XFEL-based $\gamma\gamma$ Collider Higgs Factory

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AF03 Summary Report Meeting

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SLAC NATIONAL ACCELERATOR LABORATORY

XFEL-based $\gamma\gamma$ Collider Higgs Factory Schematic

$$\sqrt{s_{\gamma\gamma}} = 125 \text{ GeV}$$

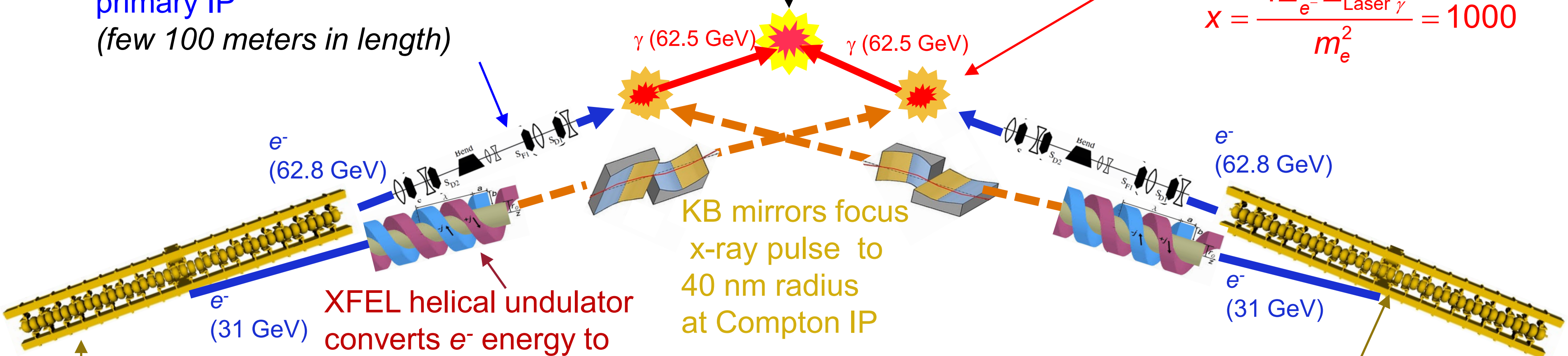
30,000 Higgs bosons/year

$$\begin{array}{lcccc} & e^-e^- , & e^-\gamma , & \gamma\gamma , & e^+e^- \\ L = & 7.5 : & 6.7 : & 0.9 : & 0.3 \times 10^{33}\ \text{cm}^{-2}\ \text{s}^{-1} \end{array}$$

62.8 GeV electrons converted to 62.5 GeV photons through Compton collision with 1 keV x-rays

$$x = \frac{4E_{e^-}E_{\text{Laser }\gamma}}{m_e^2} = 1000$$

Final focus squeezes round e^- beam to radius σ_r= 8 nm at primary IP
(few 100 meters in length)



KB mirrors focus x-ray pulse to 40 nm radius at Compton IP

XFEL helical undulator converts e^- energy to 1 keV x-rays, 0.7 Joules/pulse
(few 100 meters in length)

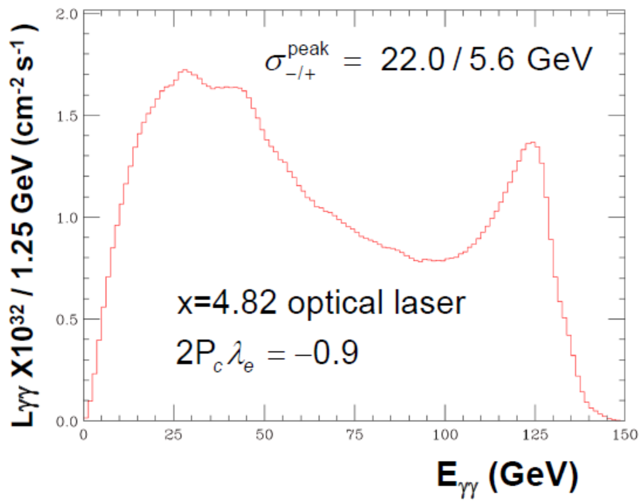
Every other bunch in train is kicked to XFEL line at the 31 GeV point in LINAC
(2 ns bunch separation

