Open discussion for physics motivation, future designs, and possible paths for $\gamma\gamma$ colliders

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Physics motivation

- Complementarity of $\gamma\gamma$ colliders to e^+e^- Higgs factories due to:
  - – large cross section of $\gamma\gamma$ to h, H, A and hh etc.
  - – strength of having both:
    - circular (J=0 or 2) polarization
    - linear polarization -- separation of odd and even states

is all well documented.

- Production of more exotic states also well developed

➔ **Question: Why $\gamma\gamma$-colliders are not more advanced and better known?**

So what is the problem?… in my opinion

- So far, mostly consider as an EXTRA OPTION of a much bigger project, like ILC

- Technical issues associated with the Laser Compton Back-Scattering needed to produce high energy photon beams makes the more conservative members of our community concern about the design

➔ If we want a $\gamma\gamma$ collider, we need to address these two issues!

My suggestions

- Request ICFA (& Snowmass) support to look at the physics case and possible designs of $\gamma\gamma$ colliders on their own

- Do not necessarily start with the Higgs factory, but a simpler design that can do both:
  - Interesting and relevant physics, and
  - Advance the technical aspects

Some examples of physics topics

- Lower energy $\gamma\gamma$ or medium energy $e\gamma$ machines that can give good physics and serve as stepping stone for higher energy $\gamma\gamma/e\gamma/e^-e^-$ colliders
- Examples,
  - $\gamma\gamma \rightarrow \tau^+\tau^-$, $\gamma\gamma \rightarrow \tau^+\tau^-\gamma$ with E_{cm} (e^-e^-) ~ 10 GeV
    - Tau properties, including Magnetic-Moment of τ
    - Significant number of inconsistencies among LEP and B-factory based measurements
      - Since taus are the heaviest lepton, it is very important to understand them well!
  - $\gamma e^- \rightarrow W^- \nu \rightarrow \tau^- \nu_\tau \nu_e$ (only one e^- converted to γ)
    - Well control environment for τ production via W^-
    - Precise measurements of the Γ_W and M_W starting from an E_{cm} (e^-e^-) = 120 GeV

$\gamma\ e \rightarrow W\ \nu$: Already discussed by us in the past in a CLIC based design

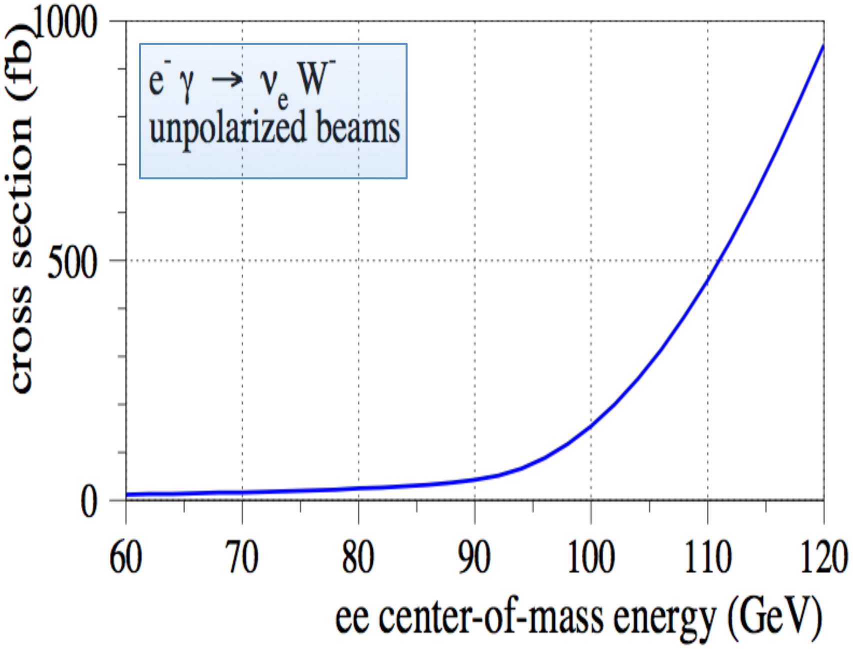


Figure 19: *The rise of the cross section for* $e^-\gamma \rightarrow \nu W^-$ *as a function of* $E_{CM}(e^-e^-)$.

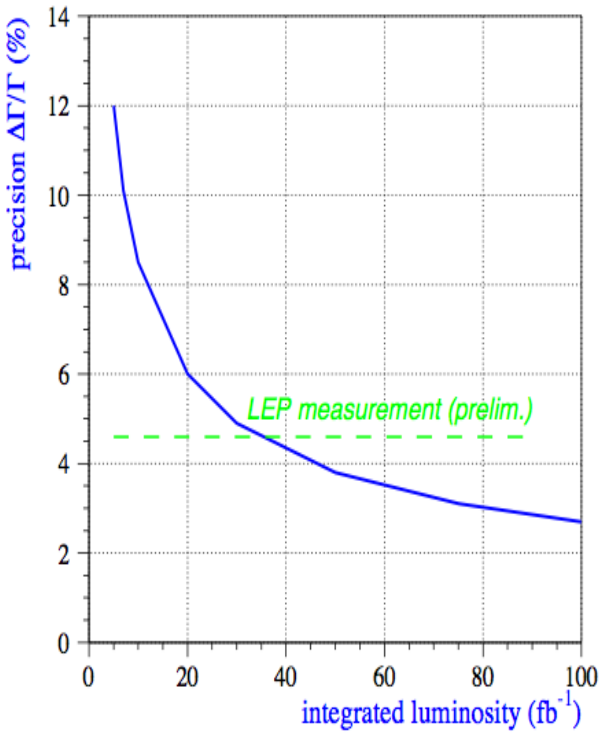


Figure 20: *The sensitivity with which* Γ_W *might be measured at in* $e^-\gamma$ *collisions, as a function of the integrated luminosity available.*

$\gamma\ e \rightarrow W\ \nu$: CLIC based CLICHÉ Design ~70% Conversion efficiency for both e- beams and polarized

