Test beam studies of cluster counting

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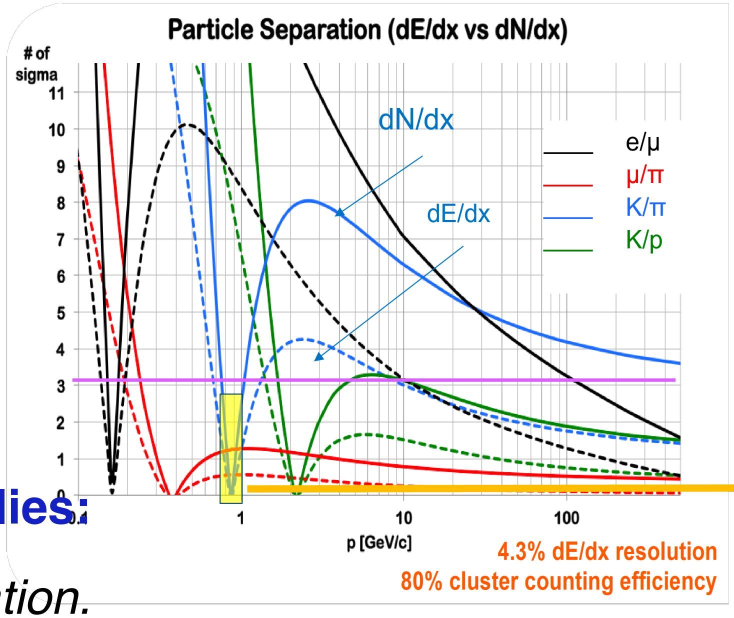
on behalf of cluster counting test beam team

CEPC day, 21Jun 2023

Why Cluster counting?

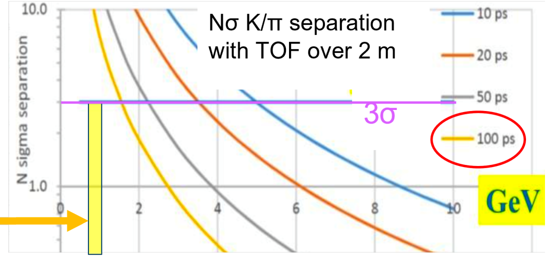
➢ **We deal with a Poissonian physics process:**

- *independent from cluster size fluctuations*
- *insensitive to highly ionizing δ-rays*
- *independent from gas gain fluctuations*



Analytical Results :

dN/dx performance is 2 times better than dE/dx in a wide transverse momentum range with He:IsoB 90/10

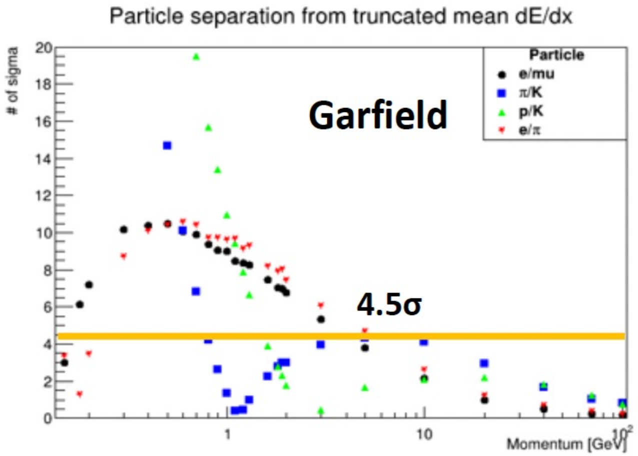


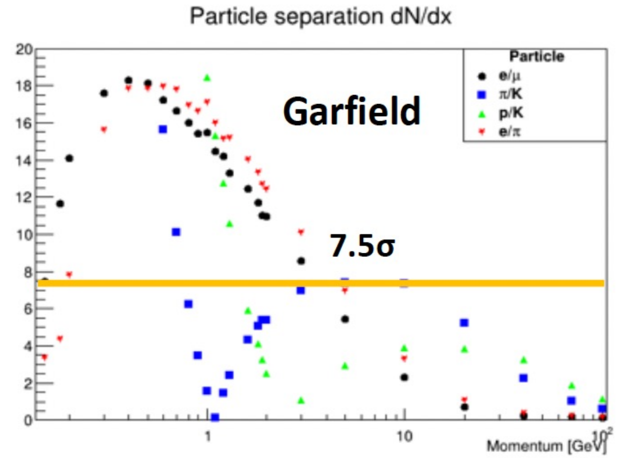
➢ **The choice of a He-based gas mixture implies:**

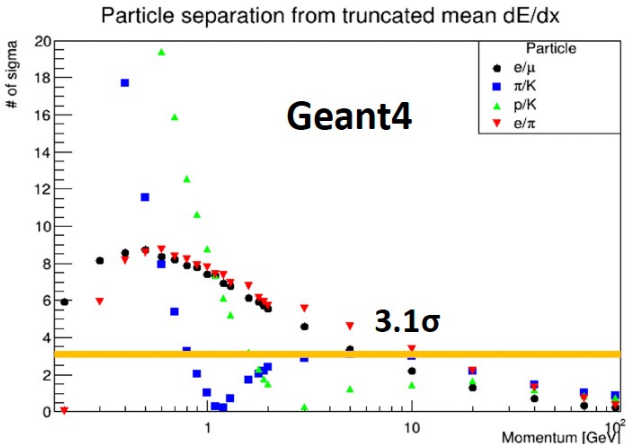
- *low primary ionization density ⇨ large time separation.*
- *low drift velocity ⇨ even larger time separation (v_{drift} ~ 2.5 cm/μs)*
- *low average cluster size (< $N_{electrons}$/cluster> ~ 1.6)*
- *low single electron diffusion (< 110 μm for 0.5 cm drift, or < 4.5 ns)*

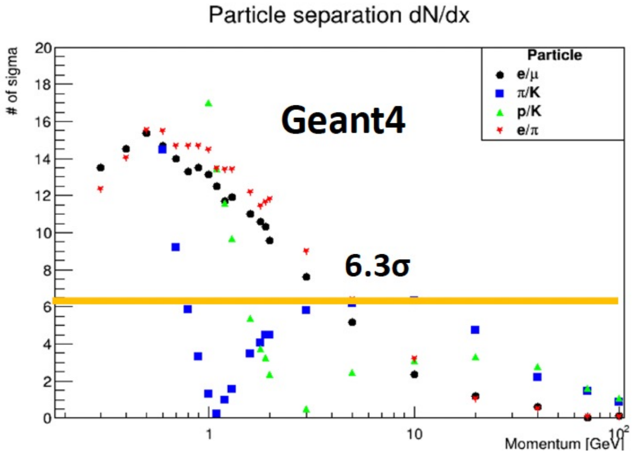
The simulation of the cluster counting

We have developed an algorithm, which uses the energy deposit information provided by Geant4, to reproduce, in a fast and convenient way, the clusters density and the cluster size distributions predicted by Garfield++.









Garfield++ in reasonable agreement with analytical calculations up to 20 GeV/c momentum, then falls much more rapidly at higher momenta.

Despite Geant4 uses the cluster density and the cluster size distributions from Garfield++, it disagrees from Garfield++ and, therefore, from the analytical calculations also.

Beam test motivation

1. **Lack of experimental data** on cluster density and cluster population for He based gas. Particularly in the relativistic rise region to compare predictions.

2. Despite the fact that the Garfield++ model in GEANT4 reproduces reasonably well the Garfield++ predictions, why particle separation, both with dE/dx and with dNcl/dx, in **GEANT4** is considerably **worse than in Garfield++?**

3. Despite a higher value of the dNcl/dx Fermi plateau with respect to dE/dx, why this is reached at **lower values of $\beta\gamma$ with a steeper slope?**

- These questions are crucial for establishing the particle identification performance at FCCee, CEPC and SCTF.
- The only way to ascertain these issues is an experimental measurement!

Beam test goals

Need to demonstrate the **ability to count clusters** at a **fixed βγ** (e.g. muons at a fixed momentum – 165 GeV, 180 GeV) by changing:

- track length (different cell size - 1 cm, 1.5 cm and 2 cm) and changing the track angle (0° to 60°);
- gas mixture (He:IsoB 90/10, 80/20, 85/15).

Establish **the limiting parameters** for an efficient cluster counting:

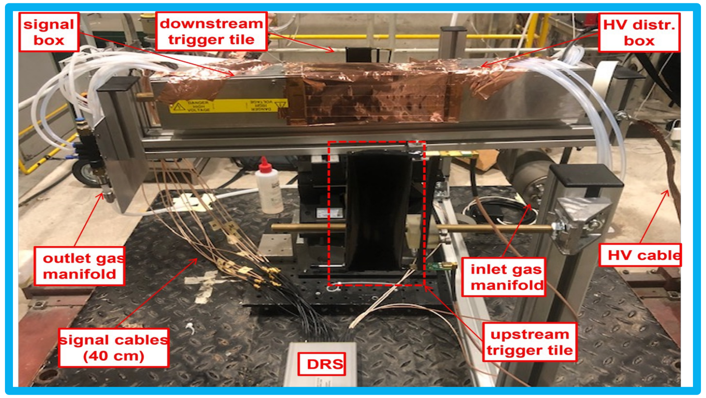
- cluster density (by changing **the gas mixture**)
- space charge (by changing **gas gain**, **sense wire diameter**, **track angle**)
- gas gain saturation

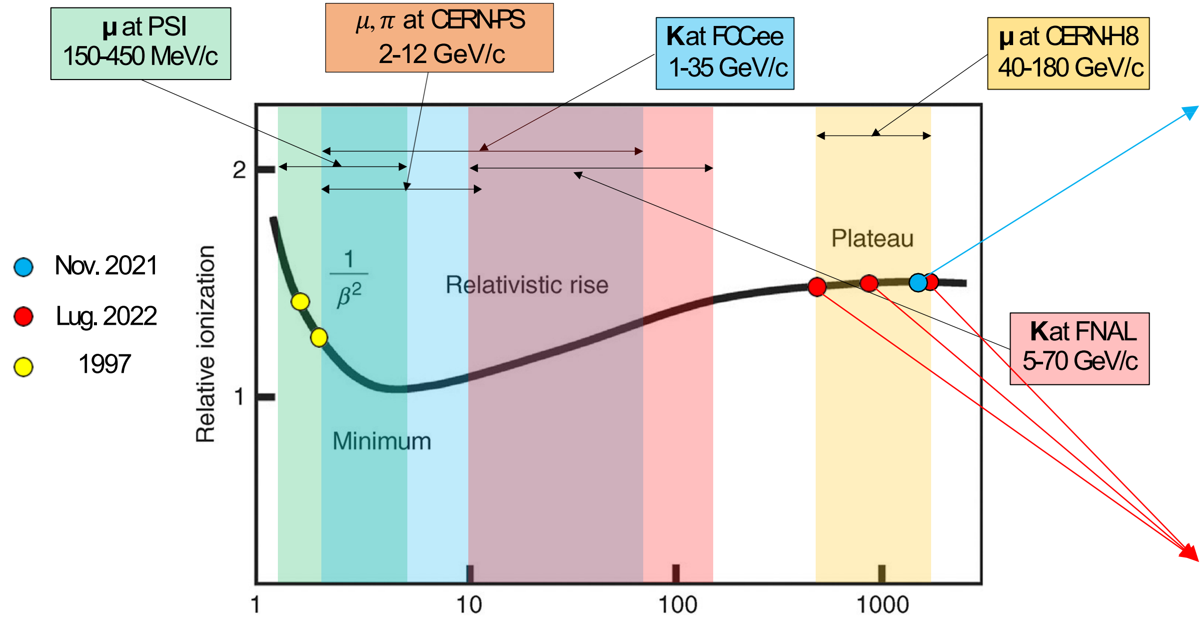
For the Future data taking campaigns: In optimal configuration, **measure the relativistic rise as a function of βγ**, both in dE/dx and in $dN_{cluster}/dx$, by scanning the muon momentum from the lowest to the highest value (from **a few GeV/c** to about **250 GeV/c**).

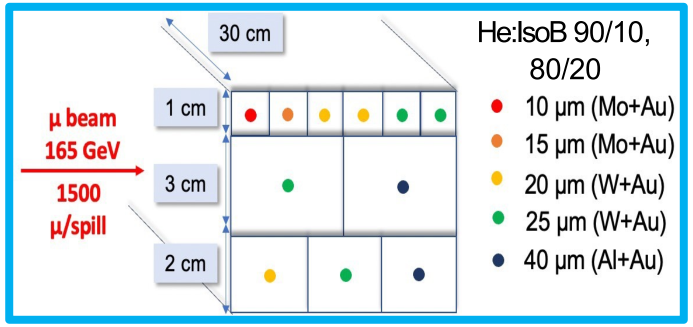
Beam Tests in 2021 & 2022

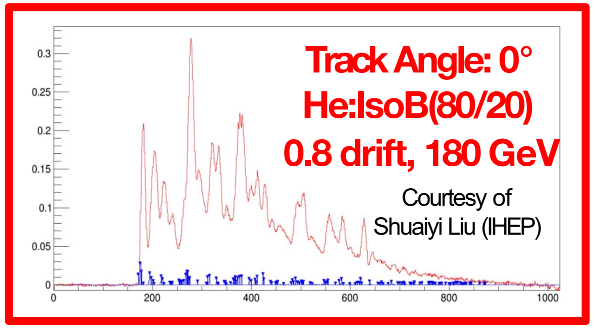
Beam tests to experimentally asses and optimize **the performance of the cluster counting/timing** techniques in strict collaboration with the IHEP Beijing group:

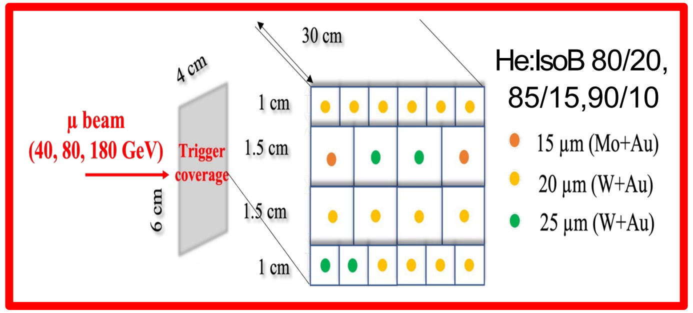
- Two muon beam tests performed at CERNH8($\beta\gamma > 400$) in Nov. 2021 and July 2022.
- More **muon beam tests** planned in 2023 at **CERN** and **PSI** **($\beta\gamma$ = 1–4)** in 2023 (not foreseen).
- Another test is planed to be done at FNAL-MT6 with π and K ($\beta\gamma$ = 10–140) to fully exploit the relativitic rise.

