neBEM Updates and Applications

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on behalf of

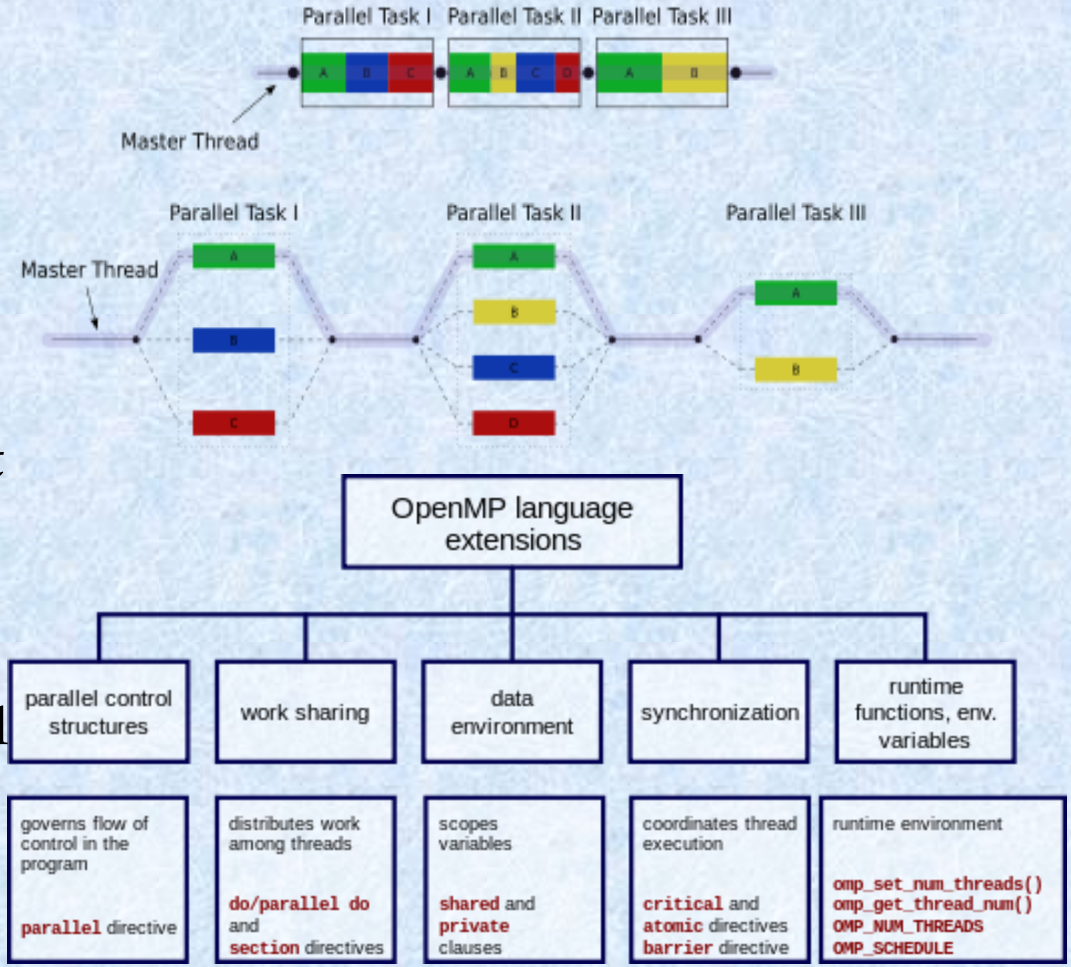
the RD51 group at SINP

Outline

- Updates
  - Code parallelization
  - Adaptive Modelling
  - Fast Volume
- Applications
  - Effects of spacers in Micromegas
  - Gain of a triple GEM

Code Parallelization - OpenMP

- Open Multi-Processing (OpenMP) is an Application Programming Interface (API).
- Supports multi-platform shared memory multiprocessor programming in C, C++ and Fortran on most processor architectures and operating systems.
- Consists of a set of compiler directives, library routines and environment variables that influence run-time behavior.



OpenMP for neBEM

- Parallelized several computation-intensive sub-functions of the toolkit, such as computation of the influence coefficient matrix, matrix inversion and evaluation of field and potential at desired locations.
  - user inputs related to invocation of OpenMP during a specific solution is passed to neBEM via a file (named, neBEMProcess.inp) residing in the directory from where Garfield is being executed.
- Precision of the solution found to be preserved.
- Upgraded toolkit executed using 1, 2, 4, 6, 8 and 16 cores.

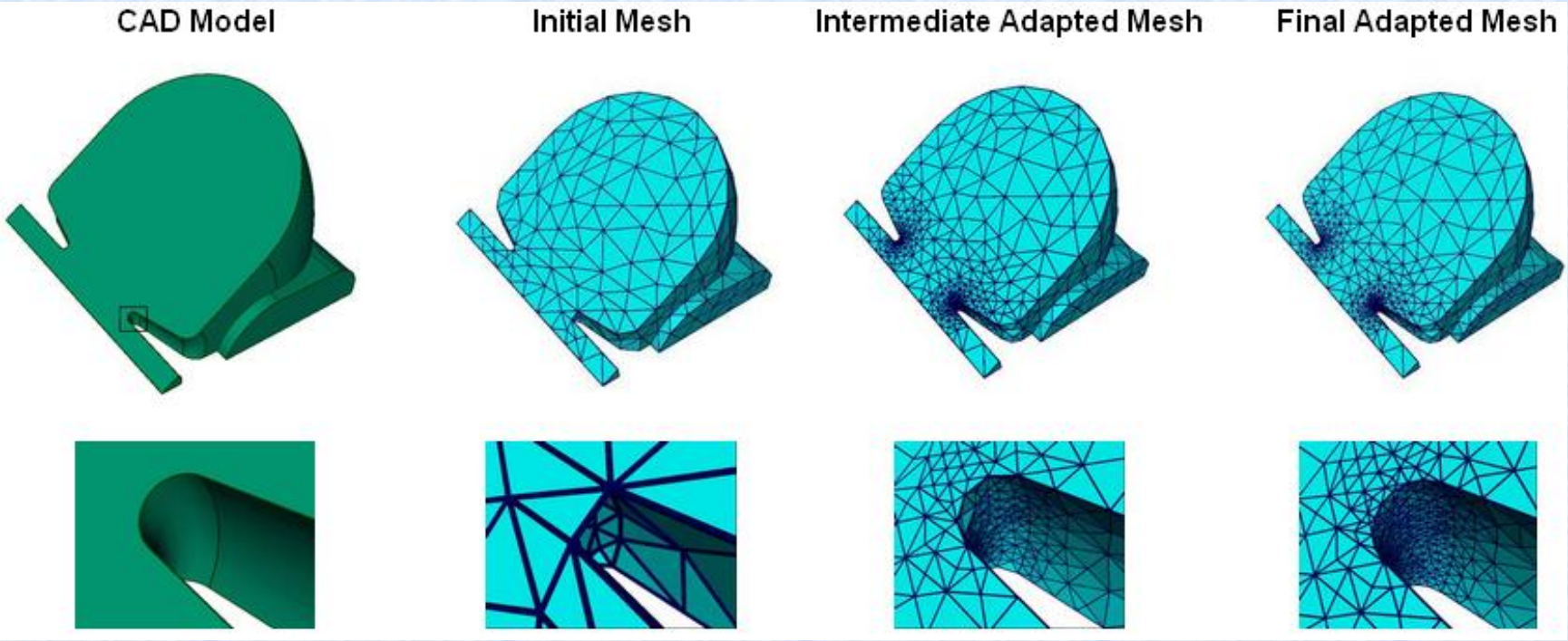
Code Parallelization in neBEM

Typical numerical simulation related to a bulk Micromegas					
Number of elements = 3089; Repetition = 24	1 thread	2 threads	4 threads	6 threads	7 threads
Charge density	8m10s	4m31s	3m13s	2m52s	2m40s
Axial potential and field	35m35s	20m14s	16m44s	16m12s	16m04s
Field map (~29000 nodes)	75m47s	38m49s	19m32s	13m25s	11m40s

