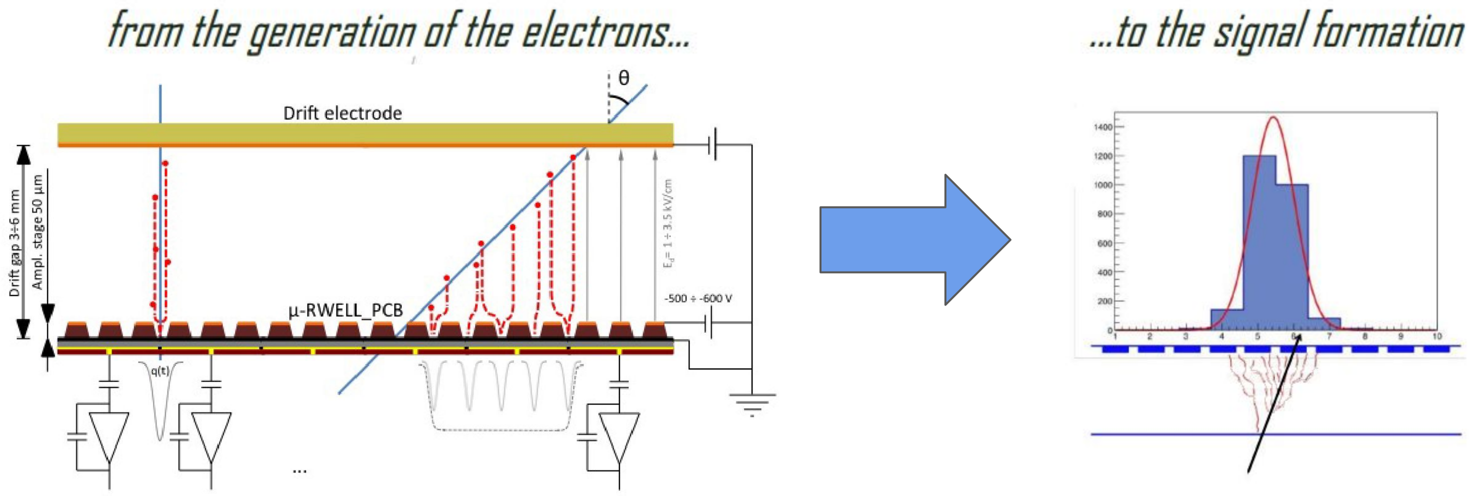
A parametric simulation of the µ-RWELL detector

E. De Lucia, R. Farinelli, M. Giovannetti, L. Lavezzi, G. Morello

Outline

The parametrization

The main effects taking place in the gaseous detector are parametrized as described in a previous RD51 meeting on the triple-GEM -> [LINK]



The parametrization

- Ionization
- Electron drift
- Amplification
- Resistive
- Induction
- Readout
- Reconstruction

Available tool: GARFIELD++

STRAIGHTFORWARD CHOICE!

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

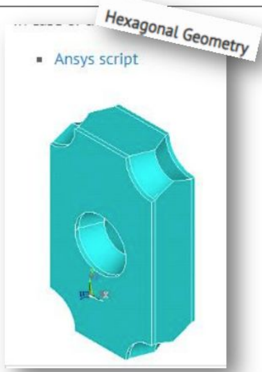
is a toolkit for the **detailed simulation of detectors which use gases** or semi-conductors as sensitive medium.

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



RD51 - GTS 4

GARFIELD++ capabilities + More speed → Parametrization!

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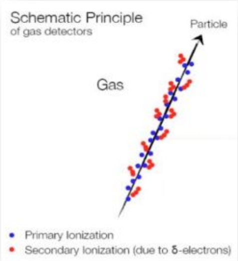
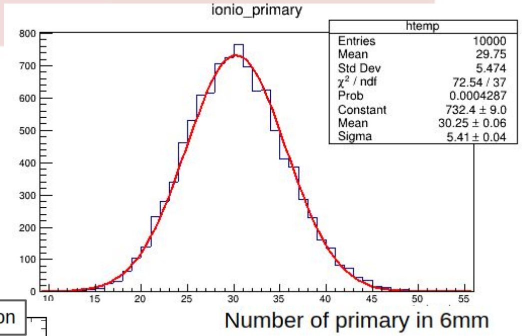


- **primary ionization** – Poissonian process
→ *relative position* from exponential distribution
→ the number of the ionizations follows
- **secondary ionization** – from tables [F.Sauli (1977) *Principles of Operation of Multiwire Proportional and Drift Chambers*; A. Sharma *Properties of some gas mixture used in tracking detectors*]
→ consistent with GARFIELD++ simulations

