Find-Electron Peaks and Find-Ionization Cluster algorithms

November 2021 CERN Test Beam Offline Analysis

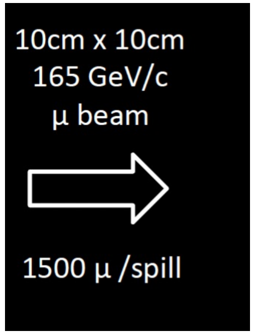
brunella.danzi@ba.infn.it

Speaker:
Brunella D'ANZI

Date:
17.03.2022

Context

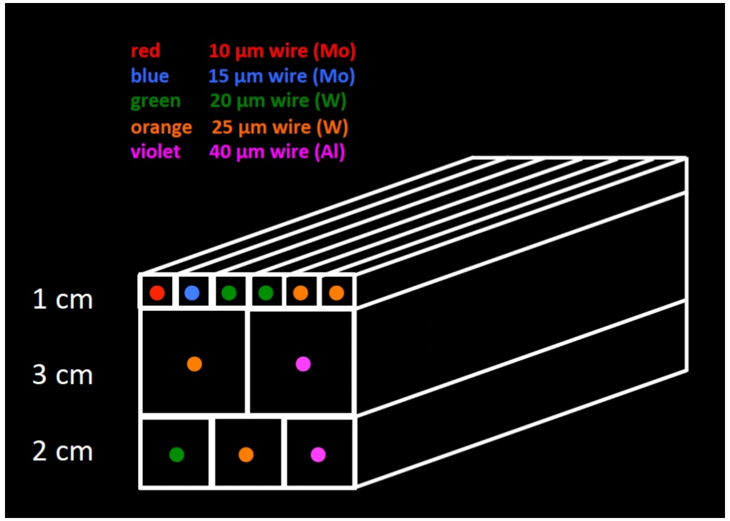
- ❑ Offline analysis on November test beam data taken with 165 GeV/c muons beams from 11st November
- ❑ Dealing with 11 drift tubes having cell sizes of 1-cm,2-cm and 3-cm:



- ➢ **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

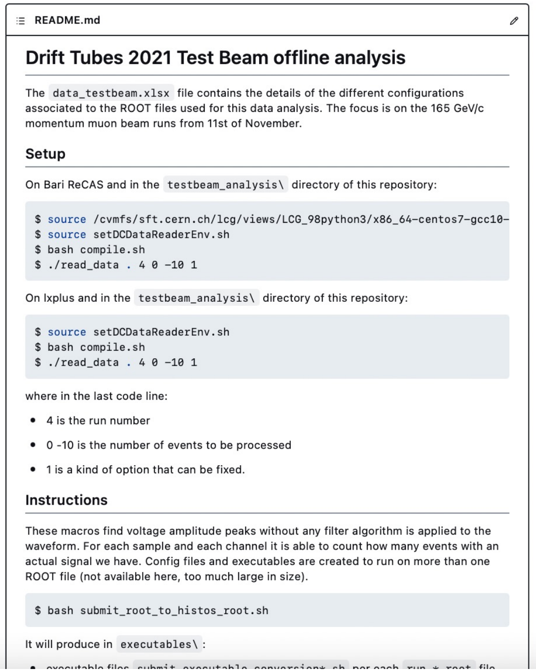
Signal acquisition window is out of the signal range

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} ;

- 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**



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\` :

Preliminary Signal Processing

The electron peaks search is performed:

- by working on the **waveform spectrum in time**, which is a 1024-bins sampled signal (for example for 1.2 GSPS it corresponds to almost 853.33 ns) with the assumption that the baseline is set to zero.

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

NOTE:

Baseline for each waveform (event,channel) = Average wave amplitude on the first signal-less bins (30 bins corresponding to 25 ns for 1.2 GSPS runs)

Find Electron Peaks strategy

- Some NEWS for the SIGNAL event definition:

- We loop on the **j-th channels of an i-th event,** and we count how many 1-cm and 2-cm drift tubes satisfies the following conditions. In this way we are able to eliminate the tails in the (Npeaks/Ncluster/Max etc.)distributions correspondings to only-noise events:
  - First Condition: Waves_normalized[channel].max > 10 r.m.s. ;
  - Motivation: looking by eye to our noise-only spectra in time, this is a reasonable cut ;
  - Second Condition: Integral of the Waveform (sum of the waveform amplitudes) must be >=100 mV from 20-th bin to the 700-th bin (excluding the first and last bins where the only-noise signal is present) corresponding to 1 Coulomb ;
  - Motivation: Number expected by looking at the maximum amplitude of the waveform spectra + Amplitude of the Electron Peaks expected.
- **BEFORE** starting the Electron Peaks search for the **j-th channel of an i-th event**, we check if it satisfies the previous two conditions and if at least four (three) 1-cm (2-cm) tubes in the event have passed the previous requests in the i-th event.
- **AFTER** performing the Electron Peaks search for including an event and its observablers into distributions associated to a specific run:
  - Second Condition: if ((NPeak>1 && channel<=9 && NPeak<100) || (NPeak>9 && channel>=10 && channel<=12 && NPeak<150));
  - Motivation: Theoretical expectation on the number of Electron Peaks found (see next slides).

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

Find Electron Peaks strategy (cont.)

- **DURING** the Electron Peaks search:
- Search range: exclusion of the last bins for the research (424 for 1 cm drift tubes, 64 for 2 cm drift tubes)
- Motivation: DRS calibration peak at the end of the spectrum + physical constraint related to the upper limit on the drift time of the electrons
- Requirements for a good peak candidate in the 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

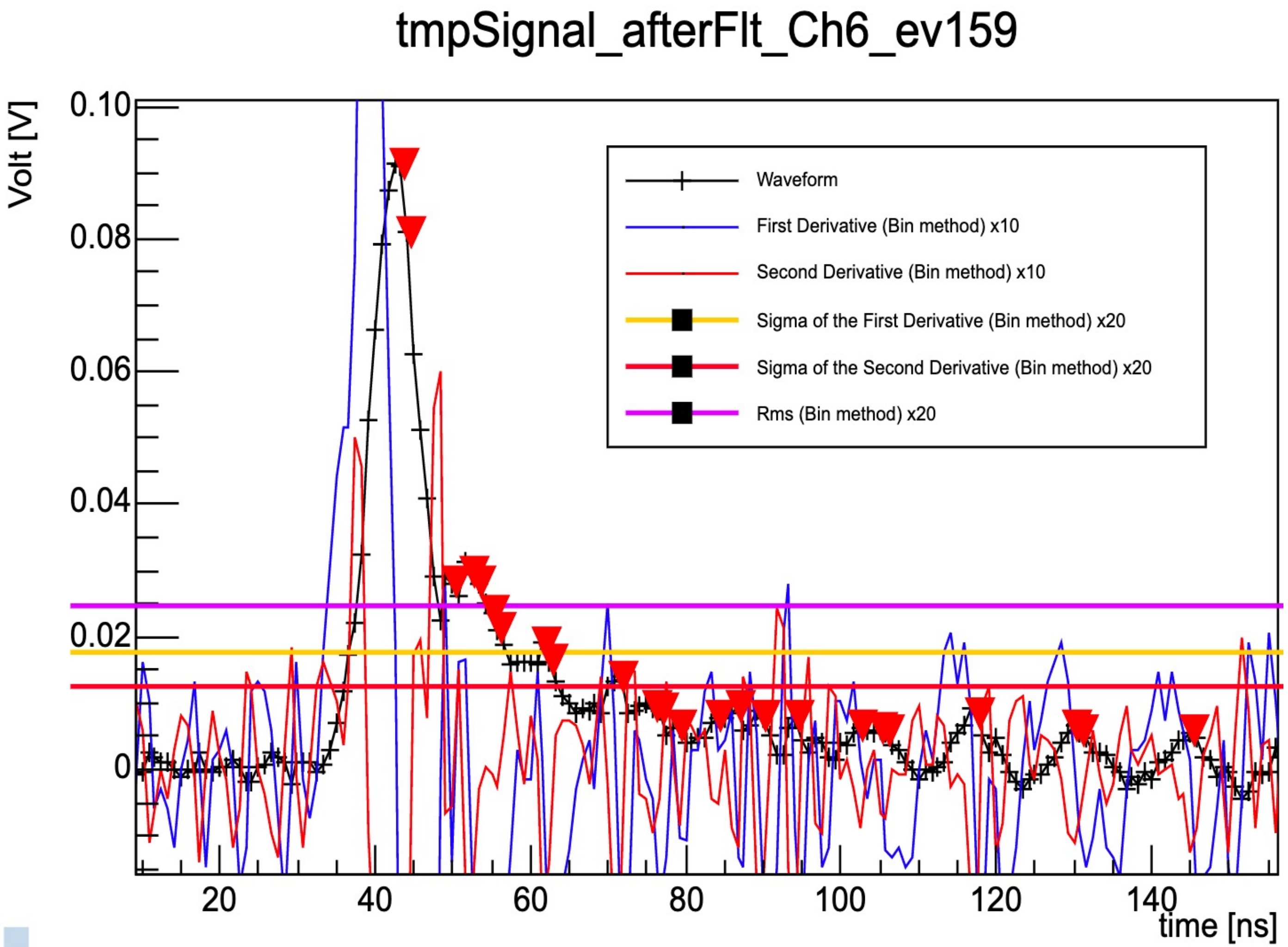
sigd1 = rms/sqrt(2)

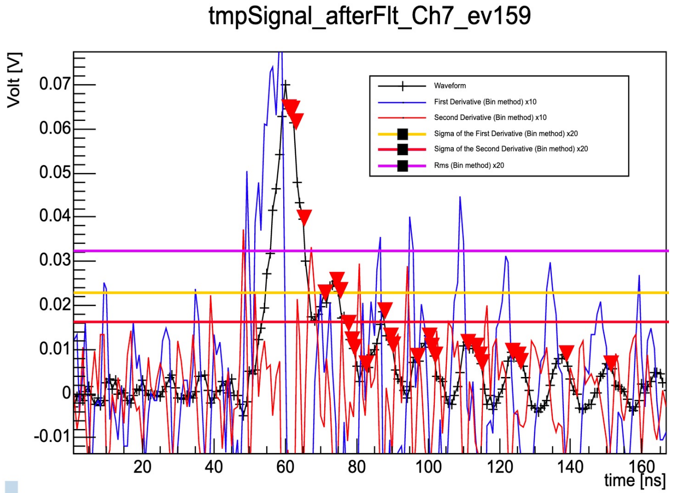
sigd2 = rms/2

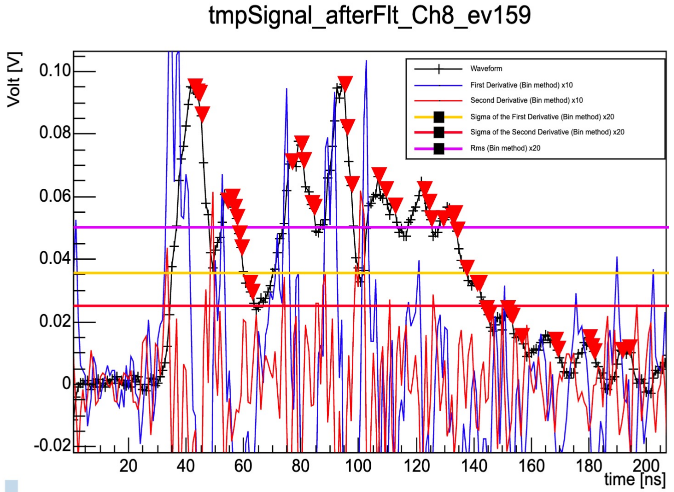
Normalized waveform spectrum with peaks found

1 cm drift tubes

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



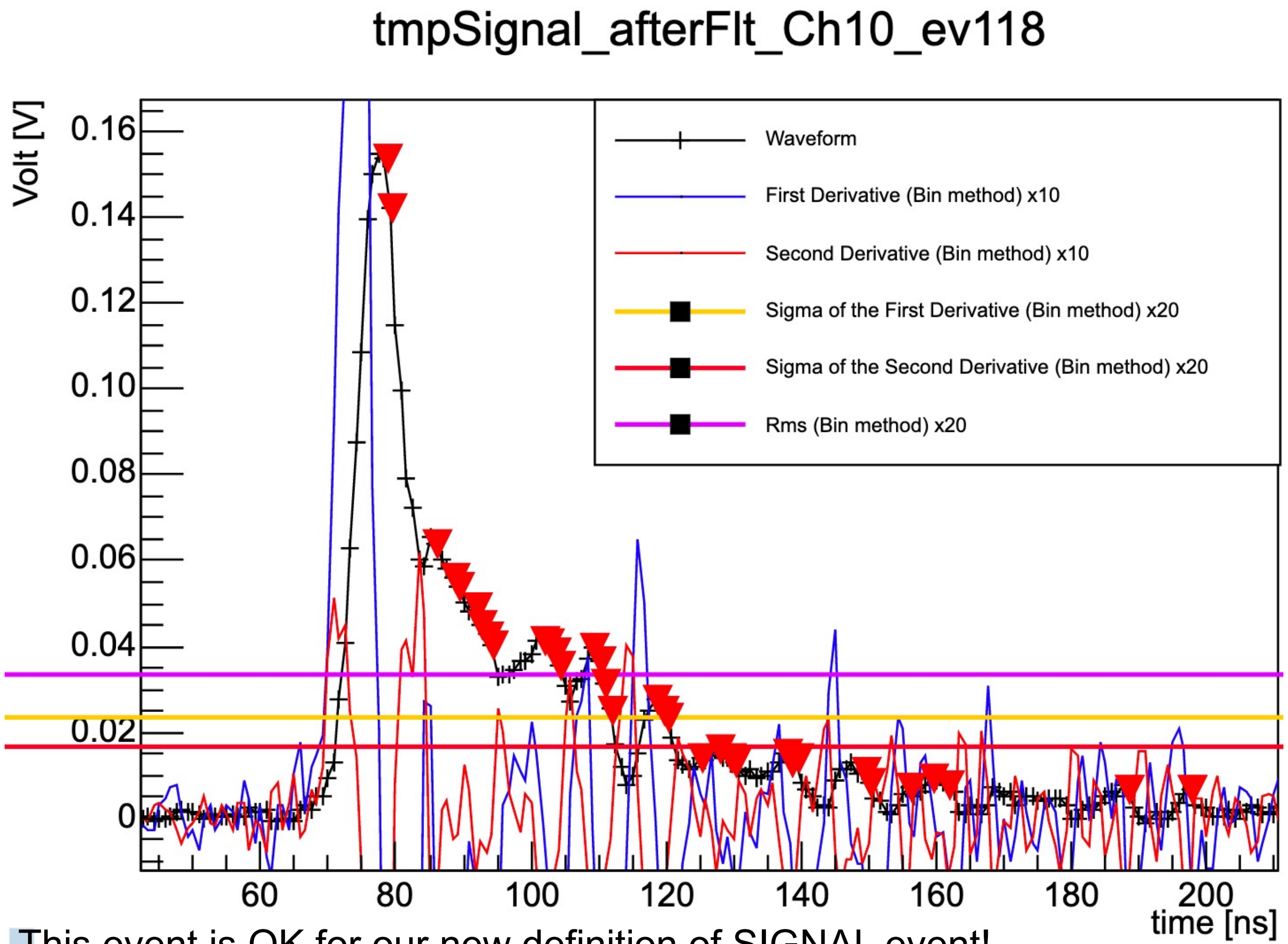




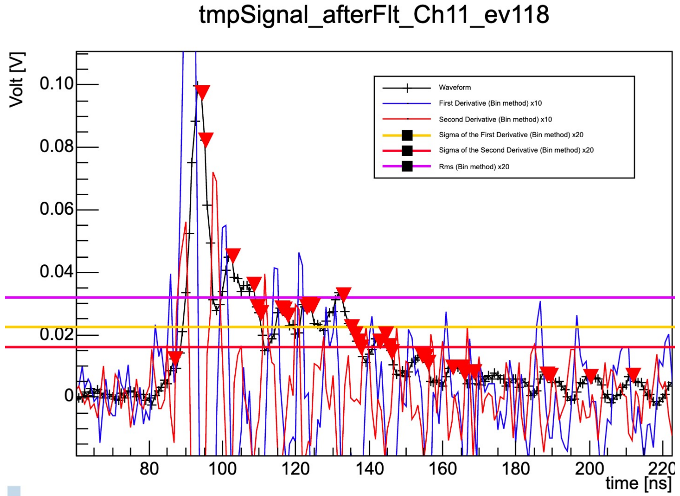
Normalized waveform spectrum with peaks found

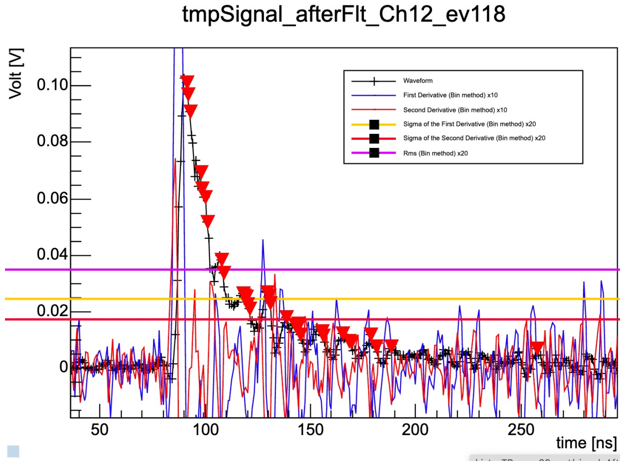
2 cm drift tubes

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



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

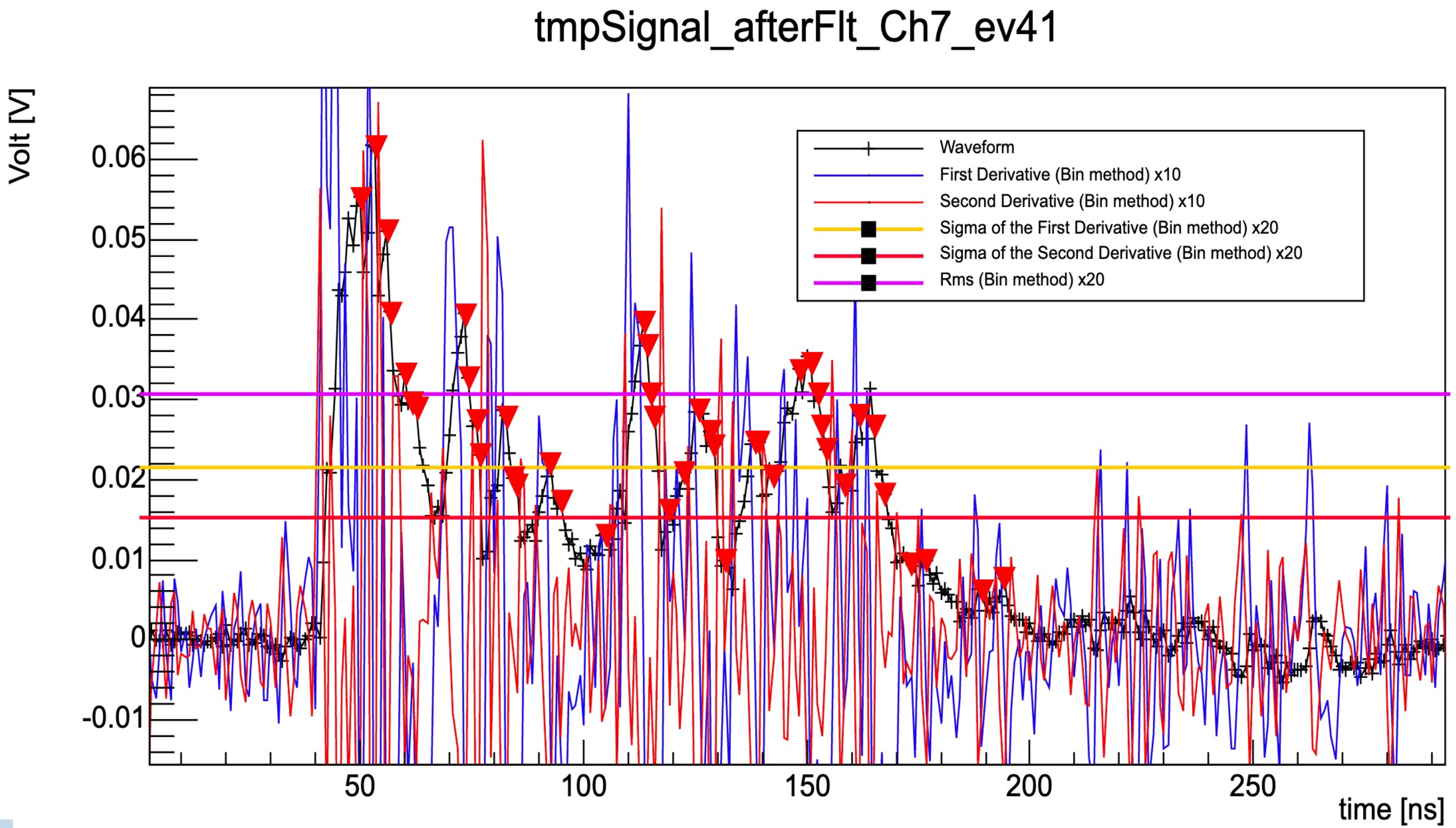




Normalized waveform spectrum with peaks found

1 cm drift tubes

Run: **run_127.root; Track angle(deg): 60° ; Gas mixture:** ***80%He20%iC$_4$H$_{10}$*** **; HV = +20**

