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Analysis of the micro-scale dynamics of X-Ray emission profiles collected with a GEM detector in needle-plane experiments at HVPTF

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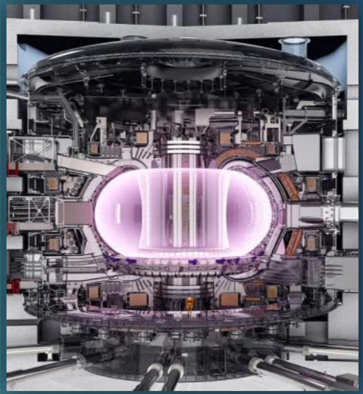
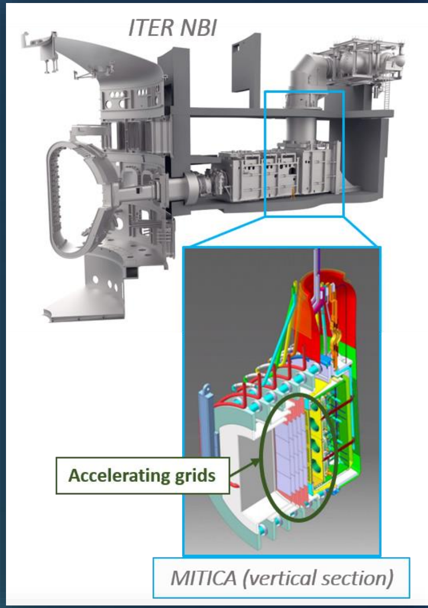
MITICA and HVPTF

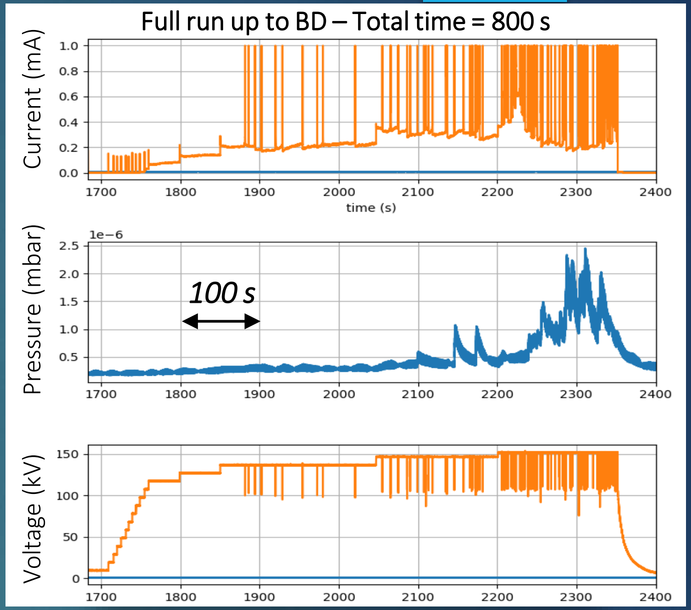
- MITICA is the full-scale prototype of the Neutral Beam Injector for ITER
  - ITER is a new tokamak under construction in France, aiming at Q > 10
  - The NBI is one of the external heating systems needed to heat up the plasma
  - NBI operation foresees the acceleration of a negative ion beam up to 1 MeV, followed by neutralization and injection in the plasma
  - One of the major challenges in the NBI operation is high voltage holding over long vacuum gaps
- HVPTF is an experiment built in support of MITICA operations
  - Large vacuum vessel with two replaceable electrodes
  - Voltage studies with different configurations up to 800 kV_{DC}
  - Current, voltage and pressure inside the chamber are sampled at 100 Hz
  - X-Rays (bremsstrahlung) are monitored as well, plus visible-IR-UV cameras

