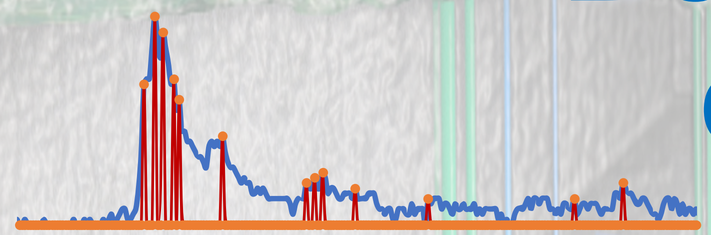
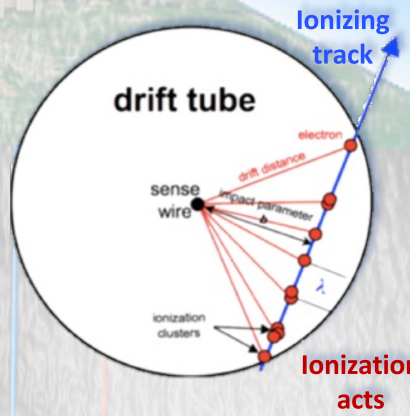
The 2022 international Workshop on the High Energy Circular Electron-Positron Collider (CEPC 2022)
October 24th – 28th 2022
Nanjing University, Nanjing, China

# Beam test results on cluster counting



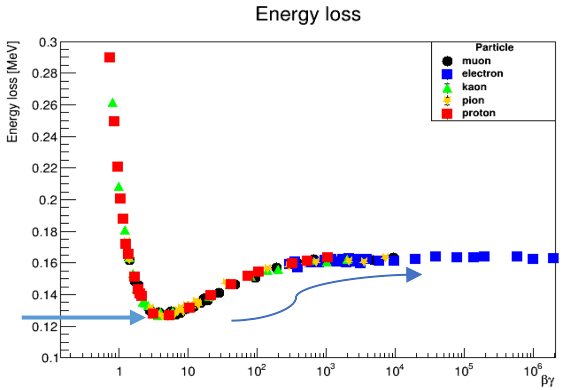


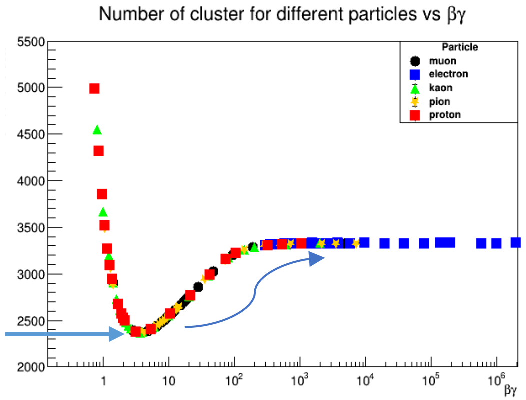

**Brunella D'Anzi (Bari University & INFN)**
on behalf of the H8/CERN cluster counting Test Beam Community
26th October 2022

# Beam test motivations



- **Lack of experimental data** on cluster density and cluster population for **Helium-based gas mixtures**, particularly in the relativistic rise region to be compared with predictions [1].
- Despite the fact that the Heed model in Geant4 reproduces reasonably well the Garfield predictions, why **particle separation**, both with dE/dx and with dN/dx, in **Geant4** is considerably **worse** than in **Garfield** (see Federica Cuna's Talk *PID performance study with IDEA Drift Chamber* by Federica Cuna)?
- Despite a **higher value** of the **$dN_{clusters}$/dx Fermi plateau** with respect to **dE/dx**, why this is reached at **lower values of βγ** with a **steeper slope**?




These questions are crucial to **predict the particle identification performance** at FCC-ee, CEPC: use the experimental results to fine tune the predictions on cluster counting performance for **flavor physics** and for **jet flavor tagging** both in **DELPHES** and in **full simulation**.

## Beam test plans (presented in Nicola De Filippis's Talk *The IDEA Drift Chamber*)

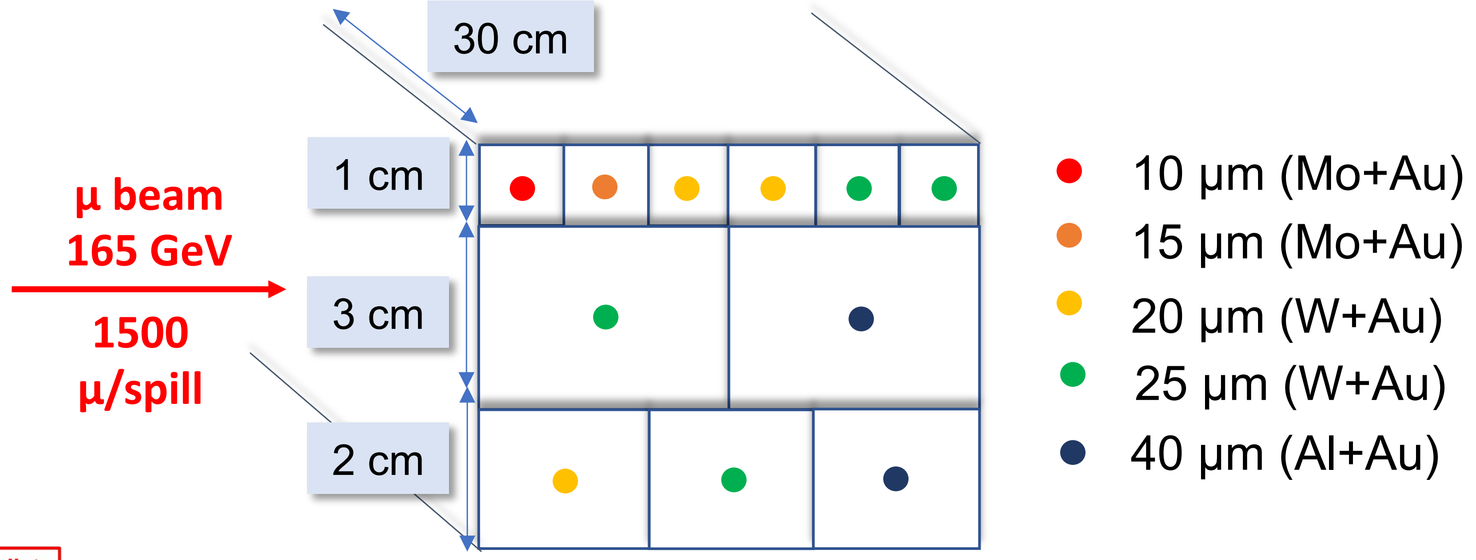
- Need to demonstrate the **ability to count clusters** at a **fixed βγ** (e.g. muons at a fixed momentum):
  - doubling and tripling the **track length** (**different cell size**) and changing the **track angle**;
  - changing the **gas mixture**.
- Establish **the limiting parameters for an efficient cluster counting:**
  - cluster density (by changing **the gas mixture**)
  - space charge (by changing **gas gain**, **sense wire diameter**, **track angle**)
  - **gas gain saturation**
- In optimal configuration, **measure the relativistic rise as a function of βγ**, both in dE/dx and in $dN_{cluster}$/dx, by scanning the muon momentum from the lowest to the highest value (from **a few GeV/c** to about **250 GeV/c** at CERN/H8).

