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Software for tracks and primary vertex reconstruction for SPD experiment

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(on behalf of LPI group)

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Development and implementation of components of reconstruction software for tracks, vertex and clusters in electromagnetic calorimeter, optimization of detectors for SPD experiment on NICA accelerator at Dubna. Study of diffraction processes in small-angle scattering of polarized particles. Upgrade of the S-25R Pakhra calibration beam line and deployment of setup for pixel detector and electromagnetic calorimeter prototypes tests.

Разработка и создание компонентов программного обеспечения реконструкции треков, вершин и кластеров в электромагнитном калориметре, оптимизация детекторов эксперимента SPD на коллайдере НИКА в Дубне. Исследование дифракционных процессов в рассеянии поляризованных частиц под малыми углами. Модернизация калибровочного канала ускорителя С-25Р «ПАХРА» и создание стенда для проведения тестовых измерений прототипов пиксельных кремниевых детекторов и элементов электромагнитного калориметра.

The short review of our work for development and implementation of components of reconstruction software for tracks and vertex will be presented.

Introduction

1. Track and vertex reconstruction is an essential part of most HEP experiments

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

3. Track finding (or pattern recognition):
  - division set of measurements in a tracking detectors into subsets
  - each subset contains measurements believed to originate from the same particle

4. 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

5. 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

6. Kalman Filter is used in many HEP experiment and we also propose to use this algorithm in a track fitter program for SPD experiment

Kalman fitter (standalone program)

SPDroot → Interface → Kalman fitter (standalone)

1. possible configuration of SPD tracker system will contain of 5 layers of silicon vertex detector (barrel), 5 disks (end-cup) and some number of layers in straw-tube tracker (exact number can be determined from special studies)

2. as the first step, special standalone program with Kalman fitter was developed on the base of GenFit2 package (arXiv:1902.04405, 19.02.2019) with our modification

3. use SPDroot simulation package with different tracker geometries and magnetic field configurations (constant, hybrid, pseudo-solenoidal and another types of field)

4. generate different type of primary particles with inline generator, run SPDroot simulation and finally produce output-root file with simulated MC hits in various detectors (silicon vertex and straw tube tracker)

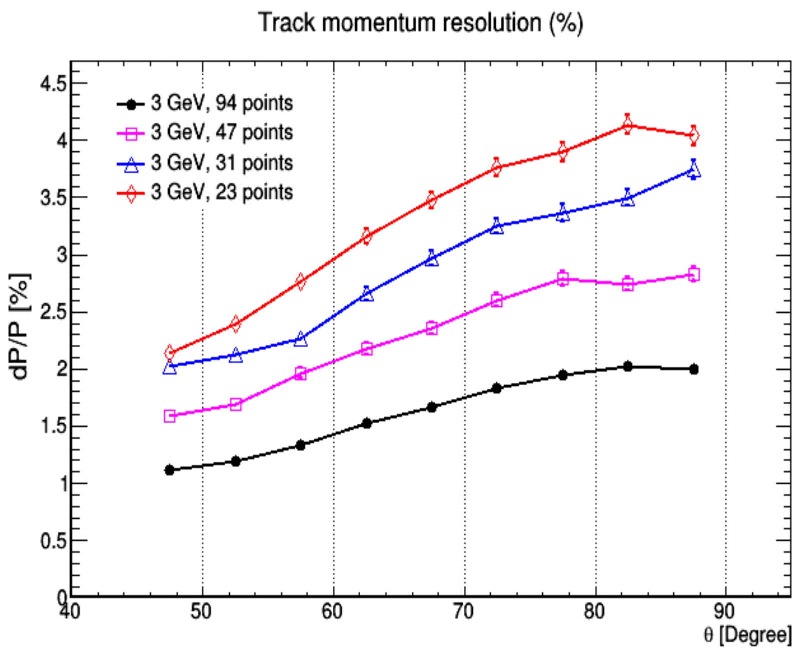
5. use interface program and produce the special file with MC hits (x,y,z –coordinates) as input for standalone Kalman fitter program

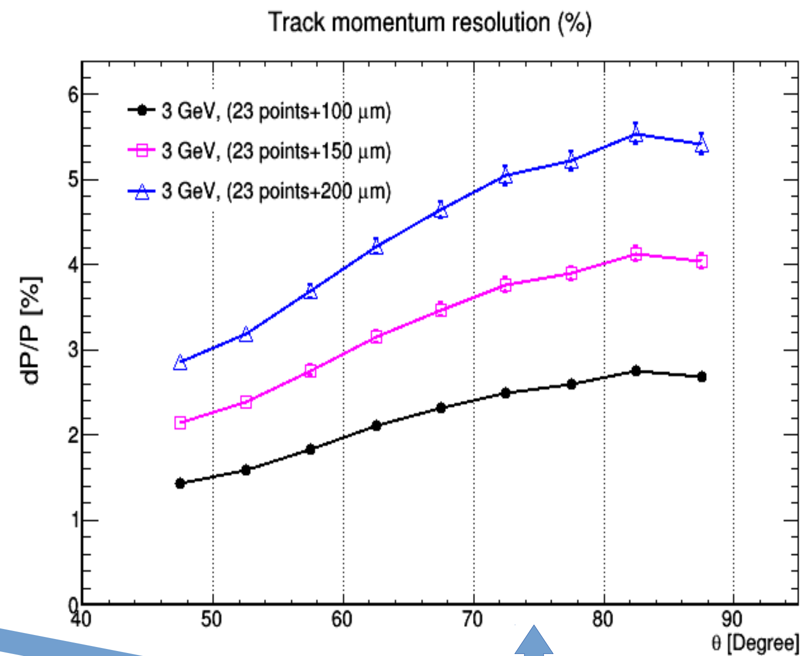
6. add corresponding magnetic field configuration in standalone program

