CLIC Re-baselining: Physics Arguments

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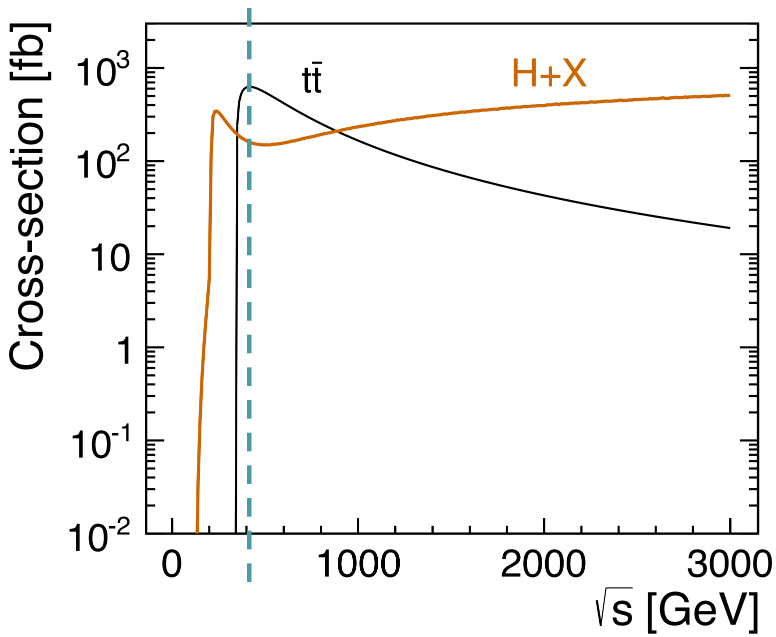
on behalf of CLICdp

CLIC Physics Landscape

CLIC is foreseen as a staged machine:

★ First stage focuses on precision SM physics
- ~350-375 GeV : Higgs and top



★ Not the peak of Higgs cross section
- But, luminosity scales with $\sqrt{s}$

★ 250 GeV and 350 GeV give similar precision for coupling measurements

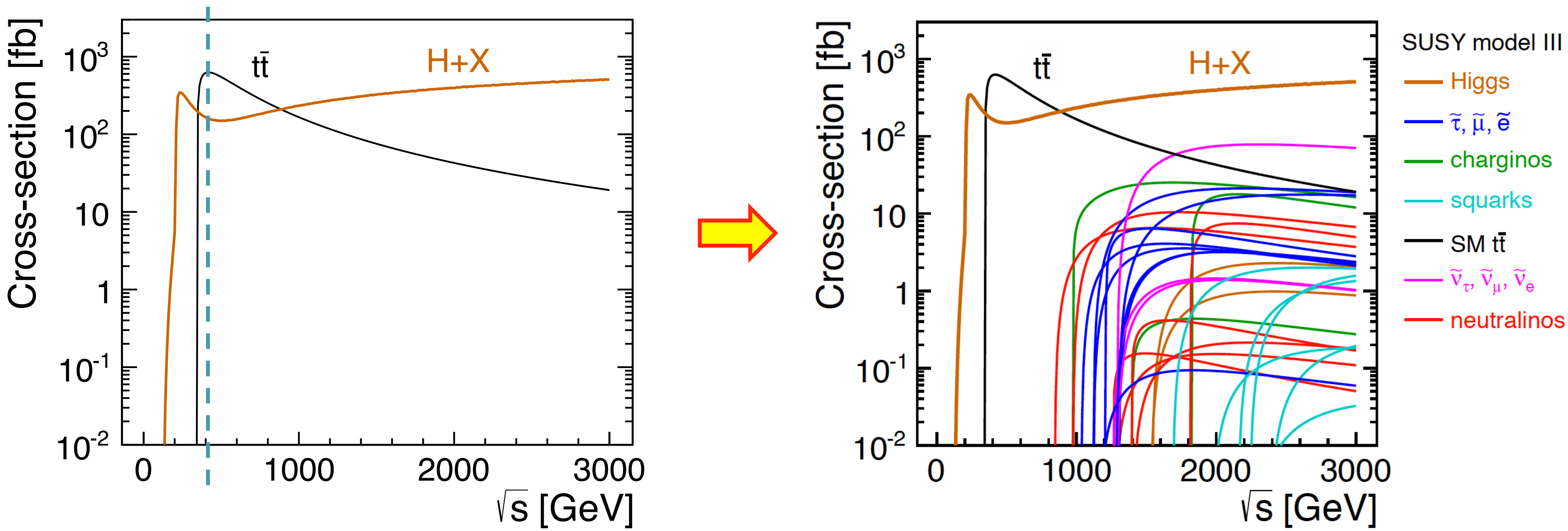
★ With >350 GeV as a first stage:
- provides access to top physics

★ Energies of subsequent stages motivated by physics
- results from ~14 TeV LHC operation
- direct dark matter searches,

The Physics Landscape

★ **For example, illustrative SUSY "Model III*" of Vol.3 of CLIC CDR**
- **Gauginos and sleptons at √s ~ 1.5 TeV**
- **Squarks at √s ~2.5 TeV**

} **Precision measurements at CLIC**



*mSUGRA with non-universal squark masses with tanβ = 10, Allanach *et al.*, CERN LCD-Note 2012-003

