Multi-TeV PWFA $\gamma\gamma$ Colliders

Beam-Beam and MDI Working Group Meeting

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Outline

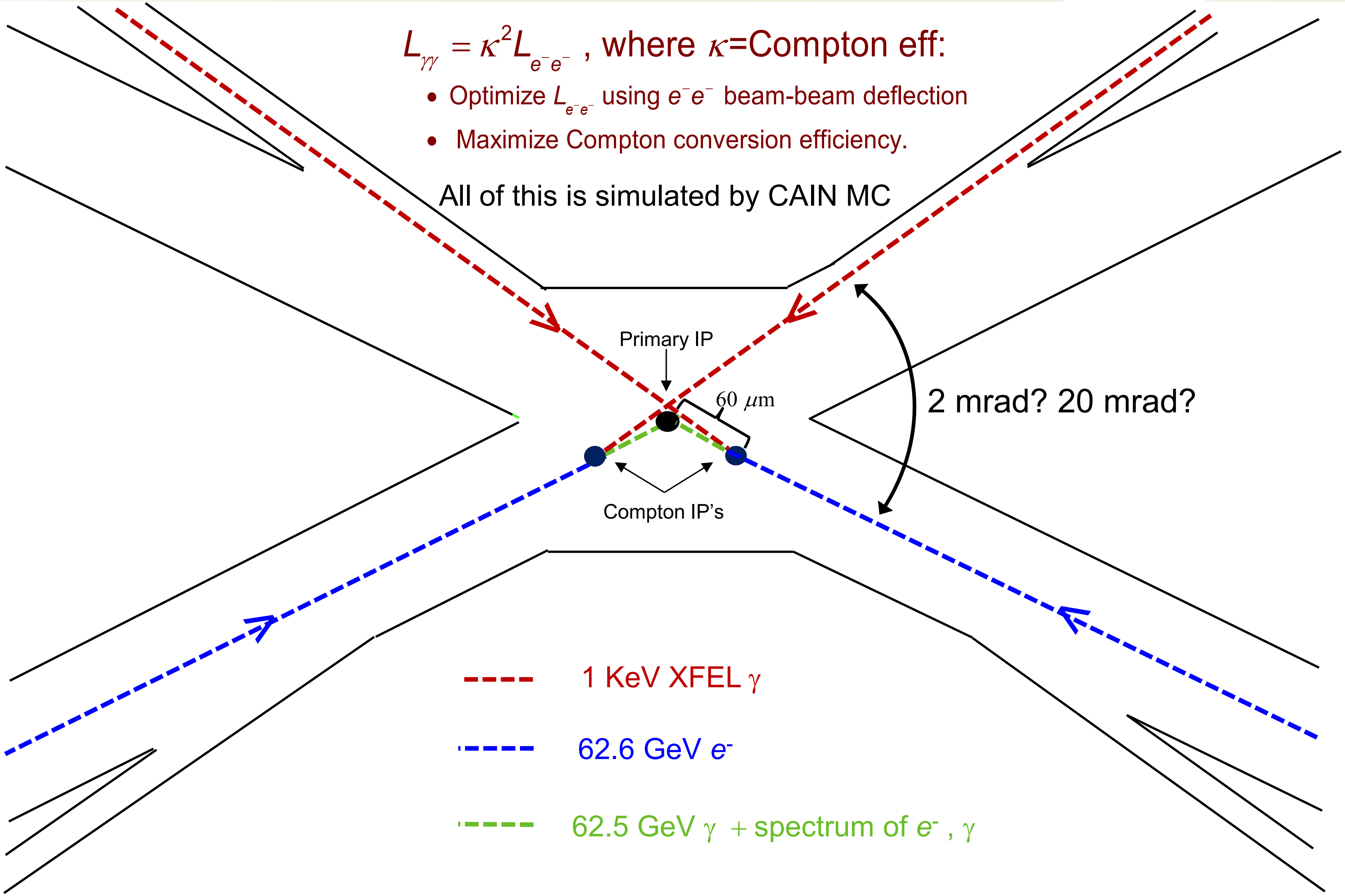
- Introduction to $\gamma\gamma$ Colliders
- $\gamma\gamma$ Collider Higgs Factories
- Multi-TeV $\gamma\gamma$ Colliders
- Future Work

XCC layout of 1 keV XFEL , 63 GeV e^- Beams near Interaction Point

$L_{\gamma\gamma} = \kappa^2 L_{e^-e^-}$, where κ=Compton eff:

- Optimize $L_{e^-e^-}$ using e^-e^- beam-beam deflection
- Maximize Compton conversion efficiency.

All of this is simulated by CAIN MC



Optical → X-ray Laser Produces Narrower $\gamma\gamma$ Luminosity Spectra

$x = \frac{4E_{e^-}\omega_0}{m_e^2}$ determines luminosity spectra

$\omega_0 =$ laser photon energy

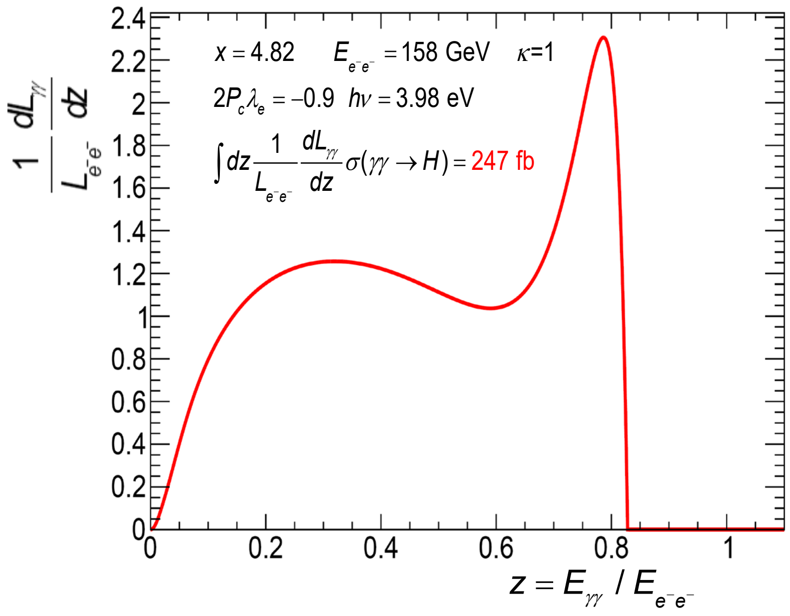
maximum Compton photon energy $\omega_m = \frac{x}{x+1}E_{e^-}$

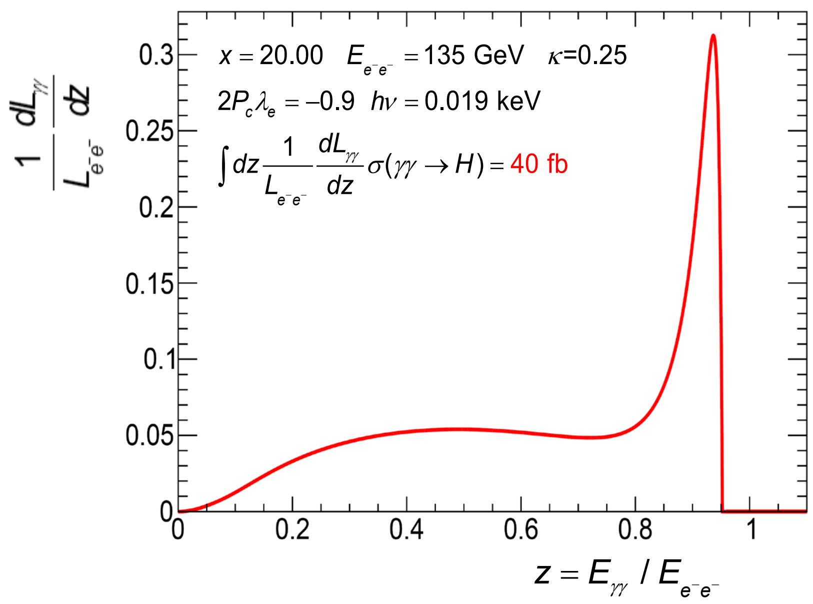
Important threshold in x:

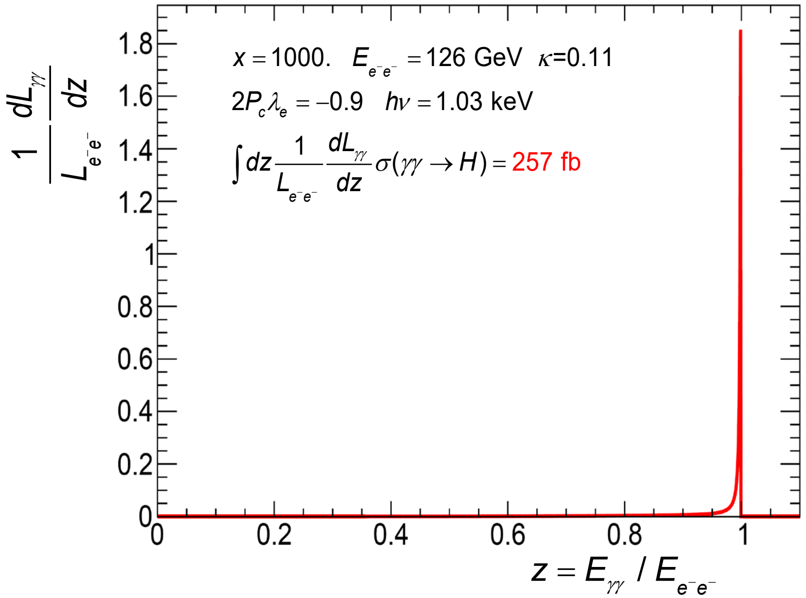
At $x = 4.82$ $\gamma\gamma_{\text{laser}} \to e^+e^-$ opens up which depletes the high energy photon beam.

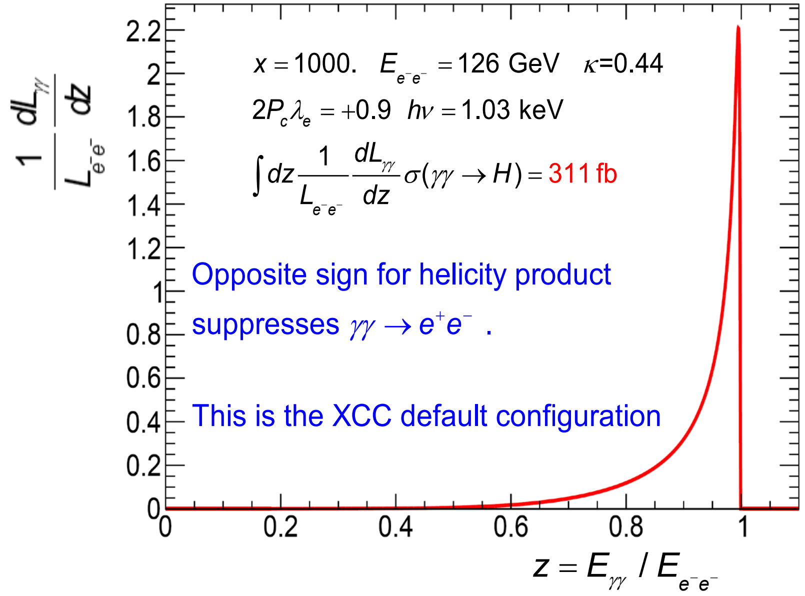
κ= 1 – prob that Compton γ annihilates with laser γ

$$\sigma(\gamma\gamma \to H) = \frac{8\pi\Gamma_{\gamma\gamma}\Gamma_{tot}}{(s-M_H^2)^2+\Gamma_{tot}^2M_H^2}(1+\xi_1\xi_2)$$
$$\approx \frac{4\pi^2\Gamma_{\gamma\gamma}}{M_H^3}(1+\xi_1\xi_2)z_H\delta(z-z_H)$$









Opposite sign for helicity product suppresses $\gamma\gamma \to e^+e^-$.

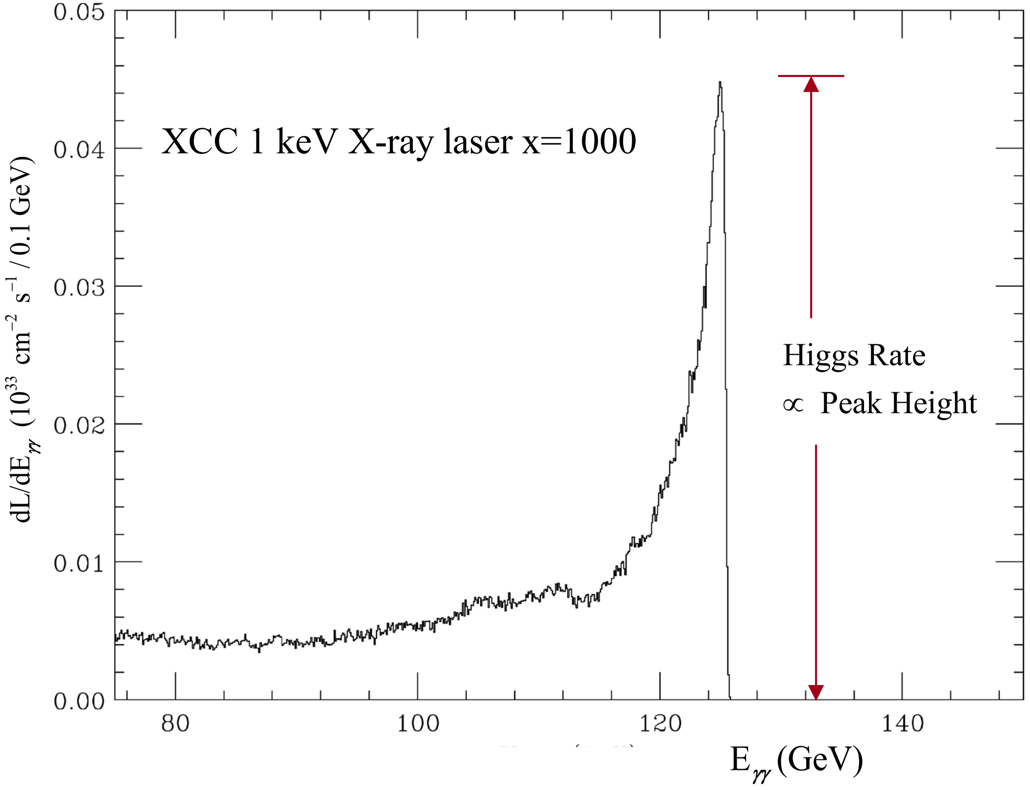
This is the XCC default configuration

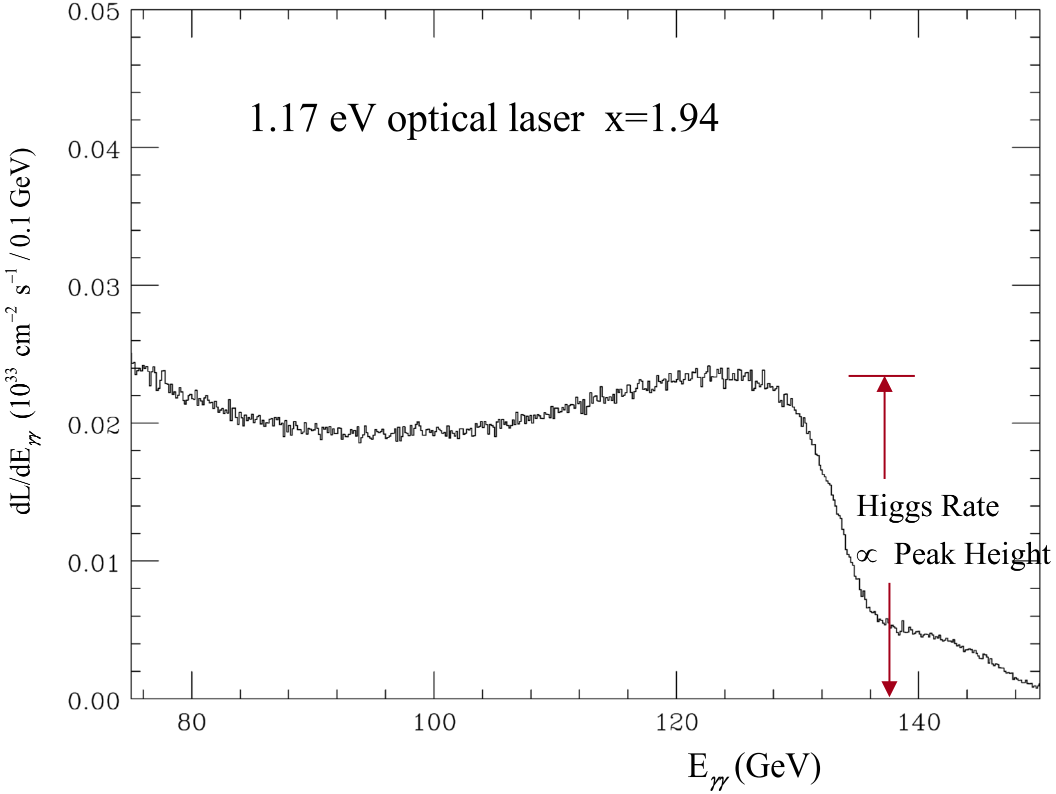
X-ray vs. Optical Laser $\gamma\gamma$ Higgs Factories

job	Laser E_γ (eV)	$\sqrt{s_{ee}}$ (GeV)	w_{max} (GeV)	N_{bunch} / train	Rep Rate (Hz)	$L_{\gamma\gamma}$ $(cm^{-2}s^{-1})$	$N_H/1.0\times10^7s$	$N_{bb}^{(1)}/1.0\times10^7s$	$N_{bb}^{(1)}/N_H$	$\langle\mu\rangle$
v06972	1.17	216.00	218.16	2820	5	3.618×10^{34}	25,000	64,390	2.58	0.90
v06980	1.04×10^3	125.72	126.97	165	120	3.570×10^{34}	72,200	58,220 $^{(2)}$	0.81	0.63

$^{(1)}M_{bb} > 100$ GeV , $|\beta_z| < 0.1$

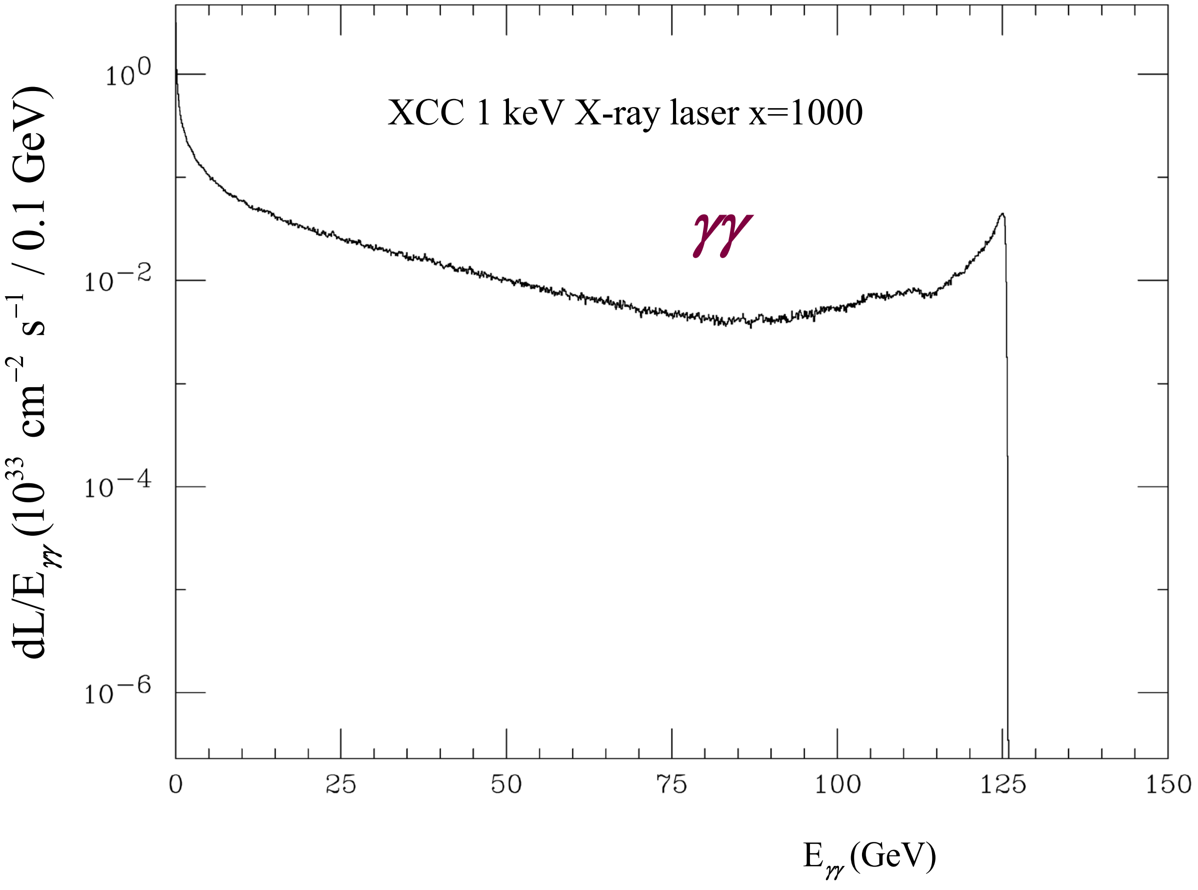
$^{(2)}$15,800 from $e^+e^- \to b\bar{b}$

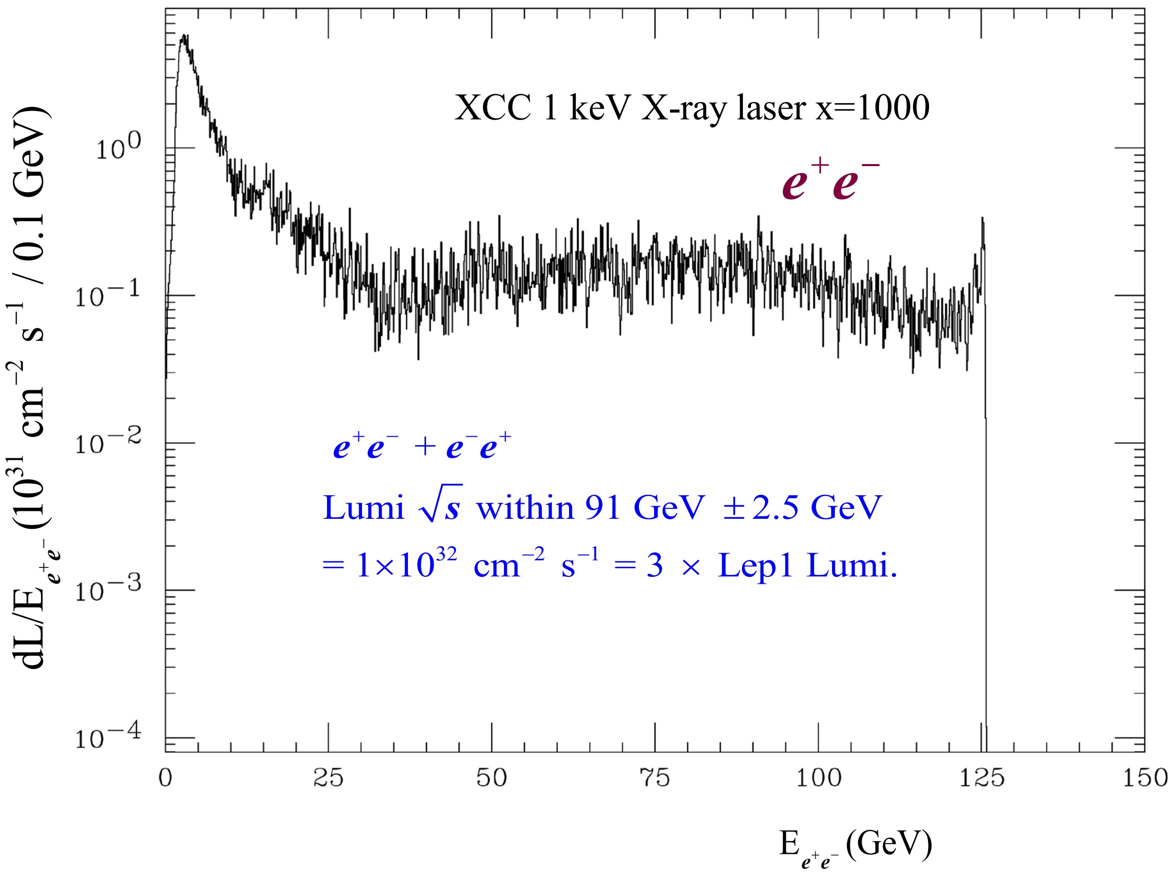




$\gamma\gamma$ and e^+e^- Luminosity at X-ray Higgs Factories

Note factor of 100 vertical scale difference





$e^+e^- + e^-e^+$

Lumi $\sqrt{s}$ within 91 GeV ± 2.5 GeV

$= 1\times10^{32}$ cm^{-2} s^{-1} $= 3 \times$ Lep1 Lumi.