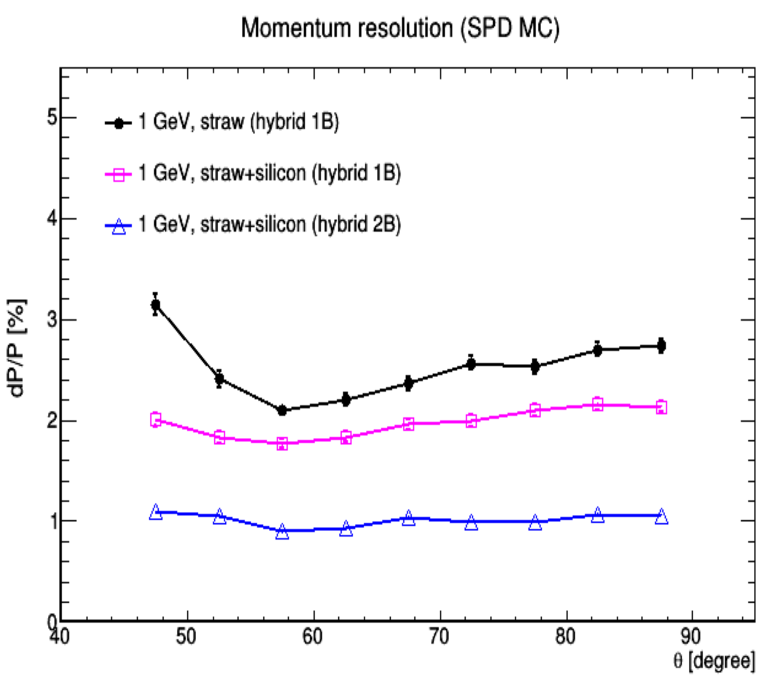
7. add detector resolution effect for each hit point x,y,z – coordinate (for example, Gaussian smearing of 150 μm for straw and 50 μm for silicon detectors)

8. do Kalman fitter procedure and determine track parameters

Kalman fitter (standalone program)



