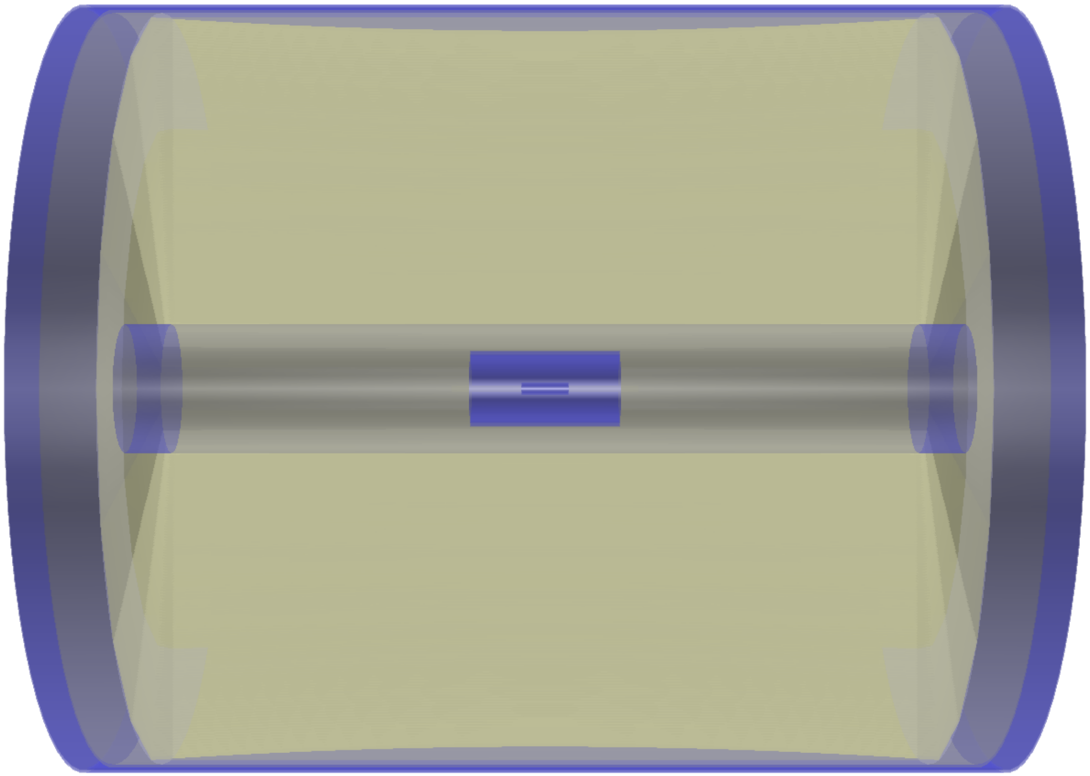
IDEA Tracking
Simulation Status and Future Plans



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IDEA tracking system geant simulation

Currently we implemented a standalone geant4 simulation as a starting point:

- **Geant4 10.01 p03**
- Physics List: QGSP_BERT 4.0
- 2T Constant Magnetic Field, G4ClassicalRK4 particle motion integrator engine
- particles generator used: General Particle Source

The code is organized in a **modular** way, the geometry description is **“quite” plug and play**, it is possible to import in a framework with minor changes.

We use the **ROME** (developed for MEG experiment) framework to manage the output data and run the track fitting and reconstruction:

https://midas.psi.ch/rome/

The **GenFit2** is interfaced to perform this preliminary study on the expected tracking system performances on track fitting.

We started to perform Pattern Recognition studies

IDEA tracking system geant simulation

Simulation status:

- The Drift Chamber (**DCH**) geometry is described at a great level of details
- A simplified Hit creation module is used for this preliminary studies:
  - no XT relation used (is easy to switch it on), only pure geometrical information are used
  - eventual tracks hits pile-up is not well taken into account
  - Single Cell resolution is assumed constant and gaussian at a level of 100 μm

- The Silicon Vertex (**SVX**) is simplified, just a layer of equivalent material arranged in ladders
- A simplified Hit creation module is used for this preliminary studies:
  - no sensor dead time is taken into account
  - eventual tracks hits pile-up is not well taken into account

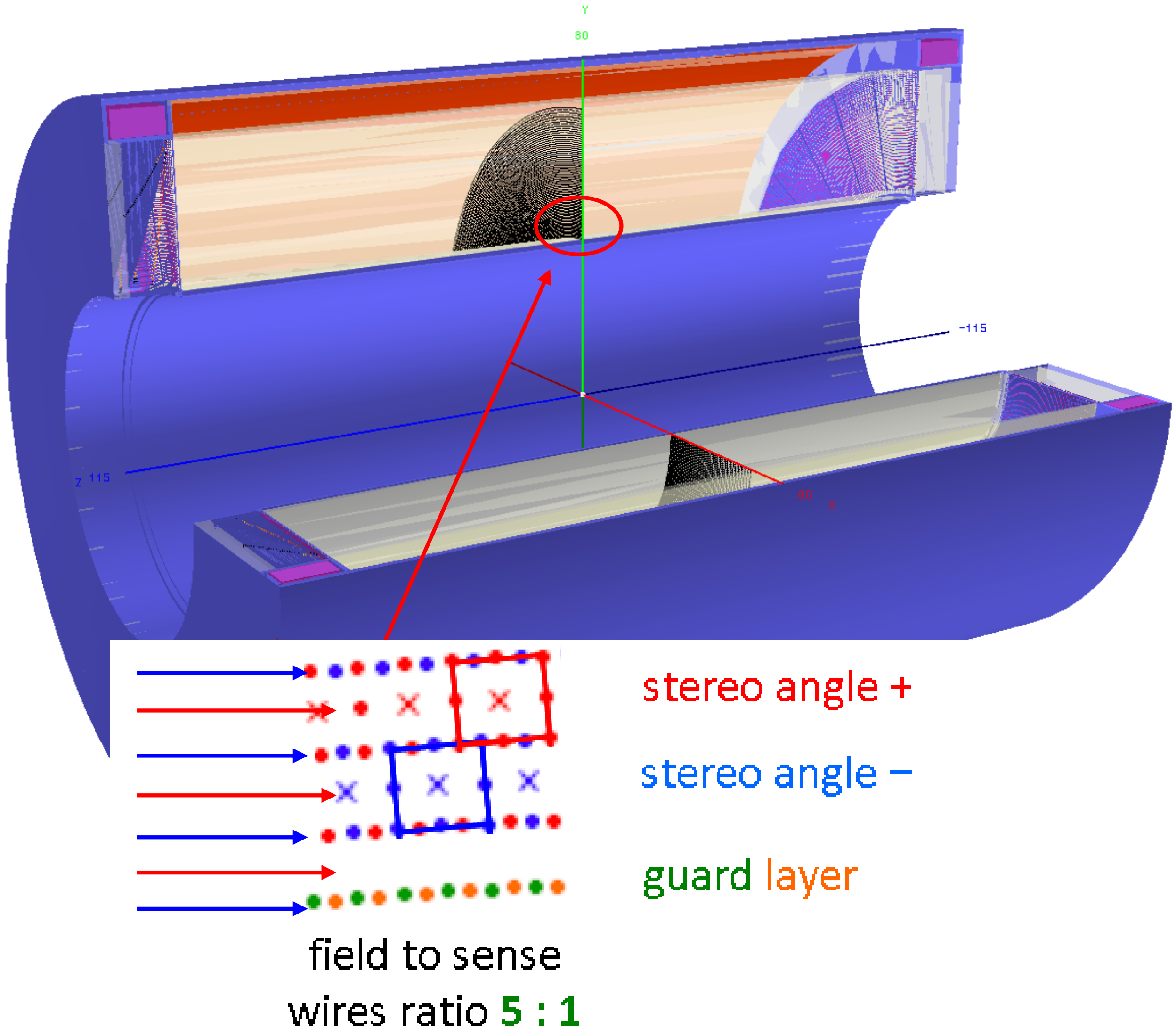
- The Pre-Shower Tracker (**PSHW**) is a copy of the SVX just with different dimensions

The geometry description is parametric, it is easy to try different configurations.

IDEA DCH geometry simulation

It is simulated with a high level of details (~99%) and is ***fully parametric***.

The geometry description was optimized for geant4 navigation (run time).
The gas volume is divided in a set of hyperboloid shells (Blue and Red arrows) and the right voxelization factor is chosen for each layer.
Blue ones to contain only the field wires.
Red ones to contain the central layers wires.

