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Tracking resolution,fitting and detector optimization

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Topics to be discussed

- Limits on resolution for track parameters
- Different track fitting methods
- Discussion of results of track fitting with SLD-like fitter (weight matrix based)
- Comparison with simple circle fitter
- Effects of detector design
- Conclusions

Limits on resolution

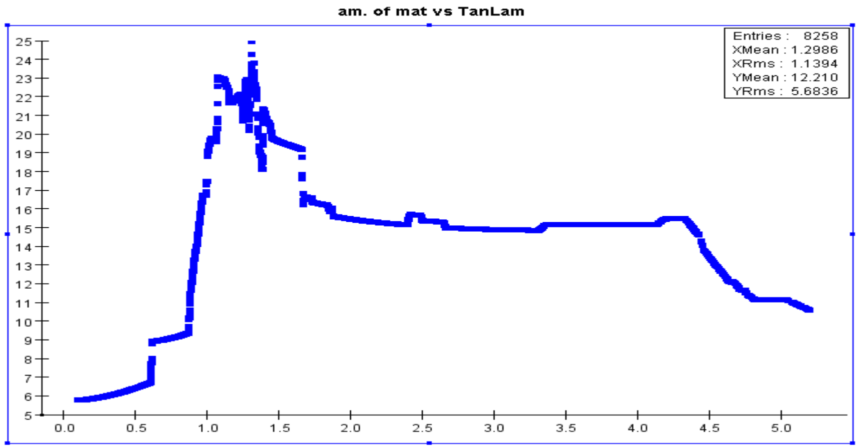
- We may have perfect spatial resolution of tracking sensors, however still have limited resolution of the tracking system because of multiple scattering. According to Keisuke Fujii ,

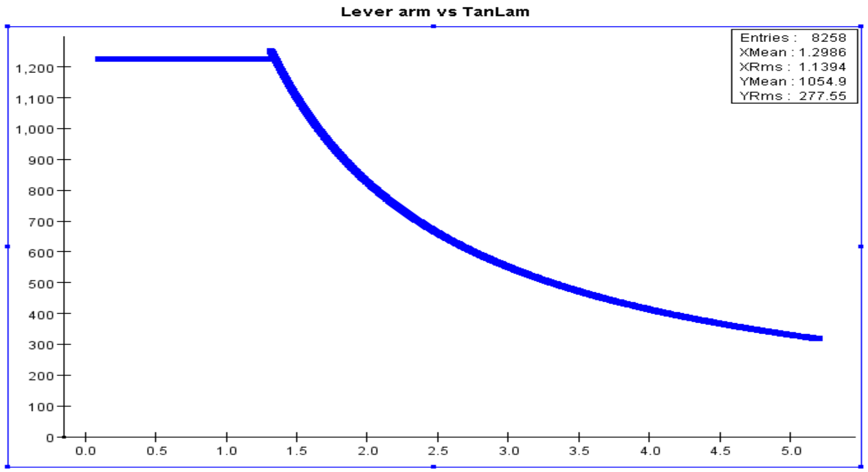
$$\delta_\omega/\omega=(\alpha C/LB)\sqrt{10/7(X/X_0)}$$

Here α=333.56 cm•T•Gev^{-1}, C=0.0141 GeV,
(X/X_0) total amount of material expressed in rad. len.
L – lever arm (cm) B – magnetic field (T).

