Simulations of MPD Straw End-Cap Tracker

Jan Fedorishin, XXII International
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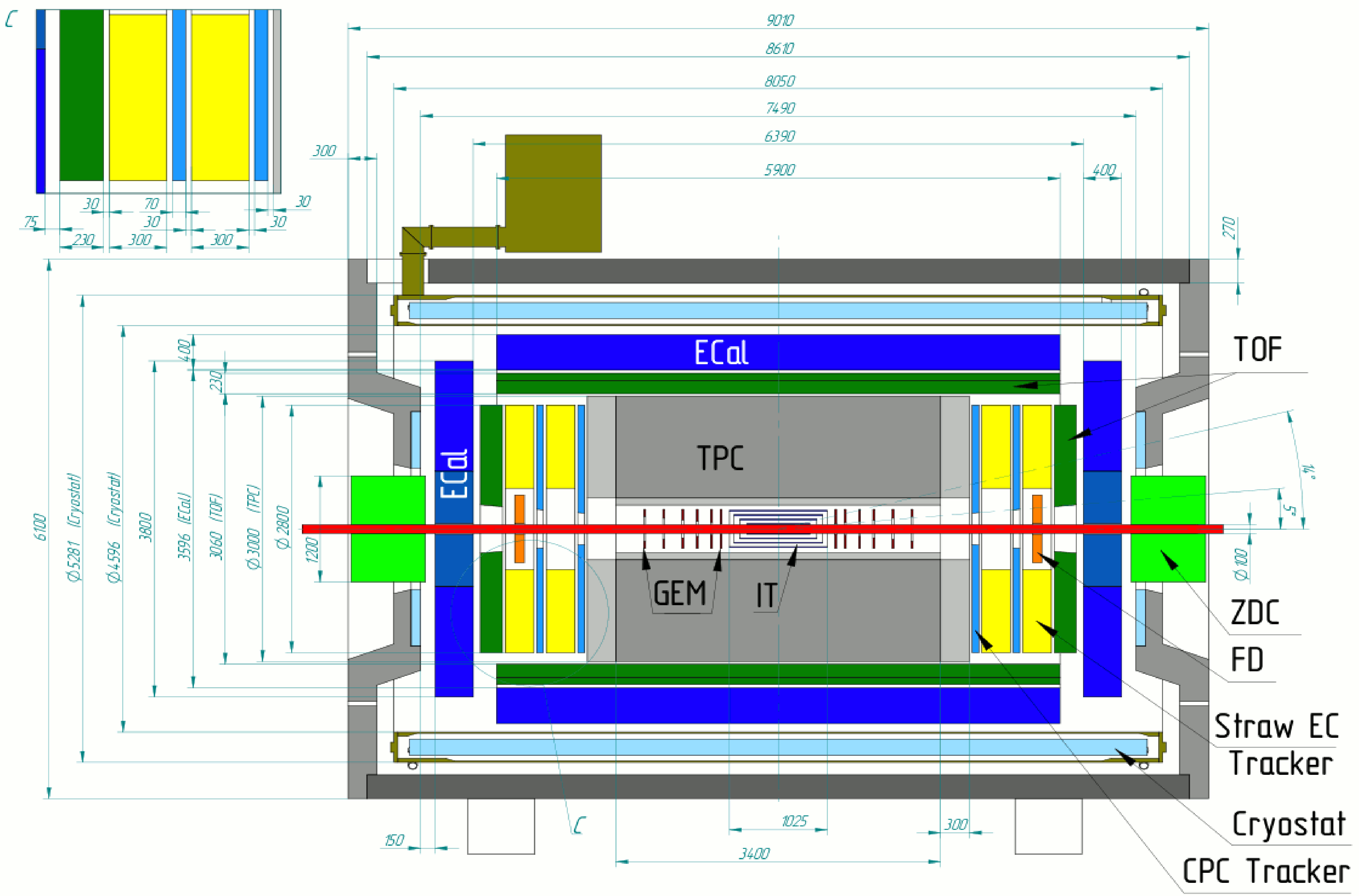
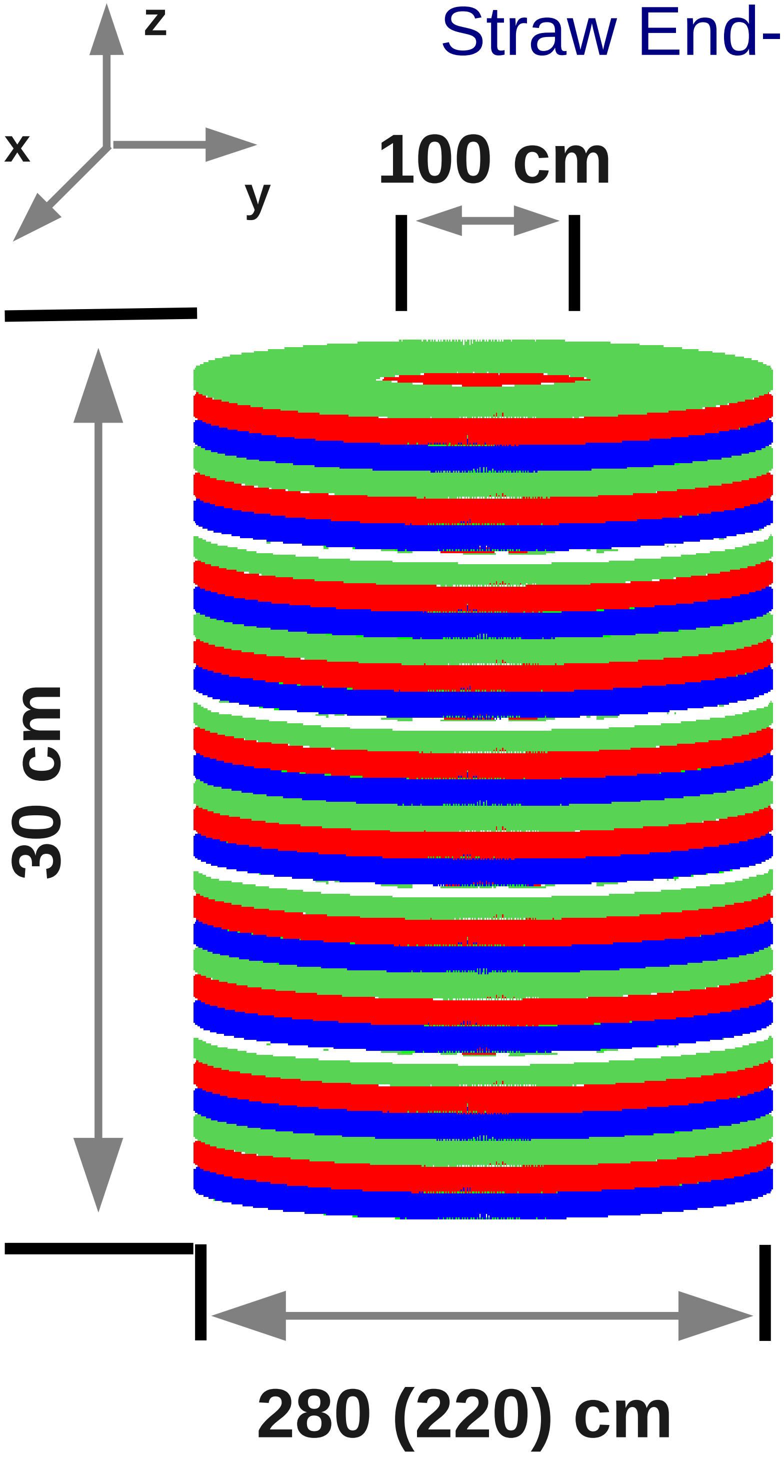


