Parallelizing particle track simulations in gas based charged particle detectors

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OUTLINE

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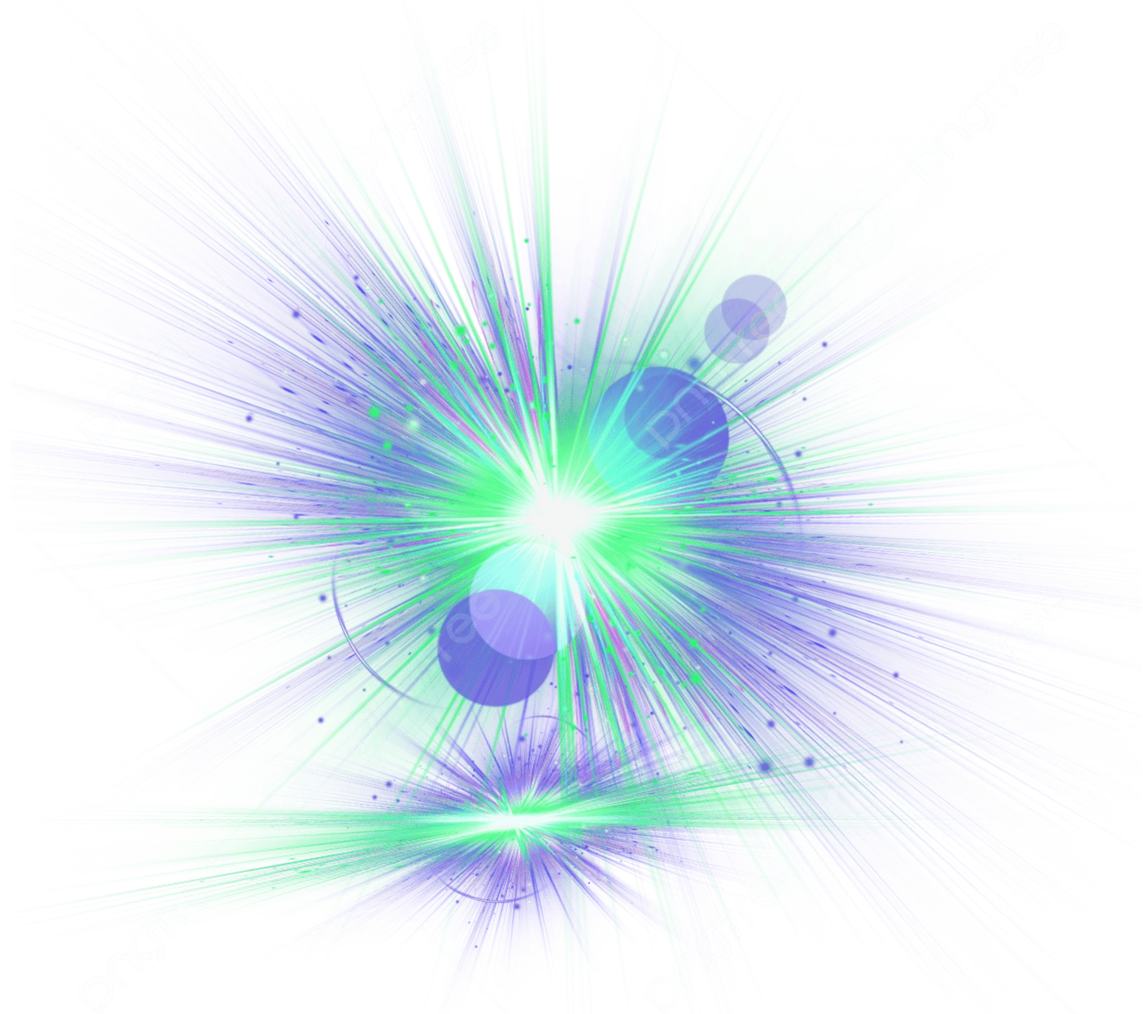
- Parallelization
- Methodology & Results