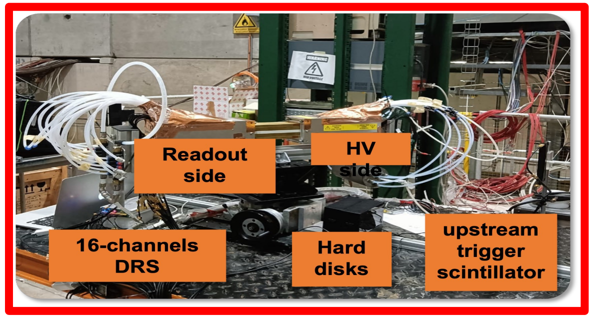












Find Electron peaks Algorithms (Bari & Lecce)

Derivative Algorithm (DERIV)

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

- Compute the first and second derivative from the amplitude average over two times the timing resolution 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.

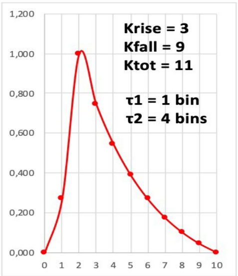
- Require that the amplitude at the peak candidate position is greater than a r.m.s. signal-related small quantity and the amplitude difference among the peak candidate and the previous (next) signal amplitude is greater (less) than a r.m.s. signal-related small quantity.

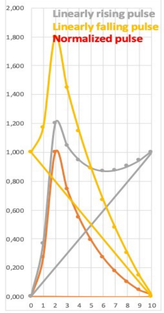
- NOTE: R.m.s. is a measurements of the noise level in the analog signal from first bins

Running Template Algorithm (RTA)

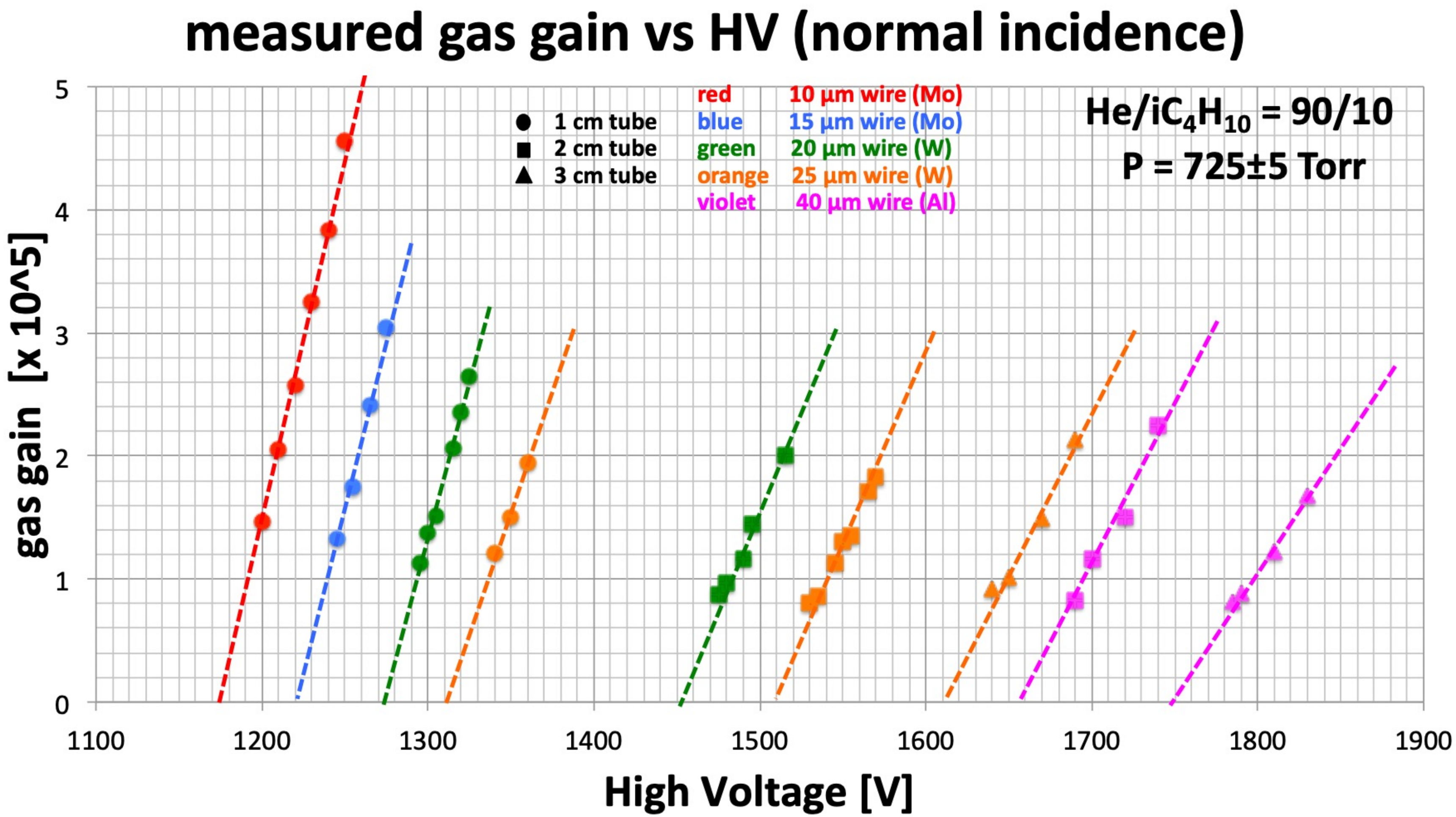
- Define an electron pulse template based on experimental data.
- Raising and falling exponential over a fixed number of bins (Ktot).
- Digitize it (A(k)) according to the data sampling rate.
- The algorithm scan the wave form and run over Ktot bins by comparing it to the subtracted and normalized data (build a sort of χ^2).
- Define a cut on χ^2.
- Subtract the found peak 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

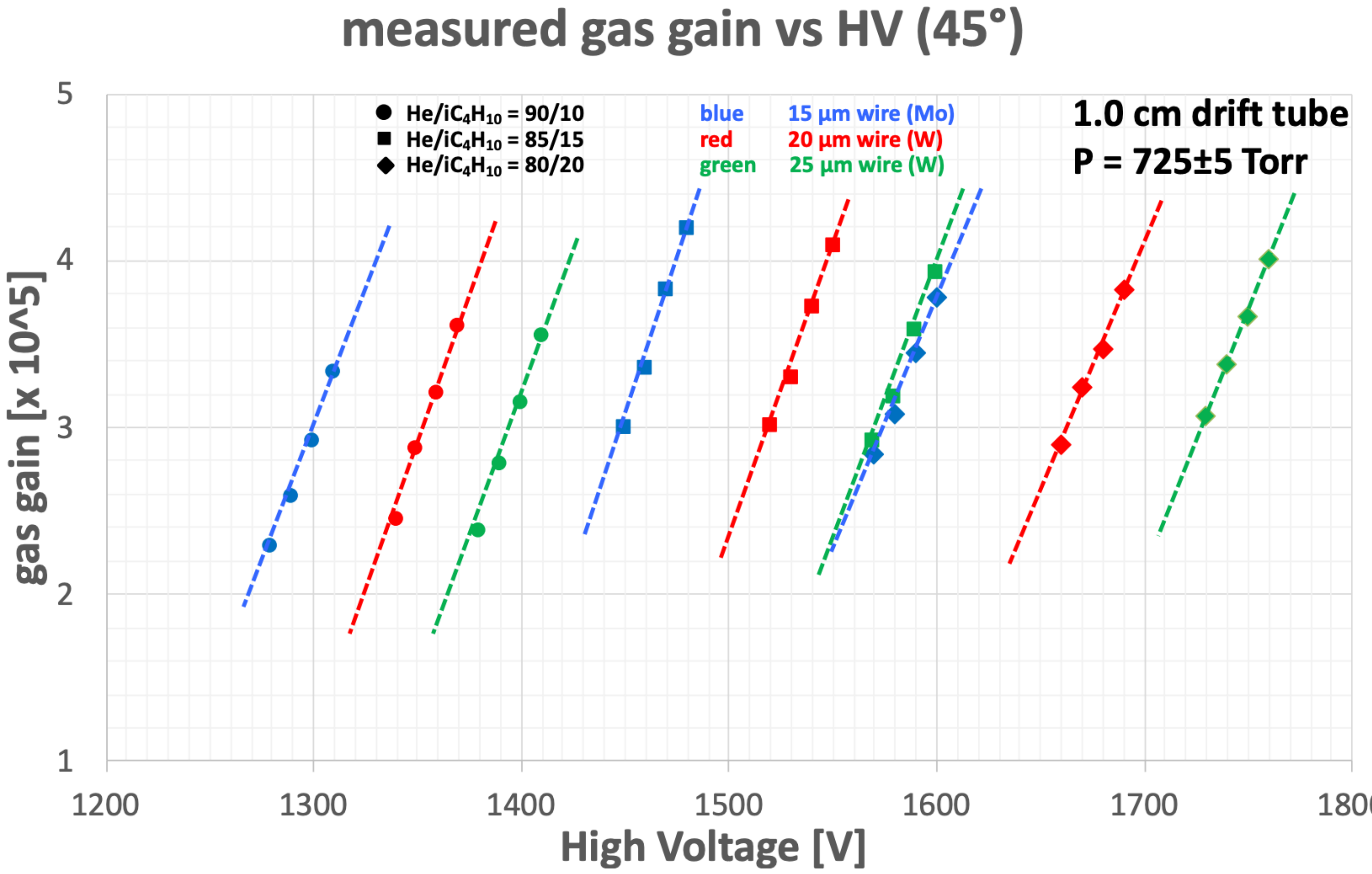




Gas gain (Test Beam Nov 2021)

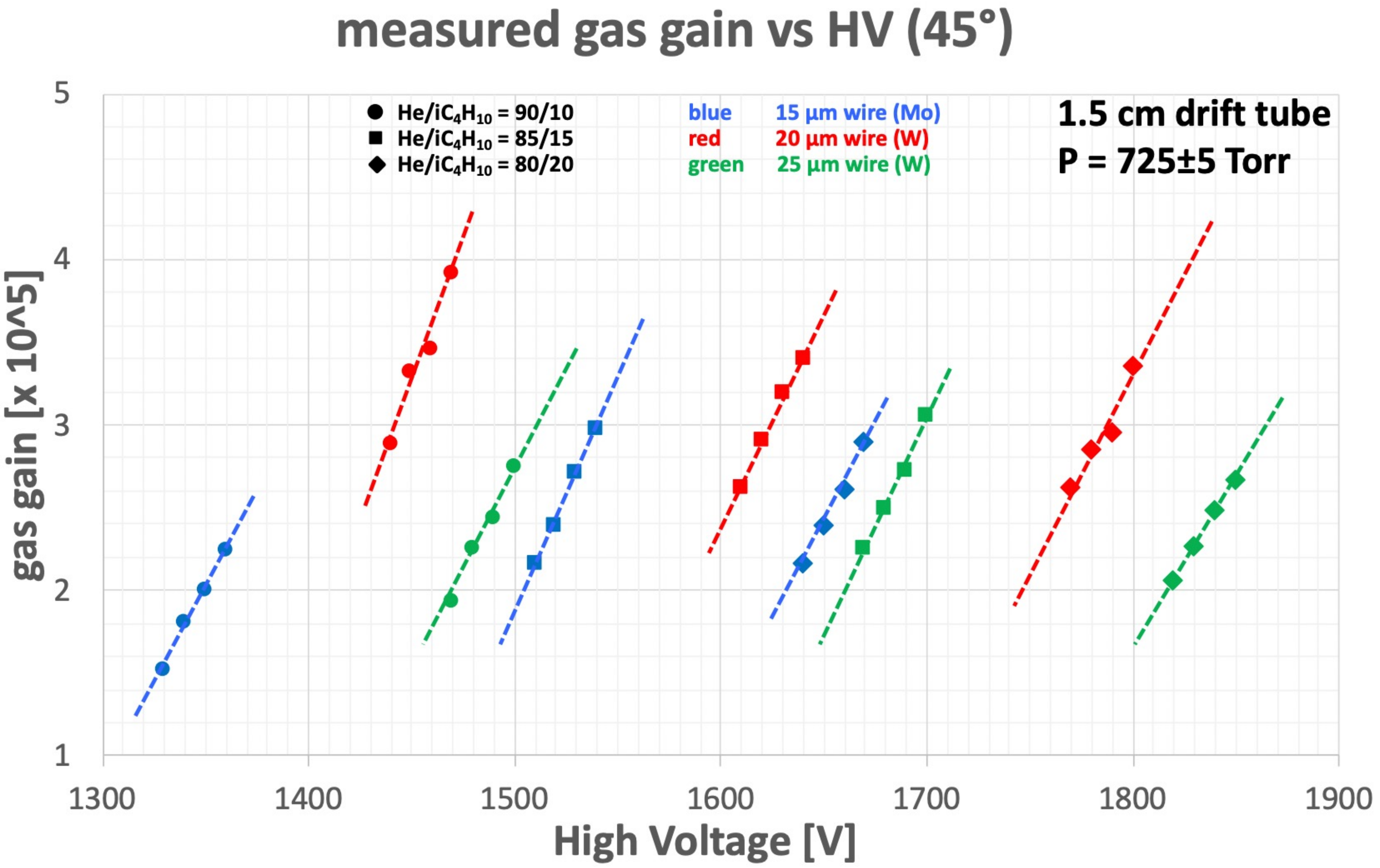


Gas gain (Test Beam Jul 2022)