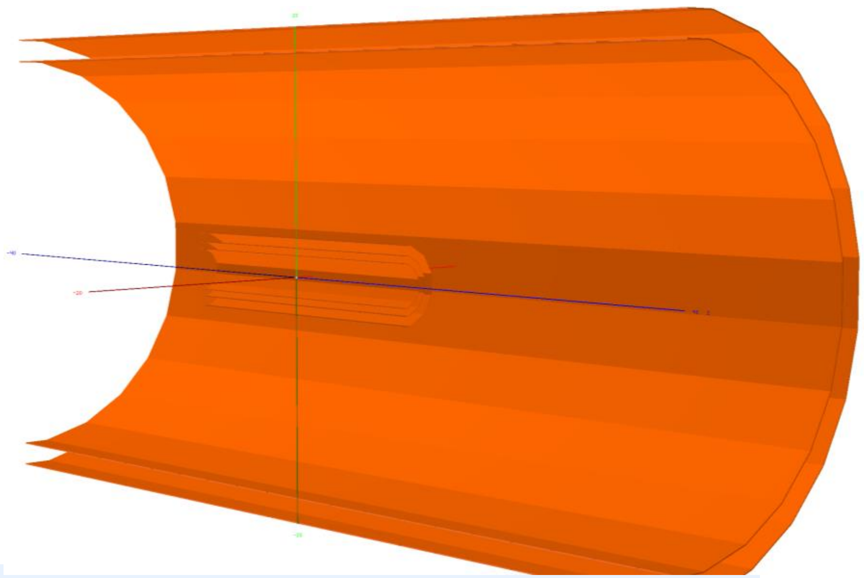


Starting point: Hit simulation approaches

- Common steps:
  - reject the ionization acts releasing less that 10 eV in the gas or that has a G4Step length less than 5µm;
  - assign the G4Step to the corresponding drift cell (resolve some geometric equations);
  - evaluate the Distance of Closest Approach for each track crossing a cell;
  - convert the DCA in time, smear it with the resolution (converted in time) and sum it to the signal propagation time along the wire and to the particle flight time;
  - all the obtained hit times for a cell are time ordered;
- Simple model for the hit creation:
  - Constant drift velocity (ex. 2 cm/µs), B field effects neglected;
  - spatial resolution, gaussian and constant with respect to the impact parameter, (~ 100µm);
  - the hits with a time difference shorter than the maximum drift time (for the cell) are grouped together;
  - (eventually evaluate the expected Number of Clusters);
  - Create the hit needed by the reconstruction;
- *Detailed model (not yet implemented):*
  - *Use a realistic XT relation;*
  - *Simulate in detail the Cluster generation and the Signal Waveforms;*
  - *Analyze the waveform and extract the reconstructed Impact parameter and dN/dX and dE/dx.*

IDEA SVX geometry simulation

- Currently the layers are just made of Si with thickness equivalent to the expected layer X_0 (it is possible to describe a layer as a stack of different shells of different materials);
- The dimensions of the ladders are just evaluated to cover the space with reasonable dimensions;
- The ladders are disposed close to each other (not in a realistic way), there can be some dead space (at a level of few µm);



Example of the SVX configuration file

```
string svx.motherVolMat = "G4_AIR";

string svx.extFile          =    "";
double svx.z0               =     0;

int    svx.geomType         =    00;   //decimal digit:magior version, unit digit:minor version
                                       //  00:dummy geometry, the ladder has cylindrical shape instead of plan

//double svx.voxelization     =     0;   //Choose voxelization method for the gas volumes that contain wires, 

bool   svx.doDetailedSurfCheck = false;
bool   svx.debugLayer       = false;

// Cell parameter needed only for the square cell case

int    svx.nLayers          =     7;
vector<double> svx.LayersInRad        = { 17.0, 23.0, 31.0, 180.0, 200.0, 330.0, 340.0};
vector<int> svx.nPhiSectors           = {12, 12, 12, 24, 24, 36, 36};
vector<int> svx.nLaddersPerSector     = {10, 10, 10, 20, 20, 30, 30};
vector<double> svx.LaddersHalfLength  = {12.5, 12.5, 12.5, 20, 20, 25, 25};  // Per Layer (The ladder are supp
vector<double> svx.LaddersThickness   = {0.28, 0.28, 0.28, 0.94, 0.94, 0.94, 0.94}; // Per Layer
vector<int> svx.ROTypes               = {1, 1, 1, 1, 1, 1, 1}; //1: Pixel; 2: Strip // Per Layer
vector<double> svx.ROfirstSideDim     = {0.02, 0.02, 0.02, 0.02, 0.02, 0.02, 0.02}; // Per Layer
vector<double> svx.ROfirstSideInsul   = {0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005}; // Per Layer
vector<double> svx.ROSecondSideDim    = {0.02, 0.02 0.02, 0.02, 0.02, 0.02, 0.02}; // Per Layer
vector<double> svx.ROSecondSideInsul  = {0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005}; // Per Layer
vector<double> svx.ROangle            = {0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0}; // Per Layer


// First Layer Ladder description
int    svx.l1.ld.nShells =       1;
vector<string> svx.l1.ld.ShellsMaterial = { "G4_Si" };
vector<double> svx.l1.ld.ShellsThickness = { 0.28 }; //summed with RO thickenss must be consisten with the tot
int    svx.l1.ro.nShells =       1;
vector<string> svx.l1.ro.ShellsMaterial = { "G4_Si" };
vector<double> svx.l1.ro.ShellsThickness = { 0.0 }; //summed with Ladder thickenss must be consisten with the
```

IDEA geometry simulation

Following dimensions reported by Mogens talks at FCC-Berlin

- **Pipe**: equivalent to 0.48% X_0 at radius of 15.6 mm (170 µm of Ti, *to avoid overlaps*)
- **SVX:** (for this study) 7 layers of Si:
  - radii: 17.0, 23.0, 31.0, 180.0, 200.0, 330.0, 340.0 mm;
  - lengths: 250, 250, 250, 800, 800, 1500, 1500 mm (coverage not checked);
  - thickness 0.28, 0.28, 0.28, 0.94, 0.94, 0.94, 0.94 mm
  - pixel 20 µm;
- **DCH**: (gas He 90% i-C_4H_{10} 10%)
  - radii: 345, 2000 mm:
  - length: 4000 mm;
  - Cell: 56448;
  - Layers: 112;
  - Cell size: 11.85 – 14.7 mm;
  - Stereo angle: 48 - 250 mrad.
- **PSHW**: 2 active layers (+ 2 Lead radiator layers):
  - radii: 2012, 2027 mm (2004, 2014);
  - Lengths: 4800, 4800 mm (4800, 4800);
  - thickness 0.94, 0.94 mm (6, 11)
  - pixel 70 µm;

IDEA single track fitting

We simulated single tracks at fixed theta (65 deg) and we fitted all tracks hits with Kalman filter (genfit2).

Moreover we performed a scan of the resolutions as a function of the theta angle for tracks of fixed momenta (1, 3, 10, 30, 100 GeV).

Only a quality cut on Chi2/nDof < 25 was applied.

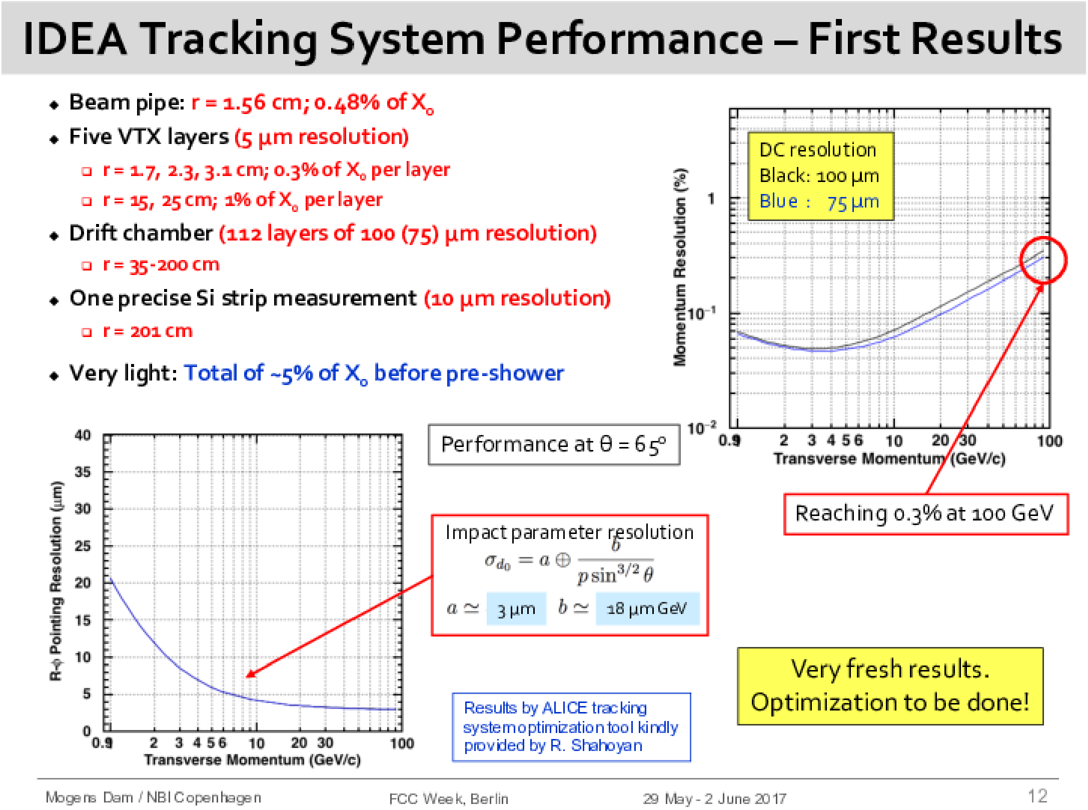
To be compared with Mogens fast MC results:

$\sigma_p(1\text{GeV}) \sim 0.07\ \%$

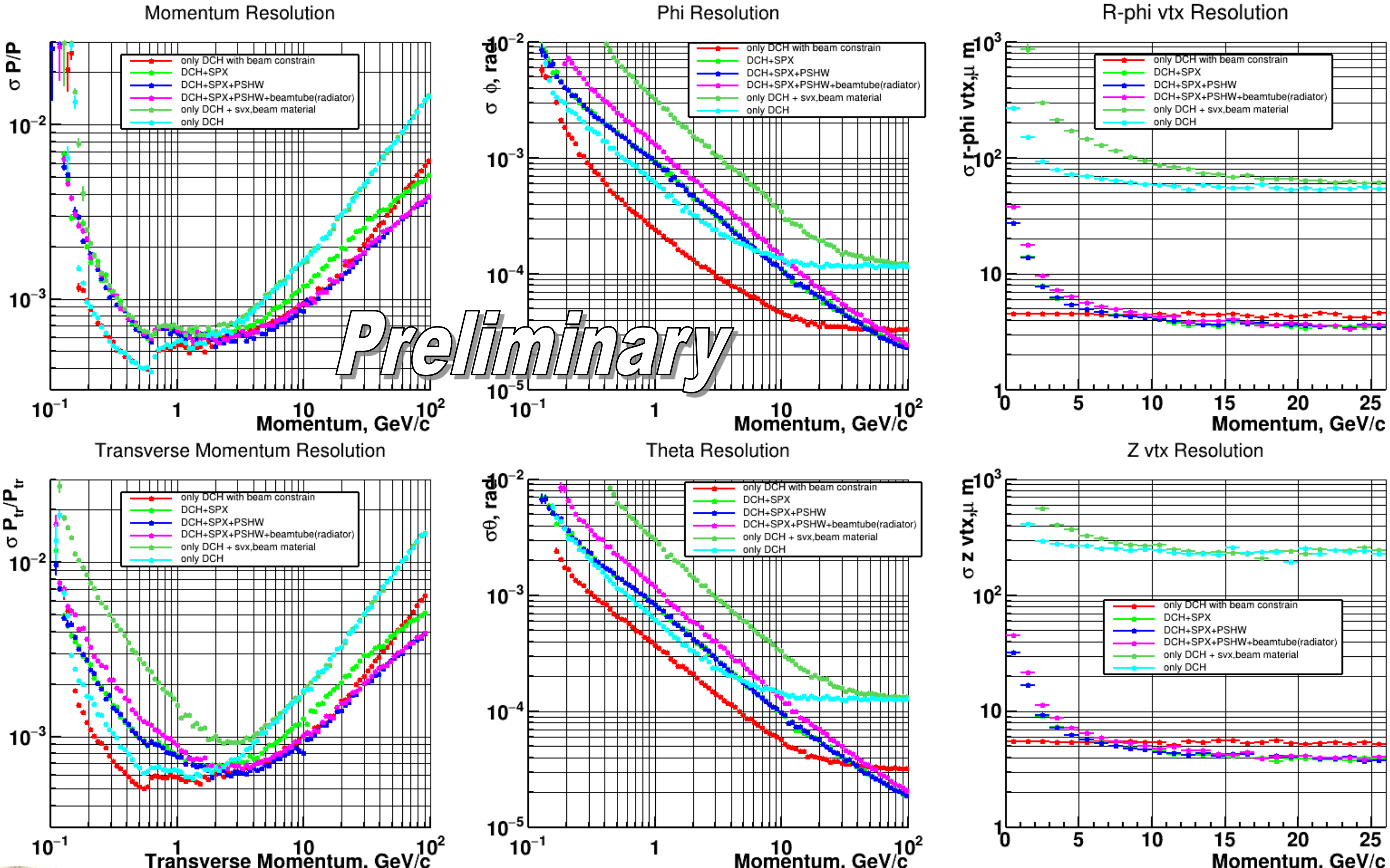
$\sigma_p(100\text{GeV}) \sim 0.4\ \%$

$\sigma_d(1\text{GeV}) \sim 20\ \mu m$

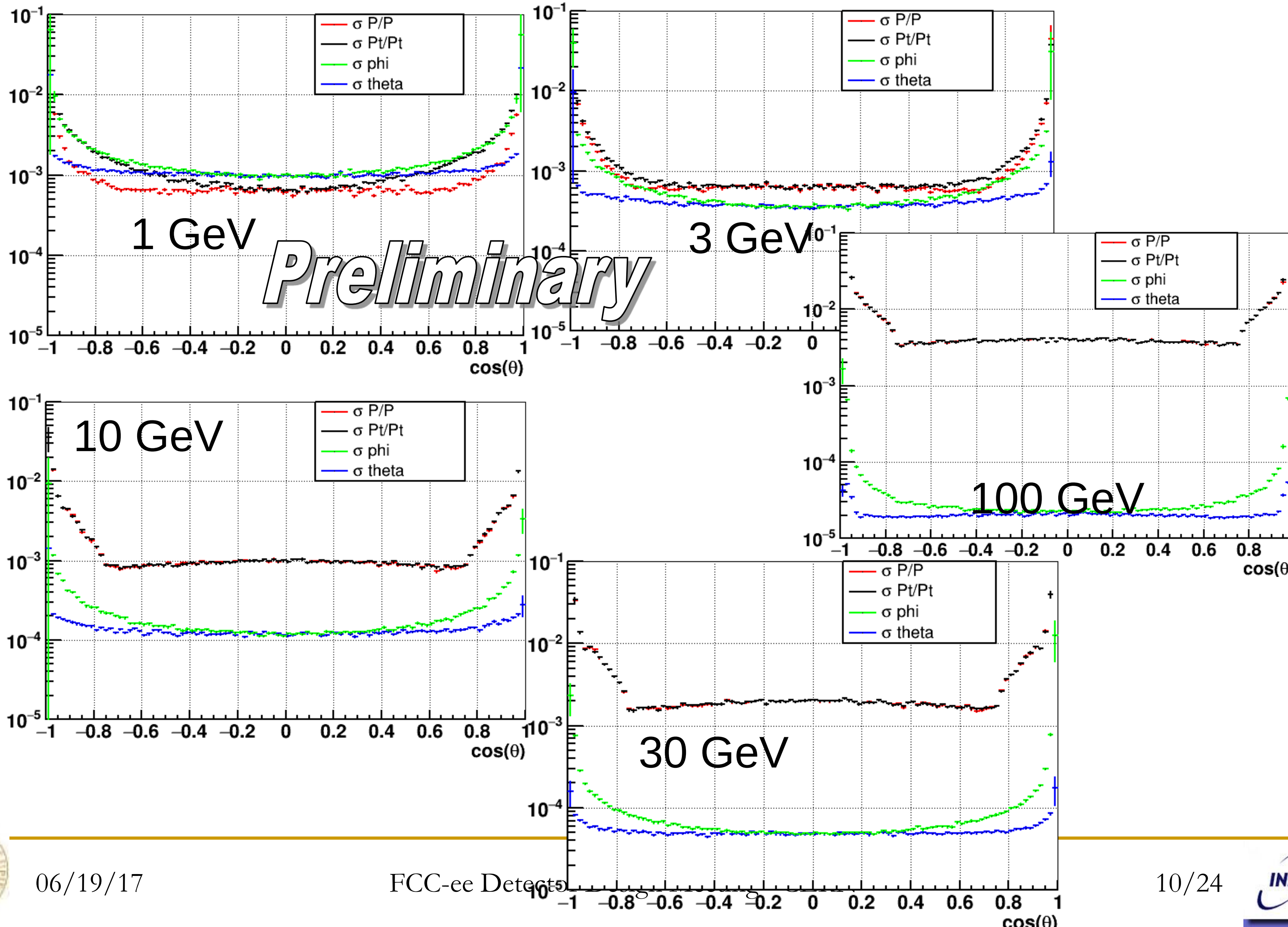
$\sigma_d(100\text{GeV}) \sim 3\ \mu m$



Resolutions (pi$^+$ at fixed **θ**=65deg)



Resolutions (pi$^+$ as function of θ)



track finding strategies

track finding strategies possible alternatives: global vs local

- global methods:
  - treat hits in all detector layers simultaneously
  - find all tracks simultaneously
  - result independent of starting point or order of hits
  - examples: template matching, hough transforms, neural nets, cellular automation, ….
- local methods ('track following'): (currently used)
  - start with construction of track seeds
  - add hits by following each seed through detector layers
  - eventually improve seed after each hits (e.g. with Kalman filter technique)

Pattern Recognition code borrowed from MEG2

Part of the code has been initially developed by Alice Off-line Project (AliRoot),

then it was adapted to specific cases:

→ 2005: as MEG1 initial framework (as MEGRoot),

→ 2007: ILC 4th concept design performance studies (as ILCRoot),

→ 2010: Mu2e I-tracker proposal,

→ 2013: MEG2 DCH tracking.