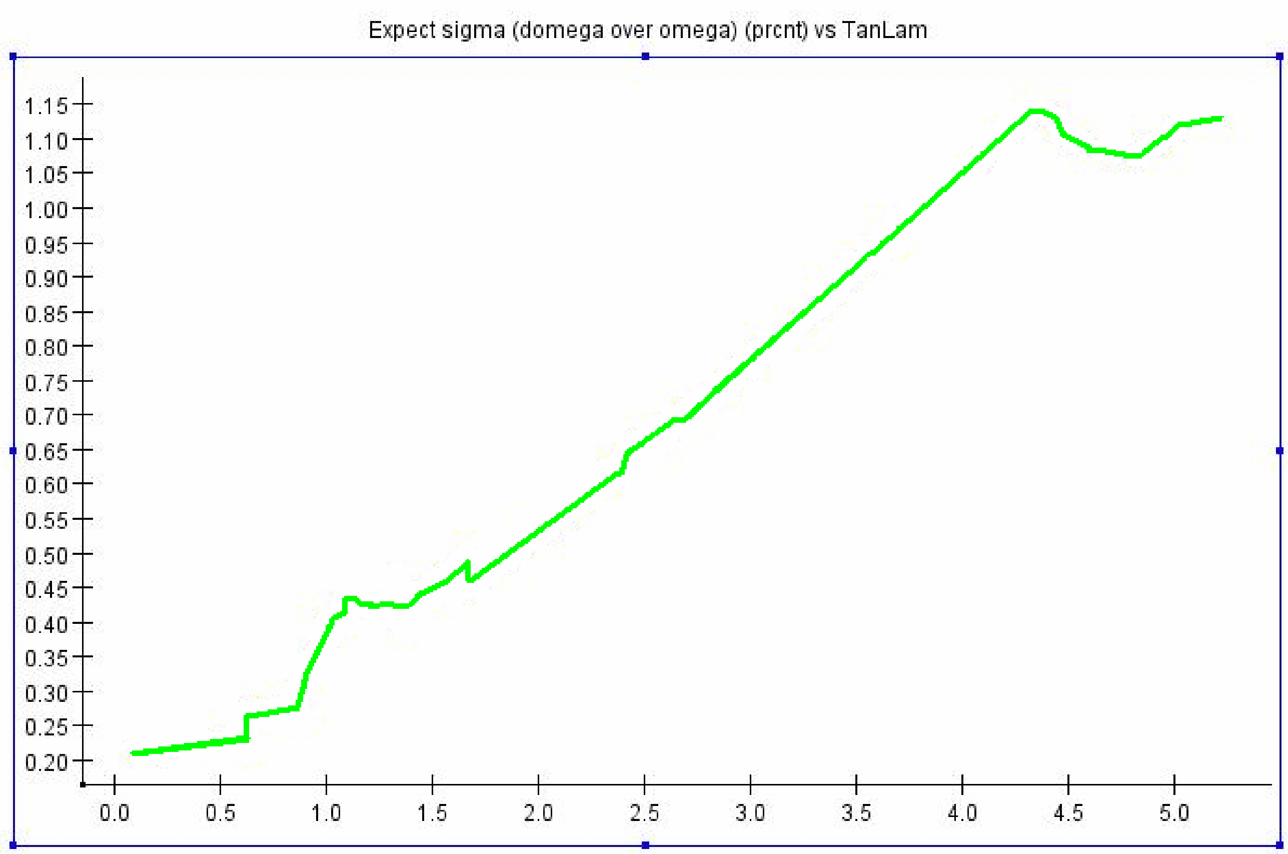
SiD detector parameters

- On the right amount of material and lever arm is shown for our SiD detector (sid00) as function of Tangent Lambda





Limits on curvature resolution, applying Keisuke Fujii formula



Numerical values of hit displacement due to MS (mm)

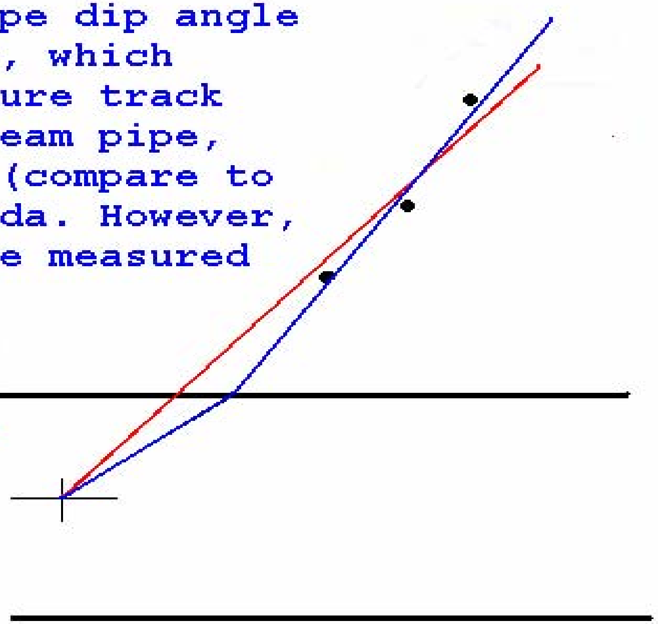
Total track momentum	Barrel middle	Barrel outer	End cap mid.out	End cap mid.in	End cap out out	End cap out in
1 GeV	2.8	6.7	4.0	3.5	7.5	6.4
5 GeV	0.44	0.91	0.78	0.68	1.47	1.25
20 GeV	0.1	0.21	0.19	0.16	0.36	0.6
100 GeV	0.02	0.04	0.038	0.032	0.072	0.12

