Gaseous detector applications and developments in the Brazilian HEP community

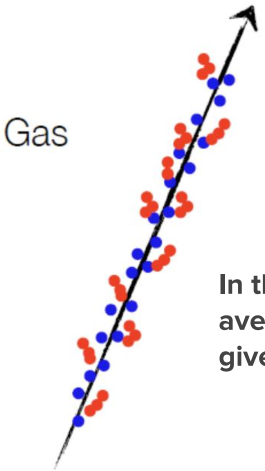
Sandro Fonseca de Souza (UERJ)
Felipe Silva (UEA)
Tiago Fiorini da Silva (USP)
Luis Miguel Domingues Mendes (CBPF and LIP/Portugal)

Outline

- Gaseous radiation detectors: Fundamentals and Applications
- Applications in Collider Machines
  - Resistive Plate Chamber (RPC): CMS Experiment
  - Gas Electron Multiply (GEM): ALICE Experiment
- Applications in Cosmic-Ray Experiment
  - Resistive Plate Chamber (RPC): MARTA (Muon Array with RPCs for Tagging Air showers) Project
    1. Gas regeneration for RPCs
- Summary and Conclusions

Gaseous radiation detectors: Fundamentals and Applications

Gas Ionization



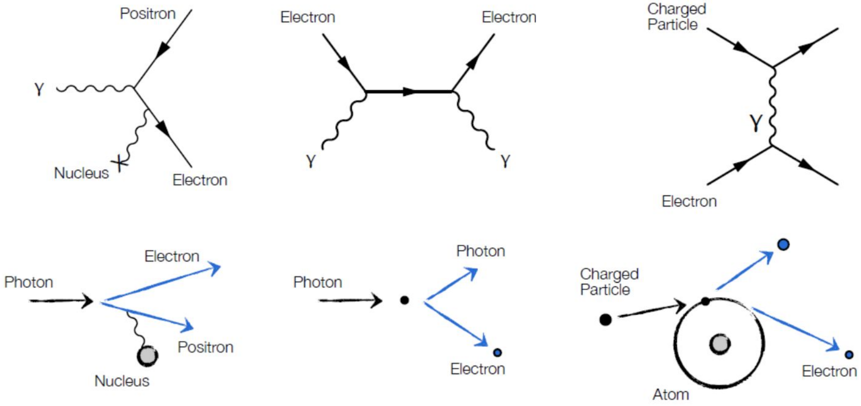
In the interaction of radiation with matter, the average number of electron-ion pairs produced is given by:

$$\langle n_T \rangle = \frac{L \cdot \langle \frac{dE}{dx} \rangle_i}{W_i}$$

L → thickness of the gas layer
E → ionization energy
W → average energy for production of electron-ion pairs

Interaction of radiation with matter: (+Bremsstrahlung + Cherenkov + excitement + …)

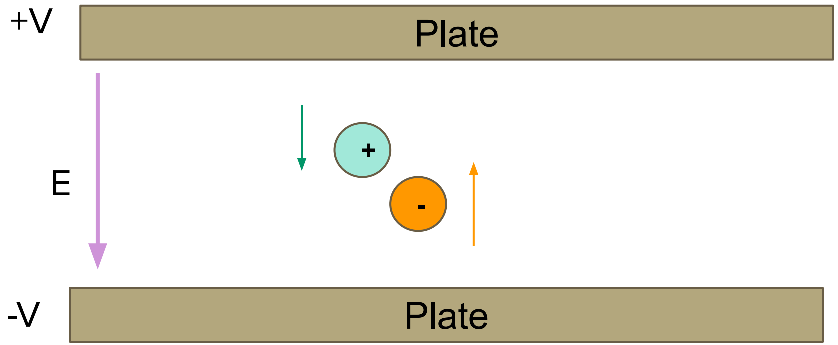
Pair Production Compton Effect Ionization

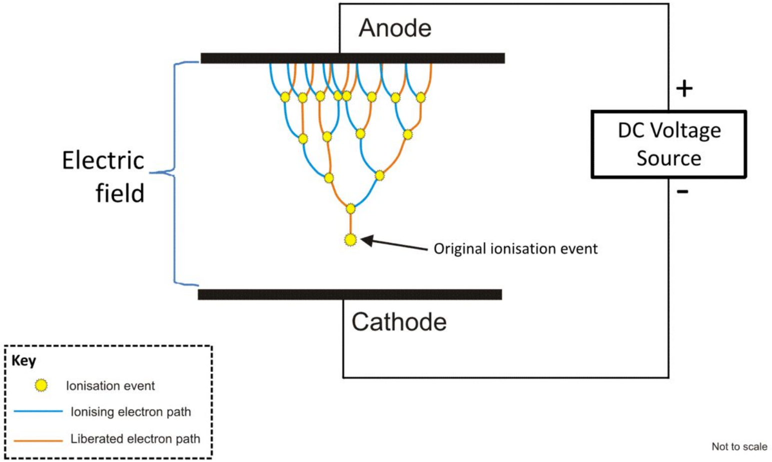


H.-C. Schultz-Coulon & J. Stachel —
http://www.kip.uni-heidelberg.de/~coulon/Lectures/Detectors/

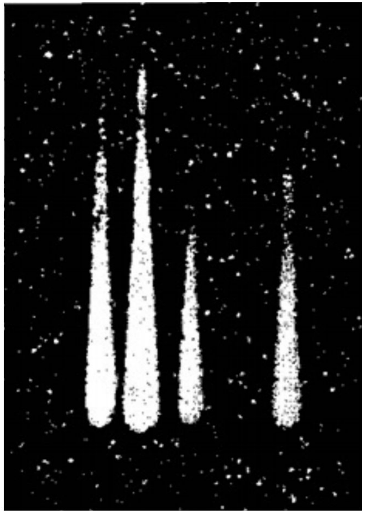
sandro.fonseca@cern.ch

Gas Ionization



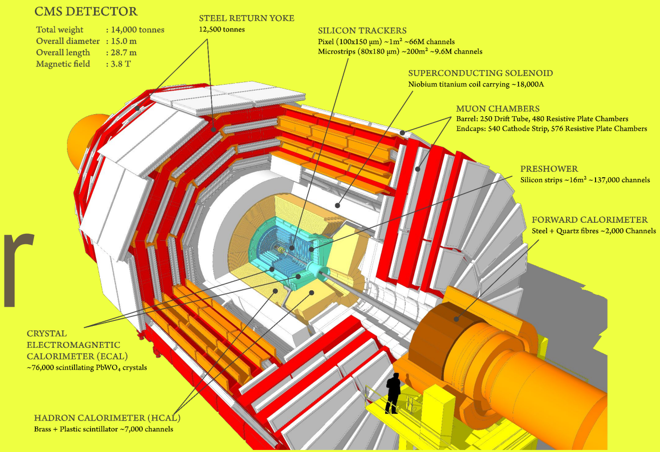


- In an electric field, the ions and electrons will drift in opposite directions.
- If the field is large enough, electrons produced in primary ionization can interact with the gas and generate new pairs.
  - $10^4 - 10^5$ V/cm
- this cascading effect generates **electron avalanches (Townsend Discharge).**



Electron avalanches in cloud chamber (H. Raether, Butterworth (1964))

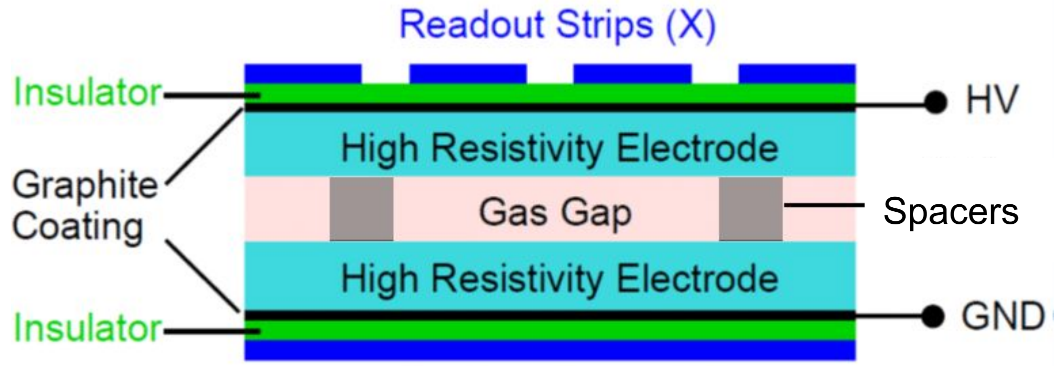
Applications in Collider Machines

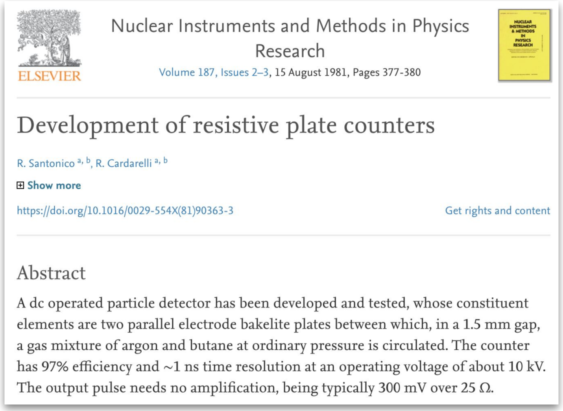


Resistive Plate Chamber (RPC): CMS Experiment

sandro.fonseca@cern.ch

Typical structure of a RPC - Resistive Plate Chamber




Nuclear Instruments and Methods in Physics Research
Volume 187, Issues 2–3, 15 August 1981, Pages 377-380

ELSEVIER

Development of resistive plate counters

R. Santonico [a, b], R. Cardarelli [a, b]

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https://doi.org/10.1016/0029-554X(81)90363-3 Get rights and content

Abstract

A dc operated particle detector has been developed and tested, whose constituent elements are two parallel electrode bakelite plates between which, in a 1.5 mm gap, a gas mixture of argon and butane at ordinary pressure is circulated. The counter has 97% efficiency and ~1 ns time resolution at an operating voltage of about 10 kV. The output pulse needs no amplification, being typically 300 mV over 25 Ω.

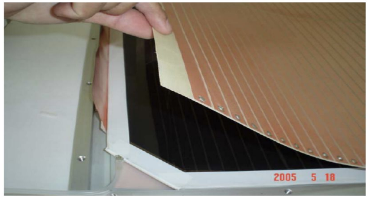
- The volume of gas (Gas Gap) is where ionization and avalanche occur.
- The electrodes are made of high resistivity material and are said to be "transparent" to the signal.
- High voltage is applied to a graphite layer on the outside of the electrodes and is responsible for sustaining the electric field.
- Readout strips are copper structures that capture the induced signal.

