Numerical Studies on Time Resolution of Micro-Pattern Gaseous Detectors

Purba Bhattacharya,

On behalf of RD51 Group at SINP and NISER

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RD51 Activities

Simulation

- Development of neBEM
- Interface with Garfield
- Upgrade and maintenance
- Simulation of MPGDs
- Plan for interface with Garfield++

Experiment

- Test bench setup
- Characterization of MPGDs
- Upgrade for new measurements
- Explore other applications

Important parameters: **Field, Gain, Resolution, Transparency, Ion Backflow**

Topic of Today's Presentation: Temporal Resolution

- To disentangle the overlapping events in the drift volume, a resolution in the drift direction is necessary.

- It depends on the transit time i.e the time between the arrival of the radiation and the rise of the electronic pulse which leads to a finite temporal resolution

: Simulation tools :

Garfield + neBEM + Heed + Magboltz *combination*

- **Detector Modelling: GARFIELD**
- **Ionization:** energy loss through ionization of a particle crossing the gas and production of clusters – **HEED**
- **Transport and Amplification:** electron drift velocity and diffusion coefficients (longitudinal and transverse), Townsend and attachment coefficients – **MAGBOLTZ**
- **Detector Response:** charge induction using Reciprocity theorem (Shockley-Ramo's theorem), particle drift, charge sharing (pad response function), charge collection – **GARFIELD**
- **Electrical Solver: neBEM (nearly exact Boundary Element Method** – A formulation based on green's function that allows the use of exact close-form analytic expressions while solving 3D problems governed by Poisson's equation.

neBEM developments that were crucial for the study:

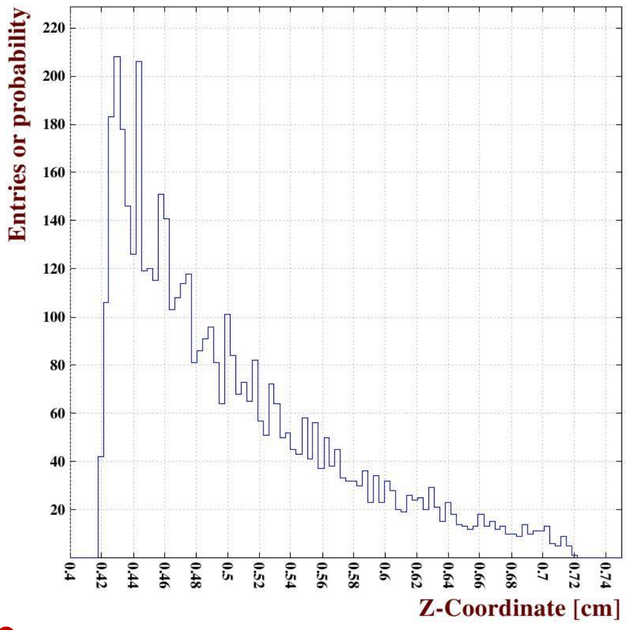
•Optimization of field calculations to achieve a large range of fields

•Extensive use of the recently developed fast-volume approach, code parallelization, reduced order modelling so that a reasonable statistics (*around 10,000 events*) is maintained in all the studies

Temporal Resolution

- **Depends on:**

1) **Primary Statistics,** 2) **Diffusion**



Primary Statistics:

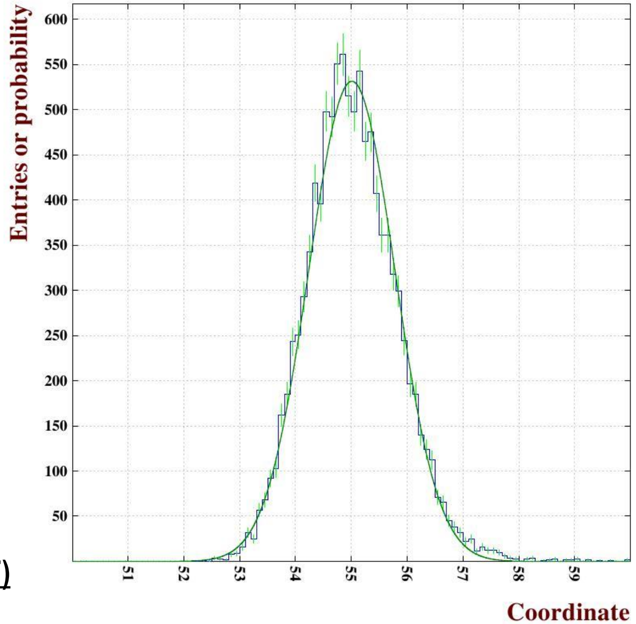
✓ From event to event the first electron is not produced at the same distance from the read-out plane of the detector under consideration.