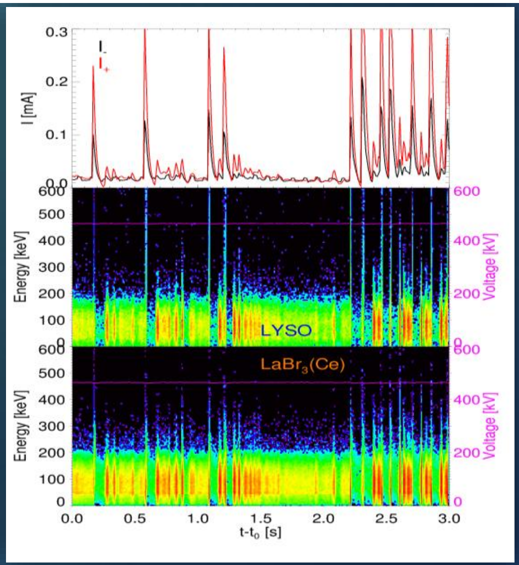




Micro-Discharges

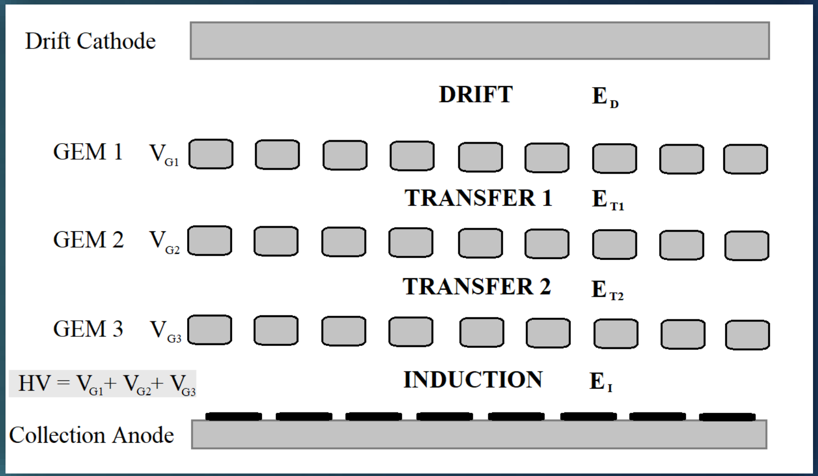
- Voltage holding in vacuum is hindered by the occurrence of discharges
  - Spikes of current which can translate also in voltage drops
  - Micro-Discharges are faster and milder, the system can recover
  - Breakdowns are more violent phenomena with larger timescales that can truly damage the apparatus
  - The study of micro-discharges and breakdown precursors can be of help in the design of a control system for safe operation
- Correlations have been observed in the past between the current signal and the X-ray emissions of the chamber, with the use of scintillators
- A faster detector can help in the analysis of the very short time scales, adding information in the search for the breakdown precursors

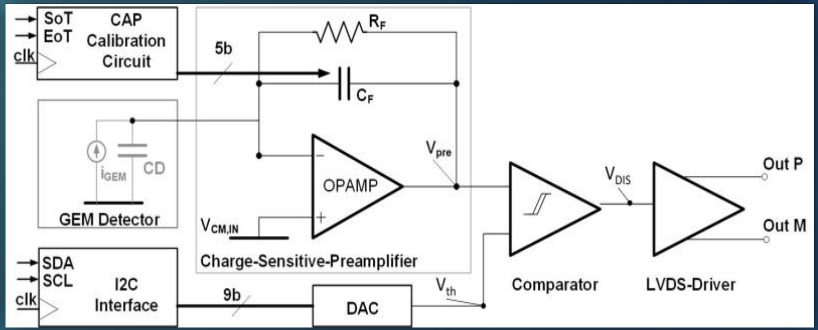




GEM Detector

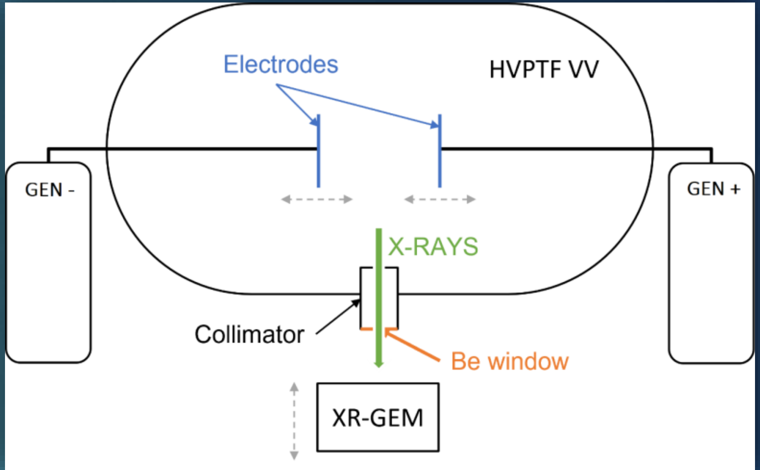
- Gaseous detector exploiting electron multiplication in GEM foils
  - GEM foils (CERN, since 1997) are sheets of Kapton (50µm) metal-coated on both sides by Cu (5µm)
  - A high-density pattern of micro-holes allows for high dipole fields with a voltage difference applied between faces
  - X-Rays directly ionize the gas ($ArCO_2$) in the drift region, primary electrons are accelerated and multiplied in the holes
  - Signal is collected on a pixelated anode (or strips)
  - Multiple foils stacked help achieving higher gains with lower risks
- Fast and accurate photon counting with digital readout
  - Combination of custom-made ASICs (GEMINI) and FPGA boards
  - Great temporal resolution (< 1ms) with low risk of pile-up
  - Good spatial resolution (few mms), with different possibilities for anode
  - Information on energy (ToT), discrete energy resolution (20% at 6keV)