MPD – the current layout

Straw End-Cap Tracker (ECT) module structure



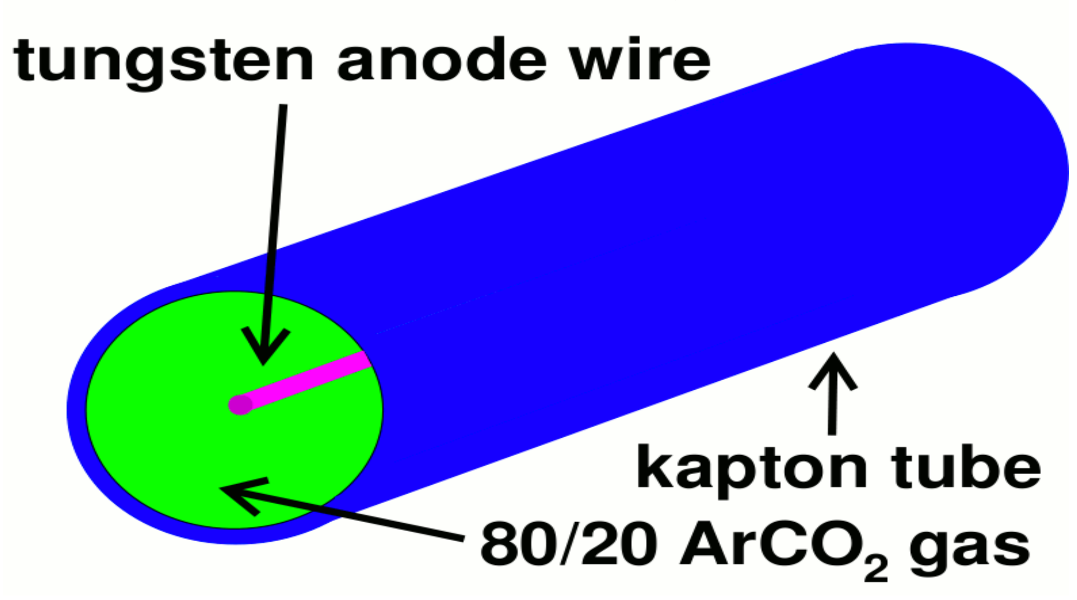
module = 5 submodules

submodule = 6 layers

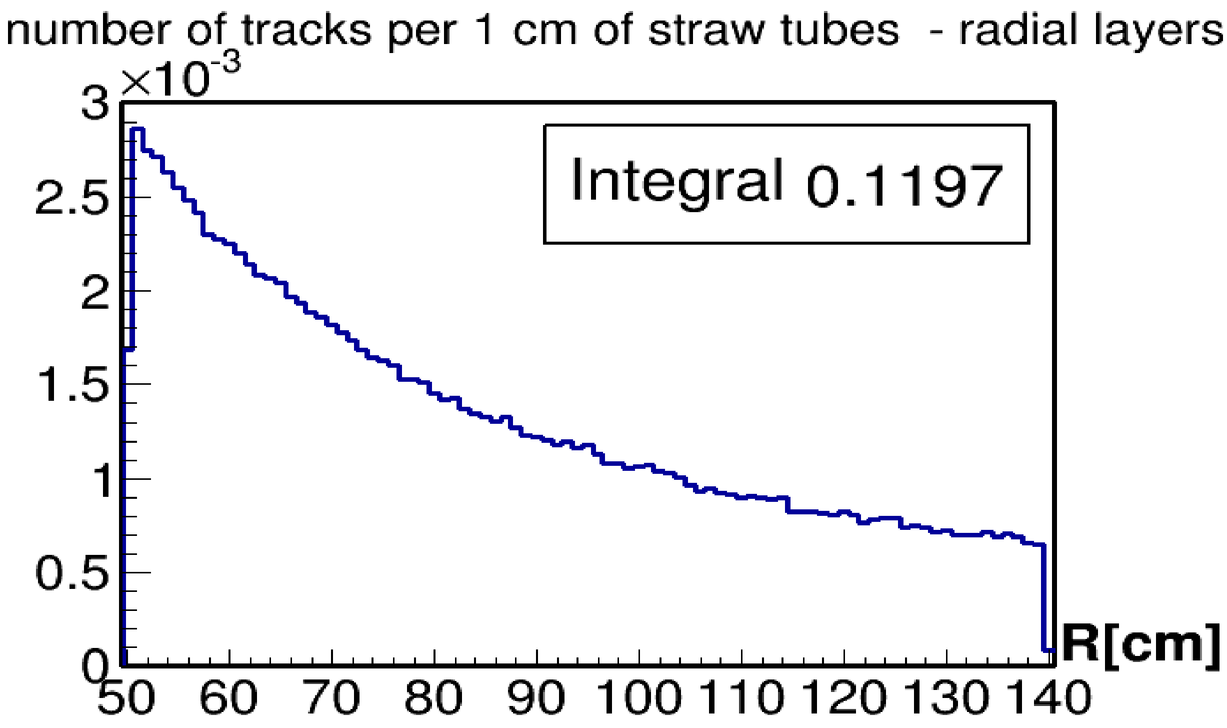
layer = **600** kapton tubes

72×10^3 channels

$r_{tube} = 2$ mm

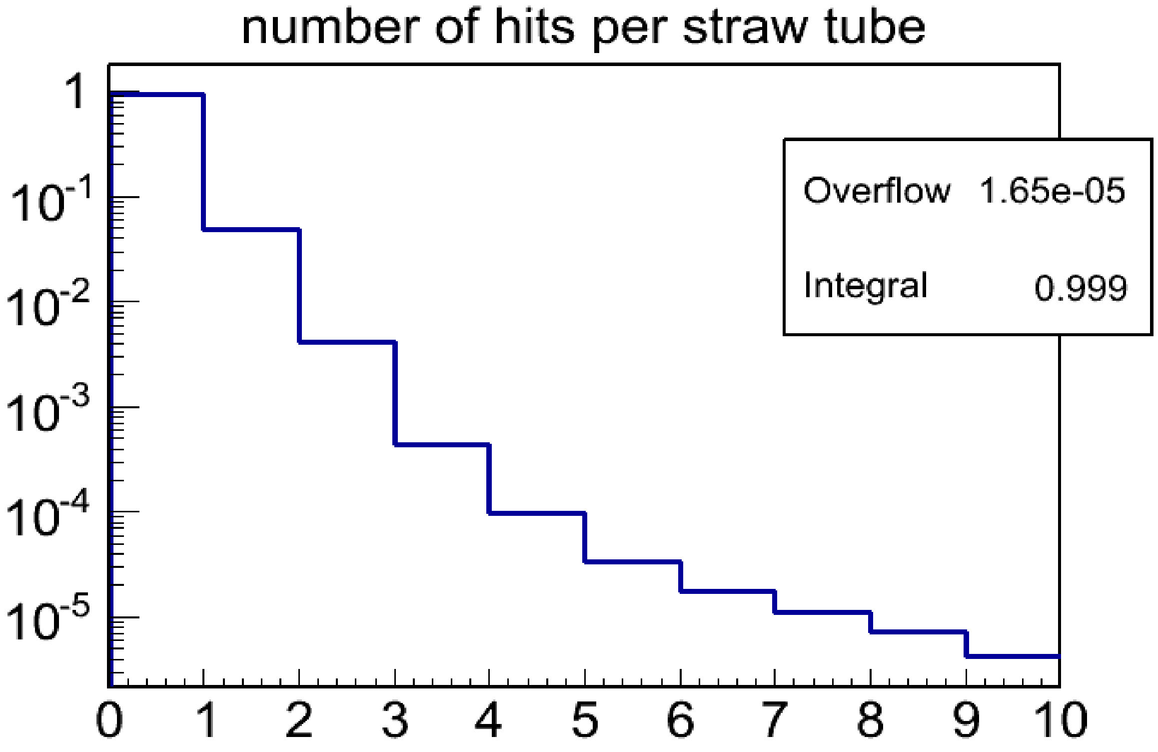


anode voltage V_A=1650 V


number of tracks per 1 cm of straw tubes - radial layers

GEANT simulations with UrQMD Au+Au collisons at $\sqrt{s}_{NN}$ = 9 GeV

the detector occupancy estimation ≈ 12%


number of hits per straw tube

multiple hits occur in ≈ 0.5% of all tubes, i.e. in about 3 tubes (out of 600) per layer

Simulations with GARFIELD++

- object-oriented program toolkit for the detailed simulations of particle detectors which use a gas mixture or a semiconductor material as sensitive medium

- described at http://cern.ch/garfieldpp

- provides interface also to other simulation programs such as HEED, Magboltz, Ansys, Synopsys Sentaurus, ...

- simulates sensitive media, electric and magnetic fields, ionization by charged particles, charge transport (drift of electrons and ions under the influence of electric and magnetic fields), signals induced on electrodes

Signal simulation – consists of a few partial tasks

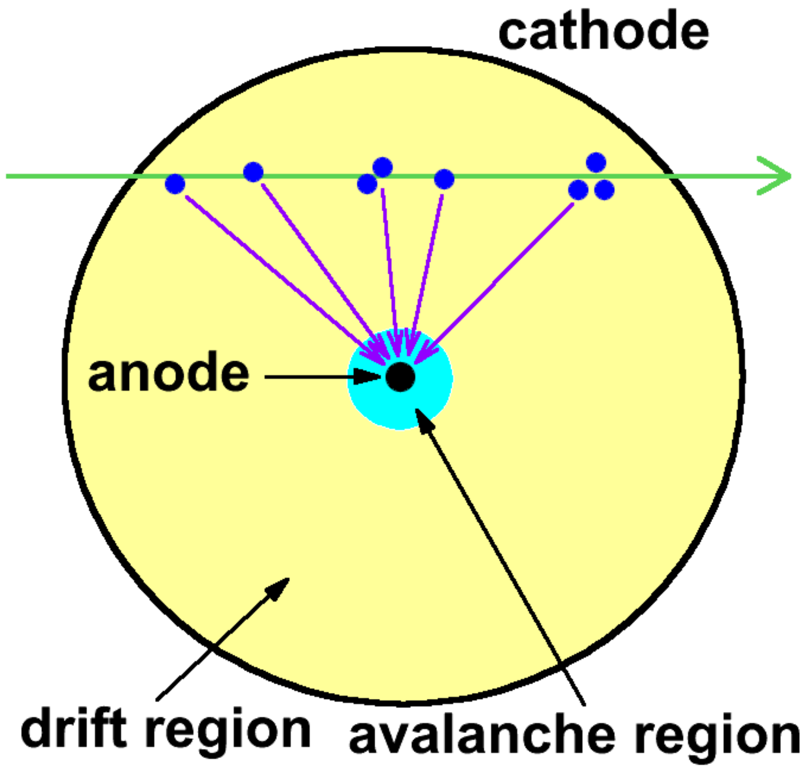
1.) Primary charge generation (distribution of electron-ion clusters along particle path in active detector volume)

2.) Drift of primary charge towards the electrodes, avalanche near the anode, gas amplification (the magnetic field neglected)

Hit simulation, based on GARFIELD output

3.) Anode signal simulation

Signal analysis:
particle coordinates determination (tracking), energy loss estimation?)



Cluster generation

basic cluster properties:

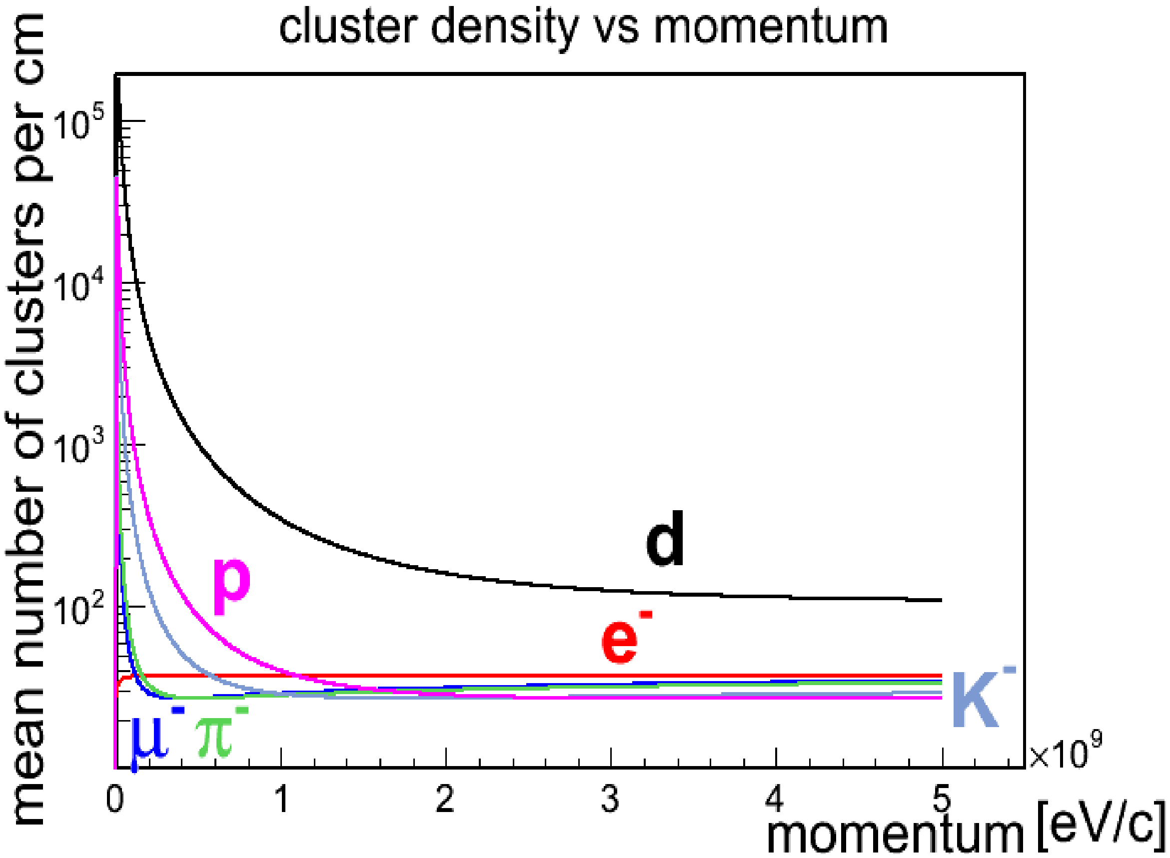
- mean number of electron clusters/cm
- number of electrons per cluster

Both the characteristics depend on the working gas properties (chemical composition, pressure, temperature). They also depend on particle type and momentum.

Probability to create k clusters on path d inside a tube is described by Poisson distribution:

$$p_\lambda(k)=\lambda^k\exp(-\lambda)/k! \qquad \lambda=\rho d$$

where ρ is a mean number of clusters per cm. Inverse $1/\rho$ is then a mean free path of particle in tube volume.

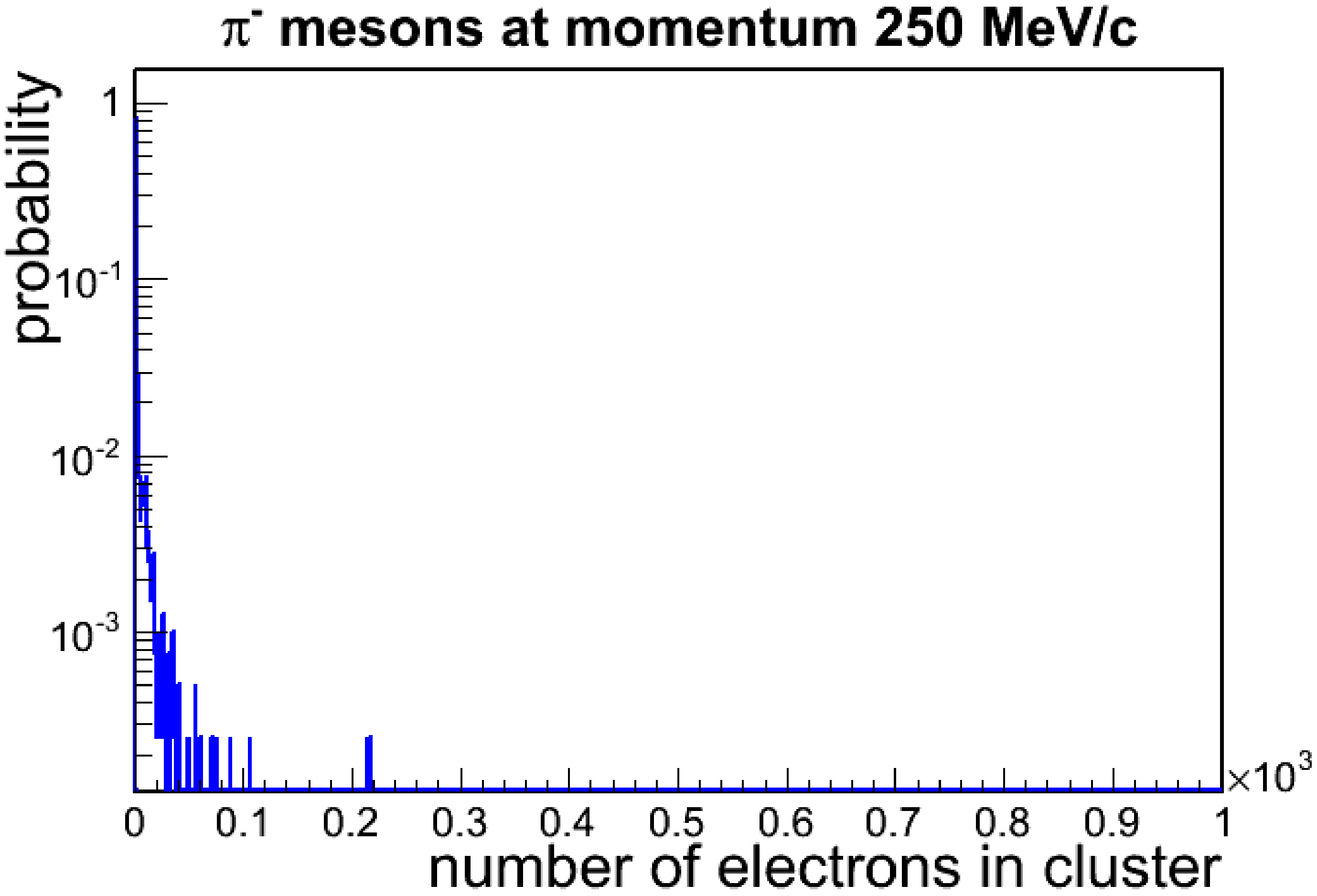


Spatial distribution of clusters on path d is in general obtained as a chain of consecutive exponential probabilities:

$$\frac{1}{\rho}\exp(-l\rho)$$

If $1/\rho \ll d$, the distribution of clusters can be regarded as uniform.

