$\gamma\gamma$ Higgs Factory Parameter Optimization

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For SM Higgs, $M_H = 125$ GeV

$\Gamma_{tot} = 4.03$ MeV

$\Gamma_{\gamma\gamma} = 9.33$ KeV

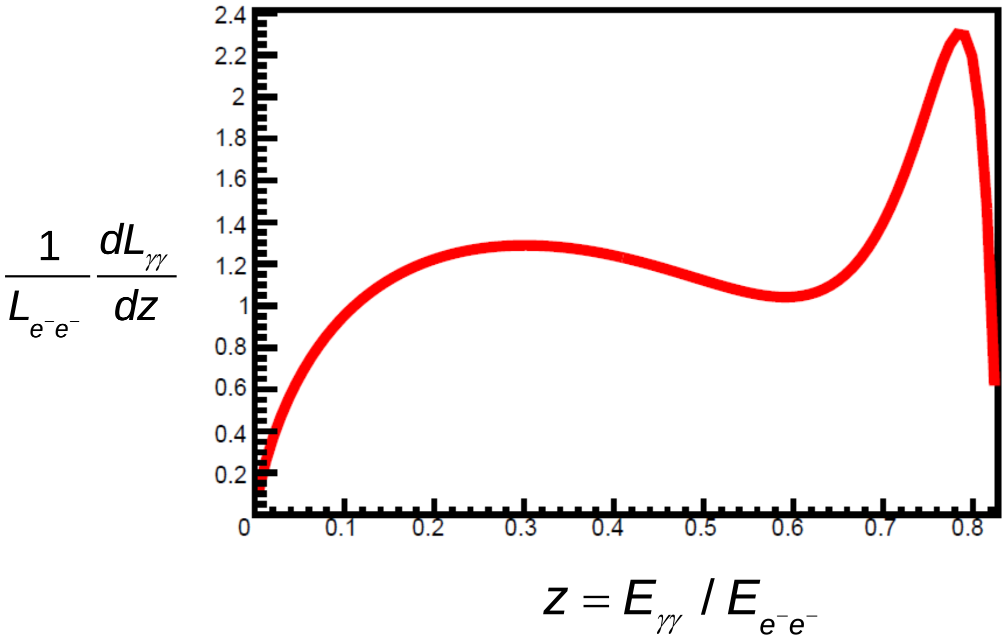
$\Gamma_{\mu^+\mu^-} = 0.89$ KeV

Coupling of Higgs to $\gamma\gamma$ is 10 times the coupling to $\mu^+\mu^-$.

Proposed muon collider Higgs factories operate with $\Delta E_{beam}/E_{beam} < 0.01\%$ in order to match $\Gamma_{tot} = 4.03$ MeV.

Is there any way to operate a $\gamma\gamma$ collider with a very small $\gamma\gamma$ center of mass energy spread to take advantage of the relatively large $\gamma\gamma$ partial width?

Note: In the following slides, all Higgs cross sections must be multiplied by the γe conversion probability squared.

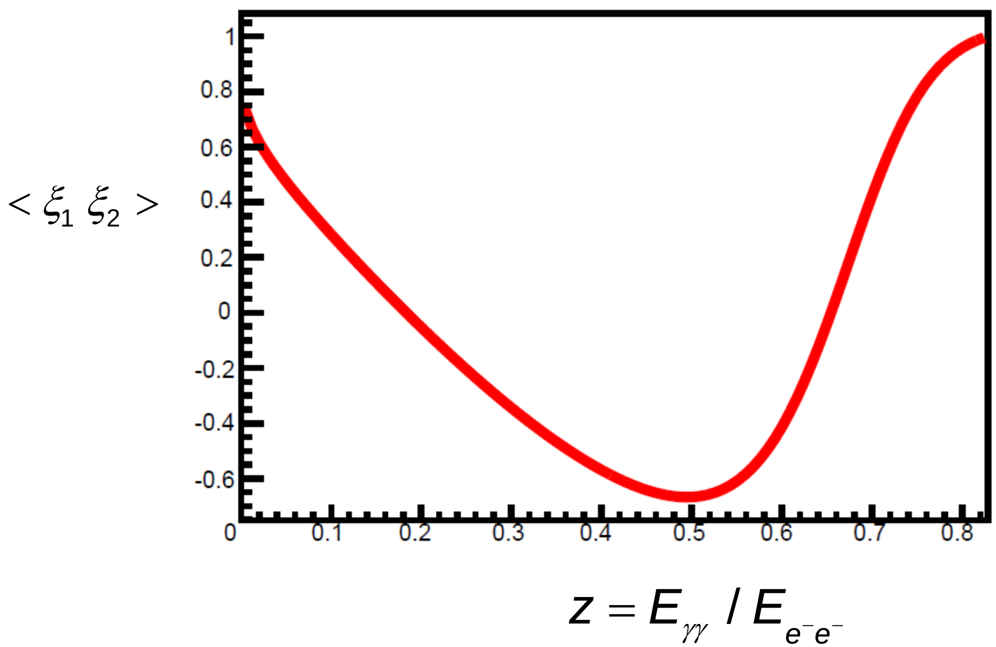


$x = 4.82 \quad E_{e^-e^-} = 158 \text{ GeV} \quad \kappa = 1$

$\text{pol}(e^-) = 90\% \quad 2P_c\lambda_e = -0.9$

(κ = 1 – prob that γ annihilates with laser γ)

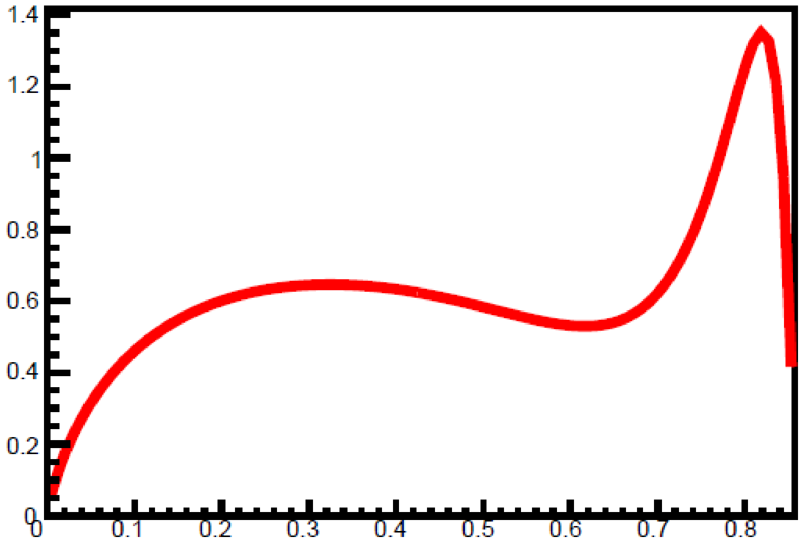
$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 247 \text{ fb}$$



$$\sigma(\gamma\gamma \to H) = \frac{8\pi\,\Gamma_{\gamma\gamma}\Gamma_{tot}}{(s - M_H^2)^2 + \Gamma_{tot}^2 M_H^2}(1 + \xi_1\,\xi_2)$$

$$\approx \frac{4\pi^2\Gamma_{\gamma\gamma}}{M_H^3}(1 + \xi_1\,\xi_2) z_H \delta(z - z_H)$$

