Adapting the ILD Detector for HALHF

Shriyansh Ranjan, Mikael Berggren, Lucy Jane Bishop, Jenny List, Matthew Wing
LCWS 2027
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KEK



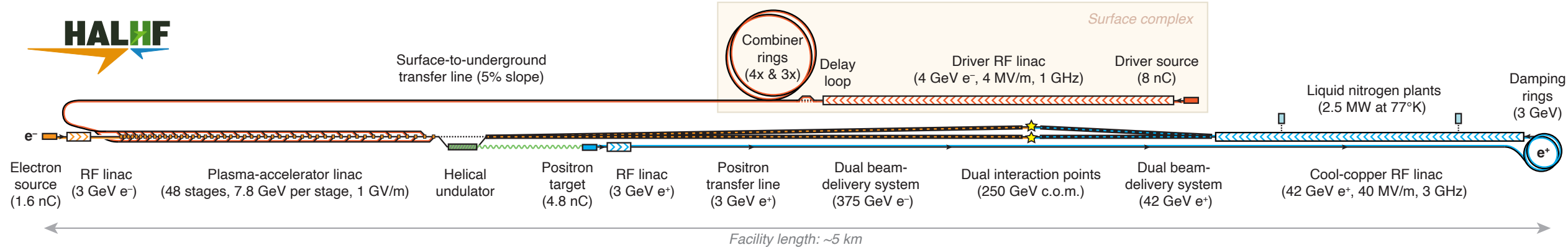




The Hybrid Asymmetric Linear Higgs Factory

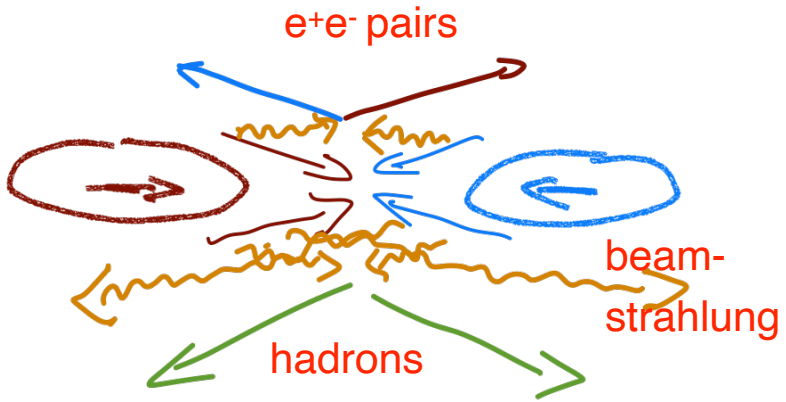
Could we build a Higgs Factory for less than 5 BCHF?

- Construction cost of “classic” Higgs Factories range from ~7-9 BCHF (CLIC/LCF 1st stage) to 15 BCHF (FCC-ee)
- Can advanced accelerator technology bring this to < 5 BCHF?
- Plasma Wakefield Acceleration made huge progress for electron beams — not so much for positrons…
- Go asymmetric:
  - Technology: e- beam-driven PWA ; e+ conventional RF
  - Beam energies for 250 GeV: E(e-) = 375 GeV; E(e+) = 41.7 GeV (Lorentz-boost γ = 1.67)
  - Bunch charge: Q(e+) = 3x Q(e-) (improves power efficiency, helps PWA)
- What does all this imply for luminosity spectrum, pair backgrounds, detector and physics?



Beam-Beam Interaction

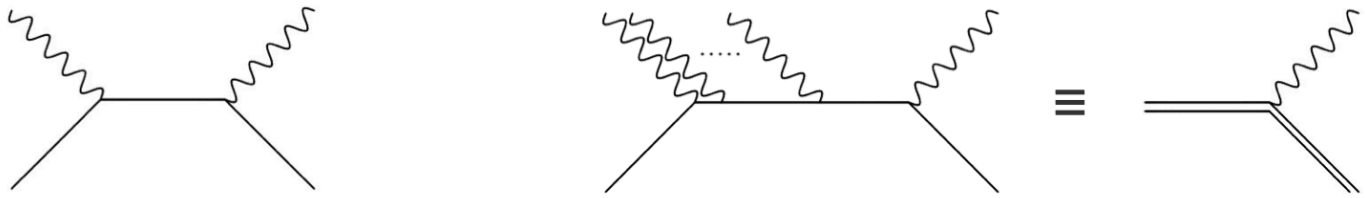
Luminosity Spectrum & Pair Background



- Governed by beamstrahlung parameter Υ (= χ in SF-QED)
- Υ larger for e- direction:
  - high-E (= high-γ) e- see very strong em field of high Ne+ bunch
  - low-E (= lower γ) e+ see much lower em field from lower Ne- bunch
- expect more e+e- pairs in e- direction
- deflection / attraction in addition depends on bunch length (duration of em field presence)
- need to simulate strong-field effects with GuineaPig / WarpX

$$\Upsilon = \frac{\cancel{\frac{2}{3}}\,\cancel{\langle E_\gamma \rangle}}{\cancel{\frac{2}{3}}\,E_{\mathrm{beam}}} = \frac{5 r_e^2 \gamma N_e}{6\alpha_e \sigma_z (\sigma_x^* + \sigma_y^*)}$$

Detailed comparisons done,
c.f. talk by L.J.Bishop in AA session



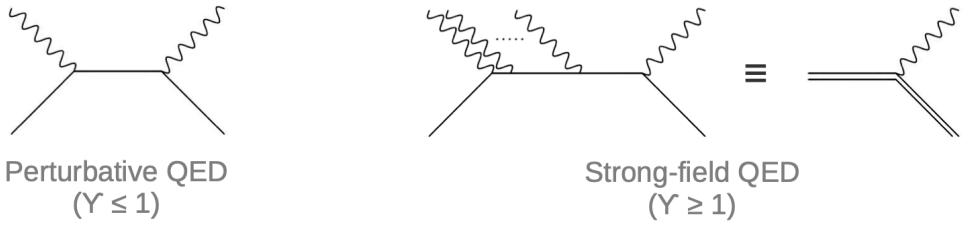
Perturbative QED
($\Upsilon \leq 1$)

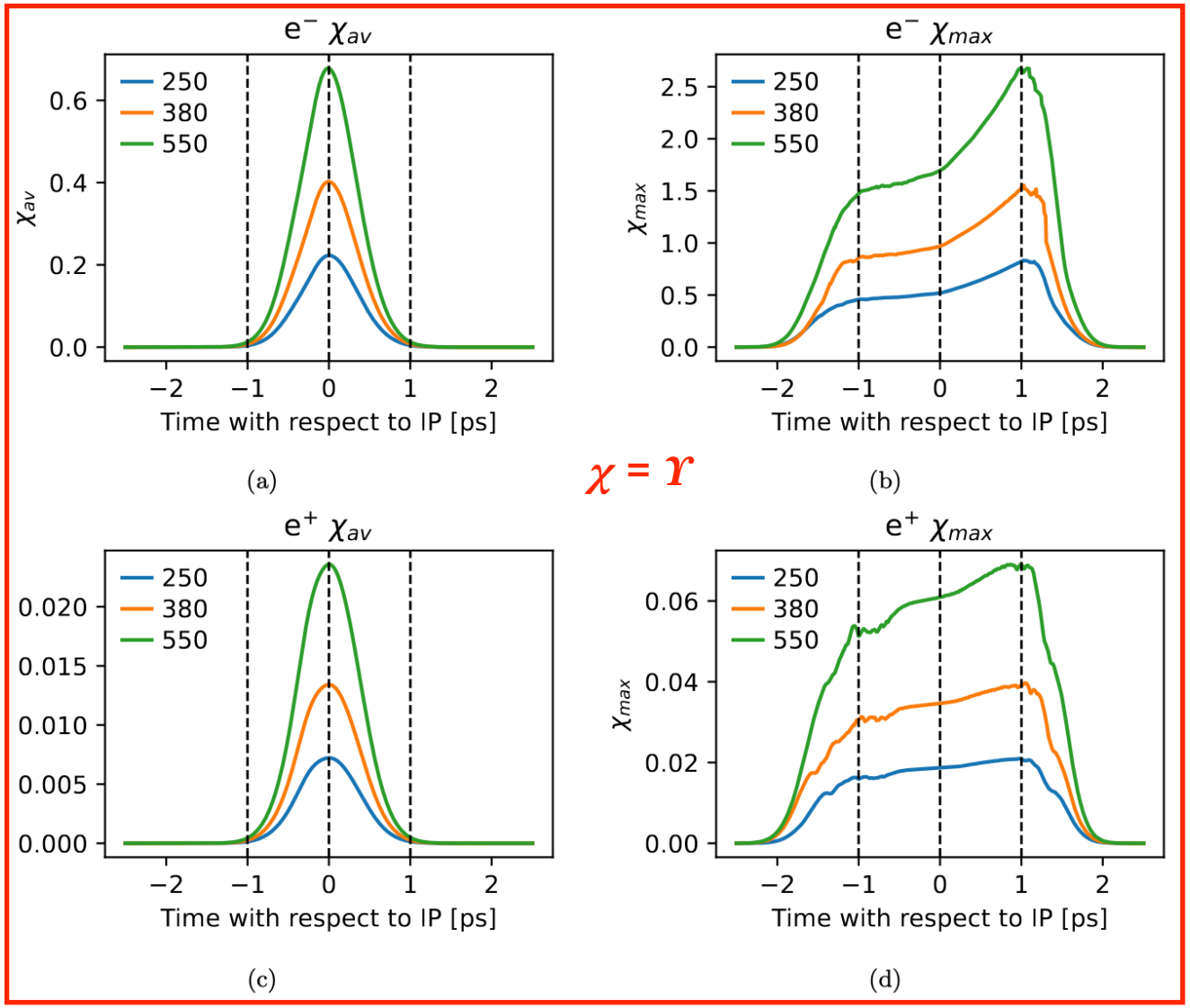
Strong-field QED
($\Upsilon \geq 1$)

Reaching SF-QED Regime?

Simulated $\chi = \Upsilon$ evolution during bunch crossing with WarpX

- Positrons see ~20 lower $\chi = \Upsilon$ than electrons
- $\chi = \Upsilon$ increases with energy
- Maximum $\chi = \Upsilon$ for electrons
  - Up to 0.7 at 250 GeV
  - Up to 2.5 at 550 GeV
- Coherent pair creation matters!



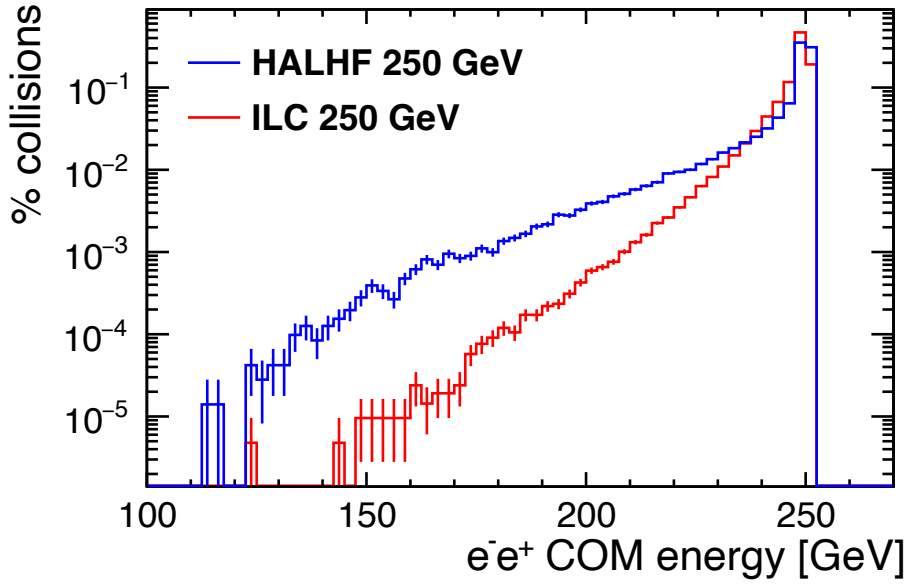


HALHF Luminosity Spectrum

Compared to ILC for reference

HALHF:

- Longer tail from strong BS off e- beam
- Sharper peak due to less BS off e+ beam
- Much harder γ spectrum from e- beam
- Much softer γ spectrum from e+beam

