

# Particle identification with the cluster counting technique

Federica Cuna for the cluster counting team



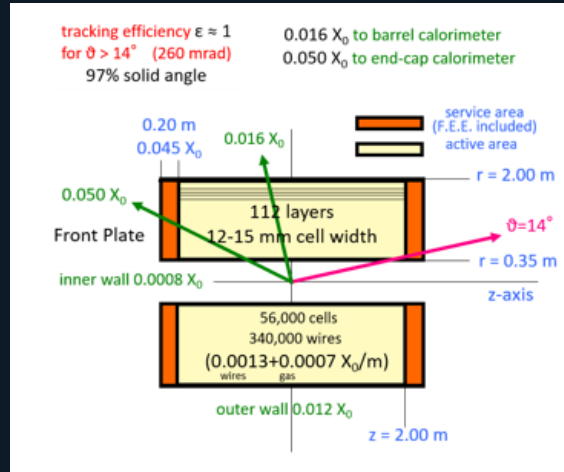
# Outline

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- 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<sub>4</sub>H<sub>10</sub>)
- 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 (15°) 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%  $X_0$ , whereas in the forward and backward directions it is equivalent to about 5.0%  $X_0$ , including the endplates instrumented with front end electronics.

- **Cluster timing:**

allows to reach spatial resolution  $< 100 \mu\text{m}$  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

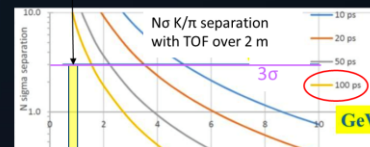
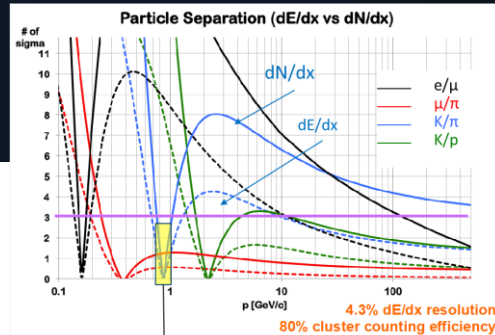
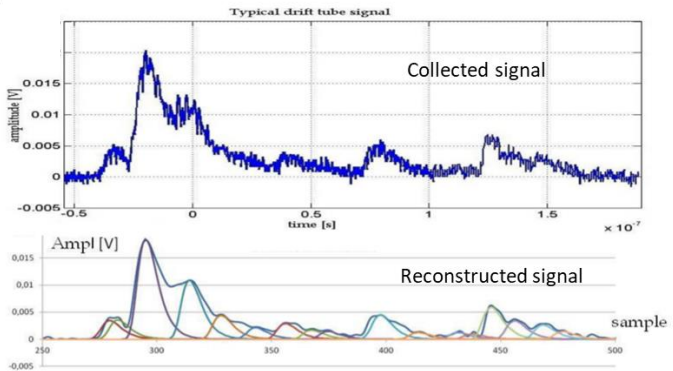
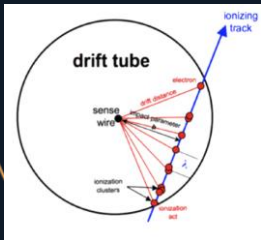
## The traditional technique: $dE/dx$

Using the information about energy deposit by a track in a gaseous detector, particle identification can be performed.

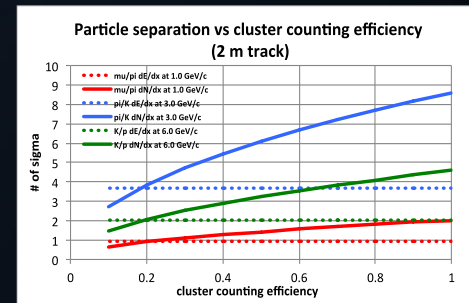
The large and intrinsic uncertainties in the total energy deposition represent a limit to the particle separation capabilities.