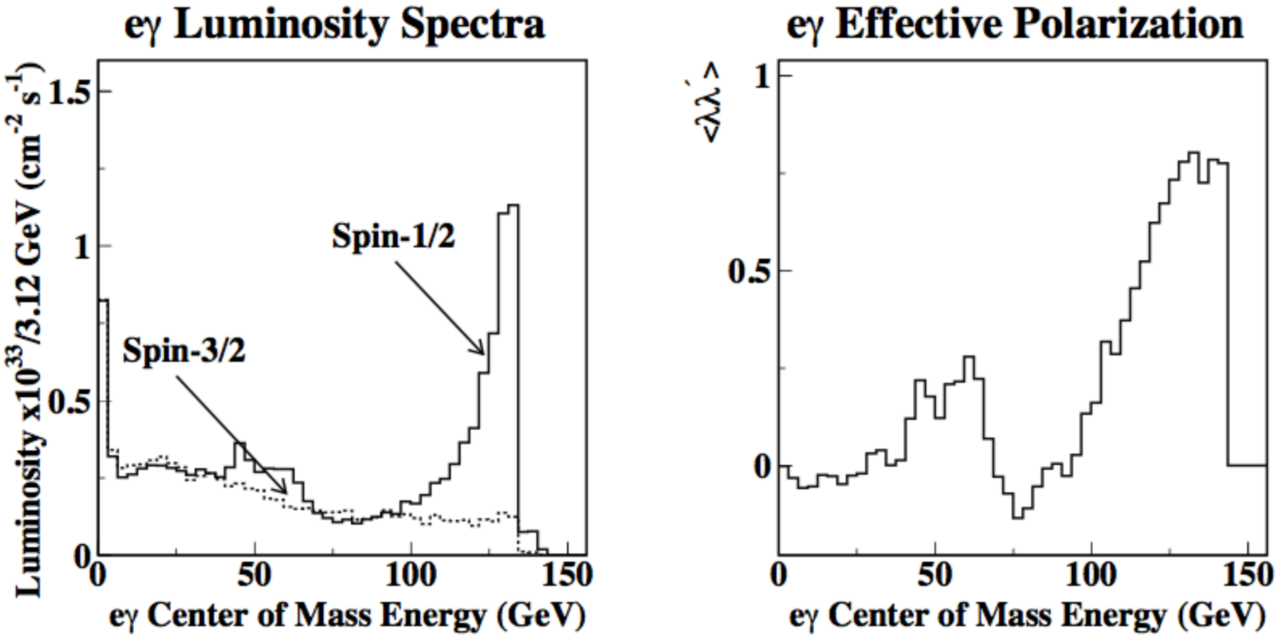


Figure 18: *Luminosity spectra and polarization for different spin states as functions of* $E_{CM}(e^-\gamma)$*, assuming the CLIC 1 parameters for 75 GeV electrons obtained with* DIMAD *[20] and* CAIN *[26] for* $\mathcal{L}_{ee} = 4.8 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

For a pure eγ designed only one photon beam used and the Luminosity will be ~2 times large than this

In this operation mode we are capable of making measurements to keep beam systematic under control: Ex. Polarization

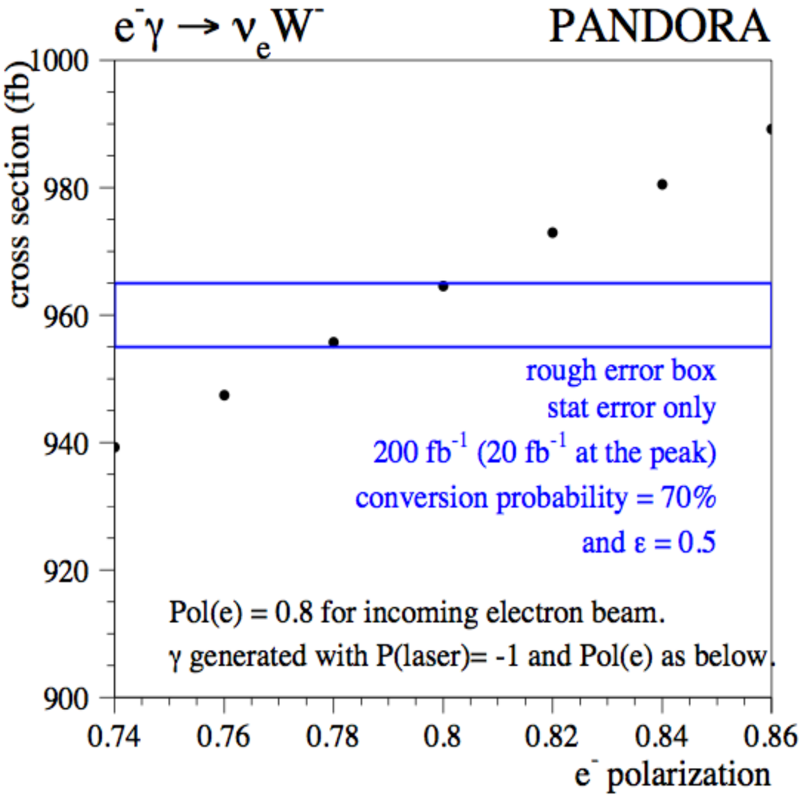


Figure 3: *The variation in the cross section for the* $e\gamma \rightarrow W\nu$ *process as a function of polarization. This analysis includes the full photon spectrum in the cross section calculation. The attainable statistical error in the cross-section measurement is also indicated.*

