Tracking algorithms for the IDEA Drift Chamber

N. De Filippis
Politecnico and INFN Bari
on behalf of the INFN team

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Requirements of tracking system for an experiment at a leptonic collider

Central tracker system:

- state-of-the-art momentum and angular resolution for charged particles;
- B field limited to ~ 2 T to contain the vertical emittance at Z pole. Large tracking radius needed to recover momentum resolution.
- High transparency required given typical momenta in Z, H decays (far form the asymptotic limit where the Multiple Scattering contribution is negligible).
- Particle ID is a valuable additional ability.

Vertexing:

- excellent b- and c-tagging capabilities : few μm precision for charged particle origin;
- small pitch, thin layers, limited cooling, first layer as close as possible to IP.

Challenges:

- Physics event rates up to 100 kHz (at Z pole) → strong requirements on sub-detectors and DAQ systems

Basic concepts of the IDEA Drift Chamber

The IDEA detector at e^+e^- colliders (1)

Innovative Detector for E+e- Accelerator

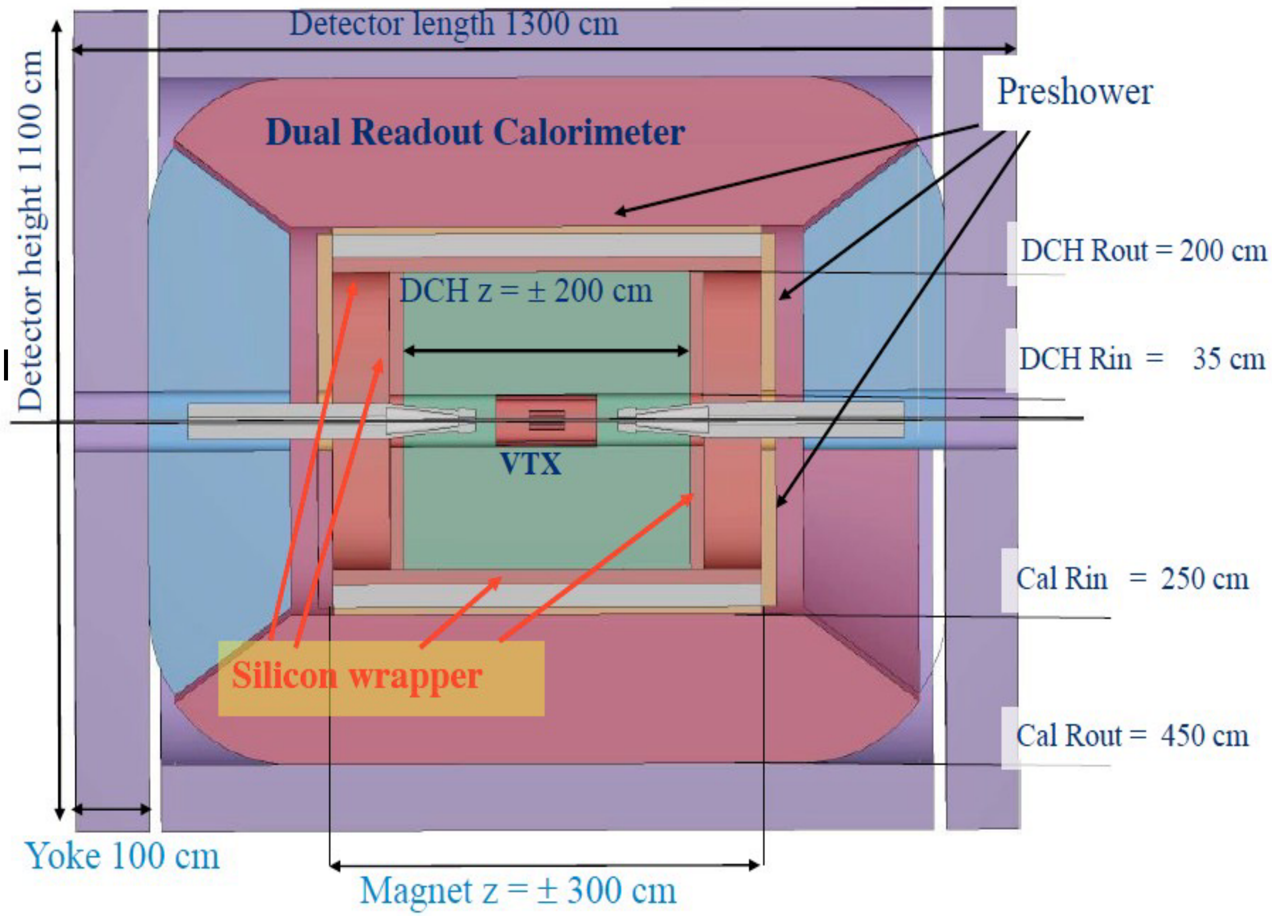
IDEA consists of:

- a silicon pixel vertex detector
- a large-volume extremely-light drift wire chamber
- surrounded by a layer of layer of silicon micro-strip detectors
- a thin low-mass superconducting solenoid coil
- a preshower detector
- a dual read-out calorimeter
- muon chambers inside the magnet return yoke

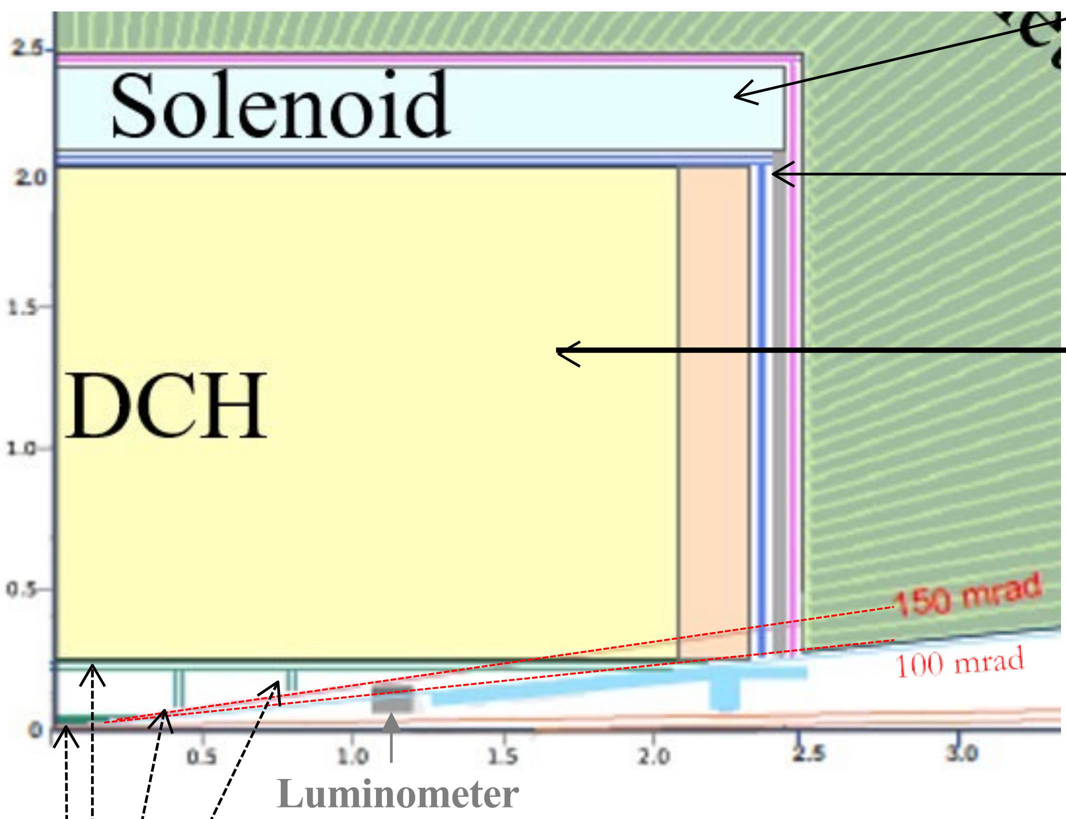
Low field detector solenoid to maximize luminosity
→ optimized at 2 T

FCC-ee at CERN

CEPC at IHEP-China



The IDEA tracking system

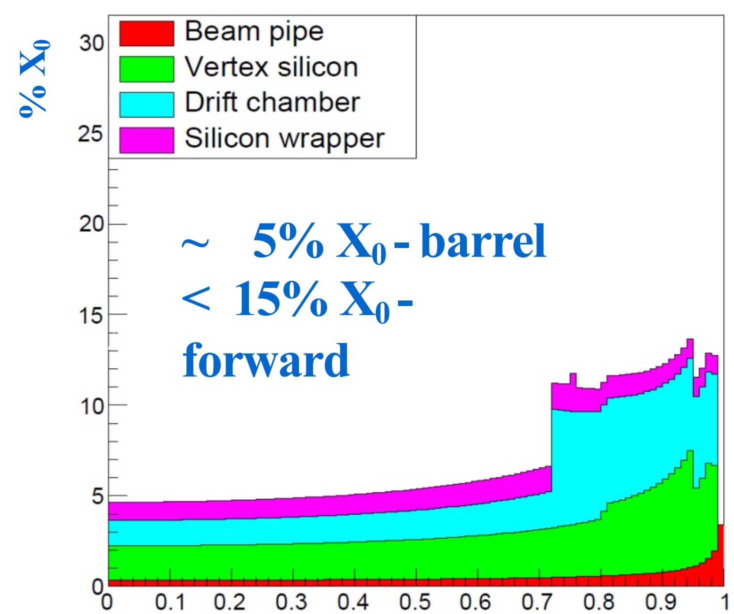


Solenoid: 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X_0, 0.16 λ @ 90º

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

IDEA: Material vs. cos(θ)



Vertex:

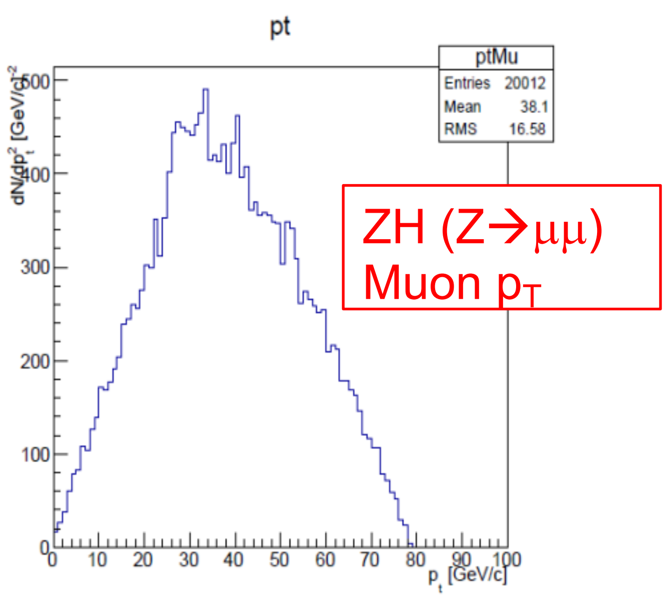
inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0

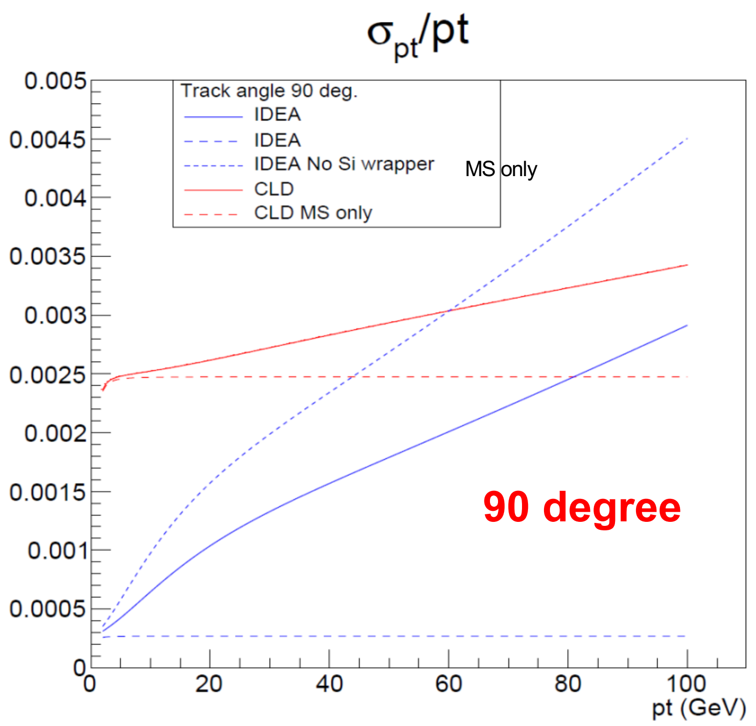
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

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

Design guidelines: momentum resolution

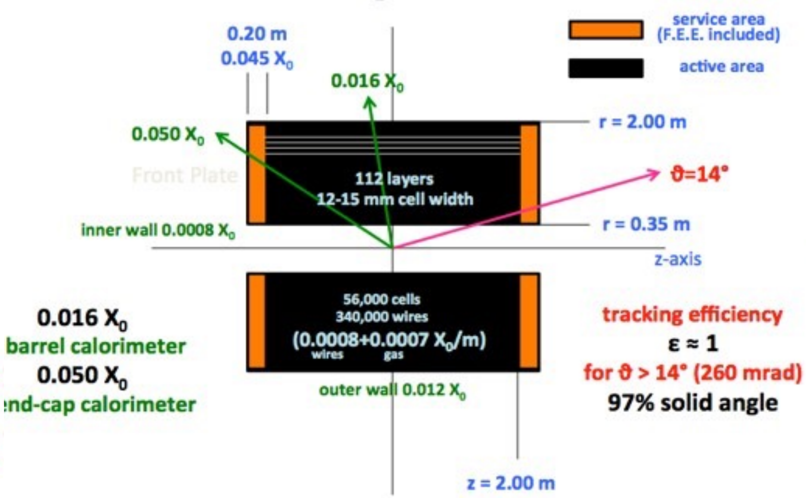
- Z or H decay muons in ZH events have rather small/medium p_T
  - **Transparency** (against multiple scattering) more relevant than asymptotic resolution

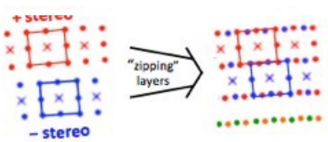


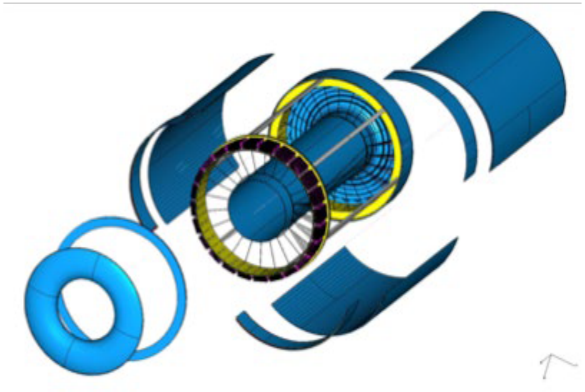


Design guideline: the Drift Chamber

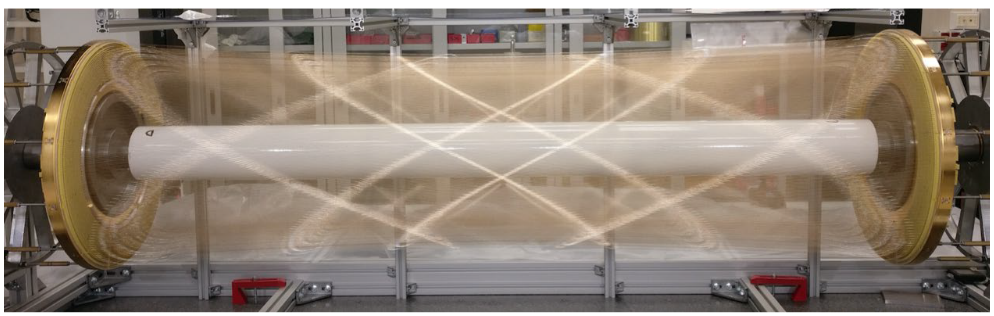
Drift Chamber







New concept of construction allows to reduce material to ≈ 10^{-3} X_0 for the barrel and to a few x 10^{-2} X_0 for the end-plates.



