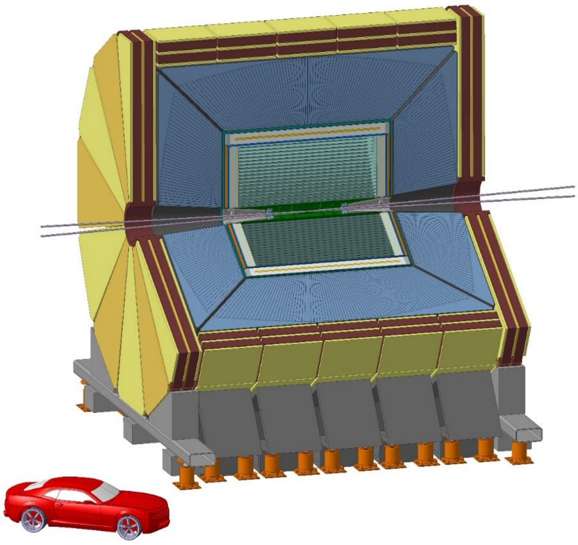
DCH full simulation and full IDEA description integration

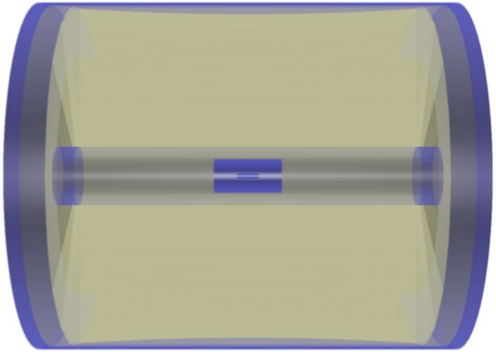


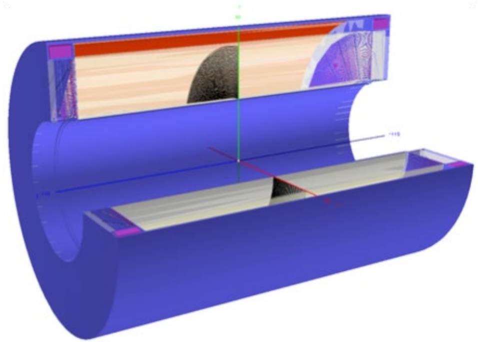
G.F. Tassielli,
F. Cuna, N. De Filippis, W. Elmetenawee, L. Lavezzi

Outline

- Drift Chamber simulation
  - Review geometry and reconstruction status
  - Cluster Counting/Timing simulation
- Integration with the Calorimeter
- Summary and Plans

Drift Chamber simulation - Review geometry and reconstruction status



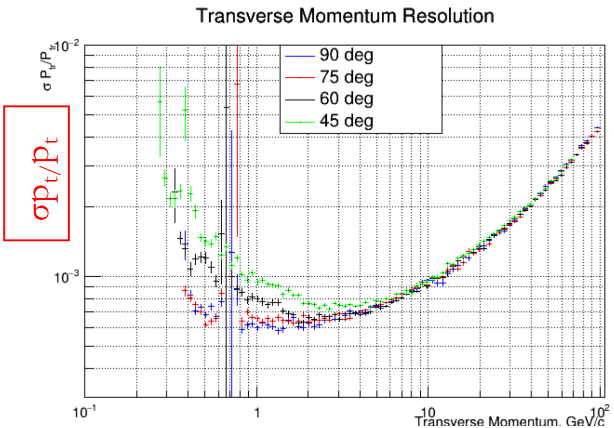


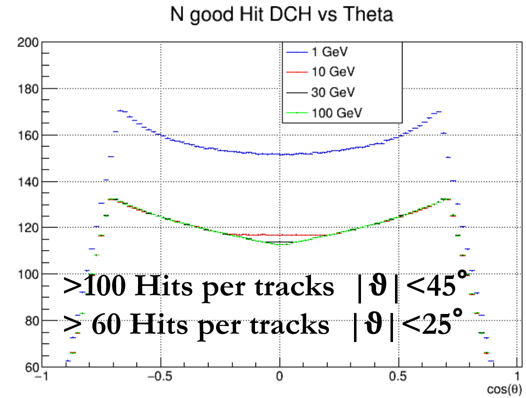
- A full geant4 simulation of the IDEA tracking system was developed to test the tracking performance
- The **DCH** is simulated at a good level of geometry details, including detailed description of the endcaps;
- **SVX** and **Si wrapper** and **PSHW** are simulated as simple
layer or overall equivalent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

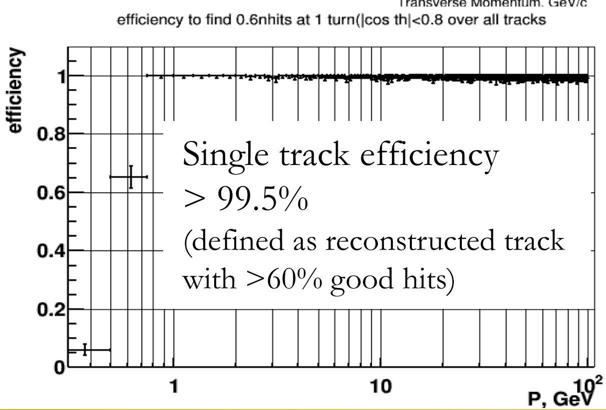
More details in: G. Tassielli: "Tracking performance with the updated geometry of the IDEA detector ", 11th FCC-ee workshop, CERN, January 2019"
N. A. Tehrani: "Simulation and tracking studies for a drift chamber at the FCC-ee experiment", CERN-ACC-2019-0043

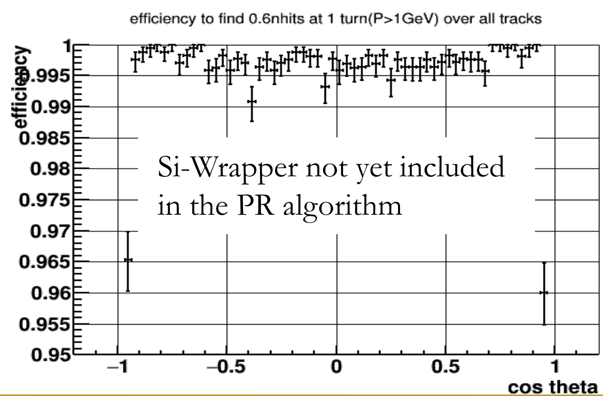
Drift Chamber simulation - Review geometry and reconstruction status

assumed: $\sigma_d = 100\ \mu m$ and (conservative for Si) $\sigma_{Si} = \text{pitch}/\sqrt{12}\ \mu m$



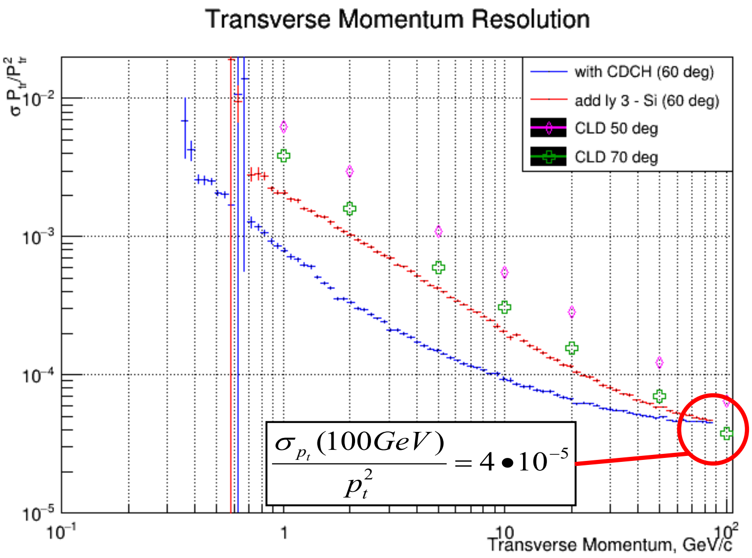






Drift Chamber simulation - Review geometry and reconstruction status

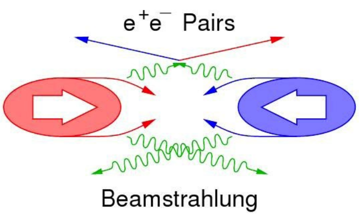
Transparency more relevant than asymptotic resolution, the particle range is far from the asymptotic limit where MS is negligible.



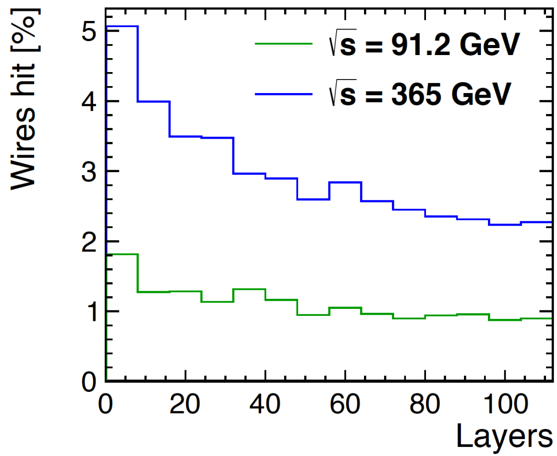
CLD: a detector concept for FCC-ee with a full Si-tracker system, inspired by CLIC detector.

