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

- Improve time and spatial resolution for gaseous detectors with long-term stability
- 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
- Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
- Achieve high sensitivity in both low and high-pressure TPCs
- Time and spatial resolution
- 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
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.

- new ASD for sMDT
- high spatial resolution

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.).

The ATLAS muon spectrometer drift tubes have wire position measured to within ±10 µm.

Results are consistent with ATLAS Run 2 MDT resolution. Includes a Geant4 estimate of the multiple Coulomb scattering correction.

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

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

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

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.

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

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

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

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

- **Detector calibration**

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

- **Gas monitoring tool**

  - 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.

  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
- Mechanical design

**Applied method for drift velocity measurements**

Simple geometrical considerations lead to the following relation:

$$ \left\{ \begin{array}{l} \theta_+ = \frac{\delta \theta}{\nu_D} \\
\theta_- = -\frac{\delta \theta}{\nu_D} \end{array} \right. $$

left track \hspace{2cm} right track

The drift velocity $\nu_D$ can be measured thanks to the sense wire staggering.

The drift velocity depends on $\delta \theta = \theta_+ - \theta_-$, which is the distance between the two gaussian peaks distribution of $\theta$.

- $\nu_D = 2.488 \pm 0.006 \text{ cm/\mu s}$

**Simulations**

Garfield++ simulations show the double gaussian distribution of the $\theta$ variable.
- **New design for high transparency**
- **Cluster counting technique**

**The drift chamber of CMD-3 detector**

G. Chiarella\textsuperscript{(a)}, A. Corvaglia\textsuperscript{(c)}, F. Cuna\textsuperscript{(b),(c)}, N. De Filippis \textsuperscript{(b),(d)}, E. Gorini\textsuperscript{(b),(c)}, F. Grancagnolo\textsuperscript{(c)}, A. Miccoli\textsuperscript{(c)}, M. Panareo\textsuperscript{(b),(d)}, M. Primavera\textsuperscript{(c)}, G. F. Tassielli\textsuperscript{(b),(d)}, A. Ventura\textsuperscript{(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; (e) Politecnico di Bari; (a) Università degli Studi di Bari «Aldo Moro»

TraPId (Tracking and Particle Identification), 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.

- An ultra-low mass drift chamber for a generic flavour factory with a material budget $<1.5\times10^{-2}X/X_0$ in the radial direction and $<5\times10^{-2}X/X_0$ 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.
- $\Delta p_t/p_t = 2.0\times10^{-3}$, $\Delta \theta = 0.70$ mrad, $\Delta \phi = 0.78$ mrad at $p = 1$ GeV/c.
- Particle identification at the level of 3.6% with cluster counting allowing for $\pi/K$ separation $\geq 3\sigma$ over a wide range of momenta.
- Cluster counting technique: \(dN/dx \text{ vs } dE/dx\)
- 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 demonstrated 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 \(\beta y\) 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
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 \( \partial(1/pt) \sim 10^{-4} /\text{GeV/c} \) can be fulfilled. Pixel-based readout gives lower occupancy, better \( dE/dx \) res., no angular pad effect, etc.

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 ($\approx 100\%$)
- Electromagnetic ($\approx 1.5 \times 10^{-5}$)
- Internal Pair Creation ($\approx 5.5 \times 10^{-8}$)

Hexagon Timepix3
- Event driven pixelated detector (fast response);
- 256x256 55 $\mu$m pixels (high granularity);
- 1.6 ns time resolution;
- 14x14 mm$^2$ (fits inside the vacuum tube).
- Designed in collaboration with FEE-UWB.

IEAP CTU in Prague

Multi-Wire Proportional Chamber
- 3D tracking (event topology)
- Particle ID
- Background rejection

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

Contact: andre.cortez@cvut.cz

15th Pisa Meeting on Advanced Detectors, 22nd to 28th May 2022, La Biodola (Italy)
- **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?..
- CMS GEM: present and future upgrades
- Studies on GEM performance in different conditions
- Cylindrical GEM for inner trace row BESIII

- Long term neutron irradiation of MicroMegas
- Operation of low pressure MicroMegas
- RHUM project: MicroMegas rate capability above MHz/cm²
- Development of MicroMegas for AMBER experiment
- MicroMegas combined with Tungsten absorber for diphoton signatures

