Drift Chamber R&D for CEPC/FCCee

Offline Analysis of Nov. 2021 Beam Test at CERN

(stolen to B. D'Anzi)

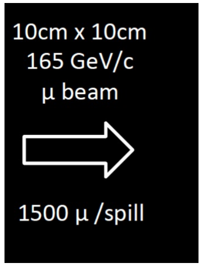
Speaker:
Francesco Grancagnolo

Date:
24.05.2022

Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022

Context

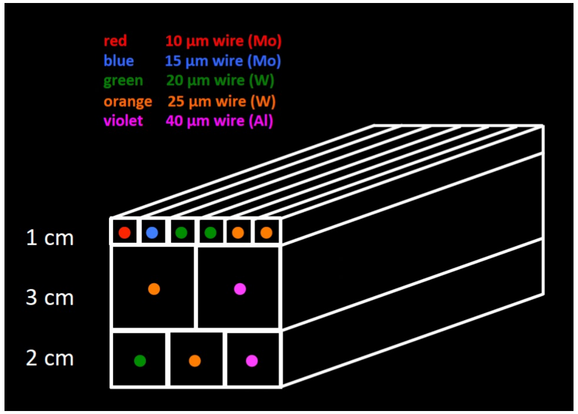
- Offline analysis on November test beam data taken with 165 GeV/c muons beams from 11st November
- Dealing with 11 drift tubes having cell sizes of 1-cm,2-cm and 3-cm:



- **Channels 0,1,2,3** are Trigger Counters

- **Channels 4,5,6,7,8,9** are the 6 Drift Tubes of 1 cm cell size respectively:
  - Channel 4 with a wire diameter of 10 micrometer
  - Channel 5 with a wire diameter of 15 micrometer
  - Channel 6 and 7 with a wire diameter of 20 micrometer
  - Channel 8 and 9 with a wire diameter of 25 micrometer

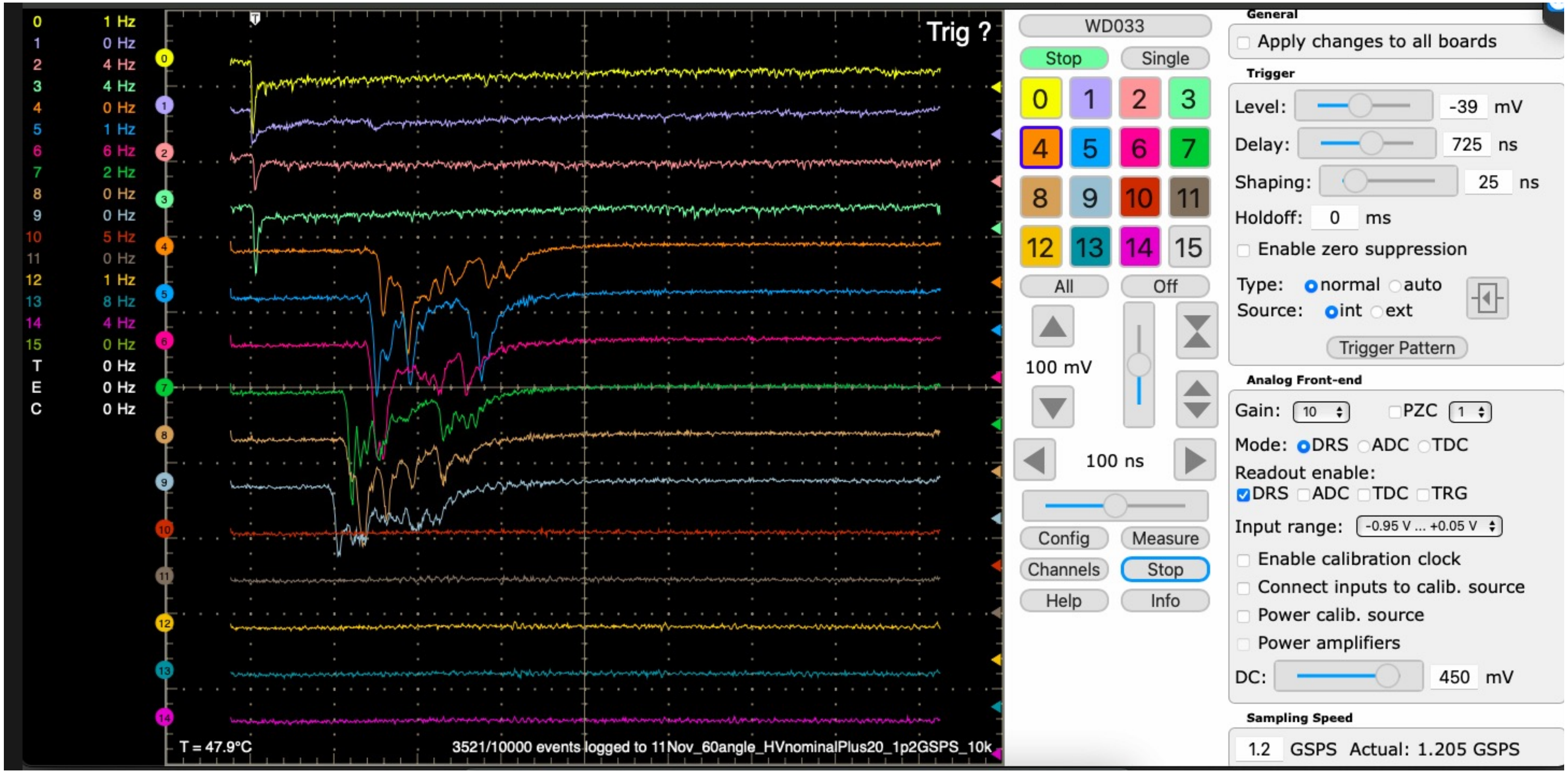
- **Channels 10,11,12** are the 3 Drift Tubes of 2 cm cell size respectively:
  - Channel 10 with a wire diameter of 20 micrometer
  - Channel 11 with a wire diameter of 25 micrometer
  - Channel 12 with a wire diameter of 40 micrometer



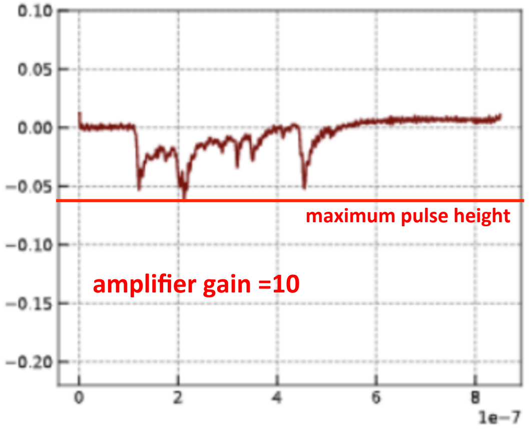
- **Channels 13,14** are the 2 Drift Tubes of 3 cm cell size respectively:
  - Channel 13 with a wire diameter of 25 micrometer
  - Channel 14 with a wire diameter of 40 micrometer

