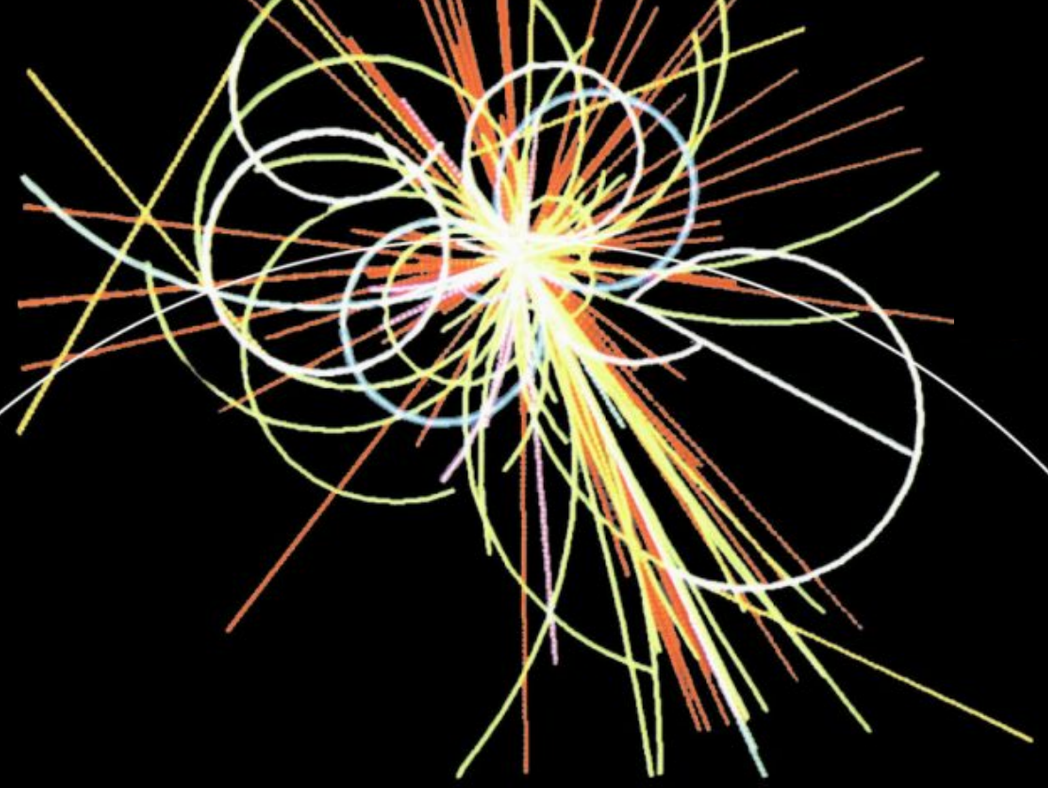
Frontier Detectors for Frontier Physics

15th Pisa meeting on advanced detectors

La Biodola • Isola d'Elba • Italy
22 - 28 May, 2022



Poster Review: Gaseous Detectors

Beatrice Mandelli (CERN)
Maxim Titov (CEA)

Poster review: intro

40 posters in the gaseous detector session

Wire chambers (8 posters)

TPC (3 posters)

MPGD (17 posters)

RPC (6 posters)

Gases (6 posters)

ECFA Roadmap for Gaseous Detectors

DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs) & DETECTOR COMMUNITY THEMES (DCTs)

		< 2030	2030-2035	2035-2040	2040-2045	> 2045
Gaseous	**DRDT 1.1** Improve time and spatial resolution for gaseous detectors with long-term stability					
	DRDT 1.2 Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes					
	DRDT 1.3 Develop environmentally friendly gaseous detectors for very large areas with high-rate capability					
	DRDT 1.4 Achieve high sensitivity in both low and high-pressure TPCs					

time and spatial resolution

high sensitivity in TPC

long-term stability

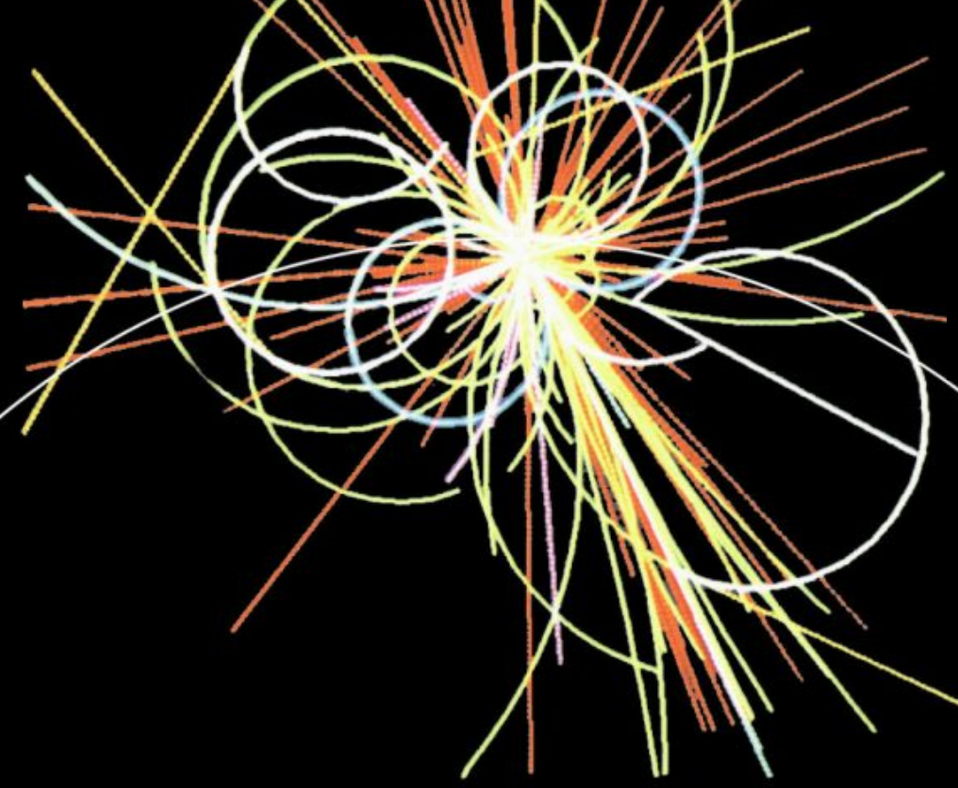
dE/dx and dN/dx

eco-friendly gas mixtures

● Must happen of main physics goals cannot be met

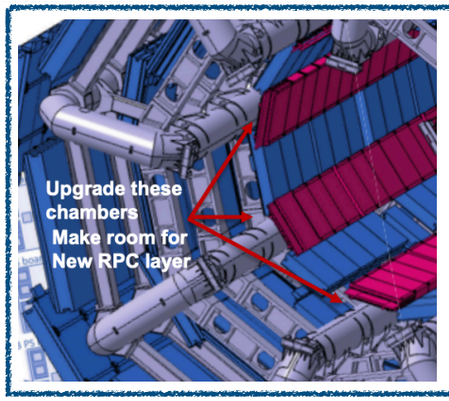
From Ian Shipsey's talk on Monday

Drift chambers



- ATLAS upgrade: new sMDT
- CMS upgrade: new electronics
- MEG: wire investigation and gas monitoring system
- IDEA: cluster counting technique, simulation and test-beam
- CMD-3: ultra low mass drift chamber

sMDT Construction and Testing for HL-LHC

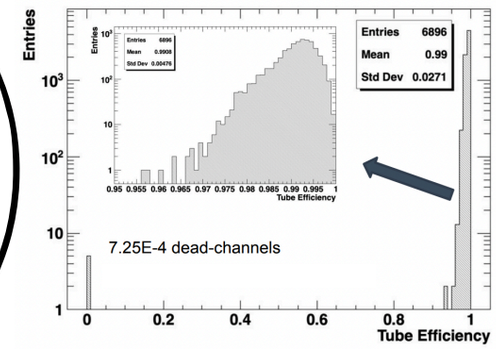


The ATLAS muon spectrometer sMDT upgrade will use smaller radius drift tubes to make room for a new RPC layer for muon triggering.

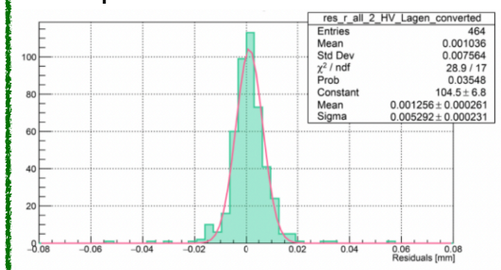
55 of 96 chambers have been constructed at MPI Munich and the University of Michigan. The upgrade will include 46080 new drift tubes.

Results from cosmic-ray test: each tube is on average **99% efficient**.

Less than 1E-3 tubes have wire removed for various issues (wire snap, etc.).



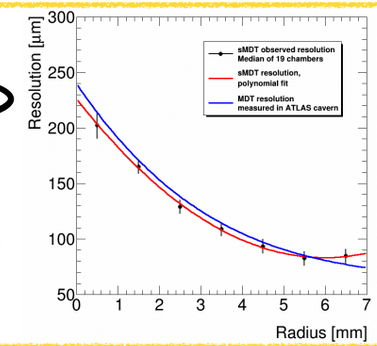
Wire position is measured to within $\pm 10\mu m$.



Observed (expected) single-hit resolution is **102.9±8.1μm (106 μm)**.

Results are consistent with ATLAS Run 2 MDT resolution.

Includes a Geant4 estimate of the multiple Coulomb scattering correction.



Kevin Nelson (University of Michigan),
on behalf of the ATLAS Muon Collaboration

Pisa Meeting on Advanced Detectors
May 22-28, 2022

ATLAS EXPERIMENT

- 46080 new sMDTs

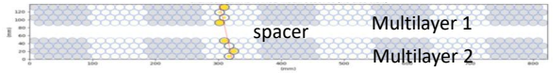
- new ASD for sMDT
- high spatial resolution

Rate capability of small-diameter Muon Drift Tube precision tracking chambers with new fast readout electronics for HL-LHC and Future Hadron Colliders

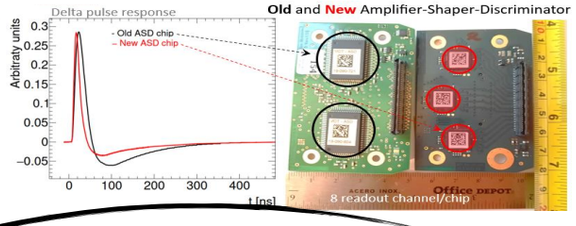
D. Cieri[1], G. Eberwein[1], O. Kortner[1], H. Kroha[1], E.Voevodina[1] - elena.voevodina@cern.ch
[1] Max-Planck-Institute for Physics, Munich (Germany)

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

The new small-diameter Monitored Drift Tube (sMDT) detectors with 15 mm tube diameter have proven to be excellent candidates for precision muon tracking detectors in experiments at future hadron colliders like HL-LHC and FCC-hh where unprecedentedly high background rate capabilities are required.



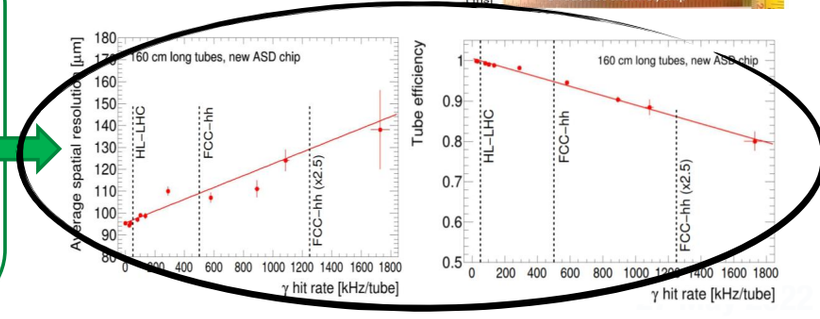
The rate capability of the sMDT drift tubes in terms of muon detection efficiency and spatial resolution is limited by the performance of the readout electronics. At the Max-Planck Institute in Munich, a new sMDT Amplifier-Shaper Discriminator (ASD) readout chip for use at the HL-LHC and future hadron colliders with a faster peaking time compared to the old chip has been developed, reducing the discriminator threshold crossing time jitter and thus improving the time- and spatial resolution with and without γ-background radiation.



Extensive tests using sMDT test chamber have been performed at the CERN Gamma Irradiation Facility (GIF++). Detector equipped with new readout chips with improved pulse shaping and discrete readout circuits with baseline restoring functionality have been tested:

→ We have shown that sMDT precision muon tracking detectors with new readout electronics are well suited to operate with the high spatial resolution and muon detection efficiencies up to the highest background rates expected at future hadron collider experiments.

→ We have demonstrated that faster signal shaping improves the spatial resolution and muon detection efficiency of sMDT drift tubes at the high γ background radiation.



- *Upgrade of electronics*
- *Slice test installed in LS2*

The Phase 2 upgrade of CMS Drift Tube Detector for High Luminosity LHC

Archana Sharma on behalf of CMS Muon collaboration

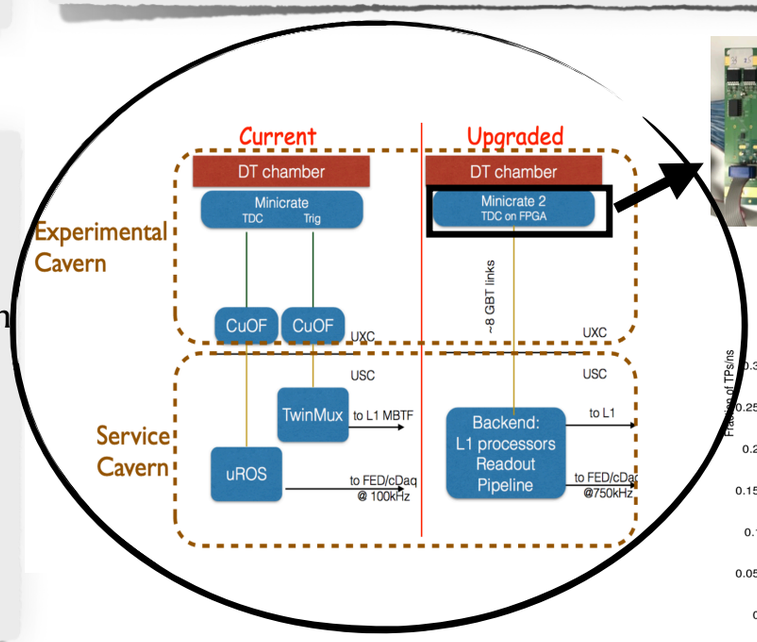
Physics Institute III A | RWTH AACHEN UNIVERSITY

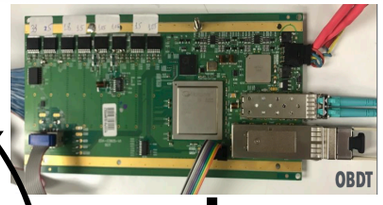
Motivation

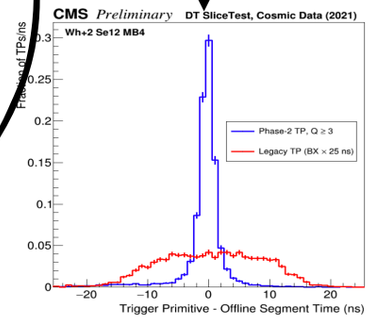
- In order to meet the challenges posed by the high radiation environment of HL-LHC, Drift tube detector in the barrel region of CMS muon are ongoing the upgrade of its electronics during Long shutdown 3
- The upgrade contains new generation of the on-chamber electronics
  - TDCs (implemented in FPGAs)
  - Optic transceivers directly on board
  - Radiation tolerant components
  - Trigger logic moves completely to the Backend at service cavern

DT Phase 2 Slice Test

- Four DT chambers in Sec 12 of wheel YB+2 have been equipped with Phase 2 On Boards DT electronics (OBDT) : DT Slice Test
- **OBDTs :** On Board Electronics for Drift Tubes for HL-LHC consist of a single type of board performing < 1 ns time digitisation in FPGA of chamber signal
- Data from OBDTs goes to backend electronics (AB7) based on TM7 boards, where they are used for trigger primitive generation and readout







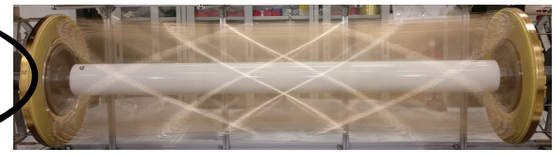
Summary & Plans

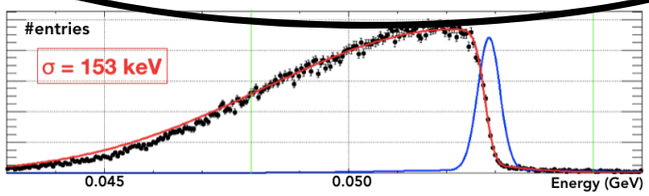
- The Phase 2 DT Slice Test successfully installed & operated over the LHC LS2
  - The performance is in line with the one of the Phase 1 system already exploiting the DT cell resolution
- Aiming to operate the present DT Phase 2 Slice Test setup at the beginning of Run 3 in parallel to the legacy system
  - Updated DT DQM (data quality monitoring) for checking online the Slice Test plots
  - Dedicated offline analysis frame work to process Slice Test data
- Further developments of OBDT prototype versions and integration plans with the Phase 2 Muon Trigger Backend also ongoing in parallel

Calibration tools for the MEG-II experiment

Hicham Benmansour on behalf of the MEG-II collaboration

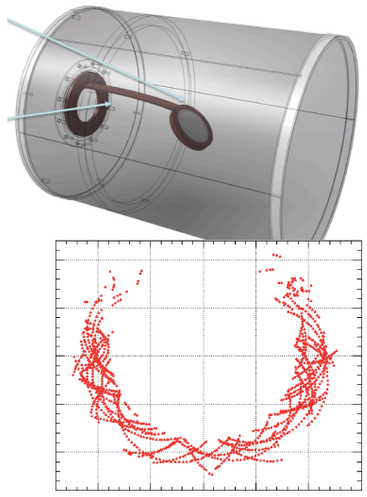
- The MEG-II experiment is looking for the rare $\mu^+ \to e^+\gamma$ decay. To achieve a 6e-14 branching ratio upper limit, the calibration of the state-of-the-art cylindrical drift chamber is critical.





- Complementary and redundant methods are used for that purpose: cosmic rays, Mott positrons and fits of the Michel spectrum edge.

- A novel idea to evaluate the basic parameters of the CDCH (active cells, working channels, gain alignment) is to make use of the 17.6 MeV Li line, obtained by sending protons on a lithium target. With magnet off and through External Pair Conversion, it leads to ~ 9 MeV e+ and e- straight tracks.



- With magnet on, the curved EPC tracks can be used to extract the particles' kinematic resolutions. Simulations are ongoing to compare the resolutions at high and low momenta.

- *Detector calibration*

- *Gas monitoring tool*

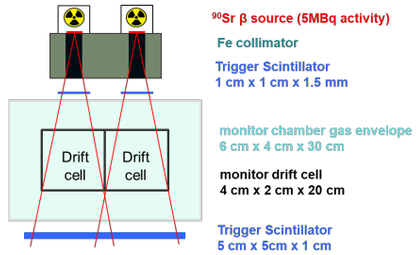
A monitoring chamber for high precision measurements of the drift velocity in gas detectors

G. Chiarello[d], A.Corvaglia[c], F. Cuna[a],[c], N. De Filippis [b],[d], E.Gorini[a],[c], F. Grancagnolo[c], M.Manta[f], A.Miccoli[c], M.Panareo[a],[c], M.Primavera[c], , G.F.Tassielli [b],[e], A.Ventura[a],[c]

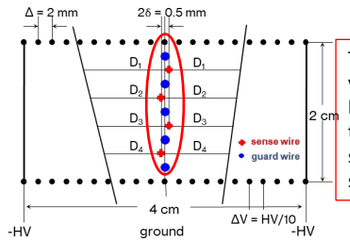
(a) Dipartimento di Matematica e Fisica, Università del Salento, Italy; (b) Istituto Nazionale di Fisica Nucleare, Bari, Italy; (c) Istituto Nazionale di Fisica Nucleare, Lecce, Italy; (d) Istituto Nazionale di Fisica Nucleare, Pisa, Italy; (d) Politecnico di Bari; (e) Università degli Studi di Bari »Aldo Moro», (f) Istituto Nazionale di Fisica Nucleare, Pavia, Italy

The tracker detector of MEG II and the one under developments of FCC and CEPC experiments consists of ultralight drift chambers, operated with a mixture of Helium and Isobutane. In order to have a continuous monitoring of the quality of gas, we plan to install a small drift chamber, with a simple geometry that allows to measure very precisely the electron drift velocity in a prompt way.

Schematical setup

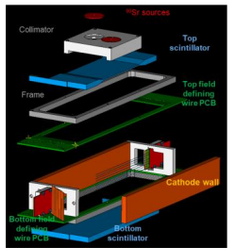


Drift cells details

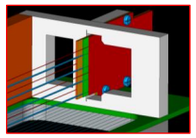


The drift velocity v_d can be measured thanks to the sense wire staggering.

Mechanical design



Custom wire PCB for wires staggering



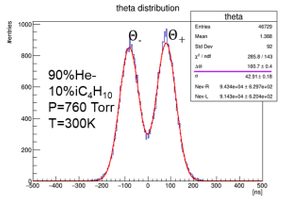
Applied method for drift velocity measurements

Simple geometrical considerations lead to the following relation:

$$\begin{cases} \Theta_+ = +\dfrac{8\delta}{v_d}, & left\ track \\ \Theta_- = -\dfrac{8\delta}{v_d}, & right\ track \end{cases} \qquad \begin{cases} v_d = \dfrac{16\delta}{\Delta\Theta} \\ \sigma_{v_d} = \sqrt{\left(\dfrac{16\delta}{\Delta\Theta}\right)^2 \sigma_\delta^2 + \left(-\dfrac{16\delta}{\Delta\Theta^2}\right)^2 \sigma_{\Delta\Theta}^2} \end{cases}$$

The drift velocity depends on $\Delta\Theta = \Theta_+ - \Theta_-$, which is the distance between the two gaussian peaks distribution of Θ

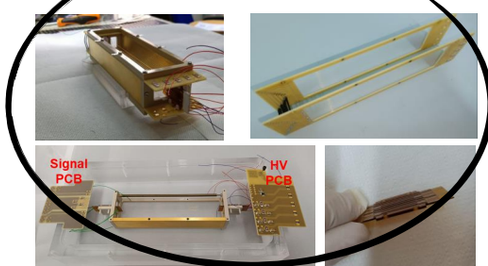
Simulations



Garfield++ simulations show the double gaussian distribution of the Θ variable.

$$v_D = 2.488 \pm 0.006\ cm/\mu s$$

Construction of the chamber



- *New design for high transparency*
- *Cluster counting technique*

The drift chamber of CMD-3 detector

G. Chiarello[(d)], A.Corvaglia[(c)], F. Cuna[(a),(c)],N. De Filippis [(b),(d)], E.Gorini[(a),(c)] , F. Grancagnolo[(c)], A.Miccoli[(c)], M.Panareo[(a),(c)], M.Primavera[(c),] , G.F.Tassielli [(b),(e)], A.Ventura[(a),(c)]

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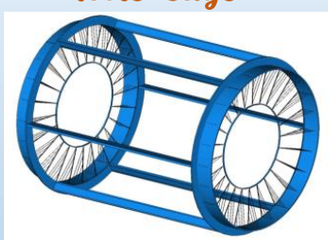
TraPId (**Tra**cking and **P**article **Id**entification), the Central Tracker proposed by the Bari and Lecce INFN groups for the detector at a generic flavour factory is an ultra-light drift chamber equipped with cluster counting/timing readout techniques.

Main peculiarities of this design are the **high transparency** in terms of multiple scattering contributions to the momentum measurement of charged particles and the very promising particle identification capabilities.

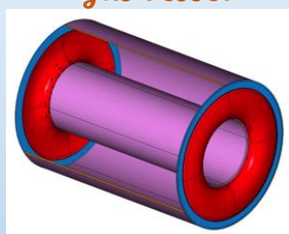
HIGH TRANSPARENCY

A significant reduction in the amount of material at the end plates is obtained by separating the gas containment function from the wire tension support function.
The wires are anchored to a self-sustaining light structure ("wire-cage") surrounded by a thin skin ("gas vessel") of suitable shape to compensate for the gas differential pressure with respect to the outside.