Simulation of 15 TeV $\gamma\gamma$ Collider

Replace 62.5 GeV C^3 e- beam w/ 7500 GeV PWFA e- beam and simulate $\gamma\gamma$ Collisions using CAIN MC

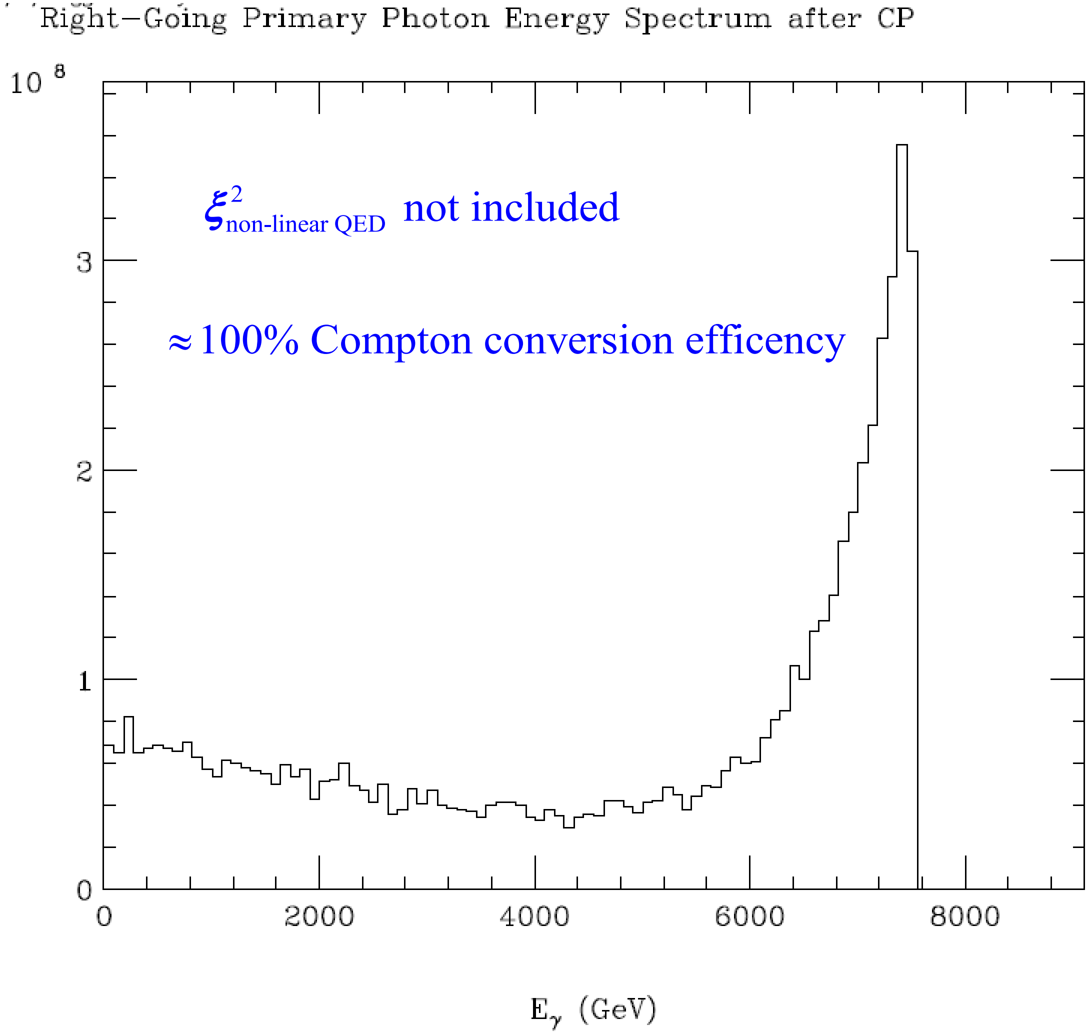
Technology	PWFA	$\gamma\gamma$ PWFA
Aspect Ratio	Round	Round
CM Energy	15	15
Single beam energy (TeV)	7.5	7.5
Gamma	1.47E+07	1.4E+07
Emittance X (mm mrad)	0.1	0.12
Emittance Y (mm mrad)	0.1	0.12
Beta* X (m)	1.50E-04	0.30E-04
Beta* Y (m)	1.50E-04	0.30E-04
Sigma* X (nm)	1.01	0.48
Sigma* Y (nm)	1.01	0.48
N_bunch (num)	5.00E+09	6.2E+09 (or 5.00E+09)
Freq (Hz)	7725	7725
Sigma Z (um)	5	5
Geometric Lumi (cm-2 s-1)	1.50E+36	6.58E+36

Start with x=4.8 because this was considered the typical $\gamma\gamma$ collider x value before this study was performed

x=4.8 adjust parameters to get ~ 100 % conversion w/ linear QED

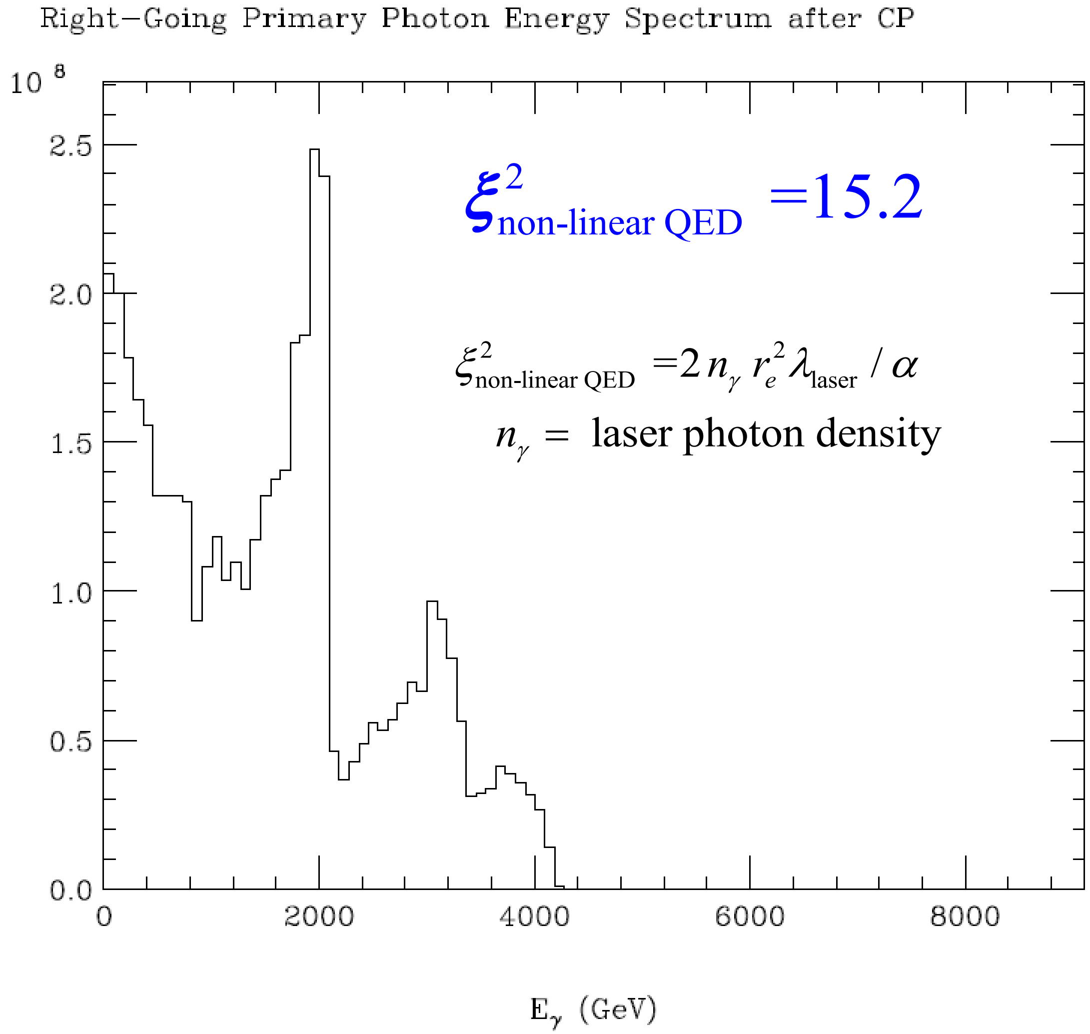
$x = 4.8 \Rightarrow 9100$ GeV $e^- + 0.034$ eV γ (λ=36 μm) $a_{\gamma FWHM} = 2.1$ mm $\sigma_{\gamma z} = 0.79$ mm $d_{cp} = 2.4$ mm

$\sigma_{ez} = 5\ \mu$m $N_{e^-} = 1$ nC $\gamma\varepsilon_{x,y} = 120$ nm $2P_c\lambda_e = -0.9$ $E_{pulse} = 4400$ J


Right−Going Primary Photon Energy Spectrum after CP

$\xi^2_{\text{non-linear QED}}$ not included

$\approx$100% Compton conversion efficency


Right−Going Primary Photon Energy Spectrum after CP

$\xi^2_{\text{non-linear QED}} = 15.2$

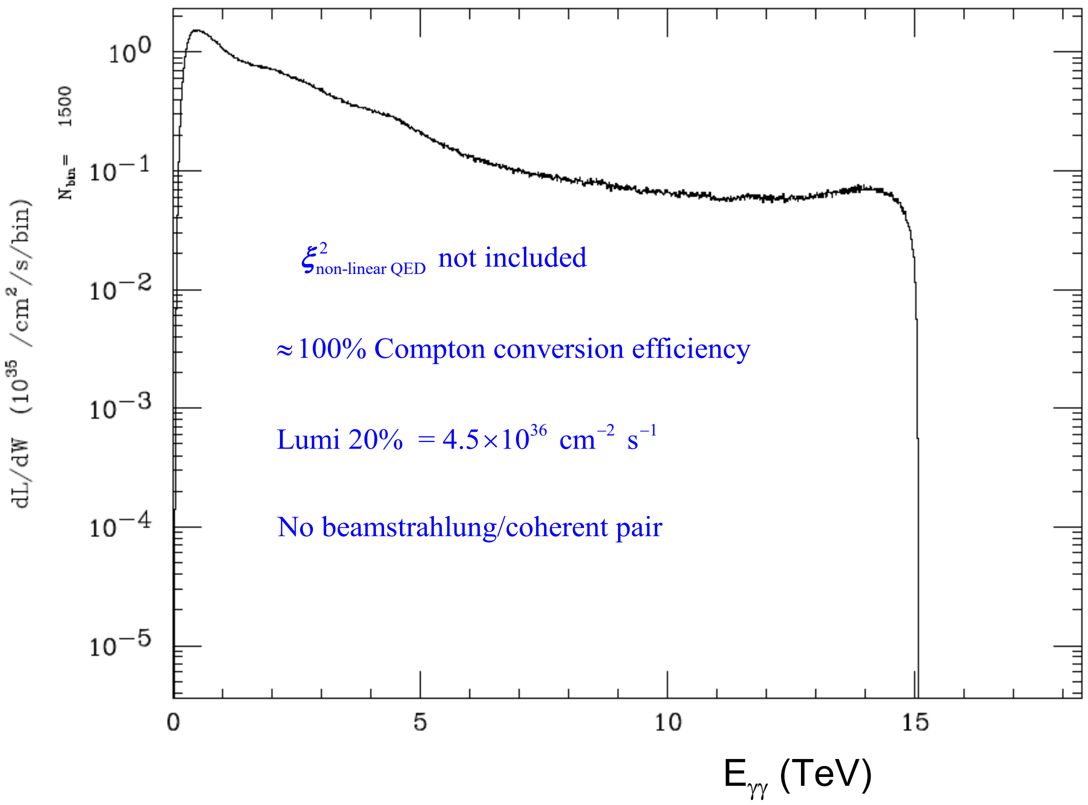
$\xi^2_{\text{non-linear QED}} = 2 n_\gamma r_e^2 \lambda_{\text{laser}} / \alpha$

n_γ = laser photon density

x=4.8 , parameters with ~ 100 % conversion w/ linear QED

$\boldsymbol{x} = 4.8 \;\Rightarrow\; 9100\ \text{GeV}\ \boldsymbol{e}^{-} + 0.034\ \text{eV}\ \boldsymbol{\gamma}\quad (\boldsymbol{\lambda}=36\ \boldsymbol{\mu}\text{m})\quad \boldsymbol{a}_{\gamma FWHM} = 2.1\ \text{mm}\quad \boldsymbol{\sigma}_{\gamma z} = 0.79\ \text{mm}\quad \text{d}_{\text{cp}} = 2.4\ \text{mm}$

$\boldsymbol{\sigma}_{e z} = 5\ \boldsymbol{\mu}\text{m}\quad \text{N}_{e^-} = 1\ \text{nC}\quad \gamma\boldsymbol{\varepsilon}_{x,y} = 120\ \text{nm}\quad 2\boldsymbol{P}_c\boldsymbol{\lambda}_e = -0.9\qquad \text{E}_{\text{pulse}} = 4400\ \text{J}$