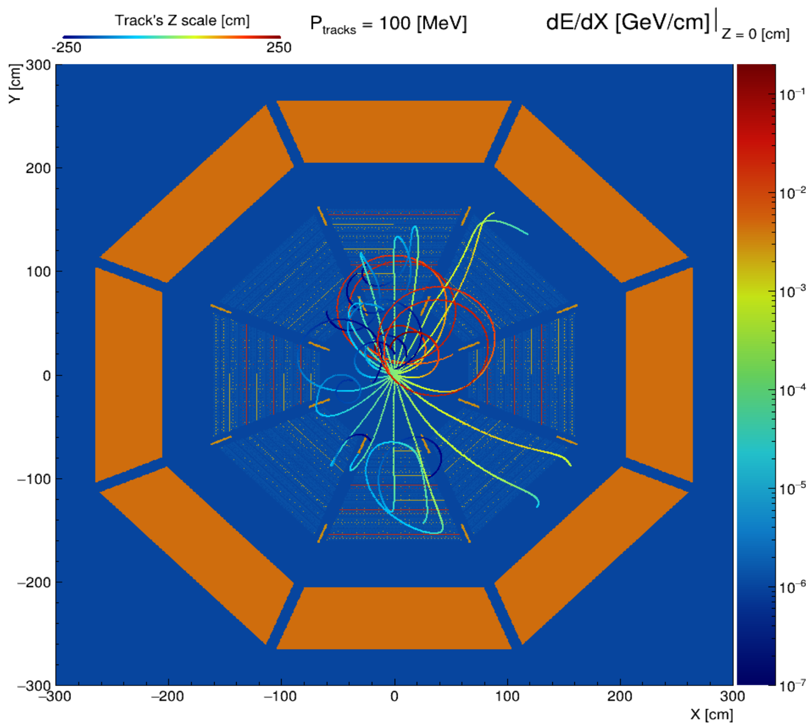


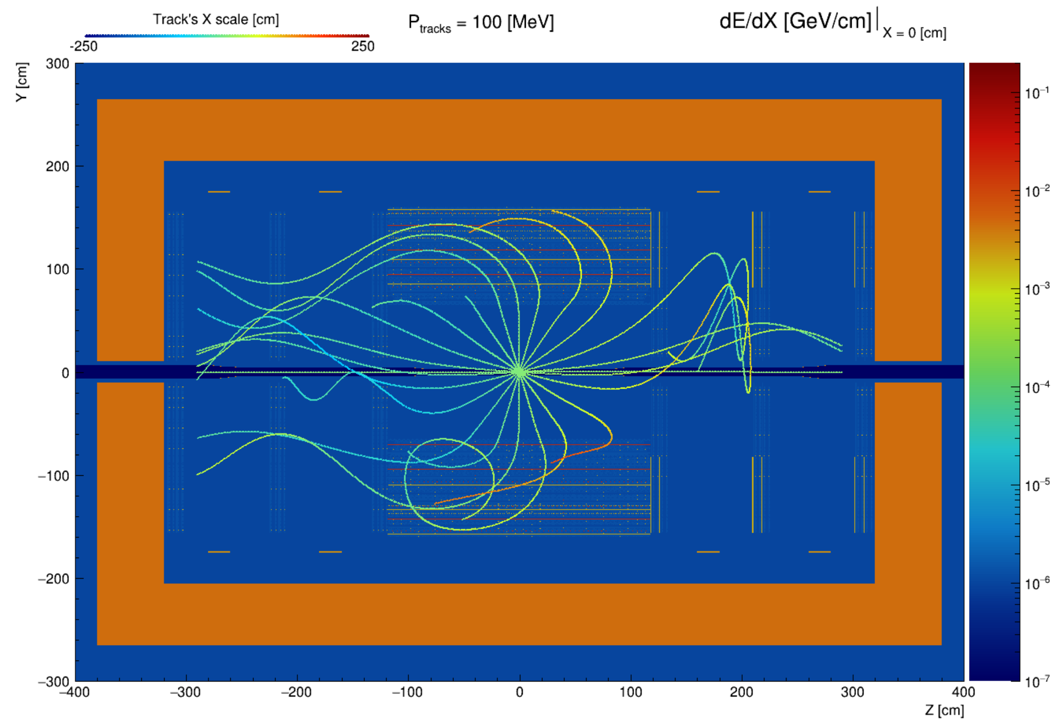


Track momentum resolution for ideal straw tube tracker (without material effect) as function of number straw layers and value of hit resolution for 3 GeV muons

Track momentum resolution of 1 GeV muons for different configuration of SPD tracker detectors

Special software utilities



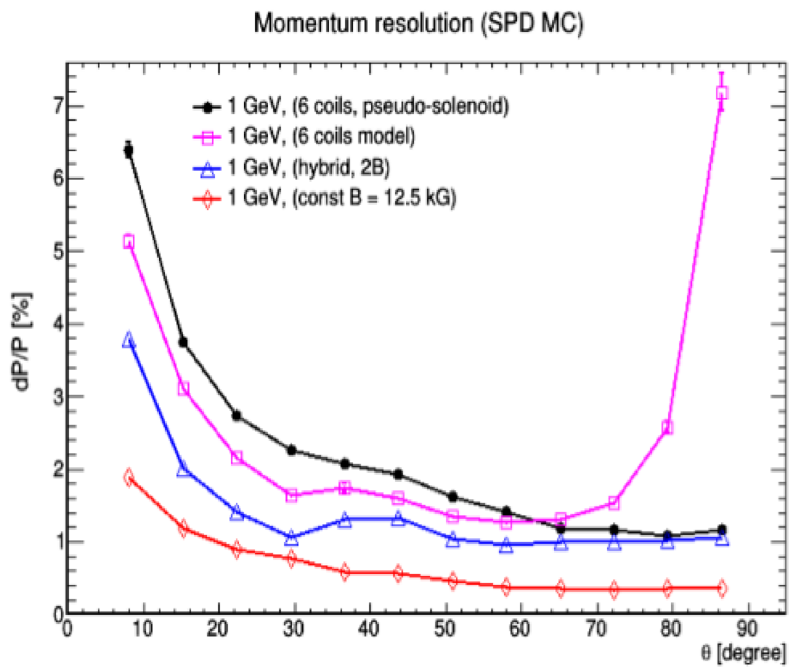


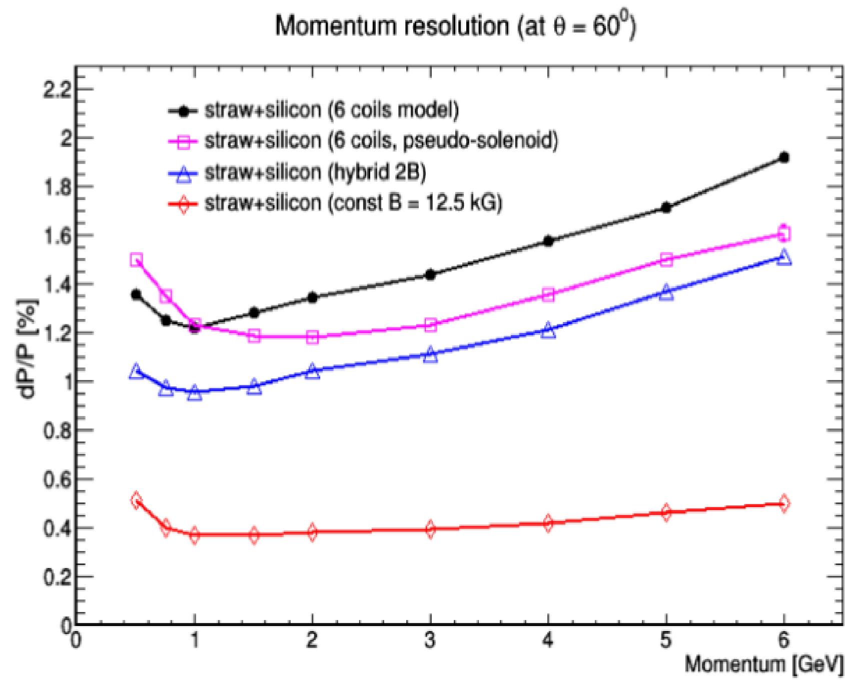
Special software utilities for visualization of magnetic field and materials map as well as for calculation of field integrals and materials budget were also developed.

