GTS

Garfield-based Triple-GEM Simulator

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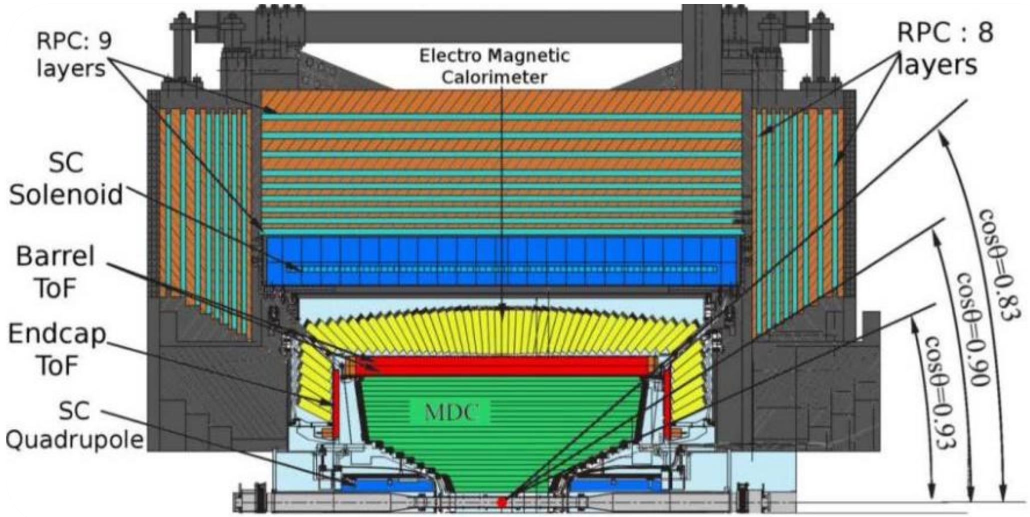
RD51 Collaboration Meeting - 21-23 Oct 2019, Meyrin (CERN)

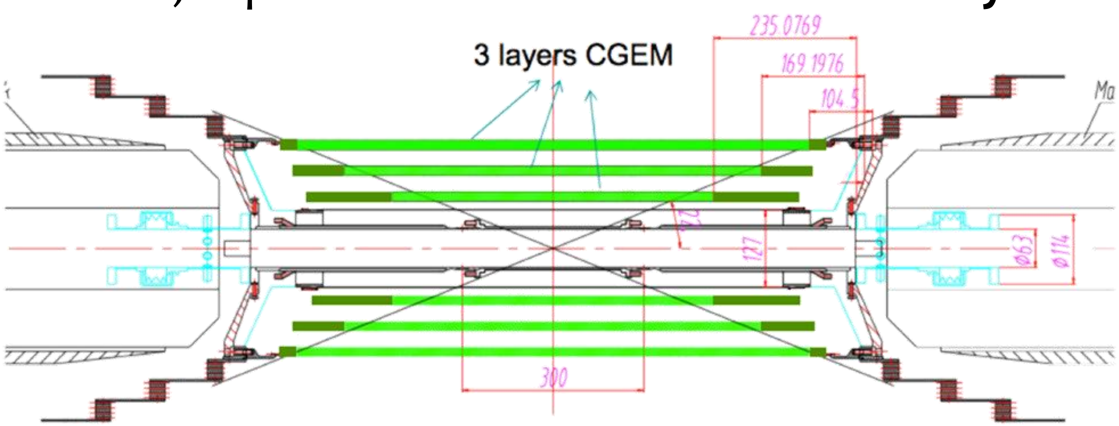
CGEM-IT project, BESIII experiment



BEijing Spectrometer III
- τ & charm factory
- E_{cms} = 2 – 4.6 GeV
- @BEPC, Beijing, P.R.C.
- current tracking system:

inner + outer drift chamber

In 2020, replace the inner chamber with a **Cylindrical Triple-GEM - Inner Tracker**

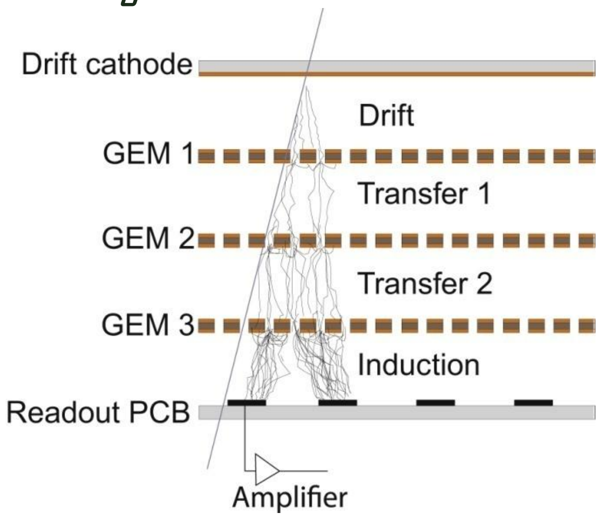


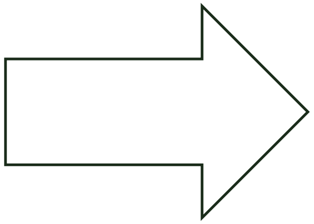
- σ_p/p = 0.5% @1 GeV/c
- σ_x = 130 μm
- σ_z = 1 mm
- solid angle coverage 93%
- X_0 < 1.5%
- particle rate ~10^4 Hz/cm^2

Digitization of a triple - GEM

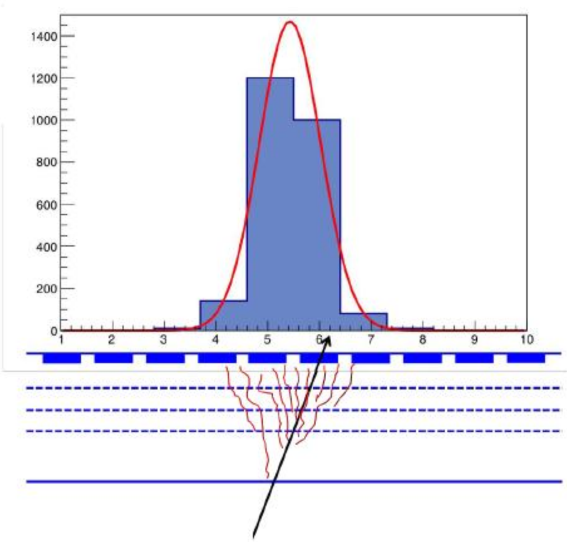
simulate the triple-GEM response to the passage of the ionizing particle

from the generation of the electrons…





…to the signal formation



Available tool: GARFIELD++

STRAIGHTFORWARD CHOICE!

Reading from the webpage https://garfieldpp.web.cern.ch

is a toolkit for the **detailed simulation of detectors which use gases** or semi-conductors as sensitive medium.

the main area of application is currently in **micropattern gaseous detectors.**

Ionisation → Heed generates ionisation patterns of fast charged particles

Electric fields → interfaces with the finite element programs (Ansys, Elmer, Comsol and CST) which can compute approximate fields in nearly arbitrary 3D configurations with dielectrics and conductors

Transport of electrons → Magboltz is used for computing electron transport and avalanches in nearly arbitrary gas mixtures

Available tool: GARFIELD++

BUT (CPU) TIME IS PRECIOUS!

GOAL: use this digitization <u>inside</u> the full detector simulation → needs to be <u>fast</u>

We tried to run the **complete simulation** of a triple-GEM:

- ionization
- three stages of amplification
- drift of the electrons

on the distributed computing environment based on DIRAC (THE INTERWARE) for BESIII experiment, **but it took more than one day!**

GARFIELD++ capabilities

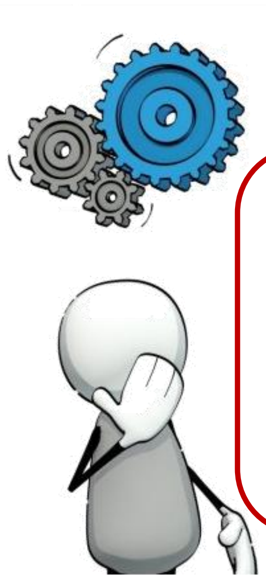
+

More speed

→

Parametrization!

Looking for inspiration



IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 4, AUGUST 2002

A Complete Simulation of a Triple-GEM Detector

W. Bonivento, A. Cardini, G. Bencivenni, F. Murtas, and D. Pinci

Primary Ionization

clusters

electrons/cluster

GEM properties

Gain

Transparency

Drift properties

Lorentz angle &

Diffusion

[in the four gaps]

