Probing axion-like particles at the LUXE experiment

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for the LUXE collaboration

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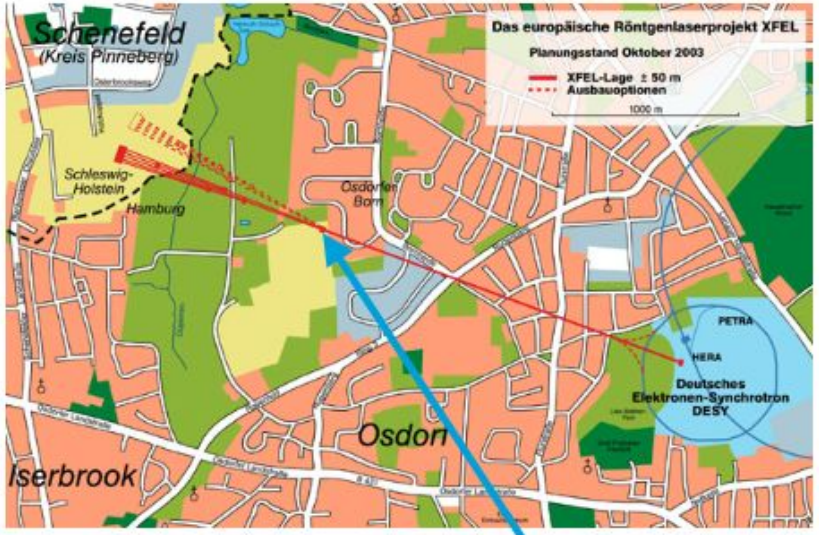
LUXE DESY.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

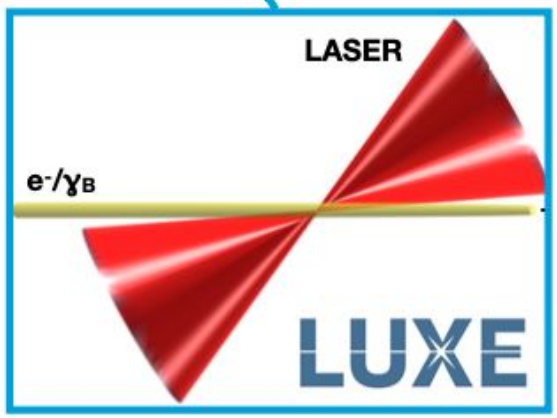
The LUXE experiment

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 for the first time non-perturbative QED**

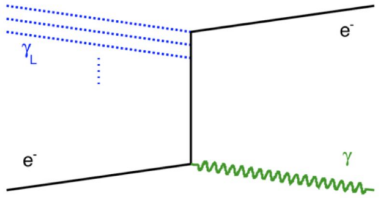


More Information at:

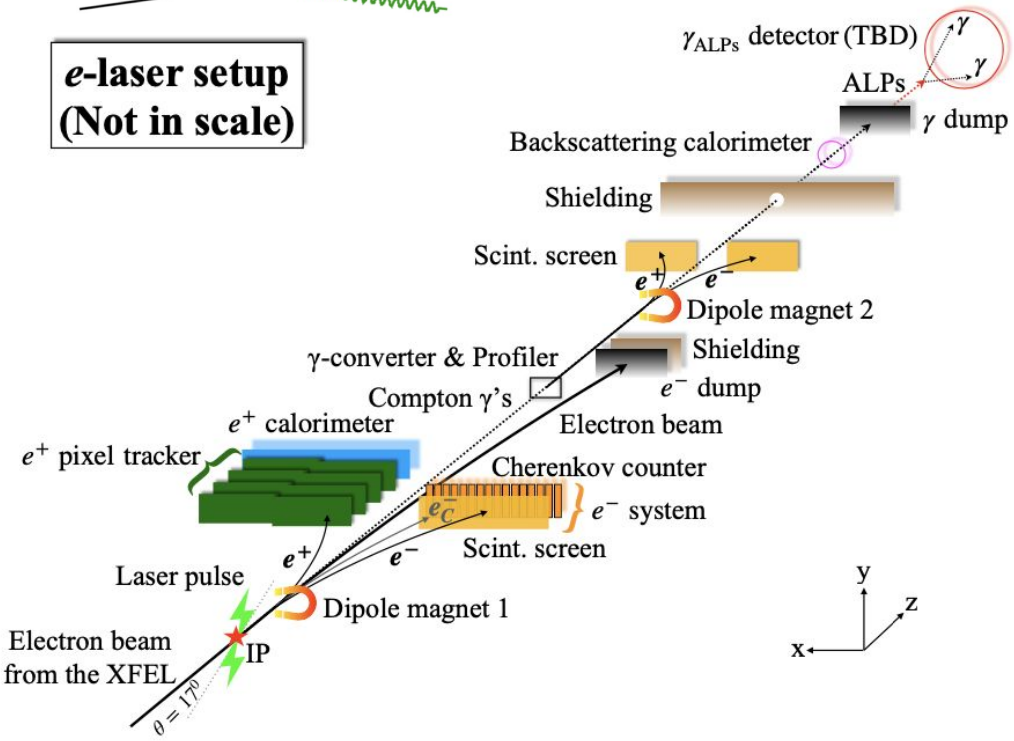
- CDR arXiv: 2102.02032
- Website https://luxe.desy.de

A novel type of beam dump experiment

And a description of the experimental setup



e-laser setup (Not in scale)



