Development of thin gap MPGDs for EIC Trackers

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Micro Pattern Gaseous Detector (MPGD) overview

Gas Electron Multiplier (GEM)

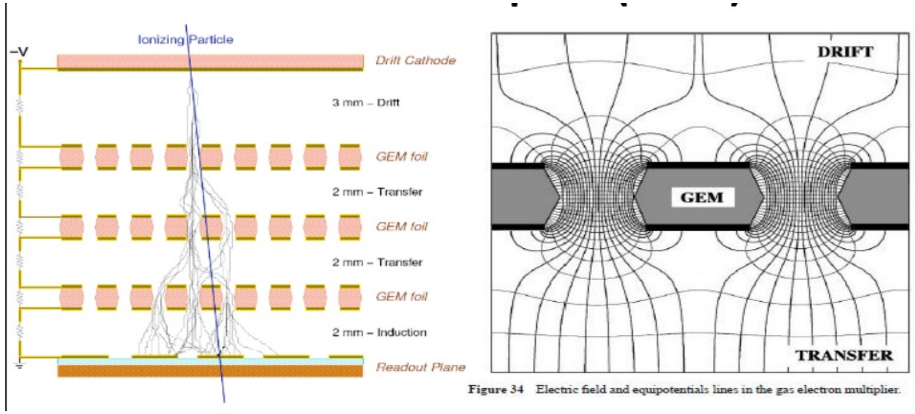
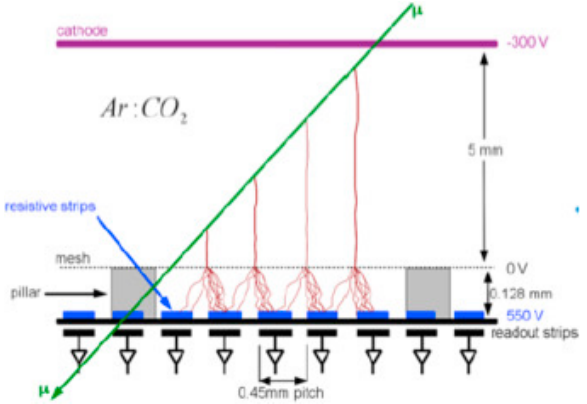


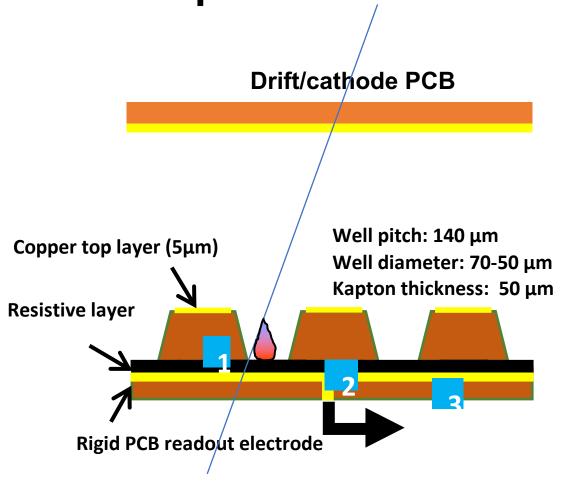
Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

F.Sauli, Nucl. Intr. And Meth. A386(1997)531

Micromegas

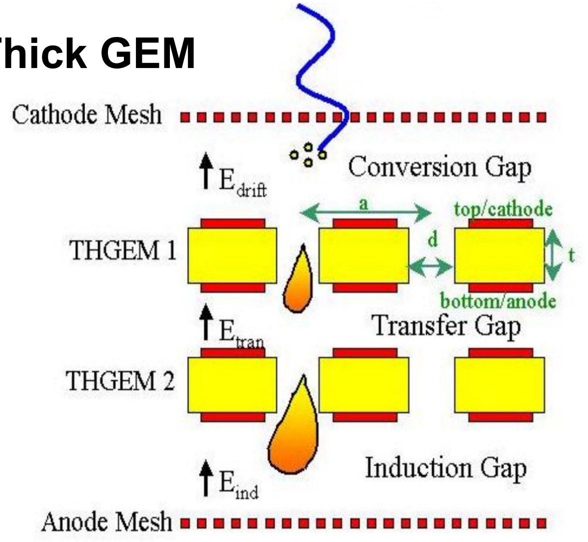


μ-RWELL PCB



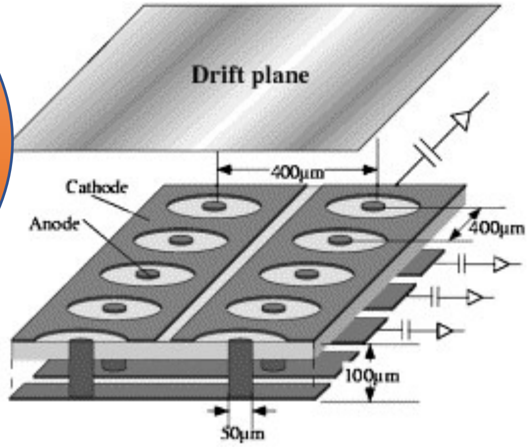
G. Bencivenni et al., 2015_JINST_10_P02008

Thick GEM



- Many more variant of MPGDs are available.
- All of them are based on same basic principle of amplification of ionized electrons in gaseous medium under the passage of charge particle.