GAS BASED CHARGED PARTICLE DETECTORS

Gas based charged particle detectors

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- There are many gas based charged particle detectors being used across the various experiments throughout the world
- The gaseous detectors being used for muon detection at the Compact Muon Solenoid (CMS) Experiment at LHC are:
  - Cathode Strip Chambers
  - Drift Tubes
  - Resistive Plate Chambers
- During the LS2, CMS has introduced **gaseous electron multiplier** (GEM) detectors which is a micropattern gaseous detector

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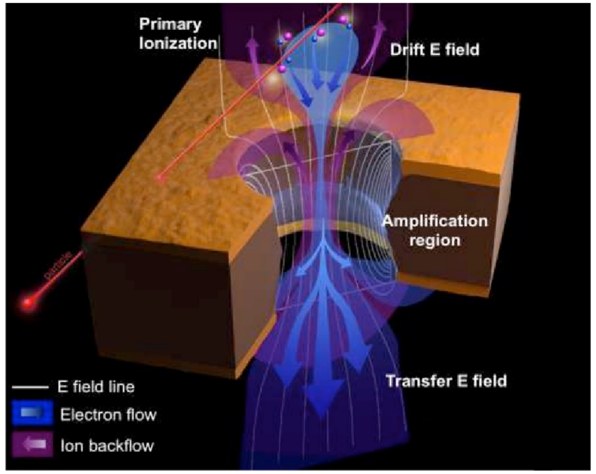
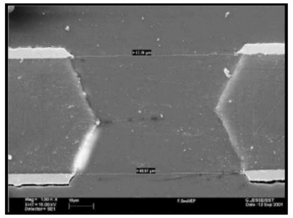
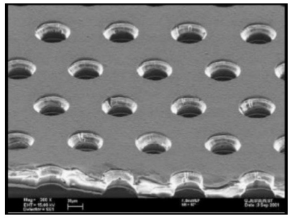
GEM DETECTORS

