



WG5.1 - Detectores gasosos

Marco Bregant & Tiago Fiorini Da Silva

Updates and Status report

IX Reunião Geral - Projeto Temático FAPESP "Física e Instrumentação de Altas Energias com o LHC-CERN"
26-27 de maio do 2026

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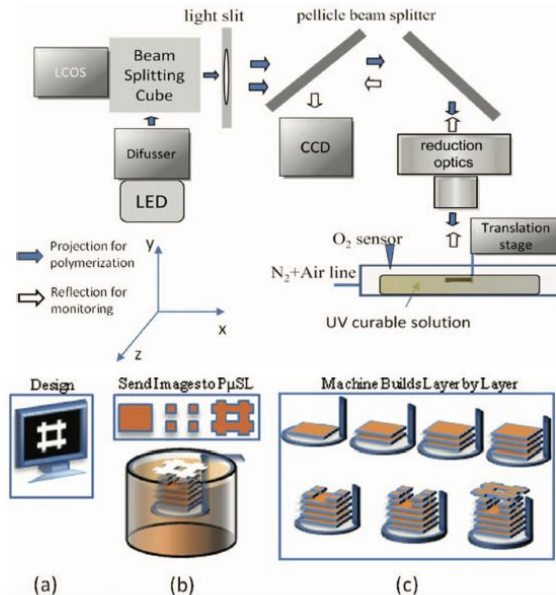
Marco Bregant

Tiago Silva

Paulo Costa

Produção de GEMs por métodos alternativos

- 3D printing technique based on a layer by layer production process utilizing photopolymerization reaction

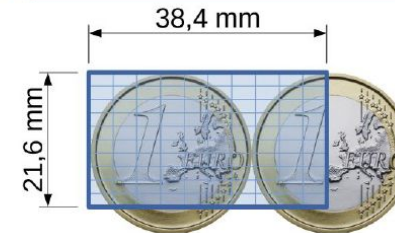


Schematic illustration of μ SLA system and its functioning [3]

[3] Xiaoyu Zheng, Joshua Deotte, Matthew P. Alonso, George R. Farquar, Todd H. Weisgraber, Steven Gemberling, Howon Lee, Nicholas Fang, and Christopher M. Spadaccini. Design and optimization of a light-emitting diode projection micro-stereolithography three-dimensional manufacturing system. *Rev. Sci. Instrum.*, 83(12), 2012

Why this technique?

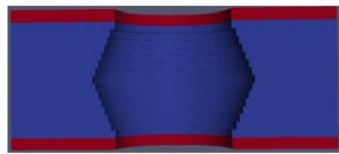
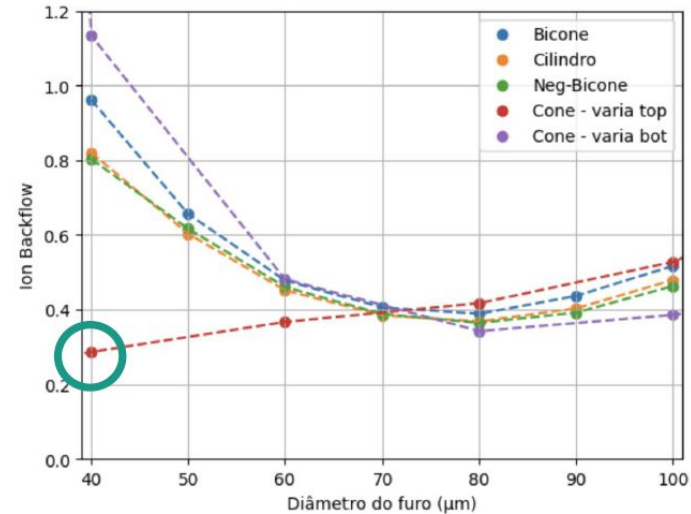
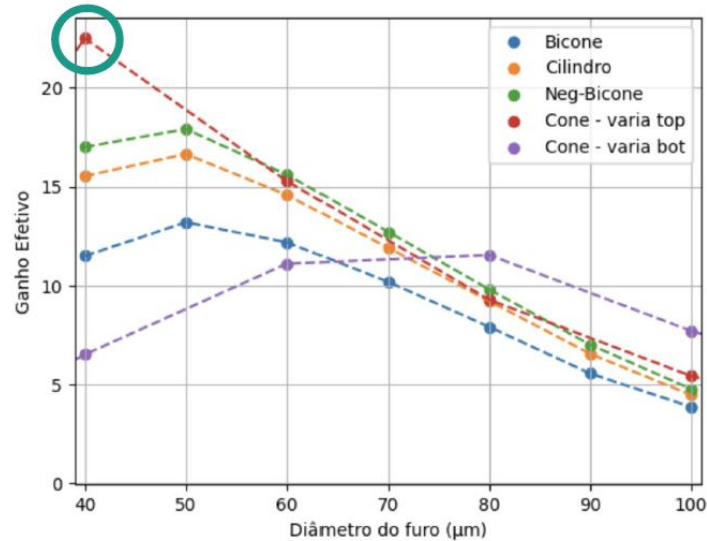
- ★ It has adequate spatial resolution for GEMs production ($2-3 \mu\text{m}$)
- ★ Adequate printing volume for prototyping: maximum size ($38.4 \times 21.6 \times 10$)mm



GEM por impressão 3D:

Daniel Magpali Estevão (DD-FAPESP)

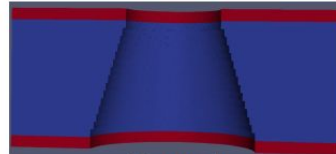
Goal: maximize the Effective Gain and minimize the Ion Backflow by varying the hole shape - since the additive manufacturing easily allows the flexibility of different holes - across different diameters



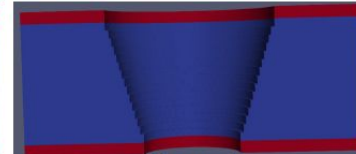
Biconical



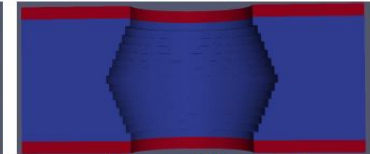
Cylinder



Conical
Narrow -> Wide

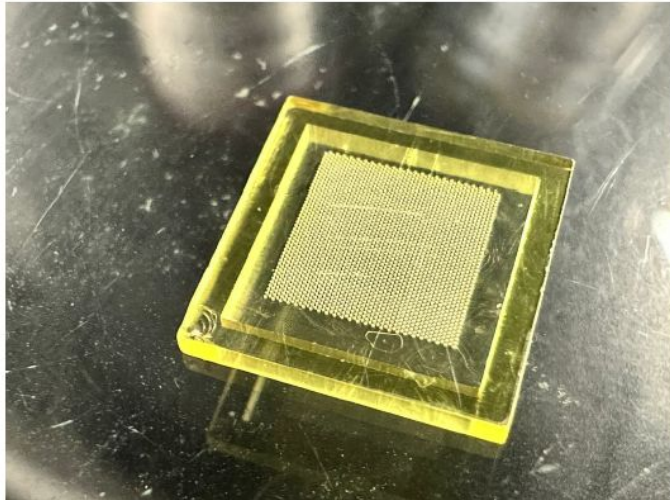


Conical
Wide -> Narrow

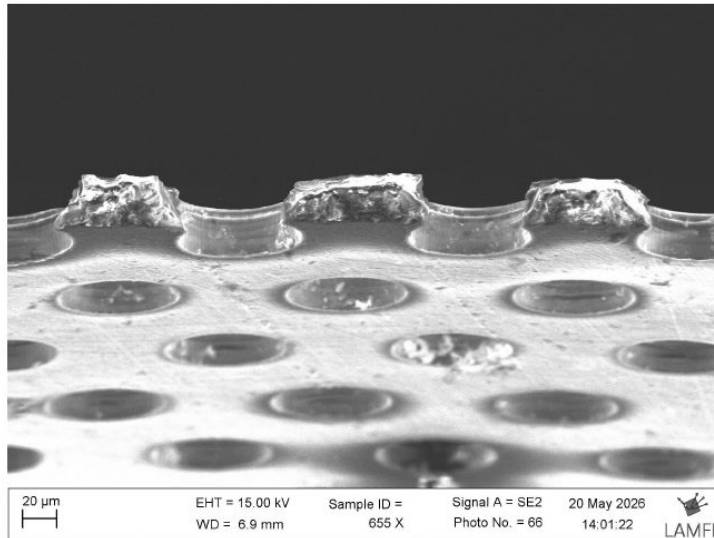


Inverse Biconical

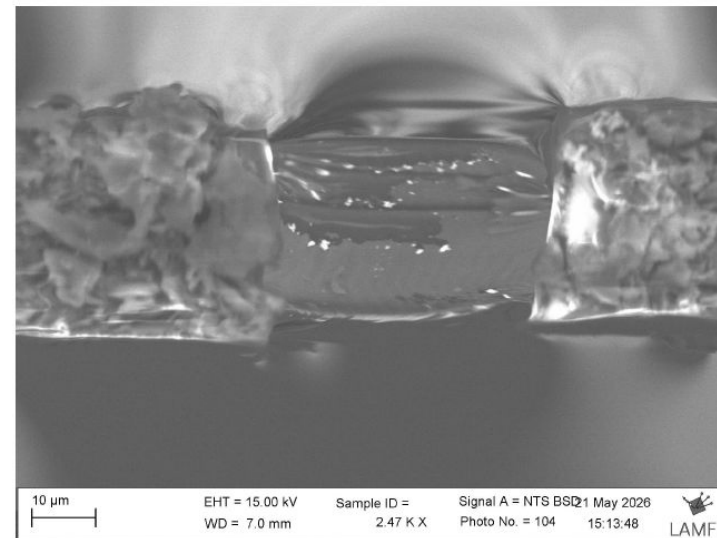
- First tests performed on the nanoArch S130 printer by BMF Technology in Nottingham University
- During the time spent there:
 - learned how to operate the printer, including software controls, calibration and maintenance;
 - Printed several samples varying UV light intensity, exposure time, printing speed and other relevant parameters.