The presented pictures show the trajectories of positively charged particles for hybrid magnetic field configuration (with doubled field value):

- 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)

Momentum resolution (standalone program)





Momentum resolution for different magnetic filed configurations:

1. so called hybrid system where the setup has a toroidal field in the barrel part while two coils provide a solenoidal field in each end-caps (**blue line**);
2. so called pseudo-solenoidal system where 6 coils (2 in the barrel and 4 in the end-caps) with different current and the same orientation of the individual fields generate a solenoid-like field in the whole detector (**black line**);
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 (**magenta line**);
4. constant solenoidal field that is taken as ideal reference (**red line**).

Primary vertex reconstruction

1. reconstruction of primary vertex (PV) is also important part of software

2. we developed the special standalone program for primary vertex reconstruction (on the base of PV reconstruction program used in CBM experiment, CBM-SOFT-note-2006-001) which used the Kalman filter technique

3. general schema of stand-alone PV reconstruction program is presented below

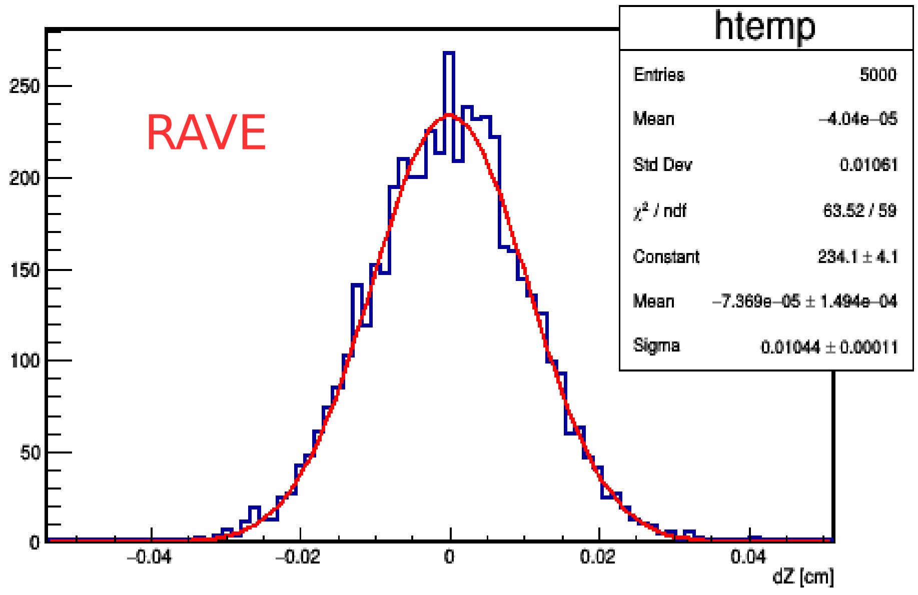
SPDroot → Interface → Kalman fit for tracks (standalone) → PV reconstruction (standalone)

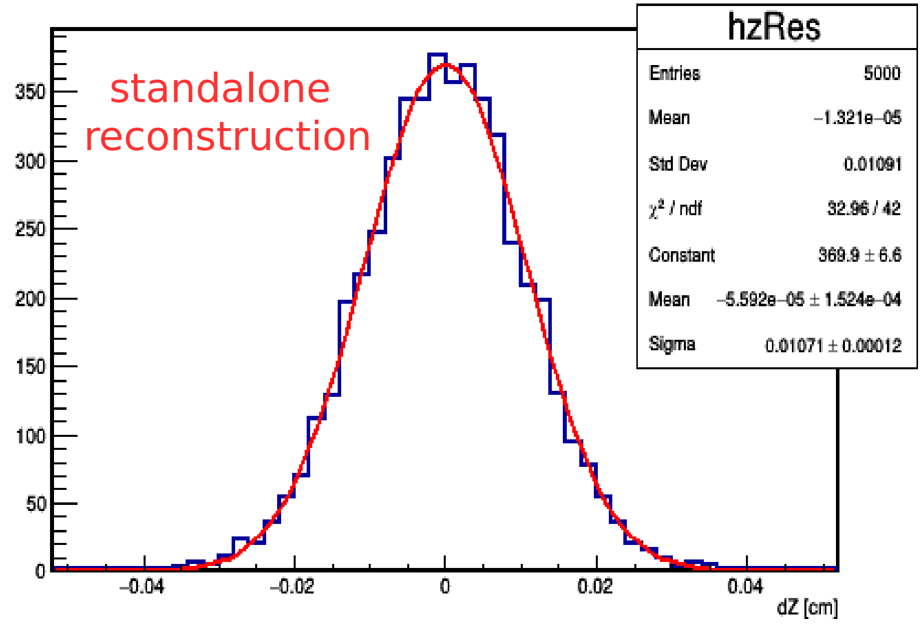
4. we combine the standalone program for tracks fit with the primary vertex reconstruction program

5. this program can also work with the different configuration of magnetic field in SPD experiment (hybrid magnetic field, constant field or another configuration)

6. we also studied the program RAVE - detector-independent toolkit for reconstruction of vertices (was developed in CMS experiment https://rave.hepforge.org/). This program is used as cross check at the constant magnetic field.