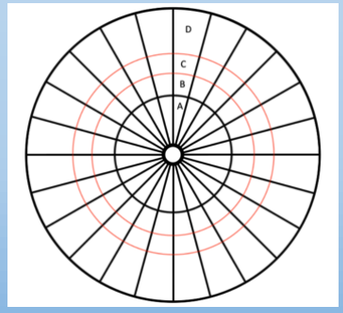
Wire-cage



Gas vessel

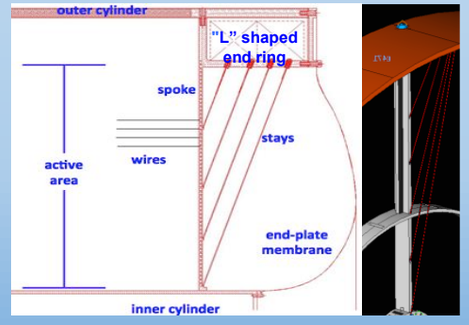


Chamber layout

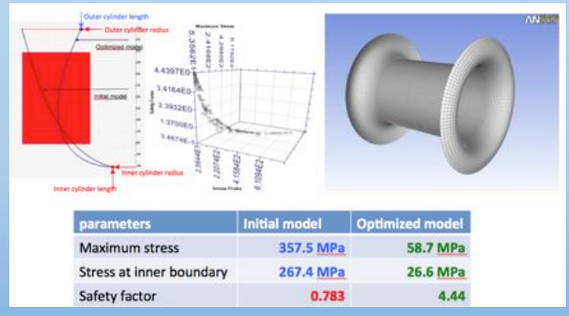


The missing end-plate

The tension recovery scheme

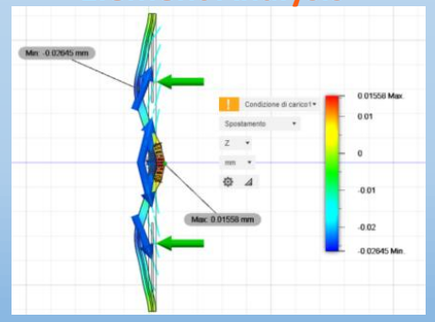


The gas containment



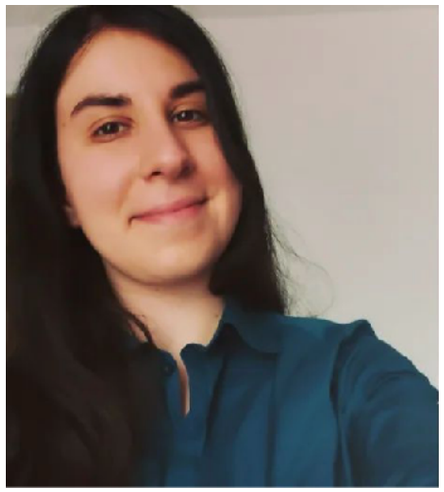
parameters	Initial model	Optimized model
Maximum stress	357.5 MPa	58.7 MPa
Stress at inner boundary	267.4 MPa	26.6 MPa
Safety factor	0.783	4.44

Preliminary Finite Element Analysis

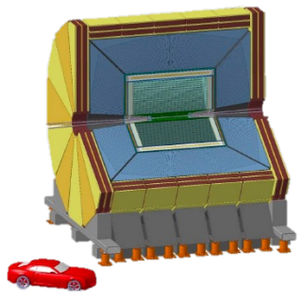


- An ultra-low mass drift chamber for a generic flavour factory with a material budget <1.5x10-2 X/X_0 in the radial direction and <5x10-2 X/X_0 in the forward and backward directions (including HV and FEE services) can be built with the novel technique adopted for the successful construction of the MEG2 drift chamber.
- $\Delta pt/pt = 2.0\times10^{-3}$, $\Delta\theta = 0.70$ mrad, $\Delta\phi = 0.78$ mrad at $p = 1$ GeV/c.
- Particle identification at the level of 3.6% with cluster counting allowing for π/K separation $\geq 3\sigma$ over a wide range of momenta.

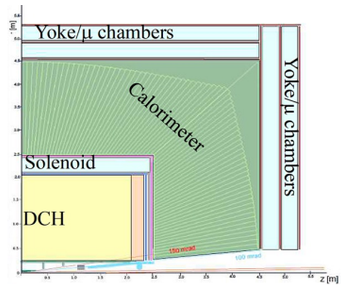
- *Cluster counting technique: dN/dx vs dE/dx*
- *Simulation and beam test*



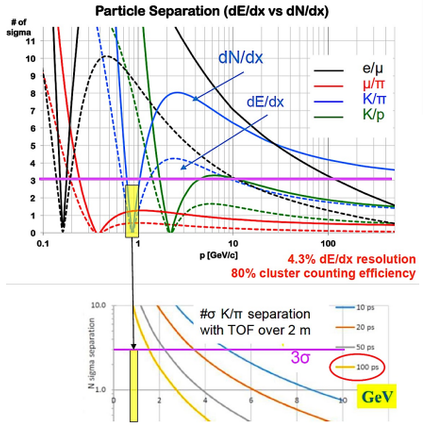
"Particle identification with the cluster counting technique for the IDEA drift chamber" Summary

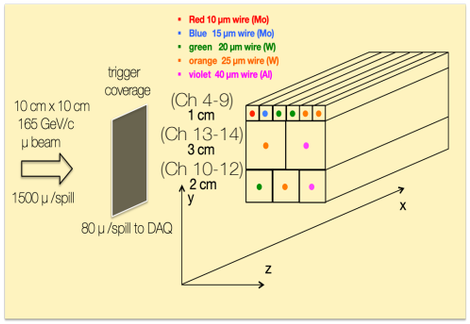


The IDEA (Innovative Detector for an Electron-positron Accelerator) drift chamber is supposed to provide an excellent particle identification (PID) by exploiting the application of the electron cluster counting (CC) technique. The effectiveness of the CC algorithms' usage for PID has been demostrated by theoretical results.

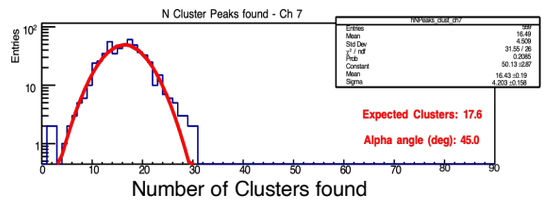


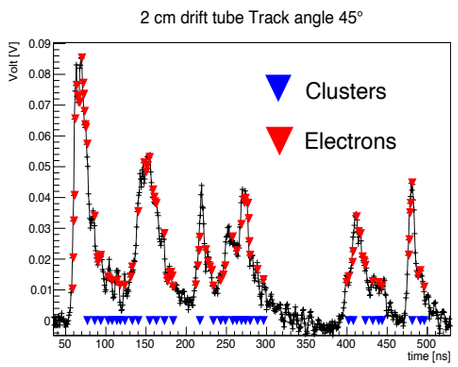
- A simulation of the ionization clusters generation has been done by developing an algorithm which can use the energy deposit information provided by Geant4 toolkit to reproduce the clusters number distribution (Poissonian) and the cluster size distribution predicted by Garfield++. The analytical and full simulation results agree reasonably and confirm that the cluster counting technique dN/dx allows to reach a resolution 2 times better than the traditional dE/dx method which has not seen progress since 40 years.

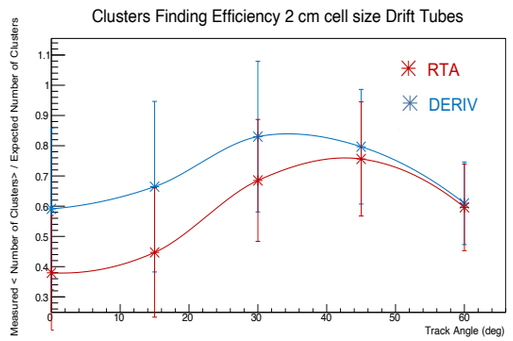




- A beam test has been performed at H8 CERN:
  - to select the most efficient cluster counting algorithms, the Running Template Algorithm (RTA) and the Derivative Algorithm (DERIV), many others have been discarded
  - to define the limiting effects for a fully efficient cluster counting (space charge effect + attachment + recombination)
  - to demonstrate the ability to count the number of electron clusters released by an ionizing track at a fixed $\beta\gamma$ as a function of the operative parameters (track angle, HV, gas mixtures)
  - to define a set of parameters optimizing the cluster counting efficiency, to undergo a new test with the same setup in a muon beam of momenta in the relativistic rise range, in order to define the PID capabilities of the cluster counting approach over the full range of interest for all future lepton machines.

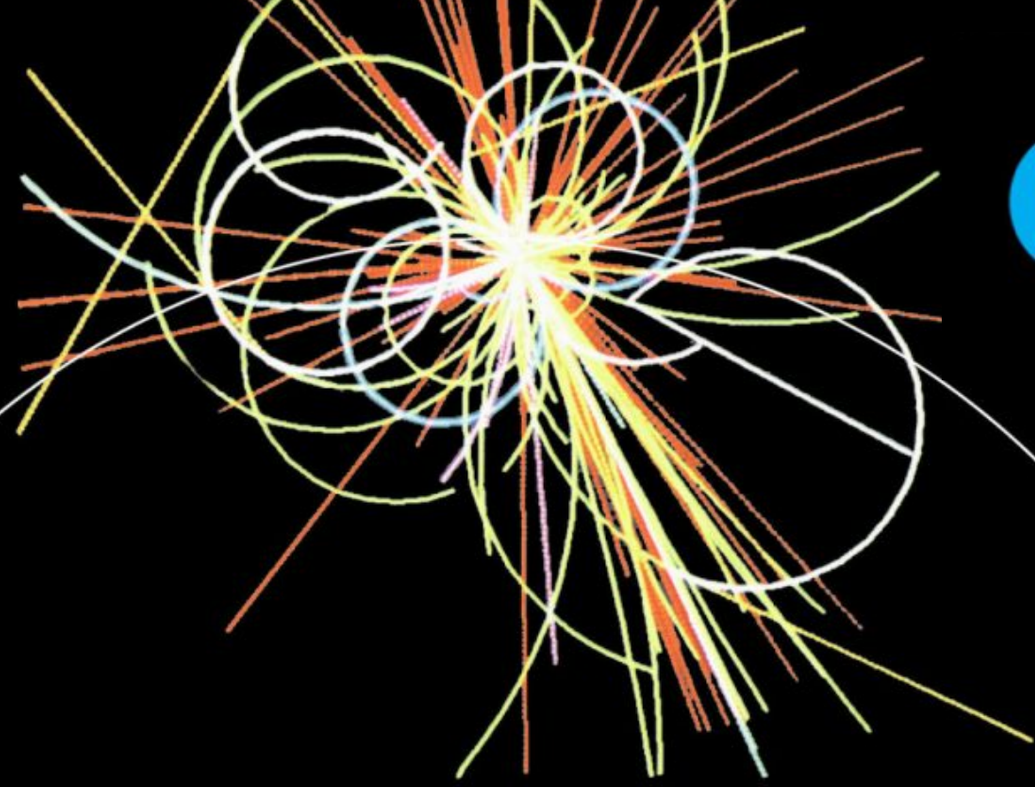






Brunella D'Anzi

TPC



- Studies on a TPC for IEAP spectrometer
- Fast simulation of TPC thanks to factorisation
- Development of TPC for ILD with MPGD readouts

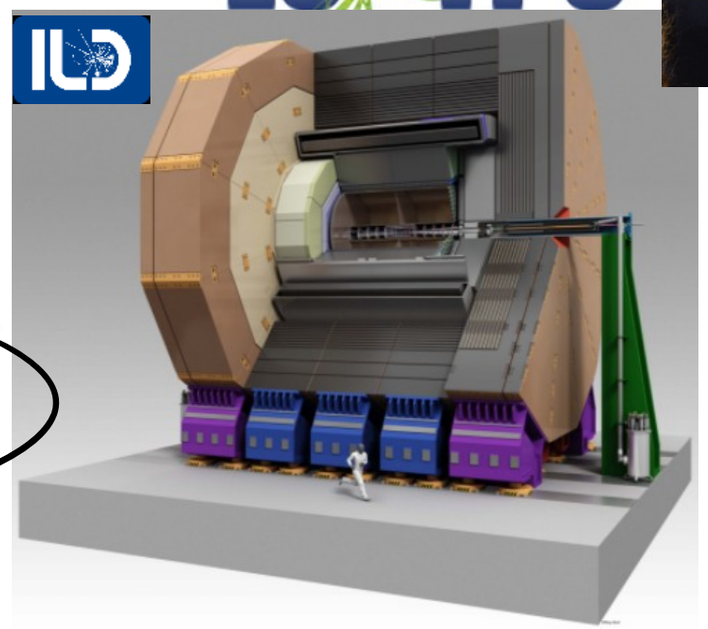
- *TPC for ILD, CEPC, FCCee*
- *Read-out with MPGD*

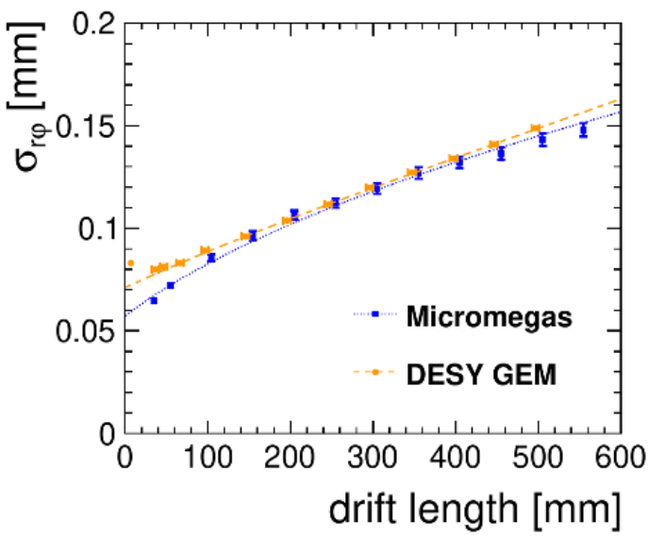
TPC Development for the ILD

The International Large Detector (ILD) was originally developed for ILC, but is now studied for more Higgs factories (ILC, CEPC, FCCee).

The central tracking detector is a large TPC (length: 4.5m, outer radius: 1.8m) to be operated in B = 3.5 T.

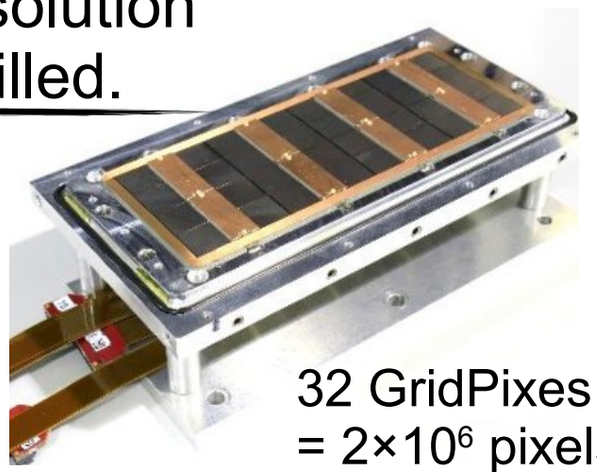
LCTPC-collaboration studies various MPGD readouts: GEMs, Micromegas, GEMs with double thickness, GEM + MM stack and GridPixes.





Pad-based readouts show a very similar performance in tracking, dE/dx and double track resolution. ILD-requirements for momentum resolution ($\partial(1/pt) \sim 10^{-4}$ /GeV/c) can be fulfilled.

Pixel-based readout gives lower occupancy, better dE/dx res., no angular pad effect, etc.



32 GridPixes = 2×10^6 pixels

LCTPC is planning on intensifying its simulation efforts to evaluate also other applications of its detectors.

- *Spectrometer*
- *TPC with triple GEM*
- *Use of SRS (RD51)*

Measurement of anomalies in the angular correlation of electron and positron internally produced in excited ^{8}Be and ^{4}He

A.F.V. Cortez | H. Natal da Luz | R. Sykora | B. Ali| L. Fajt

Construction of a spectrometer for the tracking and measurement of the energy of light charged particles.

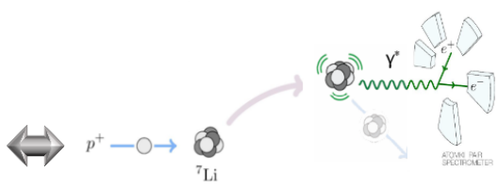
The spectrometer is formed by:

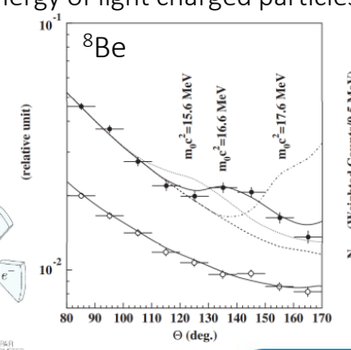
- Hexagon Timepix3
- Multi-Wire Proportional Chamber
- Time Projection Chamber

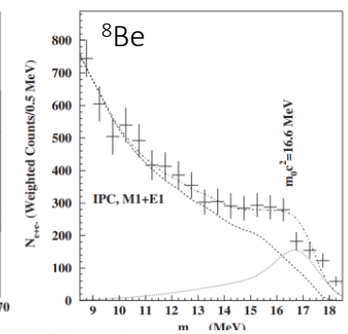
Setup in construction @ IEAP's Van de Graaff facility.

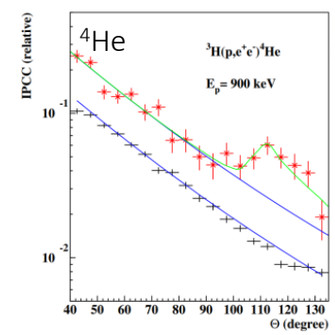
^{8}Be decay

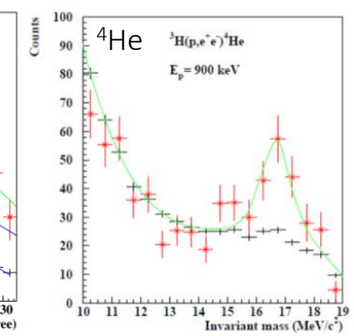
- Hadronic (≈ 100%)
- Electromagnetic (≈ 1.5 x 10^{-5})
- Internal Pair Creation (≈ 5.5 x 10^{-8})









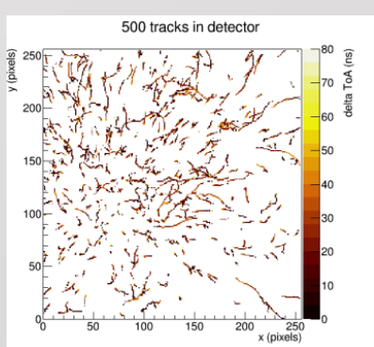


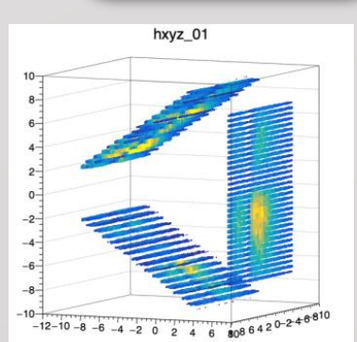
André Cortez

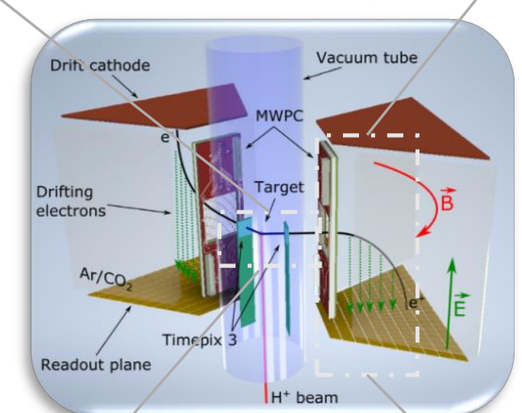
IEAP CTU in Prague

Hexagon Timepix3

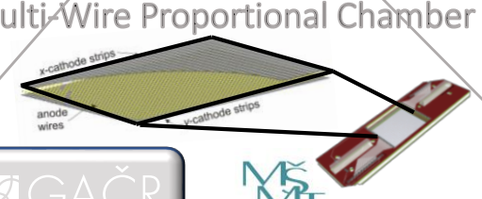
- Event driven pixelated detector (fast response);
- 256x256 55 µm pixels (high granularity);
- 1.6 ns time resolution;
- 14x14 mm^2 (fits inside the vacuum tube).
- Designed in collaboration with FEE-UWB.





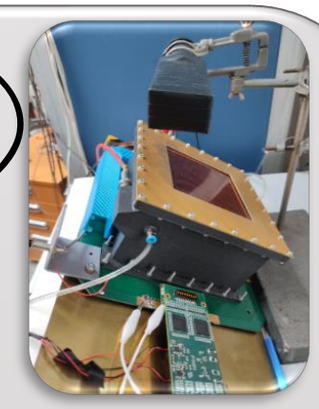


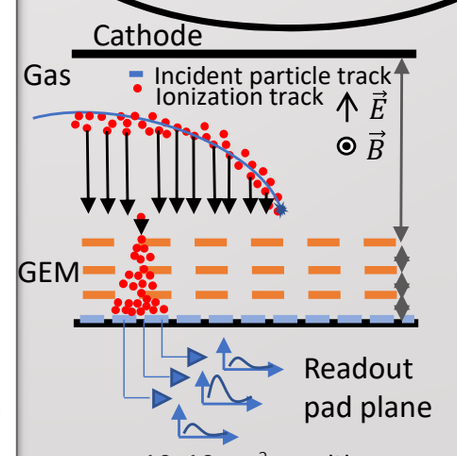
Multi-Wire Proportional Chamber

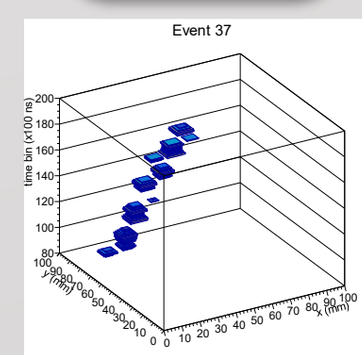


Time Projection Chamber

- 3D tracking (event topology)
- Particle ID
- Background rejection







- 10x10 cm^2 sensitive area;
- 8 cm drift volume;
- Standard triple-GEM;
- 120 pad readout (independently-read);
- SAMPA integration in SRS (RD51/CERN).

GAČR
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

15th Pisa Meeting on Advanced Detectors, 22nd to 28th May 2022, La Biodola (Italy)

Contact: andre.cortez@cvut.cz

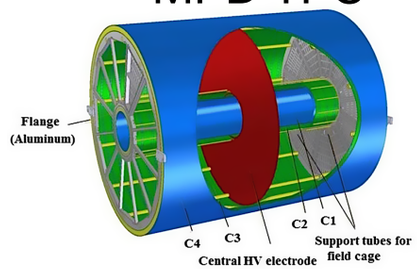
- *Specific software for instrumentation (ECFA GSR3)*
- *Important to have simulation up-to-date*

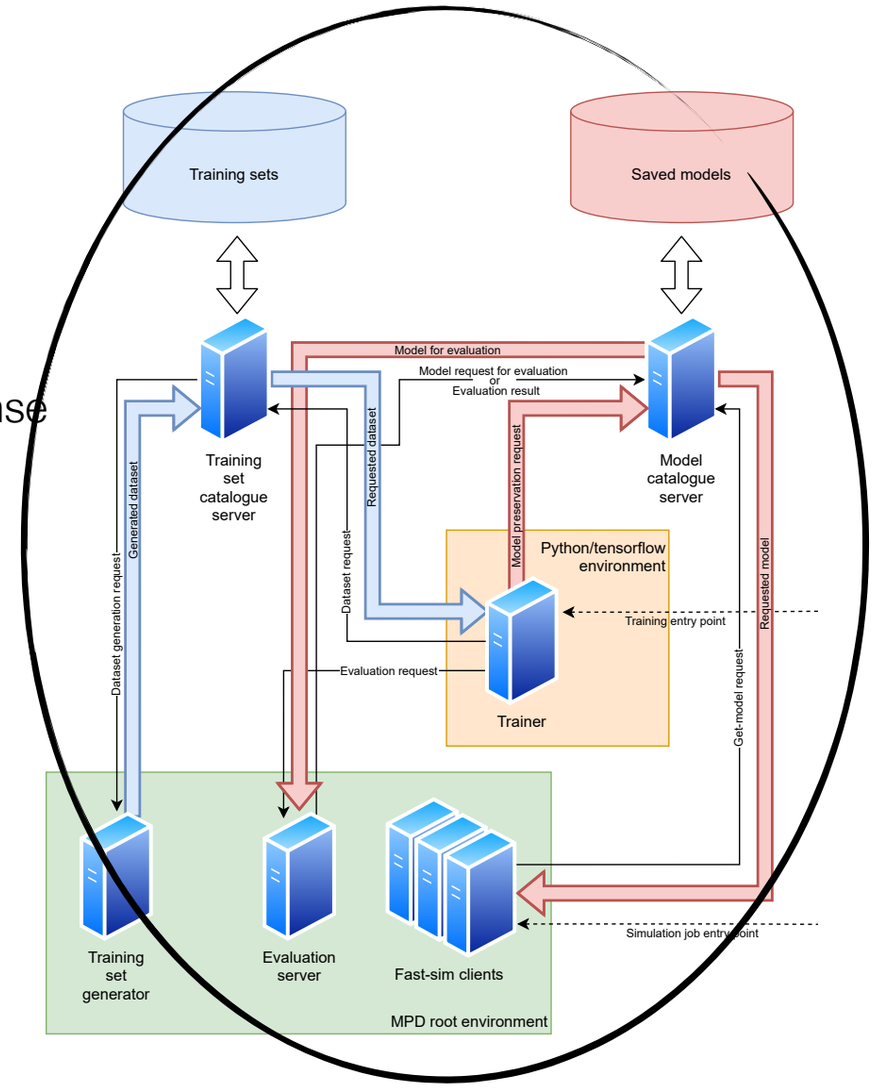
Generative Surrogates for Fast Simulation: TPC Case

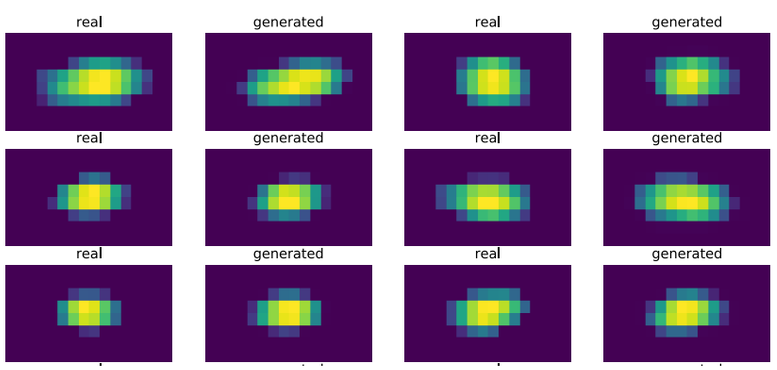
A. Maevskiy, F. Ratnikov, A. Zinchenko, V. Riabov, A. Sukhorosov , D. Evdokimov

