Particle identification with the cluster counting technique for the IDEA drift chamber

(Innovative Detector for an Electron-positron Accelerator)

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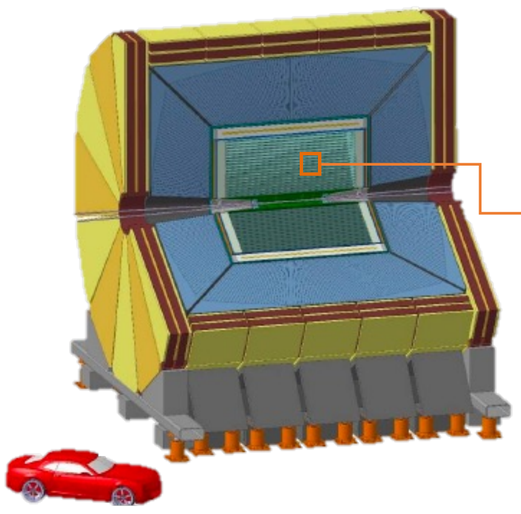
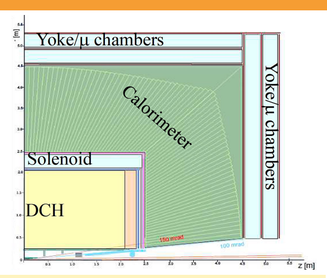


The IDEA general-purpose detector concept has been designed to study electron-positron collisions in a wide energy range provided by a very large circular leptonic collider [1,2].



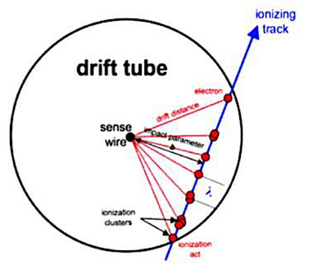
Drift chamber

It is supposed to provide an efficient tracking, a high precision momentum measurement and an excellent particle identification (PID) by exploiting the application of the cluster counting (CC) technique [3]. The effectiveness of the CC algorithms' usage for PID has been demostrated by theoretical results.

- He-based, unique-volume, R_{in} (0.30 m), R_{out} (2 m), L (4 m), ~ 0.016 X_0 (barrel), ~ 0.05 X_0 (end-caps)
- high granularity, low mass, fully stereo
- co-axial with the 2 T solenoid field
- 112 co-axial layers, at alternating-sign stereo angles, in 24 azimuthal sectors

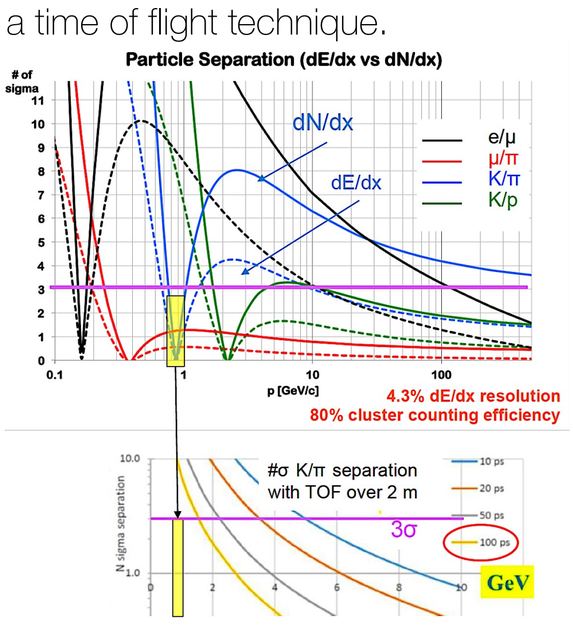
Cluster Counting and PID expected performance

Using the information about energy deposit by a track in a gaseous detector, PID can be performed.The large and intrinsic uncertainties in the total energy deposition represent a limit to the particle separation capabilities. Cluster counting (CC) technique can improve the particle separation capabilities.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 primary ionization act (dN_{Cl}/dx).



1 Analytical calculations

Expected excellent K/π separation for He/iC_4H_{10} = 90/10 over the entire range except 0.85 < p < 1.05 GeV (blue lines), which could be recovered with a time of flight technique.