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

- PicoSec technology for Muon Collider detector
- u-RWELL for the IDEA detector
Commissioning and operation in magnetic field of CMS GE1/1 station

Simone Calzaferri
on behalf of the CMS Muon Group
INFN sezione di Pavia

Actor: GE1/1 station in CMS (Gas Electron Multiplier detectors) 
1.55 < |η| < 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

- GEM successfully installed in CMS in LS2
- Operation in magnetic field
PERFORMANCE OF TRIPLE-GEM DETECTORS FOR THE PHASE-2 CMS UPGRADE AND A HIGH-RESOLUTION GEM TELESCOPE MEASURED IN A TEST BEAM

- GEM for CMS Phase 2
- High space resolution

- GEM for HL-LHC
- High particle rate

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

Hi-Lumi UPGRADE
- The phase-II CMS muon endcap upgrade will include a new forward station at high $\eta \rightarrow ME0$
- The ME0 ring (18 detectors $\times$ 6 layers $\times$ 2 endcaps) will be the closest muon station to LHC beam line $- 2.0 < |\eta| < 2.8$

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 $\rightarrow$ azimuthal

Antimo Cagnotta on behalf of CMS muon group
Università degli studi di Napoli ‘FedericoII’ & INFN Napoli

Novel GEM foil layout for high-rate particle environment in the CMS ME0 muon detector
- 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 granUarity Micromegas) R&D project ongoing, aiming 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

Marco Sessa, on behalf of RHUM Collaboration
- 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.

Test beam with planar detectors

Planar GEM detectors
Detectors can be tilted to scan different incidence angles

80 GeV Muon trigger system with scintillators and PMT

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

- 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.

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

- 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 value.

Study of space charge phenomena in GEM based detectors

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:

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

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

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.

Five combinations of Fe55 primary seed clusters have been chosen:

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Spread in r (µm)</th>
<th>Spread in z (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Mean</td>
<td>132</td>
<td>154</td>
</tr>
<tr>
<td>Case 3</td>
<td>Enlarged</td>
<td>203</td>
<td>214</td>
</tr>
<tr>
<td>Case 4</td>
<td>Compact</td>
<td>61</td>
<td>74</td>
</tr>
<tr>
<td>Case 5</td>
<td>z-elongated</td>
<td>61</td>
<td>234</td>
</tr>
<tr>
<td>Case 6</td>
<td>r-elongated</td>
<td>203</td>
<td>74</td>
</tr>
</tbody>
</table>

When the number of electrons is maximum

470V
500V
520V
540V

ΔE = EW - EWO

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.
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-CO₂; 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

- 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 ≤ d ≤ 300 μm
  - 57% - 70% for 500 ≤ d ≤ 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

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

- Active area – up to 180x150 mm²
- Rates ~150kHz/mm² (centre), 1-2 kHz/mm² (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

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 FE cards 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
ATHENA’s MPGD Tracking Detectors for the Electron-Ion Collider

M. Posik on behalf of ATHENA

ATHENA

- A Totally Hermetic Electron-Nucleus Apparatus (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 |η| < 1.1, triple-GEM annular rings are used in the forward and backward directions to extend tracking coverage in the range 1.1 < |η| < 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.
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.

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

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

---

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.

---

**Muon system at a Muon Collider**

Current technology: Glass Resistive Plate Chambers

Proposed technology: Picosec

---

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{cm}$</td>
<td>3 TeV, 10 TeV, 14 TeV</td>
</tr>
<tr>
<td>$\mathcal{L}$</td>
<td>$1.8 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, $20 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, $40 \times 10^{34}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>$N_{mu/bunch}$</td>
<td>$2.2 \times 10^{12}$, $1.8 \times 10^{12}$, $1.8 \times 10^{12}$</td>
</tr>
</tbody>
</table>

---

**Neutron Hit Rate (Hz/cm$^2$)**

- **Triple GEM**
- **RPC**
- **GRPC**
- **PicoSec**

---

**Diagram:**

- Particle
- Cherenkov Radiator: 1-5 mm
- Photocathode: 8-30 nm
- Drift: 100-300 µm
- Amplification: 50-150 µm
- Cathode
- Mesh (Bulk Micromegas)
- Anode
- HV1, HV2, E-Field
- Preamp + DAQ