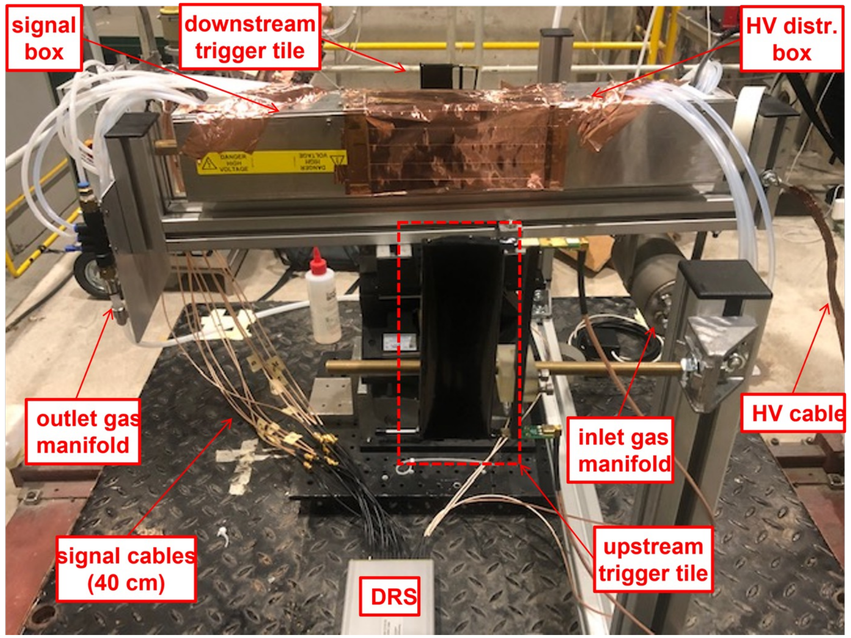
**Two data-taking beam tests!**

# November 2021 beam test setup at H8/CERN

*Keep it simple!*

**11 drift tubes** with **different cell size, material** and **diameter sense wires**, to test different configurations.



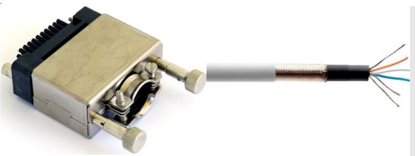

The set up consists of:

- **6 drift tubes 1 cm × 1 cm × 30 cm**
  - **1 with 10 μm sense wire, 1 with 15, 2 with 20 μm, 2 with 25 μm**
- **3 drift tubes 2 cm × 2 cm × 30 cm**
  - **1 with 20 μm sense wire, 1 with 25 μm, 1 with 40 μm**
- **2 drift tubes 3 cm × 3 cm × 30 cm**
  - **1 with 20 μm sense wire, 1 with 40 μm**
- **DRS** for data acquisition
- **Gas mixing**, control and distribution (only He and $iC_4H_{10}$)
- **Trigger scintillators (x2)**

# The connecting scheme

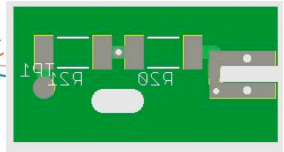
SY 1527 Mainframe

1535P 24ch



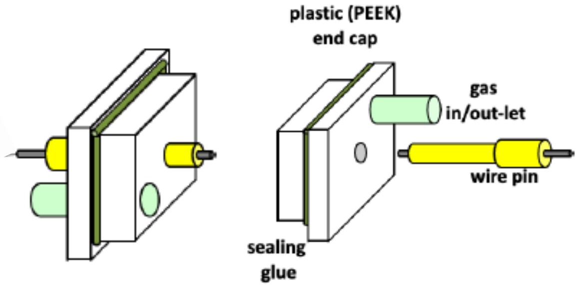
CAEN A996 Radiall 691803004

24 leads HV cable



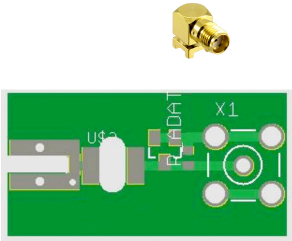
HV distribution board

connecting pin




drift tube end cap

connecting pin



HV decoupling board

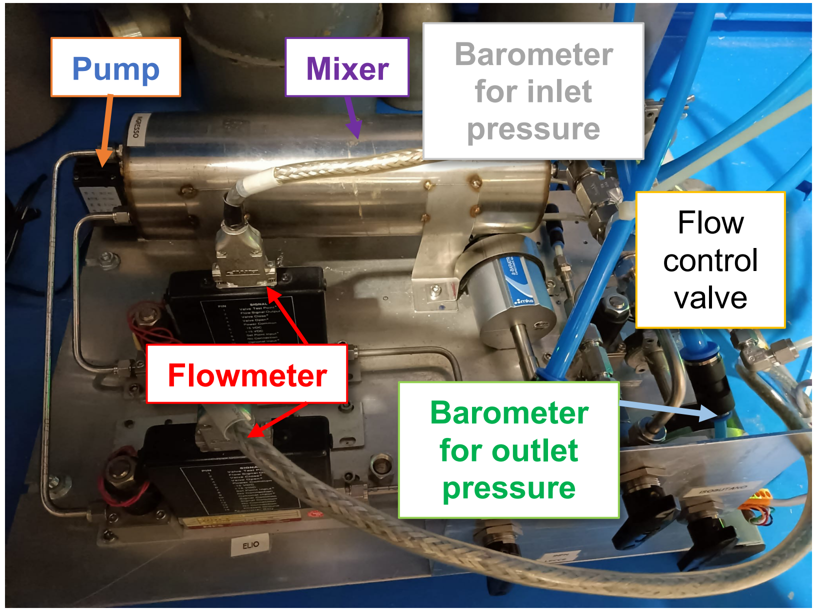
## Trigger scintillator

**Two scintillator tiles** (12 cm x 4 cm), placed **upstream** and **downstream** of the drift tubes pack, instrumented with SiPM.

## The gas system

- sets the **needed gas mixture**
- checks the **gas pressure** at the entrance and at the exit of the tubes
- keep the **gas pressure constant** inside the tubes, by using a proportional valve and a pump.