Signal formation

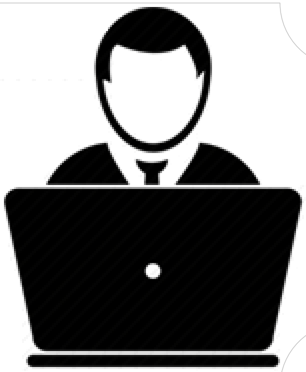
Induction

Readout

Our final solution

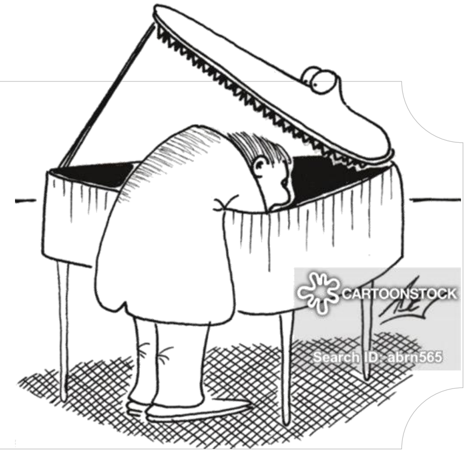
GARFIELD++
studies of various parameters

implementation of a standalone code



comparison between the standalone code and GARFIELD

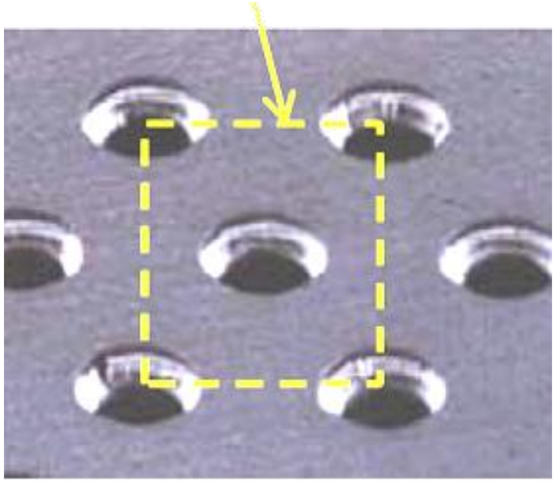
tuning to testbeam data



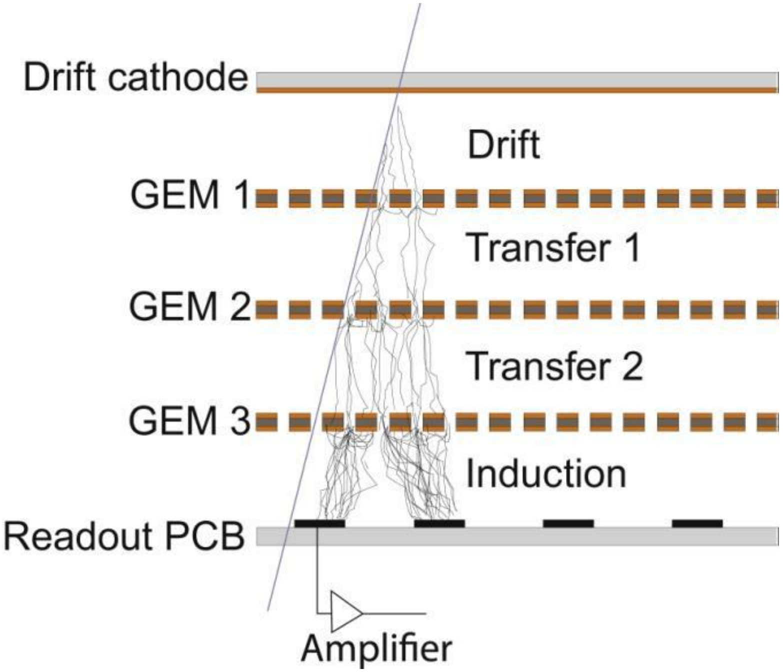
GARFIELD–based
Triple–GEM
Simulator

GARFIELD++ simulations

GARFIELD++ simulations



- geometry, field, HV described in **ANSYS**
- development of the avalanche from **GARFIELD++**
- planar GEM chambers considered



The triple-GEM was simulated in steps

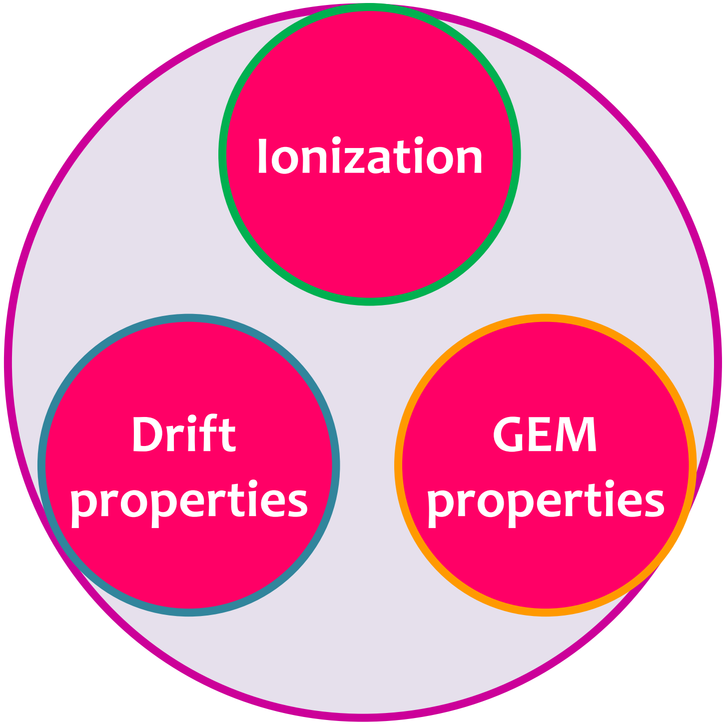
more details will follow

- used different HV settings
- used different field settings
- with and without magnetic field *on*

GTS implementation
&
comparison to GARFIELD++

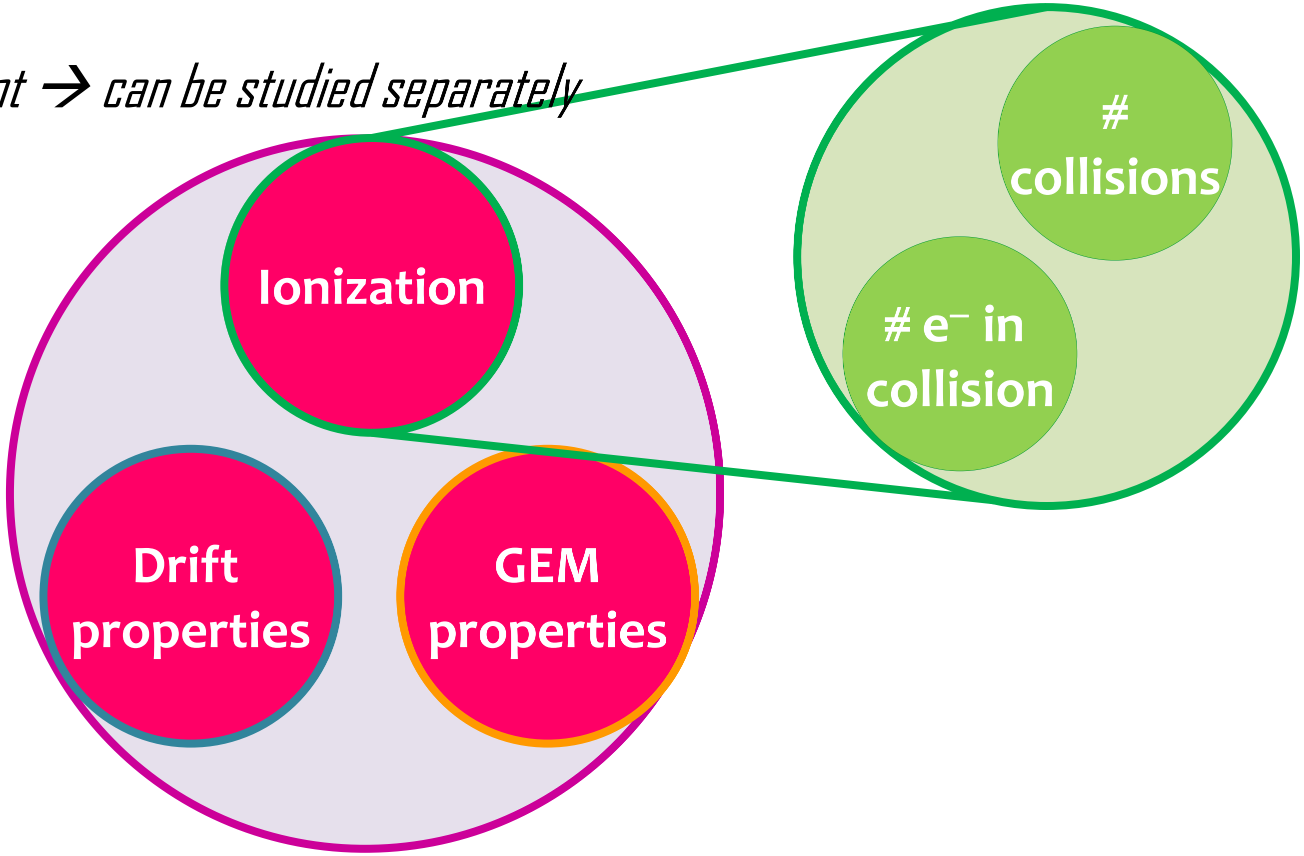
GTS scheme

various steps are independent → can be studied separately

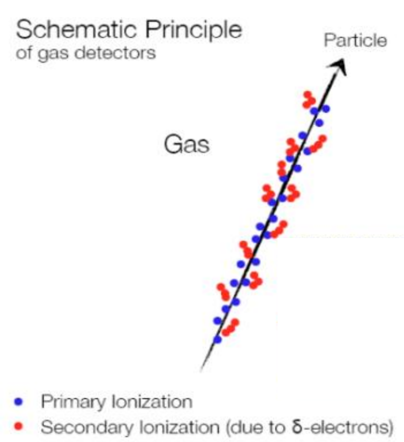


Ionization

various steps are independent → can be studied separately



Ionization



- **primary ionization** – Poissonian process

→ *relative position* from exponential distribution

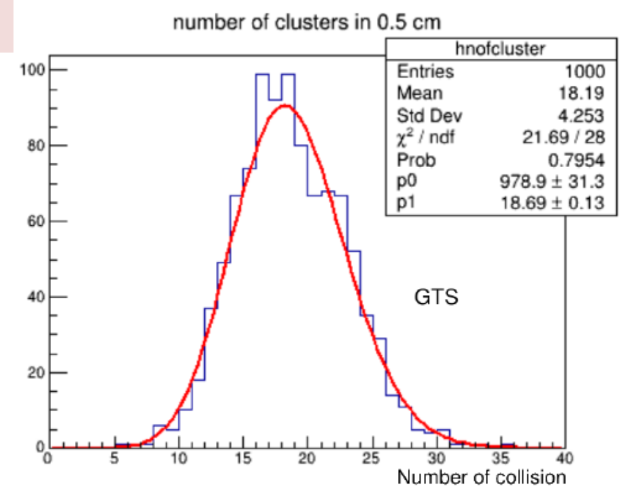
→ the number of the ionizations follows

- **secondary ionization** – from tables [F.Sauli (1977) *Principles of Operation of Multiwire Proportional and Drift Chambers*; A. Sharma *Properties of some gas mixture used in tracking detectors]*