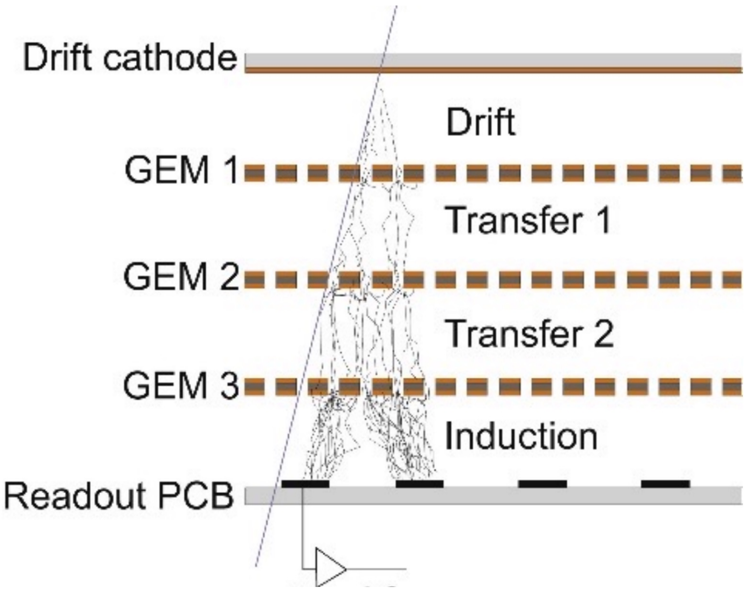
GEM Detectors

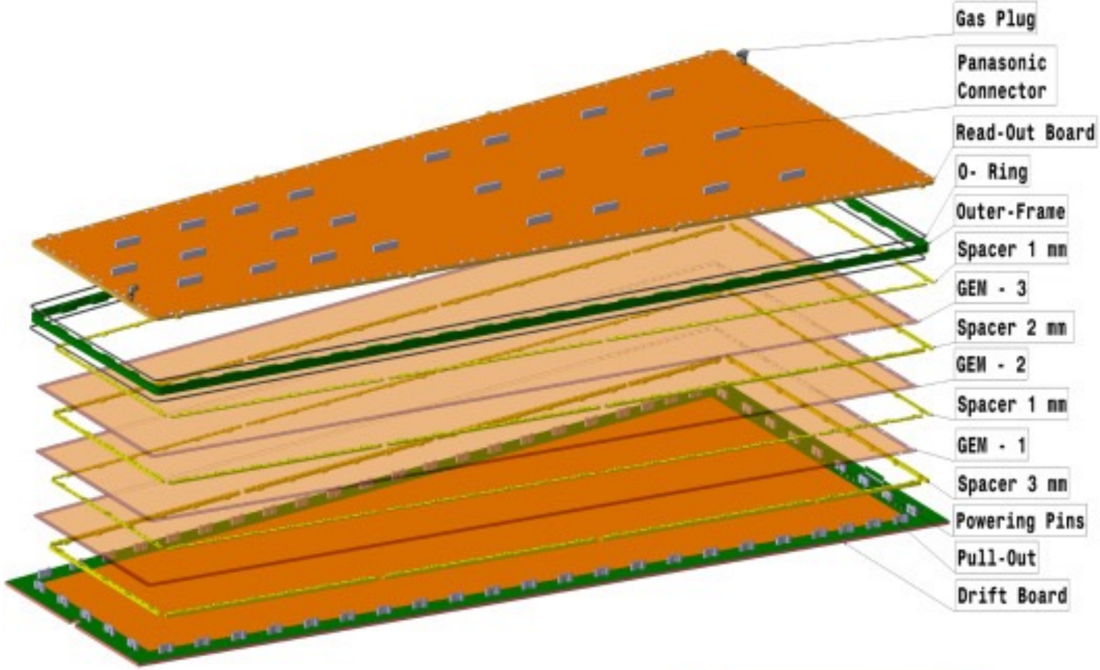
- Gaseous Electron Multiplier (GEM) Detectors are built with GEM foils which were introduced by Fabio Sauli in 1997
- A typical GEM foil is made up of Kapton which is perforated with holes of 50/70μm and a pitch of 140 μm with 5 μm of Copper at top and bottom to apply a potential difference.
- They can be produced in different shapes and sizes as per the requirement











