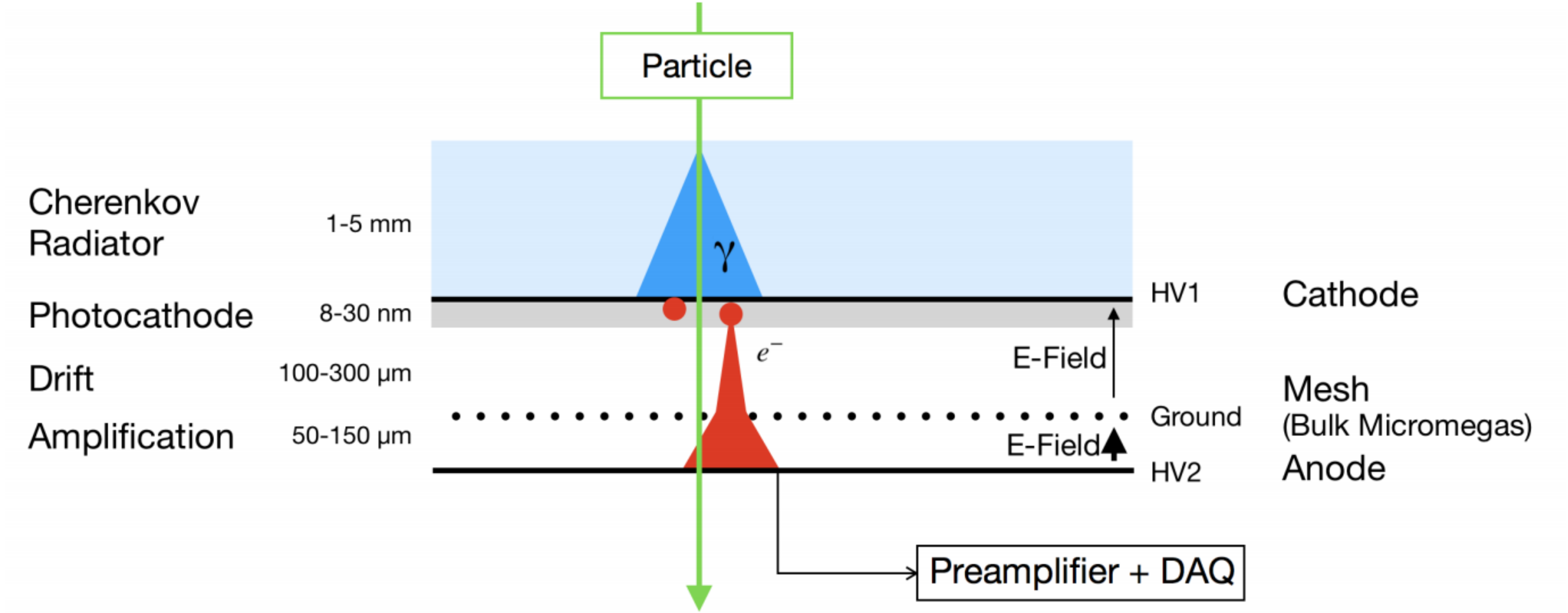
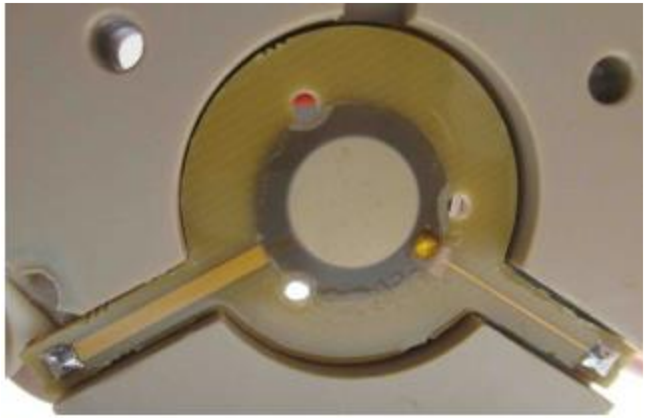
PICOSEC update: improvements in gain uniformity of 100 channel prototype and single pad detector tests

Antonija Utrobicic on behalf CERN EP-DT-DD GDD group

and PICOSEC Micromegas Collaboration

PICOSEC detector concept

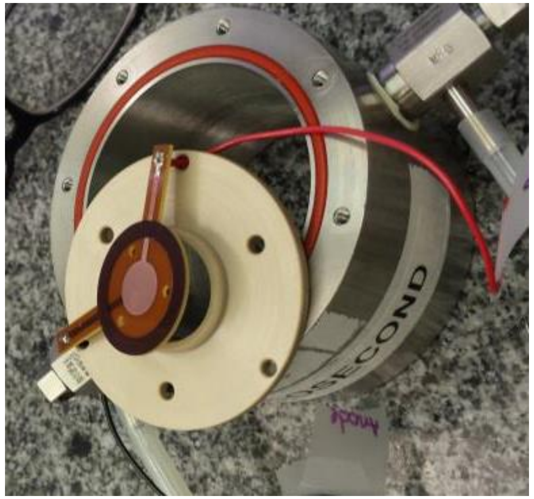




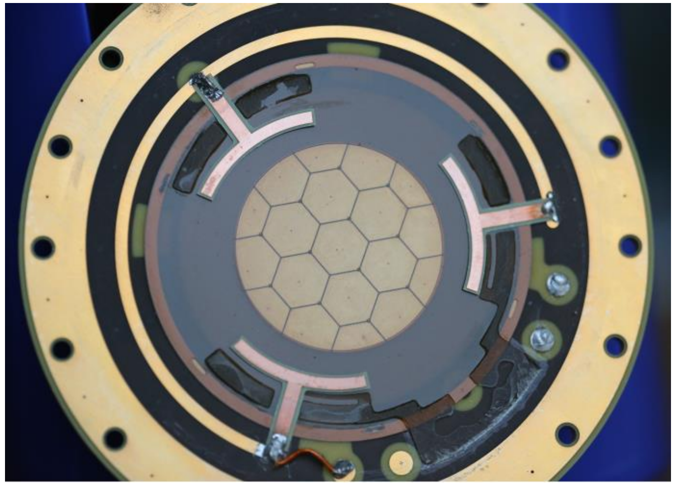
- Purpose: give **precise timing** information in the passage of the particle. Timing resolution of order of tens ps.
- **Cherenkov radiator:** passage of relativistic charged particle creates UV photons.
- **Photocathode:** conversion of UV photons into electrons.
- **Drift /preamplification region:** Preamplification of electrons in high drift field region (~20 kV/cm)
- **Anode/amplification region:** final electron amplification in high electric field (~40 kV/cm)
- Arrival of the amplified electrons to the anode creates a signal.
- First single pad detector prototype ->**time resolution below 25~ps.**

Bortfeldt, J., et al. "PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 903 (2018): 317-325.

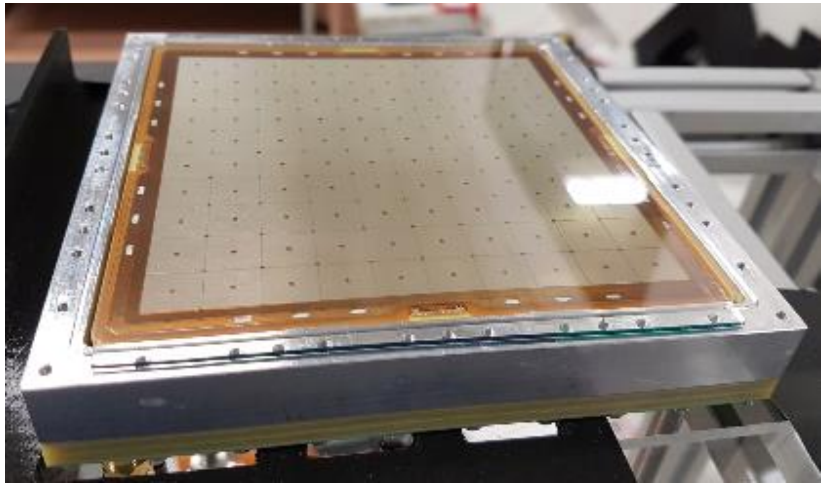
Towards the large area multi-channel PICOSEC detector



Active area Φ= 1cm
Number of channels: 1



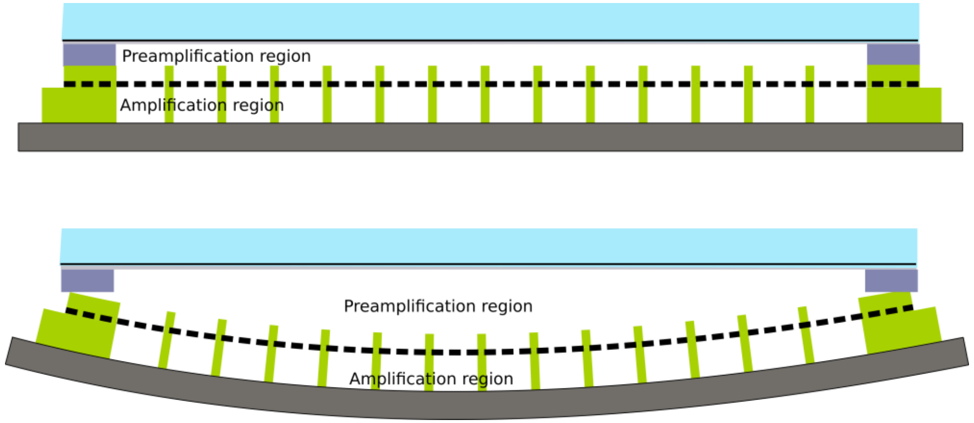
Active area Φ= 3.6 cm
Number of channels: 19

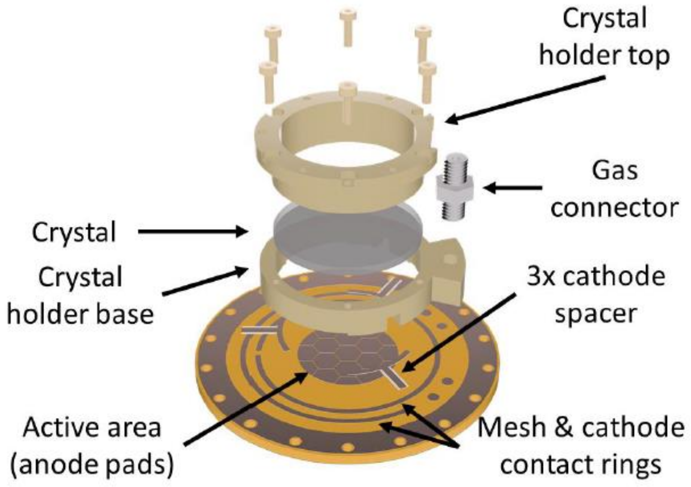


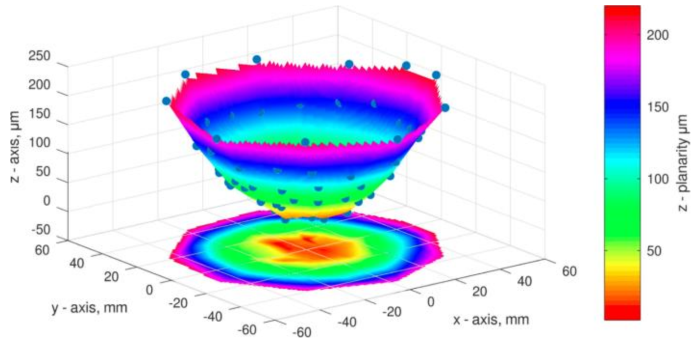
Active area 10 cm x 10 cm
Number of channels: 100

First picosec multipad detector

- **Drift/ preamplification region:** similar thickness (~150 um) and similar electric field as amplification.
- Uniform detector response ->uniform gap over entire active area.
  - Change in a drift gap thickness -> change in the **drift field** and **length** of preamplification avalanche evolution.
  - This would affect detector gain and timing performance.
- **First multi pad PICOSEC detector:** observed deformations in range of **30 µm** in **active area** (due to the attachment to the chamber & non flatness of the board itself).
- Gap height difference of **15 um** would result in time error of **100 ps**.





