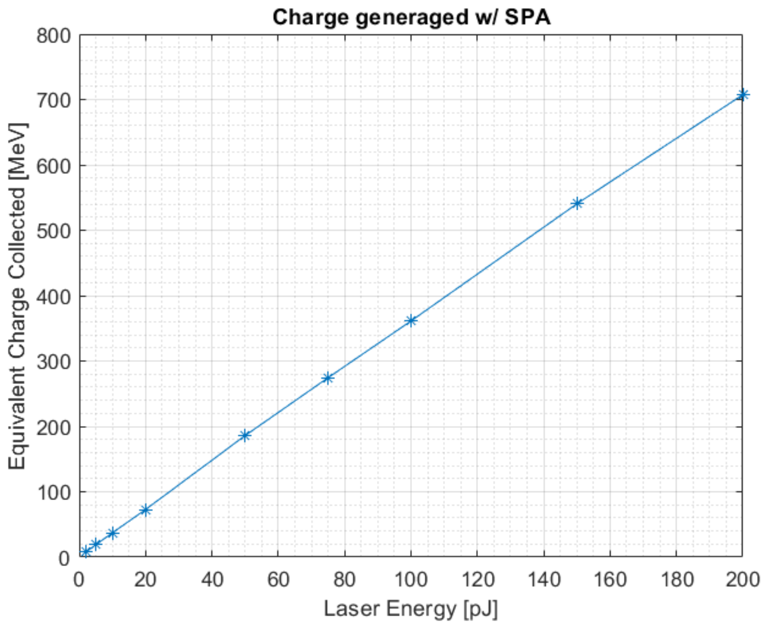
Calibration Plan

Detector
- Breadboard model
- Diode from the same batch
- -80V
- Same front-end (ASIC)

Laser Tests
- Energies encompass the ASIC dynamic range
- Fast (tuneable rate)
- Physically not the same as heavy ions

Beam tests at RADEF
- Energy calibration with Heavy Ions
- Slow and expensive
- Limited configuration space characterization

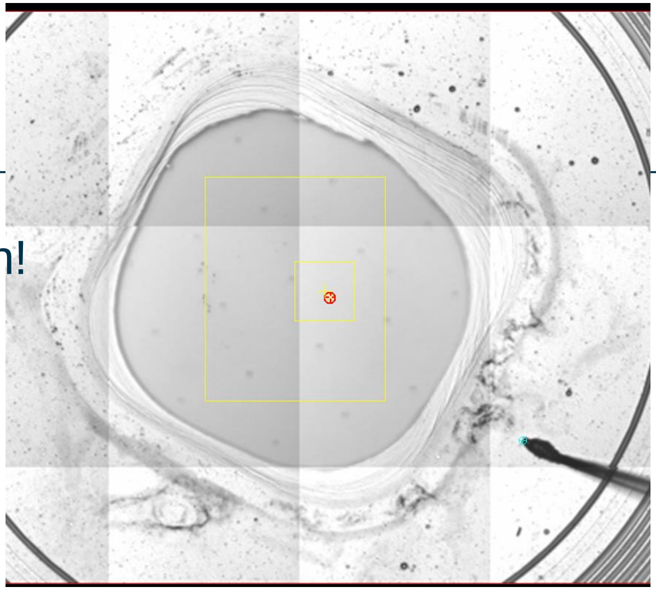
Comparison done before with a PIPs diode



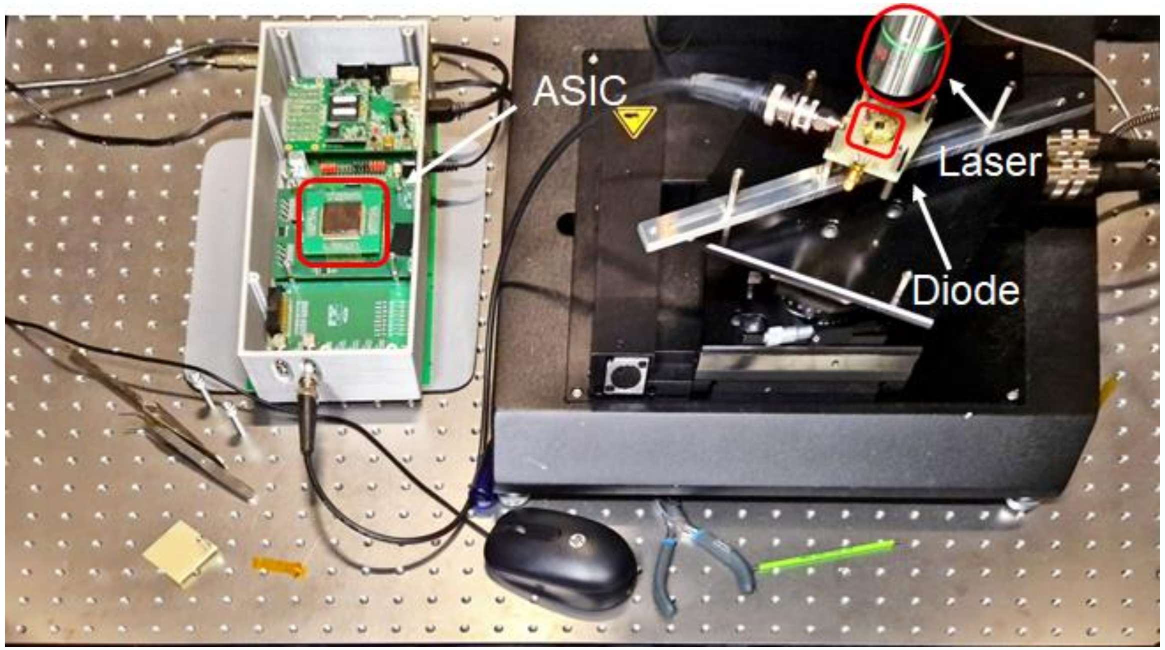
Laser Testing

Test conditions
- Single Photon Absorption
- Polished diode (done at ESTEC)

Thanks Florian!