→ consistent with GARFIELD++ simulations

Simulations

Electron clusters were extracted for M.I.P. (150 GeV/c muons) → will be extended to other particles and energies

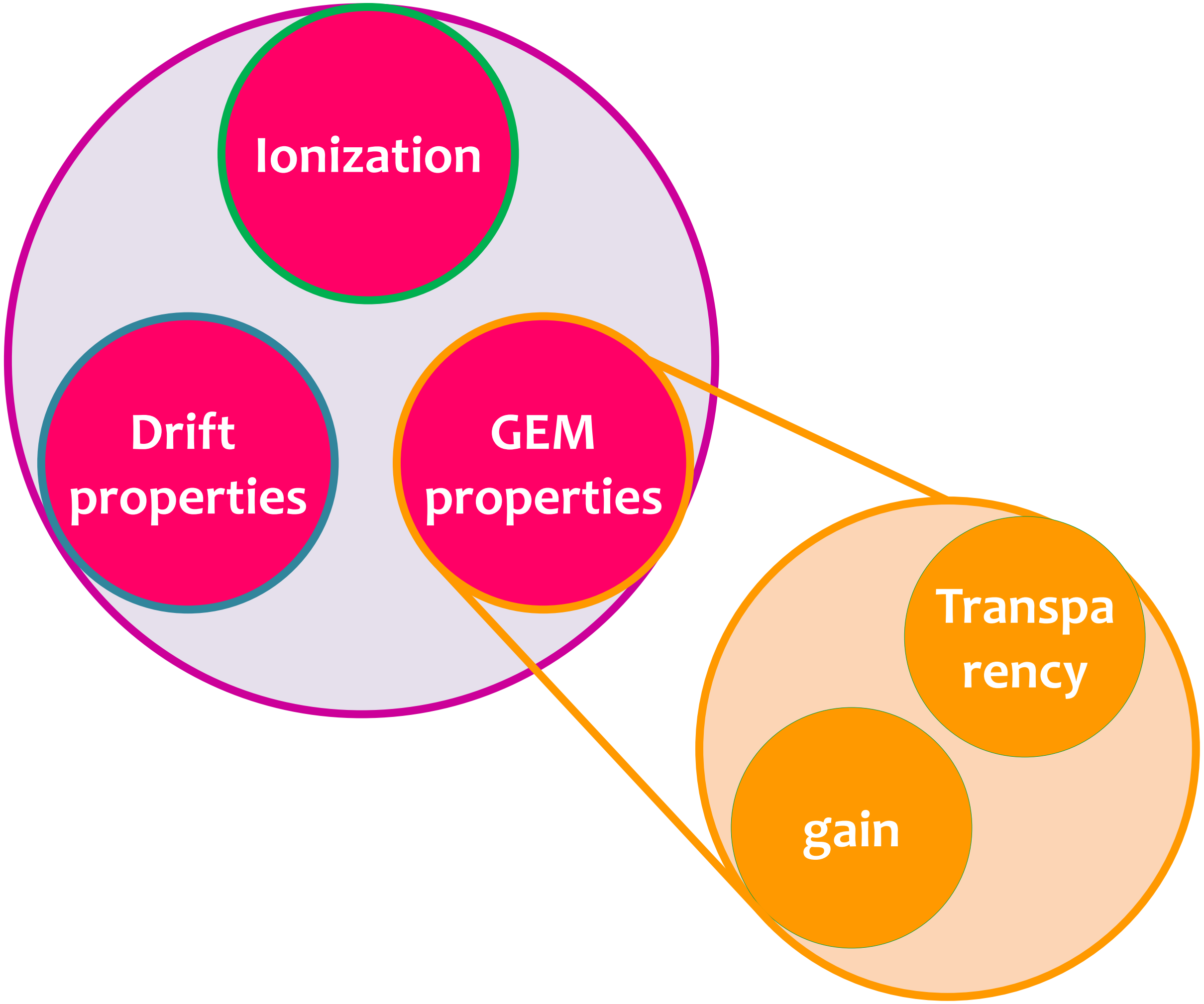


Two approximations

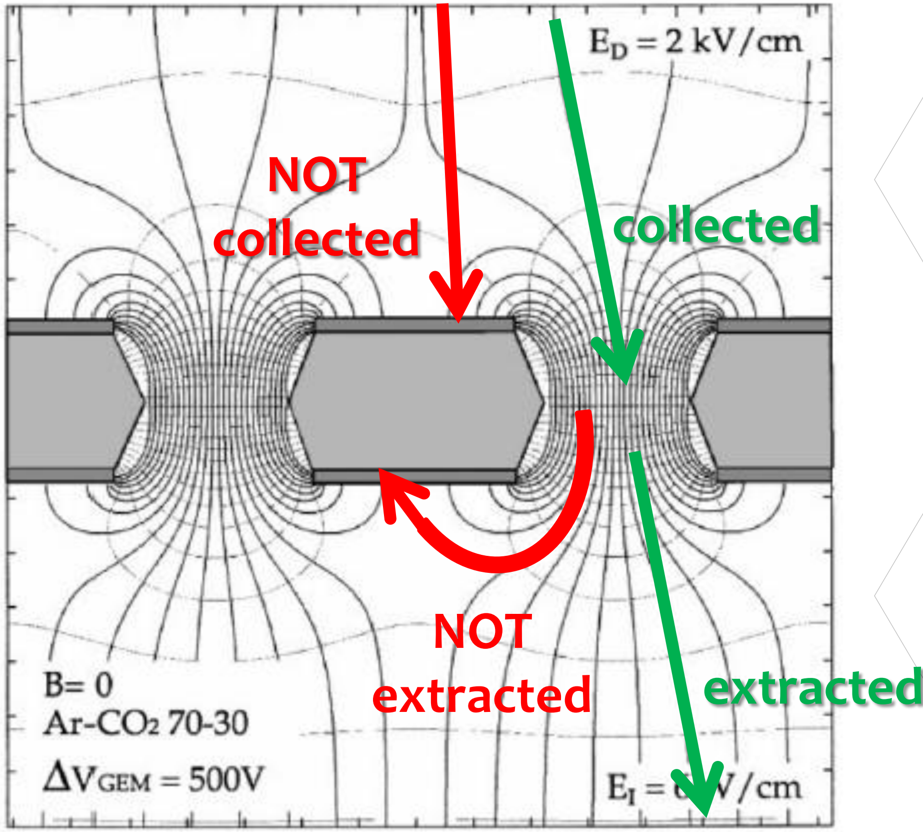
- ionization electrons generated only in the drift gap
- secondary electrons with the same origin of the primaries

GEM properties

various steps are independent → can be studied separately



Transparency



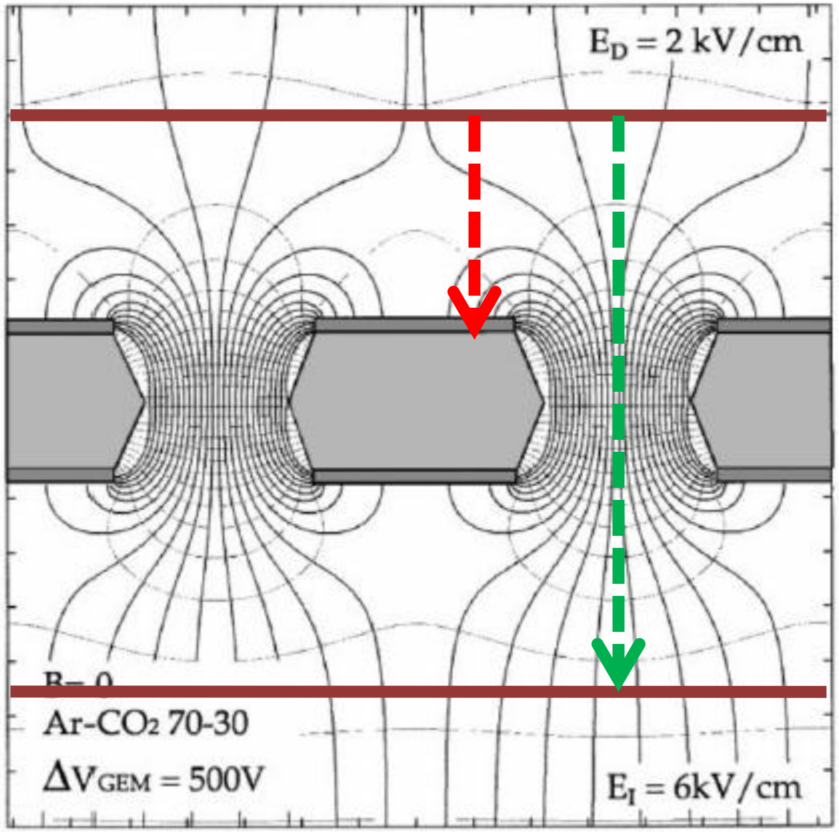
Collection efficiency

$$\frac{\#\ \text{electrons into the hole}}{\#\ \text{generated electrons}}$$

Extraction efficiency

$$\frac{\#\ \text{electrons from the hole}}{\#\ \text{electrons in the avalanche}}$$