Drift Chamber simulation - Review geometry and reconstruction status

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



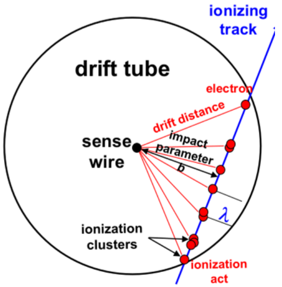
Drift Chamber simulation - Cluster Counting/Timing simulation

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.

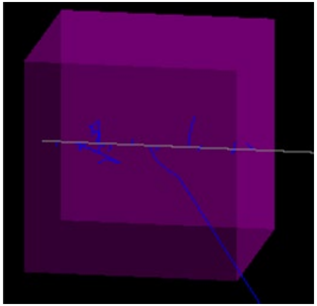
So Garfield can study and characterize the properties and performance of single cell or drift chamber with simple geometry, but is not designed to simulate a full detector neither study collider events.



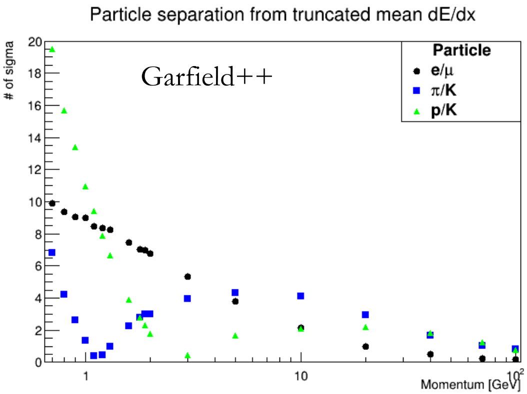
Geant4:

- 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.

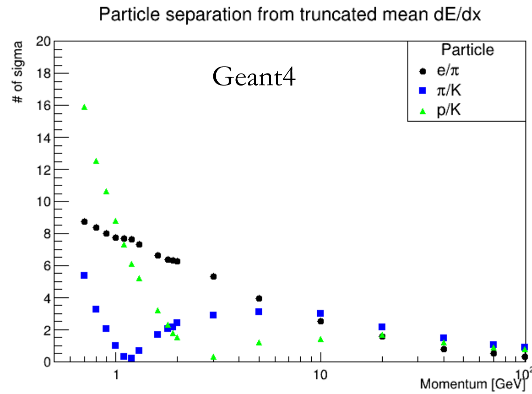
It is very useful to simulate a the elementary particle interaction with the material of a full (complex) detector and to study collider events. The fundamental properties and performance of the sensible elements (drift cells) have to be parametrized or ad-hoc physics models have to be defined.

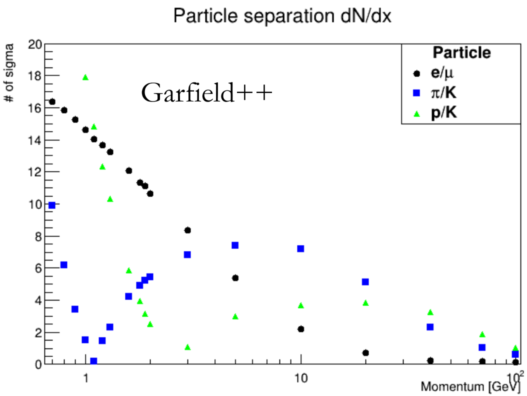


Drift Chamber simulation - Cluster Counting/Timing simulation



Truncated mean at 70%





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

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

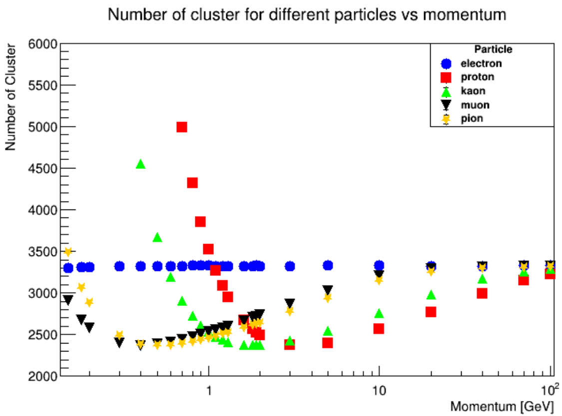
$<\sigma_{A,B}>$ is the average of the two resolutions.

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

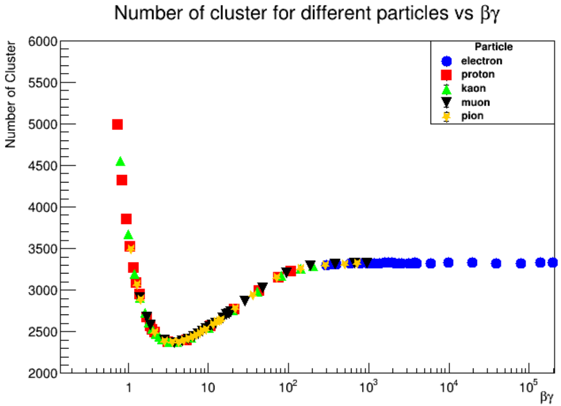
Studying the results from Garfield++ simulations, we can interpret correctly the results obtained from Geant4 simulations with the goal of reconstruct the number of clusters and the cluster size generated from different particles with different momenta passing through the tracker detector.

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 $\beta\gamma$.



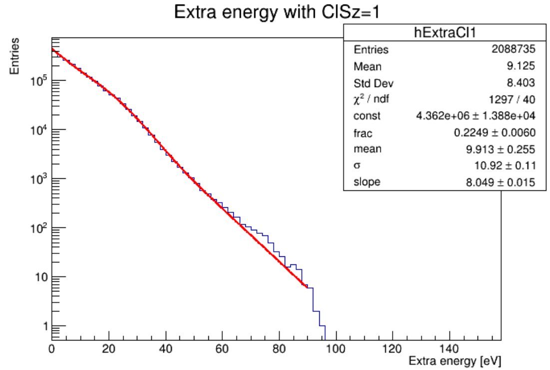
Number of cluster from Garfield++

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

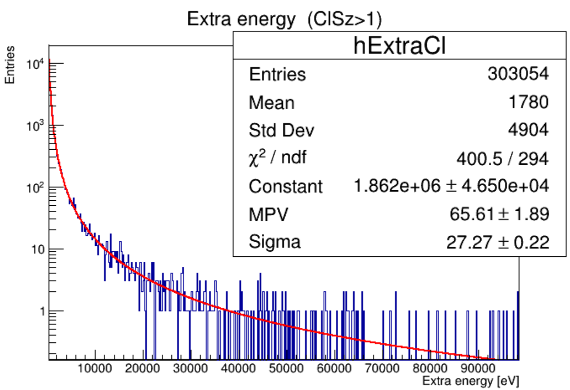


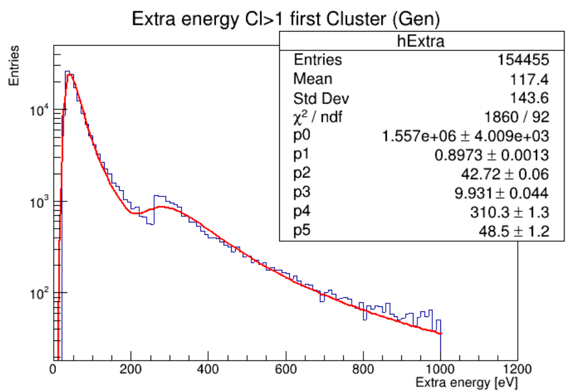
Drift Chamber simulation - Cluster Counting/Timing simulation

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



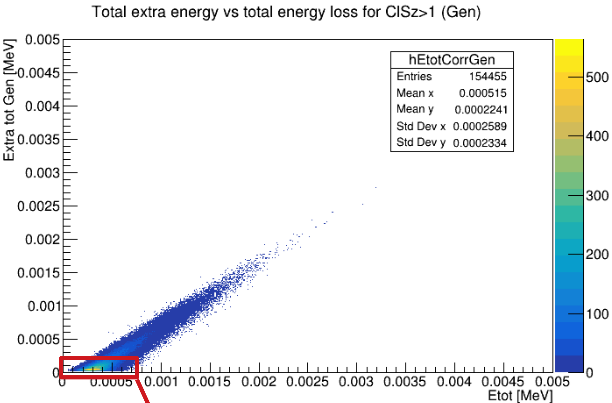
Kinetic energy distribution for cluster with cluster size higher than 1 (left) and up to 1keV cut (right). The fits are performed with a Landau functions.