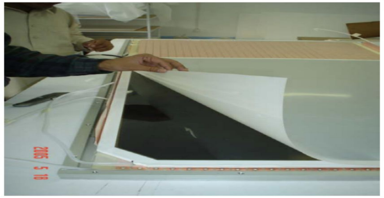
sandro.fonseca@cern.ch

CMS RPCs

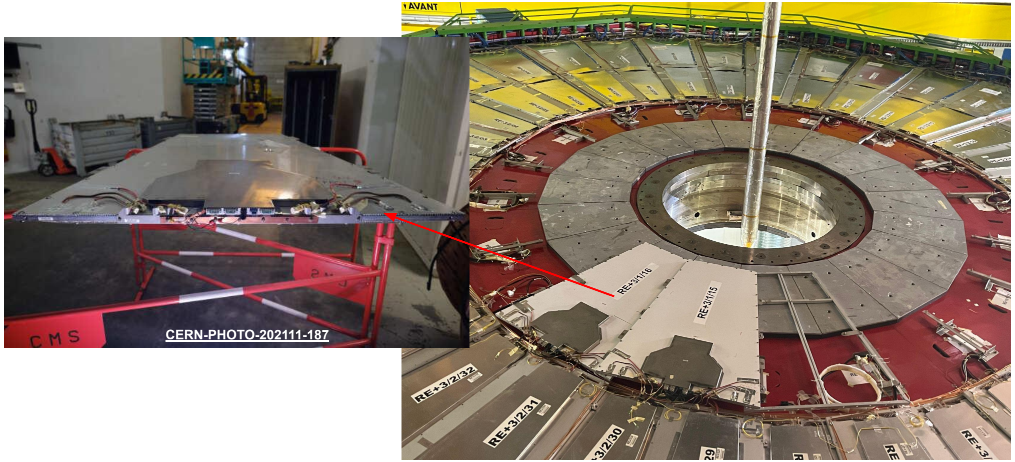
- Closed loop gas system for **present system**:
  - Mixture: 95.2% $C_2H_2F_4$ **(Freon)**, 4.5% iC_4H_{10} **(Isobutane)**, 0.3%**(Sulphur Hexafluoride)** SF_6
  - Humidity: 40%
  - Replenishing rate: 10%

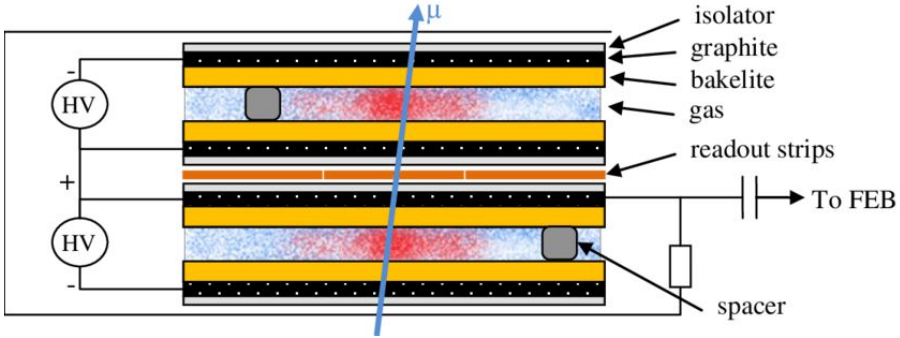
Due to its very good time resolution, the RPC is very important for CMS Trigger.





- **~1056 Bakelite double gap chambers**
  - $10^{10} - 10^{11}$ Ω·cm
- Barrel and Endcap
- Time Resolution: ~2 ns (LHC Bx: 25 ns)
- **Rate Capability (present system): ~300 Hz/cm²**
- **Contributes to triggering and reconstruction**



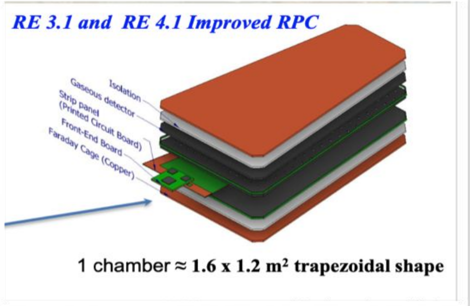


- Avalanches can be produced in one of two gaps.
- **Allows to operate at high efficiency with lower high voltage.**
- The signal reading is taken between the two gaps.
- **Time resolution improves by up to 1/√2.**

Presented during RENAFAE 2021 workshop

CMS-RPC Upgrade Phase II

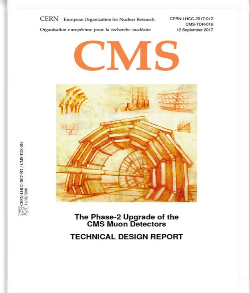
Rate Capability: ~2KHz/cm^2

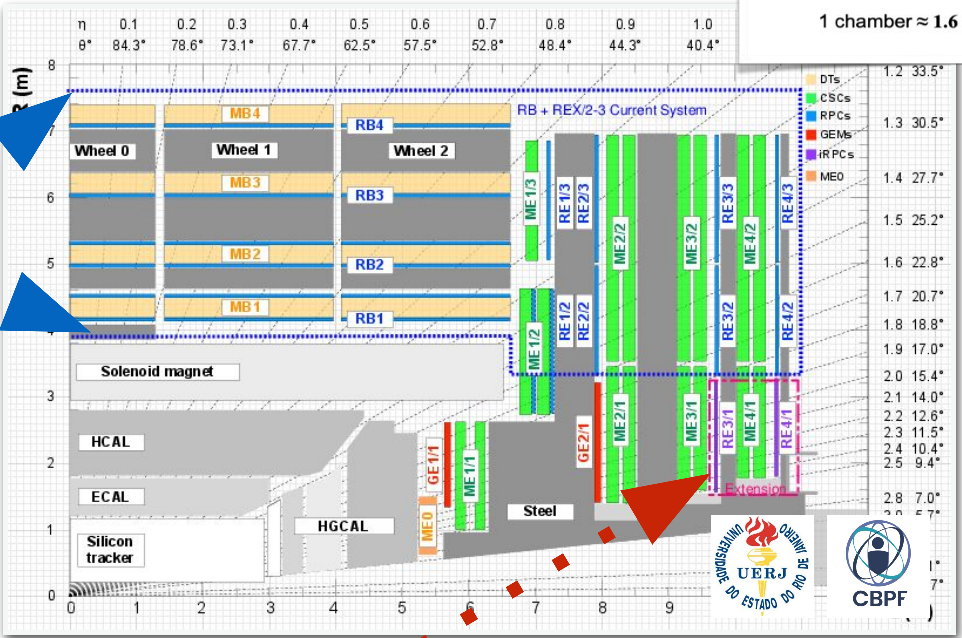


Eco-gas studies to reduce the Global Warming Potential (GWP)

Upgrade of Link Board System (LB) to improve timing resolution for existing RPC (|η| < 1.9) installation during LS3

New Slow Control project was presented by Fabio Marujo (CBPF) during RENAFAE 2022 workshop


CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire
CERN-LHCC-2017-012
CMS-TDR-016
12 September 2017
CMS
The Phase-2 Upgrade of the CMS Muon Detectors
TECHNICAL DESIGN REPORT



iRPC demonstrator chambers installed on Dec 21 and Jan 22

Extend the RPC coverage up to |η | < 2.4 to increase redundancy in high eta region in stations 3 and 4. (72 iRPCs)

CMS CR-2018/130

sandro.fonseca@cern.ch

Eco Gas Studies

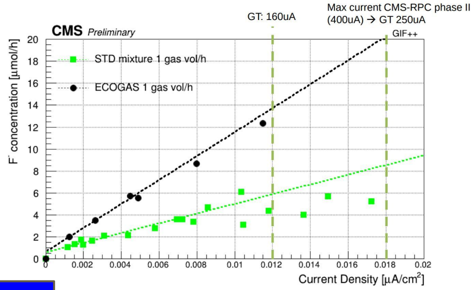
Contact persons: Sandro Fonseca (CMS-RPC Deputy Project Manager) and Mapse Barroso (PhD student)

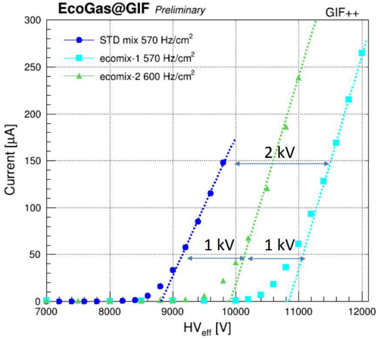
- Collaboration (since 2019) with different groups and institutes: CMS-RPC, ATLAS-RPC, EP-DT, ALICE-MTR, LHCb, SHiP.
- CERN is pushing the LHC experiments to replace the $C_2H_2F_4$, as it has a high global warm potential (GWP) ~ 1430, with gases with lower GWP.
- Goal of the collaboration: Characterization of HFO-Based gas mixtures with LHC-like background.
- Detectors with different technologies and shared parts: CMS-RPC WebDCS, CMS Mechanics Trolley, EP-DT Gas System, EP-DT Monitoring tools.

EP-DT Detector Technologies

Hydro-Fluoro-Olefin (HFO)
- Contains C=C bound
- Contains Fluorine
- Contains Hydrogen

RPC	Gap type
CMS-GT	2 mm, double gap
CMS-K	1.4 mm, double gap
ALICE	2 mm, single gap
EP-DT	2 mm, single gap





National possibilities and developments discussed during the RENAFAE 2021 workshop

Results
- HFO-based gas mixture chosen to be tested: HFO 35 %, CO_2 60 %, iC_4H_{10} 4 %, SF_6 1 %.
- No clear sign of aging so far.
- Detector working point found 1 kV higher than the standard gas mixture.
- Stable ohmic current, while some increase and/or fluctuation (under study) is visible at working voltage.
- Ongoing studies: (F^- production, rate scan studies, long term monitoring).
- Test beam 2021: First beam test on the setup to be done this year -> Study of rate, cluster size, efficiency.

CMS awards 2021 for Mapse

Ageing studies for the RPC at CMS Experiment

Longevity Studies

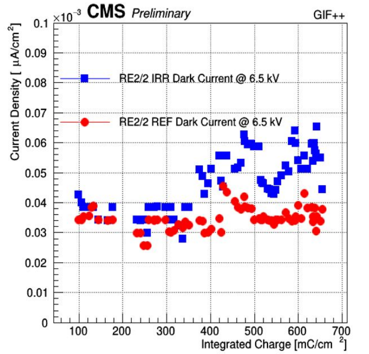
- Aim: Validation of the present RPC system in view of the HL-LHC Phase
- Setup at GIF++ since July 2016
  -2 RE2 chambers (Irrad. & Ref.)
  - 2 RE4 chambers (Irrad. & Ref.)

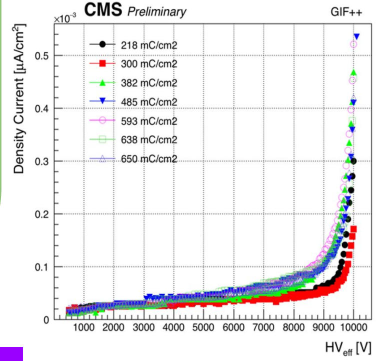
- Expected conditions at HL-LHC
  - Expected integrated charge:
    - ~ 840 mC/cm² (safety factor 3)
    - ~ 600 Hz/cm² (safety factor 3)

- Two chamber are continuously irradiated & two are used as reference.
- So far:
  - RE2: 95.8 % of charge accumulated
  - RE4: 56.2 % of charge accumulated
- Efficiency at WP remains stable in time up to the maximum expected rate (600 Hz/cm²)
- **No evidence of any ageing effects has been observed.**
- **Plans**
  - To continue studies
    - Accumulate the rest of charge.
    - Monitor noise level
    - Monitor efficiency performance.

iRPC longevity studies

- Aim: iRPC certification for HL-LHC conditions.
- Expected conditions at HL-LHC
  - Expected integrated charge:
    - ~ 1C/cm² (safety factor)
  - Expected rate:
    - ~ 2KhZ/cm^2 (safety factor 3
- One chamber with kodel (Kodel C) electronics is under test.
  - Some problems with gas circulation at the beginning of the studies which caused increase in the currents.
  - Problem has been solved and the current increase has stopped
  - Good performance during test beams.
  - Around 30 mC/cm² of accumulated charge.
- **New two gaps installed in the December 2021**
  - **Good performance up to 9 mC/cm²**
  - **No signs of ageing**
- **Plans**
  - Install new double gap chamber (ready for preliminary tests in 904) at GIF++ to monitor the signal in function of the integrated charge.