✓ In particular, the distribution of the pair closer to one end of the detection volume, is given by $N_P e^{-N_P u_{vel} t}$ with variance $\left(1 / N_P u_{vel} \right)$

Diffusion:

➢ Electrons starting from same position arrive at different times, Gaussian distribution with variance $\left(D_{diff} \sqrt{z_{dist}} / u_{vel} \right)$

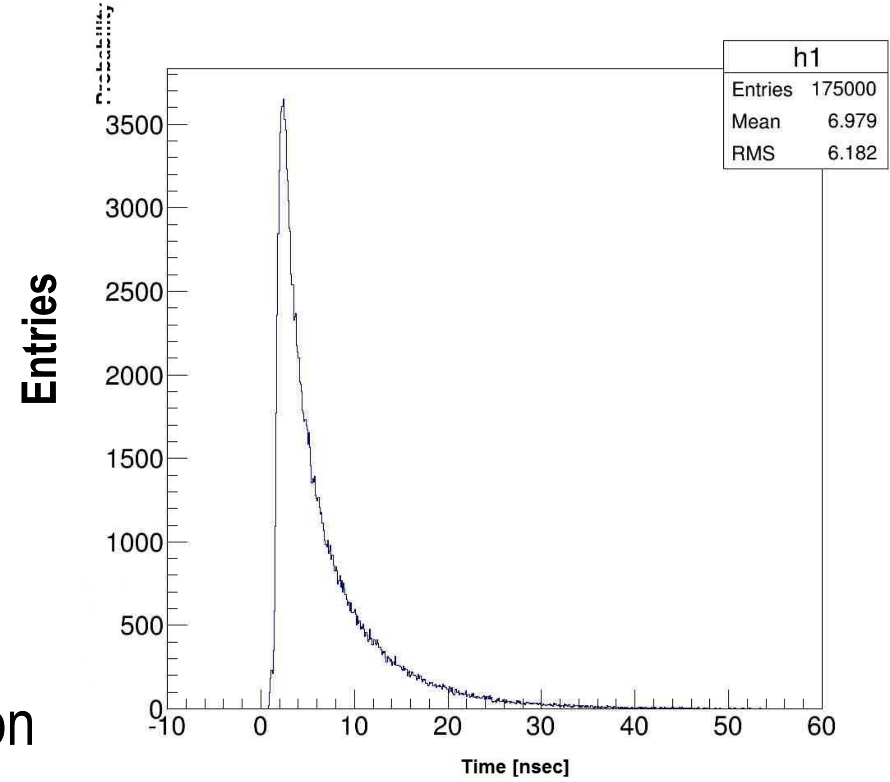
➢ With varying distance, the mean and the sigma change accordingly



Ref: 1) F. Sauli, Yellow Report, CERN 77-09 (1977)
2) M. Alfonsi, Ph.D Thesis

Our calculation:

- Consider cosmic Muon (energy 1 – 3 GeV) track
- For a particular track, recorded the drift time of electron which hits the readout plane first
- Due to the above two reasons, the first hit time varies from track to track



Temporal Resolution: RMS of the Distribution

Assumption:

- Equal contribution of all the track, inclined at different angle
- The first electron that reaches the readout, produce considerable signal

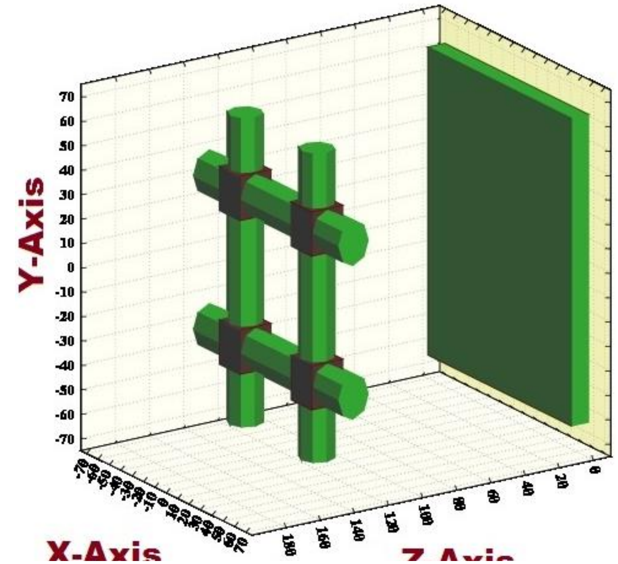
Ignored:

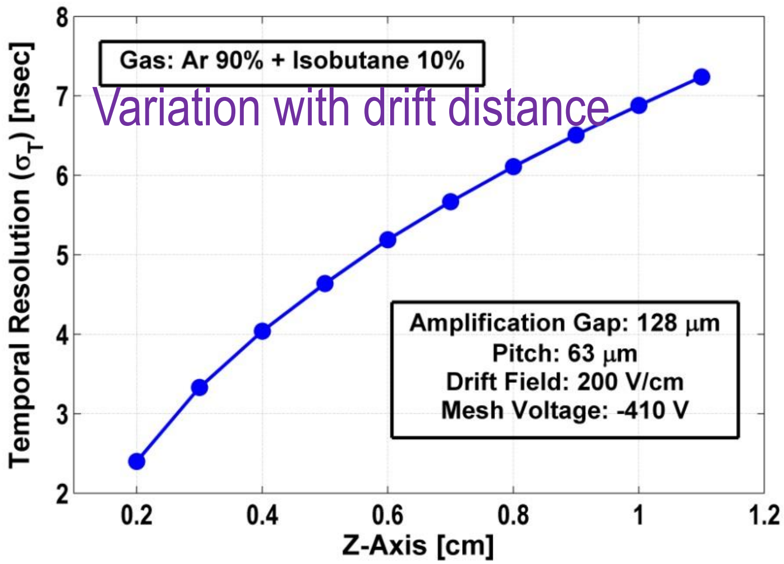
- Multiplication of electrons
- Effects of electronics such as shaping
- No upper or lower threshold