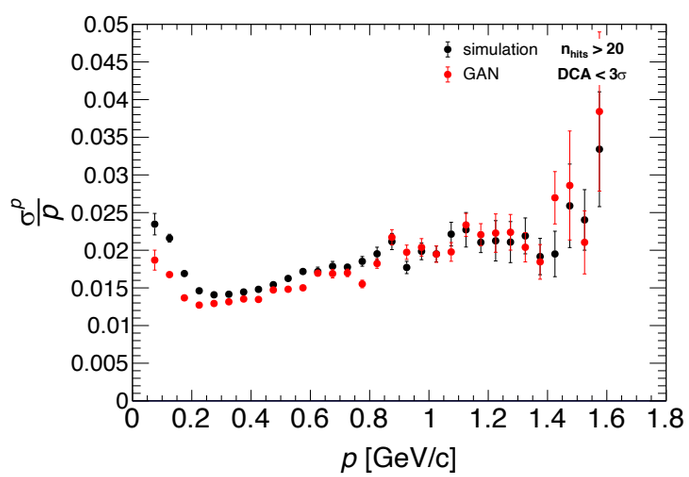
- Our GAN-based TPC simulation model provides **x12 acceleration** with good quality of samples
- The model is being integrated into **a continuous pipeline** with automated training data generation, model training, evaluation and selection
- We also study a simpler (wrt our model above) low-dimensional detector response representation
  - Aiming for a simpler model
  - In practice, requires a lot of hyper-parameter tuning
    - **Do GANs "prefer" higher-dimensional representations?..**

MPD TPC









Eur. Phys. J. C 81, 599 (2021)

MPGD

- CMS GEM: present and future upgrades
- Studies on GEM performance in different conditions
- Cylindrical GEM fro inner trace row BESIII

- Long term neutron irradiation of MicroMegas
- Operation of low pressure MicroMegas
- RHUM project: MicroMegas rate capability above MHz/cm^2
- Development of MicroMegas for AMBER experiment
- MicroMegas combined with Tungsten absorber for di-photon signatures

- MPGDs for the ATHENA experiment
- 2D interleaved readout for MPGDs

- PicoSec technology for Muon Collider detector
- u-RWELL for the IDEA detector

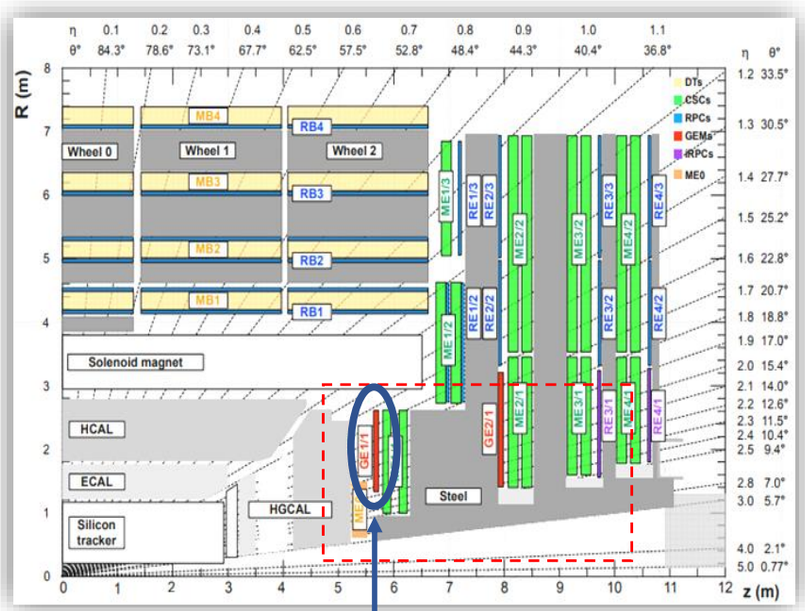
- *GEM successfully installed in CMS in LS2*
- *Operation in magnetic field*

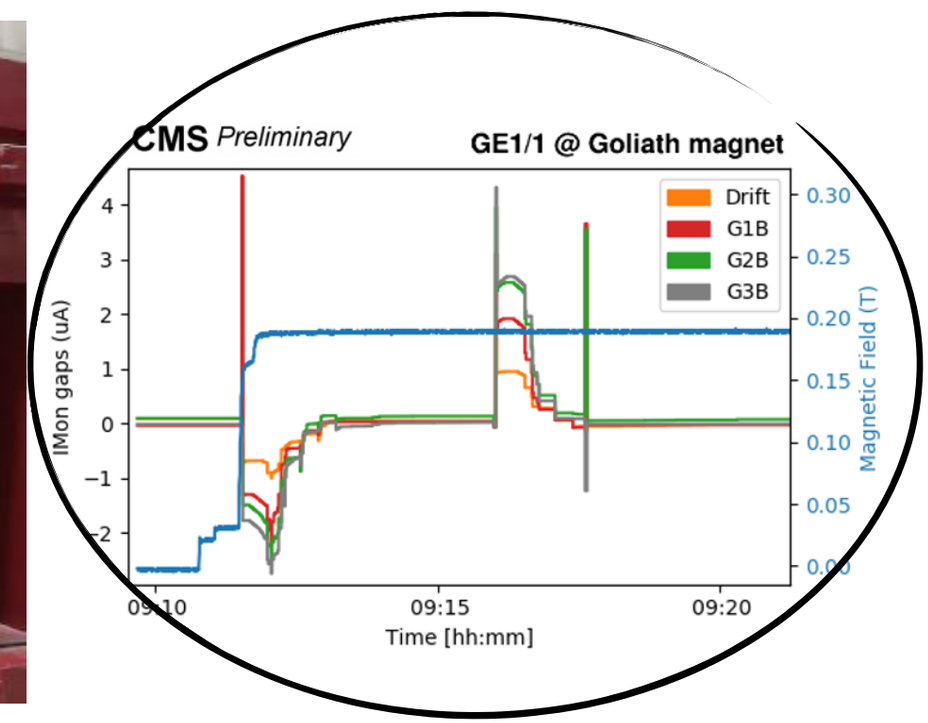
Commissioning and operation in magnetic field of CMS GE1/1station

Simone Calzaferri[1]

on behalf of the CMS Muon Group

INFN sezione di Pavia



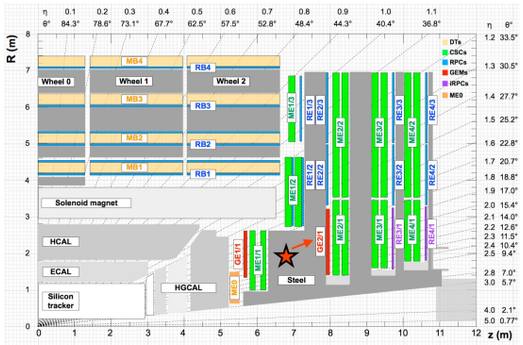


Actor: GE1/1 station in CMS (Gas Electron Multiplier detectors) $1.55 < |\eta| < 2.18$

Task: test GE1/1 chambers in Goliath magnet (CERN North Area) to reproduce phenomena observed during CMS magnet ramps

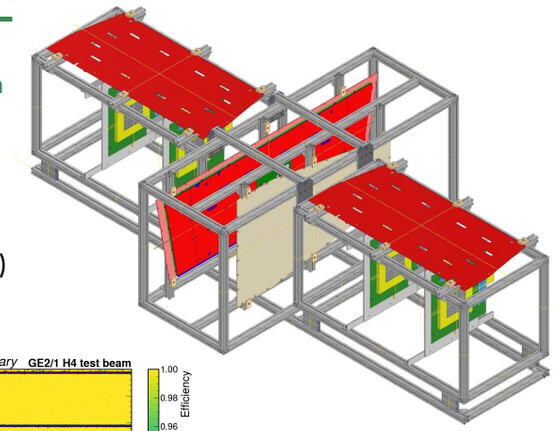
Goal: Define safe operation procedure during CMS magnet ramps

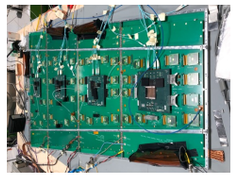
PERFORMANCE OF TRIPLE-GEM DETECTORS FOR THE PHASE-2 CMS UPGRADE AND A HIGH-RESOLUTION GEM TELESCOPE MEASURED IN A TEST BEAM

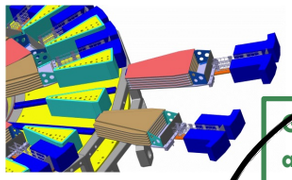


Phase-2 CMS GEM detectors + triple-GEM tracker tested in CERN North Area with muon and pion beam

- GE2/1 final design detector
- ME0 second-generation detector (azimuthal segmentation)
- 4x 10x10 cm^2 high-resolution (250 µm pitch) triple-GEM telescope
- 20x10 cm^2 triple-GEM prototype with random-hole segmentation







Final front-end electronics and DAQ software

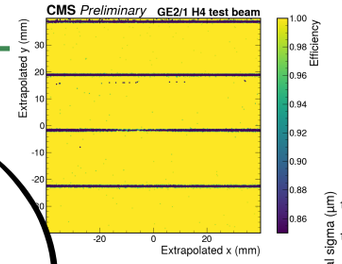
- VFAT3 front-end ASIC
- OptoHybrid on-detector FPGA
- Custom back-end FPGA (Xilinx VU13P)

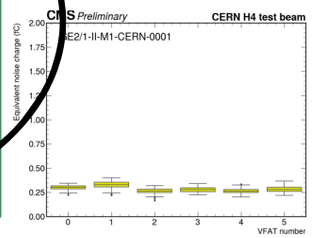
GE2/1 and ME0 detector performance and design validation

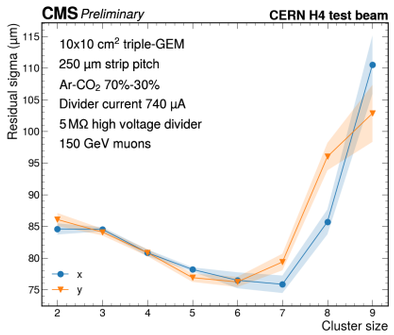
- *Excellent noise levels (<0.5 fC)*
- *Efficiency over 99%*

Good triple-GEM tracking performance

- Average *81 µm space resolution*
- Strong dependency on cluster size effects of delta rays and reduced efficiency effects





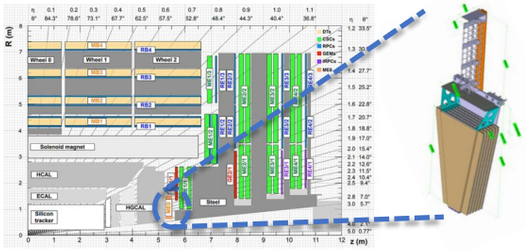


- *GEM for CMS Phase 2*
- *High space resolution*

- *GEM for HL-LHC*
- *High particle rate*

Antimo Cagnotta on behalf of **CMS** muon group
Università degli studi di Napoli **'Federico II'** & INFN **Napoli**

Novel GEM foil layout for high-rate particle environment in the CMS ME0 muon detector



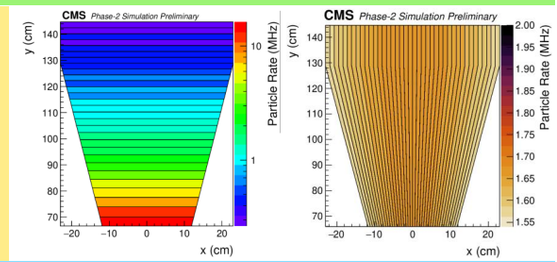
Hi-Lumi UPGRADE

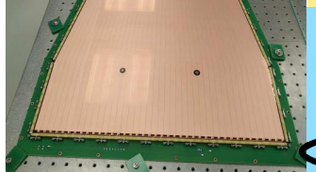
- ❑ The phase-II CMS muon endcap upgrade will include a new forward station at high η → **ME0**
- ❑ The ME0 ring (18 detectors × 6 layers × 2 endcaps) will be the closest muon station to LHC beam line -> $\mathbf{2.0 < |\eta| < 2.8}$

MOTIVATION

Possible source of gain drop at high rates:

- ❑ Ion space charge
- ❑ Drop in voltage difference across GEM foil





PROPOSED SOLUTION

- ❑ Dedicated study for the high particle rate expected in the ME0 region
- ❑ New type of segmentation → azimuthal

- *MicroMegas for rates above MHz/cm²*
- *Different spark protection resistive schemes*

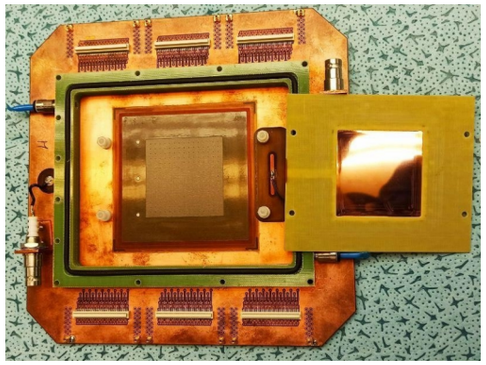
High Granularity Small-Pad Resistive Micromegas for Rates above MHz/cm²

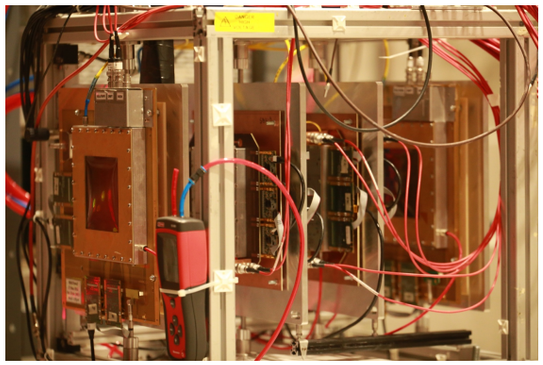
Resistive Micromegas demonstrated to be a solid detector technology for HEP experiments (recently employed for the upgrade of the ATLAS Muon Spectrometer)

RHUM (Resistive High granUlarity Micromegas) R&D project ongoing, aming to develop a detector able to efficiently work at particle rates up to several tens MHz/cm²

The goals of RHUM project are summarized below:

- develop an MPGD able to efficiently work at particle rates up to several tens MHz/cm²
- implement a small pad readout to reduce the occupancy
- optimize the spark protection resistive scheme to have stability of operation at high rate/gain
- demonstrate the detector scalability to large surfaces
- simplify the construction techniques for industrial production





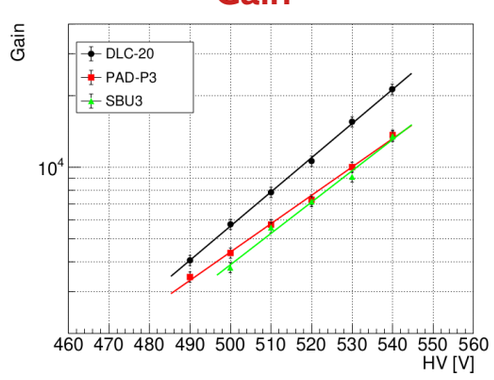
Results shown for four different small-pad Micromegas prototypes with different layouts of the spark protection resistive scheme

From tests and comparison among them we reached:

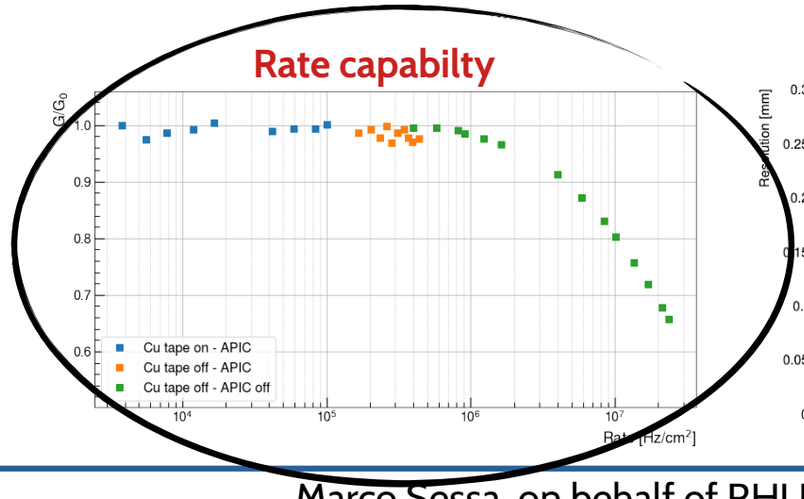
- stable operation up to 20 MHz/cm² with gain >10⁴
- detector efficiency > 97%
- position resolution < 100 μm

R&D project still ongoing. Future activities will focus on: tracking in high rate environment, detector scalability to larger area, time resolution and ageing studies

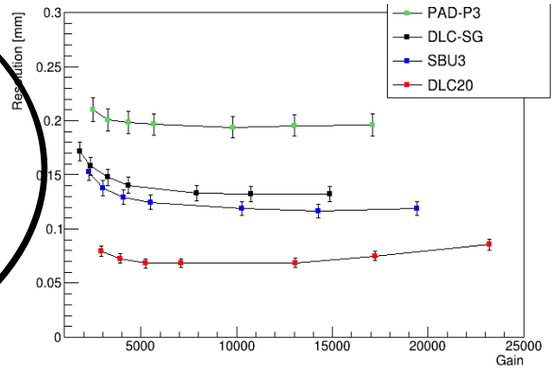
Gain



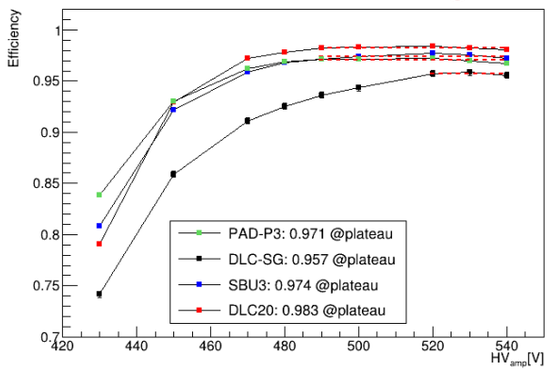
Rate capabilty



Position resolution vs gain



Tracking efficiency vs amplification voltage

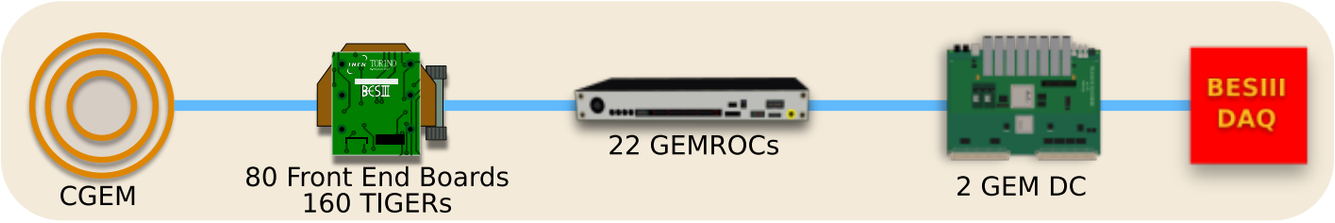


- *Cylindrical shape for inner tracker requirements*

Development and operation of the CGEM Inner Tracker for the BESIII experiment

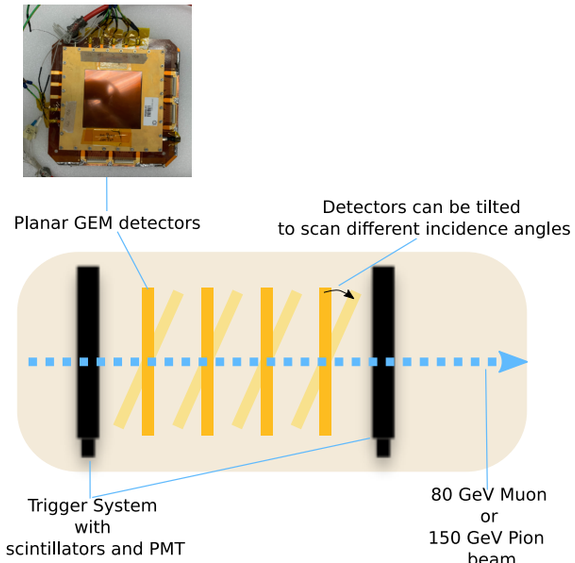
Alberto Bortone on behalf of the CGEM-IT working group

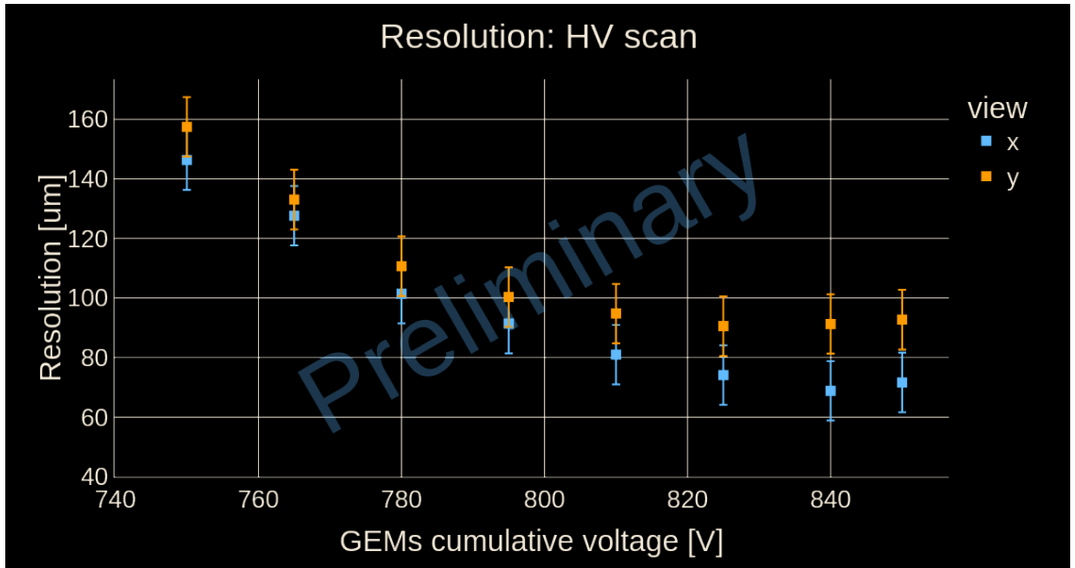
The **CGEM-IT** (Cylindrical GEM Inner Tracker) detector consists of **three detector layers** with independent gas volume, power management and readout electronics.
Each layer consists of **three GEM foils** (Gas Electron Multiplier), a cathode and an anode for signal collection.
The detector will upgrade the internal tracking system of the **BESIII** experiment by improving spatial resolution in both the r/φ-plane and z-axis without compromising material budget and radiation tolerance.



CGEM-IT electronic chain main components

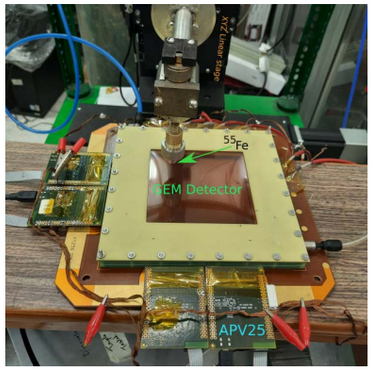
Test beam with planar detectors

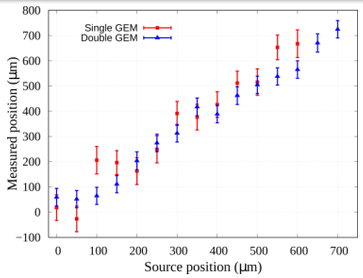




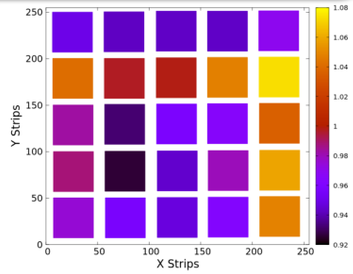
Studies on position resolution & gain mapping of Gas Electron Multipliers (GEM) using Scalable Readout System (SRS)

Poster ID: 111
Presented by: Vishal Kumar[1]
1. Saha Institute of Nuclear Physics, Bidhannager, Kolkata, India





Position data is plotted by moving the source 50 µm at a time.



Gain map of a double GEM

- Data acquisition with APV25 & SRS based DAQ system.
- Position resolution measurement by changing source position with a precise positioning system.
- Gain uniformity scan of 10 by 10 cm GEM detector.

- In the x-direction, the measured position resolution of single and double GEM are 66.47 and 36.76 µm, respectively.
- The detector's gain variation is ± 8 % from its mean valu

- *Studies on position resolution*
- *SRS (RD51) multi purpose*

- *Simulation to study effects on space charge phenomena*

Study of space charge phenomena in GEM based detectors

Promita Roy [1], Prasant Kumar Rout [2], Jaydeep Datta [3], Purba Bhattacharya [4], Supratik Mukhopadhyay [1], Nayana Majumdar [1] and Sandip Sarkar[1]*

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Accumulation of charges inside the GEM holes results in the modification of the electric field within the GEM foil which in turn can modify the effective gain.

