TRIPLE-GEM SIMULATION FOR A POTENTIAL CMS Upgrade

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(CMS Collaboration)

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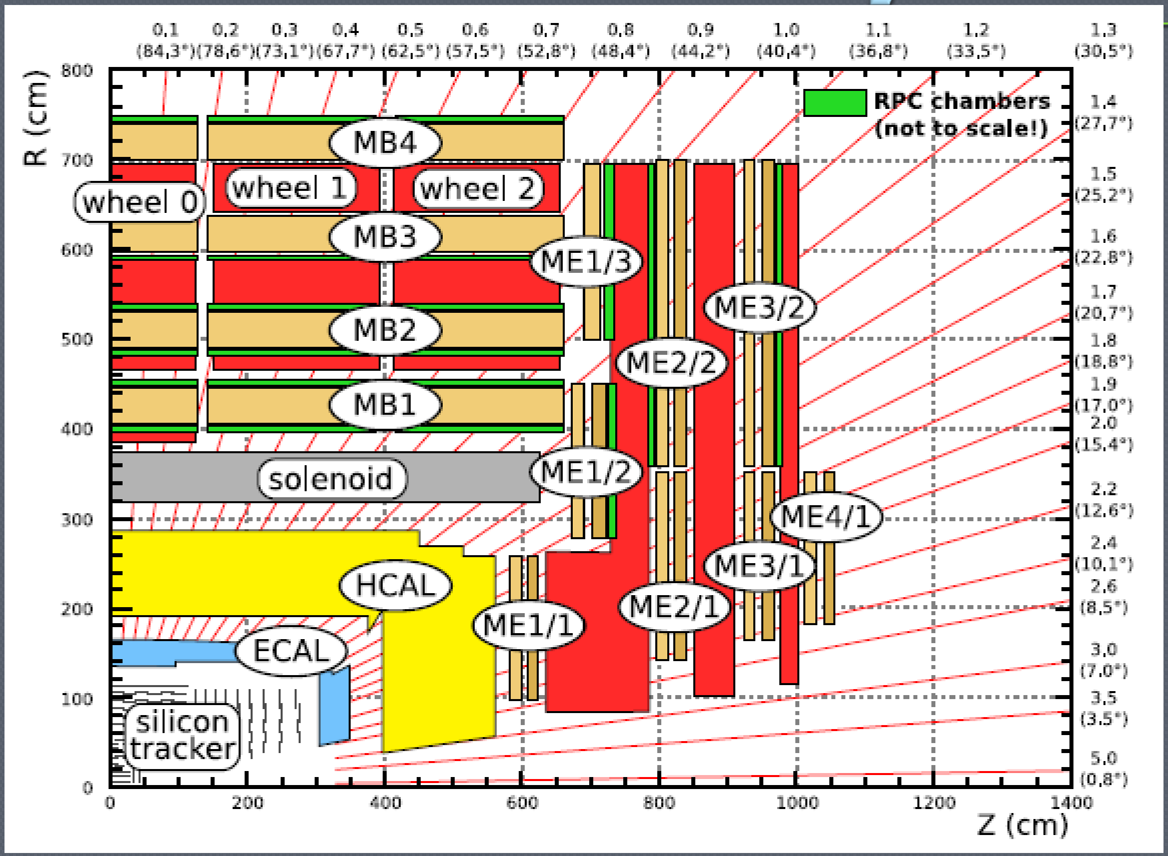
9-14 Jun 2011, Chicago, USA.

On behalf of GEMs for CMS collaboration

Upgrade plans

- LHC currently running at 7 TeV at about 10^{33} /cm^2/s luminosity.
- Phased Shutdowns planned as Phase I and Phase II
  Phase I : (2012-2020), Phase II (>2020)
  - Phase I :
    - First shutdown (LS1) (Energy Upgrade): 2012 for 1.5 – 2.0 years ; Commencement : 2014 (Ramp to 14 TeV)
    - Second shutdown (LS2) (Luminosity upgrade): 2017/2018 for ~ 1 yr ; Commencement 2018/2019 : to increase luminosity towards end of this period 10^{34} /cm^2/s
    - Phase II (SLHC):
      - Sometime after 2020, a long shutdown (LS3) - major machince and detctor upgrades to achieve integrated luminosity a factor of 10 higher than achieved towards end of Phase I.

The Muon system upgrade



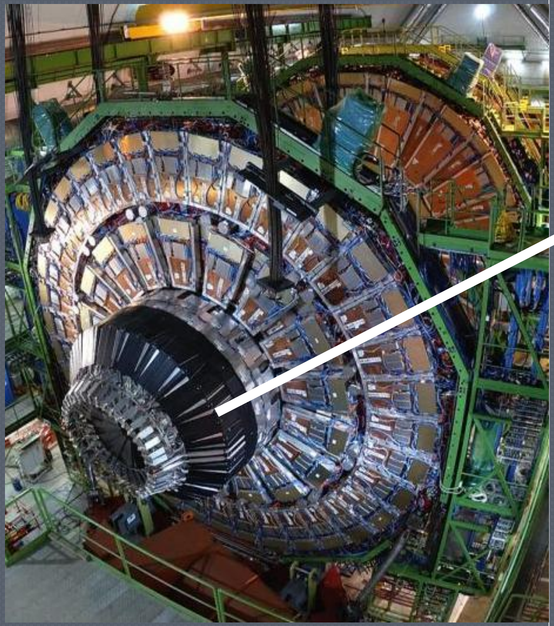
MPGD

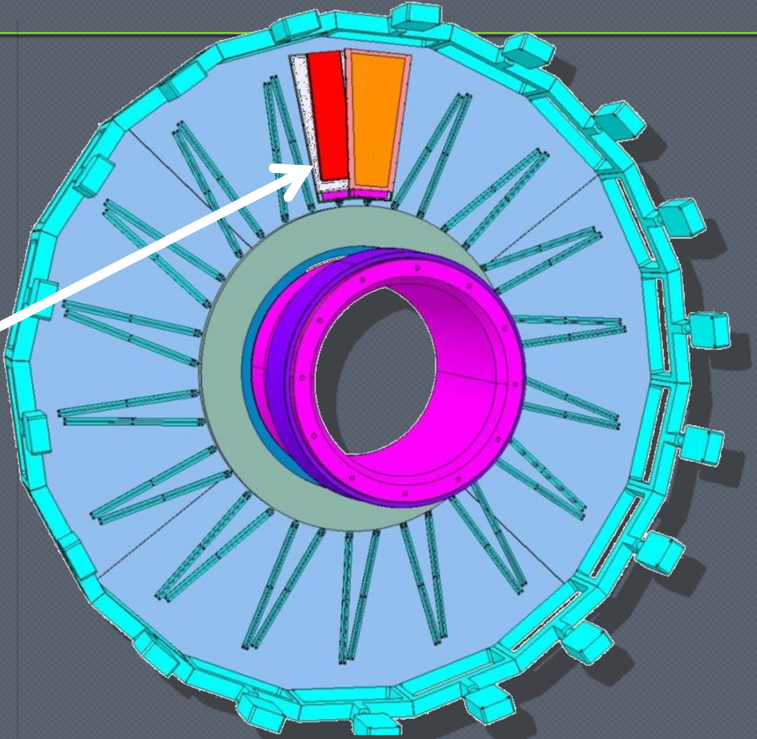
or

RPC

Necessary redundancy needed to reject low pT muons at high luminosities, and maintain trigger efficiency, study QGP, b-tagging, Improvments in Z/W mass resolution

RE1/1 or GE1/1?

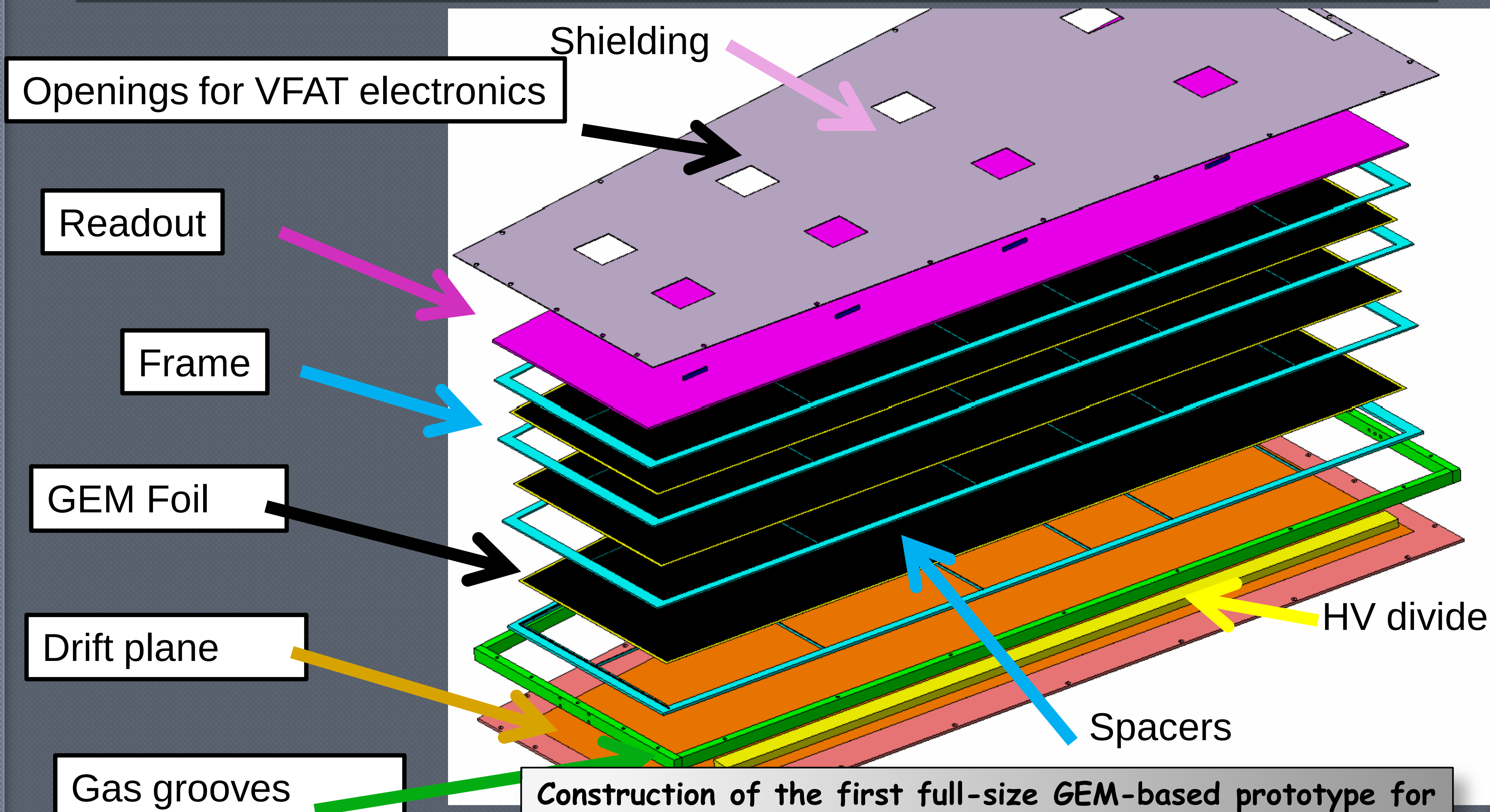




Forward Muon RPC system equipped with detectors up to |η|<1.6.
RPC Upscope planned in two phases – A fourth muon station :
- **RE4/3 (|η|<1.6)**
- **R&D for RPC's designed to handle high rates RE4/2 (1.6 – 2.1)**

Other option – MPGD's instead of RPC's (1.6 – 2.4), GE1/1 instead of RE1/1

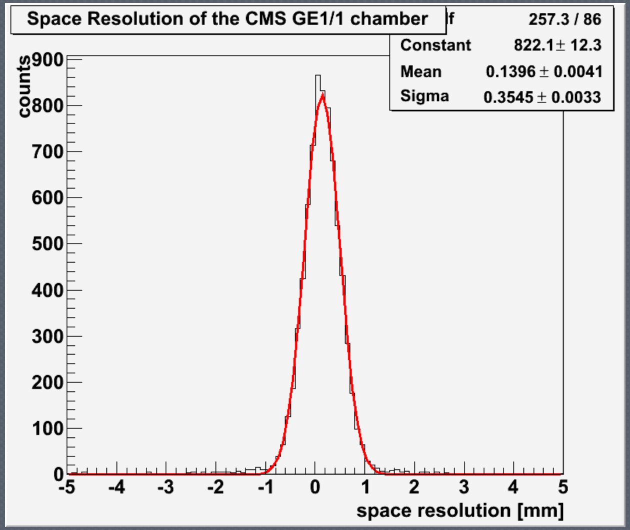
GE1/1 Proto I Layout

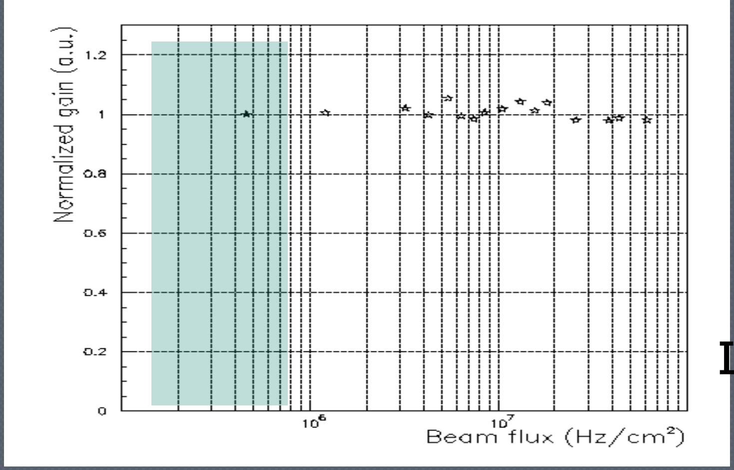


Construction of the first full-size GEM-based prototype for the CMS high-eta muon system, *D. Abbaneo et al.*, arXiv:1012.1524v2 [physics.ins-det]

Why GEM?