μ-PIC



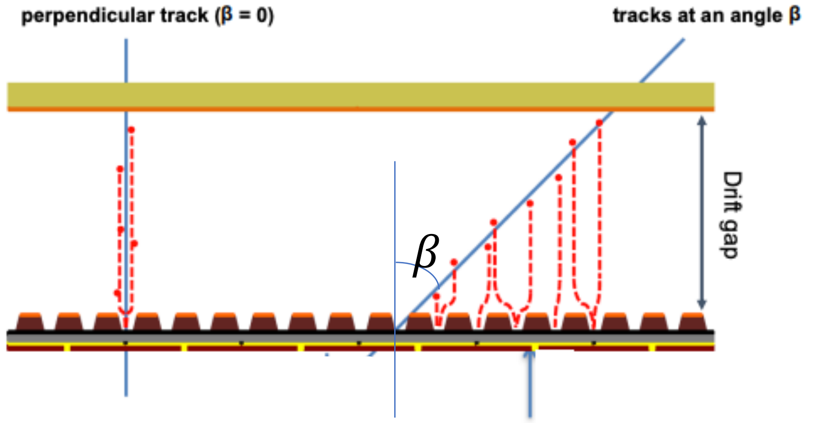
Motivation for the proposed R&D

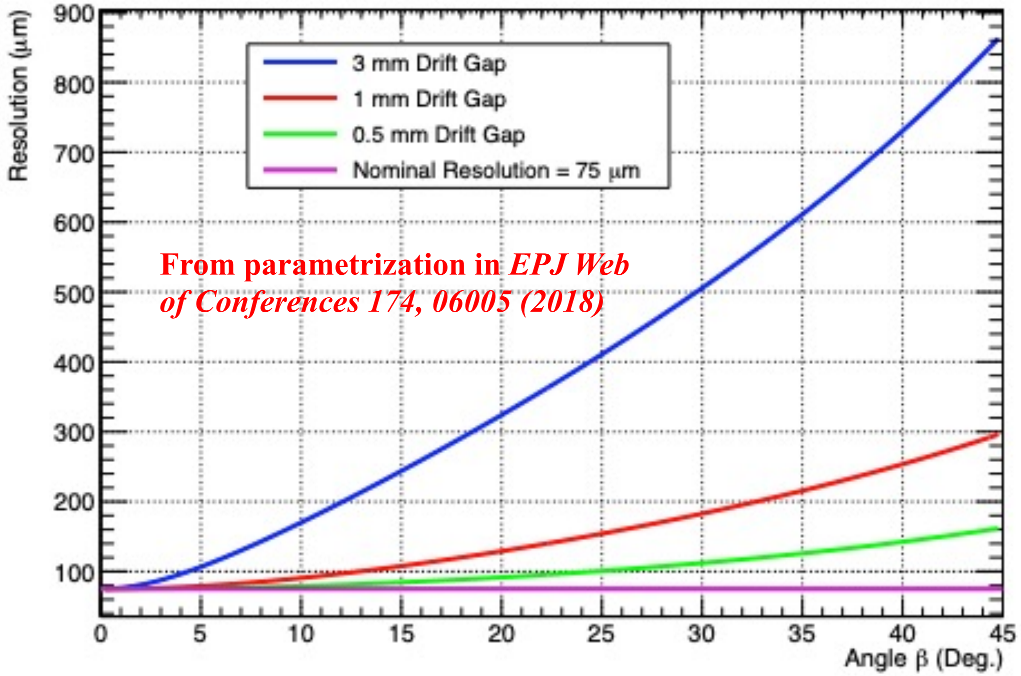
- **Current challenges with MPGD trackers**

1. Deterioration of spatial resolution with track angle .
2. Minimization of E x B effect inside magnetic field.

- **Steps for addressing the above issues**

1. Reduce drift gap to circumvent dependence of spatial resolution on track angle.
2. Use various gas mixtures to optimize the detector performance in terms of stability and efficiency.





Answers to questions by committee

1. Is the efficiency expected to decrease as the ionization gas gap thickness is reduced?

Answer : Yes, with Argon based gas mixture, we expect significant drop in efficiency, that is why we propose in this R&D to:

- Investigate different gas mixture. This include heavier gases like Xenon, Krypton and nPentane …
  - nPentane was used in Thin Gap Chamber (1.4 mm drift gap) in past experiment such as STAR, ATLAS, OPAL.
- Develop hybrid amplification structure such as GEM-µRWELL for high gain and stable operation
  - High gain ➔ high S/N will help recover the efficiency

