Strong-Field QED with Electron-Laser Interactions and New Physics Searches with Photons

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28th of November 2024, CERN

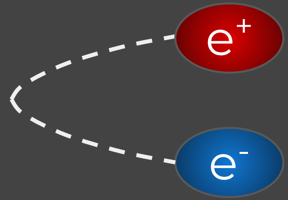
Other Science Opportunities at the FCC-ee

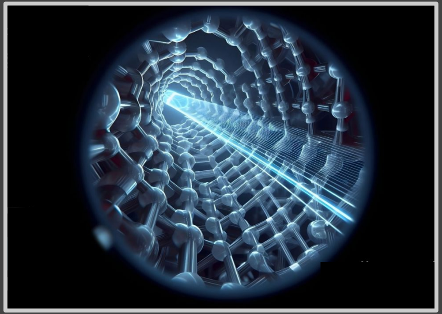
Strong-Field QED

Strong-Field QED

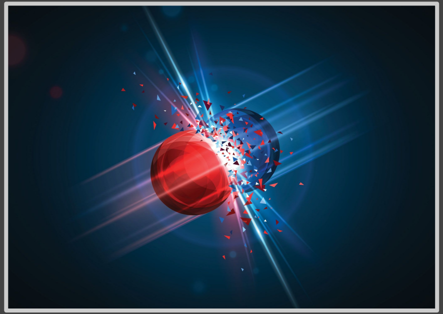
Motivation

fundamental science

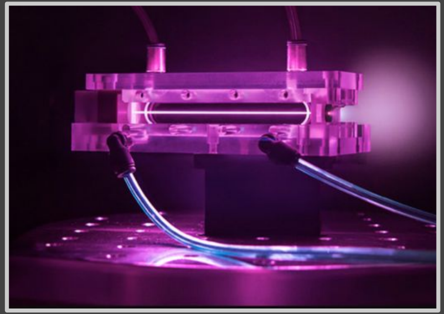




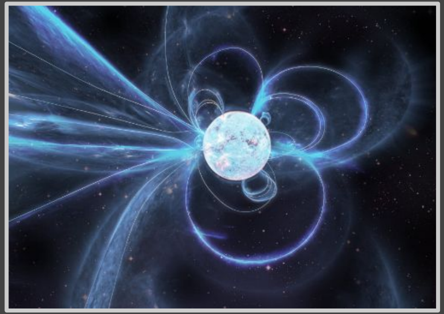
channeling and radiation



Higgs factories and e^+e^- collider



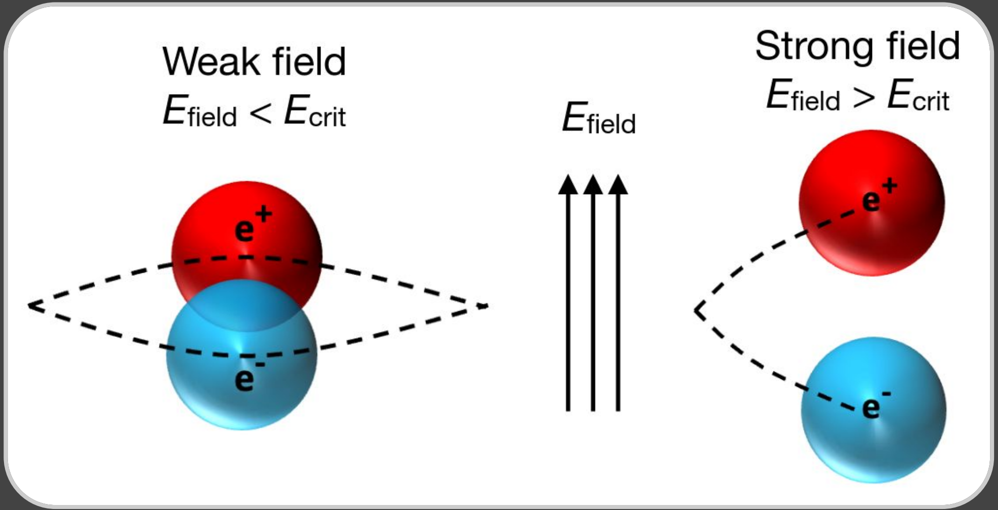
laser physics and novel accelerators



magnetars, neutron stars and black holes

Strong-Field QED

Introduction



$$E_{\text{crit}} = \frac{mc^2}{e\lambda_c} = 1.3 \times 10^{18}\ \text{V/m}$$

determined by beam energy ($\propto \eta$) and laser intensity ($\propto \xi$)

