Probing new physics with a LUXE-type experiment at future Higgs factories

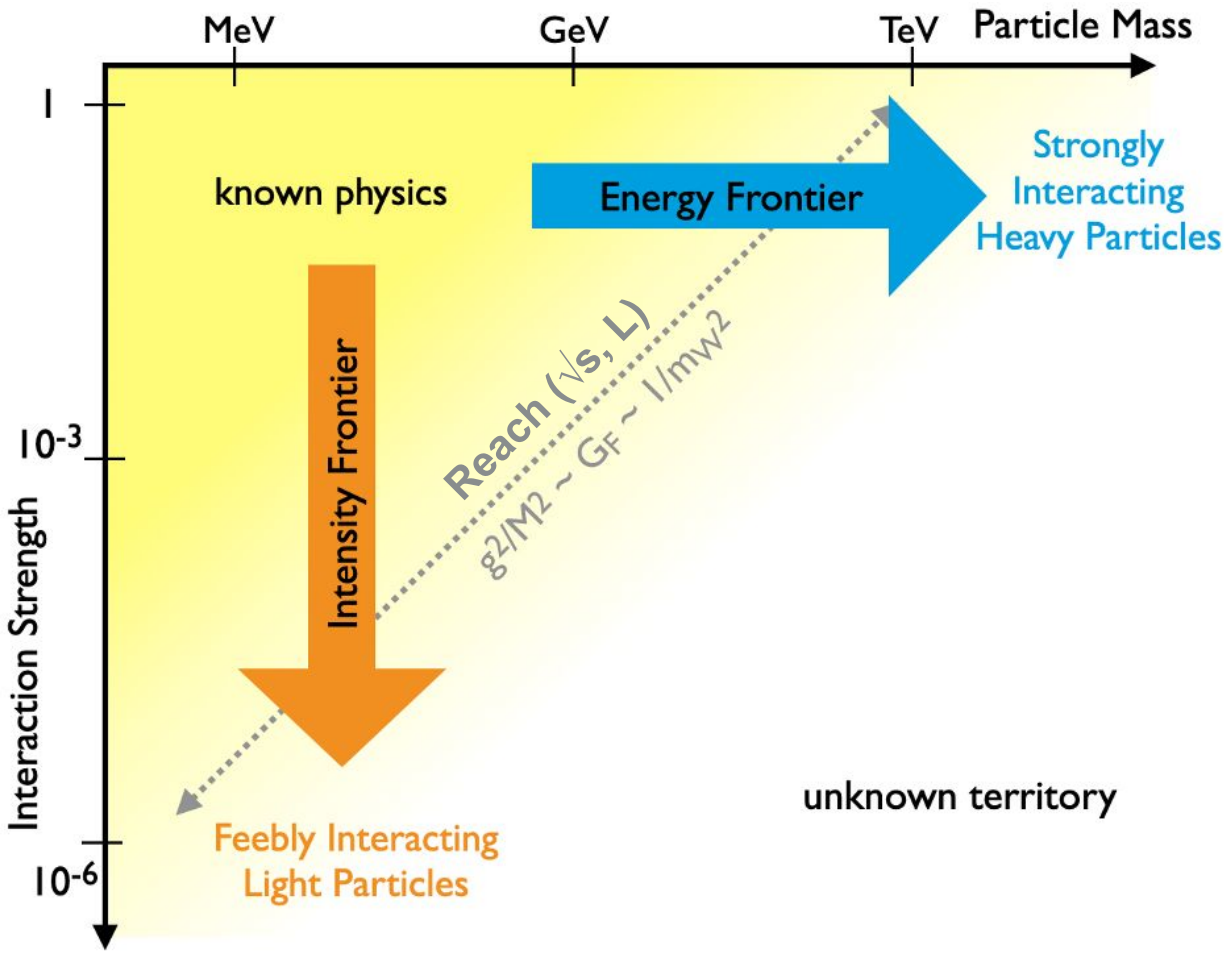
Federico Meloni (DESY),
for the LUXE collaboration

1st ECFA workshop on e^+e^- Higgs/EW/Top Factories
05/10/2022

LUXE DESY.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Experimental exploration in particle physics

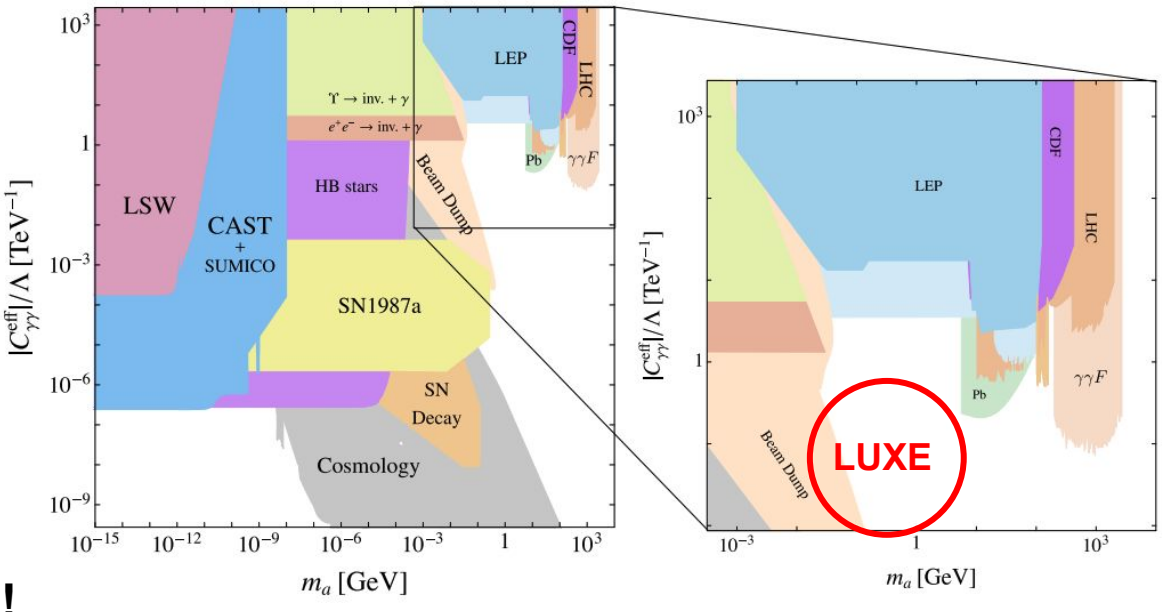


Axion-like particles

Eur. Phys. J. C 79, 74 (2019)

The Axion is part of a solution to the strong CP problem

- portal to dark matter and/or dark sector
- if very light, it is a dark matter candidate



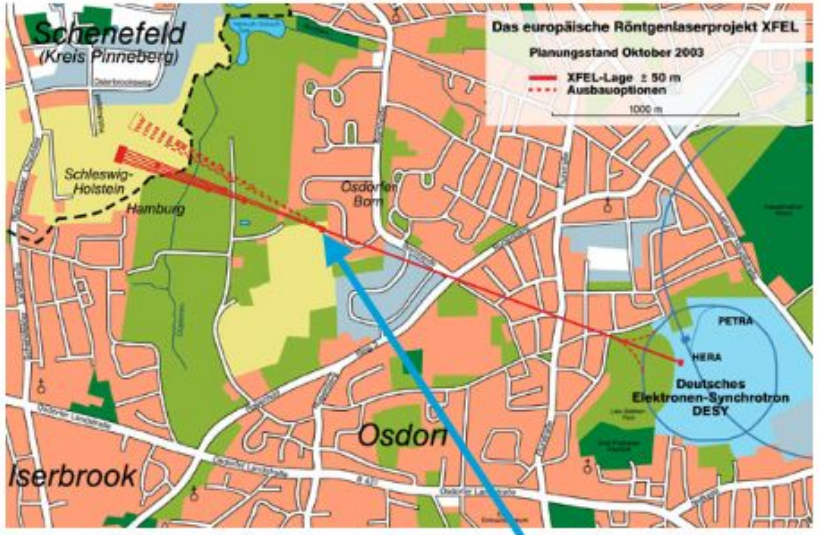
Well motivated BSM scenario!

