NELSON MANDELA UNIVERSITY

The 3rd African Conference on Fundamental and Applied Physics

25 – 29 September 2023

Venue: Protea by Marriot Hotel King George, George, South Africa

Large Detector Systems in Particle Physics Experiments & the Role Africa Will Play in Detector Technologies of the Future

Kondo Gnanvo

Jefferson Lab, Newport News, Virginia 23606, USA

3rd African Conference on Fundamental and Applied Physics

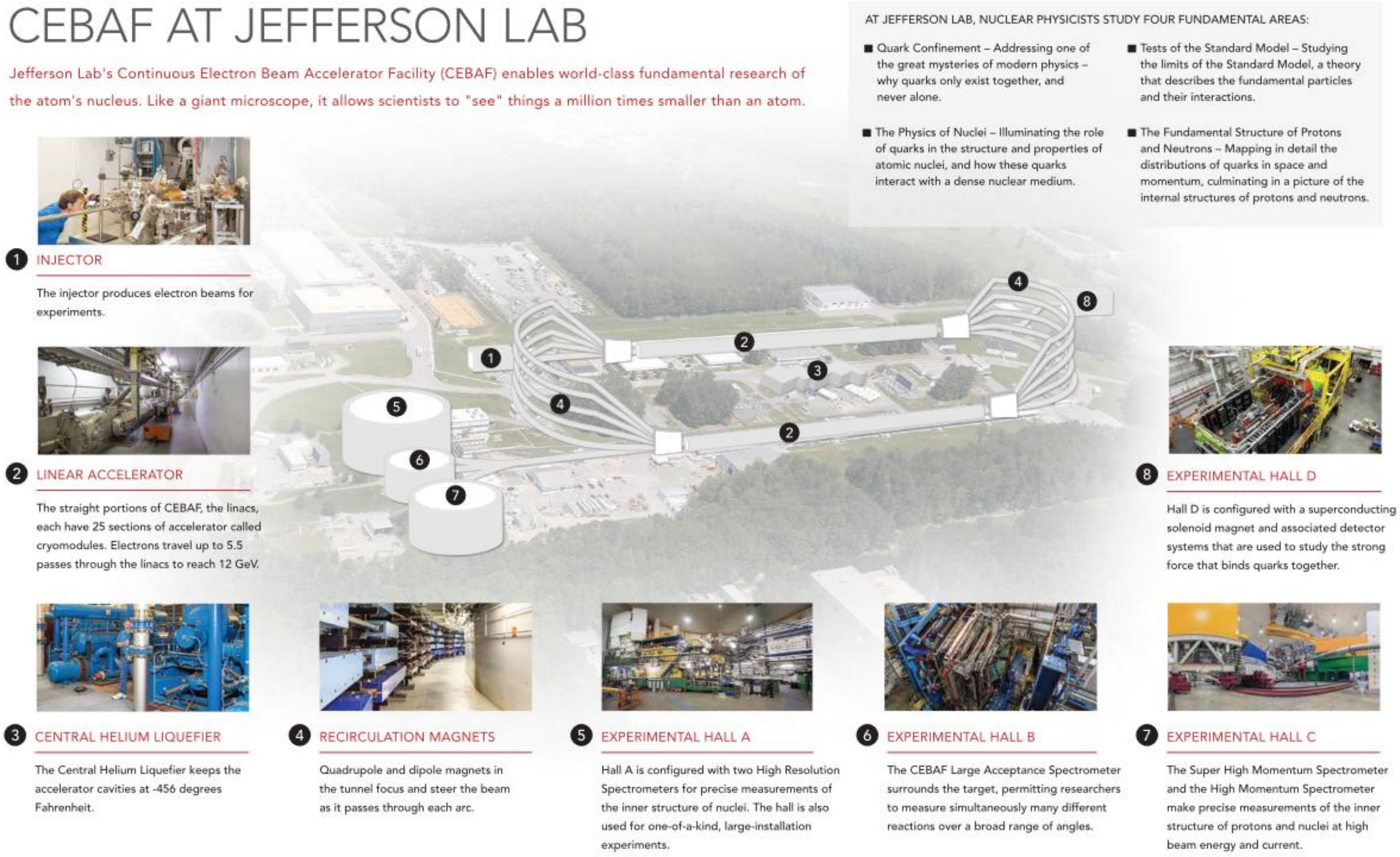
25-29 September 2023

George, South Africa

Outline

- ❖ Large Detector System in Particle Physics Experiments
- ❖ Overview of Micro Pattern Gaseous Detectors (MPGDs)
- ❖ Some Personal Opinions on Detector Development in Africa

Introduction to Jefferson Lab



Jefferson Lab is partner of BNL for the Electron Ion Collider and specially playing a leadership role in many aspect of EIC detector subsystems

JLab's Radiation Detector & Imaging Group:

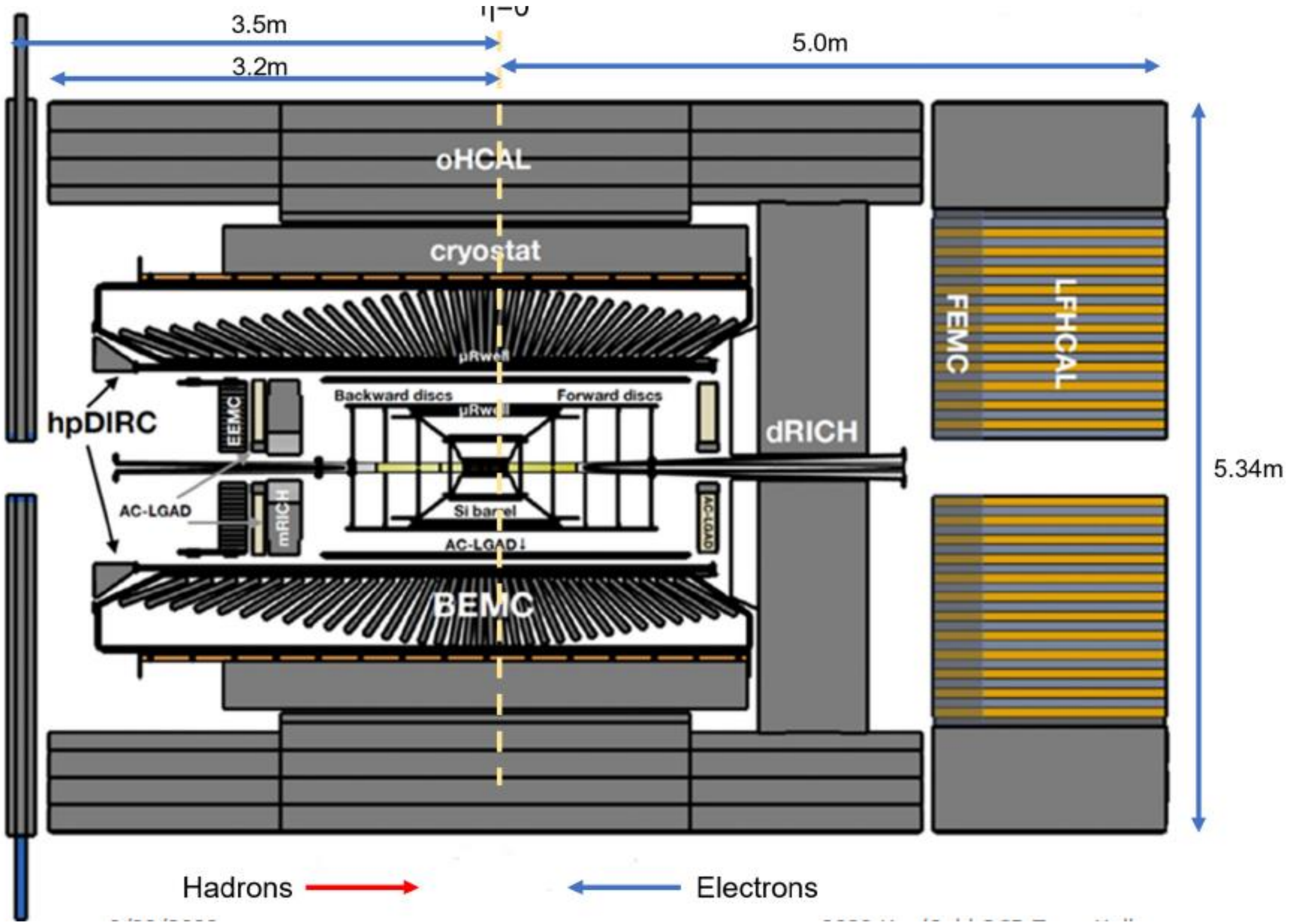
Explore new methods and technologies in supporting detector development for the experimental nuclear physics program at Jefferson Lab.