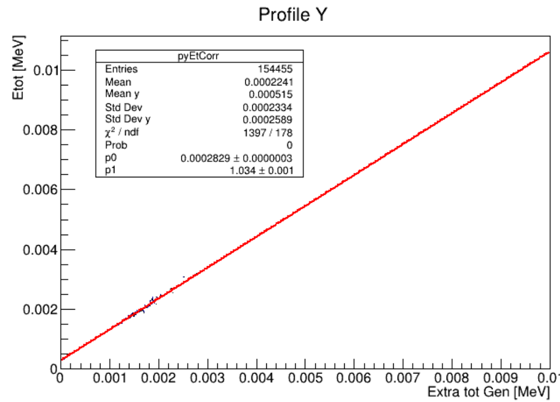


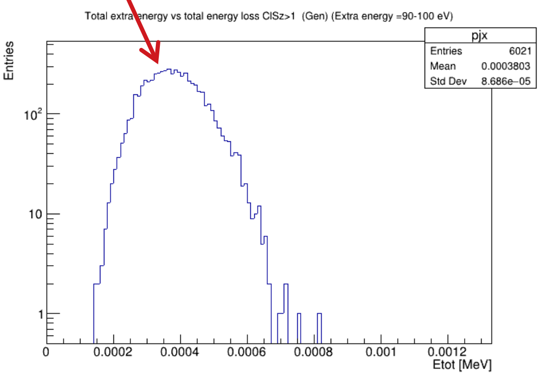


1keV cut is equivalent to the single interaction range cut set (by default) in Geant4

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.

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

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

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.

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.

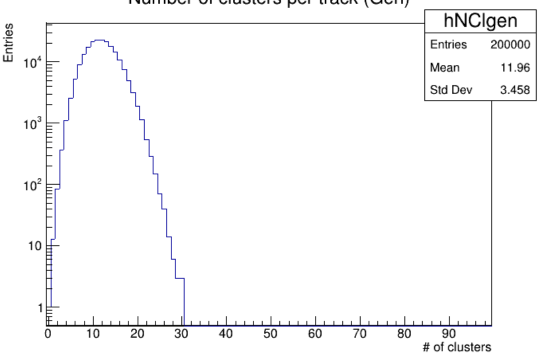
7)The last algorithm is similar to the second algorithm but generates the kinetic energy for cluster with cluster size higher than one by using the fit of kinetic energy distribution.

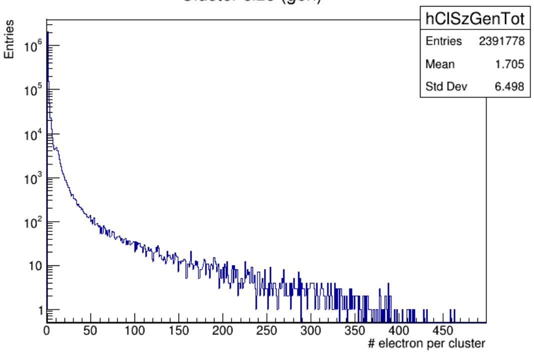
List of variables
maxExEcl : total kinetic energy spent to create clusters with cluster size higher than 1
ExECl : kinetic energy generated per cluster
Ncl1 : number of clusters with cluster size equal to one
Nclp : number of clusters with cluster size higher than one
maxCut : energy value equivalent 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

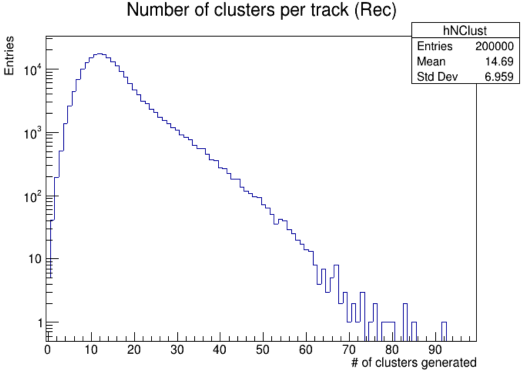
Case of study: muon at 300 MeV

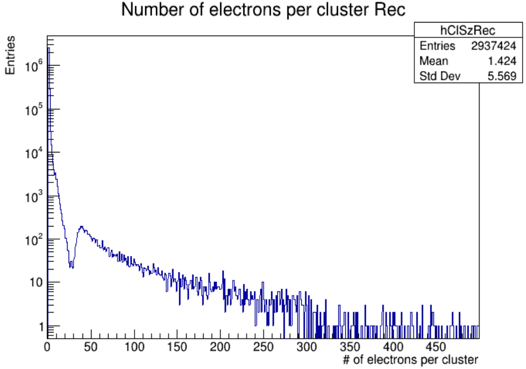
MC Truth





1st algorithm

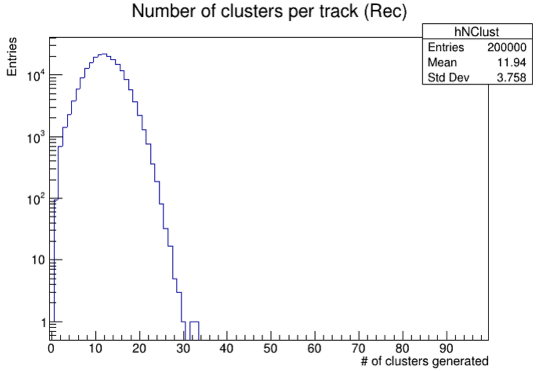


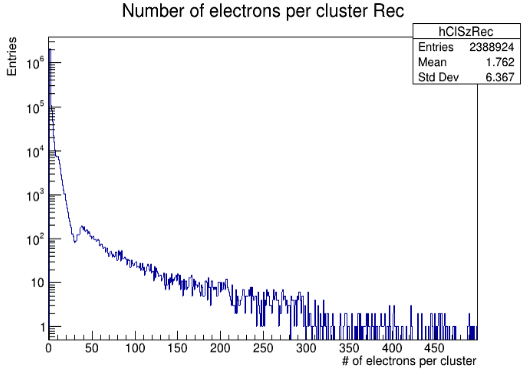


Drift Chamber simulation - Cluster Counting/Timing simulation

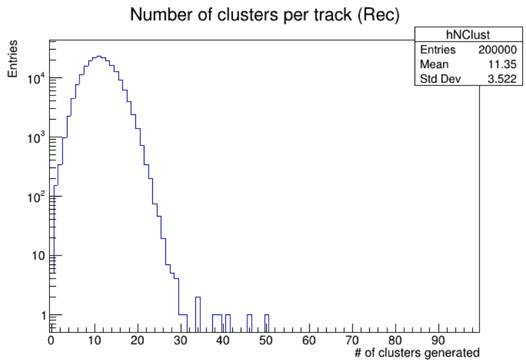
Case of study: muon at 300 MeV

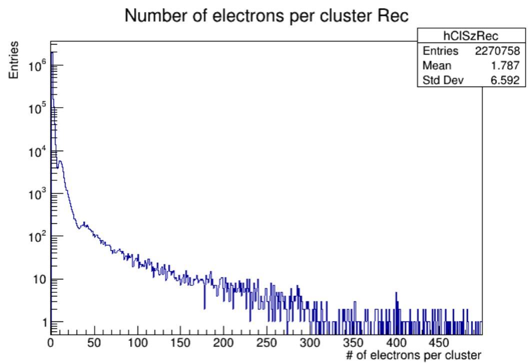
3th algorithm





6th algorithm





Drift Chamber simulation - Cluster Counting/Timing simulation

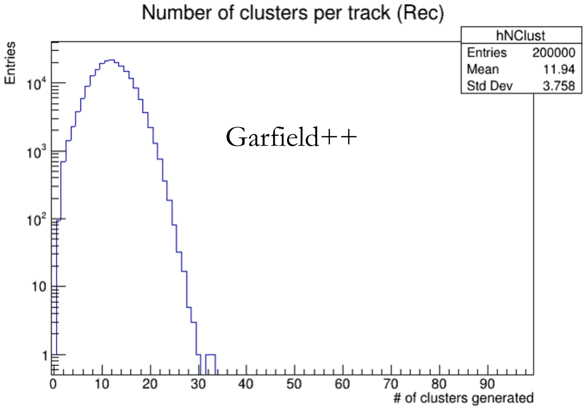
	Ncl	σNcl	Ncl1	σNcl1	Nclp	σNclp	maxNclp	eff. Nclp	ClSz	σClSz
MC. T.	**11.96**	**3.458**	**10.44**	**3.228**	**1.912**	**1.04**	**10.05**		**1.705**	**6.498**
1	14.69	6.959	12.85	6.426	2.157	1.25	13.5	1.082	1.424	5.569
2	**11.53**	**3.612**	**9.225**	**3.633**	**3.448**	**2.602**	**25.5**	**0.899**	**1.775**	**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