- **First tests:** deposition of gold layer by sputtering (estimate thickness of 500nm)
- Investigation of hole contamination by analyzing their cross section images:
 - Secondary Electrons: topography investigation of the inside of the holes ;
 - BackScattered Electrons + Energy-Dispersive X-ray Spectroscopy: investigation of gold contamination inside the holes;



SEM



BSD

Realização de processos litográficos PCB-like para criação de bordas e eletrodos em folhas de GEM

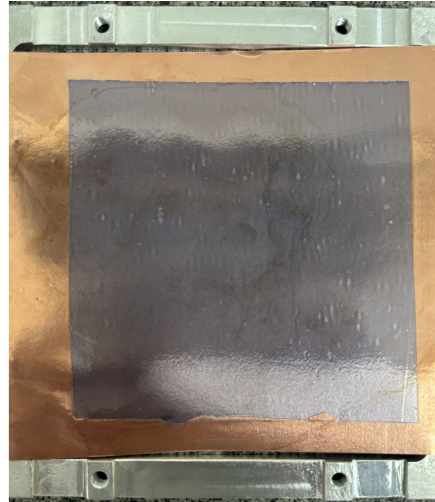
→ Protocolo utilizado com os laminados DuPont:

- ◆ Laminação de Dry Film photoresist nos dois lados da folha;
- ◆ Ativação por luz UV com uma máscara para exposição;
- ◆ Remoção de filme não ativado: solução 1% Na_2CO_3 (carbonato de sódio)
- ◆ Remoção do cobre: solução 20% FeCl_3 (cloreto férrico)
- ◆ Remoção de filme ativado: $\text{C}_2\text{H}_6\text{O}$ (etanol)



- Para folhas de GEM do CERN basta adicionar uma etapa de remoção da camada de cromo
- ◆ produção em andamento

Imagens extras se quiser adicionar (infelizmente não tirei foto de mais etapas do processo)



Método: Perfuração de furos em folha comercial de kapton revestida com cobre através do uso de ablação por laser UV de pulso curto

Objetivos: Abrir a possibilidade de replicação da tecnologia para obter competitividade local, superar barreiras comerciais e expandir a oferta de tecnologia no mercado.

Configuração Experimental: Equipamento de microfabricação a laser LPKF ProtoLaser U3, desenvolvido pela empresa alemã LPKF Laser & Electronics AG, presente no Microelectronic Laboratory da Polytechnic School of University of São Paulo (LME-POLI-USP). Este equipamento permite a execução de diferentes estratégias de usinagem – como corte, furação e remoção de camadas – através do ajuste de parâmetros como número de passadas, frequência de repetição, potência média e velocidade de varredura.

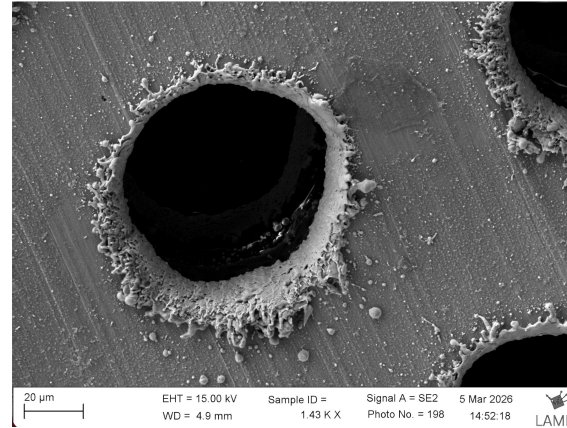
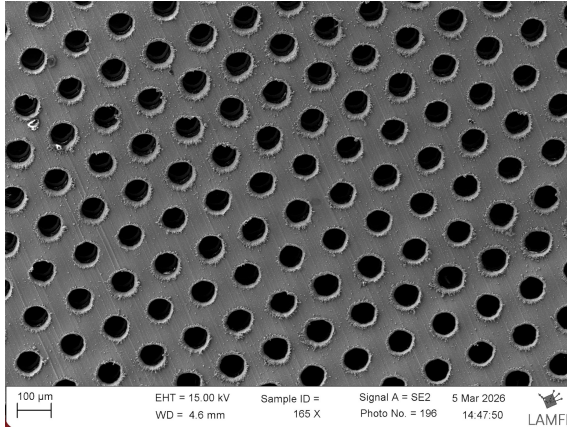


LPKF ProtoLaser U3 no LME-POLI-USP

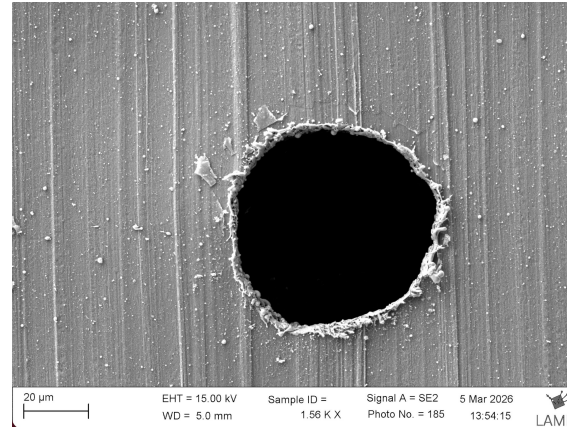
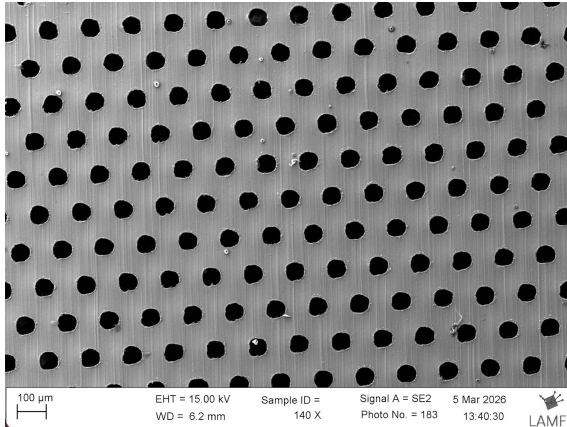
Ablação a laser - Manufatura alternativa de GEMs

Amostras produzidas com os últimos parâmetros do laser registrados pelo Eduardo

Entrada
do laser



Saída
do laser



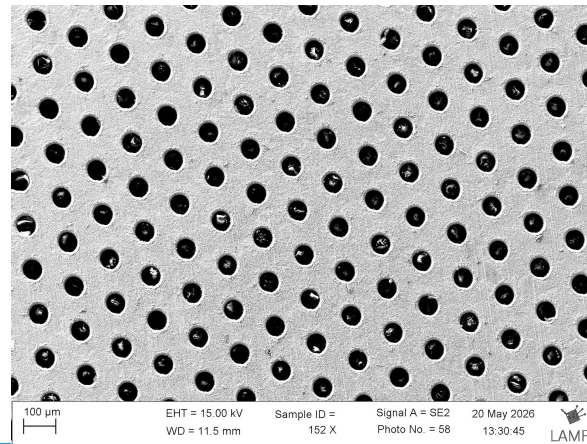
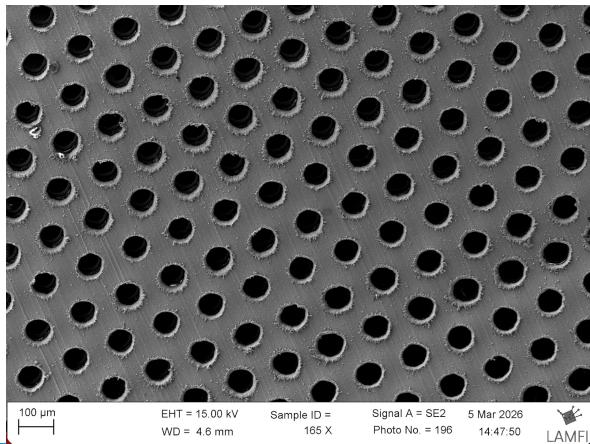
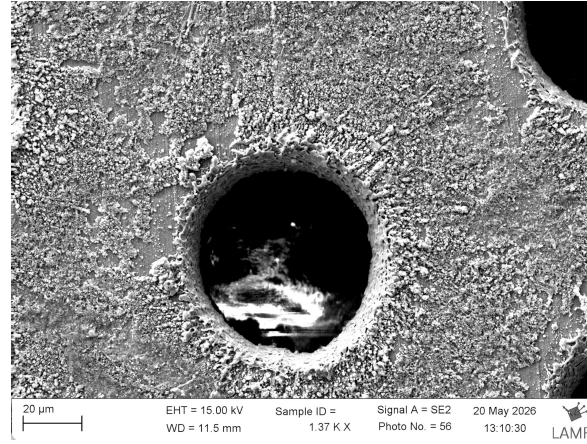
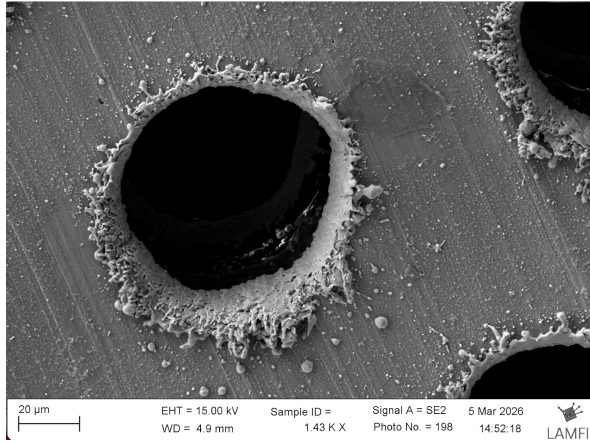
- **Ideia:** diminuir a potência e frequência do laser para diminuir o calor transferido ao material, que fazem o cobre derreter (em vez de sublimar por ablação) e criar a camada de metal na entrada do furo.

- Para compensar:
 - ◆ aumentar o número de repetições do laser (quantas vezes ele passa por cada furo);
 - ◆ aumentar a velocidade de passo, tanto para diminuir o tempo que o laser fica em cada posição (diminuir os efeitos térmicos) quanto para compensar um pouco o tempo de processamento da amostra.

Otimização de parâmetros do laser

6W - 40kHz - 1 rep - 50 mm/s

4,5W - 25kHz - 10 rep - 200 mm/s



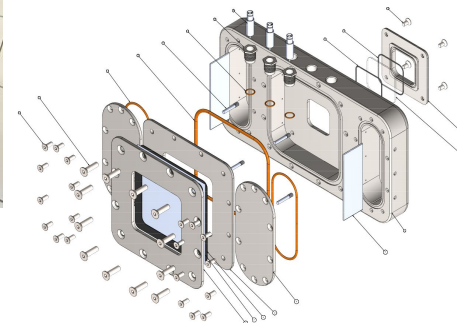
Estudos de degradação de GEMS

Atividades atuais:

- ~~Caracterização de tempos de resposta~~
- ~~Calibração para quantificação~~
- ~~Montagens internas~~
- Estudos de aquecimento/degaseificação e filamento
- Compra de CH₄

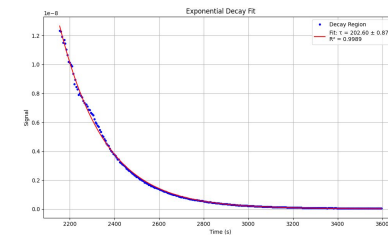
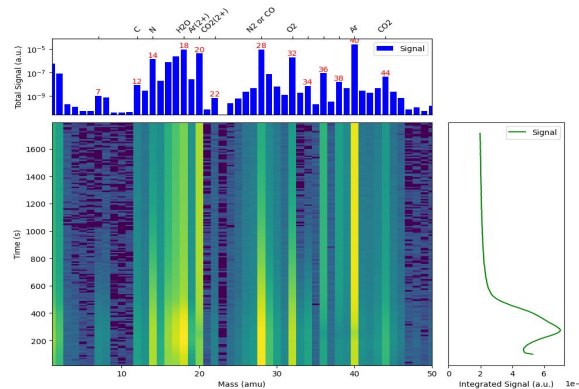


