Exploring New Physics in Electron-Laser Collisions at LUXE and with Future e^+e^- Beams

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27th of June 2024 - ILC IDT WG3 Physics Group Meeting

Deutsches Elektronen-Synchrotron DESY

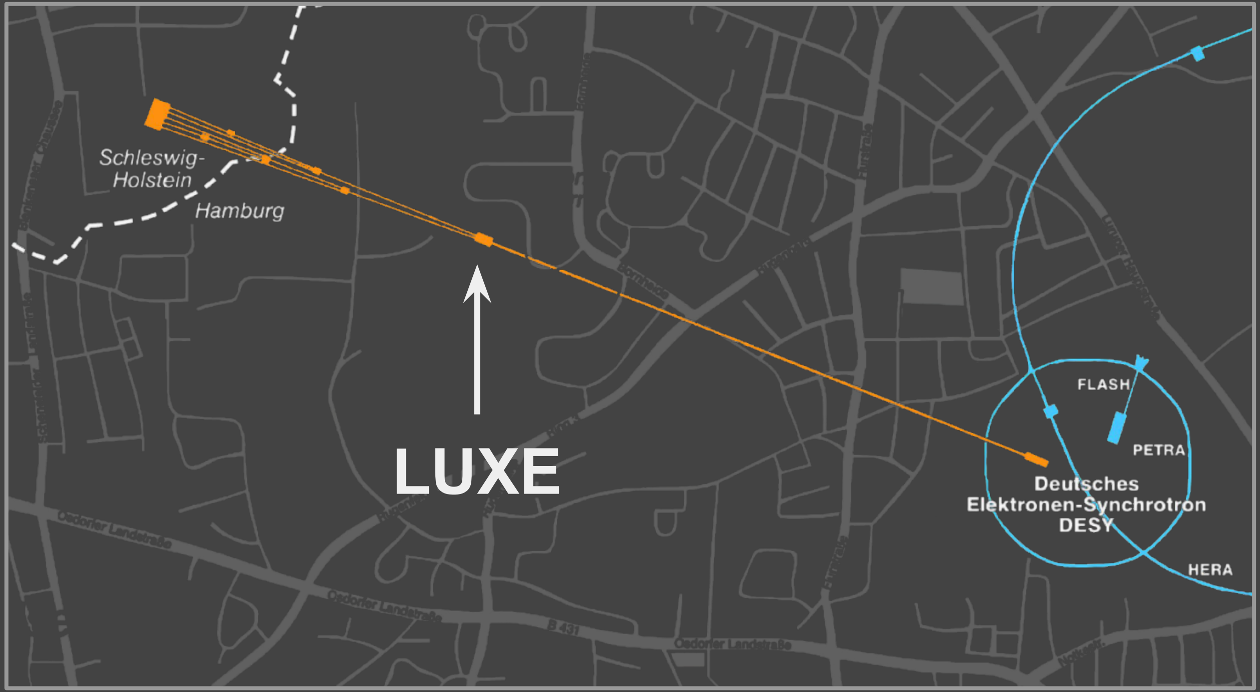
Laser Und XFEL Experiment LUXE

Laser Und XFEL Experiment LUXE

The Collaboration

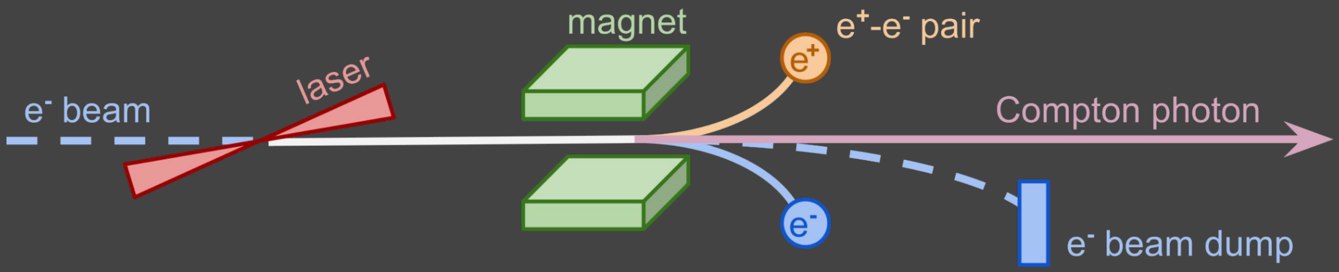
Laser Und XFEL Experiment LUXE

DESY and European XFEL Site



Laser Und XFEL Experiment LUXE

Experimental Schematic: Electron-Laser Mode



electrons
- 10 Hz bunches
- up to 17.5 GeV
- 10^9 e^-/bunch

laser
- 1 Hz
- 40 TW (phase-0)
- 350 TW (phase-1)