Signal acquisition window is out of the signal range

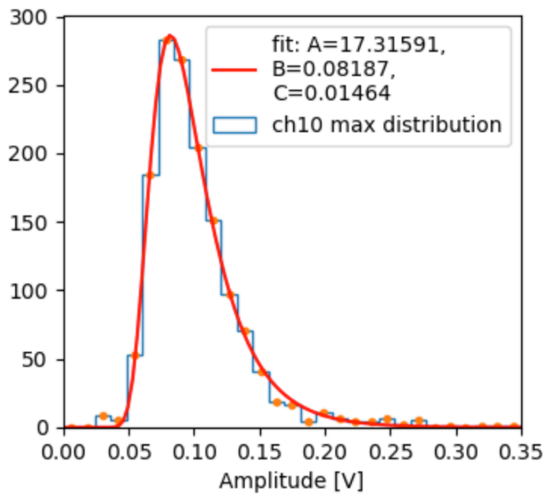
Test setup: event display



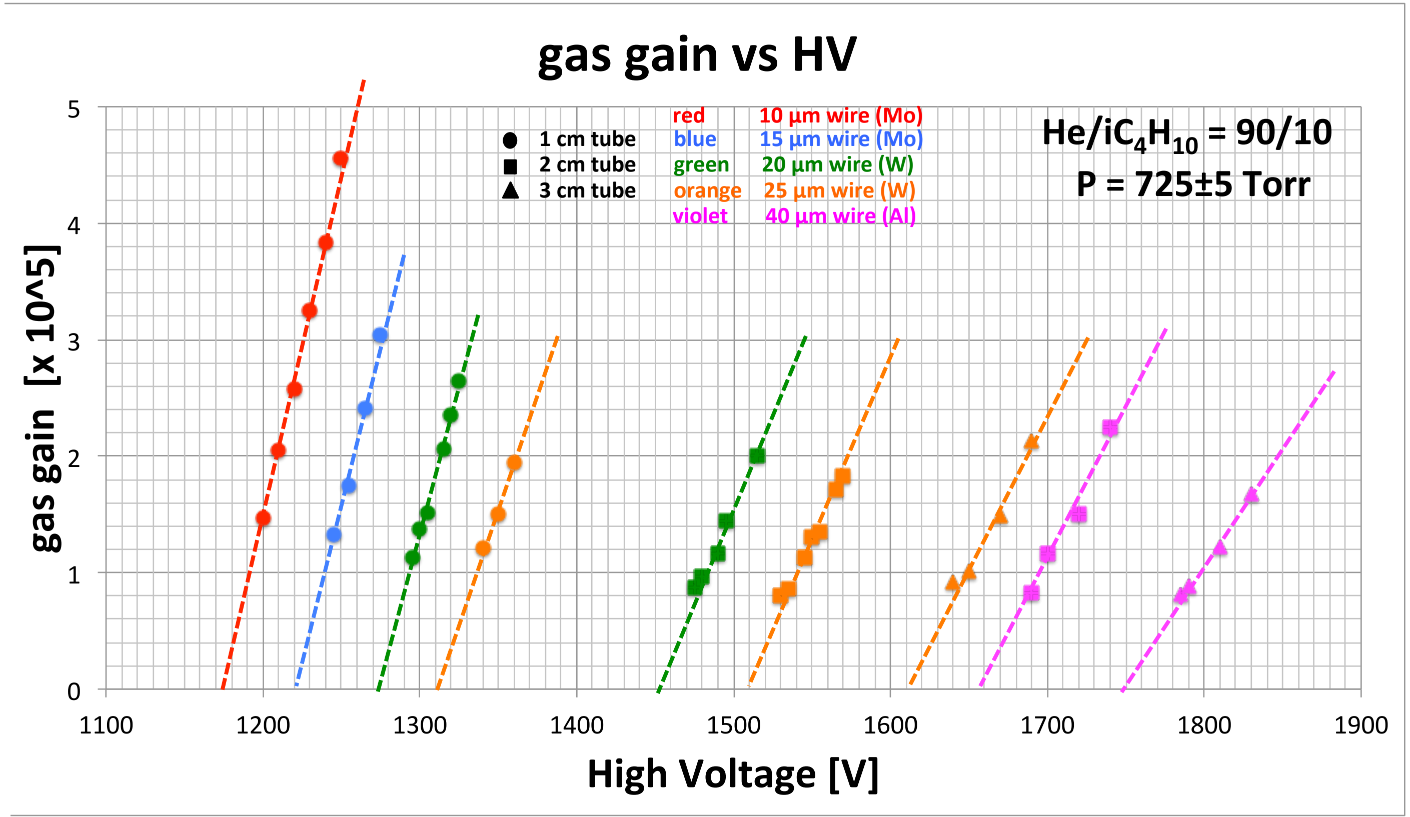
gas gain



maximum pulse height
amplifier gain =10
1e−7

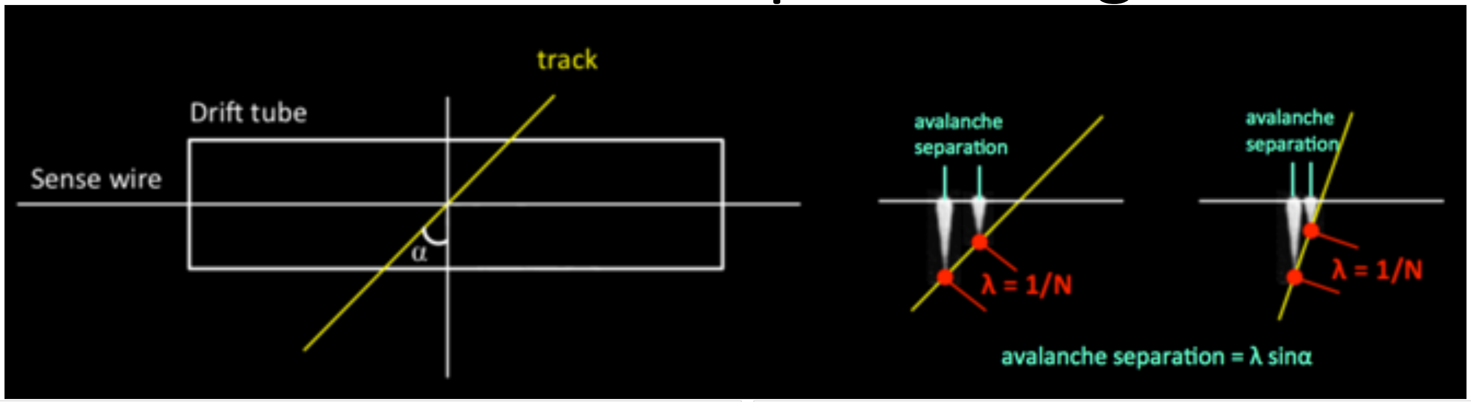


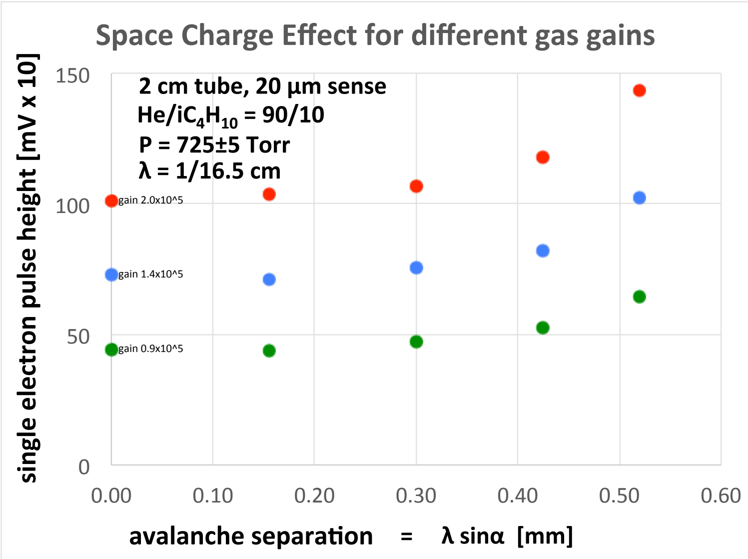
fit: A=17.31591,
B=0.08187,
C=0.01464
ch10 max distribution
Amplitude [V]

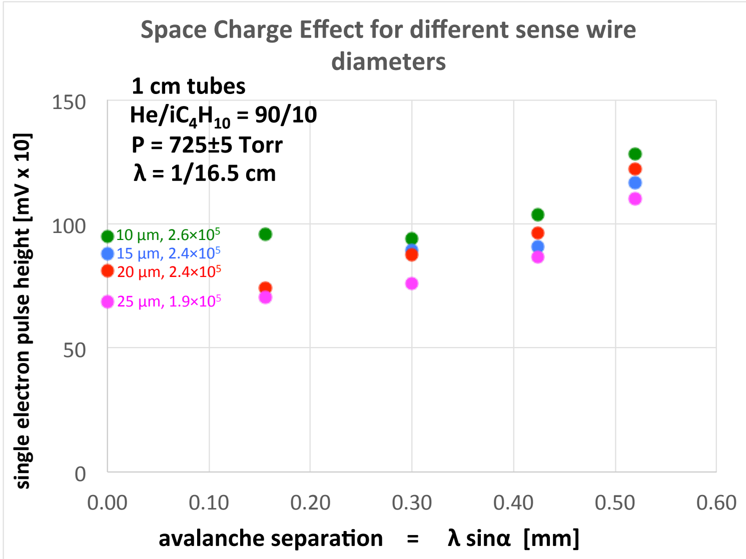


gas gain vs HV
1 cm tube
2 cm tube
3 cm tube
red 10 µm wire (Mo)
blue 15 µm wire (Mo)
green 20 µm wire (W)
orange 25 µm wire (W)
violet 40 µm wire (Al)
He/iC4H10 = 90/10
P = 725±5 Torr
gas gain [x 10^5]
High Voltage [V]

space charge







no dependence of space charge effects from the gas gain, no dependence of space charge effects from the sense wire diameter at least in this range of gas gain values

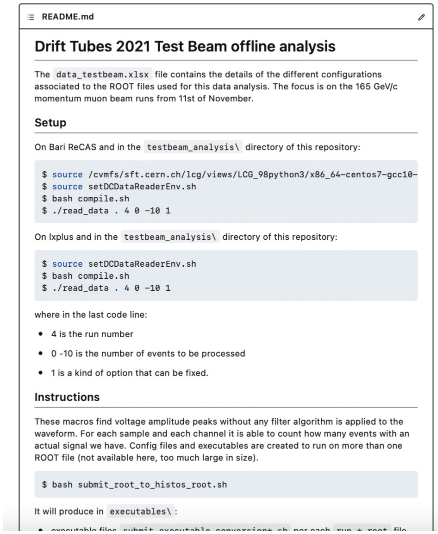
The **space charge effect** for this gas mixture, results in approximately **≈ 30% avalanche suppression, at α=0°**.

A **naive model** based on **spherical avalanche profile** gives, for these particular configurations, an **avalanche radius r_{av} ≈ 450 μm**.

The condition of **no avalanche overlap: λ sinα ≥ 2 r_{av}**, in this case, is met for 1/λ = **N ≤ 11/cm**. Any helium/isobutane gas mixture richer than 10% isobutane (corresponding to N = 12/cm for a m.i.p.) will, therefore, **necessitates space charge effects corrections**.

Data analysis storage

- ❑ Binary Raw Data files are converted into ROOT files **run_*.root** containing the waveform spectrum and stored in CERNBox (send an email to matteo.greco@le.infn.it for the access rights).
- ❑ Each **run_*.root file** correspond to a different configuration (gas mixture, HV, data-taking day,trigger, track incident angle w.r.t. drift tube, sampling frequency) under which data are taken.
- ❑ Up to now, we are using:
  - ❖ run_99.root; Track angle: 0 ; Gas mixture: 90%He10%iC_4H_{10} ;
  - ❖ run_98.root; Track angle: 15 ; Gas mixture: 90%He10%iC_4H_{10} ;
  - ❖ run_96.root; Track angle: 30 ; Gas mixture: 90%He10%iC_4H_{10} ;
  - ❖ run_94.root; Track angle: 45 ; Gas mixture: 90%He10%iC_4H_{10} ;
  - ❖ run_91.root; Track angle: 60 ; Gas mixture: 90%He10%iC_4H_{10} ;
  - ❖ run_127.root; Track angle: 60 ; Gas mixture: 80%He20%iC_4H_{10} ;
  - ❖ run_117.root; Track angle: 0 ; Gas mixture: 80%He20%iC_4H_{10} ;



README.md

Drift Tubes 2021 Test Beam offline analysis

The `data_testbeam.xlsx` file contains the details of the different configurations associated to the ROOT files used for this data analysis. The focus is on the 165 GeV/c momentum muon beam runs from 11st of November.

Setup

On Bari ReCAS and in the `testbeam_analysis\` directory of this repository:

```
$ source /cvmfs/sft.cern.ch/lcg/views/LCG_98python3/x86_64-centos7-gcc10-
$ source setDCDataReaderEnv.sh
$ bash compile.sh
$ ./read_data . 4 0 -10 1
```

On lxplus and in the `testbeam_analysis\` directory of this repository:

```
$ source setDCDataReaderEnv.sh
$ bash compile.sh
$ ./read_data . 4 0 -10 1
```

where in the last code line:

- 4 is the run number
- 0 -10 is the number of events to be processed
- 1 is a kind of option that can be fixed.

Instructions

These macros find voltage amplitude peaks without any filter algorithm is applied to the waveform. For each sample and each channel it is able to count how many events with an actual signal we have. Config files and executables are created to run on more than one ROOT file (not available here, too much large in size).

```
$ bash submit_root_to_histos_root.sh
```

It will produce in `executables\` :

- ❑ Github repository https://github.com/bdanzi/drifttubes_offline_analysis to collect :
  - ▪ the **data_testbeam.xlsx** (***drifttubes_offline_analysis/*** *directory*) reporting the association of the run number to the particular configuration
  - ▪ binary conversion macros (***drifttubes_offline_analysis/dchdatareade_test_beam/*** directory)
  - ▪ the offline analysis (***drifttubes_offline_analysis/testbeam_analysis/*** directory) by using the **Derivative Finding Peaks algorithm and the Bari-Lecce Cluster algorithm**

Preliminary Signal Processing

The electron peaks search is performed:

Waveform time spectrum = a 1024-bins sampled signal (at 1.2 GSPS, corresponding to about 853.33 ns) over 1 V dynamic range.