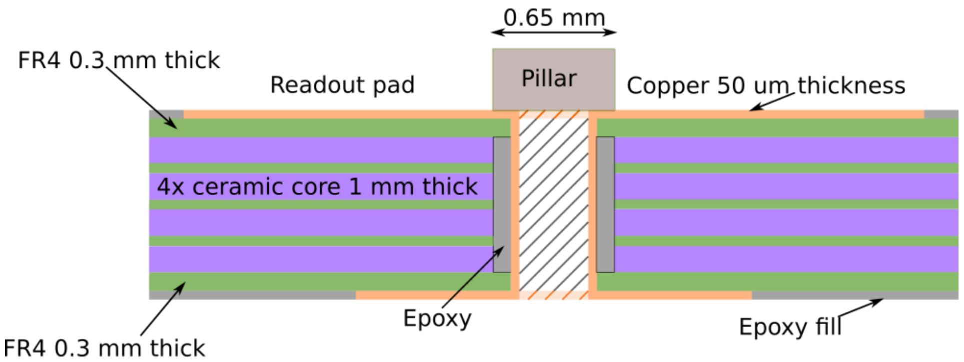


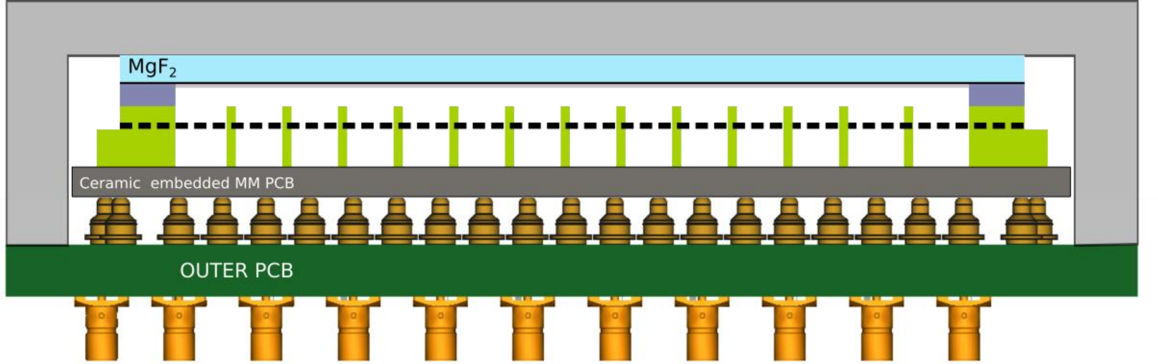
Aune, S., et al. "Timing performance of a multi-pad PICOSEC-Micromegas detector prototype." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2021): 165076.

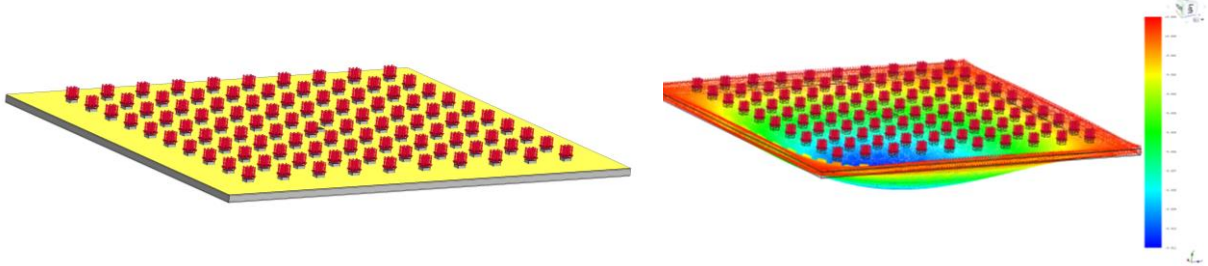
Sources of mechanical stress on the MM board

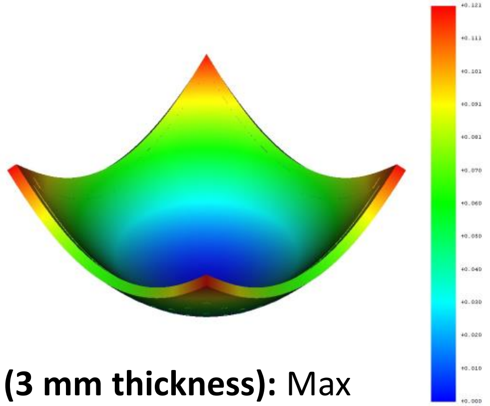
1. **Fixation of the MM board to the housing**-> detach the MM from the chamber.
2. **Spring-loaded pin pressure** on the MM board-> mechanical simulation to estimate the deformations < 5 µm.
3. **Mesh tension**- due to the mesh stretching over the board- mechanical simulation to estimate the deformations due to this effect. Study of board various material and thickness.

- **MM BOARD design:** use more rigid (ceramics instead FR4) and thicker MM board material (4 mm instead 2 mm).

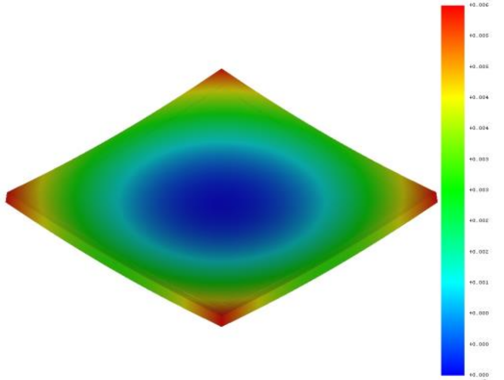








FR4 (3 mm thickness): Max displacment in the active area is around 100 um.

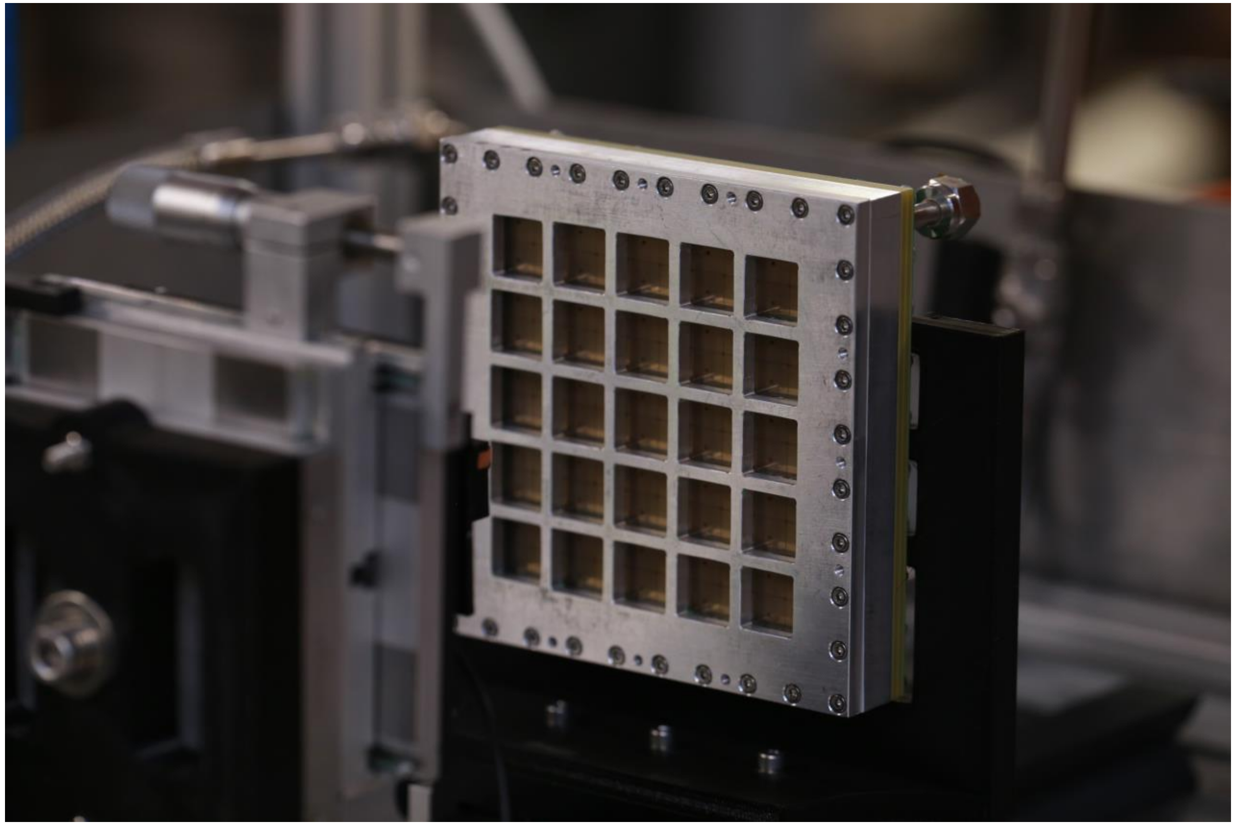


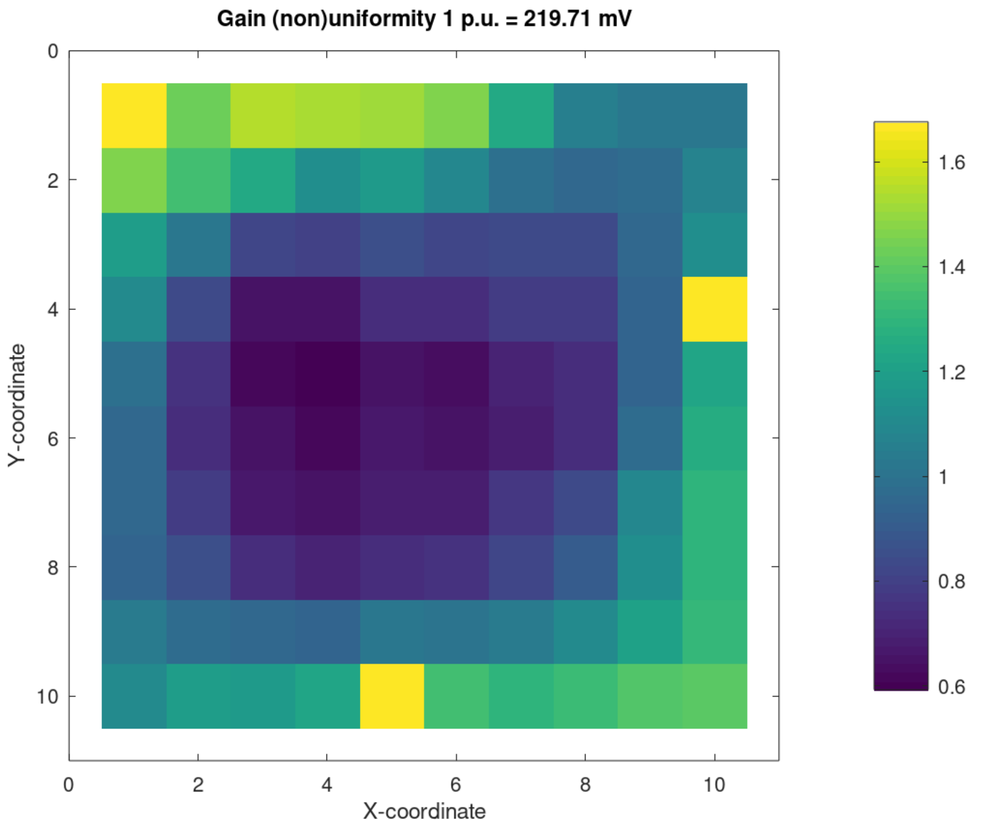
Ceramic (4 mm thickness) Max displacment in the active area is around 4 um.

