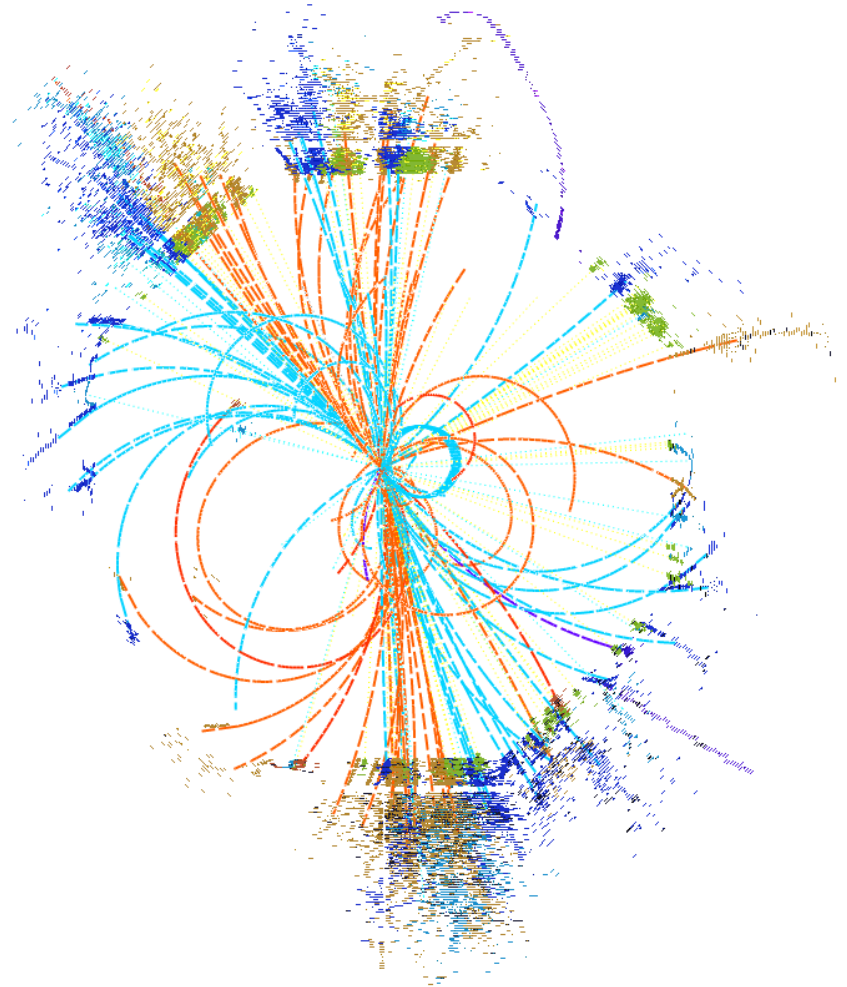# Status and plans for future CLIC physics benchmark studies

Philipp Roloff (CERN)

CLICdp Monthly Meeting, 03/08/2015, CERN

Motivation for physics benchmark studies

- Illustrate the CLIC physics potential
- Demonstrate the capabilities of the CLIC detector concepts based on realistic simulations

Physics benchmarks studies lead to:
hardware requirements, physics-based detector optimisation (not always easy, e.g. reconstruction of multi-jet final states not just driven by detector performance)

Example issues not (sufficiently) addressed so far:
- Reconstruction of jets/resonances in the forward direction
- Boosted top quarks (common issue with hadron colliders)
- Impact of beam polarisation

Outline

- **Higgs studies after the paper**

- **Plans for the top paper**

- **Other studies with focus on BSM physics**

Higgs topics after the paper

Reanalysis of double Higgs production

Planned extensions:
- Add analysis for the
HH → bb̄WW* final state (40% more events
compared to HH → bb̄bb̄ alone)
- Simultaneous extraction of the Higgs
self coupling and the quartic HHWW coupling
from differential distributions

Detector / reconstruction issues:
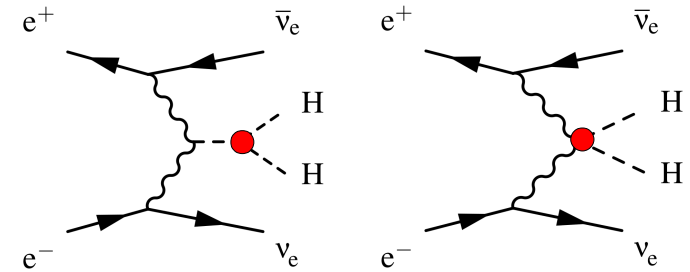- (Forward) jet reconstruction
- b-tagging