$$\frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}$$



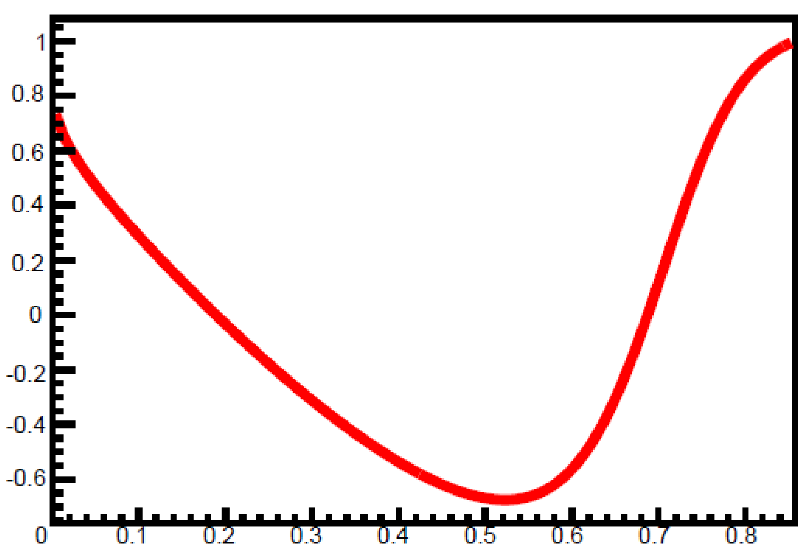
$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$x = 6.00 \quad E_{e^-e^-} = 150$ GeV $\quad \kappa$=0.73

pol(e^-) = 90% $\quad 2P_c\lambda_e = -0.9$

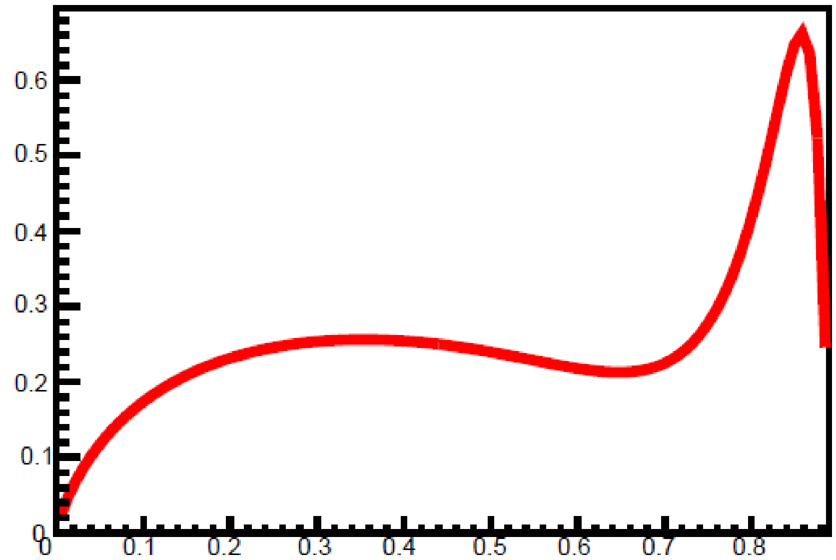
$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \rightarrow H) = 130 \text{ fb}$$

$$< \xi_1 \, \xi_2 >$$



$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$$\frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}$$



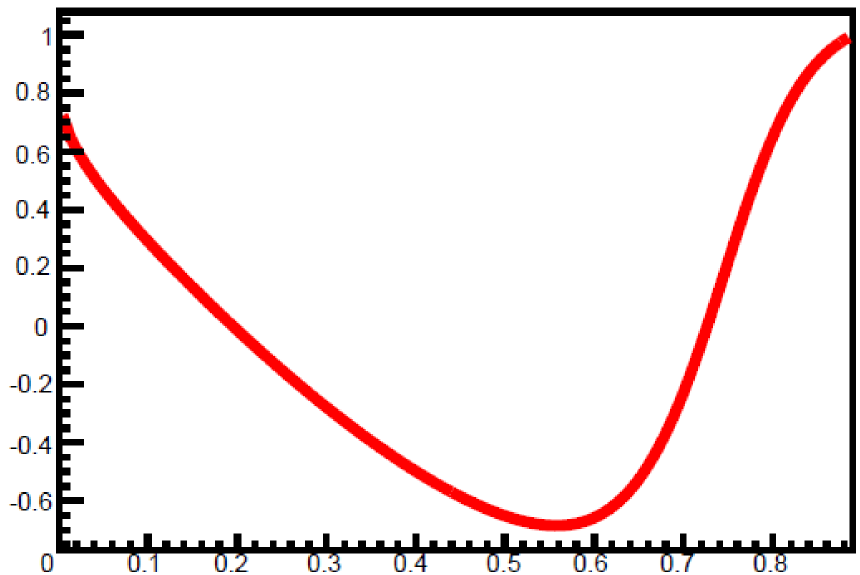
$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$$x = 8.00 \qquad E_{e^-e^-} = 146.5 \text{ GeV} \qquad \kappa = 0.48$$

$$\text{pol}(e^-) = 90\% \qquad 2P_c\lambda_e = -0.9$$

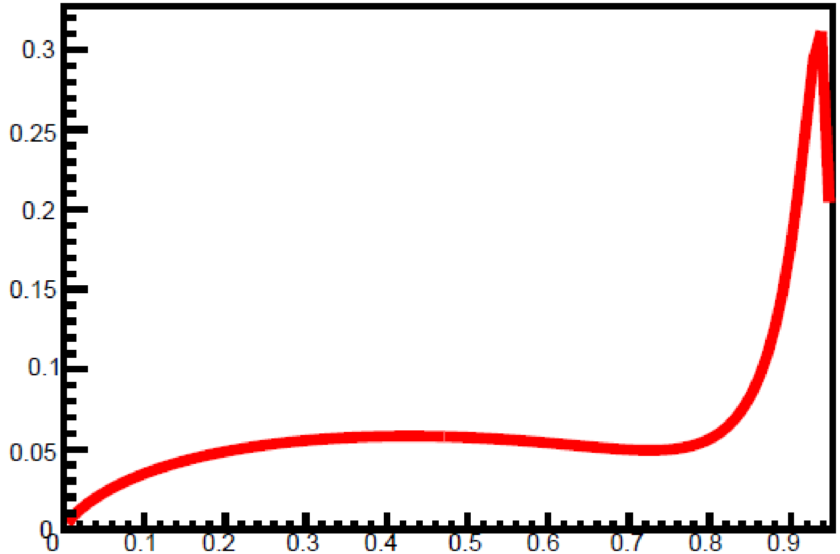
$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 78 \text{ fb}$$

$$< \xi_1 \, \xi_2 >$$



$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$$\frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}$$



