RENAFAE Workshop 2021

Development of GEMs and its technological applications

An overview of the research done at HEPIC-USP and perspectives

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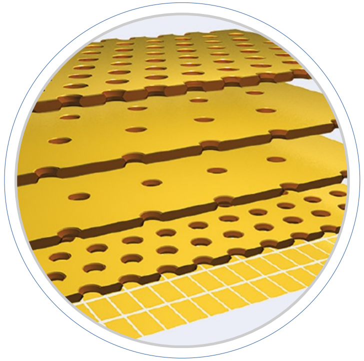
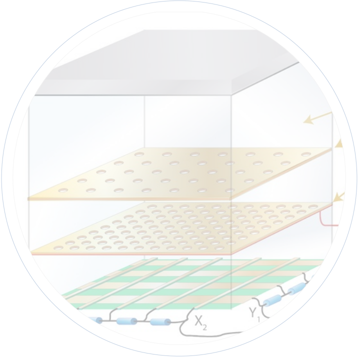
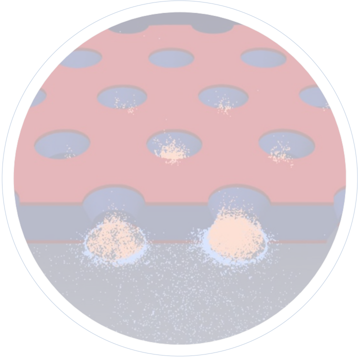
Goals

HEPIC
IFUSP

- **Support** the GEM based **ALICE-TPC** during Run 3
  - *Aging and degradation*
  - *Sanity check and monitoring*
- Develop a **fully functional prototype** of a GEM based radiation detector aiming applications in science and technology
  - *Energy and position sensitivity*
  - *Develop local expertise*
  - *Sensor and data acquisition system*
- **Research under the RD51 collaboration**