Small couplings can lead to long lifetimes

- Exciting handle to look for new pseudo-scalars (and scalars)

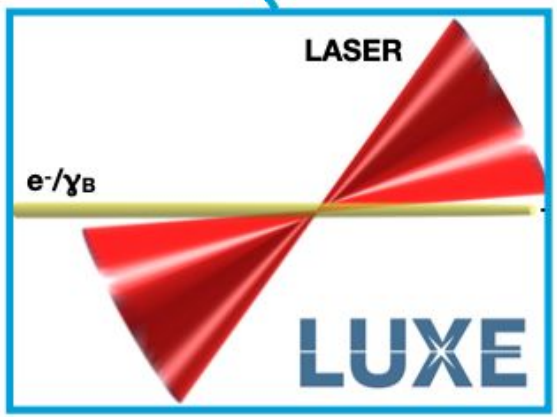
The LUXE experiment

LUXE
LASER Und XFEL Experiment



LUXE is a new experiment at DESY and Eu.XFEL

- Collisions of electron beam and a high-power laser
- Study the transition into non-perturbative QED regime



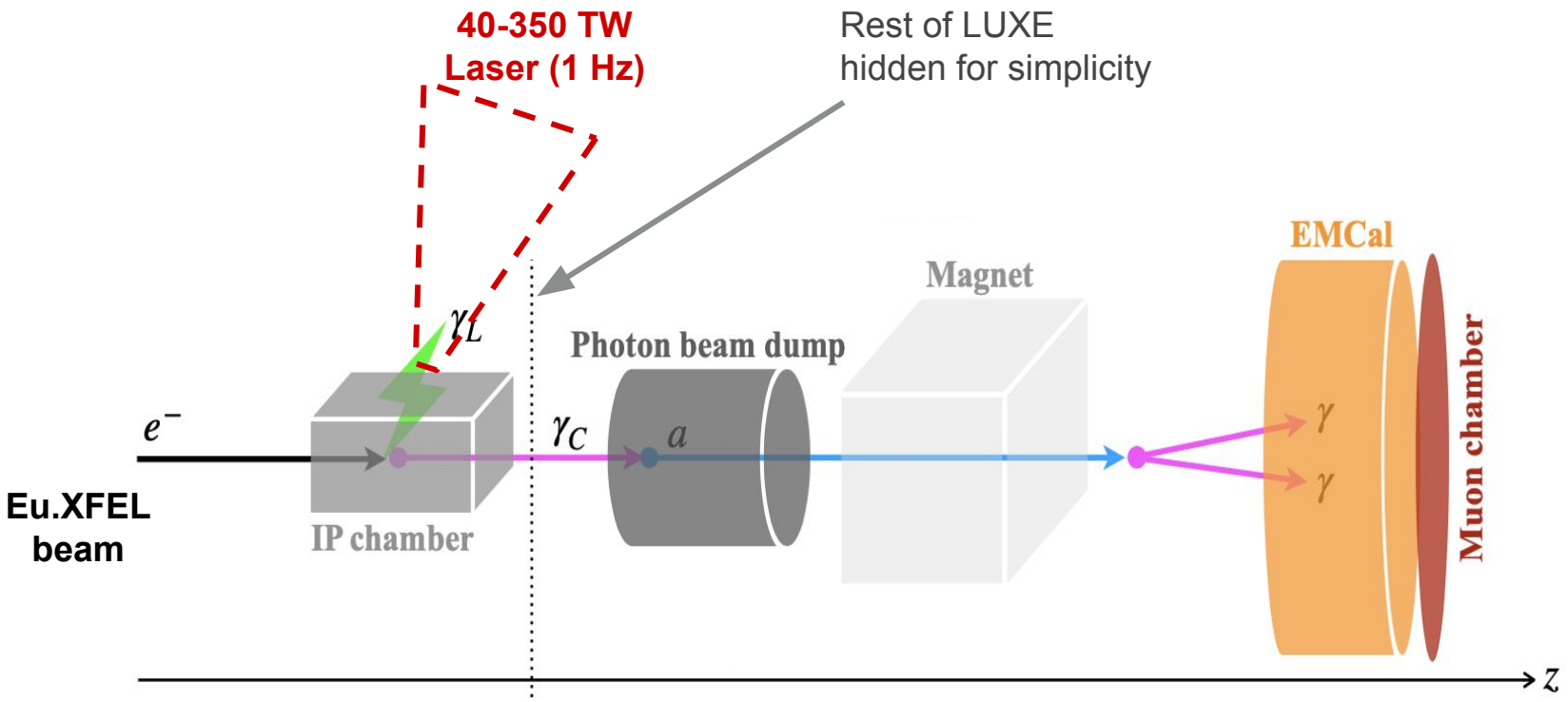
More Information at:

- CDR arXiv: 2102.02032
- Website https://luxe.desy.de

LUXE NPOD

New Physics search with Optical Dump

Bai, Blackburn, Borysov, Davidi, Hartin, Heinemann, Ma, Perez, Santra, Soreq, Tal Hod, 2107.13554

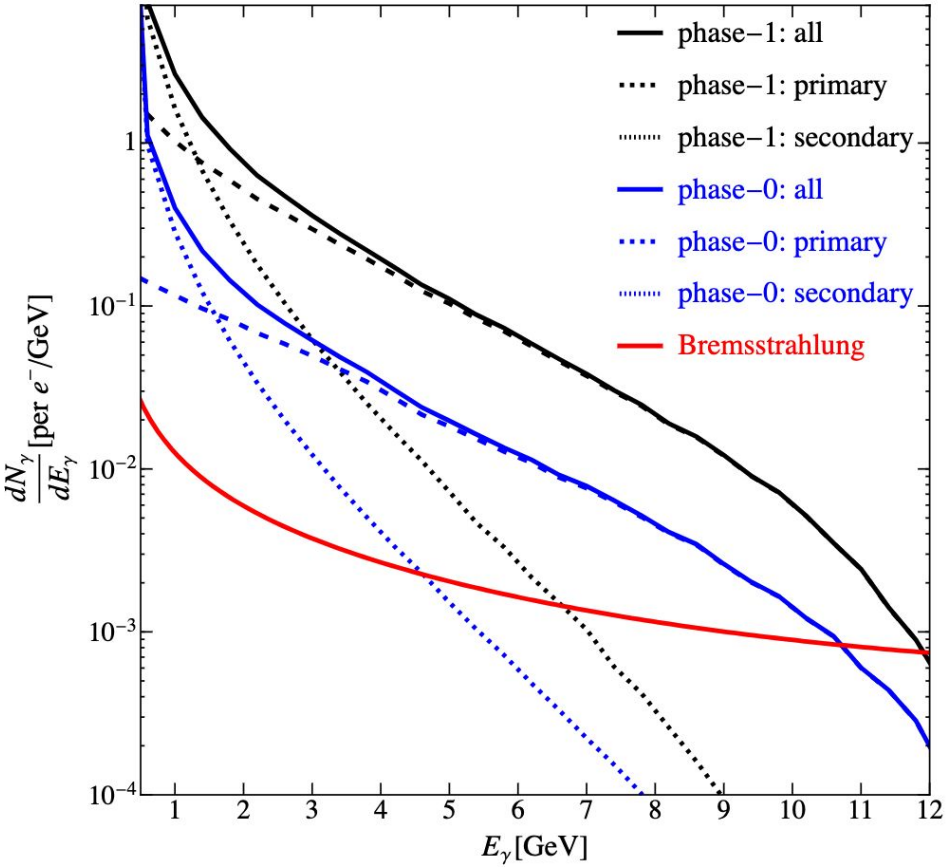


The laser as a “transparent dump”