25µm wire He:IsoB 85/15 has the same gain of 15µm wire He:IsoB 80/20

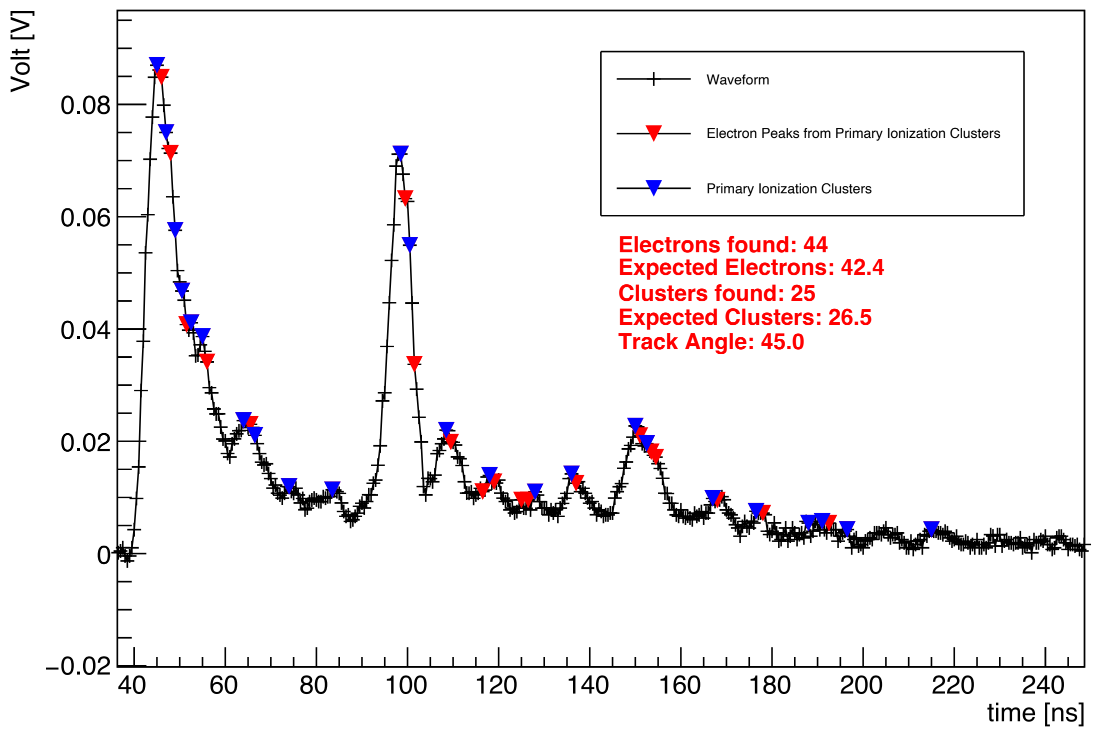
Gas gain (Test Beam Jul 2022)



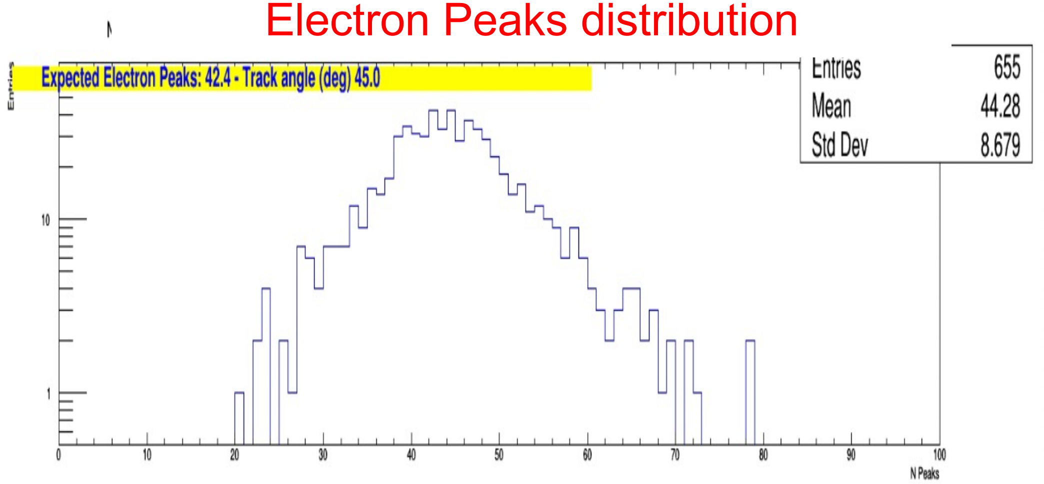
20µm wire excluded from physical quantities mean computation

Reconstruction of Electron Peaks (RTA Algorithm)

Sense Wire Diameter 15 μm; Cell Size 1.0 cm; Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20



Electron Peaks distribution



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

α = angle of the muon track w.r.t. normal direction to the sense wire.
δ cluster/cm (mip) changes from 12, 15, 18 respectively for He:IsoB 90/10, 85/15 and 80/20 gas mixtures.
drift tube size are 0.8, 1.2, and 1.8 respectively for 1 cm, 1.5 cm, and 2 cm cell size tubes.

Reconstruction of Primary Ionization Clusters

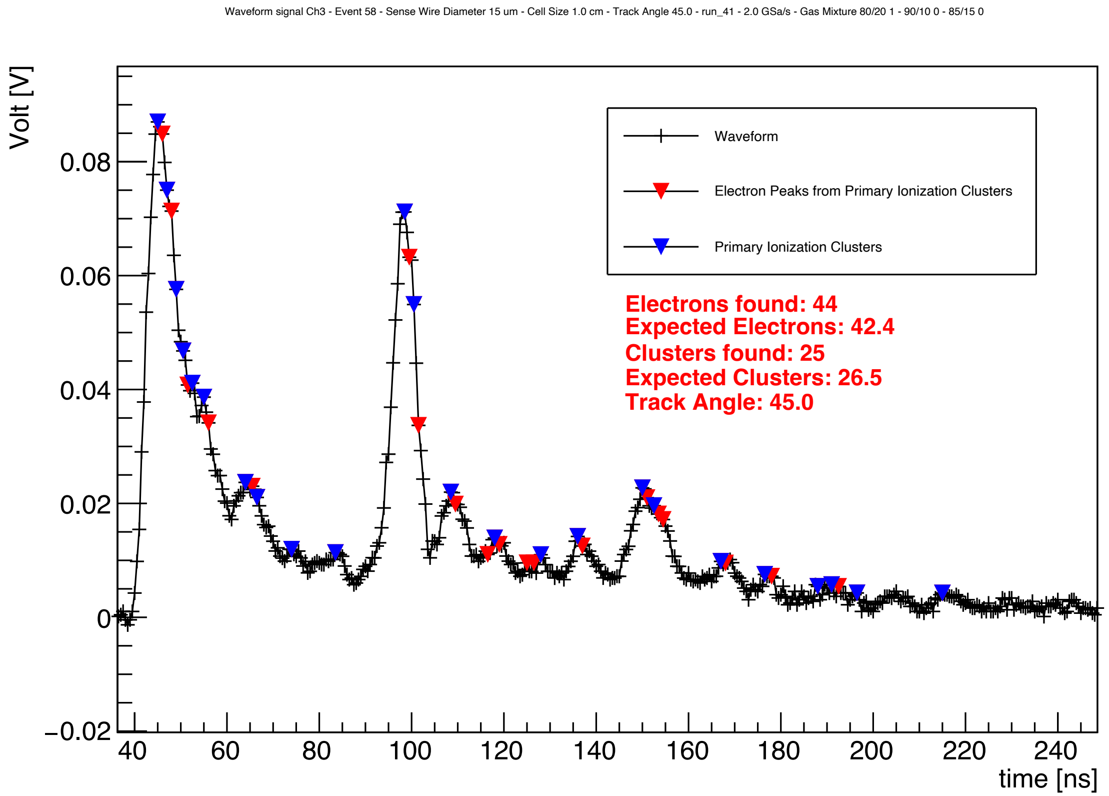
Sense Wire Diameter 15 µm; Cell Size 1.0 cm; Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20

- ***Merging of electron peaks** in consecutive bins in a single electron to reduce fake electrons counting.*

- ***Contiguous electrons peaks** which are compatible with the electrons' diffusion time (it has a $\sim\sqrt{t_{ElectronPeak}}$ dependence, different for each gas mixture) must be considered belonging to the **same ionization cluster**. For them, a counter for electrons per each cluster is incremented.*

- ***Position and amplitude** of the clusters corresponds to the position and height of the electron having the maximum amplitude in the cluster.*

- ***Poissonian distribution for the number of clusters!***



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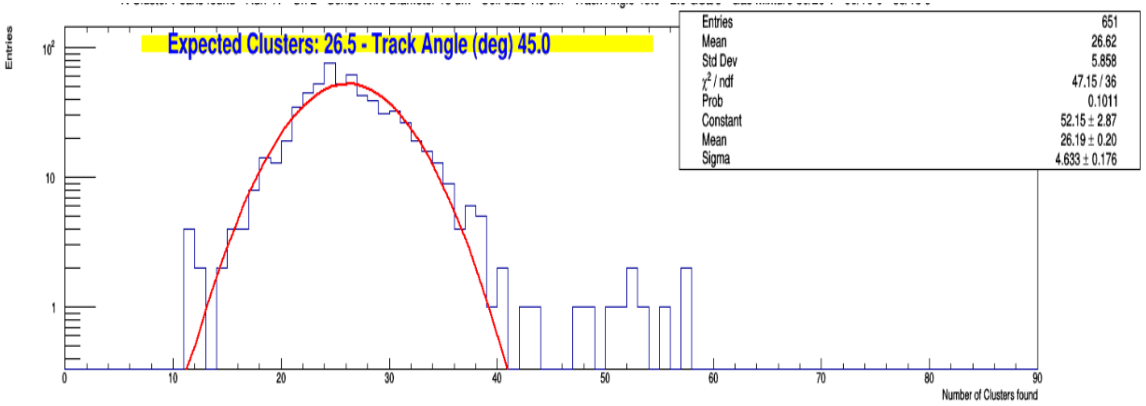
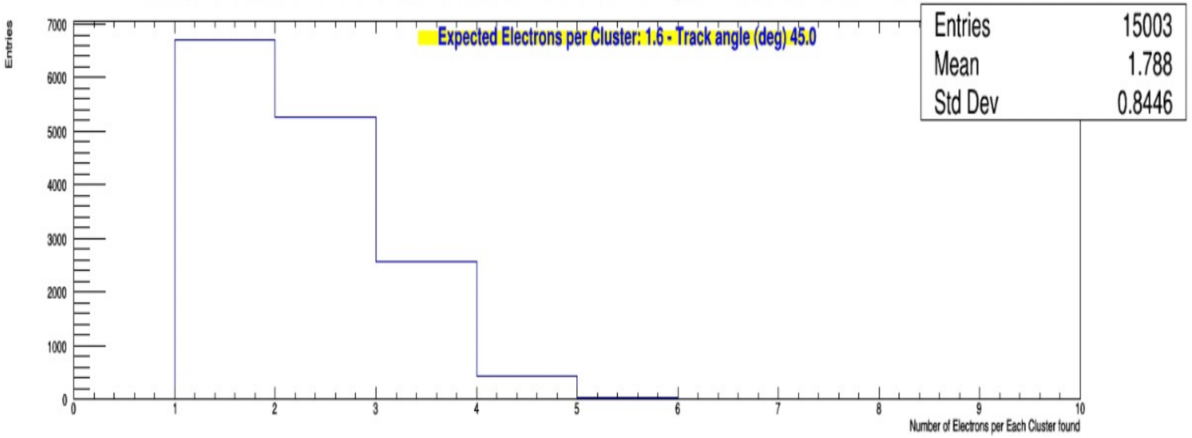