The Group also seeks opportunities to apply its resources to more immediate societal needs

Jefferson Lab

Example of Detector in Particle Physics Experiments

ePIC: The Electron Ion Collider (EIC) Detector



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

- hpDIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

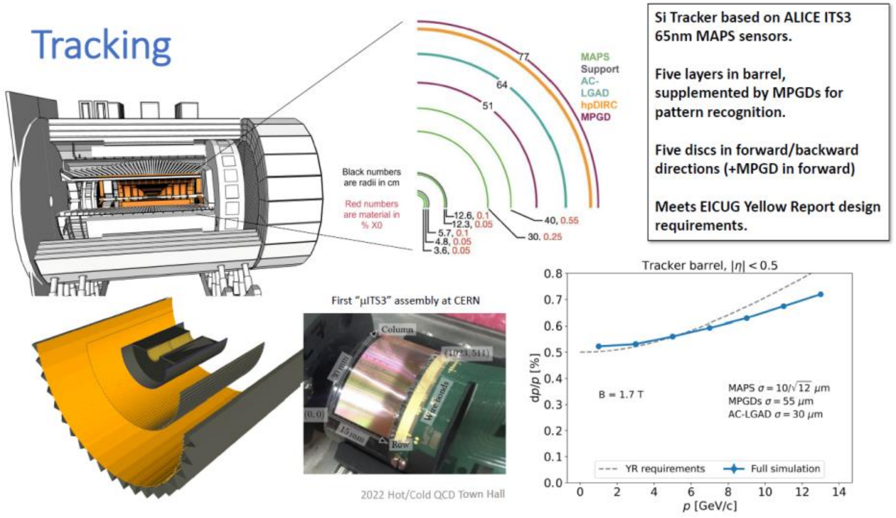
Calorimetry:

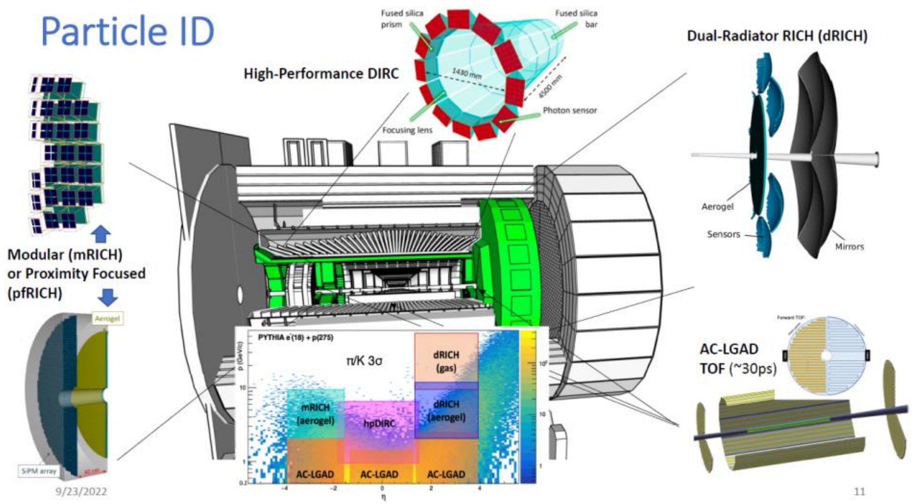
- SciGlass/Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)

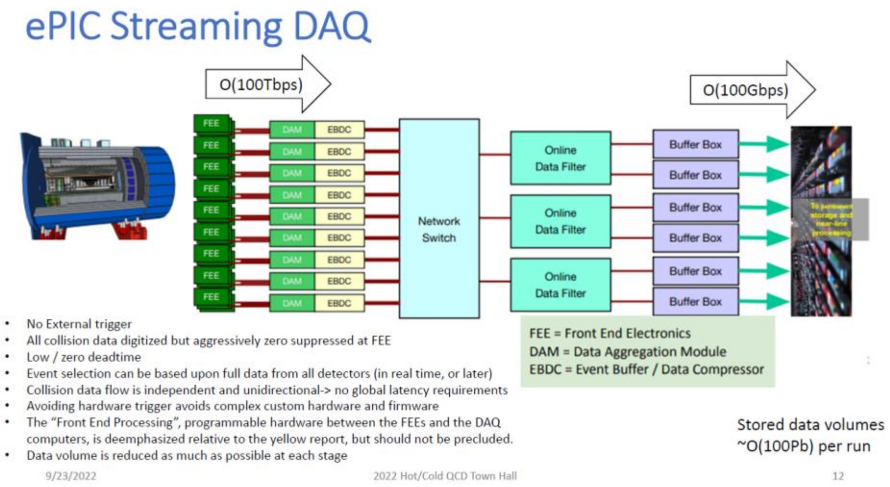
ePIC Detector Subsystems

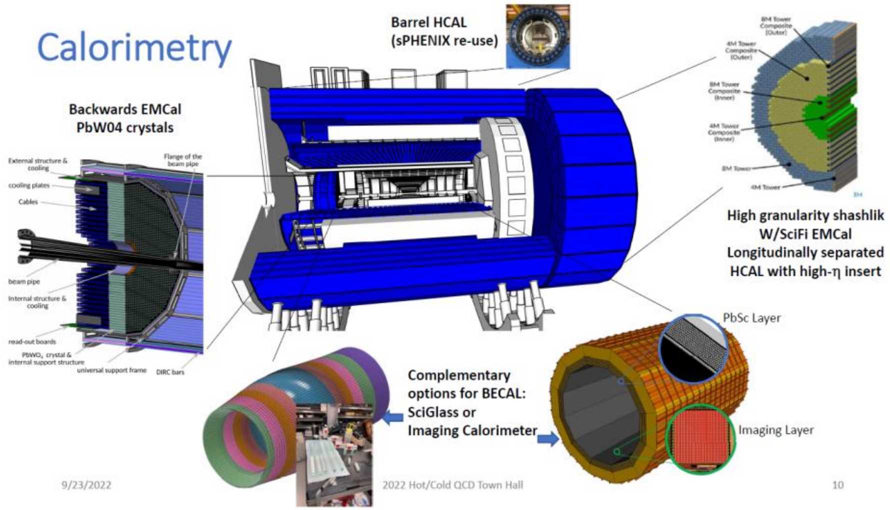
ePIC Detector:

- **Subsystems**: Tracking, PID, Calorimetry, Forward and Backward Detectors…
- **Each subsystem**: different detector technologies i.e (Silicon, MPGDs for tracking, Time Of Flight, Cerenkov for PID …