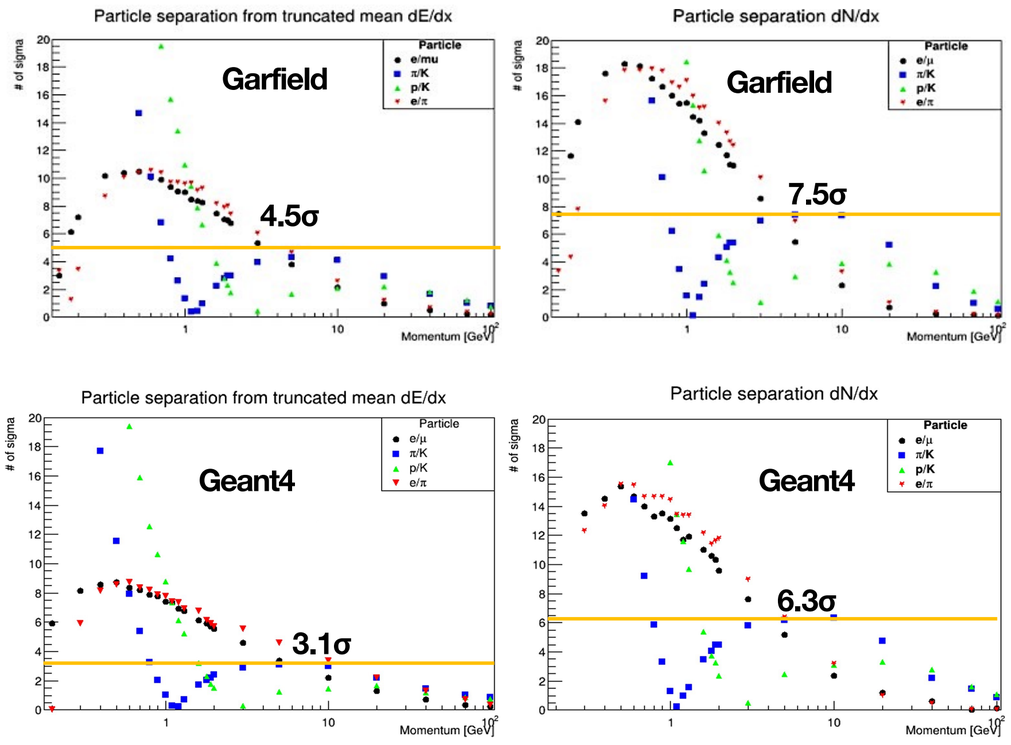


N_{Cl} number of primary ionizations follows Poisson statistics

- independent from cluster size fluctuations
- insensitive to highly ionizing δ-rays
- independent from gas gain fluctuations
- a 2 m track in a He – mix gives N_{Cl} > 2400 (for a m.i.p.): $\sigma_{dNcl/dx}/(dN_{Cl}/dx) = N_{Cl}^{-1/2} < 2.0\%$
- resolution scales with $L^{-0.5}$ (not $L^{-0.37}$ as in dE/dx)

2 Full simulation results

Starting from detailed studies of Garfield++ simulations results about the ionization process in Helium-based gas mixtures, an algorithm which reproduces the cluster size and cluster distribution using the energy deposit information by Geant4 has been developed under the assumption of a 100% cluster counting efficiency [4]. dN_{Cl}/dx improves particle separation capabilities of a factor of 2.



A simulation of the ionization process in 200 drift cells, 1 cm wide, in 90% He and 10% iC_4H_{10} gas mixture has then been performed both in Garfield++ and in Garfield-modeled Geant4

3 Conclusions

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

The Garfield++ model in GEANT4 reproduces reasonably well the Garfield++ predictions, but the particle separation, both with dE/dx and with dN_{Cl}/dx, in GEANT4 is considerably worse than in Garfield++. Why?

Why the dN_{Cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of βγ with a steeper slope?