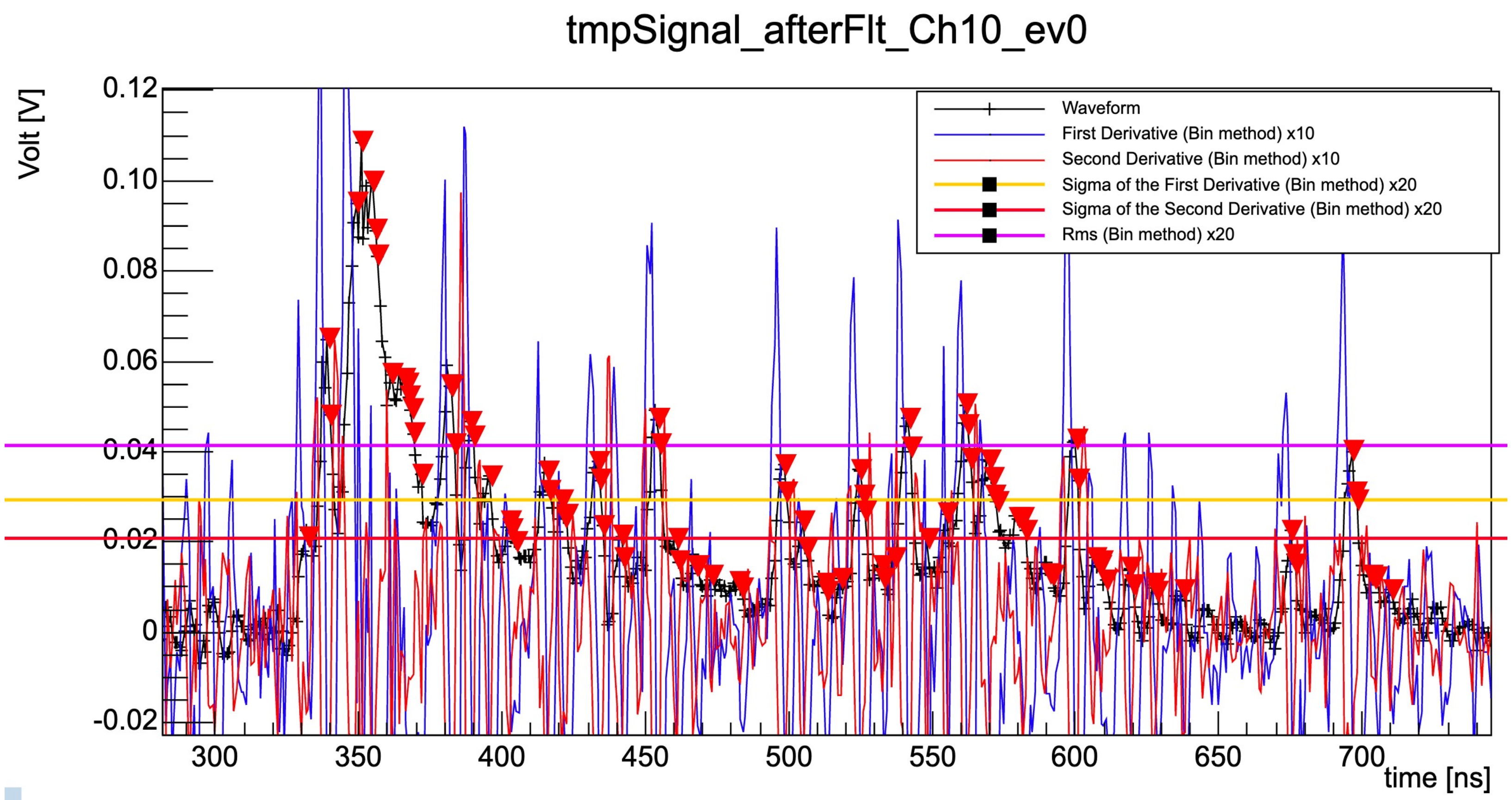


As it is expected, cluster near the wire correponds to larger amplitude and narrow time of arrival for the electrons

Normalized waveform spectrum with peaks found

Run: **run_127.root; Track angle(deg): 60° ; Gas mixture: *80%He20%iC$_4$H$_{10}$* ; HV = +20**

2 cm drift tubes



Cluster far from the wire corresponds to a smaller amplitude and larger time of arrival for the electrons

Expected number of Electron Peaks

Observable to be checked for understanding if we are going in the right direction with our Electron Peak (Cluster) algorithm :

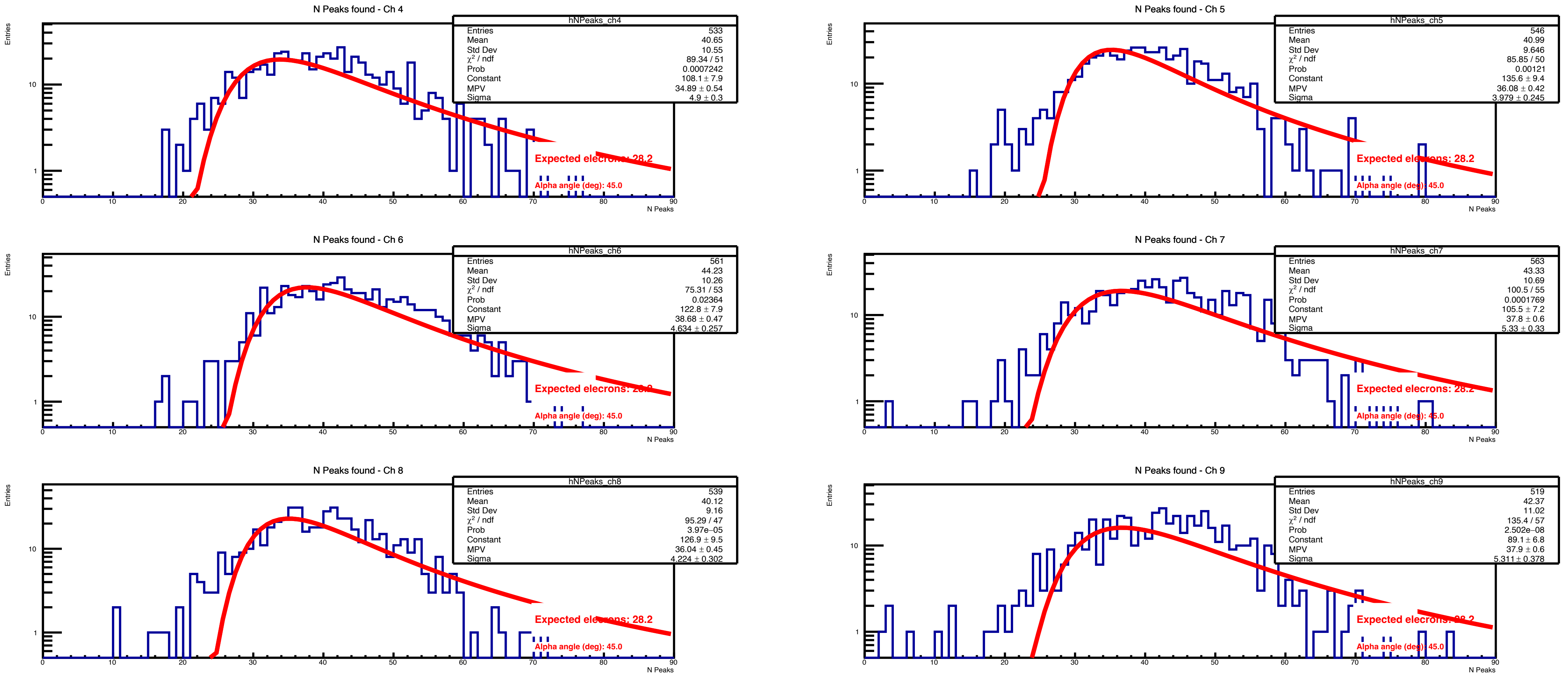
- NPeak (Expected number of electron peaks; Landau distribution) = δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise)* 1.6 electrons/cluster * 1/cos(α)
- NCluster (Expected number of clusters; Poissonian/Gaussian distribution) = δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise)* 1/cos(α)

- α corresponds to the angle of the muon track w.r.t. drift tube direction
- 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

Npeak distribution for signal events

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

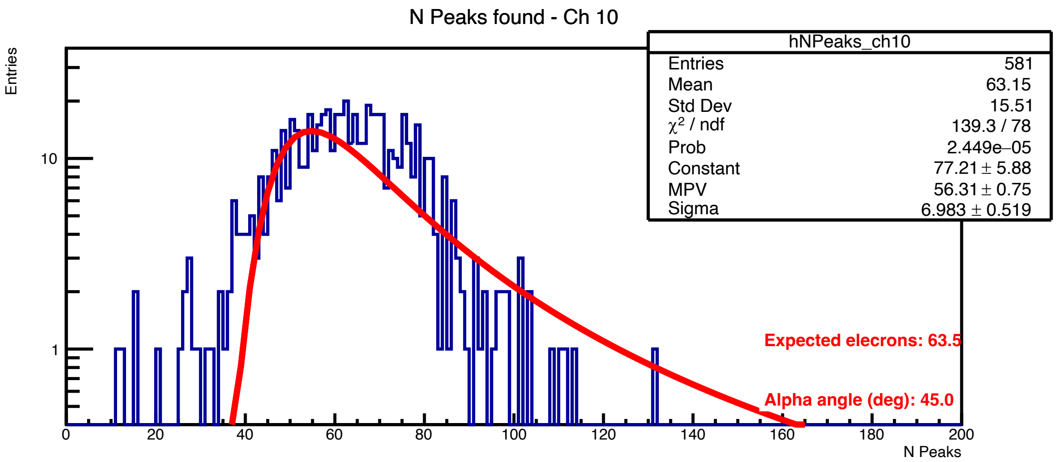
1 cm drift tubes

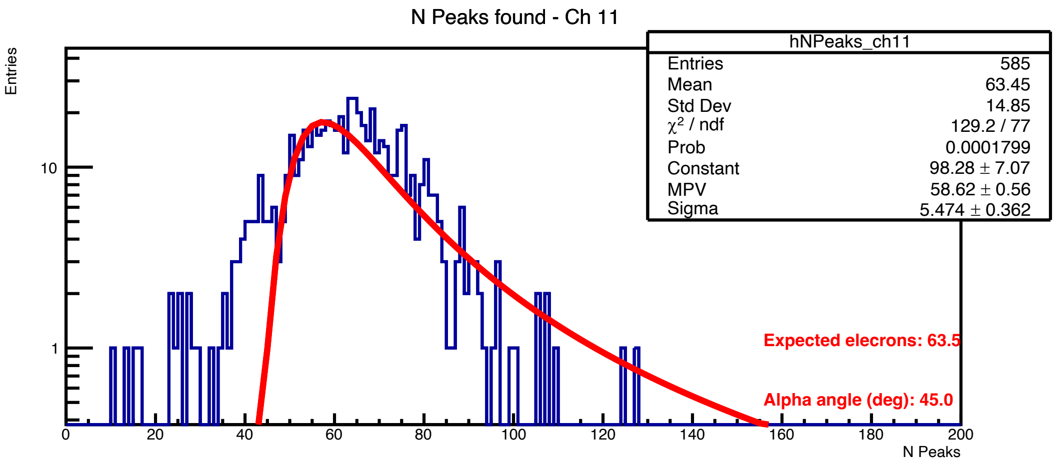


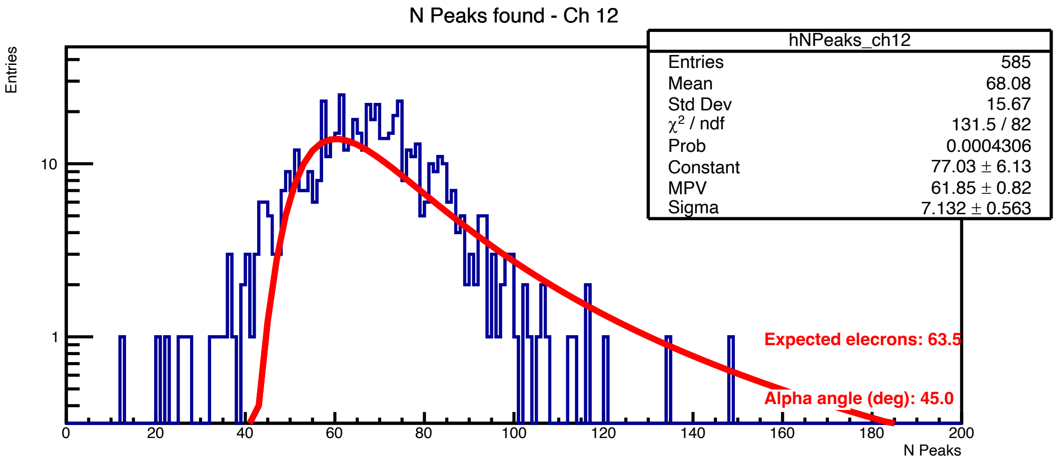
Npeak distribution for signal events

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

2 cm drift tubes



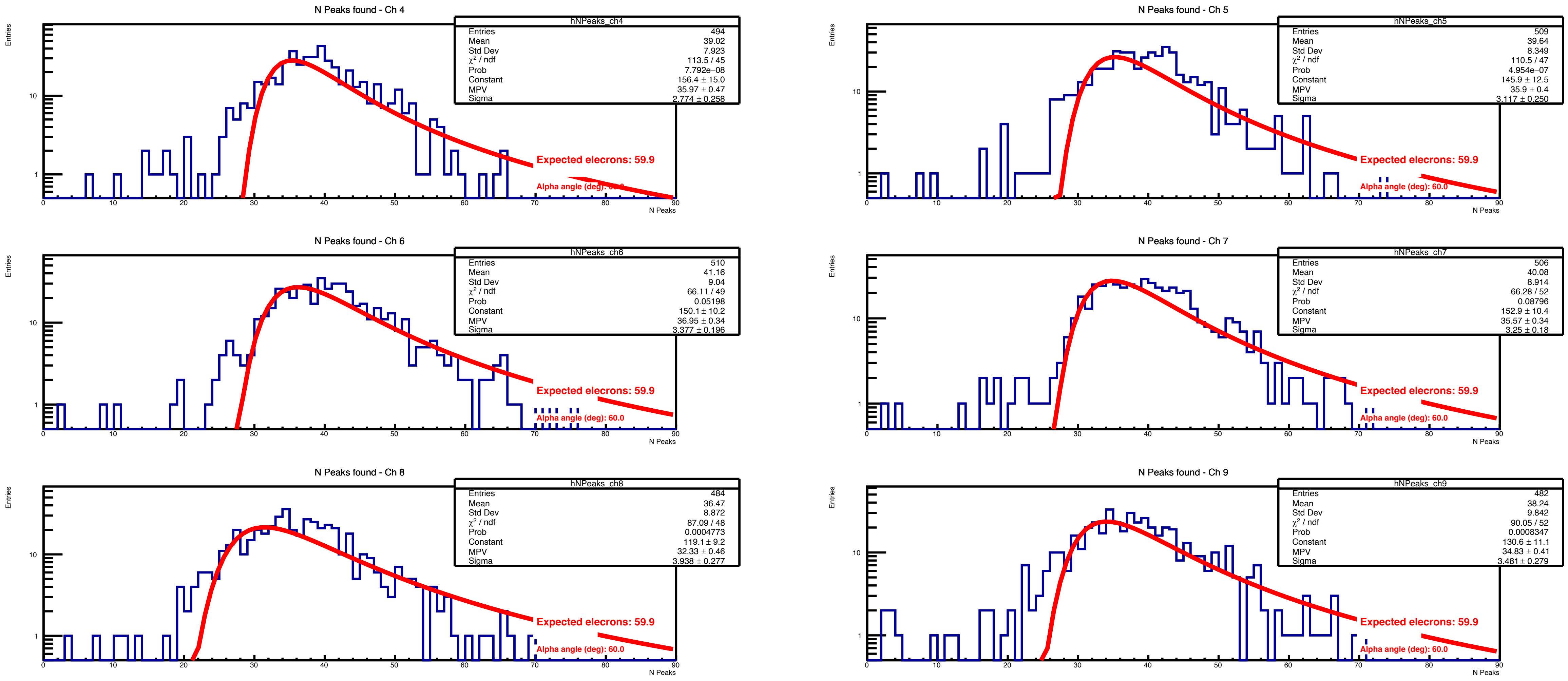




Npeak distribution for signal events

Run: run_127.root; Track angle: 60° ; Gas mixture: 80%He ; HV = +20V

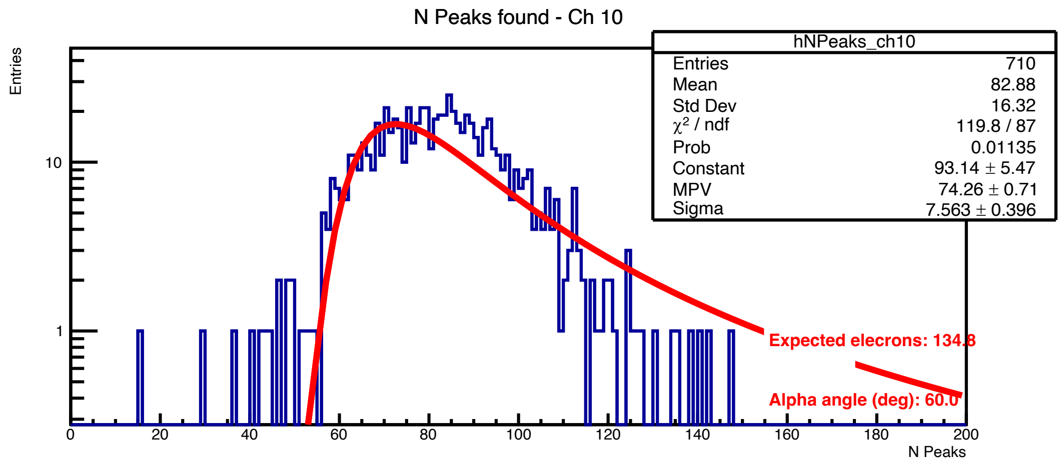
1 cm drift tubes

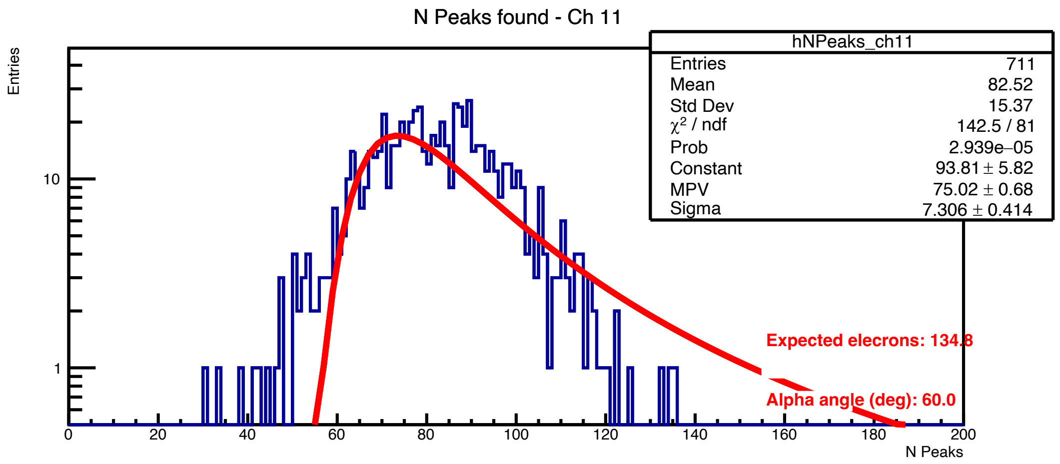


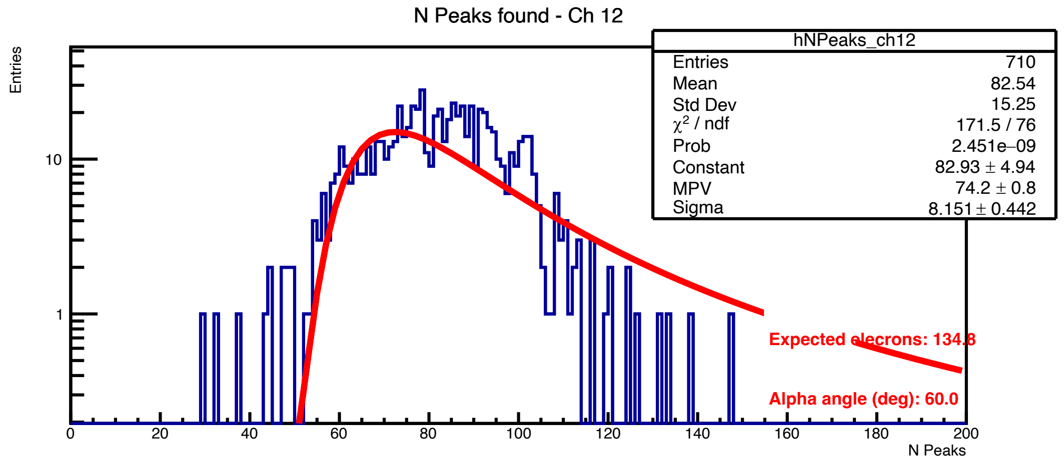
Npeak distribution for signal events

Run: run_127.root; Track angle: 60° ; Gas mixture: 80%He ; HV = +20V

2 cm drift tubes







Drift velocity of Electrons from First Time Peaks distributions

Observable to be checked for understanding if we are going in the right direction with our Electron Peak algorithm:

Experimental Electrons Drift velocity for 1cm (2cm) cell drift tubes

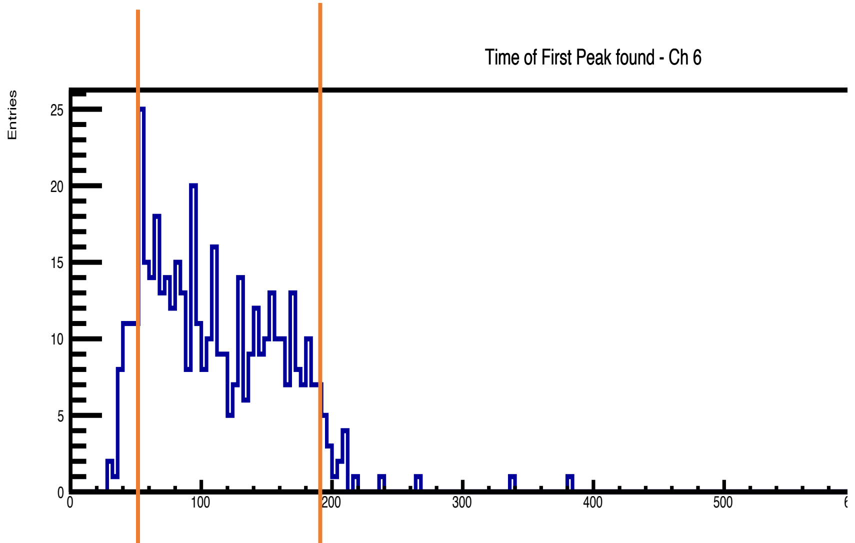
= maximum impact parameter/drift time ~ 2.5 $cm/\mu s$ (2.2 $cm/\mu s$)

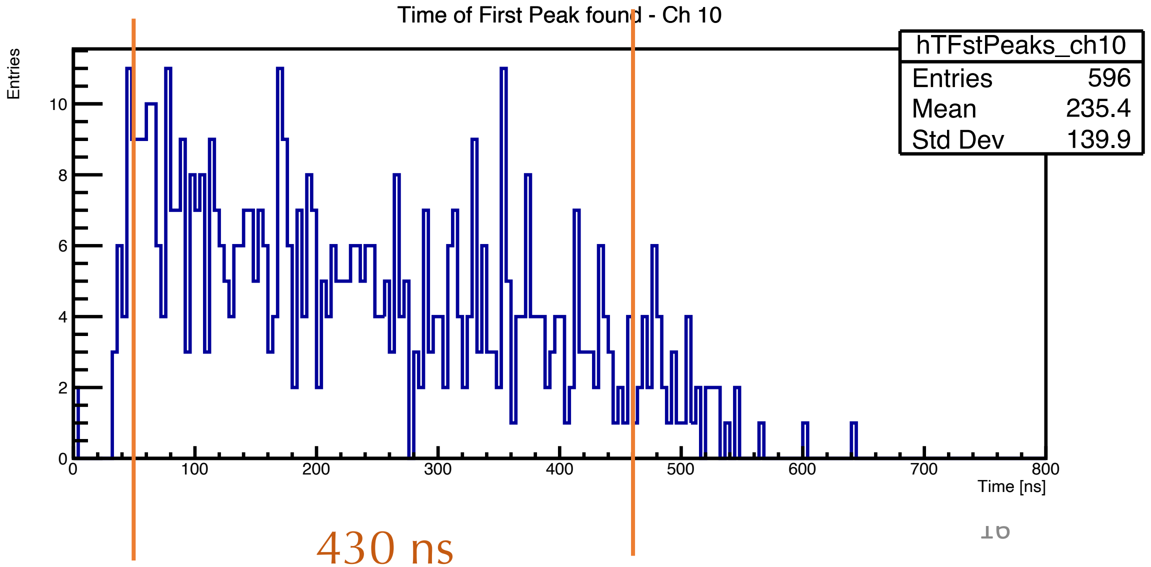
Compatible with simulation expectations!