## 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  $K/\pi$  separation over the entire range except  $0.85 < p < 1.05$  GeV (blue lines)

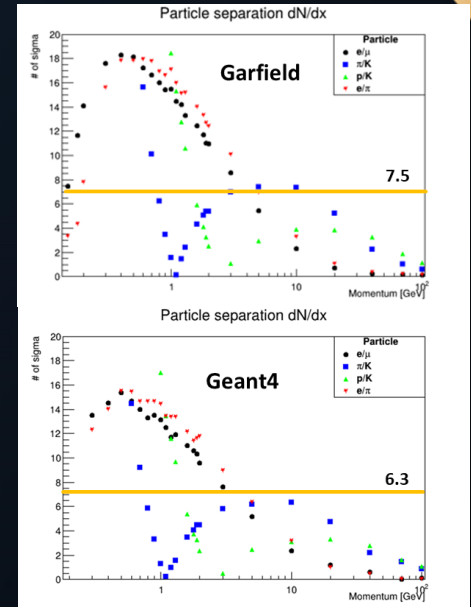
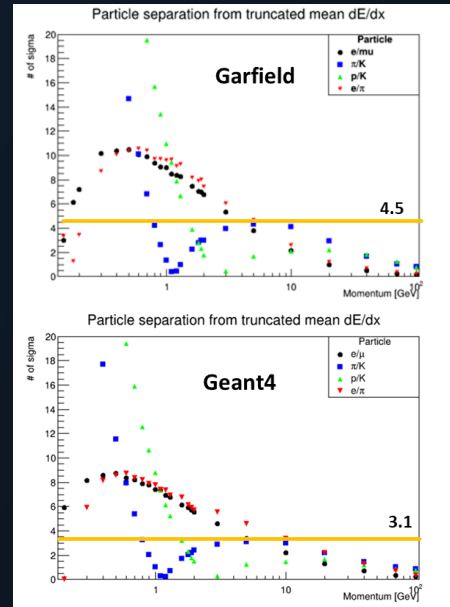
Could recover with timing layer

# Simulation results with Garfield++ and Geant4

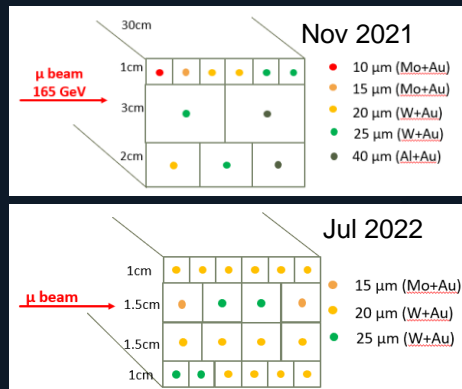
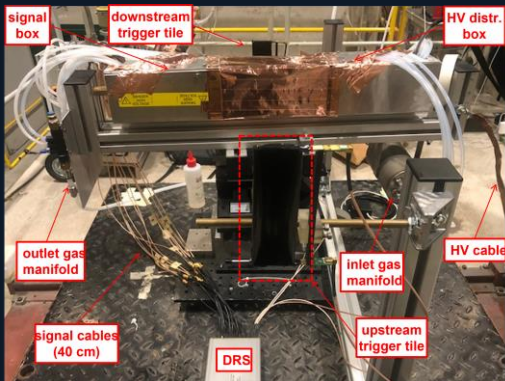
A simulation of the ionization process in 1 cm long side cell of 90% He and 10%  $iC_4H_{10}$  has been performed in **Garfield++** and **Geant4**.

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  $dE/dx$  !

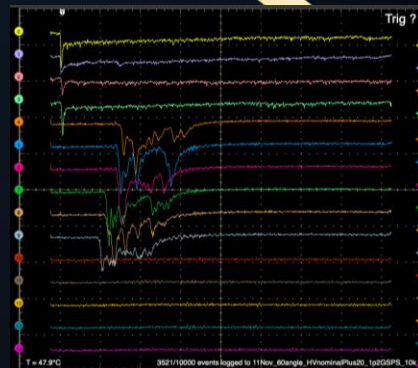


# Beam tests to validate the simulations results



## A "minimal" setup

- A pack of drift tubes
- DRS for data acquisition
- Gas mixing, control and distribution (He and  $\text{iC}_4\text{H}_{10}$ )
- 2 trigger scintillators