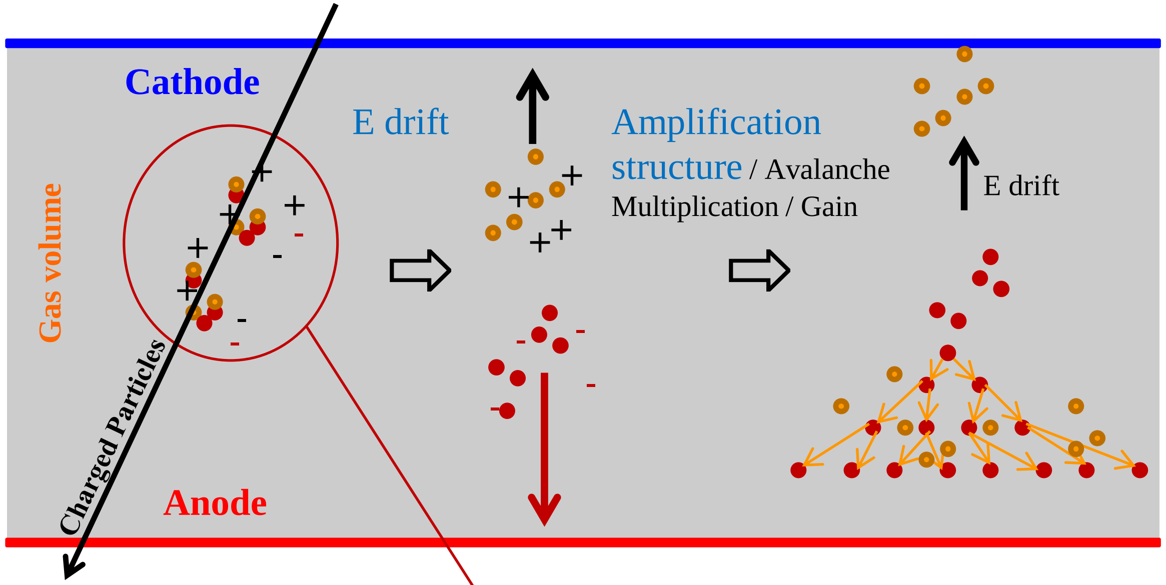


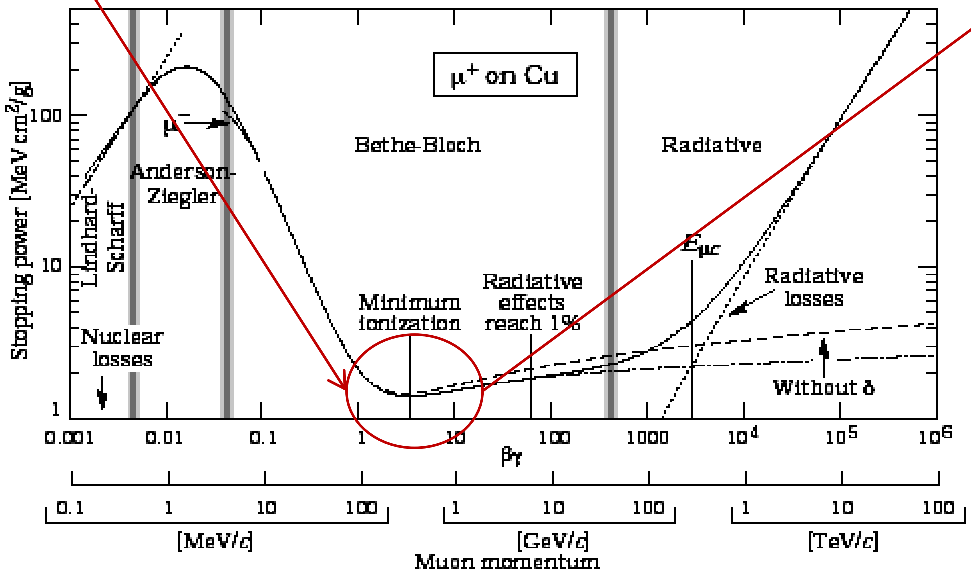
Other systems

- Muon Detectors like in LHC experiments ,,,

Micro Pattern Gaseous Detectors

Basic Principle of Gaseous Detectors in Particle Physics





Energy loss to electromagnetic interaction: MIP ≈ 2 MeV / cm^2

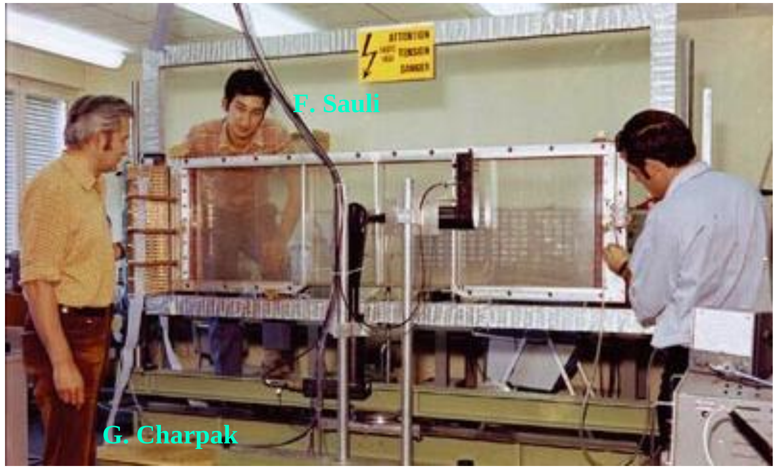
$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

où

- $\beta = v/c$
- v vitesse de la particule
- E énergie de la particule
- x longueur du chemin
- c vitesse de la lumière
- $z\,e$ charge de la particule
- e charge élémentaire
- m_e masse au repos de l'électron
- n densité numérique des électrons du matériau
- I potentiel d'excitation moyen du matériau

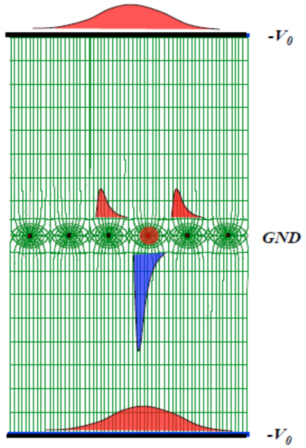
Evolution of Gaseous Trackers: From Wires to Micro Holes

Multi Wire Proportional Chambers (MWPCs) - Charpak; Nobel Prize 1992

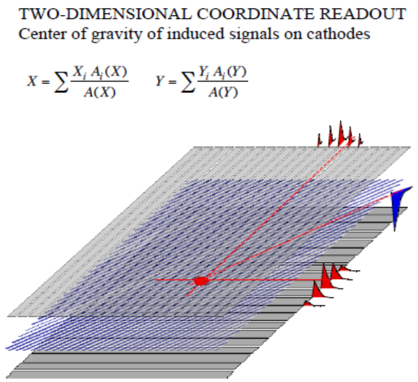


Performances of MWPCs:

- Fast Position Sensitive Devices
- **"High"** rate, Sub mm position accuracy
- Drift chambers as a variation of MWPCs



G. Charpak et al, Nucl. Instr. and Meth. 62(1968)235



G. Charpak and F. Sauli, Nucl. Instr. and Methods 113(1973)381

Limitation of MWPCs

- **Limited multi-track separation:** mechanical instabilities due to electrostatic repulsion - critical length of about 25 cm for 10µm wires and 1mm spacing
- **Fast gain drop at high fluxes:** field-distorting space charge accumulation due to the long time taken by the ions to clear the region of multiplication
- **Aging:** permanent damage of the structures after long exposure to radiation

Development of Micro Pattern Gaseous Detectors (MPGDs)

- Overcome rate limitation of the MWPCs ⇨ fast ions evacuation allow higher rate capabilityes
- Semiconductor technology**: Photolithography, Etching, Lift-off, Coating, Doping, …**

Pioneer: Micro Strip Gaseous Counter (MSGCs) [Oed (1988)] :

- Cathode strips and anode strips on the same substrate
- pitch ~ 100 µm ⇨ Excellent spatial and high rate capability
- But high discharge rate ⇨ impossible to operate in real experiment

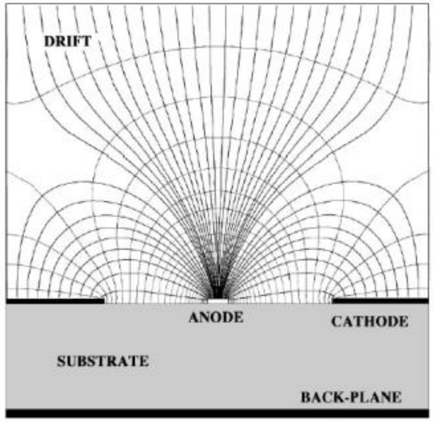
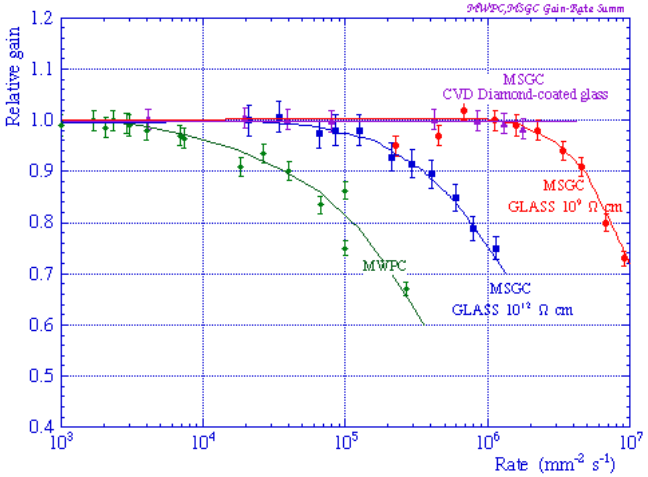


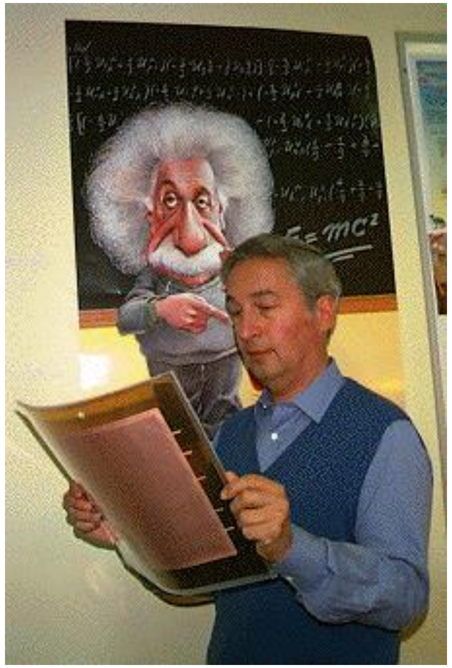
Figure 2 Equipotentials and field lines in the microstrip chamber, computed close to the substrate. The back-plane potential has been selected to prevent field lines entering the dielectric.



GEM – Gas Electron Multipliers

- Thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm^2
- Voltage of ~ 350 V across the Cu electrode creates a strong field in the hole leading to amplification
- The ionization pattern is preserved by design with the E field focusing the charges inside the holes
- **UNIQUE FEATURE:** Charge amplification is decoupled from the charge collection

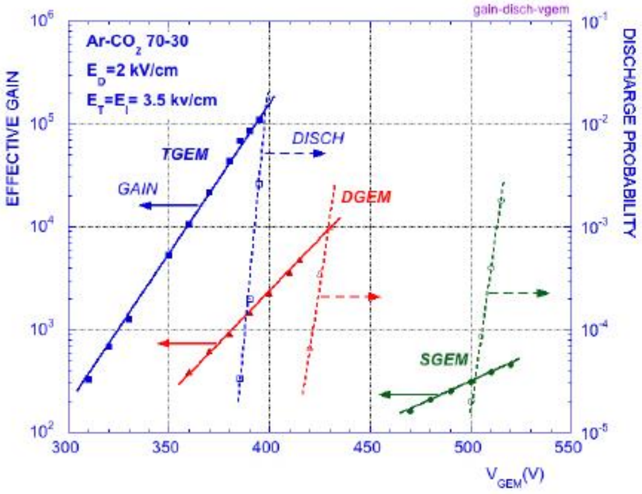
⇨ **Allow multi-stage amplification**



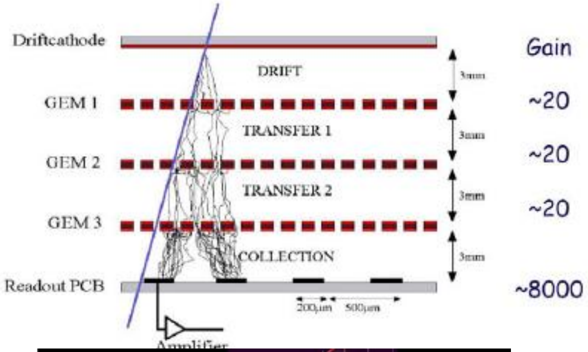
F. Sauli, NIMA A386 (1997) 531

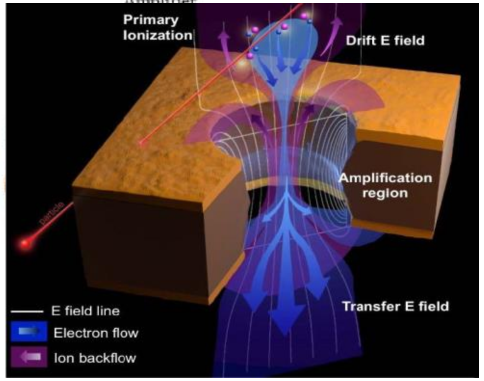
Discharge Probability on Exposure to 5 MeV Alphas

Multiple structures provide equal gain at lower voltage.
Discharge probability on exposure to α particles is strongly reduced.