The Physics Landscape

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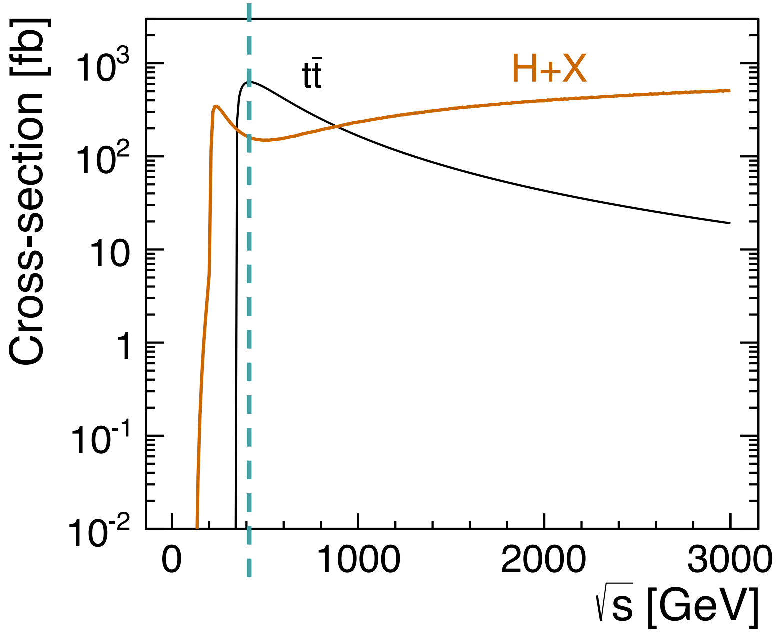
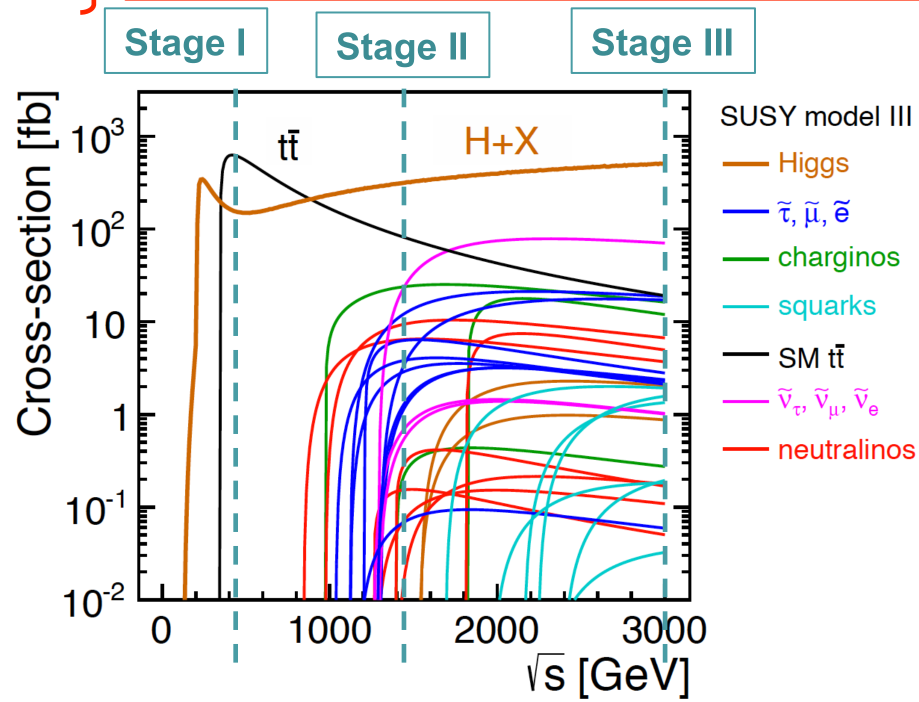
Precision measurements at CLIC





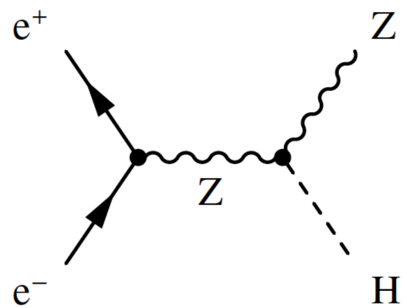
For example: (CDR)

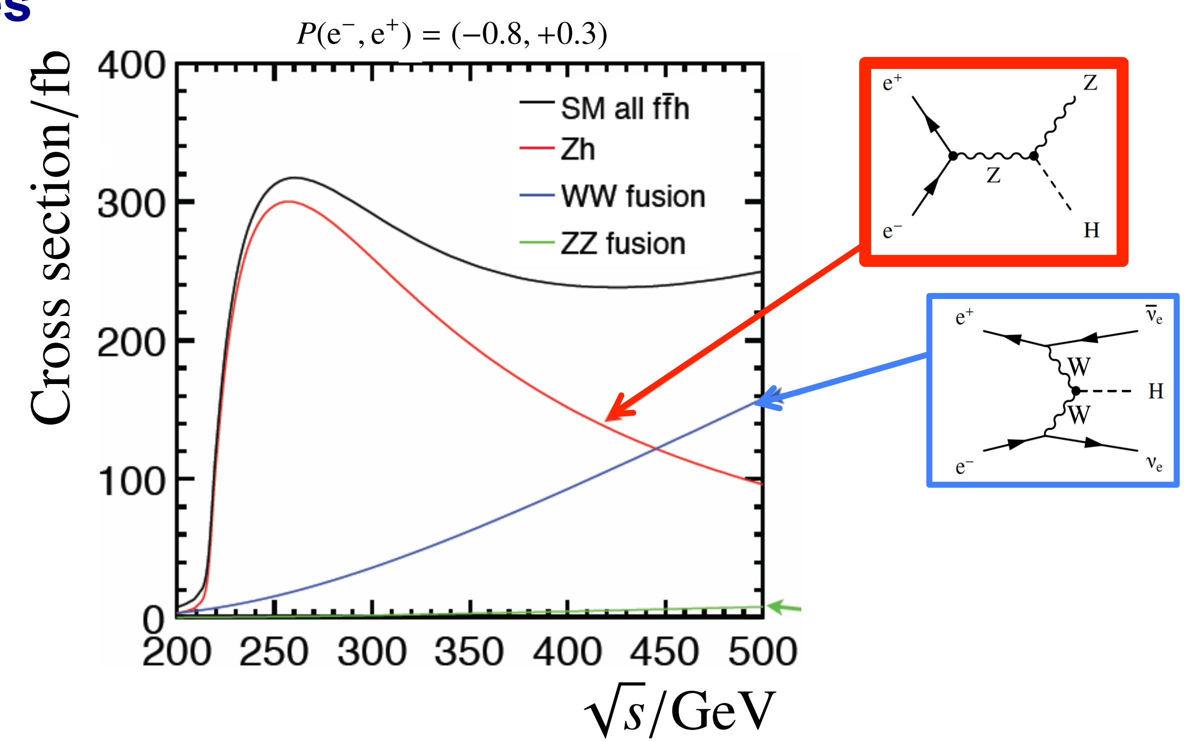
Stage I	~350 GeV	Higgs, Top
Stage II	~1.5 TeV	Higgs, gauginos, sleptons
Stage III	~ 3 TeV	Higgs, squarks, ?

Standard Model Higgs

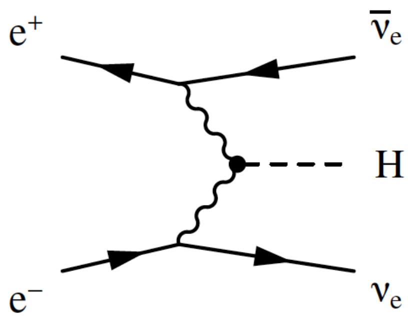
★ A number of SM Higgs processes accessible at CLIC

★ Below √s ~ 300 GeV
Higgs-strahlung dominates





★ Above √s ~ 500 GeV
WW fusion dominates

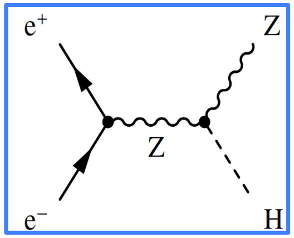


★ At √s ~ 350-450 GeV both contribute

Why Does it Matter

★ **Higgs-strahlung**

Total HZ cross section (recoil mass)



$$\sigma(\mathrm{HZ}) \propto g^2_{\mathrm{HZZ}}$$

+exclusive cross sections

$$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \rightarrow XX) \propto g^2_{\mathrm{HZZ}} \cdot \frac{g^2_{\mathrm{H}XX}}{\Gamma_{\mathrm{H}}}$$