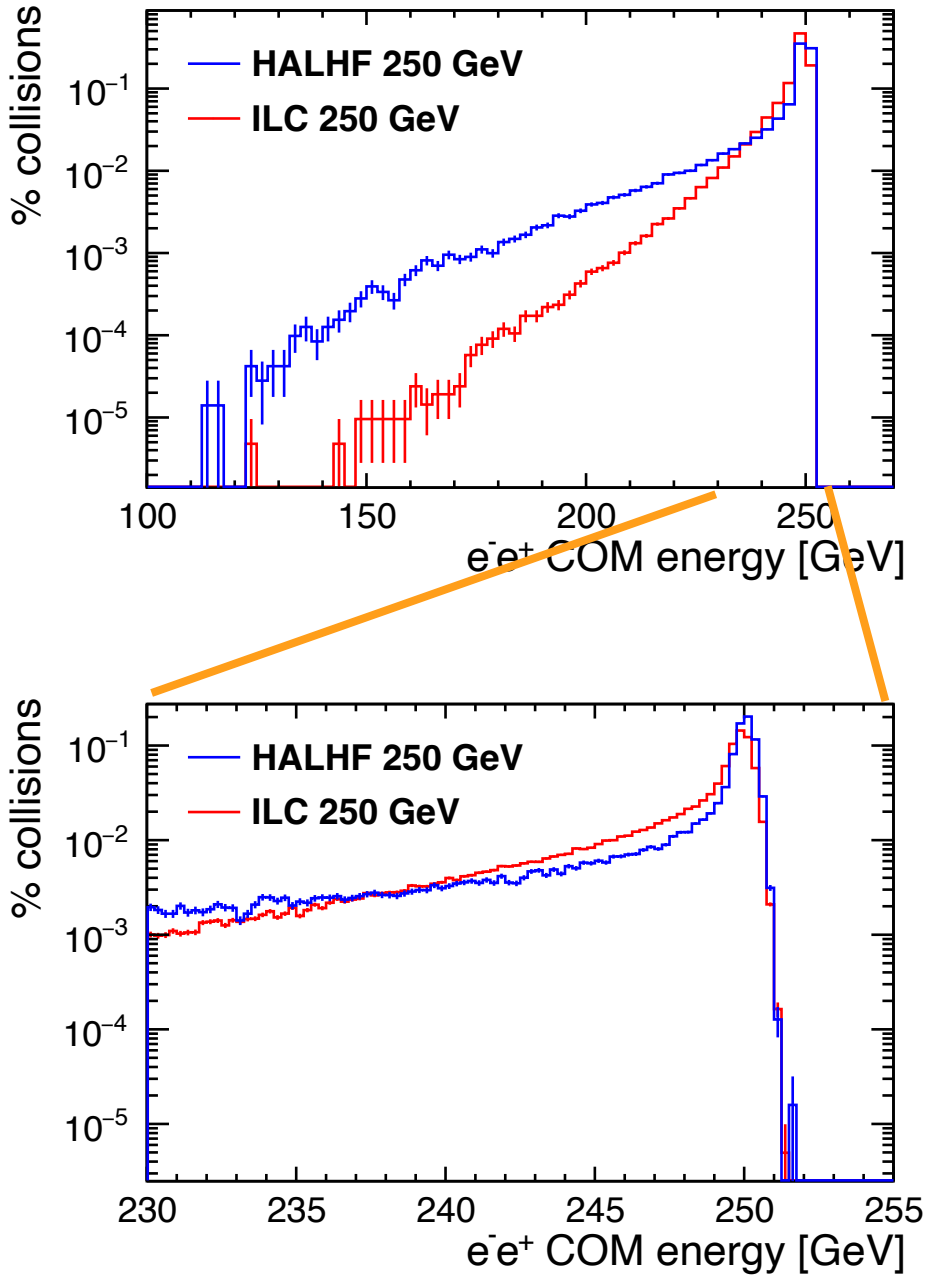


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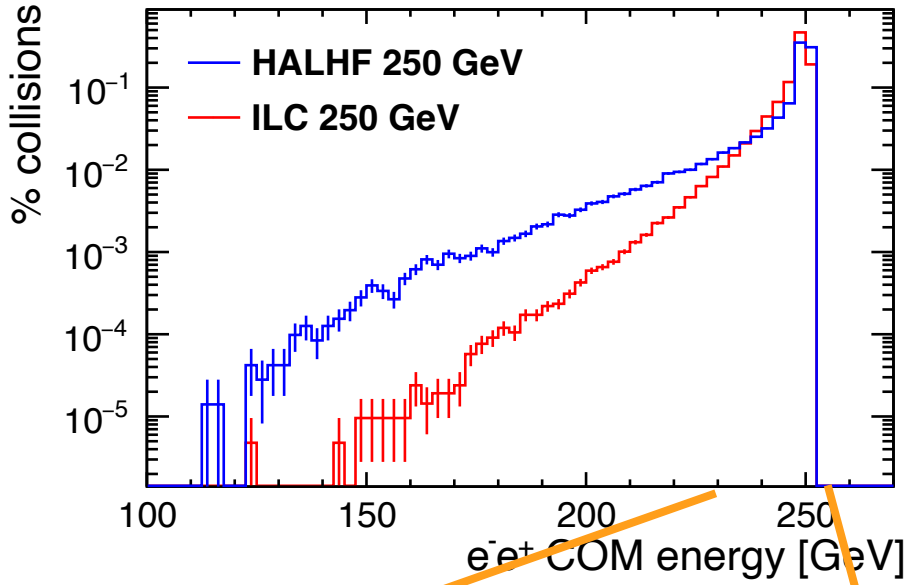


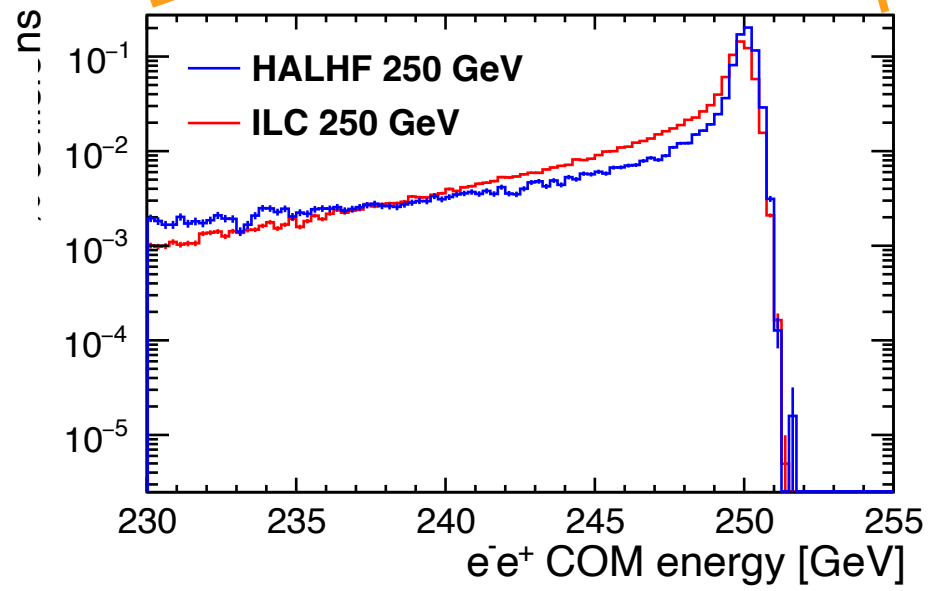
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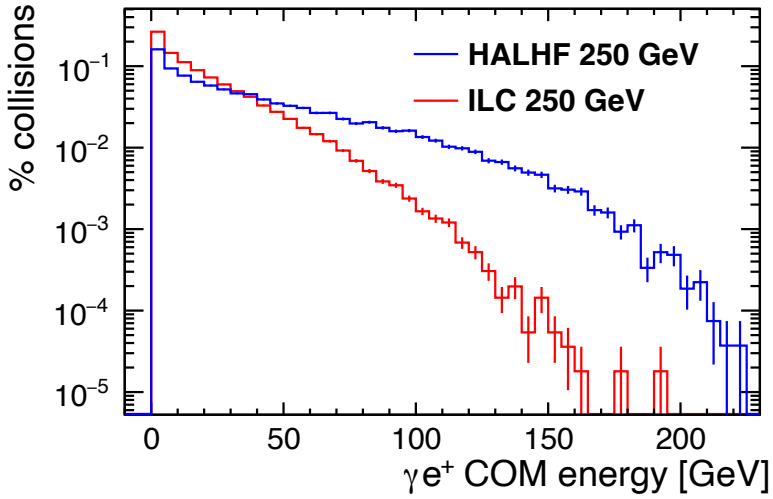
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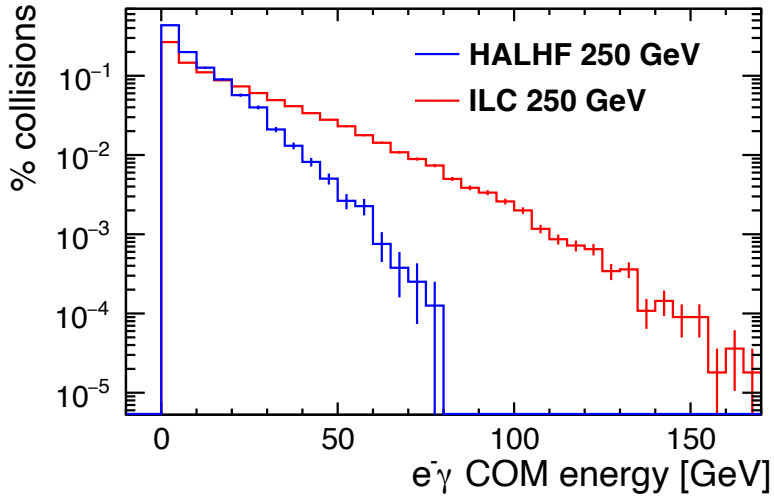




e+ on γ from e-

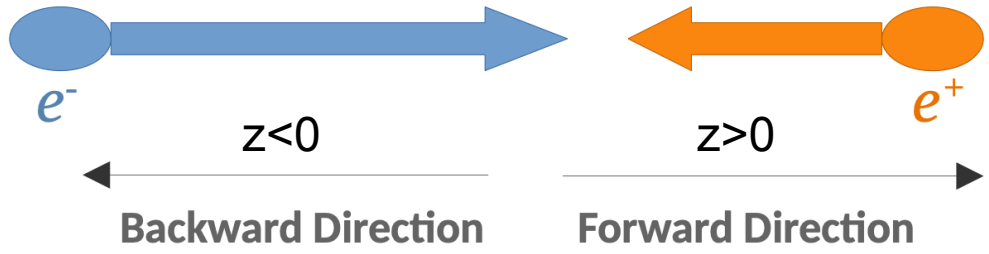


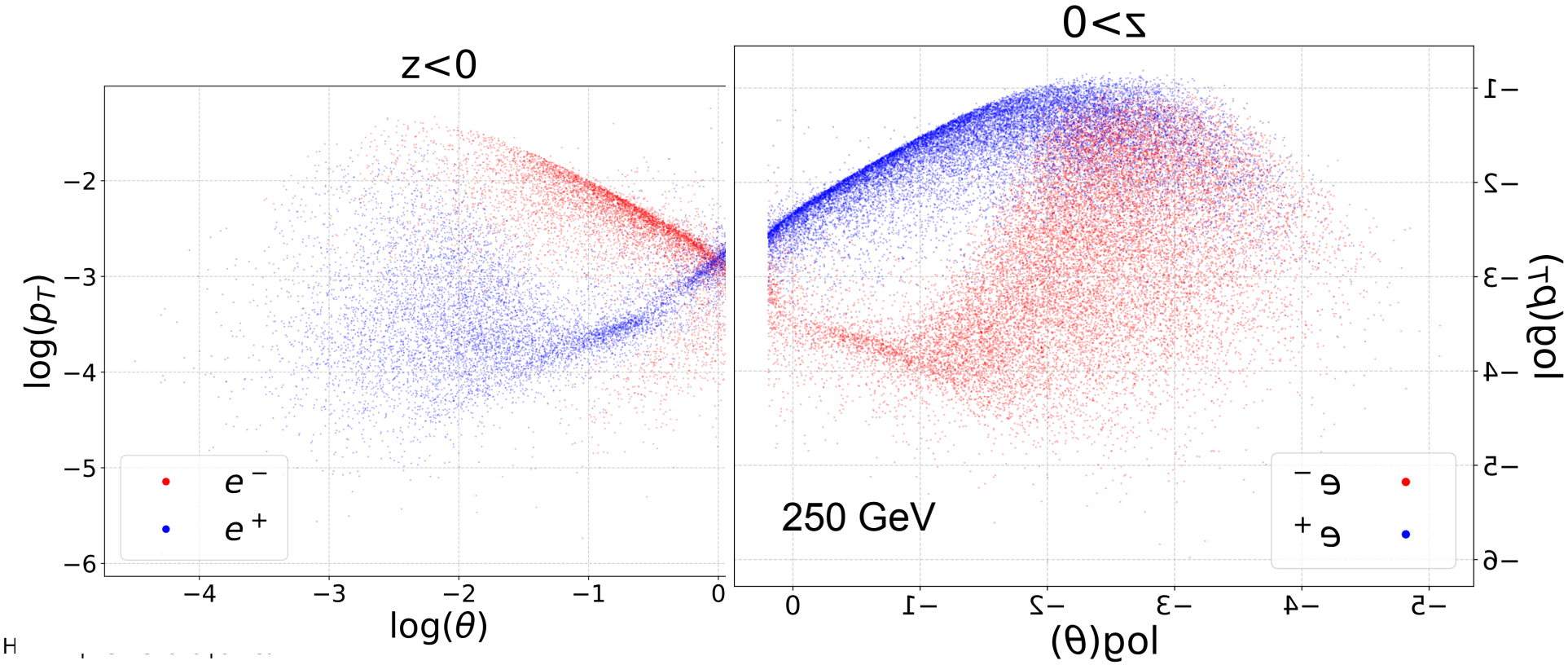
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HALHF Pair Background