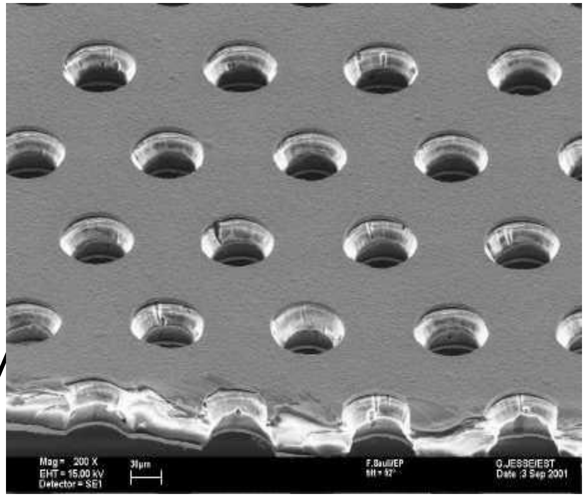


S. Bachmann et al Nucl. Instr. and Meth. A479(2002)294

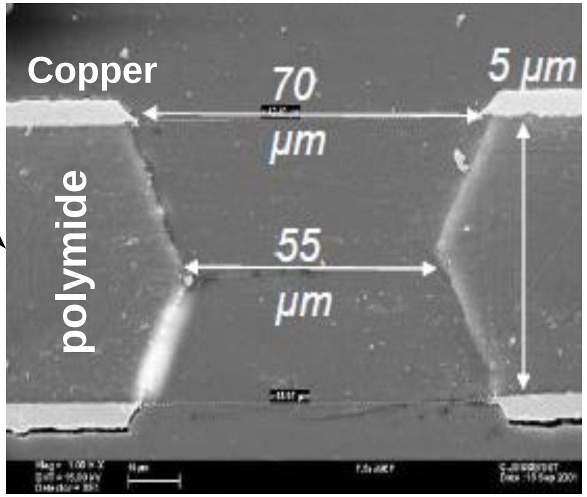




SEM picture of a GEM foil



Zoom view of a GEM hole

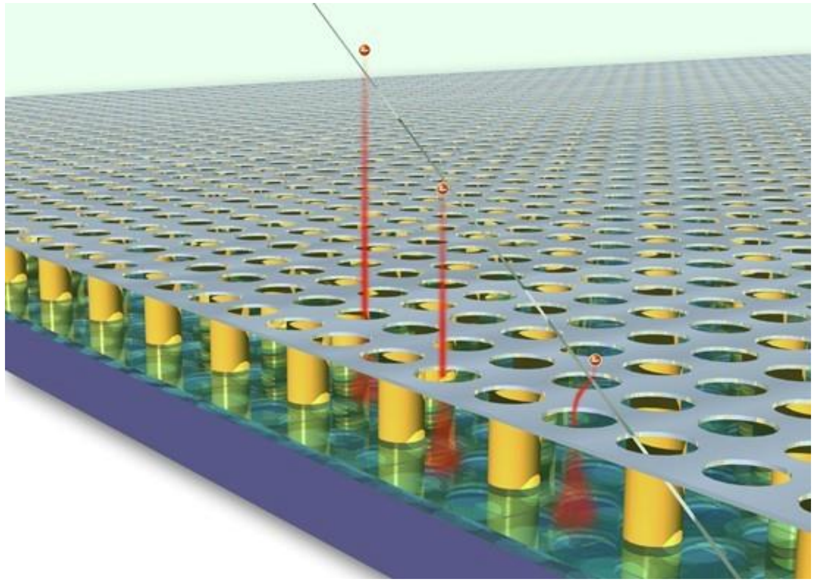


Micromegas - Micro Mesh Gaseous Structures

⇨ Two-stage parallel-plate avalanche chamber of small amplification gap

❖ Fine structure metallic mesh as amplification device

❖ Amplification in the (~100 µm) gap between the mesh and the anode

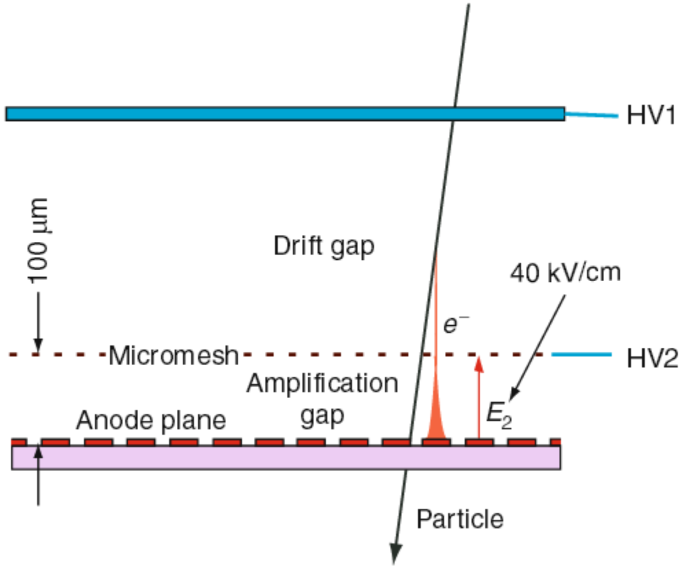


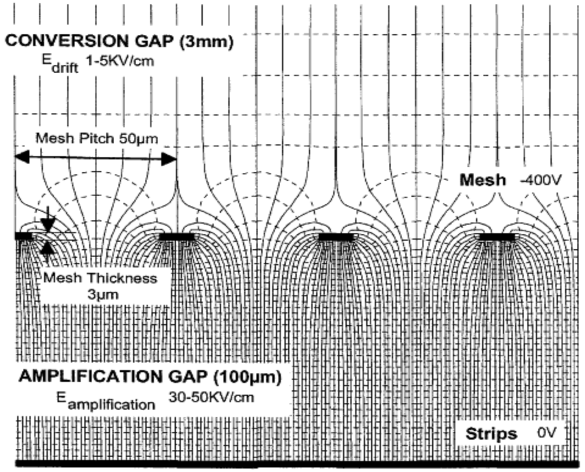
Small gap, high field:

⇨ fast movement of positive ions that are mostly collected on the mesh

⇨ small space-charge accumulation and very fast signals

⇨ Resistive Micromegas to reduce sark rate and energy

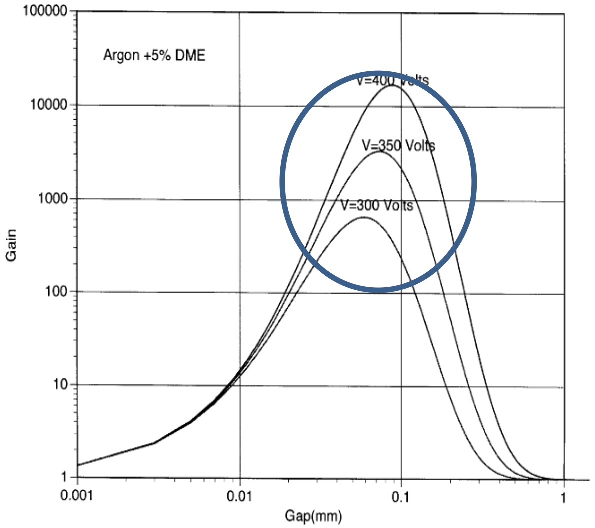




Y. Giomataris, Nucl. Instr. and Meth. A419 (1998)

⇨ Gap around 100 µm: small gap variations compensated by an inverse variation of amplification factor

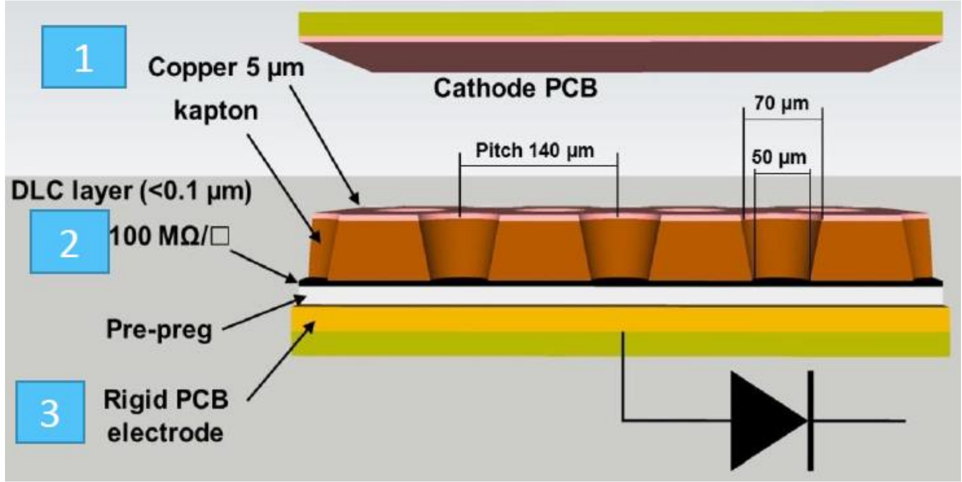
⇨ i.e. good uniformity and stability of response over a large area.