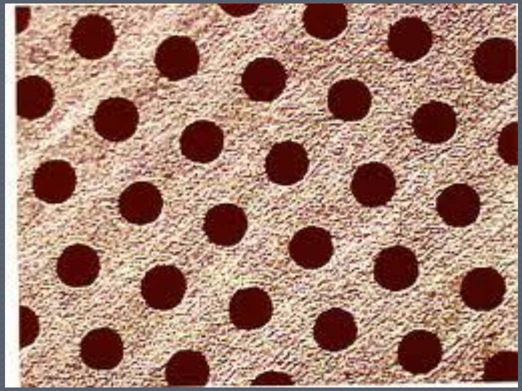
- The Triple GEM-MPGD solves the discharge problem at high gains in MSGC's by cascading gains over 3 layers – Voltages over 3 layers low enough so as to not exceed Raether limit.
- Decoupling of amplification and detection.
- High rate capability (~10^5/mm^2) with high and stable gains.
- Good spatial (~100 μm) and timing resolution (4-5 ns) – Use for trigger.

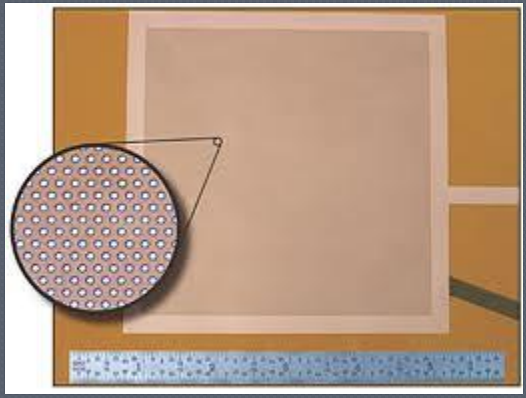


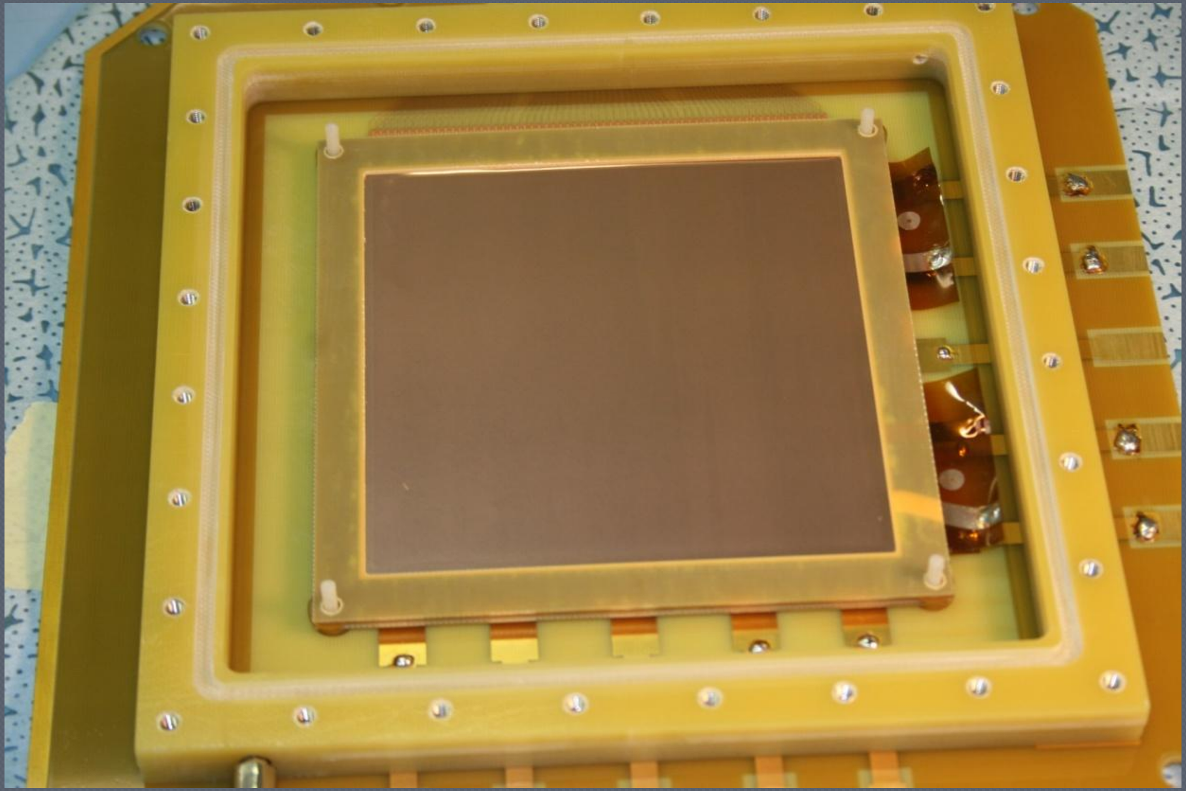


LHCb

Gas Electron Multiplier (GEM)

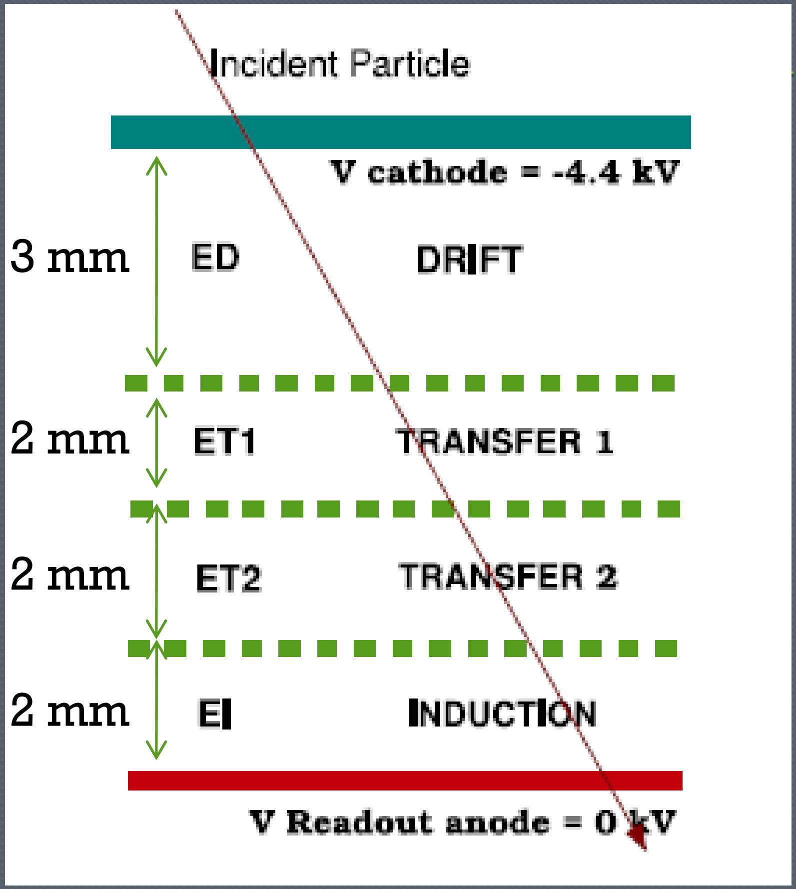






Hole diameter = 70 μm, Pitch = 140 μm, size = 10x10 cm²

The Triple-GEM Layout



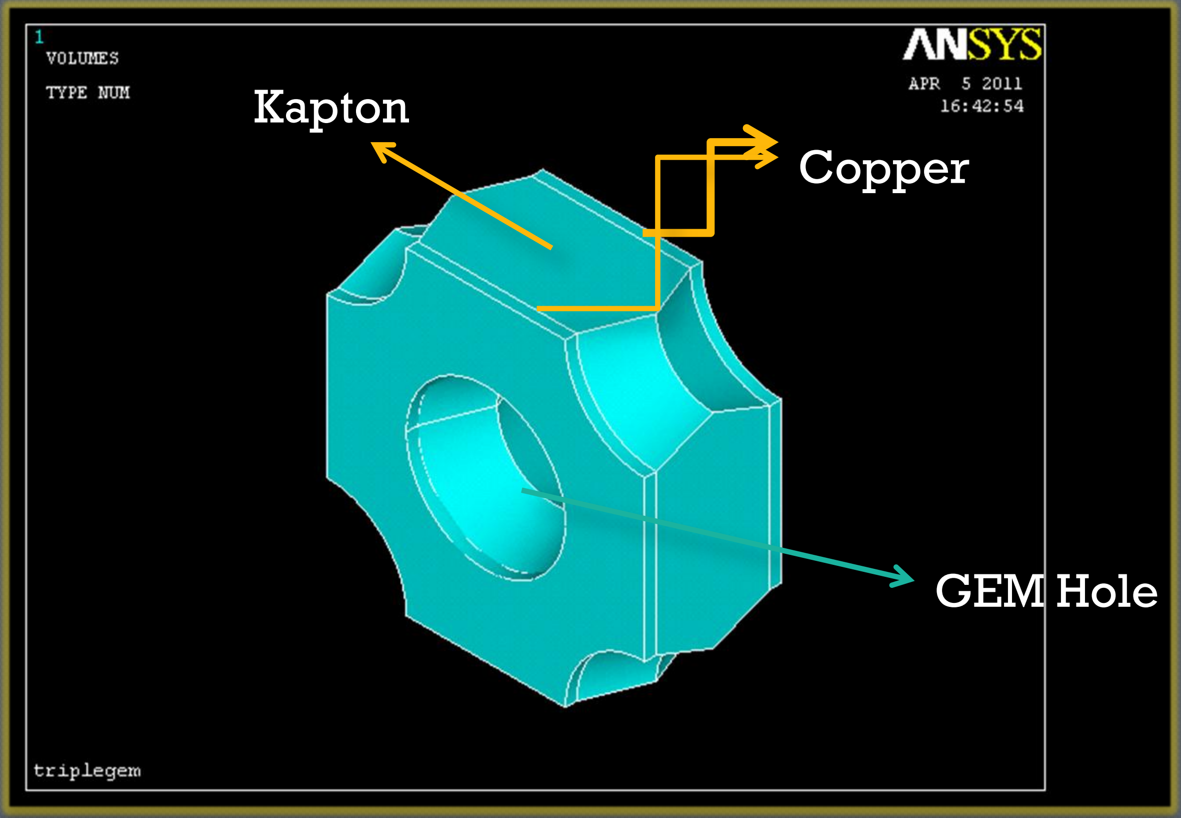
VOLTAGE AND ELECTRIC FIELDS

Parameter	Value
VD	-4.4 kV
ED	2.4 kV/cm
ΔVGem1	397 V
ET1 (Transfer 1)	3.6 kV/cm
ΔVGem2	361 V
ET2 (Transfer 2)	3.6 kV/cm
ΔVGem3	315.5 V
EI (Induction)	3.6 kV/cm