From GuineaPig

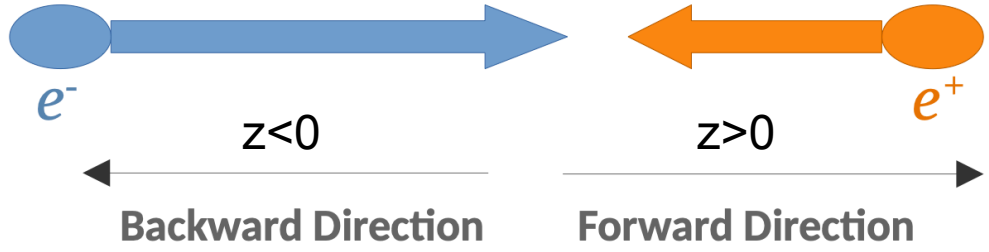


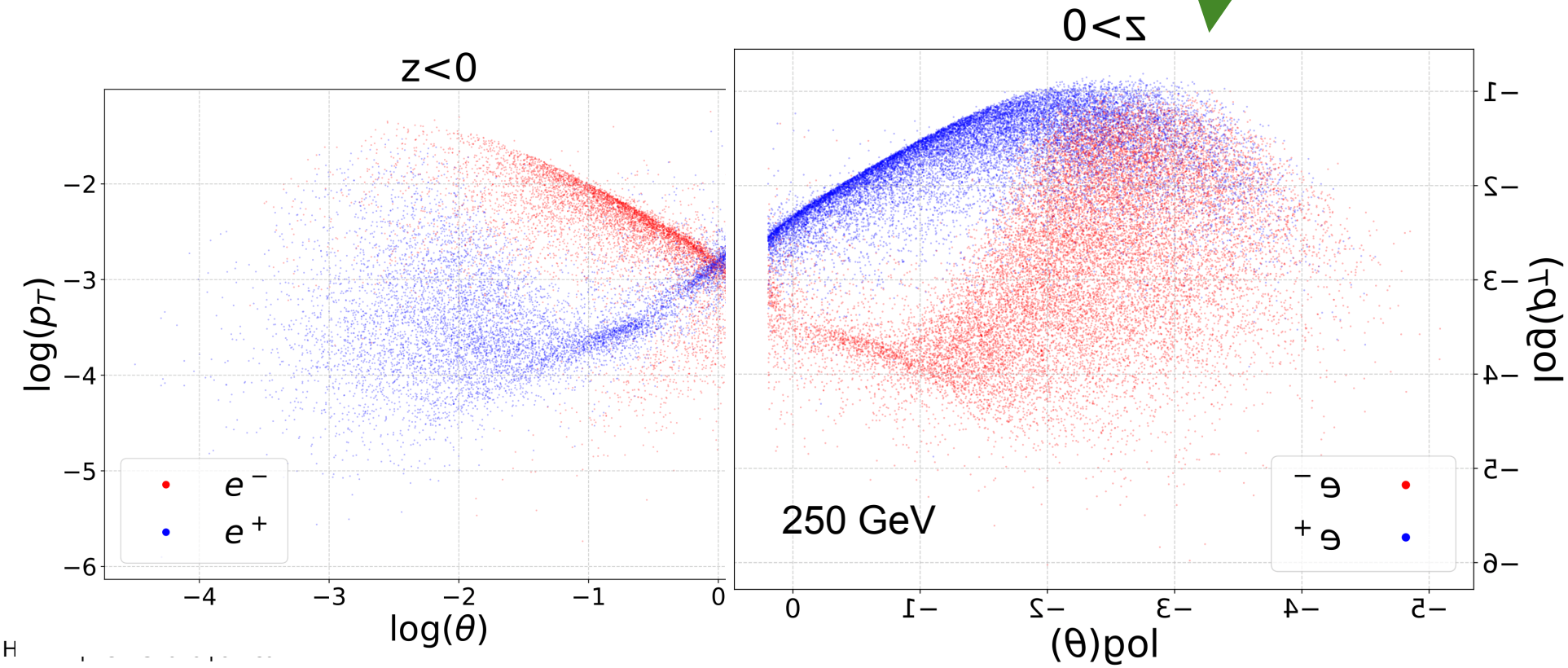


HALHF Pair Background

From GuineaPig

e+/e- have higher pt in forward direction, up to 100 MeV



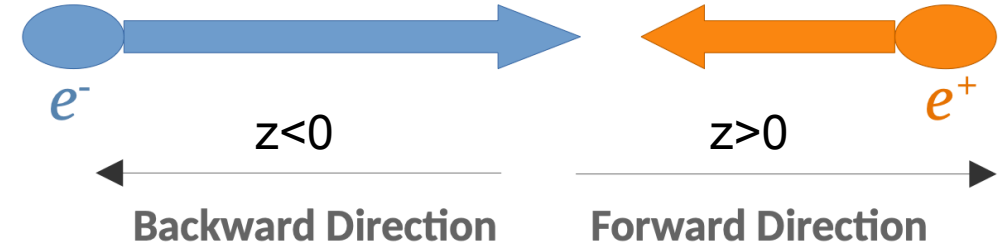


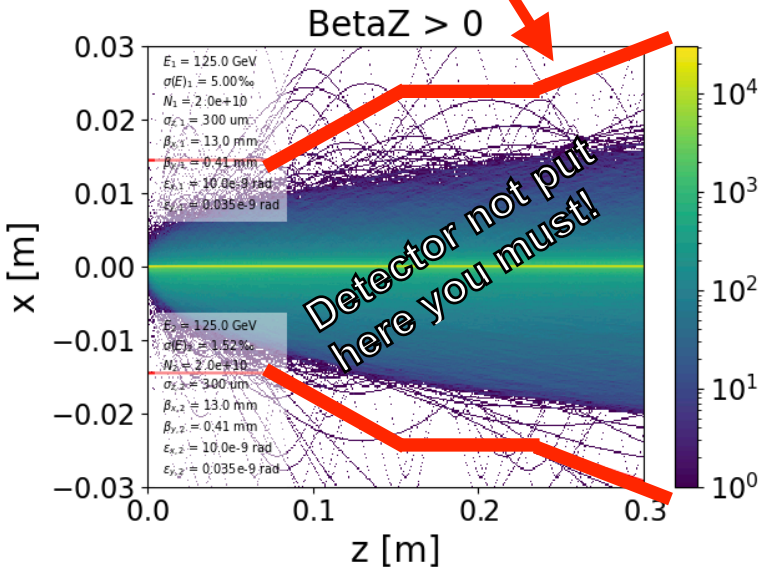
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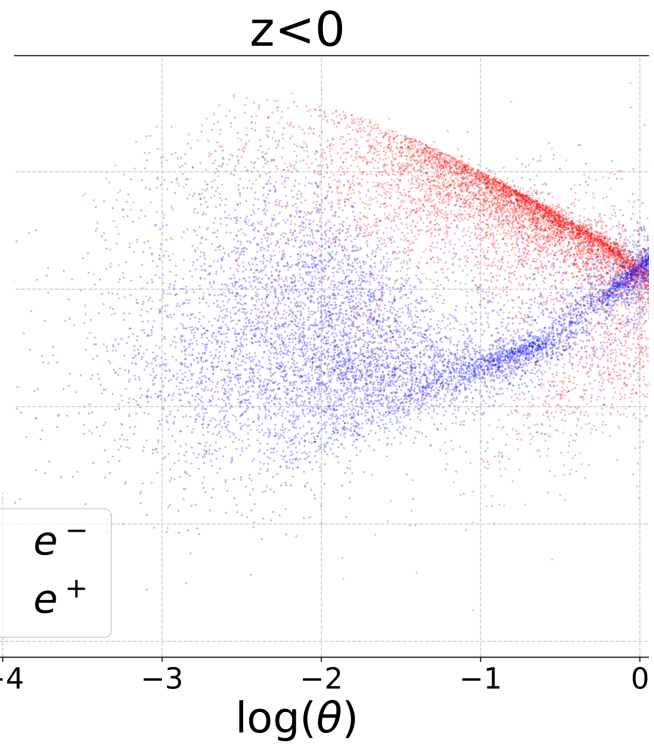
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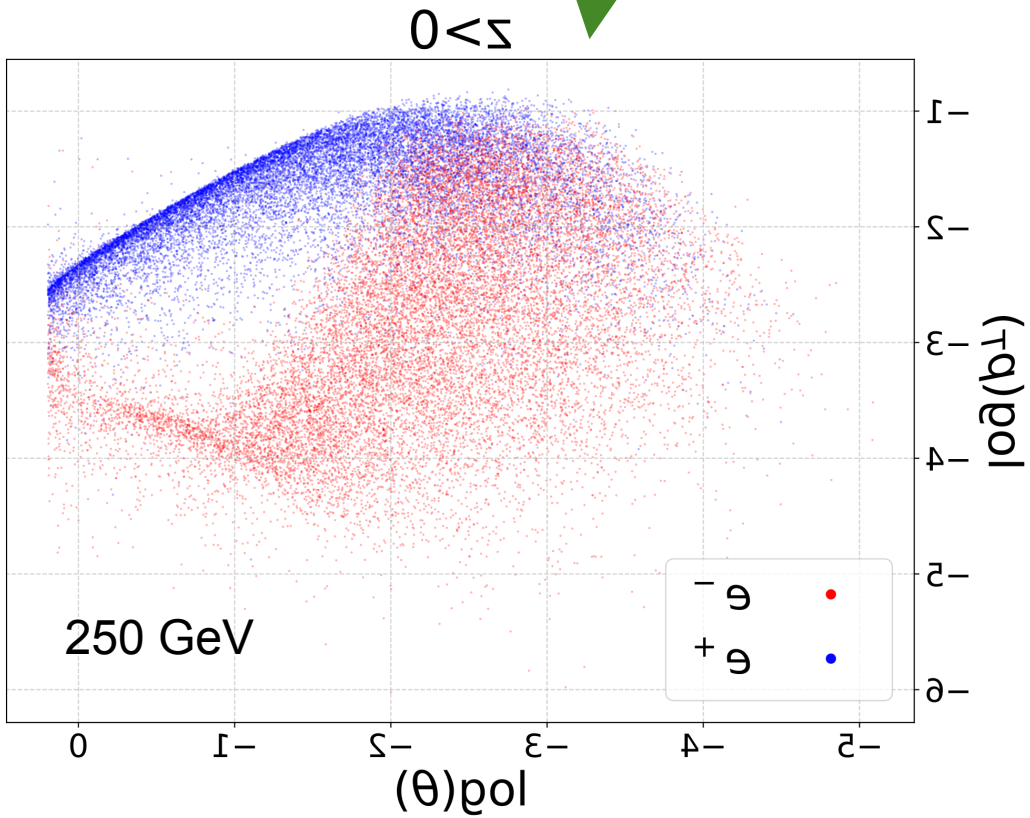
Adapt beam stay clear from ILD@ILC shown here!

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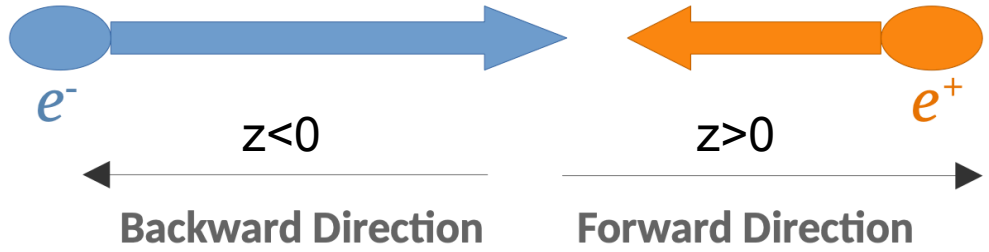


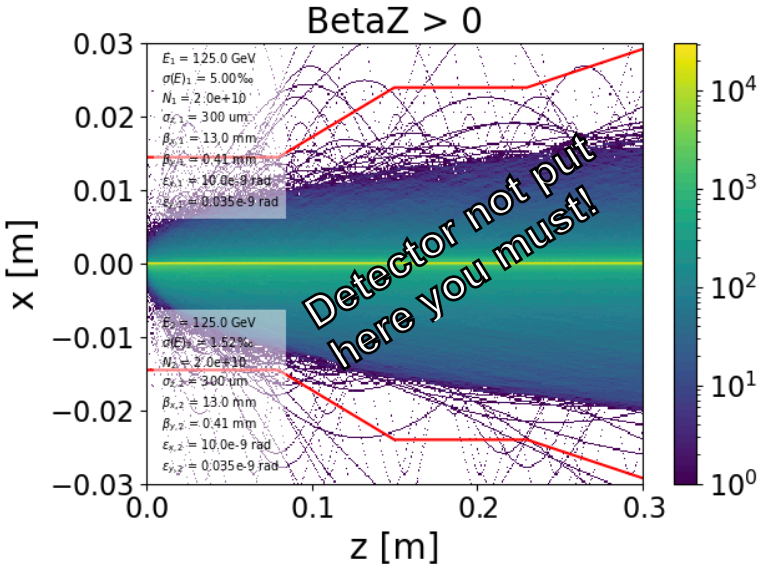


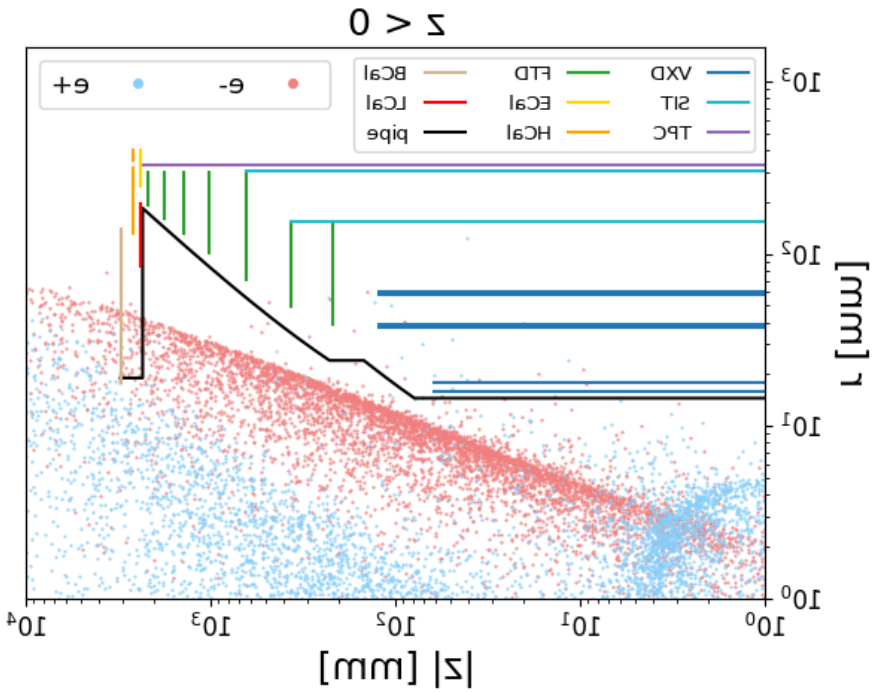


Impact on Detector?