$$\eta = \gamma_0 \frac{\omega_L}{m_e} \, (1 + \cos(\theta))$$

$$\xi = \sqrt{4\pi\alpha} \left(\frac{\epsilon_L}{\omega_L m_e} \right) = \frac{m_e \epsilon_L}{\omega_L \epsilon_c}$$

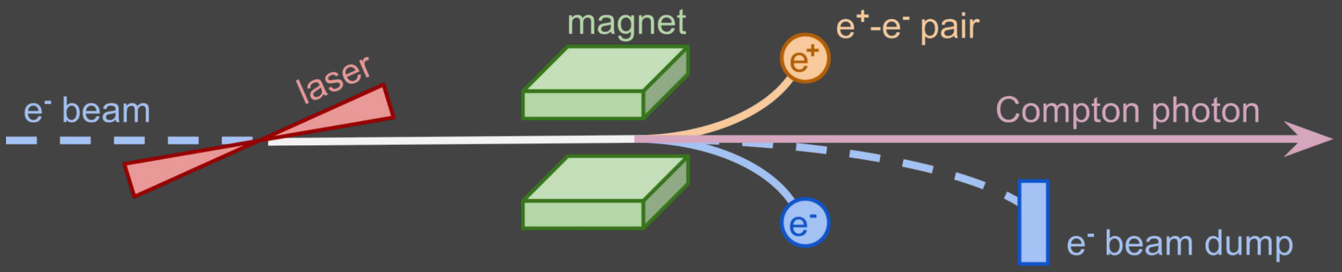
Strong-Field QED

Possible Probes

- highly charged ions ➔ not considered at e^+e^- colliders
    - collisions
    - spectroscopy
- solid-state / crystals ➔ covered by Laura Bandiera
- beam-beam interaction ➔ Beamstrahlung
- **beam-laser interaction** ➔ this talk

Strong-Field QED

Beam-Laser Interaction (Example LUXE, DESY)



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

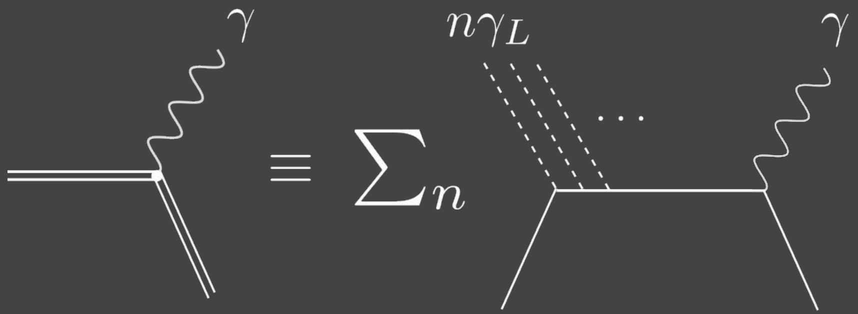
laser
- 1 Hz
- 40 TW (phase-0)
- 350 TW (phase-1)

