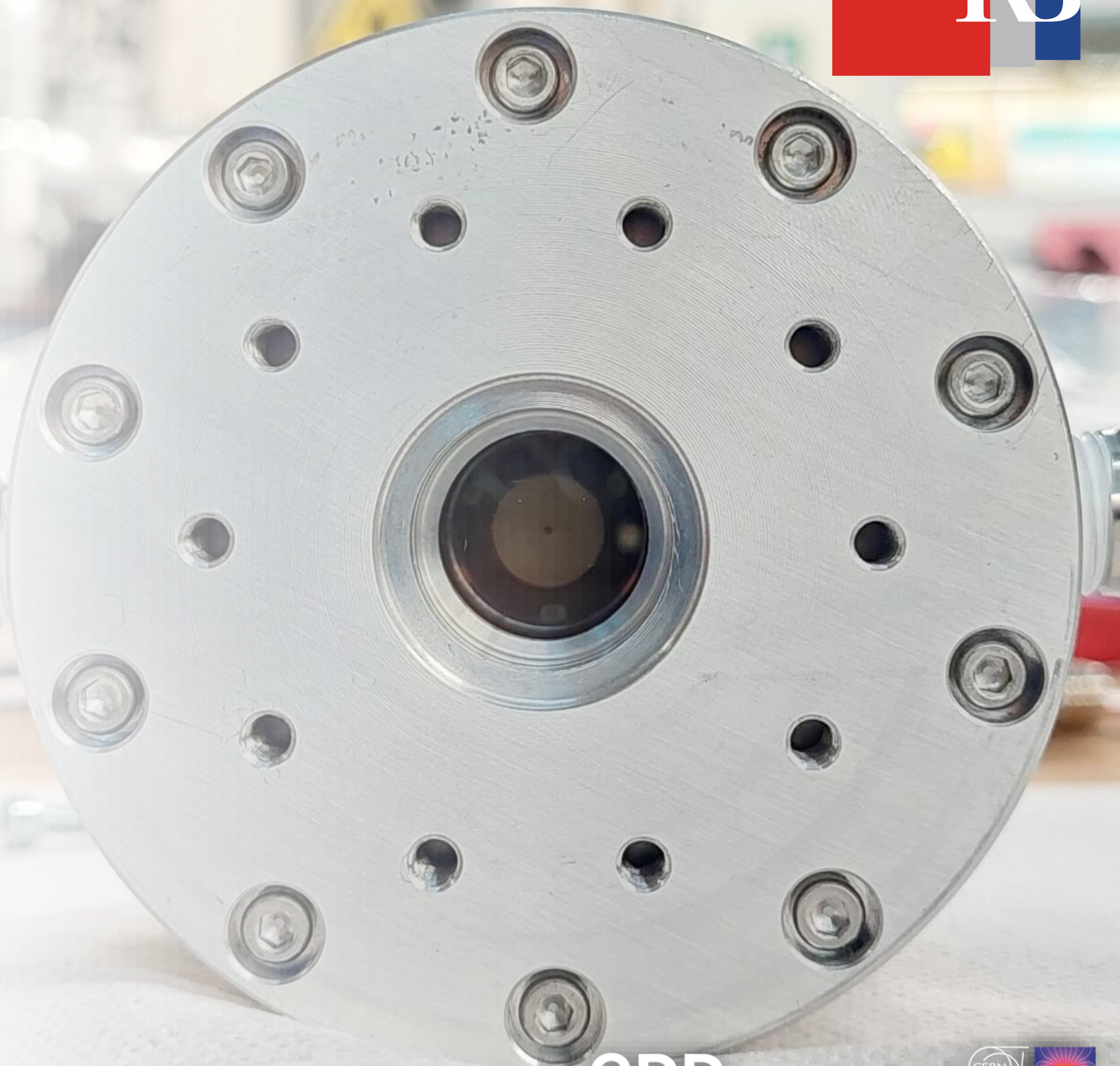
PICOSEC Micromegas

Design features and timing performance of new single-channel PICOSEC MM detector



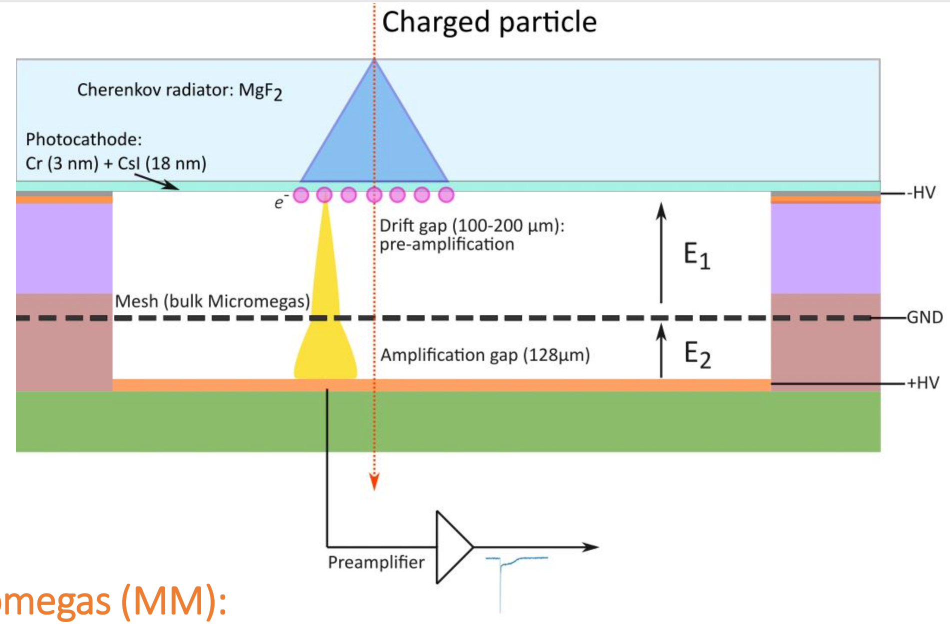
Antonija Utrobicic on behalf of the Picosec Micromegas Collaboration

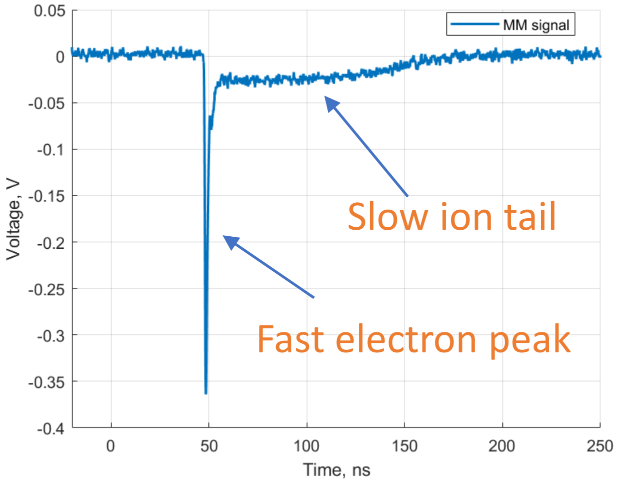
Ruđer Bošković Institute, Croatia

RD51 Collaboration meeting, 4 - 8 December 2023.

GDD
Gas Detectors Development Group

PICOSEC Micromegas detector concept





PICOSEC Micromegas (MM):

- precise timing (*O* tens ps) gaseous detector based on a Cherenkov radiator coupled to a semi-transparent photocathode and a MM amplifying structure.

Operation principle:

- **Cherenkov radiator:** passage of relativistic charged particle creates UV photons.
- **Photocathode:** conversion of UV photons into electrons. All the e^- created at the same z position.
- **Preamplification region:** preamplification of electrons in high drift field region (E_1~20 - 40 kV/cm).
- **Amplification region:** final electron amplification in high electric field (E_2 ~20-30 kV/cm).
- **Two component signal:** fast electron peak (~ 700 ps) and slow ion tail (~ 100 ns).

Three main detector components:

- **Cherenkov radiator** (3 mm thick MgF_2) crystal with photocathode (3 nm Cr with 18 nm CsI).
- **Spacer** (100-200 μm thickness) defining preamplification gap thickness.
- **Micromegas board**.

Cherenkov radiator (MgF_2 with photocathode)

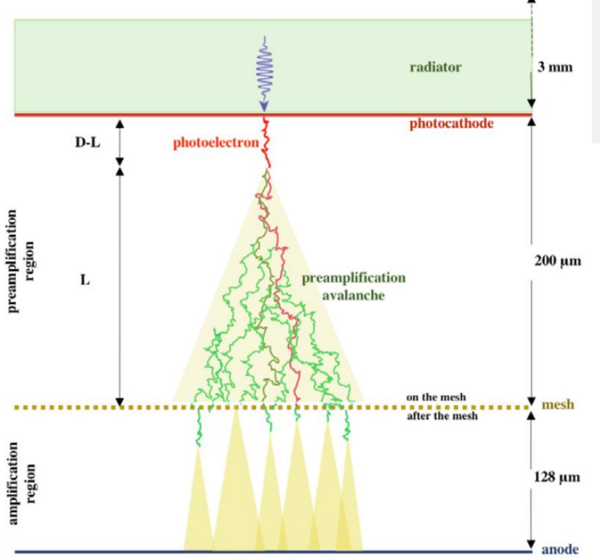
Spacer (defines drift gap thickness)

Micromegas board

Bortfeldt, J., et al. "PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector." *NIM A* 903 (2018):

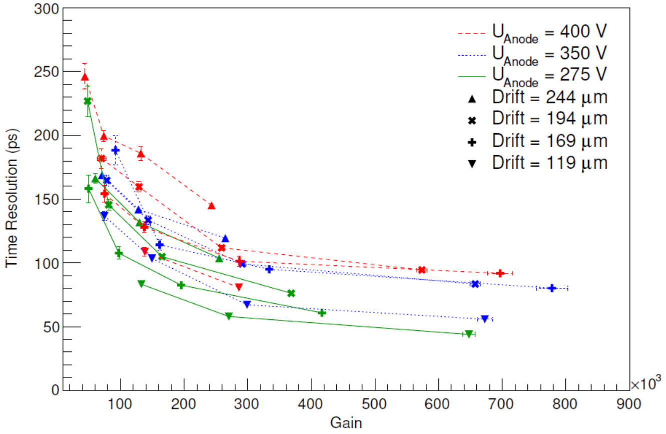
Motivation and design guidelines

- Development of a small and compact prototype that will maintain timing performance of previous Picosec MM prototypes and be suitable for research on detector geomety/ photcathode materials/ amplification structures/electronics…
- Cost reduction will widen usage and growth of PICOSEC MM R&D.
- Ability to reach the limits of the timing performance PICOSEC MM technology.



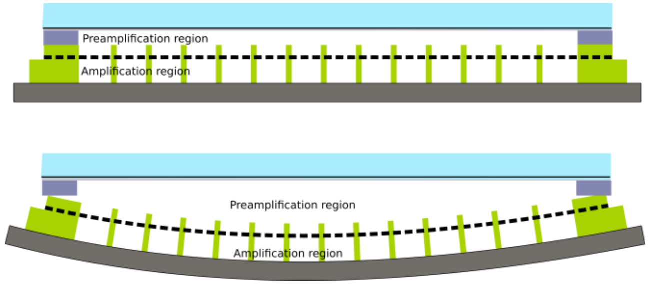
Bortfeldt, J., et al. NIM A 993 (2021): 165049

- Drift region geometry and field crucial for timing.
- Recent measurements show
  - time resolution <50 ps at single p.e with a shorter drift gap (120 µm) and 18.3 ps for MIP measurements in the center of the pad (5 mm x 5 mm) with CEA Saclay single channel chamber.
  - Improvement in the 100 channel detector timing performance (24 ps ->17 ps) for MIPs by reducing drift gap thickness (220 µm->180 µm).



Sohl, L., et al. JINST 15.04 (2020): C04053.

