JINR meeting,
23 December 2019

Software for track fit and results of it's usage for various geometries

V. Andreev, S. Gerassimov

(on behalf of LPI group)

Introduction

- Track reconstruction is an essential part of most HEP experiments

- Track reconstruction is traditionally divided into separate sub-tasks:
  - track finding
  - track fitting

- Track finding:
  - division of set of measurements in a tracking detectors into subsets
  - each subset contains measurements believed to originate from the same particle

- Track fitting:
  - starts with the measurements inside one subset as provided by the track finder
  - aims to estimate a track parameters using the information from the measurements
  - evaluates the quality and final acceptance of the track candidate

- There are several different track fitters:
  - Least Square Track fit;
  - Global Broken Line fit (GBL);
  - Kalman Filter Track fit and it's varieties;
    - Gaussian Sum Filter fit ;
    - Deterministic Annealing Filter fit.

- We propose to use Kalman filter algorithm in a track fitter program (at this moment)

Kalman Filter

Kalman filter is an algorithm that adds progressively the information from each detector hits to estimate track parameters using a linear model of measurement and track propagation

Kalman fitter, in general, has 2 main steps – extrapolation and update:

Extrapolation uses the standard Runge-Kutta method with some modification (for example, similar method is used in ATLAS experiment)

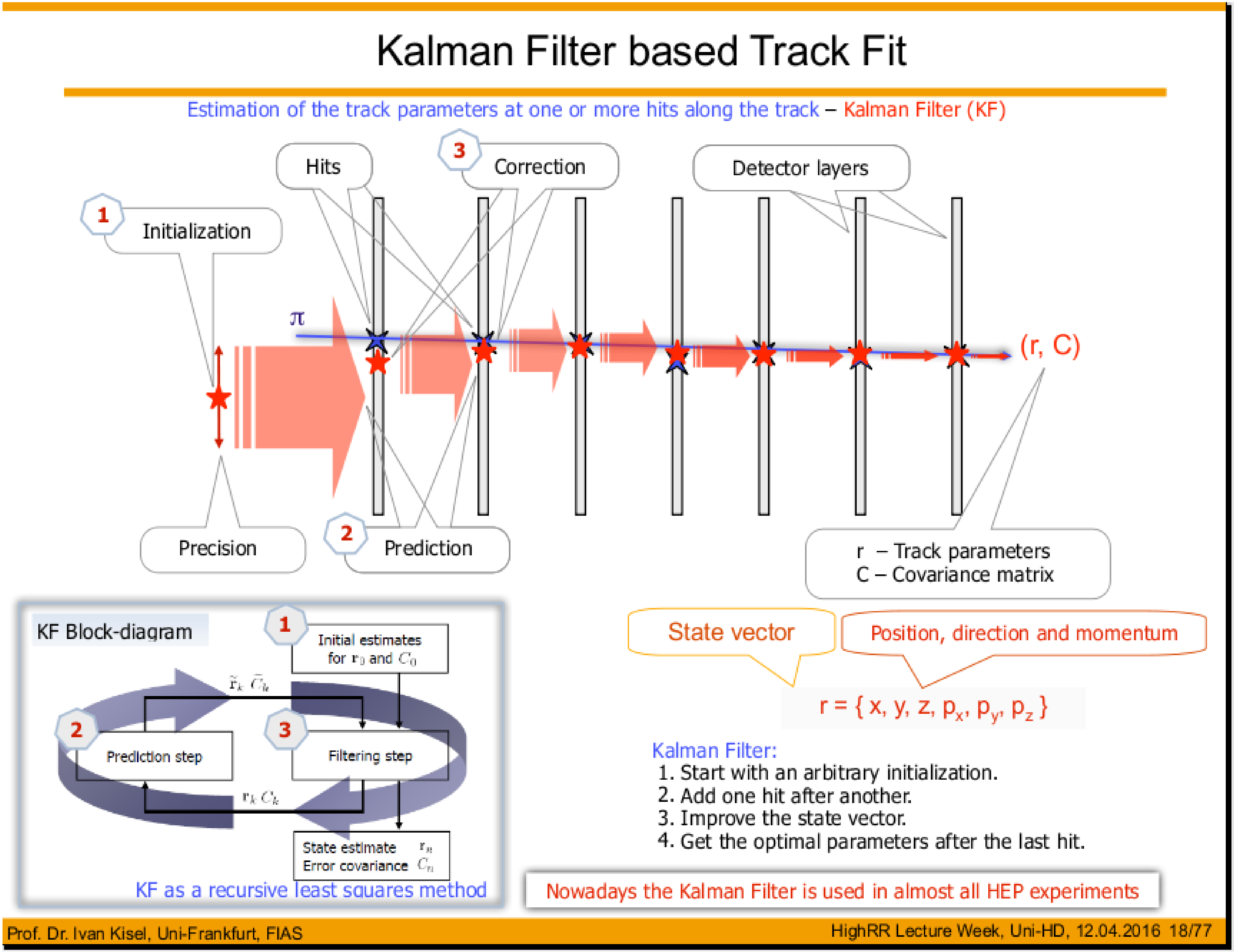
During the Runge-Kutta extrapolation global track parameters (**x, T**, q/p) are used, namely q/p, spatial coordinate (**x**) and unit tangent vector (**T**) pointing along track

After the extrapolation has reached the target surface global coordinate are converted to local coordinate (q/p, u', v', u, v)

Update track parameters and covariance matrix taking into account measurement on detector plane with covariance matrix

Track can be fitted in forward and backward direction:

- forward direction gives the best estimation of track parameters at the end;
- backward direction gives the best estimation of the track parameters at the interaction vertex;
- “smoothing track” state can be estimated as weighted mean these 2 direction fits (forward and backward)