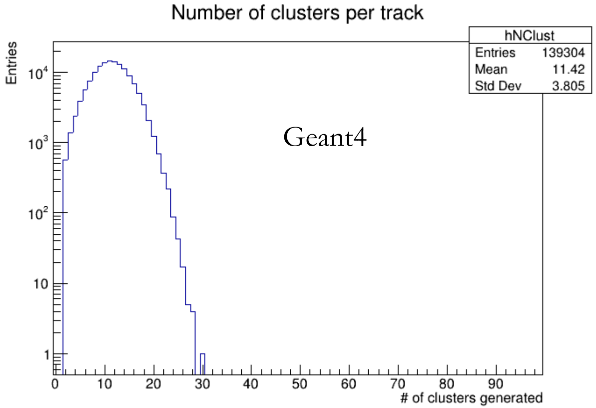
The **second** and **third** algorithms produce a number of cluster distribution, which follows the Poissonian shape and gives a mean value compatible with the one expected.
The **sixth** algorithm produces a number of cluster distribution, which follows the Poissonian shape and gives a mean value compatible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

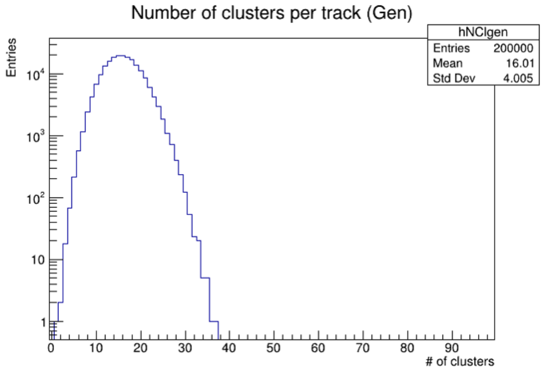


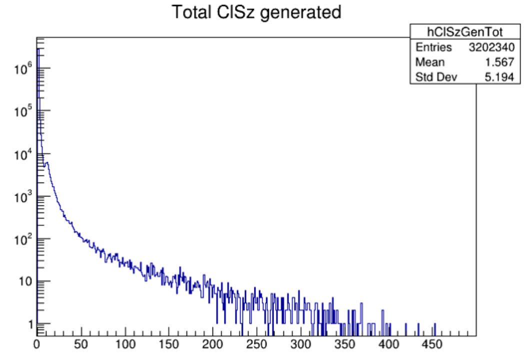


Drift Chamber simulation - Cluster Counting/Timing simulation

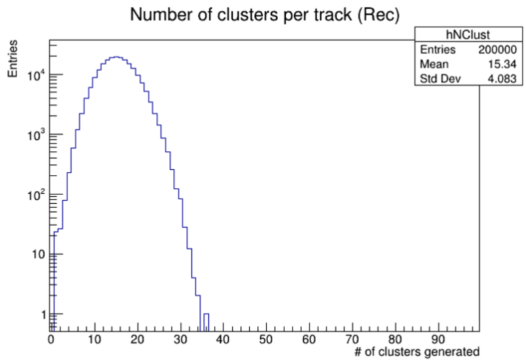
Case of study: pion at 10 GeV

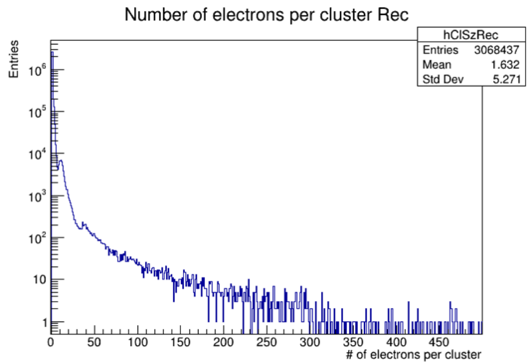
MC Truth





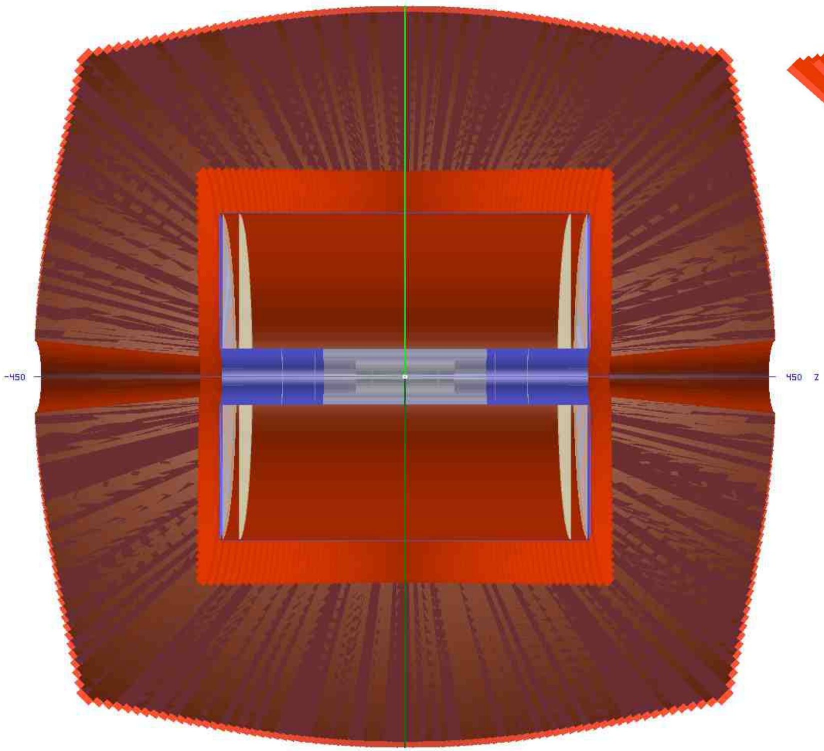
6th algorithm

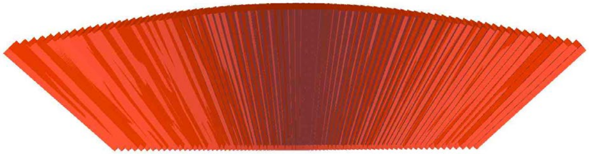




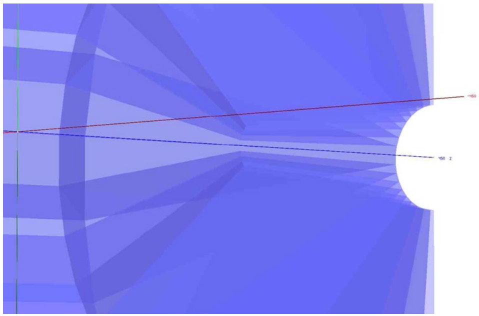
Integration with the Calorimeter

The integration of the Calorimeter geometry description was performed





Phi volume (barrel)



Phi volume (Endcap)

Summary

- A Geant4 simulation of the Drift Chamber and tracking system is set and working.
- Reasonable algorithms to simulate the Ionization Clusters by using the Geant4 data are developed
- The DR calorimeter geometry description is integrated with the other detectors.

https://github.com/welmeten/DriftChamberPLUSVertex/tree/master

To do and Plans

- Import the DR calorimeter step/hit creation (*Walaa is working*)
- Update the code to use the key4hep stack environment to run and migration form Make to Cmake (*Lia is working*)
- Convert the data output to EDM4hep formats (*Lia is working*)
- Finalize the Cluster simulation algorithms (*Federica is working*)and implement it in the DCH hit creation (*To be assigned*)
- Integrate the "correct" preshower description (geometry and hit creation) (*To be assigned*)
- Studies on C.C., improvements on track reconstruction, P.R. ….
- improve Clustering algorithm validation
- improve synergies with BINP colleges

To speed up the processes more people are needed!!!