- Design guidelines for detector chamber and Micromegas board:
  - HV stable detector: decreasing drift gap thickness not to influence stability.
  - Easy exchange of main detector elements (Crystal with PC, spacer and Micromegas board.): Important to reduce CsI exposure to the humidity.
  - Signal integrity: minimize noise and improve the gain.
  - Uniform time response over the active area-> Uniform drift gap-> need for planar MM board (within 5 µm) over the active area.



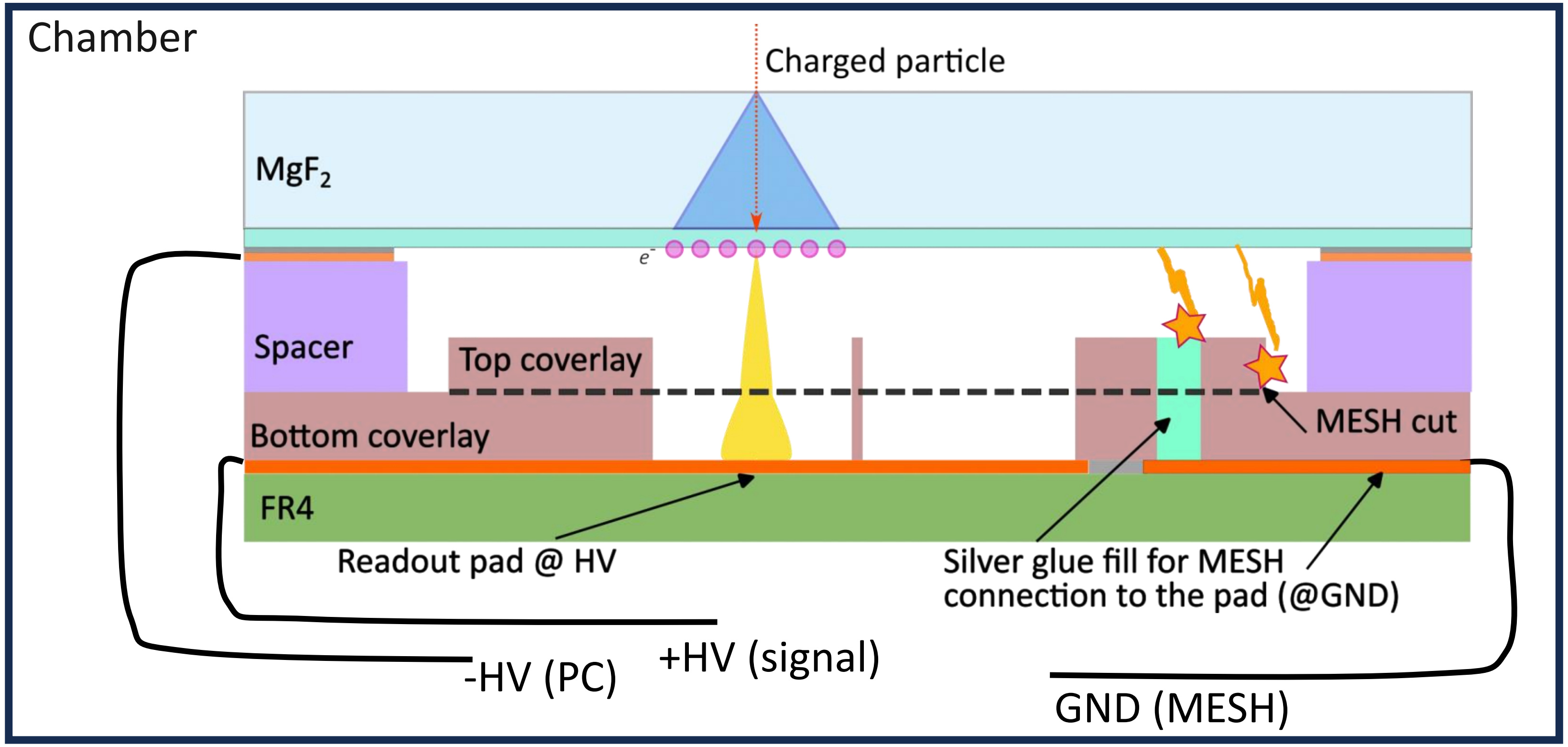
Aune, S., et al. NIM A 993 (2021): 165076.

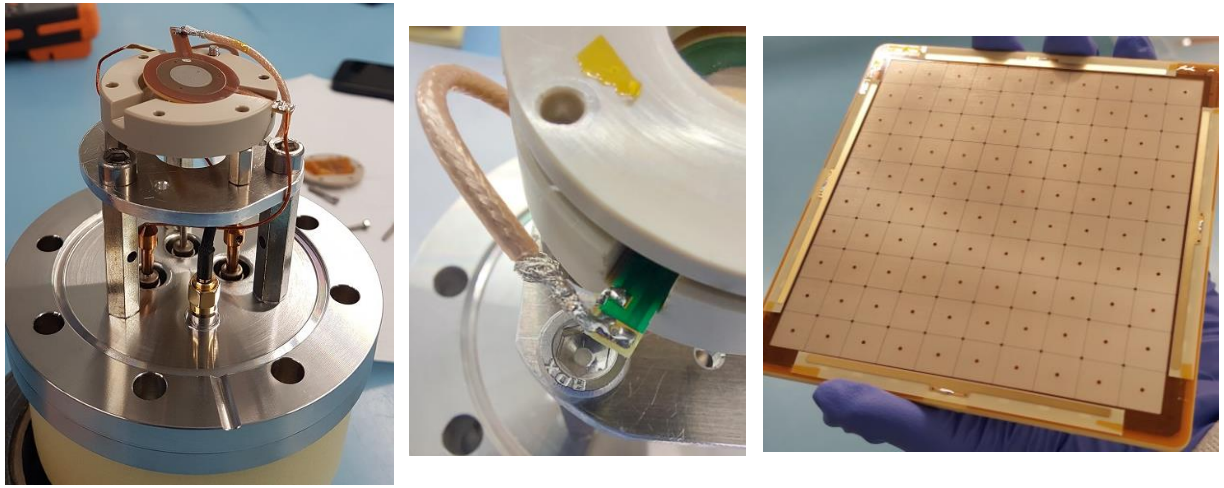
HV stability

Reduce or mitigate discharge formation:

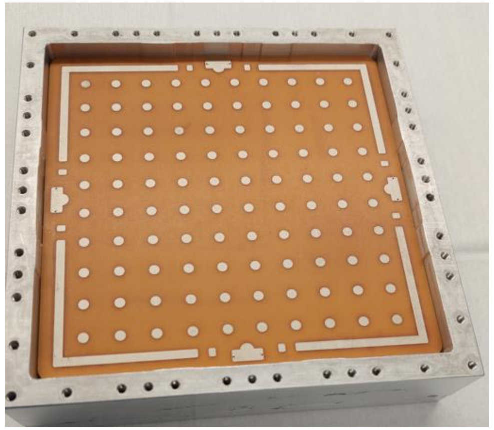
<u>Possible sources of instabilities:</u>

- Soldering within the chamber:
  - <u>NO wire/cable soldering:</u> reducing probably of discharge formations due to the sharp solder tips/ outgassing solder flux.
- Vicinity of the detector parts at HV to the metallic chamber walls.
  - Use of insulating barrier between the chamber walls and detector elements.





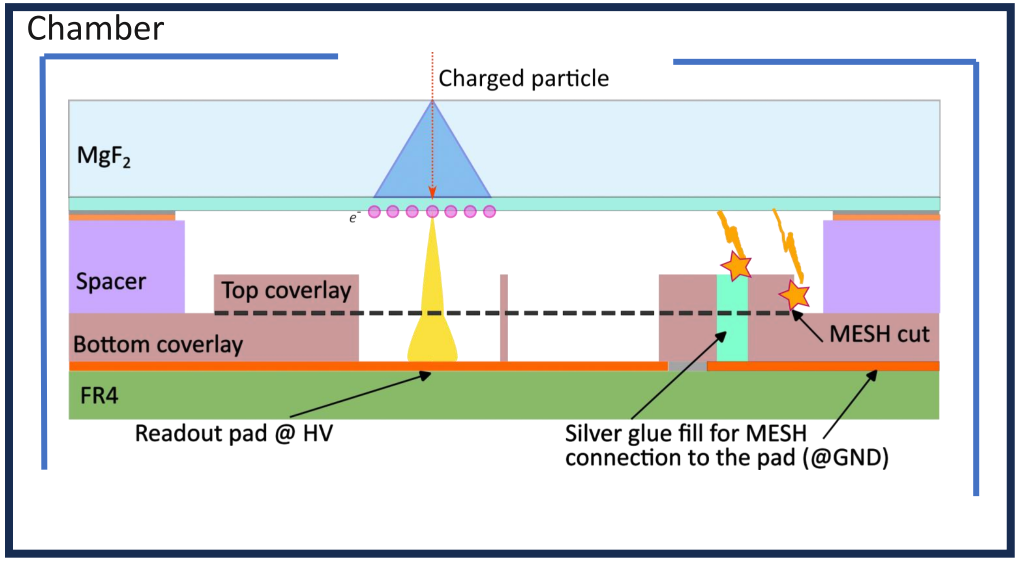
Example of wire and spacer soldering on single and 100 channel detector.



Example of close placement of the MM board to the chamber.

Possible sources of instabilities due to the drift gap thickness reduction:

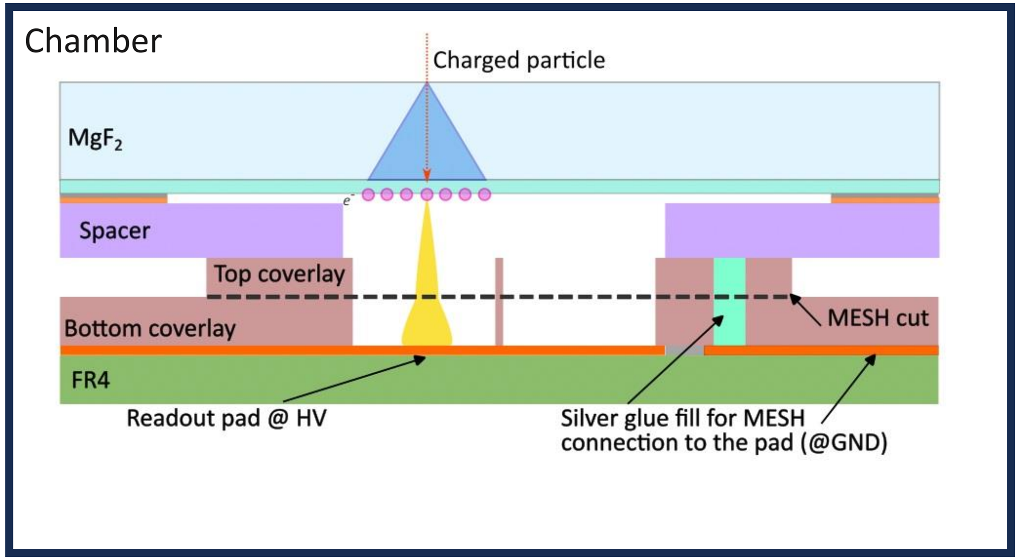
- Discharge development **between silver glue fill imperfections and photocathode**.
- Discharge development **between MESH cut and photocathode** (even with mesh cut passivation).

