Main tracker optimisation and tracking performance

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CLIC workshop 26-30 January 2015

Outline

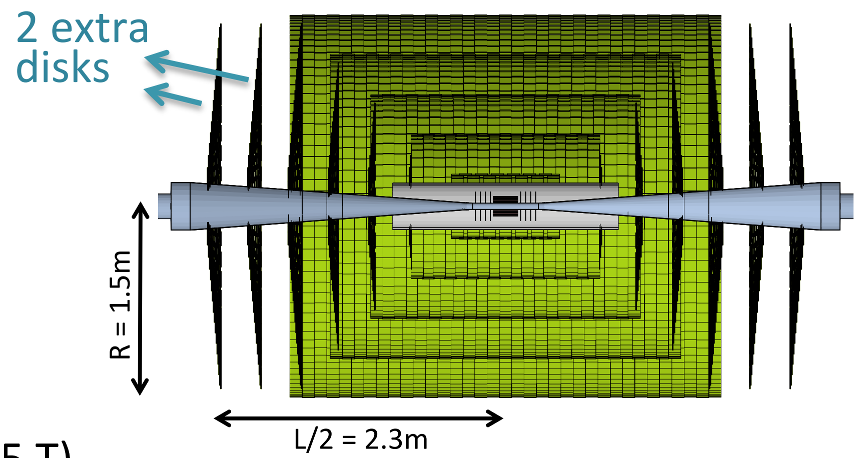
- Reminder of agreed parameters for the tracker simulation
- Next steps in the main tracker optimisation
- Preliminary results for layer layout optimisation
- Requirements for the tracking code
- Status of the extrapolation procedure for a full Si tracking

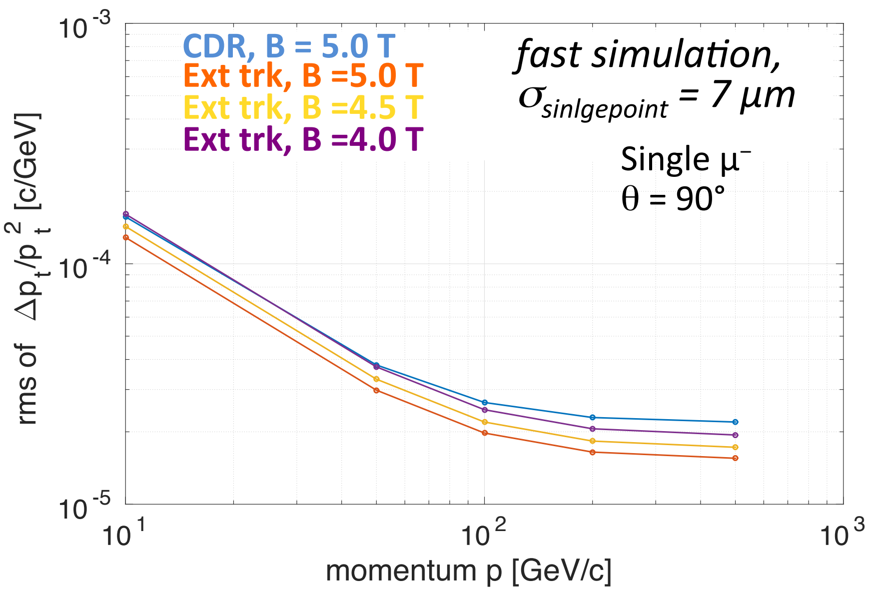
R & B optimisation – reminder

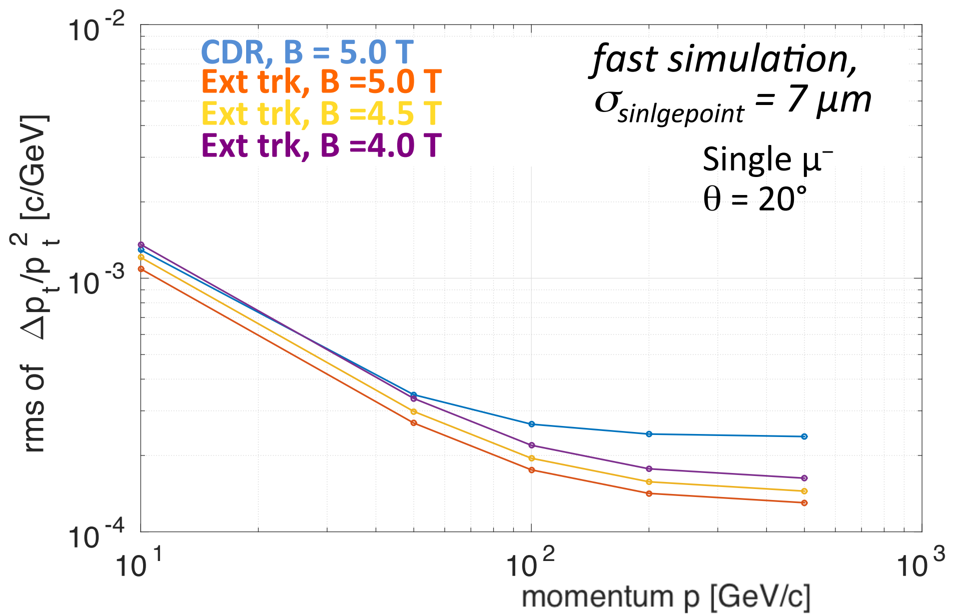
- Gluckstern's formula

$$\frac{\sigma(p_T)}{p_T^2} \propto \frac{\sigma}{\sqrt{N+4}BR^2}$$

- Improvement *extending tracker size*
  - R = 1.25 m → *R = 1.488 m* (R^{Ecal} = 1.5 m)
  - L/2 = 1.6 → *L/2 = 2.3 m* (add 2 disks)
- Worsening *decreasing B* (~10% for each 0.5 T)
  - For *B = 4T*, after trk extension similar or still better performance than CDR case



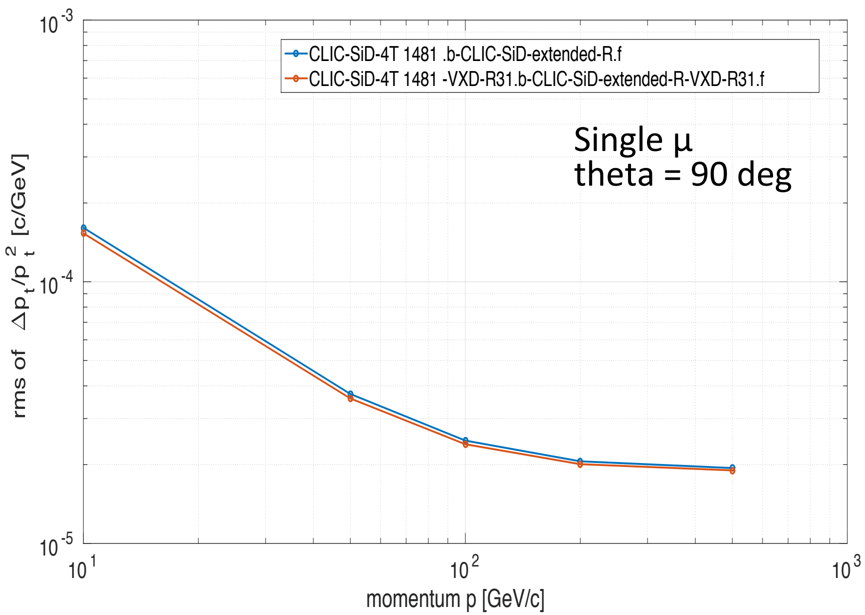


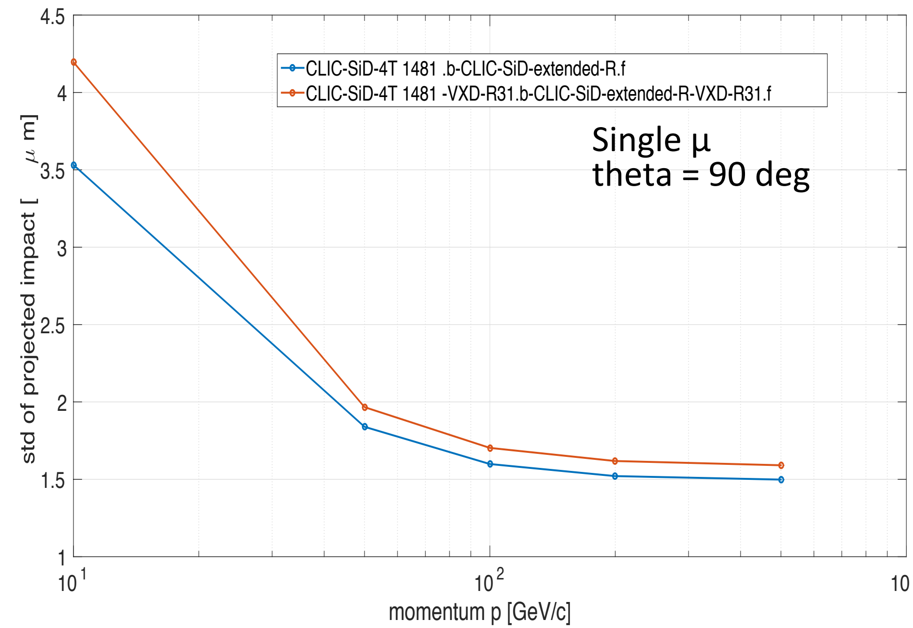


Effect of VXD R_{in}=31 mm on tracking

Choice of B=4T increase the occupancy in the first layer of the vertex detector
→ Move the first layer from ***R=27mm to R=31mm***

- From Nilou's results: *small effect* on quark-tagging performance
- The effect on tracking performance is also small:
  - None on momentum resolution
  - Up to 15% on d_0 resolution (from Nilou's: worsening on b-tag perf within 10%)
  - 15% on angular variables





Next steps

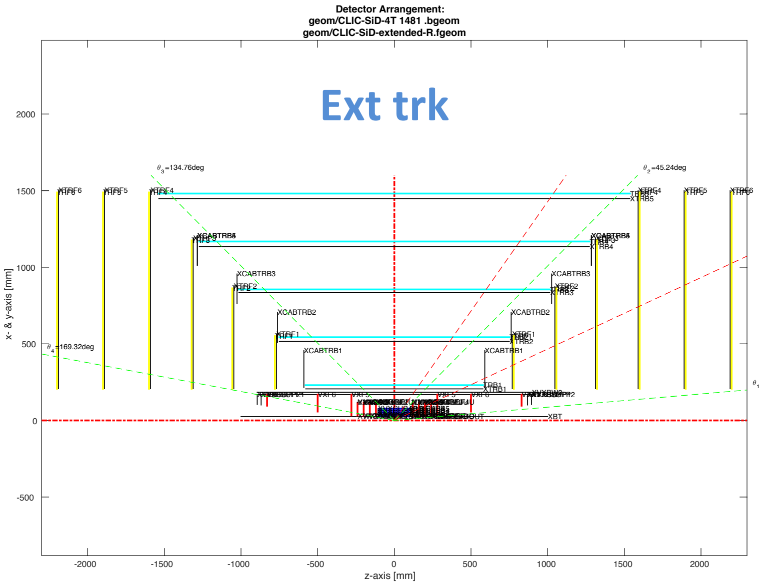
- Layer ***layout optimisation*** *– started* (see slides 6-9)
  - Input needed from engineer design
  - No large effect on tracking performance
  - To do: efficiency study

- ***Background occupancy*** *studies – ongoing* (see slide 10)
  → New CERN PhD student: Magdalena Munker

