Measurement of Higgs Couplings Using $\gamma\gamma \rightarrow H$ & $e^-\gamma \rightarrow e^-H$

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U.S. DEPARTMENT OF ENERGY
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SLAC NATIONAL ACCELERATOR LABORATORY

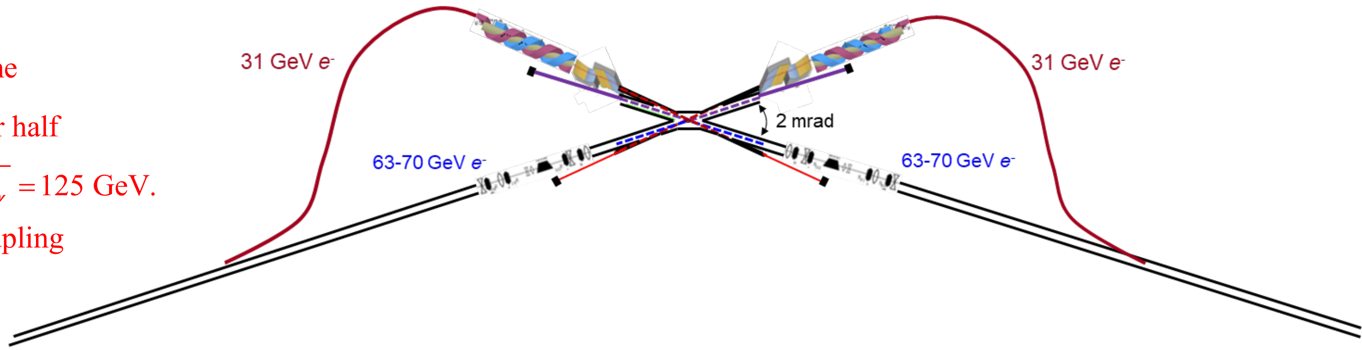
XCC – XFEL Compton Collider

Run $\gamma\gamma \to H$ at $\sqrt{s_{\gamma\gamma}} = 125$ GeV half the time

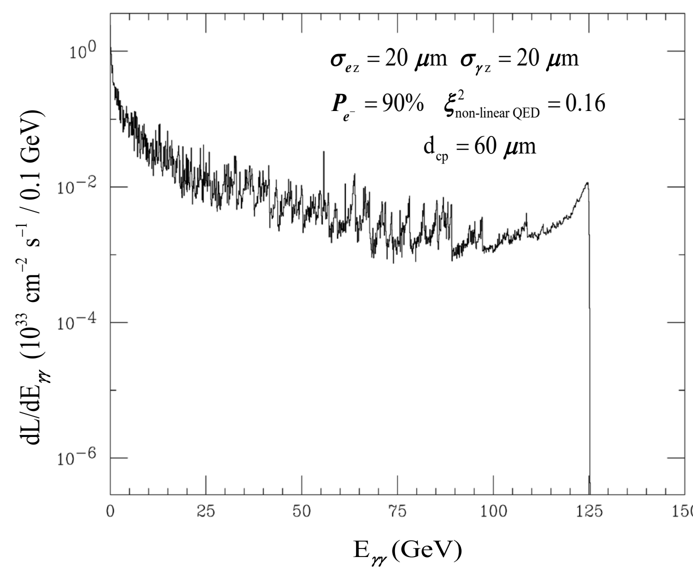
and $e^-\gamma \to e^- H$ at $\sqrt{s_{e\gamma}} = 140$ GeV the other half

to calibrate the $\sigma \times$ BR measurements at $\sqrt{s_{\gamma\gamma}} = 125$ GeV.

This produces model independent Higgs coupling measurements, just like the ILC.