Transparency



Collection efficiency

$$\frac{\text{\# electrons into the hole}}{\text{\# generated electrons}}$$

Extraction efficiency

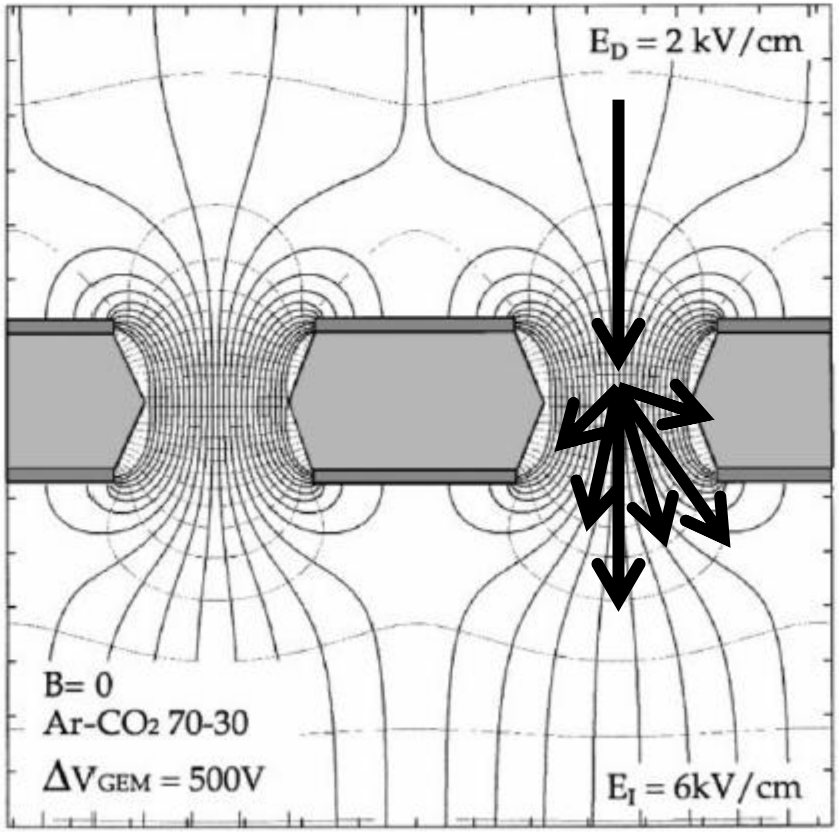
$$\frac{\text{\# electrons from the hole}}{\text{\# electrons in the avalanche}}$$

Simulation

- shoot 10k e^-, 150 μm above the GEM
- count e^-, 150 μm below the GEM
- avalanche *OFF*

$$T = \varepsilon_{coll}\,\varepsilon_{extr}$$

Gain



Gain fluctuations → Polya distribution

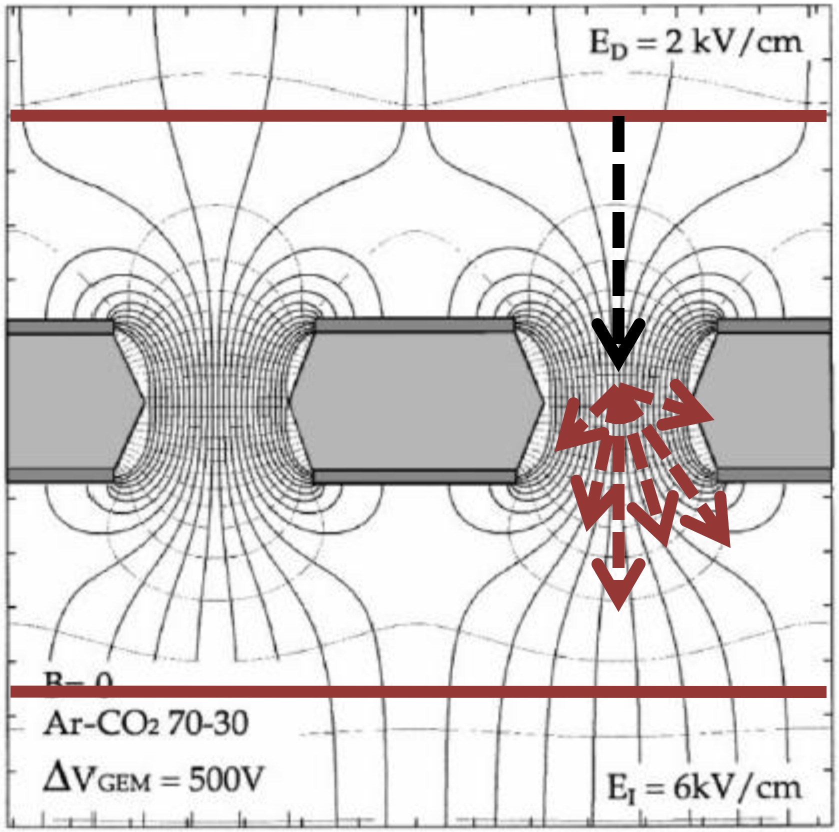
[G. Iakovidis PhD Thesis, Research and Development in Micromegas Detector for the ATLAS Upgrade]

$$P(G) = C_0 \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{G}{\overline{G}}\right)^{\theta} \exp\left[-(1+\theta)\frac{G}{\overline{G}}\right]$$

$\overline{G}$ = intrinsic gain mean value

θ → connected to variance

Gain



$$G_{\mathrm{eff}} = T\, G_{\mathrm{intr}}$$

For each of the three GEMs

Gain fluctuations → Polya distribution

[G. Iakovidis PhD Thesis, Research and Development in Micromegas Detector for the ATLAS Upgrade]

$$P(G) = C_0 \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{G}{\overline{G}}\right)^{\theta} \exp\left[-(1+\theta)\frac{G}{\overline{G}}\right]$$

$\overline{G}$ = intrinsic gain mean value

θ → connected to variance

Simulation

- shoot 10k e^-, 150 μm above the GEM
- count e^- in the avalance

→ intrinsic gain

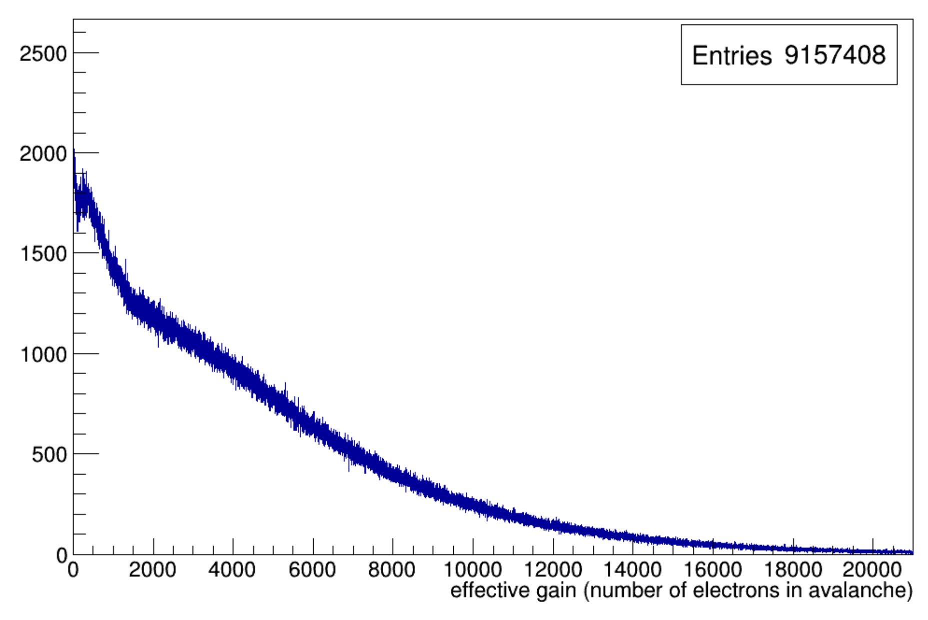
- avalanche *ON*

Triple – GEM full gain

Studies have shown that the actual triple-GEM full gain is not simply the product of GEM1, GEM2 and GEM3 gains!