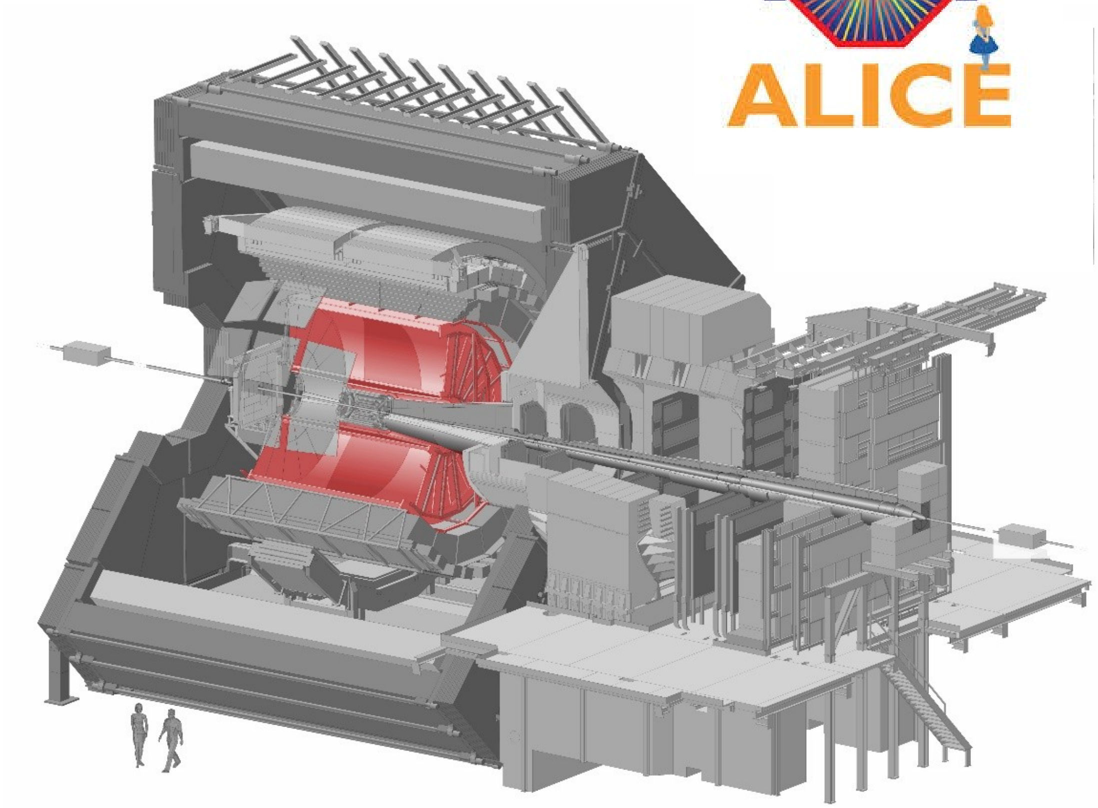


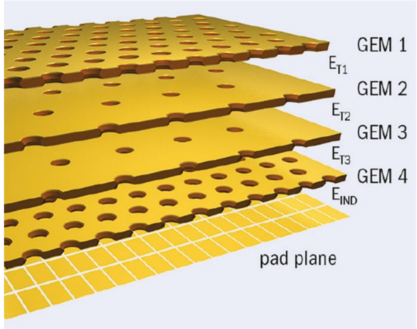
Introduction

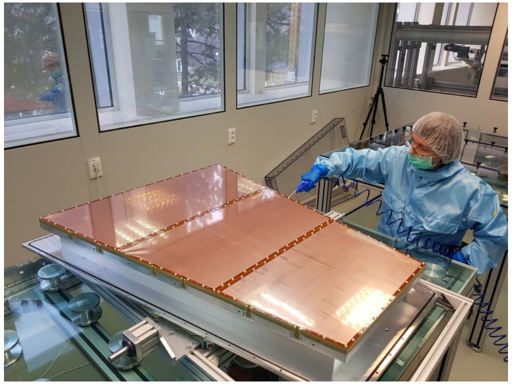
Applications

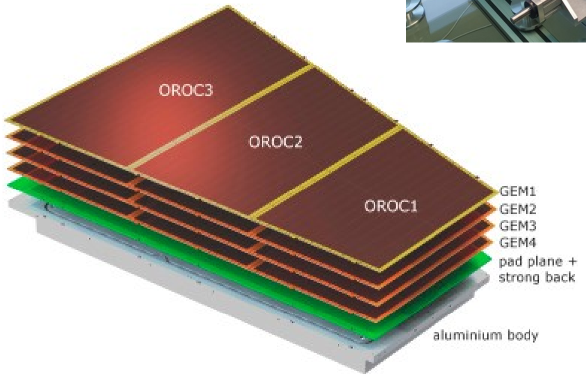
Developments

ALICE-TPC upgrade for the Run 3

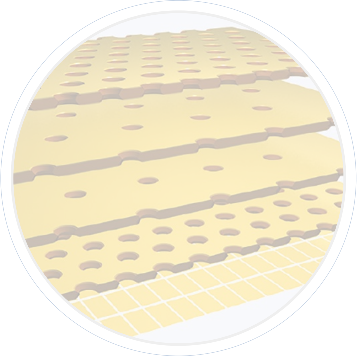




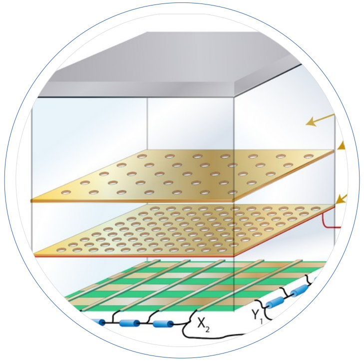




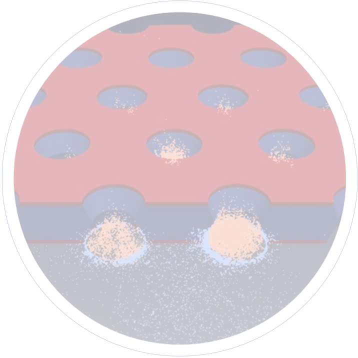
P. Gasik, Nucl. Instr. and Meth. A, v. 845, 222-225, 2017,



Introduction



Applications

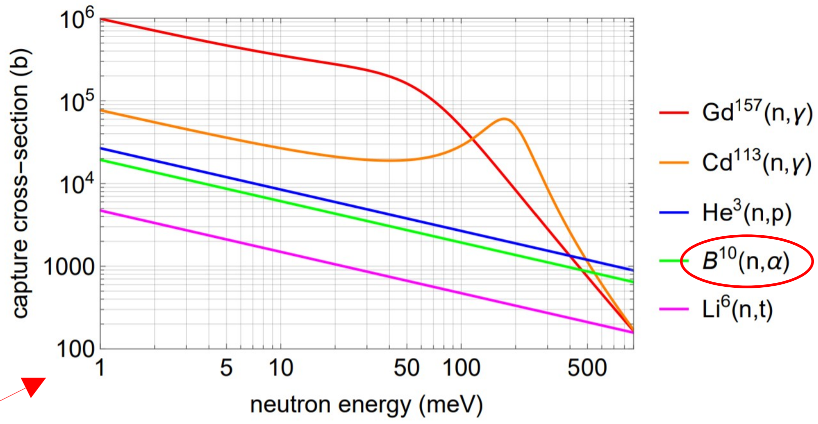


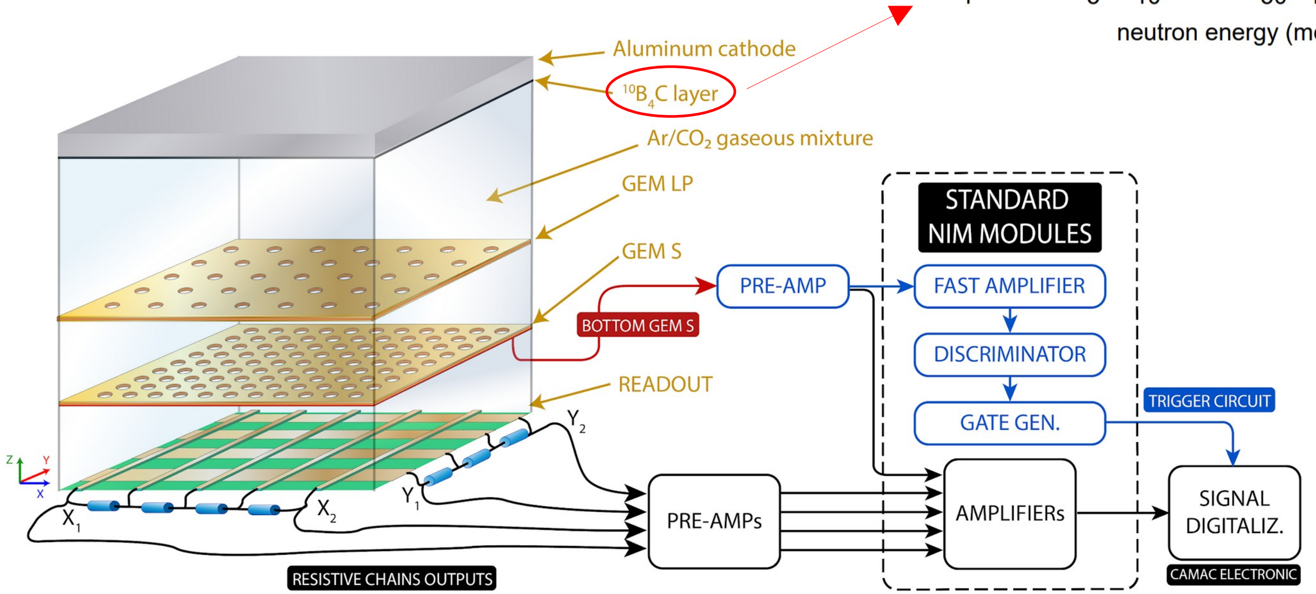
Developments

Neutron detection with imaging capabilities

Neutron detector schematics

- Enabling GEM sensitivity to neutrons by a conversion layer
- Boron carbide to neutron absorption with emission of alpha and lithium ion (both ionize the gas)

