Electroweak precision measurements at CLIC

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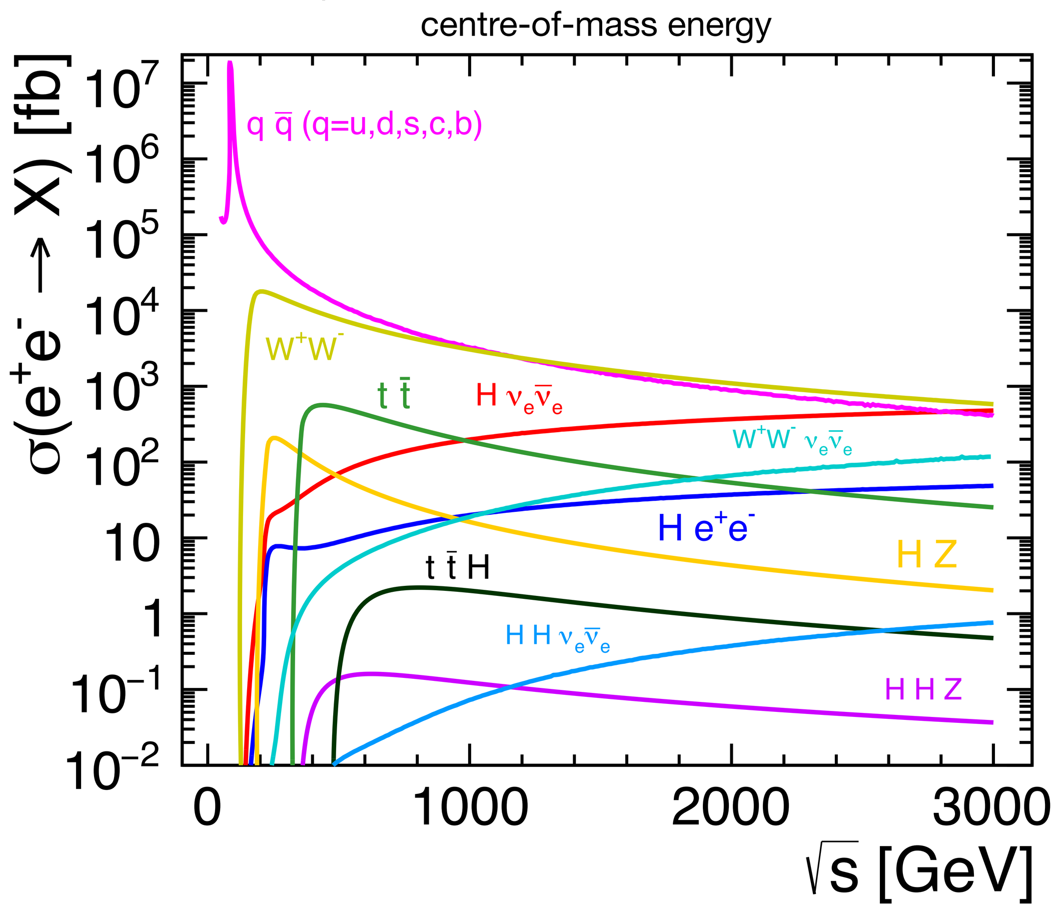
on behalf of the CLIC detector and physics (CLICdp) collaboration