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	

Expected performance:

$\Delta p_t/p_t = (0.7 p_t + 8.3) \times 10^{-4}$

$\Delta\vartheta = (1.1 + 9.4/p) \times 10^{-4}$ rad

$\Delta\varphi = (0.33 + 9.4/p) \times 10^{-4}$ rad

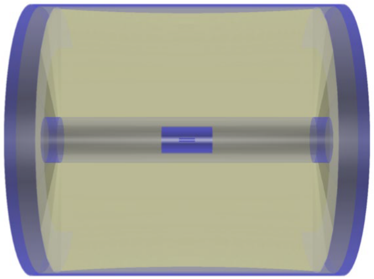
dE/dx = 4.3 %

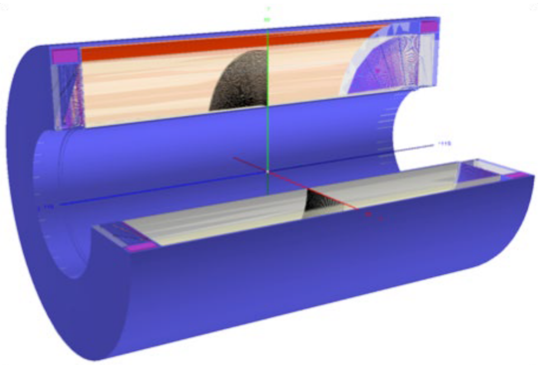
dN/dx = 2.2 % (at ε_N = 80 %)

Detector simulation

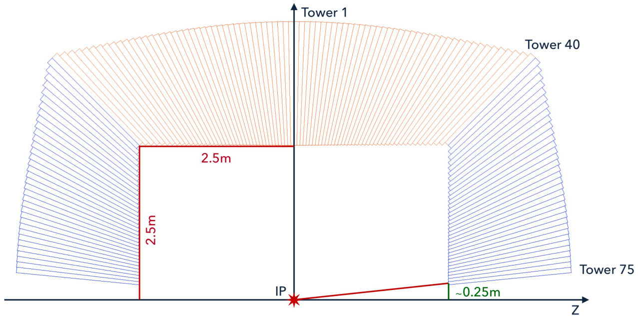
Geant4 full simulation of IDEA

A full standalone geant4 simulation of the IDEA **Silicon Vertex (and Si wrapper), DriftChamber, DR Calorimeter (and Muon)**

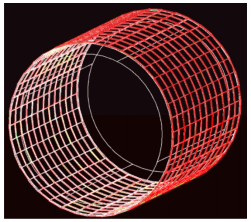




- The DCH is simulated at a good level of geometry details, including detailed description of the endcaps; hit creation and track reconstruction code available
- SVX and Si wrapper are simulated as simple layer or overall equivalent material
- Dual readout calorimenter simulated with geant4 too
  - Towers are trapezoidal physical volumes with slightly different shapes changing with θ.
  - Fibers are 1mm diameter tubes, 0.5 mm of absorber material (copper) between two adjacent
  - → 130 milion fiber for the whole IDEA detector



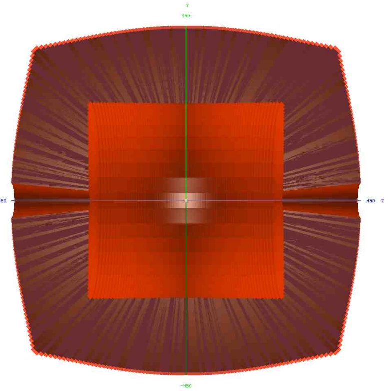
- Muon detector



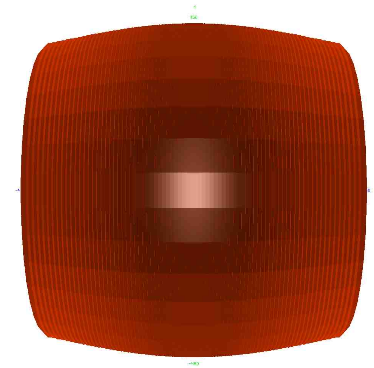
Integration of all the detectors on going

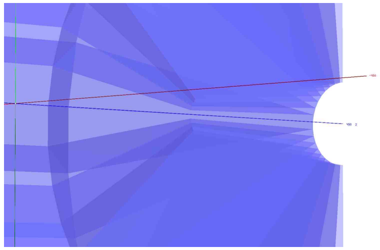
Integration of DCH and DR calo volumes

- **Standalone code for Drift Chamber already developed**
- **geometry of the dual readout calorimeter (courtesy of L. Pezzotti) adapted to cope with DCH geant4 framework :**
  - Towers are G4Trap() physical volumes with slightly different shapes changing with θ.
  - Fibers are 1mm diameter G4Tubs(), 0.5 mm of absorber material (copper) between two adjacent fibers is considered.
  - Barrel Inner length: 5m - Outer diameter: 9 m @ 90° .
  - 2 m long coper based towers: ~ 8.2 λ
  - 36 rotation around z axis
  - Number of Towers in the barrel: 40 × 2 × 36= 2880
  - Number of Towers in per endcap: 35 × 36= 1260



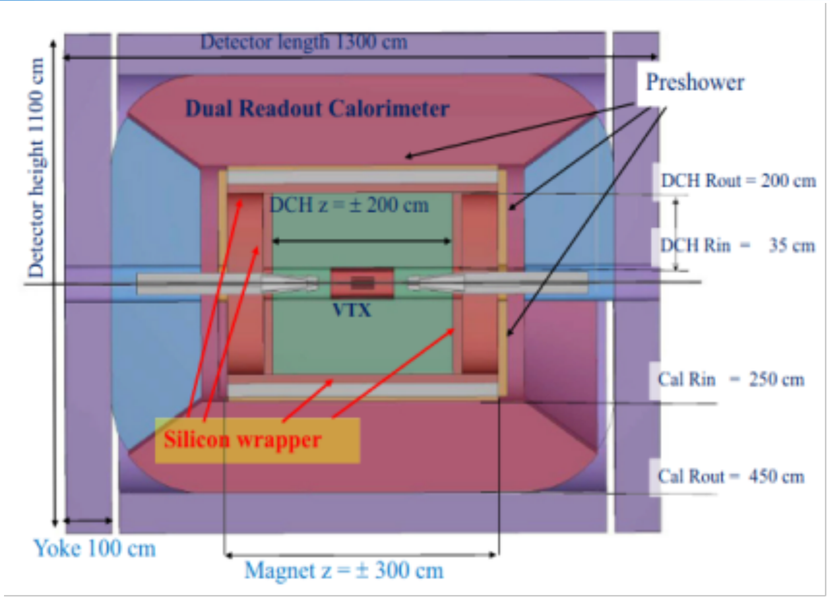
Calorimeter mother volume





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

Integration of IDEA detector in Key4Hep



NOW: simulation in a standalone code GEANT4 – based
NOW: reconstruction in a standalone code ROME – based

GOAL: integrate the IDEA detector in Key4Hep framework

Different ways to proceed:

- port the geometry description
- port the algorithms implementation
- port the the data format

First step is to translate to EDM4Hep format

- GEANT4 Monte Carlo hits
- Standalone reconstructed tracks

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

Everything is working with these versions

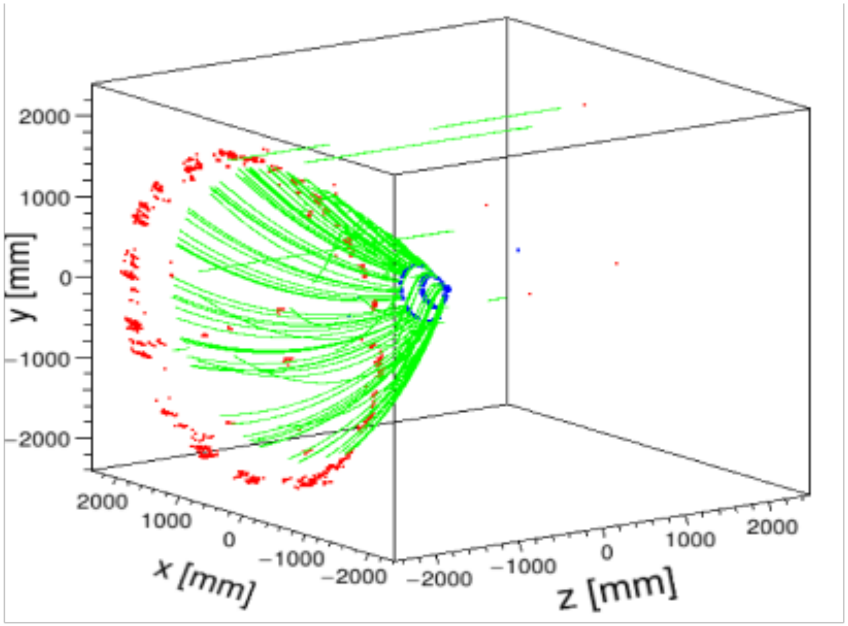
- key4hep-stack/2021-09-01:
- gcc8.3.0
- geant4-10.7.1
- clhep-2.4.4.0
- root-6.24.00
- genfit master2019110
- rome-v3.2.15.1

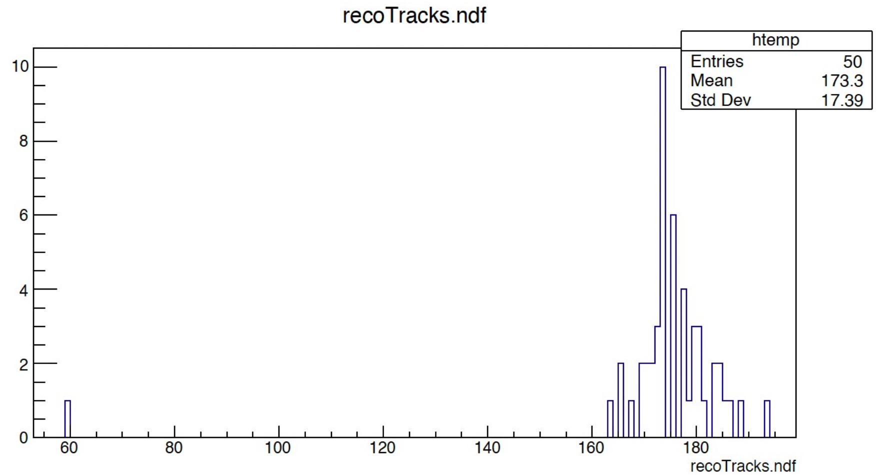
INSTALLATION via installer

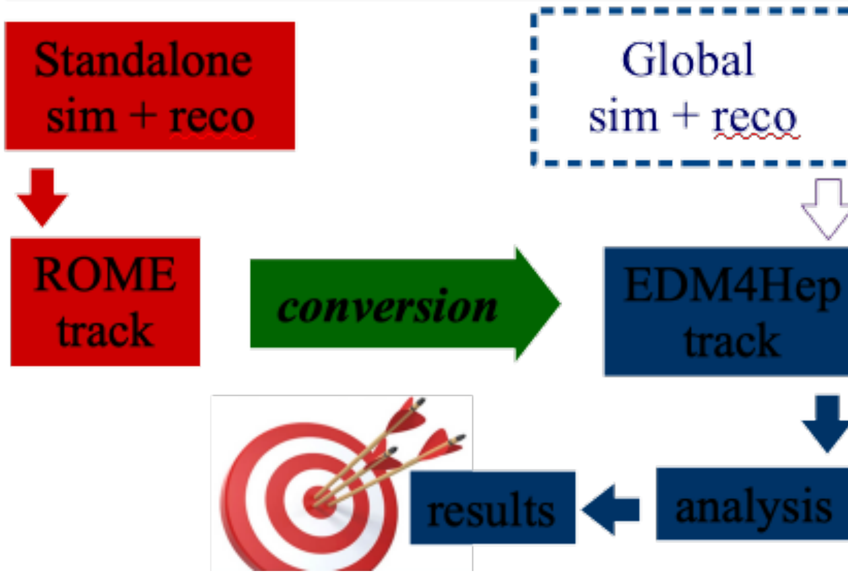
Instructions:

- Download the file install_standalone.sh
- Edit it and set STANDALONE_INSTALL_DIR to the directory where you want to install everythin
- Make it executable with: chmow u+x install_standalone.sh
- Execute it with: ./install_standalone.sh

MC hit conversion and reco tracks conversion







- standalone code adapted for compilation on Key4Hep stack
- For now, silicon vertex tracker, drift chamber, preshower
- The class **convertHits** has been written: it translates GEANT4 hits to EDM4Hep model

Track reconstruction

Track reconstruction principles

- Track fitting
  - general consideration and Kalman Filter
  - specific implementation aspects

- Track finding (Pattern Recognition)
  - general aspects
  - useful options for IDEA case
  - some details on current IDEA PR

Track fitting – general consideration

Kalman Filter is a standard method for Track fitting in HEP (*alternatives exist but are still not good as KF for this problem*)

- 1960: R. Kalman, "A New Approach to Linear Filtering and Prediction Problems", **Trans. ASME (J. Basic Engineering), 82 D, 35-45, 1960**

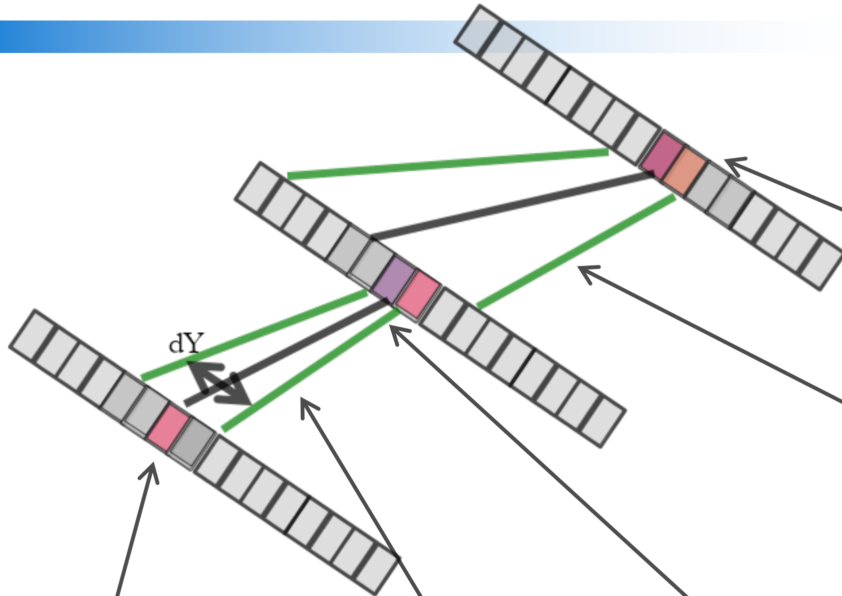
One of the first applications: guiding Apollo 13 to the moon
Now widely used: in just about every inertial navigation system(GPS, gyro systems), radar tracking

- First paper in HEP with equivalent equations:
  1984: P. Billoir, "Track Fitting With Multiple Scattering: A New Method," **NIM A (1984) 352**
- Classic author of Kalman Filter for HEP:
- 1987: R. Fruhwirth, "Application of Kalman filtering to track and vertex fitting", **NIM A 262 (1987) 444**

peculiarities:

