GEM Simulation Studies

Henning Keller, Kerstin Hoepfner, Giovanni Mocellin, Moritz Seidel

21.10.2019

RD51 Collaboration Meeting

Physics Institute III A | RWTH AACHEN UNIVERSITY

SPONSORED BY THE
Federal Ministry of Education and Research

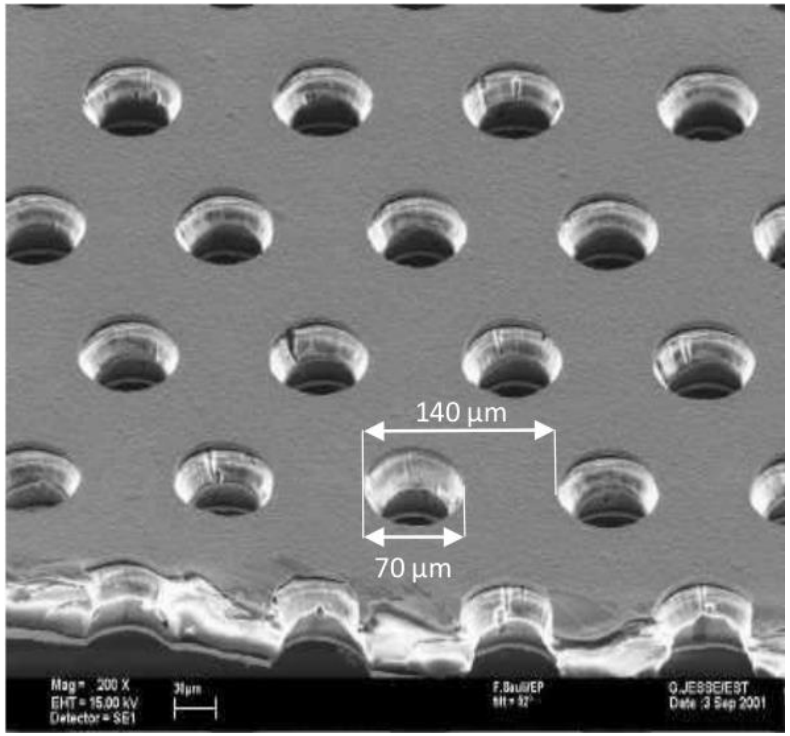
Overview of activities

- Hole asymmetry or double-mask vs. single-mask foils
  - Gain study of different hole geometry (data and simulation)
- Variation of electric fields
  - Drift, transfer, induction fields
- Long standing issue of lower gain in simulation
  - Investigations on microscopic simulation step

  ➡ **Discuss studies with a broader audience**

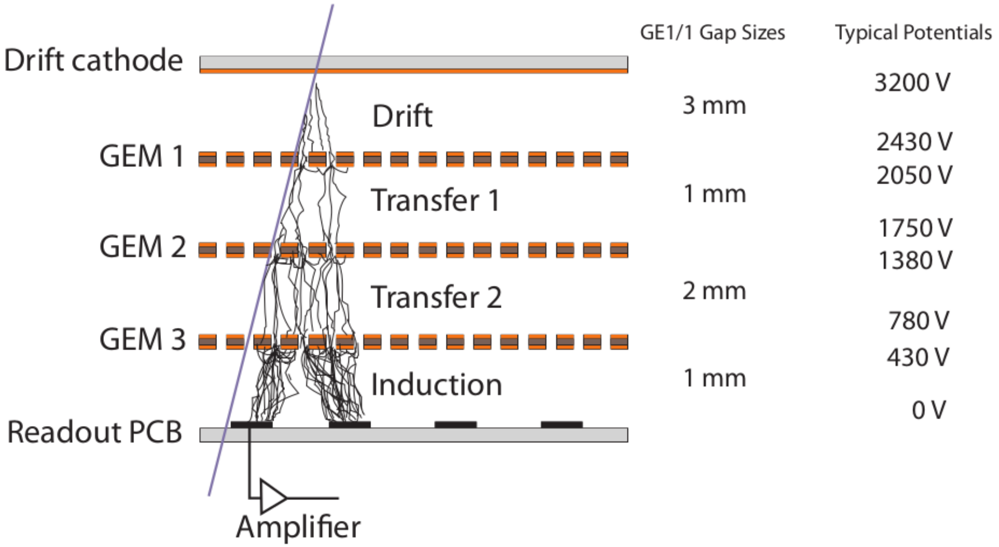
CMS GEM foil design

- Kapton foil as bulk material (50 um)
- Copper cladded on both sides (5 um)
- Foil perforated with hexagonal pattern of holes (pitch of 140 um)
- Double semi-conical holes: standard dimensions 70/50/70 um (depends on etching procedure)

