Particle identification with the cluster counting technique

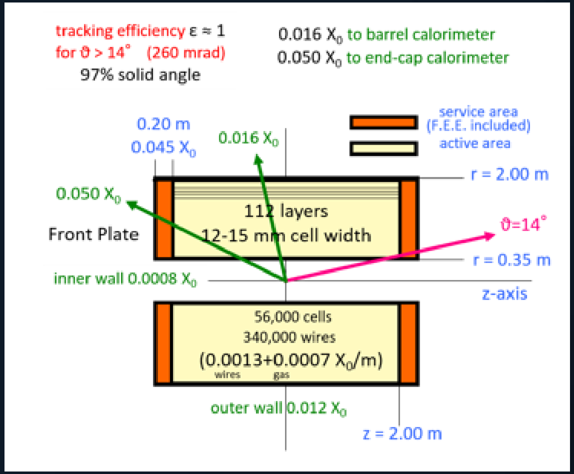
Federica Cuna for the cluster counting team

Outline

- The IDEA drift chamber: an innovative tracker with high particle identification potential
- The cluster counting technique: a promising method for the particle identification
- The simulations results with Garfield++ and Geant4: first hint of great results
- Beam tests for the validation of the great expectations

The IDEA drift chamber

The IDEA drift chamber (DCH) is the tracker of FCC-ee and CEPC. It is designed to provide efficient tracking, high precision momentum measurement and excellent particle identification by exploiting the application of the cluster counting technique.



- **He based gas mixture** (90% He – 10% i-C_4H_{10})
- **Full stereo configuration** with alternating sign stereo angles ranging from 50 to 250 mrad
- 12÷14.5 mm wide square cells 5 : 1 field to sense wires ratio
- 56,448 cells
- 14 co-axial super-layers, 8 layers each (112 total) in 24 equal azimuthal (15º) sectors

- **Gas containment – wire support functions separation**:
  the total amount of material in radial direction, towards the barrel calorimeter, is of the order of 1.6% X0, whereas in the forward and backward directions it is equivalent to about 5.0% X0, including the endplates instrumented with front end electronics.
- **Cluster timing**:
  allows to reach spatial resolution < 100 μm for 8 mm drift cells in He based gas mixtures (such a technique is going to be implemented in the MEG-II drift chamber under construction)
- Cluster counting:
  allows to reach dN/dx resolution < 3% for particle identification (a factor 2 better than dE/dx)