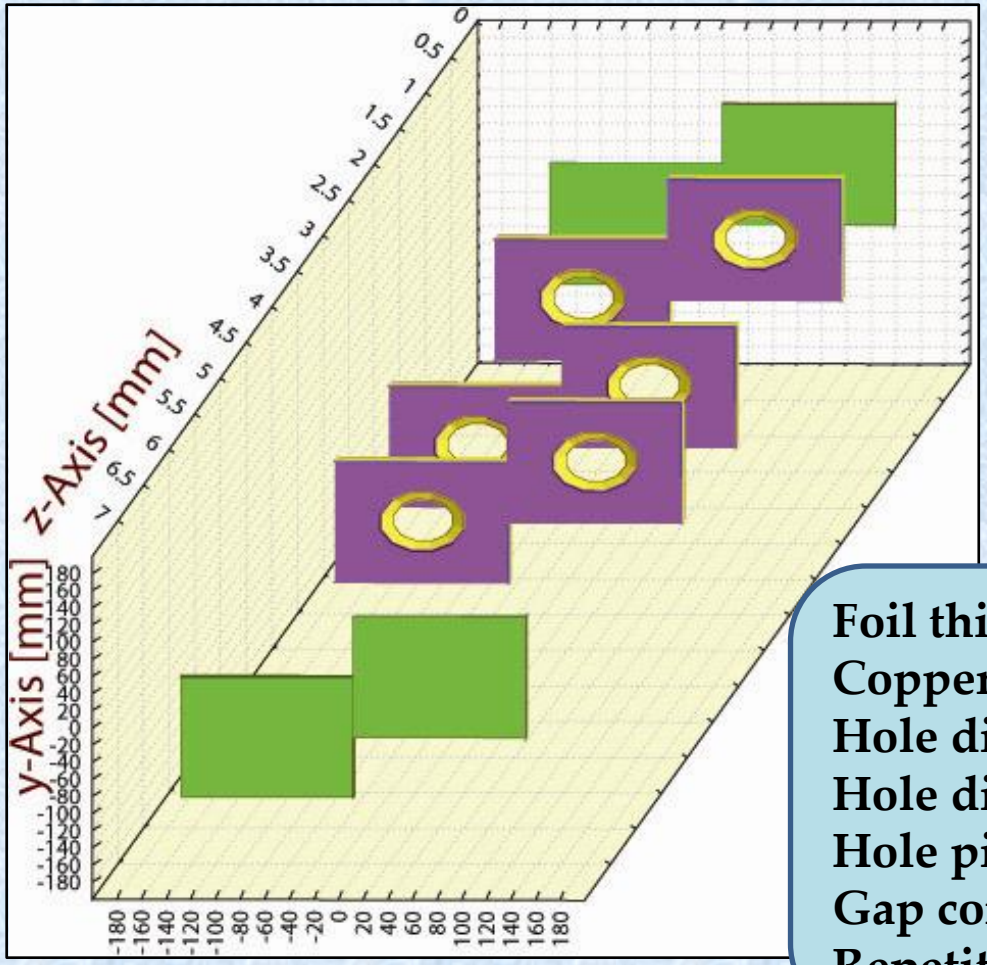
Adaptive Modelling (AM)

- This concept is quite commonly used in numerical simulation of complex physical systems such as turbulent fluid flow, plasma dynamics etc.
- The idea is simple and essentially maintains the details of modeling of physical phenomena to an optimum level. A common example is the Reduced-Order Modelling (ROM).
- A similar approach, when applied only to spatial discretisation of a problem, is called adaptive meshing.
  - the solution is usually attempted at a given spatial discretisation and the solver is expected to increase or decrease the meshing to meet the desired accuracy specifications.

Adaptive Meshing



A typical MPGD geometry



Each surface is composed of rectangular and triangular primitives.
Each primitive is discretised further into smaller rectangular and triangular elements.
The question is:
Can we ignore the variation of charge density on a virtual surface that is far away from the base device?

Foil thickness :	**50 μm**
Copper thickness :	**5 μm**
Hole diameter (outer) :	**70 μm**
Hole diameter (inner) :	**50 μm**
Hole pitch :	**140 μm (staggered)**
Gap configuration :	**3:1:2:1 (mm)**
Repetition:	**~ 100**

AM in neBEM

- Implemented AM algorithm which allows us to ignore the finer variations of charge densities on a primitive provided
  - it is not on the base device (as opposed to repetitive virtual devices generated in order to simulate periodic nature of a detector geometry) and,
  - it is at a far enough location so that the influence of the average charge density on the primitive is equivalent to the influence that is estimated preserving the real charge density variation on the primitive.
- AM implemented only at the evaluation stage of potential and field, and not while actually computing the charge densities on each of the elements.

AM in neBEM

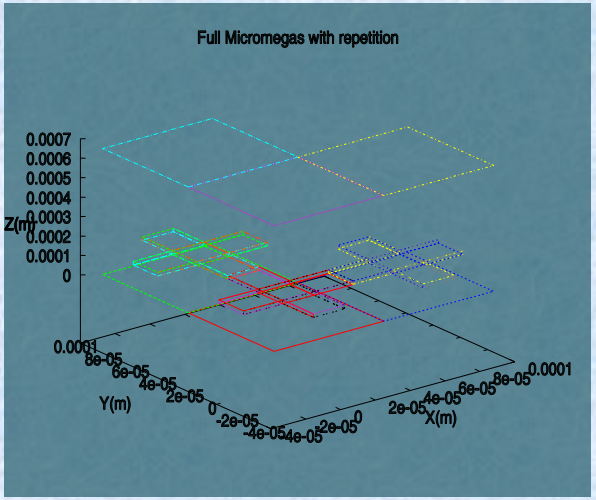
- Although implemented only for periodic geometries at present, it can be very useful also in non- periodic geometries.
- No reason to stop the order reduction at the primitive level.
  - It can continue through merging of original primitives to larger ones and even to lumping of several primitives into a component of the complete device, where the average charge density is assumed to be representative of the component itself.
- User input for controlling the AM level is done through the same neBEMProcess.inp mentioned above.