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

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

From Run_91, Track angle 60°

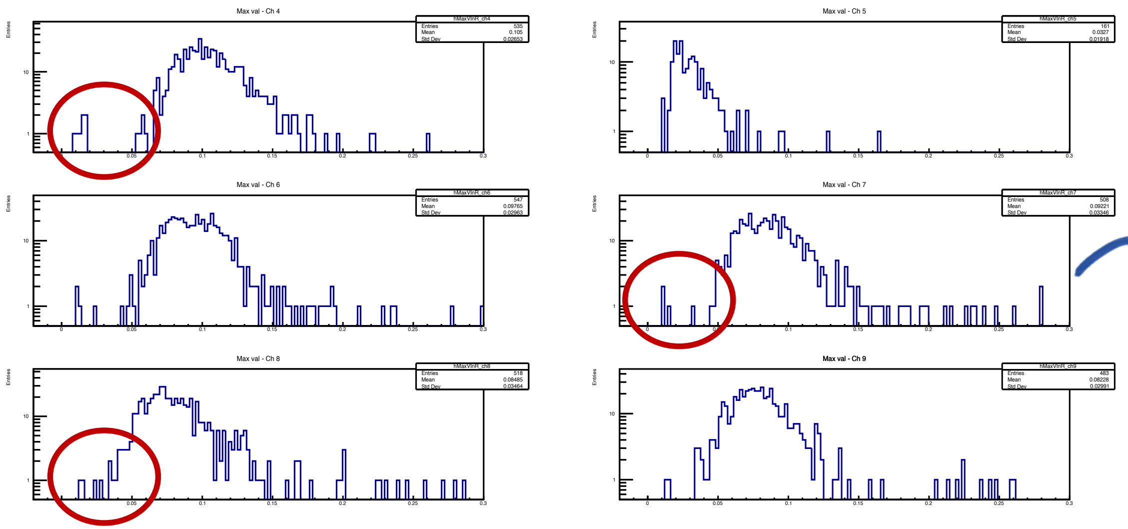




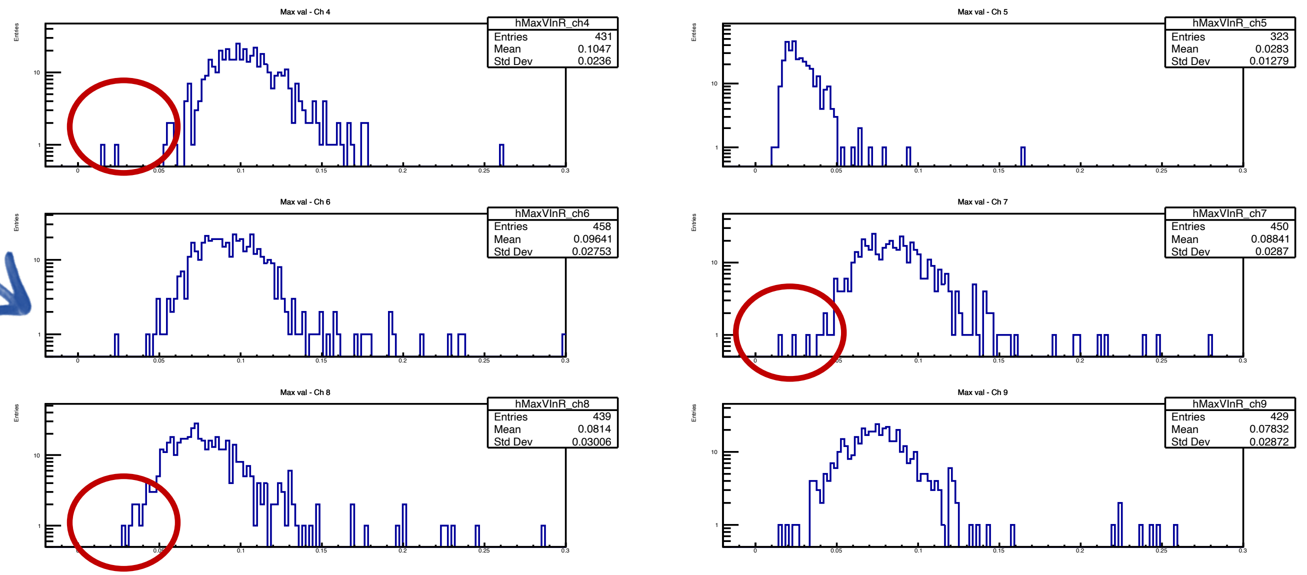
Maximum amplitude for signal events

Run: run_99.root; Track angle: 0° ; Gas mixture: 90%He ; HV = +20V

1 cm drift tubes



PREVIOUS Maximum amplitude distributions (V)

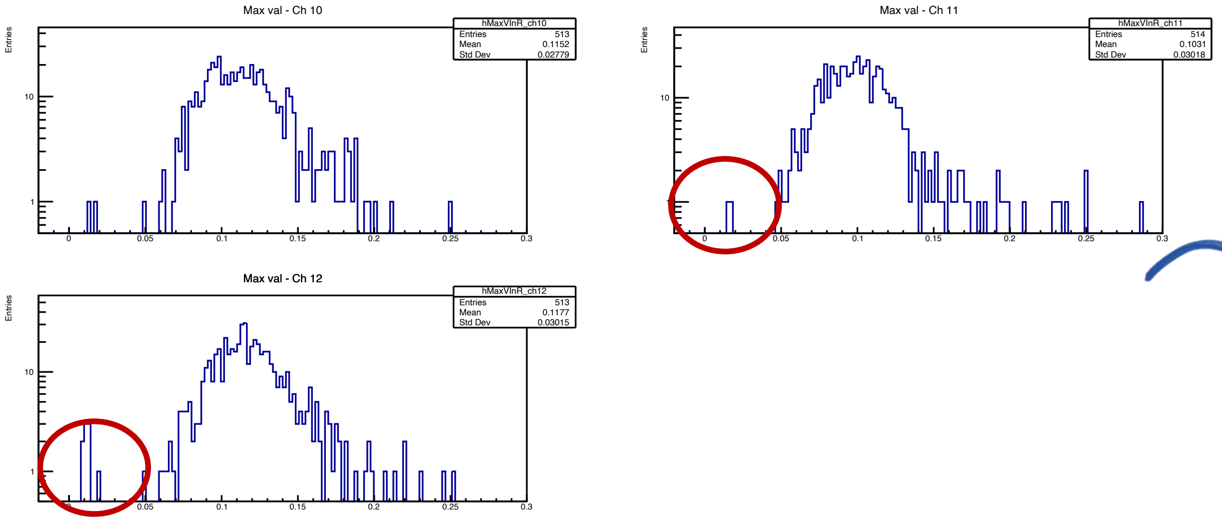


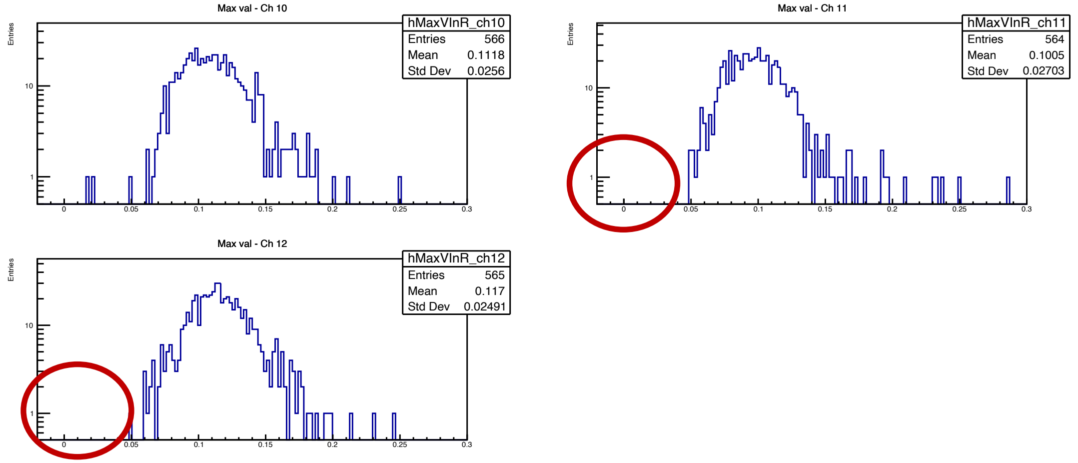
CURRENT Maximum amplitude distributions (V)

Maximum amplitude for signal events

Run: run_99.root; Track angle: 0° ; Gas mixture: 90%He ; HV = +20V

2 cm drift tubes





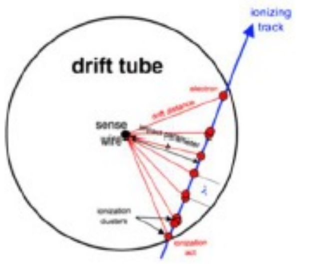
PREVIOUS Maximum amplitude distributions (V)

CURRENT Maximum amplitude distributions (V)

Clusterization counting strategy

Next step we implemented is the clusterization of the electron peaks into ionization clusters. The method consists in singling out, in ever recorded detector signal, the isolated structures related to the arrival on the anode wire of the electrons belonging to a single ionization act (dN/dx).

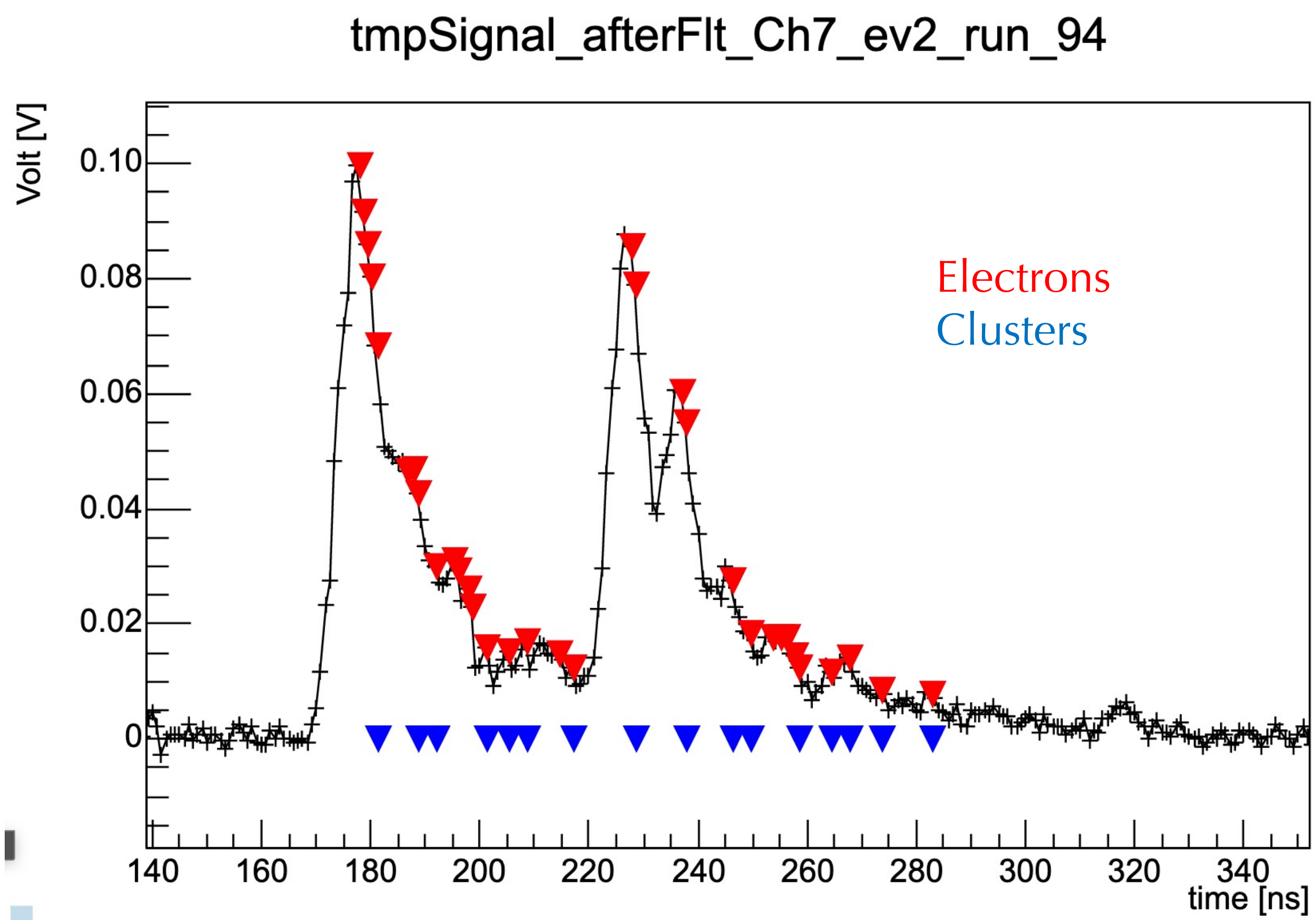
1) Association of electron peaks consisting in consecutive bins (difference in time == 1 bin) electrons to a single electron in order to correct the current over-counting for 1-cm drift tubes and eliminate fake electrons. In this way, the inefficiency for 2-cm drift tubes will be slightly increased.
2) Contiguous electrons peaks which are compatible with the electrons diffusion time (2.5 ns or 3 bins) must be considered belonging to the same ionization cluster. For them, a counter for electrons per each cluster is incremented.
3) Position of the clusters is taken as the position of the last electron in the cluste.
4) We expect a poissonian distribution for the number of cluster distributions! It tends to a gaussian when the mean value tends to values higher than 20. For this reason we fitted to a poissonian/gaussian depending on the run chosen.

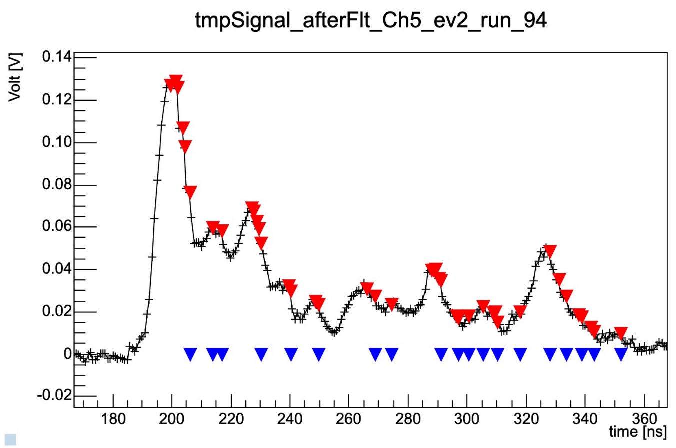


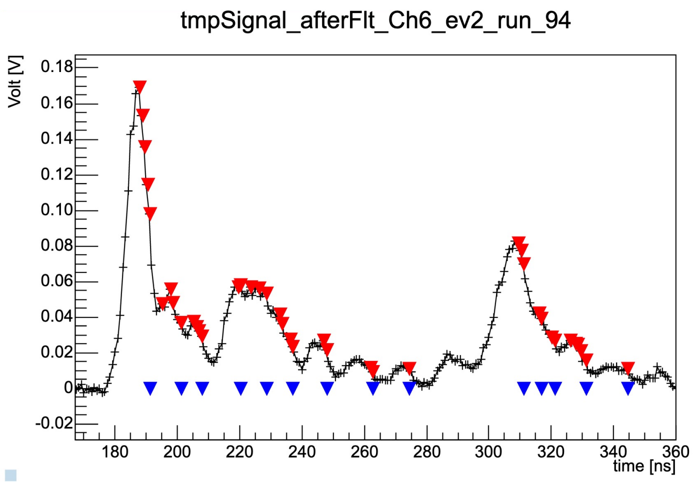
Clusters and Electrons in Waveform spectra

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

1 cm drift tubes



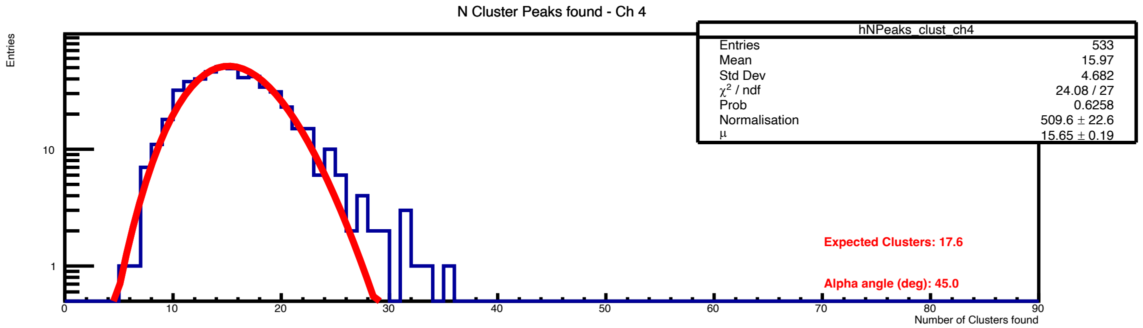


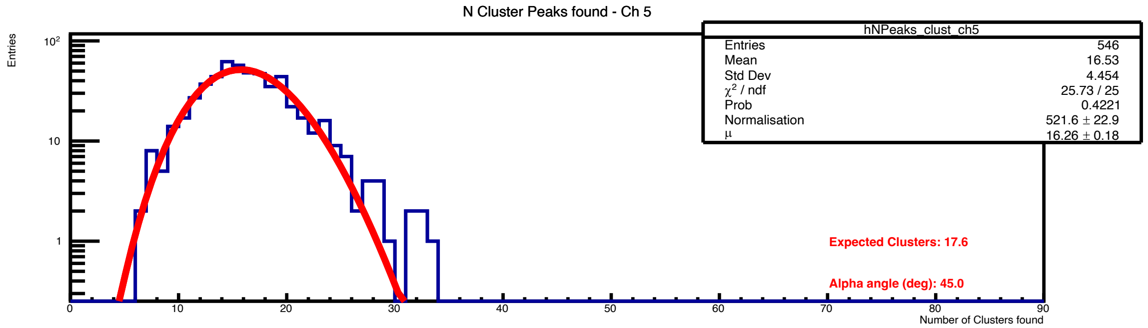


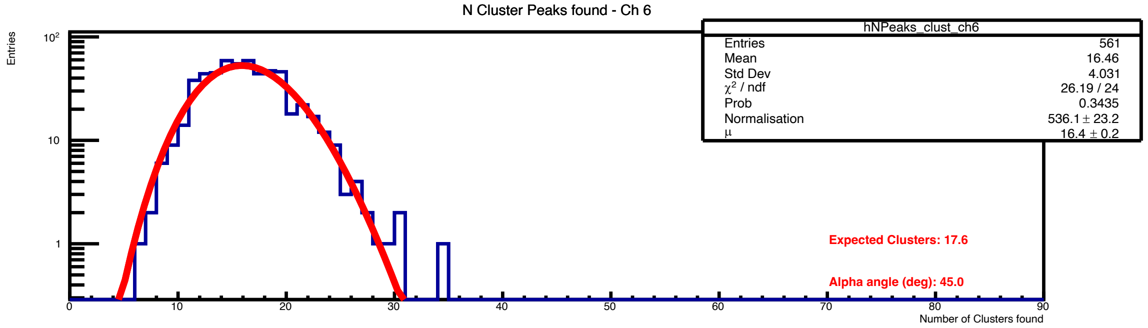
NCluster distribution for signal events

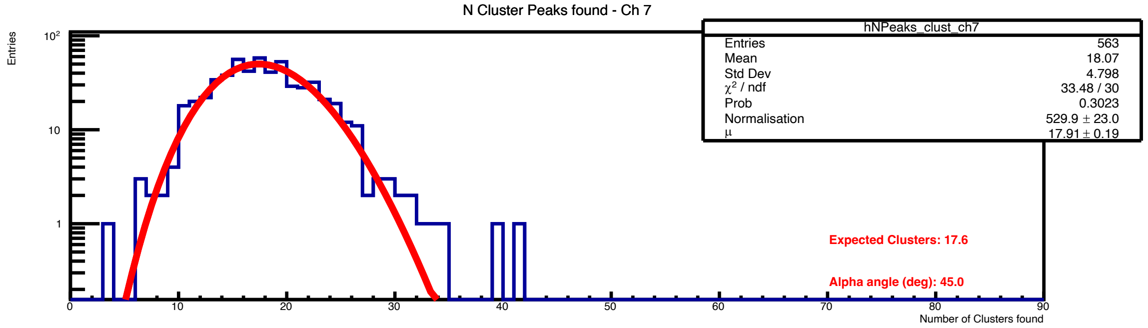
Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

