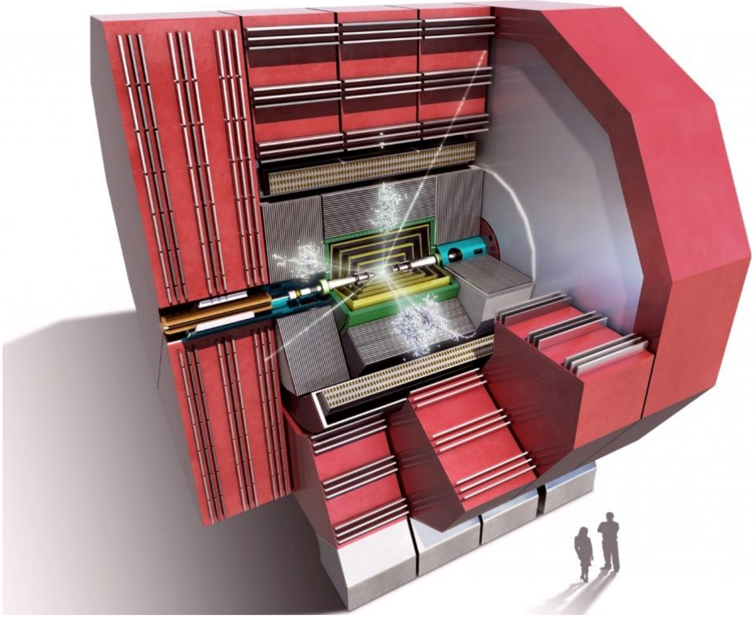
Upcoming CLIC staging baseline, *and trade off between Higgs and top physics at CoM energies of a few-hundred GeV*



Lucie Linssen

with help of Philipp Roloff, Eva Sicking, Frank Simon, Mark Thomson, Marcel Vos

This presentation serves to illustrate the question.
Not based on any in-depth analysis

outline

- Defining a new CLIC staging baseline
- Trade-off between Higgs physics and top physics
- Higgs physics at ~360-500 GeV
- Top physics at ~360-500 GeV

new CLIC staging baseline (1)

A **new CLIC staging baseline**, aimed at providing:

- New reference for physics simulation (e.g. luminosity spectrum)
- Consistent set of information for public presentations

Scope:

- Define ***one CLIC staging baseline***
- Documented in a compact note/publication
- Document will also include one chapter on alternative optimised schemes for the lowest energy stage (e.g. a klystron-based option)

Timeline:

- be ready CLIC workshop, January 2015

Small **"editing team"**:

Phil Burrows, Philippe Lebrun, Daniel Schulte, Eva Sicking
Steinar Stapnes, Mark Thomson, LL

new CLIC staging baseline (2)

Further CLIC optimisation promised in the CDR:

- Accelerator optimisation with a staged approach in mind
- Reduce cost
- Reduce power consumption
- Update on physics input
- Lessons learnt….

Ongoing re-baselining activity for CLIC accelerator

- Re-visiting many parameters
- Parametrised approach allowing to choose optimal combined solutions

E.g. see presentation Daniel Schulte at CLICdp 2-day meeting in June
http://indico.cern.ch/event/314222/session/0/contribution/9

Re-baselining from the physics side

- Fold in lessons learnt from CLIC benchmark analyses (e.g. Higgs studies)
- Any new physics input (e.g. LHC physics, theory, new insights)

reminder on CLIC energy stages

The current CLIC staging baseline was introduced in 2012, for CDR volume 3

- It foresees three stages
- The lower and middle stages require only one drive beam complex

"A"

√s	GeV	500	1400	3000
L	10^{34} $cm^{-2}sec^{-1}$	2.3	3.2	5.9
$L_{0.01}$	10^{34} $cm^{-2}sec^{-1}$	1.4	1.3	2
Gradient	MV/m	80	80/100	100
Site length	km	13.2	27.2	48.3

"B"

√s	GeV	500	1500	3000
L	10^{34} $cm^{-2}sec^{-1}$	1.3	3.7	5.9
$L_{0.01}$	10^{34} $cm^{-2}sec^{-1}$	0.7	1.4	2
Gradient	MV/m	100	100	100
Site length	km	11.4	27.2	48.3

CLIC CDR Vol 3 => Luminosity scenarios

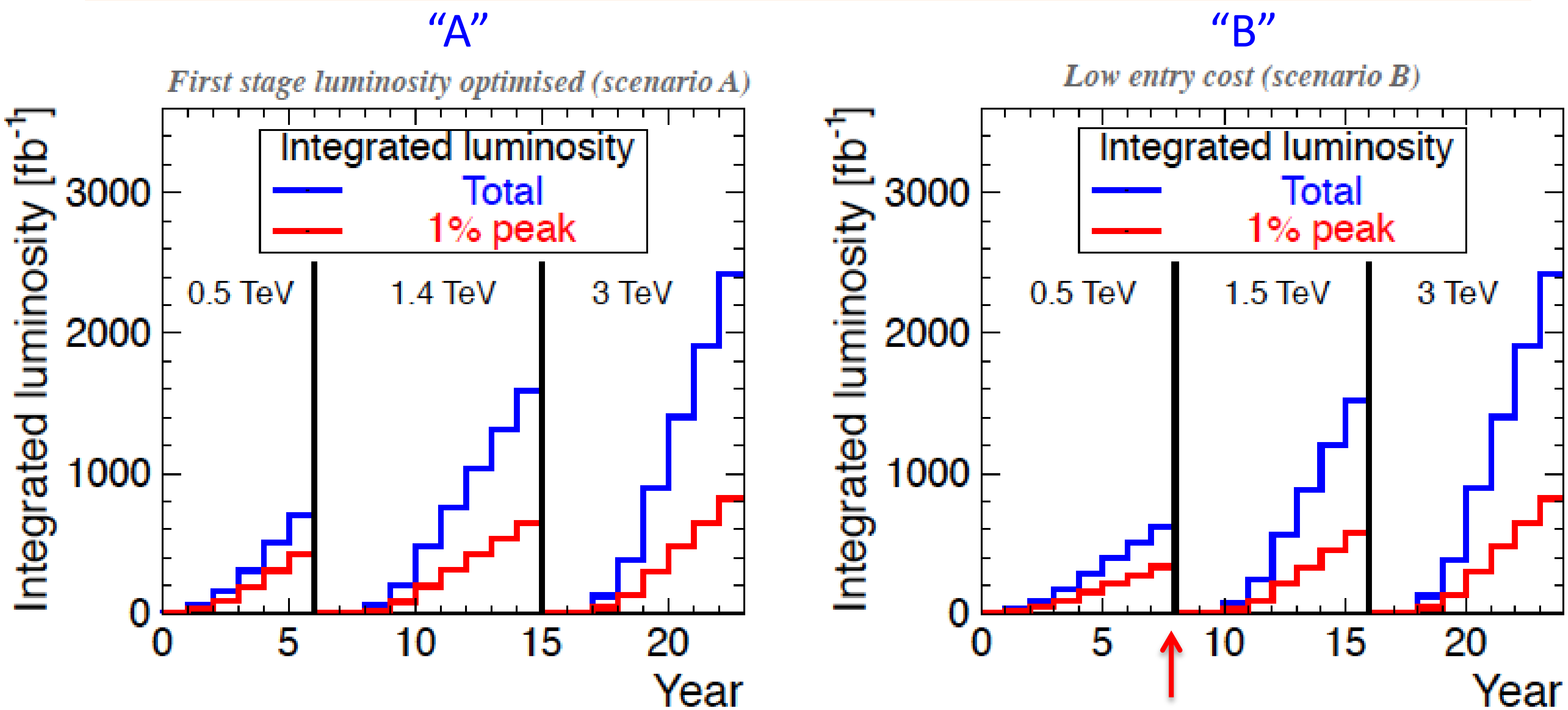


Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)

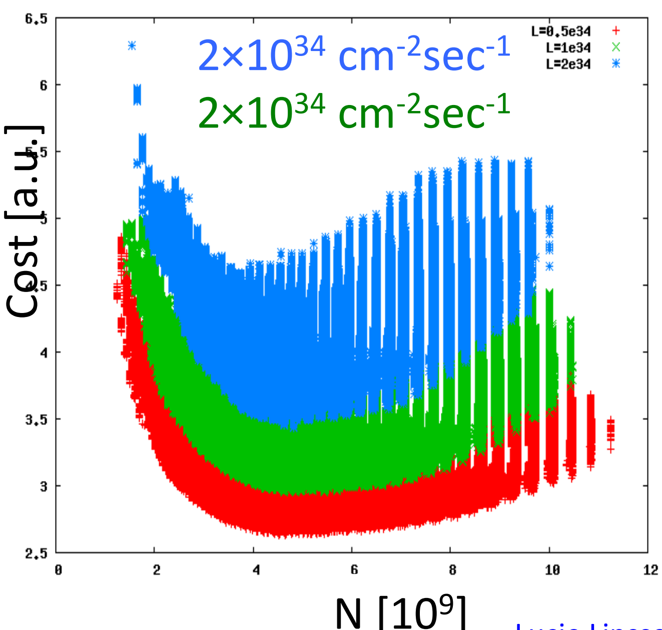
Target figures: >600 fb^{-1} at first stage, 1.5 ab^{-1} at second stage, 2 ab^{-1} at third stage

