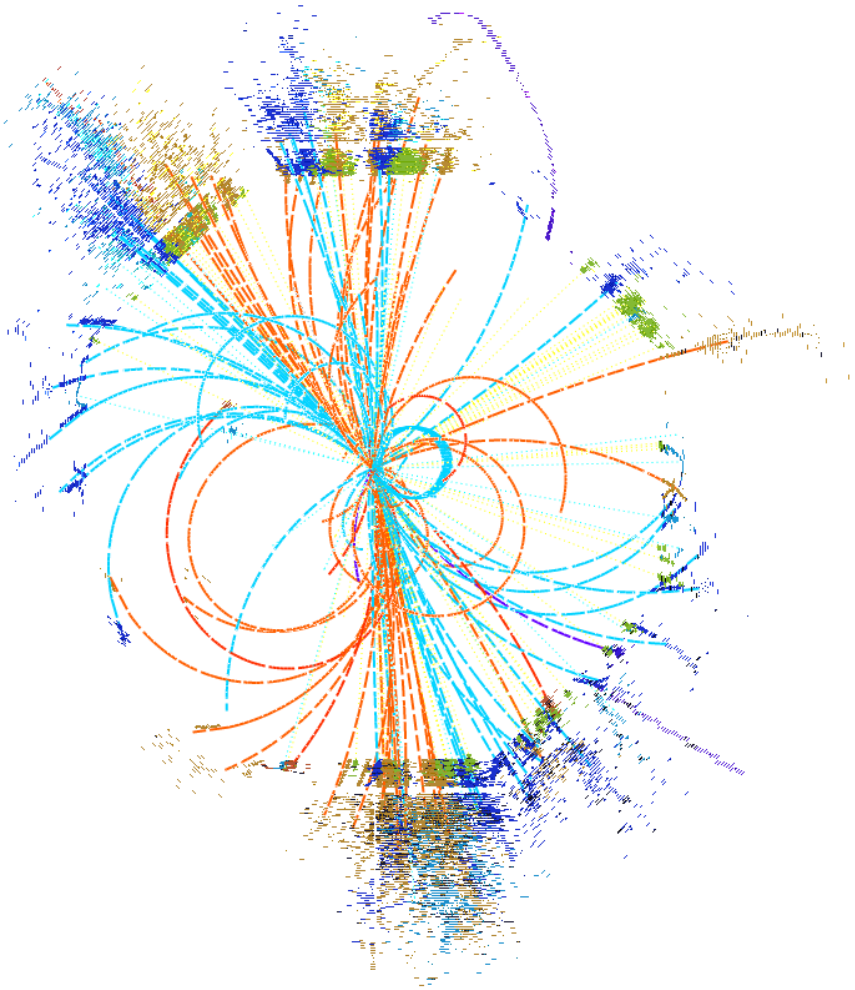
Plans for physics studies at CLIC, covering studies to define the first energy state as well as upcoming full benchmark studies

Philipp Roloff (CERN)



CLICdp Monthly Meeting, 07/10/2014, CERN

Introduction

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)
- Input for staging scenario

Example issues not (sufficiently) addressed so far:

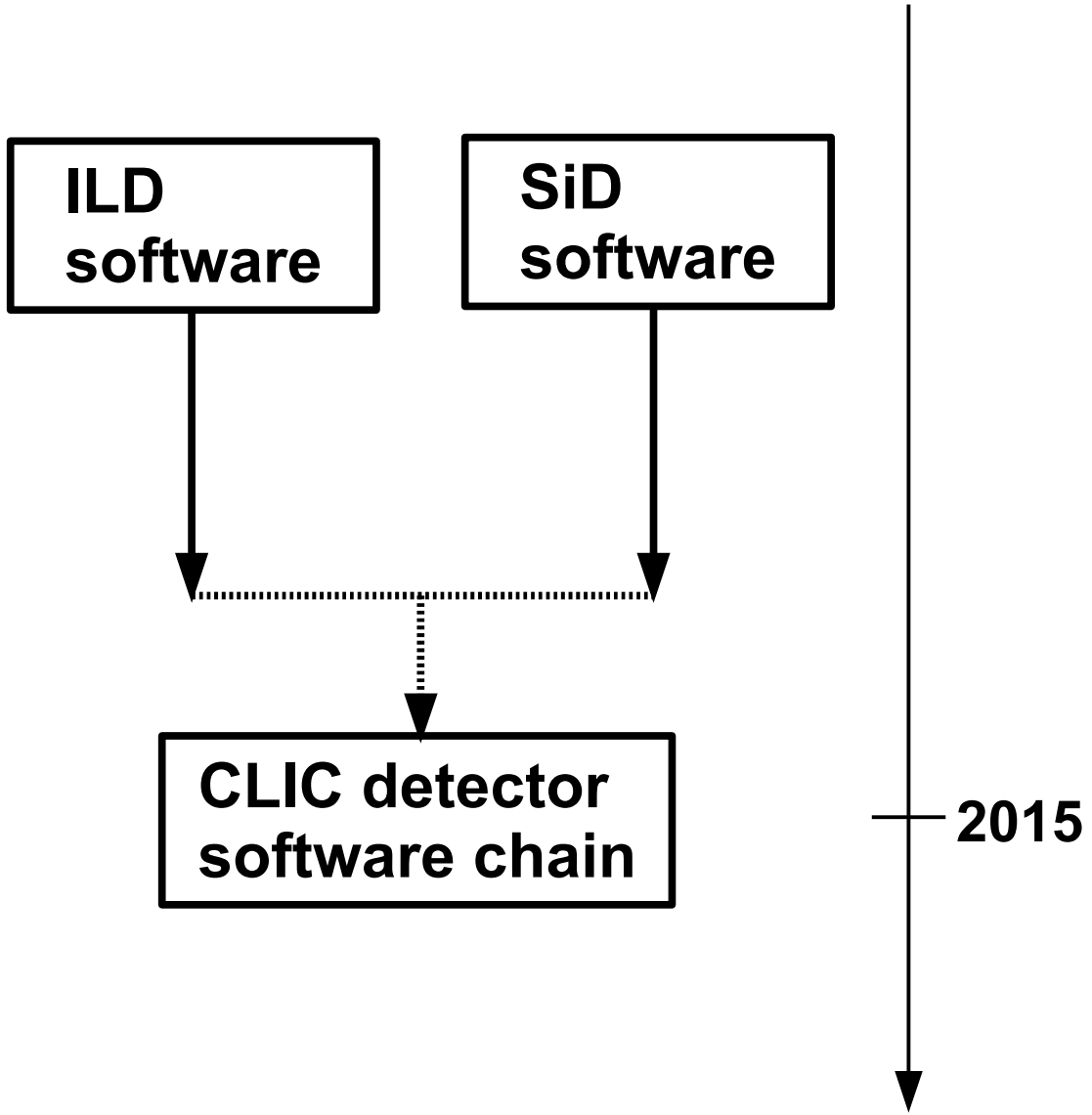
• Reconstruction of jets/resonances in the forward direction
• Boosted top quarks (common issue with hadron colliders)
• Impact of beam polarisation
(tradeoff between BSM sensitivity and precision Higgs physics)

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?

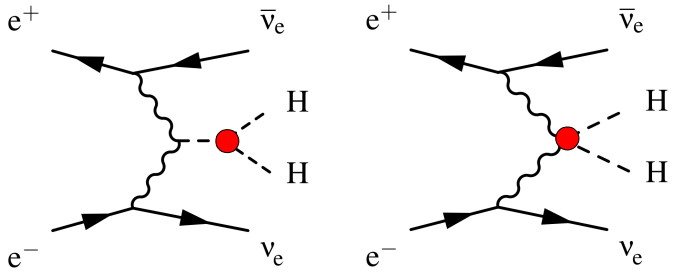


Higgs topics after the paper

Reanalysis of double Higgs production

Planned extensions:

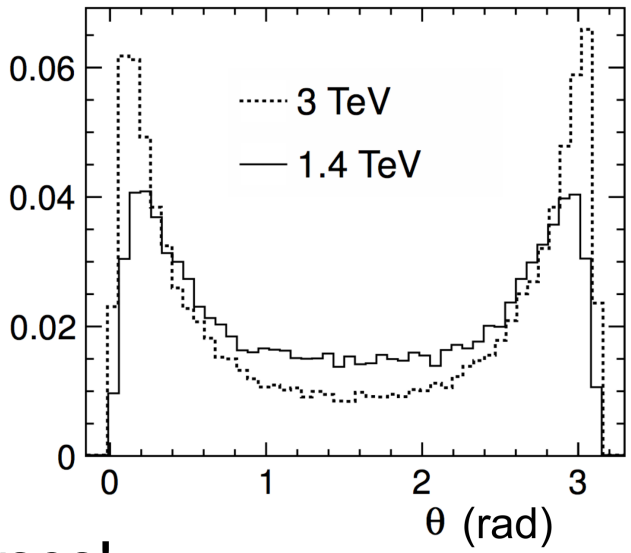
- Add analysis for the HH → bb̄WW* final state (40% more events compared to HH → bb̄bb̄ alone)
- Simultaneous extraction of the Higgs self coupling and the quartic HHWW coupling from differential distributions



Detector / reconstruction issues:

- Forward jet reconstruction using the new CLIC detector concept
- b-tagging

Higgs polar angle in $e^+e^- \to HH\nu\bar{\nu}$ events



People:

- Rosa Simoniello (bb̄bb̄ final state)
- Tomas Lastovicka
- Philipp Roloff
- More help welcome, this is one of the flagship analyses!

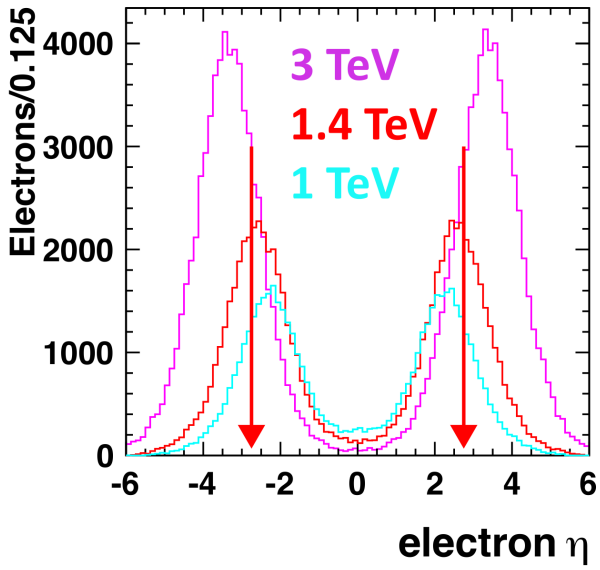
Other new Higgs analyses

Addressing a few issues not covered in the Higgs paper:

- **H→WW* using WW fusion at 350 GeV:**
Continuation of the ongoing H→WW* analyses using HZ events, WW fusion at 350 GeV so far only studied using H→bb̄
People: Mila Pandurovic

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

- **Higgs production in ZZ fusion at 3 TeV:**
Extension of the ongoing analysis at 1.4 TeV
Detector / reconstruction issues:
- Reconstruction of forward electrons
- b-tagging
People: Aidan Robson, more people welcome



CP properties of the Higgs boson

Not studied for the the Higgs paper:

- **Using $e^+e^- \rightarrow t\bar{t}H$ events:**

Extension of the finished
top Yukawa study at 1.4 TeV

Detector / reconstruction issues:

- b-tagging
- Jet reconstruction in complex final states
- Lepton identification

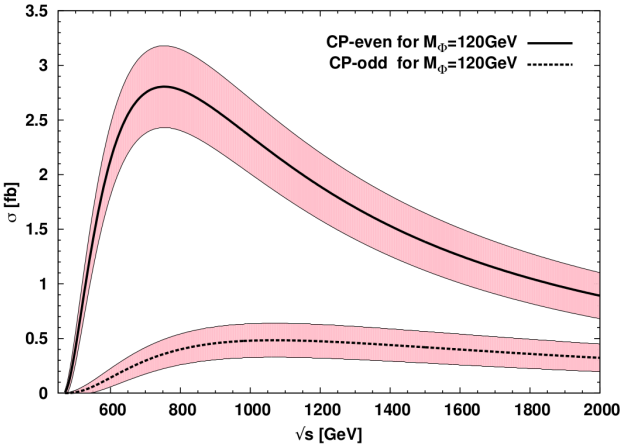
People: Sophie Redford, Marcello Vogel

- **Using WW and ZZ fusion events:**

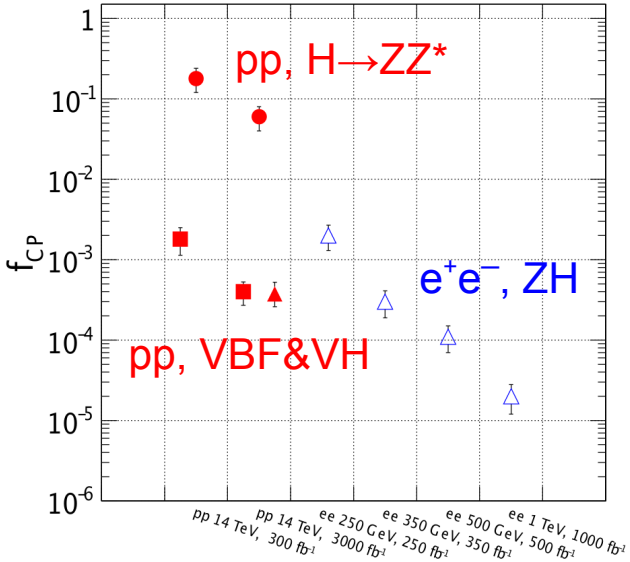
Large statistics at CLIC promising

People: not covered yet

More details on the physics
→ presentation at CLICdp workshop in June



Eur. Phys. J. C71, 1681



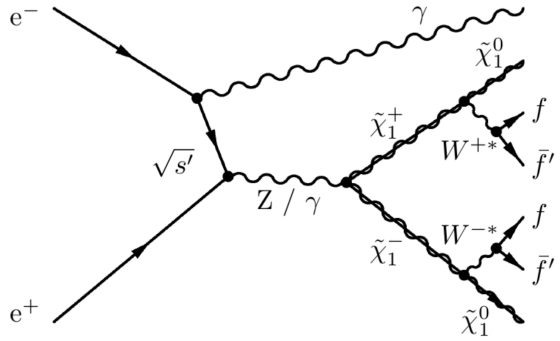
arXiv:1310.8361

Possible future CLIC physics benchmark studies

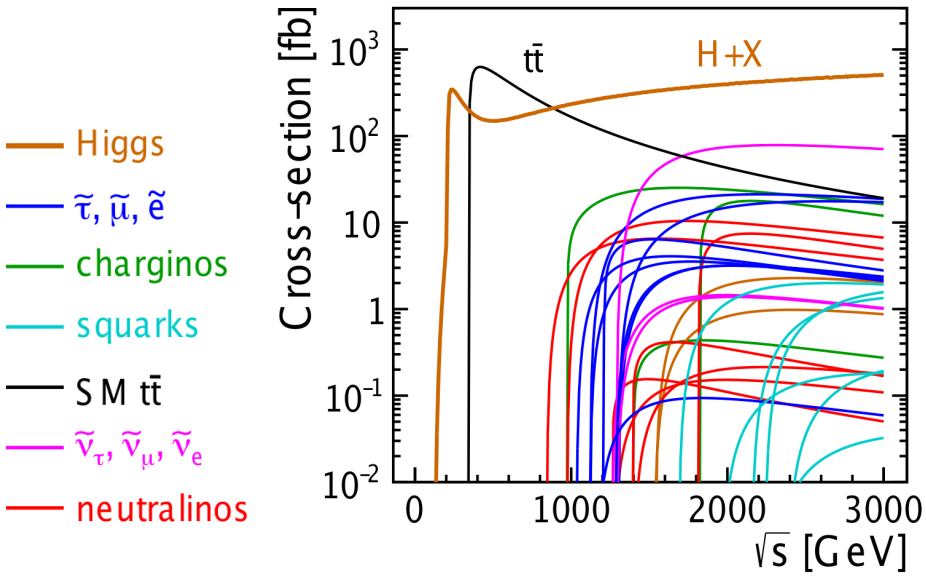
Supersymmetry

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
People: not covered yet



• **Top squark production:**
Starting using CDR model III
Detector / reconstruction issues:
- Boosted top quarks
- Missing energy
People: Victoria Marin, Alan Taylor, Theo Galy-Fajou