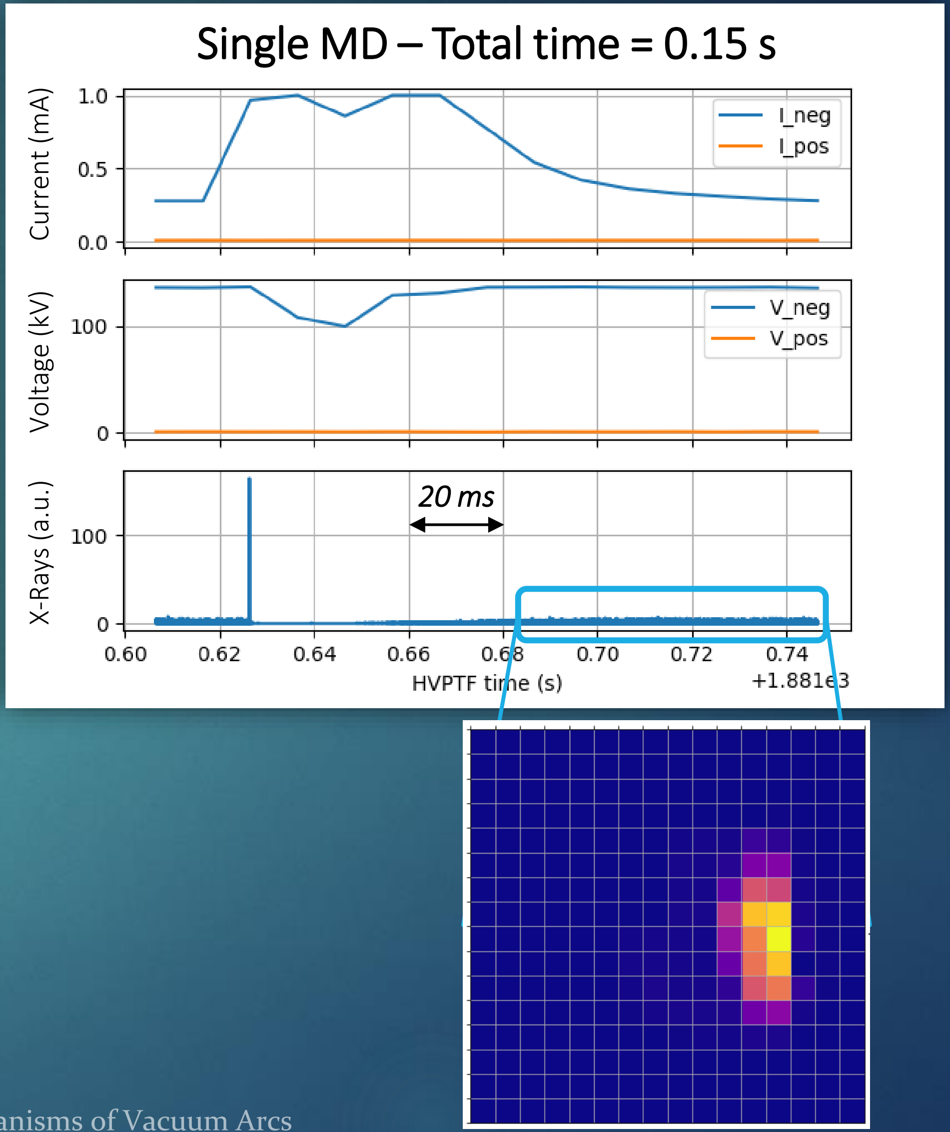
GEM Installation with needle-plane

- GEM detector was installed on a radial line of view of the chamber
  - Be window with pinhole collimator (Pb)
  - View range adjustable by moving the detector on the supports
  - Higher magnification obtained by moving GEM further away
- Needle-plane electrodes were mounted in the chamber
  - Both stainless steel, with no treatment
  - Plane 108 mm diameter, needle 29 mm long, 0.04 mm curvature
  - Distance between electrodes = 39 mm
  - Single polarity used, with needle at negative voltage and plane at ground



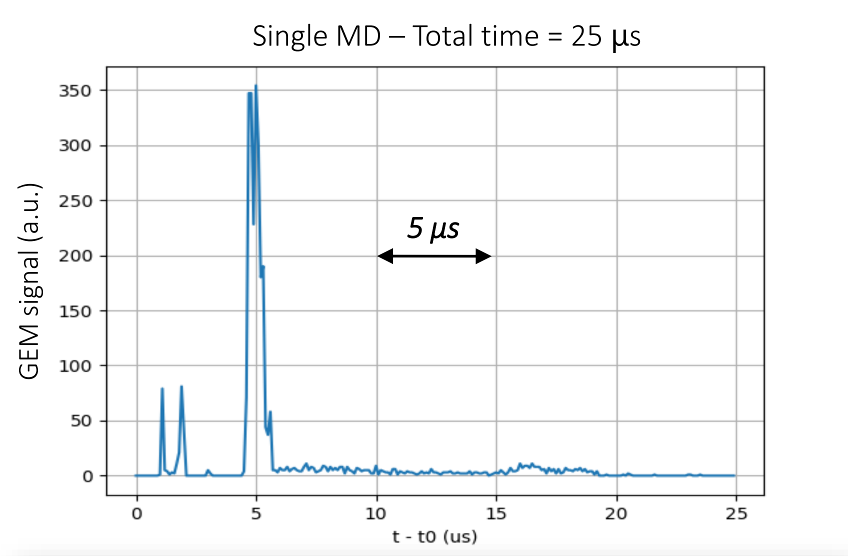
Temporal analysis - Macro-structure

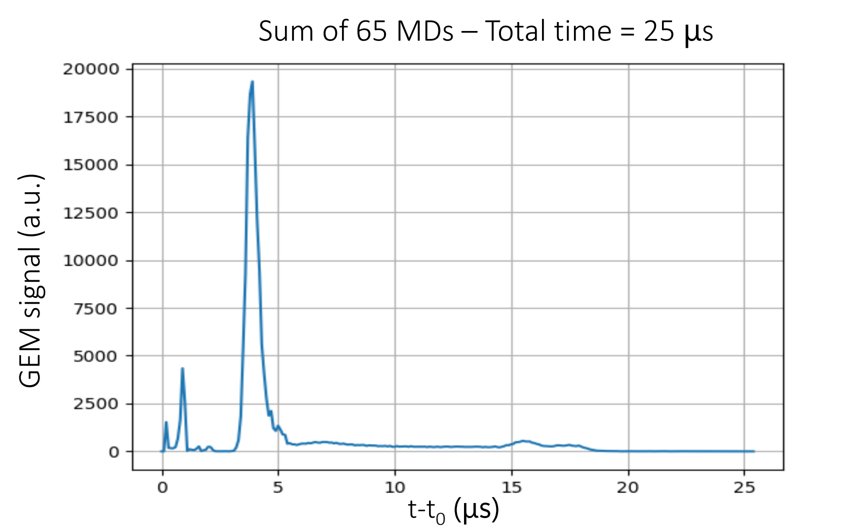
- Studies performed with the use of a custom data analysis software under continuous development specialized for GEM detector data
- During the whole run we have a continuous "background" of counts from the plane electrode, interrupted by the MDs
- MDs appear with a characteristic structure already at time-scales of tens of ms
- Current shows two rising features, the first one is the MD itself, the second is caused by the system getting the voltage back up to level
- X-rays shows single spike, followed by silence and then again background