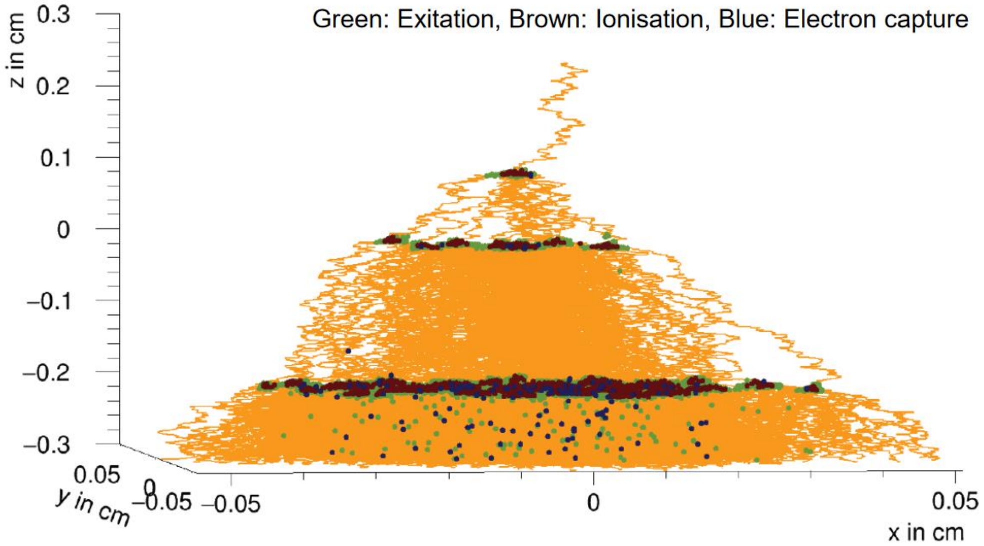


Taken from F. Sauli, “GEM: A new concept for electron amplification in gas detectors”

Triple-GEM simulation



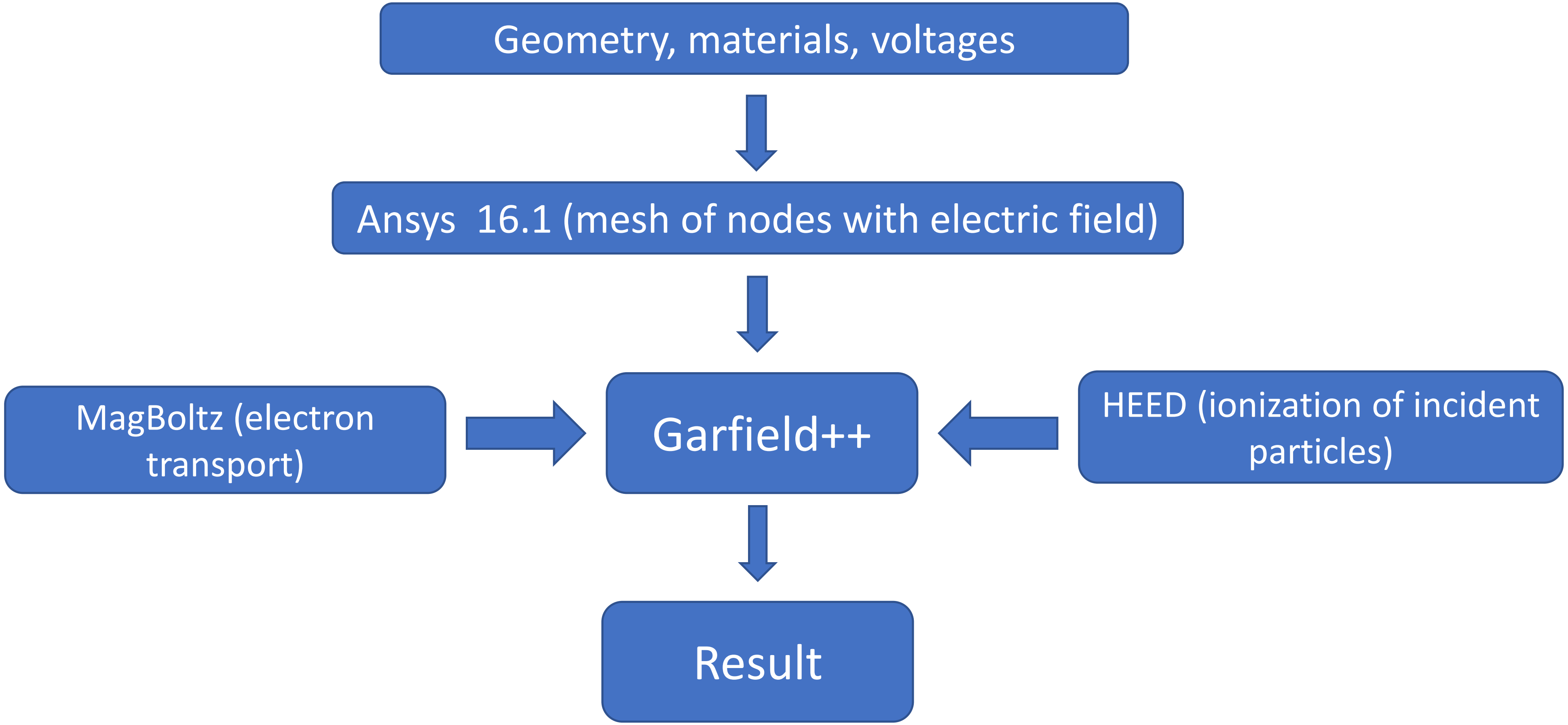
Taken from CERN-LHCC-2015-012



- Triple-GEM detector
- Spacing of 3/1/2/1 mm
- Gas mixture: Ar/CO2 (70/30)
- Nominal voltages for CMS GE1/1 configuration shown