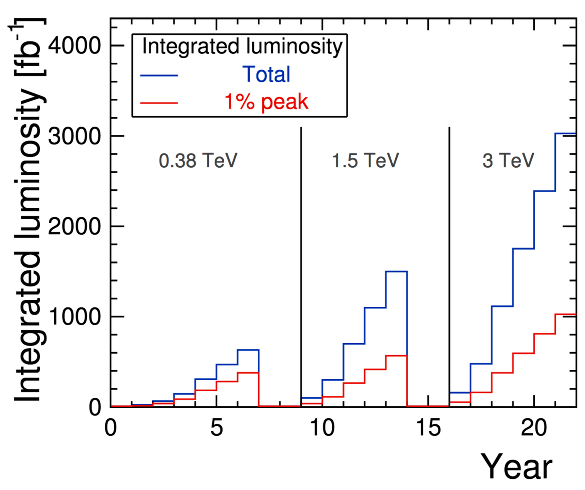
The Compact Linear Collider (CLIC) is an option for a future electron-positron collider operating at centre-of-mass energies from a few hundred GeV up to 3 TeV. Following an overview of precision electroweak measurements possible at a high-energy electron-positron collider like CLIC, details will be presented on two recent physics benchmark analyses based on full detector simulations and assuming centre-of-mass energies of 1.4 and 3 TeV. Vector boson scattering gives insight into the mechanism of electroweak symmetry breaking. The processes $e^+e^- \to WW\nu\bar{\nu}$ and $e^+e^- \to ZZ\nu\bar{\nu}$ were studied using fully hadronic events which provide the full kinematic information on the final-state bosons. The expected precisions on anomalous gauge couplings are extracted. The process $e^+e^- \to \gamma\gamma$ allows for a search for deviations from QED. The expected sensitivities to a finite electron size and other scenarios are discussed.

CLIC physics programme in energy stages:

- Allows for a guaranteed physics program for the first stage in a timely manner
- Higher energy stages can be adapted in case of discoveries by the LHC
- Highest stage motivated by technology/realistic costs

e^+e^- production cross sections as function of centre-of-mass energy

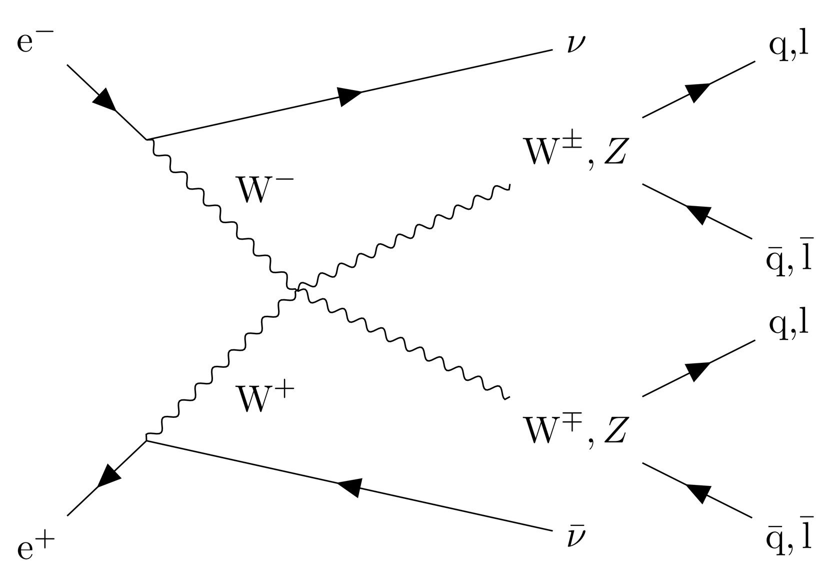




Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{int}$ (fb^{-1})
1	380 350	500 100
2	1500	1500
3	3000	3000

- 380 GeV: concentration on Higgs measurements (production dominated by HZ and WW fusion) and top measurements, e.g. top asymmetry
- Top threshold scan for top mass determination around 350 GeV
- At higher energies, boosted tops as probe of Beyond Standard Model (BSM) physics; Higgs self coupling measurements
- Precision measurements as probe for BSM physics: WW scattering and di-photon production

WW Vector Boson Scattering at 1.4 and 3 TeV



Sensitive to anomalous gauge couplings; massive gauge bosons described by effective field theory:

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{\text{dimension}} \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