- **recursive least-squares estimation;**
- **suitable for combined track finding and fitting;**
- **mathematically equivalent to least squares fit;**
- **avoids time-consuming large matrix inversion inherent in least-squares fits;**
- **straightforward to take into account material effects in extrapolation step.**

Basic principle of Kalman Filter (1)



parameter vector with error matrix
on the current plane
defined by angle and distance to origin

$$\eta_k^k = \left\{ y, z, \sin(\varphi), \tan(\lambda), \frac{1}{pt} \right\}$$

$$C_k^k = \langle \delta\eta\delta\eta \rangle$$

propagated to next plane

$$\eta_k^{k+1}, C_k^{k+1}$$

select new hit by chisquare

$$\eta_{k+1}^{k+1}, C_{k+1}^{k+1}$$

Updated by weighted mean of
parameter vector and measurement

updated

propagated
(k+2)

Some matrix formalism underlie, but meaning is simple:
recursive usual χ^2 averaging

Prediction

$$\bar{p}_{k|k-1} = \mathbf{F}_k \bar{p}_{k-1|k-1}$$

$$\mathbf{C}_{k|k-1} = \mathbf{F}_k \mathbf{C}_{k-1|k-1} \mathbf{F}_k^T + \mathbf{P}_k \mathbf{Q}_k \mathbf{P}_k^T$$

updated step

$$\bar{p}_{k|k} = \bar{p}_{k|k-1} + \mathbf{K}_k (\bar{x}_k - \mathbf{H}_k \bar{p}_{k|k-1})$$

$$\mathbf{K}_k = \mathbf{C}_{k|k-1} \mathbf{H}_k^T (\mathbf{V}_k + \mathbf{H}_k \mathbf{C}_{k|k-1} \mathbf{H}_k^T)^{-1}$$

$$\mathbf{C}_{k|k} = (\mathbf{I} - \mathbf{K}_k \mathbf{H}_k) \mathbf{C}_{k|k-1}$$

Basic principle of Kalman Filter (2)

Filtering procedure (track fitting)

Prediction step

with equation of motion $\frac{d\vec{v}}{ds} = \frac{kq}{p}\left(\vec{v}\times\vec{B}\right)$ → η_k^{k+1}

and energy Loss $-\frac{dE}{dx}$

with transportation matrix $\frac{\partial\eta_k^{k+1}}{\partial\eta_k^k}$ → C_k^{k+1}

multiple scattering, energy loss fluctuation

Correction step

Updated by weighted mean of parameter vector and measurement

$$\eta_{k+1}^{k+1} = C_{k+1}^{k+1}\left[\left(C_k^{k+1}\right)^{-1}\eta_k^{k+1} + H^T V_k^{-1} m_k\right]$$ → η_{k+1}^{k+1}

$$C_{k+1}^{k+1} = \left[\left(C_k^{k+1}\right)^{-1} + H^T V_k^{-1} H_k\right]^{-1}$$ → C_{k+1}^{k+1}

m_k - measurement with errors = $V_k = \langle \delta m_k \delta m_k \rangle$

H - projection matrix from parameters to measurement

Variations of Kalman Filter

It can be some variations in implementation(most of them just matter of terminology for specific cases) or with extensions

SRKF – Square Root Kalman Filter:

Covariance matrix decompose in square root form
– can give numerical stability

Information Kalman Filter:

rewritten in form of inverse covariance matrix
- useful when some parameters can have infinite sigma

GSF – Gaussian-Sum Filter:

to deal with not gaussian fluctuations - instead of single Gaussian, pdfs modeled by mixture of Gaussians (implemented as a number of Kalman Filters run in parallel)

CKF - The Combinatorial Kalman Filter

Integrate track fitting and pattern recognition
– track splitted in case of few compatible hits

DAF – Deterministic Annealing Filter

On a same surface, several hits may compete for track with different weights
– good for outliers removal

Track fitting – implementation aspects

How to use?
Many software packages implement KFs and are available and 'easy to use':

- **genFit2**: https://github.com/GenFit/GenFit
  (arXiv:1410.3698 , NIN A620(2010)518–525) used by:
  - PANDA
  - Belle II
  - …
- **ACTS**: http://acts.web.cern.ch/ACTS/index.php
  - ATLAS
  - *FCC-sw*
- etc…

Track fitting – implementation aspects

What do we need to do?

- pass measurement points with their proper description
  - 3D (2D) point (pixel)
  - 1D point (strip)

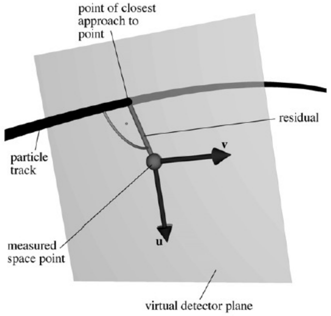


Fig. 2. Virtual detector plane (spanning vectors $\vec{u}$ and $\vec{v}$) for a space-point hit.

  - Drift distance

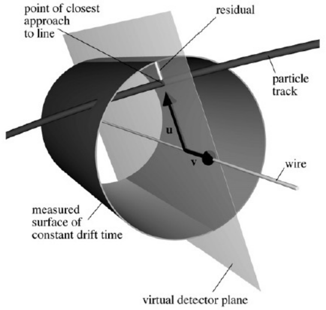


Fig. 3. Virtual detector plane (spanning vectors $\vec{u}$ and $\vec{v}$) for a wire-based drift detector.

- delivery a description of the material to allow the MS and ΔE evaluation
  - genFit2: GDML description
  - *ACTS: DD4Hep*

Track finding – general aspects

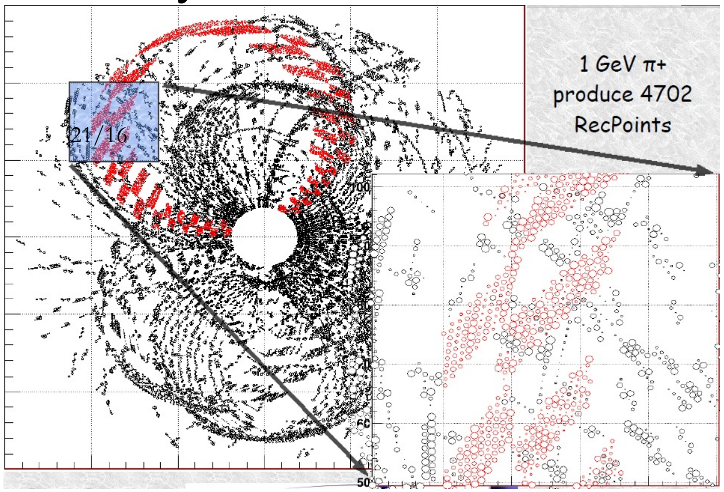
Track finding possible strategies: global vs local methods

- global methods
  - treat hits in all detector layers simultaneously
  - 'find all' tracks simultaneously
  - result independent of starting point or hits order

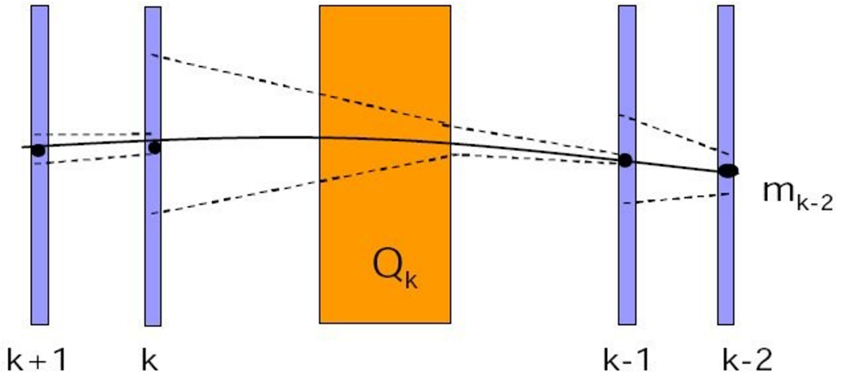
  examples: template matching, Hough transforms (conformal mapping), neural nets, cellular automation, ….
- local methods ('track following')
  - start with construction of track seeds
  - add hits by following each seed through detector layers
  - eventually improve seed after each hits

Stereo Drift Chamber issue for PR:

- Left/Right single cell ambiguity
- Longitudinal position along the wire (in the transverse plane appear two separate circonpherences for the same track before applying a correction for the position along the wire)



Track finding – current IDEA PR (local method)



Follow track candidate iteratively through detection layers

start from an initial track segment (“seed”)

requires dedicated algorithm

extrapolate: estimate the expected track position in the next detection layer

search: look for hits within a window around the estimated track position

update: if a hit is found inside this search window, add it to the track candidate and update the track parameters

iterate: extrapolate the updated track candidate to the next detection layer

should be broad seeding: track reconstruction efficiency can depend on it, compromise between efficiency and CPU performance

allow for detector inefficiencies: if no hit is found in one layer, continue with the next layer; abandon the candidate if no hits are found in several consecutive layers

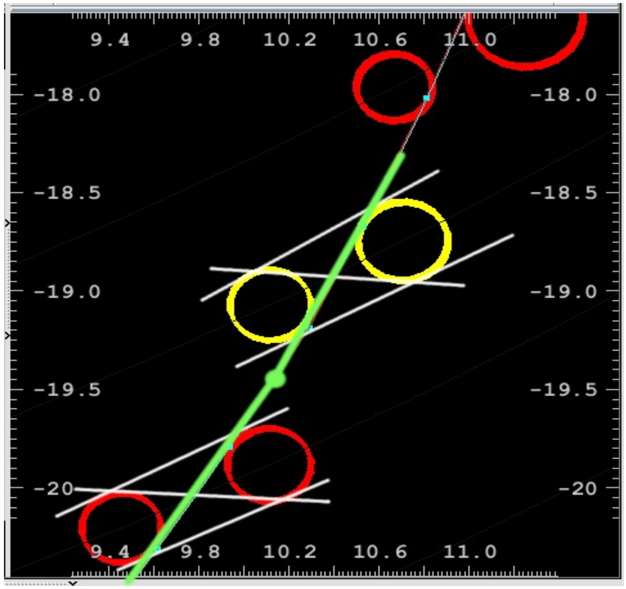
allow for combinatorics: if more than one hit is found inside the search window, create a separate “branch” for each candidate; follow all branches concurrently

Track finding – local method for DCH only

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: |Δcos(φ(direction)-φ(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 Δφ correction from Pt)
- Pz = 0 at beginning

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



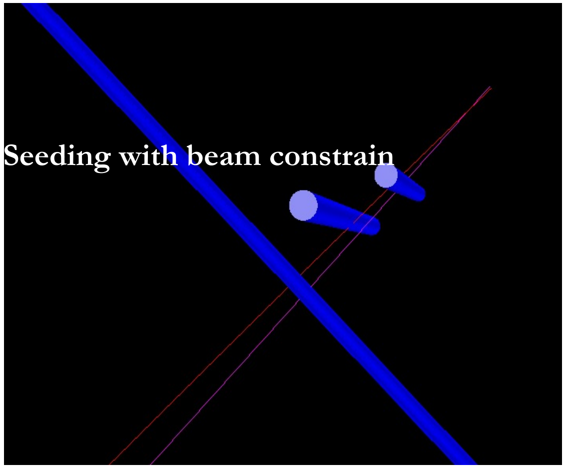
Red hits **projection at z=0 plane**
Yellow **rotated according to φ**

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

Track finding – local method for DCH only

Seeding from 3 hits in different layers with origin constraint

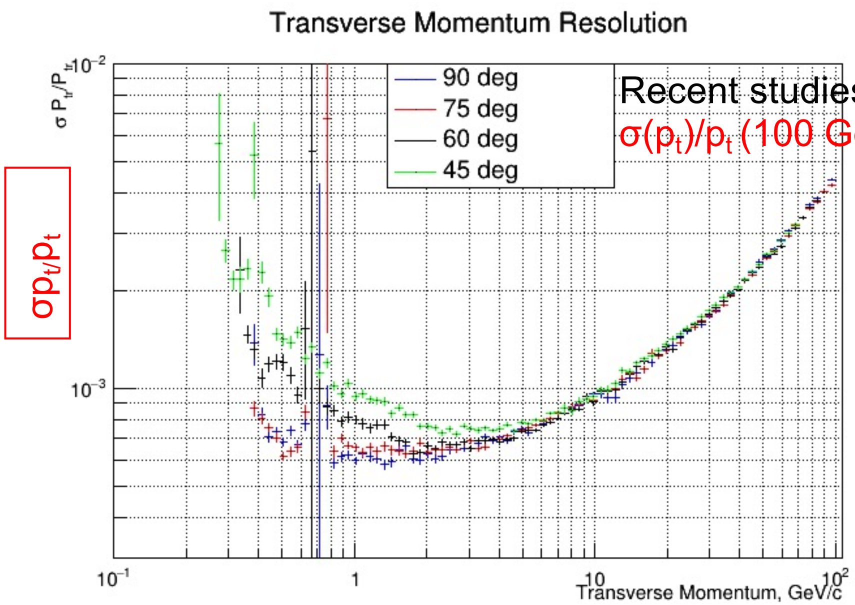
- Take any 2 free hits from different stereo layers with a gap (4 or 6 layers)
- Cross Point of 2 wires give Z-coordinate (must be inside DCH volume)
- Select nearest free hits at middle (+-1) layer
- 2 hits from same stereo layer give initial angle in Rphi
- origin added with sigma Rphi~ 1mm Z ~ 1mm
- 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:
  - χ^2/NDF < 4
  - number of hits found (>=7)
  - number of shared hits (<0.4Nfound)



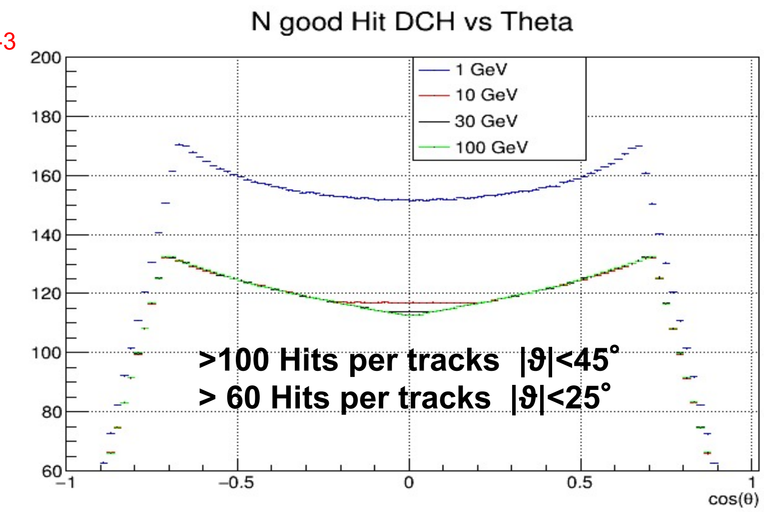
Combinatory high:
local compatibility over different layers,
+ 1 from different stereo view