## Portable gas system



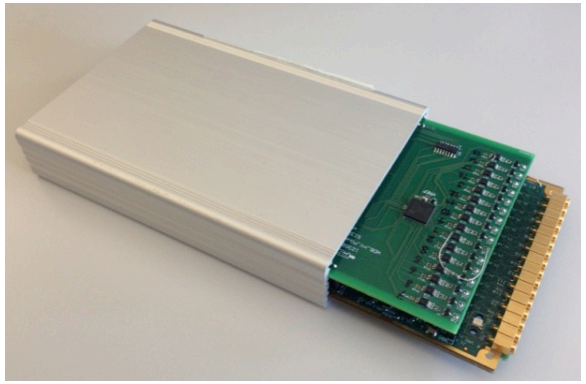
# The DAQ system: WDB wave dream board

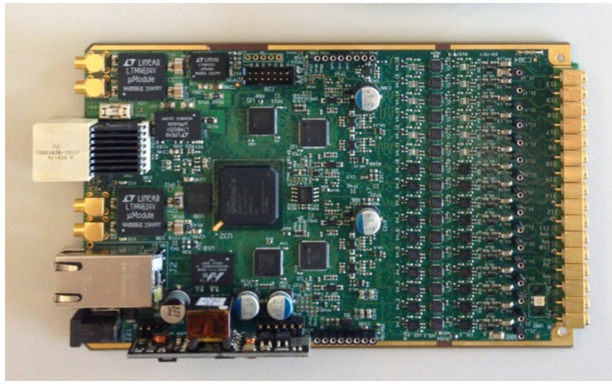
16 ch **D**rs4 **REA**dout **M**odule

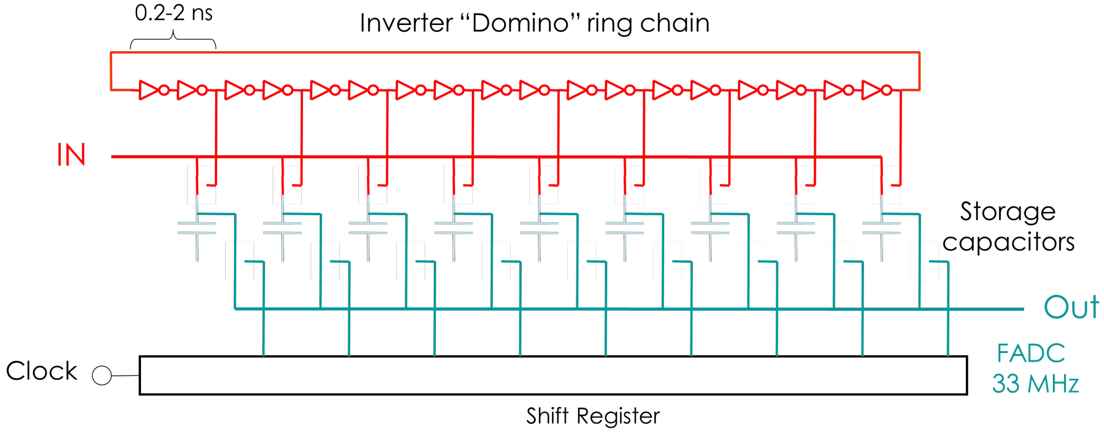


*Special thanks to the MEG collaboration*

16 channels data acquisition board designed and used by the **MEG-2 experiment** at PSI (μ → e + γ)








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

- **500 MSa/s ↔ 5 GSa/s sampling speed** with 11.5 bit signal-noise ratio
  - 8 analog channels + 1 clock-dedicated channel for sub 50 ps time alignment.

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

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 data files have been converted in **ROOT format** to accomplish the data analysis.
Data at **different configurations** have been collected:

- **90%He - 10%i$C_4H_{10}$**
- 80%He - 20%i$C_4H_{10}$
- HV nominal (+10,+20,+30,-10,-20,-30)
- Angle between the anode wire direction and the ionizing tracks **0°, 30°, 45°, 60°**
- **1.2 GSa/s** sampling rate

# The DAQ system: an oscilloscope interface



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

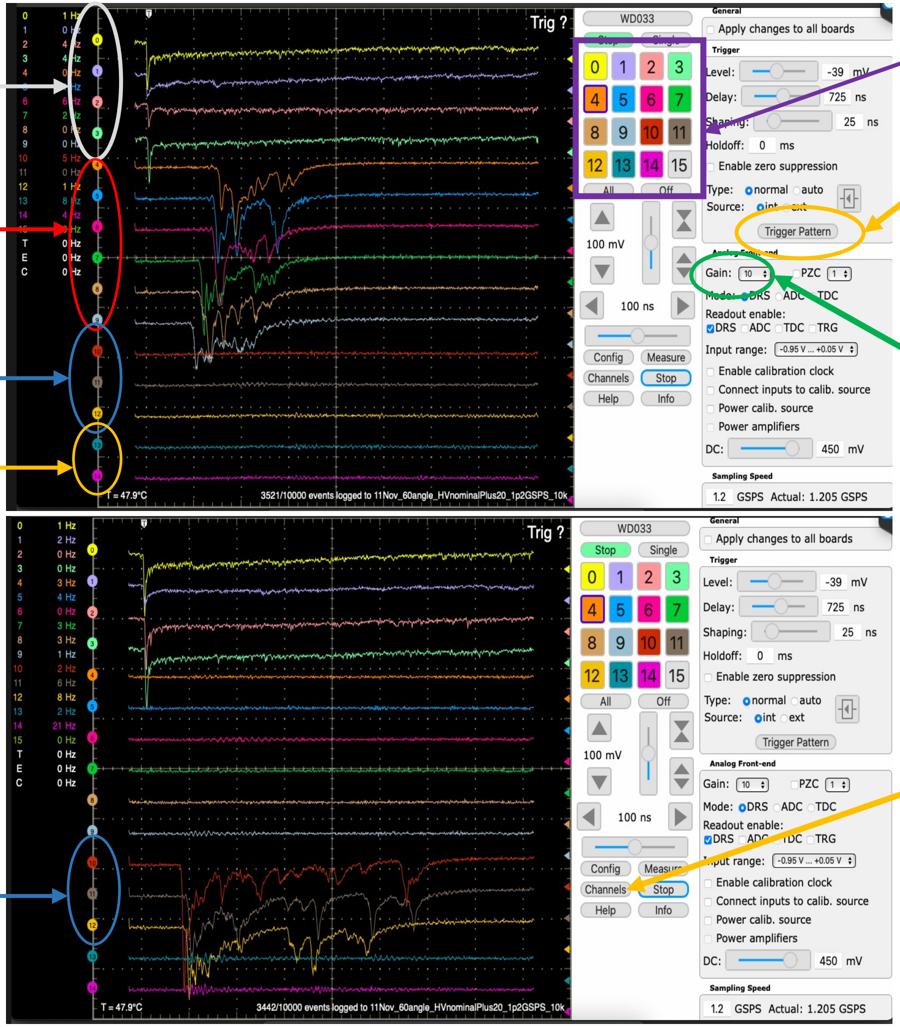
4 trigger channels

6 tubes 1 cm cell size with typical event

3 tubes 2 cm cell size

2 tubes 3 cm cell size

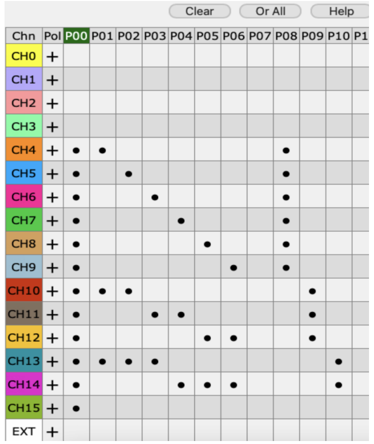
typical event




Channel selection panel

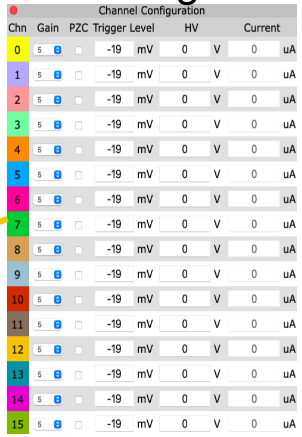
Trigger selection pattern

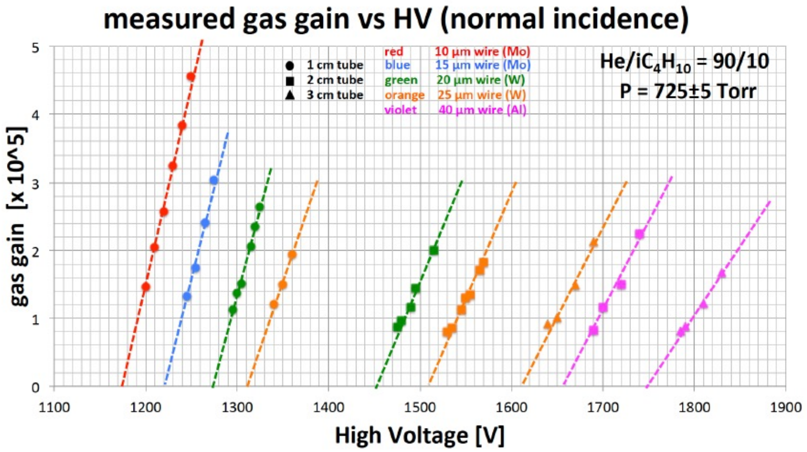
Gain selection




~ 100.000 events!