Preliminary step: Normalization of the Waveform time spectrum to a **zero baseline**

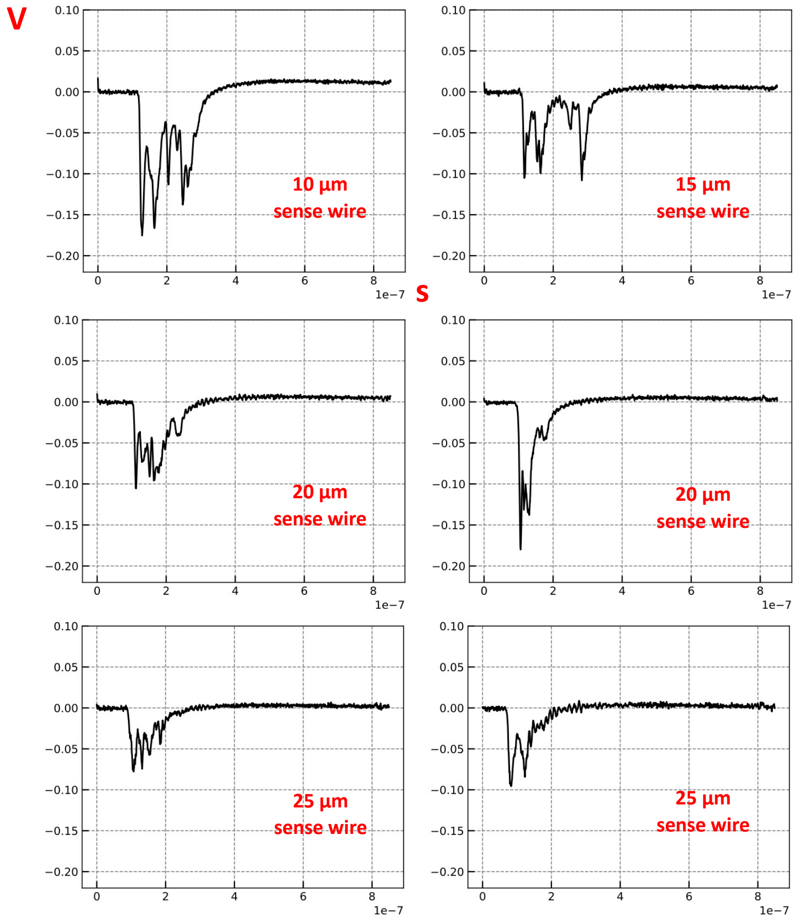
Waveform baseline = average wave amplitude on the first signal-less bins (30 bins corresponding to 25 ns for 1.2 GSPS runs)

Noise r.m.s. = defined over the first 30 bins as $r.m.s. = \sqrt{\frac{\sum_{i=0}^{30}(Wave\_normalized[channel].Y - bsln)^2}{30}}$

Find Electron Peaks strategy

- Drift tube SIGNAL selection:
  - No waveform smoothing
    - to avoid reducing signal/noise ratio
  - At least one bin with amplitude > 10 r.m.s. of noise
    - probability of noise event over 700 bins ≅ 3%
  - Integral of the Waveform (sum of the waveform amplitudes) ≥ 100 mV over 700 bins (0.833 ns/bin) corresponding to ≅ 5 electrons;
    - at an average gas gain of 2×10^5 over 50 Ω load
- EVENT selection:
  - For 1 cm drift tubes: at least 4 out of 6 tubes with signal
  - For 2 cm drift tubes: at least 2 out of 3 tubes with signal

1 cm drift tubes



90% He – 10% iC_4H_{10}

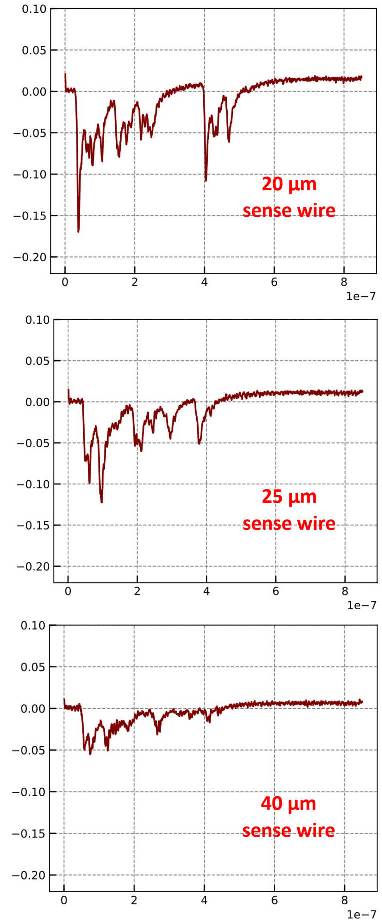
gas gain
3×10^5

amplifier gain
×10

sampling rate
1.2 GSPS

60° angle

2 cm drift tubes



Find Electron Peaks strategy (cont.)

- **Search range:** exclusion of the last bins above maximum drift time
- **Requirements for a good peak candidate at bin position [ip]:**

➢ Amplitude constraints:

- amplitude[ip] > 4*rms
- amplitude[ip] – amplitude[ip–1] > rms || amplitude[ip+1] – amplitude[ip] < rms

➢ First derivative constraint:

- fderiv[ip] < sigd1/2
- fderiv[ip–1] > sigd1 || fderiv[ip+1] < – sigd1

➢ Second derivative constraint:

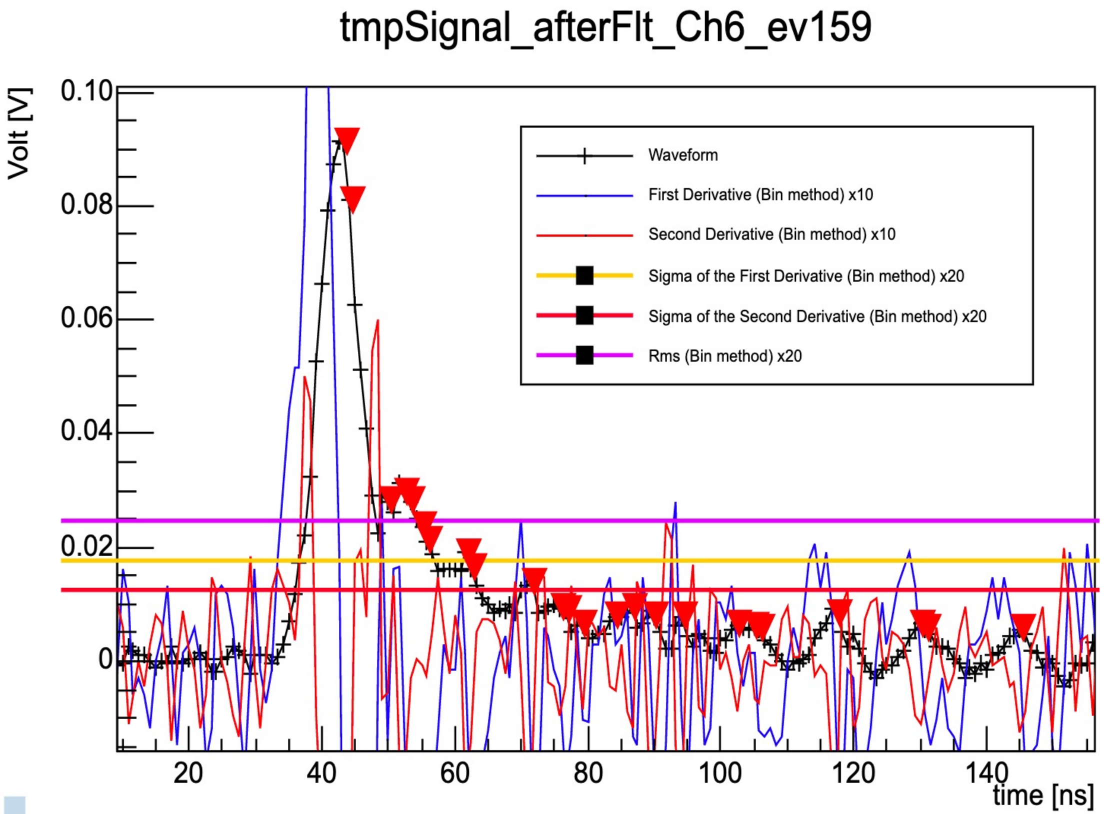
- sderiv[ip]< 0

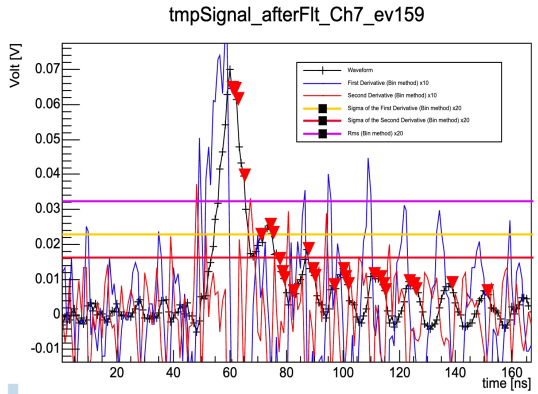
NOTE:
fderiv[ip] = (Waves_normalized.Y[ip+1]-Waves_normalized[ip-1])/2
sderiv[ip] = (fderiv[ip+1]-fderiv[ip-1])/2
sigd1 = rms/sqrt(2)
sigd2 = rms/2

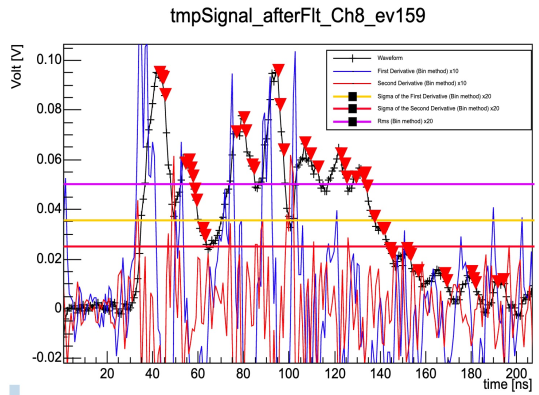
Normalized waveform spectrum with peaks found

1 cm drift tubes

Run: run_99.root; **Track angle(deg)**: 0° ; **Gas mixture**: *90%He10%iC$_4$H$_{10}$* ; **HV = +20**



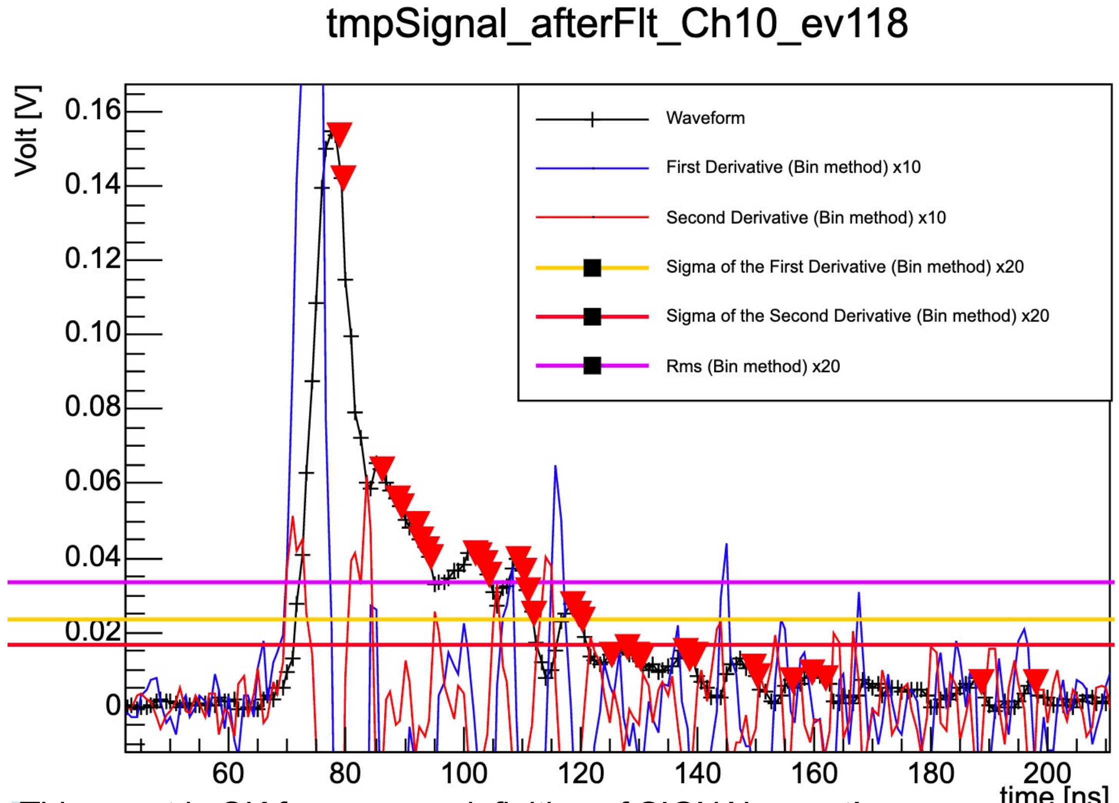


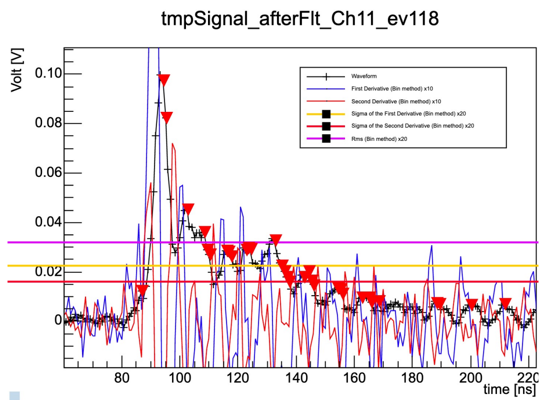


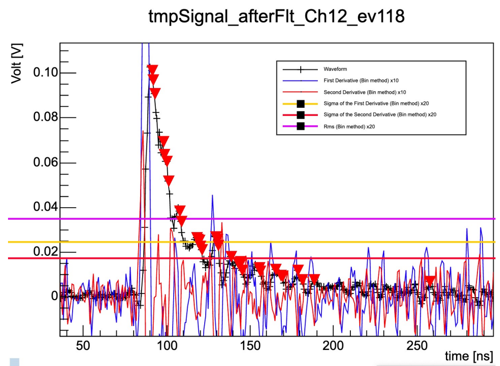
Normalized waveform spectrum with peaks found