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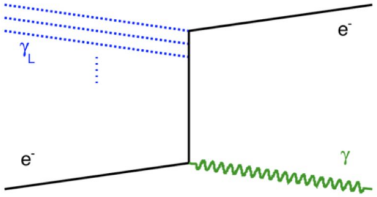

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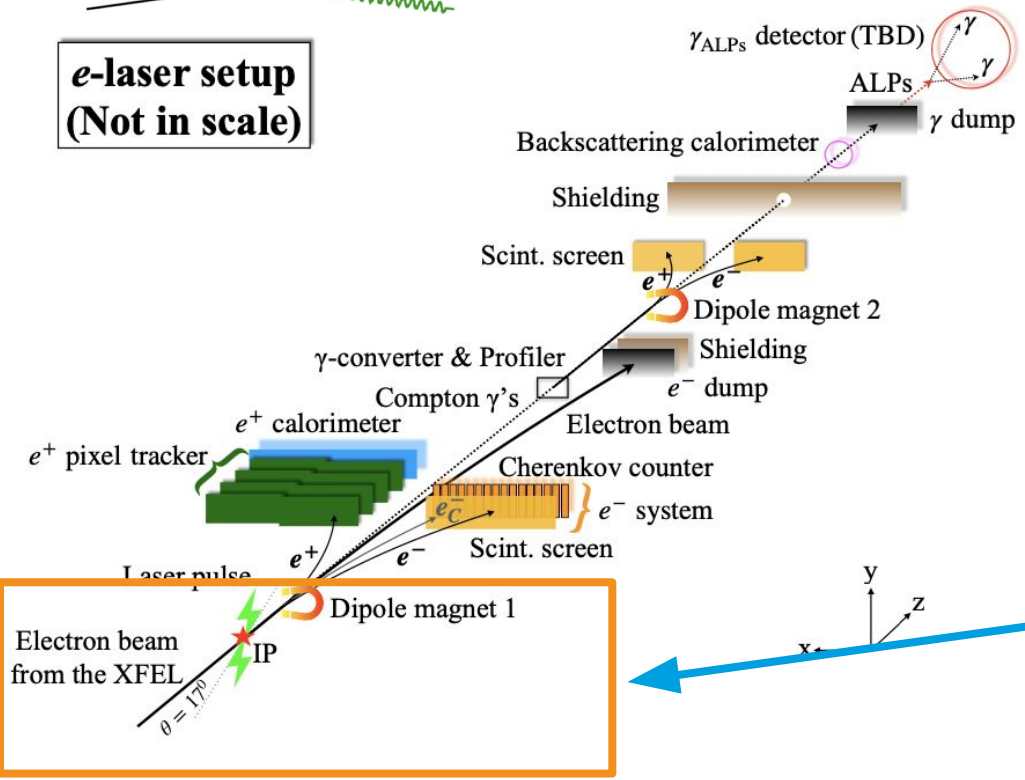

Interaction region

A novel type of beam dump experiment

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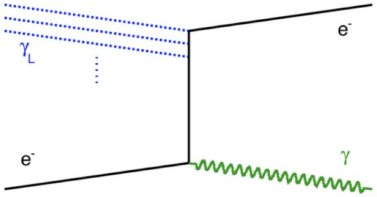

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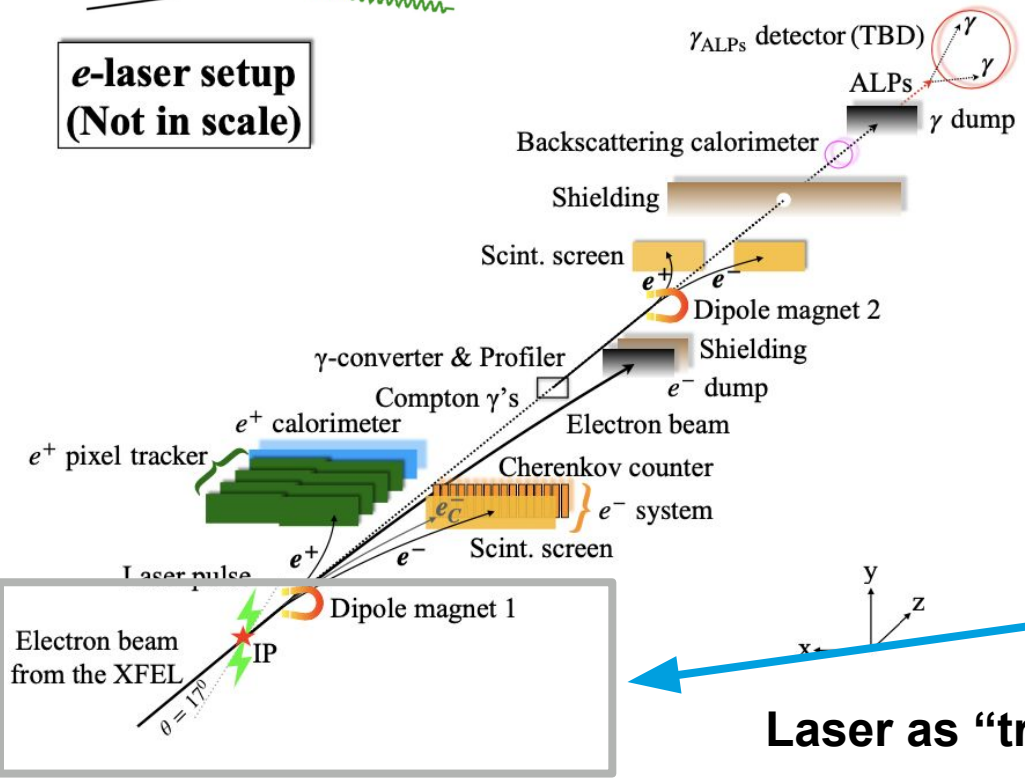