Physical Tests
- Energy response
- Deadtime
- GLOBAL_GAIN characterization
- Temperature dependence



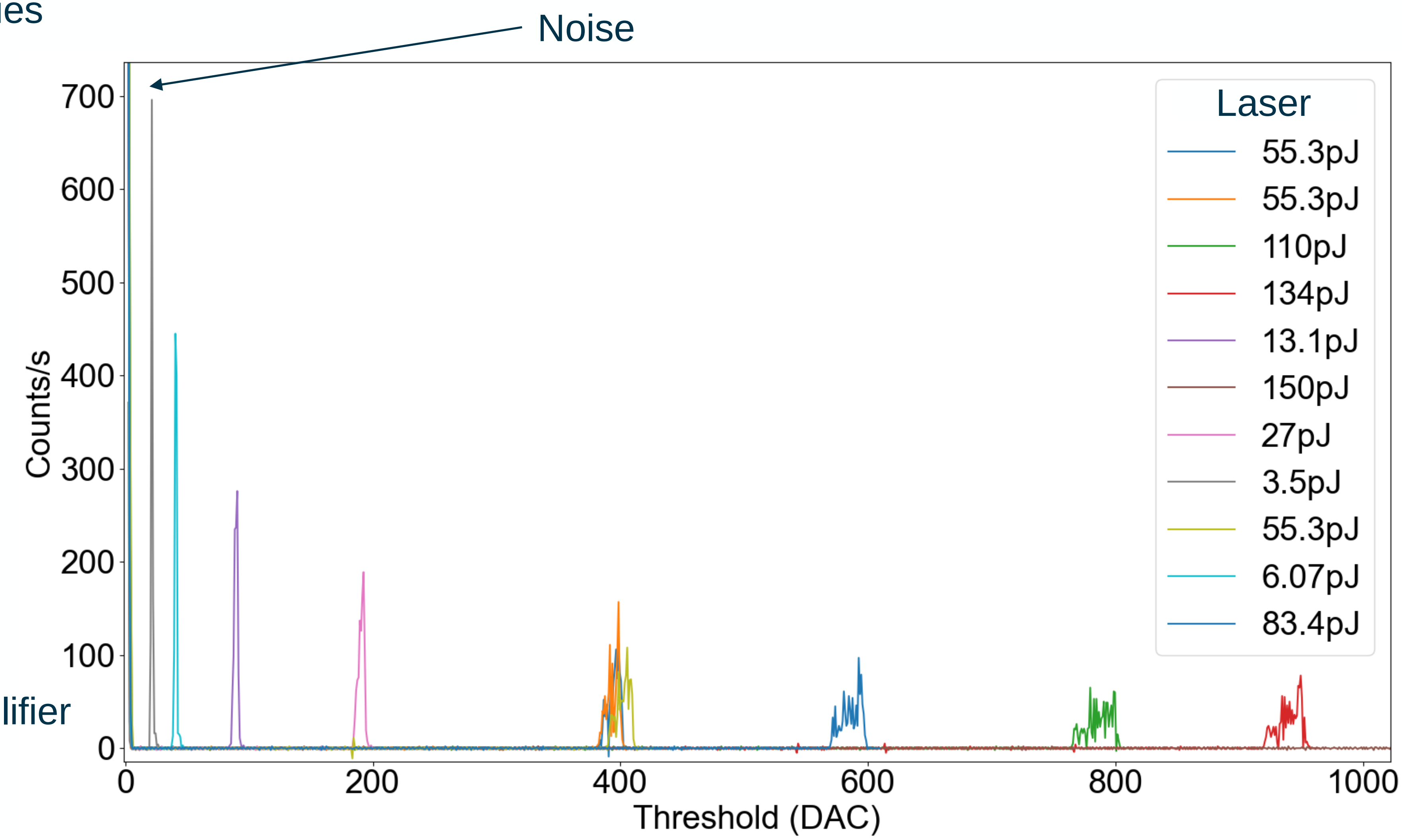
Laser Test – Energy scan

- Tested with several laser energies
- 55.3 pJ repeated 3 times
- 1kHz
- 1 second acquisition