Temporal analysis - Micro-structure

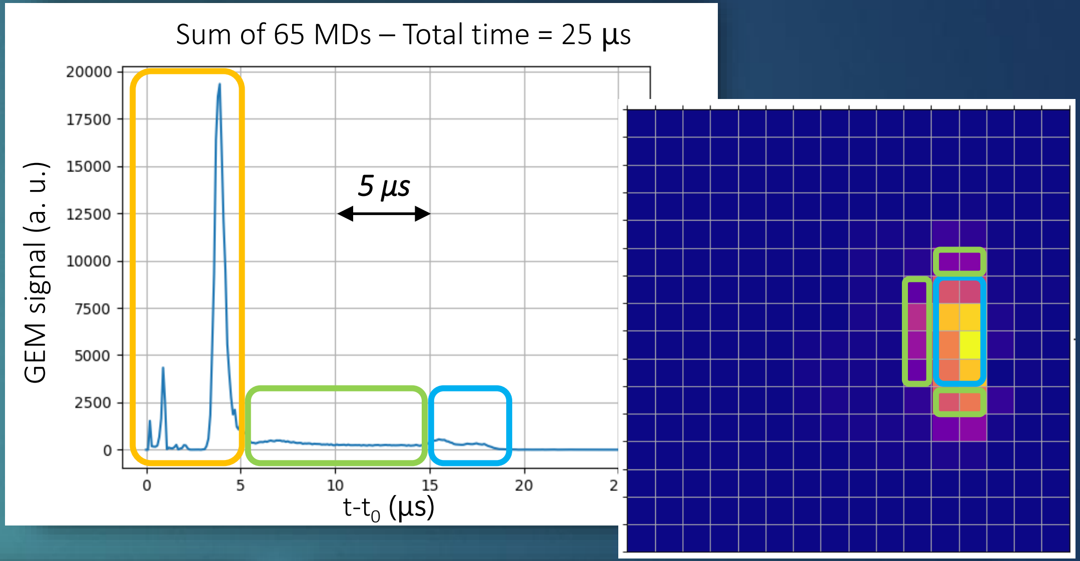
- A micro-structure becomes apparent by sampling below 1µs - 100 ns was chosen (trade-off between details and statistics). Multiple features can be distinguished:
  - A first peak with "medium" intensity, apparently bifurcated, with a duration of about 1µs
  - Some silence (about 2µs) after that, with a second smaller peak appearing in some runs
  - Then, the real spike, with high intensity (the detector unfortunately reached saturation at about 3-4 Gcps)
  - Finally, a smoother descent of about 10 to 15 µs
  - After this, the voltage drops, and we have no more emission until it is brought back up again (about 20 ms)
- The structure is heavily consistent across all MDs, so that the counts can be summed to have more statistics