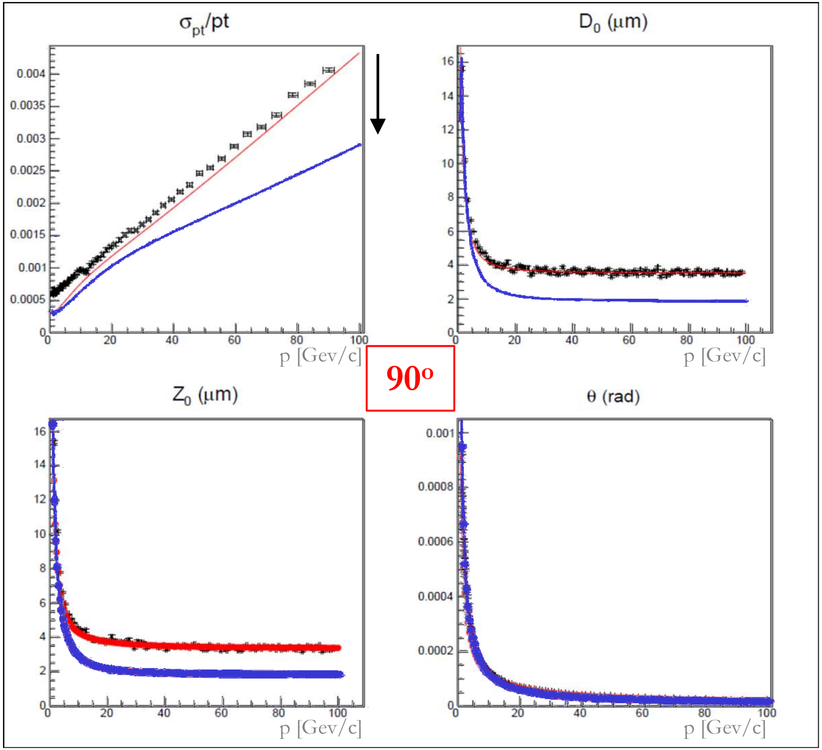
Backup

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

Expected simulated performance



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

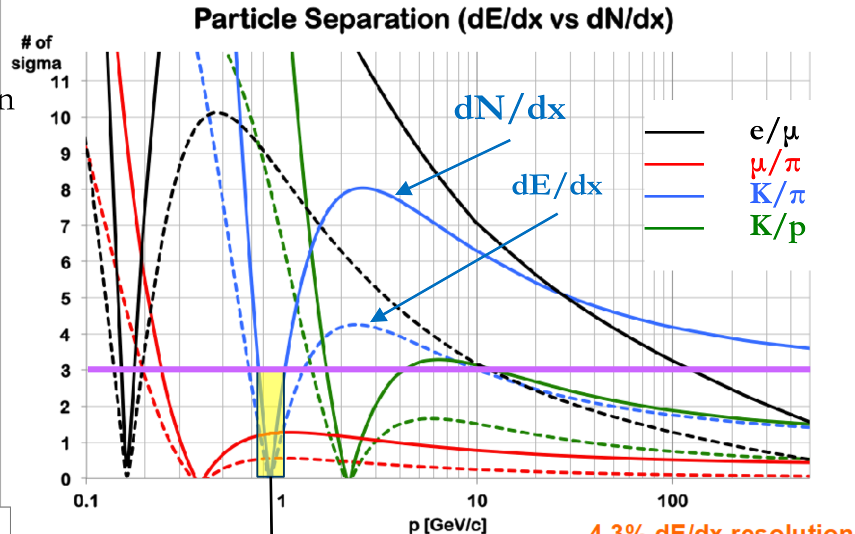
$$\frac{\sigma_{p_t}(100GeV)}{p_t^2}: \quad 4\cdot10^{-5} \rightarrow 2.9\cdot10^{-5}$$

More details in F. Bedeschi: "Fast Simulation Tracking", Workshop on the Circular Electron-Positron Collider, Oxford, UK, April 2019"

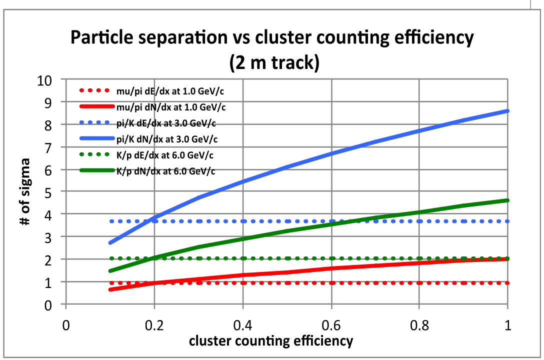
Cluster Counting/Timing and P.Id. expected performance

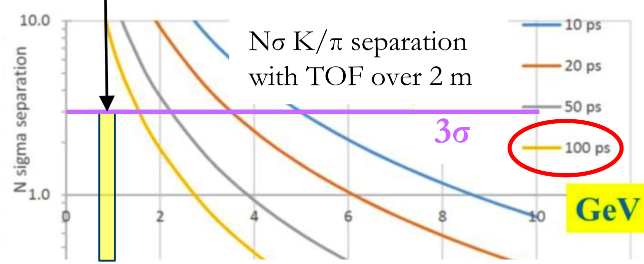
- Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)
- Could recover with timing layer

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

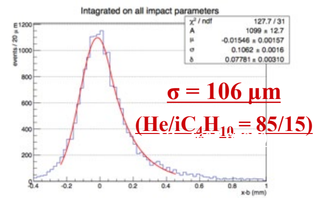


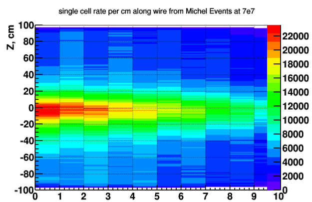
4.3% dE/dx resolution
80% cluster counting efficiency

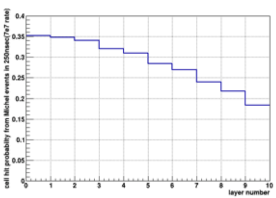


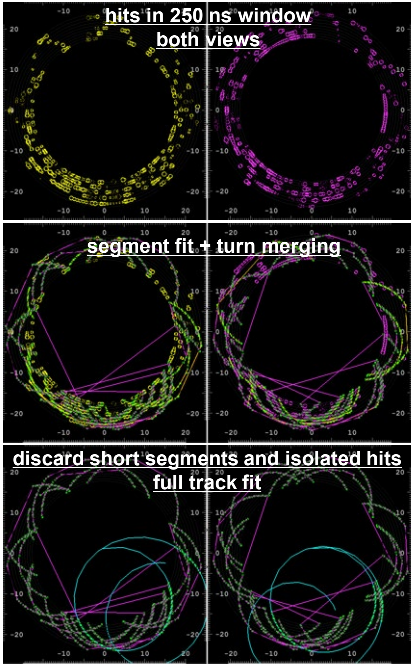


The MEG-II Drift Chamber Performance

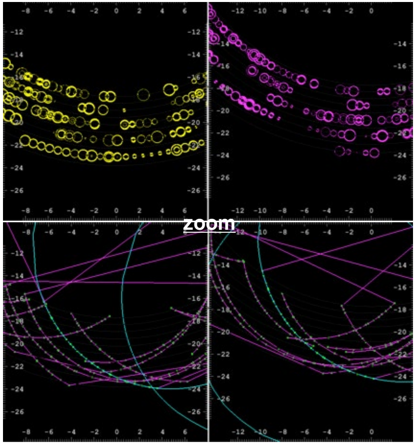








3D track finding and fit



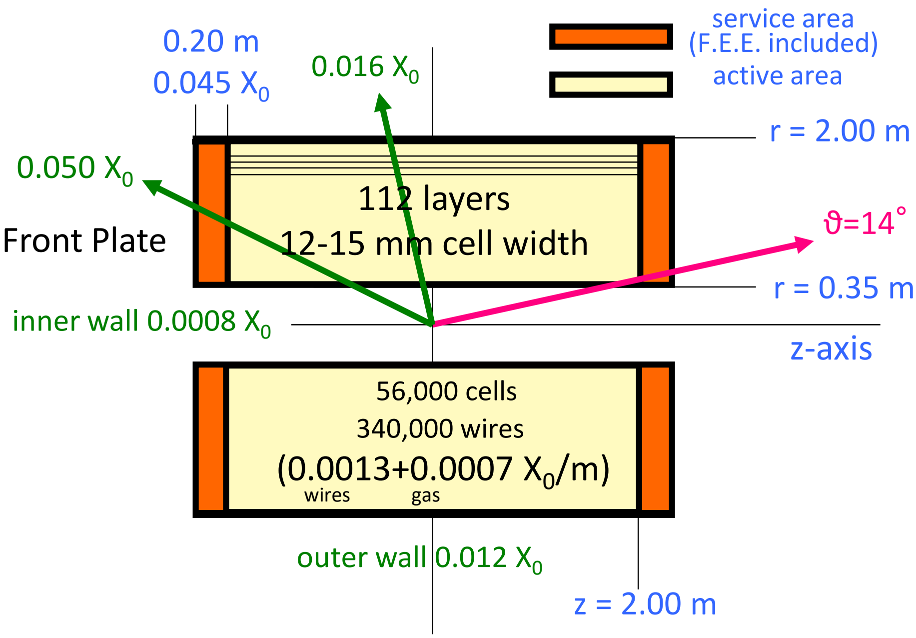
signal track

michel tracks

The IDEA drift chamber

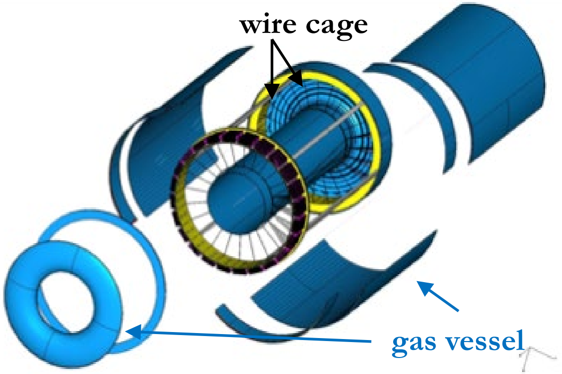
tracking efficiency $\varepsilon \approx 1$
for $\vartheta > 14^\circ$ (260 mrad)
97% solid angle