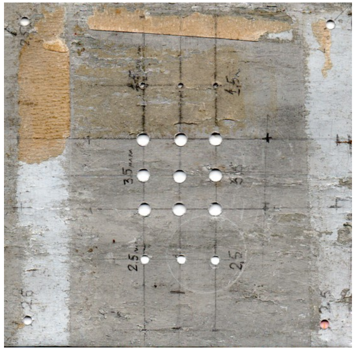




Neutron detection with imaging capabilities

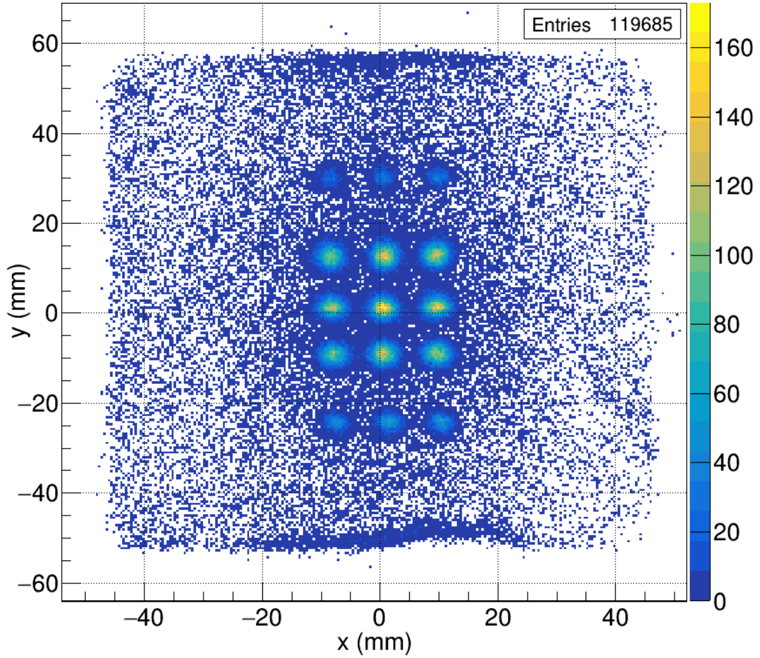
Deep understanding of the physical model

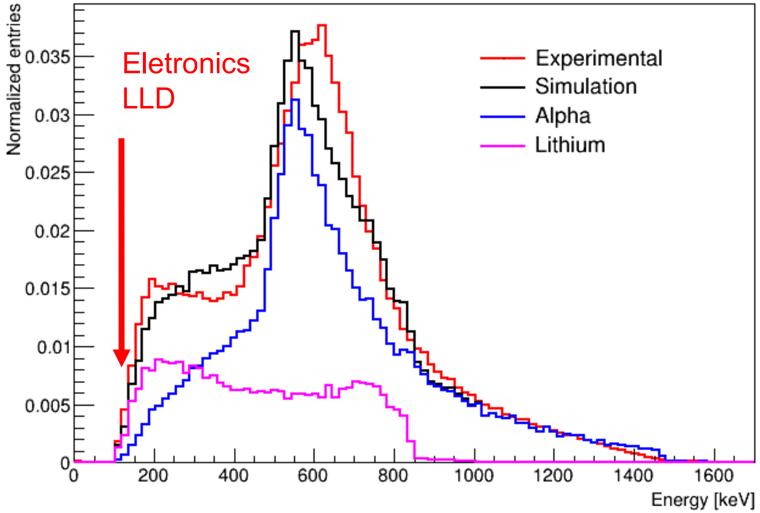
- Good agreement between experimental observation and Geant4 simulations.



Cadmium absorber (mask)

Neutron detected image





Observed image resolution of **2.71(7) mm**

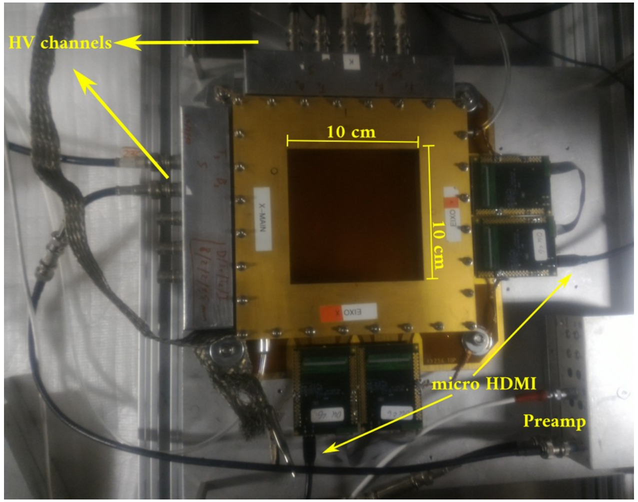
Predicted efficiency using Geant4 simulations: **3.14(4)%**

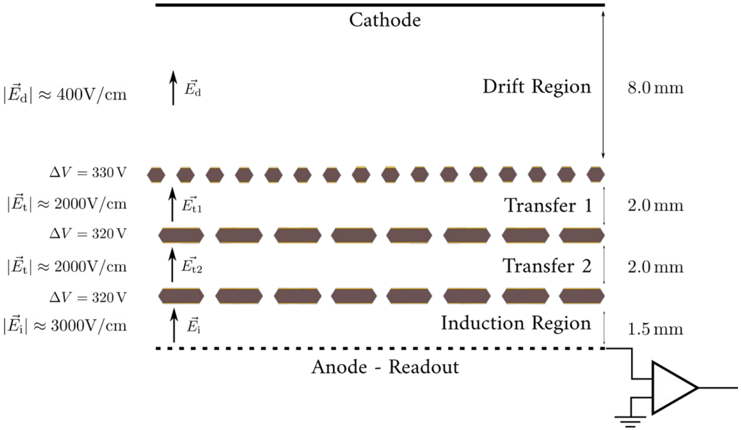
Efficiency obtained experimentally: **2.66(30)%**