Space charge phenomena gets significantly affected by:

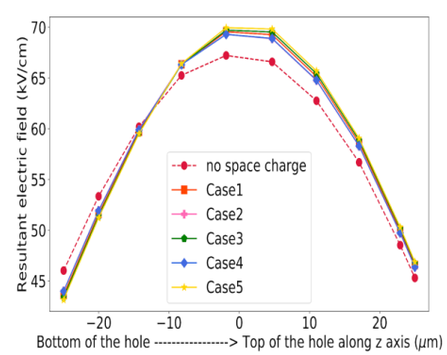
- Spatial distribution of primary seed cluster
- Mean z-position (height) of the primary seed cluster in the drift gap
- Applied GEM voltage

Five combinations of Fe55 primary seed clusters have bee chosen:

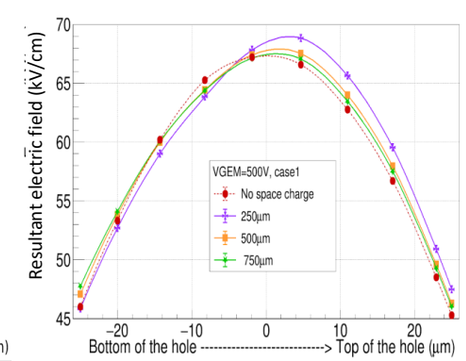
Cases	Description	Spread in r (µm)	Spread in z (µm)
Case 1	Mean	132	154
Case 2	Enlarged	203	234
Case 3	Compact	61	74
Case 4	r-elongated	203	74
Case 5	z-elongated	61	234

Simulation results:

1. Variation of electric field with the spatial distribution of primaries



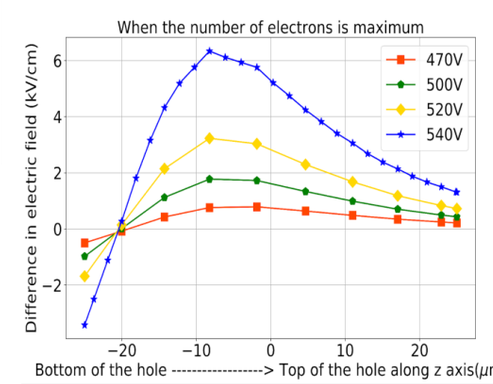
2. Variation of electric field with different heights of primaries in drift gap



3. Variation of electric field due to space charge accumulation with increasing GEM voltages

E_{WO} = Electric field without space charge effect
E_W = Electric field with space charge effect
then the difference in electric field is

$$\Delta E = E_W - E_{WO}$$



Conclusion:

- Effect of space charge phenomena is more in radially compact and z-elongated cases (case 3 and case 5).
- Space charge effect is maximum when the primary cluster height is the least in the drift gap.
- Space charge effect (ΔE) increases with increasing GEM voltage.

- *MicroMegas to detect low energy x-ray*
- *Operation at low pressure*

CHARACTERIZATION OF A LOW-PRESSURE MICROMEGAS-LIKE GASEOUS DETECTOR WITH LOW ENERGY X-RAY SOURCES

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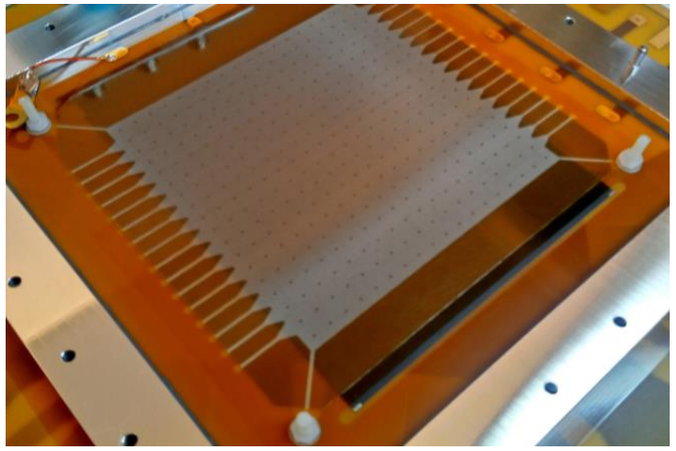
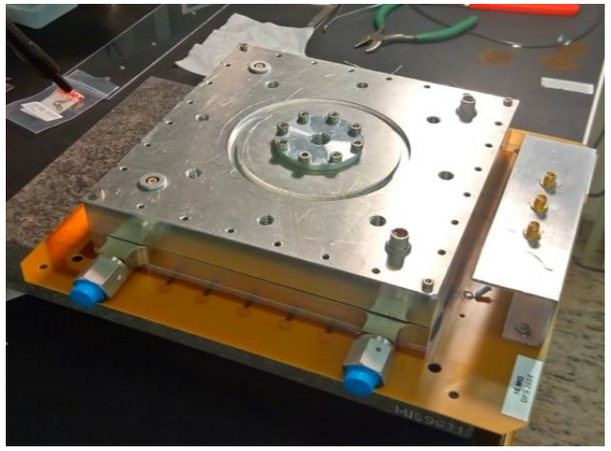
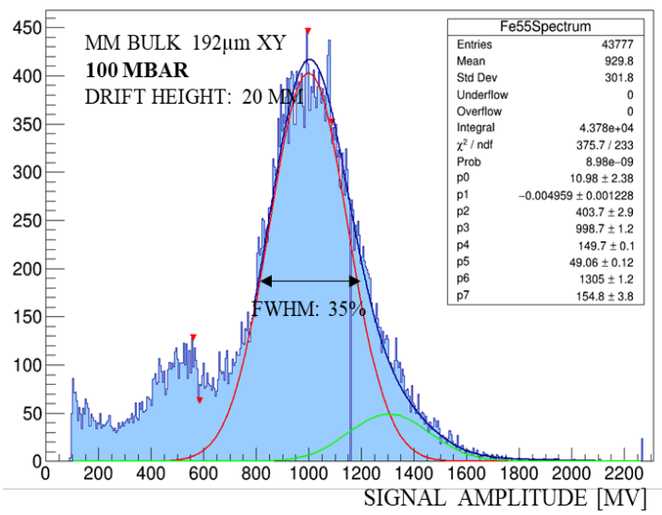
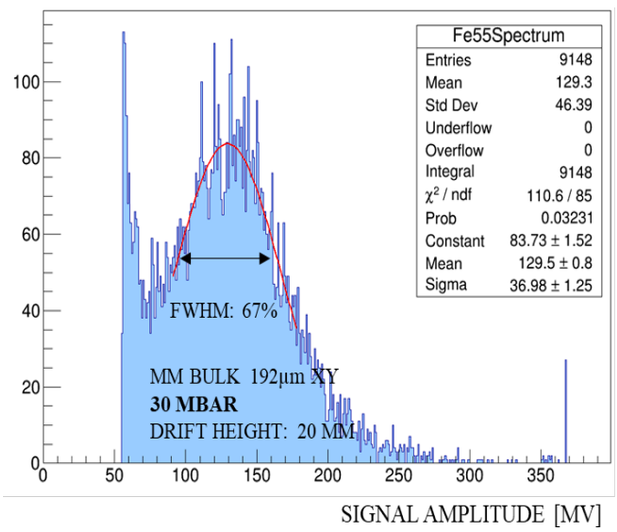
- We have evaluated the possibility to use the Micro-Megas (MM) technology to detect low energy (below 100 keV) ionizing particles.
- The intrinsic characteristics of the MM device are promising for the construction of an instrument to be operated as a TPC gas chamber in a low-pressure regime, capable to reconstruct the incoming particles track.
- Here we present the main properties of a low-pressure bulk MM detector. Two configurations with a 128 µm and a 192 µm gap were studied, both filled and operated with a gas mixture (Ar-CO_2 ; 93: 7) at pressures below 100 mbar.
- Using a specifically developed test bench, the dependence of the gain, the energy resolution, the mesh transparency on the amplification field, gas pressure and drift field have been evaluated.
- The reliability of the measured performance, make it an attractive choice for applications where track length of low energy particles is detected by using a low-pressure filling gas.







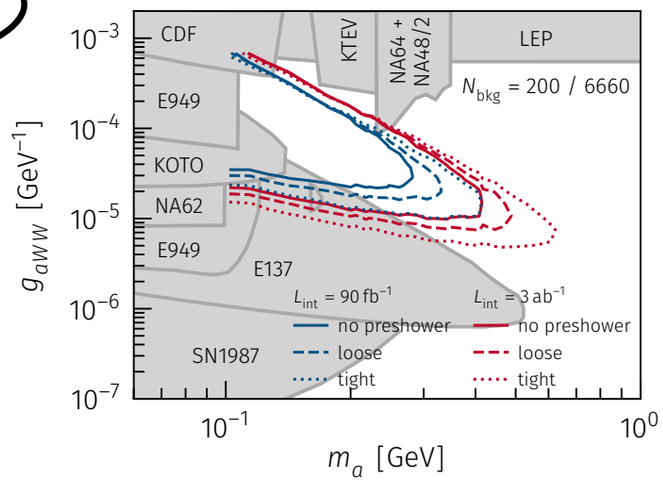


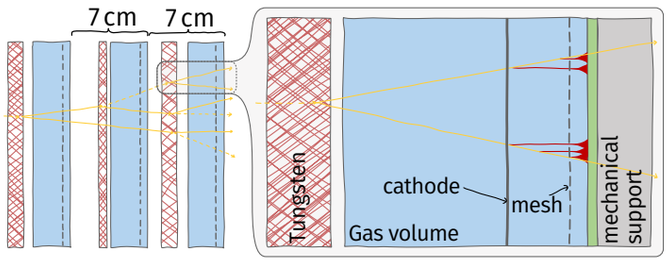
Detection of collinear high energetic di-photon signatures with Micromegas Detectors

Friedemann Neuhaus, Elisa Ruiz-Choliz, Matthias Schott

Johannes Gutenberg Universität Mainz

- identify collinear high energetic di-photon signatures with separation of 100 µm - 2 mm
- use three Micromegas detectors interleaved with Tungsten absorbers
- so far simulation based studies validated with testbeam data
- at 90 % background rejection achieve efficiencies of:
  - 20 % - 30 % for $0 \leq d \leq 300$ µm
  - 57 % - 70 % for $500 \leq d \leq 1000$ µm
- exemplary evaluated physics reach for FASER with significant improvement over no preshower baseline





- *pre-shower detector based on MicroMegas*

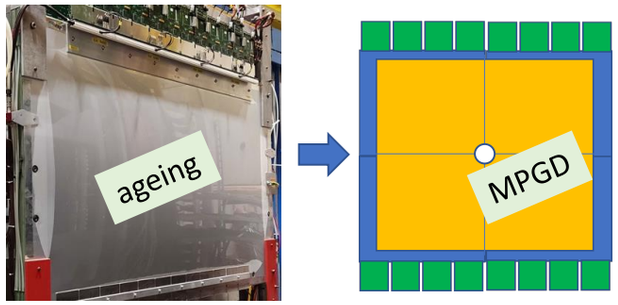
Development of a Micromegas prototype for the AMBER experiment at CERN

M. Alexeev on behalf of working group

AMBER
Apparatus for Meson and Baryon Experimental Research

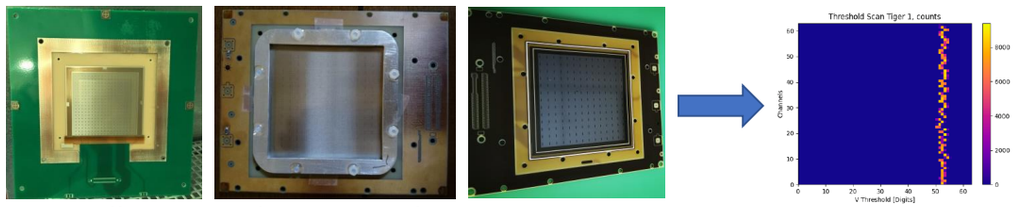
- *MicroMegas with different geometrical properties under study*

We are designing a Micromegas (MM) prototype that would fulfil the future requirements of the AMBER (NA66) experiment and would eventually substitute some of the ageing detectors



- Active area – up to 180x150 mm^2
- Rates - ~150kHz/mm^2 (centre), 1-2 kHz/mm^2 (periphery)
- Thickness – 0.3-0.5%/plane
- Possibly, proven design

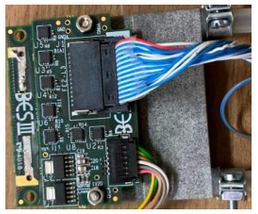
A series of prototypes with different manufacturing and geometrical properties are studied both in laboratory and at Beam

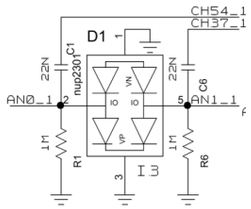


Bulk Floating Mesh Resistive

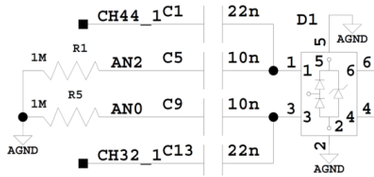
For the readout we are qualifying the option of using a TIGER ASIC based FE together with a study for a dedicated ASIC requirements

Initial FEs identical to the BESIII FEB





New FE cards with a new protection circuit & form factor



A dedicated ASIC is expected to be submitted within 2022

- *MPGD synergies of development for Nuclear and High Energy Physics*
- *MPGD for tracking in EIC detector*

College of Science and Technology
TEMPLE UNIVERSITY

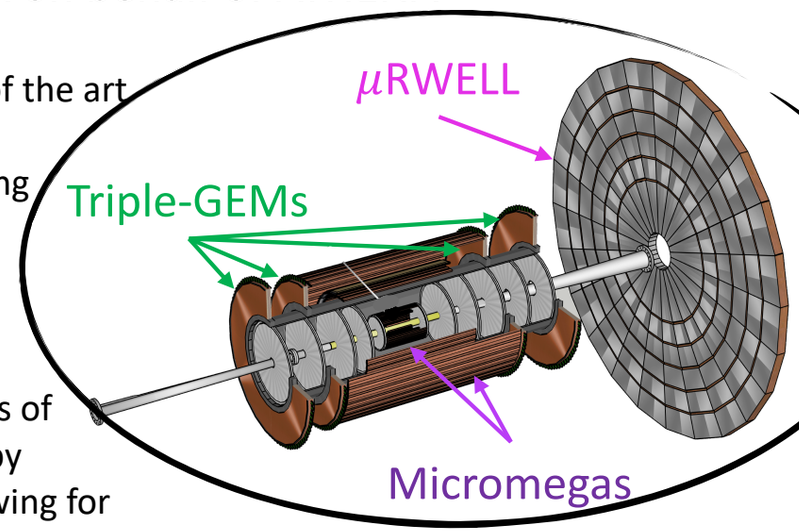
ATHENA's MPGD Tracking Detectors for the Electron-Ion Collider

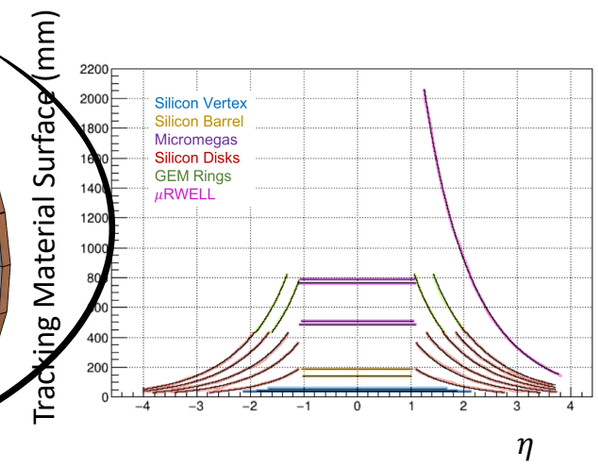
M. Posik on behalf of ATHENA

ATHENA

ATHENA

- **A T**otally **H**ermetic **E**lectron-**N**ucleus **A**pparatus (ATHENA) is a state of the art detector concept which was proposed as a potential EIC detector.
- The EIC physics program places stringent requirements on the tracking system, requiring it to have a low material budget, cover a large pseudorapidity range, and provide excellent momentum resolution.



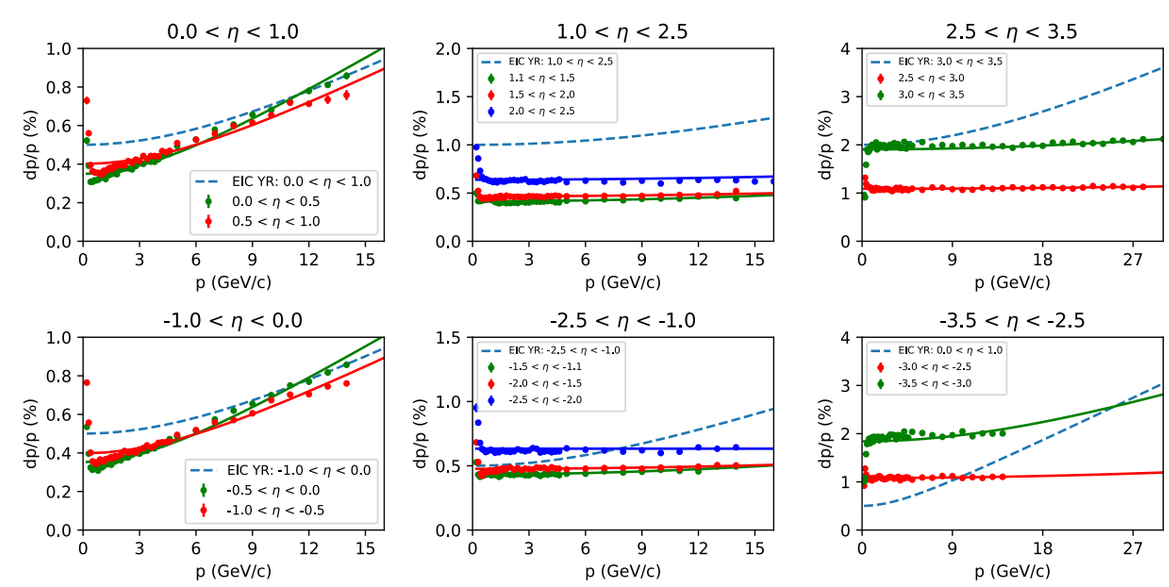


ATHENA MPGD Tracking Detectors

- The tracking system is built around a 3T solenoid magnet and consists of silicon detectors at small radii (< ~50 cm), which are complimented by Micro-Pattern Gas Detectors (MPGDs) at larger radii (> ~50 cm), allowing for a large tracking lever arm.
- A **micromegas barrel** provides tracking in the range $|\eta| < 1.1$, **triple-GEM** annular rings are used in the forward and backward directions to extend tracking coverage in the range $1.1 < |\eta| < 2.0$, and a large-area **μRWELL** detector is positioned behind the dRICH to aid in its PID capabilities.

ATHENA Performance

- ATHENA's tracking performance is able to meet nearly all of the physics requirements that were set in the EIC Yellow Report (arXiv:2103.05419).



R&D

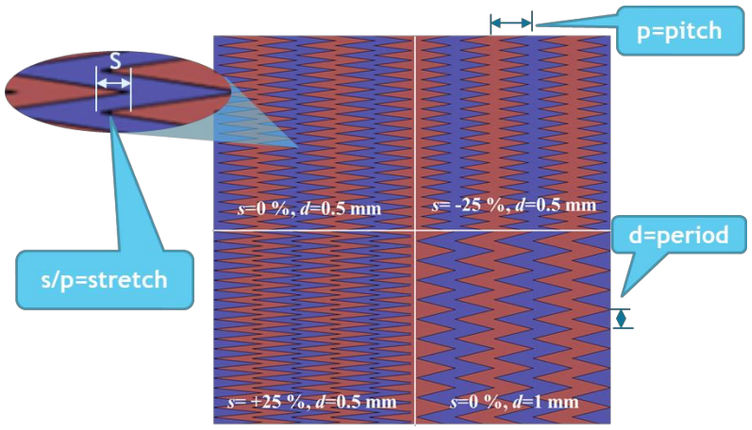
- R&D focused on EIC MPGD detectors is currently being carried out through eRD108 and is focusing on material budget reduction, lowering readout channel counts, and developing large-area μRWELL detectors

- *enhanced spatial resolution wrt straight strip arrays*
- *suitable for EIC applications*

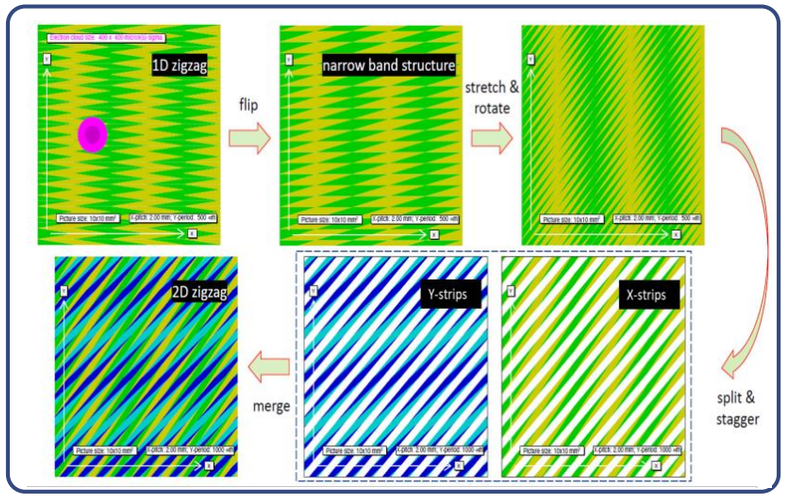
2D Interleaved Readouts for MPGDs

Introduction: Once the geometric parameters of interleaved anodes (such as zigzags) are precisely tuned for a specific detector application, coarsely segmented (pitch > 1 mm) strip arrays maintain high position resolution, a uniform detector response, do not require correction functions, and minimize the readout channel count.

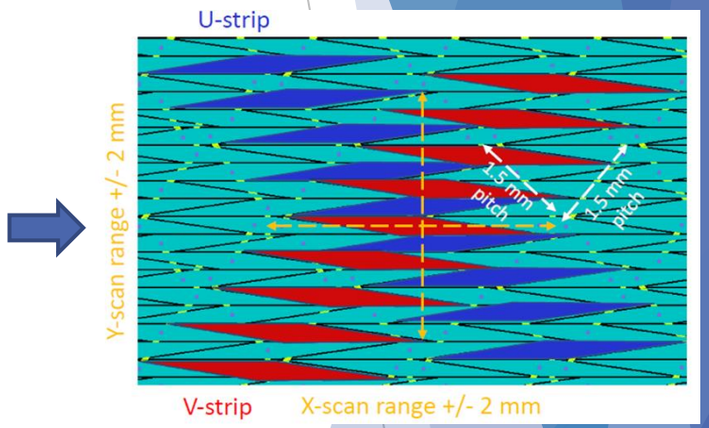
1D ZZ patterns

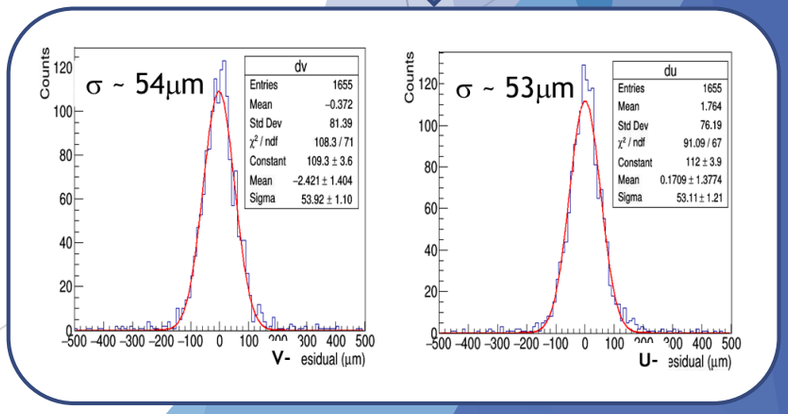


Interleaved anodes can be extended to the 2D case



2D ZZ pattern





Summary

- We have shown that 2D interleaved anode structures can be constructed by a relatively simple rearrangement of the 1D zigzag diamond-shaped elements
- The resulting 2D patterns with relatively coarse pitch are capable of producing excellent position resolution and a relatively uniform detector response both in a lab and beam test setting for both GEM and μRWELL (so far)
- While the 2D designs investigated did show a relatively small DNL, we expect this contribution to the overall resolution will be significantly minimized once the anode parameters are optimized, as was demonstrated for the 1D case

- *MPGD for Muon Collider*
- *PicoSec technology under investigation*

Muon detector for a Muon Collider

C. Aimè, S. Calzaferri, M. Casarsa, D. Fiorina, C. Riccardi, P. Salvini, I. Vai, N. Valle, P. Vitulo
on behalf of the Muon Collider Physics and Detector working group

International MUON Collider Collaboration

INFN Istituto Nazionale di Fisica Nucleare

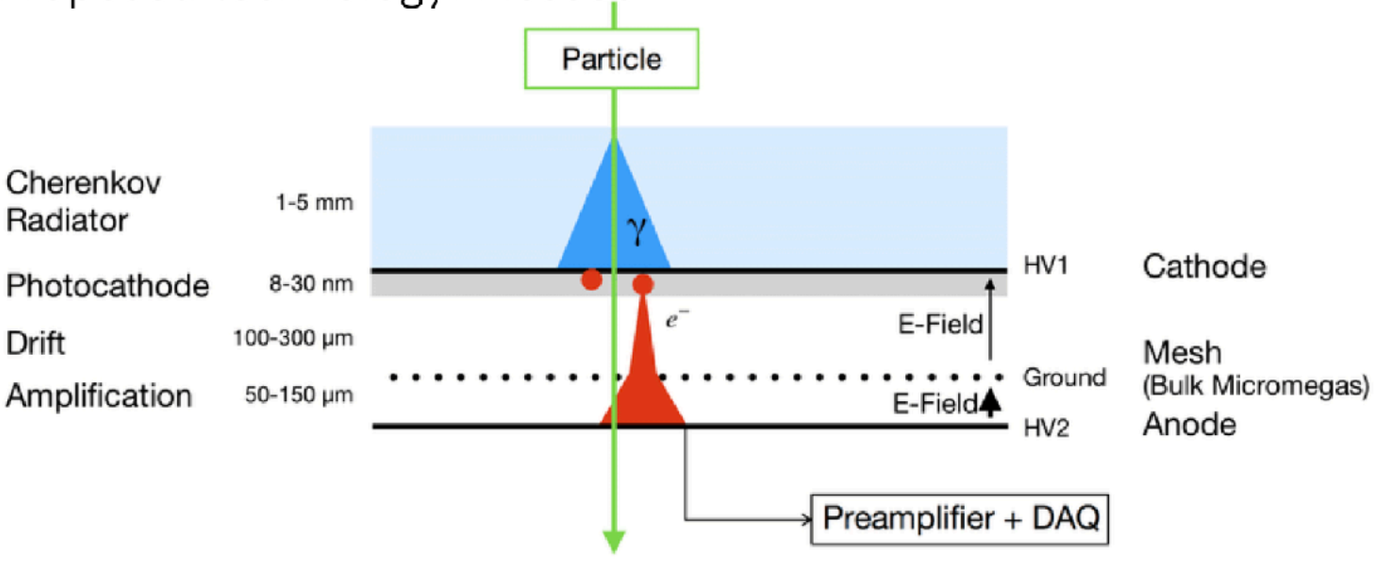
UNIVERSITÀ DI PAVIA

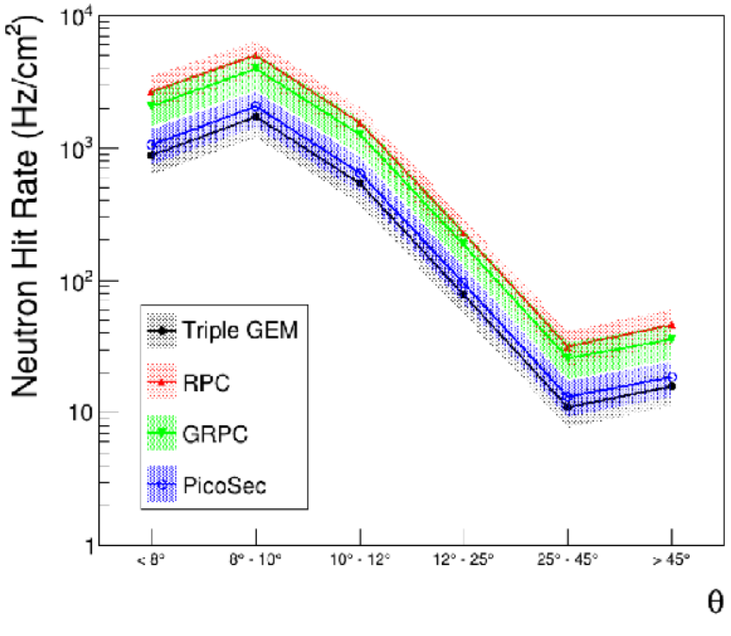
A muon collider has a great potential for the future of high energy physics.
The main challenge arise from the short muon lifetime and the harsh Beam Induced Background.