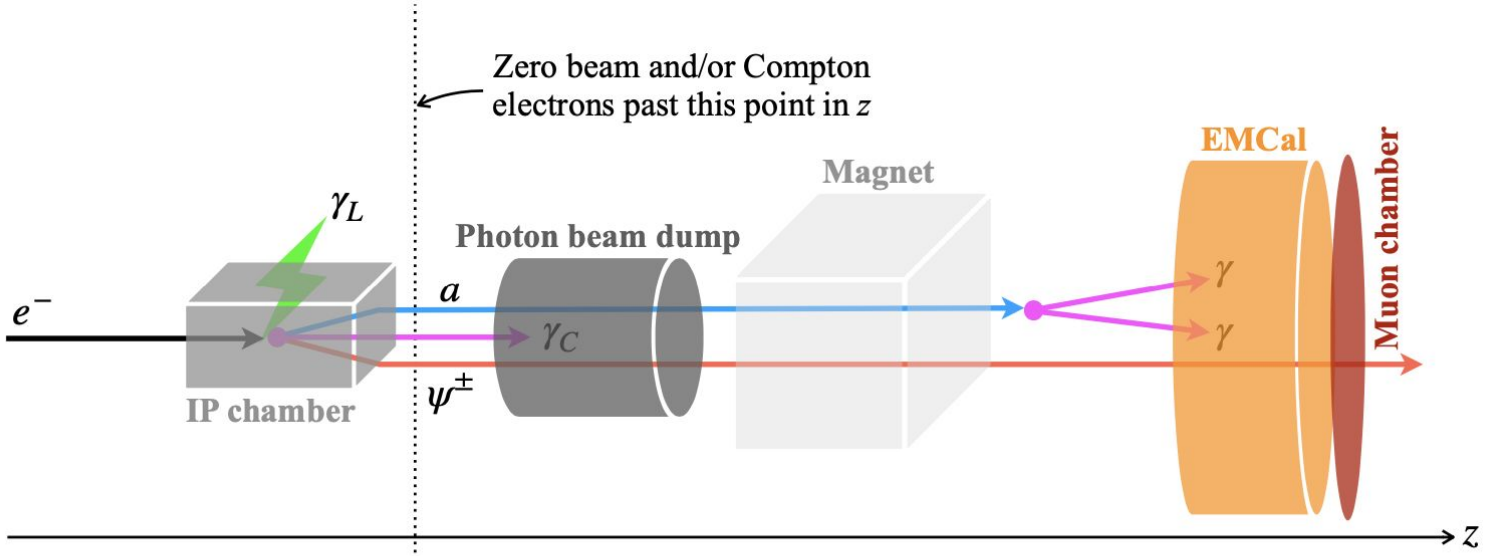
A long laser pulse can transfer O(1) of the initial electron energy to the photons

- Multiple GeV photons can be produced for every initial electron
- Competitive with photon production from thin targets

E_γ > 1 GeV	**#Photons (per e^-)**	**Background (per e^-)**
LUXE	1.7	~0
Thin e-dump	0.03	~0
Thick e-dump	6.7	x 100



BSM production modes at LUXE



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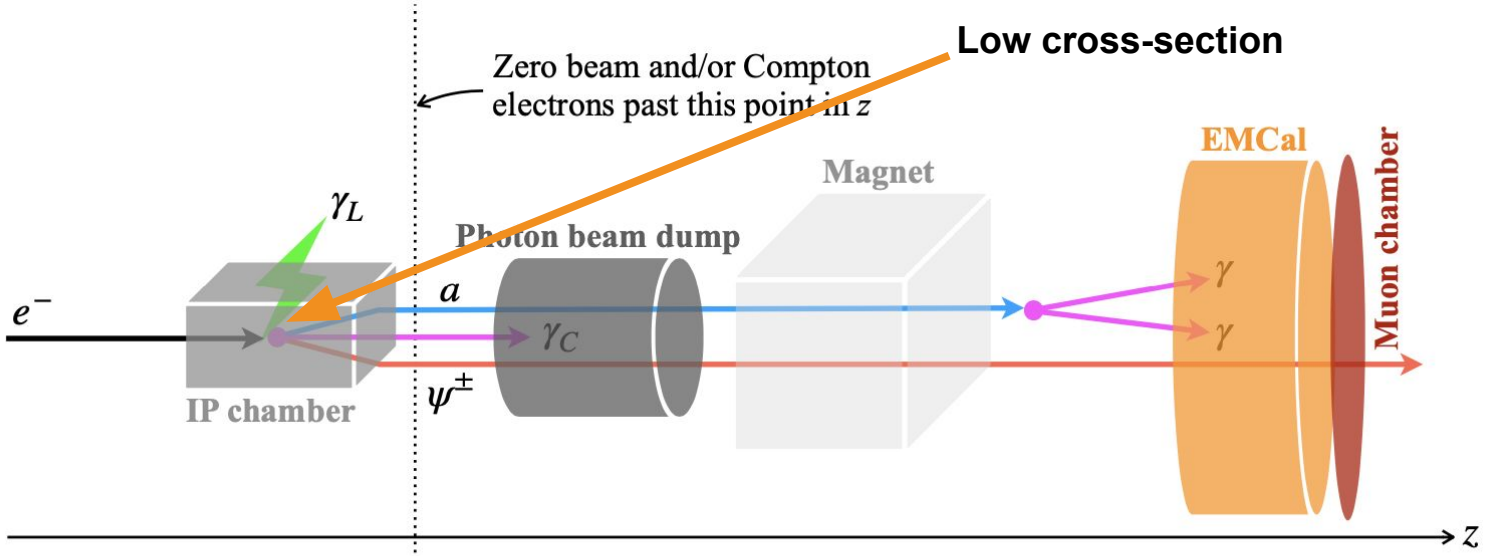
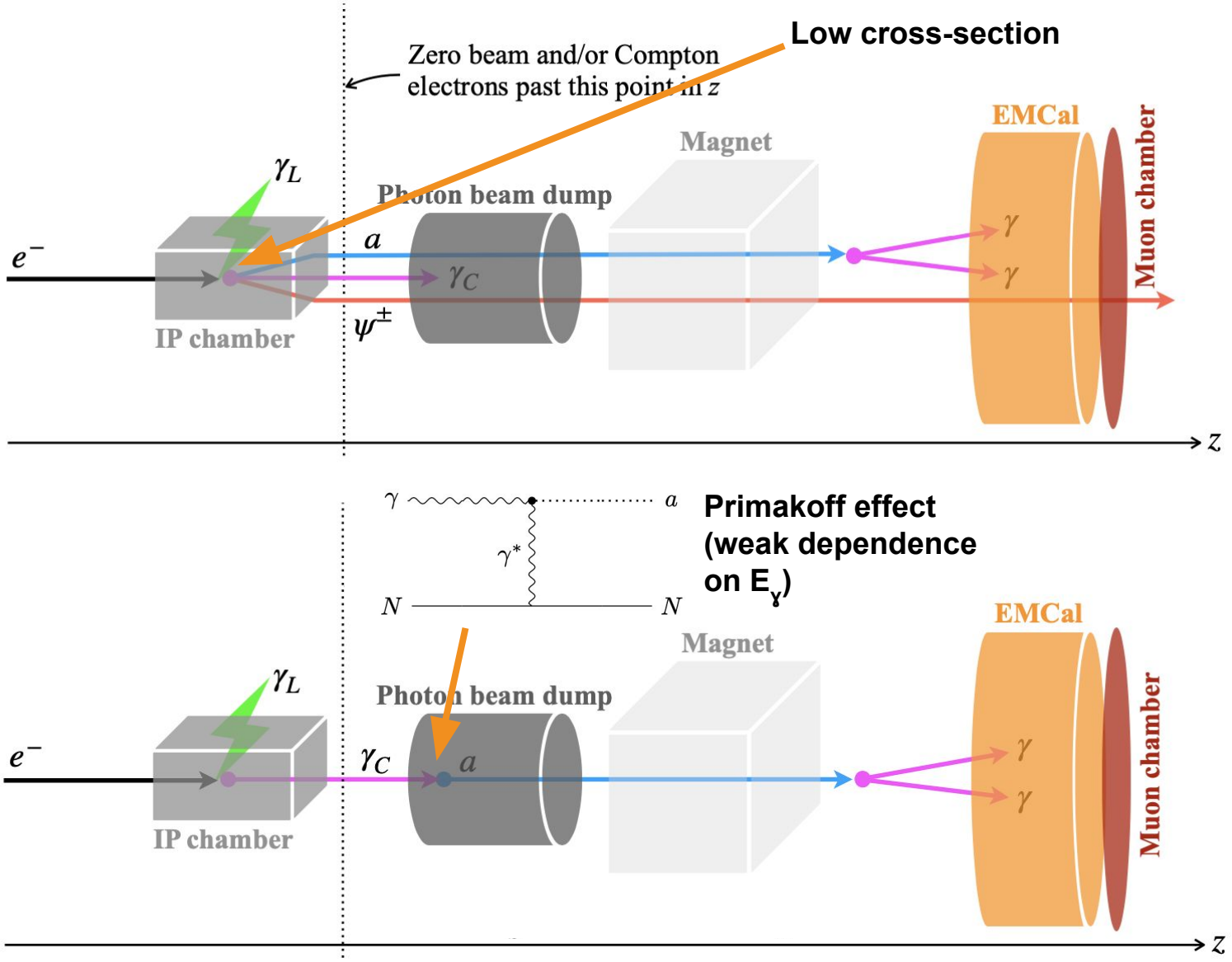
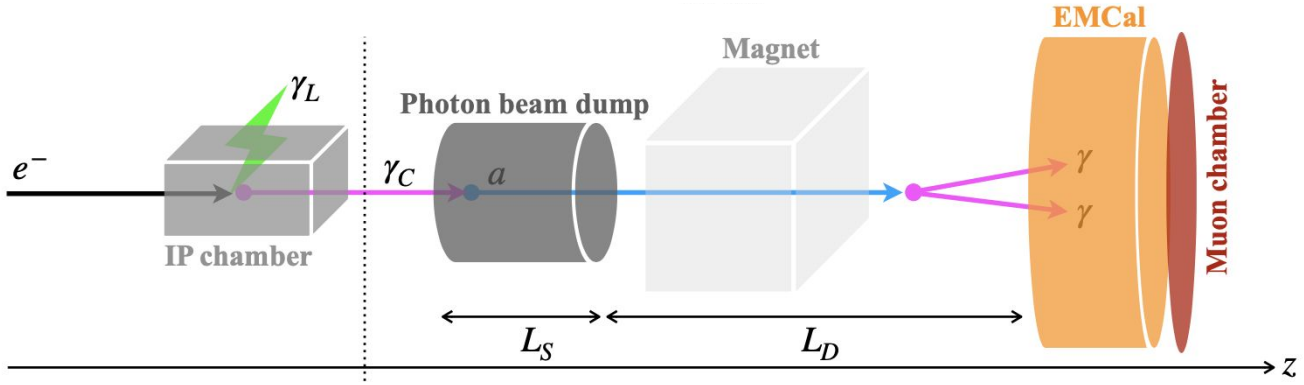
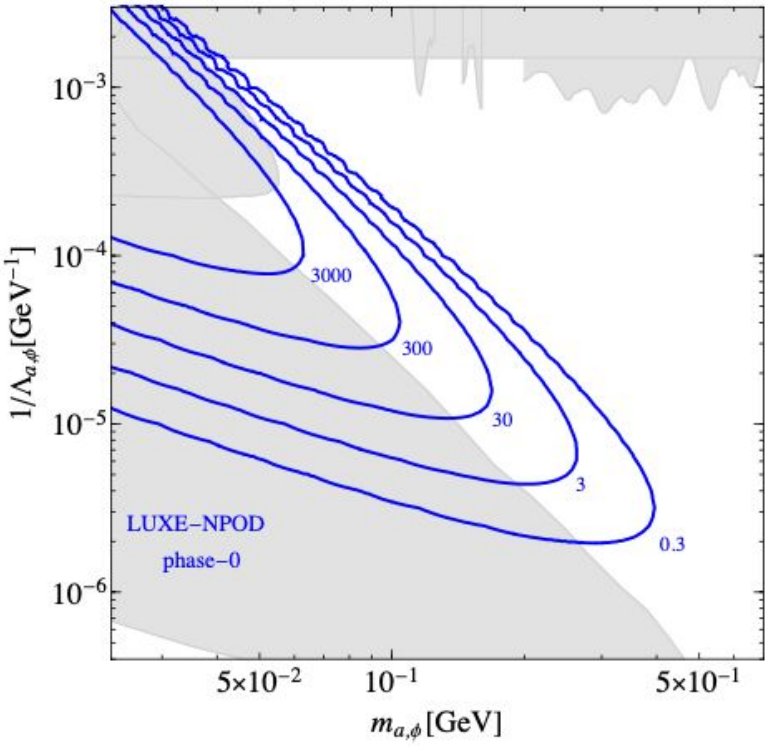