- ✓ Detector responds to energy
- ✓ Full range tested

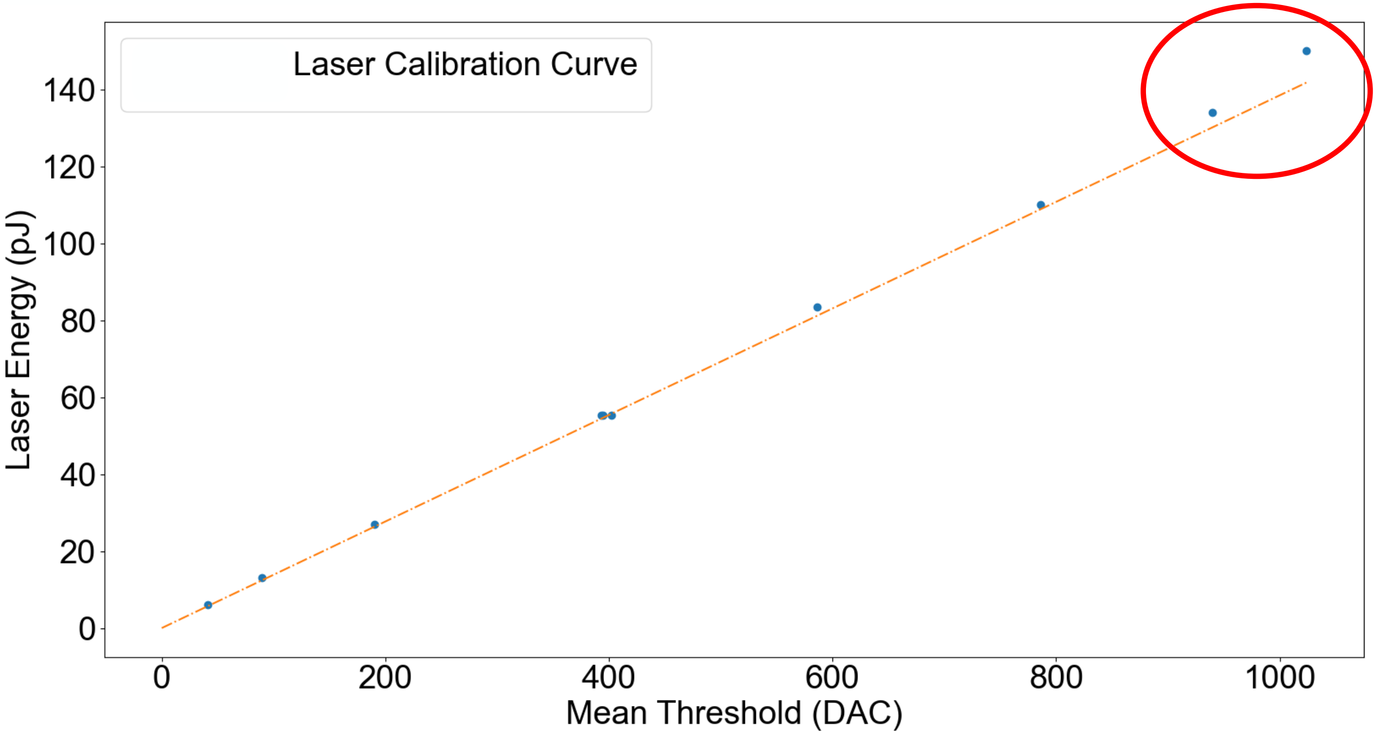
- ❖ Spread increases with energy
- ❖ Energy fluctuates over time

- Both observed with charge amplifier
- Laser?



Laser Test – Energy scan

- ✓ Mean peak value increases linearly with laser energy
- × Exception at very high DAC – ASIC feature