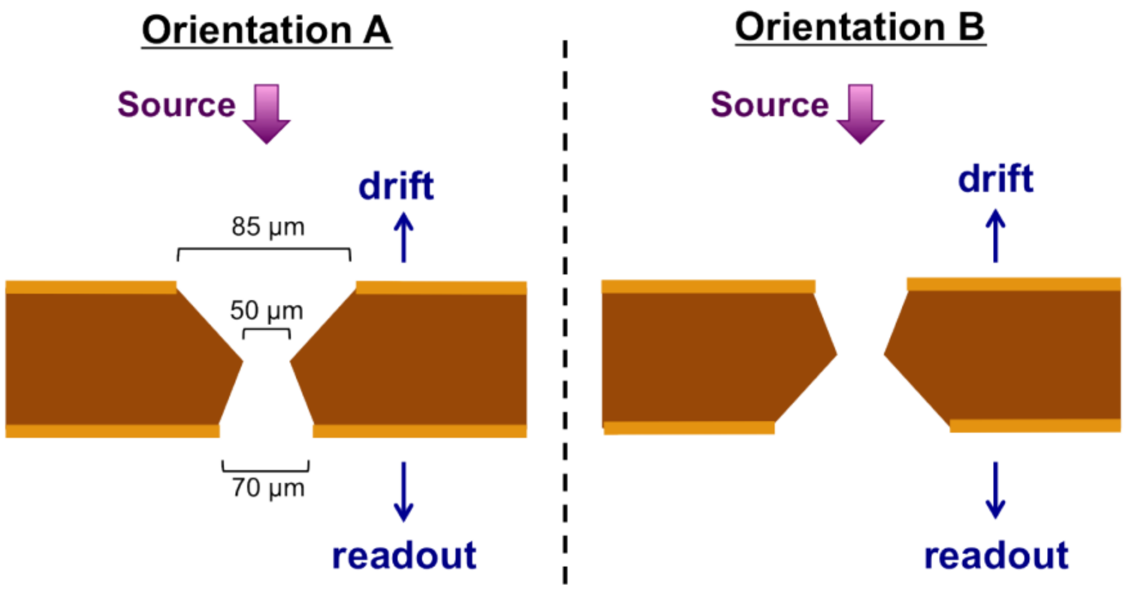
- Electron avalanche in triple-GEM detector
- **Effective gas gain defined as factor between P+S electrons and electrons reaching the readout**

Simulation workflow



Hole asymmetry studies or double-mask vs. single-mask

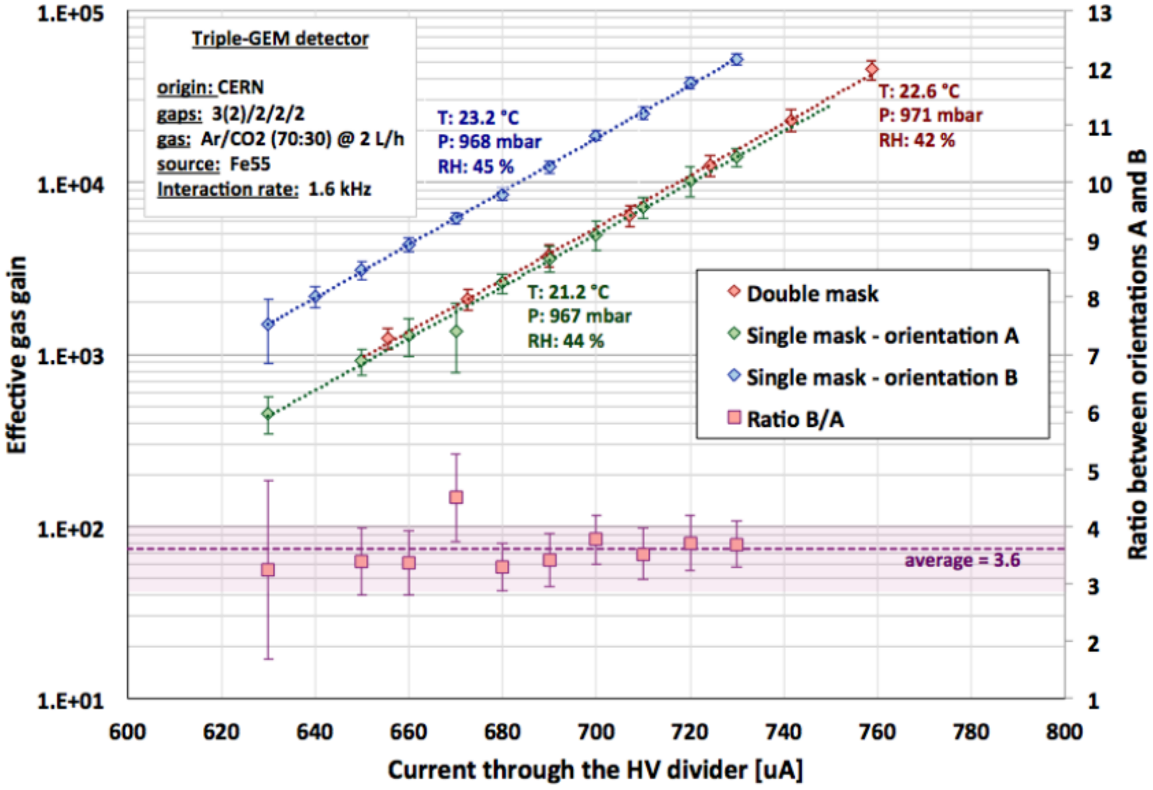
- Hole asymmetry can be introduced by different etching procedures (DM/SM)
- Typical hole geometries
  - SM Orientation A
  - SM Orientation B
  - DM: 70/50/70 μm
- **What is influence on effective gas gain?**



Taken from CERN-THESIS-2016-041 (J. Merlin)