Different track fitting methods

- Simple circle fitting with weights defined by MS + detector resolution
- Simple circle fitting with equal weights for all layers
- Weight matrix based fitting (SLD fitter)
  - With MS+detector resolution weights
  - With equal weights
  - include / exclude correlations btw layers
  - Include dE/dx energy loss.
  - IP constrained
  - Best

Effect of IP constraining

Due to MS in beam pipe dip angle of the track changes, which affect Pt.If we measure track accurately outside beam pipe, we'll get distorted (compare to original)Pt and Lambda. However, full momentum will be measured correctly.



If we do IP constrained fit,full momentum will be more distorted in spite of closer to original Lambda

Best Fit Procedure

- From the previous slide we can derive procedure for best estimation of track parameters at point of origin for tracks originated at IP:
  - 1.Use unconstrained fit to estimate track parameters outside beam pipe, and use this parameters to calculate full momentum of the track.
  - 2.Use constrained fit for best estimate of track's direction at IP. Combine full momentum from first fit and direction from second to get best estimation of track at IP

Comparison of different fitting methods.

- For long time I was puzzled by the fact, that weight matrix fitter does not improve curvature measurement compare to circle drawn through 3 points. I suspected bug in the program. So I compared it's results with results of non-iterative circle fitter algorithm, developed by V.Karimaki in 1991, and encoded into JAS by Norman Graf.

Comparison of different fitting methods - continue

- It appeared, that both methods give absolutely the same results if we disable energy loss corrections in WM based fitter (as it is not available in simple circle fitter) and remove correlation terms in weight matrix (again as it is not included in simple circle fitter). And if measurement errors are MS dominated, such fitting gives worse estimation of the curvature, than just circle drawn through 3 points (no fitting case).

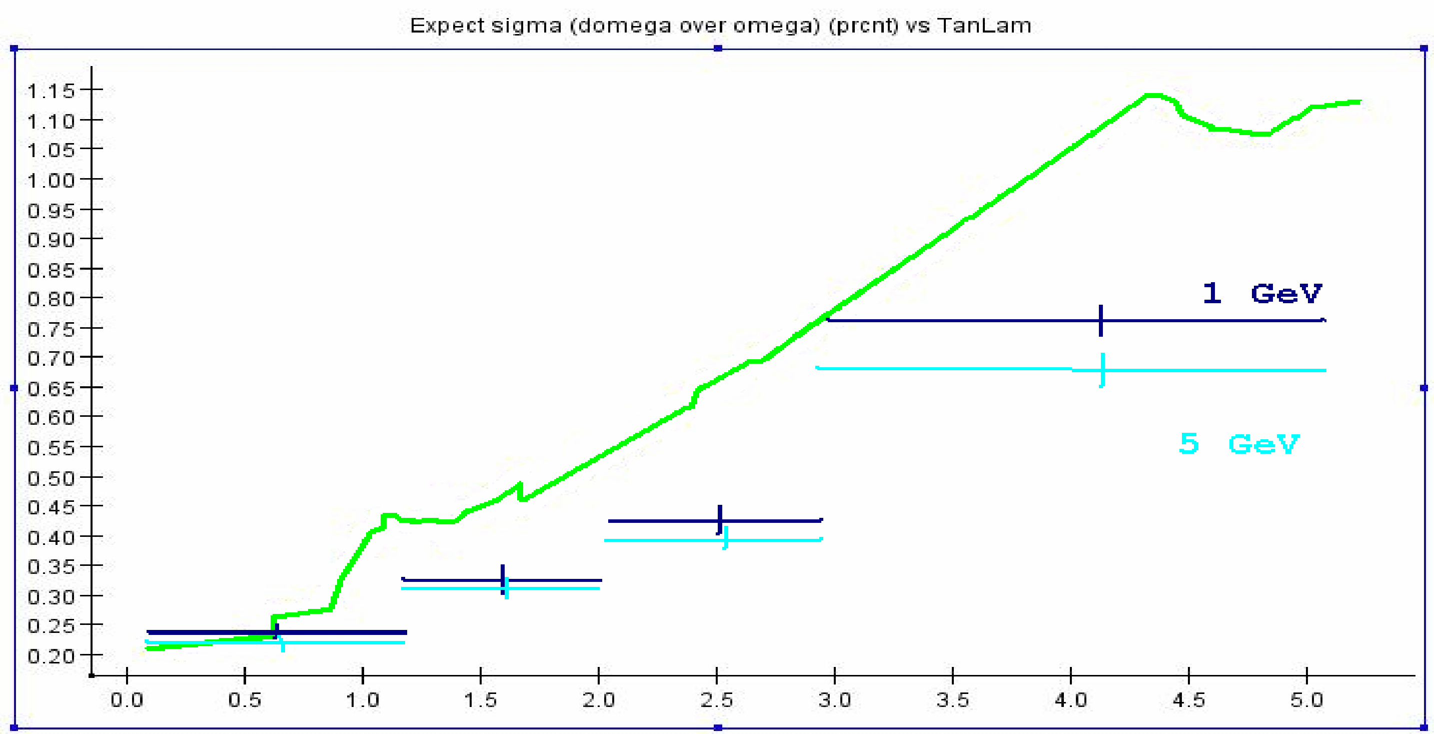
Comparison of different fitting methods - continue