2. How is the dE/dx response expected to change as the ionization gas gap thickness is reduced ?

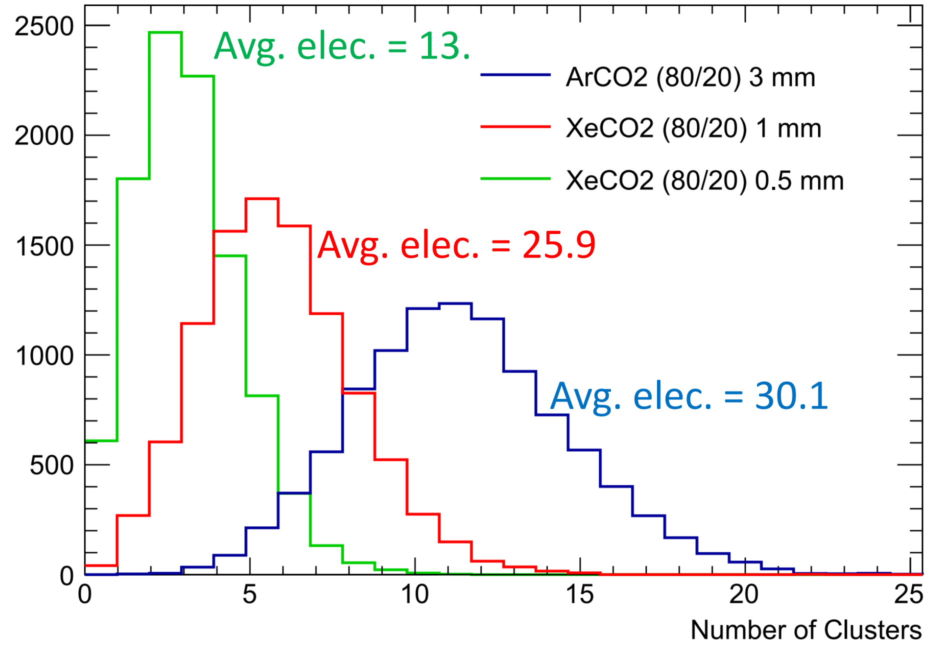
Answer : This proposal is meant for tracking detector so dE/dx for PID purpose is not primary concern. However, as already mentioned, the number of primary ionizations for thin gap MPGD is a concern so we propose to:

- simulation will be performed with several gas mixtures and suitable gas will be selected for the test beam campaign.
- Next slide shows properties of few noble gas.

Properties of viable Gas mixtures

Gas	Z	A	δ (g/cm³)	E_{ex}	E_i (eV)	I_0 (eV)	W_i	dE/dx (MeV/g cm^{-2})	dE/dx (keV/cm)	n_p (i.p./cm) a)	n_T (i.p./cm) a)
H_2	2	2	8.38×10^{-5}	10.8	15.9	15.4	37	4.03	0.34	5.2	9.2
He	2	4	1.66×10^{-4}	19.8	24.5	24.6	41	1.94	0.32	5.9	7.8
N_2	14	28	1.17×10^{-3}	8.1	16.7	15.5	35	1.68	1.96	(10)	56
O_2	16	32	1.33×10^{-3}	7.9	12.8	12.2	31	1.69	2.26	22	73
Ne	10	20.2	8.39×10^{-4}	16.6	21.5	21.6	36	1.68	1.41	12	39
Ar	18	39.9	1.66×10^{-3}	11.6	15.7	15.8	26	1.47	2.44	29.4	94
Kr	36	83.8	3.49×10^{-3}	10.0	13.9	14.0	24	1.32	4.60	(22)	192
Xe	54	131.3	5.49×10^{-3}	8.4	12.1	12.1	22	1.23	6.76	44	307
CO_2	22	44	1.86×10^{-3}	5.2	13.7	13.7	33	1.62	3.01	(34)	91
CH_4	10	16	6.70×10^{-4}		15.2	13.1	28	2.21	1.48	16	53
C_4H_{10}	34	58	2.42×10^{-3}		10.6	10.8	23	1.86	4.50	(46)	195

MAGBOLTZ simulation

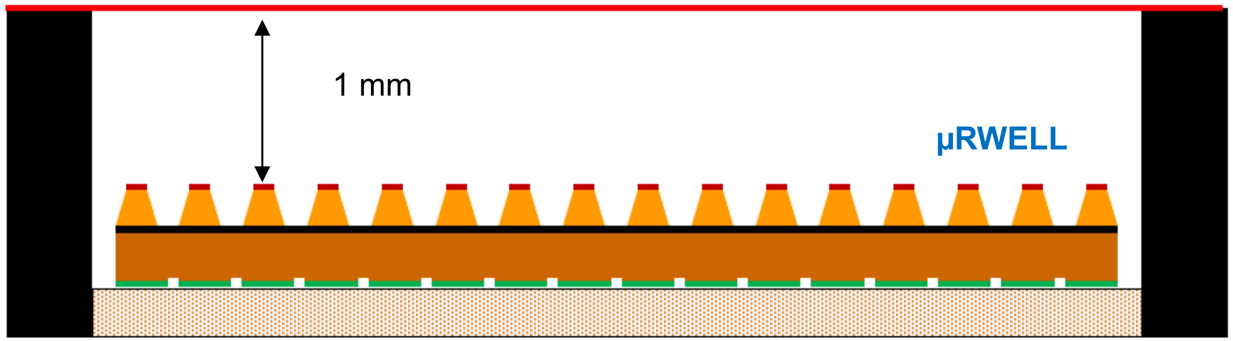


- **Heavier gas Xe and Kr produces more primaries and total ionization compared to Ar. Suitable for thin gap detector.**