Kalman Filter based Track Fit
Estimation of the track parameters at one or more hits along the track – Kalman Filter (KF)
1 Initialization
Hits
3 Correction
Detector layers
π
(r, C)
Precision
2 Prediction
r – Track parameters
C – Covariance matrix
KF Block-diagram
1 Initial estimates for r_0 and C_0
$\tilde{r}_k$ $\tilde{C}_k$
2 Prediction step
3 Filtering step
r_k C_k
State estimate r_n
Error covariance C_n
KF as a recursive least squares method
State vector
Position, direction and momentum
r = { x, y, z, p_x, p_y, p_z }
Kalman Filter:
1. Start with an arbitrary initialization.
2. Add one hit after another.
3. Improve the state vector.
4. Get the optimal parameters after the last hit.
Nowadays the Kalman Filter is used in almost all HEP experiments
Prof. Dr. Ivan Kisel, Uni-Frankfurt, FIAS
HighRR Lecture Week, Uni-HD, 12.04.2016 18/77

Kalman fitter realization

1) 1-st step => use the special standalone program in which Kalman fitter is realized;

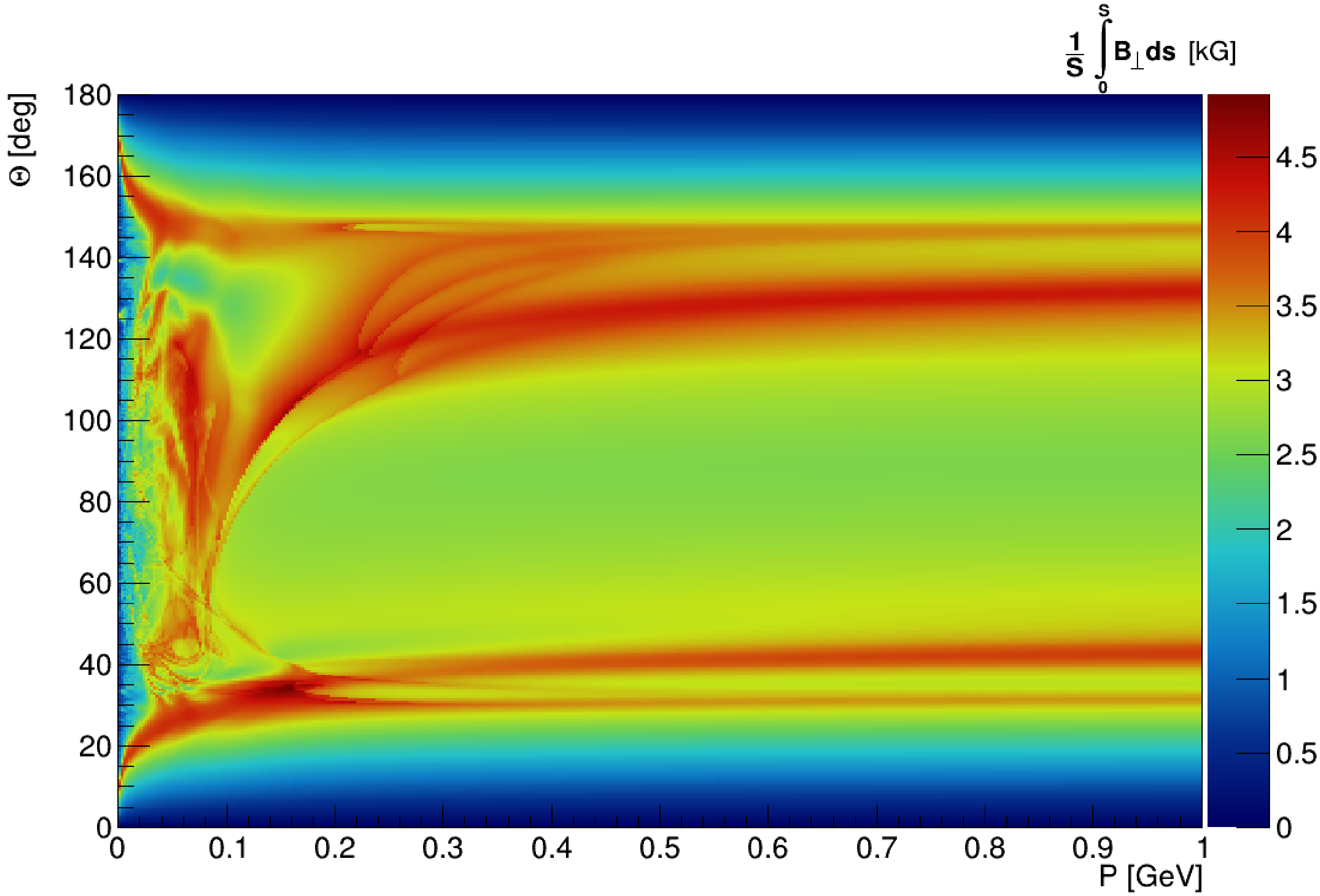
2) this standalone program was developed on the base of GenFit2 package (arXiv:1902.04405, 19.02.2019) with our modification;

3) program gives possibility to do track fit using as input hits from tracker detector for various geometries of tracker and different configuration of magnetic field;

4) the program for primary vertex fit is created;

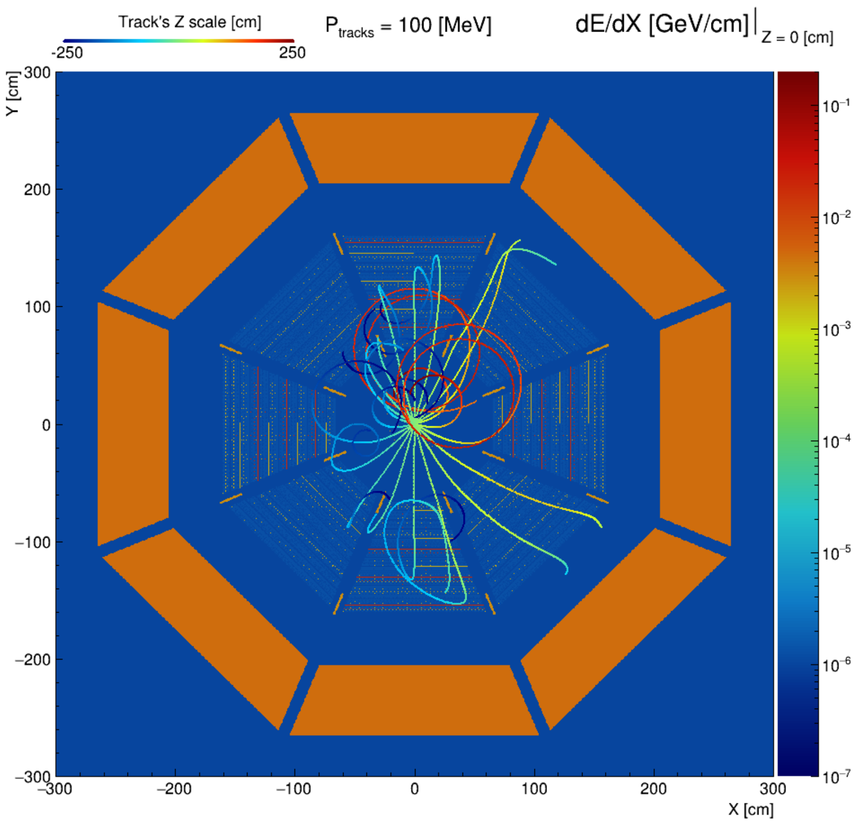
5) special software utilities for visualization of magnetic field and materials map as well as for calculation of field integrals and materials budget was developed.