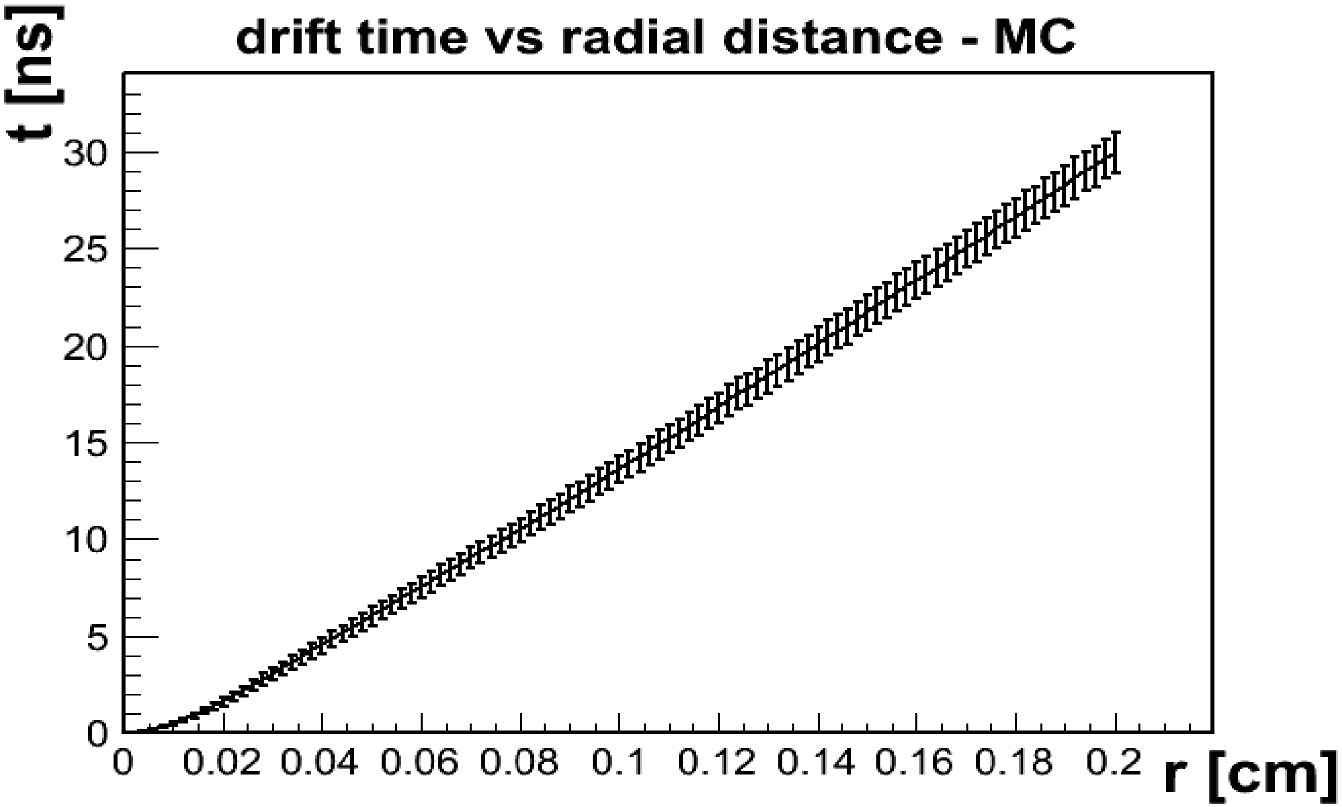
Number of electrons per cluster – shown example of probability distributions for π^- at momentum 250 MeV/c



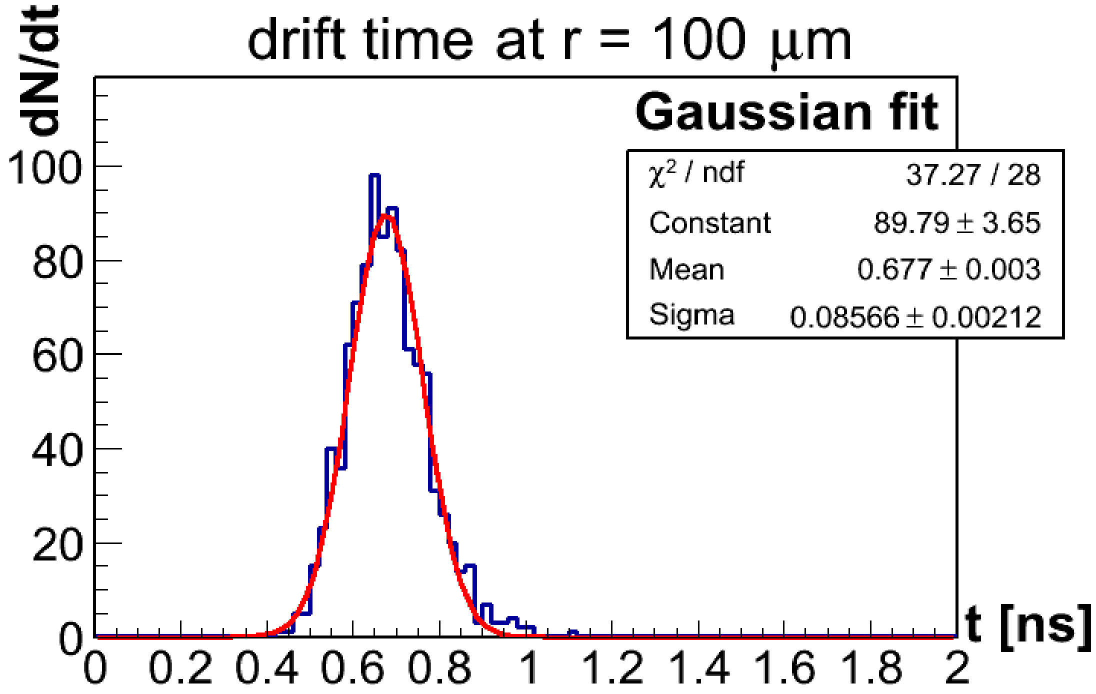
maximum at 1 electron/cluster, mean at ≈ 3 electrons/cluster for all the studied particles

Yet, occasionally even large electron cluster may appear.

Electron drift simulation



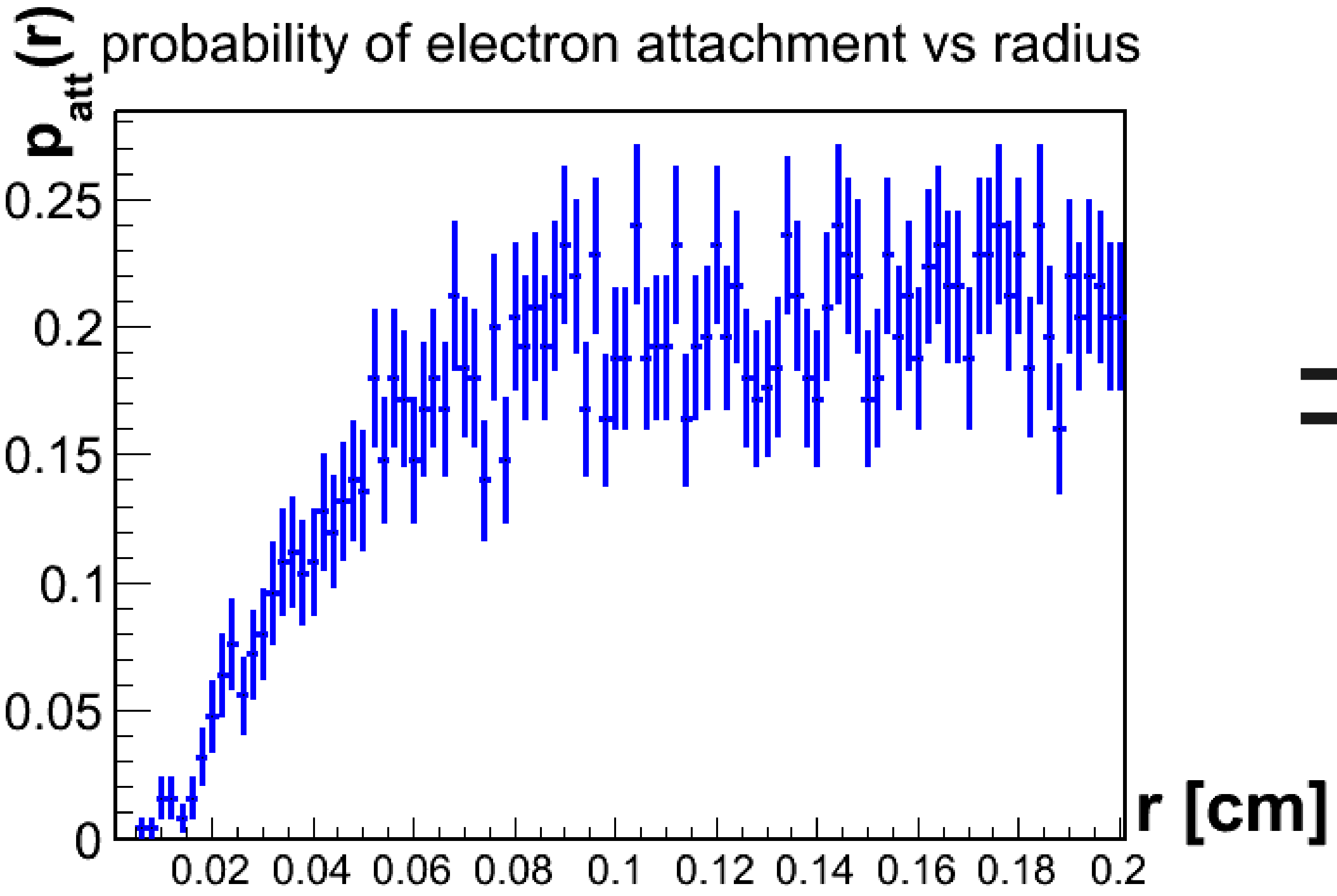
drift time as a function of radial distance from anode ($t_{max} \approx 30$ ns)