Machine	Polarization	$N_{\text{Higgs}} / (10^7 \text{ s})$	$N_{\text{Hadronic Events}}(\sqrt{\hat{s}} > 60 \text{ GeV}) / N_{\text{Higgs}}$	$N_{\text{minbias/BX}}$
XCC	$90\%\ e^-$	25,000	130	9.5
ILC	$-80\%\ e^-\ \ +30\%\ e^+$	42,000	230	1.3
ILC	$+80\%\ e^-\ \ -30\%\ e^+$	28,000	55	1.3



XCC – XFEL Compton Collider w/ 10 GeV Deflector Beams

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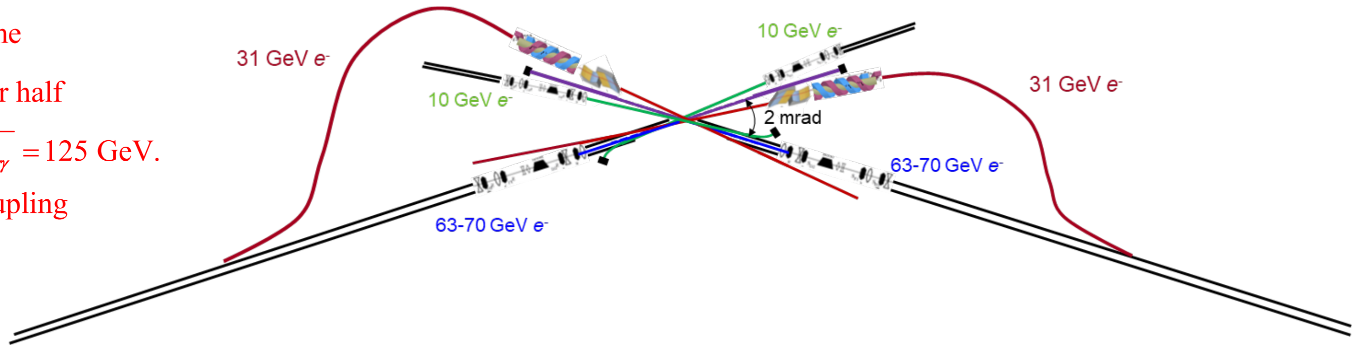

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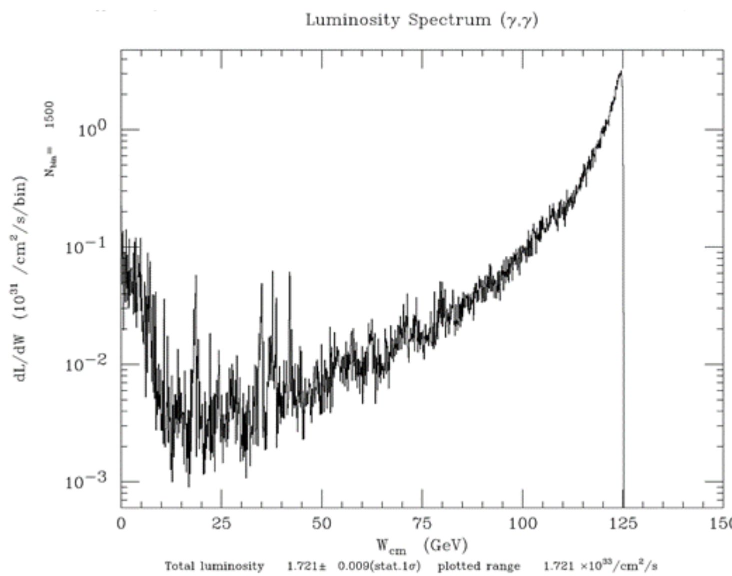
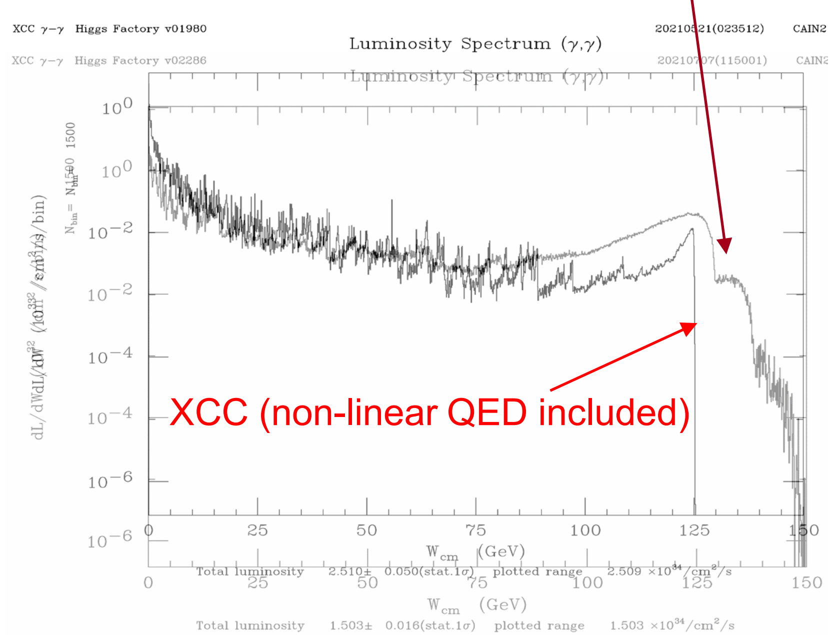
Here beam-beam deflection is used as a tool to kick the e^- beams away from each other in the 100 μm space between the Compton IP and the Primary IP.