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



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

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 $\approx 10^{-3}\ X_0$ 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)

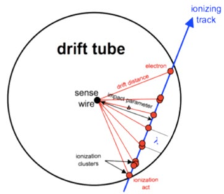
- Cluster counting:

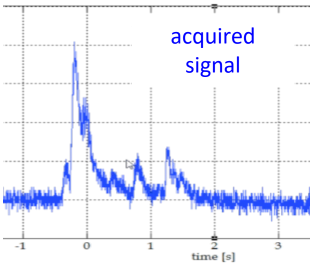
  allows to reach dN_{cl}/dx resolution < 3% for particle identification (a factor 2 better than dE/dx as measured in a beam test)

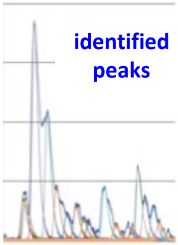
Cluster Counting/Timing and P.Id. expected performance

From the ordered sequence of the electrons arrival times, considering the average time separation between clusters and their time spread due to diffusion, reconstruct the most probable sequence of clusters drift times:

$$\{t_i^{cl}\} \qquad i = 1, N_{cl}$$







dE/dx

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot \left(L_{track}[m] \cdot P[atm]\right)^{-0.32}$$

from *Walenta parameterization (1980)*

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

σ ≈ 4.3%

Increasing P to 2 atm improves resolution by 20% (σ ≈3.4%) but at a considerable cost of multiple scattering contribution to momentum and angular resolutions.

dN_{cl}/dx

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = \left(\delta_{cl} \cdot L_{track}\right)^{-1/2}$$

from *Poisson distribution*

δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track give

σ ≈ 2.0%

A small increment of iC_4H_{10} from 10% to 20% (δ_{cl} = 20/cm) improves resolution by 20% (σ ≈1.6%) at only a reasonable cost of multiple scattering contribution to momentum and angular resolutions.

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

IDEA DCH geometry (simulation)

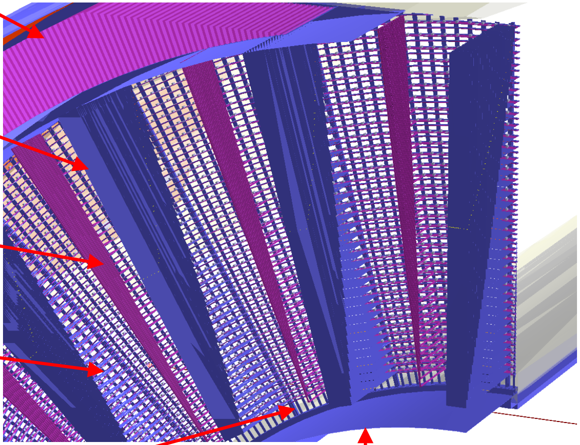
Electronics boards: 12 cm x 6 cm x 3mm G10 (FR4);

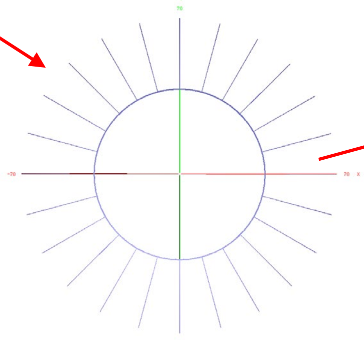
signal cables:
2.032 cm x 25 μm Kapton
+ 40 μm 16 pairs of Copper wires;

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

Wire anchoring (see next slide);

Carbon fiber wire support.



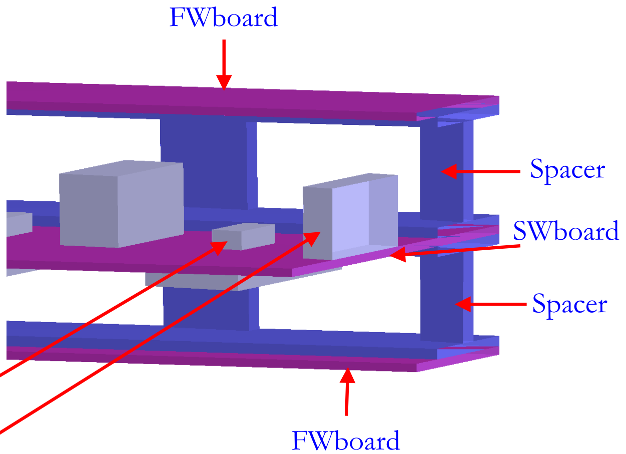


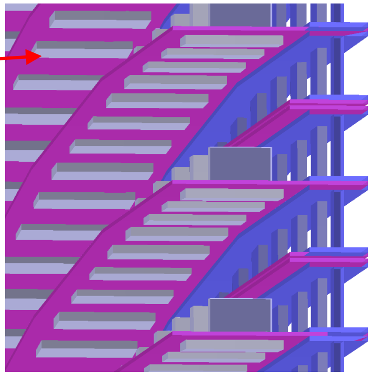
Connecting ring is described as a circular layer:
0.5 cm x 1.5 cm Carbon fiber

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 tacking system – ly1 - SVX

Layer	R [mm]	L [mm]	Si eq. thick. [μm]	X_0 [%]	pixel size [mm^2]	area [cm^2]	# of channels
1	17	±110	300	0.3	0.02 × 0.02	235	60M
2	23	±150	300	0.3	0.02 × 0.02	434	110M
3	31	±200	300	0.3	0.02 × 0.02	780	200M
4	320	±2110	450	0.5	0.05 × 1.0	85K	170M
5	340	±2245	450	0.5	0.05 × 1.0	96K	190M

Disks	R_{in} [mm]	R_{out} [mm]	z [mm]	Si eq. thick. [μm]	X_0 [%]	pixel size [mm^2]	area [cm^2]	# of channels
1	62	300	±400	300	0.3	0.05 × 0.05	5.4K	220M
2	65	300	±420	300	0.3	0.05 × 0.05	5.4K	220M
3	138	300	±900	300	0.3	0.05 × 0.05	4.4K	180M
4	141	300	±920	300	0.3	0.05 × 0.05	4.4K	180M

IDEA tacking system – ly1 - DCH

	R_{in} [mm]	R_{out} [mm]	z [mm]
drift chamber	350	2000	±2000
service area	350	2000	±(2000÷2250)

	inner wall	gas	wires	outer wall	service area
thickness [mm]	0.2	1000	1000	20	250
X_0 [%]	0.08	0.07	0.13	1.2	4.5

active volume	50 m^3	
readout channels	112,896	r.o. from both ends
max drift time	400 ns	800 × 8 bit at 2 GHz

# of layers	112	min 11.8 mm – max 14.9 mm
# of cells	56448	192 at 1st – 816 at last layer
average cell size	13.9 mm	min 11.8 mm – max 14.9 mm
average stereo angle	134 mrad	min 43 mrad – max 223 mrad
transverse resolution	100 μm	80 μm with cluster timing
longitudinal resolution	750 μm	600 μm with cluster timing

IDEA tacking system – tentative layout

Geometry is not yet optimized:

	Base Line	Option 1	Option 2	
	value	value	value	dim.
R_{in}	345	200*	250	mm
R_{out}	2000	2150	2000	mm
active area length	4000	4000	4000	mm
total length	4500	4500	4500	mm
total cells	56448	34560	52704	n.
layers	112	96	112	n.
Superlayers	14	12	14	n.
Layers per Superlay.	8	8	8	n.
phi sector	12	12	12	n.
smaller cell	11.85	14.2	11.65	mm
larger cell	14.7	22.5	15.25	mm
min. stereo angle	48	25	35	mrad
max. stereo angle	250	240	245	mrad

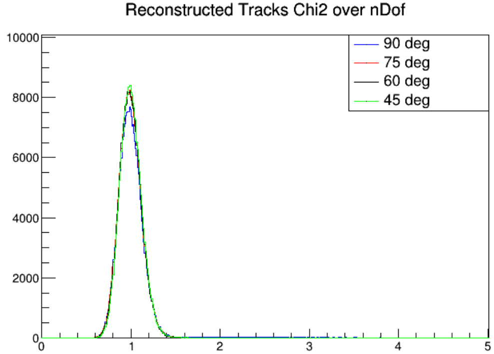
* not over the entire length, to avoid overlap with beam pipe etc.
A possible construction strategy is available.