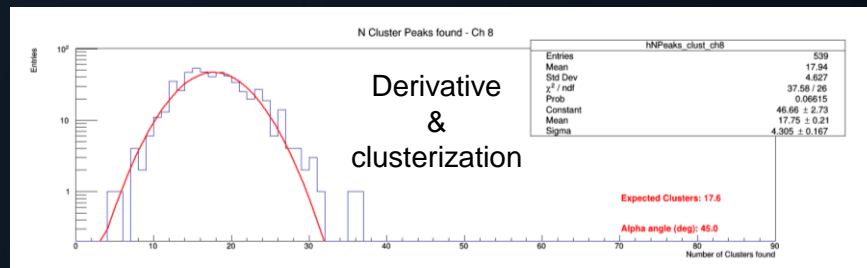


Two algorithms for peaks finding:

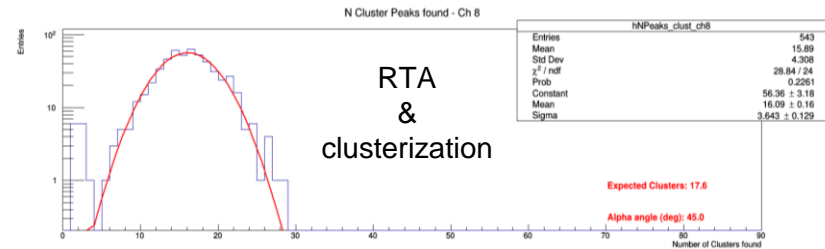
- Derivative algorithm
- Running template algorithm (RTA)

An algorithm to associate the peaks found in clusters:

- Clusterization algorithm



Poissonian nature



# Thank you

## The cluster counting team

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The background is a dark blue gradient. There are several gold-colored decorative elements: a thick arc in the top-left corner, a thin arc in the bottom-right corner, and a thin arc in the bottom-left corner. The word "Backup" is centered in a gold serif font, with a thin gold underline beneath it.

# Backup

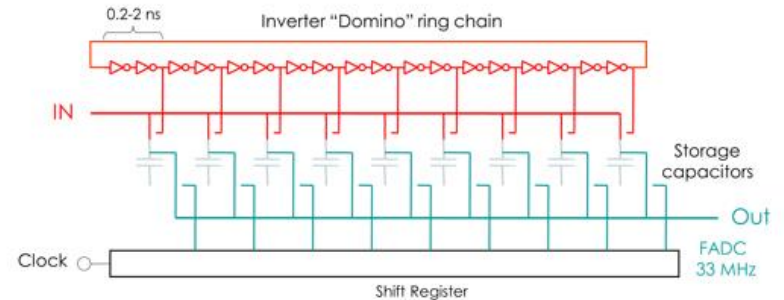


## The DAQ system: WDB wave dream board

Special thanks to the MEG collaboration

16 ch Drs4 REAdout Module

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  $O(\sim 10 \text{ ns})$
- Time measurement  $O(10 \text{ ps})$
- 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<sub>4</sub>H<sub>10</sub>
- 80%He-20%iC<sub>4</sub>H<sub>10</sub>
- 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

The image displays the WDB DAQ system interface, which functions as a 16-channel oscilloscope. The main display shows multiple colored waveforms corresponding to different channels. Annotations on the left side of the interface indicate the physical size of the tubes used for data collection:

- 4 trigger channels (indicated by a yellow oval around channels 0-3)
- 6 tubes 1 cm cell size with typical event (indicated by a red oval around channels 4-9)
- 3 tubes 2 cm cell size (indicated by a purple oval around channels 10-12)
- 2 tubes 3 cm cell size (indicated by a yellow oval around channels 13-14)
- typical event (indicated by a purple oval around channels 15 and 16)

On the right side, there are several control panels:

- Channel selection panel:** A 4x4 grid of buttons labeled 0 through 15, used to select which channels are active.
- Trigger selection pattern:** A grid of buttons used to define the trigger pattern for the acquisition.
- Gain selection:** A control for setting the gain for each channel, currently set to 10.
- Channels setting table:** A detailed configuration table for each channel.