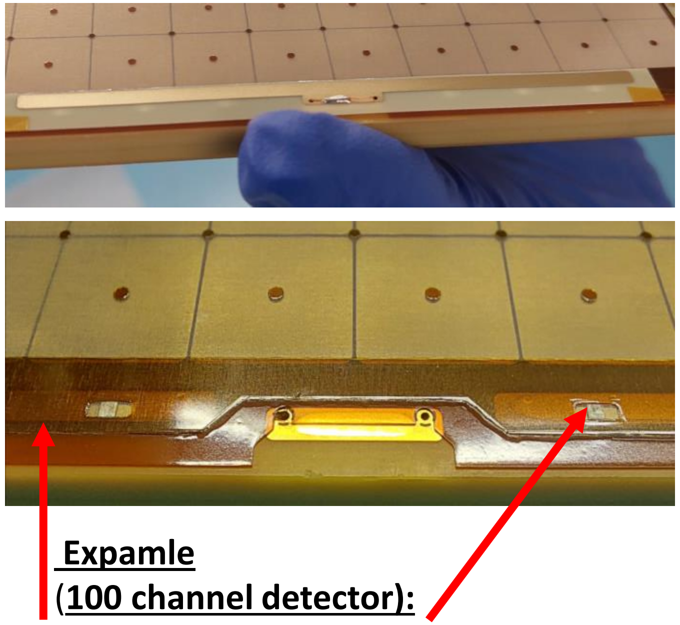


Example of discharge development in mesh cut region on a single channel prototype with a thin gap (~100 um)

Potential design improvements:

- **MESH connection points** outside PC area or protected with dielectric barrier.
- **MESH cut edge** outside the photocathode (PC) area.
- 100 channel detector with this design features was operating stable with a thinner (180um) drift gap.



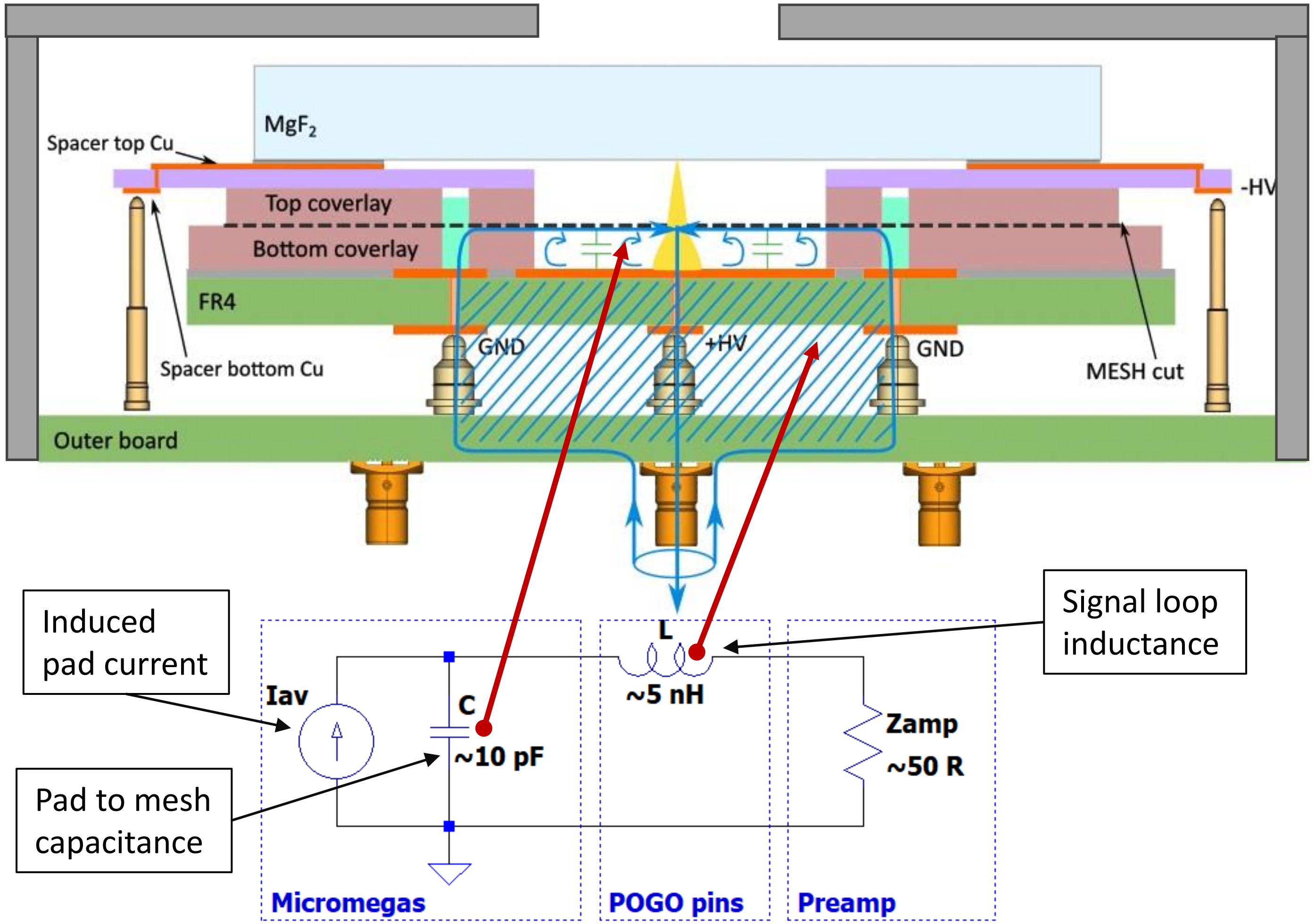


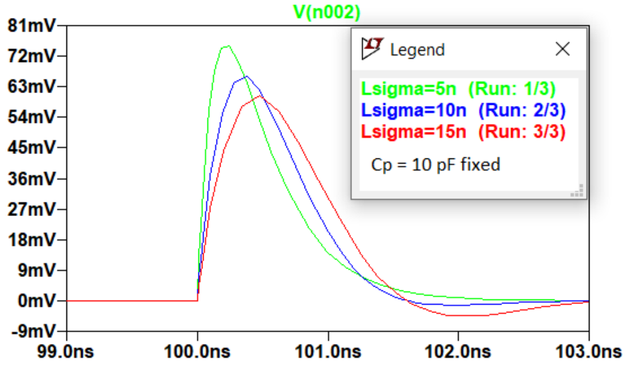
Expamle
(100 channel detector):
MESH cut and silver glue fill are outside PC area and covered with spacer.

Signal integrity considerations

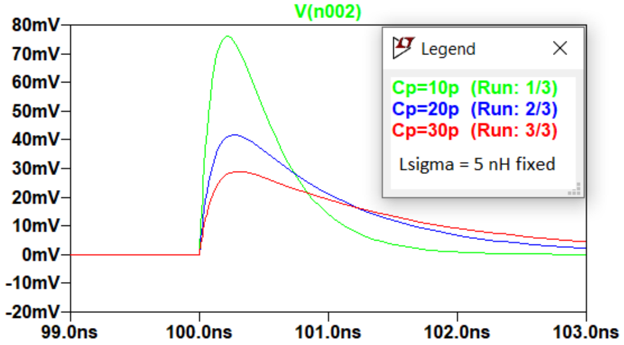
Maintain or improve signal characteristics: low noise, high amplitude, short rise time, minimize reflections.

- "Direct" connection of the readout pad to the preamplifier connector:
  - Reduced signal path length – no transmission line effects (**less reflections**).
  - Smaller signal **loop inductance** with multiple GND pin connections – high influence to signal rise-time and amplitude results.
  - Overall better SNR and timestamp reconstruction – **gain in time resolution**.
  - No interconnecting coaxial cable capacitance.
- Improvement in noise pickup immunity:
  - Multi-layer Outer PCB with ground planes as the shielding element.
  - Aluminum vessel in good electrical connection with the Outer PCB forms RF shielded box.
  - Filters for HV biasing integrated to the Outer PCB improve immunity and simplify operation.





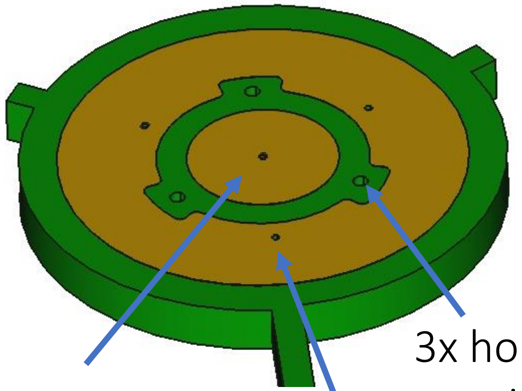
Sensitivity to inductance (Impulse response)



Sensitivity to PAD capacitance integrated

New single channel PICOSEC MM: Micromegas board & spacer design

FR4 + Top Cu

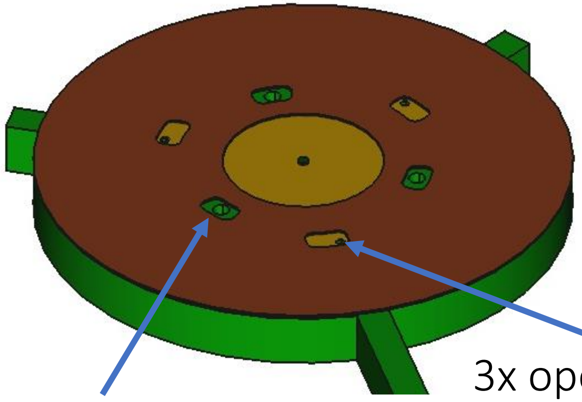


Readout pad and signal via.

GND plane ring

3x holes for gas circulation.

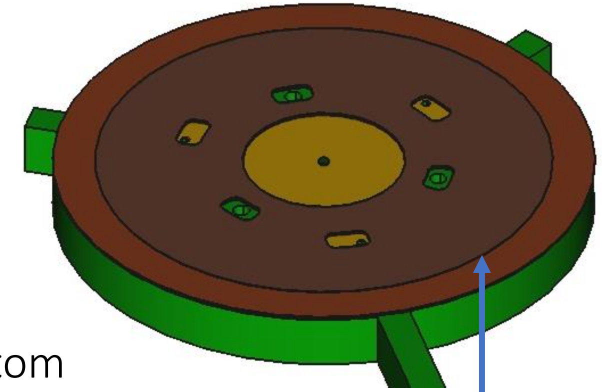
FR4 + Top Cu + Bottom insulating layer



3x openings in bottom insulating layer for gas circulation.

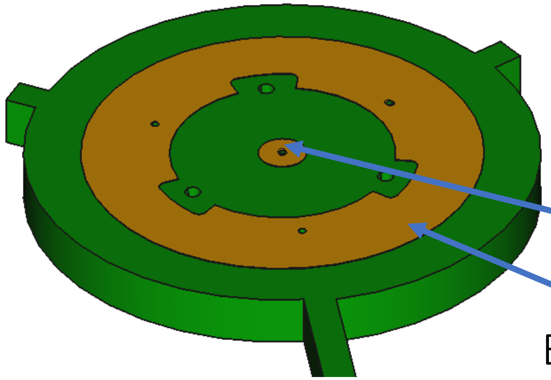
3x openings in bottom insulating layer for MESH connection to GND ring.

FR4 + top Cu + Bottom insulating layer (127 um) + Top insulating layer (50 um)



Top insulating layer edge is defining position of the mesh cut.

