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Status of track reconstruction and momentum measurement

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Introduction

- Track reconstruction is an essential part of most nuclear and particle 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

- Several experiments in high-energy-physics implement their own track fitters, however, they use similar algorithms, such as well known *Kalman filter*

- We propose to use Kalman filter algorithm in a track fitter program

Coordinate system

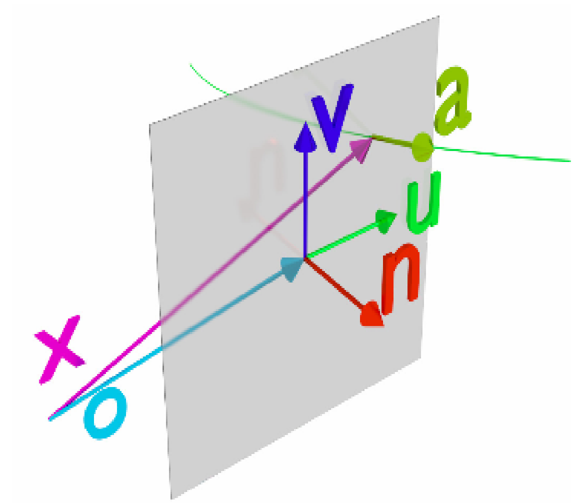
3 different sets of variable to characterize a trajectory:

6D – coordinates (**X, P**) + q => define the helix

Local coordinates (q/p, *u'*, *v'*, *u*, *v*) => on plane

Global coordinates (**x, T**, q/p)

u', *v'* – direction of cosines relative to the plane
u,*v* – local coordinate to the plane
q – charge
X – position coordinate
P – momentum coordinate
p – momentum module
T – direction unit vector



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 code which used in ATLAS experiment)

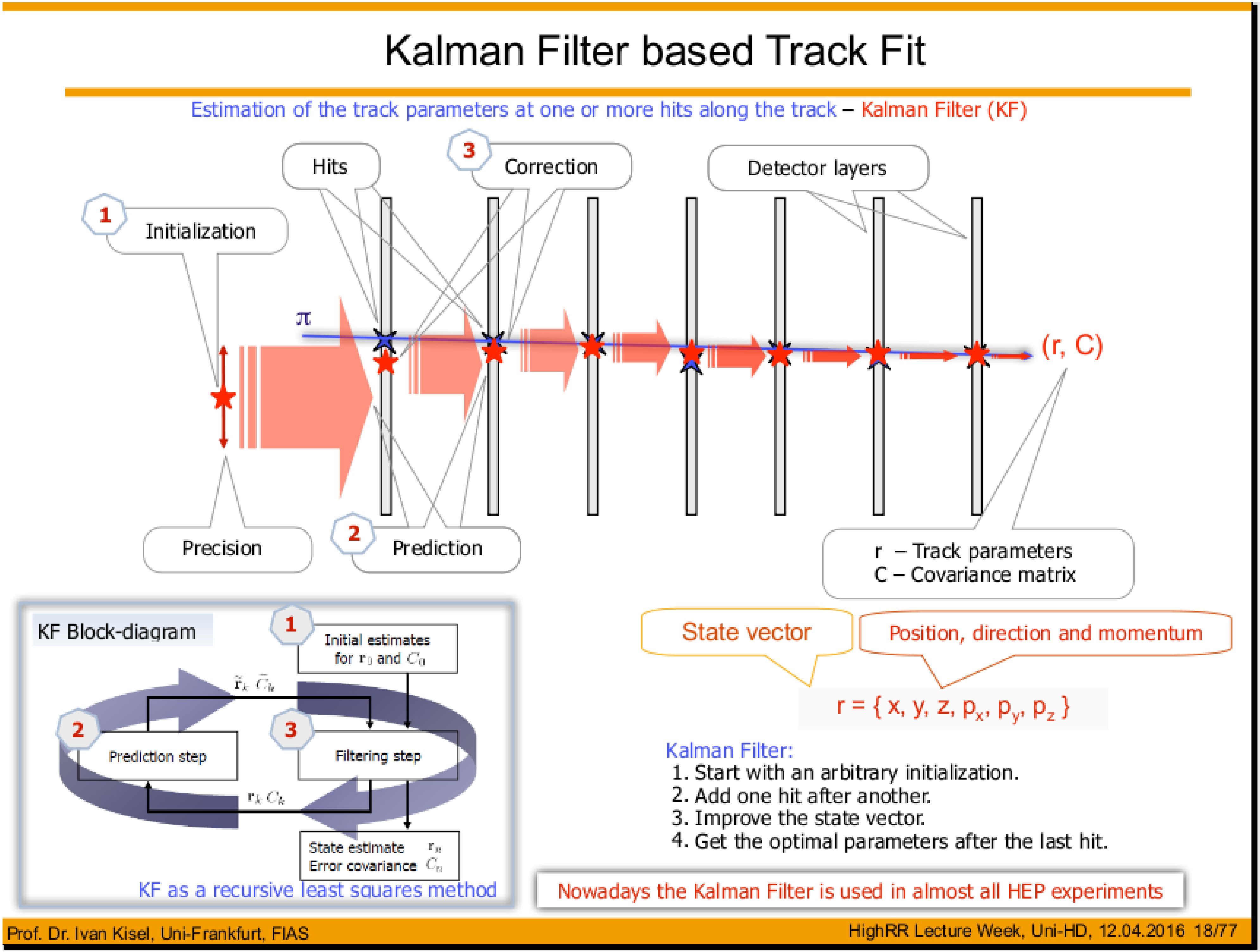
During the Runge-Kutta extrapolation global track parameters (**x, T**, q/p) are used, namely q/p, spatial coordinate (**x**) and unit tangent vector (**T**) pointing along track

