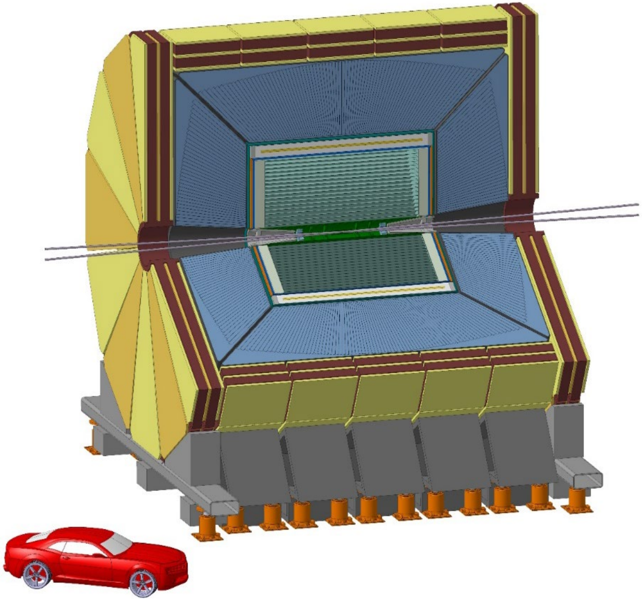
IDEA light Drift Chamber

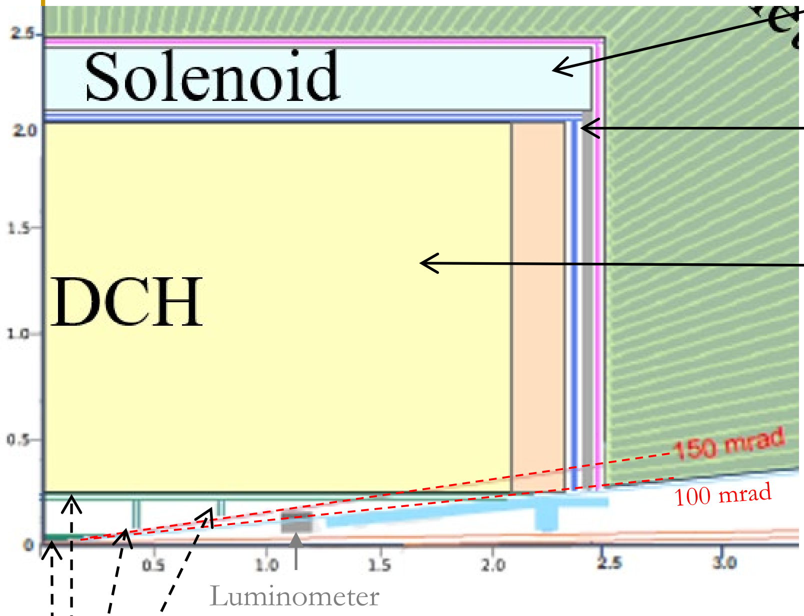


G.F. Tassielli *on behalf of IDEA DCH group*
INFN Bari and Università degli Studi di Bari

Outline

- The IDEA tracking system
- IDEA Drift Chamber
- IDEA Drift Chamber simulations
    - Full detector standalone simulations
    - Delphes model
    - Migration to EDM4hep and Key4hep
    - Cluster Counting/Timing
    - Signal generation
    - Cluster Finding algorithm
- Summary and Plans

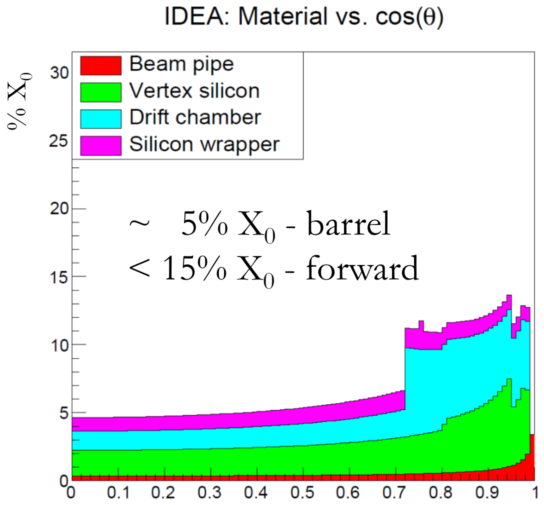
The IDEA tracking system



Solenoid: 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X_0, 0.16 λ @ 90°

Si Wrapper:
2 layers of μ-strips (50 μm x 1 mm)
both barrel and forward regions

DCH: 56448 (~1.2 cm) cells
He based gas mixture
(90% He – 10% i-C_4H_{10})


IDEA: Material vs. cos(θ)

~ 5% X_0 - barrel
< 15% X_0 - forward

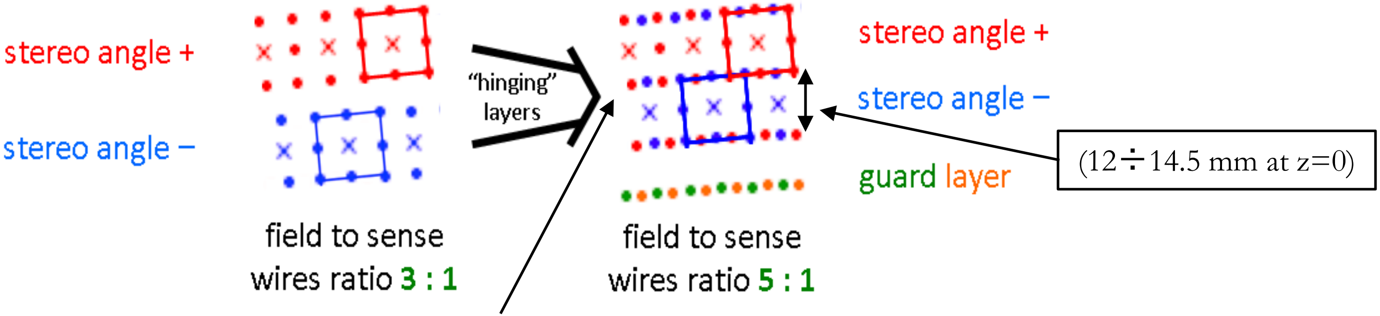
Vertex:

inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0

outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0

The IDEA drift chamber



The wire net created by the combination of + and – orientation generates a more uniform equipotential surface

sense wires:	20 mm diameter W(Au)	=>	56448 wires
field wires:	40 mm diameter Al(Ag)	=>	229056 wires
f. and g. wires:	50 mm diameter Al(Ag)	=>	58464 wires

343968 wires in total

High wire number requires a non standard wiring procedure and needs a feed-through-less wiring system. The novel wiring procedure developed and used for the construction of the ultra-light MEG-II drift chamber must be used.

MEG-II: muon to e-gamma search experiment at Paul Scherrer Institut - "The design of the MEG II experiment", Eur. Phys. J. C (2018) 78:380 - https://doi.org/10.1140/epjc/s10052-018-5845-6

The IDEA drift chamber: novel approach at construction technique of high granularity and high transparency Drift Chambers

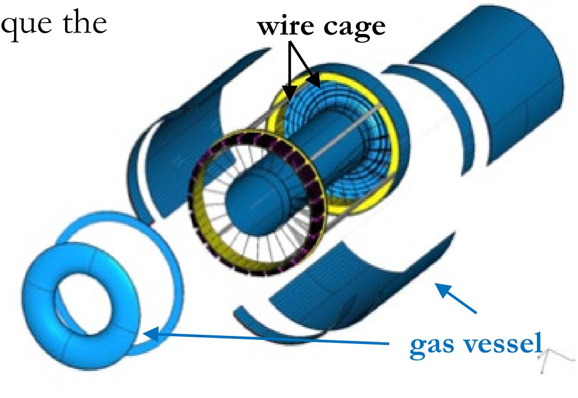
Based on the MEG-II DCH new construction technique the IDEA DCH can meet these goals:

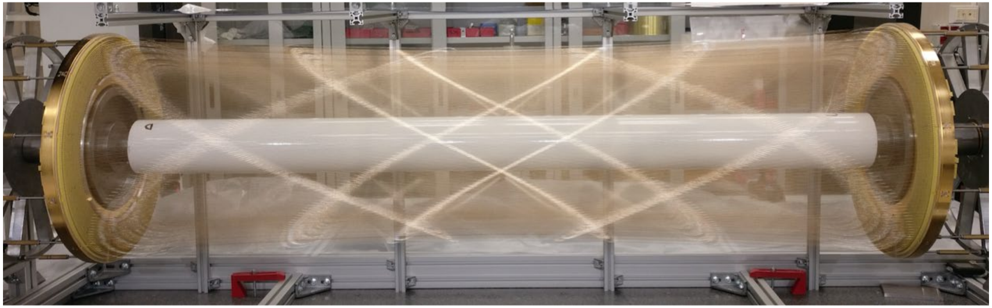
- Gas containment – wire support functions separation:

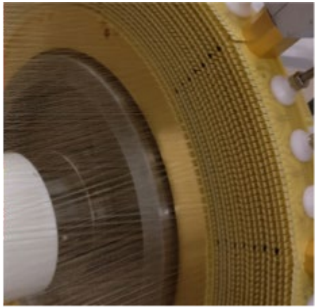
  allows to reduce material to ≈ 10^{-3} X_0 for the inner cylinder and to a few x 10^{-2} X_0 for the end-plates, including FEE, HV supply and signal cables

- Feed-through-less wiring:

  allows to increase chamber granularity and field/sense wire ratio to reduce multiple scattering and total tension on end plates due to wires by using thinner wires







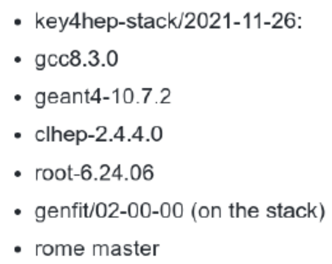
IDEA Drift Chamber simulation - Full detector standalone simulations

- The standalone code was adapted for compilation on Key4hep stack
- It works with the latest key4hep stack on CERN lxplus machines (source /cvmfs/sw.hsf.org/key4hep/setup.sh)

The stack environment ←

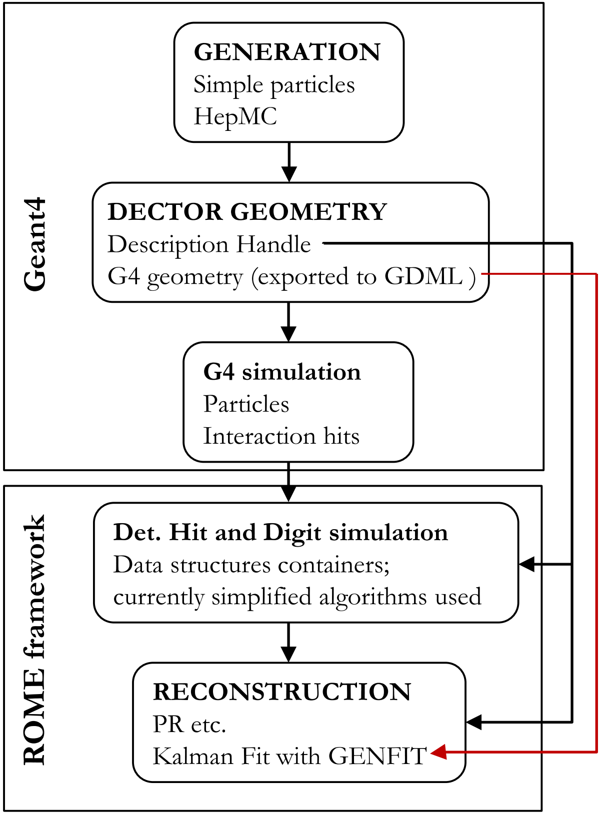
SWs from the stack

External package to be installed locally ←

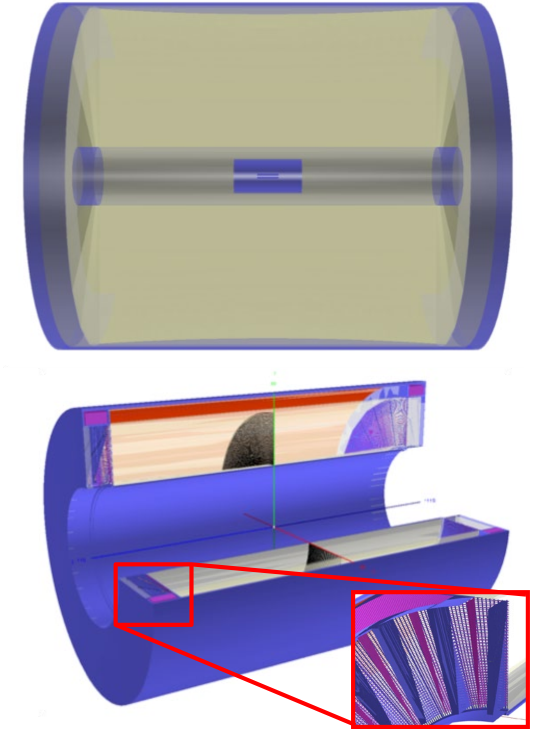


- key4hep-stack/2021-11-26:
- gcc8.3.0
- geant4-10.7.2
- clhep-2.4.4.0
- root-6.24.06
- genfit/02-00-00 (on the stack)
- rome master

https://github.com/lialavezzi/DriftChamberPLUSVertex/tree/uptodate



IDEA Drift Chamber simulation - Full detector standalone simulations



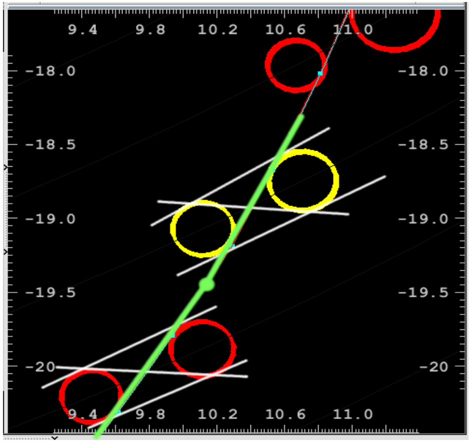
- A full geant4 simulation of the IDEA tracking system was developed to test the tracking performance
- The **DCH** is simulated at a good level of geometry details, including wires and detailed description of the endcaps
- **SVX** and **Si wrapper** and **PSHW** are simulated as simple layer or overall equivalent material
- *Dual Readout calorimeter simulation is included*
- KF with simple track selection criteria was used: *only a quality cut on Chi2/nDof < 25 was applied*;
- A preliminary SVX and DCH with DD4hep description was implemented inside the FCC-sw