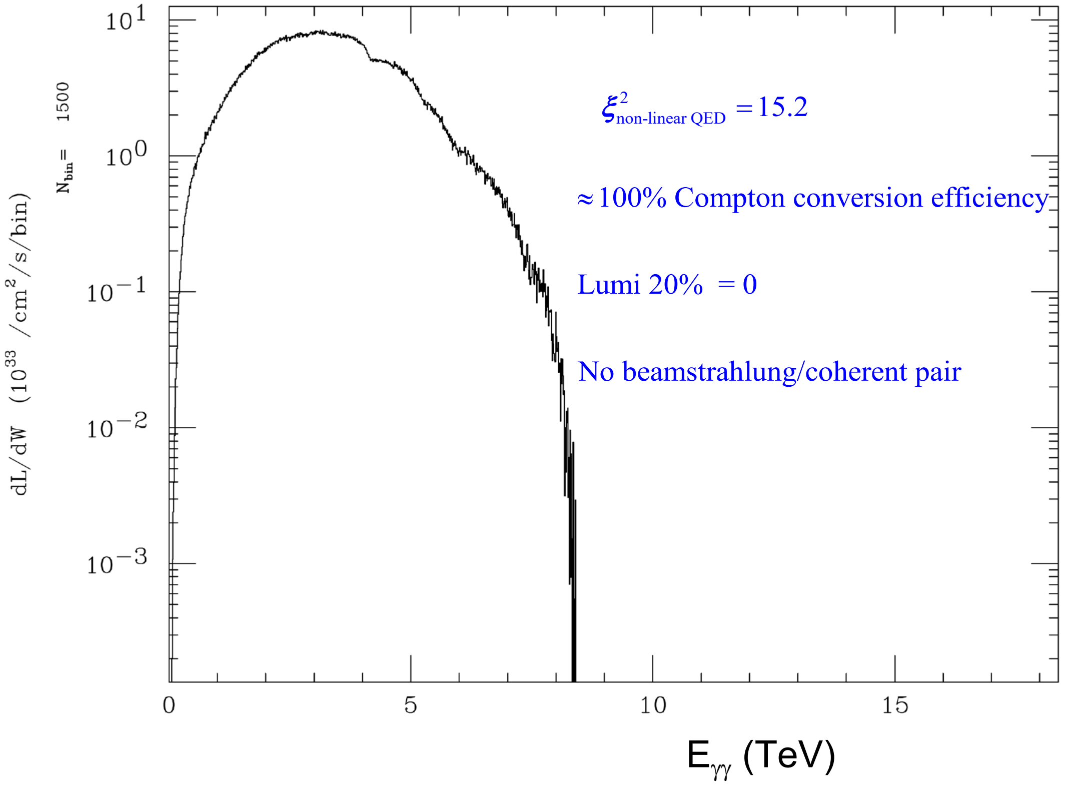


$\xi^2_{\text{non-linear QED}}$ not included

≈100% Compton conversion efficiency

Lumi 20% $= 4.5\times10^{36}\ \text{cm}^{-2}\ \text{s}^{-1}$

No beamstrahlung/coherent pair



$\xi^2_{\text{non-linear QED}} = 15.2$

≈100% Compton conversion efficiency

Lumi 20% = 0

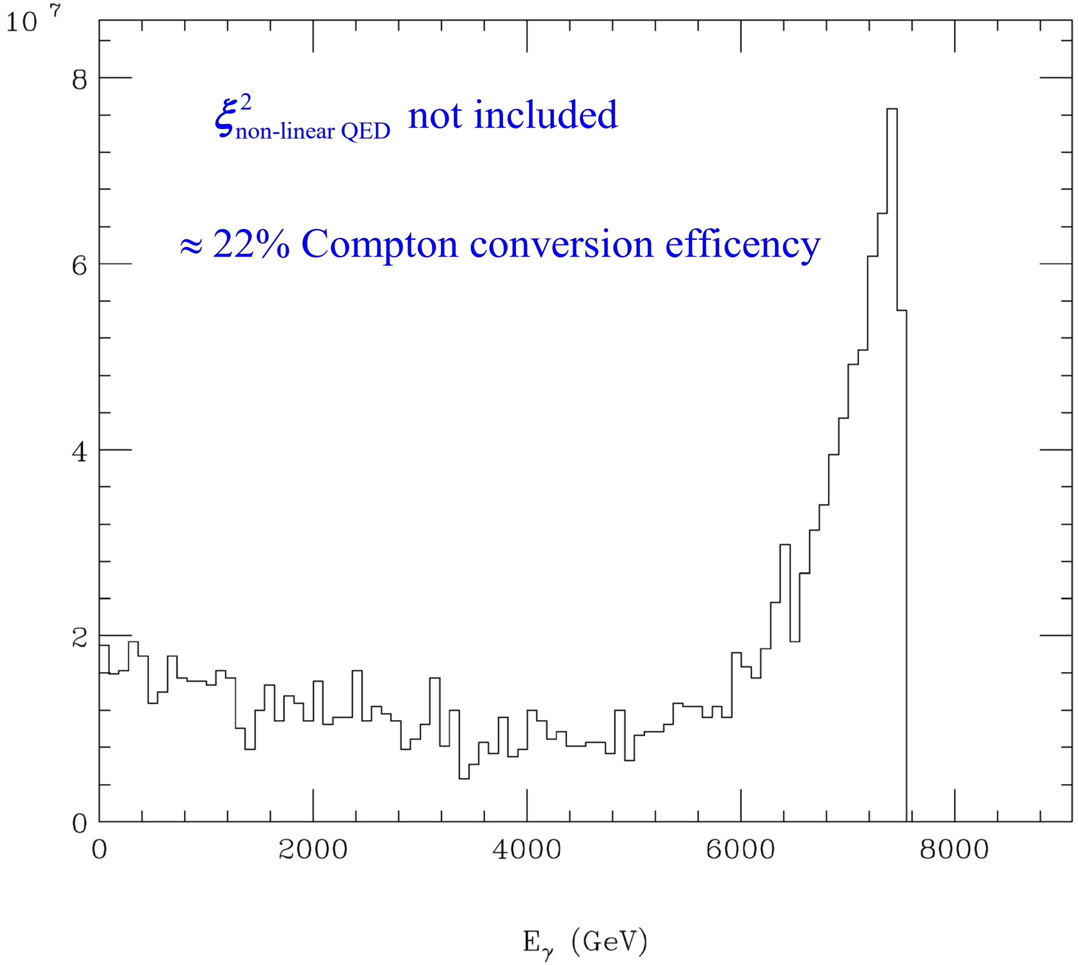
No beamstrahlung/coherent pair

x=4.8 dial back E_{pulse} to get $\xi^2 < 1$

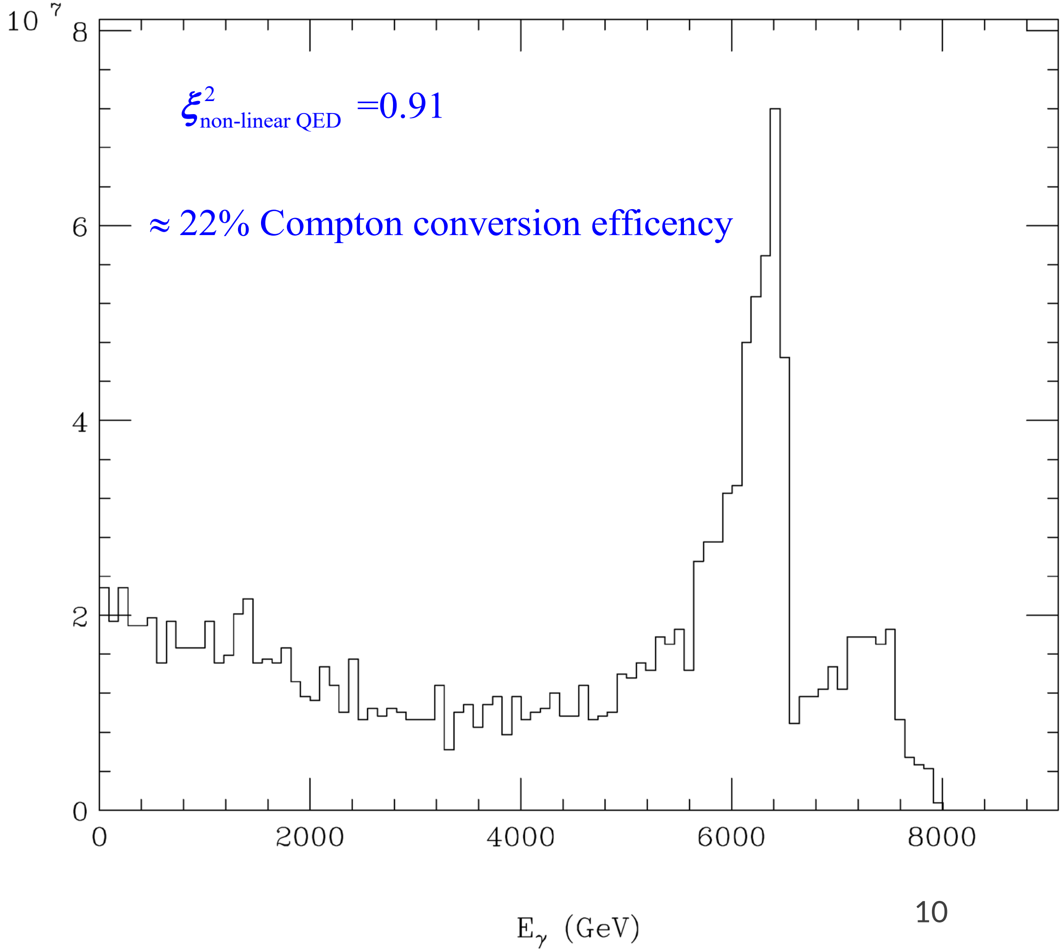
$x = 4.8 \Rightarrow$ 9100 GeV $e^- +$ 0.034 eV γ (λ=36 μm) $a_{\gamma FWHM} = 2.1$ mm $\sigma_{\gamma z} = 0.79$ mm $d_{cp} = 2.4$ mm

$\sigma_{ez} = 5\ \mu$m N_{e^-} =1 nC $\gamma\varepsilon_{x,y} = 120$ nm $2P_c\lambda_e = -0.9$ $E_{pulse} = 260$ J

Right−Going Primary Photon Energy Spectrum after CP



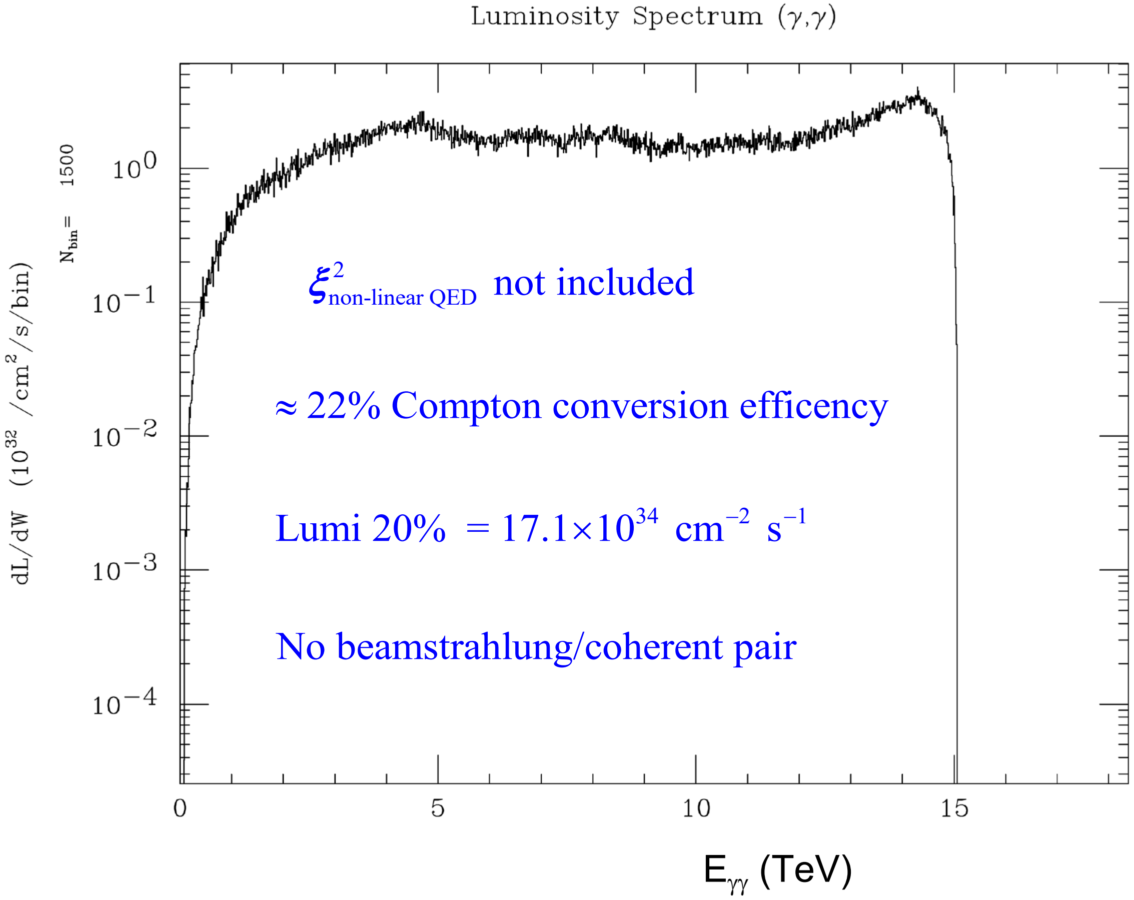
Right−Going Primary Photon Energy Spectrum after CP



x=4.8 dial back E_{pulse} to get $\xi^2 < 1$

$\boldsymbol{x} = 4.8 \;\Rightarrow\; 9100\text{ GeV } \boldsymbol{e}^- + 0.034\text{ eV } \boldsymbol{\gamma} \;\; (\boldsymbol{\lambda}{=}36\;\boldsymbol{\mu}\text{m}) \quad \boldsymbol{a}_{\gamma FWHM} = 2.1\text{ mm} \quad \boldsymbol{\sigma}_{\gamma z} = 0.79\text{ mm} \quad \text{d}_{\text{cp}} = 2.4\text{ mm}$

$\boldsymbol{\sigma}_{ez} = 5\;\boldsymbol{\mu}\text{m} \quad \text{N}_{e^-} = 1\text{ nC} \quad \boldsymbol{\gamma\varepsilon}_{x,y} = 120\text{ nm} \quad 2\boldsymbol{P}_c\boldsymbol{\lambda}_e = -0.9 \qquad \text{E}_{\text{pulse}} = 260\text{ J}$

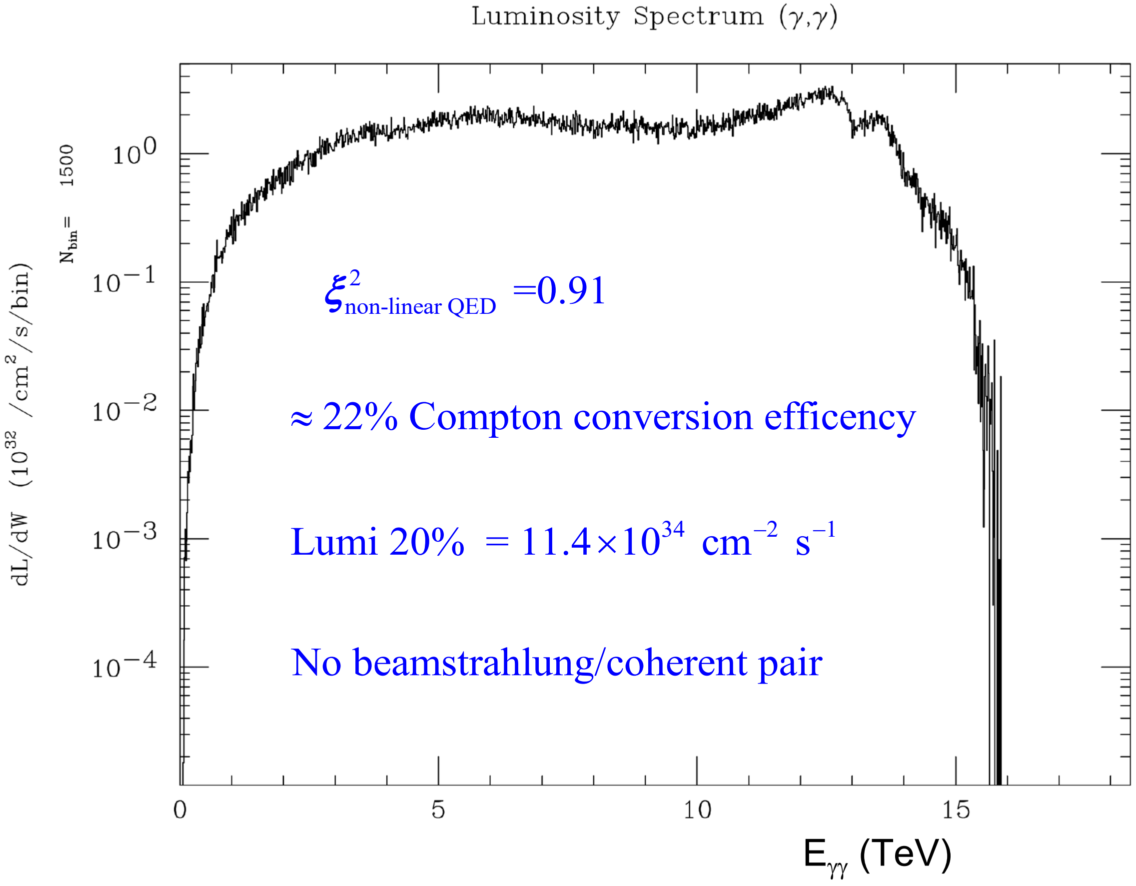


$\xi^2_{\text{non-linear QED}}$ not included

≈ 22% Compton conversion efficency

Lumi 20% $= 17.1\times10^{34}\text{ cm}^{-2}\text{ s}^{-1}$

No beamstrahlung/coherent pair



$\xi^2_{\text{non-linear QED}} = 0.91$

≈ 22% Compton conversion efficency

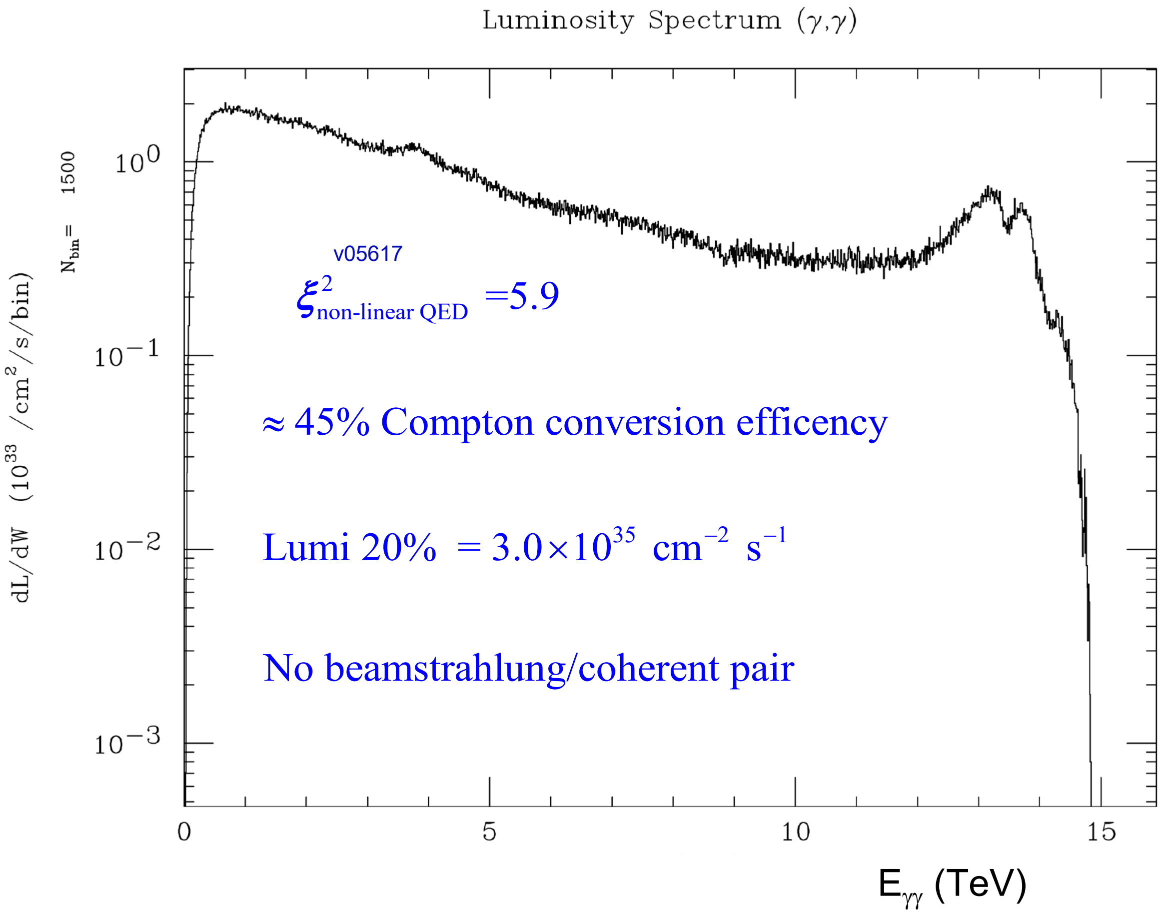
Lumi 20% $= 11.4\times10^{34}\text{ cm}^{-2}\text{ s}^{-1}$

No beamstrahlung/coherent pair

x=40 use spreadsheet bunch charge of N_e=5x10^9

$\boldsymbol{x} = 40 \;\Rightarrow\; 7875\ \text{GeV}\ \boldsymbol{e}^- + 0.33\ \text{eV}\ \boldsymbol{\gamma}\quad (\lambda=3.7\ \mu\text{m})\quad \boldsymbol{a}_{\gamma FWHM} = 0.24\ \text{mm}\quad \boldsymbol{\sigma}_{\gamma z} = 270\ \mu\text{m}\quad \text{d}_{\text{cp}} = 0.82\text{mm}$

$\boldsymbol{\sigma}_{ez} = 5\ \mu\text{m}\quad \text{N}_{e^-} = 5\times 10^9\quad \gamma\varepsilon_{x,y} = 120\ \text{nm}\quad 2P_c\lambda_e = -0.9\quad \text{E}_{\text{pulse}} = 590\ \text{J}$



$\xi^2_{\text{non-linear QED}} = 5.9$

≈ 45% Compton conversion efficency

Lumi 20% $= 3.0\times 10^{35}\ \text{cm}^{-2}\ \text{s}^{-1}$

No beamstrahlung/coherent pair

15 TeV and x=40 Turn on coherent processes

$\boldsymbol{x} = 40 \;\Rightarrow\; 7875\ \text{GeV}\ \boldsymbol{e}^- + 0.33\ \text{eV}\ \boldsymbol{\gamma}\quad (\boldsymbol{\lambda}{=}3.7\ \boldsymbol{\mu}\text{m})\quad \boldsymbol{a}_{\gamma FWHM} = 0.24\ \text{mm}\quad \boldsymbol{\sigma}_{\gamma z} = 270\ \boldsymbol{\mu}\text{m}\quad \text{d}_{\text{cp}} = 0.82\text{mm}$

$\boldsymbol{\sigma}_{ez} = 5\ \boldsymbol{\mu}\text{m}\quad \text{N}_{e^-} = 5\times10^9\quad \boldsymbol{\gamma\varepsilon}_{x,y} = 120\ \text{nm}\quad 2\boldsymbol{P}_c\boldsymbol{\lambda}_e = -0.9\quad \text{E}_{\text{pulse}} = 590\ \text{J}$

Halfway through the collision CAIN complains:

```
(SUBR.COHPAR) Algorithm of coherent pair generation wrong.
   Call the programmer prob,pmaxco=   8.309E-01  8.000E-01
```

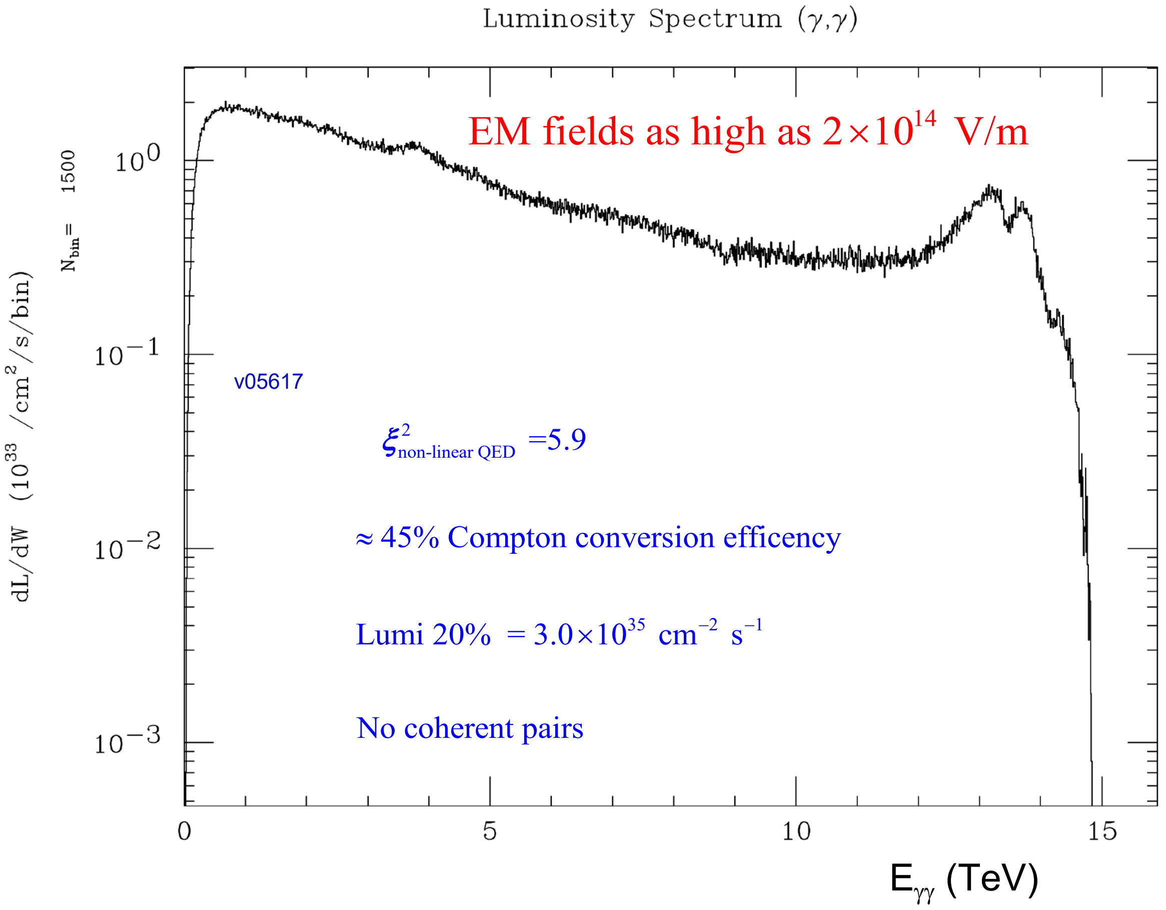
Solution:

number of macro particles produced per coherent beamstrahlung photon = 1 → 0.01
number of pairs of macro particles produced per coherent e+e- pair = 1 → 0.0001
number of macro particles produced per incoherent particle = 1 → 0.01