Hole asymmetry studies or double-mask vs. single-mask

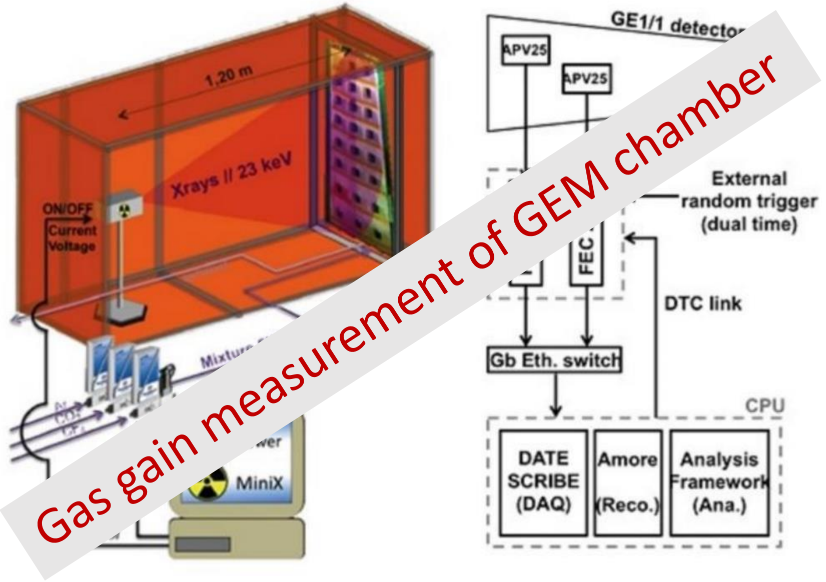
- Studies performed by Jeremie M. et al.
- **Outcome: higher gain for single-mask compared to double-mask**
- Not compatible with simulation results

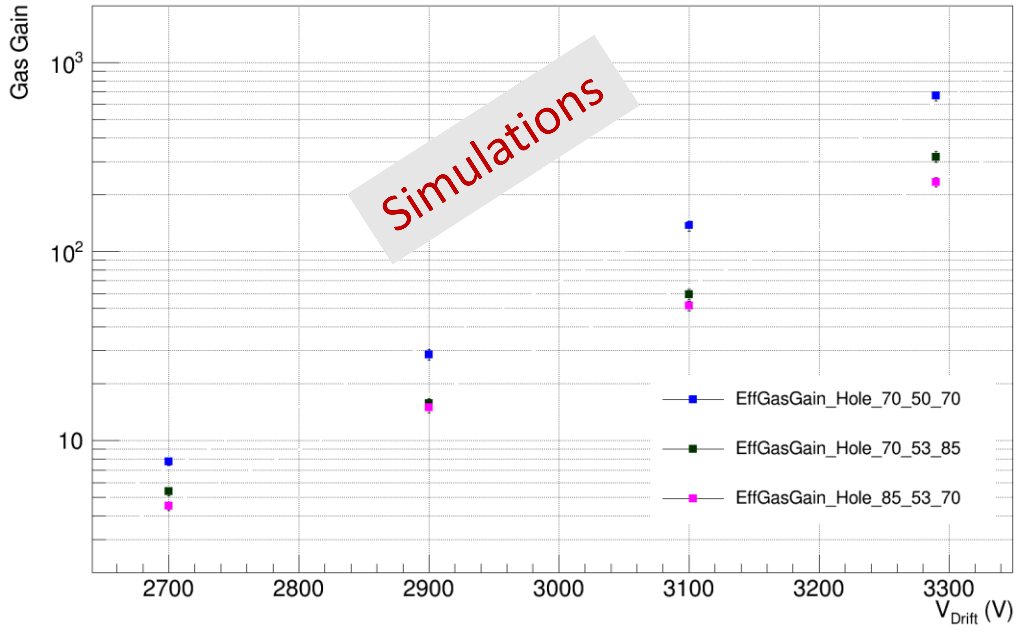


Taken from CERN-THESIS-2016-041 (J. Merlin)

Hole asymmetry studies or double-mask vs. single-mask

- Studies of influence of hole asymmetry on gas gain ongoing in CMS GEM group
- Provide simulations and measurements