Channels setting



# Find electron peaks algorithms (1/2)

**Find good electron peak candidates at position bin *n* and amplitude $A_n$:**

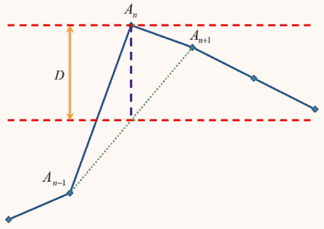
## FIRST AND SECOND DERIVATIVE (DERIV) ALGORITHM

- Compute the first and second derivative from the **amplitude average** over **two consecutive bins (1.6 ns for 1.2 GSa/s)** and require that, at the **peak candidate position**, they are **less than** a **r.m.s. signal-related small quantity** and they increase (decrease) **before (after) the peak candidate position** of a r.m.s. signal-related small quantity.

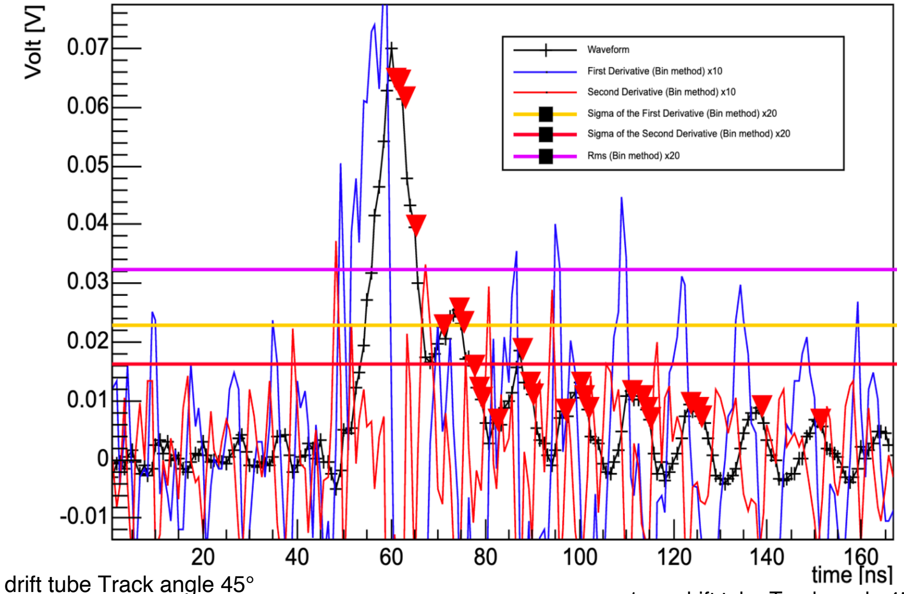
- Require that **the amplitude** at the **peak candidate position** is greater than a r.m.s. signal-related small quantity and the **amplitude difference** among the **peak candidate** and the **previous (next) signal amplitude** is greater (less) than a r.m.s. signal-related small quantity.

**NOTE:**

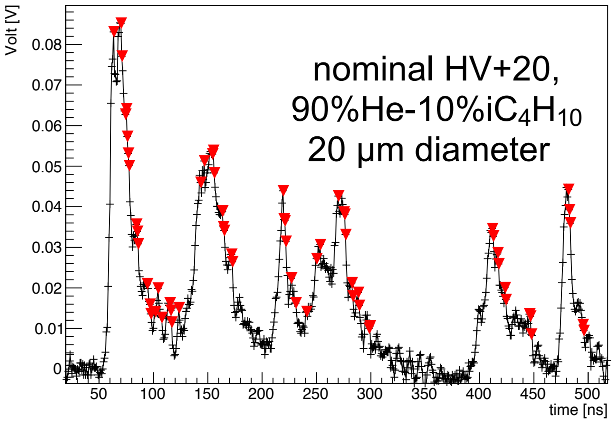
- R.m.s. is a measurements of the **noise level** in the analog signal



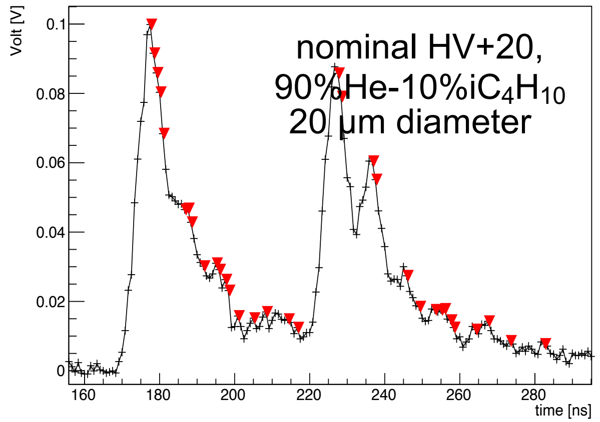

0°, nominal HV+20, 90%He-10%i$C_4H_{10}$
Tube with 1-cm cell size and 20 μm diameter




2 cm drift tube Track angle 45°




1 cm drift tube Track angle 45°



# Find electron peaks algorithms (2/2)

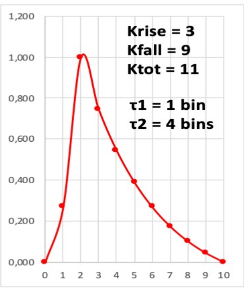


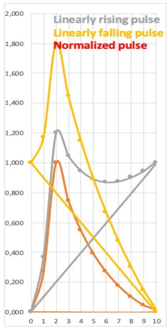
**Find good electron peak candidates at position bin *n* and amplitude $A_n$:**

## RUNNING TEMPLATE ALGORITHM (RTA)

- Define an **electron pulse template** based on experimental with a **raising** and **falling exponential** over a fixed number of bins ($K_{tot}$) and **digitized (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 $\chi^2$ and define a cut on it)**.
- **Subtract the found peak** to the signal spectrum and **iterate the search** and **stop** when no new peak is found.

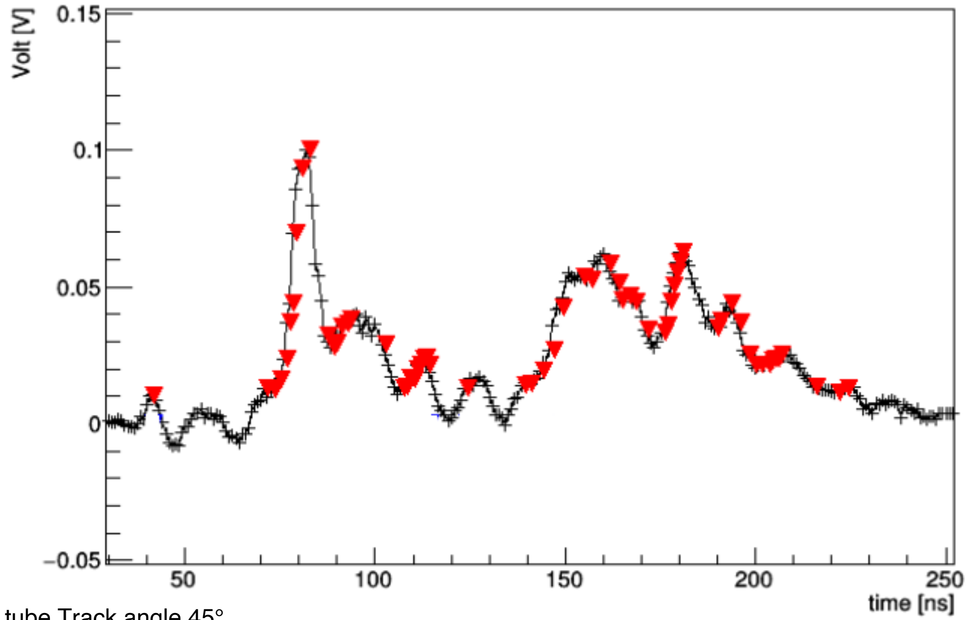
| k | A(k) |
|---|---|
| 0 | 0.0 |
| 1 | 0.269 |
| 2 | 1.0 |
| 3 | 0.744 |
| 4 | 0.545 |
| 5 | 0.390 |
| 6 | 0.269 |
| 7 | 0.175 |
| 8 | 0.102 |
| 9 | 0.044 |
| 10 | 0.0 |