Electrons per cluster distribution



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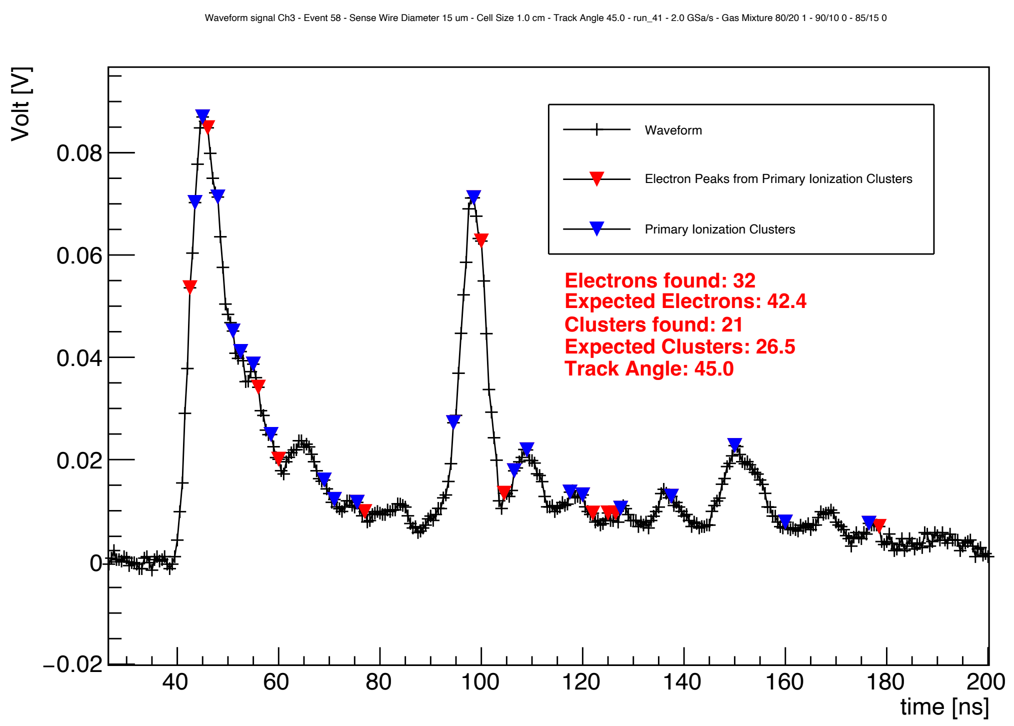
Comparison between DERV and RTA algorithm

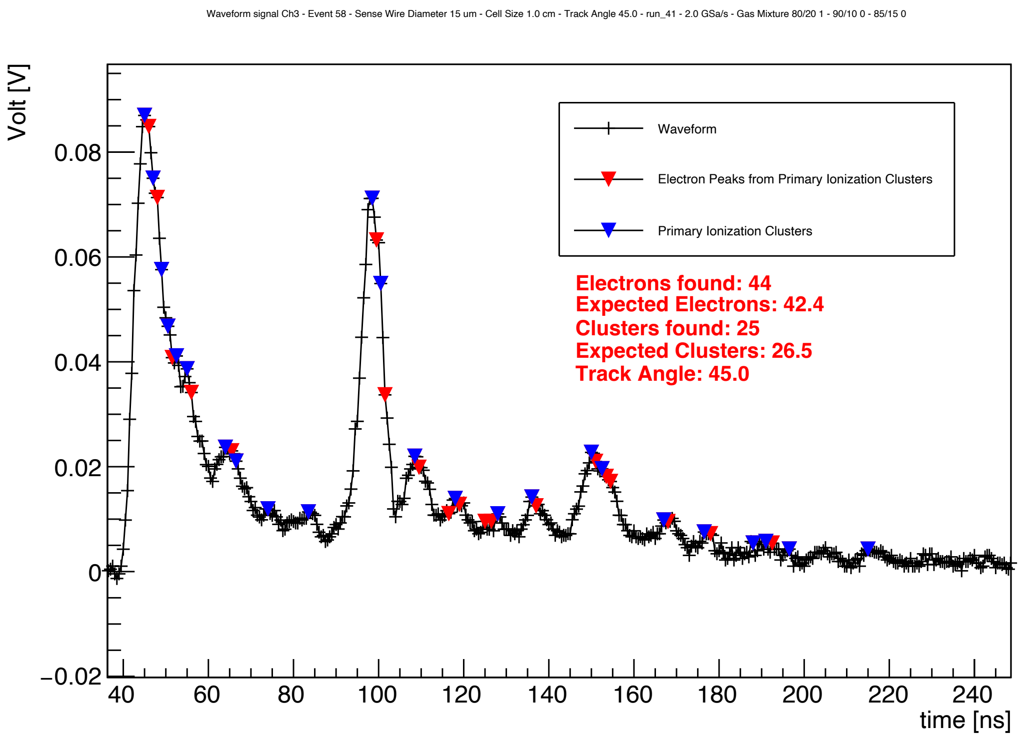
1 cm drift tubes

Run: 41; Track angle: 45^0; Gas mixture: 80% He 20% iC_4H_{10} ; HV = Nominal Sampling rate= 2 Gsa/s

DERIV Algorithm



RTA Algorithm



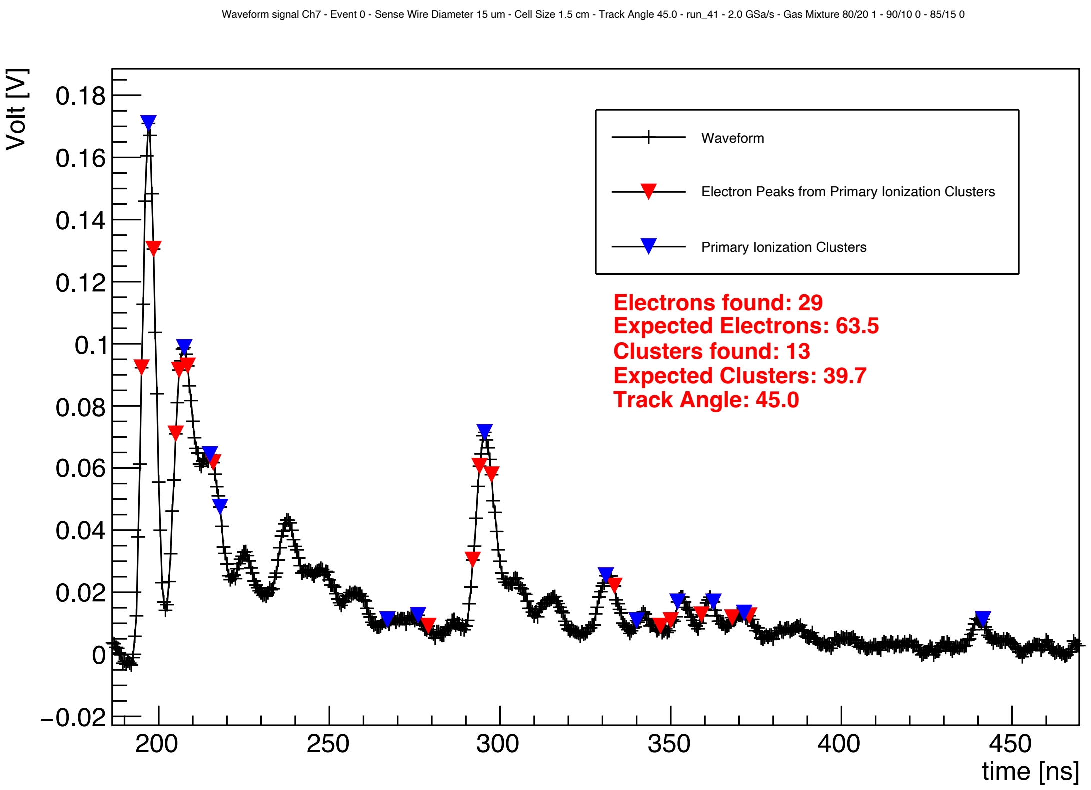
Comparison between DERV and RTA algorithm

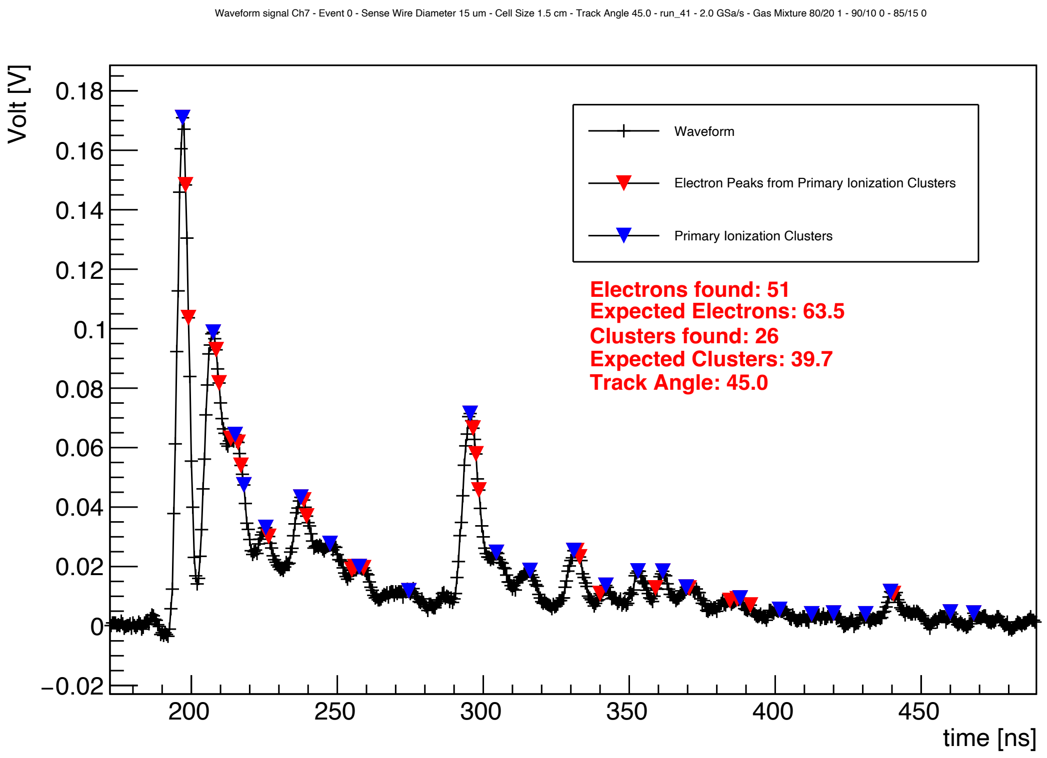
1.5 cm drift tubes

Run: 41; Track angle: 45^0; Gas mixture: 80% He 20% iC_4H_{10} ; HV = Nominal Sampling rate= 2 Gsa/s

DERIV Algorithm

RTA Algorithm



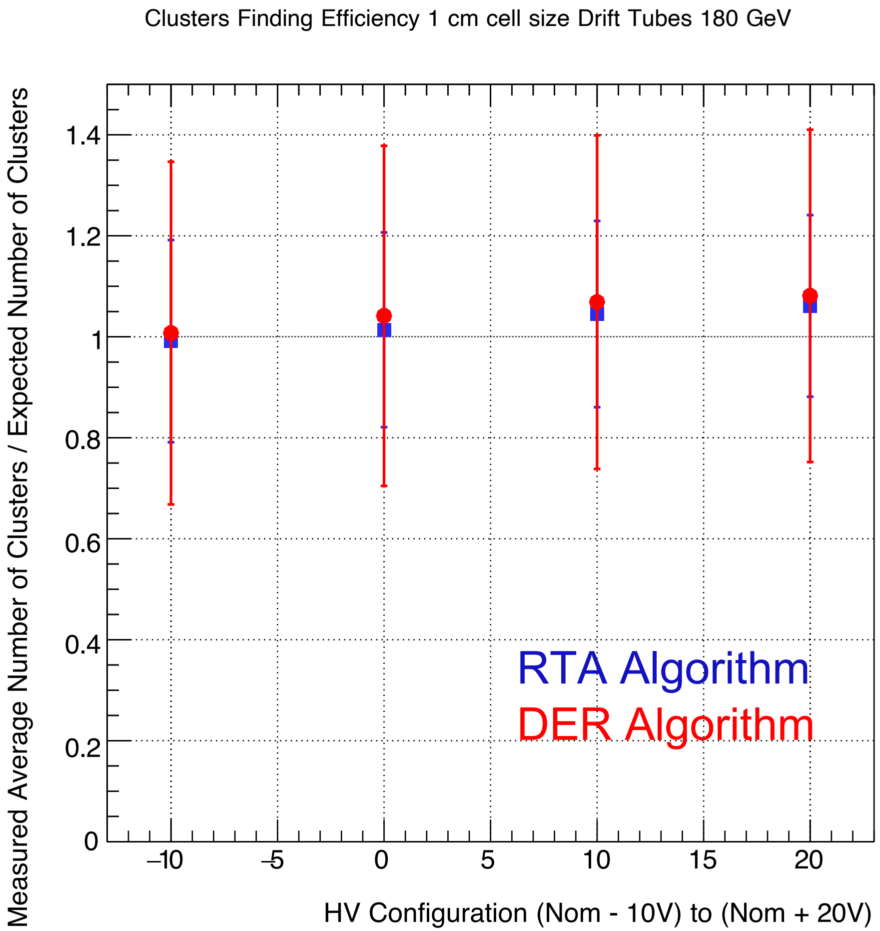


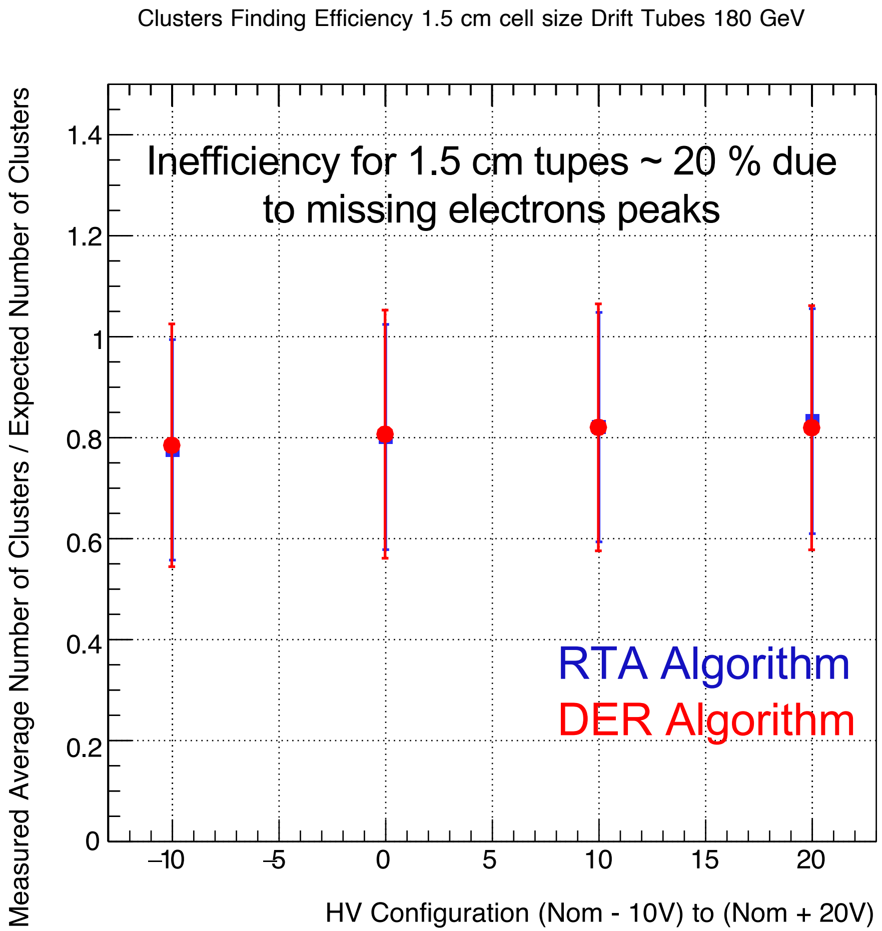
Comparison between DERV and RTA algorithm