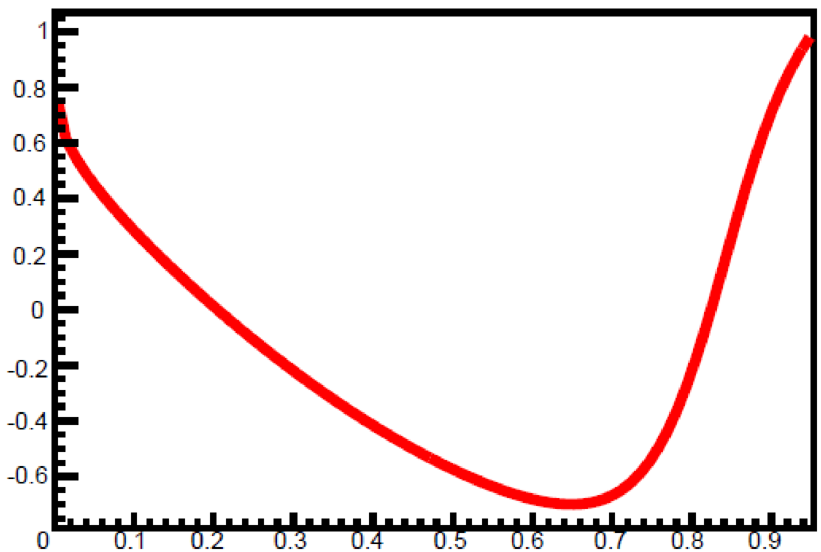
$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$x = 20.00 \qquad E_{e^-e^-} = 134.8\ \text{GeV} \qquad \kappa = 0.25$

$\text{pol}(e^-) = 90\% \qquad 2P_c\lambda_e = -0.9$

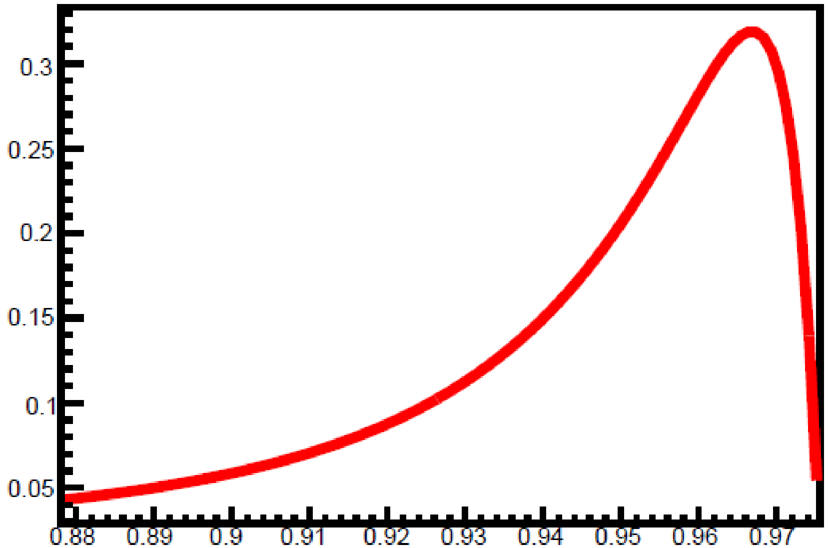
$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 40\ \text{fb}$$

$$< \xi_1\ \xi_2 >$$



$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$$\frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}$$



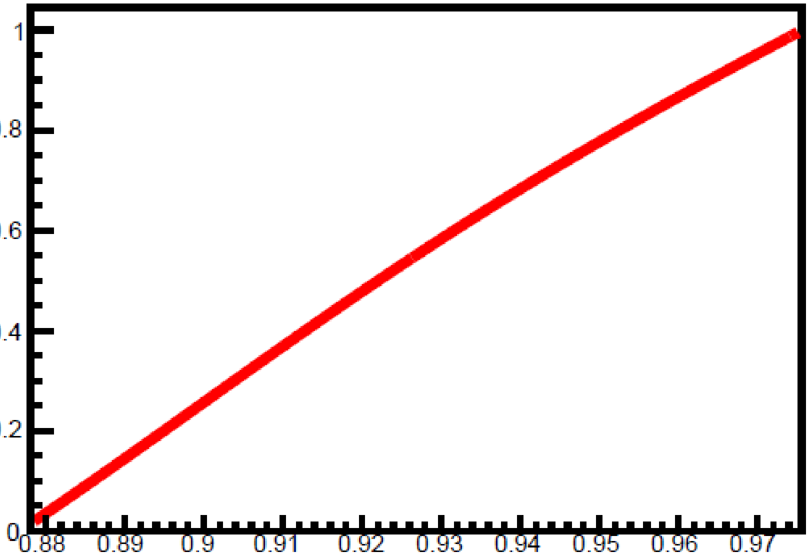
$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$x = 40.00$ $\quad E_{e^-e^-} = 130.3$ GeV $\quad \kappa = 0.19$

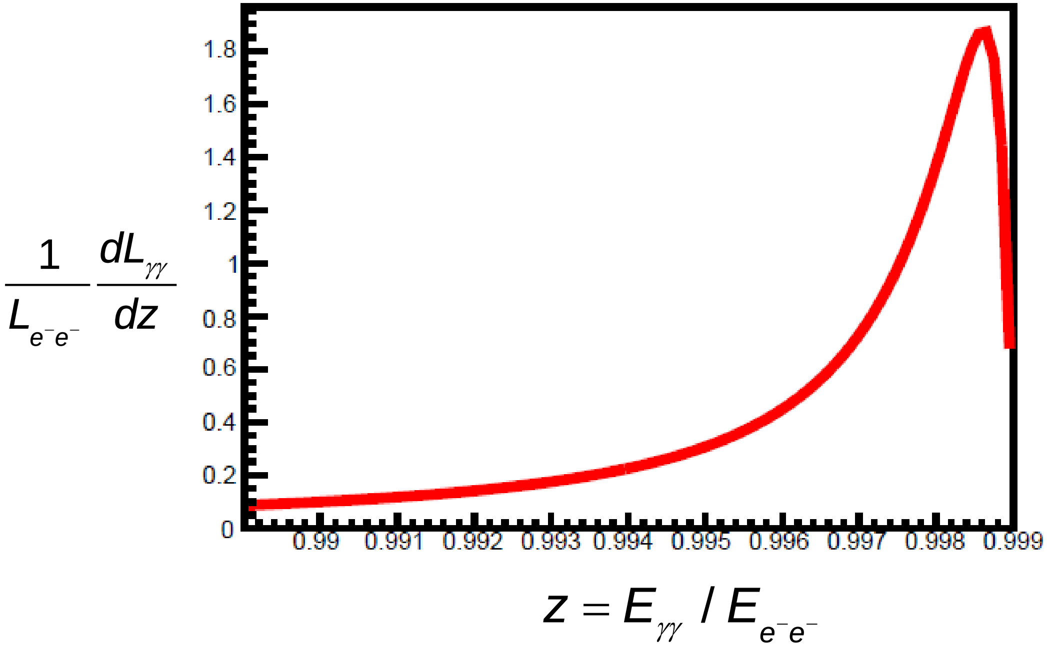
$\mathrm{pol}(e^-) = 90\%$ $\quad 2P_c\lambda_e = -0.9$