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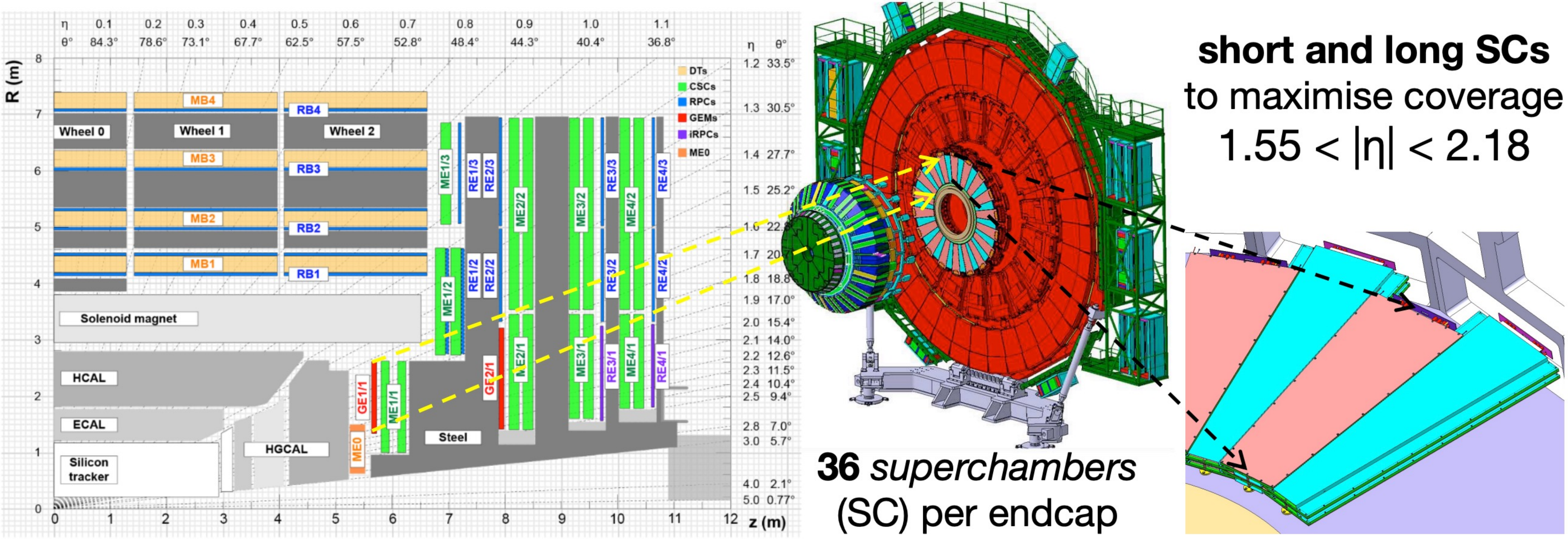
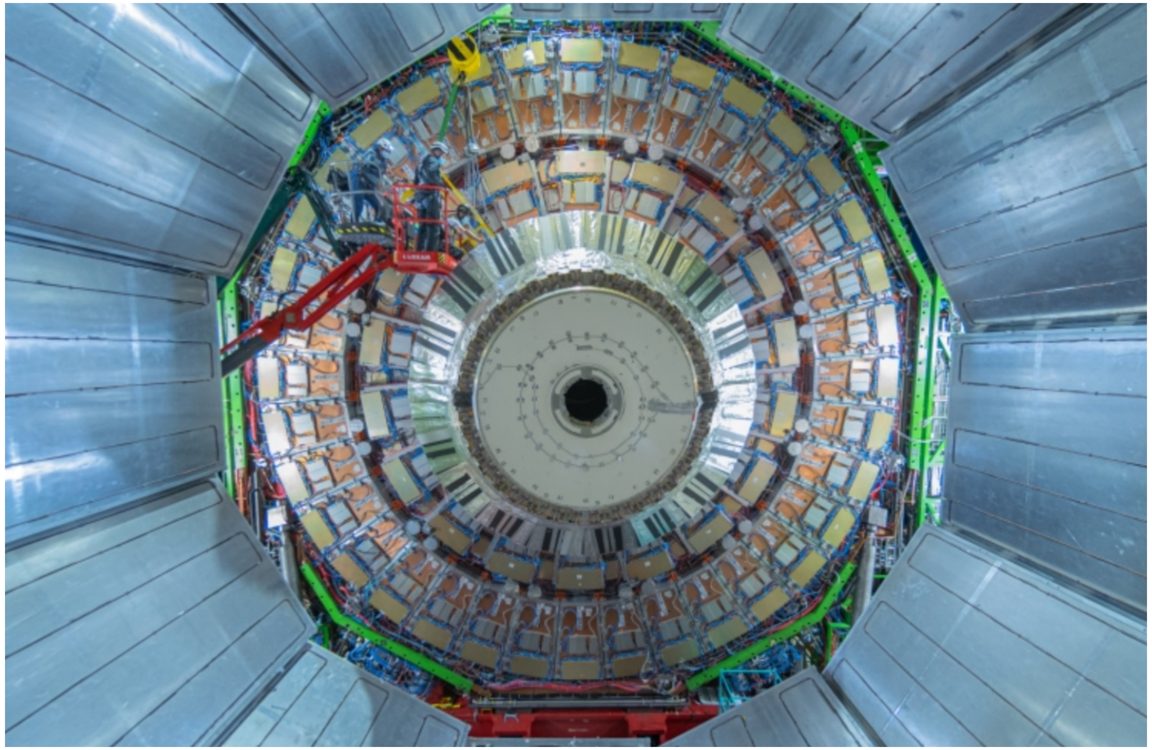
UPGRADES AT CMS