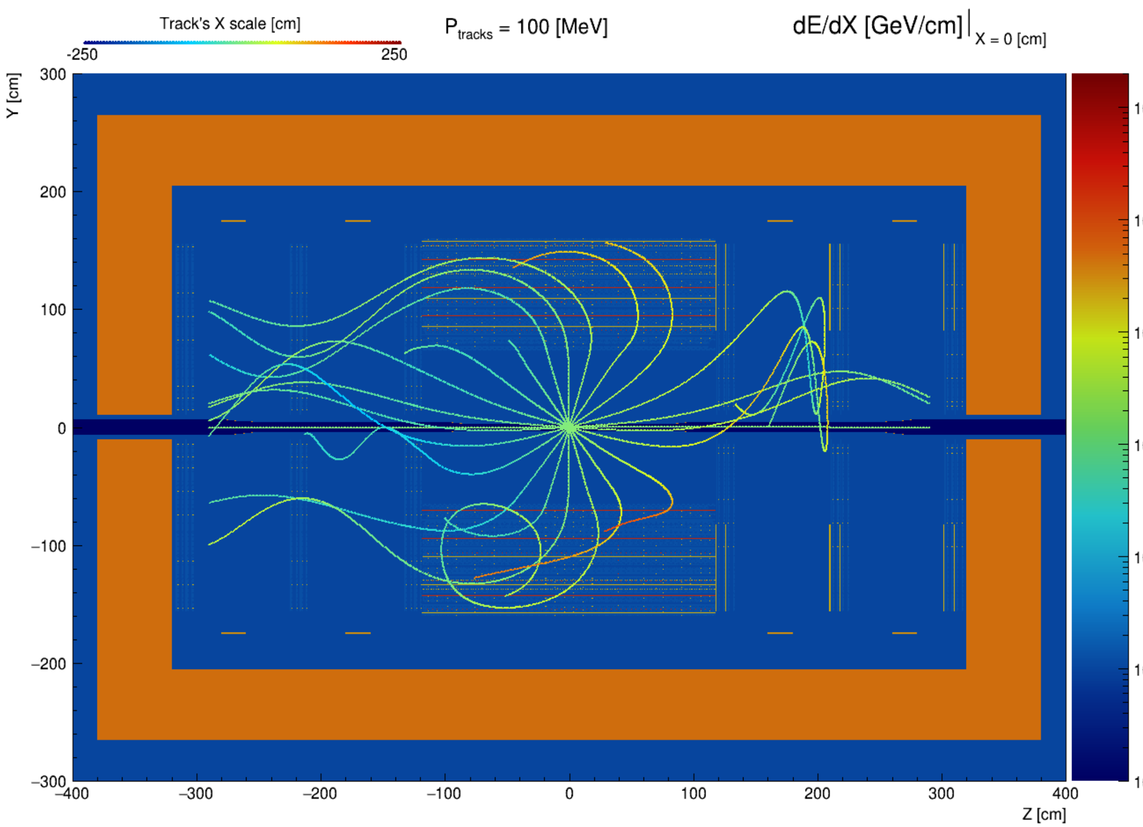
Field integrals calculation



Integral of transverse hybrid field (2B) (field component perpendicular to positively charged particle motion direction) normalized on the path length of the particle in the field, as function of *P* and θ angle (integrated over all ϕ angle)

Material effect (energy loss)





Hybrid magnetic field (with 2B field) had been "probed" by extrapolation of positively charged particles:

- in momentum range: 0 – 1 GeV (step 25 MeV)
- in θ angle range: $0^0 \leq \theta \leq 180^0$ (step 0.5 degree)
- in φ angle range: $0^0 \leq \varphi \leq 360^0$ (step 5 degree)

Primary vertex fit

1) we have checked 2 different programs for primary vertex fit in our study

2) RAVE - detector-independent toolkit to reconstruct vertex (was developed in CMS experiment https://rave.hepforge.org/). This program is used only for cross check (as need to apply some additional efforts for implementation of non-solenoidal magnetic field and non-helix track extrapolation)

3) at the present moment for primary vertex fit we developed program on the base of Kalman fit procedure (similar to program in CBM experiments, CBM-SOFT-note-2006-002)

4) we combine stand-alone program for Kalman fit of tracks and the primary vertex fit program

5) as the result the primary vertex fit program can provide vertex reconstruction as function of the different tracker and vertex detectors geometries and magnetic field configuration

General scheme for SPD track and primary vertex fits

1) use SPDroot simulation package with different tracker geometries and magnetic field Configurations;

2) use inline generator for muons generation and run SPDroot simulation to produce output-root file with simulated hits in various detectors;

3) run interface program to produce the special file with MC hits (x,y,z –coordinates) as input for Kalman track fit program;