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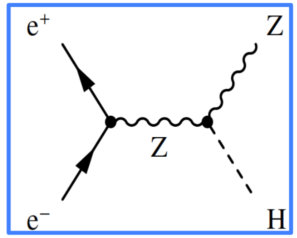

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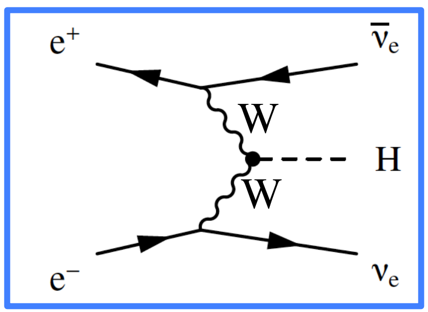
★ Total Higgs width determined from WW fusion process



e.g.

$$\frac{\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \rightarrow \mathrm{b\bar{b}})}{\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \rightarrow \mathrm{b\bar{b}})} \propto \frac{g^2_{\mathrm{HZZ}}}{g^2_{\mathrm{HWW}}}$$

$$\Rightarrow g_{\mathrm{HWW}}$$

and

$$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \rightarrow \mathrm{WW}^*) \propto \frac{g^4_{\mathrm{HWW}}}{\Gamma_{\mathrm{H}}}$$

$$\Rightarrow \Gamma_{\mathrm{H}}$$

everything else follows…. all fully M.I.

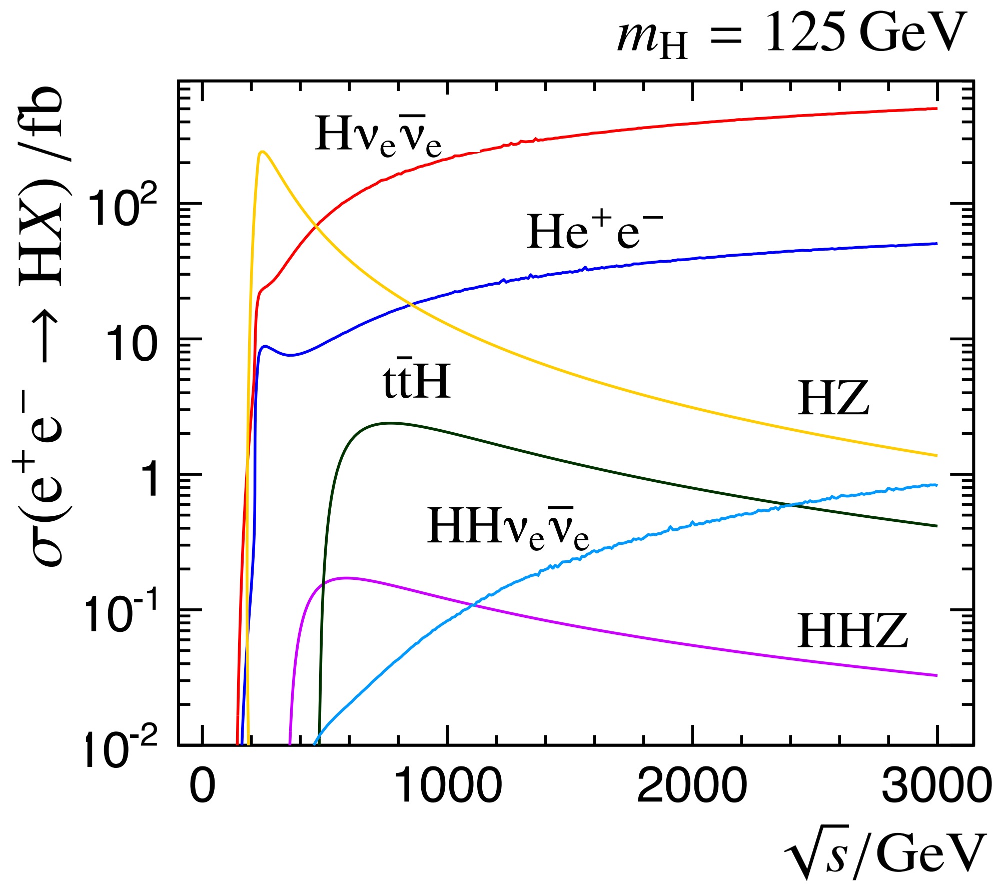
First CLIC Stage

★ **Mandatory measurement: HZ cross section**

- Fixes scale of all other Higgs cross sections: Model Independence
- Cross section falls away at higher energies

HZ production

⇨ $\sqrt{s}$ ~ 250-450 GeV

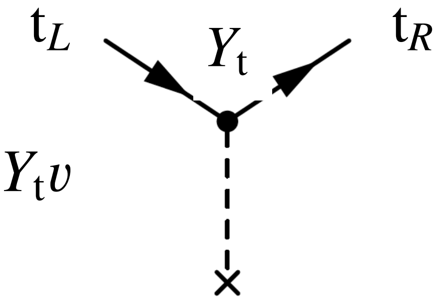


Top Physics

★ **The top quark appears to be special**

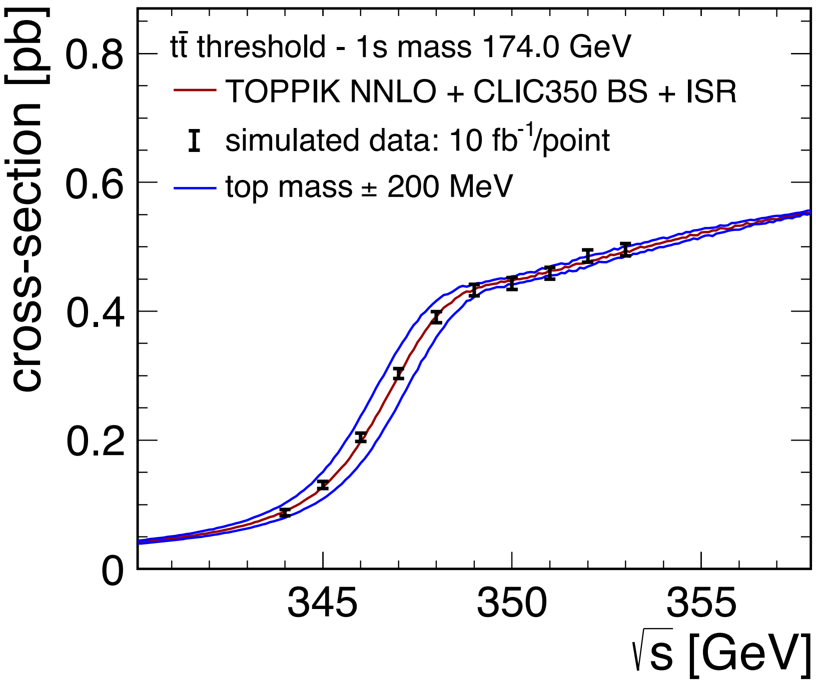
- **fermion mass at the electroweak scale**
- **Yukawa coupling suspiciously close to 1**

$$m_t = \frac{1}{\sqrt{2}} Y_t v$$



★ **CLIC @ √s > 350 GeV ⇨ precision top physics**

- **e.g. top quark mass from threshold scan**



★ **Scan with modest lumi (10 fb^{-1}/pt):**

⇨ m_t : ±33 MeV (stat.)