(Symmetric) ILD as example

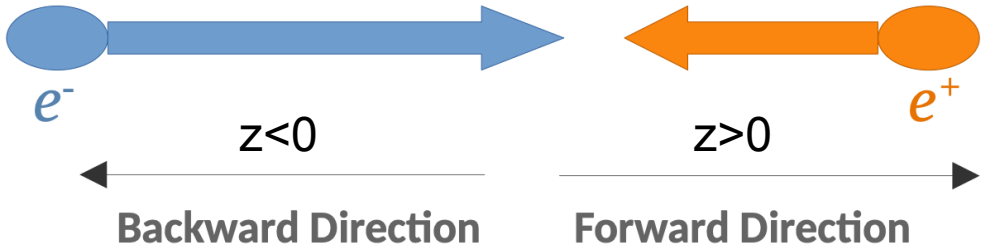




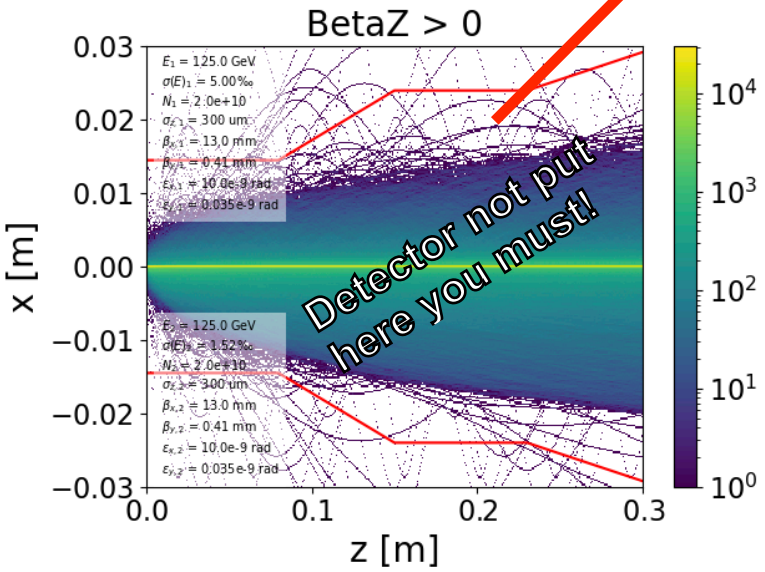


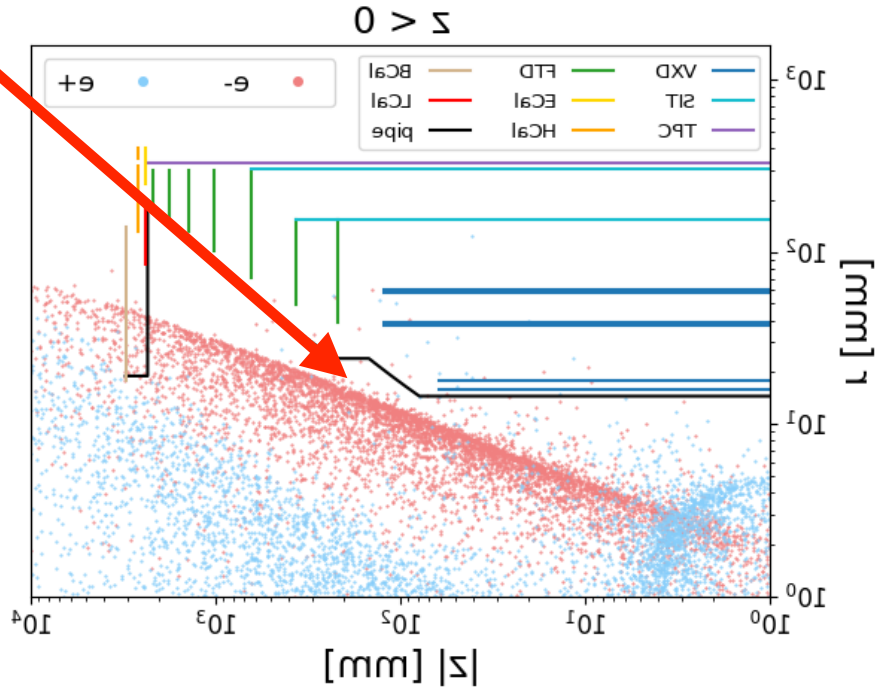
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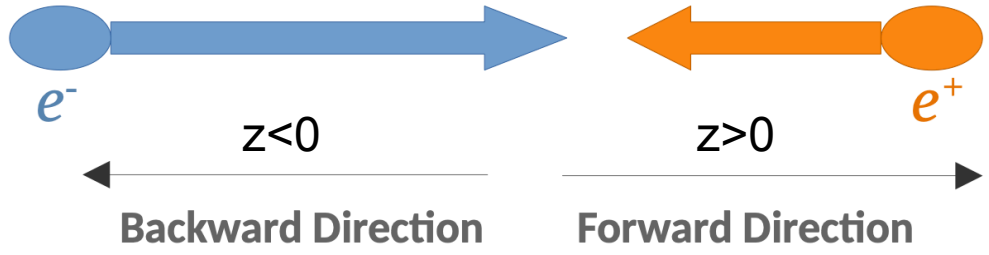
Draw point corresponding to maximal radius of trajectory (B=3.5T)



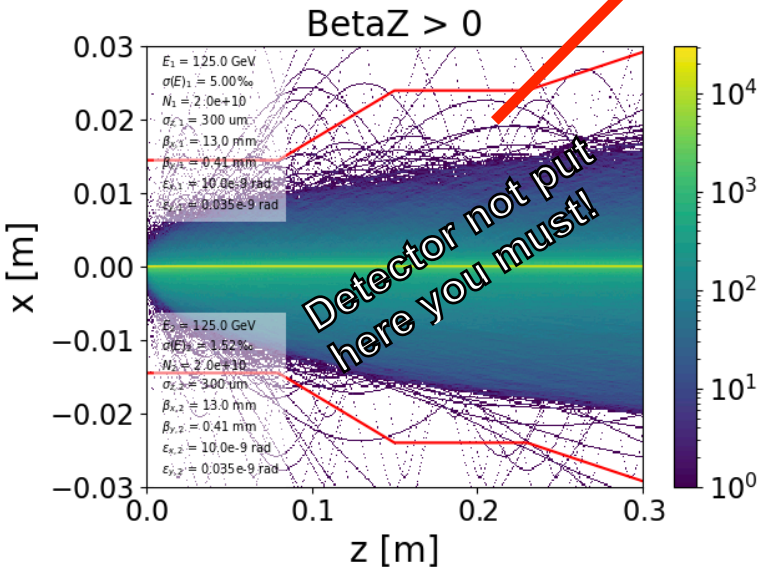


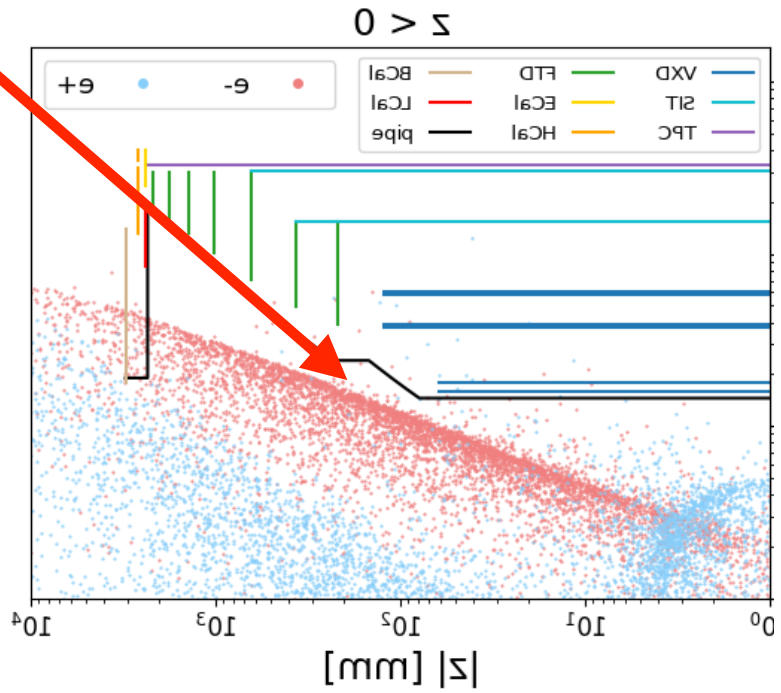
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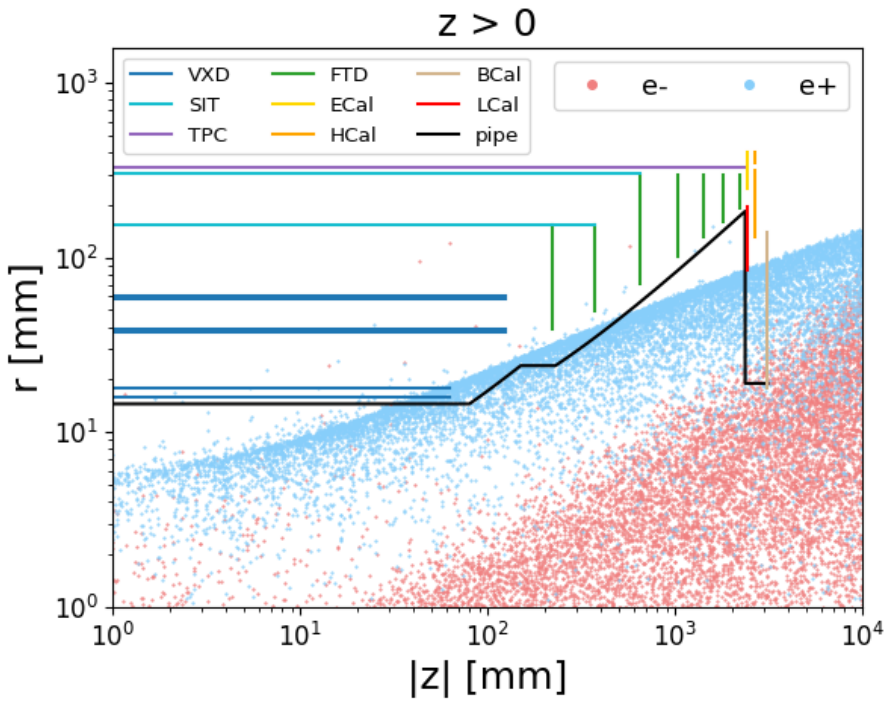
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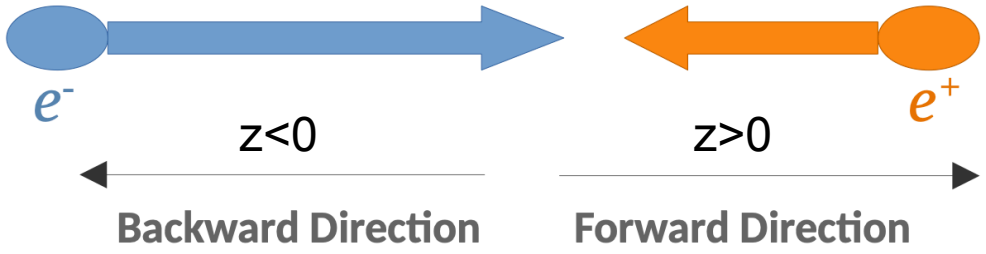