1 cm drift tubes

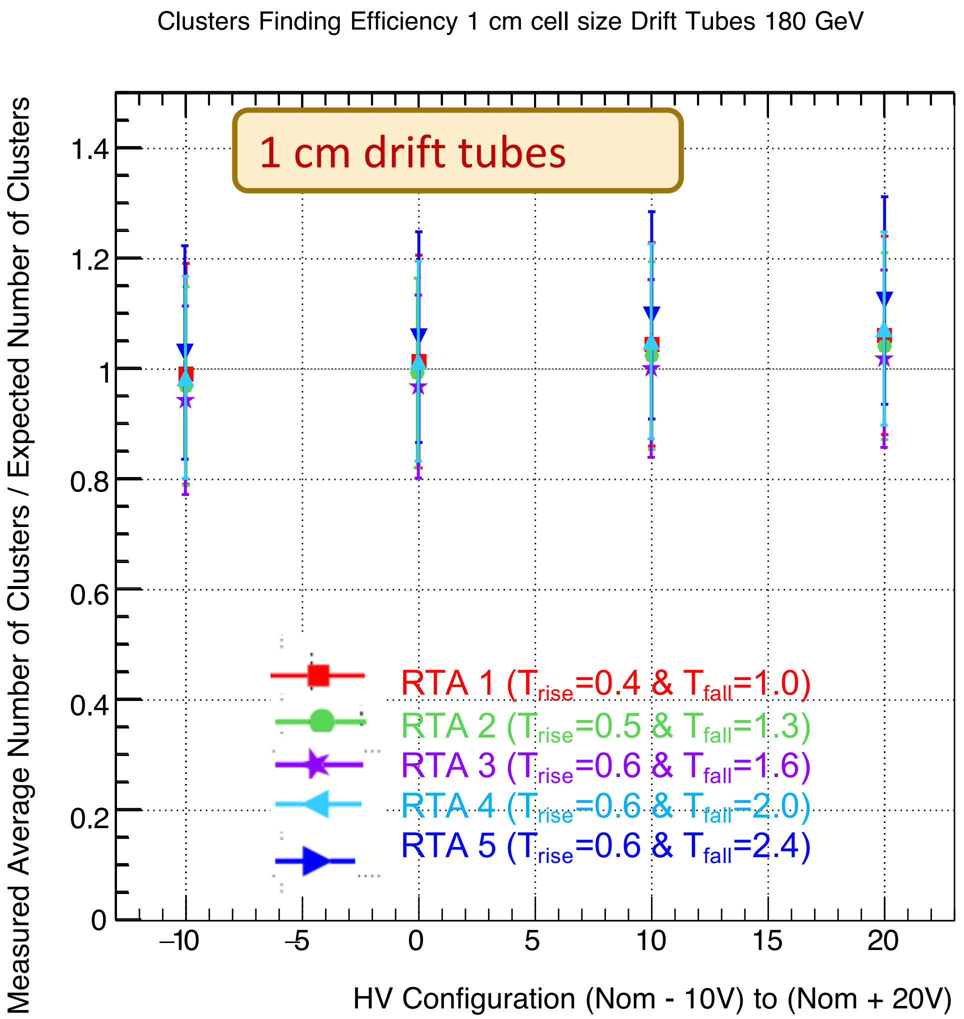
HV scan

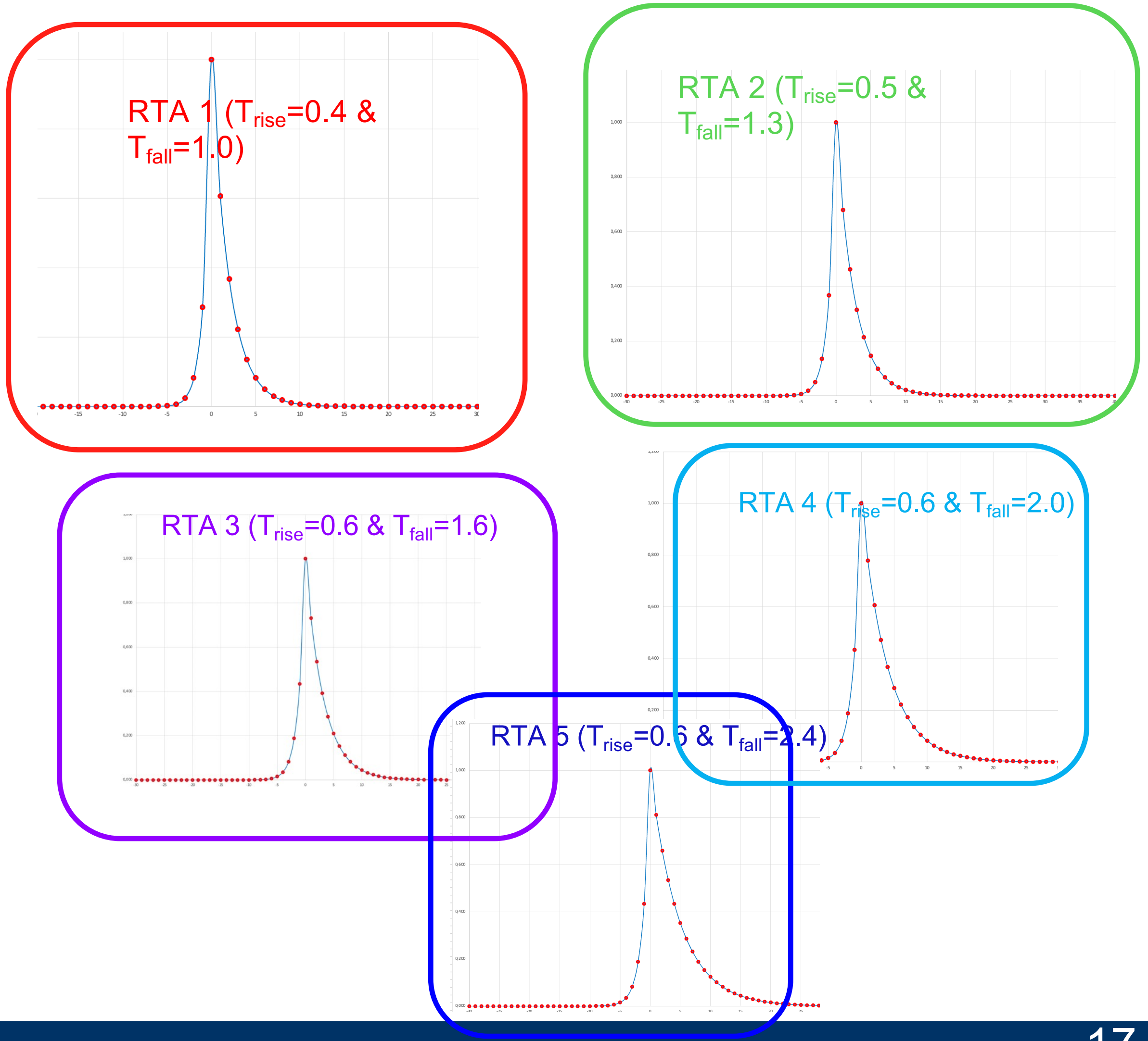
1.5 cm drift tubes



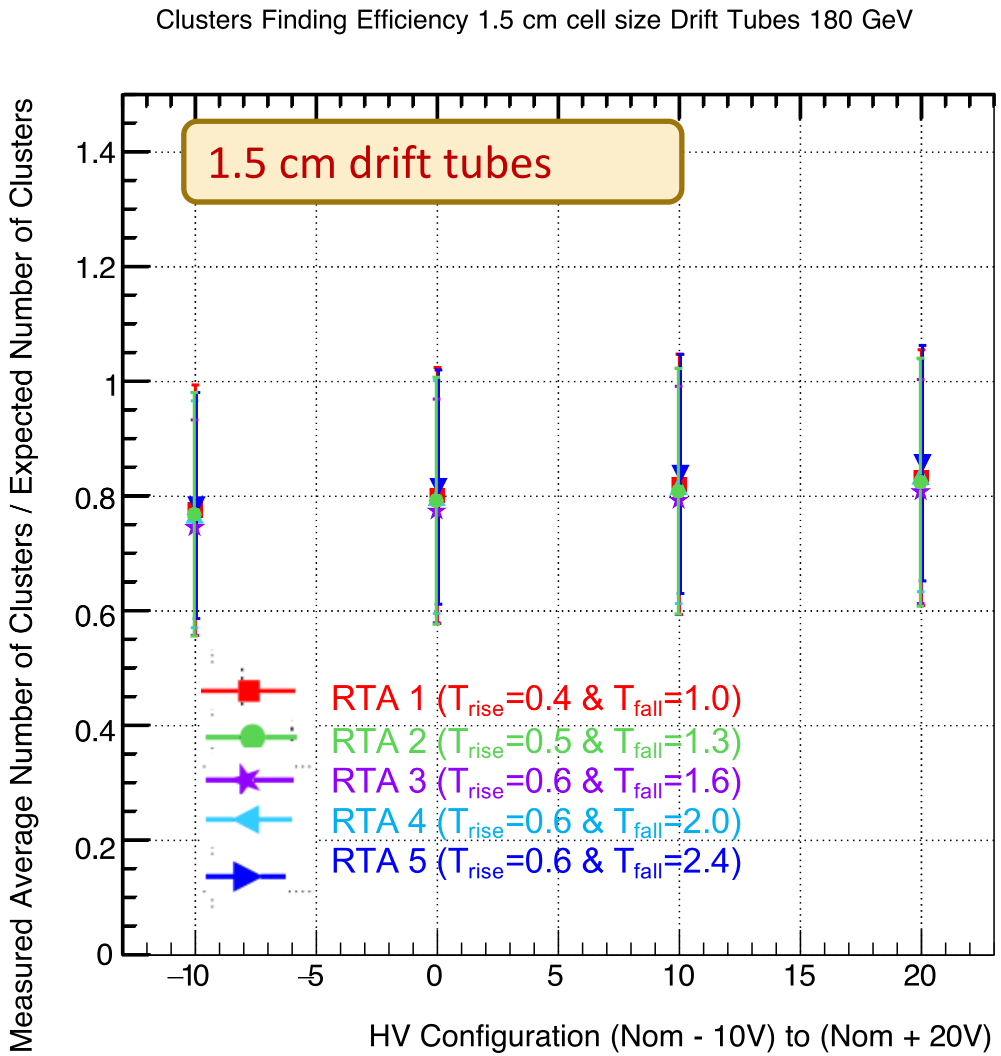


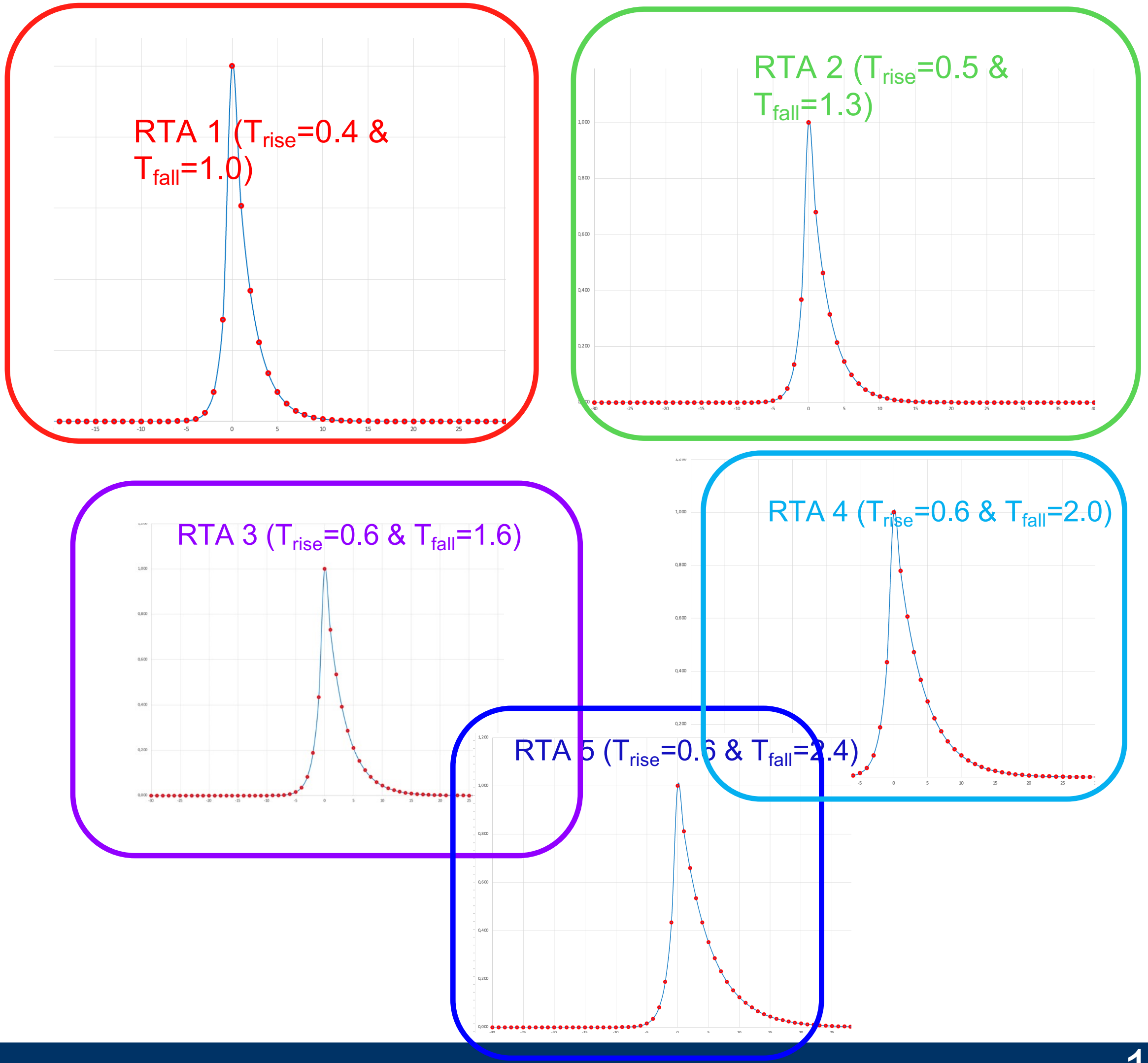