Wire measurement, stereo layers

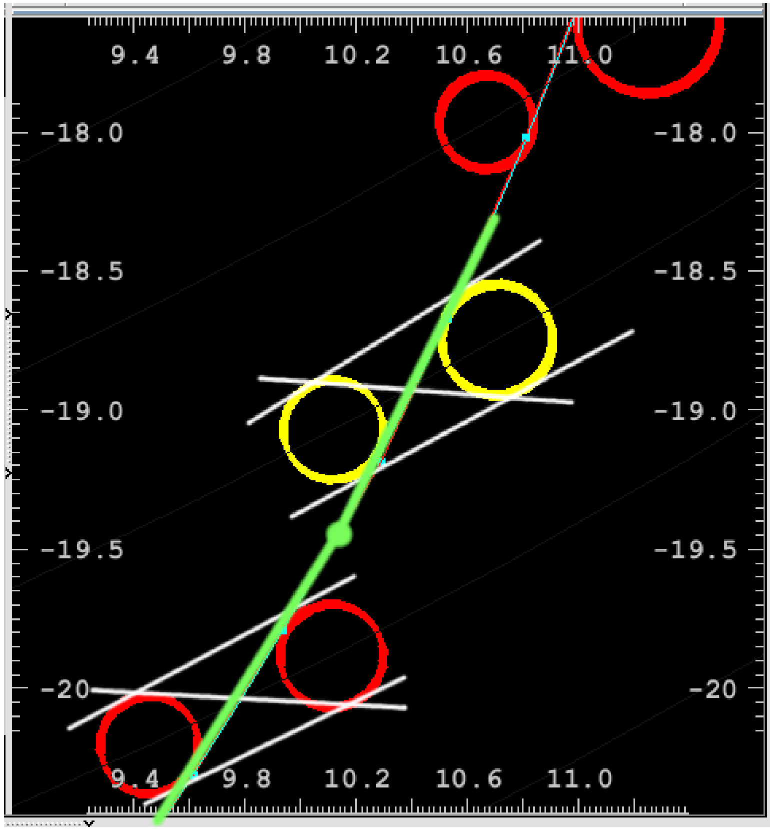
Code not yet completely cleaned up

2 pairs seed construction (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



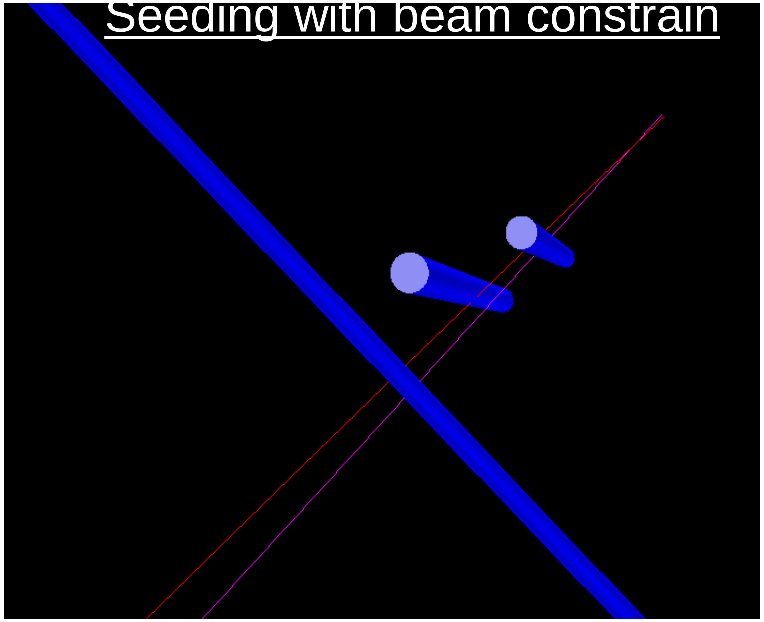
Red hits projection at z=0 plane
Yellow rotated according to φ

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

additional seed construction (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~ 4cm Z ~ 100 cm (Mu2e case)
- 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)

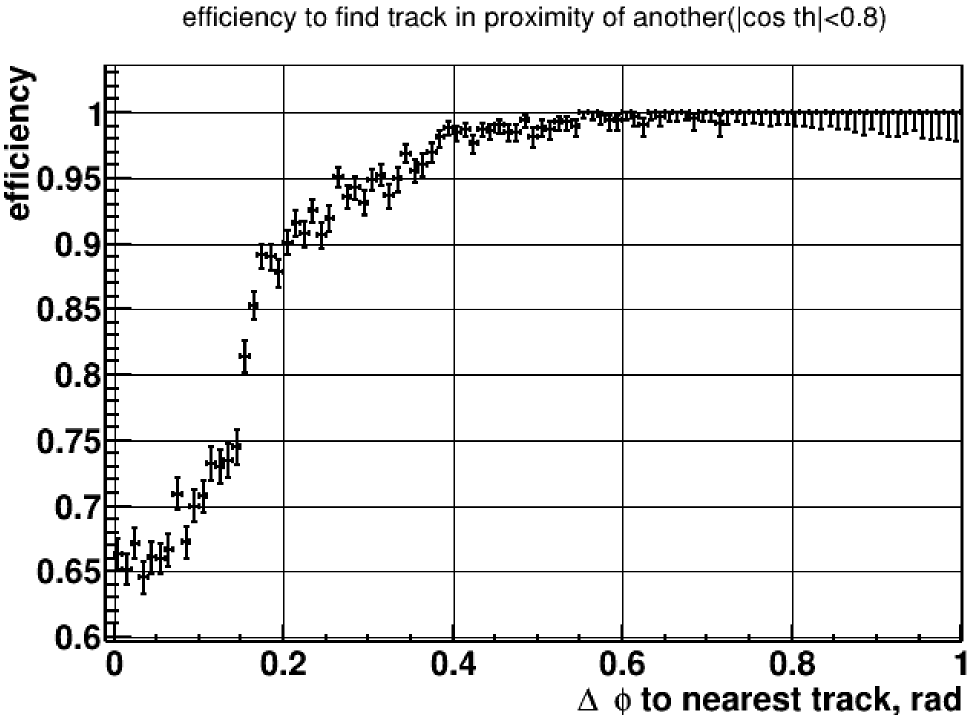


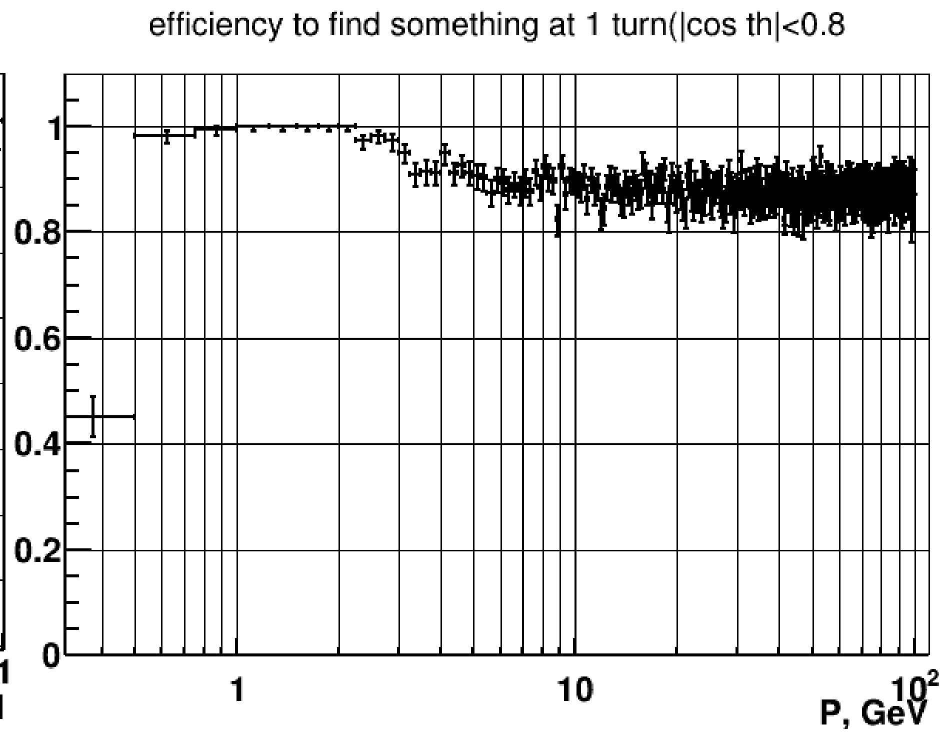
Combinatory high:
local compatibility over different layers,
+ 1 from different stereo view

Track finding preliminary results

- We studied the double track separation by simulating 10 tracks events.
- We checked the performance for the case of a PR based on DCH only and with the help of external tracker (SVX)
- We checked the main limiting factor for the DCH only in the actual configuration.

10 μ's (0-100 GeV), **DCH only** (no longitudinal info used)





<u>Efficiency defined as fake ratio <0.3</u>

Efficiency for 10 muons ~ 0.85

Ineffective up to 0.15-0.5 rad presence of another track

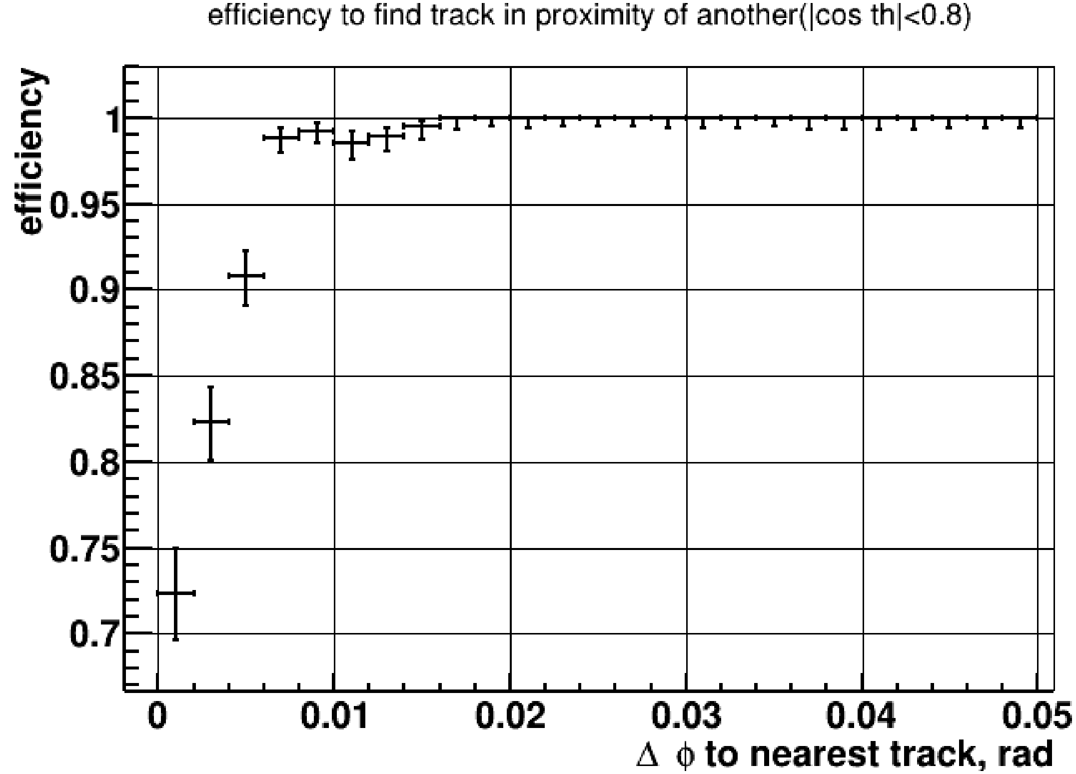
Mostly random stereo view matching (eff ~ 50%) for <0.15 rad