- **measurement relatively easy to interpret – "know what you are measuring"**
- **theory uncertainties relatively small**

HZ production

⇨ $\sqrt{s}$ ~ 250-450 GeV

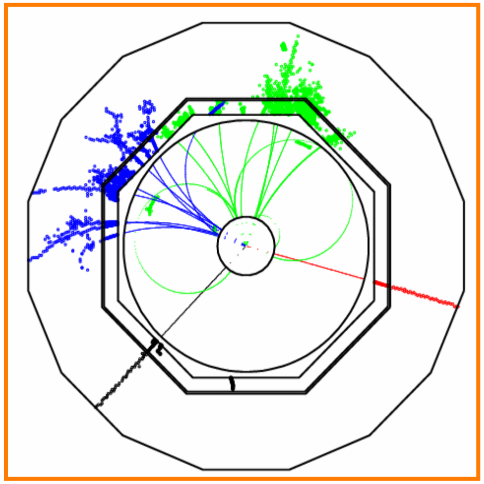
Top at theshold

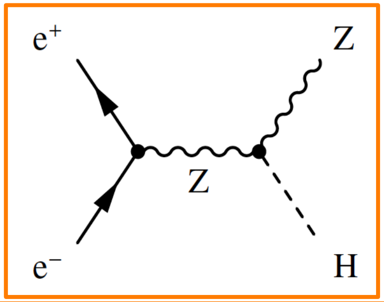
⇨ $\sqrt{s}$ > 350 GeV

What is optimal ?

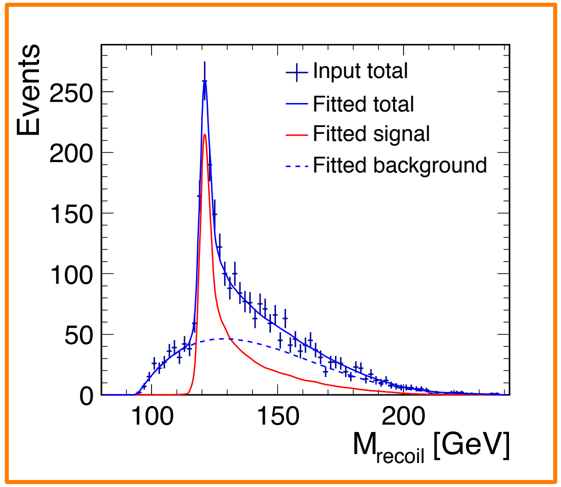
HZ Cross Section revisited

★ During first stage of CLIC: study the Higgs-strahlung process





★ **<u>Model independent</u> analysis**
- Select Higgs from mass recoiling against leptonically decaying Z
- Measure Higgs BRs



★ Measure Higgs production cross section independent of Higgs decay
- Sensitive to invisible Higgs decay modes
- Absolute measurement of HZ coupling

★ Recent studies demonstrated:

MI measurements with $Z \to q\bar{q}$

What Energy ?

★ **Recoil mass**

$$m_{\text{rec}}^2 = (\sqrt{s} - E_Z)^2 - (-\mathbf{p}_Z)^2$$
$$= s - 2\sqrt{s}\,E_Z + E_Z^2 - \mathbf{p}_Z^2$$
$$= s + m_Z^2 - 2\sqrt{s}(E_1 + E_2)$$

E_1 & E_2 are jet energies

$$\Rightarrow \quad \sigma_{m_{\text{rec}}} = \frac{\sqrt{s}}{m_{\text{rec}}}\left(\sigma_1^2 + \sigma_2^2\right)^{\frac{1}{2}}$$

for PFA: $\sigma_{E_{\text{jet}}} \sim \alpha E_{\text{jet}}$

$$\sigma_{m_{\text{rec}}} = \frac{1}{\sqrt{8}m_{\text{rec}}}\alpha\left(s - m_H^2 + m_Z^2\right)$$

$$\Rightarrow \quad \sigma_{m_{\text{rec}}} \sim s$$

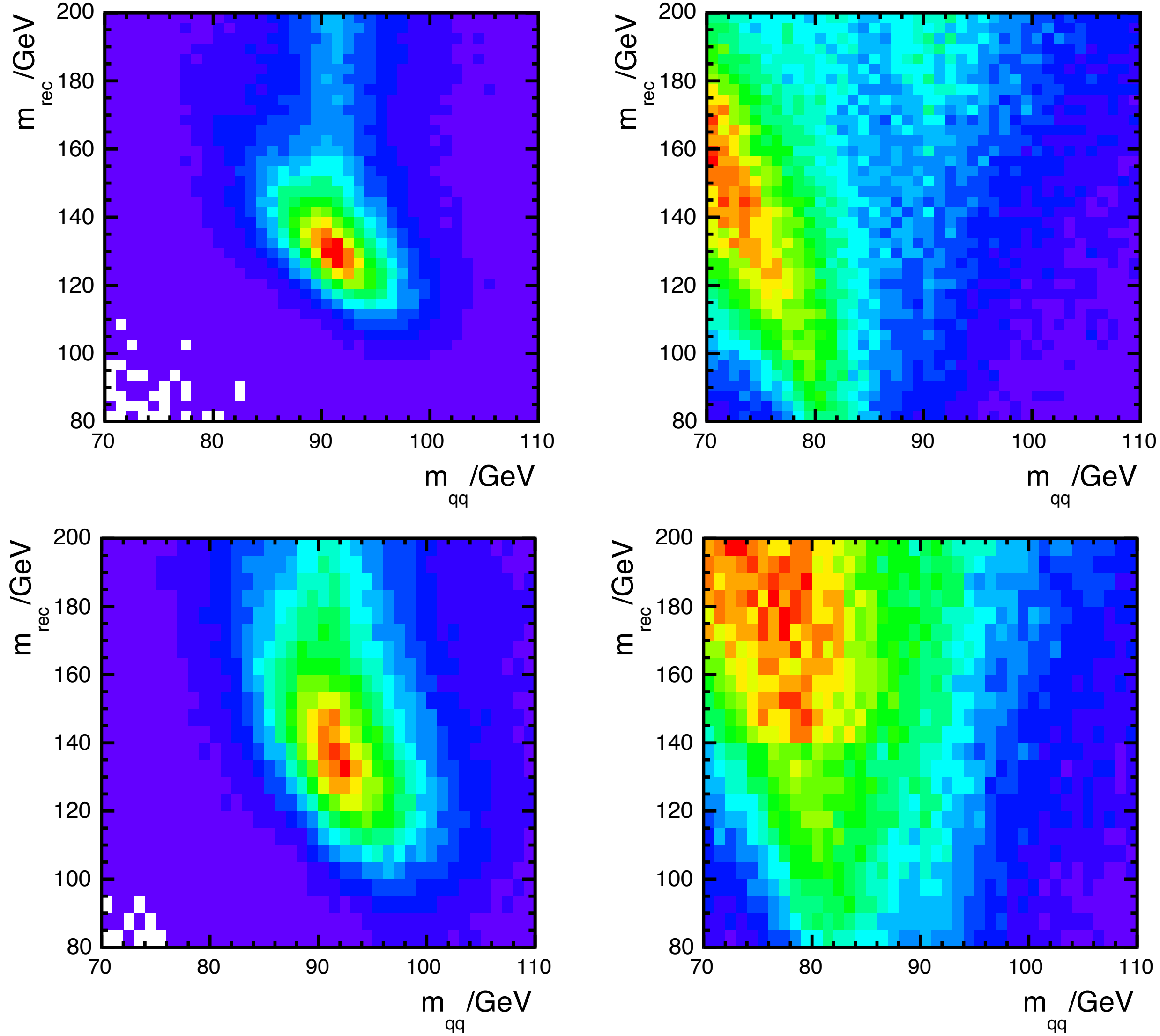
★ **Recoil mass resolution approximately scales with squared C.o.M. energy**