μRWELL – Resistive Micro Well Detectors

The μRWELL PCB is realized by coupling:

1. "Suitable WELL patterned Kapton foil as "amplification stage"
2. "Resistive stage" for discharge suppression & current evacuation:
   i. "Low rate" (LR) << 100 kHz/cm^2: single resistive layer (~100 MΩ/□)
   ii. "High rate" (HR) >> 100 kHz/cm^2: more sophisticated resistive scheme
3. a standard readout PCB with strip or pad readout



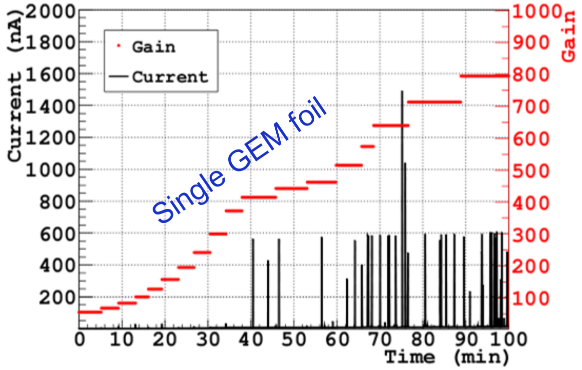


Figure 9. Monitoring of the current drawn (in black) by the single-GEM detector for different gas gain (in red). Discharge amplitudes as high as 1μA are recorded at higher gains.

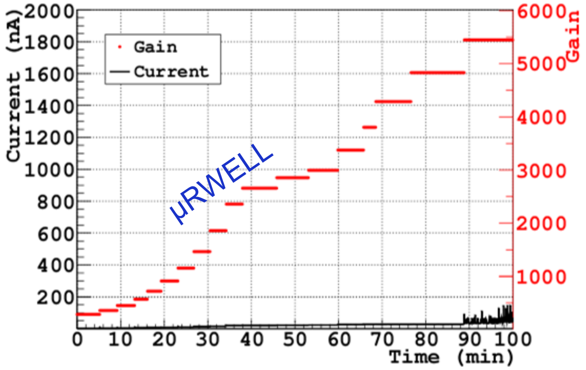
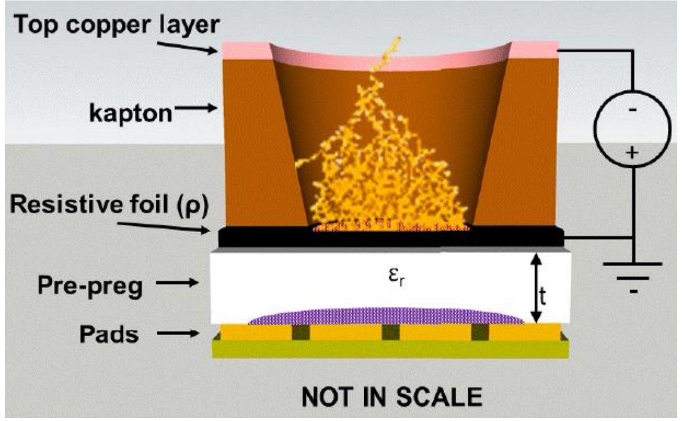


Figure 10. Monitoring of the current drawn (in black) by the μ-RWELL detector for different gas gain (in red). Discharges are quenched down to few tens of nA even at high gains.

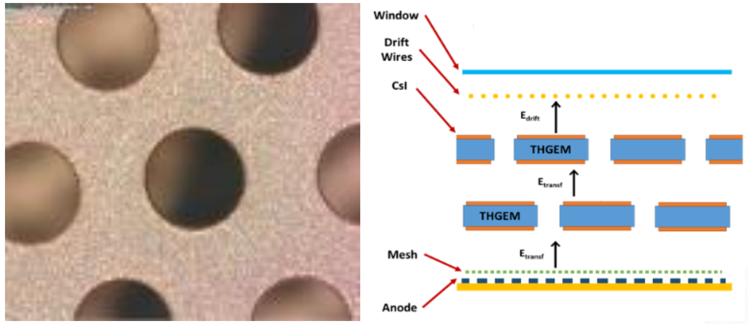


G. Bencivenni et al.; 2015_JINST_10_P02008

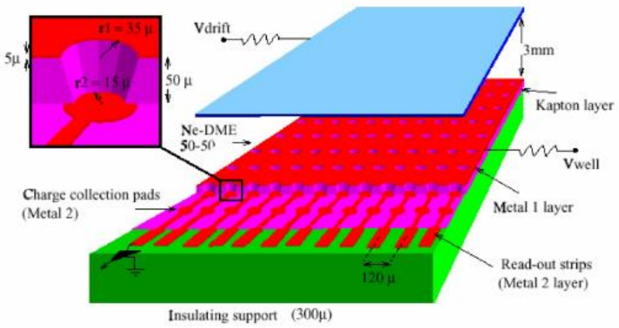
- **Like Micromegas ⇨ Single amplification stage, no stretch**
- **Like GEM ⇨ Same amplification device structure**

Rich Family of MPGD technologies

Thick GEM (THGEMs)

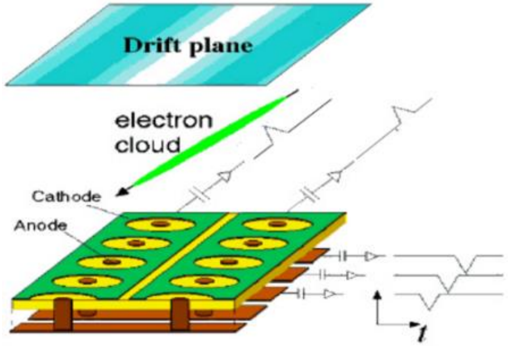


MicroWELL



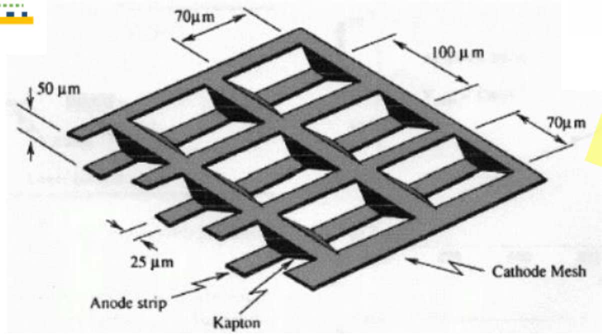
R. Bellazzini, NIMA 423 (1999) 125

μ-PIC



Ochi et al NIMA 471 (2001) 264

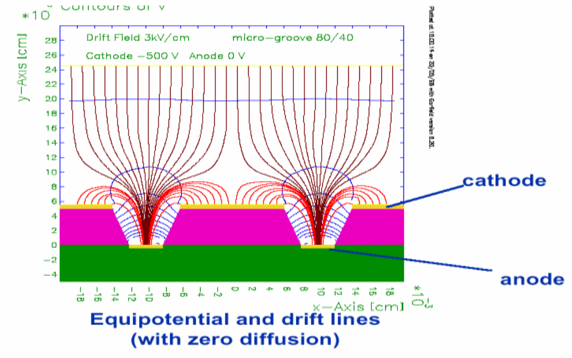
Micro Wire Chamber



B. Adeva et al., NIMA 435 (1999) 402

… and so many others

Micro Groove



R. Bellazzini , NIMA 424 (1999) 444

MicroDot

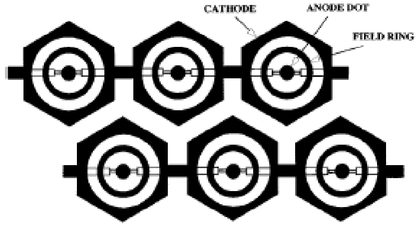


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

Biagi SF, Jones TJ. NIM A361:72 (1995)

Micro Gap Chambers

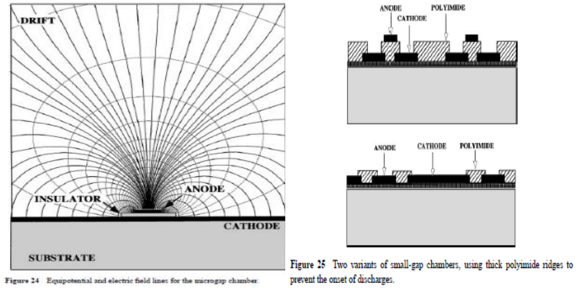


Figure 24 Equipotential and electric field lines for the microgap chamber.

Figure 25 Two variants of small-gap chambers, using thick polyimide ridges to prevent the onset of discharges.