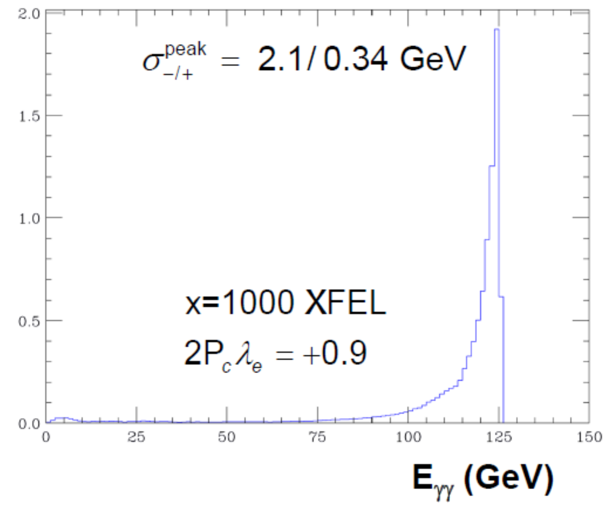
C^3 LINAC with 100 MeV/m accelerates electrons to 62.8 GeV
(650 meters in length)

~2 km total length

Polarized RF gun produces low emittance round e^- beams (no need for damping rings)

$\gamma\gamma$ Luminosity Spectra x=4.8 vs. x=1000 (CAIN MC)





Higgs production rate same as ILC with 15X smaller luminosity

Compared to x=4.82, background from $\gamma\gamma$ processes is small at x=1000, but must still contend with

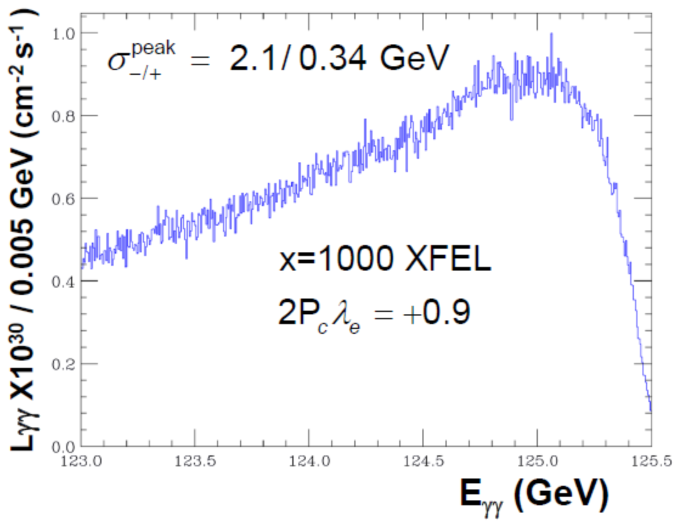
$e^{-}\gamma \rightarrow e^{-}Z$ & $e^{+}e^{-} \rightarrow \gamma Z$

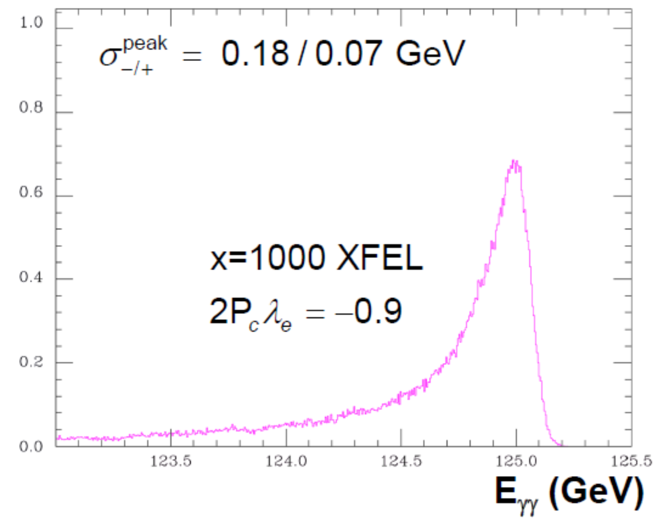
Table 1: Summary of Compton and Primary IP parameters.

	x=1000 $2P_c\lambda_e = +0.9$	x=1000 $2P_c\lambda_e = -0.9$
Laser wavelength λ (nm)	1.2	1.2
Laser waist radius a_γ (nm)	37.7	37.7
Laser pulse length $= 2\beta_\gamma = \frac{4\pi a_\gamma^2}{\lambda}$ (μm)	15.0	15.0
Laser pulse energy (J)	0.72	0.72
e^- Compton conversion efficiency (%)	44.2	37.1
peak non-linear QED $\xi^2 = \frac{2n_\gamma r_e^2 \lambda}{\alpha}$	0.17	0.17
$\mathcal{L}_{\gamma\gamma}$ (10^{33} cm^{-2} s^{-1})	0.92	0.13
$\mathcal{L}_{e^-\gamma}$	6.21	2.4
$\mathcal{L}_{e^+\gamma}$	0.54	0.24
$\mathcal{L}_{e^-e^-}$	7.5	8.0
$\mathcal{L}_{e^+e^-}$	2.54	3.64
$\mathcal{L}_{e^+e^-}$, $\sqrt{s} > 50$ GeV	0.34	0.38
N_{Higgs}/yr	30,800	21,700
$\Delta\Gamma_H$ from 1 yr energy scan (MeV)	34	8

$\gamma\gamma$ Luminosity Spectra $2P_c\lambda_e = +0.9$ vs -0.9

Bin size $\approx$ SM $\Gamma_H = 4$ MeV





Helicity product $2P_C\lambda_e$=+0.9 is chosen to optimize Higgs production rate.