Reference: link

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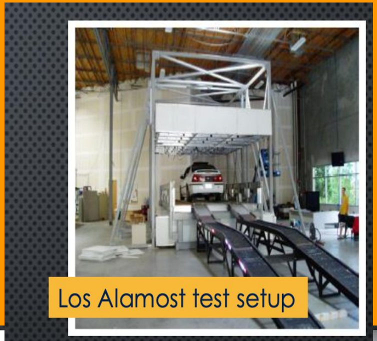
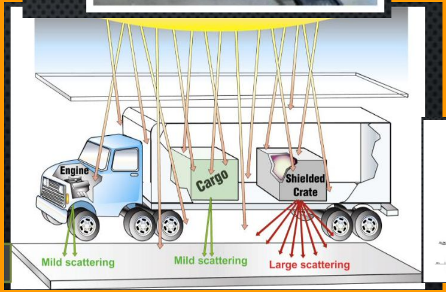
sandro.fonseca@cern.ch

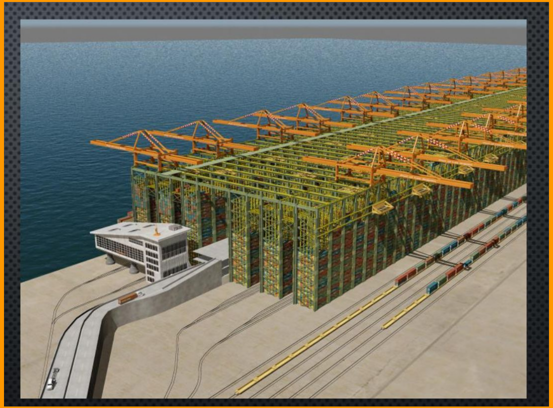
National possibilities and developments discussed during the RENAFAE 2021 workshop

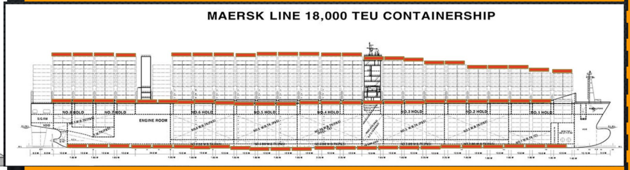
Contact persons: Sandro Fonseca (CMS-RPC Deputy Project Manager) and Mapse Barroso (PhD student)

RPC Applications



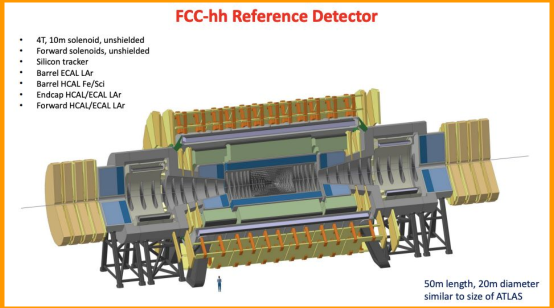




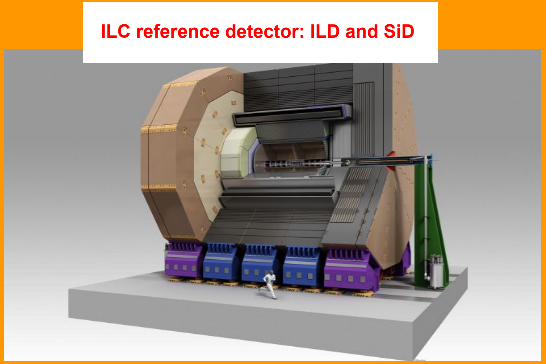


Muon Tomography: reference: P. Baesso *et al* 2014 *JINST* **9** C10041

Future Colliders



Muon system reference: Drift Tubes + RPC
https://doi.org/10.1140/epjst/e2019-900087-0



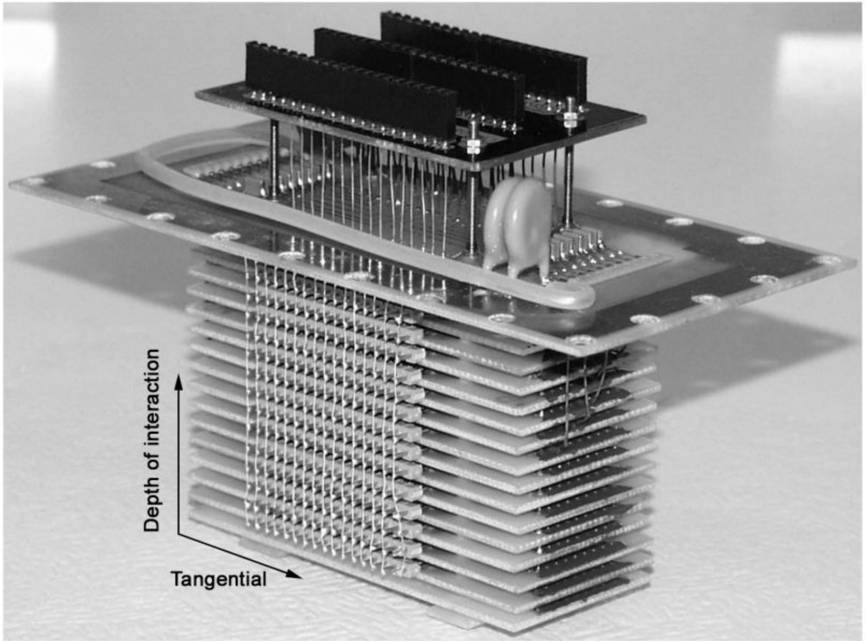
Hadronic Calorimeter reference: RPC based
https://arxiv.org/abs/1306.6329

sandro.fonseca@cern.ch

Medical application in next slides

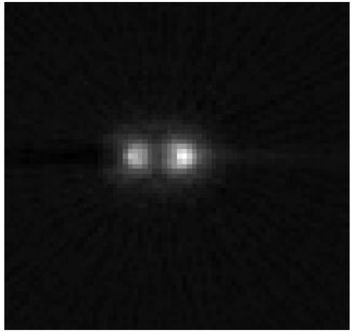
RPC Applications: RPC-PET

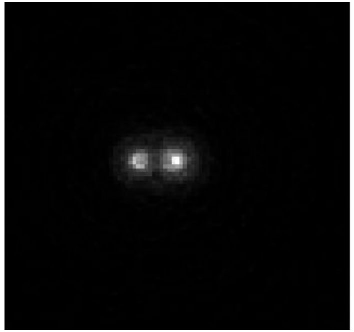
https://ieeexplore.ieee.org/document/1462730?arnumber=1462730



RPC-PET

- POSITRON EMISSION TOMOGRAPHY, based in RPCs for medical applications.





https://arxiv.org/abs/1706.07075

sandro.fonseca@cern.ch

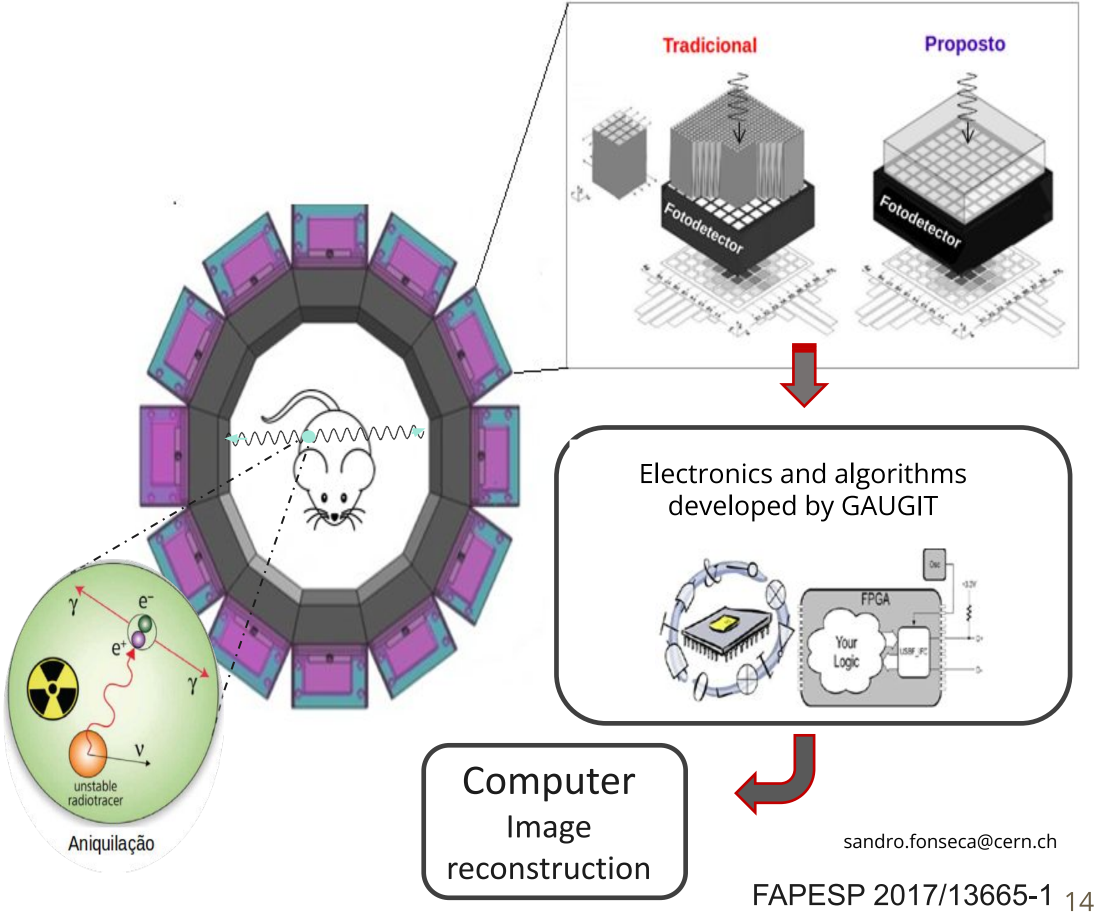
Programs and partnerships

EMERGE PEIEX PIXEL AUSPIN cietec INCUBADORA SP SEBRAE SP

Micro PET

Development of instrumentation for PET systems, aiming to:

- **Improve system sensitivity** by using monolithic crystals
- **Decrease the administered dose** or examination time
- Improve or maintain **spatial resolution**, with algorithms for estimating the 3D position of photon interaction in the crystal
- **Reduce equipment cost**, reducing the requirement for channels and electronic modules



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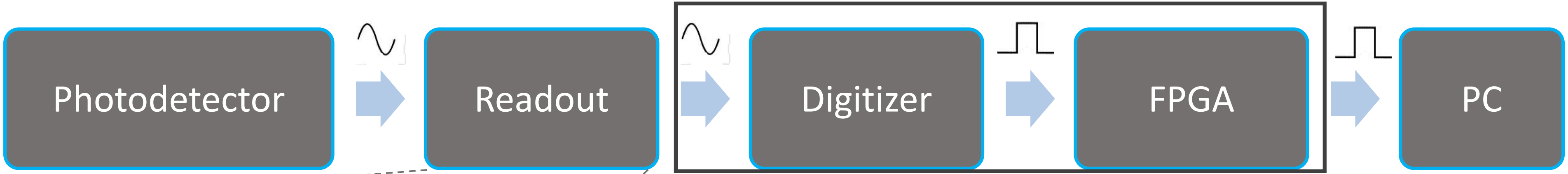
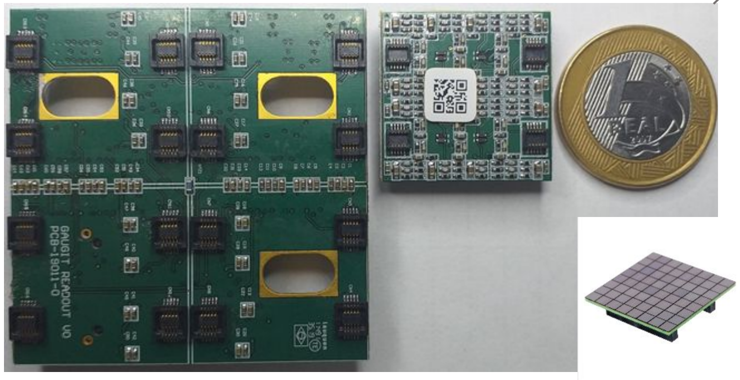
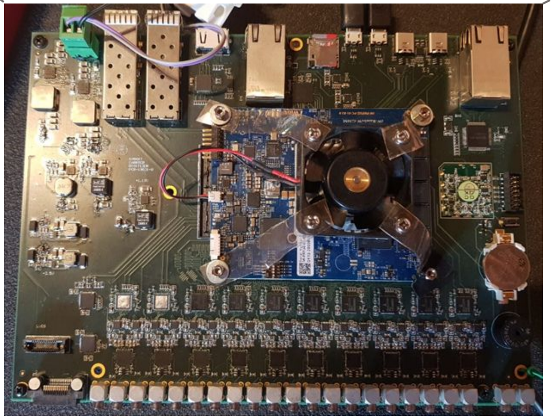
FAPESP 2017/13665-1

PET Instrumentation - Gaugit





Reading system and summing in line and column the signals of the 2 x 2 matrices of the 8 x 8 photodetector (256 channels → 16 channels)