Recursos:



Projeto com contribuições de:

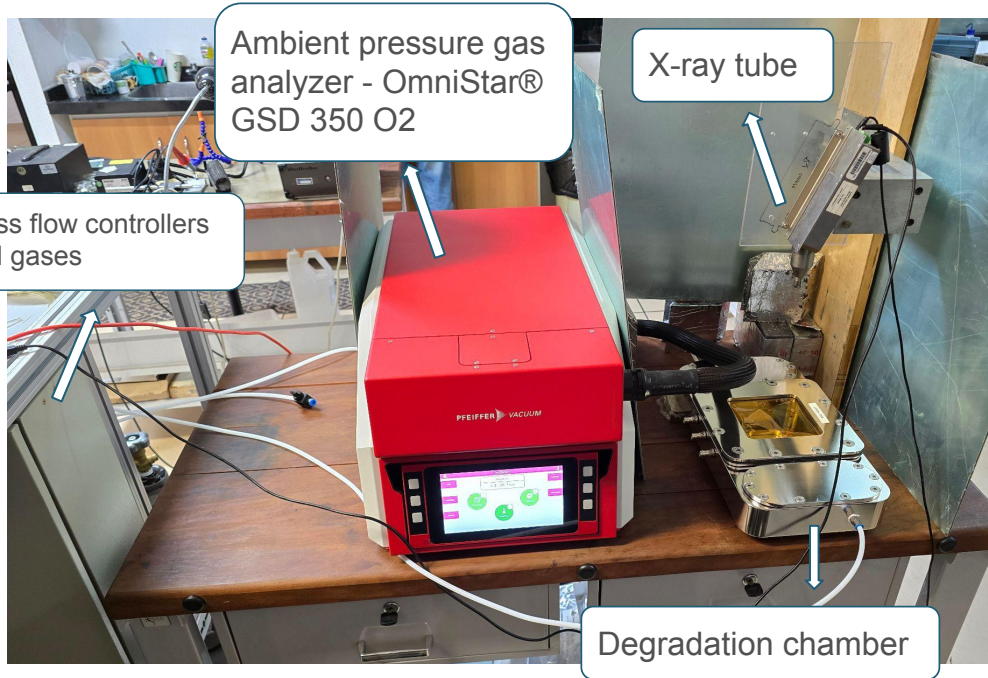
Thiago Badaró Saramela (DD-CNPq)
Eduardo dos Santos Palermo (MS-CNEN)
Daniel Neves Fachieri (DD-FAPESP)



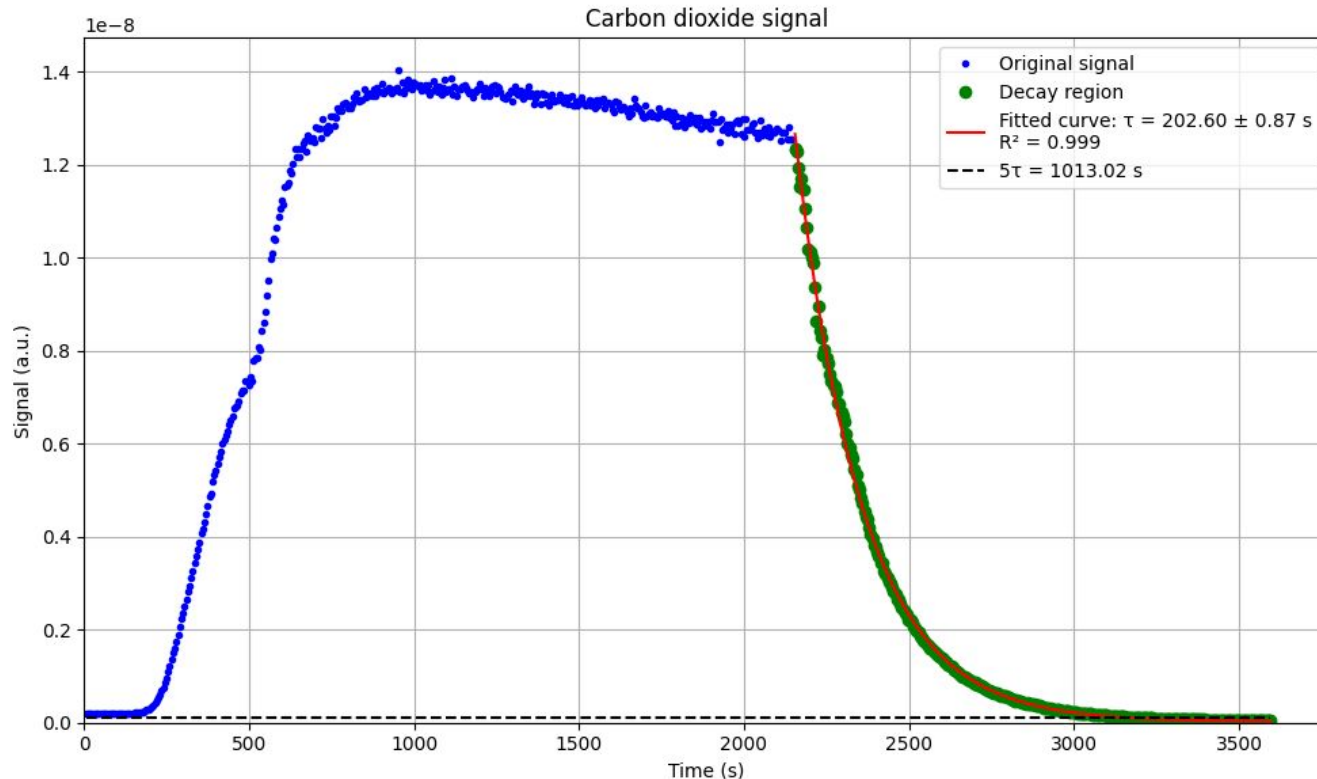
Tempo de resposta de 203 s (3m23s)

Degradação de GEMs:

Willian Wallace Ribeiro Alves da Silva (DR-FAPESP)



- Experimental conditions:
- Flow rate: 6L/h
 - Mixture: Ar(70)/CO2(30)
 - Distance between the x-ray tube and the degradation chamber: 25cm
 - Kapton window



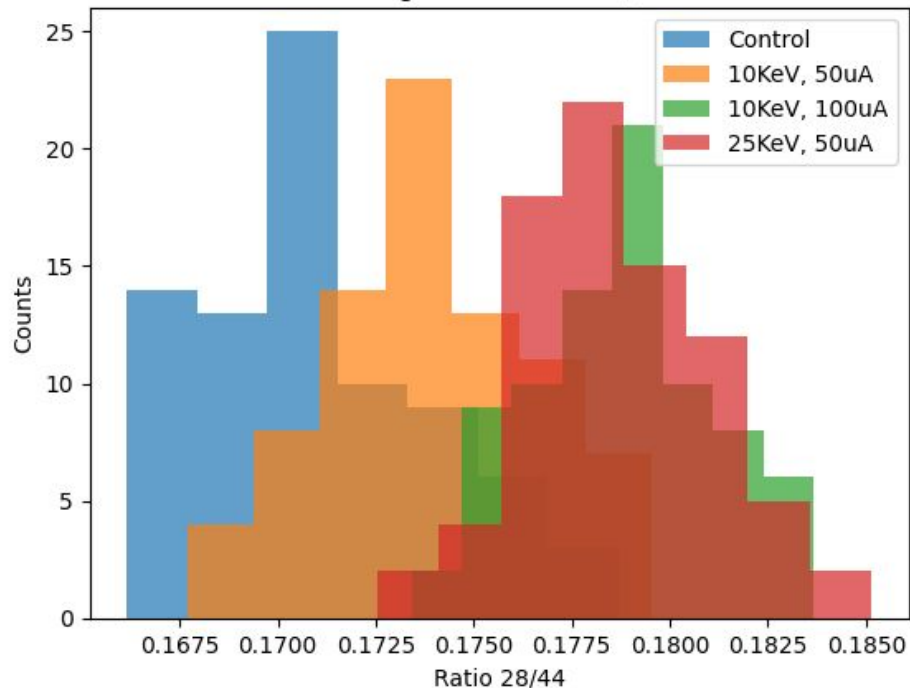
Value obtained for a flow rate of 7 L/h.

$5\tau \approx 17$ minutes.

For a gas flow rate of 6 L/h, the measurements were taken over 20 minutes with a 5-minute waiting period.

Studying the ratio 28/44 (CO/Ar):

Histogram of Ratio 28/44



Control -> Mean: 0.1710 | Std: 0.0030

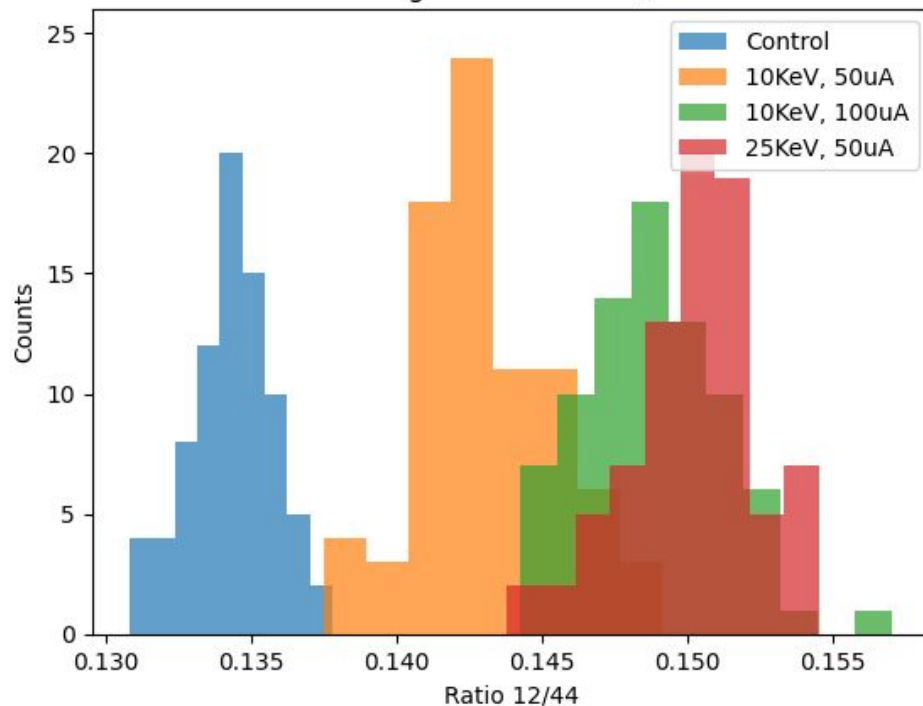
10KeV, 50uA -> Mean: 0.1739 | Std: 0.0027

10KeV, 100uA -> Mean: 0.1788 | Std: 0.0024

25KeV, 50uA -> Mean: 0.1786 | Std: 0.0024

Studying the ratio 12/44 (C/Ar):