Interaction region

Laser as "transparent dump":

- effective way of producing an intense GeV photon beam

A novel type of beam dump experiment

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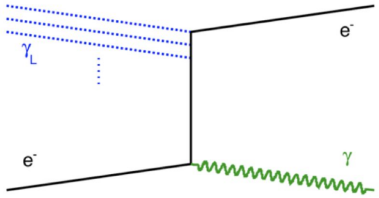

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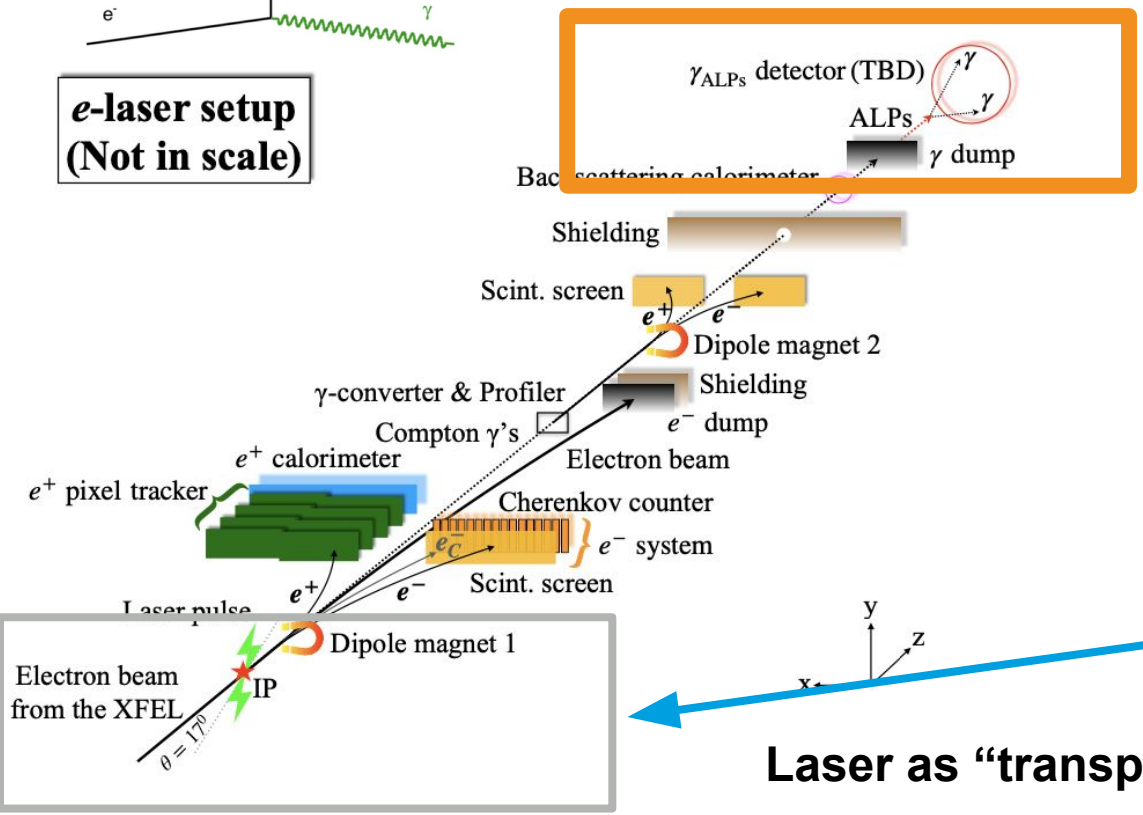


γ-dump experiment!
Dedicated detector

Interaction region

Laser as "transparent dump":

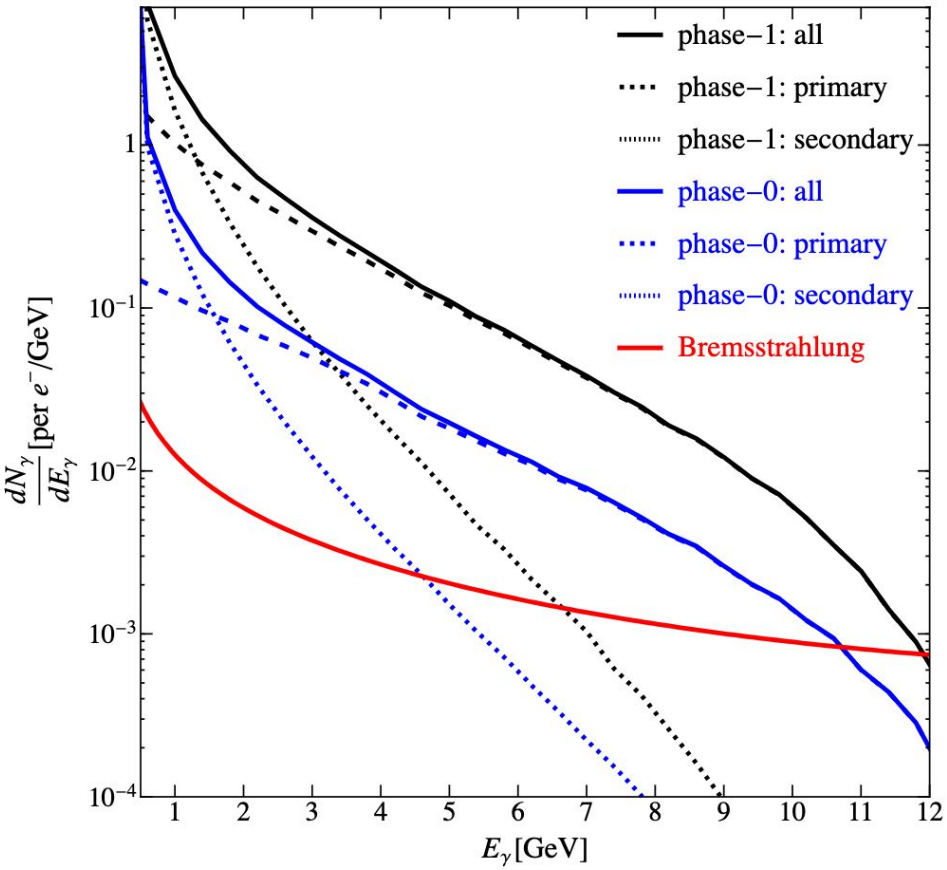
- effective way of producing an intense GeV photon beam