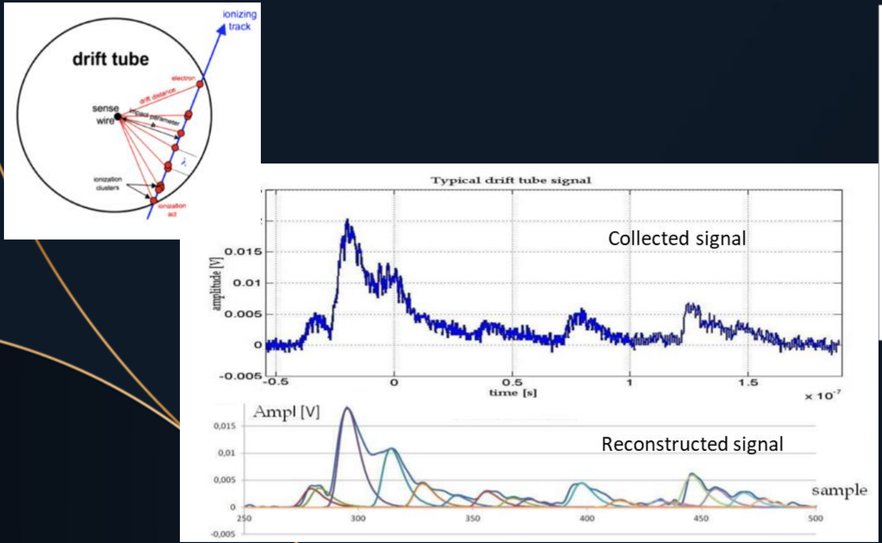
The cluster counting technique

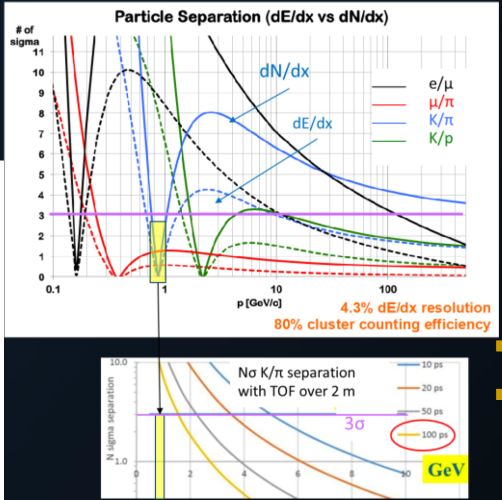
The traditional technique: dE/dx

Using the information about energy deposit by a track in a gaseous detector, particle identification can be performed.
The large and intrinsic uncertainties in the total energy deposition represent a limit to the particle separation capabilities.

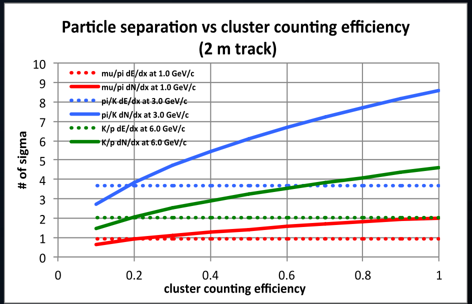
The cluster counting technique : dN/dx

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.





Analytical evaluation by F.Grancagnolo



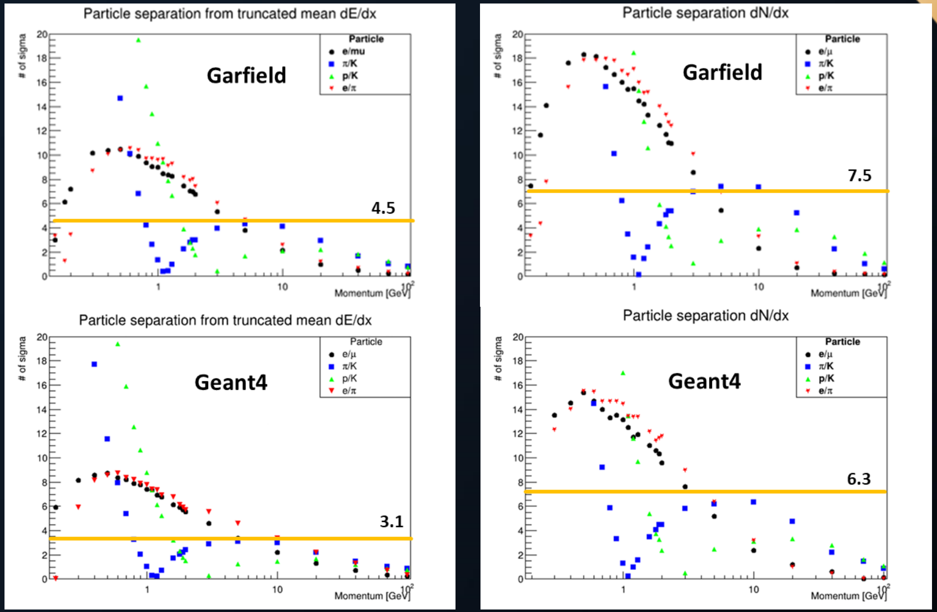
- 80% cluster counting efficiency.
- Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)
- Could recover with timing layer

Simulation results with Garfield++ and Geant4

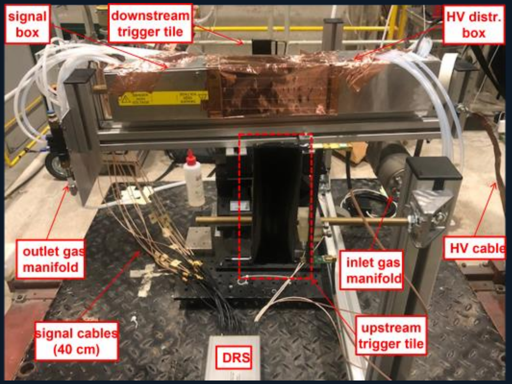
A simulation of the ionization process in 1 cm long side cell of 90% He and 10% iC_4H_{10} has been performed in **Garfield++** and **Geant4**.