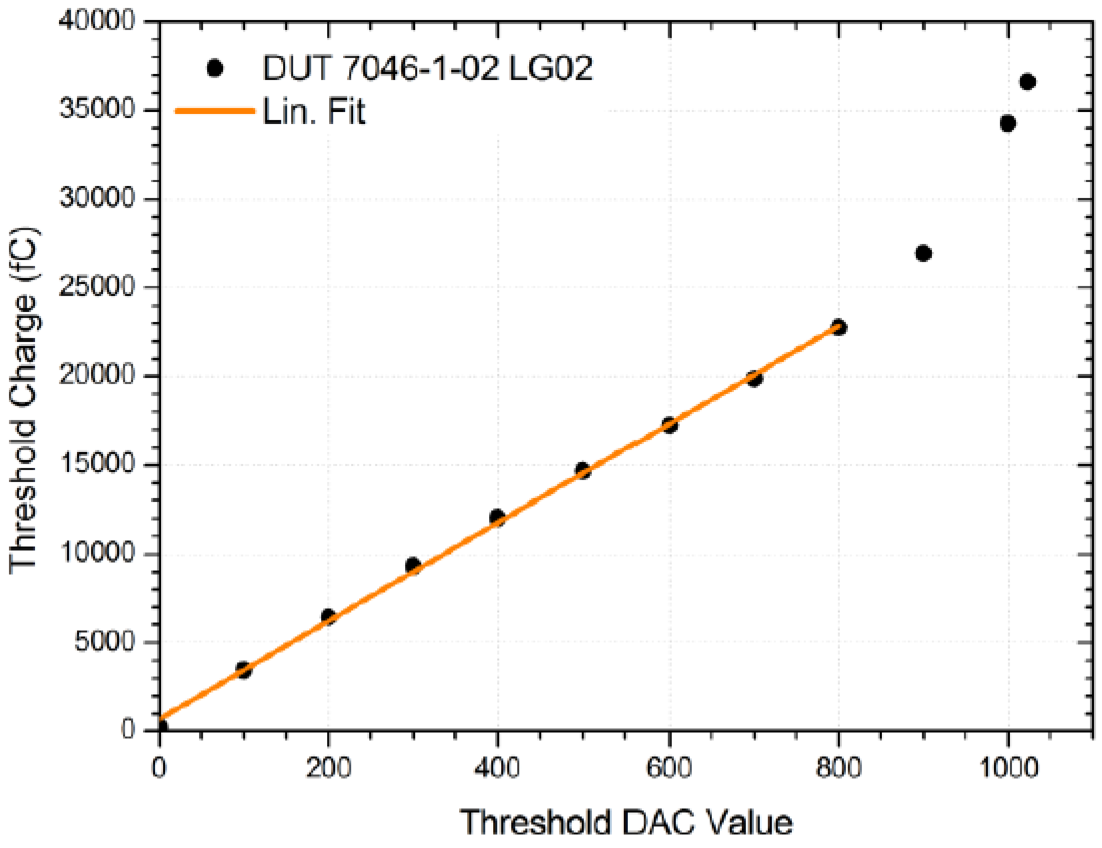


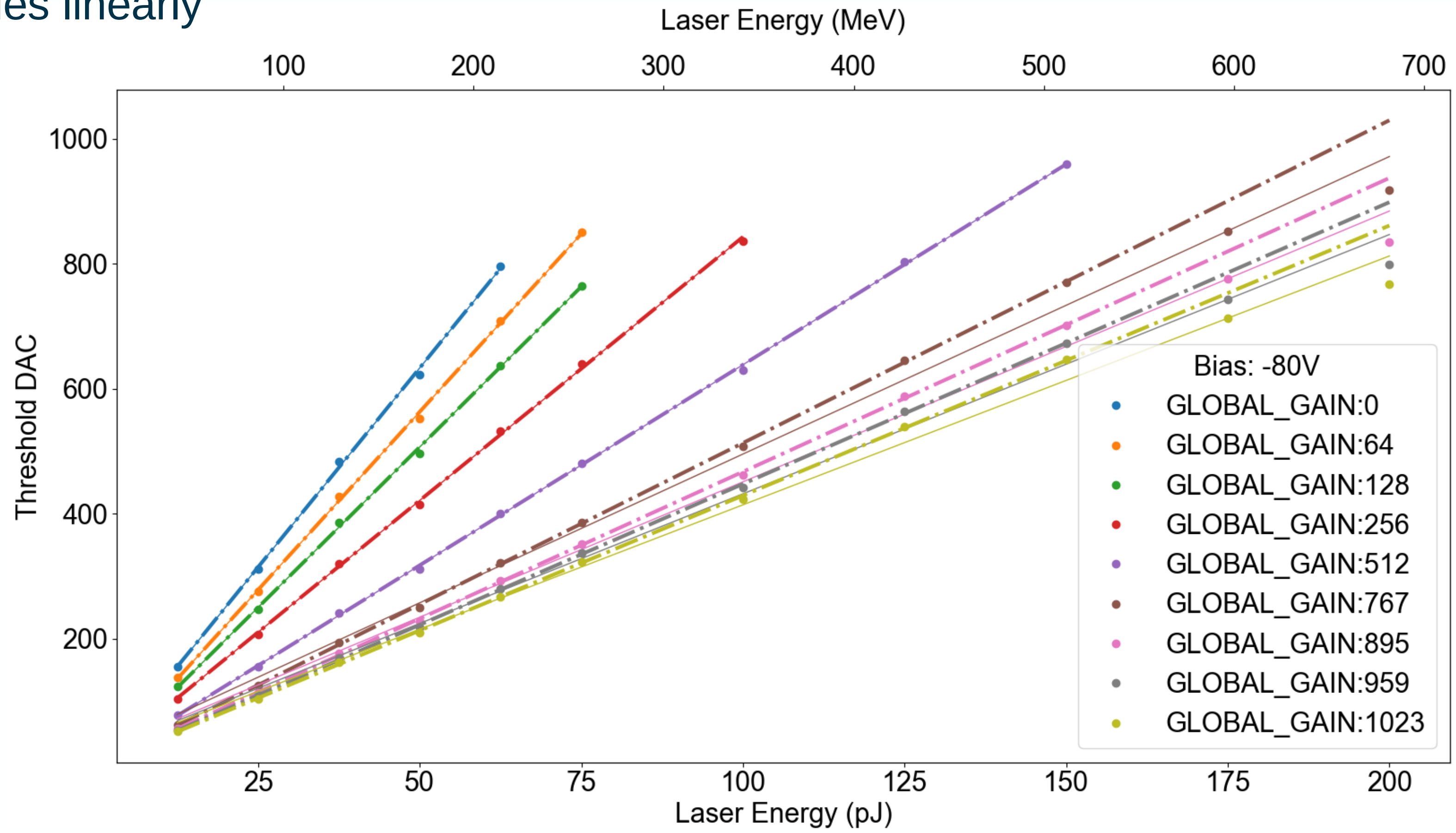
Figure 16: Calibration of the threshold charge over threshold DAC value in a low-gain channel.