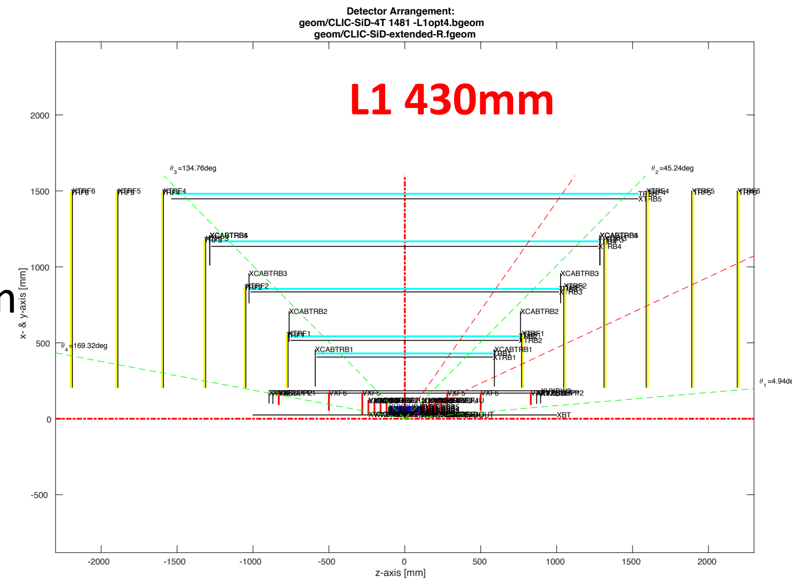
- R&D and studies for ***main tracker technology*** *– starting soon*
  → New CERN fellow: Andreas Nurnberg
  - Technology (stereopairs / single strips)
  - Strips size and thickness
  - Power consumption (ongoing – S. Kulis' results)

- Not crucial a.t.m. but do not forget: ***single point resolution*** *in digi*
  - In fast simulation and ILD software, simple gaussian smearing
  - In SiD software chain: charge sharing considered, retuning needed

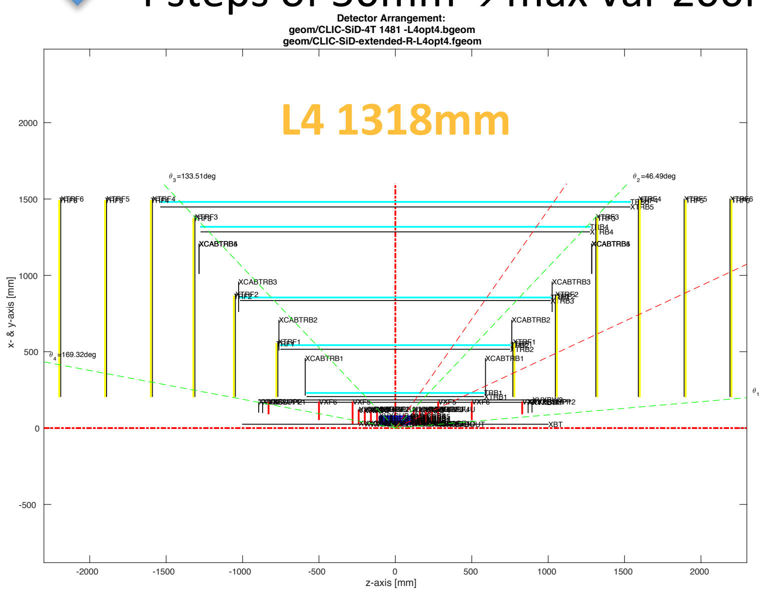
Layer layout optimisation



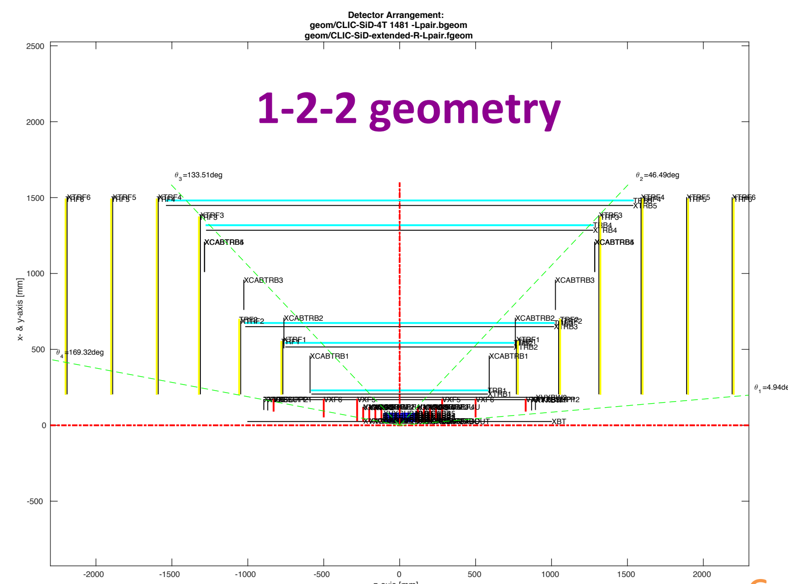
First barrel layer:
4 steps of 50mm
→ max var 200mm



Fourth barrel layer:
4 steps of 50mm → max var 200mm

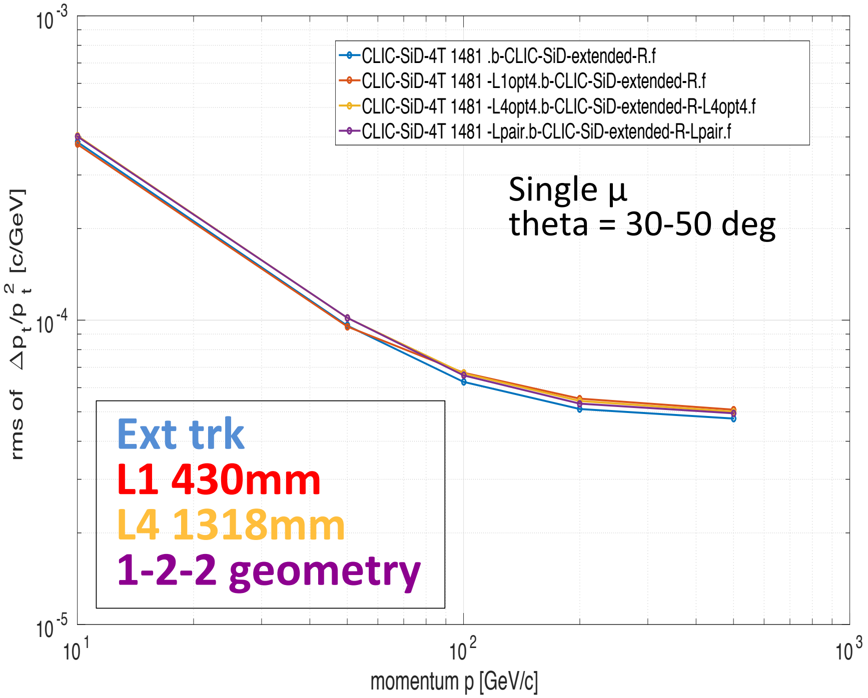


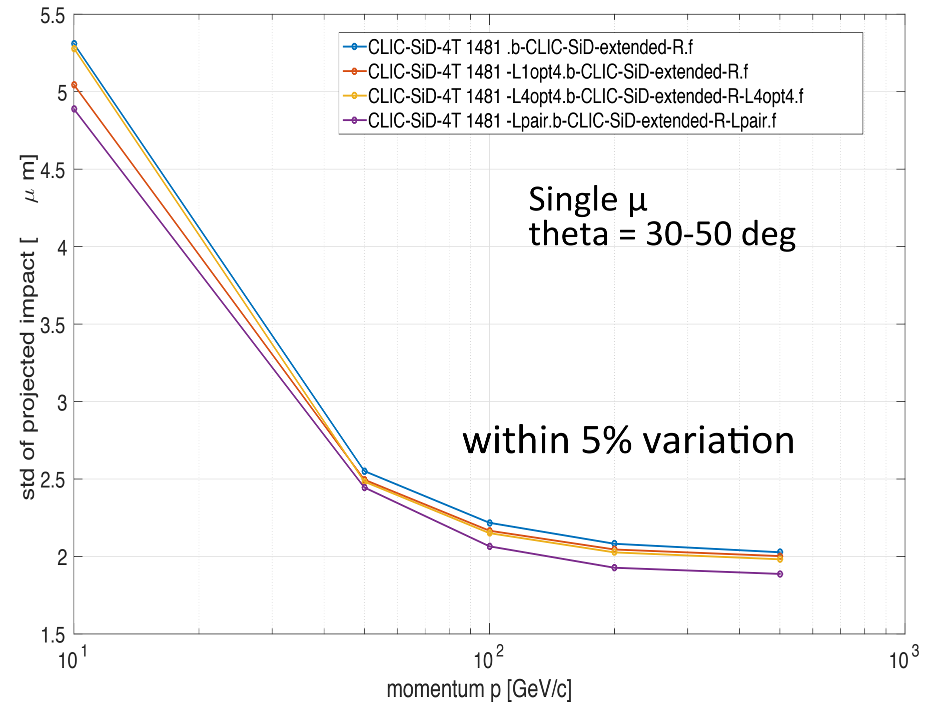
Move third and fourth layers



Results

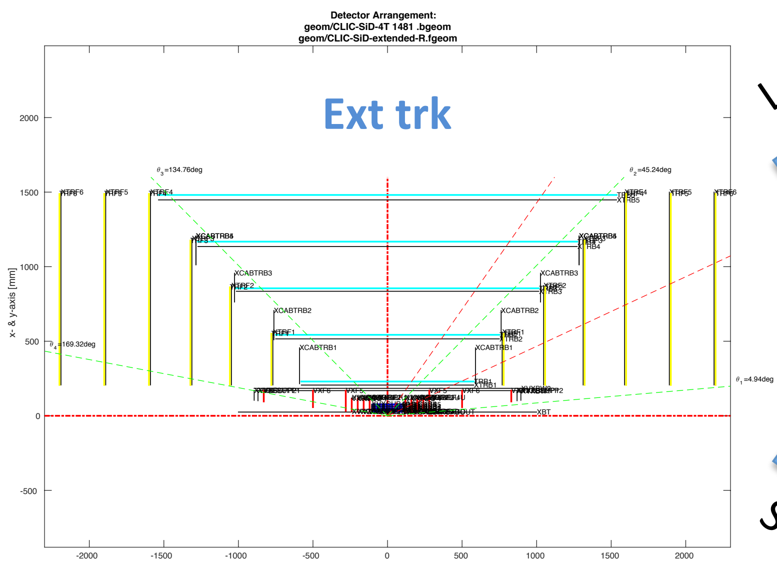
- Basically no variation observed



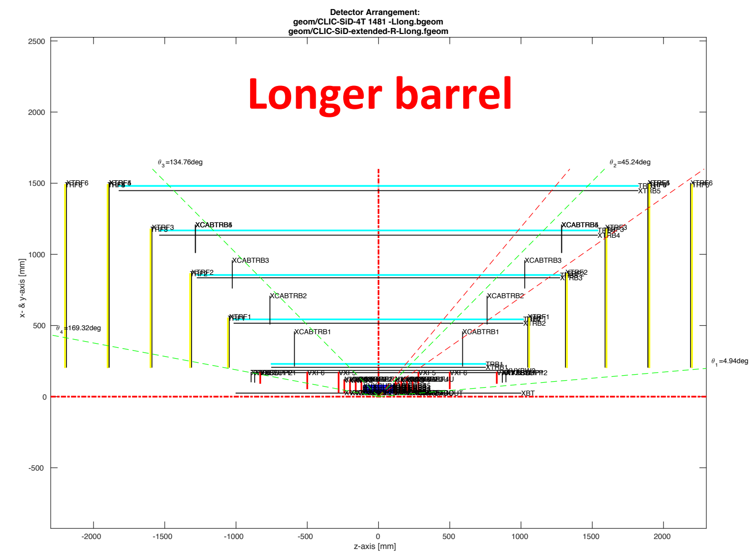


Change barrel length

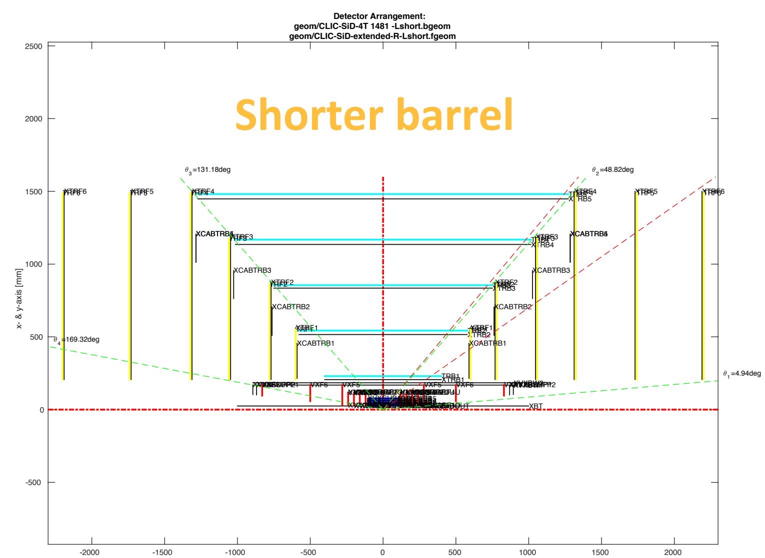
- Make barrel longer/shorter keeping the overall maximum z size