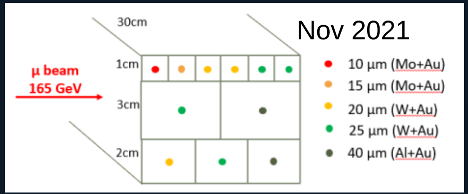
Three different algorithms have been implemented to simulate in Geant4, *in a fast and convenient way*, the number of clusters and clusters size distributions, using the energy deposit provided by Geant4.

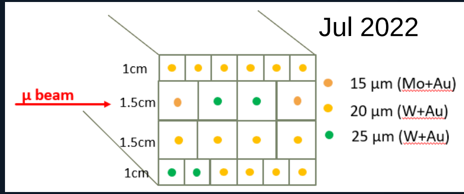
The simulations confirm the predictions: a factor 2 better than dE/dx !



Beam tests to validate the simulations results

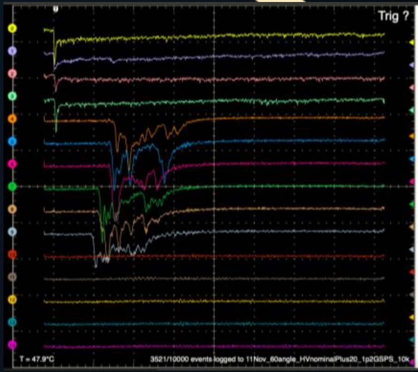






A "minimal" setup

- A pack of drift tubes
- DRS for data acquisition
- Gas mixing, control and distribution (He and iC_4H_{10})
- 2 trigger scintillators

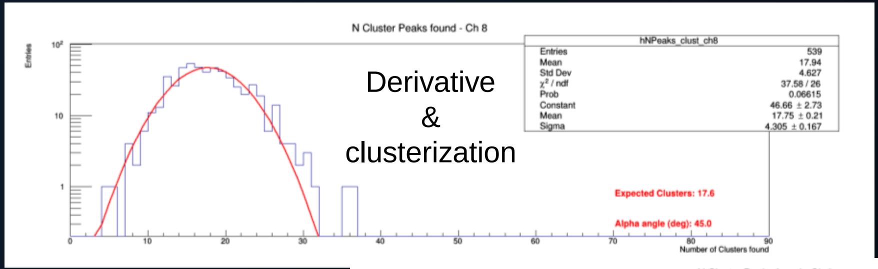


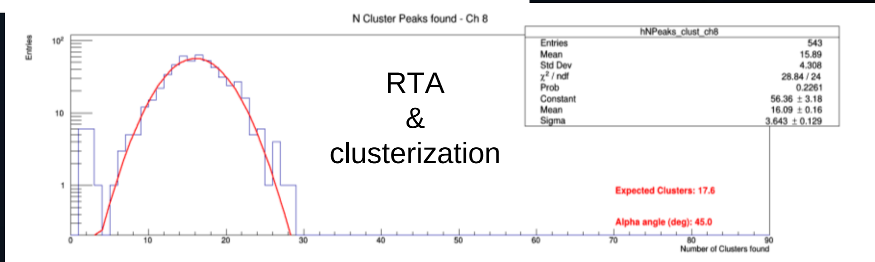
Two algorithms for peaks finding:

- Derivative algorithm
- Running template algorithm (RTA)

An algorithm to associate the peaks found in clusters:

- Clusterization algorithm





Poissonian nature

Thank you

The cluster counting team

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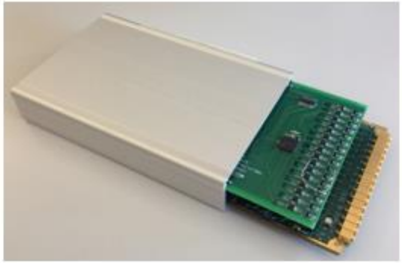
Backup