More details on new PICOSEC planarity simulations: Antonija Utrobicic, RD51 CM June 2020, *https://indico.cern.ch/event/911950/sessions/348123/#20200626*

First gain uniformity measurements of 100 channel prototype

- First gain uniformity measurement showed larger gain variations than expected.
- **Micromegas board is fully decoupled from housing and thoroughly tested to flattens specs.**
- Source of deformations?

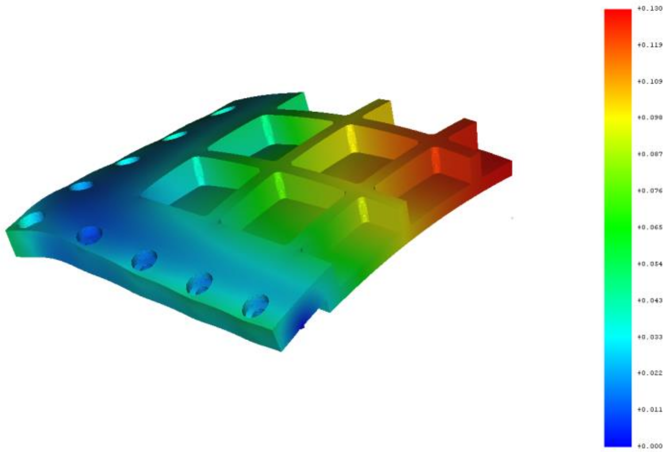


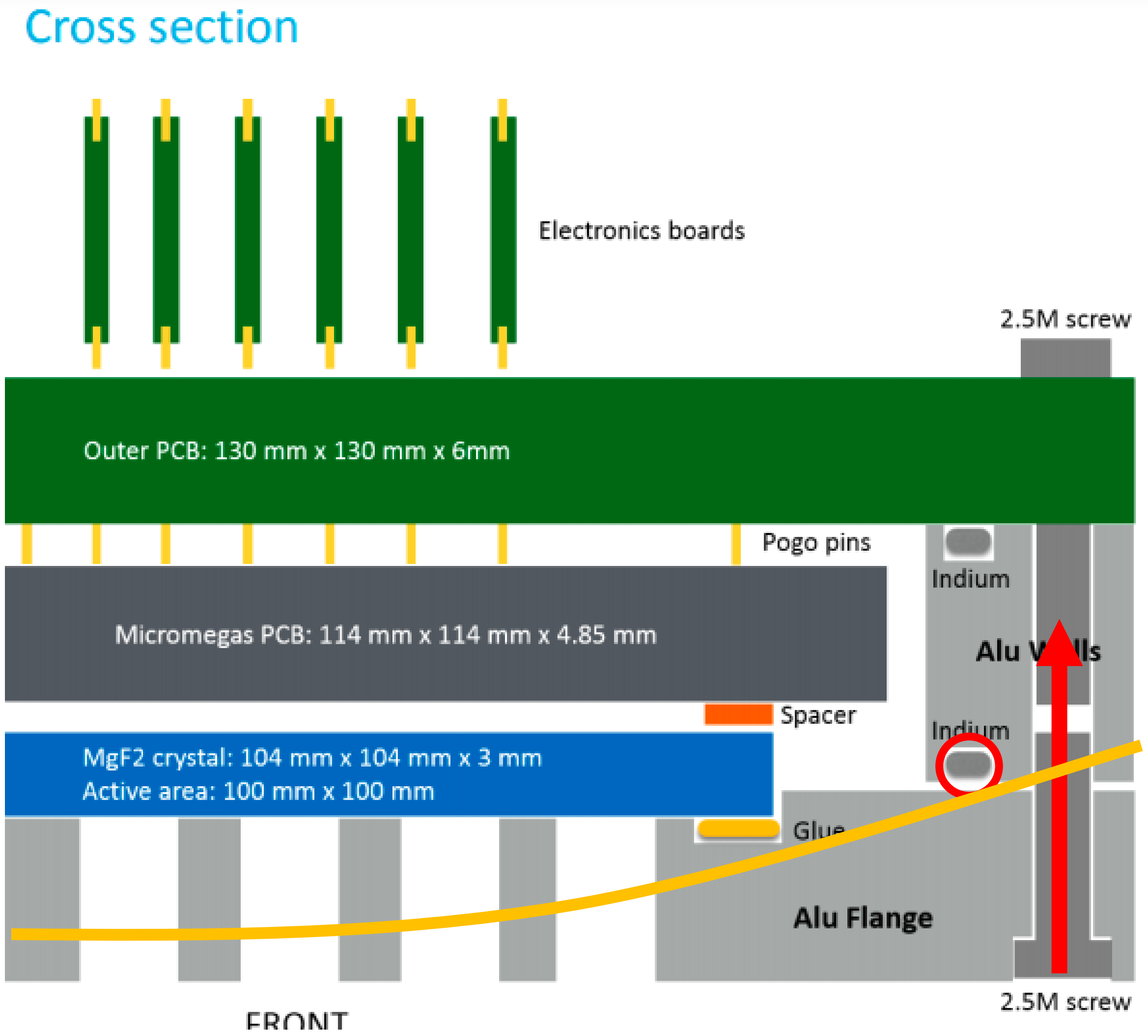


σ = 28 %

Sources of the gap-nonuniformity-bending of the crystal

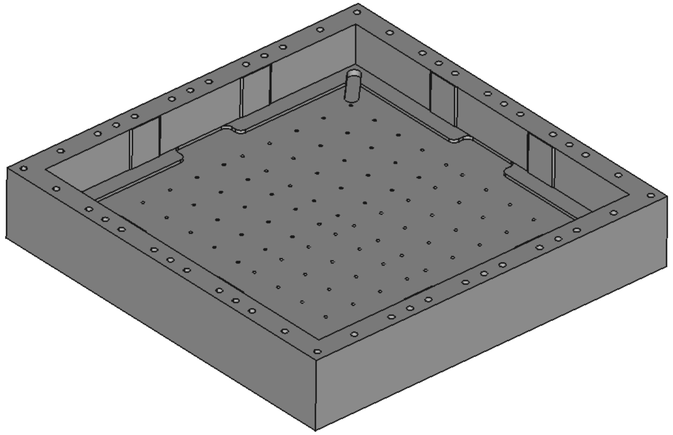
- MgF_2 crystal is glued to the aluminum flange that is tightened with M2.5 screws to the chamber housing.
- Pressing force from each M2.5 screw torqued to 0.6 Nm is around 119 kg.
- Total: 36x119 kg = 4284 kg.
- Flange can bend over the Indium o-ring when being pressed with the screws.

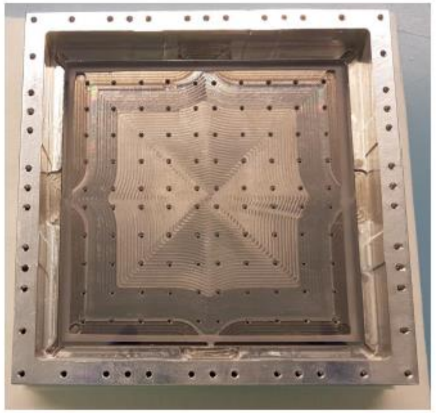


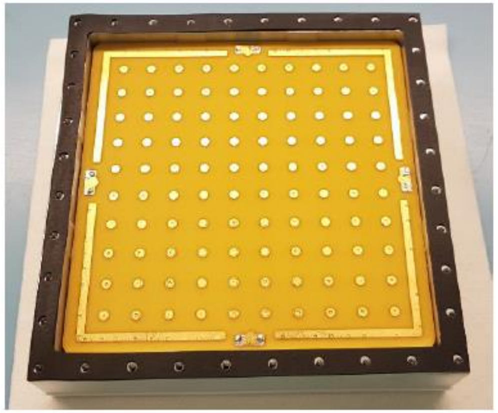


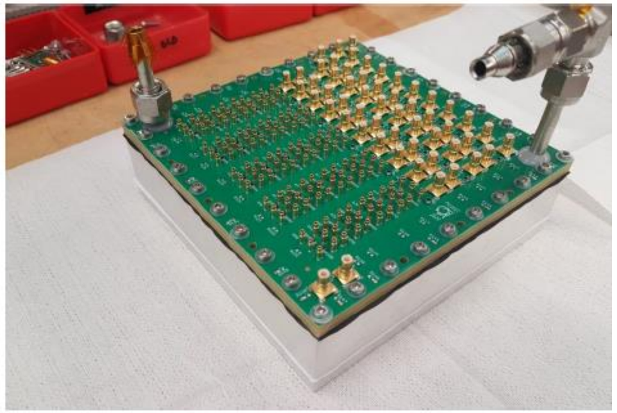
Chamber modification - decoupling the crystal from housing

- Assembly procedure significantly simplified.
- First the crystal is placed in the housing. MM board with spacers is placed facing down. Finally, the chamber is closed with Outer board. Spring loaded pins on the bottom side of the OB are pressing the MM board against the crystal.