Longer barrel

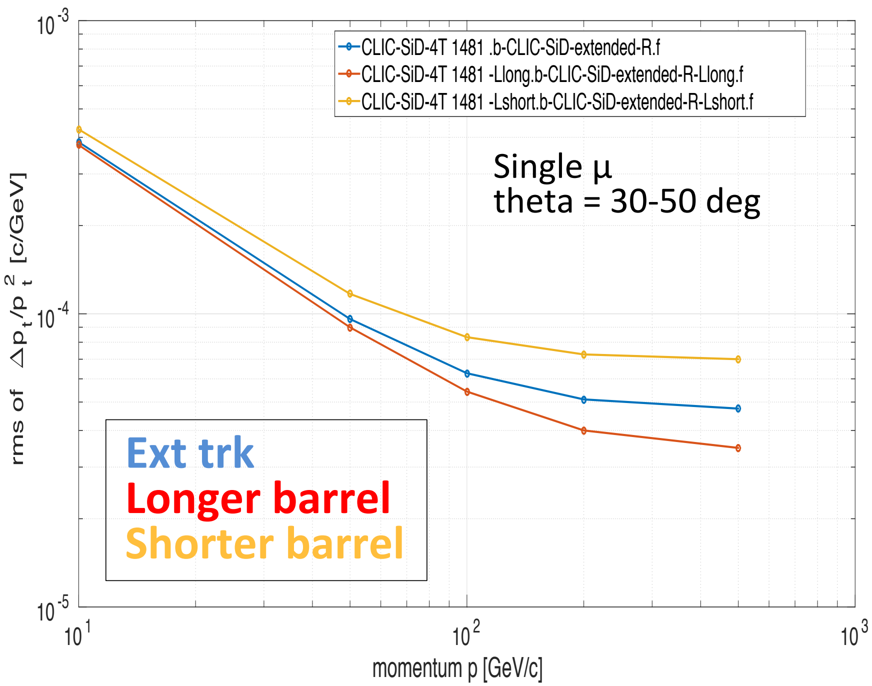


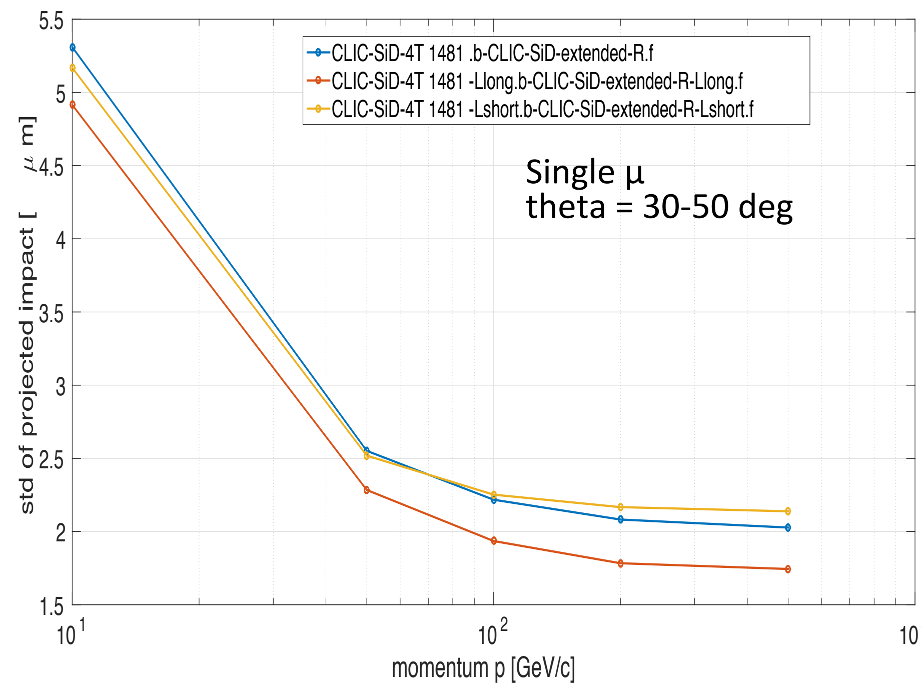
Shorter barrel



Results

- Some variations observed
  - >10% momentum resolution improvement for longer barrel
  - 10% improvement in d0 resolution for longer barrel



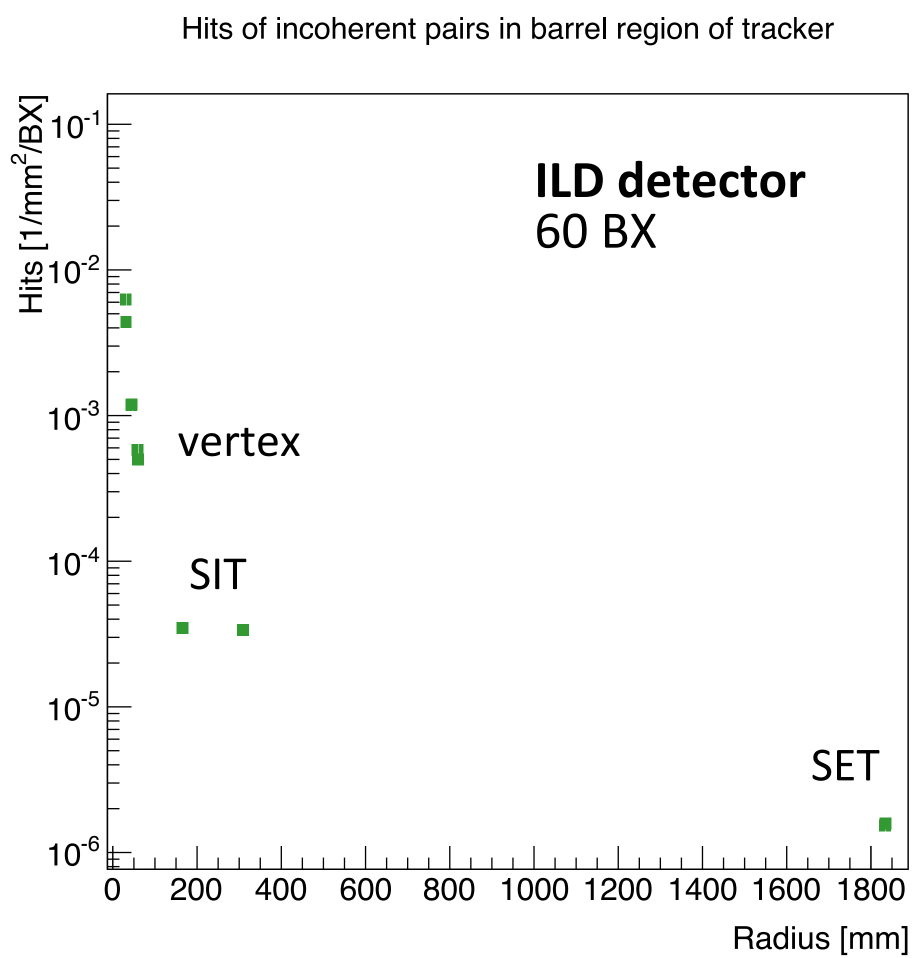


- Version with shorter barrel penalized also from having conjunction points between barrel and endcap more pointing to the IP

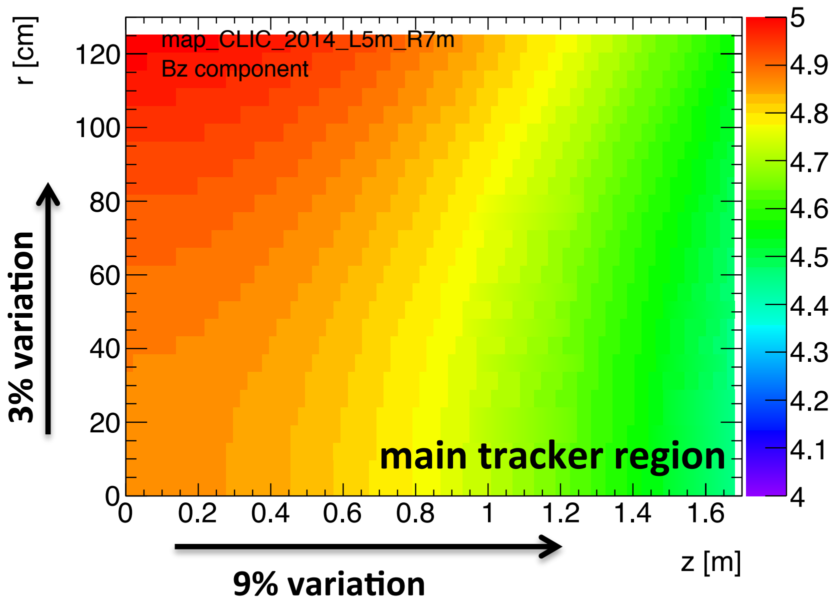
Occupancy studies

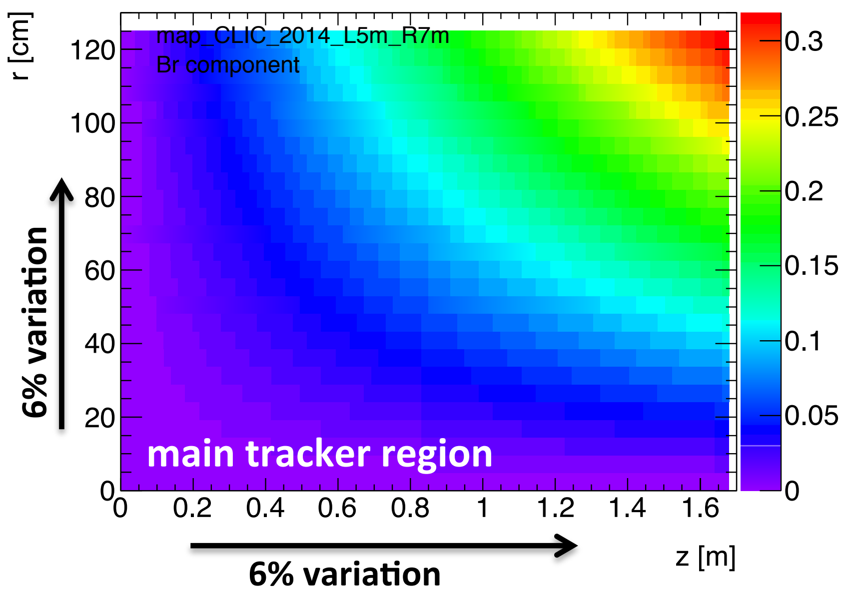
Magdalena Munker's study

- Old study by Andre Sailer
- Study the *occupancy* due to incoherent pair background in Si vertex and main tracker
- *Machinery is set* and running (in ILD software framework + ILD detector model) : able to reproduce occupancy plots
- **Next**: *implement the SiD geometry*



B field – reminder





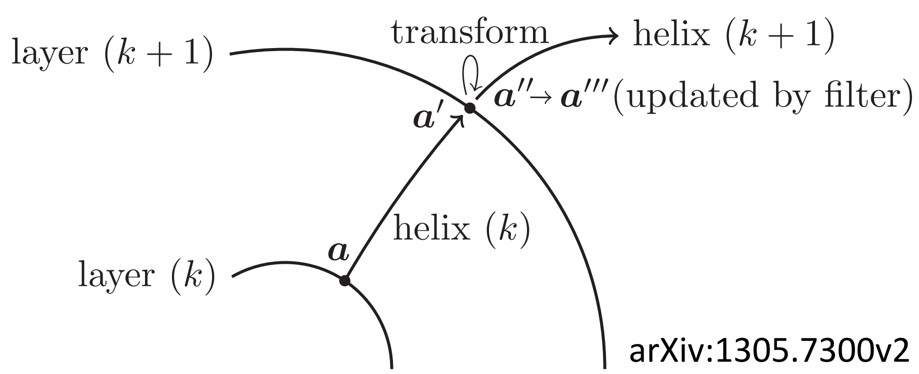
- Worst case foreseen: maximum variation of 9% along z
  - Shorter endcape yoke (1.4m) → few % distortion by the field of special ring coils needed to contain the stray field outside the detector
- Change the coil size for the new model should not affect much the quality of the field