The advantages of a “transparent dump”

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

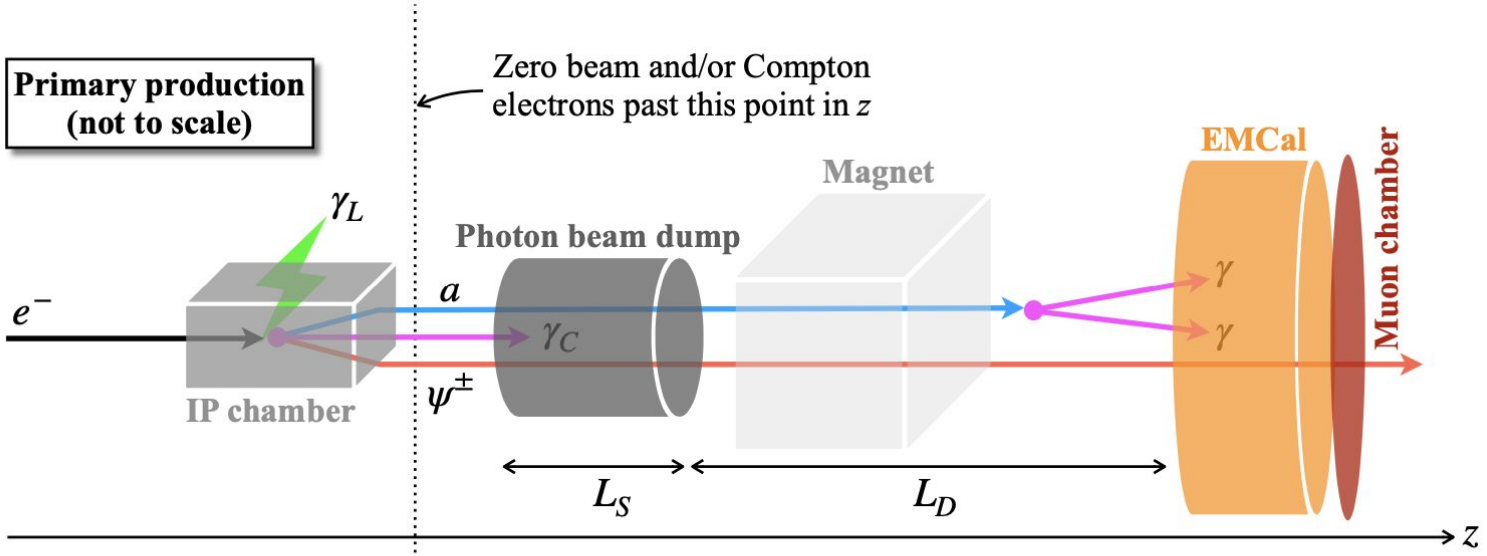
- Multiple GeV photons can be produced for every initial electron.
- Competitive with photon production from thin targets

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



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

BSM production modes at LUXE



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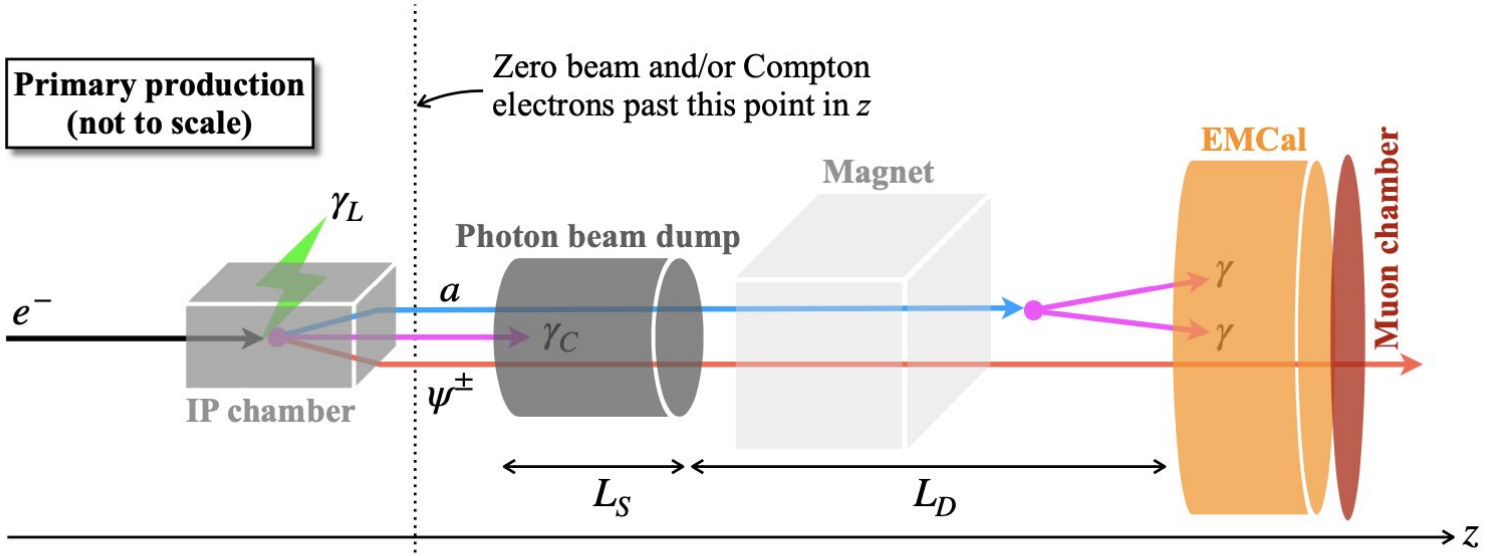