Simulation

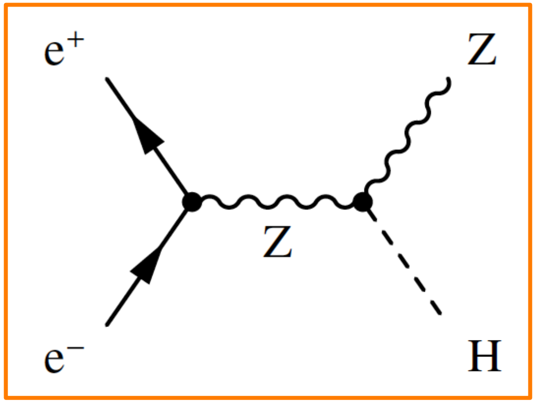
Full Simulation

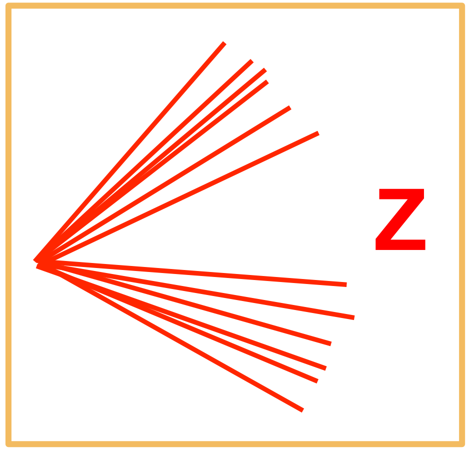
350 GeV

420 GeV



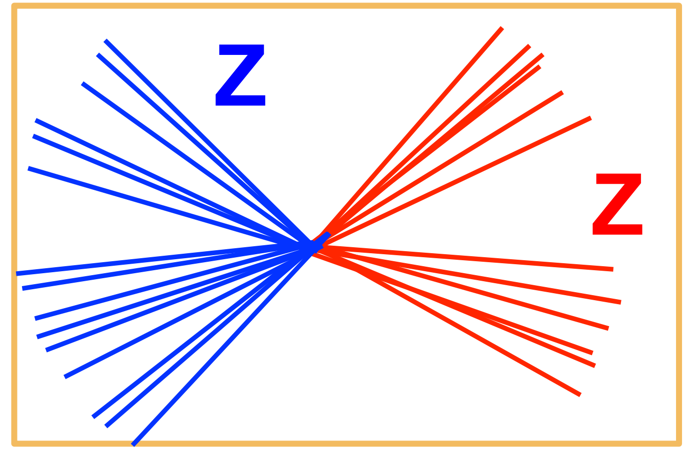
Summary: 350 GeV vs 420 GeV





invisible

+



visible

		350 GeV	420 GeV	
	$\Delta\sigma(HZ)_{vis}$	1.7 %	2.4 %	x 1.4
500 fb^{-1}	$\Delta\sigma(HZ)_{invis}$	0.6 %	1.0 %	x 1.8
	$\Delta\sigma(HZ)$	1.8 %	2.6 %	x 1.5

★ **Big hit in going from 350 GeV → 420 GeV: ~factor 2 in luminosity**

HZ production

⇨ $\sqrt{s}$ ~ 250-450 GeV

Top at theshold

⇨ $\sqrt{s}$ > 350 GeV

Recoil Mass

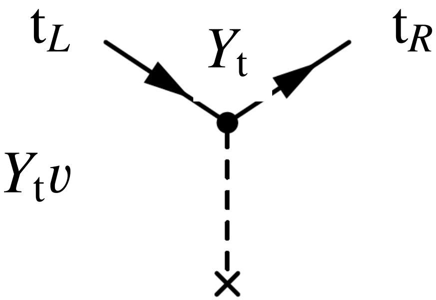
⇨ $\sqrt{s}$ < 400 GeV

What about top?

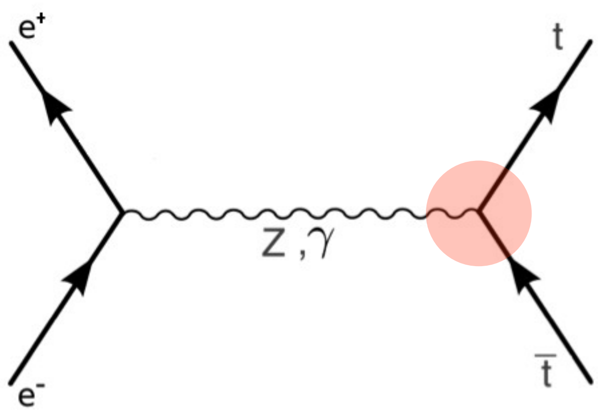
New: see Marcel Vos's talk from yesterday

- ★ **The top quark appears to be special**
  - **fermion mass at the electroweak scale**
  - **Yukawa coupling suspiciously close to 1**

$$m_\mathrm{t} = \frac{1}{\sqrt{2}} Y_\mathrm{t} v$$



- ★ **Various BSM models**
  - **e.g. composite top**
  - **predict modifications to top quark coupling to photon and Z**
  - **probe through top quark production above threshold**



