Ionization clustering simulation and beam test for cluster counting

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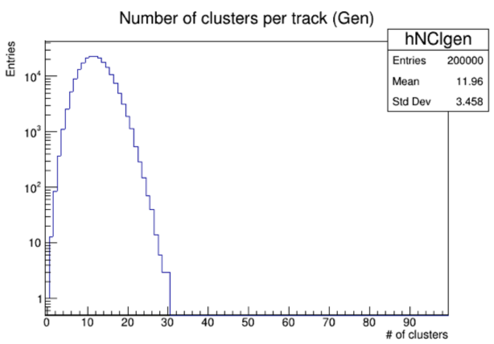
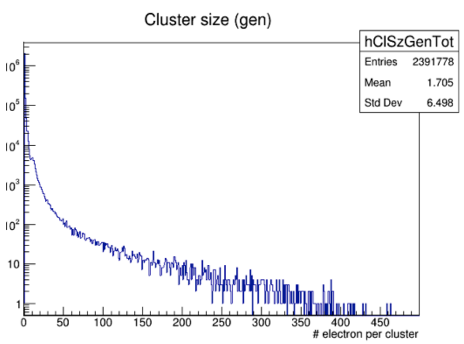
PID full simulation with cluster counting

- **Garfield++ (Heed)** simulates in deep detail the ionization processes in the gas, but it would be extremely cumbersome to follow an ionization particle inside the large volume of a tracking detector.
- **GEANT4** simulates the interaction of a particle with all the materials of a large detector but it doesn't simulate the ionization clustering process which is essential for cluster counting.
- **Define a model** for a fast simulation of the cluster density and the cluster size distribution according to the predictions of **Heed**, to be used taking into account the results of the particle interactions calculated by **GEANT4**.