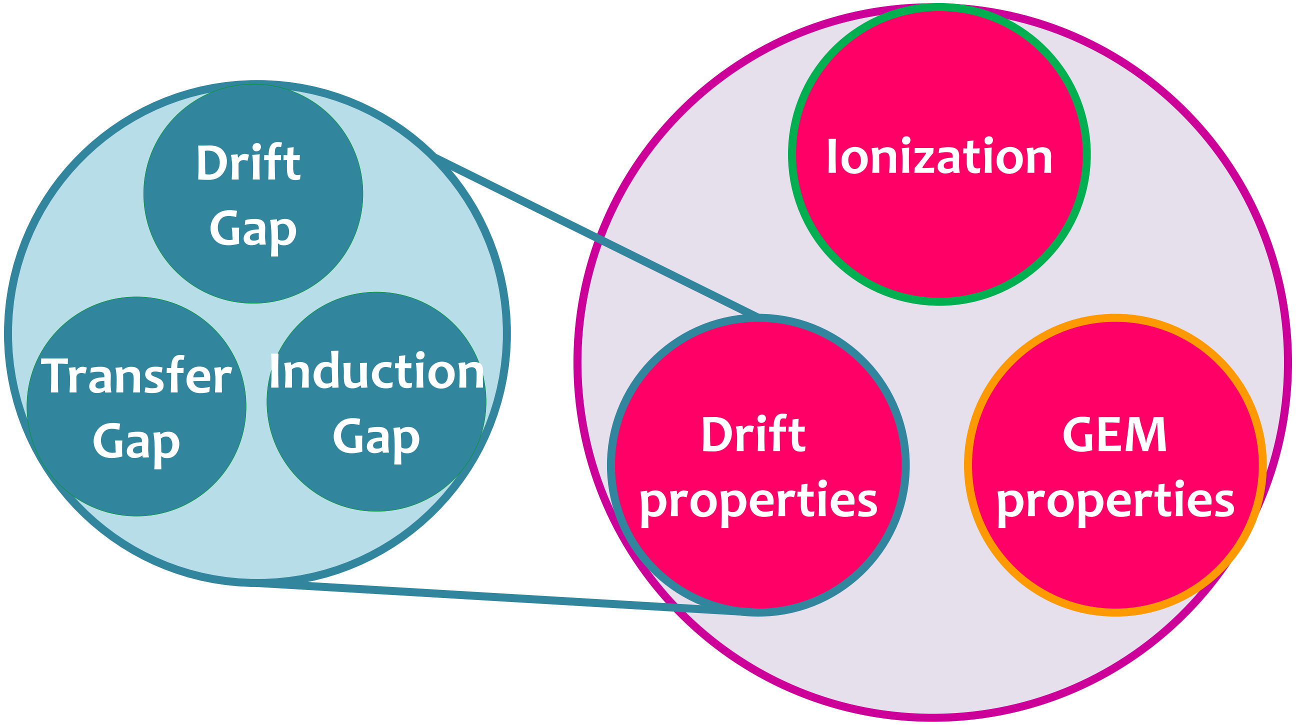
Procedure

1. evaluate transparency + intrinsic gain by GARFIELD++
2. apply them to GEM1, GEM2, GEM3
3. fill the **effective gain** histogram will 1M events with full simulation chain, *i.e.* sampling:
   $\varepsilon_{coll,\ GEM1} \rightarrow gain_{GEM1} \rightarrow \varepsilon_{extr,\ GEM1} \rightarrow$
   $\varepsilon_{coll,\ GEM2} \rightarrow gain_{GEM2} \rightarrow \varepsilon_{extr,\ GEM2} \rightarrow$
   $\varepsilon_{coll,\ GEM3} \rightarrow gain_{GEM3} \rightarrow \varepsilon_{extr,\ GEM3}$
4. sample from it!

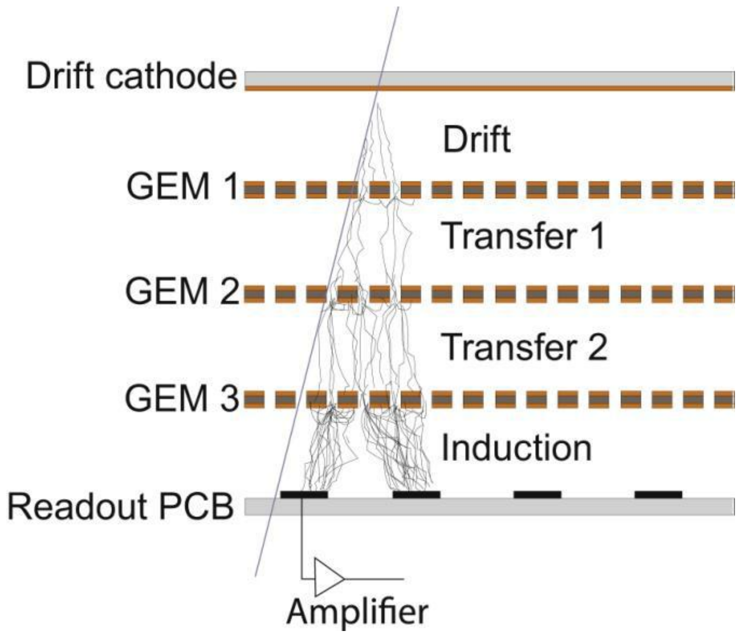


Drift properties

various steps are independent → can be studied separately



Drift properties



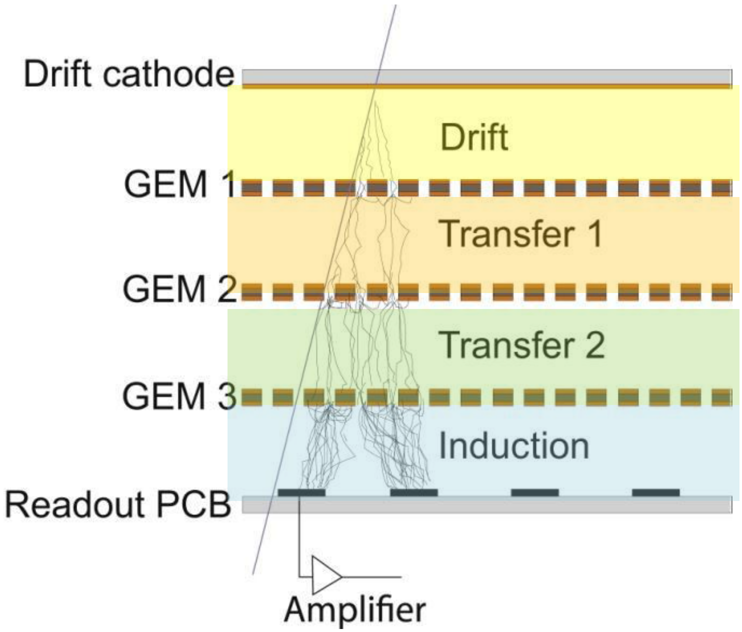
Presence of gas → Diffusion

- spread in position
- spread in time

Presence of mag. Field → Lorentz force

- shift in position
- longer times

Drift properties



Presence of gas → Diffusion
- spread in position
- spread in time

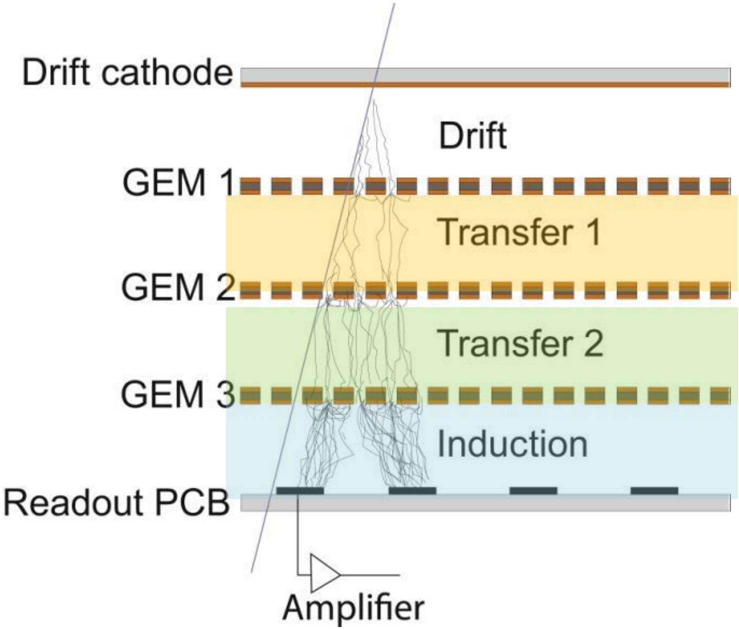
Presence of mag. Field → Lorentz force
- shift in position
- longer times

Study the different gaps separately

for each gap:
→extract Δx and Δt distributions
→ fit the σ_X, σ_t, μ_X, μ_t distributions to parametrize them

Simulation
- shoot 10k e^- in each gap
- magnetic field B = 1T
- avalanche *OFF*
- only drift *ON*

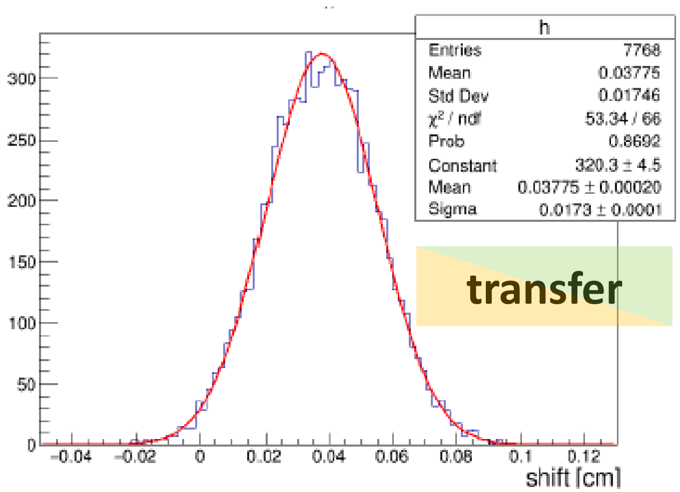
Position/time: shift & spread

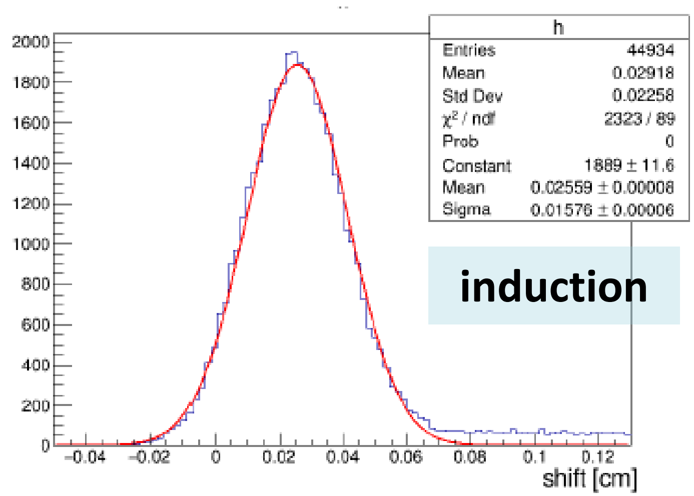


Transfer/Induction gaps

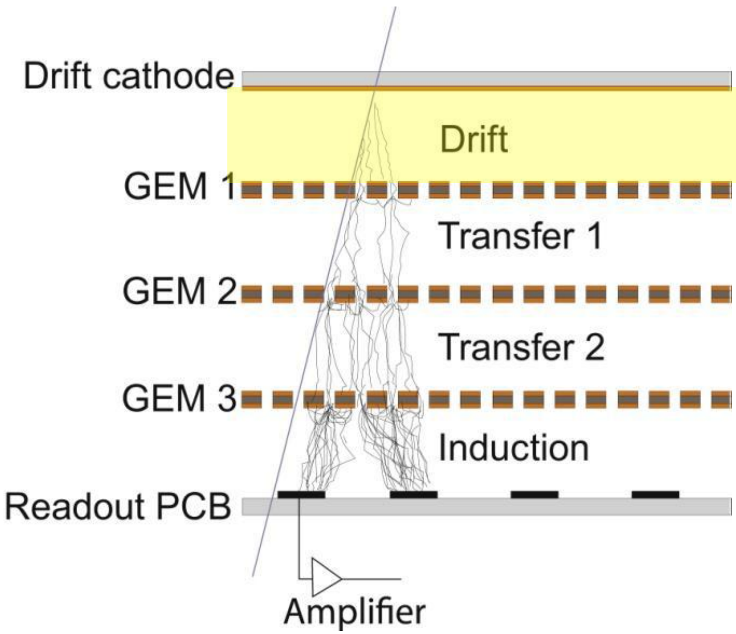
- the electrons all enter each gap from the same level → **NO z dependence** of spread and sigma of position distribution