Thin Gap µRWELL prototypes

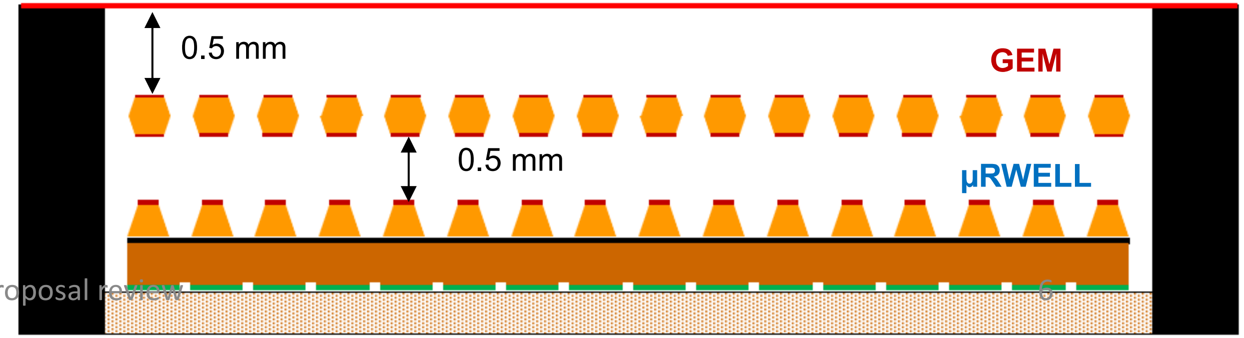
Single stage amplification tg-µRWELL prototype

- **Detector configuration**
  - Single amplification ➔ Have to operate at high gain > 10^4
  - 1 mm drift gap µRWELL
- **Pros**
  - Simple configuration ➔ straight forward assembly
  - Suitable for curved or fully cylindrical trackers
- **Cons**
  - Require high gain ➔ delicate balance between efficiency & stability
  - Drift gap < 1 mm not realistic ➔ limit on optimal spatial resolution
  - Less flexibility in the choice of gas for full efficiency operation



Two-stage amplification tg-GEM- µRWELL prototype

- **Detector configuration**
  - GEM Pre-amplification gain range of 10 to 30
  - µRWELL amplification: Gain 1000 to 5000
  - 0.5 mm drift gap and 0.5 mm transfer gap (between GEM uRWELL)
- **Pros**
  - High gain capability 10^4 to 10^5 ➔ higher S/N & efficiency
  - Flexibility for high gain operation ➔ detector stability
  - More flexibility in the selection of suitable gas
- **Cons**
  - Delicate configuration ➔ large area GEM stretching
  - Gap uniformity between GEM and cathode / anode stages
  - Not trivial for cylindrical / curved tracker geometry



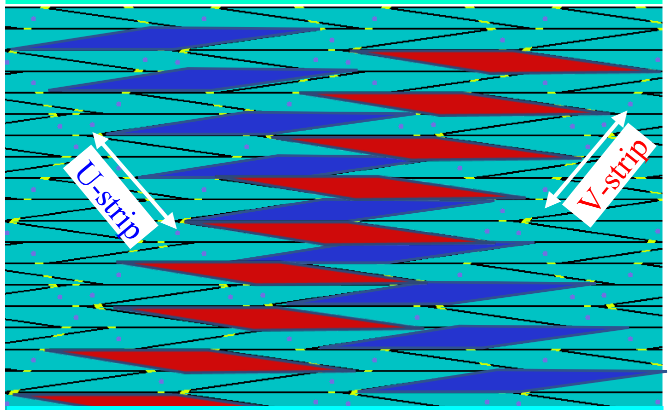
Low-channel count & high-resolution readout

With thin gap MPGD structures, the charge cluster size seen by the readout strips is smaller, this will impact the spatial resolution performance when using standard readout structures. We plan in this proposal to investigate new readout structures to be able achieve spatial resolution requirements with low channel count readout electronics.