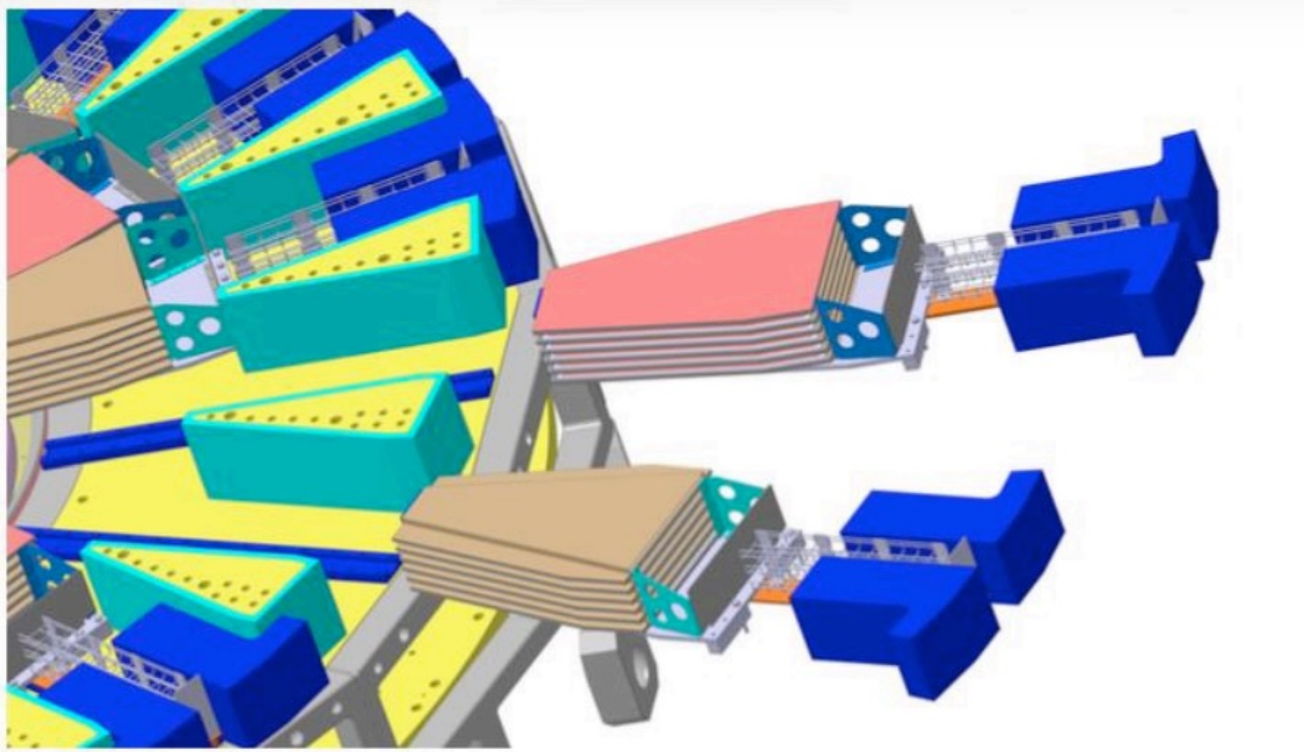
GEMs at CMS

- During Phase-I of **muon endcap upgrade**, GEM detectors (GE1/1) were installed in the CMS detector
- Two layers of triple-GEM detectors are instrumenting the two endcaps (total: 144 GE1/1 detectors)



GEMs at CMS





- During the next upgrade, planning to install GE2/1 & ME0 detectors
- Lot of simulation work has already been done and more is required for the same

GEM DETECTOR SIMULATION

GEM Detector Simulation

- Micropattern Gaseous Detectors (MPGDs) rely heavily on the simulation of the particle passage
- Being one of the conveners of the GEM Detector Simulation group at CMS, we are constantly asked to perform various simulation studies which can be helpful for the future development
- In the past, we have been asked to optimize the hole geometry of the GEM foils, gas gap to be used between the GEM foils for building a GEM detector, dead area on the GEM foil, interstrip capacitance study to decide the gap between the readout strips for GE2/1.
- Currently we are working on the simulation study for the background hit rate for GE1/1 detectors, time resolution, anomalous large cluster size observed and segmentation of the GEM foils to be used for ME0 foils.
- To give the feedback to the CMS community on time we need to perform these studies as fast as possible. The motivation for introducing parallelization is to **reduce the computing time** specially while simulating larger foil size or higher detector gain.