Compare XCC with $\gamma\gamma$ Higgs Factory Based on Optical Laser

Here we take the XCC, replace the XFEL with the laser specified in the recent DESY optical $\gamma\gamma \to \eta_b$ paper, and increase the e^- beam energy from 62.5 GeV to 86.5 GeV to compensate for the much larger optical wavelength.

Non-linear QED included in Optical Compton Collision



Machine	e^- Energy (GeV)	Deflector Beam	Polarization	$N_{\text{Higgs}}/(10^7\ \text{s})$	$N_{\text{Hadronic Events}}(\sqrt{\hat{s}} > 60\ \text{GeV})/N_{\text{Higgs}}$	$N_{\text{minbias/BX}}$
Optical	86.5	N	90% e^-	31,000	322	9.5
Optical	86.5	Y	90% e^-	40,000	135	9.5
XCC	62.5	N	90% e^-	25,000	129	9.5
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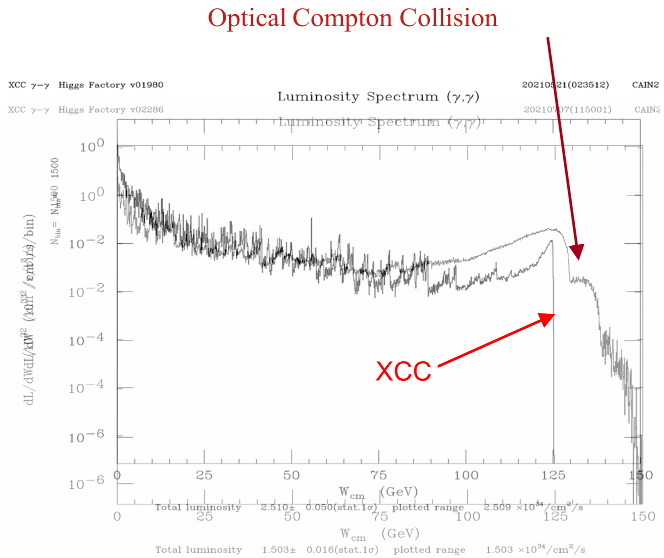