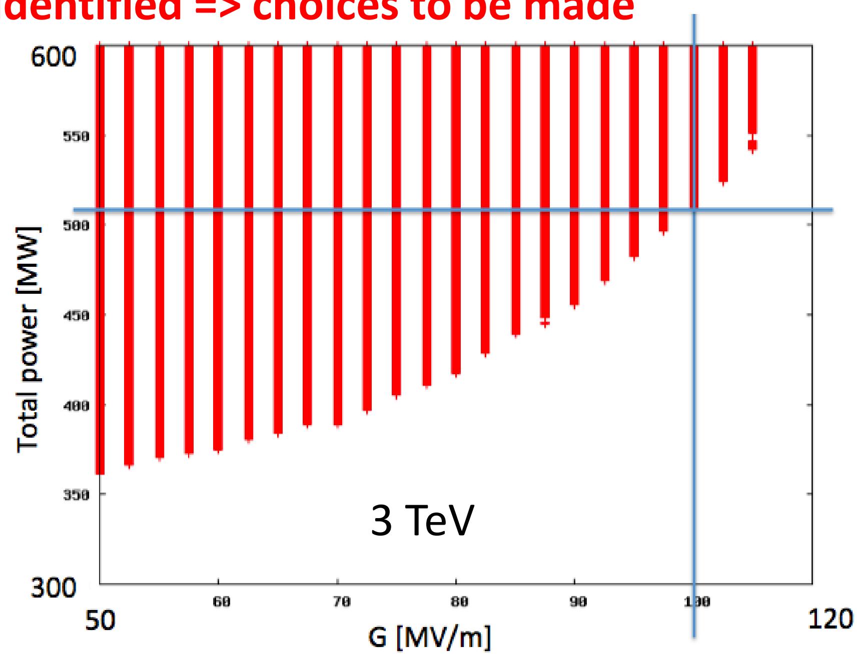
accelerator optimisation

Just a few observations:

- Several cost-savings identified (e.g. no pre-damping ring needed)
- Power saving can be significant (>100 MW) for some options
- Luminosity increase at 360 GeV: 1×10^{34} => 2×10^{34} $cm^{-2}sec^{-1}$ at significant cost increase
- Optimised design at 360 GeV has gradients around 70-90 MV/m
- Cost-optimal options at 3 TeV have higher gradients
- High power options may be overall cost-effective, but not easily seen as acceptable
- 3 TeV machine options with low power have lower gradients => exceed 50 km length
- Matching of 360 GeV and 3 TeV designs put constraints (e.g. pulse length, DB current)

Several effective solutions have been identified => choices to be made





some directions taken.....

Within the editing team, we drew the following preliminary conclusions:

- Will most likely choose an option that will add different structures to the existing linac after the first energy stage
- Aim for L of 1.5×10^{34} $cm^{-2}s^{-1}$ at the lower energy stage
- Annual operation: 250 days (~8 months) of operation at 50% efficiency => 1.08×10^{7} seconds per year
- Choose the lowest energy stage based on trade-off between Higgs and top physics at the first stage

trade-off Higgs physics ⇔ top physics

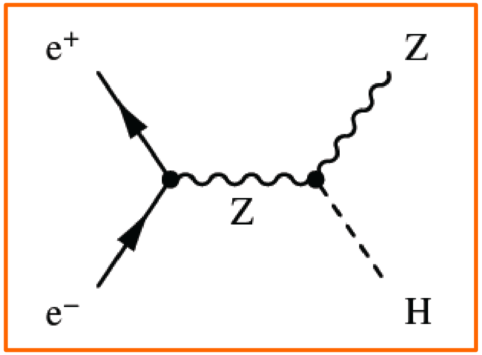
Higgs couplings:
- Requires access to **Higgsstrahlung *and* WW-fusion** (initially to determine g_{HZZ}, g_{HWW}, Γ_H, followed by all other couplings)
- Precision of g_{HZZ} dominated by looking at recoil in Higgsstrahlung with Z=>qq
- *~350 GeV seems a good choice* for Higgs physics at the first CLIC energy stage
  Could Higgs physics actually profit from a somewhat higher energy?

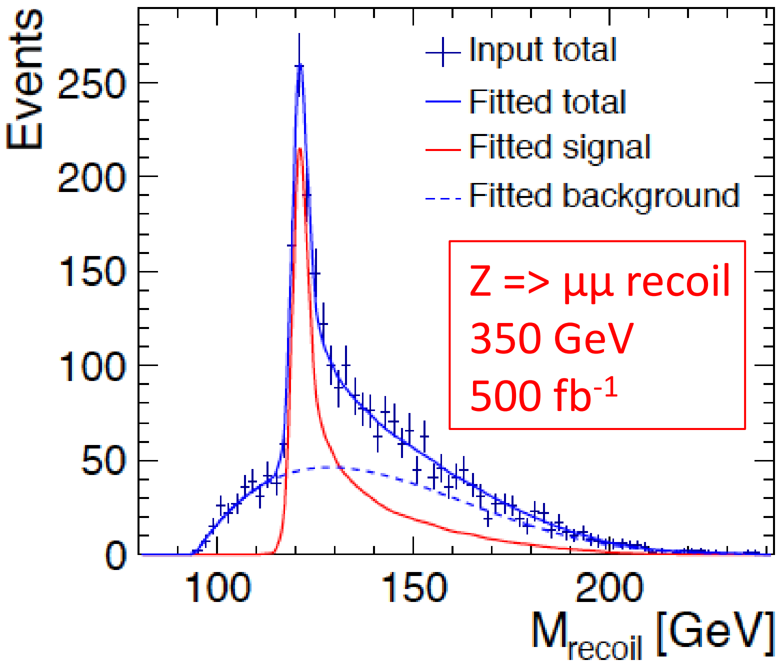
Higgs mass:
- Accurate mass peak in Higgsstrahlung with Z=>μμ. Best at ~250 GeV
- Higgs mass reconstruction from H=>bb: *better at higher energies ?* Depending on boost, jet resolution and statistics

Top physics:
- Mass measurement, threshold scan at *≈360 GeV*
- Coupling of the top to Z, gamma, W
  - making use of forward-backward asymmetry, top production, top decay
  - Kinematic properties => will probably require *~420 GeV or more*

How to choose optimal energy stage in the 360-500 GeV range ?

Higgsstrahlung at CLIC





model-independent Higgs measurement
(coupling and mass)
yields absolute coupling value g_{HZZ}

Identify Higgs through Z recoil

Z => μμ	~3.5%	very clean	$\Delta\sigma_{(HZ)} = \pm 4.2\%$
Z => ee	~3.5%	very clean	
Z => qq	~70%	model independent ?	$\Delta\sigma_{(HZ)} = \pm 1.8\%$

$\Delta g_{(HZZ)} = \pm 0.8\%$

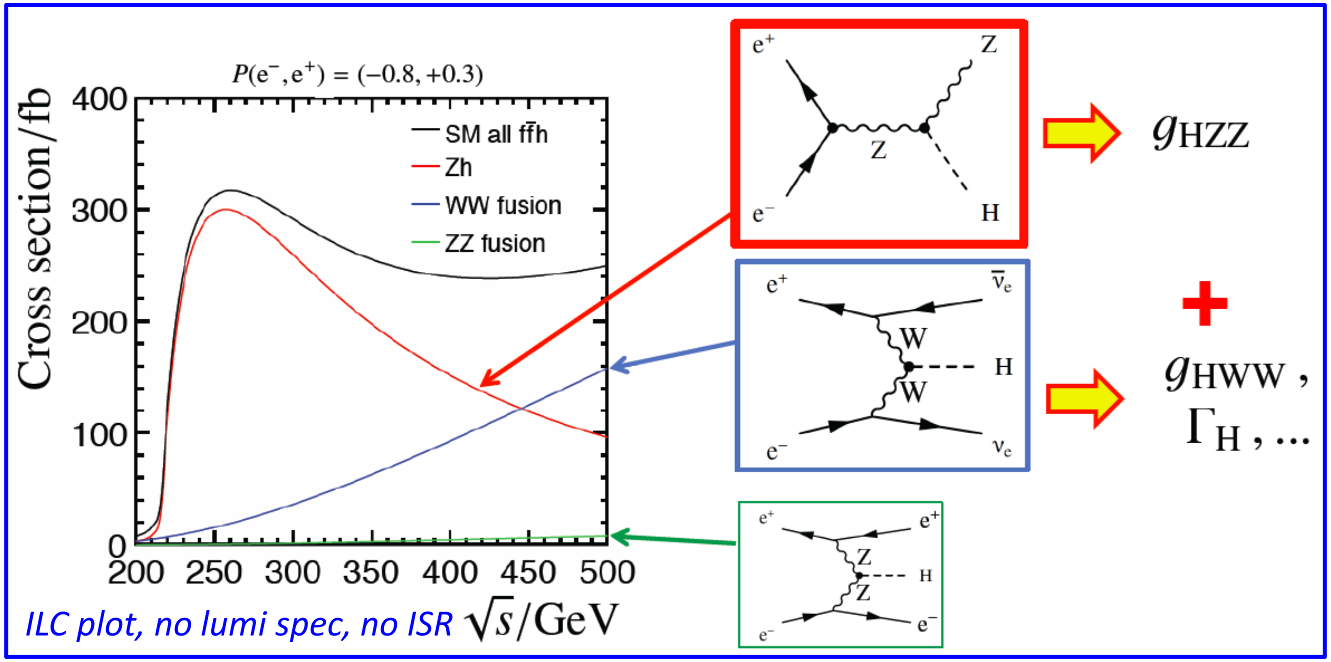
$$\Delta\left(\sigma_{HZ}\frac{\Gamma_{vis}}{\Gamma}\right) = \pm\ 1.7\%$$