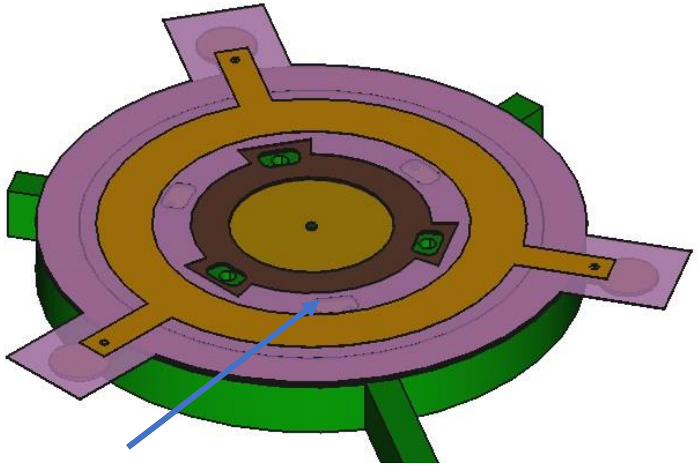
FR4 + Bottom Cu



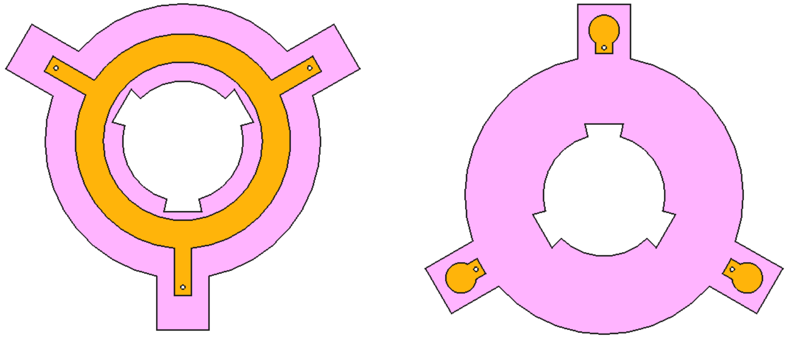
Signal pad for connection towards amplifier (spring-loaded pin contact).

Bottom GND plane ring.

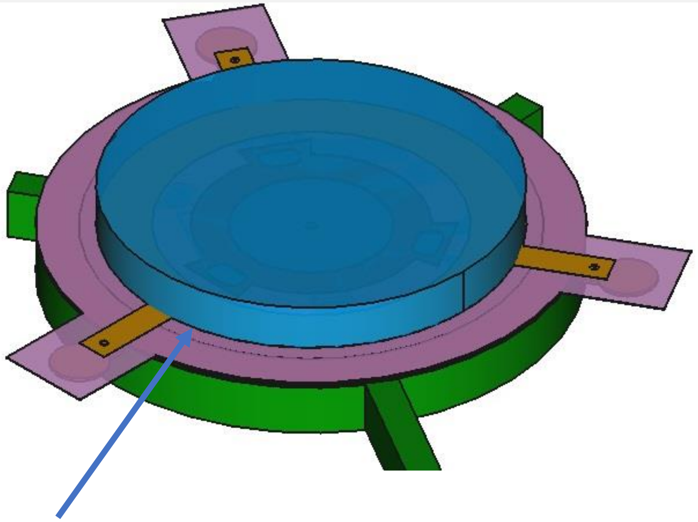
New single channel PICOSEC MM: Micromegas board & spacer design



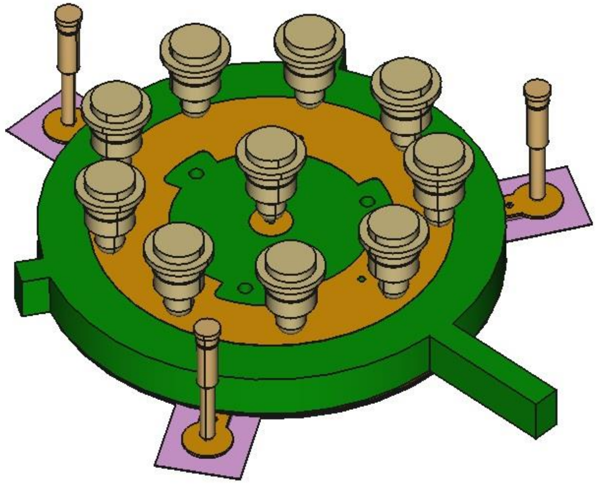
Spacer is placed on top of the MM board covering MESH connection points and Mesh cut edge.



Spacer top (right) and bottom (left) side. Two-layer copper clad Kapton. Total thickness 70 ± 5 µm.



MgF2 on top of the spacer and MM board



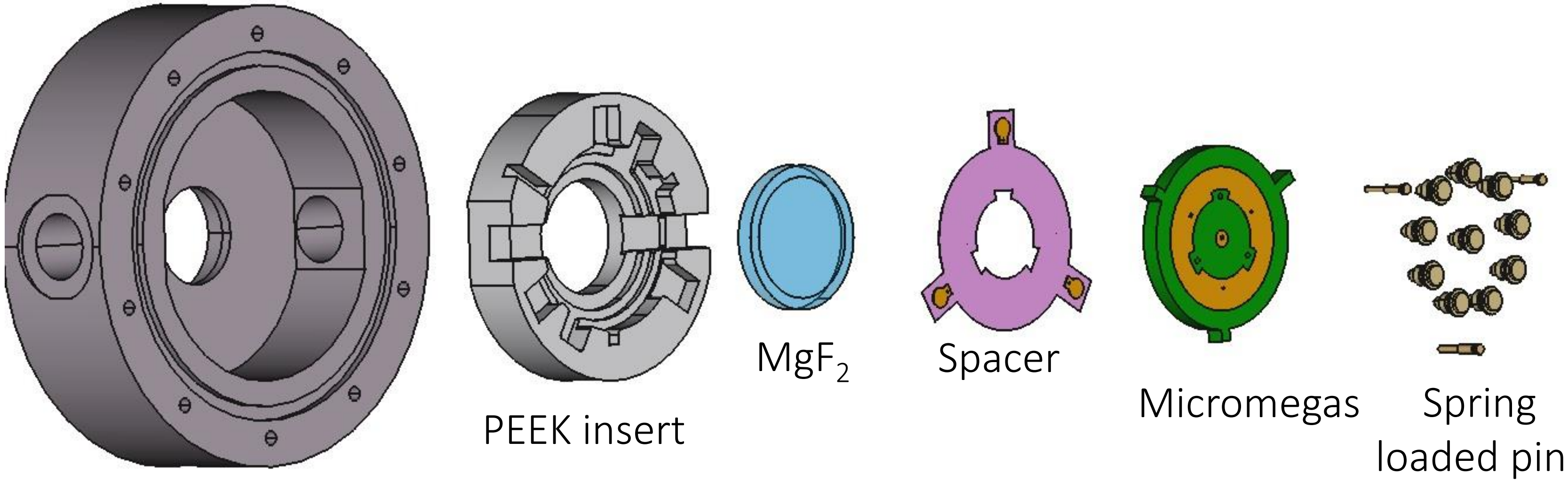
MM board and spacer bottom view.

- 9 x Heavy spring-loaded pins (156 g) were used at the outer perimeter to evenly press the board against the MgF2 crystal totaling 1.4 kg of pressing force.
- One light (23g) spring loaded pin in the center for signal readout.
- Photocathode HV connection is implemented with three spring loaded pins pressing bottom Cu pads on spacer.

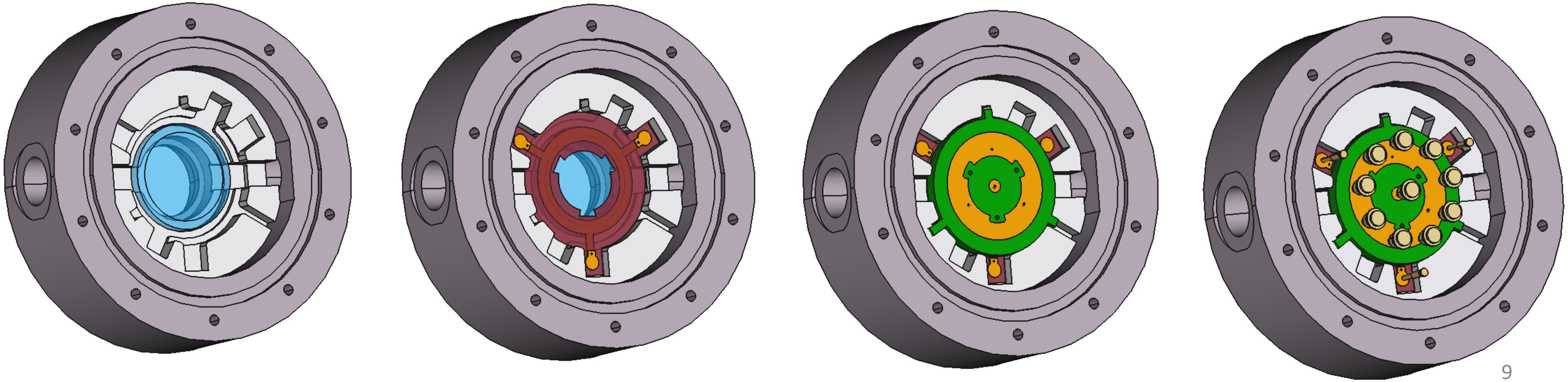
- Mesh cut and silver glue fill covered with dielectric barrier (spacer Kapton).
-“Direct” connection (no wires or soldering).

New single channel PICOSEC MM: Chamber & assembly concept

- Metallic (Al) housing with insulating insert (made from PEEK) for accommodation of main detector parts.
- Decreased probability of spark formation to the metallic housing.
- Enables easy exchange of main detector parts (MgF_2, Spacer, Micromegas).
- Reduced assembly time -> minimize CsI exposure time to the humidity.

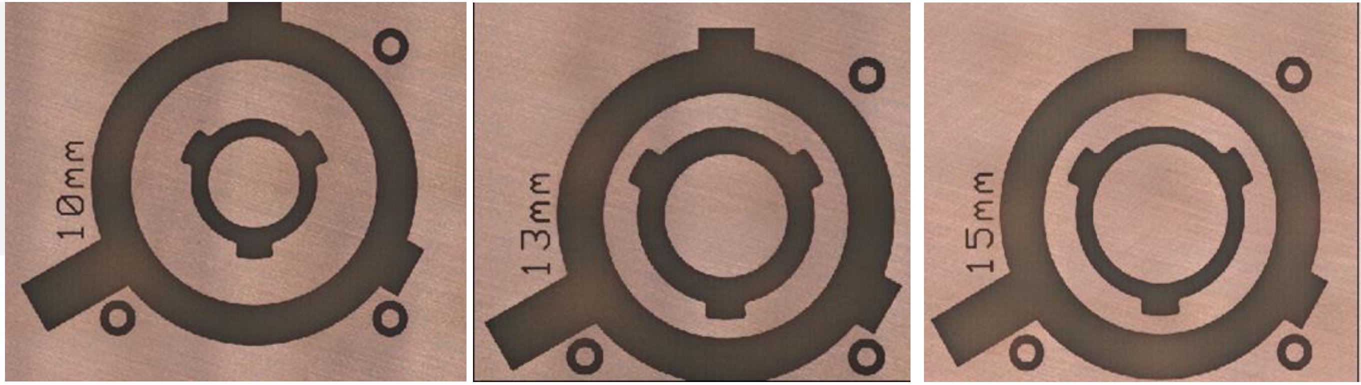


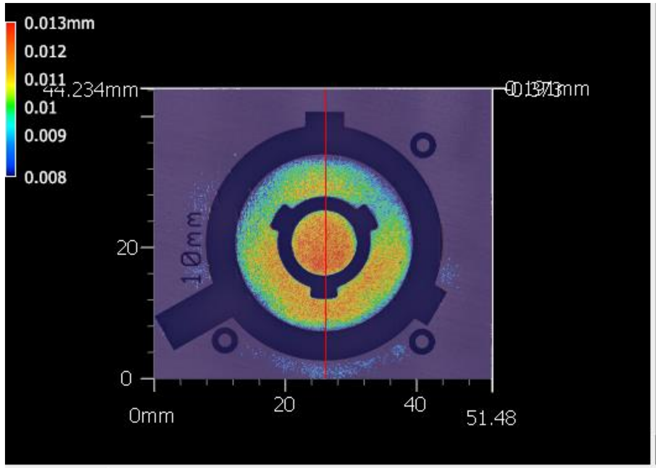
Al chamber PEEK insert MgF_2 Spacer Micromegas Spring loaded pins