- Analogous behavior for time distribution



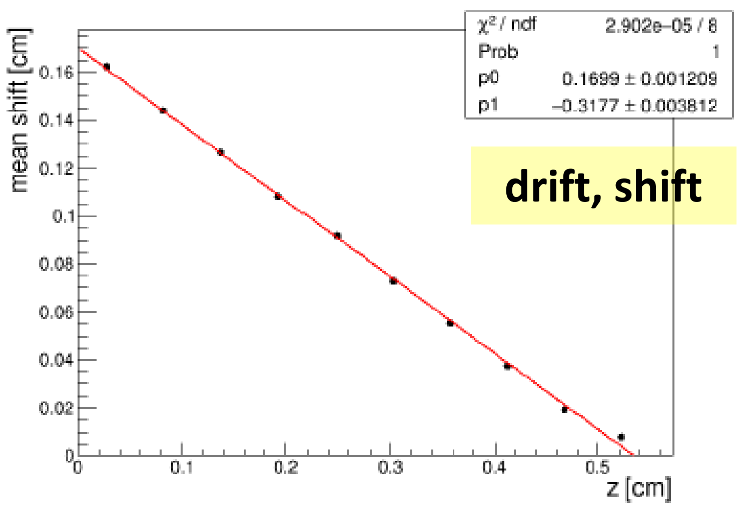


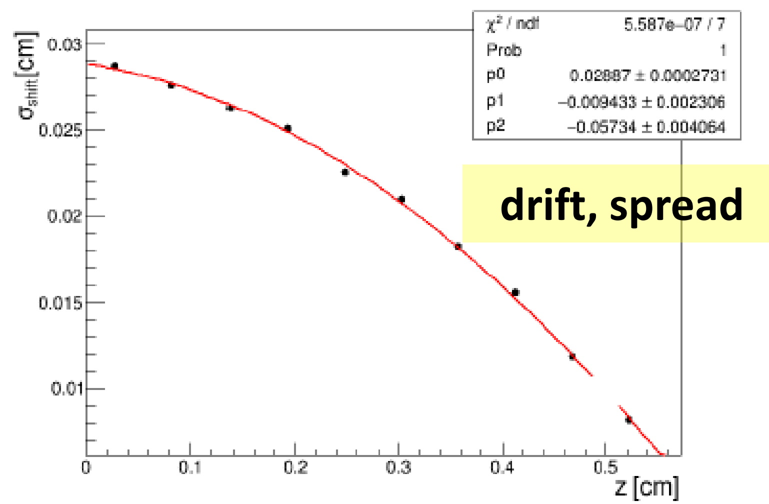
Position/time: shift & spread



Drift gap

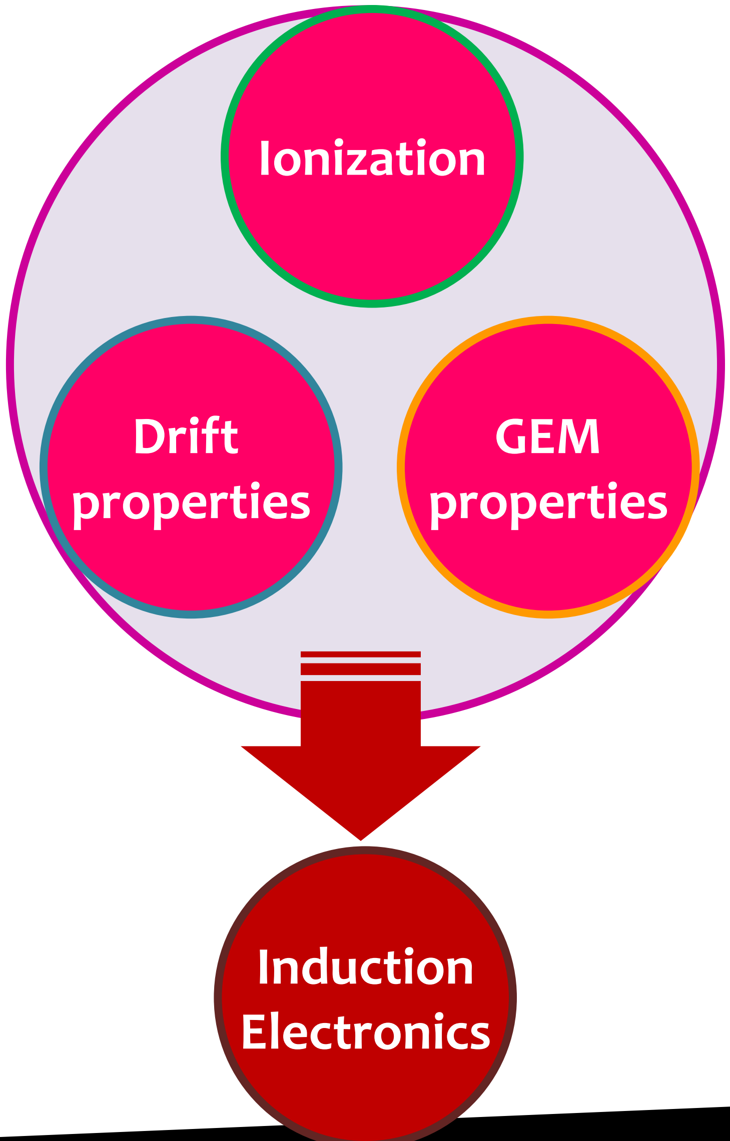
- The ionization position is different from electron to electron → **z dependence** of spread and sigma of position distribution
- Analogous behavior for time distribution



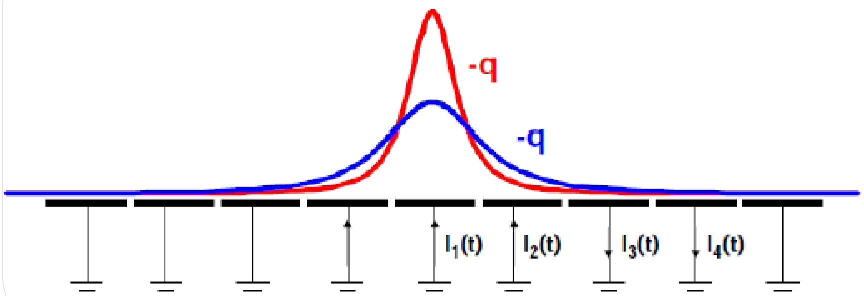


Signal formation

various steps are independent → can be studied separately



Induction of the signal: basics

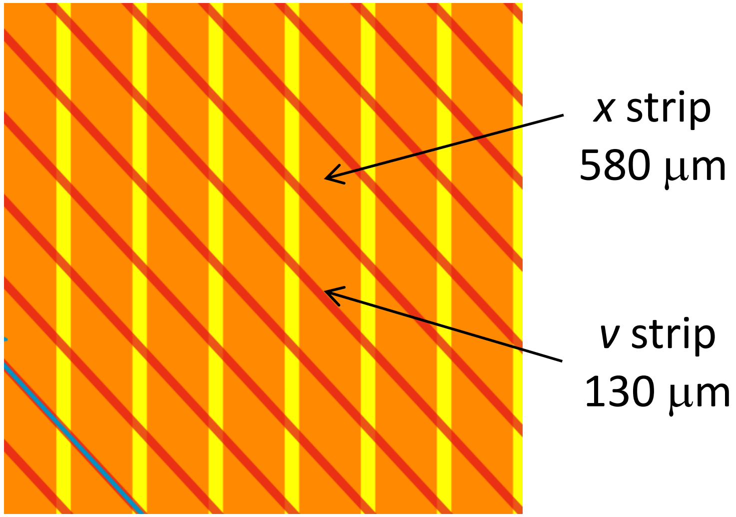


[W. Riegler, CERN seminar]

The current induced on a strip on the anode:
- depends on the position
- ends when the electron arrives on the strip

To be also considered
(in our case)
- we have a **double view** anode
- we still need to be **fast**!