Track finding – performance of the current IDEA PR

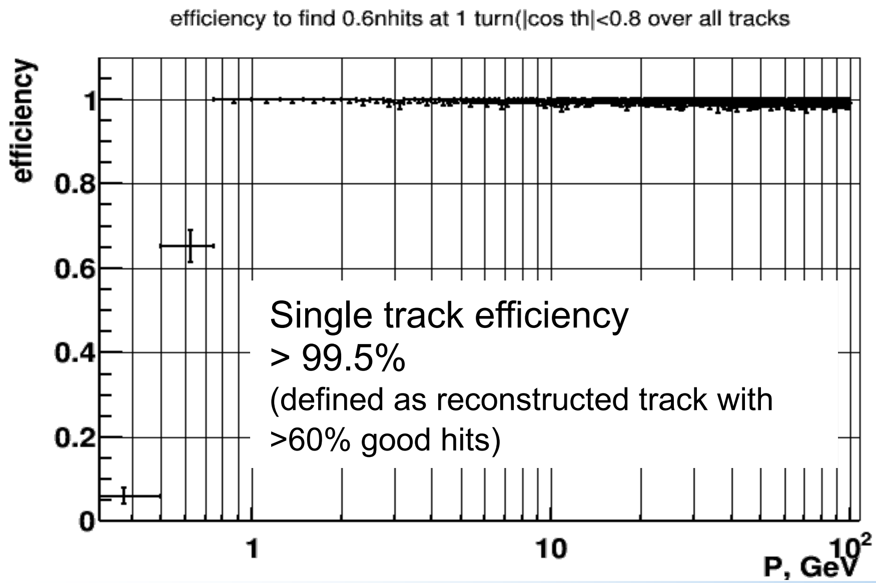
DCH + SVX but no Si-Wrapper



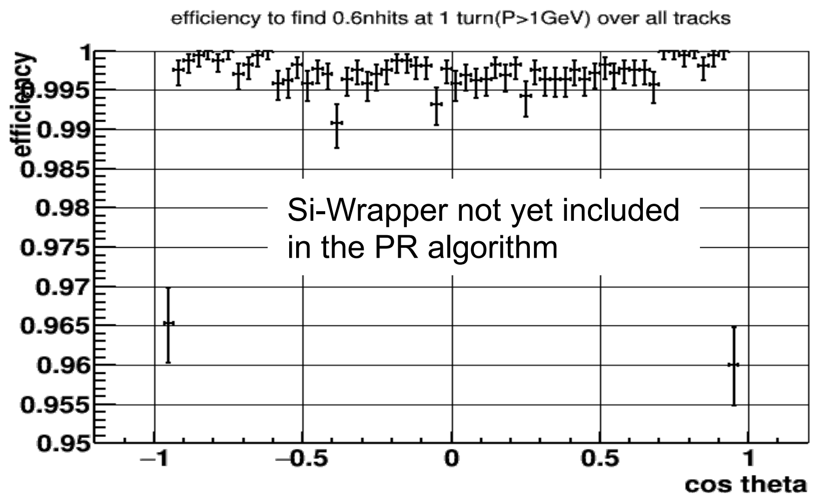
Recent studies with
$\sigma(p_t)/p_t$ (100 GeV) = 3x10^{-3}



>100 Hits per tracks |ϑ|<45°
> 60 Hits per tracks |ϑ|<25°



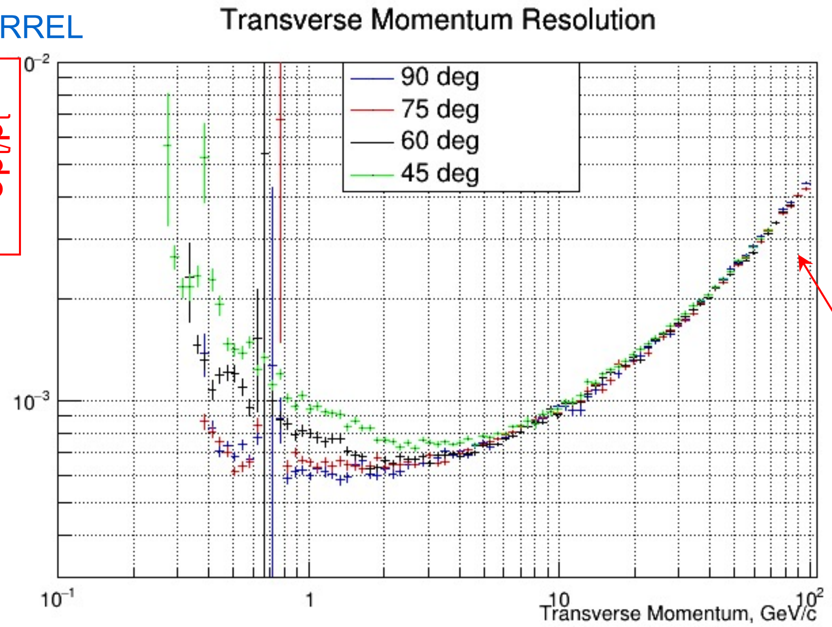
Single track efficiency
> 99.5%
(defined as reconstructed track with
>60% good hits)



Si-Wrapper not yet included
in the PR algorithm

Expected tracking performance with IDEA full simulation

BARREL



DCH + SVX but no Si-Wrapper

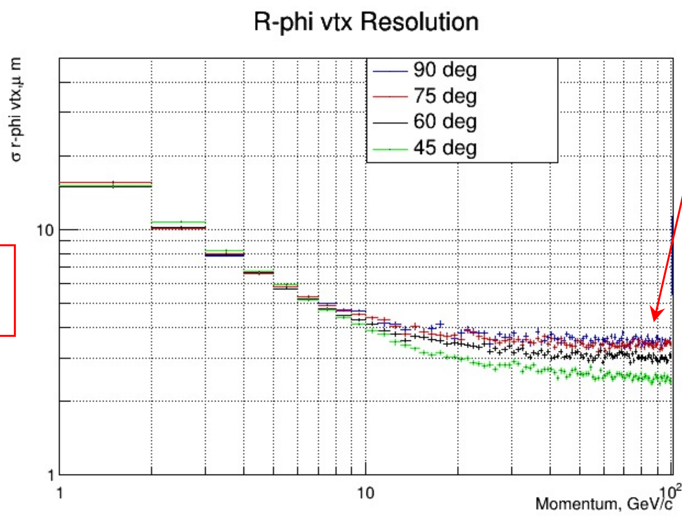
Recent studies with

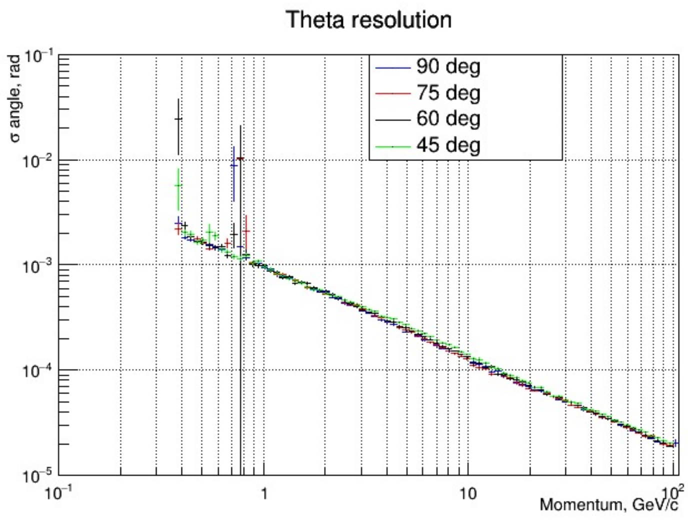
$\sigma(p_t)/p_t$ (100 GeV) = 3×10^{-3}

$\sigma(d_0)$ (100 GeV) = 2μm

BARREL

impact parameter





IDEA fast simulation with Delphes

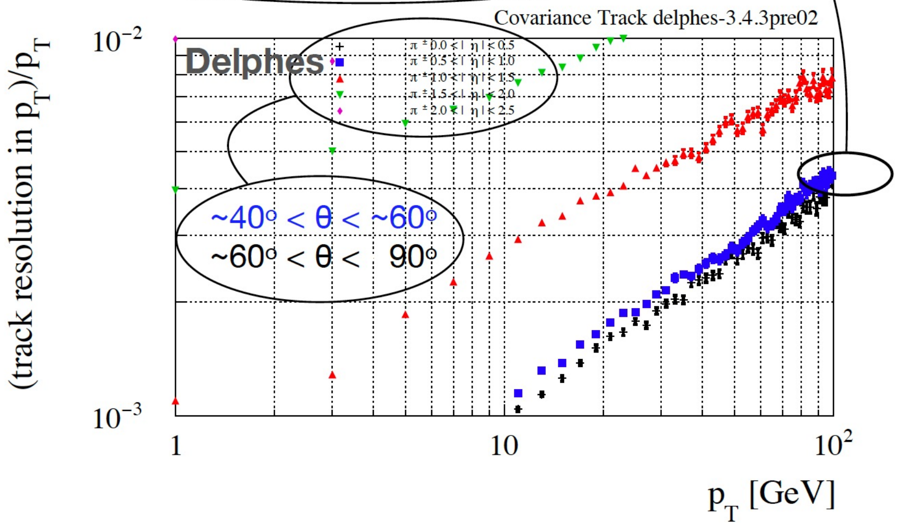
- DELPHES provides the response of a detector in a parameterised way
- Addition to the official IDEA Delphes card (containing already the DR calo) of the covariance matrix description for tracks → validation plots below
- Crucial feature for improving development of b- and c-tagging algos in a more realistic way

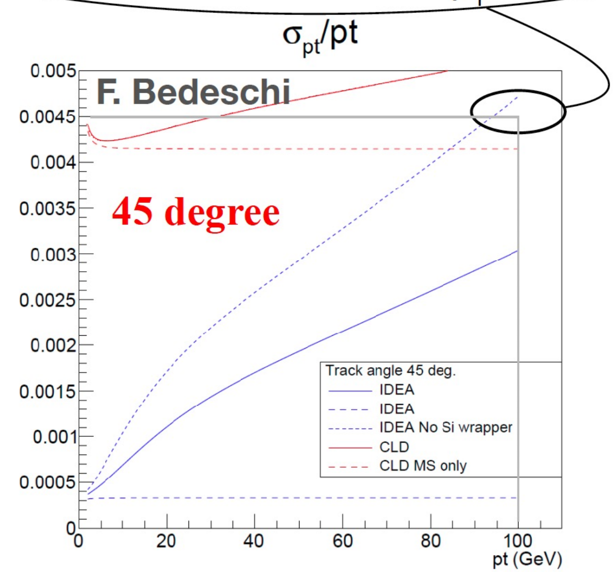
p_T resolution versus p_T

IDEA Baseline Geometry NO SILICON WRAPPER

Delphes [40° - 60°]@100 GeV: $\frac{\sigma_{p_T}}{p_T} \simeq 4.5 \cdot 10^{-3}$

Standalone [45°]@100 GeV: $\frac{\sigma_{p_T}}{p_T} \simeq 4.5 \cdot 10^{-3}$





Summary/Conclusions

- Full simulation of DCH is available in Geant4 and Key4Hep (integrated in the IDEA detector) + hits and tracks
- Kalman Filter using genFit2 is implemented for the IDEA detector
- Current PR for the IDEA detectors is developed using a local method approach
- It reached a good performance but need to be tested with jets and with expected background and improvements are possible
- Different PR approach based on Global method (ex. Hough transform based) could be investigated.
- Performance in agreement with expectations

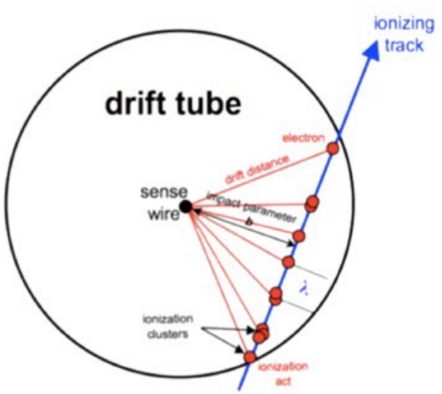
Backup

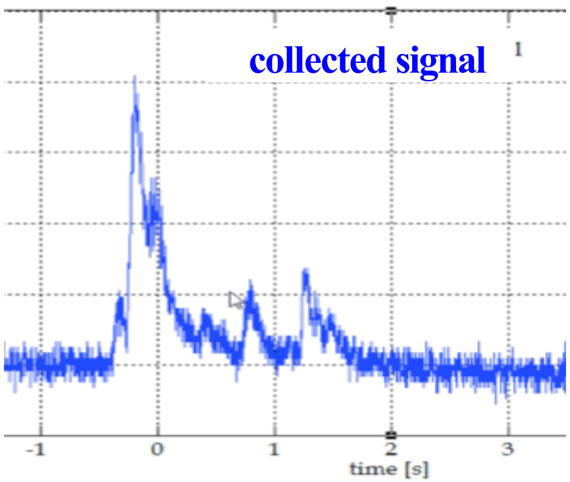
Particle identification

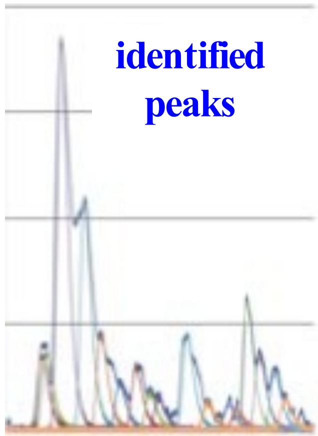
Cluster Counting/Timing and P.Id. principles

Principle: 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 identified efficiently.

- By counting the number of ionization acts per unit length (dN/dx), it is possible to identify the particles (P.Id.) with a better resolution w.r.t the dE/dx method.







- record the time of arrival of electrons generated in every ionisation cluster (≈12cm-1)
- reconstruct the trajectory at the most likely position

The cluster counting is based on replacing the measurement of an ANALOG information (the [truncated] mean dE/dX) with a DIGITAL one, the number of ionisation clusters per unit length:

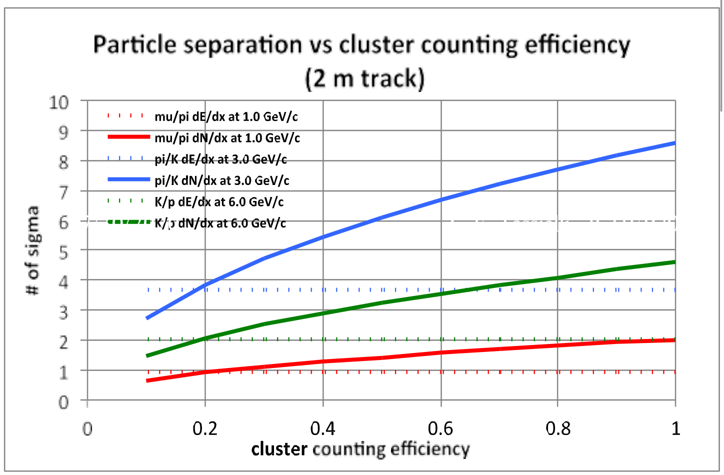
dE/dx	dN_{cl}/dx
Truncated mean cut (70-80%) reduces the amount of collected information. n = 112 and a 2m track at 1 atm give σ ≈ 4.3%	δ_{cl}= 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track give σ ≈ 2.0%