Source: ASIC datasheet

Laser Test – GLOBAL_GAIN calibration

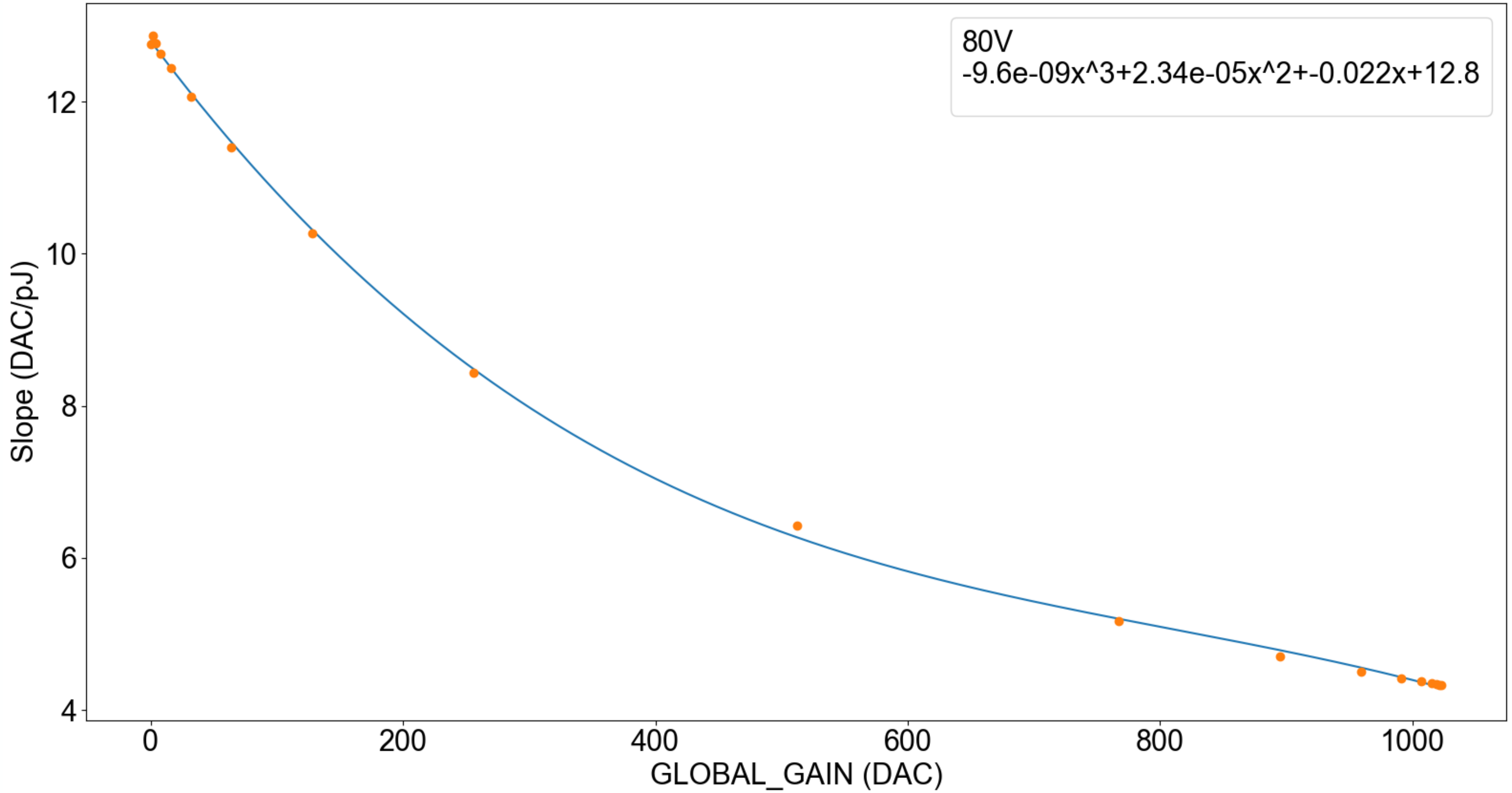
GLOBAL_GAIN can be tuned

- Tests done with several GLOBAL_GAIN Values and laser energies
- Threshold varies linearly