Parameter	Target value		
E_{cm}	3 TeV	10 TeV	14 TeV
$\mathcal{L}$	$1.8\ 10^{34}\ cm^{-2}\ s^{-1}$	$20\ 10^{34}\ cm^{-2}\ s^{-1}$	$40\ 10^{34}\ cm^{-2}\ s^{-1}$
$N_{mu/bunch}$	$2.2\ 10^{12}$	$1.8\ 10^{12}$	$1.8\ 10^{12}$

Muon system at a Muon Collider

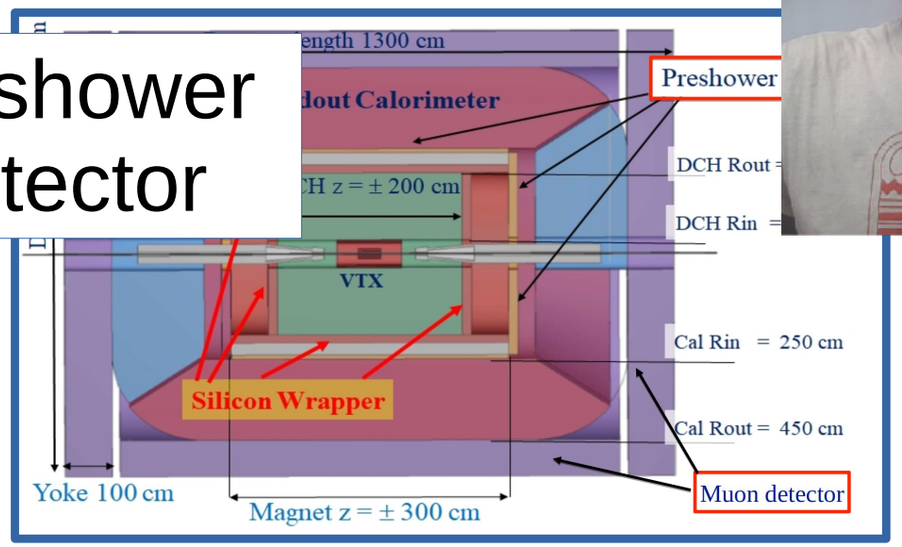
Current technology: Glass Resistive Plate Chambers
Proposed technology: Picosec





- *uRWell for pre-shower and muon detector in IDEA*
- *studies on resistivity effects*

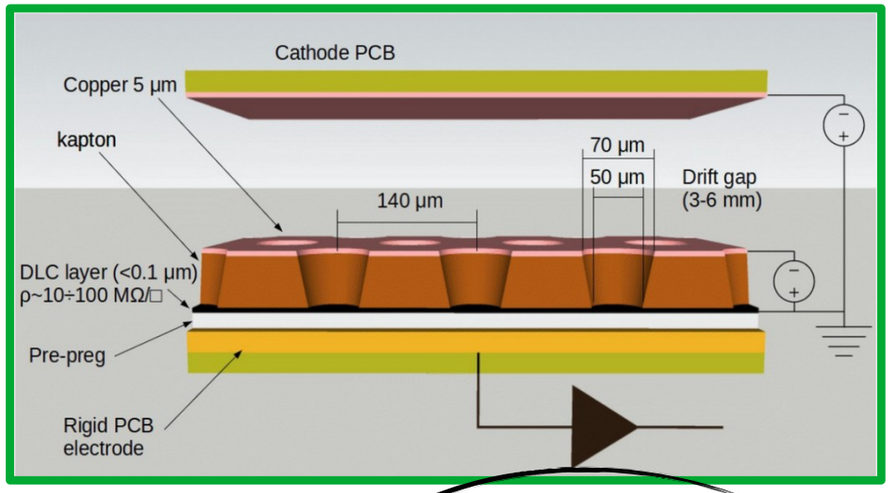
The **μ-RWELL** technology for the preshower and muon detectors of the **IDEA** detector

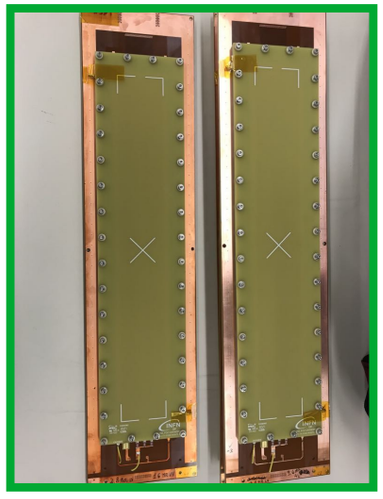


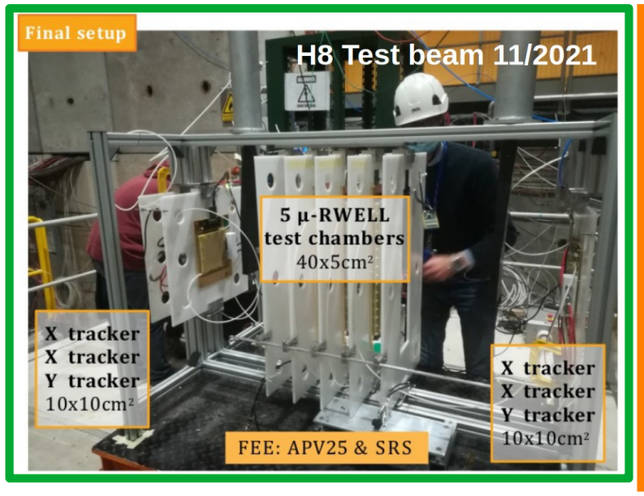
IDEA is detector concept for e^+e^- collisions considered both by FCC-ee and CEPC. The **μ-RWELL** technology is proposed for the pre-shower and the muon detector.

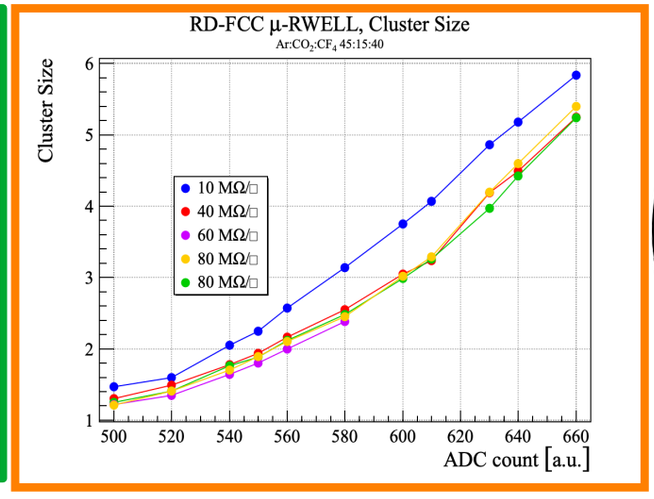
This resistive single stage amplification MPGD measures the position of charged particle tracks with a resolution better than 100μm with a compact design.

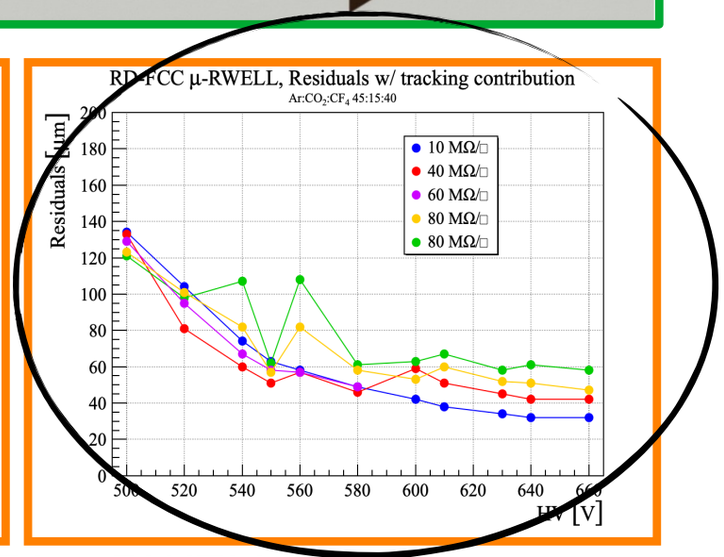
A **resistivity scan** between 10 and 80 MΩ/□ has been studied with a testbeam to evaluate the charge dispersion effect in order to optimize the strip pitch and the spatial resolution of the detector.





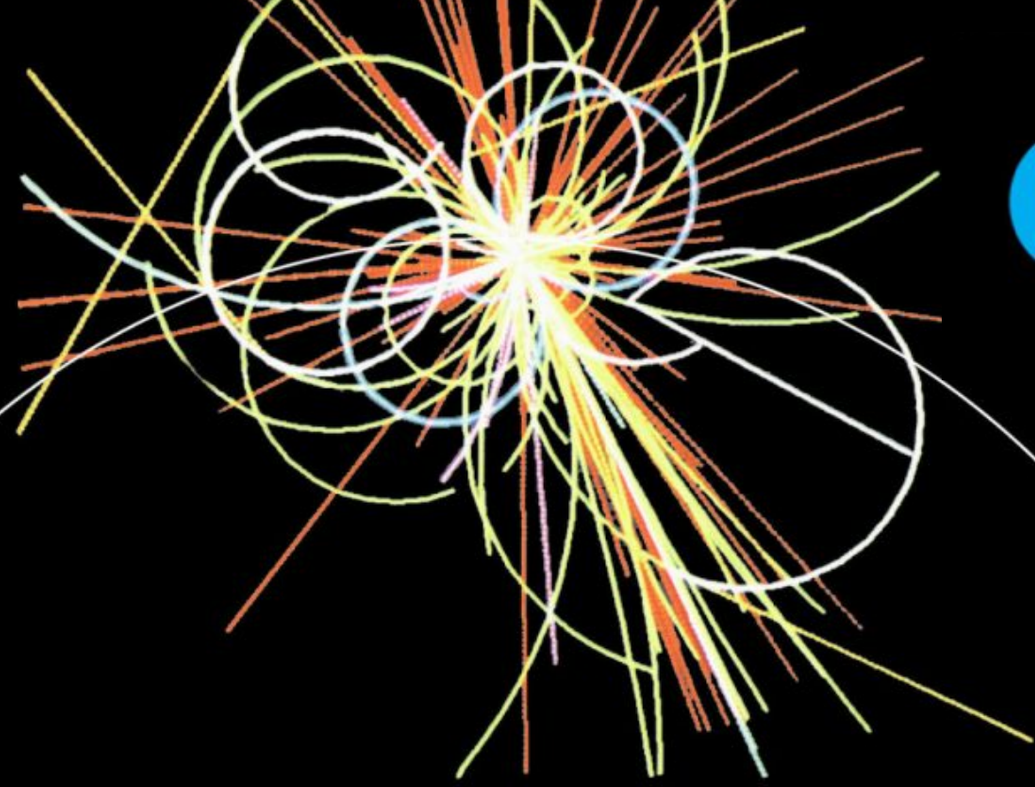






presented by: Riccardo Farinelli INFN – sez. Ferrara on behalf of the IDEA μ-RWELL working group

RPC



- Improving rate capability:
  resistive MPGD technology or temperature
- Improving RPC construction
- CMS upgrade: iRPC
- MRPC telescope of the EEE project

- *Based on development of DLC for MPGD in RD51*
- *Resistivity is a key element for RPC*
- *High rate capability with a high density current evacuation scheme*

sRPC: an RPC based on resistive MPGD technology

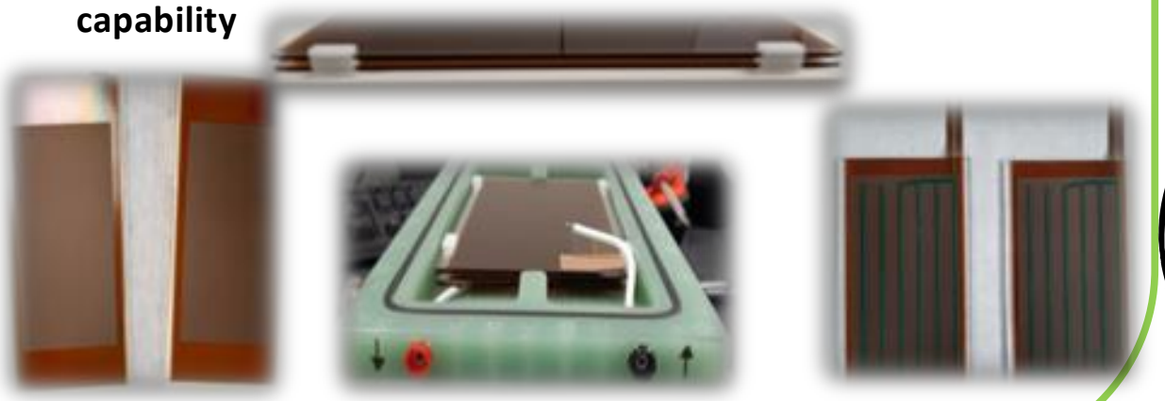
G. Bencivenni [1], R. De Oliveira[2], G. Felici[1], M. Gatta[1], M. Giovannetti[1], G. Morello[1], G. Papalino[1], M. Poli Lener[1] - [1] LNF – INFN, [2] CERN

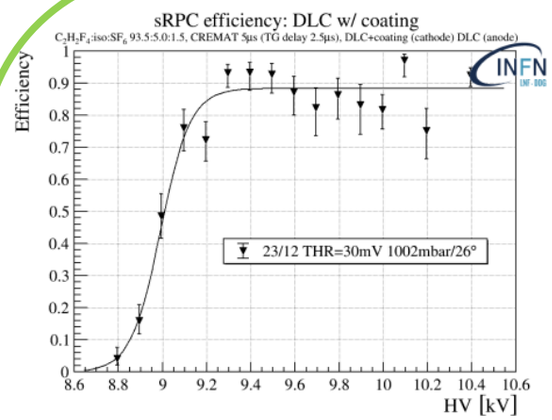
Classical RPC

- **bulk resistivity electrodes**
- **recovery time** proportional to **volume resistivity** and **electrode thickness**

Surface-RPC

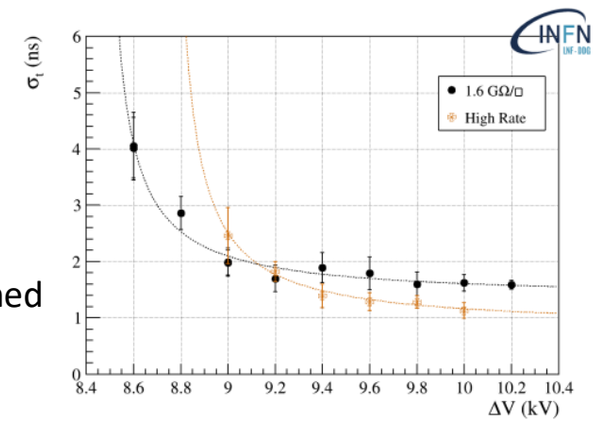
- **surface resistivity electrodes** manufactured with sputtering techniques of **Diamond-Like-Carbon on flexible supports** (**scalable and cost-effective technology**)
- **electrodes with a surface resistivity** in a **very wide range, 0.001 ÷ 10 GΩ/□**
- **high density current evacuation schemes**, (similar to those used for **μ-RWELL),** can be implemented **to achieve high rate capability**





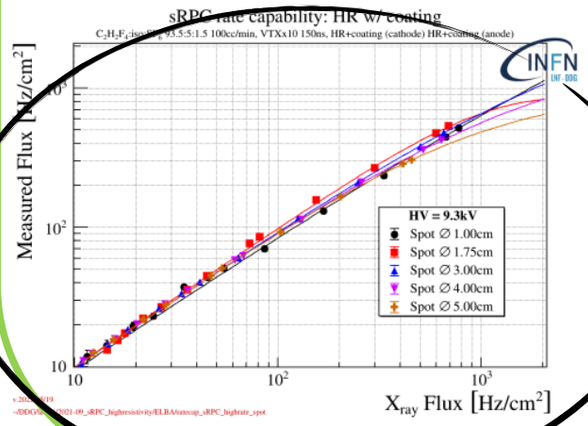
High stability

>1kV wide operating voltage achieved with **cathode passivation**



Time resolution

Typical ~**1 ns time resolution** obtained with different **sRPC prototypes**



High-rate layout

- **Conductive grid: ground pitch ~1 cm, DLC resistivity ~ 7GΩ/□**
- **Optimizing ground-pitch & reducing surface resistivity a rate capability > 20kHz/cm² with m.i.p should be easily achievable**

- *decrease the resistivity by increasing operational temperature*
- *improving count rate capability*

Improving count rate capability of timing RPCs by increasing the detector working temperature

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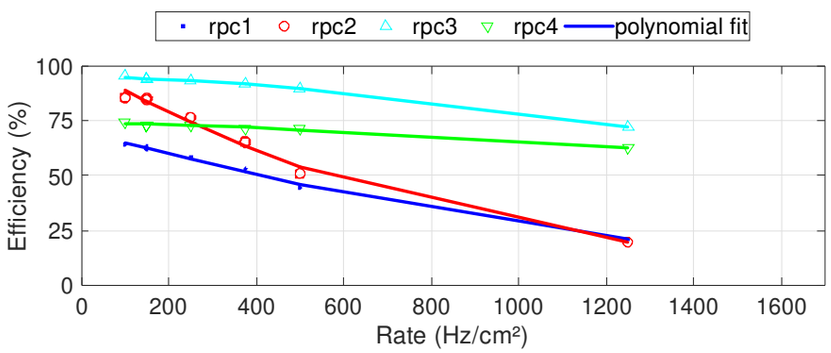
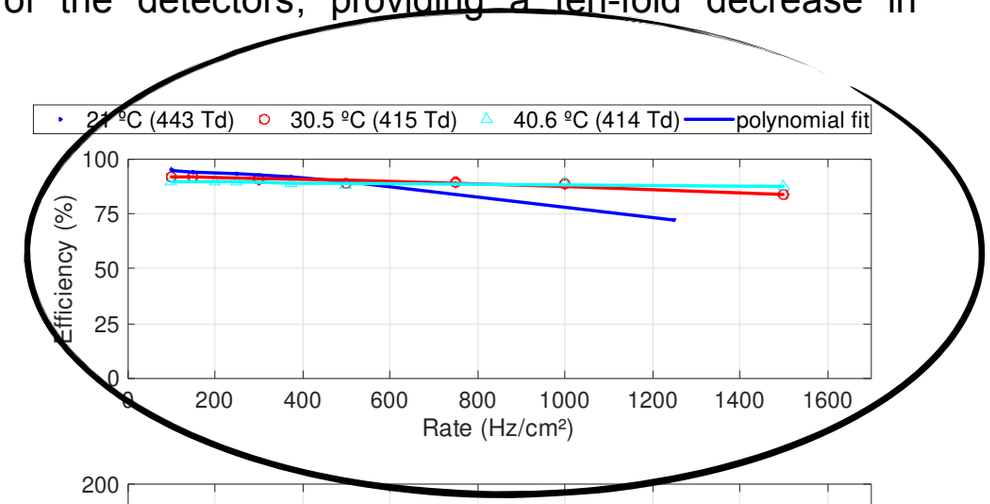
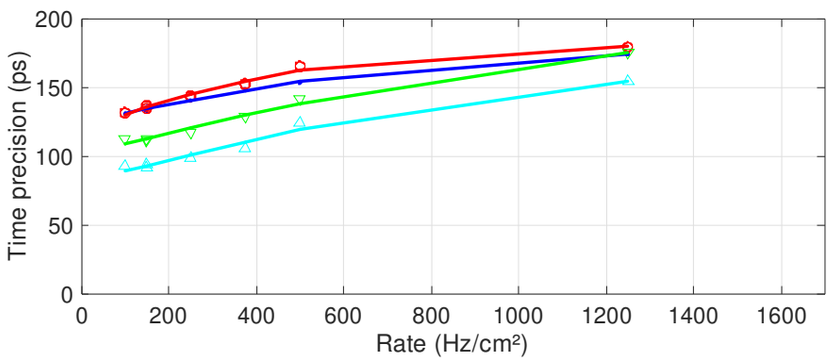
[1] Laboratory of Instrumentation and Experimental Particles Physics, Coimbra, Portugal

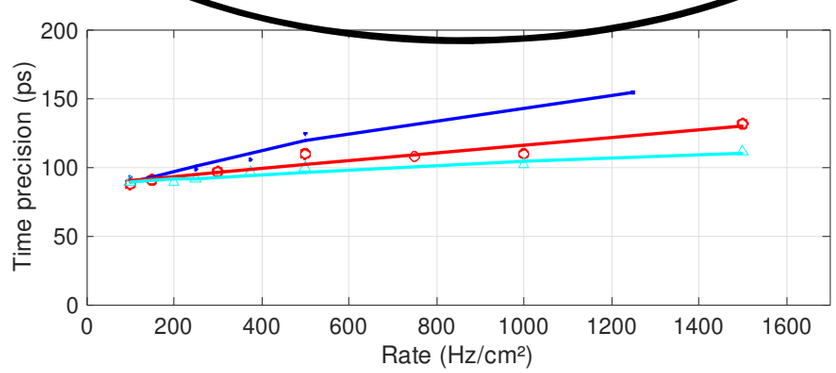
[2] Coimbra Polytechnic - ISEC, Coimbra, Portugal

tRPC have traditionally been **used with relatively low particle flux density (< kHz/cm²)** due to the inherent **limitation** to the counting rate imposed by the commonly used float **glass electrode resistivity**. One possibility, still very little explored, is to **decrease the resistivity** of standard float glass **by increasing the operational temperature** of the detectors, providing a ten-fold decrease in resistivity every 25 ºC.



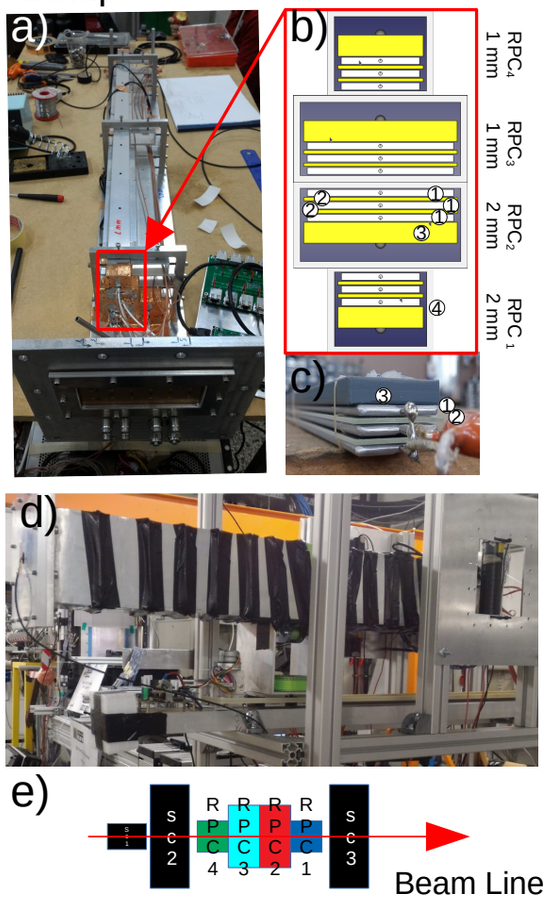






We have shown that **increasing the working temperature of a tRPC can substantially improve its counting rate capability.** In particular, individually shielded strip-like tRPC chambers with an active area of 750 x 44 mm equipped with 4 gaps of 0.270 mm, show the same efficiency, 90 %, and approximately the same timing precision, 100 ps, over a range of incident particle fluxes up to 1500 Hz/cm² when their working temperature is raised to 40.6 ºC. This contrasts with a 20 % loss of efficiency and a worsening of temporal precision of more than 60 ps when operated at 21 ºC.

