Detector benchmarks : Overall ILD dimensions and the ILD tracker

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Outline

Present optimisation studies

Detector-component optimisation in ILD (post DBD):

- Mainly has been about calorimeters.
- 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

This will have implications on the tracker! What is the prize to pay in tracker - and ultimately physics - performance !?

For more details: https://agenda.linearcollider.org/event/6557/session/10/contribution/22/material/slides/0.pdf

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Effects of Tracking geometry

Reminder:

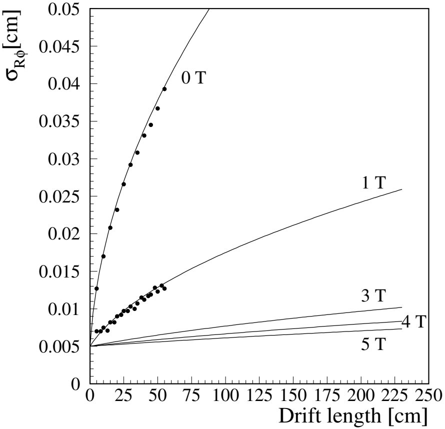
- $\Delta(1/p_T) \propto L^{-2.5}$ (2 purely geometric + ($\geq$) 0.5 because of less points in TPC).
  - But only linear in σ_{point} and B-field
- Please note: Stored energy in B-field $\propto B^2 V$, so at equal stored energy, a smaller detector can have a higher field.
- Also: $\sigma^2_{point,TPC}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

The tool for the study: SGV fast simulation

SGV is a machine to calculate tracking covariance matrices (and simulate events accordingly, if requested).

Example of detail: 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 ⇒
- 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.
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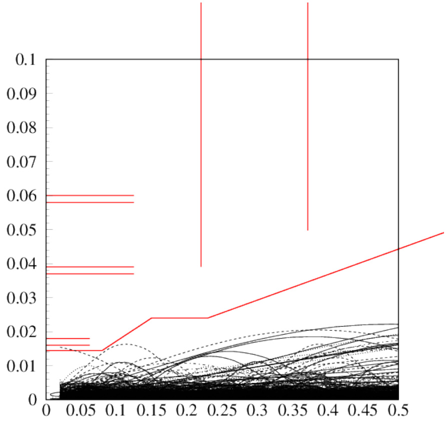

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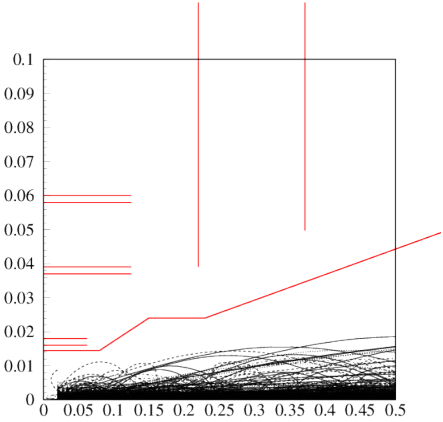

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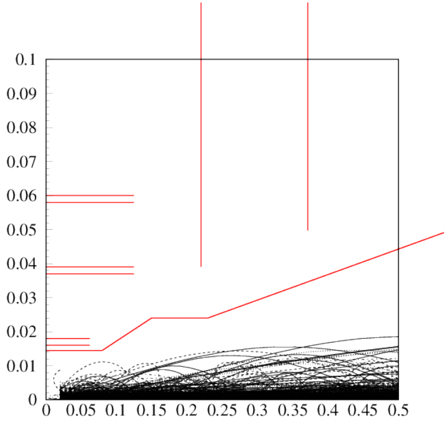

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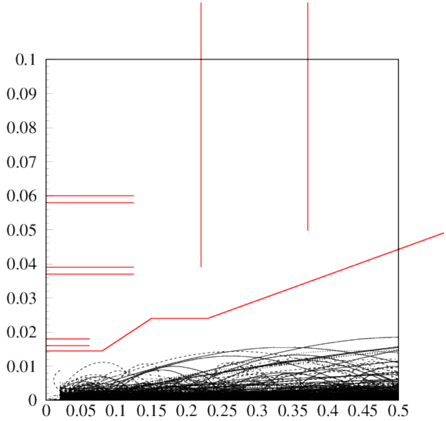

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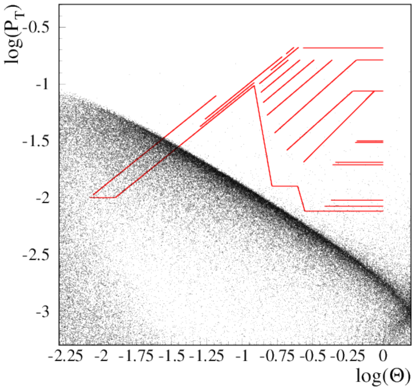

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⇒ Reduce $R_{VTX-inner}$ in proportion to B ⇒ better σ_{ip}.

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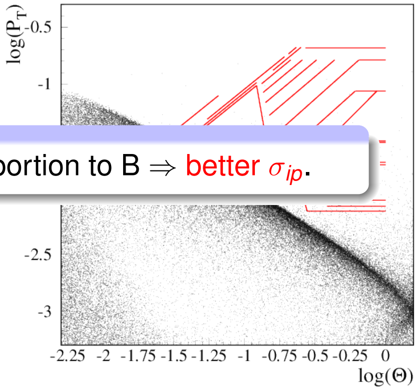

Geometries used

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

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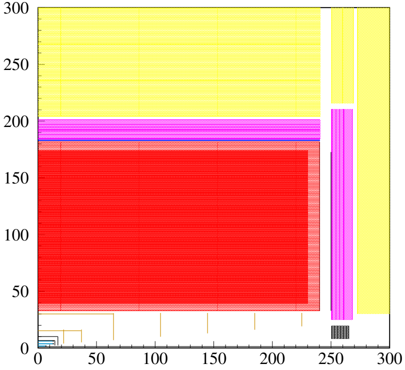

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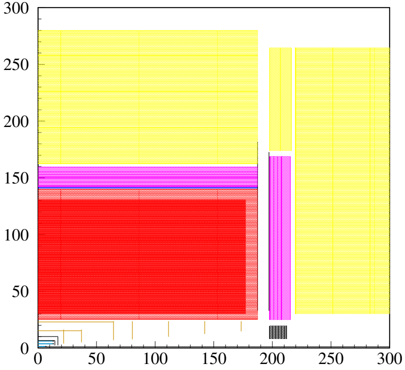

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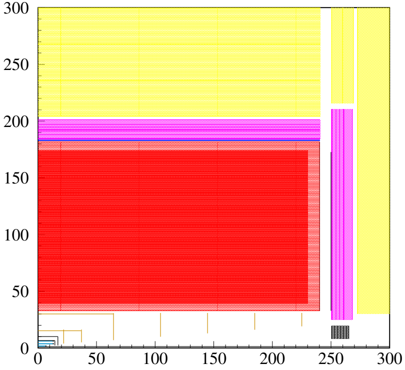

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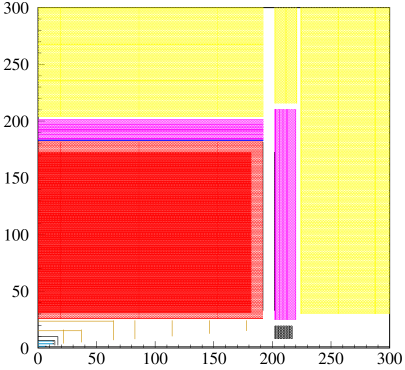

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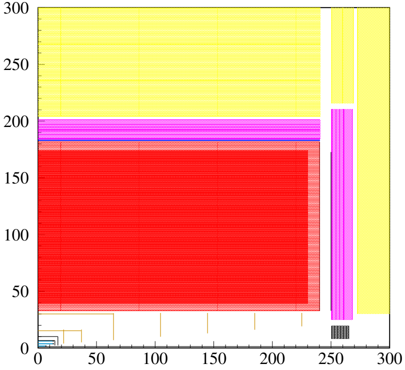

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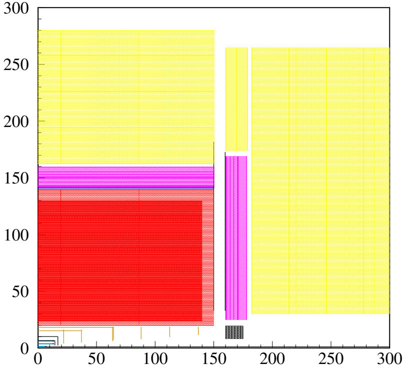

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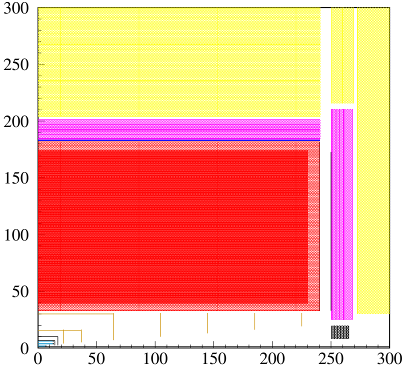

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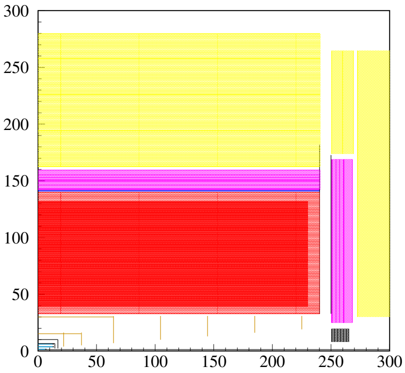

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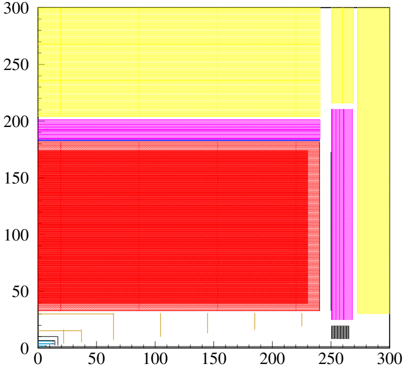

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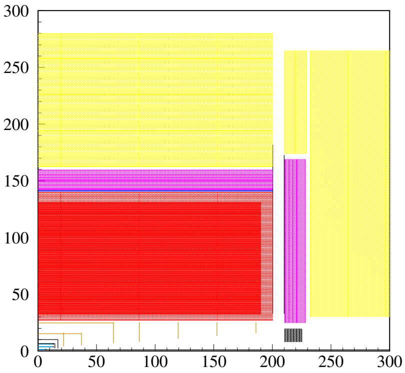

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Other options

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.
6. Scale B and beam-pipe/VTX-inner, but not TPC inner radius.

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In Total:

$2 \times 5 \times 5 \times 6 = 300$ 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 $\cos\theta$
The point of the exercise is to reduce the size (=area) of the calorimeters (in particular ECal). Here I show the performance as a function of $A_{ECal}/A_{ECal,TDR}$

- Circles/triangles: fixed aspect-ratio.
- Squares: fixed R.
- Stars/inv. triangles: fixed Z.
- $\Delta(1/p)$, barrel.
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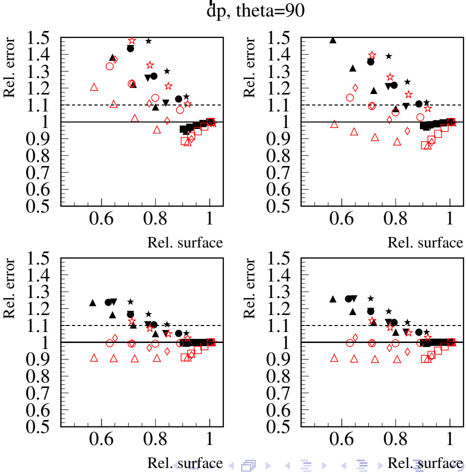

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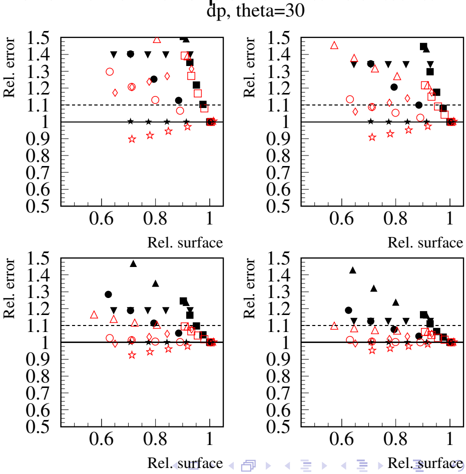

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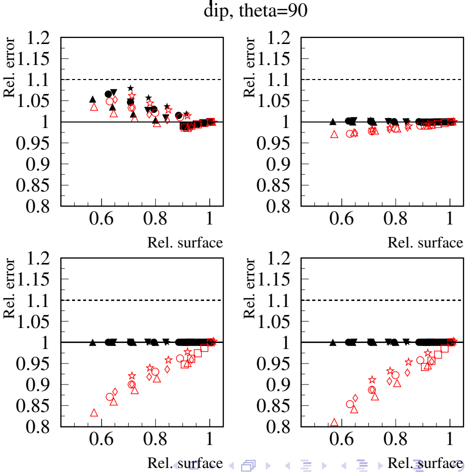

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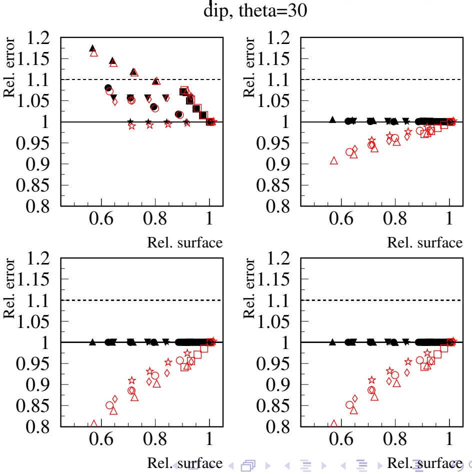

Higgs recoil-mass @ 350 GeV: mesurables

- Look at $e^+e^- \rightarrow ZH$, $Z \rightarrow \mu^+\mu^-$, $H \rightarrow X$.
- 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.
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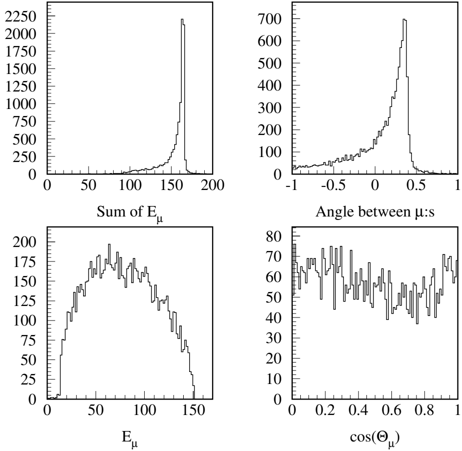

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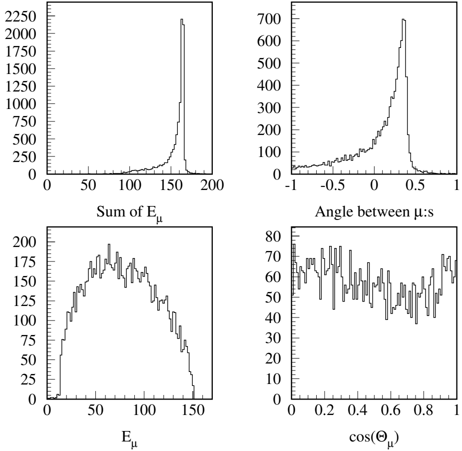
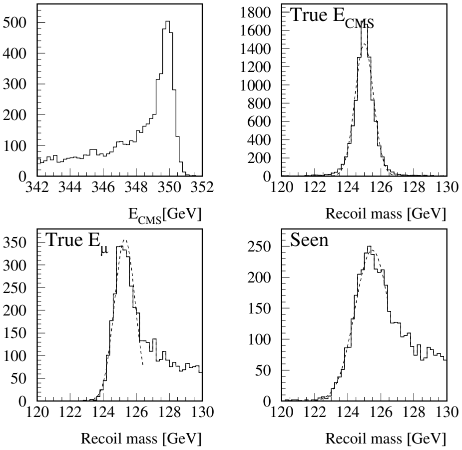


Higgs recoil-mass @ 350 GeV: The recoil mass

- $E_{CMS} \neq$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

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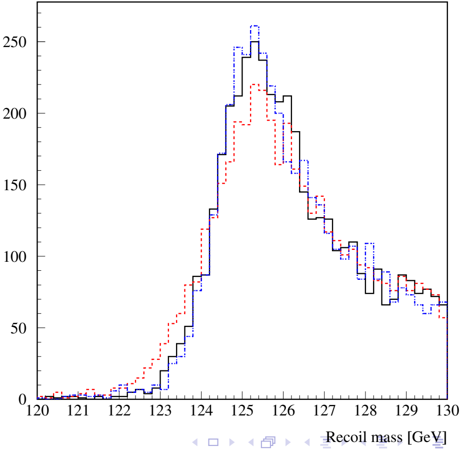

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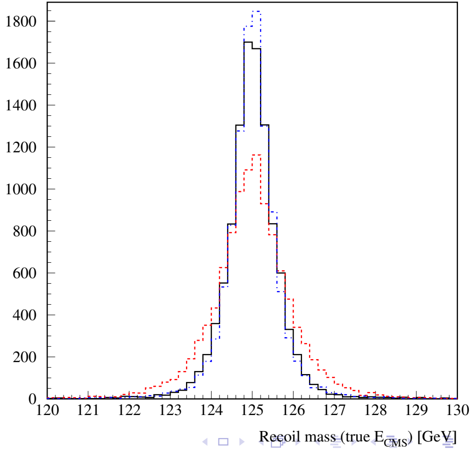
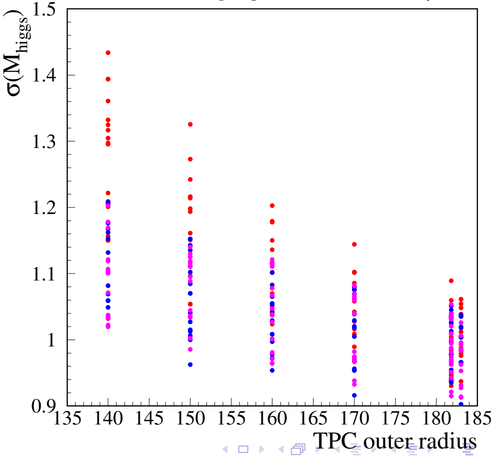


Higgs recoil-mass @ 350 GeV: fits with different options

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 all options vs. TPC radius.
- $\sigma_{M-recoil}$ for a representative set of options. Baseline B=3.5(4) T for filled (open) circles.



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)

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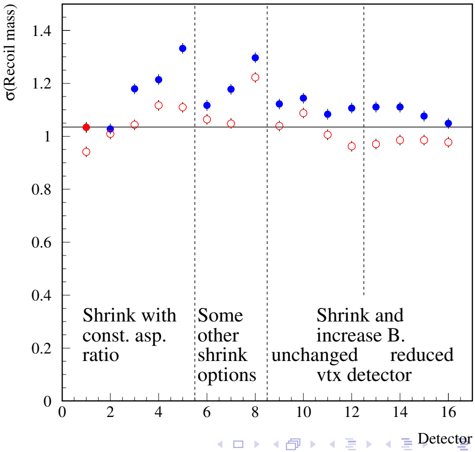

Physics: b-tagging

$e^+e^- \rightarrow Zh \rightarrow \mu\mu h$ is fine but ..

- Mostly sensitive to barell tracks at high *p*.
- Doesn't care about impact-parameters.

So need something where ...

- Performance at low angles/momenta matters
- Impact-parameters matters.

$\Rightarrow$ b-tagging for $e^+e^- \rightarrow Z \rightarrow q\bar{q}$ @ 500 GeV, no ISR

- Use simple method based on impact-parameters and primary vertex probability only.
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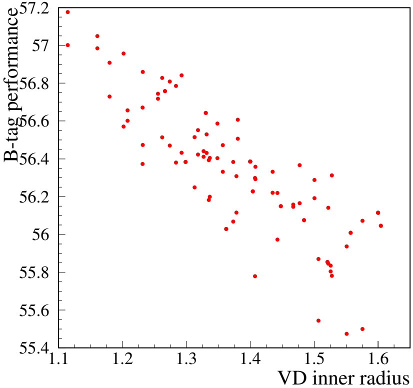
- $S/\sqrt{S+B}$ depends on radius of inner layer of the VD.
- Which in turn depends on the possibility to increase the B-field for a smaller detector.



Metrics

Performance:

- Use two metrics:
  - Get score (1-300) in each of the properties (39 of them) for each geometry.
  - Calculate weighted sum of the relative difference wrt DBD of all properties.
    - Higher for physics (Higgs mass, b-tagging), zero for ip's at 10 degrees, lower for 250 GeV track-properties ....
  - Only changing size ...
  - Mitigation, except radius of VD...
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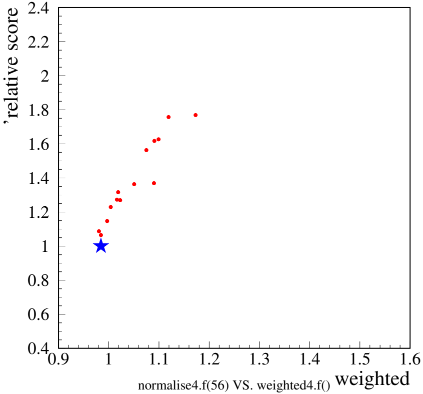

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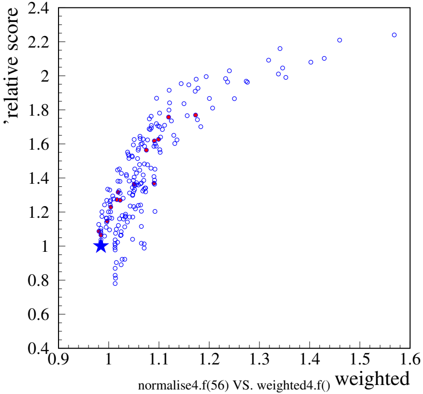

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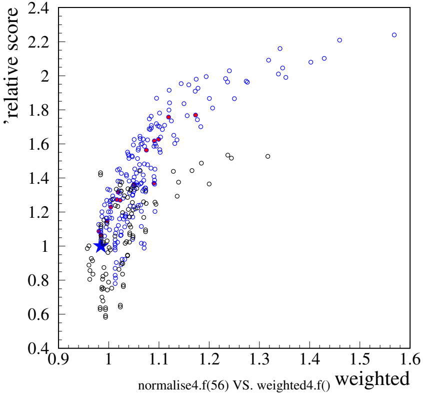
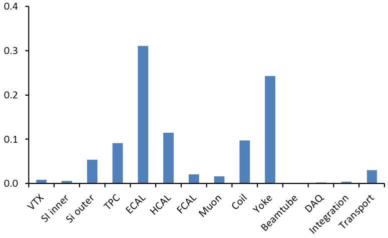


Metrics

Savings

- Take cost-profile in DBD.
- For calorimeters: 90 % is sensors ($\propto$ Area), 10 % is absorber ($\propto$ Volume)
- For SET: 100 % sensors ($\propto$ Area)
- For TPC: Assume 100 % is area of end-plates.
- For Yoke: Scales with Volume - volume restricted by keeping the same flux.
- Master formula vs TPC radius.



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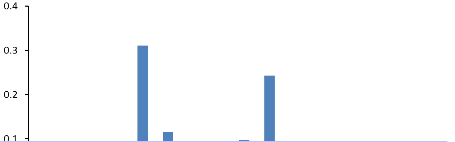

Master formula:

$$\mathrm{AreaRatio}_{TPC} \times 0.08 + \mathrm{AreaRatio}_{Ecal} \times 0.3 \times 0.9 + \mathrm{VolumeRatio}_{Ecal} \times 0.3 \times 0.1 + \mathrm{AreaRatio}_{Hcal} \times 0.1 \times 0.9 + \mathrm{VolumeRatio}_{Hcal} \times 0.1 \times 0.1 + \mathrm{AreaRatio}_{SET} \times 0.05 + \mathrm{VolumeRatio}_{Yoke} \times 0.25$$

area of end-plates.

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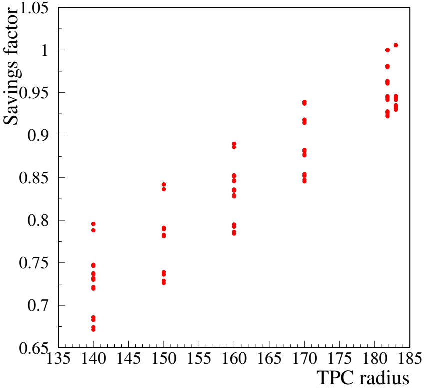
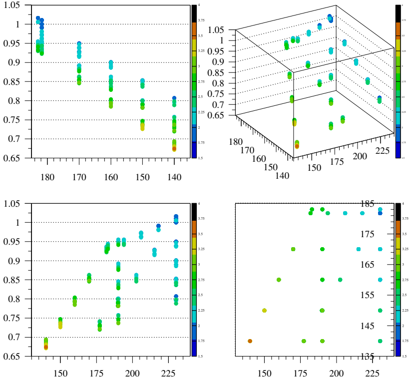


Putting it together

All in a few 4D-plots

- savings vs. size - performance colour-coded (blue is good - red is bad)
- Cut out worst out worst performers ...
- ... and then ...



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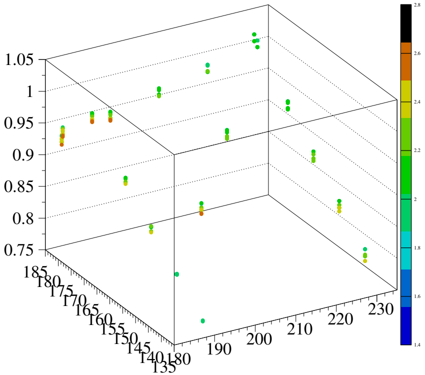

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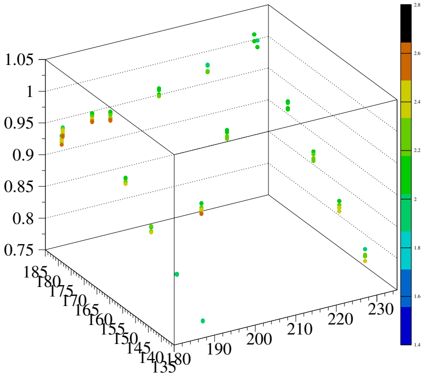
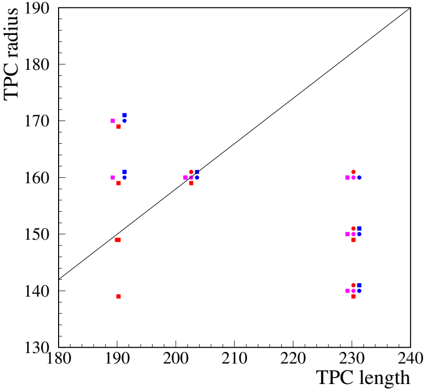


Putting it together

... project on size

- Only at least 10 % savings, best ∼ 5 performances in each of the 6 groups of mitigation strategies.
  - (⇒ different performance cut for different strategies)
- For ∼ all strategies, the same sizes remain.
- ... except the smallest option, which needs all tricks to be a player.
- performance and savings iso-curves.



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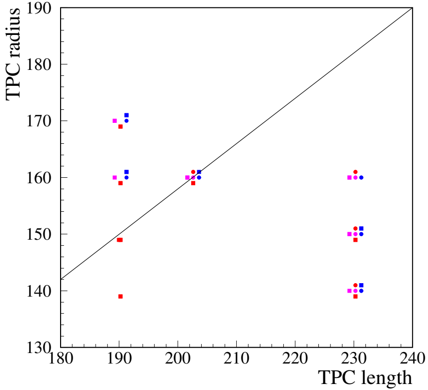

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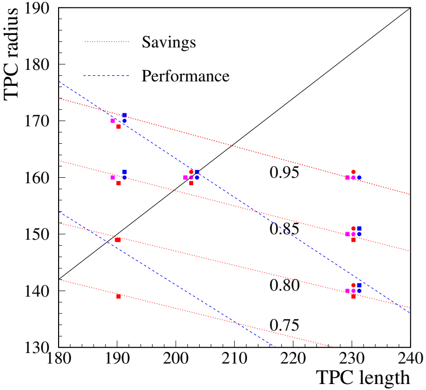

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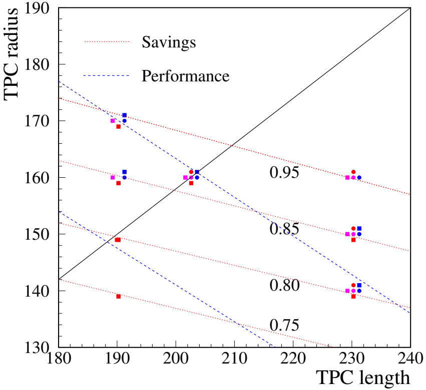
... project on size

- Only at least 10 % savings, best ~ 5 performances in each of the 6 groups of mitigation strategies.
  - (⇒ different performance cut for different strategies)
- For ~ all strategies, the same sizes remain.
- ... except the smallest option, which needs all tricks to be a player.
- performance and savings iso-curves. We want to be at the right edge !



Recommendations

- For all assumptions on how to mitigate the effects of a smaller detector the three cases 160-230, 160-200 and 140-230 covers the region with good cost/performance, and spans the interesting region well.
- With full mitigation, 2 of the points performs better than the DBD detector, but not as well as the DBD detector with 4 T.
- To see if full mitigation is possible, paramount to study:
  - Can the DBD solenoid deliver 4T ?
  - And can a smaller solenoid deliver even more, if the stored energy is kept constant ?
  - Can the the VD inner radius be reduced with higher B field, and how much? (NB: SiD says Yes.)
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The suggested points in detail, with performance under different schemes:

option option	$R_{Outer, TPC}$	$Z_{max, TPC}$	$R_{Inner, TPC}$	$R_{VD-inner}$	B	Savings (= 1 for DBD)	Performance (=2 for DBD)
113	160.	230.25	32.9	1.6	3.5	0.886	2.29
113				1.5206	3.6827	0.8898	2.11
113				1.6	4.	0.8965	2.35
113				1.3305	4.2088	0.9008	1.62
23	160.	202.62	28.952	1.6	3.5	0.8469	2.70
23				1.4672	3.8167	0.8528	2.25
23				1.6	4.	0.8562	2.31
23				1.2838	4.362	0.8629	1.87
115	140.	230.25	32.9	1.6	3.5	0.7882	2.46
115				1.4477	3.8682	0.7957	2.10
115				1.6	4.	0.7984	2.30
115				1.2667	4.4208	0.8069	2.10
DBD	181.8	230.25	32.9	1.6	4	1.0105	1.79
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As usual:

There's No free lunch !

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 and the b-tagging performance was evaluated with with SGV.
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Recommendations

- Three best points (TPC radius/length): 160/230, 160/200, 140/230
- With mitigation sometimes better performance than DBD detector can be achieved.
- However: The DBD detector **geometry** always performs better.

savings.