$H \rightarrow b\bar{b}/c\bar{c}/gg$ at high-energy CLIC operation

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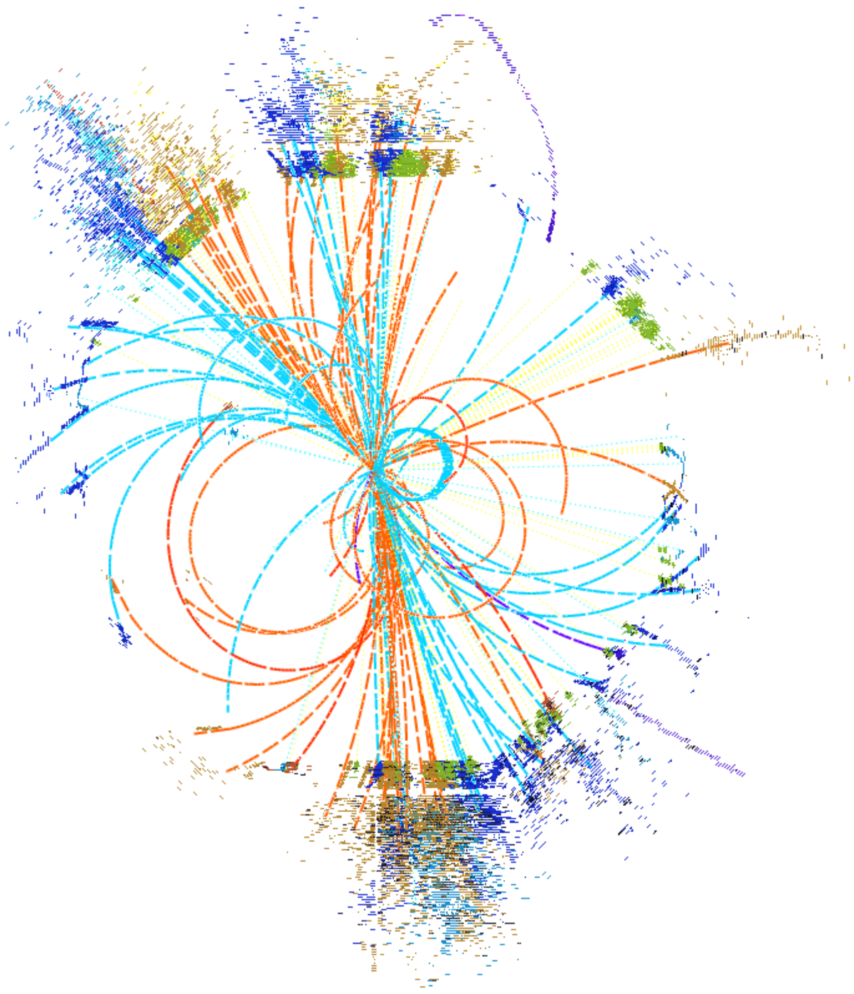
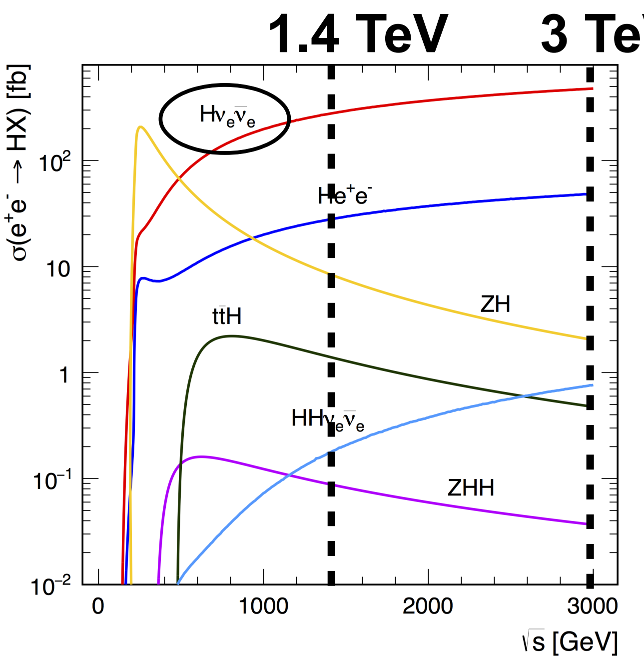


International Workshop on Future Linear Colliders (LCWS15)
04/11/2015, Whistler, Canada