2 cm drift tubes

Run: run_99.root; Track angle(deg): 0° ; Gas mixture: $90\%He10\%iC_4H_{10}$; HV = +20







This event is OK for our new definition of SIGNAL event!

Expected number of Electron Peaks

Observable to monitor the Electron Peak (Cluster) algorithm :

- NPeak (Expected number of electron peaks; Landau distribution)
  = δ cluster/cm (m.i.p.) * drift tube size [cm] * 1.3 (relativistic rise)* 1.6 electrons/cluster * 1/cos(α)
- NCluster (Expected number of clusters; Poissonian/Gaussian distribution)
  = δ cluster/cm (m.i.p.) * drift tube size [cm] * 1.3 (relativistic rise)* 1/cos(α)
  - α corresponds to the angle of the muon track w.r.t. the normal to the sense wire
  - δ cluster/cm (mip) changes from 12 to 18 respectively for 90He and 80He gas mixtures
  - Drift tube size changes from 0.8 to 1.8 respectively for 1-cm and 2-cm cell size tubes

From literature

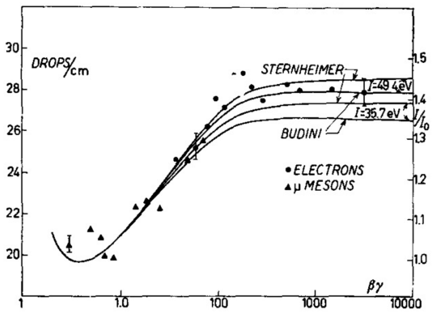
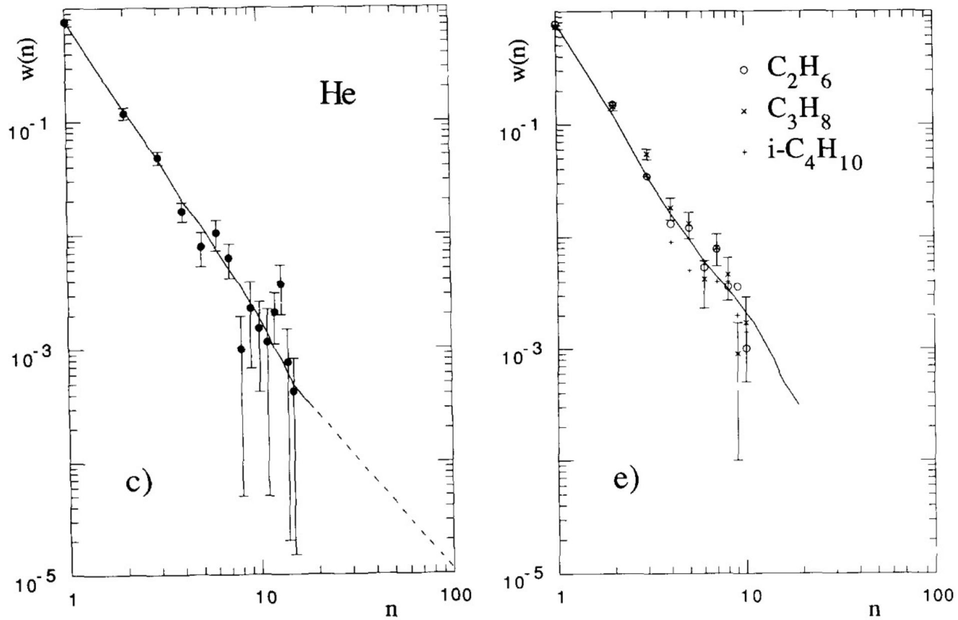


Fig. 1. – Ionization loss in helium. The theoretical curves are normalized to the μ-mesons with $\beta\gamma < 30$, and are calculated for different values of the average ionization potential for the mixture of gases in the cloud chamber. Standard deviations are indicated for a few of the experimental points.



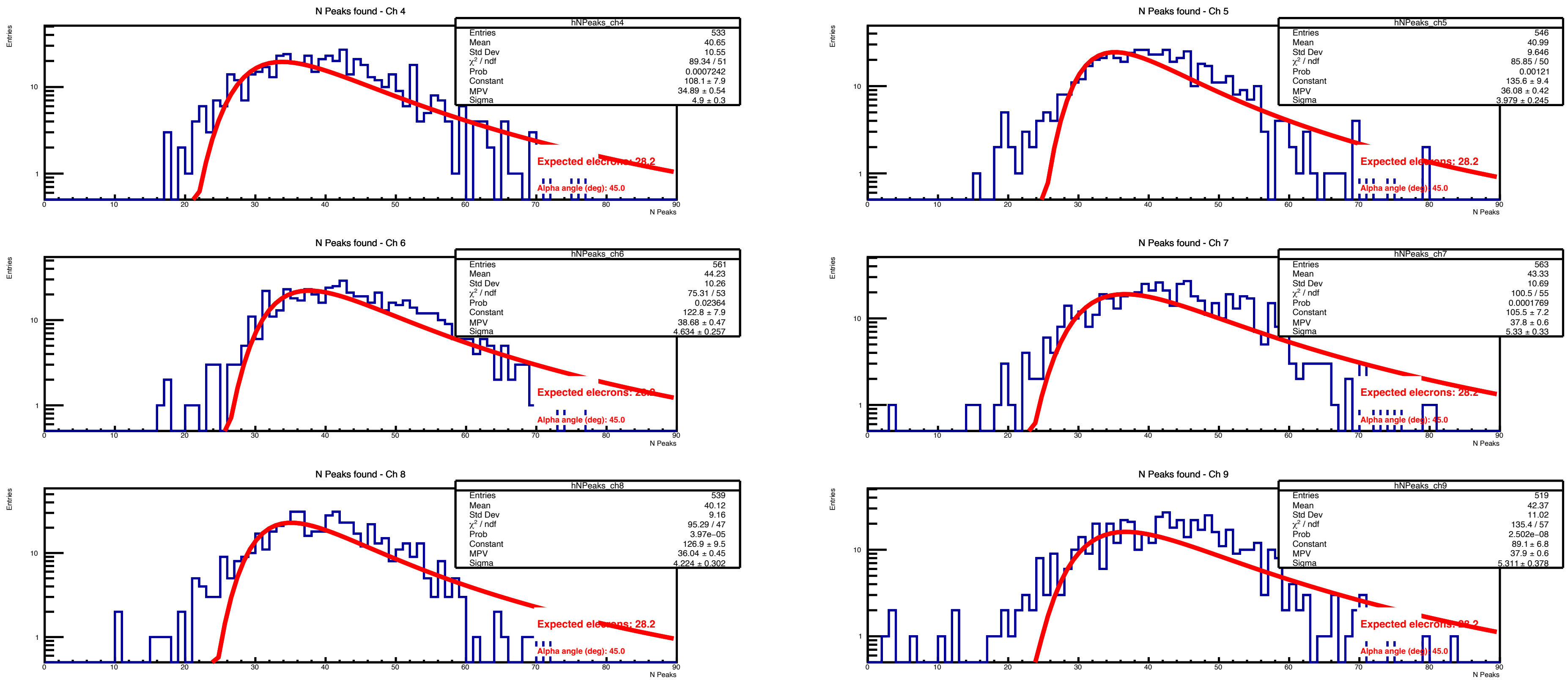
R. G. KEPLER, C. A. D'ANDLAU, W. B. FRETTER and L. F. HANSEN
Relativistic Increase of Energy Loss by Ionization in Gases
IL NUOVO CIMENT0 VOL. VII, N. 1 - 1 Gennaio 1958

H. Fischle , J. Heintze and B. Schmidt
Experimental determination of ionization cluster size distributions in counting gases
Nuclear Instruments and Methods in Physics Research A301 (1991) 202-214

Npeak distribution for signal events

Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

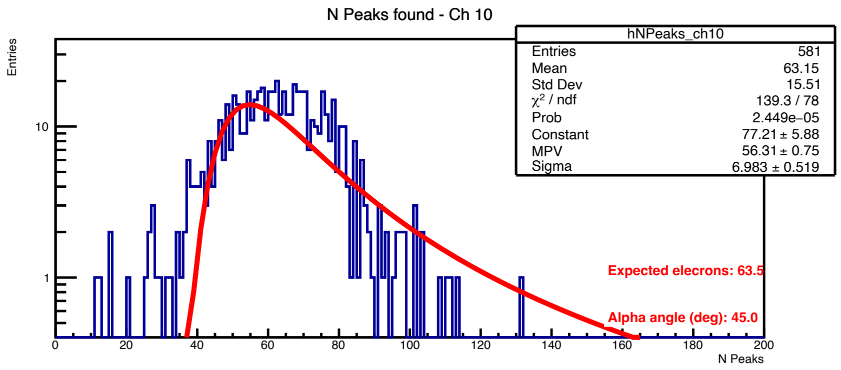
1 cm drift tubes

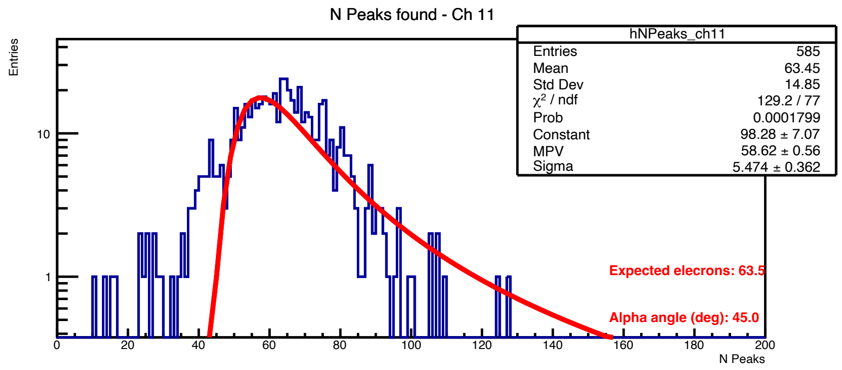


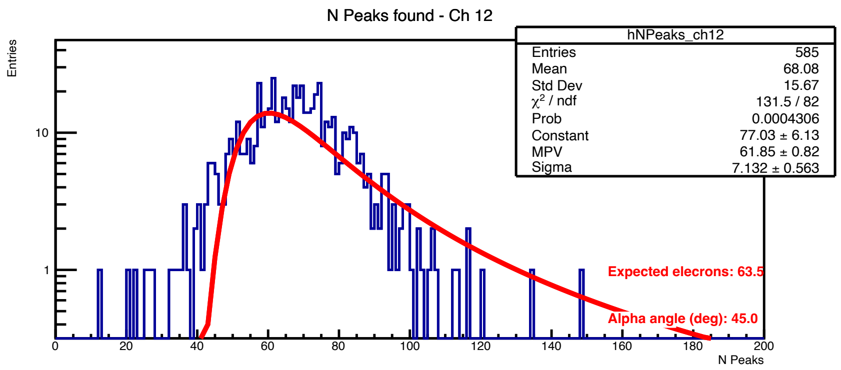
Npeak distribution for signal events

Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

2 cm drift tubes







Electrons drift velocity

Observable to monitor the Electron Peak (Cluster) algorithm :