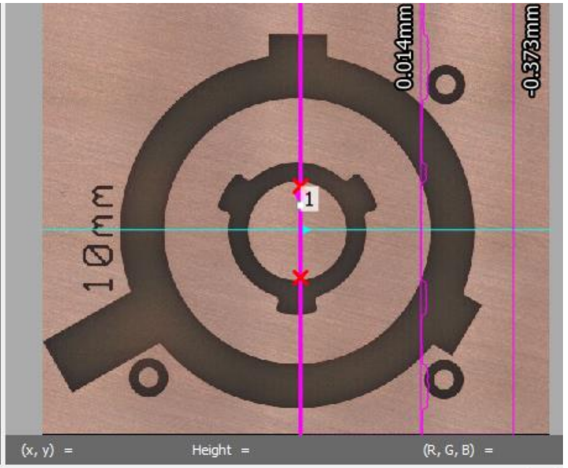


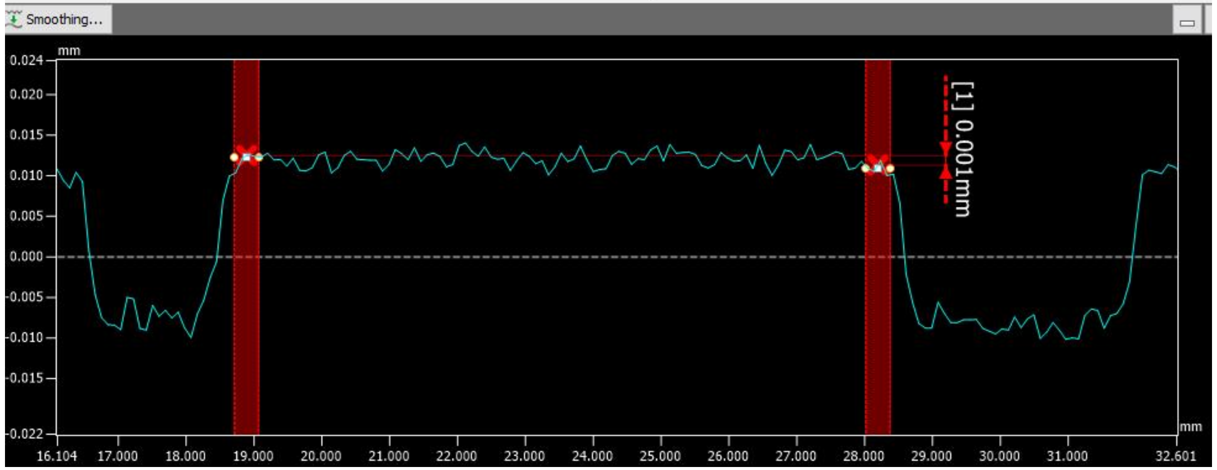
Micromegas production: planarity

- Three single channel Picosec of 10 mm, 13 mm and 15 mm active area were produced.
- **Thicker FR4 (3.2 mm)** material was used for production of the MM board to prevent board deformations due to the mesh stretching.
- MM board was polished up to the 5 µm planarity over the active area.
- Planarity measurements before the bulking show **highly uniform active area** without any deformations at vias positions.



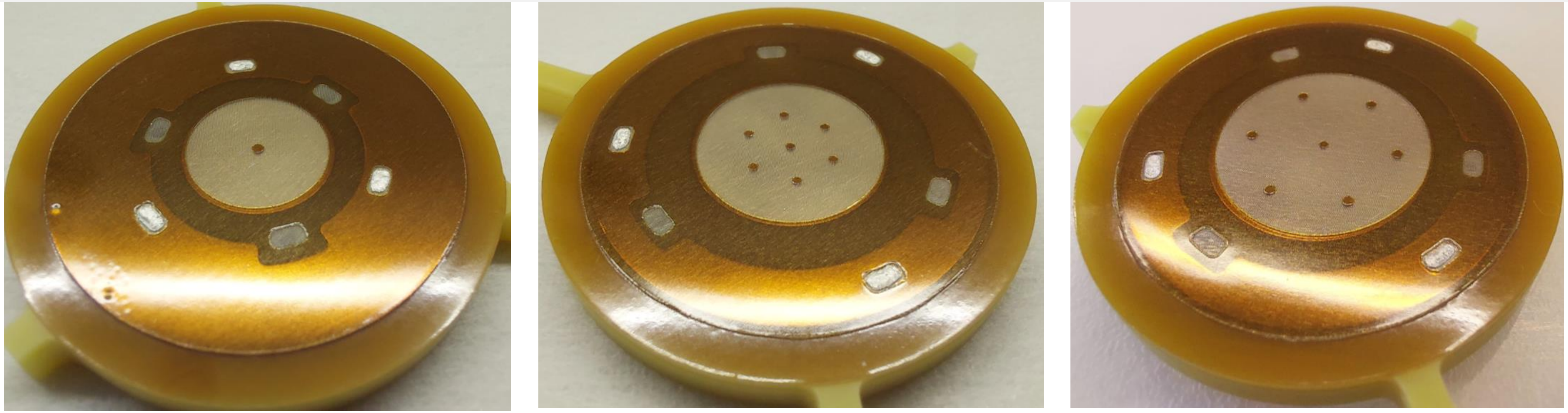






Huge thanks to CERN MPT workshop team.

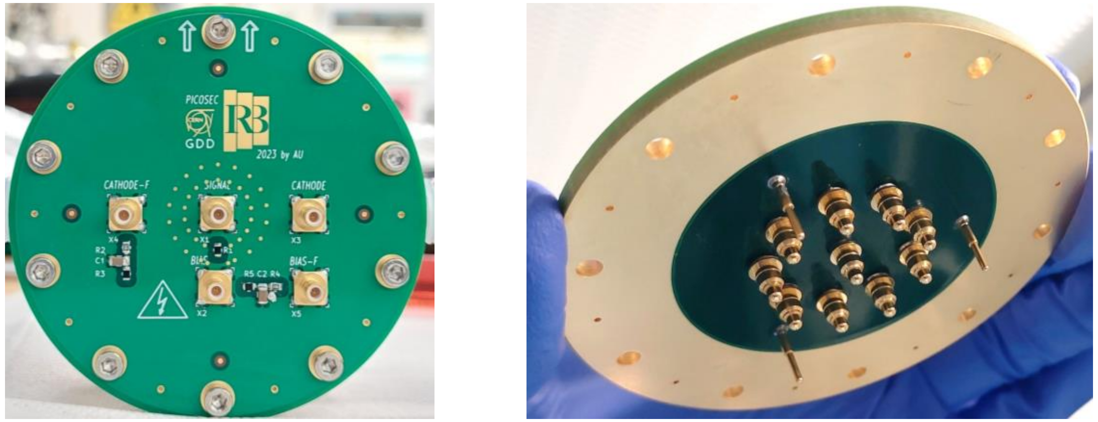
Production of detector components (Micromegas, spacers, PEEK insert and Outer board)



Three single channel Picosec (10 mm, 13 mm and 15 mm active area)

PEEK insert

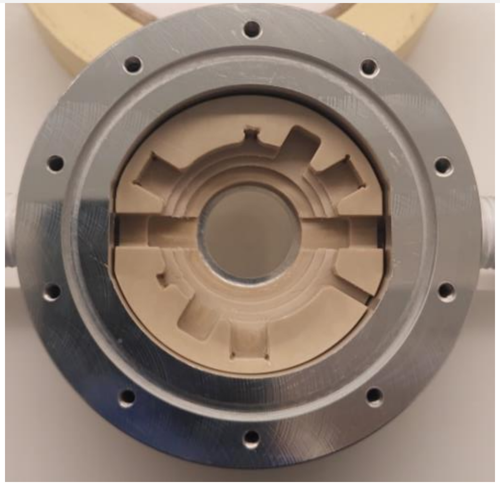
Spacer (top side)

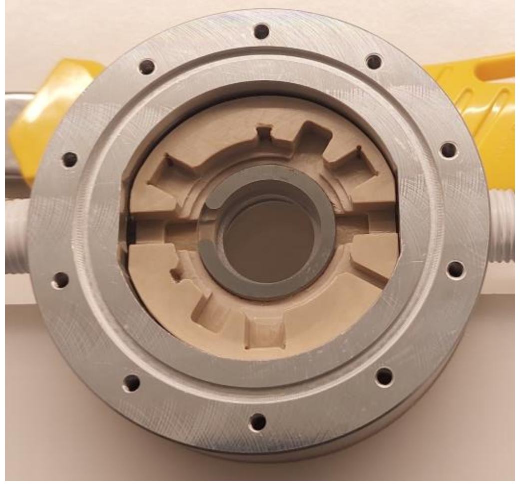


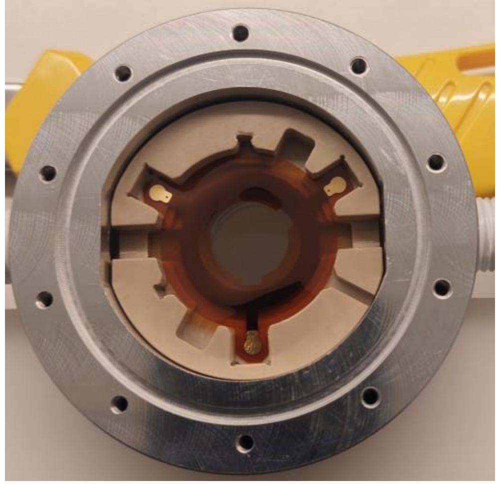
Outer board top and bottom side

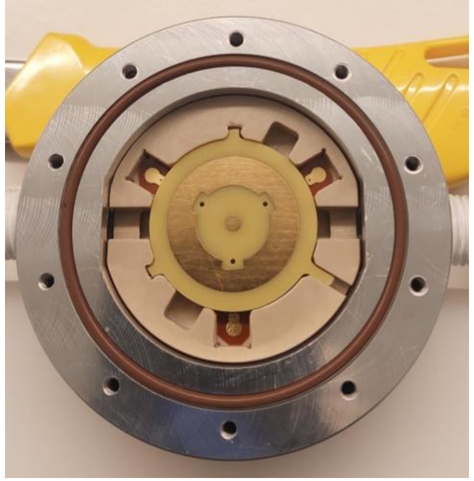
Huge thanks to Miranda VAN STENIS.