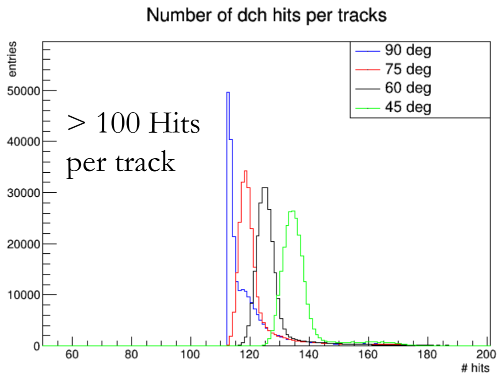
IDEA – layout v1 – Expected tracking performance

χ^2 /ndof

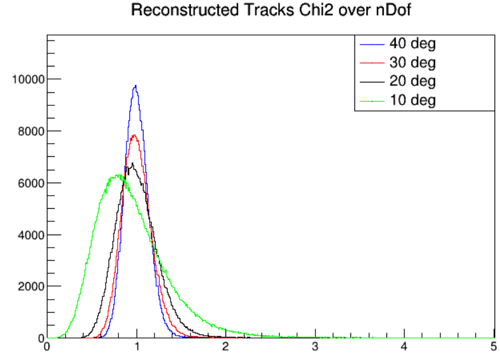
N hits fitted (DCH)

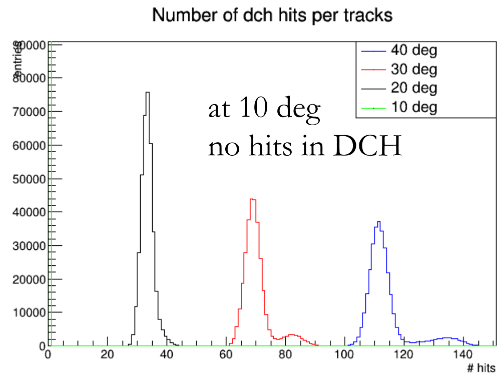
BARREL:





FORWARD:

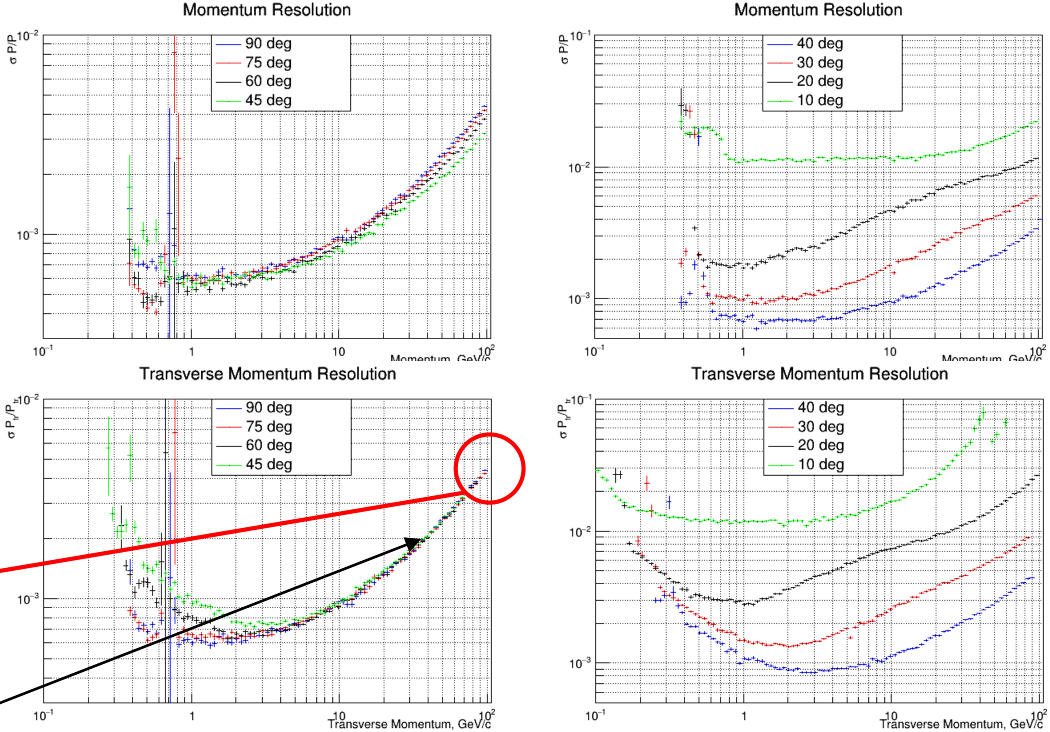




IDEA – layout v1 – Expected tracking performance

BARREL: FORWARD:

p



p_t

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

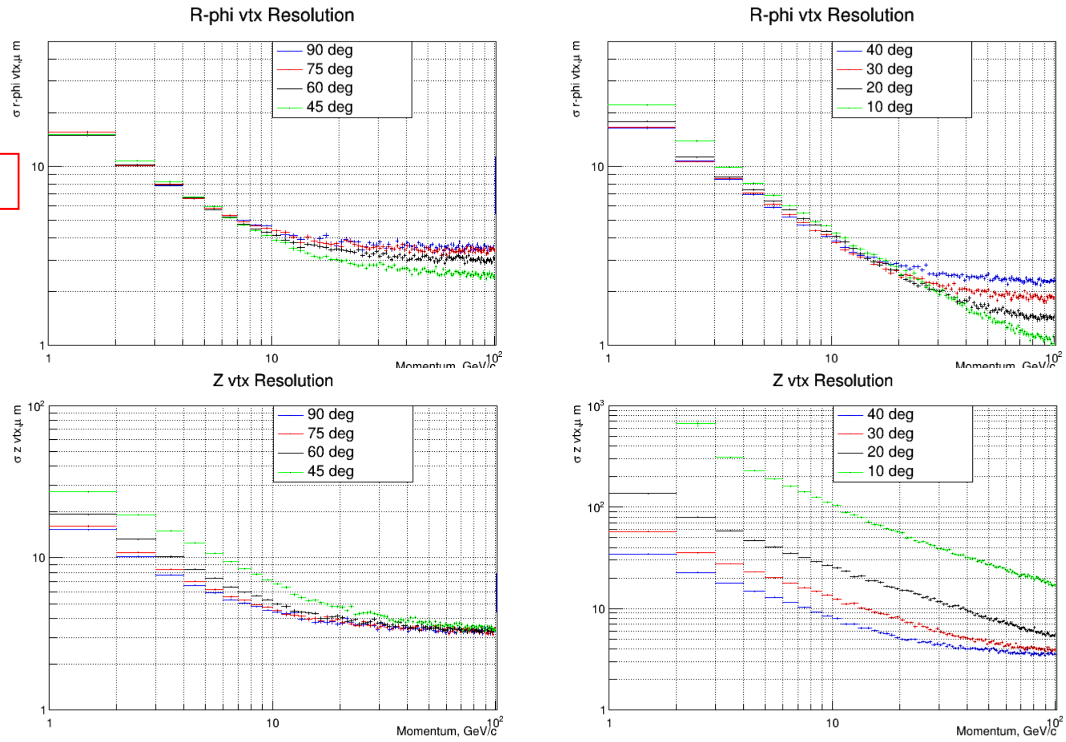
$$\frac{\sigma_{p_t}}{p_t^2} = 5 \bullet 10^{-5}$$

IDEA – layout v1 – Expected tracking performance

BARREL: FORWARD:

impact parameter

Z

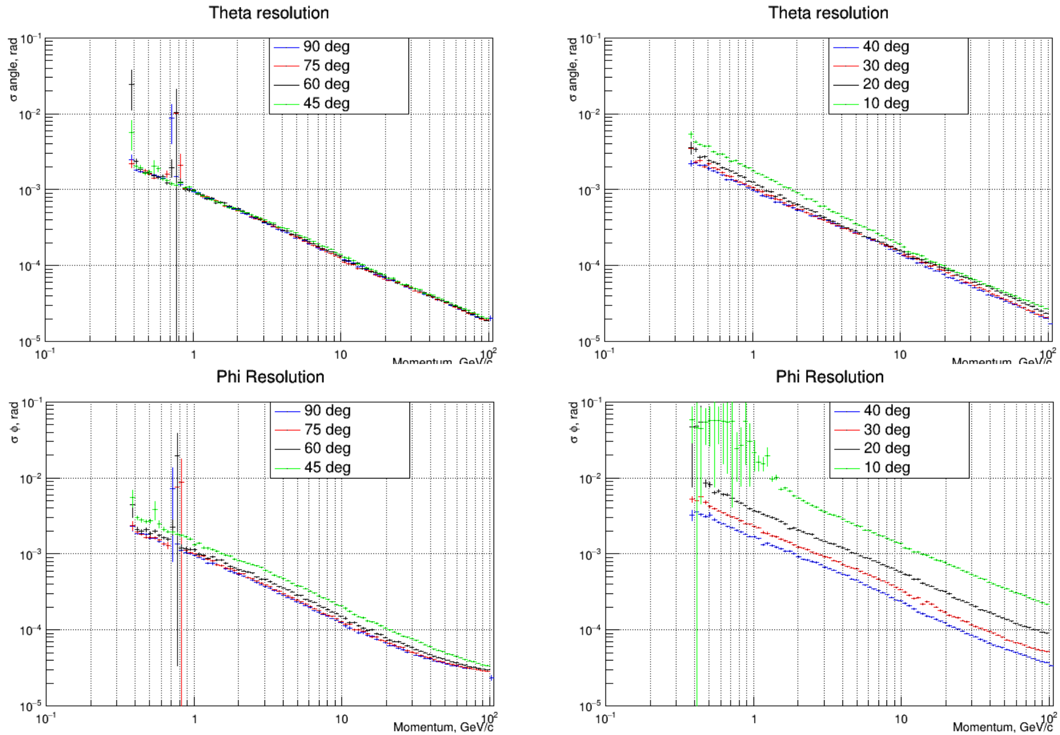


IDEA – layout v1 – Expected tracking performance

BARREL: FORWARD:

theta

phi

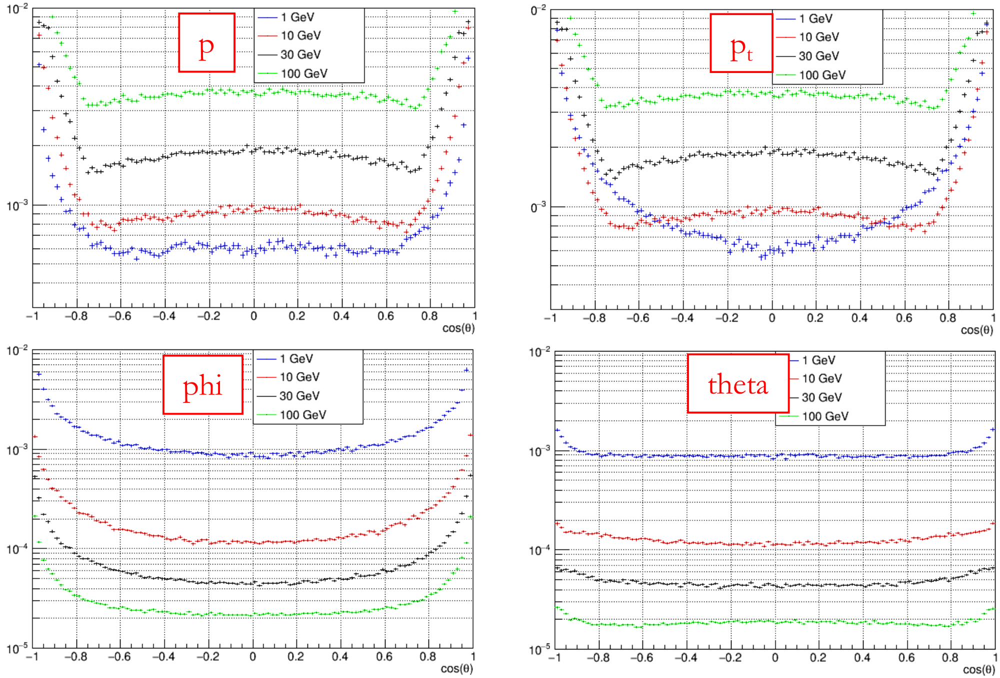


IDEA tracking system – Expected tracking performance
(single muon as function of ϑ)

base line option

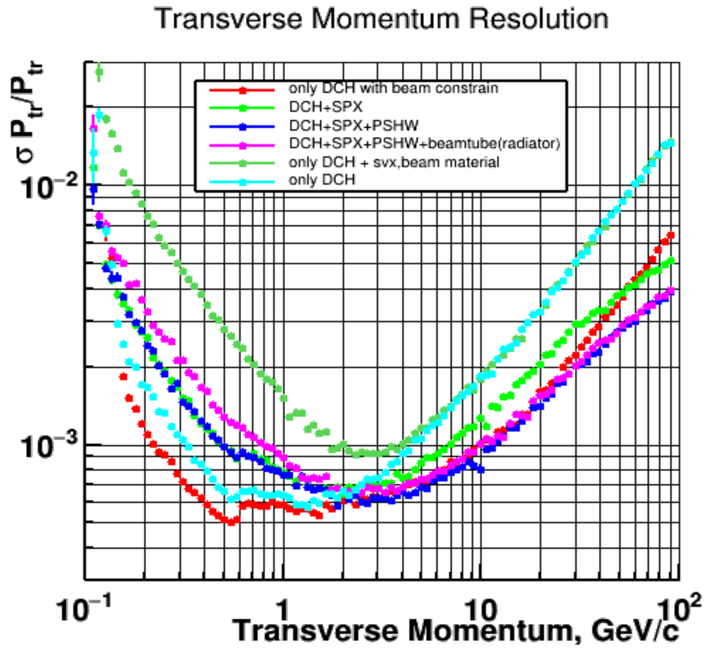
momentum resolution:

angular vertex resolution:

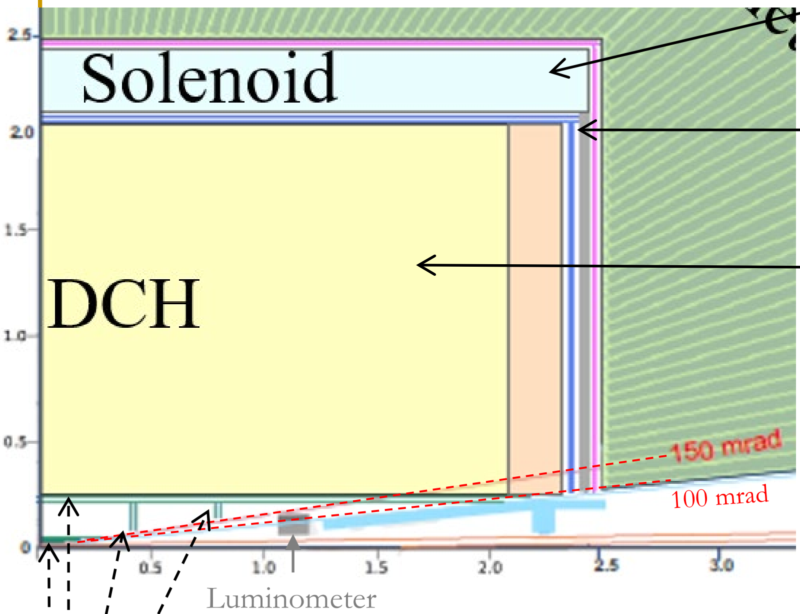


IDEA tracking system – Expected tracking performance (single pi+ at fixed θ=65deg)

Note: DCH layout differs a bit from the final IDEA one, only to compare the relative effects



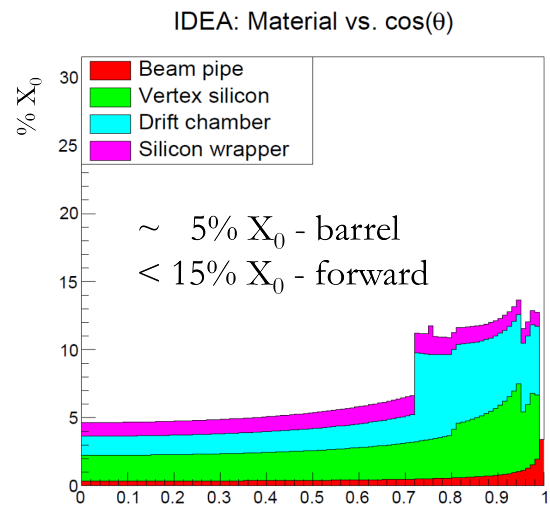
The IDEA tracking system



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% $i\text{-}C_4H_{10}$)



Vertex:

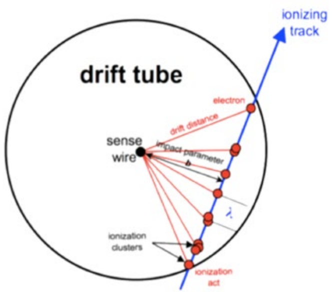
inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0

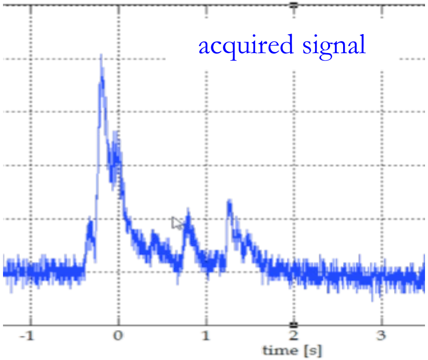
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

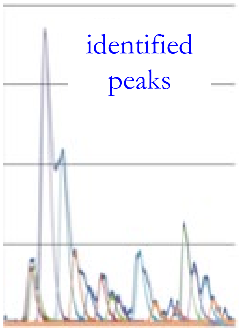
forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0

Cluster Counting/Timing and P.Id. expected performance

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