---

The neutron hit rate varies with the angle $\theta$. The hit rate is highest for angles close to 0° and decreases as the angle increases up to 45°.
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
- 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. Bencivenni¹, R. De Oliveira², G. Felici¹, M. Gatta¹, M. Giovannetti¹, G. Morello¹, G. Papalino¹, M. Poli Lener¹ - ¹LNF – INFN, ²CERN**

### 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 \( \div 10 \) 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
Improving count rate capability of timing RPCs by increasing the detector working temperature

A. Blanco¹, P. Fonte¹², L. Lopes¹, J. Saraiva¹
¹ Laboratory of Instrumentation and Experimental Particles Physics, Coimbra, Portugal
² Coimbra Polytechnic - ISEC, Coimbra, Portugal

trRPC 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 °C.

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 °C. This contrasts with a 20 % loss of efficiency and a worsening of temporal precision of more than 60 ps when operated at 21 °C.
linseed oil coating before closing the gap

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

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

The efficiency and noise rate as a function of the voltage for 100% C₂H₃F₂

The efficiency and noise rate as a function of the voltage for C₂H₃F₂ / i-C₃H₁₀ : 90/10 volume ratio

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

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

linseed oil coating before closing the gap

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

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

A new graphene-based RPC fully built with additive manufacturing
Roberto Campagnola (Laboratori Nazionali di Frascati- INFN) et al.

linseed oil coating before closing the gap

linseed oil coating before closing the gap

linseed oil coating before closing the gap

linseed oil coating before closing the gap

linseed oil coating before closing the gap
- 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\cite{1} installation of new RPCs.

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

Edoardo Bossini\textsuperscript{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\textsubscript{2}H\textsubscript{2}F\textsubscript{4} and 2% SF\textsubscript{6}. Given its high Global Warming Potential (GWP), the collaboration started a R&D on alternative mixtures environmentally sustainable. Latest results on C\textsubscript{3}H\textsubscript{2}F\textsubscript{4} + He mixture are presented in the poster.

- 60 detectors made of 3 MRPC operated with 98% C\textsubscript{2}H\textsubscript{2}F\textsubscript{4}
- Encouraging results with a mixture containing C\textsubscript{3}H\textsubscript{2}F\textsubscript{4} and He
- searching for eco-friendly gas mixtures for LHC experiments
- alternatives to both C₂H₂F₄ and SF₆
- 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: cosmosics 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
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.
- 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 author: filomena.santos@coimbra.lip.pt

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 substrat, 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.
Dual Polarity Ion Drift Chamber: Results with Xe-SF$_6$ mixtures

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/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.

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

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

A. M. Baldini\(^{(c)}\), G. Cavoto\(^{(a,b)}\), F. Cej\(^{(cd)}\), G. Chiarello\(^{(c)}\), M. Chiappini\(^{(c)}\), A. Corvaglia\(^{(d)}\), M. Francesconi\(^{(cd)}\), L. Galli\(^{(c)}\), F. Grancagnolo\(^{(d)}\), M. Grassi\(^{(c)}\), H. Bennmansour \(^{(cd)}\), D. Nicolò\(^{(a,b)}\), M. Panareo\(^{(e)}\), A. Papa\(^{(c,d,g)}\), F. Raffaelli\(^{(c)}\), F. Renga\(^{(a,b)}\), G. Signorelli\(^{(d)}\), G. F. Tassielli\(^{(e)}\), B. Vitali\(^{(a,b)}\), C. Voena\(^{(e)}\)

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.

- 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.
• 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/CO₂ gas mixture in 70/30 volume ratio
  → Irradiated with Fe55 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

- ultrasonic bath to remove short path in GEM

- GEM performance in presence of H₂O

Visual investigation of possible degradation in GEM foil under test

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

Two different types of gas mixtures were investigated (Ar:CO₂ 93:7 vol% & Ar:CO₂:iC₄H₁₀ 93:5:2 vol%):

- Equal gains at 570 V & 512 V
- 575 V breakthrough voltage under Ar:CO₂
- Possible gain increase of 70 % under Ar:CO₂:iC₄H₁₀ at 530 V

Constant irradiation of the quadruplet detector for two years:
- Better discharge quenching under Ar:CO₂:iC₄H₁₀
- 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)