X-ray detection with energy and position sensitivity

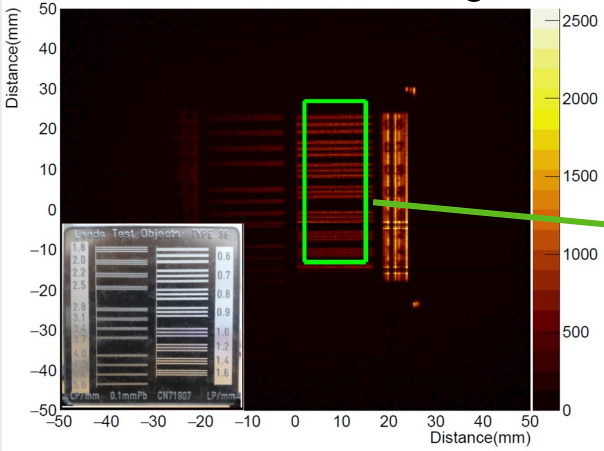
Images in transmission mode

- Triple-GEM with strip read-out
  (256 strips for each dimension)
- 100 cm² active area
- Operating with Ar/CO_2 (70/30) at atmospheric pressure
- Gain of the order of 10^4
- Acquisition rate ≈ 1.2kHz

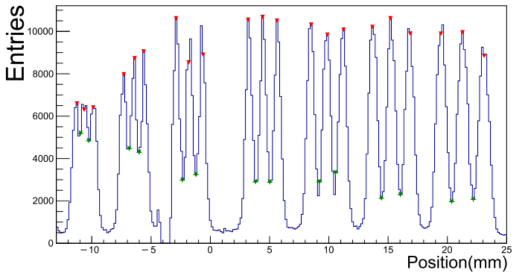




Resolution mask image

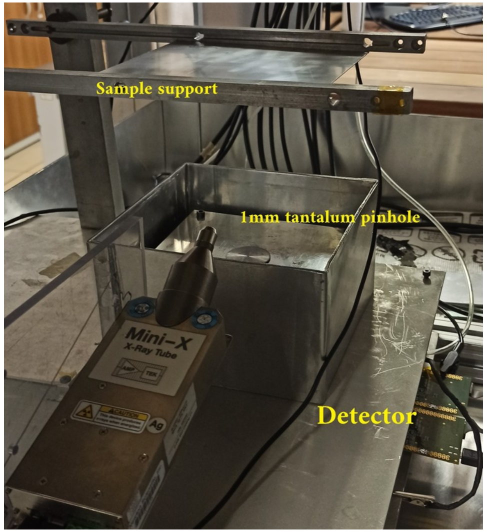


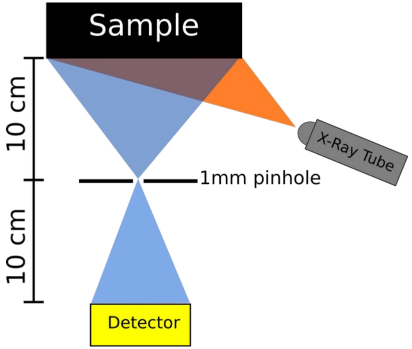
Resolution mask profile



X-ray detection with energy and position sensitivity

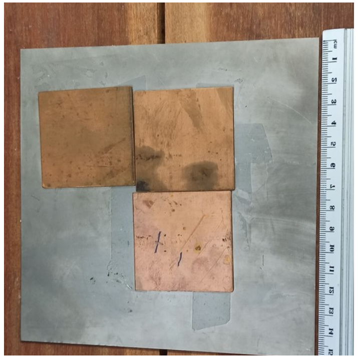
Images in fluorescence mode

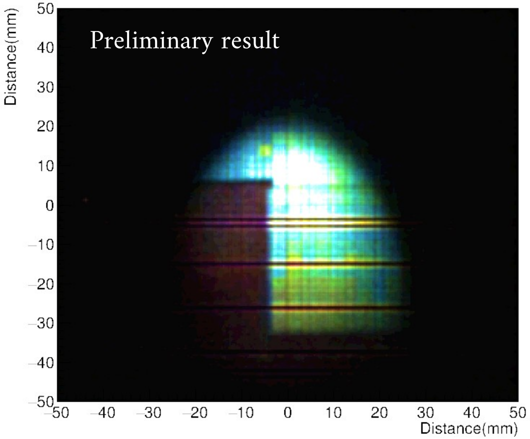


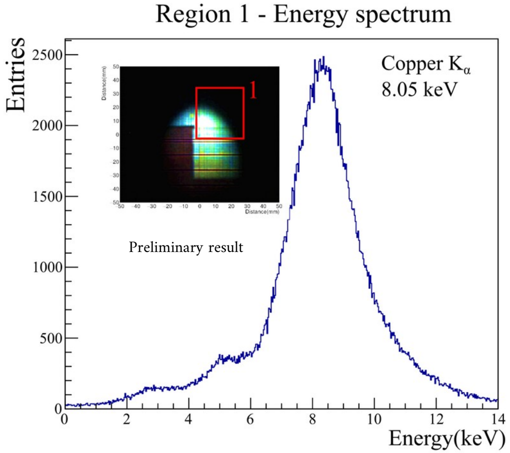


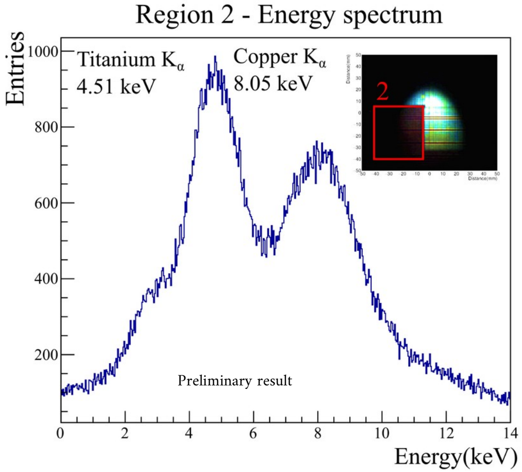
- Detector field of view limited by a 1 mm tantalum pinhole enabling near field images
- Acquisition rate ≈ 250Hz