BSM production modes at LUXE



Expected signal yields





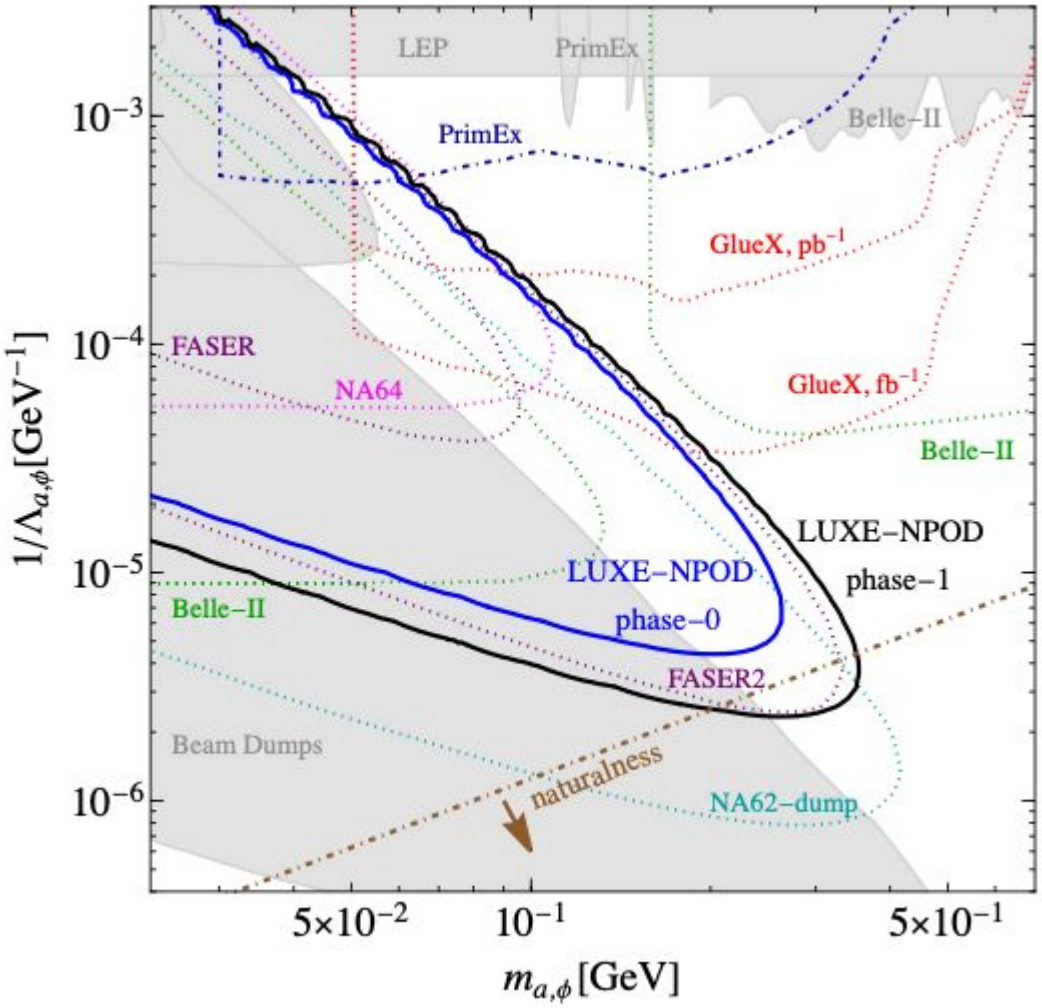
$$N_a \approx \mathcal{L}_{\text{eff}} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \sigma_a \left(e^{-\frac{L_S}{L_a}} - e^{-\frac{L_D+L_S}{L_a}} \right) \mathcal{A}$$