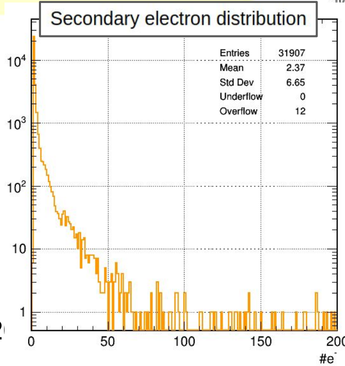
Simulations

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



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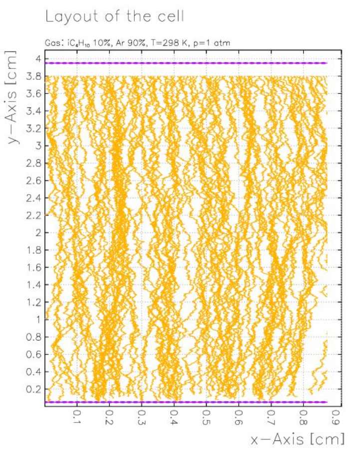
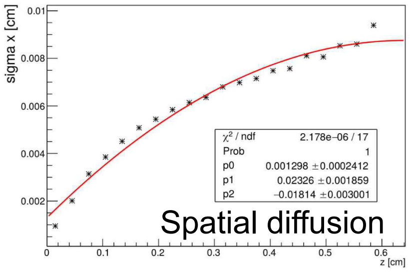
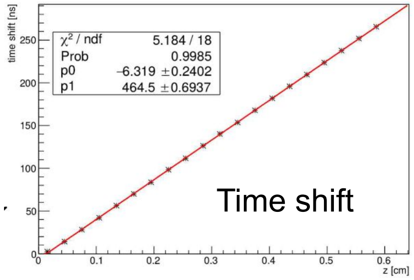
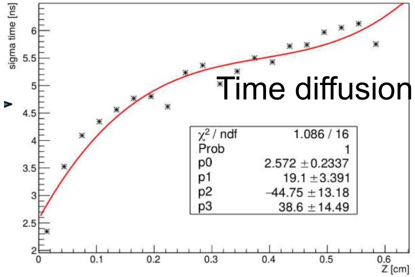


Drift gap

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







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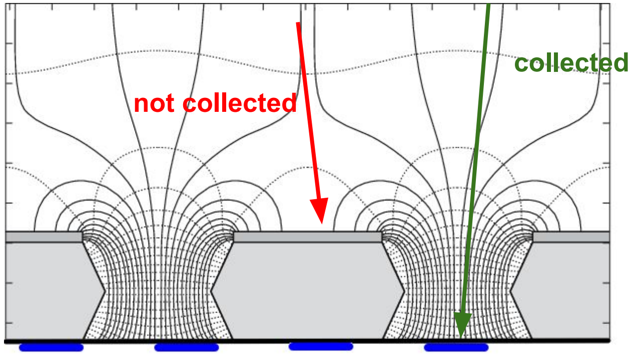
Gain fluctuations → Polya distribution

[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



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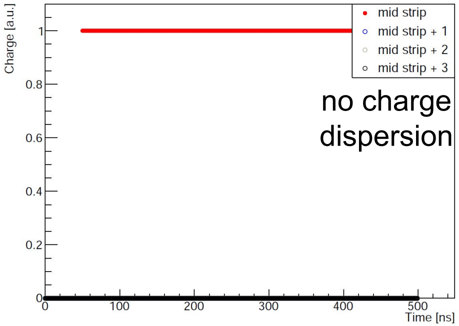
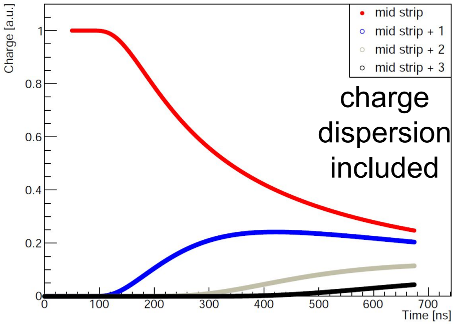
Simulating the charge dispersion phenomena in Micro Pattern Gas Detectors with a resistive anode

M.S. Dixit[a,b,*], A. Rankin[a]

customized for strip 1D

$$
\begin{aligned}
Q(t) &= \int_{x_1}^{x_2} \rho(x,t)\mathrm{d}x \\
&= \frac{q}{\sqrt{2\pi}\left[\sigma_0\left(1+\frac{t-t_0}{\tau}\right)\right]}\int_{x_1}^{x_2} \exp\left[-\frac{(x-x_0)^2}{2\sigma_0^2\left(1+\frac{t-t_0}{\tau}\right)^2}\right]\Theta(t-t_0)\,\mathrm{d}x \\
&= \frac{q}{2}\left[\mathrm{erf}\left(\frac{x_2-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right)-\mathrm{erf}\left(\frac{x_1-x_0}{\sqrt{2}\sigma_0\left(1+\frac{t-t_0}{\tau}\right)}\right)\right]\Theta(t-t_0)
\end{aligned}
$$