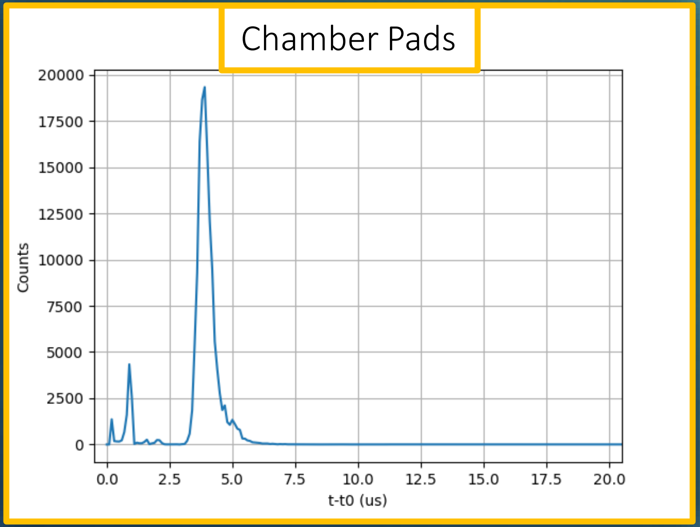


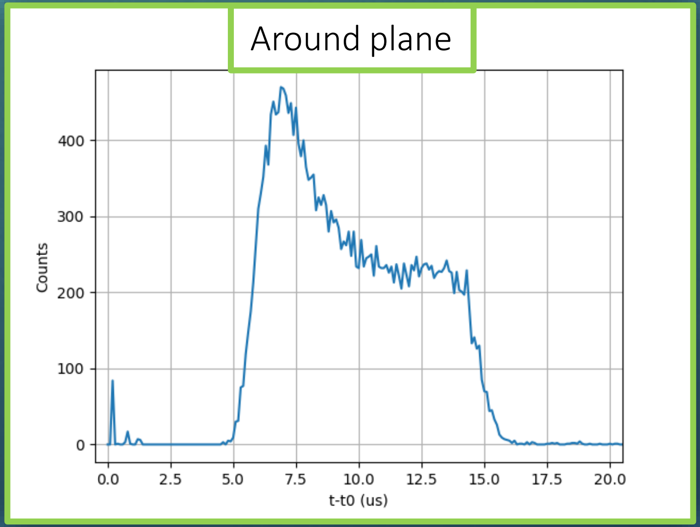


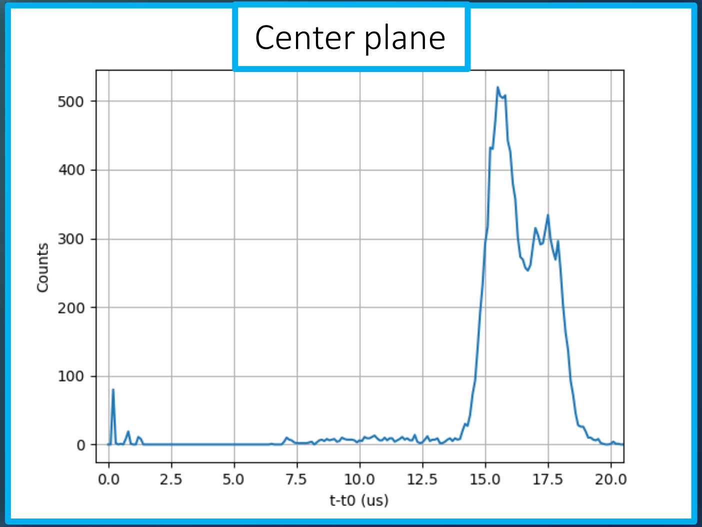
Spatial analysis – Pad Groups

- Combined space-time distribution analysis highlighted the presence of **three** distinct **groups of pads**, based on their temporal traces
  - **First peak** and **big spike** exhibit counts **only** for the pads pointing to the **chamber** rather than the electrodes
  - Pads with a line of sight directly on the **plane** show **no contribution during the MD** peaks, but only signal at the end of the descent
  - **During** the **descent**, signal is coming mainly from **around the plane**