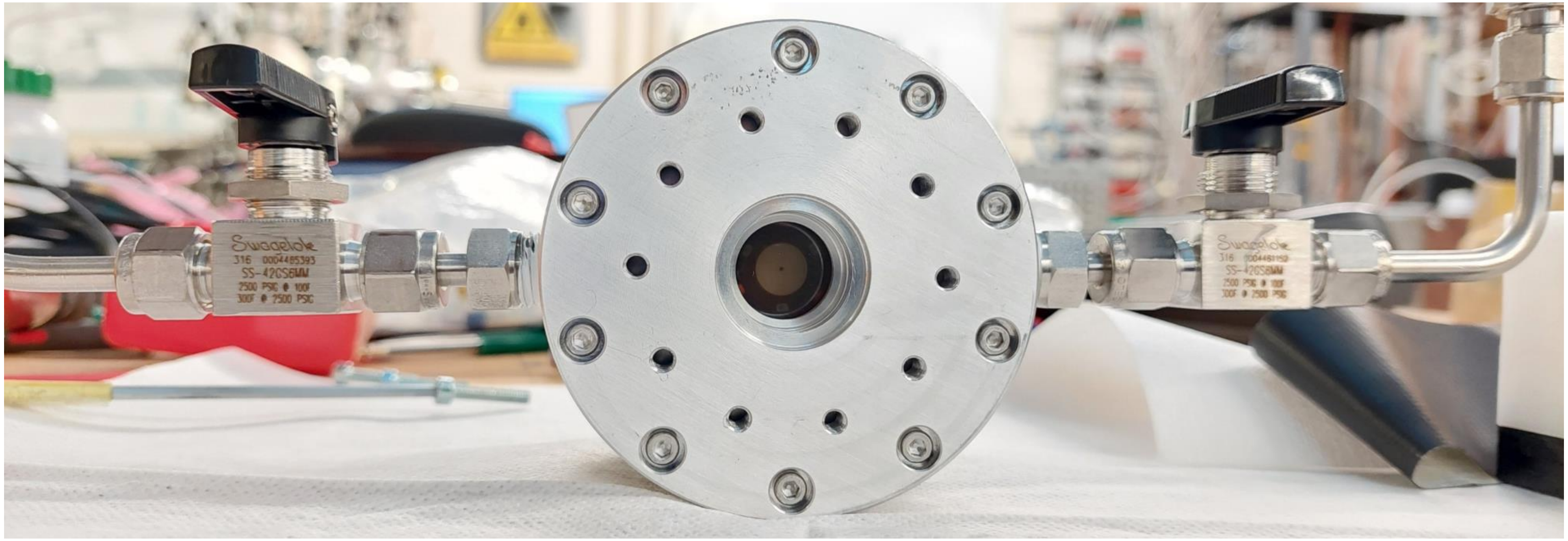
New single channel PICOSEC MM: Assembly



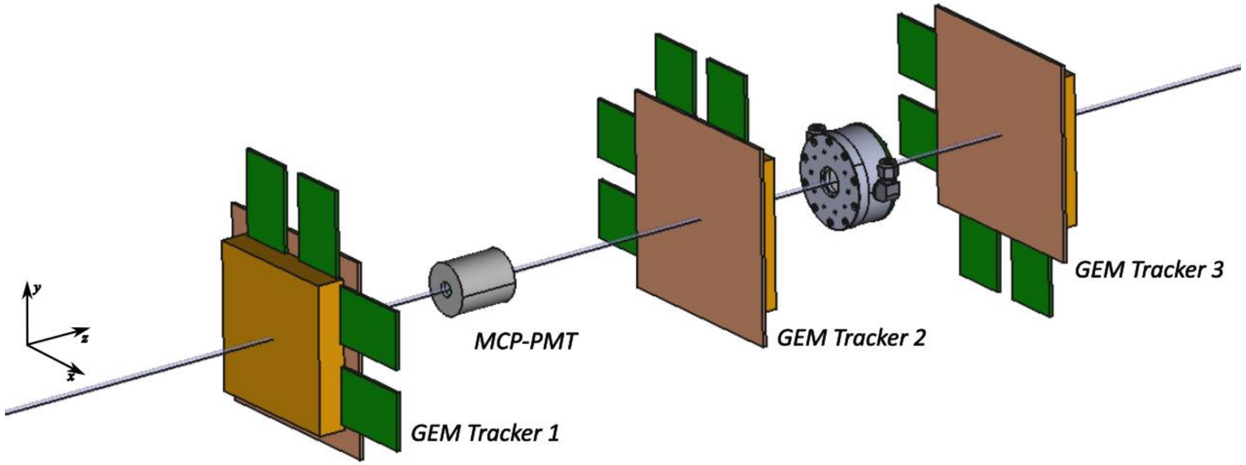




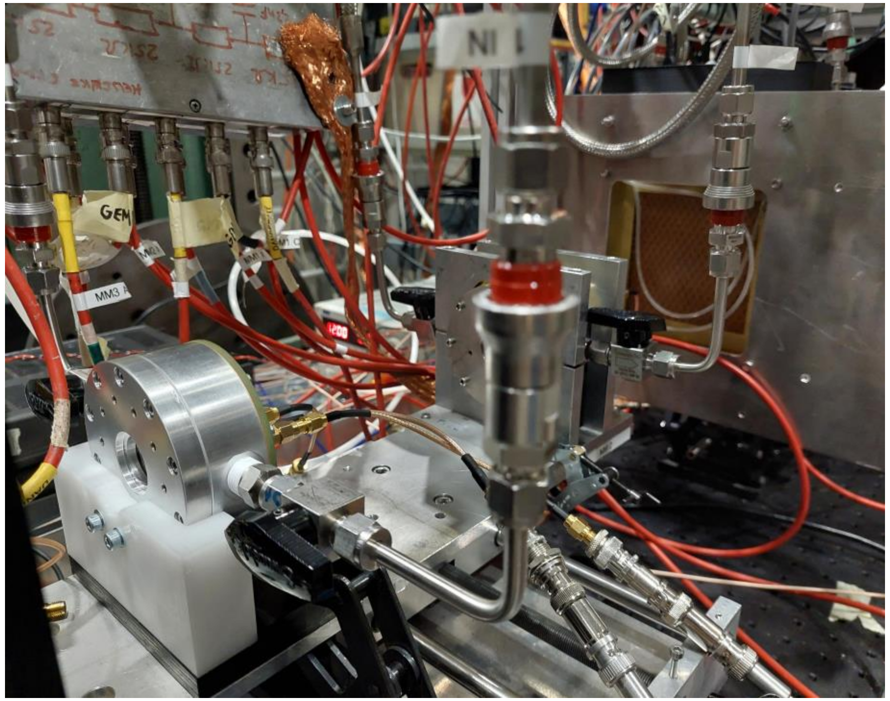




PICOSEC Micromegas test beam setup @ CERN SPS H4 beam line

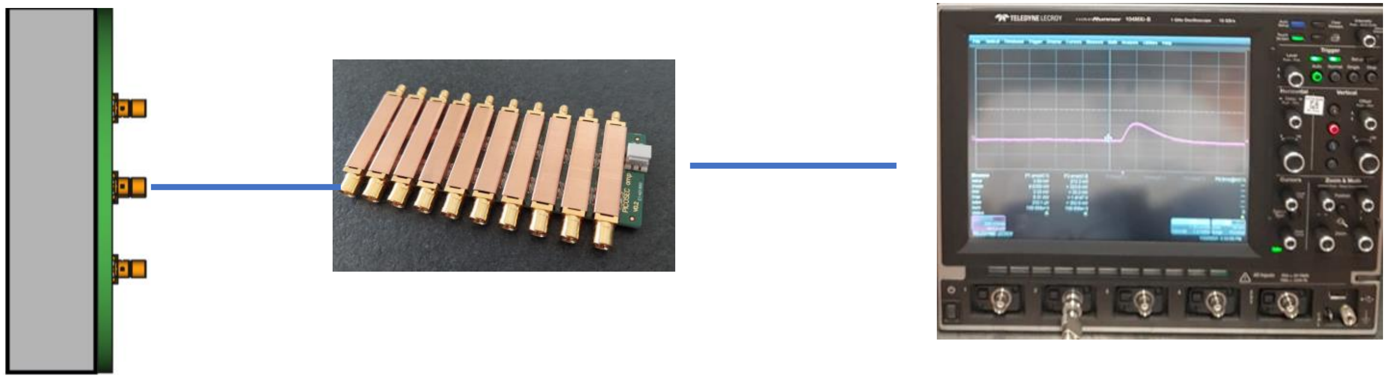


- **Test beam period July/August 2023**
- **Triggering/tracking/timing telescope**
  - **Timing and triggering**
    - MCP-PMT R3809U-50 Hamamatsu (11 mm diameter useful photocathode).
    - 2 x split MCP. Fixed and automated scan measurements.
  - **Tracking**
    - Triple GEM detectors, XY readout.



PICOSEC DUTs and FE and Data Acquisition:

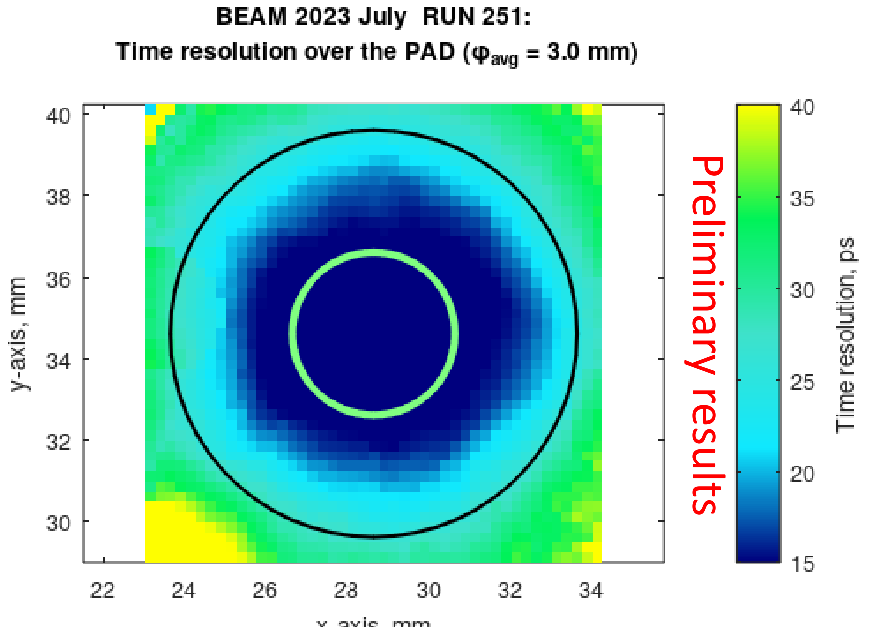
- Three single channel Picosec (10 mm, 13 mm and 15 mm active area).
- Custom preamplifiers (38 dB, 650 MHz, 75 mW per ch).
- Oscilloscopes: LECROY WR8104 operated at 1.0 GHz analogue bandwidth and at a sampling rate of 10 GS/s.