Histogram of Ratio 12/44



Control -> Mean: 0.1343 | Std: 0.0015

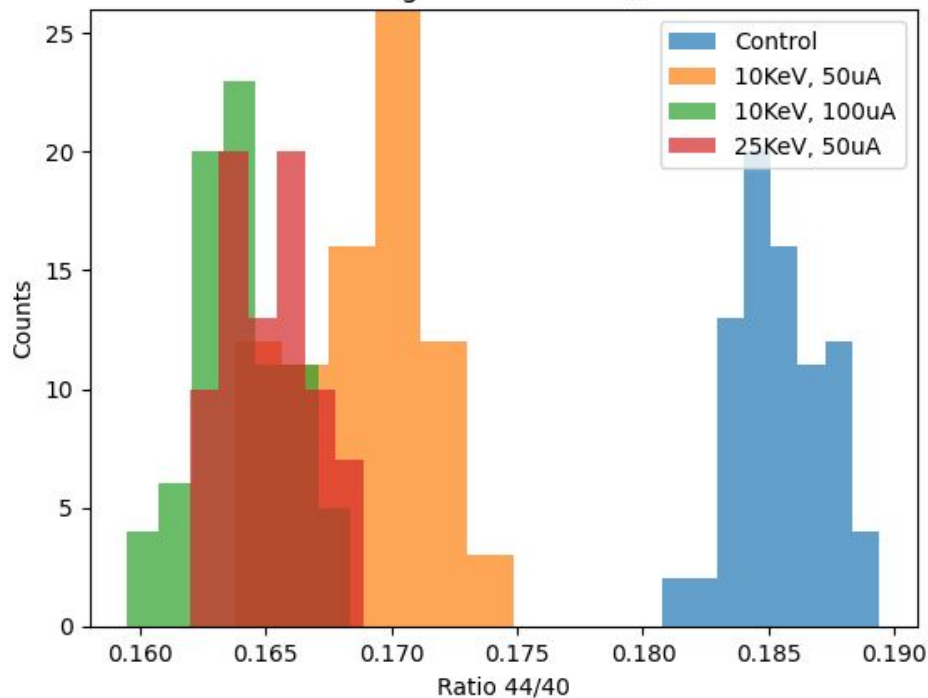
10KeV, 50uA -> Mean: 0.1431 | Std: 0.0024

10KeV, 100uA -> Mean: 0.1488 | Std: 0.0024

25KeV, 50uA -> Mean: 0.1502 | Std: 0.0022

Studying the ratio 44/40 (CO_2/Ar):

Histogram of Ratio 44/40



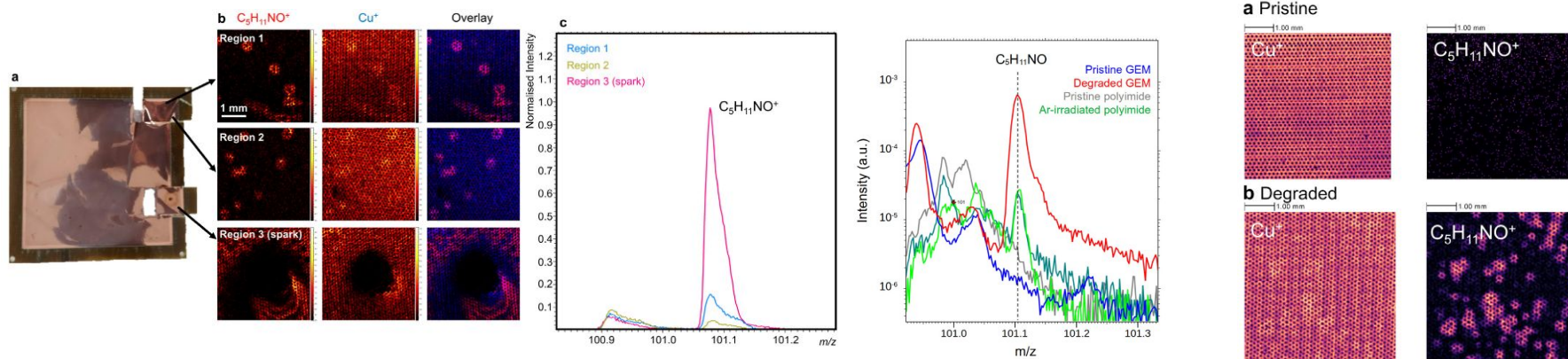
Control -> Mean: 0.1854 | Std: 0.0018

10KeV, 50uA -> Mean: 0.1690 | Std: 0.0026

10KeV, 100uA -> Mean: 0.1640 | Std: 0.0019

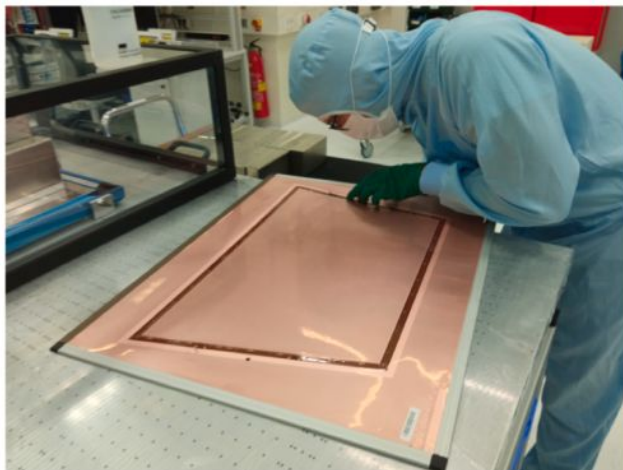
25KeV, 50uA -> Mean: 0.1652 | Std: 0.0017

Análise de material orgânico usando ToF-SIMS mostrou deposição de poliimida na superfície dos GEMs.




Análises de superfície:

Thiago Badaró Saramela (DD-CNPq)



Nuclear Instruments and Methods in Physics Research A 1090 (2026) 171638

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

 Nuclear Inst. and Methods in Physics Research, A


journal homepage: www.elsevier.com/locate/nima

Full Length Article

Surface mechanisms governing long-term stability of GEM detectors in CO₂-based gaseous mixtures

Tiago F. Silva^{a,*}, Thiago B. Saramela^a, Willian W.R.A. da Silva^a, Camilla de S. Codeço^{b,c}, Maria do C.M. Alves^c, Jonder Moraes^d, Niklaus U. Wetter^e, Anderson Z. de Freitas^c

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^e Instituto de Pesquisas Energéticas e Nucleares, Av. Prof. Lineu Prestes 2242, 05508-000 São Paulo, Brazil

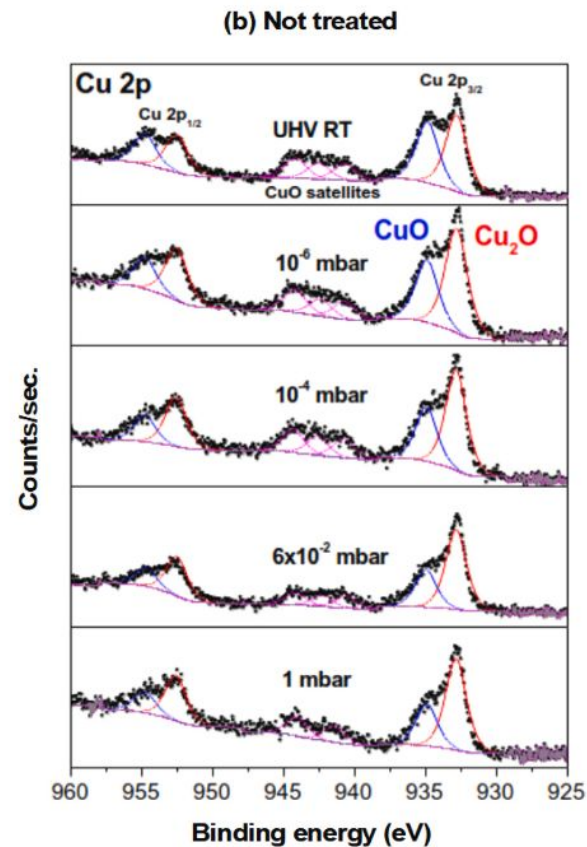
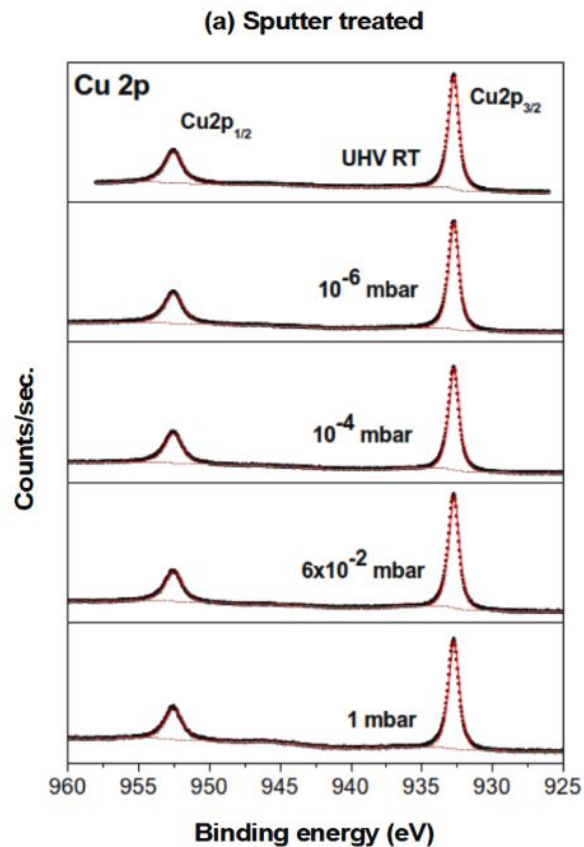


Análise in situ de amostra com a superfície limpa e como entregue.
Processo de limpeza: bombardeamento de Ar⁺ à 1 keV por 1 h. Estimativa de camada removida em 10 nm.