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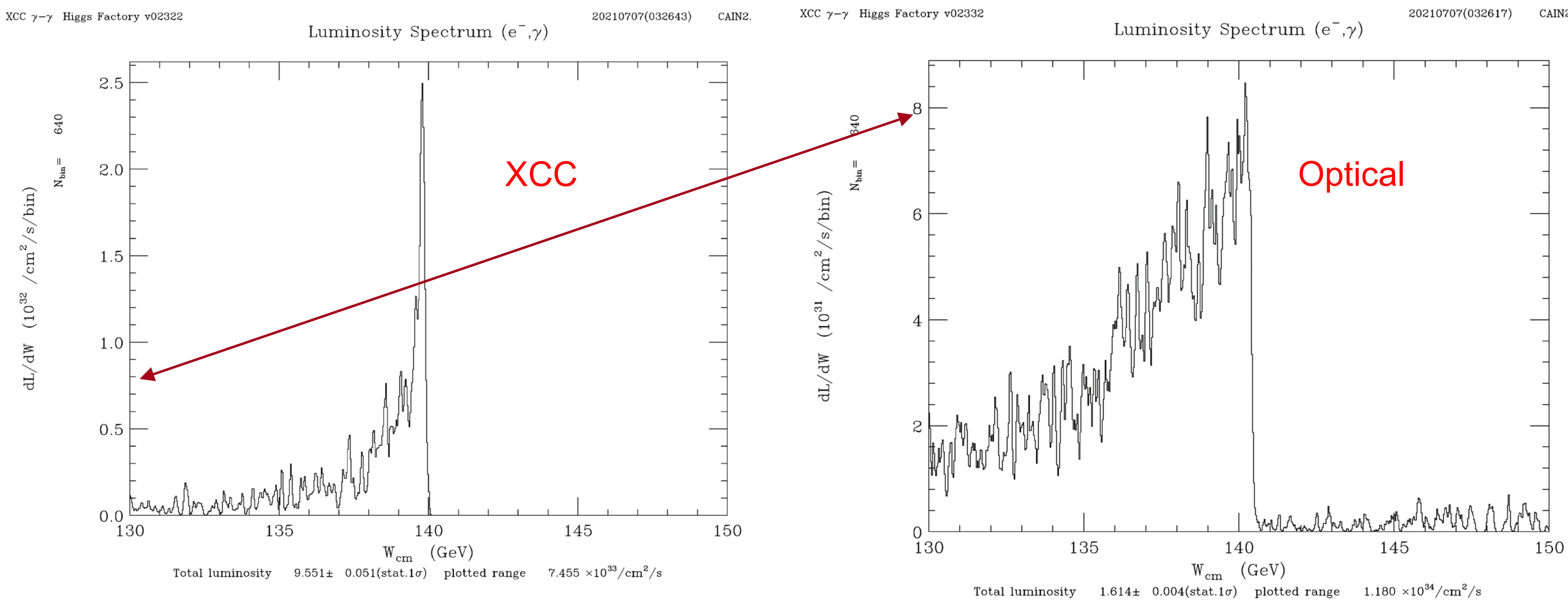
- The optical design has good $\gamma\gamma$ luminosity and a reasonable signal-to-background which is 2.4 (7.9) times worse than XCC for configurations with (without) deflector beams. However, the required e^- beam energy is 40% larger for optical.

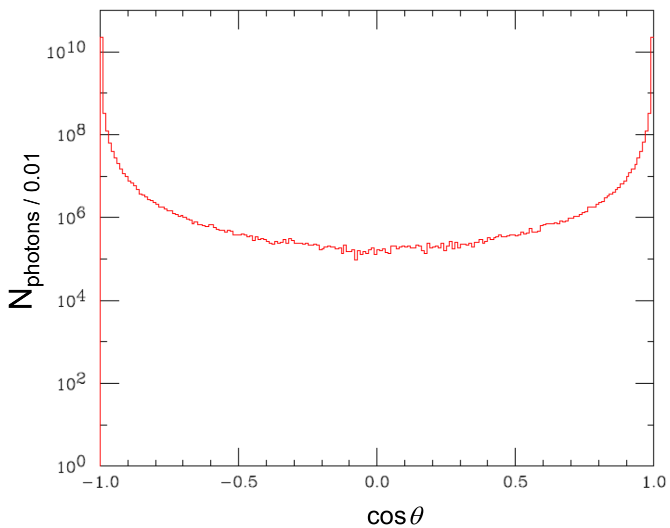
- The 45 MeV leading edge width of the XCC lumi distribution is dominated by the 0.05% e^- energy spread. This is not good enough, by itself, to match the few percent ILC Higgs total width error, if the width is the SM value of $\Gamma_H = 4$ MeV. But the XCC leading edge width is small enough to set limits on the total Higgs width on the order of 10 MeV via energy scans. No Higgs width information can be obtained from the optical design.