$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 42 \text{ fb}$$

$$<\xi_1\ \xi_2>$$



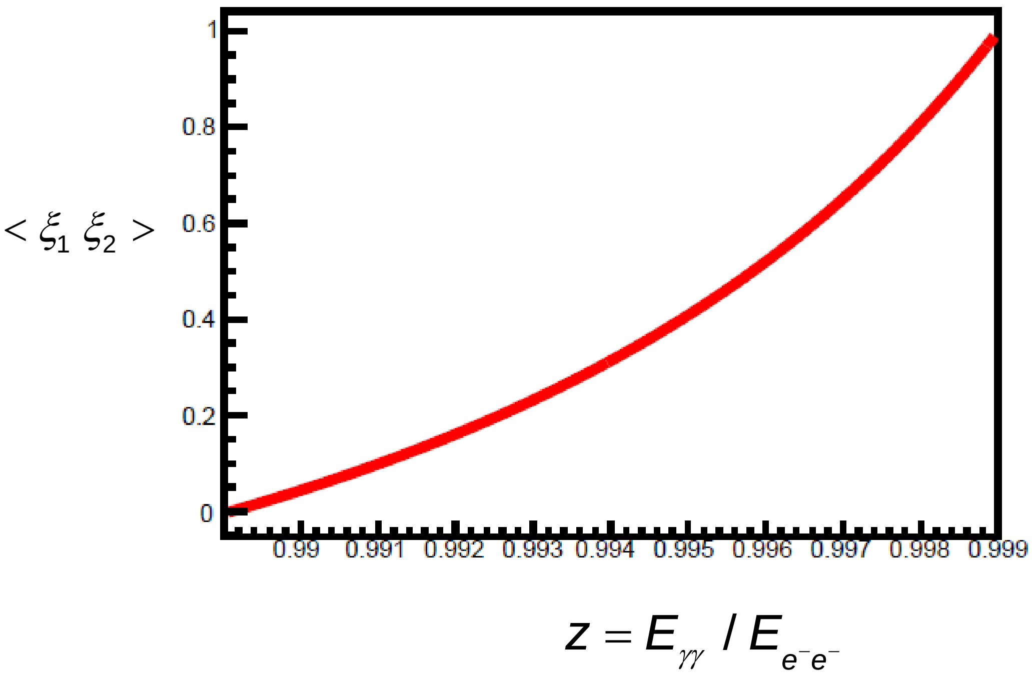
$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

