PERFORMANCE STUDIES

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Outline

- How to design and optimise Your own ILC detector on the back of an envelope:
  - Why size matters.
  - Only a TPC: Analytical calculations and fast simulation
  - Adding the rest: VD+SIT, SET, forward trackers
- Leading to:
  - A modest proposal
- Detailed studies of the SIT-SET-ECT
- Conclusions

Expected momentum resolution

- What we measure directly is curvature($\rho = 1/R$), or more directly the *sagita* (S) over the length of the *coda* (L).
- $\rho = 2S/\left[(L/2)^2 + S^2\right] \Rightarrow \sigma(\rho) = \sigma(S)/L^2 \star 8 \left| \frac{1-8(S/L)^2}{[1+4(S/L)^2]^2} \right| \approx 8\sigma(S)/L^2$if $S \ll L$, but $\sigma(S) = 2\sigma(S)/L^2$if $S = L/2$ (ie. if the track turns back).
- $\sigma(S) = \sqrt{(\sigma_{start}/2)^2 + (\sigma_{end}/2)^2 + \sigma_{mid}^2}$ for 3 evenly spaced points.
- $p \sin\theta = p_\perp = 0.003B/\rho$ ie. $1/p = 330 \sin\theta\rho/B$
- $\sigma(1/p) = (330/B) \sin\theta\sigma(\rho)$ (ie. $\sigma(p) = (330/B)\, p^2 \sin\theta\sigma(\rho)$)

Expected momentum resolution

- SO:

$$\sigma(1/p) = (8 \star 330/B)\ \sin\theta\sigma(S)/L^2 \text{ at high } p$$

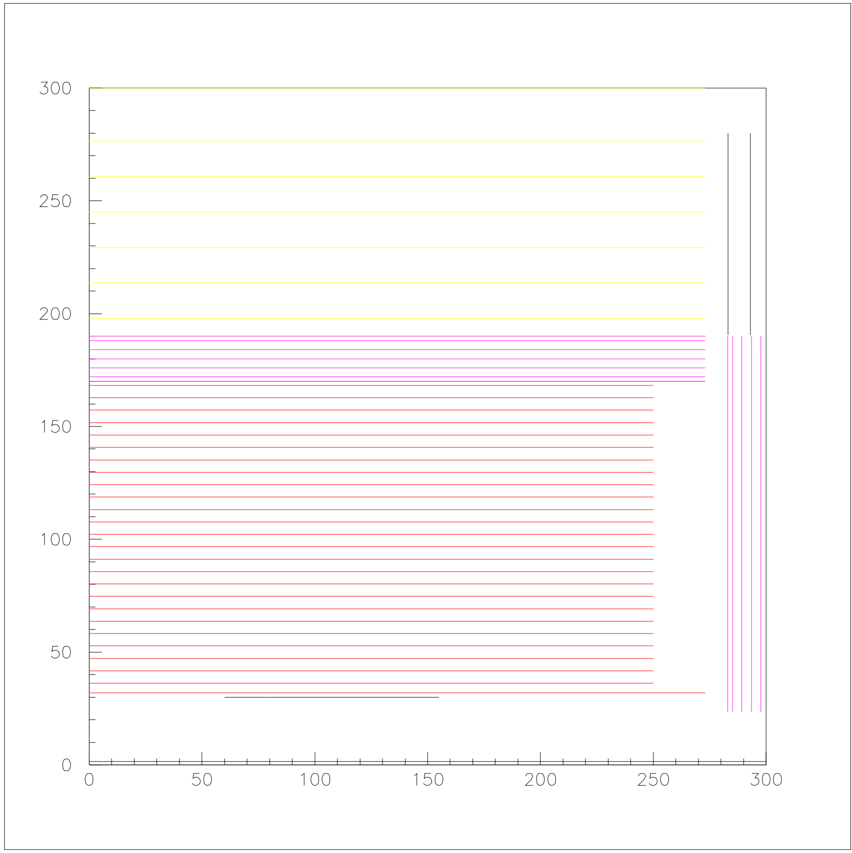
Sagita errors:

- Three points, all with the same error: $\sigma(S) = \sigma_{point}\sqrt{6}/2$
- Three points, first point “fixed” $\sigma(S) = \sigma_{point}\sqrt{5}/2$
- Three points, first and last point “fixed”: $\sigma(S) = \sigma_{point}$
- Many points, all with the same error:
  - group the points in the first, second and third thirds.
  - Then $\sigma(S) \approx (\sigma_{point}/\sqrt{n/3})\sqrt{6}/2$.
  - L should be reduced by one third since the first point is in the middle of the first third, the last in the middle of the last third!

This simple rule is good to $\sim$30 %.

TPC alone

Lets see what the TPC alone gives. As an example: $R_{inner} = 36.2\text{cm}$ $R_{outer} = 168.2$ cm, (ie $L = 132\text{cm}$), $Z_{max} = 250$ cm, $B = 4\text{T}$, σ_{point} =60 μ, 25 layers.