Vertex position resolution





1. comparison RAVE and standalone primary vertex reconstruction programs is presented on pictures for constant magnetic field

2. 6 charged tracks of 3 GeV momentum inside range $45^0 \le \theta \le 135^0$ and $0^0 \le \varphi \le 360^0$ angle range are simulated with SPDroot (only straw tracker, barrel part)

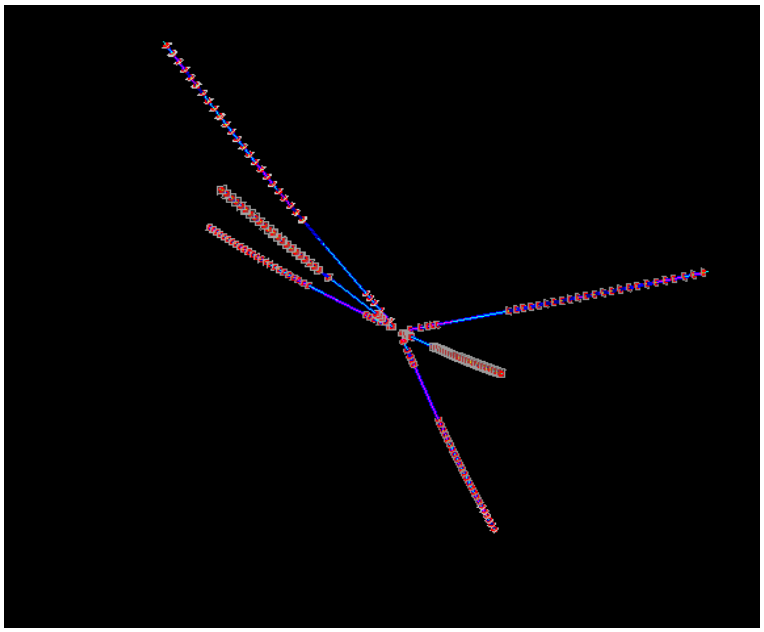
3. Gaussian smearing of 150 μm is applied for each hits in the straw tracker

4. we can conclude that RAVE and standalone reconstruction show similar result

Primary vertex reconstruction

1. as was mentioned the possible configuration of SPD tracker system will contain of 5 layers of silicon vertex detector and several layers of straw-tube tracker

2. hits from silicon vertex detector are also added in standalone primary vertex reconstruction program



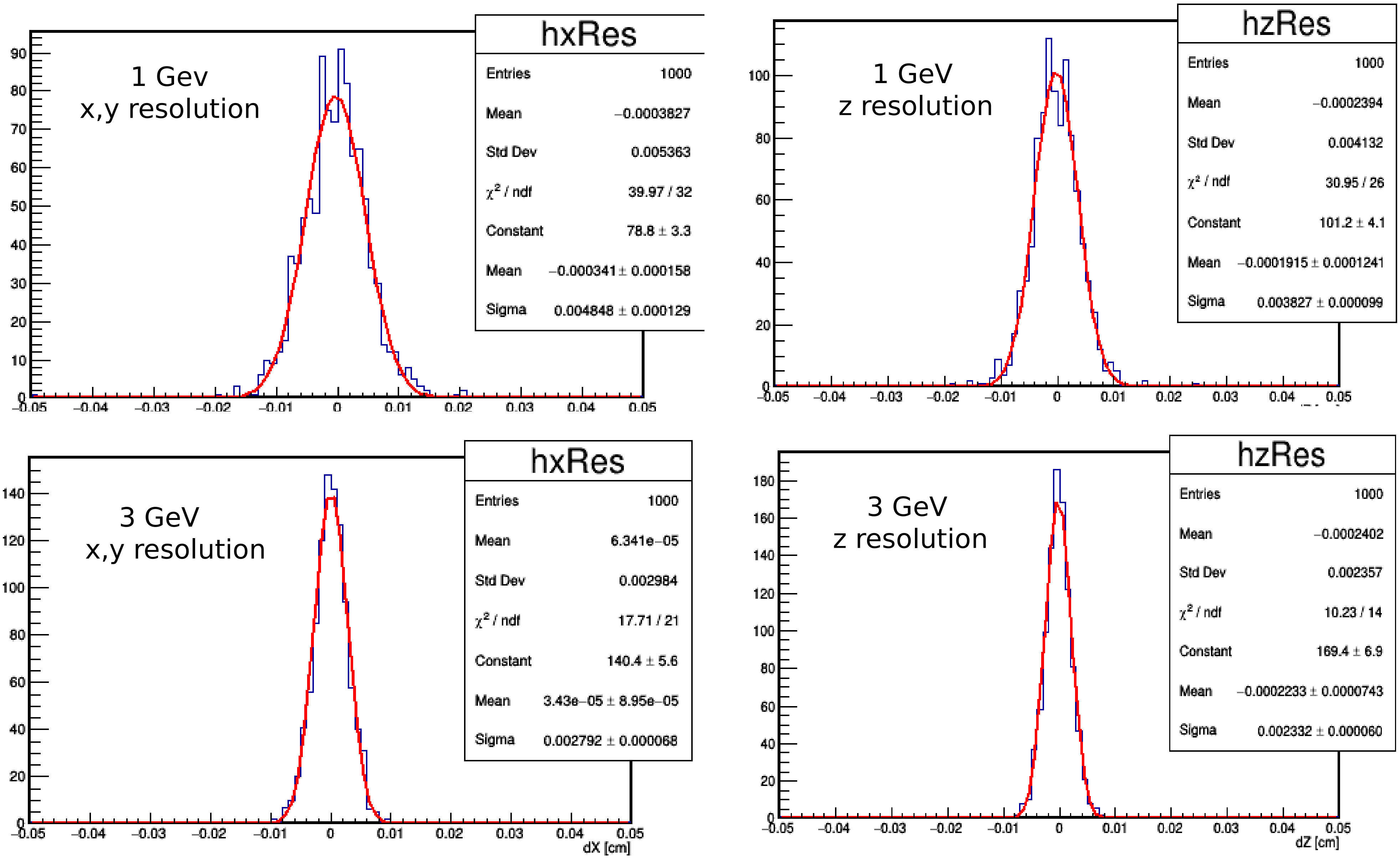
3. we considered 23 layers in straw tracker and 5 cylinders in silicon vertex detector and hybrid magnetic field configuration