	B [T]	R_{coil} [mm]	Z_{coil} [mm]	R/Z
SiD	5	2624	3245	0.81
ext trk + 60L Fe Hcal	4	3359	4175	0.80

Requirements for the software

B field variation needs to be included in the reconstruction for a fair, not biased evaluation of the tracking performance

- In ILD (Bo Li et al.): till a 10% B variation, it is possible to restore the performance to the homogeneous field using a segmented-wised helix track fitting integrated in a Kalman filter

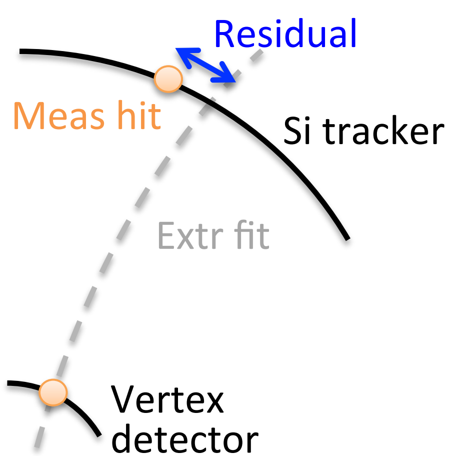


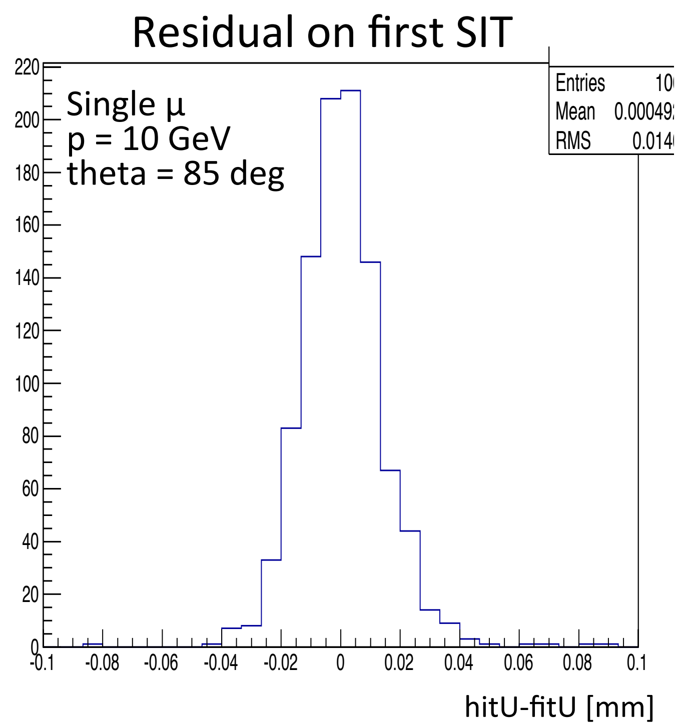
arXiv:1305.7300v2

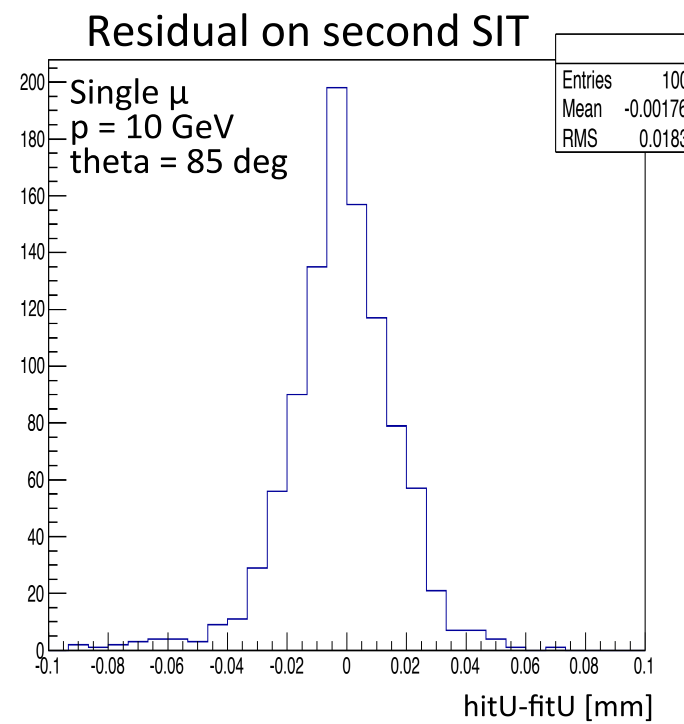
- We need a tracking code able to support this!
- ***We are getting close!***
  Frank's talk: https://indico.cern.ch/event/336335/session/7/contribution/126/material/slides/0.pdf

Tracking code for full Si tracker

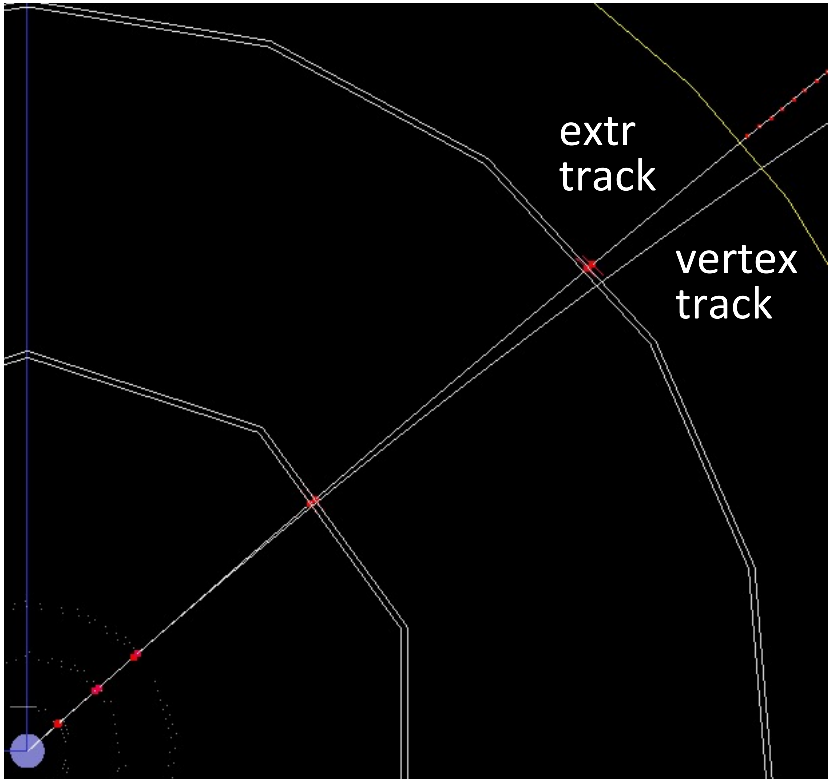
- Idea: use vertex tracks as a seed and extend to the main tracker
- Interface with DD4hep CLIC geometry (Nikiforos, Frank): **SOON** ☺ *but not in this talk*
  - Results still with ILD detector → vertex + 2 SIT stereostrips layers
  - To do: a.t.m. vertex seed track for CLIC are computed with SiTracking → move to cellular automaton + mini-vectors computation → implementation + retuning needed

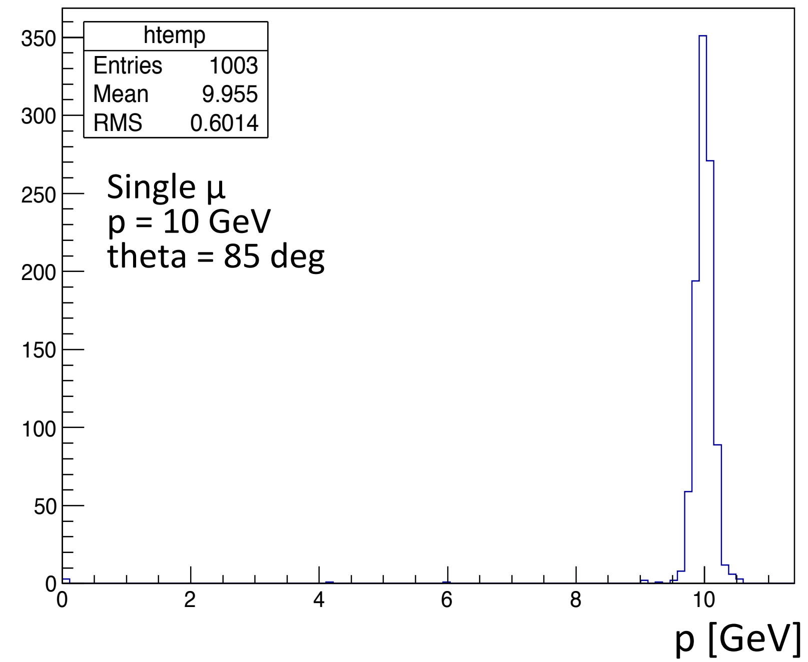






Extrapolation in single mu

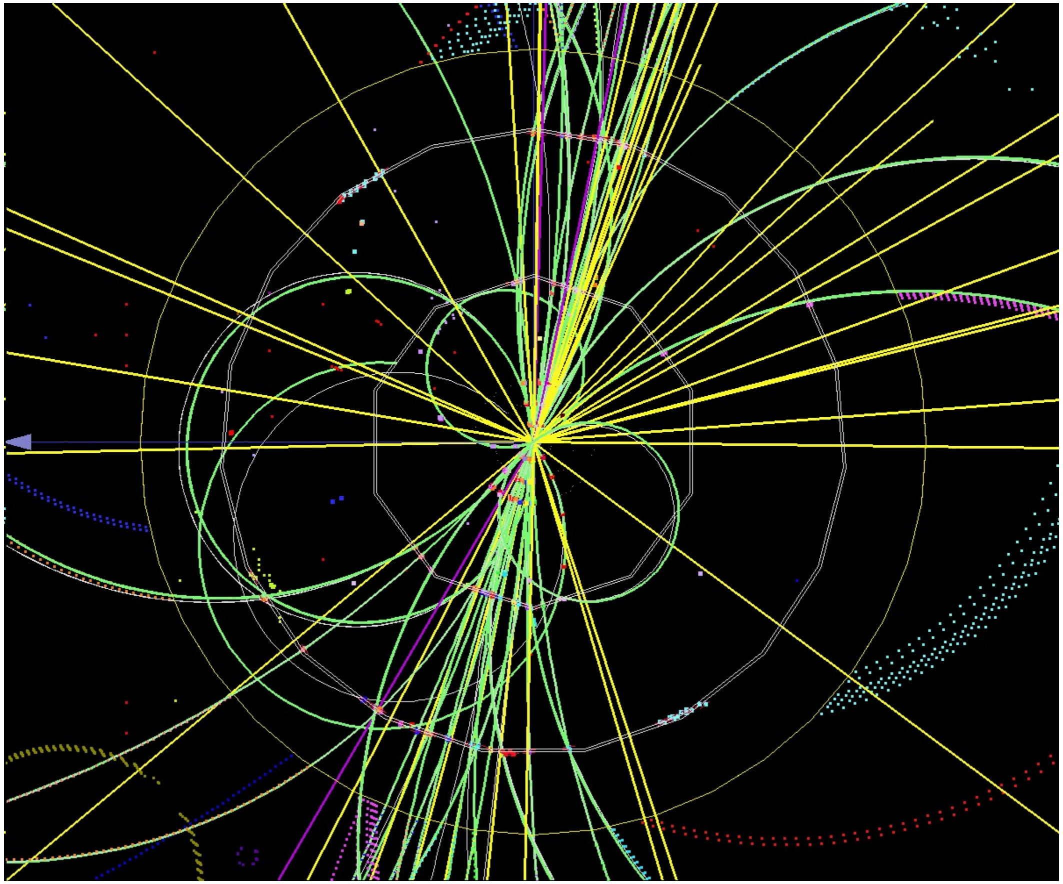


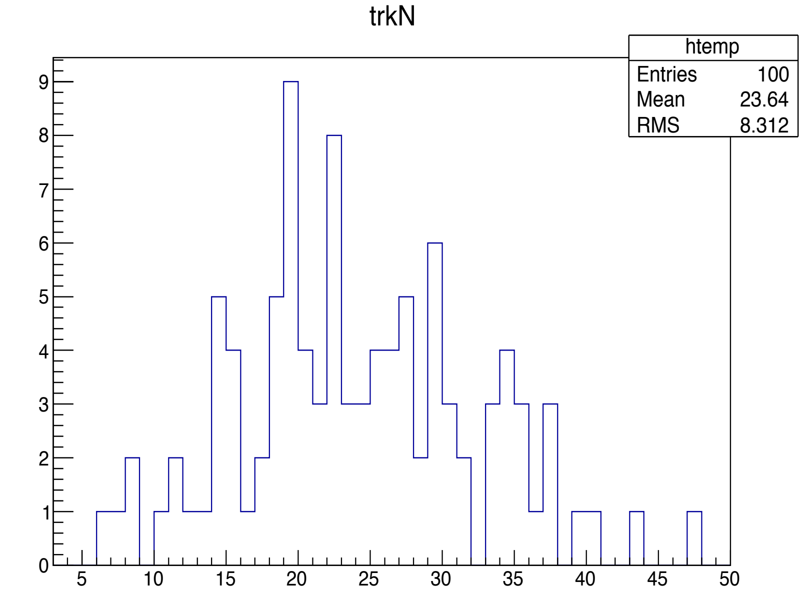


- Correct momentum measurement, probably room for improvement
- Next steps:
  - Study the tracking performance in terms of efficiency, fake rate, momentum and impact parameter resolution → Interface with ILDPerformance package
  - When this is ok, start to investigate strategy for CPU optimisation