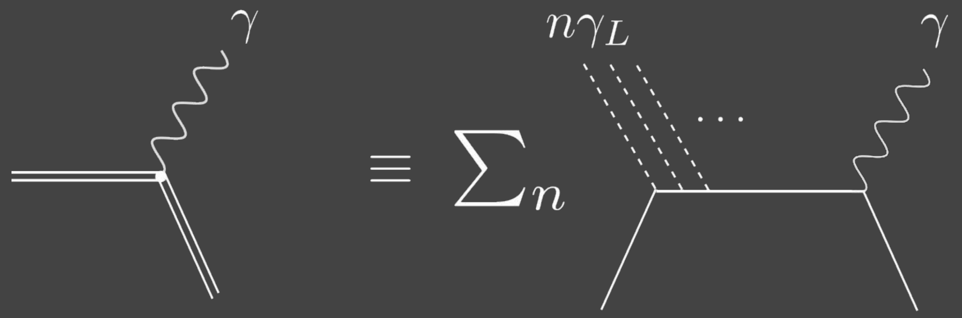
photons
- 3.5 γ/e^-
- 1.7 γ/e^- (>1 GeV)

Laser Und XFEL Experiment LUXE

Strong-Field QED Processes

non-linear Compton

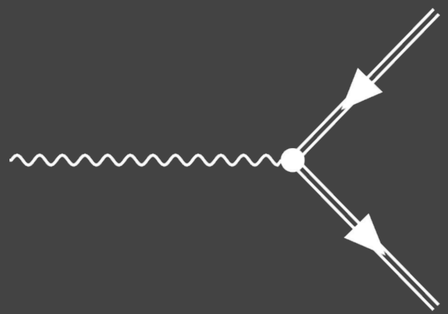
$e^{\pm} \rightarrow e^{\pm} + \gamma$

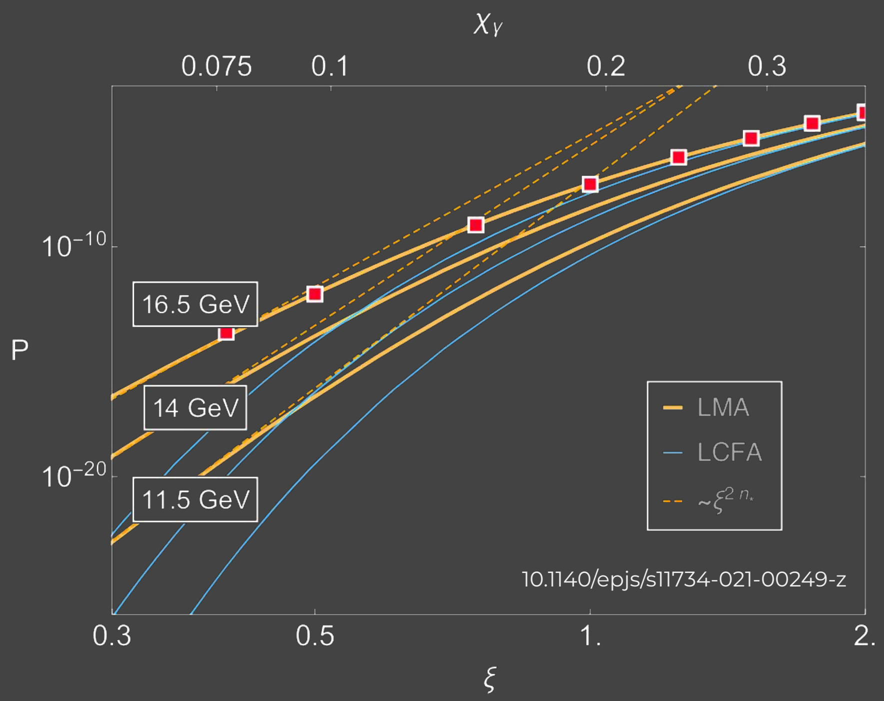


Laser Und XFEL Experiment LUXE

Strong-Field QED Processes

non-linear Breit-Wheeler
$\gamma \rightarrow e^+e^-$

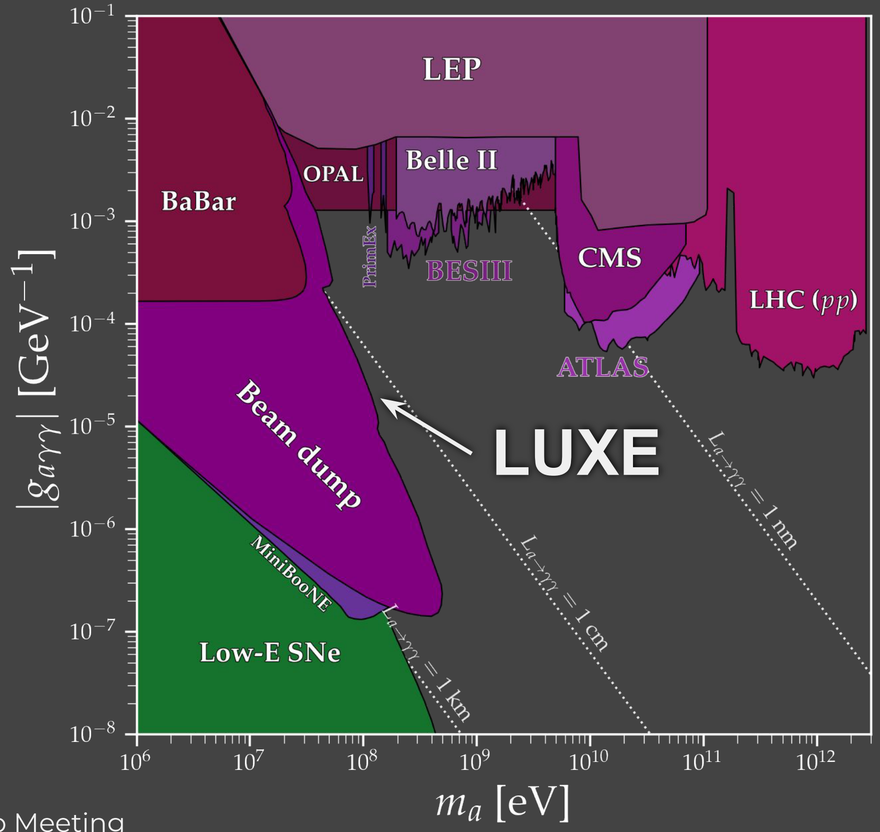