Modelling in ANSYS

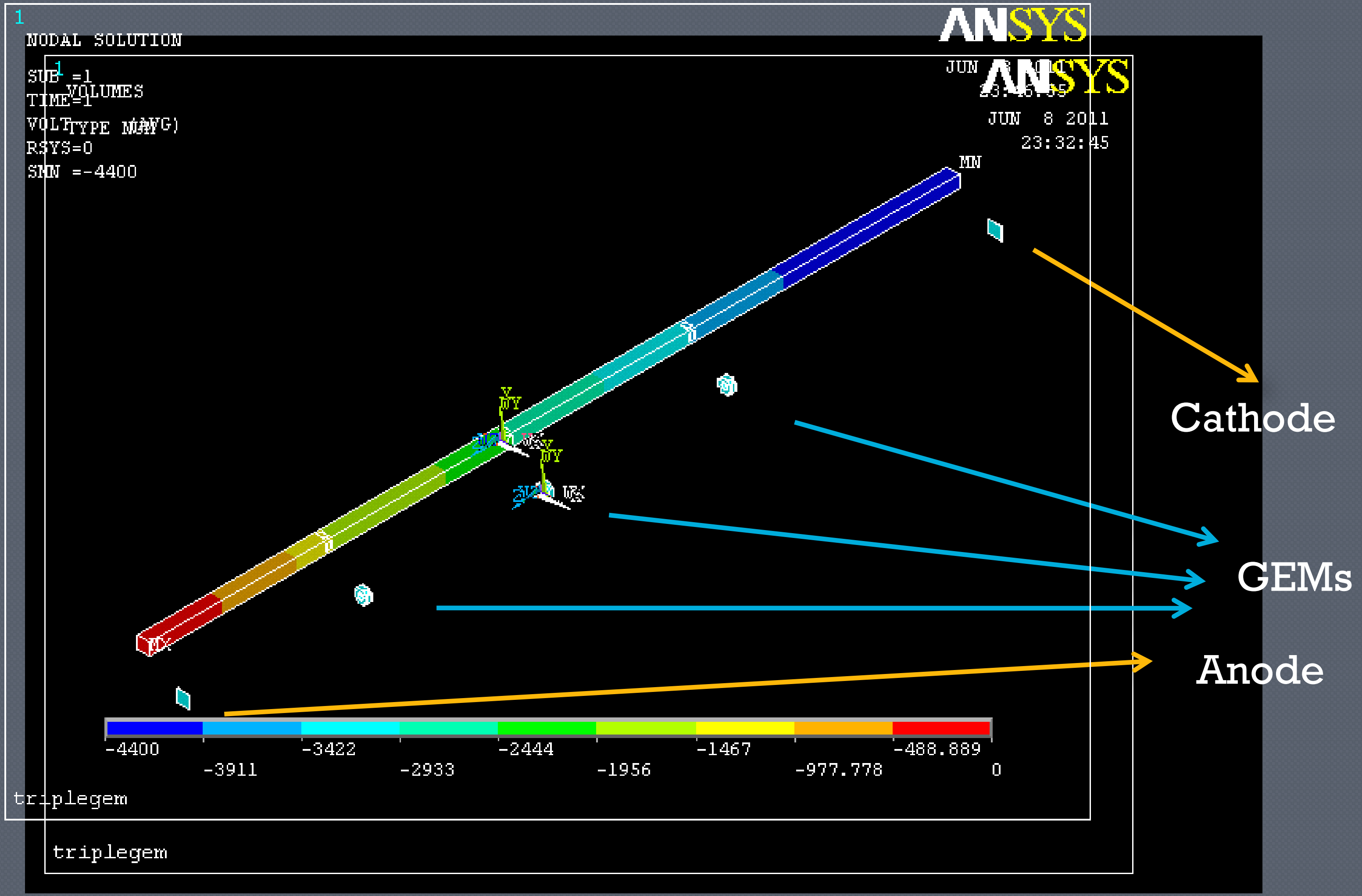
- Previous simulations have been done in MAXWELL – Bonivento et. al., IEEE Transactions on nuclear science, Vol. 49, No. 4, Aug 2002.
- This simulation uses ANSYS. ANSYS improves on Maxwell in the meshing methods provided : Free and Mapped. We use Free with no restrictions on element size.
- Model generation can be accomplished in two ways : direct and solid.
  - The direct method define the nodes and elements of a model directly. The volume of data to be entered for the direct method would be about ten times that of the solid generation. We have used solid modelling.
  - Material definition and properties : Air, copper, and kapton. The common property to be defined is the permitivity of the materials. Assign material properties to the various volumes created from the boolean operations in the first step (Solid Volumes)
  - Assign loads to the geometry - DOF (Degrees of Freeedom) of the various solid materials. In the detector case it is the voltage configuration which is the load.
- Solve the problem and generate the electric field, and potential field maps which are input to GARFIELD.

Modelling in ANSYS

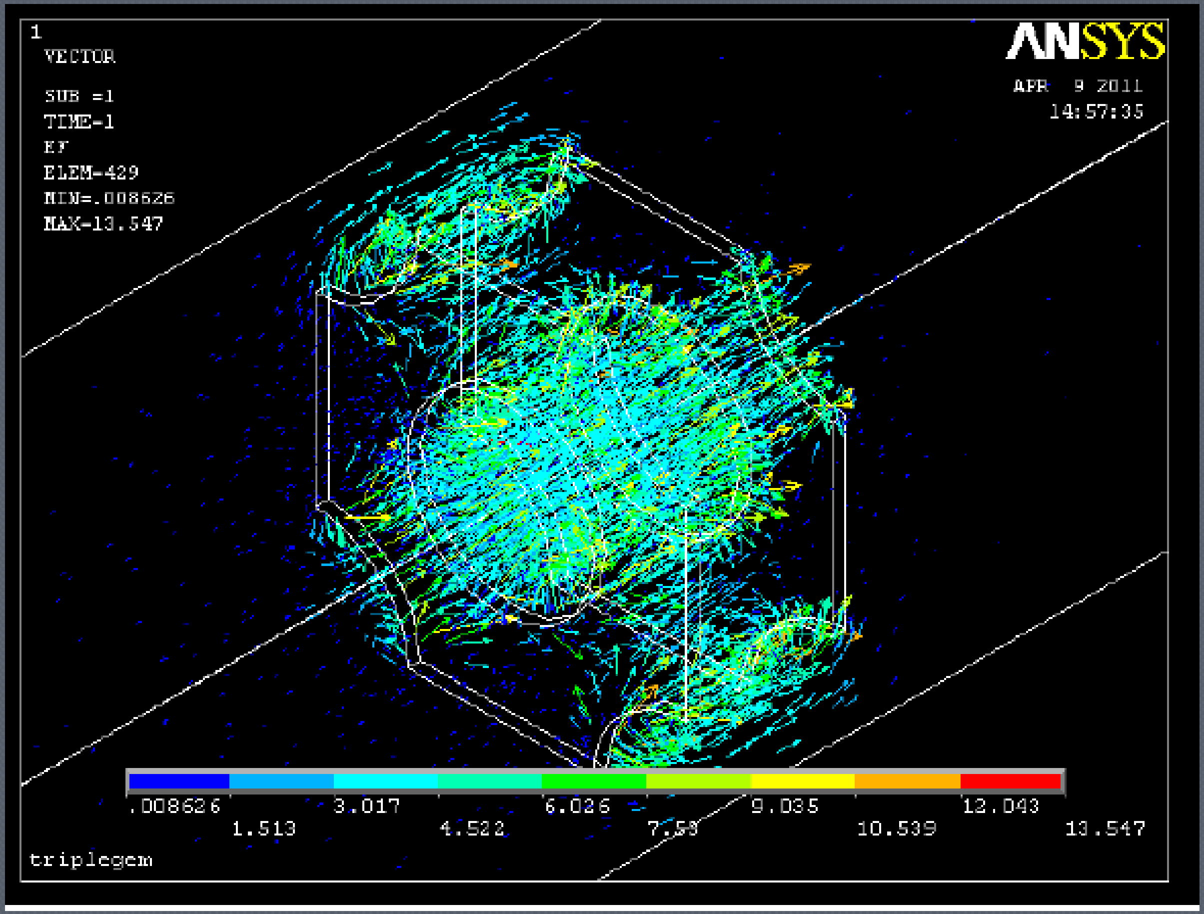


A single GEM cell, showing one hole and quarter of a hole on the corners.

Basic triple GEM cell

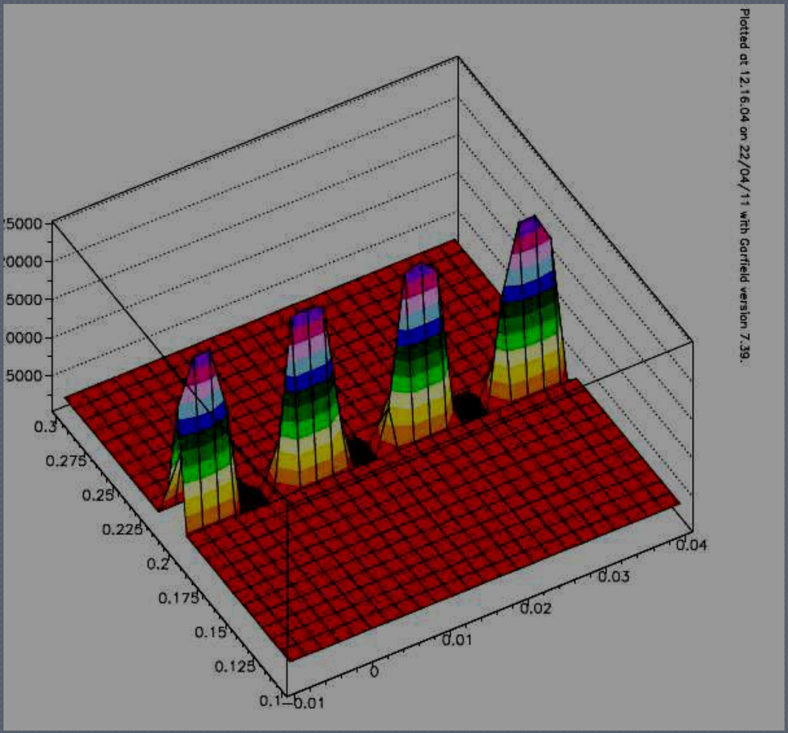


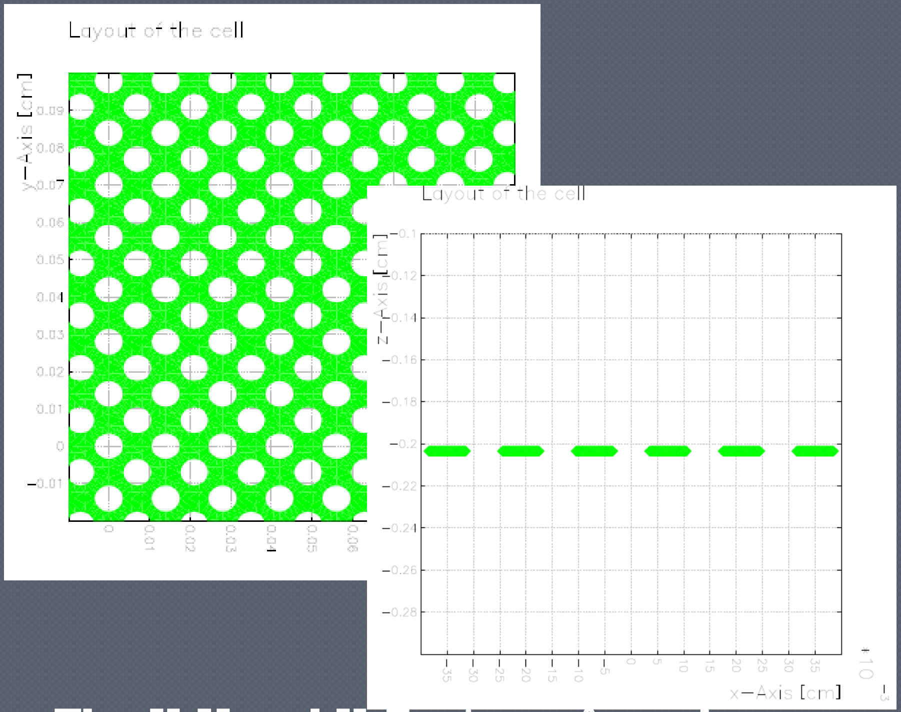
Electric field lines



High electric fields are seen inside the GEM hole and very low elsewhere.

ANSYS → GARFIELD

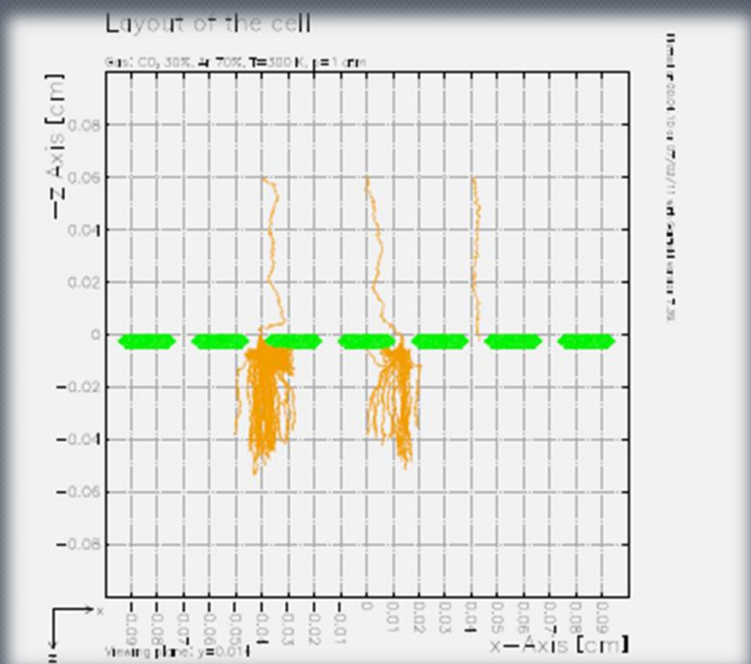


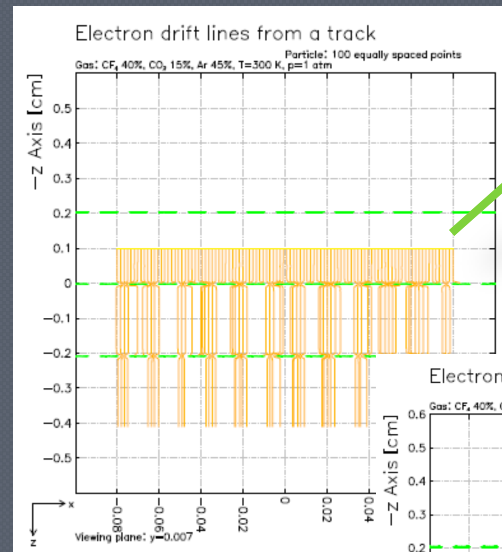


The electric field map files generated by ANSYS is read correctly by GARFIELD as can be seen by the high electric fields generated at the holes

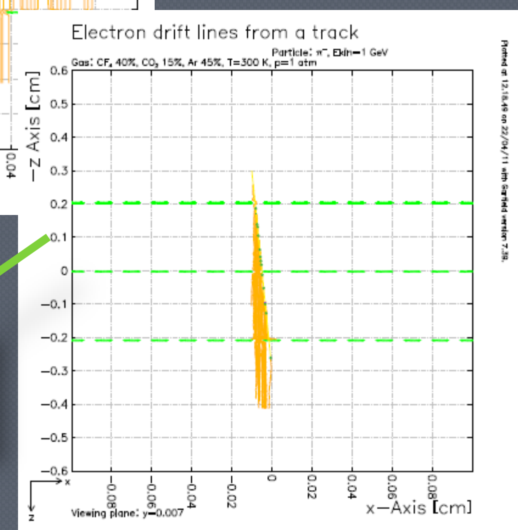
The X-Y and X-Z view of one layer of the detector as seen in GARFIELD. The GEM cell can be replicated in GARFIELD. Only the Kapton is seen as the conductor layers are removed.