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

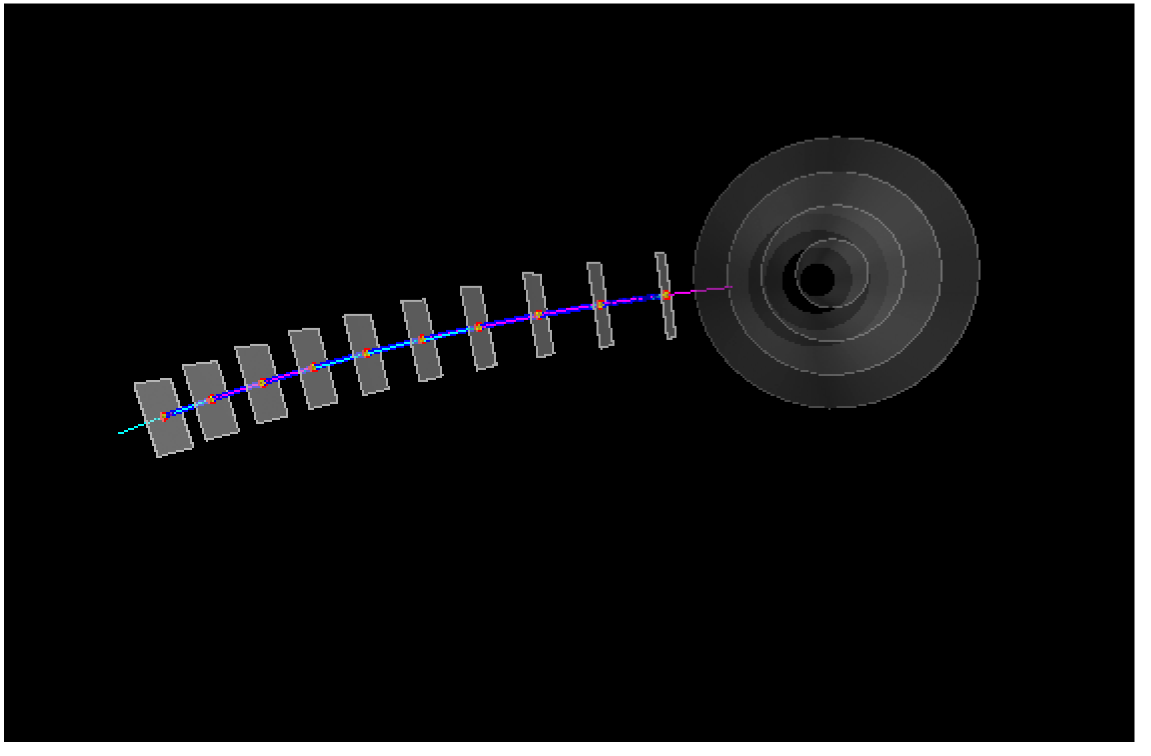
Track can be fitted in forward and backward direction:
- forward direction gives the best estimation of track parameters at the end
- backward direction gives the best estimation of the track parameters at the interaction vertex