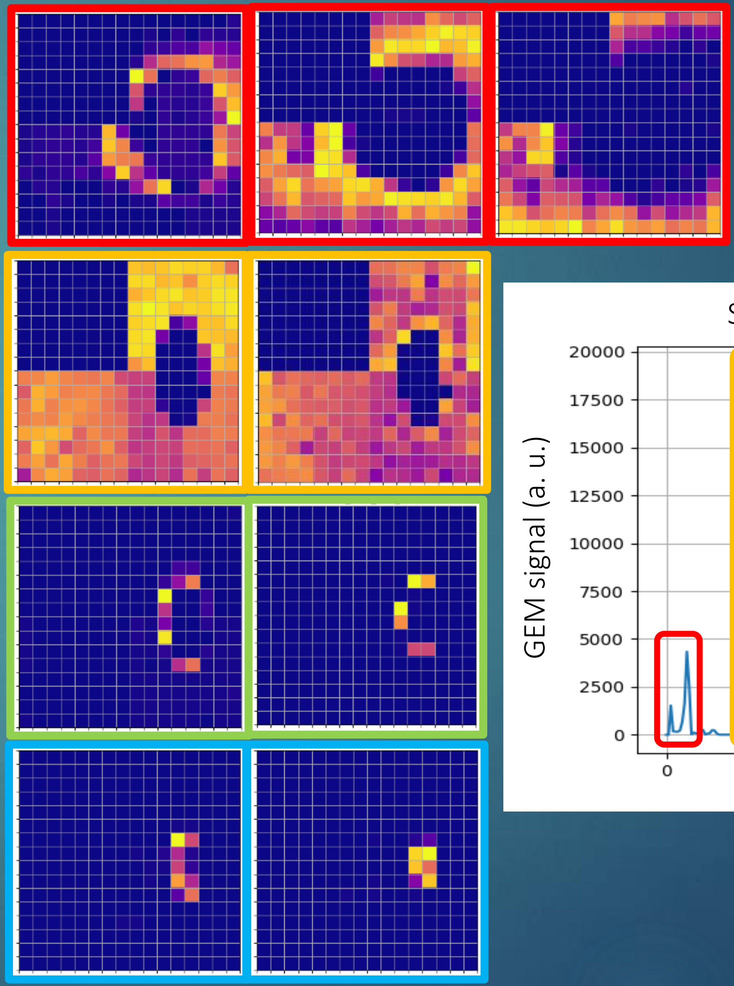


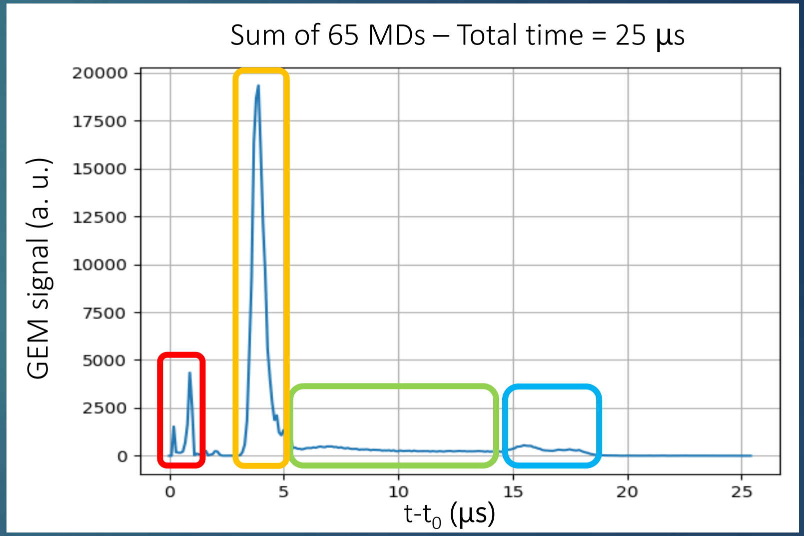




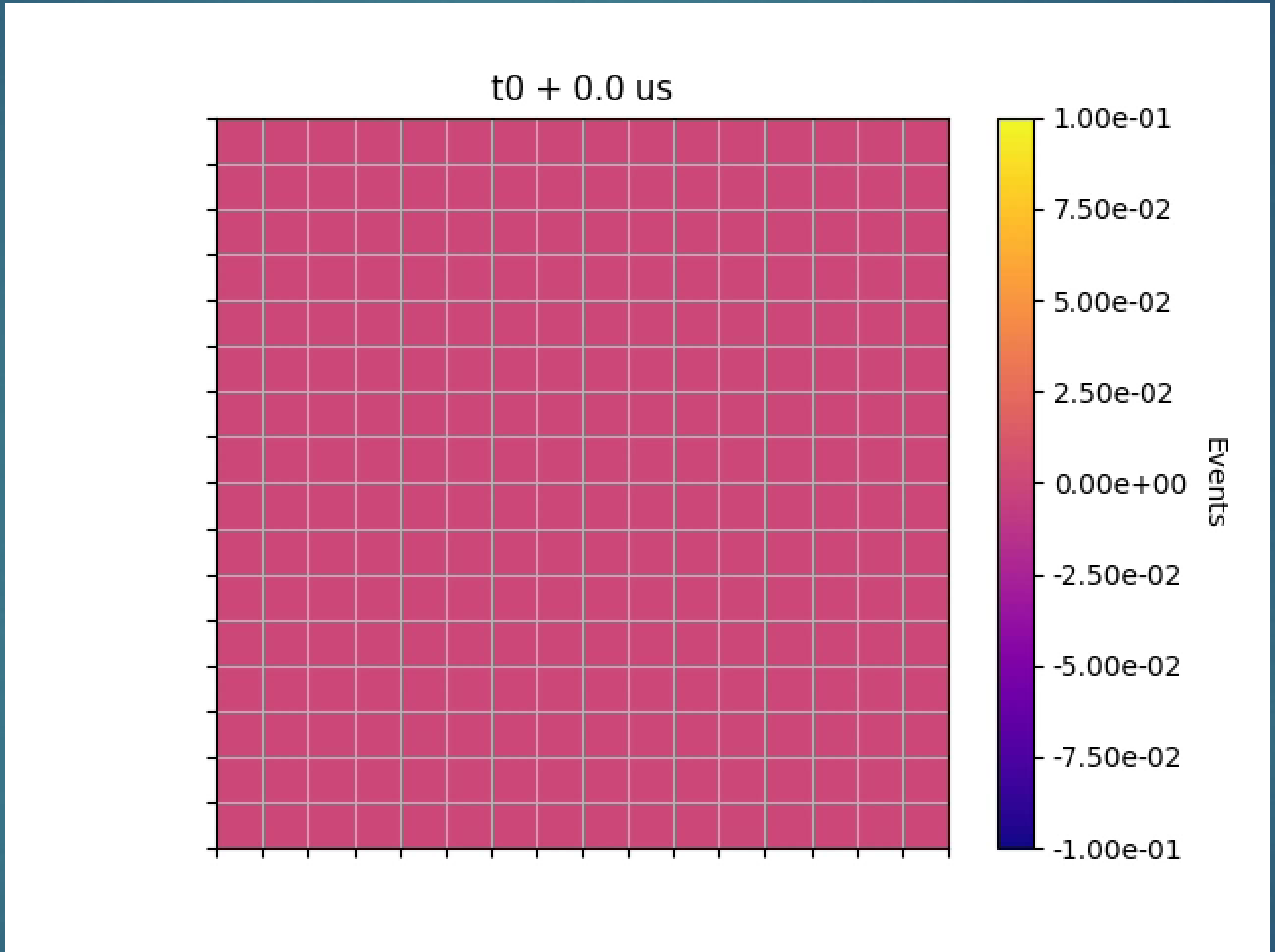
Spatial analysis – Map Sequence

- The consistency of the temporal structure allows to sum all MDs to obtain better statistics – this helps also with the spatial analysis
- Emission during the first peak starts from around the plane electrode and goes out to the chamber (twice)
- Then, the whole chamber lights up, leaving the plane apparently “switched off” on the big spike
- During the descent, emission from the chamber disappears and only the pads with view around the plane emit (longest component)
- Finally, emission is back on the plane only





Spatial analysis – Sequence Video



Discussion and Perspectives

- The dynamics of the micro-discharges observed can suggest phenomena as those of virtual anode and plasma sheath
  - Electrons can be deviated towards the chamber by a local modification of the voltage around the plane electrode (at ground)
  - The missing emission from the plane during the actual spike can indicate the presence of something like a plasma layer around it during the discharge
- A simulation code, based on the calculation of the voltage map and electron transport in the HVPTF domain, is being developed to try and reproduce the conditions leading to the observed dynamics
- Another experimental session with a new GEM detector (smaller pads) has been set up at HVPTF, to compare the results obtained on the needle-plane configuration with something different (sphere-plane this time)

Many thanks to the coworkers and contributors from:

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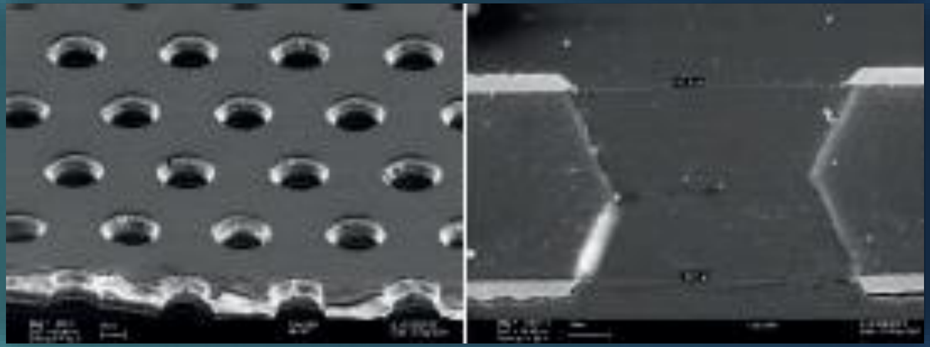
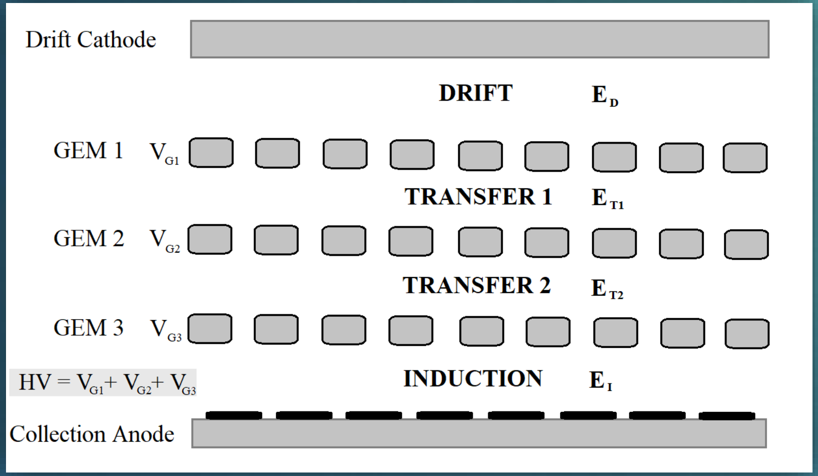
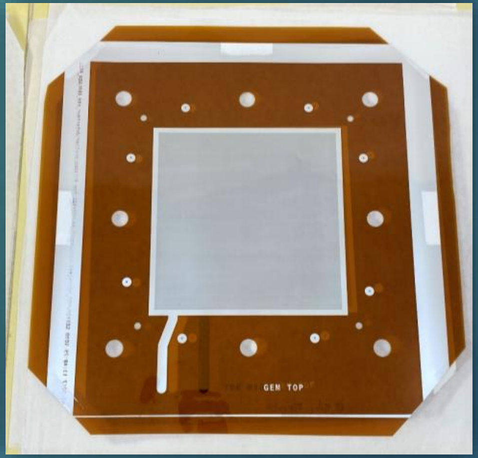
And thank you all for your attention!

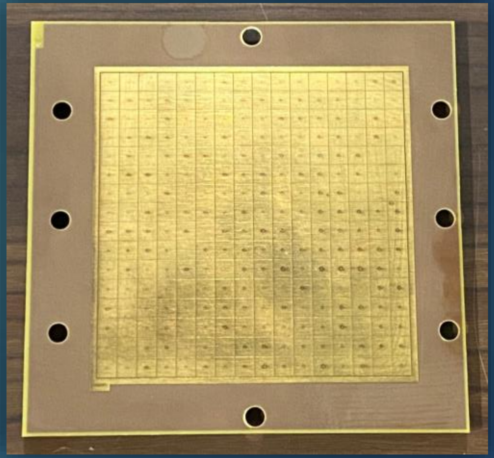
Backup Slides – GEM detector configuration

- Detector configuration:
  - Micro-holes pattern: 70 µm diameter, 140µm pitch
  - Pixelated anode: 10x10cm with 256 6x6mm pads
  - Gap dimensions: Drift=4mm, T1=2mm, T2=1mm, IND=2mm
  - HV value for detection: 1050-1080 V – gain approx. 10^4