Some comments in $\gamma\gamma \to ff$ and γff

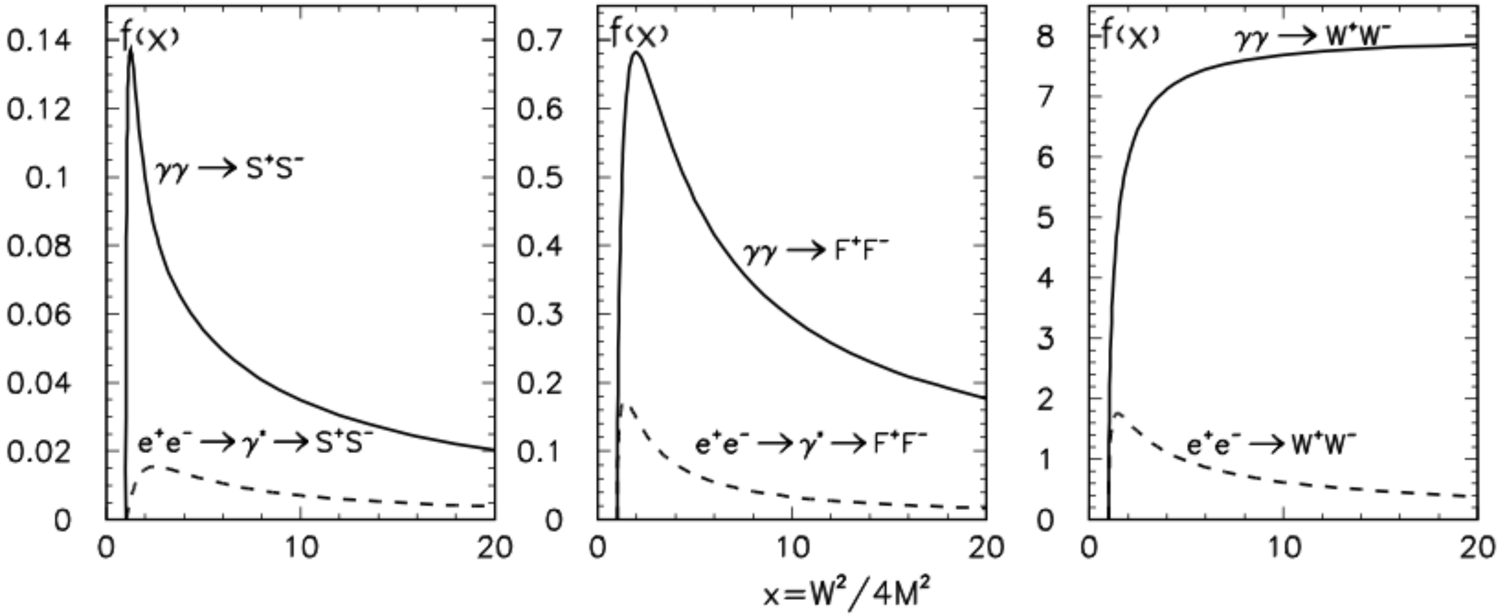
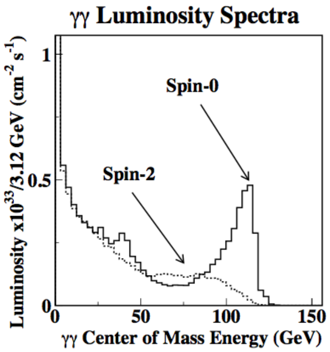


Figure 1.1.3: *Comparison between cross sections for charged pair production in unpolarised e^+e^- and $\gamma\gamma$ collisions. S (scalars), F (fermions), W (W bosons); $\sigma = (\pi\alpha^2/M^2)f(x)$, M is the particle mass, W is the invariant mass (c.m.s. energy of colliding beams), $f(x)$ are shown. Contribution of Z boson for production of S and F in e^+e^- collisions was not taken into account, it is less than 10%*

The $\sigma(\gamma\gamma \to \tau\tau) >> 100$ pb at low energy

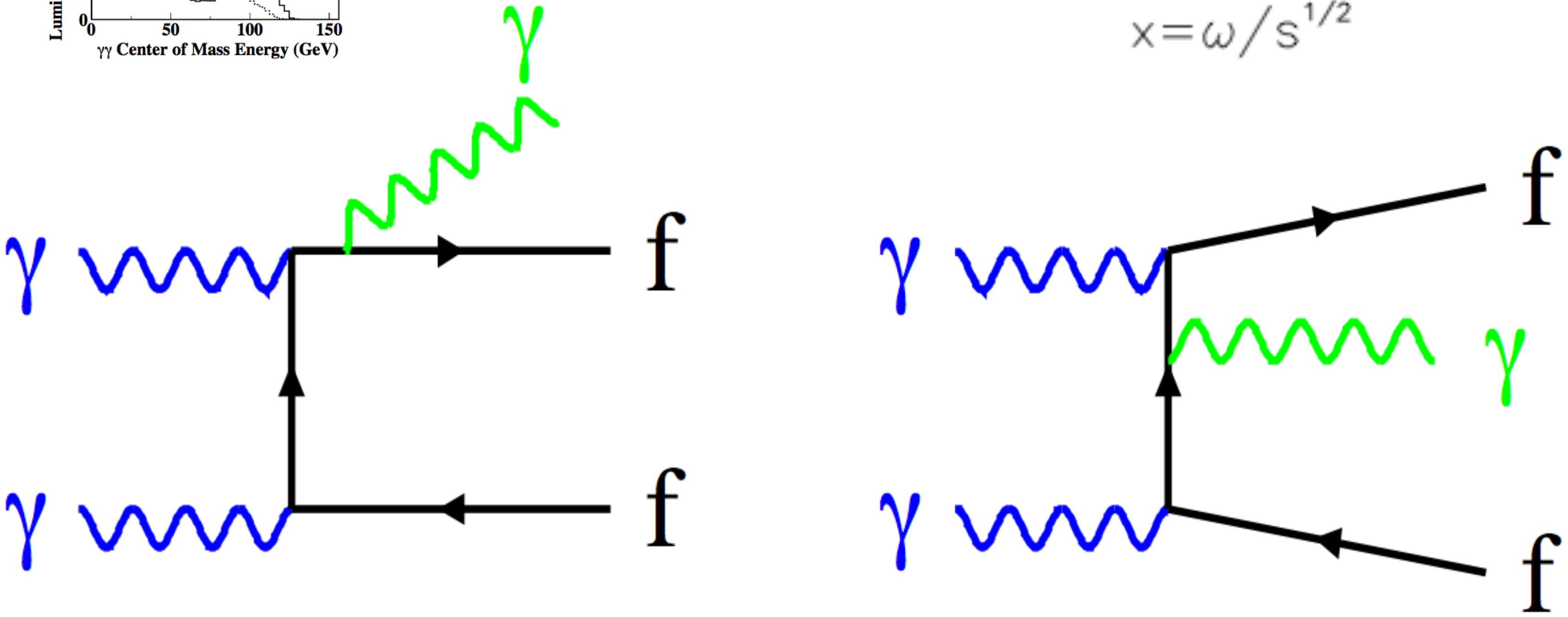
Contributions to $\gamma\gamma \to \gamma f f$ (f=charged fermions):