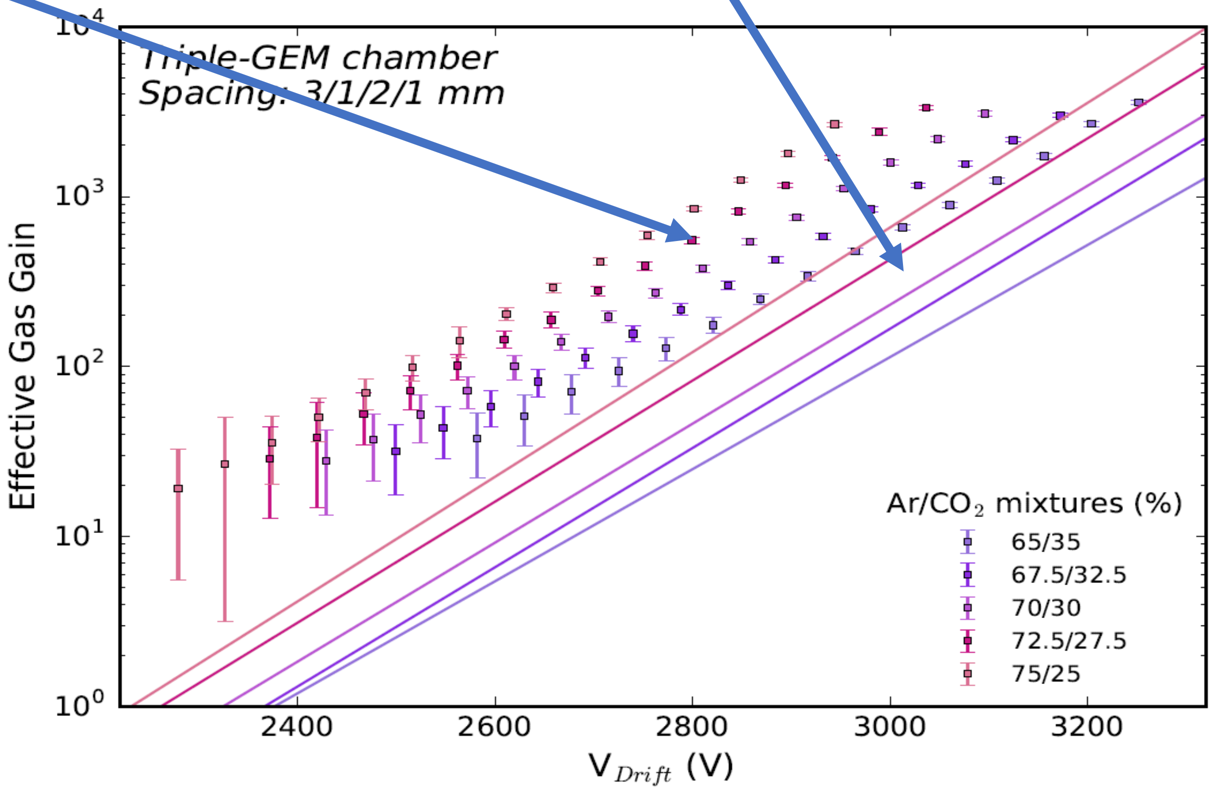
Gas gain measurements

- Experience with gas gain measurements
  - GE1/1 mass production, prototypes, 10x10 chambers
- We have ordered 3 sets of GEM foils for our 10x10 chamber from TECHTRA (specs of 3 um on hole dimensions)
  - SM with 70/53/85 um
  - DM with 70/50/70 um
  - DM with 70/50/85 um

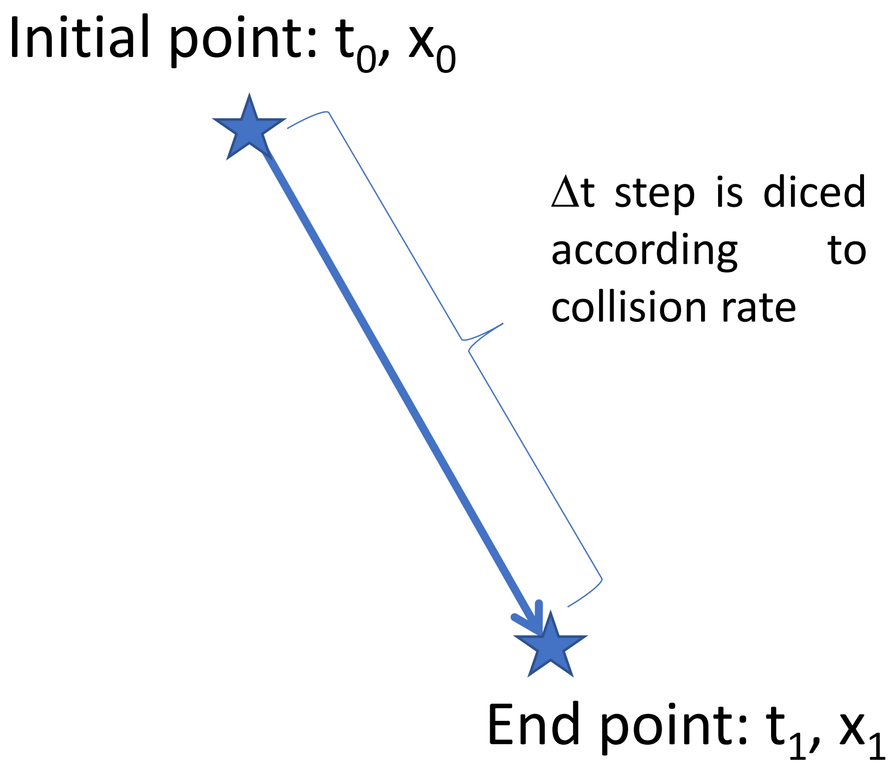
GEM number	Holes dimension in copper on the side with number inscription [µm]	Holes dimension in kapton [µm]	Holes dimension in copper on the side without number inscription [µm]	Type pf GEM
1	83	51	70	Single mask
2	83	55	71	Single mask
3	80	51	71	Single mask
4	85	53	70	Double mask
5	85	50	70	Double mask
6	86	47	71	Double mask
7	69	51	70	Double mask
8	71	48	68	Double mask
9	69	48	70	Double mask

Discrepancy between gain in simulation and measurements

- Well-known feature that simulations give less gas gain than observed in measurements.
- Investigating microscopic simulation step