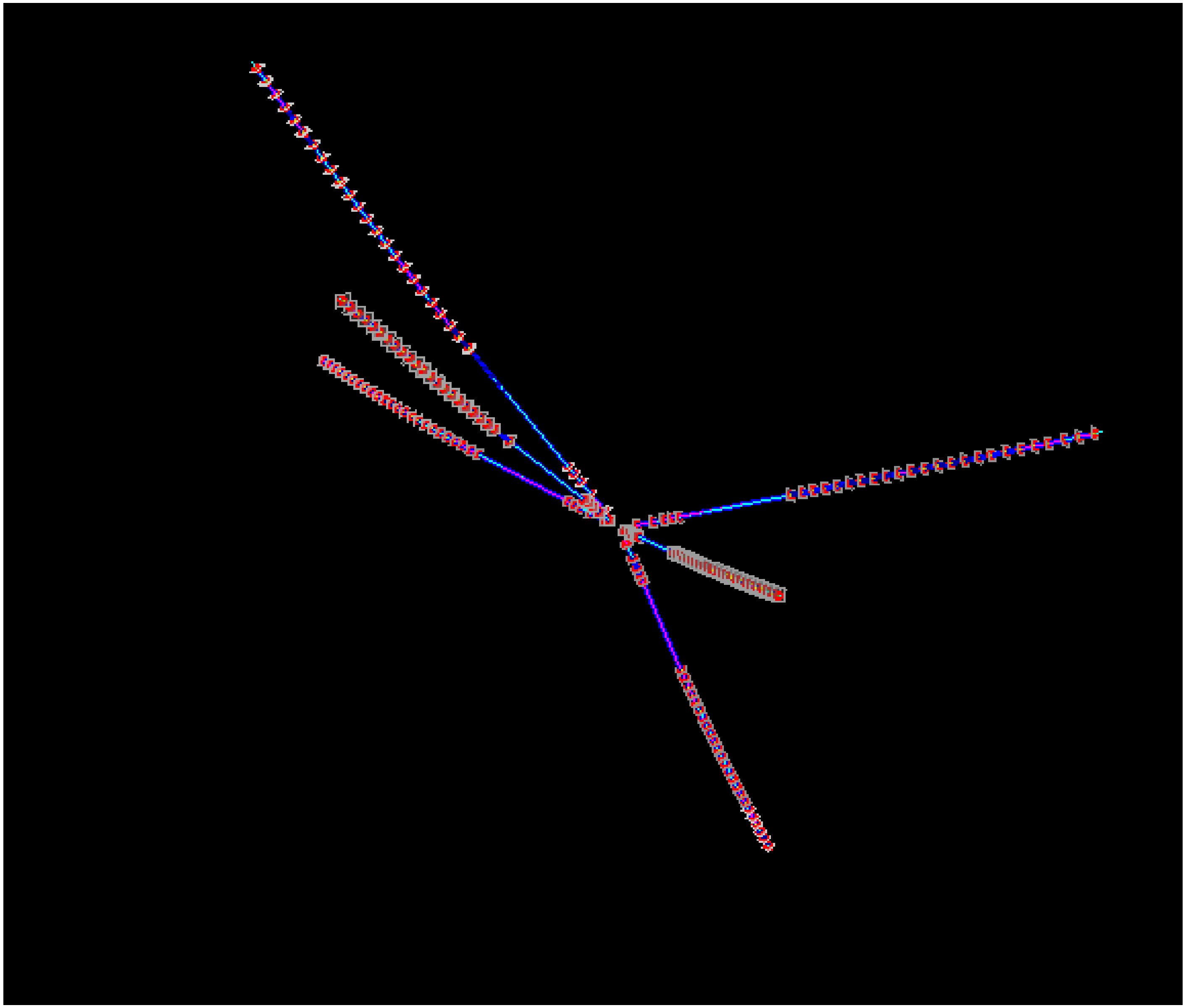
4) add corresponding magnetic field configuration in Kalman fitter stand-alone program;

5) read simulated MC hits in stand-alone program and add detector resolution effect for each hit point x,y,z – coordinate (for example 150 μm, Gaussian);

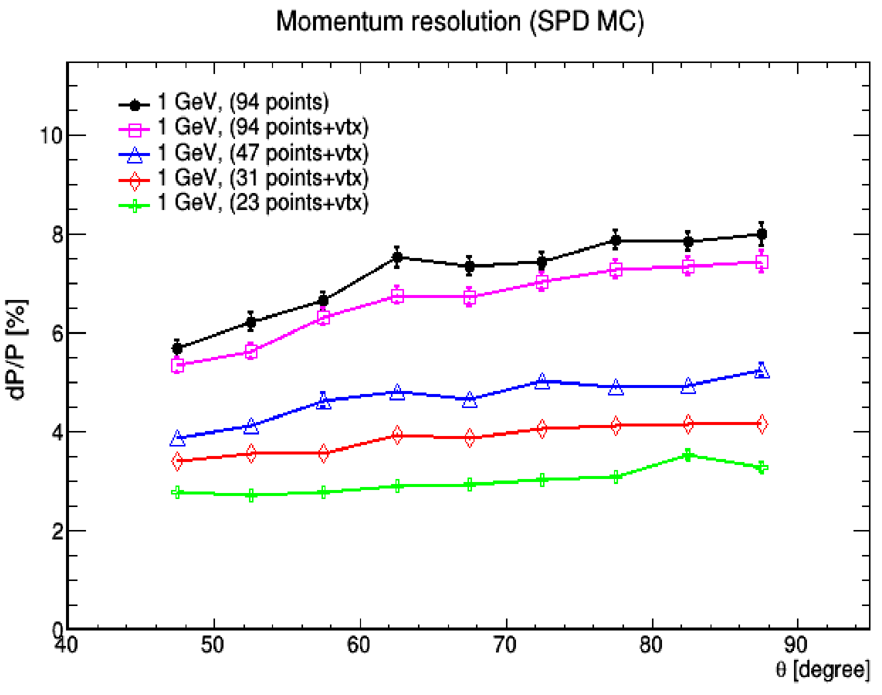
6) do Kalman fitter procedure and determine track parameters;