Eu.XFEL parameters	Experimental design
E_e = 16.5 GeV	Dump depth L_S = 1.0 m
N_e = 1.5×10^9	Decay path L_D = 2.5 m
N_{BX} = 10^7	R_D = 1.0 m

Absolute rate depends on:

- Geometrical acceptance
- Photons on target

Expected sensitivity



Current coverage

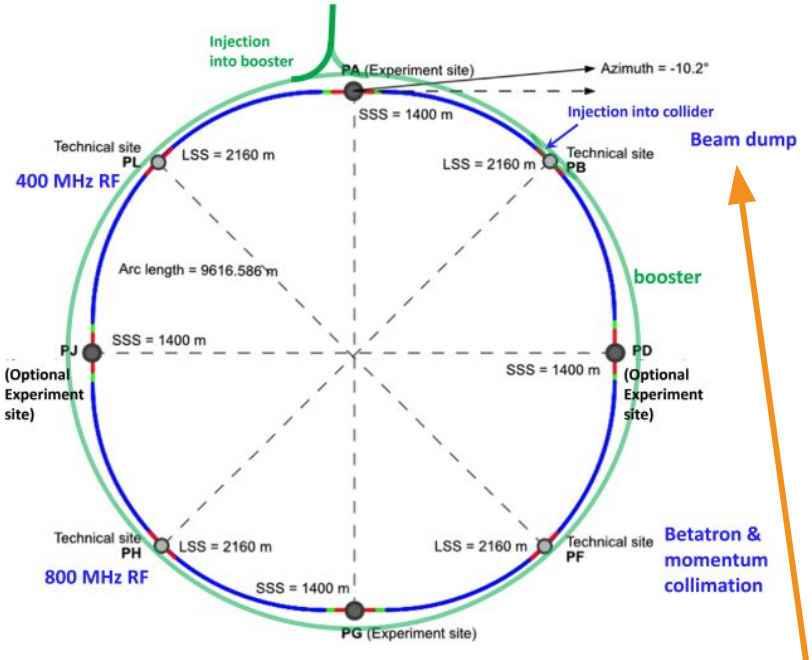
Proposed and future experiments

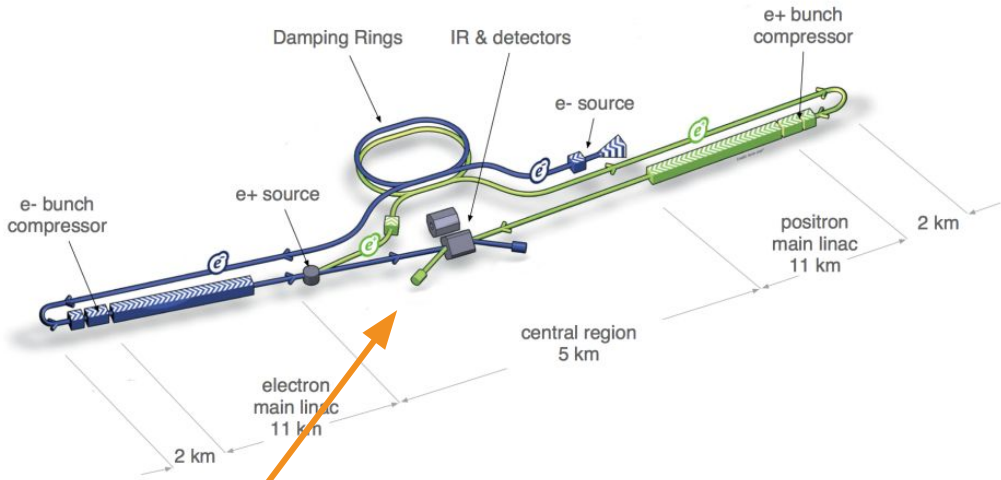
Assume background-free scenario

95% CL limits competitive with projections of FASER2 and NA62

- Similar model parameter coverage in completely different kinematic regime!

NPOD at a Higgs factory?