Setup



a) Internal arrangement of the tRPC chambers. b) Cross section of the four chambers arrangement. c) RPC chamber: 1 aluminum and 2 glass electrodes, 3 plastic support bar, 4 aluminum tube. d) Panoramic view of the setup in the beam line, showing the tRPC chambers gas box, surrounded by the heating wire, and the last scintillator of the telescope. e) Cross section of the scintillator and tRPC chambers in the beam line.

INFN Istituto Nazionale di Fisica Nucleare

EMU

A new graphene-based RPC fully built with additive manufacturing

Roberto Campagnola (*Laboratori Nazionali di Frascati- INFN*) *et al.*

- *3D printing*
- *new electrode material graphene-doped PLA*

A fully automated 3D printing of a detector would reduce drastically:

- *Detector construction cost and assembly time*
- *The probability of mistakes during construction*

Introduced and optimized a new electrode material (graphene-doped PLA) to match the properties of the existing Bakelite featured in RPC detectors. The new material is extruded in a filament form, readily usable by any general-purpose desktop 3D printers

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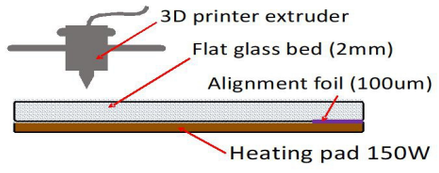
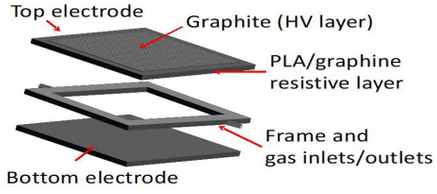
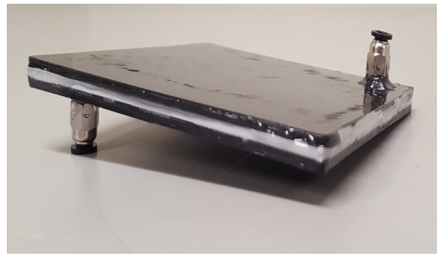






- Additive manufacturing dramatically reduces **prototyping costs** and the need for an industrial partner
- In-house design and fabrication allows **complete control** of the **costs, timeline** and **design** optimization
- Prototyping and testing is a formative learning **educational tool** that shapes young students

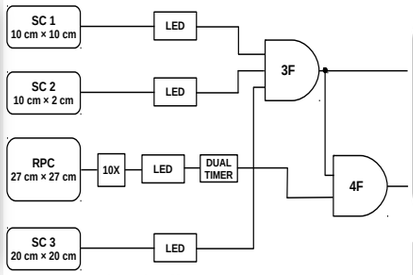
linsed oil coating before closing the gap

PM2021 - 15th Pisa Meeting on Advanced Detectors - Edition 2022 May 22 – 28, La Biodola - Isola d'Elba (Italy)

Characterisation of a new RPC prototype using conventional gas mixture

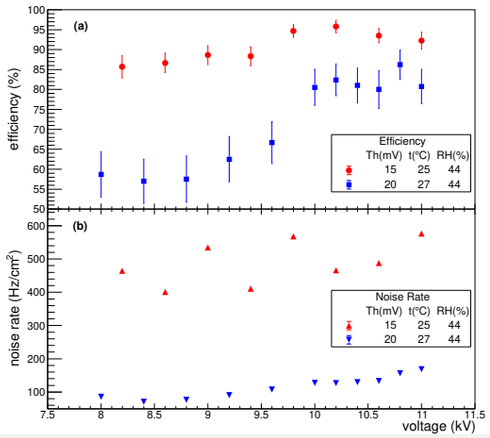
A. Sen, S. Chatterjee, S. Das, S. K. Ghosh, S. Biswas
Department of Physics, Bose Institute, Kolkata-700091, INDIA

Oil coated bakelite surface — Complete RPC module

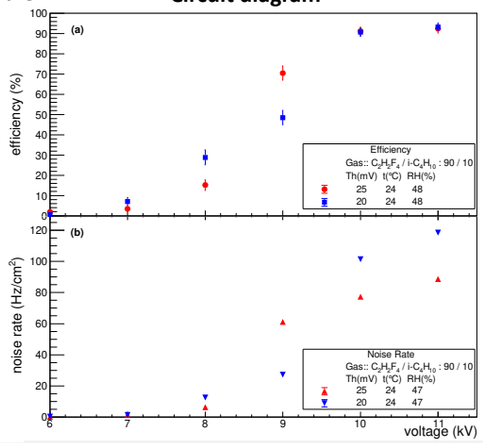


Circuit diagram

The linseed oil coating is done before making the gas gap. The advantage of this procedure is that after linseed oil coating it can be checked visually whether the curing is properly done or any uncured droplet of linseed oil is present.



The efficiency and noise rate as a function of the voltage for 100% $C_2H_2F_4$



The efficiency and noise rate as a function of the voltage for $C_2H_2F_4$ / i-C_4H_{10} : 90/10 volume ratio

- **~ 2 g of linseed oil is applied over each surface. Based on the specific gravity (0.930 at 15.5°C) of the fluid, the estimated coating thickness would be ~ 30 µm**
- ***For 100% $C_2H_2F_4$***

@Threshold: -15 mV
efficiency ~95% noise rate ~500 Hz/cm²
@Threshold: -20 mV
efficiency ~85% noise rate ~200 Hz/cm²

- ***For $C_2H_2F_4$ / i-C_4H_{10} : 90/10***

@Threshold: -20 mV
efficiency ~95% noise rate ~120 Hz/cm²
@Threshold: -25 mV
efficiency ~95% noise rate ~90 Hz/cm²

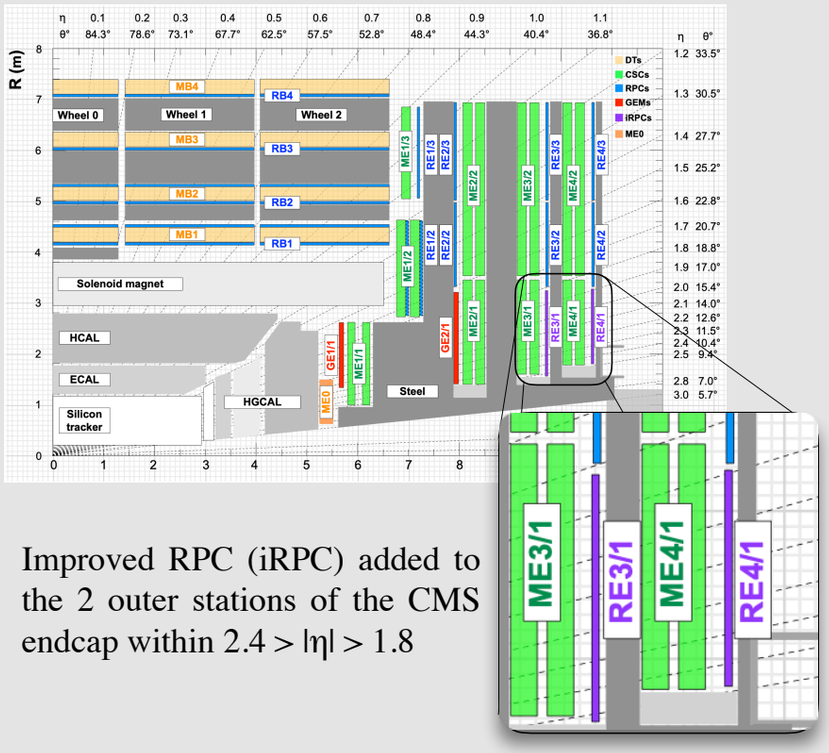
- *CMS upgrade with iRPC with 1.4 mm gas gap*
- *new FEB*

Performance of the improved RPC demonstrators for the CMS Phase II upgrade

Ece Asilar on behalf of the CMS collaboration
Hanyang University, Seoul, Republic of Korea

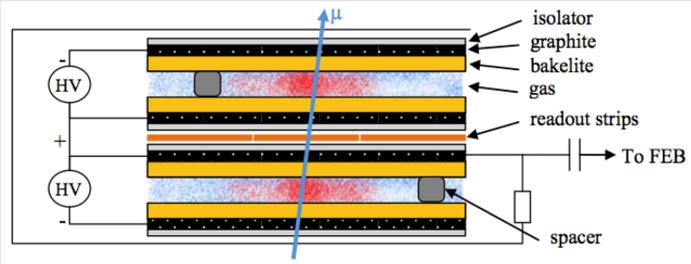
Motivation

In order to cope with the high particle rate and high pileup environment of the HL-LHC, the CMS collaboration proposed[1] installation of new RPCs.



Improved RPC (iRPC) added to the 2 outer stations of the CMS endcap within $2.4 > |\eta| > 1.8$

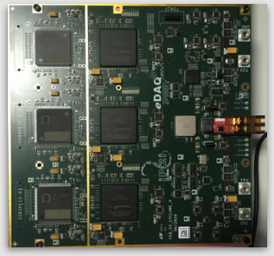
The iRPC Chamber

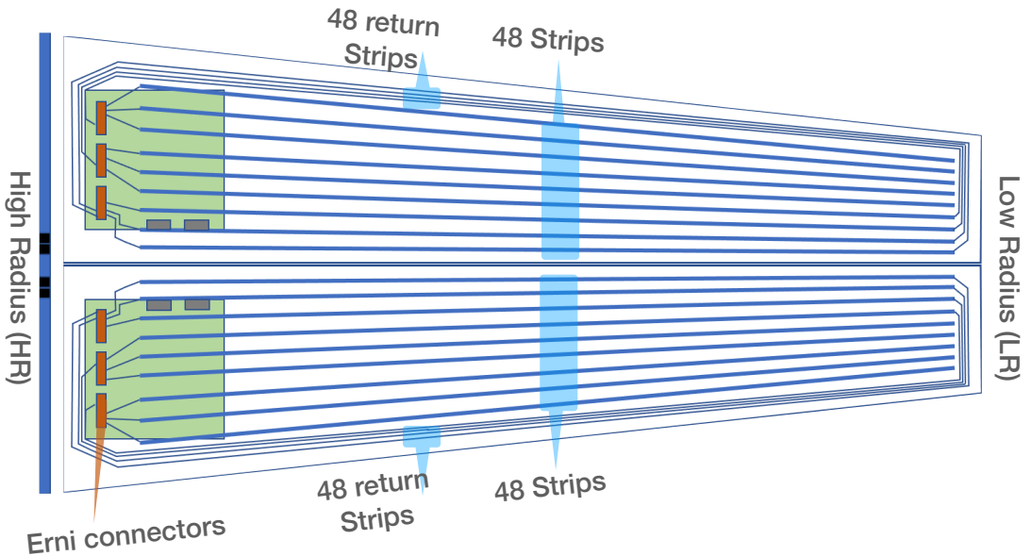


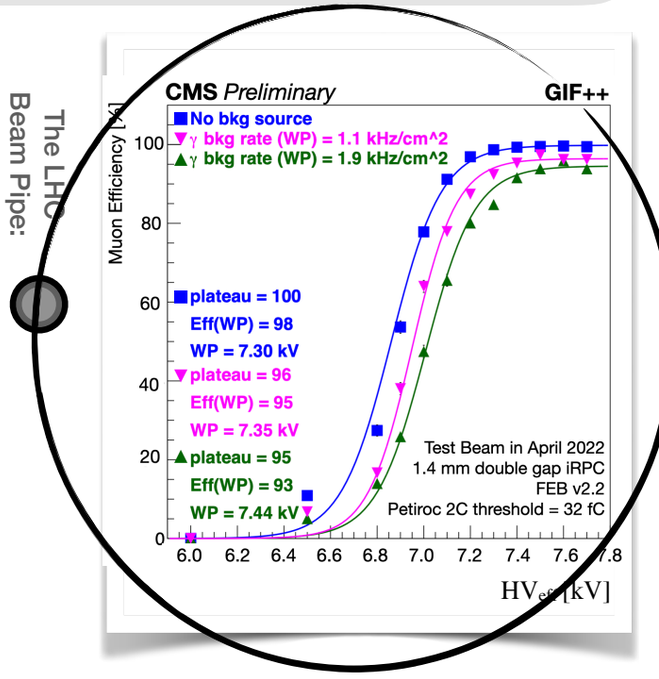
Double-gap iRPC detectors with each gap made of two 1.4 mm low-resistivity High Pressure Laminate electrodes are separated by a gas gap of the same thickness.

The Front End Board

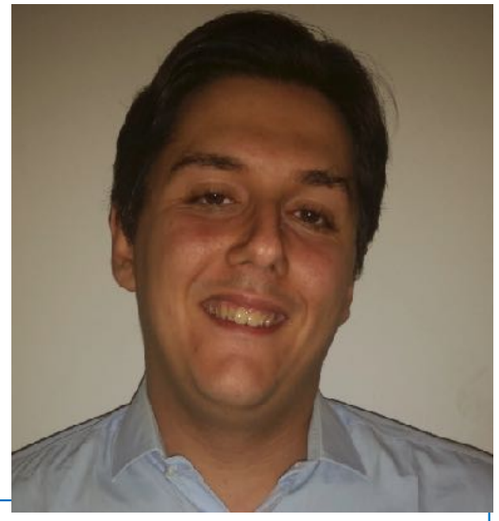
To cope with the lower charge signal of the iRPC at the same time to keep the iRPC efficiency high, the new front-end electronics (FEB 2.2) are designed. The new FEB is sensitive, has low-noise and high time resolution.







- *MRPC as muon telescope for EEE project*
- *WaveBoard to prepare a streaming and synchronized GPS acquisition system*



A cosmic muon test facility with the MRPC telescopes of the EEE Project

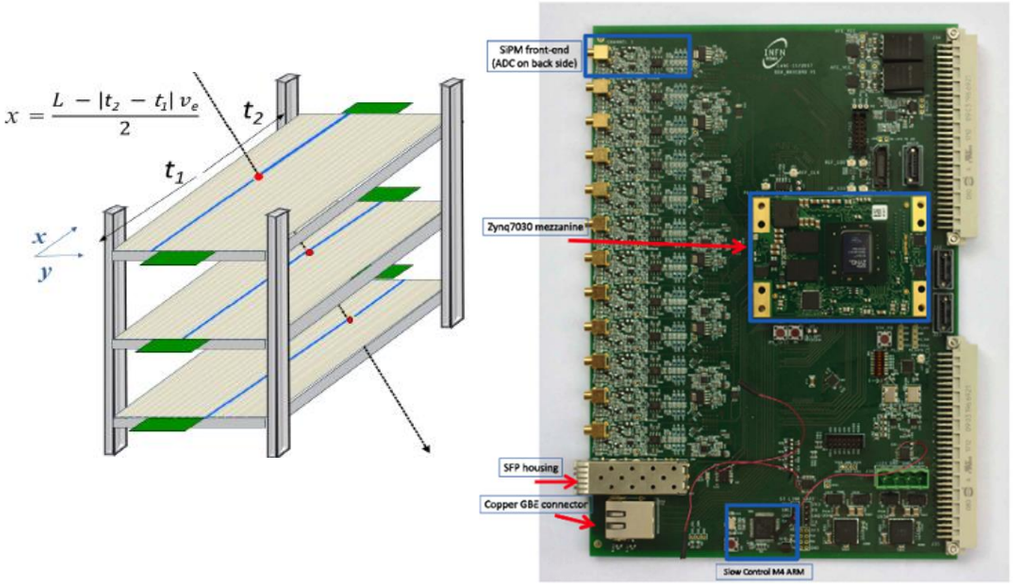
Extreme Energy Events (EEE) detectors (telescopes) are designed to measure secondary cosmic ray tracks, with good spatial resolution, to study high energy primary cosmic rays.

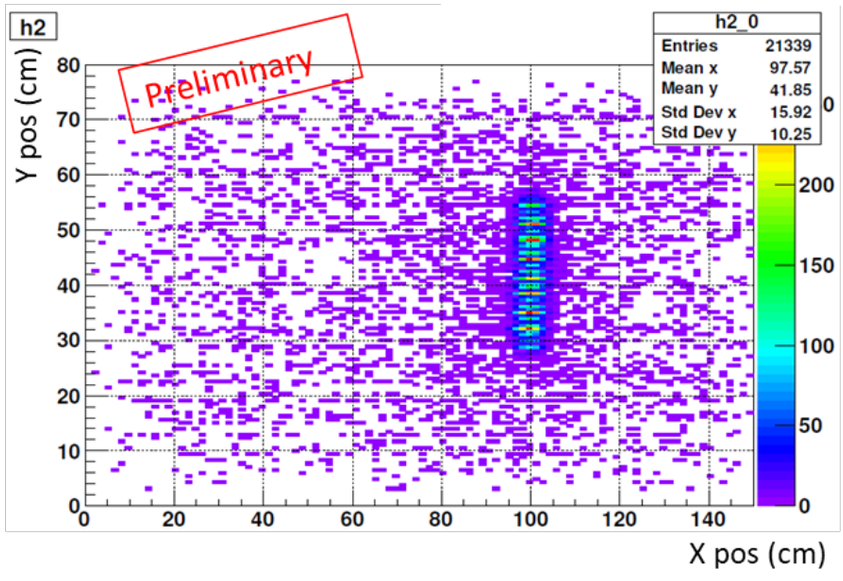
A Highly configurable digitizer board (**Waveboard**) is developed for Beam Dump eXperiment (BDX) at Jefferson Laboratory (Jlab) but is usable also for other kind of detector.

The simultaneous presence, in the INFN section of Genova, of an EEE telescope, the INFN-Waveboard (WB) and experts in both devices led to the creation of a collaboration. The result is the development of a detectors test facility that integrated the EEE large area detector tracking capabilities with the WB's multi-device simultaneous streaming data acquisition.

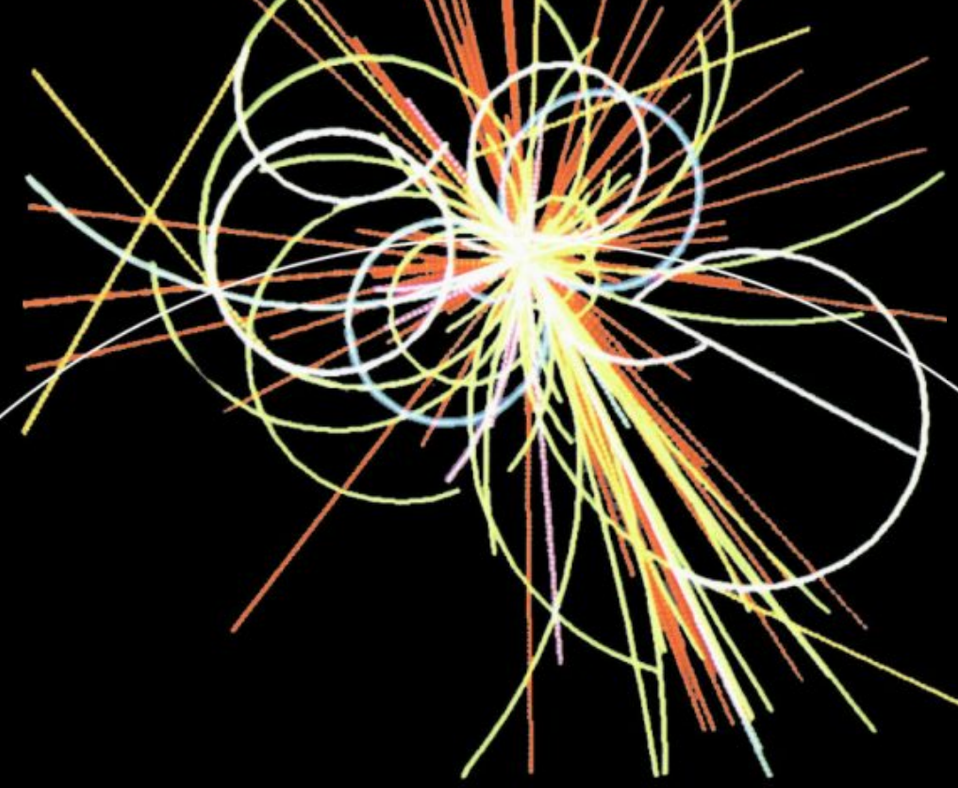
The link between the EEE track and signals from the detector under test detector is obtained by implementing a streaming DAQ with a common time reference between the two systems given by the GPS signal.

According to the detector under examination, different measurements can be performed: in a scintillator crystal bars, for example, the efficiency and optical attenuation along the detector length can be easily tested. In a first test run, we characterized some scintillator crystal of PbWO4 from the POKER detector.





Gas properties and eco-gas



- Eco-gas mixtures for EEE and LHC experiments
- Low gas consumption for RPC detector
- New set-ups for measurement of e- transverse diffusion and ion mobility
- Investigating effects of hydrocarbons in He-CF_4 mixtures

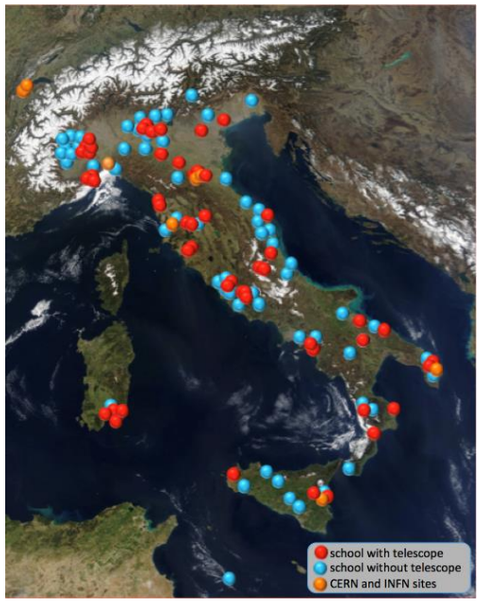
- *60 detectors made of 3 MRPC operated with 98% $C_2H_2F_4$*
- *Encouraging results with a mixture containing $C_3H_2F_4$ and He*

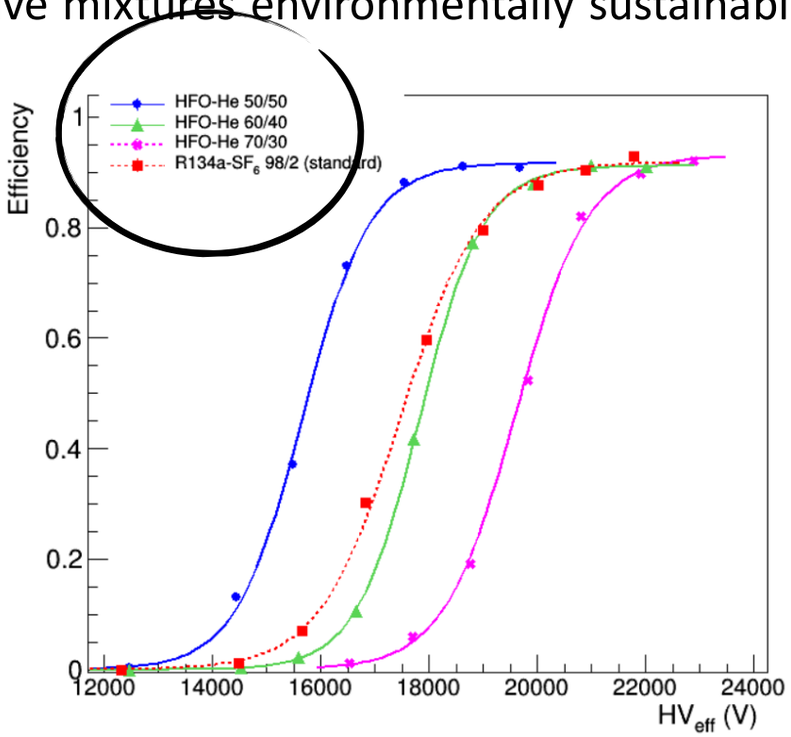
Studies on new Eco-gas mixtures for Extreme Energy Events Project

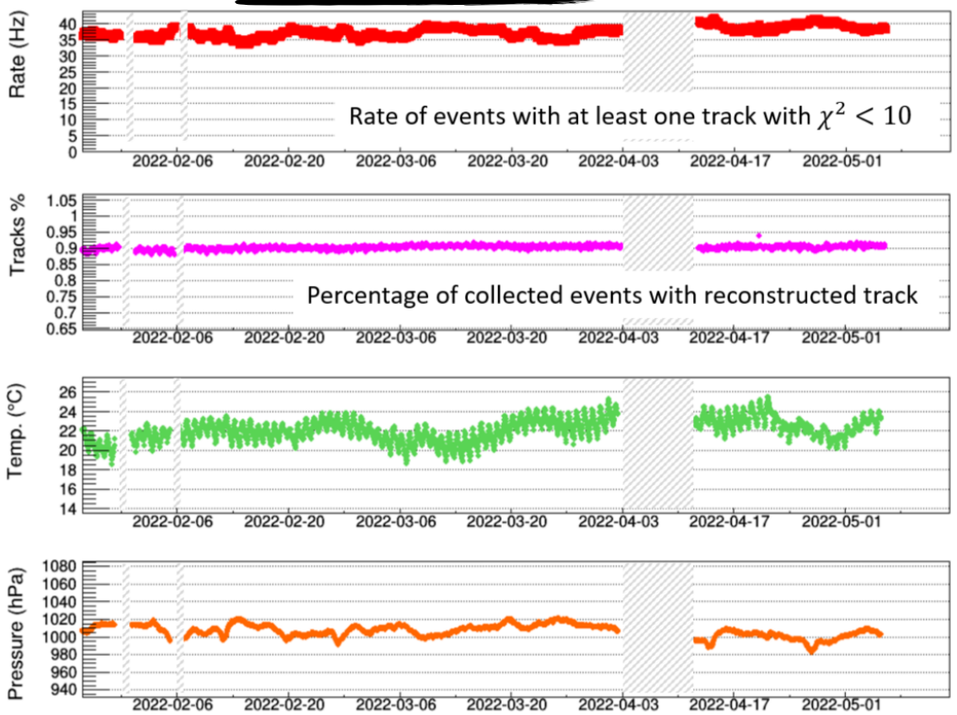
Edoardo Bossini[1,2] on Behalf of the **CMS** Collaboration

1) Università di Pisa, Pisa, Italy 2) INFN-Sezione di Pisa, Italy

The Extreme Energy Events (EEE) experiment, a joint project of the Centro Fermi and INFN national research institutes, has a dual purpose: a scientific research program for measurements of the cosmic rays fluxes at ground level and an intense outreach program with an active contribution of students and teachers in the construction and operation of the detectors. The network counts 60 tracking detectors, each made by three Multigap Resistive Plate Chambers (MRPC) , operated so far with a gas mixture composed by 98% $C_2H_2F_4$ and 2% SF_6. Given its high Global Warming Potential (GWP), the collaboration started a R&D on alternative mixtures environmentally sustainable. Latest results on $C_3H_2F_4$ + He mixture are presented in the poster.