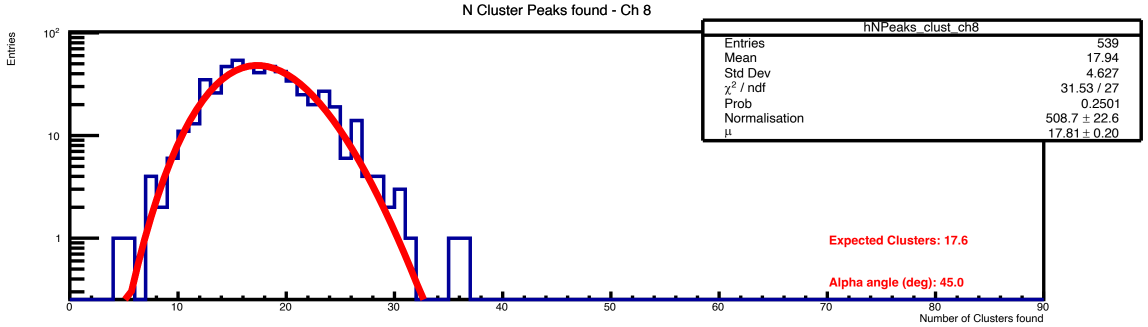
1 cm drift tubes

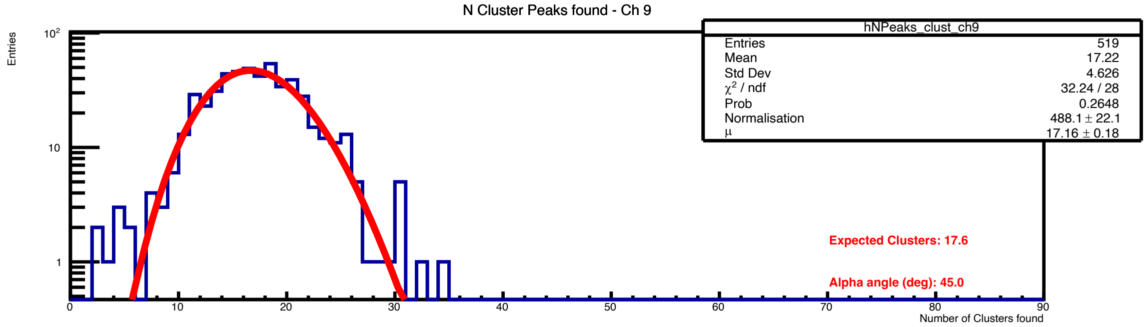








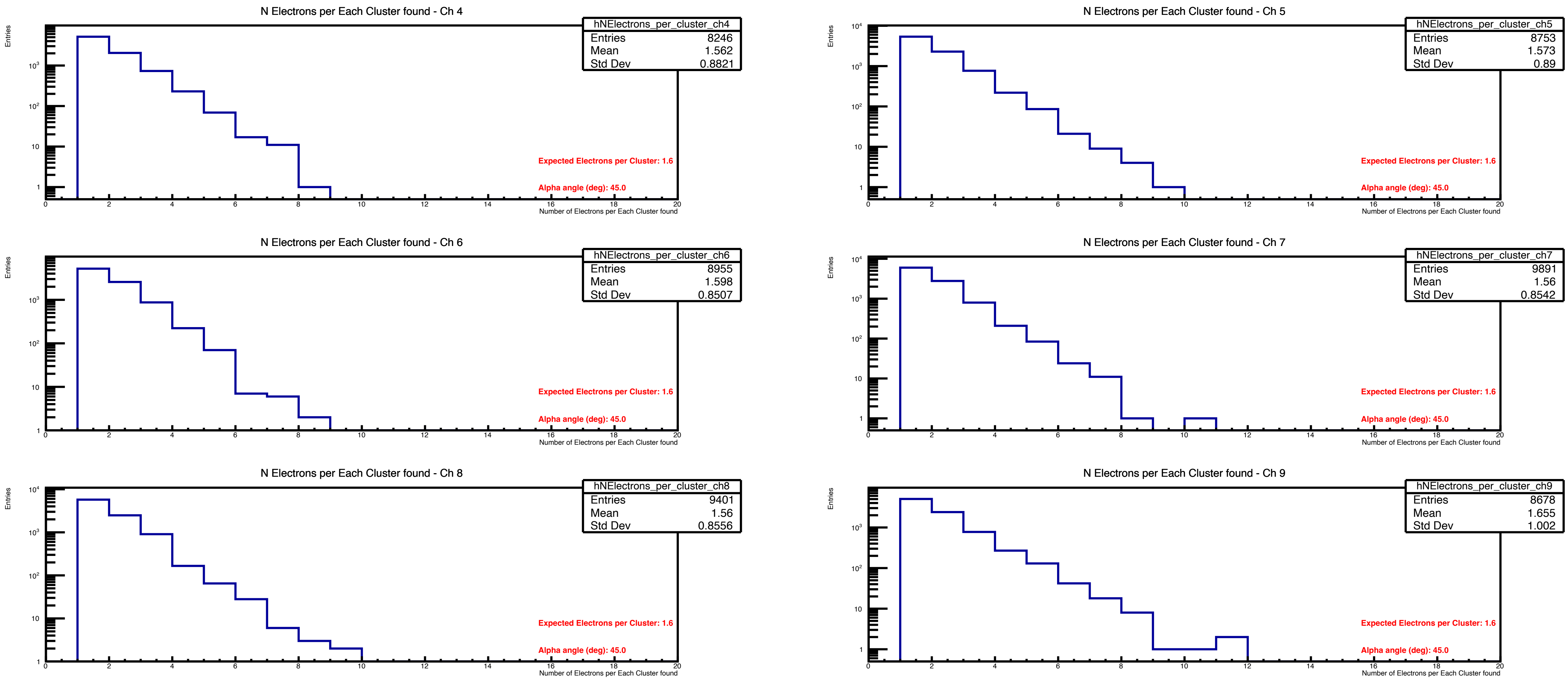




NElectronsPerCluster distribution for signal events

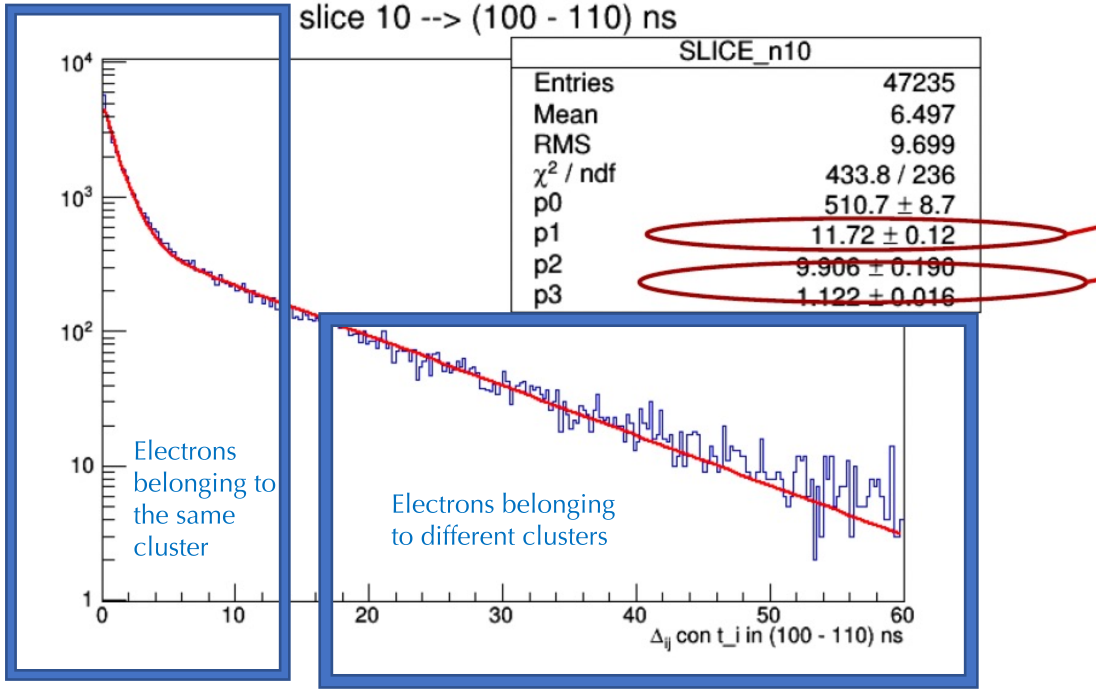
Run: run_94.root; Track angle: 45° ; Gas mixture: 90%He ; HV = +20

1 cm drift tubes



As expected from theory!

Expected Time difference distribution between electrons



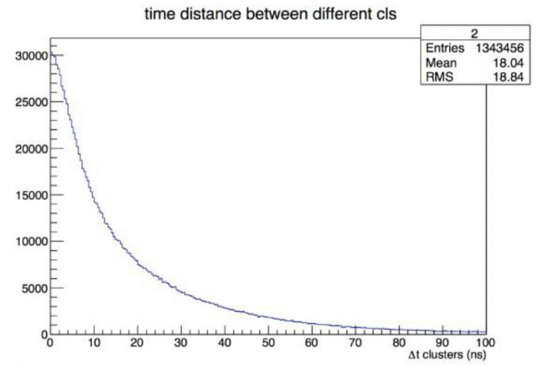
$$f(t) = Ae^{-t/\tau 1} + \mathrm{B}\, e^{-t/\tau 2}$$

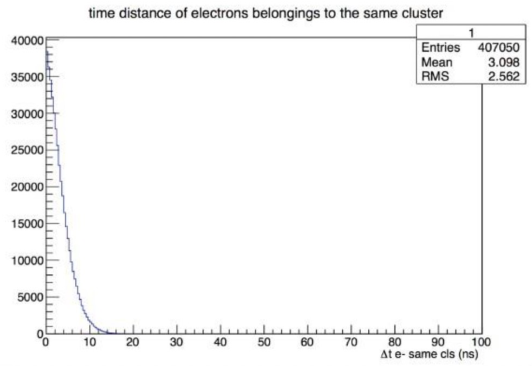
τ1 describes time distance for different clusters

τ2 describes time distance for same cluster

Expected order of magnitude for the Time distance between two electrons beloning to the same cluster = 3 ns

Expected order of magnitude for the Time distance between two ionization clusters = 10 ns

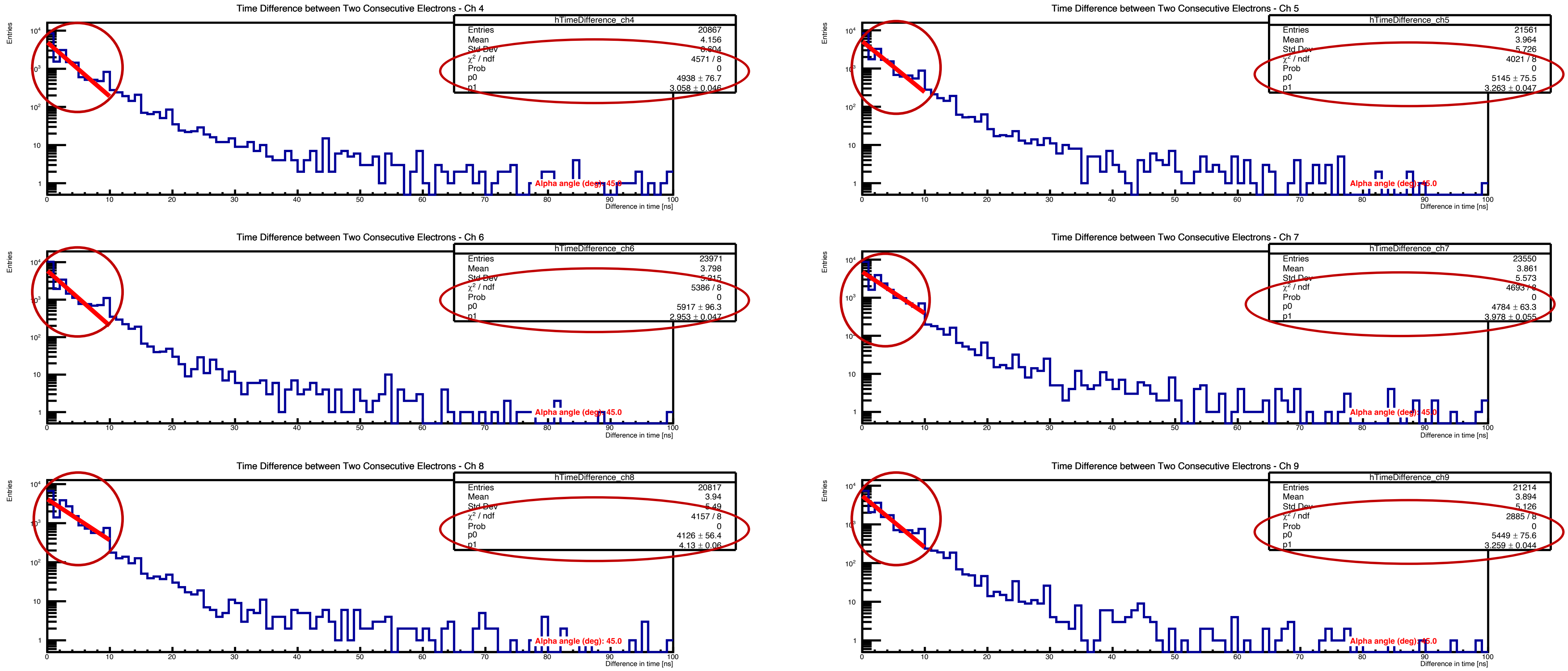




Time difference distribution between electrons

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

1 cm drift tubes

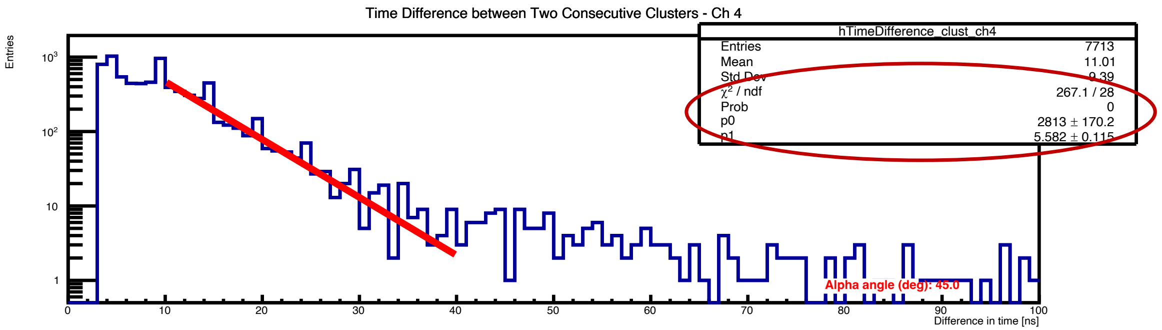


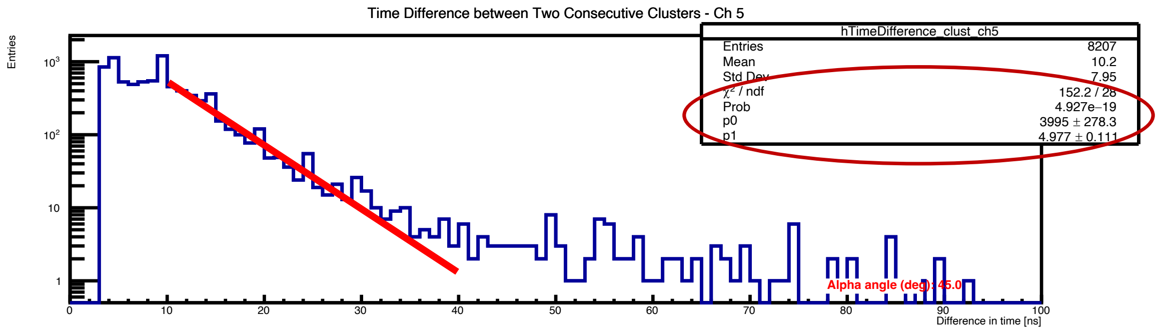
Differences of 0 up to 10 ns = contribution of Fake Electrons + Electrons belonging to the same cluster with a time distance of 3 ns

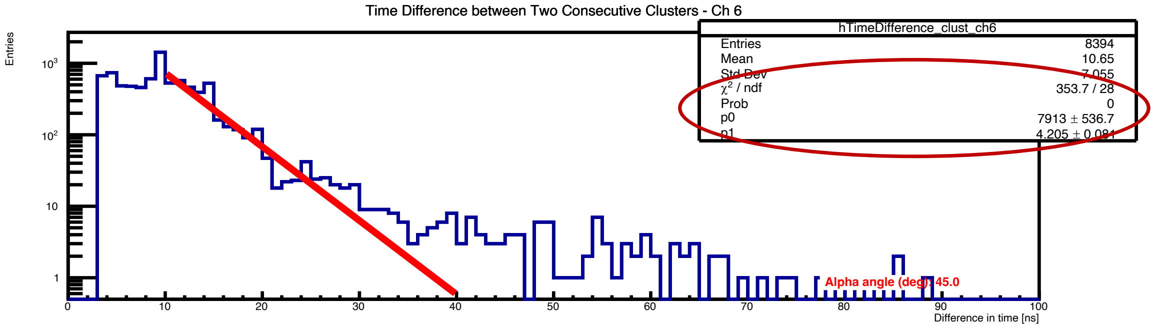
Time difference distribution between clusters

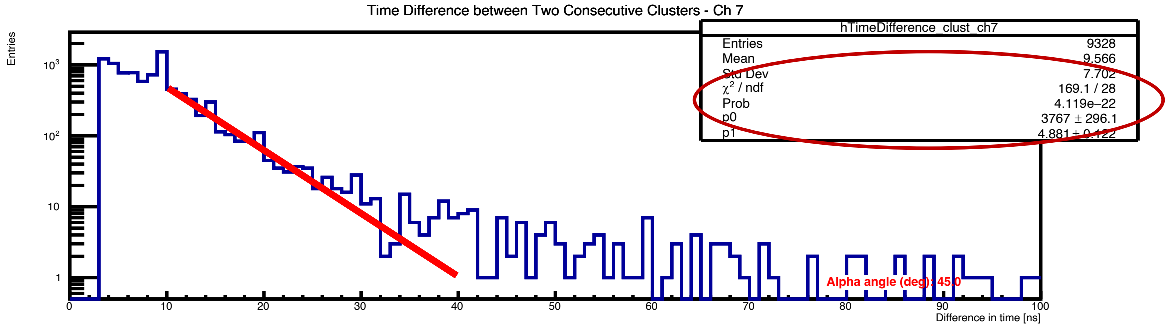
Run: run_94.root; Track angle: **45°** ; Gas mixture: **90%He** ; **HV = +20**

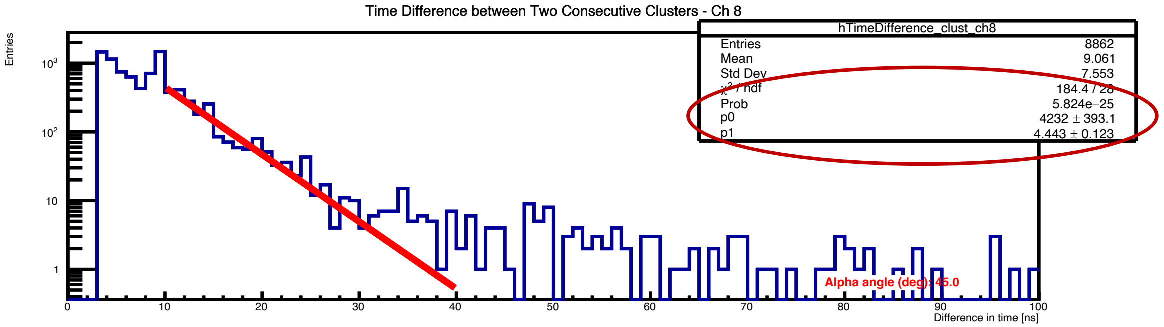
1 cm drift tubes

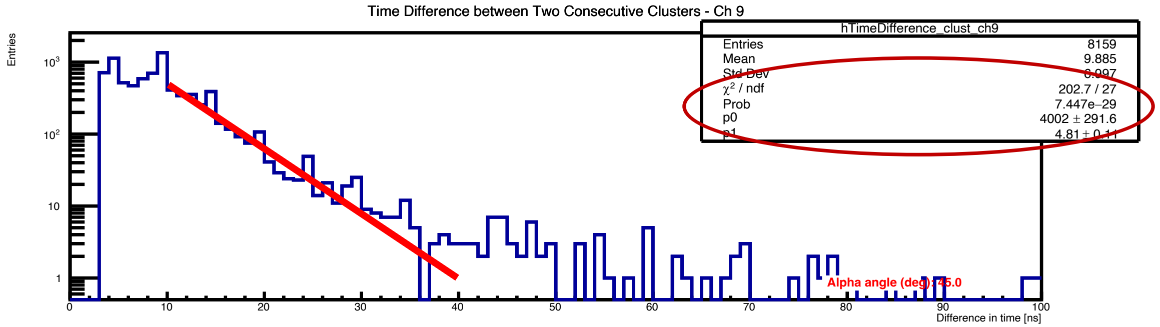










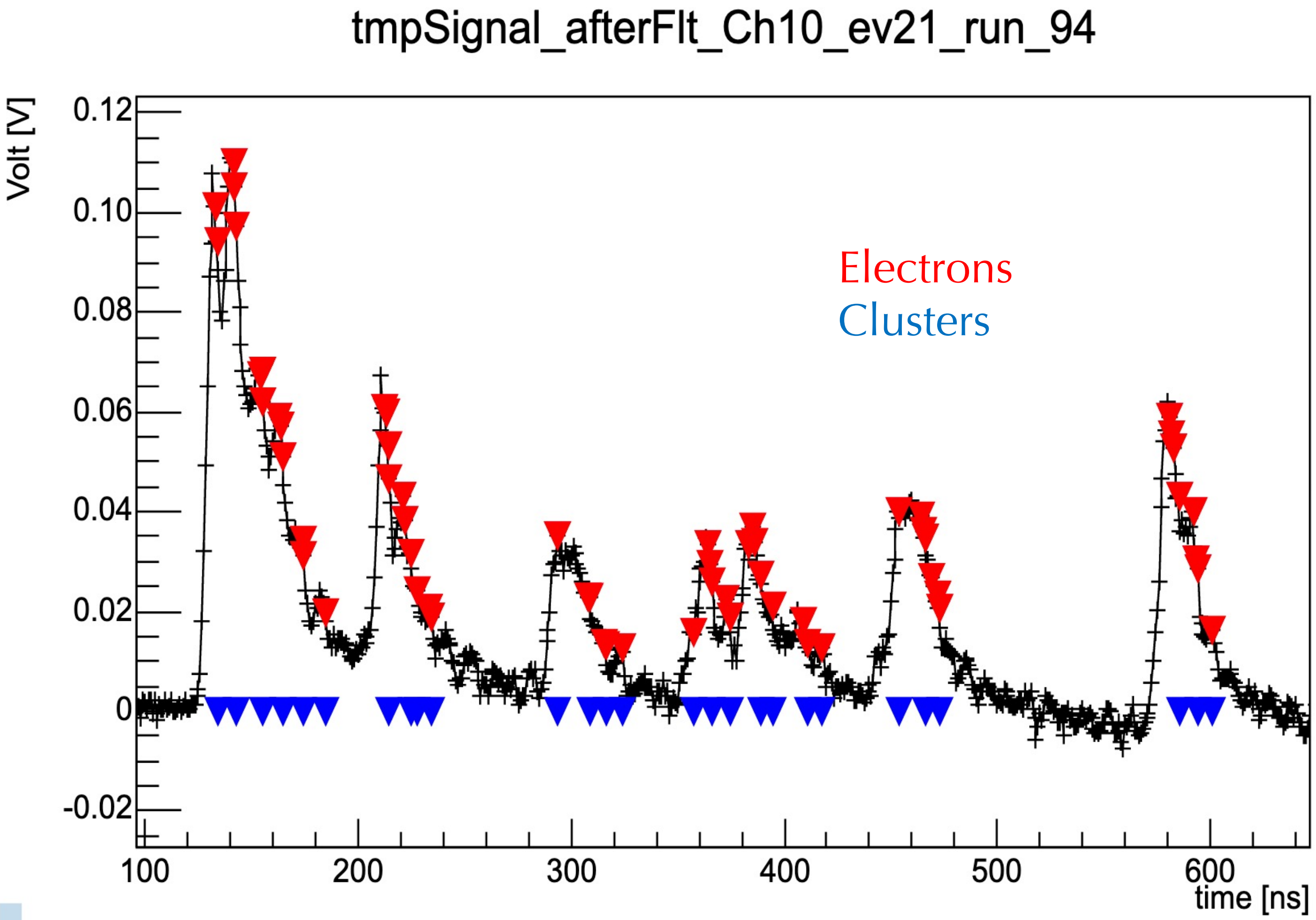


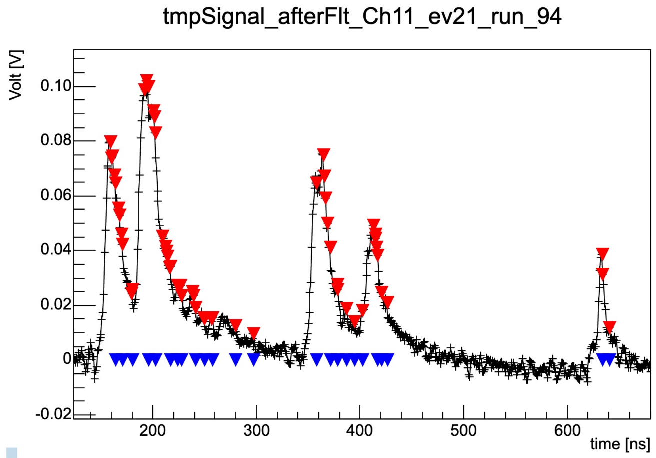
From 10ns up to 40ns = contribution of separated clusters with a time distance of 4/5 ns (> electrons time distance)