Análises de superfície:

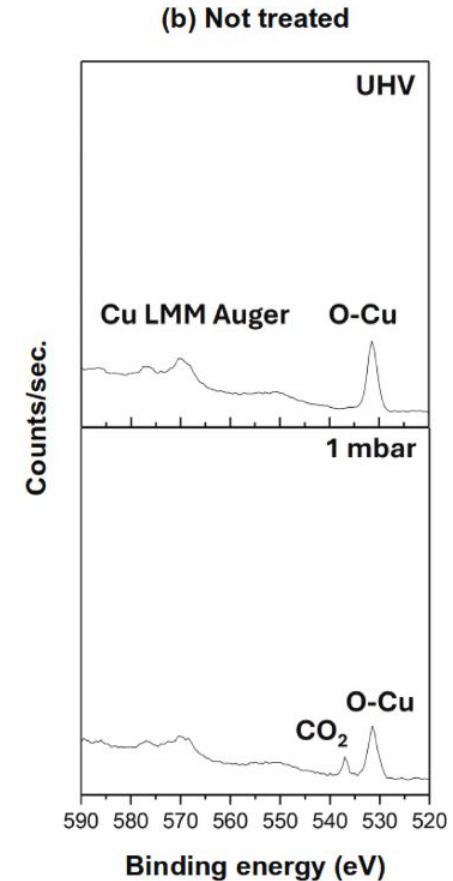
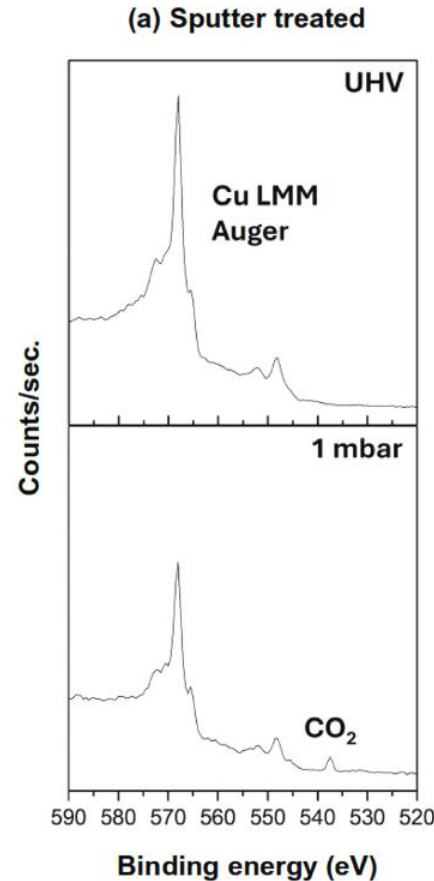
Thiago Badaró Saramela (DD-CNPq)

Análise na janela de energia de ligação do Cu 2p mostrou que a superfície do GEM limpa tem a assinatura do cobre metálico (puro), enquanto que a sem tratamento tem assinatura de uma mistura de CuO (Cu^{+2}) com Cu_2O (Cu^{+1}).



Na janela de energia de ligação do O 1s mostrou que a superfície do GEM sem tratamento é totalmente oxidada.

O que surpreende é a mistura das duas fases, que requerem processos diferentes, sendo o Cu_2O o que ocorre naturalmente.

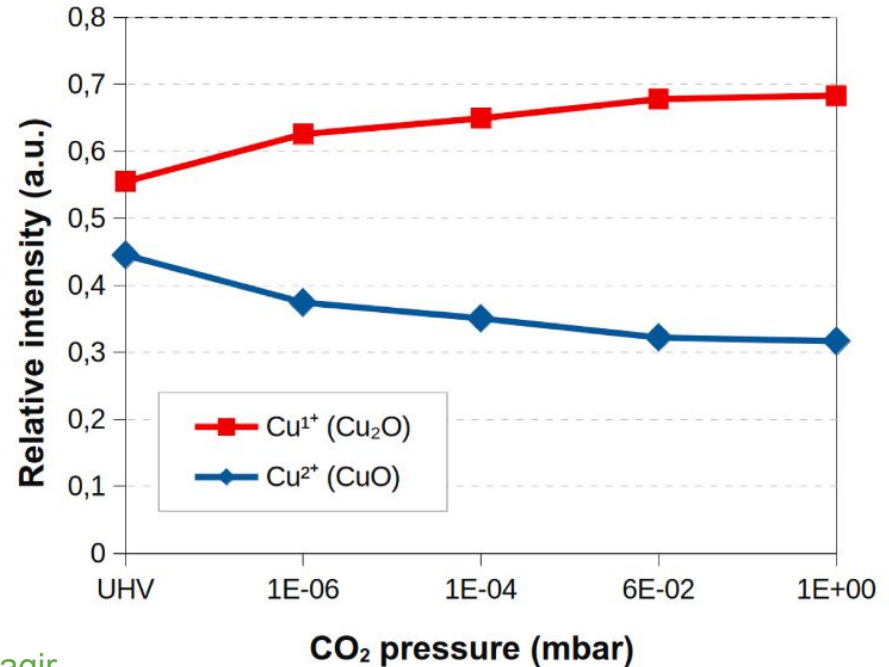


Ao expor a superfície às pressões gradativamente mais altas de CO_2 (in situ) observa-se uma conversão da fase CuO em Cu_2O .

Estudos da literatura mostram que a fase Cu_2O é estável à reações de adsorção do CO_2 .



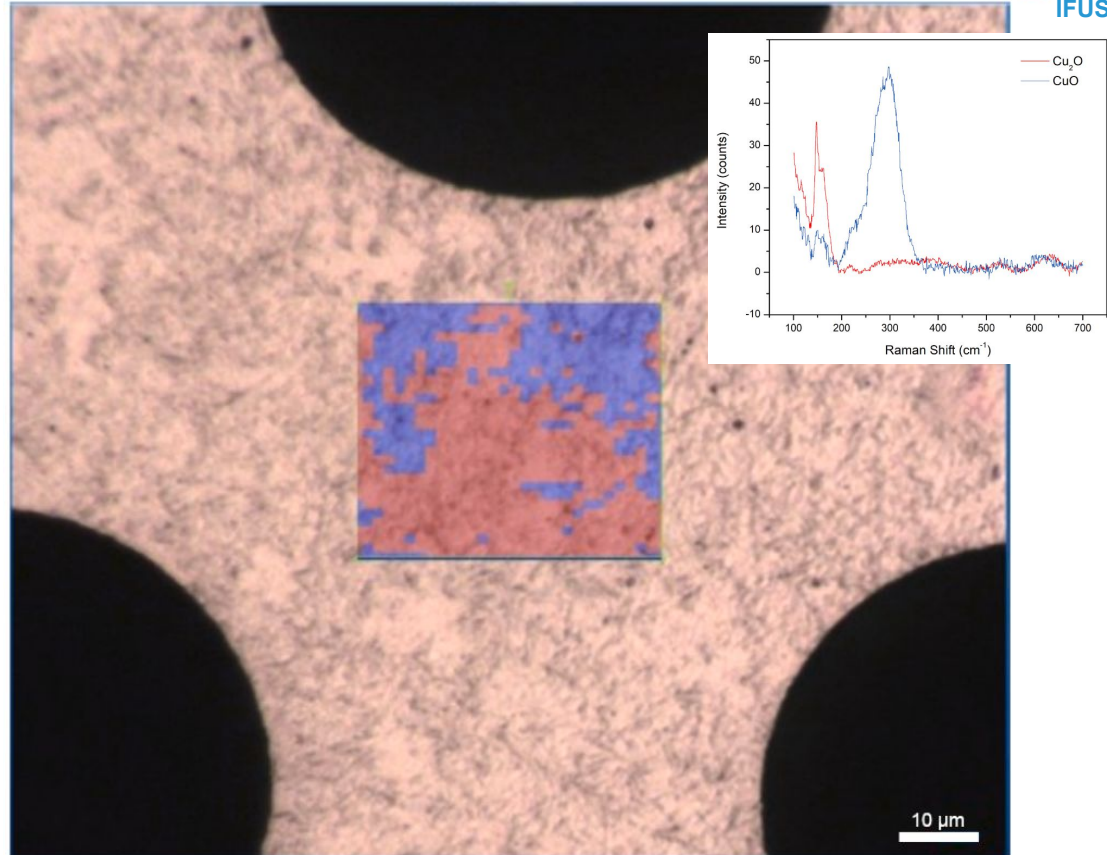
GEM tende a reagir cada vez menos com o CO_2 .



Como essas fases se distribuem na superfície?

Mapas de microscopia Raman mostram que as fases estão inicialmente segregadas.

Estudos em andamento para melhor entender a distribuição perto dos buracos e após exposição ao CO_2 .



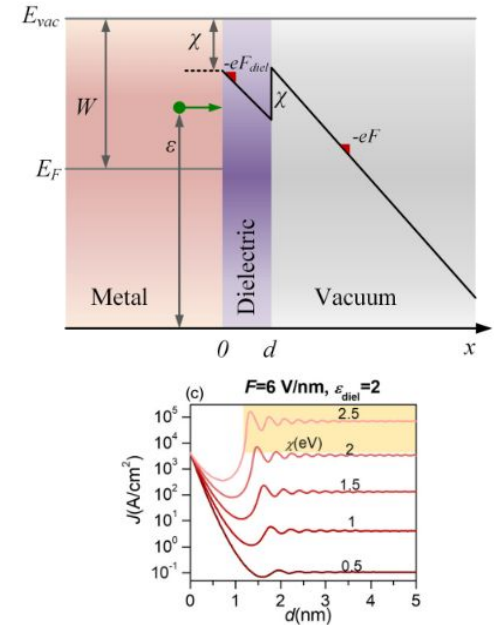
Simulações

Efeito Malter: Ejeção de elétrons devido à camada isolante formada no eletrodo que impede a neutralização de íons positivos, levando à formação de uma carga superficial. A carga induz um alto campo elétrico que pode ser aumentado o suficiente para extrair elétrons do eletrodo.

Consequências:

- Aumento da corrente de escuro
- Saturação das ionizações e redução do ganho
- Formação de streamers e indução de descargas elétricas

Simulações de acúmulo de carga:
Bruna T. Francisco (MSC-FAPESP)



YANG ZHOU AND PENG ZHANG, PHYSICAL REVIEW RESEARCH 2, 043439 (2020)

Ionic current model:

- Number of collisions/cm²/pC in the readout obtained from Garfield++ simulations
- Parametric curve fitted to the ion collisions distribution
- The readout charge is modeled as $Q_{read} = 4.0 \times 10^{-5} f G_{eff}$, where f is the event rate and G_{eff} is the effective gain (for 6 keV photons).

Dielectric layer model:

- Can be treated as a leaky capacitor ($CdV/dt + V/R = i_{ionic}$);
- Polymer resistivity $10^{13} - 10^{15} \Omega m$
- $\rho = \rho_0 \exp(-A/(E_b - E))$, where E is the electric field and E_b is the breakdown electric field of the polymer (may spark > 300 MV/m)
- Electric field given by: $\frac{E}{\rho_0} \cdot \exp\left(\frac{A}{E_b - E}\right) = J_0$

Field Emission model:

- Fowler-Nordheim equation:
 $J(F) = (A_{FN} F^2 / \Phi) \exp(-B_{FN} \Phi^{3/2} / F)$

where $A_{FN} \approx 1.5414 \times 10^{-6} [AeVV^{-2}]$ and $B_{FN} \approx 6.830 \times 10^9 [Vm^{-1}eV^{-3/2}]$.

- The electric field F is given by $F = \beta E$, where β is a local enhancement factor due to surface roughness.

The Malter effect:

- Field emitted electrons propagated using Garfield++
- Initial energy of 7 eV (Copper Fermi energy)
- Varying distances to the GEM hole

Figure 6 – Calculation of the dark current as a function of the event rate, considering the electrons emitted by the Malter effect.