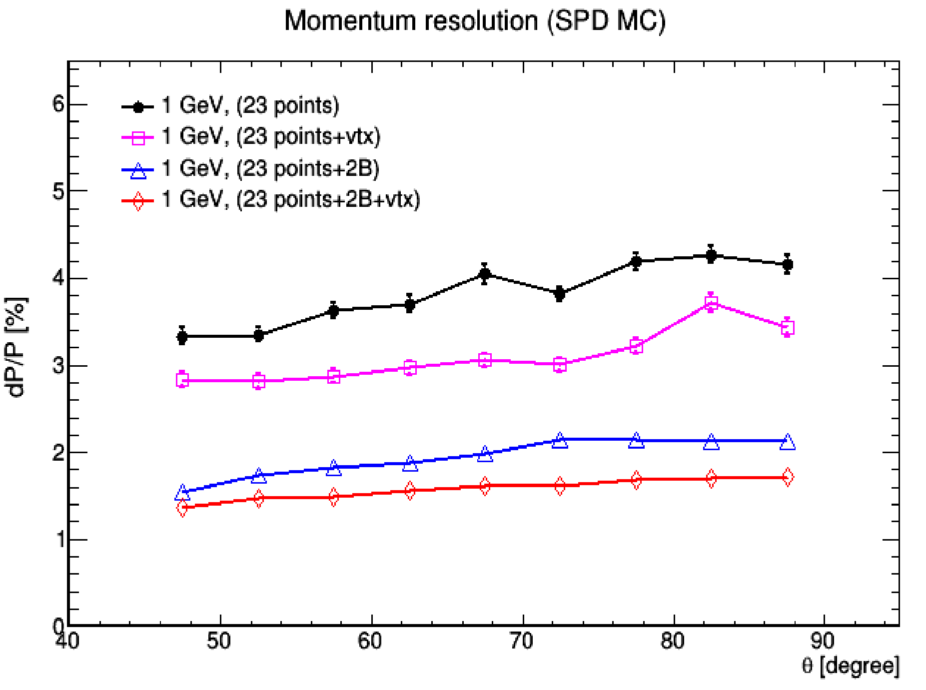
7) reconstruct primary vertex in events using the tracks after Kalman fit.

Tracks and primary vertex fits



Track momentum resolution + vertex detector (SPD MC)





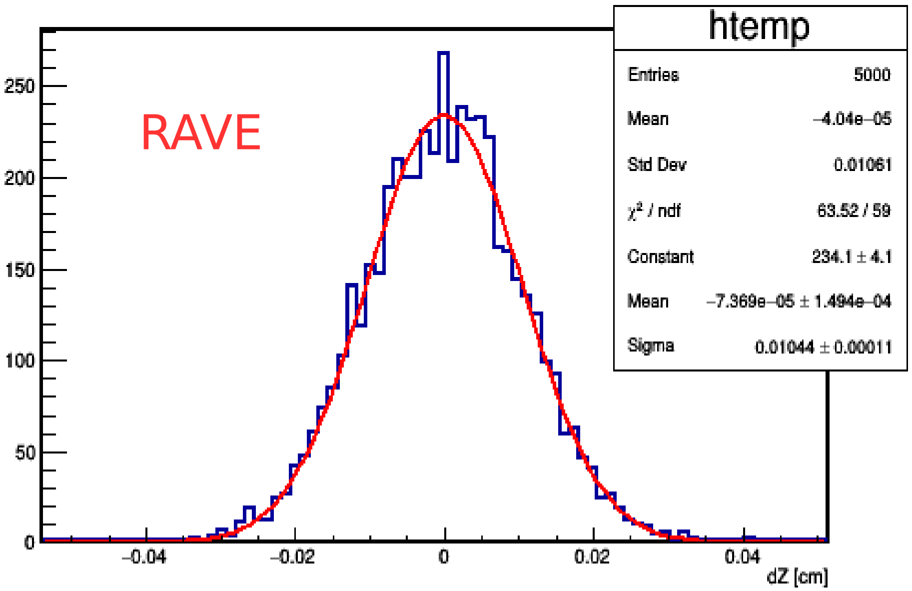
1) adding vertex detector => 5 silicon detector based layers (R = 7.0, 13.6, 18.2, 21.2 and 24.1 cm) give 5 additional points with 50 μm space resolution;

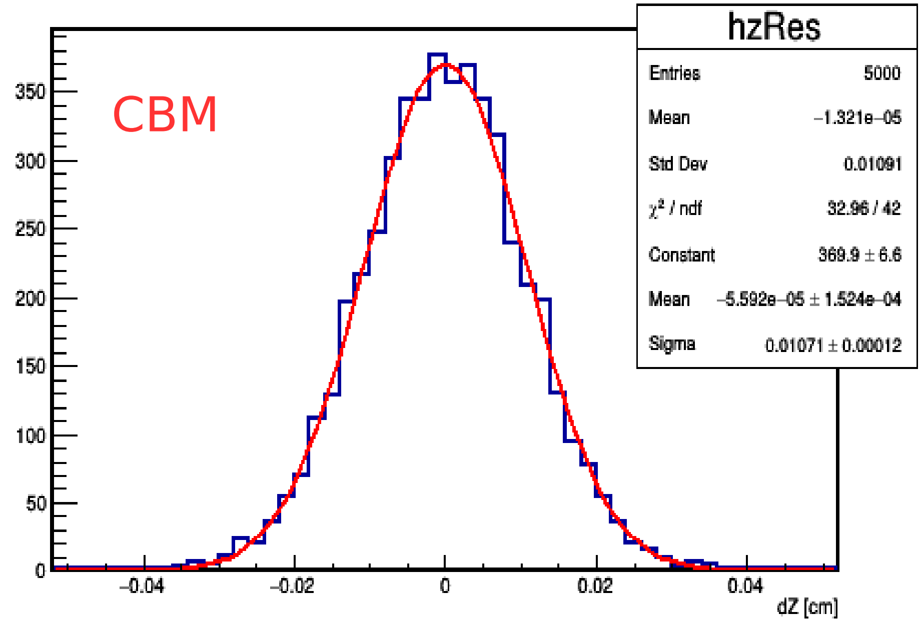
2) decrease number of layers in straw tracker detector => improve track's momentum resolution (decrease multiple scattering in tracker material, left plot);