4. 6 tracks of 1 GeV and 3 GeV momentum are simulated with SPDroot program inside next angle range $45^0 \le \theta \le 135^0$ and $0^0 \le \varphi \le 360^0$

5. interface program used for transformation SPDroot MC hits to standalone Kalman fitter program format

6. determine track parameters with standalone Kalman fit procedure (150 μm point resolution for straw tracker and 50 μm (or 25 μm) point resolution for silicon vertex are added) and after PV reconstruction is performed

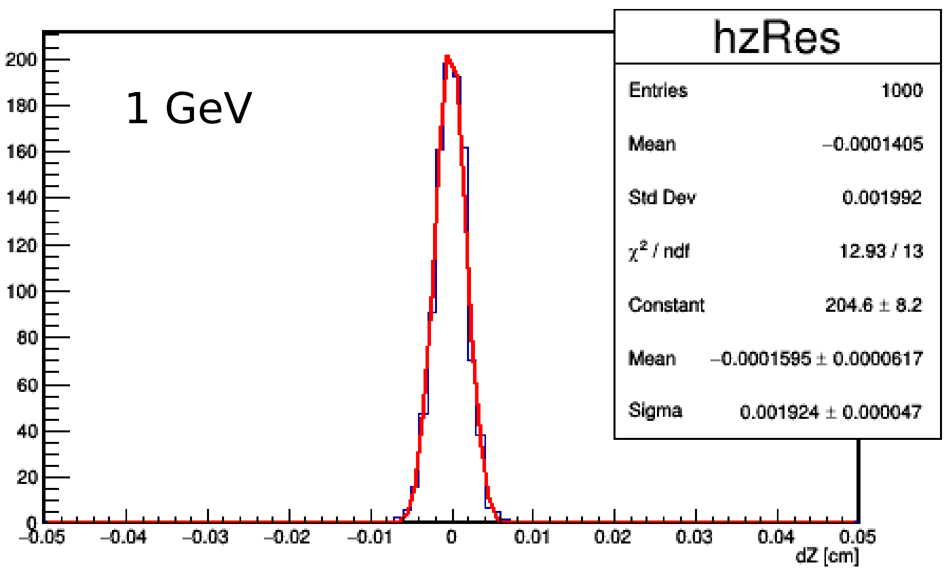
Vertex resolution (vertex+straw detectors)

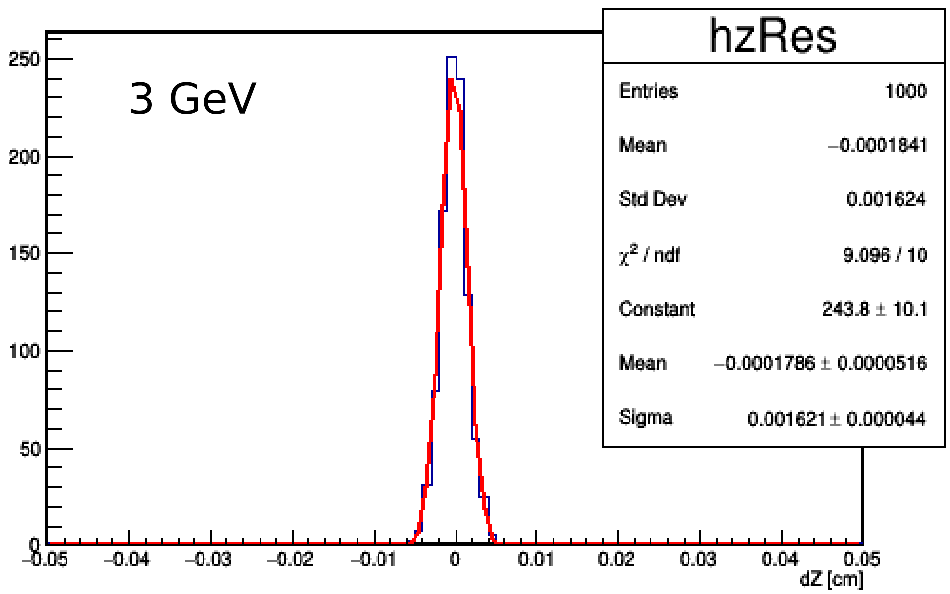


x,y resolution ~50 μm for 1 GeV
~30 μm for 3 GeV

z-resolution ~40 μm for 1 GeV particles
~25 μm for 3 Gev particles

Vertex position resolution





1. change space point resolution in silicon vertex detector since 50 μm to 25 μm and stay the same 150 μm resolution in straw tracker. As usually 6 charged particles are simulated

2. resolution of z coordinate reconstruction is improved both for 1 GeV and 3 GeV particles:
   - since ~40 μm => ~20 μm for 1 GeV momentum and
   - since ~25 μm => ~16 μm for 3 GeV particle momentum

3. conclusion => primary vertex position resolution is strongly depended on resolution in silicon vertex detector