Reminder: Higgs production

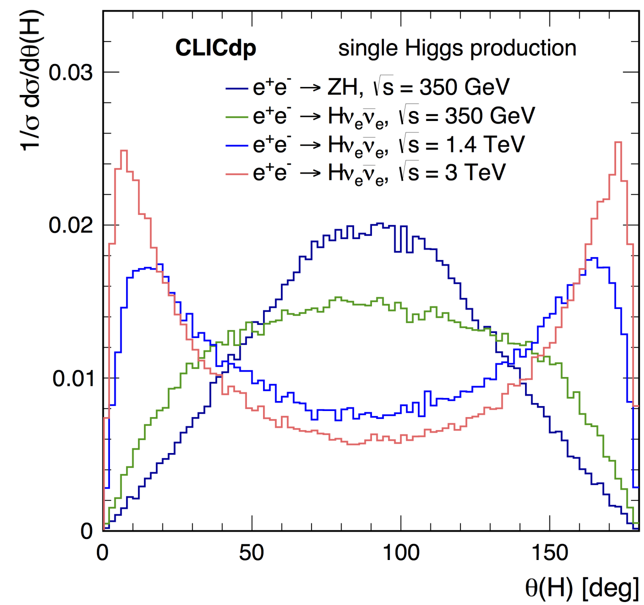


- **Aim of this study:**
Physics potential for measurements of
$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$, $\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$, $\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$ and m_H at 1.4 and 3 TeV

- Older results exist (EPJ **C 73**, 2290 and arXiv:1307.5288), but did not include $e\gamma \to X$ and $\gamma\gamma \to X$ backgrounds

	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

m_H = 126 GeV, ISR, unpolarised beams



→ Measurements at high energy benefit from good detectors in the forward region

Monte Carlo samples at 1.4 TeV

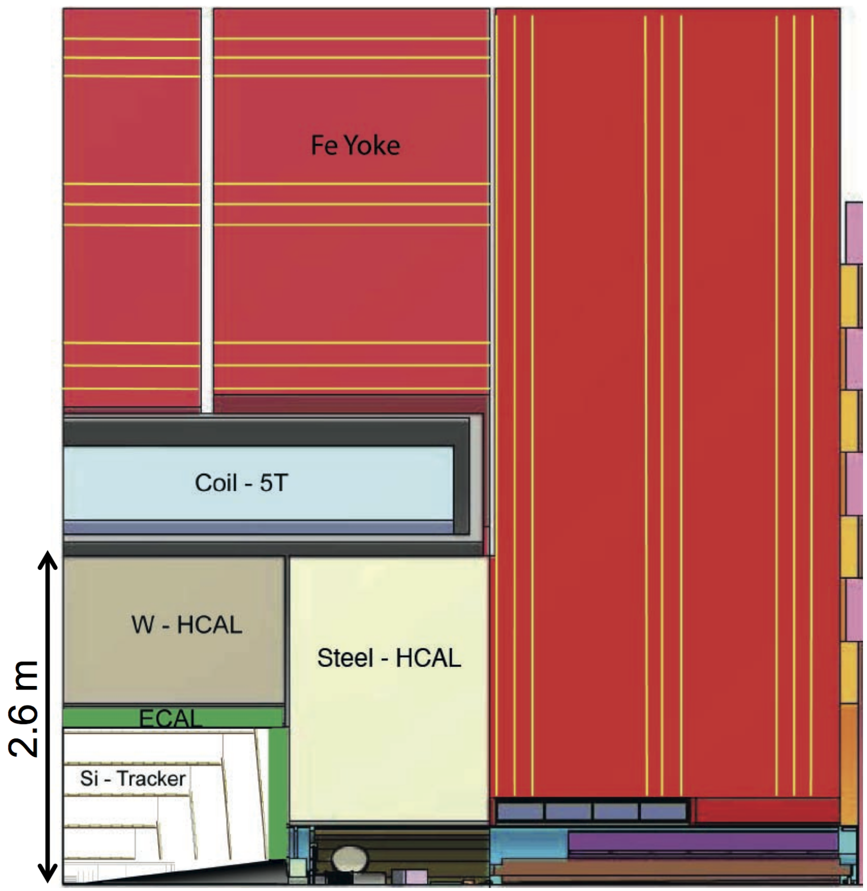
Process:	Cross section [fb]:	Comments:
$e^+e^- \to Hv\bar{v}$, m(H) = 126 GeV	244.02	
$e^+e^- \to Hv\bar{v}$, m(H) = 125.95 GeV	243.93	
$e^+e^- \to Hv\bar{v}$, m(H) = 126.1 GeV	244.07	
$e^+e^- \to qqvv$	788	
$e^+e^- \to qq$	4000.8	
$e^+e^- \to qqlv$	4312.9	
$e^+e^- \to qqll$	2726.7	
$e\gamma \to qqe$ (EPA)	2664.5	m(q,q) > 50 GeV
$e\gamma \to qqe$ (BS)	7517.2	m(q,q) > 50 GeV
$\gamma e \to qqe$ (EPA)	2664.6	m(q,q) > 50 GeV
$\gamma e \to qqe$ (BS)	7529.5	m(q,q) > 50 GeV
$e\gamma \to qqv$ (EPA)	3874.6	m(q,q) > 50 GeV
$e\gamma \to qqv$ (BS)	14407.9	m(q,q) > 50 GeV
$\gamma e \to qqv$ (EPA)	3875.1	m(q,q) > 50 GeV
$\gamma e \to qqv$ (BS)	14386.0	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (EPA/EPA)	3495.4	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (EPA/BS)	17335.4	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (BS/EPA)	17328.0	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (BS/BS)	73600.5	m(q,q) > 50 GeV