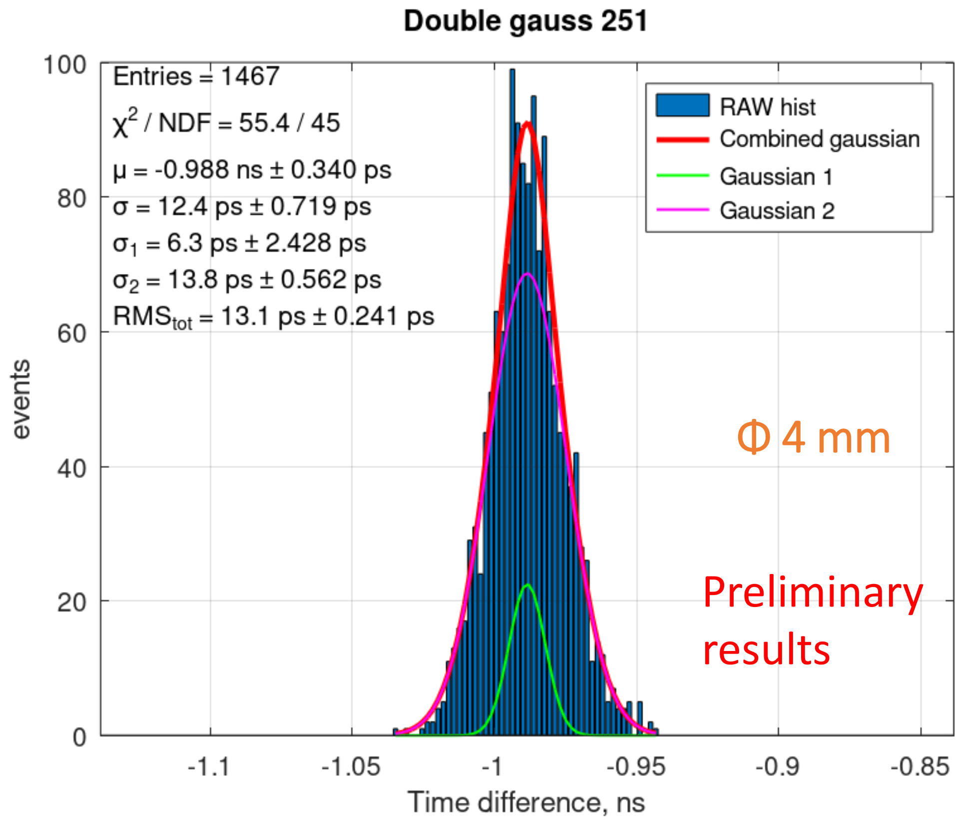


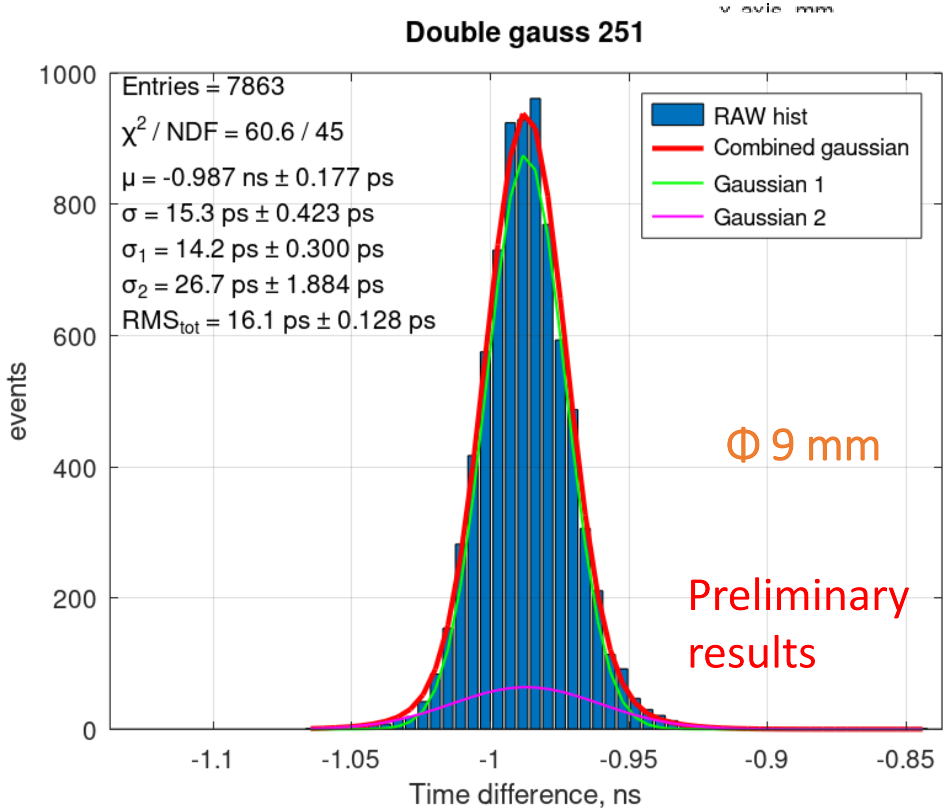
Test beam results for single ch. PICOSEC (Φ10 mm active area)

Photocathode: Cr (3 nm) +CsI (18 nm).
Operating voltage settings: -415 V on cathode / +275 V on anode. Fixed MCP.

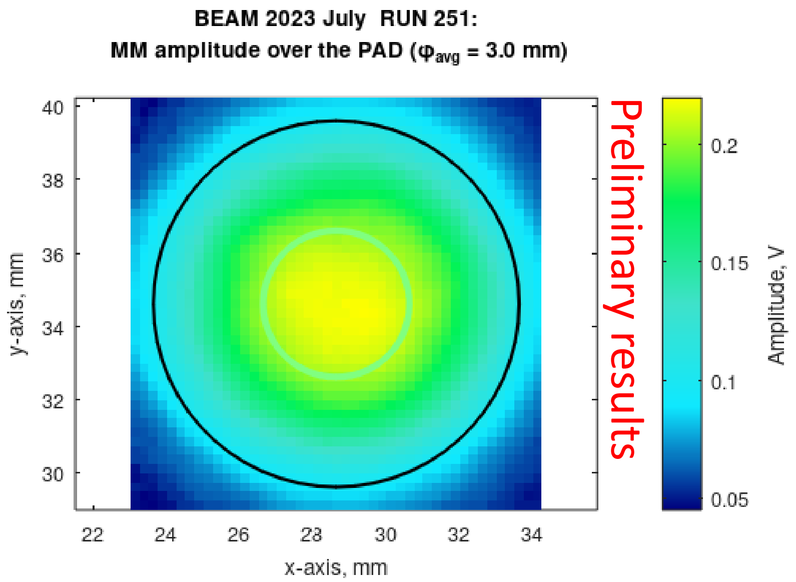
- Detector with very thin drift gap (**120 ± 10 µm**) operated stable for the entire test beam period.
- Best performing measurement was 12.4 ± 0.7 ps in the pad center region (Φ 4 mm) and 15.3 ± 0.4 ps over almost entire active area (Φ 9 mm) – MCP jitter not subtracted.

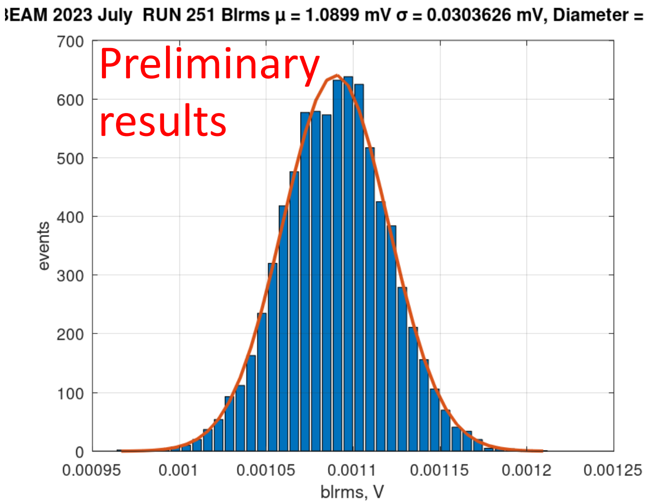


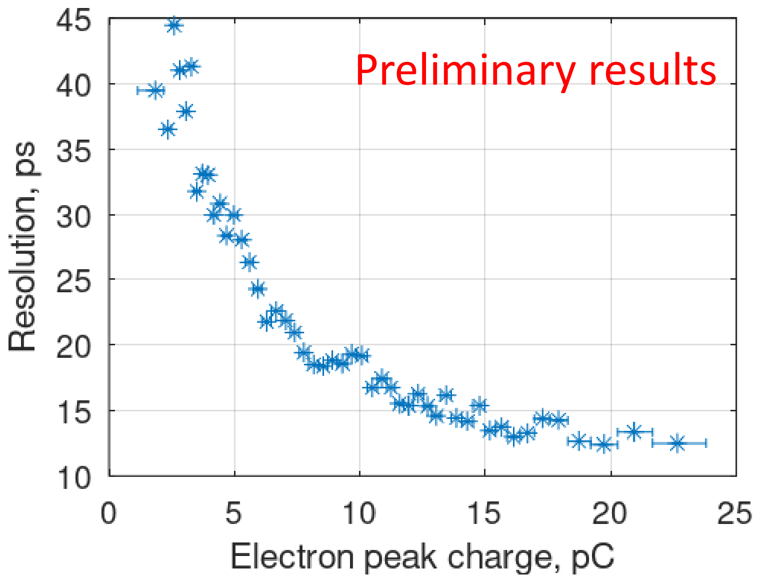


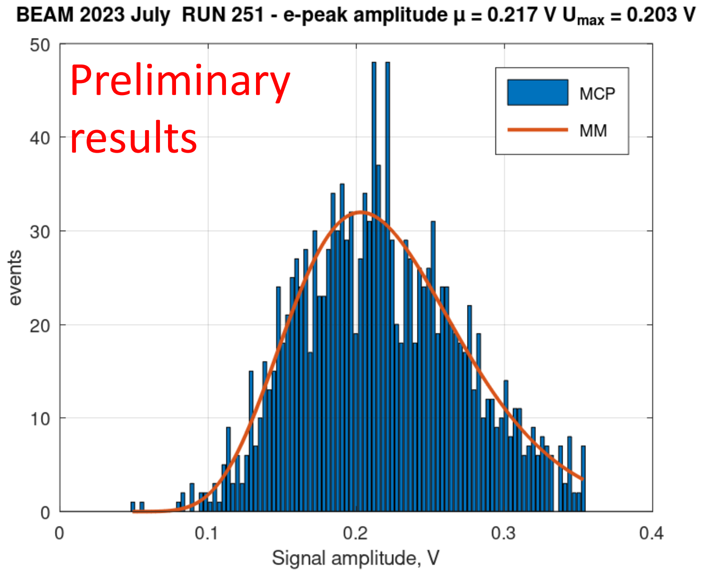


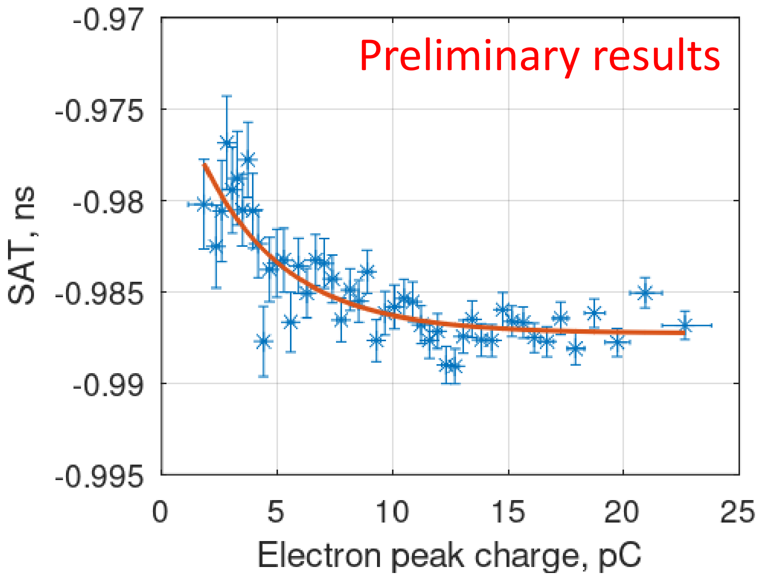
Test beam results for single channel PICOSEC (Φ10 mm active area)











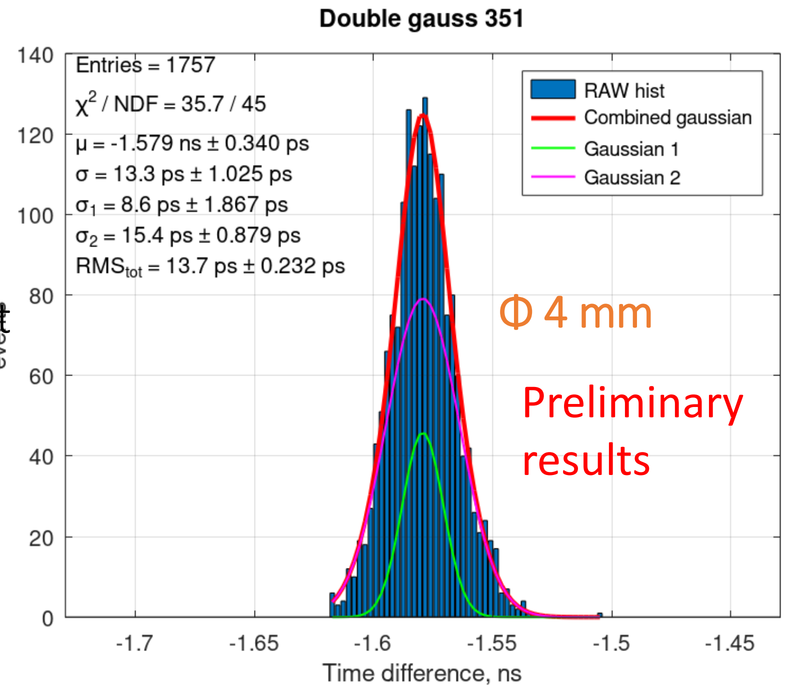
- Rise time (10 – 90%): approx. 680 ps.
- Mean e-peak amplitude: approx. 220 mV.
- Noise: 1.09 mV
- Very small difference (~10 ps) of SAT between small and large amplitude signals in time-walk curve.