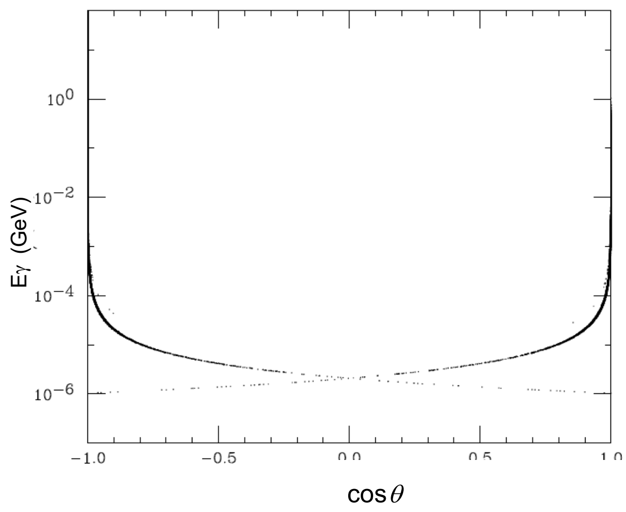
Compare XCC $e^-\gamma$ with $e^-\gamma$ Collider Based on DESY Optical Laser



Cannot use the optical design to perform the $e^-\gamma \rightarrow e^-$H measurement of a mono-energetic electron recoiling against the Higgs, which is needed to convert $\sigma \times$ BR measurements into absolute Higgs couplings and to make a few percent measurement of the Higgs total width.

XCC detector background: 1 – 30 keV γ from Compton IP



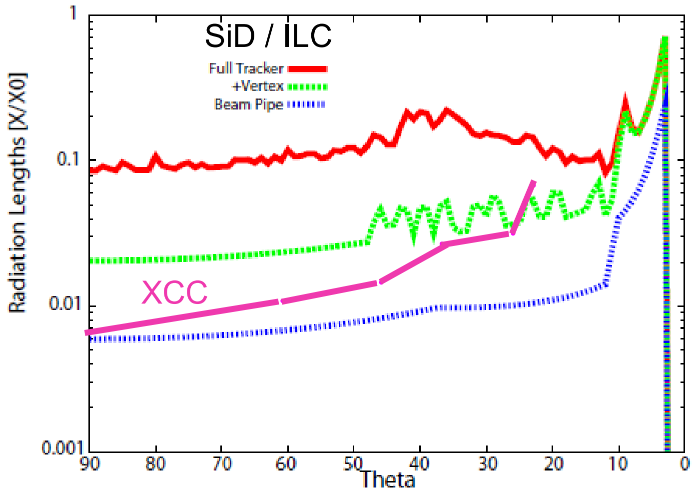


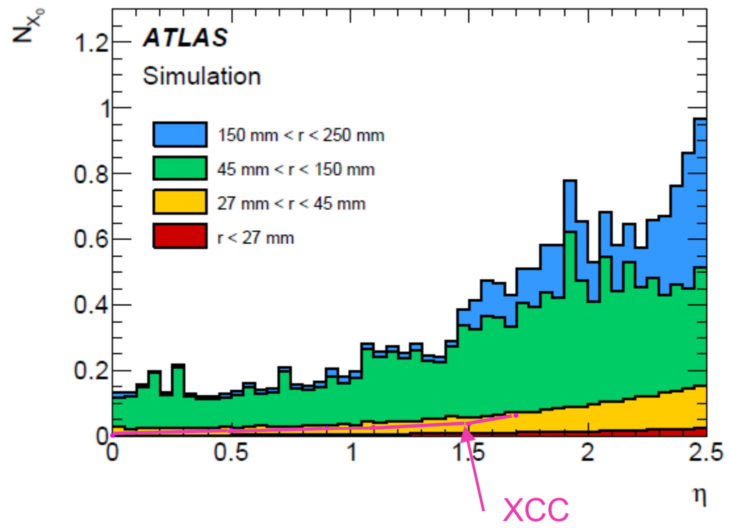
Calculate N_γ & N_{hits} at $R = 4$ cm,
assuming 400 μm thick Be beampipe at $R = 2.5$ cm
and 100 μm Si thick layer at $R = 4$ cm