Monte Carlo samples at 3 TeV

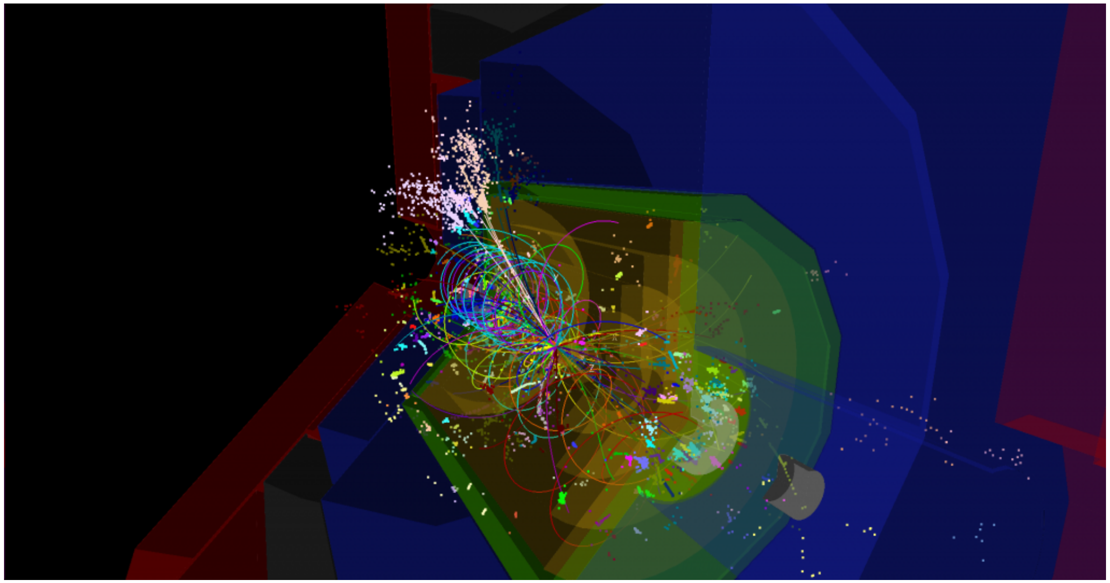
Process:	Cross section [fb]:	Comments:
$e^+e^- \to H\nu\bar{\nu}$, m(H) = 126 GeV	415.05	
$e^+e^- \to H\nu\bar{\nu}$, m(H) = 125.95 GeV	415.1	
$e^+e^- \to H\nu\bar{\nu}$, m(H) = 126.1 GeV	414.9	
$e^+e^- \to qq\nu\nu$	1305	
$e^+e^- \to qq$	3076	
$e^+e^- \to qqe\nu$	5255	
$e^+e^- \to qqee$	3341	
$e\gamma \to qqe$ (EPA)	3525.2	m(q,q) > 50 GeV
$e\gamma \to qqe$ (BS)	8530.8	m(q,q) > 50 GeV
$\gamma e \to qqe$ (EPA)	3523.4	m(q,q) > 50 GeV
$\gamma e \to qqe$ (BS)	8533.2	m(q,q) > 50 GeV
$e\gamma \to qq\nu$ (EPA)	6417.5	m(q,q) > 50 GeV
$e\gamma \to qq\nu$ (BS)	21234.9	m(q,q) > 50 GeV
$\gamma e \to qq\nu$ (EPA)	6414.1	m(q,q) > 50 GeV
$\gamma e \to qq\nu$ (BS)	21230.6	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (EPA/EPA)	4228.2	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (EPA/BS)	21893.8	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (BS/EPA)	21888.7	m(q,q) > 50 GeV
$\gamma\gamma \to qq$ (BS/BS)	77365.9	m(q,q) > 50 GeV