drift time fluctuations

Electron attachment

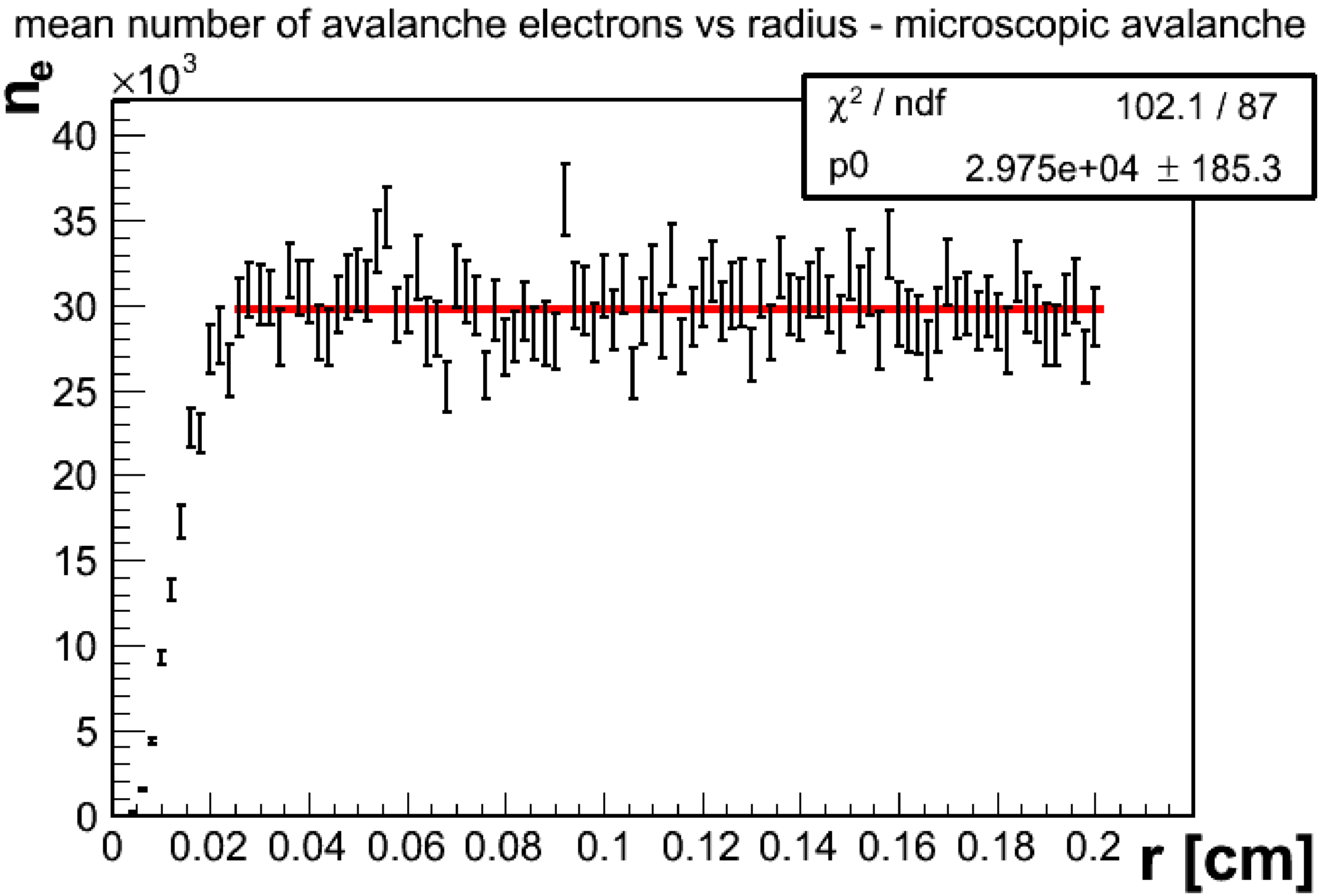
Some electrons are captured by gas molecules while drifting to the anode.



⇒ almost 20% of the primary charge is lost

Gas gain

- multiplication factor of the avalanche



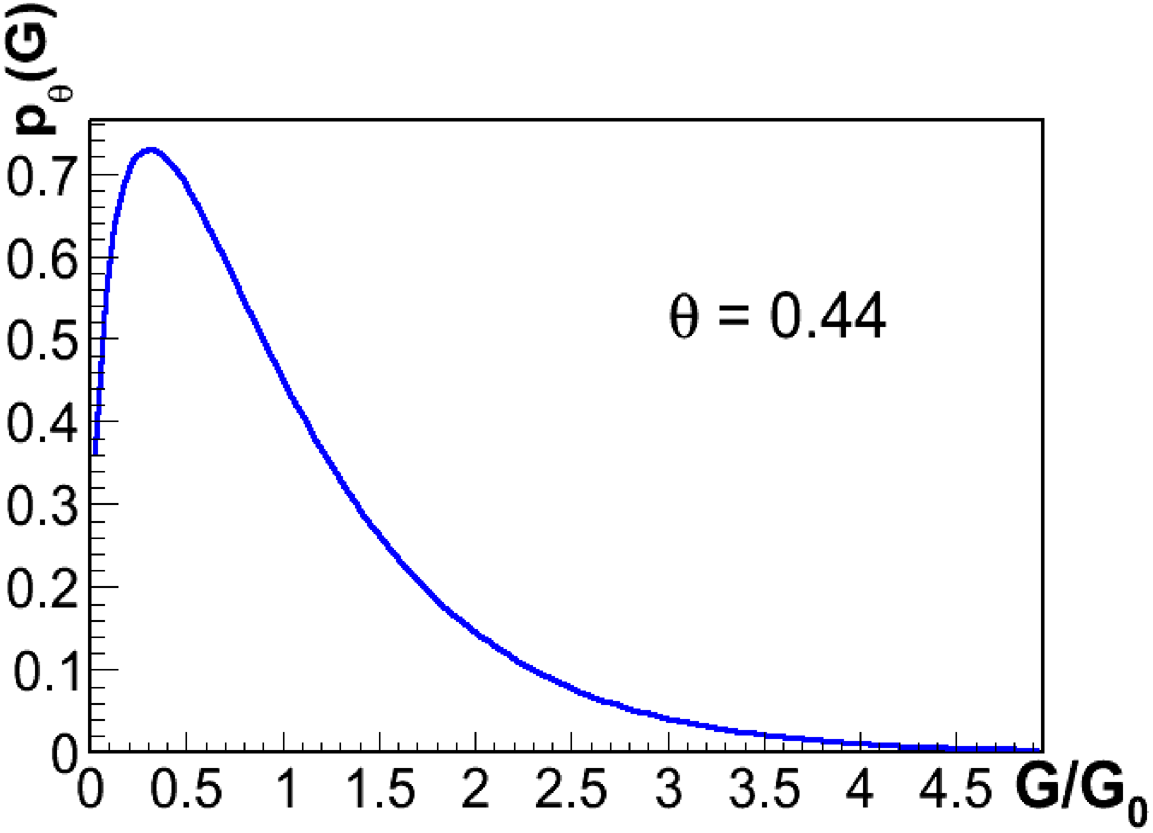
mean gas gain ≈ **3×10^4** (for primary electrons originated in the drift region)

The fluctuations of gas gain G are described by **Polya distribution:**

$$p_\theta(G)=\frac{1}{G_0}\frac{(\theta+1)^{(\theta+1)}}{\Gamma(\theta+1)}\left(\frac{G}{G_0}\right)^\theta \exp\left(-(\theta+1)\frac{G}{G_0}\right)$$

, where $\theta+1=\frac{G_0^2}{\sigma_G^2}$

and G_0 is a mean gas gain.



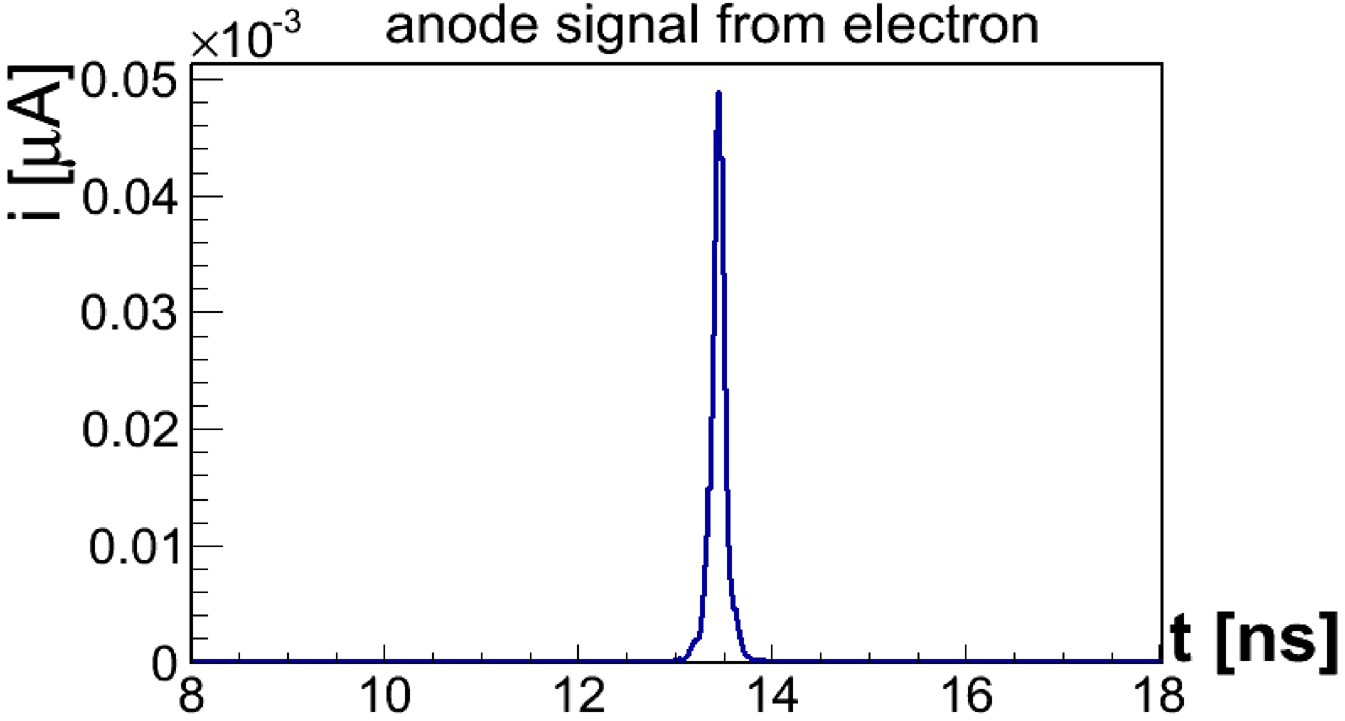
Anode signals

Ramo-Shockley theorem:

$$i_{ind}(t) = -q\vec{v} \cdot \vec{E}_w(\vec{r})$$

$i_{ind}(t)$ – the electric current induced by charge *q* moving at a velocity ***v*** at a radial distance *r* from the anode

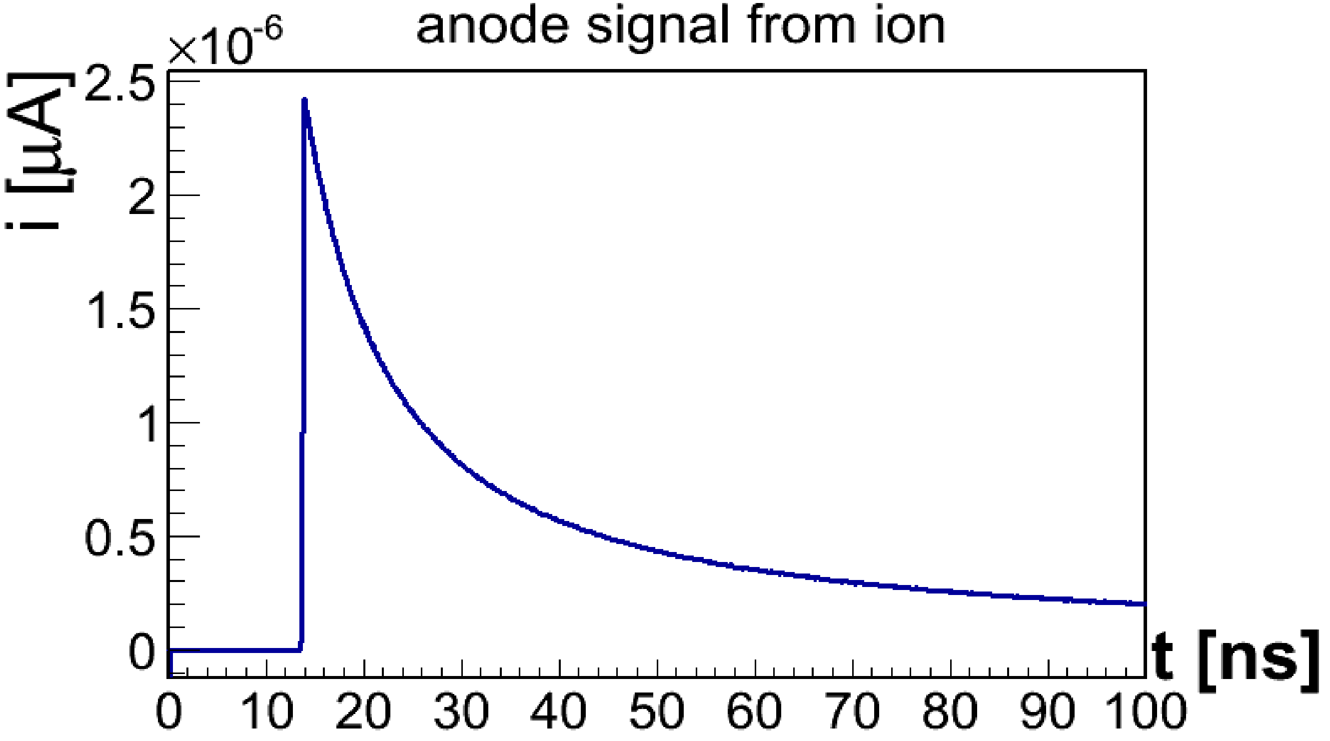
$\boldsymbol{E_w(r)}$ – weighting field (produced by unit potential applied to the anode and 0 to the cathode) spikey short-lived electron signal