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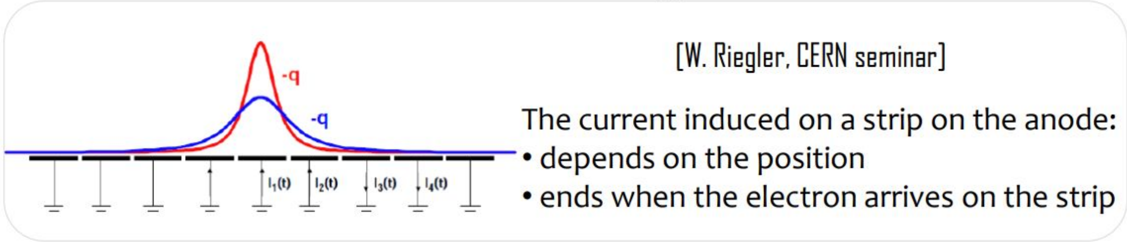

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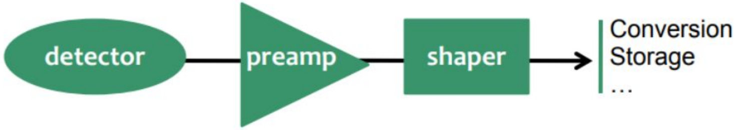
APV-25 ASIC simulation



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

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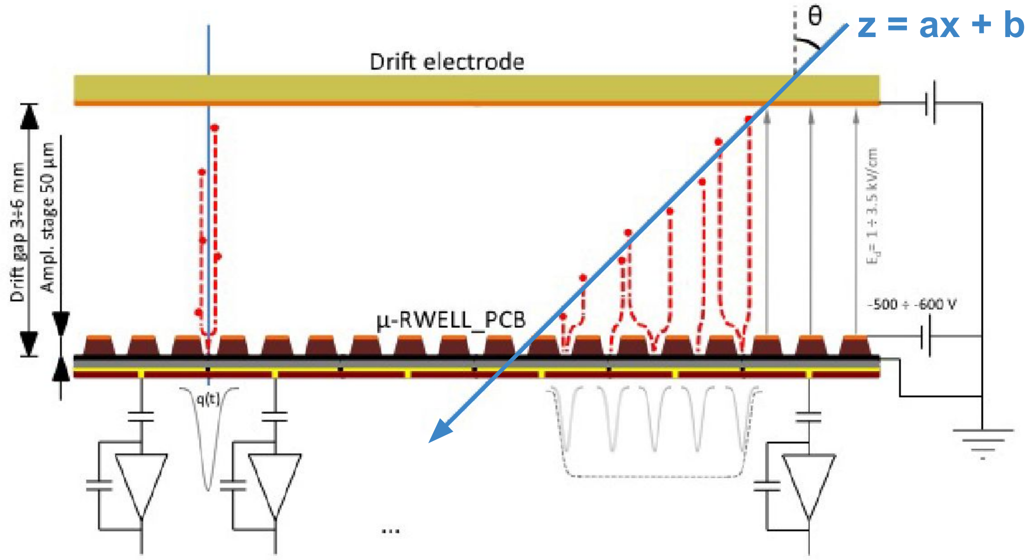


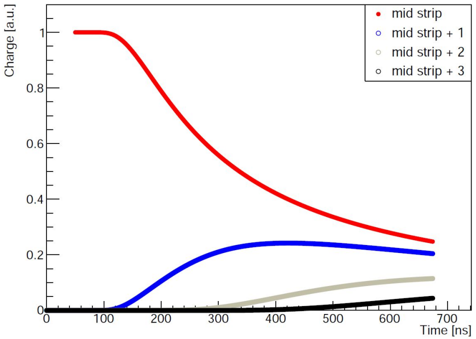
$$x = \frac{\sum x_i * q_i}{Q_{TOT}}$$

$$x = \frac{\frac{gap}{2} - b}{a}$$

The charge dispersion on a single electron

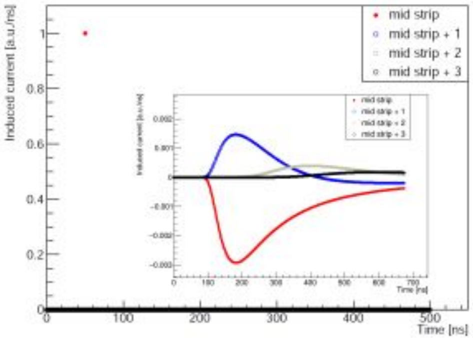
A charge q=1 is injected at t=50ns, using a tau=10ns (see prev. formula).