Event simulation

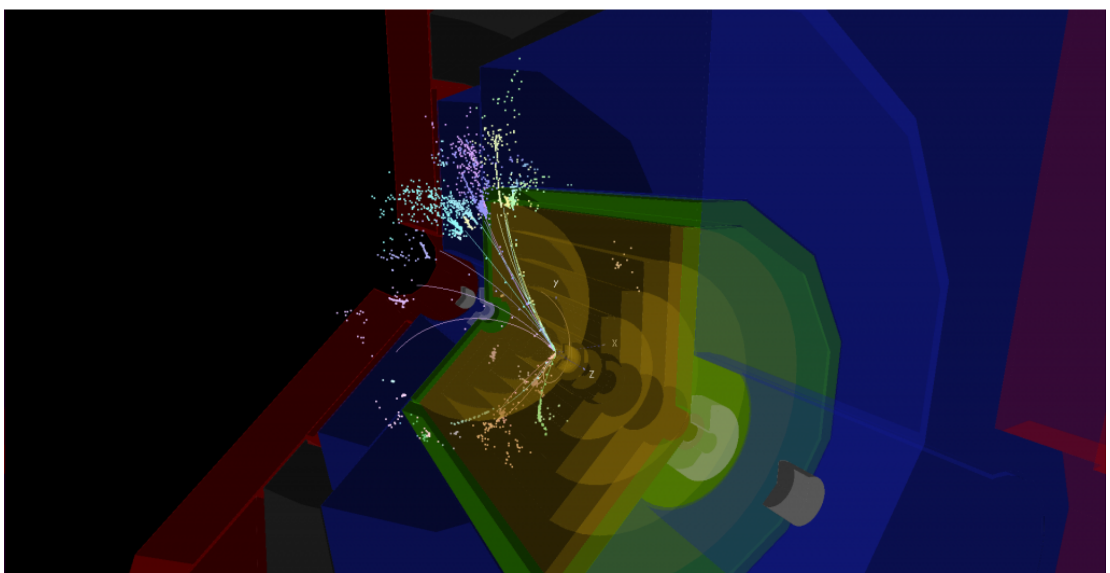
- Pile-up from $\gamma\gamma \rightarrow$ hadrons interactions overlaid (60 BX)
- Simulation of the CLIC_SiD detector based on Geant4
- Reconstruction of particles using the Particle Flow technique (Pandora)
- Suppression of beam-induced backgrounds using combined timing and momentum cuts