+

$$\Delta\left(\sigma_{HZ}\frac{\Gamma_{invis}}{\Gamma}\right) = \pm 0.6\ \%$$

dominated by analysis
using recoil from Z=>qq

Higgs physics at ~350 GeV or above ?



Move from 350 GeV to 420 GeV centre-of-mass:

Higgsstrahlung =>=> decease ~32% in cross section

WW fusion =>=> increase ~71% in cross section

From 350 GeV to 500 GeV centre-of-mass:

Higgsstrahlung =>=> decease ~51% in cross section

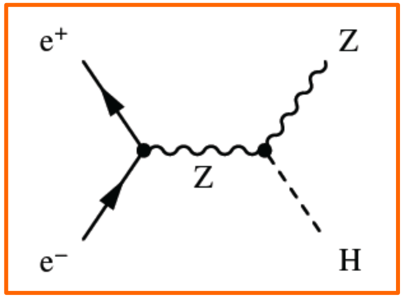
WW fusion =>=> increase ~150% in cross section

Additionally: gain in luminosity expected for higher energy

Higgs mass measurements

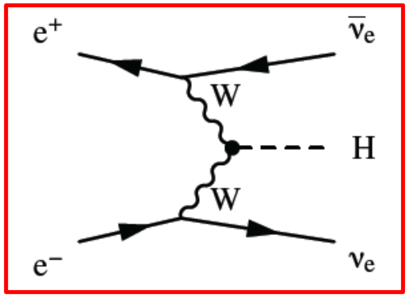
Excellent Higgs mass measurement from **Z=>μμ** recoil in Higgsstrahlung

- Best result at 250 GeV => Δm_H = ~30 MeV
- At 350 GeV => Δm_H = ~120 MeV



Alternative: Higgs mass reconstruction from WW fusion with **H=>bb**

- Can reach Δm_H <50 MeV at 350 GeV ? (tbc, M. Szalay)
- Δm_H <40 MeV at 1.4 TeV



To be confirmed/studied:

- Which ***mass resolution*** is really required (50 MeV?)?
  - e.g. would mass resolution impact significantly on knowledge of SM couplings?
- ***Detector calibration*** for tracking and jet energy measurement
  - Look into possibility of using Z-production through WW fusion

top physics at CLIC lower energy stage

Which top physics subjects do we want to address at the lower energy stage ?

Criteria:

- Subjects with high physics relevance
- Significant improvement over HL-LHC

Note: for some studies >1 TeV CLIC gives even better perspectives. But results >1 TeV will come significantly later. So it's good to include the measurement at the lower energy stage and then again at the higher energy stage.

See detailed info in talk by Marcel Vos

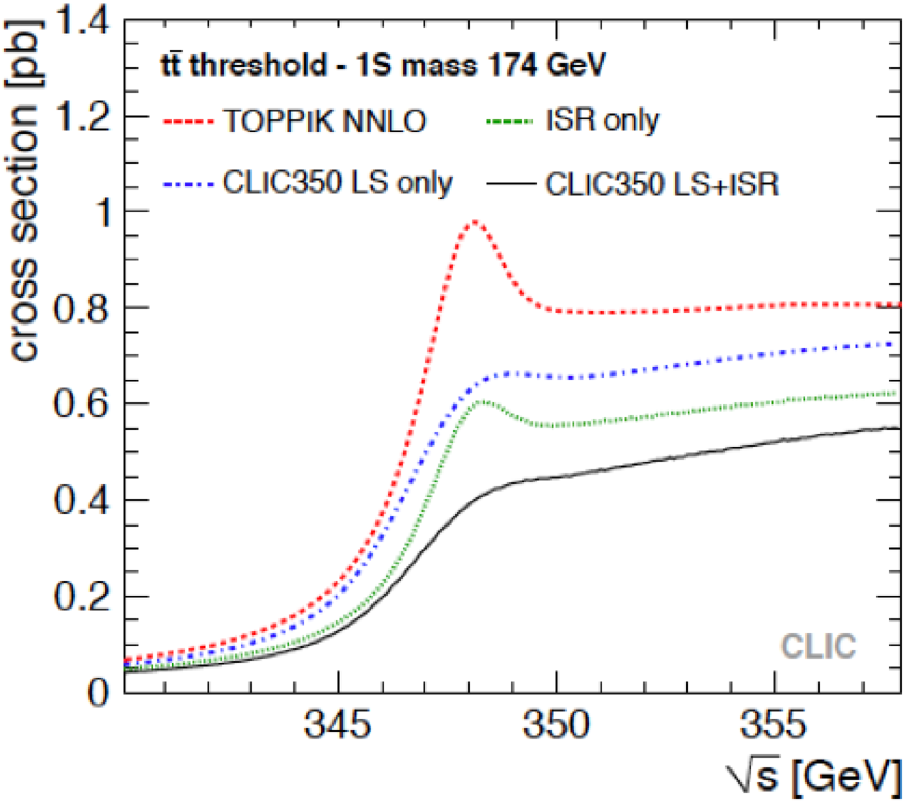
possible top physics subjects

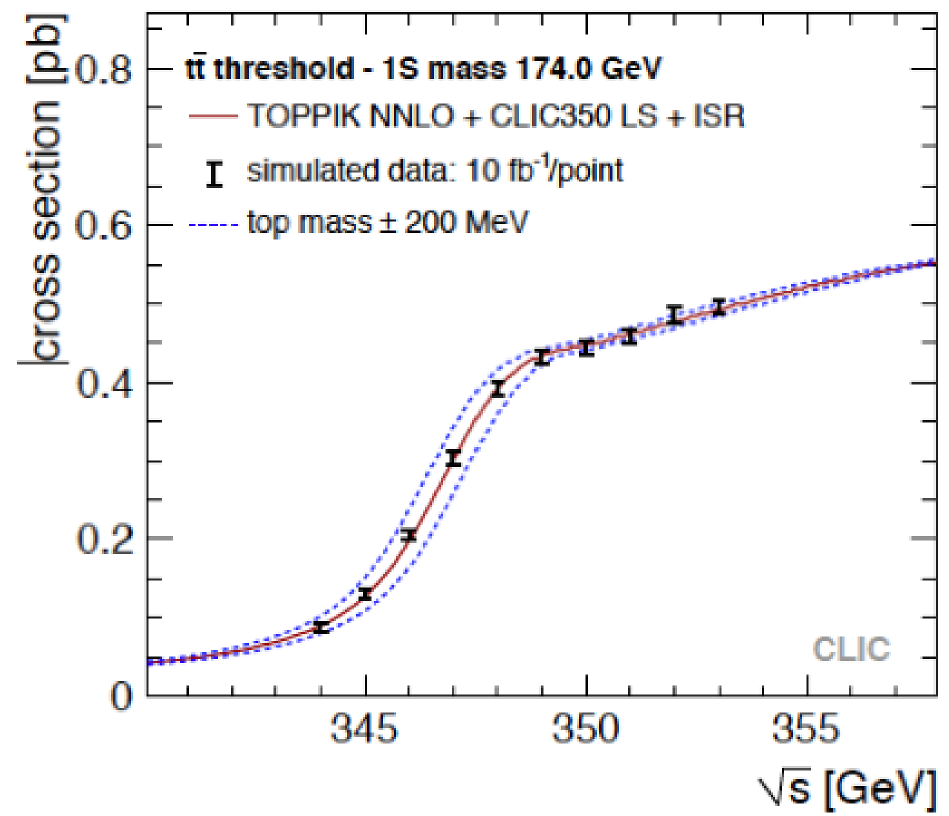
Assessment of possible top physics subjects for the first CLIC energy stage:

Physics subject	Energy (GeV)	Integrated Lumi (fb^{-1})	Better than HL-LHC?	Do it?
Top mass threshold scan	~344 - 353	~100	+ +	✔
A_{FB} (etc.) and top couplings to Z, γ	>400 GeV (tbd)	~500	+ +	✔
top coupling to W (from production/decay)	>400 GeV (tbd)	~500	+ +	✔
ttH, top-Yukawa coupling	≥500 GeV	~500	-	
CP-violating top decays	studied for 500	~500	-	
Flavour changing top decays	Studied for 500	~500	-	
V_{tb} from single top events	?	~500	?	