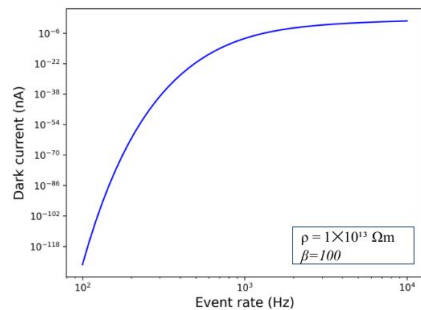


Figure 7 – Calculation of the dark current as a function of the bulk electrical resistivity, considering the electrons emitted by the Malter effect.

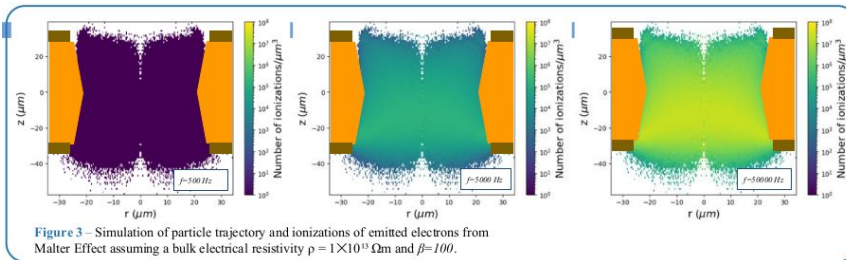
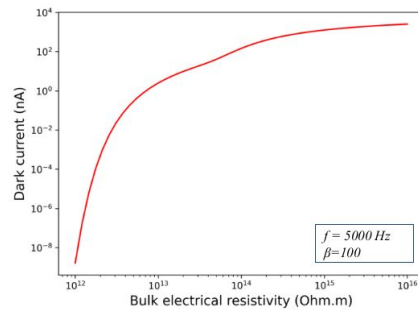


Figure 3 – Simulation of particle trajectory and ionizations of emitted electrons from Malter Effect assuming a bulk electrical resistivity $\rho = 1 \times 10^{13} \Omega\text{m}$ and $\beta = 100$.

CONCLUSIONS

- Increased ionizations as the dielectric electrical resistivity increases.
- Increased ionizations as the field enhancement factor (surface roughness) increases.
- Dark current from Malter-effect ionizations increases with dielectric resistivity and event rate.

NEXT STEPS

- Attempt to evaluate how the dark current affects the readout sensitivity.
- Try to measure the space charge distortions caused by the Malter effect–induced charge.

Poster presentation at the 6th DRD1 Collaboration Meeting



Meeting with the Frankfurt group in Germany:
Dr. Jens Wiechula and Dr. Matthias Kleiner

Drift-Field Distortions and Specific Energy Loss Calibration of the ALICE TPC in LHC Run 3

Dissertation
zur Erlangung des Doktorgrades
der Naturwissenschaften

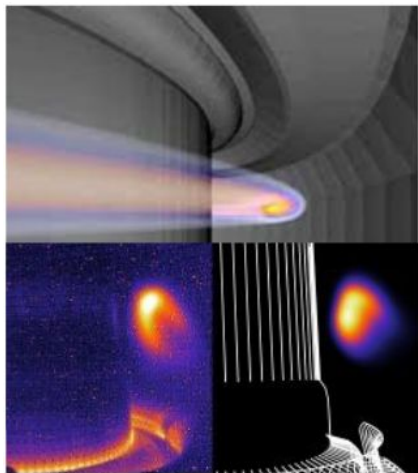
vorgelegt beim Fachbereich Physik
der Johann Wolfgang Goethe-Universität
in Frankfurt am Main
von

Matthias Kleiner

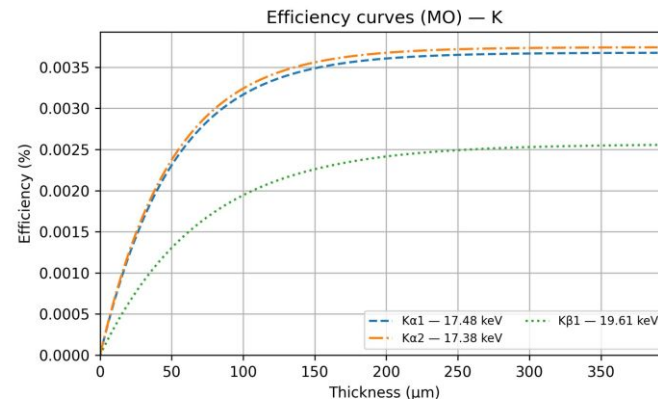


Aplicações

Tuning Gaseous Detector Sensitivity for Monitoring Applications in Fusion Reactors

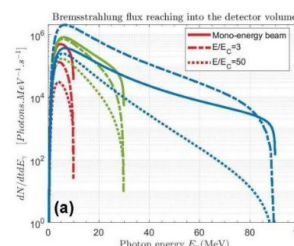


Runaway electrons (RE) are electrons in a plasma that are continuously accelerated by an electric field to relativistic energies. When runaway electrons interact with matter they generate Bremsstrahlung radiation, producing a broad spectrum of hard X-rays and gamma rays that can be used for runaway-electron diagnostics.



Considering 1 cm and 1 ATM of pressure for pure Ar in the gaseous detector.

Because a high flux in RE monitoring applications is expected, efficiencies as low as 10^{-5} can still be reasonable, considering that the expected flux can be very high ($\Phi \sim 10^7 - 10^8$ photons/s)

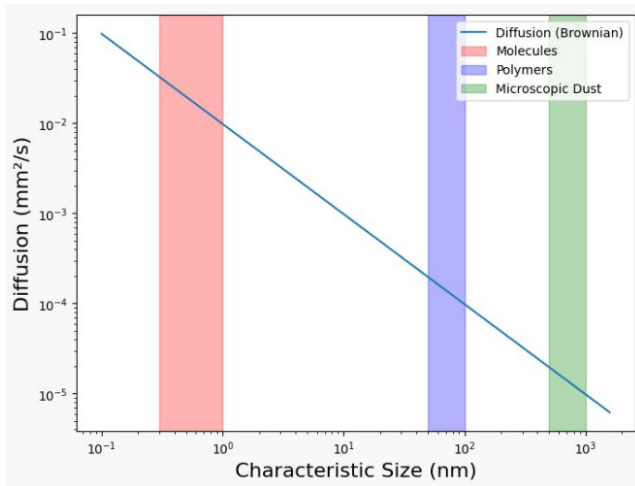


$$S_f = \eta \cdot \Phi_\gamma$$

$$S_b = 3.5 \times 10^{-5} \times 10^7 \approx 350 \text{ counts/s.}$$

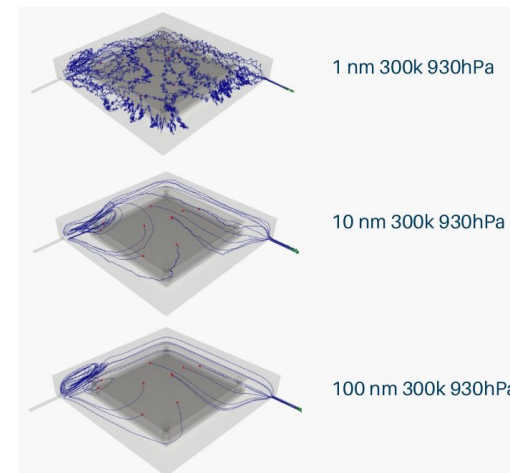
$$\text{SNR} \approx \sqrt{N} \approx 19$$

S. P. Pandya *et al.*, "Modeling of bremsstrahlung emission from the confined runaway electrons and applications to the hard X-ray monitor of ITER," *Physica Scr.* **93**, 115601 (2018).



$$\vec{x}_{n+1} = \underbrace{\vec{x}_n + \vec{v}(\vec{x})\Delta t}_{\text{Advection}} + \underbrace{\vec{\eta}}_{\text{Diffusion}}$$

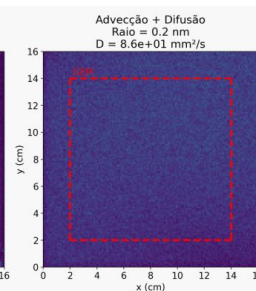
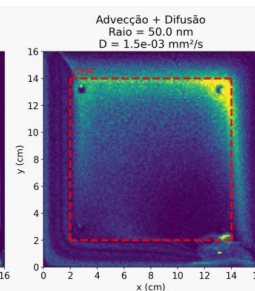
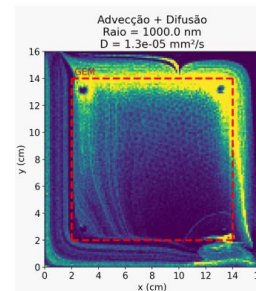
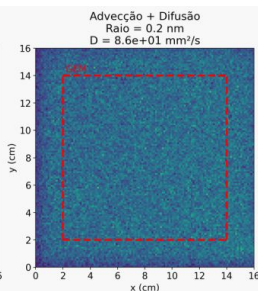
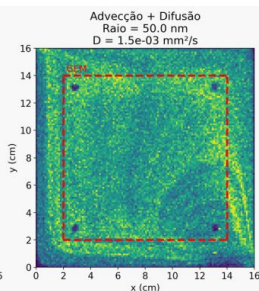
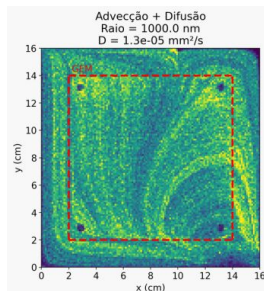
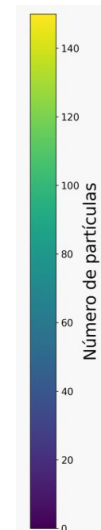
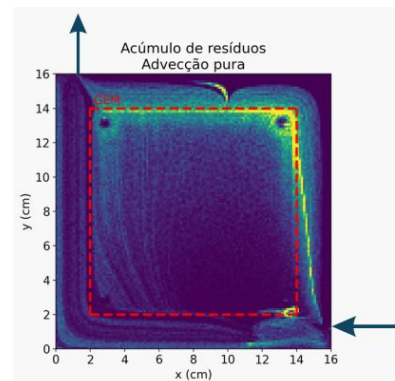
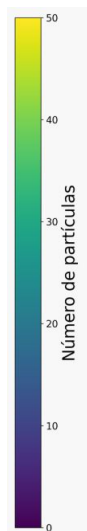
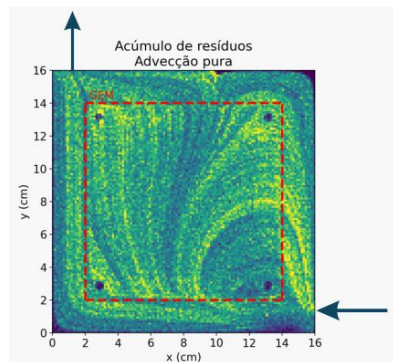
Element	Characteristic size
Individual molecules (e.g. O_2 , H_2O)	0.3–1 nm
Polymers (e.g. Poliimida)	50–200 nm
Microscópico dust	0.5–1 μm



Estabilidade de detectores baseados em GEM:

Juliano Henrique Leite dos Santos (IC-PUB)