A typical $H\nu_e\bar{\nu}_e \to b\bar{b}\nu_e\bar{\nu}_e$ event at 1.4 TeV



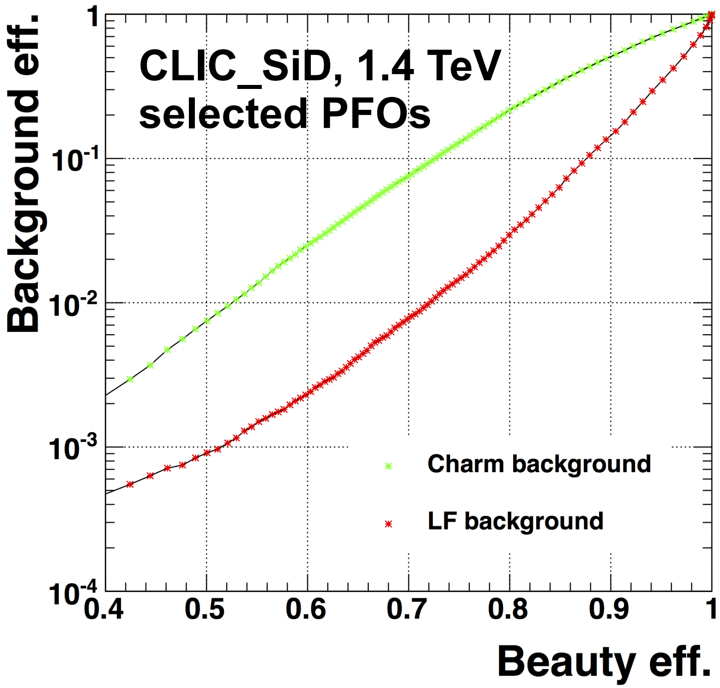
all particles

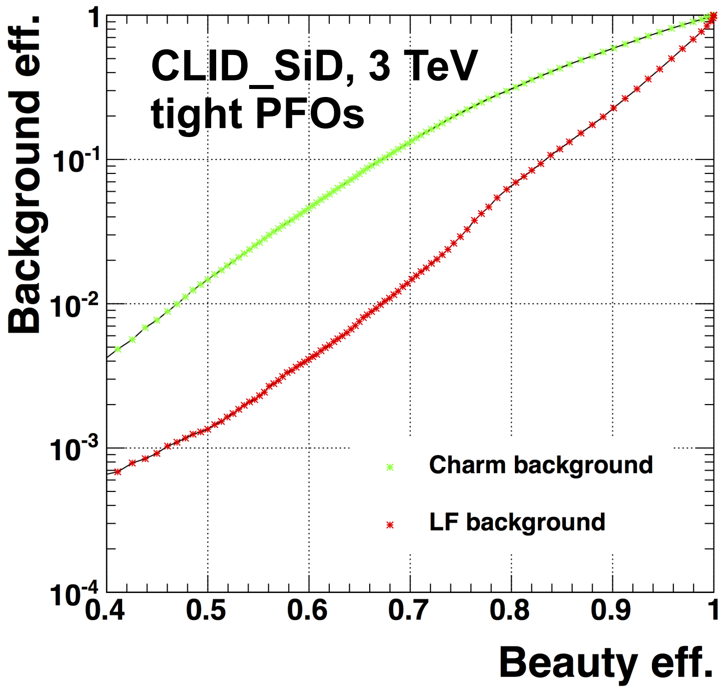


selected particles
(combined timing
and momentum cuts)

Jet reconstruction and flavour tagging

• Longitudinally invariant k_t algorithm in the exclusive mode with 2 jets:
R = 1.0 at 1.4 TeV, R = 0.7 at 3 TeV
• The particles in the jets are passed to LCFIPlus for vertex reconstruction and flavour tagging





Beauty tagging performance in $Z\nu_e\bar{\nu}_e$ events
(the Z has similar kinematics as the H in signal events)

Event selection

1.) Preselection cuts:

- $60 < m^{j1,j2} < 160$ GeV
- $E^{j1} + E^{j2} > 75$ GeV
- $p_T^{miss} > 20$ GeV
- $\Delta R(j1, j2) < 4$

j1: first jet
j2: second jet

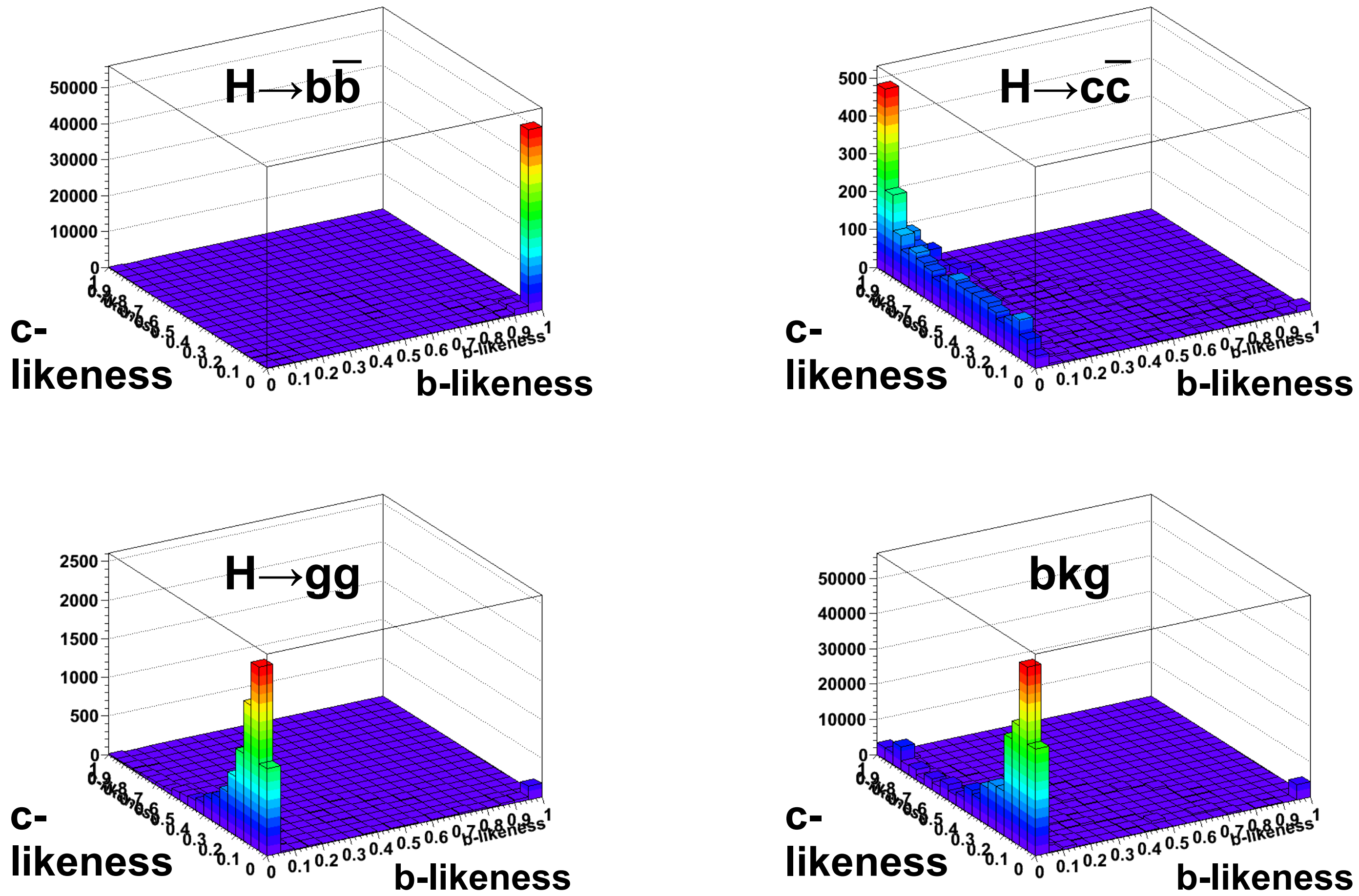
2.) Multivariate classifiers (BDT with gradient boost)