The central control panel includes various settings such as Level (-30 mV), Delay (725 ns), Shaping (25 ns), Holdoff (0 ms), and Trigger Pattern (PZC). It also features a 'Trigger Pattern' section with a 'Gain' dropdown set to 10 and a 'PZC' button.

Chn	Gain	PZC	Trigger	Level	mV	Current
0	10			-19	mV	0 uA
1	10			-19	mV	0 uA
2	10			-19	mV	0 uA
3	10			-19	mV	0 uA
4	10			-19	mV	0 uA
5	10			-19	mV	0 uA
6	10			-19	mV	0 uA
7	10			-19	mV	0 uA
8	10			-19	mV	0 uA
9	10			-19	mV	0 uA
10	10			-19	mV	0 uA
11	10			-19	mV	0 uA
12	10			-19	mV	0 uA
13	10			-19	mV	0 uA
14	10			-19	mV	0 uA
15	10			-19	mV	0 uA
16	10			-19	mV	0 uA

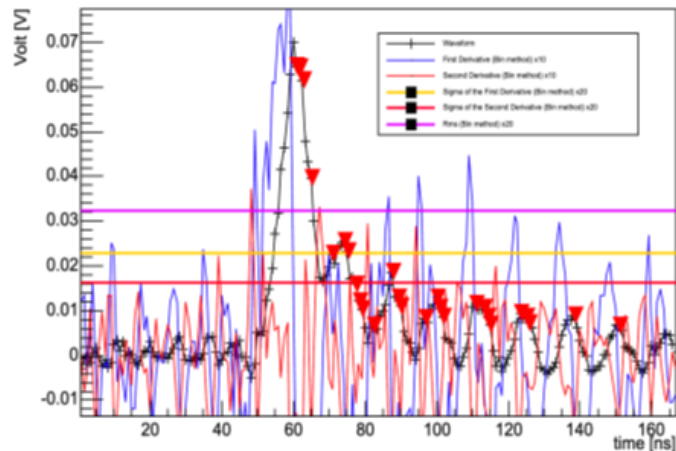
## Preliminary results: an efficient algorithm to count electrons

### The first and second derivative algorithm (DERIV)

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

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

0°, nominal HV+20, 90%He-10%iC<sub>4</sub>H<sub>10</sub>  
Tube with 1 cm cell size and 20 μm diameter

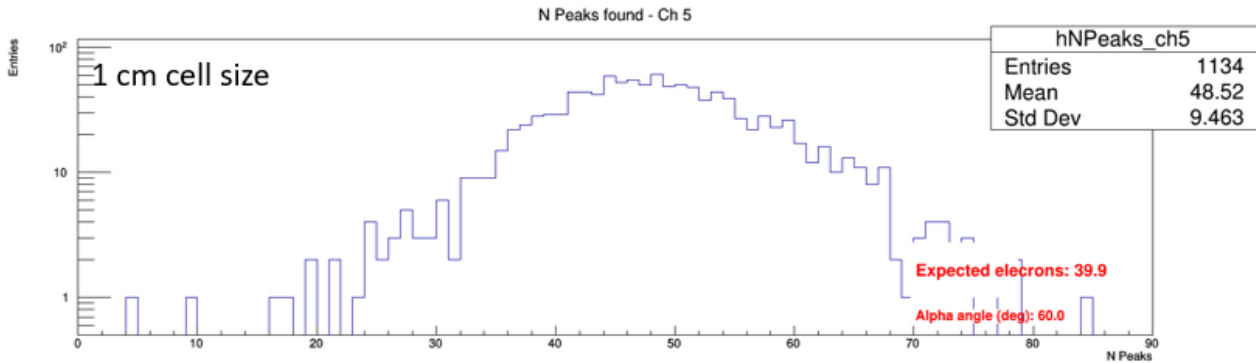


Expected number of electrons peaks:

$$N_{\text{peak}} = \delta_{\text{cluster/cm(M.I.P.)}} * \text{drift tube size[cm]} * 1.3(\text{relativistic rise}) * 1.6 \text{ electron/cluster} * 1/\cos(\alpha)$$