✔ it seems **worth adapting the CLIC lower energy** choice to cover these three items

top-mass threshold scan

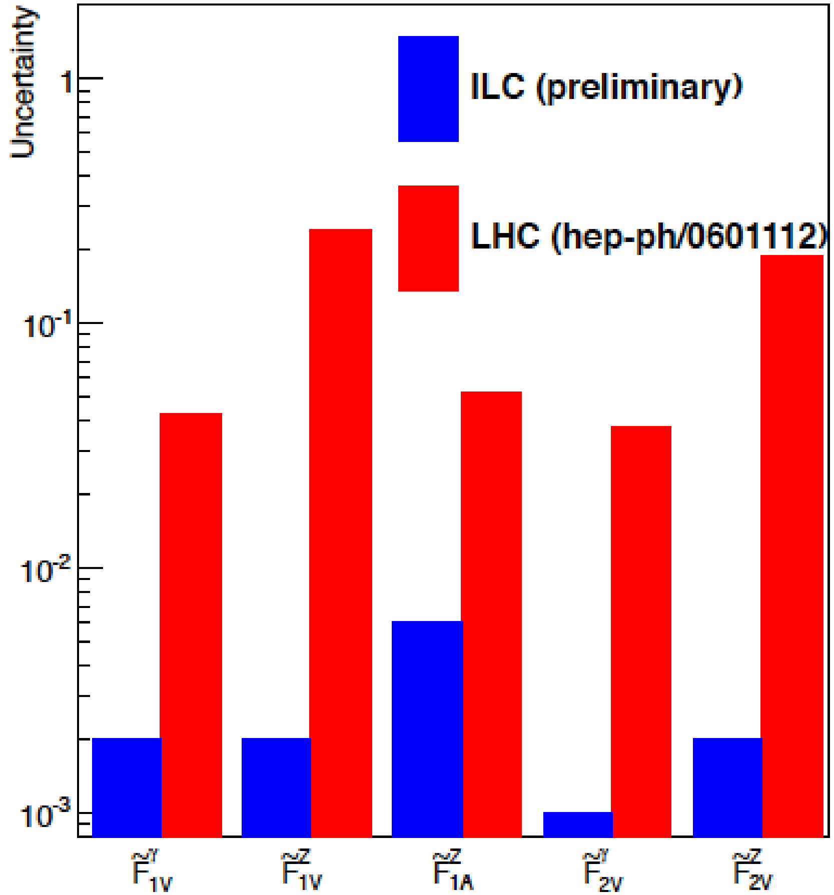




Include a top threshold scan with 10 tuned-down energy steps around ~350 GeV
Total ~100 fb^{-1}

A_{FB} (etc.) => top coupling to Z, γ

LHC/ILC comparison, using ILC study at 500 GeV and 500 fb^{-1}



arXiv:1307.8102

Figure 11: *Comparison of statistical precisions on CP conserving form factors expected at the LHC, taken from [3] and at the ILC. The LHC results assume an integrated luminosity of $\mathcal{L} = 300$ fb^{-1}. The results for ILC assume an integrated luminosity of $\mathcal{L} = 500$ fb^{-1} at $\sqrt{s} = 500$ GeV and a beam polarisation $\mathcal{P} = \pm 0.8, \mathcal{P}' = \mp 0.3$.*

Collider	LHC		ILC/CLIC
CM Energy [TeV]	14	14	0.5
Luminosity [fb^{-1}]	300	3000	500
SM Couplings			
photon, F^{γ}_{1V} (0.666)	0.042	0.014	0.002
Z boson, F^{Z}_{1V} (0.24)	0.50	0.17	0.003
Z boson, F^{Z}_{1A} (0.6)	0.058	–	0.005
Non-SM couplings			
photon, F^{γ}_{1A}	0.05	–	–
photon, F^{γ}_{2V}	0.037	0.025	0.003
photon, F^{γ}_{2A}	0.017	0.011	0.007
Z boson, F^{Z}_{2V}	0.25	0.17	0.006
Z boson, ReF^{Z}_{2A}	0.35	0.25	0.008
Z boson, ImF^{Z}_{2A}	0.035	0.025	0.015

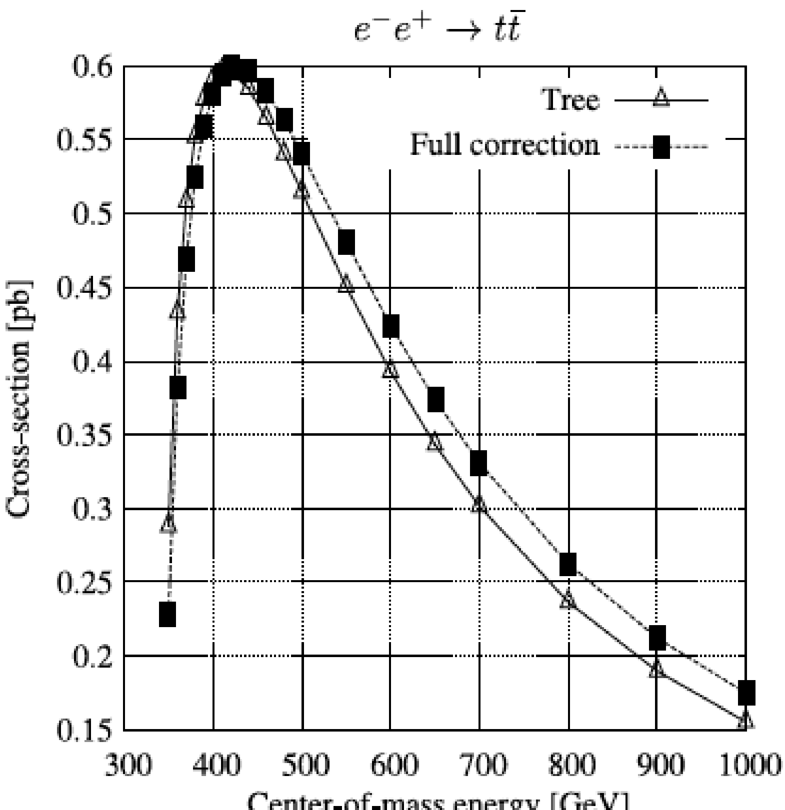
Snowmass top report: arXiv:1311.2028
Referring to the ILC TDR

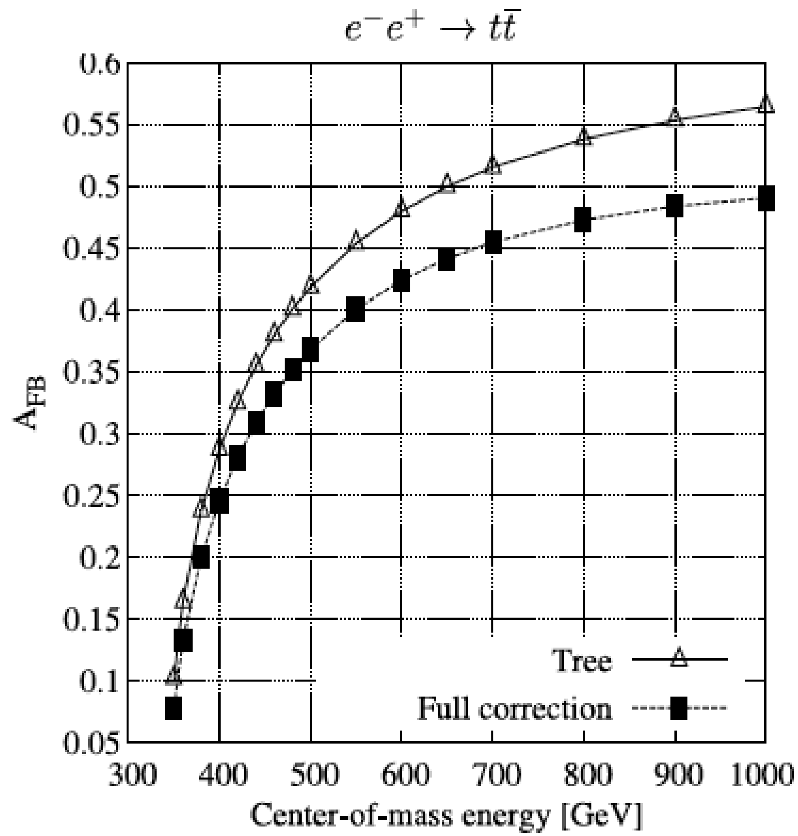
ttbar cross section and A_{FB}

Eur. Phys. J. C (2013) **73**: 2400
http://dx.doi.org/10.1140/epjc/s10052-013-2400-3
Regular Article - Theoretical Physics