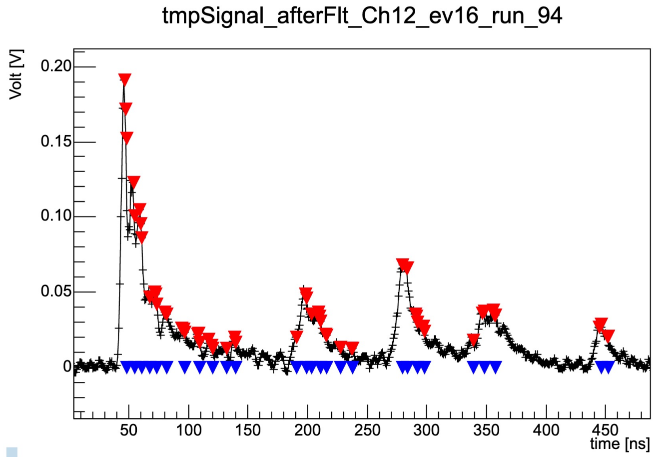
Clusters and Electrons in Waveform spectra

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

2 cm drift tubes



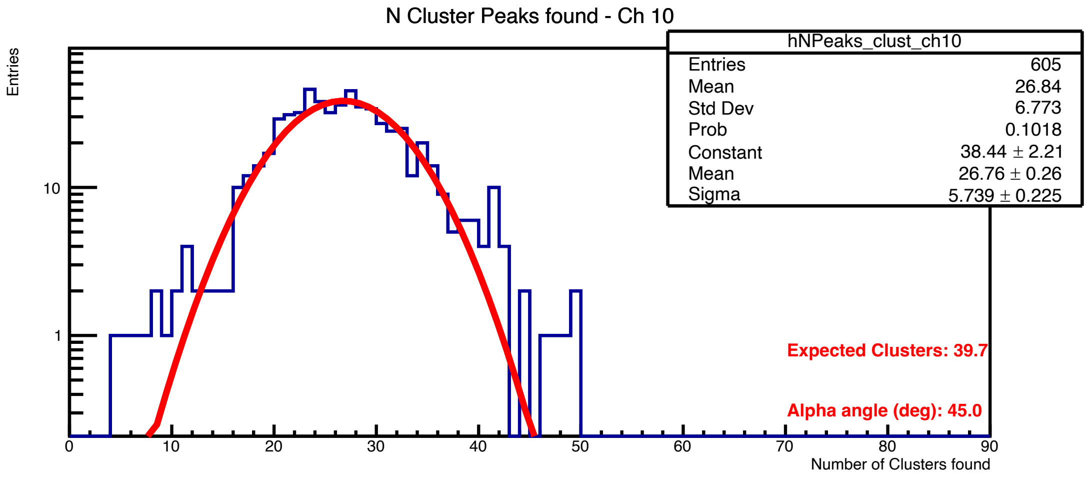


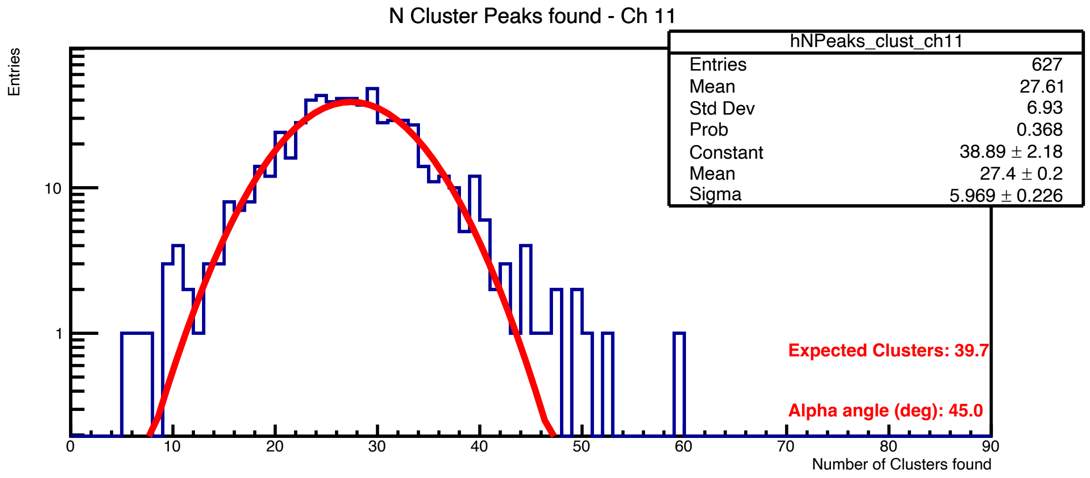


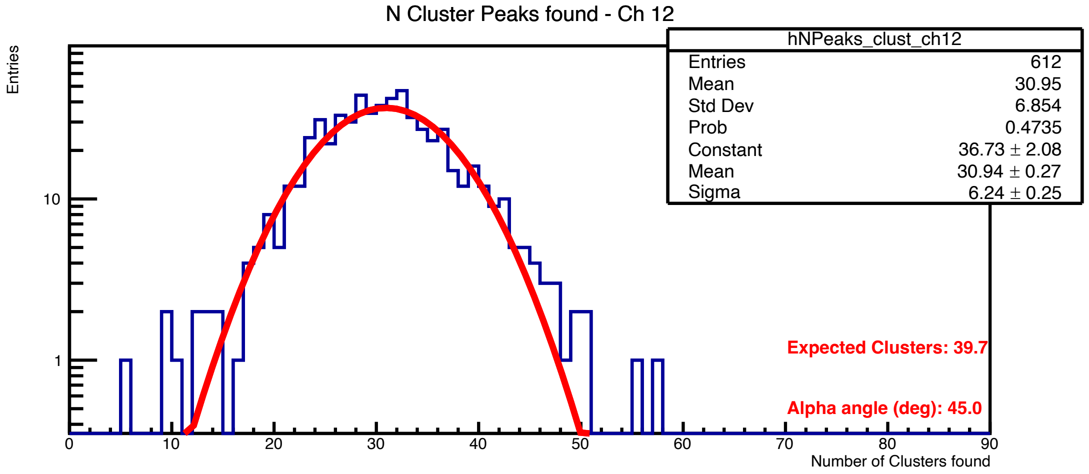
Npeak distribution for signal events

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

2 cm drift tubes





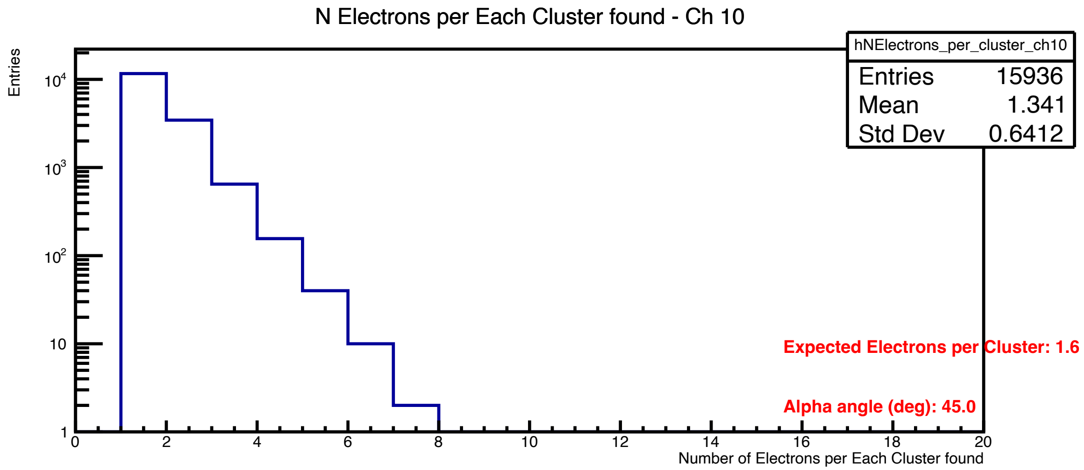


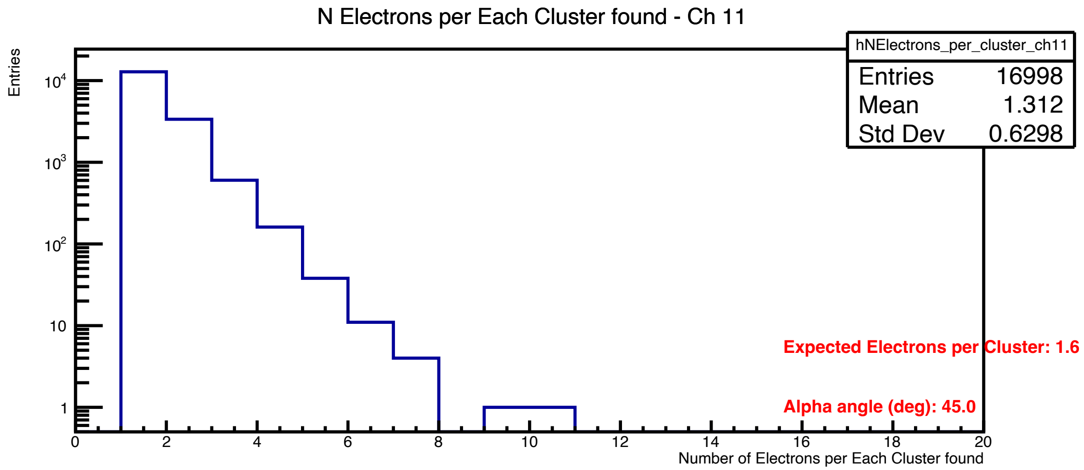
Underestimation due to under-counting of the electron peaks.

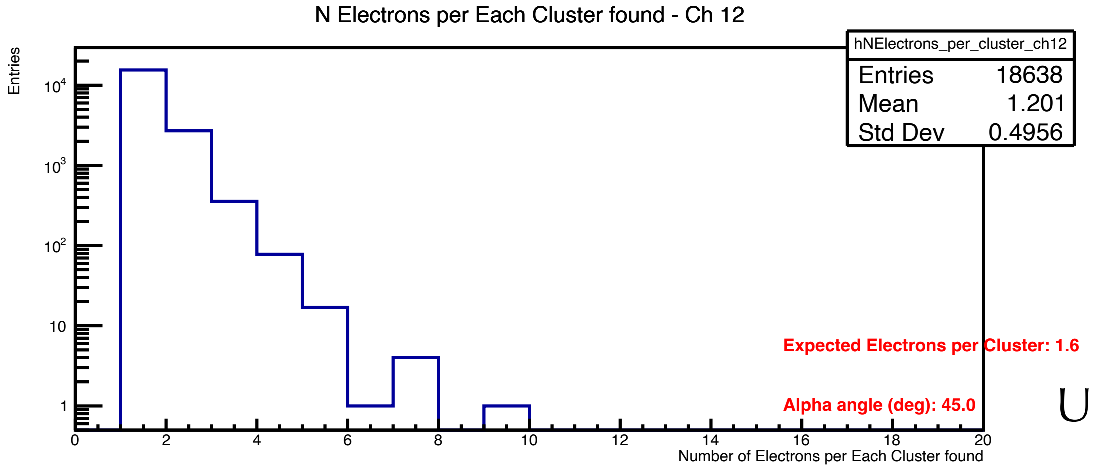
NElectronsPerCluster distribution for signal events

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

2 cm drift tubes





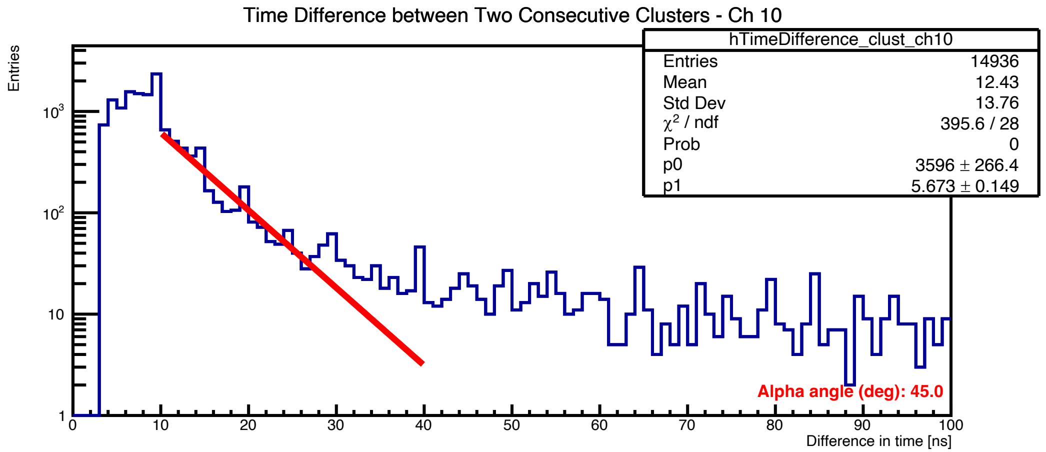


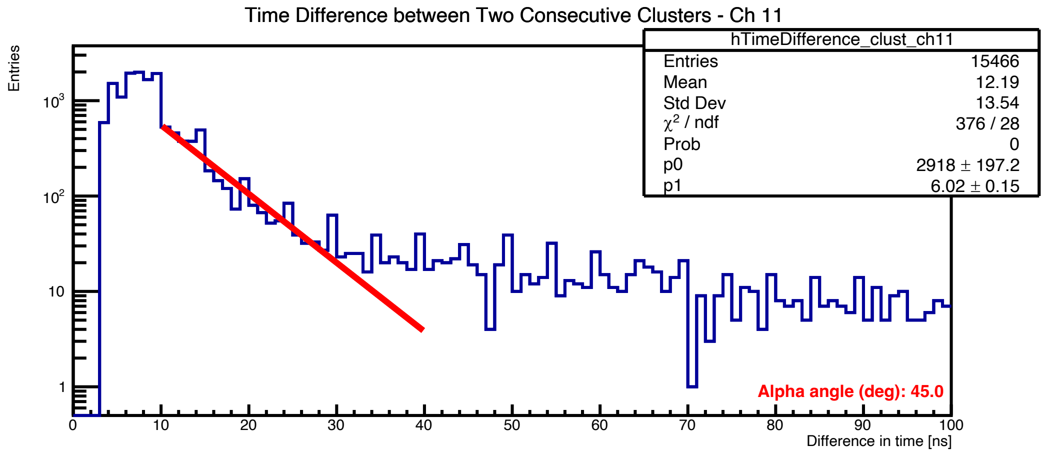
Underestimation due to under-counting of the electron peaks.

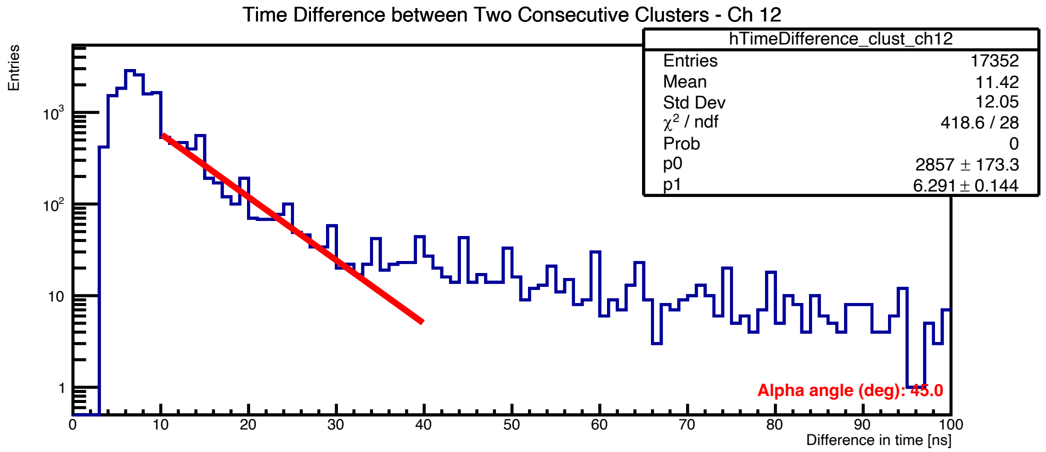
Time difference distribution between clusters

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

2 cm drift tubes





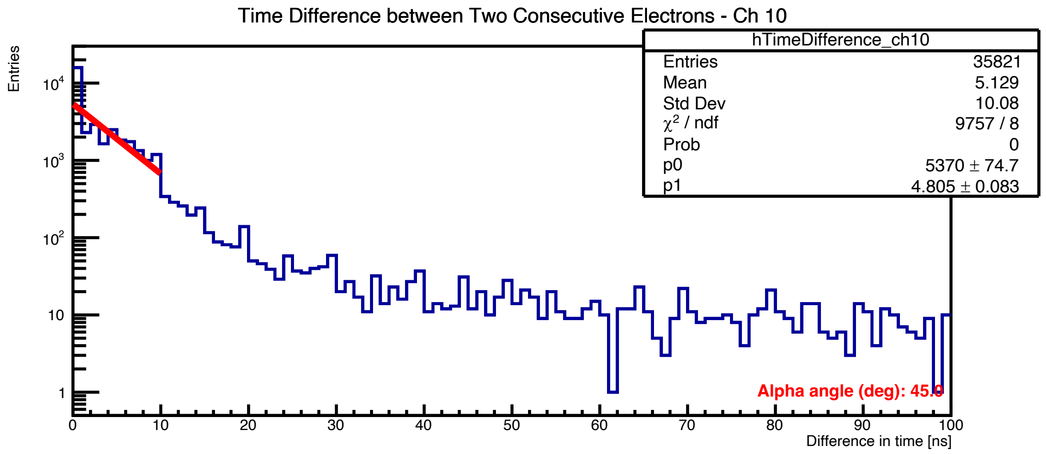


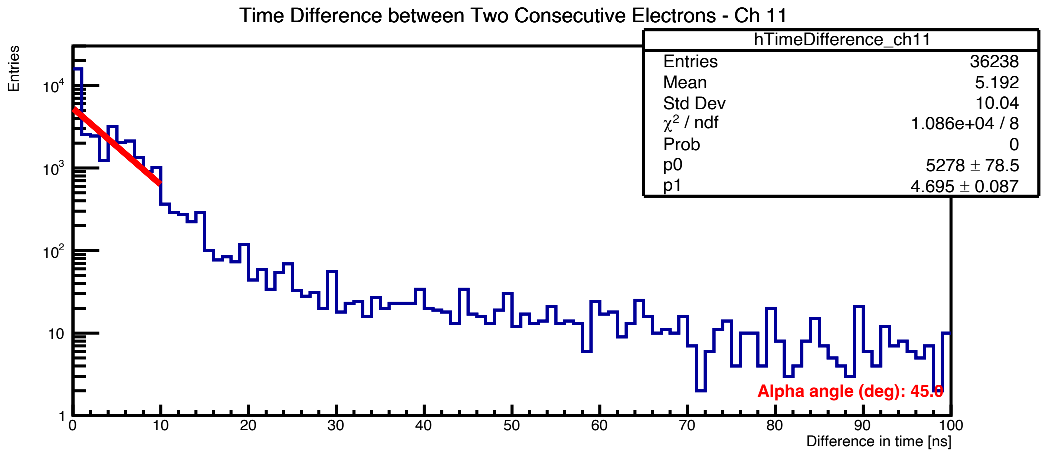
Underestimation due to under-counting of the electron peaks.

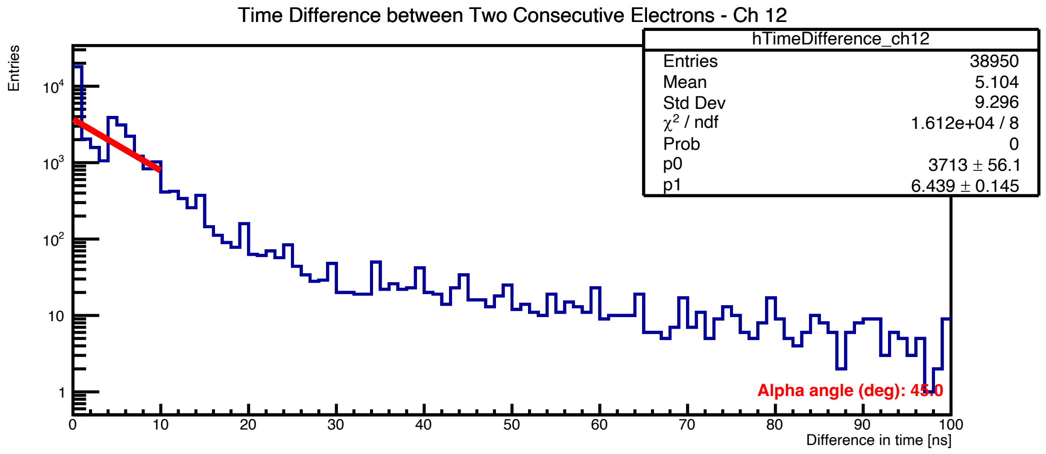
Time difference distribution between electrons

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

2 cm drift tubes





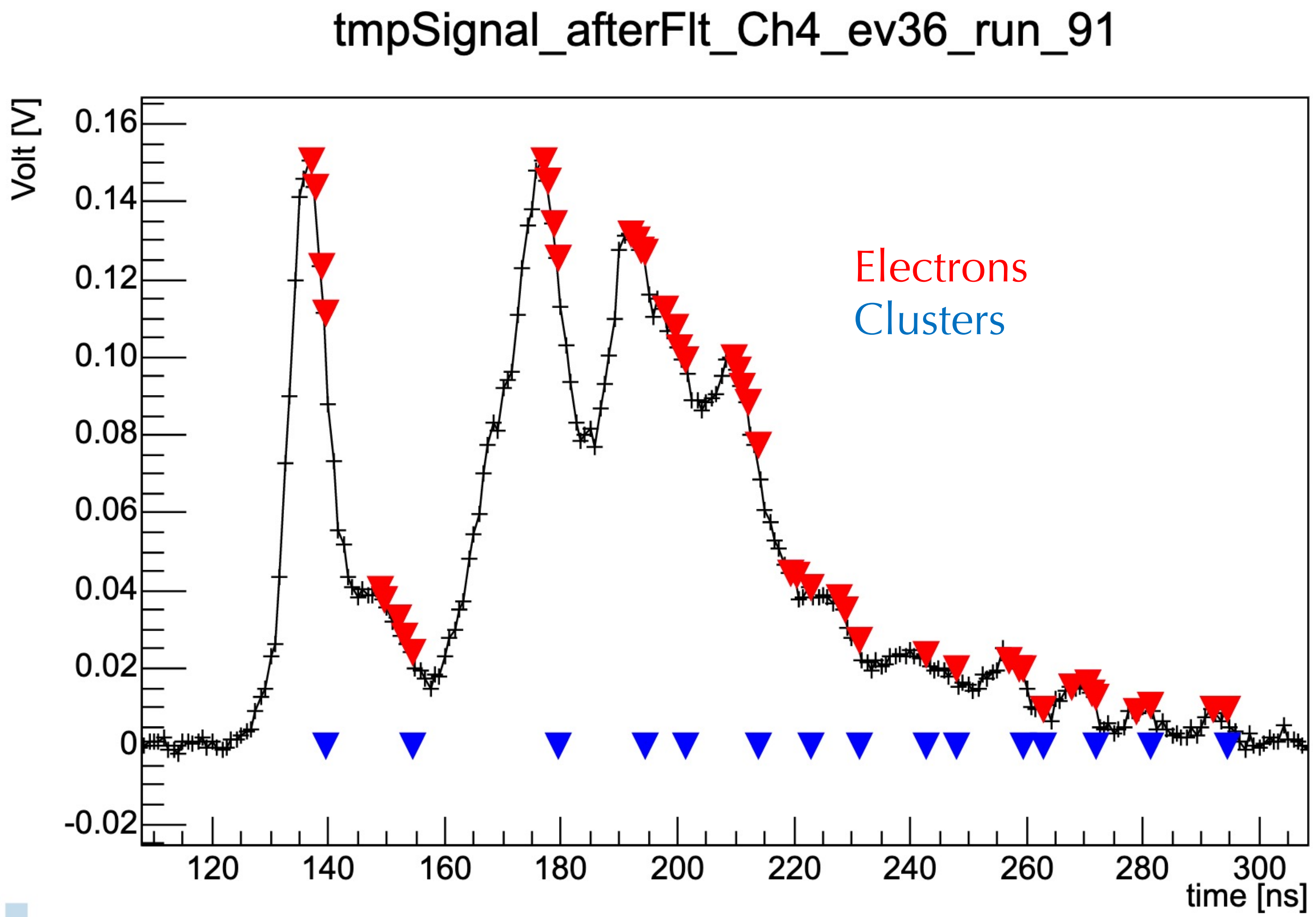


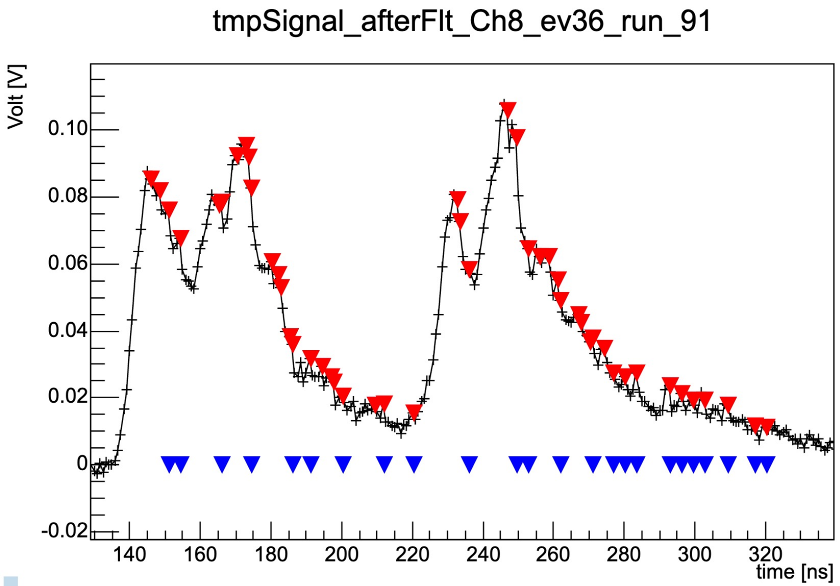
Underestimation due to under-counting of the electron peaks.

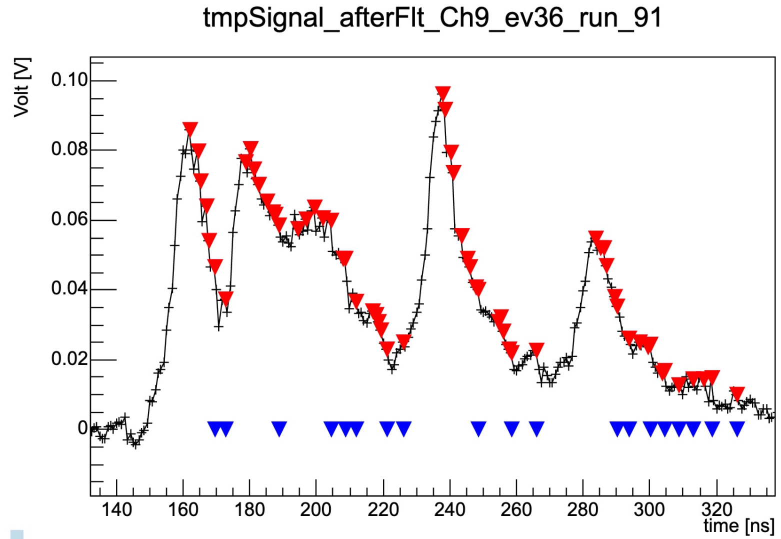
Clusters and Electrons in Waveform spectra

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

1 cm drift tubes



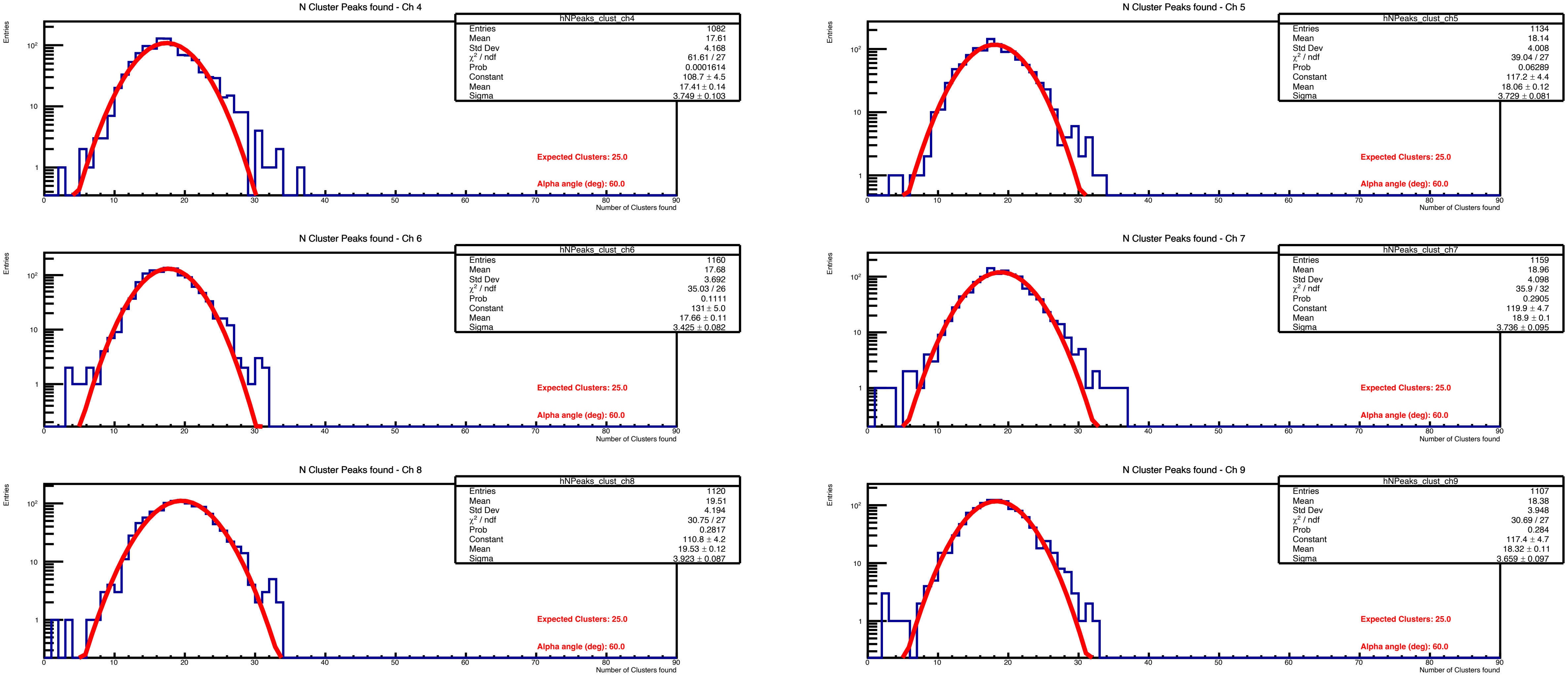




NCluster distribution for signal events

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; **HV = +20**

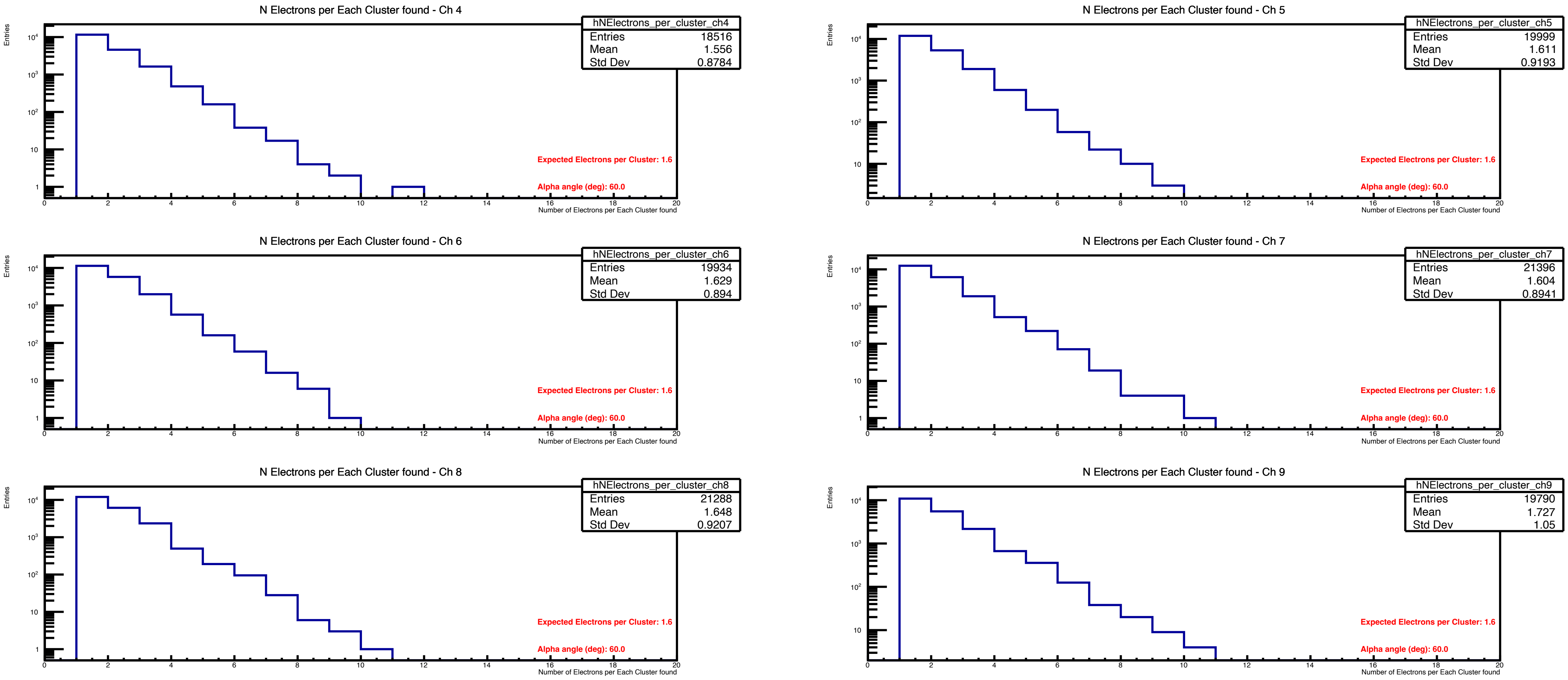
1 cm drift tubes



NElectronsPerCluster distribution for signal events

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

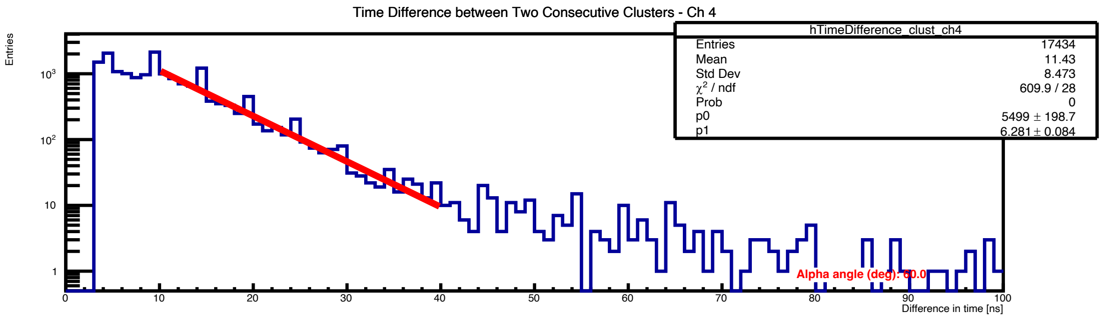
1 cm drift tubes

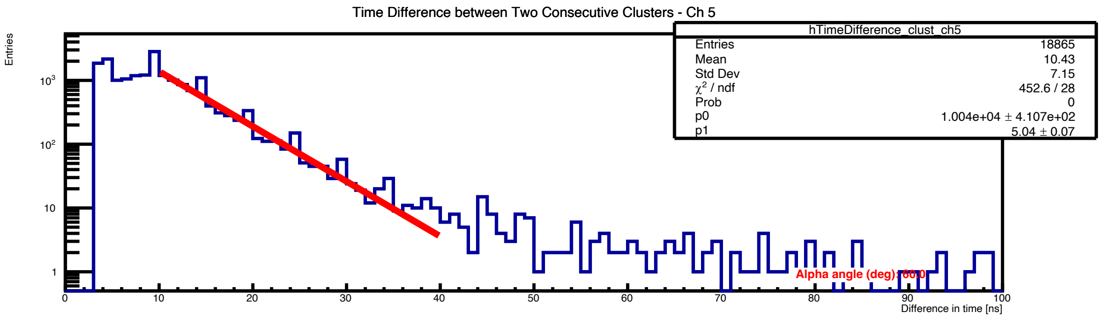


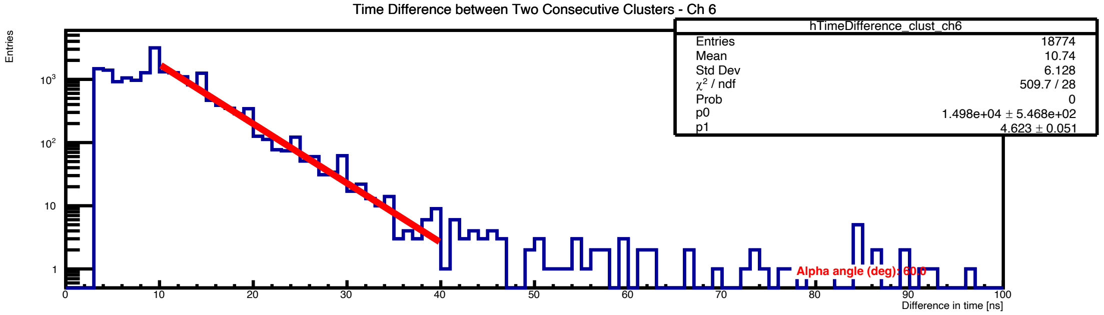
Time difference distribution between clusters

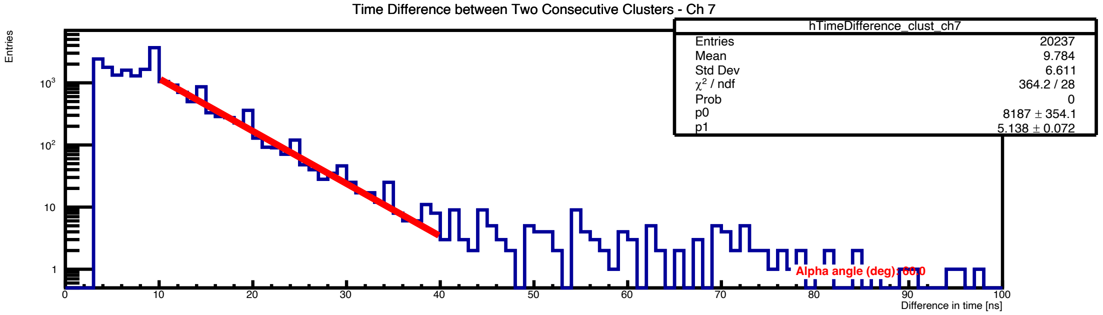
Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; **HV = +20**

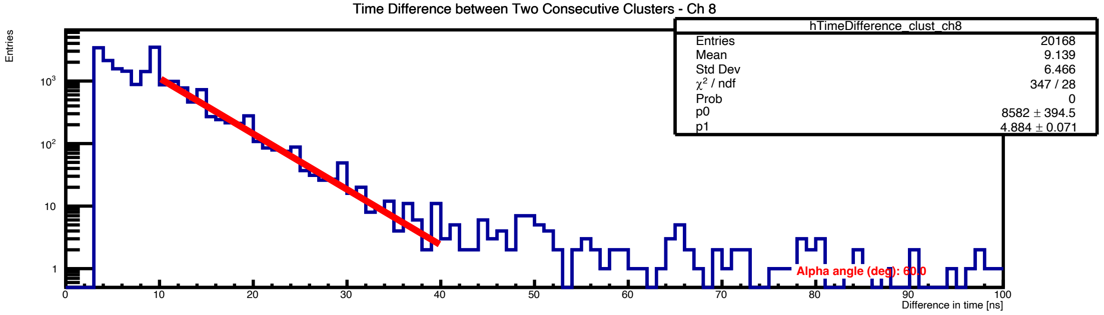
1 cm drift tubes

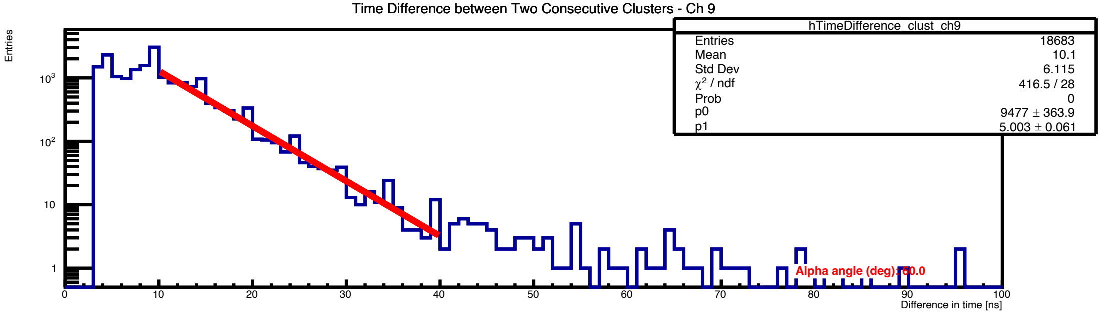








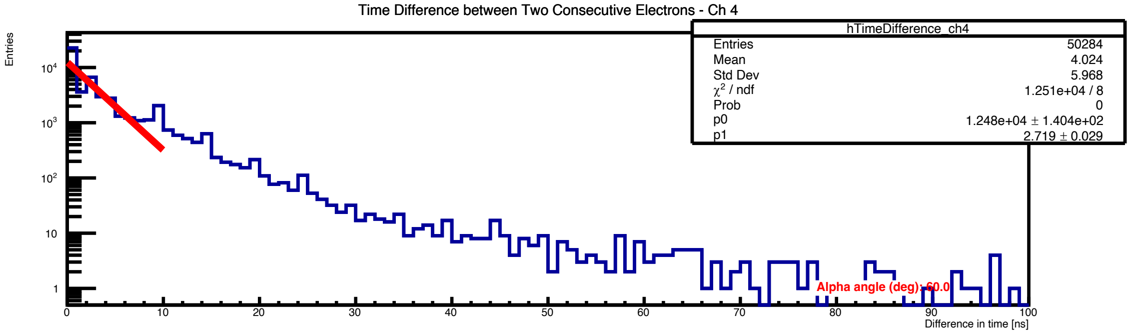


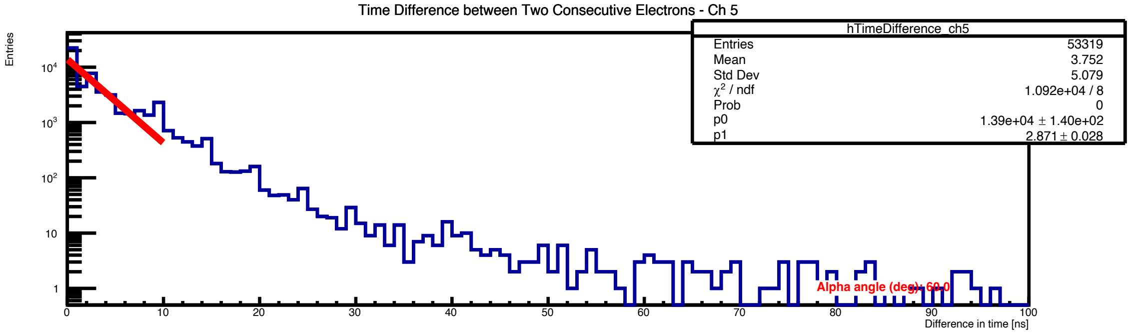


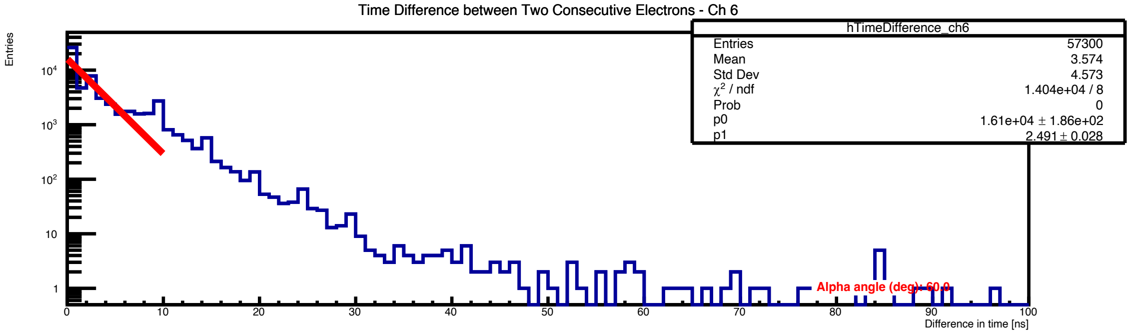
Time difference distribution between electrons