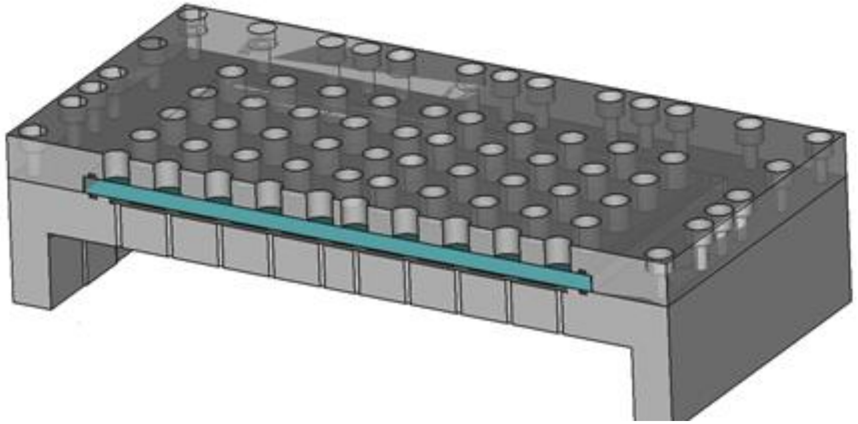


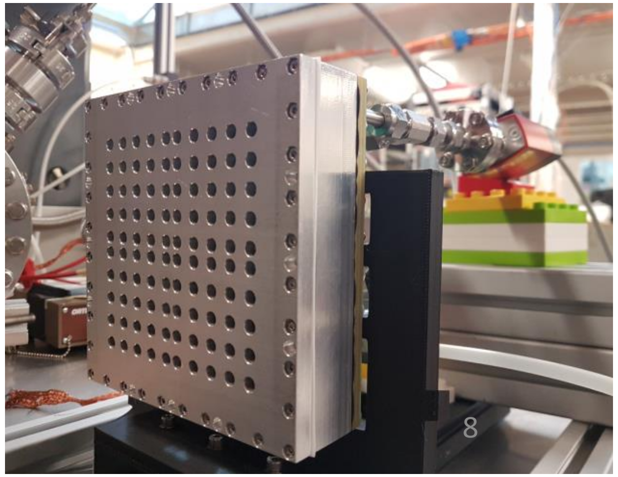




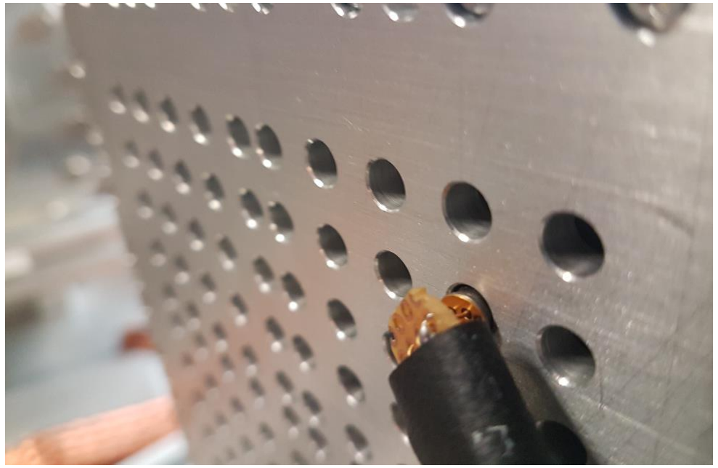


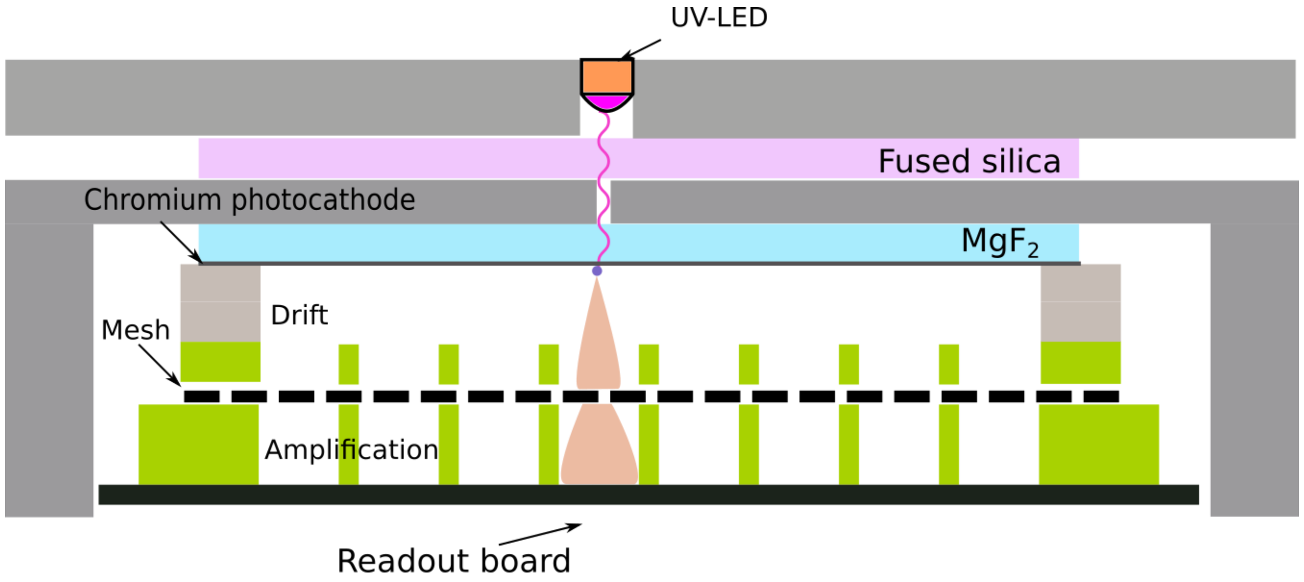
- Holes in flange (ϕ=5 mm) and housing (ϕ=1.5 mm and 9 mm long) for UV-light collimation.
- Fused silica in between the flange and housing to make chamber gas tight.



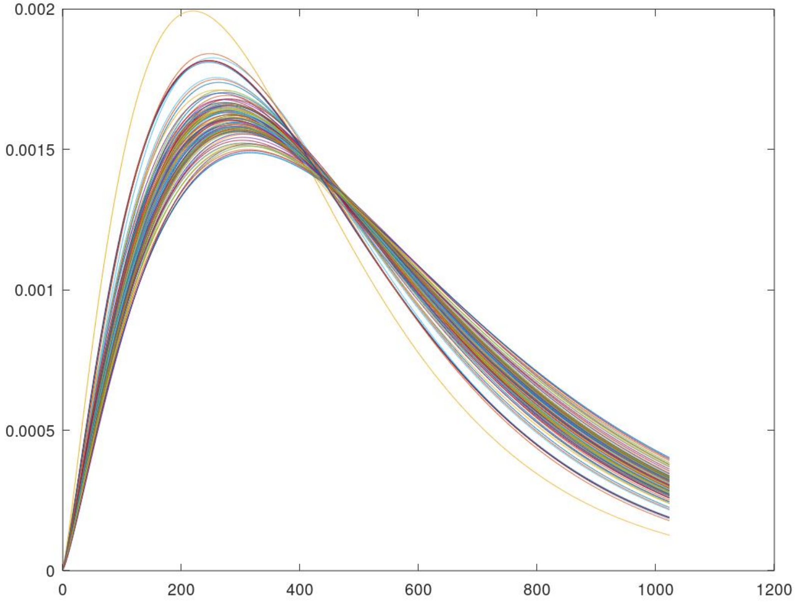


Gain uniformity measurements with new housing

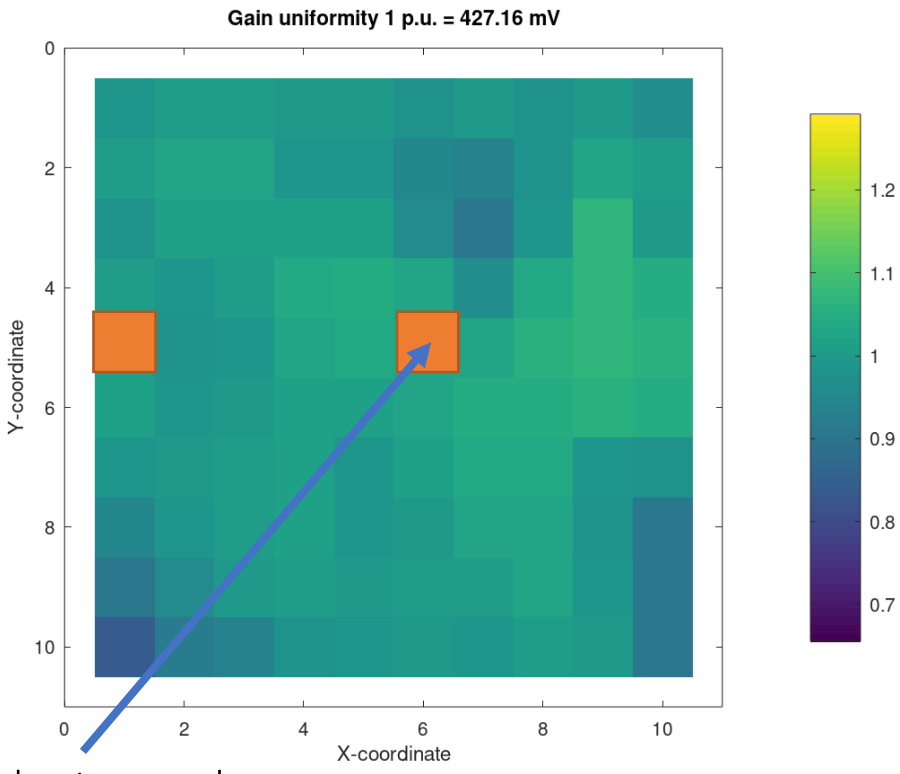




- Spectrum was measured for all 100 channels for both produced ceramic MM boards.
- Polya fit was used to extract the mean value of the spectrum.
- Small variation in the mean value observed.



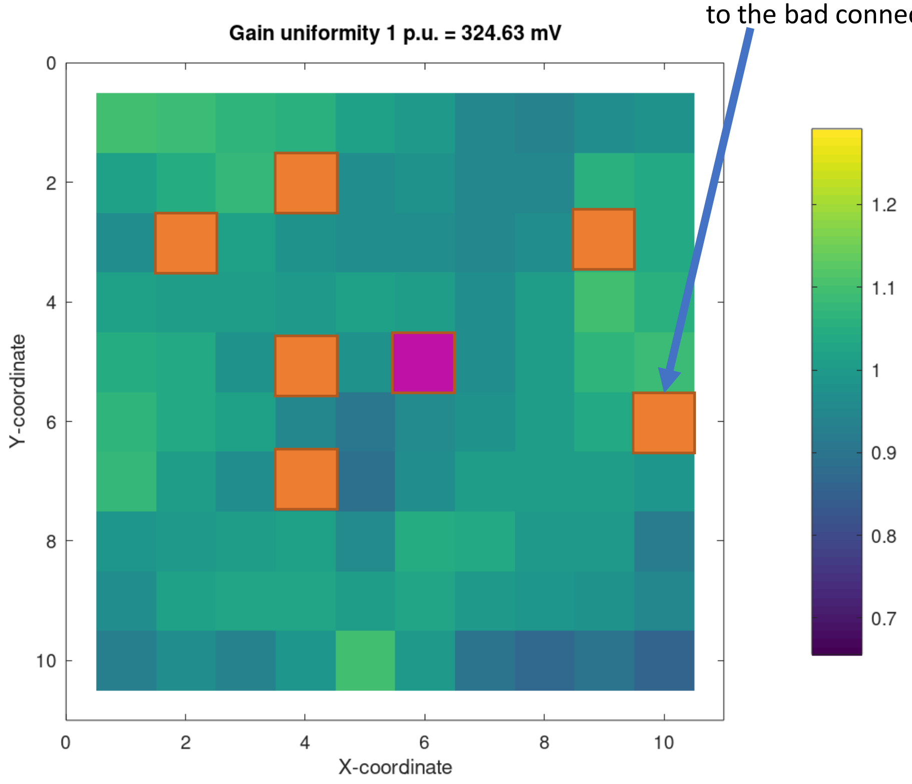
Gain uniformity measurements of two produced ceramic boards



2 channels not measured- one had very small gain and other was disconnected on the OB.