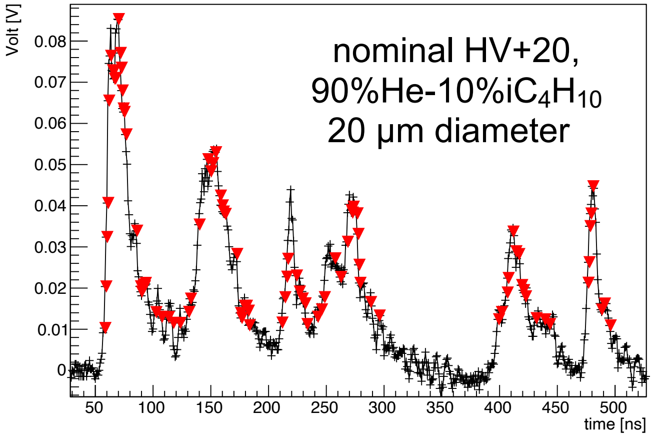




30°, nominal HV+20, 90%He-10%iC$_4$H$_{10}$

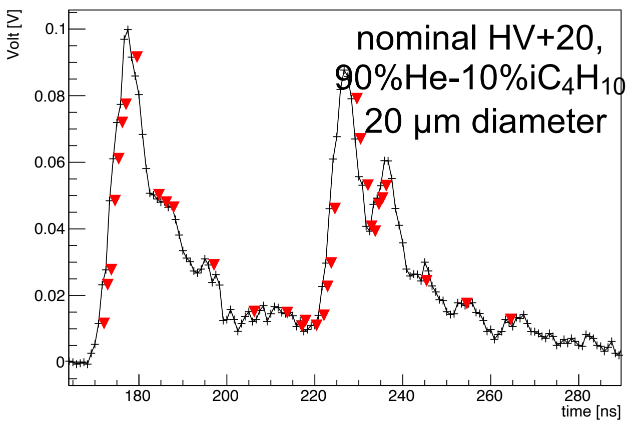
Tube with 1 cm cell size and 20 μm diameter




2 cm drift tube Track angle 45°




1 cm drift tube Track angle 45°



# Clusterization algorithm



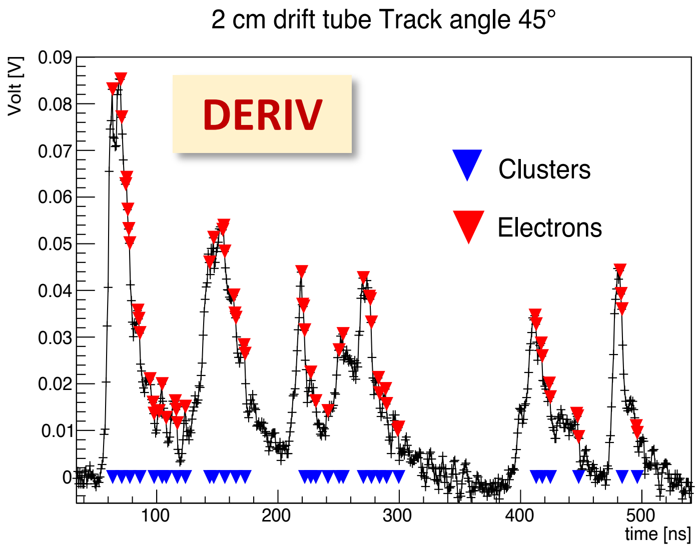
Once electron peaks have been found, clusterization of the electron peaks into ionization clusters has been implemented:

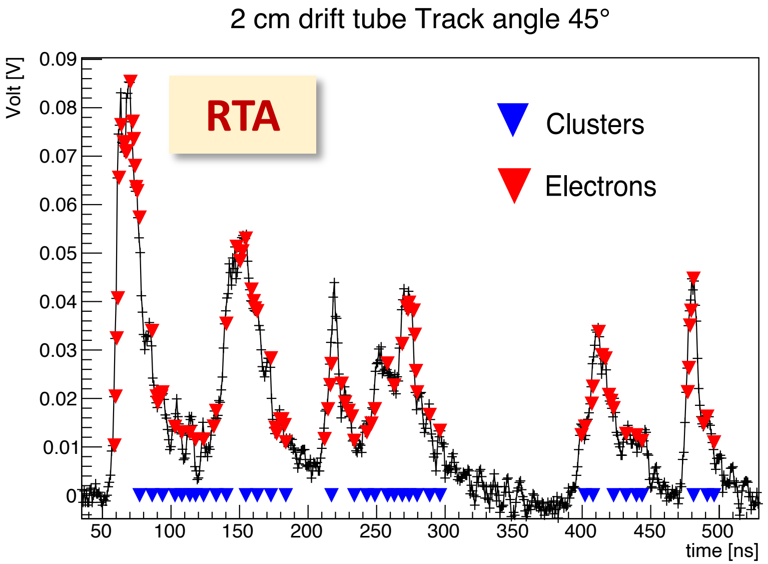
1) **Association of electron peaks** in consecutive bins (difference in time 0.833 ns == 1 bin) electrons to **a single electron** to remove **fake electrons**.

2) **Contiguous electrons peaks** which are compatible with the electrons diffusion time (2.5 ns) 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** corresponds to the position of the **last electron** in the cluster.

4) We expect a **Poissonian distribution for the number of cluster distributions [2]!** It tends to a gaussian when the mean value tends to values higher than 20.



# The DERIV algorithm: results



**Theoretical expectations of physical variables:**

**A** **NCluster (Expected number of cluster** = δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise [3])* 1/cos(α)

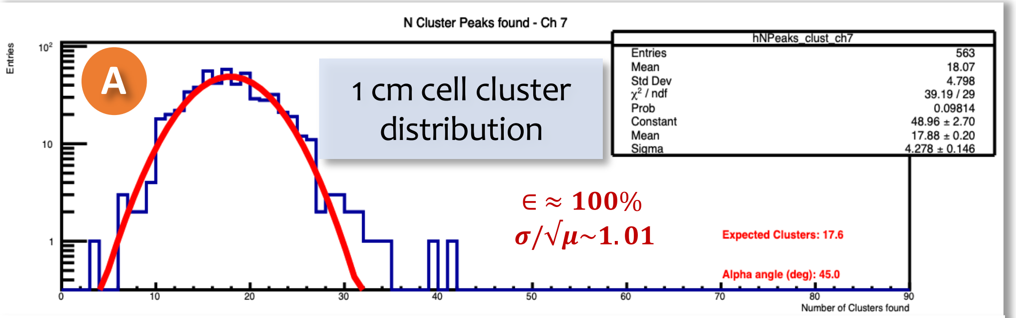
- **α corresponds to the angle of the muon track w.r.t. drift tube direction**
- **δ cluster/cm (mip) changes from 12 to 18 respectively for 90%He and 80%He gas mixtures**
- **drift tube size changes from 0.8 to 1.8 respectively for 1-cm and 2-cm cell size tubes**