Using both these results "smoothing track" state can be calculated


Kalman Filter based Track Fit
Estimation of the track parameters at one or more hits along the track – Kalman Filter (KF)
Hits
3 Correction
Detector layers
1 Initialization
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 (standalone program)

1) at this moment we have some standalone program in which Kalman fitter is realized
2) this program gives possibility to construct the set of tracking detectors with different parameters
3) one can define the number of plane for each tracking detector and add detector resolution for measurements
4) program produces hit points in “virtual” detectors and apply resolution for each point
5) simple example of track after Kalman fitter is shown bottom with hit points on virtual planes



Kalman fitter for SPD solenoid type geometry

1) the next step was done for checking Kalman fitter for SPD solenoid type geometry

2) set the constant magnetic field Bz = 10 kG

3) introduce 46 cylinders with radius started from R = 65.5 cm and step size = 1.0 cm
as the prototype of SPD tracking system for solenoid type geometry

4) produce the “virtual” hit points in position of crossing track with the detector's cylinder

5) add some detector resolution effects to each x,y,z – coordinates (Gaussian)

6) do Kalman fitter procedure

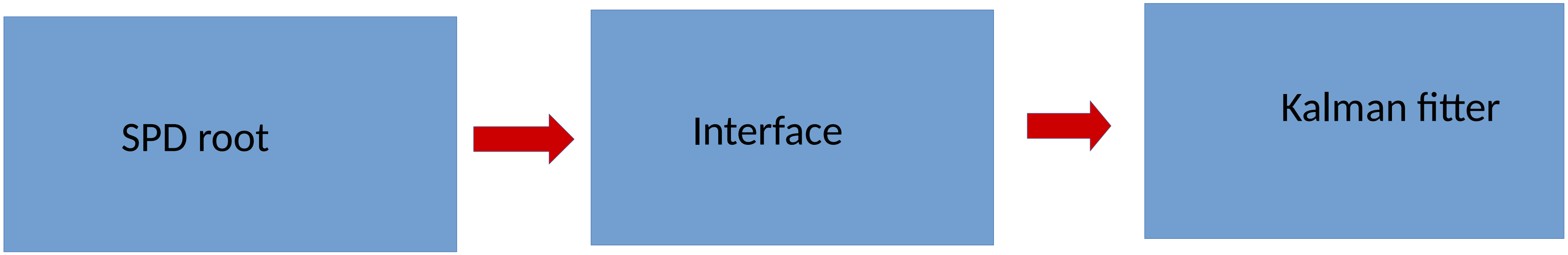
Track resolution of Kalman fitter for solenoid type geometry

Particles q = 1; with $\theta = 90^0$ and $\varphi = 90^0$

P [GeV/c]	500 µm	350 µm	200 µm	100 µm
3.0	9.0 %	6.2 %	3.6 %	1.8 %
2.5	7.5 %	5.4 %	3.1 %	1.6 %
2.0	6.2 %	4.4 %	2.5 %	1.3 %
1.5	4.6 %	3.3 %	1.9 %	0.9 %
1.0	3.1 %	2.2 %	1.3 %	0.6 %
0.5	1.6 %	1.2 %	0.8 %	0.4 %