Full $\mathcal{O}(\alpha)$ electroweak radiative corrections to $e^+e^- \to t\bar{t}\gamma$ with GRACE-Loop

P. H. Khiem[1,2*], J. Fujimoto[1], T. Ishikawa[1], T. Kaneko[1], K. Kato[3], Y. Kurihara[1], Y. Shimizu[1], T. Ueda[4], J. A. M. Vermaseren[5] and Y. Yasui[6]

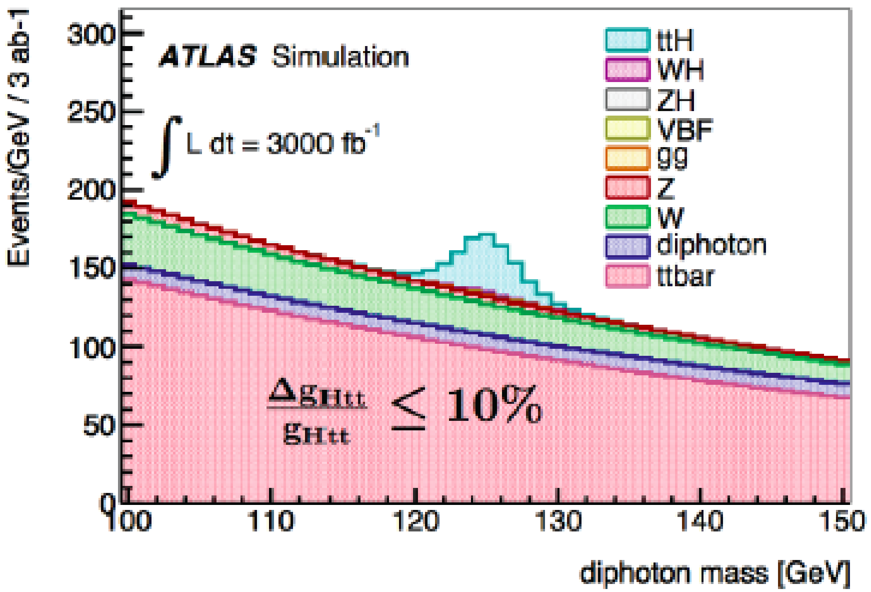


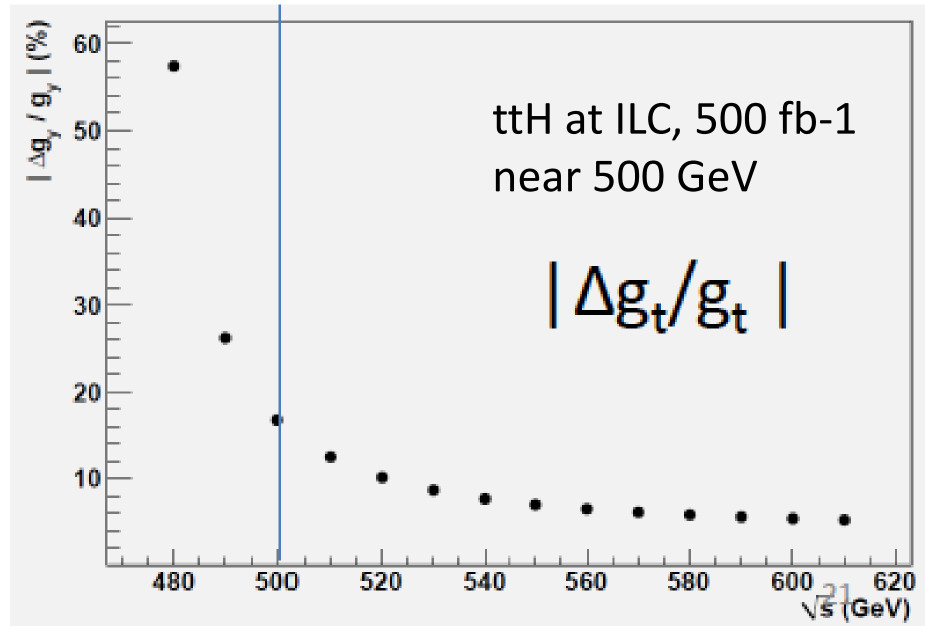


ttbar cross section peaks at ~420 GeV

A_{FB} raises with energy, ~0.28 at 420 GeV
~0.37 at 500 GeV

ttH at ~500 GeV ?



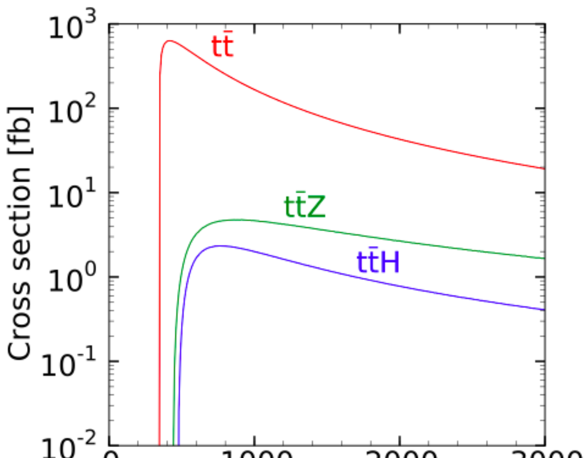


See talk by A. Loginov @ LCWS14

See talk by Y. Sudo @ LCWS14

Note :CLIC result at 1.4 TeV: $\Delta g_t/g_t$ = 4.5%

See talk by S. Redford @ LCWS14

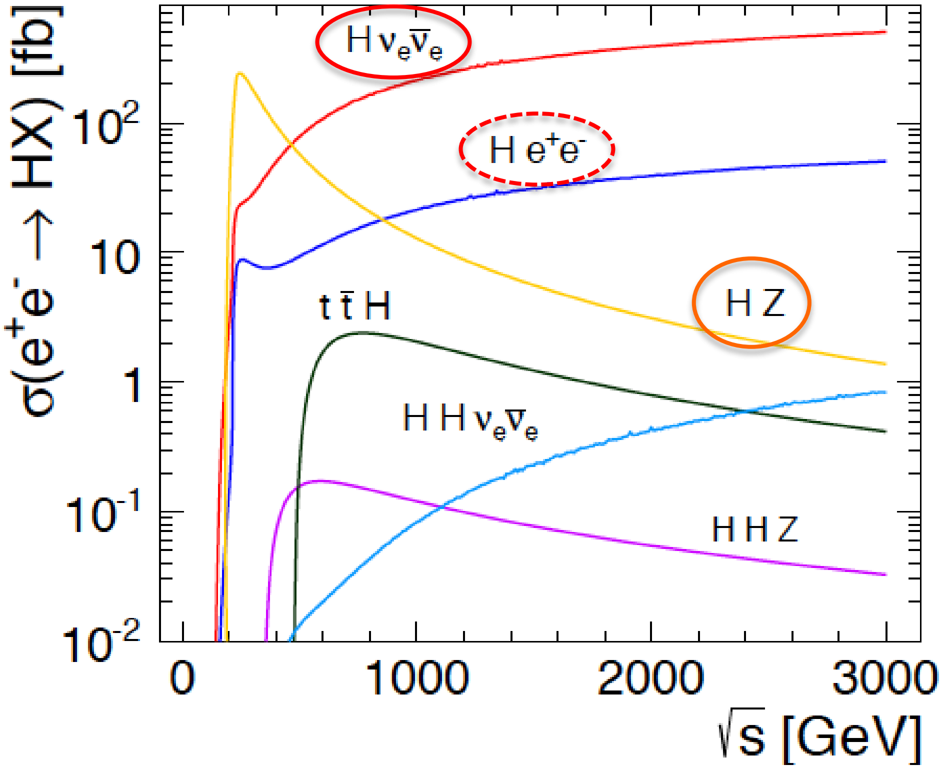


Next talks:

- Frank Simon => $\sqrt{s}$ and combined Higgs fits
- Marcel Vos => top physics
- Philipp Roloff => plans of physics benchmark studies
  - Plans for BSM studies and further Higgs studies
  - Higgs and top studies to determine CLIC lower energy choice

spare slides

Higgs physics at CLIC



Expected enhancement with polarisation

Polarisation	Enhancement factor		
$P(e^-):P(e^+)$	$e^+e^- \rightarrow ZH$	$e^+e^- \rightarrow H\nu_e\bar{\nu}_e$	$e^+e^- \rightarrow Ze^+e^-$
unpolarised	1.00	1.00	1.00
−80% : 0%	1.12	1.80	1.12
−80% : +20%	1.31	2.16	1.15
−80% : +30%	1.40	2.34	1.17