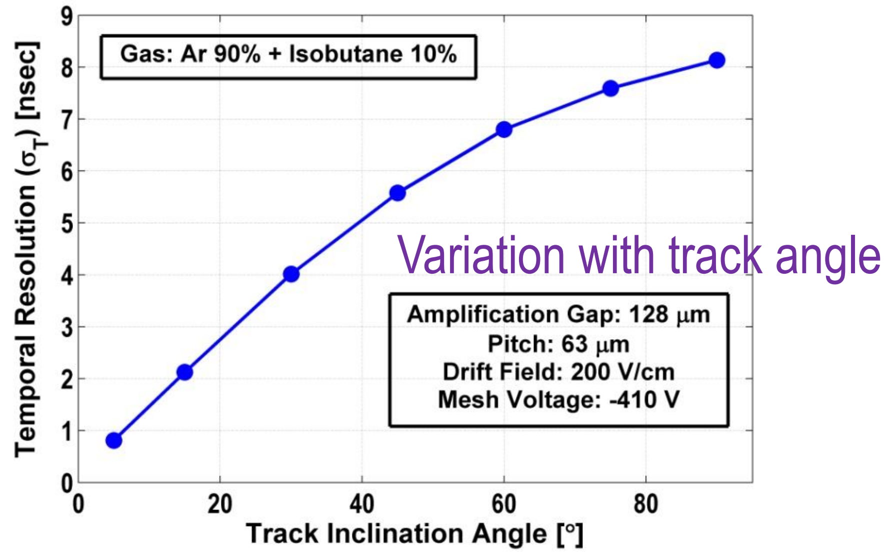
Temporal Resolution of Bulk Micromegas

Detector Geometry:

Amplification Gap:	**128 μm**
Wire dia:	**18 μm**
Hole dia:	**45 μm**
Hole pitch :	**63 μm**
Drift gap:	**1 cm**