New Physics at Optical Dump

New Physics at Optical Dump NPOD

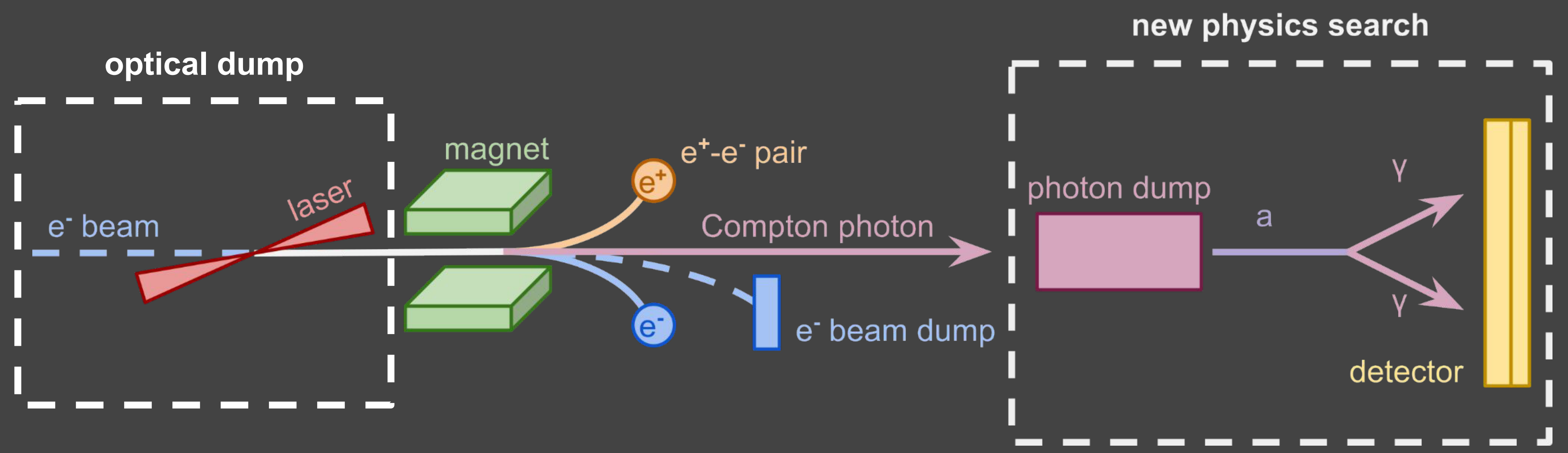
Beam Dump and Collider Constraints



courtesy:
C. O'Hare, *AxionLimits*,
10.5281/zenodo.3932430

New Physics at Optical Dump NPOD

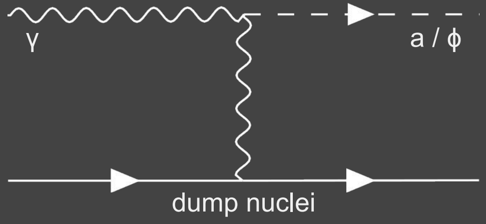
Optical Dump Concept



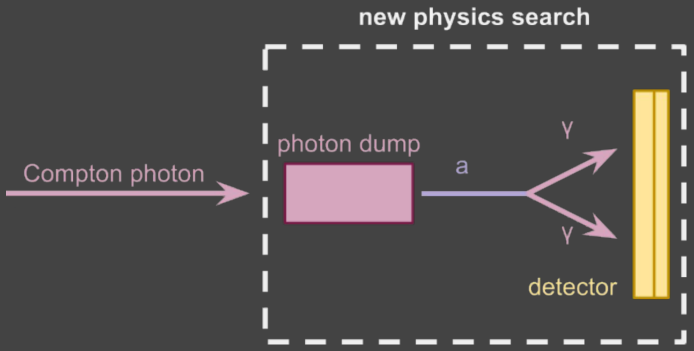
New Physics at Optical Dump NPOD

Production and Decay Mechanisms

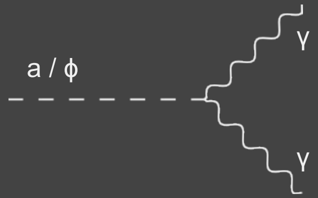