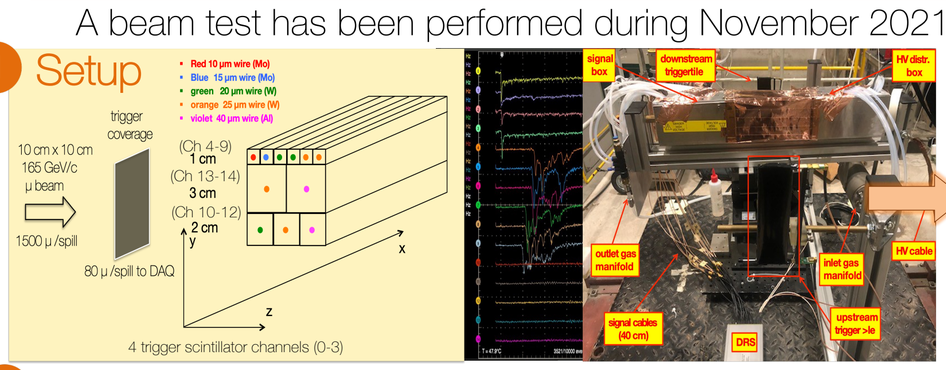
Further advantages of Helium

- Low primary ionization density implies a large time separation
- (λ ≈ 800 μm in 90% He, or 30 ns)
- low drift velocity means larger time separation (v_{drift} ≈ 2.5 cm/μs)
- low average cluster size $\langle N_{electrons}/cluster \rangle$ ≈ 1.6
- low single electron diffusion (< 110 μm for 0.5 cm drift, or < 4.5 ns)

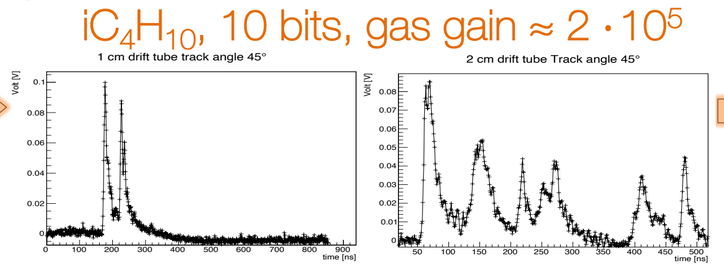
Cluster counting algorithms applied to H8 CERN test beam data

A beam test has been performed during November 2021 at CERN on the H8 line in a parasitic mode to validate the simulations results by using a muon beam.

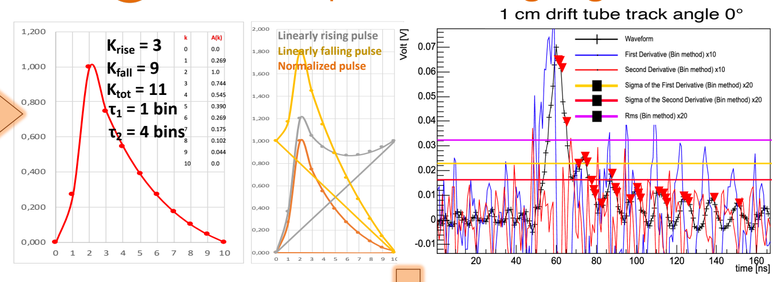
1 Setup



2 1.2 GSPS (853.33 ns), 90%He10% iC_4H_{10}, 10 bits, gas gain ≈ $2 \cdot 10^5$



3 Electron peak finding algorithms



Running Template Algorithm (RTA)

First and Second Derivative Algorithm (DERIV)

4 Same cluster counting algorithm

5 Independent compatible results

6 Beam test conclusions and plans

1. Establish the limiting conditions for an efficient CC:
   - gas gain saturation
   - cluster density (by changing the gas mixture)
   - space charge (gas gain, sense wire diameter, track angle)

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2. Demonstrate the ability to count clusters:
   - at a fixed βγ (muons at a fixed momentum) count the clusters by doubling the track length, changing the track angle and the gas mixture

3. In optimal configuration, measure the relativistic rise as a function of βγ, both in dE/dx and in dN_{Cl}/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) to define the particle identification capabilities of the cluster counting approach over the full range of interest for all future lepton machines.

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