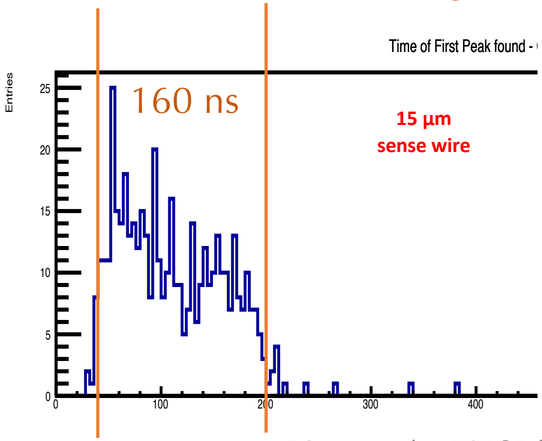
Experimental average electrons drift velocity for 1cm (2cm) drift tubes = maximum impact parameter/drift time ~ 2.5 $cm/\mu s$ (2.0 $cm/\mu s$)

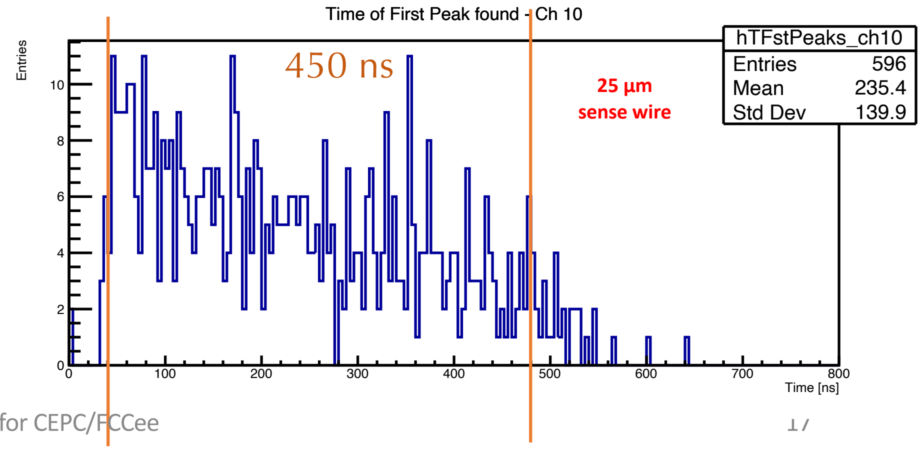
Run_91, Track angle 60°

Compatible with simulation expectations!

Maximum impact parameter for 1-cm cell drift tubes = 0.4 cm

Maximum impact parameter for 2-cm cell drift tubes = 0.9 cm



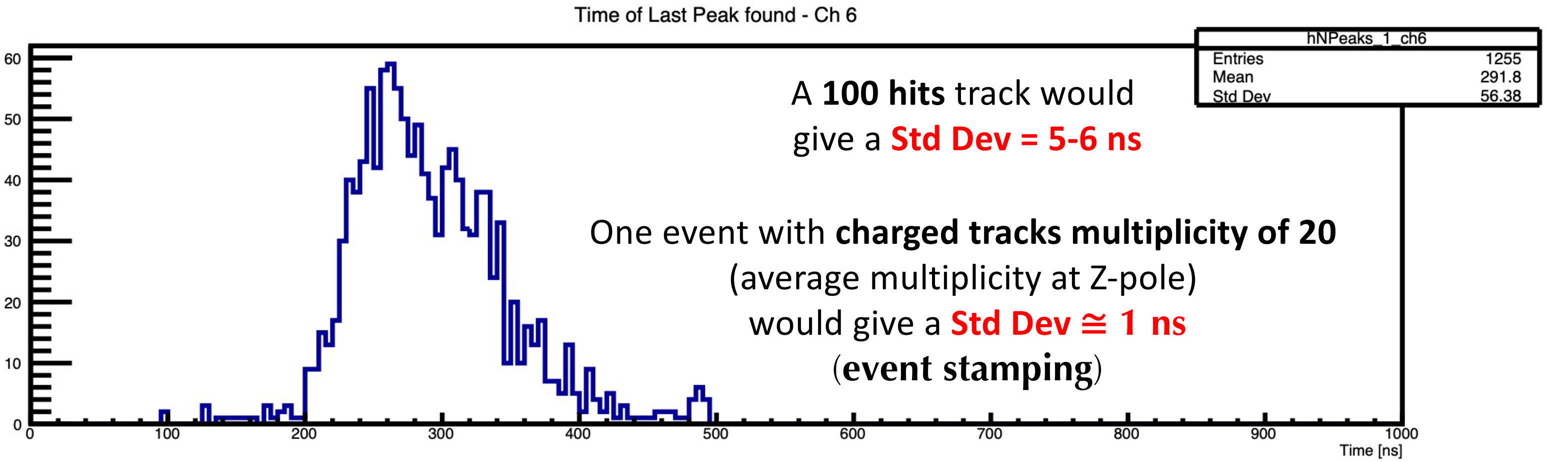


Last electron drift time spread

Observable to monitor the Electron Peak (Cluster) algorithm :

Spread of maximum drift time due to lower drift velocity at cell boundary, ionization statistics and diffusion = 50 ns expected from simulations

Maximum impact parameter for 1 cm drift tubes = 0.4 cm corresponding to 160 ns after t_0



A **100 hits** track would give a **Std Dev = 5-6 ns**

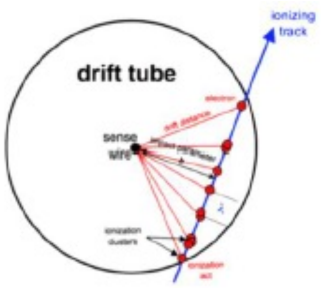
One event with **charged tracks multiplicity of 20** (average multiplicity at Z-pole) would give a **Std Dev ≅ 1 ns** (**event stamping**)

Clusterization counting strategy

Crucial step is the **clusterization of the electron peaks into ionization clusters**.

1) Association of electron peaks in consecutive bins (difference in time == 1 bin) to a single electron to correct over-counting and to eliminate fake electrons.

2) Contiguous electrons peaks which are compatible with the electrons diffusion time (2.5 ns or 3 bins relative delay) are considered as belonging to the same ionization cluster. For them, a counter for electrons per cluster is incremented.

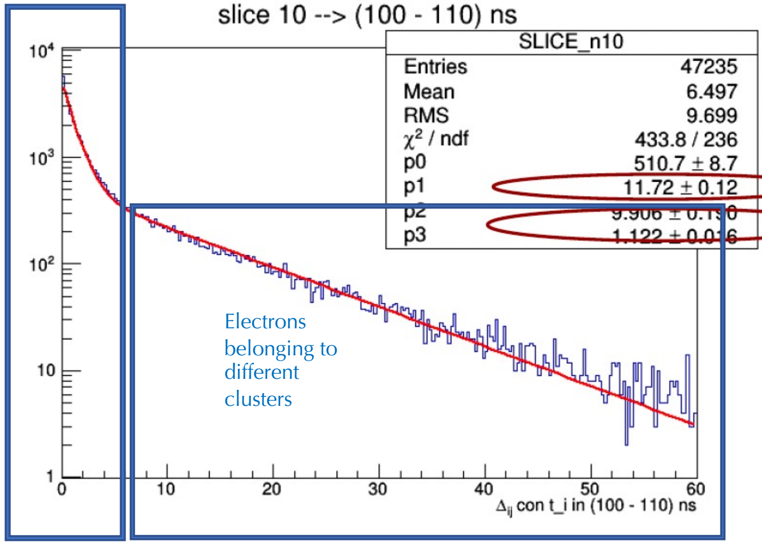


3) Position of the clusters is taken as the position of the last electron in the cluster.

4) Expect a poissonian distribution for the number of clusters!

Expected Time difference distribution between electrons

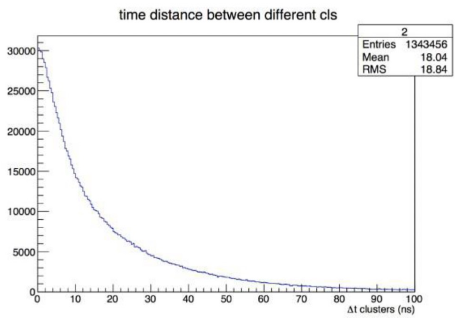
Electrons belonging to the same cluster

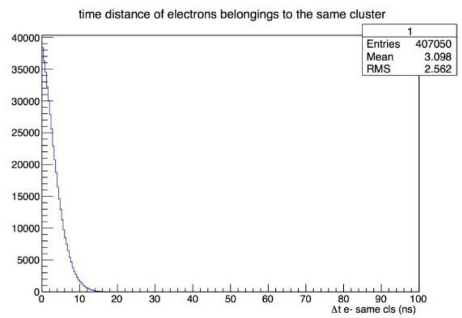


$$f(t) = Ae^{-t/\tau 1} + \mathrm{B}\, e^{-t/\tau 2}$$

τ1 describes time distance for different clusters **(10-15 ns)**
τ2 describes time distance for same cluster **(1-3 ns)**

full MC simulations (Garfield++)