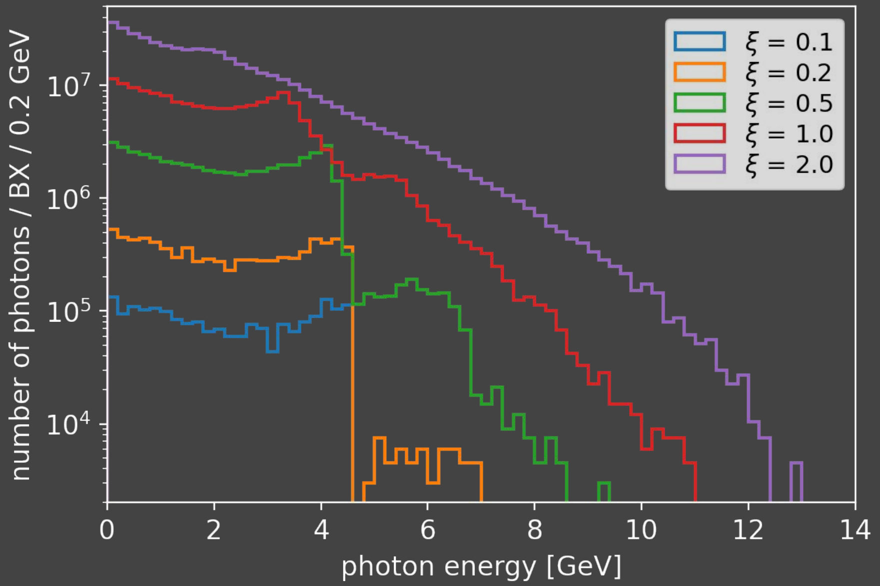
photons
- 3.5 γ/e^-
- 1.7 γ/e^- (>1 GeV)