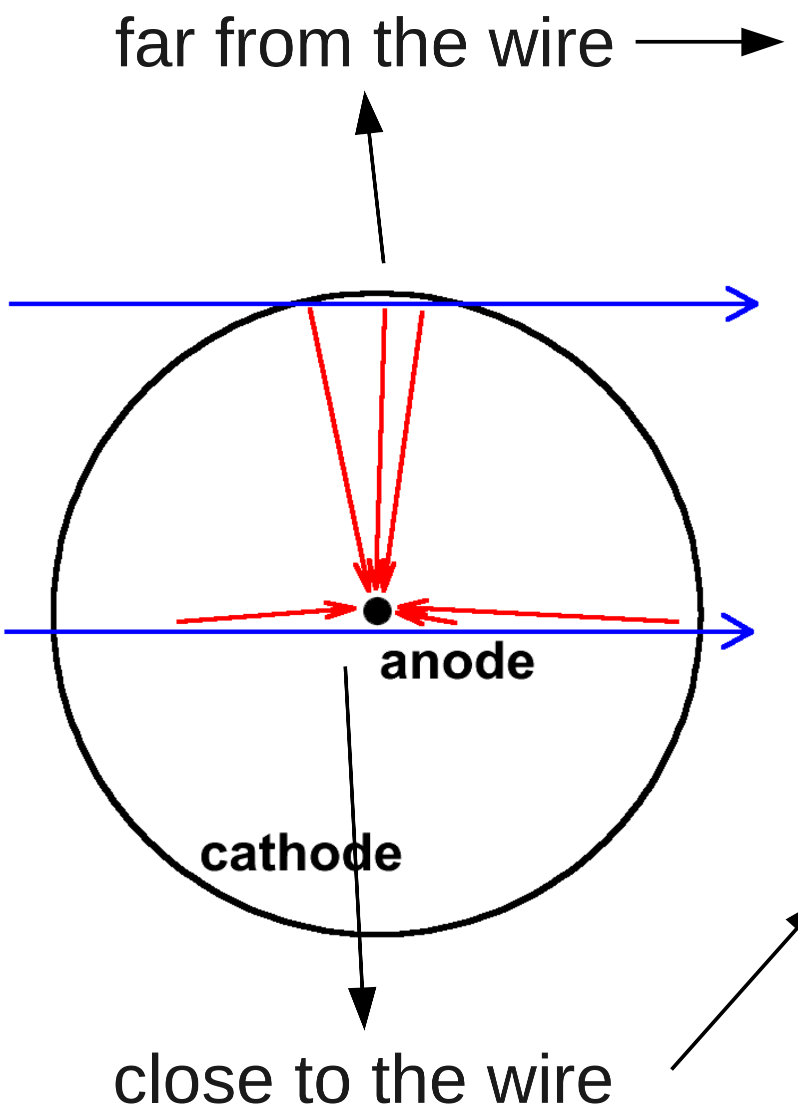
Two types of anode signals

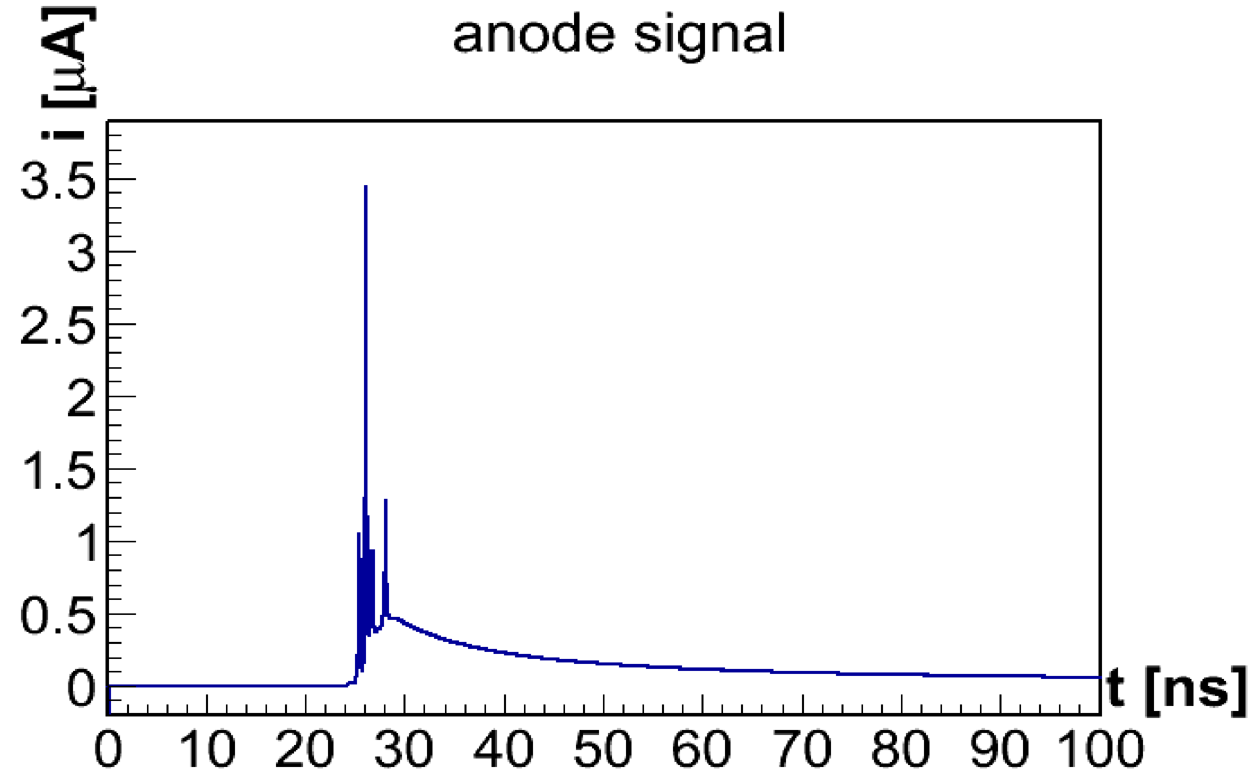
long tailed ion signal

(maximal ion drift time ≈ 40 µs)



Examples of anode signals





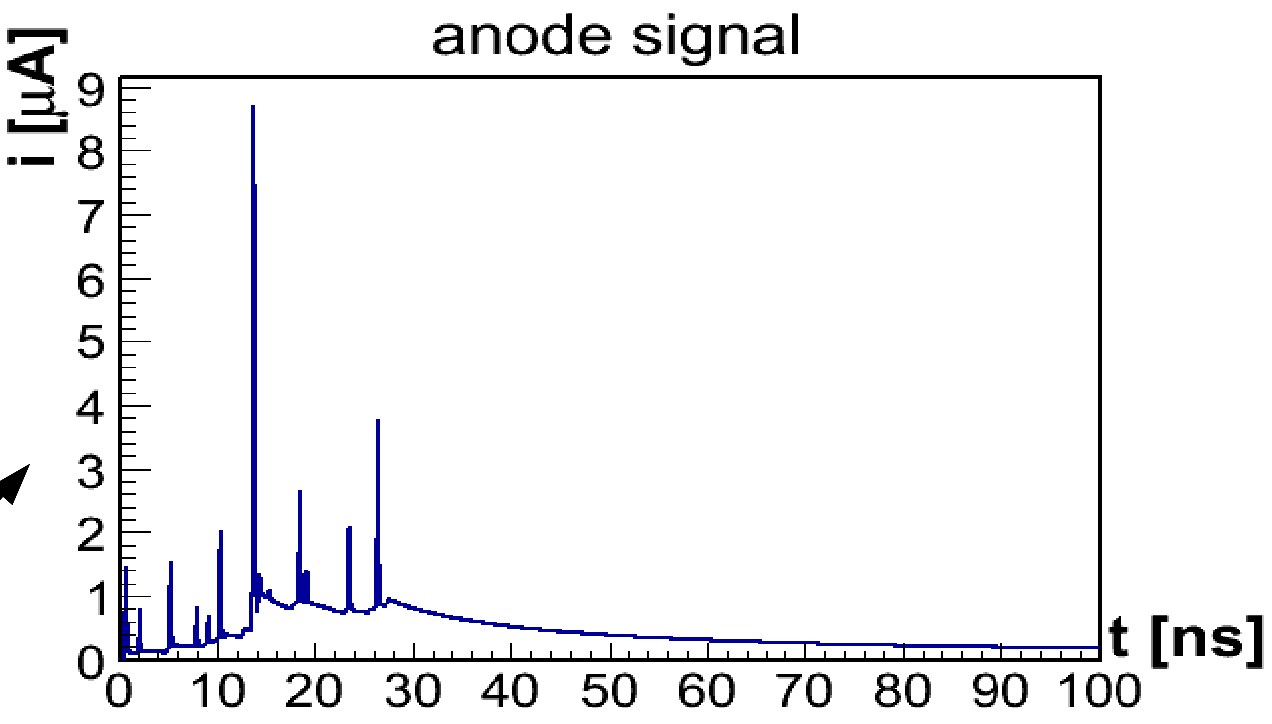
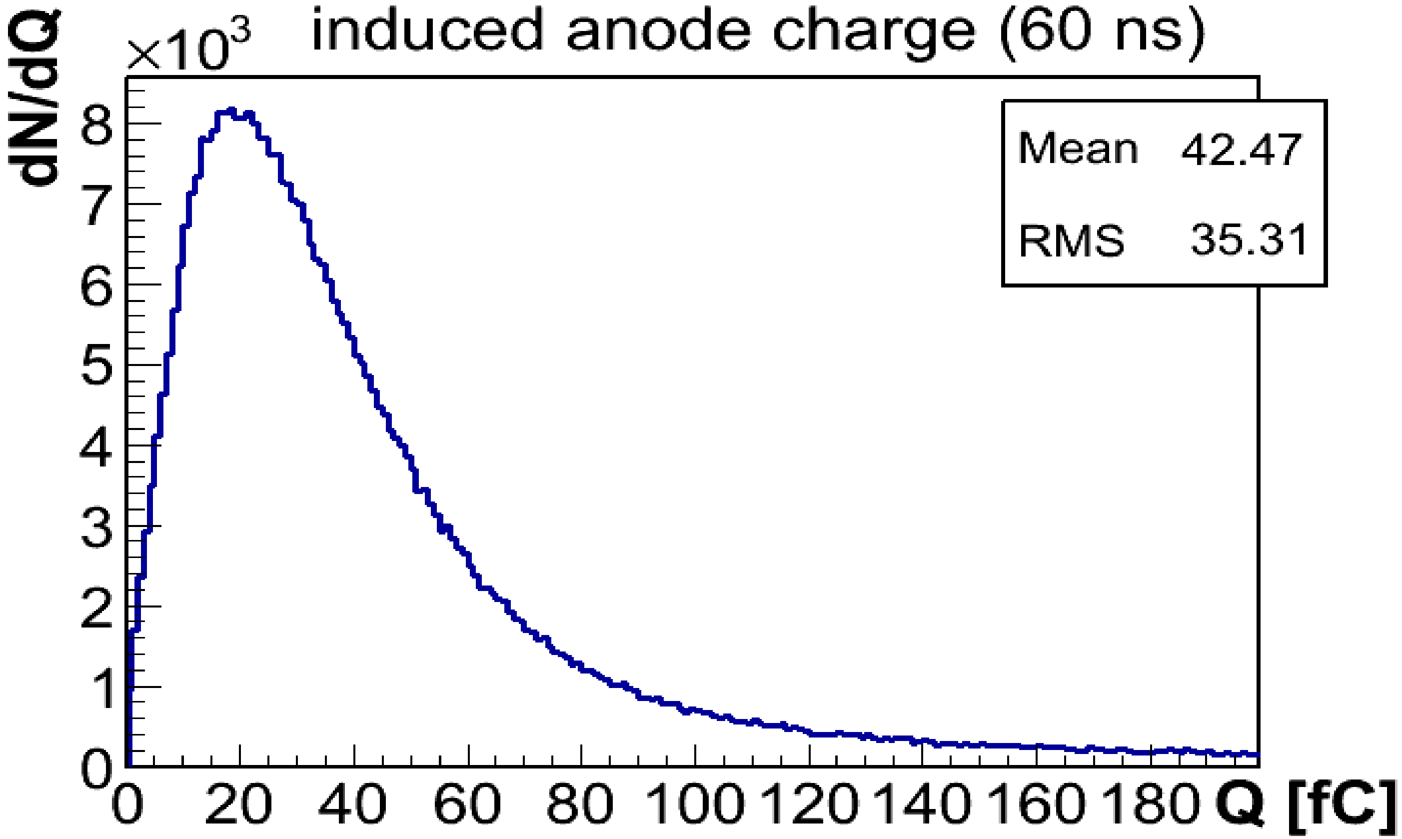