CHARGE



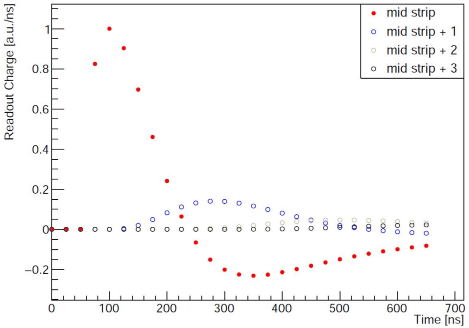
At t=50ns the charge is collected on the middle strip and then the charge is moved from the mid strip to the neighbors

CURRENT



At t=50ns the current has a delta to 1 and then a small current value flows from the mid strip to the neighbors. There the total current is conservated

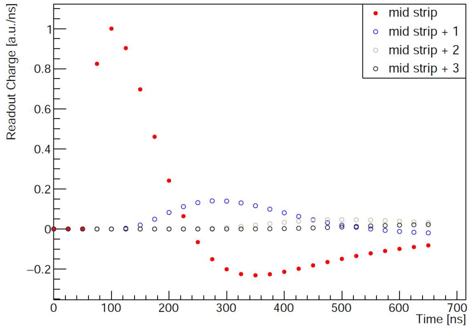
ELECTRONICS

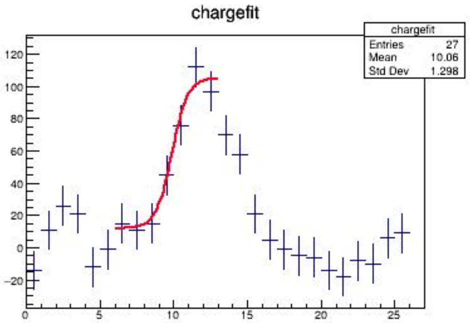


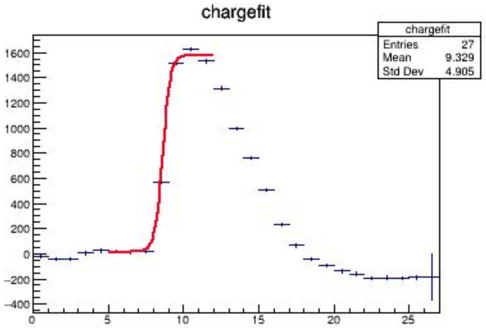
The induced current is readout by the electronics and it is simulated by means of a shaper (50ns) and an integrator

The charge dispersion - electronics

Check: the negative current observed in the simulation is it present in the real data?
If the current flows away from the strips, it seems reasonable to measure a negative current.



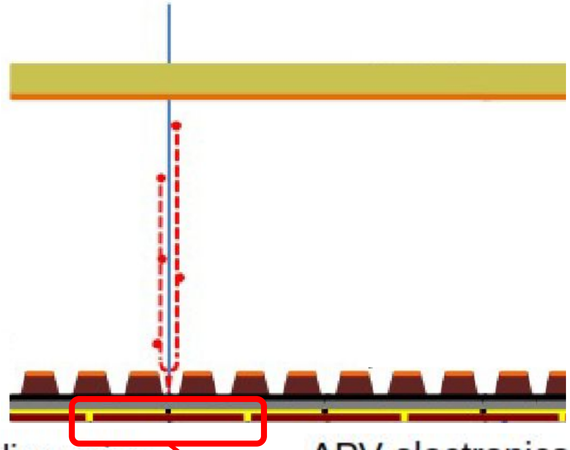


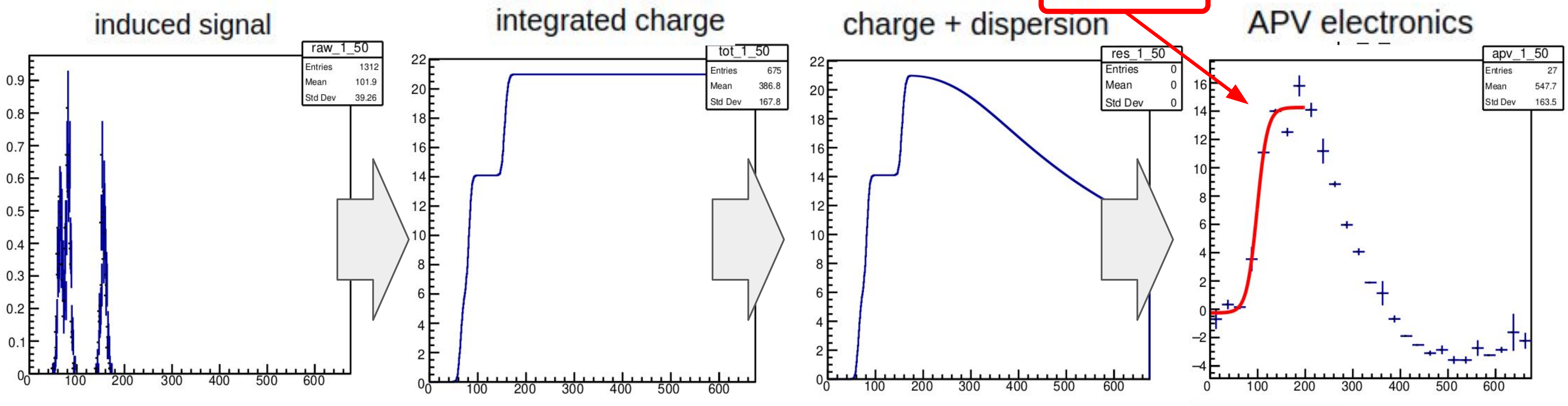


The behavior seems shared between data and simulation.

