ILD tracker performance: the prize for a smaller detector

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Outline

Present optimisation studies

Detector-component optimisation in ILD (post DBD):

- Presently
- Mainly has been about ECal
- Aimed at cost-reduction.
- Only considers JER as metric - mainly for highest energy jets.
- Studies on:
  - Sensitive detector technology
  - Number of layers
  - Radius and/or length

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Effects of Tracking geometry

Reminder:

- $\Delta(1/p_T) \propto L^{-2.5}$ (2 purely geometric + ($\geq$) 0.5 because of less points in TPC).
  - But only linear in σ_{point} and B-field
- Please note: Stored energy in B-field $\propto B^2 V$, so at equal stored energy, a smaller detector can have a higher field.
- Also: $\sigma^2_{point,TPC} = \sigma^2_0(\sin\phi) + \frac{C^2_d(B)}{N_{eff}(\sin\theta)} Z$, $C^2_d(B) \propto 1/(1+(\mu B)^2) \Rightarrow$ complicated relation, but gets better with shorter drift-length and higher B.
- Also: Higher B-field $\Rightarrow$ possible to have smaller beam-pipe/vertex-detector $\Rightarrow$ better IP-resolution.

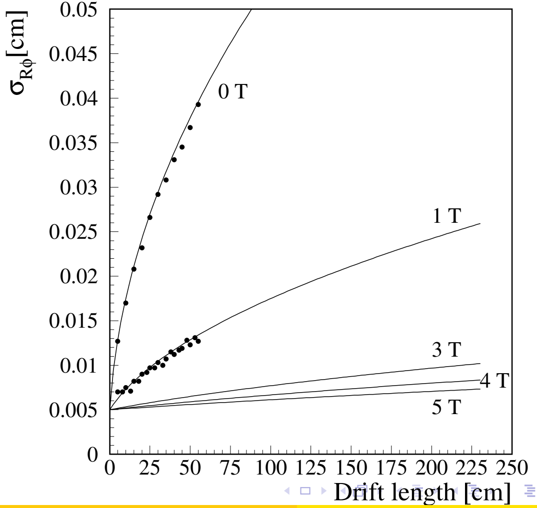
Detailed estimation: SGV

- The description of the point-errors in the TPC have been extended to include all the terms in the description. Inputs:
  - $\sigma_{R\phi}$ and at σ_Z zero drift length.
  - Zero B-field diffusion in Rϕ.
  - Mobility.
  - Track-radial direction angle dependence of $\sigma_{R\phi}$.
  - Ratio of diffusion in Z and Rϕ, default 2.

  Numbers (mostly) from Ron Settles for T2K gas.
- Replace the default simplified TPC layer structure (pad-rows grouped by 9) to the full 225 layers ILD to simplify scaling.
- Script to scale the default ILD.

TPC point-resolution vs. Z and B in SGV and DBD

- Points: Prototype measurements (from DBD/DBD SVN)
- Lines: Formula used in SGV.



Vertex-detector size and B

- If the B field goes from
- ... 3.5 T ... to 5 T,
- the cone of bs pairs get squeezed.
- The "cone" is a parabola $\Rightarrow$
- The radius of the edge of the "cone" $\propto 1/\sqrt{B}$ at a given Z.
- However:
  - The particles directly hitting the VTX are not from the "cone", and have no $P_T - \theta$ correlation.
  - The back-scatters from the BCal that hits the VTX are not produced at a given Z if the detector shrinks.

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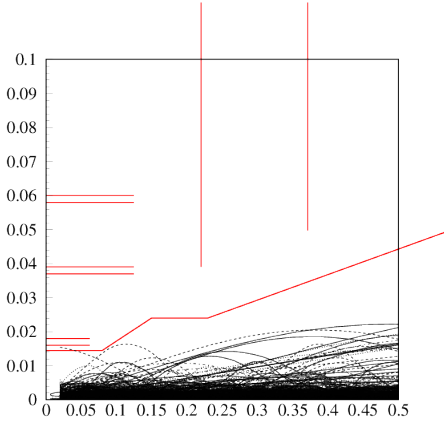

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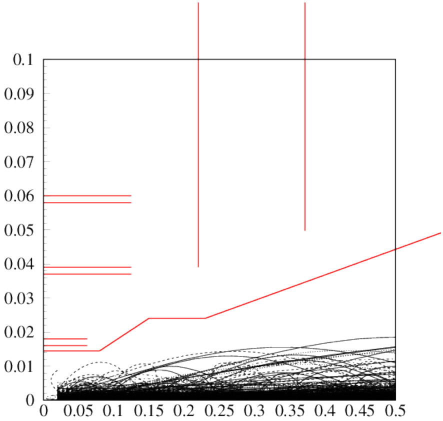

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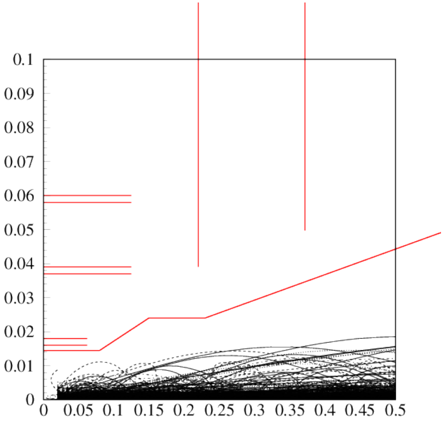

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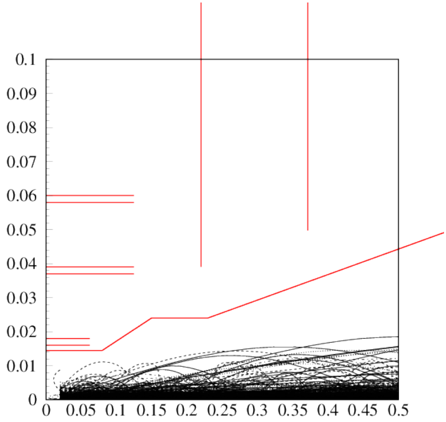

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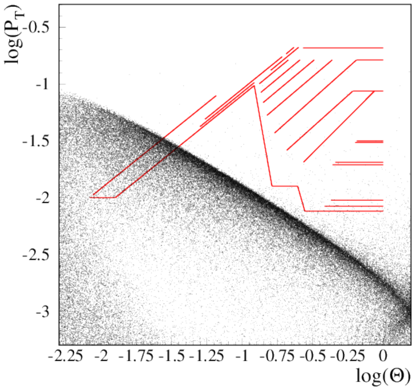

Vertex-detector size and B

- If the B field goes from
- ... 3.5 T ... to 5 T,
- the cone of bs pairs get squeezed.
- The "cone" is a parabola [illegible]
- Th [illegible] "cone" $\propto 1/\sqrt{B}$ at a given Z.

$\Rightarrow$ Reduce $R_{VTX-inner}$ in proportion to B $\Rightarrow$ better σ_{ip}.

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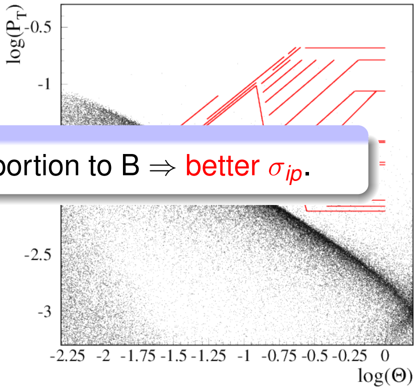

Geometries used

I studied five different ways to change the ILD baseline geometry. For each of these I did modifications in 5 steps:

1. Keep baseline aspect ratio.
2. Keep baseline radius.
3. Keep aspect ratio = 1
4. Keep baseline length.
5. Keep length = baseline-40 cm.

(All showing the largest modification using SGV:s detector description visualiser)

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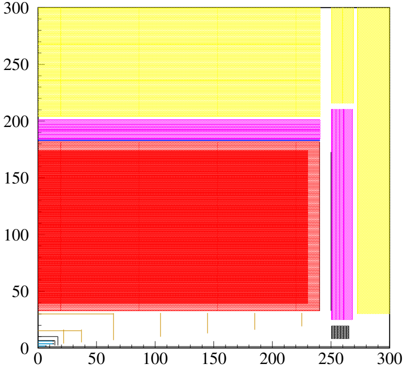

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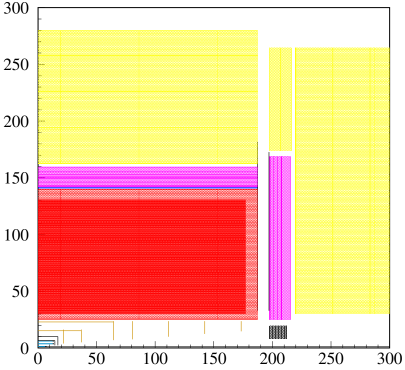

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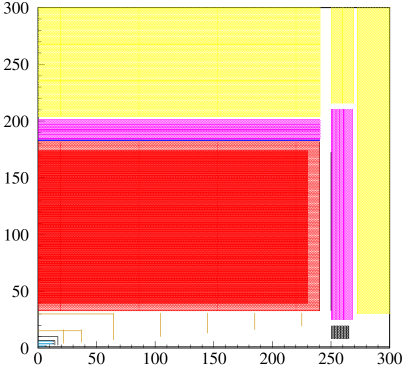

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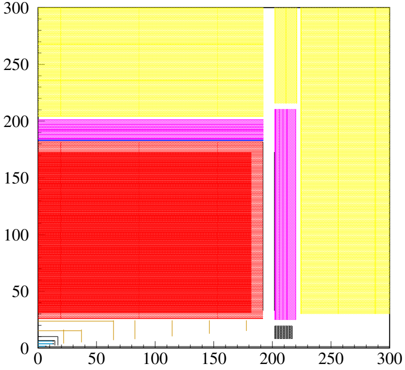

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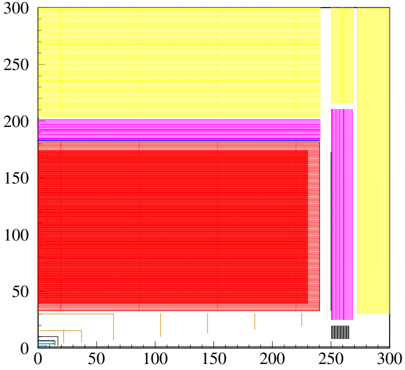

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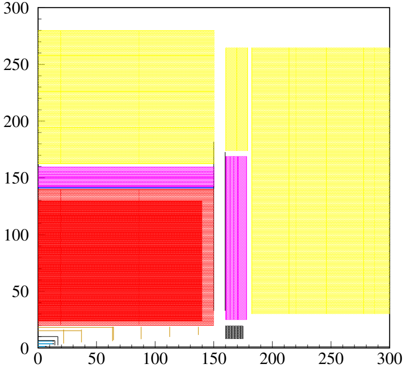

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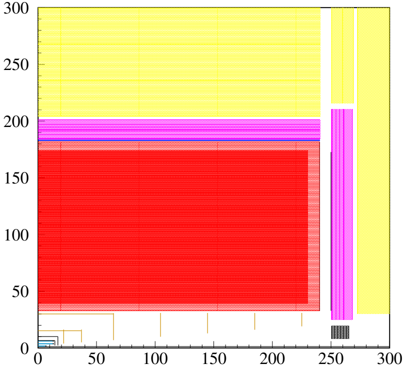

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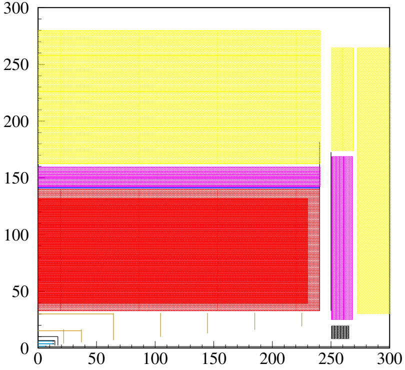

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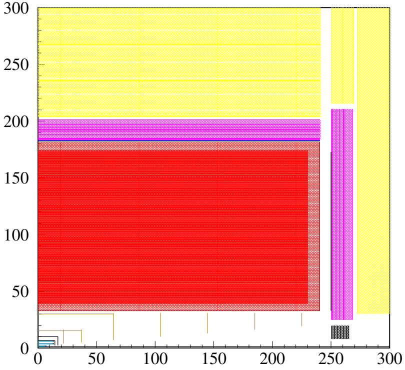

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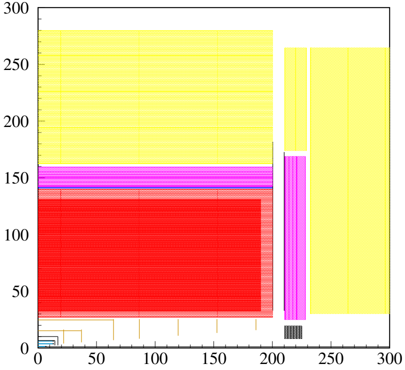

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Other options

Apart from the pure modifications of the geometry, I considered

1. Only Outer extent of the TPC modified. Everything outside was also moved, as was the FTD strip-discs. VTX, SIT and FTD pixels unchanged.
2. Also modify B, keeping $B^2 V$ constant (V=volume of solenoid).
3. Keep B fixed, but modify TPC inner radius (and hence the outer layer of the SIT and the outer radius of the FTD discs.)
4. Both 2 and 3.
5. In addition to 4, also scale beam-pipe and VTX-inner with B.
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In addition to this, I also considered changing the default ILD B from 3.5T to 4T (as the magnet is designed for 4T)

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$2 \times 5 \times 5 \times 6 = 300$ cases !

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Effects of Tracking geometry on helix parameters

Check $\Delta(1/p)$ and $\Delta(ip_{R\phi})$ at different p and $\cos\theta$ ($\Delta(ip_Z)$ similar to $\Delta(ip_{R\phi})$, angles not relevant - the other uncertainties dominate)

- Red/magenta: fixed aspect-ratio, decrease size.
- Blue: fixed R, decrease Z.
- Green/orange: fixed Z, decrease R.
- Black: TDR detector.
- $\Delta(1/p)$ vs. $\cos\theta$
- Rel. $\Delta(1/p)$ vs. $\cos\theta$
- Rel. $\Delta(1/p)$ vs. p
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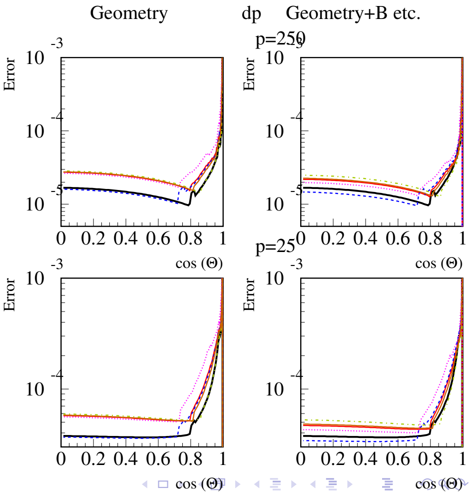

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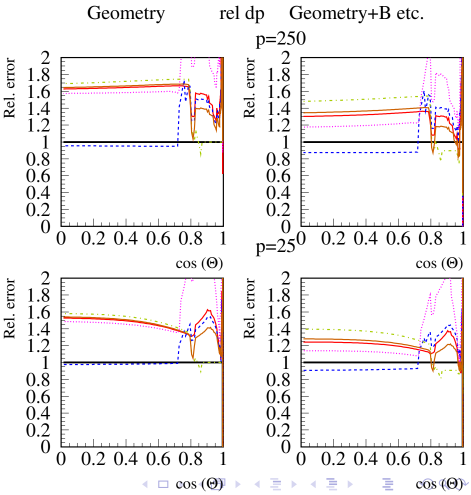

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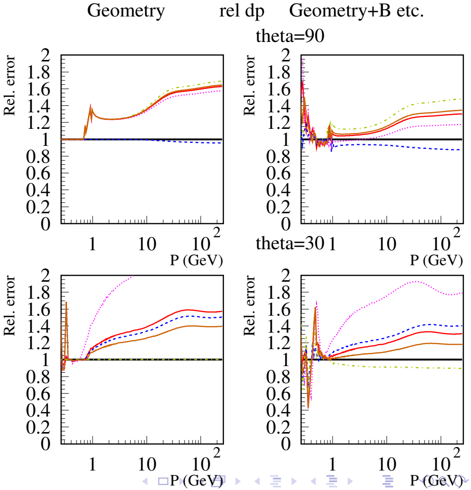

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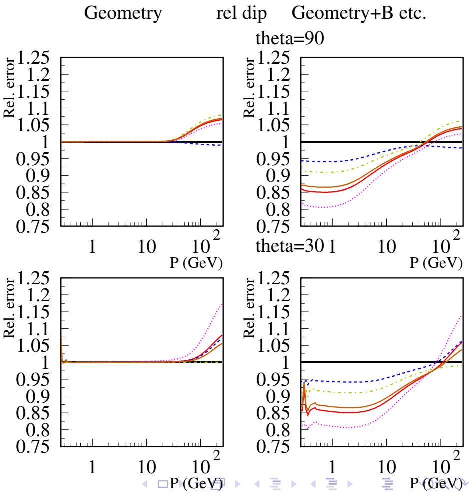

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- Circles/triangles: fixed aspect-ratio.
- Squares: fixed R.
- Stars/inv. triangles: fixed Z.
- $\Delta(1/p)$, barrel.
- $\Delta(1/p)$, endcap.
- $\Delta(ip_{R\phi})$, barrel.
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Filled: Only modify geometry; Open: also do other changes.

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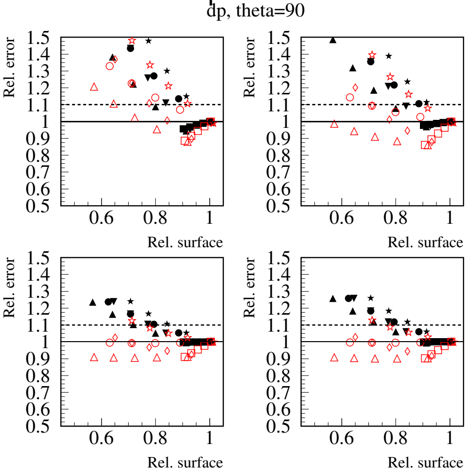

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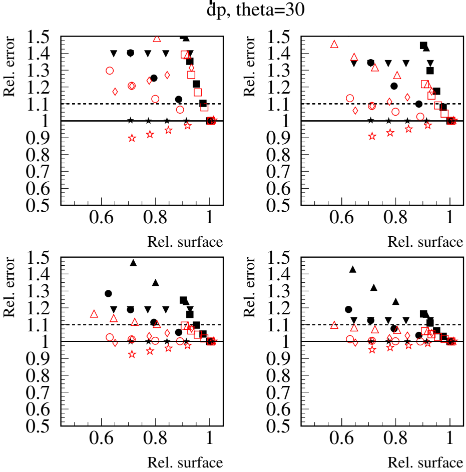

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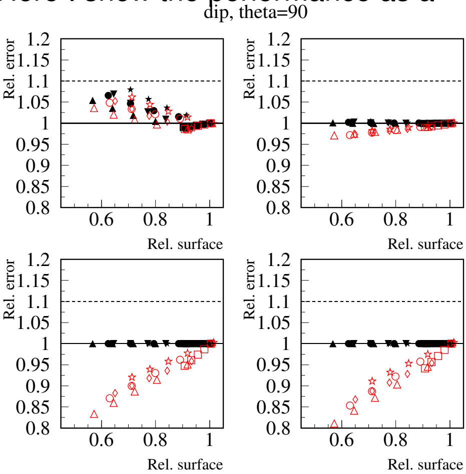

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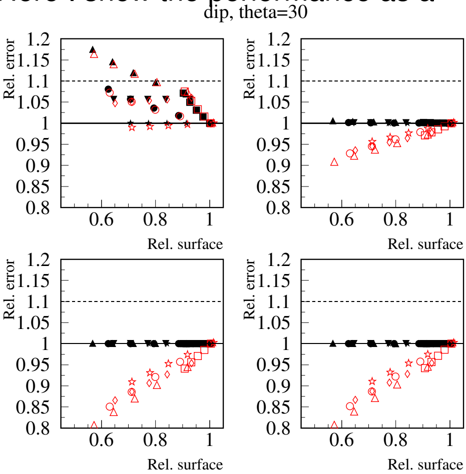

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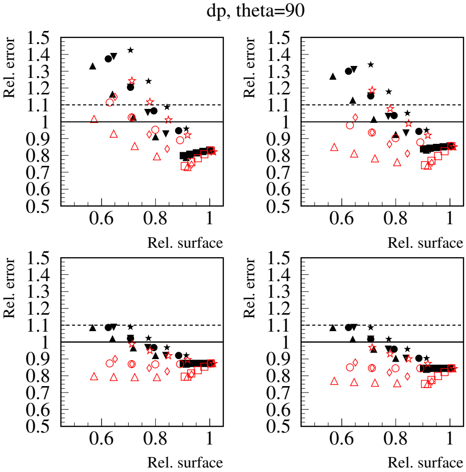

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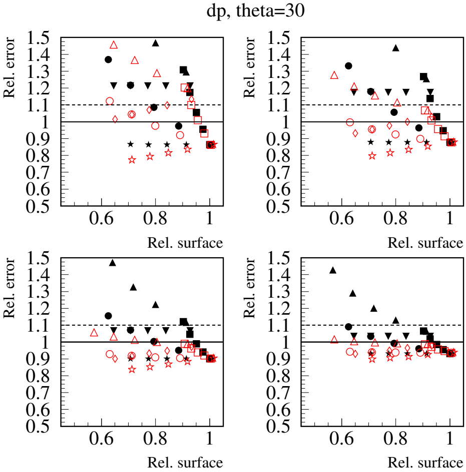

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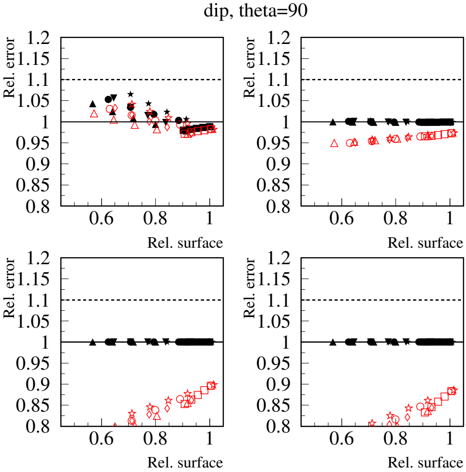

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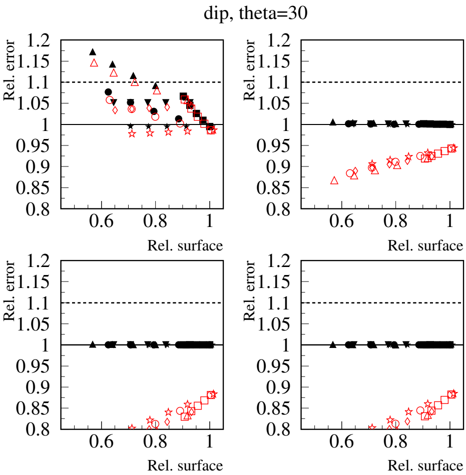

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Higgs recoil-mass @ 350 GeV: mesurables

- Look at $\mathrm{e}^+\mathrm{e}^- \rightarrow ZH$, $Z \rightarrow \mu^+\mu^-$, $H \rightarrow X$.
- Signal only, perfect μ finding, SGV.
- Recoil-mass = $\sqrt{(E_Z - E_{CMS})^2 - \bar{p}_Z^2}$, where $E_Z = E_{\mu^+} + E_{\mu^-}$, $\bar{p}_Z = \bar{p}_{\mu^+} + \bar{p}_{\mu^-}$, E_{CMS} =nominal=350.
- So,it's all about measuring the μ:s !
- Note: E range 20 to 150, θ in barrel.

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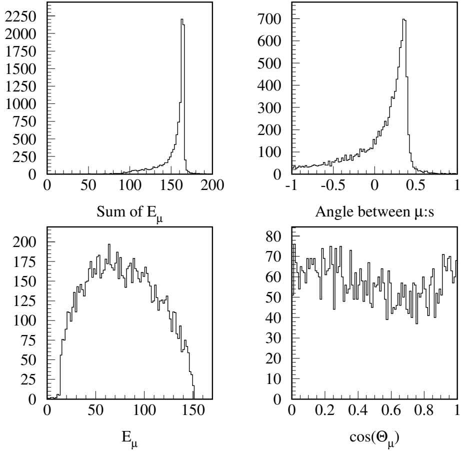

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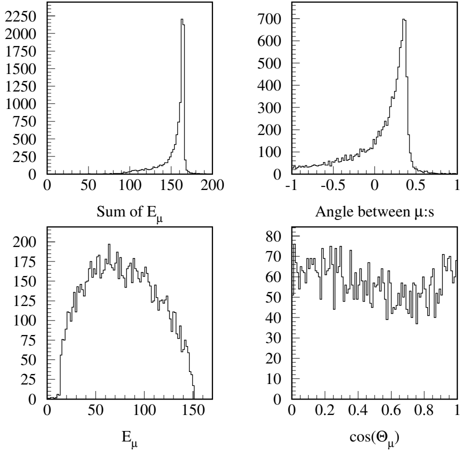
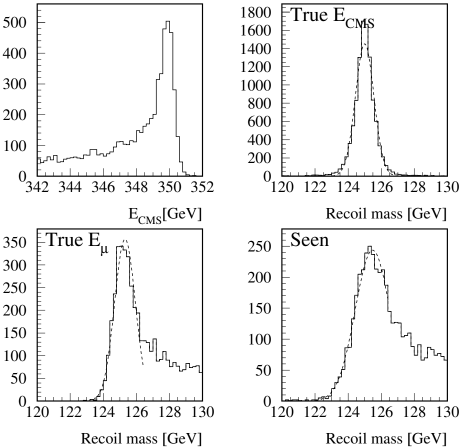


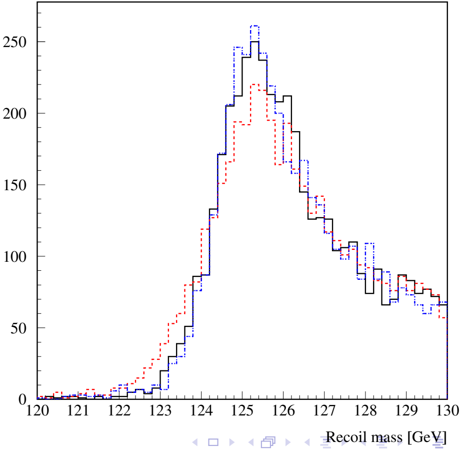
Higgs recoil-mass @ 350 GeV: The recoil mass

- E_{CMS} $\neq$nominal, due to beam spectrum.
- Assume E_{CMS} known $\Rightarrow$ see effect of detector alone.
- Or: Assume μ:s perfectly measured $\Rightarrow$ see effect of beam-spectrum alone.
- Fold the two: the observable distribution.



Higgs recoil-mass @ 350 GeV: The good, the bad, the ugly

- This shows observable recoil-mass for the nominal ILD (black), the worst case (red) and the best case (blue)
- ... and this shows the case if E_{CMS} would be known, ie. the pure detector effect.



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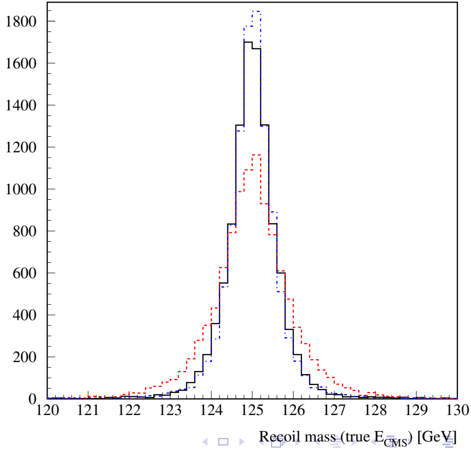

Higgs recoil-mass @ 350 GeV: fits with different options

To substantiate: Fit the recoil-mass (Gaussian from 120 to 126.5 GeV in the observable case, free Gaussian in the E_{CMS}-known case)

- $\sigma_{M-recoil}$ for a representative set of options.
- Same, but in the "4T" case.
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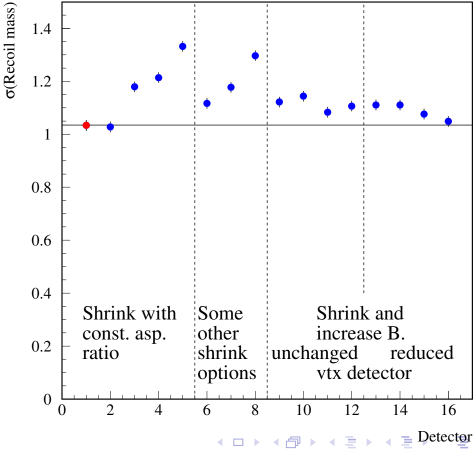

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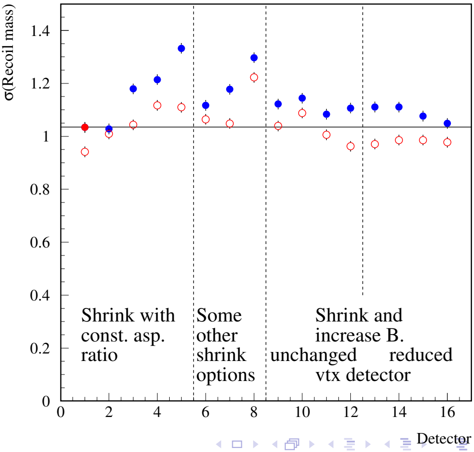

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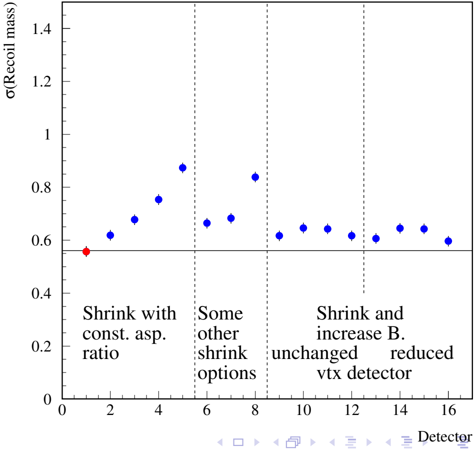

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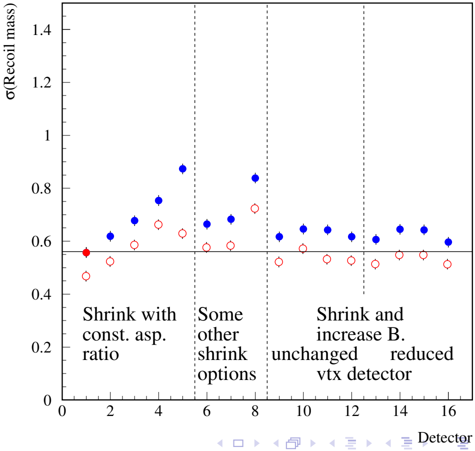

Conclusions

- A large number of possible ways to reduce the size of the ILD tracking system were studied.
- A number of auxiliary changes that a reduced size would allow for were also studied: Increased B-field, changes of the inner radius of the TPC and/or the vertex detector.
- The errors of the basic helix parameters were evaluated for all of these scanning in momentum at a few fixed θ angles or in θ at a few fixed momenta.
- In addition, the precision on M_H from the recoil-mass method was evaluated with with SGV for a sub-set of the options.
- All taken together, the option with R_{TPC}=160 cm and/or $Z_{max,TPC}$ between 230 and 190 cm would be a viable option, provided the B-field is increased. Corresponds to $N_{padrows} = 225 \rightarrow \sim 190$.
- These values correspond to a reduction of the ECal area of between 15 and 25 %, and a B-field between 3.7 and 3.9 T (or 4.2 to 4.4, if the baseline field would be increased to 4 T)

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