People:
- HH → bb̄bb̄:
Rosa Simoniello, Ph. R.
- HH → bb̄WW*:
Bono Xu

Higgs polar angle in
$e^+e^- \to$ HHνν̄ events
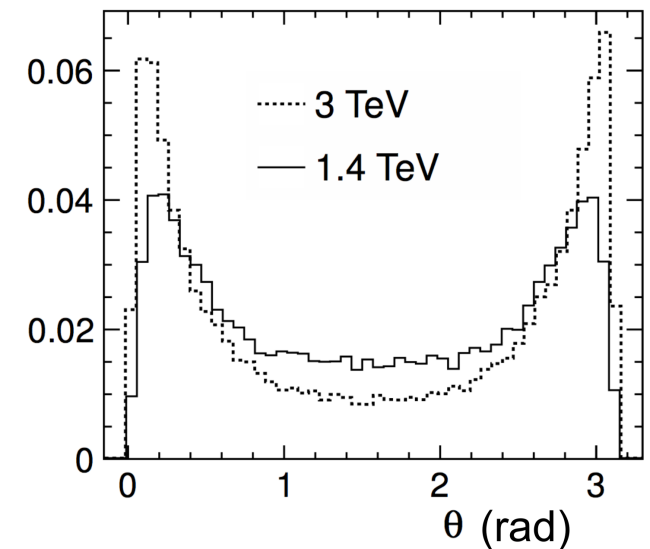
Other new Higgs analyses (1)

Addressing a few issues not covered in the Higgs paper:

• **H→WW*→qqlv using WW fusion at 350 GeV:**
Continuation of the ongoing H→WW* analyses using HZ events
People: Mila Pandurovic

• **H→γγ at 3 TeV:**
Detector / reconstruction issues: test of photon reconstruction using the new CLIC detector concept
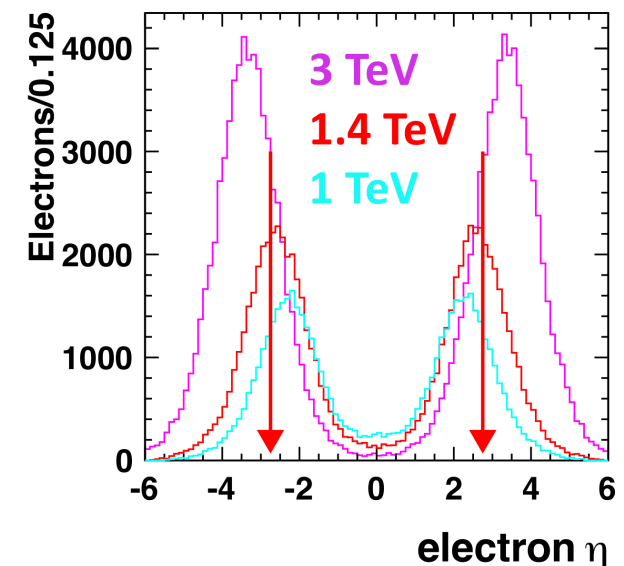**People:** Goran Kacarevic, Strahinja Lukic

• **Higgs production in ZZ fusion:**
Extension of the ongoing analysis at 1.4 TeV
Detector / reconstruction issues:
- Reconstruction of forward electrons
- b-tagging
People: Aidan Robson, more people welcome

Other new Higgs analyses (2)

- **$\sigma(HZ)$ using $Z \rightarrow l^+l^-$ at 380 GeV**
Check impact of new CLIC staging baseline
People: Molly Herman, Tianqi Tang, Shawn Hayes, Nikiforos Nikiforou

- **Reanalysis of $H \rightarrow b\bar{b}/c\bar{c}/gg$ at 1.4 and 3 TeV**
Additional backgrounds and bugfixes compared to CDR results, extension to measure the Higgs CP properties in the HWW coupling possible
People: Philipp Roloff

Paper on top physics at CLIC

Paper on top physics

Aim: Comprehensive paper on top physics at CLIC

Timescale: finish within 1 – 1.5 years

**Assumed running scenario will be the new CLIC staging baseline:**

1.) 100 fb^{-1} around 350 GeV + 500 fb^{-1} at 380 GeV
2.) 1.5 ab^{-1} at 1.4 TeV
3.) 2 ab^{-1} at 3 TeV