More details in: G. Tassielli: "Tracking performance with the updated geometry of the IDEA detector " at 11th FCC-ee workshop, CERN, January 2019"

IDEA Drift Chamber simulation - Full detector standalone simulations: (one) Pattern Recognition (Local Method)

Seeding from 2 pairs of hits (each pair on same layer) pointing at the origin

- 2 consecutive hits in same layer
  → 4=2x2(Left-Right) pairs with direction
- 2 pairs from nearest layers compatible:
  $|\Delta\cos(\varphi(\text{direction})-\varphi(\text{position}))|<0.2$,
  crossing Z inside DCH
- 1 pair with origin → Pt estimate (averaged over 2 pairs)
- Cross Point of 2 opposite stereo pairs give Z-coordinate (with $\Delta\varphi$ correction from Pt)
- $P_z = 0$ at beginning



Red hits **projection at z=0 plane**
Yellow **rotated according to φ**

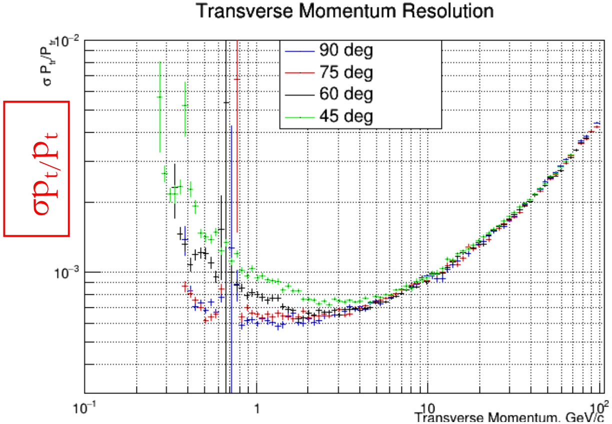
Z measurement give additional compatibility check between 2 hits and between 2 pairs

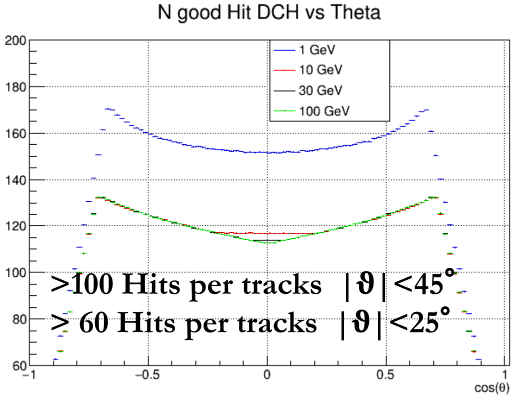
Combinatory low: 2 local compatibilities + 1 from opposite stereo view, but with direction angle check

IDEA Drift Chamber simulation - Full detector standalone simulations

assumed: σ_d = 100 μm and (conservative for Si) σ_{Si} = pitch/√12 μm

$\sigma p_t/P_t$

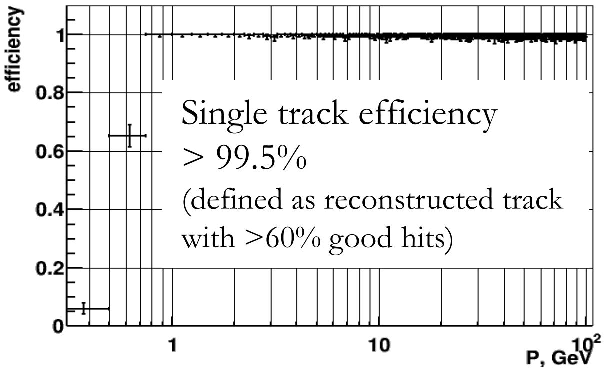




>100 Hits per tracks |ϑ|<45°

> 60 Hits per tracks |ϑ|<25°

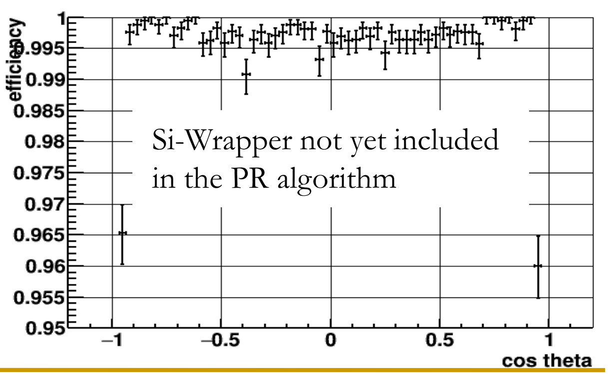
efficiency to find 0.6nhits at 1 turn(|cos th|<0.8 over all tracks



Single track efficiency > 99.5%

(defined as reconstructed track with >60% good hits)

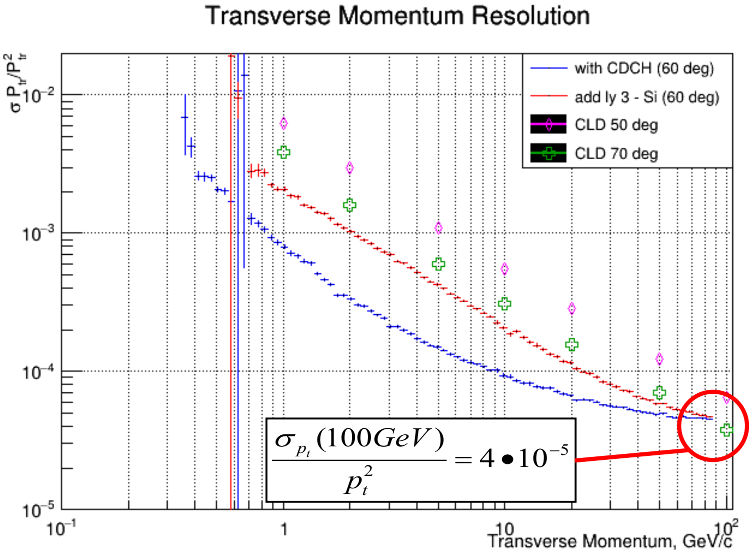
efficiency to find 0.6nhits at 1 turn(P>1GeV) over all tracks



Si-Wrapper not yet included in the PR algorithm

IDEA Drift Chamber simulation - Full detector standalone simulations

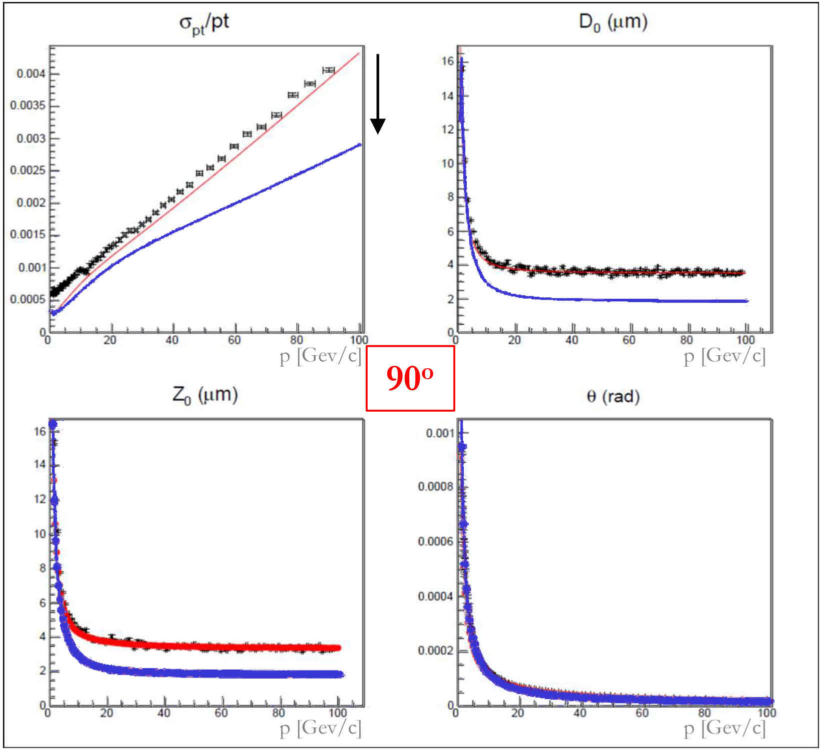
Transparency more relevant than asymptotic resolution, the particle range is far from the asymptotic limit where MS is negligible.



$$\frac{\sigma_{p_t}(100GeV)}{p_t^2} = 4 \bullet 10^{-5}$$

CLD: a detector concept for FCC-ee with a full Si-tracker system, inspired by CLIC detector.

IDEA Drift Chamber simulation – Delphes model



Analytic model to evaluate full covariance matrix

black point: Full simulation
red line: analytic model with Si resolution as Full sim.
blue line: analytic model with improved Si resolutions*

* Vertex:
- inner 3x3 μm
- outer/forward 7x7 μm

Si wrapper: 7x90 μm

$$\frac{\sigma_{p_t}(100GeV)}{p_t^2}:$$

$4 \cdot 10^{-5}$

↓

$2.9 \cdot 10^{-5}$

More details in F. Bedeschi: "IDEA model in Delphes "

IDEA Drift Chamber simulation - Migration to EDM4hep and Key4hep

Goal: port the simulation and the algorithms to a common FCC framework to develop studies, physics analysis and algorithms in the standard/final environment

standalone

FCC framework

Shorter and intermediate path:

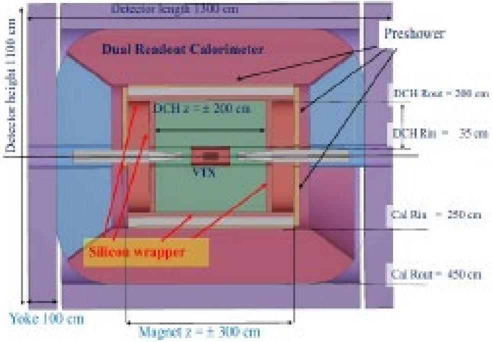
Geant4 Monte Carlo hits
(possible other data structures)
reconstructed tracks

convert to

EDM4HEP

Longer path:

simulation + reconstruction



port the geometry

port the algorithms

port the data format

Key4HEP

IDEA Drift Chamber simulation - Migration to EDM4hep and Key4hep

Goal: port the simulation and the algorithms to a common FCC framework to develop studies, physics analysis and algorithms in the standard/final environment

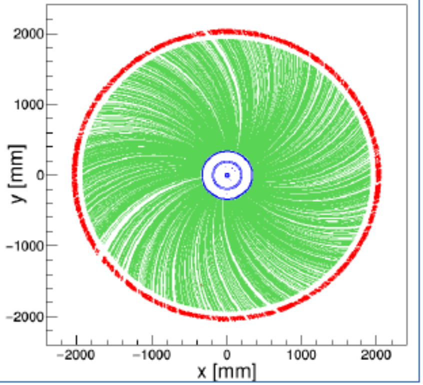
Shorter and intermediate path (***thanks to L. Lavezzi***):

present only the tracker hits: **silicon vertex tracker, drift chamber, pre-shower**

Example of simulation

particle
- 1090 events
- 1 muon/event
- theta in [88.5, 90.5] deg
- energy = 1 GeV

geometry
- Beam pipe
- SVX
- DCH
- PSHW
- magnetic field = 2.0 T



I. Vivarelli and L. Pezzotti is porting the DR calo hits to EDM format
I.Grazia is adding the geometry of the muon chambers
W. Elmwntenawee is merging some updates to release an base common version

More details in: L. Lavezzi: "Lesson learned when migrating the IDEA drift chamber software to EDM4hep" at 5th FCC Physics workshop, Liverpool, February 2022"

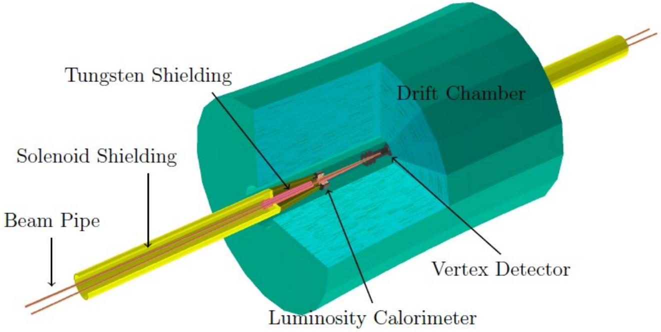
IDEA Drift Chamber simulation - Migration to EDM4hep and Key4hep

Goal: port the simulation and the algorithms to a common FCC framework to develop studies, physics analysis and algorithms in the standard/final environment

Longer path:

A preliminary simplified implementation of the Drift Chamber simulation with DD4HEP, a preliminary PR based on Hough transformation and some preliminary studies was done by N. A. Tehrani: http://cds.cern.ch/record/2670936

An implementation of the Drift Chamber (similar to the IDEA one) simulation with DD4HEP is under development for Super Tau Charm factory studies



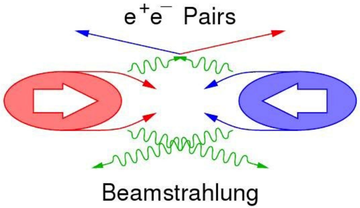
To do (it will in few months):

- the right DD4HEP Drift Chamber geometry description (~ 4-6 months)
- implement the segmentation and the (reco-)hits (~ 2 months)
- Port/implement the reconstruction (at least 6 months)

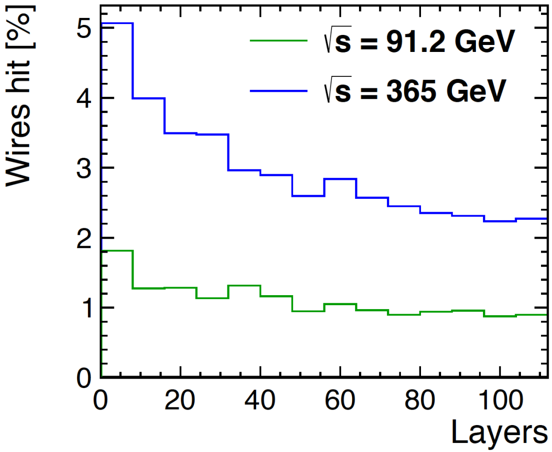
More details in: N. A. Tehrani: "Simulation and tracking studies for a drift chamber at the FCC-ee experiment"