15 TeV and x=40 Turn on coherent processes

$x = 40 \;\Rightarrow\; 7875\ \text{GeV}\ e^- + 0.33\ \text{eV}\ \gamma \quad (\lambda = 3.7\ \mu\text{m}) \quad a_{\gamma FWHM} = 0.24\ \text{mm} \quad \sigma_{\gamma z} = 270\ \mu\text{m} \quad d_{cp} = 0.82\text{mm}$

$\sigma_{ez} = 5\ \mu\text{m} \quad N_{e^-} = 5\times10^9 \quad \gamma\varepsilon_{x,y} = 120\ \text{nm} \quad 2P_c\lambda_e = -0.9 \quad E_{pulse} = 590\ \text{J}$



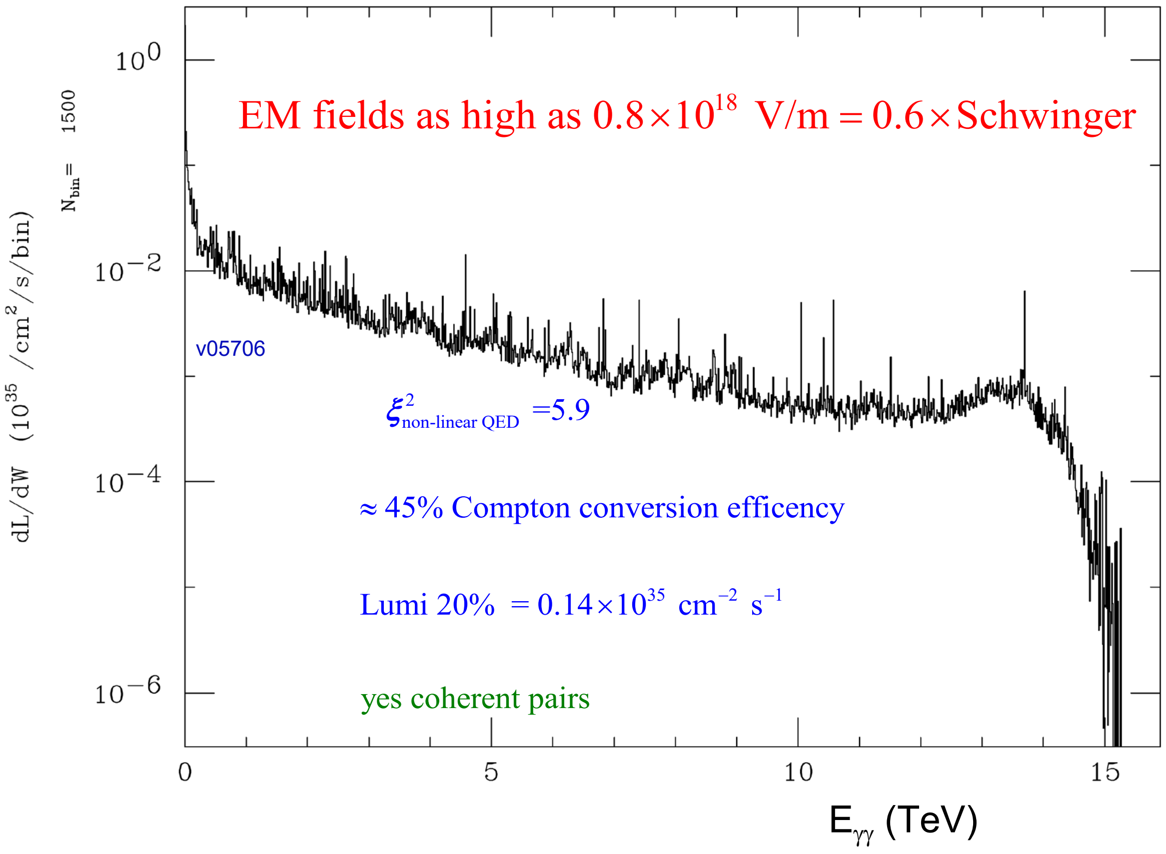
EM fields as high as 2×10^{14} V/m

$\xi^2_{\text{non-linear QED}} = 5.9$

≈ 45% Compton conversion efficency

Lumi 20% $= 3.0\times10^{35}\ \text{cm}^{-2}\ \text{s}^{-1}$

No coherent pairs



EM fields as high as 0.8×10^{18} V/m = 0.6×Schwinger

$\xi^2_{\text{non-linear QED}} = 5.9$

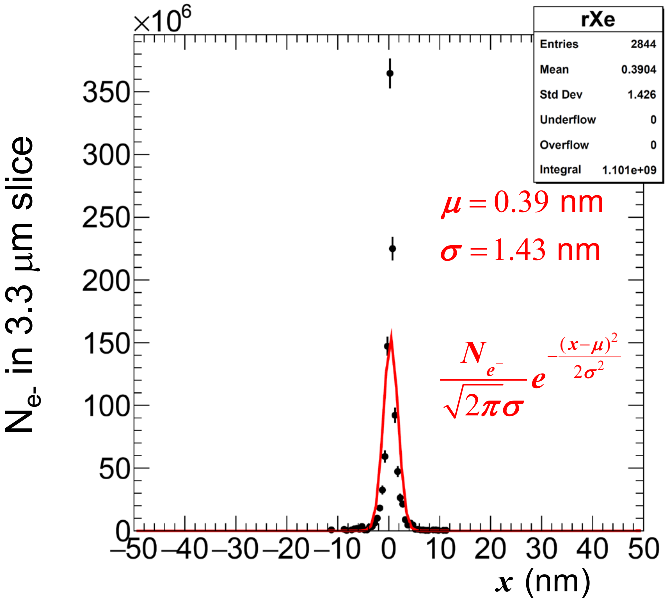
≈ 45% Compton conversion efficency

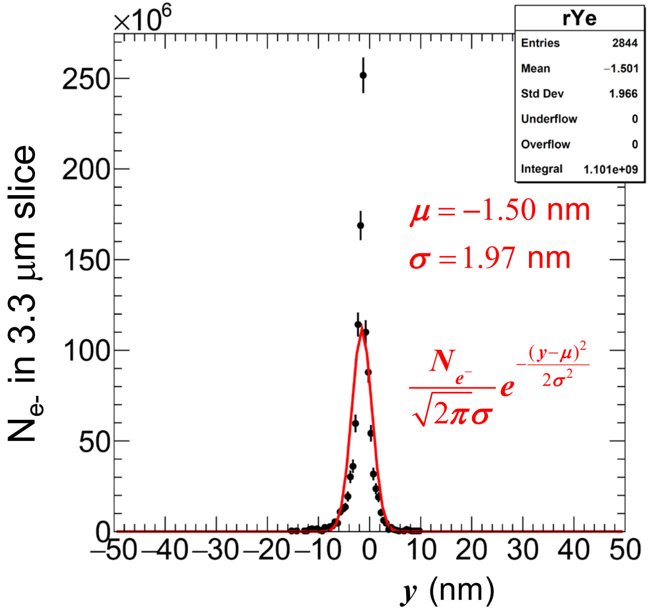
Lumi 20% $= 0.14\times10^{35}\ \text{cm}^{-2}\ \text{s}^{-1}$

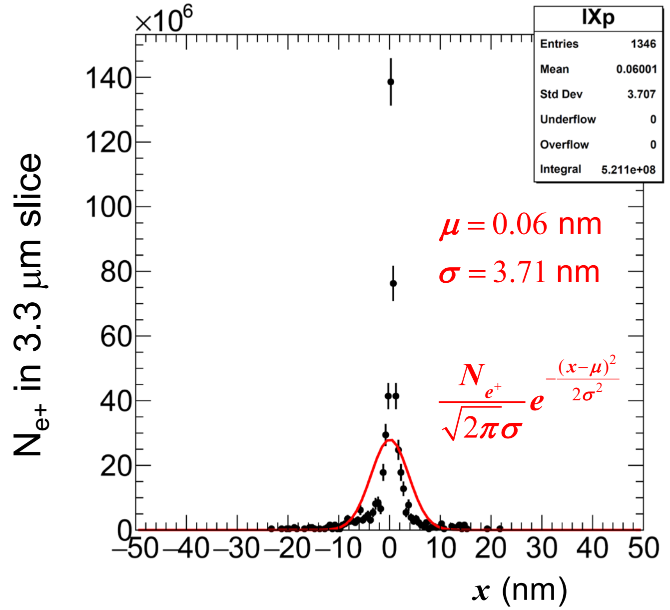
yes coherent pairs

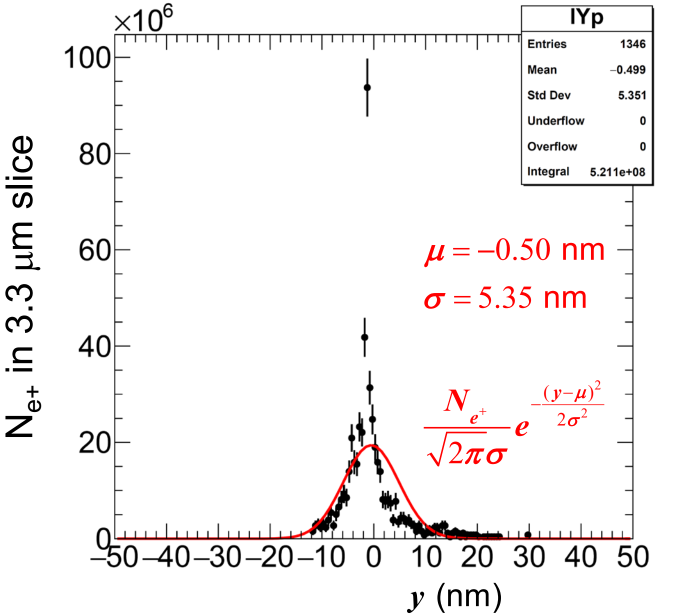
Coherent pair production eats up the 7.5 TeV photons and produces many e+ that pinch the e- beam leading to higher fields and even more coherent pair production.

$e^- \gamma$ collisions at $E_{e\gamma}$=140 GeV   I.P. geometric e^- σ_x,σ_y=5.1 nm









During the collision, the e^+ from coherent e^+e^- production are focused by the EM field of the oncoming e^- beam. This leads to focusing (pinching) of the e^- beam.

This pinching creates very high fields which leads to even more coherent pair production and even higher fields.

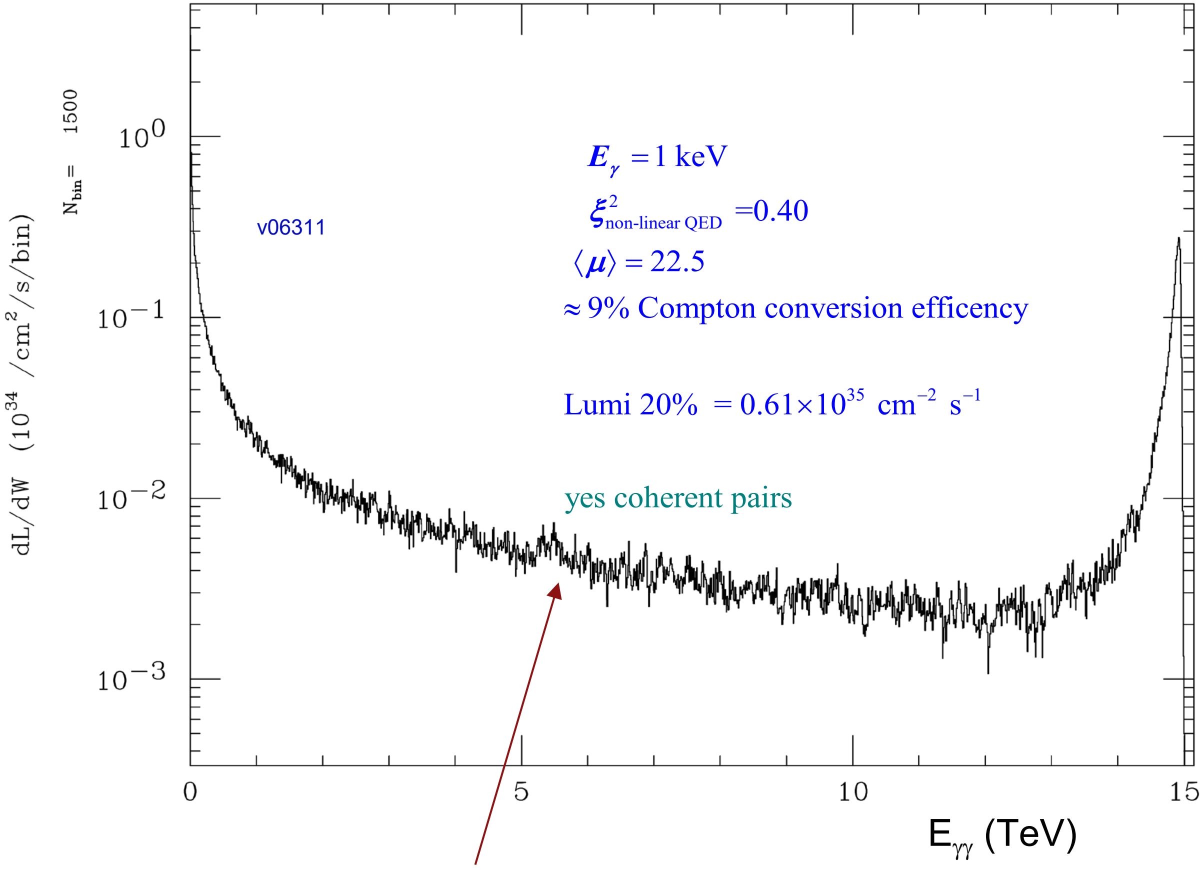
x=1.2x10^5 (1 keV γ) not affected as much by coherent processes

$\boldsymbol{x} = 1.2\times10^5 \;\Rightarrow\; 7500\ \mathrm{GeV}\ \boldsymbol{e}^- + 1\ \mathrm{keV}\ \boldsymbol{\gamma}\quad (\boldsymbol{\lambda}{=}1.2\ \mathrm{nm})$

$\boldsymbol{a}_{\gamma FWHM} = 70\ \mathrm{mm}\quad \boldsymbol{\sigma}_{\gamma z} = 5\ \boldsymbol{\mu}\mathrm{m}\quad \mathrm{d}_{cp} = 15\ \boldsymbol{\mu}\mathrm{m}$

$\boldsymbol{\sigma}_{ez} = 5\ \boldsymbol{\mu}\mathrm{m}\quad \mathrm{N}_{e^-} = 6\times10^9\quad \gamma\boldsymbol{\varepsilon}_{x,y} = 120\ \mathrm{nm}$

$2\boldsymbol{P}_c\boldsymbol{\lambda}_e = +0.9\qquad \mathrm{E}_{\mathrm{pulse}} = 0.72\ \mathrm{J}$

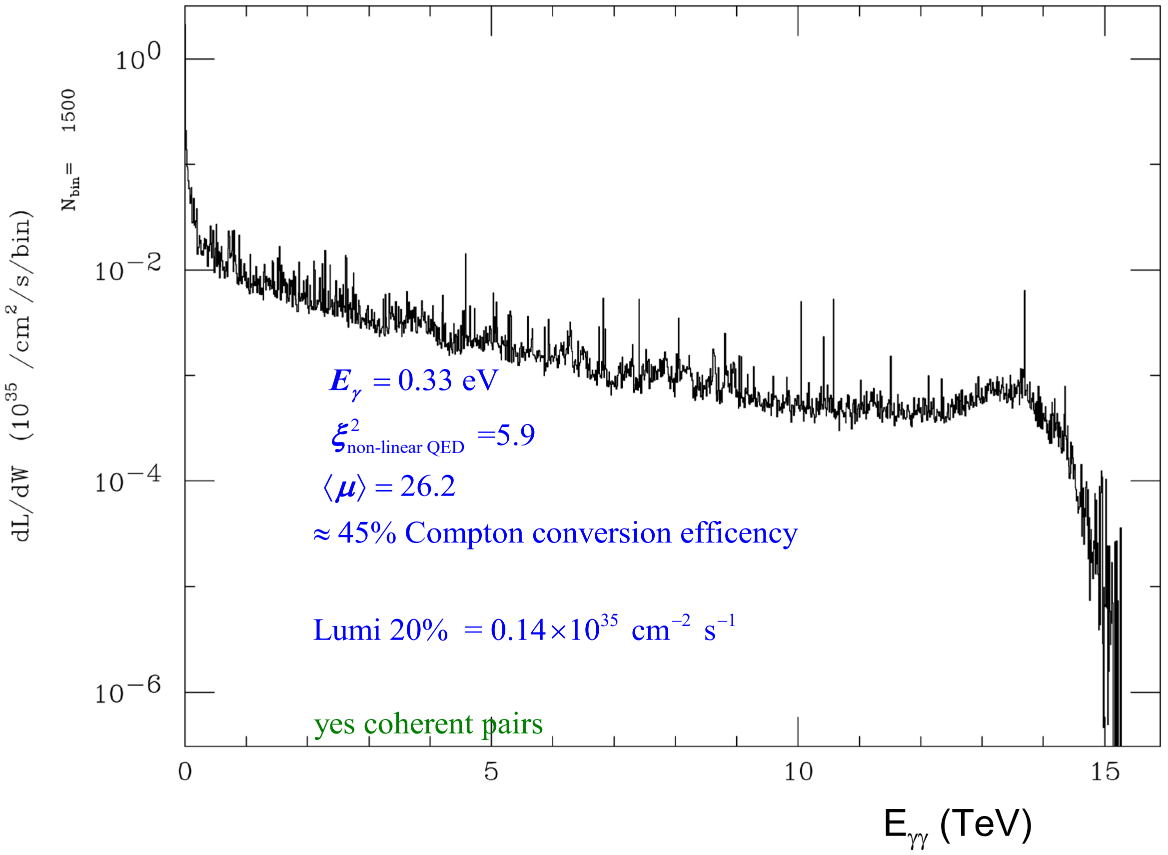


$\boldsymbol{x} = 40 \;\Rightarrow\; 7875\ \mathrm{GeV}\ \boldsymbol{e}^- + 0.33\ \mathrm{eV}\ \boldsymbol{\gamma}\quad (\boldsymbol{\lambda}{=}3.7\ \boldsymbol{\mu}\mathrm{m})$

$\boldsymbol{a}_{\gamma FWHM} = 0.24\ \mathrm{mm}\quad \boldsymbol{\sigma}_{\gamma z} = 270\ \boldsymbol{\mu}\mathrm{m}\quad \mathrm{d}_{cp} = 0.82\mathrm{mm}$

$\boldsymbol{\sigma}_{ez} = 5\ \boldsymbol{\mu}\mathrm{m}\quad \mathrm{N}_{e^-} = 5\times10^9\quad \gamma\boldsymbol{\varepsilon}_{x,y} = 120\ \mathrm{nm}$

$2\boldsymbol{P}_c\boldsymbol{\lambda}_e = -0.9\qquad \mathrm{E}_{\mathrm{pulse}} = 590\ \mathrm{J}$

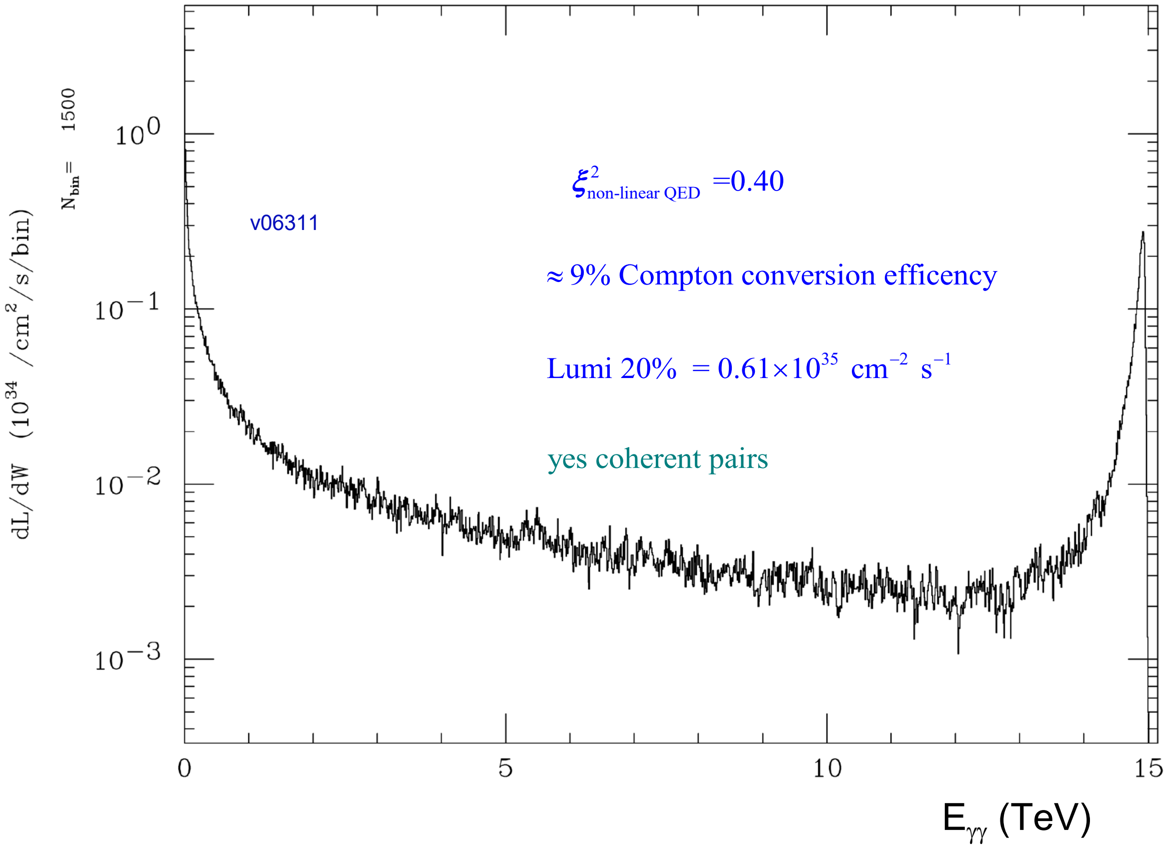


e^- from Compton IP have much reduced energy due to multiple trident $e^-\gamma \rightarrow e^-e^+e^-$. EM fields are 3 orders of magnitude smaller.