80% electron beam polarisation assumed at all stages

First stage (350 - 380 GeV)

Threshold scan (350 GeV):
• Extract theoretically well-defined top mass

• Currently 50 MeV theoretical uncertainty seem reachable
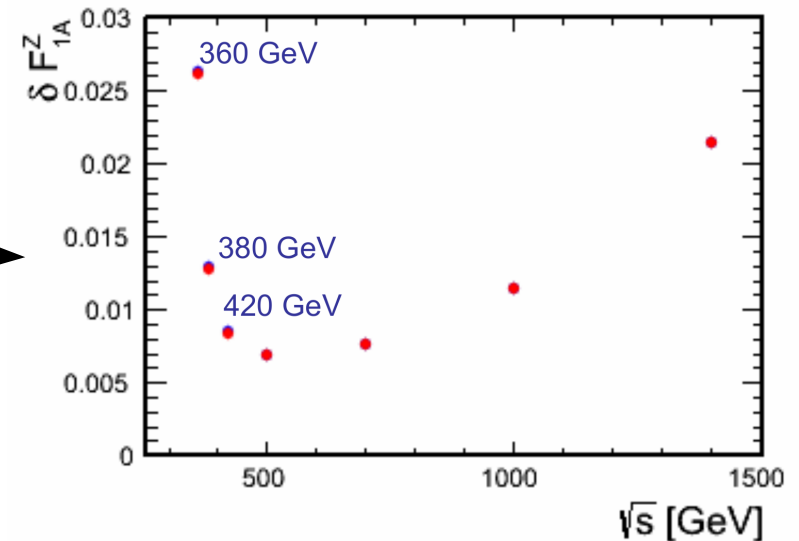→ Systematic uncertainties need to be controlled on that level
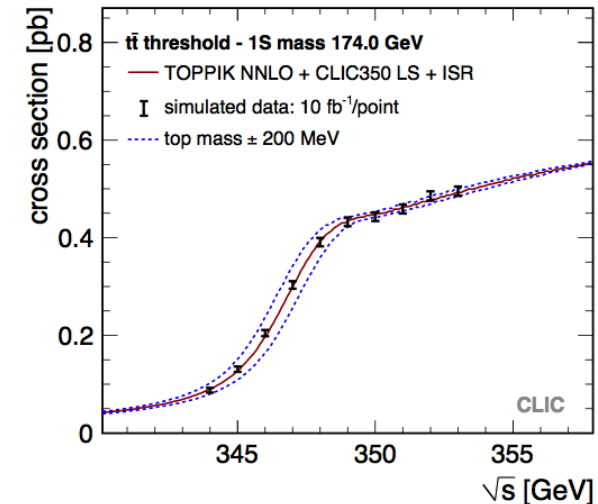
380 GeV:
• Sensitivity to BSM phenomena through precision measurements (A^{LR}, A^{FB}) of $t\bar{t}$ production.
Example: precision measurement of top quark couplings to Z and γ

• Close to maximum of $t\bar{t}$ production cross section (400000 $t\bar{t}$ pairs in 500 fb^{-1})
→ suitable for rare decays, e.g. t → cH, t → cγ, ...

Marcel Vos at CLIC workshop 2015

ttH production:
- 1.4 TeV not far from maximum
of cross section
→ extraction of the top Yukawa coupling
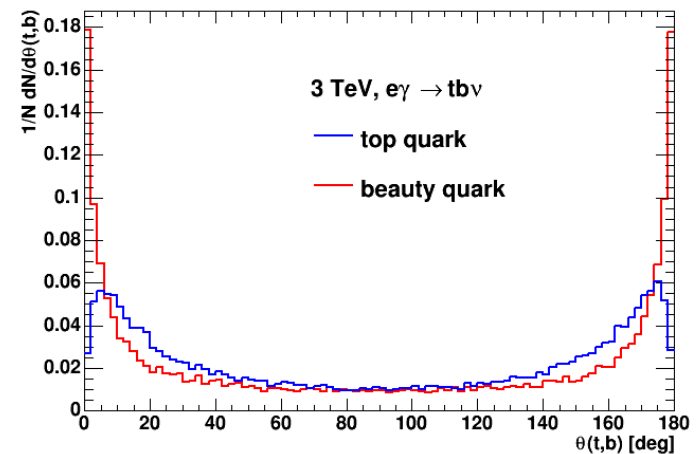→ Higgs CP properties in ttH coupling