DAQ System

PDP algorithms embedded in the FPGA to estimate:

- Energy
- Pulse arrival 3D time
- Position of photon interaction

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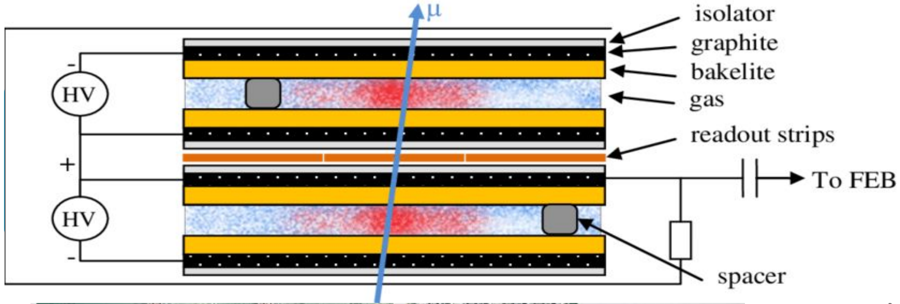
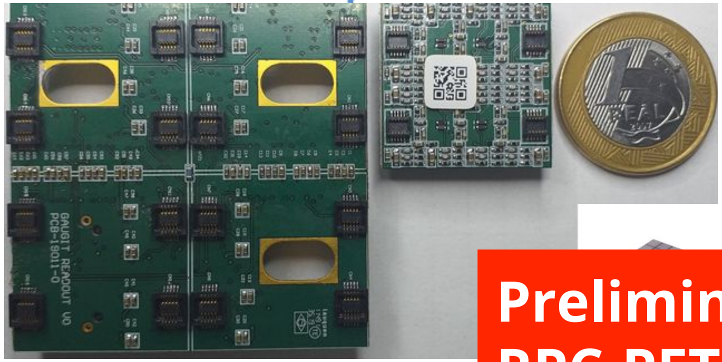
2017/13665-1

PET Instrumentation - Gaugit





Preliminary discussion to develop RPC-PET Full-body scan (SpinOff)

Reading system and summing in line and column the signals of the 2 x 2 matrices of the 8 x 8 photodetector (256 channels → 16 channels)

DAQ System

PDP algorithms embedded in the FPGA to estimate:

- Energy
- Pulse arrival 3D time
- Position of photon interaction

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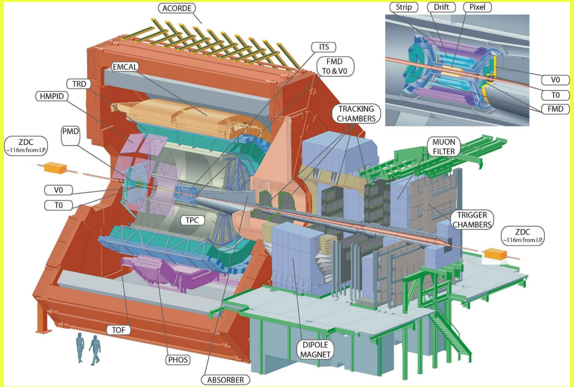
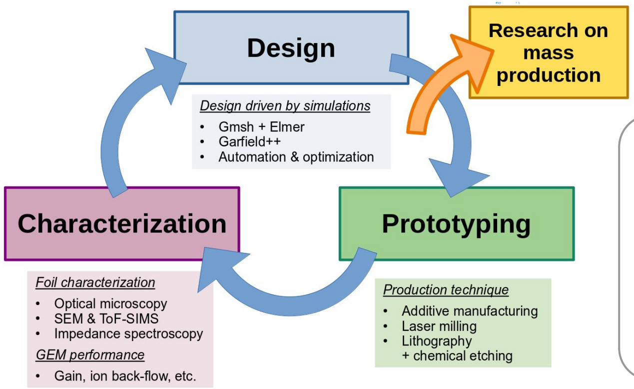
Applications in Collider Machines

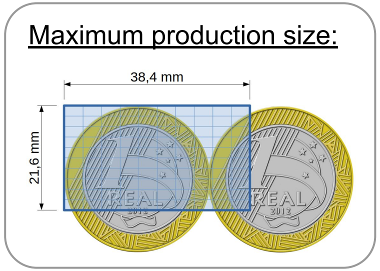


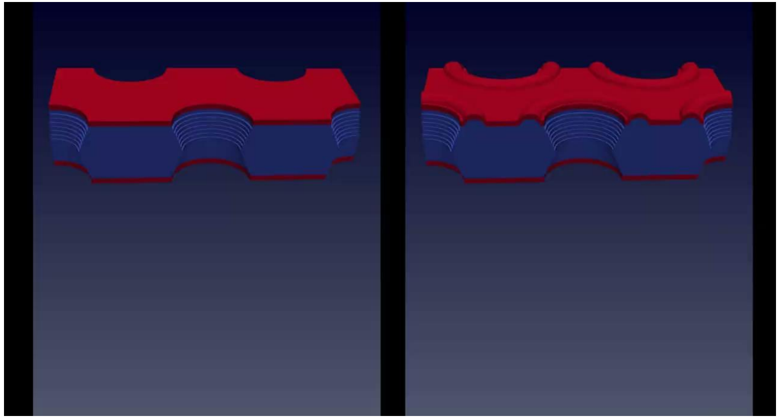
Gas Electron Multiply (GEM): ALICE Experiment

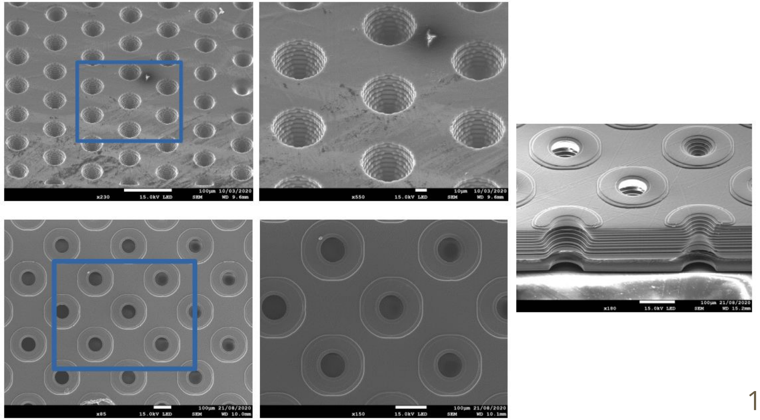
3D printing of MPGDs

Goal: Enable fast prototyping for tests of new geometries. Smooth integration between modeling and tests.





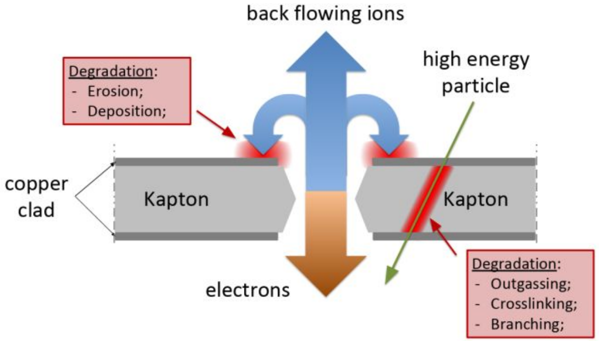


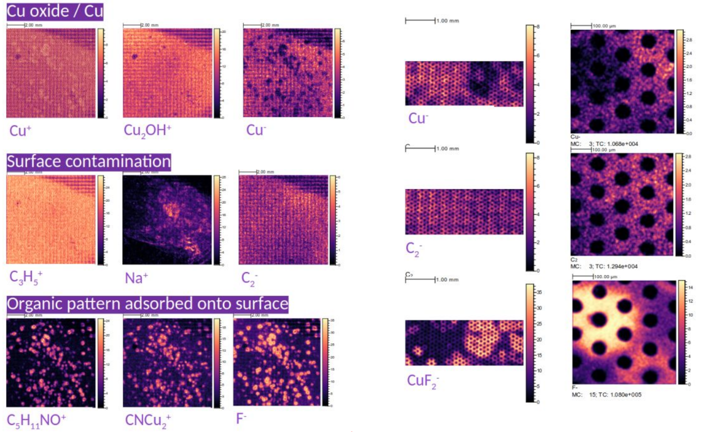


Challenges: Multi-material printing in high-resolution.
Partners: Univ. of Nottingham and NPL.
Motivation: Suppression of charging up, ion backflow and mitigation of degradation.
Research leader: Prof. Dr. Tiago F. da Silva

GEM aging and degradation studies

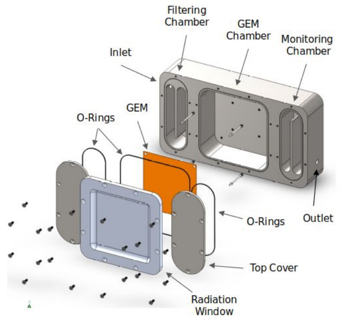
Goal: Develop a deeper understanding on aging and degradation processes of Gas Electron Multipliers (GEMs).



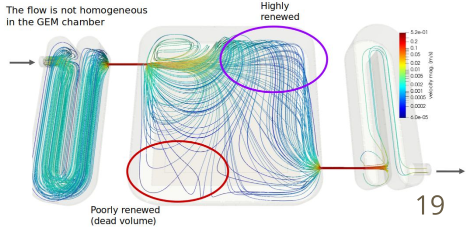


Evidence of kapton redeposition!

Design of degradation chamber:



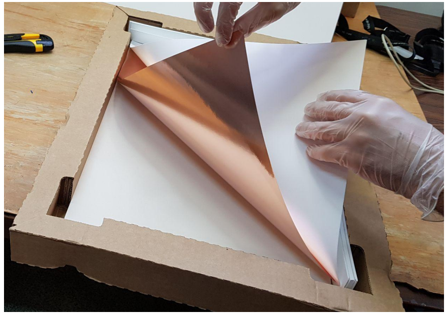
Gas flow simulation:

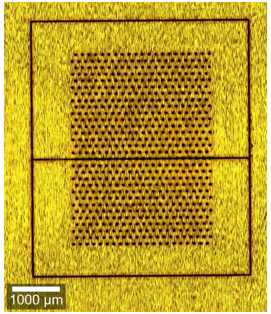


Challenges: Definition of controlled environment
Partners: Univ. of Nottingham and NPL.
Motivation: Enable longer lifetime and stability.
Innovation: Use of advanced surface analysis.
Research leader: Prof. Dr. Tiago F. da Silva

Local production of GEM foils

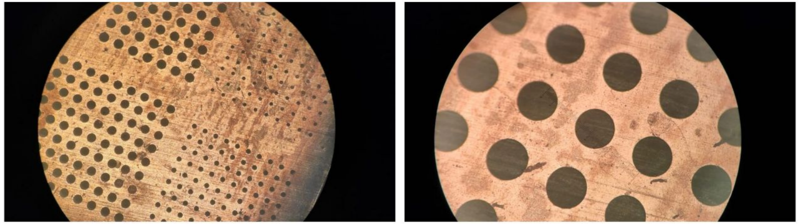
Goal: Develop a self-sufficient production of Gas Electron Multipliers (GEMs).