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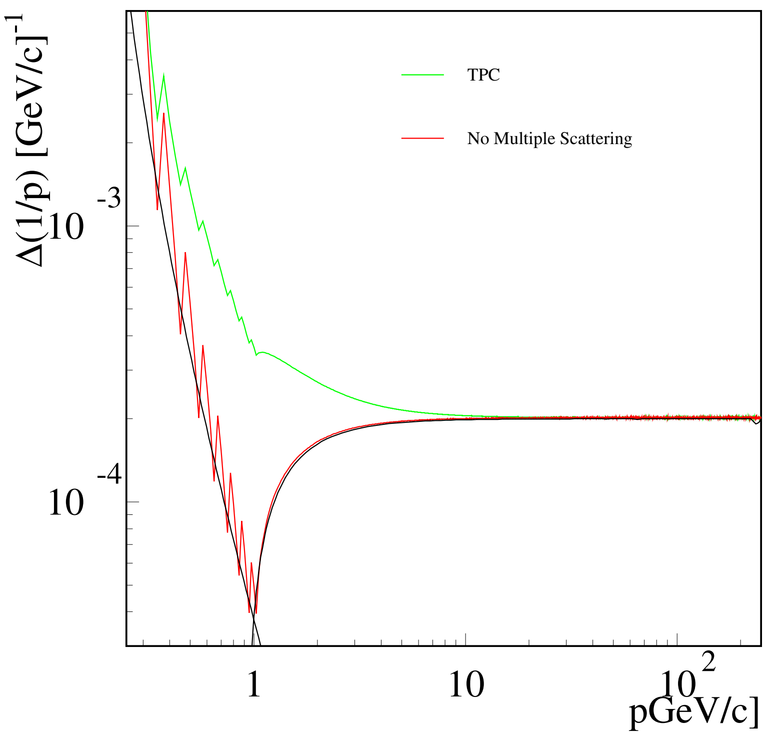
- Expect $\sigma(1/p) \propto \sin\theta/L^2$ in the barrel, and $\propto \sin\theta/(\tan^{5/2}\theta - (Z_{max}/R_{inner})$ in the forward. The extra $1/\sqrt{\tan\theta}$ because in the forward region, $n_{points} \propto L$. At 90°. The thu.mb-rule gives 35 % more than the exact result from SGV.



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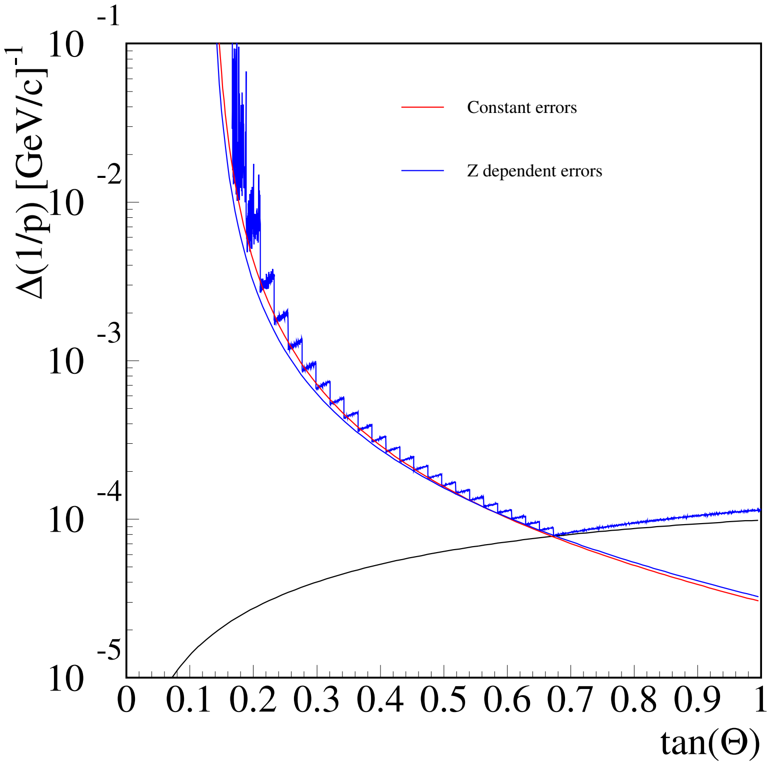

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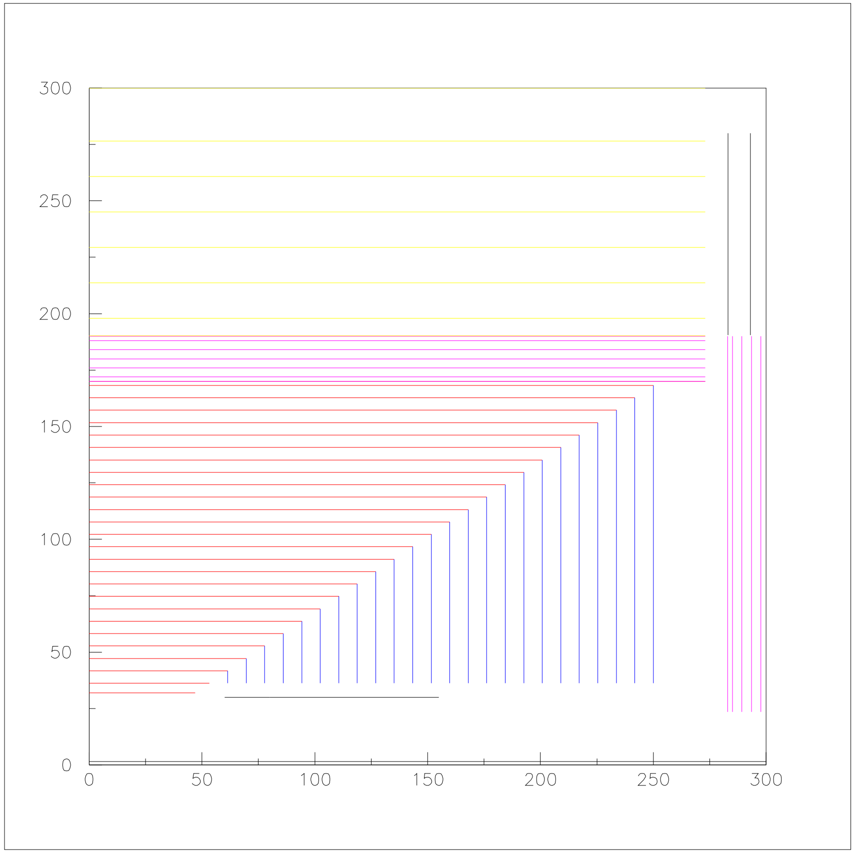