tt̄ production:
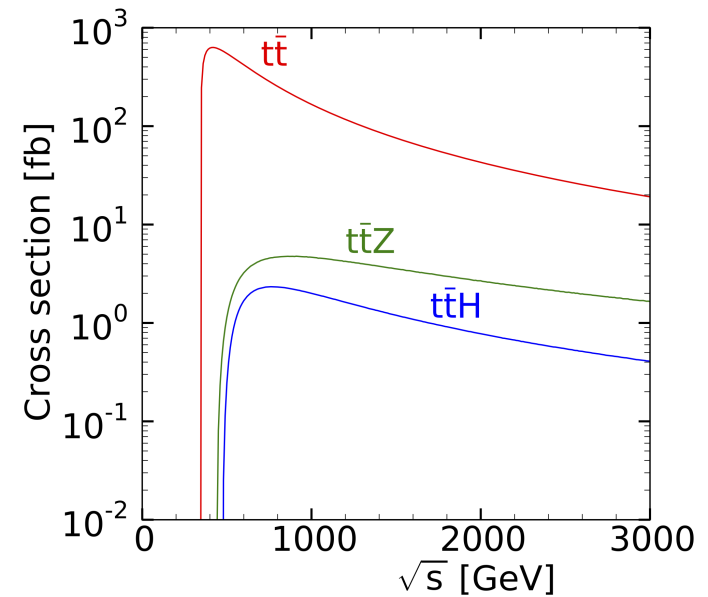- Often contributions from New Physics
rise with the interaction energy as E^2 / Λ^2,
where Λ is the scale of New Physics

Single top production:
- $e\gamma \to tb\nu$ has no background from $t\bar{t}$
- 200000 events expected at 3 TeV for 2 ab^{-1}
→ measurement of V_{tb}

New particle searches using boosted tops:
- Example: light stop quarks

Possible content of the paper

• Reconstruction strategies for top quarks
(boosted and near threshold)

• **Benchmark analyses:**
1.) Threshold scan around 350 GeV
2.) Measurement of A^{LR}/A^{FB} for different polarisation configurations and extraction of the couplings to the Z boson and photon
at 380 GeV, 1.4 TeV (and 3 TeV?)
3.) FCNC top quark decays: $t \rightarrow cH$ (+ $t \rightarrow c\gamma$ and others?) at 380 GeV
4.) Analysis of $t\bar{t}H$ events at 1.4 TeV: top Yukawa coupling
and CP properties in the ttH coupling
5.) V_{tb} from single top events at 3 TeV?
6.) Top squark pair production at 3 TeV (using CDR Model 3)?

• Phenomenological interpretations of the results where possible

Existing results and ongoing work

- Threshold scan (Eur.Phys.J. C73 (2013) 2530)
→ to be adapted to new developments (improved theory, systematics, …)

- Top Yukawa coupling (CLIDdp-Note-2015-001, CLIDdp-Note-2015-001)
→ add study of Higgs CP properties

- Decay $t \rightarrow cH$ at 380 GeV
→ generator study by Filip Zarnecki, will be extended to full simulation

- $t\bar{t}$ production at 380 GeV and Z and γ couping at 380 GeV
→ ongoing study by Nacho Garcia, Martin Perello and Marcel Vos

- $t\bar{t}$ production at 1.4 TeV
→ very first look by Megan Wilson

- Top squark production (CDR model 3)
→ ongoing study by Alan Taylor, Andrew Thornbury and Victoria Martin

$\boxed{\rightarrow \text{A lot of open topics / opportunities to contribute}}$

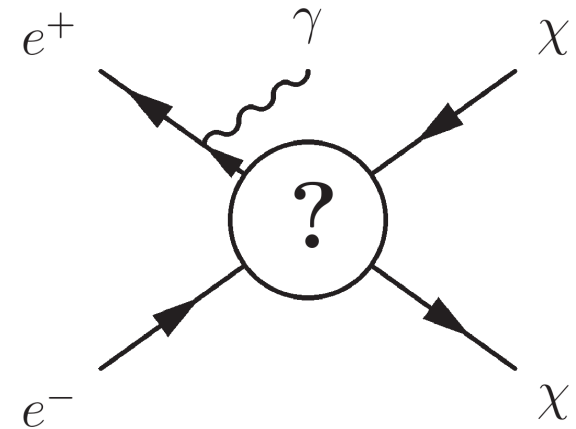# Other topics with focus on BSM physics

Ongoing and starting studies (1)