RTA Templates scan





RTA Templates scan

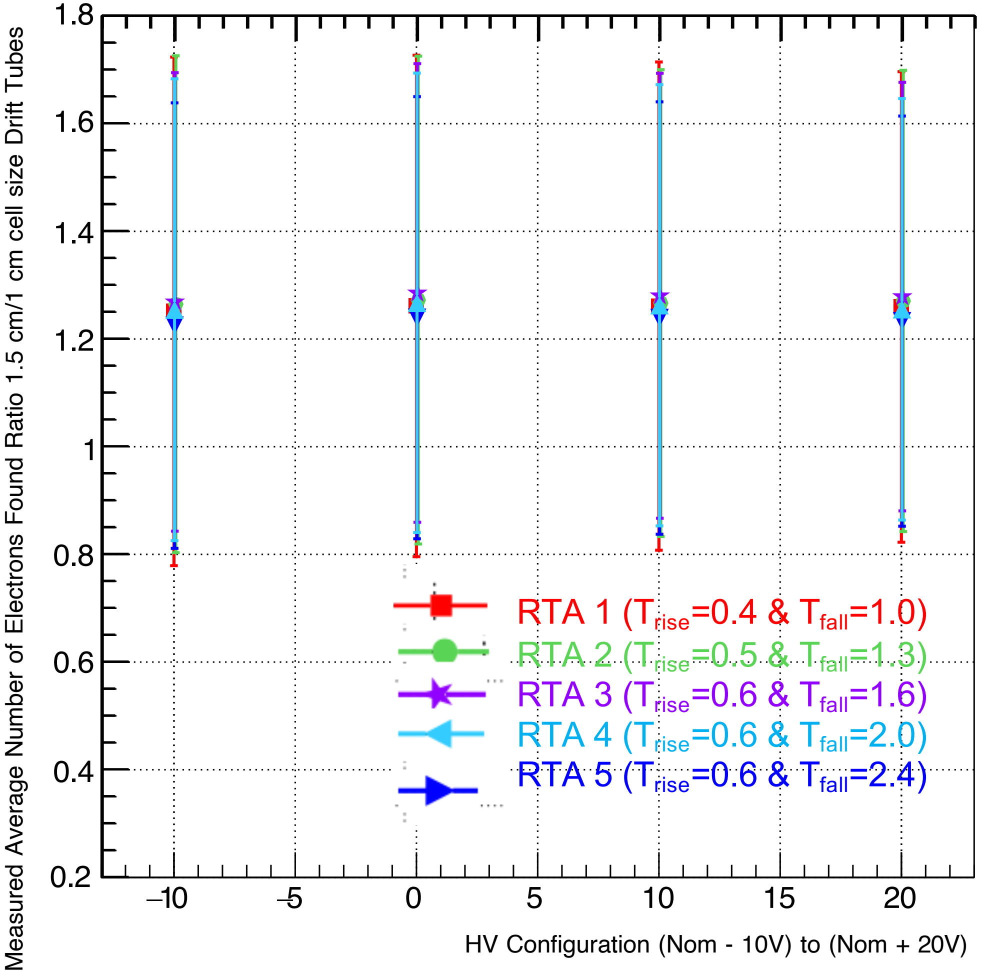


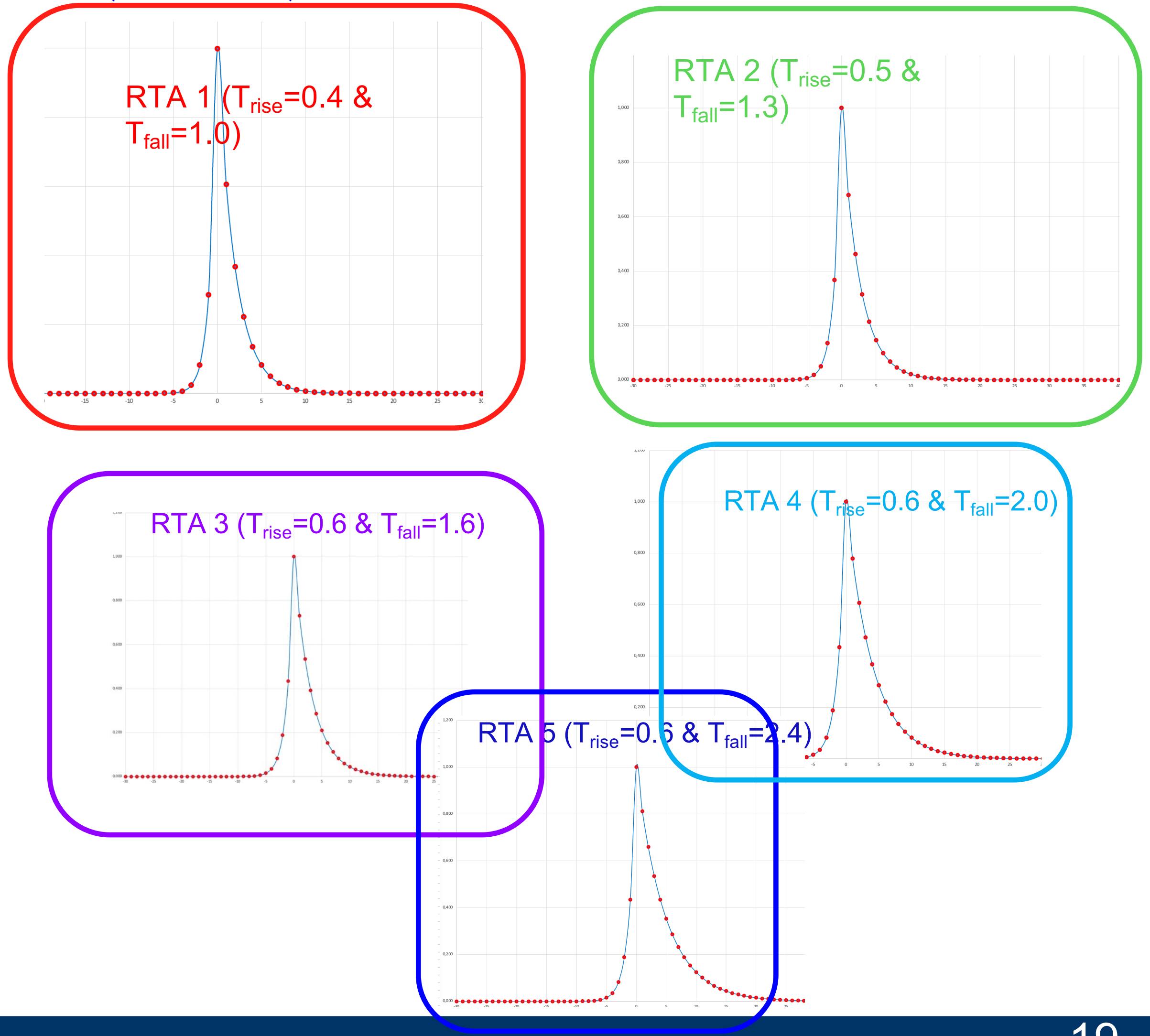


RTA scan ratio (1.5/1 cm tupes)

Ratio of drift tube size (1.2/0.8)