IDEA Drift Chamber simulation – with old FCCsw implementation

Preliminary study of the machine background induced occupancy on the DCH, indicate that, it will be not an issue



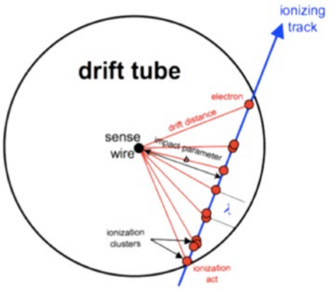
Background	Average occupancy $\sqrt{s}$ = 91.2 GeV	Average occupancy $\sqrt{s}$ = 365 GeV
e^+e^- pair background	1.1%	2.9%
$\gamma\gamma \to$ hadrons	0.001%	0.035%
Synchrotron radiation	negligible	0.2%

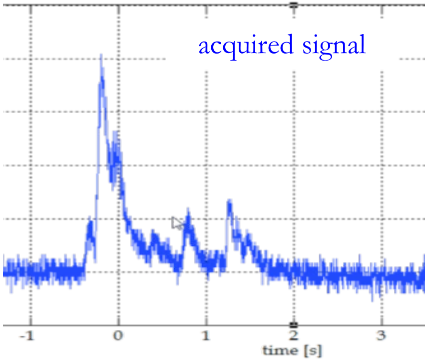


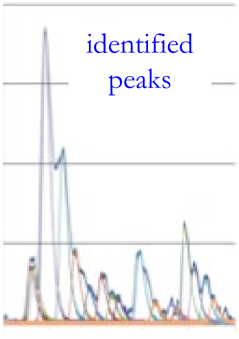
IDEA Drift Chamber simulation - Cluster Counting/Timing

In He based gas mixtures the signals from each ionization act can be spread in time to few ns. With the help of a fast read-out electronics they can be efficiently identify.

Counting the number of ionization acts per unit length (dN/dx) is possible to identify the particles (P.Id.) with a better resolution than dE/dx method.







dE/dx

truncated mean cut (70-80%) reduces the amount of collected information. n = 112 and a 2m track at 1 atm give **σ ≈ 4.3%**

dN_{cl}/dx

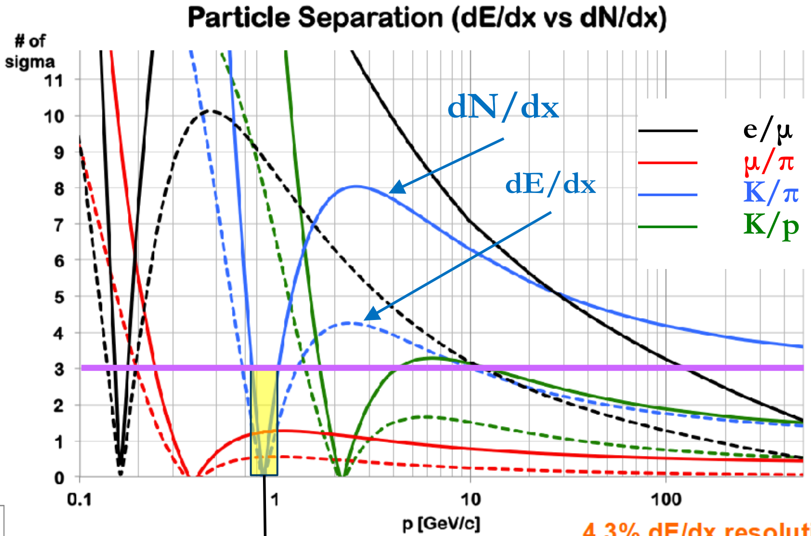
δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track give **σ ≈ 2.0%**

Moreover, C.C. may improve the spatial resolution < 100 μm for 8 mm drift cells in He based gas mixtures

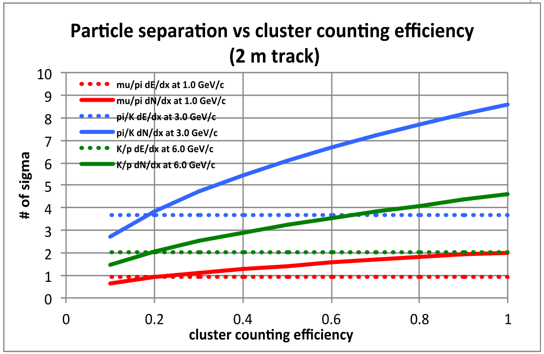
IDEA Drift Chamber simulation - Cluster Counting/Timing

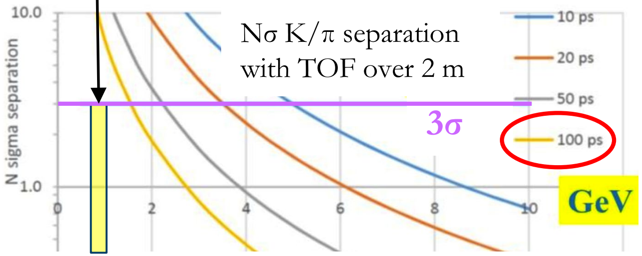
- Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)
- Could recover with timing layer

analytic evaluation, to be checked with detailed simulations and test beams


Particle Separation (dE/dx vs dN/dx)

4.3% dE/dx resolution
80% cluster counting efficiency

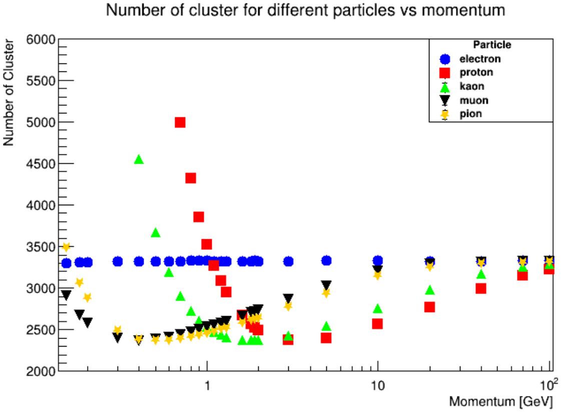

Particle separation vs cluster counting efficiency (2 m track)


Nσ K/π separation with TOF over 2 m

Drift Chamber simulation - Cluster Counting/Timing simulation

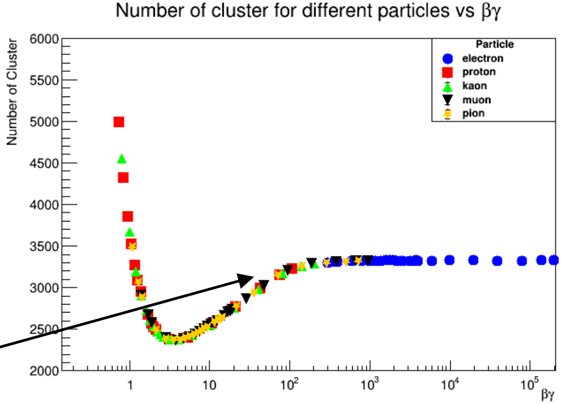
Studying the results from Garfield++ simulations, we can interpret correctly the results obtained from Geant4 simulations with the goal of reconstruct the number of clusters and the cluster size generated from different particles with different momenta passing through the tracker detector.

The goal is to extract from Garfield++ the relevant parameters to create models to convert the energy loss to cluster and then extract them as function of the primary particle βγ.



Number of cluster from Garfield++

Here the distribution of number of cluster produced by different particle at different momenta, obtained with Garfield++



Test beams are on going to measure the relativistic plateau starting position

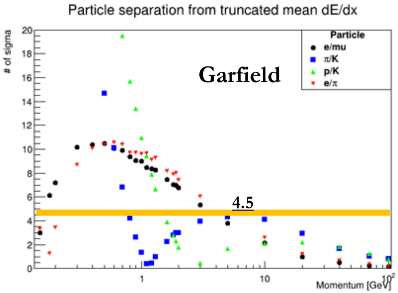
IDEA Drift Chamber simulation - Cluster Counting/Timing

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.

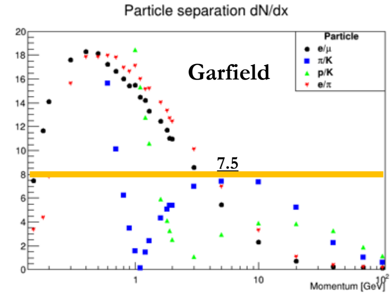
Geant4 software can simulate in details a full-scale detector, but the fundamental properties and the performances of the sensible elements have to be parameterized or an "ad hoc" physics model has to be implemented.

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.

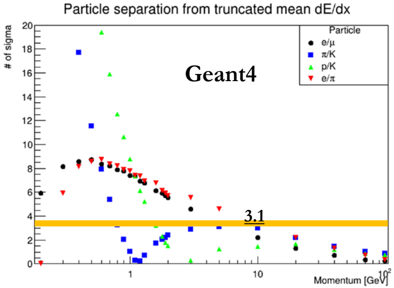
Particle separation from truncated mean dE/dx



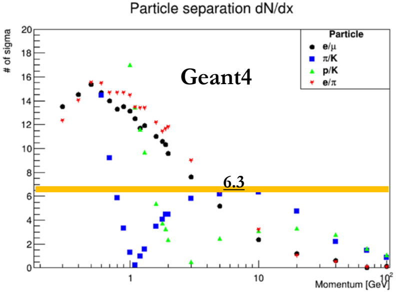
Particle separation dN/dx



Particle separation from truncated mean dE/dx



Particle separation dN/dx

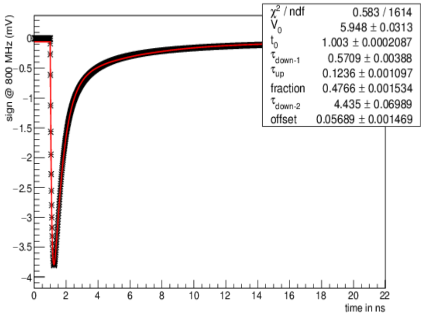


We are assuming a cluster counting efficiency of 100%.

To be ported inside the full detector simulation

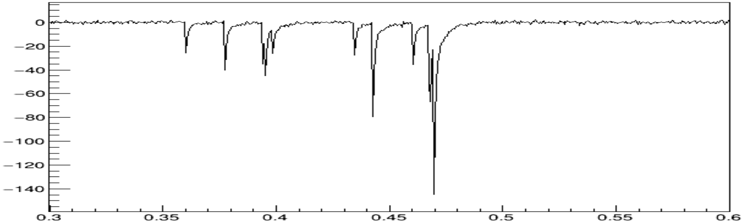
IDEA Drift Chamber simulation - Signal generation

- Generate the clusters
- Smearing the time drift using the diffusion coefficient
- Simulate the gas gain for each electrons of the clusters
- method-1:
- Transform each cluster collected charge to a signal by applying a parametric formula
- Superimpose each single signal avalanche in the acquisition time window
- Add noise and digitizing



$$a(t) = \frac{V_0}{k}\frac{\tau_{D1}+\tau_{UP}}{\tau_{UP}+\tau_{D2}}(1-e^{-(t-t_0)/\tau_{UP}})\left[\frac{R}{\tau_{D1}}e^{-(t-t_0)/\tau_{D1}}+\frac{1-R}{\tau_{D2}}e^{-(t-t_0)/\tau_{D2}}\right]$$

- method-2:
- Superimpose each single charge avalanche in the acquisition time window
- Apply the drift cell and electronics Transfer Function (using the FFT).



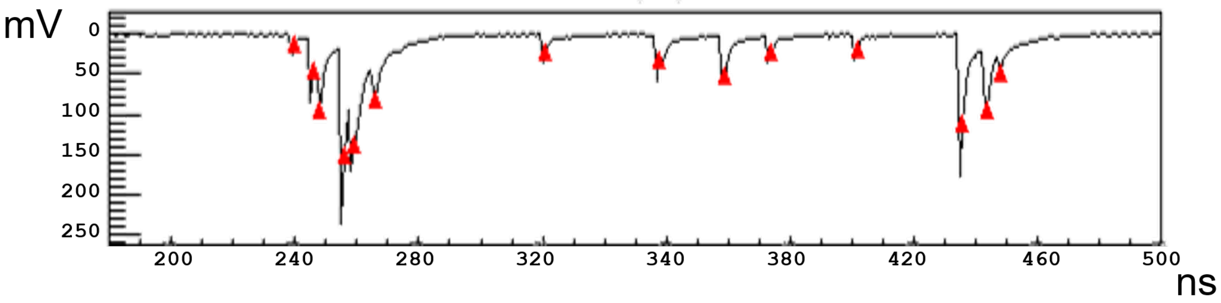
To be ported inside the full detector simulation

IDEA Drift Chamber simulation - A Peak finder algorithm

A simple peak finder algorithm, based on the first and second derivative of the digitized signal function f, is defined for each time bin i, Δb being the number of bins (signal rise time) over which the average value of f is calculated:

$$f'(i) = \frac{f(i) - \bar{f}(i - \Delta b)}{\Delta b}$$

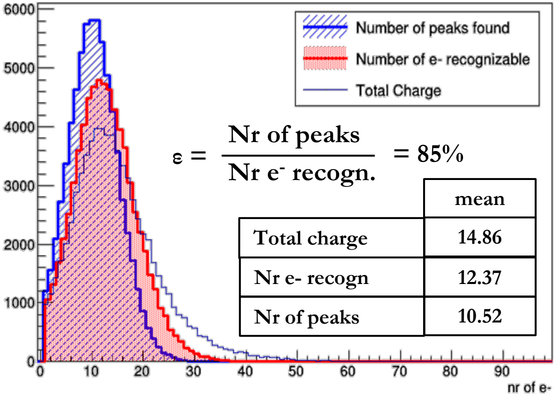
A peak (assumed to be an ionization electron) is found when Δf, f' and f'' are above a threshold level, defined according to the r.m.s. noise of the signal function f, and when the time difference with a contiguous peak is larger than the time bin resolution.