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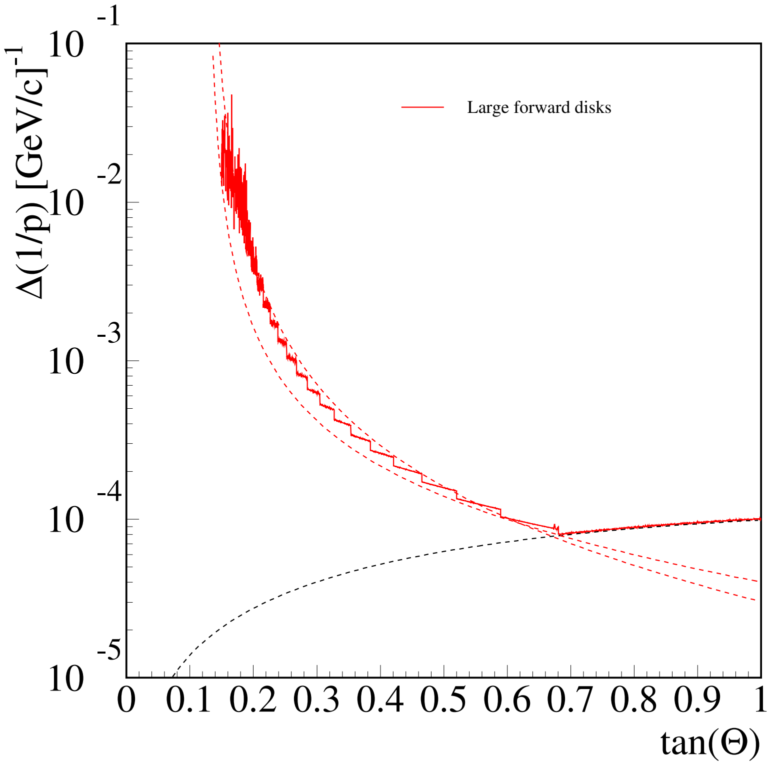

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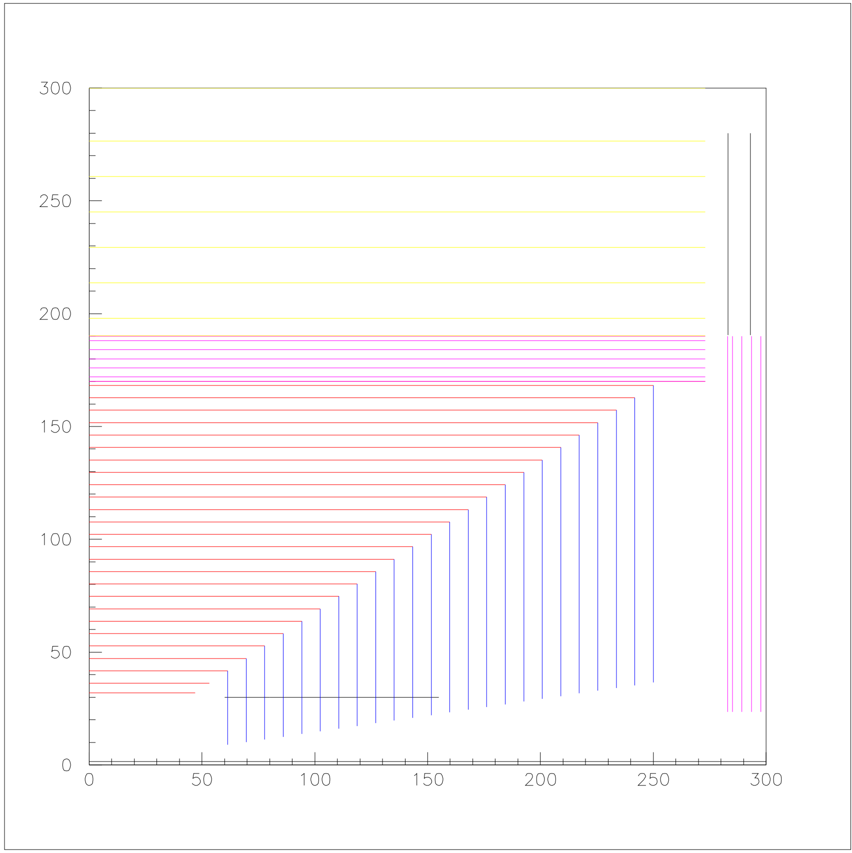
- Better Discs: Extend to lower inner radius for lower Z, ie. the tracks traverse all disks down to the edge of the acceptance. Big effect: $\sigma(1/P) \propto \sin\theta/(\tan^2\theta)$, ie the term Z_{max}/R_{inner} above vanishes.