Electrons ratio

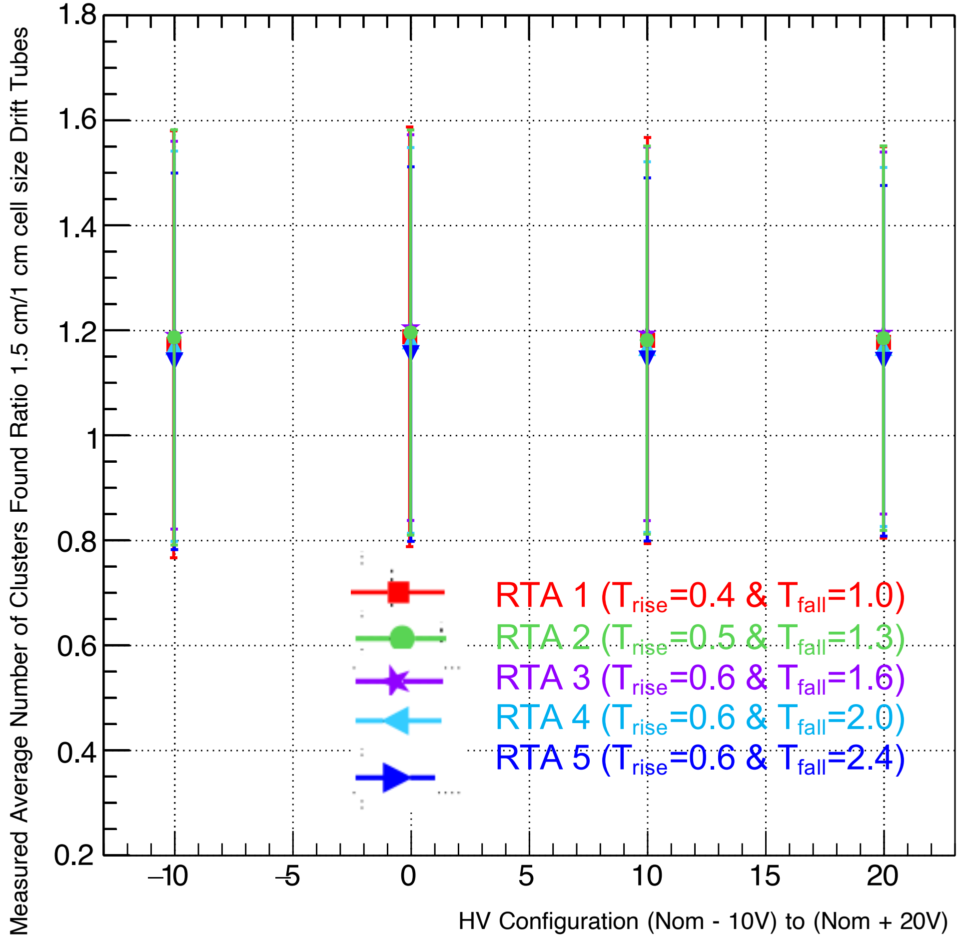


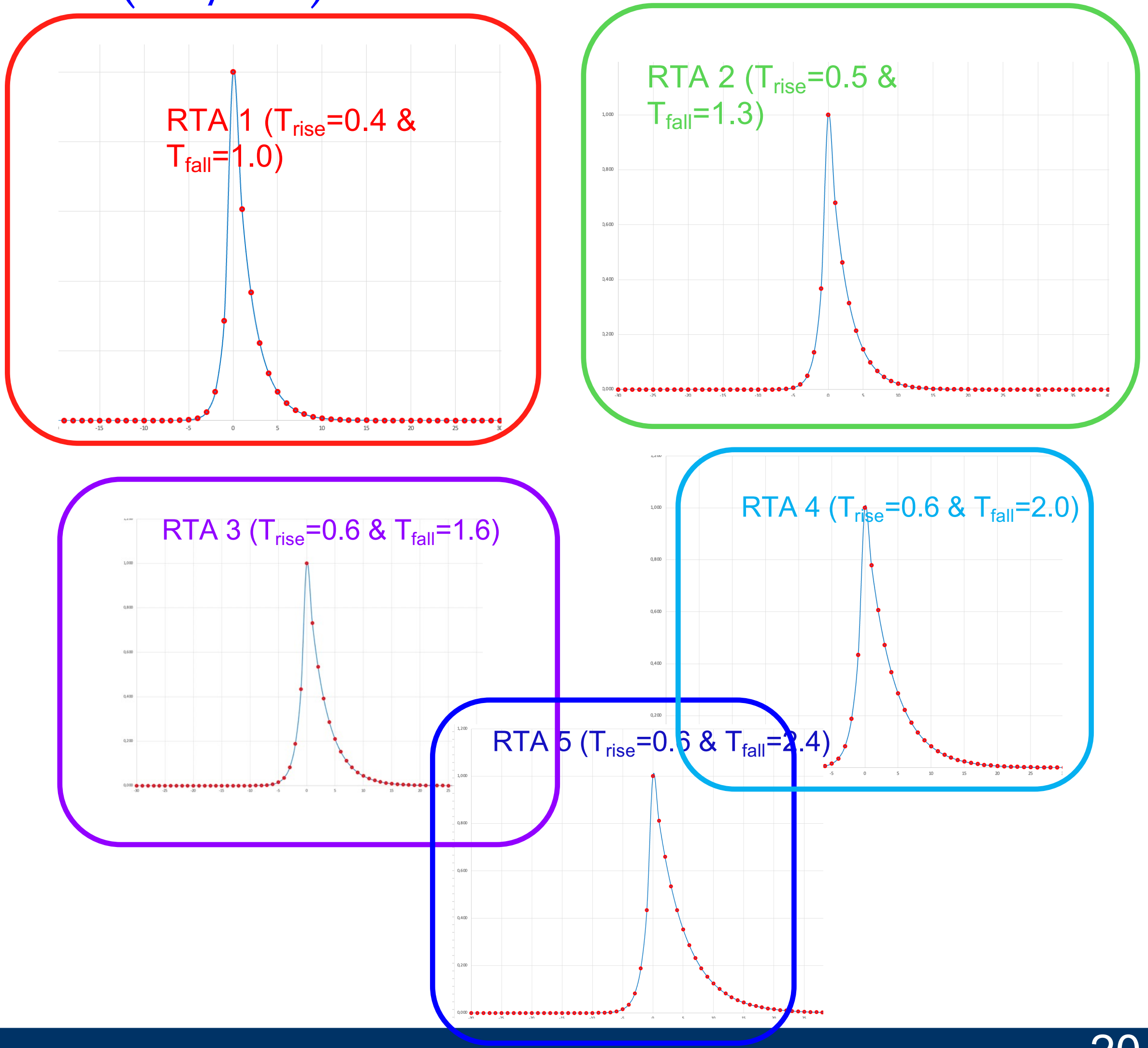


RTA scan ratio (1.5/1 cm tupes)

Ratio of drift tube size (1.2/0.8)

Clusters ratio

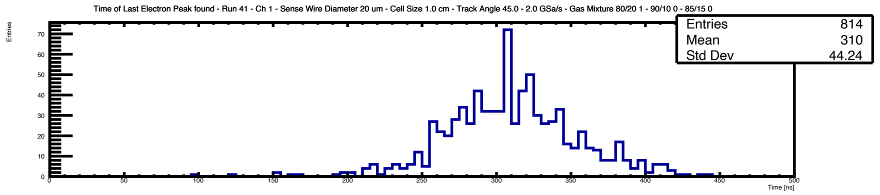


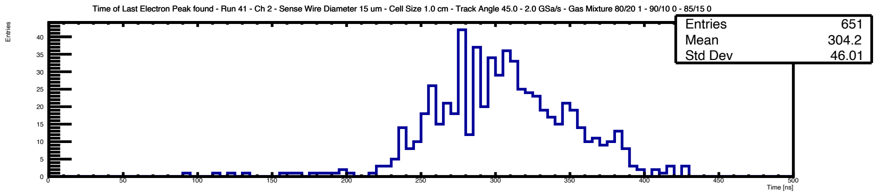


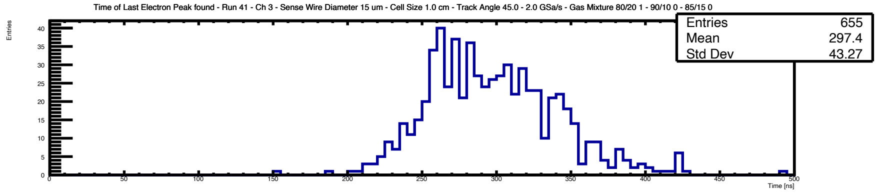
Time of the last electron peak

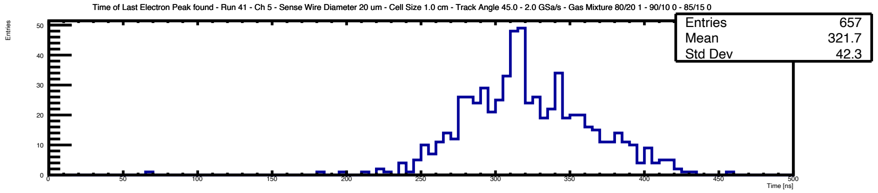
Time of the last electron peak 1 cm tupes

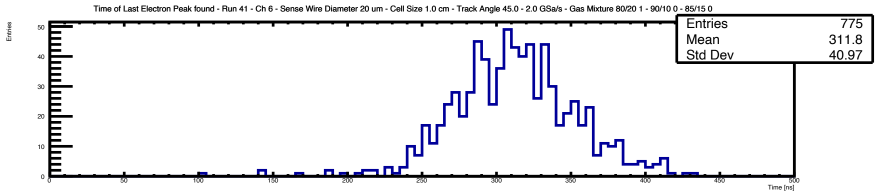
Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20

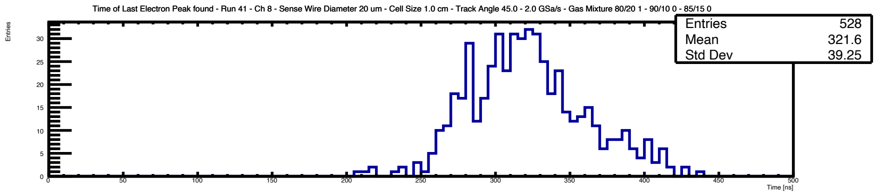


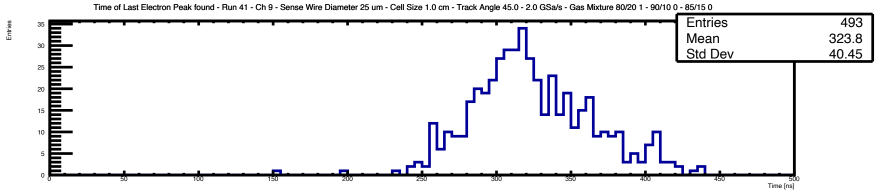


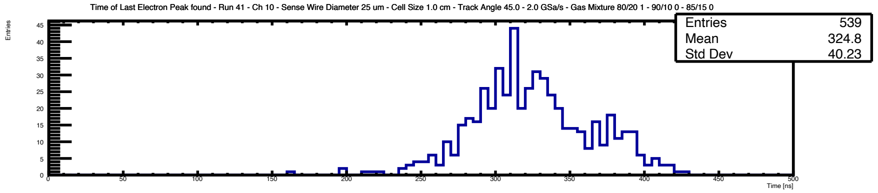








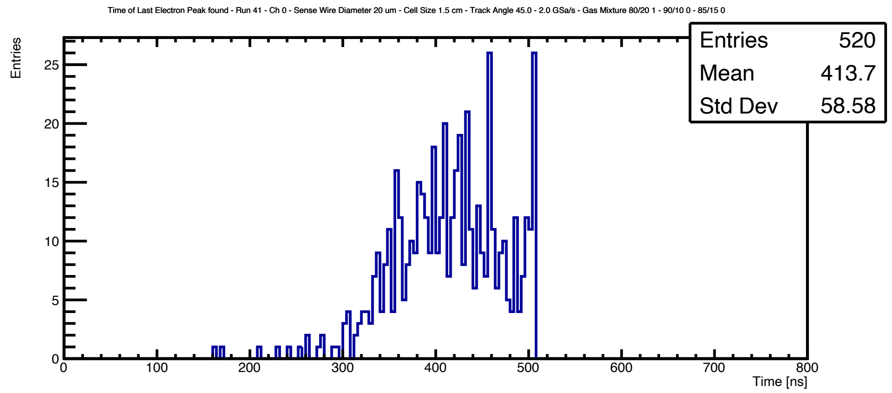


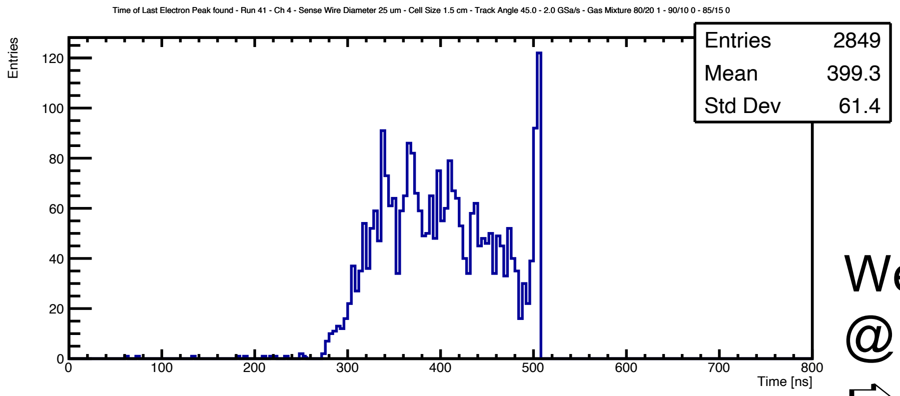


Time of the last electron peak

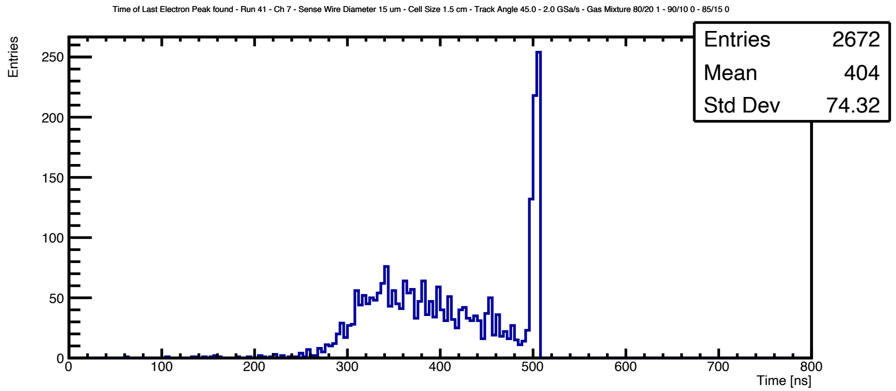
Time of the last electron peak 1.5 cm tupes
Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20

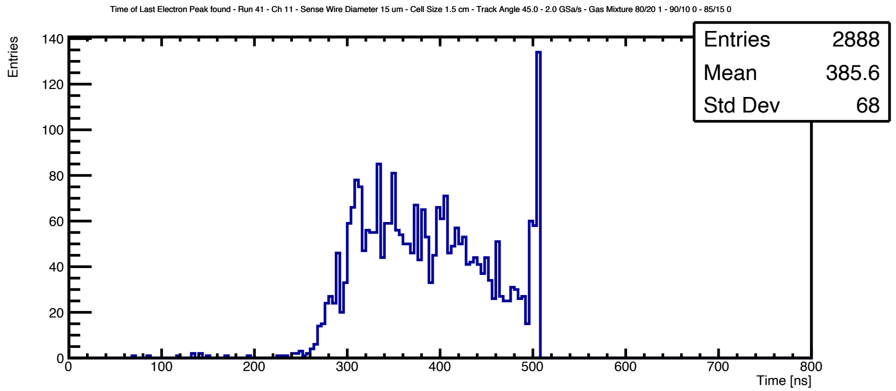
Issue in 1.5 cm tubes due to 512 ns don’t cover the full range.





We have 1024 bins,
@ 2GSa ➪ 1/2 ns/bin
➪ 512 ns.