Laser Test – GLOBAL_GAIN calibration

- Large variability
  - Min ~4.32 DAC/pJ
  - Max ~12.74 DAC/pJ



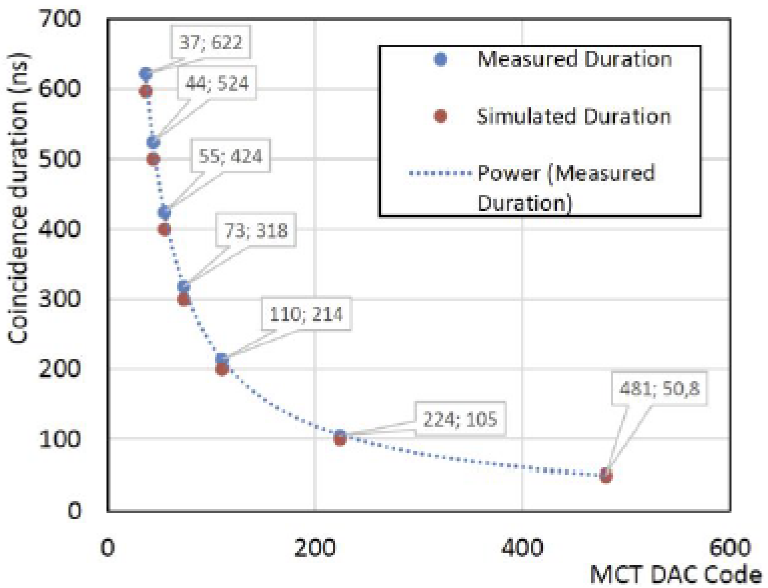
Deadtime

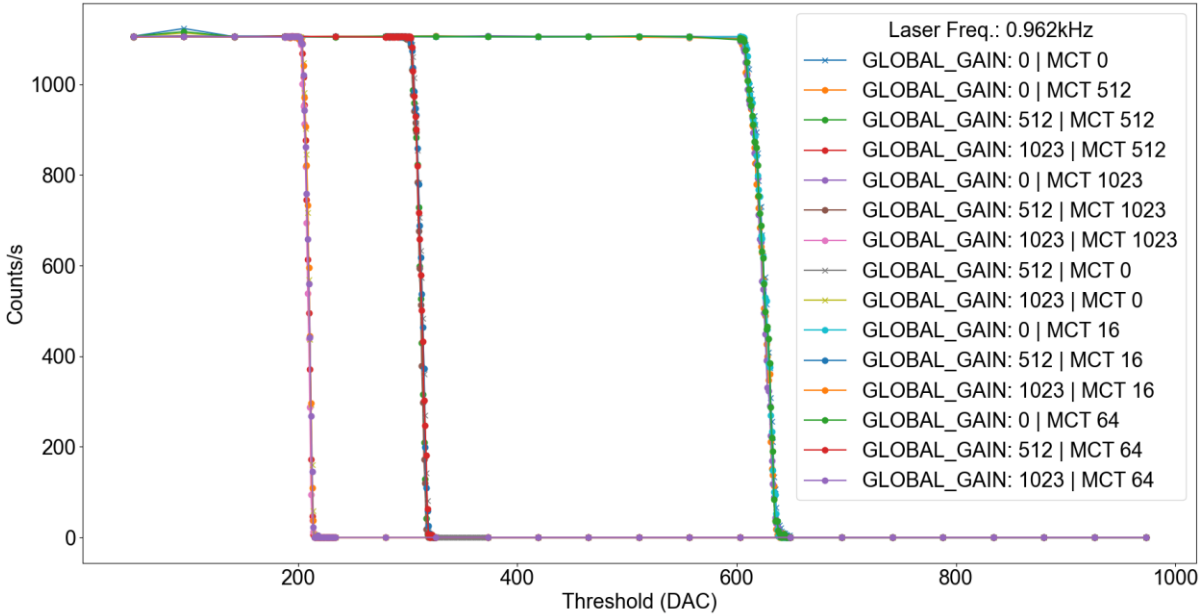
Tested response to increase of flux

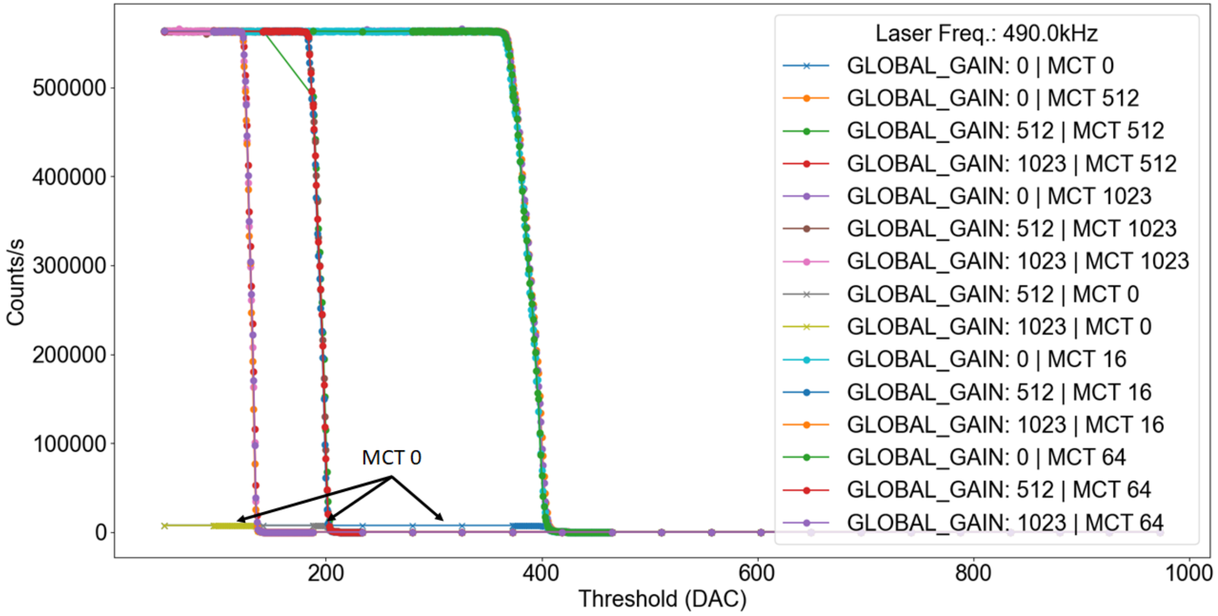
- ❑ Laser energy 50 pJ
- ❑ Freq. from 1 kHz to 490 kHz
- ❑ Several GLOBAL_GAIN and Coincidence time (MCT) tested