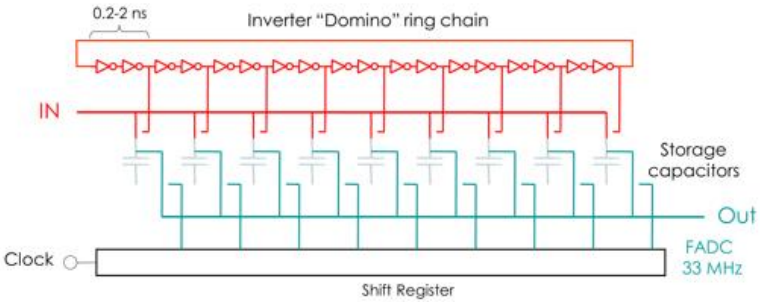
The DAQ system: WDB wave dream board

16 ch **D**rs4 **REA**dout **M**odule

Special thanks to the MEG collaboration

16 channels data acquisition board designed and used by the MEG2 experiment at PSI ($\mu \rightarrow e + \gamma$)





- **Analog switched capacitor array**: analog memory with a depth of 1024 sampling cells, perform a "**sliding window**" sampling.

- **500MSPS ↔ 5GSPS sampling speed** with 11.5 bit signal-noise ratio
  - 8 analog channels + 1 clock-dedicated channel for sub 50ps time alignment

- Pile-up rejection O(~10 ns)
- Time measurement O(10 ps)
- Charge measurement O(0.1%)

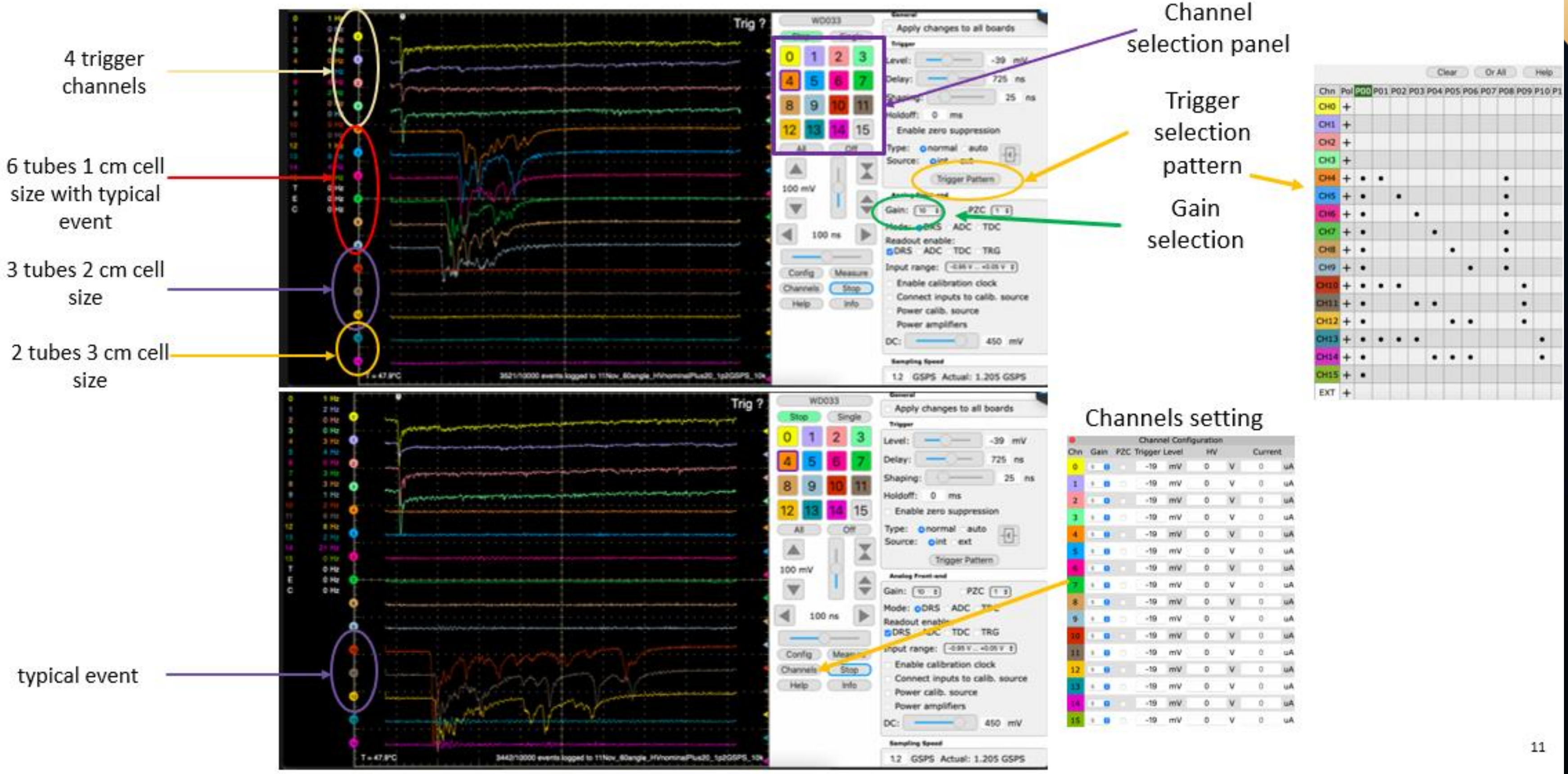
The data files have been converted in root format to accomplish the data analysis.
Data at different configuration have been collected:

- 90%He-10%iC_4H_{10}
- 80%He-20%iC_4H_{10}
- HV nominal (+10,+20,+30,-10,-20,-30)
- Angle 0° ,30 °,45 °,60 °

Details at: Application of the DRS chip for fast waveform digitizing, Stefan Ritt, Roberto Dinapoli, Ueli Hartmann, *Nuclear Instruments and Methods in Physics Research A 623 (2010) 486–488*

The DAQ system: an oscilloscope interface

WDB interface is similar to the interface of an oscilloscope with 16 channels



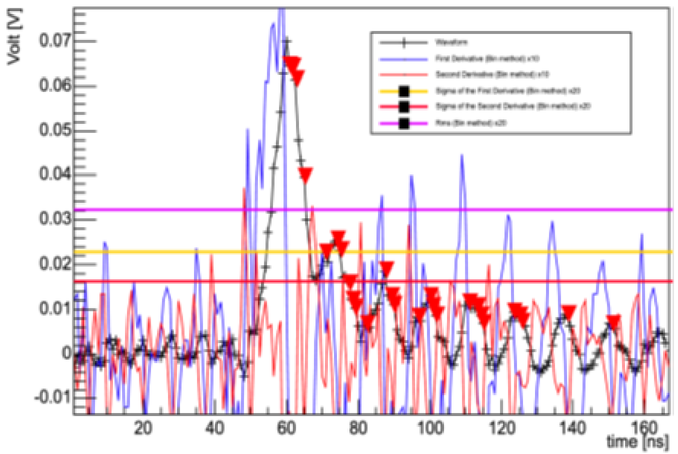
Preliminary results: an efficient algorithm to count electrons

The first and second derivative algorithm (DERIV)

Requirements for a good peak candidate in the bin position [ip]:

1. Amplitude constraint:
   - Amplitude[ip]>4*rms
   - Amplitude[ip]- Amplitude[ip-1]>rms || Amplitude[ip+1]-Amplitude[ip-1]>rms
2. First derivative constraint:
   - Fderiv[ip]< $\sigma_{der1}/2$
   - Fderiv[ip-1]> σ_{der1} ||Fderiv[ip+1]<- σ_{der1}
3. Second derivative constraint:
   - Sderiv[ip]<0