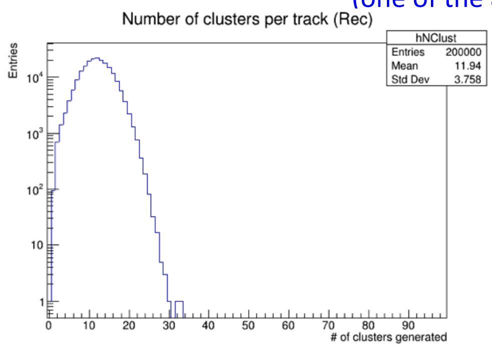
Heed

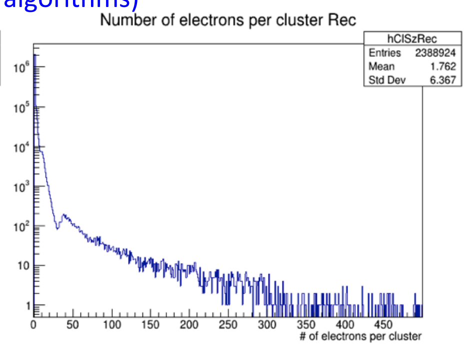




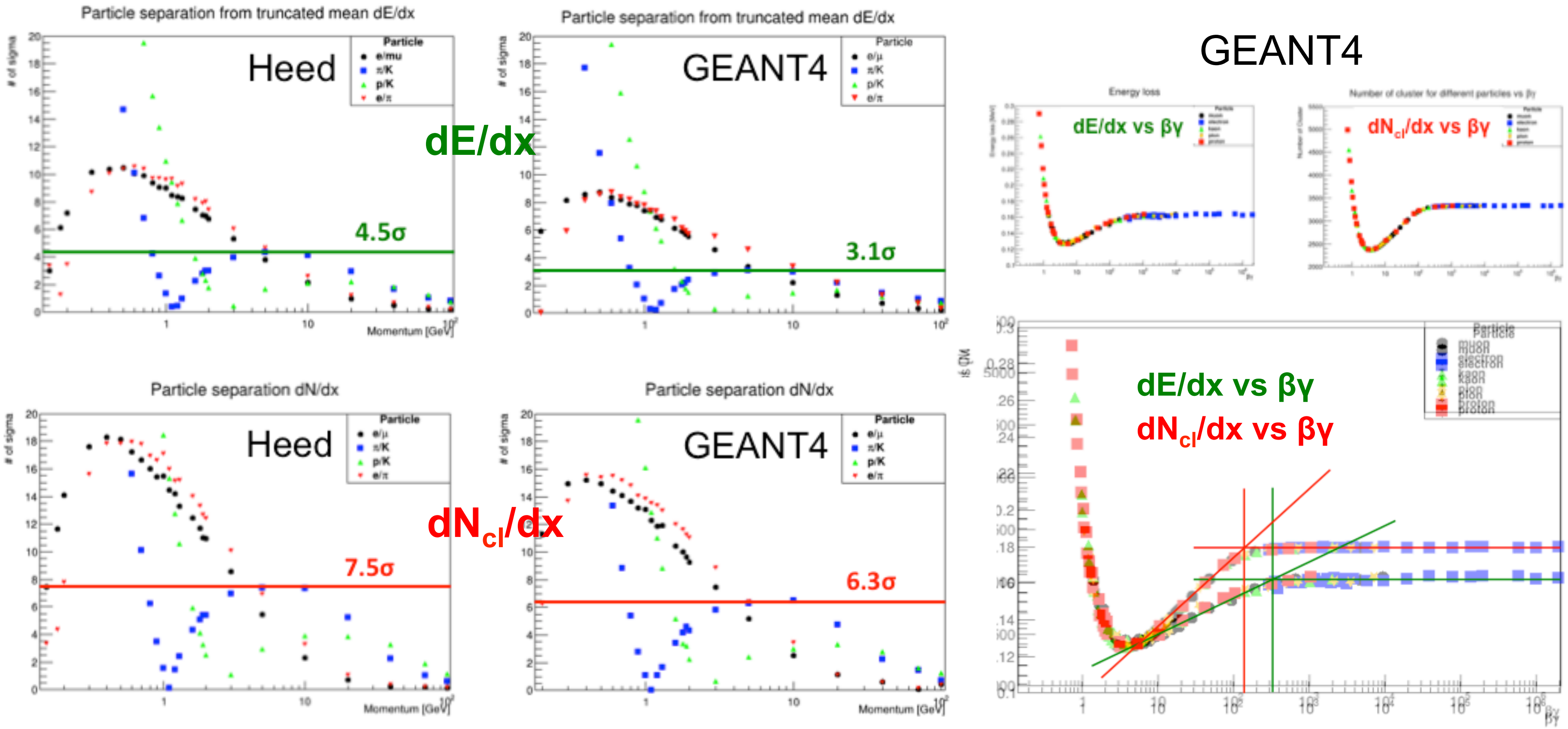
model

(one of the algorithms)





PID full simulation with cluster counting



PID full simulation with cluster counting

Open questions:

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 Heed model in GEANT4 reproduces reasonably well the Heed predictions, why particle separation, both with dE/dx and with dN_{cl}/dx, **in GEANT4 is** considerably **worse than in Heed**?
3. Despite a higher value of the dN_{cl}/dx Fermi plateau with respect to dE/dx, why this is reached at **lower values of βγ with a steeper slope**?
4. We are still waiting for answers from Heed and Geant4 developers to try to shed light on these questions
5. These questions are crucial for establishing the particle identification performance at **FCCee**, **CEPC** and **SCTF**
6. However, **the only way to ascertain these issues is an experimental measurement!**

Motivations for a beam test

Beam test plans:

1. First of all, need to demonstrate the **ability to count clusters**:
   at a fixed βγ (e.g. muons at a fixed momentum) count the clusters by
   - doubling and tripling the track length and changing the track angle;
   - changing the gas mixture.
2. 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
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).
4. Use the experimental results to fine tune the predictions on performance of **cluster counting** for **flavor physics** and for **jet flavor tagging** both in **DELPHES** and in **full simulation**

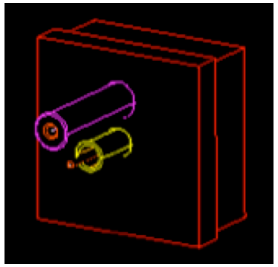
Motivations for a beam test

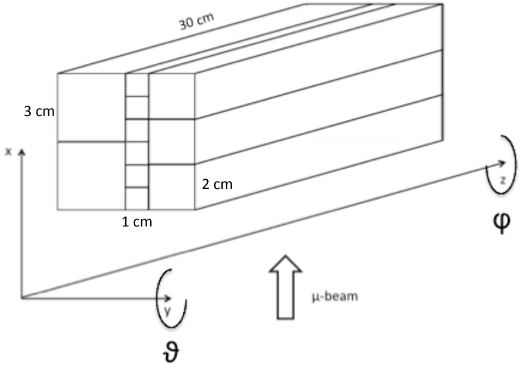
Advantages:

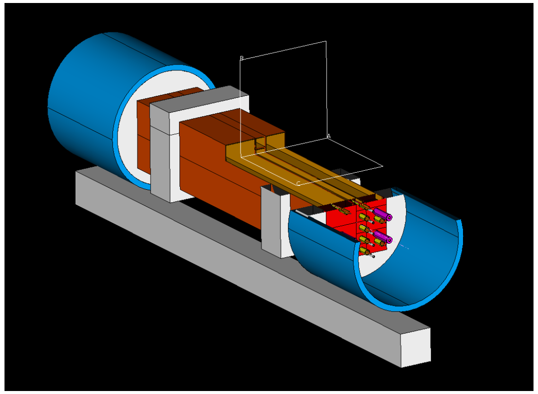
- no need of **external trackers**: only interested in **path length** inside the drift tube active volume
- no need of **internal tracking** (time-to-distance and t_0 **calibrations**, alignment, track finding and fitting algorithms, ...)
- no need to convert **time to distance** (just count clusters in the **time domain**)
- no worry of **multiple scattering** (irrelevant for path length differences)
- no need of **particle tagging** in hadron beams: use only **muon beams** at different momenta (**different $\beta\gamma$**)
- use selected **commercial amplifiers** (adapting tube impedance to 50 Ω) to minimize electronics performance limitations (**bandwidth, gain, noise**, ...) and neglecting **power consumption**
- use only **fully integrated digitizers** (**O-scope**, 16-ch. **WDB**) for ease of readout

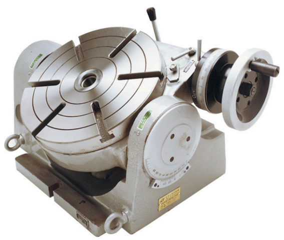
Motivations for a beam test

conceptual setup:









test configuration:

- 6 drift tubes 1 cm × 1 cm × 30 cm
  - 2 with 15 μm sense wire, 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 30 μm
- 2 drift tubes 3 cm × 3 cm × 30 cm
  - 1 with 20 μm sense wire, 1 with 30 μm
- 11 preamplifier cards (1 GHz, 20 db) + termin.
  - more configurations to choose from
- 11 independent HV power supply channels
- 11 digitizer (2 GSa/s, 12 bit) (WDB + O-scope)
  - max drift time ≈ 2μs for 3 cm drift at 45°
- gas mixing, control and distribution (only He and iC_4H_{10})
- 2-3 trigger scintillators (HV, discr., coinc., TU)

Aim of a parasitic beam test in 2021

- Compare, at a fixed muon p (to be agreed upon with main user)
- **number of clusters** versus **cell size** and **gas mixture** (He/iC_4H_{10}) and **gas gain**:
  - **from 12 cm^{-1}** (gas: 90/10) to **25 cm^{-1}** (gas: 70/30) for a **m.i.p.**
  - **test and optimize counting algorithms**
  - **measure cluster density for both He and iC_4H_{10}**
  - **measure counting efficiency versus cluster density**
  - **(estimate cluster size distribution for both He and iC_4H_{10})**
- **number of clusters** versus **space charge effects**:
  - different **gas gain** (from $1x10^5$ to $5x10^5$) for He/iC_4H_{10} = 90/10
  - **sense wire diameters** 15, 20, 25, 30 µm for the same **gas gain** ($5x10^5$)
  - **angle between track and wire**: 0°, 30°, 45°, 60° for the same **gas gain** ($5x10^5$)

must be done at a fixed muon momenta

- Choose optimal operating conditions (counting efficiency):
  gas mixture, gas gain, sense wire diameter, track angle
- scan muon momentum ($\beta\gamma$ = 40 ÷ 1800) and **measure relativistic rise**: essential to **predict particle separation independently of the assumptions in Heed and Geant4 simulations**.

must be done by scanning the muon momenta

Configurations of the parasitic beam test in 2021

tube	anode				amplifier
	15 µm	20 µm	25 µm	30 µm	
1x1 cm^2	✓	✓	✓		A
1x1 cm^2	✓	✓	✓		B
2x2 cm^2		✓	✓	✓	C
3x3 cm^2		✓		✓	D