Long term stability of GEMs: flow optimization



Miniaturized HV Power Supply for Portable MPGD Detectors

As part of the portable GEM detector development project, a portable high-voltage power supply model is being developed;

A30N-5 transformer, with an output voltage of 3 kV at 330 μ A (1 W), and AH60N-5, with an output voltage of 6 kV at 250 μ A (1.5 W);

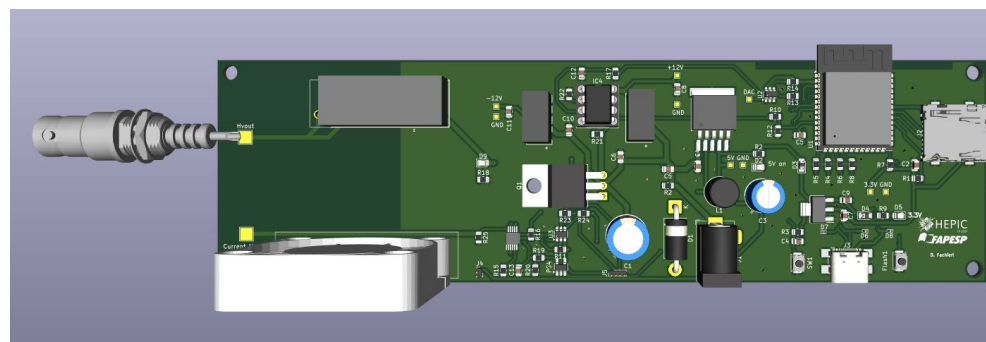
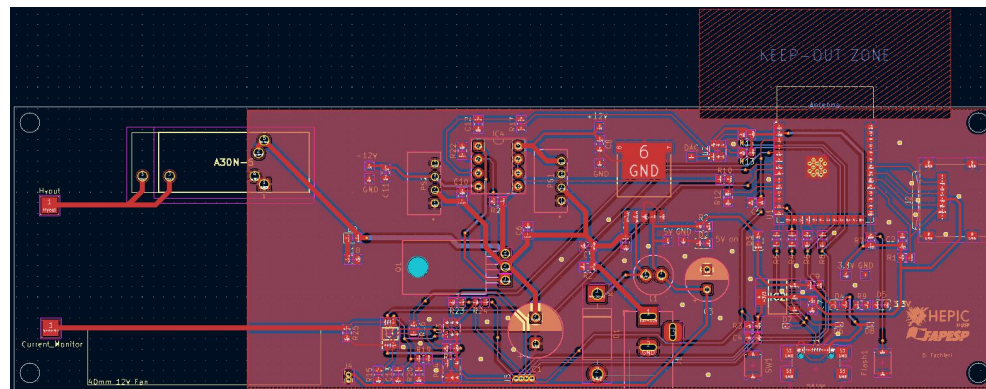
ESP32-S3 microcontroller for control, monitoring, communication, and data logging;

Wi-Fi/Bluetooth communication with other sensors for corrections related to environmental variations, such as temperature and pressure;

Current monitoring through a sensor, ensuring protection in case of overcurrent;

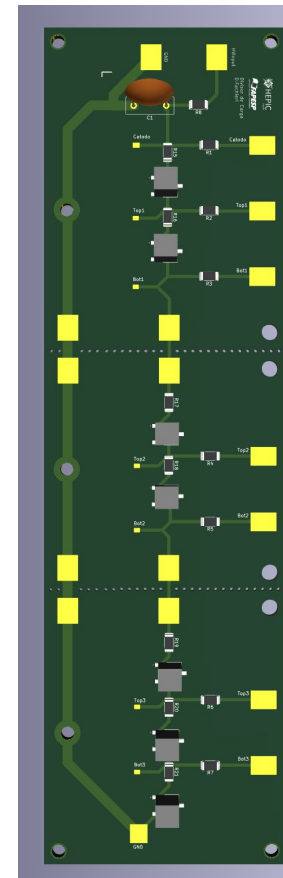
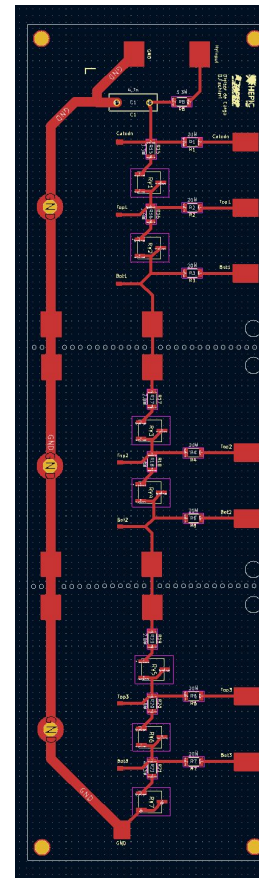
Powered by a 12 V / 3 A supply;

This version features a single channel, but studies are being conducted to implement seven individual channels without compromising the portability of the power supply.



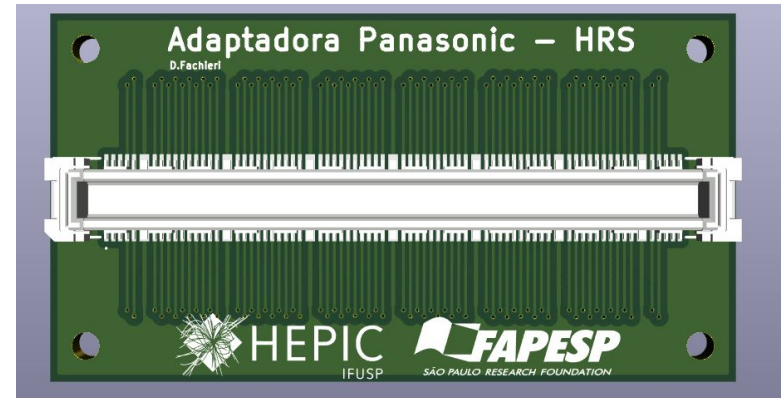
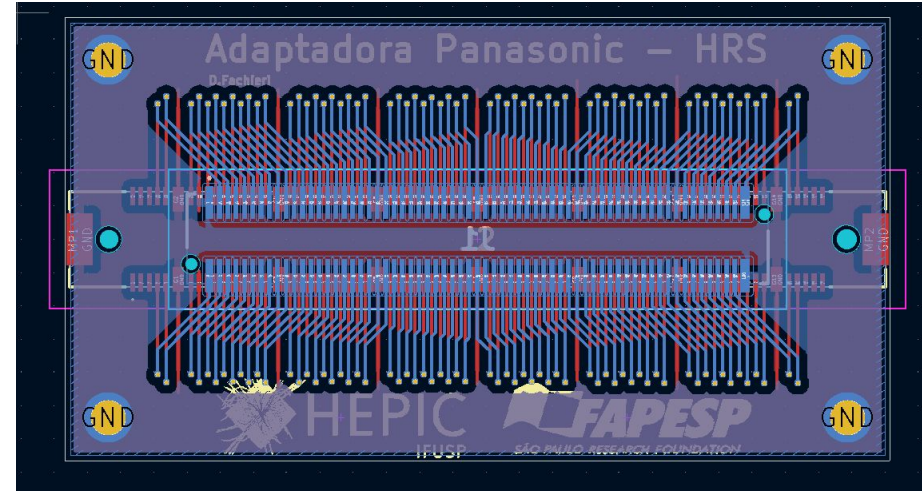
Voltage Dividers for Operating Multiple Detectors

- Currently, the laboratory has three GEM detectors under operational study, requiring a total of 21 high-voltage channels to operate all of them (7 channels for each GEM detector), while only 7 high-voltage channels are currently available.
- A voltage divider was developed to enable the simultaneous operation of these detectors.
- Detectors with already established operating voltages will use the voltage divider. New detectors will undergo a preliminary voltage scan before a new divider is manufactured.
- Each stage is divided by a resistor ranging from $2\text{M}\Omega$ to $5\text{M}\Omega$, with a $0.5\text{M}\Omega$ potentiometer for fine adjustment.



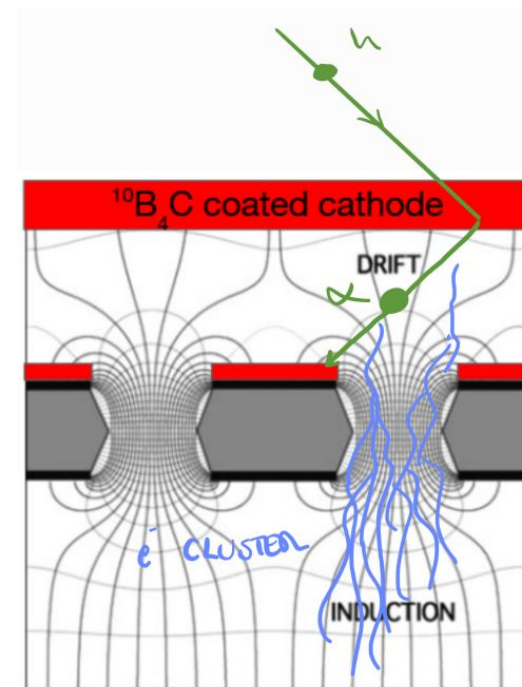
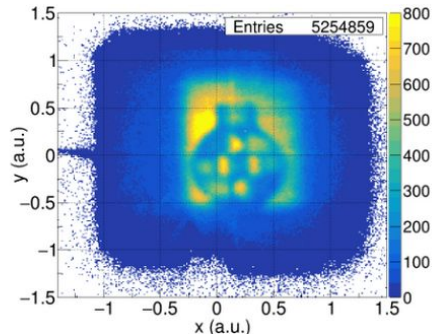
Panasonic-to-Hirose Adapters

- Adapters for the Hybrid Sampa-SRS System
- Some older readout planes were designed with Panasonic connectors, such as the neutron GEM detector, which are not compatible with the system.
- As a result, we now have six readout planes compatible with the Sampa-SRS system.



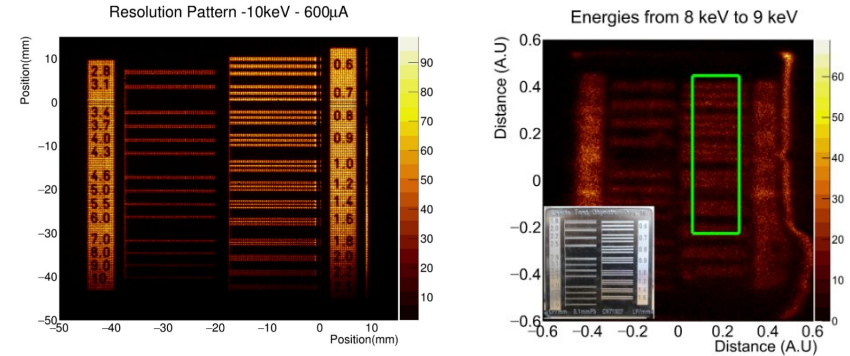
- Neutrons are converted into charged particles. This is frequently done with a thin boron carbide layer ($^{10}\text{B}_4\text{C}$)
- Previous student in 2022 developed a prototype that achieved ~ 700 Hz rates with under 3 mm spatial resolution
- System used resistive chains to read out data from all 256 X and Y strips
- Our plan is to upgrade this still working prototype and patch some of its shortcomings

From: SERRA FILHO, Lucas de Arruda. *Detector de nêutrons térmicos baseado em GEM com deposição de $^{10}\text{B}_4\text{C}$ sobre cátodo de alumínio*



Pedro (Mestrado)

- Upgrading the readout electronics to the Sampa chip, we can read each individual channel of the readout with rates up to 15 kHz triggered and 40 kHz in zero suppression
- Event reconstruction with micro-TPC (Time Projection Chamber) techniques can enhance spatial resolution even further
- Results in literature have shown up to 120 μm resolutions with this technique!