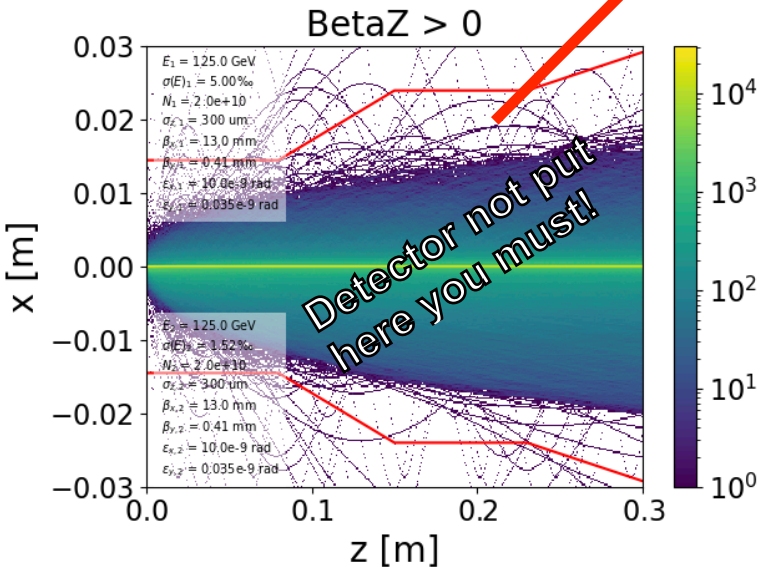


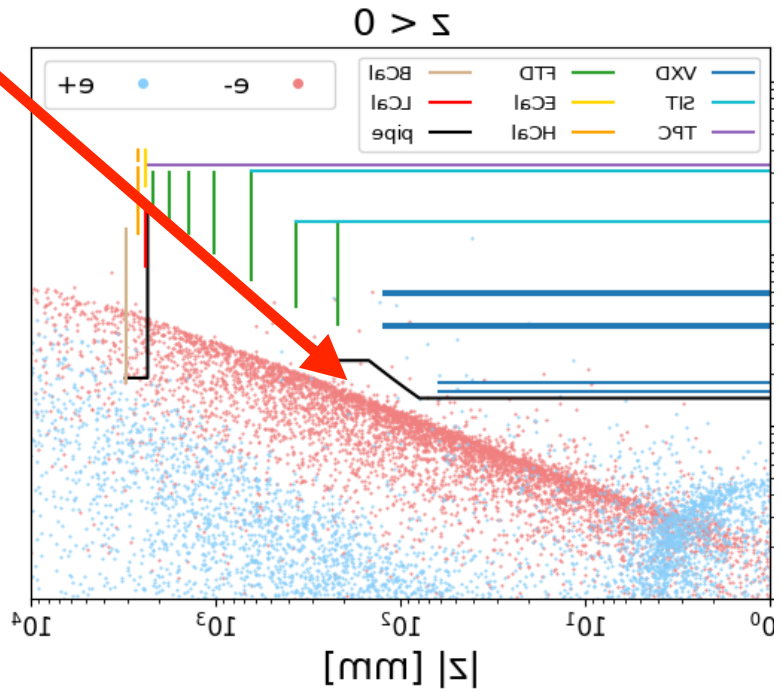
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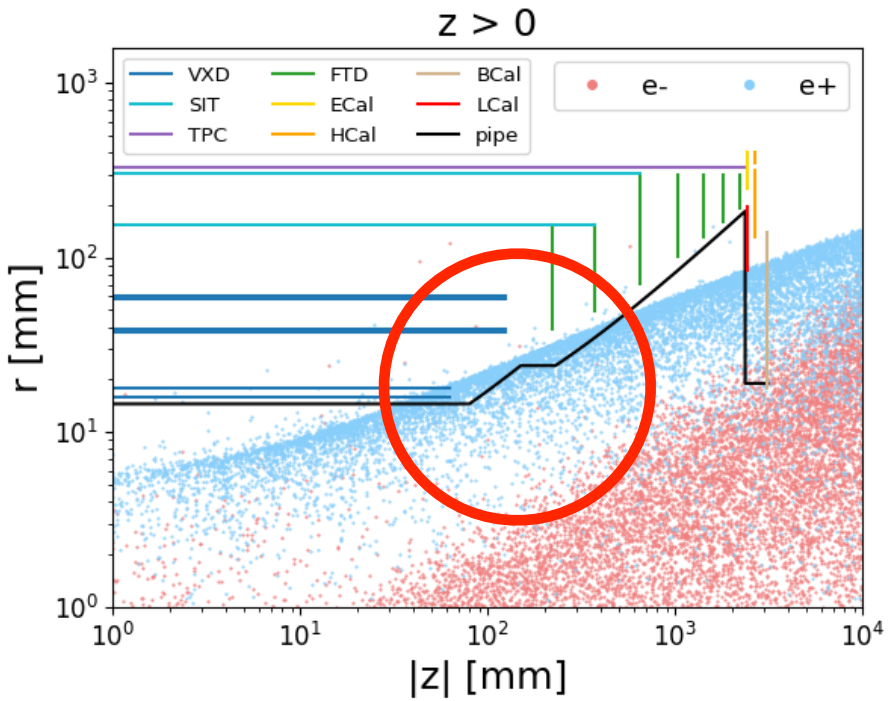
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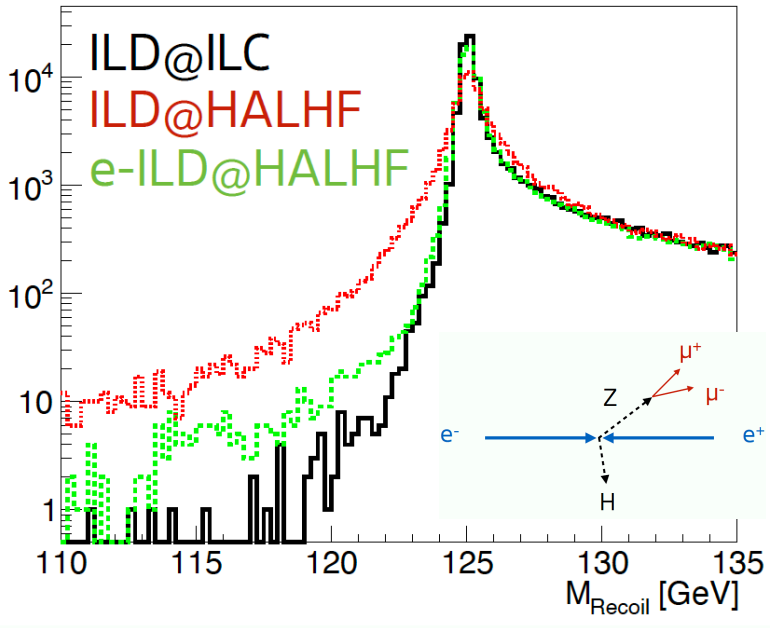


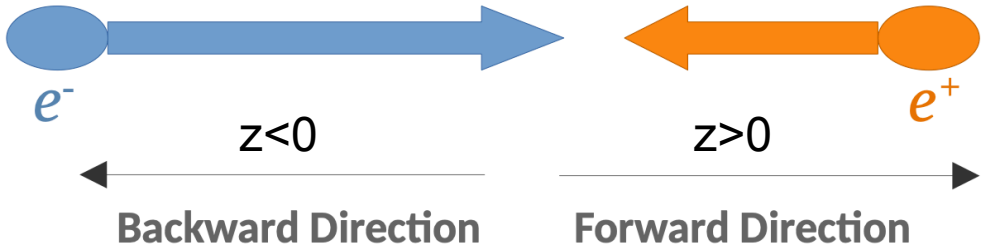


250 GeV: Already this doesn't work
— worse at higher energies

Adapting ILD for HALHF

Version 1 from a few years ago

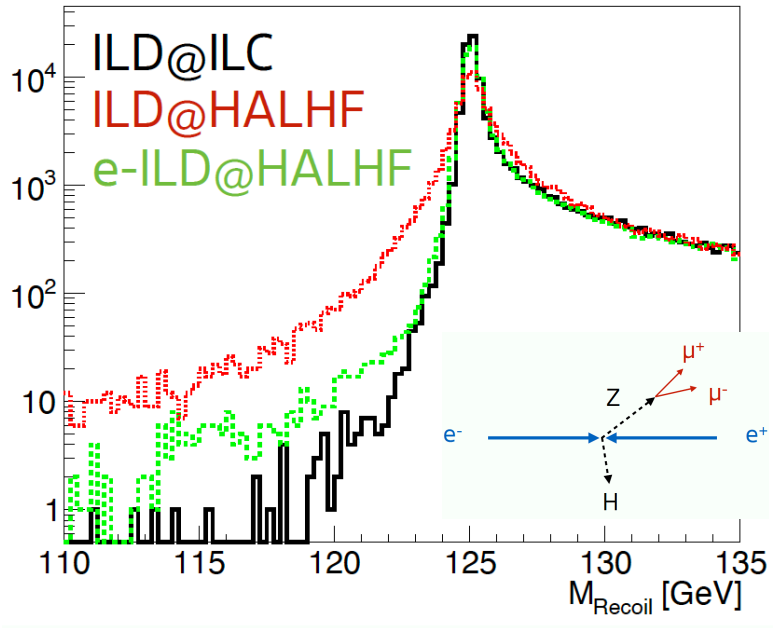


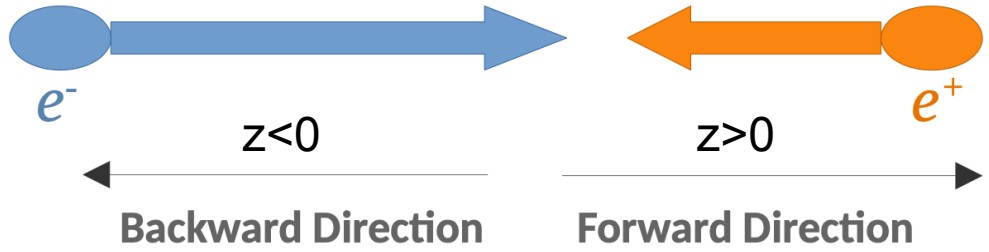


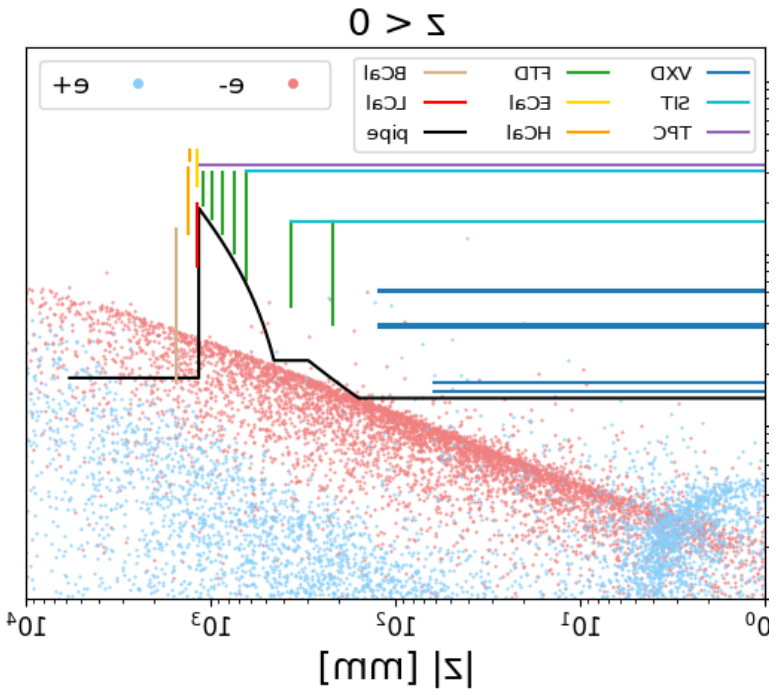
"e-ILD": extended barrel in the forward region to recover momentum resolution eg for Higgs recoil mass measurement

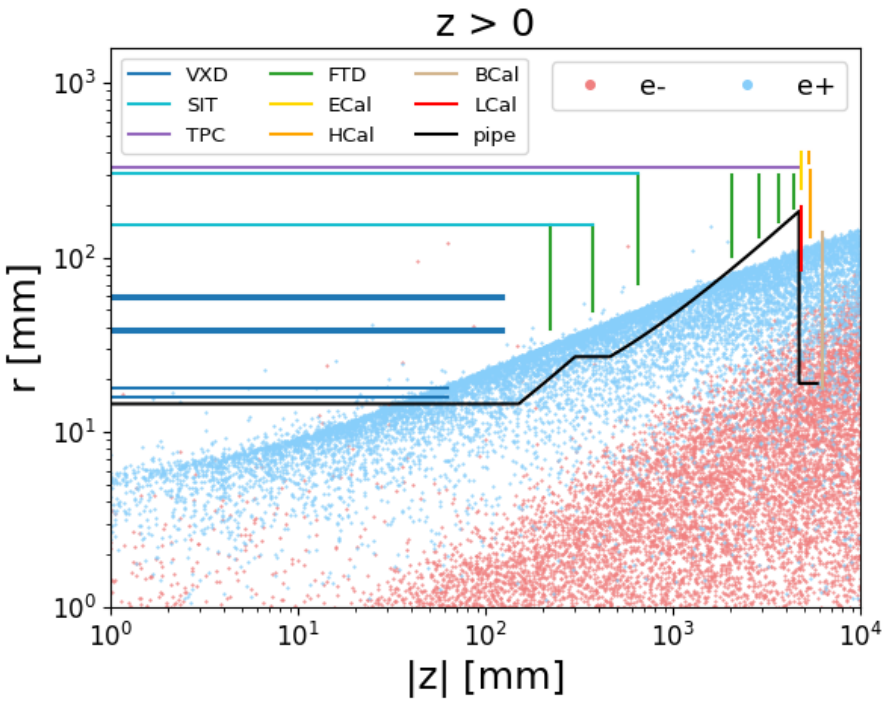
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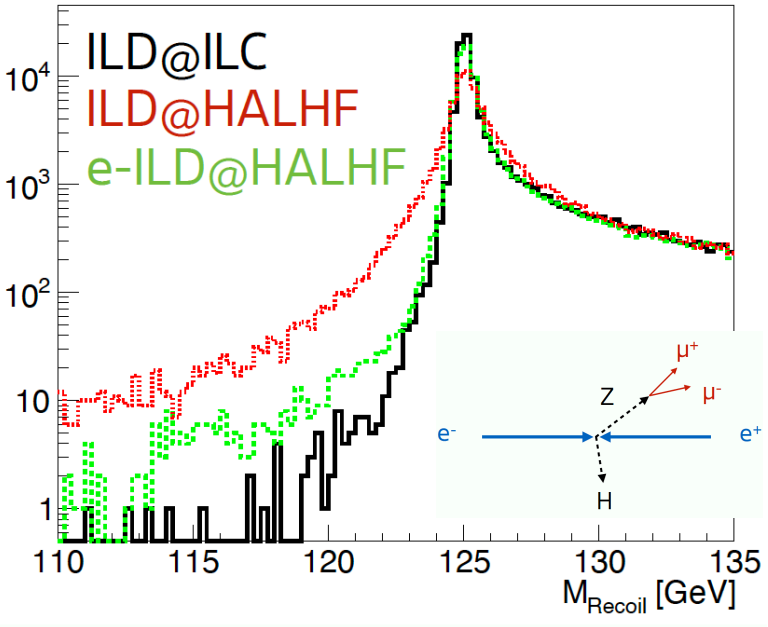