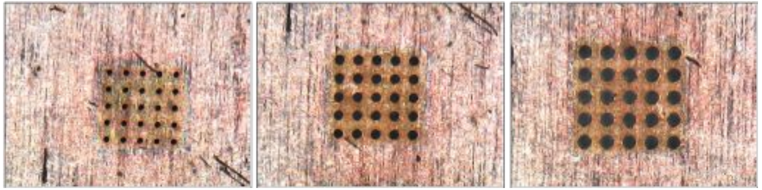


Challenges: Microfabrication with homogeneous quality
Partners: Escola Politécnica da USP
Motivation: Enable the GEM production in different shapes and reduce the costs.
Innovation: Use of laser milling for fast production.
Research leader: Prof. Dr. Tiago F. da Silva

Method: Optical lithography and chemical etching

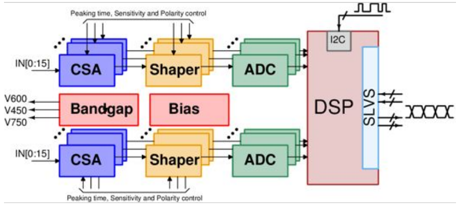


Method: Laser milling
Why? - New, clean (free of KOH) and fast



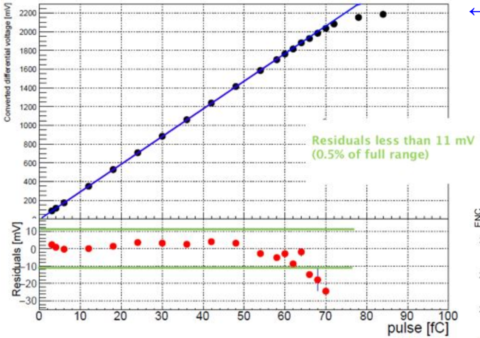
21 µm 35 µm 49 µm

Electronics and data acquisition: the SAMPA chip



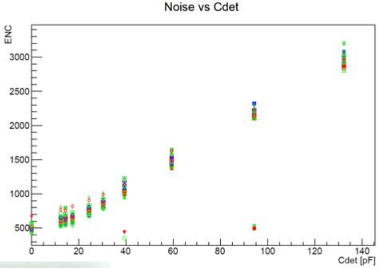
- A new ASIC for the readout of gaseous detector of high energy experiments (ALICE @LHC [CERN], STAR and sPHENIX @ RHIC [EUA] , MPD @NICA [Russia])
- Developed in São Paulo by LSI, Escola Politécnica (design) and local HEPIC group (validation)
- Specs
  - TSMC CMOS 130 nm, 1.25 V technology
  - 32 channels, Front-end + ADC + DSP
  - package size ≤15x15 mm^2 (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



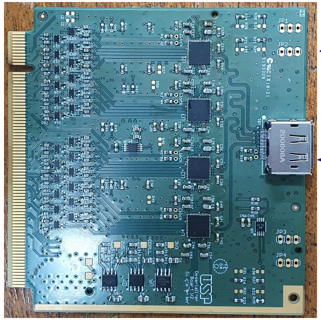
← Good Linearity

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



Low Noise →

Tuned to be below 650 ENC at ~18 pF



← SAMPA-SRS Interface board

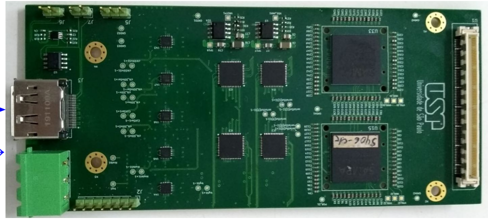
Interface board to the SRS FEC.
Contains the demultiplexer

← Display port cable →

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

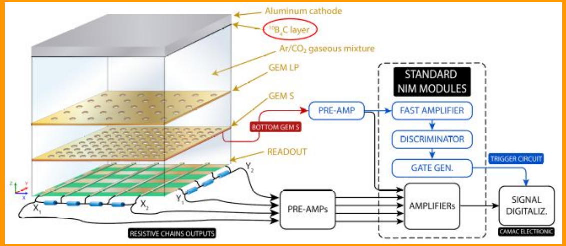
SAMPA-SRS Hybrid →

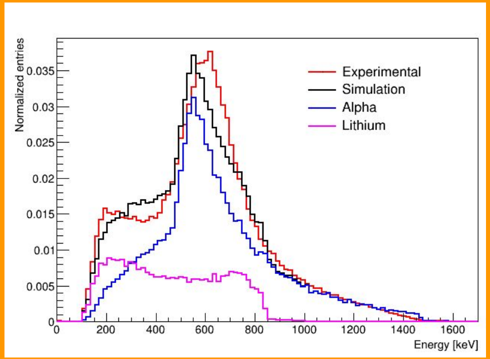
Hybrid with 4 SAMPAS, readying 128 channels.
Each SAMPA has a devoted multiplexer to send out 4 e-links via one higher speed data link

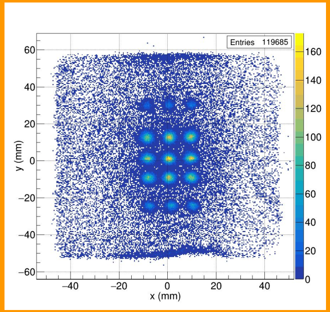


GEM Applications

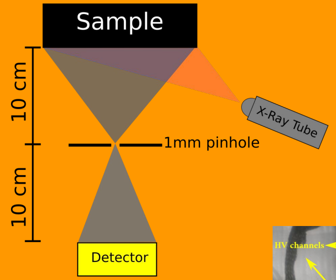
Neutron imaging

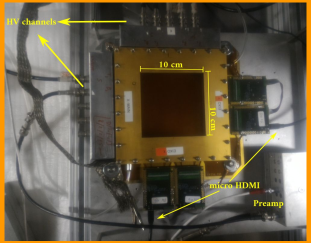


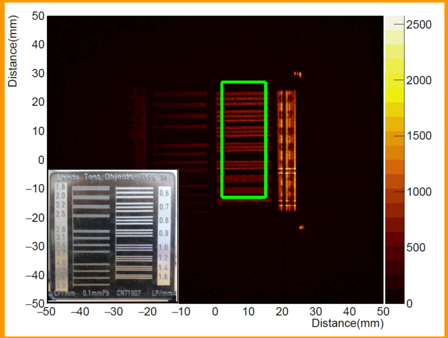




X-ray hyperspectral imaging



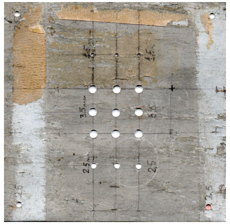




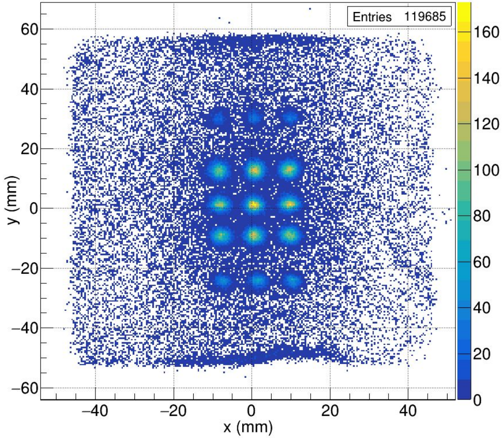
MPGD application: Position sensitive neutron detection

- 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)

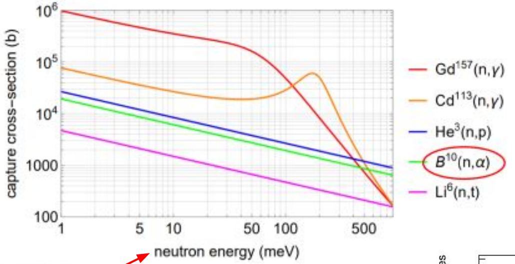
Cadmium absorber (mask)

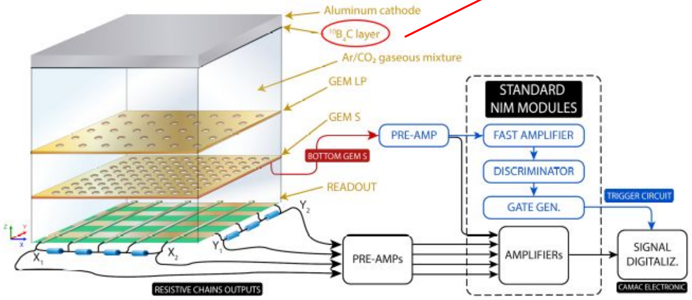


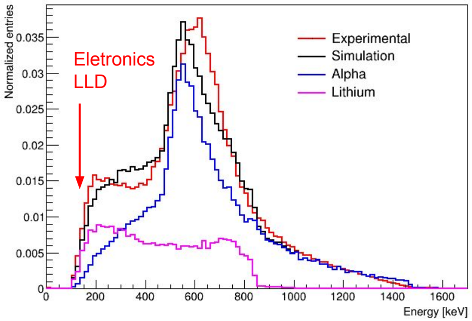
Neutron detected image



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



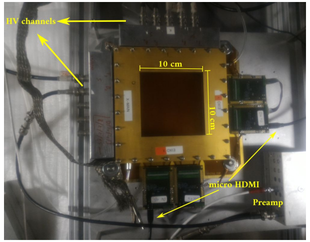




Predicted efficiency using Geant4 simulations: **3.14(4)%**

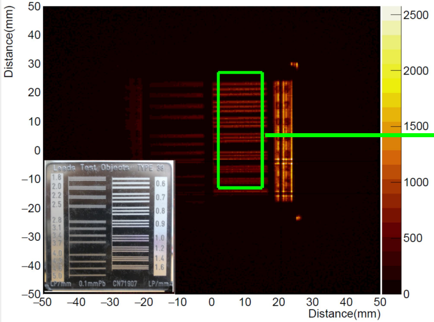
Efficiency obtained experimentally: **2.66(30)%**

MPGD application: Position and energy sensitive x-ray detection

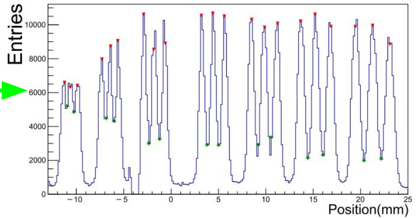


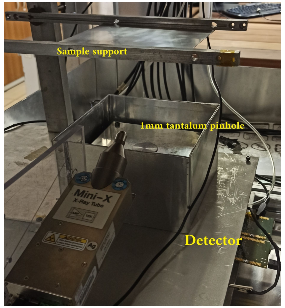
- Triple-GEM with strip read-out
  (256 strips for each dimension)
- 100 cm² active area
- Ar/CO2 (70/30) at atmospheric pressure
- Gain of the order of 104
- Acquisition rate ≈ 1.2 kHz
- Detector field of view limited by a 1 mm tantalum pinhole for near field images
- Acquisition rate ≈ 250 Hz

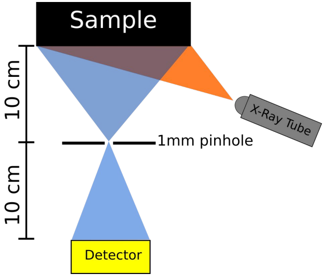
Resolution mask image



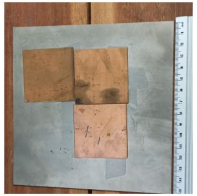
Resolution mask profile



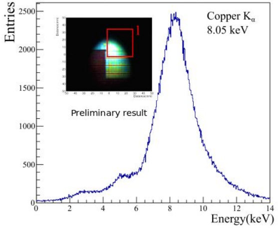


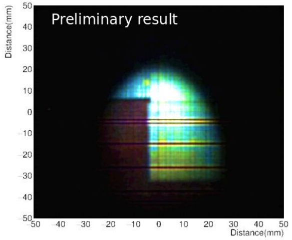


Test sample of a titanium plate with cooper sectors

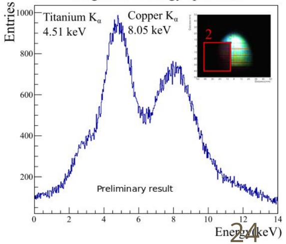


Region 1 - Energy spectrum





Region 2 - Energy spectrum



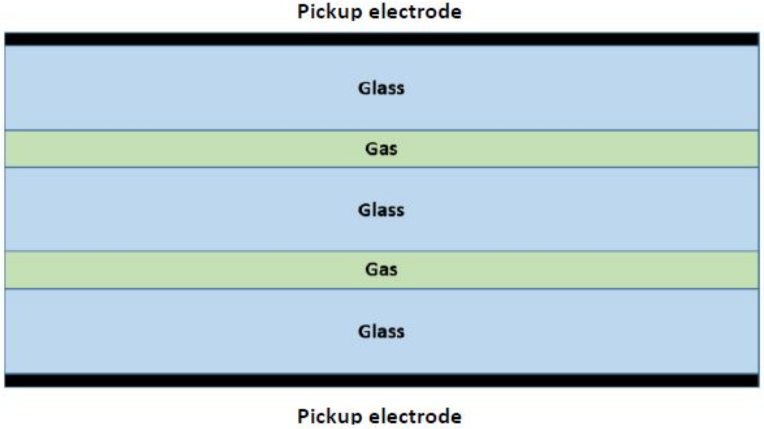
The first station of the MARTA engineering array is now installed