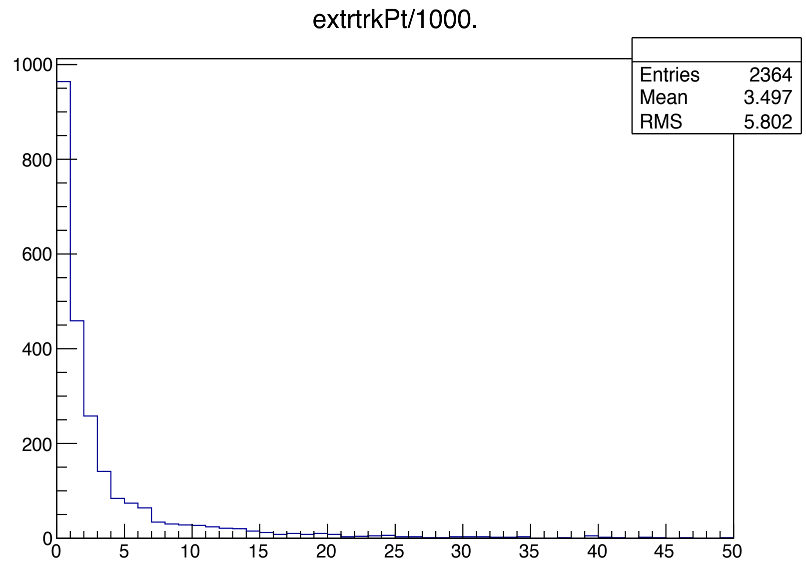
Zqq

- Centre-of-mass energy = 200 GeV
- Denser track environment
- Mostly low p_T track (reconstructed)





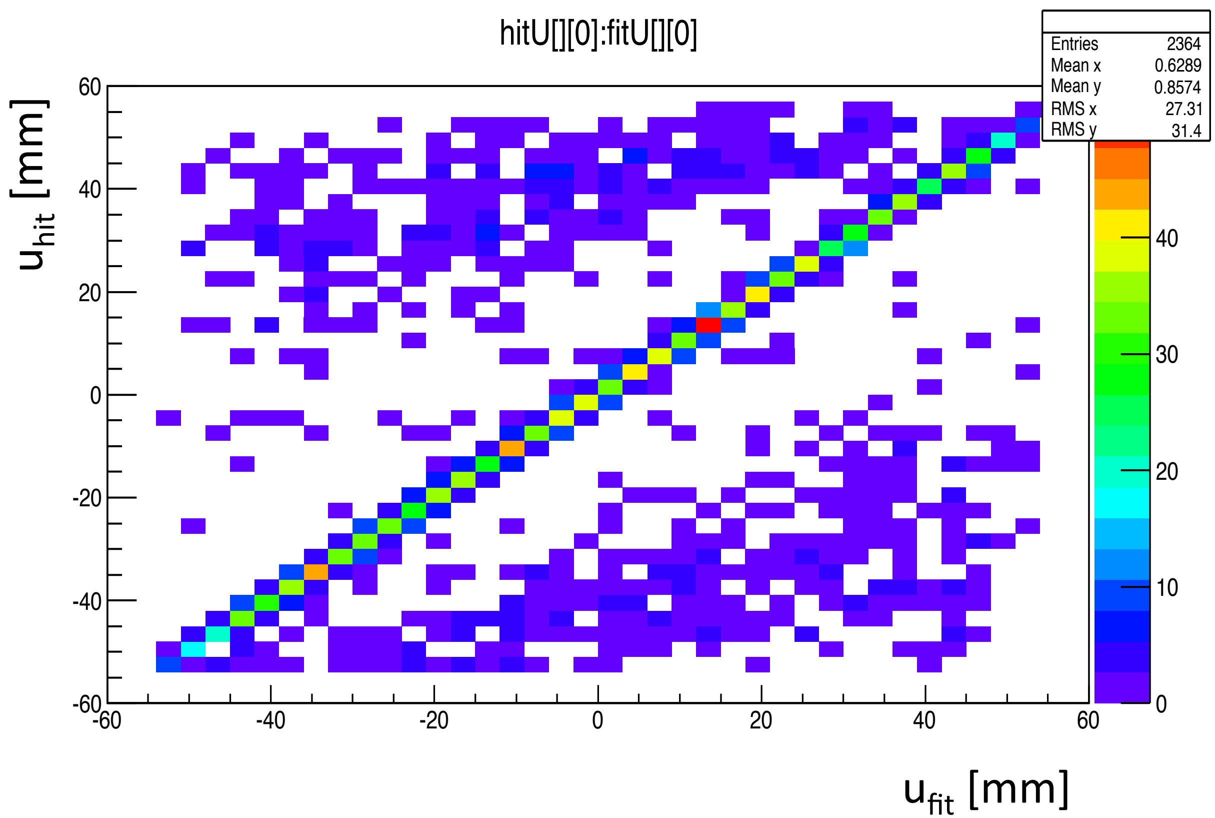
Ntrk

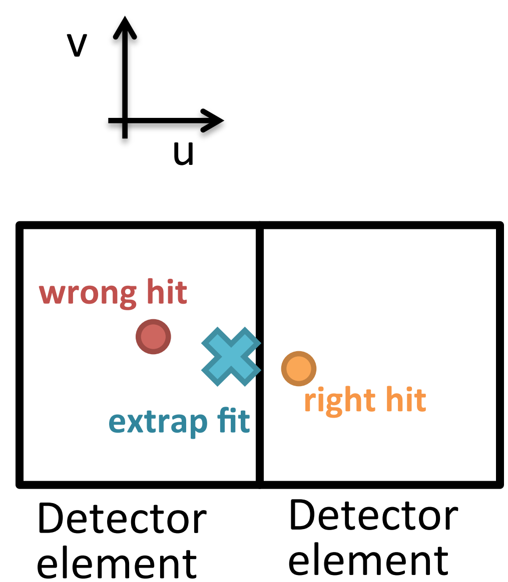


pT [GeV]

Results

- Very preliminary, few statistics
- When the extrapolated fit is close to the edge of the module it may happen that the corresponding hit is on a different module (a.t.m. hit association is done in the same module of the fit, close modules not considered)
  → a wrong hit can be included → part of the tails
- Study of the track hit association and comparison with the truth information is needed