$\cos\theta$	E_γ(keV)	$N_\gamma(cm^{-2})$	$N_{\text{hits}}(cm^{-2})$
0	2	1×10^3	1×10^3
0.5	4	2×10^5	2×10^5
0.7	7	8×10^5	7×10^5
0.8	11	2×10^6	1×10^6
0.9	21	9×10^6	8×10^5
0.93	30	2×10^7	6×10^5

ATLAS upgrade for HL-LHC assumes 60 hits/cm^2 per event in 100 μm Si thick layer at $R = 4$ cm so we make this our goal.

XCC detector beampipe X_0 vs ILC and LHC





$\cos\theta$	$\theta(°)$	η	XCC X_0(Be+Pb) (%)	XCC X_0(BP total) (%)*	SiD / ILC X_0(Be 400 μm) (%)	SiD / ILC X_0(BP total) (%)	ATLAS / LHC X_0(BP total) (%)	ATLAS / LHC X_0(BP+IBL) (%)
0	90	0	0.15	0.64	0.11	0.60	0.41	2.4
0.5	60	0.5	0.24	0.91	0.13	0.80	0.48	2.8
0.7	46	0.9	0.60	1.3	0.16	0.84	0.60	3.5
0.8	37	1.1	1.5	2.3	0.19	1.0	0.71	4.1
0.9	26	1.5	2.1	2.8	0.26	1.0	0.97	5.7
0.93	22	1.7	5.1	5.8	0.31	1.0	1.2	6.8

$^*X_0(\text{BP total})_{\text{XCC}} = X_0(\text{Be+Pb}) + [X_0(\text{BP total})_{\text{SiD/ILC}} - X_0(\text{Be } 400\ \mu\text{m})]$

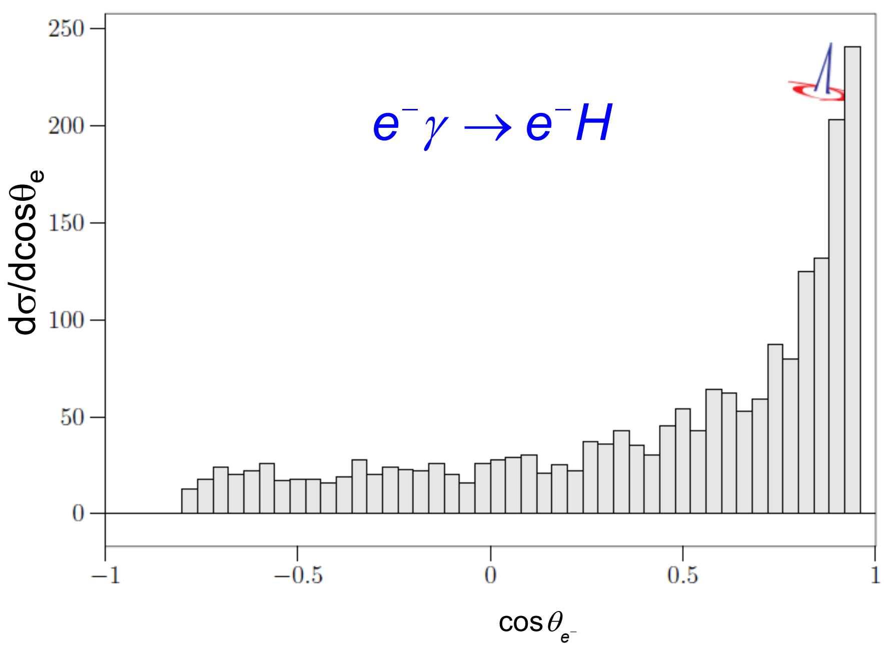
Detector for $\gamma\gamma \rightarrow H$ at E_{cm}=125 GeV - Summary