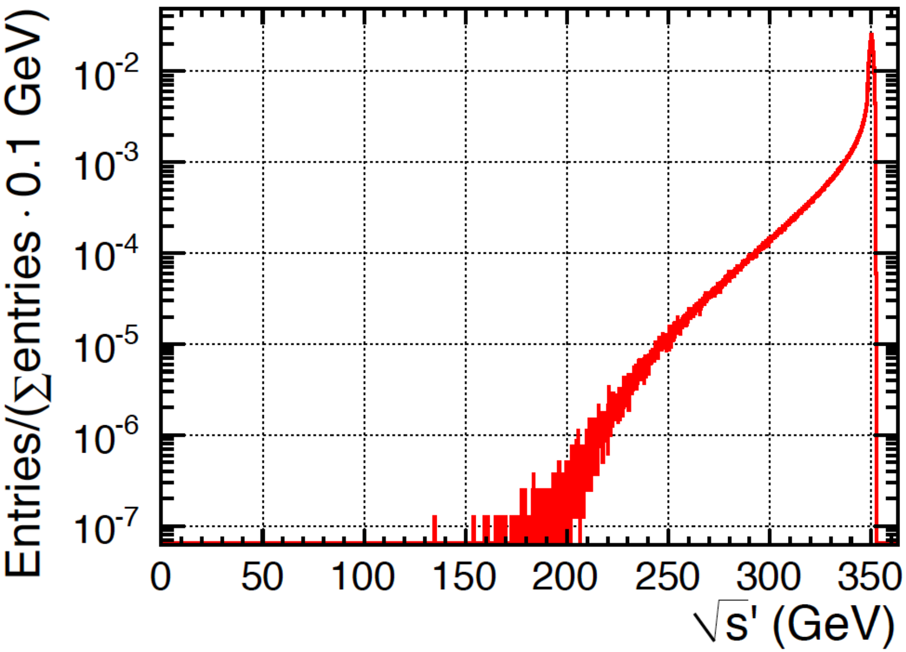
Numbers without polarisation	350 GeV	1.4 TeV	3 TeV
L_{int}	500 fb^{-1}	1.5 ab^{-1}	2 ab^{-1}
# ZH events	68 000	20 000	11 000
# $H\nu_e\bar{\nu}_e$ events	17 000	370 000	830 000
# He^+e^- events	3 700	37 000	84 000

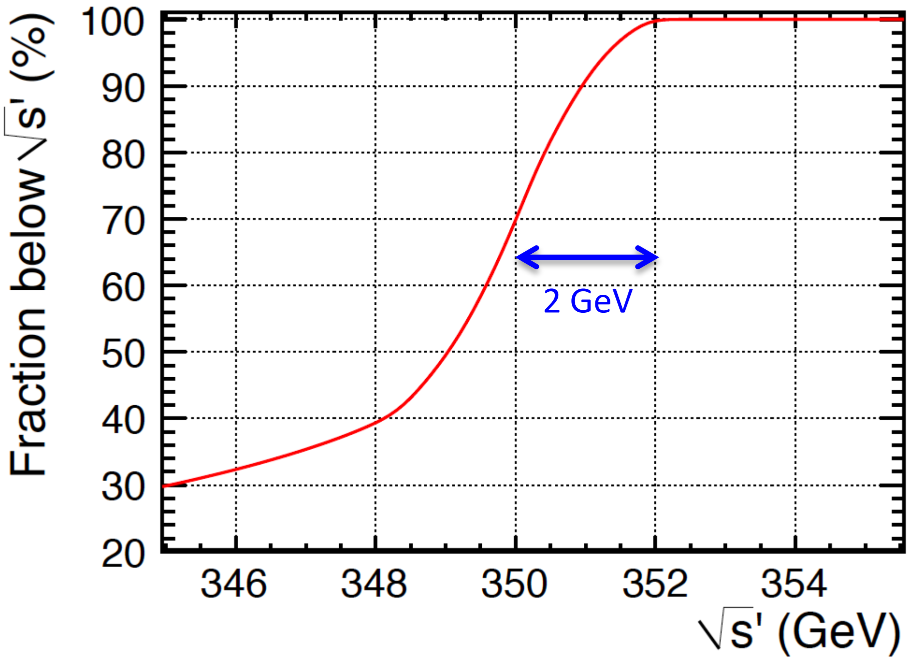
CLIC Higgs studies

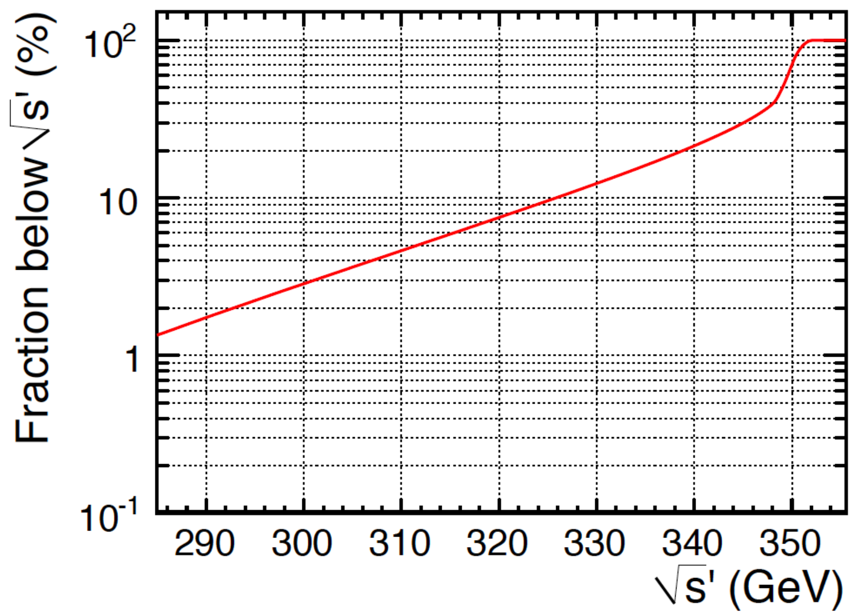
Channel	Measurement	Observable	Statistical precision		
			350 GeV 500 fb^{-1}	1.4 TeV 1.5 ab^{-1}	3.0 TeV 2.0 ab^{-1}
ZH	Recoil mass distribution	m_{H}	120 MeV	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{invisible})$	Γ_{inv}	0.6%	–	–
ZH	$\mathrm{H} \to \mathrm{b\bar{b}}$ mass distribution	m_{H}	tbd	–	–
$\mathrm{H}\nu_e\bar{\nu}_e$	$\mathrm{H} \to \mathrm{b\bar{b}}$ mass distribution	m_{H}	–	40 MeV*	33 MeV*
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{Z} \to \ell^+\ell^-)$	g^2_{HZZ}	4.2%	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{Z} \to \mathrm{q\bar{q}})$	g^2_{HZZ}	1.8%	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{b\bar{b}})$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{Hbb}}/\Gamma_{\mathrm{H}}$	1%†	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{c\bar{c}})$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{Hcc}}/\Gamma_{\mathrm{H}}$	5%†	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{gg})$		6%†	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \tau^+\tau^-)$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{H\tau\tau}}/\Gamma_{\mathrm{H}}$	6.2%	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{WW}^*)$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{HWW}}/\Gamma_{\mathrm{H}}$	2%†	–	–
ZH	$\sigma(\mathrm{HZ}) \times BR(\mathrm{H} \to \mathrm{ZZ}^*)$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{HZZ}}/\Gamma_{\mathrm{H}}$	tbd	–	–
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{b\bar{b}})$	$g^2_{\mathrm{HWW}} g^2_{\mathrm{Hbb}}/\Gamma_{\mathrm{H}}$	3%†	0.3%	0.2%
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{c\bar{c}})$	$g^2_{\mathrm{HWW}} g^2_{\mathrm{Hcc}}/\Gamma_{\mathrm{H}}$	–	2.9%	2.7%
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{gg})$		–	1.8%	1.8%
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \tau^+\tau^-)$	$g^2_{\mathrm{HWW}} g^2_{\mathrm{H\tau\tau}}/\Gamma_{\mathrm{H}}$	–	4.2%	tbd
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mu^+\mu^-)$	$g^2_{\mathrm{HWW}} g^2_{\mathrm{H\mu\mu}}/\Gamma_{\mathrm{H}}$	–	38%	16%
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \gamma\gamma)$		–	15%	tbd
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{Z}\gamma)$		–	42%	tbd
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{WW}^*)$	$g^4_{\mathrm{HWW}}/\Gamma_{\mathrm{H}}$	tbd	1.4%	0.9%†
$\mathrm{H}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{H}\nu_e\bar{\nu}_e) \times BR(\mathrm{H} \to \mathrm{ZZ}^*)$	$g^2_{\mathrm{HWW}} g^2_{\mathrm{HZZ}}/\Gamma_{\mathrm{H}}$	–	3%†	2%†
$\mathrm{He^+e^-}$	$\sigma(\mathrm{He^+e^-}) \times BR(\mathrm{H} \to \mathrm{b\bar{b}})$	$g^2_{\mathrm{HZZ}} g^2_{\mathrm{Hbb}}/\Gamma_{\mathrm{H}}$	–	1%†	0.7%†
$\mathrm{t\bar{t}H}$	$\sigma(\mathrm{t\bar{t}H}) \times BR(\mathrm{H} \to \mathrm{b\bar{b}})$	$g^2_{\mathrm{Htt}} g^2_{\mathrm{Hbb}}/\Gamma_{\mathrm{H}}$	–	8%	tbd
$\mathrm{HH}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{HH}\nu_e\bar{\nu}_e)$	g_{HHWW}	–	7%*	3%*
$\mathrm{HH}\nu_e\bar{\nu}_e$	$\sigma(\mathrm{HH}\nu_e\bar{\nu}_e)$	λ	–	32%	16%
$\mathrm{HH}\nu_e\bar{\nu}_e$	with −80% e$^-$ polarization	λ	–	24%	12%

*: preliminary
†: estimated

lumi spectrum at 350 GeV







If we want to use >90% of the beam to study a process at threshold T, the nominal beam energy has to be set to (T+25) GeV

If we want to use >80% of the beam to study a process at threshold T, the nominal beam energy has to be set to (T+12) GeV

top couplings from kinematic studies

- Measure asymmetries (e.g. A_{FB}), top production, top decays
  - ⇒ Access to top-electroweak couplings (Z, photon, W)
  - ⇒ Good sensitivity to various BSM models
- Near threshold, with small boost, this does not work
  - E.g. forward-backward asymmetry is very small at threshold, then rises quickly with energy
- ILC studies at 500 GeV and 500 fb^{-1} => works well
- Polarisation adds left-right information. How crucial is this? Compatible with Higgs physics (which prefers negative e^- polarisation)?