SIMULATION TOOLS

HPC Facility

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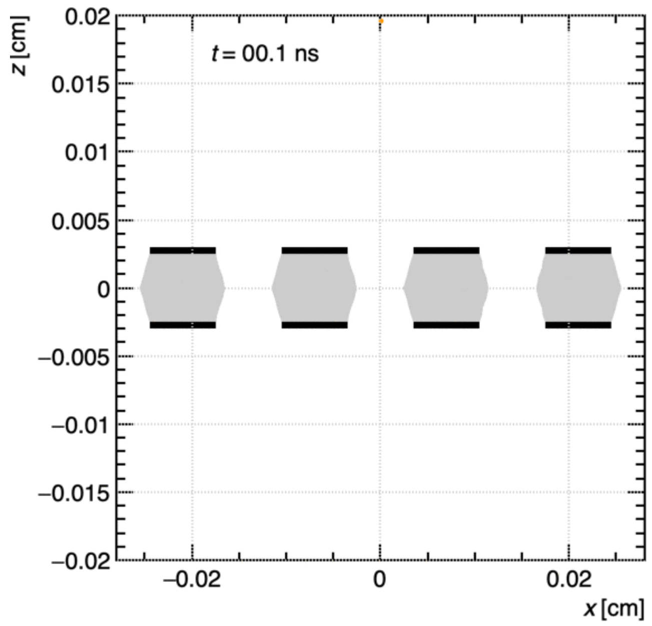
- Texas A&M University have a **High Performance Computing** (HPC) facility (at its Qatar campus) called raad2 and most of the simulation studies over the CMS and other collaborations are done using this facility.
- Raad2 is a Cray XC40 with 4,128 Intel Xeon Haswell cores
- It has **172 compute nodes**, and each compute node contains 2 sockets with 12 physical cores per processor chip; giving a total of **24 cores per node**, along with 128GB of RAM.
- The Cray is served by a Lustre (DDN EXAScaler) shared storage system with a usable capacity of 800TB, and a filesystem peak aggregate read bandwidth of about 16GB/s
- Raad2 uses SLURM as its workload manager to allocate and manage compute resources

Garfield++

- Garfield++ is a toolkit for the detailed simulation of particle detectors based on ionization measurement in gases and semi-conductors (*https://garfieldpp.web.cern.ch/garfieldpp*)
- Garfield++ accepts two- and three-dimensional **field maps** computed by finite element programs such as ANSYS, COMSOL, etc. as basis for its calculations for **detector geometry & electric field**
- An interface to the Magboltz is provided for the computation of **electron transport properties** and avalanches in nearly arbitrary gas mixtures
- Transport of particles, including diffusion, avalanches and current induction are treated in three dimensions



HEED

- **High Energy Electrodynamics** (HEED) simulates an incident particle passing through the MPGD by generating ionization patterns
- In addition, it provides atomic relaxation processes and dissipation of high-energy particles
- Relativistic particle interaction through gaseous detectors can be simulated using the **Photo Absorption and Ionization** (PAI) model in the HEED toolkit.
- The PAI model's computations are crucial for determining the **particle's path** through the detector and the **energy it transfers** to the primary electrons.
- Both Garfield++ and the HEED must be integrated in order to fully simulate fast-charged particles using gaseous detectors.

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PARALLELIZATION

Parallelization

- Garfield++ and HEED are both serial codes and usually run in sequential mode. So, the integration of both Garfield++ and the HEED lead to a long simulation time consumption due to the heavy calculations involved
- Therefore, parallelizing these operations significantly reduces the time required for entire simulations (**parallel Garfield or pGarfield**)
- In this study, the GEM detector will serve as the simulation's baseline detector throughout testing.

- There should be no loss of generality in the results when applying to different detectors