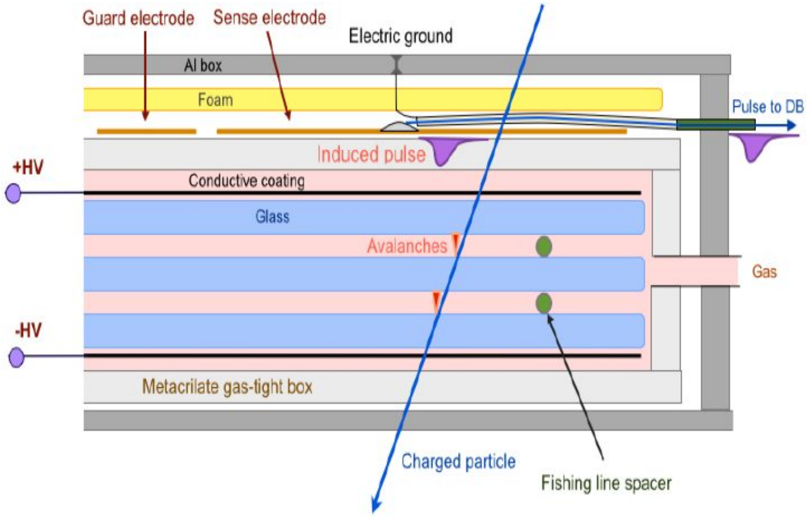
Applications in Cosmic-Ray Experiment

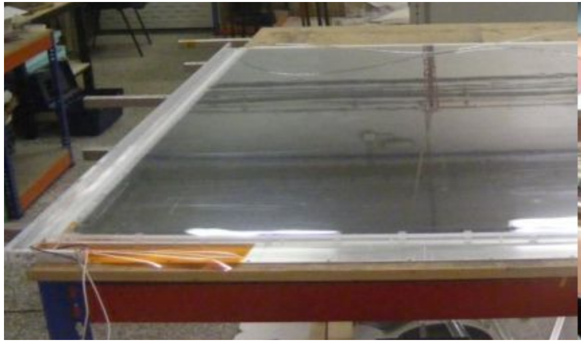
Resistive Plate Chamber (RPC): MARTA Project

RPC type MARTA

- RPC detectors for cosmic ray experiments in outdoor environment
- Avalanche mode
- Very low percentage of streamers
- 2 GAPS
- Low gas flow (2CC/Minute)



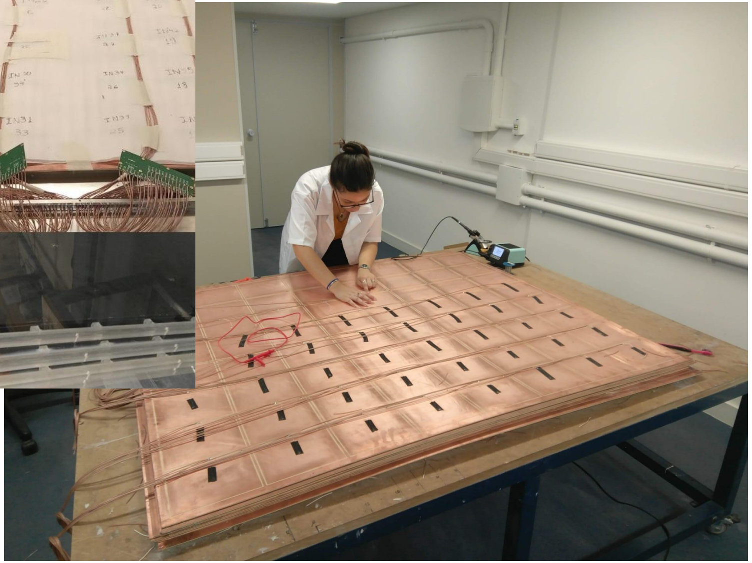




RPC Assembly Lab.

LIP UNICAMP USP SÃO CARLOS CBPF

Lab. of Detector Development
(Lab. Neusa Amato - CBPF)



- ❑ Gaseous volumes with 2 GAPs
- ❑ HV Power Supply (+6000V and -6000V)
- ❑ Sensor network (temp., pressure and humidity)
- ❑ Matrix with 8x8 PADs
- ❑ Faraday shield (Aluminum box)
- ❑ Gas flow monitoring bubblers
- ❑ DAQ with ASIC MAROC and FPGA (Cyclone IV)

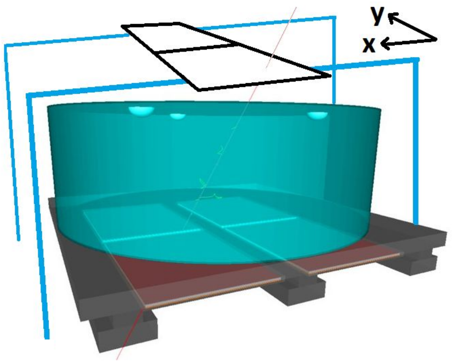
Current and future productions:

- 20 RPC for the MARTA project
- 10 RPC for SWGO calibration

RPC for detector characterization

Hybrid detector consisting of:

- ❑ RPC Hodoscope assembly
- ❑ 4 RPC Down as MARTA (256 PADs)
- ❑ 2 RPC TOP, with programmable X offset
- ❑ In the center a cherenkov water tank (20m^2 of water). With 3 PMTs.



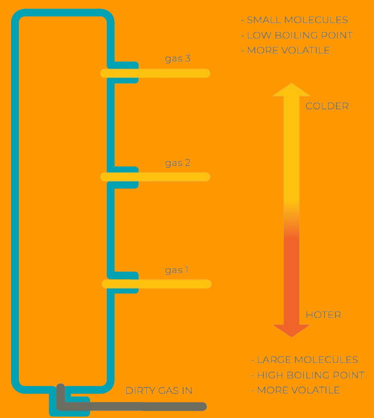
It will be used to characterize and test detectors:

- MARTA Station (AUGER)
- Hodoscope prototype to measure MIP of SSD and VEM of tank with UUB (AUGER)
- Mercedes detector prototype for SWGO
- C-ARAPUCA
- Hydrophones setup
- Etc…

Gas regeneration for RPCs

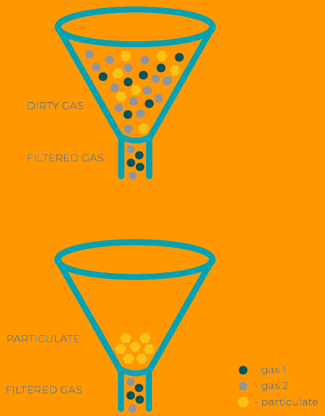
Techniques

DISTILLATION

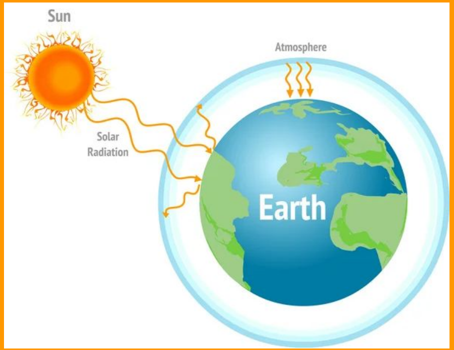


X

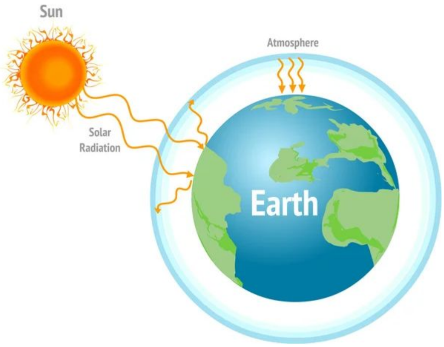
FILTRATION



Environment



Gas regeneration



Why?

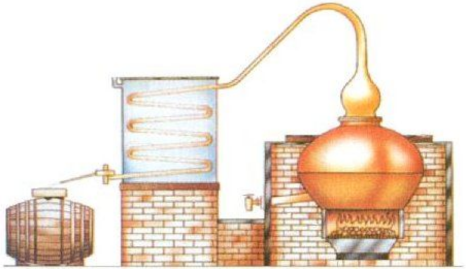
Environment:

- They are polluting substances and controlled by environmental agencies.
- Greenhouse effect

Financial:

- Gas expensive and are getting more and more expensive.
- Regenerating is much cheaper than crafting.

What's the best option?

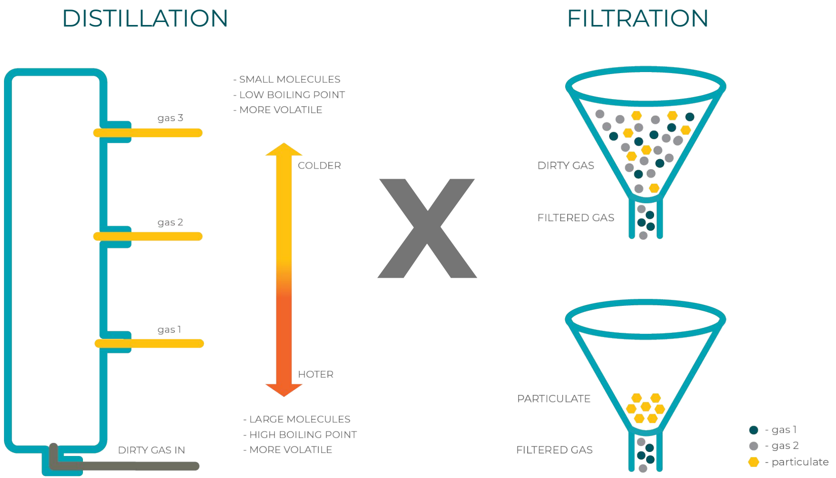


Gas regeneration

Using regenerated gas R134a (tetrafluorethane) for 3.5 years in the detector characterization laboratory (CBPF)

We count on the support of the Brazilian industry:

- ❑ Company specialized in gas regeneration
- ❑ Chemical engineer of renowned gas manufacturer
- ❑ Staff specialized in gas regeneration



Collaboration with the Brazilian industry to develop a dedicated system for gas regeneration to RPCs, in a closed circuit.

Distiller produced by Recigases

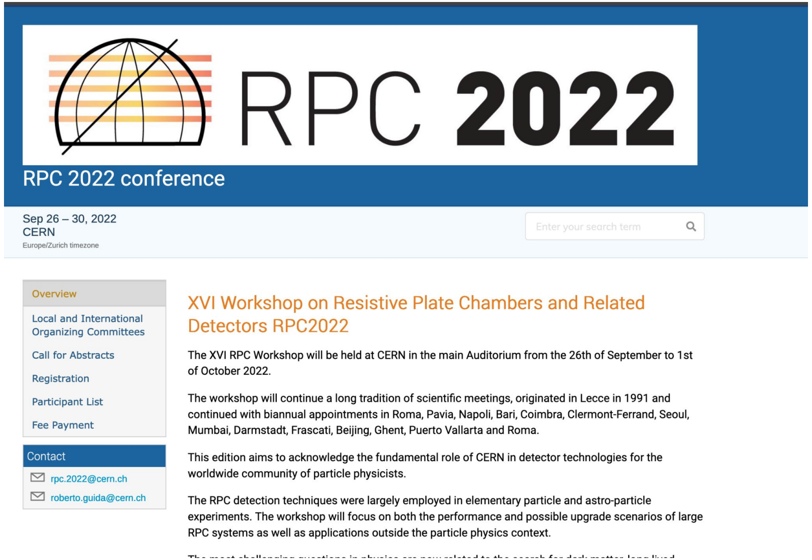
Closed loop regeneration process control - will be developed at the Lab of Detector Development (Lab. Neusa Amato - CBPF)

Summary and Conclusions

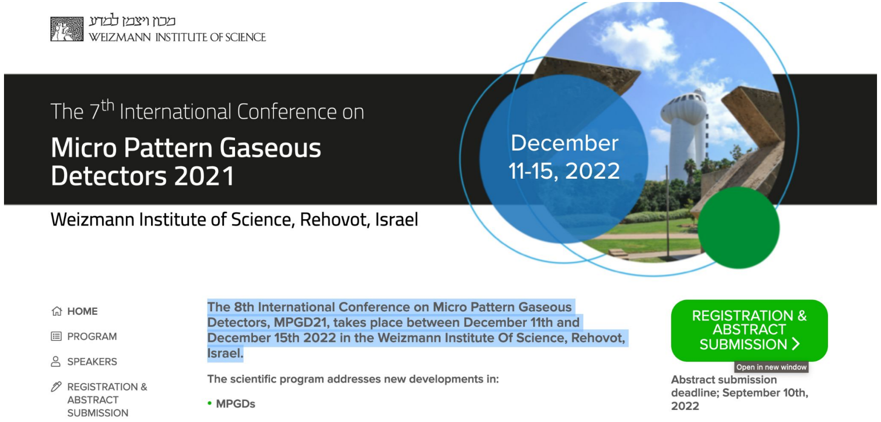
Summary and Conclusions

- Different local groups are using gas detector technologies in the HEP experiments in Brazil;
- Expertise and know-how can be combined finding synergy between groups;
- However, using the same technologies, there are different challenges between collider machines (high rate capability and high radiation damage) and cosmic ray experiments operating in different environments;
- There are opportunities for industrial applications in medical science and beyond.
- Recent presentations have covered this subject - refer to backup slides.

