XCC as a SLAC Project

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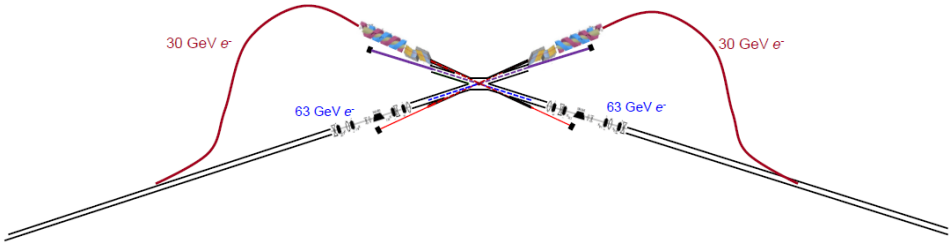
e+e- Collider Informal Meeting

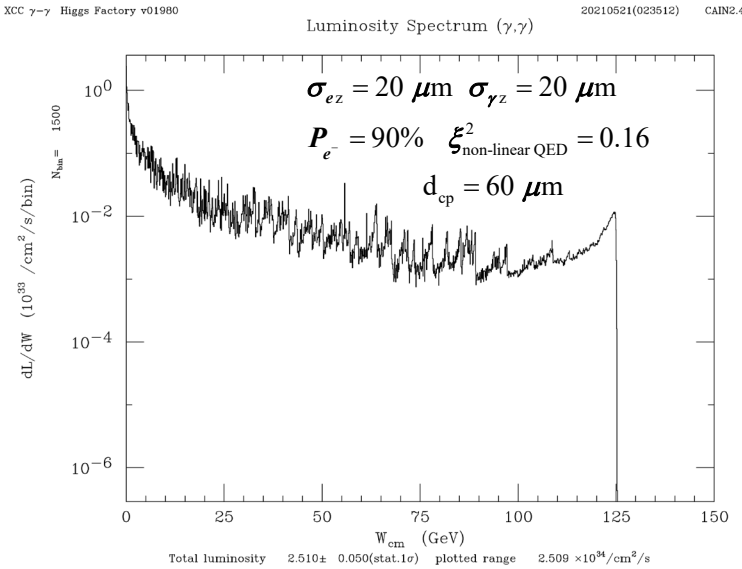
May 21, 2021

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Config with σ_z=20 μm d_{cp}=60 μm P_{e-} =0.9





N_{Higgs} / yr = 25,000 $N_{hadronic\ events}(\sqrt{\hat{s}} > 60\ \text{GeV}) / N_{Higgs} = 70$

$N_{mbias/bx} = 9.5$

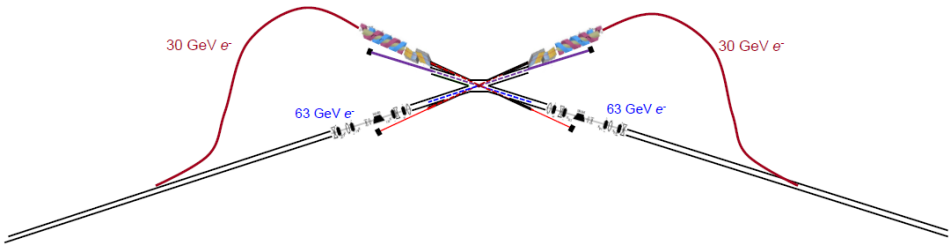
	e^-e^-	$e^-\gamma$	e^+e^-	$\gamma\gamma$
$L(10^{33}\ \text{cm}^{-2}\ \text{s}^{-1})$	3.1	22.4	10.3	25.1