Strong-Field QED

Processes: Compton Scattering

non-linear Compton
$e^{\pm} \rightarrow e^{\pm} + \gamma$

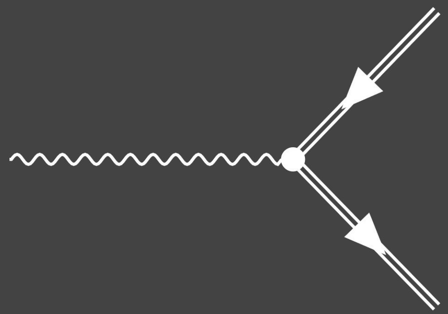


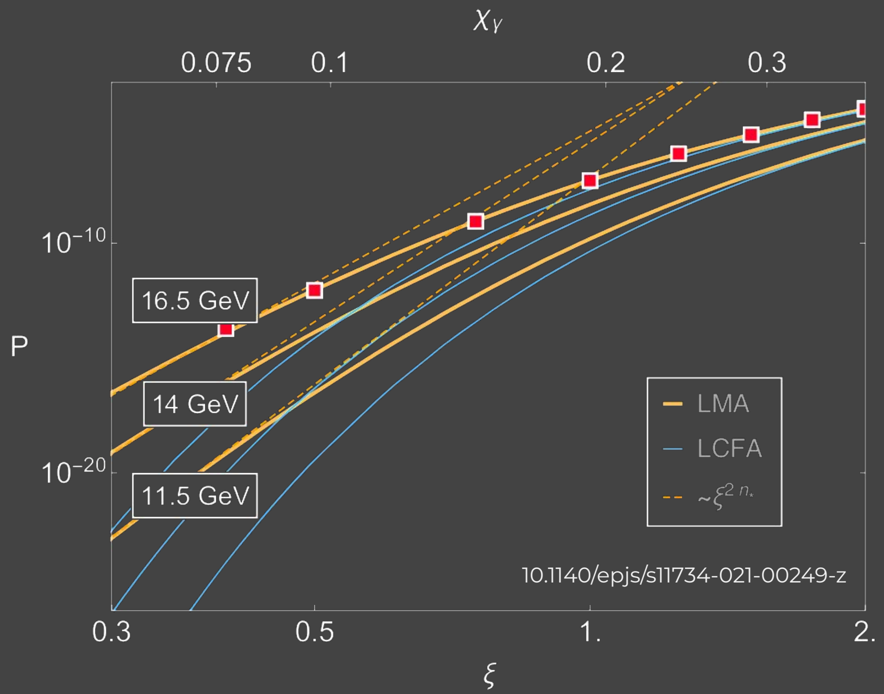


Strong-Field QED

Processes: Breit-Wheeler Pair Production

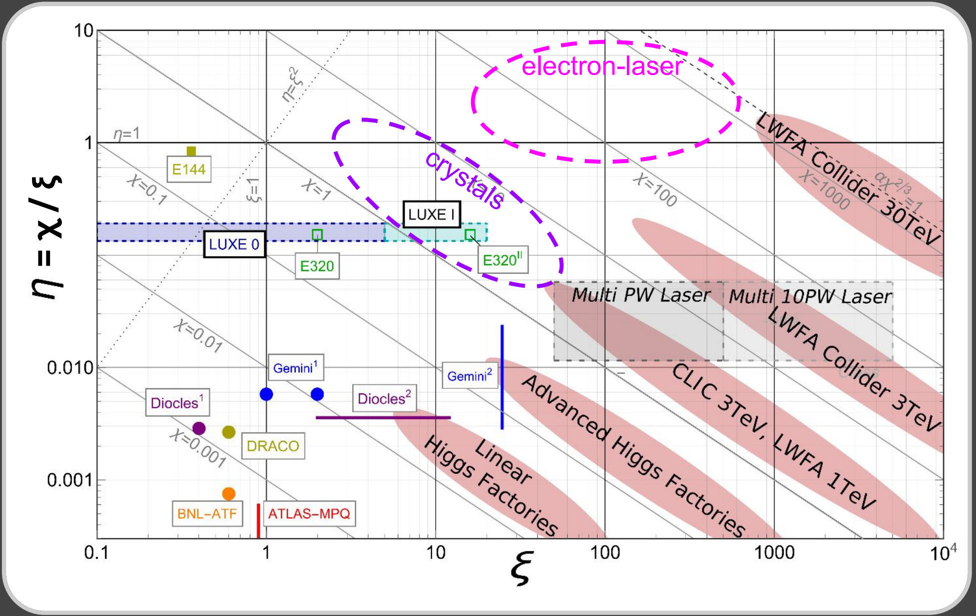
non-linear Breit-Wheeler
$\gamma \rightarrow e^+e^-$





Strong-Field QED

Parameter Space and Experiments



courtesy: A. Fedotov et al. & J. List (LCWS 2023)

physics reach:

- fundamental understanding of QED
- beam-beam interaction becomes relevant at higher energies

status:

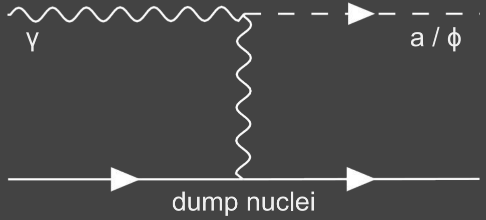
- experience from current experiments (e.g. NA63, E320, LUXE)