Angelini F., NIMA 335:69 (1993)

Micro Gap Wire Chamber

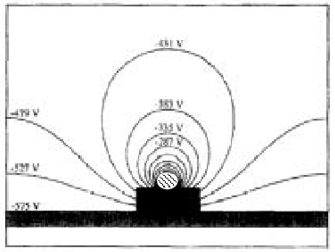


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

NIMA 398 (1997) 195

MPGDs in HEP experiments – Examples @ LHC

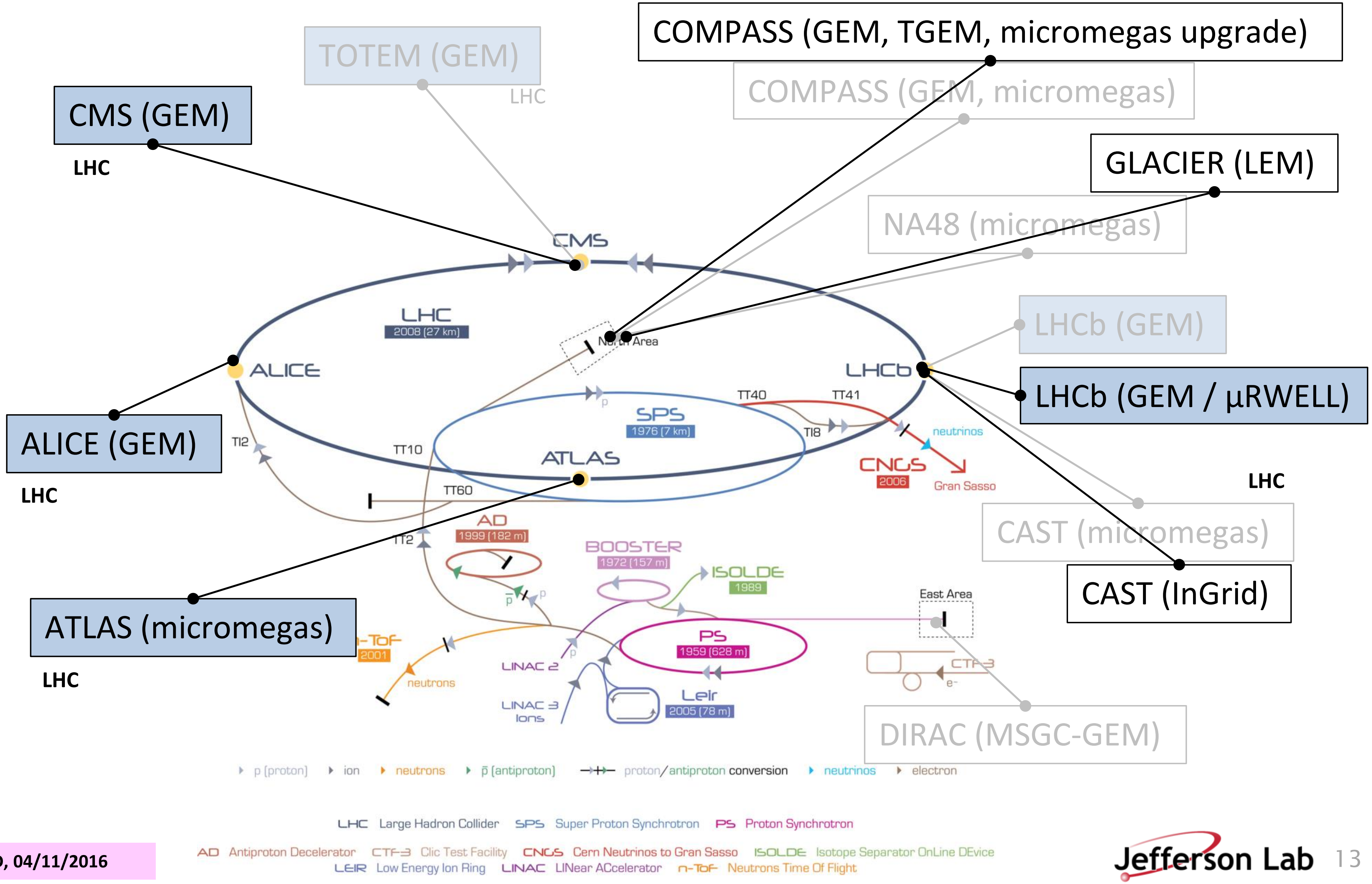
HL-LHC upgrade

- ATLAS NSW– Micromegas
- CMS Muon chambers – GEM
- ALICE TPC - GEM readout
- LHCb – GEM / µRWELL

But also:

COMPASS – GEM

CAST – Micromegas …



E. Oliveri, PH Detector Seminar – MPGD, 04/11/2016

MPGDs in NP Experiments – Examples @ Jefferson Lab

Hall A:

- ❖ SoLID GEM
- ❖ Super BigBite – GEM
- ❖ MOLLER – GEM

HALL B:

- ❖ CLAS12 - Cyl Micromegas (central tracker) µRWELL (forward Tracker update
- ❖ BoNUS - GEM

…

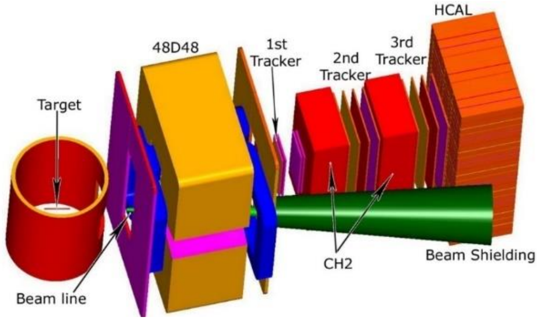
GEMs for Super Bigbite Spectrometer (SBS) in Hall A

SBS physics program

- ➢ **GEP** : 12 (GeV/c)^2
- ➢ GMN: 13.5 (GeV/c)^2
- ➢ GEN: 10 (GeV/c)^2
- ➢ SSA in nSIDIS: 30,000 gain vs HERMES

================================

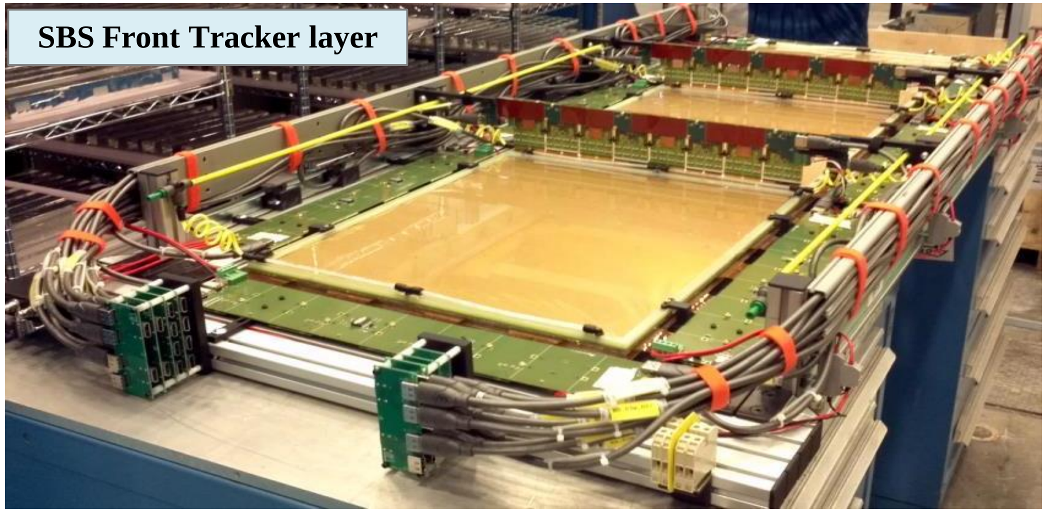
- ➢ **A1n**/d2n – gain ~ 20-30 compared with HMS/SHMS
- ➢ TDIS meson DIS
- ➢ WACS-ALL, full proposal, 100x gain in productivity
- ➢ GEnRP, ready for full proposal,10+x gain in productivity
- ➢ pol H(γ,φ p), H(γ,π° p)
- ➢ PVDIS – gain 10-15 compared with two HRSs
- ➢ A1p/d2p – gain ~20-30
- ➢ D(e,e'd) - A,T20
- ➢ J/Psi as gluon probe of QCD – well matched to BB/SBS
- ➢ A(e,e'p), A(e,e'π$^{+/-}$)



Front Tracker (FT): Track of the recoil protons 6 GEM layers

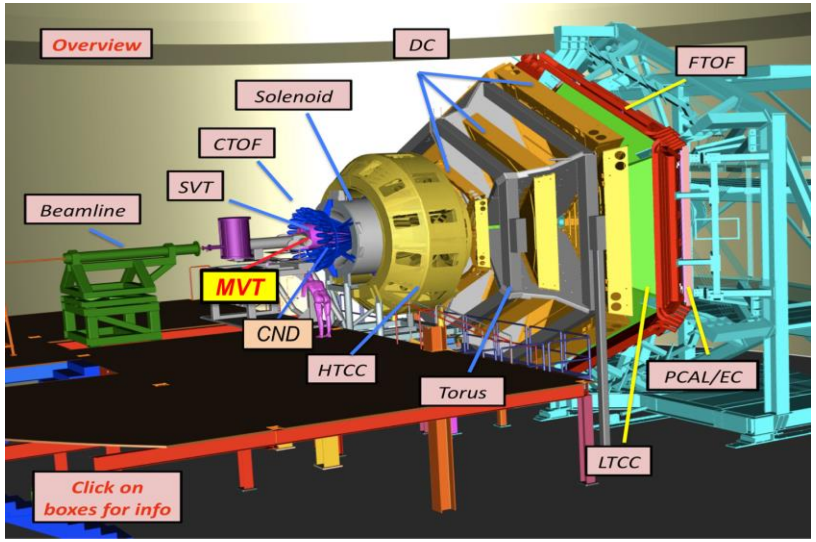
Back Tracker (BT): Polarimetry of the recoil protons 10 layers