- Using $H\rightarrow b\bar{b}$, $H\rightarrow c\bar{c}$ and $H\rightarrow gg$ as signal in one classifier (18 input variables) and then template fitting using flavour tagging information

- Separate classifier for each flavour as a cross check

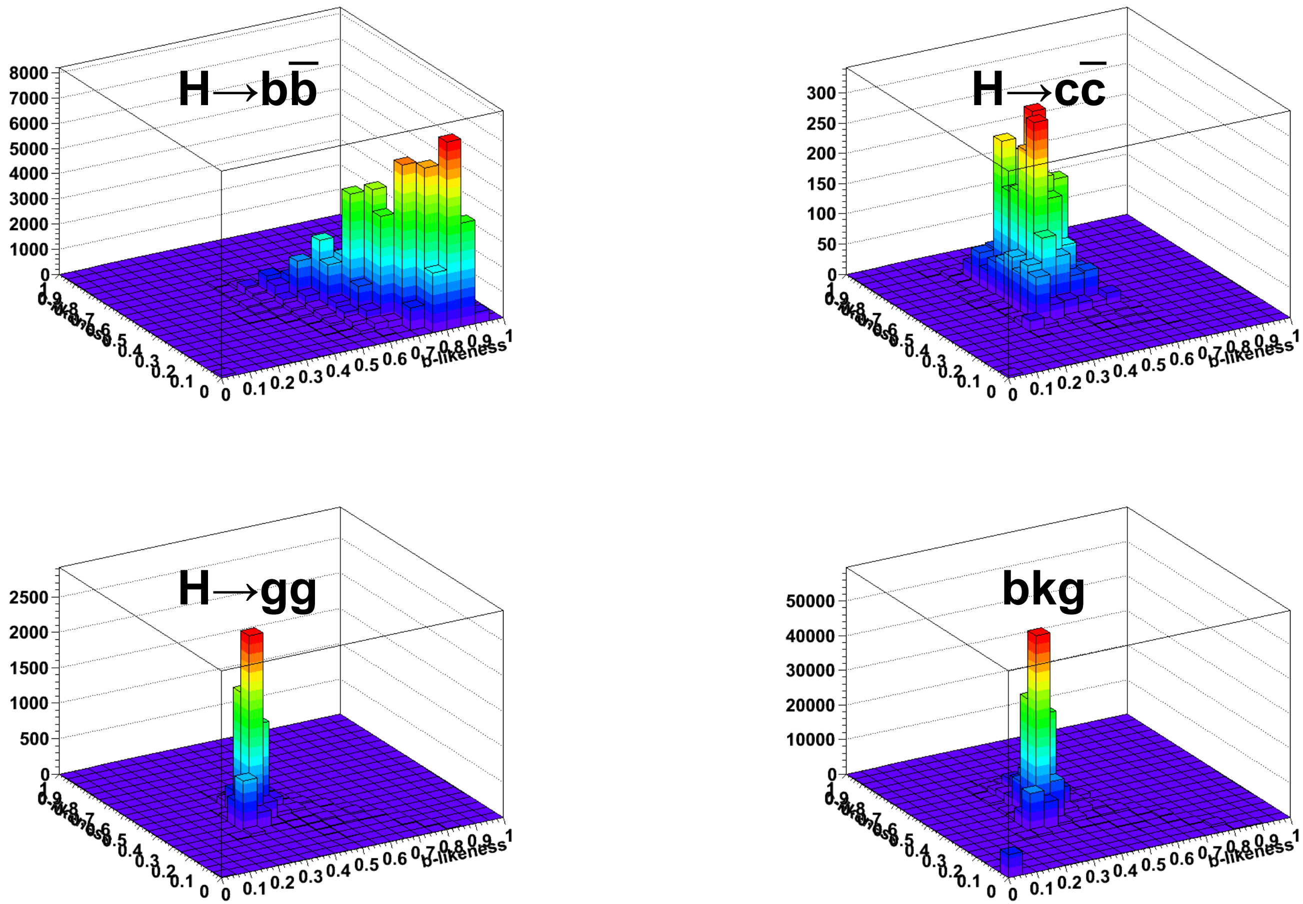
Templates at 1.4 TeV

b-likeness: btag1 * btag2 / (btag1 * btag2 + [1 - btag1] * [1 - btag2])
c-likeness: ctag1 * ctag2 / (ctag1 * ctag2 + [1 - ctag1] * [1 - ctag2])



Templates remapped at 1.4 TeV

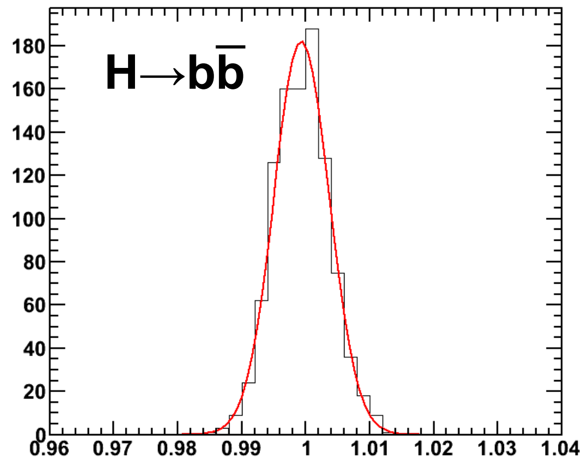
b-likeness → [AtanH((2 * b-likeness – 1) * TanH(β)) + β] / (2 * β) with β = 8
c-likeness → [AtanH((2 * c-likeness – 1) * TanH(β)) + β] / (2 * β) with β = 5