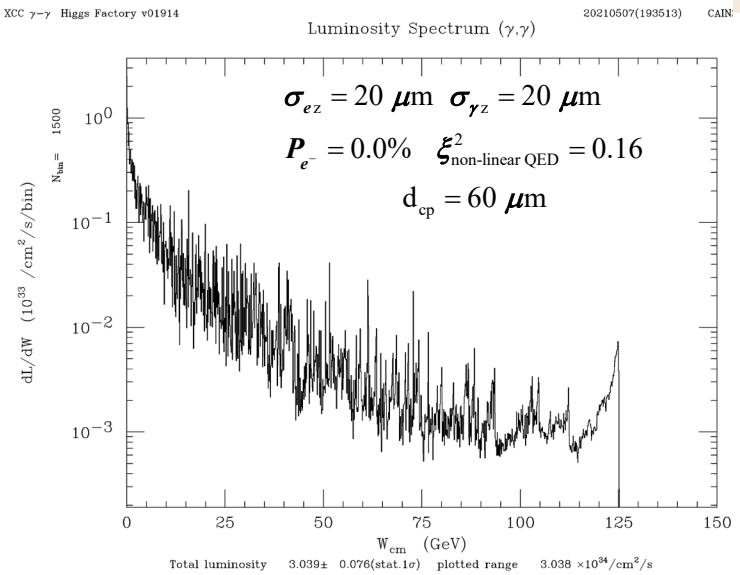
ILC

Polarization	$-80\%\ e^-$ $+30\%\ e^+$	$+80\%\ e^-$ $-30\%\ e^+$
N_{Higgs} / yr *	19,000	13,000
$N_{hadronic\ events}(\sqrt{\hat{s}} > 60\ \text{GeV}) / N_{Higgs}$	230	55
$N_{mbias/bx}$	1.3	1.3

* assumes 45% of year spent at each of these polarizations

Config with σ_z=20 μm d_{cp}=60 μm P_{e^-} =0





N_{Higgs} / yr = 5,300 $\quad N_{hadronic\ events}(\sqrt{\hat{s}} > 60\ \text{GeV}) / N_{Higgs} = 220$

$N_{mbias/bx} = 9.5$

	e^-e^-	$e^-\gamma$	e^+e^-	$\gamma\gamma$
$L(10^{33}\ \text{cm}^{-2}\ \text{s}^{-1})$	2.6	15.5	3.8	13.4

ILC

Polarization	$-80\%\ e^-$ $+30\%\ e^+$	$+80\%\ e^-$ $-30\%\ e^+$
N_{Higgs} / yr *	19,000	13,000
$N_{hadronic\ events}(\sqrt{\hat{s}} > 60\ \text{GeV}) / N_{Higgs}$	230	55
$N_{mbias/bx}$	1.3	1.3

* assumes 45% of year spent at each of these polarizations

Without polarization the XCC Higgs statistics are low. However, the XCC would provide model independent measurements of the Higgs couplings from the outset (recall that the $\sigma \times$ BR measurements at $\sqrt{s} = 125$ GeV are calibrated with $\sigma(e^-\gamma \to e^- H)$ measurementat $\sqrt{s} = 140$ GeV). These model independent measurements would be unique with respect to the LHC