10 μ's (0-100 GeV), **DCH only** (no longitudinal info used) with Z vtx preselection of seeds

short initial 7 hit track segment must match in Z with SVX seeds with distance <1 cm

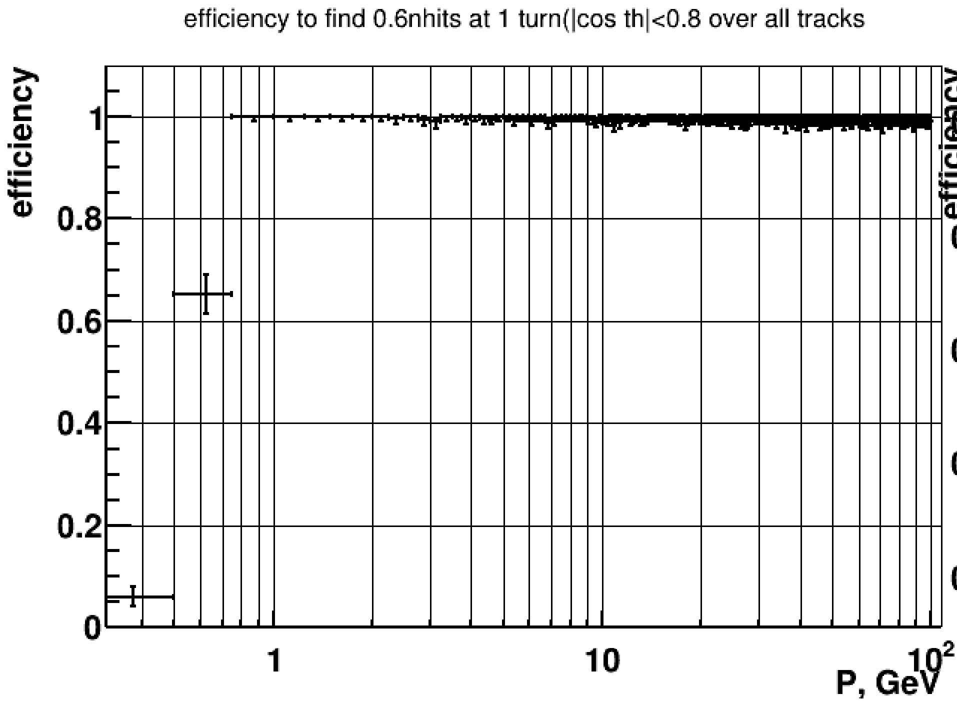
Min $\Delta\varphi_0$ ~ 0.005 rad

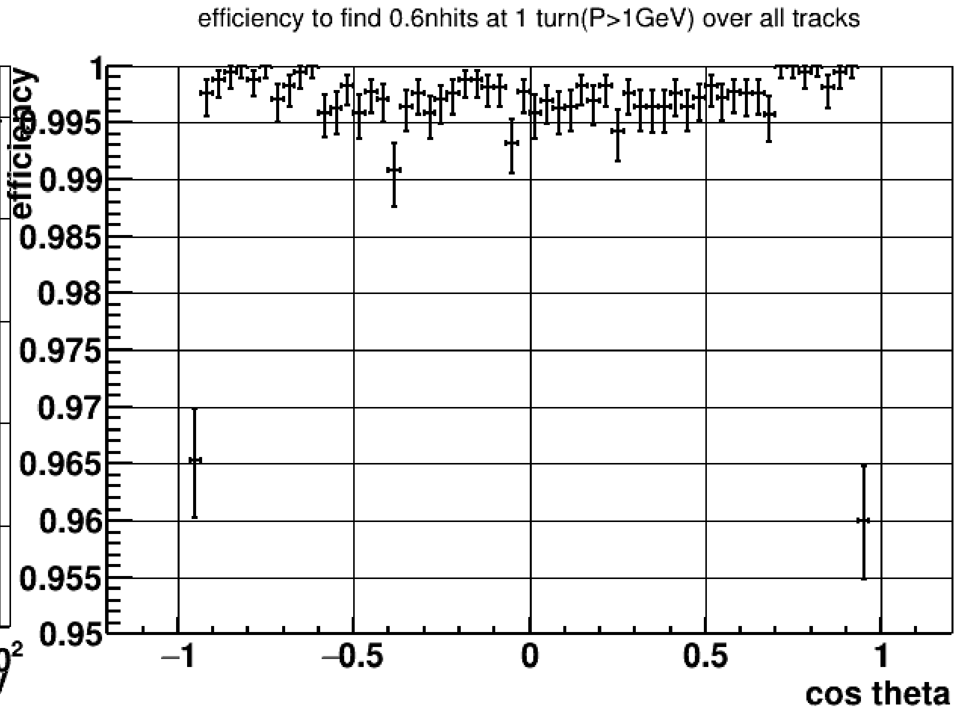
But will not help for decaying tracks after the SVX



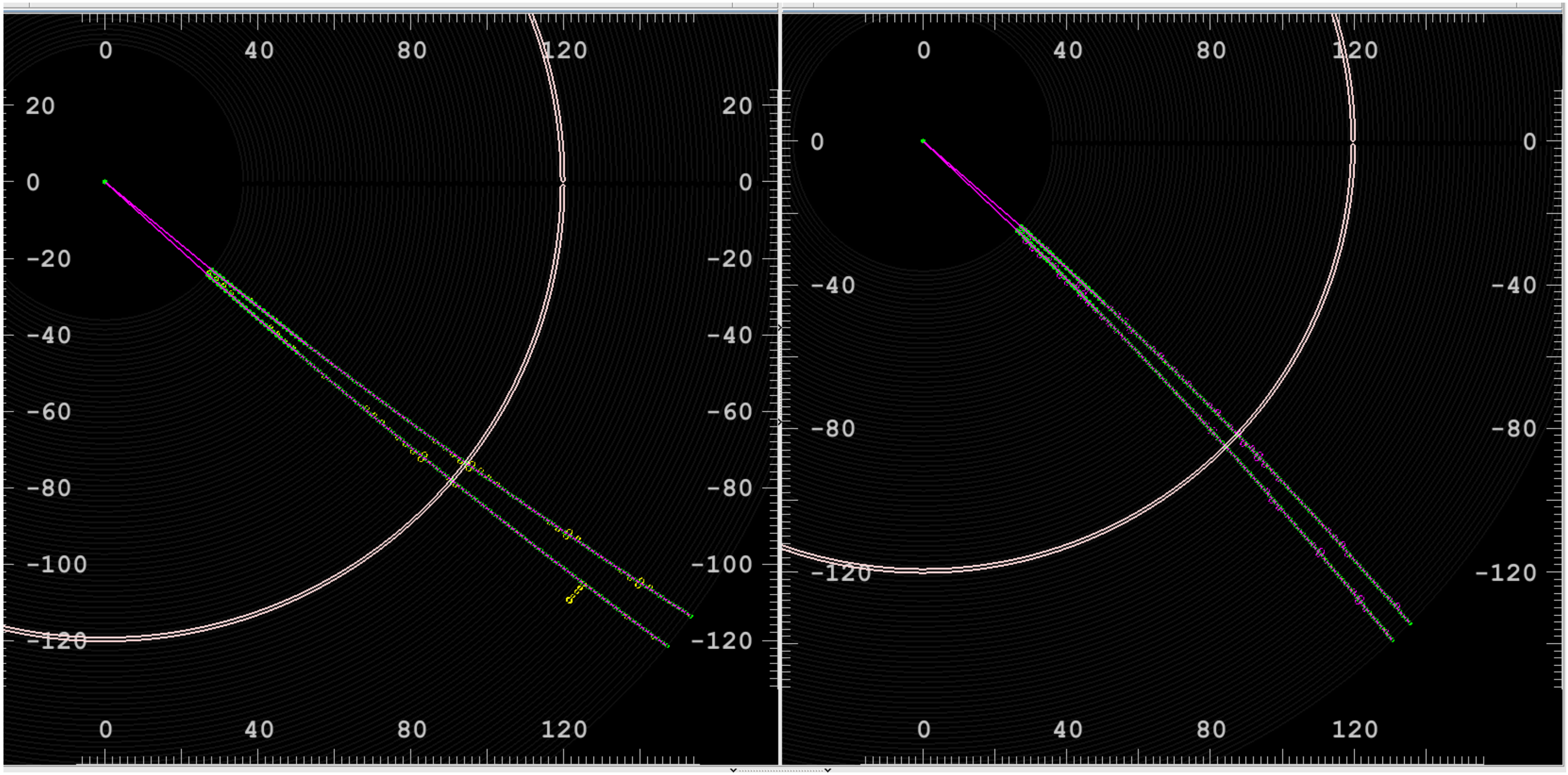
10 μ's (0-100 GeV), **DCH only** (no longitudinal info used) with Z vtx preselection of seeds