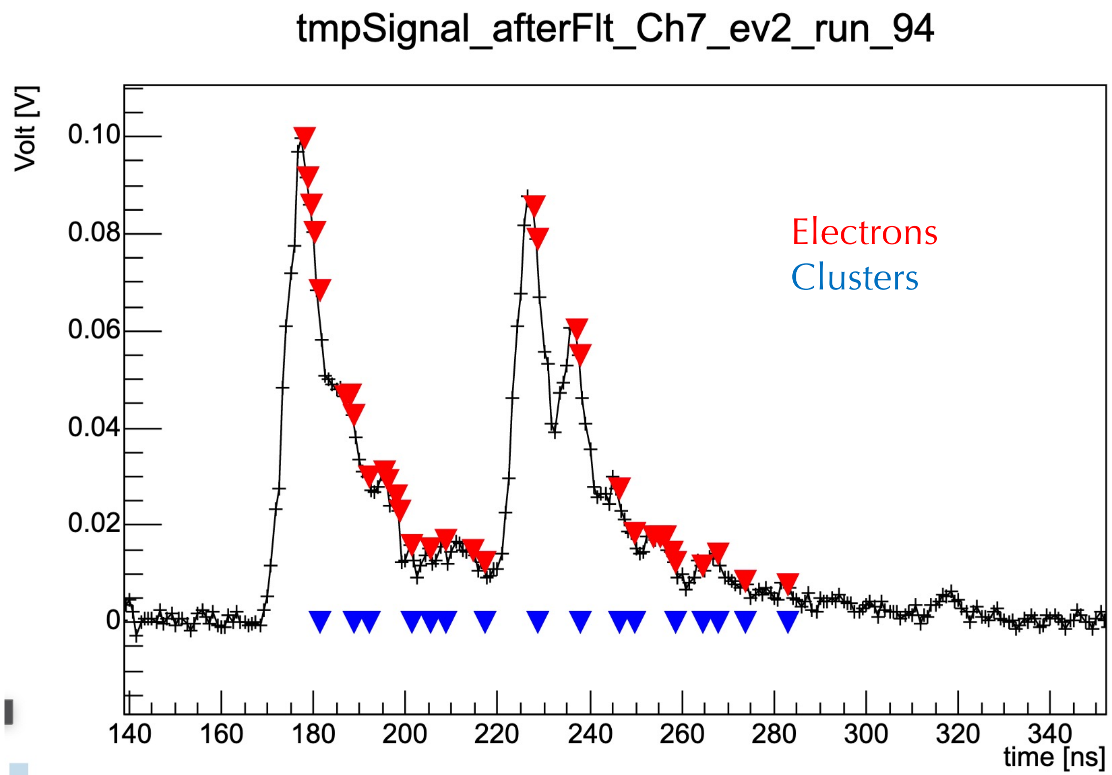


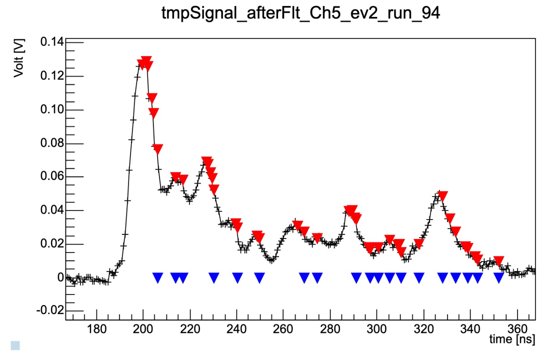


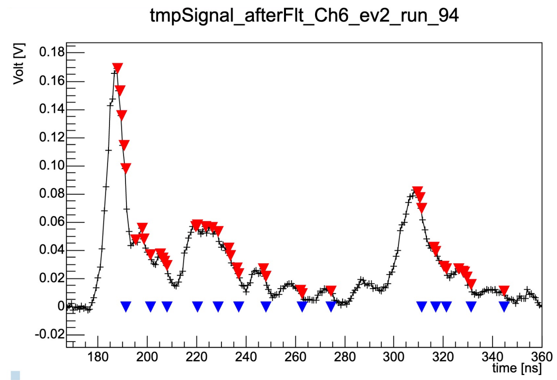
Clusters and Electrons in Waveform spectra

Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

1 cm drift tubes



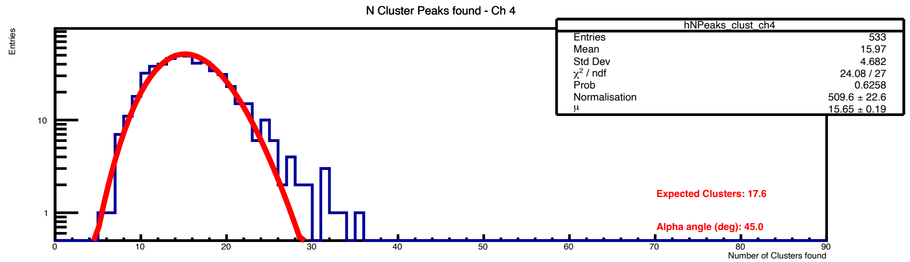


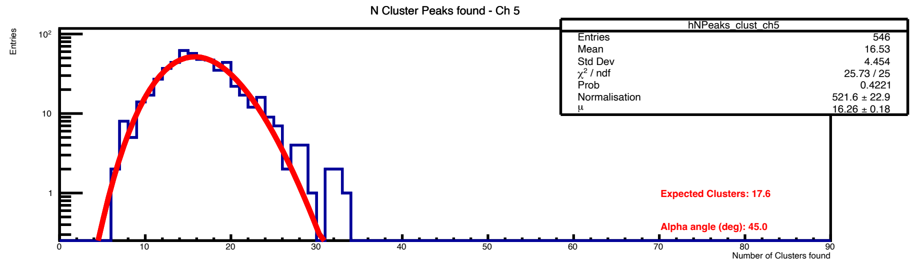


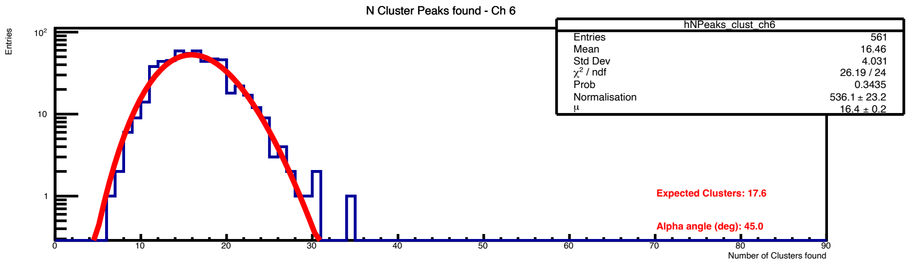
NCluster distribution for signal events

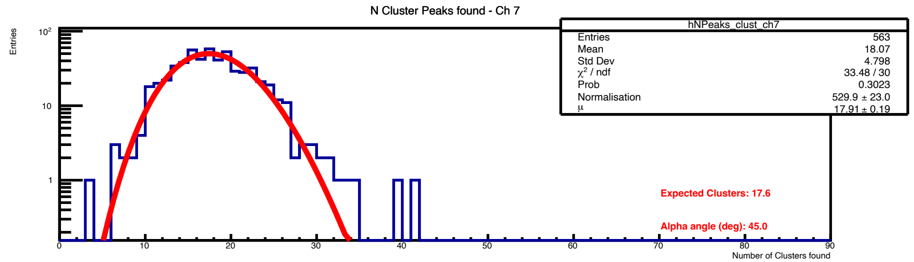
Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

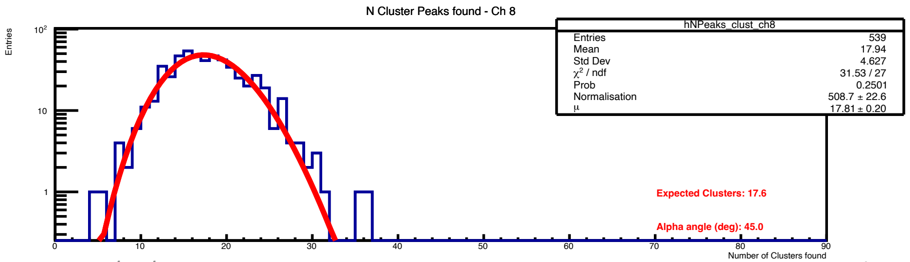
1 cm drift tubes

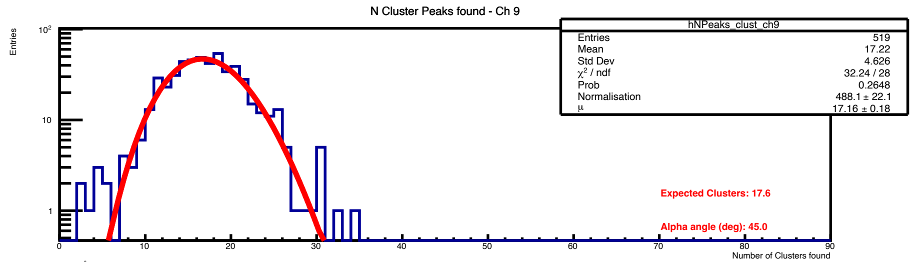








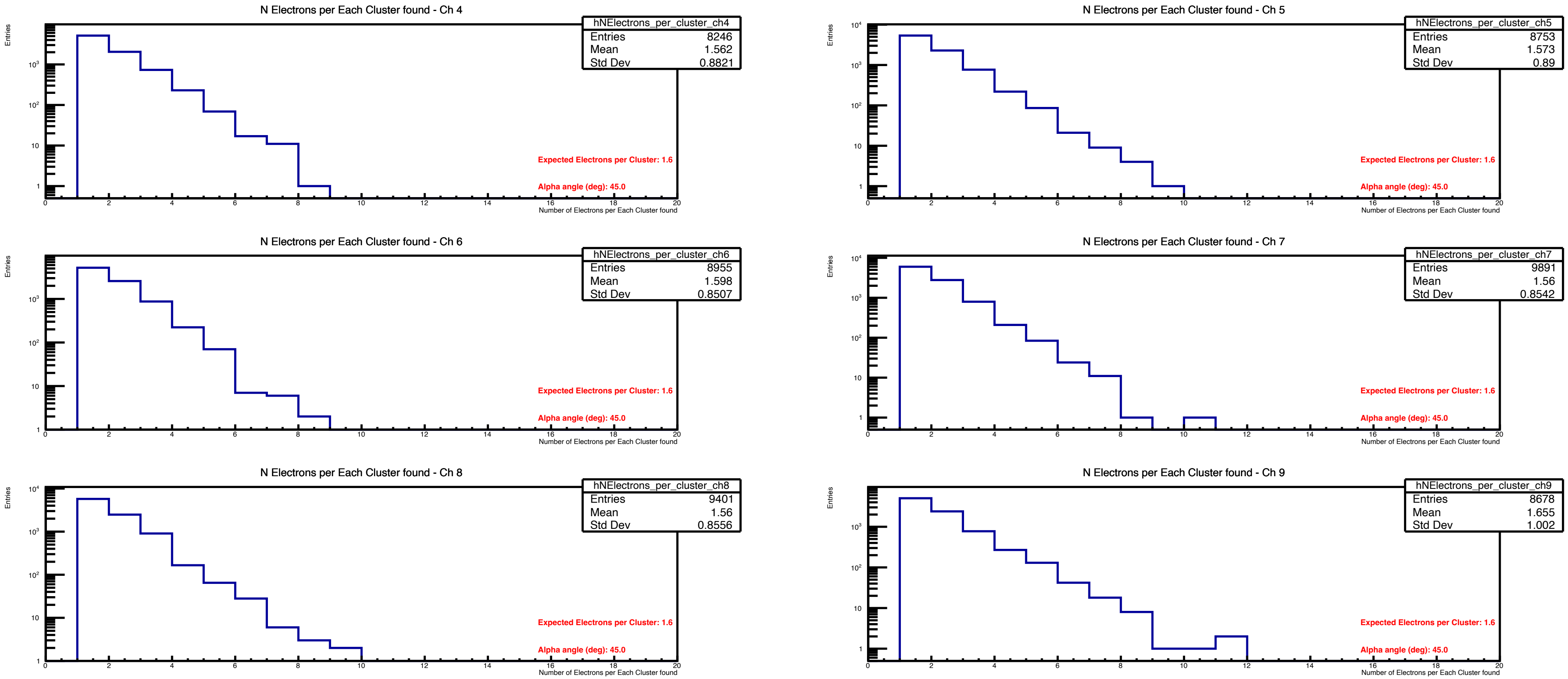




NElectronsPerCluster distribution for signal events

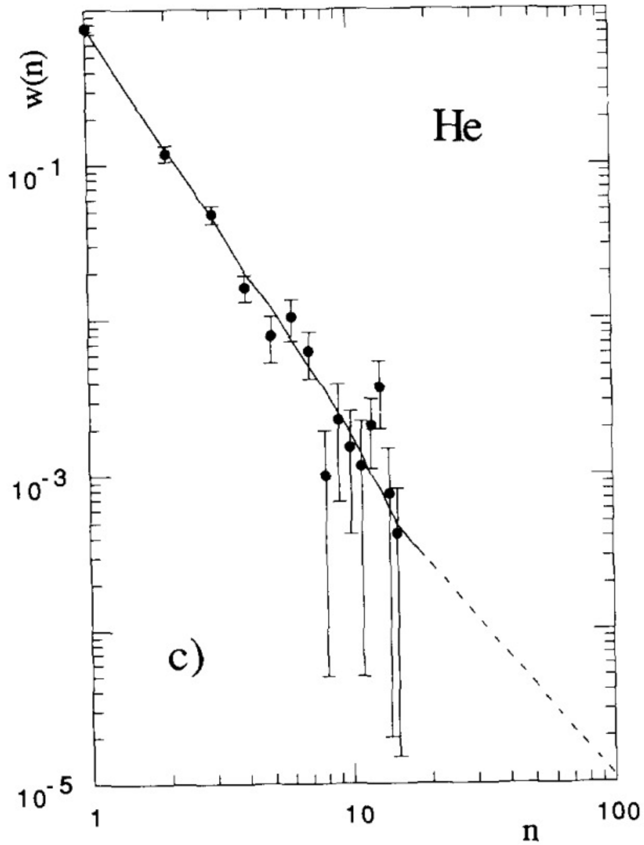
Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