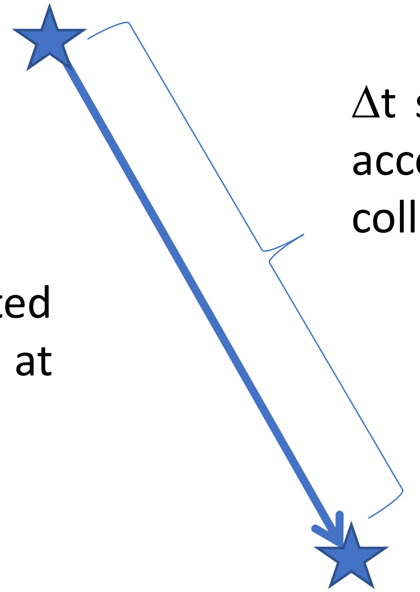
Time Step in Garfield



Parameter of simulation step	Typical values
Time step Δt	10 ps
Distance step (v_D= 5 cm/µs)	5 nm
Variation of E-Field on that scale (in GEM hole)	5 V/cm (very small)

Note: values are typical for drift fields, not for higher elctric fields (in GEM hole)

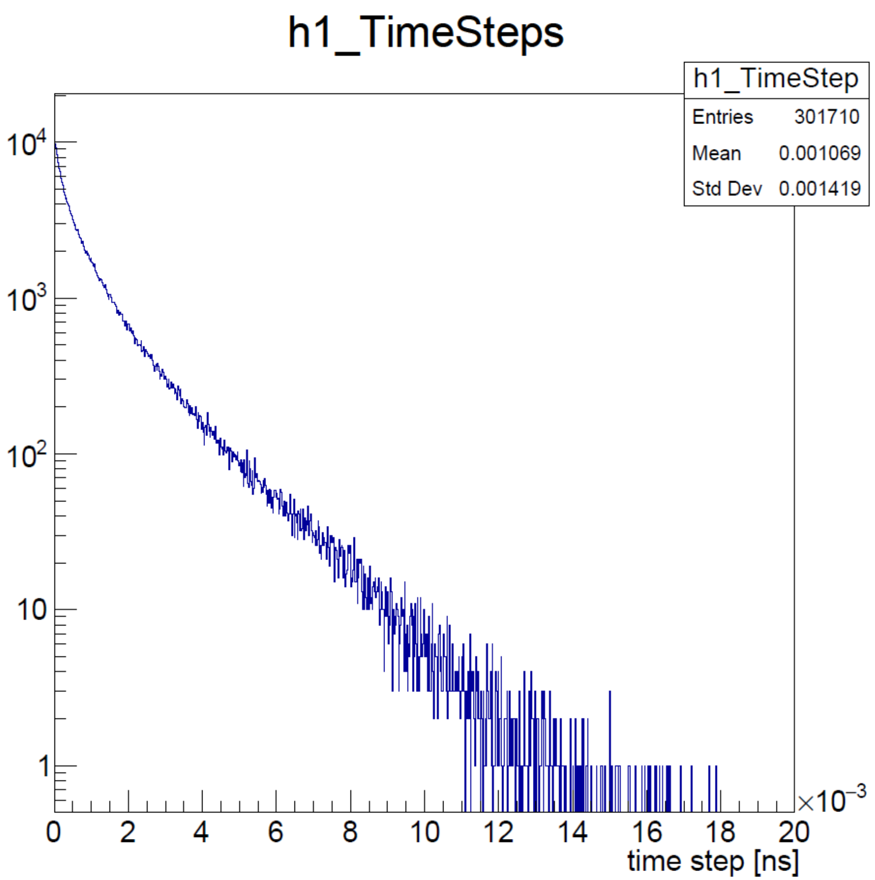
Time Step in Garfield

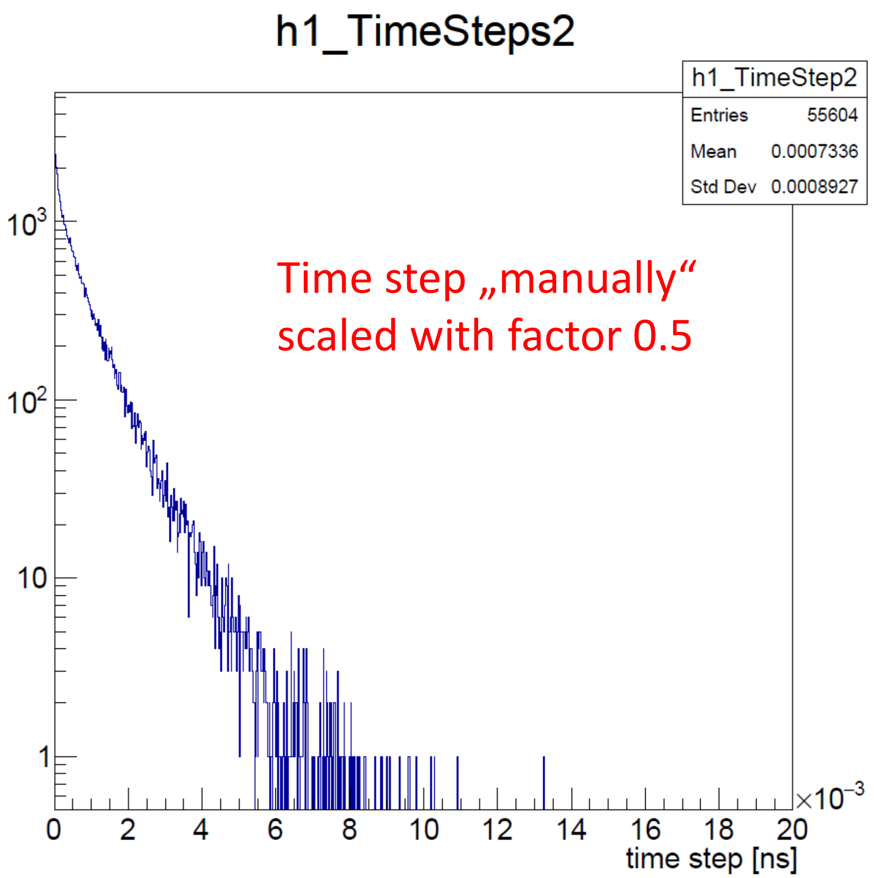


Conclusions:

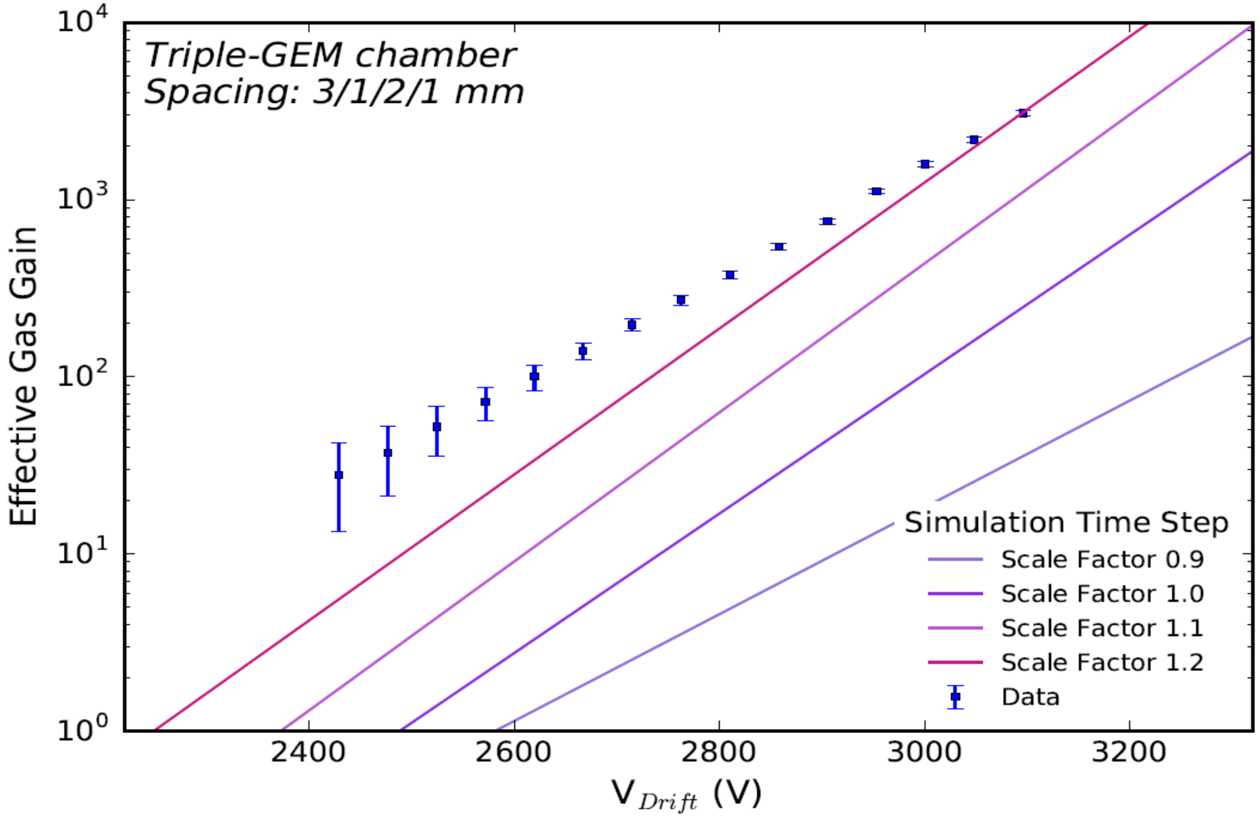
- Distance step in simulation << mean free path
- In code, E-Field is constant for one simulation step
    - Good approximation even inside GEM hole (large variations on small scale)
- Is it good enough though? ~5% error propagates exponentially to absolute gas gain value

Distribution of time step in Garfield





Influence of time step on gas gain



- Smaller time step -> lower gain; larger time step -> higher gain
- First and preliminary comparison of absolute numbers, dependency (slope of exponential) on HV not really matching, more investigations needed…

Summary

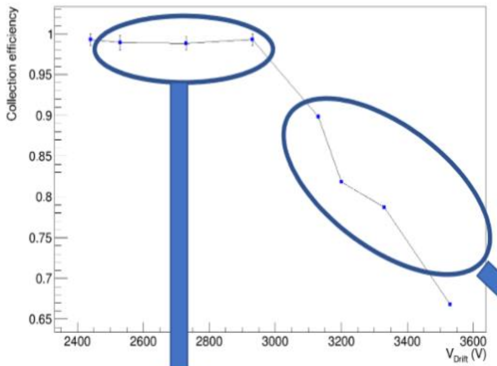
- Gained experience of Garfield++ simulations with single-GEM and triple-GEM configurations
- Studies on hole asymmetry ongoing, results will be ready soon, comparison with lab measurements
- Microscopic simulation step investigated
  - Large dependence of gain on time step observed

Backup

Results from other studies

Variations of VDrift

- Triple-layer GEM simulation



Compare with literature (Sauli et al.):