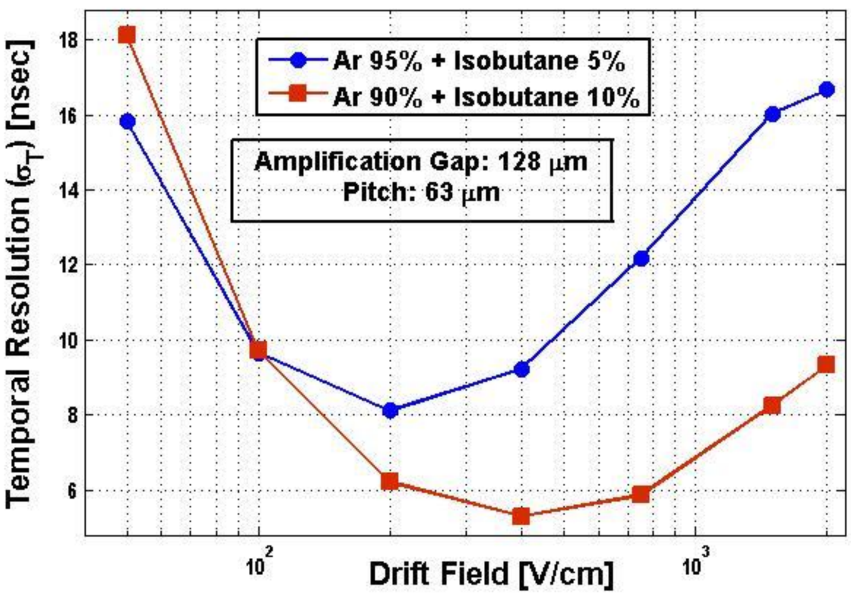




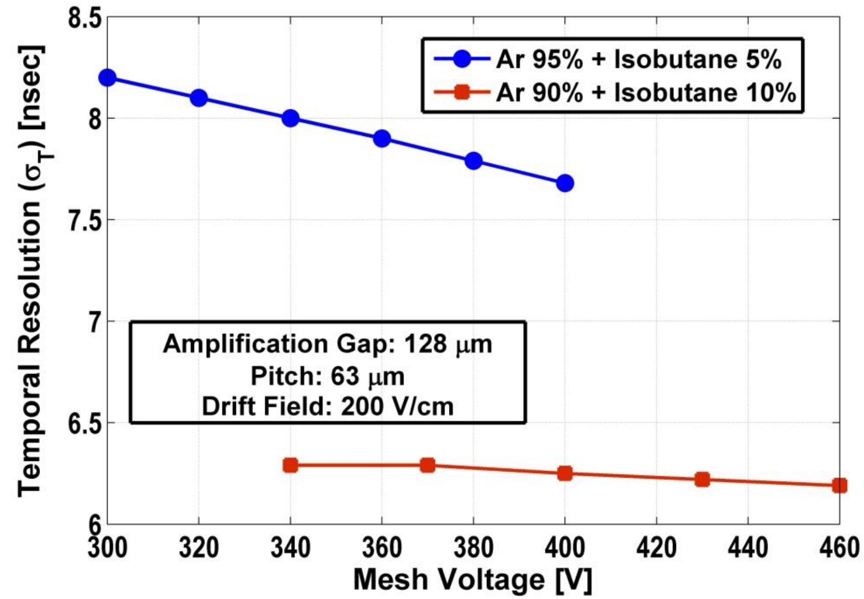


Due to diffusion with increasing distance temporal resolution worsen

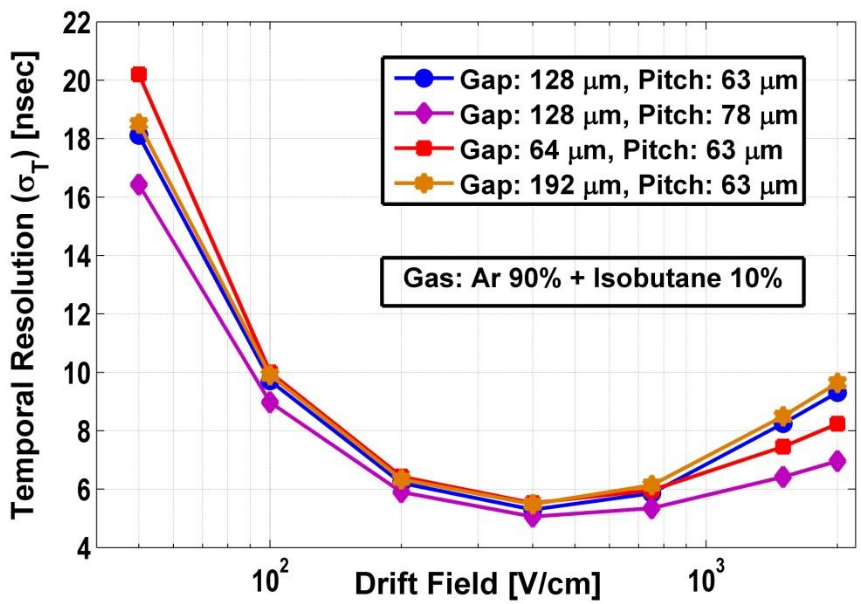
With the increase of inclination angle, the electrons have to travel much longer path which causes worsening of the resolution



Variation with drift field



Variation with mesh voltage



Variation with drift field

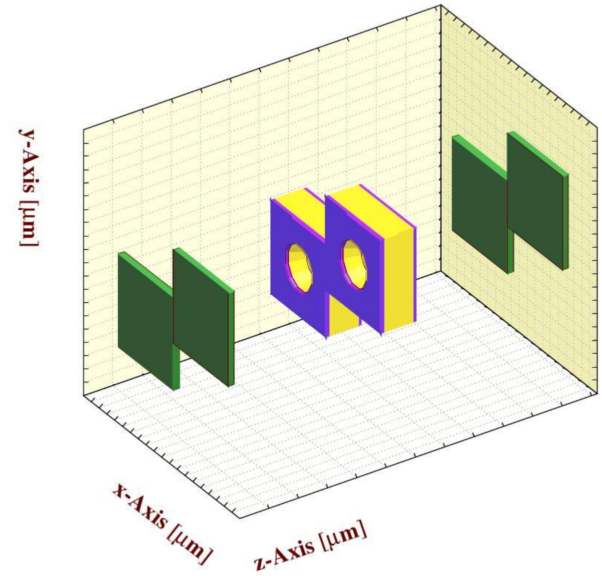
- ❑ At lower drift field larger transverse diffusion and at higher drift field poor funneling is responsible for worse resolution
- ❑ At higher amplification field, because of better funneling and less transverse diffusion, the resolution improves
- ❑ No significant effect of detector geometry has been observed except at higher drift field where detector with larger pitch and smaller gap show better resolution