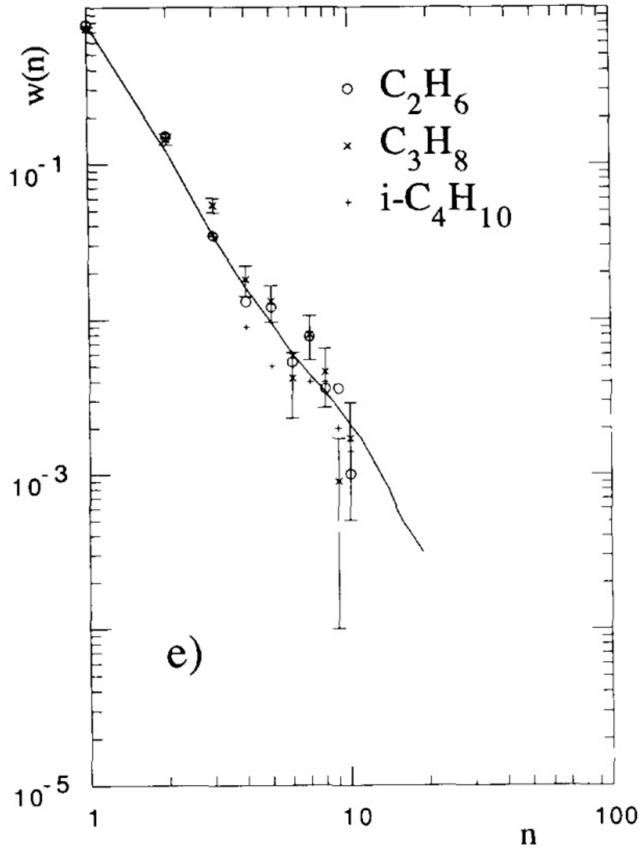
1 cm drift tubes



As expected from theory!

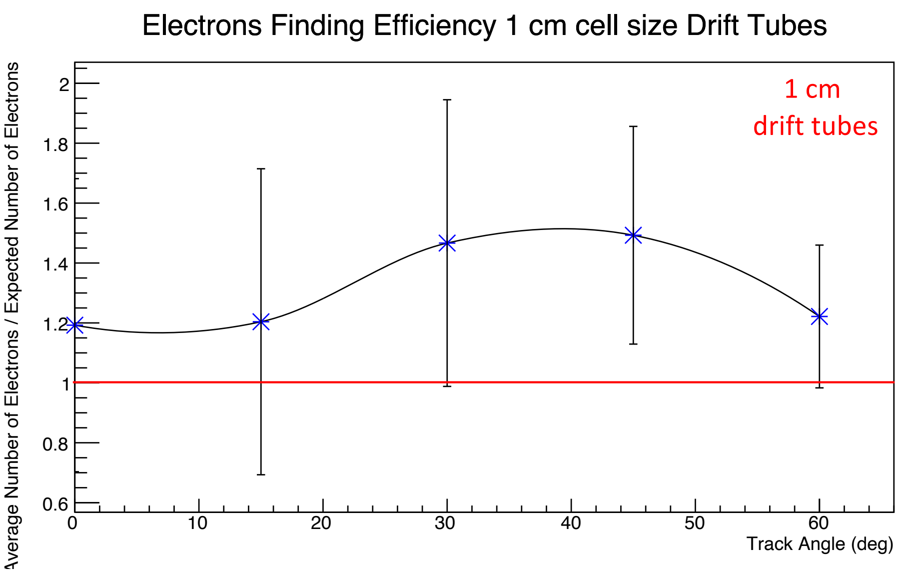
Experimental $\langle N_{electrons}/cluster \rangle \simeq 1.6$

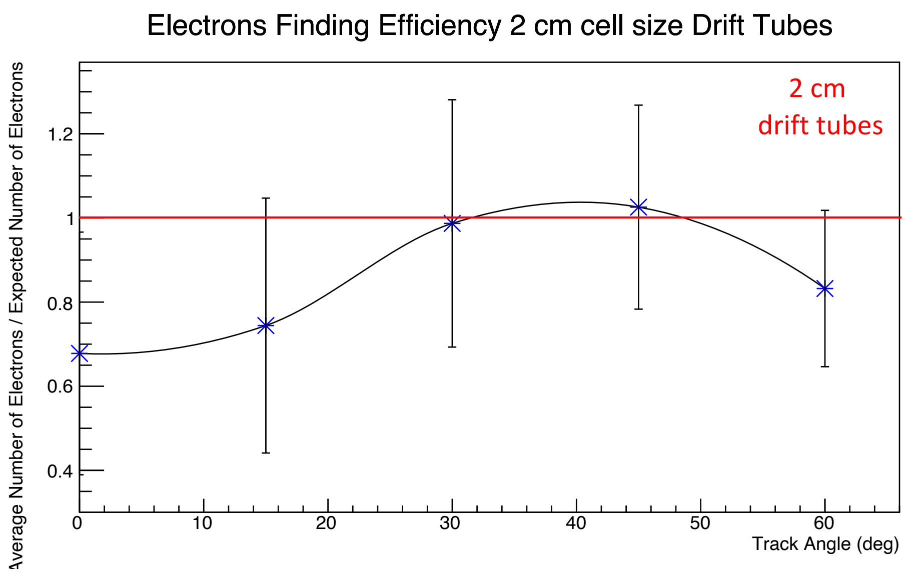




H. Fischle , J. Heintze and B. Schmidt
Experimental determination of ionization cluster size distributions in counting gases
Nuclear Instruments and Methods in Physics Research A301 (1991) 202-214

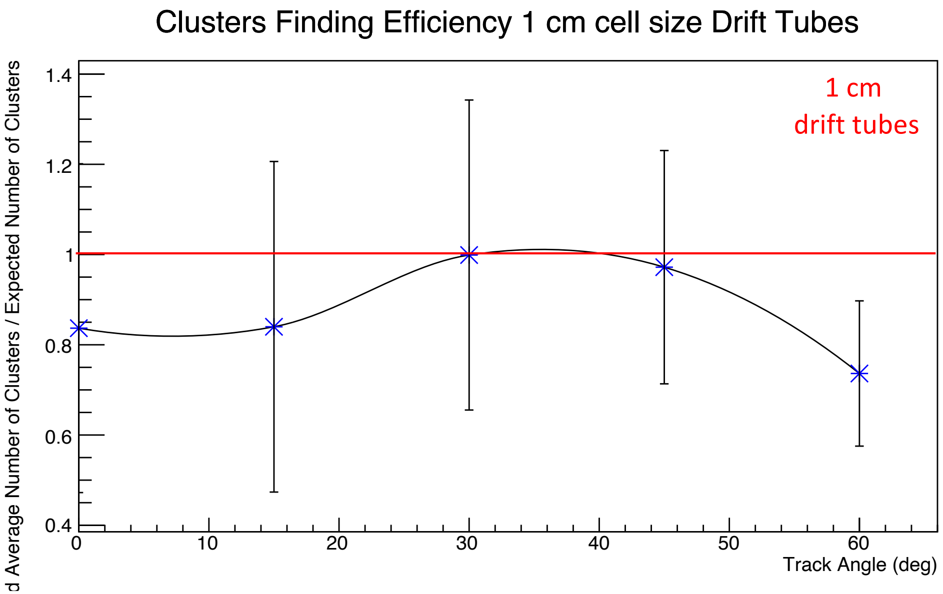
Electron peaks counting

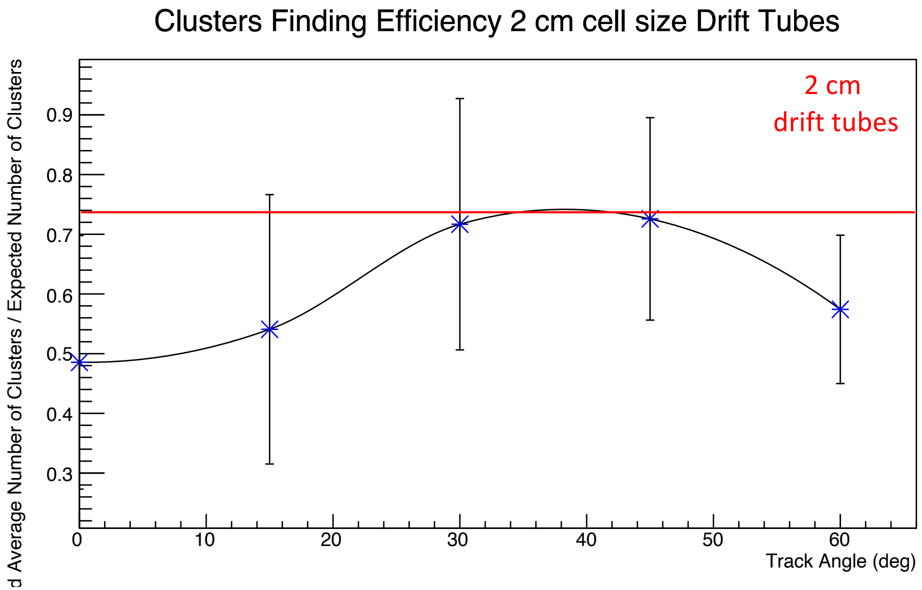




- Electrons **overcounting** due to fake electron peaks in adjacent bins (easily corrected in the clusterization algorithm)
- **Inefficiency** for 2 cm drift tubes under investigation
- **Undercounting** for $\alpha < 30°$ due to space charge effects
- **Undercounting** for $\alpha > 45°$ due to high electron peaks density (average 5 bins at 60°) → **real inefficiency** (can be corrected)