Simulation of a single event

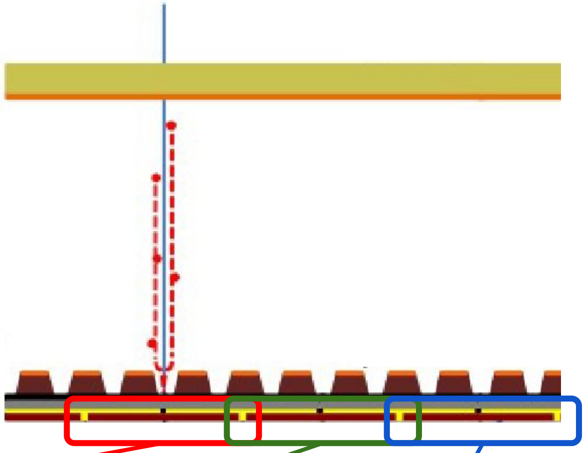
Let’s simulate a single event and check the middle strips



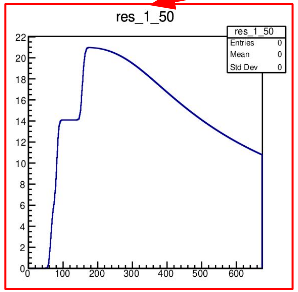


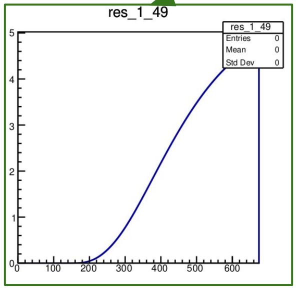
Simulation of a single event

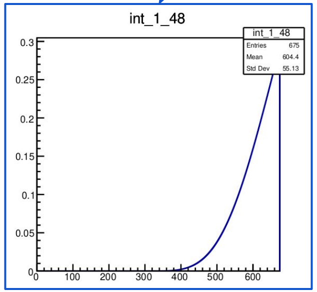
Let's simulate a single event and check the middle strips
and the neighbors