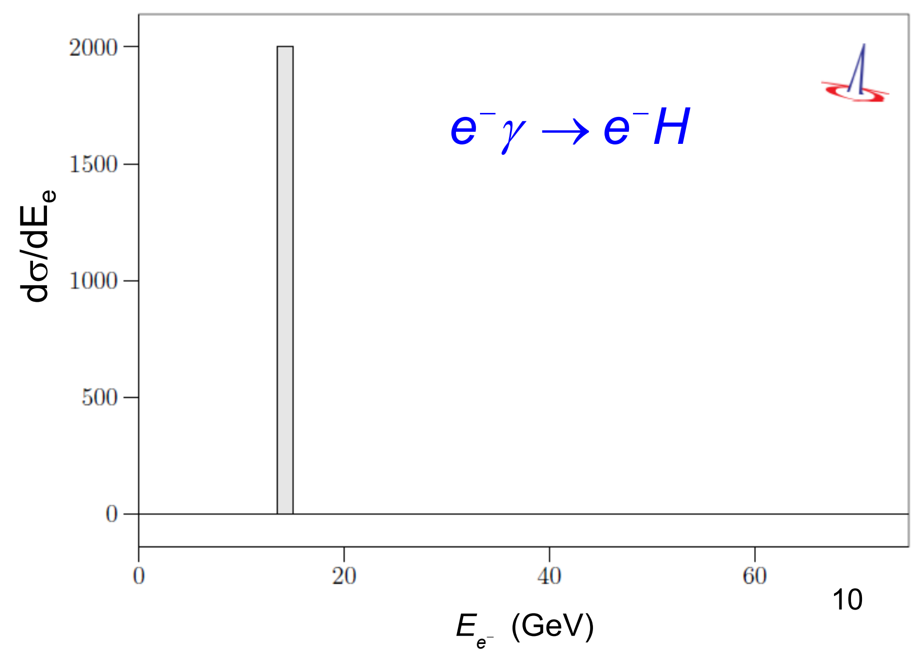
Have taken SiD detector and made minimal modifications necessary to adapt it to the XCC experimental environment

- Increase beampipe radius from R=1.2 cm to R=2.5 and reduce barrel tracker $|\cos\theta|_{max}$ from 0.98 to 0.93 to accommodate larger electron envelope.
- Coat beryllium beam pipe with z-dependent layer of lead (2 – 100 μm) to reduce tracker hit occupancy to level of ATLAS upgrade inner tracker at HL-LHC.
- Move BeamCal from $0.999 < |\cos\theta| < 0.999999$ to $0.97 < |\cos\theta| < 0.98$, where background energy flux is the same as that expected at the ILC.
- Endcap tracker and calorimeter are undefined at the moment.

Detector for $e^- \gamma \rightarrow e^- H$ at E_{cm}=140 GeV - Summary

Most of the detector differences going from $\gamma\gamma$ to $e^- \gamma$ collisions are favorable.
The signal is in the forward direction, where the detector and the experimental environment are now completely ILC-like. The detector in the backward region is degraded a little bit w.r.t. what can be built for $\gamma\gamma$ collisions, but luckily this should have a small impact given the nature of the signal.





σ x BR Measurements

Machine	e^- Energy (GeV)	Deflector Beam	Polarization	$N_{\text{Higgs}}/(10^7\ \text{s})$	$N_{\text{Hadronic Events}}(\sqrt{\hat{s}} > 60\ \text{GeV})/N_{\text{Higgs}}$	$N_{\text{minbias/BX}}$
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No event generation for the XCC has been done. The WHIZARD-based estimates for $N_{\text{Hadronic Events}}(\sqrt{\hat{s}} > 60\ \text{GeV})/N_{\text{Higgs}}$ serve for now to justify using the ILC $\sigma \times BR$ results, where the normalization is performed with respect to the $+80\%\ e^-$ $-30\%\ e^+$ polariation.