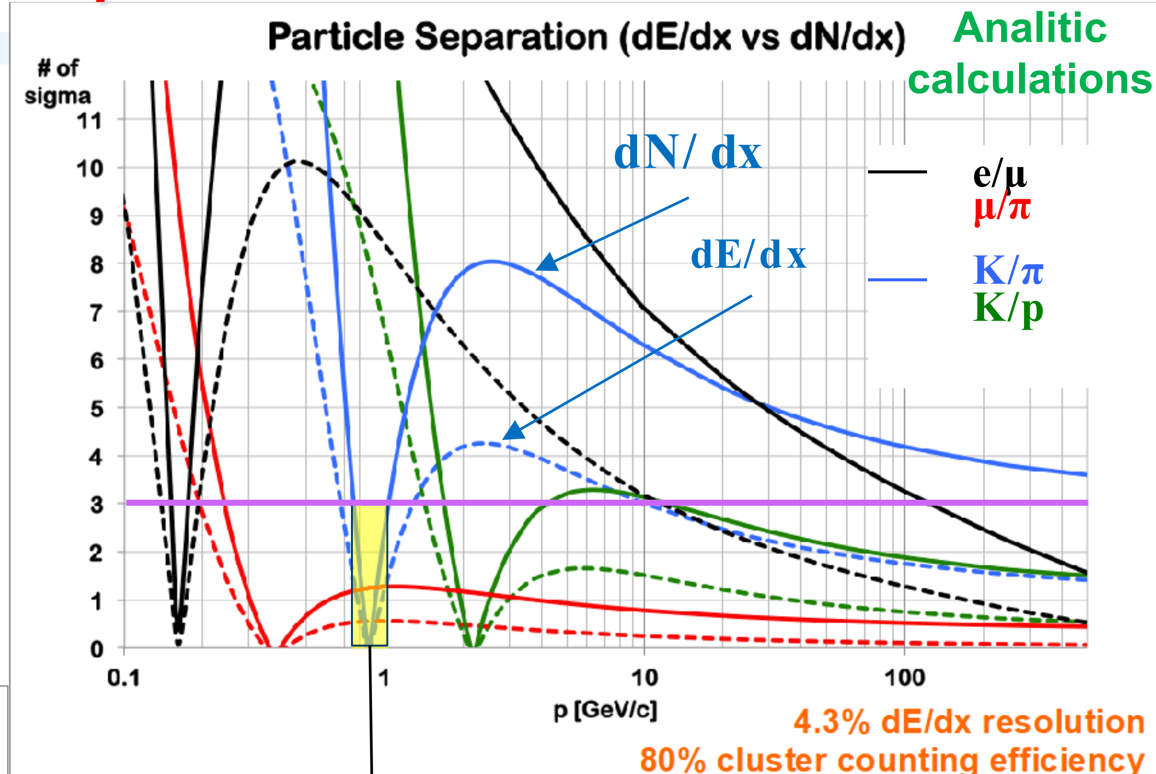
→ could improve also the spatial resolution

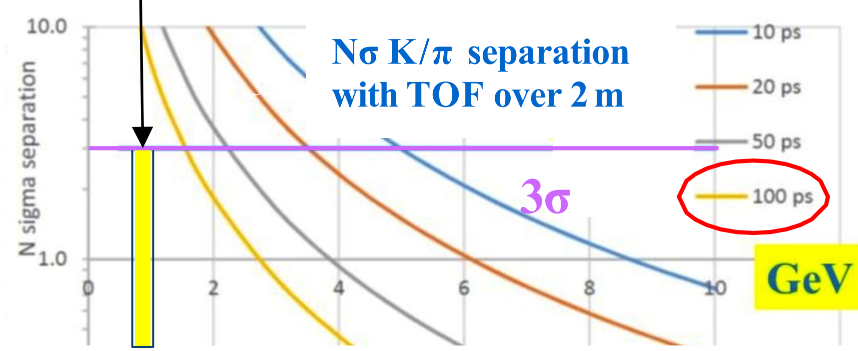
Design guidelines: particle identification

Cluster Counting/Timing in DCH for good P.Id. performance

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

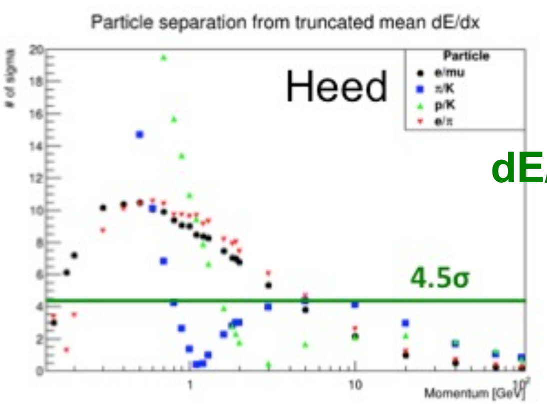




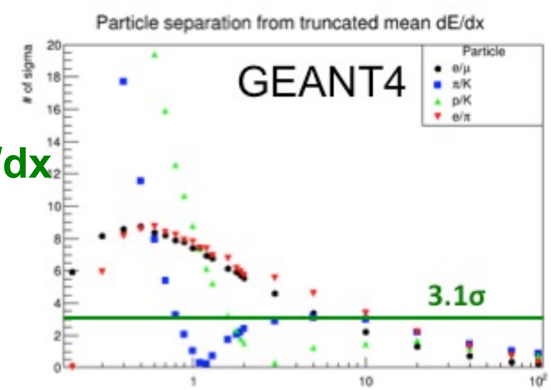


PID full simulation with cluster counting

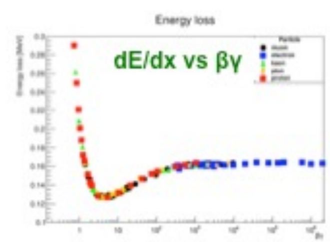
- **Garfield++ (Heed)** simulates in deep detail the ionization processes in the gas, but it would be extremely cumbersome to follow an ionization particle inside the large volume of a tracking detector.
- **GEANT4** simulates the interaction of a particle with all the materials of a large detector but 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**.

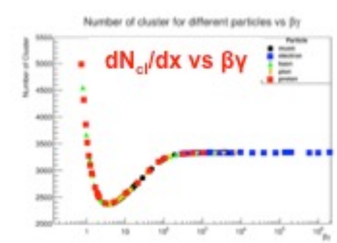


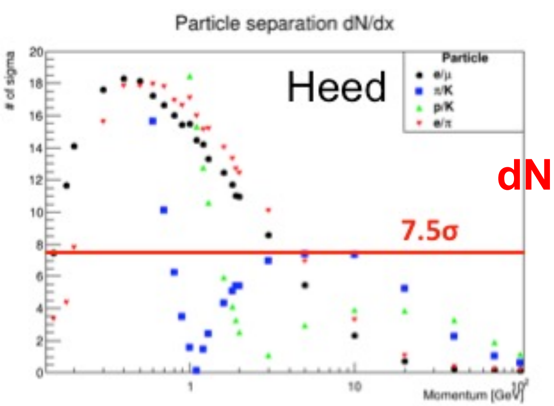
dE/dx



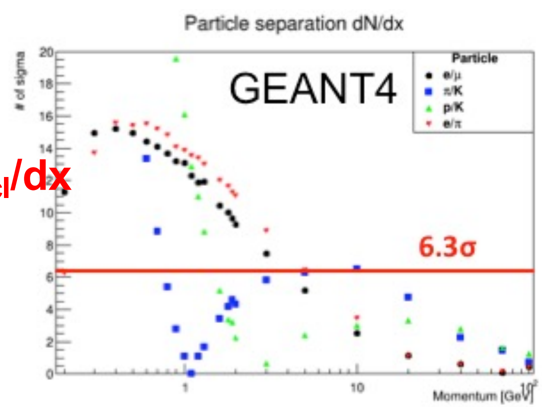
GEANT4







dN_{cl}/dx



dE/dx vs βγ

dN_{cl}/dx vs βγ

Motivations for a beam test:

PID full simulation with cluster counting

Open questions:

- Lack of experimental data on cluster density and cluster population for He based gas. Particularly in the relativistic rise region to compare predictions.
- 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?
- Despite a higher value of the dN_{cl}/dx Fermi plateau with respect to dE/dx, why this is reached at lower values of $\beta\gamma$ with a steeper slope?
- We are still waiting for answers from Heed and Geant4 developers to try to shed light on these questions
- These questions are crucial for establishing the particle identification performance at FCCee, CEPC and SCTF
- However, the only way to ascertain these issues is an experimental measurement!

Motivations for a beam test in 2021 and 2022 (1)

Beam test plans:

- 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.

- 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

- 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).

- 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

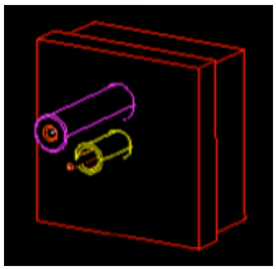
Motivations for a beam test in 2021 and 2022 (2)

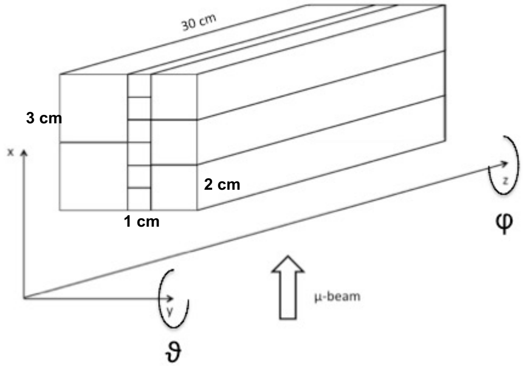
Advantages:

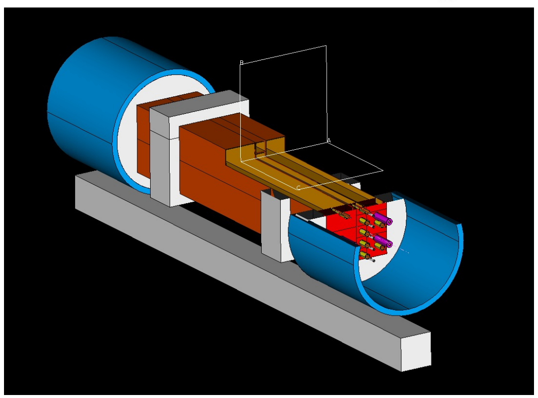
- no need of external trackers: only interested in path length inside the drift tube active volume
- no need of internal tracking (time-to-distance and t_0 calibrations, alignment, track finding and fitting algorithms, ...)
- no need to convert time to distance (just count clusters in the time domain)
- 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

Detector configuration for the beam test

conceptual setup:





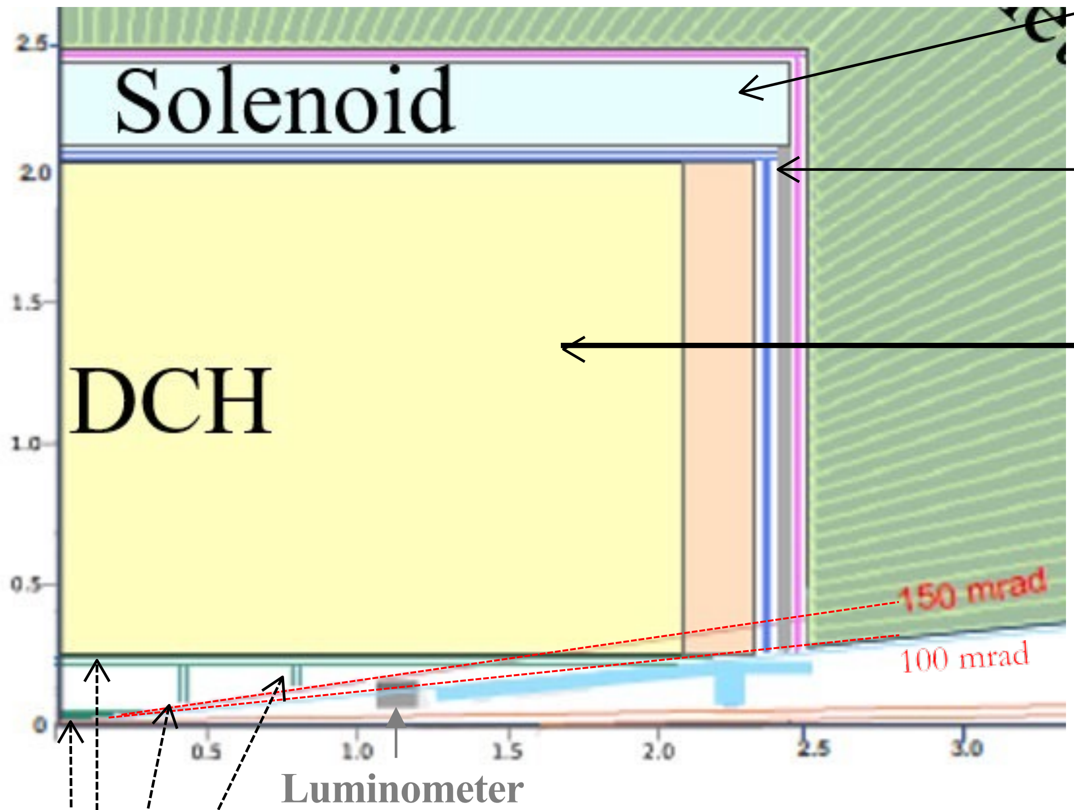


test configuration:

- 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)

Miscellanea

The IDEA tracking system



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

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})

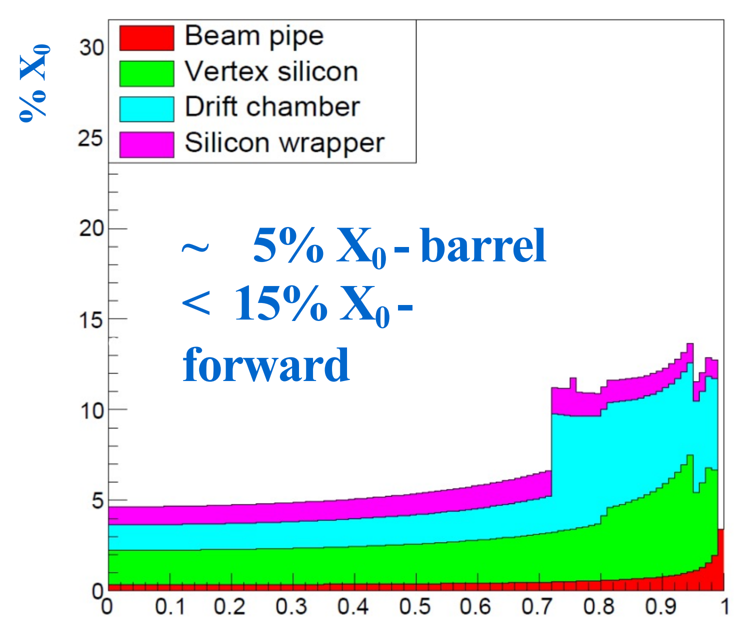
Vertex:

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

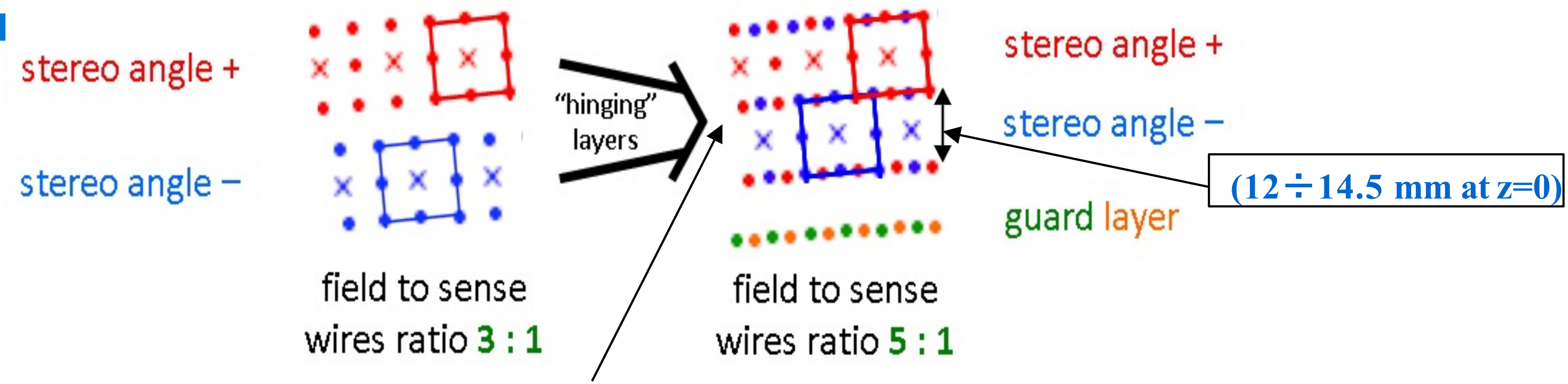
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

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

IDEA: Material vs. cos(θ)