To be ported inside the full detector simulation

IDEA Drift Chamber simulation - A Peak finder algorithm

Hypothesis: an e- is recognized when its peak amplitude is over the noise threshold and the time difference with the followed is greater than time bin resolution



$$\varepsilon = \frac{\text{Nr of peaks}}{\text{Nr e}^{-}\text{ recogn.}} = 85\%$$

	mean
Total charge	14.86
Nr e- recogn	12.37
Nr of peaks	10.52

Theoretical calculation and preliminary simulation on C.C. indicates that the 80% efficiency is enough

Application of the Cluster Counting/Timing techniques to improve the performances of high transparency Drift Chamber for modern HEP experiments
Journal of Instrumentation, Volume 12 n.7 C07021
doi: 10.1088/1748-0221/12/07/C07021

To be ported inside the full detector simulation

Summary

- A Geant4 simulation of the Drift Chamber and tracking system is set and working.
- The track fitting performance of the whole system (SVX+DCH+SWR+PSHW) are compatible with the preliminary estimations
- Data output conversion to EDM4Hep has been developed
- Reasonable algorithms to simulate the Ionization Clusters by using the Geant4 data have been developed
- Some Cluster Finder algorithm are under developed (one was proved to be implemented on an FPGA and tested on a test bench)

Plans

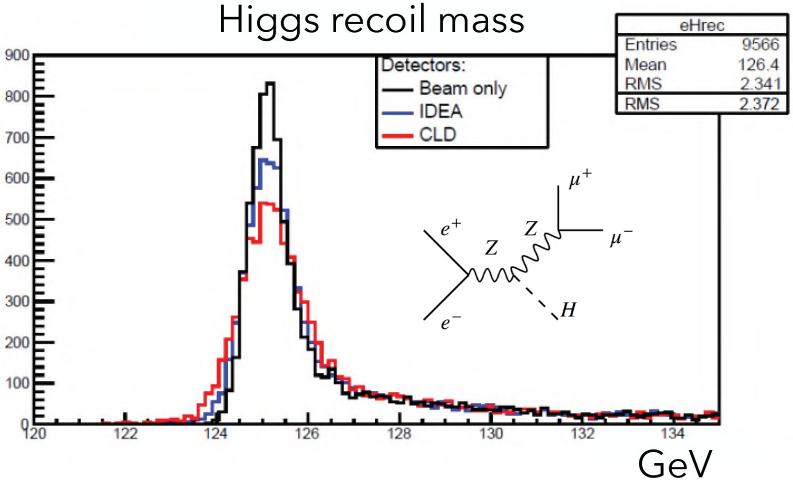
- Updates the full IDEA simulation (SVX+DCH+SWR+PSHW+DRCALO) and deliver a base version (few weeks) to:
    - Update performance studies
    - start studies with full IDEA description
- Import the Cluster Counting simulation inside the Drift Chamber simulation (~1 month)
- Import the full waveform simulation (not a priority)
- Start the implementation of the Drift Chamber in DD4Hep and in KEY4Hep (in a few months)
- …

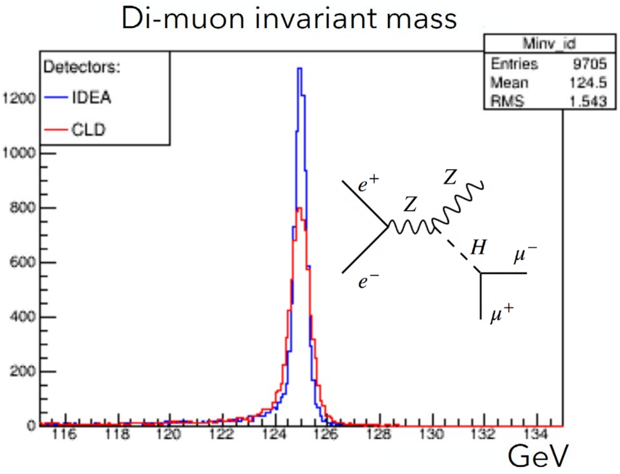
Backup

Expected simulated performance

Transparency more relevant than asymptotic resolution

Fast simulation studies


Higgs recoil mass


Di-muon invariant mass

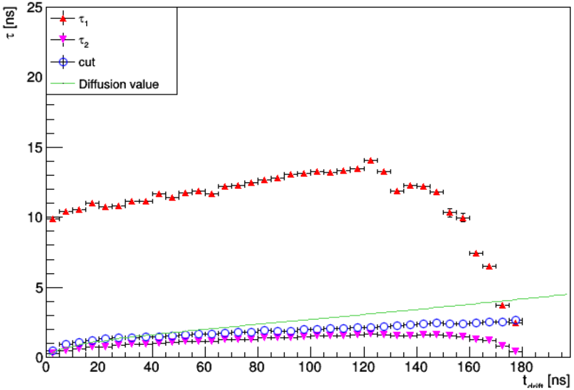
Beam only: assuming 0.136% beam spread and an ideal detector.

Event generate with Pythia8: e+e- → ZH.

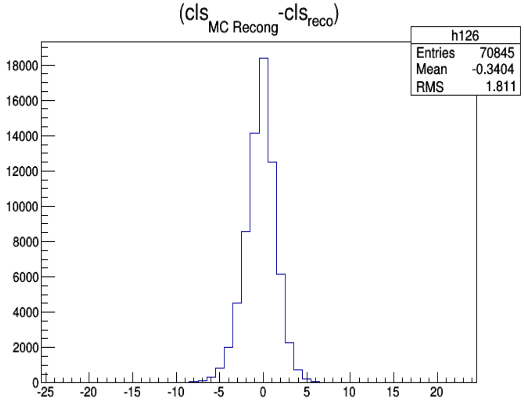
DELPHES model under test

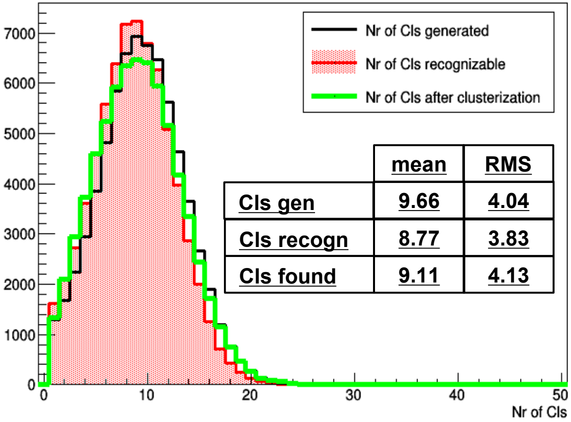
A Peak finder algorithm

The association of electrons in clusters is based on the time difference between consecutive electrons. Electrons belonging to same cluster are separated by time differences which are compatible with single electron diffusion.



Time difference between MC generated cluster and reconstructed cluster

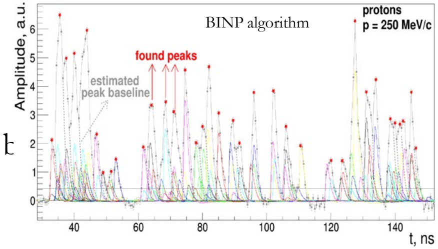


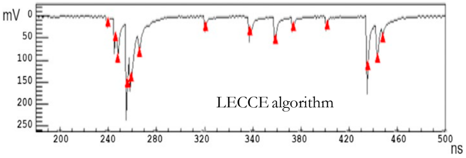


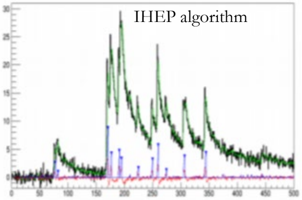
	mean	RMS
Cls gen	9.66	4.04
Cls recogn	8.77	3.83
Cls found	9.11	4.13

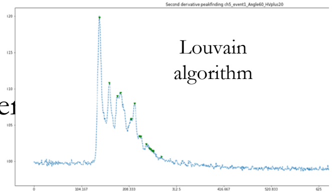
Cluster counting for particle identification: TEST BEAM

Goals







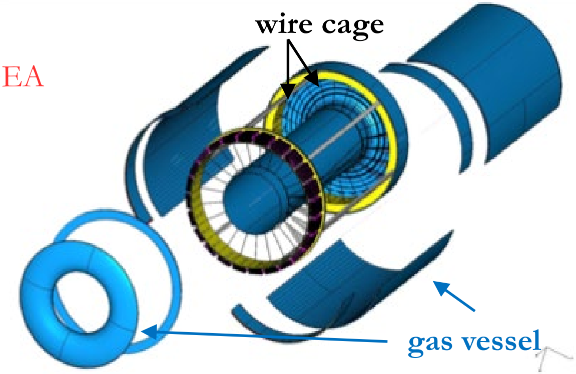


- Demonstrate the ability to count clusters:

  at a fixed βγ (e.g. muons at a fixed momentum) count the clusters b

  - the cell size (1 – 3 cm)
  - the track angle (1- 6 cm)
  - the gas mixture (90/10: 12 cl/cm, 80/20: 20 cl/cm)
- Establish the limiting parameters for an efficient cluster counting:
  - cluster density as a function of impact parameter
  - space charge (by changing gas gain, sense wire diameter, track angle)
  - gas gain stability
- In optimal configuration, measure the relativistic rise as a function of βγ, both ir dE/dx and in dNcl/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).
- Use the experimental results to fine tune the predictions on performance of cluster counting for flavor physics and for jet flavor tagging both in fast and in full simulation.

Novel approach at construction technique of high granularity and high transparency Drift Chambers



Based on the MEG-II DCH new construction technique the IDEA DCH can meet these goals:

- Gas containment – wire support functions separation:

  allows to reduce material to ≈ 10^{-3} X_0 for the inner cylinder and to a few x 10^{-2} X_0 for the end-plates, including FEE, HV supply and signal cables
- Feed-through-less wiring:

  allows to increase chamber granularity and field/sense wire ratio to reduce multiple scattering and total tension on end plates due to wires by using thinner wires
- Cluster timing:

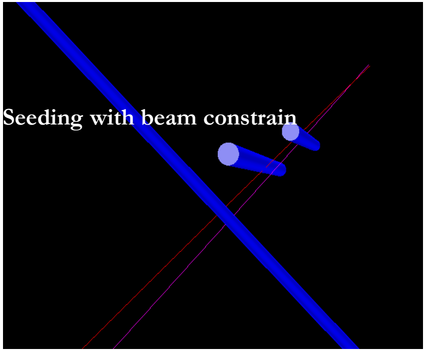
  allows to reach spatial resolution < 100 μm for 8 mm drift cells in He based gas mixtures (such a technique is going to be implemented in the MEG-II drift chamber under commissioning)
- Cluster counting:

  allows to reach dN_{cl}/dx resolution < 3% for particle identification (a factor 2 better than dE/dx as measured in a beam test)

Track finding - current IDEA PR (Local Method) (DCH only)

Seeding from 3 hits in different layers with origin constraint

- Take any 2 free hits from different stereo layers with a gap (4 or 6 layers)
- Cross Point of 2 wires give Z-coordinate (must be inside DCH volume)
- Select nearest free hits at middle (+-1) layer
- 2 hits from same stereo layer give initial angle in Rphi
- origin added with sigma Rphi~ 1mm Z ~ 1mm
- Seeds constructed for all 2x2x2=8 combination of Left-Right possibilities
- Checked that at -4 (+-1) layer are available free hits with $\chi^2 < 16$
- Extrapolate and assign any compatible hits (by χ^2) from last to first hits
- Refit segment to reduce beam constraint
- Check quality of track segment:
  - $\chi^2/NDF < 4$
  - number of hits found (>=7)
  - number of shared hits (<0.4Nfound)



Combinatory high:
local compatibility over
different layers,
+ 1 from different stereo view

Conceptual design of SCTF DCH

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SCTF drift chamber

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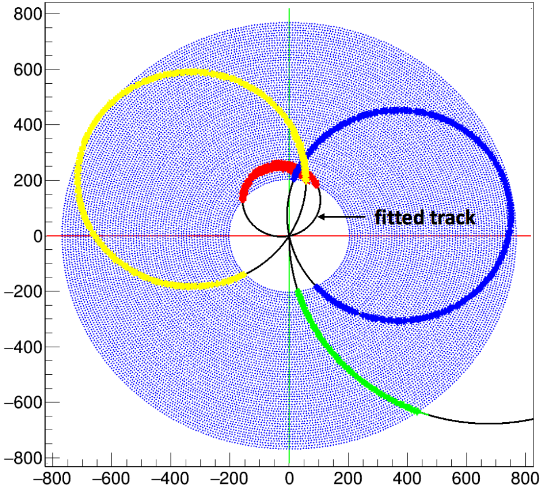
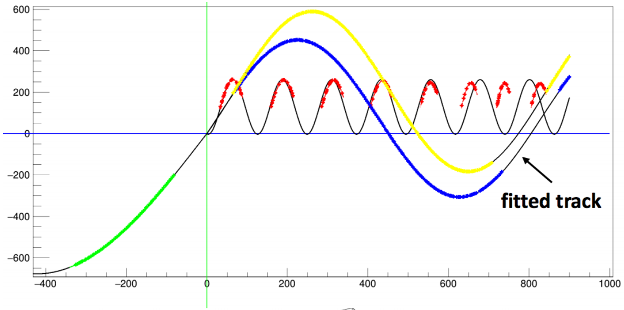
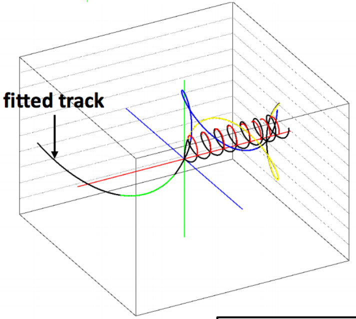
Riemann Fit PR.
Fit result on multiple tracks







Vyatcheslav Ivanov, BINP

Front-end ASIC: a two stage amplifier for cluster counting/timing

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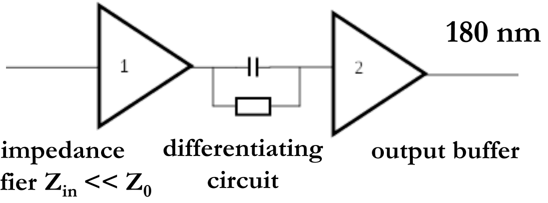
CMD-3 drift chamber