In case of polarization…

$$\sigma(J=0)/\sigma(J=2) \simeq 0.33 \text{ at } x \simeq 0.2$$

$$x=\omega/s^{1/2}$$



$$\Rightarrow \sigma(\gamma\gamma \to \gamma f f) > 100 \text{ pb}$$

Example, at 120 GeV
About 10% of events
Survive with basic cuts

Examples of machines #1

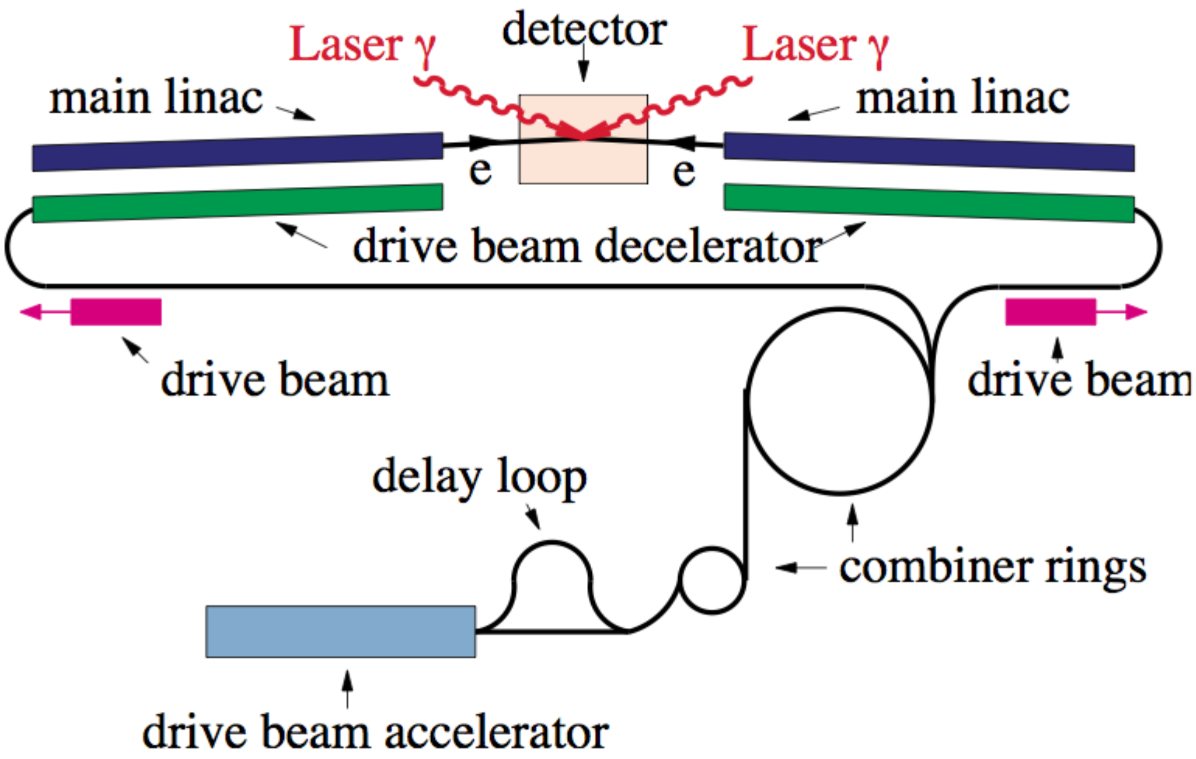


Figure 1: *Sketch of the possible layout of a* $\gamma\gamma$ *collider based on CLIC 1, the CLICHE concept [3].*

Examples of machines #2

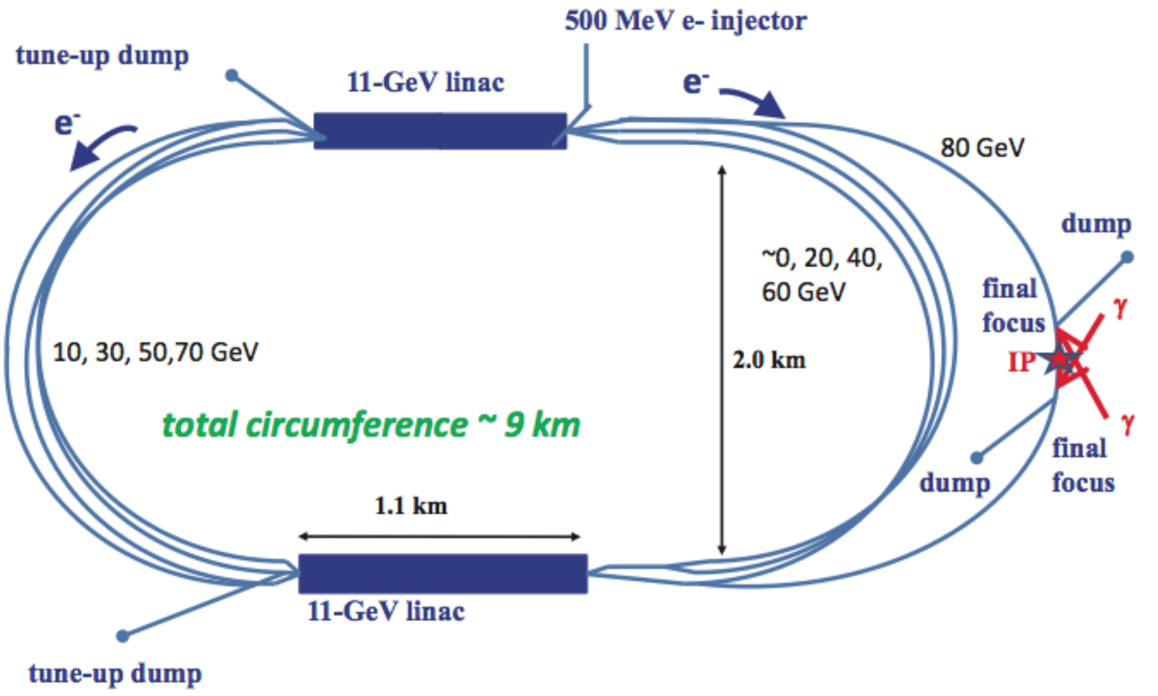


Figure 3: *Sketch of a layout for a $\gamma\gamma$ collider based on recirculating superconducting linacs – the SAPPHiRE concept.*