Here: Quartic coupling terms

$$\alpha_4 \mathrm{Tr}[V^\mu V_\nu]\mathrm{Tr}[V^\nu V_\mu]$$

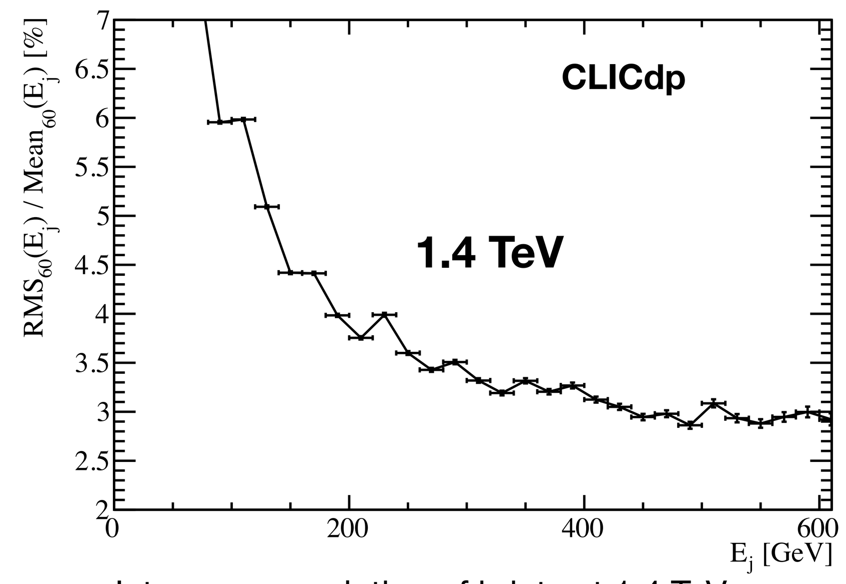
V^μ corresponds to a linear combination of massive gauge bosons $W^\pm$ and Z

$$\alpha_5 \mathrm{Tr}[V^\mu V_\mu]^2$$

- Largest sensitivity and branching for full hadronic channel.
- Main background from $e\gamma$ processes with four quark final states (photon picked up from beamstrahlung).

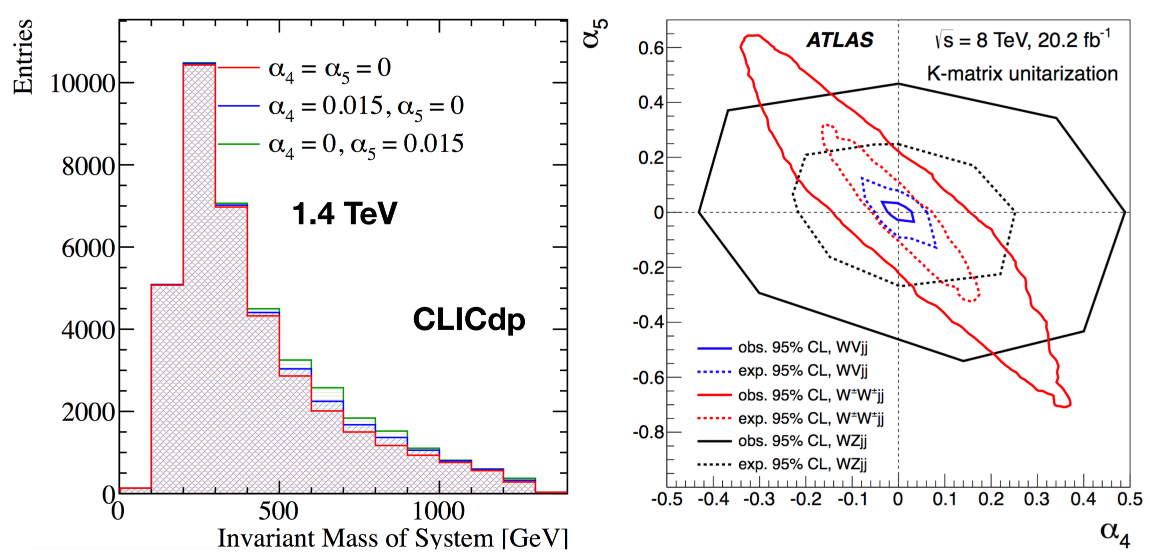
<u>Analysis Strategy:</u>

- Particles grouped into four jets, pair jets into two candidate bosons
- Pair jets, that invariant masses of boson candidates closest to each other.
- k_t algorithm with R=0.9 (1.1) used for jet clustering at 1.4 (3) TeV