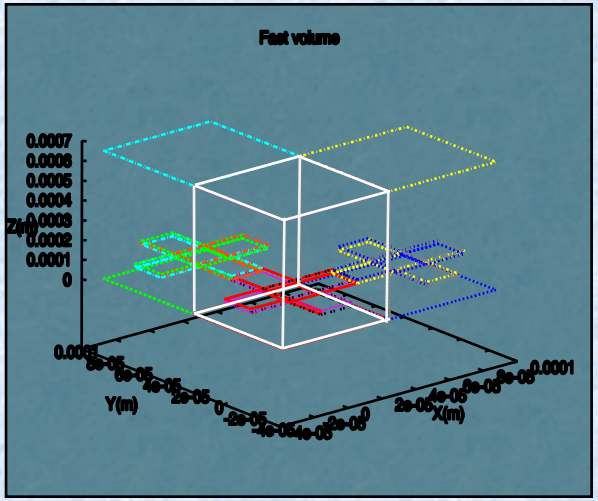
Advantage AM

Computational time for calculation of charge density, potential and field map with and without AM and estimates of resulting error			
PrimAfter	Charge density	Potential and field	Error
2	4m42s	27m69s	0.5%
5	4m27s	52m56s	0.3%
10	3m26s	71m28s	0.1%
Complete mesh (specified by PrimAfter = 0)	3m25s	141m2s	$<10^{-8}$ at the collocation points

Fast Volume

- Typical problem related to MPGD
  - Hundreds of primitives, thousands of elements and hundreds of repetitions.
- Time to estimate potential and electric field at each point is significant.
- Complex processes such as avalanche, Monte-Carlo tracking and Micro-Tracking take enormous amount of time.
- Way out is to use pre-computed values of potential and field at large number of nodal points in a set of suitable volumes.
- These, so called Fast Volumes, are chosen such that they can be repeated to represent any region of a given device and simple trilinear interpolation is used to find the properties at non-nodal points.





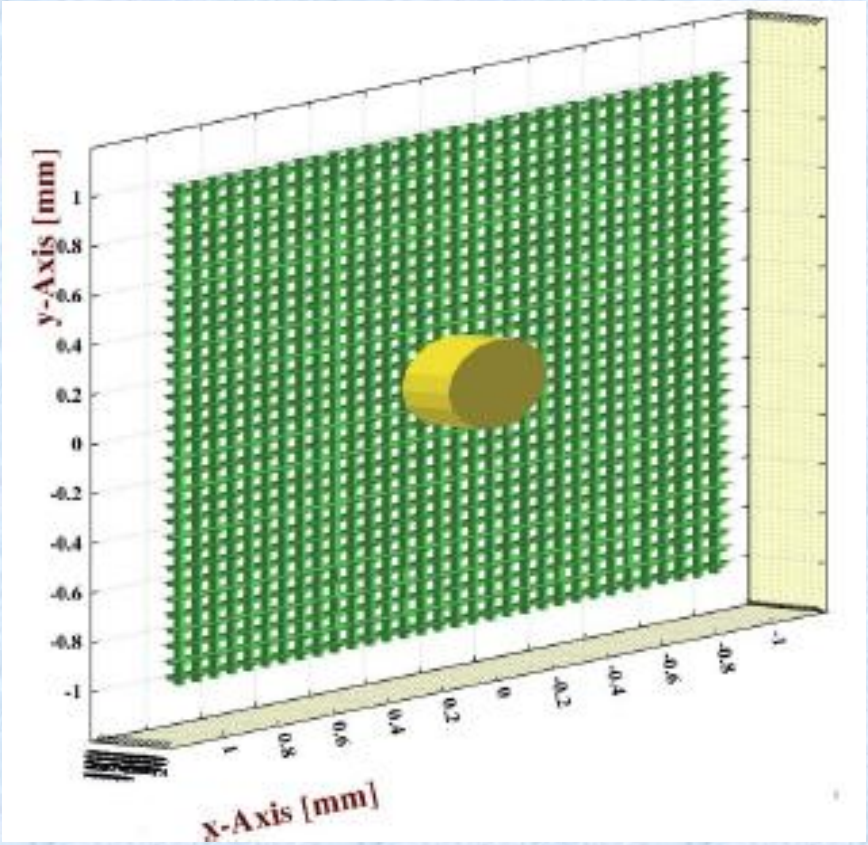
Fast Volume

- Staggered volumes are allowed (takes care of GEM and other similar structures).
- Possible to omit parts of a FastVol from being computed (inside a dielectric, or unimportant regions).
- Possible to ignore computed FastVol values in certain regions so that the more complete and accurate evaluation is used for points in those regions.
- The nodes should be chosen such that they are sparse in regions where potential and fields are changing slowly and closely packed where these properties are changing fast.
- The singular surfaces and edges should be avoided as much as possible to coincide with the nodes since very sharp gradients are found to occur in these regions which are very unlikely to be correctly modelled under the assumption of linear variations.
- Parameters controlled by a user input file: FastVol.inp

Fast Volume Advantages

Effect of using Fast Volume for a typical Micromegas simulation		
Computation time	Without FastVol	With FastVol
Charge density	15s	5m16s (includes calculation of FastVol)
Field map	6m33s	1s (error 0.3%)
Ten drift lines	7m54s	2s
Number of avalanche electrons	712	726
Hundred avalanches	3 days	21s