-80% e^-, +30% e^+ polarization:

	250 GeV		350 GeV		500 GeV	
	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
~~σ~~	~~2.0~~		~~1.8~~		~~4.2~~	
~~$h \to invis.$~~	~~0.86~~		~~1.4~~		~~3.4~~	
$h \to b\bar{b}$	1.3	8.1	1.5	1.8	2.5	0.93
$h \to c\bar{c}$	8.3		11	19	18	8.8
$h \to gg$	7.0		8.4	7.7	15	5.8
$h \to WW$	4.6		5.6*	5.7*	7.7	3.4
$h \to \tau\tau$	3.2		4.0*	16*	6.1	9.8
$h \to ZZ$	18		25*	20*	35*	12*
$h \to \gamma\gamma$	34*		39*	45*	47	27
$h \to \mu\mu$	72		87*	160*	120	100
a	7.6		2.7*		4.0	
b	2.7		0.69*		0.70	
$\rho(a,b)$	-99.17		-95.6*		-84.8	

$\sigma(e^-\gamma \rightarrow e^-H)$ Measurement

A WHIZARD-based analysis has been peformed including $e^-\gamma \to e^-\gamma$ and all $e^-\gamma \to e^- f \bar{f}$ processes. Nominal EM calorimeter resolution is assumed.

The largest background is $e^-\gamma \to e^- e^+ e^-$

We require 1 electron with E=14.1 GeV and $0.75 < \cos\theta < 0.99$ and no other EM calorimeter cluster with E > 54 GeV and $-0.8 < \cos\theta < 0.999$.

Fit for Couplings Using Michael's EFT Higgs Program

Adapting Michael Peskin's EFT Higgs fitting program for XCC was straightforward. The ZH cross-section is replaced by the cross section for $e^- \gamma \to e^- H$ and the invisible width measurement is eliminated. The coupling errors are optimized by running half the time at Ecm=125 GeV with $\gamma\gamma \to H$ and half at Ecm=140 GeV with $e^- \gamma \to e^- H$ to measure $\Gamma_{\gamma\gamma}$

To compare with the full ILC program, the XCC also assumes an upgrade, which for the XCC corresponds to an increase in the number of bunches per train from 76 → 200 (500) for the deflector beam (no deflector beams) configuration. The same running time is assumed.

ILC

Higgs total width: 0.0235778

Higgs coupling errors :

bb	: 0.0102134
cc	: 0.018383
gg	: 0.0163973
WW	: 0.00549084
tautau	: 0.0115883
ZZ	: 0.0056596
gamgam	: 0.0112247
mumu	: 0.0397616
Z gam	: 0.0911103

95% conf upper limits

inv	: 0.00358854
other	: 0.0159841

XCC

Higgs total width: 0.0229239

Higgs coupling errors :

bb	: 0.00961959
cc	: 0.0122023
gg	: 0.0114985
WW	: 0.00923716
tautau	: 0.00998536
ZZ	: 0.00917532
gamgam	: 0.00366321
mumu	: 0.0344765
Z gam	: 0.100054

95% conf upper limits

other	: 0.0131059

Summary

(1) A 0th order characterization of the physics background created by the beamstrahlung luminosity indicates that the physics background at the XCC is about the same as the ILC.

(2) As a possible upgrade, the beamstrahlung can be eliminated by introducing dedicated 10 GeV e- beams to deflect the electron beams between the Compton and primary IP's. All we know at this time is that this idea works using the CAIN MC. We haven't studied the required tolerances. This would make the XCC physics background much better than ILC's.

(3) Detector backgrounds have been studied. w.r.t. the ILC, the forward coverage is reduced a bit, and you have to coat the beampipe with a thin layer of lead to absorb keV photons.

(4) The best way to avoid hitting the superconducting final quad is to widen the aperture so that the photon and e- beams pass through it. This config would use a 2 mrad crossing angle. Trying to avoid the quad by going around it with a large crossing angle won't work.

(5) We are developing staging plans for testing the XFEL with 100's of mJ per pulse, x-ray focusing, and the Compton collision.

(6) By running half the time producing e- gamma --> e- Higgs at Ecm=140 GeV, and half the time producing gamma gamma --> Higgs at 125 GeV the XCC Higgs physics program matches the ILC program at Ecm=250 GeV