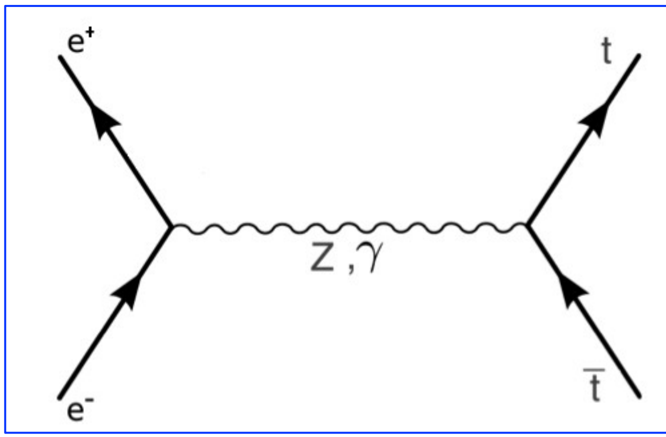
Form factors:

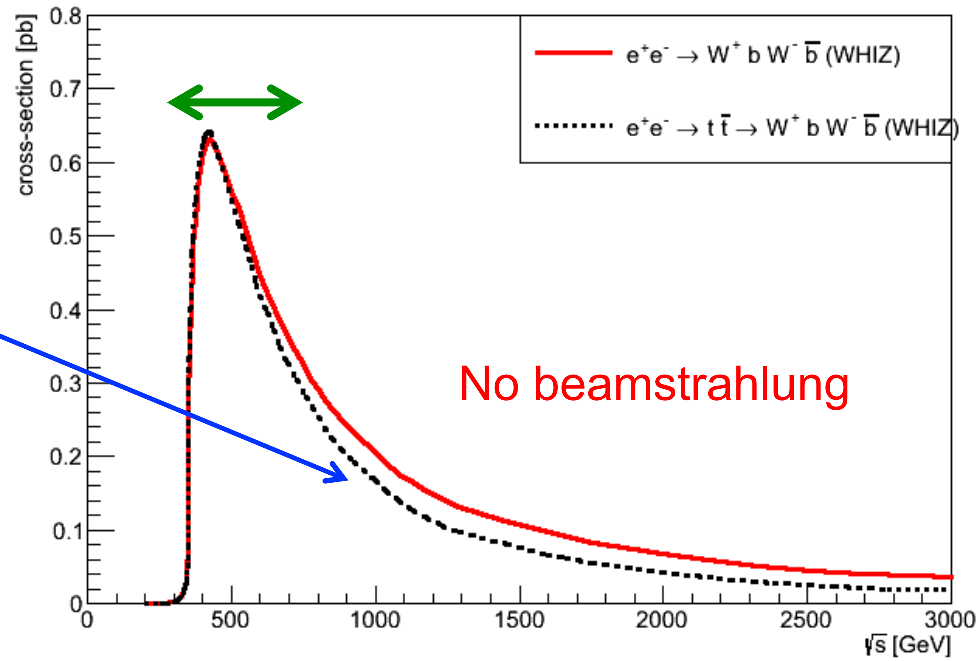
$$\Gamma^{\mu}_{\mathrm{t\bar{t}}} = ie\left[\gamma^{\mu}\left(\tilde{F}^{\gamma,Z}_{1V} + \tilde{F}^{\gamma,Z}_{1A}\gamma^5\right) + \frac{(p_\mathrm{t} - p_{\bar{\mathrm{t}}})^{\mu}}{2m_\mathrm{t}}\left(\tilde{F}^{\gamma,Z}_{2V} + \tilde{F}^{\gamma,Z}_{2A}\gamma^5\right)\right]$$

or Effective higher dimensional operators:

$$\mathcal{L}_{\mathrm{eff}} = \ldots + \frac{C_i}{\Lambda^2} O_i + \ldots$$

★ **Can only effectively study top pair production in first CLIC energy stage**
- **s-channel, so 1/s dependency**
- **single top production becomes increasingly important**