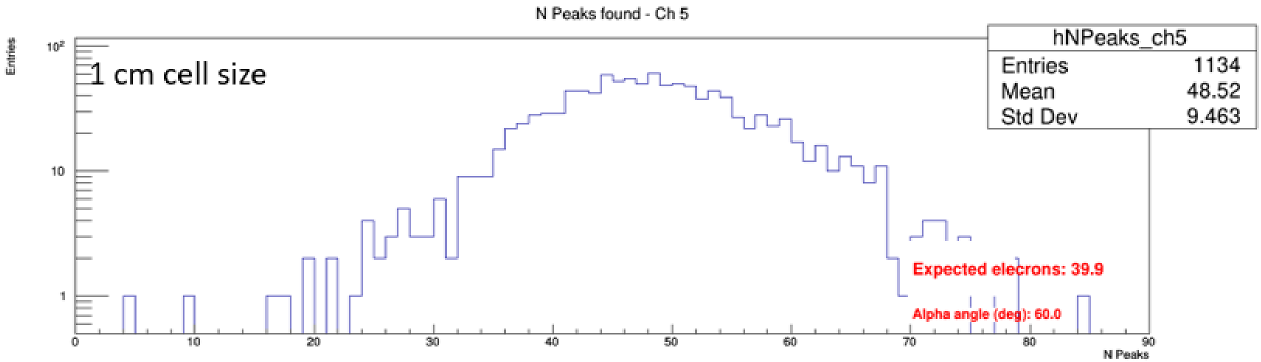
0°, nominal HV+20, 90%He-10%iC_4H_{10}
Tube with 1 cm cell size and 20 µm diameter



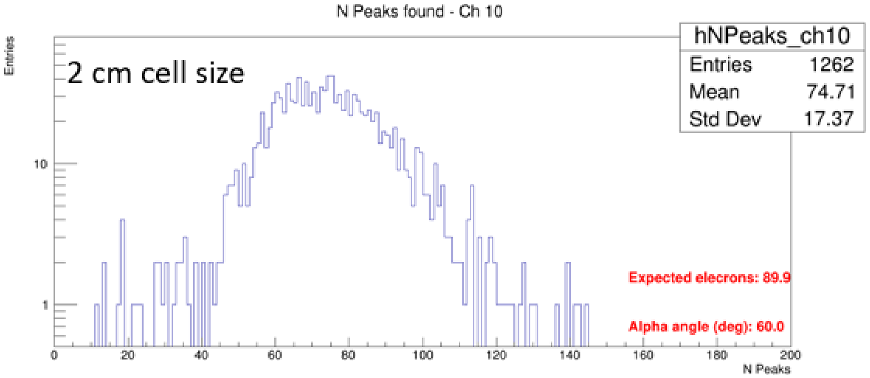
Expected number of electrons peaks:
Npeak=δcluster/cm(M.I.P.)*drift tube size[cm]*1.3(relativistic rise)*1.6 electron/cluster*1/cos(α)

- δcluster/cm(M.I.P.) changes from 12 to 18 respectively for 90%He and 80%iC_4H_{10}
- Drift tube size changes from 0.8 to 1.8 respectively for 1 cm and 2 cm cell size tube.
- α is the angle of the muon tracks to the detector

The first and second derivative algorithm: results



90%He-10%iC_4H_{10}
60°
nominal HV+20

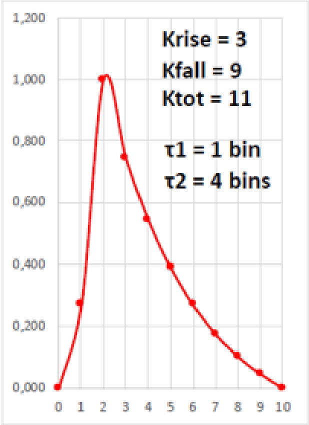


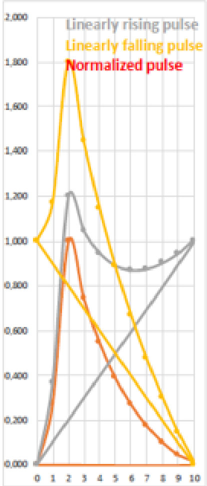
The mean values are compatible with the ones expected!

The running template algorithm (RTA)