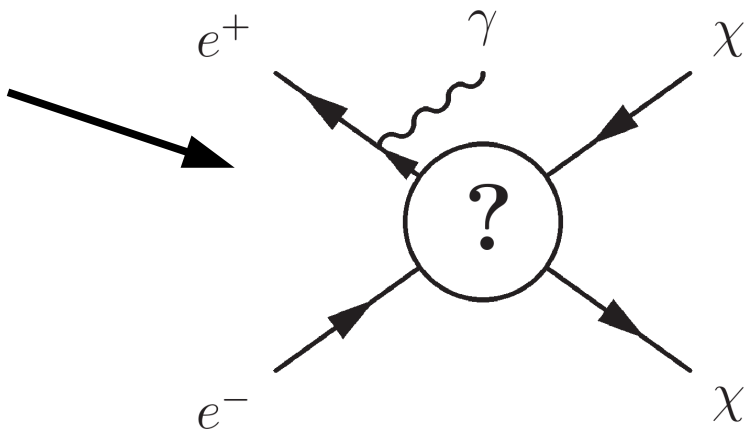
More details on the physics
→ presentation at CLICdp workshop in June

Other BSM physics studies

Mayor focus of CLIC physics at high energy:

• **Generalisation of higher-dimensional effective operator searches at the various CLIC energy stages:**
People: not covered yet

• **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



• **Searches for weakly interacting exotic particles:**
People: not covered yet

• **(Higgs) compositeness:**
One topic is double Higgs production (see earlier), other processes not covered yet

Top physics at high energy

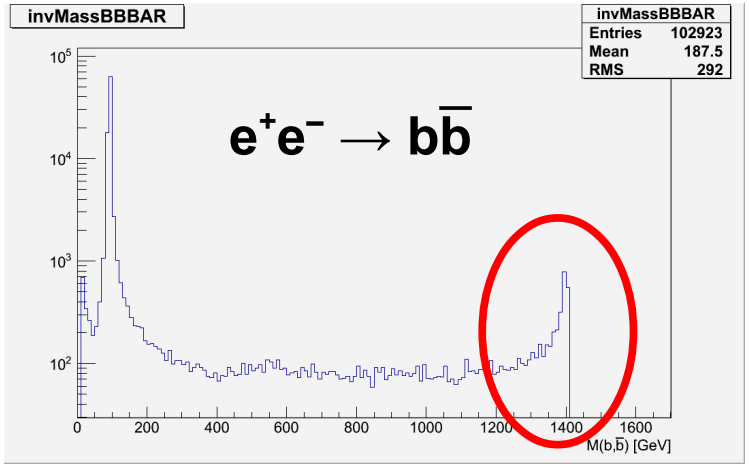
- **A_{FB} at high energy:**

First step is $b\bar{b}$ production asymmetry, later extend to $t\bar{t}$ production

Detector / reconstruction issues:

- Jet change reconstruction
- b-tagging for high-energy jets

People involved: Pawel Sopicki, Tadeusz Lesiak



- **Other possible studies using $t\bar{t}$ production at high energy:**

- $\sin^2\theta_W$
- Couplings to γ, W and Z

→ Looking for volunteers

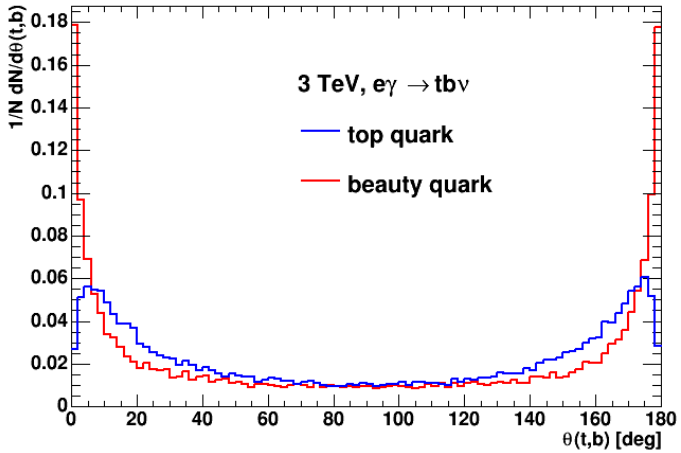
- **V_{tb} from single top:**

200000 eγ→tbν events expected at 3 TeV
(no $t\bar{t}$ contribution in contrast
to $e^+e^- \rightarrow tbev_e$ or $\gamma\gamma \rightarrow tbev_e$)