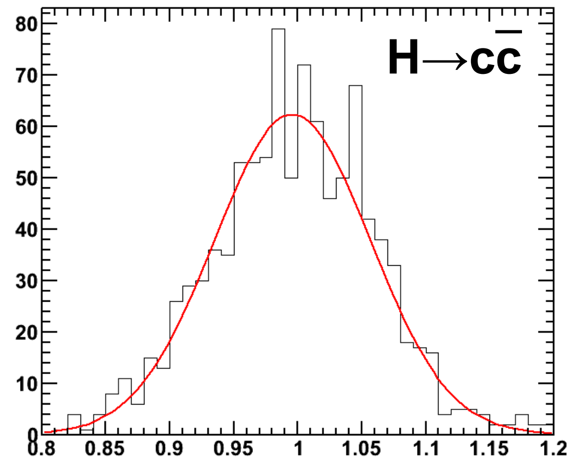


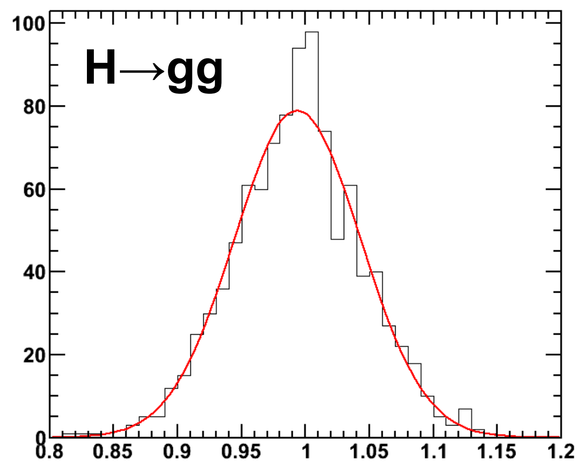
→ More bins contribute to the fit

Results from templates at 1.4 TeV

Toy Monte Carlo (1000 iterations to extract precisions):







$\Delta(\sigma \times BR(H\to b\bar{b}) = 0.43\%$
$\Delta(\sigma \times BR(H\to c\bar{c}) = 6.1\%$
$\Delta(\sigma \times BR(H\to gg) = 5.0\%$

L = 1.5 ab^{-1}, unpolarised beams

Individual BDTs

Now train a BDT for each Higgs decay
(flavour tagging variables included):

$\Delta(\sigma \times BR(H \rightarrow b\bar{b}) = 0.37\%$
$\Delta(\sigma \times BR(H \rightarrow c\bar{c}) = 6.2\%$
$\Delta(\sigma \times BR(H \rightarrow gg) = 4.9\%$