Fig. Distribution of the anode charge

- anode current integrated over 60 ns time interval (collection time)

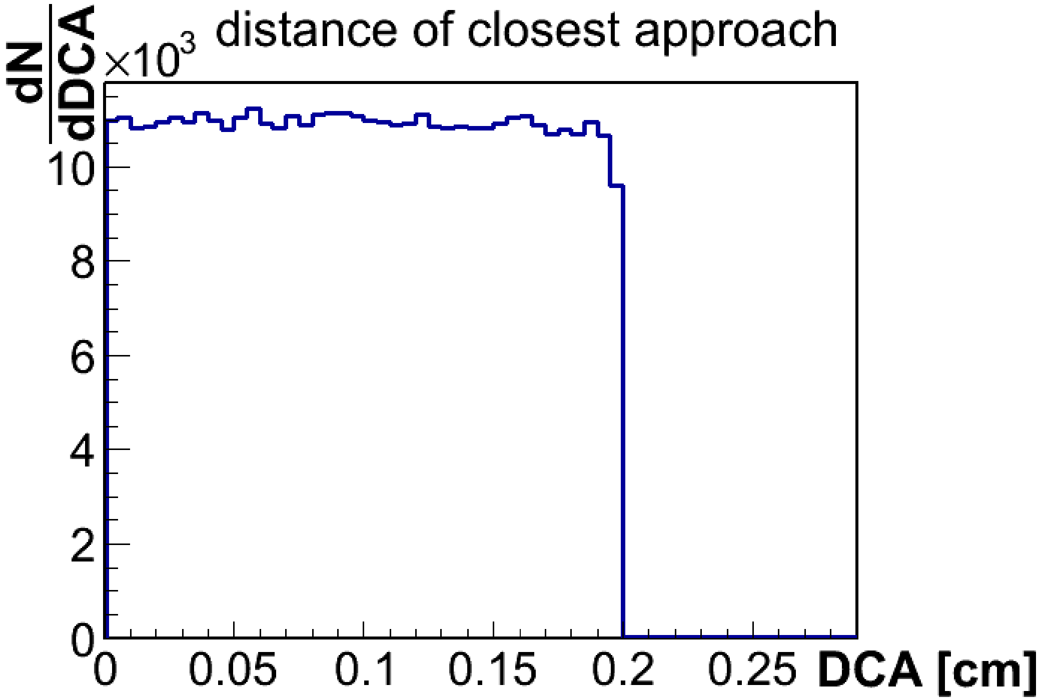


The anode charge is contributed mainly by ions *(follows from Ramo-Shockley formula)*.

Calibration method

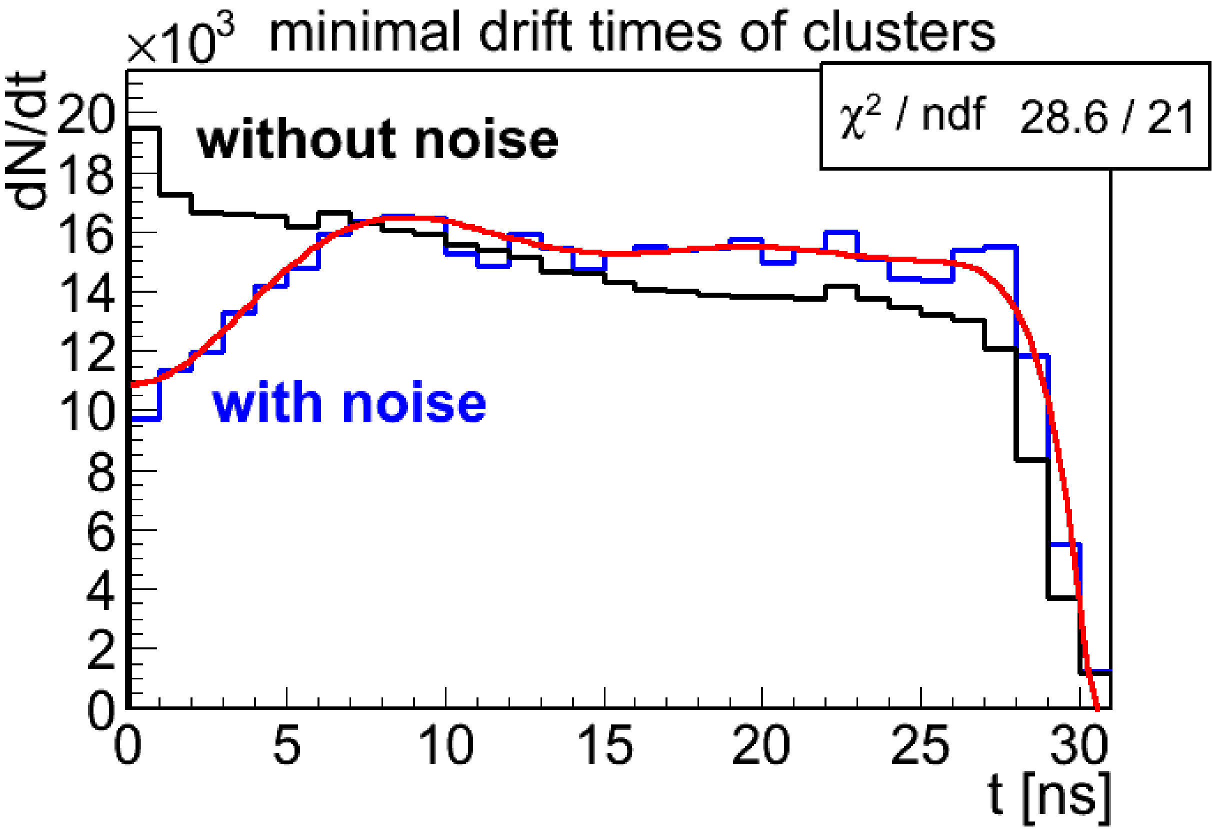
estimation of particle DCA coordinate (DCA – distance of closest approach to the anode wire)

The calibration metod is applicable providing the straw tubes are illuminated uniformly and the efficiency is constant over the tube volumes.



The method uses as input the spectra dN/dt_{min} of minimal drift times obtained for many straw tubes (from many events).

Fig. Spectrum of minimal drift times



Added white Gaussian noise with amplitude equal to 3% of maximum electric current value.

The threshold is then set to 5 times higher value to get rid of the noise.

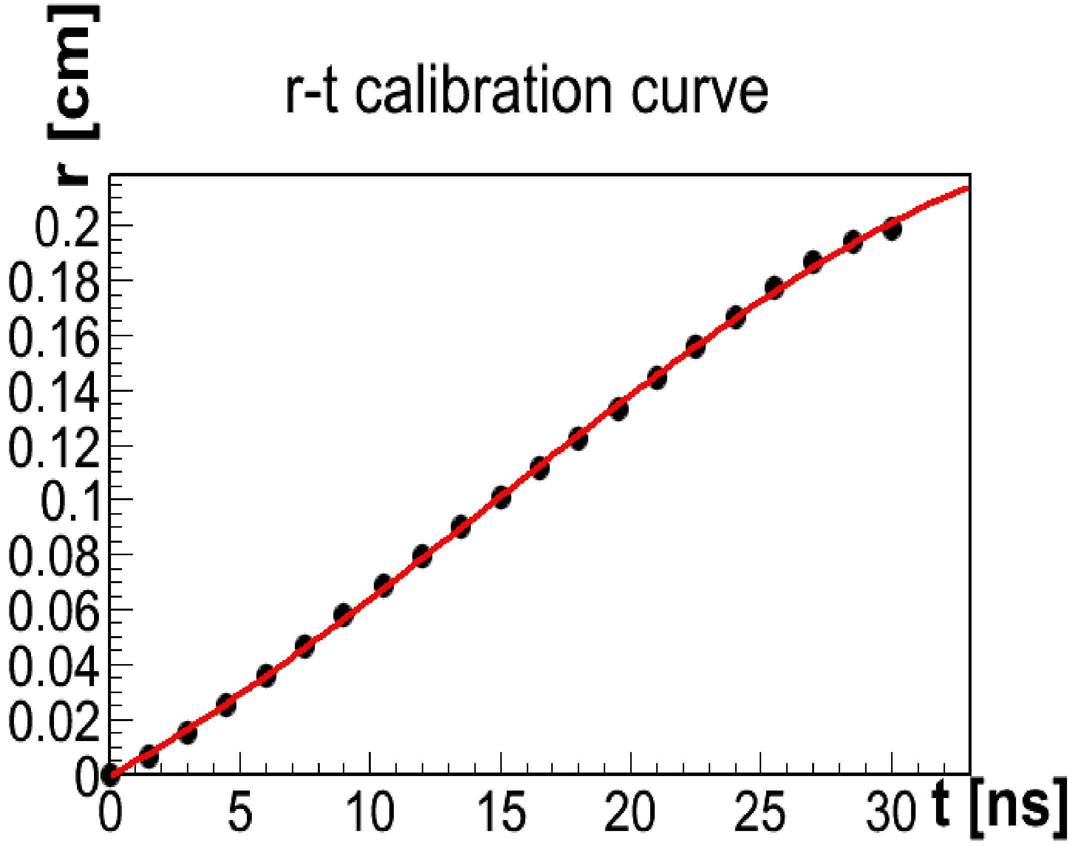
- can be fitted by the higher-order polynomial

Isochronous radius-time relation is estimated as:

$$r(t) = \frac{r_{max}}{N_{tot}} \int_0^t \frac{dN}{dt'} dt'$$

where N_{tot} is the total number of tracks.

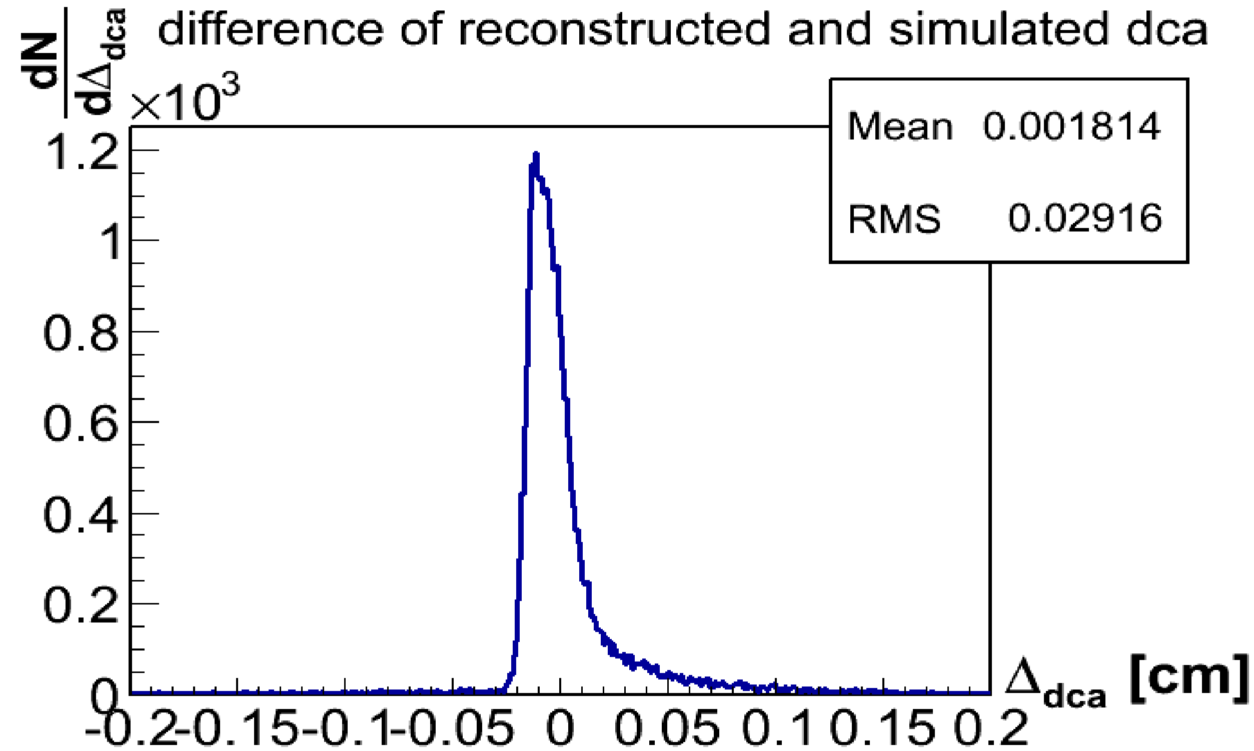
The radius-time relation is approximated by higher-order polynomial which is then used as a calibration curve converting the measured drift times to radii.