Comparison between images of a resolution pattern obtained with the same detector when, on the left, data was acquired with the Sampa chip and on the right with a resistive chain setup. From: SOUZA, Geovane Grossi Araújo de. *X-Ray fluorescence imaging system based on Thick-GEM detectors*

Caracterização de GEMs

Problemática:

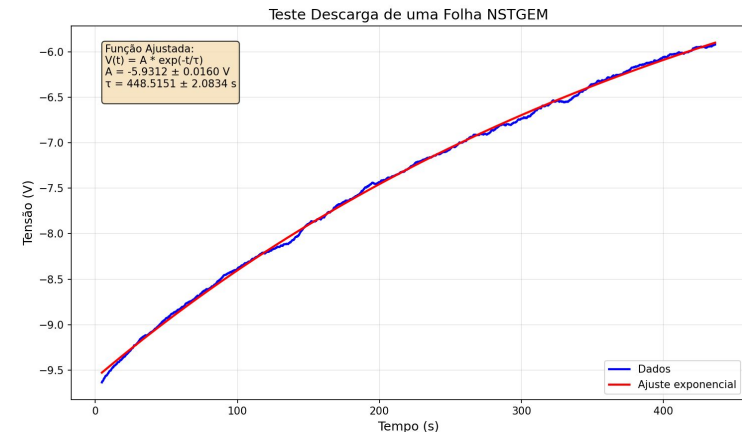
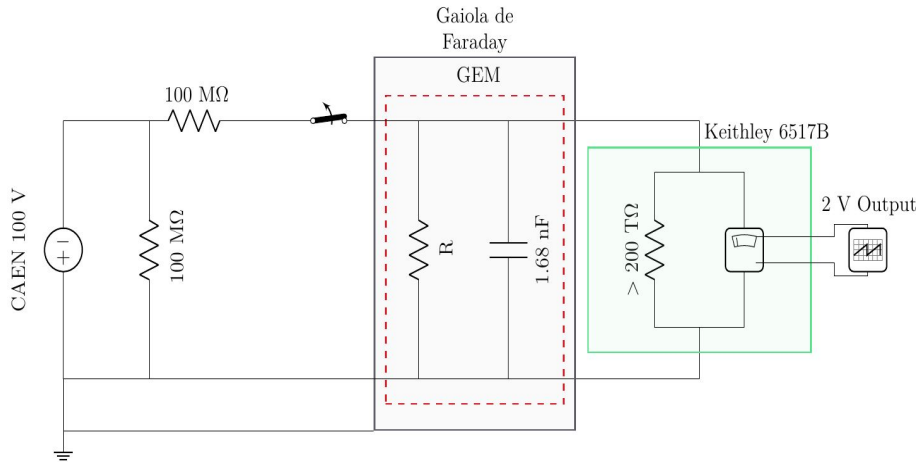
Devido a instabilidades do detector previamente montado com folhas Not so Thick GEM, tornou-se evidente a necessidade de testes de qualidade dessas folhas, sendo assim, a partir do conceito da descarga de um capacitor, projetou-se um experimento para medir as resistências entre as faces das folhas GEM.

Teste:

Um fluxo de uma mistura gasosa (Ar 70% e CO₂ 30%) foi utilizado a fim de controlar as condições ambientais dos testes simulando as condições de uso do detector. Uma tensão de -100 V foi aplicada no circuito (Figura 1) que em seguida foi aberto com o auxílio de um disjuntor fazendo o capacitor descarregar e tornando possível medir o tempo.

Resultado:

Como exemplo se utilizará o resultado de somente um dos testes. Os dados coletados por um osciloscópio de mesa foram ajustados em uma exponencial (Figura 3) retornando o tempo característico de $\tau = 449(2)$ s que em conjunto com a capacitância medida de $C = 1.60(5)$ nF resulta em uma resistência de $R = 280.62 \pm 8.9$ G Ω .

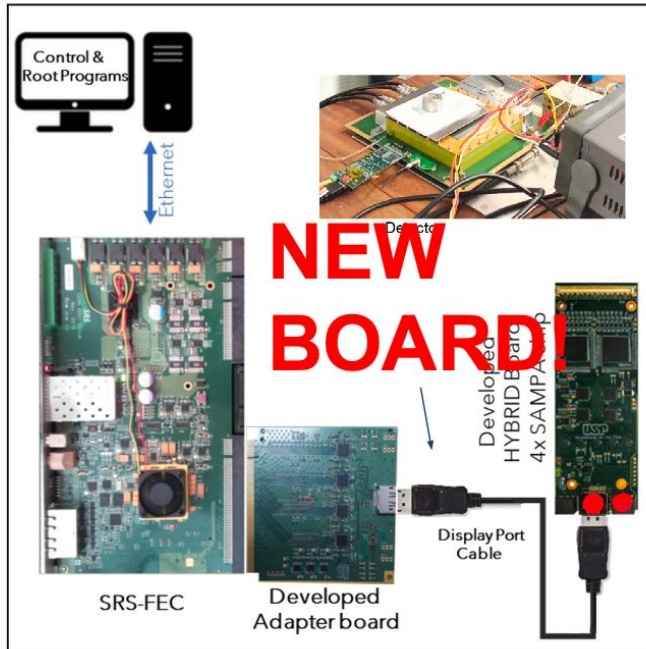


- Generalizar o teste para os GEMs padrão do laboratório.
- Remontar o detector com as duas folhas NSTGEM que se saíram melhor no teste (já feito).
- Efetuar testes de calibração obtendo espectros de Raios-X .
- Integrar os detectores com o sistema Sampa-SRS.
- Montar um segundo detector para trabalhos em 2 linhas paralelas:
 1. Entender como condições ambientais influenciam no ganho e nas resoluções temporal e espacial do detector.
 2. Reconstruir e analisar imagens, inicialmente unidimensionais e por fim bidimensionais, a partir dos sinais coletados pelo detector.

Eletrônica

temos um sistema **funcionando**, **porém com instabilidades que estão sendo investigadas.**

The complete setup

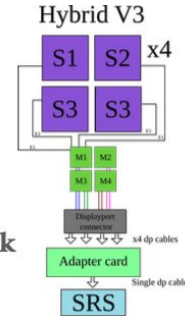


Hybrid v3 board overview:

Each hybrid provides 128 channels

Number of active links can be changed using just one multiplexer

Reduced bandwidth but possibility to work with multiple hybrids



Adapter board overview:

Each SAMPA chip is connected to one high speed serializer

A single Display-Port cable is used to connect the hybrid and the adapter board

The adapter board has four deserializers and a PCIx16 standard to connect a Front-End Card (FEC).

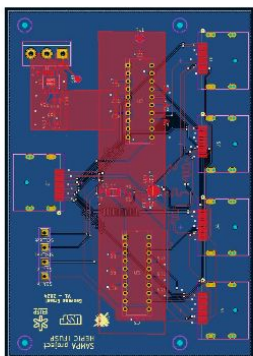
FEC:

Ethernet communication limit to 1Gbit/s

versão com 1 FEC lendo um detector inteiro (4 Hybrids, 512 chs): completado o debugging:

FUNCIONADO porém com instabilidades que estão sendo investigadas.

Replicator V1:



Integrate all the components into a single board -
Reading up to 512 channels with each application.



Wrong routing of the first differential pair

However, the replicator board works!

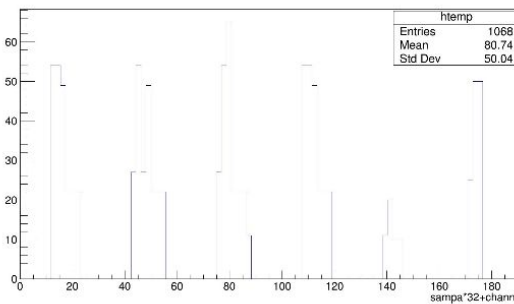
Routing all signals

Replicate clocks, RESET, I2C signals

The wires are crossed inside the displayport cable.

DisplayPort Standard Cable					
Source Side Plug		Cable Wiring	Sink Side Plug		
Signal Type	Pair		Signal Type		
Out	MT_Lane 0(p)	1	1	MT_Lane 3 (p)	In
GND	GND	2	2	GND	GND
Out	MT_Lane 0 (n)	3	3	MT_Lane 2 (p)	In
Out	MT_Lane 1 (p)	4	4	MT_Lane 1 (n)	In
GND	GND	5	5	GND	GND
Out	MT_Lane 1 (n)	6	6	MT_Lane 2 (n)	In
Out	MT_Lane 2 (p)	7	7	MT_Lane 1 (p)	In
GND	GND	8	8	GND	GND
Out	MT_Lane 2 (n)	9	9	MT_Lane 0 (p)	In
Out	MT_Lane 3 (p)	10	10	MT_Lane 0 (n)	In
GND	GND	11	11	GND	GND
Out	MT_Lane 3 (n)	12	12	MT_Lane 0 (n)	In
CONFG0	CONFG0	13	13	CONFG0	CONFG0
CONFG1	CONFG1	14	14	CONFG1	CONFG1
IO	IO	15	15	IO	IO
GND	GND	16	16	GND	GND
IO	ATX_CTL (n)	17	17	ATX_CTL (n)	IO
In	Hot Plug Detect	18	18	Hot Plug Detect	Out
Out	Hot Plug Detect	19	19	Hot Plug Detect	Out
Out	SP_2.5A	20	20	SP_2.5A	Out

sampa*32+channel



A rede DRD1 está bem estabelecida. Em julho vai já renovar várias posições de “gestão”, em particular os coordenadores dos WGs e dos WPs, assim como “converners” dos WGs e os “liaisons” com os outros DRDs (o mandato começou faz dois anos, já na fase de transição entre RD51 e DRD1).

Precisamos assinar o MoU... ainda não foi feito devido ao receio de não conseguir pagar a Collaboration Fee :-)

Próxima reunião de colaboração DRD1 na semana 29/6-3/7.

- Confirmado o compromisso com o Work Package 4 (“INNER AND CENTRAL TRACKING WITH PID CAPABILITY, TIME PROJECTION CHAMBERS”), Task 4 (“FEE for TPCs”) que nós nós declaramos interessados em participar.
- A ser avaliado se entrar (se comprometer!) em outros Work Packages.
- Continuando a participar do WG5-Eletrônica.