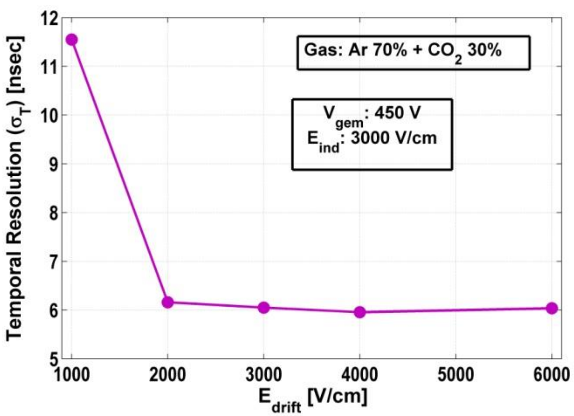
Ref: 1) J. Bortfeldt, Diploma Thesis (2010)
2) P. Lengo, Proc. Sci. EPS-HOP 080 (2013)

Temporal Resolution of Single GEM

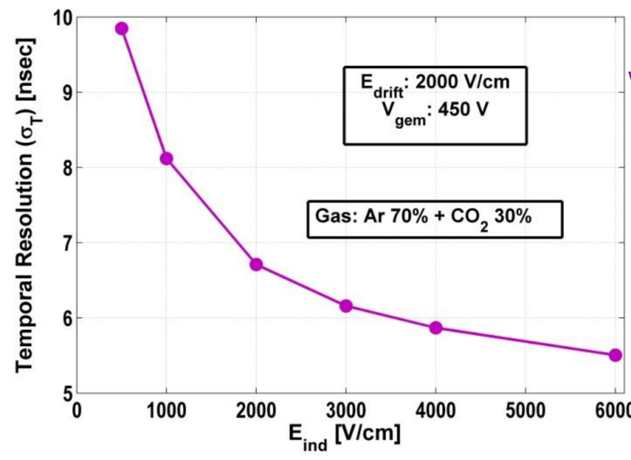
Detector Geometry:

Foil thickness :	50 µm
Copper thickness :	5 µm
Hole dia (outer) :	70 µm
Hole dia (inner) :	50 µm
Hole pitch :	140 µm (staggered)
Gap configuration :	3:1