charge + dispersion



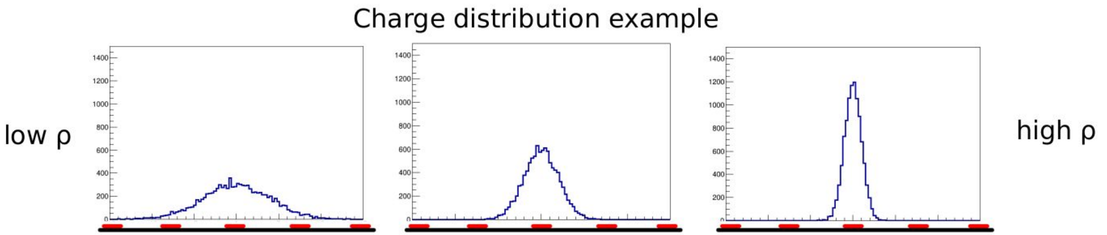




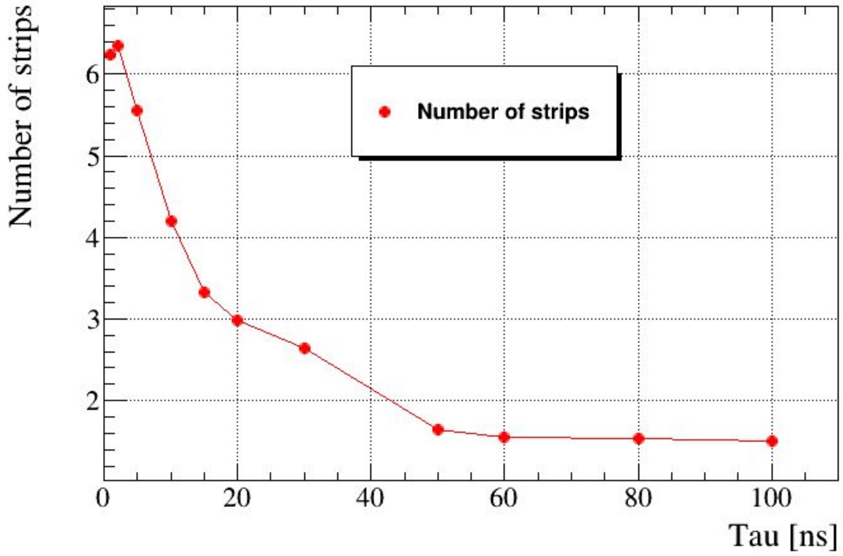
Now simulate 10k events

and test the charge dispersion

Tau scan vs cluster size

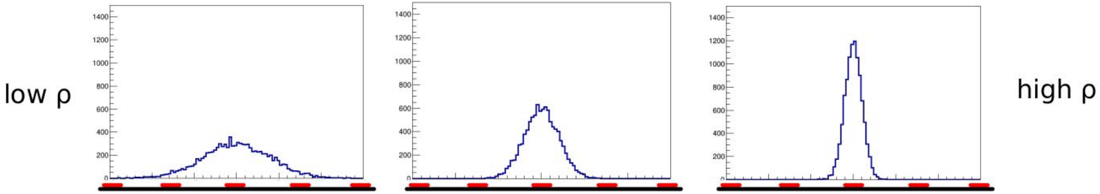


If tau > 60 ns, then the resistivity is too large to observe any spread

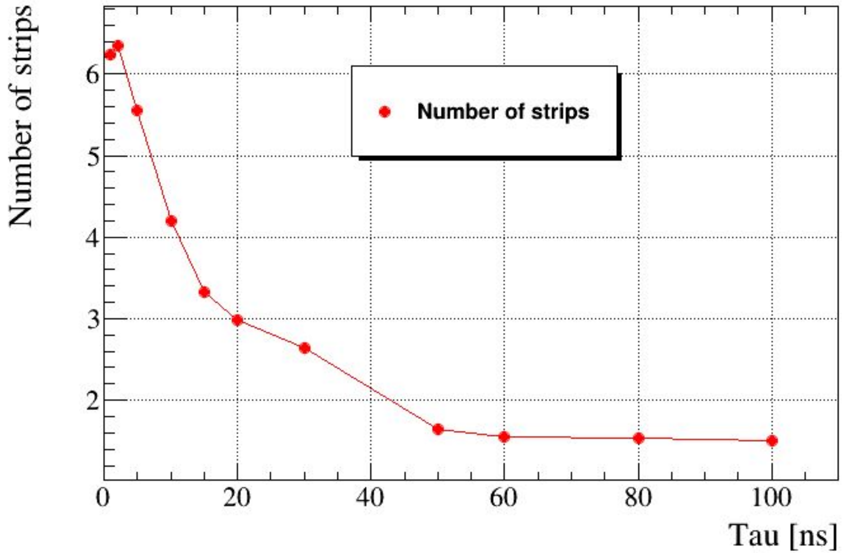


Tau vs cluster size

Charge distribution example



This behavior copies the one in [Performance of µ-RWELL detector vs resistivity of the resistive stage]



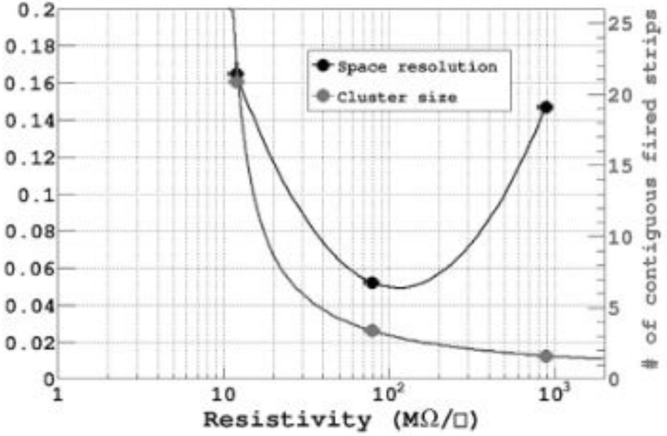
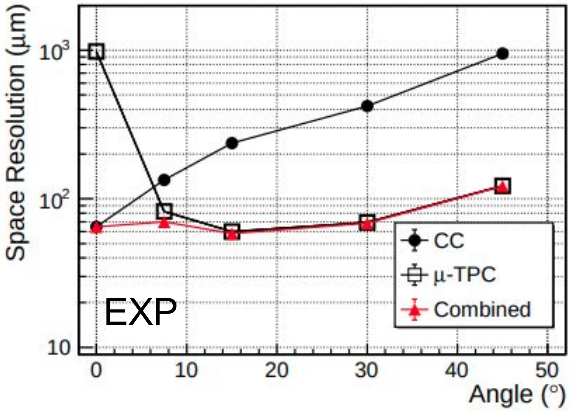


Fig. 11. Space resolution and strip cluster size as a function of the DLC resistivity. The detector has been operated at gains ensuring full efficiency.