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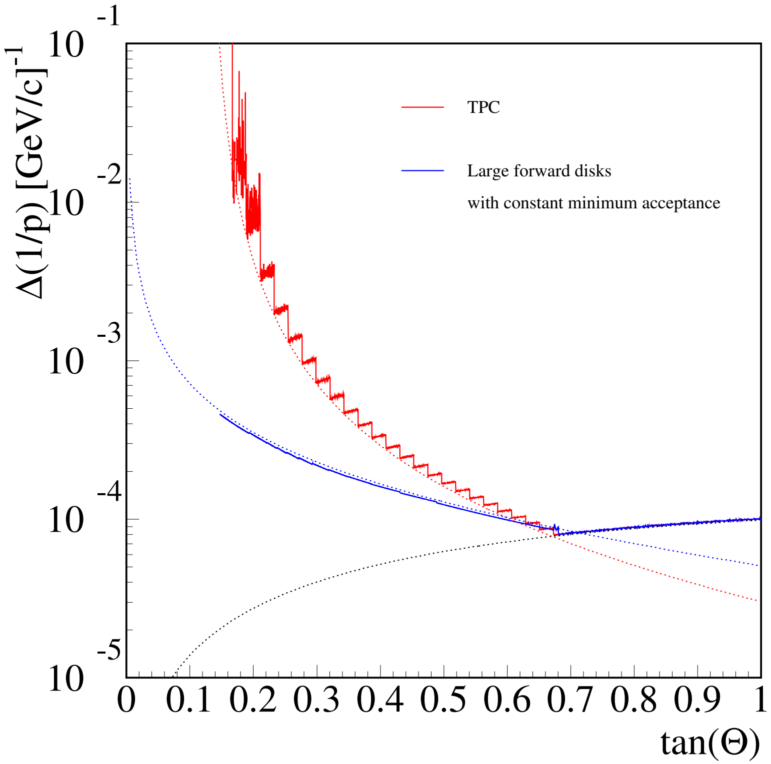

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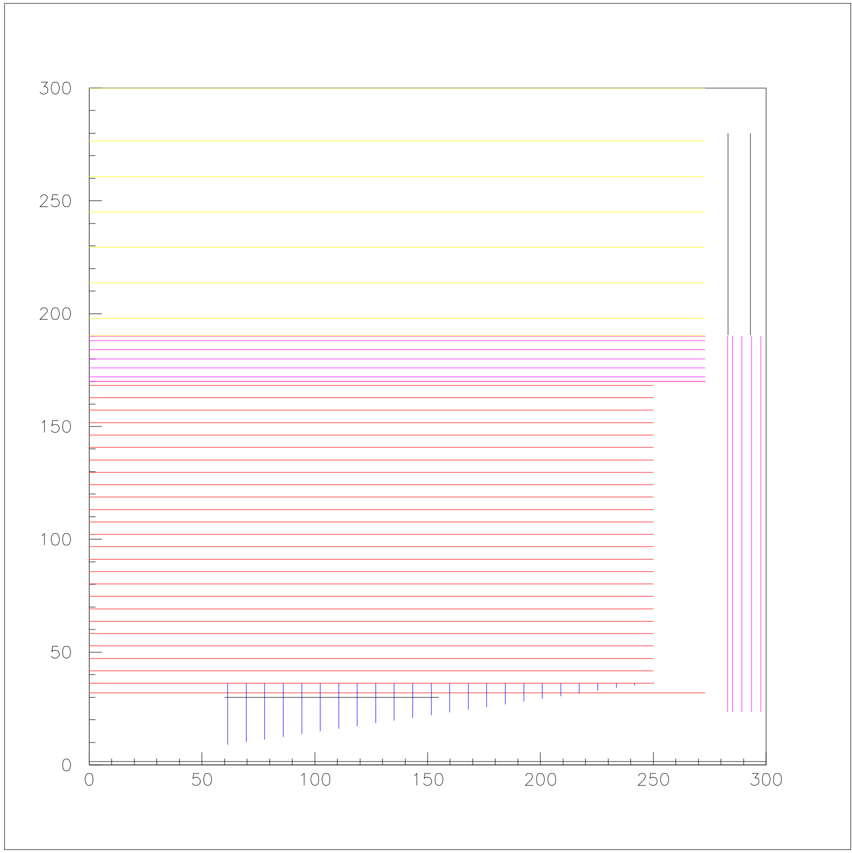
- *Almost* equivalent: The FTD, ie. only disks inside the TPC.