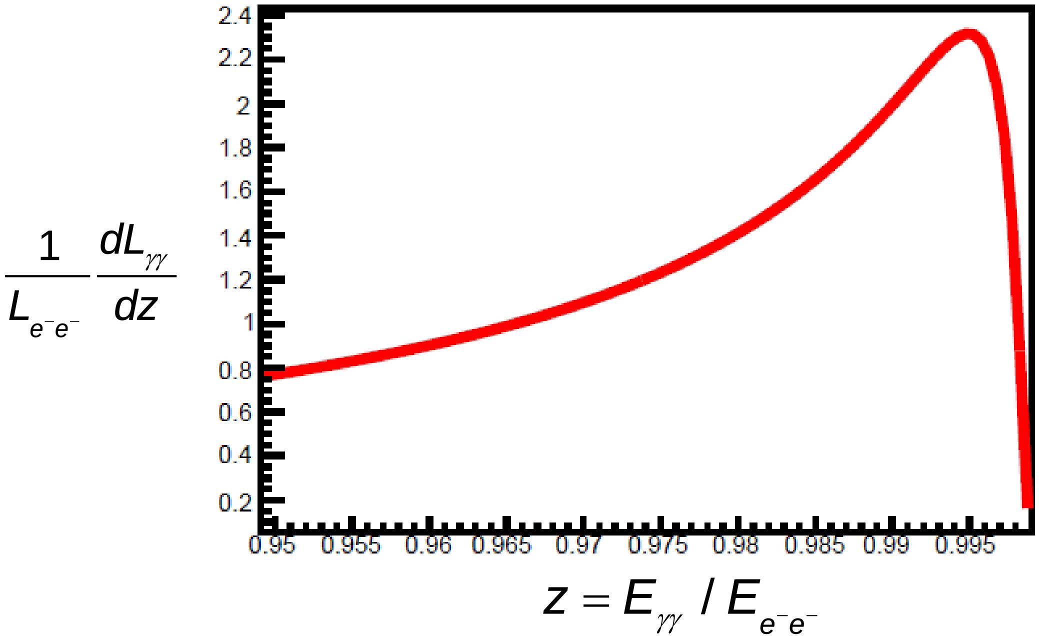


$x = 1000. \quad E_{e^-e^-} = 126.2$ GeV $\quad \kappa = 0.11$

pol(e^-) = 90% $\quad 2P_c\lambda_e = -0.9$

$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 257 \text{ fb}$$

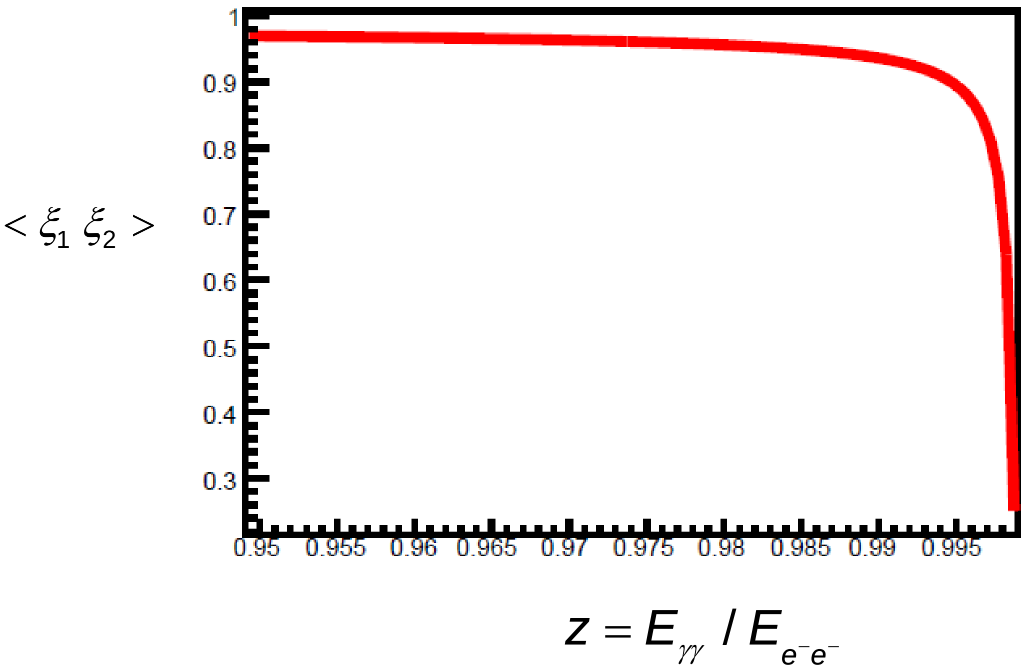


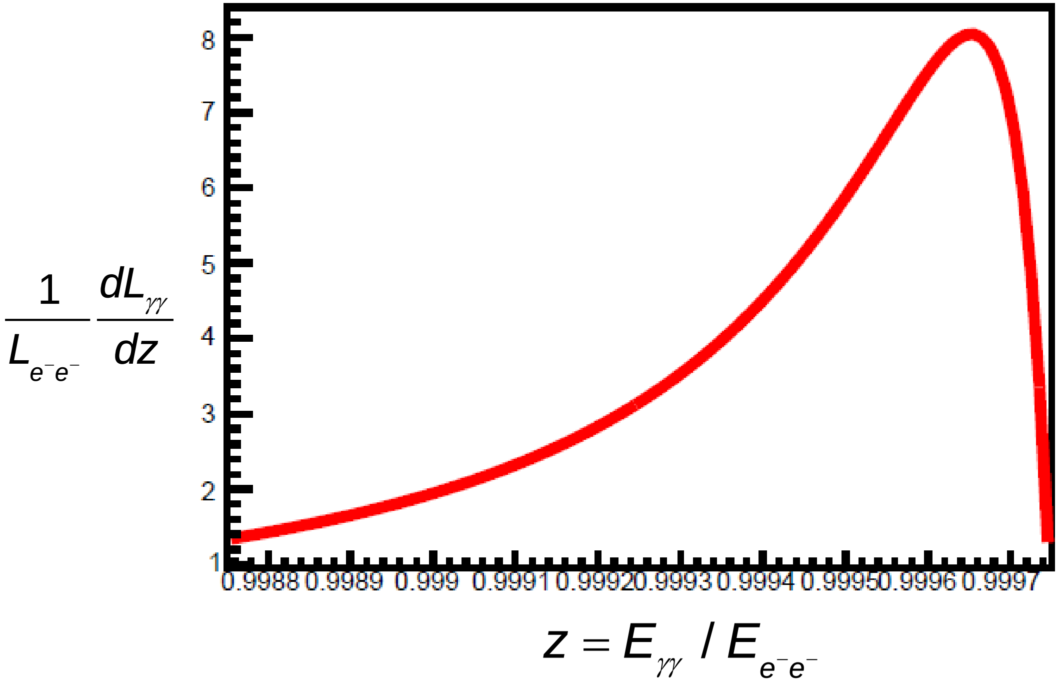


$x = 1000.$ $E_{e^-e^-} = 126.6$ GeV κ=0.44

pol(e^-) = 90% $2P_c\lambda_e = +0.9$

$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 311 \text{ fb}$$

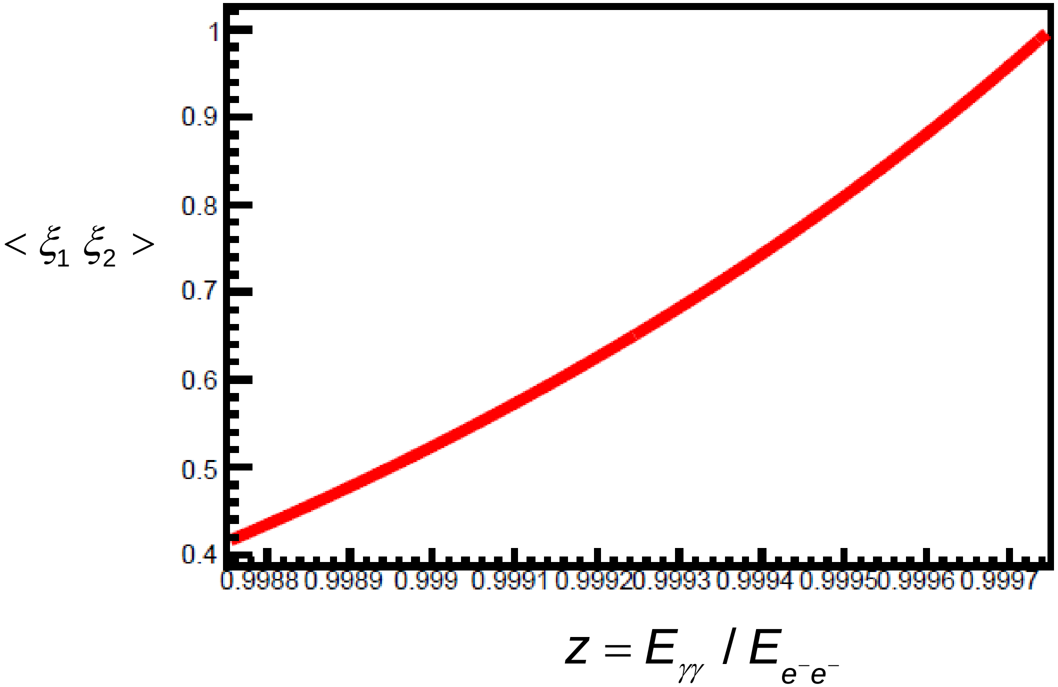


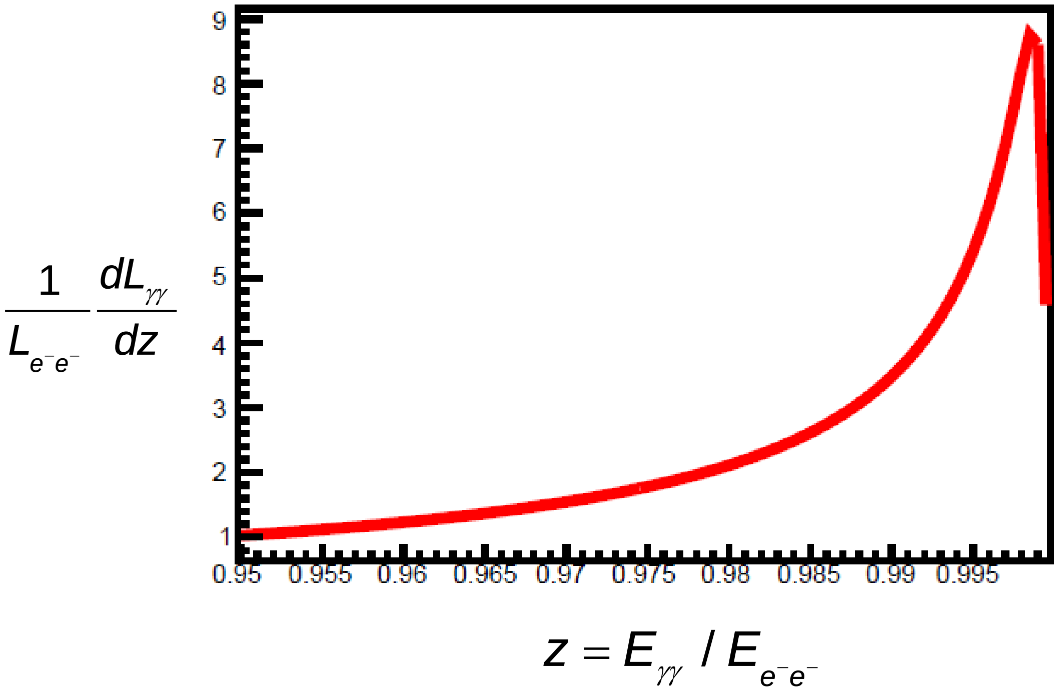


$x = 4000.$ $\quad E_{e^-e^-} = 126\ \mathrm{GeV}$ $\quad \kappa = 0.12$

$\mathrm{pol}(e^-) = 90\%$ $\quad 2P_c\lambda_e = -0.9$