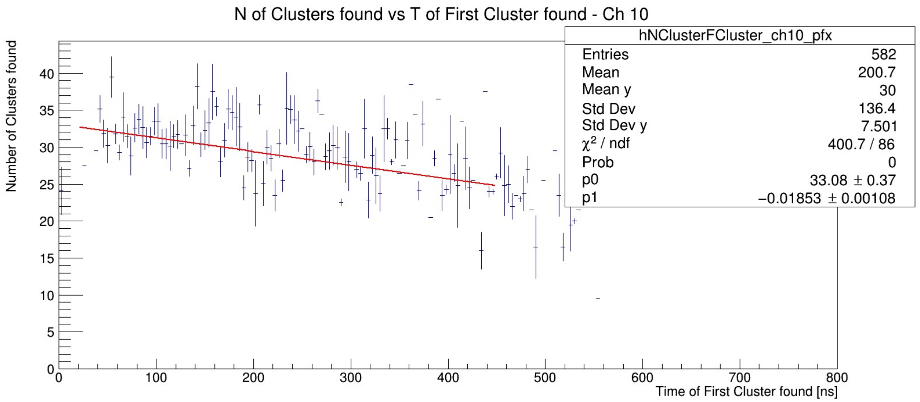
Cluster counting

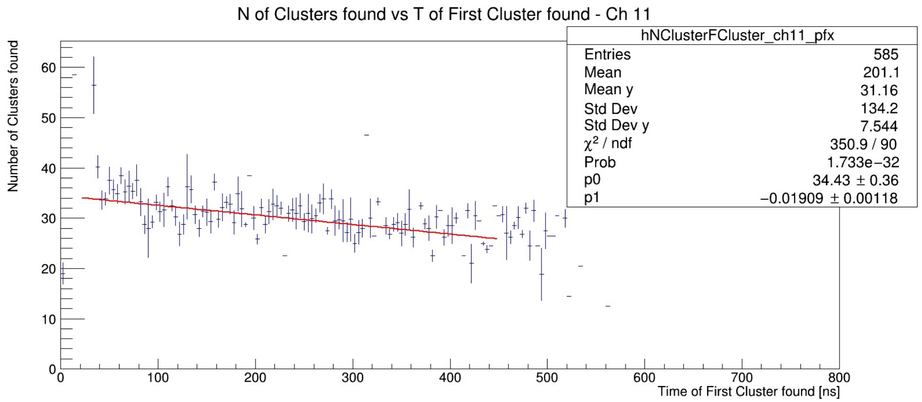


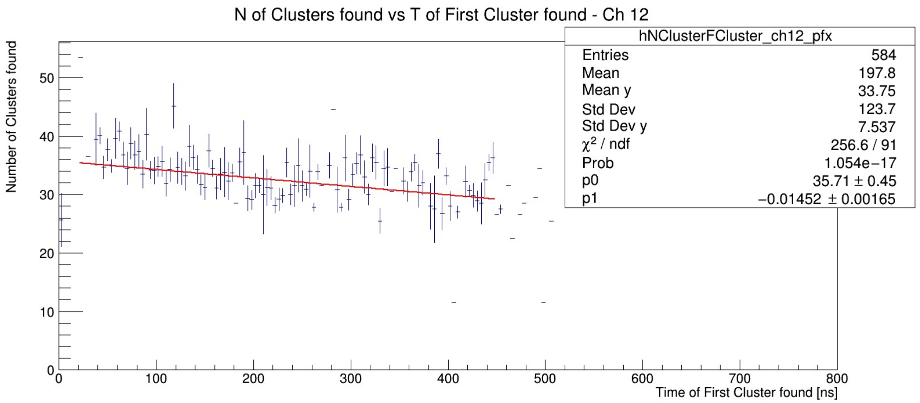


- Same effects seen in the electron peaks counting (**space charge** and high **electron peaks density**)
- **Full efficiency** and **Poisson distribution** for 1 cm drift tubes
- **25-30% average inefficiency** for 2 cm drift tubes (electron inefficiency)
- **Inefficiency** may be cured by increasing the sampling rate (more bins per peak)

Attachment and recombination





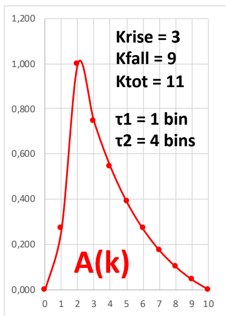


Running Template Algorithm

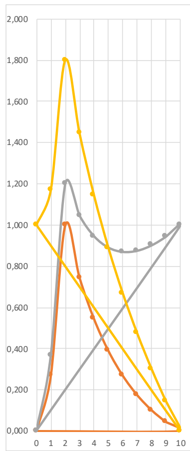
- Define an electron pulse template A(k) based on experimental data
- Raising and falling exponential over a fixed number of bins (Ktot)
- Digitize it (A(k)) according to the data sampling rate
- Run over Ktot bins by comparing it to the subtracted and normalized data (build a sort of χ^2)
- Define a cut on χ^2
- Subtract the found peak from the signal spectrum
- Iterate the search
- Stop when no new peak is found

Example 1

k	A(k)
0	0.0
1	0.269
2	1.0
3	0.744
4	0.545
5	0.390
6	0.269
7	0.175
8	0.102
9	0.044
10	0.0

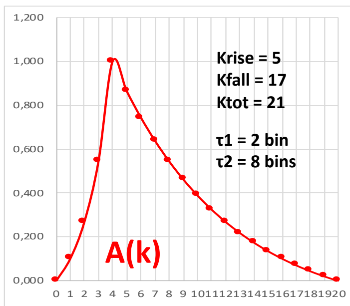


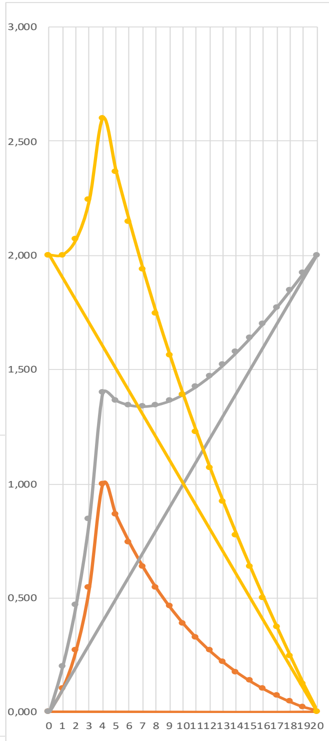
Linearly rising pulse
Linearly falling pulse
Normalized pulse



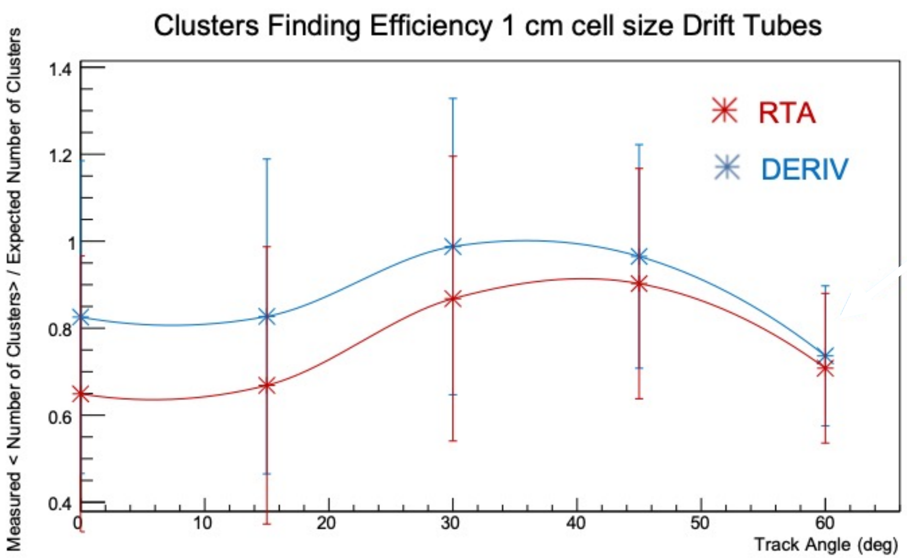
k	A(k)
0	0,000
1	0,102
2	0,269
3	0,545
4	1,000
5	0,864
6	0,744
7	0,638
8	0,545
9	0,463
10	0,390
11	0,326
12	0,269
13	0,219
14	0,175
15	0,136
16	0,102
17	0,071
18	0,044
19	0,021
20	0,000

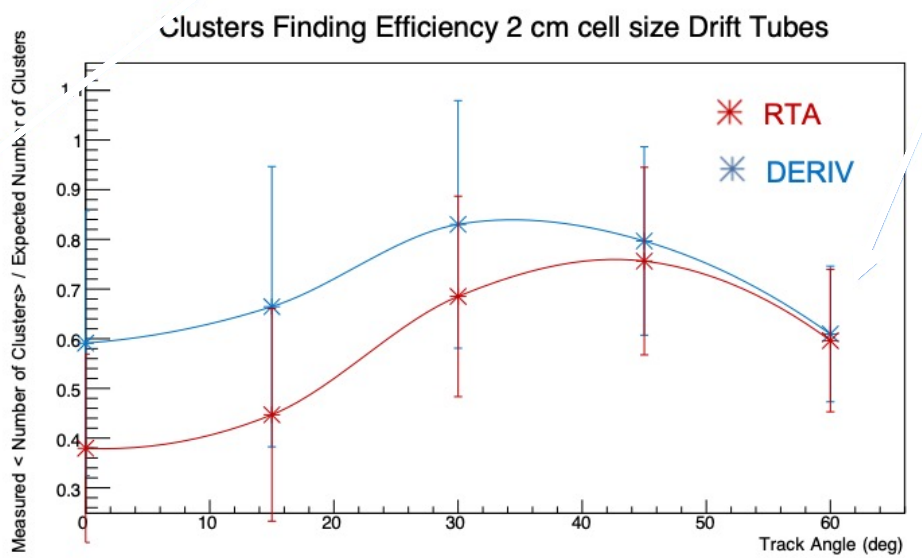
Example 2





Comparison between RTA and DERIV





- **preliminary** performance comparison
- both algorithms are quite simple from the computational point of view and have few parameters to be optimized
- both algorithms can be easily implemented in FPGA's
- new, orthogonal algorithms (Guang NN attempt) are very welcome

Considerations

- ➢ Evidence of space-charge effects and indication of space-charge dimension (essential for simulating in a realistic way the drift chamber behavior beyond Garfield++)
- ➢ Are we really counting electrons and ionization clusters?

- The number of found clusters is consistent with the expected number
  (the lower efficiency for 2 cm drift tubes needs to be fully understood)
- The first cluster drift time is distributed as expected with the expected drift velocity
- The time spread of the last cluster is distributed as expected, allowing for an event time stamping at the Z-pole at the level of 1 ns
- The average number of electrons per cluster, 1.6, is consistent with experimental measurements
- Two completely different approaches (DERIV and RTA) provide consistent results

Conclusions

- **Particle identification** via **dE/dx** has essentially made **no progress since over 40 years**.
- **Cluster counting** may provide the at length awaited jump in performance.
- Both analytical and montecarlo simulations suggest an **improvement of a factor 2 of dN/dx versus dE/dx**.
- Byproduct of the **cluster counting** technique is the **cluster timing** technique, which offers **improvements in the impact parameter resolution** (directly coupled to transverse momentum resolution) and allows for **a precise event time-stamping**.
- Absolute performance of **particle separation power in the relativistic region** (crucial for FCC-ee and CEPC) needs to be assessed with **experimental measurements**.
- A strongly motivated **beam test campaign** has begun. So far, we have concentrated our efforts in successfully demonstrating the **ability to efficiently count ionization clusters**.
- Next step will be the experimental measurement of the **cluster density** and **cluster size distributions over the relativistic rise region**, which will begin this coming summer at CERN H8.