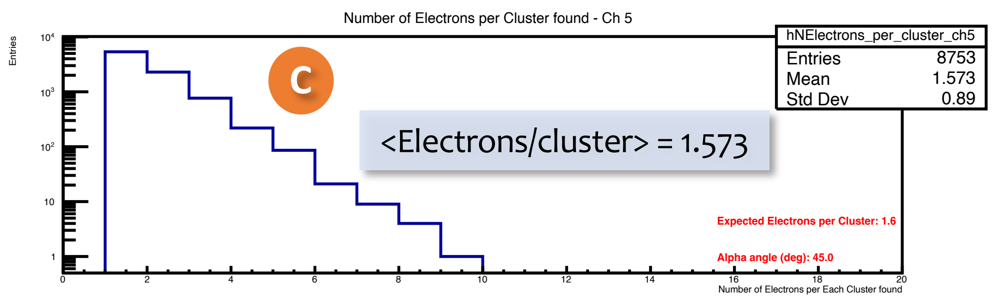
**Poissonian distribution**

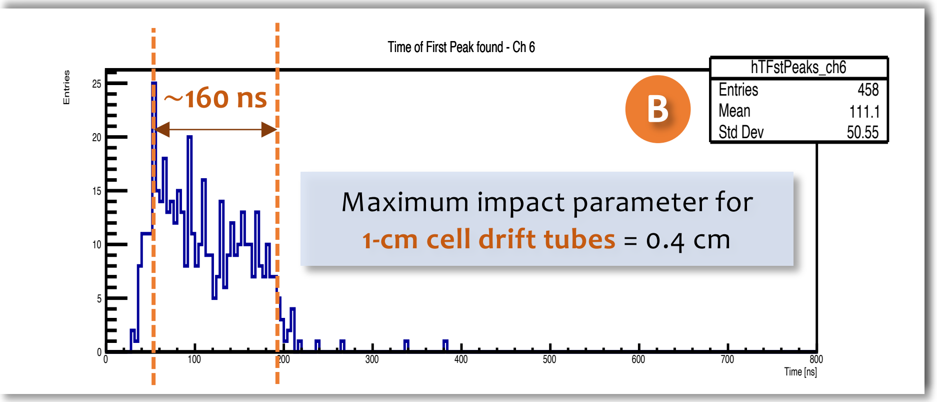
**B** **Experimental Electrons Drift velocity for 1 cm (2 cm) cell drift tubes =** maximum impact parameter/drift time ~ $2.5\ cm/\mu s$ ($2.2\ cm/\mu s$)

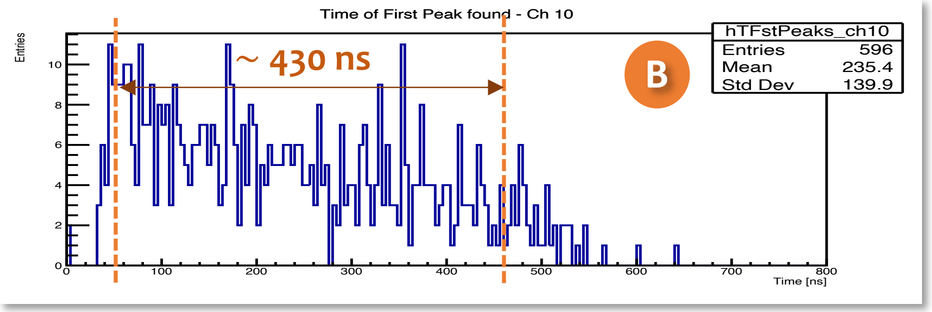
**C** **Cluster population** = 1.6 electrons/cluster

90%He-10%i$C_4H_{10}$ nominal HV+20, 45°, Gas gain ~ $2 \cdot 10^5$, 165 GeV/c




Maximum impact parameter for **2-cm cell drift tubes** is 0.9 cm

- **Poissonian** behaviour
- Meaurements vs predictions about the number of clusters are in **very good agreement**
- **Same results in independent drift tubes with same features**

# The RTA algorithm: results

## Theoretical expectations of physical variables:

**A** **NCluster (Expected number of cluster** = δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise [3])* 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 90%He and 80%He gas mixtures**
- **drift tube size changes from 0.8 to 1.8 respectively for 1-cm and 2-cm cell size tubes**

**Poissonian distribution**

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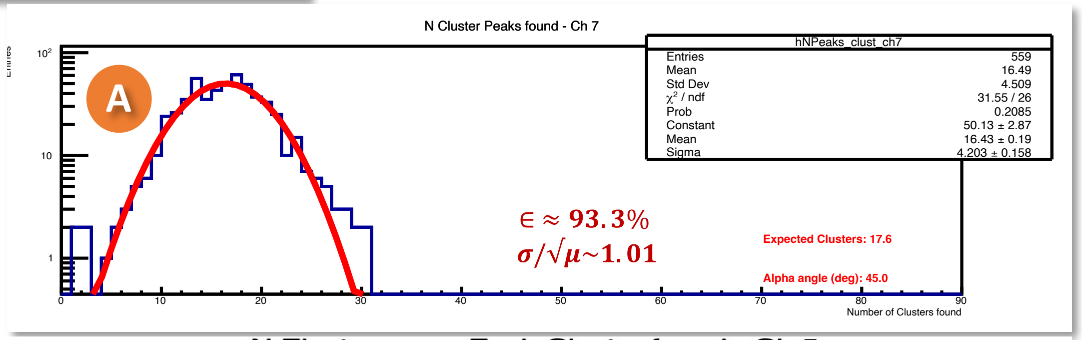
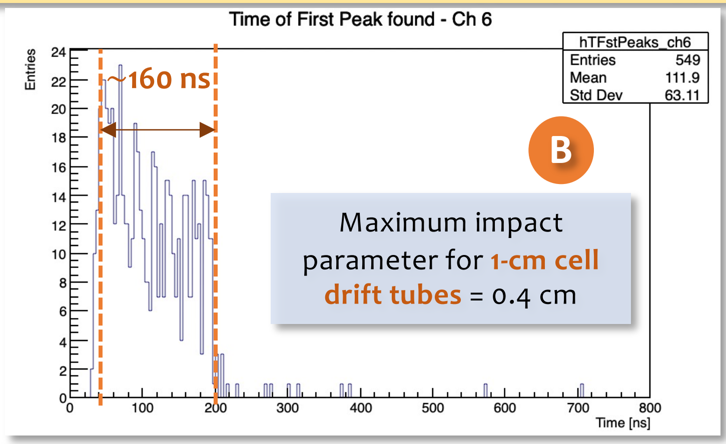
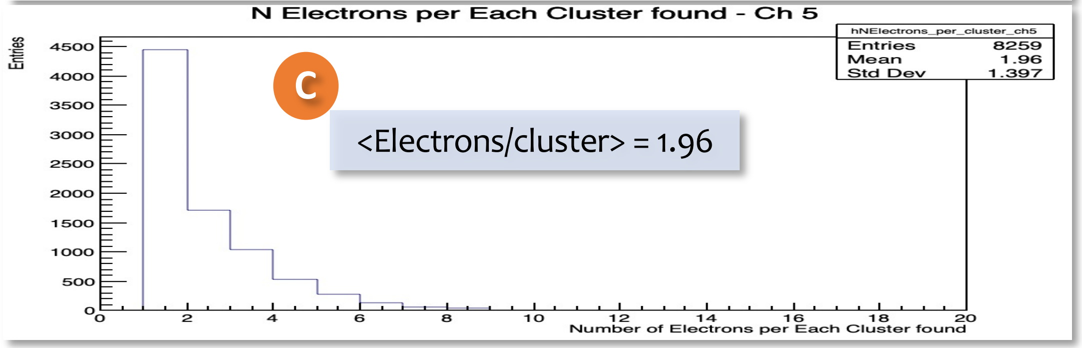
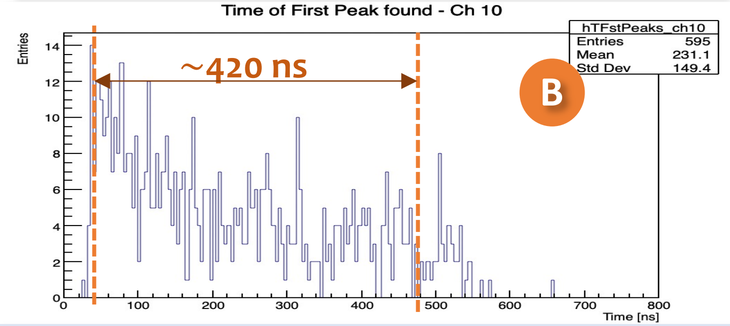
**C** **Cluster population** = 1.6 electrons/cluster