New Physics Searches with Photons

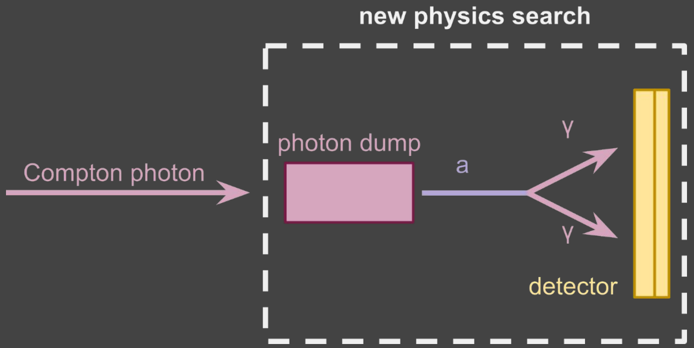
New Physics Searches with Photons

Fixed-Target Experiments with Photons

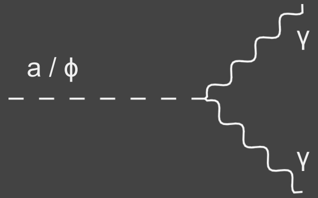
Primakoff production



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



photon decay channel



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

New Physics Searches with Photons

Assumptions

- geometrical
  - dump length: 2 m
  - decay volume: 10 m
  - detector size: 5 m

- background free
  - 3 signal event boundary

- only primary photons

New Physics Searches with Photons

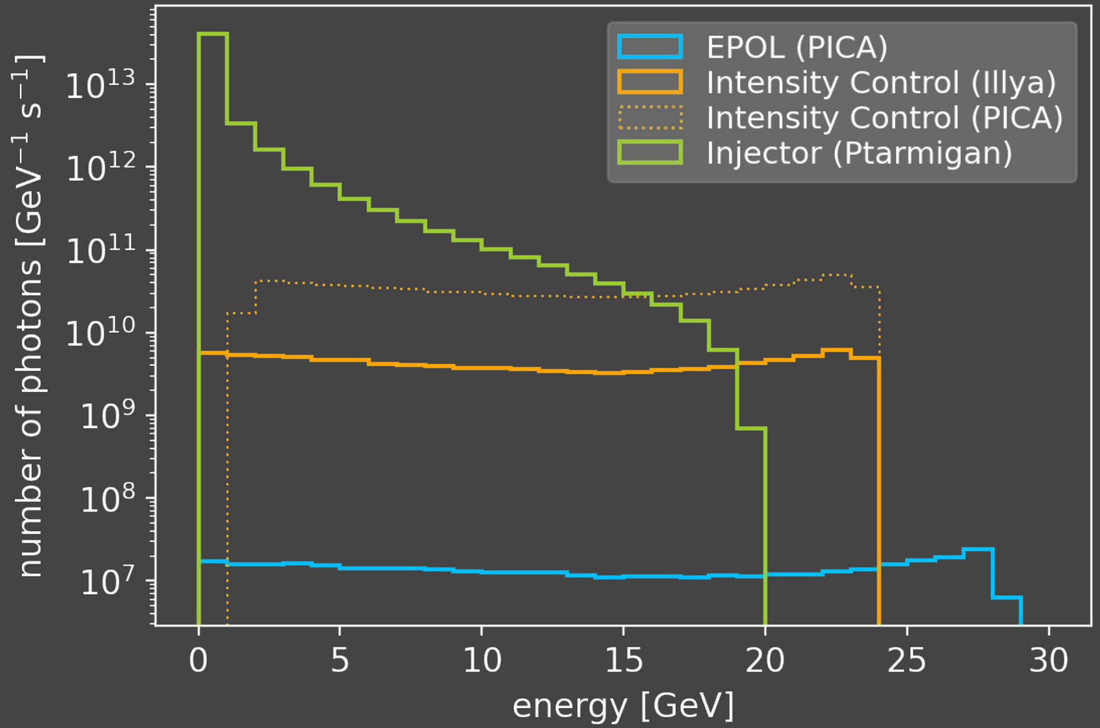
Assumptions

	EPOL [1]	**intensity control [2]**	**injector [3]**
electron energy [GeV]	45.6	45.6	20
trigger rate [Hz]	3000	1000	100
bunch population	2.17×10^{11}	2.17×10^{11}	2.5×10^{10}
availability	0.3	0.3	0.24 x 0.3
laser intensity [norm.]	4×10^{-6}	2×10^{-3}	43
laser waist [μm]	250	100	2

[1]: Blondel et al. (2019)
[2]: Drebot et al. (2023)
[3]: Bartosik et al. (2024)