$\gamma\gamma \to N\times e^+e^-$, $e^-\gamma \to e^- + N\times e^+e^-$, $N = 2,3,\ \ldots$

$x = 1.2\times10^5 \Rightarrow$ 7500 GeV e^- + 1 keV γ (λ=1.2 nm) $a_{\gamma FWHM} = 70$ mm $\sigma_{\gamma z} = 5\ \mu$m $\mathrm{d_{cp}} = 15\ \mu$m

$\sigma_{ez} = 5\ \mu$m $\mathrm{N}_{e^-} = 1$ nC $\gamma\varepsilon_{x,y} = 120$ nm $2P_c\lambda_e = +0.9$ $\mathrm{E_{pulse}} = 0.72$ J



$\gamma\gamma \to N\times e^+e^-$, $e^-\gamma \to e^- + N\times e^+e^-$, $N = 2,3,\ \ldots$ are not simulated by CAIN.

$N \geq 2$ cross sections relatively small for $x \leq 1000$, but what about at $x \sim 10^5$?

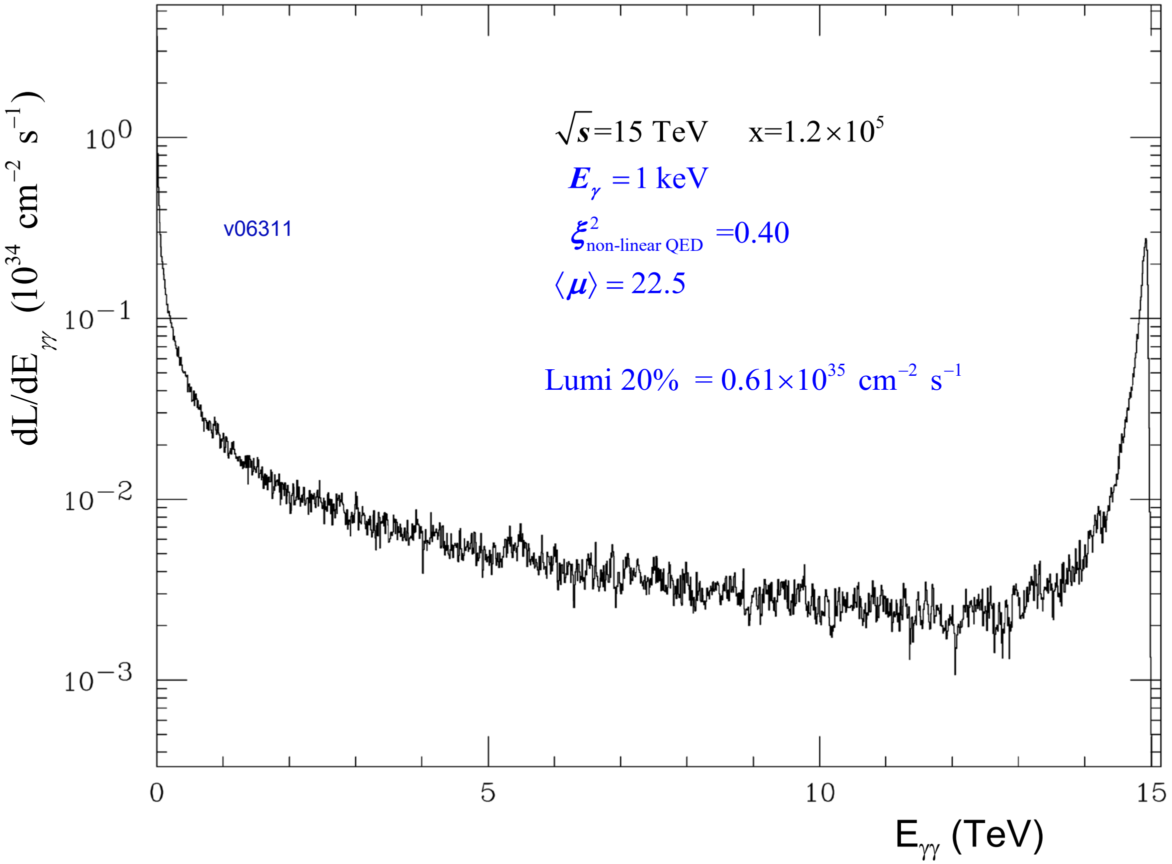
Cross section Table for 1 keV laser γ calculated using Tree-level MC Integration:

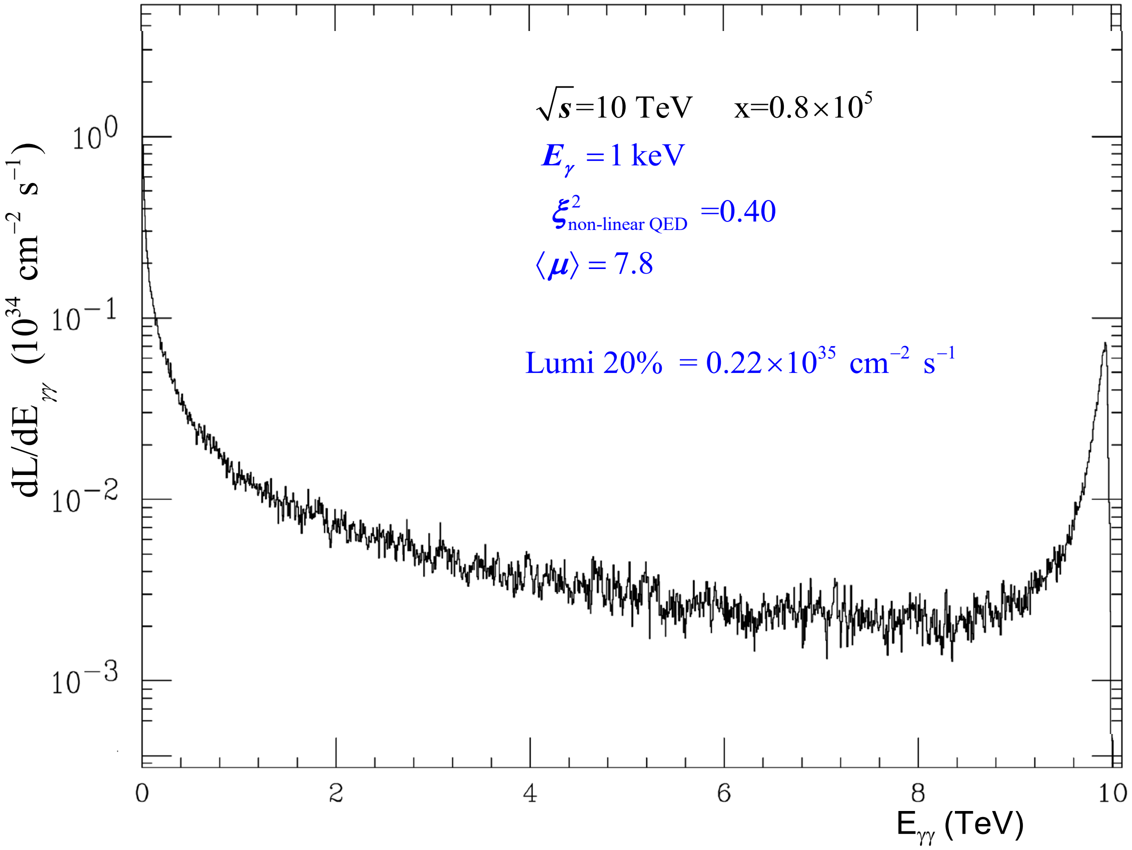
Note: processes colored red are included in the CAIN MC

process	E_{e^-} (GeV)/x = 62.6 / 1000	E_{e^-} (GeV)/x = 5000 / 80,000	E_{e^-} (GeV)/x = 7500 / 120,000
$\gamma\gamma \to e^+e^-$	$2.16\times10^{12} \pm 0.03\%$	$2.68\times10^{10} \pm 0.07\%$	
$\gamma\gamma \to e^+e^-e^+e^-$	$3.26\times10^{9} \pm 0.27\%$	$5.70\times10^{9} \pm 0.92\%$	
$\gamma\gamma \to e^+e^-e^+e^-e^+e^-$		$2.33\times10^{4} \pm 11.9\%$	
$e^-\gamma \to e^-e^+e^-$	$8.22\times10^{12} \pm 0.22\%$	$9.55\times10^{11} \pm 13.4\%$	$4.61\times10^{10} \pm 30.4\%$
$e^-\gamma \to e^-e^+e^-e^+e^-$	$1.63\times10^{7} \pm 0.78\%$	$5.68\times10^{6} \pm 21.1\%$	$7.47\times10^{5} \pm 17.4\%$

The relative MC integration statistical error increases for $x \sim 10^5$ but it is good enough to demonstrate that the $N = 1$ processes still dominate at $x \sim 10^5$ and therefore the current CAIN MC is valid.

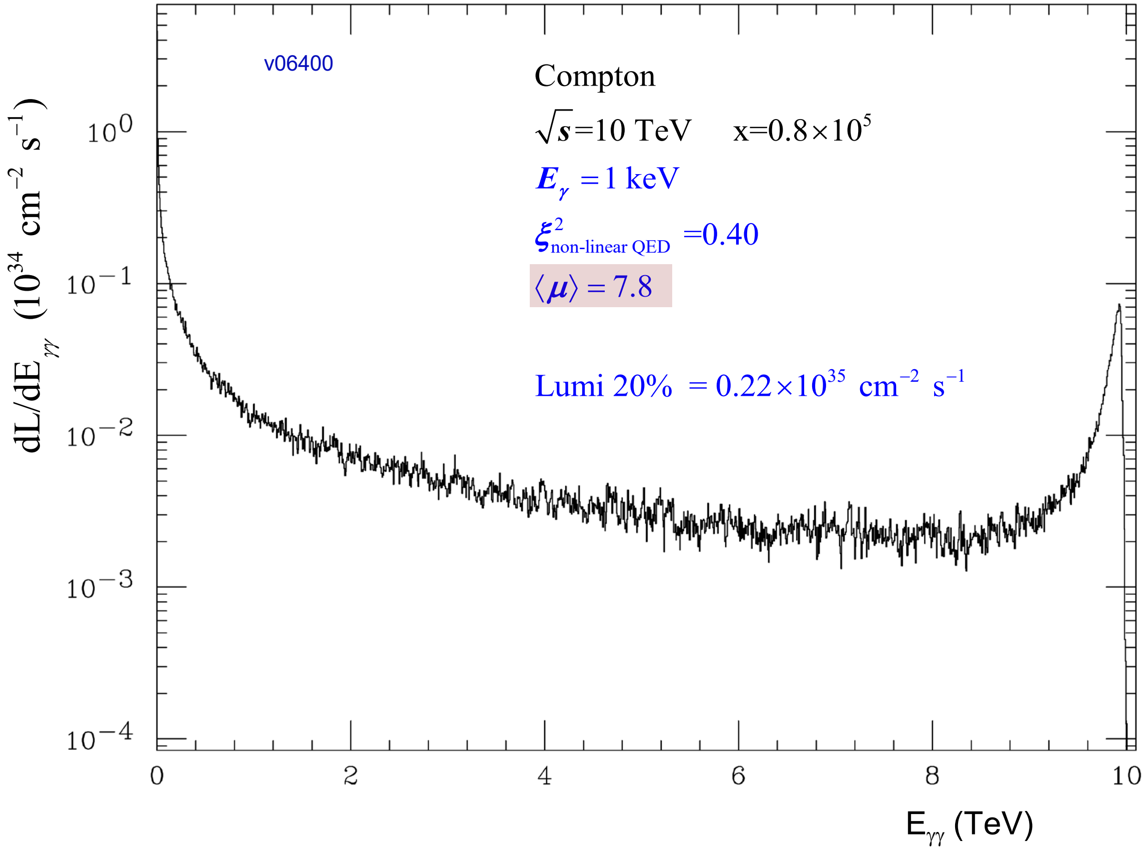
Compare 15 and 10 TeV



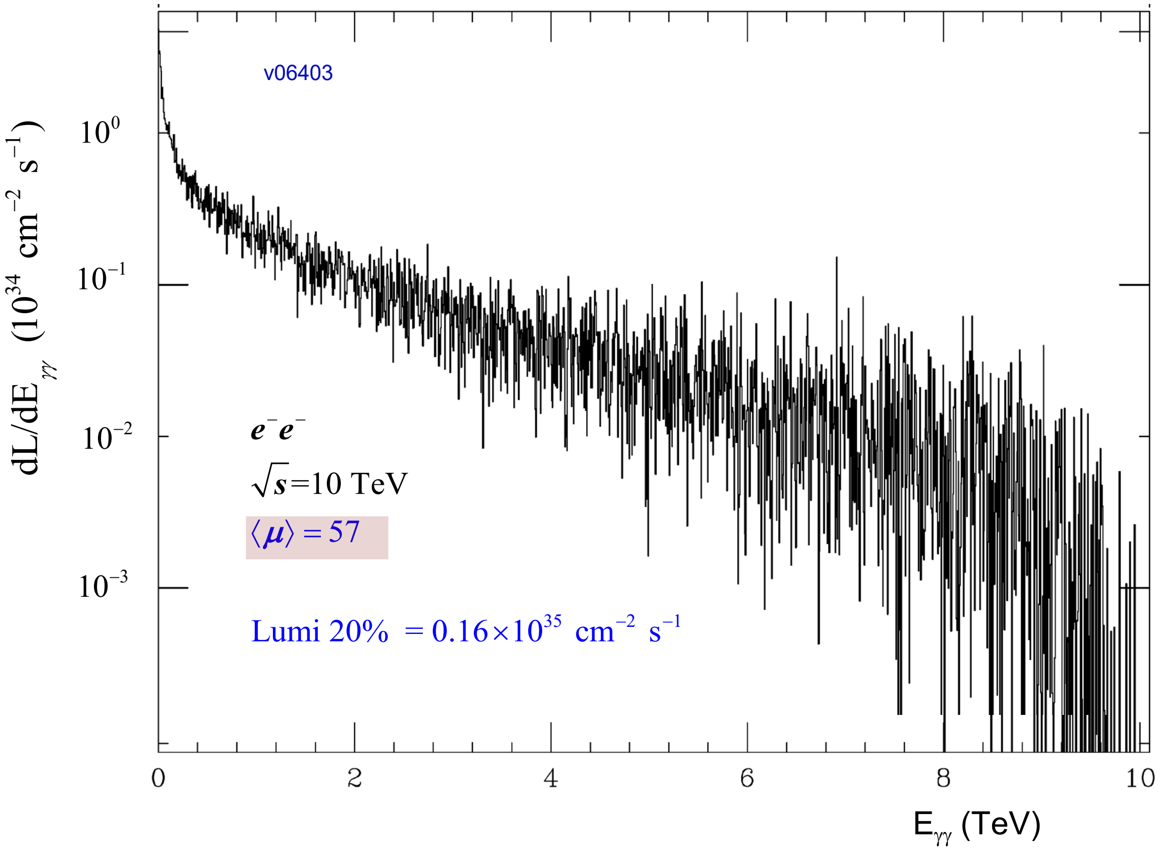


10 TeV $\gamma\gamma$ Luminosity: Compton vs e^-e^- Collider

Compton Collider



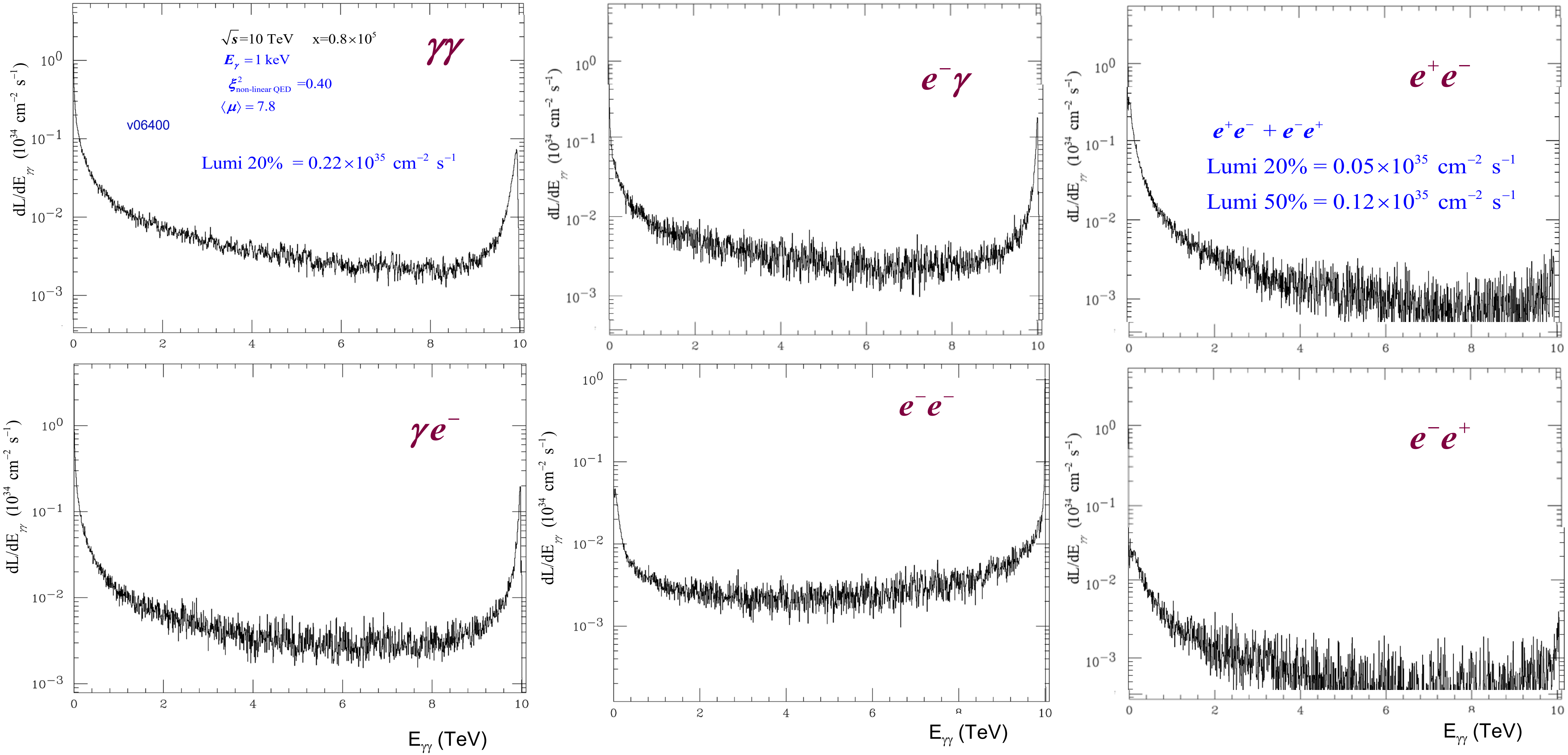
e^-e^- Collider



The top 20% Compton $\gamma\gamma$ Lumi is only 38% larger than the top 20% from e^-e^- beamstrahlung.

But at $\langle\mu\rangle = 57$ the e^-e^- Collider pileup is over seven times that of Compton, and the same as Run3 LHC.

10 TeV Compton Collider $\gamma\gamma$ $e^-\gamma$ γe^- e^-e^- e^+e^- e^-e^+



$\sqrt{s}$=10 TeV x=0.8×10^5

E_γ = 1 keV

$\xi^2_{\text{non-linear QED}}$ =0.40

$\langle\mu\rangle$ = 7.8

v06400

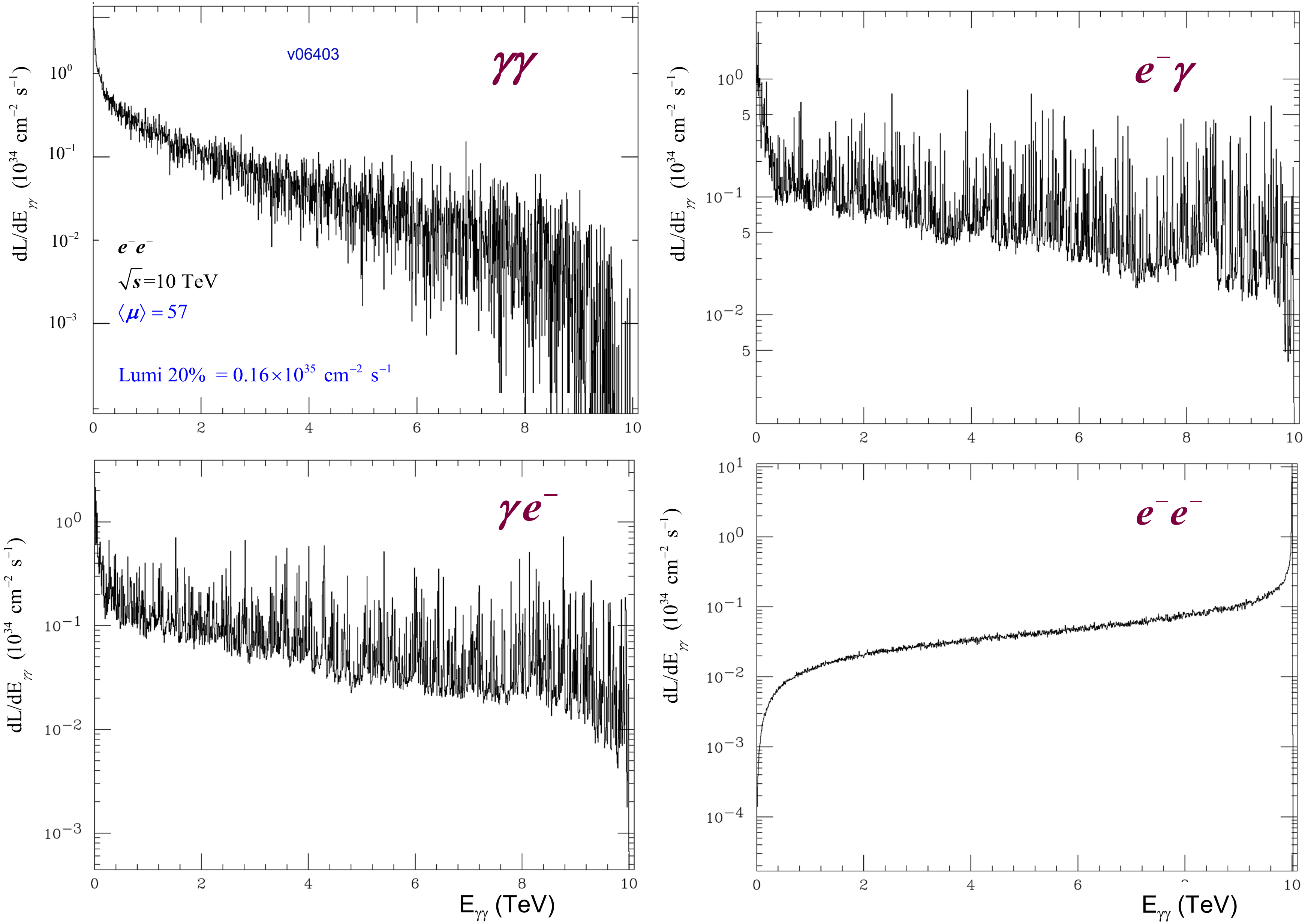
Lumi 20% = 0.22×10^{35} cm^{-2} s^{-1}

$e^+e^- + e^-e^+$

Lumi 20% = 0.05×10^{35} cm^{-2} s^{-1}

Lumi 50% = 0.12×10^{35} cm^{-2} s^{-1}

10 TeV e^-e^- Collider $\gamma\gamma$ $e^-\gamma$ γe^- e^-e^-



CAIN reports e^+e^- Luminosity = 0

When simulating an e^-e^- collider the macroparticle for a coherent e^+e^- is given a weight of 10,000 w.r.t. the photon macroparticle that produced it. (In contrast the coherent e^+e^- pair is given a weight of 1 in the Compton collider simulation.)