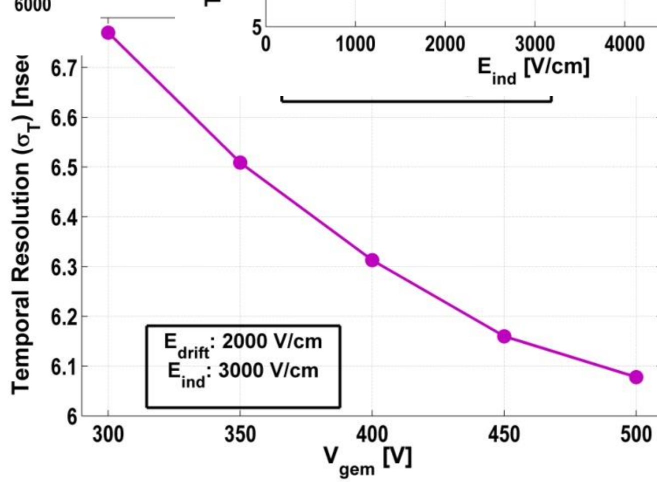




Variation with drift field



Variation with induction field



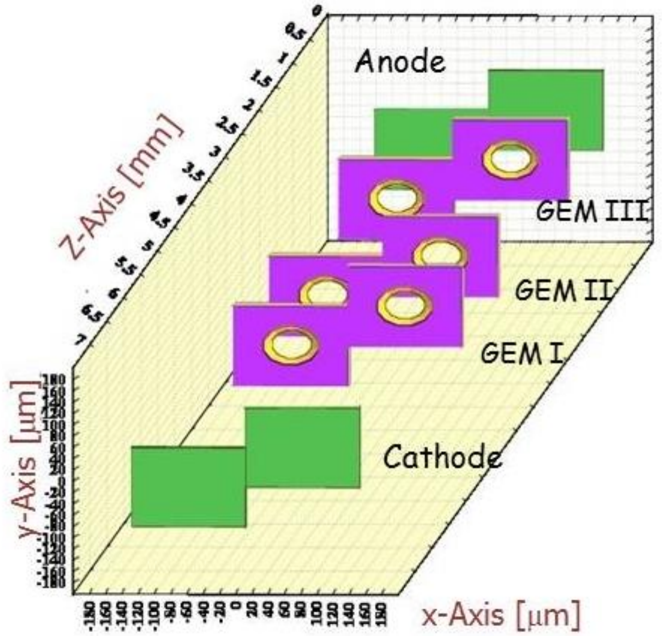
Variation with GEM voltage

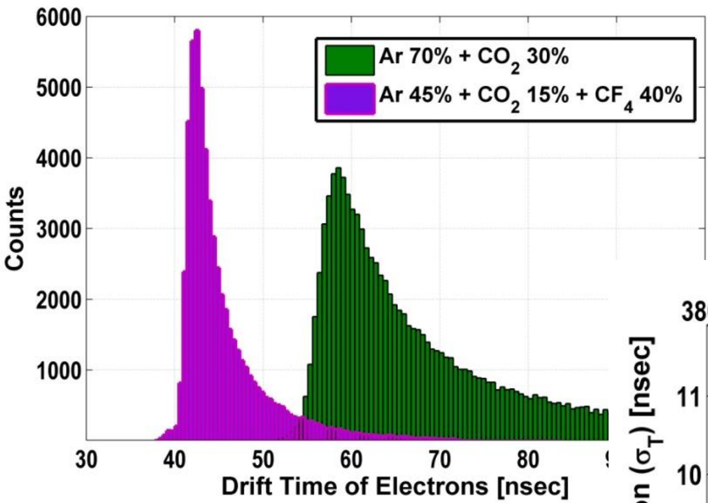
- ✓ At lower drift field, larger diffusion is responsible for worsening of the resolution
- ✓ At high V_{GEM} and higher induction field, due to the funneling, electrons have to travel smaller path to reach anode with increased drift velocity and lower transverse diffusion – better resolution

Temporal Resolution of Triple GEM

Detector Geometry:

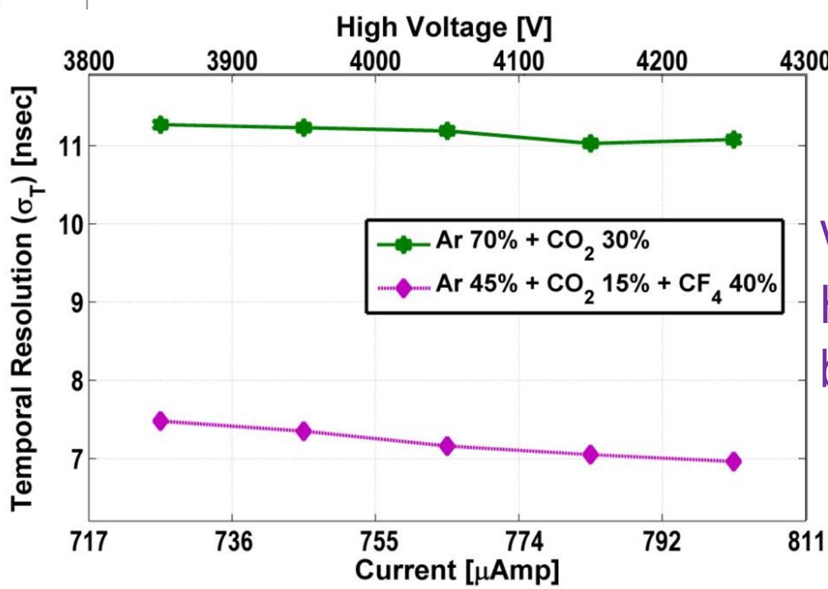
Foil thickness :	50 µm
Copper thickness :	5 µm
Hole dia (outer) :	70 µm
Hole dia (inner) :	50 µm
Hole pitch :	140 µm (staggered)
Gap configuration :	3:1:2:1 (mm)





Time Spectrum

A larger value of applied high voltage increases the field in the respective regions and improves the resolution.



Variation with applied HV in different Argon-based gas mixtures

Ref: 1) G. Bencivenni et al., NIMA 494 (2002) 156
2) D. Heereman, Diploma Theis
3) M. Alfonsi et al., NIMA 518 (2004) 106

Modification of Simulation Approach:

- ***Consider:***

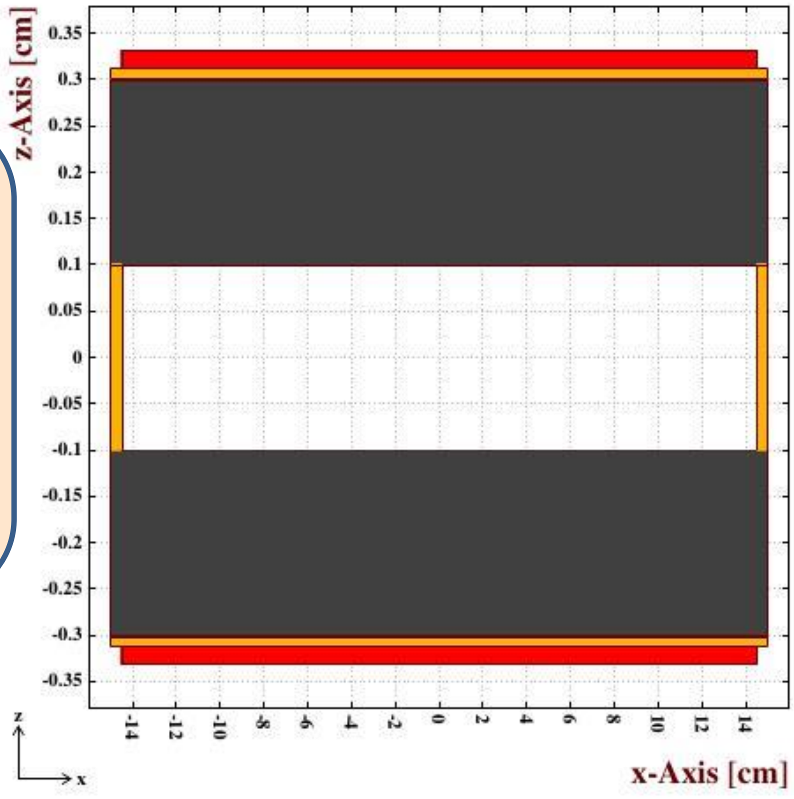
❑ Multiplication factor

❑ Lower threshold

Implementation on RPC

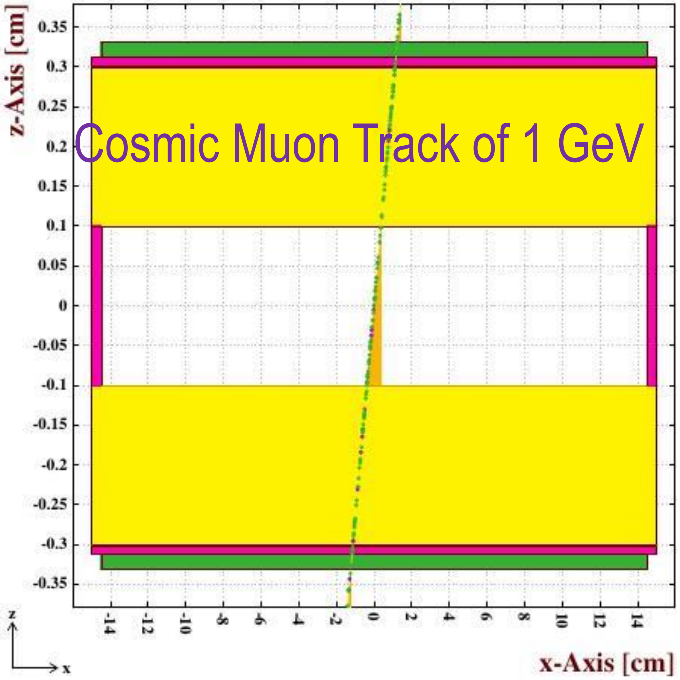
Detector Geometry:

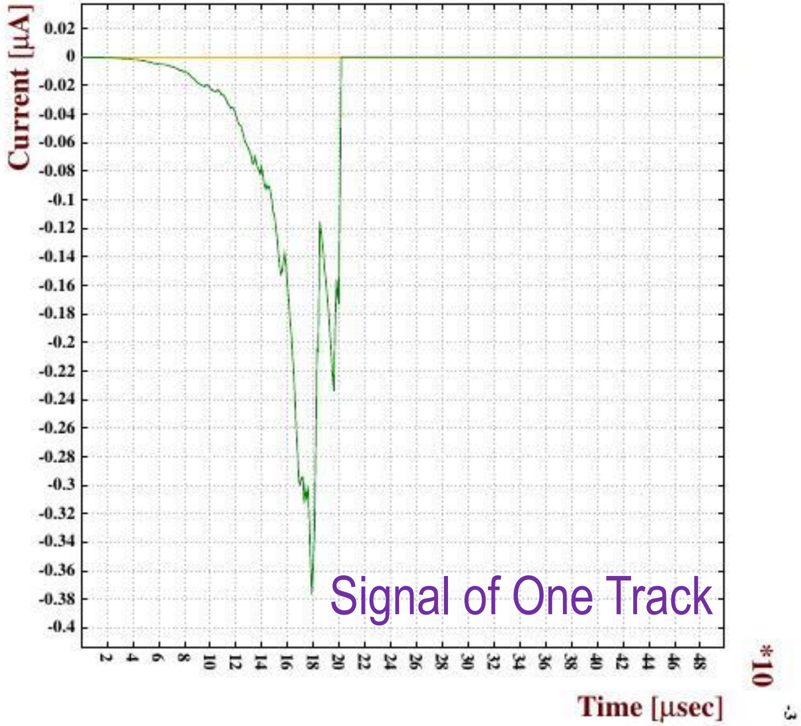
Bakelite thickness :	2	mm
Graphite coating thickness :	20	μm
Mylar thickness :	100	μm
Copper strip thickness :	200	μm
Gas gap :	2	mm