$\Delta\varphi_0 \sim 0.005$ rad
eff ~ 99.5%





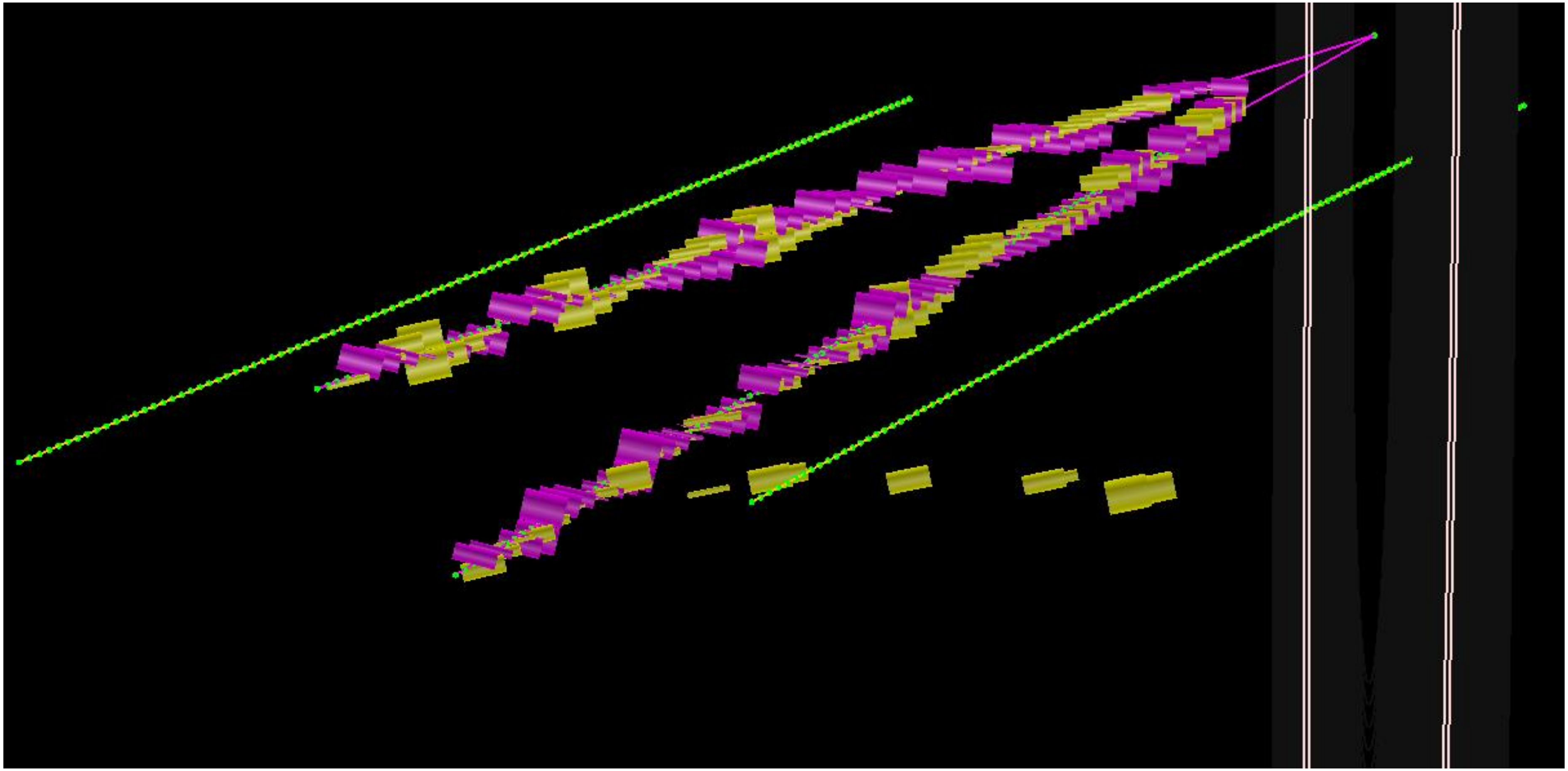
DCH limiting factor, Stereo view mismatching



One full segment is connected with wrong from another stereo view

Chi2 - perfect

DCH limiting factor, Stereo view mismatching



One full segment is connected with wrong from another stereo view

Chi2 - perfect

DCH limiting factor, Stereo projection mismatching

The limiting factor comes from the linear increasing of the stereo angle with the radius and the track topology, possible solution to solve the issue are:

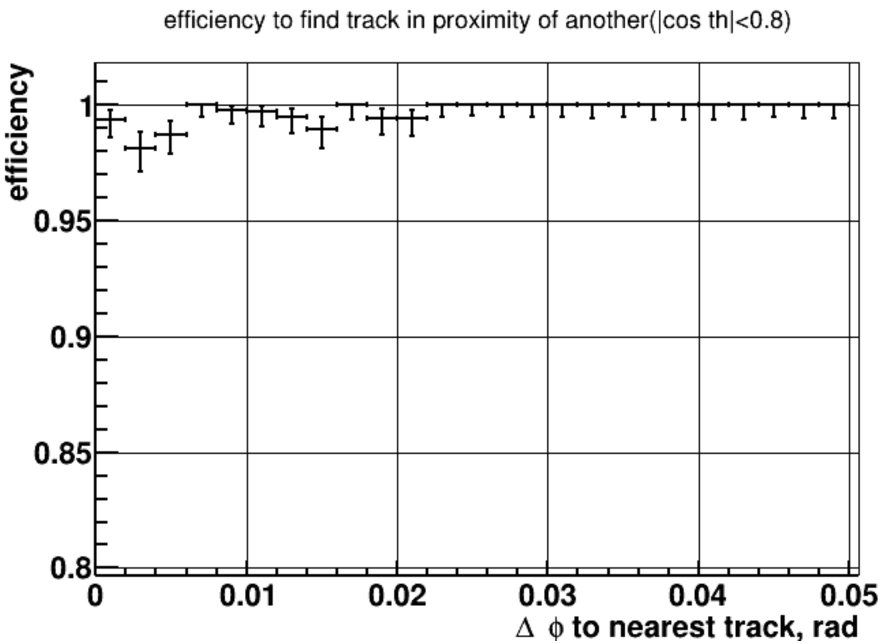
- use an external system to solve mismatching
- change finding approach:
  - If good track was found, hits are removed from next iteration seeding
  - Mismatched track at first iteration may not be a good track after cleaning

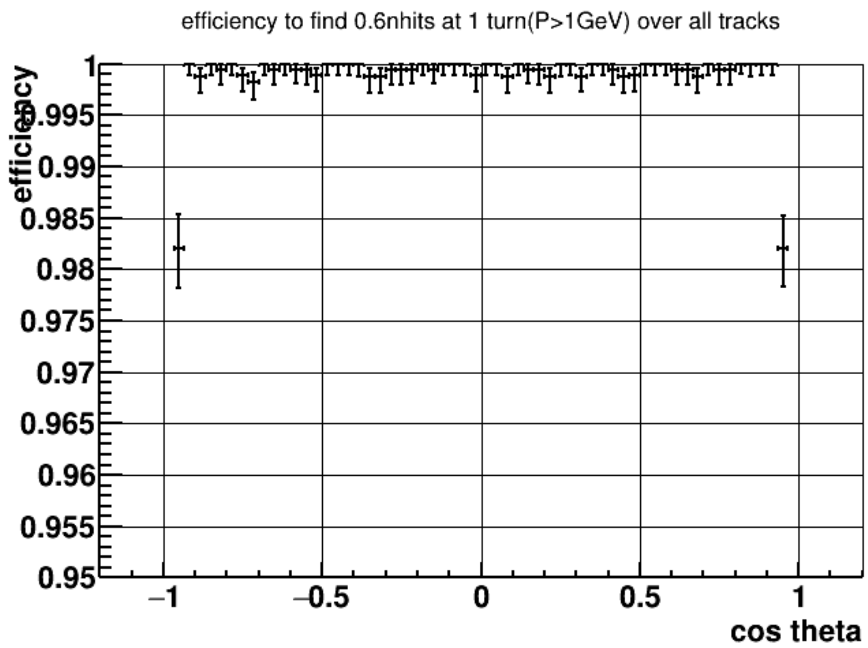
- or start seeding from PSHW layers
- or seeding with Z vertex constraint
- or step back from 3D finding to 2D track finding per stereo view and then global stereo segment matching

Possible gain: can be much faster track finding - seeding only from nearest wires (if no Z coordinate information)

10 μ's (0-100 GeV), **DCH only** (using longitudinal info)

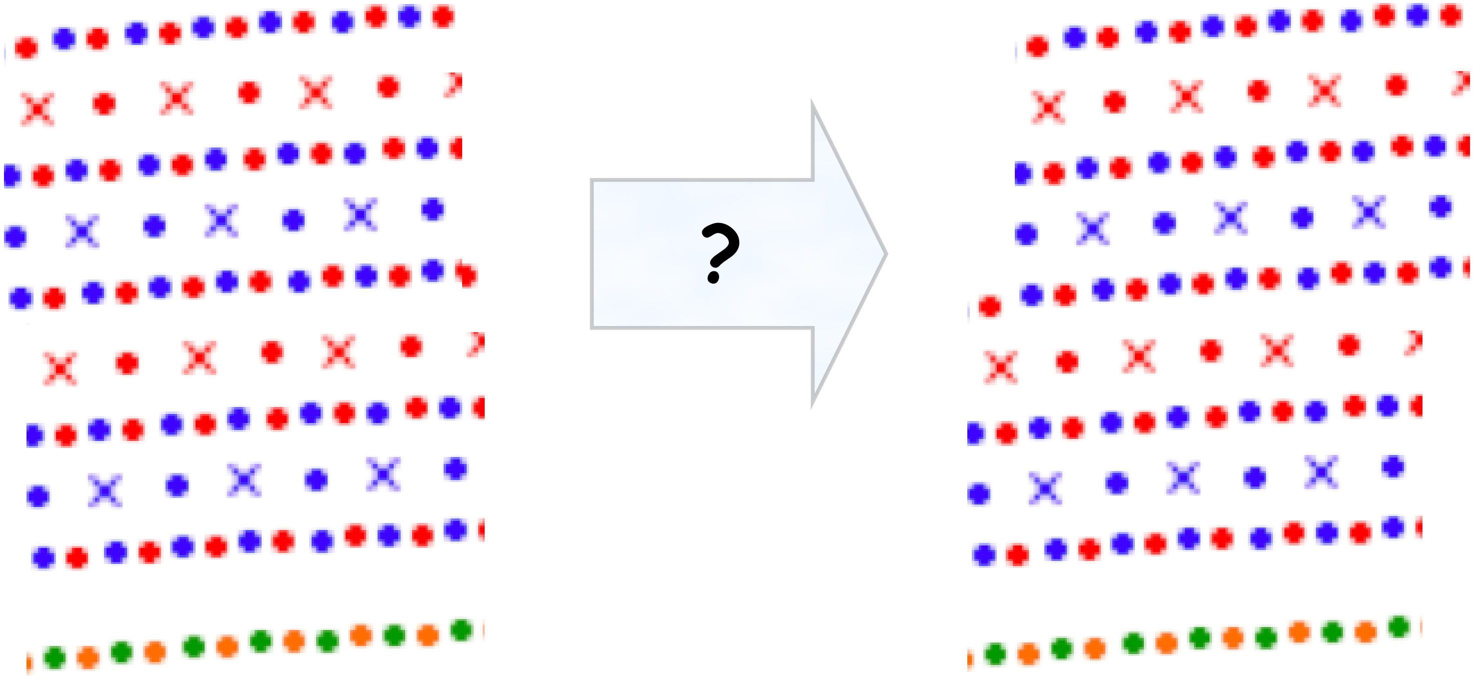
Assuming a σ_Z 3 cm per hit → σ_Z ~ 0.3 cm for tracks
helps to resolve mismatching at this level for Δz,
and in addition over Δtanλ