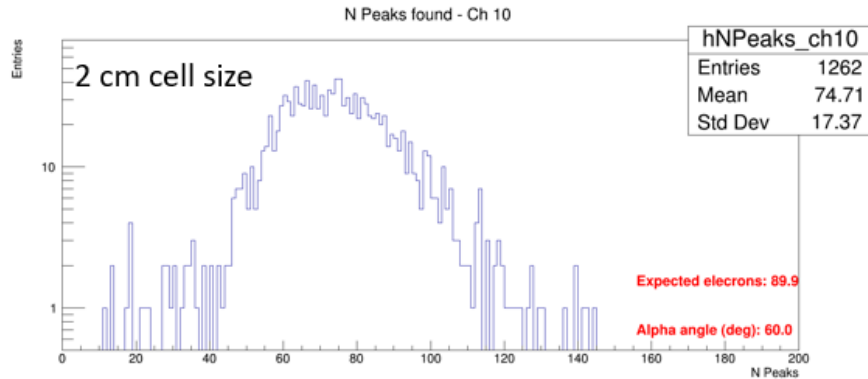
- $\delta_{\text{cluster/cm(M.I.P.)}}$  changes from 12 to 18 respectively for 90%He and 80%iC<sub>4</sub>H<sub>10</sub>
- Drift tube size changes from 0.8 to 1.8 respectively for 1 cm and 2 cm cell size tube.
- $\alpha$  is the angle of the muon tracks to the detector

## The first and second derivative algorithm: results



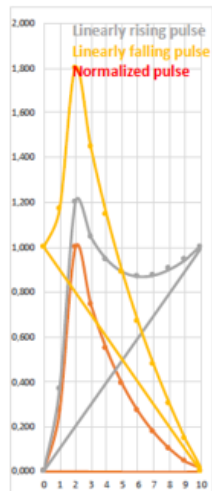
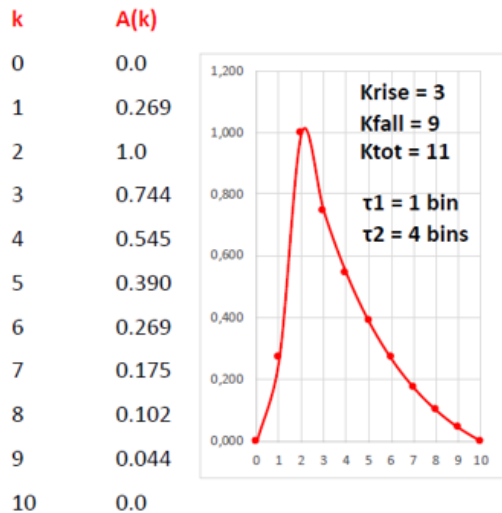
90%He-10%<sup>i</sup>C<sub>4</sub>H<sub>10</sub>  
60°  
nominal HV+20

The mean values are compatible with the ones expected!