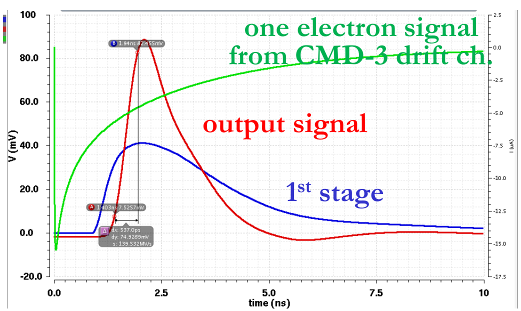


180 nm

trans-impedance amplifier $Z_{in} << Z_0$

differentiating circuit

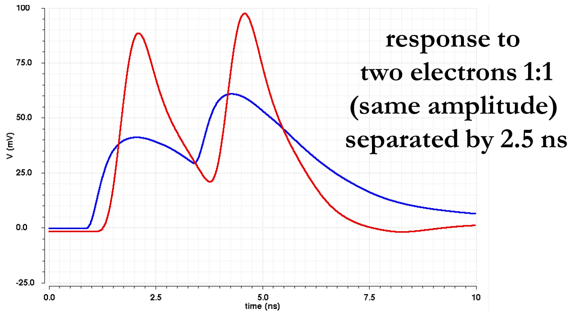
output buffer



one electron signal from CMD-3 drift ch.

output signal

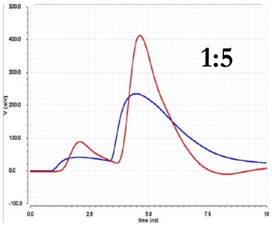
1^{st} stage



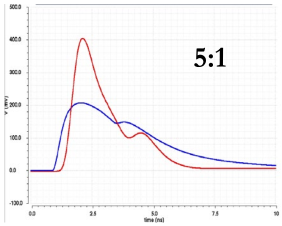
response to
two electrons 1:1
(same amplitude)
separated by 2.5 ns

Output signal parameters:

- leading edge	**0.6 ns;**
- width at the half of amplitude	**1.4 ns;**
- width at 10% of amplitude	**2.9 ns;**
- noise (RMS)	**3 mV;**
- S/N	**30.**



1:5



5:1

Front-end ASIC: a two stage amplifier for cluster counting/timing

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CMD-3 drift chamber

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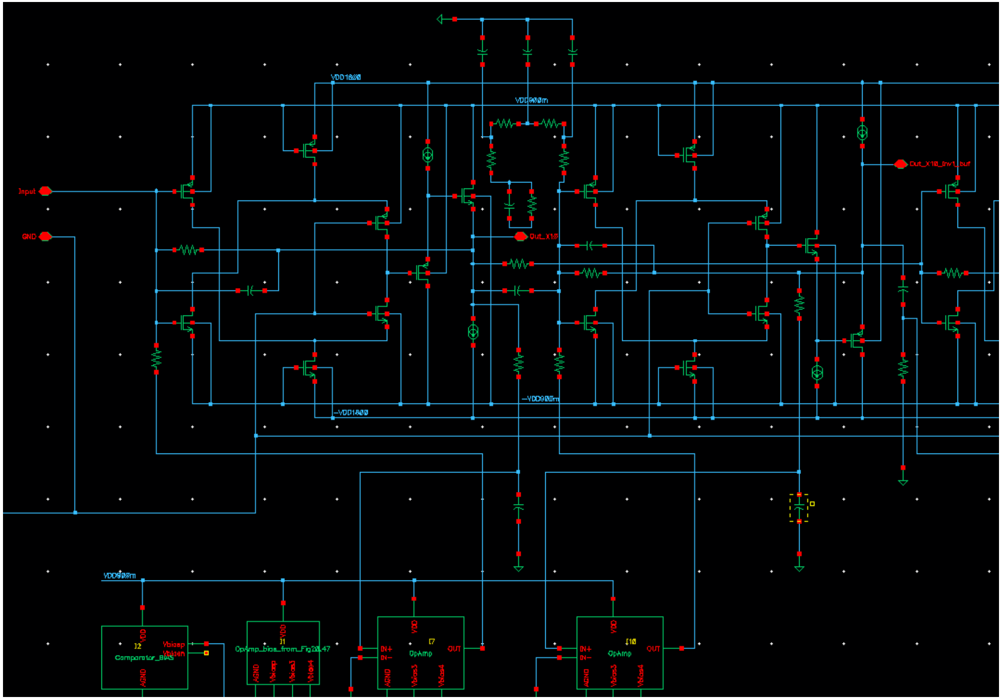

Fragment of the schematic diagram of the amplifier

Front-end ASIC: a two stage amplifier for cluster counting/timing

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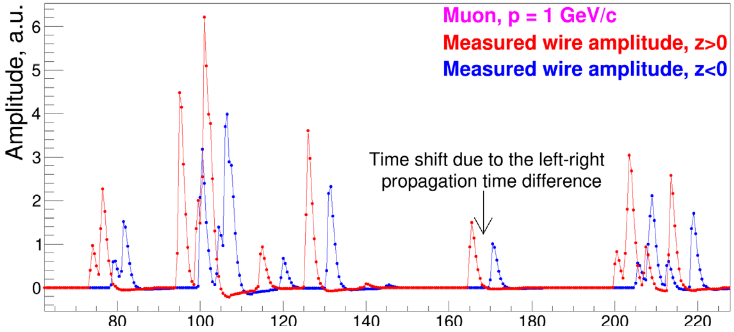
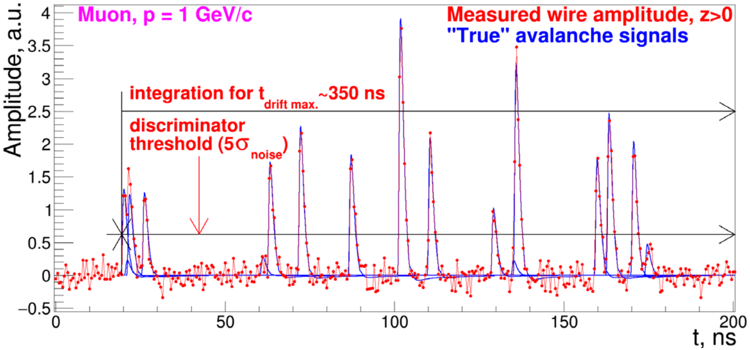
SCTF drift chamber simulation
(directly derived from **IDEA** drift chamber)

- The waveform for all wires is scanned with 2 GHz frequency (for cluster counting)
- The signal shape is provided by the V.M. Aulchenko, signal/noise ratio is estimated to be ~1/8



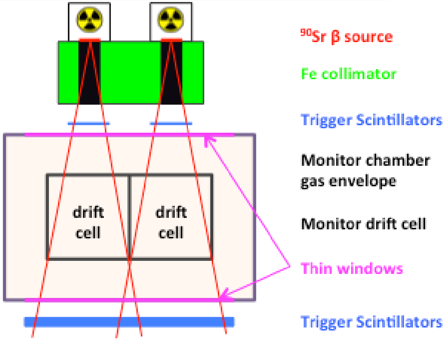
- The charge integration starts from the discriminator threshold ($5\sigma_{\text{noise}}$) crossing

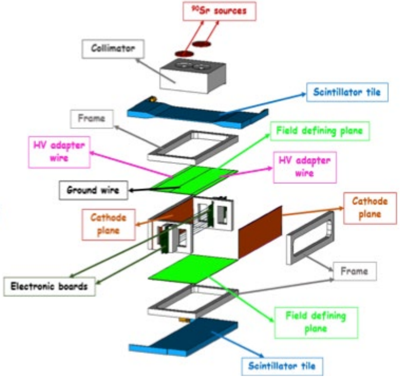


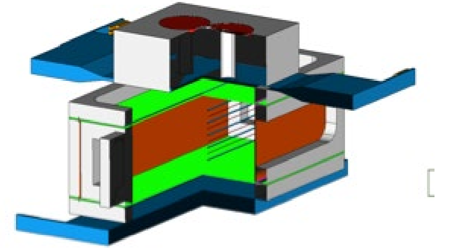
v_{drift} monitoring chamber

v_{drift} is the most sensitive parameter for the operation of a drift chamber with respect to even tiny variations of the gas mixture.

The goal of the **v_{drift} monitor chamber** is to have a prompt response (within a minute) to drift velocity trends in the gas mixture, **at the 10^{-3} level**.







$$\Delta v_{drift}/v_{drift} = \pm 1 \times 10^{-3}$$

at 1 KV/cm/bar

(v_{drift} = 2.3 cm/μs with He/iC_4H_{10} = 90/10) is equivalent to:

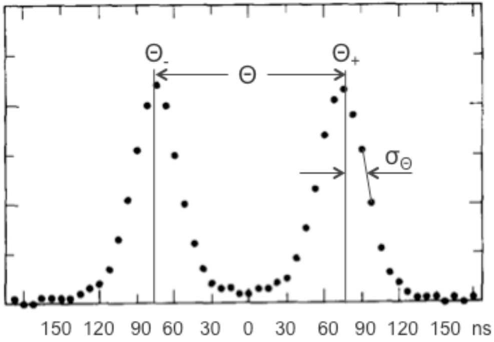
+ 0.4% in iC_4H_{10} content (from 10.0% to 10.4%)

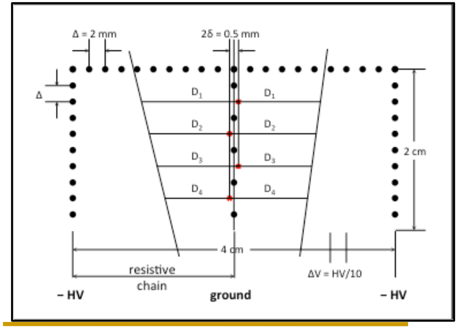
− 0.2% in iC_4H_{10} content (from 10.0% to 9.8%)

± 0.4% in E/p (≅ 6% in gas gain) at gain ≈ 5×10^5

- ± 4 V at p ≈ 1 bar, T ≈ 25° C
- − 4 mbar at V ≈ 1500 V, T ≈ 25° C
- − 0.3° C at p ≈ 1 bar, V ≈ 1500 V

+ 2% increase in H_2O vapor content at (3500 ppm)



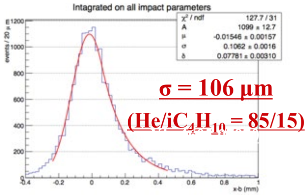


Expected performance

Machine background will be not an issue

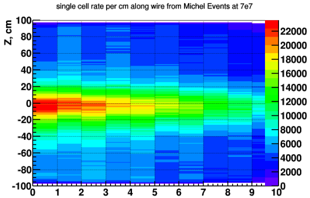
- average machine background occupancy of the DCH is ~ 0.3% (3%) per bunch crossing at 91:2 (365) GeV, in the innermost layers.
- The maximum drift time (400ns) will impose an overlap of some (20 at Z pole) bunch crossings bringing the hit occupancy to ~ 10% in the inner-most drift cells. Based on MEG-II experience, this occupancy, which allows over 100 hits to be recorded per track on average in the DCH, is deemed manageable.
- However, signals from photons can therefore be effectively suppressed at the data acquisition level by requiring that at least three ionization clusters appear within a time window of 50 ns.
- In addition, cluster signals separated by more than 100 ns are not from the same signals, this effectively bring the BXs pile-up from 20 to 4

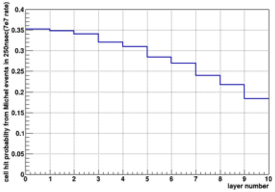
The MEG-II Drift Chamber Performance

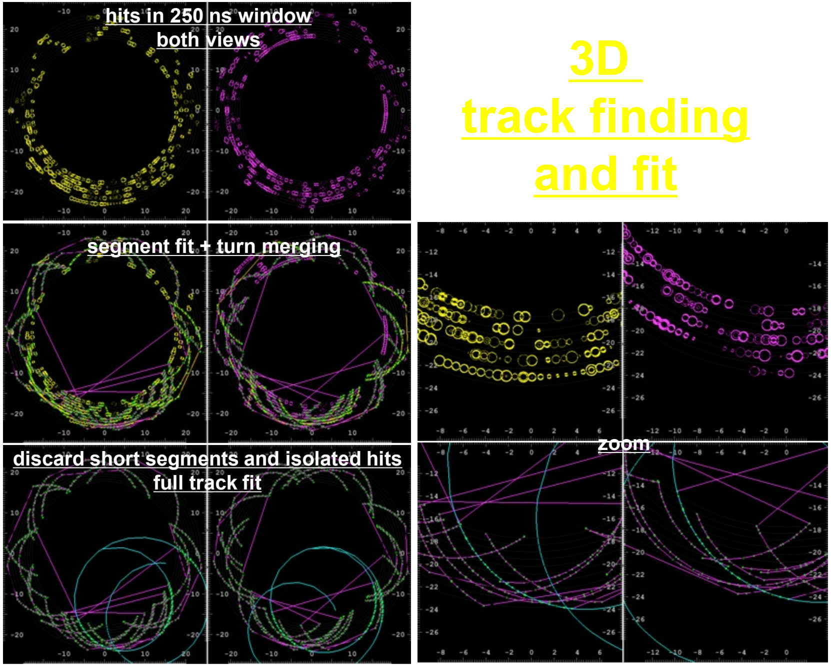


σ = 106 μm

(He/iC_4H_{10} = 85/15)







