Gamma-gamma considerations for CLIC

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special thanks to Daniel Schulte

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Photon Beams Workshop
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Outline

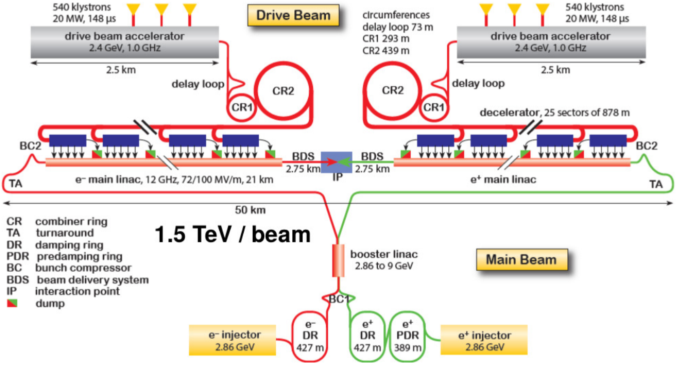
CLIC Project

Project

2-beam scheme allows to sustain a gradient of 100 MeV/m

$\Downarrow$

Footprint $<$ 50 km for collisions at $E_{\mathrm{CM}} = 3$ *TeV*



CLIC is the only e^-e^+ LC capable of reaching multi-TeV

CERN Strategy

Scientific strategy: 3 main directions

F. Gianotti,
A great year ahead of us

Full exploitation of the LHC:

- successful Run 2 (~100 fb^{-1} of good data) and LS2
- construction of LIU/HL-LHC on track and financially secured (accelerator and experiments)

Complementary diverse programme serving a broad community, e.g.:

- ongoing experiments and projects at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE 2)
- participation in (global) neutrino projects outside Europe (presently mainly LBNF in the US) through CERN Neutrino Platform

Preparation for the future of CERN (and of the discipline):

- vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (→ enhance worldwide coordination)
- design studies for future accelerators: CLIC, FCC (including HE-LHC*)
- develop a compelling diverse scientific programme complementary to high-E colliders → "Physics with injectors" WG (involving accelerator experts, experimentalists, theorists) is being set up → explore future exciting opportunities (beam dump experiments, precision measurements, etc.) using unique capabilities of CERN's rich accelerator complex, complementary to other efforts in the world → produce report by ~ 2018

CLIC Strategy

Preparing input for European Strategy Particle Physics 2020

- Project Plan for CLIC as a strong post-LHC option
  - Suited for conducting precise studies of potential LHC findings
- Initial costs compatible with CERN budget
  - Cost optimization from 380 Gev $\Rightarrow$3 TeV
  - Reduce power consumption
    - High-efficiency Klystrons (380 GeV case)
    - Permanent magnets (3 TeV case)
- Upgradeable in stages over 20-30 years

$\Downarrow$ **"Rebaselining"**† $\Downarrow$

Optimize machine design w.r.t. cost and power for a staged approach to reach multi-TeV scale

† Updated baseline for a staged CLIC, *CERN-2016-004, arXiv:1608.07537*

Parameters

Parameter	Unit	380 GeV	1.5 TeV	3 TeV
Total Lumi. ($\mathcal{L}$)	$[10^{34} cm^{-2} s^{-1}]$	1.5	3.7	5.9
Peak Lumi. ($\mathcal{L}_{\text{peak}}$)	$[10^{34} cm^{-2} s^{-1}]$	0.9	1.4	2.0
IP beam size ($\sigma^*_{x/y}$)	[nm]	149/2.9	60/1.5	45/1.0
Emittance ($\gamma\epsilon_{x/y}$)	[nm]	920/20	660/20	660/20
Bunch Charge (Q)	$[10^9]$	5.2	3.72	3.72
Bunch length (σ_z)	$[\mu m]$	70	44	44
Linac Rep. Freq.	[Hz]	50	50	50
# Bunches / train		352	312	312
Bunch separation	[ns]	0.5	0.5	0.5
Acc. Gradient	[MV/m]	72	100	100
Site Length	[km]	11	29	50
Total site power	[MW]	252	364	589

Efforts are focus on reducing cost and power consumption at all stages

Parameters II

Parameter choices are determined by beam dynamics studies;

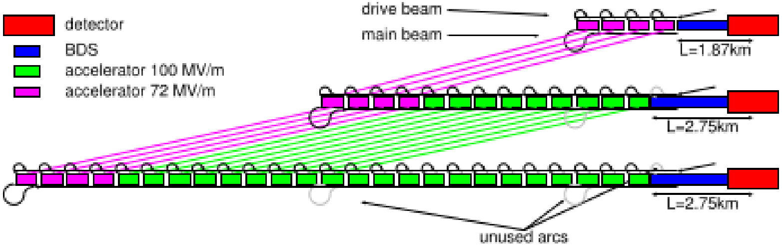
- Q, σ_z and bunch spacing are limited by wakefield in the ML
- ϵ_x is mainly determined by the DR as a function of Q
- ϵ_y is given by the DR, RTML, ML and BDS
- σ_y^* is determined by FFS
- σ_x^* has two sources for the lower limit
  - FFS
  - beamstrahlung effect $\Rightarrow$ Q,$\mathcal{L}$-spectrum

Thinking forward to $\gamma\gamma$-collider:

- Only clear parameter which could be further pushed is σ_x^*
  What is then the limitation from FFS?
- Other parameters may be optimized
  - Different parameters choice may provide an overall $\mathcal{L}$ gain, despite compromising one of the mentioned variables

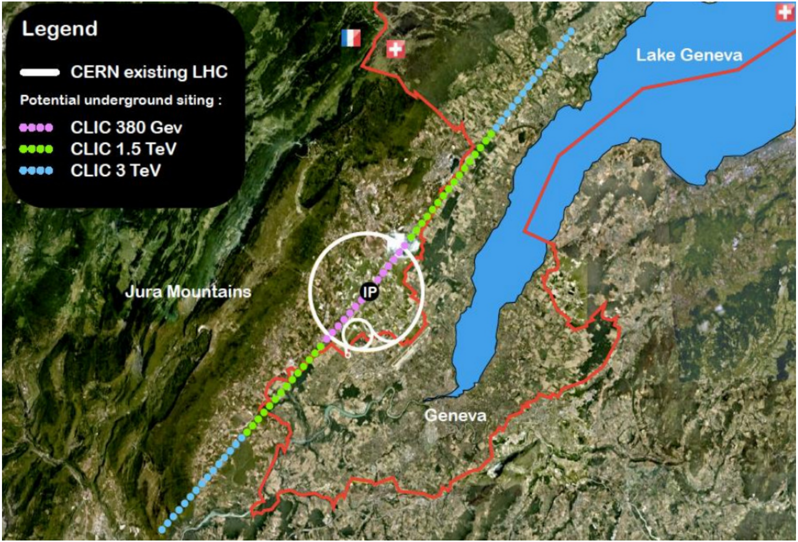
Stages

- The accelerator is foreseen to be built in three stages with center-of-mass energies of 380 GeV, 1.5 TeV and 3 TeV
- At each energy stage the center-of-mass energy can be tuned to lower values ($\approx 1/3$), with limited loss of luminosity



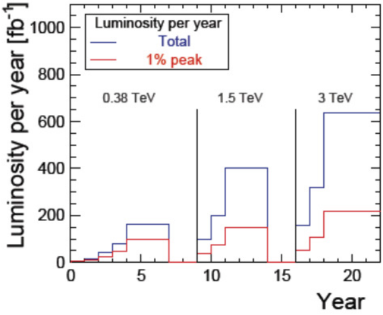
- Only 1 DB is required for feeding both ML at $E_{\rm CM} \leq 1.5$ TeV

Site


Legend
CERN existing LHC
Potential underground siting :
CLIC 380 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva

Run Model

- The overall duration of the three-stage program is 22 years
- 3 energy stages (0.38/1.5/3.0) each lasting 7, 5 and 6 years



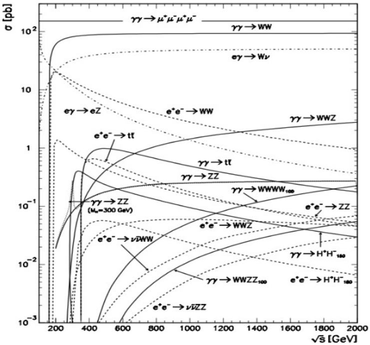
Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{int}$ (fb^{-1})
1	380	500
	350	100
2	1500	1500
3	3000	3000

- Initial 7 years of construction
- 2 years upgrade periods between stages

$\gamma\gamma$-Collider

Physics Case

- Higher sensitivity due to higher cross sections[†]
- Ability to manipulate the photon beam polarization



- Unique in understanding CP structure (linearly polarized beams)
- High precision measurements $\Gamma_{\gamma\gamma}$ to 2% (Model independent)

[†] *Physics at Photon Colliders*, Mayda M. Velasco, ICFA mini-workshop $\gamma\gamma$-colliders, 2017

Codes Implemented

- PLACET is used to obtain particle distributions at the IP
- Scatter† function in *C*
  - Beam is backtracked to conversion plane
  - Interaction with the laser
  - Scattered electrons and hard photons propagated to IP
- GUINEA-PIG calculates luminosity
  - for $e^- - e^-, e^- - \gamma, \gamma - \gamma$
  - Coherent and incoherent pairs
  - Photons production
  - Hadrons

PLACET and GUINEA-PIG have been cross-checked with similar codes (Elegant, MADX) and CAIN respectively, with reasonable agreement

† more details in D. Shulte, *TESLA-Report 1997-08*.

CLIC FFS Parameters

Parameter	Unit	380 GeV
Total Lumi. ($\mathcal{L}$)	$[10^{34} cm^{-2} s^{-1}]$	1.5
Peak Lumi. ($\mathcal{L}_{\mathrm{peak}}$)	$[10^{34} cm^{-2} s^{-1}]$	0.9
IP beam size ($\sigma^*_{x/y}$)	[nm]	149/2.9
IP betas ($\beta^*_{x/y}$)	[mm]	8.2/0.1
Emittance ($\gamma\epsilon_{x/y}$)	[nm]	920/20
Energy spread ($\Delta p/p$)	[%]	0.3
Bunch Charge (Q)	$[10^9]$	5.2
Bunch length (σ_z)	[μm]	70
# Bunches / train		352
Chromaticity (ξ_y)		43000
$\mathrm{L}_{\mathrm{QD0-IP}}$	[m]	4.3

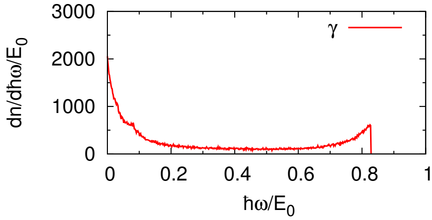
Conversion

e^--beam and γ-beam parameters after conversion

Parameter	Unit	e^-	γ
IP beam size ($\sigma^*_{x/y}$)	[nm]	149/4.4	219/190
Energy spread ($\Delta p/p$)	[%]	135	170

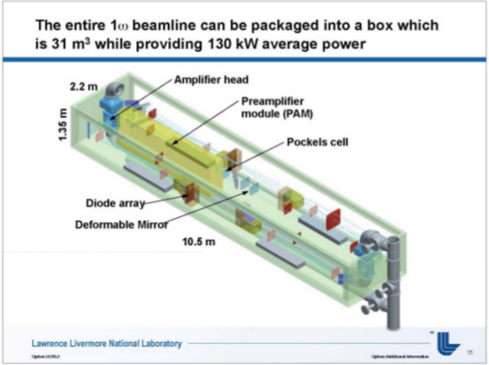
Assumed values for conversion :

- d = 1 mm (dist. from laser to IP)
- $\rho = \frac{d}{\gamma \sigma^*_y} = 1$
- $k = 1$ (conversion efficiency)
- max E_γ=157 GeV ($x = 4.83$)
- $\lambda_e = 80\%$ (electron helicity)
- P_γ= -1 (laser polarization)



Laser

- Resonator cavities are not possible since train length is too small
- Laser ignition thermonuclear facility (Project LIFE @ LLNL) †

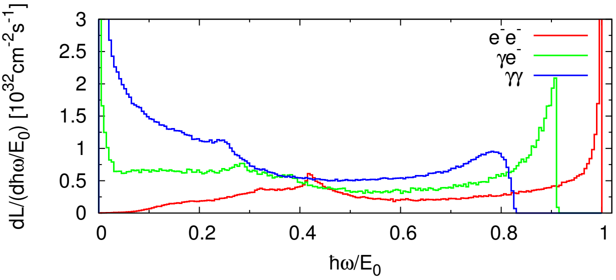


16 Hz
8.125 kJ/pulse
130 kW aver. power

† https://web.archive.org/web/20120724051005/https://life.llnl.gov/life_design/laser_system.php

$\mathcal{L}$-Spectra

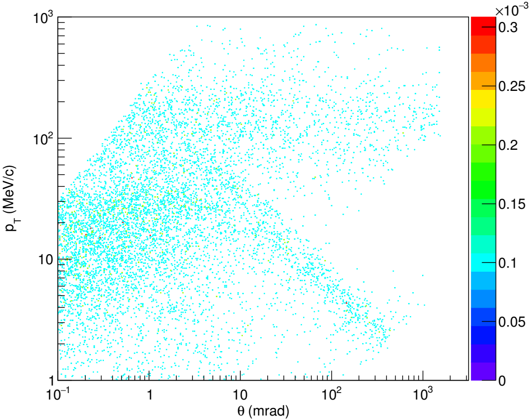
Parameter	Unit	e^-e^-	$e^-\gamma$	$\gamma\gamma$
Total Lumi. ($\mathcal{L}$)	$[10^{33} cm^{-2} s^{-1}]$	0.7	1.1	1.73
Peak Lumi. ($\mathcal{L}_{\mathrm{peak}}$)	$[10^{33} cm^{-2} s^{-1}]$	0.3	-	0.9



Incoherent Pairs

Criteria for hitting the BeamCal:

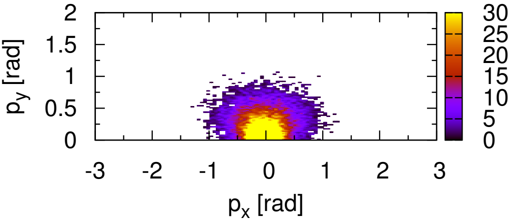
- polar angle $\theta \geq 10mrad$
- transverse momentum $p_T \geq 20MeV$

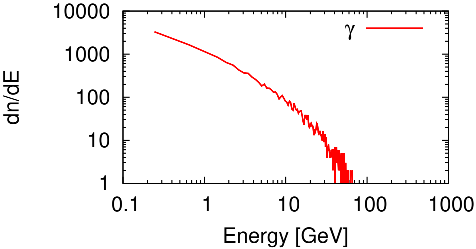


Pairs captured by detector 18%

Dissipated Power : 15 W

Photons



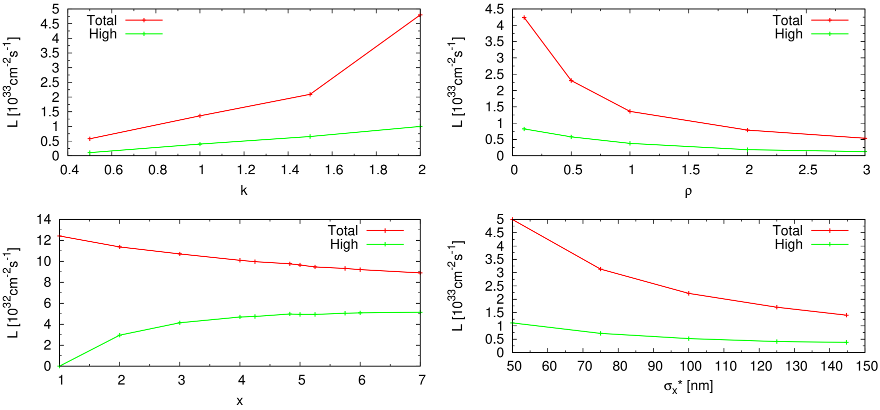


Photons captured by detector 70%

Dissipated Power : 3.1 W

Parameters Scan

Scan of k, ρ, x and σ_x^* parameters



Reducing σ_x^* a factor 2 is possible

CLIC FFS Parameters

Parameter	Unit	380 GeV
Total Lumi. ($\mathcal{L}$)	$[10^{34} cm^{-2} s^{-1}]$	5.9
Peak Lumi. ($\mathcal{L}_{\mathrm{peak}}$)	$[10^{34} cm^{-2} s^{-1}]$	2.0
IP beam size ($\sigma^*_{x/y}$)	[nm]	45/1.0
IP betas ($\beta^*_{x/y}$)	[mm]	10/0.07
Emittance ($\gamma\epsilon_{x/y}$)	[nm]	660/20
Energy spread ($\Delta p/p$)	[%]	0.3
Bunch Charge (Q)	$[10^9]$	3.7
Bunch length (σ_z)	$[\mu m]$	44
# Bunches / train		312
Chromaticity (ξ_y)		50000
$L_{\mathrm{QD0-IP}}$	[m]	3.5

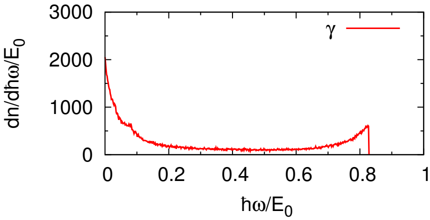
Conversion

e^--beam and γ-beam parameters after conversion

Parameter	**Unit**	e^-	γ
IP beam size ($\sigma^*_{x/y}$)	[nm]	45/1.8	77/77
Energy spread ($\Delta p/p$)	[%]	135	170

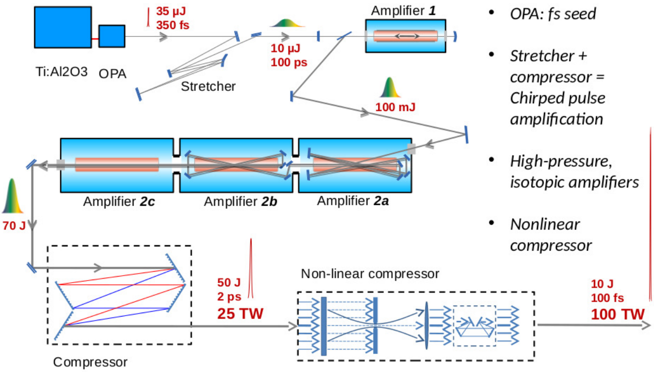
Assumed values for conversion :

- d = 1 mm (dist. from laser to IP)
- $\rho = \frac{d}{\gamma \sigma^*_y} = 0.3$
- $k = 1$ (conversion efficiency)
- max E_γ=1243 GeV ($x = 4.83$)
- $\lambda_e = 80\%$ (electron helicity)
- P_γ= -1 (laser polarization)



Laser

- CO_2 lasers are well suited † in terms of λ

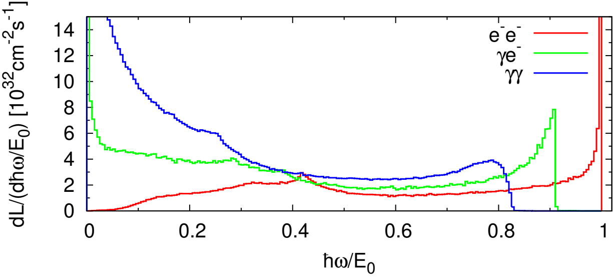


0.2 Hz
100 fs
100 TW

† *CO2 lasers for Compton x-ray sources and gamma colliders*, I. Pogorelsky @ Photon Beams Workshop, 2017

$\mathcal{L}$-Spectra

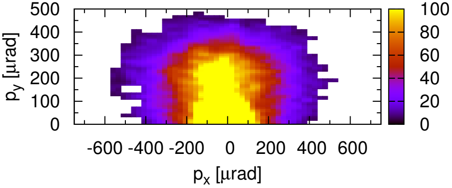
Parameter	Unit	e^-e^-	$e^-\gamma$	$\gamma\gamma$
Total Lumi. ($\mathcal{L}$)	$[10^{33} cm^{-2} s^{-1}]$	2.3	6.1	10.0
Peak Lumi. ($\mathcal{L}_{\text{peak}}$)	$[10^{33} cm^{-2} s^{-1}]$	0.9	-	3.9

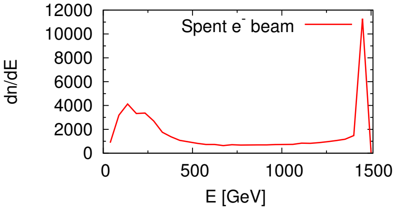


Spent e^- beams

Criteria for hitting the BeamCal:

- polar angle $\theta \geq 10$ *mrad*
- transverse momentum $p_T \geq 20$ *MeV*





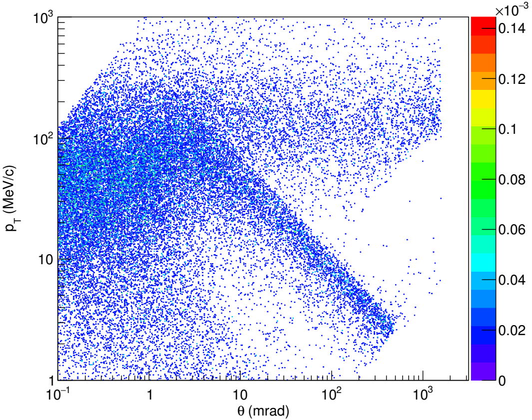
e^- captured by detector 0%

Dissipated Power : 0 W

Incoherent Pairs

Criteria for hitting the BeamCal:

- polar angle $\theta \geq 10$ *mrad*
- transverse momentum $p_T \geq 20$ *MeV*



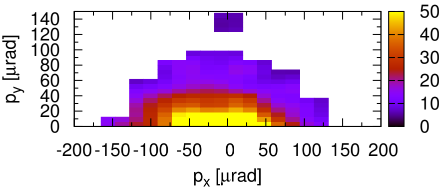
Pairs captured by detector 26%

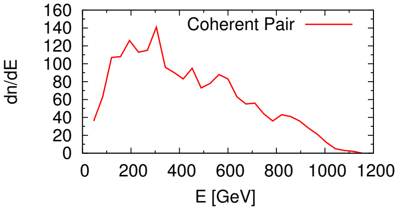
Dissipated Power : 60 W

Coherent Pairs

Criteria for hitting the BeamCal:

- polar angle $\theta \geq 10\ mrad$
- transverse momentum $p_T \geq 20\ MeV$

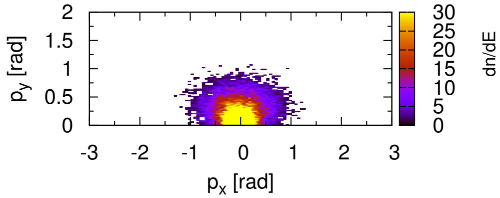


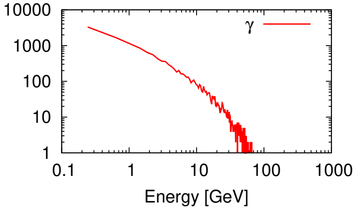


Pairs captured by detector 0%

Dissipated Power : 0 W

Photons





Photons intercepted by detector 87%

Dissipated Power : 32 W

Hadrons

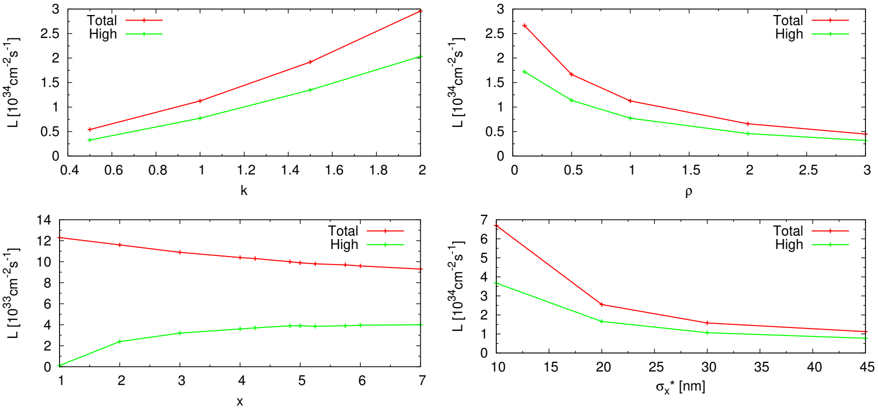
Number of Hadronic events per bunch crossing:

Collision	Beam	Rate [x b.c.]	Beam	Rate [x b.c.]
e^-e^-	1	0.02	2	0.014
$e^-\gamma$	1	0.12	2	0.010
γe^-	1	0.12	2	0.010
$\gamma\gamma$	1	0.35	2	0.35
Sum	1	0.6	2	0.55

Tracking of these hadronics events is pending

Parameters Scan

Scan of k, ρ, x and σ_x^* parameters



Again reducing σ_x^* improves total and peak $\mathcal{L}$. others could be studied in detail

CONCLUSIONS

Summary

Parameter	Unit	380 GeV	Opt	3 TeV	Opt
Total Lumi. ($\mathcal{L}$)	$[10^{33} cm^{-2} s^{-1}]$	1.73	3.5	10	15
Peak Lumi. ($\mathcal{L}_{\rm peak}$)	$[10^{33} cm^{-2} s^{-1}]$	0.9	1.8	3.9	7.7

- Attractive luminosities for both 380 GeV and 3 TeV options with the current designs
- Even more when reducing σ_x^* by half
  - Understanding limitations of FFS on σ_x^* (common interest in the acc, community)
- A detailed study would be necessary to optimize x, ρ and k parameters
  - Evaluate the impact on background and others
  - Lasers are getting closer to requirements