METHODOLOGY & RESULTS

Methodology

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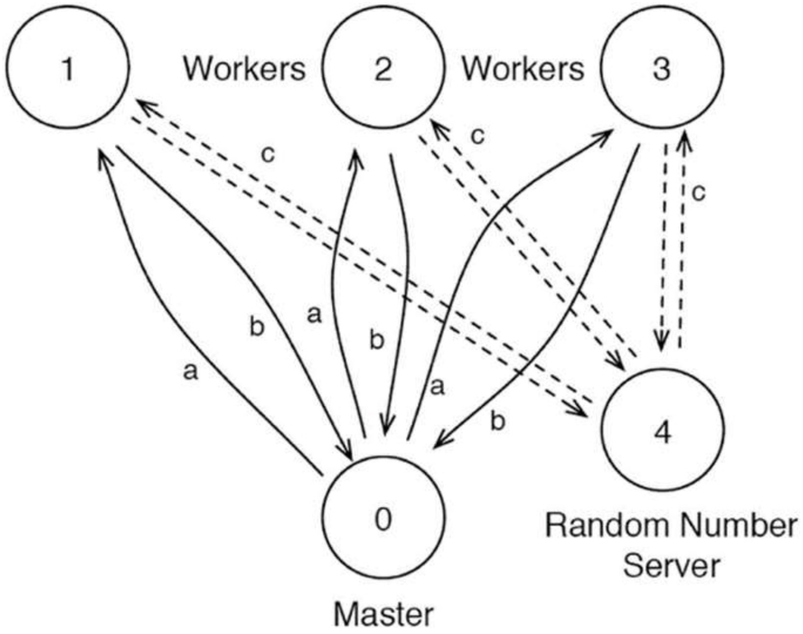
- To create parallel jobs, we use the concept called **Message Passing Interface** (MPI)

- The new pGarfield/HEED implementation will compute the primary electrons produced by an **ionizing particle** passing through the detector using HEED, and then provide those electrons to Garfield++ for the computation of the **gain for each electron**

- We implemented a **distributed memory model** that is based on events (specifically the ionizing particle passing through the detector) and as a result, we were able to remove the dependency of a coherent global cache in shared memory architectures.

Methodology



Workflow in the new pGarfield/HEED implementation

- Here, the master process distributes events to worker processes and collects their results.
- A **random number server** is also required for the pGarfield/HEED implementation (in addition to the worker and master processes) in order to produce the random numbers required for each event.
- The master sends requests to the workers to simulate an event (labeled as *path a*). Each worker will then complete the work desired and then send the results back to the master, which is waiting for a response (labeled as *path b*). If there is another event that is required to be sent, the master will then send it to the worker. The interactions between the workers and the random number server are labeled as *c*.