Kalman fitter and primary vertex programs are now the part of SPDroot software (thanks to Artur Tkachenko and SPD JINR team)

Track reconstruction (first preliminary study)

Track reconstruction => track finding and then track fitting

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

sim → digi → pattern recognition → Kalman fit

1. simulation => produce sim-hits using SPDroot with different generators and tracker's geometries

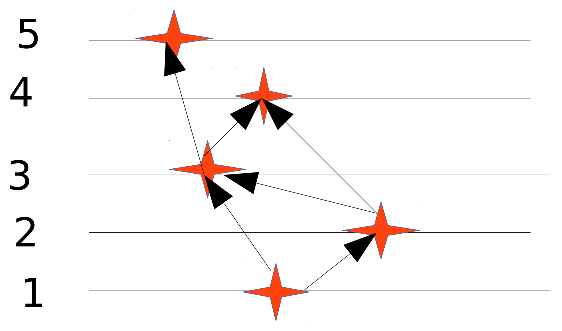
2. digitization => produce digi-hits (contains x-y coordinates on detector plane with smearing, detector position and etc.)

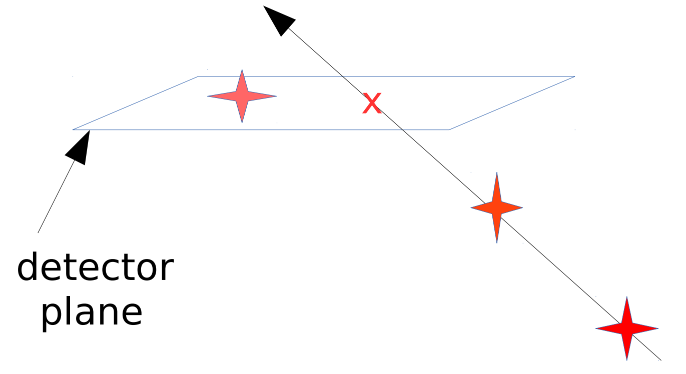
3. pattern recognition:
   - construct track seed in silicon vertex detector
   - add straw detector hits to vertex track seed
   - create track candidates which contains as vertex and tracker straw hits

4. final => do Kalman fit

Track seeds in vertex detector

Silicon vertex detector => 5 cylinders in barrel part and 5 disks in end-cap part (plane pixel detector is considered, xy – coordinate)





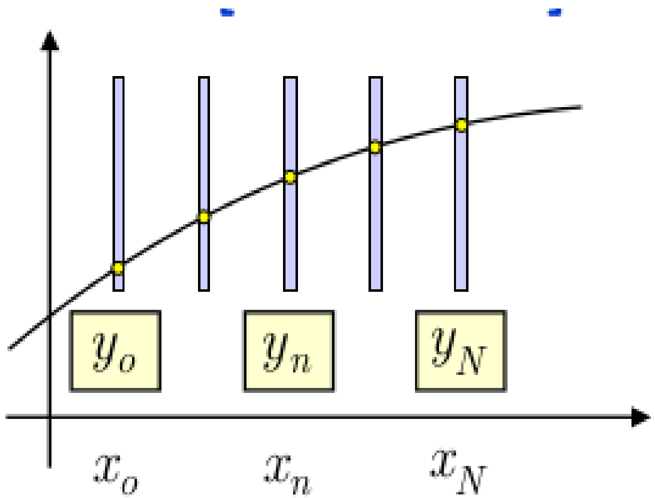
1. consider all possible 2-points combinations between hits in different silicon layers (1-st layer <=> 2-nd layer, 1-st layer <=> 3-d layer and ...) => construct primary 2-points seeds

2. use 2-points seed => construct space line and check the distance between hit point on the next layer ( ) and point which is obtained by crossing line and detector plane (x). Accept new point if the distance is inside some range => first level of selection

3. particle trajectory in the vertex detector is described by helix for pseudo-solenoidal field. This type of field is considered as the base magnetic field configuration for SPD experiment at the present time

Track seeds in vertex detector

1. projection of track trajectory on a plane (xy) perpendicular to the magnetic field is a circle
2. we propose to use parabolic approximation of the trajectory projection (in the area of vertex detector)



$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i + nc = \sum_{i=1}^{n} y_i, \\ a\sum_{i=1}^{n} x_i^3 + b\sum_{i=1}^{n} x_i^2 + c\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i y_i, \\ a\sum_{i=1}^{n} x_i^4 + b\sum_{i=1}^{n} x_i^3 + c\sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} x_i^2 y_i; \end{cases}$$

3. new point is added on the base of chi2 value estimation $\chi^2 = \sum_{n=0}^{N} \frac{\left(y_n - a - bx_n - cx_n^2\right)^2}{\sigma_n^2}$

4. this procedure starts from 2-points seed => produce 3-points seed => use 3-points seed => produces 4-points seed =>use 4-points seed => produce 5-points seed

5. then merging and cleaning procedures are applied => finally the set of 3, 4 and 5 points vertex seeds are produced

Track candidate in straw detector

1. use silicon vertex seeds as start approximation of track candidate

2. extrapolate this track candidate to 1-st straw layer (from IP)

3. all straw hits on 1-st layer (in some area) are checked on consistence with this track candidate (distance and chi2 criteria)

4. add “good” straw hit to track candidate points, update parameters of track candidate (do new Kalman fit) and then extrapolate track candidate to the next straw layer

5. if 2 or more straw hits on one tracker layer are consisted with the track candidate => the new track candidate is created, then fitting and extrapolating procedures are applied for all new created track candidates