• **Model-independent searches for Dark Matter using the photon + missing energy final state:**
Continuation of the ongoing study
Detector / reconstruction issues:
Forward photon reconstruction, missing energy
People: Jean-Jacques Blaising

• **Triple and quartic gauge couplings using**
$e^+e^- \rightarrow W^+W^- (\nu\bar{\nu}/e^+e^-)$:
Important to choose parametrisation comparable to other studies/experiments
Detector / reconstruction issues:
Separation of highly boosted W/Z bosons
People: Steve Green

Ongoing and starting studies (2)

• **Hidden valley searches using Higgs decays:**
Ongoing study
Detector / reconstruction issues:
Reconstruction of vertices from long-living particles
People: Marcin Kucharczyk

• **b$\bar{\text{b}}$ production asymmetry at 1.4 TeV**
Ongoing study, synergy with t$\bar{\text{t}}$ studies
Detector / reconstruction issues:
Identification of boosted b-quark jets
People: Pawel Sopicki

Open topics

Many interesting aspects not yet investigated for CLIC yet:

• **Gauginos/Higgsinos with small mass splittings:**
Impossible at hadron colliders?
Detector / reconstruction issues:
- Soft particles in the presence
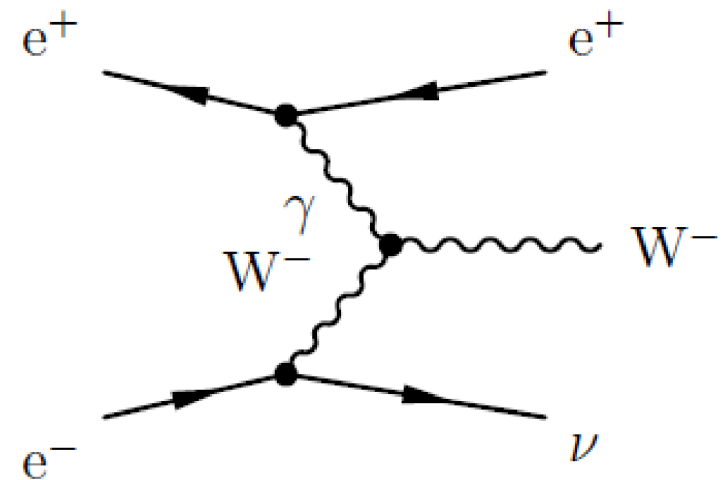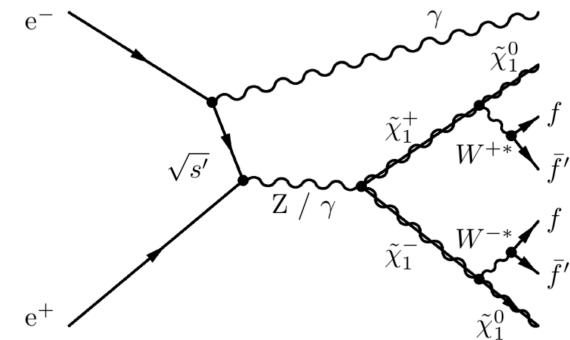of beam-induced background
- Photon reconstruction
- Missing energy

• **W boson mass determination
at high energy:**
Large samples of single W events
produced at high-energy CLIC
Detector / reconstruction issues:
Systematics (jet energy scale calibration
using Z decays)

• **Higher-dimensional effective operators,
weakly interacting exotic particles**

How to get involved

Regular analysis meetings at CERN (every 2-3 weeks):

http://indico.cern.ch/categoryDisplay.py?categId=3222

Remote participation by webex is always possible!

If interested, please contact us:

marshall@hep.phy.cam.ac.uk
philipp.roloff@cern.ch

Summary and outlook

- CLIC physics benchmark studies are a very active area

- **In the foreseeable future, the focus will be on:**

1.) Sensitivity to BSM physics, also through precision EW measurements
→ Be prepared for new input from the LHC at 13 TeV

2.) Overview paper on top physics

3.) Benchmarking of the CLICdet_2015 detector model using the new simulation and reconstruction chain

- Lots of opportunities to contribute
(many examples in this presentation)

Backup slides

Future detector model and software chain

• All current benchmarks are performed either for the CLIC_ILD or the CLIC_SiD detector model

• **New detector concept optimised for CLIC:** move to single software chain in the future

• **On the same time scale:** WHIZARD 1.95 → WHIZARD 2 PYTHIA 6.4 → PYTHIA 8?