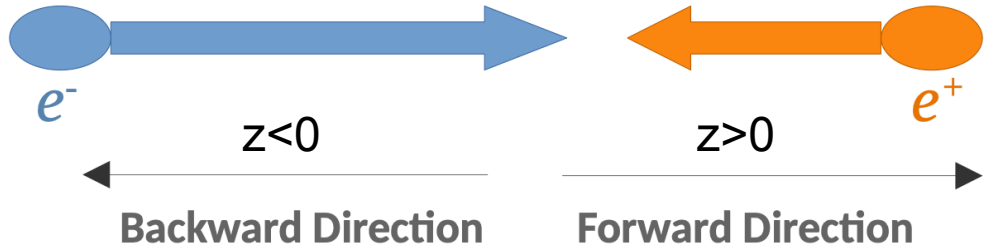


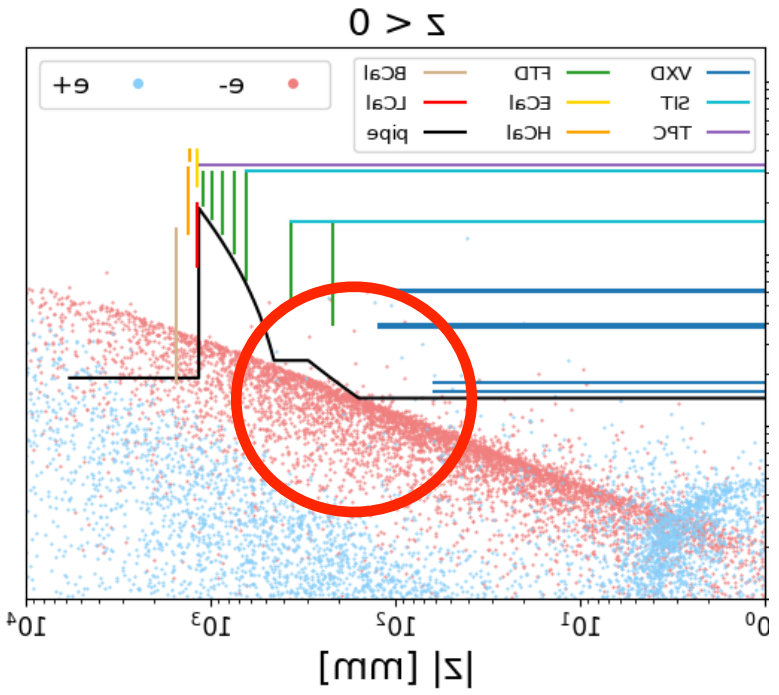
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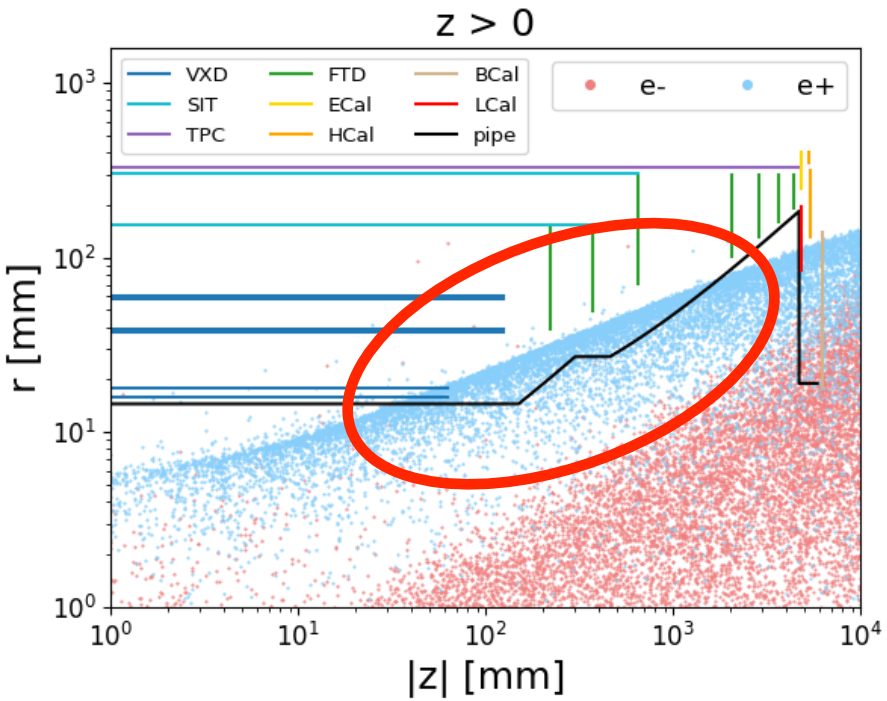
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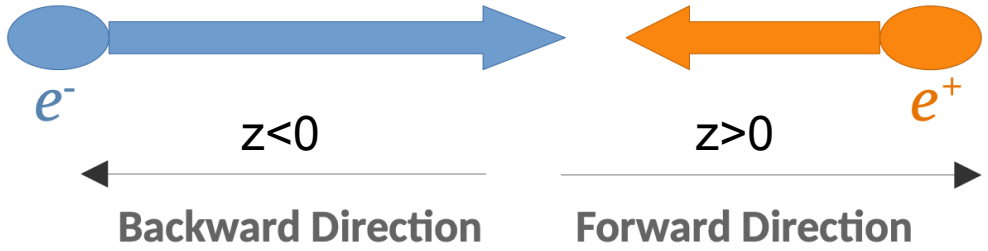


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Adapting ILD for HALHF

Version 2 for pre-CDR

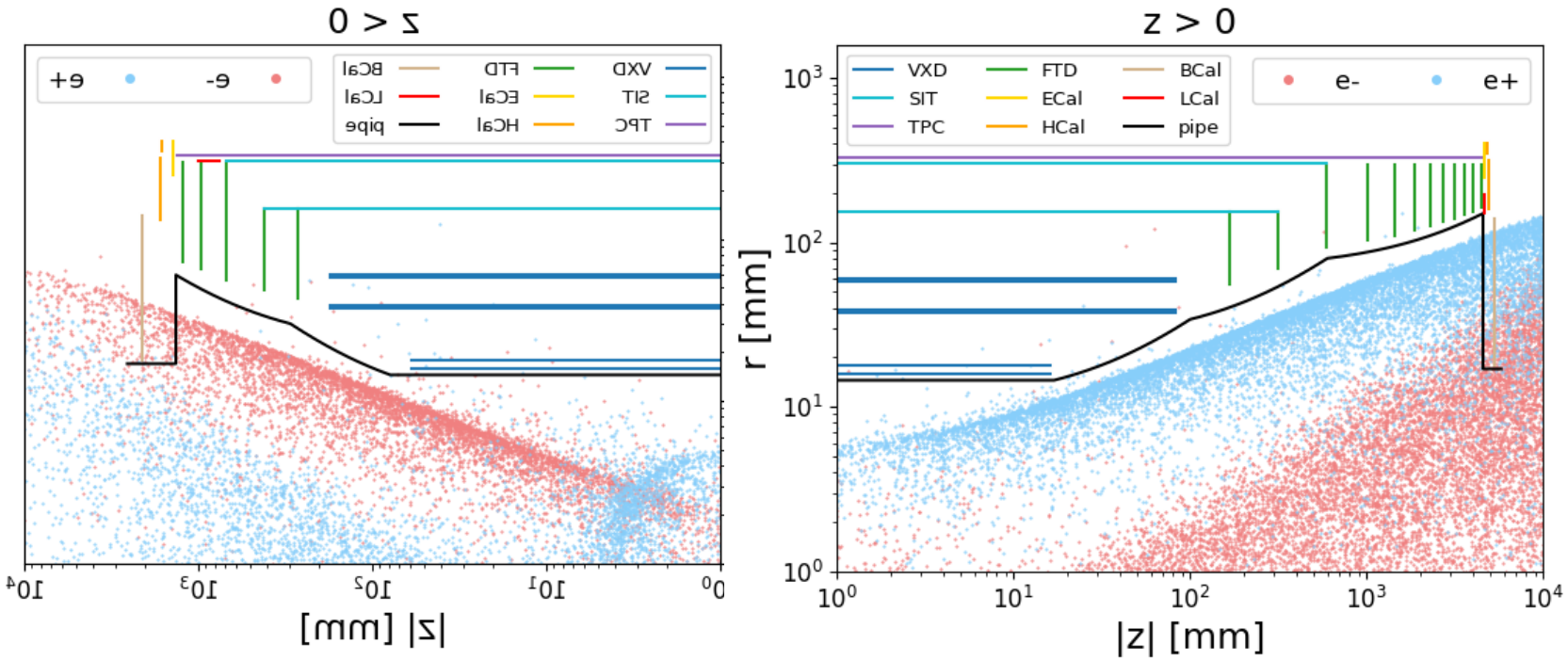


e-ILDv2:

- **Shortened vertex detector**
- **Increased inner radius of FTD discs**
- **Modified beampipe shape**

Not yet addressed:

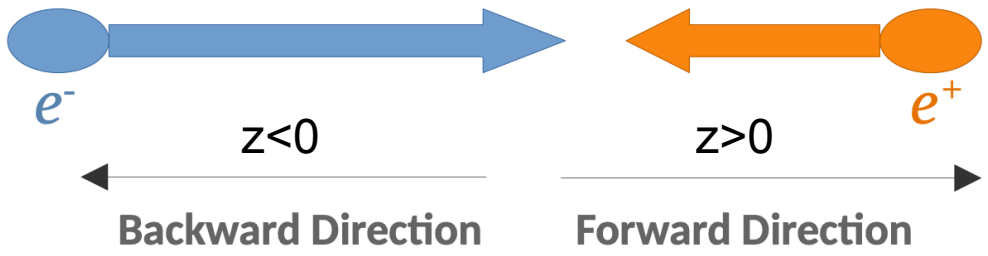
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- **Impact on flavour tagging**
- **Luminosity measurement**
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250 GeV

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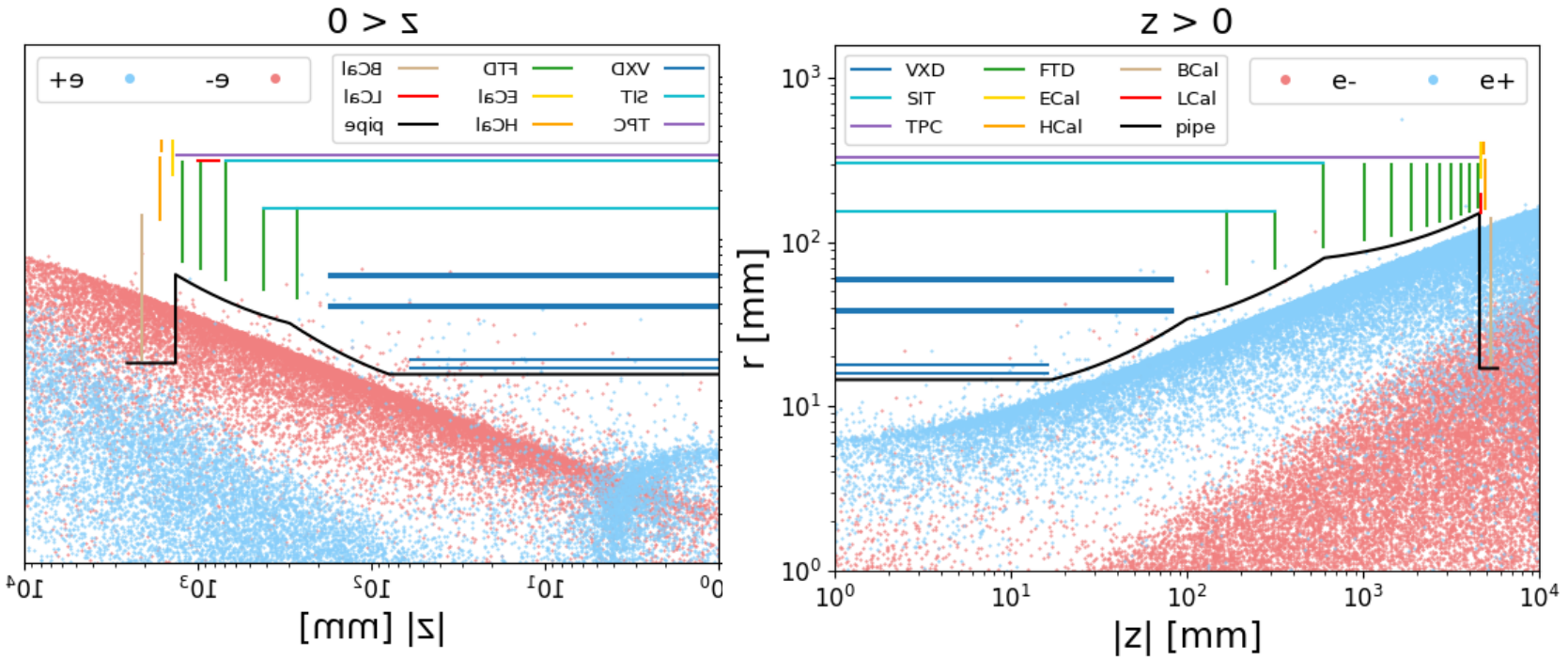


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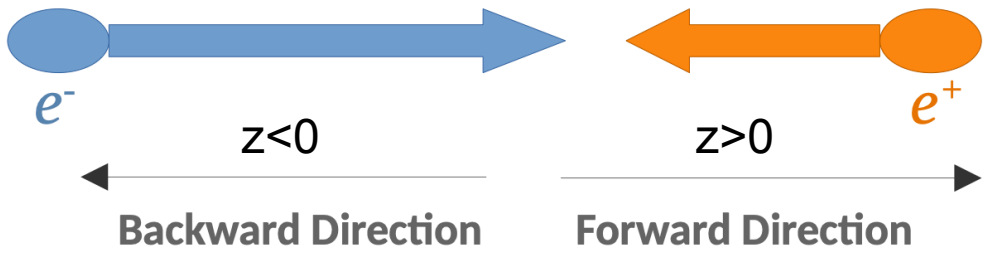
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Also works at 500 GeV

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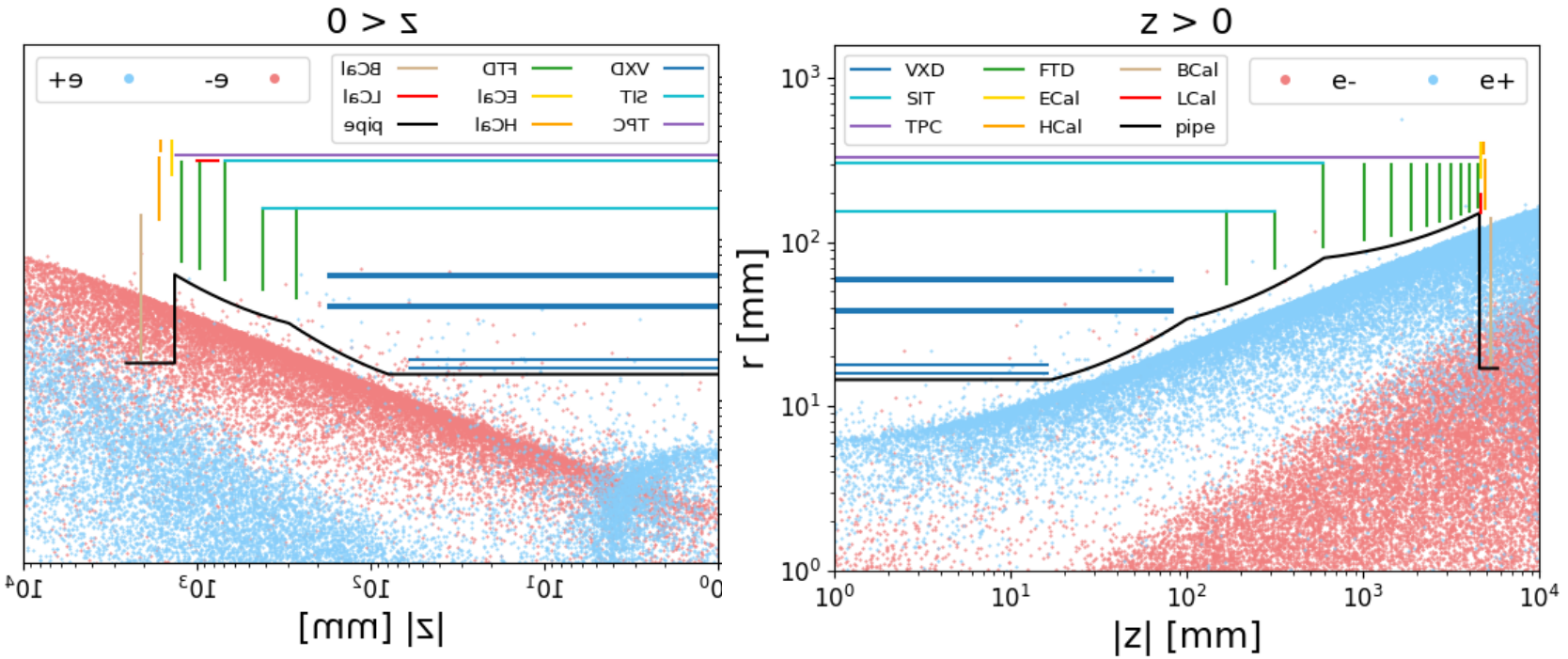