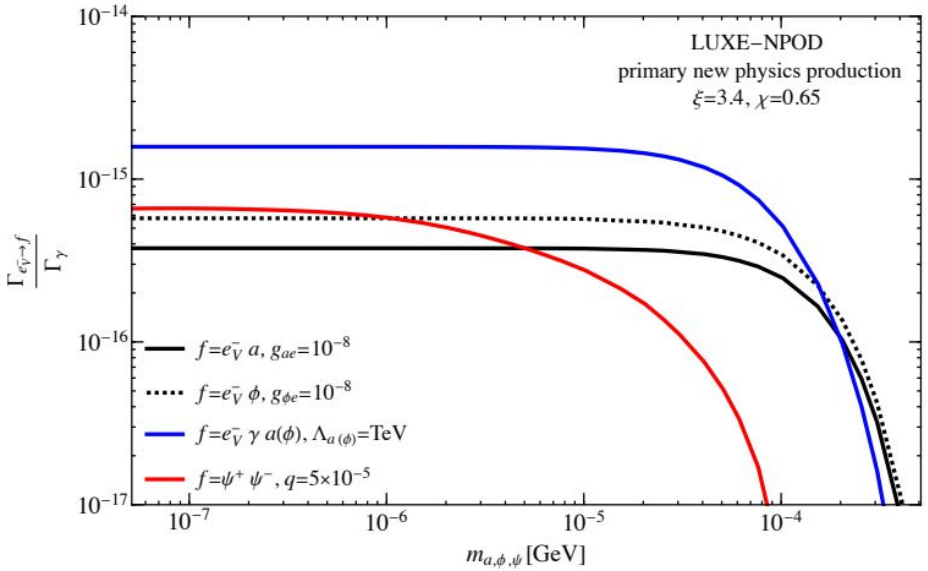

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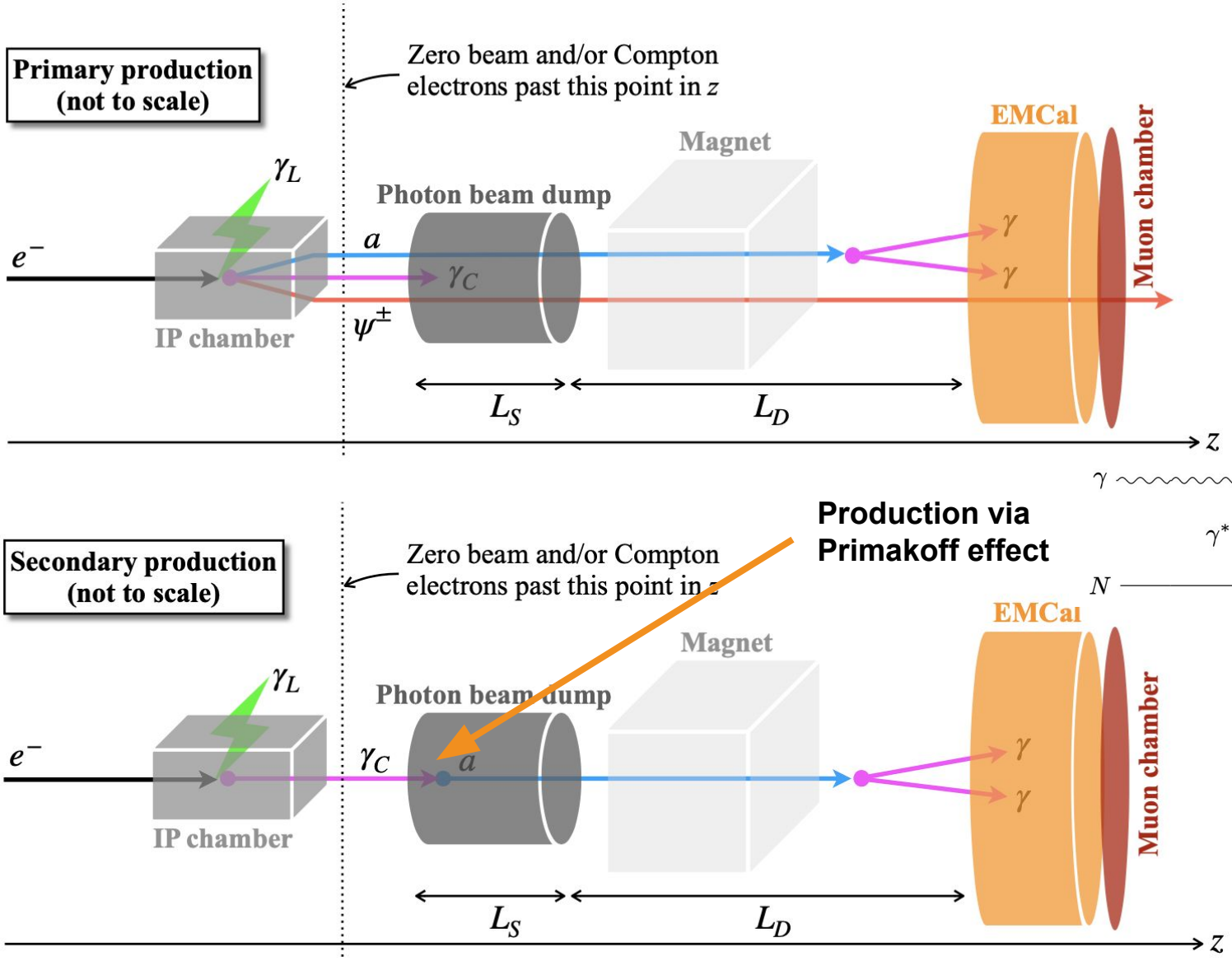


