XCC

XCC - XFEL Compton Collider Higgs Factory

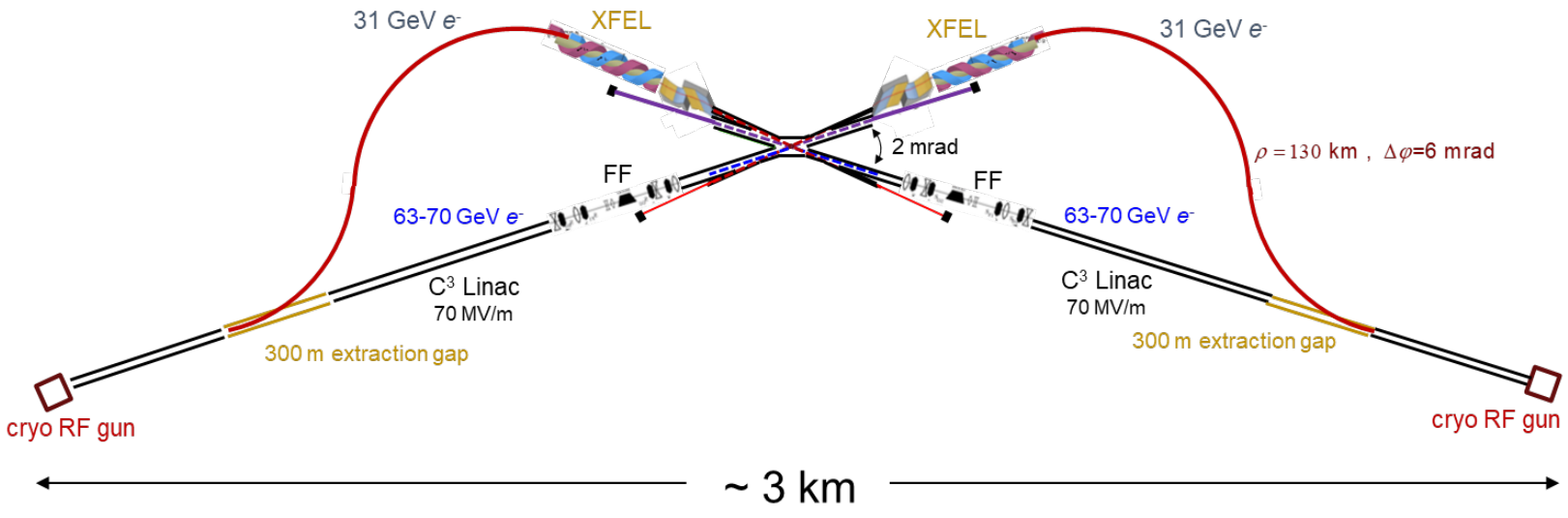
Tim Barklow

AF03 Discussion

7/18/22

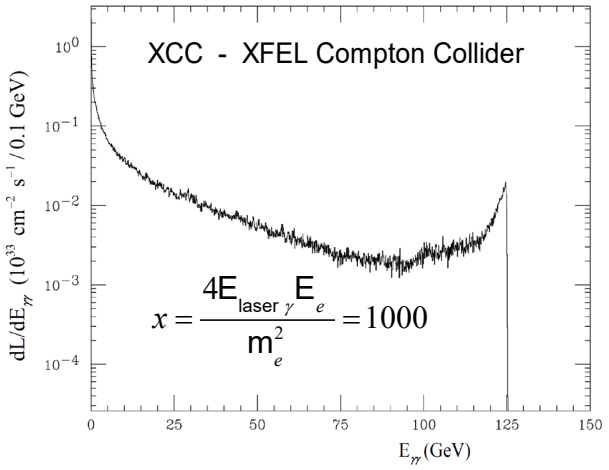
Baseline Design/Layout and Parameters

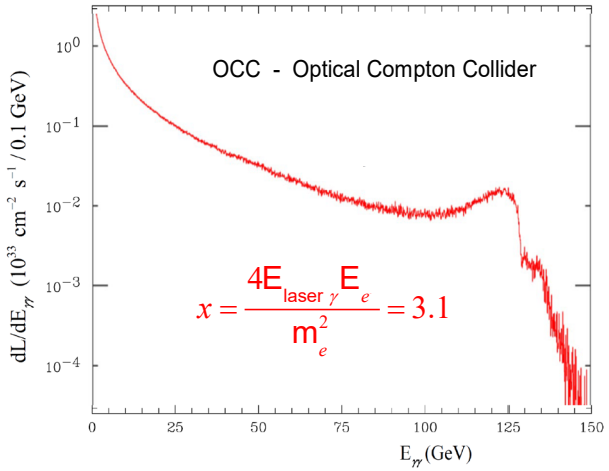
XCC



Final Focus parameters	Approx. value	XFEL parameters	Approx. value
Electron energy	62.8 GeV	Electron energy	31 GeV
Electron beam power	0.57 MW	Electron beam power	0.28 MW
β_x/β_y	0.03/0.03 mm	normalized emittance	120 nm
$\gamma\epsilon_x/\gamma\epsilon_y$	120/120 nm	RMS energy spread $\langle\Delta\gamma/\gamma\rangle$	0.05%
σ_x/σ_y at e^-e^- IP	5.4/5.4 nm	bunch charge	1 nC
σ_z	20 μm	Linac-to-XFEL curvature radius	133 km
bunch charge	1 nC	Undulator B field	$\gtrsim$ 1 T
Rep. Rate at IP	240 × 38 Hz	Undulator period λ_u	9 cm
σ_x/σ_y at IPC	12.1/12.12 nm	Average β function	12 m
$\mathcal{L}_{\text{geometric}}$	9.7×10^{34} cm^2 s^{-1}	x-ray λ (energy)	1.2 nm (1 keV)
δ_E/E	0.05%	x-ray pulse energy	0.7 J
L^* (QD0 exit to e^- IP)	1.5m	pulse length	40 μm
d_{cp} (IPC to IP)	60 μm	$a_{\gamma x}/a_{\gamma y}$ (x/y waist)	21.2/21.2 nm
QD0 aperture	9 cm diameter	non-linear QED ξ^2	0.10

Site parameters	Approx. value
crossing angle	2 mrad
total site power	85 MW
total length	3.0 km





Machine	E_{e^-} (GeV)	N_{e^-} (nC)	Polarization	N_H/yr	N_{Hadronic}/N_H	$N_{\text{minbias/BX}}$
XCC	62.8	1.0	90% e^-	34,000	170	9.5
OCC	86.5	1.0	90% e^-	30,000	540	50
ILC	125	3.2	-80% e^- +30% e^+	42,000	140	1.3
ILC	125	3.2	+80% e^- -30% e^+	28,000	60	1.3

Key Technologies

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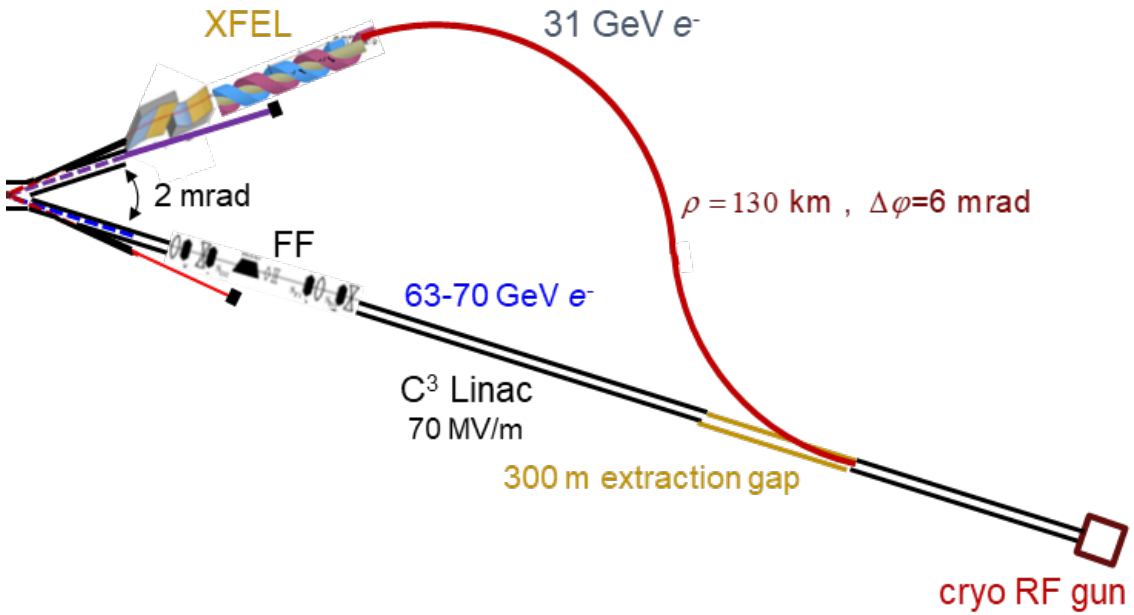

- Cryo Cu RF Gun, 120 nm-rad emittance, 76 1nC bunches, 240 Hz, 90% pol.
- Cryo Cu Linac, 70 MV/m, 76 1nC bunches, 240 Hz
- 700 mJ/pulse 1 keV γ XFEL
- X-ray focusing to 70 nm FWHM for 700 mJ/pulse 1 keV γ

Accelerator design and challenges

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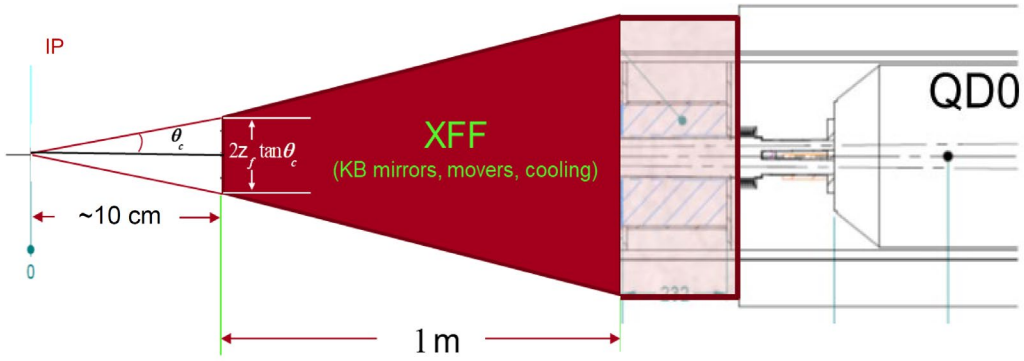
- Focus Round Beam to $\sigma_{x,y}$ = 5.5 nm
  - Round beam FF, not tested experimentally
  - 5X smaller beta function than CLIC; demands investigation of tolerances
  - Integration of FF with X-ray optics, L* optimization, etc.
- 1 keV γ XFEL with 700 mJ/pulse
  - Current soft x-ray XFEL's run with a few mJ/pulse
  - XCC XFEL design validated with GENESIS but clearly an XFEL with ~100 mJ/pulse must be demonstrated
- Focus 1 keV γ XFEL with 700 mJ/pulse to 70 nm FWHM
  - Soft X-rays more challenging to focus than harder x-rays
  - Big unknown is how to focus such a powerful beam.



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Civil Engineering

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- 3 km total footprint
- Rely on C^3 for civil engineering development

Sustainability

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Table 6: Summary of design parameters for $e^-\gamma$ mode at $\sqrt{s} = 140$ GeV.

Final Focus parameters	Approx. value	XFEL parameters	Approx. value
Electron energy	70.0 GeV	Electron energy	31 GeV
Electron beam power	0.64 MW	Electron beam power	0.28 MW
β_x/β_y	0.03/0.03 mm	normalized emittance	120 nm
$\gamma\epsilon_x/\gamma\epsilon_y$	1200/12 nm	RMS energy spread $\langle\Delta\gamma/\gamma\rangle$	0.05%
σ_x/σ_y at e^-e^- IP	16.2/1.6 nm	bunch charge	1 nC
σ_z	10 μm	Linac-to-XFEL curvature radius	133 km
bunch charge	1 nC	Undulator B field	$\gtrsim$ 1 T
Rep. Rate at IP	240 × 38 Hz	Undulator period λ_u	9 cm
σ_x/σ_y at IPC	17.1/1.71 nm	Average β function	12 m
$\mathcal{L}_{\text{geometric}}$	1.1×10^{35} cm^2 s^{-1}	x-ray λ (energy)	1.2 nm (1 keV)
δ_E/E	0.05%	x-ray pulse energy	0.7 J
L^* (QD0 exit to e^- IP)	1.5m	pulse length	40 μm
d_{cp} (IPC to IP)	10 μm	$a_{\gamma x}/a_{\gamma y}$ (x/y waist)	15.3/10.0 nm
QD0 aperture	9 cm diameter	non-linear QED ξ^2	0.29
Site parameters	Approx. value		
crossing angle	2 mrad		
total site power	88 MW		
total length	$\sim$ 3.0 km		

Parameter	Units	Value
Single Beam Power (70 GeV e$^-$)	MW	0.64
Single Beam Power (31 GeV e$^-$)	MW	0.28
Total Beam Power	MW	1.84
Electrical Power for RF	MW	23
Electrical Power for Cryo-Cooler	MW	34
Accelerator Complex Power	MW	31
Site Power	MW	88

Proposals for upgrades and extensions

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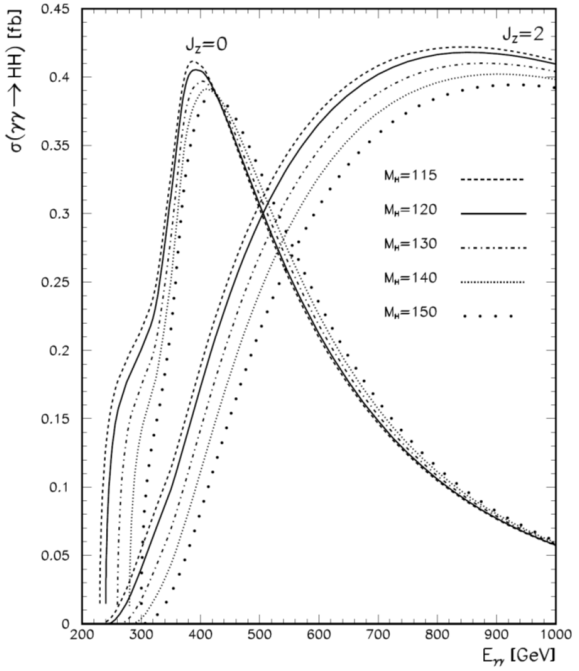
- 0.5 X 10^6 Higgs Events in 8 years by doubling number of bunches from 76 to 152
- Larger lumi upgrade required for e- γ -> e- H program at 140 GeV: 76 to 290
- Higgs Self Coupling study with $\gamma\gamma$->HH through energy upgrade to 280 GeV
  - 3.3 km footprint assuming gradient upgrade 70 MV/m -> 120 MV/m

Coupling precision
ILC vs XCC
0.5 x 10^6 Higgs events

coupling a	ILC Δa (%)	XCC Δa (%)
HZZ	0.57	1.2
HWW	0.55	1.2
Hbb	1.0	1.4
$H\tau\tau$	1.2	1.4
Hgg	1.6	1.7
Hcc	1.8	1.8
$H\gamma\gamma$	1.1	0.77
$H\gamma Z$	9.1	10.0
$H\mu\mu$	4.0	3.8
Γ_{tot}	2.4	3.8
Γ_{inv} †	0.36	–
Γ_{other} †	1.6	2.7

† 95% C.L. limit



$\sigma(\gamma\gamma \to HH)$ @ $\sqrt{s} = 280$ GeV $\approx$ $\sigma(e^+e^- \to ZHH)$ @ $\sqrt{s} = 500$ GeV

Relevance to far-future experiments

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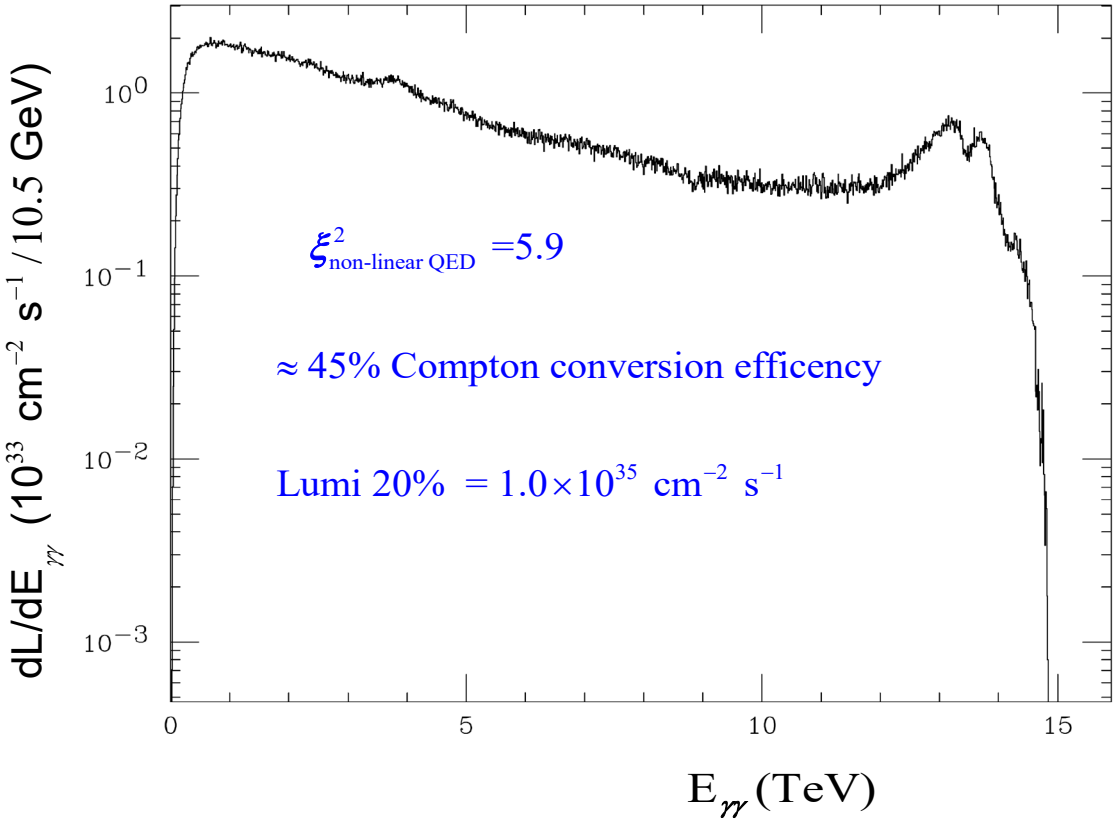
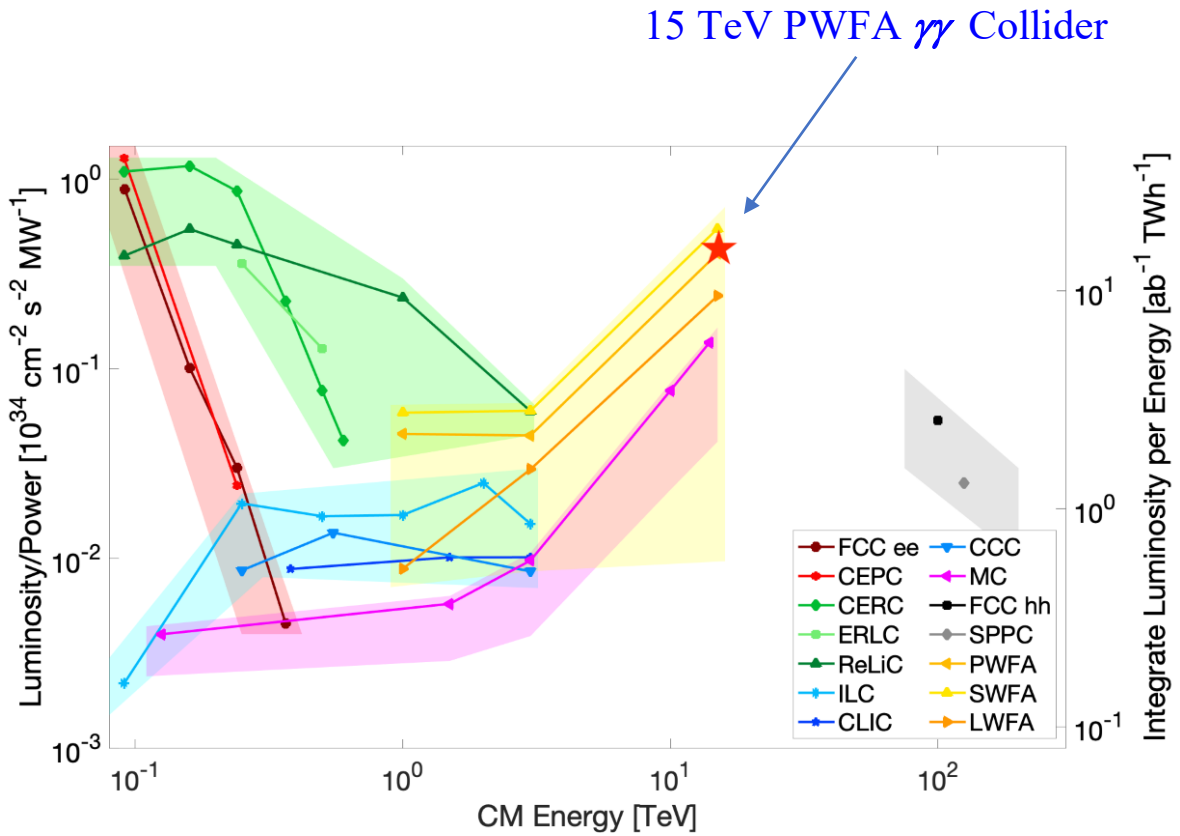
15 TeV PWFA $\gamma\gamma$ Collider

$x = 40 \Rightarrow$ 7875 GeV $e^- + 0.33$ eV γ (λ=3.7 μm) $E_{pulse} = 590$ J

$a_{\gamma FWHM} = 0.24$ mm $\quad \sigma_{\gamma z} = 270\ \mu$m $\quad d_{cp} = 0.82$mm

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

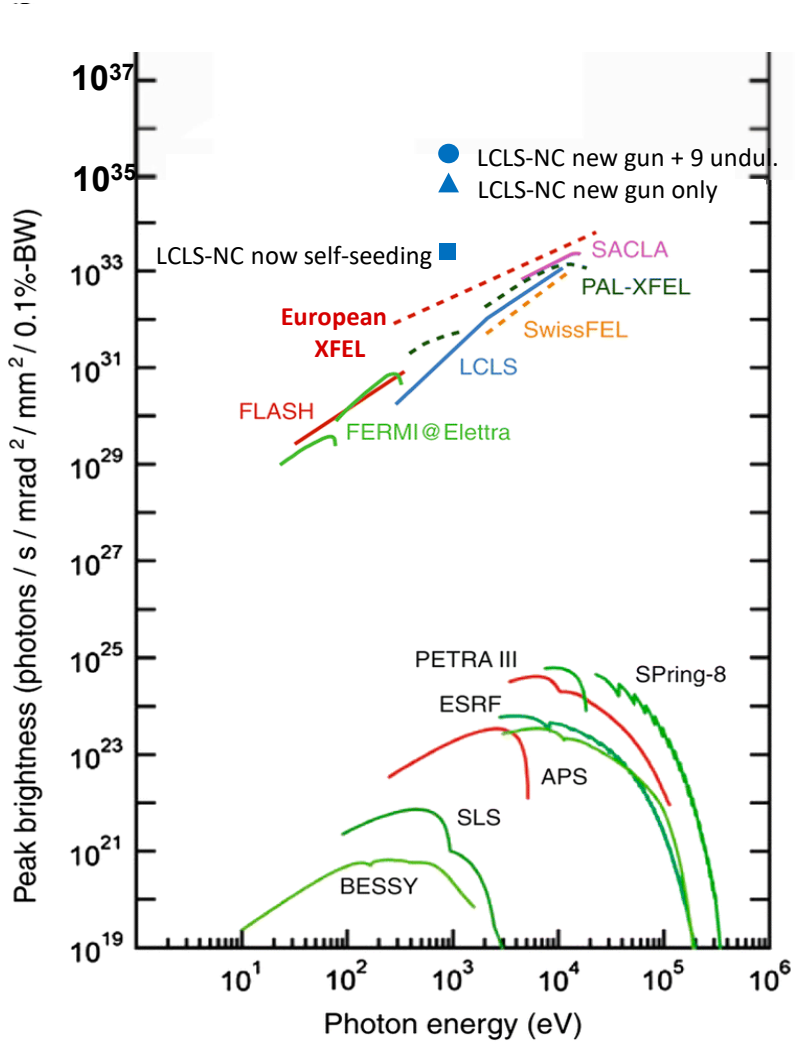




State of Proposal and R&D needs (5-10 years) XCC

100 mJ soft x-ray production and focusing Demo concurrent with C3 Demo:

	2019-2024	2025-2034
C^3 Demo: Demo proposal		
C^3 Demo: Demo test		
LCLS-X: 100 nm Cu RF Injector		
LCLS-X: 100 mJ LCLS soft x-ray		



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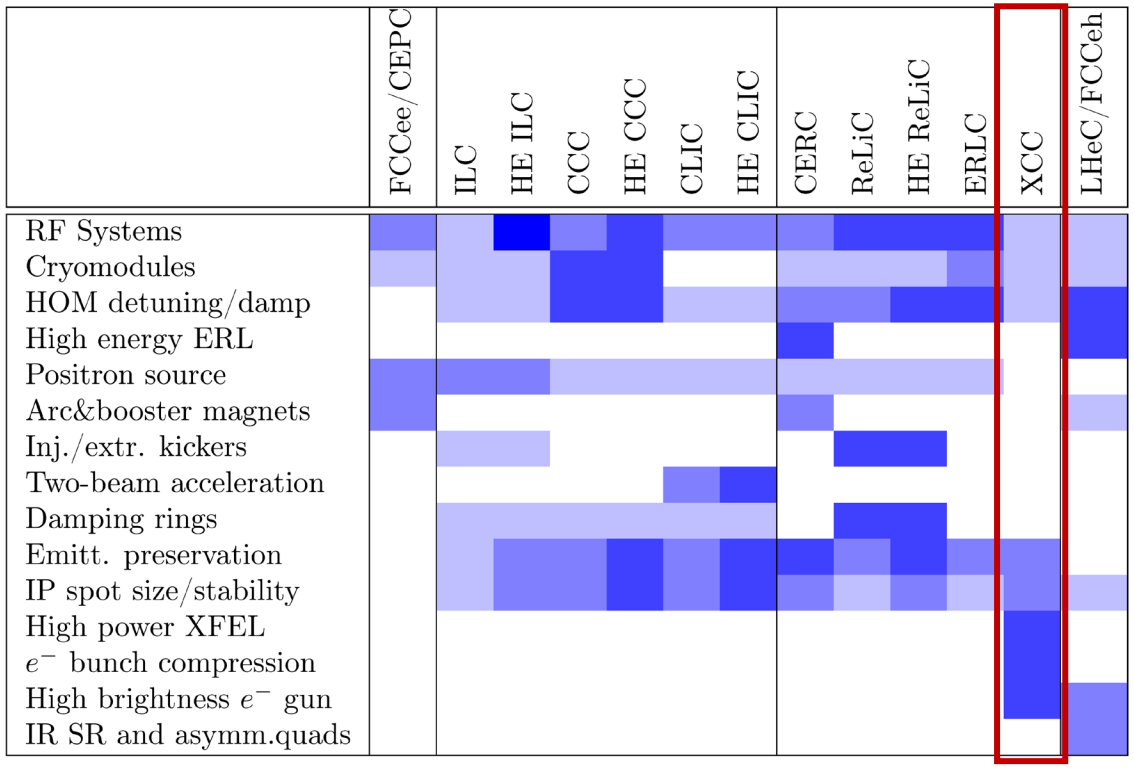
ITF Technical Readiness

Technical Readiness Registry



Technical Readiness Summary

Proposal Name (c.m.e. in TeV)	Collider Design Status	Lowest TRL Category	Technical Validation Requirement	Cost Reduction Scope	Performance Achievability	Overa Risk Tier
FCCee-0.24	II					1
CEPC-0.24	II					1
ILC-0.25	I					1
CCC-0.25	III					2
CLIC-0.38	II					1
CERC-0.24	III					2
ReLiC-0.24	V					2
ERLC-0.24	V					2
XCC-0.125	IV					2
MC-0.13	III					3

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Summary

- The XCC is presented as a lower cost alternative to e+e- Higgs factories
  - --- 140 GeV vs 250 GeV Linac
  - --- No damping rings
  - --- No positron source

- The XCC at E_{cm}=125-140 GeV can measure absolute Higgs couplings in a model independent manner with an accuracy of order 1% , which is close to the ILC precision. To fully match or exceed the ILC Higgs coupling accuracy, a way must be found to increase the top 1% e-γ luminosity at E_{cm}=140 GeV.

- There are strong synergies between XCC and the XFEL programs. Solutions to high energy/pulse XFEL production and focusing issues at XCC will lead to new opportunities in XFEL photon science.