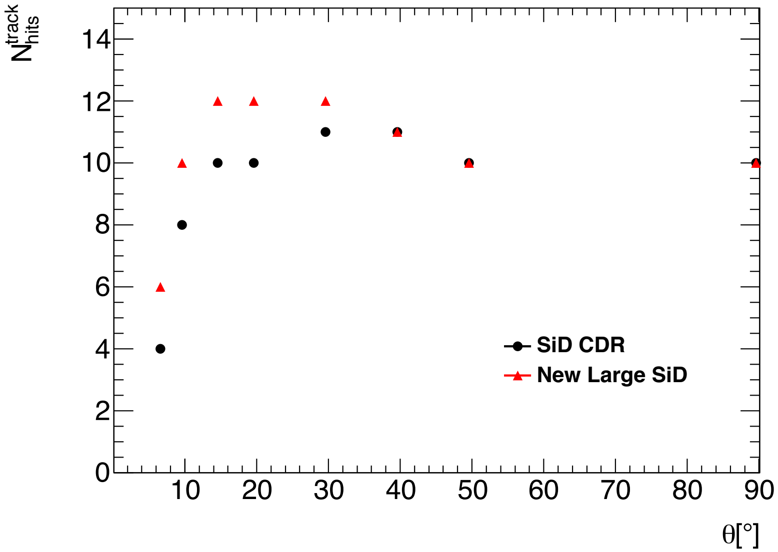


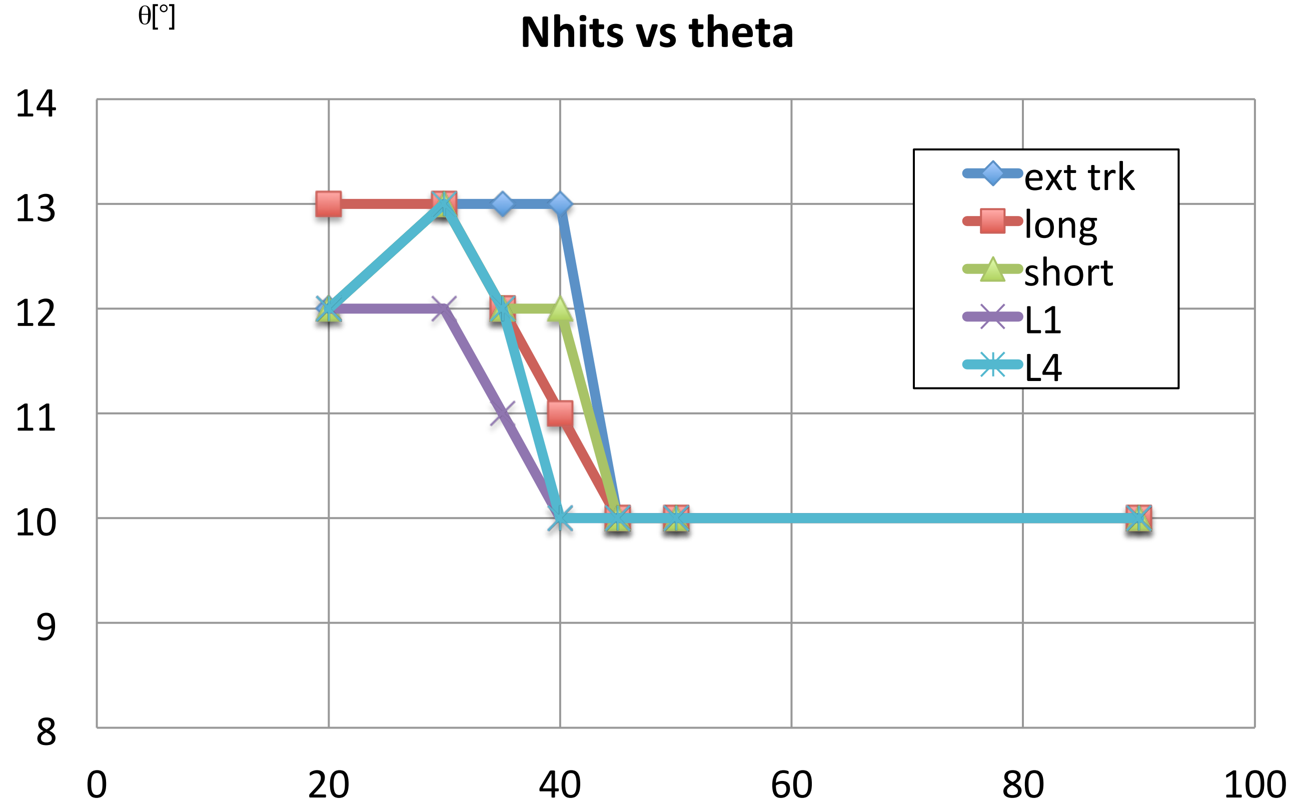


Conclusion

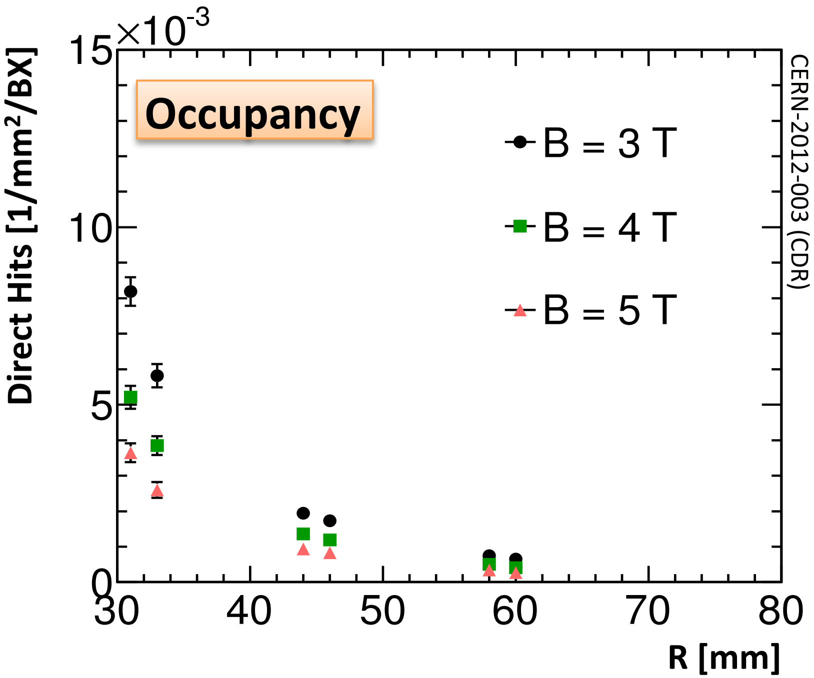
- Tracker optimisation studies are on-going
- New group investigating the tracker technology can provide interesting inputs for the simulation
- New tracking code is coming together
  - Track extrapolation seems feasible
  - Move to the CLIC geometry for all studies
  - Validation and more study on tracking performance and truth information comparison

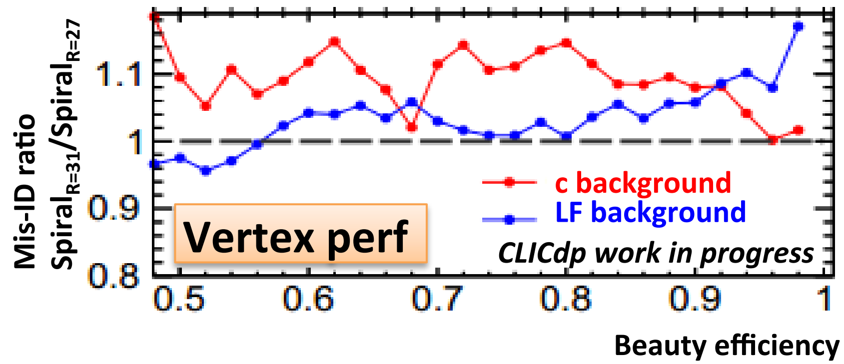
BACK-UP


N_{hits}^{track}
14
12
10
8
6
4
2
0
10 20 30 40 50 60 70 80 90
θ[°]
SiD CDR
New Large SiD


Nhits vs theta
14
13
12
11
10
9
8
0 20 40 60 80 100
ext trk
long
short
L1
L4

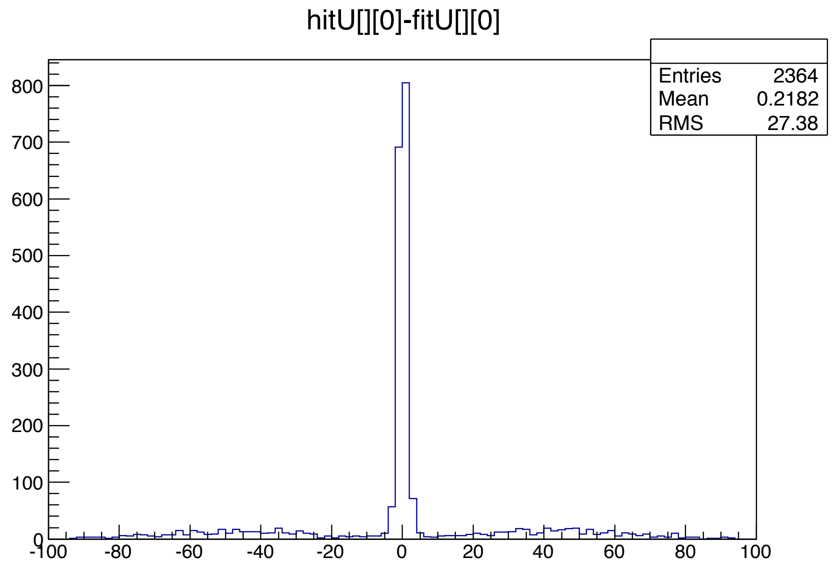
Occupancy in vetex detector

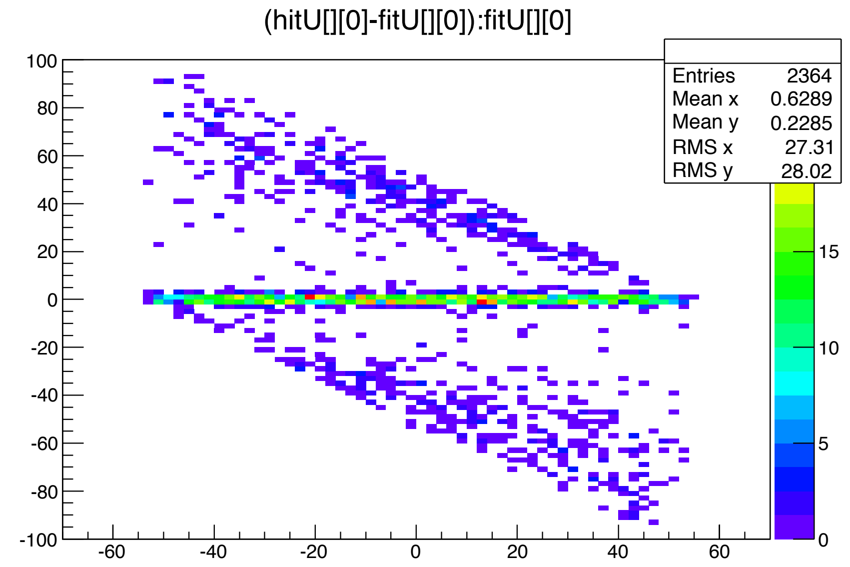


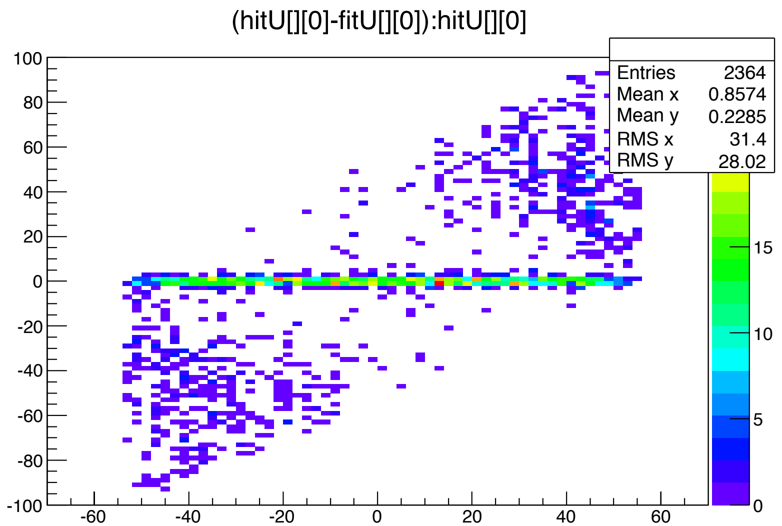


- Lower B gives more occupancy in the vertex detector
  - At 31mm 25% increase from B=5T to B=4T
- Possibility for larger inner radius for the vertex detector is investigated
  - R_{in} from 27mm to 31mm

Zuds


hitU[][0]-fitU[][0]
Entries 2364
Mean 0.2182
RMS 27.38

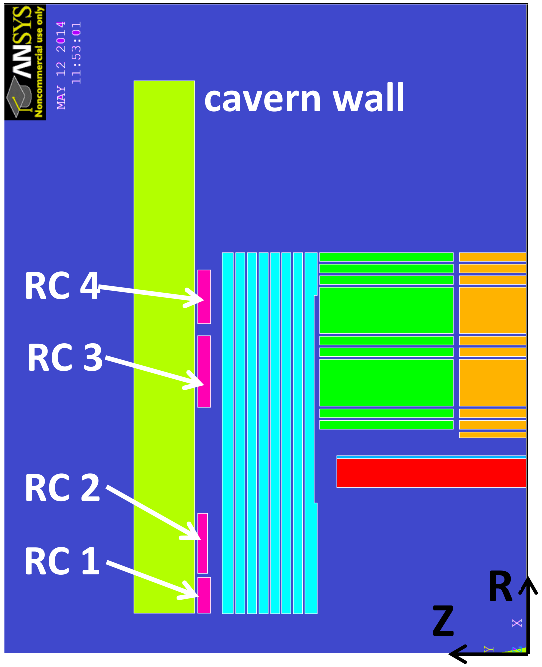

(hitU[][0]-fitU[][0]):fitU[][0]
Entries 2364
Mean x 0.6289
Mean y 0.2285
RMS x 27.31
RMS y 28.02

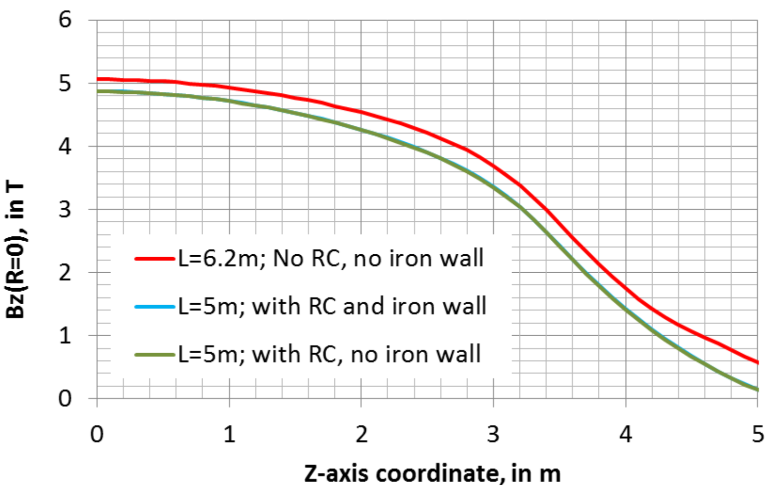

(hitU[][0]-fitU[][0]):hitU[][0]
Entries 2364
Mean x 0.8574
Mean y 0.2285
RMS x 31.4
RMS y 28.02