3D

track finding

and fit

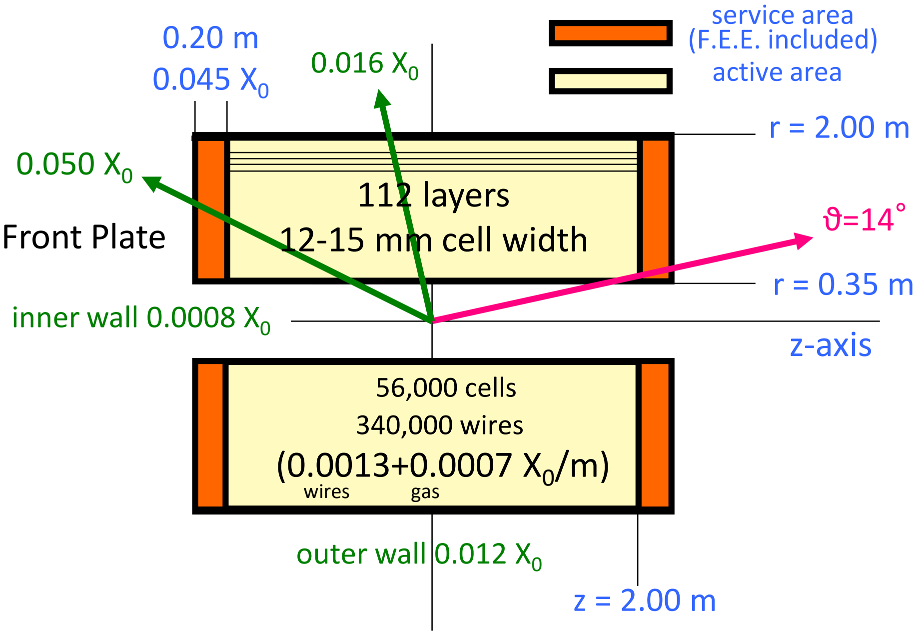
signal track

michel tracks

The IDEA drift chamber

tracking efficiency ε ≈ 1
for ϑ > 14° (260 mrad)
97% solid angle

$0.016\ X_0$ to barrel calorimeter
$0.050\ X_0$ to end-cap calorimeter



- **He based gas mixture** (90% He – 10% i-C_4H_{10})
- **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 ($N_i = 192 + (i - 1) \times 48$)

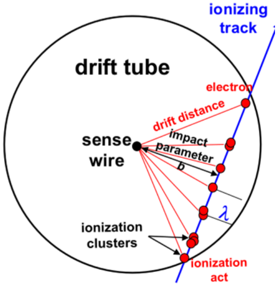
Drift Chamber simulation - Cluster Counting/Timing simulation

To investigate the potential of the Cluster Counting technique (for He based drift chamber) on physics events a reasonable simulation/parameterization of the ionization clusters generation in Geant4 is needed.

Garfield/Garfield++:

- (Heed) simulates the ionization process in the gasses (not only) in a detailed way.
- (Magboltz) computes the gas properties (drift and diffusion coefficients as function of the fields value)
- solves the electrostatic planar configuration and simulates the free charges movements and collections on the electrodes.

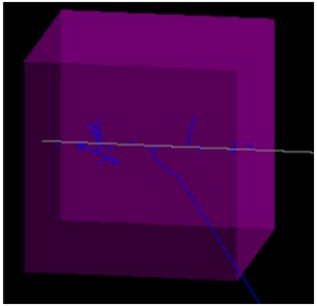
So Garfield can study and characterize the properties and performance of single cell or drift chamber with simple geometry, but is not designed to simulate a full detector neither study collider events.



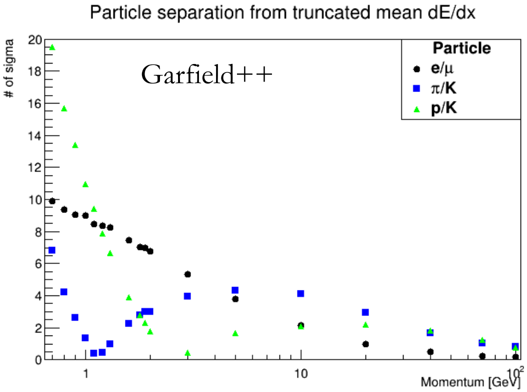
Geant4:

- Simulates the elementary particle interaction with material of a full detector
- Studies colliders events
- It doesn't simulate (normally) the ionization clustering process
- It doesn't simulate (normally) the free charges movements and collections on the electrodes.

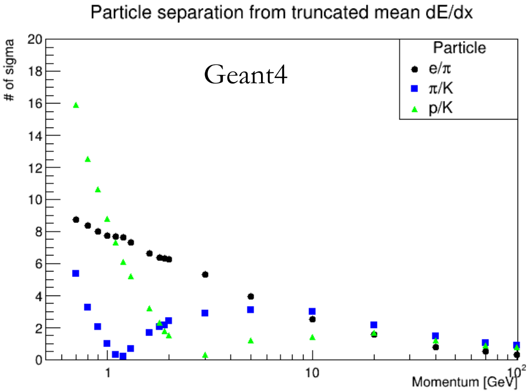
It is very useful to simulate a the elementary particle interaction with the material of a full (complex) detector and to study collider events. The fundamental properties and performance of the sensible elements (drift cells) have to be parametrized or ad-hoc physics models have to be defined.

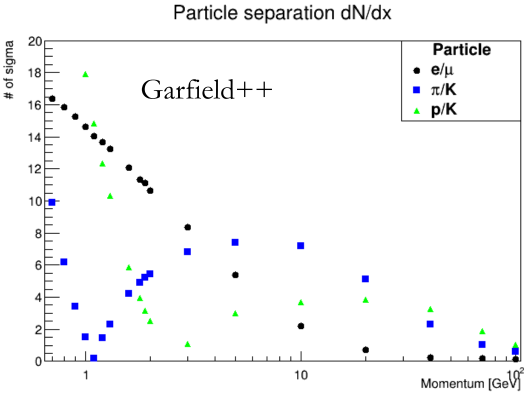


Drift Chamber simulation - Cluster Counting/Timing simulation


Particle separation from truncated mean dE/dx

Truncated mean at 70%


Particle separation from truncated mean dE/dx


Particle separation dN/dx

We are simulating 2m long tracks which pass through a 1 cm long side box of 90% He and 10% iC4H10 , with Garfield++ and Geant4

$$n_\sigma = \frac{\Delta_A - \Delta_B}{\langle \sigma_{A,B} \rangle}$$

$<\sigma_{A,B}>$ is the average of the two resolutions.

Cluster counting leads to an **improvement** on particle separation power.
As example, around 5 GeV the power separation of a pion from kaon obtained with traditional method is about 4, the one obtained with cluster counting is around 8.

Drift Chamber simulation - Cluster Counting/Timing simulation

We implemented seven different algorithms trying to reproduce the number of cluster and the cluster size.
The first step common to all algorithm is the evaluation of the total kinetic energy for cluster with cluster size higher than one (maxExEcl) event by event.

1) The first algorithm uses a reference value of the ratio between clusters containing a single electron and clusters containing more than one electron (Rt). Using the Rt value, the algorithm chooses to create cluster with cluster size one or higher. Then, it assigns the kinetic energy to each cluster by using the proper distributions. If the cluster has more than one electron, a check on the total kinetic energy is performed and its cluster size is evaluated. The procedure is repeated until the sum of primary ionization energy and kinetic energy per cluster saturate the energy loss of the event.

2) The second algorithm, if maxExEcl is higher than zero, generates the kinetic energy for clusters with cluster size higher than one by using its distribution and evaluates cluster size. This procedure is repeated until the sum of primary ionization energy and kinetic energy per cluster saturate the maxExEcl of the event.
Then, using the remaining energy (Eloss-maxExEcl), the algorithm creates clusters with cluster size equal to one by assigning their kinetic energy according to the proper distribution.
The reconstruction of clusters with cluster size equal to one remains the same for all next algorithms.

3) The third algorithm (similar to the previous), during the generation of cluster with cluster size higher than one, assigns the kinetic energy to them, choosing the best over five extractions that makes the total kinetic energy for cluster with cluster size higher than one approximating better the maxExEcl.
To correct a systematic underestimation of the mean number of clusters, an additional correction to the residual energy for generating cluster with cluster size equal to one can be used.

More details in Federica's talk:
https://indico.ihep.ac.cn/event/13845/contribution/8/material/slides/0.pdf

Drift Chamber simulation - Cluster Counting/Timing simulation

4)The fourth algorithm (similar to the previous), during the generation of cluster with cluster size higher than one, assigns (by extracting from the proper distribution) the kinetic energy to them, until the total kinetic energy better approximates the maxExEcl.

5)The fifth algorithm is similar to the fourth with almost differences in the technical implementation.

6)The sixth algorithm follows a different methodology. Indeed it uses the total kinetic energy of the event to evaluate a priori the number of cluster, applying the most likelihood criterium.

7)The last algorithm is similar to the second algorithm but generates the kinetic energy for cluster with cluster size higher than one by using the fit of kinetic energy distribution.

List of variables
maxExEcl : total kinetic energy spent to create clusters with cluster size higher than 1
ExECl : kinetic energy generated per cluster
Ncl1 : number of clusters with cluster size equal to one
Nclp : number of clusters with cluster size higher than one
maxCut : energy value equivalent to the range cut set in Geant4
totExECl : total kinetic energy reconstructed to create clusters with cluster size higher than one
Eloss : energy loss from a track passing through the cell
ClSz : cluster size
Eizp : primary ionization energy, 15.8 eV
Eizs : secondary ionization energy, 25.6 eV

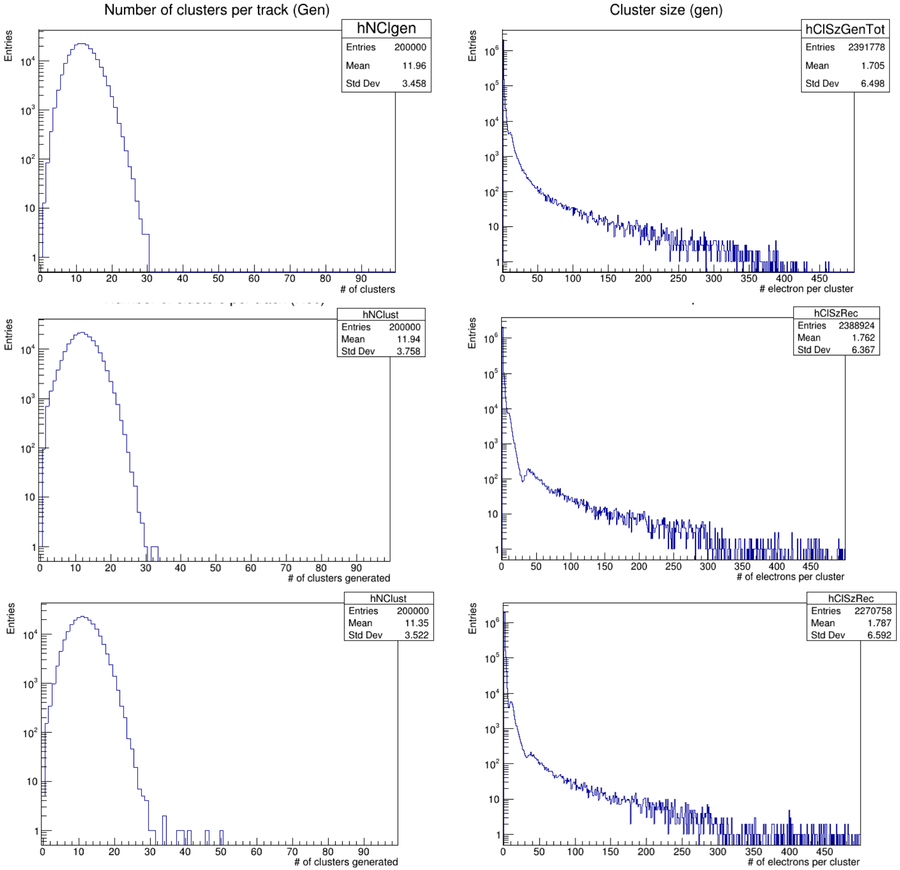
Drift Chamber simulation - Cluster Counting/Timing simulation

MC Truth

Case of study:
muon at 300 MeV

3th algorithm

6th algorithm



Drift Chamber simulation - Cluster Counting/Timing simulation

	Ncl	σNcl	Ncl1	σNcl1	Nclp	σNclp	maxNclp	eff. Nclp	ClSz	σClSz
MC. T.	**11.96**	**3.458**	**10.44**	**3.228**	**1.912**	**1.04**	**10.05**		**1.705**	**6.498**
1	14.69	6.959	12.85	6.426	2.157	1.25	13.5	1.082	1.424	5.569
2	**11.53**	**3.612**	**9.225**	**3.633**	**3.448**	**2.602**	**25.5**	**0.899**	**1.775**	**6.483**
3 (no corr.)	10.99	3.72	9.339	3.608	2.428	1.321	14.5	0.886	1.828	6.695
3 (+ corr.)	**11.94**	**3.758**	**10.25**	**3.69**	**2.429**	**1.317**	**12.5**	**0.889**	**1.762**	**6.367**
4	11.63	3.642	9.388	3.633	3.349	2.675	24.5	0.889	1.753	6.434
5	12.11	3.808	9.533	3.935	4.186	2.972	24.5	0.820	1.698	6.231
6	**11.36**	**3.525**	**9.501**	**3.511**	**2.724**	**1.311**	**12.5**	**0.886**	**1.787**	**6.67**
7	7.012	4.026	7.593	3.862	2.286	1.258	12.5	1.295	2.485	9.012

The **second** and **third** algorithms produce a number of cluster distribution, which follows the Poissonian shape and gives a mean value compatible with the one expected.

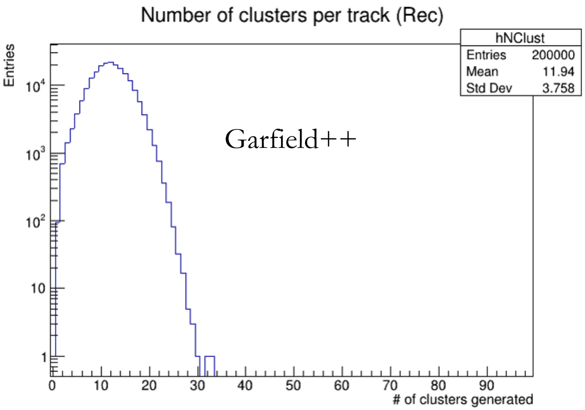
The **sixth** algorithm produces a number of cluster distribution, which follows the Poissonian shape and gives a mean value compatible with the one expected and also reconstructs a cluster size distribution whose shape is similar to the one expected.