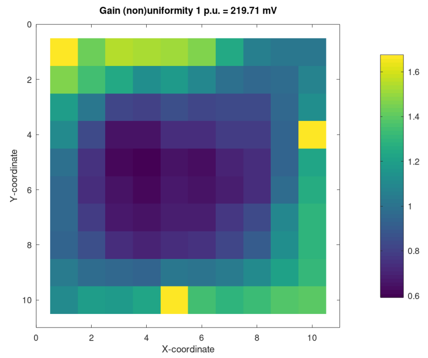
σ = 3.9 %

Six channels not meaured due to the bad connection- FIXED.



σ = 5.1 %

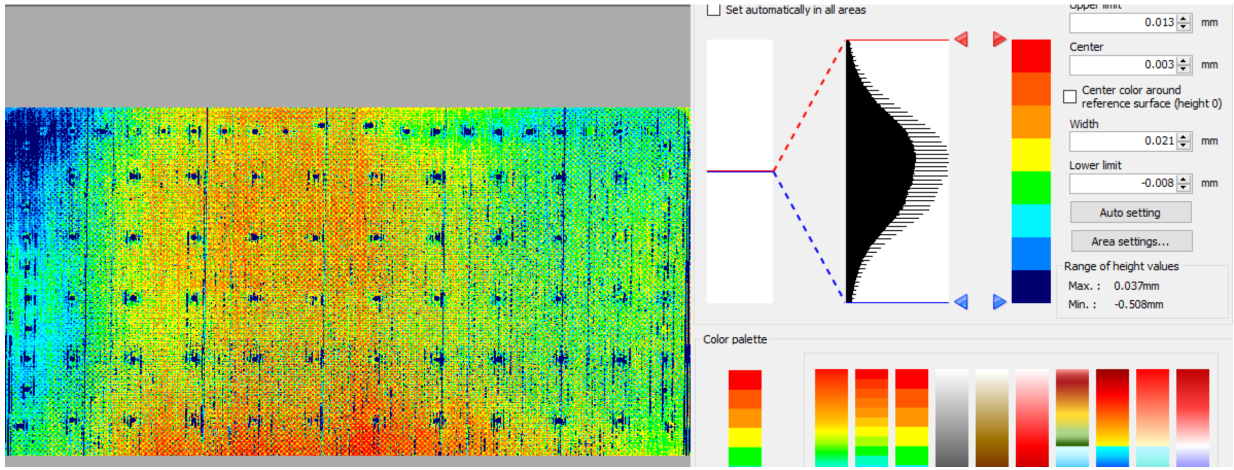
- Gain uniformity is improved ~7 times when compared with first measurements.
- Variation of gain over the pad still needs to be verified.
- We will know more on planarity from the timing measurements. Beam tests soon.



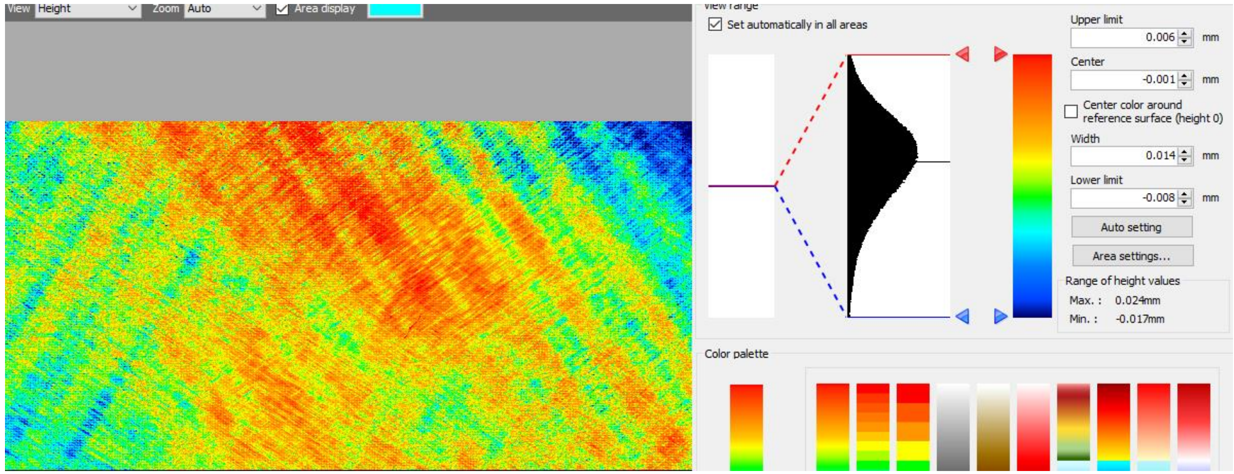
New MM ceramic board production status

- Third 100 ch picosec MM board is currently in production.
- **Improvement in board flattening process:** manual polishing is replaced with precise grinding.
- First results from the planarity measurements are promising. Slightly better initial planarity is achieved (14 um vs. 21 um).
- Currently Cu deposition ongoing.
- **Additional improvements that are foreseen:**
    - Thicker Cu to have margin to correct with manual polishing if needed in the later steps.
    - Partial cutting of the board from the frame just before the bulking to reduce the possibility of board deformation during temperature cycling.
    - Considering using FR4 material with higher T_g to minimize the possibility of deformations due to heating processes in production.

Manual flattening

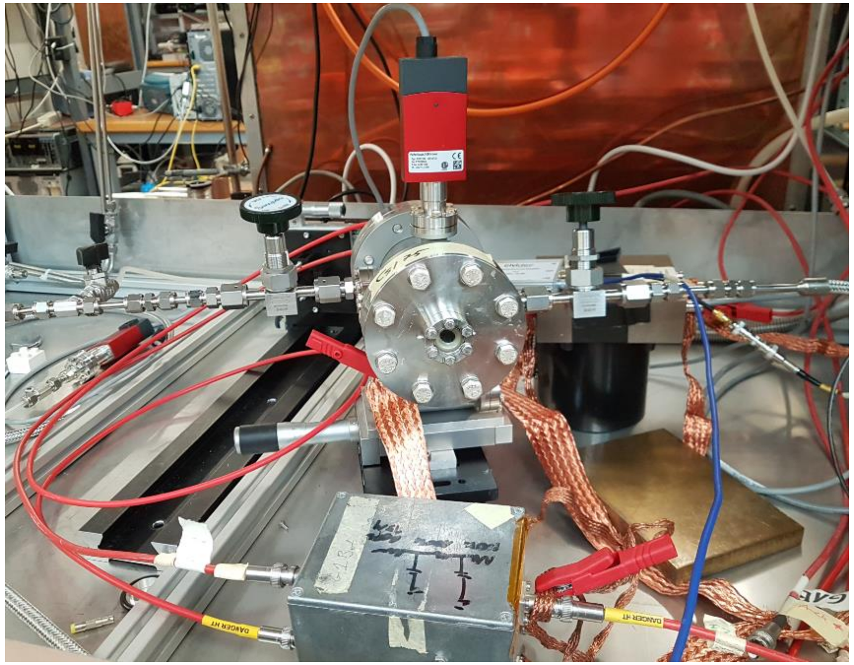


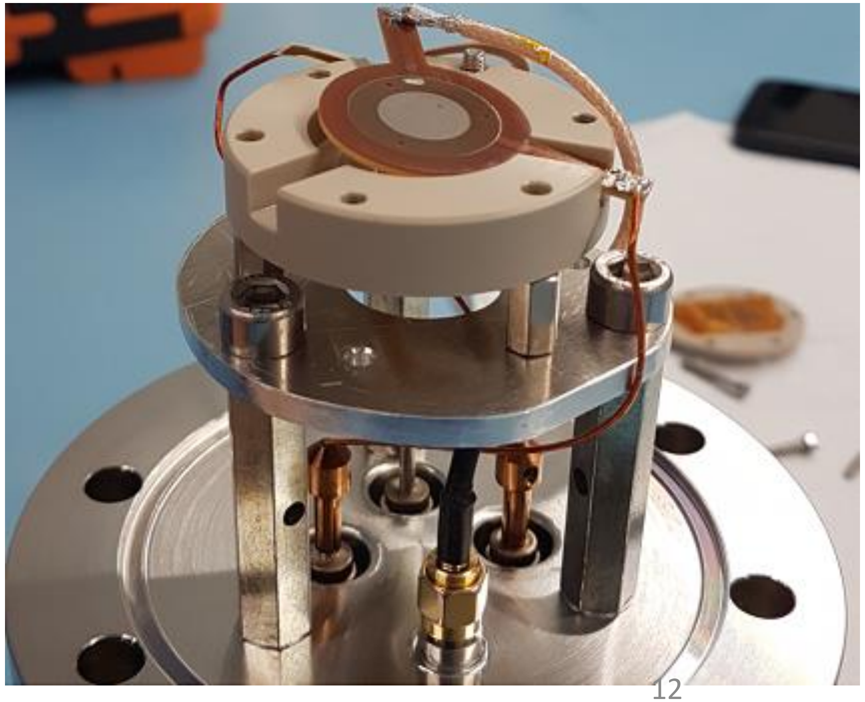
Machine flattening



Gain characterization - Single vs. double stage

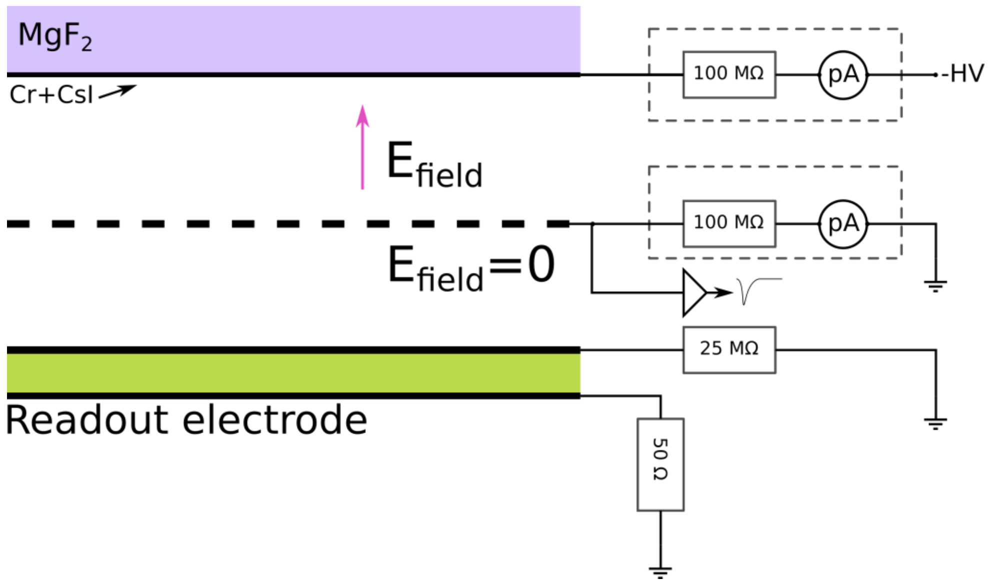
- **Motivation:**
  - measure detector gain and **ion back flow** in high preamplification (25-30 kV/cm) and amplification field configuration (25 kV/cm).
  - test **maximum gain** of double gap and single gap detector configuration before reaching instabilities.
  - obtain signals with fast preamplifier (CIVIDEC).
  - clarify the limitations and benefits of double gap configuration.
- **Detector:**
  - Resistive MM board with active area of 1 cm in diameter.
  - Amplification gap 110 um, preamplification gap ~ 200 um.