Conferences Opportunities



https://indico.cern.ch/event/1123140/



Backup slides

Contributions for gaseous detector applications during 2022 Workshop

- Research on Micro-Patterned Gaseous Detectors in Brazil
  - Tiago Fiorini Da Silva (USP and ALICE Experiment)
  - https://indico.cern.ch/event/1124802/contributions/4834531/

- Development of the Slow Controller of the RPC System Link for LS2 Update of the CMS/HL-LHC Experiment
  - Fabio Marujo (CBPF and CMS Experiment)
  - https://indico.cern.ch/event/1124802/contributions/4834540/

- ASICs and Front-end electronics development at USP
  - Marco Bregant (USP and ALICE Experiment)
  - https://indico.cern.ch/event/1124802/contributions/4834522/

- The MARTA Project in AugerPrime: RPCs to detect muons in the Pampa
  - Pedro Jorge Assis (LIP)
  - https://indico.cern.ch/event/1124802/contributions/4845652/

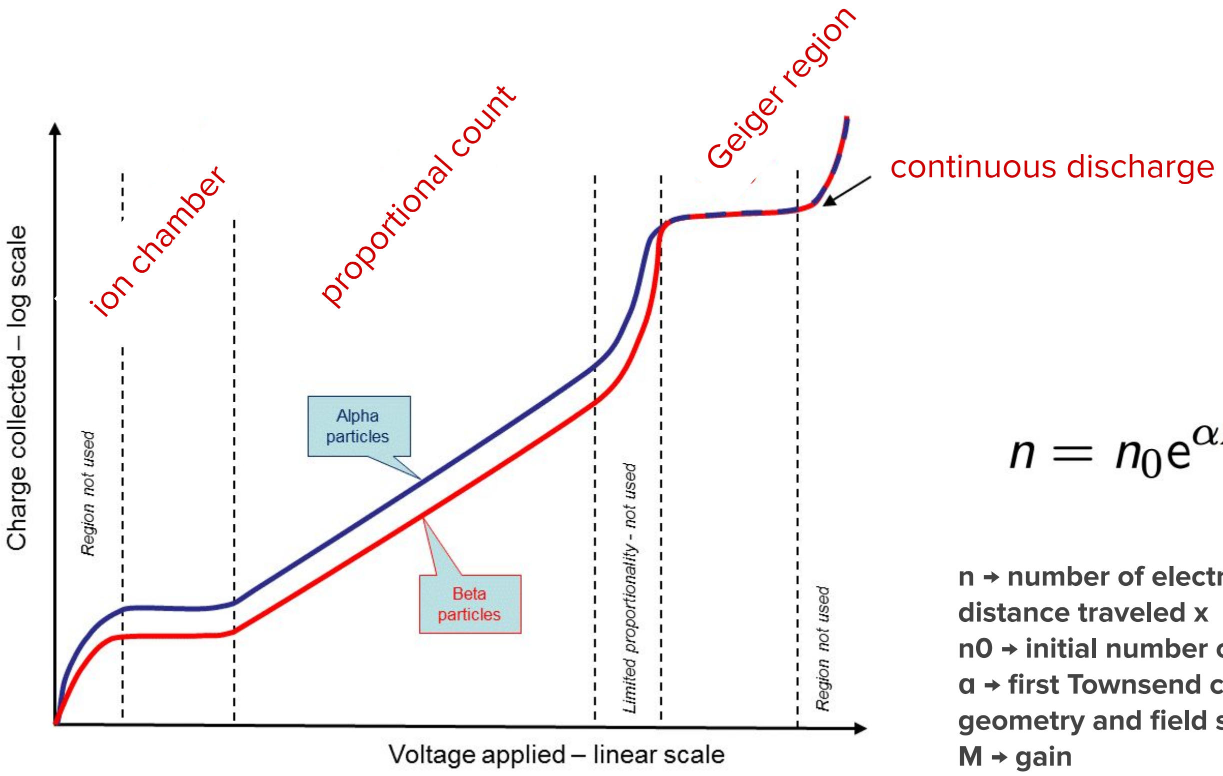
Contributions for gaseous detector applications during previous Workshop

- Brazilian Participation on the Resistive Plate Chambers (RPC) upgrade project of the CMS muon system
    - Sandro Fonseca de Souza (UERJ and CMS Experiment)
    - https://indico.ifsc.usp.br/event/6/contributions/851/attachments/28/60/UERJ_RPC_group_RENAFAE_2021_12_July_2021.pdf

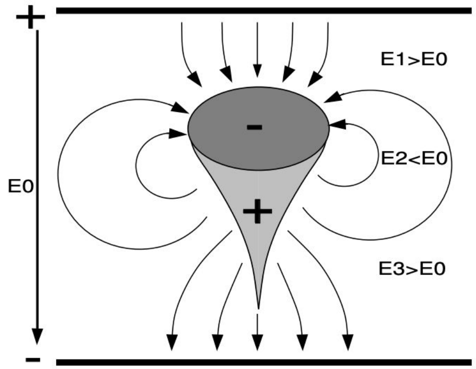
- Gas detector lab in view of present and future colliders
    - Felipe Silva (UEA and CMS Experiment)
    - https://indico.ifsc.usp.br/event/6/contributions/863/attachments/30/62/gas_lab_RENAFAE_workshop_12_07_2021.pdf

- Development of gas electron multiplier and its technological applications
    - Tiago Fiorini Da Silva (USP and ALICE Experiment)
    - https://indico.ifsc.usp.br/event/6/contributions/876/attachments/37/70/ID42%20Development%20of%20GEMs%20and%20its%20technological%20applications%20_public.pdf

Gas Ionization



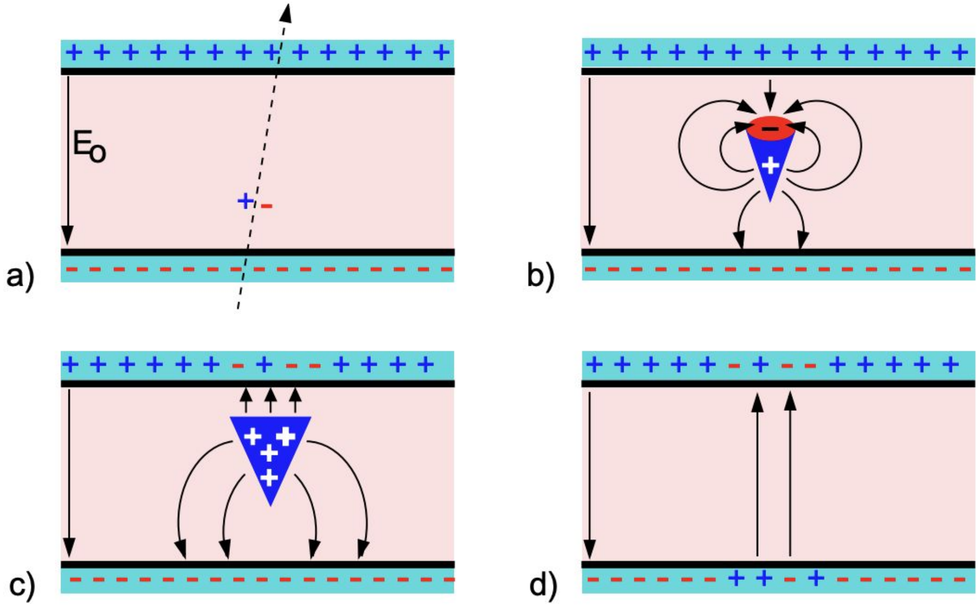
Load variation x applied voltage



$$n = n_0 e^{\alpha x} = n_0 \cdot M$$

n ➔ number of electrons produced as a function of distance traveled x
n0 ➔ initial number of electron avalanches
α ➔ first Townsend coefficient (depends on geometry and field strength)
M ➔ gain

Townsend Discharge



a) Some atoms are ionized by the passage of gas. An avalanche is started.

b) The avalanche is large enough to deform the electric field of the chamber.

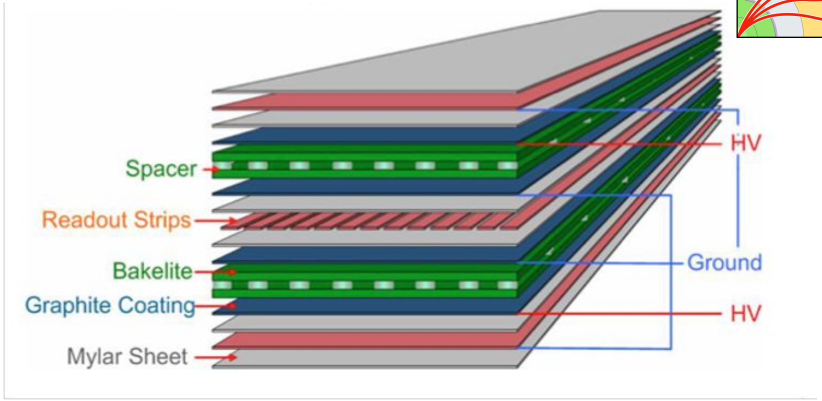
c) The electrons reach the anode. Ions move more slowly.

d) The ions arrive at the cathode. The excess load on the resistive plates influences the field locally, in the avalanche region.

The voltage source will even out the load distribution on the plates. **RPCs are capacitors**.

CMS Resistive Plate Chambers

- **CMS** RPC **present system**
- Double gap Bakelite RPC Chamber
  - ρ: 1-6 x 10^{10} Ω·cm
  - 2 mm gas width
- Coverage: |η| < 1.9
- 1056 chambers
  - 480 in Barrel (5 Wheels)
  - 576 in Endcap. (8 Disks)
- More than 110K electronic channels
- Rate capability: ~300 Hz/cm^2
- Intrinsic time resolution ~1.5 ns
  - Link boards only read during the LHC BX (25 ns)
  - Link System upgrade will enable CMS to use full RPC timing capability.



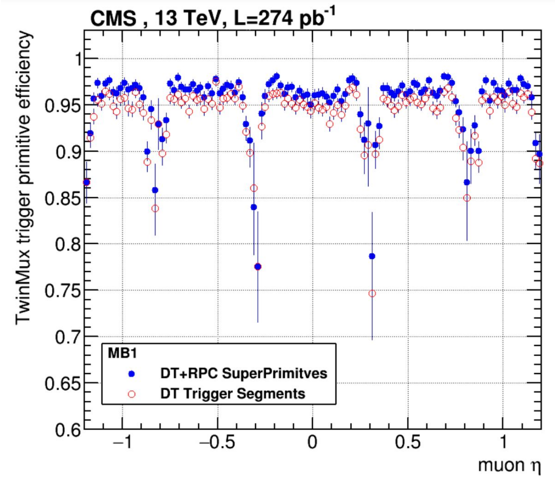
- Closed loop gas system:
  - Mixture: 95.2% $C_2H_2F_4$ **(Freon)**, 4.5% iC_4H_{10} **(Isobutane)**, 0.3%**(Sulphur Hexafluoride)** SF_6
  - Humidity: 40%
  - Replenishing rate: 10%

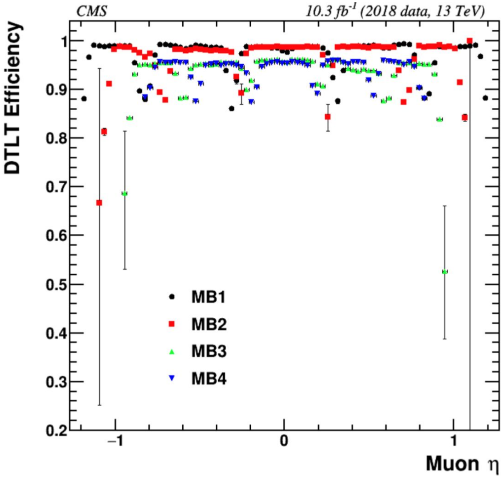
Due to its very good time resolution, the RPC is very important for CMS Trigger.