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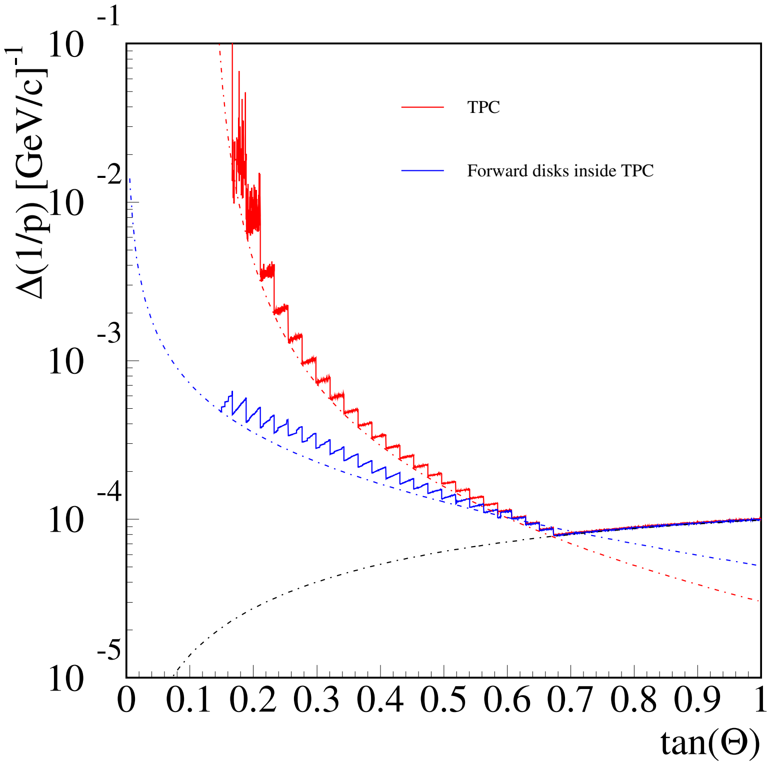
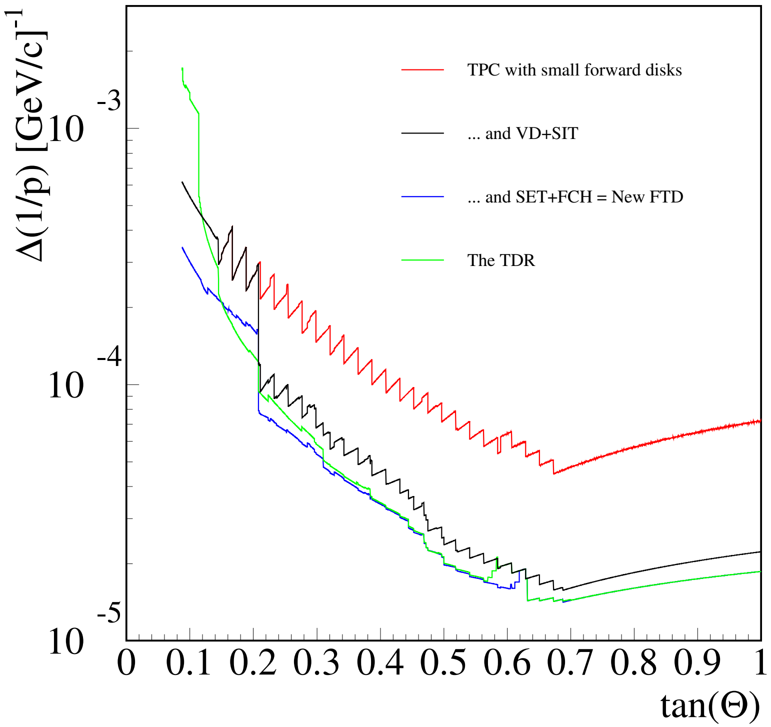


A full tracking system

Now add the other elements

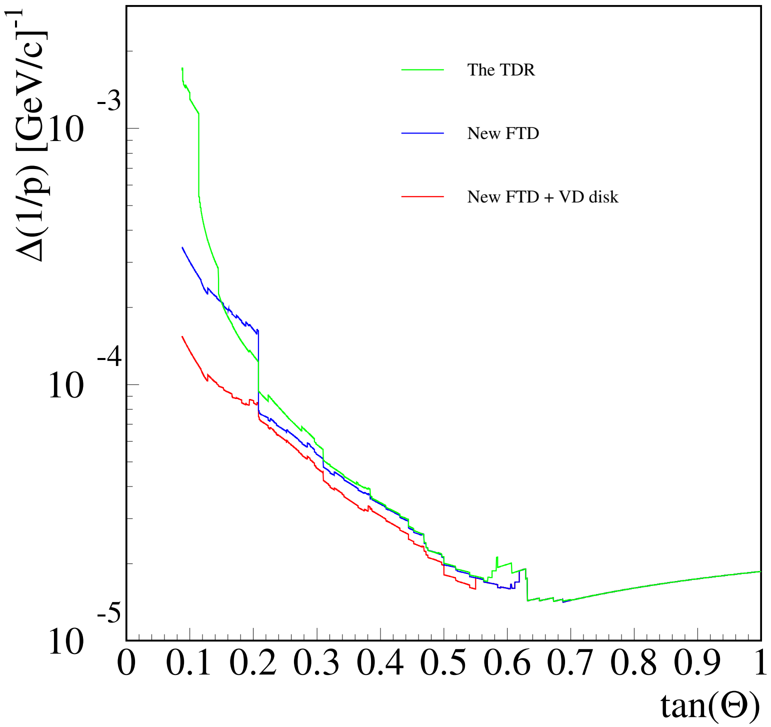
- Vertex detector and SIT: The *effective L* increases from 88 cm to 146 cm, ie $1/L^2$ decreases by a factor 2.8. The *start-point is now "fixed"* so $\sigma(S)$ decreases by 10 %. Expect a factor 3
- SET: *effective L* increases from 146 to 170 cm, and $\sigma(S)$ decreases by 10 %. Expect 35% better. Forward chambers: similar to the SET
- The base-line LDC ("TDR"): Differs in the geometry of the FTD



A full tracking system

Note:

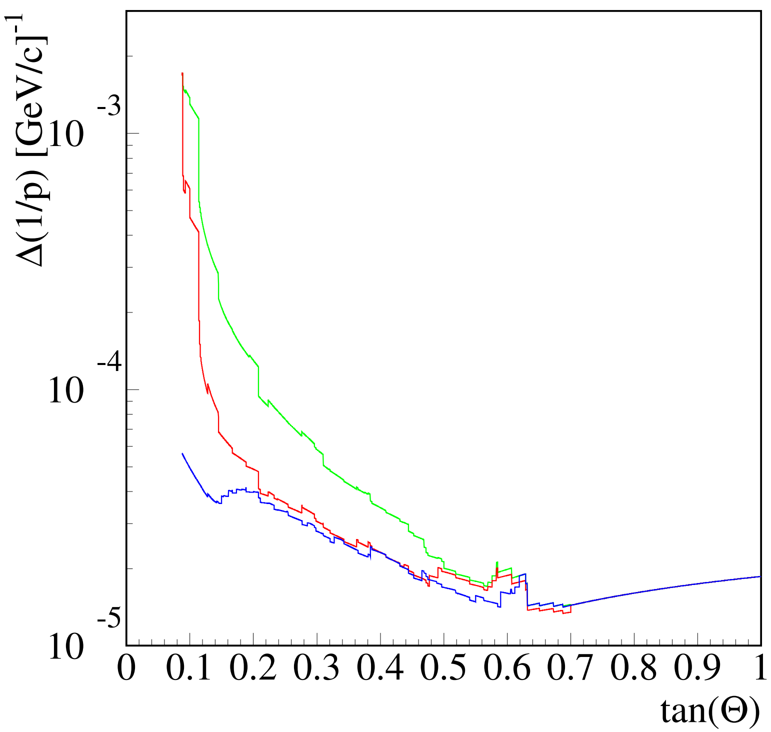
- I: The divergence in the TDR: Once the last disk is hit, the $1/\sqrt{\tan\theta}$ is back !
- II: The step: End of The Vertex Detector
- Remedy I:Add *disks* all the way to the end of the TPC (5 more strip-disks)
- Remedy II: Add a *pixel disk* with $\sigma_{point} = 4\mu$just outside the VD