The IDEA drift chamber



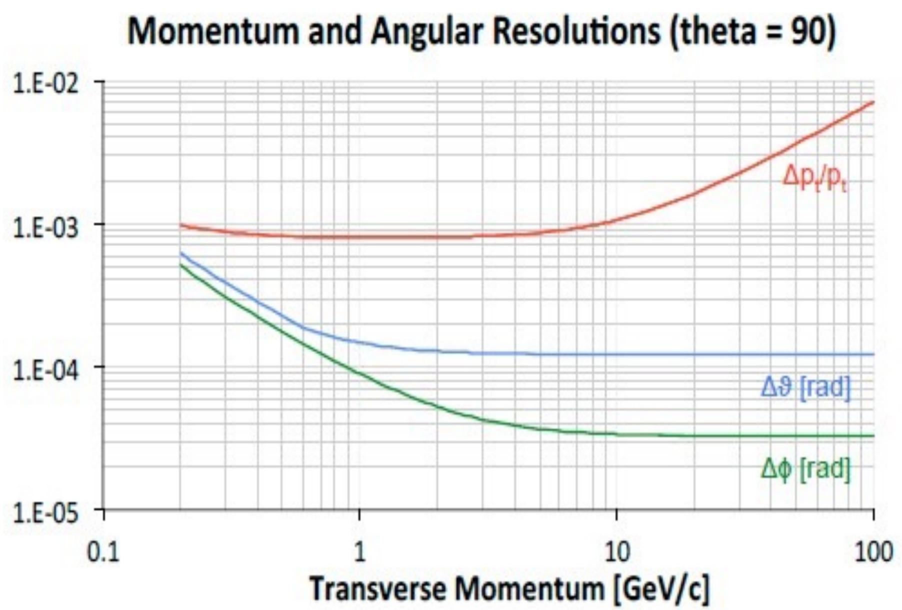
The wire net created by the combination of + and – orientation generates a more uniform equipotential surface

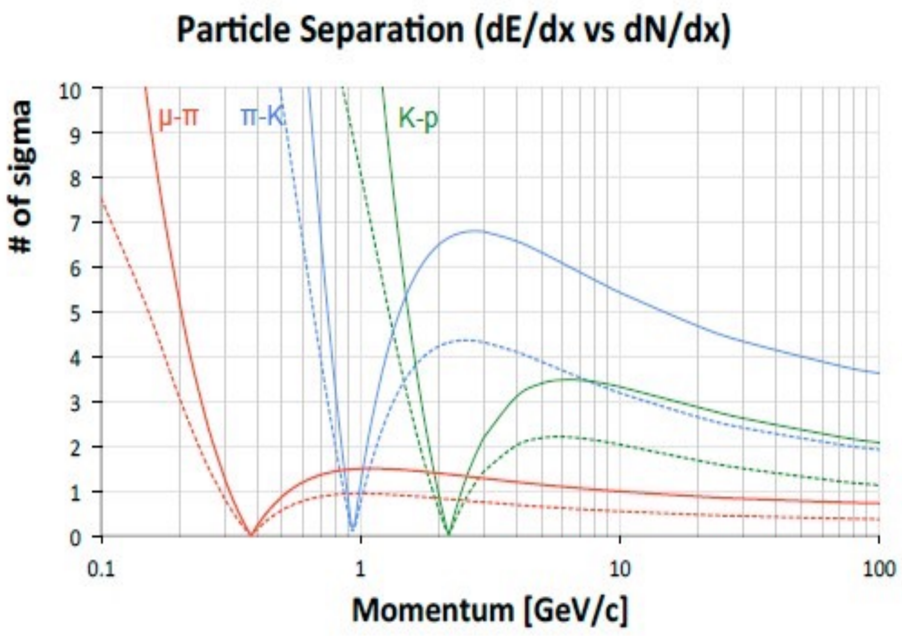
sense wires:	**20 mm diameter W(Au) =>**	**56448 wires**
field wires:	**40 mm diameter Al(Ag) =>**	**229056 wires**
f. and g. wires:	**50 mm diameter Al(Ag) =>**	**58464 wires**
	343968 wires in total	

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 Drift Chamber for the IDEA experiment





$\Delta p_t/p_t = (0.7p_t + 8.3) \times 10^{-4}$

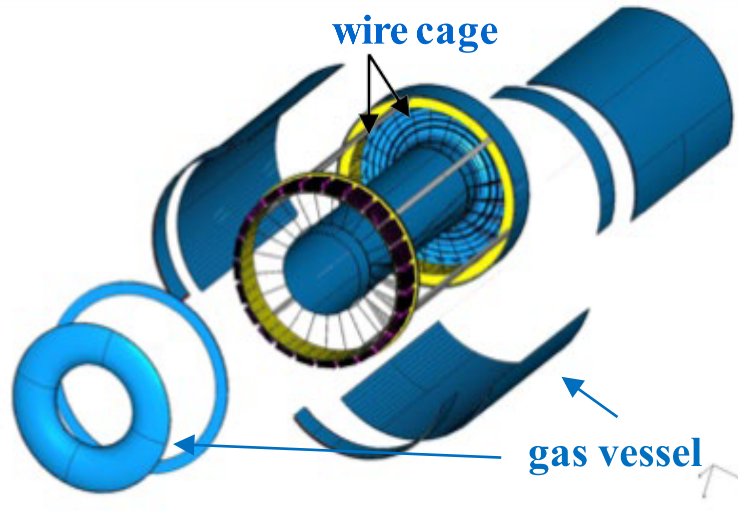
$\Delta\vartheta = (1.1 + 9.4/p) \times 10^{-4}$ rad

$\Delta\varphi = (0.33 + 9.4/p) \times 10^{-4}$ rad

dE/dx = 4.3 %

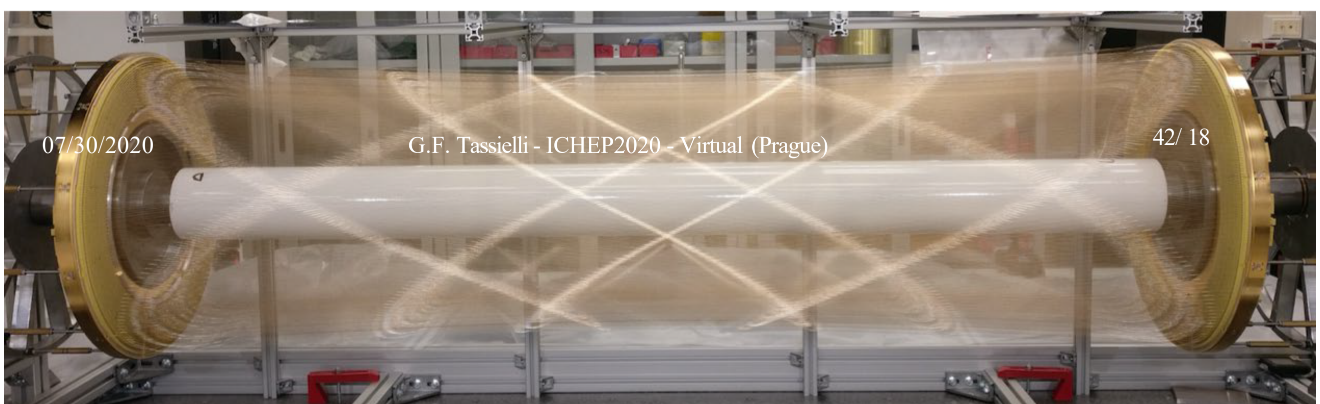
dN/dx = 2.2 % (at $\varepsilon_N = 80$ %)

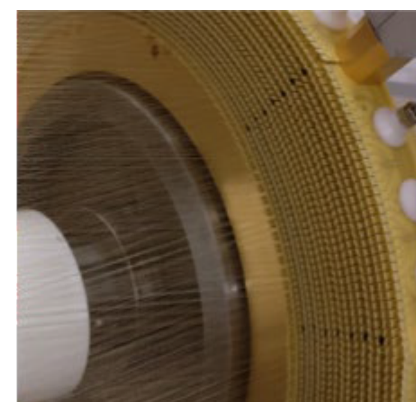
Novel approach at construction technique of high granularity and high transparency Drift Chambers



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

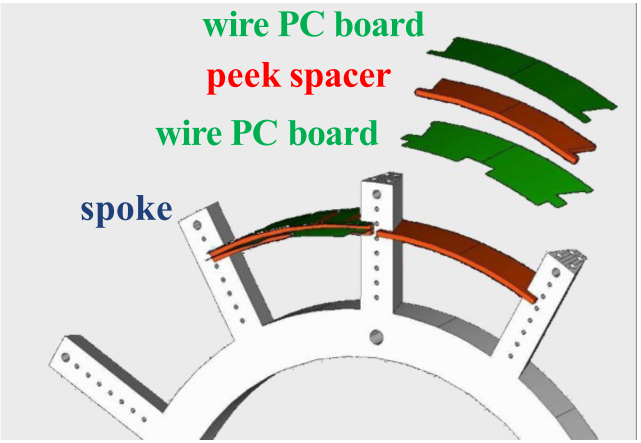




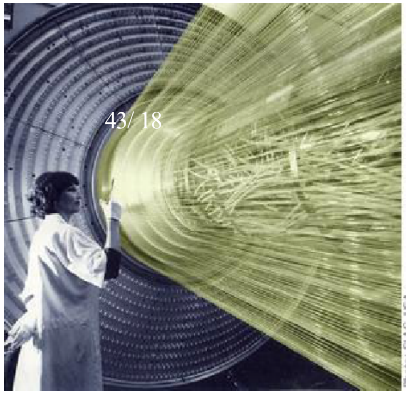
Novel approach at construction technique of high granularity and high transparency Drift Chambers

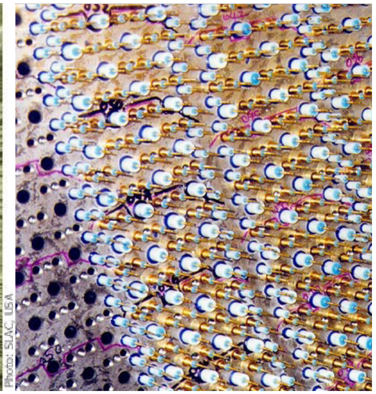
The solution adopted for MEG II:

- **end-plates numerically machined from solid Aluminum (mechanical support only);**
- **Field, Sense and Guard wires placed azimuthally by a Wiring Robot with better than one wire diameter accuracy;**
- **wire PC board layers (green) radially spaced by numerically machined peek spacers (red) (*accuracy< 20 μm*);**
- **wire tension defined by homogeneous winding and wire elongation (*ΔL = 100μm corresponds to ≈ 0.5g*);**
- **Drift Chamber assembly done on a 3D digital measuring table;**
- **build up of layers continuously checked and corrected during assembly;**
- **End-plate gas sealing done with glue.**

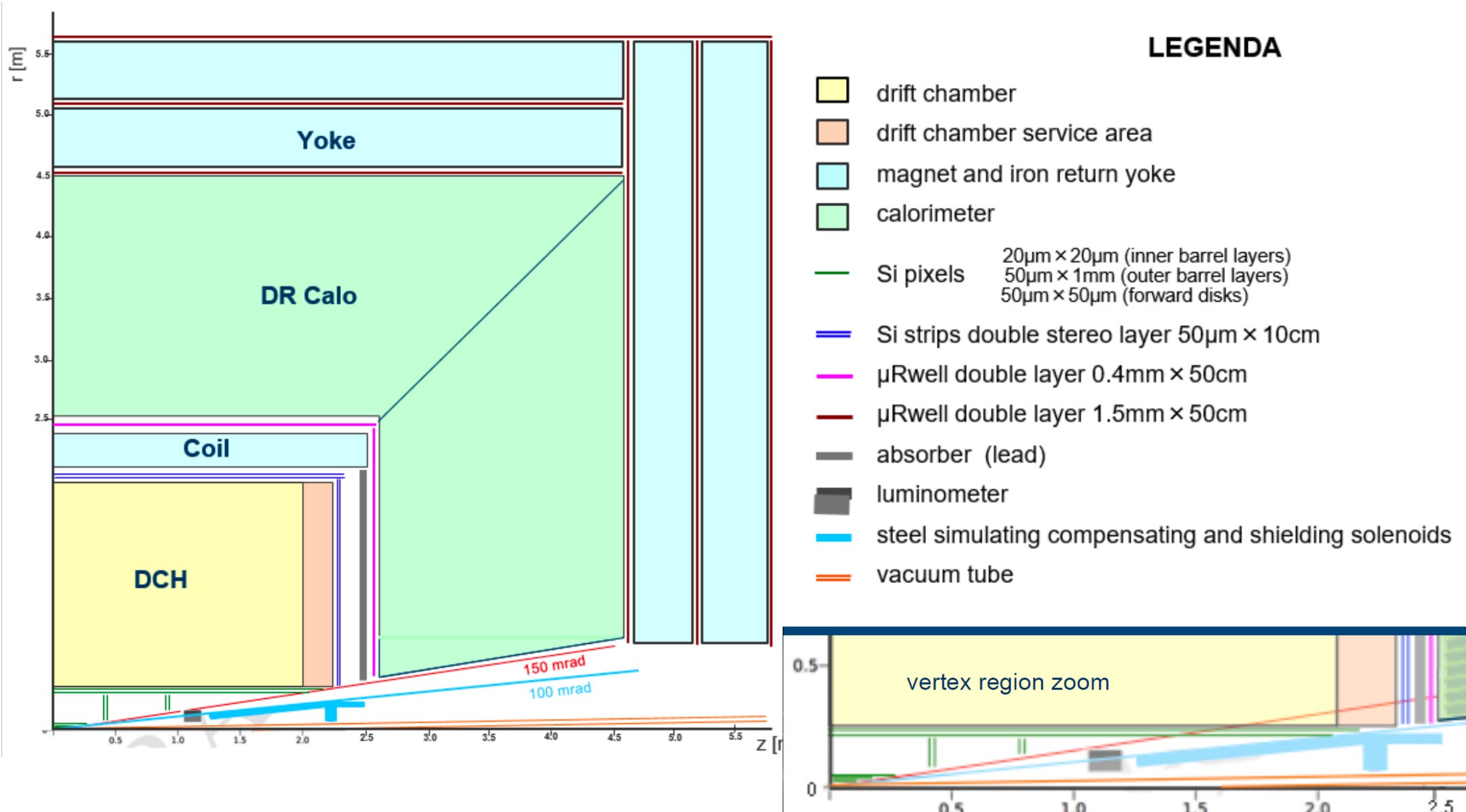


(~ 12 wires/cm²) impossible to be built with a conventional technique based on feedthrough:





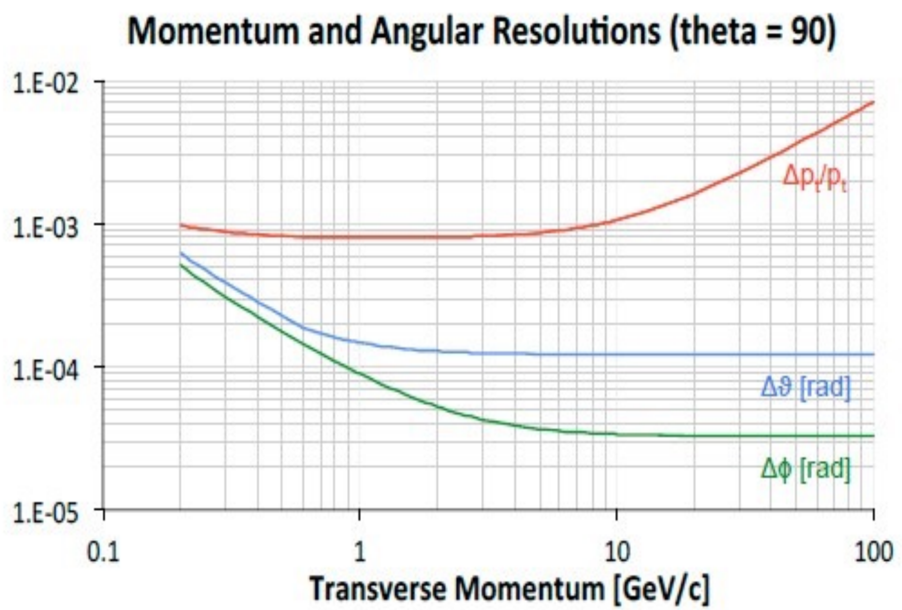
The IDEA detector at e^+e^- colliders (2)