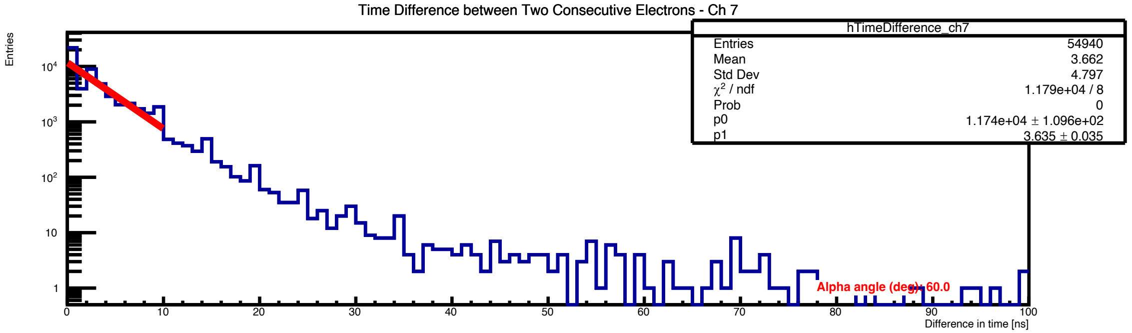
Run: **run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20**

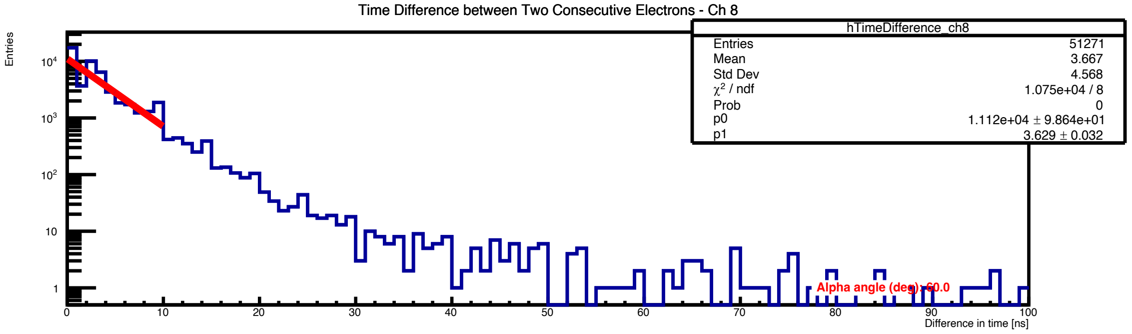
1 cm drift tubes

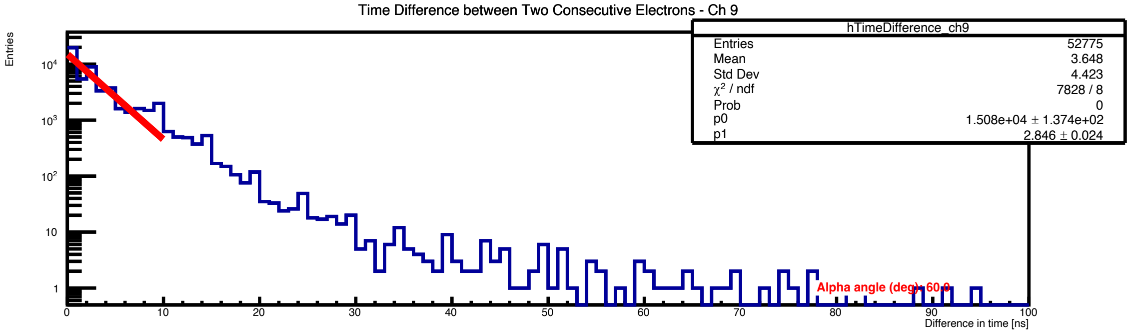








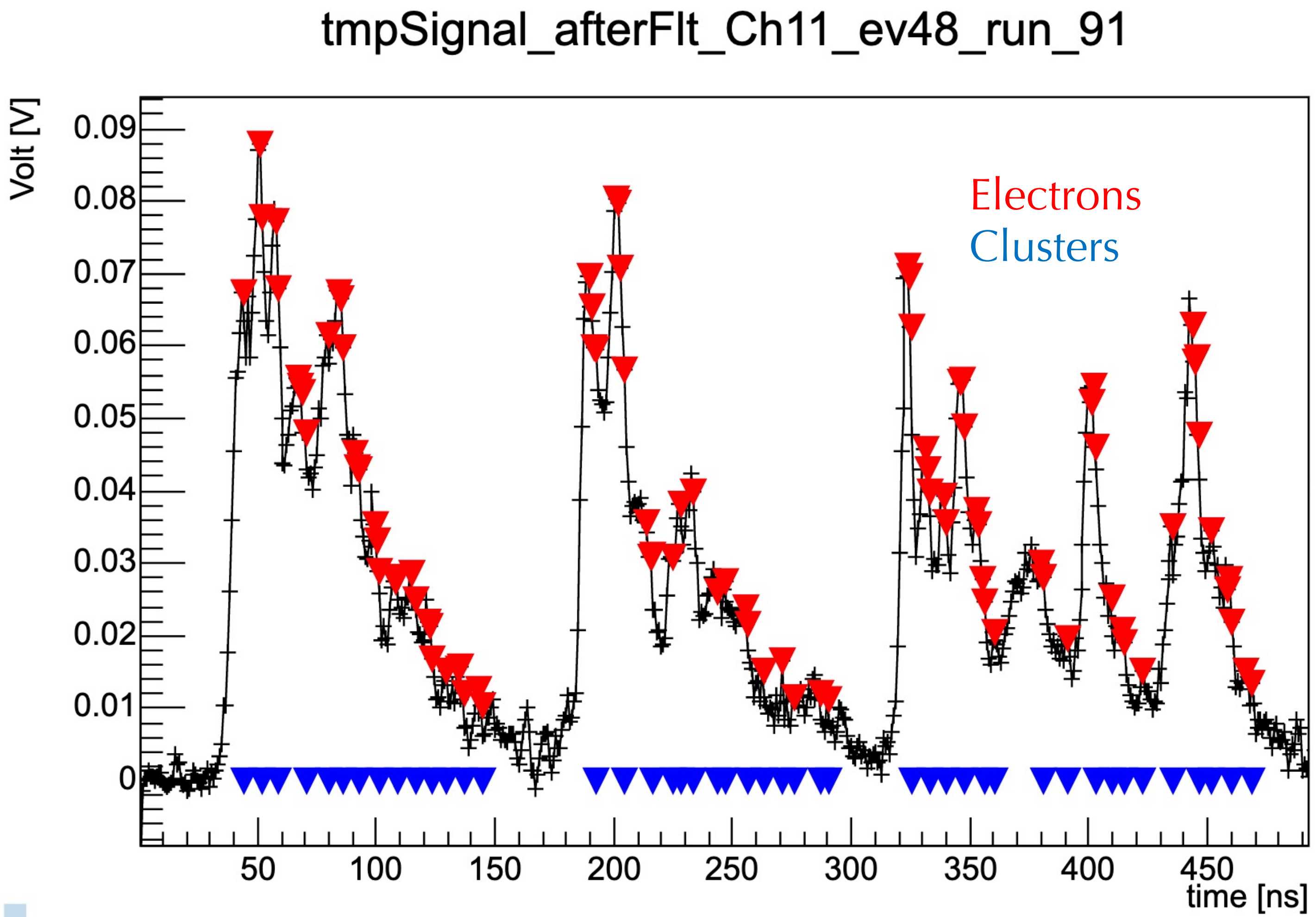


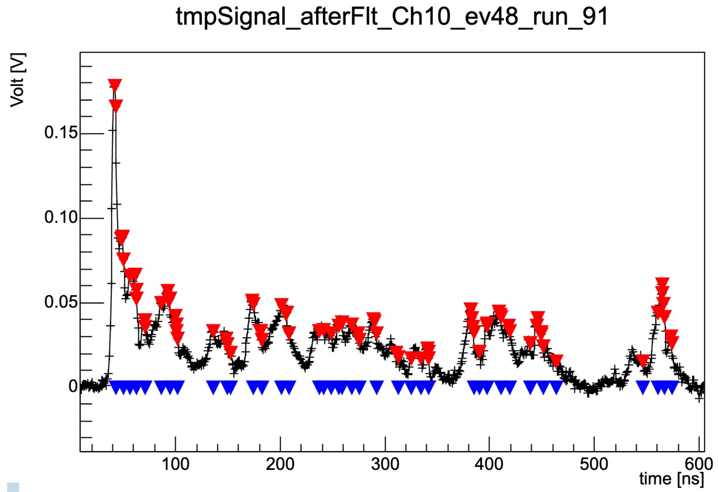


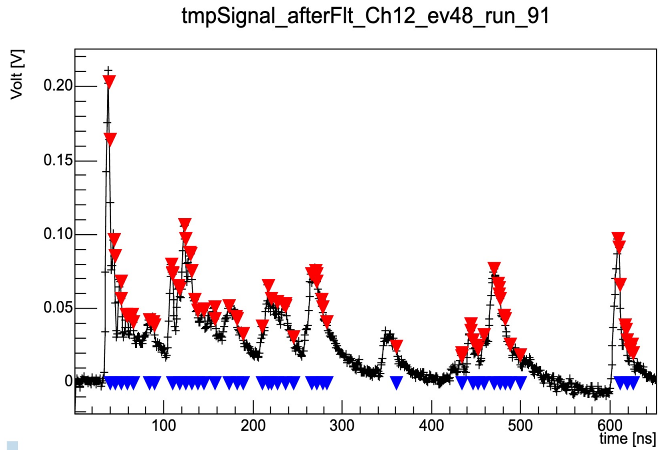
Clusters and Electrons in Waveform spectra

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

2 cm drift tubes



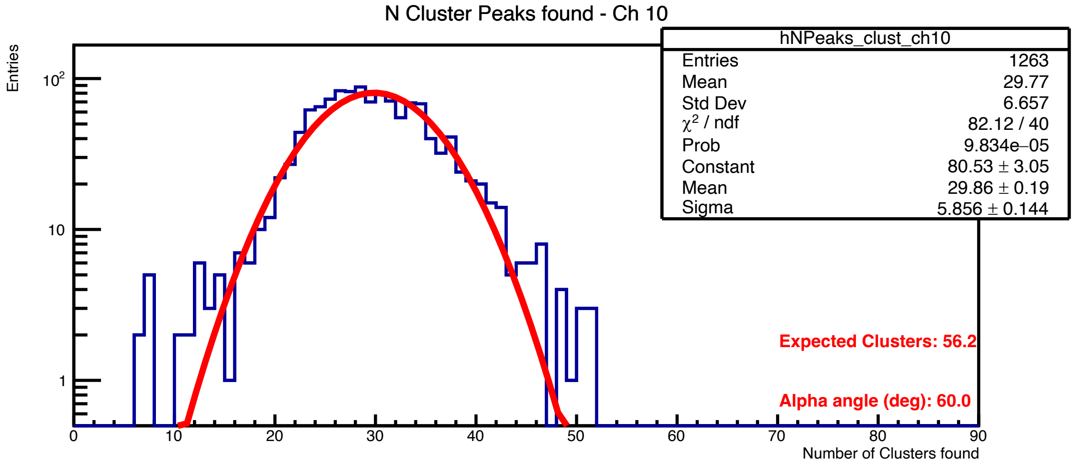


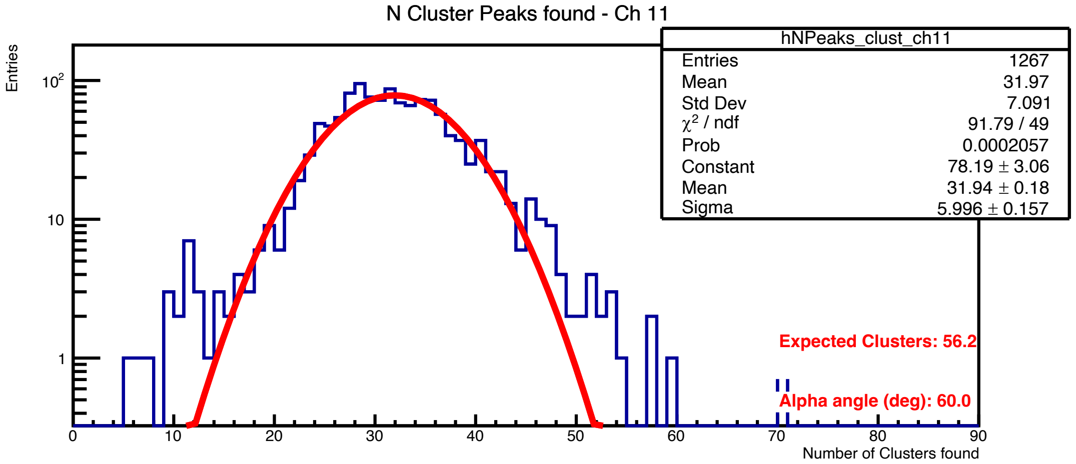


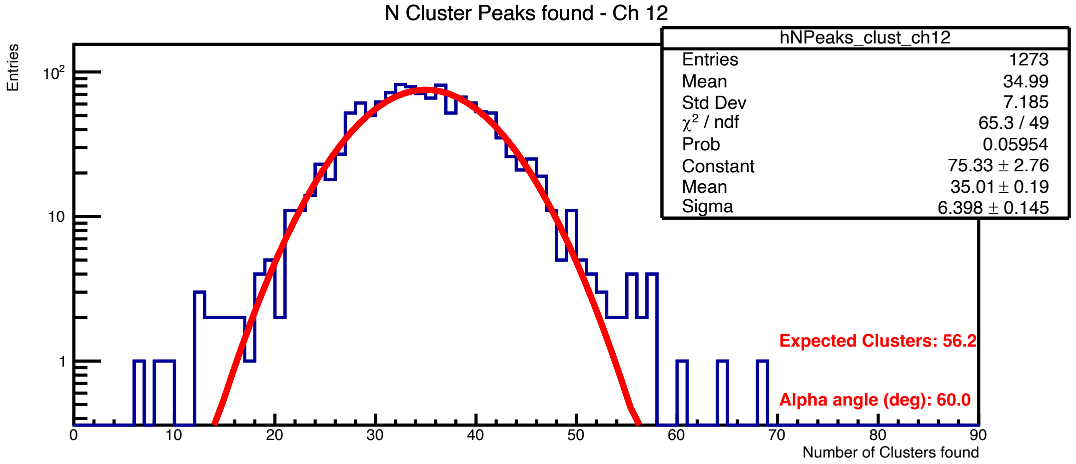
NCluster distribution for signal events

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

2 cm drift tubes



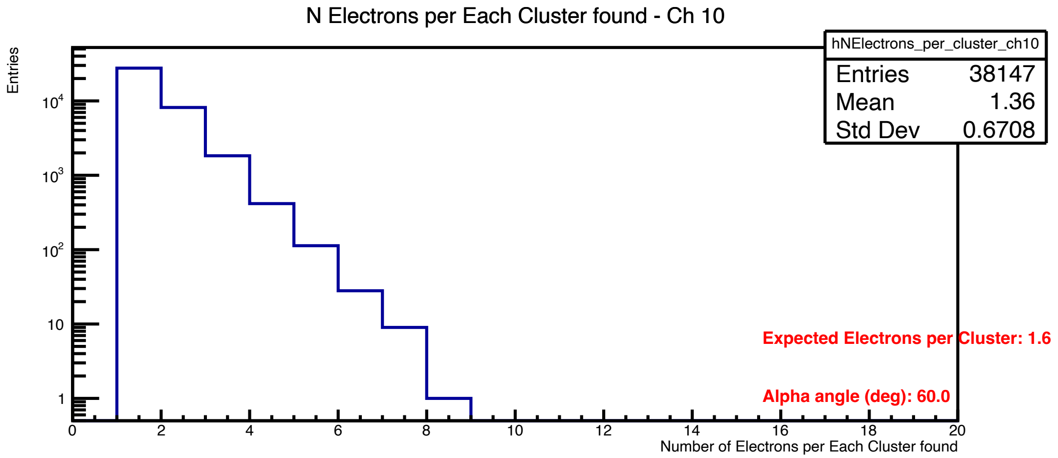


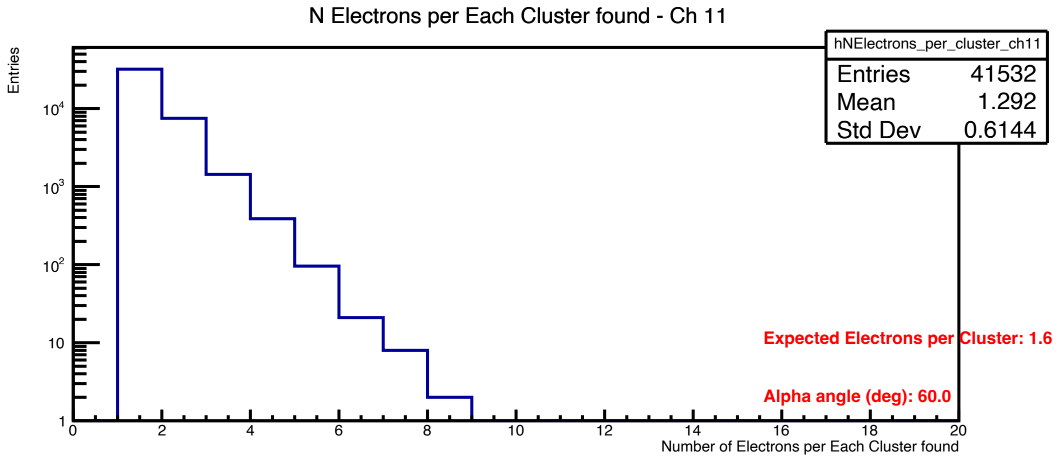


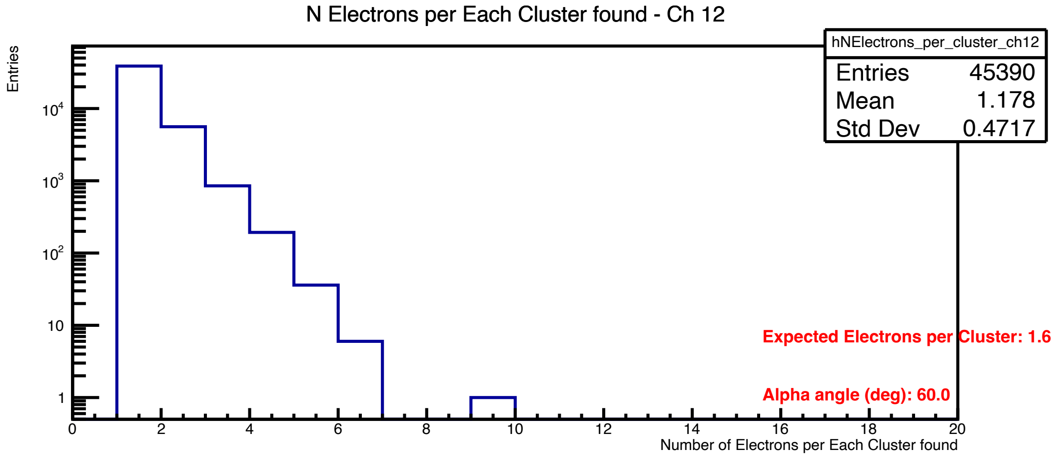
NElectronsPerCluster distribution for signal events

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; **HV = +20**

2 cm drift tubes



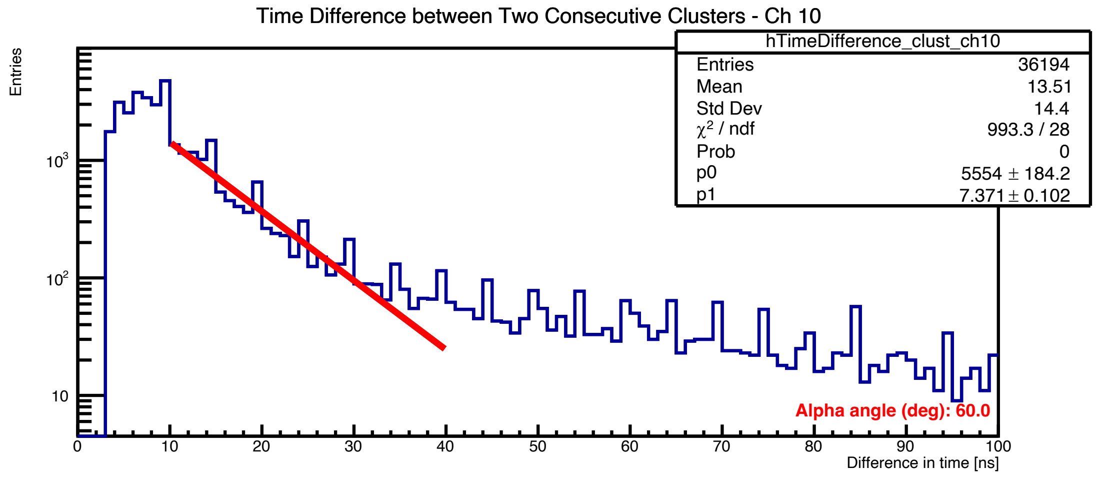


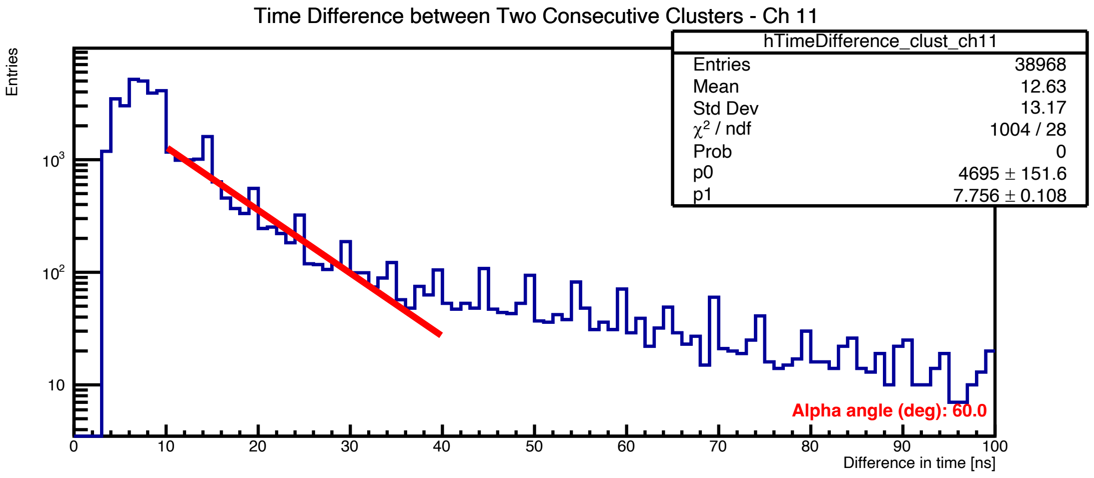


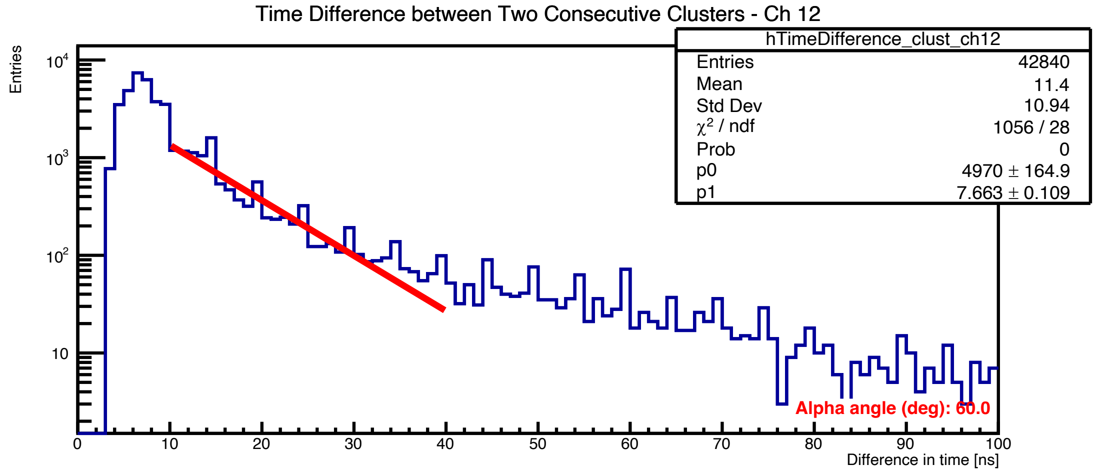
Time difference distribution between clusters