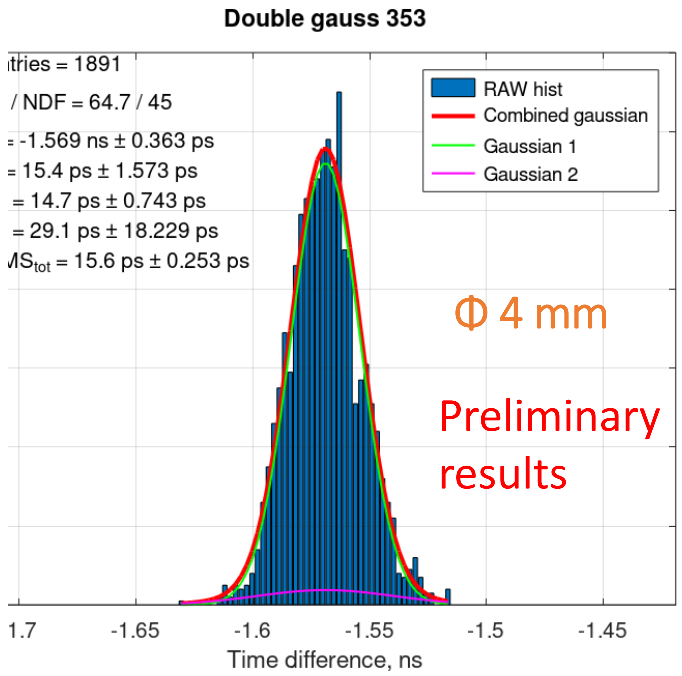
Influence of vertical digitization noise on time resolution

Single ch. PICOSEC (Φ10 mm active area):

Test beam period	Run number	Cathode/Anode	Vertical scale	E-peak mean amplitude	Noise RMS	Rise time	Time resolution RMS
2023 July	Run 351	-435 V/ +255 V	50 mV/div	215 mV	1.268 mV	709.5 ps	13.7 ± 0.2 ps
2023 July	Run 353	-435 V/ +255 V	100 mV/div	220 mV	**2.085 mV**	719.5 ps	**15.6 ± 0.3 ps**

- Degradation in time resolution observed with different vertical scales on the scope.
- Worsening of time resolution correlated to the increase in the background noise.
- At 100 mV/div digitization noise becomes dominant source of the noise.
- To achieve best timing performance, the detector, amplifier and digitizer must be optimized as a system.
- In such system, digitization noise should be at least two times lower than the noise of the amplifier and detector.
- **Problem:** Usage of lower vertical scaling results in more clipped events.
- **Idea**: try to measure with the 12-bit oscilloscope during the next test beam.

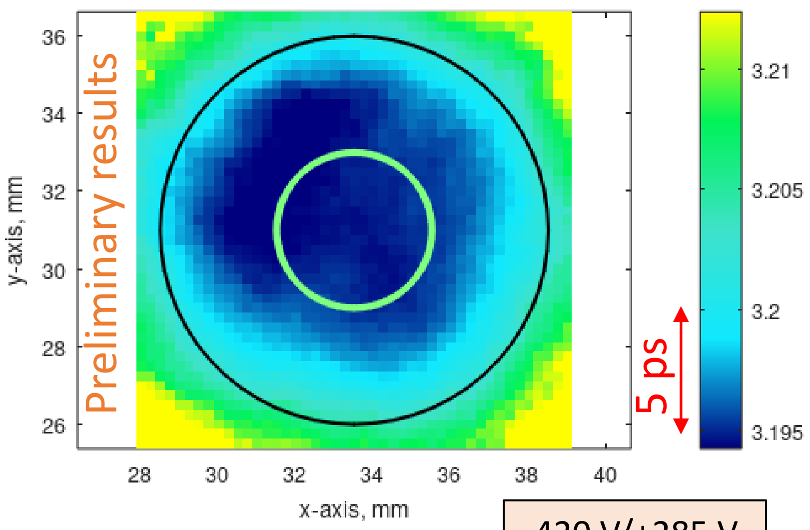




Scan measurements for single ch. PICOSEC (Φ10 mm, Φ13 mm and Φ15 mm active area)

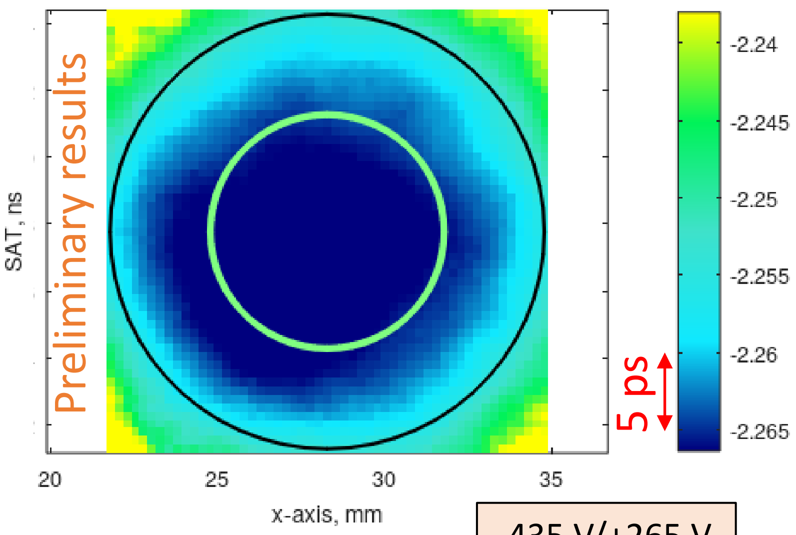
- Measurements with MCP mounted on a movable stage and scanning the entire pad area.
- Very uniform time response over the entire detector area for all three prototypes. Mean SAT well below 5 ps in the central region.

BEAM 2023 August RUN 283: SAT over the PAD (φ_{avg} = 3.0 mm) Φ10 mm



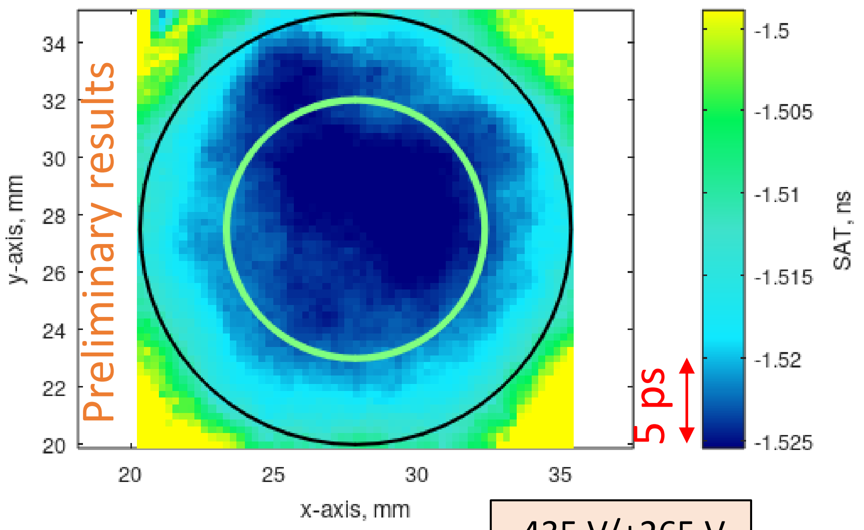
-420 V/+285 V

BEAM 2023 July RUN 434: SAT over the PAD (φ_{avg} = 3.0 mm) Φ13 mm



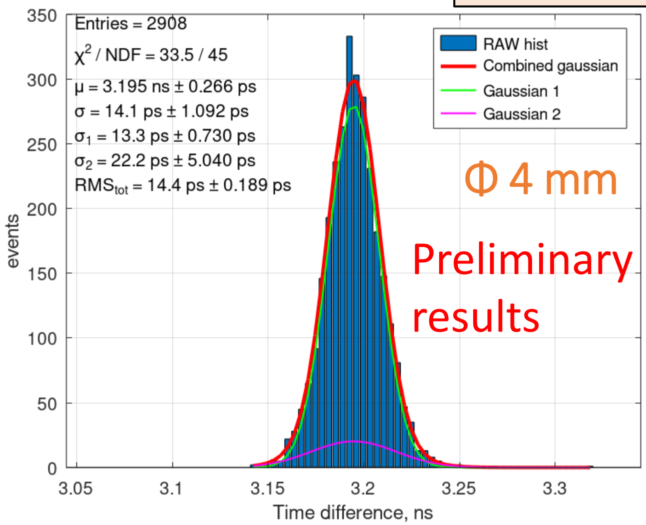
-435 V/+265 V

BEAM 2023 July RUN 401: SAT over the PAD (φ_{avg} = 3.0 mm) Φ15 mm

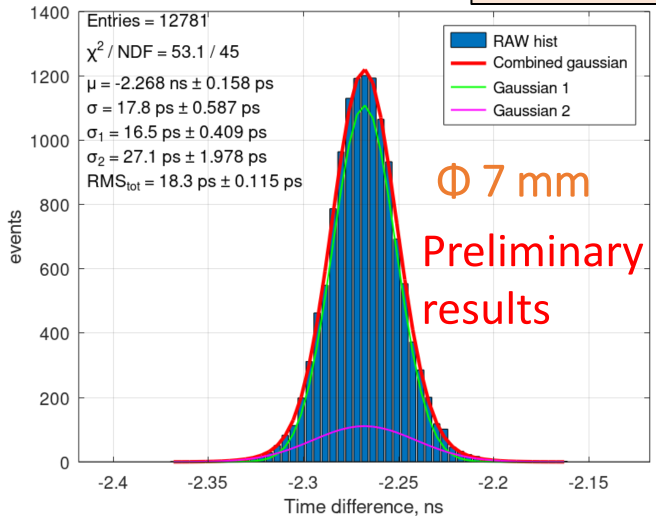


-435 V/+265 V

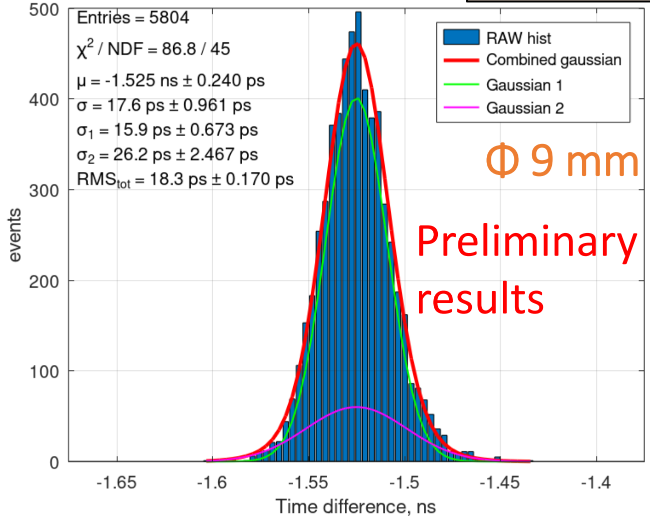
Double gauss 283



Double gauss 434



Double gauss 401



Conclusion

- The critical aspects of the design identified based on the experience with previous prototypes.
- The new single channel Picosec MM prototype designed with the improved HV stability, signal integrity considerations, time response uniformity and simplified assembly procedure.
- Three different size MM boards that are compatible to same housing were produced.
- Due to improved HV stability features, the detector was tested with very thin drift gap of 120 μm to push the limits of the technology.
- Preliminary test beam results showed that all three prototypes can operate stable with very uniform time response.
  - The 10 mm detector achieved outstanding time resolution of 12.5 ps, while larger detectors followed with resolution at level of 18 ps in central pad region (MCP jitter not subtracted).
- Additional effect of the influence of the vertical noise to the time resolution observed due to pushing the detector performance well below 20 ps.
- Optimization of the detector, amplifier and digitizer as a single system seems to be crucial in achieving new improvements (interesting topic for future application related studies).

RD51 PICOSEC Micromegas Collaboration

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Thank you for your attention! ☺