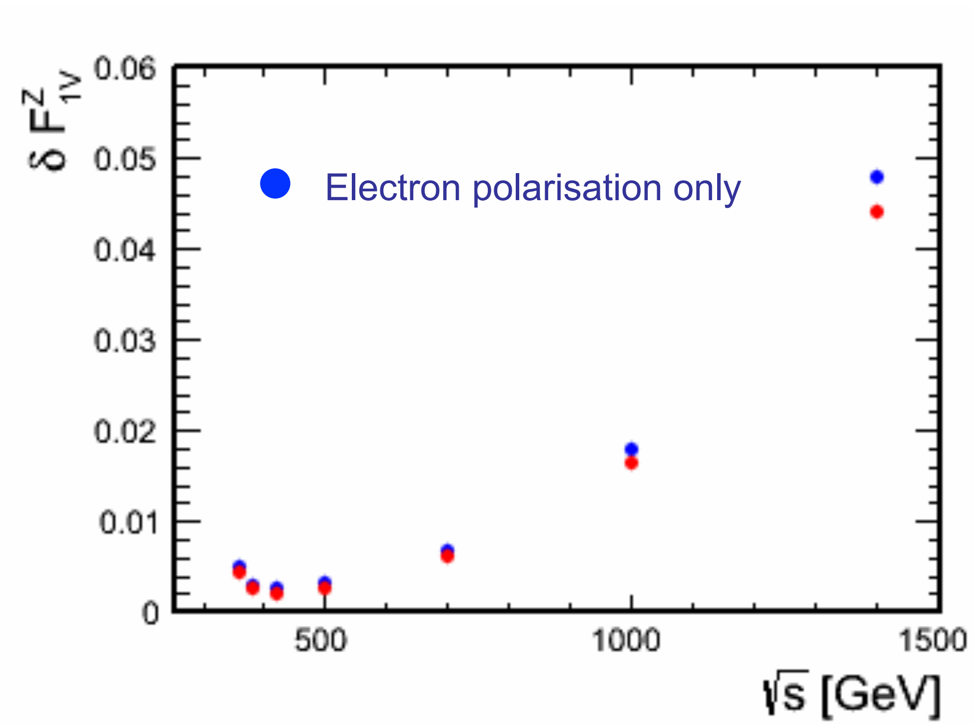


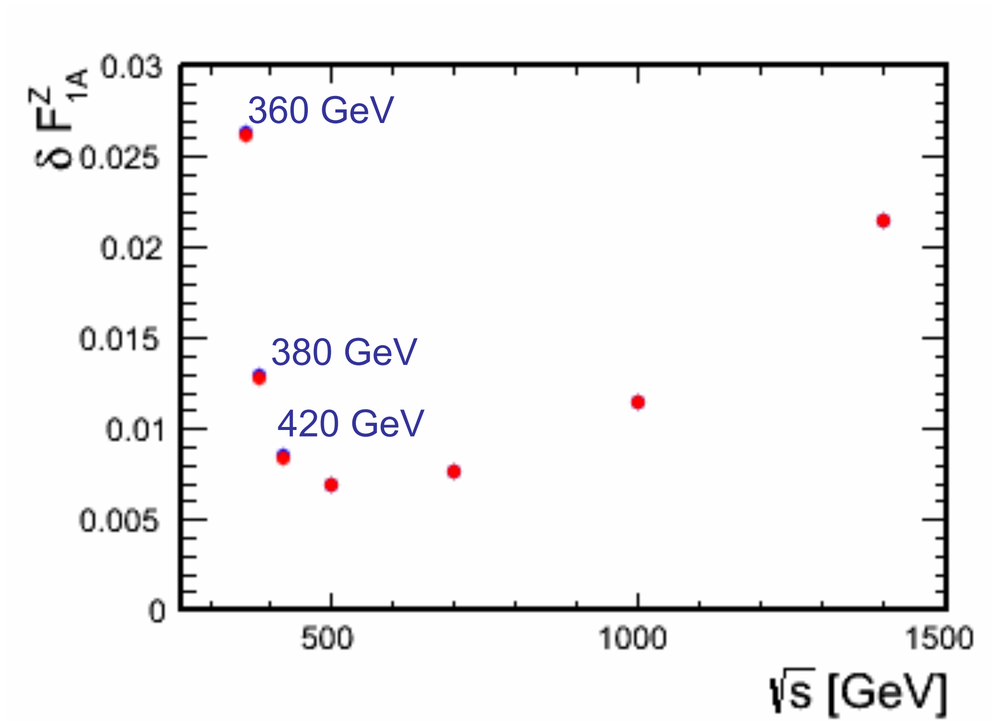


★ **Probe top vertex through cross section & A_{FB} (with e^- polarisation)**
- **measure form factors [general parameterisation]**
- **and/or interpret as effective operators: BSM sensitivity**

★ **Compare form factor sensitivity for different √s**

- **fixed luminosity: 250 fb^{-1} (-80%, +30%) + 250 fb^{-1} (+80%, -30%)**
- **centre-of-mass energy dependence varies with parameter**

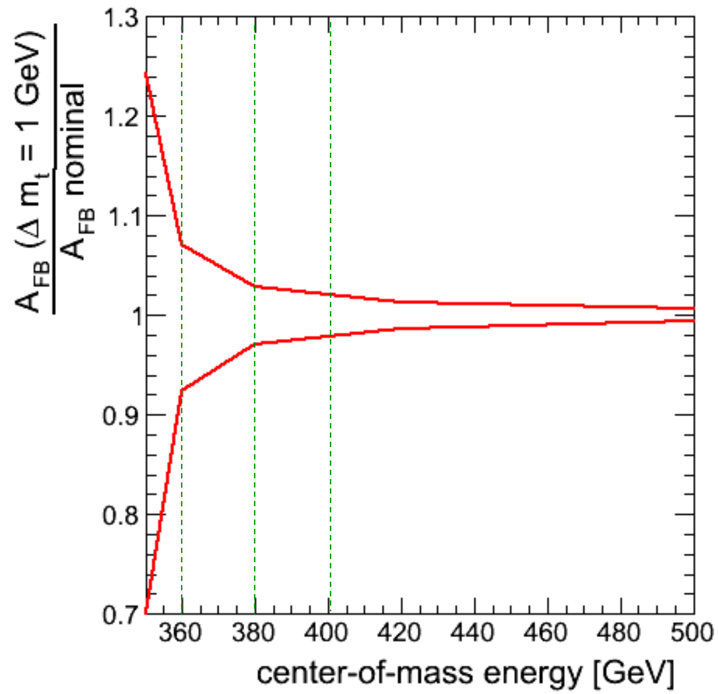




★ **360 GeV looks marginal**

Get away from threshold

★ **Close to threshold – theoretical uncertainties increase**
- **QCD**
- **parametric uncertainties (top mass, width)**