$L = 1.5\ ab^{-1}$,
unpolarised beams

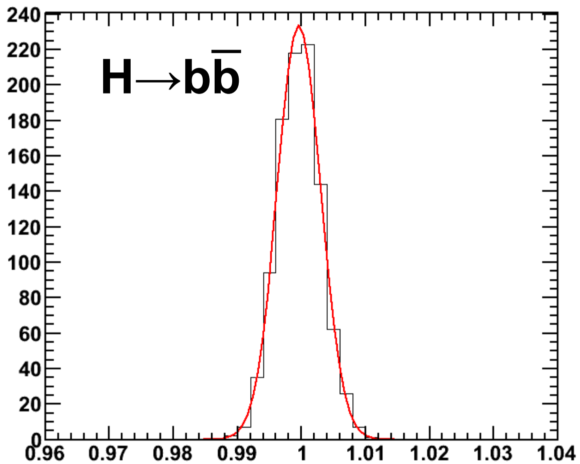
- Slightly better than template fitting for beauty
$\rightarrow$ The common selection is not ideal for beauty
(because the $m^{j1,\,j2}$ and #particles distributions are different)

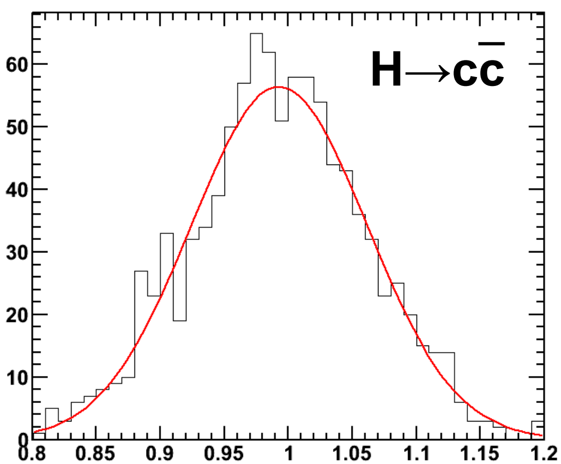
- Almost identical for charm and gluons

Template fitting preferred, because correlations are provided

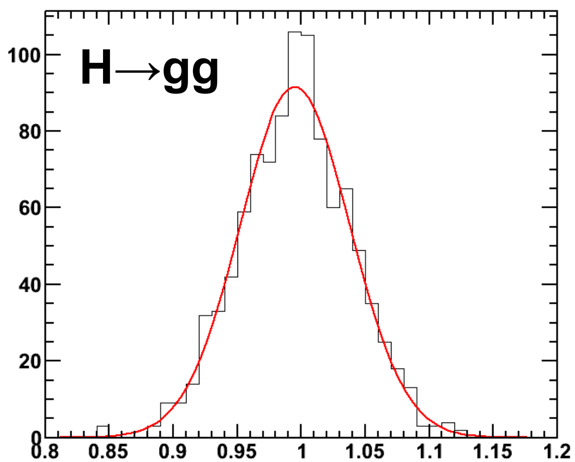
Results from templates at 3 TeV

Toy Monte Carlo (1000 iterations to extract precisions):





L = 2 ab^{-1},
unpolarised beams



$\Delta(\sigma \times BR(H \rightarrow b\bar{b}) = 0.34\%$
$\Delta(\sigma \times BR(H \rightarrow c\bar{c}) = 6.9\%$
$\Delta(\sigma \times BR(H \rightarrow gg) = 4.3\%$

Similar performance as at 1.4 TeV
(slightly better for beauty and gluons, slightly worse for charm)

Mass measurement

- Remove Higgs candidate mass from BDT for event selection
- Extract Higgs mass from visible Higgs mass distribution
- Strategy: template fit using samples generated with shifted Higgs mass
- At 1.4 TeV a precision of better than 40 MeV seems feasible (consistent with earlier preliminary results), 3 TeV tbd
- Good understanding of b-jet energy scale and flavour tagging efficiencies crucial!

Summary and conclusions

- The physics potential for measurements of hadronic decays of the SM Higgs boson decays at a high-energy CLIC collider is investigated using a full detector simulation and including pile-up from $\gamma\gamma \rightarrow$ hadrons interactions

- Two different techniques for the extraction of the fractions of Higgs decays to beauty, charm and gluons are in reasonable agreement

- The Higgs mass can be extracted from the $H \rightarrow b\bar{b}$ invariant mass distribution

- This analysis is an important test case for flavour tagging with the new CLIC detector model

- **Possible extension:** constrain CP odd contribution to WWH coupling