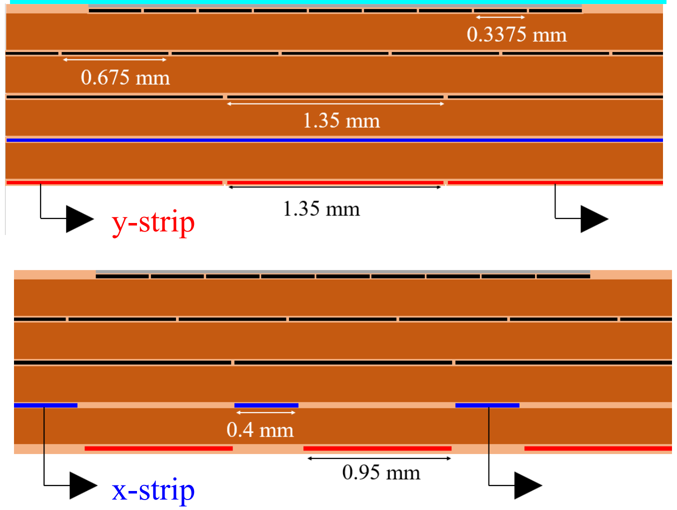
2D readout for tg-μRWELL prototypes

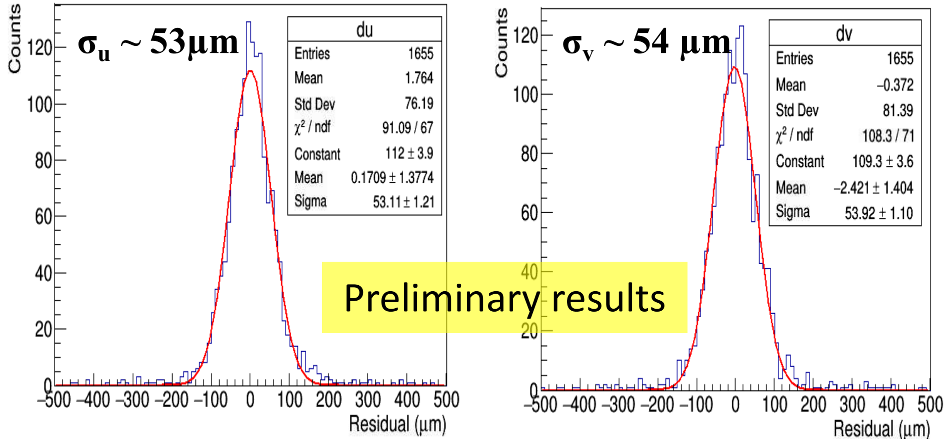
- **Low channel count & high-resolution:**
  - 2D zigzag readout structures ➔ pitch 1 mm to 2 mm
  - 2D straight strip capacitive-sharing readout structures ➔ pitch 800 μm to 2 mm
  - Suitable for large area detectors
- **Studies of spatial resolution:**
  - Nominal spatial resolution: Signal amplitude and ionization charge cloud
  - Spatial resolution vs. incoming track angle
  - Comparison of readout technologies

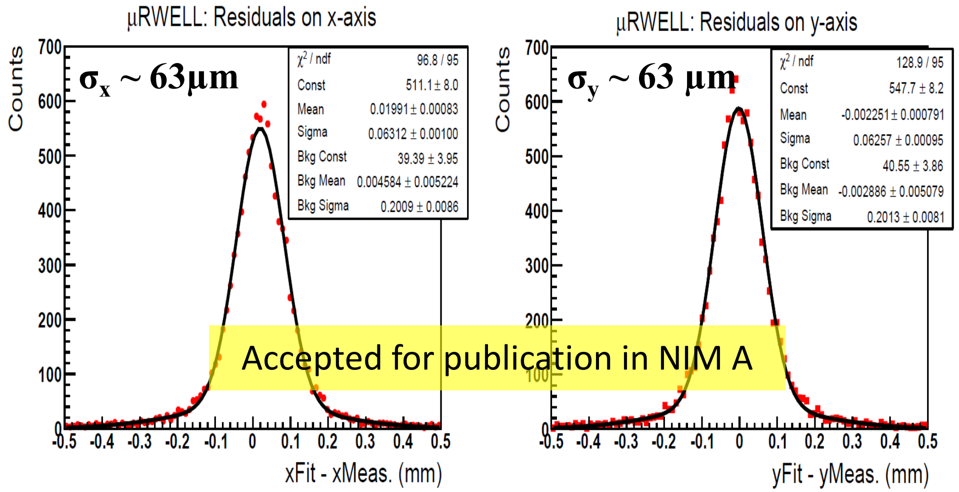
U-V zigzag readout concept (BNL)



capacitive-sharing readout (JLab)