3) add vertex detector => improve track's resolution (right plot, black and magenta colours);

4) increase field and use vertex detector => best way to improve track's momentum resolution (right plot)

Vertex position resolution (in z, RAVE vs CBM)





1) we did comparison of RAVE and CBM based primary vertex fitter programs with constant field along z-axis and ideal stand-alone geometry of SPD tracker (just for cross check):

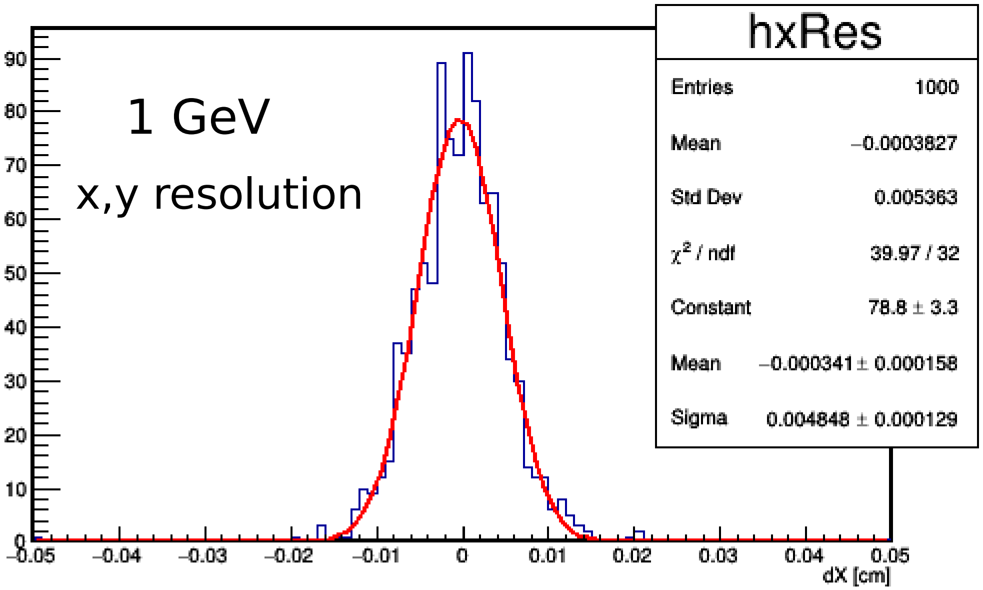
2) simulate 6 tracks of 3 GeV momentum inside range $45^0 \le \theta \le 135^0$ and $0^0 \le \varphi \le 360^0$

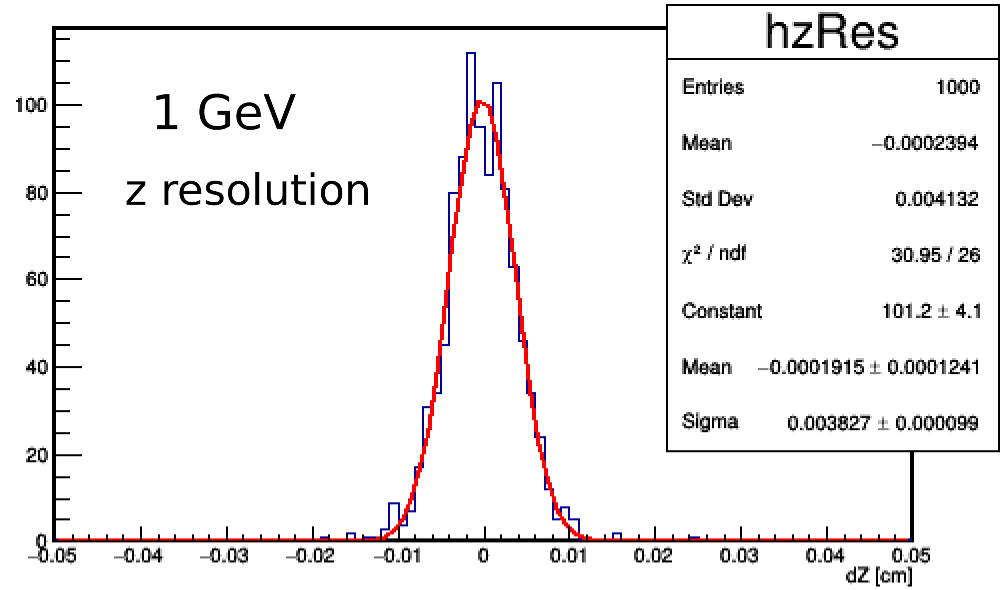
3) did primary vertex fit using these 2 programs (RAVE and CBM based);

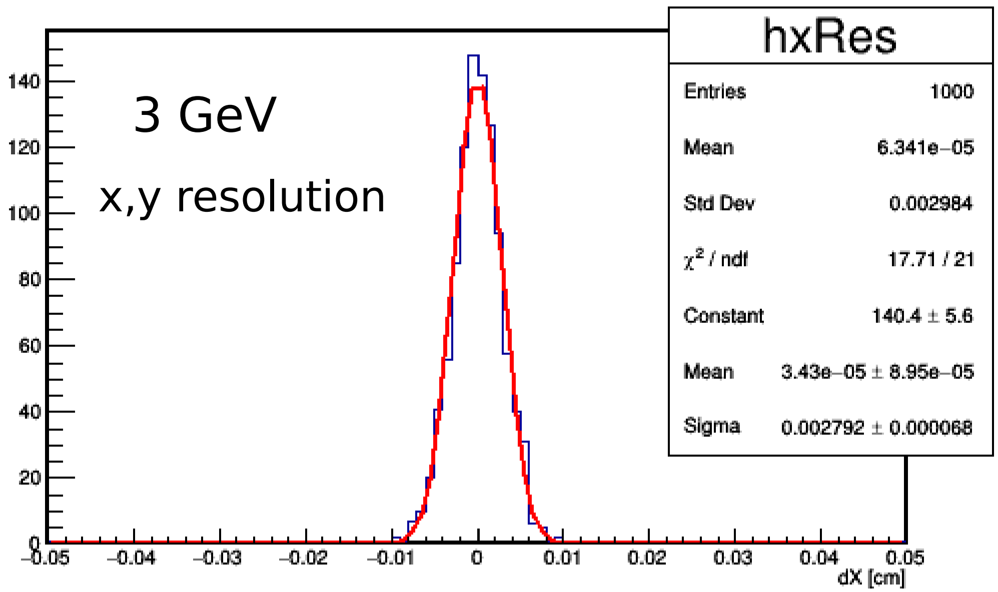
4) RAVE and CBM based show the similar results;