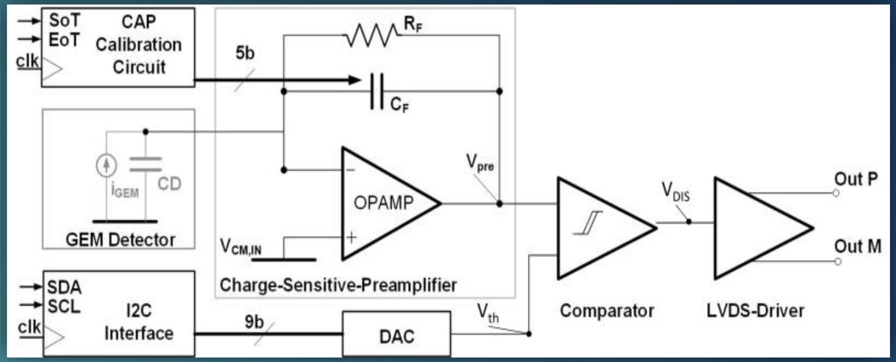


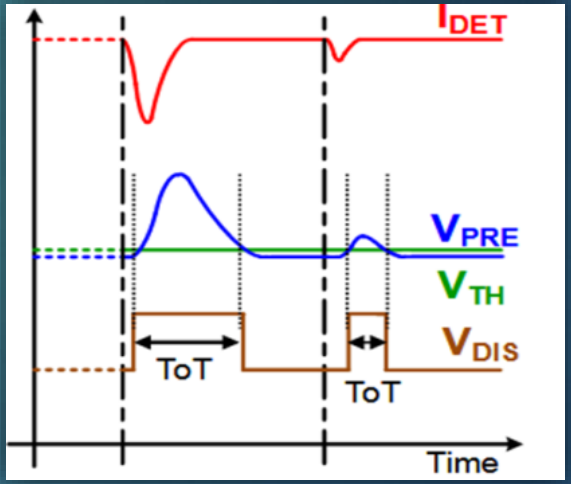




Backup Slides – GEM detector readout

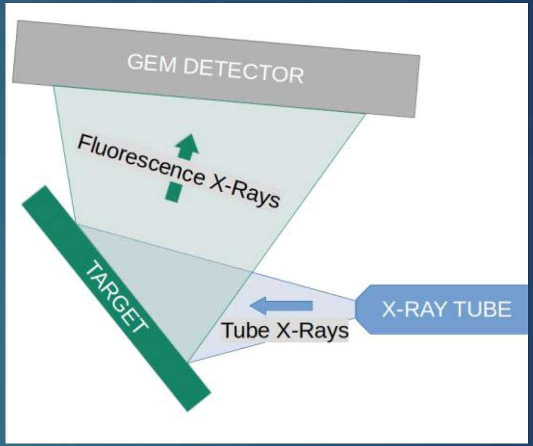
- Readout system:
  - GEMINI ASIC + FPGA boards (all custom made)
  - Digital readout for fast and accurate single photon counting.
  - GEMINI ASIC: fully integrated analog front-end electronic system. Generates information about the Time of Arrival and the “Time-over-Threshold” of each event.
  - FPGA: series of TDCs (sampling @2GHz), reading output from up to 256 GEMINI channels, and packing information of each event in a 64-bit word, to be sent to DAQ PC.
  - The final result is information about Time of Arrival, ID (pixel), Time over Threshold (charge).
  - The limiting factor for the acquisition speed is transmission of data through fiber (125 MHz approximately)

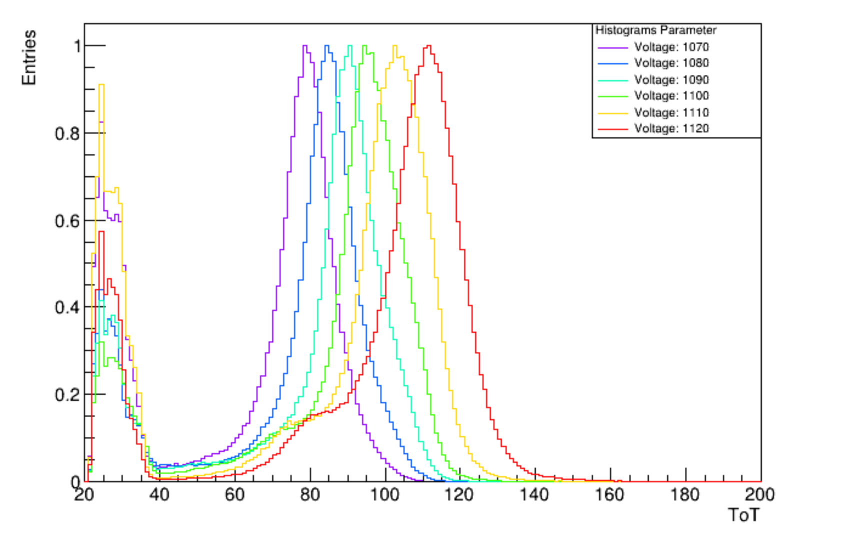


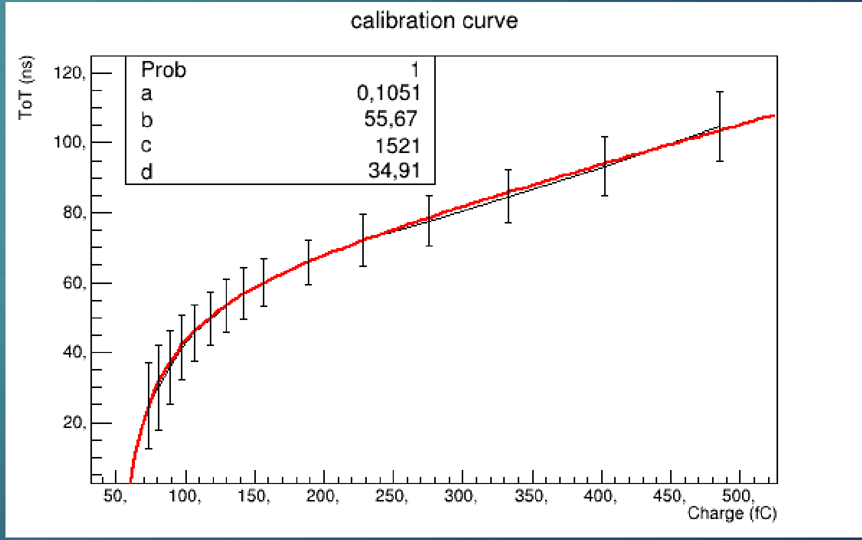


Backup Slides – GEM detector calibration

- Charge and energy information are obtained through characterization and calibration of the detector, with fluorescence from different materials.
- Titanium (Kα=4.5 keV) is used for calibration: varying HV value the peak shifts in ToT and the calibration curve is reconstructed on the fit.







Backup Slides – Needle erosion

Characteristic emission only from the electrodes

Peak around 7.5 keV – AISI 304 fluorescence spectral emission

Needle erosion clearly visible at the end of the experiments