Some ILC references (500 GeV):

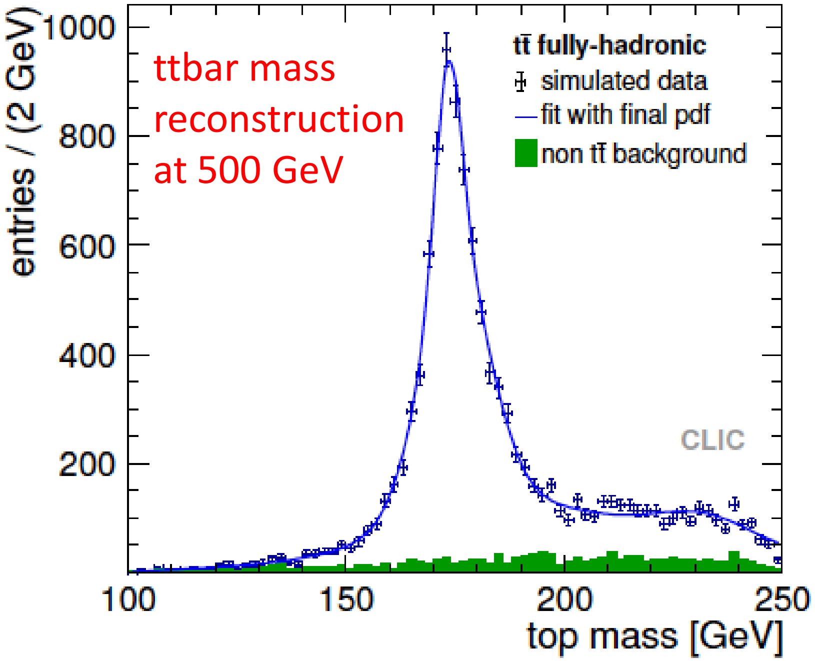
- Production asymmetry: Phys.Rev.D83:034012,2011
- Photon and Z couplings: arXiv:1307.8102

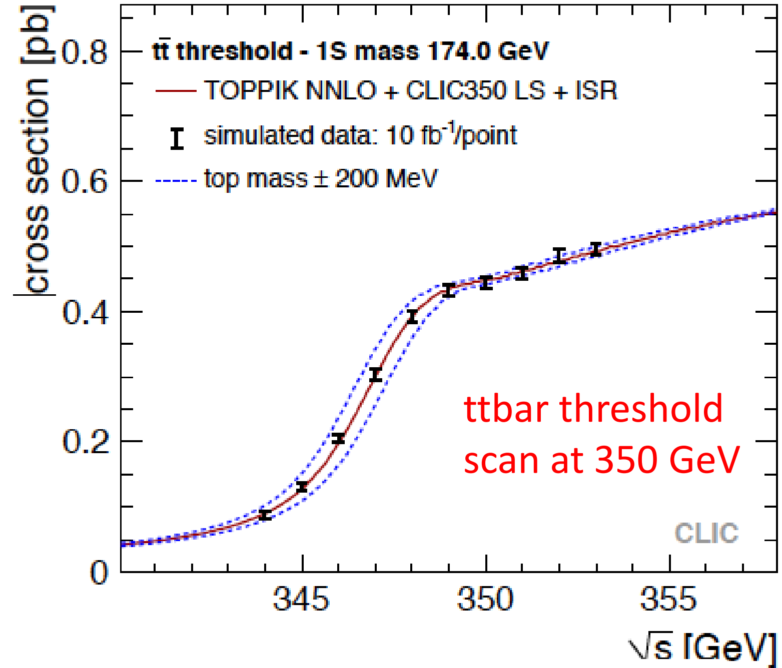
Rare decays in single top production:

- Flavour-changing neutral coupling, sensitive to new physics, Tesla 500 GeV and 800 GeV: hep-ph/0102197 (theoretical study, *limited improvement wrt LHC*).

Snowmass summary: LHC will measure top couplings (photon, gluon, Z, W) to a precision that should allow to detect deviations by generic BSM models at the TeV scale. Linear Collider will do much better in pinning down models or excluding them at much higher scales.

CLIC top-mass benchmark studies





$\sqrt{s}$ (GeV)	Technique	Measured quantity	Integrated luminosity (fb^{-1})	Unit	Generator value	Stat. error	
350	Threshold scan	Mass α_s	10×10	GeV	174 0.118	0.033 0.0009	right
500	Invariant mass	Mass	100	GeV	174	0.080	left plot

Final result is dominated by systematic errors (theor. normalisation, beam-energy systematics, translation of 1S mass to $\overline{\text{MS}}$ scheme) => 100 MeV error on top mass

Some to kinematics

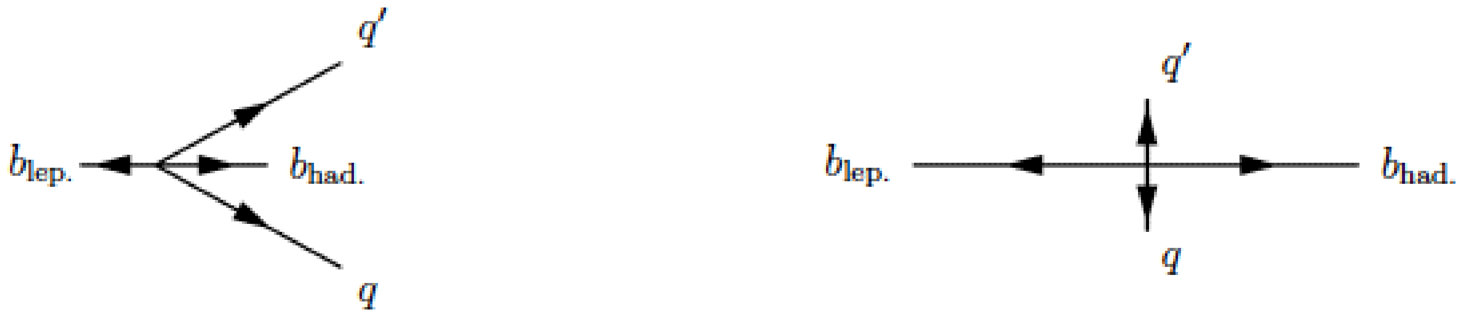
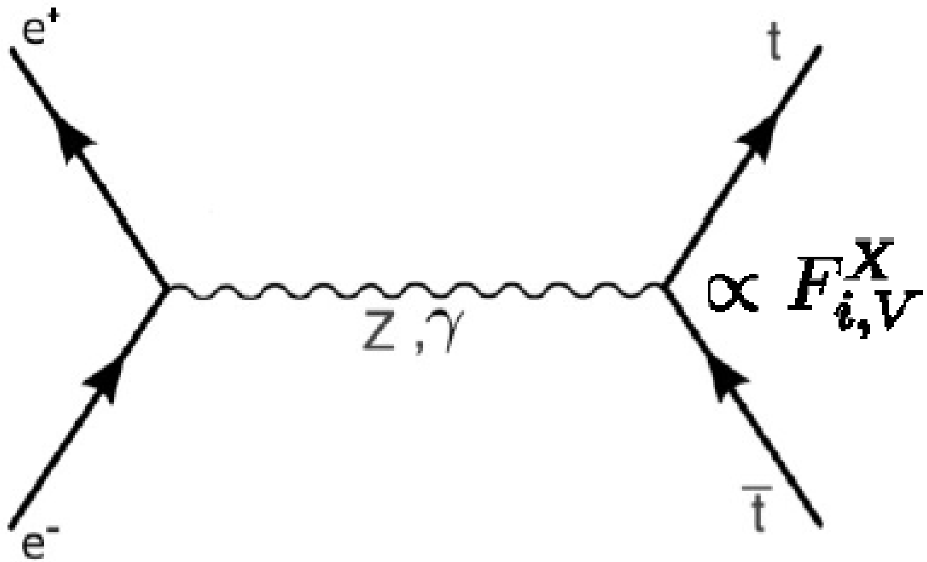