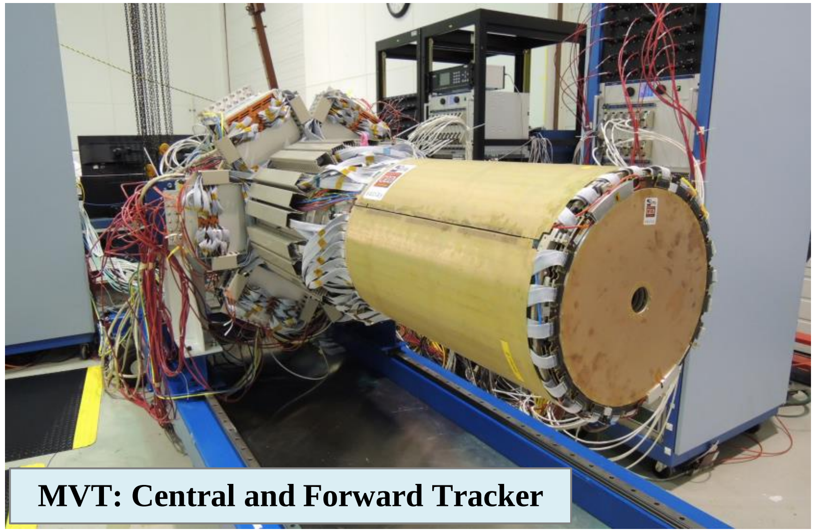
Total production of ~ 60 large GEM modules



SBS Front Tracker layer

Micromegas for CLAS12 (Hall B, JLab)





MVT: Central and Forward Tracker

Past experiments: BoNUS, PRad in the past

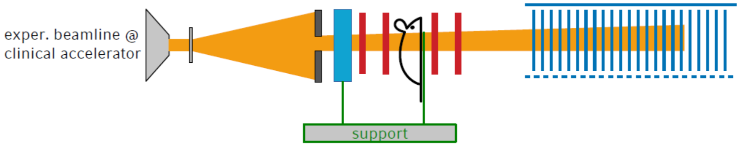
Future Experiments: SoLID, MOLLER, TDIS, BoNUS12, DarkLIGHT …

MPGDs outside HEP / NP – Medical Applications

Micromegas for Ion Computed Tomography

Ion Computed Tomography for Small Animals

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN



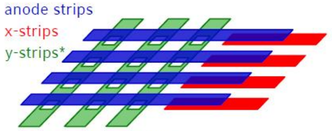
imaging concept: spatial information from 2d floating strip Micromegas trackers
residual range (→ energy loss) from TPC with vertical absorbers
reference to treatment beam from 2d strip ionization chamber

boundary conditions: 75MeV be
minimum
range reso
field of vie

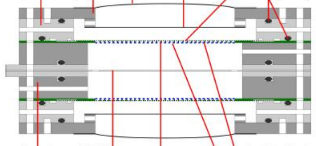
Floating Strip Micromegas Doublets: Ultra-Low Material Budget

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

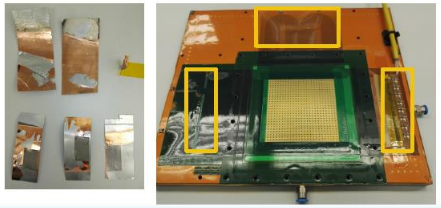
- two detectors back-to-back → 80mm distance
- flexible readout structures: overpressure stabilized
- 9µm Al anode & y-strips on 32µm Kapton & glue
  → x-readout strips outside active area



*: pattern inspired by F. Klitzner



status of aluminum detectors
- design completed
- in-house process porting from Cu to Al
  - etching (to be improved)
  - metallization (optimization ongoing)
- to be tested: robustness
- waiting for SRS VMM

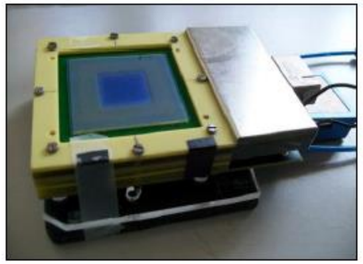


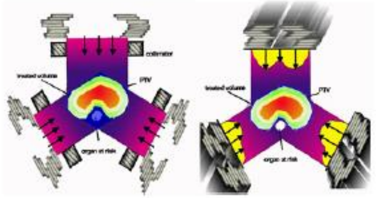
May 8, 2019 Jona Bortfeldt - MPGD Development for Ion Computed Tomography 13

https://indico.cern.ch/event/757322/contributions/3402727/attachments/1840414/3017725/bortfeldt_190508.pdf

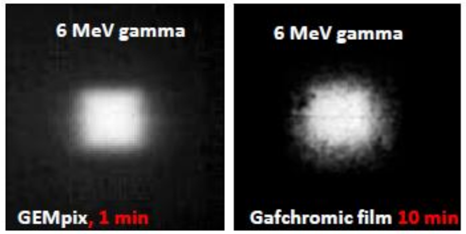
GEMPix detector for Hadrontherapy application

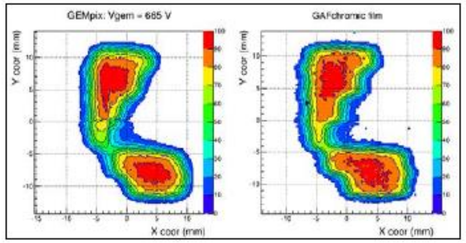
GEMPix detector (8cm² GEM detector read by 55x55µm pixels, 262 000 channels)
- 2D measurements of energy released in IMRT (Policlinico Tor Vergata Roma)





Intensity Modulated Radiation Therapy (IMRT)





F. Murtas , G. Claps, D. Falco
CERN, INFN, PTV

An optimal agreement between GEMPix and gafchromic film is obtained
Real-time measurements with GEMPix allows fast Quality Assurance procedure

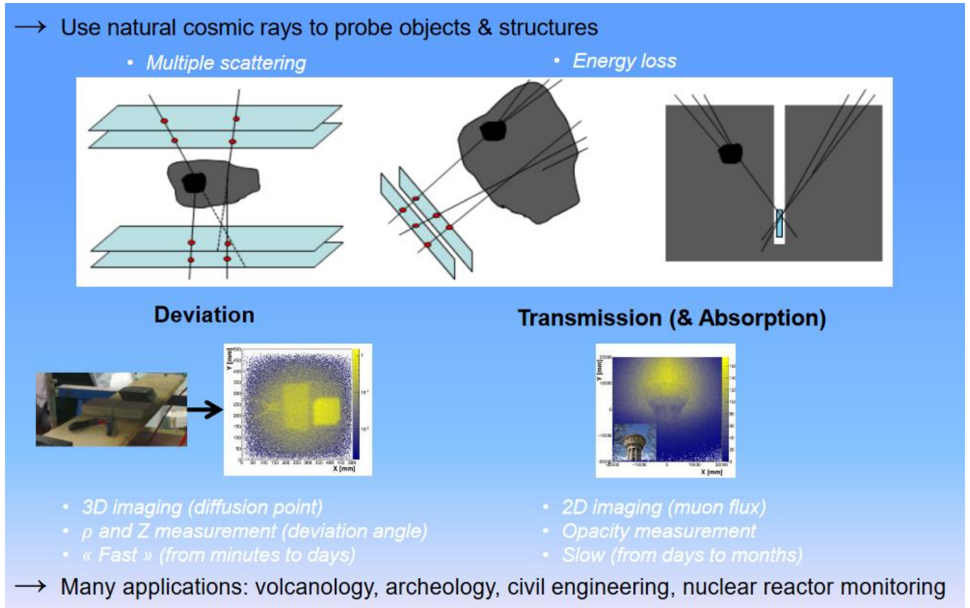
https://indico.cern.ch/event/392209/contributions/1828216/attachments/1291499/1923737/4_Fabrizio_Murtas.pdf

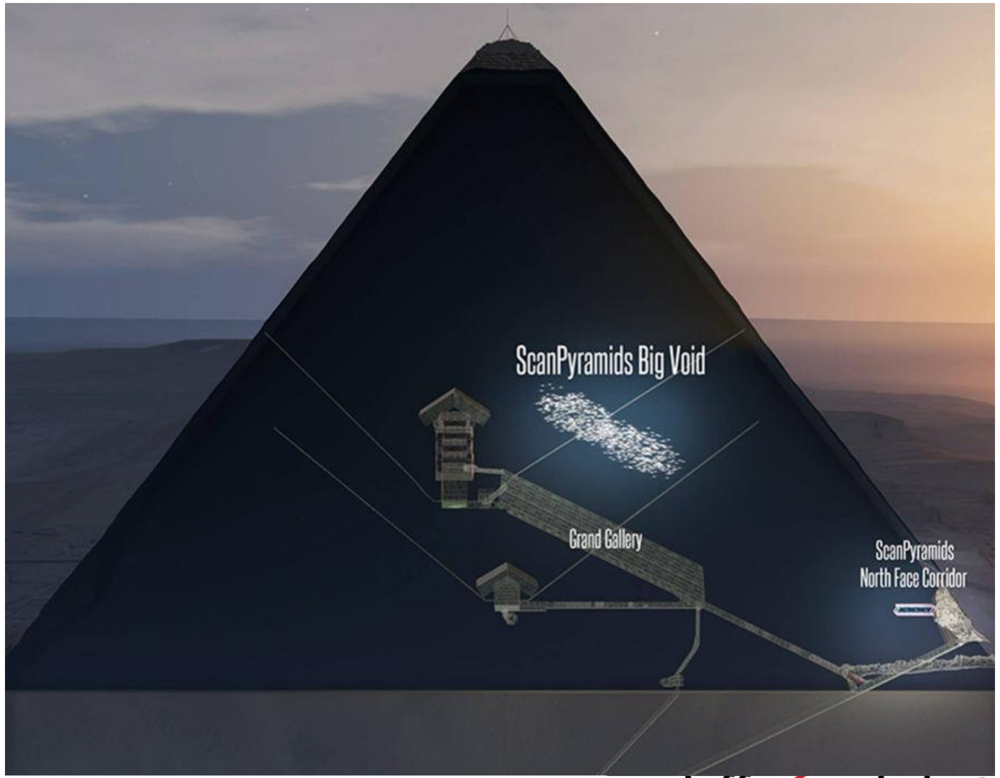
From wikipedia

The **ScanPyramids**[1] mission is an Egyptian-International project designed and led by Cairo University and the French HIP Institute (Heritage Innovation Preservation).[2] This project aims at scanning Old Kingdom Egyptian Pyramids (Khufu, Khafre, the Bent and the Red) to detect the presence of unknown internal voids and structures.[3]