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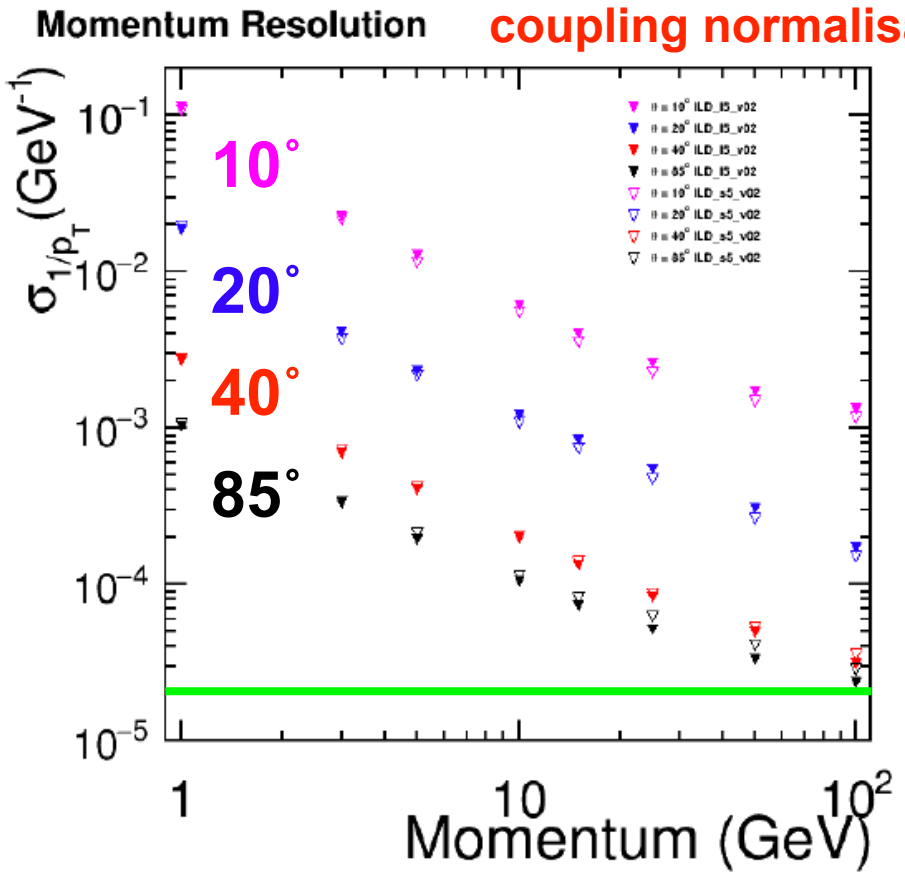
Once these are addressed, check in full simulation…

Also works at 500 GeV

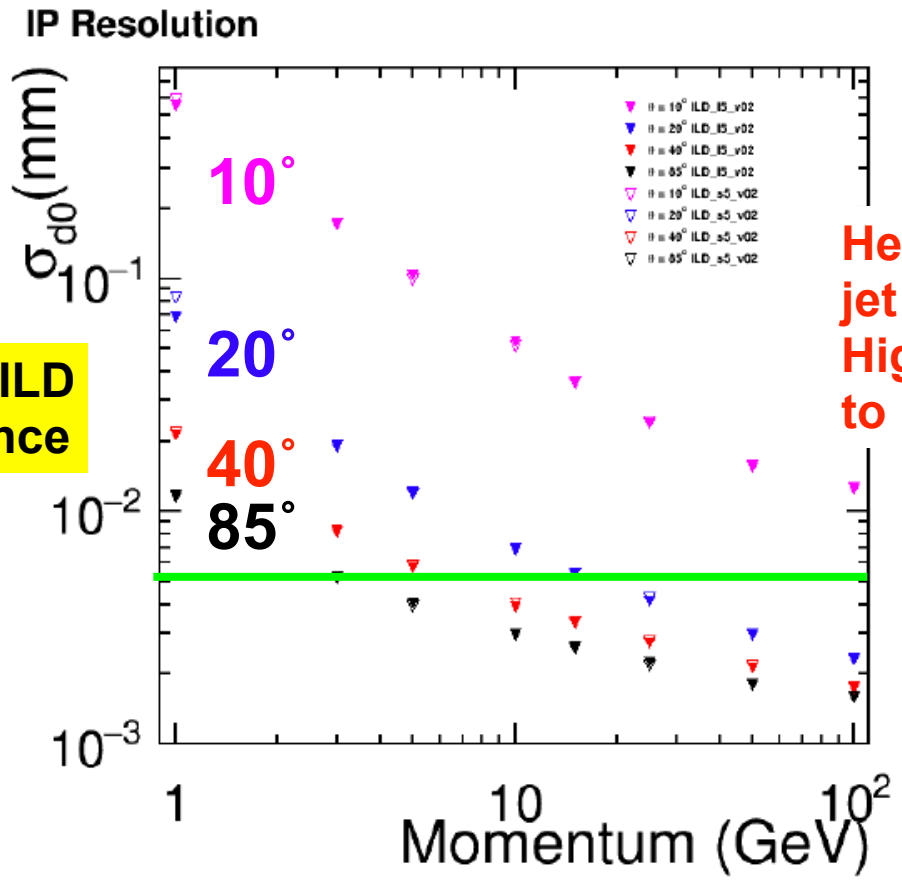
Impact of boost wrt CoM system

Symmetric ILD performance

Higgs recoil / coupling normalisation



standard-ILD performance

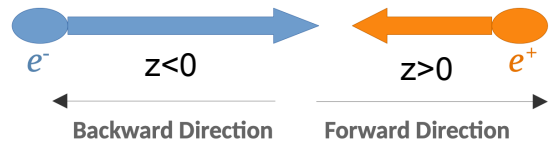


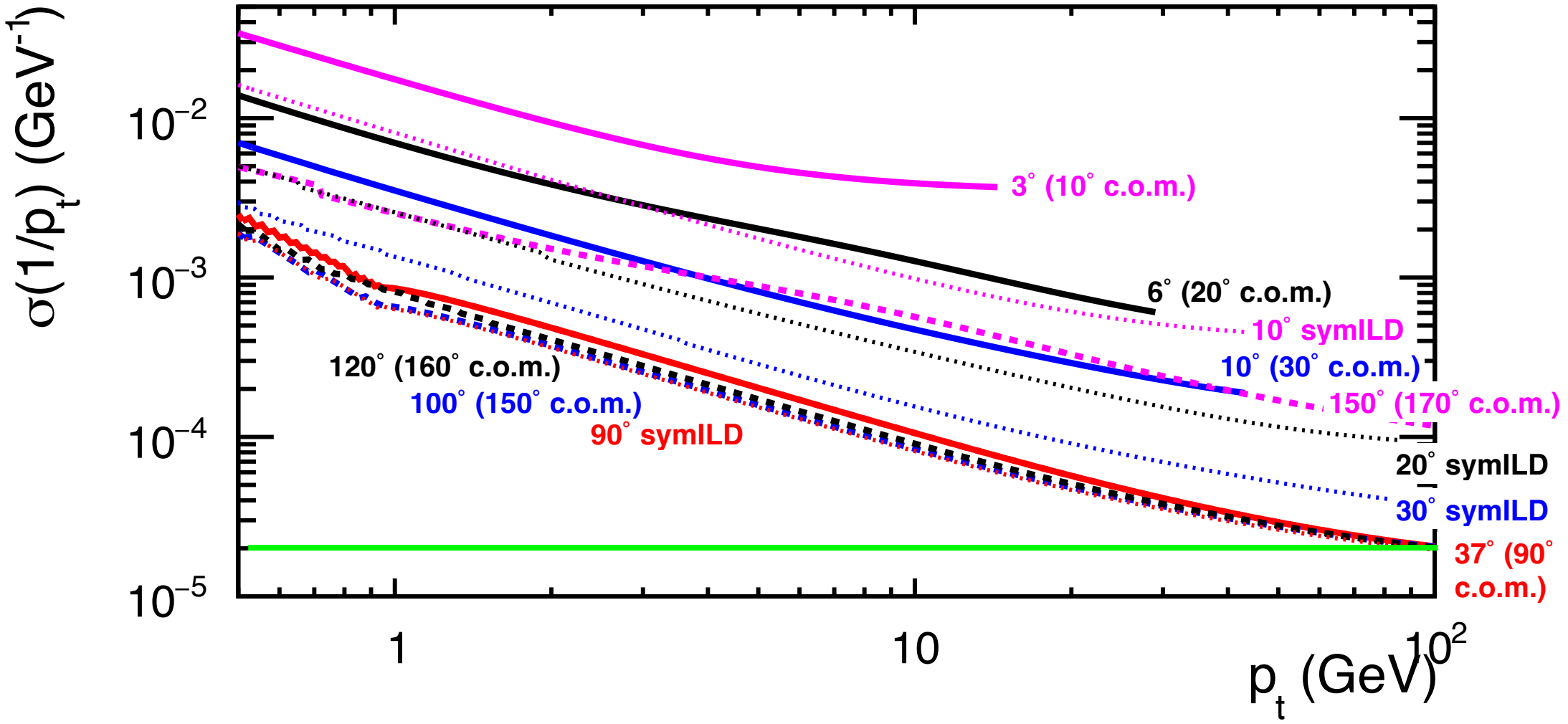
Heavy flavour jet tagging / Higgs decays to bb / cc

- small angles worse due to shallow angle with B-field / loss of VTX coverage
- low momenta worse due to scattering in material