Figure 6: *In case of a t_R decay, the jets from the W dominate the reconstruction of the polar angle of the t quark. In case of a t_L the W is practically at rest and jets from the b quark dominate the and reconstruction of the polar angle of the t quark.*

From ILC study: arXiv:1307.8102

Electroweak couplings of the top quark

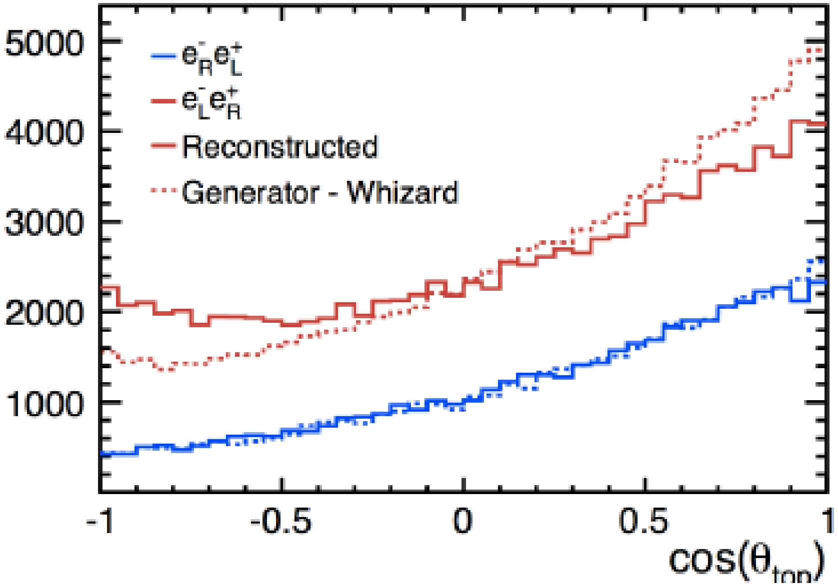


$$\Gamma^{ttX}_{\mu}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F^X_{1V}(k^2)+\gamma_5 F^X_{1A}(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF^X_{2V}(k^2)+\gamma_5 F^X_{2A}(k^2)\right)\right\}, \quad (2)$$

$$\mathcal{F}^L_{ij} = -F^\gamma_{ij}+\left(\frac{-\frac{1}{2}+s_w^2}{s_w c_w}\right)\left(\frac{s}{s-m_Z^2}\right)F^Z_{ij}$$

$$\mathcal{F}^R_{ij} = -F^\gamma_{ij}+\left(\frac{s_w^2}{s_w c_w}\right)\left(\frac{s}{s-m_Z^2}\right)F^Z_{ij},$$

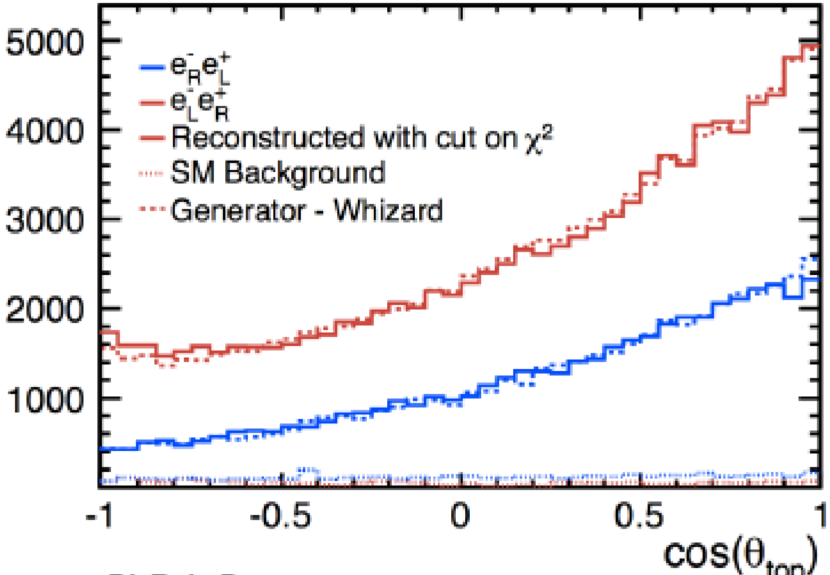
Semi Leptonic Analysis - Reconstruction of top quark production angle



Ambiguities in case of
left handed electron beams
Due to V-A structure at ttX vertex

Precise reconstruction of θ_{top}
in case of right handed electron beams

Remedy to address ambiguities:
Select cleanly reconstructed events by χ^2 analysis
or
Reconstruction of b quark charge



Precise reconstruction for both beam polarisations

- Efficiency Penalty for e_L
- ε_{tot}: $e_R \sim 50\%$, $e_L \sim 30\%$

Precision on A_{FB} ~ 2%

PhD J. Rouene

Courtesy: Roman Poeschl

Work plan ?

The case of the electroweak couplings to the top seems important enough to consider a first CLIC energy stage above 360 GeV

We would need some first-level answers on a time-scale of ~2-3 months

Possible to-do list

Higgs:

- Higgsstrahlung with Z=>qq at ~420 GeV or ~500 GeV
    - Possibly to be done at Cambridge using 500 GeV ILC samples
- Better understand required Higgs mass accuracy from theoretical perspective
- Detector calibration linked to Higgs mass accuracy
    - E.g. look into possibility of using Z-production through WW fusion

Top:

Talk to experts and perform a few key generator studies

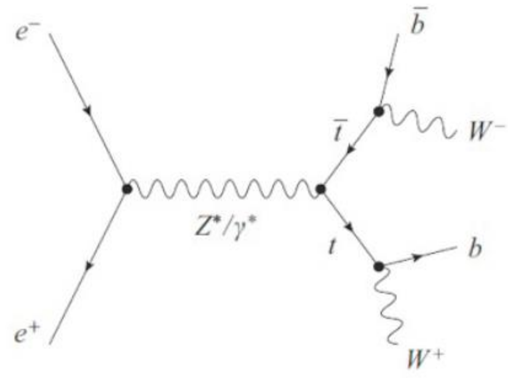
- Which observables are best to extract the couplings of the top quark to gamma, W and Z bosons? How well measurable in 360-500 GeV region ?
- Is a precision measurement of the left-right asymmetry crucial? Are beam polarisation choices compatible between Higgs and top studies?
- Would BSM sensitivity depend on √s ?

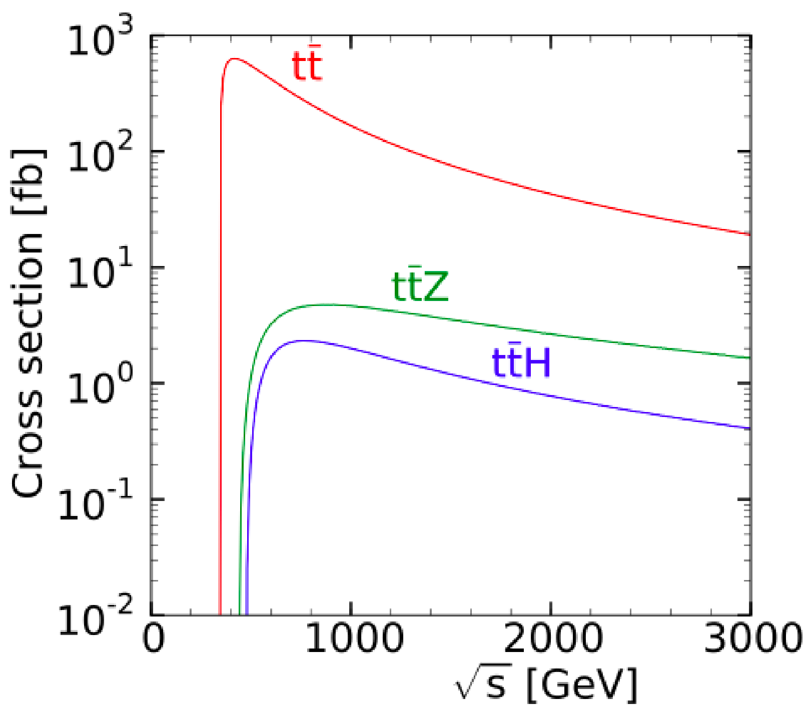
top physics at CLIC……

Possible top physics studies

- Top mass through threshold scan ☑
- Top mass reconstruction ☑
- Top coupling to Higgs (ttH) ☑
- Forward-backward asymmetries to study couplings to γ, Z
- Top production/decays to study top-W coupling
- CP violation in top decays
- Flavour-changing top decays
- V_{tb} from single top events
- ….

(e.g. 200’000 eγ=>tbν events expected at 3TeV)





Most complete reference
includes LHC comparison:
Snowmass top report: arXiv:1311.2028