The project, launched in October 2015,[4] combines several non-invasive and non-destructive techniques which may help to get a better understanding of their structure and their construction processes and techniques.[*clarification needed*] The team is currently using Infrared thermography, muon tomography, 3D simulation and reconstruction techniques.[5][6]

th Micromegas





Muography / Muon Tomography:

- ❖ Imaging of large structures such as pyramids based on cosmic ray muon scattering or transmission

S. Procureur , https://doi.org/10.1016/j.nima.2017.08.004

Some personal opinions

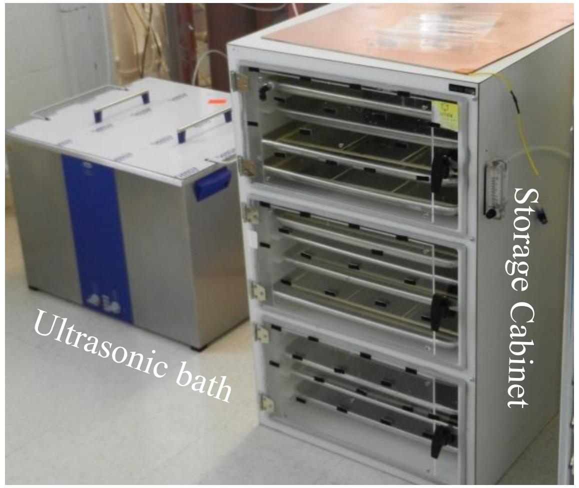
How do you get an MPGD detector in hand

- You can not purchase a GEM or Micromegas or µRWELL module from a commercial vendor
- These technologies don’t have firm application outside the particle physics community to actract the interest of companies
- You will have to fabricate your device your self (in your detector lab)
- All examples I showed are detectors assembled in clean room in Universities detector labs or in HEP / NP labs like CERN, JLab, BNL or CEA Saclay …
- This provide another path to institutions to contribute to large scale particle physics experiments (besides Physics analysis / Simulation studies
- Detector R&D should be part of African institutions strategies to participate in international collaboration (ASFAP, ASP …)

What do you need for an MPGD Development Lab

Class 1000 Clean Room and dedicated equipment for the assembly of MPGD detectors

- ❖ Mechanical stretching device
- ❖ HV Test N2 Gas box
- ❖ Picoammeter
- ❖ Ultrasonic bath
- ❖ Wiener MPOD High Voltage



Detector Test lab

- ❖ Characterization of the detectors after assembly
- ❖ R&D on new structures or technologies

Typically, you will need

- ❖ cosmic telescope stand
- ❖ Sources (^{55}Fe, ^{90}Sr …)
- ❖ Multichannel readout system

And enthusiast army detector physicists

- ❖ Master / Grad students
- ❖ Ph D / Post doctoral students
- ❖ Senior scientists to supervise the actibities

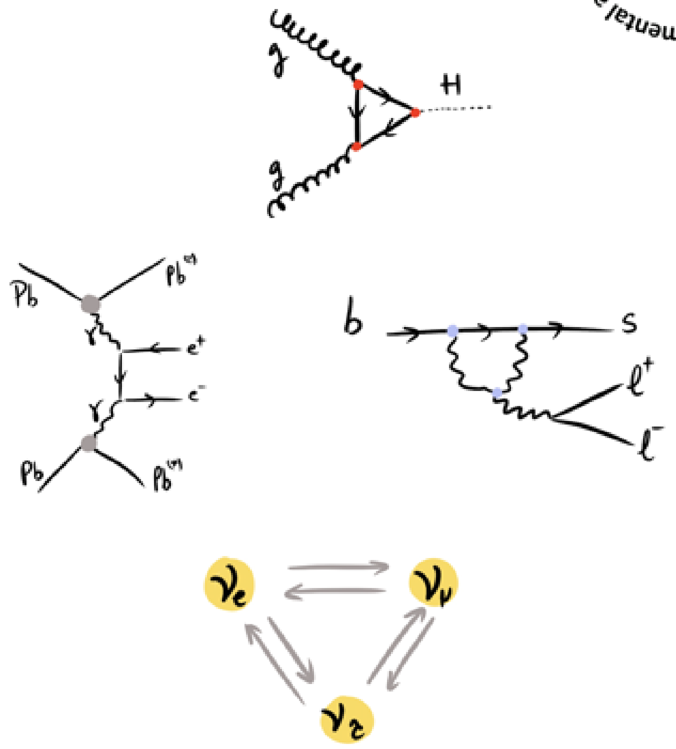
How is this relevant for Africa

- I think Detector Physics and Detector Development (R&D) … are valued in the conversation when we are talking about sciences and Physics in for Africa
- It is crucial to train young African students on the detector technologies they will be confronted to in HEP / NP experiments that they going to participate in
- Detector technologies open the door to skills and opportunities beyond the narrow scope of academia and particle physics.
  - Many of detectors we used in these experiments also find application in other field i.e. medical instrumentation
- This should fit in the SubWG IV “Infrastructure” of ASFAP program (See M. Chabab talk)
  - I am interest in get the discussion going started with the conveeners of this WG and integrate this field of particle physucs in the LRP of the ASFAP

In ASFAP Framework!

Subgroups:

- **subWG I "Fundamental constituents & forces" :**
  - Higgs physics.
  - Electroweak and BSM physics.
  - Direct searches.
- **subWG II "Symmetries and composite structures":**
  - Flavour physics, CP violation.
  - Strong interaction, hadron physics, heavy ions.
  - Indirect searches.
  - nEDM.
- **subWG III "Light messengers" :**
  - Neutrino Physics : neutrino parameters, CP violation, BSM.
- **subWG IV "Infrastructures"**
  - Detector R&D
  - Detector Development Lab
  - Test beam facilities?
  - Training and outreach programs



Community Outreach & Education

Telescope program by Beninese diaspora in the US

Commission Think Tank

Project Proposal Sheet

Title: Benin Celestial Observatory

Synopsis: The main goal of the project is to promote science and technology by encouraging the general public and students experience and become familiar with science tools with a focus on space science. The project includes three phases detailed below.

Phase 1 (2021–2022) – Planet Viewing Stations

- *Objective*: Enable the general public to view celestial objects such as the Moon and planets in the solar system.
- *Description*: Providing basic telescope(s) for good viewing resolution of the Moon and planets (e.g., rings of Saturn)
- *Partnerships:*
  For ease of management, the initial pilot phase is done in collaboration with local organizations to house and manage the telescopes:
  - Fondation Zinsou's mini-bibliotheques,
  - Fondation Vallet's Bibliotheques Excellence
  - Municipalities (e.g. Abomey-Calavi, Bohicon, Porto-Novo, Parakou, Natitingou, Djougou, Lokossa, Malanville, etc.)
- *Pilot Project*: Start with 2 telescopes in a pilot project to be implemented in Benin
  Cost:
  Telescopes : $800 x 2 = $1600
  Shipping to Benin: TBD
- *Timing*: Start date: TBD End date: TBD
- *Funding strategy*
  - Voluntary contribution from AOEE members and board for the pilot phase
  - Data collection and evaluation of the pilot project
  - Apply for funding to expand the scope and location the project.

Future phases

Phase 2 (2022–2023) – Cosmic Radiation Viewing

- Objective: Enable viewing of cosmic radiations
- Project: Provide detectors to existing telescopes for display and visualization of cosmic radiations (~$150/detector + shipping to COO)

Phase 3 (2030–2035) – A Professional Observatory

- Objective: Create a professional observatory
- Project: Provide advanced telescopes for the scientific community (astronomers and physicists) in Benin (cost and POP are TBD).

Motion: Commission Think Tank propose the adoption and implementation of this proposal as an AOEE project.

Summary

- ❖ Detector development & Detector R&D are crucial ingredient of any large-scale particle physics experiments
- ❖ Many of the detectors used in these experiment are cutting edge technologies requiring innovative approach to address the challenges imposed by ever ambitious physics programs
- ❖ African University and institutions should invest in the detector R&D infrastructures and activities and gives opportunity to youn generation to play their part in this field of physics
- ❖ It is exciting to build your customized detector and make it work later in your experiment
- ❖ ASFAP has a role to play a leadership role to bring this field into the framework of activities that it is aiming at promoting.
- ❖ We all have to contribute to succeed in this area