Cell size factor changes from 0.03 to 0.0077 from inner to outer layer
Will depend over overlapped hits reconstruction,
assuming hits separated if |Δt|>50 nsec
Maybe should be special dial in tracking of close tracks (rearrange hits,...)

A possible simple change in DCH layout could help



Now in geometry cells from same stereo view are on same phi position;
Probably it is better to make shift over half cell
to reduce initial local combinatory

Summary

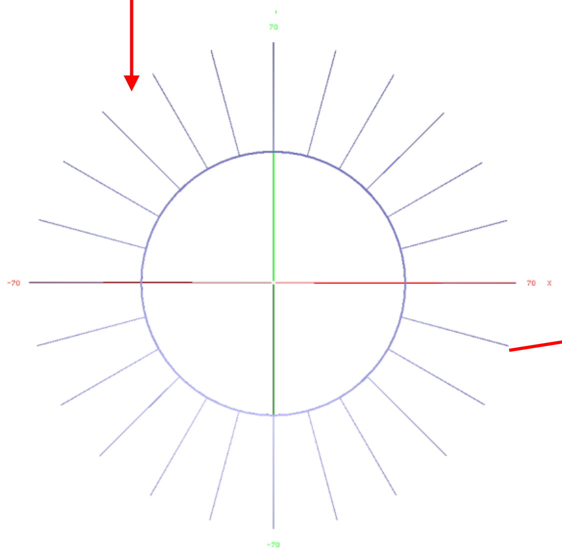
- We have a working full simulation of the IDEA tracking systems;
- The track fitting preliminary results look reasonable, in agreement with the Fast MC and show the effect of the PSHW on gain in resolution for high momentum tracks;
- We started to approach the PR problem.

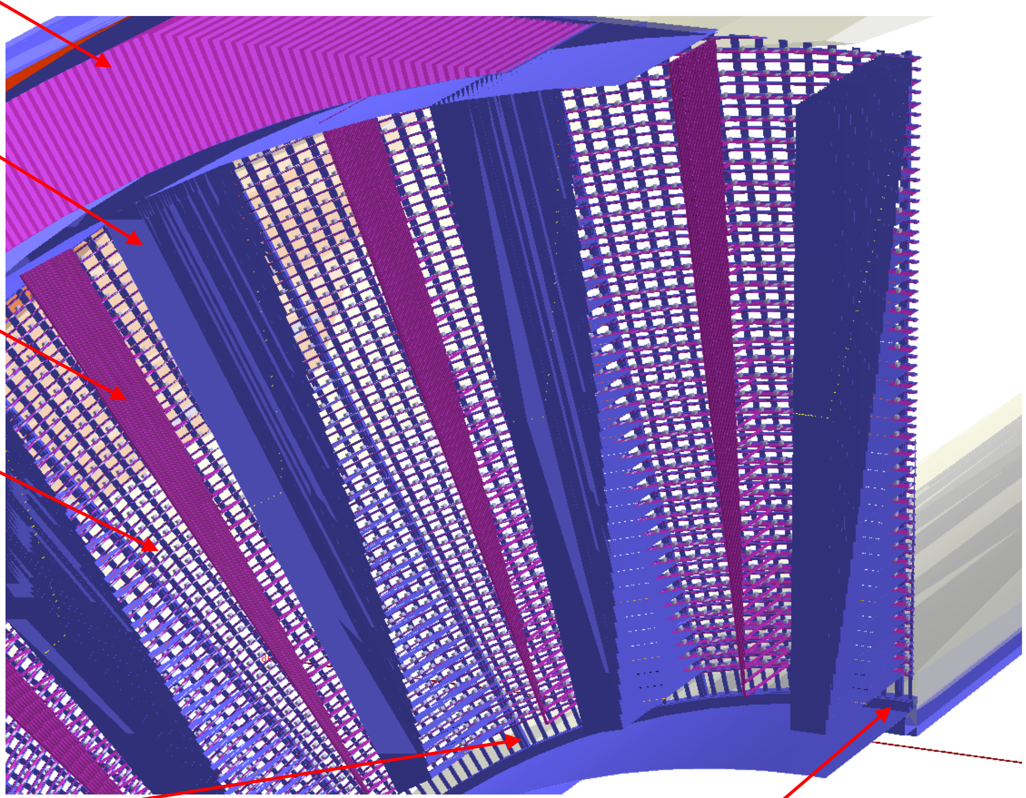
- To do:
  - continue to work on the PR to improve the results for the DCH alone case;
  - try to make an optimization of the current IDEA geometry configuration (SVX: n. layers and radii; DCH dimensions and cell layout);
  - improve the hit makers to handle correctly the tracks pile up;
  - Simulate the dN/dx and the PID;
  - Simulate and test the possible longitudinal resolution;
  - simulate some background effects?
  - porting the DCH geometry etc. into the FCC framework;
  - Interface the PR with the new framework:
  - … etc …

backup

IDEA DCH geometry simulation

- (Optional) Electronics boards: 12 cm x 6 cm x 3mm G10 (FR4);
- signal cables (only downstream): 2.032 cm x 25 µm Kapton + 40 µm 16 pairs of Copper wires;
- HV cables (only downstream): 500 µm Copper wire + 500 µm Teflon insulation;
- Wire anchoring (see next slide);
- Carbon fiber wire support.



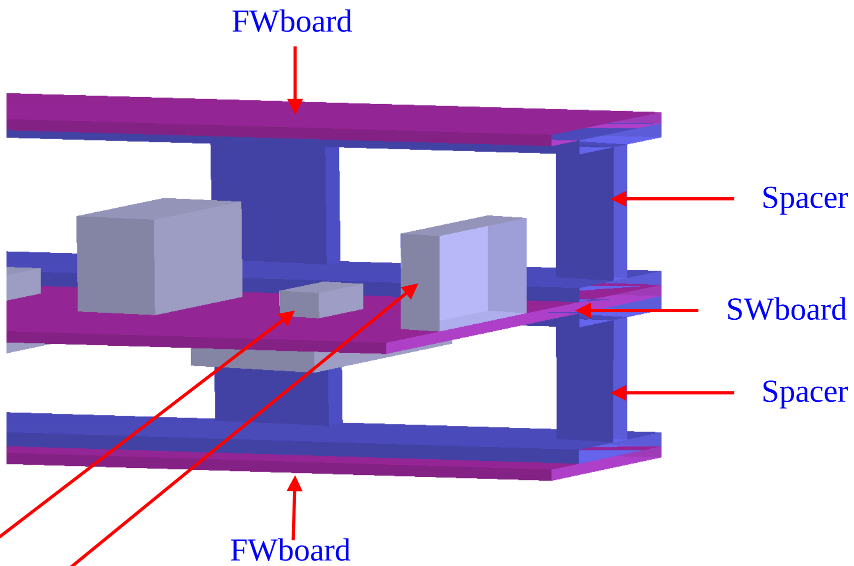


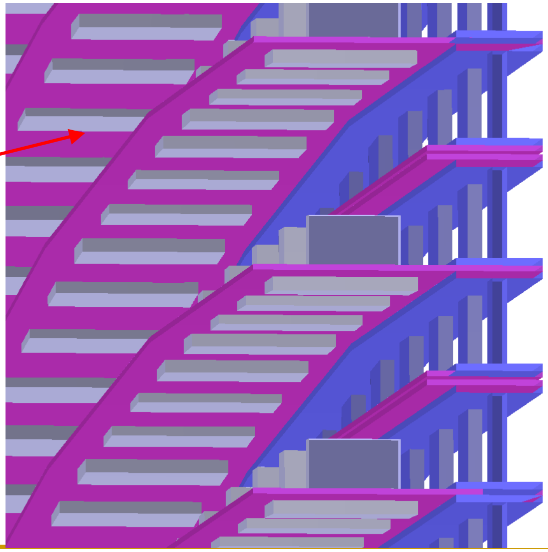
Connecting ring is described as a circular layer:
0.5 cm x 1.5 cm Carbon fiber

IDEA DCH geometry simulation

The wire anchoring system:

- Field wire board: 4 mm x 200 µm G10(FR4);
- Spacer: (see F. Grancagnolo talk for details) 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.