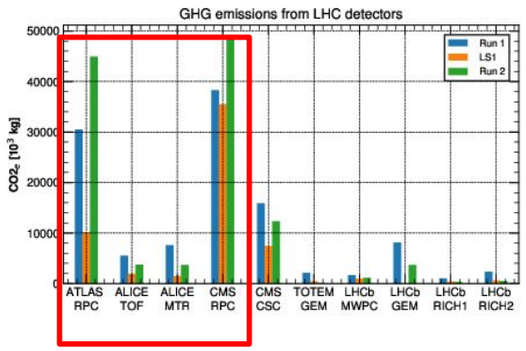


- *searching for eco-friendly gas mixtures for LHC experiments*
- *alternatives to both $C_2H_2F_4$ and SF_6*
- *studies in presence of HL-LHC background radiation*

Studies on RPC detectors operated with environmentally friendly gas mixtures in LHC-like conditions

Resistive Plate Chambers detectors at LHC

- Used in ALICE, ATLAS, CMS gas systems
- Gas mixture: ~95 % R-134a (GWP 1430) and 0.3% SF6 (GWP 22800)
- Responsible for 85% of GHG emissions, due to high GWP gas mixture and leaks at detector level

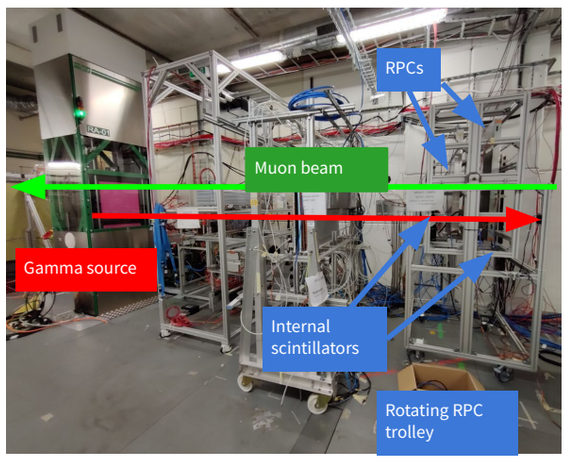


Goal:

*Find a **low-GWP** gas mixture **suitable** for **LHC-operation** that requires **no change** in the current RPC systems (i.e. no change in electronics, HV, gas systems, etc.)*

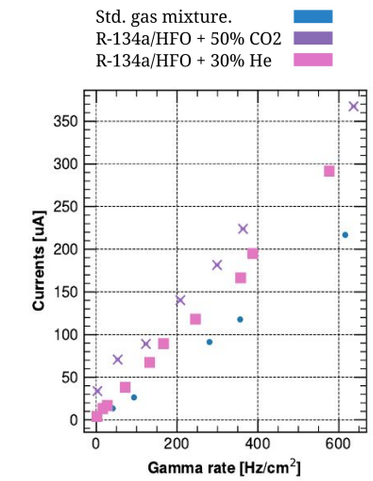
Experimental campaign

- HPL RPCs, 2 mm, single gap
- Laboratory setup: cosmics muons, low rates
- GIF++ setup: muon beam, gamma background, LHC-like conditions
- HV scans performed with different gas mixtures: characterization of efficiency, streamer probability, prompt charge, cluster size, time resolution



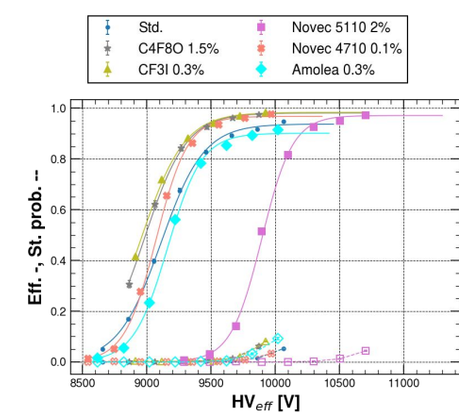
Alternatives to R-134a

- R-1234ze (HFO) main candidate
- Cannot replace 1:1 R-134a → too electronegative
- Addition of CO2 or He necessary
- Some amount of R-134a kept to stabilize performances



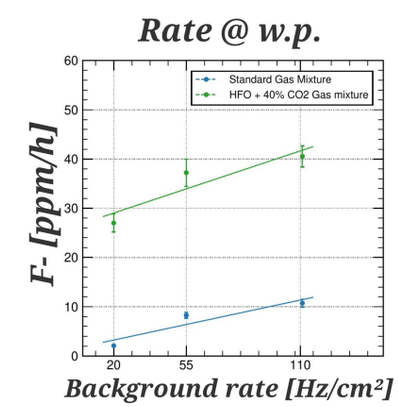
Alternatives to SF6

- 5 alternatives tested
- Novec 4710 and Amolea 1224yd matching SF6 performances
- Both gases requires more studies to understand their chemical stabilities under background radiation and electric field

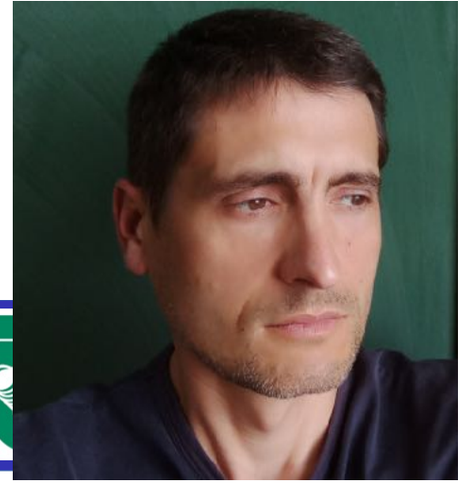


Impurities studies

- Studies on F- production from RPCs in LHC-like conditions
- Standard gas mixture and R-1234ze gas mixture characterized
- R-1234ze producing more F- ions than R-134a



- *reducing gas consumption by reducing gas flow*
- *effects in detector performance*



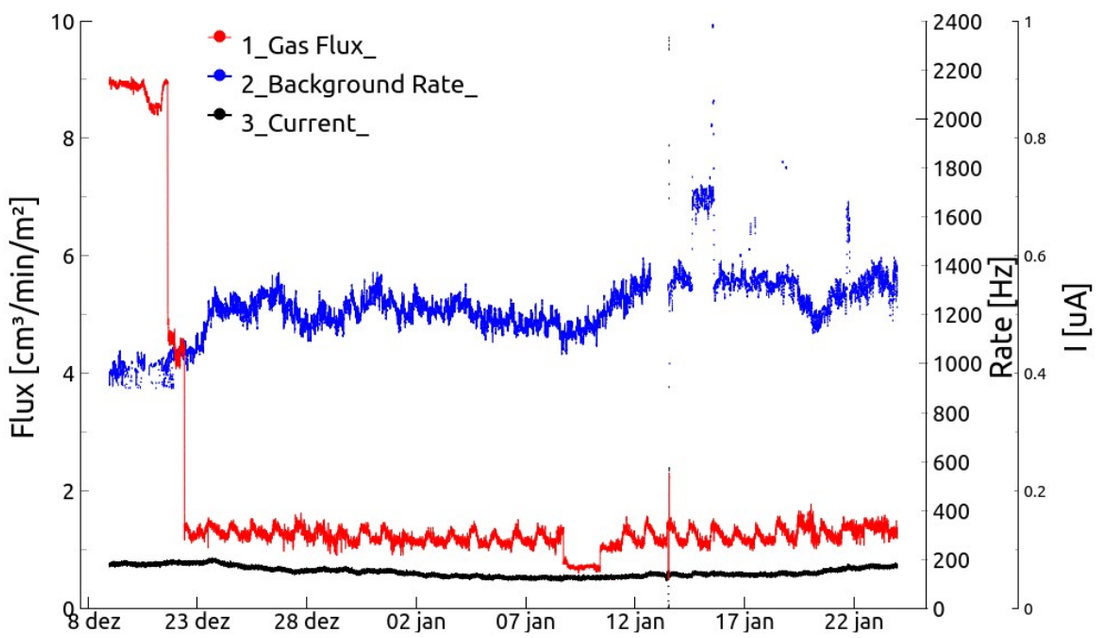
ADVANCES TOWARDS A LARGE-AREA, ULTRA-LOW-GAS-CONSUMPTION RPC DETECTOR

Large Resistive Plate Chambers (RPCs) operate with complex gas systems, equipped with re-circulation and purification units, which require a fresh gas supply of the order of 6 cm³/min/m², creating logistical, technical and financial problems.

New EU legislation established the progressive phasing out of the main gas used on RPCs (R-134a) due to its Global Warming Potential (GWP), which has further increased constraints on these systems.

In this communication, we present an RPC, with an active area of 2m², operated during more than one month in a ultra-low gas flow regime (1 cm³/min/m²) thanks to the R&D performed in its construction, namely the use of polypropylene – which presents excellent water vapor blocking properties – in several parts of the detector.

When the gas flux was reduced to a residual value, the background rate increased 50% in few days. We also show in this presentation the region of the detector that contributed the most to this increase.



FCT Fundação para a Ciência e a Tecnologia

- *new experimental set-up to measure e^- traverse diffusion*
- *e^- multiplication with GEM foil*
- *results in agreement with existing data*

A New Experimental System for Electron Transverse Diffusion Measurements

A.M.F. Trindade[a,b], J. Escada[a,b], J.M. Maia[a,c], R.M. Curado da Silva[a,b] and F.P. Santos[a,b,*]

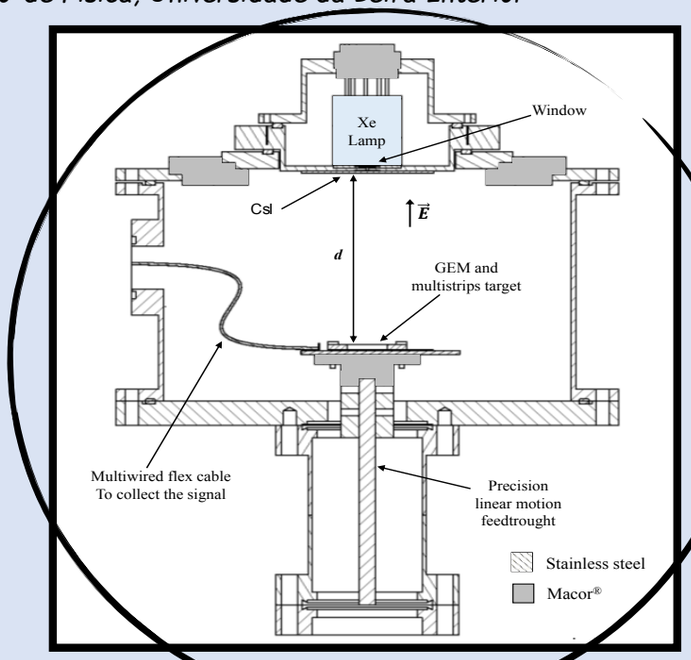
** Corresponding autor: filomena.santos@coimbra.lip.pt*

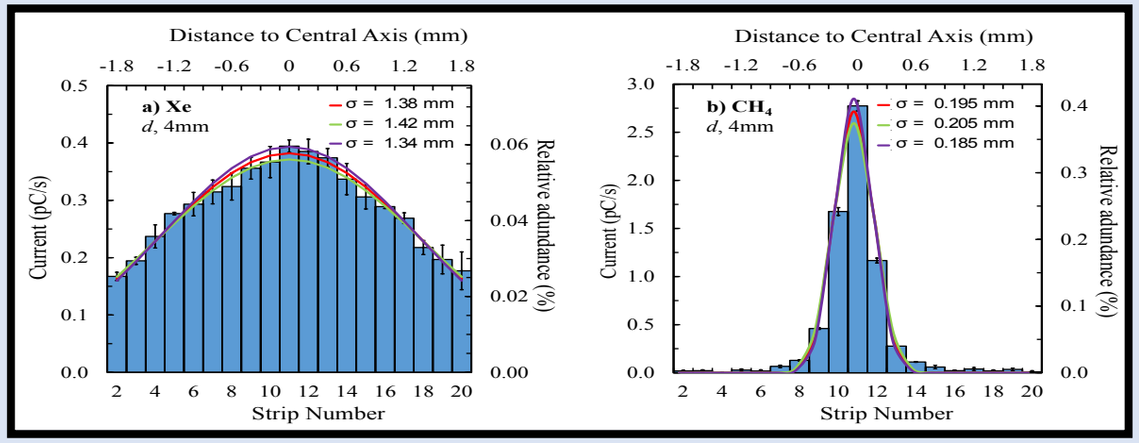
[a] LIP – Laboratório e Física Experimental de Partículas, [b] Departamento de Física da Universidade de Coimbra, [c] Departamento de Física, Universidade da Beira Interior

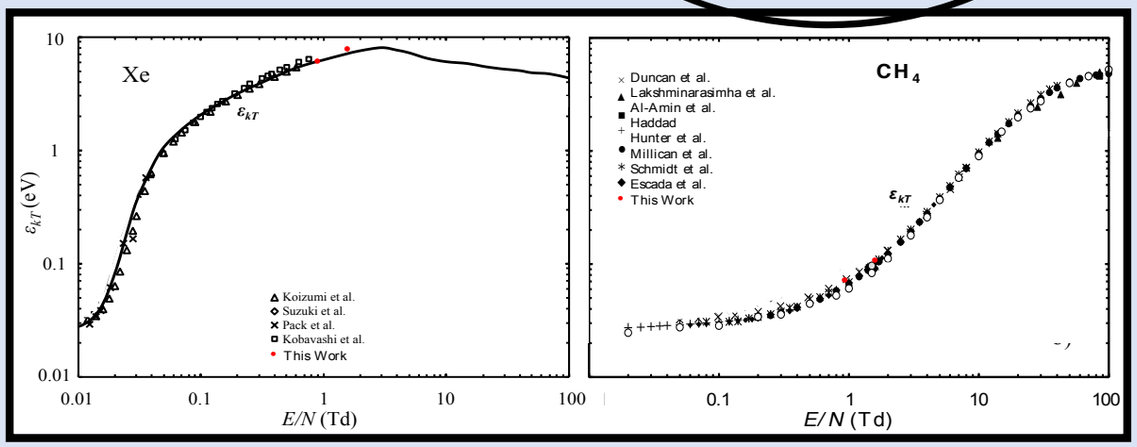
In the large size ongoing experiments for particle physics and rare event experiments new gas media are being used or sought. One of the key features required for these media is low electron transverse diffusion, to achieve good tracking accuracy that will enable the most needed background rejection. The properties of these new mixtures are mostly unknown and assessing them beforehand is paramount.

We present a new device designed to measure electron transverse diffusion in a gas medium. The device is composed of a Xe lamp and a measuring chamber separated by a quartz window. In the chamber side of the window, where a transmissive CsI photocathode was deposited, photoelectrons produced by the lamp are guided through a drift electric field to a GEM, where they are multiplied, before being collected in a flange - an insulating substract, where metal strips are deposited and duly biased, located at a fixed distance (0.5 mm) from the GEM. The flange is mounted on a precision motion feedthrough that enables to set the variable drift distance, between 3.78 and 60 mm. The charge is collected in each strip with an electrometer, at several drift distances.

Results for transverse diffusion coefficients are obtained from charge distributions for the different drift distances, taken at each setup settings. Preliminary results have already been obtained in pure Xe and CH_4 - two gases with different electron drift properties – and are in good agreement with available data.







- *new experimental set-up to measure mobility of positive and negative ions*
- *foster understanding of transport properties of ions in gases*

Dual Polarity Ion Drift Chamber: Results with Xe-SF_6 mixtures

A.P. Marques, D.J.G. Marques, N.G.S. Duarte, J.P.M. Teles, A.F.V. Cortez,
A.M.F. Trindade, J. Escada, F.P. Santos and F.I.G.M. Borges

A new experimental system was recently developed at LIP-Coimbra to measure the mobility of both positive and negative ions: the Dual-Polarity Ion Drift Chamber (DP-IDC). This new system is intended to foster the understanding of transport properties of ions in gases, as these are specially relevant for the performance of gaseous detectors, namely in large volume ones, in particular for the development/optimization of the performance of Negative Ion Time Projection Chambers (NITPCs) for rare event searches such as the experiments CYGNUS, XENON or NEXT. The optimization/fine tuning of gas mixtures for such detectors gains special relevance as drift of negative ions in these detectors can significantly affect the signal formation, the tracking capability and spatial resolution, eventually limiting their rate capability. In addition, a comprehensive understanding of the different ion species expected in particular gas mixtures, can also be of extreme importance as it may allow to identify potential minority charge carriers (negative ions) which are the basis for the development of additional internal trigger methods in NITPCs while enabling to further reduce the background on such detectors.

In this work, we present a description of the experimental setup and technique used, and the initial studies carried out in mixtures of interest in NITPC's, namely in Xe-SF_6 mixtures, whose interest has attracted attention as a possible alternative in searches for the neutrinoless double-beta decay.

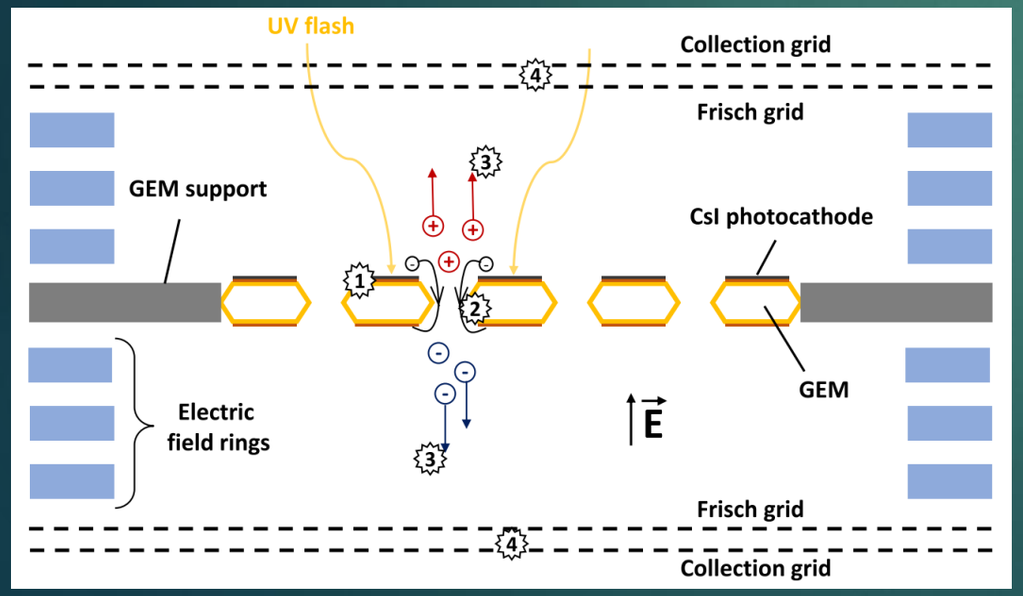


Fig. 1 – Schematic of the DP-IDC

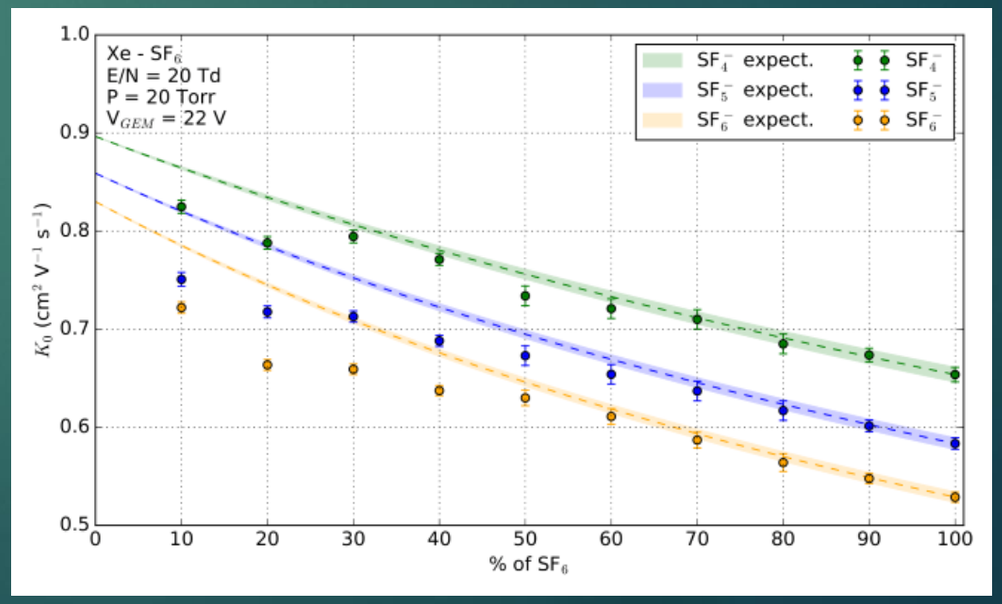


Fig. 2 – Ion mobility for Xe-SF_6 mixtures

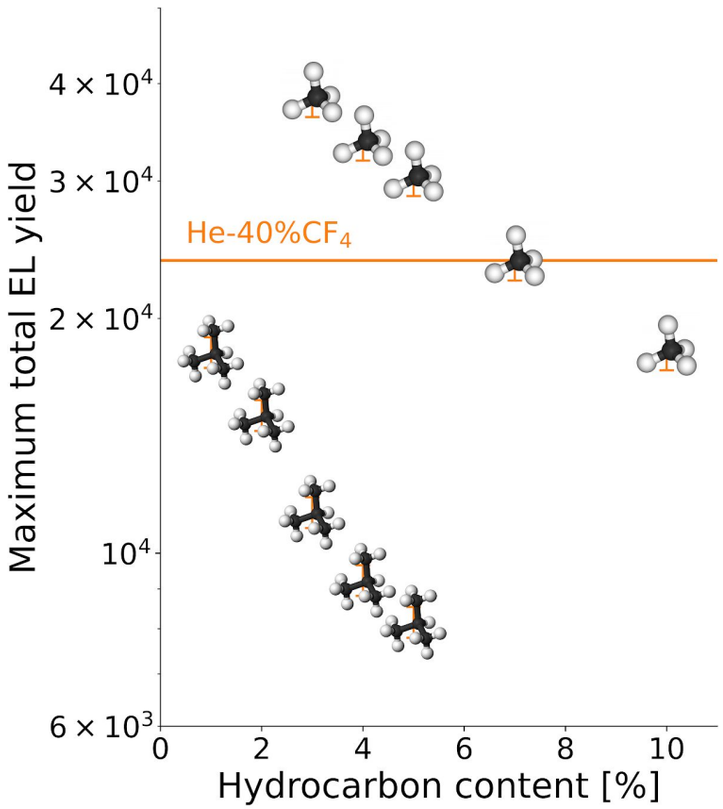
- *investigating the use of iC_4H_{10} and CH_4 in a He-CF_4 mixture for WIMP*
- *electroluminescence yield of iC_4H_{10} and CH_4 evaluated*

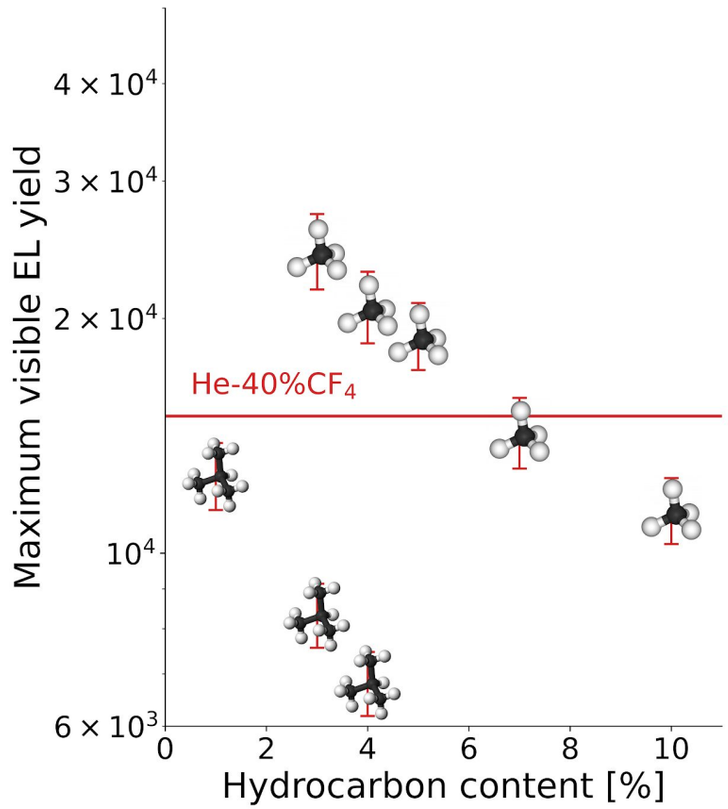
Effects of hydrocarbon admixtures to the electroluminescence yield of He-CF_4