Detector / reconstruction issues:

Forward jet reconstruction

People involved: not yet covered



Precision EW measurements

- **Triple and quartic gauge couplings using $e^+e^- \to W^+W^-(\nu\bar{\nu}/e^+e^-)$:**

Important to choose parametrisation comparable to other studies/experiments

Detector / reconstruction issues:
Separation of highly boosted W/Z bosons

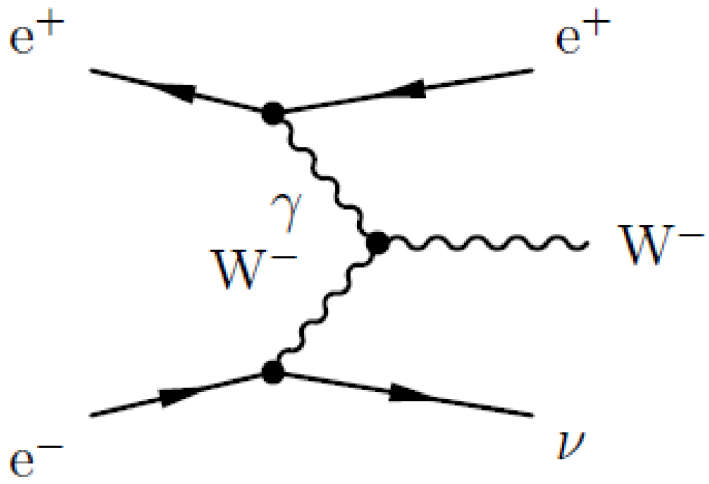
People: not yet covered

- **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)

People: Boruo Xu



Studies to define the first energy stage

Studies to define the first stage (1)

$t\bar{t}$ pair production:

• Identifiy the relevant observables sensitive to BSM effects at 420 GeV and 500 GeV (production asymmetries, cross section, …)
• Decide on energy of first stage in the near future
→ generator level studies for the different energies (350 GeV, 420 GeV, 500 GeV)
• If energy higher then 350 GeV is chosen
→ full simulation studies for imprtant observabels

Studies to define the first stage (2)

Higgs physics:

- The Higgs program should not be affected significantly by the increased energy of the first stage
- The model-independent measurement of σ(HZ) using leptonic decays not precise enough above 350 GeV
(see LCD-Note-2012-015 for full simulation study at 500 GeV)
- However, the measurement using hadronic Z decays might benefit from higher energies
(better separation of Higgs and Z boson?)
→ redo analysis at 500 GeV before decision on first energy stage (using ILC samples?)
- If energy higher then 350 GeV is chosen
→ further full simulation studies of Higgs production will follow

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:

mark.thomson@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:**

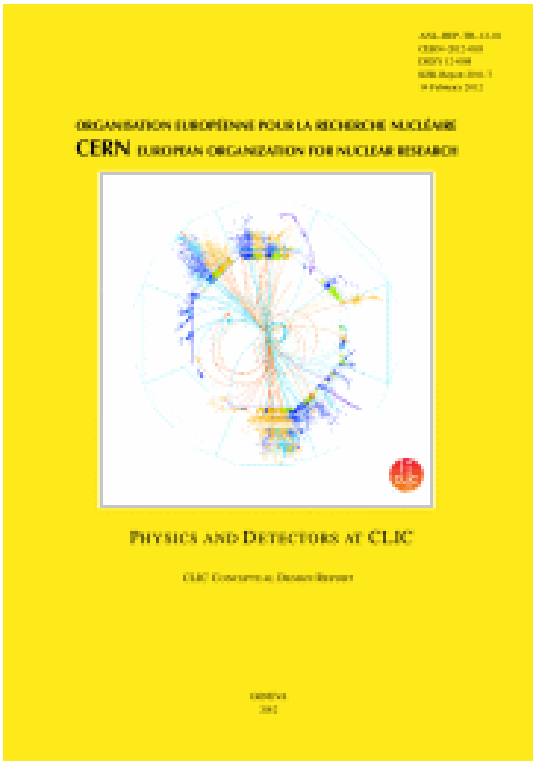
- Sensitivity to BSM physics
(also through precision Higgs, top, EW measurements)
- Physics-based optimisation of the new detector concept
- Revisit the simulation and reconstruction chain