Have now (within the past day) verified that the large macroparticle weight made CAIN drop the e^+e^- pairs from the luminosity calculation. Don't yet know if any weight > 1 does this ...

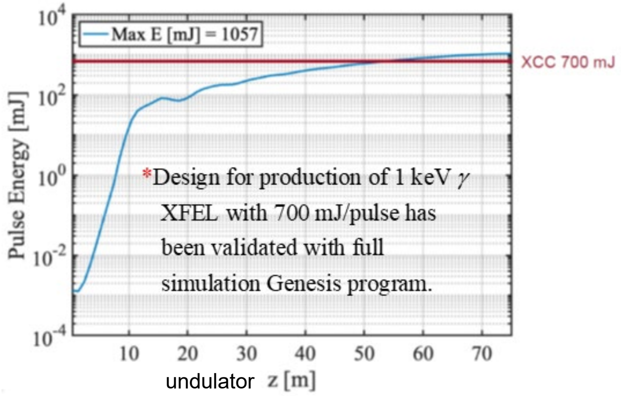
XCC Accelerator Challenges

Electron beam:

- Polarized low emittance (120 nm) e^- injector is baseline XCC
  but damping ring would also work
- Focusing of round e^- beams to $\sigma_{x,y} = 5.5$ nm $(\beta_{x,y} = 0.03$ mm, $L_{geo} = 10^{35}$ cm^{-2}s$^{-1})$
  or asymmteric e^- beams if damping ring is used.

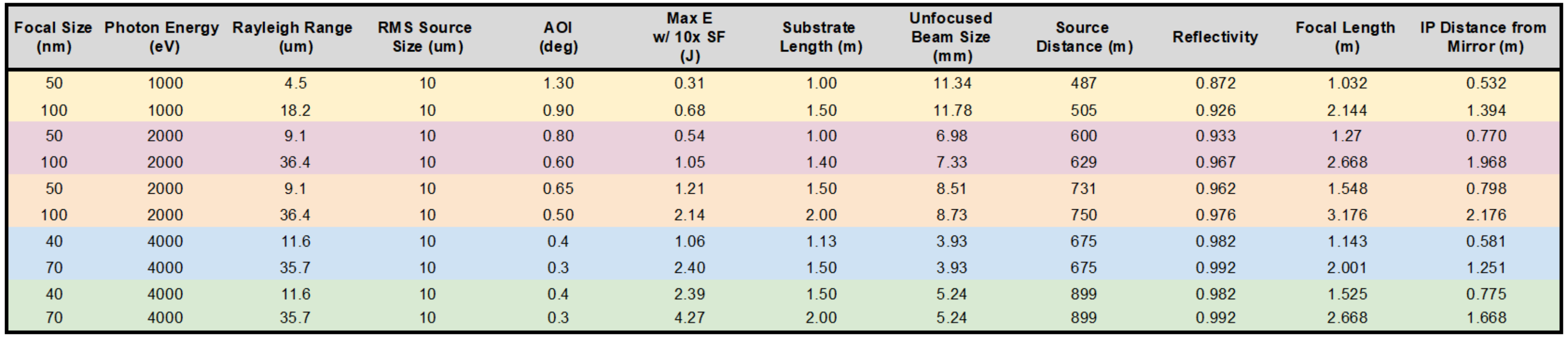
XFEL beam and Compton IP:

- Production of 1 keV γ XFEL with 700 mJ/pulse
- Focusing of 1 keV , 700 mJ/pulse XFEL beam to 70 nm FWHM waist
- XFEL and e^- beamline layouts around the IP
- Timing and position stability of the XFEL laser beam and e^- beam at Compton IP.



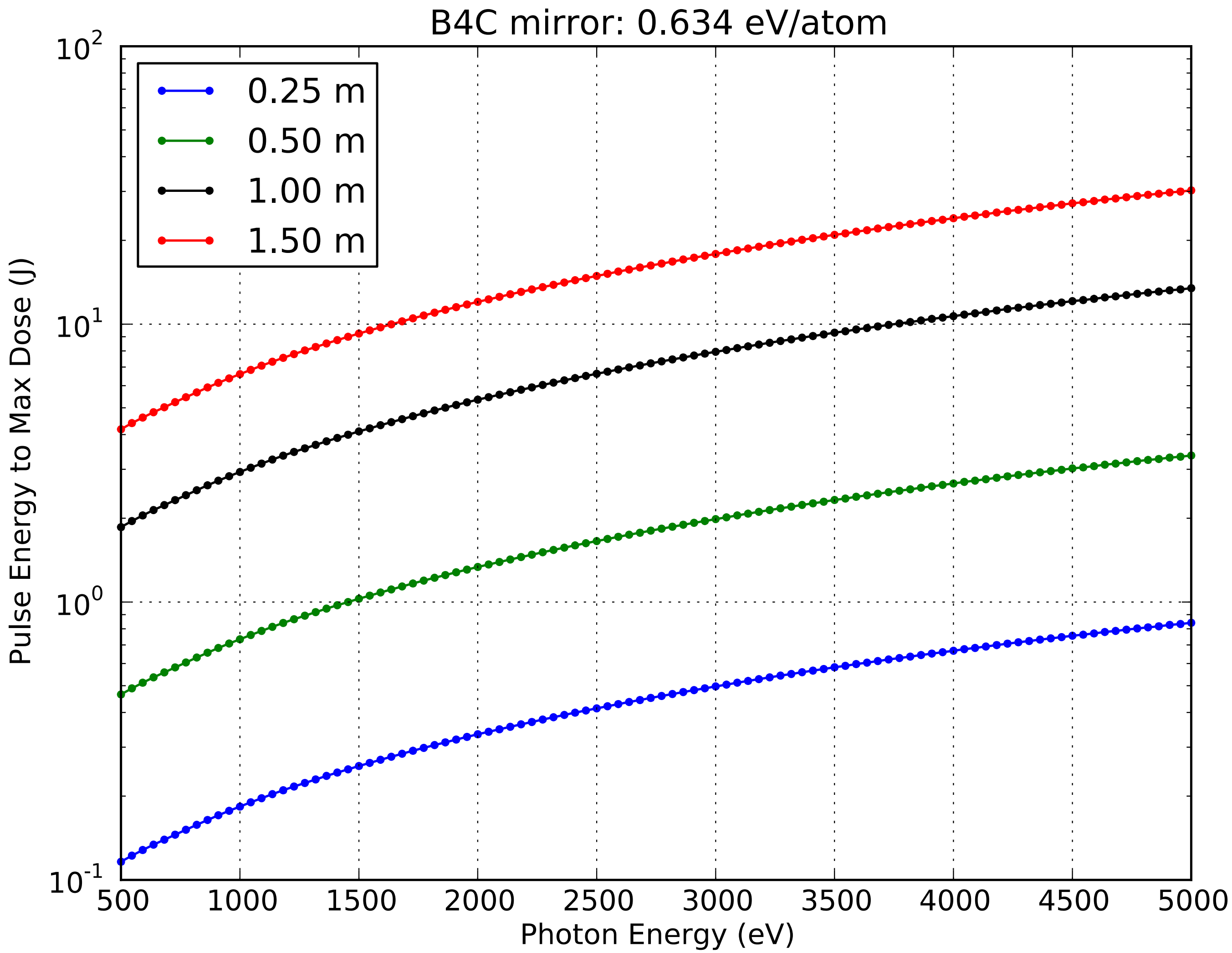
*Design for production of 1 keV γ XFEL with 700 mJ/pulse has been validated with full simulation Genesis program.

Table of XCC KB mirror parameters



Focal Size (nm)	Photon Energy (eV)	Rayleigh Range (um)	RMS Source Size (um)	AOI (deg)	Max E w/ 10x SF (J)	Substrate Length (m)	Unfocused Beam Size (mm)	Source Distance (m)	Reflectivity	Focal Length (m)	IP Distance from Mirror (m)
50	1000	4.5	10	1.30	0.31	1.00	11.34	487	0.872	1.032	0.532
100	1000	18.2	10	0.90	0.68	1.50	11.78	505	0.926	2.144	1.394
50	2000	9.1	10	0.80	0.54	1.00	6.98	600	0.933	1.27	0.770
100	2000	36.4	10	0.60	1.05	1.40	7.33	629	0.967	2.668	1.968
50	2000	9.1	10	0.65	1.21	1.50	8.51	731	0.962	1.548	0.798
100	2000	36.4	10	0.50	2.14	2.00	8.73	750	0.976	3.176	2.176
40	4000	11.6	10	0.4	1.06	1.13	3.93	675	0.982	1.143	0.581
70	4000	35.7	10	0.3	2.40	1.50	3.93	675	0.992	2.001	1.251
40	4000	11.6	10	0.4	2.39	1.50	5.24	899	0.982	1.525	0.775
70	4000	35.7	10	0.3	4.27	2.00	5.24	899	0.992	2.668	1.668

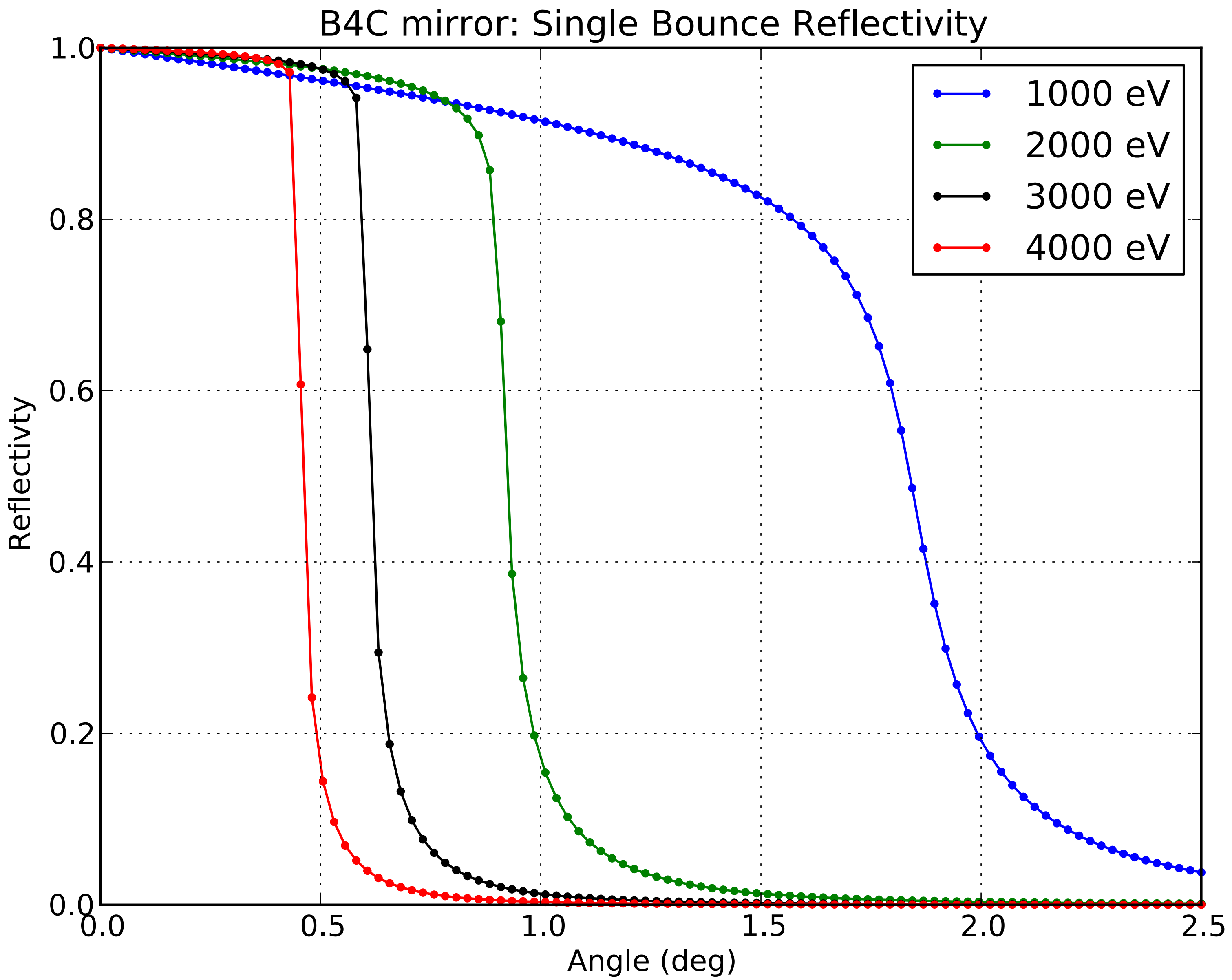
Mirror Damage Limit (single pulse)



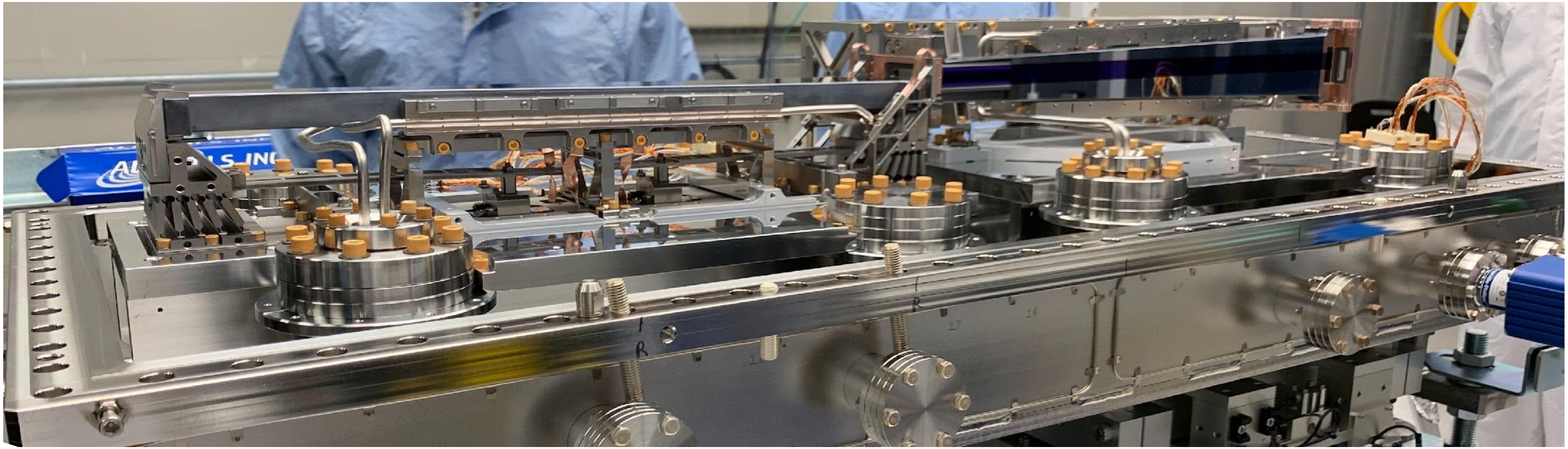
- Boron carbide is the highest damage threshold coating and is used for this calculation
- Assumes the incident fwhm beam size is ½ the substrate length
- No safety factor is included in these calculations – 5-10x below this value should be planned for
- Calculation is weakly dependent on incident angle below the mirror cutoff (0.3 deg AOI used)

A large mirror (> 1 m) is needed to survive ~ 1 J pulse energies

Mirror Reflectivity



KB Mirror Chamber

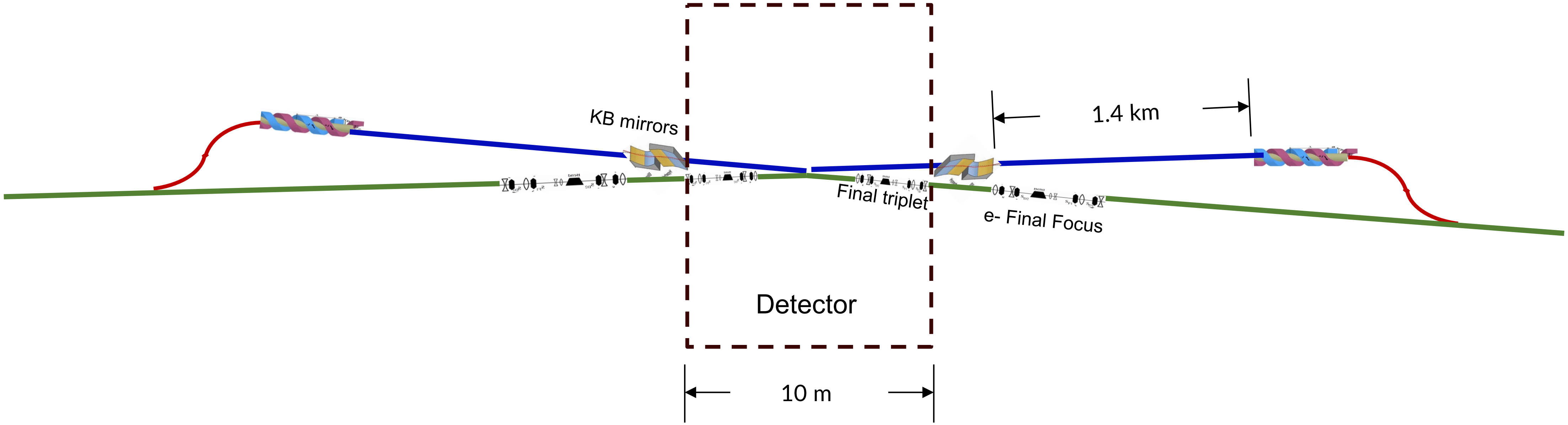


This KB mirror parameter table did not account for placement of mirrors outside detector. Substrate and focal lengths will actually be 2.5 times those shown here:

Focal Size (nm)	Photon Energy (eV)	Rayleigh Range (um)	RMS Source Size (um)	AOI (deg)	Max E w/ 10x SF (J)	Substrate Length (m)	Unfocused Beam Size (mm)	Source Distance (m)	Reflectivity	Focal Length (m)	IP Distance from Mirror (m)
50	1000	4.5	10	1.30	0.31	1.00	11.34	487	0.872	1.032	0.532
100	1000	18.2	10	0.90	0.68	1.50	11.78	505	0.926	2.144	1.394
50	2000	9.1	10	0.80	0.54	1.00	6.98	600	0.933	1.27	0.770
100	2000	36.4	10	0.60	1.05	1.40	7.33	629	0.967	2.668	1.968
50	2000	9.1	10	0.65	1.21	1.50	8.51	731	0.962	1.548	0.798
100	2000	36.4	10	0.50	2.14	2.00	8.73	750	0.976	3.176	2.176
40	4000	11.6	10	0.4	1.06	1.13	3.93	675	0.982	1.143	0.581
70	4000	35.7	10	0.3	2.40	1.50	3.93	675	0.992	2.001	1.251
40	4000	11.6	10	0.4	2.39	1.50	5.24	899	0.982	1.525	0.775
70	4000	35.7	10	0.3	4.27	2.00	5.24	899	0.992	2.668	1.668

XCC Schematic with 1.4 km line between XFEL and KB mirrors

Demagnify 20 μm FWHM
XFEL beam at undulator exit
to 70 nm FWHM at Compton IP



XCC BDS & MDI Issues

Beam Delivery and Machine Detector Interface at XCC

BDS Accelerator Issues Related to Getting Four Particle Beams In and Out of IP Region

(1) Crossing angle and Aperture of final quad (for 2 mrad crossing angle choice, e^+, e^-, γ from primary & Compton IP's must pass through this aperture; for 20 mrad angle need collimators to protect final quad)

(2) L*, KB mirror length and location

(3) Shared vacuum pipe: point of entry of XFEL beam into e^- beampipe, passing of electron beam through KB mirror chamber (?), beam dump design

Detector issues due to backgrounds from e^+, e^-, γ produced at Compton IP's and primary IP:

(1) Vertex detector inner radius (incoherent e^+e^- pairs from primary IP - same situation as e^+e^- linear colliders)

(2) Beampipe X_0 (moderate soft X-ray flux from Compton IP's $|\cos\theta| < 0.95$)