RPC Contribution to Muon Trigger

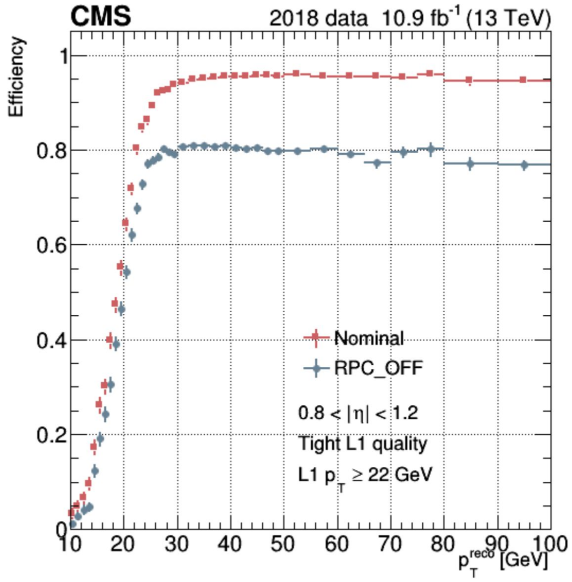
- The addition of RPC information to the DT segments increases the efficiency of the trigger primitives that will serve as input to the BMTF and OMTF.

- Also, RPC-only segments are built for stations MB1 and MB2 in case of DT segment absence. The efficiency for these stations are around 4% greater than stations MB3 and MB4.





- In the Overlap region, The RPC system plays a key role there as it provides 8 measurements for muon trajectory reconstruction. The muon trigger efficiency is increased in about 15%



HL-LHC: Muon requirements

1. Detector electronics must be upgraded

- to handle high particles rates and to deal with longer latency

2. longevity : aging electronic parts need to be replaced

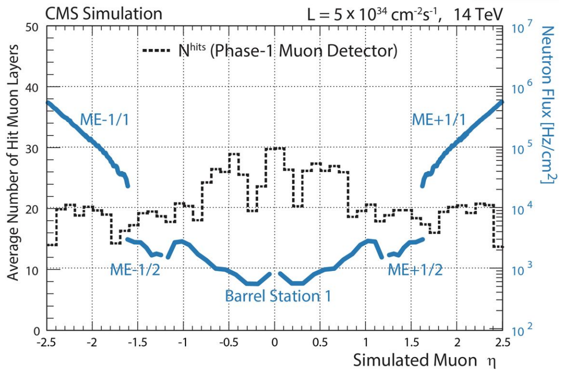
- while detector life expectancy (related to radiation damage) is more than acceptable

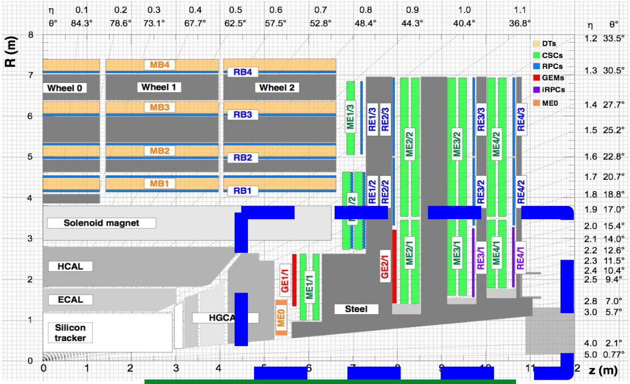
3. event reconstruction capabilities (trigger and offline) require, particularly in forward region:

- to enhance redundancy (increase # of measurements with good spatial and time resolution), to solve track reconstruction ambiguities.

4. extended acceptance

- to complement the wider tracking and calorimeter coverage and to reduce physics backgrounds from "lost leptons"

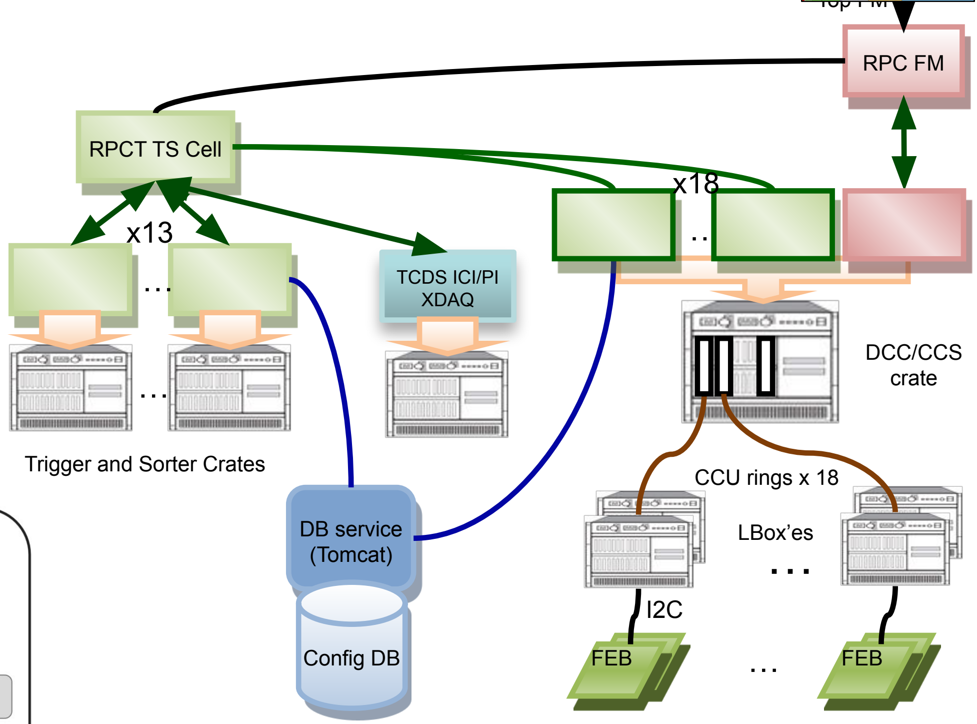


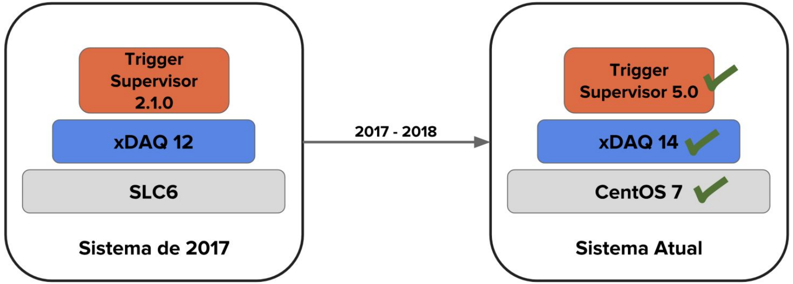


Anna Collaleo presented in ICHEP 2018

Online Software and R&D for Phase 2 Upgrade

- Trigger Supervisor is the framework for the RPC Online Software.
- Control and monitoring the RPC system (trigger, daq, configuration).
- **Maintenance and upgrade by UERJ-Rio group.**

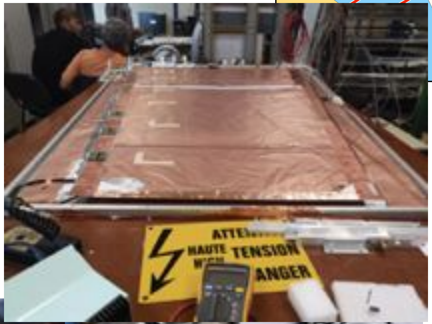


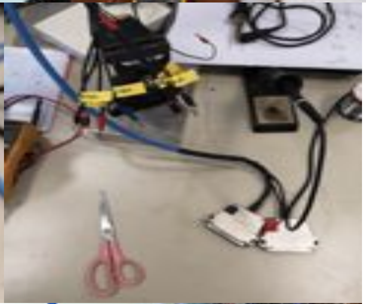


Participation in the assembly of the iRPCs

electronic instrumentation at iRPCs (KODEL and ROMAN)

- LV cables, converters, flat cables, patch panel, resistors solder SMDs
- test chamber mounting





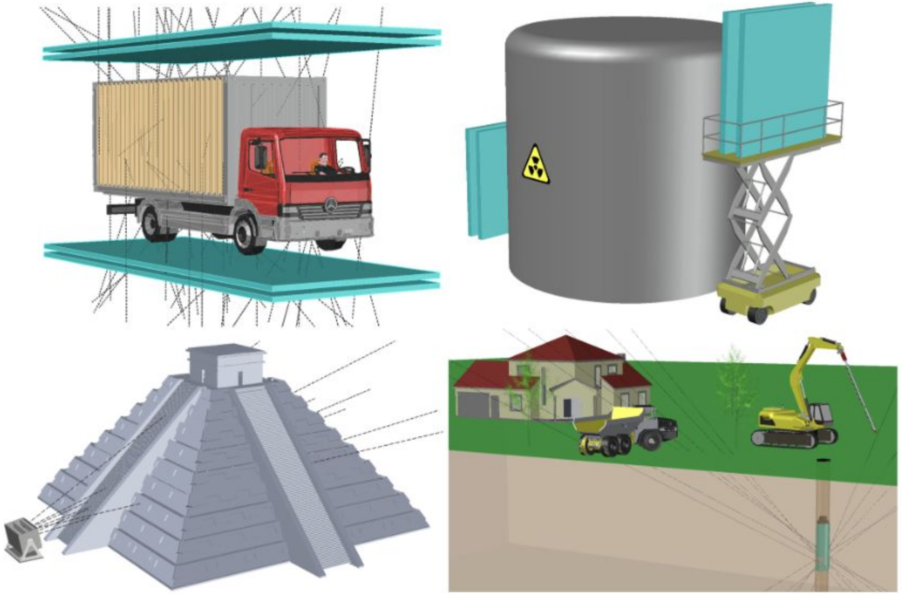
Fabio Marujo (CBPF)

Felipe Silva (UEA)

Eliza Melo (UERJ)

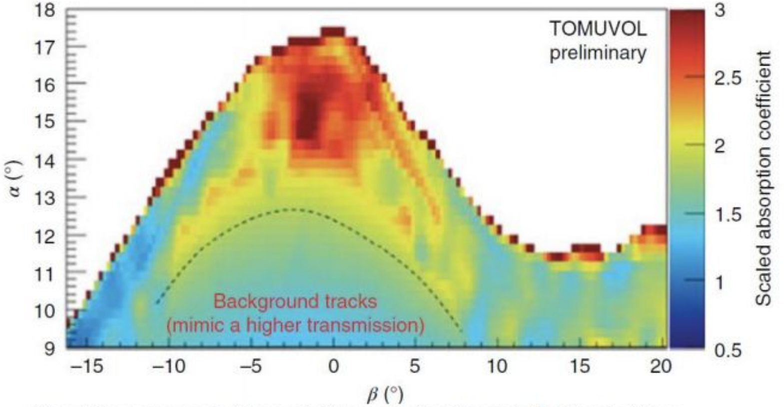
Helio Nogima (UERJ)

RPC Applications: Muon Tomograph



Muon Tomography

- RPC can be used to scan buildings, trucks, tanks and other structures.
- The deflection and absorption of cosmic muons is used to reconstruct images.



Map of the muon scaled transmission coefficient through the Puy de Dôme