A full tracking system

Since the TDR, it has been proposed to modify the FTD with better point resolution, but keeping the geometry. How does that compare, and what happens if I also use these values?

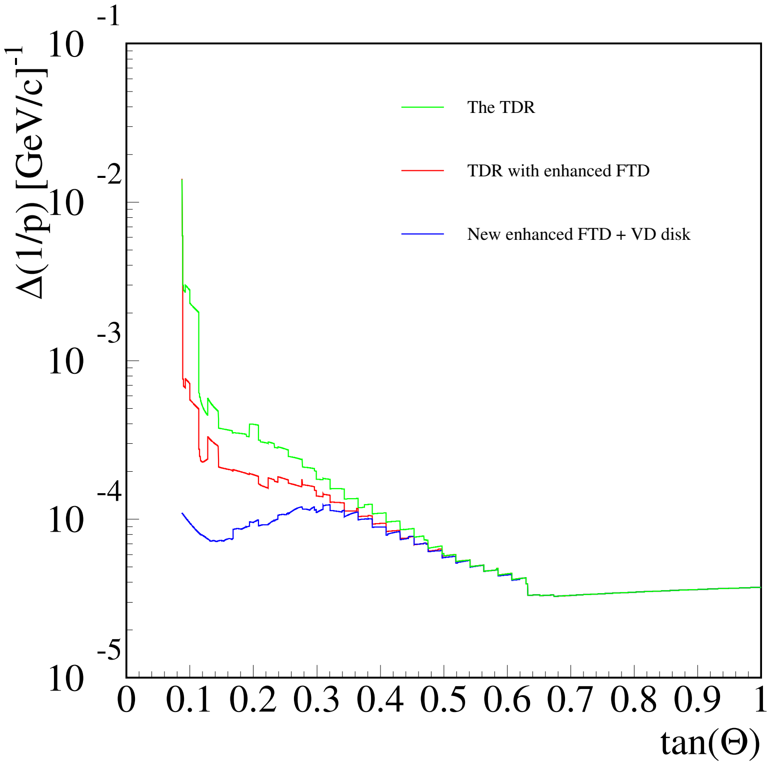
- The TDR
- The TDR, with the mini-pixel discs replaced by micro-pixels ($\sigma_{point} = 4\mu$), and the mini-strip discs by micro-strips ($\sigma_{point} = 7\mu$).
- The redesign, with the 12 discs replaced by discs with 7μresolution.



A full tracking system

How does it look at lower momenta ?

- 25 GeV: The redesign is still much more performant at low angles



A full tracking system

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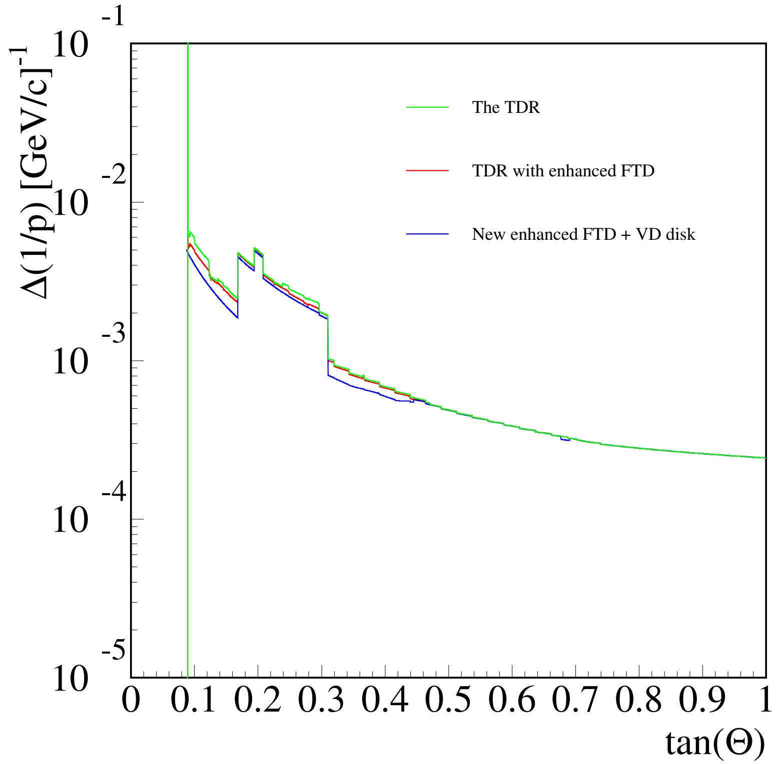
- 25 GeV: The redesign is still much more performant at low angles
- 2.5 GeV: Dominated by multiple-scattering. The bump is the VD electronics and support