$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 1099\ \mathrm{fb}$$

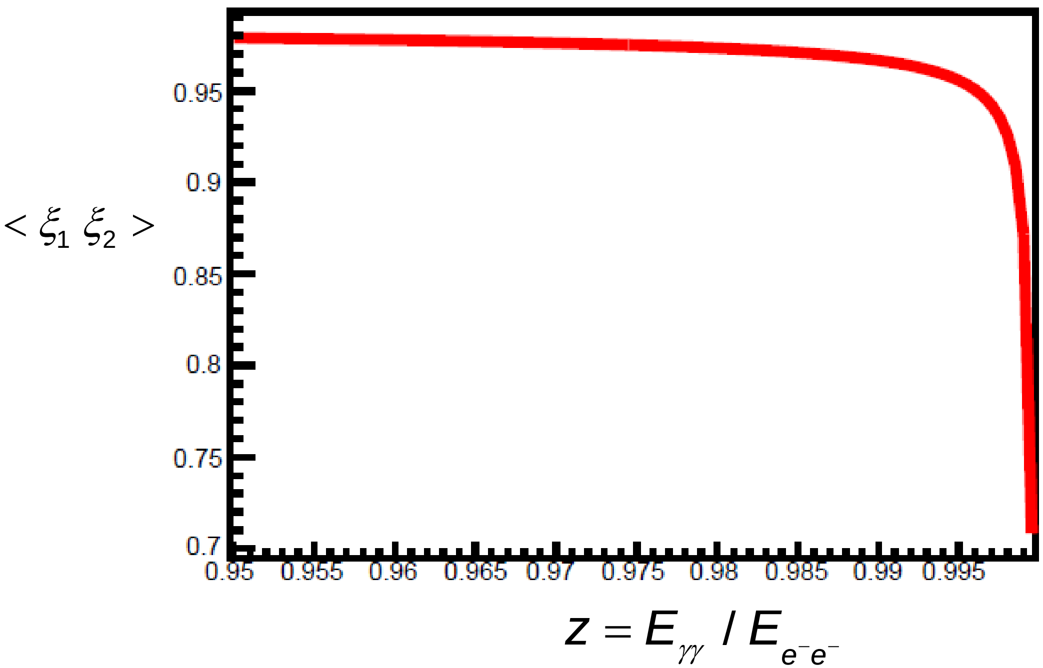




$x = 4000. \quad E_{e^-e^-} = 126.2$ GeV $\quad \kappa = 0.53$

$\text{pol}(e^-) = 90\% \quad 2P_c\lambda_e = +0.9$

$$\int dz \frac{1}{L_{e^-e^-}} \frac{dL_{\gamma\gamma}}{dz} \sigma(\gamma\gamma \to H) = 1188 \text{ fb}$$



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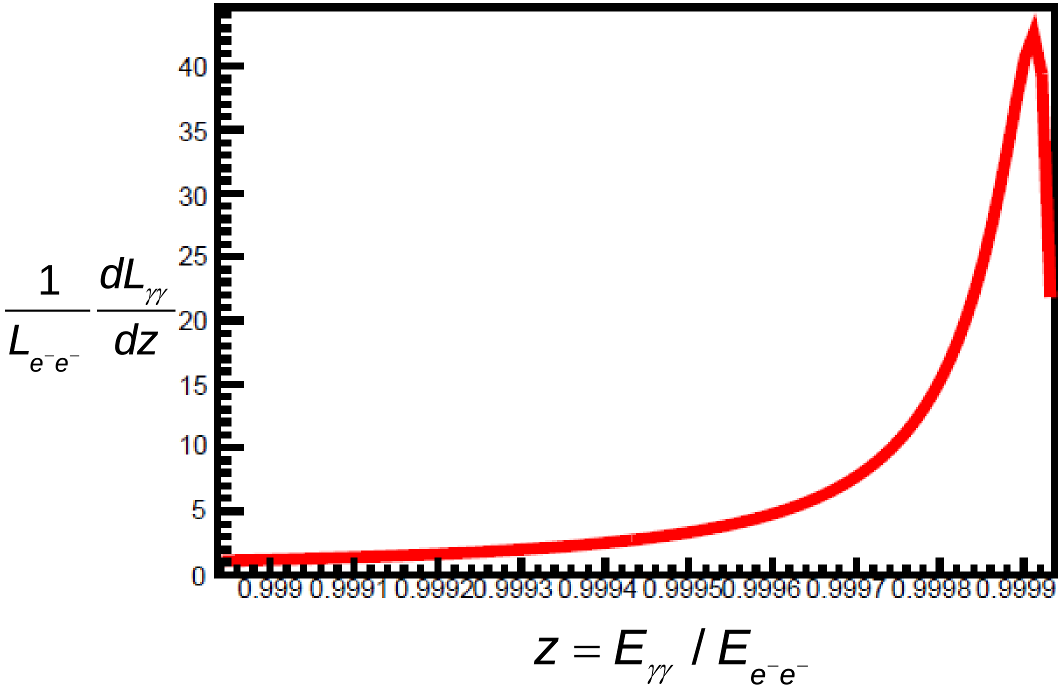
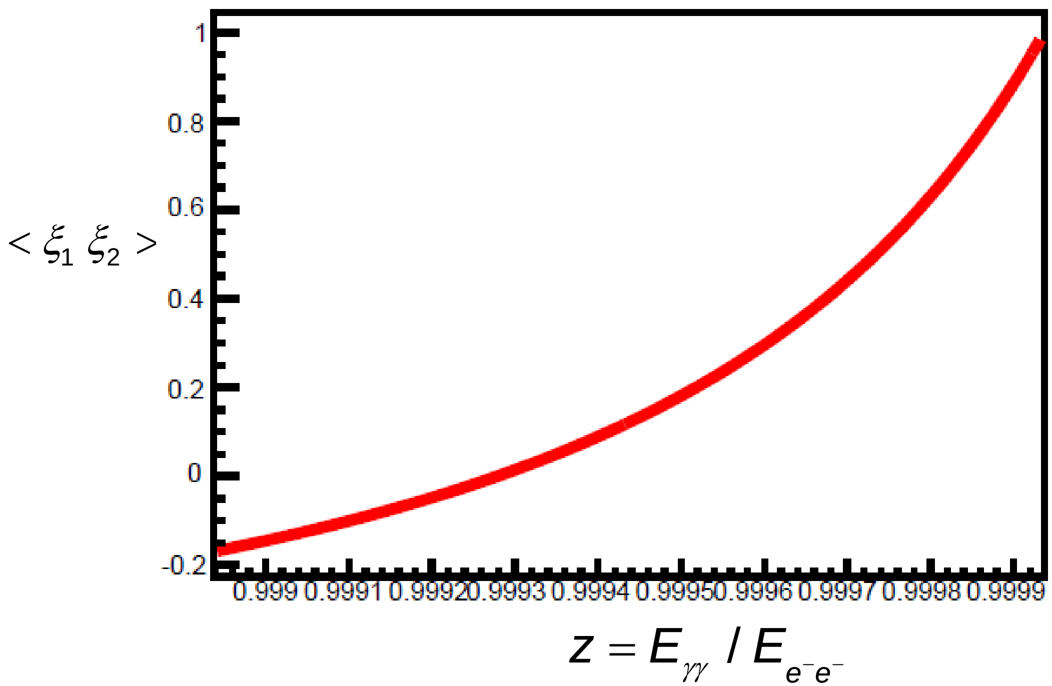


$x = 15870.$ $E_{e^-e^-} = 126$ GeV κ=0.15

pol(e^-) = 90% $2P_c\lambda_e = -0.9$

$$\int dz \frac{1}{L_{e^-e^-}} \frac{dL_{\gamma\gamma}}{dz} \sigma(\gamma\gamma \to H) = 5614 \text{ fb}$$