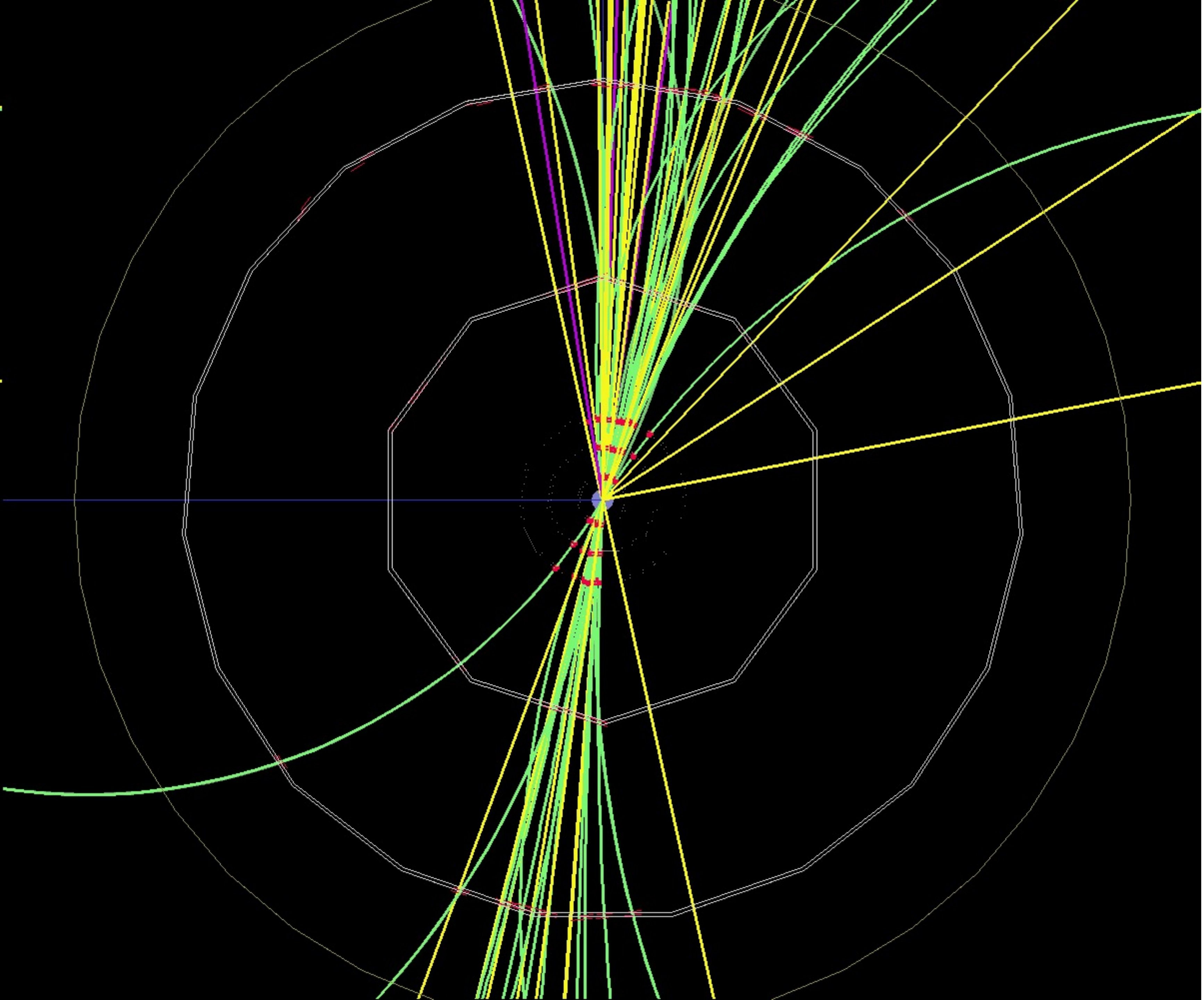
QD0 and Yoke endcap

Two main configurations under study:

- *QD0 out of the detector → L* = 6m*
  - Possibility for better HCAL acceptance → interest in t-channel physics and high energies
  - Loss in luminosity and engineering issues to be studied
  - Make the detector smaller → yoke endcap from 2.8m to 1.4m → add (copper) ring coils to reduce the stray field
    - 10% of iron in the concrete is assumed
    - Stray field lower than 3.2mT at R=15m
    - Inside the detector region: → 4% reduction of the B field → increase of field distrotion
    - Power of ring coils: 2 x 2260 kW
- *QD0 partially in the detector → L* = 4.5m*
  - Engineering issues to be studied







FROM ATLAS NOTE soft-pub-2007-005:
(A. Salzburger)

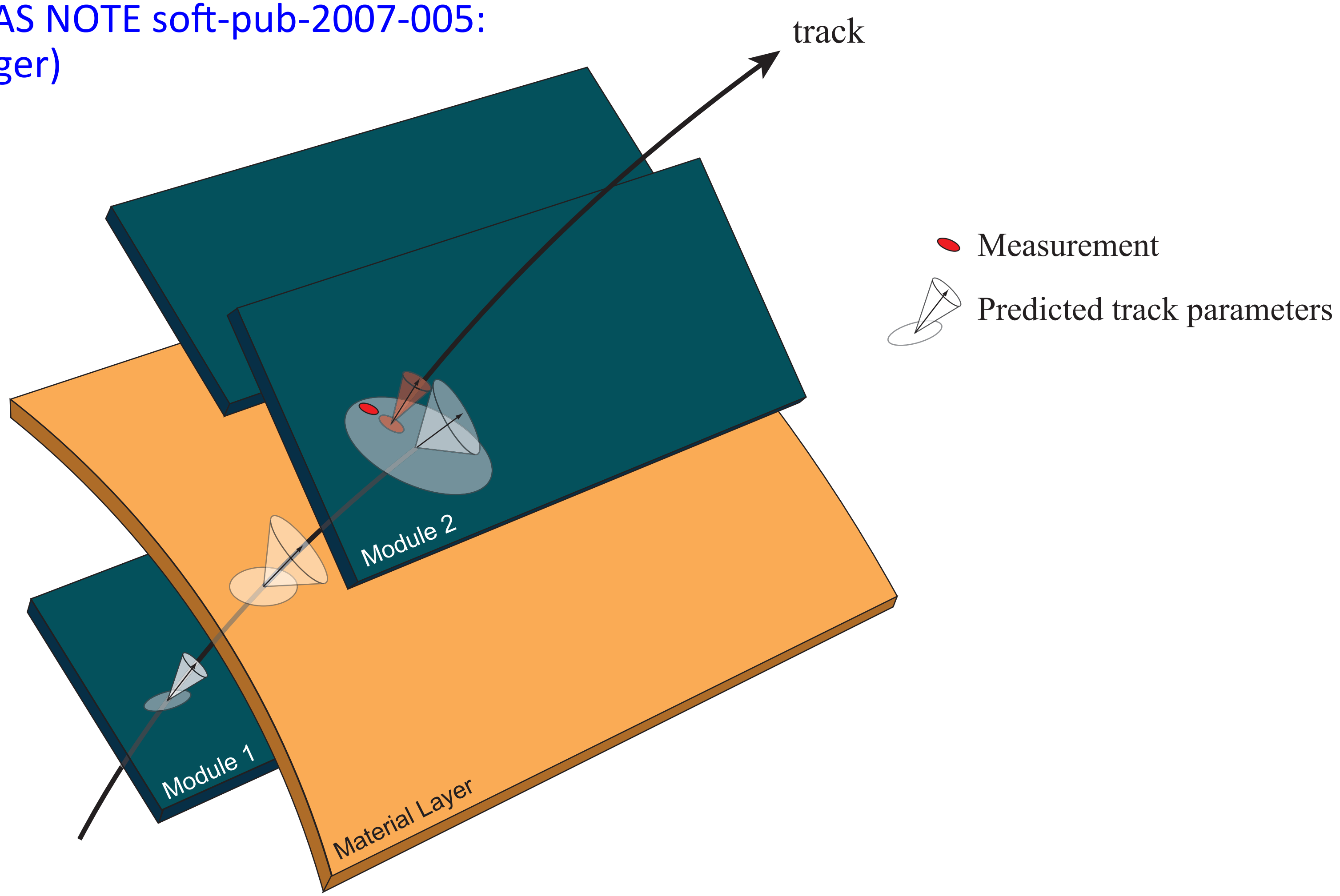
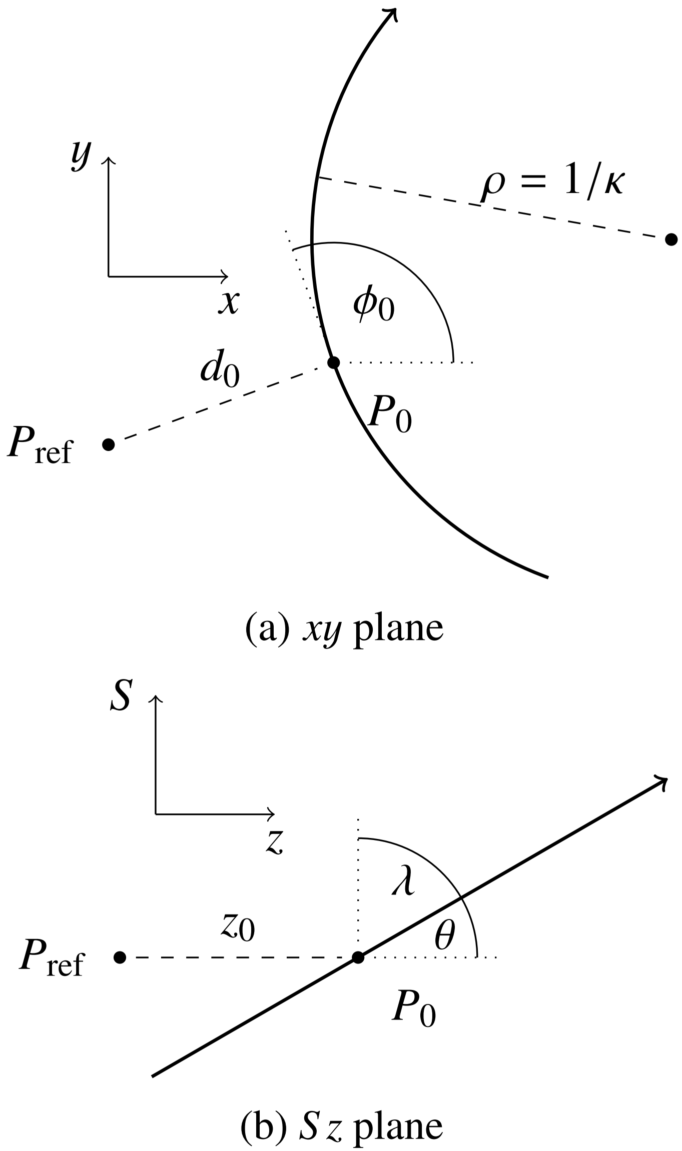


Figure 1: Simplified illustration of a typical extrapolation process within a Kalman filter step. The track representation on the detector module 1 is propagated onto the next measurement surface, which results in the track prediction on module 2. The traversing of the material layer between the two modules causes an increase of the track direction uncertainties and thus — by correlation — an increased uncertainty of the predicted track parameters. In the Kalman filter formalism, the weighted mean between prediction and associated measurement build the updated measurement which builds the start point for the next filter step; this leads to the illustrated non-continuous track model.

Helix tracking model (homo B)

FROM C. GREFE'S THESIS:



$$\text{starting point } P_0 = (x_0, y_0, z_0)$$

$$d_0 = \sqrt{x_0^2 + y_0^2}$$

$$p_\mathrm{T} = \frac{k\,B}{|\kappa|}$$

$$p_x = p_\mathrm{T}\,\cos\phi_0,$$

$$p_y = p_\mathrm{T}\,\sin\phi_0,$$

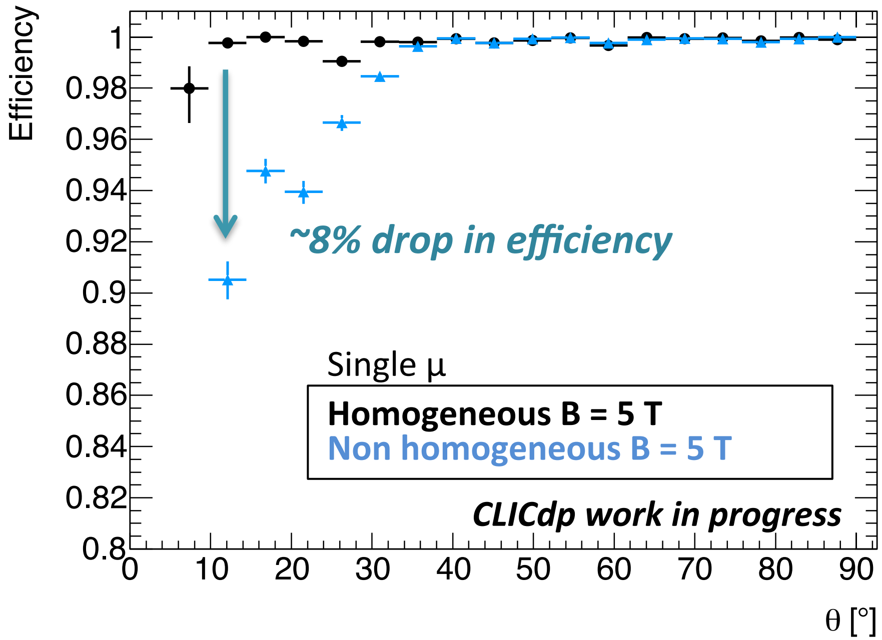
$$p_z = p_\mathrm{T}\,\tan\lambda,$$

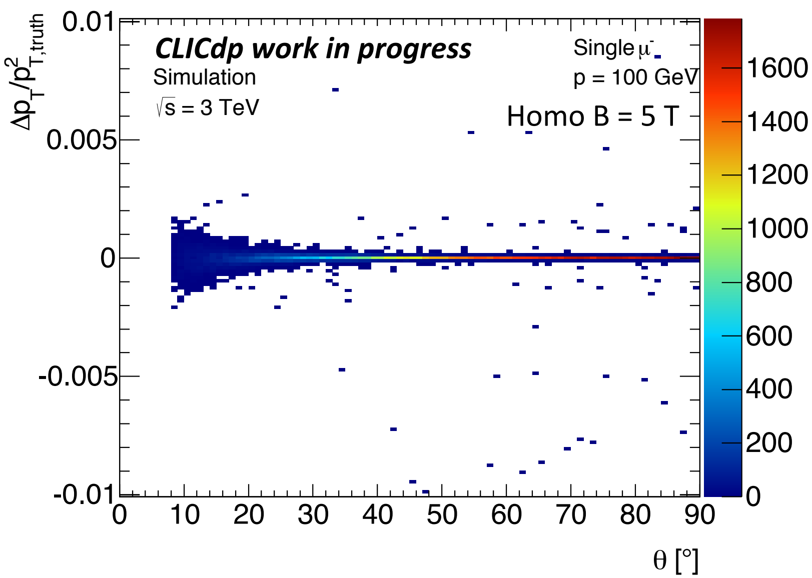
$$p = \frac{p_\mathrm{T}}{\cos\lambda} = p_\mathrm{T}\sqrt{1+\tan^2\lambda},$$