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

2 cm drift tubes



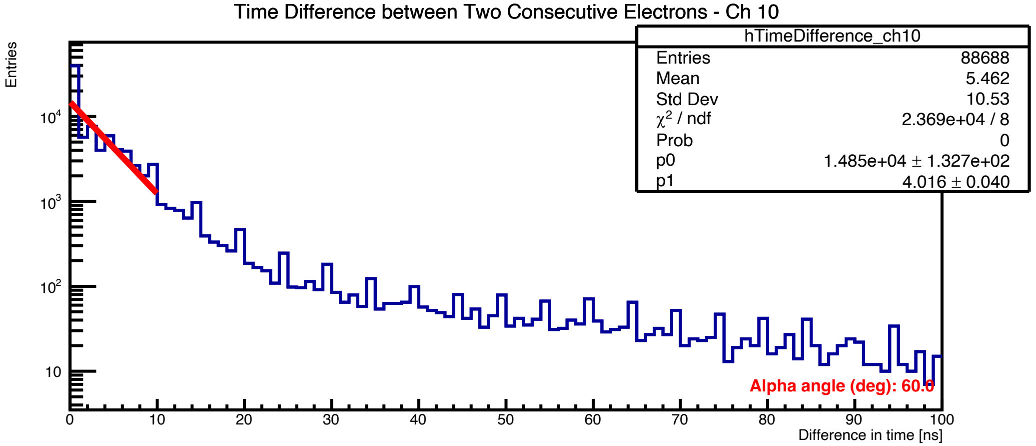


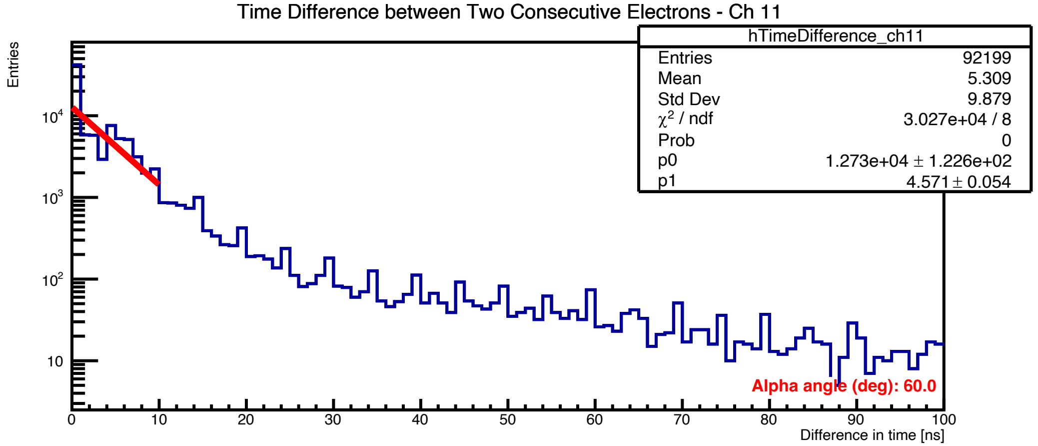


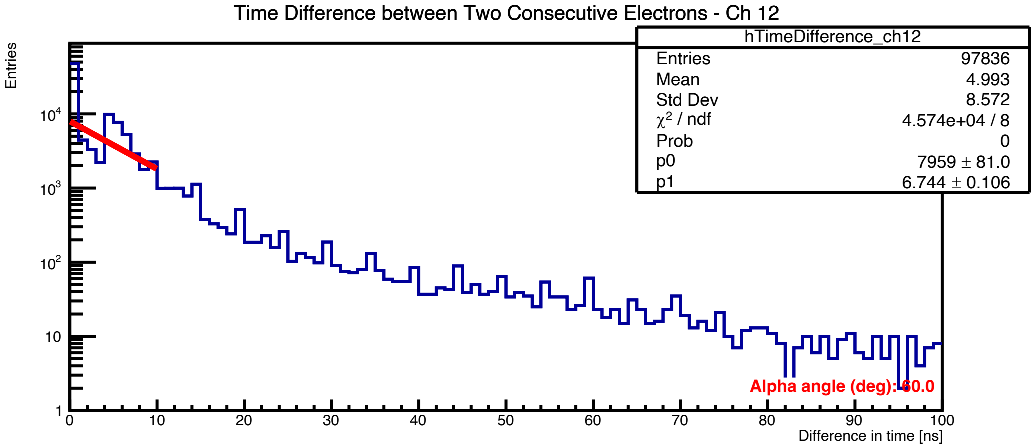
Time difference distribution between electrons

Run: run_91.root; Track angle: 60° ; Gas mixture: 90%He ; HV = +20

2 cm drift tubes







Summary of results

We expected to have a low cluster counting efficiency (# cluster counted/ # cluster expected) for lower angles due to the less evident charge screening, the ionization avalanche starts near the sensor wire.

1 cm drift tubes

Gas mixture (**90%He10%iC_4H_{10}**)

Track angle 0° : 78,6% efficiency
Track angle 15° : 79.26% efficiency
Track angle 30° : 94.7% efficiency
Track angle 45° : 94.7% efficiency
Track angle 60° : 73.3% efficiency

2 cm drift tubes

Gas mixture (**90%He10%iC_4H_{10}**)

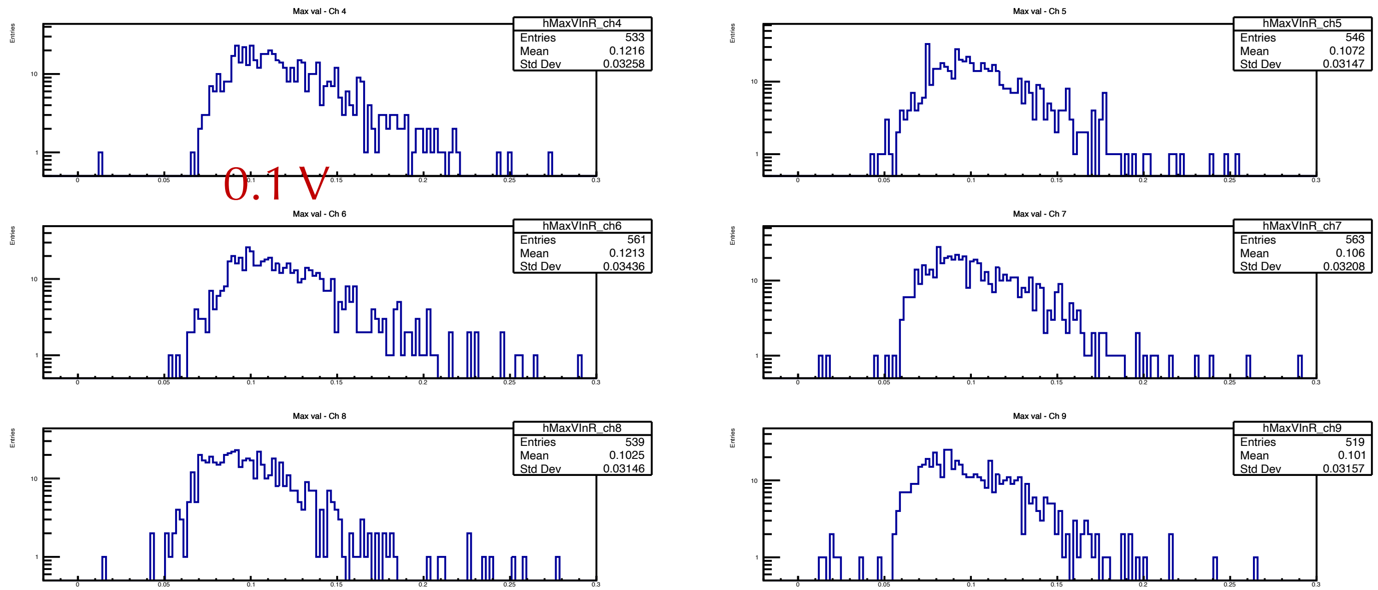
Track angle 0° : 42.2% efficiency
Track angle 15° : 47.8% efficiency
Track angle 30° : 68.9% efficiency
Track angle 45° : 71.8% efficiency
Track angle 60° : 57.4% efficiency

Probably this is due to different gas gain conditions (the mean value of the max amplitude is higher w.r.t. other runs). For the **80%He20%iC_4H_{10} gas mixture** up to now they are lower (1 cm cell tubes: run_117 0° 37.1% and run_127 60° 43.8%; 2 cm cell tubes: run_117 0° 20.3% and run_127 60° 44.2%) for the same reason.

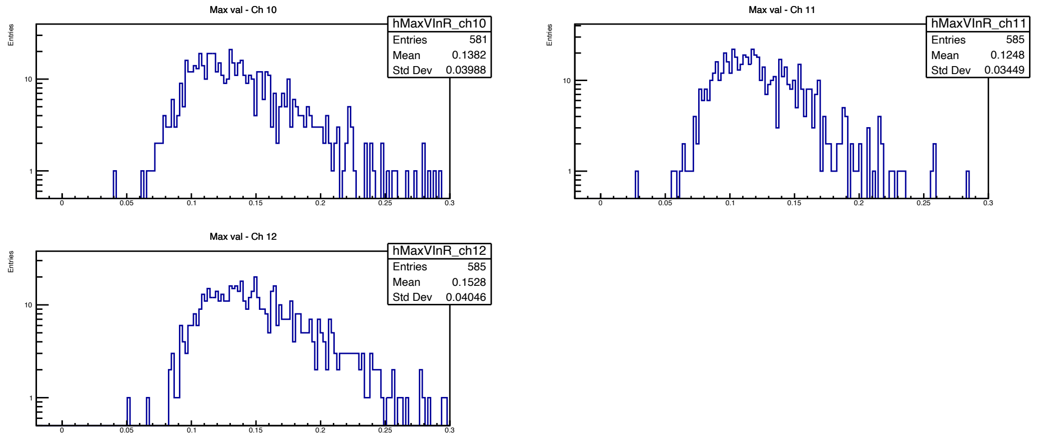
We must take into account that:

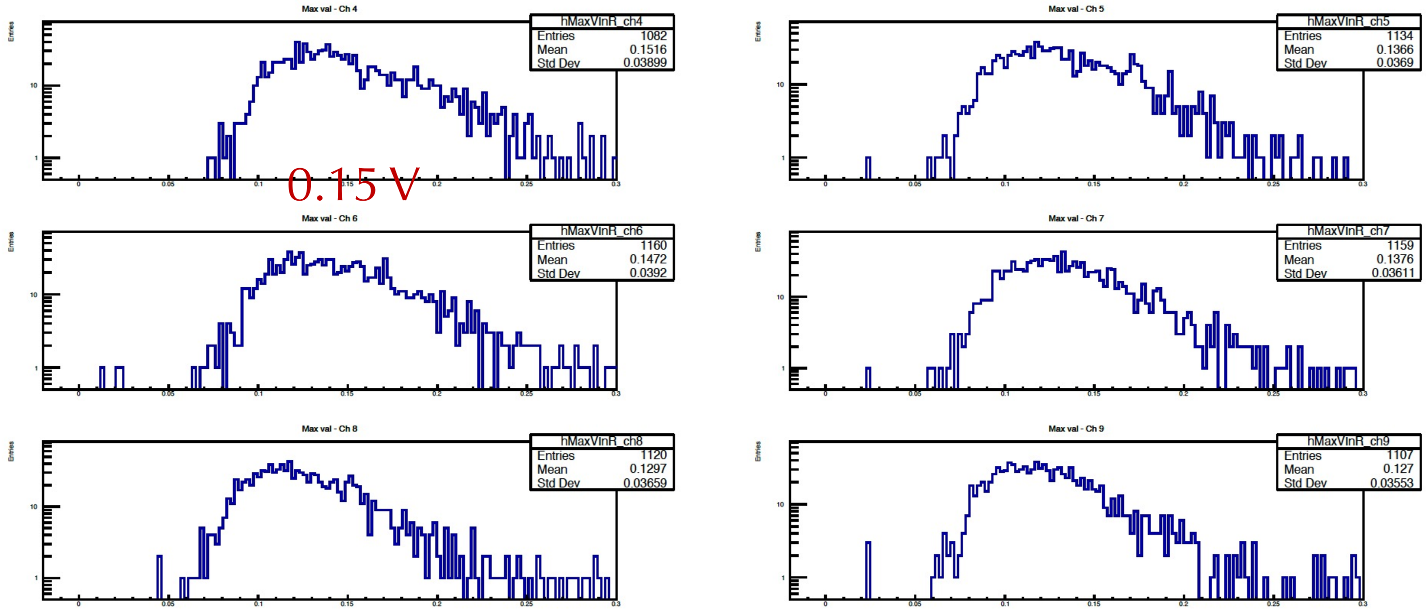
- Higher track angles means higher number of electrons which are cannot be distinguished one from another

Summary of results (cont.)

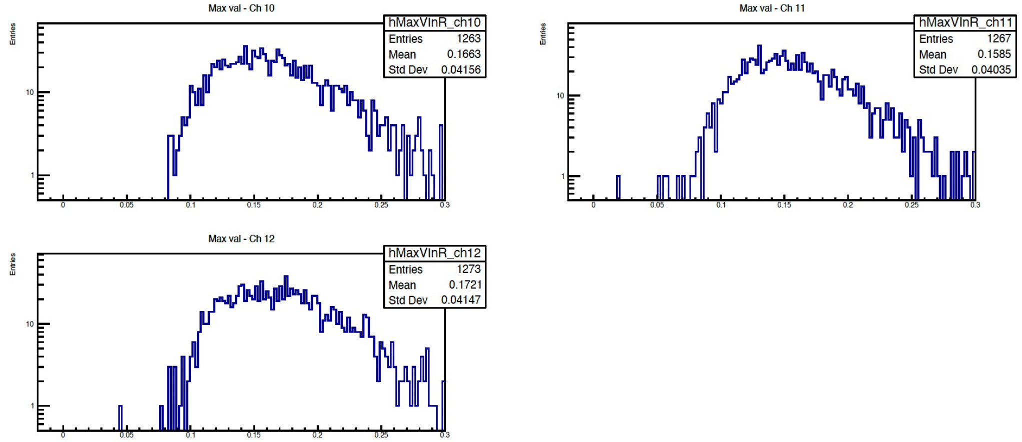


Run_94.root, 45° -> lower signal amplitudes!





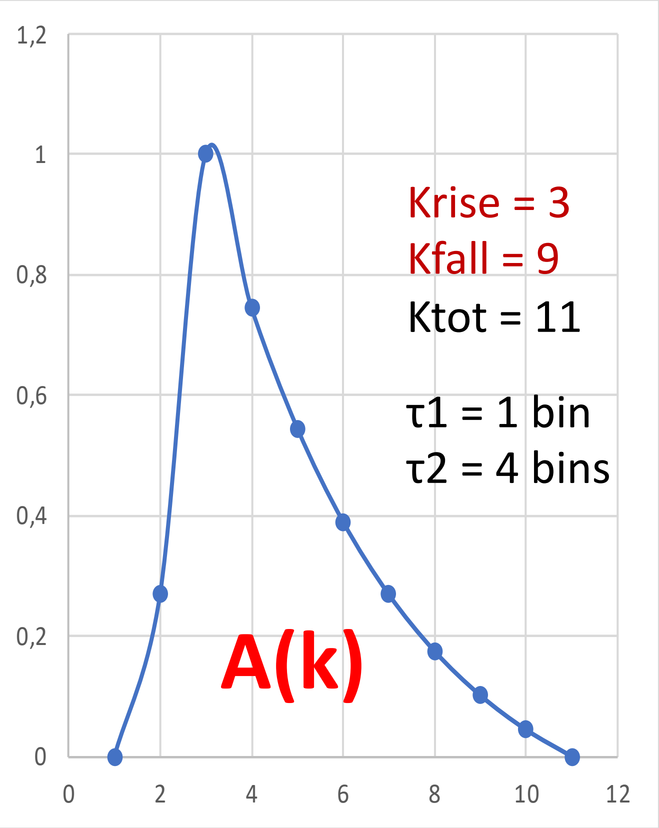
Run_91.root, 60° -> higher signal amplitudes!

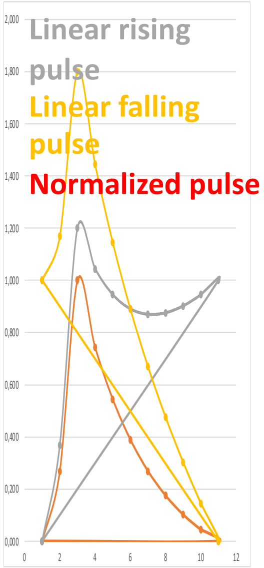


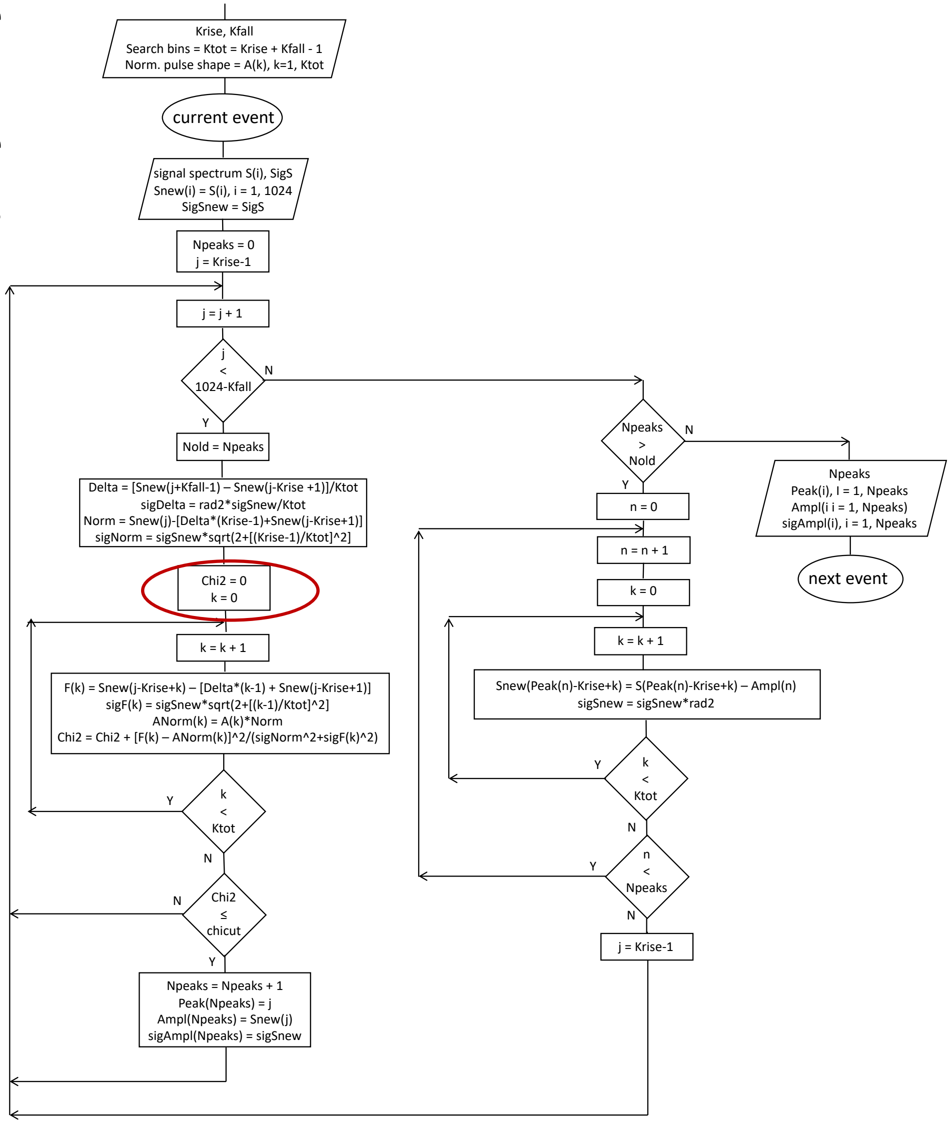
Recursive Template Algorithm

- We are working on it in order to make a performance comparison with the current algorithm!
- Both of the algorithms are quite simple from the computation point of view to be implemented in FPGAs and have few parameters to be optimized.

k	A(k)
1	0.0
2	0.269
3	1.0
4	0.744
5	0.545
6	0.390
7	0.269
8	0.175
9	0.102
10	0.044
11	0.0







Conclusion

- We tested the Derivative Find Electron Peak algorithm on runs having 1.2 GSPS and HV_nominal + 20 in order to set the constraints of our algorithm in the most favorable conditions with different gas mixture (80%He 90%He).

- Distributions of the number of clusters and electrons are compatible with the expected behaviours in most of the cases with some inefficiencies due to the presence of fake electrons and missing actual ones (in 2 cm tubes). An improvement of the efficiency by increasing the track angle is evident except for 60° which probably has different HV settings and an higher number of electrons which are too close one to each other for our discretized experimental resolution.

- Next step should be the calculation of the right timing cut for merging electrons into ionization clusters as a function of the electrons drift time. But probably we will not have enough statistics to succeed in this task.

- Hopefully, we will show comparison with the Recursive Template Find Electron Peak algorithm soon on the bottom of which we will implement the same clusterization algorithm!