Drift/Avalanche in Garfield





Fixed Model – Equally spaced points



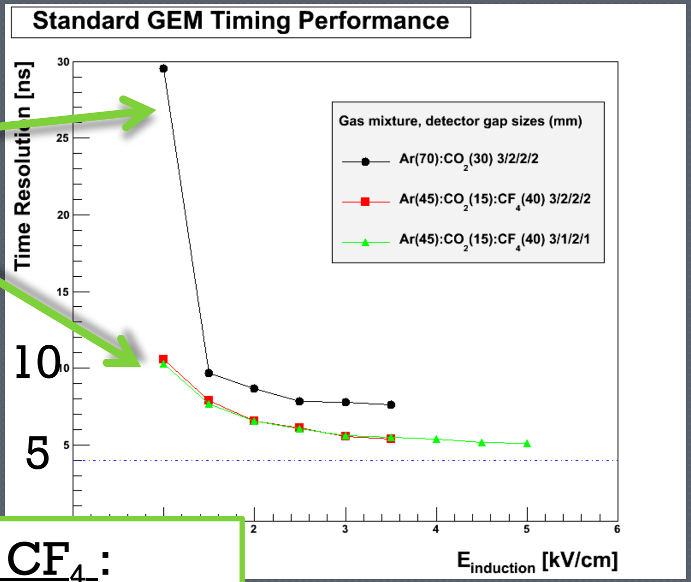
Heed Model

Avalanche formation by single electron

Electron drift lines from a track of Pion (E = 1 GeV) as calculated in HEED.

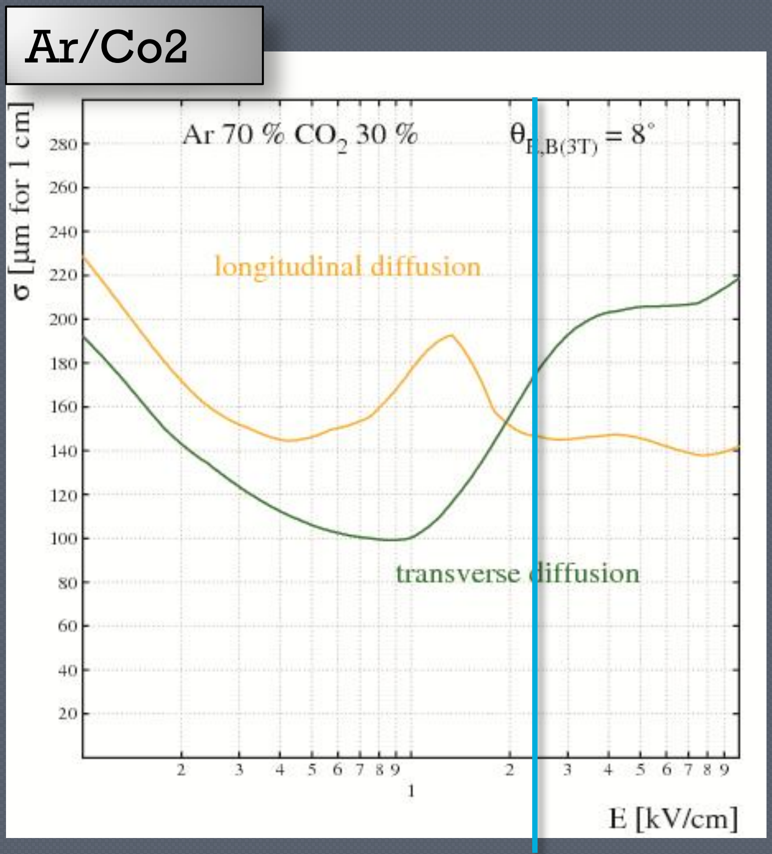
Simulation studies

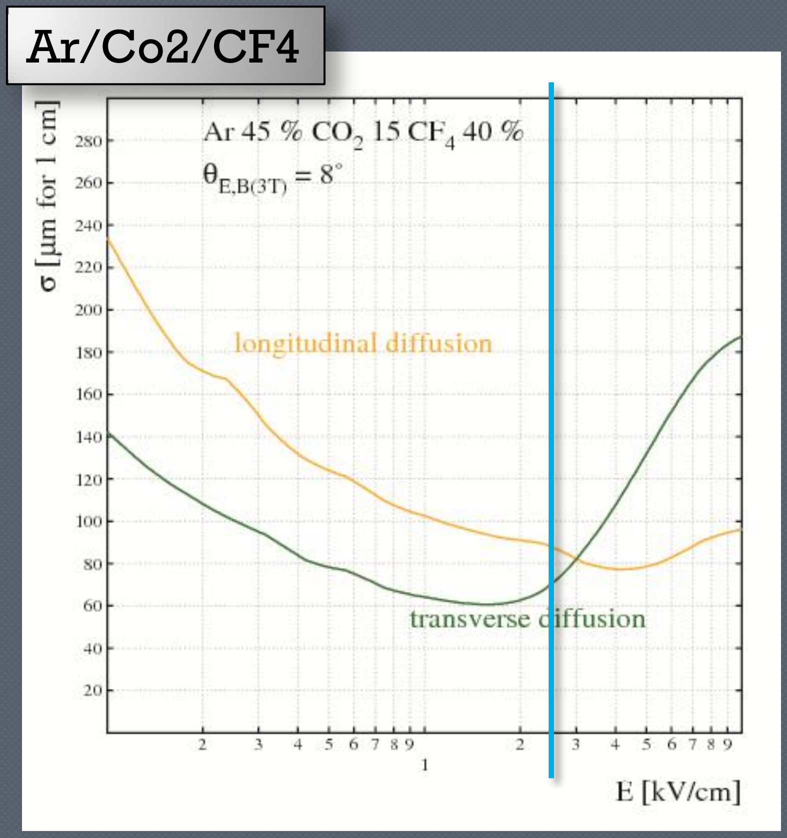
- The simulation studies two gas mixtures which have been found suitable by test beam results.
  - $Ar/CO_2/CF_4$ – 45/15/40 Ar/CO_2 – 70/30
- Calculations are done for B=3T in MAGBOLTZ within GARFIELD.
  - Diffusion coefficient
  - Drift velocity
  - Lorentz angle
  - Townsend coefficient.
- Timing resolution from Prototype I tests :



<u>Choice of CF_4</u> :
Non-flammable
Fast drift velocity
Very small diffusion

Diffusion coefficient



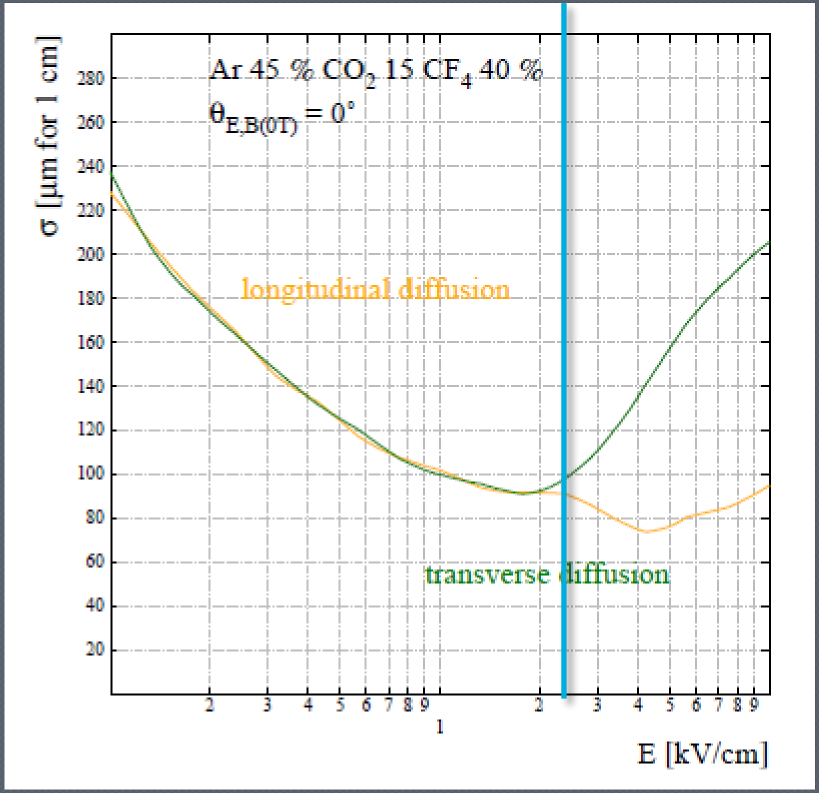


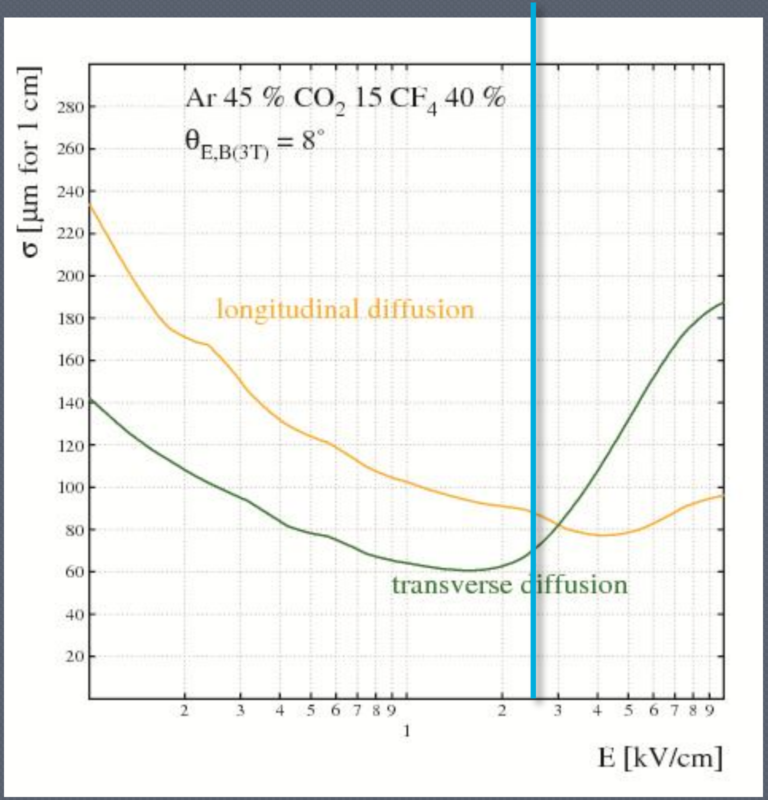
At 2.4 kV/cm, D_L ~15 μm/mm = 45μm for 3 mm drift gap