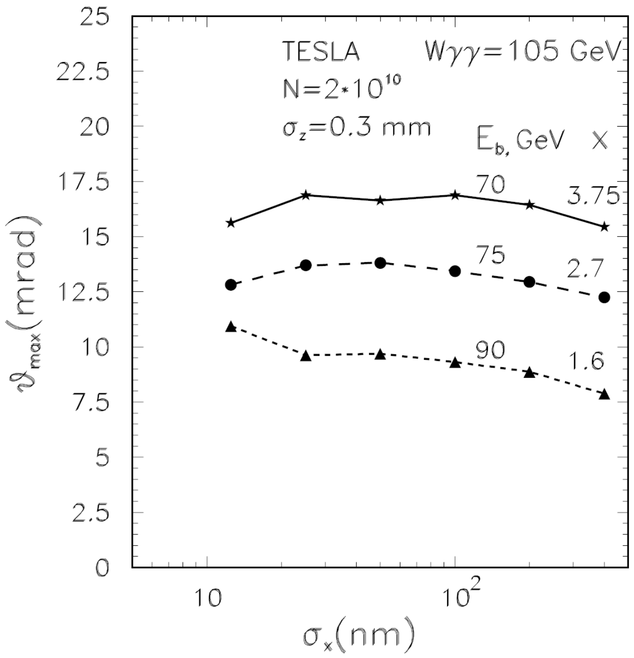
(3) Forward boundaries of the main tracker/calorimeter and solid angle coverage of forward detector (large hard X-ray flux from Compton IP's $|\cos\theta| > 0.95$)

TESLA TDR $\gamma\gamma$ Collider Specifies 34 mrad Crossing Angle

The crossing angle for the TESLA $\gamma\gamma$ collider is discussed in section 1.4.4.2 of

TESLA TDR, Part VI, Chapter 1: The Photon Collider at TESLA

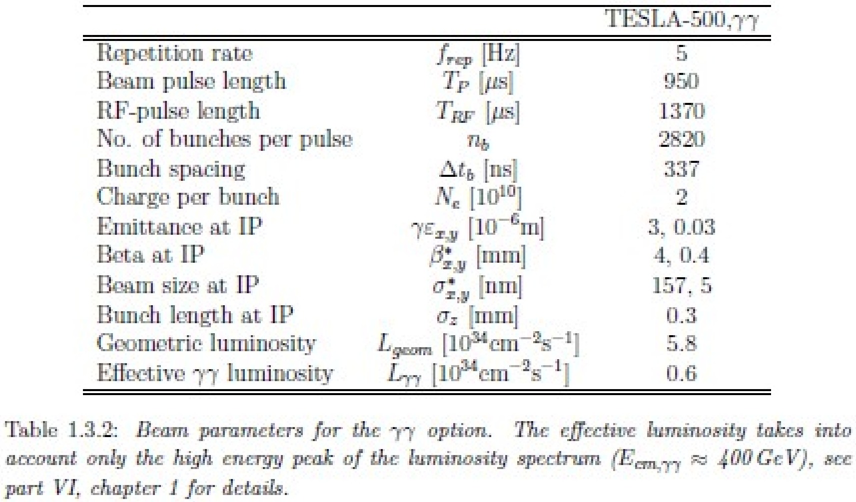
The concern is low energy, large angle particles striking the quads. For fixed $\sqrt{s_{\gamma\gamma}}$ the maximum disruption angle $\vartheta_{\max}$ is given by $\vartheta_{\max} \propto \dfrac{x}{\sqrt{(1+x)\sigma_c(x)}}$ where $\sigma_c(x)$ is the Compton cross section with leading term $\sigma_c(x) \propto \dfrac{1}{x}$.



They conclude that for a fixed laser λ=1.06 μm and 200 GeV $\leq \sqrt{s_{\gamma\gamma}} \leq$ 500 GeV, the the maximum disruption angle is $\vartheta_{\max} \approx 14$ mrad, and they set the crossing angle at $\theta_c = 34$ mrad.

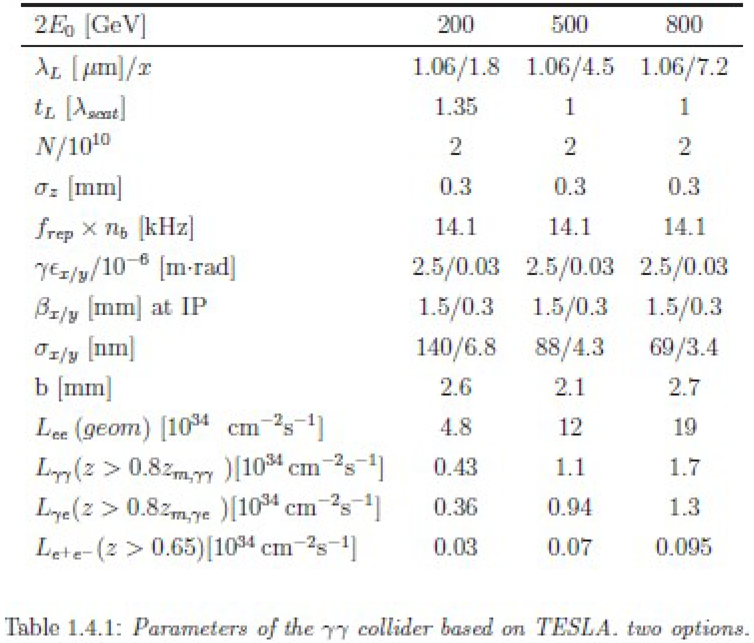
Let’s check this with CAIN. Calculate energy incident on 6 cm dia. cryostat at L*=3m.

Use parameters for TESLA TDR $\sqrt{s_{\gamma\gamma}} = 500$ GeV, $x = 4.5$



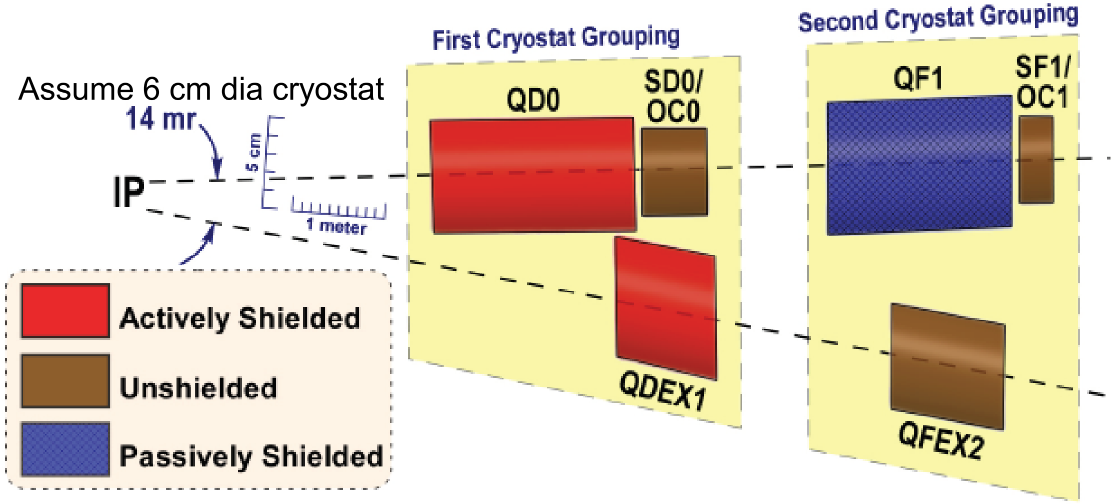
		TESLA-500,γγ
Repetition rate	f_{rep} [Hz]	5
Beam pulse length	T_P [μs]	950
RF-pulse length	T_{RF} [μs]	1370
No. of bunches per pulse	n_b	2820
Bunch spacing	Δt_b [ns]	337
Charge per bunch	N_e [10^{10}]	2
Emittance at IP	$\gamma\epsilon_{x,y}$ [10^{-6}m]	3, 0.03
Beta at IP	$\beta^*_{x,y}$ [mm]	4, 0.4
Beam size at IP	$\sigma^*_{x,y}$ [nm]	157, 5
Bunch length at IP	σ_z [mm]	0.3
Geometric luminosity	L_{geom} [10^{34}cm^{-2}s^{-1}]	5.8
Effective γγ luminosity	$L_{\gamma\gamma}$ [10^{34}cm^{-2}s^{-1}]	0.6

Table 1.3.2: *Beam parameters for the γγ option. The effective luminosity takes into account only the high energy peak of the luminosity spectrum ($E_{cm,\gamma\gamma} \approx 400$ GeV), see part VI, chapter 1 for details.*



$2E_0$ [GeV]	200	500	800
λ_L [μm]/x	1.06/1.8	1.06/4.5	1.06/7.2
t_L [λ_{scat}]	1.35	1	1
$N/10^{10}$	2	2	2
σ_z [mm]	0.3	0.3	0.3
$f_{rep} \times n_b$ [kHz]	14.1	14.1	14.1
$\gamma\epsilon_{x/y}/10^{-6}$ [m·rad]	2.5/0.03	2.5/0.03	2.5/0.03
$\beta_{x/y}$ [mm] at IP	1.5/0.3	1.5/0.3	1.5/0.3
$\sigma_{x/y}$ [nm]	140/6.8	88/4.3	69/3.4
b [mm]	2.6	2.1	2.7
L_{ee} $(geom)$ [10^{34} cm^{-2}s^{-1}]	4.8	12	19
$L_{\gamma\gamma}(z > 0.8z_{m,\gamma\gamma})$[$10^{34}$ cm^{-2}s^{-1}]	0.43	1.1	1.7
$L_{\gamma e}(z > 0.8z_{m,\gamma e})$[$10^{34}$ cm^{-2}s^{-1}]	0.36	0.94	1.3
$L_{e^+e^-}(z > 0.65)$[10^{34} cm^{-2}s^{-1}]	0.03	0.07	0.095

Table 1.4.1: *Parameters of the γγ collider based on TESLA. two options.*



As discussed in Section 1.3.2.1 the 5 μm spot size of the laser beam matches the effective crabbed horizontal beam size of

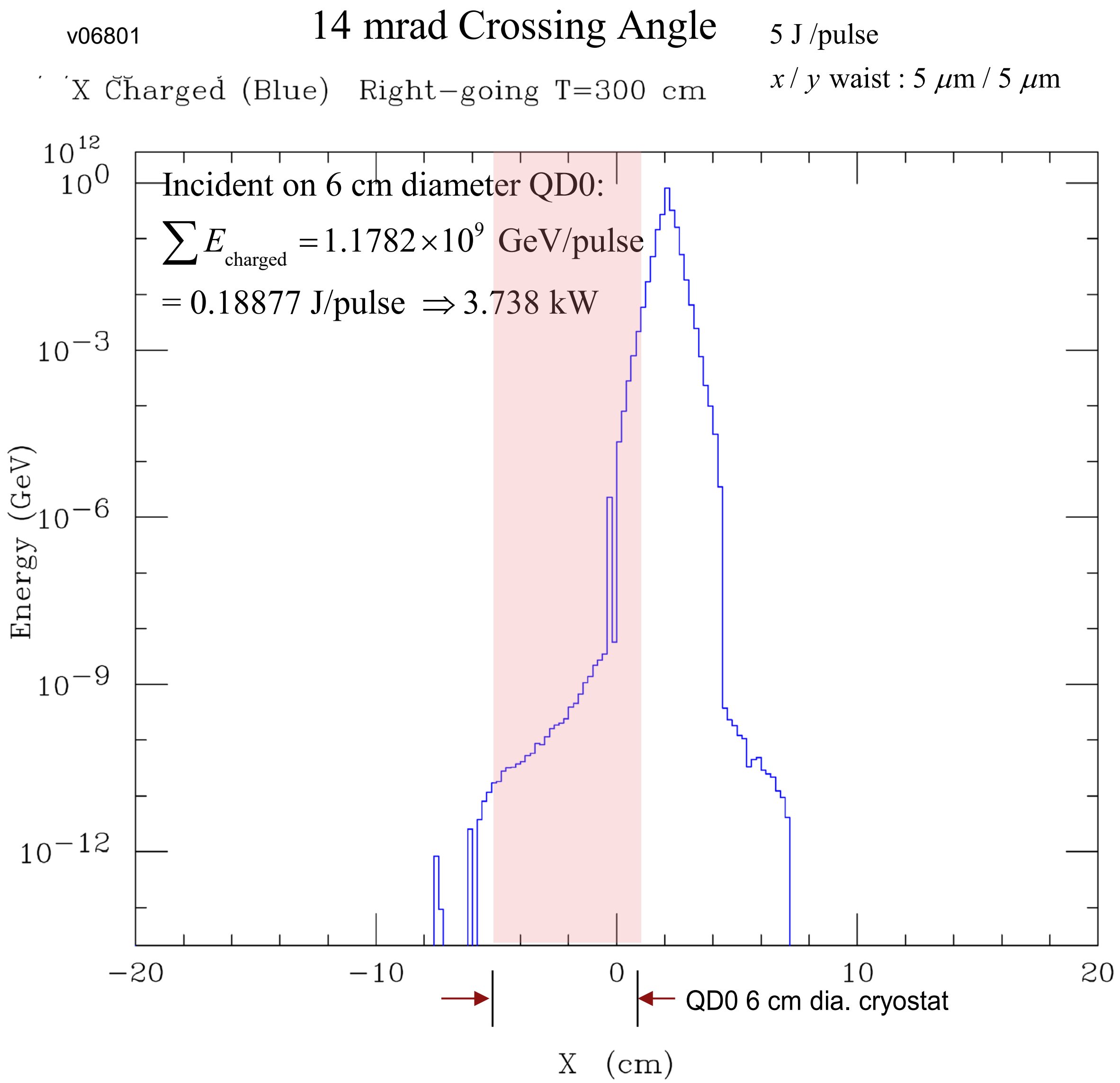
$\sigma_x = \sigma_z \alpha_c / 2 = 5\ \mu$m for $\sigma_z = 300\ \mu$m and $\alpha_c = 34$ mrad

Hence there is little luminosity degradation for $0 < \alpha_c < 34$ mrad

Not the case for XCC where laser spot size is 21 nm and

$\sigma_x = \sigma_z \alpha_c / 2 = 340\ \mu$m for $\sigma_z = 20\ \mu$m and $\alpha_c = 34$ mrad

TESLA TDR $\gamma\gamma$ Collider $\sqrt{s} = 500$ GeV


14 mrad Crossing Angle

5 J /pulse

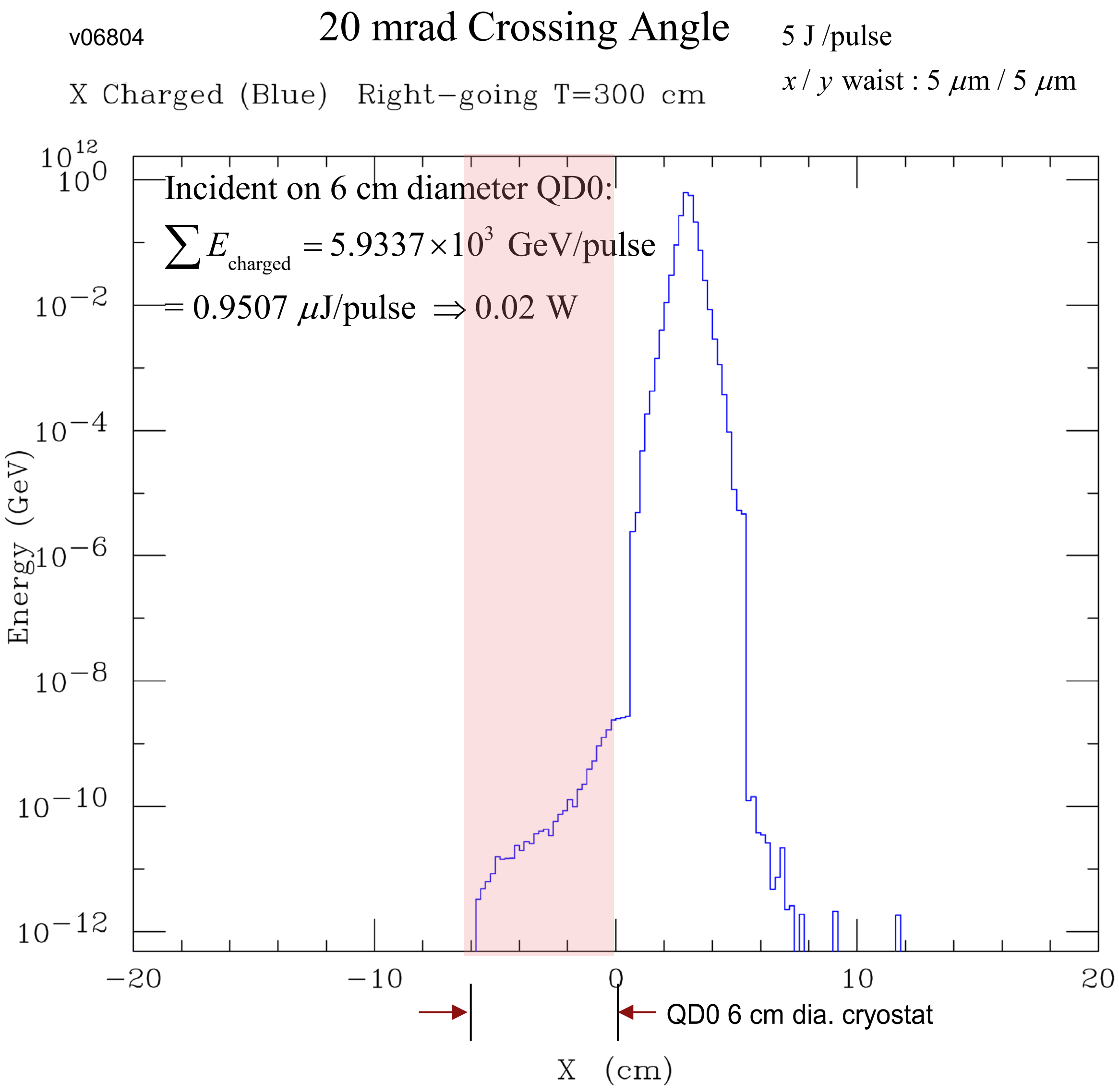
x/y waist : 5 μm / 5 μm

Incident on 6 cm diameter QD0:

$\sum E_{\text{charged}} = 1.1782\times10^{9}$ GeV/pulse

$= 0.18877$ J/pulse $\Rightarrow 3.738$ kW

QD0 6 cm dia. cryostat


20 mrad Crossing Angle

5 J /pulse

x/y waist : 5 μm / 5 μm

Incident on 6 cm diameter QD0:

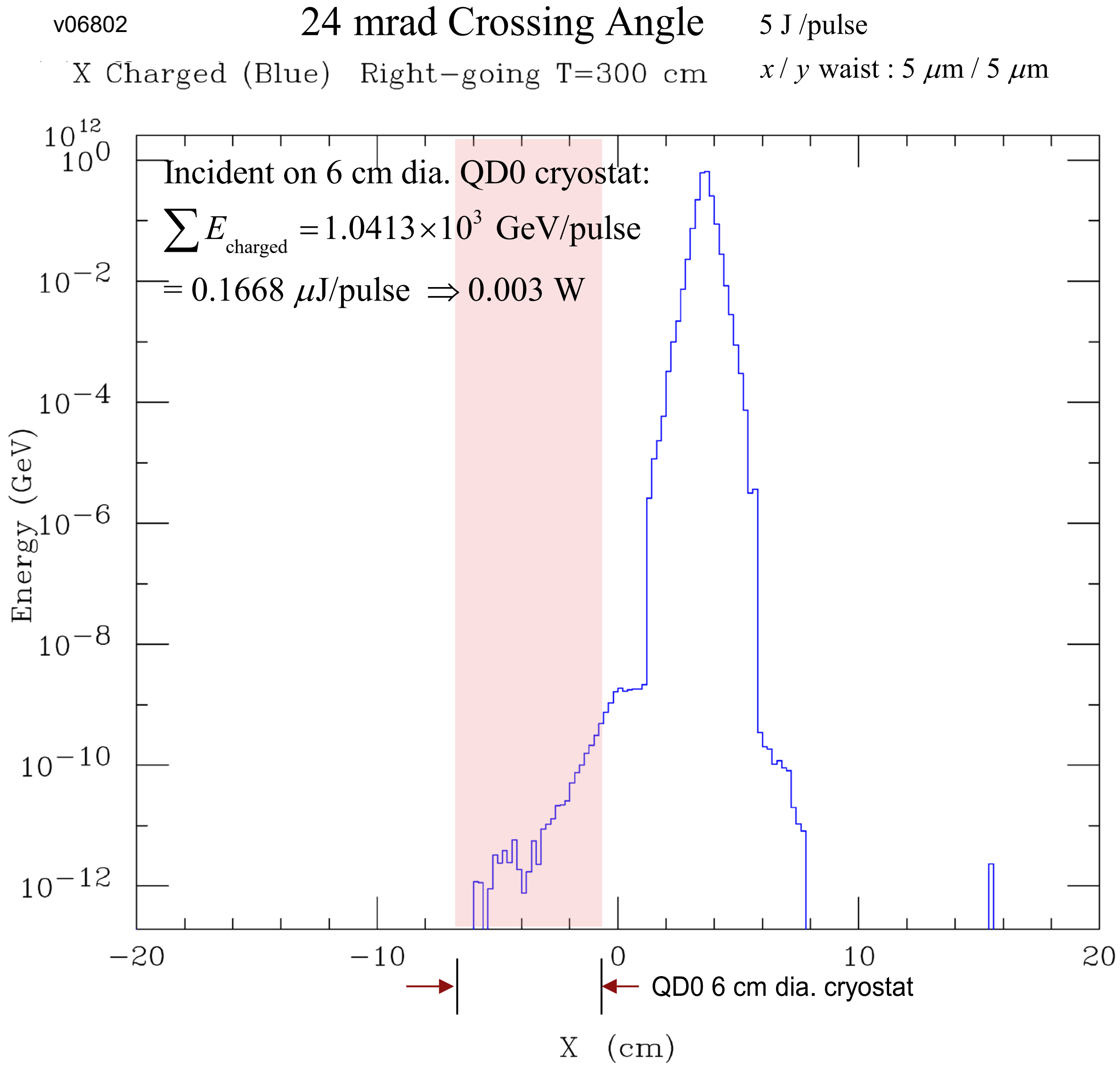
$\sum E_{\text{charged}} = 5.9337\times10^{3}$ GeV/pulse