1 configuration
(8 different geometries)
(4 different amplifiers)

gas gain	1×10^5	2×10^5	5×10^5

3 configurations

He/iC_4H_{10}	90/10	85/15	80/20	75/25

4 configurations

ϑ (between track and wire)	0°	15°	30°	45°	60°

5 configurations
at fixed gas mixture

Configurations of the parasitic beam test in 2021

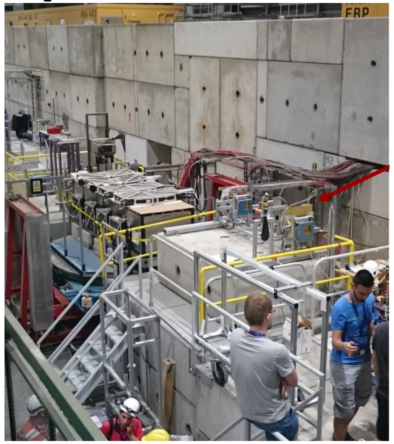
- On average, 3 tubes hit per beam muon
- Assume a 20 Hz trigger rate or 60 tubes hit/s, 1 hour run ≅ 2×10^5 hits
- 1 run provides a relative error on average number of clusters/cm of less than 0.05 clusters
- Changing gas mixture: at 24 NLH (400 sccm), 1 volume exchange (4 l) every 10 min., implies a gas mixture change in 1 h (dead time). During normal operations, depending on gas tightness of the system, a reduction of a factor 10 will provide a flow rate more than adequate.
- At fixed muon momentum (180 GeV/c in week 42 – Oct. 20-26):

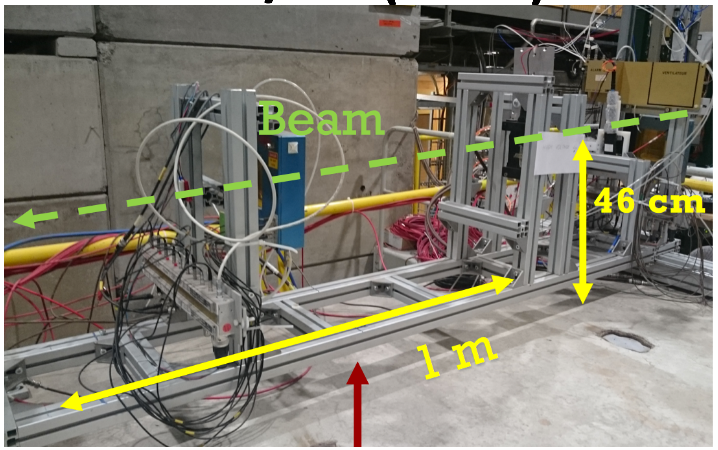
  12 counting configurations (4 gas mixture x 3 gas gain) at fixed ϑ angle **< 3 x 8 hours shift**
  10 counting configurations (2 gas gain x 5 ϑ angle) at fixed gas mixture **< 2 x 8 hours shift**

- At fixed running conditions (90/10 gas mixture, fixed gas gain, fixed beam angle), one muon momentum value per run implies **< 2 x 8 hours shift** for 12-16 different momentum values on the relativistic rise.
- At least **3-4 different running conditions** may be explored.

Beam test availability in parasitic mode at CERN/H8 (2021)

Building 887 (EHN1), CERN's biggest building, hosts several experiments and test areas fed by the SPS accelerator (Image: Maximilien Brice/CERN)





week	location	main users	beam
week 42 - Oct. 20-26	PPE168	LHCb (PPE128 and/or 138) CMS MDT (PPE158)	muons at 180 GeV/c
week 43 – Oct 27-Nov 2	PPE158	LHCb (PPE168 bis) TOTEM (PPE168)	muons and hadrons
weeks 44-45 Nov. 3-14	PPE168 PPE168 bis	ATLAS TileCal (PPE158)	muons: scan in momentum

Aim of a beam test as main user in 2022

- Fall-back eventuality in case we were not able to complete the test program, due to the beam scheduling of the main user (ATLAS TileCal) during the weeks 44-45/2021.
- The aim is to complete the described test program, eventually by optimizing the same experimental setup.
- Beam request will be of two weeks, as main users, with muon beams of momenta selected from the lowest value to the highest value (a few GeV/c to 250 GeV/c), as early as possible (spring/summer 2022).