At 2.4 kV/cm, D_L ~8 μm/mm = 24 μm for 3 mm drift gap

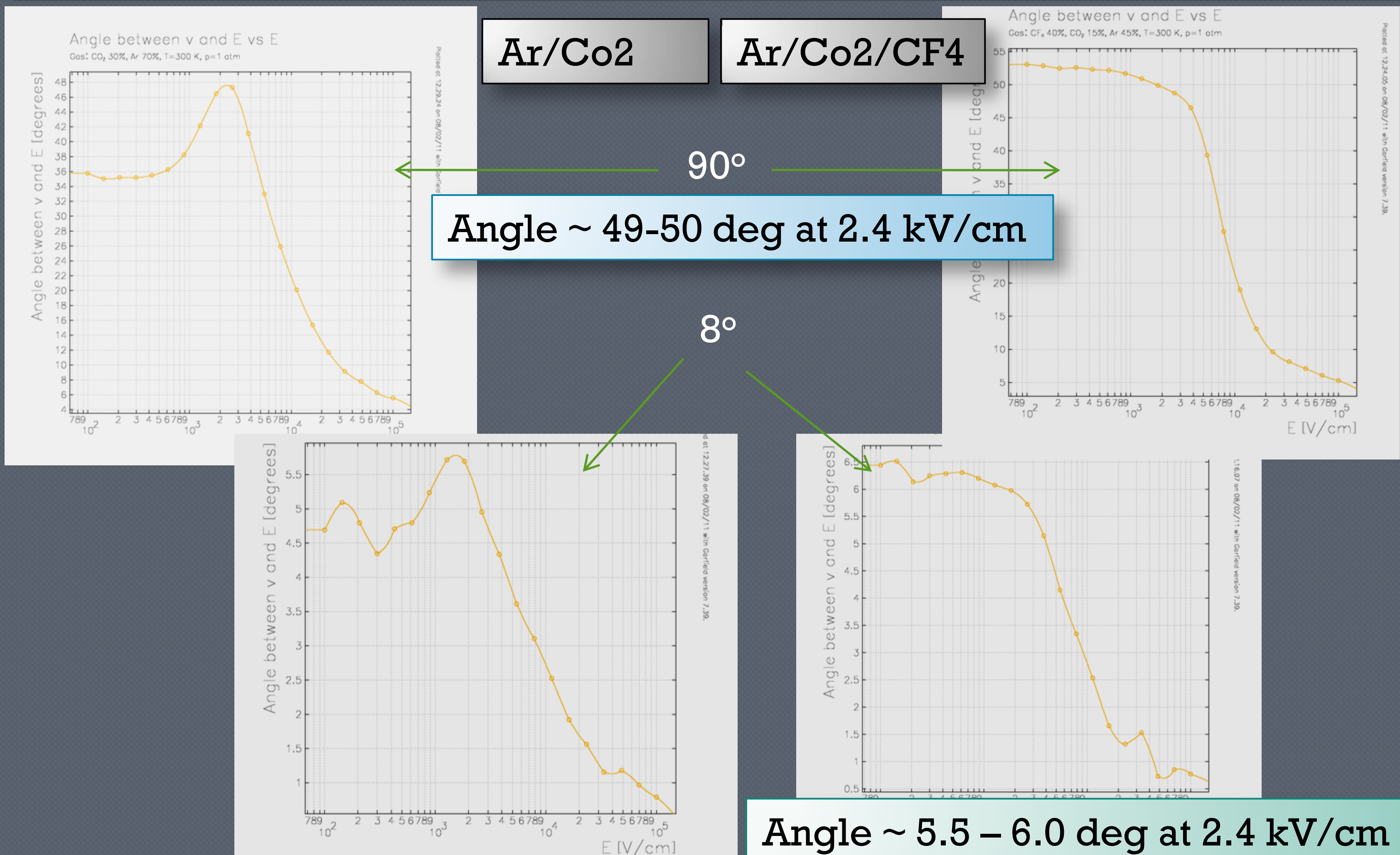
Diffusion Coefficient

- Diffusion coefficient for B=0T & B=3T

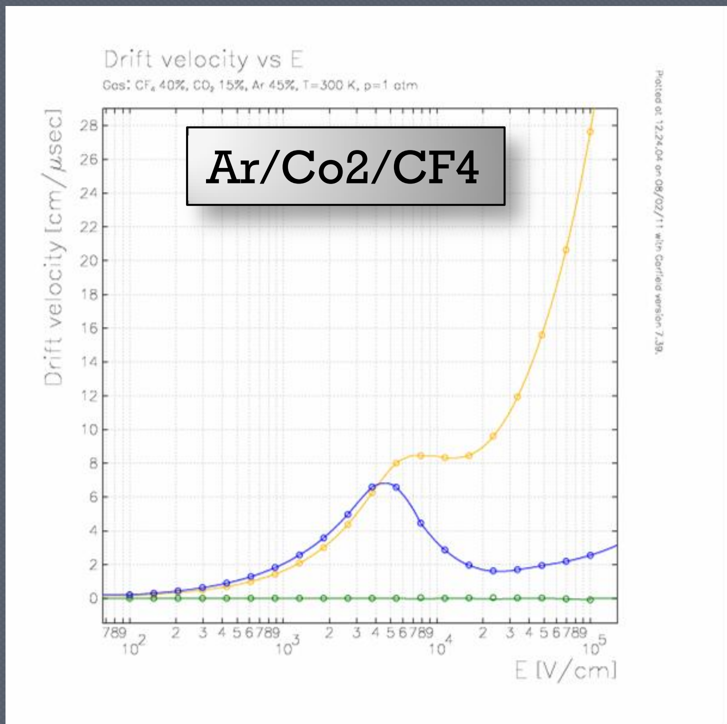


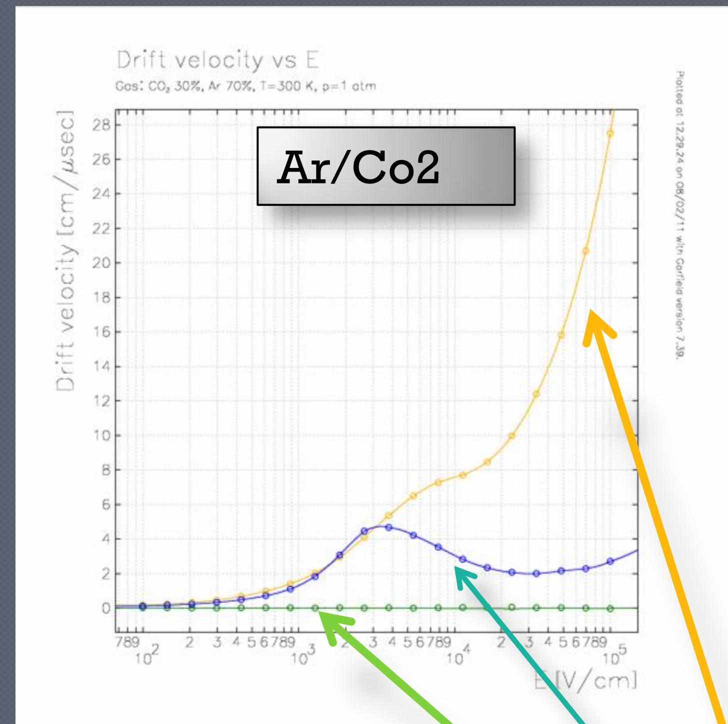


Lorentz Angle θ(E,B)=8°/90°



Drift Velocity for θ(E,B)=90°

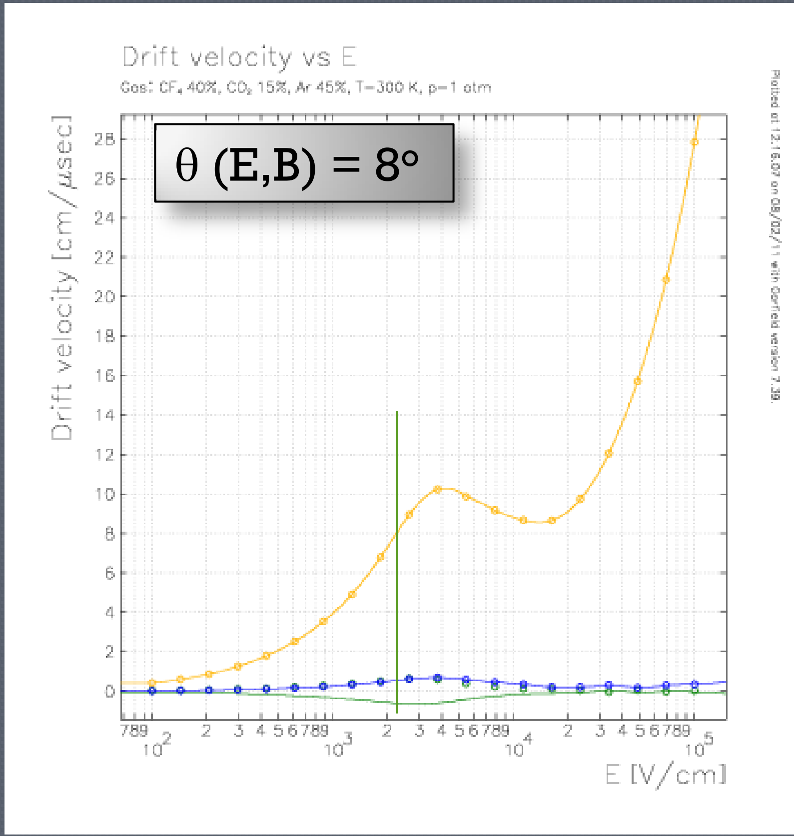


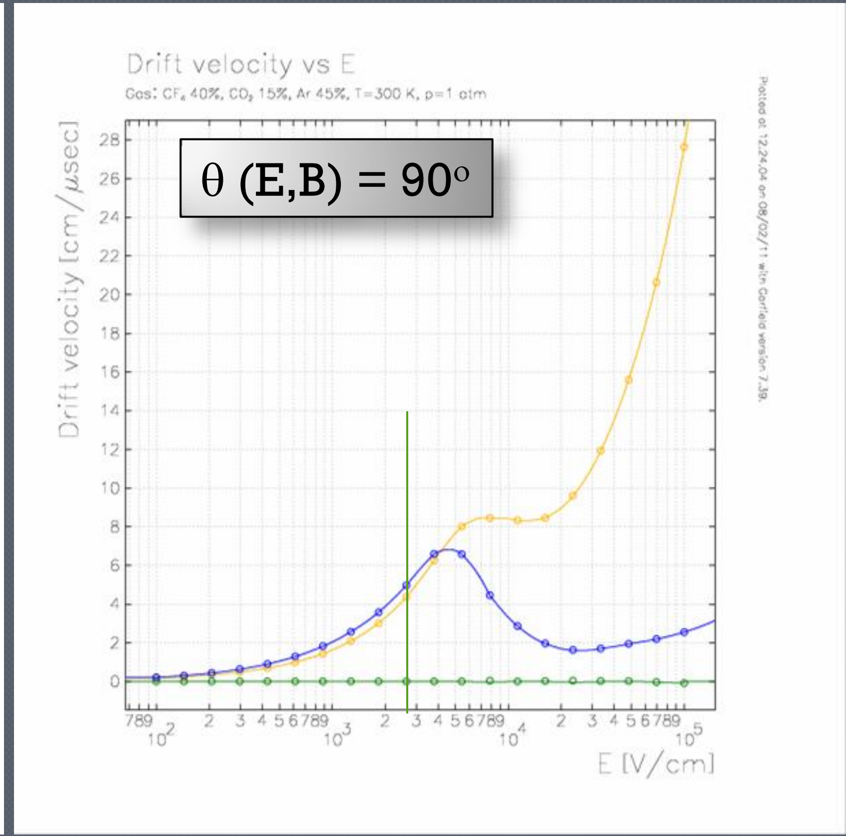


$$v_D = \frac{\mu}{1+\mu^2 B^2}(E + \mu E \times B + \mu^2 B(E \cdot B))$$

$$v = \frac{-\mu E}{1+\mu^2 B^2}\begin{pmatrix} \mu^2 B^2 \cos\theta \sin\theta \\ -\mu B \sin\theta \\ 1+\mu^2 B^2 \cos^2\theta \end{pmatrix}$$

Drift velocity Ar/CO2/CF4 (45/15/40)

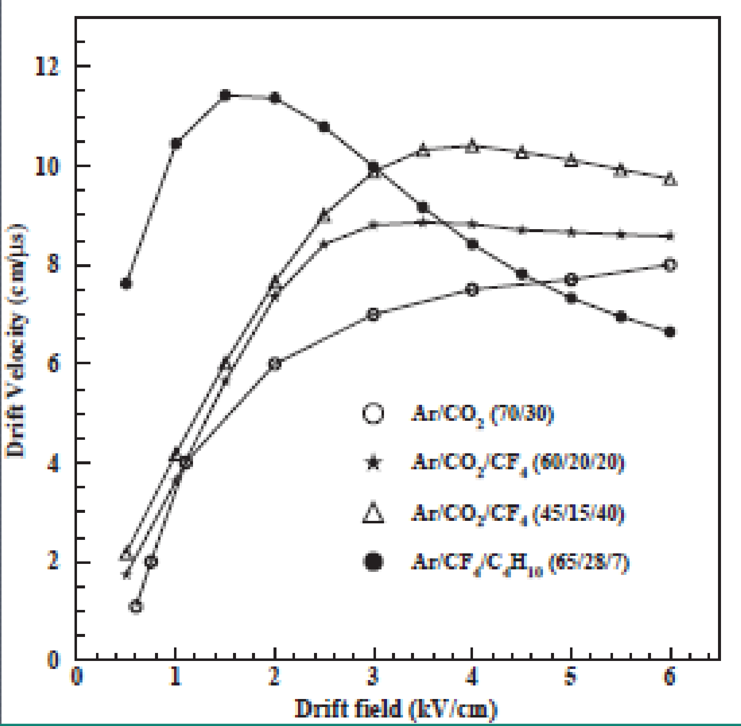




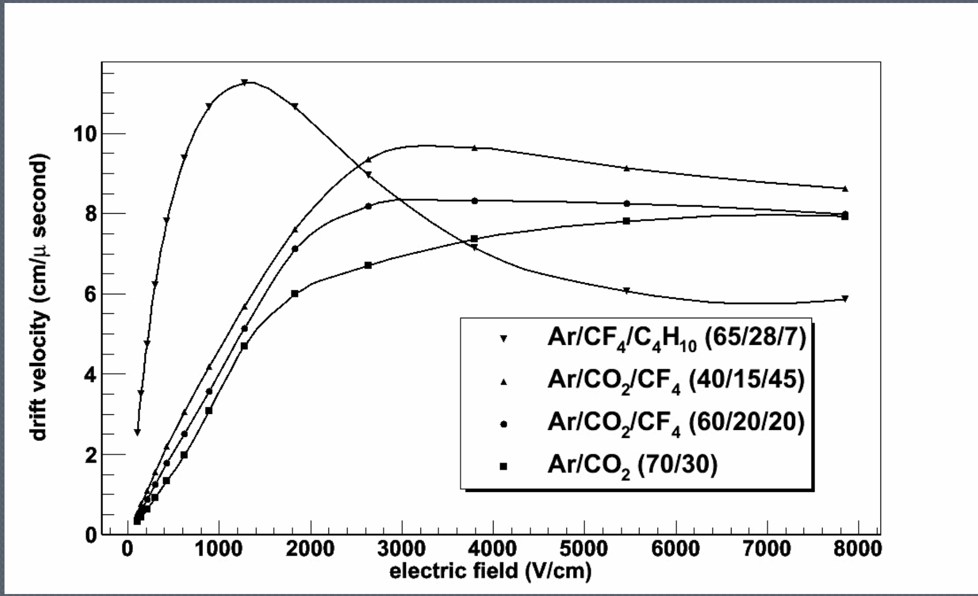
Comparison of drift velocity for θ (E,B) = 8° and θ (E,B) = 90°.
As expected, the x component is negative for θ (E,B) = 8° and for the lower angle, the z component along the E field is dominant.