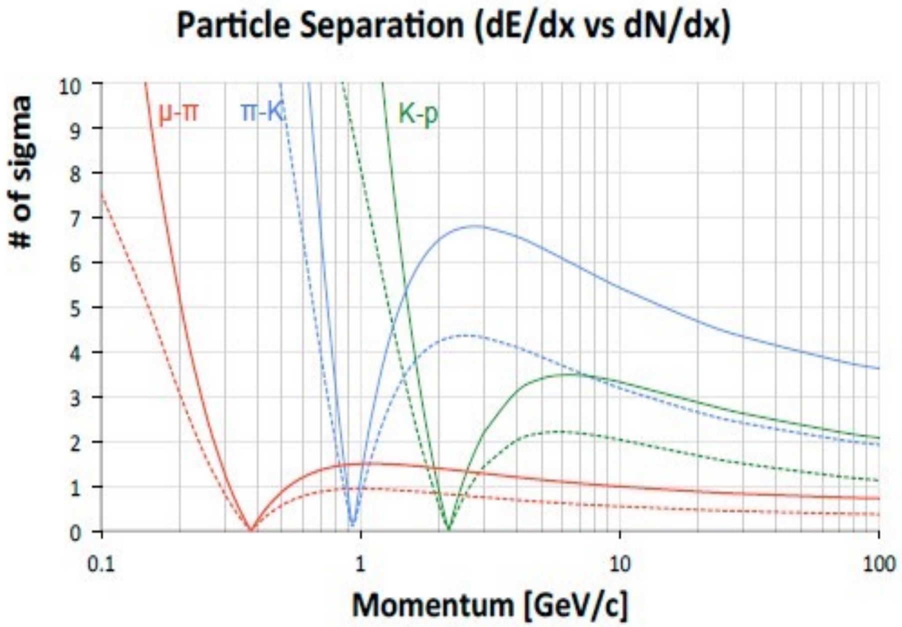


Tracking → 150 mrad → No material in front of luminometer

Calorimetry → 100 mrad

The Drift Chamber for the IDEA experiment





$\Delta p_t/p_t = (0.7 p_t + 8.3) \times 10^{-4}$

$\Delta\vartheta = (1.1 + 9.4/p) \times 10^{-4}$ rad

$\Delta\varphi = (0.33 + 9.4/p) \times 10^{-4}$ rad

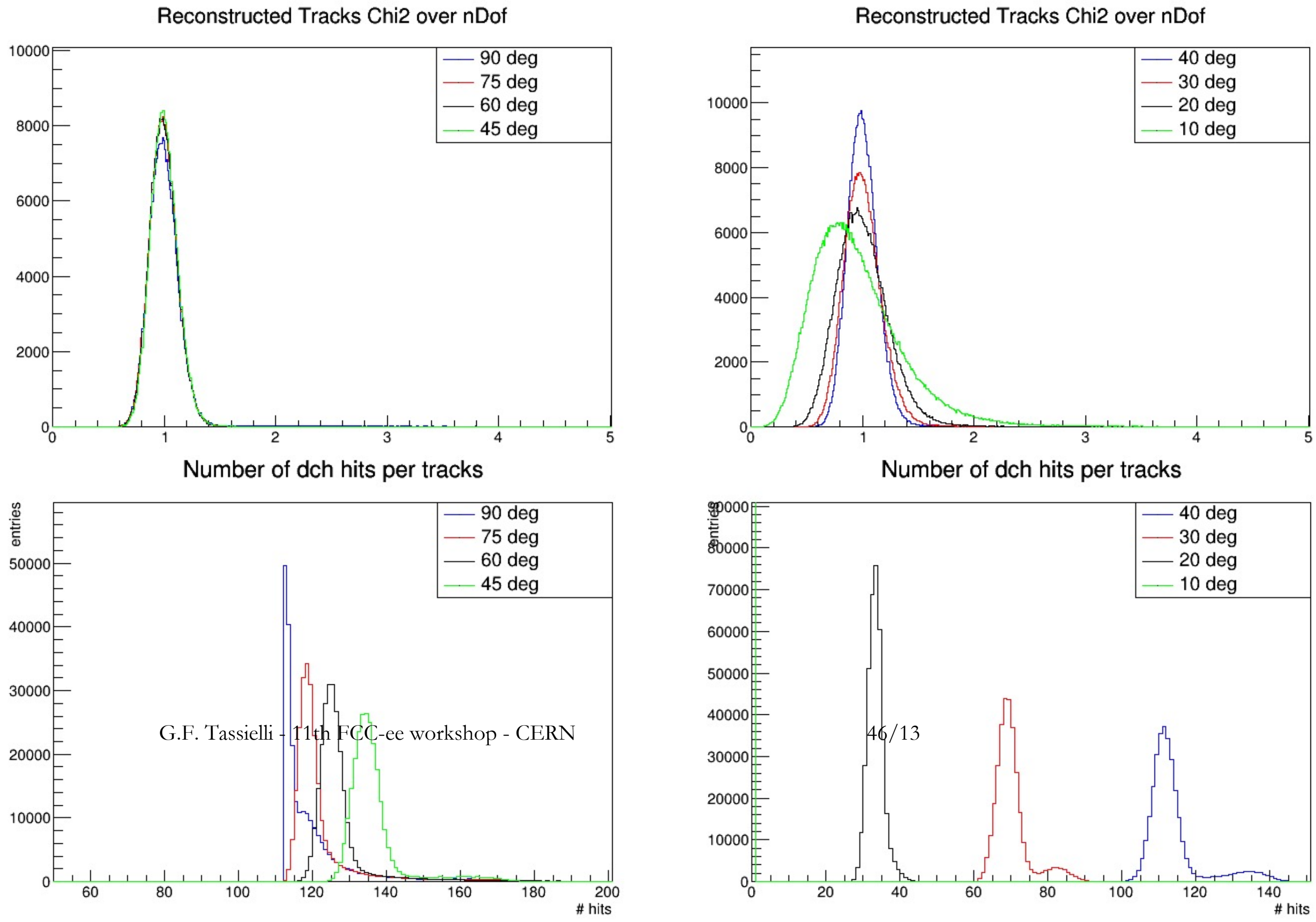
dE/dx = 4.3 %

dN/dx = 2.2 % (at $\varepsilon_N = 80$ %)

IDEA – layout v1 – Expected tracking performance

χ^2 /ndof

N hits fitted (DCH)



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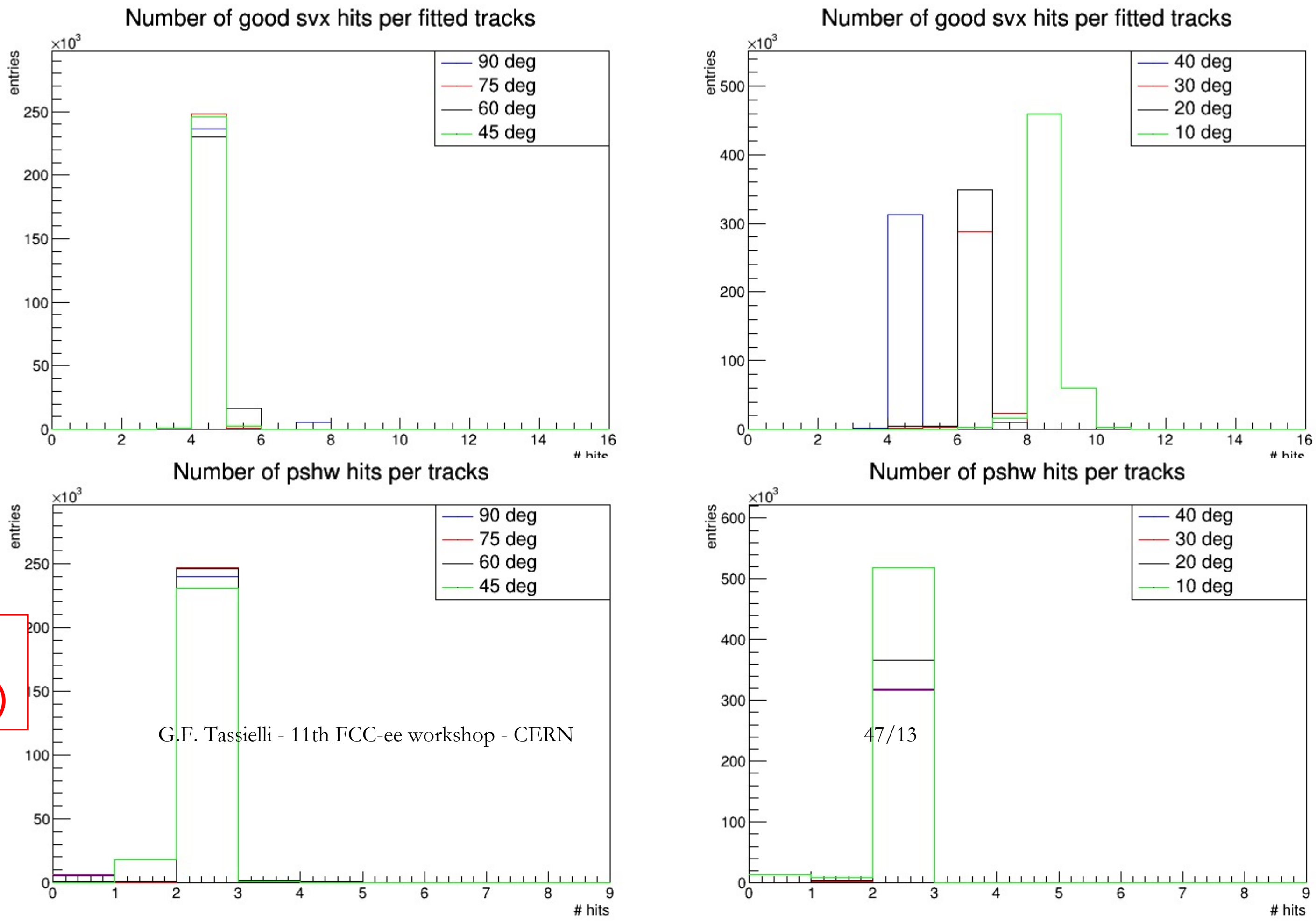
46/13

IDEA – layout v1 – Expected tracking performance

N hits fitted (SVX)

N hits fitted (SOT+PSHW)



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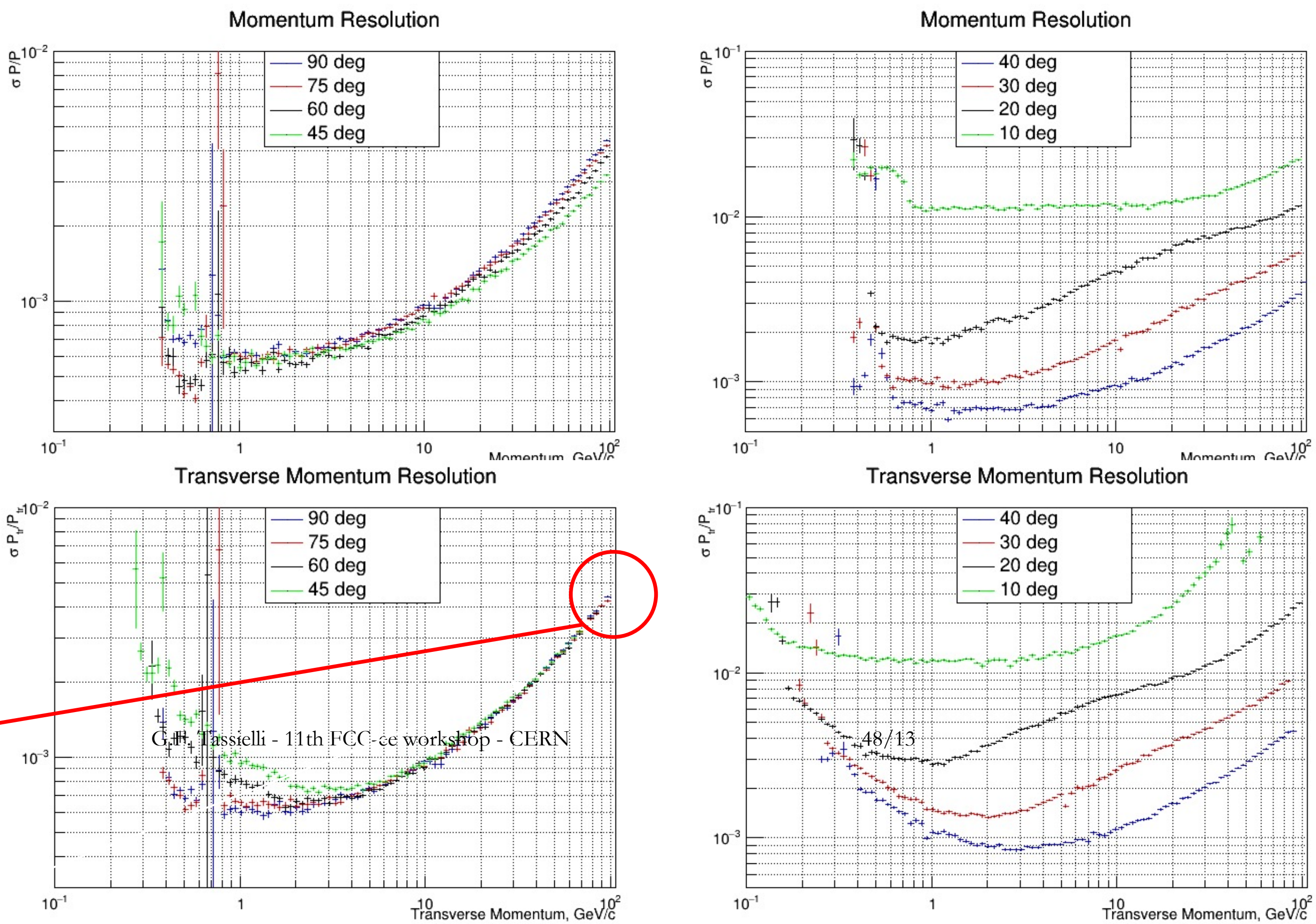
IDEA – layout v1 – Expected tracking performance