A notable target, but not the only one

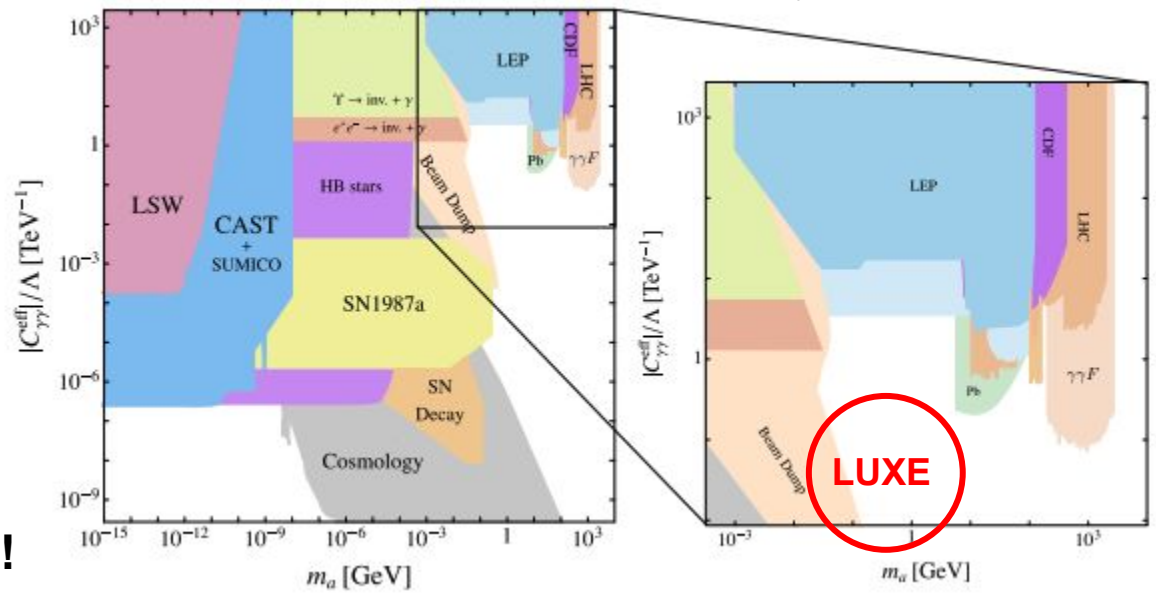
Axion-like particles or new scalars

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

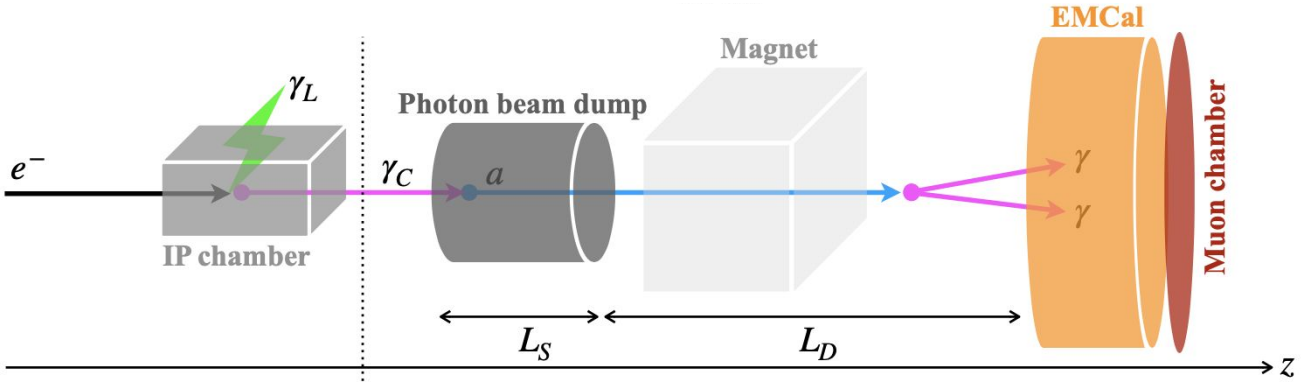
Well motivated BSM scenario!