✓ No differences found

Only exception at MCT = 0 limited at ~5k counts/s



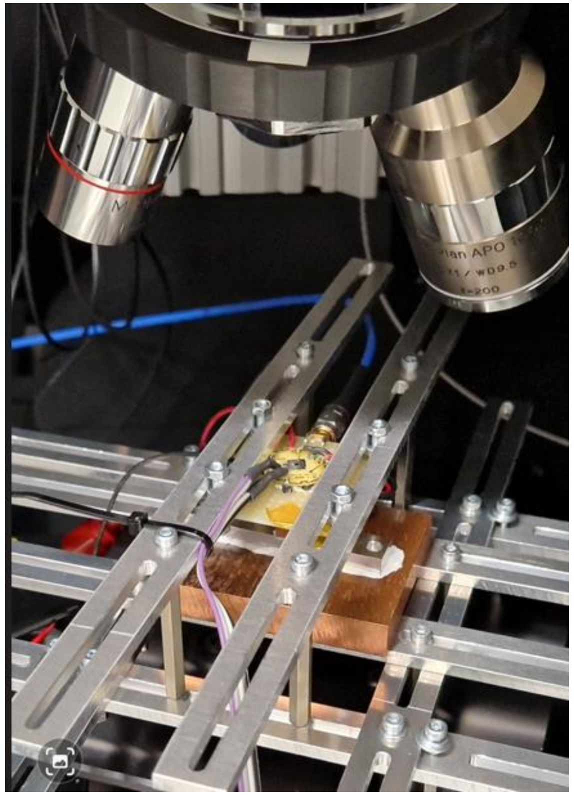


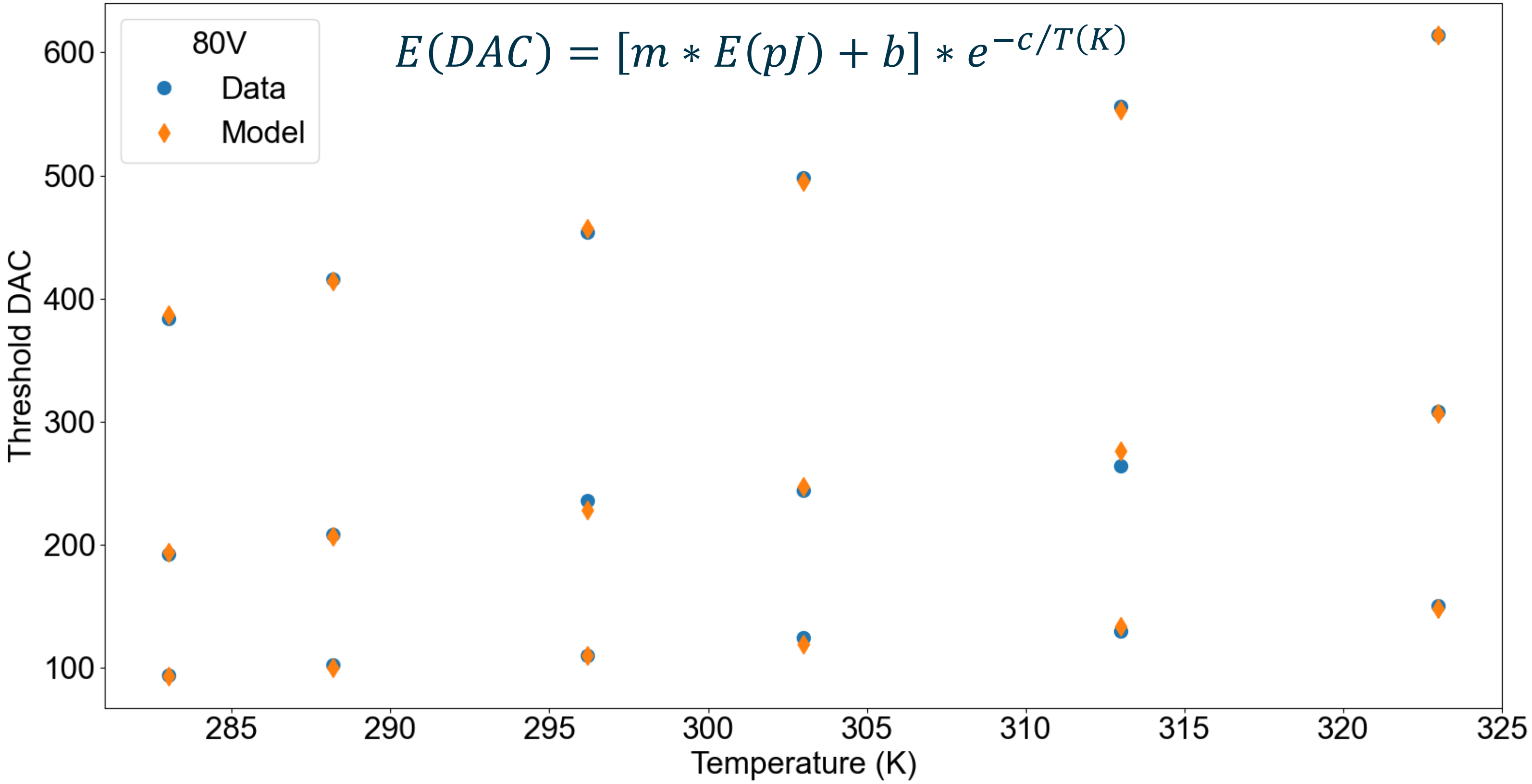


Temperature dependence

- ❑ Temperatures changed from 10 to 50 °C
- ❑ Peltier used to increase temperature
- ❑ Reversed polarity to decrease temperature
- ▪ nitrogen to stop condensation

- ❑ Model including Boltzmann distribution was fitted to the data
- ❑ Model in good agreement with the data!