Primakoff production



$$\mathcal{L}_a = \frac{a}{4\Lambda_a} F_{\mu\nu} \widetilde{F}^{\mu\nu}$$



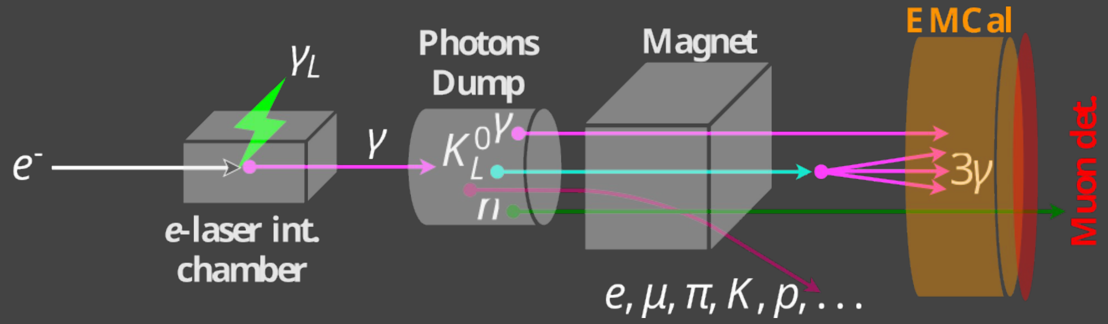
photon decay channel



$$\Gamma_{a\to 2\gamma} = \frac{m_a^3}{64\pi\Lambda_a^2}$$

New Physics at Optical Dump NPOD

Background Estimation

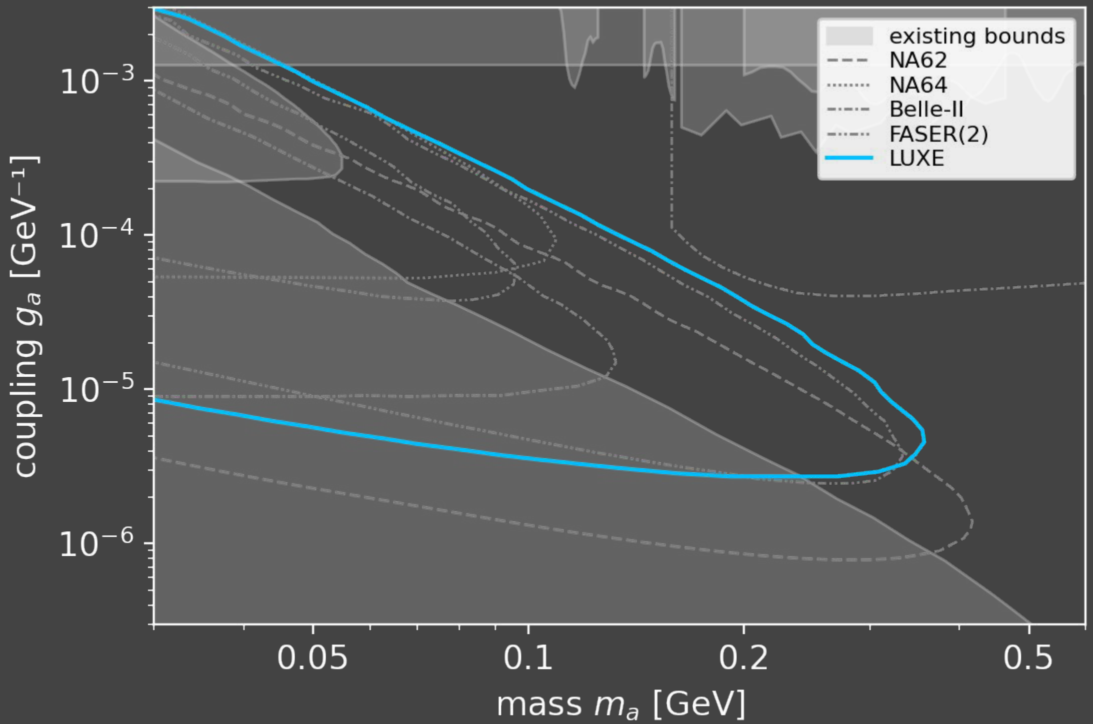


	LUXE NPOD	LUXE e^- on dump
N_a	4	16.5
N_{BG}	0.8	156.1
SNR	5	0.1

10.1103/PhysRevD.106.115034

New Physics at Optical Dump NPOD