90%He-10%i$C_4H_{10}$
nominal HV+20, 45°,
Gas gain ~ $2 \cdot 10^5$,
165 GeV/c

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- **Poissonian** behaviour
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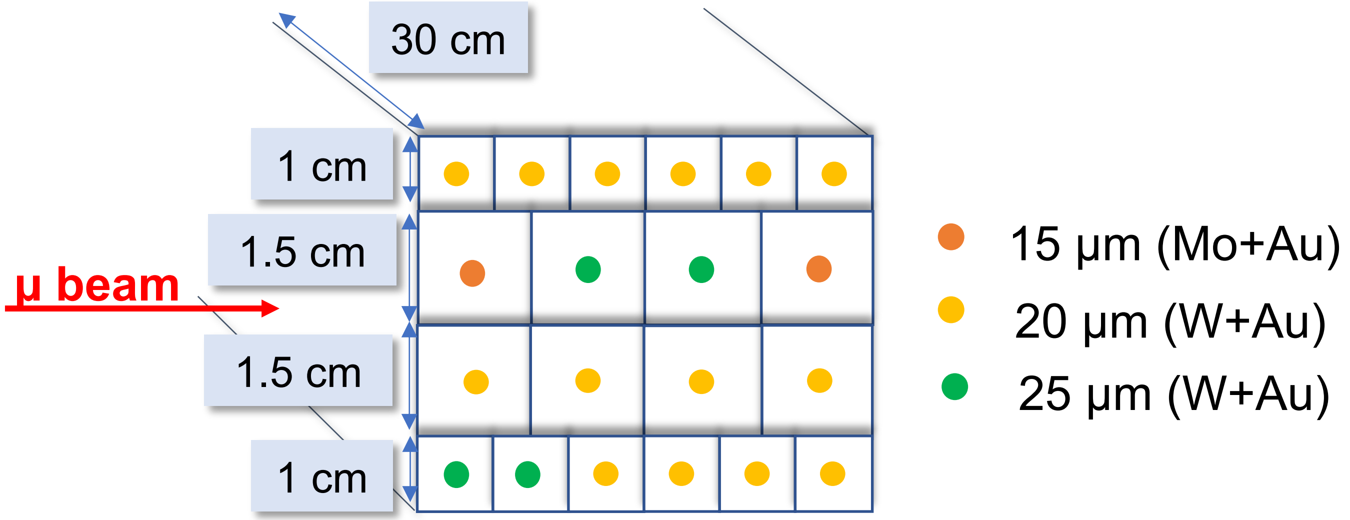
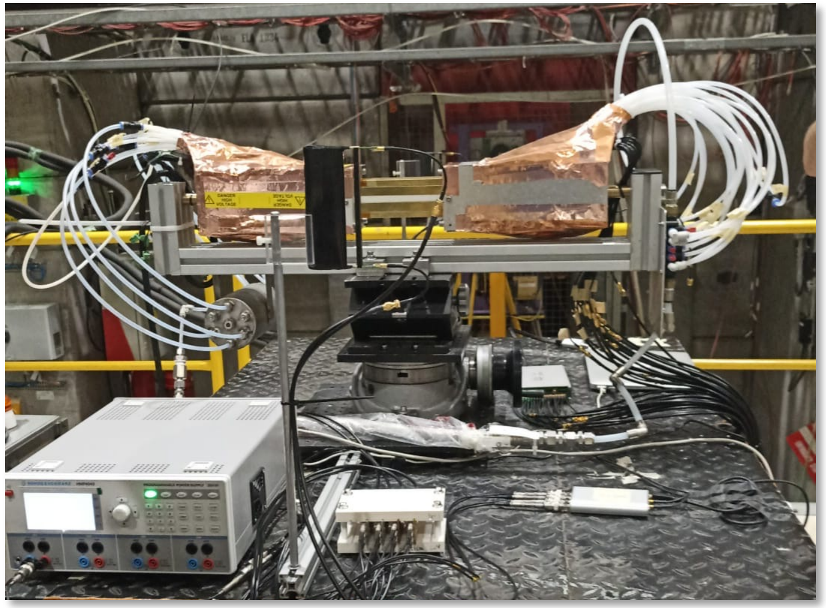
- **Same results in independent drift tubes with same features**

# July 2022 beam test setup at H8/CERN (1/2)



- **20 tubes with different (material and diameter) sense wires** and **different cell size**.
- 16-channel DRS (x1)
- 4-channel DRS (x3)
- The portable gas system
- Custom PCBs for the 2 trigger scintillators.
- Two external hard disk to store the data collected



We plan to collect data at different percentages of helium and isobutane:

- 90-10
- **85-15**
- 80-20

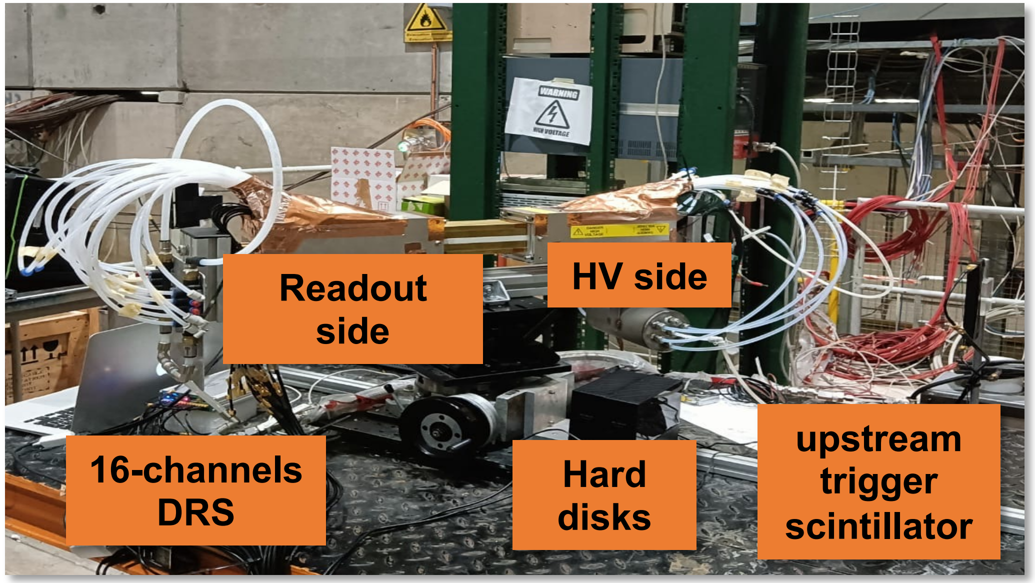
to study the **relativistic rise** of the dE/dx and the dN/dx.

**NEW CONNECTION SCHEME plan**

- Connect **the 2 trigger scintillators to a 4-channels DRS**
- **Propagate the trigger signal** to the 4-channel DRS and 16-channel DRS, where the tube are connected.