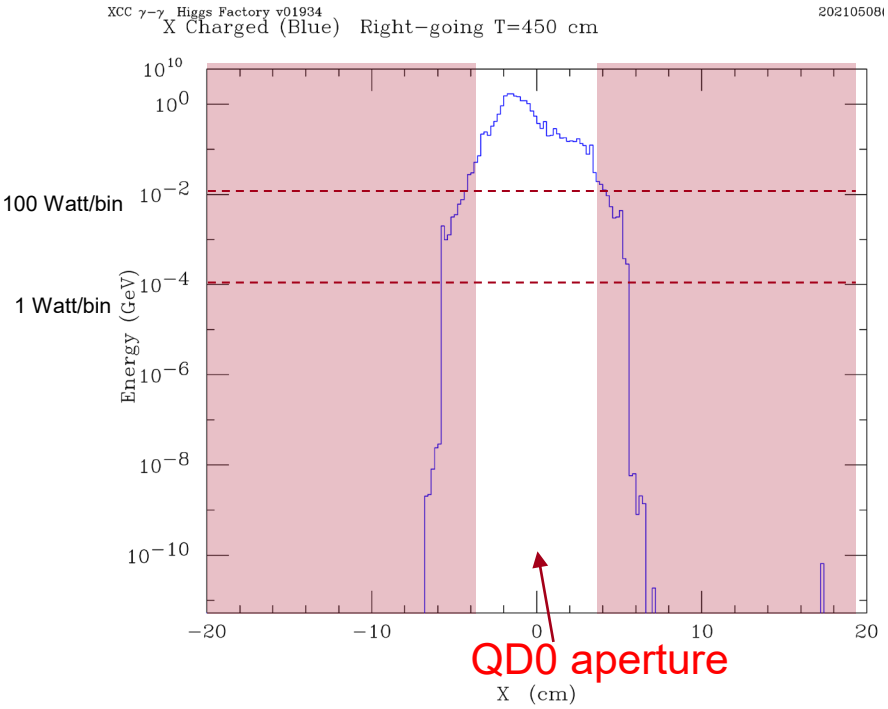
Config with σ_z=20 μm d_{cp}=60 μm

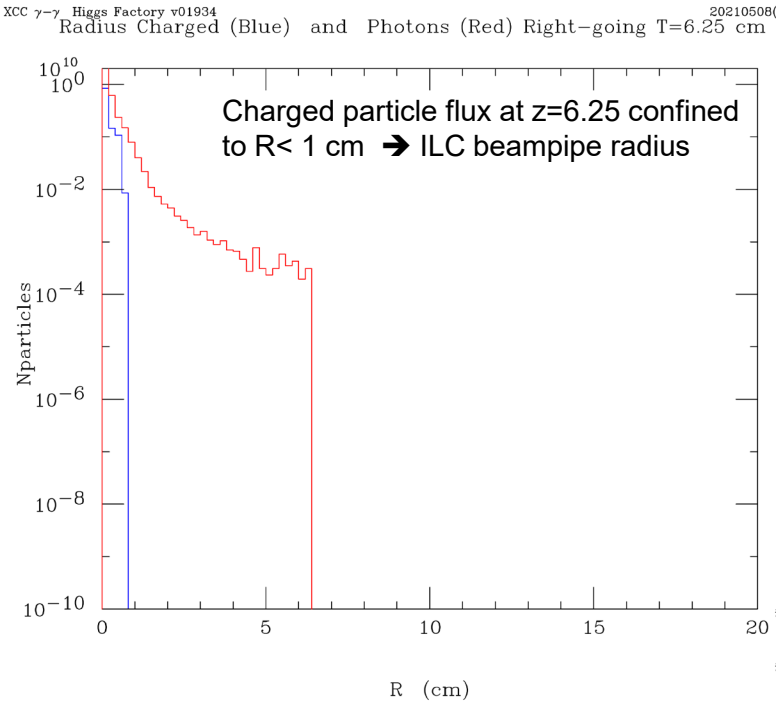
Flux at QD0 and Detector Background

$B_{solenoid}$ = 10 Tesla

$$\sigma_{ez} = 20\ \mu\text{m} \quad \sigma_{\gamma z} = 20\ \mu\text{m}$$
$$P_{e^-} = 0.0\% \quad \xi^2_{\text{non-linear QED}} = 0.16$$
$$d_{cp} = 60\ \mu\text{m}$$

2 mrad crossing angle e- Energy vs X at QD0 faces (450 cm from IP)





QD0 = final quad for 62.6 GeV beam assuming same aperture as ILC 2mrad design

XCC as a SLAC Project

Perhaps instead of selling XCC as a big global machine alternative to the ILC , we present it as a SLAC C^3 technology prototype collider project with modest ***initial*** physics goals (model independent Higgs coupling measurements with 5000 Higgs/year).

Regarding the initial physics goals, please note that we know through studies over the past months that there is an upgrade path to ILC-like Higgs precision using a polarized gun and/or 10 GeV deflector beams. We could further strengthen the case for this machine by arguing that the collider would serve as a prototype for a multi-TeV $\gamma\gamma$ Collider.

For making a rough cost estimate let's consider two configurations:

one linac + SLC Arcs + CEH
two linacs + new tunnels + new collider hall.

Layout of XCC as single C^3 accelerator + SLC Arcs + CEH (Bldg 750)

Layout of XCC as single C^3 accelerator + SLC Arcs + CEH (Bldg 750)

SLC FF straight sections are each about 100 m long.

Emittance growth in SLC Arcs

From Tor Raubenheimer, An SLC-Like Higgs Factory, SLAC Retreat 27Sep2012 :

- ISR in arcs – very strong function of beam energy

$$E_{\rm arc}[\mathrm{GeV}] = 8.846\times10^{-5}\,\frac{(E\,[\mathrm{GeV}])^4}{2\rho\,[\mathrm{m}]}\,\frac{\theta}{\pi}$$ ➡ ΔE ~ 3 GeV for 180° at 85 GeV and ρ = 800 m

$$\Delta\sigma_E^2 = \frac{55\alpha(\hbar c)^2}{48\sqrt{3}}\gamma^7\frac{\pi}{\rho^2}\frac{\theta}{\pi}$$ ➡ ΔE/E ~ 8e-4 for 180° at 85 GeV and ρ = 800 m

$$\Delta\epsilon_{/N} = \frac{2\pi}{3}\frac{c_q r_e}{\rho^2}\gamma^6\langle H\rangle\frac{\theta}{\pi}$$ ➡ $\Delta\varepsilon_{/N}$ ~ 1e-6 for 180° with 5.2 m SLC Arc cell at 85 GeV and ρ = 800 m $\Delta\varepsilon \sim 6\text{X}10^{-12}$

For SLC Arcs $\boldsymbol{\rho} = 280$ m

E_{out} (GeV)	ΔE (GeV)	ΔE/E (%)	$\Delta\boldsymbol{\gamma\varepsilon}$ (m)	$\Delta\boldsymbol{\varepsilon}$ (m)
31	0.15	0.00056	1.92×10^{-8}	3.16×10^{-13}
62.6	2.52	0.0767	1.30×10^{-6}	1.06×10^{-11}
70	3.94	0.168	2.55×10^{-6}	1.86×10^{-11}