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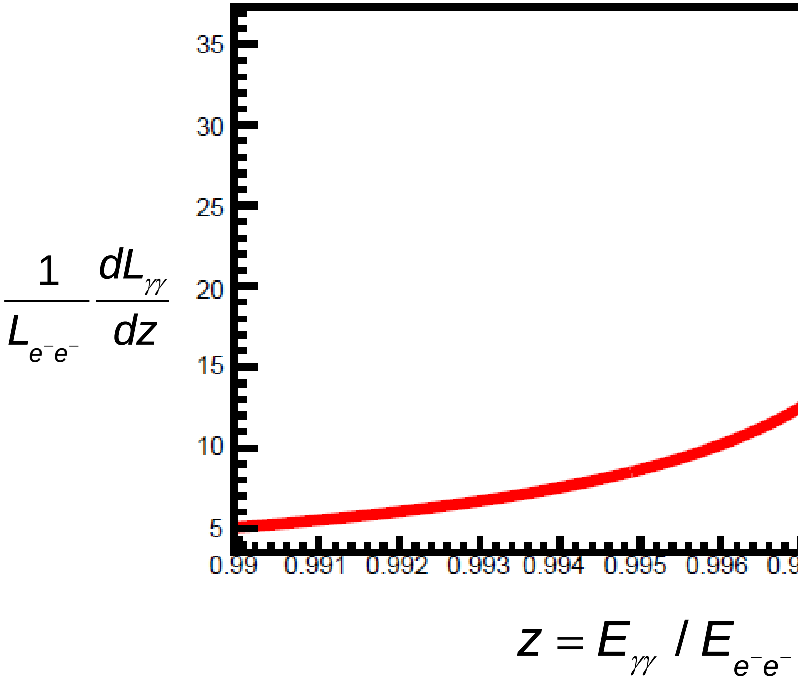
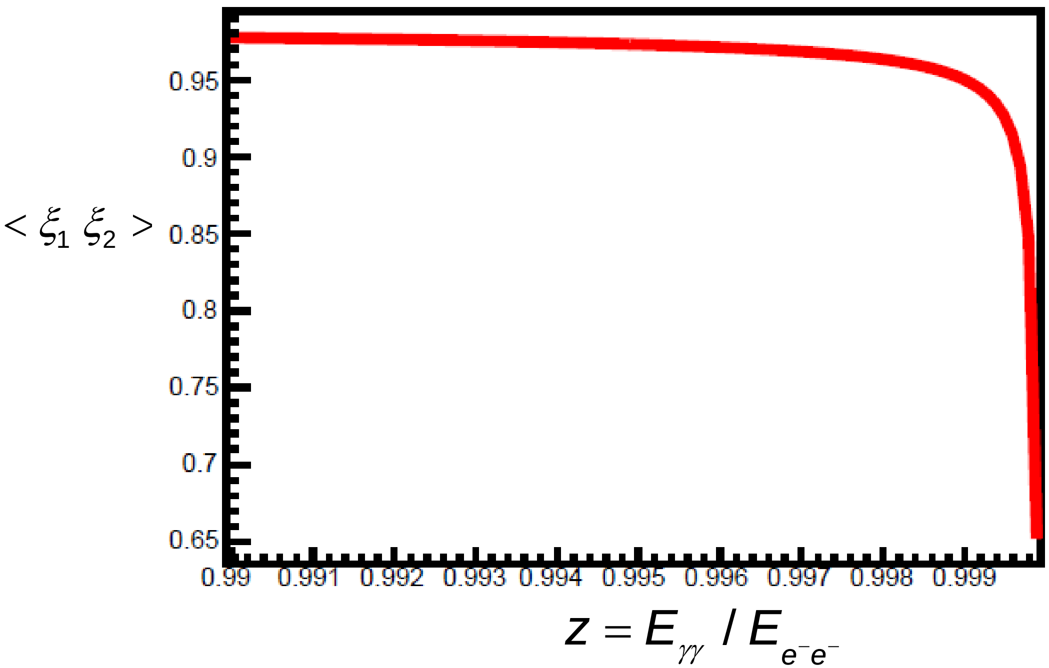


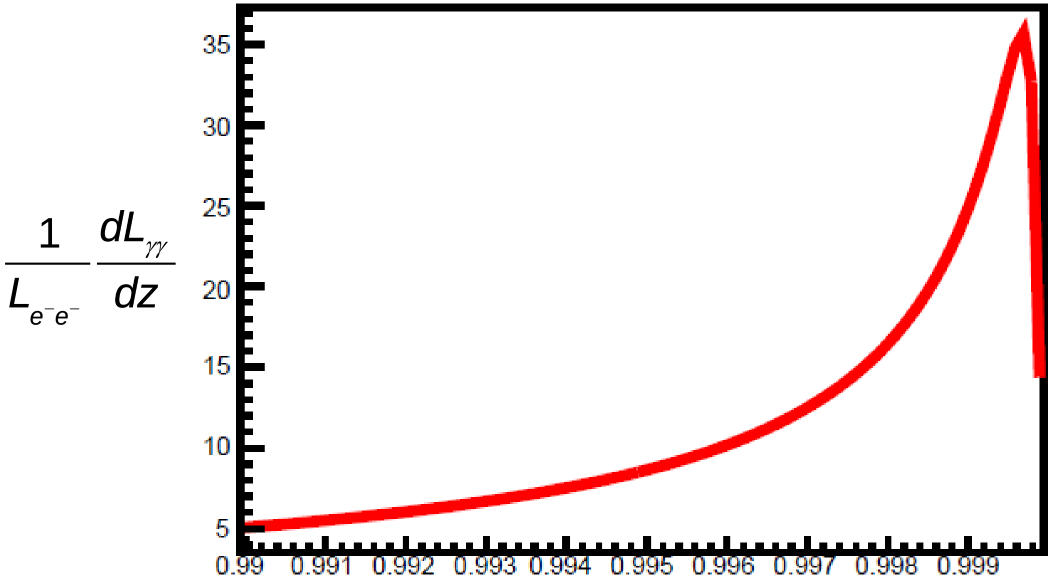
$x = 15870. \quad E_{e^-e^-} = 126$ GeV $\quad \kappa$=0.64

pol(e^-) = 90% $\quad 2P_c\lambda_e = +0.9$

$$\int dz \frac{1}{L_{e^-e^-}}\frac{dL_{\gamma\gamma}}{dz}\sigma(\gamma\gamma \to H) = 4792 \text{ fb}$$