Comparison of Parameter with Higgs-factory inn mind… need to be revise

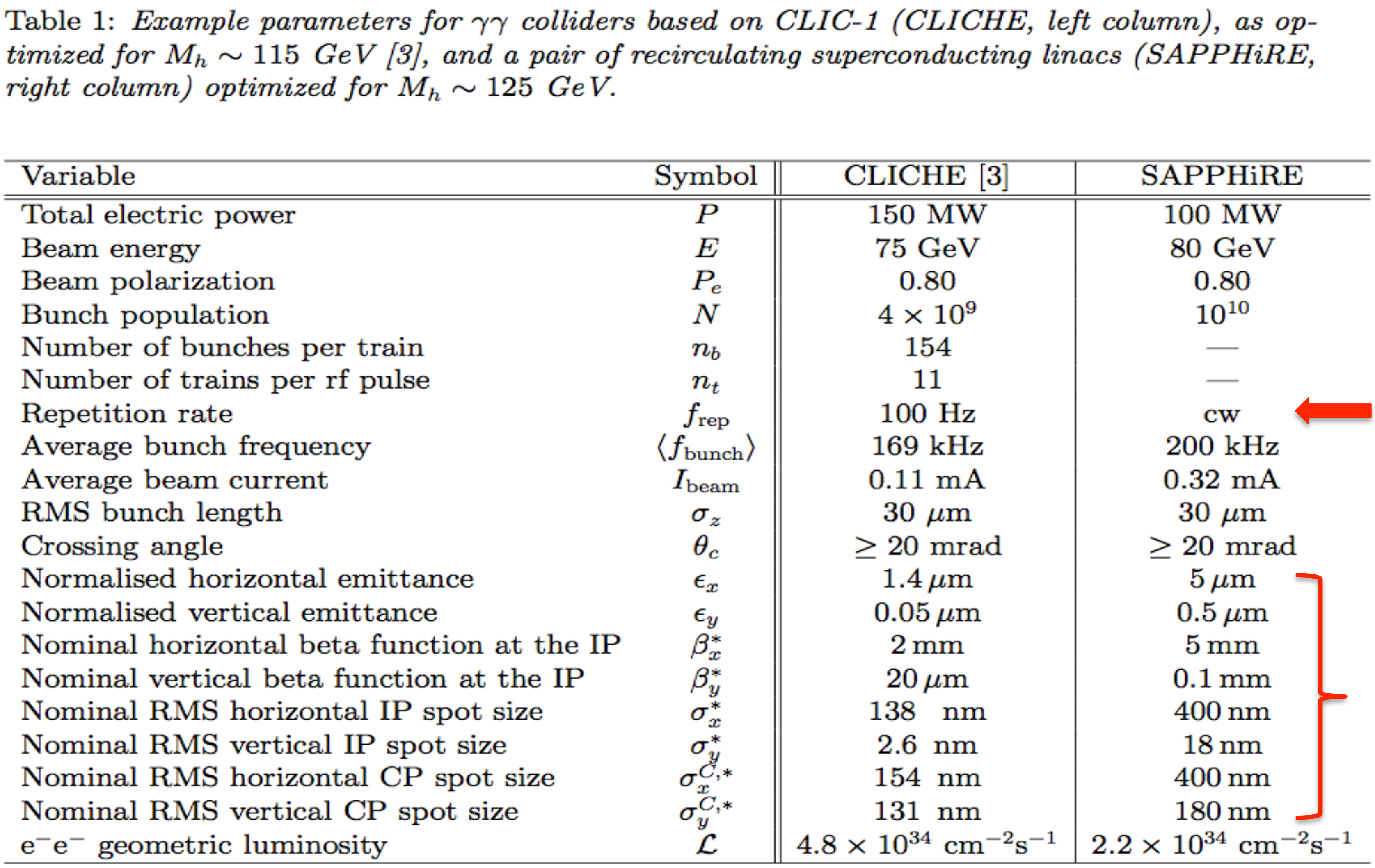


Table 1: *Example parameters for $\gamma\gamma$ colliders based on CLIC-1 (CLICHE, left column), as optimized for $M_h \sim 115$ GeV [3], and a pair of recirculating superconducting linacs (SAPPHiRE, right column) optimized for $M_h \sim 125$ GeV.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Total electric power	P	150 MW	100 MW
Beam energy	E	75 GeV	80 GeV
Beam polarization	P_e	0.80	0.80
Bunch population	N	4×10^9	10^{10}
Number of bunches per train	n_b	154	—
Number of trains per rf pulse	n_t	11	—
Repetition rate	$f_{\rm rep}$	100 Hz	cw
Average bunch frequency	$\langle f_{\rm bunch} \rangle$	169 kHz	200 kHz
Average beam current	$I_{\rm beam}$	0.11 mA	0.32 mA
RMS bunch length	σ_z	30 μm	30 μm
Crossing angle	θ_c	≥ 20 mrad	≥ 20 mrad
Normalised horizontal emittance	ϵ_x	1.4 μm	5 μm
Normalised vertical emittance	ϵ_y	0.05 μm	0.5 μm
Nominal horizontal beta function at the IP	β_x^*	2 mm	5 mm
Nominal vertical beta function at the IP	β_y^*	20 μm	0.1 mm
Nominal RMS horizontal IP spot size	σ_x^*	138 nm	400 nm
Nominal RMS vertical IP spot size	σ_y^*	2.6 nm	18 nm
Nominal RMS horizontal CP spot size	$\sigma_x^{C,*}$	154 nm	400 nm
Nominal RMS vertical CP spot size	$\sigma_y^{C,*}$	131 nm	180 nm
e^-e^- geometric luminosity	$\mathcal{L}$	4.8×10^{34} cm^{-2}s^{-1}	2.2×10^{34} cm^{-2}s^{-1}