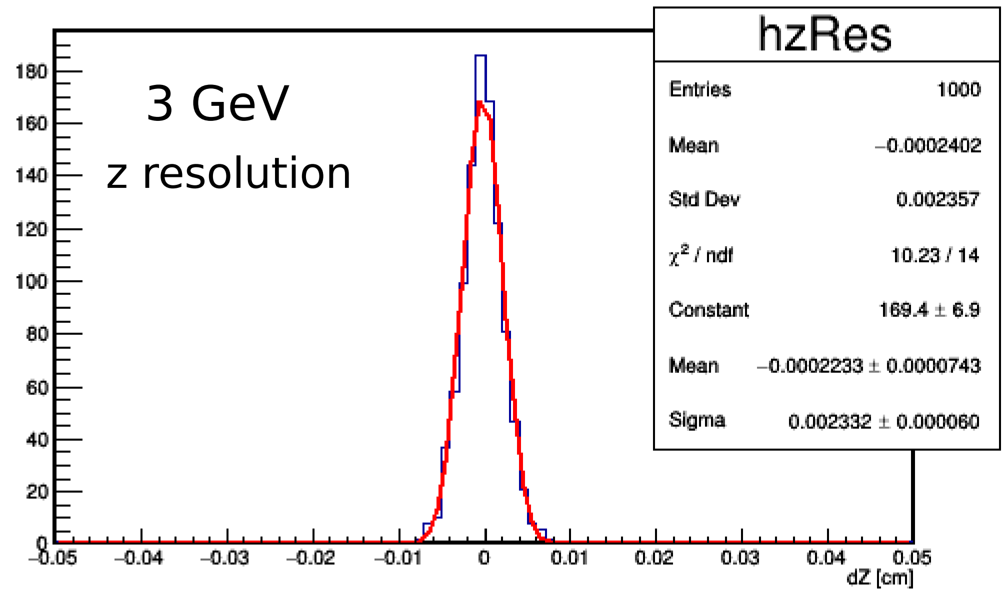
5) at this moment CBM based program is used for primary vertex fit procedure.

Vertex position resolution with vertex detector









SPD tracker system

General requirements to the SPD tracking system can be formulated as follows:

1) tracker system should provide a possibility to reconstruct track and precisely measure momentum of charged particle in wide kinematic range with reasonable accuracy;

2) it should provide a possibility to reconstruct precisely XYZ position of primary and secondary vertices with reasonable accuracy;

3) it should be transparent enough for photons produced in the interaction region

SPD magnetic field configuration

4 main configurations of the SPD magnetic system are considered in the study:

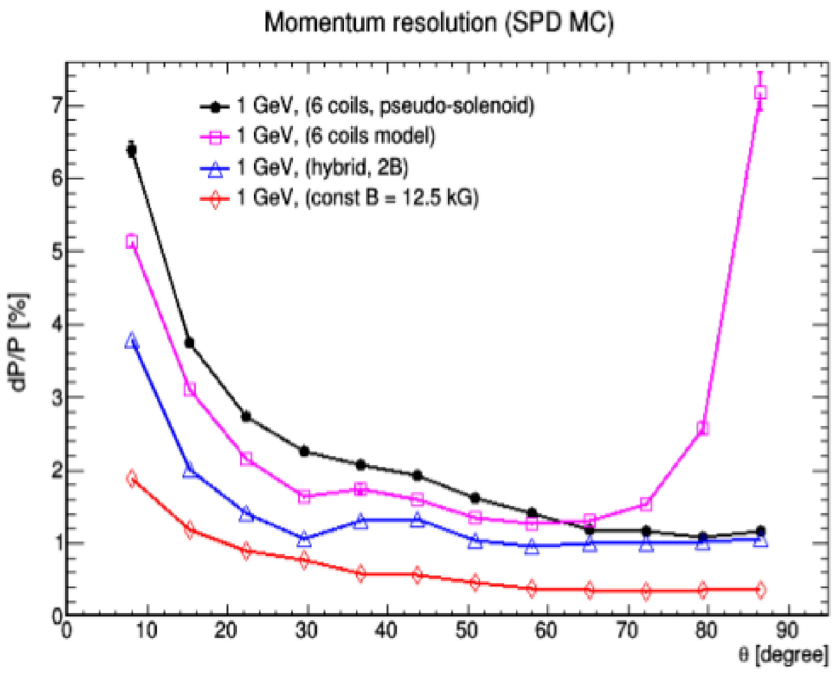
1) so-called hybrid system, where the setup has a toroidal field in the barrel part while two solenoidal coils provide a solenoidal field in each end-cap. In such configuration there is no field around the interaction region;