Impact of boost wrt CoM system

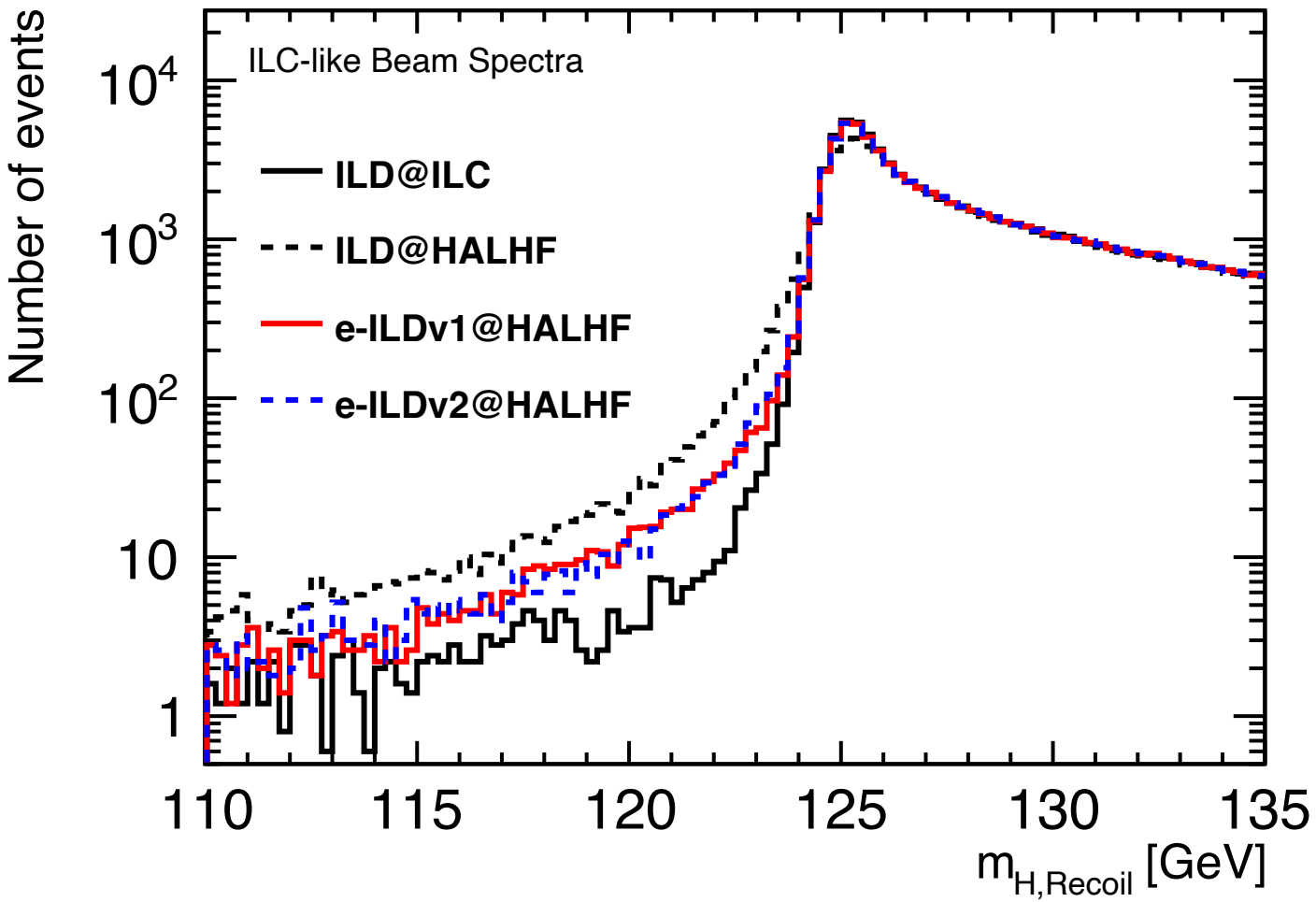
Lorentz-γ = 1.67, e-ILD_v2





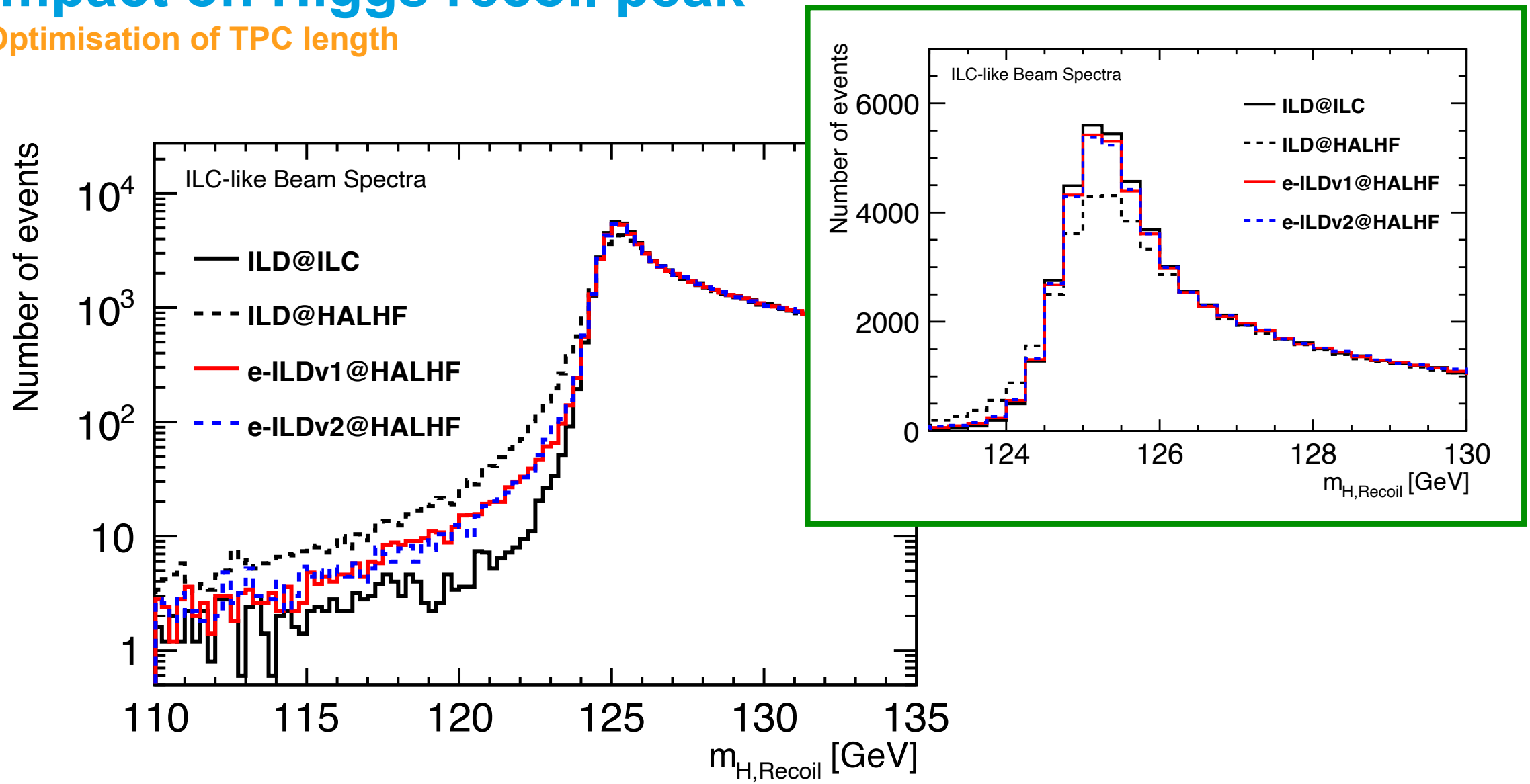
Impact on Higgs recoil peak

Optimisation of TPC length



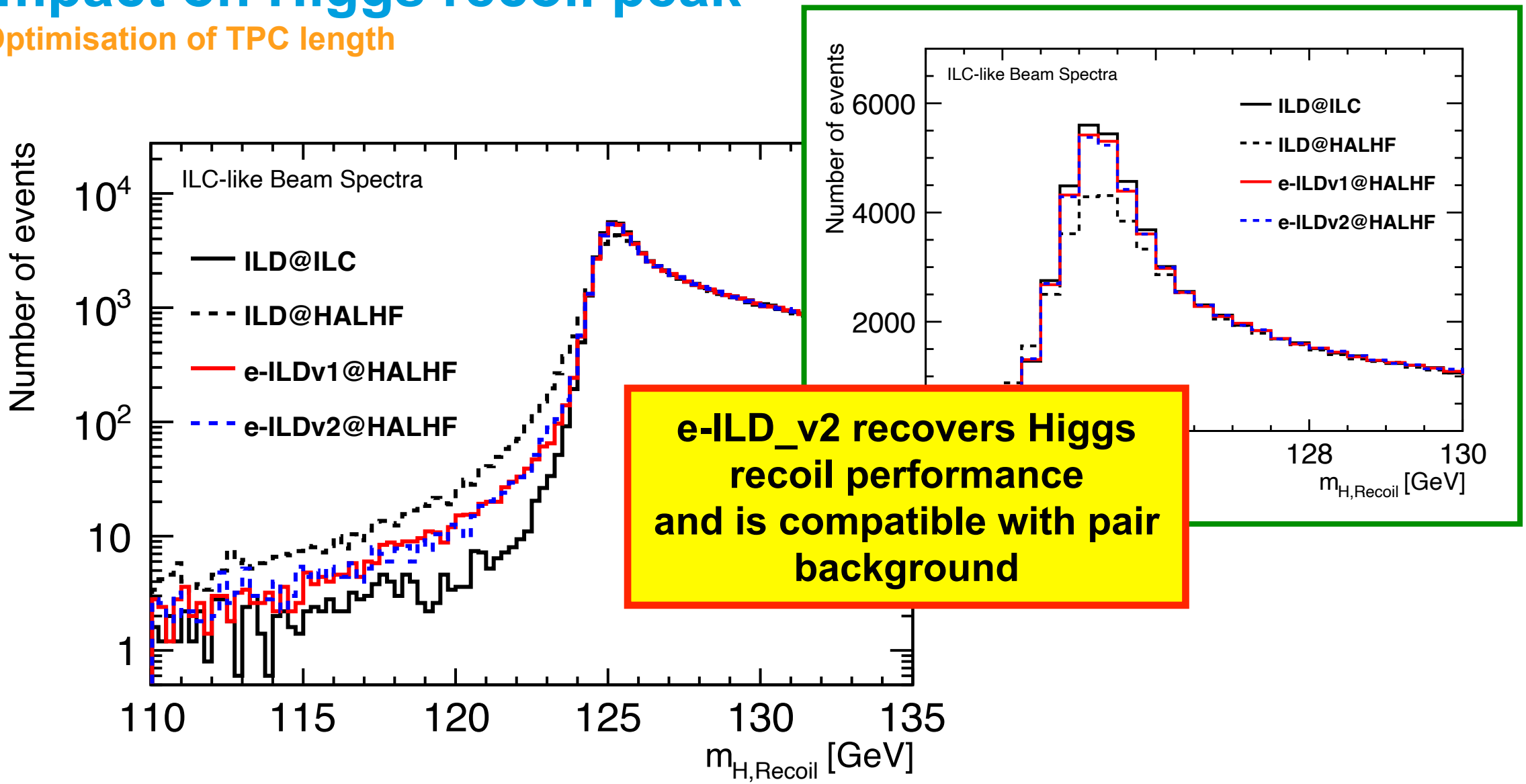
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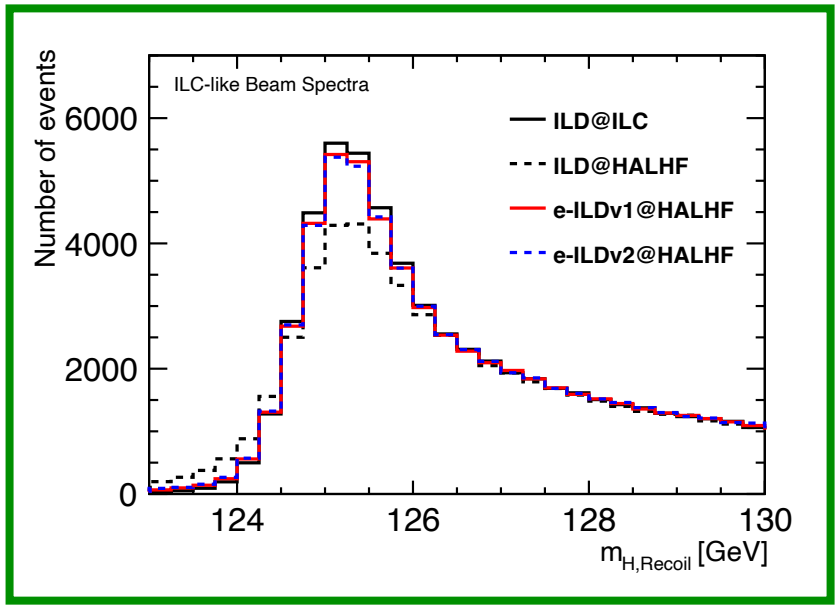
Optimisation of TPC length

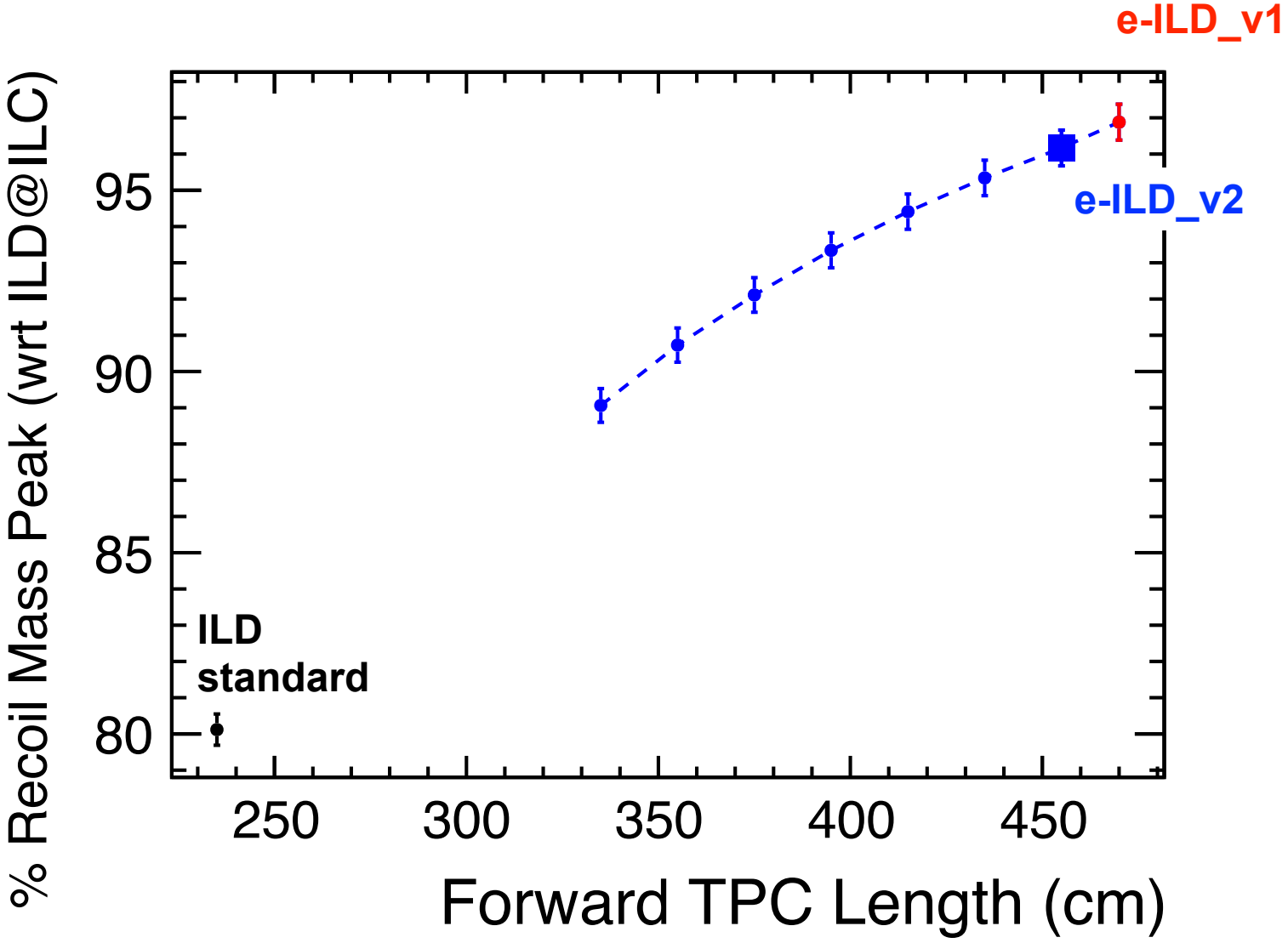


e-ILD_v2 recovers Higgs recoil performance and is compatible with pair background

Impact of TPC length

Full scan





Conclusions & Outlook

A lot of progress - a lot remains to do!

- **A lot of progress on experimental conditions & detector for HALHF**
  - Beam-beam interaction
    - Luminosity spectra
    - Pair background
  - Boost
    - Momentum resolution
    - Higgs recoil peak
- **First ILD version for HALHF recovering Higgs recoil peak & compatible with backgrounds**

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A lot of progress - a lot remains to do!

- **A lot of progress on experimental conditions & detector for HALHF**
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- **First ILD version for HALHF recovering Higgs recoil peak & compatible with backgrounds**
- **Next steps**
  - Incorporate HALHF luminosity spectrum for recoil peak (currently using ILC lumi spectrum)
  - Develop concept for luminosity measurement at HALHF
  - Optimise inner silicon and look at flavour tagging, eg with H->cc
  - Study impact of higher B-field, eg. 4T
  - Include cost considerations: where to compensate for cost increase due to longer TPC?