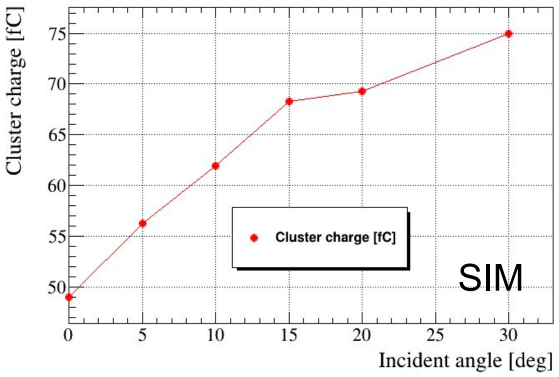
Let’s produce some benchmark

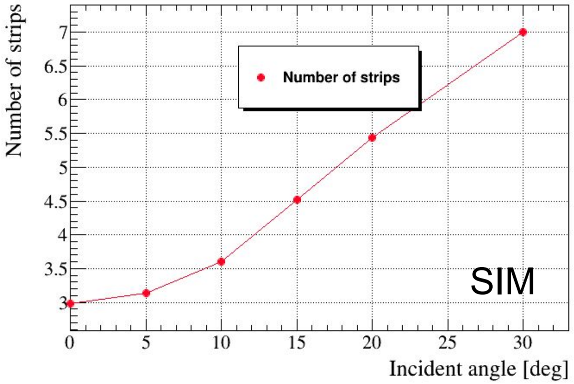
Performance vs incident angle

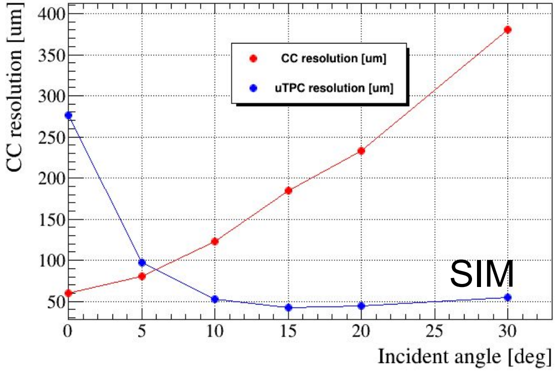


Charge and multiplicity follow the geometry of the interaction.

CC and μTPC return a reasonable behavior in agreement with the literature [On the space resolution of the μ-RWELL]

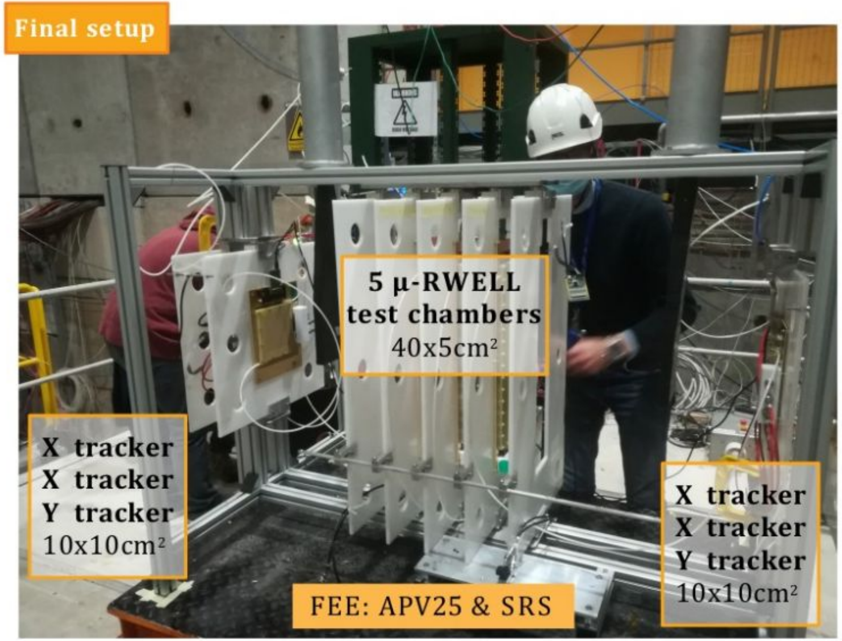






Plans for the future

Tuning the simulated data with experimental results



Beam setting:

SPS H8 line
secondary beam of muon or pion
in the range of 10-360 GeV/c

Detector setup:

5 slot available for testing chambers with beam
7 total test chamber to be tested

6 trackers (10x10 cm^2)

1D readout and 400μm pitch

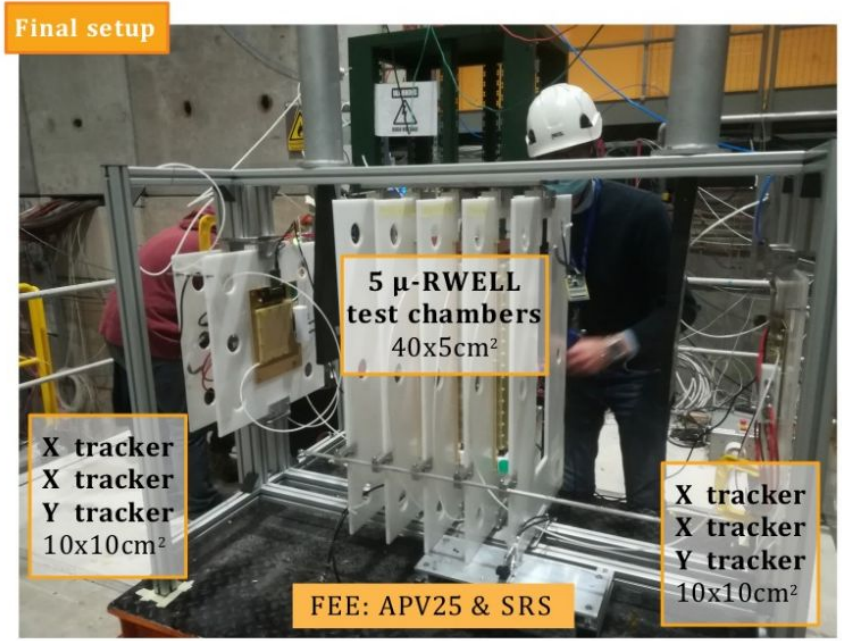
Gas mixtures:

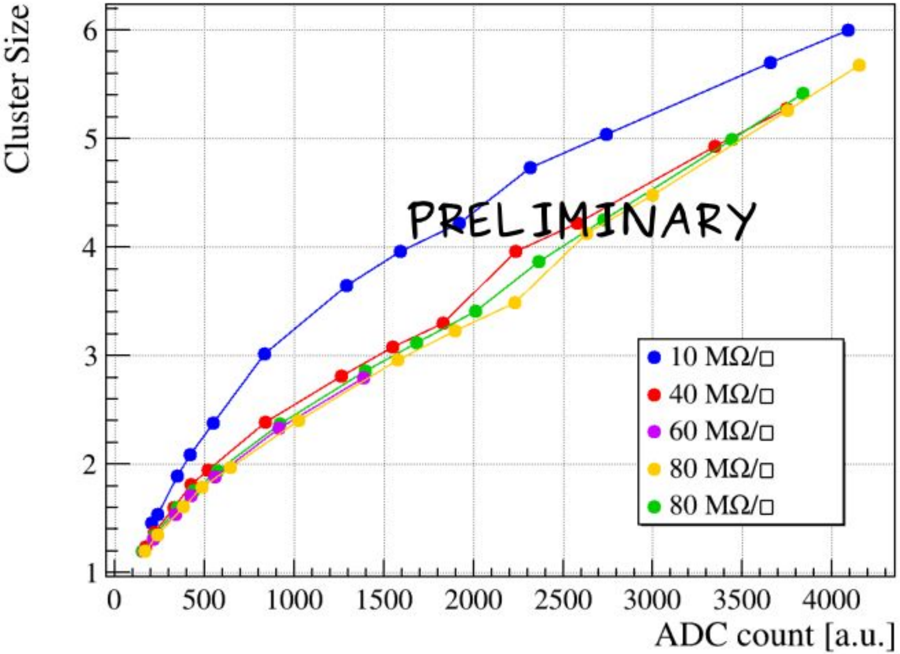
$Ar\text{-}CO_2\text{-}CF_4$ (45/15/40)

FEE:

APV-25

Tuning the simulated data with experimental results



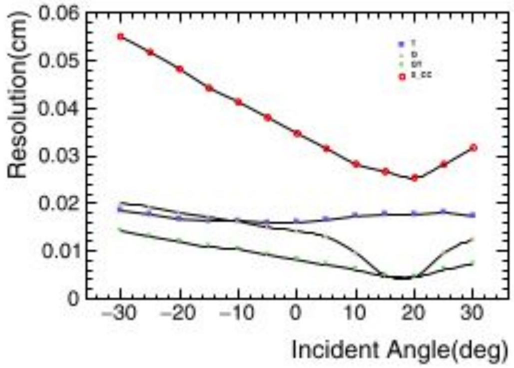


Development of Machine Learning Algorithms for MPGDs within AidaInnova WP

- MPDGs are gaseous detectors with high spatial resolution, good radiation tolerance, ideal for tracking in large-background environment

- MPGDs are widely used in experiments and planned for many upgrades
- Resistive MPGDs offer spark protection important for operational stability
- Charge centroid and microTPC algorithms guarantee tracking performance over a wide range of particle incident angles and external magnetic field

- Nevertheless, the performance of traditional algorithms are limited by the presence of high background
- Machine Learning approach can be used to overcome these limitations



Development of Machine Learning Algorithms for MPGDs within Aidainnova WP

Timeline and task: 4 years

- First year: uRWELL simulation implementation of resistive layer and tuning to test beam data
- Second year: development of cluster selection and track finding based on simulation
- Third year: track cleaning and refinement
- Fourth year: application to IDEA detector pre-shower and muon optimization

Deliverables

- A scientific paper describing the performed activity and the results.
- An open-source software suite for training and testing ML algorithms with MPGD data and simulations.

The group is composed by INFN Bologna, Ferrara, LNF and Turin

Summary

A parametric **simulation** of a µRWELL has been developed

Preliminary results of charge, multiplicity, resolution and tau seems **reasonable**

Now, we plan to **tune** and counter-check the simulation with a dedicated TB

and in the future the simulation will be used to train an **ML** algorithm to improve the detector performance

Thank you