- The weight matrix based fitter gives better curvature estimation if we include energy loss correction (that is true only for very low momentum tracks), and correlation between measurements in different layers because of MS. However, at best this leads to the same accuracy in curvature, as in no-fitting case.
- The best accuracy in the curvature both fitters can achieve if we set equal weights for all layers. In that case curvature estimation is better than no-fit case (though not much, by 10-20 % only). Other track parameters (like impact parameter and directions) have much worse errors in that case, however.

Comparison of different fitting methods - continue

- Fitting with equal weights gives best results only when errors are dominated by MS. As soon as detector resolution became comparable with MS errors, equal weights fitting looses it's advantage. (Practically at 50GeV total momentum) .

Best fit momentum accuracy



Comparison of fitted δΔPt/Pt with expected from K.Fujii formula

Discussion of momentum resolution

- As seen from previous slide, our real resolution appears better than expected. There may be a couple of reason for this:
  - 1.K.Fujii assumed scattering media filling detector volume uniformly. Results may be different for material concentrated in few dense shells.
  - 2.As we used method based on track measurement outside beam pipe, we should exclude beam pipe material. It is not done in these calculations, all materials in tracking volume are included.

Effect of sensors resolution

Next few slides will present residuals in different track parameters for different track momentums and deep angles. As can be seen from hits displacement due to MS calculations (see slide 4), even at 100 GeV we still have MS as a major contributor to momentum measurements inaccuracy. Vertex detector resolution starts affecting impact parameters residuals at as low track momentum as ~3 Gev.

Because of lack of time, I will present results mostly for “ideal” detector with perfect sensors resolution, and only for 50 and 100 GeV give comparison with real SiD detector parameters.

Pt and full momentum residuals for 1 GeV tracks

Tangent lambda	<1.2	1.2-2.	2.-3.	3.-5.
$\sigma\Delta\omega/\omega$ unfitted	0.0028	0.0069	0.01	0.014
$\sigma\Delta\omega/\omega$ fitted	0.0022	0.0031	0.0043	0.0074
$\sigma\Delta P/P$ unfitted	0.0027	0.004	0.0054	0.0077
$\sigma\Delta P/P$ fitted	0.0022	0.0031	0.0043	0.0071

Pt and full momentum residuals for 5 GeV tracks

Tangent lambda	<1.2	1.2-2.	2.-3.	3.-5.
$\sigma\Delta\omega/\omega$ unfitted	0.0021	0.0033	0.0046	0.0072
$\sigma\Delta\omega/\omega$ fitted	0.0020	0.0031	0.004	0.0066
$\sigma\Delta P/P$ unfitted	0.0021	0.0031	0.0042	0.0064
$\sigma\Delta P/P$ fitted	0.0021	0.0031	0.0041	0.0066