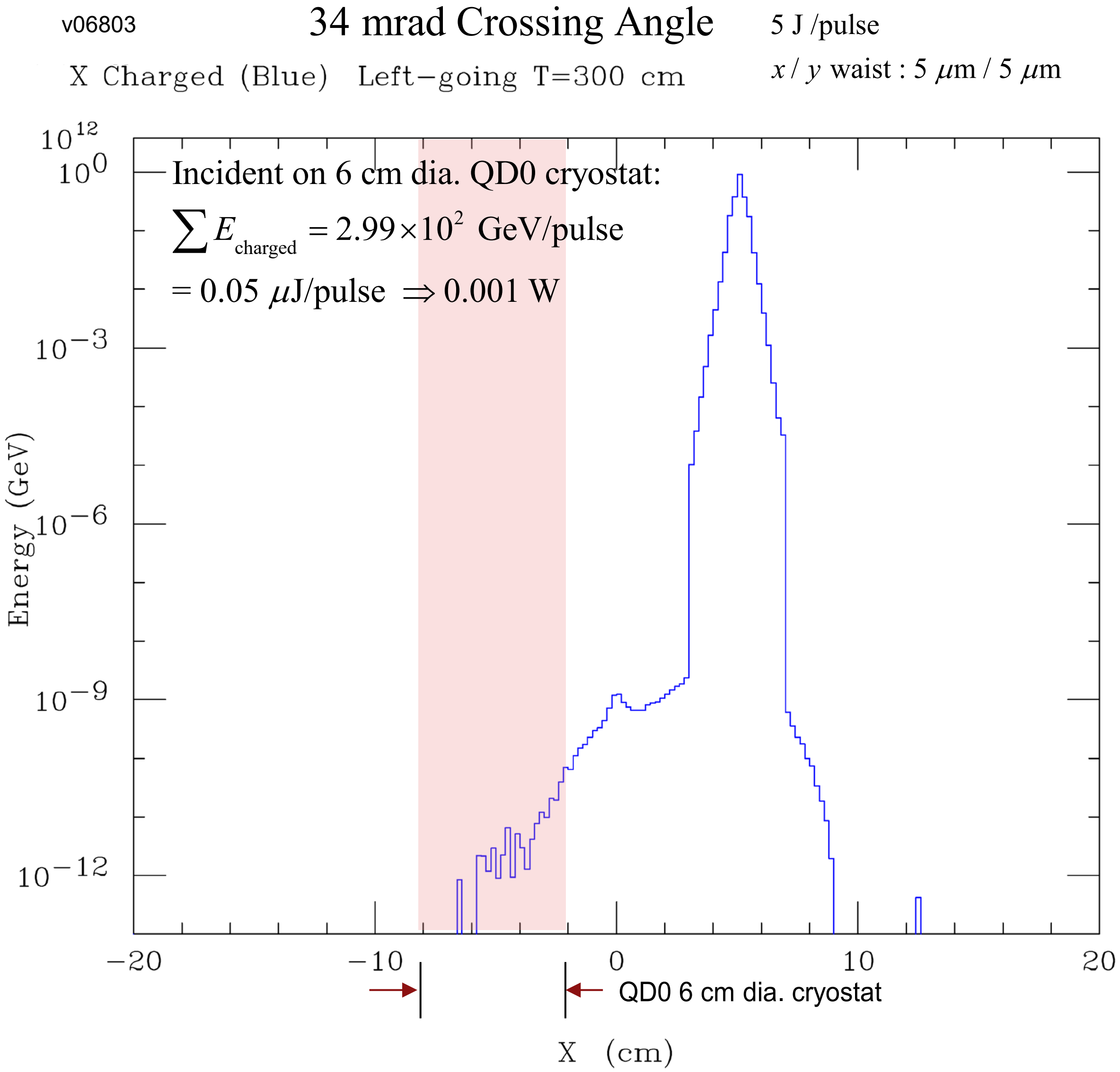
$= 0.9507$ μJ/pulse $\Rightarrow 0.02$ W

QD0 6 cm dia. cryostat

Assuming only few Watts on QD0 is tolerable, we conclude that 14 mrad is insufficient and 20 mrad is the minimum crossing angle.

TESLA TDR $\gamma\gamma$ Collider $\sqrt{s} = 500$ GeV

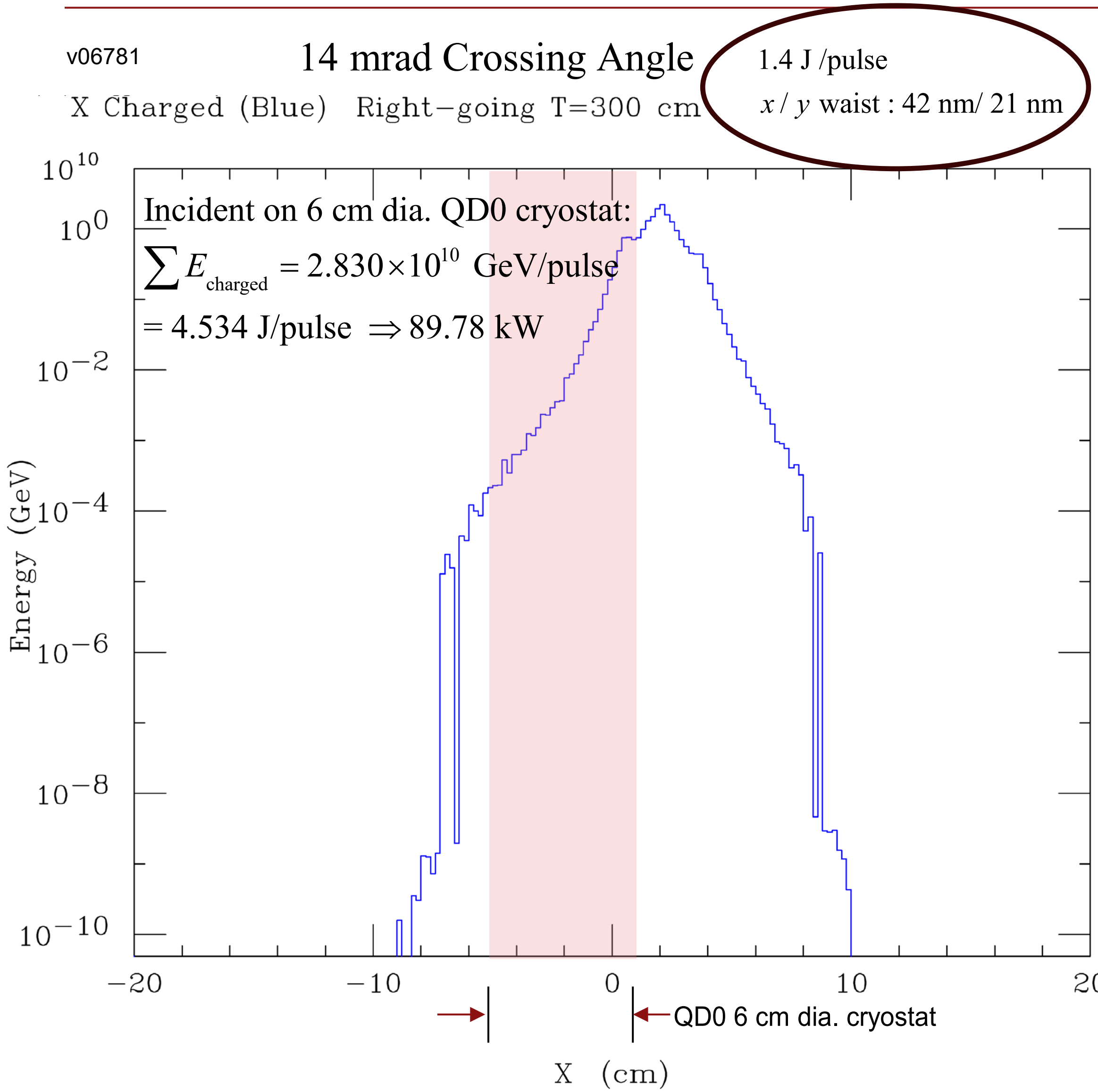




Conclude from CAIN that 24 mrad is more comfortable than 20 mrad and 34 mrad is overkill

XCC $\gamma\gamma$ Collider $\sqrt{s} = 125$ GeV

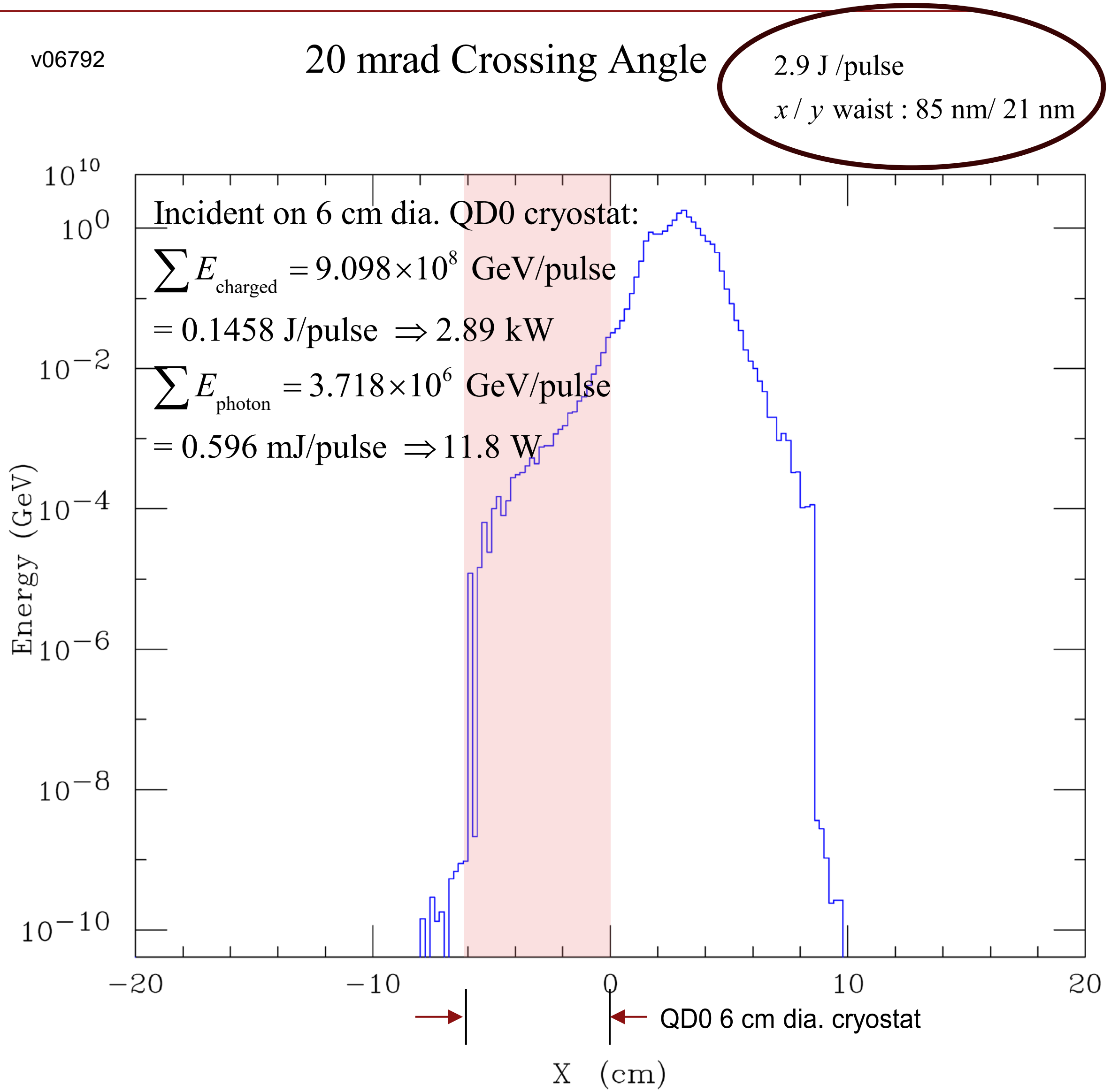
Increase horizontal laser spot size from 21 nm to 42 (85) nm to better match $\sigma_x = \sigma_z \alpha_c / 2$. Increase pulse energy to maintain laser photon density



14 mrad Crossing Angle

1.4 J /pulse
x/y waist : 42 nm/ 21 nm

Incident on 6 cm dia. QD0 cryostat:
$\sum E_{\text{charged}} = 2.830 \times 10^{10}$ GeV/pulse
$= 4.534$ J/pulse $\Rightarrow$ 89.78 kW



20 mrad Crossing Angle

2.9 J /pulse
x/y waist : 85 nm/ 21 nm

Incident on 6 cm dia. QD0 cryostat:
$\sum E_{\text{charged}} = 9.098 \times 10^{8}$ GeV/pulse
$= 0.1458$ J/pulse $\Rightarrow$ 2.89 kW
$\sum E_{\text{photon}} = 3.718 \times 10^{6}$ GeV/pulse
$= 0.596$ mJ/pulse $\Rightarrow$ 11.8 W

20 mrad will work if collimators are installed to protect QD0; must study size of collimator backscatter into detector

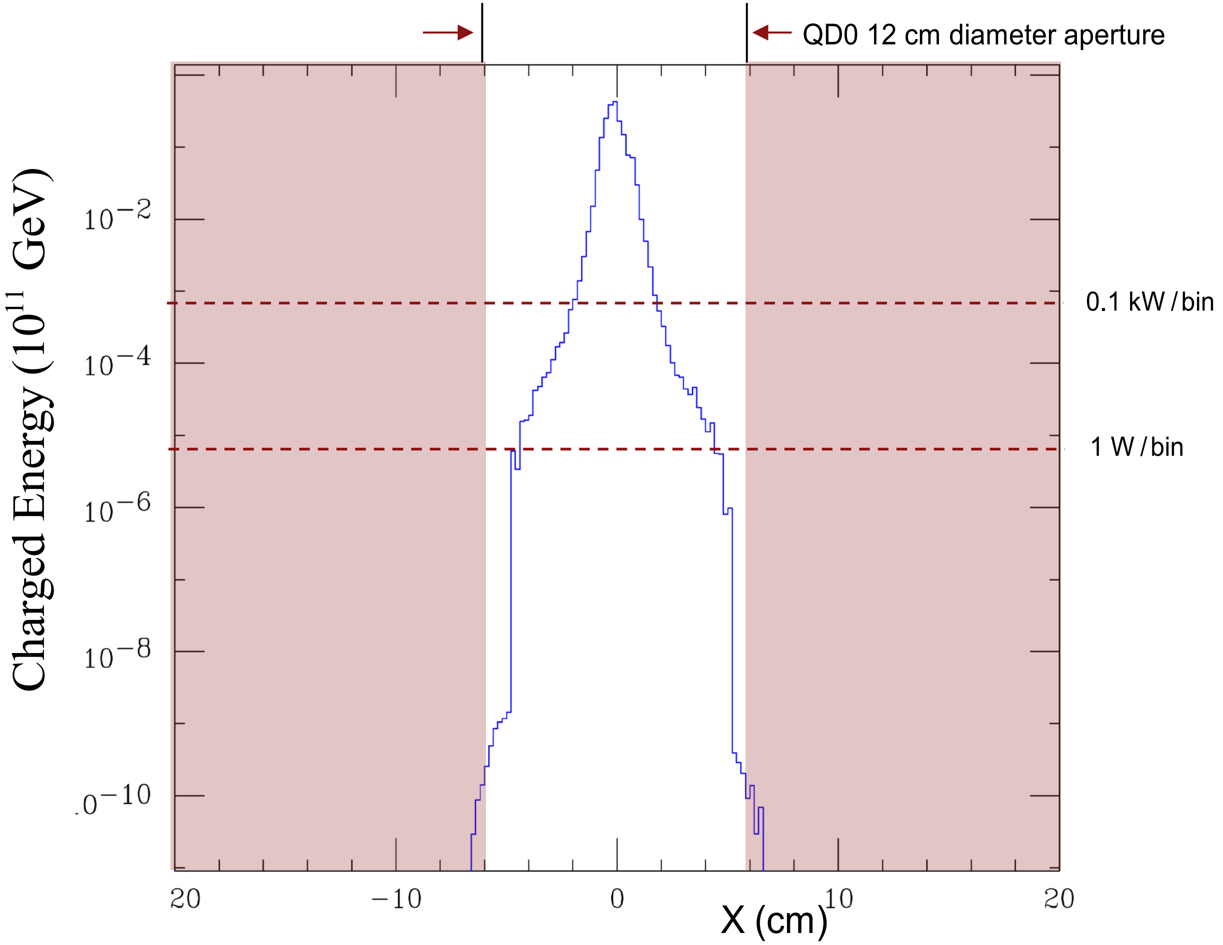
2 mrad crossing angle, L*=1.5 m

CAIN Simulation from IP to Face of Quad at L*=1.5 m, Assume 5 T Solenoid

Incident on Triplet Cryostat:

$$\sum E_{\text{charged}} = 4.2306\times10^{2}\ \text{GeV/pulse}$$

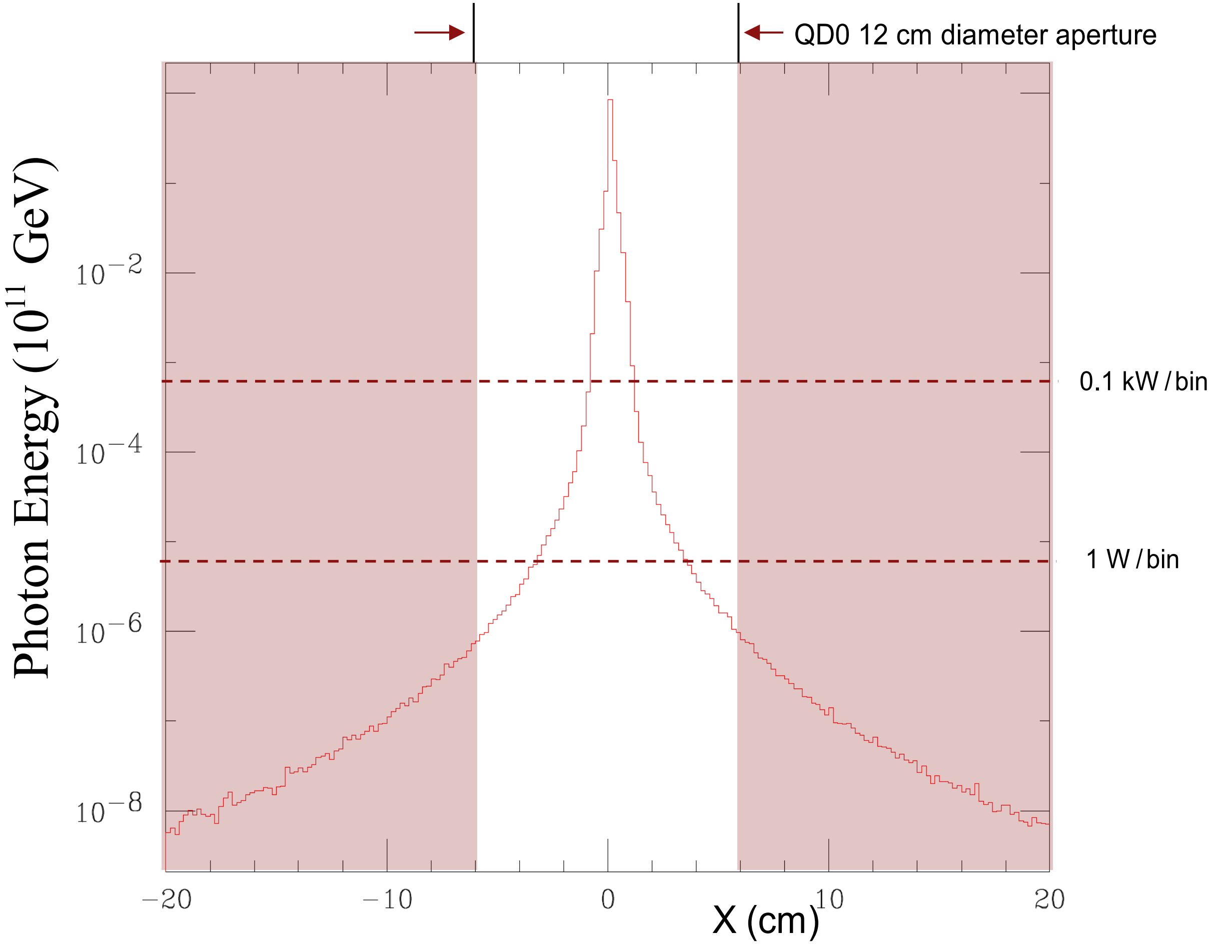
$$= 0.07\ \mu\text{J/pulse} \Rightarrow 0.001\ \text{W}$$



Incident on Triplet Cryostat:

$$\sum E_{\text{photon}} = 4.2306\times10^{2}\ \text{GeV/pulse}$$

$$= 0.29\ \text{mJ/pulse} \Rightarrow 5.8\ \text{W}$$



Solution requires large aperture HL-LHC-like final triplet. Significant departure from usual e+e- collider design

Future Work

- Explore more Compton Configurations and compare $\gamma\gamma$ $e^-\gamma$ e^+e^- spectra with that of e^-e^- Collider.
- Once converge on Compton Configuration, start producing CAIN + Whizard simulations for beam-beam and machine backgrounds
- Also define scope of accelerator / laser R&D once the Compton Configuration is settled.