Starting point: Kalman Filter Tracking

Currently performed with GenFit2

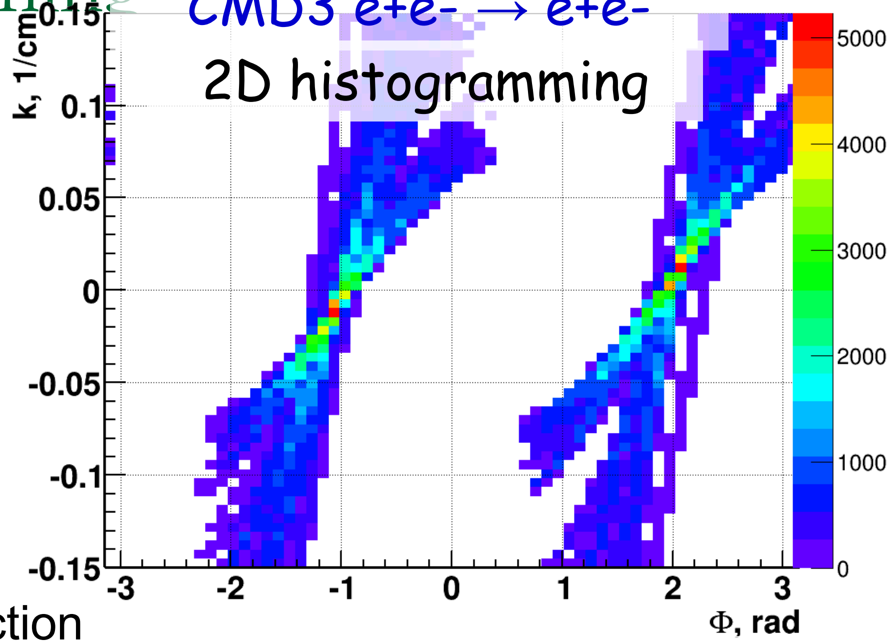
- Seeds are constructed at specific layer (begins from outer radii)
- Back interpolate to inner radii
- Tracking done in usual way:
  - Find the extrapolation to the next layer for each track segment
  - Track parameters and Covariance matrix updated at each layer (MS included)
  - Select and assign compatible hits to track
  - hit are accepted if $\chi^2 < 16$ (hit can be already used by another track)
  - Update track parameters according to accepted hits
- If a good enough track is found:
  - X^2/NDF< minX^2cut , Nhits > minNcut, density of hits > min density cut
- then attached hits to this track are signed as used (and they can't be used in seeding)
- Seeding repeats again from next layer and re-iterate
- At the end, all found tracks are refitted from inside to outside (with possible assignment of acceptable hits) and vice-versa
- Shared and double tracks are removed by selecting according to quality factors (based on chi2, number of hits, hit density) and hits from track are signed as used

Global method - histogramming

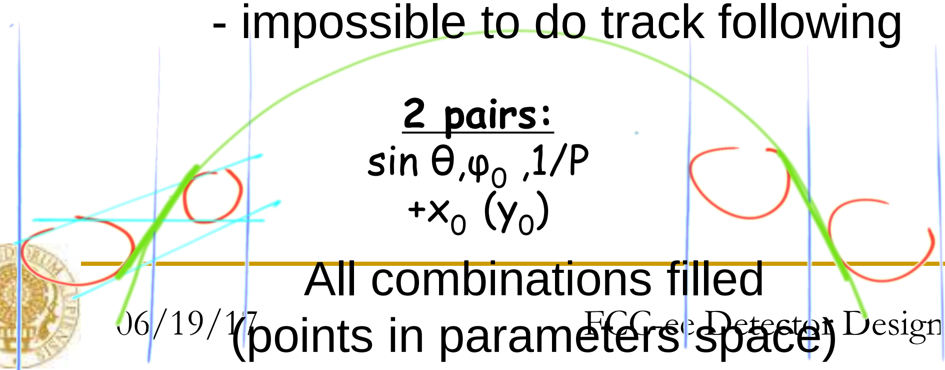
Simplest global method: Histogramming
(conformal mapping, hough transform, etc..)

Measurement transformed to
surface(line) in track parameter space
Maximum in histogram gives track candidate

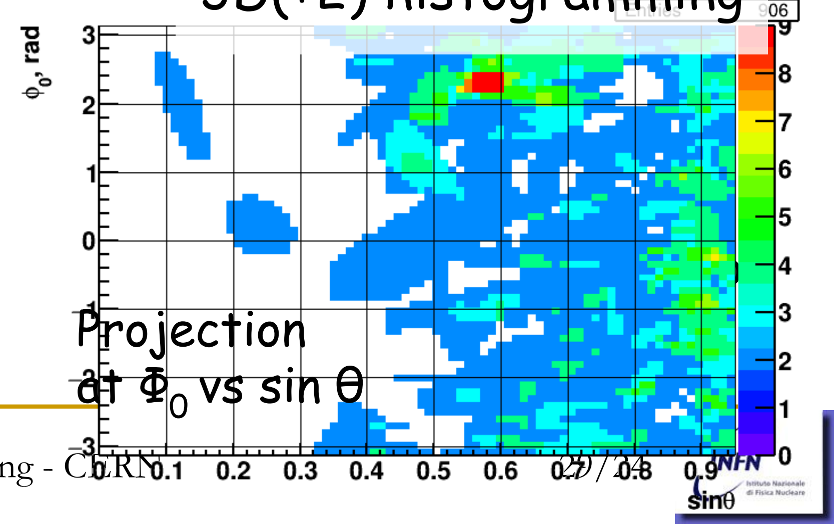
Can be done if it is additional constrains
or track parameters well splitted:
5D track with beam constrain →
Independently 2D in R-Phi and 2D in Z-θ projection



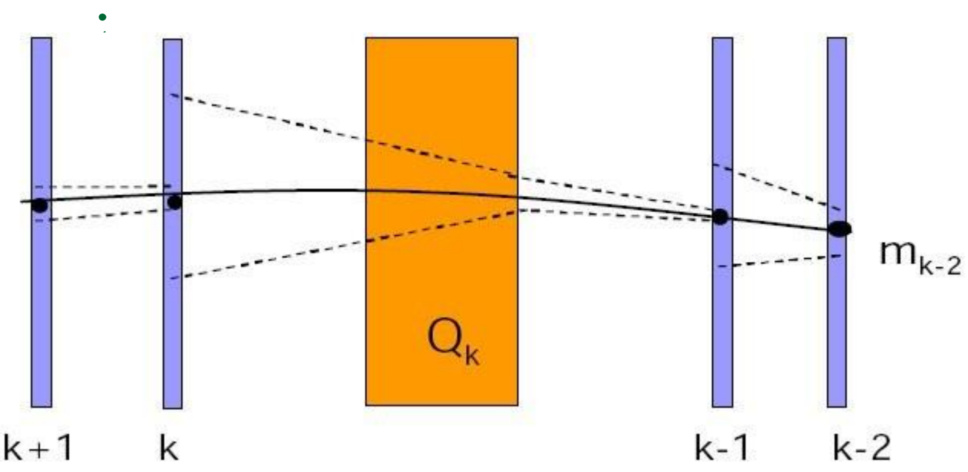
COMET straw chamber
Only 5 stations with large spacing
- low connections between layers
- impossible to do track following



All combinations filled
(points in parameters space)



Local Method: Track Foll



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

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 recogntion
– track splitted in case of few compatible hits

DAF – Deterministic Annealing Filter

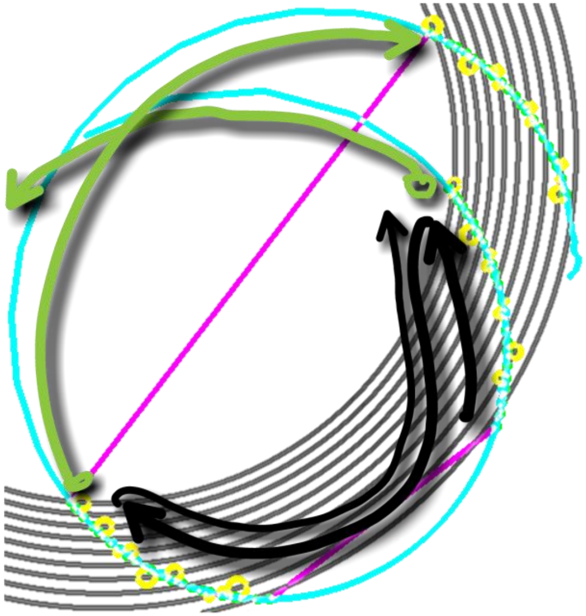
On a same surface, several hits may compete for track with different weights
– good for outliers removal

Kalman Filter Tracking (track following method)

1) Seeds constructed from outer layers (iteratively layer by layer from not used hits)

2) track prolonged by Kalman Filter (over single turn)

3) shared and double track removal by quality factor (based on χ2,N of hits,hits density)



as output from PR
Track turns
(or sometimes separated track segment)

Now matching over 2 segment in same turn are not working

Stereo projection

Trajectory:

$\varphi = \varphi_0 + \arcsin(r/2R) \sim \varphi_0 + r/2R + O(1/6 *(r/2R)^3)$

(<100 µm for >10 GeV)

Stereo configuration: $t= a*r_0$, ($a=\pm|a|$)

Stereo projection: $\varphi_{tr+-} \sim \varphi_0 + r/2R – t(r)*z/r \sim \varphi_0 + r*(1/2R – a*\tan\lambda)$

Shift of trajectory with Δz : $\Delta\varphi_0 = a*\Delta z$

Shift with Δtanλ : $\Delta 1/2R = a\, \Delta\tan\lambda$

+- stereo has different sign of shift

Enough to match any 2 tracks (arbitrary pair of P, φ_0, tanλ, z)

$a = 1.3*10^{-3}$ 1/cm, 1/R (1/cm)= 1/Pt (1/GeV)* 2Tl*$3*10^{-3}$ (GeV/cm/Tl)

Δ0.1 рад (between 2 tracks) → Δz=40 cm

Δ1/Pt = 0.43 Δtanλ : 1/50GeV → 0.05 rad