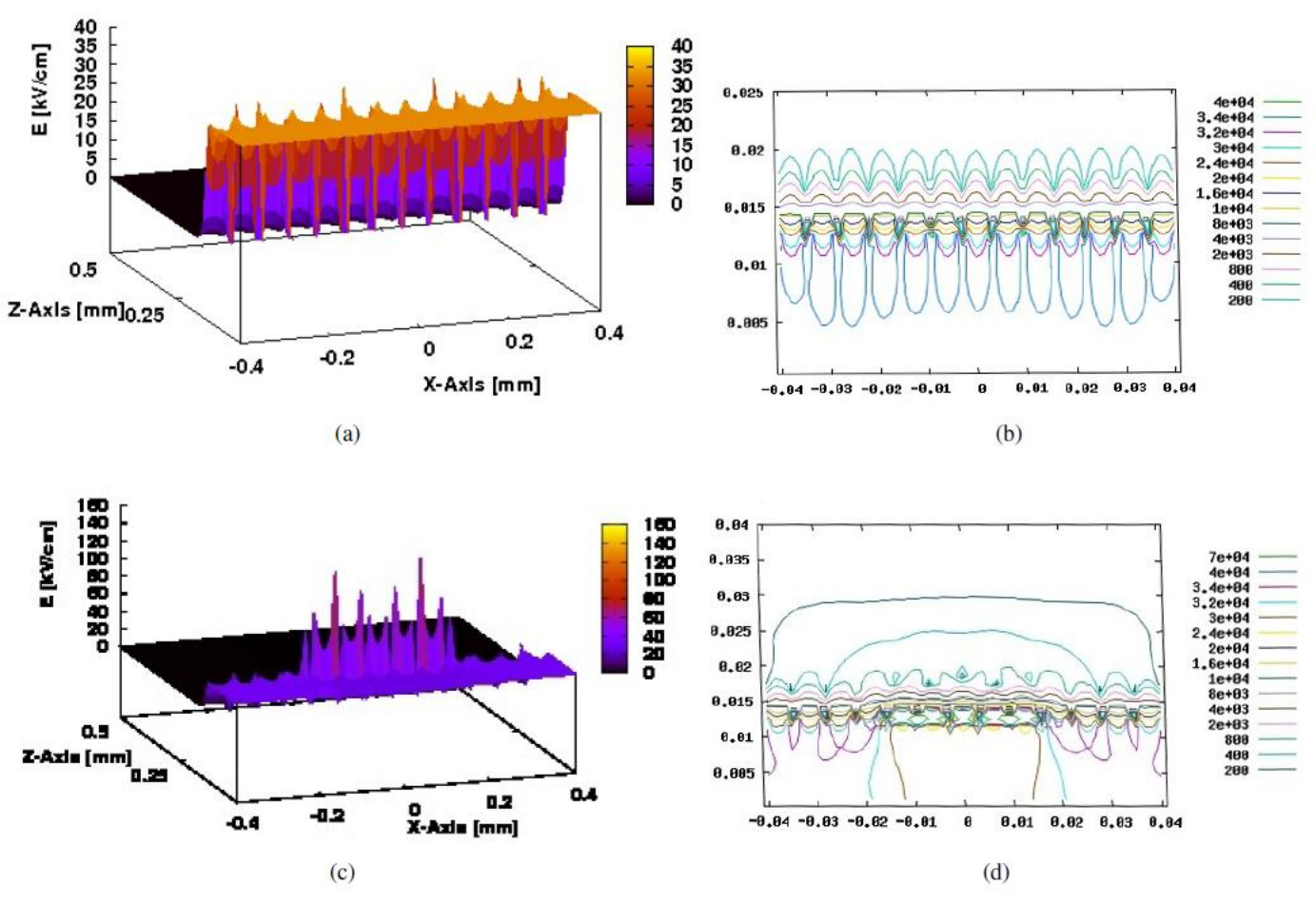
Effect of Spacers in Micromegas



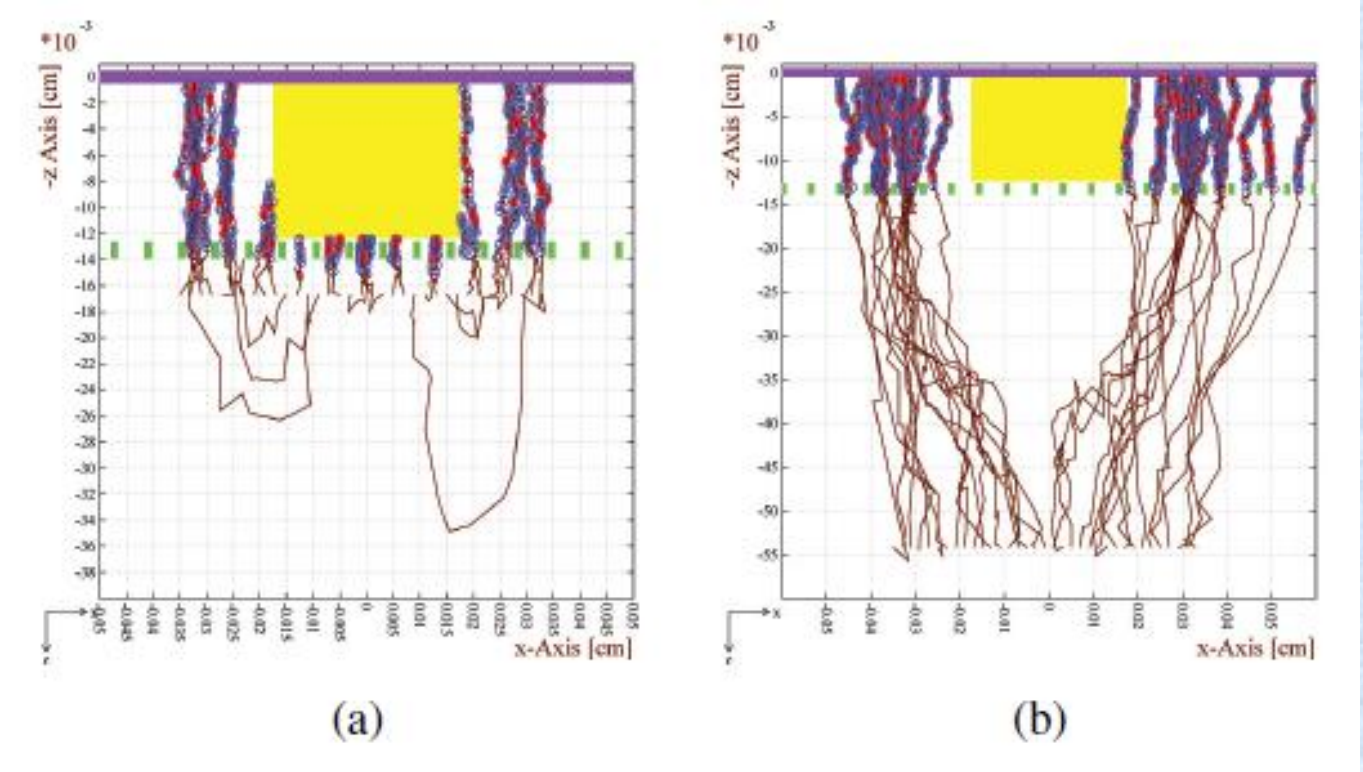
- Wire diameter: 18μm
- Pitch: 63μm
- Amplification gap: 128μm
- Spacer diameter: 350μm
- Spacer pitch: 2mm
- Size of the base device: 2mm by 2mm
- Large variations in dimensions in the base device
- Repetitive structure

- A computational nightmare!