Emittance growth in SLC Arcs

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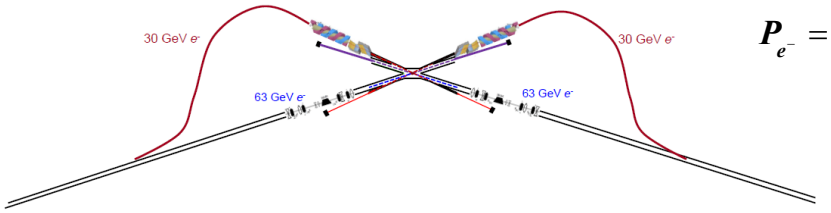
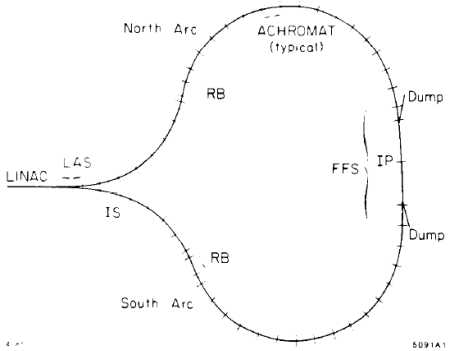


$\sigma_{ez} = 20\ \mu$m $\sigma_{\gamma z} = 20\ \mu$m

$P_{e^-} = 0.0\%$ $\xi^2_{\text{non-linear QED}} = 0.16$

$d_{cp} = 60\ \mu$m



N_{Higgs} / yr $= 5,300$ ILC $< N_{hadronic\ events} / N_{Higgs} \ll$ LHC

	e^-e^-	$e^-\gamma$	e^+e^-	$\gamma\gamma$
$L(10^{33}\ \text{cm}^{-2}\ \text{s}^{-1})$	2.6	15.5	3.8	13.4

$\gamma\varepsilon_x = 120$ nm $\gamma\varepsilon_y = 120$ nm $\sigma_E / E = 0.05\%$

N_{Higgs} / yr $= 1,000$ ILC $< N_{hadronic\ events} / N_{Higgs} \ll$ LHC

	e^-e^-	$e^-\gamma$	e^+e^-	$\gamma\gamma$
$L(10^{33}\ \text{cm}^{-2}\ \text{s}^{-1})$	2.9	11.7	3.2	9.7

$\gamma\varepsilon_x = 1200$ nm $\gamma\varepsilon_y = 120$ nm $\sigma_E / E = 0.08\%$

Cost comparison: one vs two linac XCC at SLAC

one linac

0.7 km accelerator $70M

0.4 km XFEL $20M

0.4 km FF $20M

5.4 km beam transport line with ρ=280 m

(2×2.7 km for separate 31 and 70 GeV transport lines) $270M

$380M total (and significant performance loss)

tunnel: $40k/m

Collider hall: $130M

accelerator: $100k/m

transport/XFEL/FF line: $50k/m

two linacs

1.6 km tunnel $64M

Collider hall 1 km upstream of beam switchyard $130M

1.4 km accelerator $140M

0.4 km XFEL $20M

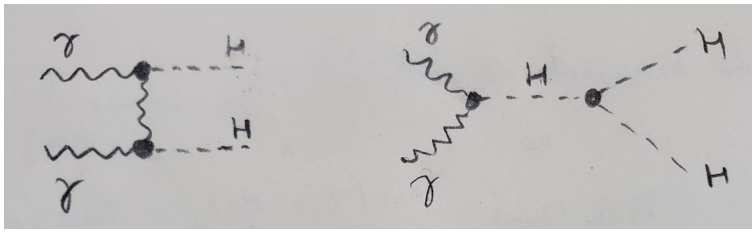
0.4 km FF $20M

$374M total

Detector cost not included, but should note that the size of the detector can be made smaller than SiD through smaller tracker radius (and perhaps also higher solenoid field). The tracker momentum resolution spec is LEP/SLC-like since we don't need to make the Z recoil measurement of $\sigma(e^+e^- \to ZH \to \mu^+\mu^- H)$

Two C^3 linacs with new collider hall at midpoint of original SLAC 2 mi linac

Two C^3 linacs with new collider hall at midpoint of SLAC property



Using WHIZARD and an effective $\gamma\gamma H$ vertex, the maximum $\sigma(\gamma\gamma \to HH) = 0.28$ fb at $\sqrt{s} = 285$ GeV which is comparable to the maximum $\sigma(e^+e^- \to ZHH) = 0.23$ fb at $\sqrt{s} = 580$ GeV.

Doubling the length of each C^3 linac gets us to $\sqrt{s} = 285$ GeV on the SLAC site.