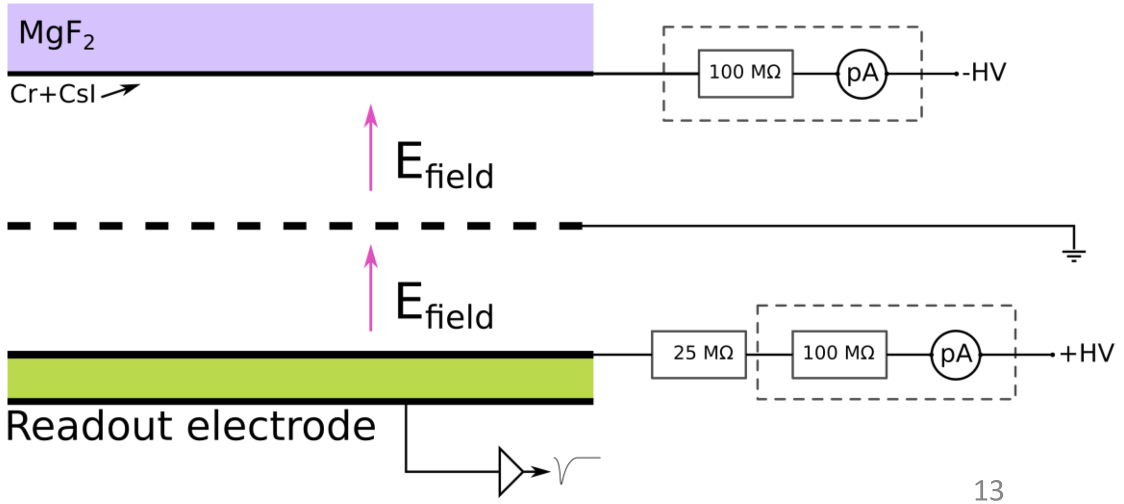




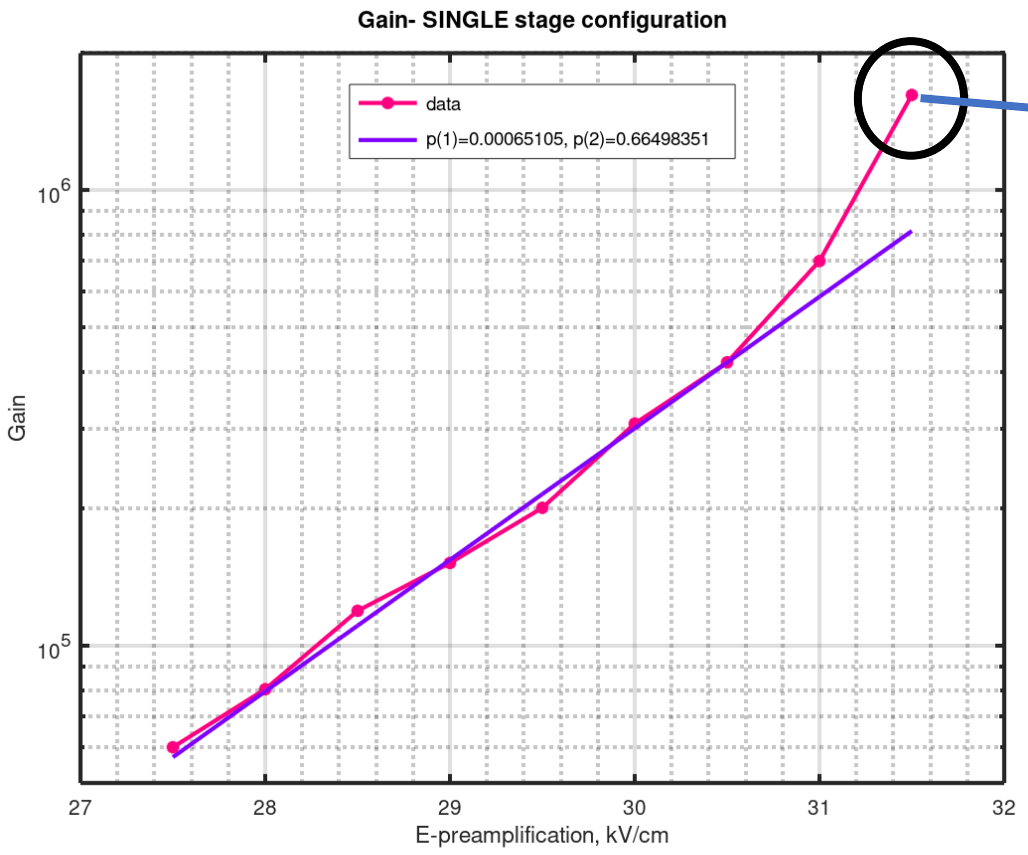
Single and double stage detector configuration

- Detector connections were adjusted to run detector in single or two stage configuration.
- Mesh can be connected to GND or to the preamplifer.
- **Single gap configuration:**
  - MESH is biased to 0V through the preamp.
  - Negative voltage is applied to photocathode through picoammeter.
  - There is electric field only in preamplification gap.
- **Double gap configuration:**
  - Mesh is on GND.
  - Negative voltage is applied through picoammeter on photocathode and positive voltage through picoammeter on anode.
  - Signal is read through readout electrode below anode.
  - High electric field in both gaps.
- Measurements were made in single photoelectron condition using UV led.
- Gain was obtained from current and rate measurements.