Two options
- **Full** induction description
- **Fast** → approximation



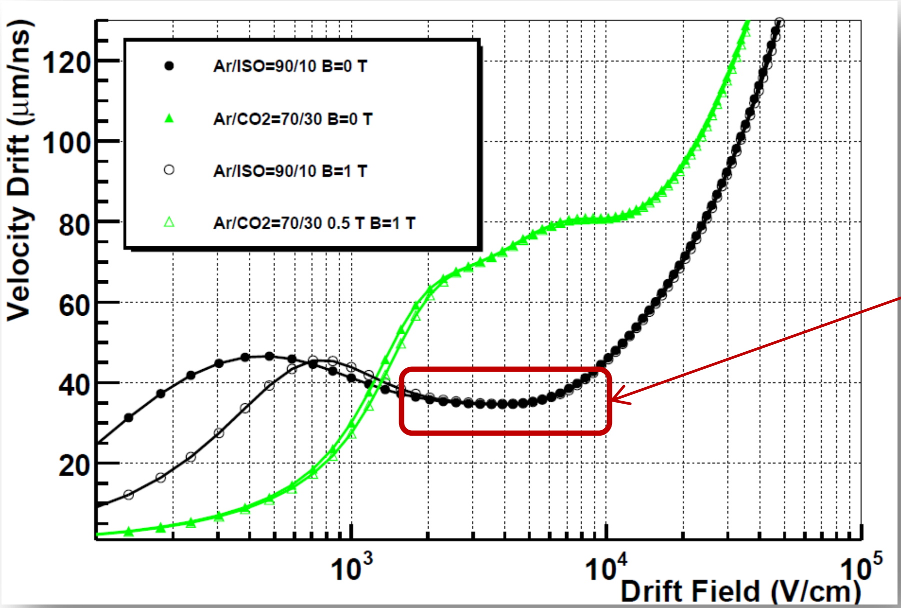
Full induction: Shokley-Ramo

[S. Ramo, in Proc. IRE 27, 584 (1939)]

The **instantaneous** current induced by a charge in motion on an electrode is

$$i(t) = q_{e-} \times V_{drift} \times W_{Loc}$$

- q_e – electron **charge**
- V_{drift} – **drift velocity**
- W_{Loc} – **weighting field,** *i.e.* the electric field generated by the electrode @ 1V, when *all the other* electrodes are set @ 0V



Approximation 1

- constant V_{drift} = 35 μm/ns
- *ok* for Ar:*i*-C_4H_{10} (90:10) @ field values = 1.5/3/3/5 kV/cm

BUT

close to the strip the field is much higher!

Full induction: Shokley-Ramo

[S. Ramo, in Proc. IRE 27, 584 (1939)]

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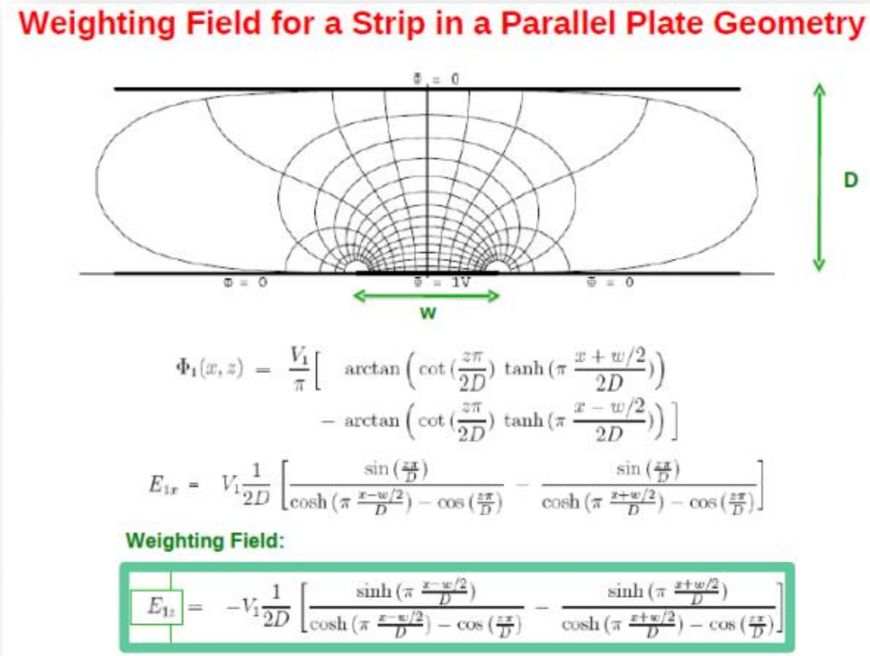
Approximation 2

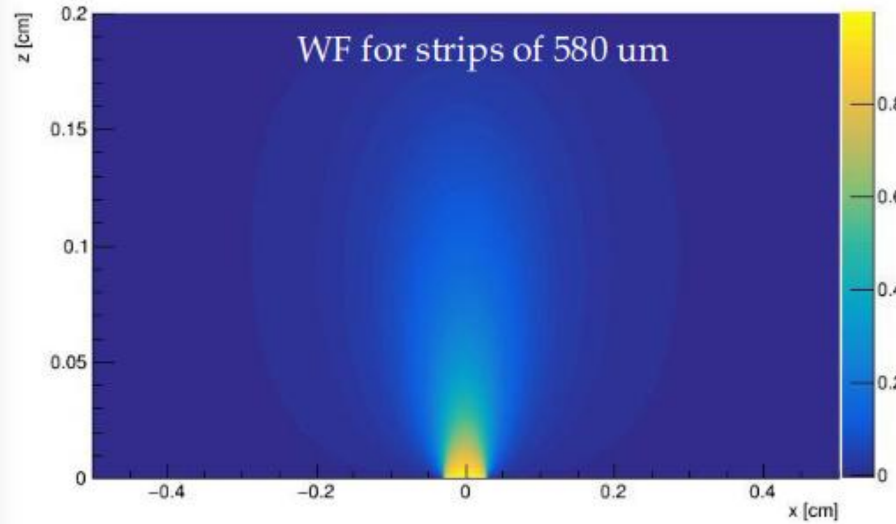
- get electron position on the anode by Lorentz angle & diffusion parametrizations
- compute induced *dq* instead of *i(t)*
- compute induced *dq* for steps of 1 ns (v_{drift} constant)

$$\frac{dq}{dt} = q_e \times \frac{dx}{dt} \times \frac{dV_w}{dx} \quad \Rightarrow \quad dq = q_e \times dV_w$$

Full induction: weighting field

[W. Riegler, CERN seminar]





Approximation 3

computed *analytically* with only one view → **charge sharing** introduced by a *tuning factor* to account for electric field focussing effect

Fast induction of the signal

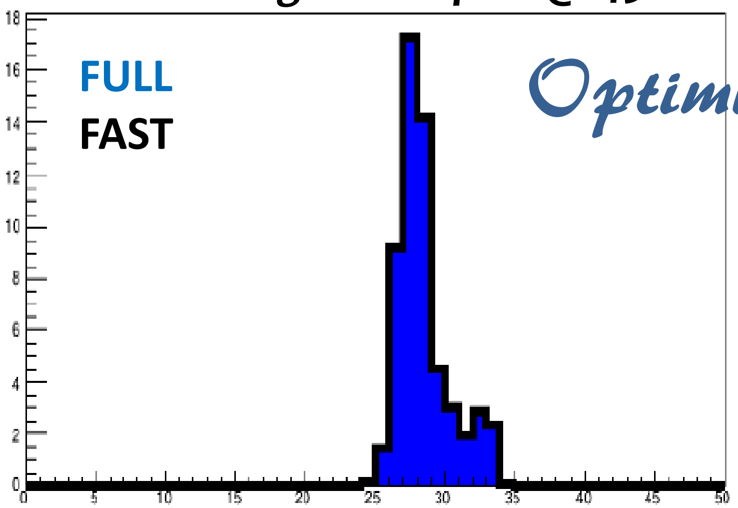
Once **all the electrons** have arrived on the anode:

- the signal is **finished**
- the charge on the *i-th* strip = the number of electrons collected by the strip

FAST INDUCTION simulates → Charge = # electrons collected by *i-th* strip

→ Time = time of arrival of the e^- on the *i-th* strip

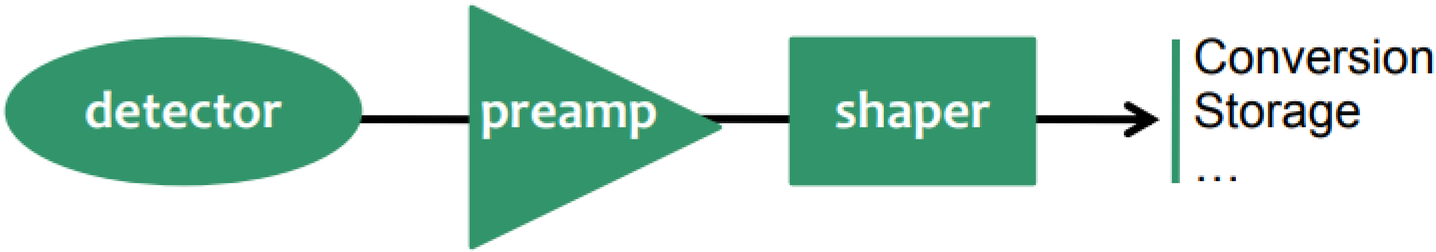
Charge vs strip ID @ 45°



Optimum matching

fast induction is x 30 faster than the full!