To measure total Higgs width with an energy scan it is better to use $2P_C\lambda_e = -0.9$ ($\Delta\Gamma_H = 34$ vs. 8 MeV).

Non-linear QED $e^-\gamma_0 \to e^-\gamma$, $\gamma_0\gamma \to e^+e^-$

linear QED $e^-\gamma_0 \to e^-e^+e^-$ & $\Delta E_{e^-} = 0.05\%$

included in all $\gamma\gamma$ luminosity plots (CAIN)

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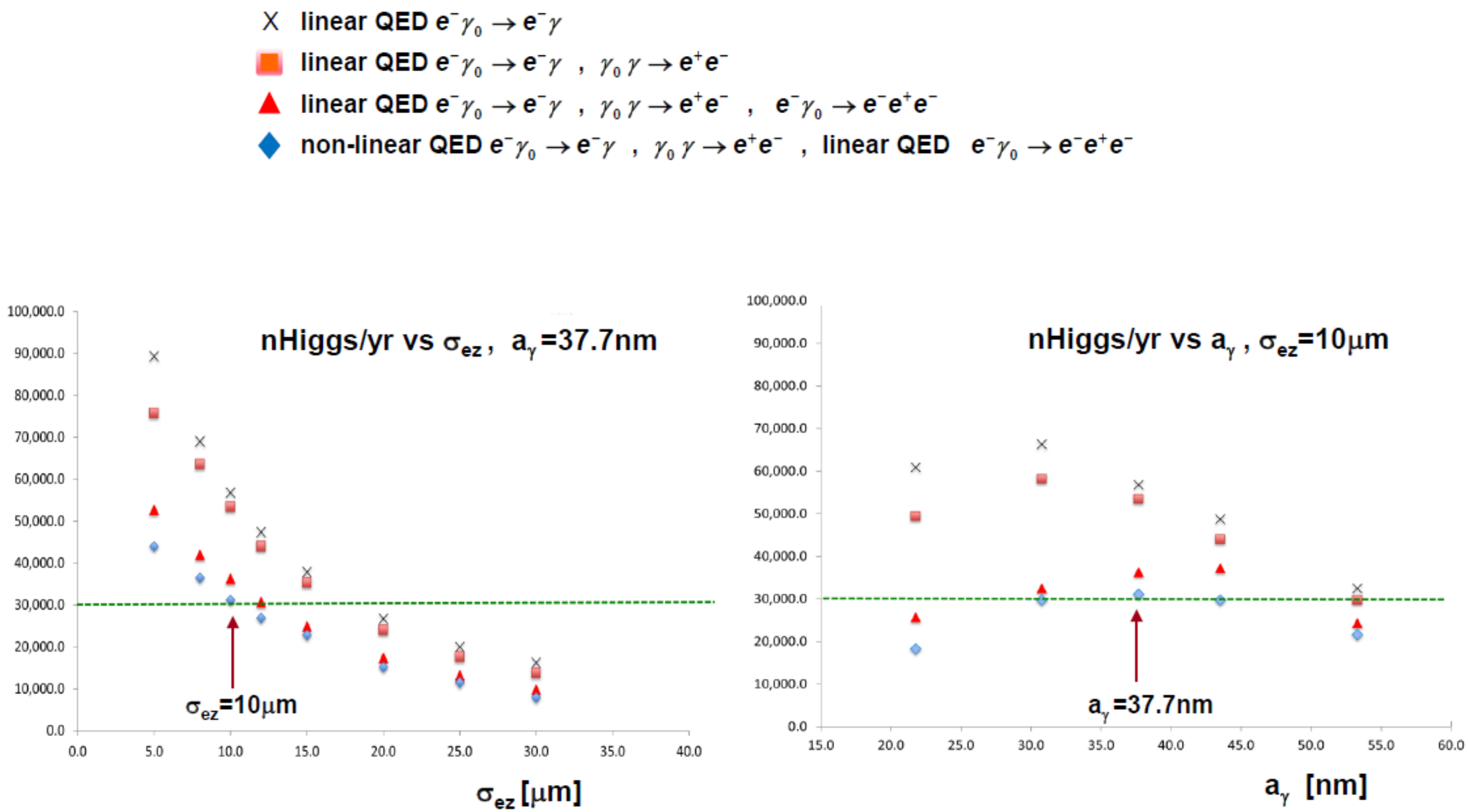
σ_{ez} and a_γ scans vs. $\gamma\gamma$ Luminosity (CAIN MC)