- Near-term issue: provide input to select energy for first energy stage

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

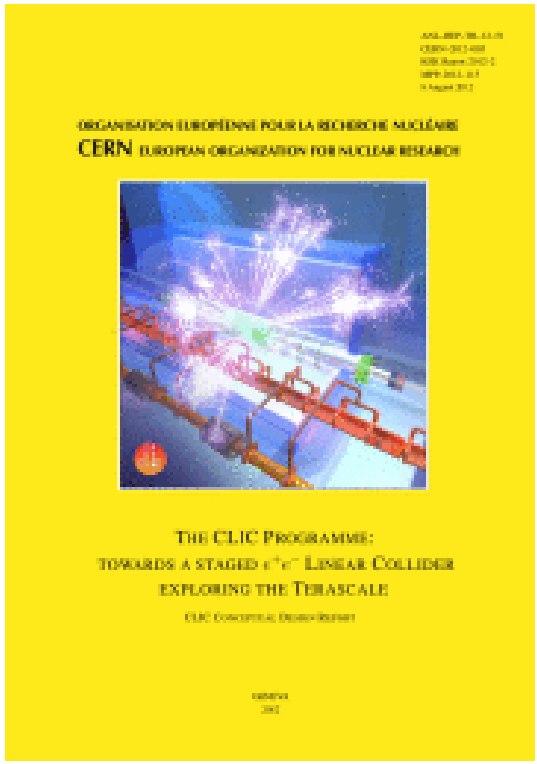
Backup slides

Reminder: CDR and Snowmass white paper



CLIC Conceptual Design Report (CDR) Vol. 2:
Physics and Detectors
(mostly at 3 TeV)

arXiv:1202.5940



CLIC CDR Vol. 3:
Staged construction,
SUSY at 1.4 TeV

arXiv:1209.2543


Physics at the CLIC e^+e^- Linear Collider
Input to the Snowmass process 2013

October 1, 2013

Snowmass white paper:
Most of the Higgs studies

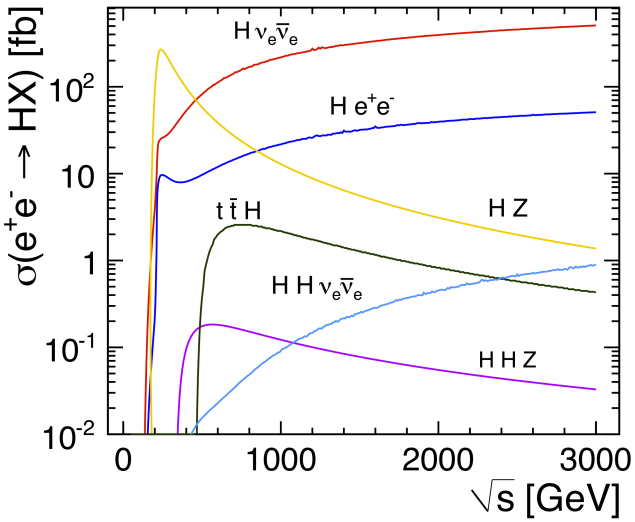
arXiv:1307.5288
(last update: 01/10/2013)

Status of the Higgs paper

- Complete set of Higgs coupling (and mass) studies at 350 GeV, 1.4 TeV and 3 TeV

- Several topics investigated for the first time:

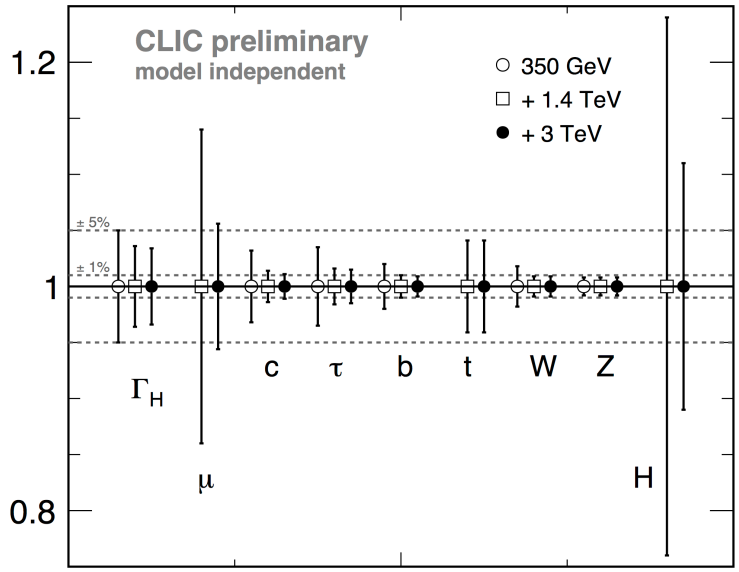
  - ZZ fusion
  - Model ind. σ(HZ) using $Z \to q\bar{q}$