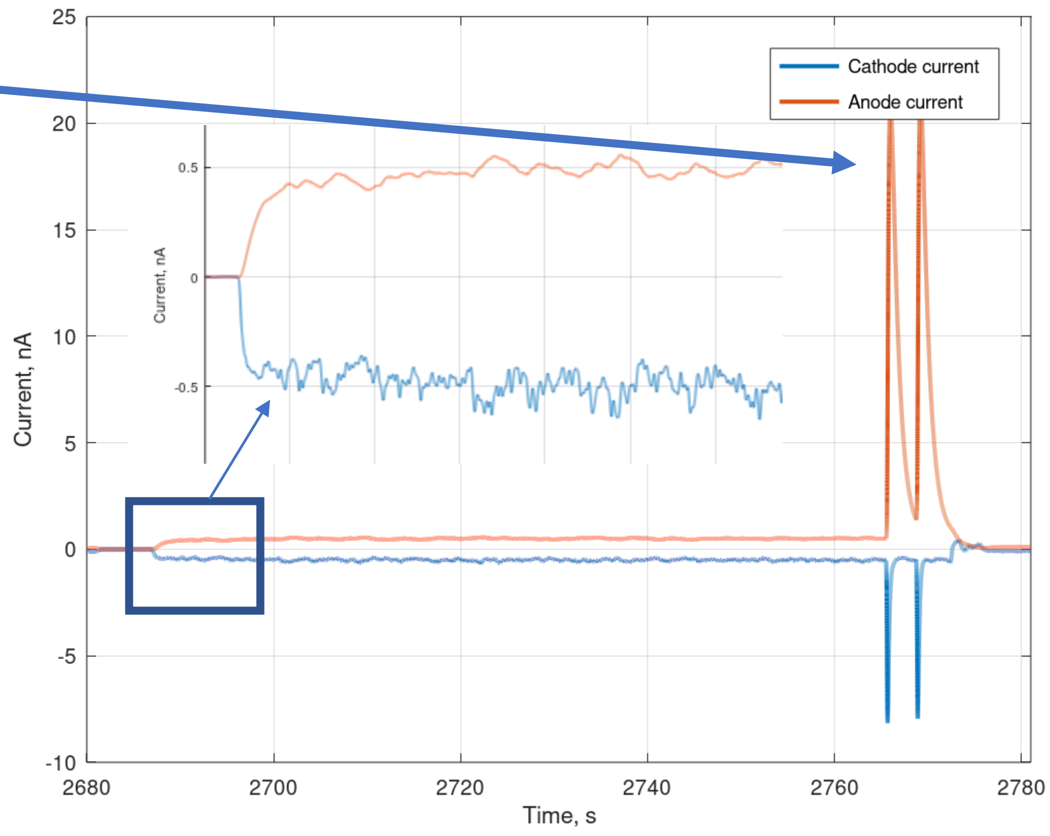




Single stage configuration gain measurements-very preliminary

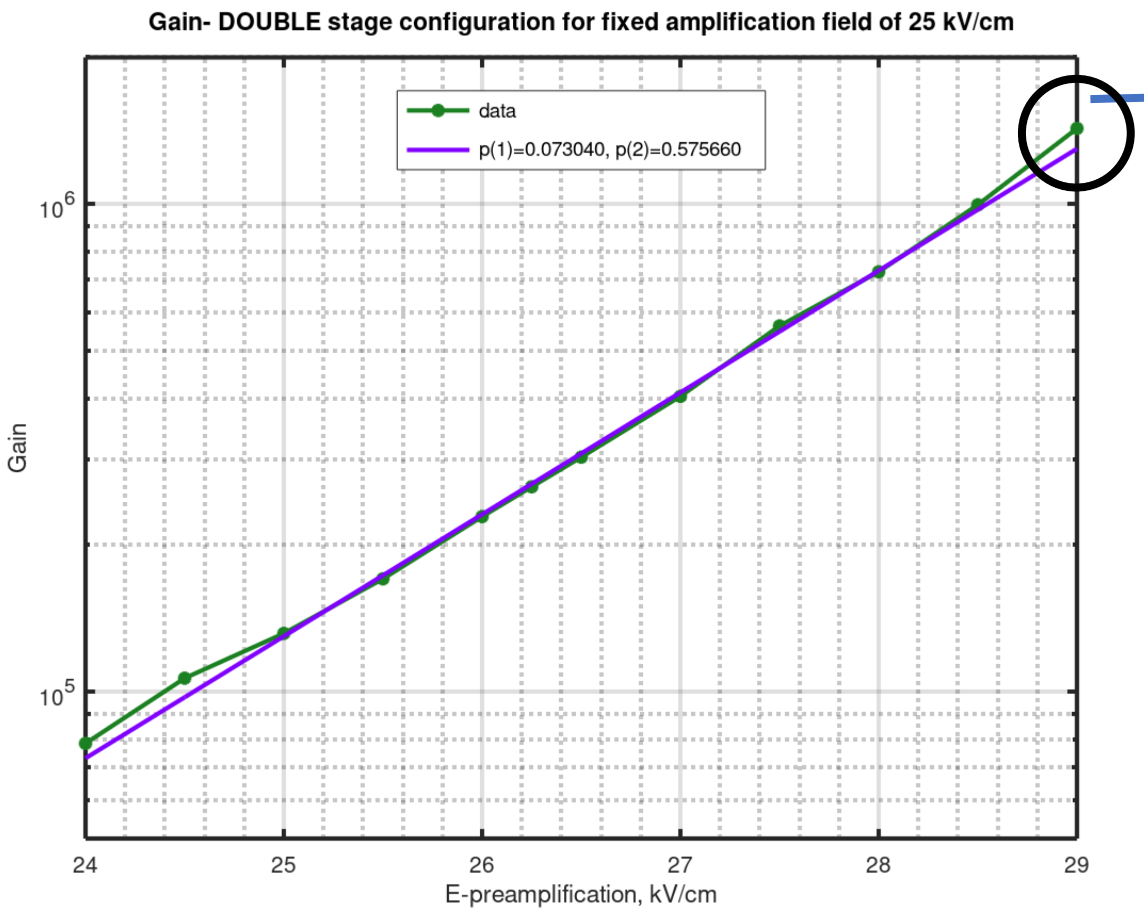


Current measurement

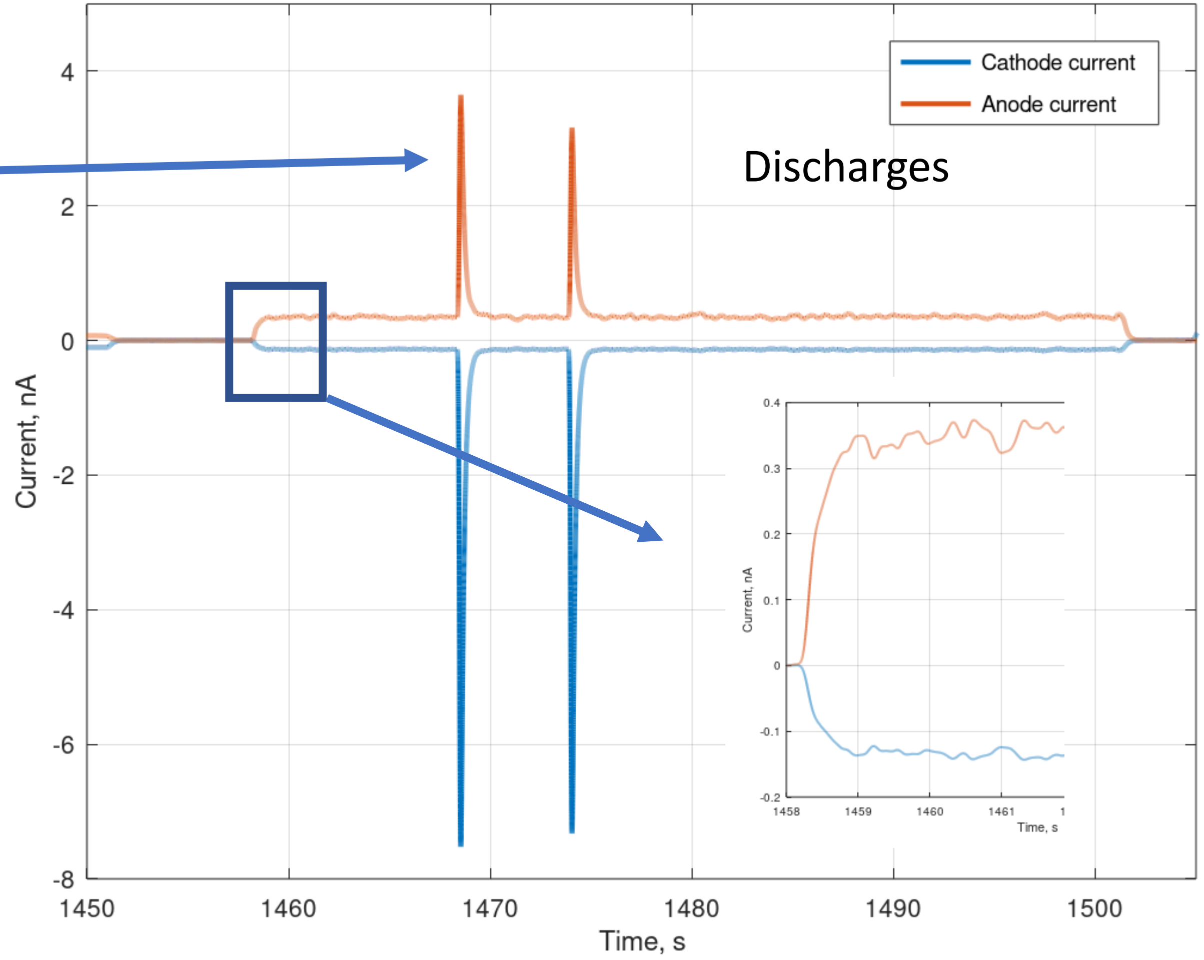


- Gain in range from 60k to 1.6M.
- Occurence of discharges at gain larger than 1M.
- Gain curve for single stage is deviating from exponential at higher gain values. Photon feedback? To be more detailed studied.

Double stage configuration gain measurements- very preliminary



Current measurement



- Gain in range from 60k to 1.6M.
- Occurence of discharges at gain larger than 1M.

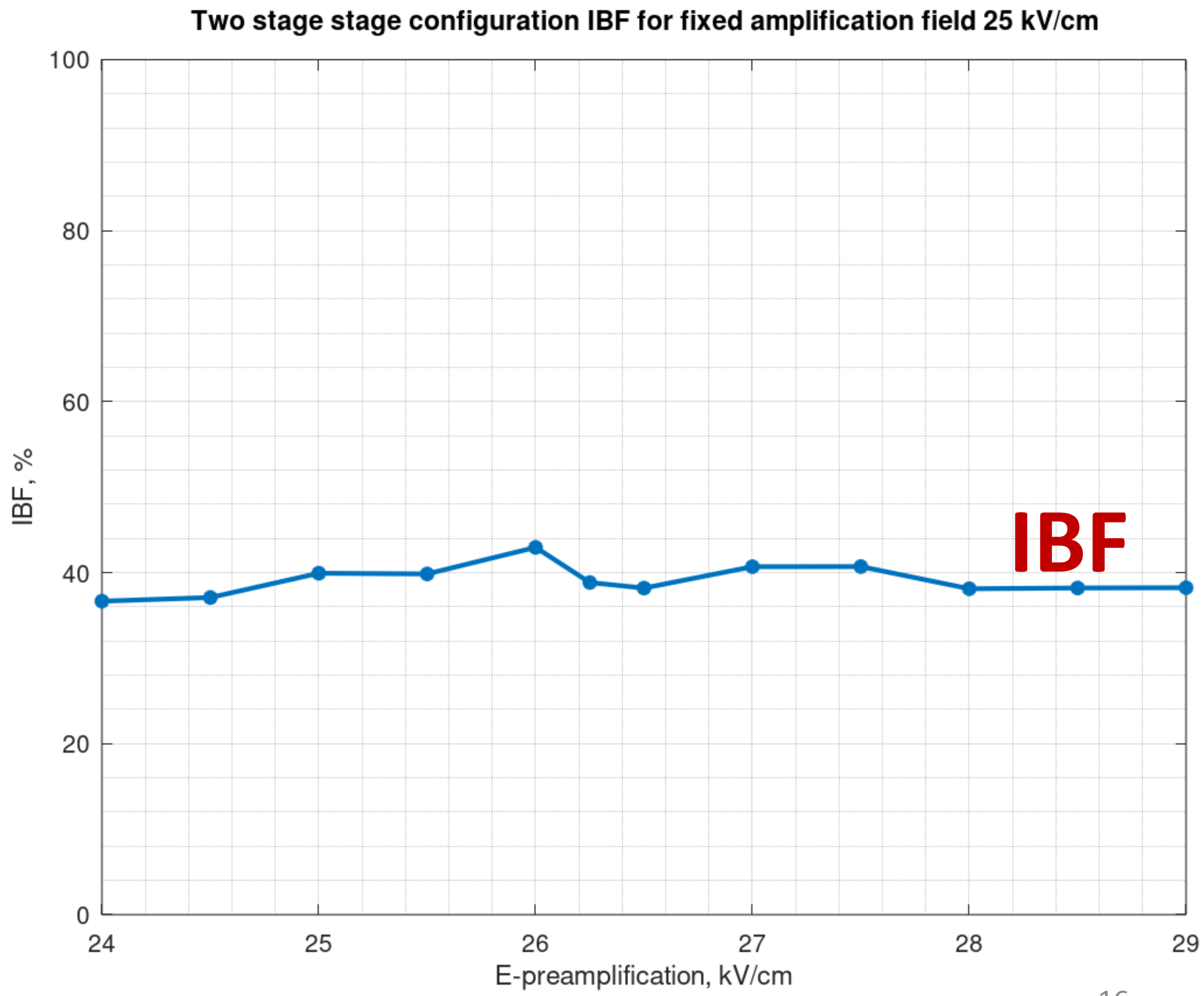
Double stage configuration IBF measurements- very preliminary

- As the cathode and anode currents were measured, the IBF was represented as the:

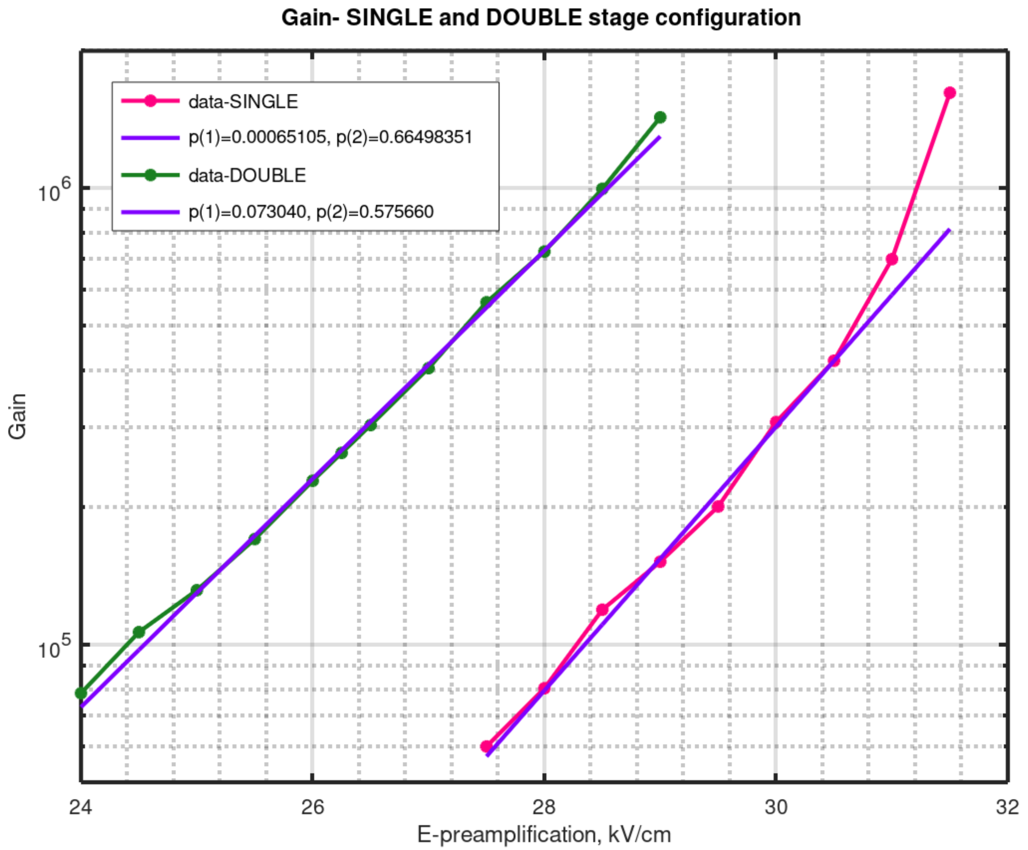
$$IBF = \frac{|I_{cathode}|}{|I_{anode}|}$$