★ **another argument for $\sqrt{s}$ > 360 GeV**

HZ production

⇨ $\sqrt{s} \sim 250\text{-}450$ GeV

Top at theshold

⇨ $\sqrt{s} > 350$ GeV

Recoil Mass

⇨ $\sqrt{s} < 400$ GeV

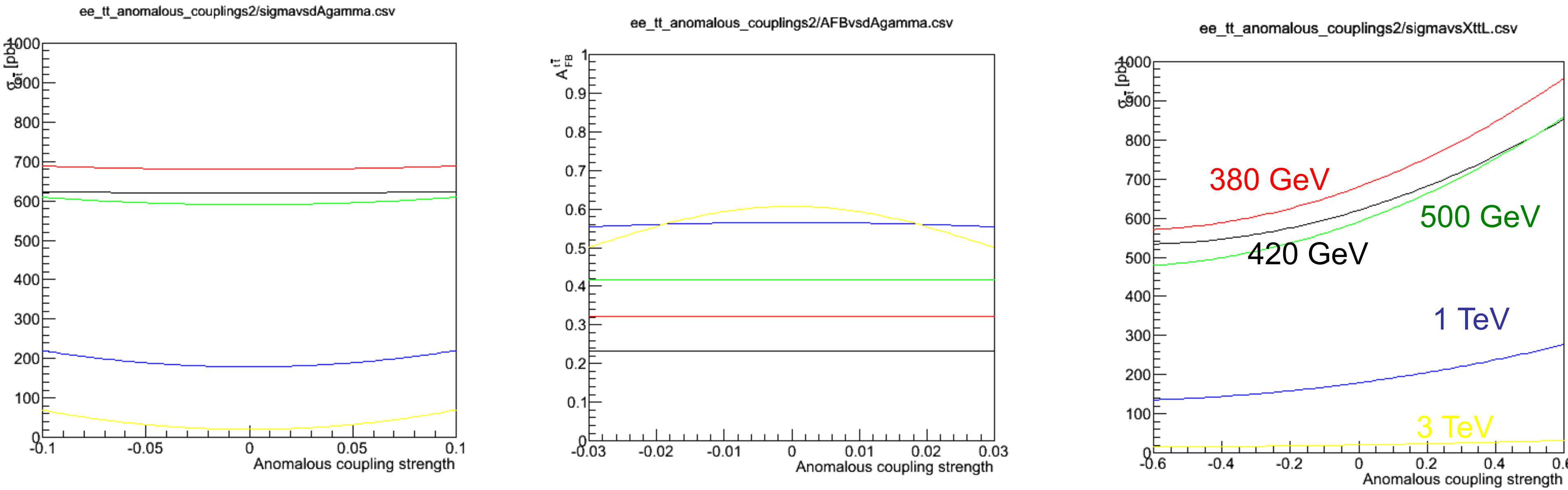
Top pair production

⇨ $\sqrt{s} > 360$ GeV

Top at higher energies

★ **Can top physics be deferred to high-energy running???**

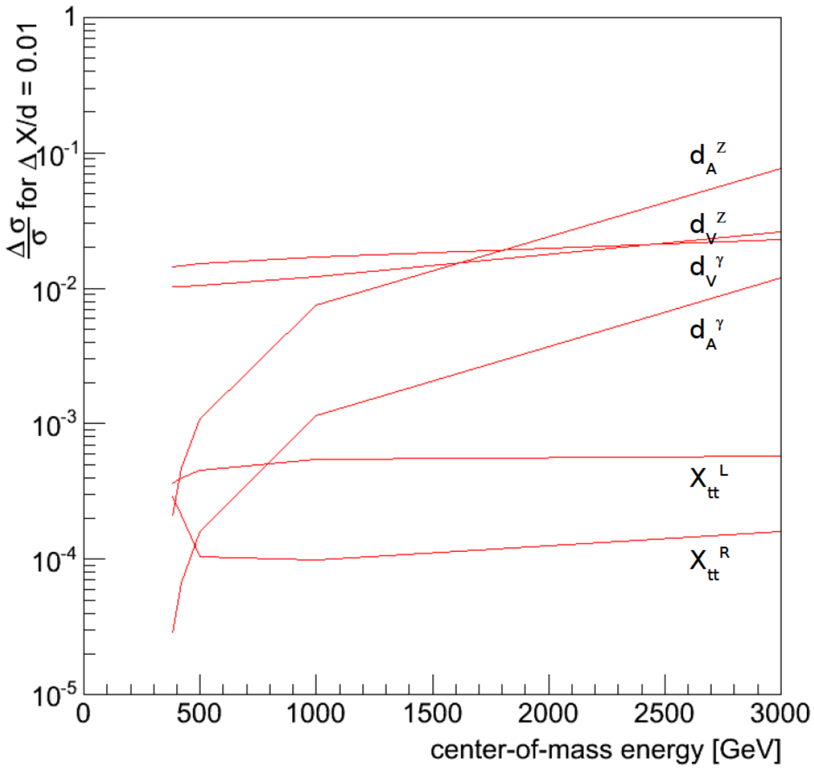
- **does higher BSM sensitivity outweigh loss in cross section**
- **no full analysis at this stage**
- **but…**

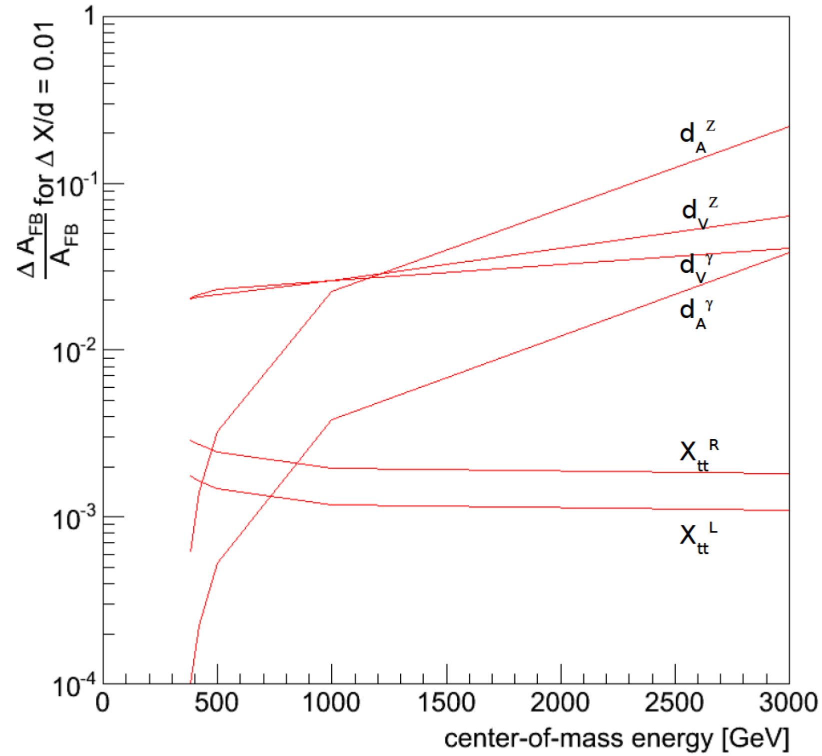


★ **Centre-of-mass dependence is different for different anom. couplings**

- **in some cases higher √s helps**
- **for others the much higher cross section at low energies wins**

Shown another way…





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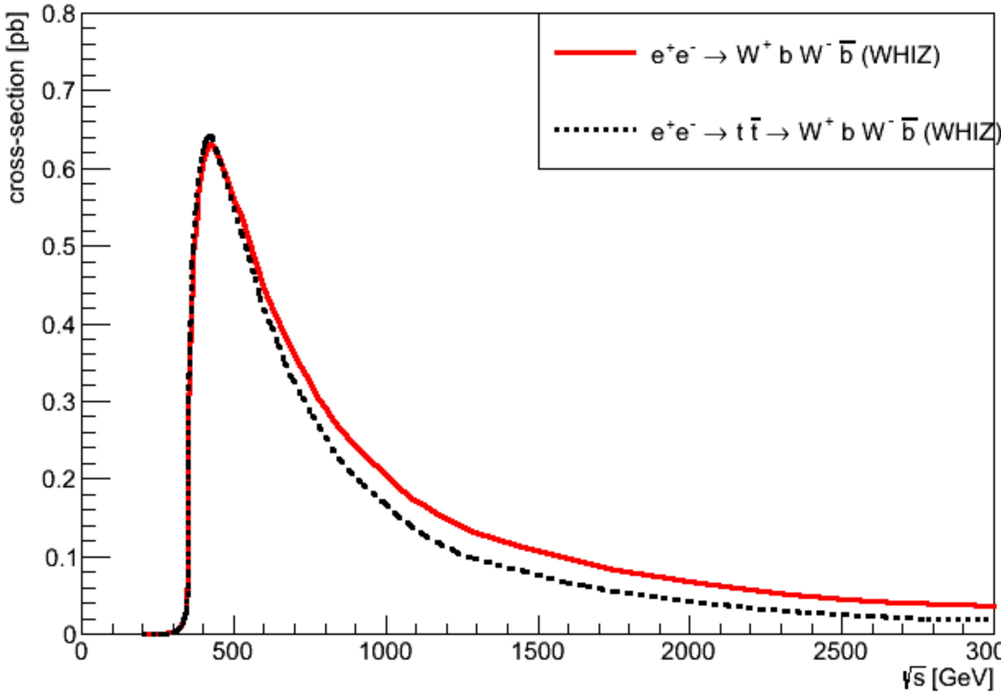
Top conclusions



★ **At this stage not confident that higher √s helps**

- **would need a full study (including beam-strahlung)**

and a full study will take time…

Conclusions

HZ production

⇨ $\sqrt{s}$ ~ 250-450 GeV

Top at theshold

⇨ $\sqrt{s}$ > 350 GeV

Recoil Mass

⇨ $\sqrt{s}$ < 400 GeV

⇨ **$\sqrt{s}$ ~ 380 GeV**

Still good for HZ
Provides valid top quark program

Top pair production

⇨ $\sqrt{s}$ > 360 GeV

Top pair BSM

⇨ $\sqrt{s}$ > 360 - ? GeV

Thank you for your attention