p

pt

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

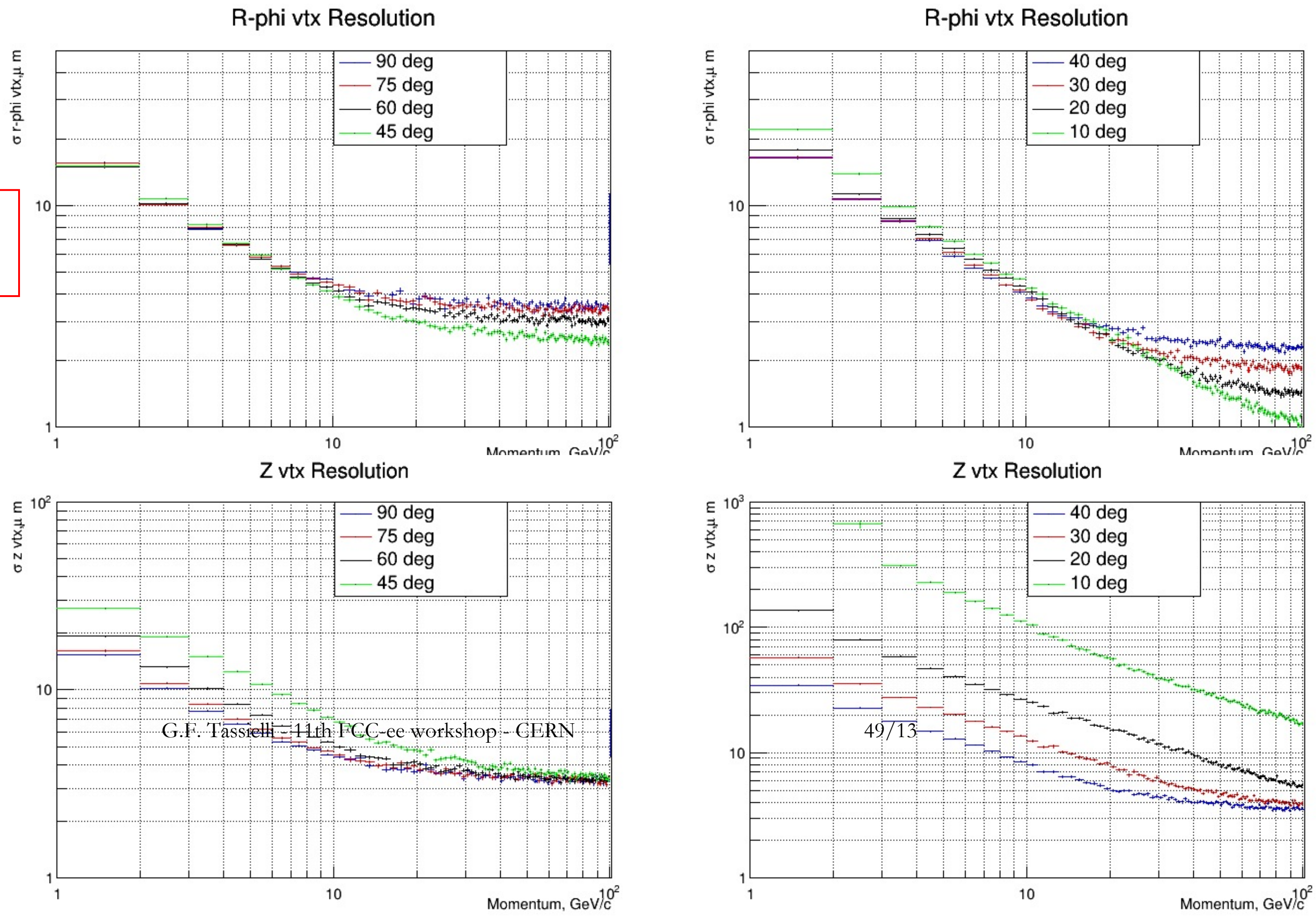
$$\frac{\sigma_{p_t}}{p_t^2} = 5 \bullet 10^{-5}$$



IDEA – layout v1 – Expected tracking performance

impact parameter

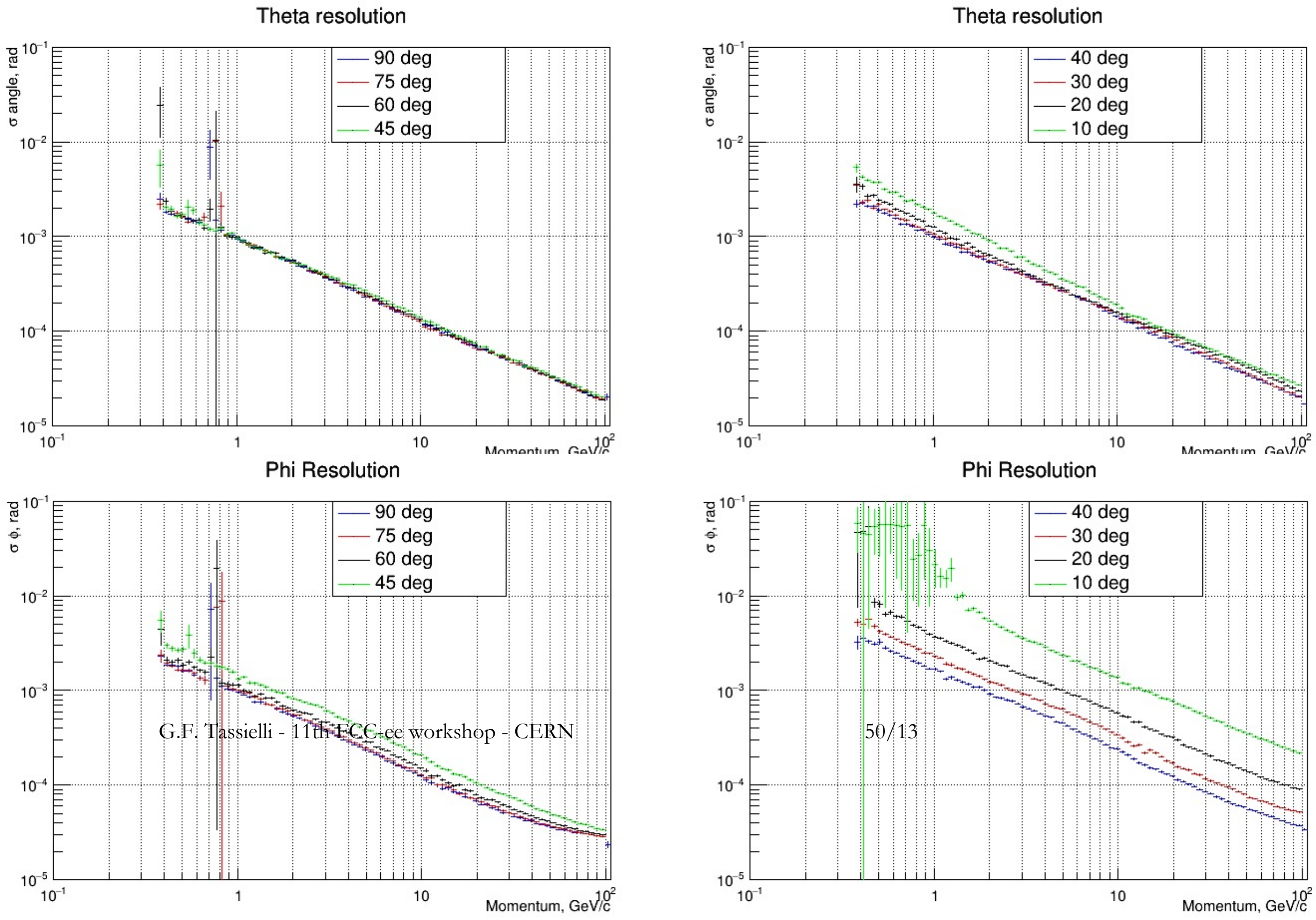
Z



IDEA – layout v1 – Expected tracking performance

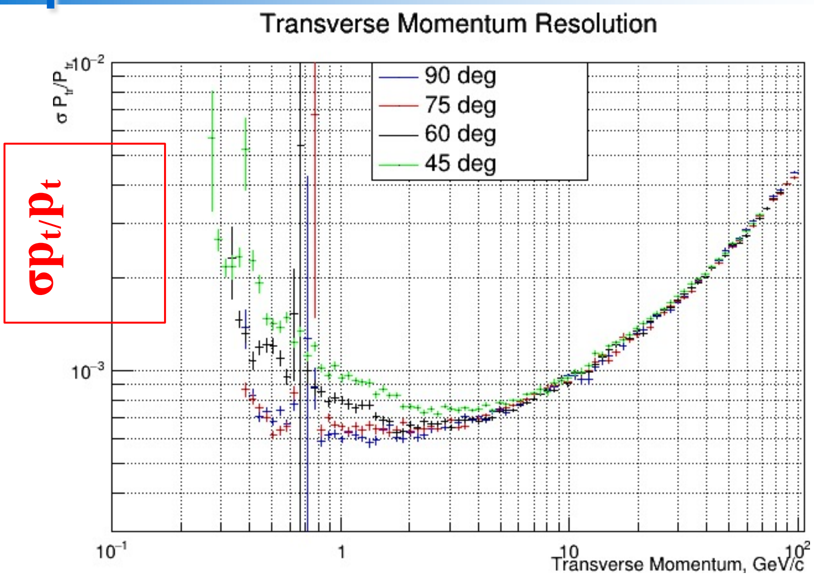
theta

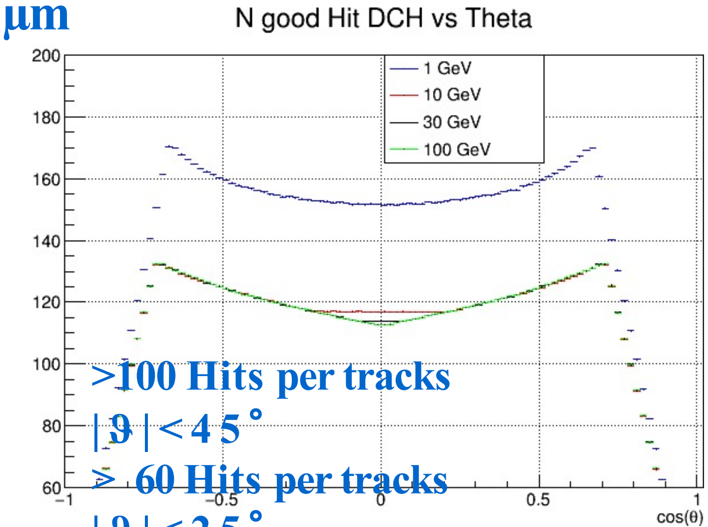
phi



Expected simulated performance

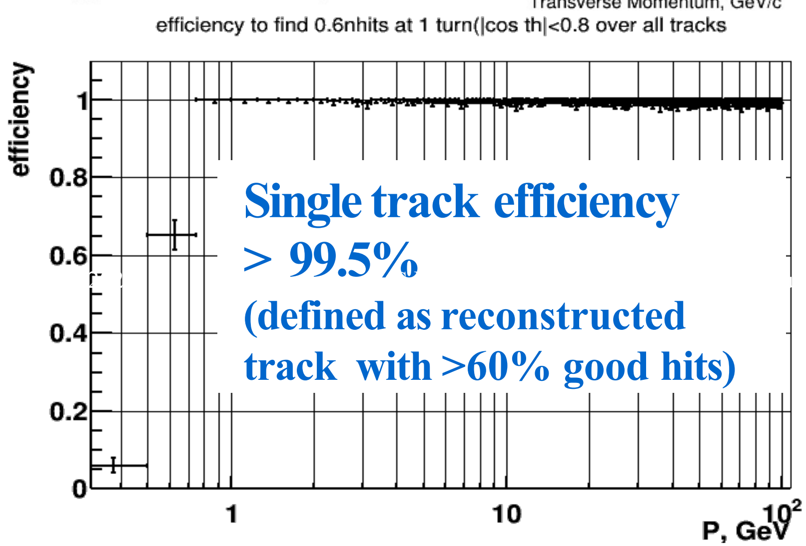
assumed: σ_d = 100 μm and (conservative for Si) σ_{Si} = pitch/$\sqrt{12}$ μm





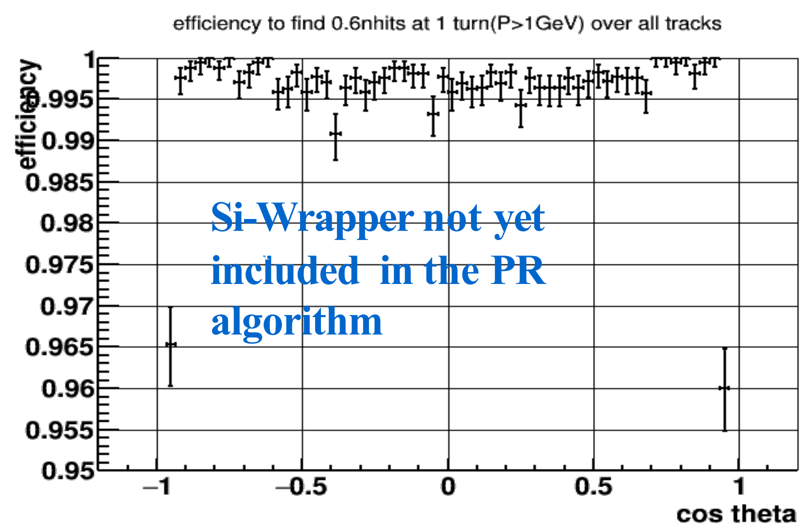
>100 Hits per tracks |ϑ|<45°

> 60 Hits per tracks |ϑ|<25°



Single track efficiency > 99.5%

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

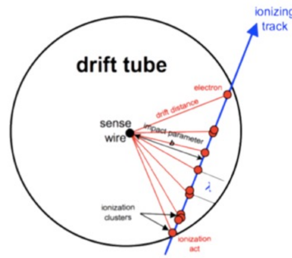


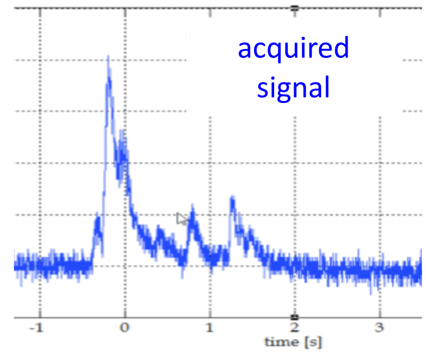
Si-Wrapper not yet included in the PR algorithm

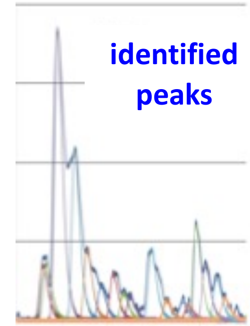
Cluster Counting/Timing and P.Id. expected performance

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*

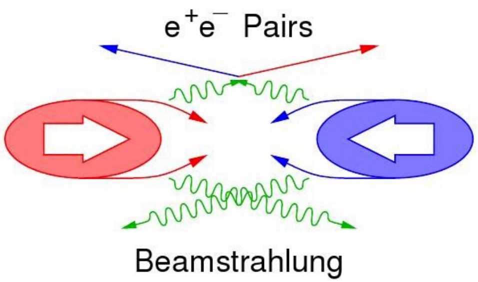
δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track give

σ ≈ 2.0%

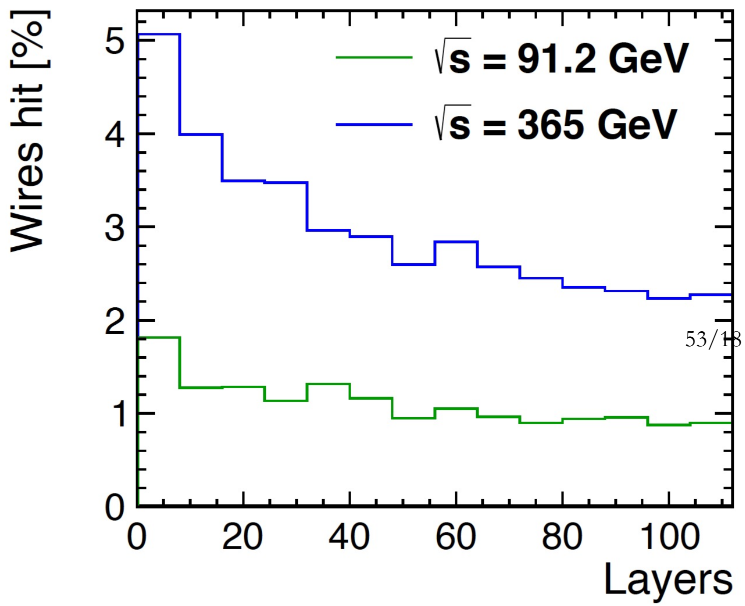
A small increment of iC_4H_{10} from 10% to 20% (δ_{cl} = 20/cm) improves resolution by 20% (σ ≈1.6%) at only a reasonable cost of multiple scattering contribution to momentum and angular resolutions.

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

Expected simulated performance



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%



G.F. 53/18