Electric field without and with spacers

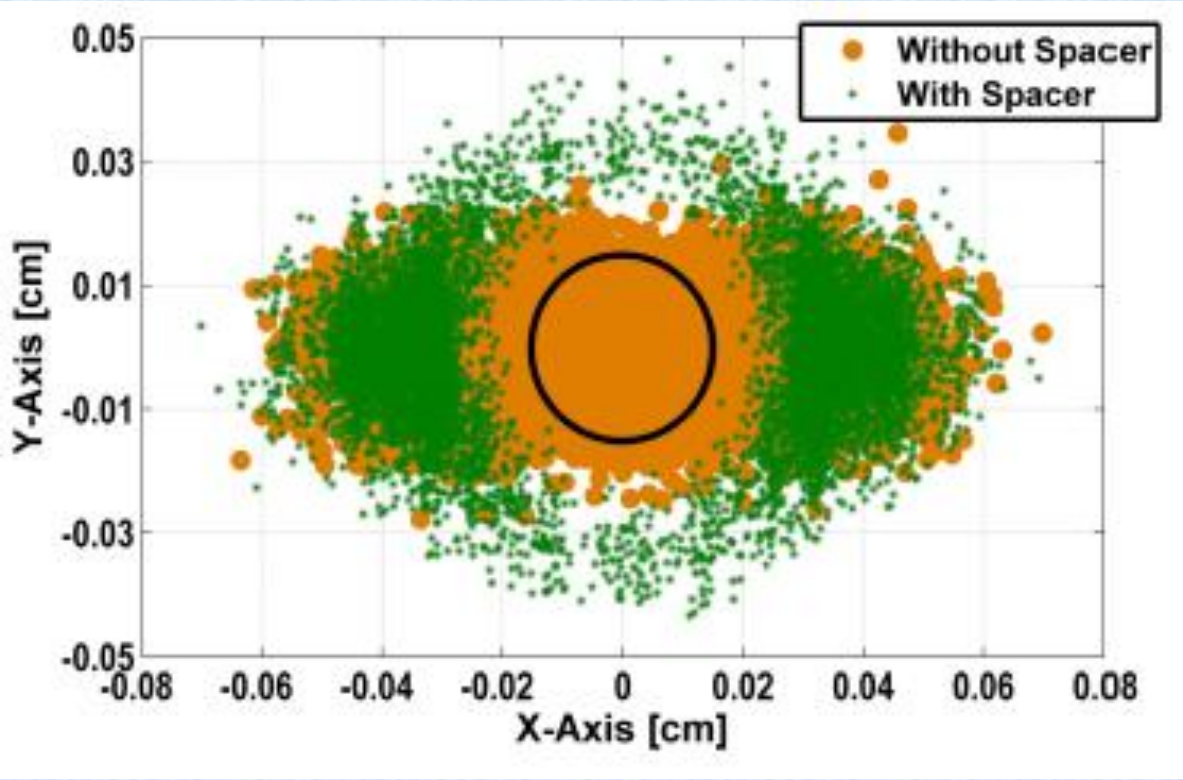


Drift of electrons close to a spacer



- Electron drift lines in Argon-Isobutane mixture (90:10) from tracks (a) 25 μm, (b) 400 μm above the micromesh. Mesh voltage = -430 V, drift field = 200 V/cm.
- Brown line: electron drift line, Blue circle: excitation, Red dot: ionization

End-point of electrons

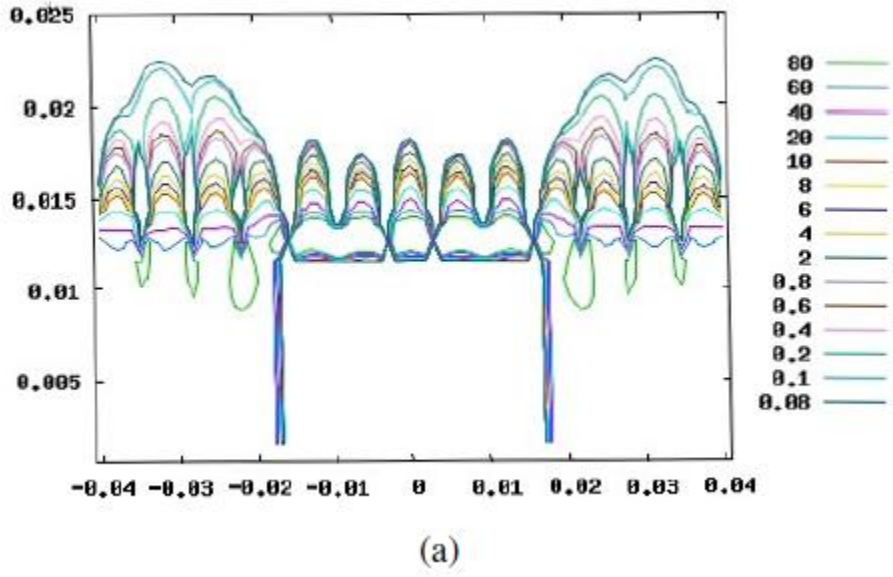


- Endpoint (X-Axis vs Y-Axis) of electrons in Argon-Isobutane mixture (90:10). Mesh voltage = -430 V, drift field = 200 V/cm

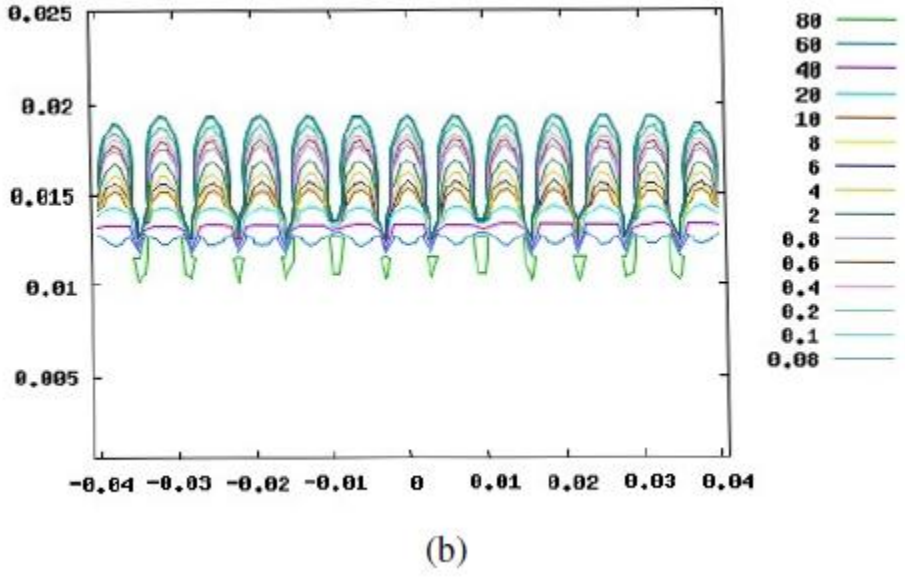
Electron Transmission and Gain

Spacer status	Track position above mesh (μm)	Fraction of electrons		Gain
		below mesh	at anode	
Without	25	87.43	87.43	1851
	50	86.72	86.72	1826
	100	87.55	87.55	1844
	200	86.92	86.92	1832
	400	87.51	87.51	1842
With	25	60.89	56.46	1195
	50	82.55	80.51	1683
	100	84.25	83.82	1755
	200	84.14	83.79	1751
	400	84.64	84.36	1768