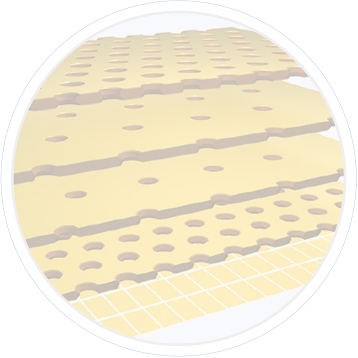
Test sample of a titanium plate with cooper sectors



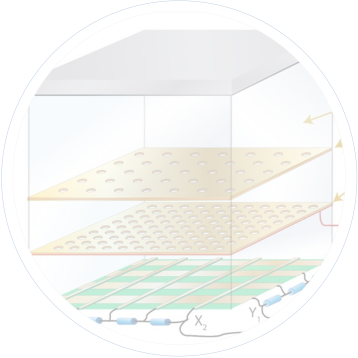




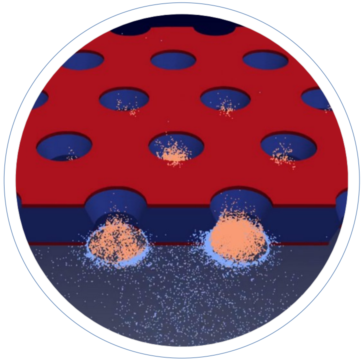




Introduction



Applications

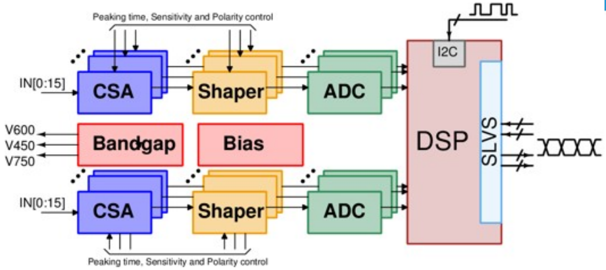


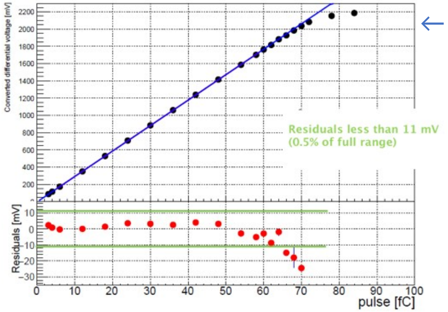
Developments

Electronics and data acquisition: the SAMPA chip

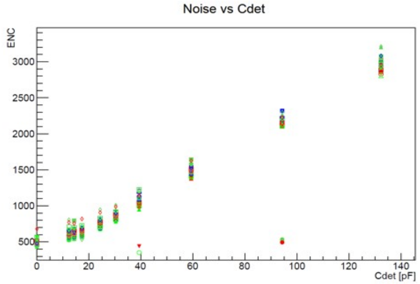
HEPIC
IFUSP

- A new ASIC for the readout of gaseous detector of high energy experiments (ALICE @LHC [CERN], STAR and sPHENIX @ RHIC [EUA] , MPD @NICA [Russia])
- Developed in São Paulo by LSI, Escola Politécnica (design) and local HEPIC group (validation)
- **Specs**
  - TSMC CMOS 130 nm, 1.25V technology
  - 32 channels, Front-end + ADC + DSP
  - package size ≤15x15mm2 (total footprint)
  - ADC: 10-bit resolution, 10MS/s, ENOB>9.2
  - DSP functions: pedestal removal, baseline shift corrections, zero-suppression
  - Data transmission: up to 11 e-link at 320 Mbps to GBTx, SLVS I/O
  - Power < 32 mW/channel (FrontEnd+ADC)
- Already in operation @STAR and @ALICE, more developments for sPHENIX and studies ongoing to wide even more its possible applications:
  Porting the SAMPA in the Scalable Readout-System (SRS), a standard in the RD51 community

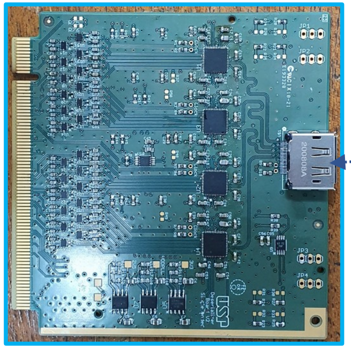




← Good Linearity
Residuals are very small (<10mV), for all channels, for more than 85% of the saturation range (e.g., up to 63 fC or more in the 30mV/fC setting)



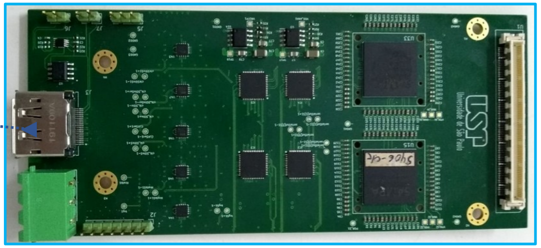
Low Noise →
Tuned to be below 650 ENC at ~18pF



← SAMPA-SRS Interface board
Interface board to the SRS FEC.
Contains the demultiplexer

← Display port cable →
A DP cable, 5 data links (4 SAMPAs + clock&controls), used to connect the hybrid and crate electronics

SAMPA-SRS Hybrid →
Hybrid with 4 SAMPAS, readying 128 channels.
Each SAMPA has a devoted multiplexer to send out 4 e-links via one higher speed data link