APV-25 ASIC simulation



1. **Detector induction →** simulate the induced *dq* in 1 ns time steps
2. **Pre-amplifier →** ∀ time step, add *dq* to the integrated charge
3. **Shaper →** create 27 functions (one for each APV-25 time bin, 25 ns each)

CR-RC with τ = 50 ns

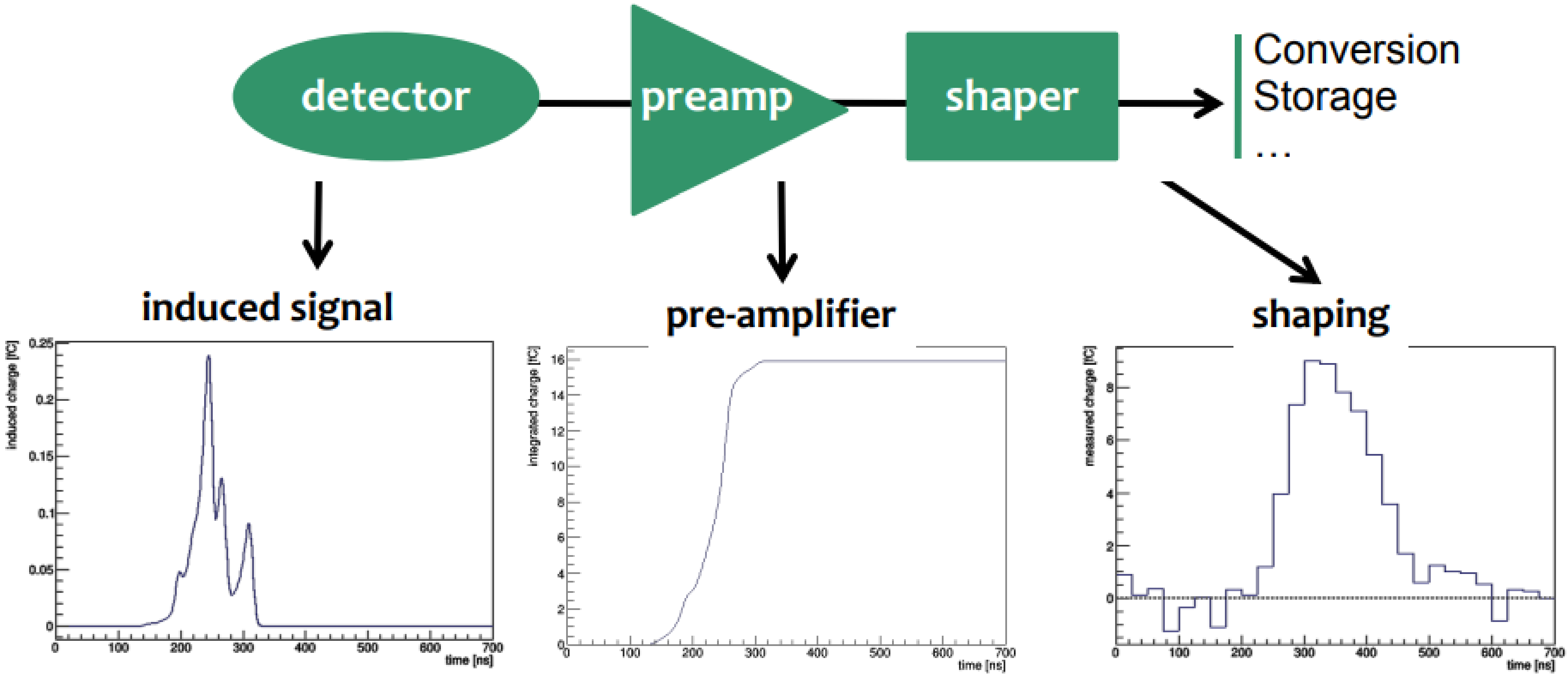
$$h(t) = S_p \times \frac{t-t_0}{\tau} exp(-\frac{t-t_0}{\tau}),$$

→ get the induced charge in each 25 ns and apply the transfer function

∀ time bin, evaluate all the previous function @ t_i and sum them up!

Compute noise → ∀ time bin, sample from Gaussian (μ, σ) → add to the charge

APV-25 ASIC simulation



The **charge** is the peak value of the signal

The **time** comes from a Fermi-Dirac fit of the rising edge

as in real signal reconstruction

Tuning to real data

Tune what to what? …and why?

comparison to the **test beam data** collected on **April 2018**

RD51 testbeam

- H4 beam line, SPS-NA (CERN)
- GOLIATH dipole magnetic field
- 150 GeV/c muons

triple-GEM specifics

- planar triple-GEM, 10 x 10 cm^2
- double view readout, APV-25
- gas: Ar:*i*-C_4H_{10} (90:10)
- HV: 275/275/275 V
- fields: 1.5/2.75/2.75/5 kV/cm
- magnetic field *off* or *on* (B = 1T)
- incident angle: 0°, 5°, 10°, 15°, 20°, 30°, 45°

Settings we kept in the GTS simulation

- conversion factor : 30 ADC = 1 fC (*)
- threshold : 45 ADC = 1.5 fC
- noise sigma: 15 ADC = 0.5 fC

(*) K. A. Ntekas, CERN-THESIS-2016-019

Tuning to real data

need to check the consistency between simulation and real data, due to:

- various approximations applied
- measured charge >> simulated one → **tuning factor** on gain!

Scan

particle incident angle [0°, 40°], B = 0

Tuning factor on

Gain, diffusion

Sentinel variables

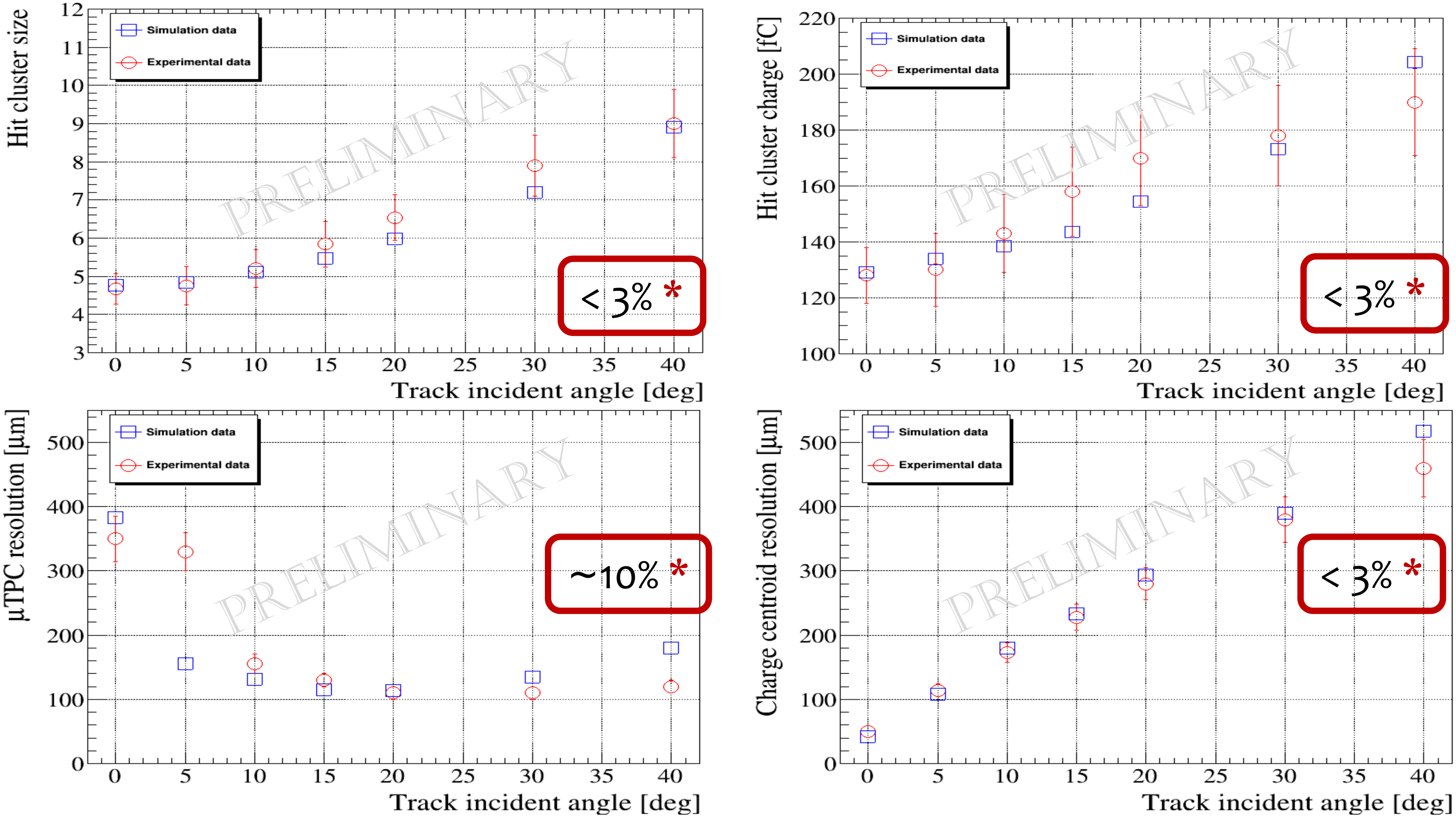
- measured charge
- cluster size
- position resolution (charge centroid)
- position resolution (μ–TPC)

Procedure

- for each gain and diffusion values, simulate 7 angles: 0, 5, 10, 15, 20, 30, 40
- for each angle, run 20k muons → statistical error around 1%
- compute $\chi^2 = \chi^2_{\mathrm{charge}} + \chi^2_{\mathrm{cl.size}} + \chi^2_{\mathrm{CCresol.}} + \chi^2_{\mu-\mathrm{TPCresol.}}$
- evaluate χ^2/NDF

Tuning to real data

Best result χ^2/NDF ~ 3 ← *gain tuning = 6.8* ← *diffusion tuning = 1.5*



* (experimental –simulated)/experimental

Conclusions

We would like to hear your opinions to understand if we are on the right path!

Our two main *source of doubts*:

• **gain evaluation**

- We obtained a **gain tuning factor = 6.8**

- GARFIELD GEM gain has a factor ~2 missing → roughly 8 on a triple-GEM

→ *we still have to account for the charge sharing: another x2 factor?*

→ *other explanations to this tuning factor? Any ideas?*

• **weighting field & induction**

- Used analytic WF for one view + matching between full and fast inductions

→ For our double view, the idea is to just count the electrons falling on the strips (x/v) with a probability (evaluated from data) to account for:

  - charge sharing between the views
  - electric field focusing effect on the strip
  - other? shall we consider the change of drift velocity close to the strips?

• other suggestions about points we did not consider?

Thank you for your attention!

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