Laser needs

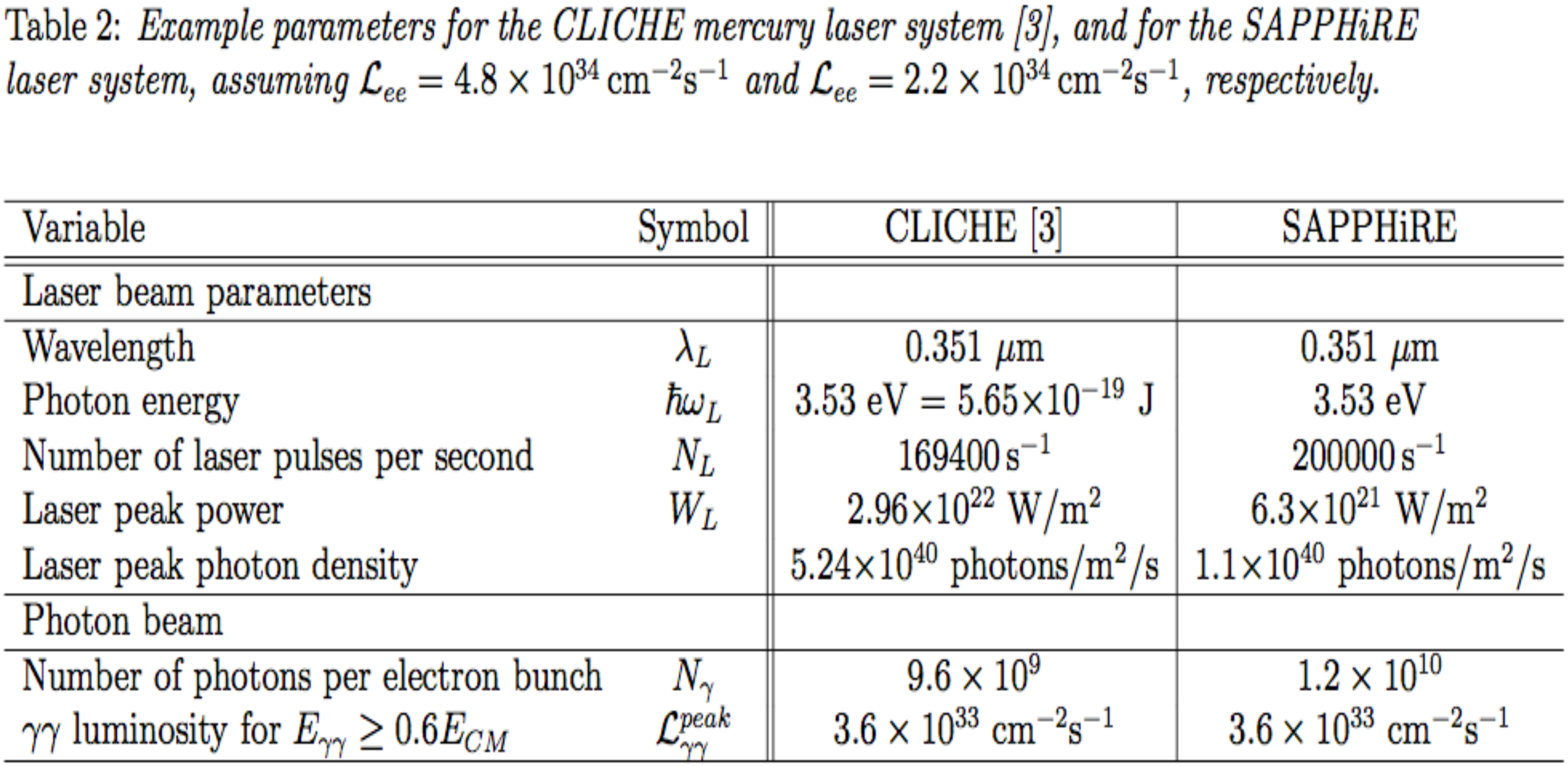


Table 2: *Example parameters for the CLICHE mercury laser system [3], and for the SAPPHiRE laser system, assuming* $\mathcal{L}_{ee} = 4.8 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ *and* $\mathcal{L}_{ee} = 2.2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, *respectively.*

Variable	Symbol	CLICHE [3]	SAPPHiRE
Laser beam parameters			
Wavelength	λ_L	$0.351\ \mu\mathrm{m}$	$0.351\ \mu\mathrm{m}$
Photon energy	$\hbar\omega_L$	$3.53\ \mathrm{eV} = 5.65\times10^{-19}\ \mathrm{J}$	$3.53\ \mathrm{eV}$
Number of laser pulses per second	N_L	$169400\,\mathrm{s}^{-1}$	$200000\,\mathrm{s}^{-1}$
Laser peak power	W_L	$2.96\times10^{22}\ \mathrm{W/m}^2$	$6.3\times10^{21}\ \mathrm{W/m}^2$
Laser peak photon density		$5.24\times10^{40}\ \mathrm{photons/m}^2/\mathrm{s}$	$1.1\times10^{40}\ \mathrm{photons/m}^2/\mathrm{s}$
Photon beam			
Number of photons per electron bunch	N_γ	9.6×10^9	1.2×10^{10}
$\gamma\gamma$ luminosity for $E_{\gamma\gamma} \geq 0.6 E_{CM}$	$\mathcal{L}_{\gamma\gamma}^{peak}$	$3.6 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$3.6 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