6. finally, as the result, the “big” number of track candidates are produced and each candidate contains some number of vertex and straw tracker hits

7. clean track candidates (on the base of chi2 and number of hits)

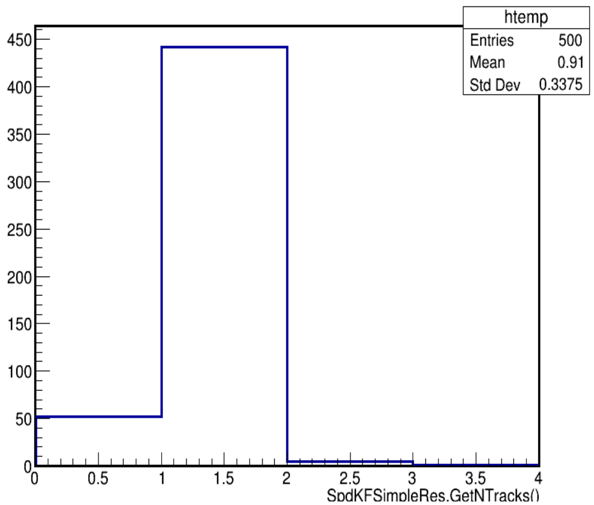
8. do final Kalman fit of each track candidates

Track reconstruction

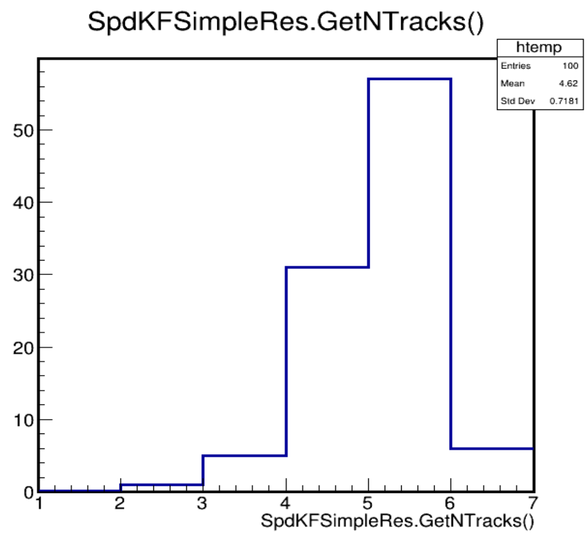
1. the next data are produced => 1 GeV muons with 1, 5 and 10 particles for event

2. figures below show the number of reconstructed tracks for these type events

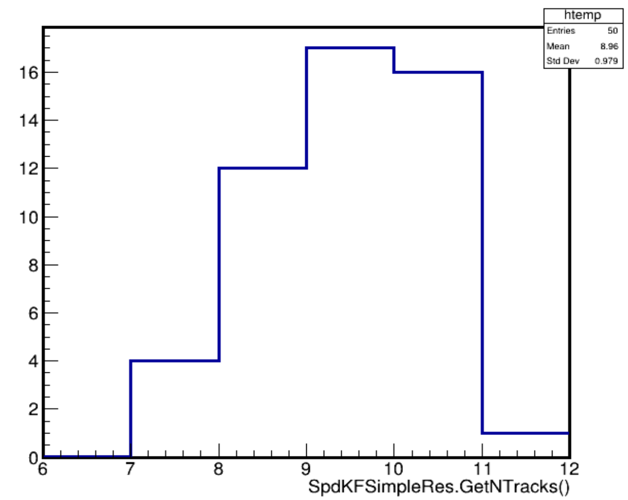
1 part./event

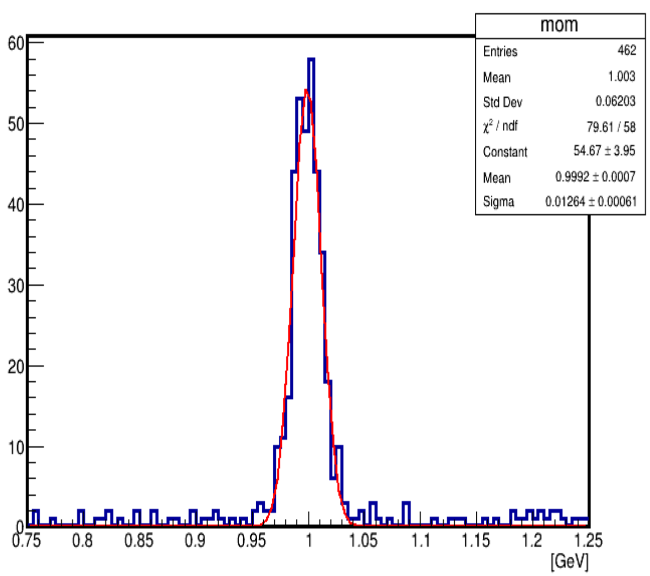


5 part./event



10 part./event





Momentum resolution for 1 GeV reconstructed tracks (~1.3%)

Summary

1. standalone programs for tracks fit and primary vertex reconstruction are prepared

2. special software utilities are also developed (interface and visualization programs)

3. different setups of SPD tracker and magnetic field configuration can be studied
   with these standalone software

4. Kalman fitter and primary vertex programs are now part of SPD software
   (many thanks to Artur Tkachenko and SPD JINR team)

5. development of software for track reconstruction is started inside SPD software
   framework. Some preliminary results are obtained.