# July 2022 beam test setup at H8/CERN (2/2)

- During the setup preparation, some of the tube broke:
  - 1.5cm 25µm
  - 1.0cm 15µm
  - 1.5cm 20µm
  - 1.5cm 2[illegible]µm
  - 1.5cm 20µm
  - 1.0cm 20µm
- The idea to propagate the trigger signal didn't work, so 4 channels of the **16 channels DRS** have been used to host the 4 trigger scintillator signals. The association between the DRS channels and the HV channels is reported in the table.
- The **minimum muon beam momentum available** was **40 GeV/c,** at an **extremely low rate** → We collected data which will be useful to **study the Fermi plateau** instead of the relativistic rise, as initially planned.




| DRS channels | HV channels | Drift Tubes sense wire (cell size – diameter) |
|---|---|---|
| 0 | 0 | 1.5cm-20µm |
| 1 | 15 | 1.0cm-20µm |
| 2 | 22 | 1.0cm-15µm |
| 3 | 13 | 1.0cm-15µm |
| 4 | 18 | 1.5cm-25µm |
| 5 | 7 | 1.0cm-20µm |
| 6 | 1 | 1.0cm-20µm |
| 7 | 21 | 1.5cm-15µm |
| 8 | 8 | 1.0cm-20µm |
| 9 | 11 | 1.0cm-25µm |
| 10 | 10 | 1.0cm-25µm |
| 11 | 23 | 1.5cm-15µm |
| 12 | - | Upstream scintillator up |
| 13 | - | Upstream scintillator down |
| 14 | - | Downstream scintillator up |
| 15 | - | Downstream scintillator down |

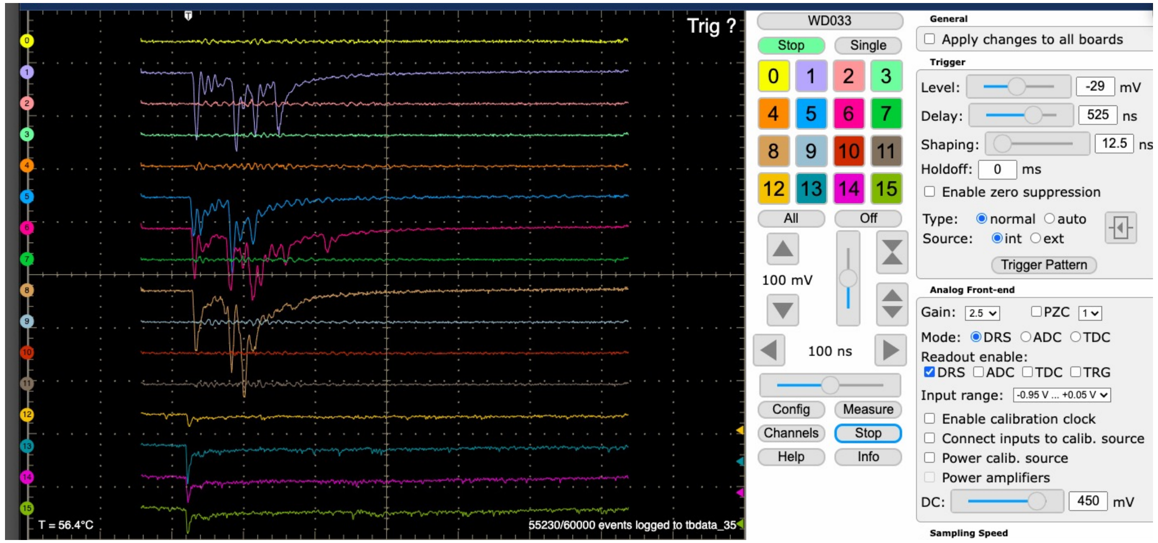
# July 2022 data sets

| Gas mixture (He-$iC_4H_{10}$) | μ beam energy | Sampling rate | Angles scan | HV scan |
|---|---|---|---|---|
| **90/10** | 180 | 1.0,1.5, 2.0 | 0°, 30°, 45°, 60° | Nominal,+10 V,+20 V,-10 V |
| | 80 | 1.0 | 45° | Nominal |
| | 40 | 1.0 | 0°, 45° | Nominal |
| **80/20** | 180 | 1.5, 2.0 | 0°, 30°, 45°, 60° | Nominal,+10 V,+20 V,-10 V |
| | 40 | 1 | 0°,45° | Nominal |
| **85/15** | 180 | 1,2 | 0°, 45° | Nominal,+10 V,+20 V,-10 V |

**~ 700.000 events (x7)!**

**Important news:**

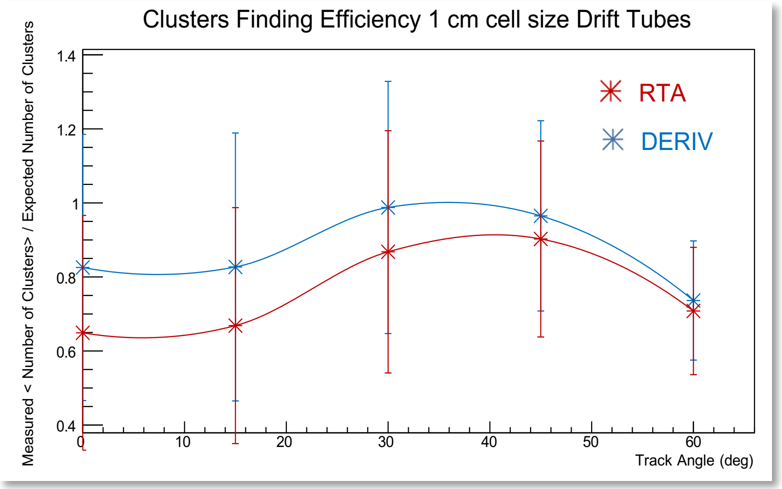
- Higher sampling rate (up to **2 GSa/s**).
- HV scan properly set for each configuration



# Conclusions and future plan



- The beam test plays a key role in predicting the **performance of cluster counting** for flavor physics and for jet flavor tagging at **future colliders**.



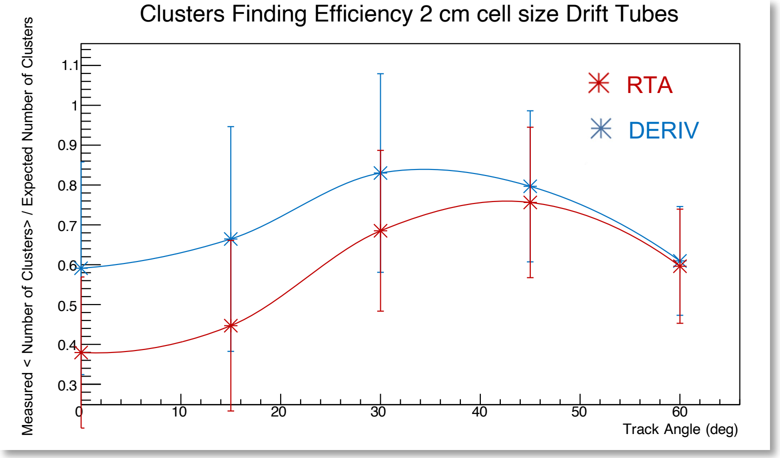

90%He-10%i$C_4H_{10}$ nominal HV+20, Gas gain ~ $2 \cdot 10^5$

## Next steps

☞ Investigate the inefficiency at **high track angle** (first hypothesis: **space charge + attachment + recombination effects**).

☞ Optimization of variable cuts for **2-cm drift tubes (1-cm drift tubes)** November 2021 Beam Test data set against **undercounting** (overcounting).

☞ Apply the algorithms to new Test Beam data sets with cuts' dependence (**rms, derivatives** for **DERIV** and **χ2** for the **RTA**) on the sampling rate and the ADC resolution.



# Thanks for your kind attention!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