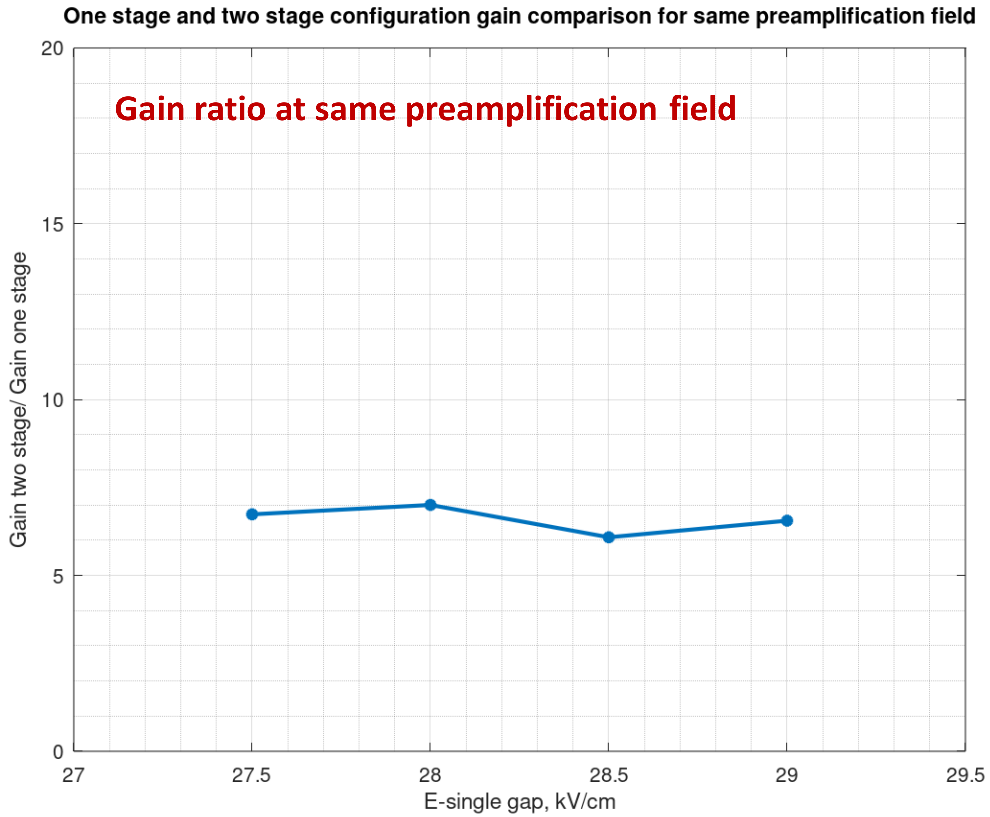
- IBF for two stage configuration with fixed amplification field (25kV/cm) is around **40%.**

- Increasing the pre-amplification field does not affect the IBF as it was expected.



Gain comparison between single and double stage configuration configuration

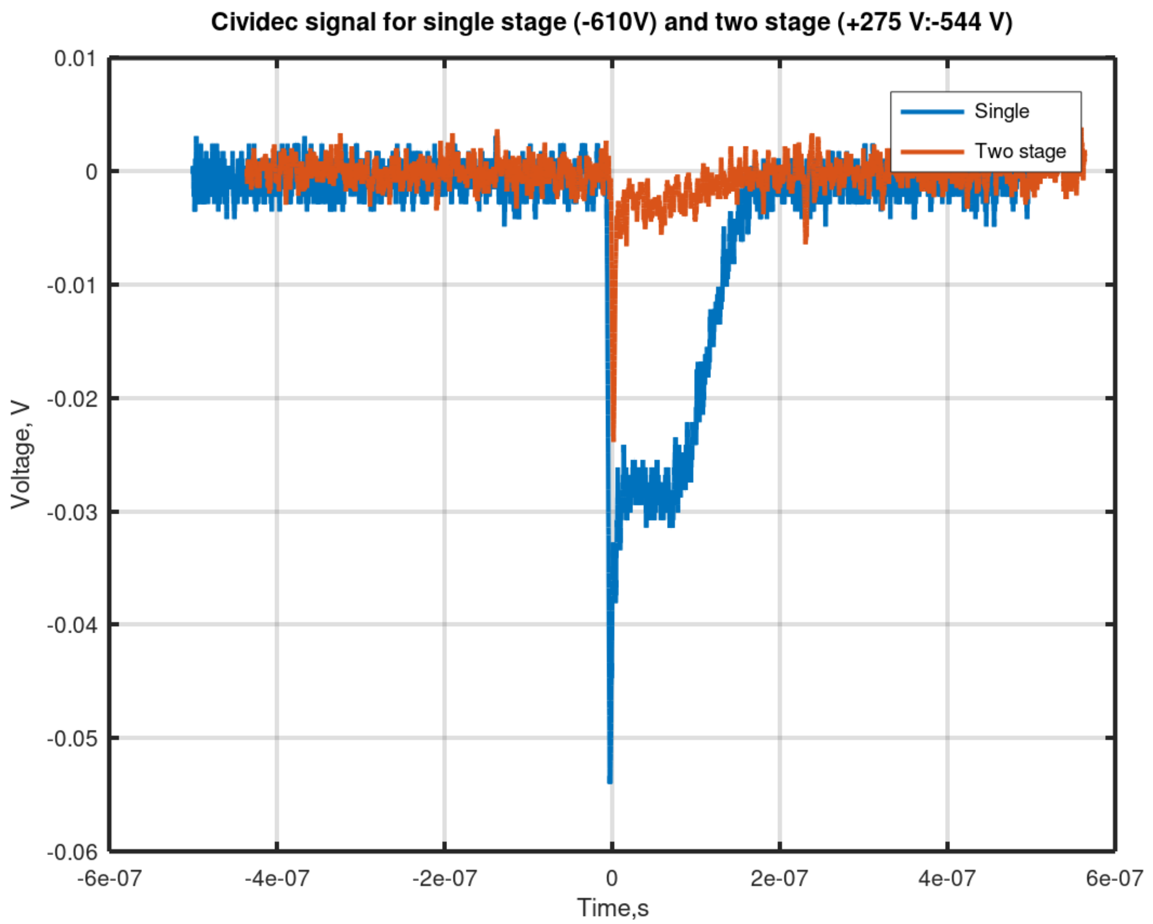


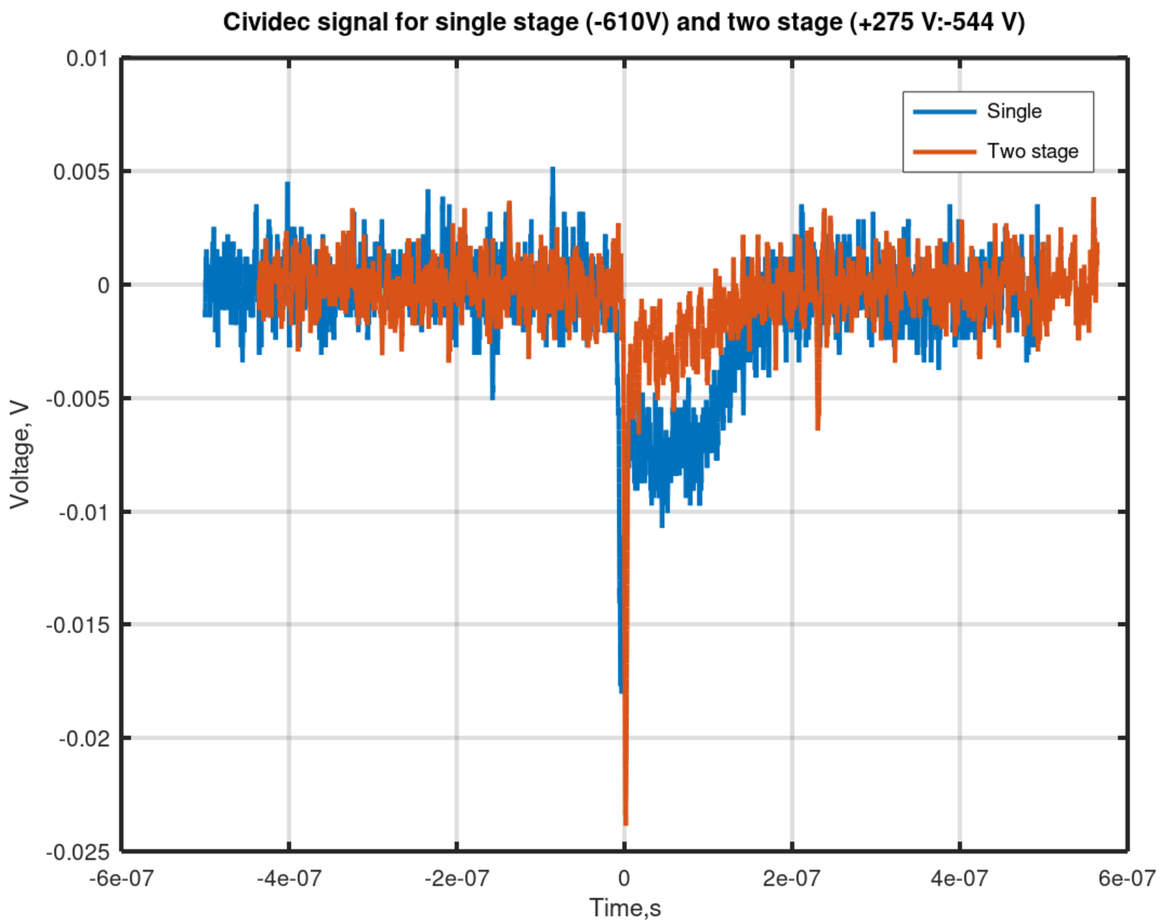


- One and two stage configuration reach similar gain.
- Around 1M gain both configuration develop instabilities.
- Single stage configuration gain curve deviates at high gain. Photon feedback?

- Effective gain (mesh transparency and amplification) the second stage to the total gain is around 7.
- Second stage reduce IBF to 40%.

Shape of the signal in single and double configuration





- Ion tail significantly reduced in double stage configuration.

Conclusion

- New housing design resulted in significantly improved gain uniformity due to the mechanical decoupling of the crystal
- Timing tests on the beam will be used to gain the information about the uniformity of time measurement performance and necessities for the correction at the pad level.
- Manufacturing process for flat micromegas is improved by introduction of the mechanical grinding (important if larger scale production will be needed).
- Gain measurements ware made on the single and double gap detectors to investigate their limits before beam tests.
- Measurements show that for single photoelectron measurements gain of up to 10^6 can be obtained with both configurations.
- A deviation is observed in single gap configuration at high gains that could indicate photon feedback mechanism (needs to be verified).
- In general, double stage has more headroom for the gain and a benefit of reduced IBF (40% IBF in considered configuration).

Thank you for your attention ☺
Questions?