R.J.C. Roque, R.D.P. Mano, F.D. Amaro, C.M.B. Monteiro, J.M.F. dos Santos

LIBPhys-UC Department of Physics, University of Coimbra, Portugal

He-CF_4 is a very attractive gas mixture for Optical Readout Detectors in Dark Matter Search, such as the CYGNO collaboration. **Small percentages of hydrocarbon would further improve their sensitivity to low WIMP mass, but their effect on the optical readout is unknown.**



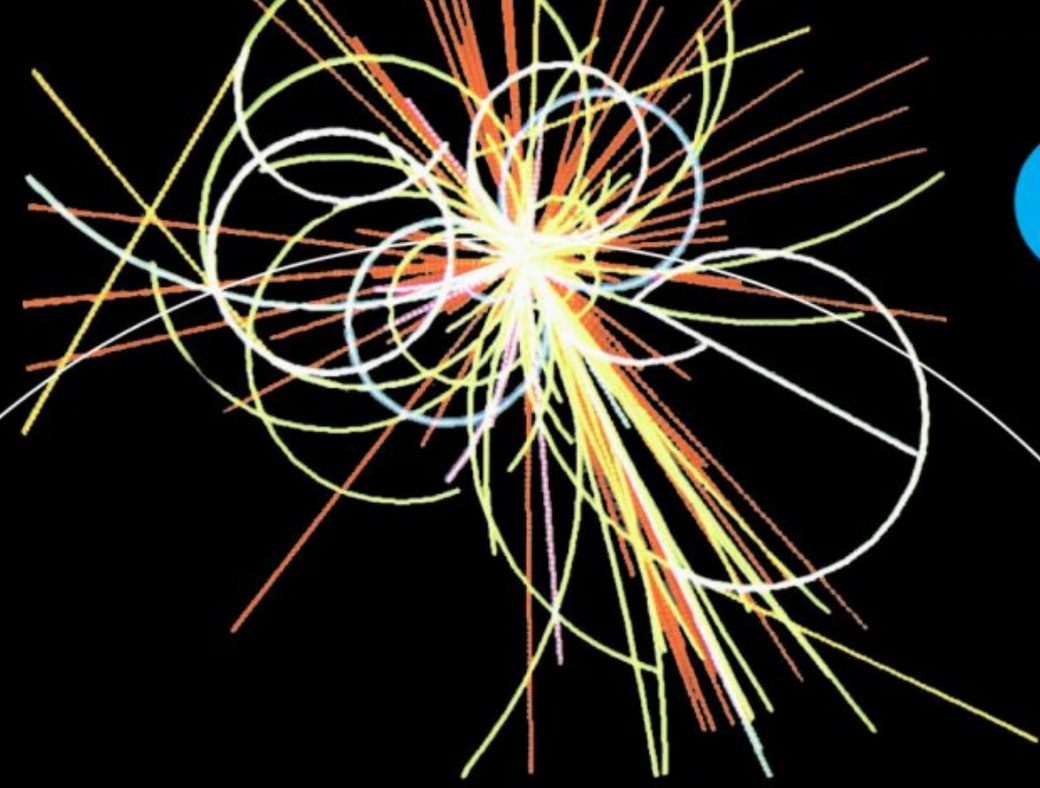


We evaluated the **total** and **visible** (>300 nm) electroluminescence (EL) yield of methane and isobutane admixtures to He-40%CF_4 to find the best ternary mixture.

Turns out no compromise is needed!

Using up to 7% methane to increase the WIMP sensitivity of Dark Matter Detectors filled with He-40%CF_4 will also improve their optical readout.

Construction and aging issues



- MEG: wire investigation
- Studies on GEM performance in different conditions
- Long term neutron irradiation of MicroMegas

- *studies on wire breaking*
- *humidity could be a problem*

Analysis and study of the problems on the wires used in the MEG CDCH and the construction of the new drift chamber

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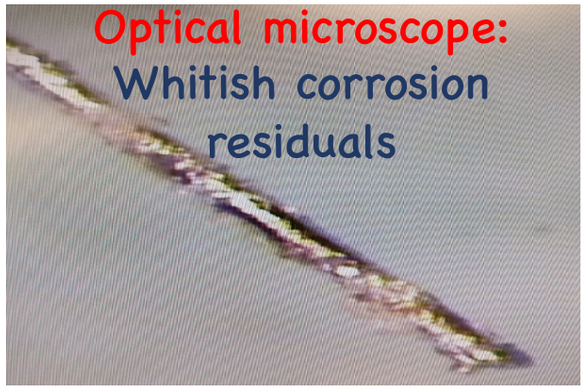
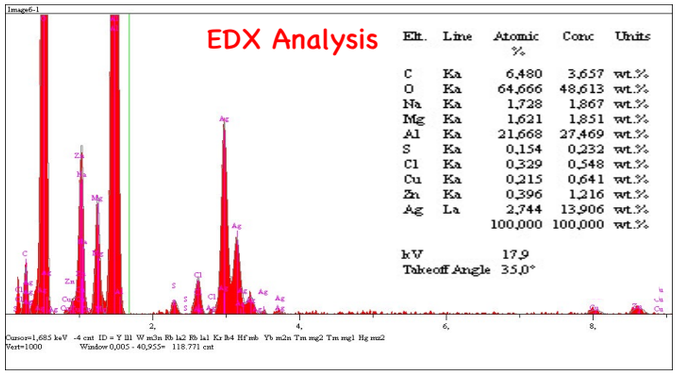
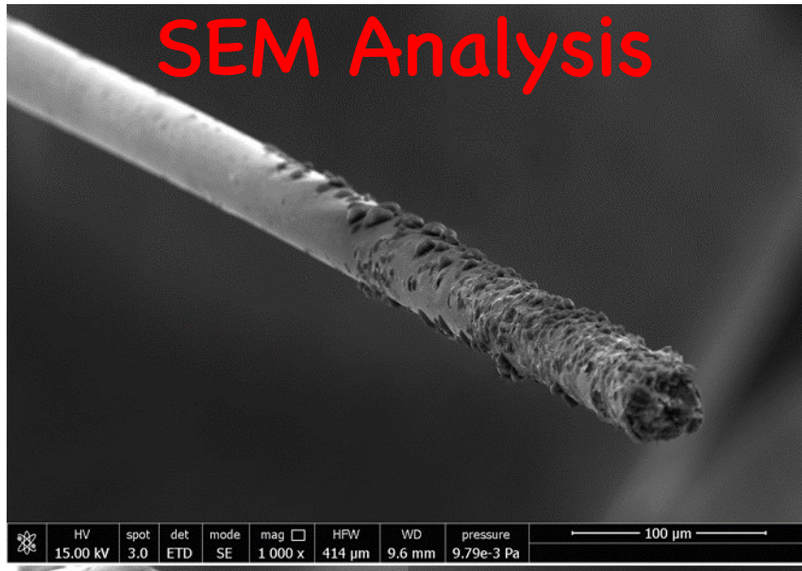
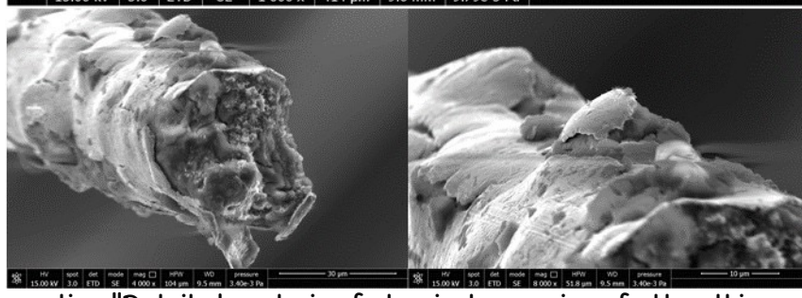
Abstract

In the MEG II detector, the measurement of the momentum of the charged particle is performed by a high transparency single volume, full stereo cylindrical Drift Chamber (CDCH). It is composed of 9 concentric layers, each consisting of 192 drift cells. The single drift cell is approximately square, with a 20 μm gold plated W sense wire surrounded 40 μm/50 μm silver plated Al field wires in a ratio of 5:1. During the construction of the first CDCH, we had the breaking of a hundred cathode wires: of these, 97 are 40 μm aluminum wires while 10 are 50 μm wires. Since the number of broken cathodes is less than 1% of the total, one can expect the influence on the track reconstruction efficiency to be not so dramatic.. Finally we will show the study carried out on new wires to overcome the weaknesses found and the process that will be used for the construction of the new drift chamber (CDCH2). It will be built with the same modular technique, as for the first, the wiring robot will be used by improving some weak points and using new wires with a diameter of 25% thicker diameter, which has very little effects on the resolution and efficiency of the detector. Furthermore these wires are made with a manufacturing process different from their used previously.









For more information "Detailed analysis of chemical corrosion of ultra-thin wires used in drift chamber detectors", JINST 16 (2021) T12003.

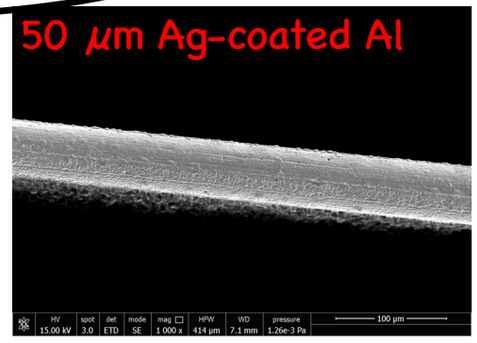
- Breakings due to corrosion of the aluminum wire core
  - Imply water as catalyst (Air moisture condensation inside cracks in the Ag coating)
- Found a good linear correlation between number of broken wires and exposure time to humidity
- The only way to stop the corrosion is to keep the wires in an inert atmosphere

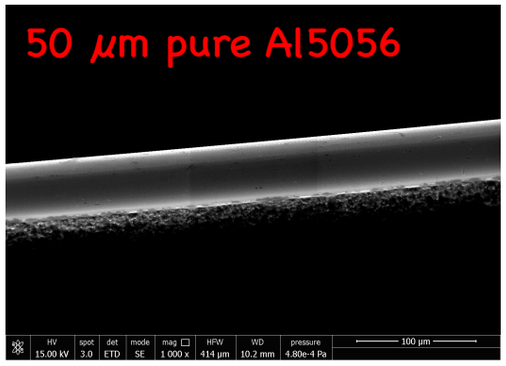
After several analyses carried out and considered different wires, we decided to use new wires with pros and cons for the CDCH2 (the choice is in progress):

- 50 μm Ag-coated Al wires in which the ultra-finishing step is avoided
- 50 μm pure Al wires (soldering plus glue)

We are doing tests to understand the best wire to avoid problems

The wiring robot has been transferred from Lecce to Pisa and is ready.

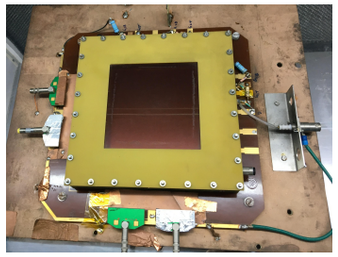


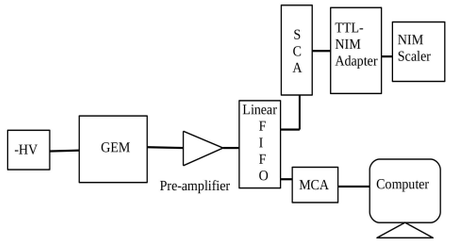


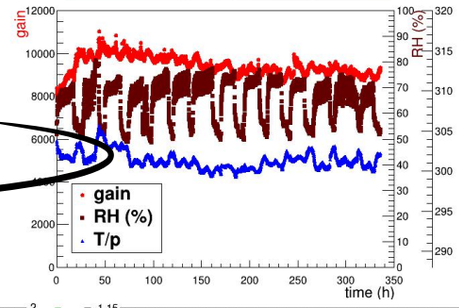
Effect of relative humidity on the long-term operation of a single mask triple GEM chamber

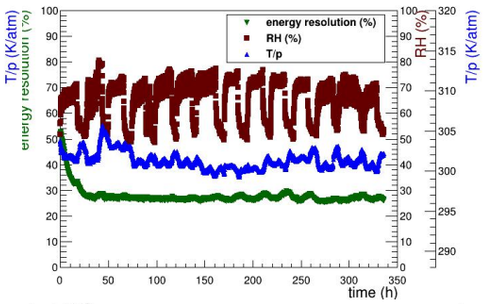
S. Chatterjee*, A. Sen, S. Das, S. K. Ghosh, S. Biswas
Department of Physics, Bose Institute, Kolkata, India

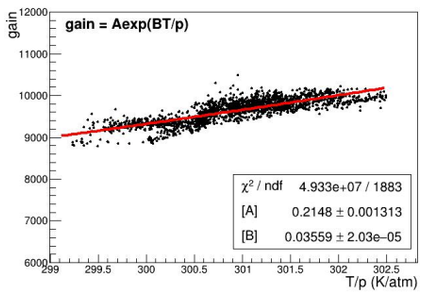
- **Long-term stability study is performed with a Single Mask triple GEM chamber**
  - → Drift gap, transfer gaps and induction gap are kept at 3 mm, 2 mm and 2 mm respectively
  - → Operated with Ar/CO_2 gas mixture in 70/30 volume ratio
  - → Irradiated with Fe^{55} X-ray source (~ 20 mCi) of characteristic energy 5.9 keV at a rate of 2 kHz/mm²
  - → ΔV across each of the GEM foils ~ 405 V
- **Normalisation of gain and energy resolution is performed to eliminate the effects of temperature (T = t+ 273 in K) and pressure (p in atm) variations**
- **No significant correlation is obtained with the T/p normalised gain and energy resolution with the relative humidity (RH)**
- **Data taking with longer period of time is ongoing and any possible correlation of detector performance with RH will be investigated**

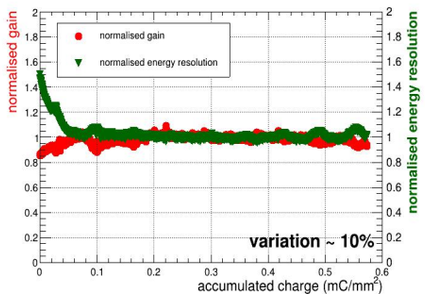


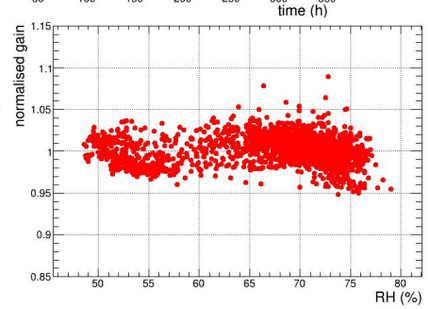


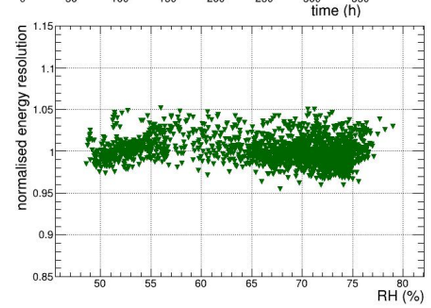










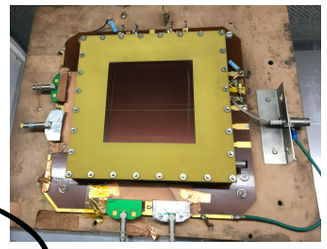


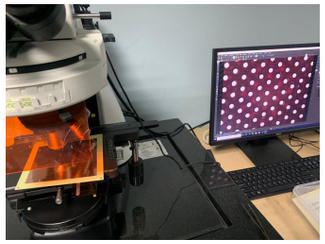
- *GEM performance in presence of H_2O*

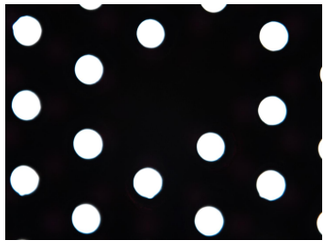
Visual investigation of possible degradation in GEM foil under test

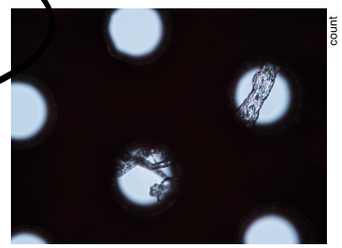
S. Chatterjee*, A. Sen, S. Das, S. K. Ghosh, S. Biswas
Department of Physics, Bose Institute, Kolkata, India

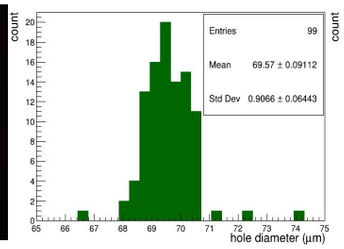
- **During the long-term study of a Single Mask triple GEM chamber, the 3rd GEM foil of the chamber is found to be damaged**
- **The measured resistance is found to be ~ 40 kΩ**
- **Optical inspection of the GEM foil reveal imperfections in the GEM foil**
- **The short paths in the GEM foil are removed by using an ultrasonic (~ 20 kHz) bath with millipore water**
  - → **The foil is kept in the ultrasonic bath for ~ 5 minutes**
  - → **The foil is dried for ~ 30 minutes under continuous heat flow and after that the resistance of the foil was found to be high**
- **The leakage current of the GEM foil is measured and found to be reasonable (at ΔV ~ 300 V, RH ~ 50%; ~ 0.3 nA)**

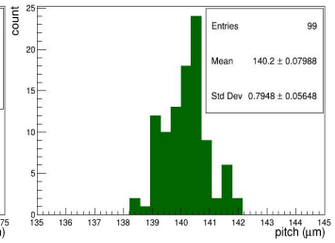




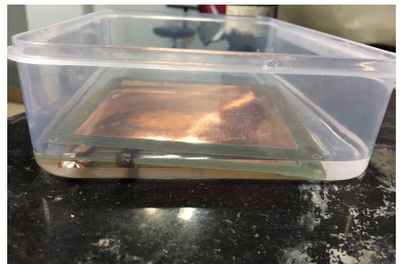


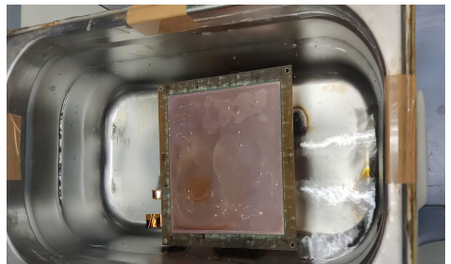


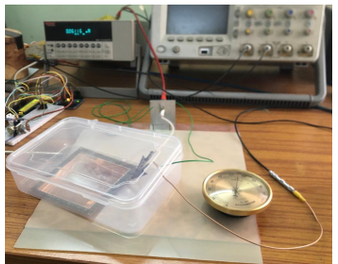


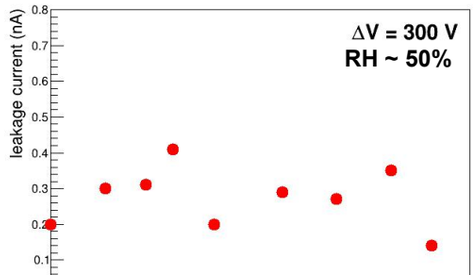


- *ultrasonic bath to remove short path in GEM*







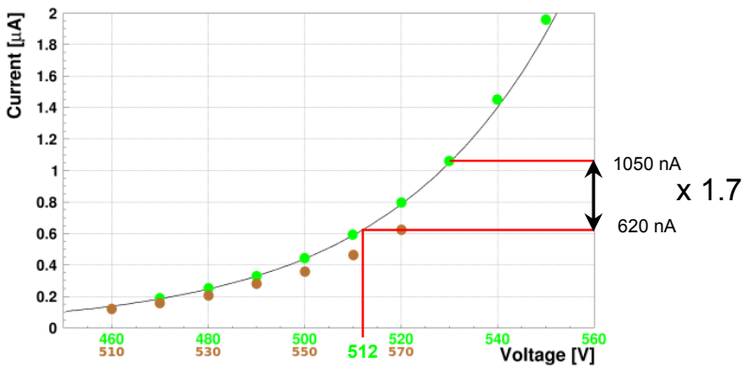


- *evaluating aging effects of MicroMegas with Neutron*
- *accumulated charge equivalent to 10 years of HL-LHC in ATLAS*
- *2 gas mixture tested (adding iC_4H_{10})*

Long Term Neutron Irradiation Studies of Square Meter Sized Resistive Strip Micromegas Detectors

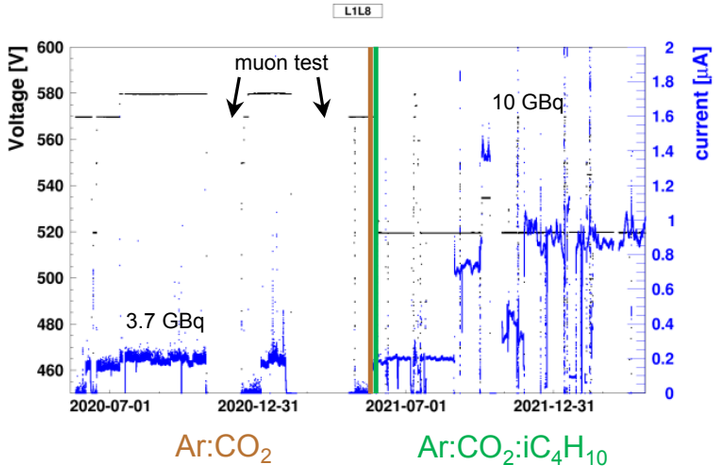
Two different types of gas mixtures were investigated ($Ar:CO_2$ 93:7 vol% & $Ar:CO_2:iC_4H_{10}$ 93:5:2 vol%):

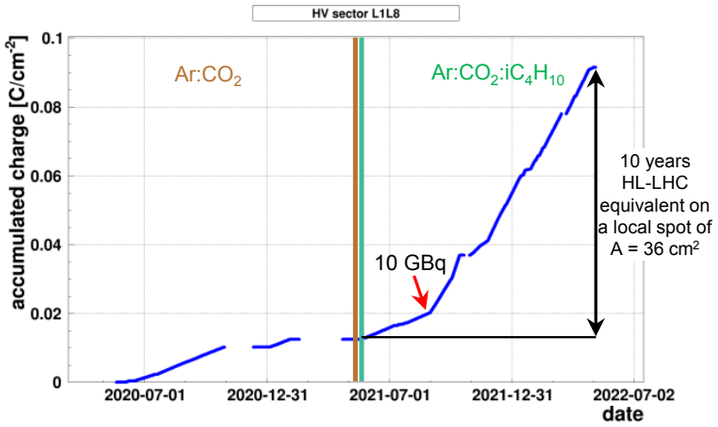
- Equal gains at 570 V & 512 V
- 575 V breakthrough voltage under $Ar:CO_2$
- Possible gain increase of 70 % under $Ar:CO_2:iC_4H_{10}$ at 530 V

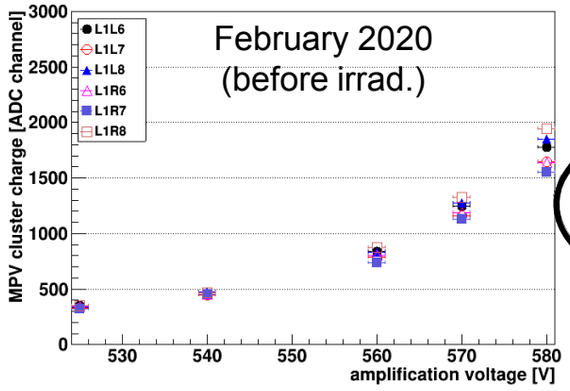


Constant irradiation of the quadruplet detector for two years:

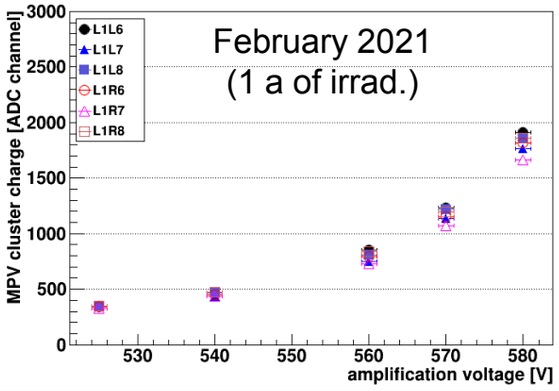
- Better discharge quenching under $Ar:CO_2:iC_4H_{10}$
- Accumulated charge equivalent to 10 years of HL-LHC in the ATLAS forward muon spectrum at η = 2.7 on a local spot of 36 cm².







No changes in pulse-height have been observed by a comparison of cosmic muon tracking at the beginning and after the first year of irradiation.



Poster review: conclusions

40 posters in the gaseous detector session

- Large interest in the field
- Several technologies under studies and improvement

- Upgrades of existing systems
- New systems in final phase of study or under construction
- Gaseous detectors in LHC and for future colliders

- Big challenges for the future —> see also ECFA roadmap
  - Rate capability
  - Spacial resolution
  - Time resolution
  - Aging effects with increase of radiation
  - Eco-gas mixtures

Gas detector Aging Workshop in 2023 or 2024
(Previous workshops in 1996 and 2001)