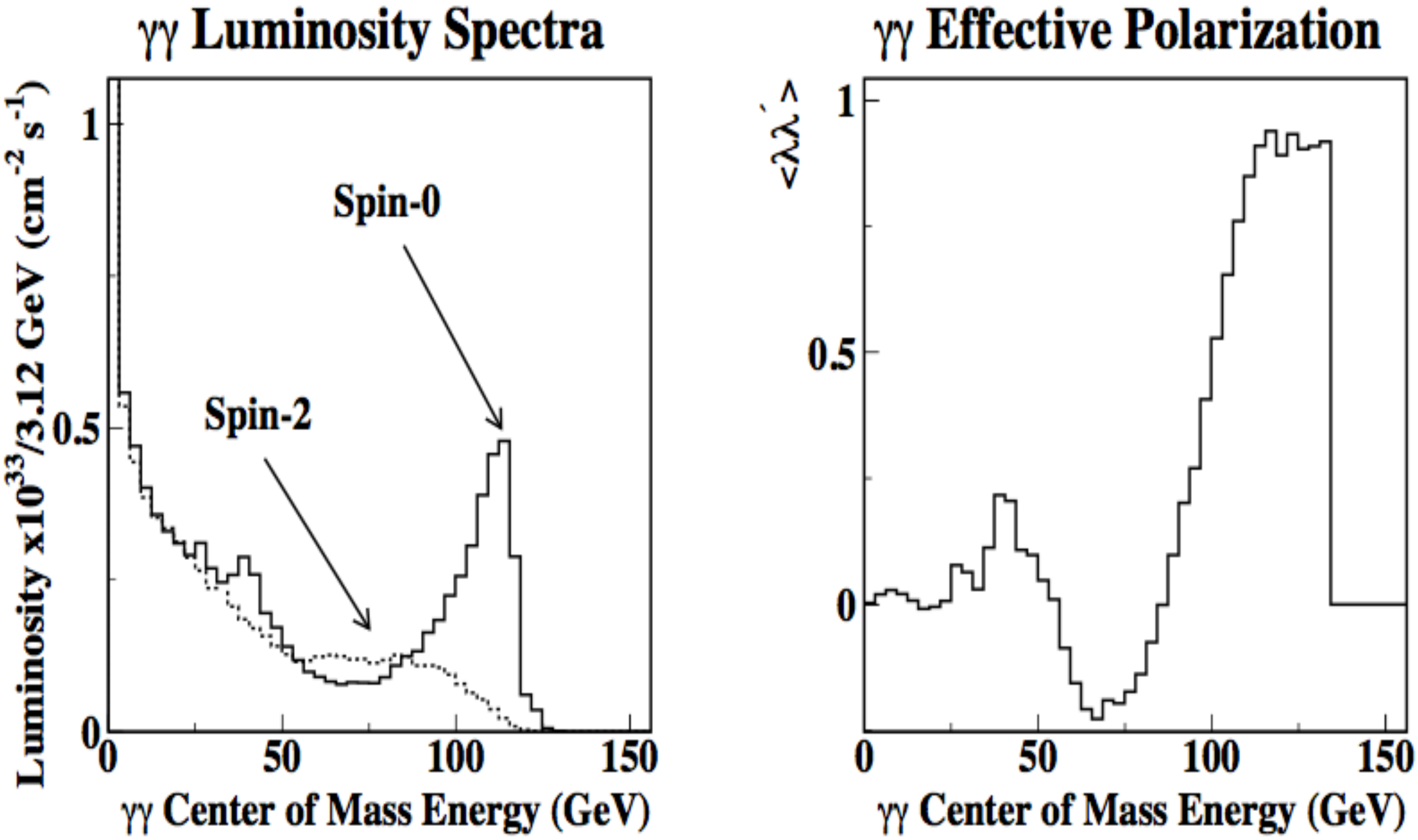


Figure 2: *Luminosity spectra and beam polarization as functions of* $E_{CM}(\gamma\gamma)$ *for the CLICHE parameters [3] for 75 GeV electrons obtained with* `DIMAD` *[6] and* `CAIN` *[7] for* $\mathcal{L}_{ee} = 4.8 \times 10^{34}\,\mathrm{cm}^{-2} s^{-1}$.