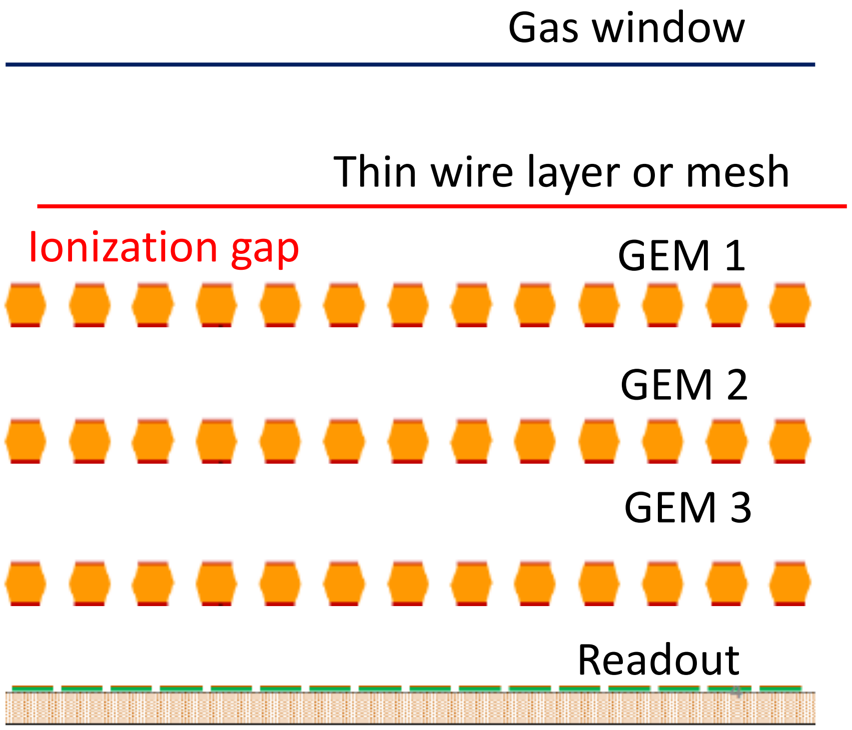






Thin Gap wire cathode GEM prototype

- Why wire/wire mesh cathode ?
- Need cathode to first GEM spacing to be 1 mm or lower
- Thin wire layer or mesh as cathode: Highly effective way to maintain the thin gap.
- Wires could be tensioned to the level that the sagging become negligible.
- Length is unlimited for wires; wire cathode plane could be very wide. This is not the case for foil cathodes
- Many decades of experience with wire planes from wire chamber R&D: proven technology.
- Mesh could be a good option too: less labor needed.
- All these developments with wire and mesh cathodes can also be applied to μRwell based detectors.

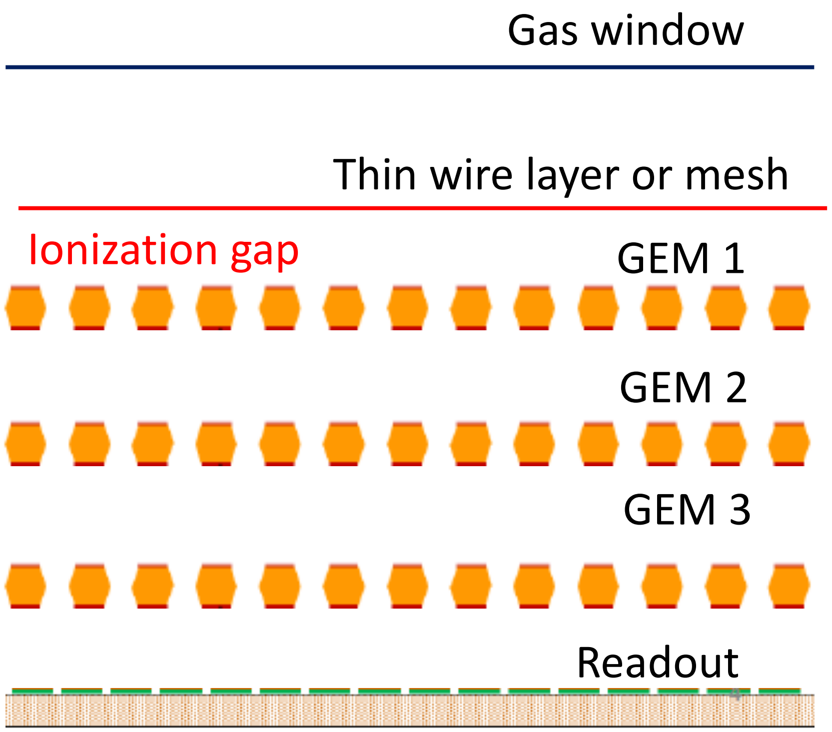


Preliminary studies with Thin Gap wire cathode GEM prototype

- Objective: Initial study of feasibility, efficiency and resolution with a thin gap wire cathode/mesh cathode GEM.

- Procedure:
  - Build a 10 x 10 cm^2 triple GEM prototype with a replaceable wire cathode layer (25 mm gold plated tungsten wires) , wire pitch 1 mm.
  - Set the ionization gap to 1 mm, while keeping transfer and induction gaps well below 1 mm.
  - Test the operation for high voltage stability.
  - Measure efficiency and resolution in a cosmic tracker and in beam test as a function of ionization gap voltage.
  - Replace the wire layer with a wire mesh and repeat the above steps.