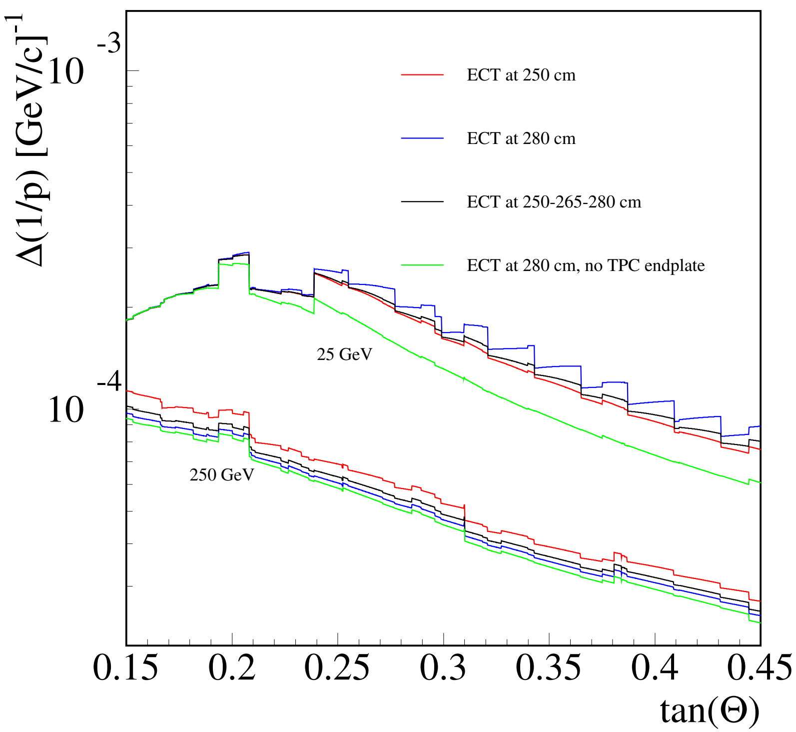


Studies of the silicon envelope: ECT

Move ECT by 30 cm: as *close* as possible, as *far* as possible, or *evenly spaced*. Study the effect of TPC end-plate

- 250 GeV: 30 cm change corresponds to a change of L^2 by 25 %, which is observed. Some effect of the scattering in the end-plate is visible even at this momentum.
- 25 GeV: Dominated by scattering. If the end-plate remains as thick as in the TDR, it is best to place the *ECT as close as possible*

It is best to have a very precise point close a scattering surface

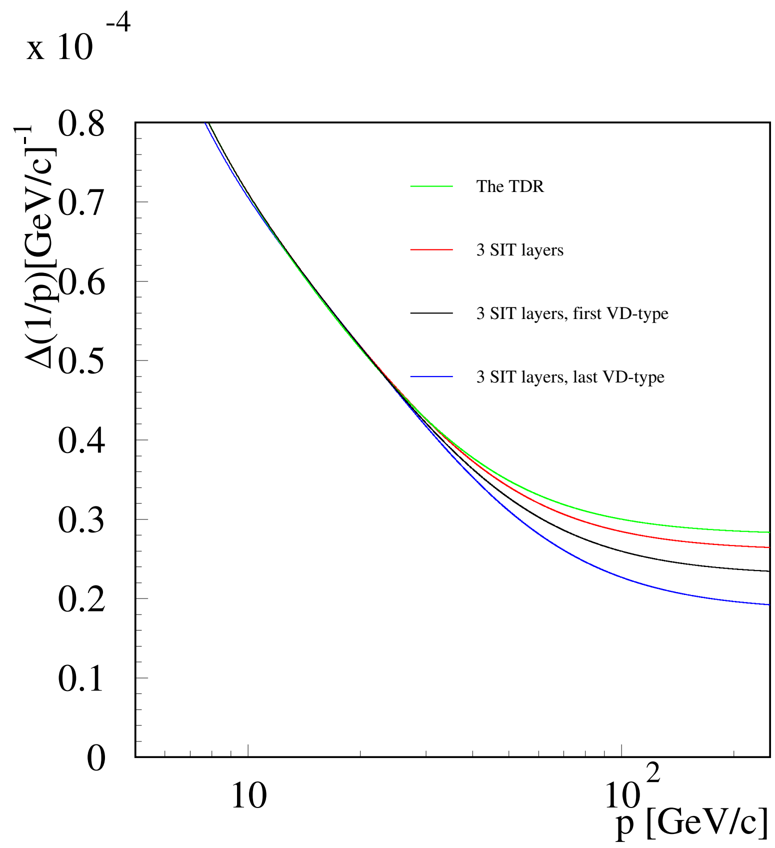


Studies of the silicon envelope: SIT

Does it help to have more layers in the SIT. Or more precise ones?