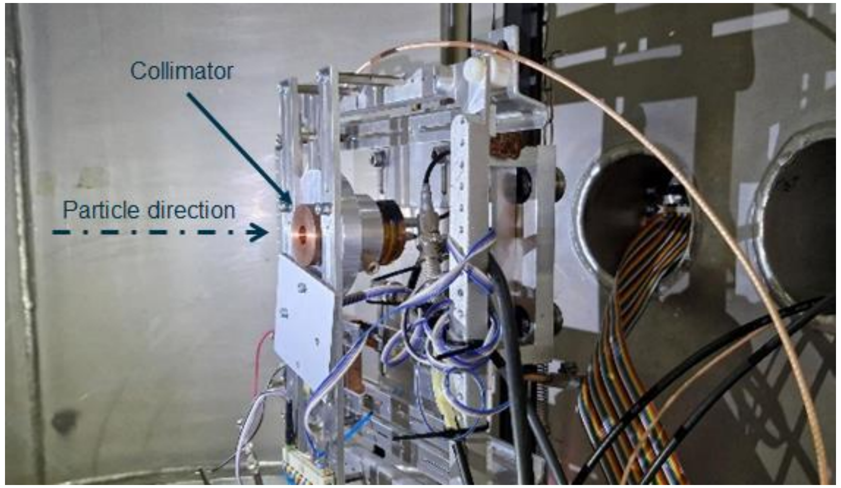




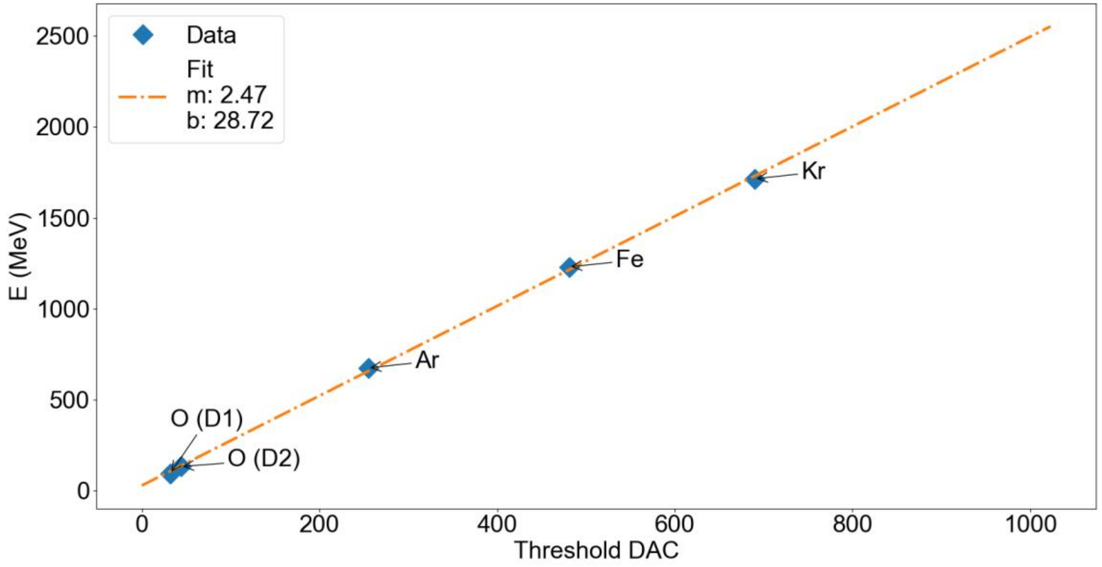
Thanks Thomas

Comparison to Heavy Ions

Energy (MeV/nucl.)	Ion Species	Total Energy (MeV)	Estimated Depos. Energy* (MeV)	
			Top Sensor (D1)	Bottom Sensor (D2)
	Kr	1826	1826	0
22.0	Fe	1254	1254	0
	O	374	95	133
16.3	Ar	657	657	0



- ❑ Several ion species tested
- ❑ Linear relationship between energy and threshold
- ❑ Technical issues made it in-practical to compare to the laser results
- ❑ Re-run would be nice



Conclusions

Full parametric characterization of the HIDH breadboard performed including:

- ❑ Energy
- ❑ Gain
- ❑ Coincidence time
- ❑ Temperature

Threshold behaves linearly up to ~ 800 DAC units

Gain can be adjusted from 4.32 to 12.72 DAC/pJ

Detector does not saturate up to ~490kHz.

Showed that temperature dependence can be modelled by a Boltzmann distribution

Lasers are cool! It would take us 1000h with heavy ions.

Special thanks to team

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