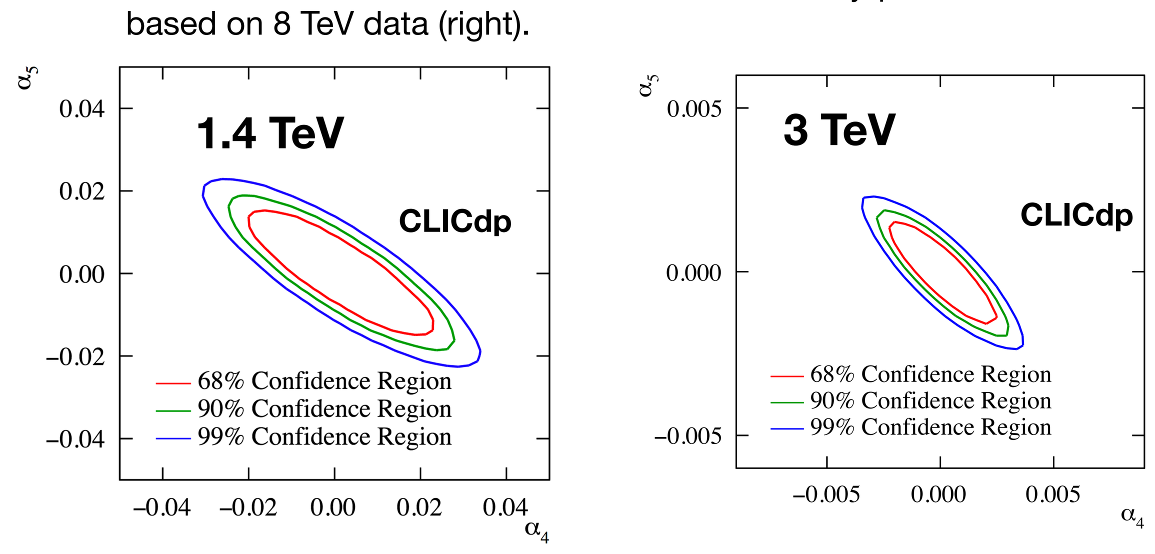


Jet energy resolution of k_t jets at 1.4 TeV

Invariant mass of total system as function of α_4 and α_5 converted into χ^2 value confidence limits with null hypothesis α_4 and α_5 are 0 (as in the SM).



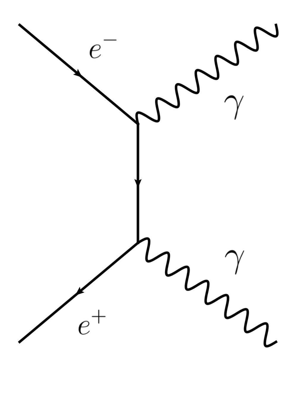
Invariant mass of the system as function of α_4 and α_5 (left) and a multi-boson interaction confidence limit summary plot from ATLAS based on 8 TeV data (right).



- Expected precision to anomalous gauge coupling measurements of CLIC at 1.4 TeV and 3 TeV.
- The 3 TeV result leads to an increased sensitivity of an order of magnitude compared to the 1.4 TeV result and tighter limits than the current LHC results.

