Simulation for high energy physics detectors

Mauro R. Cosentino

UFABC

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Universidade Federal do ABC

Motivation

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There are several high energy physics projects:

- Linear Collider Physics: precision Higgs measurements, BSM
- LHC Physics: Higgs, BSM, CPT, Heavy-Ion, ...
- FAIR Physics: hadron spectroscopy, Heavy-Ion, Applied physics...
- Many others: RHIC (heavy-ions), KEK/Belle (CPT/BSM), ...

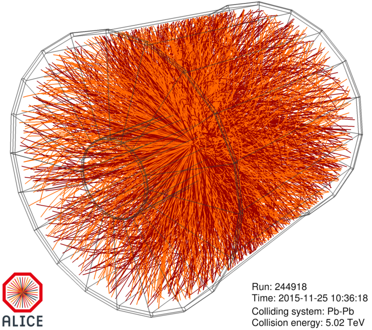
They all have (or can have) at least one experiment with gaseous detectors

Motivation

Many of these projects use, or can use, gaseous detectors for:

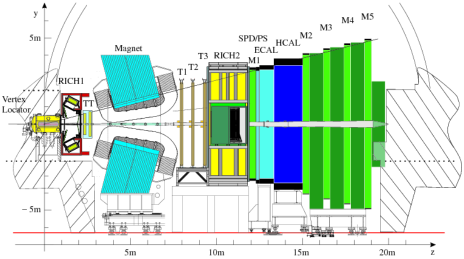
- Tracking
- Muon detection
- Charged particle veto/flag (CPV)
- Calorimetry (sampling)

- Drift chambers
- Time Projection Chambers
- Muon Tracking Chambers



Motivation: Muons

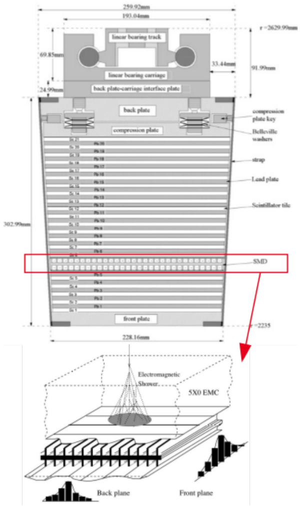
- Always behind a lot of material
- Muon PID/trigger systems
- Muon Tracking Chambers



Motivation: CPV

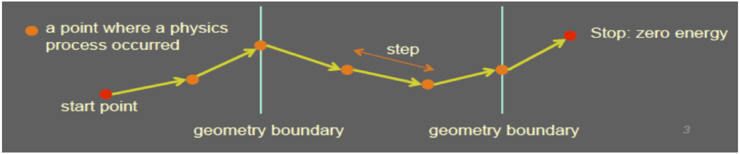
- Intended to improve photon PID
- Associated with calorimetry systems

- Active media in sampling detectors
- Full detector
- One or more layers (e.g. Shower Max)



Simulations: Main techniques

- In general these simulation tools are called:
  Monte Carlo radiation transportation codes
- There are many of them: Geant4, EGS4, FLUKA
- They model an apparatus in terms of elementary geometrical objects
- They have list of **physics processes**
  - These are model dependent
- Particles are treated one at a time and
  - Each one treated in **steps**



For each step:

- Length determined by σ_{proc} and boundaries
    - If secondaries, add them to the list
- Local energy deposit
- It is over when:
    - The particle is destroyed by the interaction
    - It reaches the end of the detector
    - Its energy is below a (tracking) threshold

After the simulation for that particle is over, it yields as outputs:

- New particles created (indirectly)
- Local energy deposits throughout the detector

The local energy deposits along the sensitive parts of the detector can be **digitized**

- It produces electric current and/or voltage signals, as in the real experiment
    - The same reconstruction chain can be applied for both real and simulated data
- Digitization is not part of the general radiation transportation codes

Simulations have to make a *trade-off* between accuracy and speed

- More precise physics models are slower and, more importantly, create more secondaries and/or steps
- There are also tracking and production *cuts* (or thresholds)
  - In general HEP experiments simulations, the secondaries production cuts are from several keV to few MeV
  - These standard cuts can make a gaseous detector simulation impossible

Why Geant4?

1. Because it is (one of) the most widely toolkit in use in HEP
   - This implies in a great number of users and communities testing and validating the physics models
2. Because it is written in `C++`, and this allows for
   - Modularity of physics models (there isn't a *one model to rule them all*)
   - As an Object-Oriented language, it allows to manipulate several objects, create new ones by class inheritance, etc
3. Because it is "multi-threadable"

Geant4 can be used to

- Define the geometry, materials and physics processes
- Trigger the primary particle
  - With a particle gun (e.g. only e^-)
  - Interfacing from an event generator (e.g. Pythia)
- Give the position, time, "size" and kind of the primary particle ionisation

For gaseous detectors, however

- Charge multiplication is not well performed by Geant4.
- Electron transport and multiplication must handled by something else

Garfield++:

- Is an electron transport and multiplication simulation toolkit
- Simulates the transport microscopically, through multiple scattering
- Has an built-in interface to ROOT analysis toolkit

- Geant4 does not simulate avalanches very well
- Garfield++ does not simulate the initial interaction
- Strategy: simulate ionisations with Geant4, **then** use Garfield++ for transport and avalanche