Weighting field



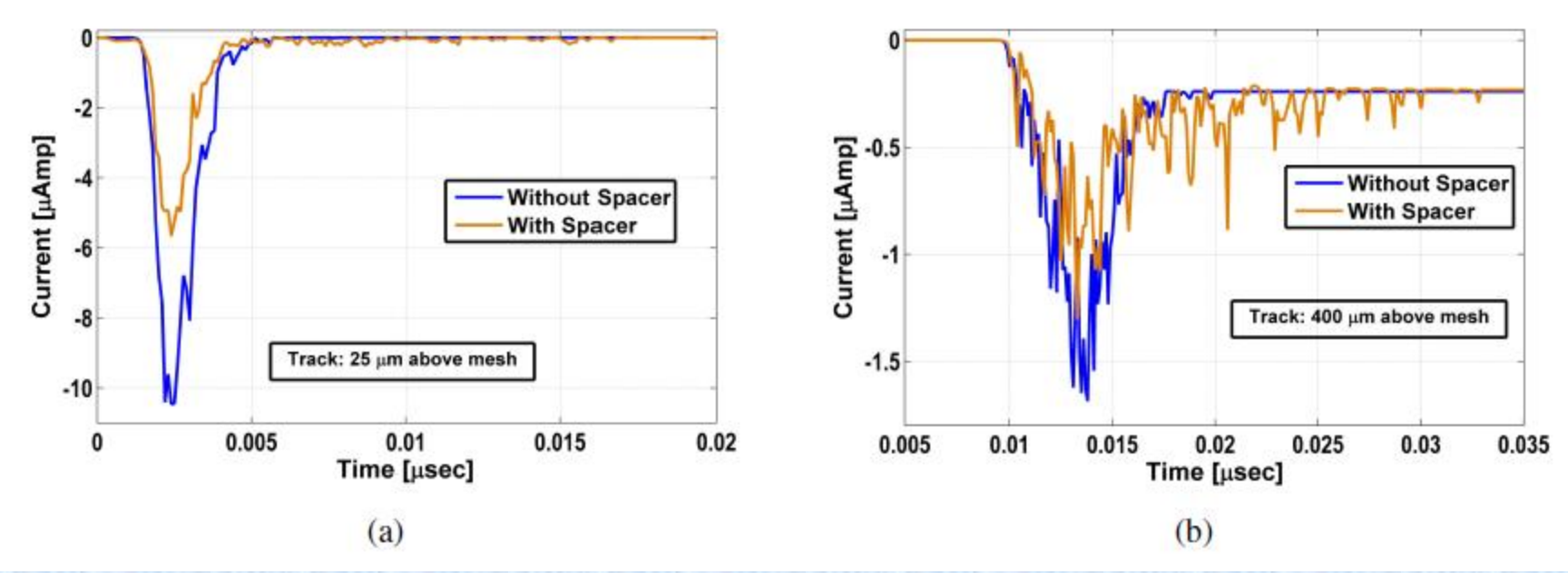
(a)



(b)

- The weighting field for bulk Micromegas detector (a) with spacer, (b) without spacer.

Signal



- The effect of spacer on cumulative signal for the bulk Micromegas due to all the electrons from a track which is (a) 25 μm and (b) 400 μm above the micromesh. Drift field = 200 V/cm.

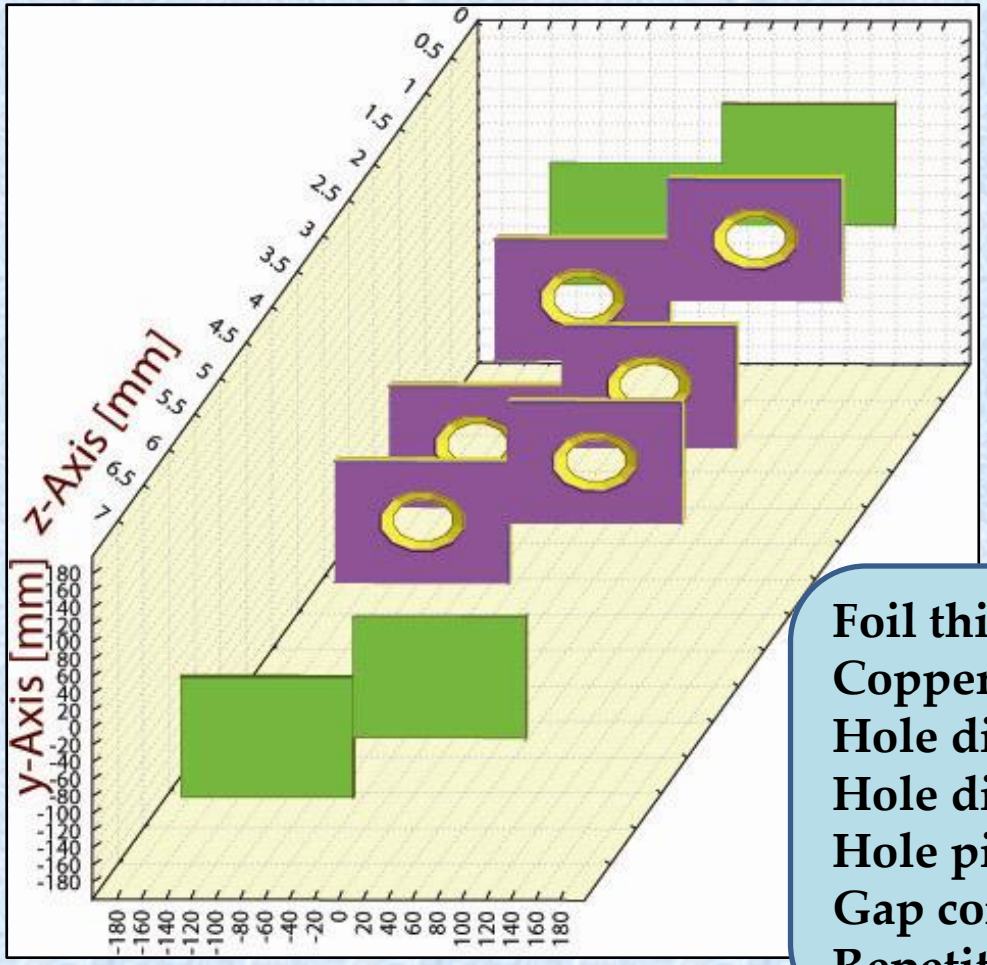
Computational advantage for the spacer problem

Number of elements: 24,000; Repetition: 2	Charge density	RKF-Drift (100)	Microscopic-drift (5000)
Old neBEM	40 hours	1 day	5 days
New neBEM	10 hours	3 hours	1 day

Resource used: a DELL Precision T7500 Workstation, 4 threads

A factor of more than 5 reduction in computational expenses!