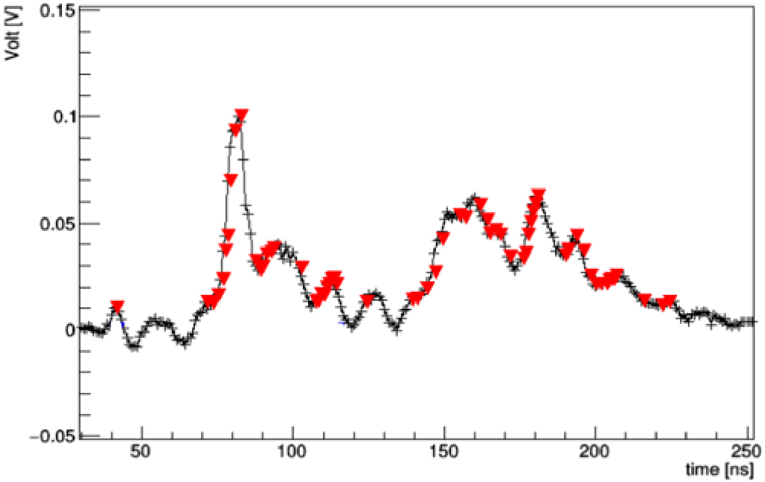
- Define an electron pulse template based on experimental data.
- Raising and falling exponential over a fixed number of bins (Ktot).
- Digitize it (A(k)) according to the data sampling rate.
- Run over Ktot bins by comparing it to the subtracted and normalized data (build a sort of χ2).
- Define a cut on χ2.
- Subtract the found peak to the signal spectrum.
- Iterate the search.
- Stop when no new peak is found.

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

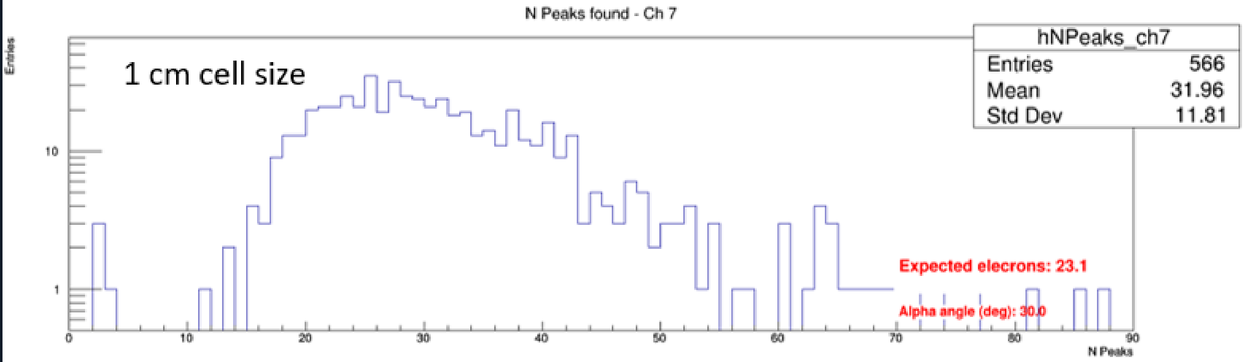




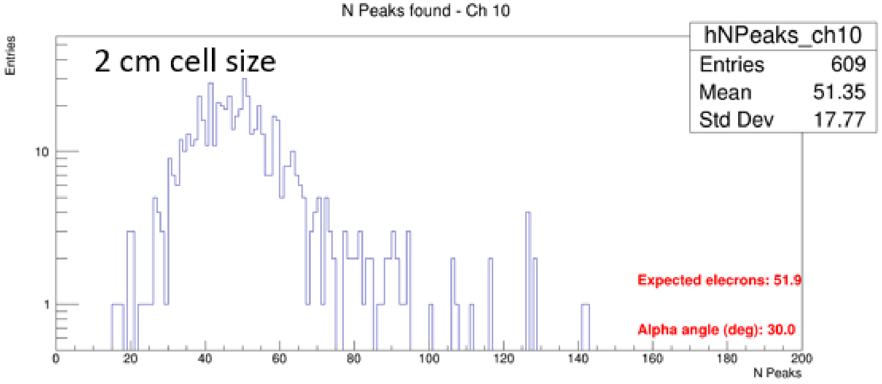
30°, nominal HV+20, 90%He-10%iC_4H_{10}
Tube with 1 cm cell size and 20 μm diameter



The running template algorithm (RTA): results



90%He-10%iC_4H_{10}
30°
nominal HV+20



The mean values are compatible with the ones expected!

A single clusterization algorithm

Once find the electron peaks, clusterization of the electron peaks into ionization clusters has been implemented:

1) Association of electron peaks consisting in consecutive bins (difference in time == 1 bin) electrons to a single electron in order to eliminate fake electrons.
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.
3) Position of the clusters is taken as the position of the last electron in the cluster.