Gaseous Detectors: working principle

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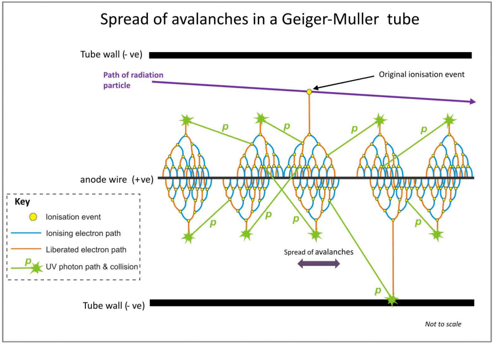
General aspects:

- Essentially for charged particle detection
- Charged particle ionises the gas, which is submitted to an applied $\vec{E}$ field
- Electron and ion drift in opposite directions
- Electrons are attracted to a very steep potential well
- Through multiple scatterings the initial electron produce secondary ionisations, which in turn induce new ones, and so on
  - This process is called "avalanche"

Typical example: Geiger-Müller tube

- It is a detector set in a way that every event creates avalanches in a chain reaction
- In this regime the tube is filled with avalanches regardless of the "size" of the initial ionisation
- No proportionality with energy

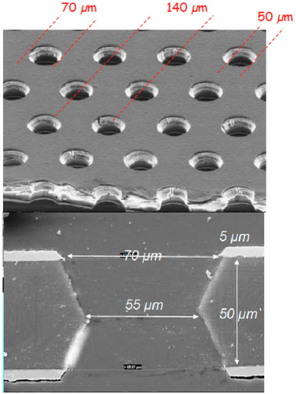


The proportional regime

- If the GM-tube is set in the proportional regime, then proportionality between the energy deposit and the total charge generated is achieved
- This is the working principle of the Multi-Wire Proportional Chambers (MWPC)
  - Several wires (such as the GM-tubes) in array
  - This set provides sensibility to the ionisation positions (tracking)
- These are "traditional macro pattern" detector
- In the last 20 years the field is moving towards Micro-Pattern Gaseous Detectors (MPGD)

MPGD: Gas Electron Multipliers

- Avalanches in microscopic scales
- Association of several GEM foils:
  - Reduces IBF
  - Increase gain
- Fast (ions trapped, electrons induce signal)



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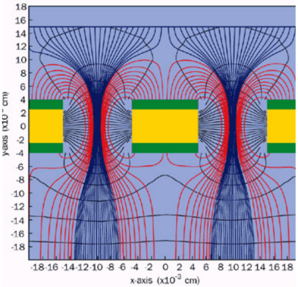

THGEM vs. GEM Pros:

- Cheaper
- More robust
- Easier to build

Cons:

- Higher Ion Back Flow
- Less performing

Gaseous Detectors: Simulation constraints

- The physics process of primary signal generation are normally in the eV scale
- The typical process threshold to be simulated is on the order of tens of keV
- One has to be able to tune this threshold down
- Lowering threshold comes with a cost in computing time of (maybe several) orders of magnitude
- Challenge: to have a realistic ionisation within a feasible computing time

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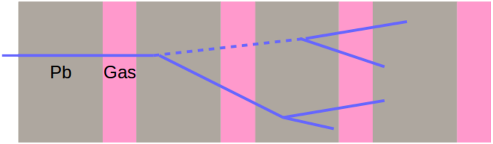
Physics motivation

- Probe gluon saturation
- Confirm (or reject) Color-Glass Condensate
- These effects are enhanced in forward rapidities
- Ideal probe: direct photons
  - There's also room for charm and jets (hence hadronic energy needed)

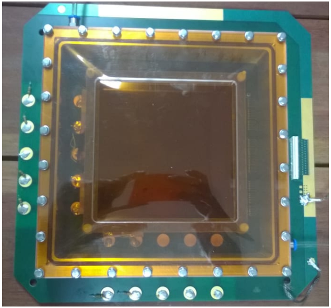


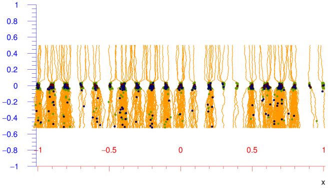
Prospects I: FoCal-H

Project motivation

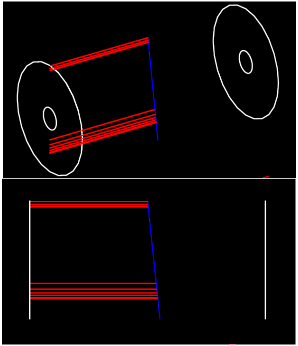
- THGEMs cheaper than scintillator/APD/SiPM
- Readout PADs of 1cm x 1cm
  - Digital calorimetry
  - Allow PFA to be used
- Readout electronics already developed (SAMPA chip)

THGEM in São Paulo and Santo André is an already ongoing project





- Physics and project motivations: see **this workshop**
- Just as an appetizer: a simulation of a (not to be) PANDA TPC



Conclusions

- Detector simulation is a business on its on right
- Lots of physics processes to be understood, modeled, etc
- Team effort: manpower is crucial
- Essential effort: physics is the main goal, but we can't get there without the simulations