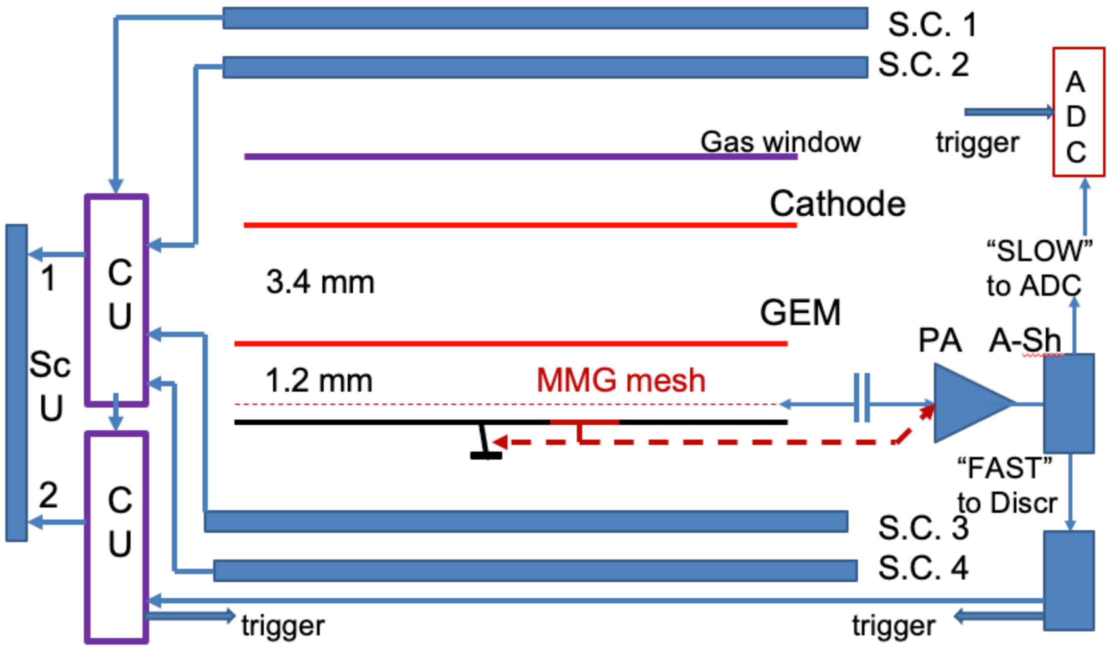
- Evaluate the electrical feasibility of a large area thin gap wire/wire mesh cathode chamber using a large length (~ 1 m) mockup triple GEM with copper coated Kapton foils in place of GEM foils.
  - Use this mockup to evaluate optimum parameters (wire tension, wire pitch, voltage) for a large area thin gap wire cathode



Thin Gap Micromegas prototypes

- Single amplification Micromegas tracker with 1 mm drift gap.
- X-Y strip readout board .
- n-Pentane gas as primary ionization gas to be used.
  - Pros : Provides better efficiency as seen by previous 1.4 mm thin chamber gaseous detectors .
  - Cons : Flammable gas , requires additional measurements for safety.
- Heavier gas like Krypton and Xenon will be used for comparing performance with other prototypes.
- Objective will be to estimate efficiency and stability as compared to standard gap MPGD trackers and also spatial resolution at different track angles.
- The funding request from Yale is only for n-Pentane gas and test beam travel.

Preliminary studies with thin gap Micromegas



- ➢ Objective : Initial study of efficiency for thin gap and standard gap detector.

- ➢ Set up
- Ar : isobutane (90 : 10)
- GEM + MMG as amplification unit
- Can be tuned as thin gap and standard gap detector by changing potentials across different HV electrodes.

- ➢ Procedure

1. Detector as thin gap (~1.2 mm)
   i. Set top and bottom of GEM at same potential while keeping cathode at -10 V. Mesh voltage set to provide effective gain of ~ 2.e+4 by using Fe55 source and connecting small number of MMG pads to pre amplifier (PA).
   ii. Estimate the ratio of scalar unit 1 (ScU1) and scalar unit 2(ScU2).
2. Detector as standard gap (~ 3.4 mm)
   i. Reduce MMG Voltage, Tune GEM and Cathode voltages to return to the same gain.
   ii. Ratio of scalar unit 1 (ScU1) and scalar unit 2(ScU2) was estimated .

3. Ratio of (ScU2/ScU1) in 1.2 mm and of (ScU2/ScU1) in 3.4 mm = 0.87

Gas simulation for Thin Gap MPGD prototypes

➢ Goals

1. Proposed thin gap MPGD trackers performance will rely heavily on type of gas mixture.

2. Testing all kinds of possible combination of gas mixtures is not possible especially with expensive heavy gas like Xenon and Krypton

➢ Steps for addressing the above issues

1. Magboltz + Garfield++ based gas simulation will address the questions of suitable gas mixture in terms of Primaries , avalanches in amplification devices .

2. Standalone Magboltz simulation for different gas mixtures to provide number of primary ionizations, drift and diffusion properties of electrons .

3. Garfield++ simulation for different amplification devices proposed in the proposal to understand the avalanche in various gas mixtures.