$\gamma_0\gamma \to e^+e^-$ relatively small effect

non-linear QED effects also small (as expected given $\xi^2 = 0.17$)

$e^-\gamma_0 \to e^-e^+e^-$ has largest impact, but not a killer

small sensitivity to a_γ

50% improvement in luminosity if $\sigma_{ez} = 10\,\mu m \to 5\,\mu m$

XFEL

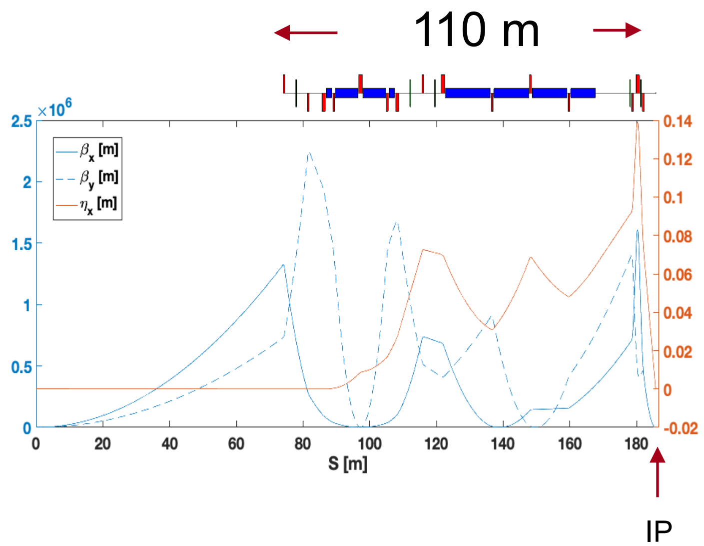
XFEL parameters	Approx. value
Electron energy	31 GeV
normalized emittance	120 nm
RMS energy spread $\langle \Delta\gamma/\gamma \rangle$	0.05%
bunch charge	1 nC
Undulator B field	$\gtrsim$ 1 T
Undulator period λ_u	9 cm
Average β function	12 m
x-ray λ (energy)	1.2 nm (1 keV)
x-ray pulse energy	0.7 J

- Due to high B field and electron energy, quantum diffusion energy spread in must be properly included in the design.
- With permanent magnet undulator, peak B field slightly above 1 Tesla, $\langle\beta\rangle$=12m, 1 keV X-rays with pulse energy ~ 0.07 J can be produced with negligible diffusion
- With seeded FEL and taper of undulator K parameter after saturation, pulse energy of 0.7 J can be achieved
- Overall length of XFEL is ~ 200 m

Final Focus (initial study by Glen White)

Design Parameters

Final Focus Parameter	Value
E	62.8 GeV
$\beta^*_{x,y}$	0.03 mm
$\gamma\varepsilon_{x,y}$	120 nm-rad
δ_E/E	0.05 %
L^* (Q0 exit to e^- IP)	3.5 m
$\sigma^*_{x,y}$	5.4 nm
η'^*_x	20 mrad
magnet aperture	2 cm diameter



- Based on local chromatic correction scheme of Raimondi-Seryi
- Includes 3 families of bend magnets, 5 sextupoles, plus octupoles & decupoles
- Round beams at the IP ➔ preference for final triplet instead of doublet. The required angular dispersion at the IP is about double that for ILC/CLIC. This will have an adverse effect on the momentum acceptance of the extraction line and may lead to increased detector backgrounds.
- The IP beta functions are 0.03 mm in both planes, compared with 11 x 0.48 mm for the baseline ILC design. The much smaller β* values generate significantly higher chromatic distortions, requiring stronger sextupole corrections ➔ tolerances become rapidly tighter and online tuning becomes harder
- Operational experience at ATF2 showed that tuning becomes more difficult with smaller $\beta^*_x : \beta^*_y$ ratios

Some current topics of study

- Overall geometric layout of accelerator, XFEL, X-ray focusing, and final focus line.
- Damage threshold of the KB mirrors
- Final focus optics
- Machine detector interface including background from the low energy e^+e^- pairs and γ's produced at the Compton IP
- Physics study of Higgs couplings -- can this collider yield precisions comparable to ILC? With an equal number of Higgs bosons and an 8 MeV total Higgs width measurement there is a chance.

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