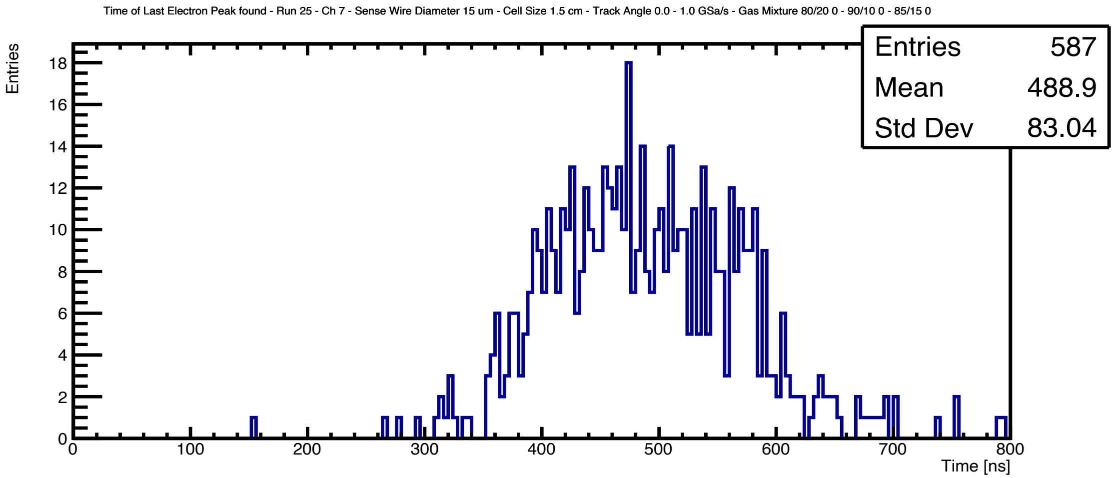




Time of the last electron peak

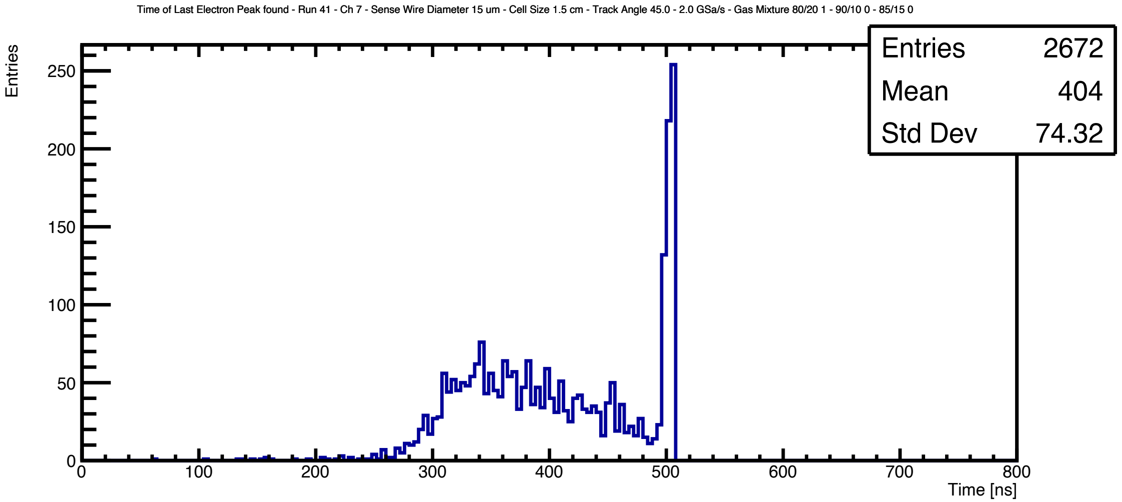
Time of the last electron peak 1.5 cm tupes, Track Angle 45; Gas Mixture He:IsoB 80/20

Sampling rate 1 GSa/s;



We have 1024 bins,
@ 1GSa ➪ 1 ns/bin ➪ 1024 ns.

Sampling rate 2 GSa/s;



We have 1024 bins,
@ 2GSa ➪ 1/2 ns/bin ➪ 512 ns.

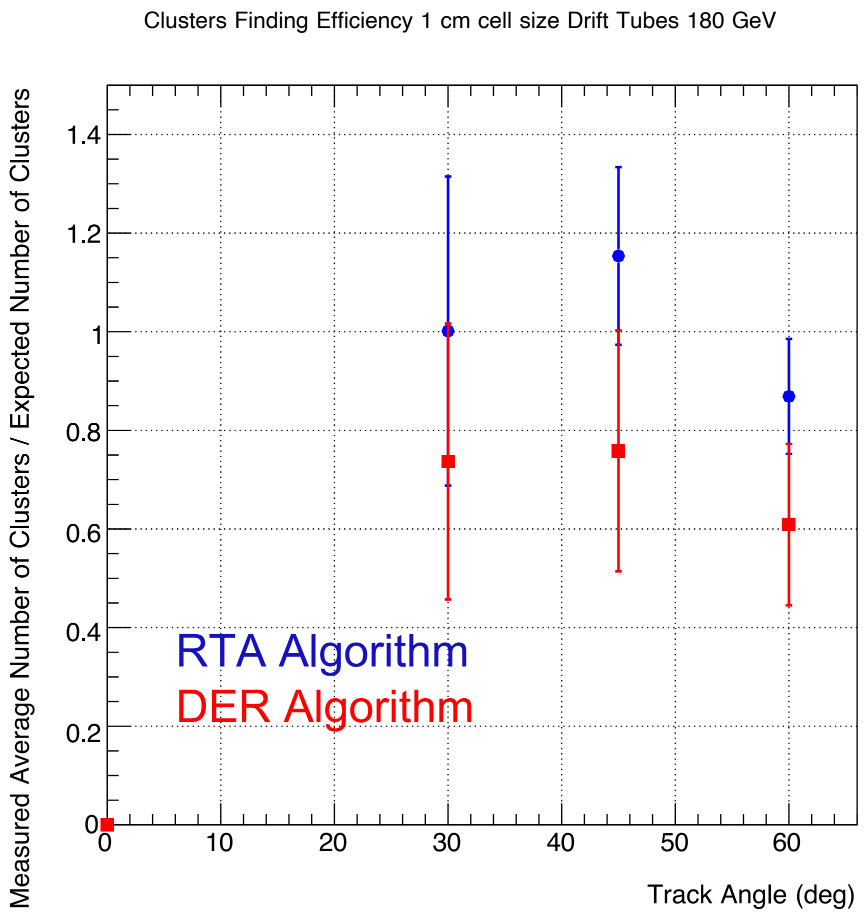
Issue in 1.5 cm tubes when using sampling rate 2GSa/s due to 512 ns don't cover the full range.

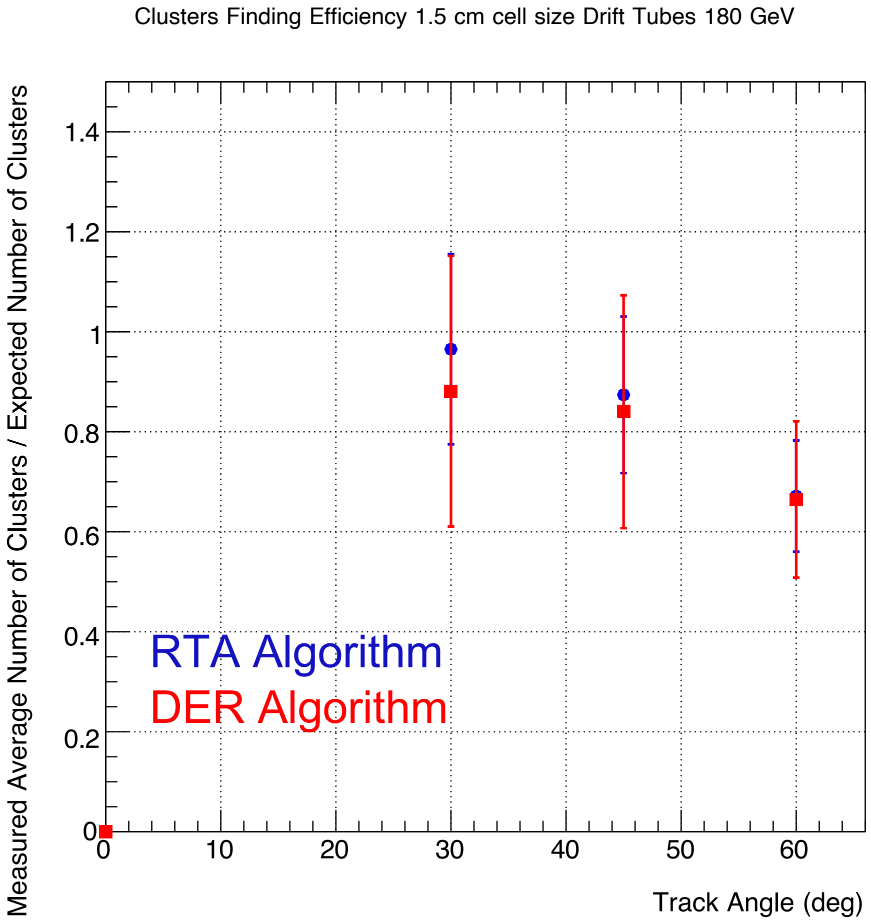
Comparison between DERV and RTA algorithm

1 cm drift tubes

Sampling rate 1 GSa/s;

1.5 cm drift tubes





- Undercounting at $\alpha > 45^0$ due to high electron peaks density.

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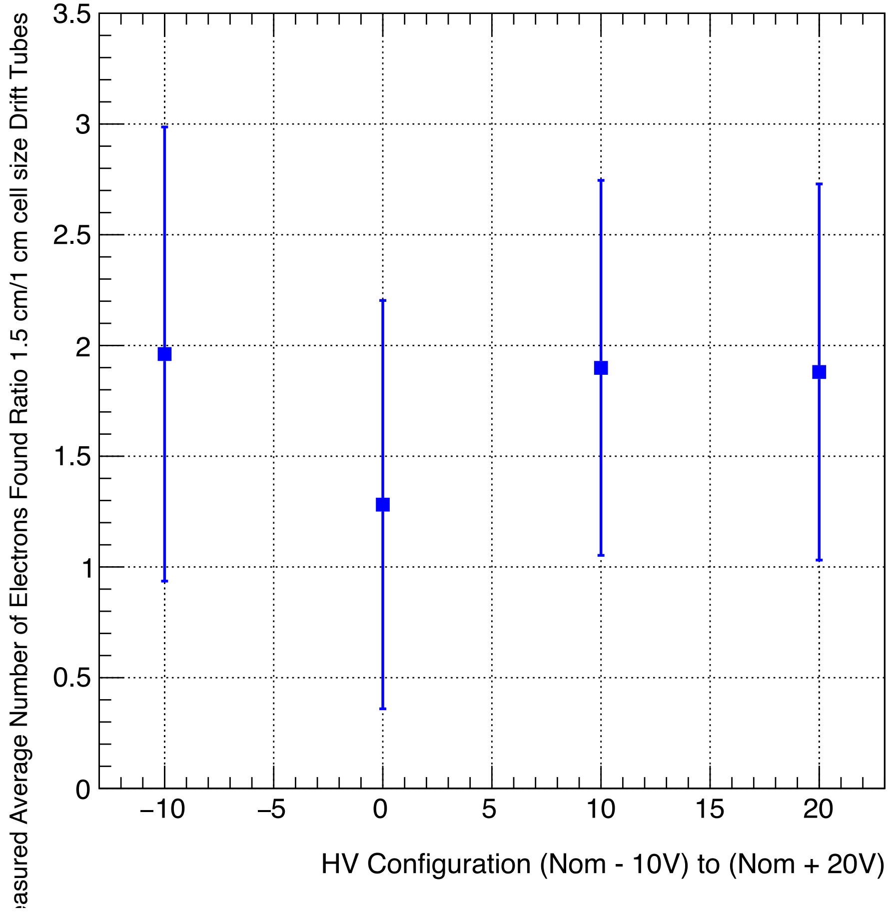
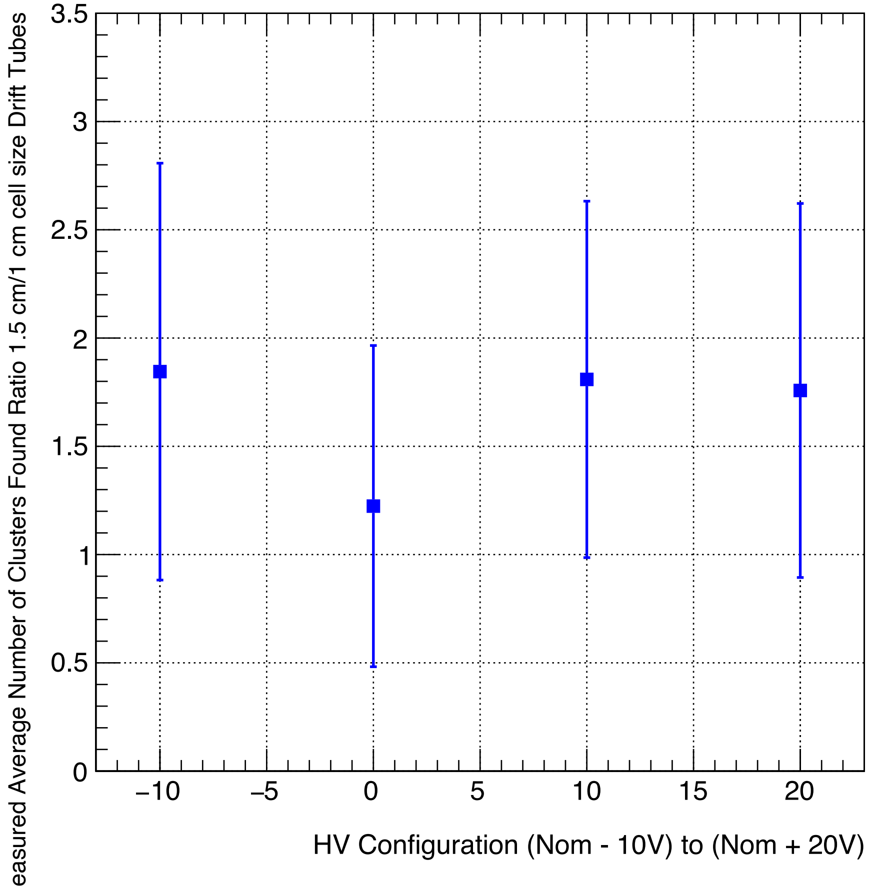
Sampling rate 1 GSa/s;

1.5 cm drift tubes





Summary

- We studied the counting efficiency, electron peaks and cluster density as a function of gas We studied mixture, gain, geometrical configuration (cell size, sense wires size), sampling rate, and track angle.
- Two different promising algorithms have been developed and used for finding the electron peaks.
- There is a good agreement between the results from the two algorithms and the expectation.
- The application of the two different algorithms will be very useful for understanding the pathologies of both algorithms, therefore, it will be extremely useful to have a third algorithm like the one being developed at IHEP with NN.

Thank You!