Expected Phase-Space Coverage



New Physics at Optical Dump NPOD

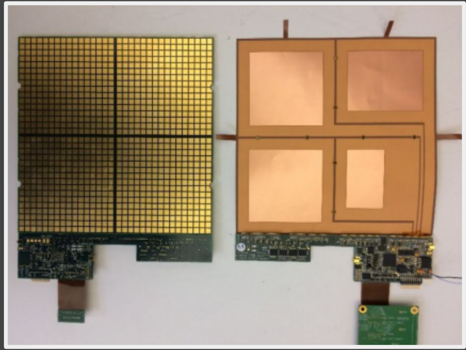
NPOD Detector Option: LUXE ECAL-E

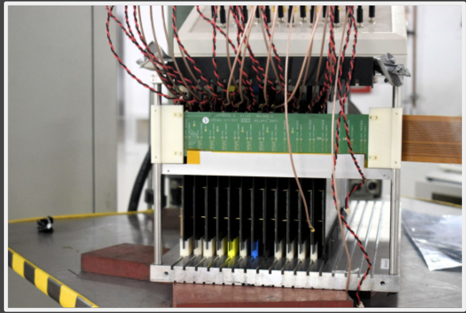
technology:

- high-granularity SiW calorimeter

configuration:

- three modules, each 18 x 18 cm^2
- 15 sandwich layers
- 0.5 mm thick silicon with a 5.5 x 5.5 mm^2 readout structure
- tungsten absorbers of 7 x 2.8 mm and 8 x 4.2 mm thickness