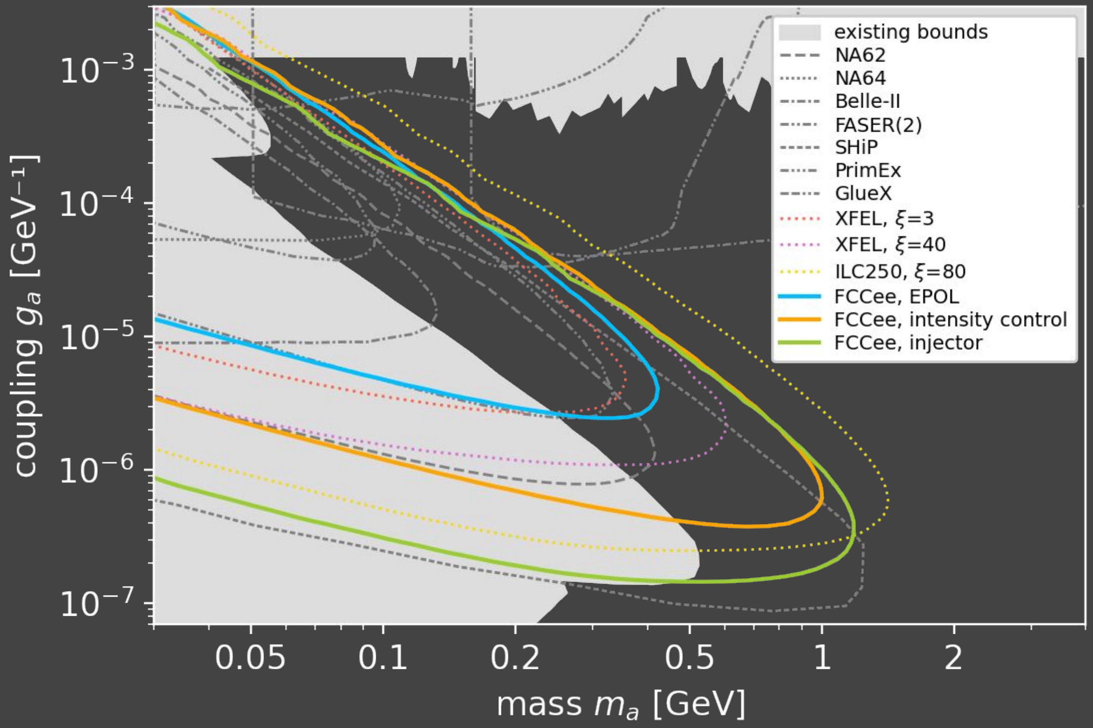
New Physics Searches with Photons

Compton Spectra at the FCCee



New Physics Searches with Photons

Expected Phase-Space Coverage



Strong-Field QED and New Physics Searches

Summary

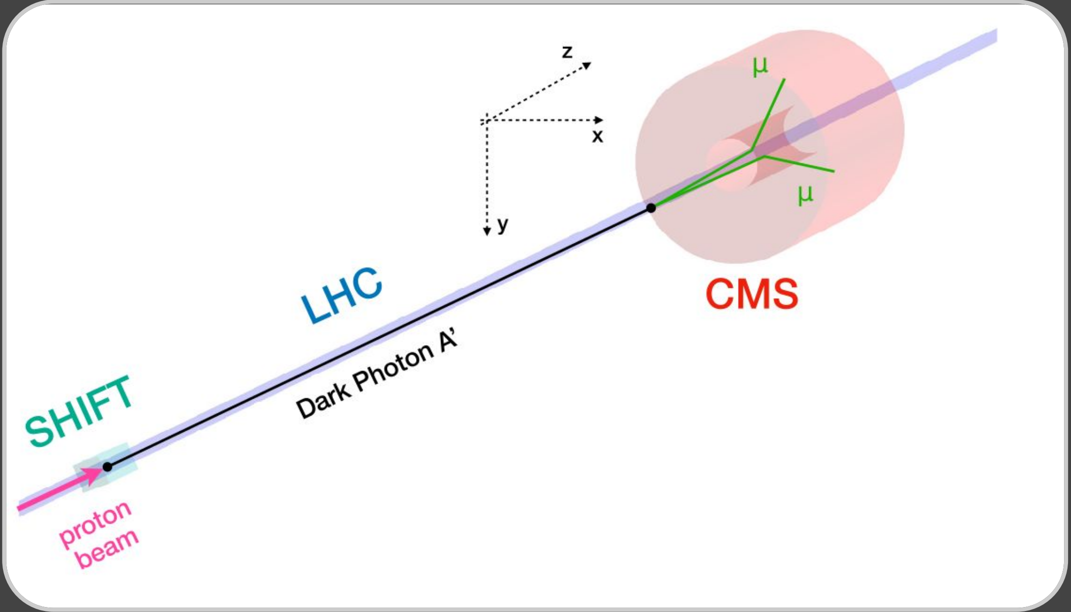
- strong-field QED
    - fundamental understanding of QED
    - test of theoretical/numerical tools
    - important for future high-energy collider

- new physics searches
    - ALPs remain promising new-physics candidate
    - FCC-ee may be able to probe new parameter space
    - what about Beamstrahlung for NP production?

SHIFTed Fixed-Target Experiment (off-topic add-on)

SHIFTed Fixed-Target Experiment

Slightly Off-Topic Add-On



physics reach:
- possible 10^2 - 10^3 improvement compared to collider LLP searches

status:
- planning phase for HL-LHC

costs:
- minimal (~300 k€)

references:
- 10.1007/JHEP10(2024)204