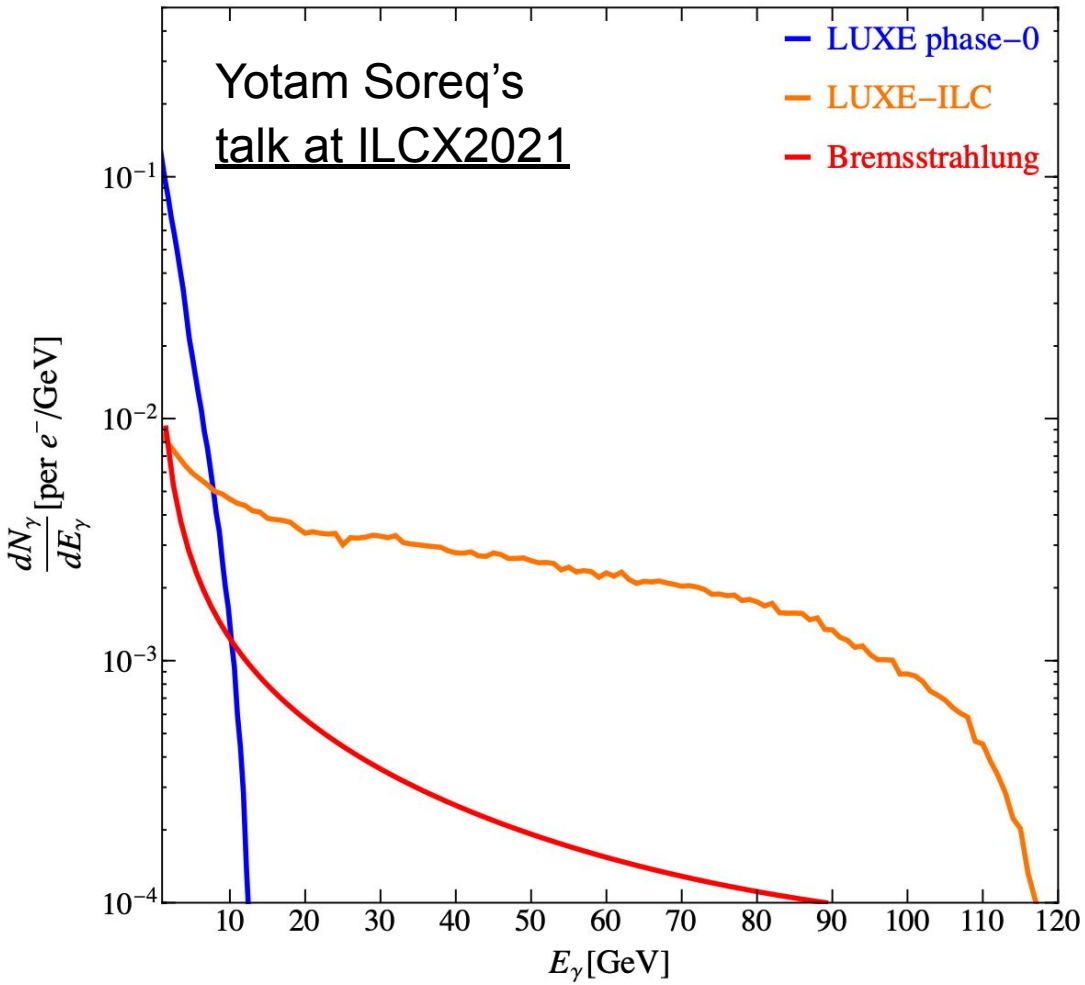




Exploring here the opportunities of beam dumps of FCC-ee (its booster) or ILC

Photon spectra at a Higgs factory

Assuming E_e = 125 GeV



Harder photon spectrum

- Average E_γ ~ 40 GeV

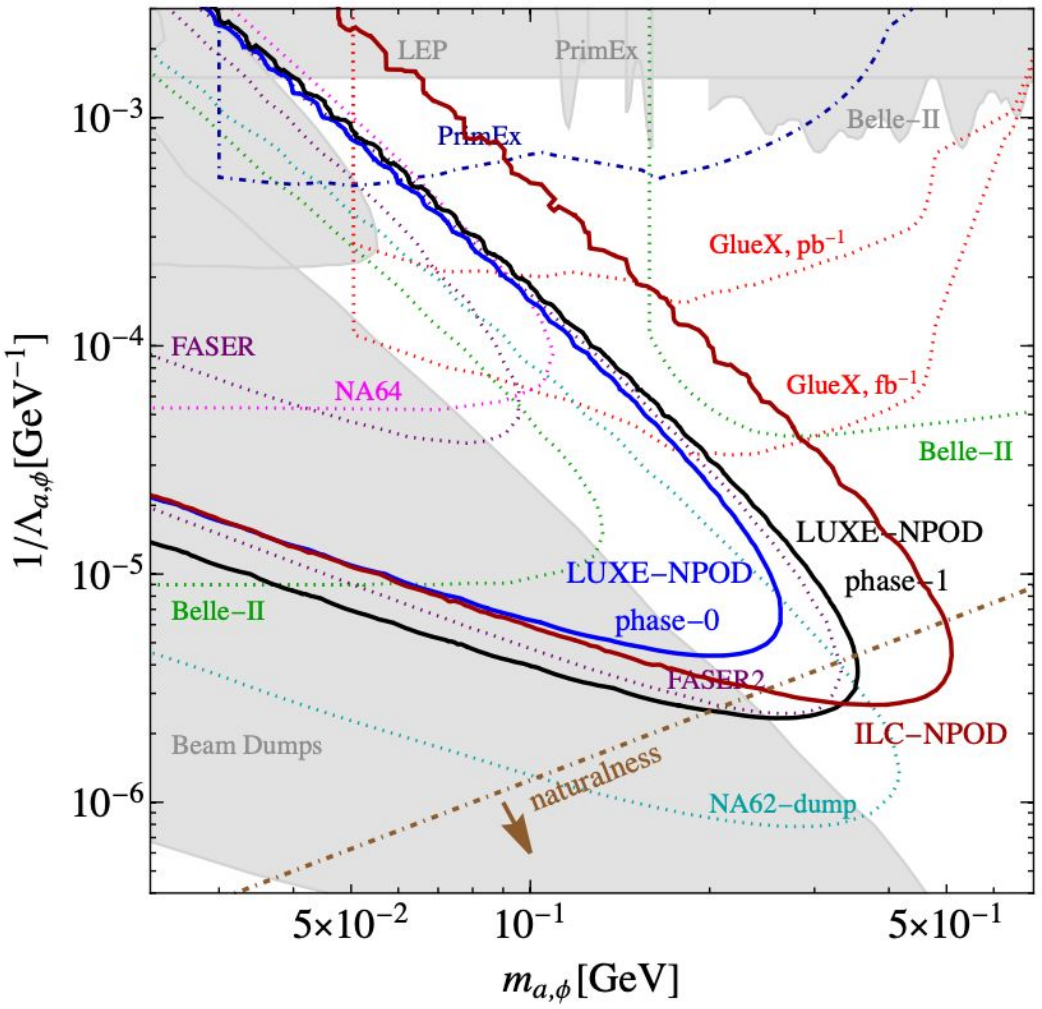
No large change in production cross-section

Significantly larger ALP lorentz boost

- Access to larger masses!

Expected sensitivity gain from energy

Yotam Soreq's
talk at ILCX2021



Current coverage

Proposed and future experiments

Assume background-free scenario

- Double dump depth

Keep all parameters as Eu.XFEL, except for the beam energy

Sizeable gain in sensitivity

Rates at ILC or FCC-ee

Eu.XFEL	ILC 250	FCC-ee	FCC-ee booster
E_e = 16.5 GeV	E_e = 125 GeV	E_e = 120 GeV	E_e = 120 GeV
$N_e = 1.5 \times 10^9$	$N_e = 2 \times 10^{10}$	$N_e = 1.8 \times 10^{11}$	$N_e = 0.5 \times 10^{10}$
$N_{BX} = 10^7$	$N_{BX} = 6.6 \times 10^{10}$	$N_{BX} = 1.1 \times 10^5$	$N_{BX} = 3.3 \times 10^8$
Signal yield:	**$\times$ 8.8 10^4**	**$\times$ 1.3**	**$\times 1.1\ 10^3$**

Assumptions:

- 10^7 seconds of data-taking time per year
- Use ILC spent beams* (broader energy spectrum is not problematic)
- Dump of FCC-ee beams 3 times per day*
- Dedicated FCC-ee booster cycles for a beam dump every 10 seconds*

*thanks to J. List and F. Zimmermann for the inputs!

Summary

LUXE can function as a **novel photon source** to create an intense GeV-scale photon beam to look for new physics in a **beam dump experiment**

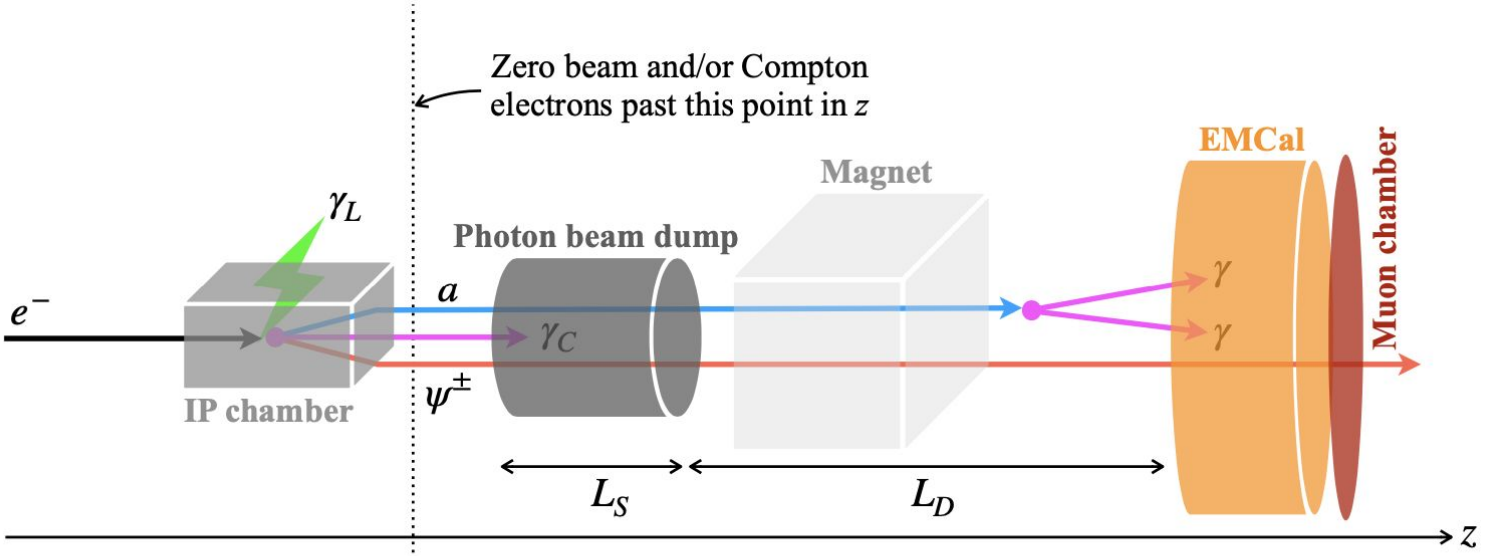
- Cover masses up to O(350) MeV and decay constant of O($10^5 - 10^6$) GeV, competitive with other proposed and ongoing experiments