Gain in a Triple GEM

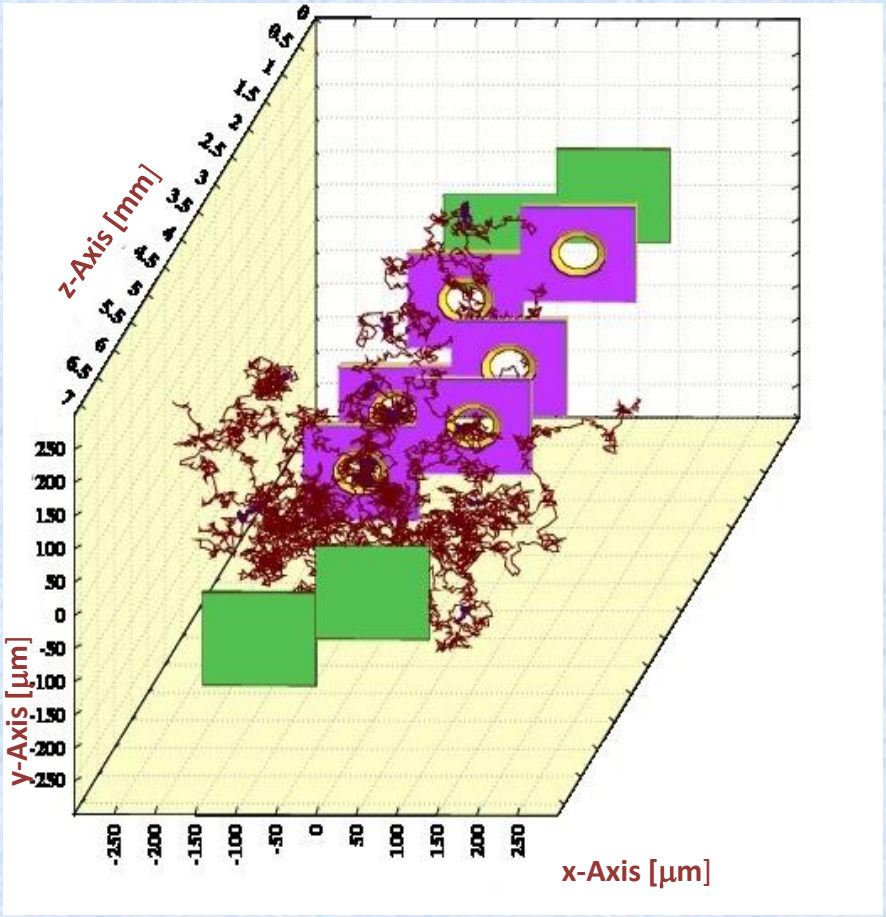


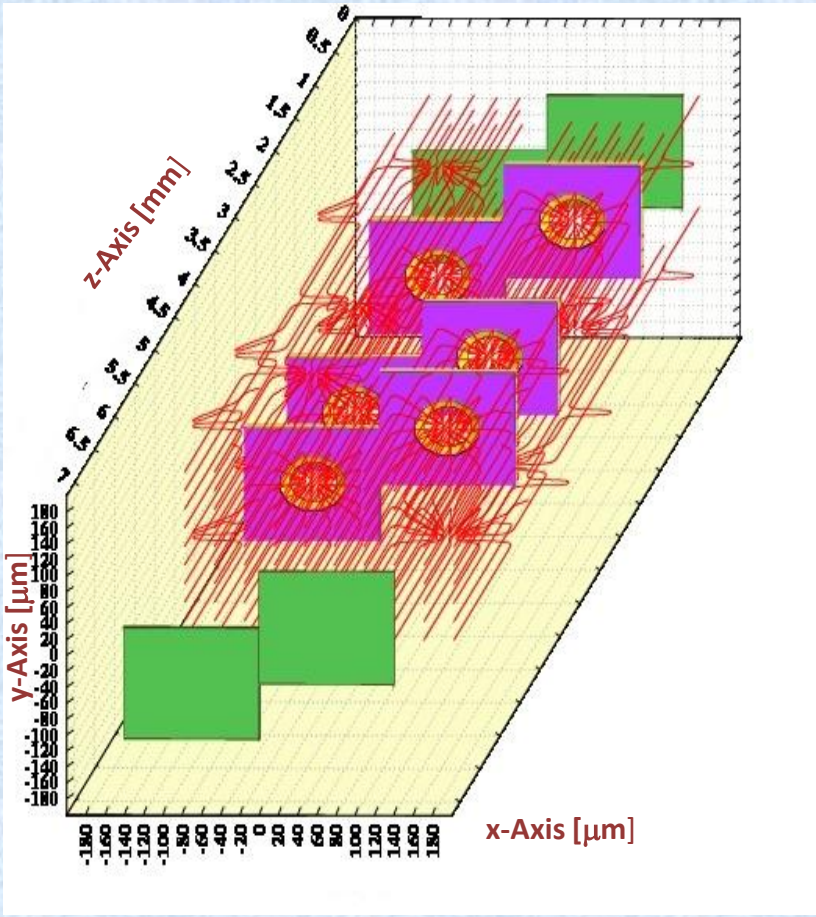
In $Ar+CO_2+CF_4$, the gain is known to reach as high as ~ 10,000.
With the low electron transmission, the demand on the computers is enormous, especially if `good' statistics is to be maintained.

This is another computational nightmare!

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)**
Repetition in X and Y: ~100