GEM production

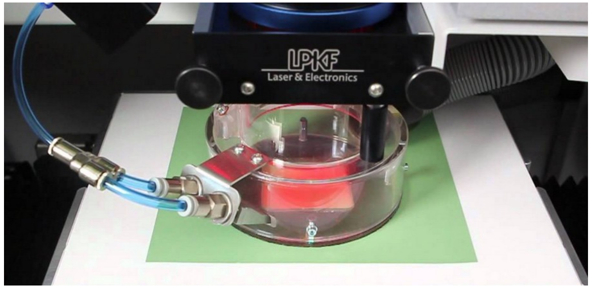
HEPIC
IFUSP

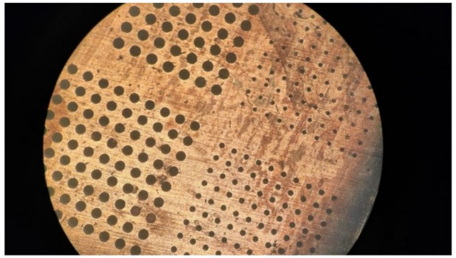
Method: Laser cut
Why? - New, clean (free of KOH) and fast
When? - Equipment maintenance

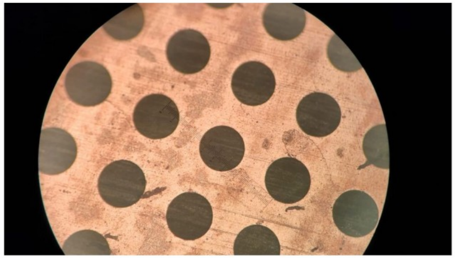
Collaboration with LSI-POLI

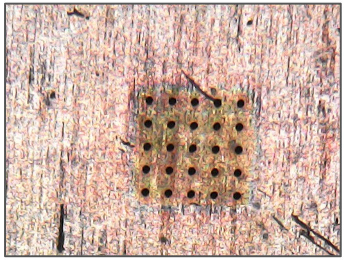
First results with optical lithography and chemical etching