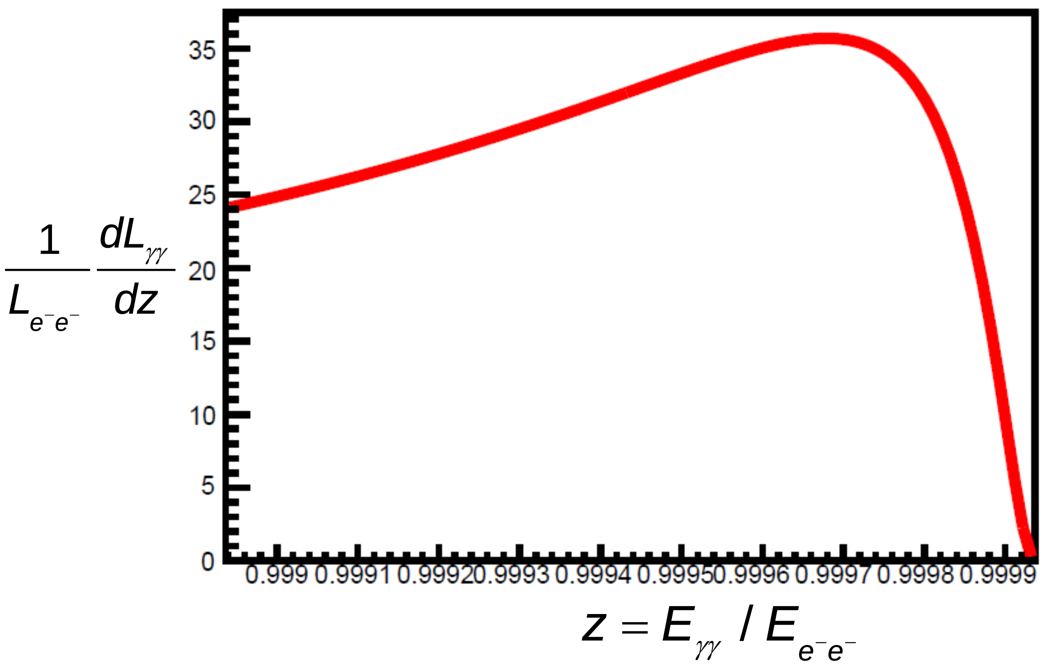


$2P_c\lambda_e = +0.9$ is a better match to $\Delta E_{beam} / E_{beam} \approx 0.1\%$ than $2P_c\lambda_e = -0.9$ for this large x value.



$x = 15870.$ $E_{e^-e^-} = 126$ GeV κ=0.64

pol(e^-) = 90% $2P_c\lambda_e = +0.9$



Laser Requirements for x=15870

$\lambda = 0.8 \times 10^{-10}$ m

$Z_R = 4.0\ \mu$m

$r_\gamma = 0.01\ \mu$m

$N\gamma$ per pulse = 2×10^{17}

Energy per pulse = 430 J

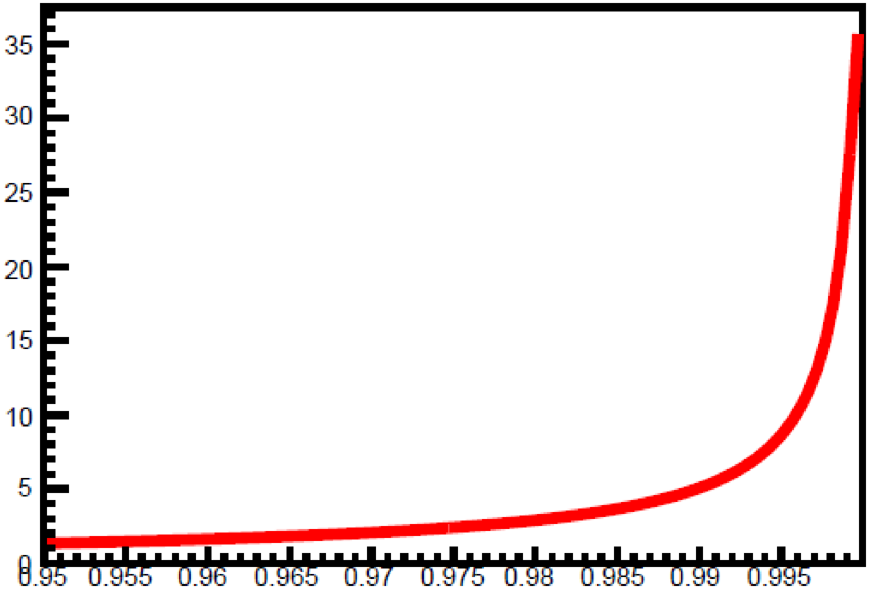
Assuming these can be achieved

and assuming ILC TDR geometric lumi for Ecm=200 GeV

is valid for Ecm=126 GeV, then we get

Higgs / year = 144,000

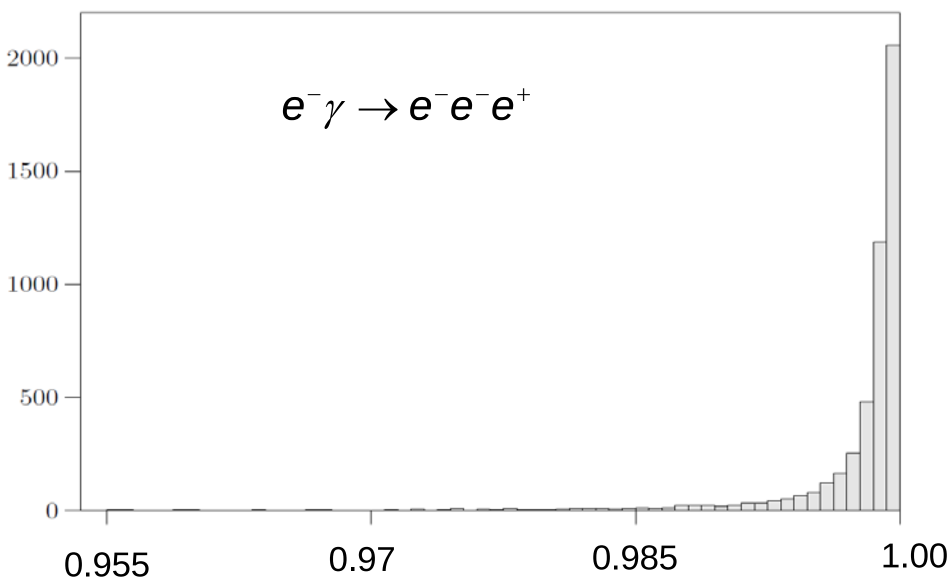
$$\frac{1}{L_{e^-e^-}} \frac{dL_{\gamma\gamma}}{dz}$$



$$z = E_{\gamma\gamma} / E_{e^-e^-}$$

$x = 15870.$ $E_{e^-e^-} = 126$ GeV κ=0.64

pol(e^-) = 90% $2P_c\lambda_e = +0.9$



E_{e^-} (final state)/E_{e^-} (initial)

Lab electron energy spectrum following single Bethe-Heitler interaction $e^-\gamma \to e^-e^-e^+$ for E_{e^-}(initial)=63 GeV, E_γ = 15 keV

Big problem:

$\sigma(e^-\gamma \to e^-e^-e^+) = 20 \times \sigma(e^-\gamma \to e^-\gamma)$

for E_{e^-}=63 GeV, E_γ = 15 keV

Summary

Existing compton collision parameters are optimal for a $\gamma\gamma$ Higgs factory unless you go to very large values of x where the lumi spectrum is sharply peaked and $\gamma\gamma \to e^{+}e^{-}$ is suppressed via polarization.

Assuming electron energy spread is dominated by accelerator energy spread, and disregarding the extreme laser technical challenges the optimal x value was x=16000 with $2P_c\lambda_e = +0.9$. The Higgs production rate in this configuration was 20 times the nominal $\gamma\gamma$ collider rate.

Unfortunately, the electron energy spread is not dominated by the accelerator but rather by the Bethe-Heitler process $e^{-}\gamma \to e^{-}e^{-}e^{+}$. This leads to $\approx$ 1% energy spread in the electron beam. It is unlikely therefore that very large x values can give enhanced Higgs production rates, even if the extreme laser technology challenges can be met.

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