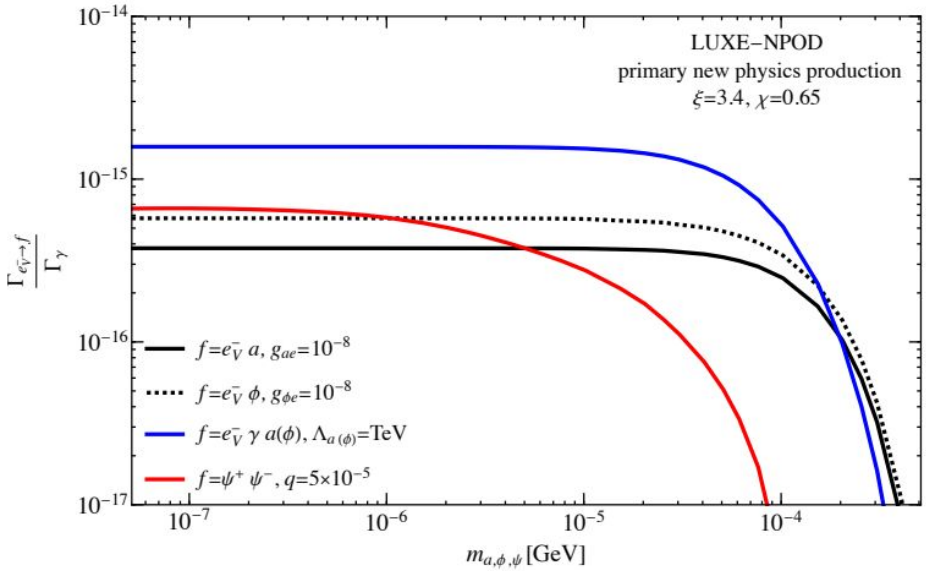
A dedicated experiment at a future Higgs factory could offer major gains

- Higher **beam energy**
- Much higher **number of bunches**
- The best scenario could cover masses up to O(1) GeV and decay constant of O(10^7) GeV

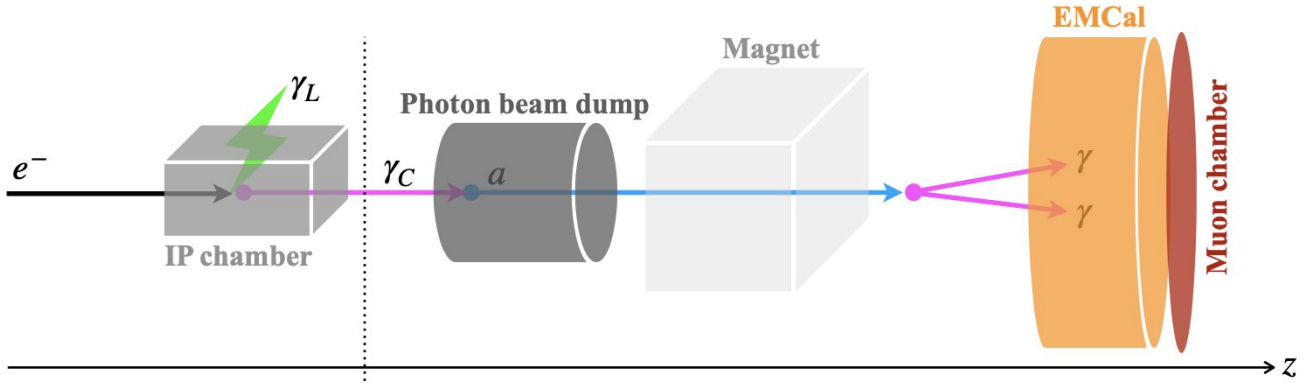
Thank you!

BSM production modes at LUXE





Detection and measurement



Assume (pseudo-) scalar to decay back into pairs of photons

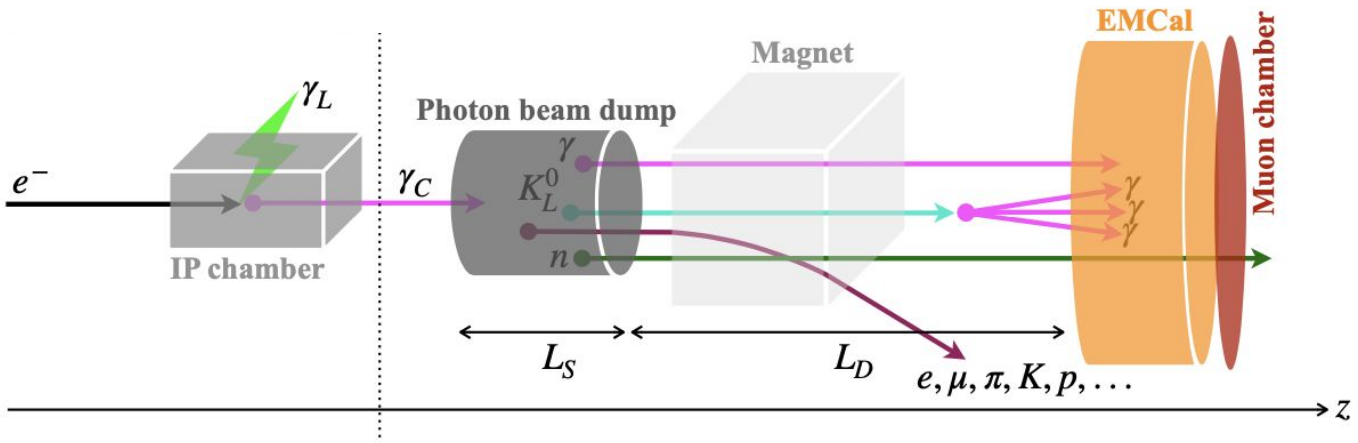
Plan to measure:

- Decay position
- Mass ($m = \sqrt{[2\ E_1\ E_2\ (1 - \cos\alpha)]}$)

Require a calorimeter system with good pointing capabilities.

- Need to optimise lever arm, tracking technology, and comply with available space in experimental area!

Background



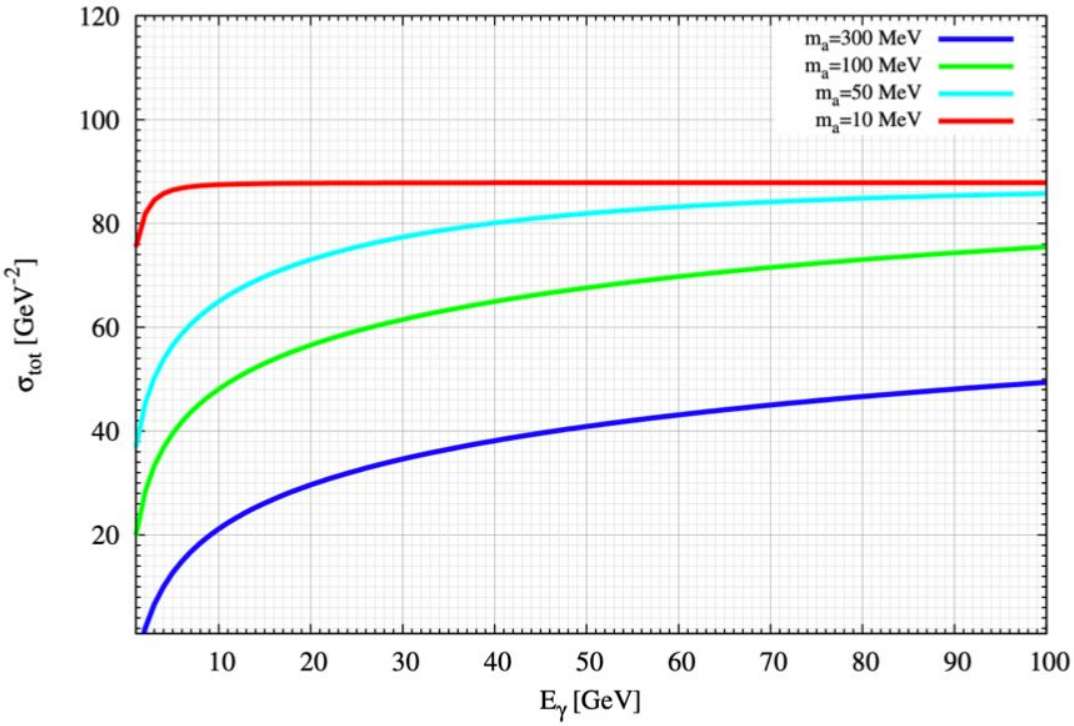
Initial estimation of the backgrounds emerging from the dump with GEANT4:

- charged particles - bent by a magnetic field (1.5 T of 1 m)
- fake photons - $N_{2n\to2\gamma} \approx 5 \times 10^8 \times P_{2n\to2\gamma}(f_{n\to\gamma}) \times R_{sel}$
  $N_{n\gamma\to2\gamma} \approx 1 \times 10^6 \times P_{n\gamma\to2\gamma}(f_{n\to\gamma}) \times R_{sel}$
- real photons - $N_{2\gamma} \approx 8 \times 10^2 \times R_{sel}$