Drift velocity (Experiment vs Simulation)

- We compare the drift velocity obtained in the simulation with the experimental result obtained by the LHCb muon station for various gases.



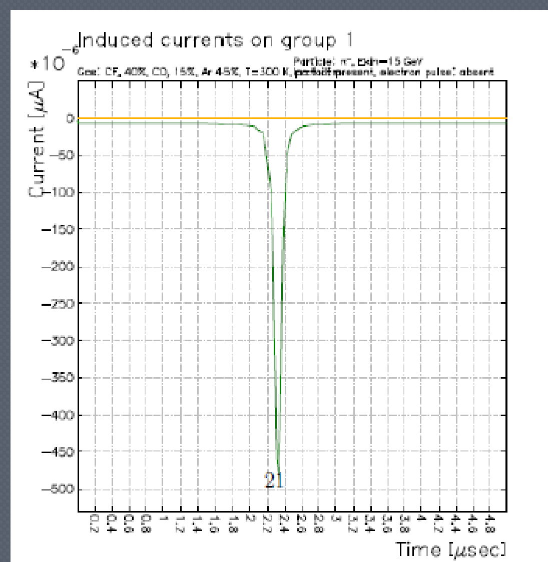
Alfonsi et. al., NIM A 518 (2004)



This Simulation

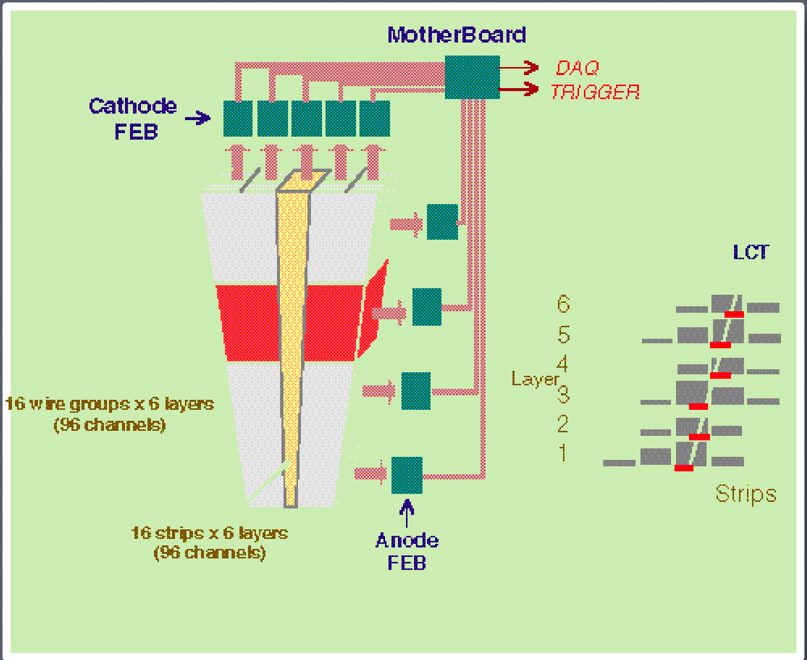
Signal formation

- Signal induced on the readout anode due to electron motion in induction gap.
- Current flow given by Ramo's theorem :
  - $I_k = - q\, v(x)\, E_k(x)/V_k$ where k=kth electrode., E_k is weighting field ($V_k = 1$)



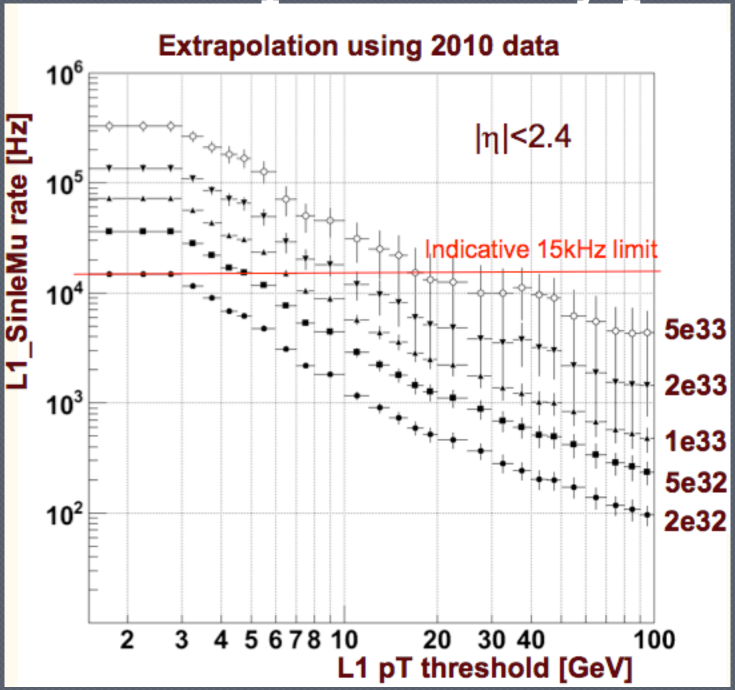
Muon trigger studies- CSCTF

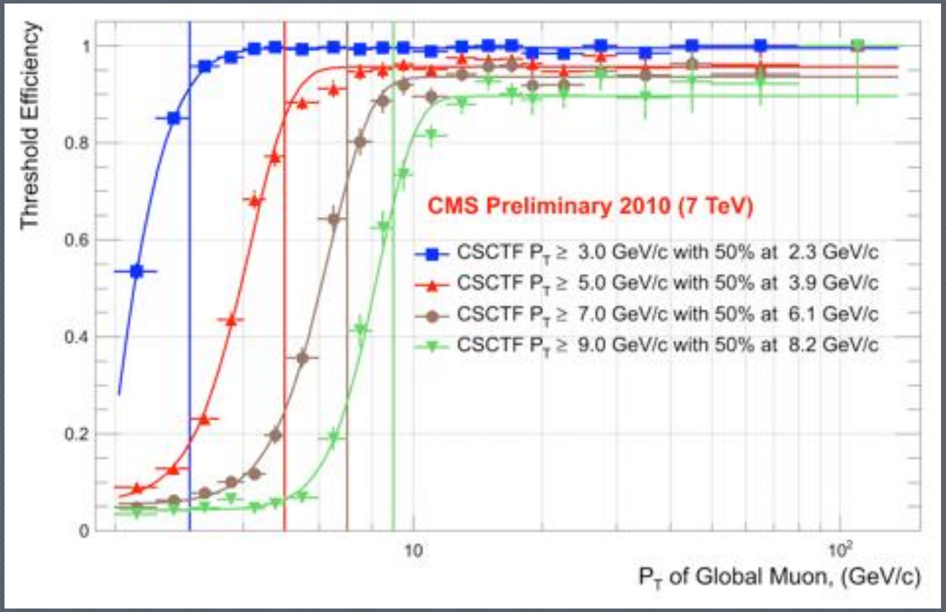
- 6 layer CSC for each endcap muon station.
- Radial strips – wires perpendicular to strips.
- A *Local Charged Track* (LCT) is formed when coincidence of at least 4 hit strips in different layers occurs
- Strips must belong to a predefined road (LUT)
- signals can be spread as much as the maximum drift time (40-50 ns) and therefore the bunch crossing is assumed to be defined by the **second** hit in time.



Muon Trigger studies

- CSC reconstructs tracks and measures momentum.
- L1 rates and Trigger turn-on curves for CSC for different pT thresholds.
- Some preliminary plans to include MPGD with CSC.

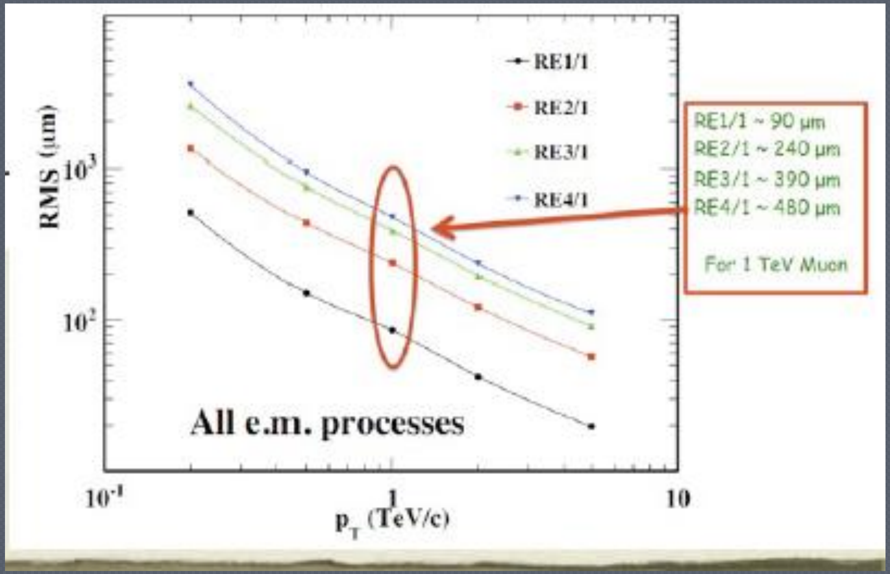




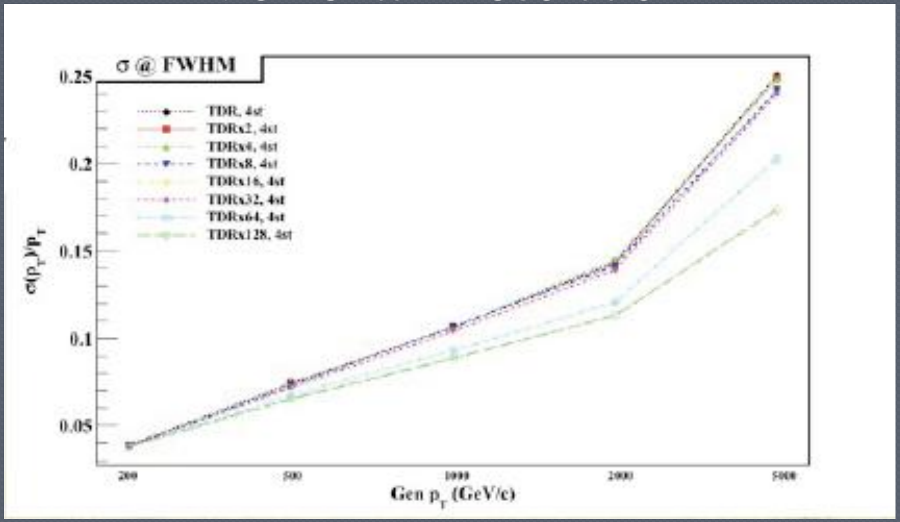
Muon Trigger studies

- Single muons (θ>1.6, uniform ϕ)
- Simulation studies using RPC in the very forward region for different strip configurations (resistive plate chambers)