Pt and full momentum residuals for 20 GeV tracks

Tangent lambda	Ideal sensors 1.3-2	Ideal sensors 2.-3.	SiD real sensors 1.3-2.	SiD real sensors 2.-3.
$\sigma\Delta\omega/\omega$ unfitted	0.003	0.0039	0.003	0.004
$\sigma\Delta\omega/\omega$ fitted	0.0029	0.0038	0.0029	0.004
$\sigma\Delta P/P$ unfitted	0.0029	0.0039	0.0029	0.0039
$\sigma\Delta P/P$ fitted	0.0029	0.0038	0.0029	0.0038

Pt and full momentum residuals for 100 GeV tracks

	Ideal sensors	SiD real sensors
Tangent lambda	0.75	0.75
$\sigma\Delta\omega/\omega$ unfitted	0.0019	0.0042
$\sigma\Delta\omega/\omega$ fitted	0.0022	0.0032
$\sigma\Delta P/P$ unfitted	0.0019	0.0042
$\sigma\Delta P/P$ fitted	0.0022	0.0032

Impact parameters and direction residuals for 1 GeV tracks

Tangent lambda	<1.2	1.2-2.	2.-3.	3.-5.
σd0 unfitted	0.028	0.09	0.12	0.13
σd0 fitted	0.01	0.021	0.037	0.073
$\sigma\psi_0$ unfitted	0.0025	0.006	0.01	0.02
$\sigma\psi_0$ fitted	0.0008	0.0017	0.0027	0.0053
σTan(λ) unfitted	0.0023	0.01	0.019	0.05
σTan(λ) fitted	0.001	0.0031	0.0073	0.017

Impact parameters and direction residuals for 5 GeV tracks

Tangent lambda	<1.2	1.2-2.	2.-3.	3.-5.
σd0 unfitted	0.007	0.018	0.024	0.036
σd0 fitted	0.002	0.004	0.007	0.017
$\sigma\psi_0$ unfitted	0.0005	0.0013	0.0017	0.0024
$\sigma\psi_0$ fitted	0.0001	0.0003	0.0005	0.0012
σTan(λ) unfitted	0.0005	0.0025	0.0047	0.0092
σTan(λ) fitted	0.0002	0.0006	0.0014	0.005

Impact parameters and direction residuals for 20 GeV tracks

Ideal sensors — SiD real sensors

Tangent lambda	1.2-2.	2.-3.	1.2-2.	2.-3.
σd0 unfitted	0.0045	0.0061	0.0056	0.0071
σd0 fitted	0.0011	0.0019	0.0043	0.0058
$\sigma\psi_0$ unfitted	0.0003	0.0004	0.0003	0.0004
$\sigma\psi_0$ fitted	0.00007	0.00013	0.0001	0.0002
σTan(λ) unfitted	0.0006	0.0011	0.0006	0.0011
σTan(λ) fitted	0.0001	0.0003	0.0002	0.0004

Impact parameters and direction residuals for 100 GeV tracks

	Ideal sensors	SiD real sensors
Tangent lambda	0.75	0.75
σd0 unfitted	0.00045	0.0035
σd0 fitted	0.0003	0.0019
$\sigma\psi_0$ unfitted	0.000018	0.000036
$\sigma\psi_0$ fitted	0.000009	0.000025
σTan(λ) unfitted	0.000025	0.0036
σTan(λ) fitted	0.00001	0.00009

Conclusions

- SiD detector tracking performance is not limited by spatial resolution of silicon tracker sensors for up to 100 GeV tracks.
- From the point of view of momentum resolution there is no benefit in extra layers. Rather smaller number of layers would be beneficial as it reduces amount of material. Of course, pattern recognition and reconstruction of lower momentum tracks may benefit from larger number of layers.In any case all efforts should be made to reduce amount of material inside tracking volume.
- Track fitter has little effect on the tracking resolution in case of multiple scatter dominated errors.There is no need to invest heavily in better fitter algorithm.