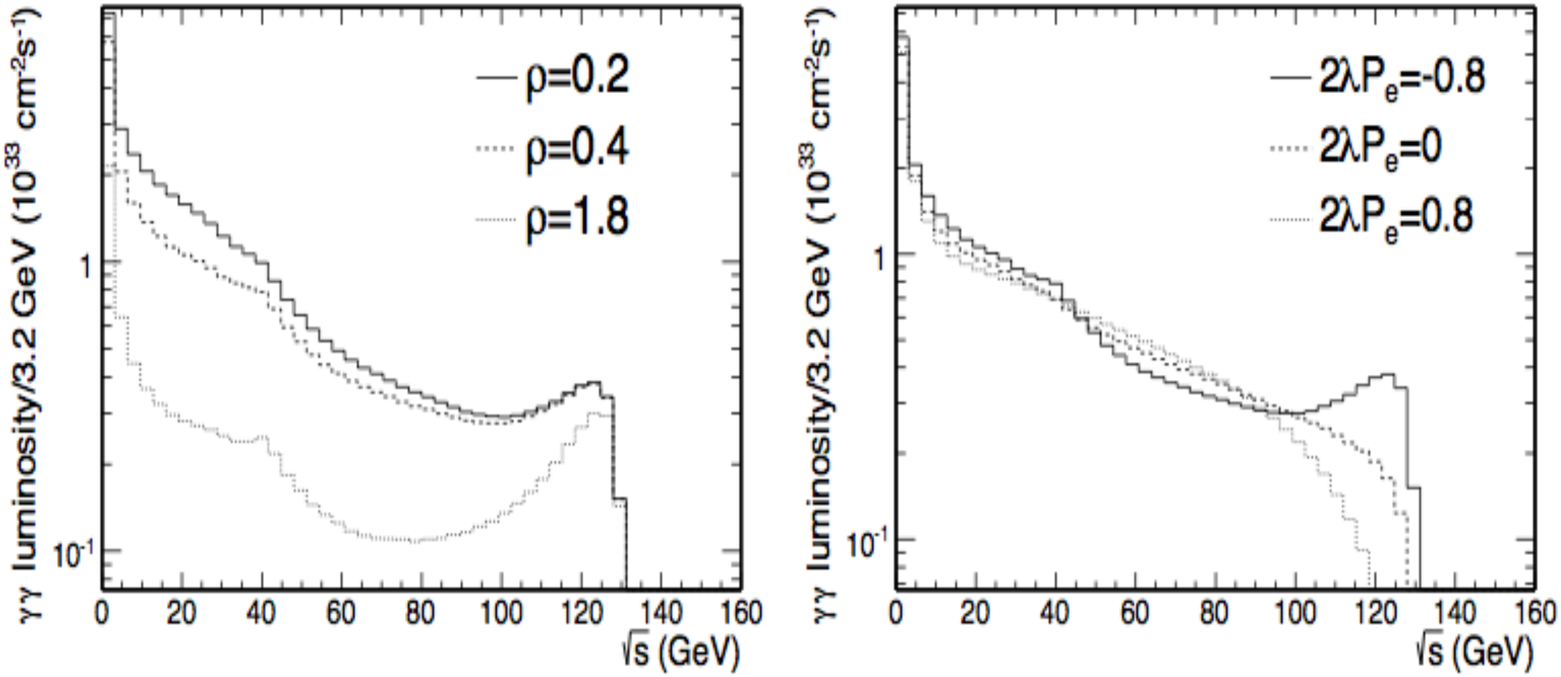


Figure 4: *Luminosity spectra for SAPPHiRE as functions of $E_{CM}(\gamma\gamma)$, computed using* `Guinea-Pig` *[9] for three possible normalized distances (left) and different polarizations of incoming particles (right).*

Energy loss not the only issue to be looked at more carefully

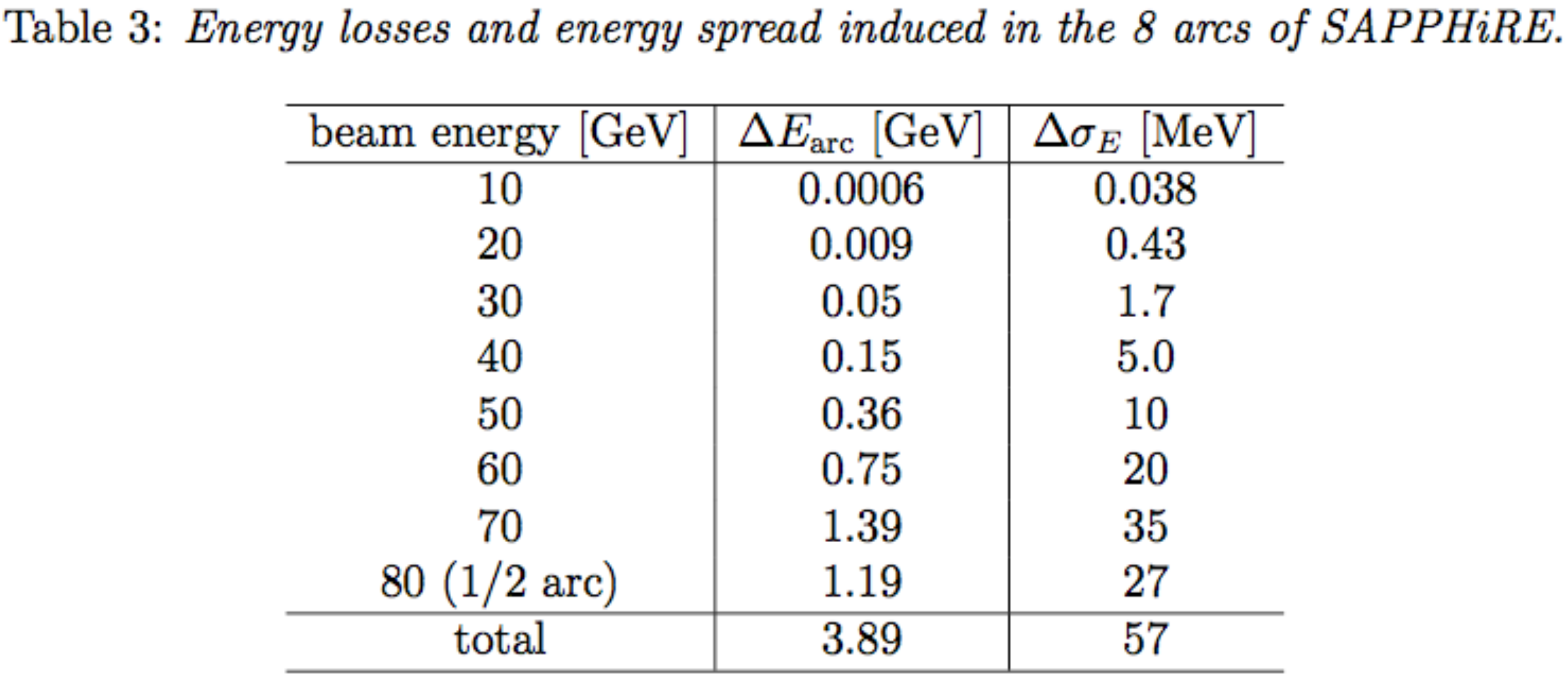


Table 3: *Energy losses and energy spread induced in the 8 arcs of SAPPHiRE.*

beam energy [GeV]	ΔE_{arc} [GeV]	$\Delta\sigma_E$ [MeV]
10	0.0006	0.038
20	0.009	0.43
30	0.05	1.7
40	0.15	5.0
50	0.36	10
60	0.75	20
70	1.39	35
80 (1/2 arc)	1.19	27
total	3.89	57

Conclusions

- We should request to ICFA & Snowmass study for support to look at the physics case and possible designs of $\gamma\gamma$ colliders
  - Independently of the e+e- collider program
- We need to keep it:
  - Simple and cost effective
  - With very interesting and relevant physics
  - While Advancing the technical aspects for future high energy $\gamma\gamma$ colliders