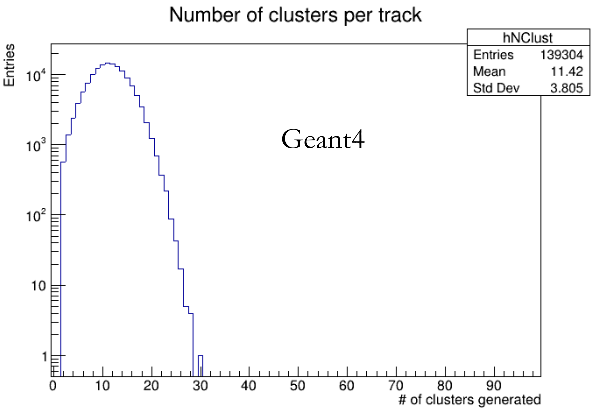
The other algorithms do not well reproduce the Poissonian shape expected for number of clusters distribution.

Drift Chamber simulation - Cluster Counting/Timing simulation

Case of study: muon at 300 MeV

Geant4 result
The algorithm is tested with Geant4 simulations and the results obtained are compatible with the ones obtained with Garfield++.

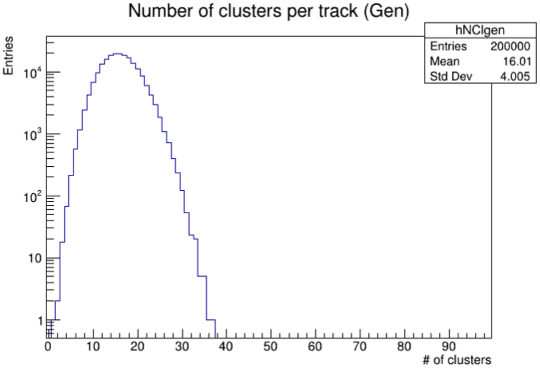


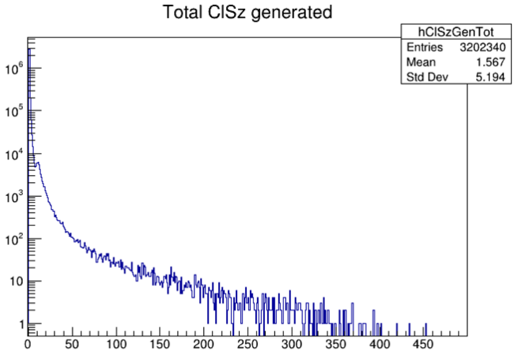


Drift Chamber simulation - Cluster Counting/Timing simulation

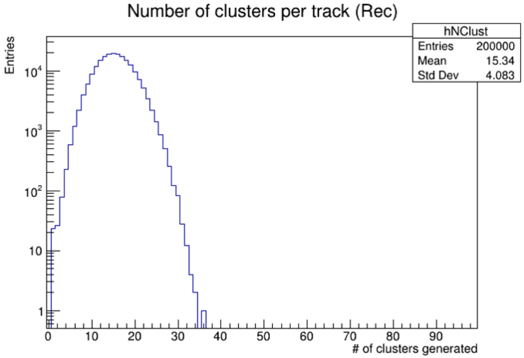
Case of study: pion at 10 GeV

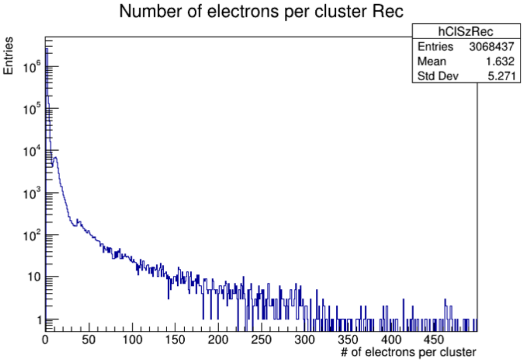
MC Truth


Number of clusters per track (Gen)


Total ClSz generated

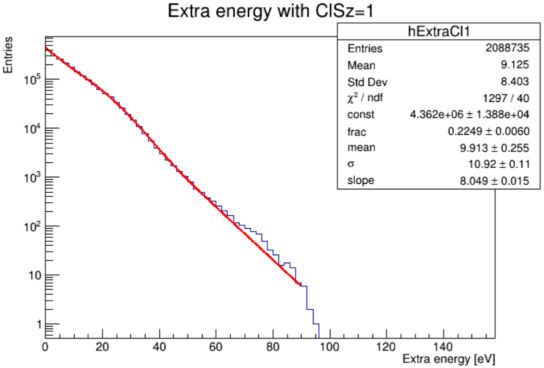
6th algorithm


Number of clusters per track (Rec)


Number of electrons per cluster Rec

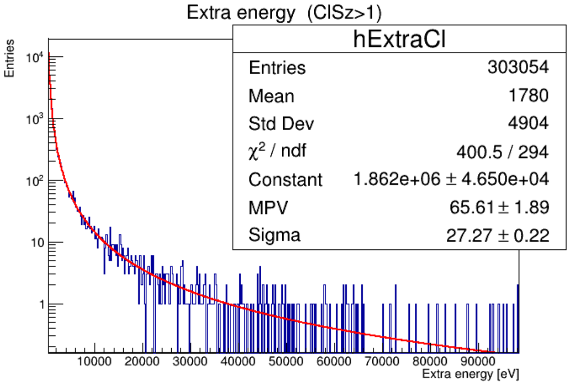
Drift Chamber simulation - Cluster Counting/Timing simulation

Kinetic energy distribution for cluster with cluster size equal to 1. The fit is the sum of an exponential function plus a Gaussian function.

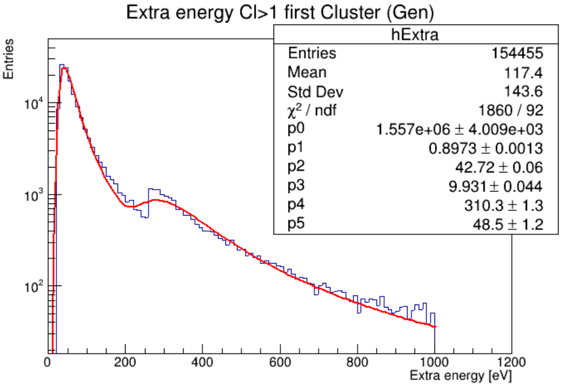


hExtraCl1	
Entries	2088735
Mean	9.125
Std Dev	8.403
χ^2 / ndf	1297 / 40
const	4.362e+06 ± 1.388e+04
frac	0.2249 ± 0.0060
mean	9.913 ± 0.255
σ	10.92 ± 0.11
slope	8.049 ± 0.015

Kinetic energy distribution for cluster with cluster size higher than 1 (left) and up to 1keV cut (right). The fits are performed with a Landau functions.



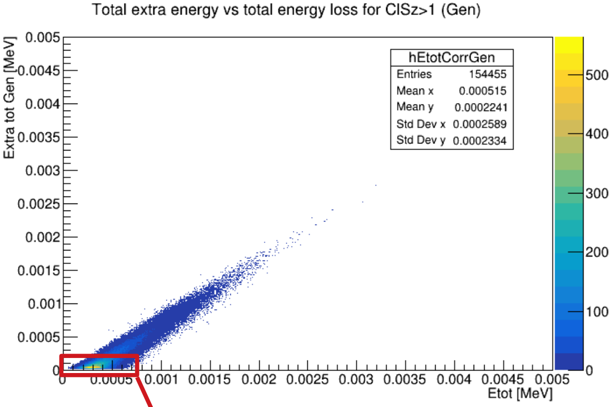
hExtraCl	
Entries	303054
Mean	1780
Std Dev	4904
χ^2 / ndf	400.5 / 294
Constant	1.862e+06 ± 4.650e+04
MPV	65.61 ± 1.89
Sigma	27.27 ± 0.22

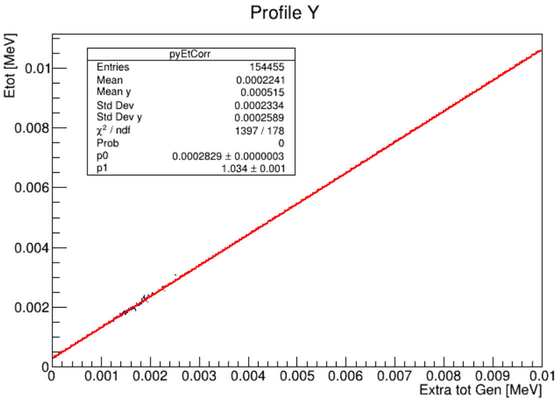


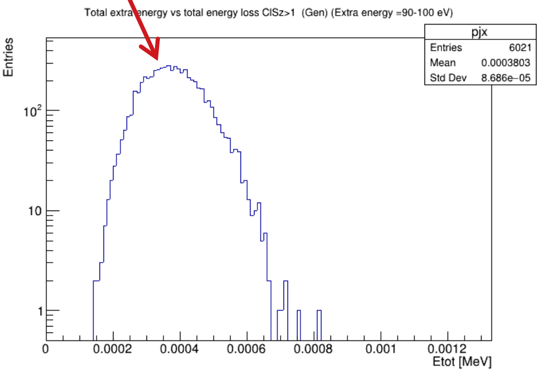
hExtra	
Entries	154455
Mean	117.4
Std Dev	143.6
χ^2 / ndf	1860 / 92
p0	1.557e+06 ± 4.009e+03
p1	0.8973 ± 0.0013
p2	42.72 ± 0.06
p3	9.931 ± 0.044
p4	310.3 ± 1.3
p5	48.5 ± 1.2

1keV cut is equivalent to the single interaction range cut set (by default) in Geant4

Drift Chamber simulation - Cluster Counting/Timing simulation







maxExEcl=(Etot-maxEx0+gRandom→Gaus(0,ExSgm))/maxExSlp
MaxEx0 is the first parameter of the linear fit
MaxExSlp is the second parameter of linear fit
ExSgm is the average of the sigma of each point in the correlation trend.

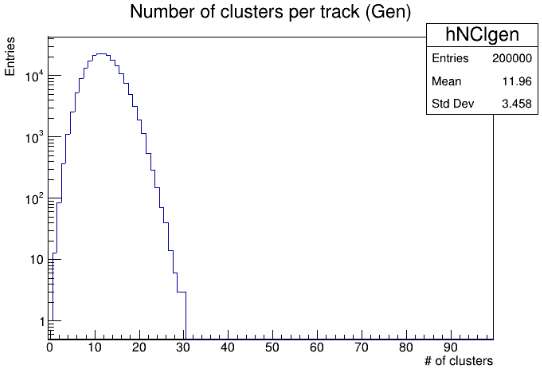
$$maxExECl = \frac{(Etot - maxEx0 + gRandom \rightarrow Gaus(0, ExSgm))}{maxExSlp}$$

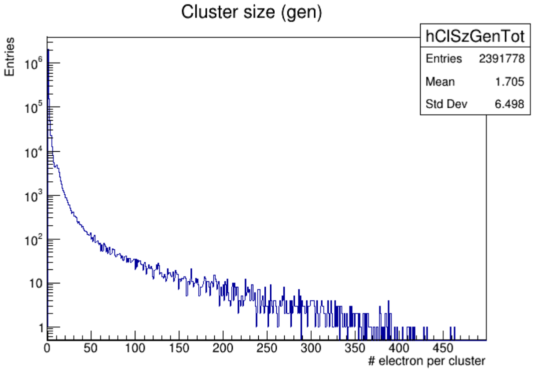
The figure shows an example of distribution of total energy loss for extra energy between 90 and 100 eV for cluster with cluster size higher than one.

Drift Chamber simulation - Cluster Counting/Timing simulation

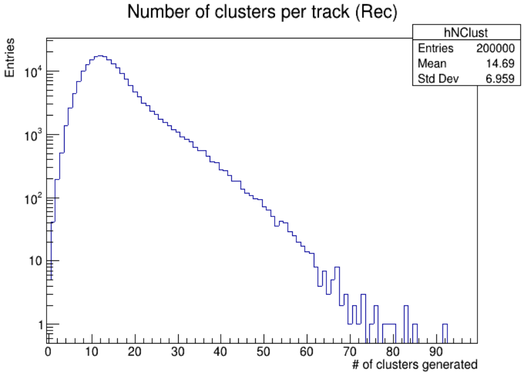
Case of study: muon at 300 MeV

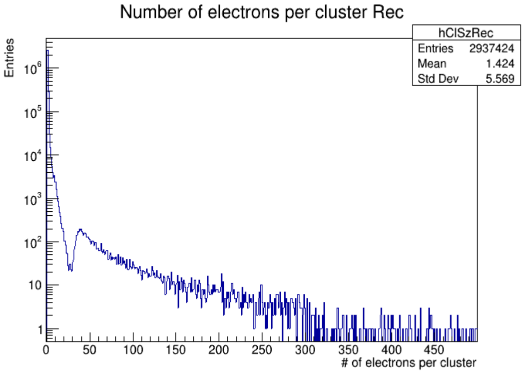
MC Truth





1st algorithm





IDEA DCH geometry (simulation)

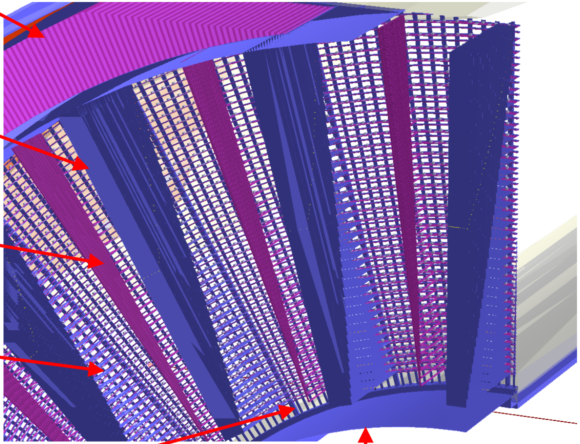
Electronics boards: 12 cm x 6 cm x 3mm G10 (FR4);

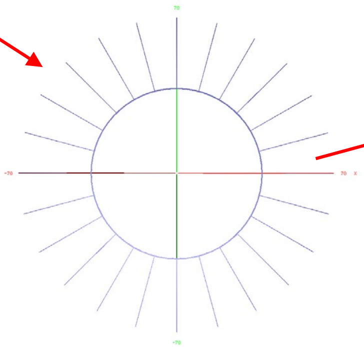
signal cables:
2.032 cm x 25 µm Kapton
+ 40 µm 16 pairs of Copper wires;

HV cables:
500 µm Copper wire
+ 500 µm Teflon insulation;

Wire anchoring (see next slide);

Carbon fiber wire support.