Preliminary Results

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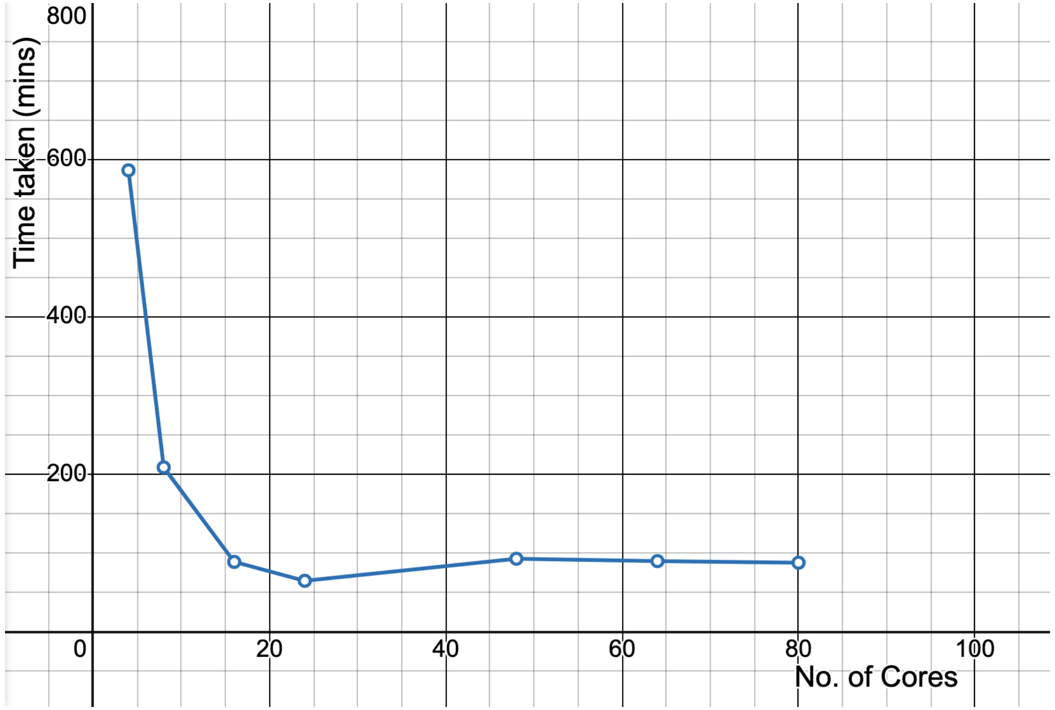
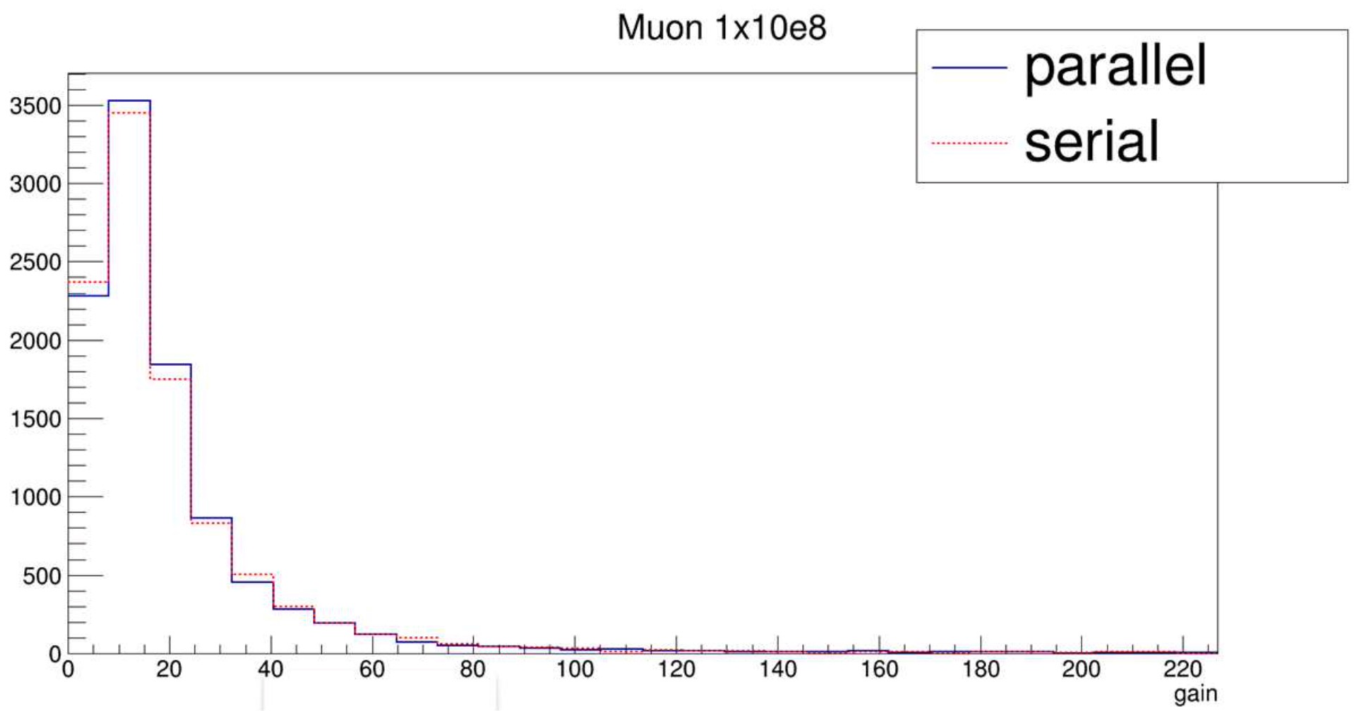


Time taken to complete 10,000 events by varying the number of cores after implementing parallelization



Distribution of the number of electrons produced during an avalanche

Summary

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- This work aims to accelerate the entire simulation of a charged particle passing via any gaseous detector
- Conducting these studies allows scientists to cut huge costs and development for prototyping
- Even though Garfield++ is a very important part of the simulation of MPGDs, it is very comprehensively intensive particularly when large detector volumes and high gas gains are required
- HEED photo absorption and ionisation model was added in the parallel Garfield toolkit (pGarfield)
- Results show speedup with the use of 24 cores, but it remained almost the same with the addition of more cores


QUESTIONS?