Di-Photon production at 3 TeV

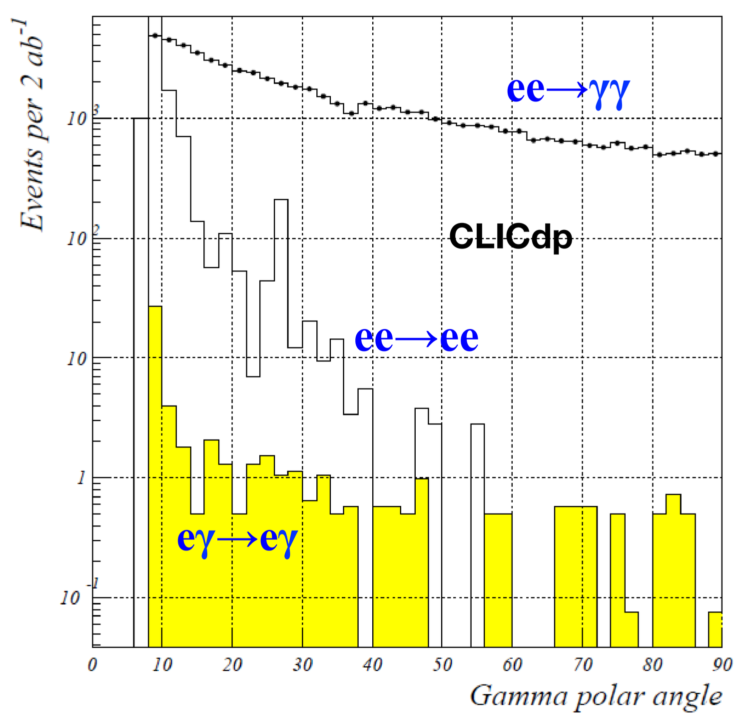
High precision QED measurements allow probing for deviations from the SM



$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} = \frac{\alpha^2}{s}\left[\frac{1+\cos^2\theta}{1-\cos^2\theta}\right]$$

Born term of di-photon cross section

Di-photon production offers a clean experimental signature at high energies, calculable to very high precision.