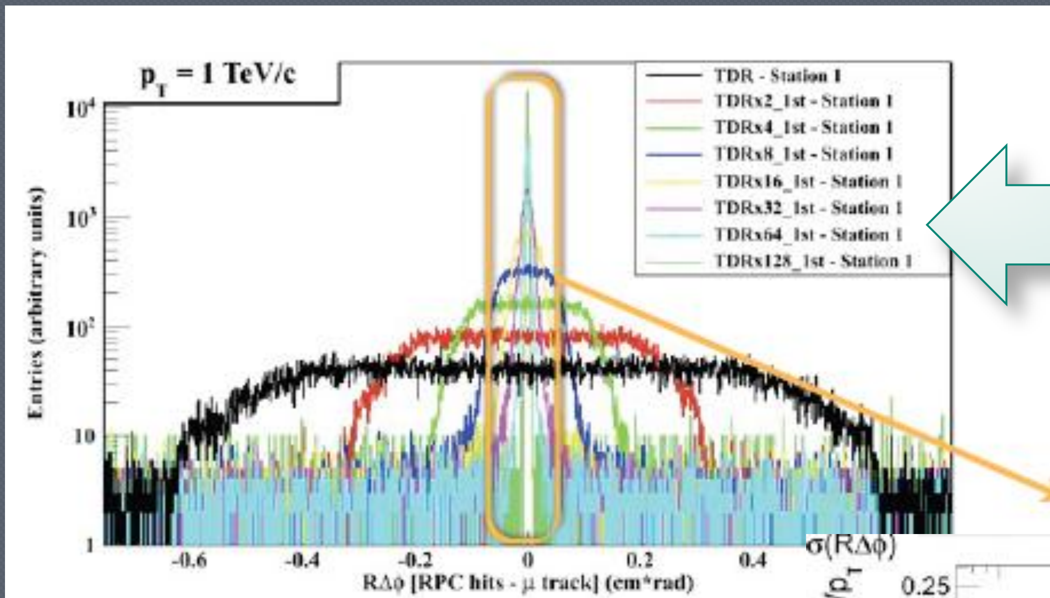
Spatial resolution



Momentum resolution

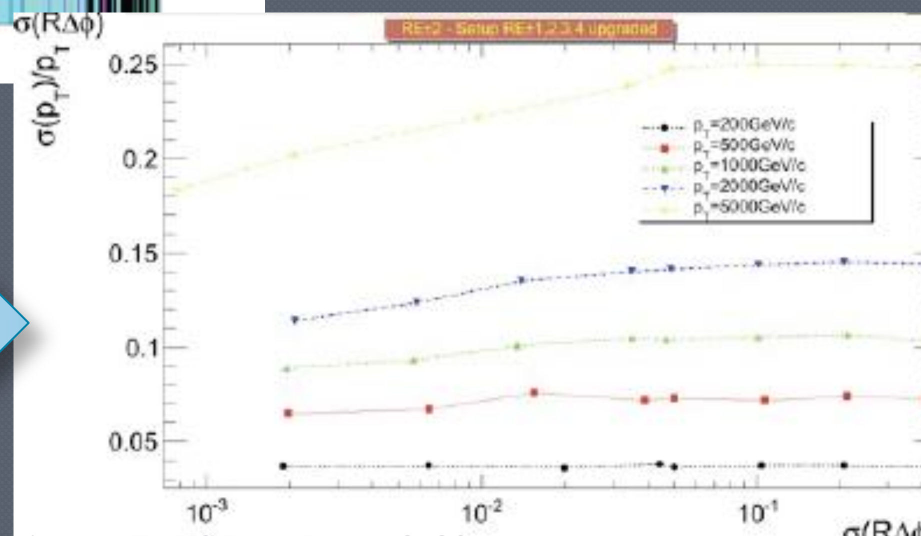


Muon trigger studies



Residual distribution is strip dominated.

Improvement in momentum resolution when spatial resolution not dominated by strip width



Summary

- Simulation of triple GEM done with ANSYS + Garfield Interface.
- Studied transport parameters for different gas configurations
- Plans to test simulation modelling in other packages like neBEM (near Boundary Element Method) and study further detector characteristics (gain, efficiency, timing resolution etc.)
- Preliminary trigger studies point to need for high eta stations in order to effectively veto low pT muons, or use low pT muons for B physics, improve Z/W mass resolution, QGP, and retain good trigger efficiency.
- Many Thanks to …

Rob Veenof (RD51), Archana Sharma (CERN),
Ankit D. Mohapatra (student-NISER),
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Thanks to…GEMs for CMS collaboration

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Tania Moulik, Ankit D. Mohapatra (NISER, India)

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Luigi Benussi, Stefano Bianco, Stefano Colafranceschi, David Piccolo, Guido Raffone, Giovanna Saviano (INFN, Frascati, Italy)

Duccio Abbaneo, Paul Aspell, Stephane Bally, Jean Bos, Jean Paul Baptiste, Antonio Conde Garcia, Eric David, Rui De Oliveira, Serge Duarte Pinto, Serge Ferry, Hans Postema, Alexis Rodrigues, Leszek Ropelewski, Archana Sharma, Michal Zientek, Nebjosa Smilkjovic, Alessandro Marchioro, Jorgen Christiansen (CERN, Switzerland)

Andrey Marinov, Michael Tytgat, Nicolas Zagandis (GHENT, Belgium.)

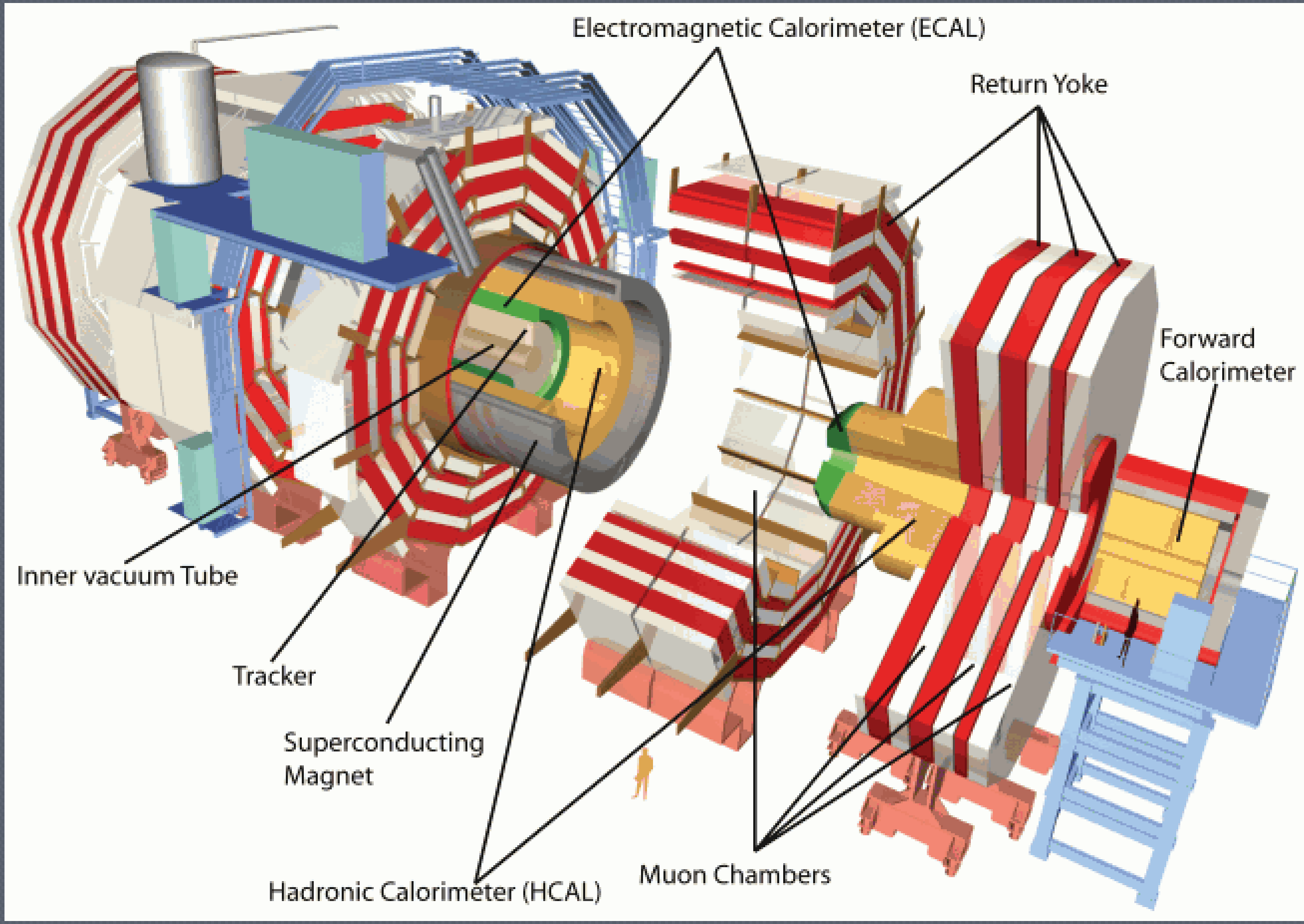
Kondo Gnanvo, Marcus Hohlmann, Michael J. Stab (Florida Inst. of technology, USA.)

Guido Magazzu, Eralo Oliveri , Nicola Turini (INFN, Pisa., Italy)

Karol Bunkowski (Warsaw, Poland)

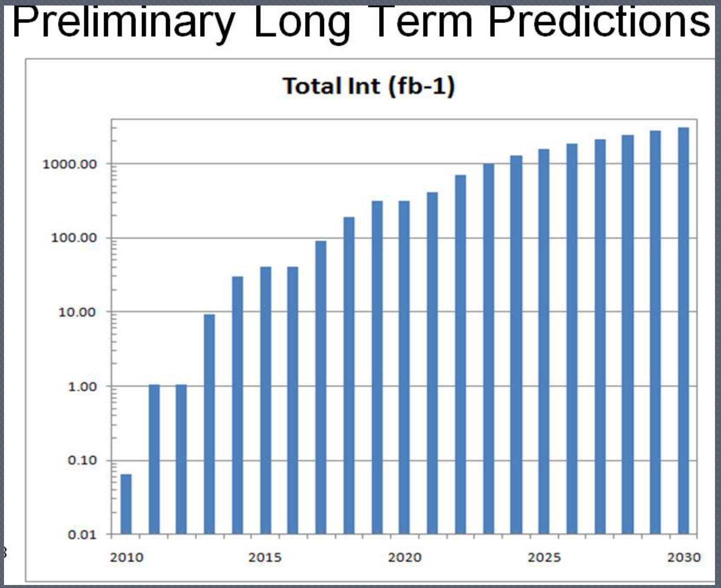
Back-up slides

Compact Muon Solenoid – CMS Detector



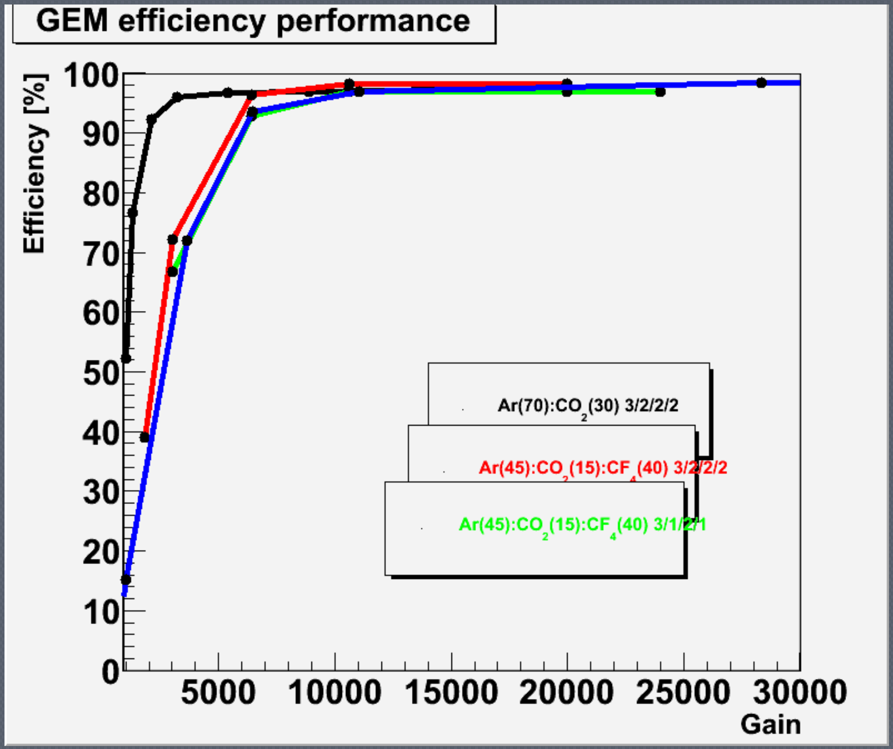
Expected Integrated Luminosities

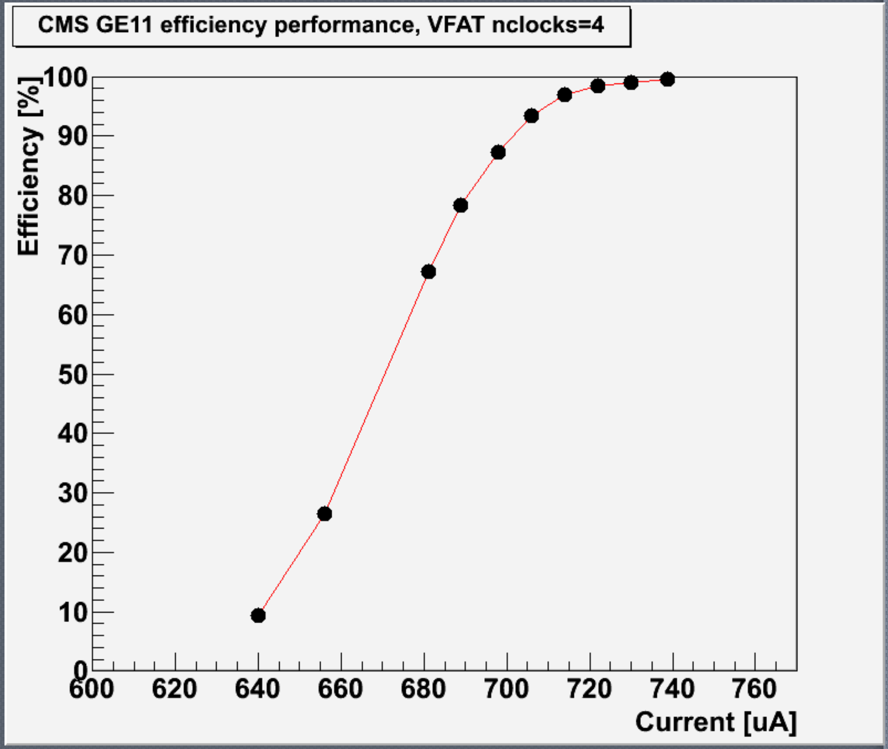
Period (In Years)	Integrated Luminosity (fb-1)
2010-2012	~1.0
2014-2017	~66.0
2019-2020	~300.0
2020-2030	~3000.0