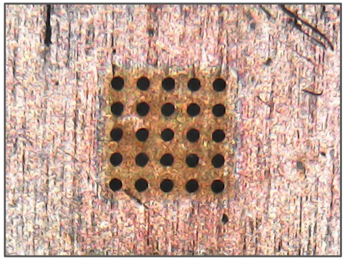
- Copper film micro-patterned

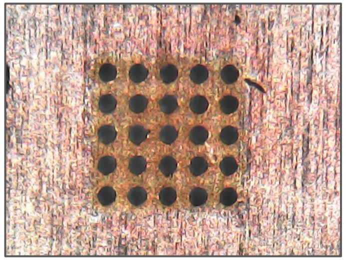










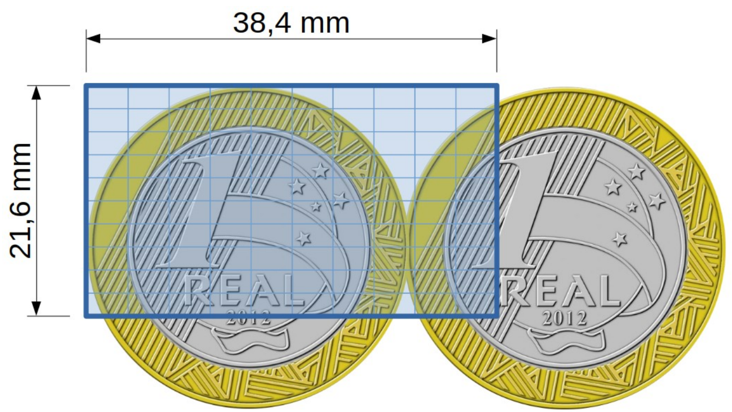


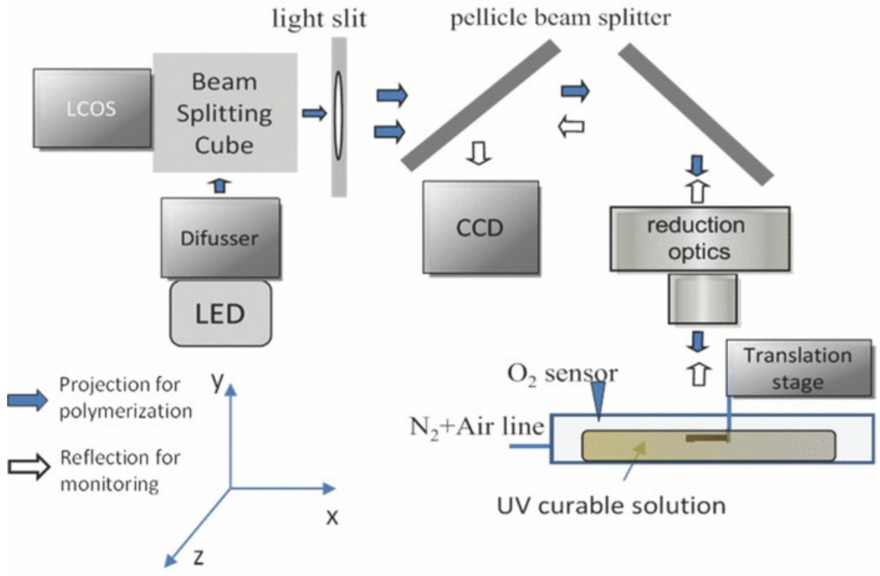
21 μm 35 μm 49 μm

Micrometer resolution 3D printing

Enabling flexibility and speed to prototyping

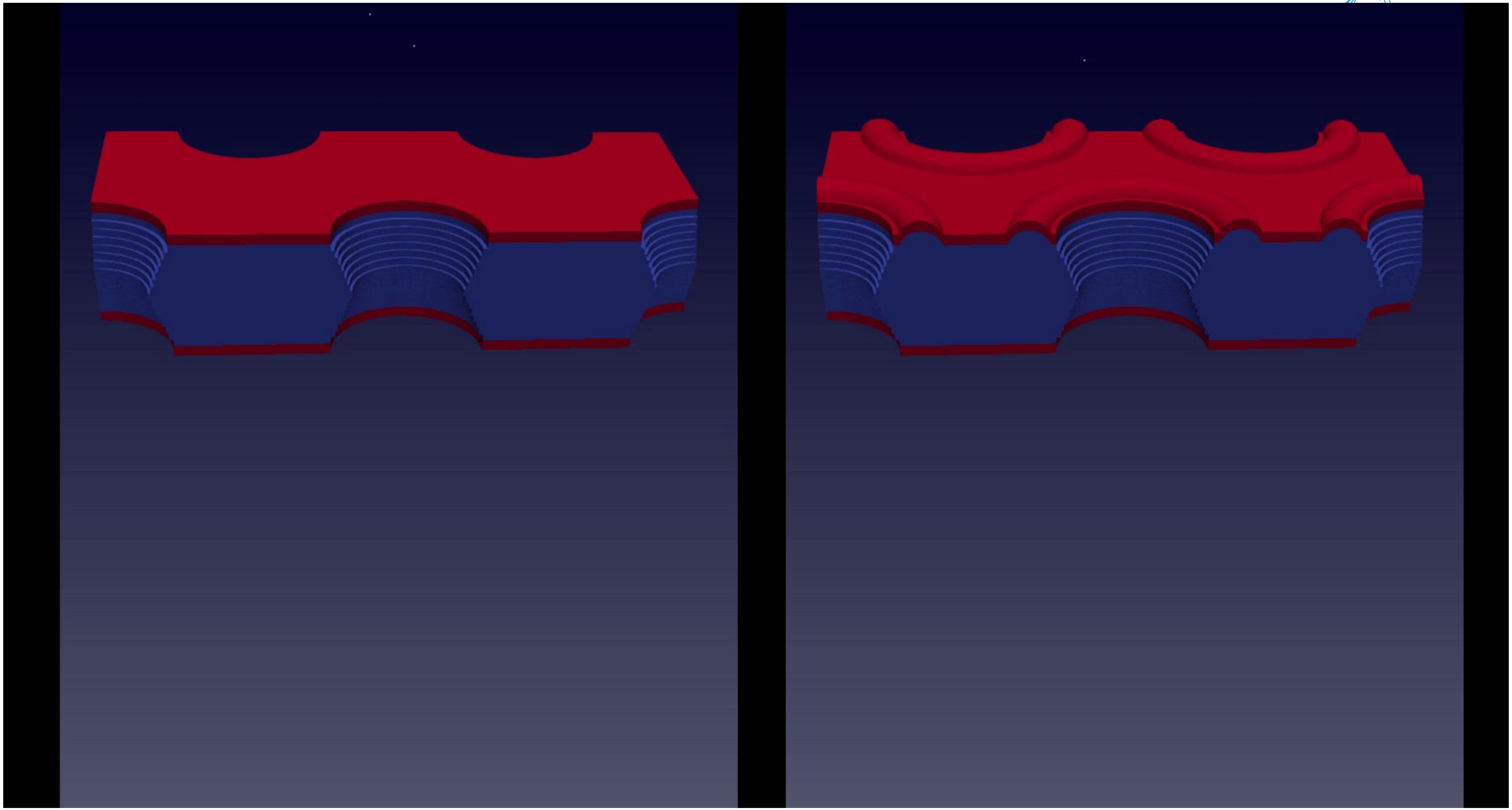
- Projection micro stereolithography (collaboration with BMF3D):
  - Printing voxel resolution: 2-3 μm
  - Single exposure size:
    3.84 mm (X) * 2.16 mm (Y) * 10 mm (Z)
  - Maximum product size:
    38.4mm (X) * 21.6mm (Y) * 10 mm (Z)





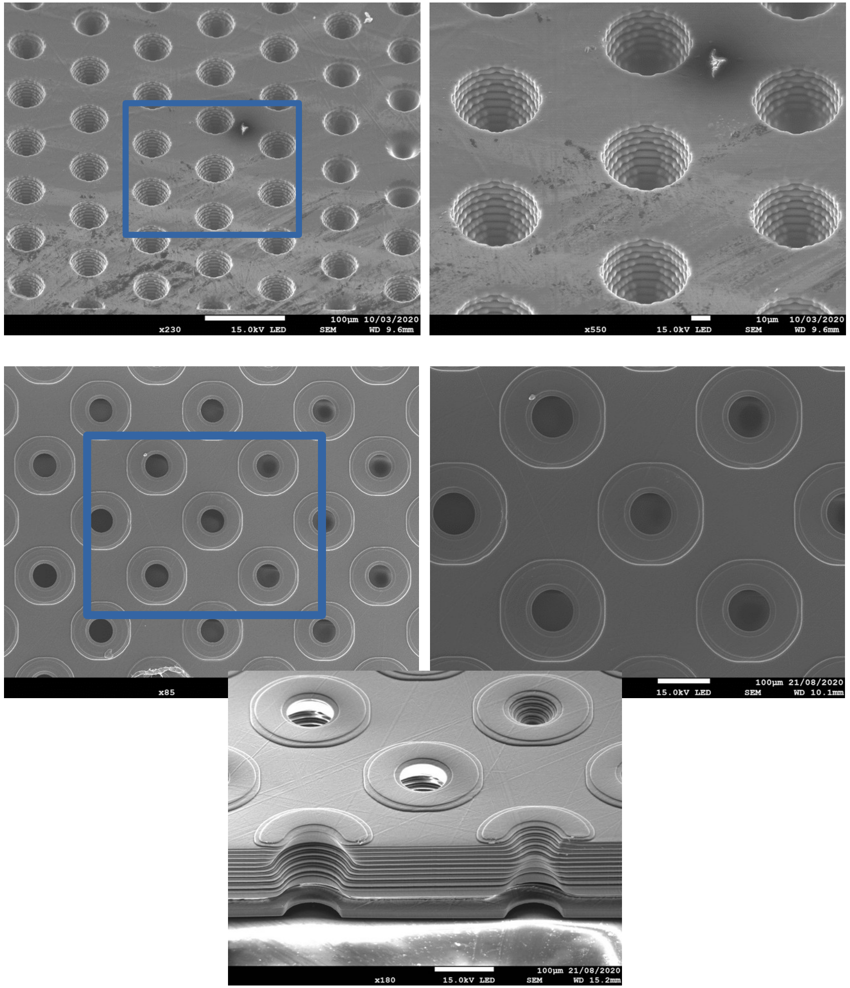
Zheng, X., Deotte, J., Alonso, M.P., Farquar, G.R., Weisgraber, T.H., Gemberling, S., Lee, H., Fang, N. and Spadaccini, C.M., 2012. Design and optimization of a light-emitting diode projection micro-stereolithography three-dimensional manufacturing system. *Review of Scientific Instruments*, *83*(12), p.125001. [link]