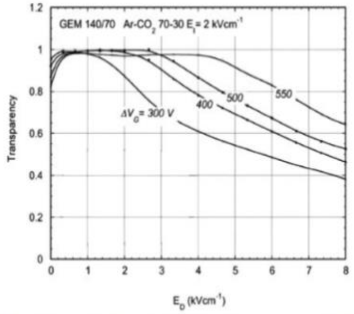
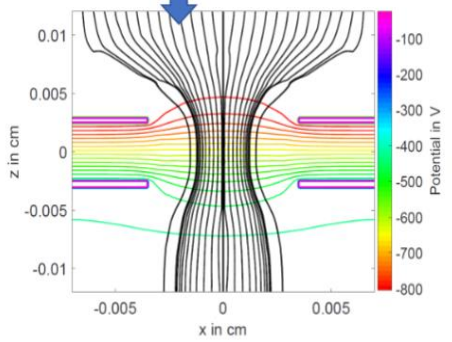
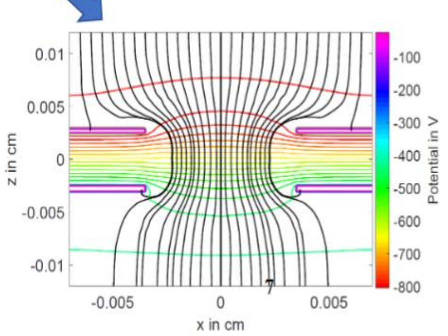


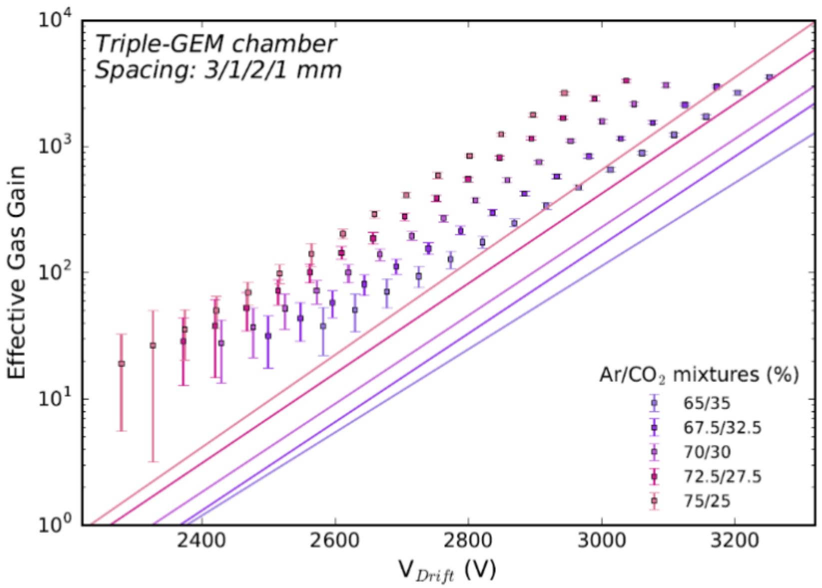
Fig. 6. Electron transparency of a standard GEM electrode (70 μm holes at 140 μm pitch) as a function of drift field for fixed induction field, for several values of GEM voltage.





Comparison: Lab vs. Garfield

- Compare measurements with simulations
- In best case, both sides can benefit
- **First study: Comparison of gas gain for different Ar/CO2 mixtures as a function of HV**



Points: Data taken with CMS GenV prototype GEM detector
Lines: Exponential fit of Garfield simulations

Details on time step variations

```
// Determine the timestep.
double dt = 0.;
while (1) {
  // Sample the flight time.
  const double r = RndmUniformPos();
  dt += -log(r) * fInv;
  // Calculate the energy after the proposed step.
  if (m_useBfield && bOk) {
    cwt = cos(wb * dt);
    swt = sin(wb * dt);
    newEnergy = std::max(energy + (a1 + a2 * dt) * dt +
                             a4 * (a3 * (1. - cwt) + vz * swt),
                         Small);
  } else if (useBandStructure) {
    const double cdt = dt * SpeedOfLight;
    newEnergy = std::max(medium->GetElectronEnergy(
                             kx + ex * cdt, ky + ey * cdt,
                             kz + ez * cdt, newVx, newVy, newVz, band),
                         Small);
  } else {
    newEnergy = std::max(energy + (a1 + a2 * dt) * dt, Small);
  }
  // Get the real collision rate at the updated energy.
  double fReal = medium->GetElectronCollisionRate(newEnergy, band);
  if (fReal <= 0.) {
    std::cerr << hdr << "Got collision rate <= 0 at " << newEnergy
              << " eV (band " << band << ").\n";
    return false;
  }
  if (fReal > fLim) {
    // Real collision rate is higher than null-collision rate.
    dt += log(r) * fInv;
    // Increase the null collision rate and try again.
    std::cerr << hdr << "Increasing null-collision rate by 5%.\n";
    if (useBandStructure) std::cerr << "    Band " << band << "\n";
    fLim *= 1.05;
    fInv = 1. / fLim;
    continue;
  }
  // Check for real or null collision.
  if (RndmUniform() <= fReal * fInv) break;
  if (m_useNullCollisionSteps) {
    isNullCollision = true;
    break;
  }
}
```

Scale time step with factors [0.9,1.0,1.1,1.2] here

- Source code Garfield+++
  - Class: AvalancheMicroscopic
  - Function: TransportElectron()