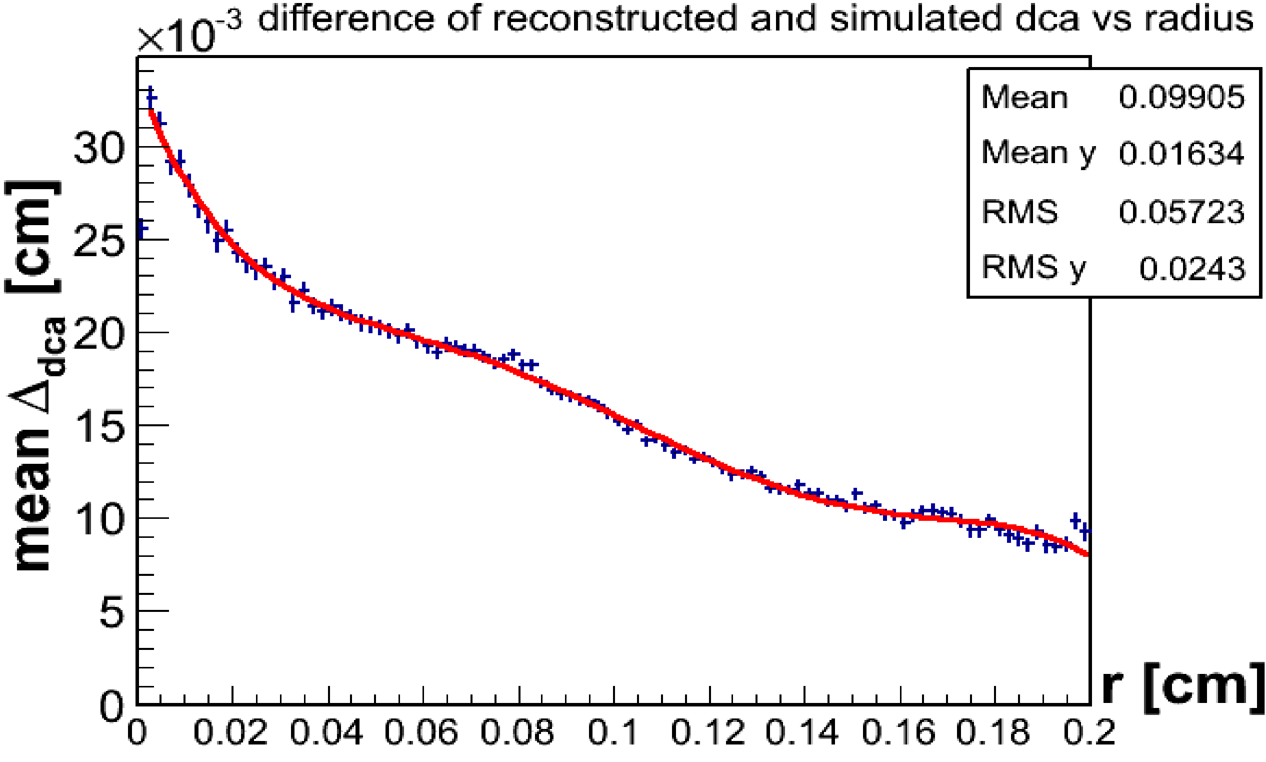
Dca resolution:
σ ≈ 250 (300) μm,
HWHM ≈ 100 μm.

The obtained values are very sensitive to the noise and threshold levels.

The coordinates are later improved in the tracking procedure (the autocalibration method).



difference of reconstructed and simulated dca

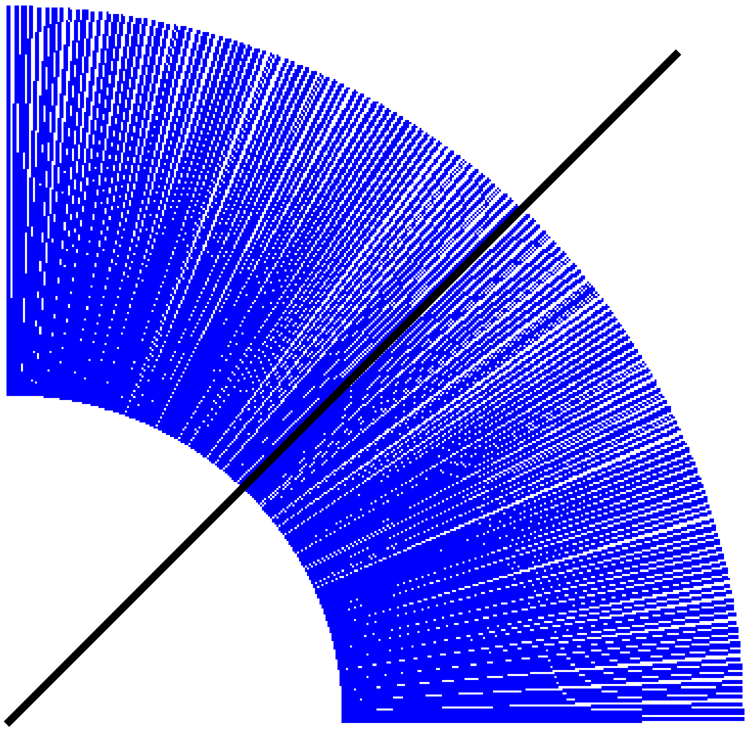


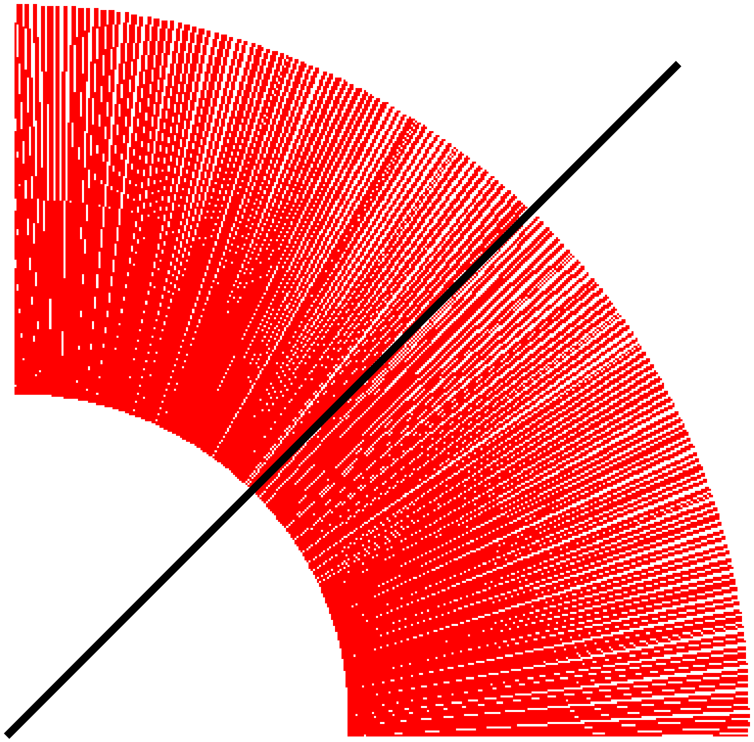
difference of reconstructed and simulated dca vs radius

Conlusions:

1. Response of the MPD Straw End-Cap Tracker has been estimated employing FAIRROOT, GEANT3, GARFIELD and the hit simulation and reconstruction programs;
2. The detector characteristics that have been estimated: the occupancy, the charge clusters distributions and energy losses, drift properties (electron and ion drift times, electron attachment probabilities, drift and lavina regions), gas gain (mean and variation), anode signals, the integrated anode charges;
3. The calibration method has been used to estimate hit distance of closest approach coordinates. The DCA resolution varies from 100 μm to 300 μm depending on the radial distance from anode wire.
4. The results are found compatible with the results from other HEP experiments employing straw tube detectors, e.g. PANDA and ATLAS.
5. The obtained results are necessary to proceed to the track reconstruction.

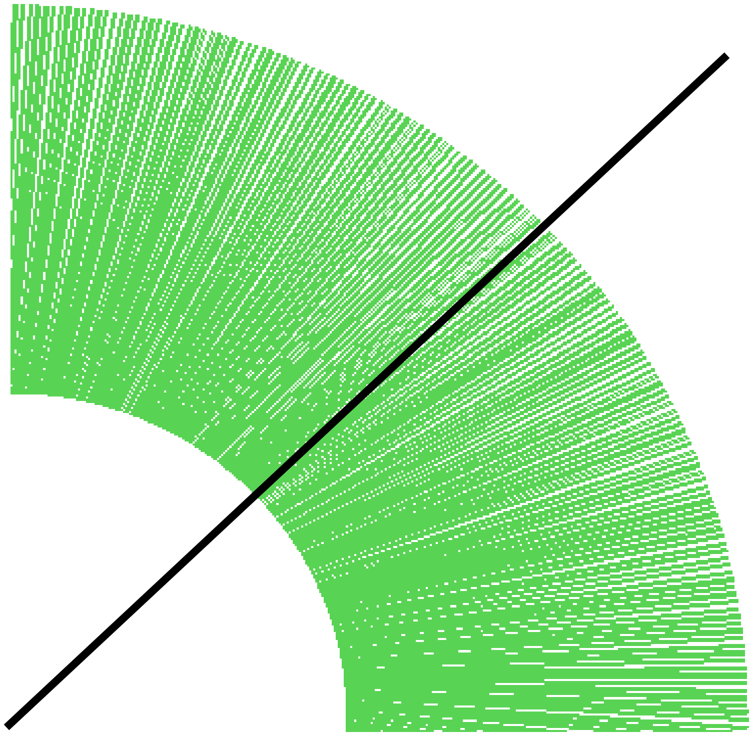
Backup slides





3 types of layers:

1.) radial tubes;
2.) tubes inclined by angle α=+7°;
3.) tubes inclined by angle α=-7°
with respect to radial tubes.



GEANT particles:

e^-, e^+, μ^-, μ^+, π^-, π^+, K^-, K^+, $\bar{p}$, p, Σ^-, Σ^+, d, He^3, triton, α

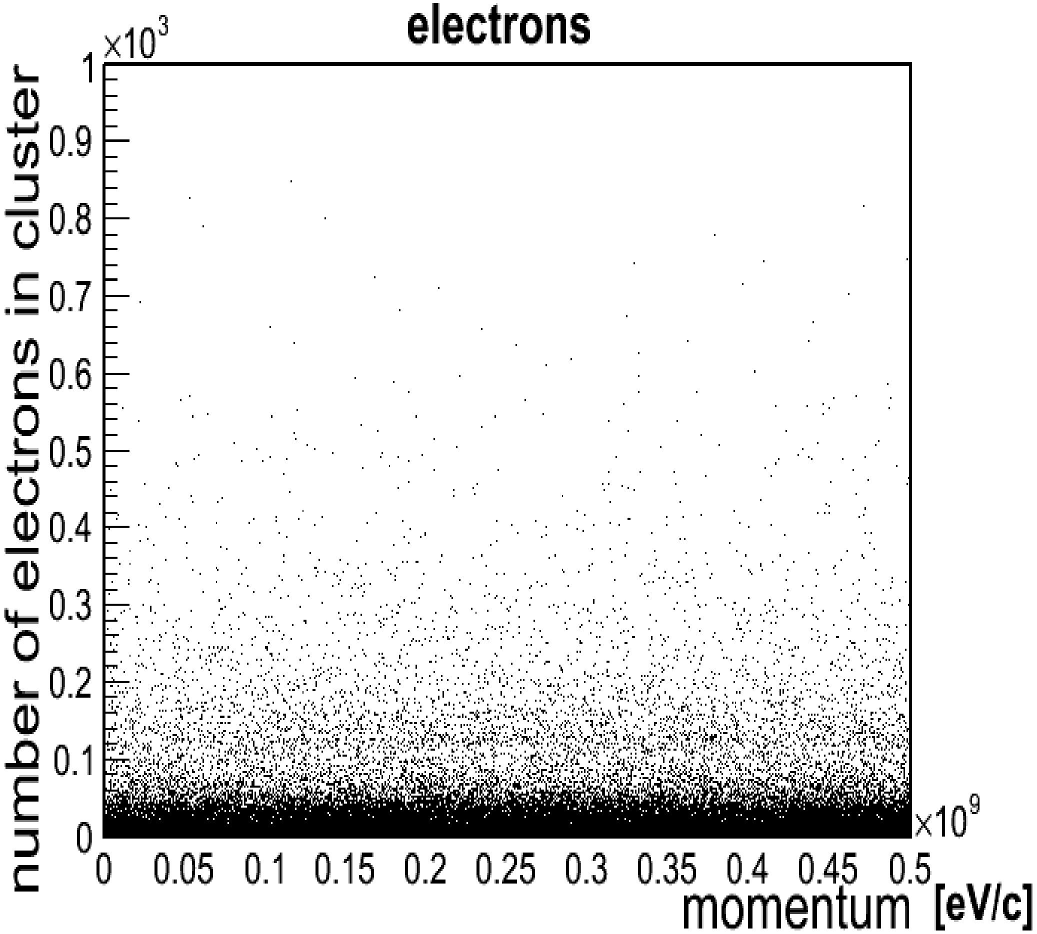
GARFIELD particles:

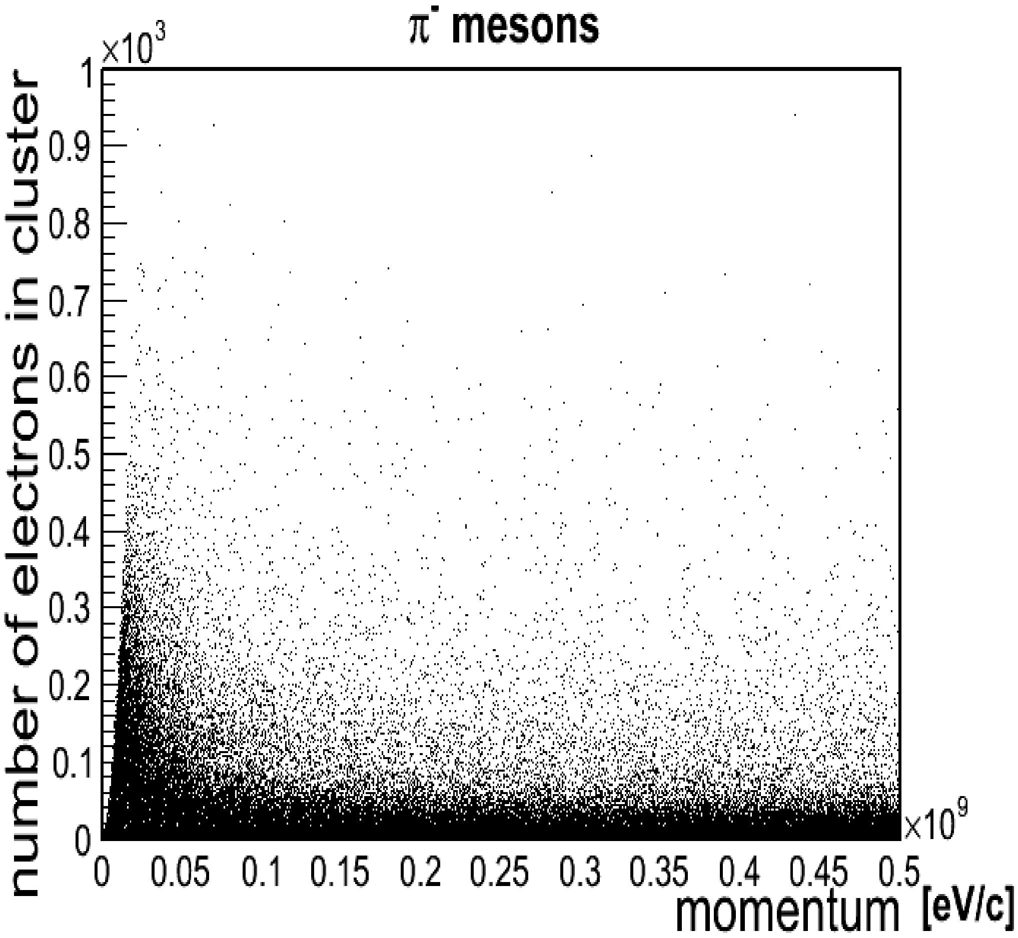
e^-, e^+, μ^-, μ^+, π^-, π^+, K^-, K^+, $\bar{p}$, p, d

i.e. some of the GEANT particles have no GARFIELD counterparts

Therefore instead of the missing GARFIELD particles, the available particles with similar properties are used: He^3, triton, $\alpha \rightarrow$ d;
Σ^- (Σ^+) $\rightarrow$ $\bar{p}$ (p)

Dependence of number of electrons/cluster on particle momenta - shown MC spectra for e^- and π^-





The spectra of most particles under study show dependence only at low momenta (up to 100-150 MeV/c) except for e^-, e^+, where a weak dependence is observed only at the lowest momenta (up to 20 MeV/c).

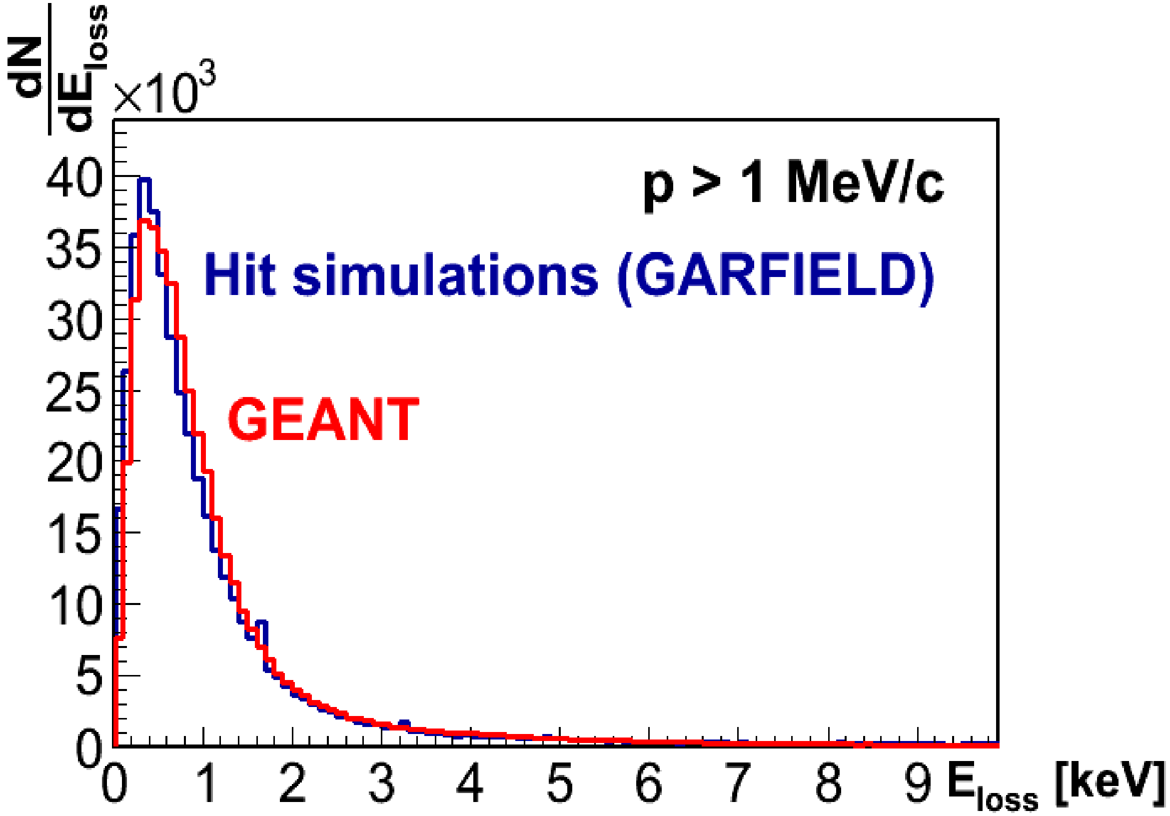
How to check if our simulations of primary charge are all right?

Basic check: the energy losses corresponding to the primary charges generated in straw tubes should match the energy losses from GEANT

The conversion of primary charge *q* to energy losses d*E*/d*x* is:

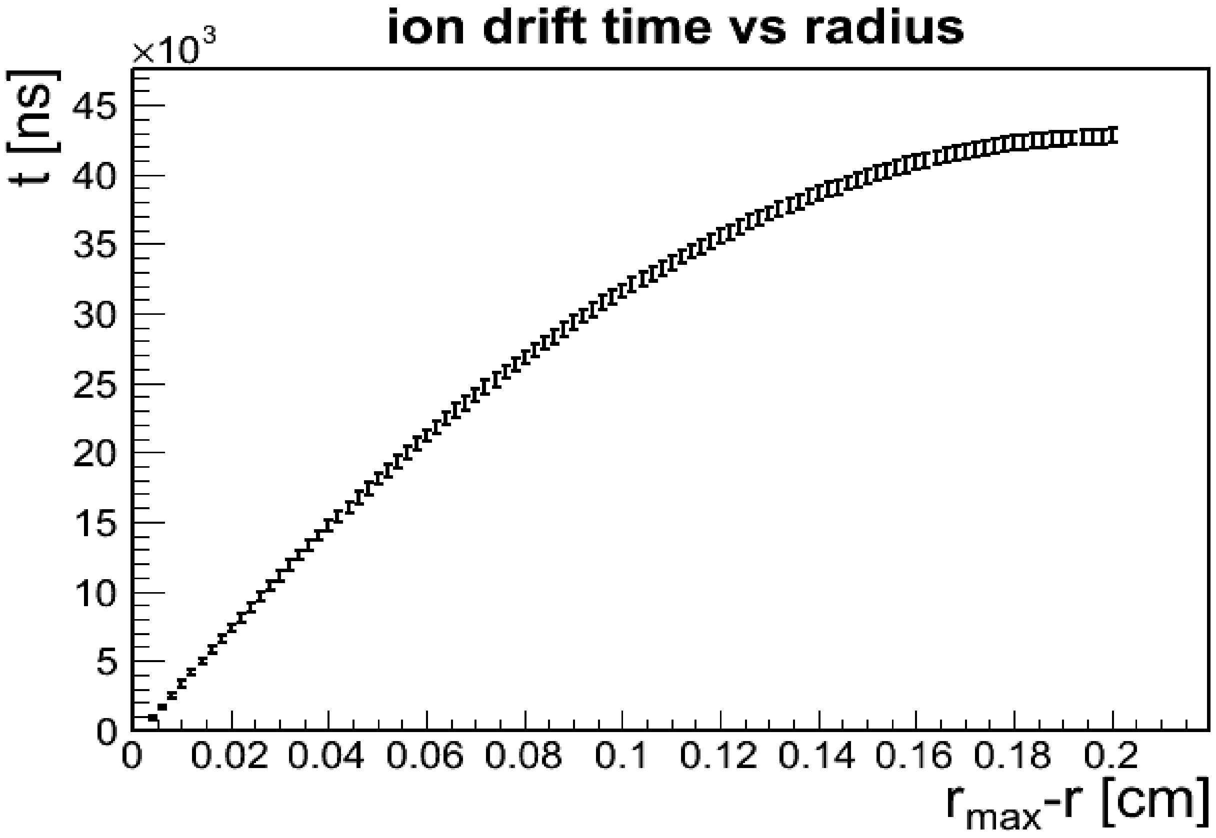
$$\frac{-dE}{dx}=n_q E_{min},$$

where $\mathbf{n_q}$ is a number of electrons (ions) with total charge *q* and $\boldsymbol{E_{min}}$ is minimal energy needed to ionize gas. In our case, $E_{min} \approx 27.5$ eV.



The attention must be turned to ions.

Fig. Ion drift time vs complementary straw tube radius r_{max}-*r*, where r_{max} is tube radius.



⇒ The maximal drift time is about 40 µs (for ions coming from the lavina region).

However, the integration (collection) time for anode charge is much lower (60 ns).

If charge q moves from point x_0 to point x_1, the induced charge is:

$$Q_{ind} = \frac{q}{V_w} \left[\Psi(x_1) - \Psi(x_0) \right],$$

where V_w is anode voltage (1650 V) and $\Psi(x)$ is a potential of weighting field.

After all the ions and electrons reach the corresponding electrodes, the anode total induced charged $\boldsymbol{Q_{ind} = q_{electrons}}$.

$$Q_{electrons} = q_{electrons} \left[1 - \frac{\Psi(x_0)}{V_w} \right] \qquad Q_{ions} = q_{electrons} \frac{\Psi(x_0)}{V_w}$$

If $x_0 \rightarrow r_{min}$ (anode radius), $\Psi(x_0) \rightarrow V_w \Rightarrow Q_{electrons} \rightarrow 0$, $Q_{ions} \rightarrow q_{electrons}$

i. e. <u>most of the induced anode charge comes from ions.</u>