Targets for the BSM detector to have O(1) background events

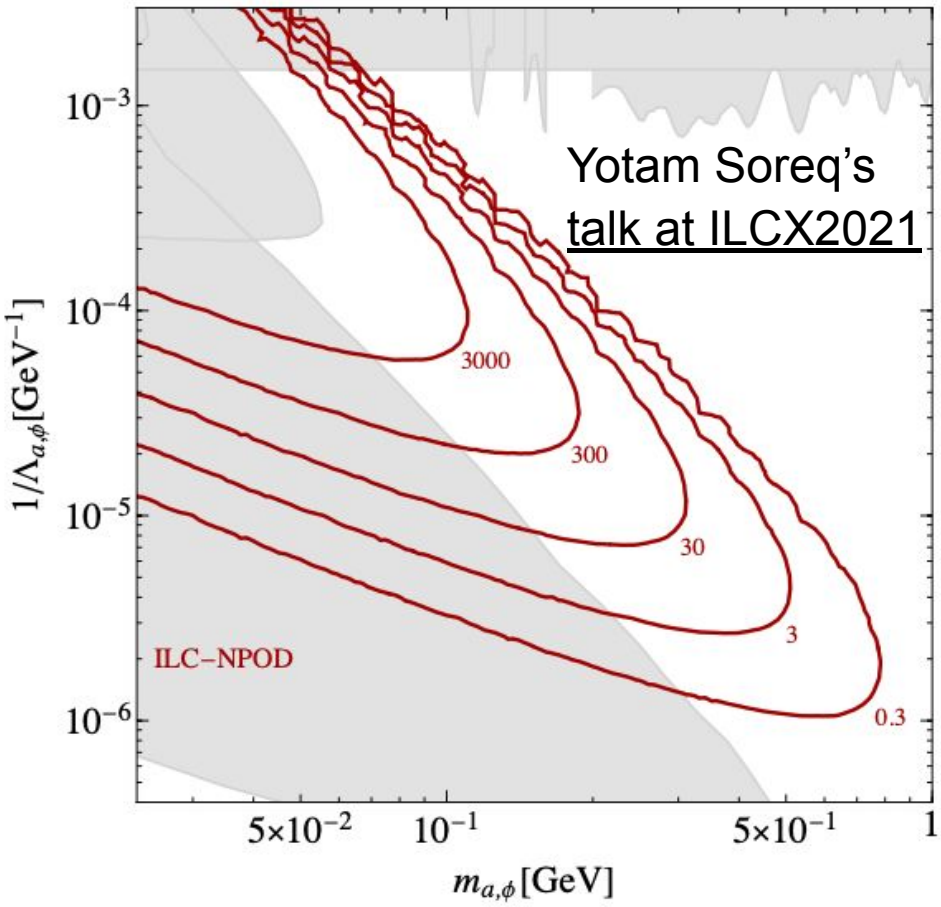
$$\mathbf{f_{n\to\gamma} \sim 10^{-3} \text{ and } R_{sel} \sim 10^{-3}}$$

Primakoff effect dependency on E_γ

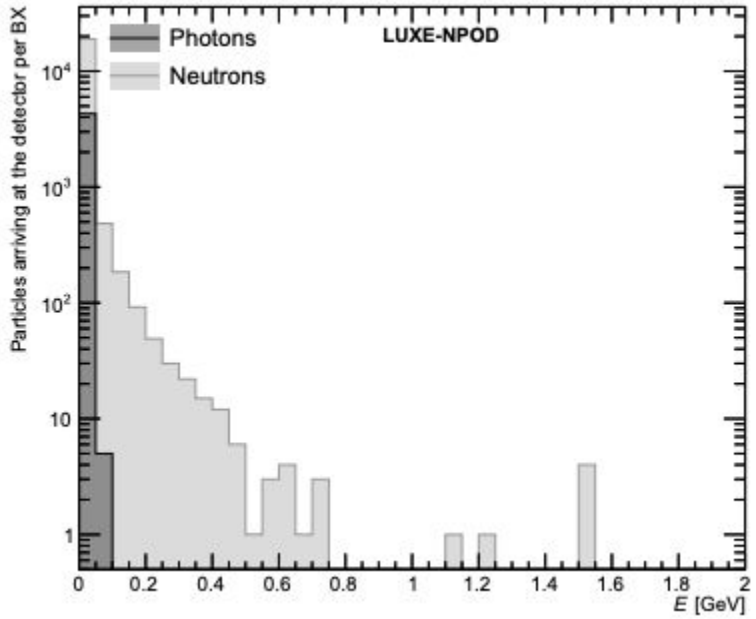


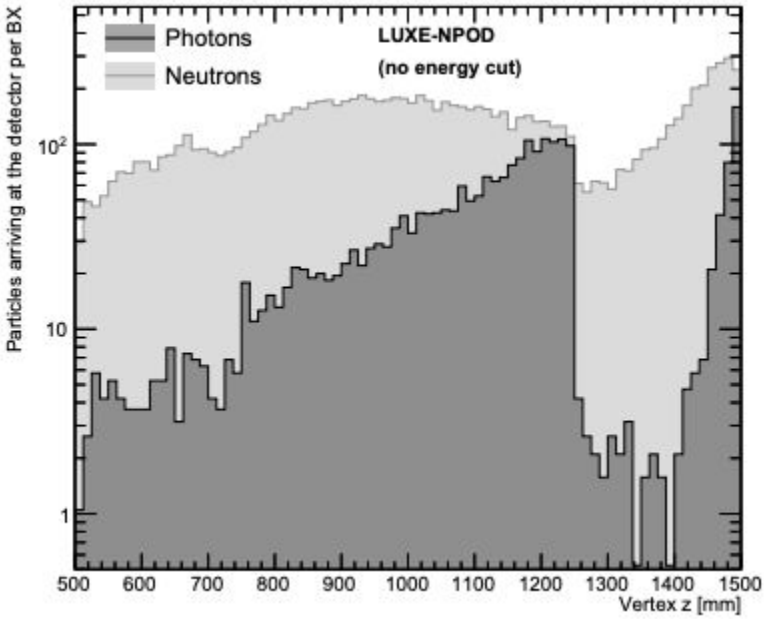
Dusaev, Kirpichnikov, Kirsanov 2004.04469

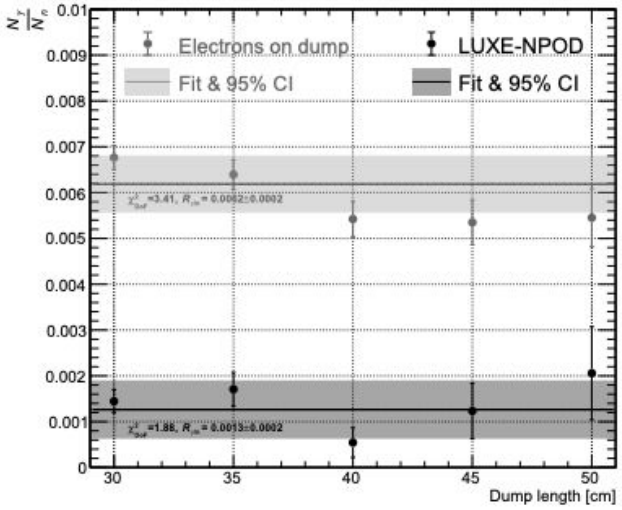
ILC NPOD


Yotam Soreq's
talk at ILCX2021
ILC–NPOD
3000
300
30
3
0.3
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$1/\Lambda_{a,\phi}$[GeV^{-1}]
5×10^{-2}
10^{-1}
5×10^{-1}
1
$m_{a,\phi}$[GeV]

Backup


Photons
Neutrons
LUXE-NPOD
Particles arriving at the detector per BX
E [GeV]


Photons
Neutrons
LUXE-NPOD
(no energy cut)
Particles arriving at the detector per BX
Vertex z [mm]


Electrons on dump
Fit & 95% CI
LUXE-NPOD
Fit & 95% CI
Dump length [cm]

A novel type of beam dump experiment

And a description of the experimental setup