Exploring new geometries



First printing results

- Tests of spatial resolution
- Hexagonal matrix of holes in dielectric material
  - Holes with 50 µm diameter
- Material HDDA based polymer
- Conclusions:
  - Consistent along the foil
  - Very reproducible
  - Flexibility of geometry



Aging study workflow

The study of aging and degradation processes enable:

- Optimization for technological applications
- Contribution to the understanding of the GEM aging of the ALICE-TPC

Molecular breakup probabilities:
1) CO_2
2) CO_2 + Ar
3) CH_4
4) CF_4
5) ...

"In flight" process:
1) CO_2 cluster formation
2) Formation in presence of Ar
3) Mobility
4) Charge exchange
5) Influence of gas quality
6) ...

Adsorption:
1) Adhesion
2) Influence of surface quality
3) Observed pattern
4) ...

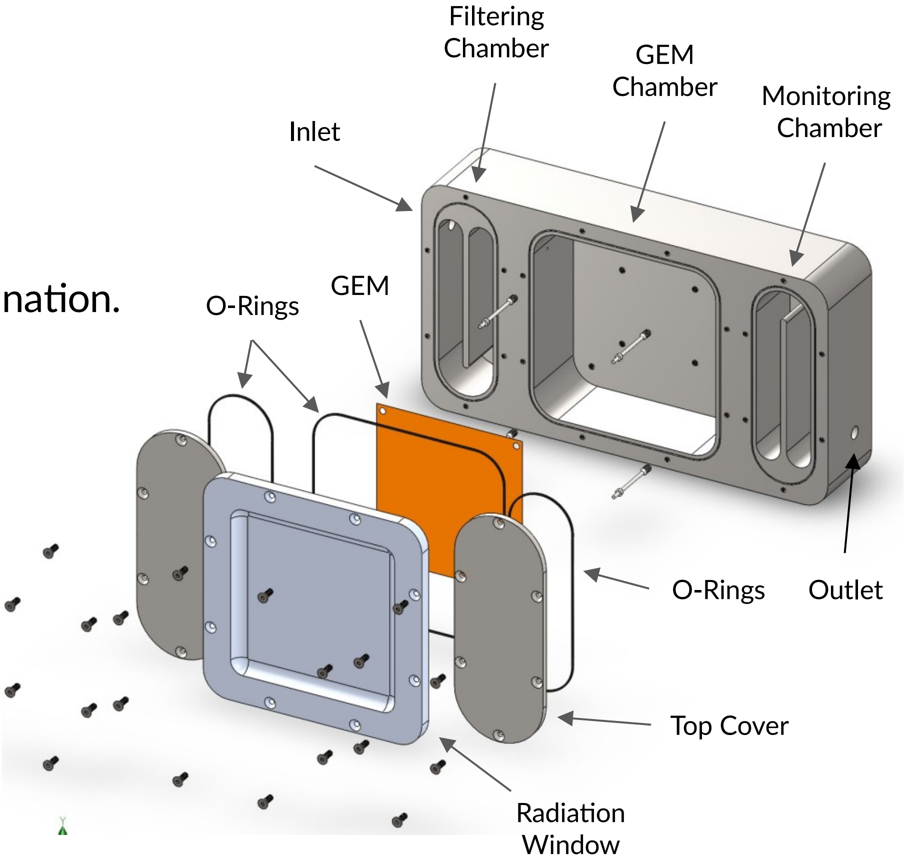
Kapton degradation:
1) H_2 release
2) Impedance spectroscopy
3) Chemical erosion
4) ...

Aging/Degradation experiments...

Degradation model:
1) What happens?
2) How to suppress?
3) How to reverse?
4) Should we use different materials?
5) ...

Controlled aging

- **Stainless steel chamber**
  - Clean ambient and avoid degassing.
- **Inlet/Filtering Chamber**
  - Filed with purifying materials.
  - Removal of eventual H_2O and O_2 contamination.
- **Outlet/Monitoring chamber**
  - Environmental sensors:
    - Temperature and pressure.
  - Gas quality monitoring:
    - H_2O, O_2 and $\mathbf{H_2}$.
- **Both attached to the GEM chamber**
  - To avoid tubes.



Investments for the future

HEPIC IFUSP

- Applications
  - Readouts (purchase or new design?)
  - Electronics based on SAMPA chip [Cost estimate in progress]
- Local production
  - Lithography and etching or laser cutting? [Cost estimate in progress]
  - Support to the 3D printing project [Supplies and services]
- Aging and degradation
  - Expenses on analysis [Cost estimate in progress]
  - Sensor to the controlled experiments [~U$20k]
  - Gas analysis in the outlet (mass spectrometer) [~U$60k]
  - Dielectric Relaxation Spectroscopy (sanity check of GEM foils) [~U$100k]

- **Possible funding:**
  - FAPESP and CNPq are already supporting projects
- **Possible spin-offs:**
  - X-ray detector with energy and position sensitivity
    - *Dosimetry and medical physics*
    - *Security and quality control*
    - *Síruis@LNLS?*
  - Neutron detector with position sensitivity
    - *Nuclear reactors like RMB and IPEN*
  - Others:
    - *Diagnostics in fusion reactors*