- TDR
- 3 layers,
- 3 layers with the inner-most of VD-type (4 μ)
- 3 layers with the outer-most of VD-type (4 μ)

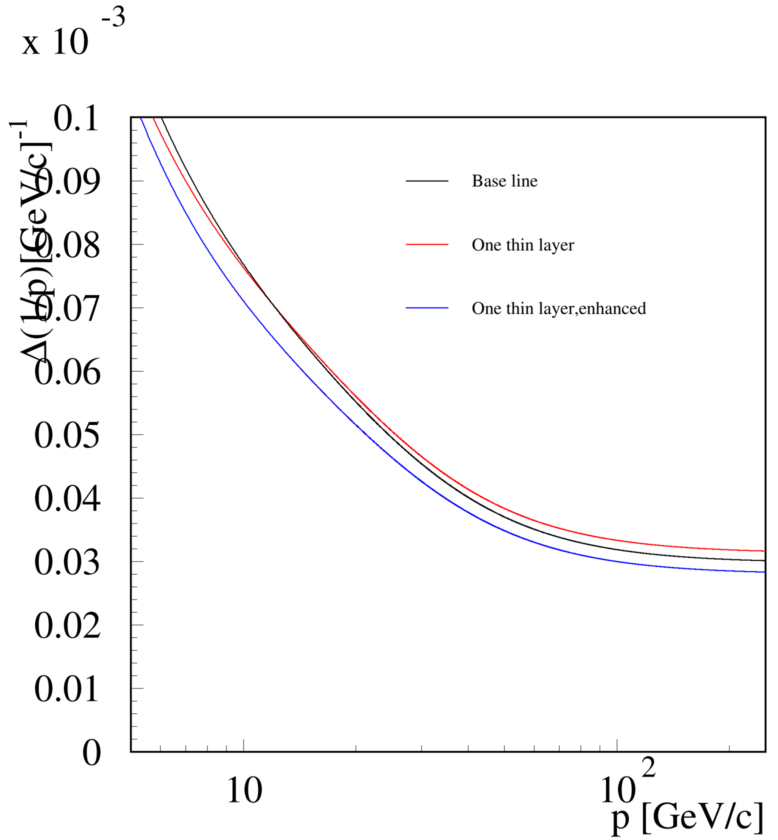
It is best to have a very precise point close a scattering surface



Studies of the silicon envelope: SET

How to distribute the SET layers?

- TDR+SET: SET takes 10 cm of the TPC, and has three layers with 25 μresolution
- TDR+thinSET: SET “nothing” of the TPC, and has one, 25 μresolution layer
- TDR+thinSET, with 14.4 $\mu (= 25/\sqrt{3})$ resolution



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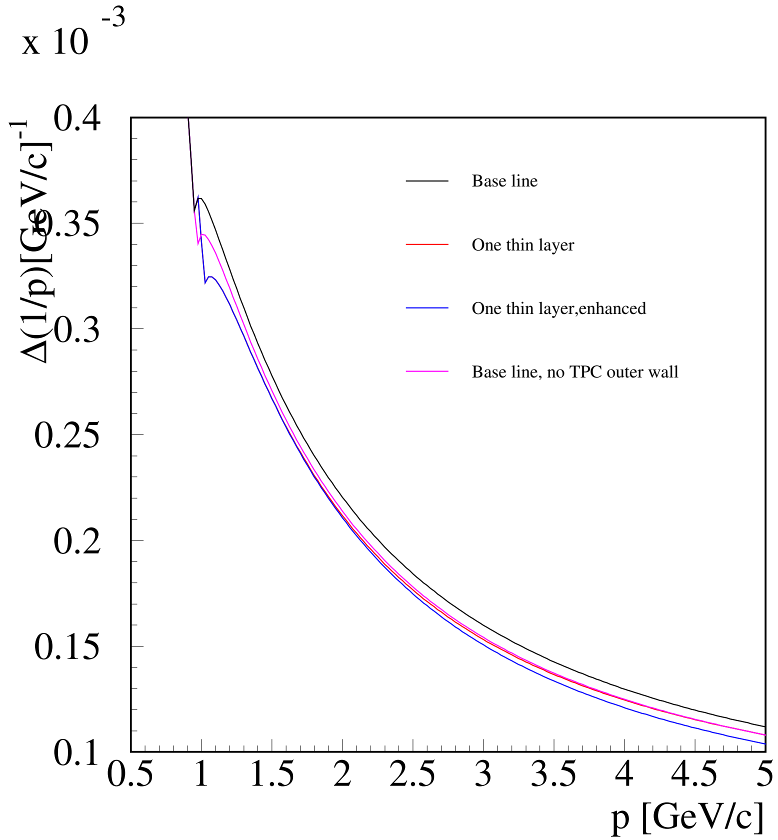
- TDR+thinSET: SET "nothing" of the TPC, and has one, 25 μresolution layer
- TDR+thinSET, with 14.4 $\mu (= 25/\sqrt{3})$ resolution
- Same thing, in the low end of the spectrum

Scattering makes little difference, since the SET is quite short. At high momentum, the $1/L^2$-factor favours pushing the SET as far out as possible, and at lower momenta, it is more worthwhile to retain as much as possible of the TPC lever-arm.



Summary and Conclusions

- A set of thumb-rules to estimate the performance of the tracking-system wrt. p measurement was presented. The important messages:
  - It's the lever-arm...
  - For p, the position of scattering surfaces is most important. MS close to the edges of the measuring range does not hurt. Consequently, adding precise points close to un-avoidable scatterers is a good idea..
  - Extremely high precisions at either edge doesn't pay: Having the end-points fixed is only 20% better than having the same error in all points..
- These principles lead to a modest proposal how to ameliorate the TDR design:
  - Extend the FTD all the way to the end of the TPC, and distribute them evenly..
  - Add a micro-pixel disk to the end-plate of the VD..
  - Extend the ECT to the same angle as the FTD. Distributing the it evenly in the between the TPC and the ECAL is the best compromise over p.
  - Fit the SIT with an outer layer with highest possible $R\phi$-precision.
  - Attempt to make the SET thin, and as close to the ECAL as possible.
- In particular the first two points will ameliorate the resolution at the lowest angles by an order of magnitude.
- These results are based on fast simulation (SGV). Hence important issues related to reconstruction are NOT addressed