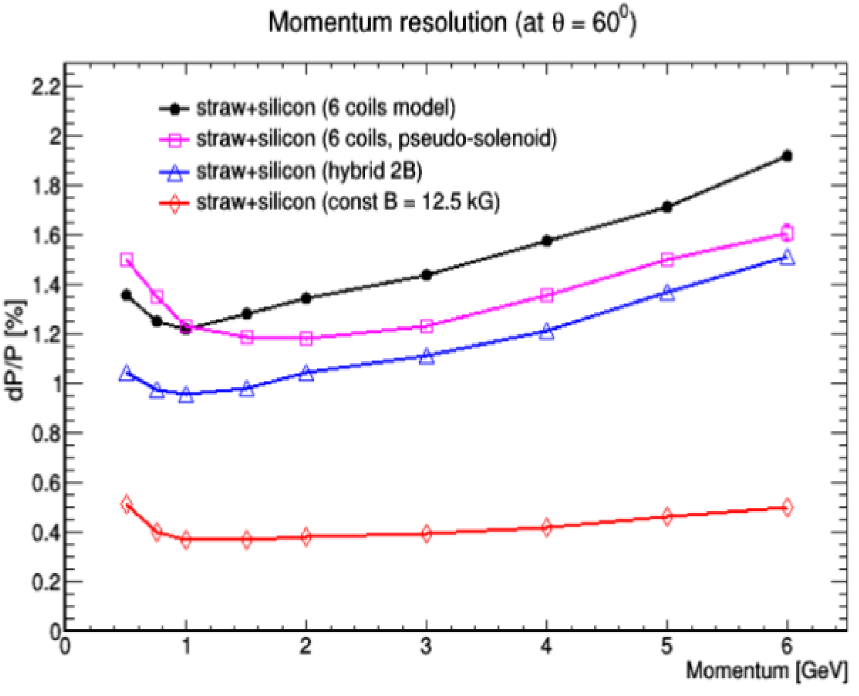
2) so-called pseudo-solenoidal system, where 6 coils (2 in the barrel and 4 in the end-caps with different current (in general case) and the same orientation of individual fields generate a solenoid-like field in the whole detector;

3) a special case where the field in the first 3 coils and in the other 3 coils has opposite direction to minimize field integral in the interaction region is also discussed.

4) constant solenoidal field that is taken as ideal reference;

SPD magnetic field configurations, track momentum resolution





Presented dependencies of momentum resolution clearly show that the hybrid configuration with doubled magnitude of the magnetic field has better momentum resolution in the broad range of the polar angle θ in comparison with the pseudo-solenoidal and special 6 coils field configurations.

More detail with results of the optimization the different magnetic field and SPD tracker configurations can be found in the SPD note “Optimization of the SPD tracking system” which was prepared and presented to SPD community in August 2019

Optimization of the SPD tracking system

Andreev V. (LPI), Gerassimov S. (LPI), Guskov A. (JINR), Ivanov A. (JINR),

Tkachenko A. (JINR), Tsenov R. (JINR)

25.08.2019

Results and future plans

1) the stand-alone programs for tracks and primary vertex fit are prepared

2) various SPD tracker geometries and magnetic field configurations were studied on the base of this special stand-alone program

3) the programs for track and primary vertex fits was incorporated in standard SPDroot package (thanks to Artur Tkachenko for this job)

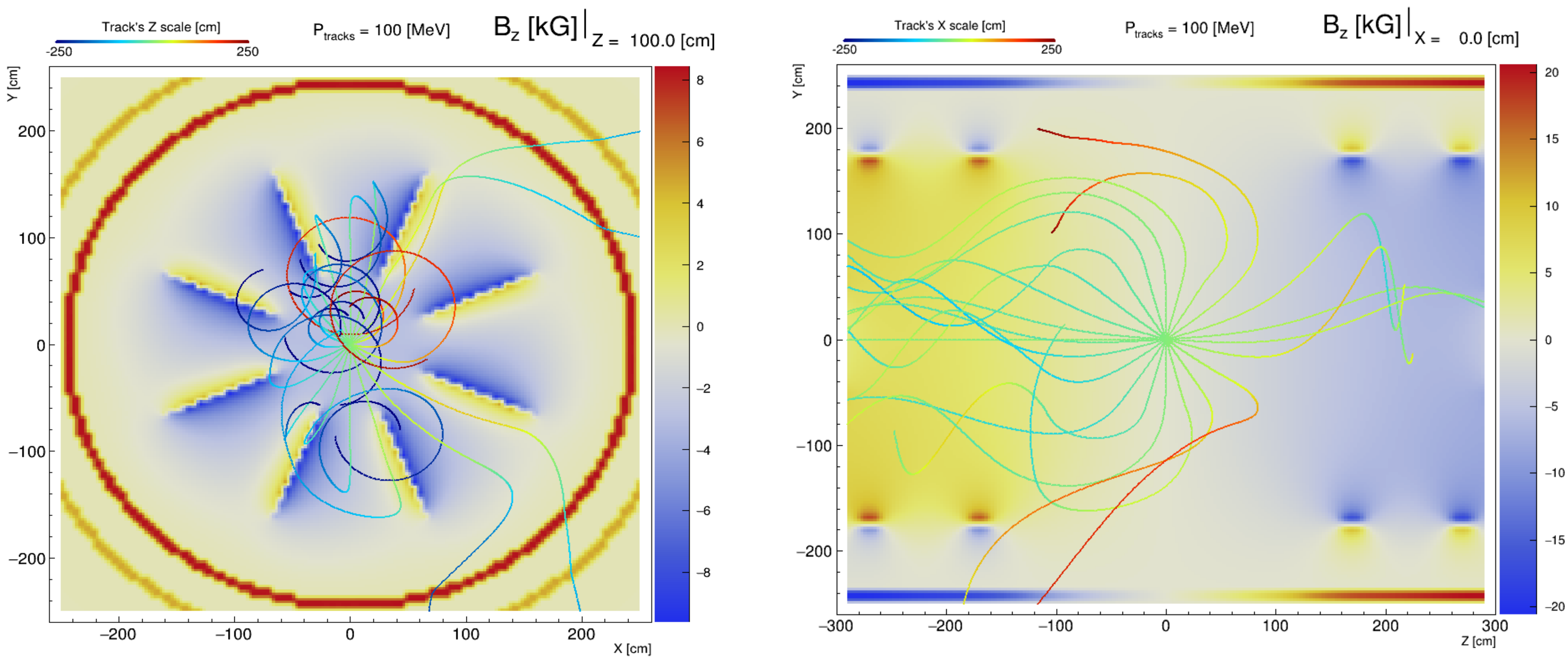
4) everyone can use now the track fit and primary vertex reconstruction program for his study of the different physics inside SPDroot package

5) program developments and results of the tracker's geometry studies were presented on JINR meeting (23.03.2019), International Workshop “SPD at NICA-2019 on 5 June 2019” at Dubna, the internal SPD note was prepared

6) future plans – track reconstruction (1-st version in 0.5 year)

Backup slides

Field integrals calculation



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