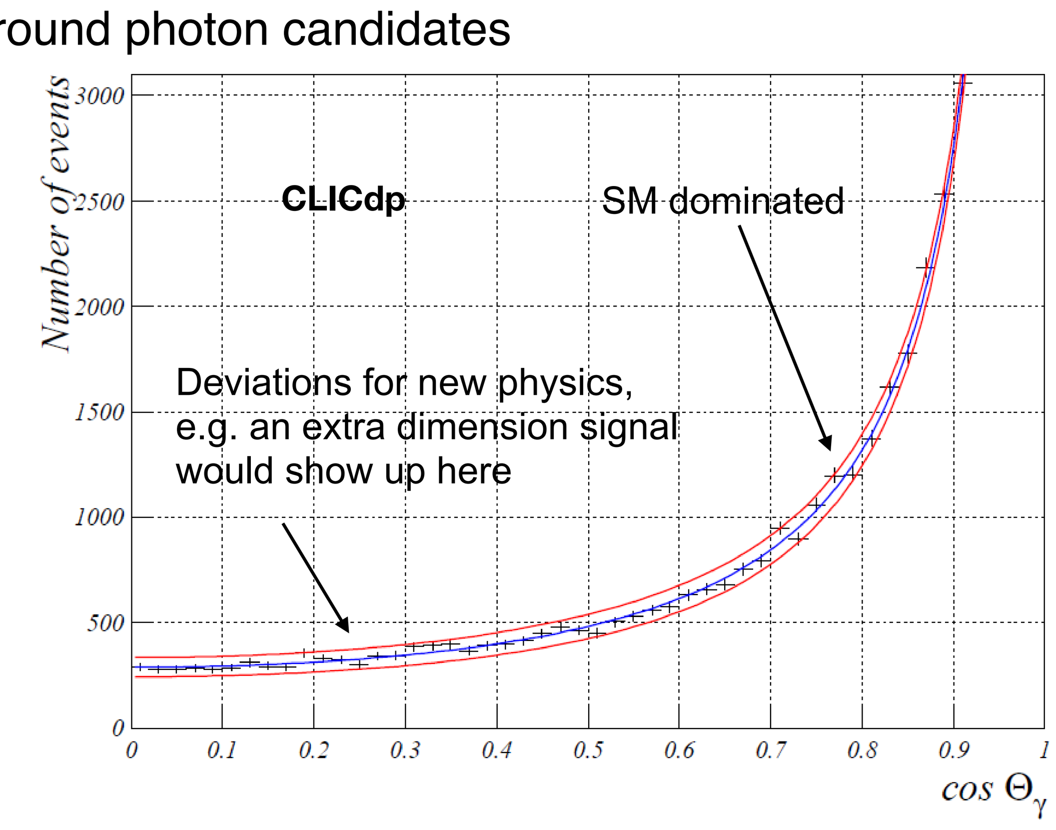


Signal and background after selection

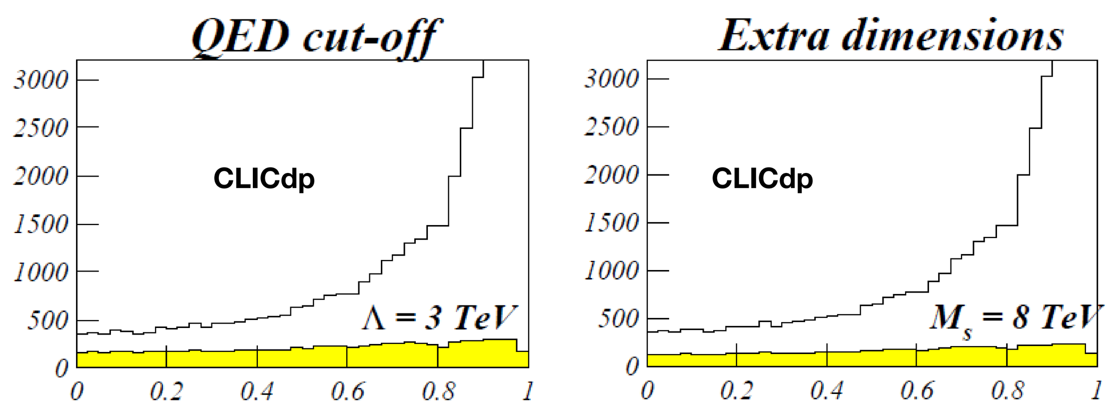
Select two high energetic photons:

- $E_{\gamma 1} > 1.3$ TeV, $E_{\gamma 2} > 1.2$ TeV
- Photons back-to-back in $\theta, \phi > 170^\circ$
- Third photon veto of 50 GeV

Reject backgrounds of electrons (Bhabha scattering) by vetoing tracks with p > 300 GeV within 20 ° around photon candidates



Measured polar angle distribution probing QED predictions



BSM signals are compared to SM di-photon cross section. The BSM signals are flat as function of the polar angle and lead to noticeable increase of events particularly at small polar angles.

Scenario	ΔL = 0.2 %	ΔL = 0.5 %	ΔL = 1 %	LEP limit
QED cut-off (finite electron size) Λ_{QED} (95% CL)	6.52 TeV	6.33 TeV	6.01 TeV	~ 390 GeV
Contact interactions Λ' (95% CL)	20.7 TeV	20.1 TeV	18.9 TeV	~ 830 GeV
Extra dimensions $M_s/\lambda^{1/4}$ (95% CL)	16.3 TeV	15.9 TeV	15.3 TeV	~ 1 TeV
Excited electron M_{e^*} (95% CL)	5.03 TeV	4.87 TeV	4.7 TeV	~ 250 GeV

- A precise polar angle measurement can probe several different models
- Numbers are extrapolated for an integrated luminosity of 2 ab^{-1} at 3 TeV, given for different assumptions on the precision of integrated luminosity.

More information about the experimental environment at CLIC and Higgs physics at CLIC available at

[1] Higgs Physics at the CLIC electron-positron collider, arXiv:1608.07538, accepted for publication by EPJC
[2] Updated Baseline for a staged Compact Linear Collider: arXiv:1608.07537, CERN-2016-004