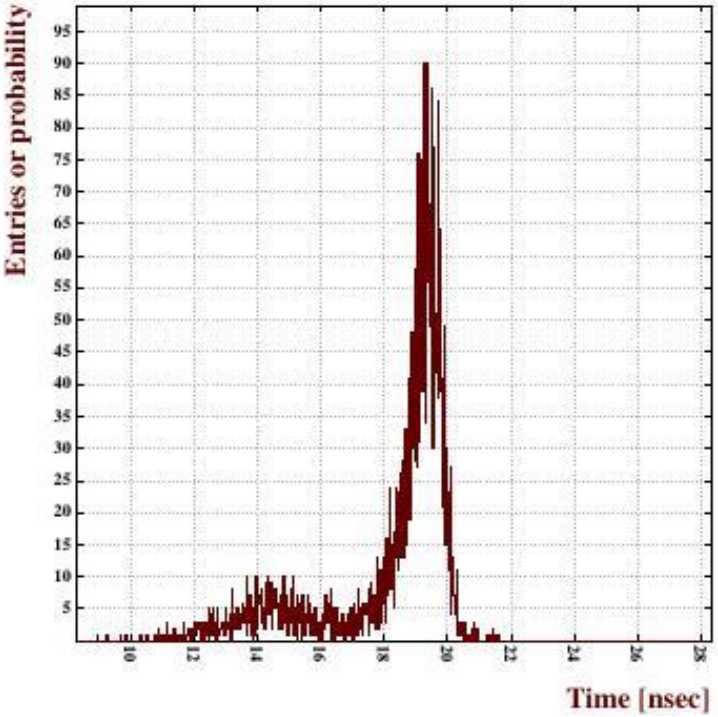


Gas: Freon 95% + Isobutane 4.5 % + SF_6

Applied Voltage: ± 5800 V







- Cosmic Muon track was considered at different inclination
- The time that takes to cross 0.1 μAmp current at the rising edge of the signal was considered – lower threshold
- The RMS of the distribution was found to be ~ 1.2 nsec which is very close to the experimental data
- Further investigation is going on understand the tail at the lower side.

Summary

- A comprehensive numerical study on the dependence of time resolution on detector design parameters, field configuration and relative proportions of gas components has been made for a few MPGDs.

- The cosmic muons at different inclination angles have been used as the event generator.

- The resolution has been estimated numerically on the basis of two aspects, statistics and distribution of the primary electrons and their diffusion in the gas medium, while ignoring the electron multiplication.

- The simulated results have been compared with available references and the agreement with the experiment is very encouraging. Note that gas compositions used for Micromegas and GEM are different because of availability of experimental data. Thus, a comparison between these two MPGDs are not possible here.

- A modification in the numerical approach considering the threshold limit of detecting the signal has been done for the RPC detector. The results agree quite well with the experimental data.

- In addition to the further improvement in the numerical work, at SINP development of a test bench for studying the MPGDs individually has been planned.

Acknowledgement

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Saha Institute of Nuclear Physics

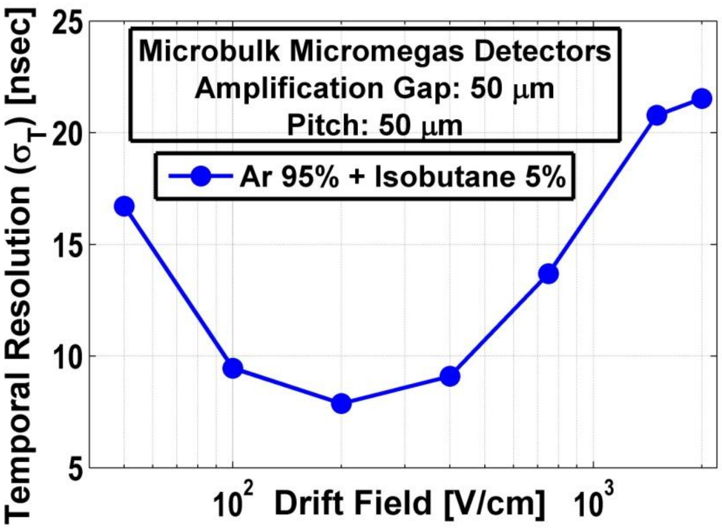
National Institute of Science, Education and Research

THANK YOU ALL !!

Temporal Resolution of Microbulk Micromegas

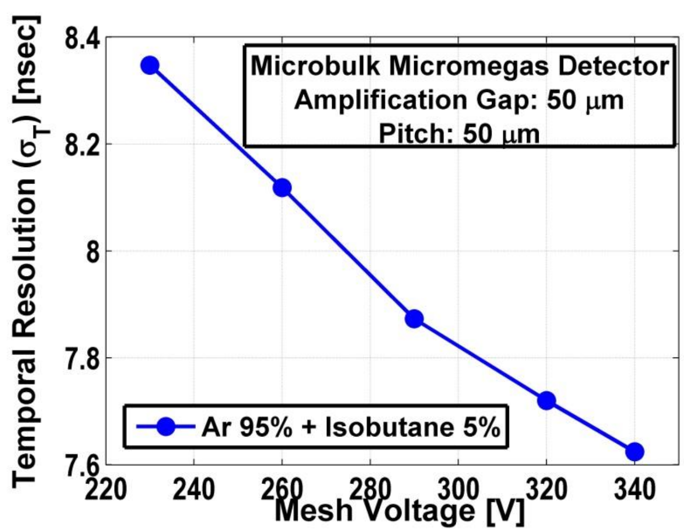
Detector Geometry:

Amplification Gap:	50 μm
Copper thickness :	5 μm
Hole dia (outer) :	30 μm
Hole pitch :	50 μm (staggered)
Drift gap:	1 cm



Variation with drift field

Temporal resolution ~ 7 nsec can be achieved with proper optimization of drift and amplification field.



Variation with mesh voltage