- A few analyses still ongoing
→ see talks on Wednesday morning

- Paper draft in progress, publication foreseen this summer

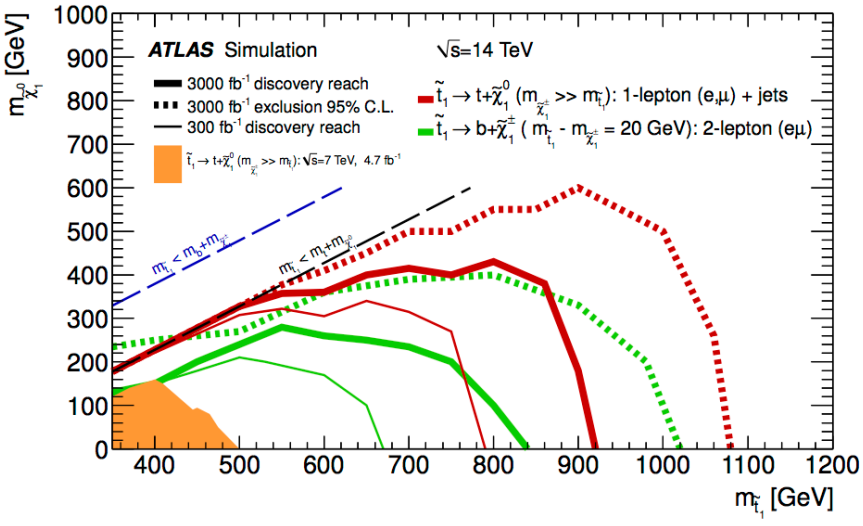
- Only total cross sections, plans for differential distributions later in this talk



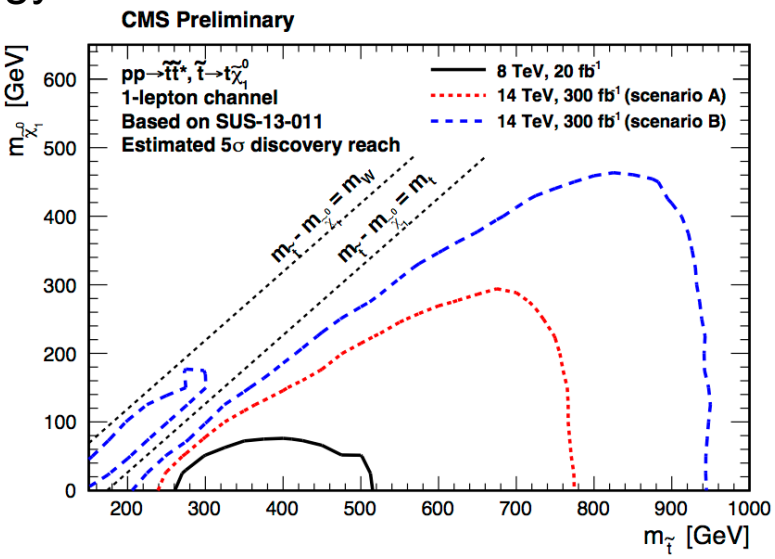
Example: light stop production

- Not too heavy stop favoured by naturalness arguments
- Discovery potential at HL-LHC up to ≈1 TeV using decays to top + LSP
- CLIC would allow for precision measurements of the stop properties or extend the exclusion limit up to ≈ $\sqrt{s}$ / 2
- Interesting reconstruction challenge: boosted top quarks

$t\bar{t}$+missing energy



arXiv:1307.7135



arXiv:1307.7292