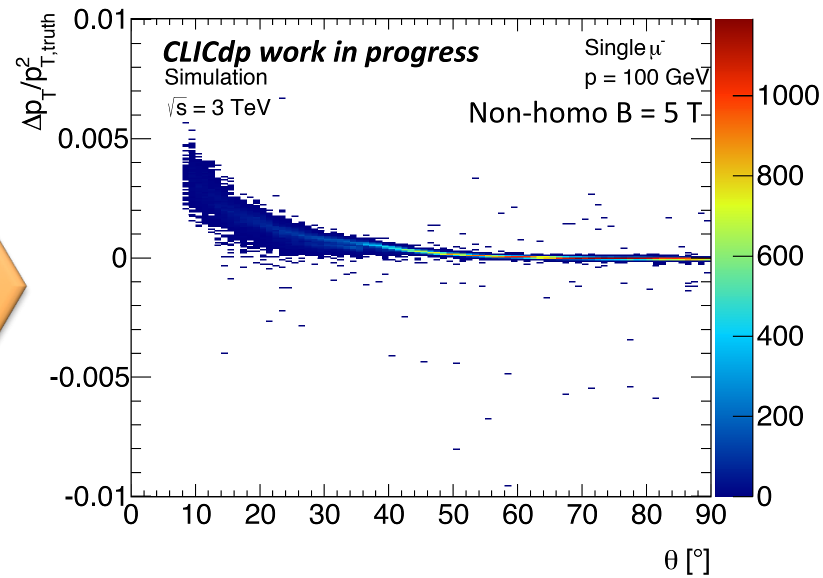
$$q = \frac{\kappa}{|\kappa|}.$$

Efficiency and p_T resolution

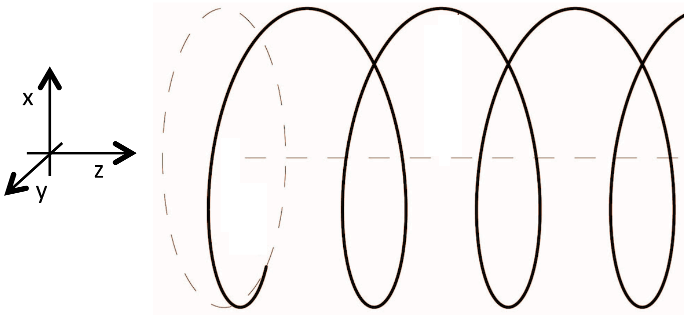
- Geometry used: *CLIC_2014_L5m_R7m* (CLIC_SiD with reduced endcaps)
- Degradation in reco efficiency and bias in the p_T reco due to the *assumption of* ***homogeneous field in the reconstruction***
  - In CLIC_SiD *helical* extrapolation and fit
  - In ATLAS use of *numerical integration method* (Runge-Kutta)





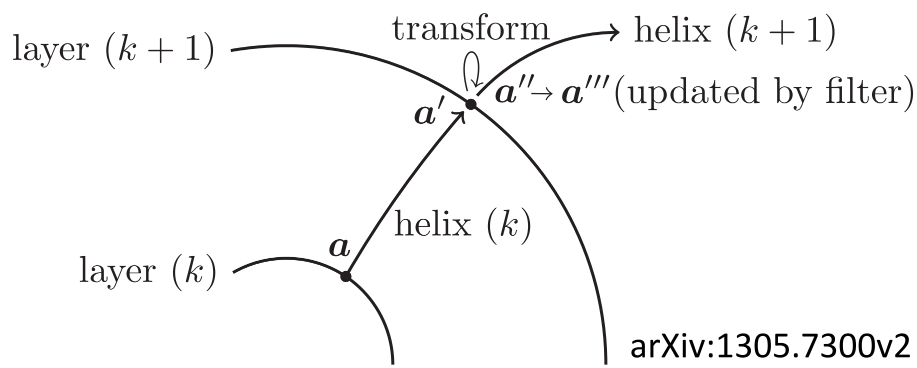


Tracking extrapolation



- **Global helical model:**
  - Homogeneous B
  - Circumference in rϕ plane
  - Straight line in Sz plane
  - 5 parameters $(\kappa, d_0, z_0, \phi_0, tan\lambda)$

- **Wise-segmented helix:**
  - Helix from layer to layer (homo B)
  - At every measurement update the B field and the reference frame
  - Impose a "sufficient" number of these steps (not only on measurement plane)
  - Kalman filter implementation



arXiv:1305.7300v2

soft-pub-2007-005

$$\frac{d^2\mathbf{r}}{ds^2} = \frac{q}{p}\left[\frac{d\mathbf{r}}{ds} \times \mathbf{B}(\mathbf{r})\right] + g(p, \mathbf{r})\frac{d\mathbf{r}}{ds}$$

Lorentz force — energy loss function

- **Runge-Kutta based extrapolator:**
  - General method, any assumption about B
  - Solve second order differential equation of motion to compute the intersection of the trajectory with the destination plane

Change of coordinate frame

FROM ILD NOTE arXiv:1305.7300v2:
(Bo Li, Keisuke Fujii, Yuanning Gao)

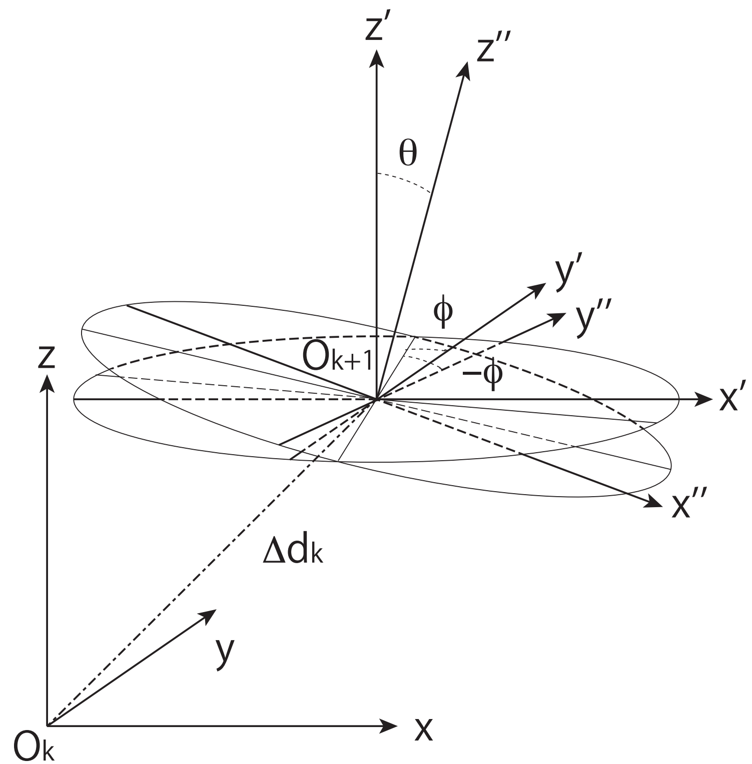


Figure 4: Transformation from one frame to the next. The θ and ϕ angles are determined by the magnetic field directions at the position $\boldsymbol{O}_k$ and $\boldsymbol{O}_{k+1}$.

Cellular automaton criteria

FROM R. Glattauer's THESIS

Table 2.1.: The different criteria available in the `KiTrack` package (The time is given relative to the fastest criterion)

name	hits	time	description
DeltaRho	2	1.00	The difference of the distances to the z-axis: $\Delta\rho = \sqrt{x_2^2 + y_2^2} - \sqrt{x_1^2 + y_1^2}$.
RZRatio	2	1.00	The distance of two hits divided by their z-distance: $\frac{\sqrt{\Delta x^2+\Delta y^2+\Delta z^2}}{\|\Delta z\|}$
StraightTrackRatio	2	1.04	Best suited for straight tracks: if the line between the two hits points towards IP. Calculated is $\frac{\rho_1}{z_1} / \frac{\rho_2}{z_2}$, where $\rho = \sqrt{x^2 + y^2}$. Is equal to 1 for completely straight tracks.
DeltaPhi	2	1.30	The difference between the ϕ angles of two hits in degrees. ϕ is the azimuthal angle in the x-y plane w.r.t. the positive x axis: $\phi = \text{atan2}(y, x)$.
HelixWithIP	2	1.43	Checks if two hits are compatible with a helix through the IP. A circle is calculated from the two hits and the IP. Let α be the angle between the center of the circle and two hits. For a perfect helix $\frac{\alpha}{\Delta z}$ should be equal for all pairs of hits on the helix. The coefficients for the first and last two hits (including the IP) are compared: $\frac{\alpha_1}{\Delta z_1} / \frac{\alpha_2}{\Delta z_2}$. This is 1 for a perfect helix around the z-axis.
ChangeRZRatio	3	1.23	The coefficient of the RZRatio values for the two 2-hit-segments. Ideally this would equal 1.
2DAngle	3	1.23	The angle between two 2-hit-segments in the x-y plane.
2DAngleTimesR	3	1.46	The 2DAngle, but multiplied with the radius of the circle the segments form, in order to get better values for low momentum tracks.
3DAngle	3	1.25	The angle between two 2-hit-segments.
3DAngleTimesR	3	1.48	3DAngle times the radius of the circle.
PT	3	1.30	The transversal momentum as calculated from a circle in the x-y plane. This criterion includes knowledge about the magnetic field and in this way differs from the rest. A more basic version would be to either use the radius of the circle or its inverse Ω. Using p_T was chosen for reasons of readability.
IPCircleDist	3	1.30	From the 3 hits a circle is calculated in the x-y plane and the distance of the IP to this circle is measured.
IPCircleDistTimesR	3	1.30	Distance of the IP to the circle multiplied with the radius of the circle to take into account higher deviations for low transversal momentum tracks.
DistOfCircleCenters	4	1.66	Circles are calculated for the first and last 3 hits. The distance of their centers is measured.
RChange	4	1.66	The coefficient of the radii of the two circles.
DistToExtrapolation	4	2.21	From the first 3 hits the relation of α to Δz is calculated. This is used to predict x and y of the fourth hit for the given z-value. The distance of this prediction to the actual position in x and y is measured.
NoZigZag	4	2.30	A criterion to sort out tracks that make a zig zag movement. The 2-D angles are measured for the first and the last three hits. Then they are transposed to the area of $-\pi$ to π and multiplied. A zig-zagging track would give angles with different signs and therefore a negative multiplication result.
2DAngleChange	4	2.30	The coefficient of the 2-D angles.
3DAngleChange	4	2.41	The coefficient of the 3-D angles.
PhiZRatioChange	4	2.50	The coefficient of the PhiZRatio of the first 3 and the last 3 hits.