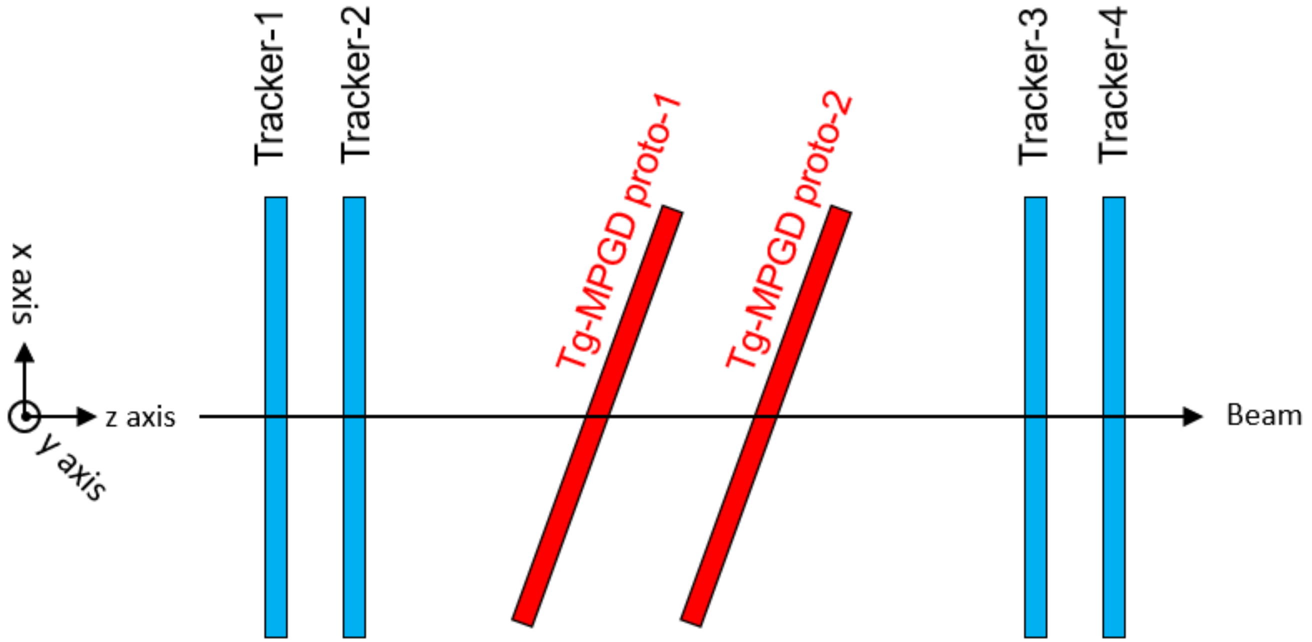
Spatial resolution & Efficiency studies

Studies in beam test at FNAL (summer 2023)

- **Efficiency studies with various gas mixtures**
  - Xe, Kr based mixture (shared with MPGD-TRD setup)
  - Pentane base mixture
  - Ar based mixture
- **Spatial resolution studies vs. track angle:**
  - Track angle scan with X-Y plane rotation
  - Remotely controlled stepper motor stand
- **Comparison of technologies & configuration**
  - Thin gap uRWELL, MM, GEMs
  - Single vs. hybrid amplification
  - Capacitive-sharing R/O vs. zigzag structures

Future beam test - Study of the impact of B-field:

- Explore opportunities for E × B measurement either at:
  - ANL for cosmic test with magnet setup
  - CERN for beam test in magnetic field



Layout of tg-MPGDs setup in beam at FNAL

(top view)

Jefferson Lab TEMPLE UNIVERSITY UNIVERSITY of VIRGINIA VANDERBILT UNIVERSITY Yale University

Summary and Outlook

- The proposed R&D on thin gap MPGD tracker will address the issue of deterioration of spatial resolution with track angle.

- Detailed R&D on effect of detector efficiency with reduced ionization gap will be done by using several gas mixtures .

- Reduce number of readout channels with large pitch readout strips will also be studied.

- Development of various wire and mesh type drift cathode will be done which will be suitable for large size and thin gap MPGD trackers.

Backup

Past experience with thin gap gaseous detectors

- **Used in three experiments for different detector technologies**

1. Opal hadronic calorimeter (ref: S. Dado, *et al.*Nucl. Instr. and Meth. A, 252 (1986), p. 511)
2. STAR small-Strip Thin Gap Chamber (sTGC)
3. ATLAS muon arm small-Strip Thin Gap Chambers (ref: K.Nagai , Nucl. Instr. Meth. A, 384 (1996), p. 219)

- **Similarity in three detectors**

1. All three detectors used drift gap of 1.0-1.4 mm
2. Used nPentane + CO_2 gas mixture

- **Performance**

1. Opal calorimeter provided good energy resolution and also small thickness served as multiple sampling layers.
2. Both STAR and ATLAS sTGC helped in avoiding dependence of track angle on spatial resolution.

- **Cons**

1. Uses wire chambers .
2. While ATLAS sTGC is for triggering purpose STAR sTGC can provide spatial resolution ~ 140 um.
3. Uses highly flammable nPentane gas

Budget

Table 7: **FY23 Budget request** Three budget scenario per institution.

	Request	**-20%**	**-40%**
JLAB	$49,749.5	$39,164.5	$30,696.5
Temple U	$9,510	$4,755	$0
UVA	$43,740	$35,640	$25,920
Vanderbilt	$48,455	$36,568	$20,717.5
Yale	$10,000	$8,000	$6,000
Total	**$161,354.5**	**$124,127.5**	**$83,334**

Table 6: **FY23 Budget request Money matrix (includes overheads and IDCs).**

	tg-MPGD Prototypes	**Telescope / Readout**	**Gas and Supplies**	**Labor**	**Travel**	**Overhead / IDC**	**Total Request**
JLAB	$12,000	$10,000	$18,000	$0	$7,000	$2,749.5	$49,749.5
Temple U.	$0	$0	$0	$0	$6,000	$3,510	$9,510
UVA	$5,000	$5,000	$5,000	$6,000	$6,000	$16,740	$43,740
Vanderbilt U.	$12,000	$0	$17,000	$0	$6,000	$13,455	$ 48,455
Yale U.	$5,000	$0	$0	$0	$5,000	$0	$10,000
Total	$34,000	$15,000	$40,000	$6,000	$30,000	$36,354.5	$161,354.5