Result looks reasonable

Check Kalman fitter for SPD hybrid type geometry



1) set last hybrid magnetic field map in SPDroot

2) use SPDroot inline generator with muons (1 GeV, barrel part) and SPDroot simulation
=> produce output root-file

3) use program **run_tst_digit.C** from SPDroot and root-file which was created on sim-step
to produce the new output text-file with only x,y,z - coordinate of each hit points

4) add hybrid magnetic field map in Kalman fitter standalone program

5) as input measurements use the hit points which were produced by SPDroot simulation

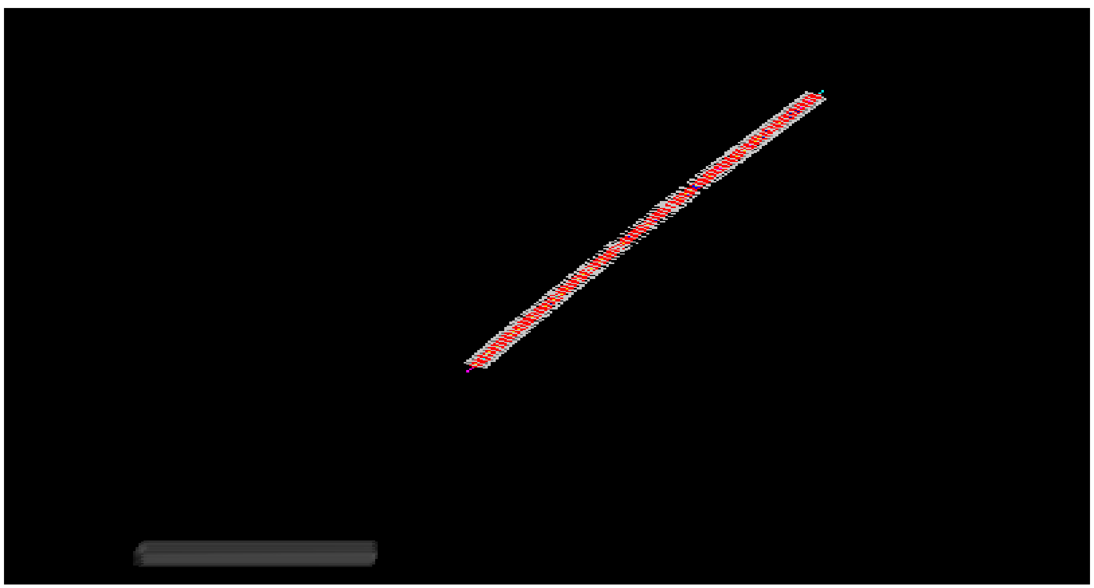
6) add detector resolution effect for each hit point x,y,z – coordinate (Gaussian)

7) do Kalman fitter procedure

Result of Kalman fitter for SPD hybrid type geometry

P [GeV/c]	500 µm	350 µm	200µm	100 µm	50µm	
1.0	3.1 %	2.2 %	1.3 %	0.6 %	-	<= solenoid
1.0	-	13.0 %	12.1 %	10.3 %	8.9 %	<= hybrid (low statistic)
1.0	-	9.0 %	8.8 %	8.2 %	7.9 %	<= hybrid (low statistic)

muons => 1 GeV , $\theta = 90^0$, $\varphi = 90^0$
muons => 1 GeV, $\theta = 60^0$, $\varphi = 90^0$



Main result is standalone Kalman fitter procedure for hybrid geometry works

Intermediate results

1) there is the standalone program with Kalman fitter working procedure

2) this program is checked for SPD solenoid type geometry => gives acceptable result

3) program can use the hybrid magnetic field from SPDroot

4) the simple interface between SPDroot and Kalman fitter program gives possibility to use the simulation points from SPD tracking system in Kalman fitter

5) Kalman fitter program was checked with SPD hybrid geometry and with hit points from SPDroot

Future plan (2-3 months)

1) re-write the interface between SPDroot and Kalman fitter program

2) add tracking detector resolution on the detector plane (now as space-point resolution)

3) tune and check Kalman fitter program

4) start work with possible vertex reconstruction program on base of tracks
from Kalman fitter