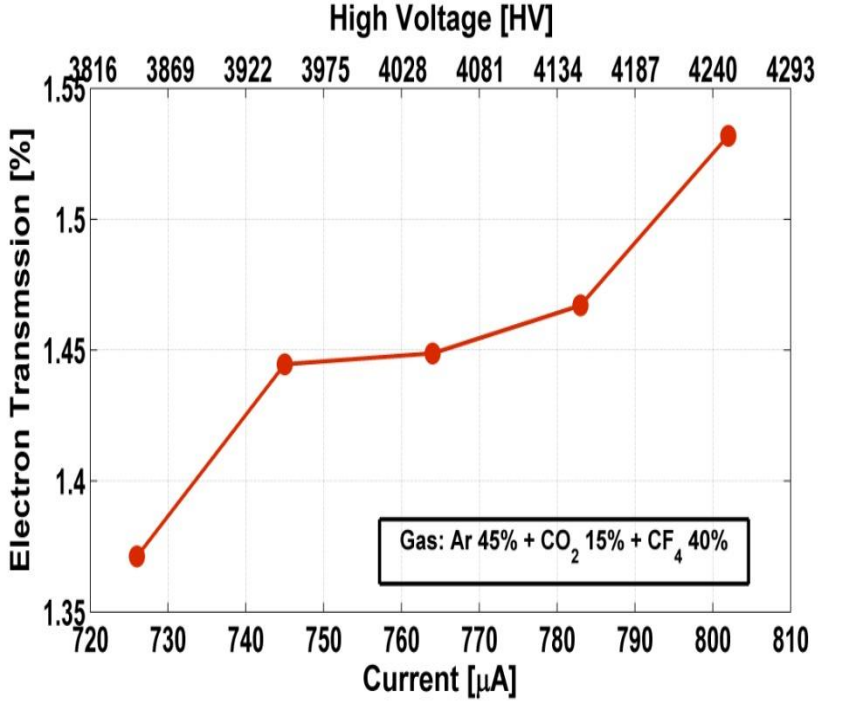
Mechanisms adopted



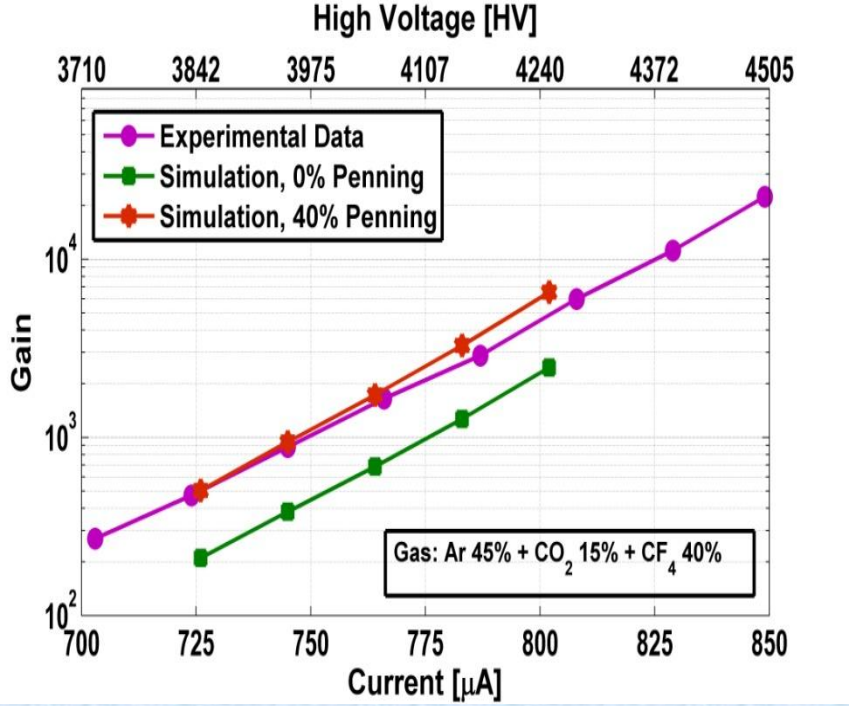


Transmission and Gain in Ar + CO_2 + CF_4

Transmission

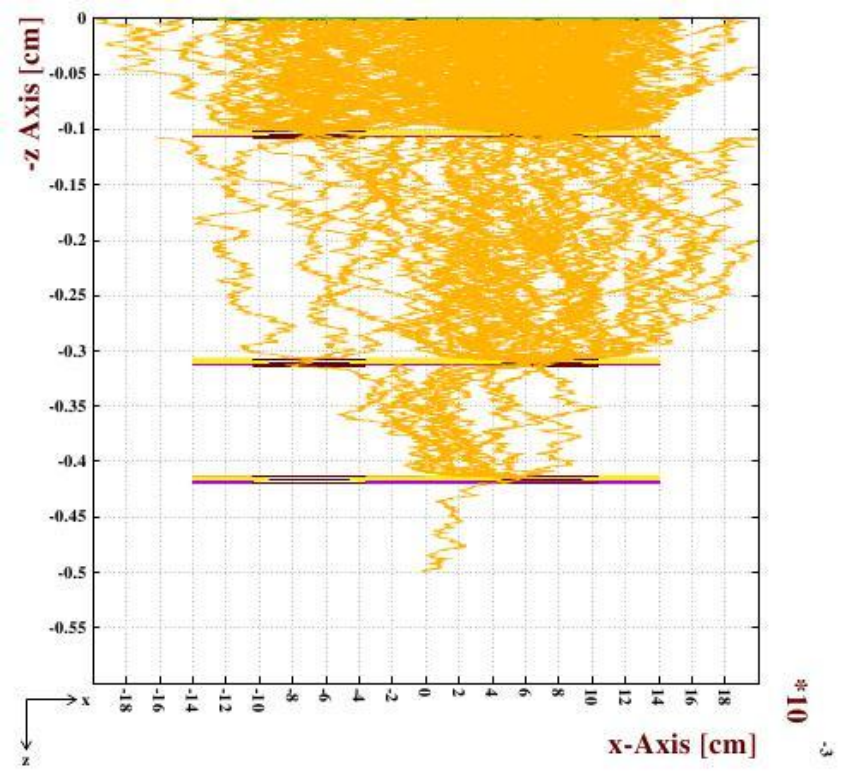


Gain (RKF)

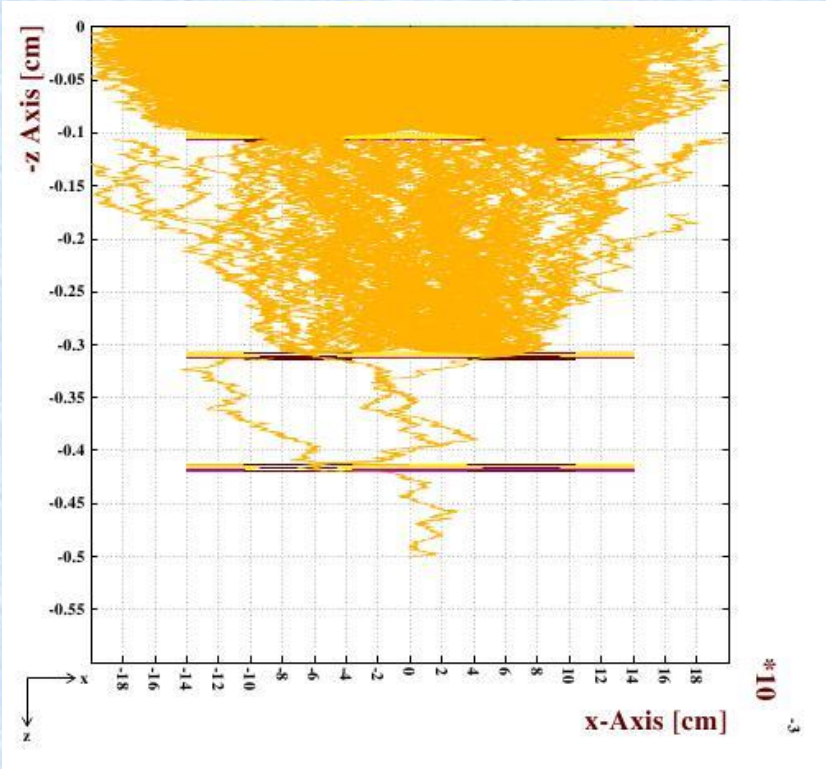


Gain using Avalanche

High voltage: 3850 V
Gain ~ 500 (5000 events)



High voltage: 4150V
Gain ~3500 (5000 events)



Computational advantage for Triple GEM

Elements: ~6000; Repetitions: ~60	Field calculation	RKF-Drift (100)	Microscopic-drift (10,000)	MC-avalanche (100)	Avalanche (single thread) (5000)
Old neBEM	3 weeks	1 day	5 days	1 – 2 weeks	Gain 500: 1 week Gain 3500: 4 weeks
New neBEM	1 week	15 minutes	1 day	1-2 days	Gain 500: 1 day Gain 3500: 5 days

Resource used: a DELL Precision T7500 Workstation, 6 threads

A factor of 10 reduction in computational expenses!

Summary and Future Plans

- Considerable increase in efficiency has been achieved without perceptible loss of accuracy.

- The new algorithms can be further optimized – Needs close study of the mechanisms.
- Huge scope of improvement in other areas of neBEM.
- Interface to Garfield++ being worked on.
  - The initial plan is to import neBEM potential and field-maps using two list files: material list and node list (as done for the other codes such as ANSYS. The FEM usually need a couple of other lists and provide the potential as the solution).
  - Integration to Garfield++ (as was done for Garfield) will take some more time.

Acnknowledgements

- Nayana Majumdar, Purba Bhattacharya, Deb Sankar Bhattacharya, Abhik Jash, Raveendrababu Karanam, Sudeb Bhattacharya
- Rob Veenhof
- RD51 Collaboration members
- CMS-GEM Collaboration members

Thank you for your kind attention!