Test-beam studies of prototype I

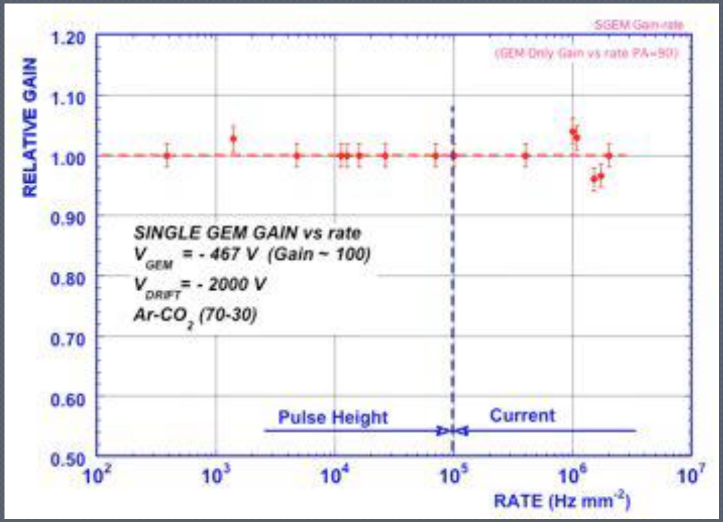
- Beam Muon = 150 GeV





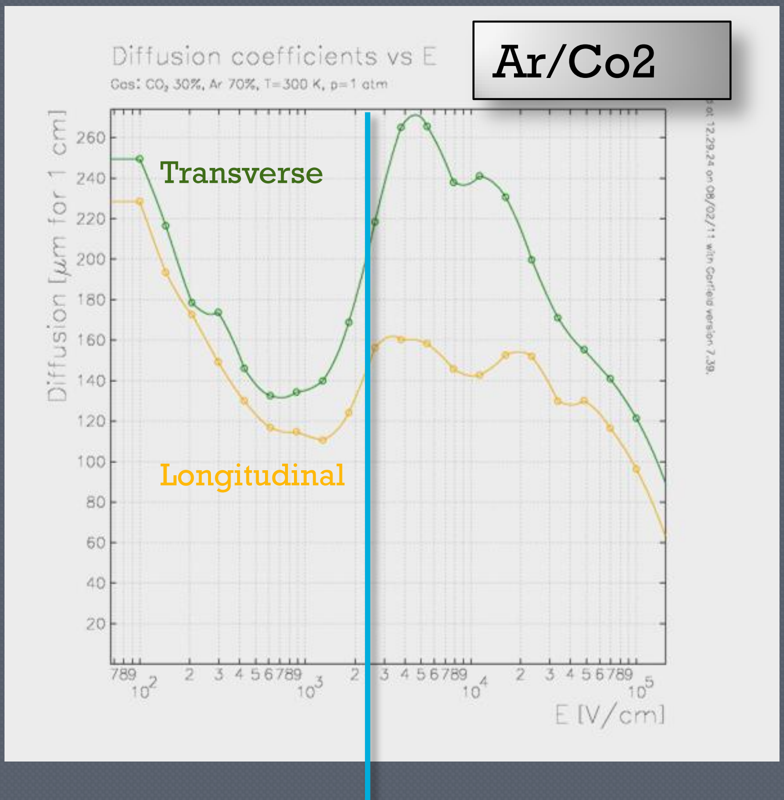
Can we try to get these plots in simulation as well

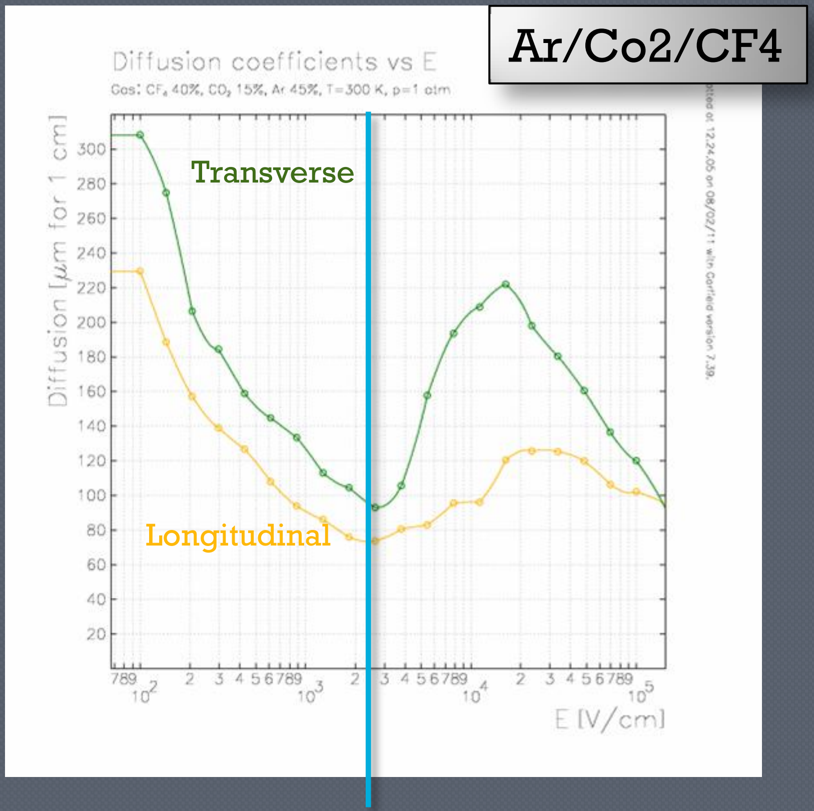
Older studies



J.. Benlloch et al,, IEEE NS45(1998)234

Diffusion coefficient

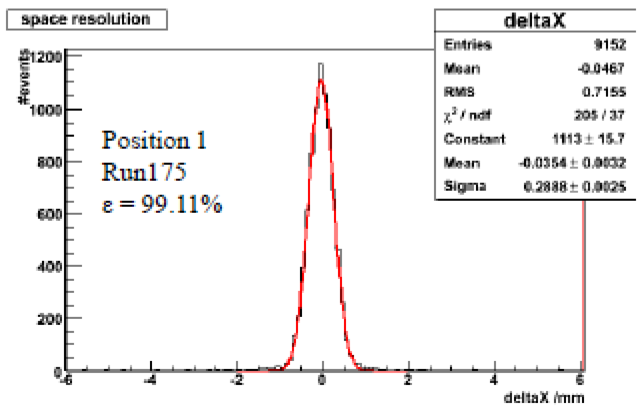


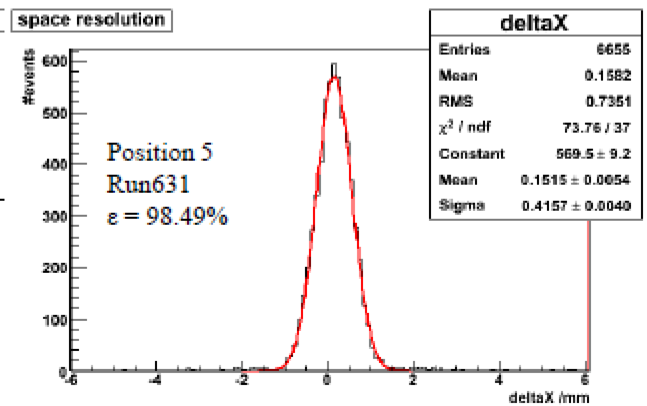


At 2.4 kV/cm, D_L is about 15 μm/mm= 45μm for 3 mm drift gap

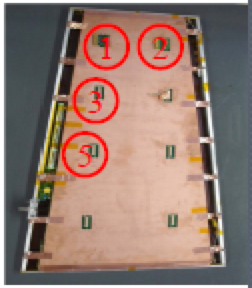
At 2.4 kV/cm, D_L is about 8 μm/mm = 24 μm for 3 mm drift gap

Testbeam studies – Spatial resolution





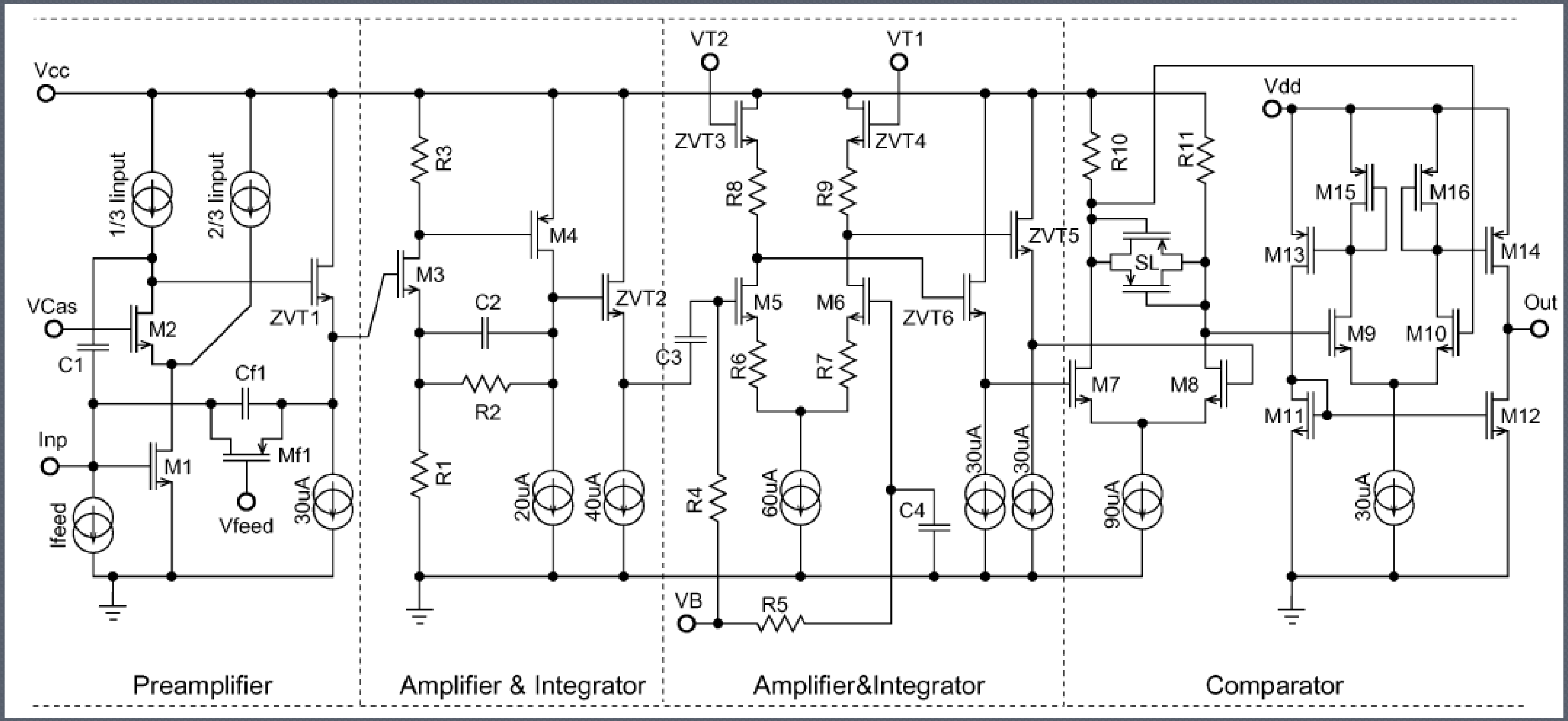
Position	1	2	3	5
space resolution (mm)	0.289	0.288	0.316	0.416
average pitch (mm)	1.06	1.05	1.16	1.49
average pitch/sqrt(12)	0.305	0.304	0.335	0.430



$$resolution \approx \frac{pitch}{\sqrt{12}}$$

5

Electronics..VFAT front-end



GndDet GndA GndD