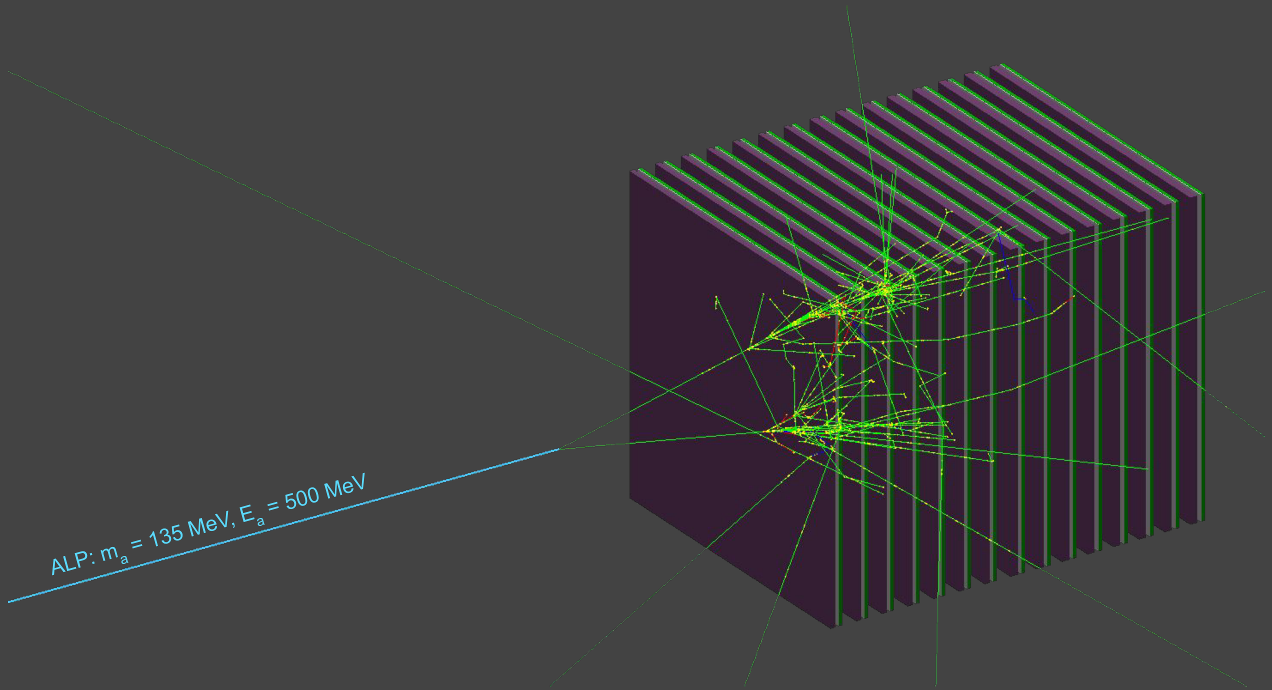




10.48550/arXiv.2004.12792
10.1016/j.nima.2019.162969

New Physics at Optical Dump NPOD

NPOD Detector in DD4HEP Framework



Prospects for Future e^+e^- Beams

Prospects for Future e^+e^- Beams

(Future) Linear Colliders

	E_{e^-}	population	BX separation	train rate
EU.XFEL [1]	17 GeV	0.15×10^{10} e^-/BX	220 ns	10 Hz
ILC [2]	125 GeV	2×10^{10} e^-/BX	554 ns	5 Hz
C^3 [3]	125 GeV	0.62×10^{10} e^-/BX	5.26 ns	120 Hz

[1] DOI: 10.1140/epjs/s11734-021-00249-z
[2] DOI: 10.48550/arXiv.2203.07622
[3] DOI: 10.48550/arXiv.2203.07646

Prospects for Future e^+e^- Beams

Colliders - Effective Luminosities

$$\mathcal{L}_{\text{eff}} = N_e N_{bx} \frac{9\rho X_0}{7Am_0}$$

fixed:
A = atomic mass number
ρ = density in [g/cm^3]
X_0 = radiation length in [cm]
m_0 = nucleon mass in [g]

collider dependent:
N_e = number of electrons per bunch
N_{bx} = number of bunch crossings

assumptions:

- 10^7 s runtime (32% uptime over 1 year)
- laser triggers at train rate (up to 120 Hz)
- tungsten dump

effective luminosities:

- EU.XFEL: 4.3 fb^{-1}
- ILC: 28.5 fb^{-1}
- C^3: 212.0 fb^{-1}

Prospects for Future e^+e^- Beams

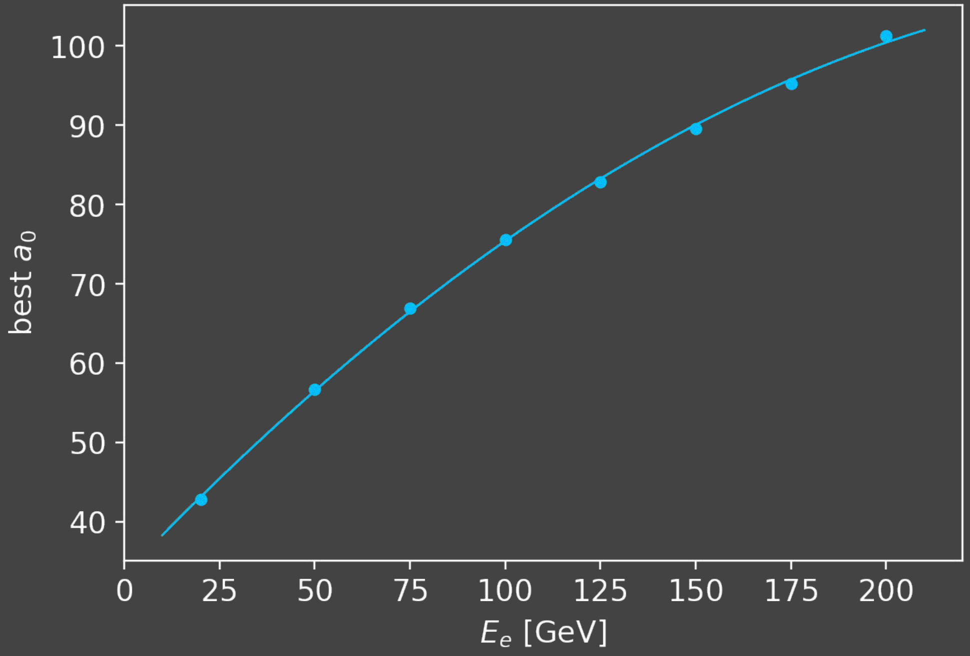
Laser Systems

	power	intensity	intensity (norm)	trigger rate
LUXE phase-0 [1]	4×10^{13} W	2.0×10^{19} W/cm^2	3	1 Hz (10 Hz)
LUXE phase-1 [1]	3.5×10^{14} W	1.2×10^{21} W/cm^2	24	1 Hz (10 Hz)
CoReLS [2]	4×10^{15} W	1.1×10^{23} W/cm^2	220	0.1 Hz
Future [3,4]	$O(10^{18})$ W	$O(10^{25})$ W/cm^2	O(2000)	O(100) Hz

[1] DOI: 10.1140/epjs/s11734-021-00249-z
[2] DOI: 10.1364/optica.420520
[3] DOI: 10.1017/hpl.2023.69
[4] DOI: 10.1016/j.optcom.2011.10.089

Prospects for Future e^+e^- Beams

Optimal Laser Parameters



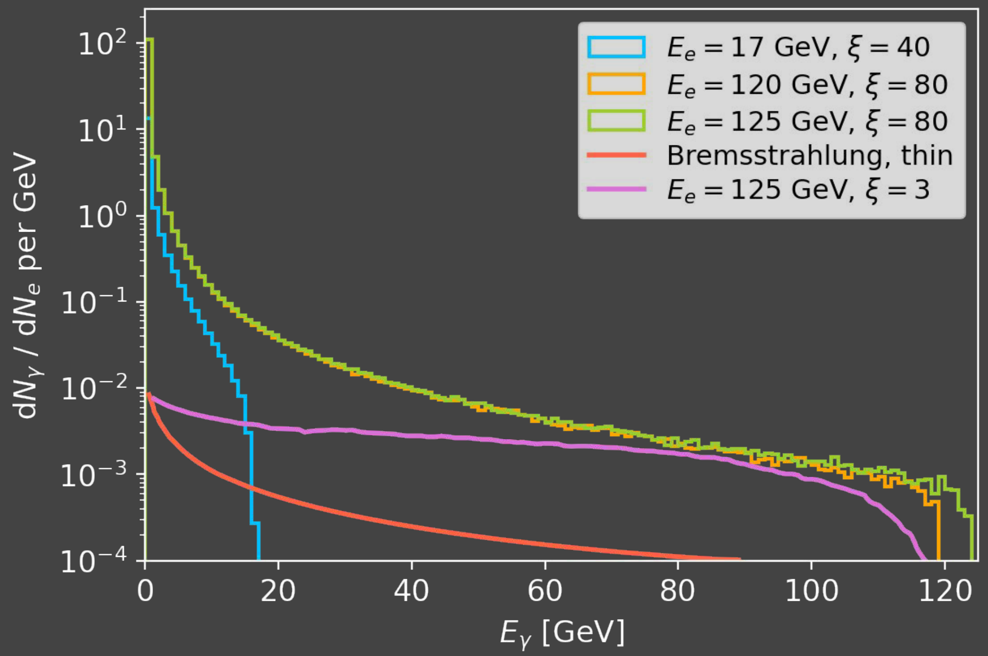
simulation parameters:

- λ = 800 nm
- w_0 = 2 µm
- τ_{fwhm} = 20 fs
- α = 17.2°
- polarization = linear

- $E_\gamma \geq$ 1 GeV
- $\theta \leq$ 2.5 mrad

Prospects for Future e^+e^- Beams

Electron-Laser Interaction - Optical Dump (Ptarmigan)



simulation parameters:

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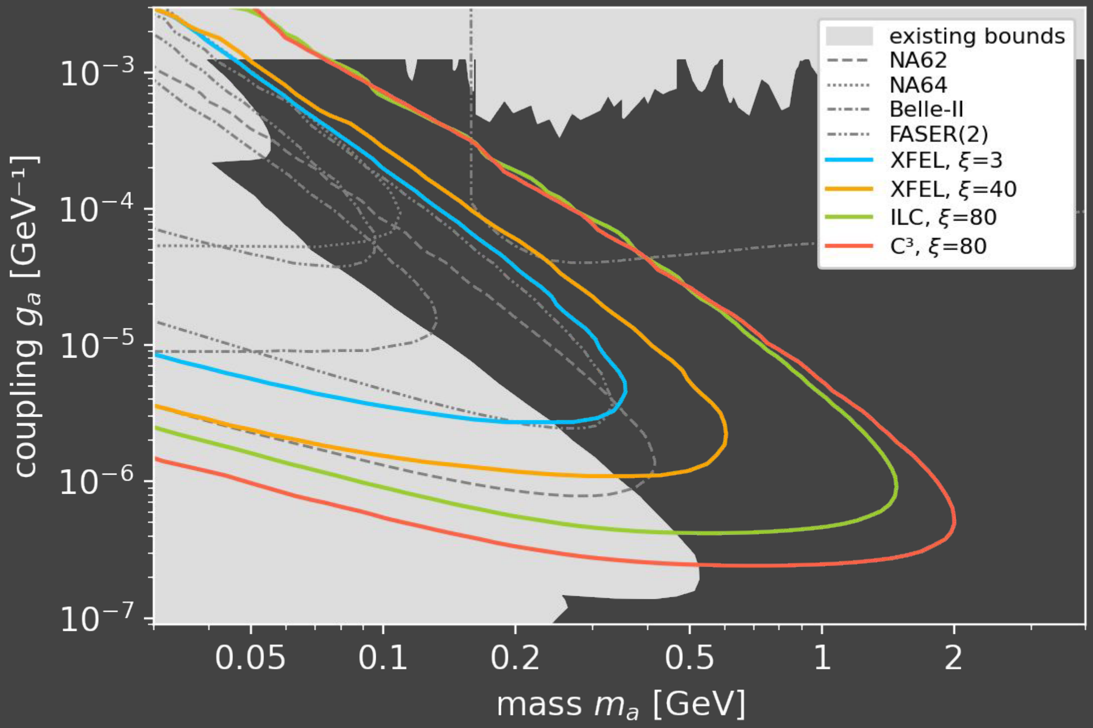
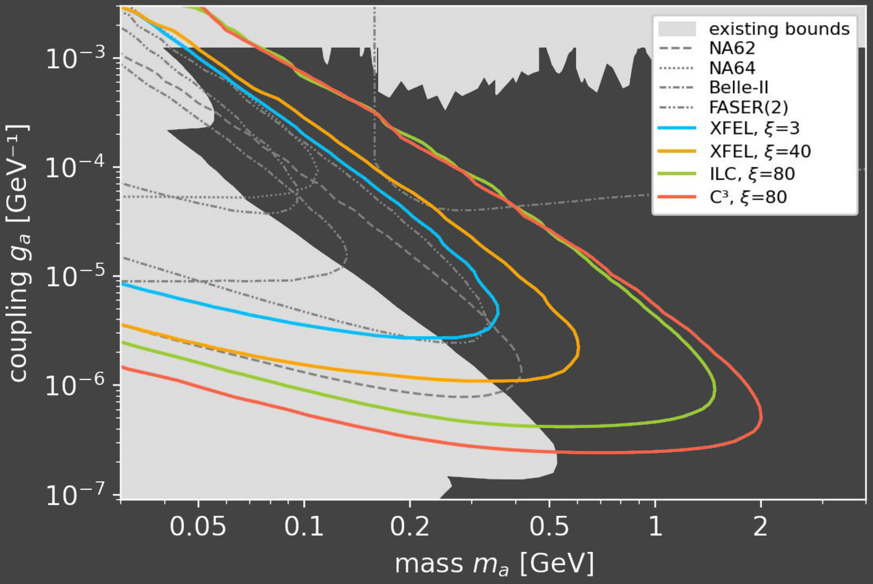
Prospects for Future e^+e^- Beams

Phase-Space Coverage of Linear Accelerators



Prospects for Future e^+e^- Beams

Conclusion



- LUXE will allow a precise investigation of strong-field QED
- it allows to search for new physics with the optical dump concept
- the concept may be applicable to future facilities