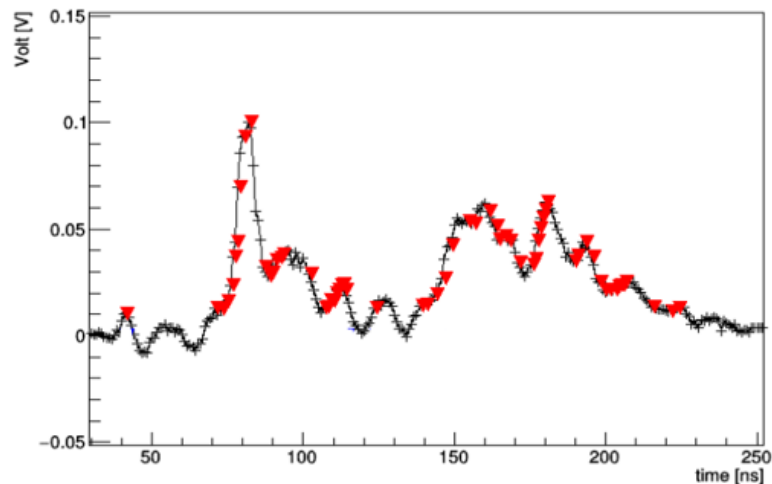


## The running template algorithm (RTA)

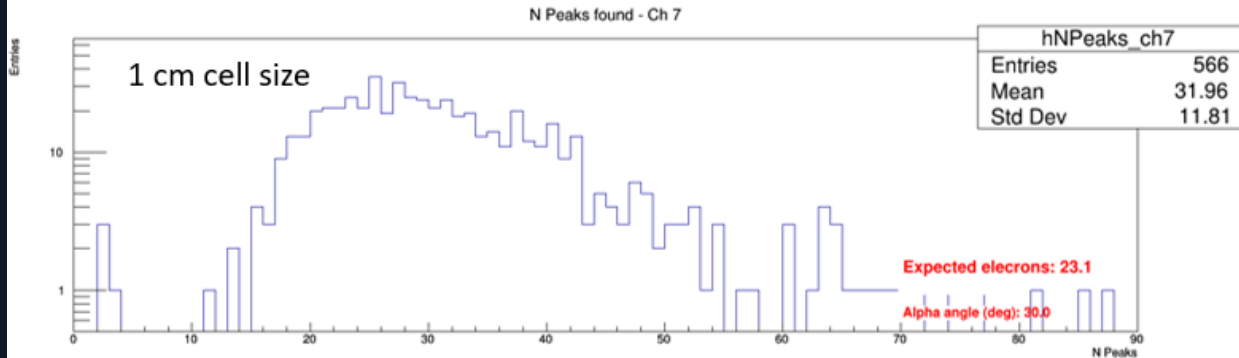
- Define an electron pulse template based on experimental data.
- Raising and falling exponential over a fixed number of bins ( $K_{tot}$ ).
- Digitize it ( $A(k)$ ) according to the data sampling rate.
- Run over  $K_{tot}$  bins by comparing it to the subtracted and normalized data (build a sort of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



30°, nominal HV+20, 90%He-10%iC<sub>4</sub>H<sub>10</sub>  
Tube with 1 cm cell size and 20  $\mu$ m diameter

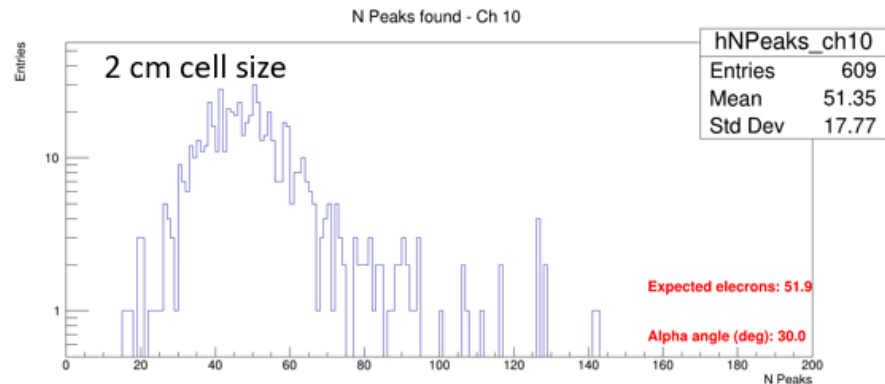


## The running template algorithm (RTA): results



90%He-10%iC<sub>4</sub>H<sub>10</sub>  
30°  
nominal HV+20

The mean values are compatible with the ones expected!

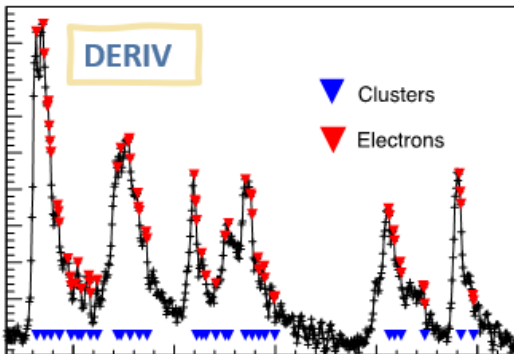


## A single clusterization algorithm

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.

2 cm drift tube Track angle 45°



2 cm drift tube Track angle 45°