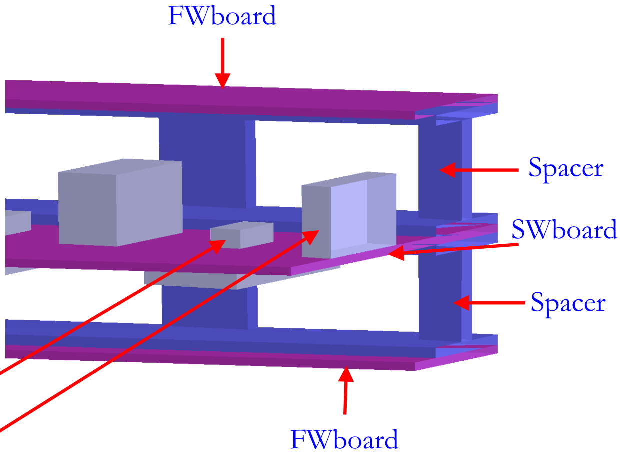


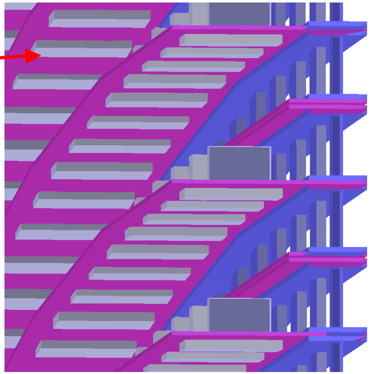
Connecting ring is described as a circular layer:
0.5 cm x 1.5 cm Carbon fiber

IDEA DCH geometry (simulation)

The wire anchoring system:

- Field wire board: 4 mm x 200 μm G10(FR4);
- Spacer: made of polycarbonate,
  instead of holes it is drawn with spokes but with the same area ratio.
- Sense wire board: 1 cm x 200 μm G10(FR4) plus components:
  1) termination resistance: 1.6 mm x 800 μm x 450 μm Aluminum;
  2) HV Capacitance: 3.17 mm x 1.57 mm x 1.7 mm Aluminum;
  3) HV resistance (only downstream): 5 mm x 2.5 mm x 550 μm Aluminum.



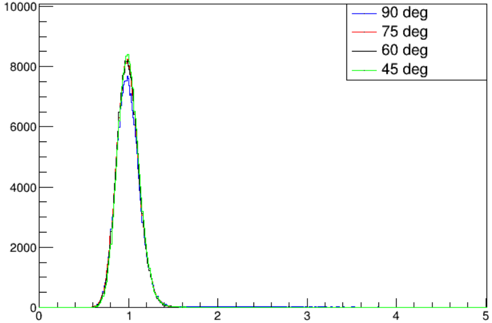


IDEA – layout v1 – Expected tracking performance

χ^2 /ndof

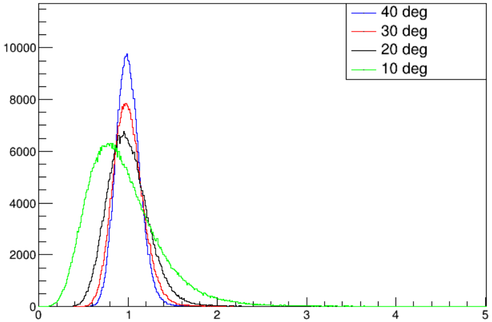
BARREL:

Reconstructed Tracks Chi2 over nDof



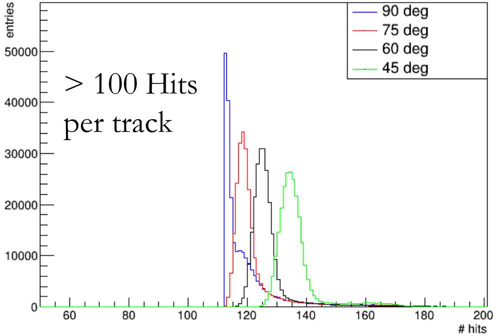
FORWARD:

Reconstructed Tracks Chi2 over nDof



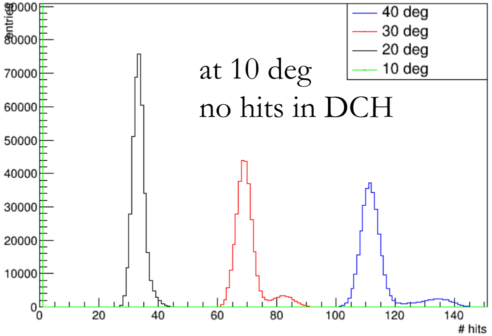
N hits fitted (DCH)

Number of dch hits per tracks



> 100 Hits per track

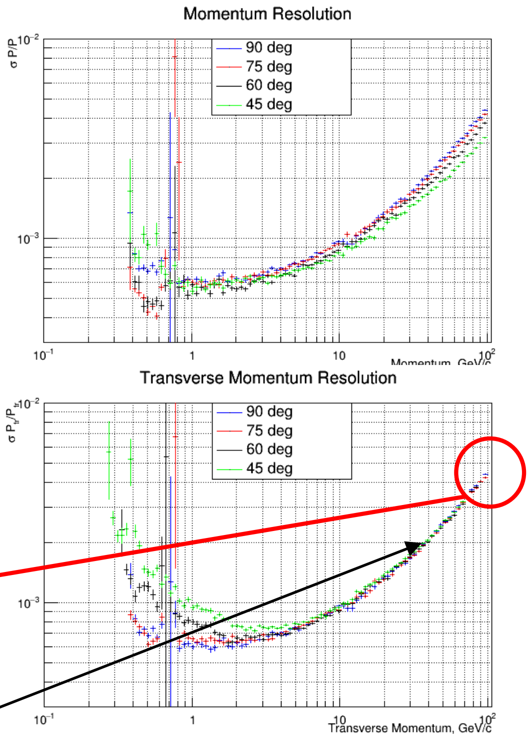
Number of dch hits per tracks



at 10 deg no hits in DCH

IDEA – layout v1 – Expected tracking performance

BARREL:



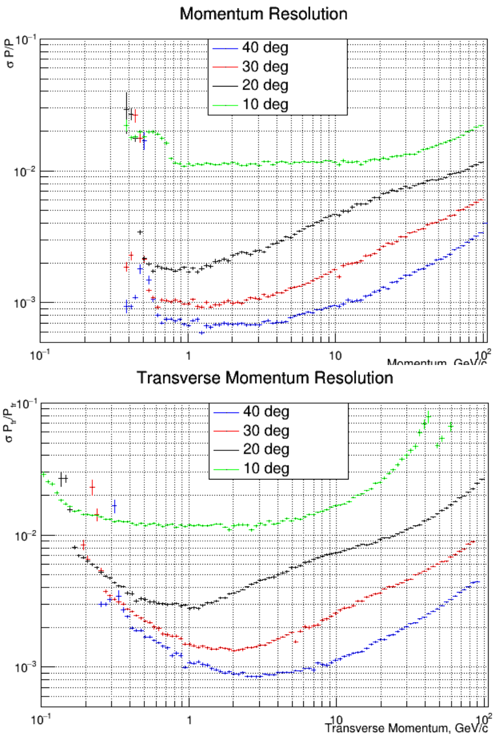
p

p_t

$$\frac{\sigma_{p_t}}{p_t^2} = 4 \bullet 10^{-5}$$

$$\frac{\sigma_{p_t}}{p_t^2} = 5 \bullet 10^{-5}$$

FORWARD:



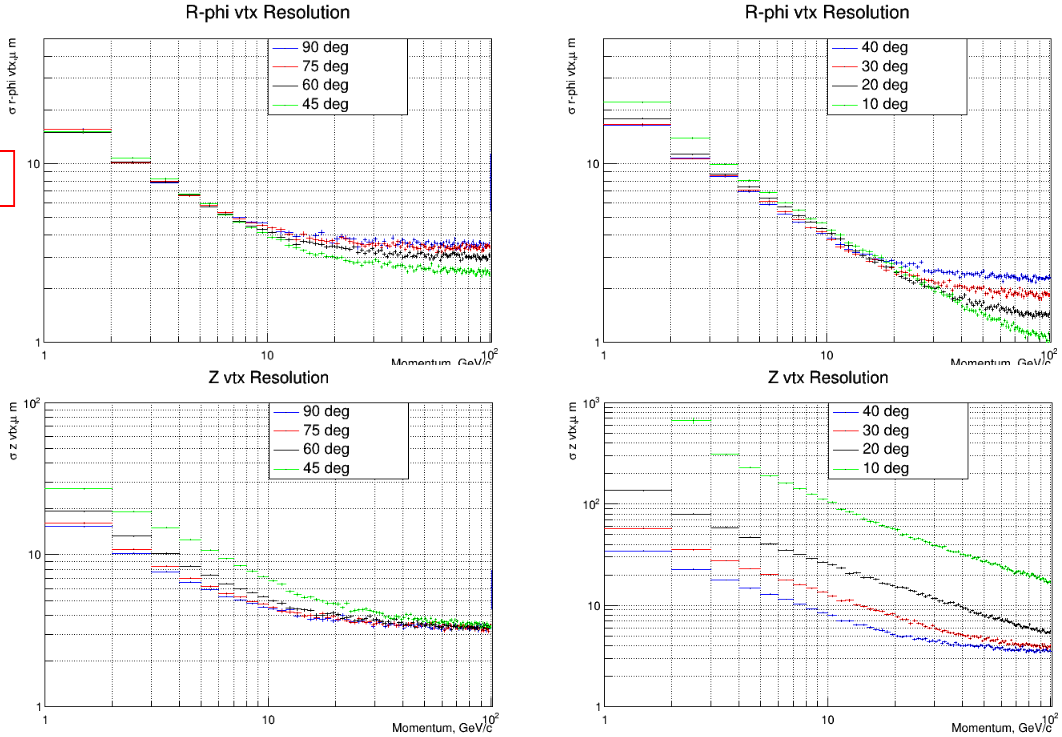
IDEA – layout v1 – Expected tracking performance

BARREL:

FORWARD:

impact parameter

Z



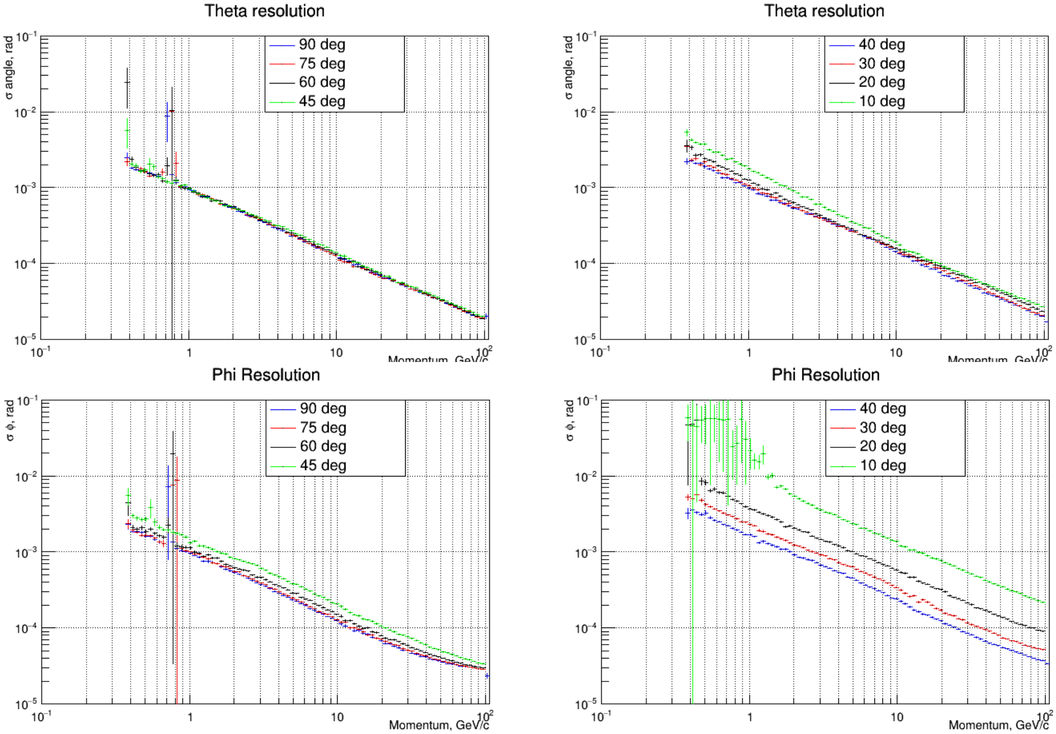
IDEA – layout v1 – Expected tracking performance

BARREL:

FORWARD:

theta

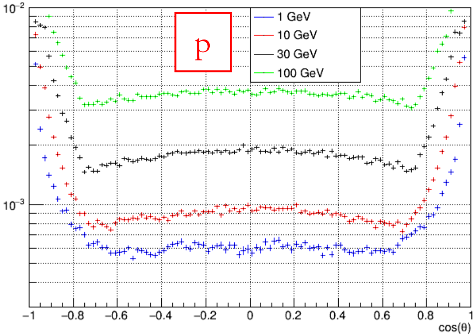
phi

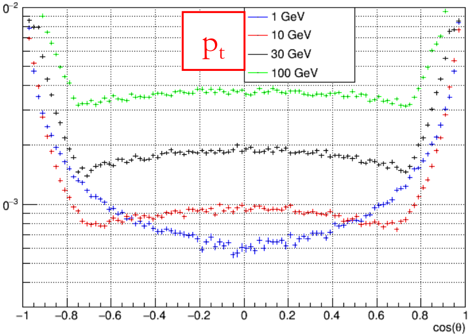


IDEA tracking system – Expected tracking performance (single muon as function of ϑ)

base line option

momentum resolution:





angular vertex resolution: