Overall ILD dimensions and the ILD tracker

Mikael Berggren[1]

[1]DESY, Hamburg

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Outline

1. Introduction
2. Effects of Tracking geometry
3. Geometry used
4. Particle level: helix parameters
5. Physics
   - Higgs recoil-mass @ 350 GeV
   - b-tagging
6. Metrics
7. Results & Recommendations
8. Conclusions

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: $\sigma^2_{point,TPC} = \sigma^2_0(\sin\phi) + \frac{C_d^2(B)}{N_{eff}(\sin\theta)} Z$, $C_d^2(B) \propto 1/(1+(\mu B)^2) \Rightarrow$ 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.

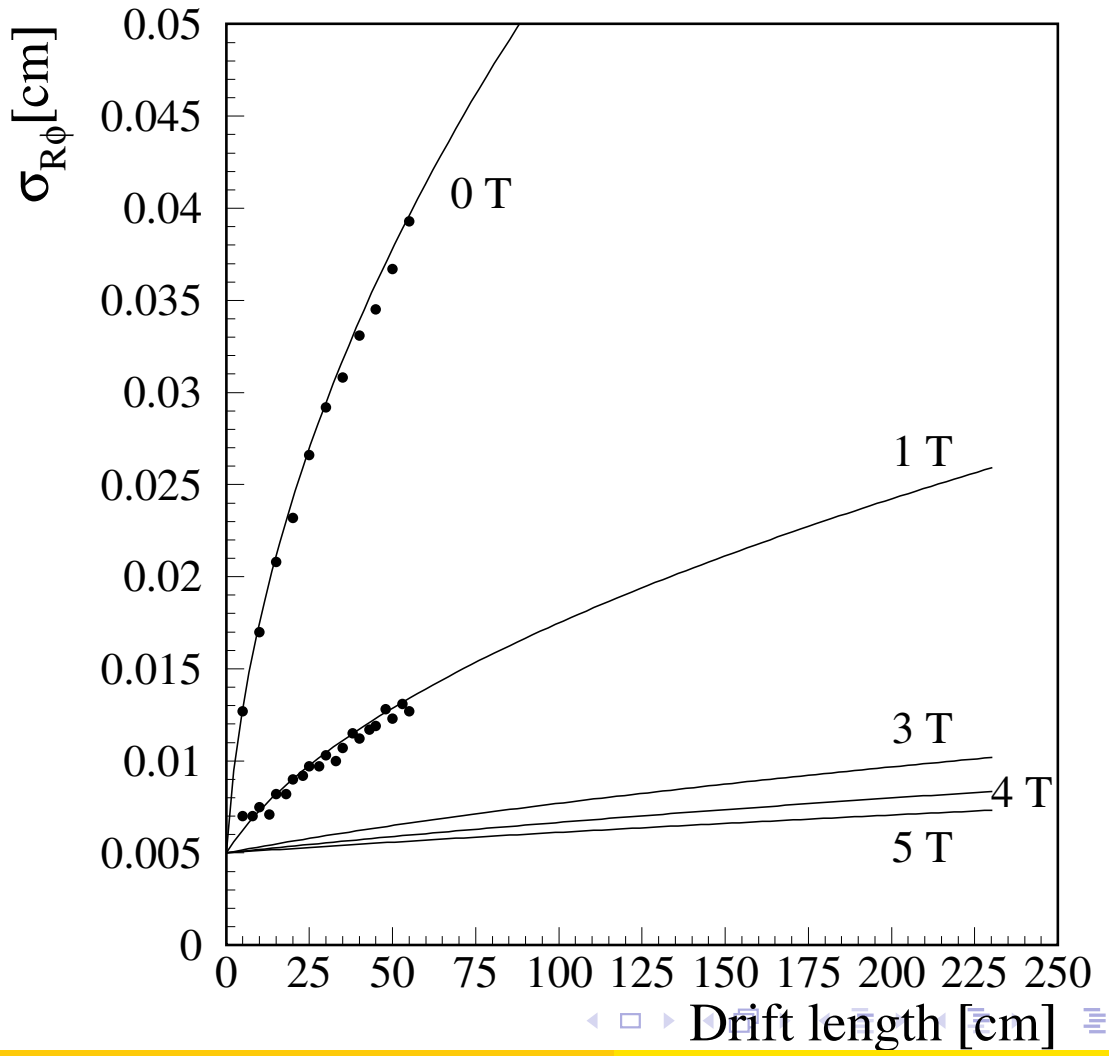
Detailed estimation: SGV

- 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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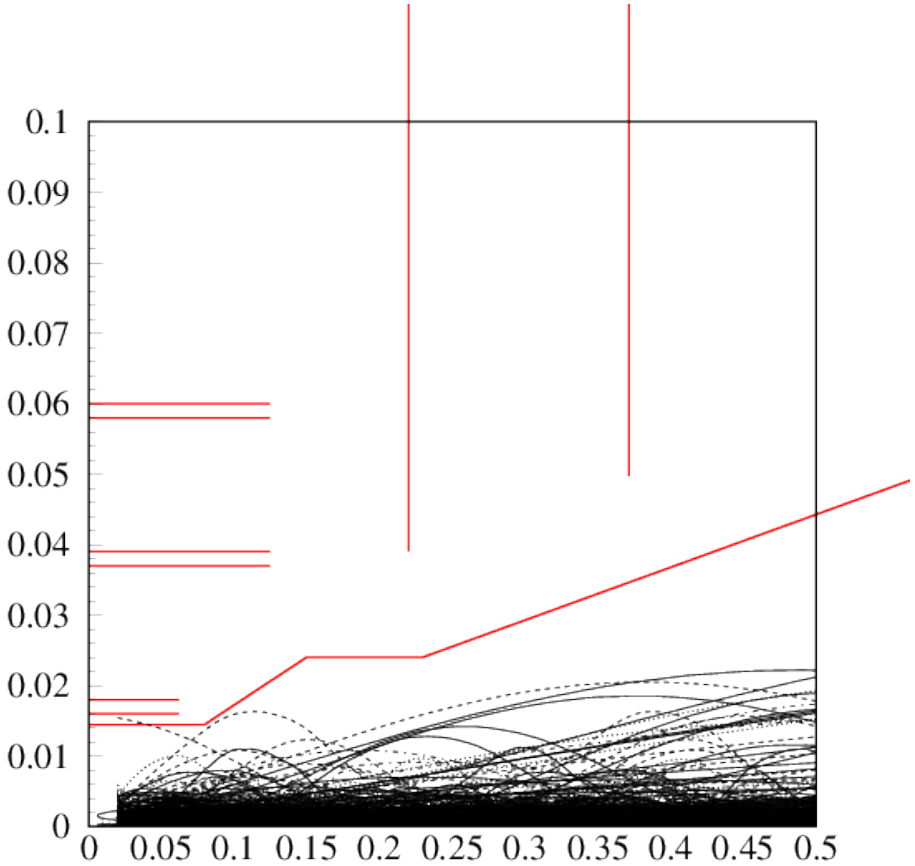

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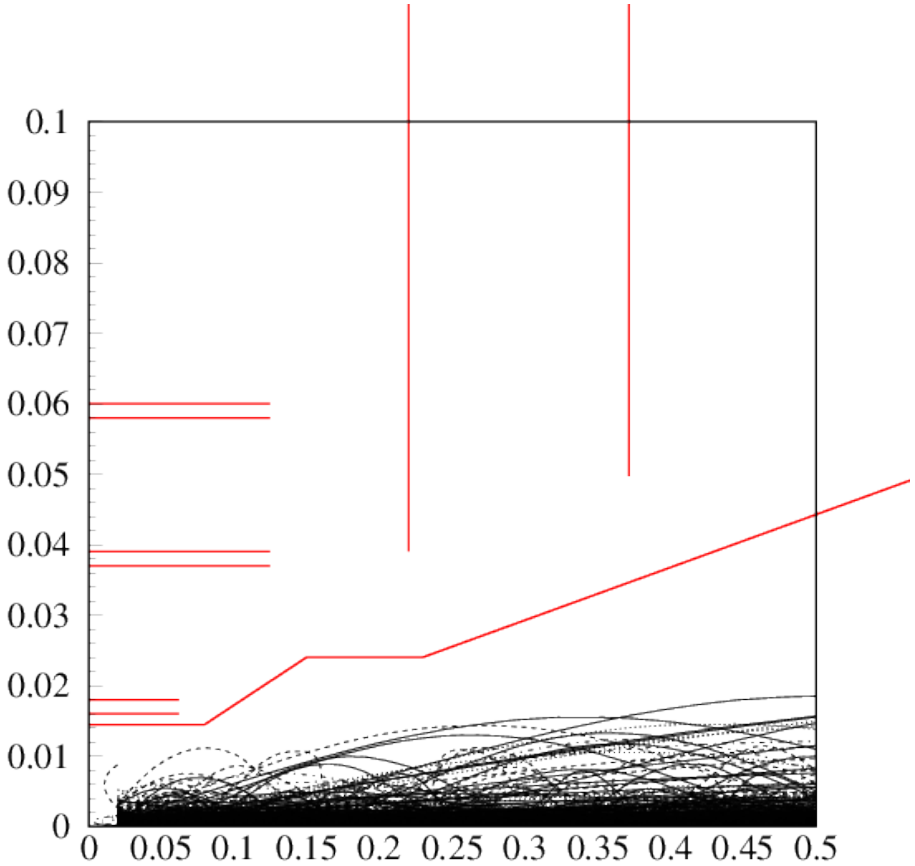

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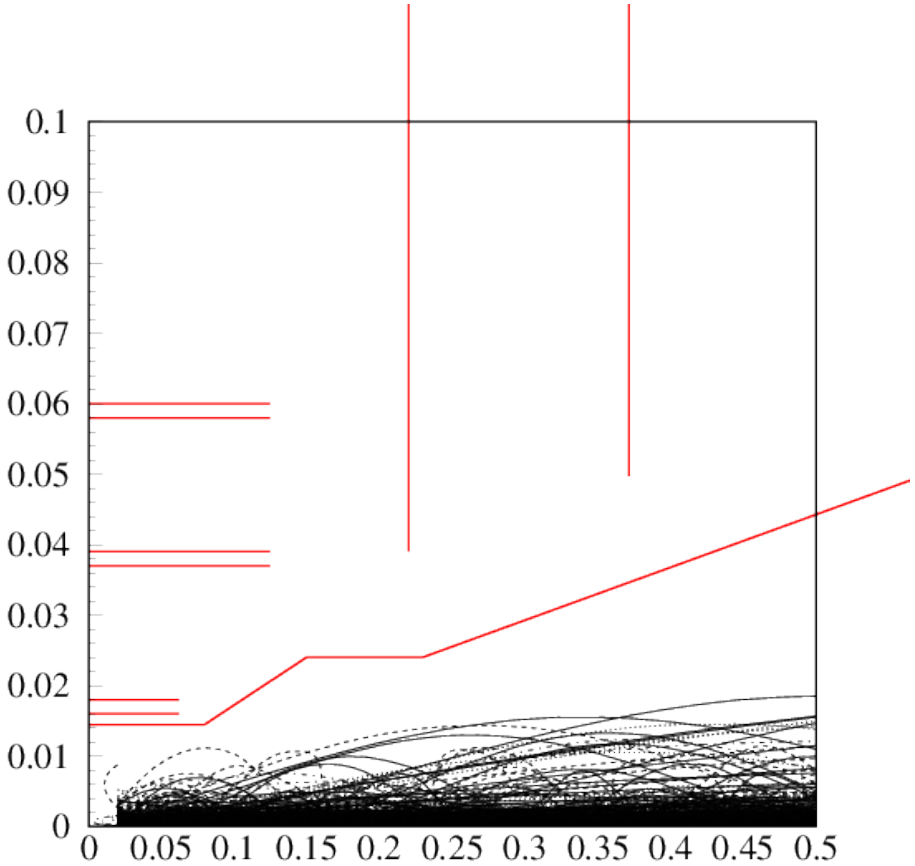

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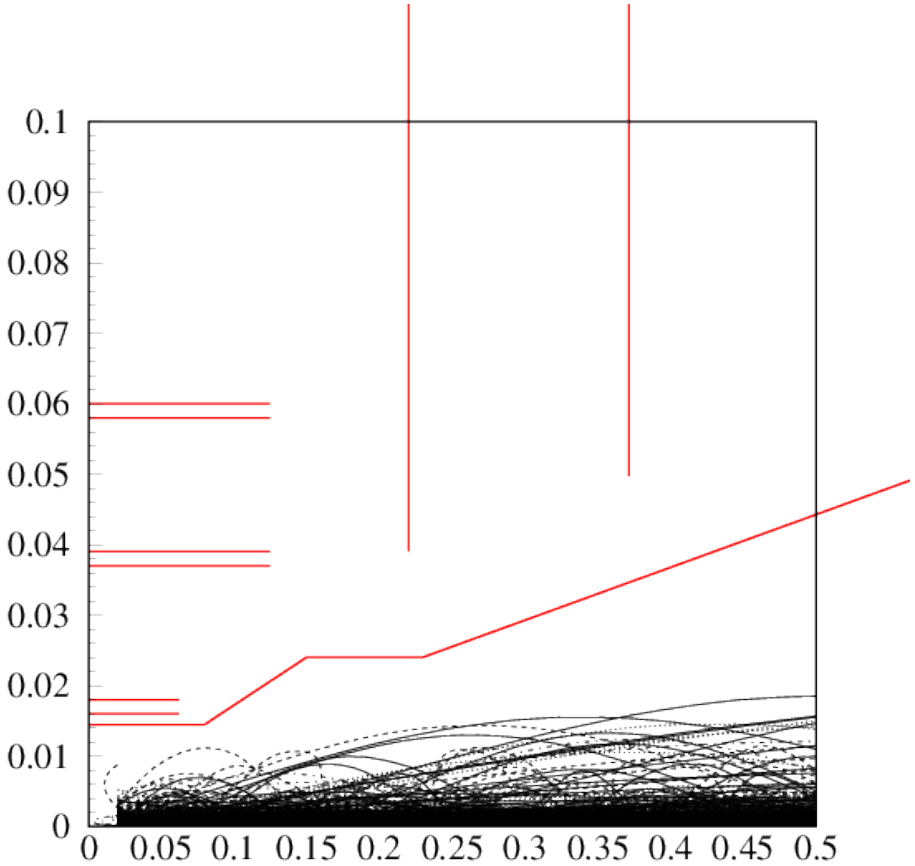

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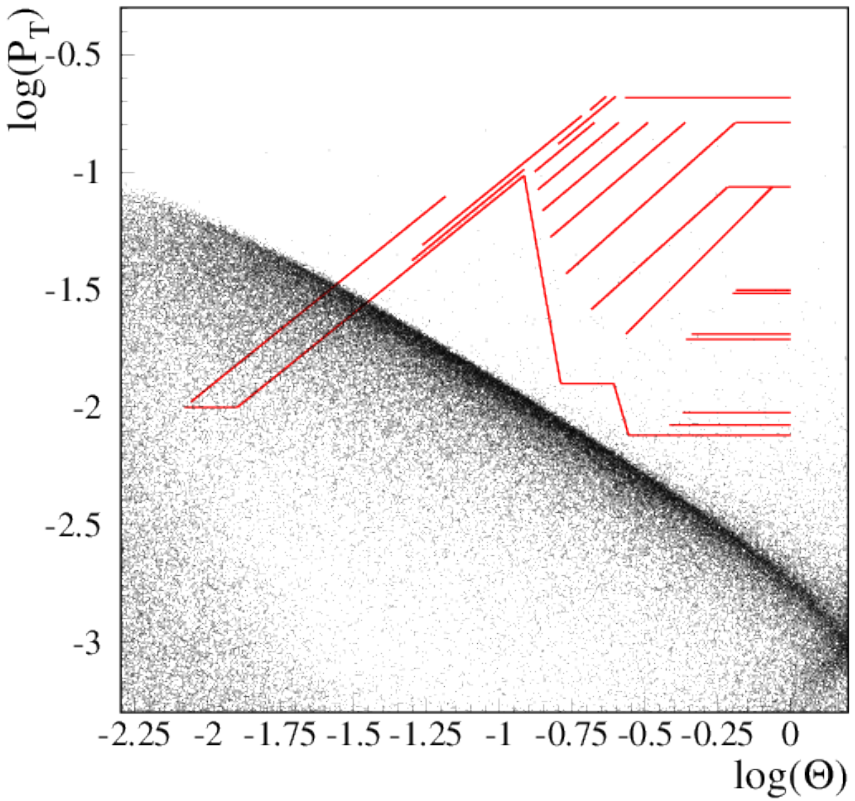

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- Th ⇒ Reduce $R_{VTX-inner}$ in proportion to B ⇒ better σ_{ip}.
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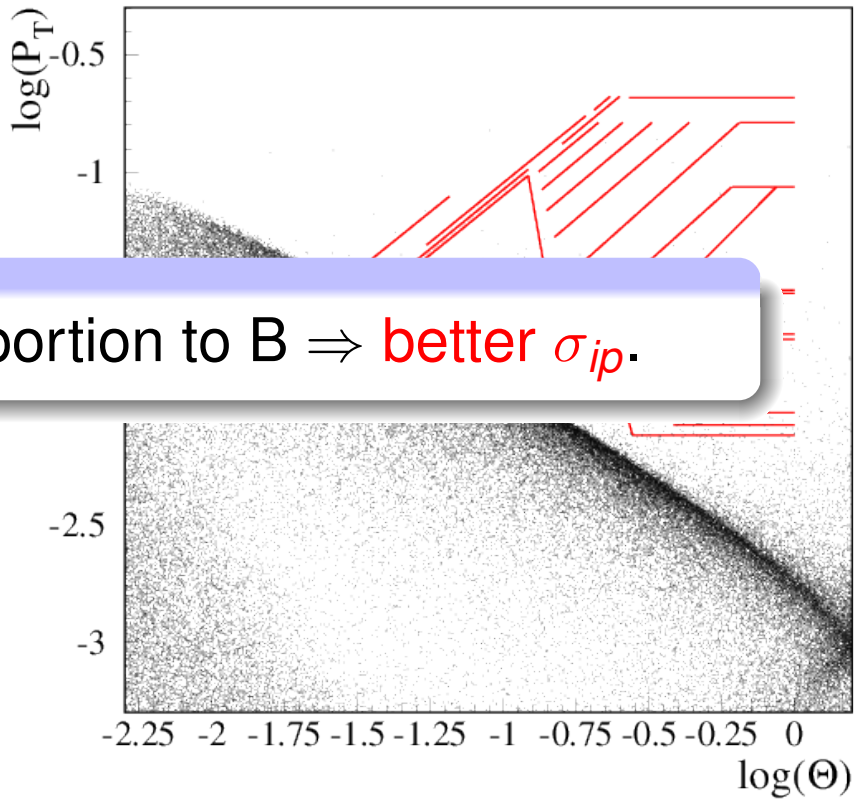

Geometries used

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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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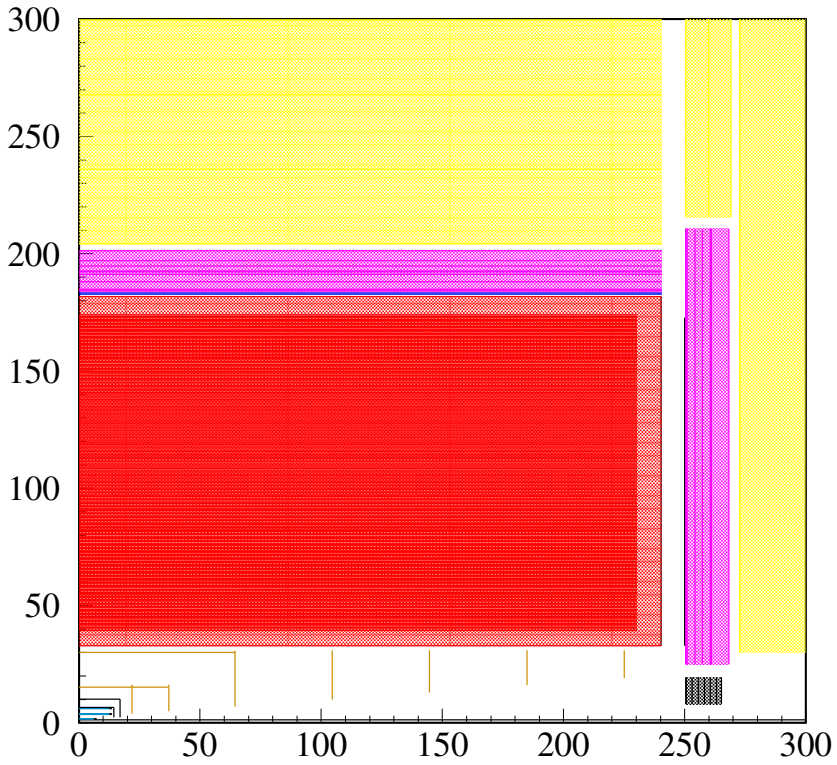

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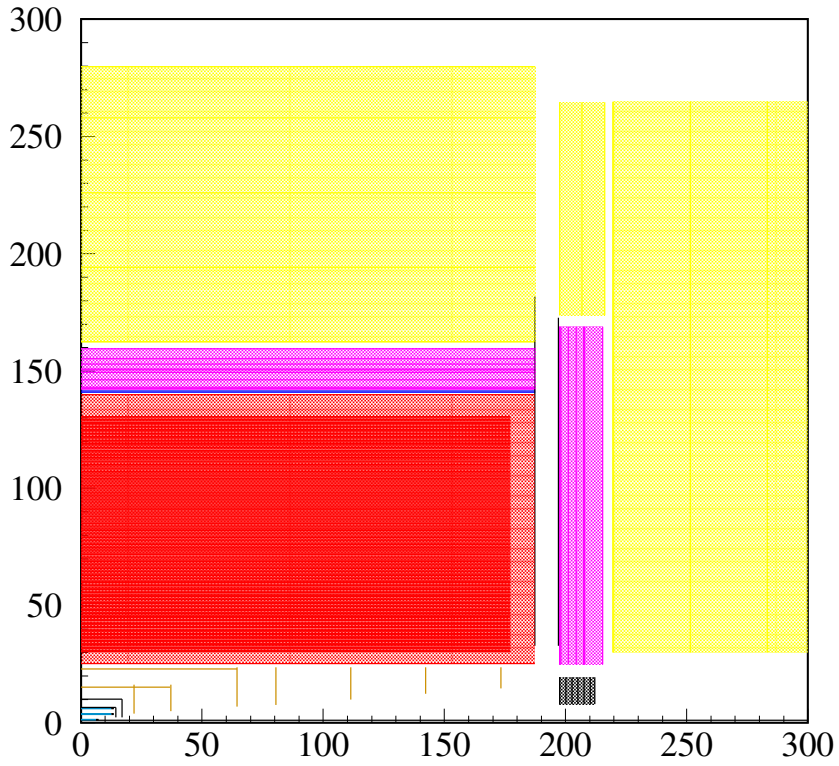

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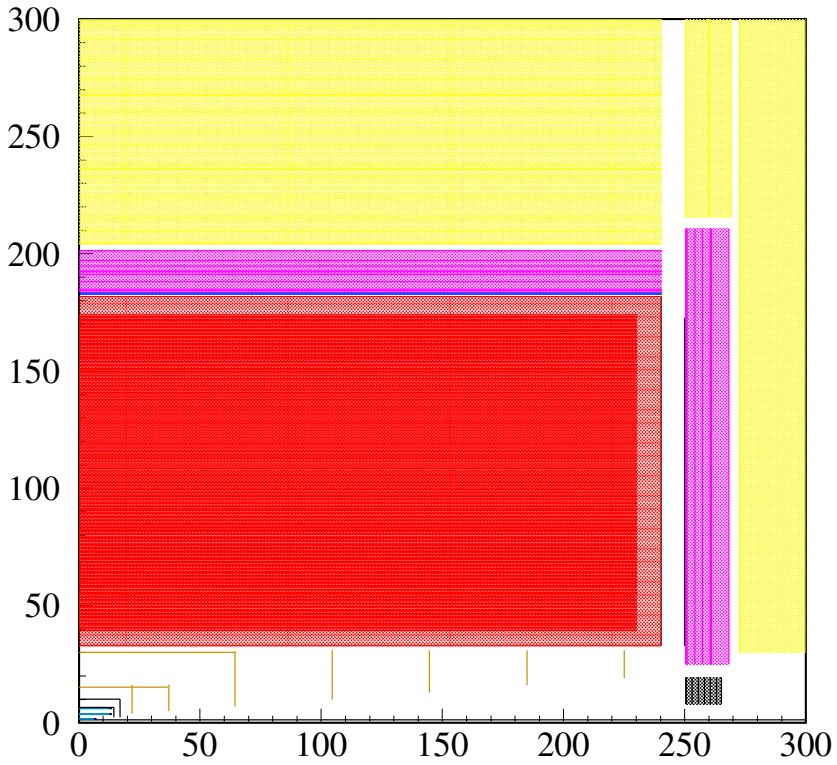

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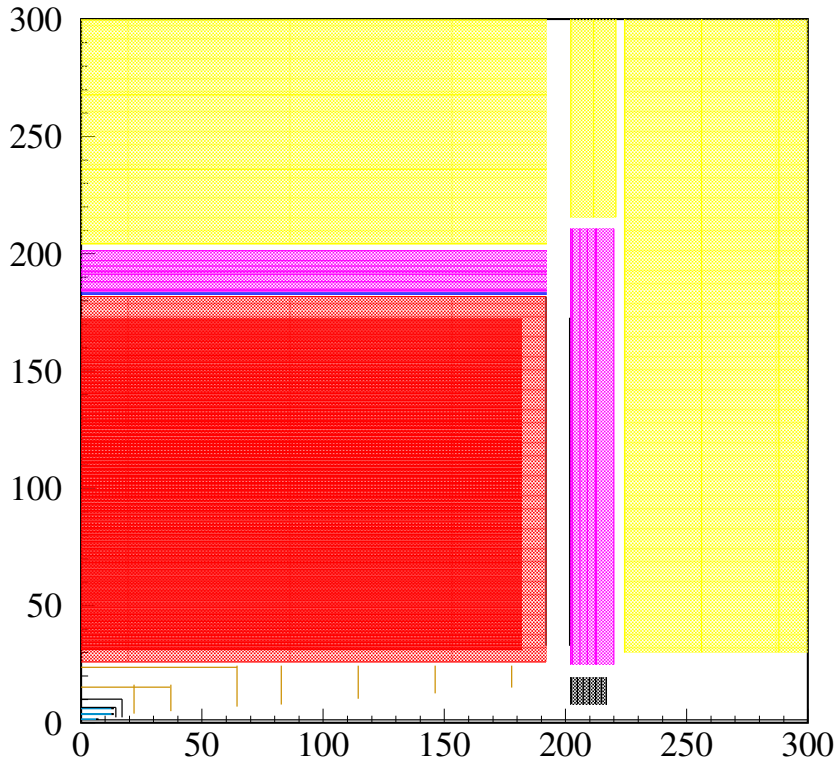

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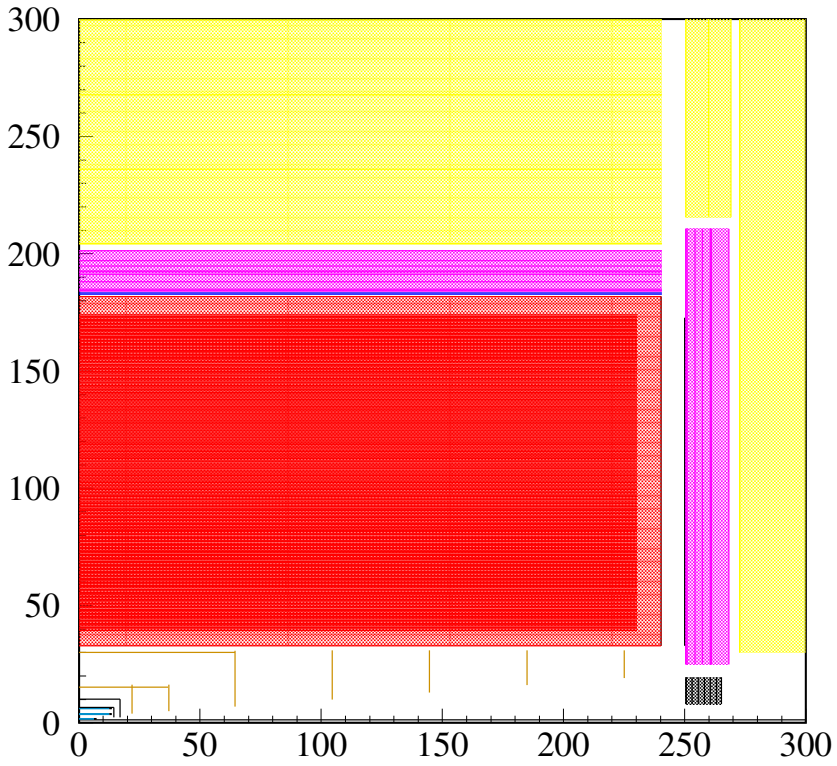

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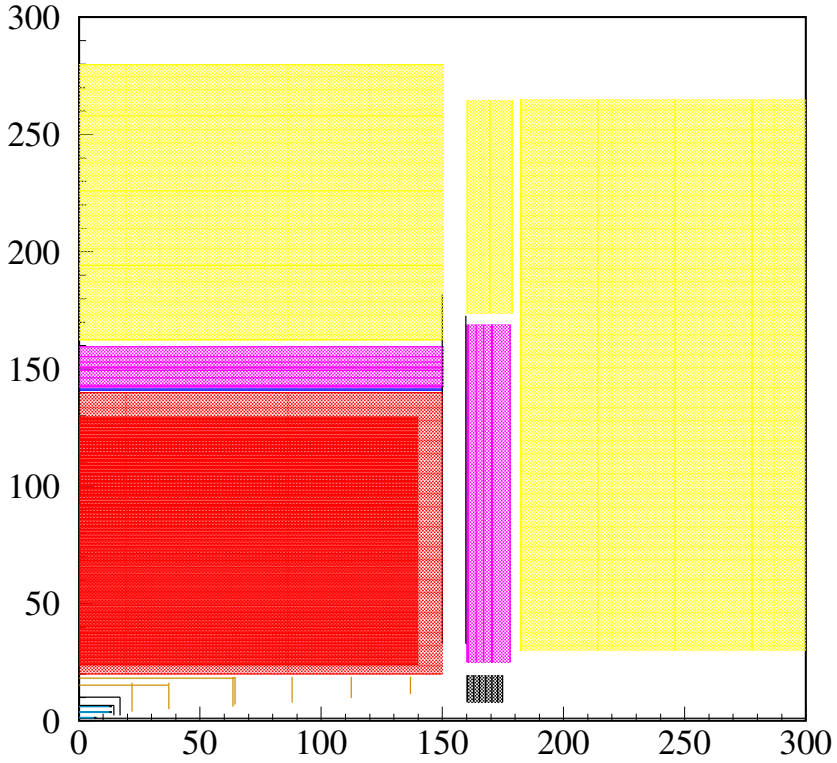

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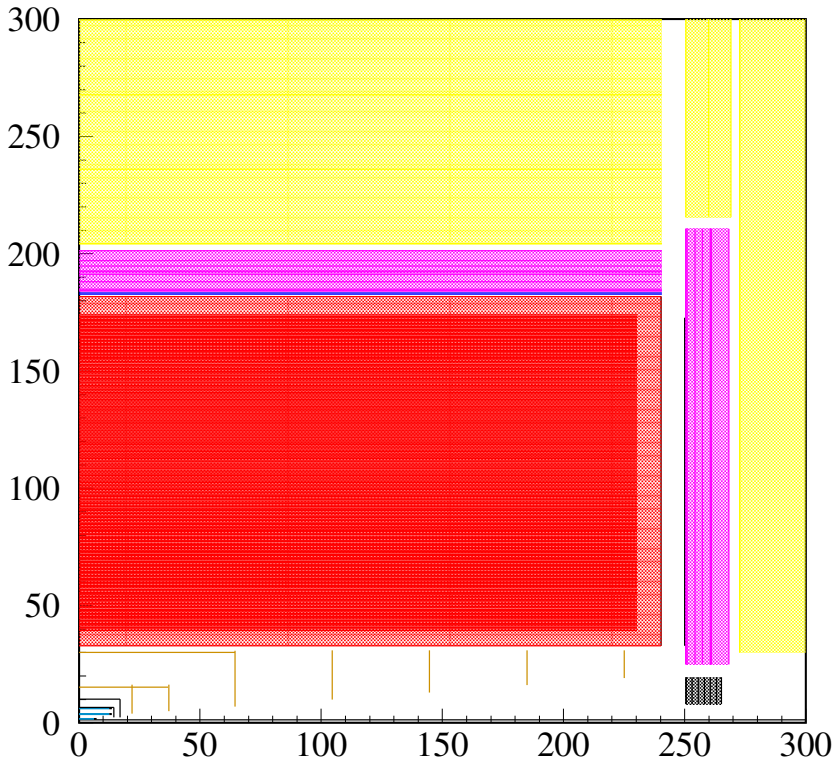

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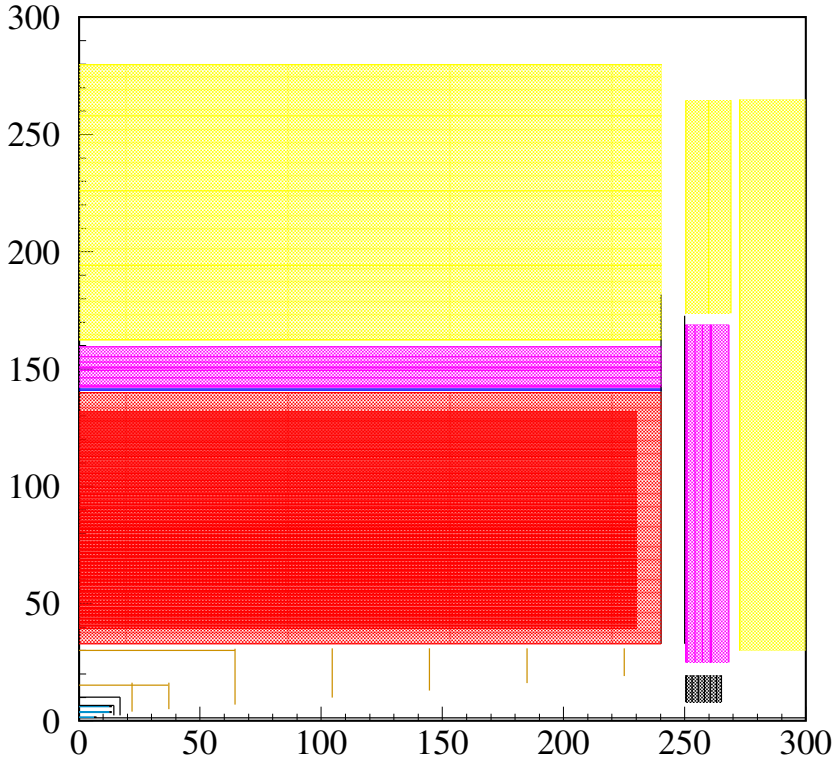

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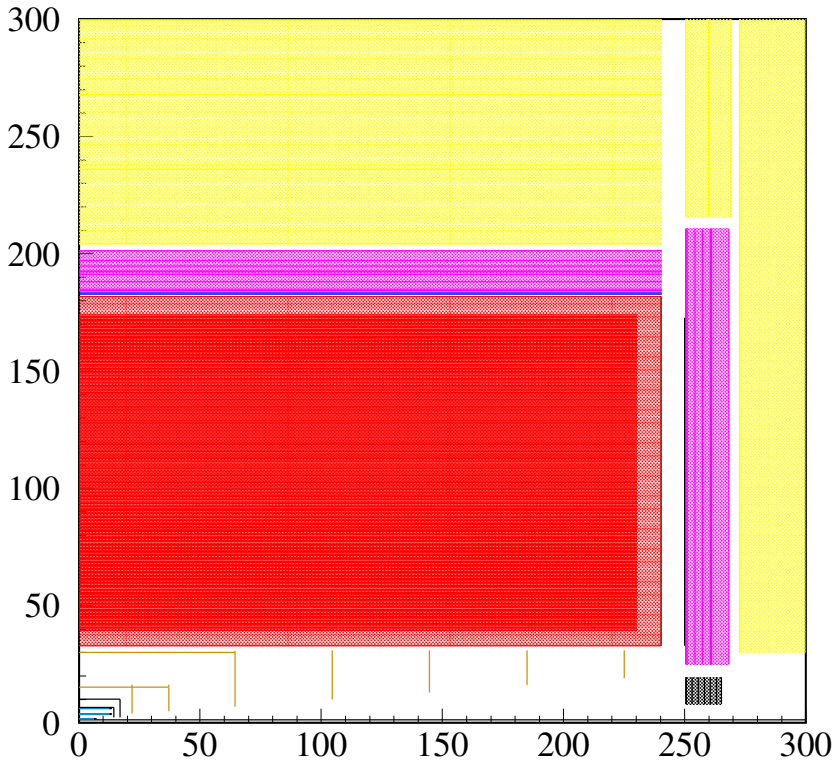

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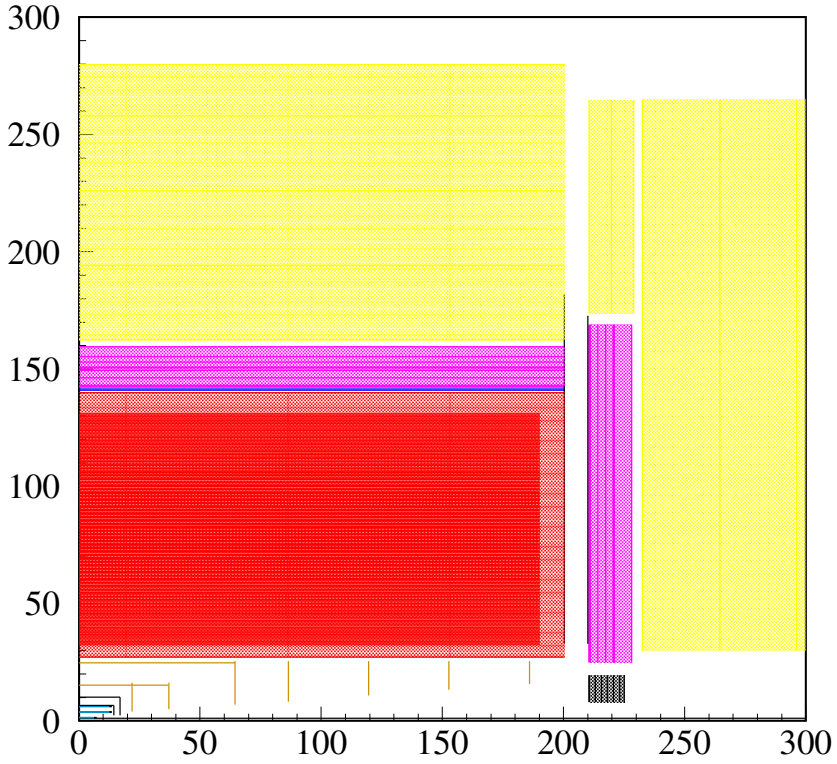

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Other options

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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$2 \times 5 \times 5 \times 6 = 300$ 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.
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- $\Delta(1/p)$ vs. $\cos\theta$
- Rel. $\Delta(1/p)$ vs. $\cos\theta$
- Rel. $\Delta(1/p)$ vs. p

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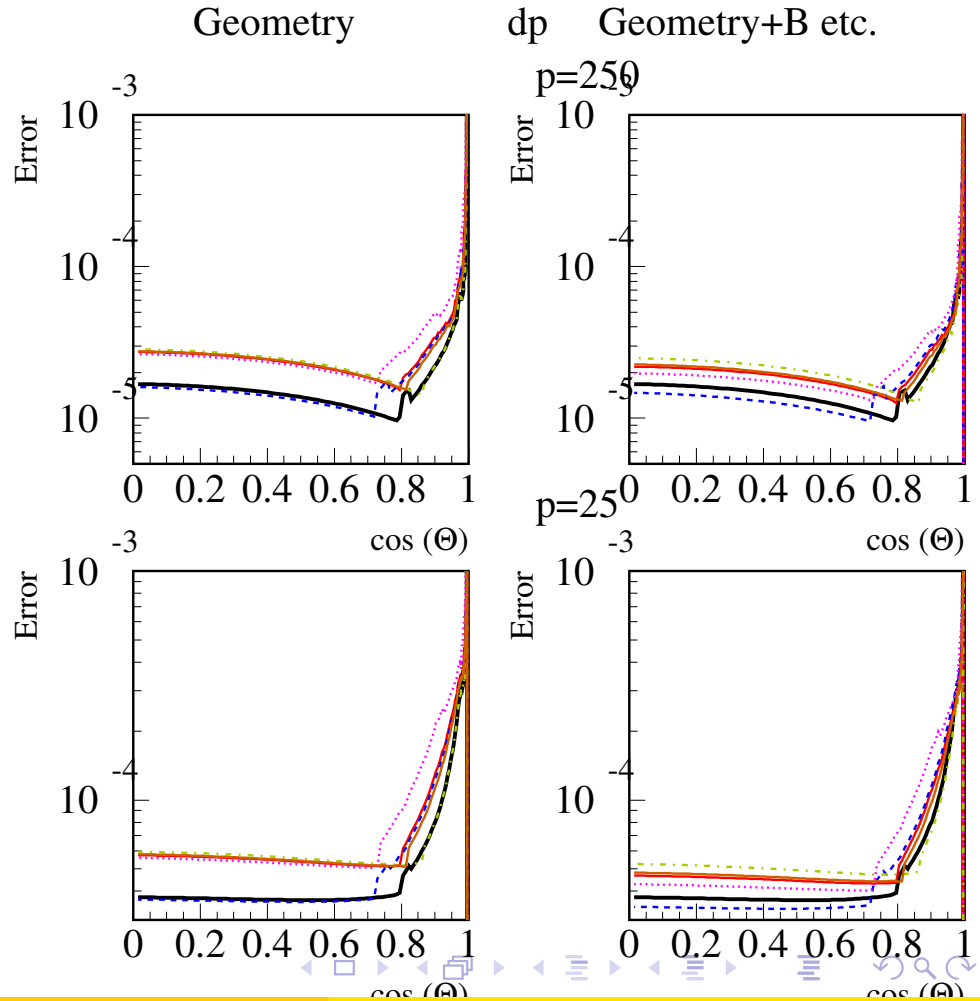

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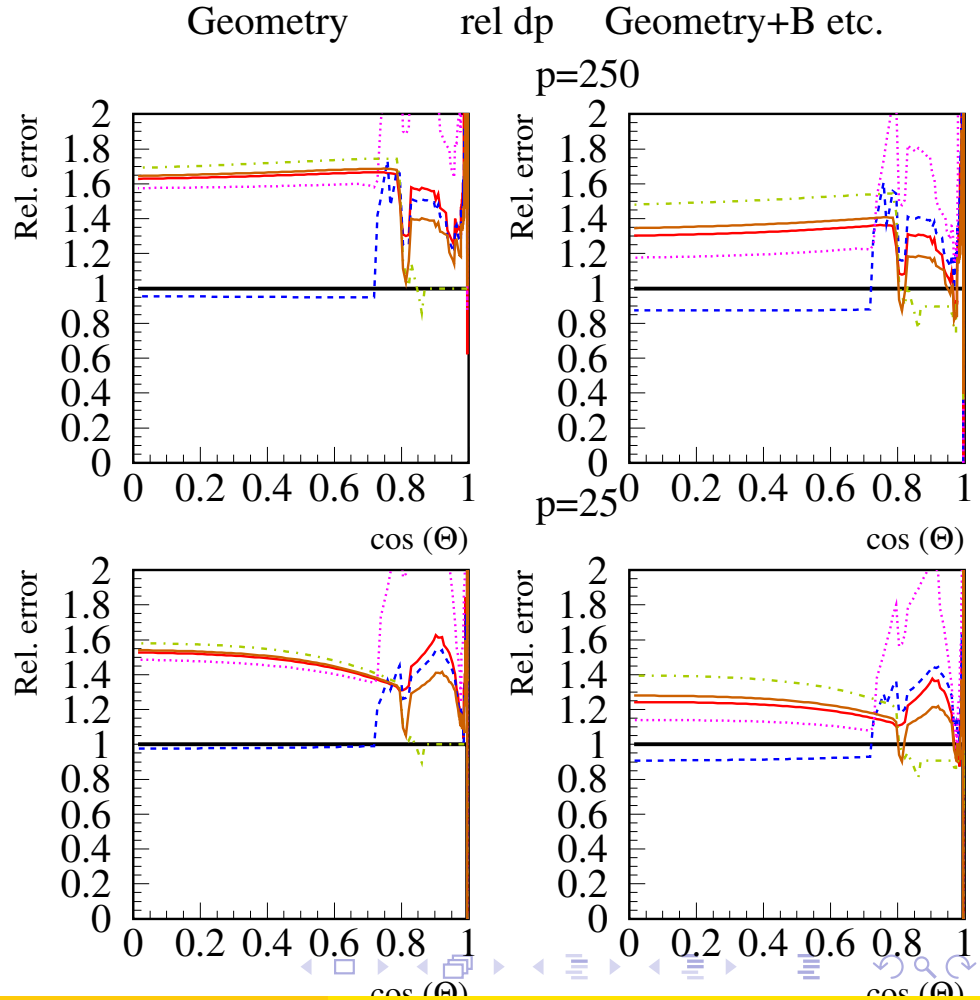

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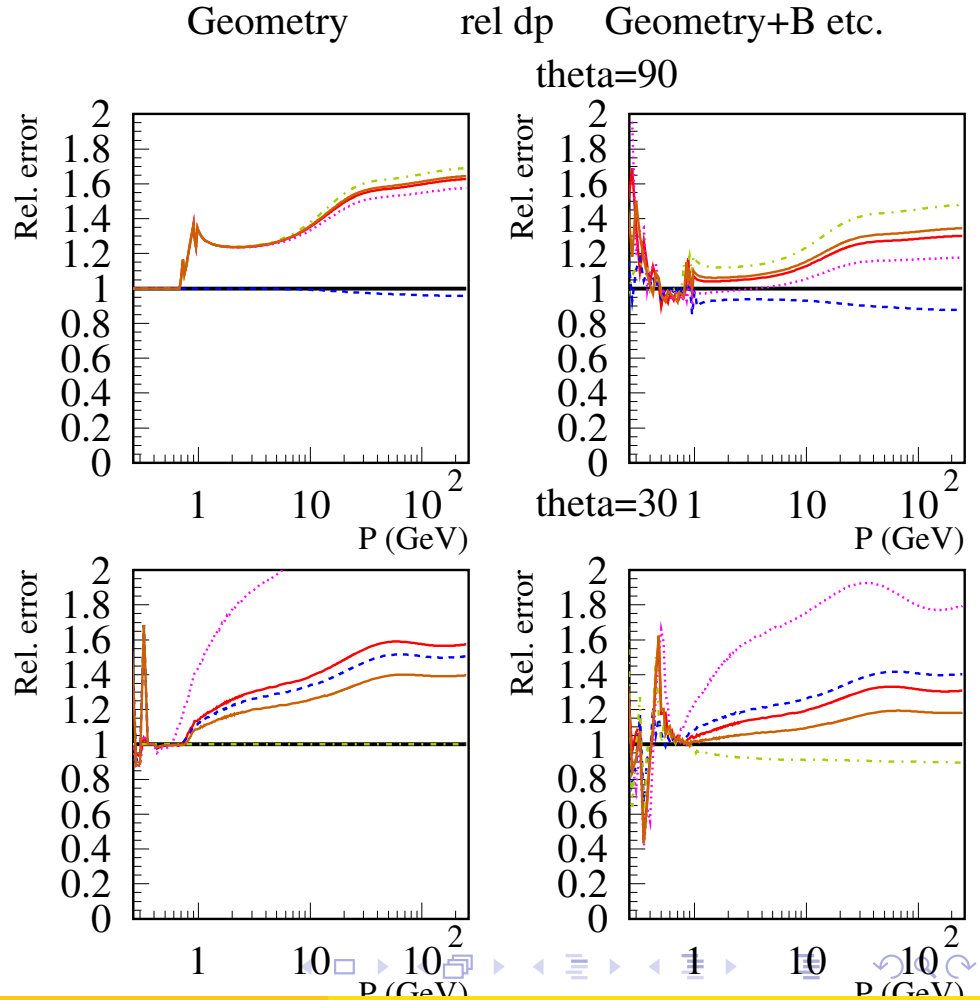

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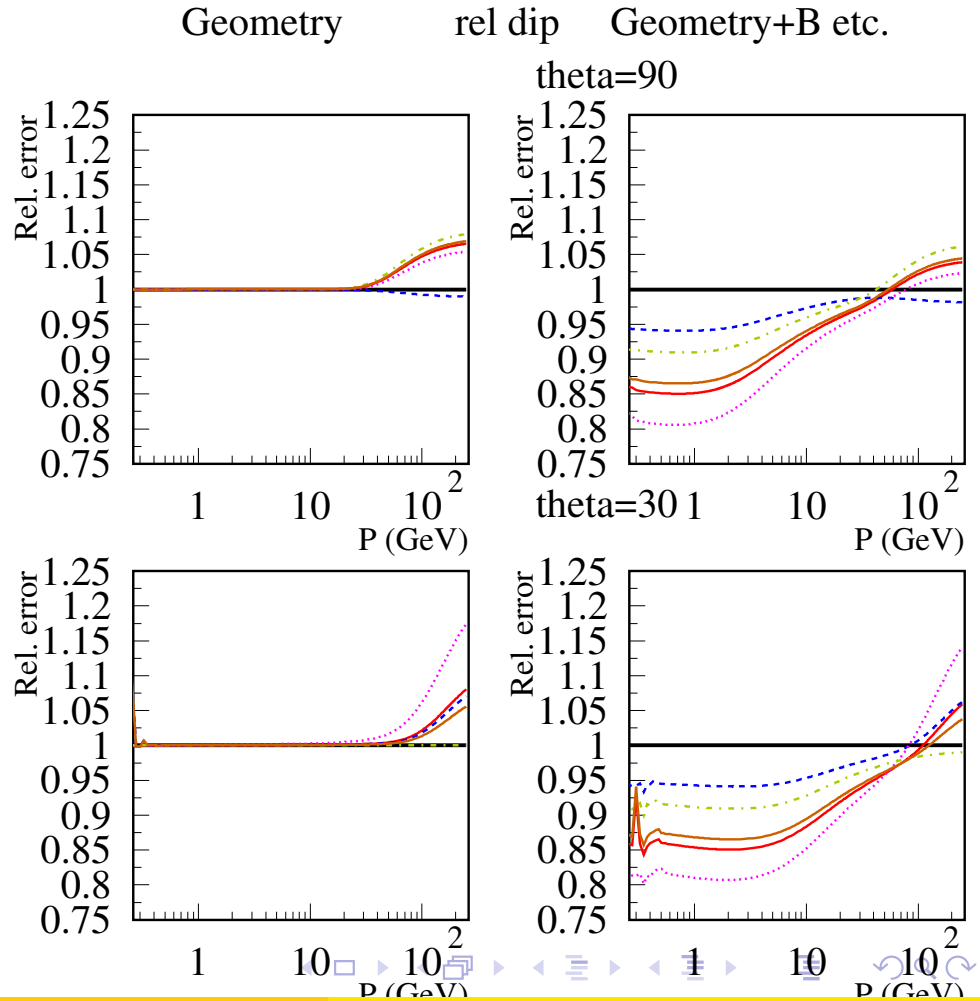
Check $\Delta(1/p)$ and $\Delta(ip_{R\phi})$ at different p and $\cos\theta$ ($\Delta(ip_Z)$ similar to $\Delta(ip_{R\phi})$, angles not relevant - the other uncertainties dominate)

- 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



Effects of Tracking geometry on helix parameters

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.
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- $\Delta(1/p)$, barrel.
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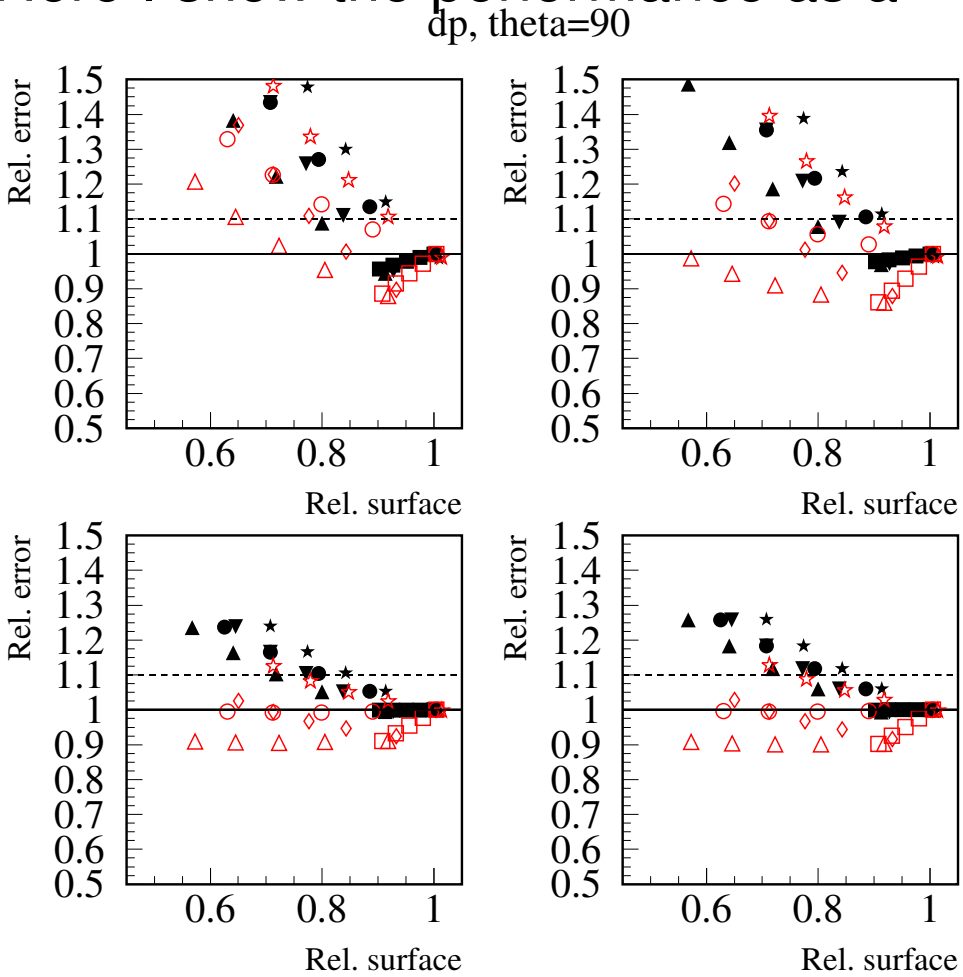

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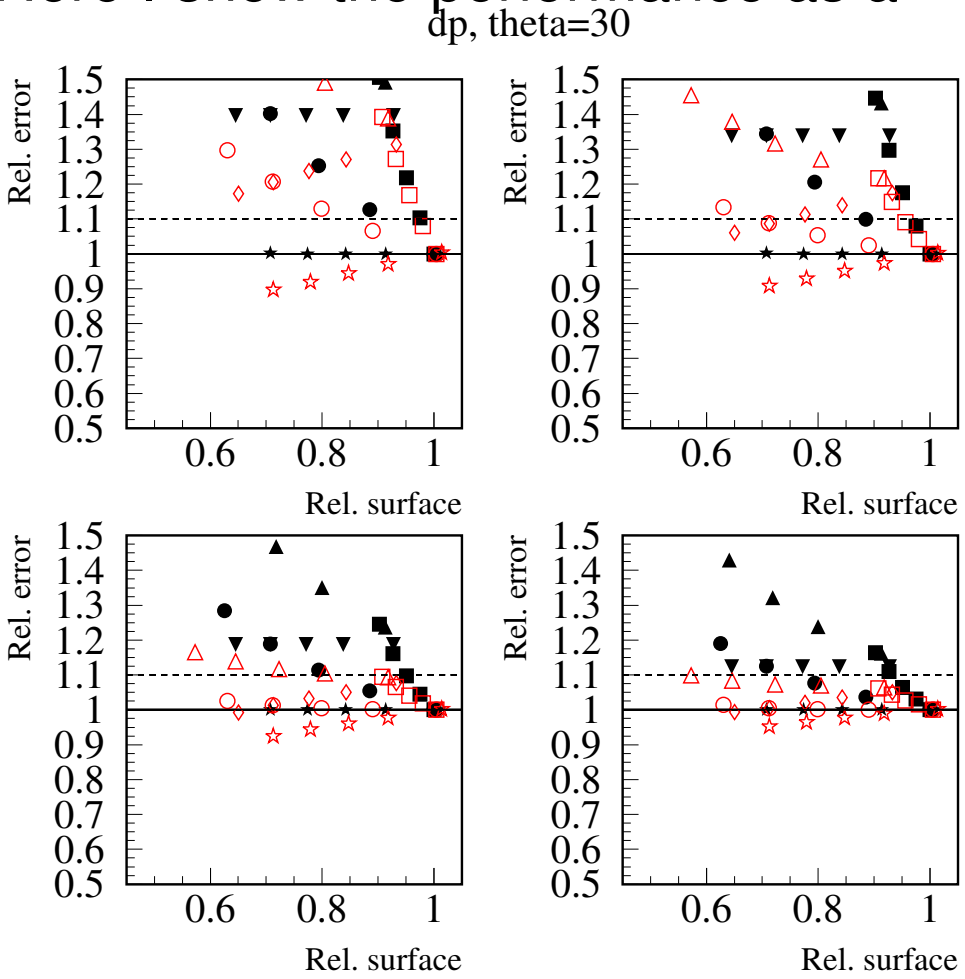

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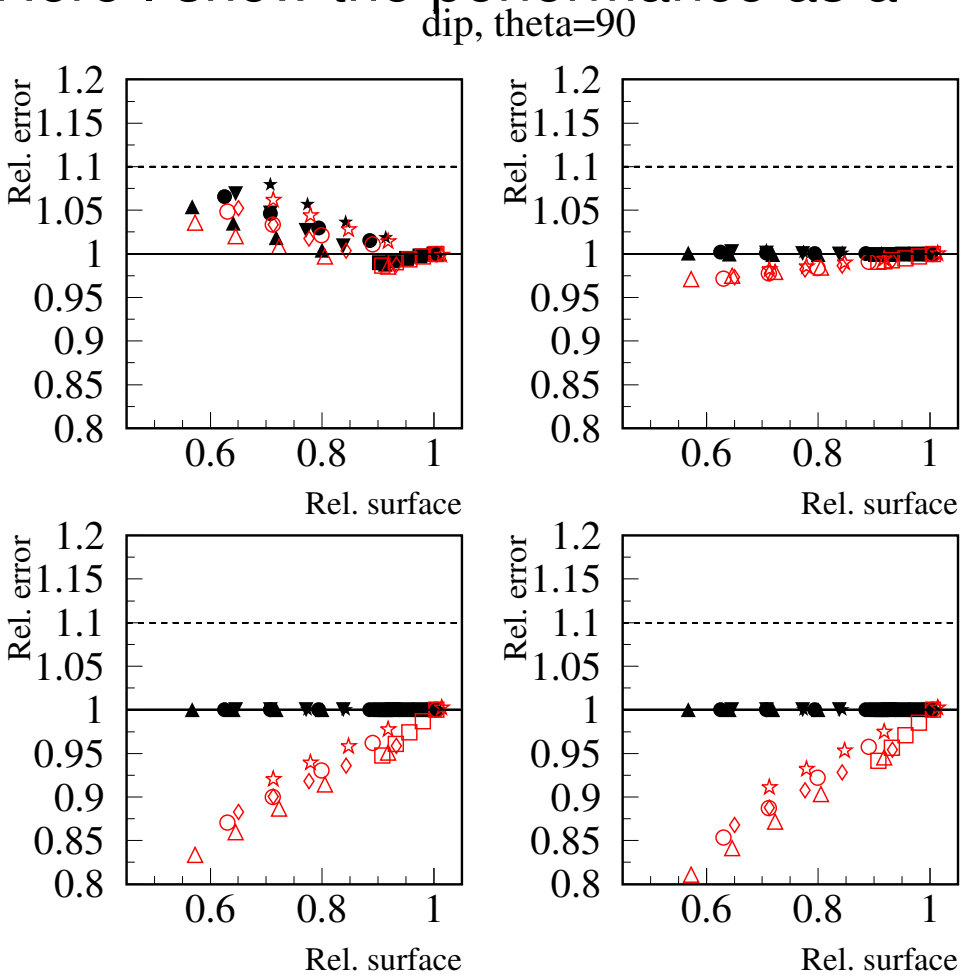

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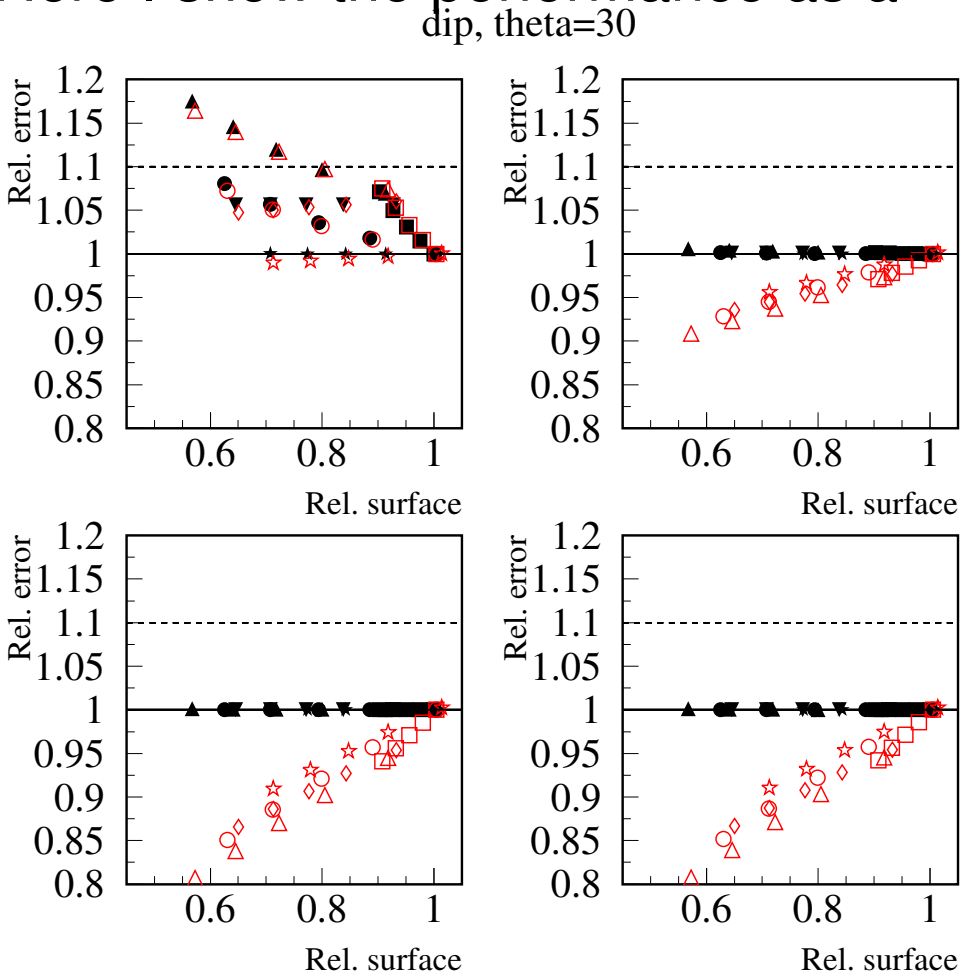

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Higgs recoil-mass @ 350 GeV: mesurables

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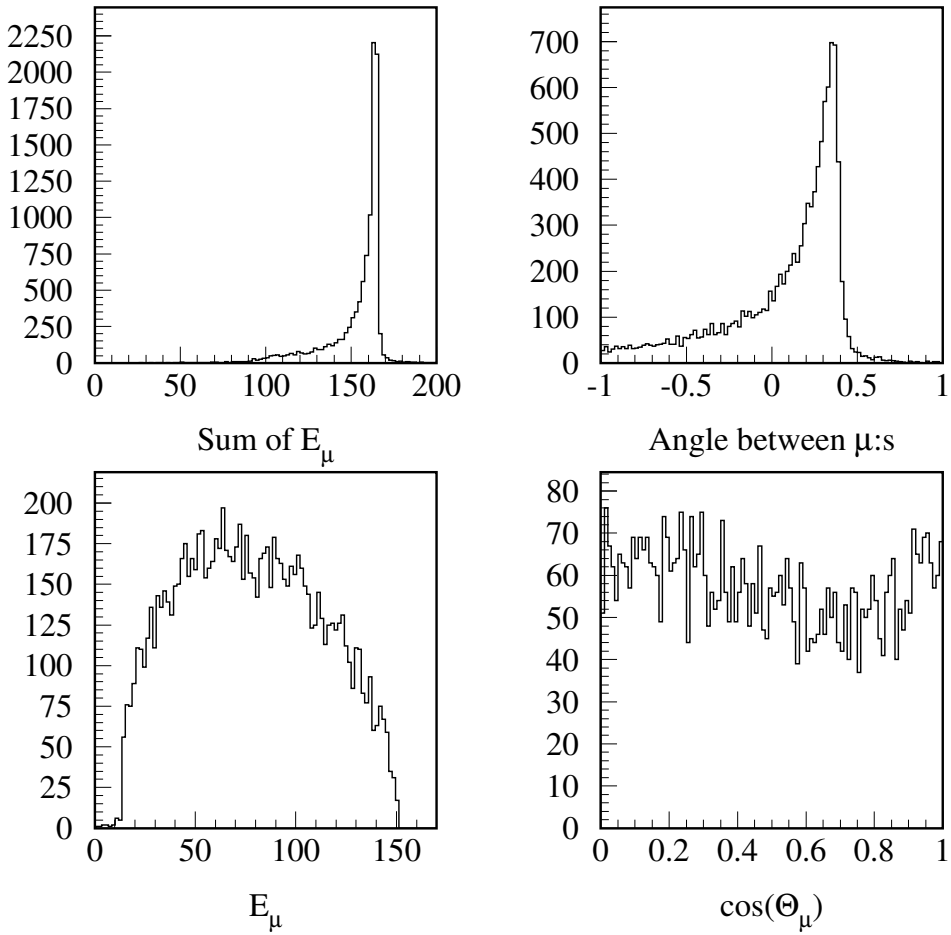

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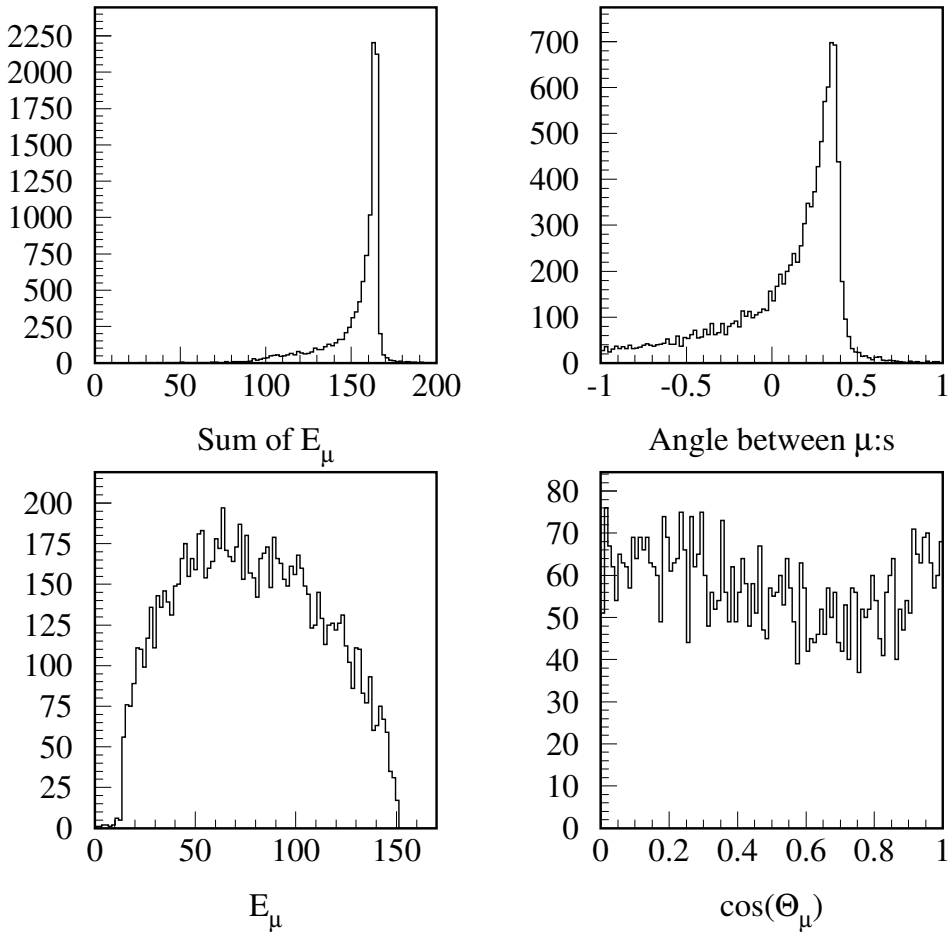
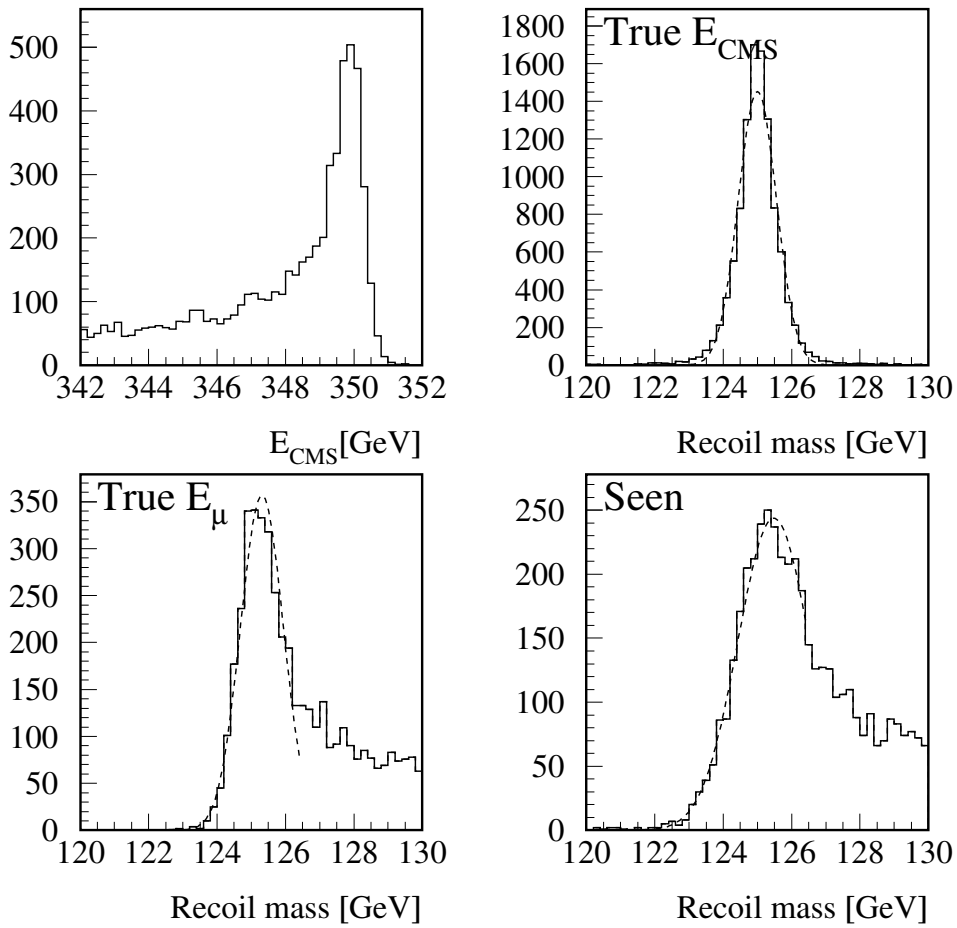


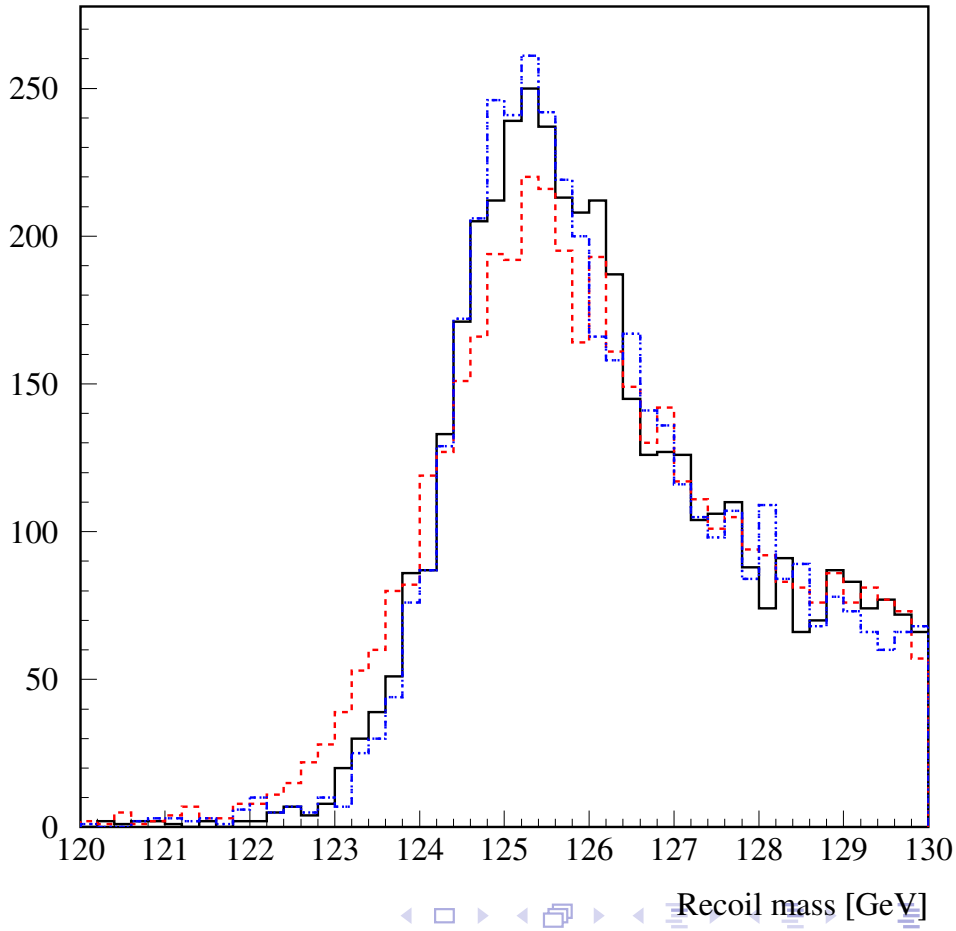
Higgs recoil-mass @ 350 GeV: The recoil mass

- $E_{CMS} \neq$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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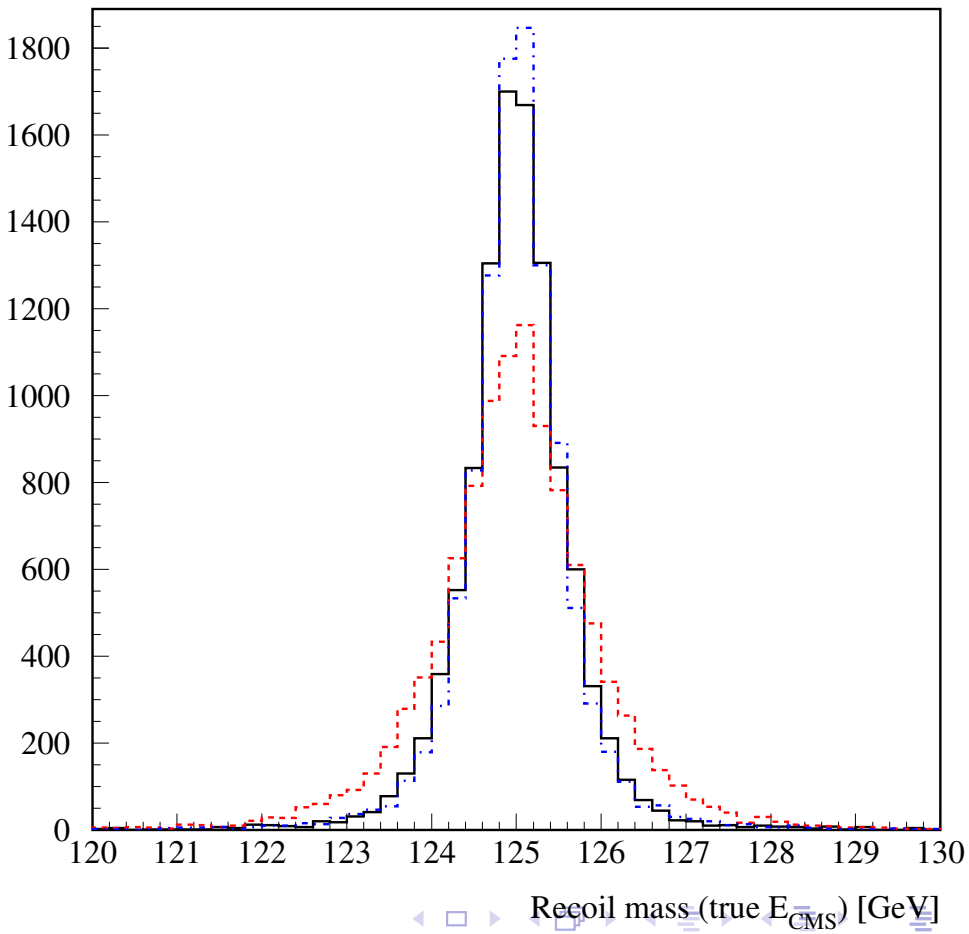

Higgs recoil-mass @ 350 GeV: fits with different options

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 all options vs. TPC radius.
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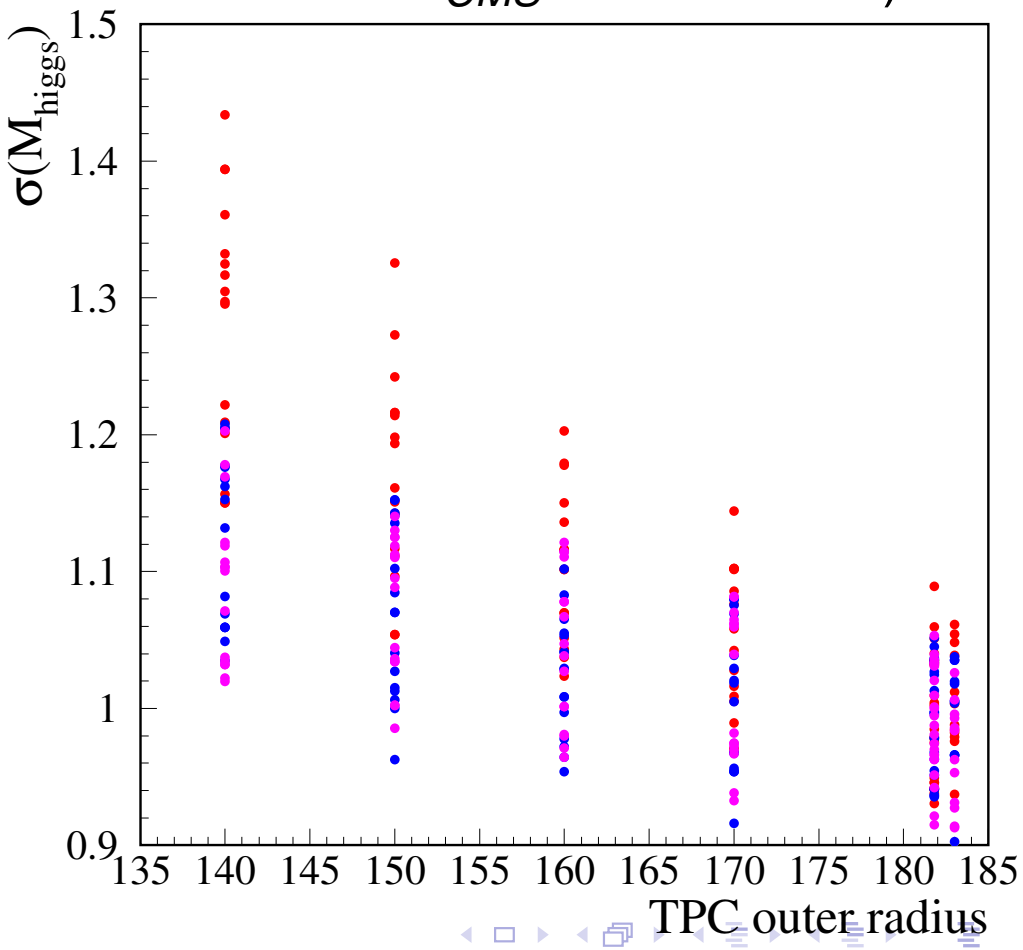
- Same, but in the "4T" case.



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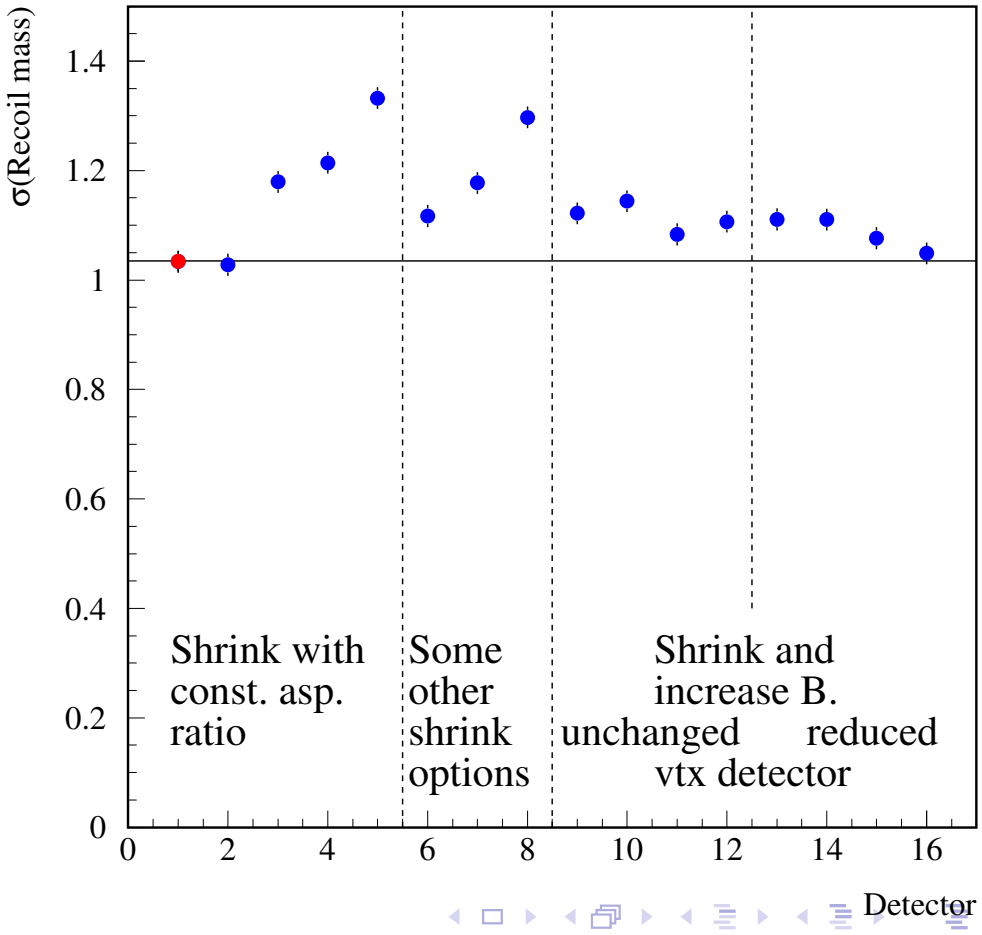

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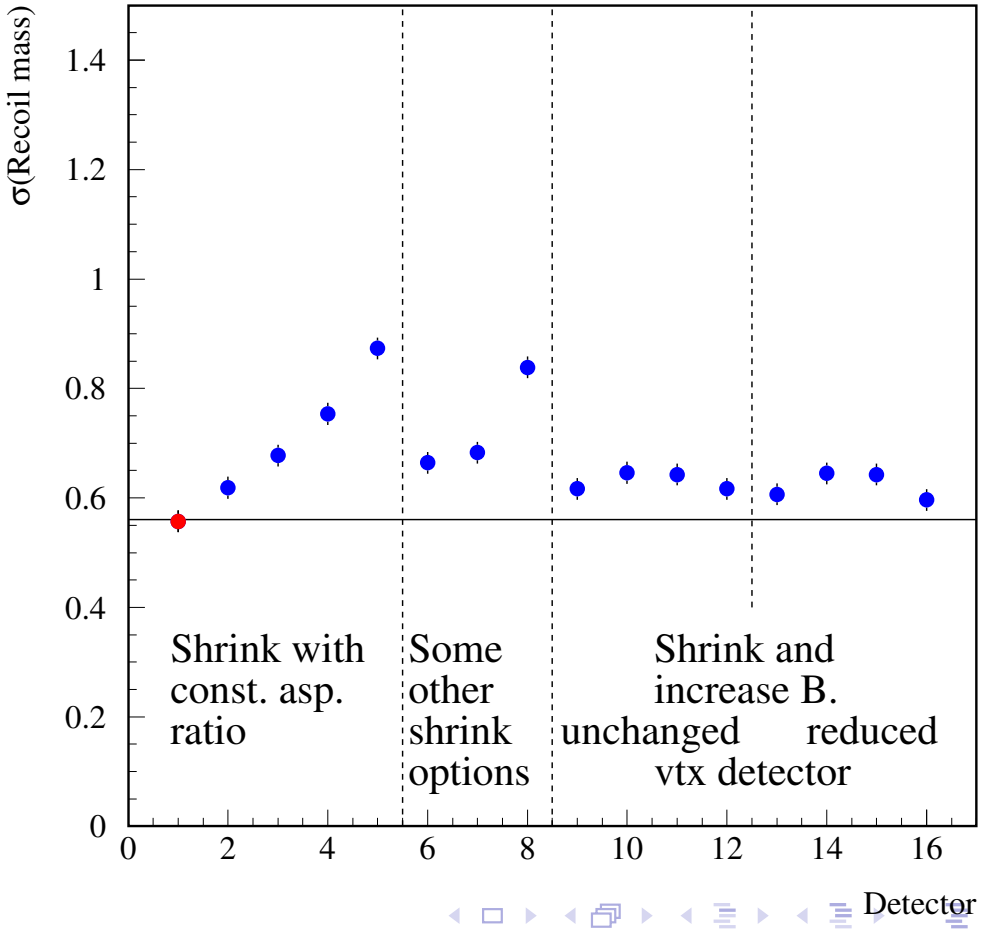

Physics: b-tagging

$e^+e^- \rightarrow Zh \rightarrow \mu\mu h$ 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

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- Two observables:
  - $\ln(-\ln(P(\text{All are primary})))$
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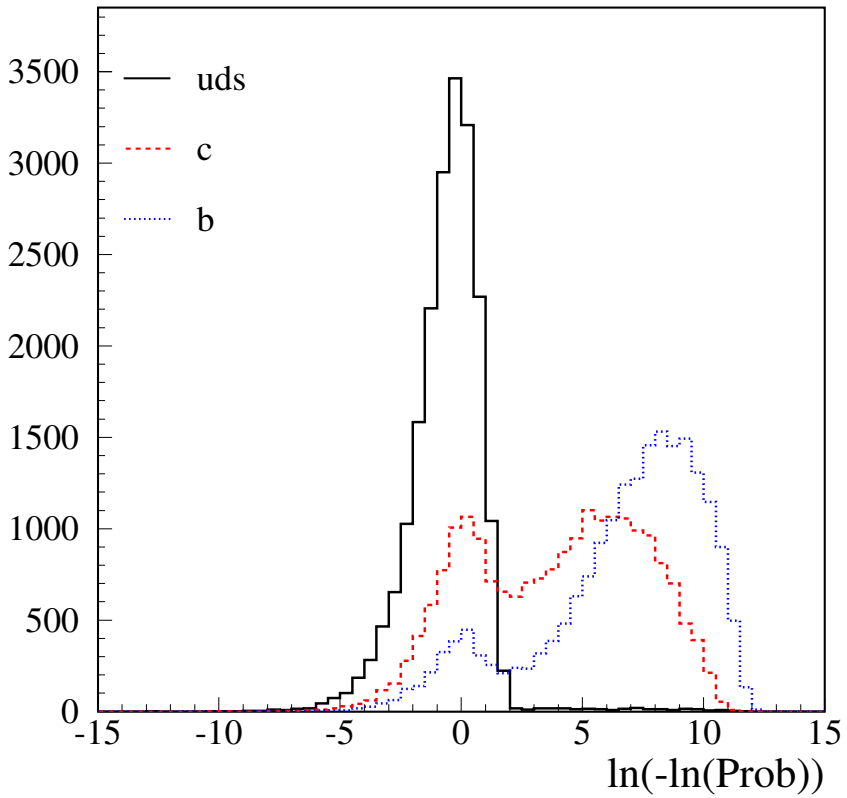
- Optimise the cuts for best $S/\sqrt{S+B}$ for each detector-geometry (on-the-fly)



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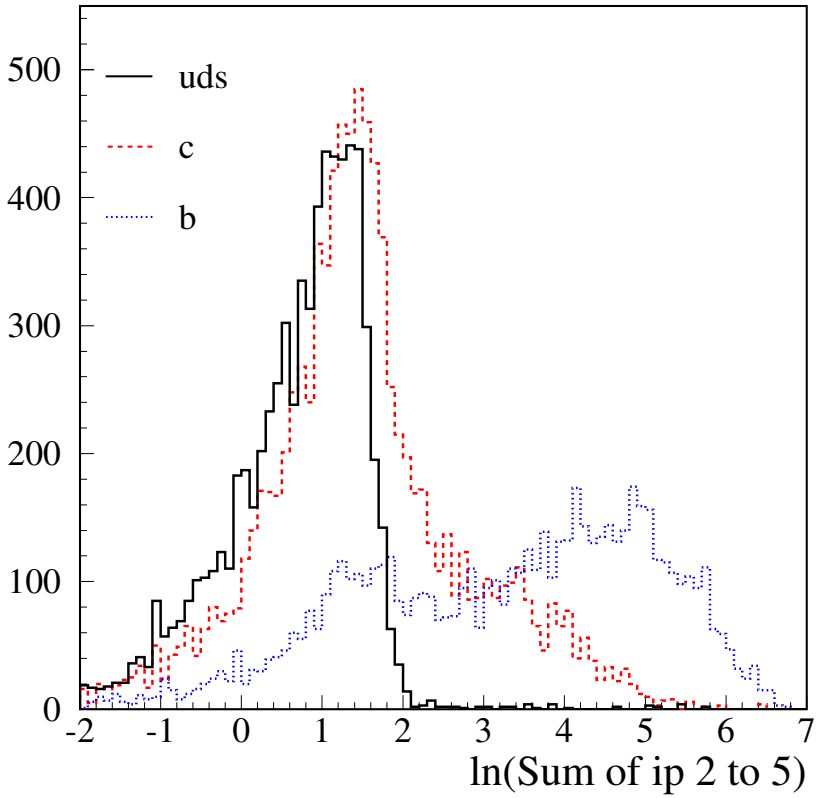

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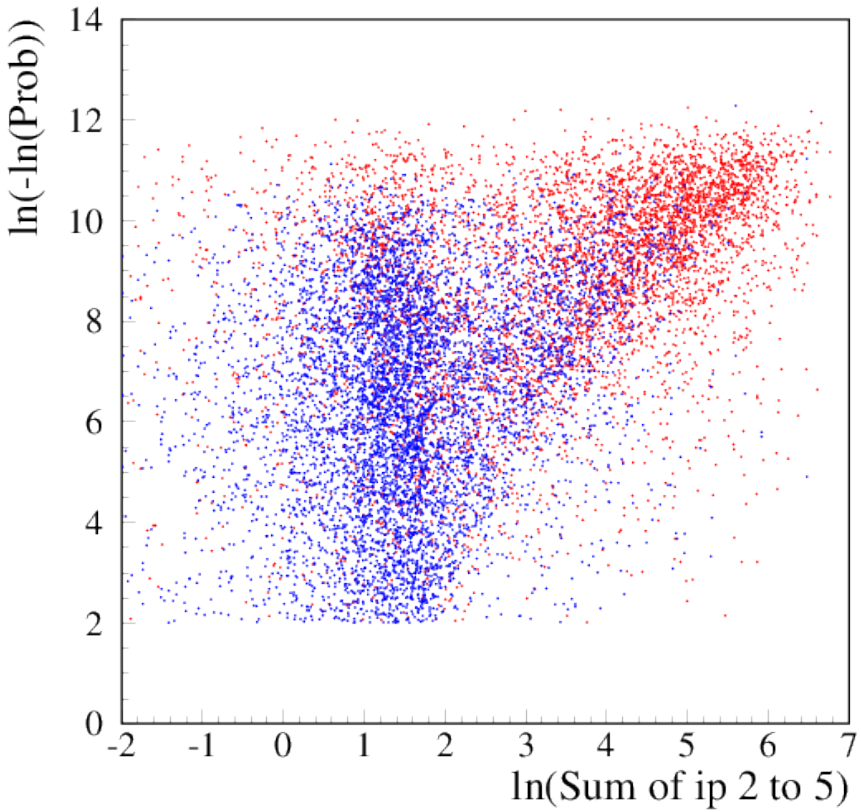

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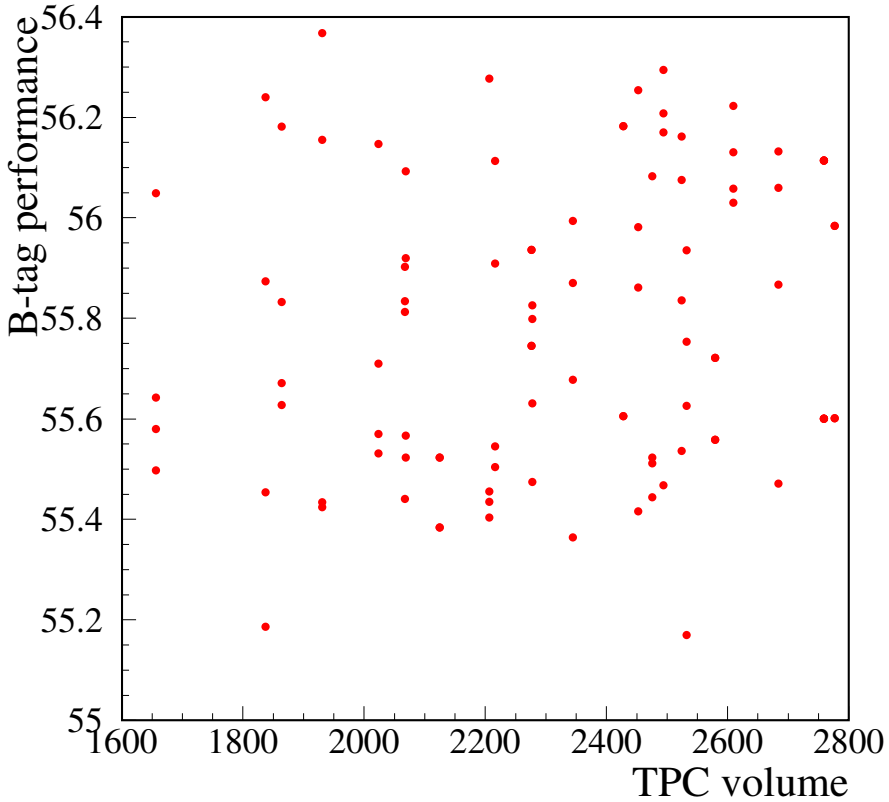

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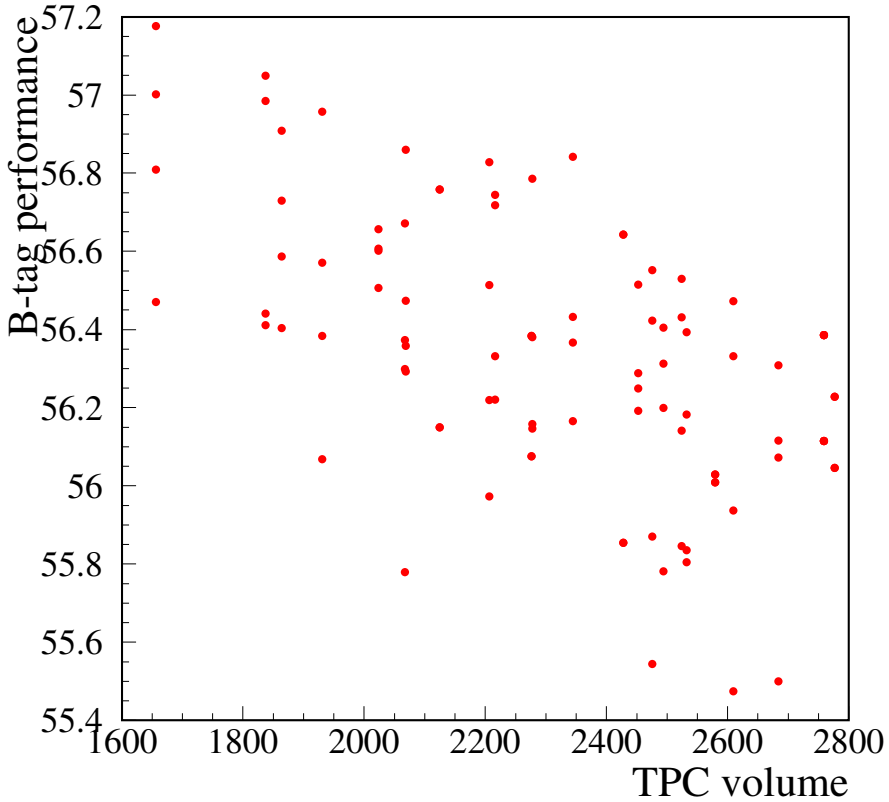

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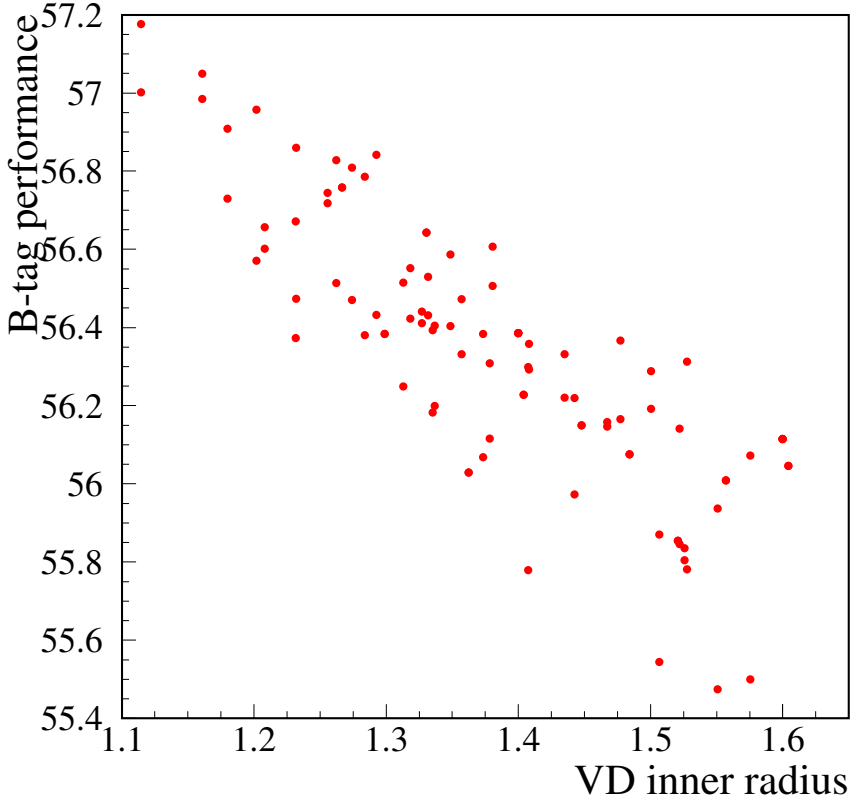

Metrics

Performance:

- Use two metrics:
  - Get score (1-300) in each of the properties (39 of them) for each geometry.
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    - Higher for physics (Higgs mass, b-tagging), zero for ip's at 10 degrees, lower for 250 GeV track-properties ....
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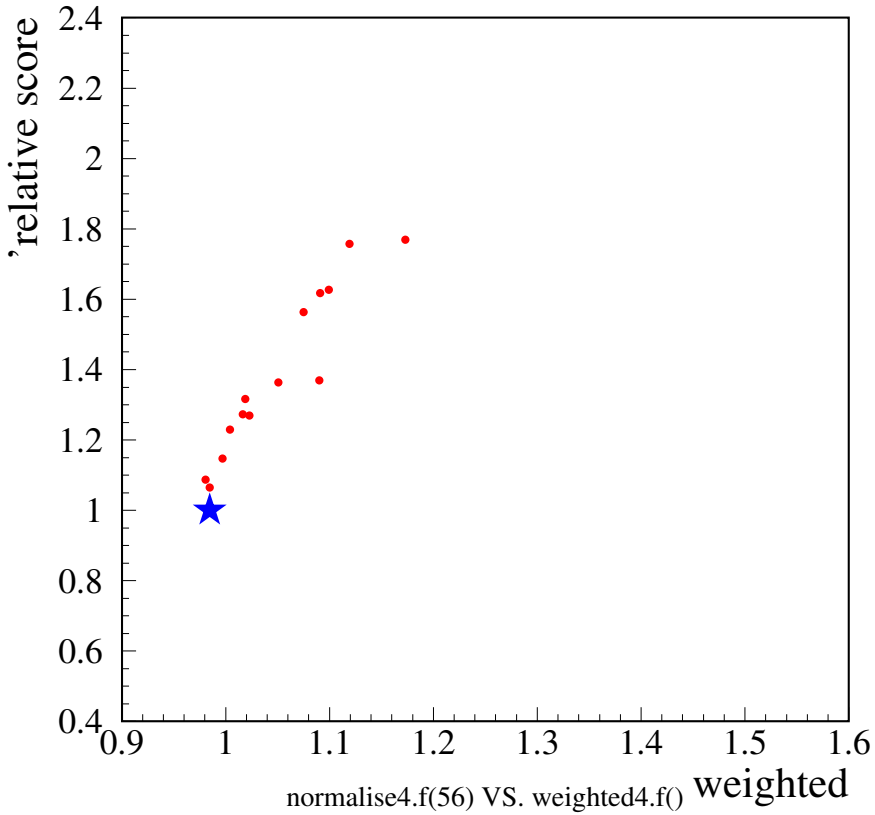

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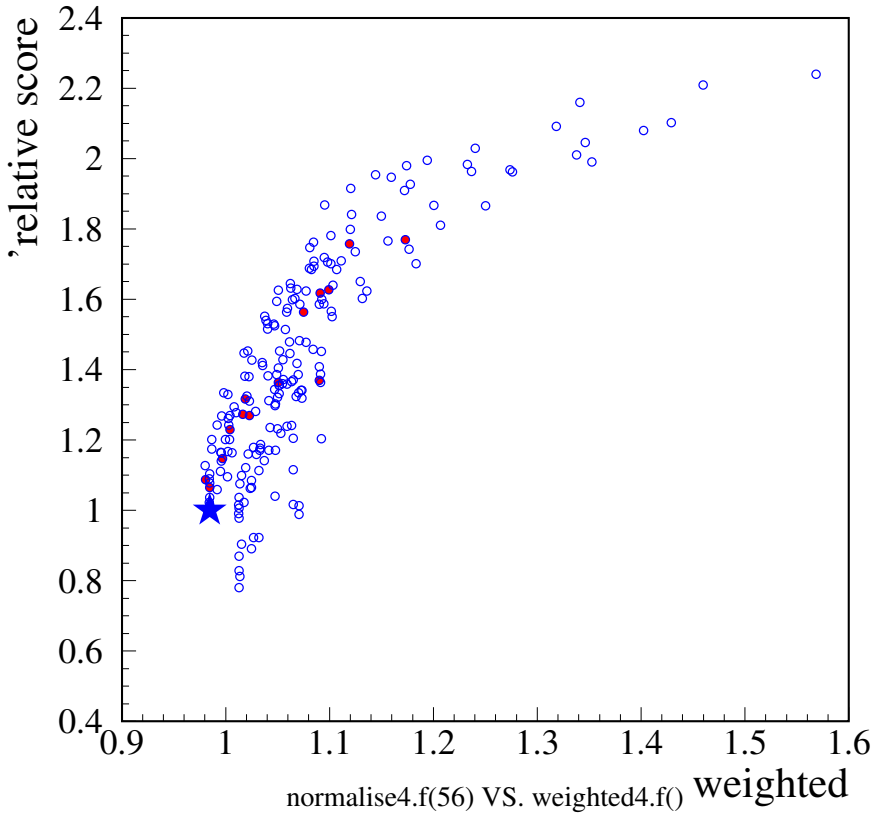

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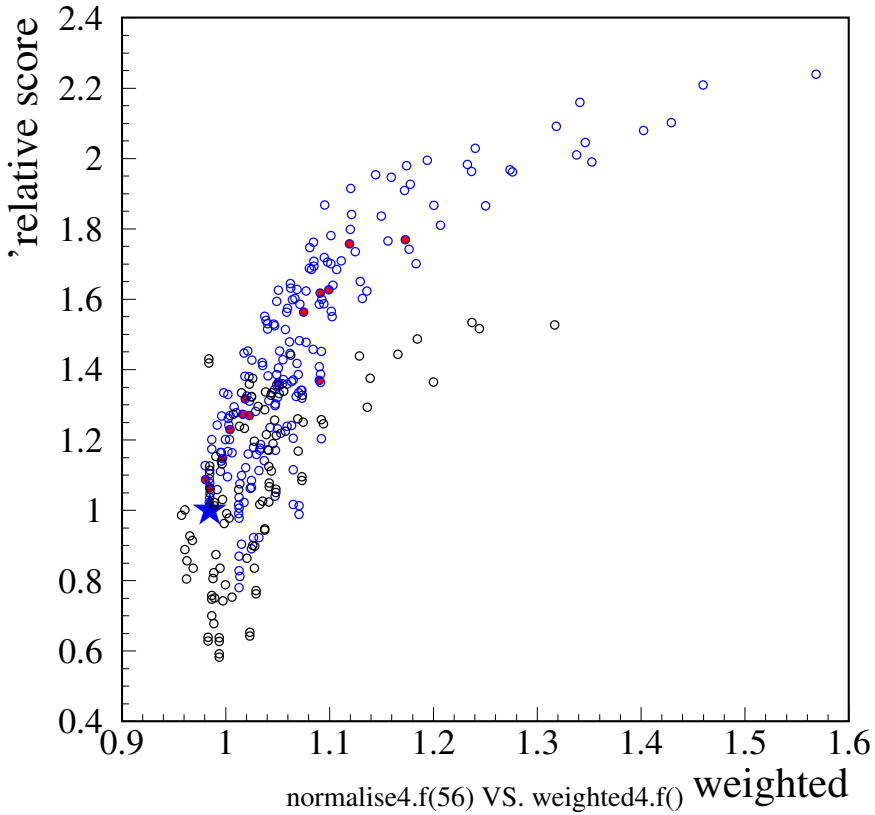

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- Take cost-profile in DBD.
- For calorimeters: 90 % is sensors ($\propto$ Area), 10 % is absorber ($\propto$ Volume)
- For SET: 100 % sensors ($\propto$ Area)
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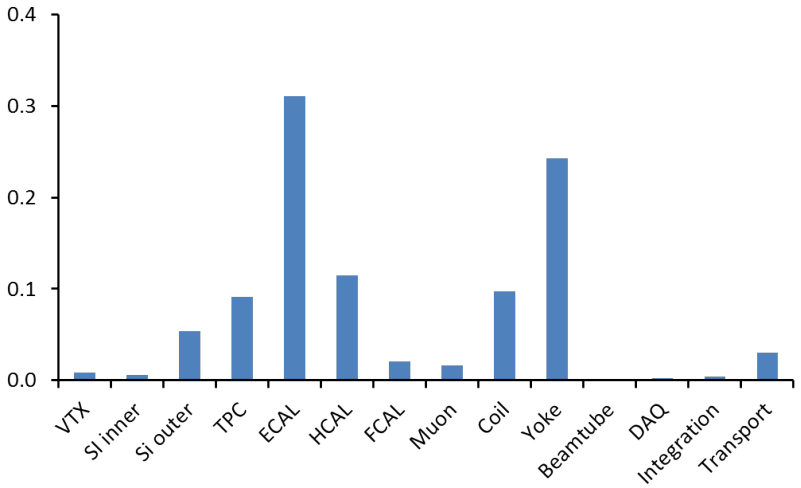
- For Yoke: Scales with Volume - volume restricted by keeping the same flux.
- Master formula vs TPC radius.



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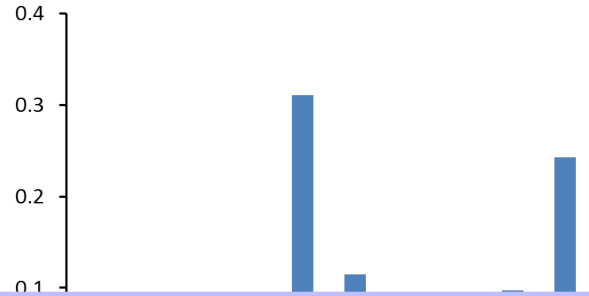

Master formula:

tpcsfact $\times$ 0.08 + ecalsfact $\times$ 0.3 $\times$ 0.9 + ecalvfact $\times$ 0.3 $\times$ 0.1 + hcalsfact $\times$ 0.1 $\times$ 0.9 + hcalvfact $\times$ 0.1 $\times$ 0.1 + setsfact $\times$ 0.05 + yokevfact $\times$ 0.25

area of end-plates.

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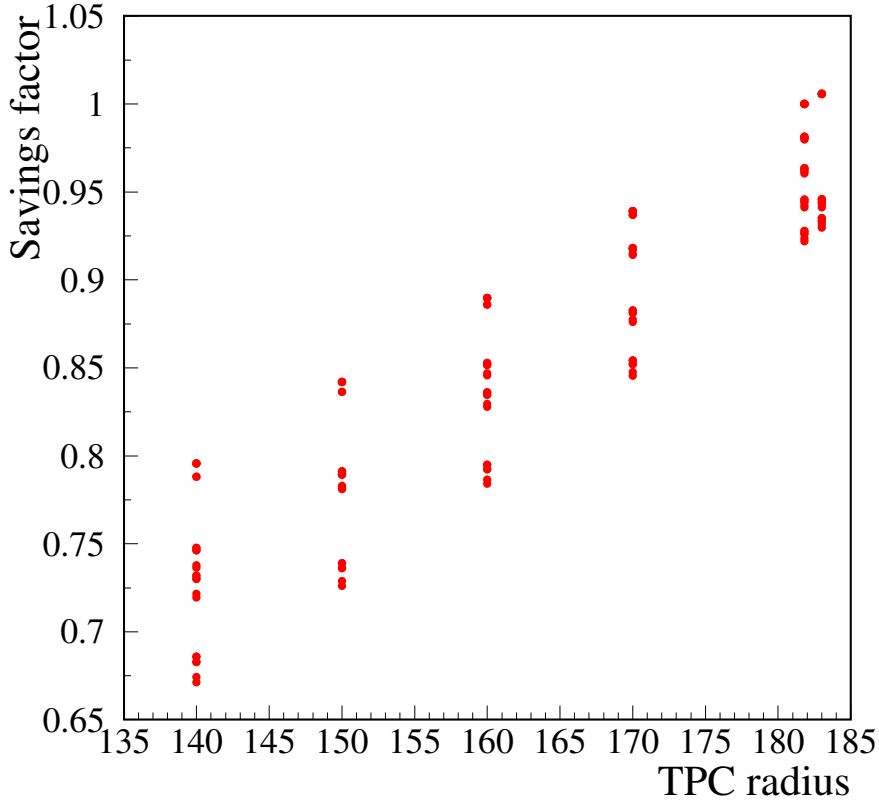
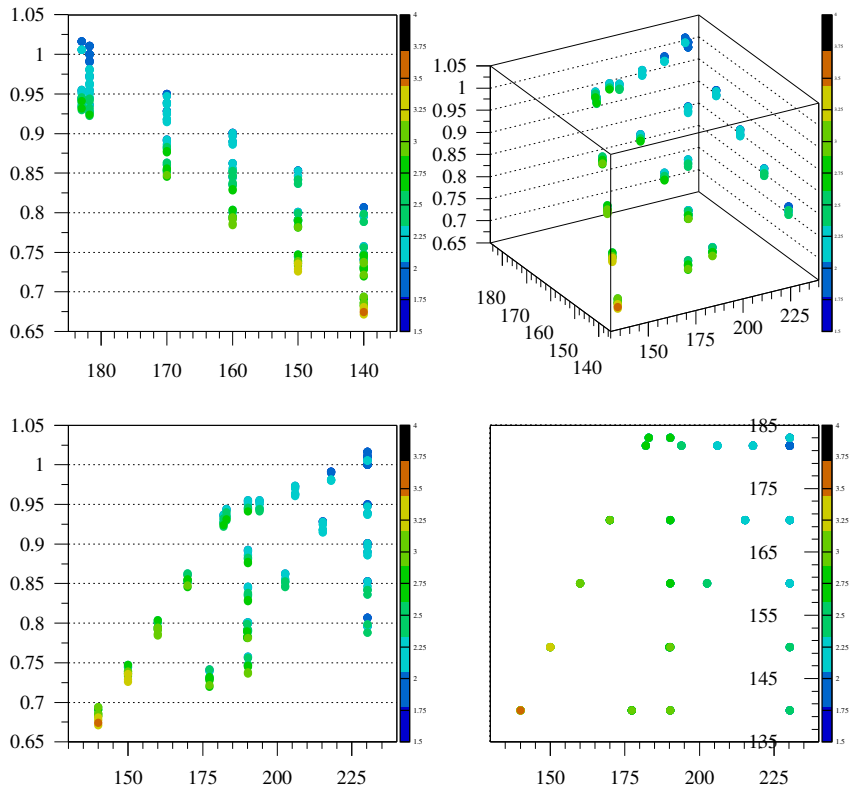


Putting it together

All in a few 4D-plots

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



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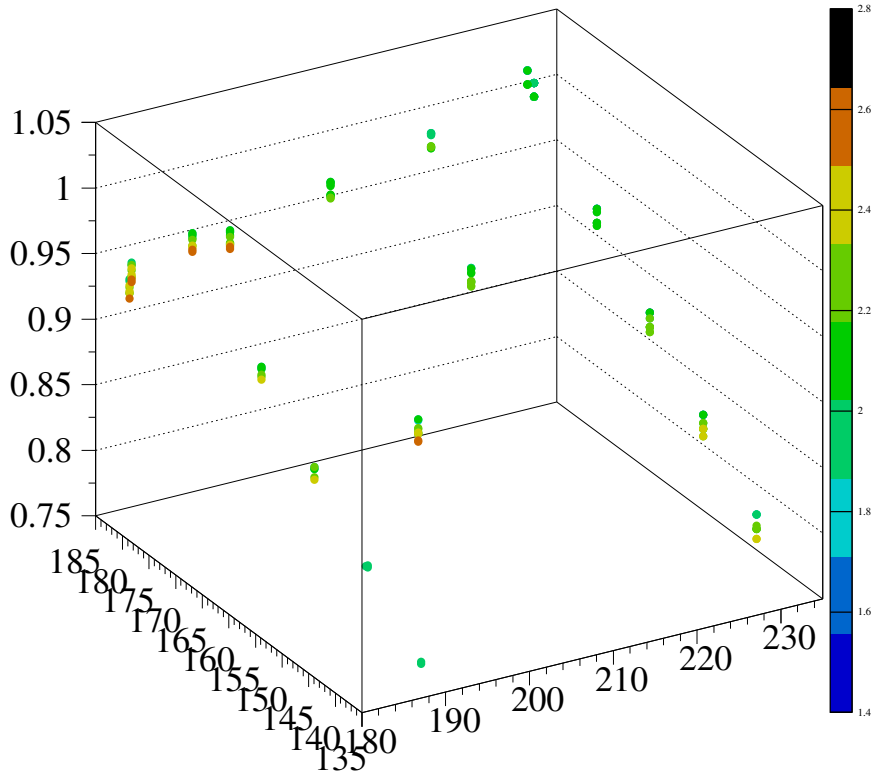
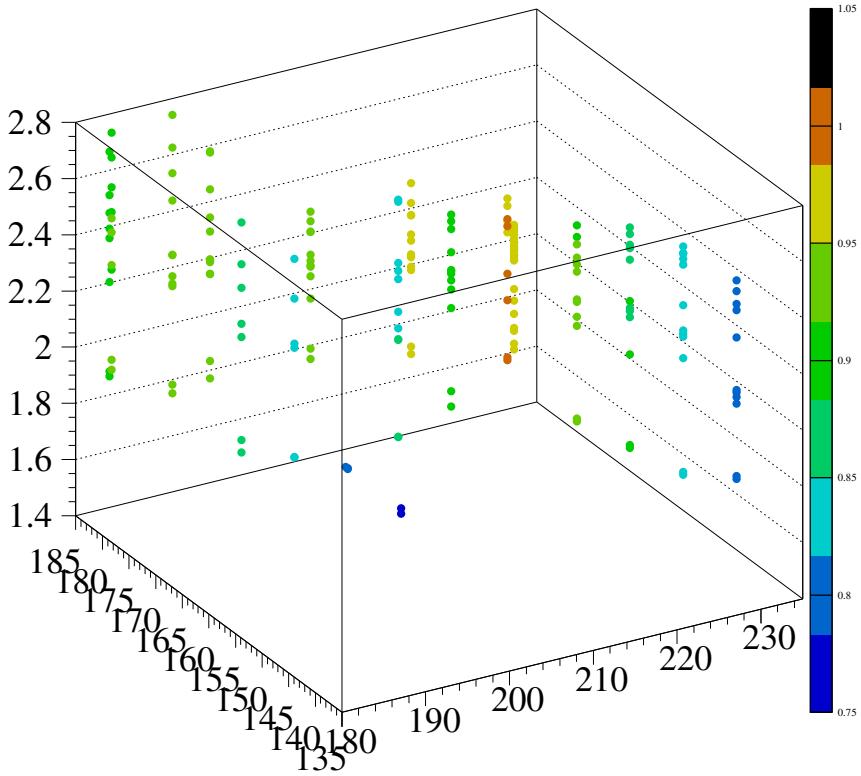


Putting it together

All in a few 4D-plots

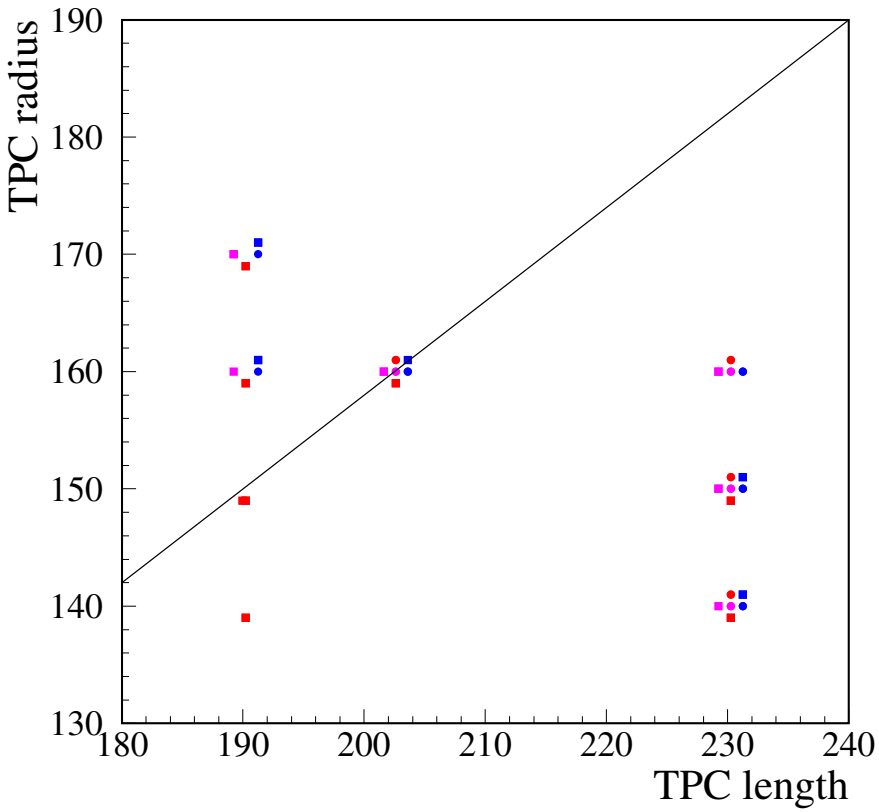
- savings vs. size - performance colour-coded (blue is good - red is bad)
- Cut out worst out worst performers ...
- ... or plot performance vs size colour coded savings



Putting it together

Project on size

- Only at least 10 % savings, best $\sim$ 5 performances in each group of mitigation strategies.
  - ($\Rightarrow$ different cut for different strategies)
- For $\sim$ 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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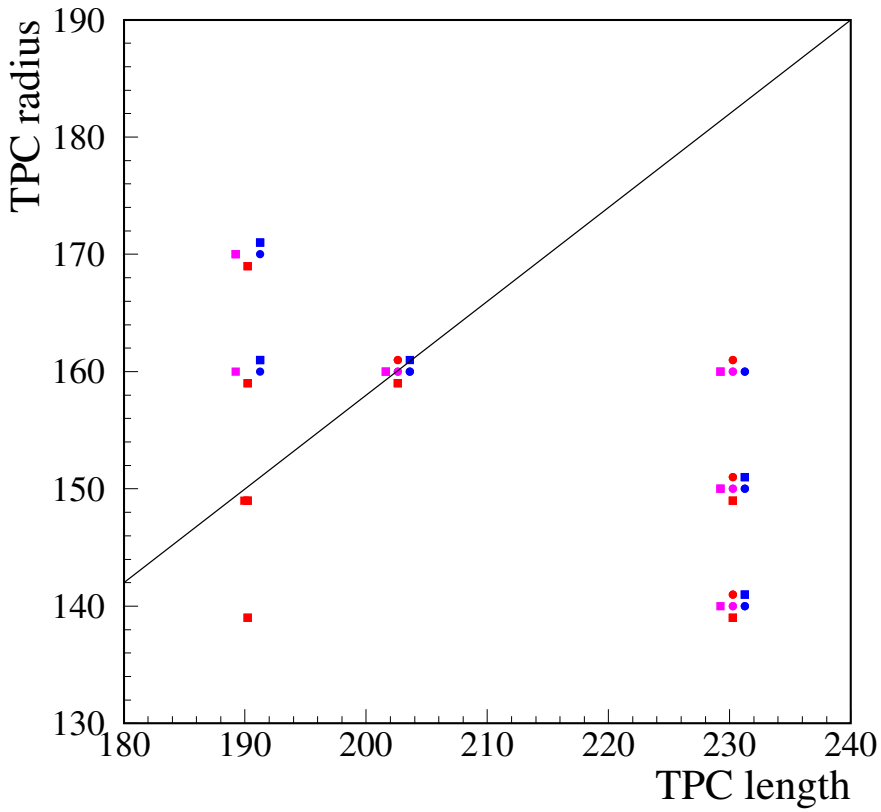

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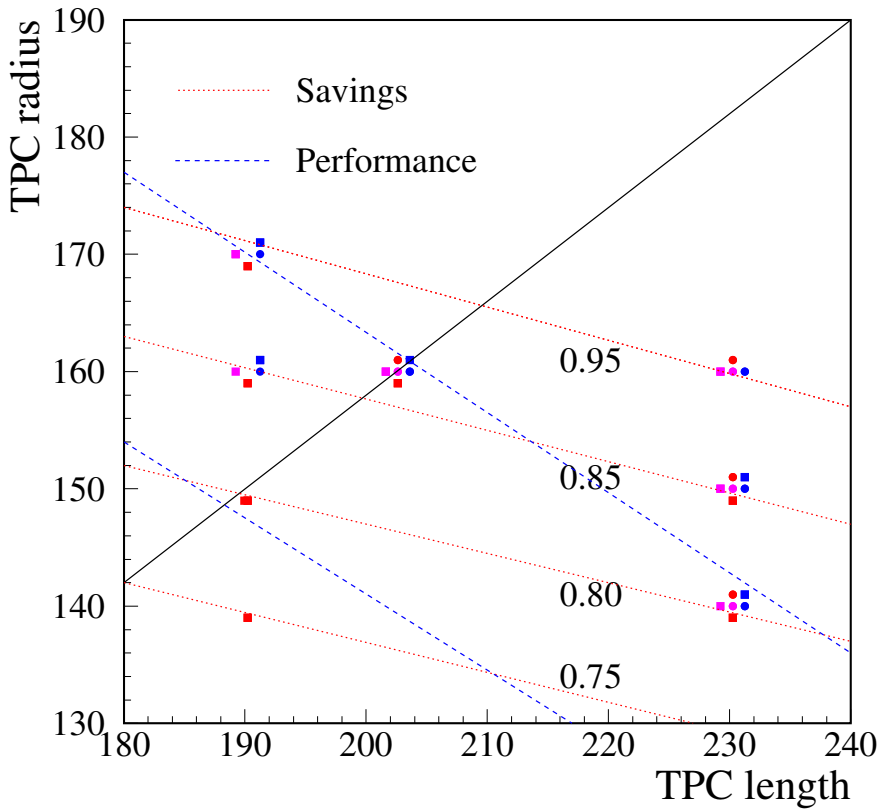

Recommendations

- 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 the best cost-performance.
- If the full mitigation (reduced safety margin on the B-field, both B and VD inner radius scaled) also 140-190 is viable.
- In this case (full mitigation) all points except 160-200 perform better than the DBD detector!
- 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 ?
  - These two points should be addressed by the Magnet experts.
  - Can the the VD inner radius be reduced with higher B field, and how much?
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Recommendations

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
145	140.	190.232	27.1819	1.6	3.5	0.7379	3.11
145				1.3733	4.0775	0.7478	2.38
145				1.6	4.	0.7464	2.68
145				1.2017	4.66	0.7576	1.96
DBD	181.8	230.25	32.9	1.6	4	1.0105	1.79
DBD				1.4	4	1.0105	1.67

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 (+ 140/190 if the most aggresive mitigation strategy is adopted)
- With mitigation sometimes better performace than DBD detector can be achived.
- However: The DBD detector **geometry** always performs better.