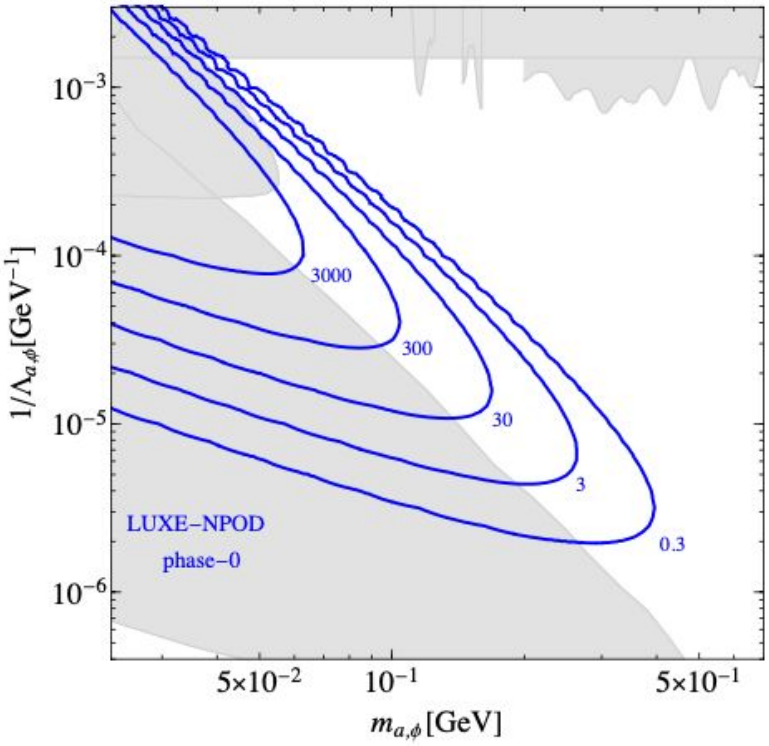


However the experimental setup bears no prejudice against other model sharing the same signature:

- Look for generic (pseudo-)scalars as a function of mass and lifetime

Expected signal yields





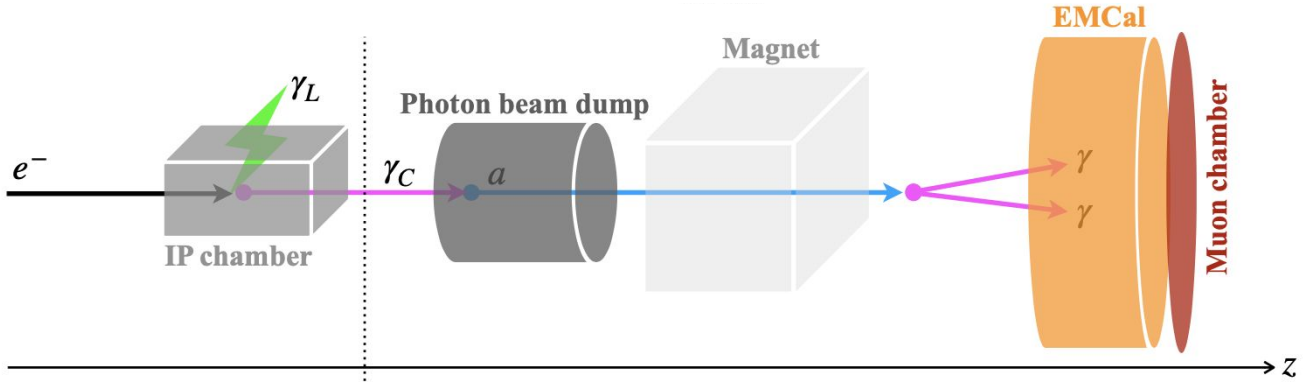
$$N_a \approx \mathcal{L}_{\text{eff}} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \sigma_a \left(e^{-\frac{L_S}{L_a}} - e^{-\frac{L_D+L_S}{L_a}} \right) \mathcal{A}$$

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
- Number of incoming photons

Detection and measurement



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

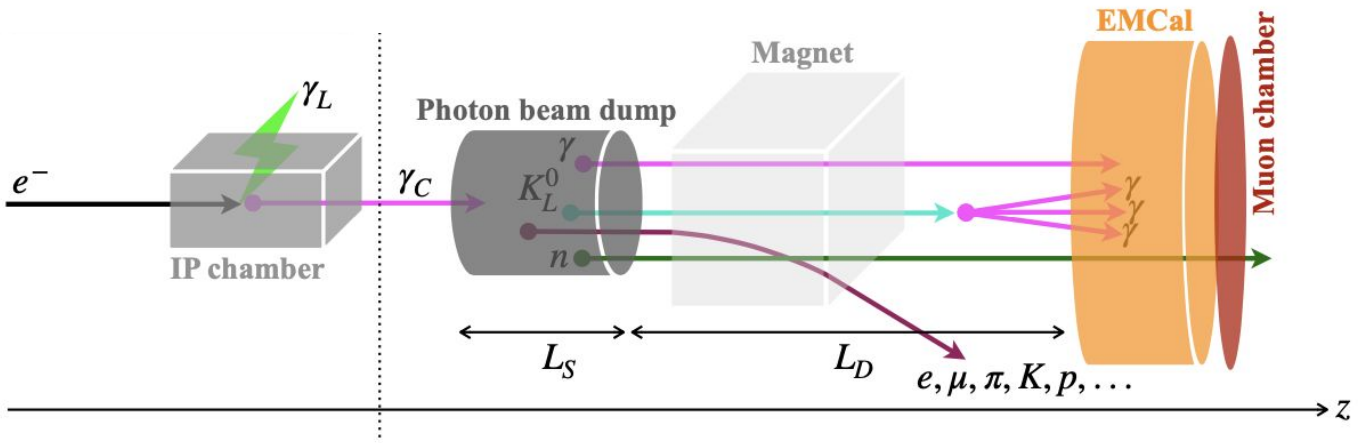
Plan to measure:

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

Plan to use 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

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

Towards a zero background experiment

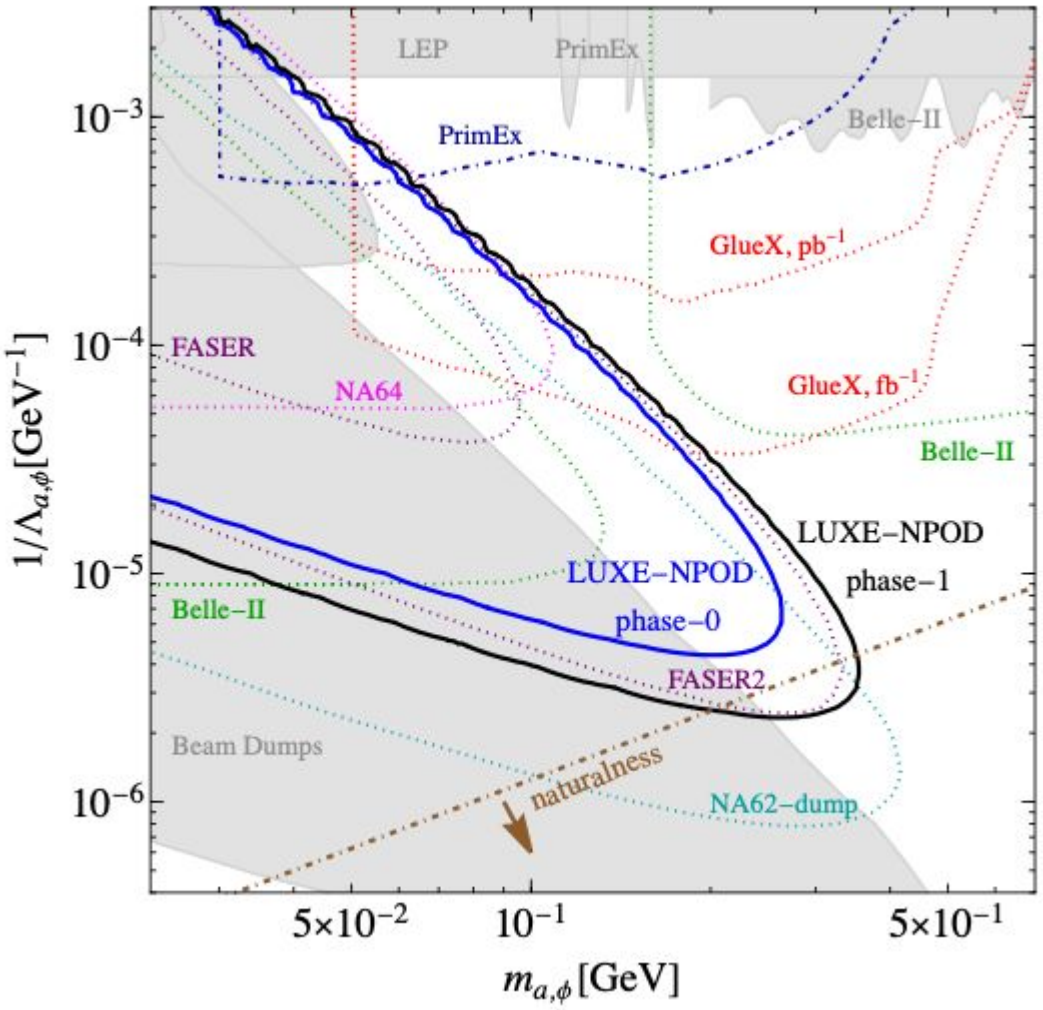
Surveying existing detectors

SpaCal from H1

Dedicated R&D

SHiP SplitCal

Expected sensitivity



Summary

LUXE's main aim is to test QED in its non perturbative regime.

- Start data-taking in 2026

However, 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**.

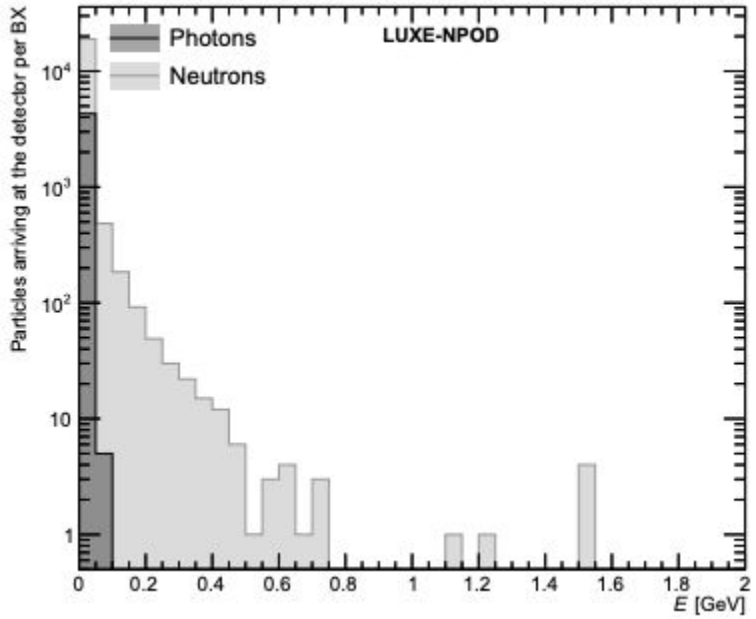
New ALP parameter space can be explored: masses up to O(350) MeV and decay constant of $O(10^5 - 10^6)$ GeV, competitive with other experiments.

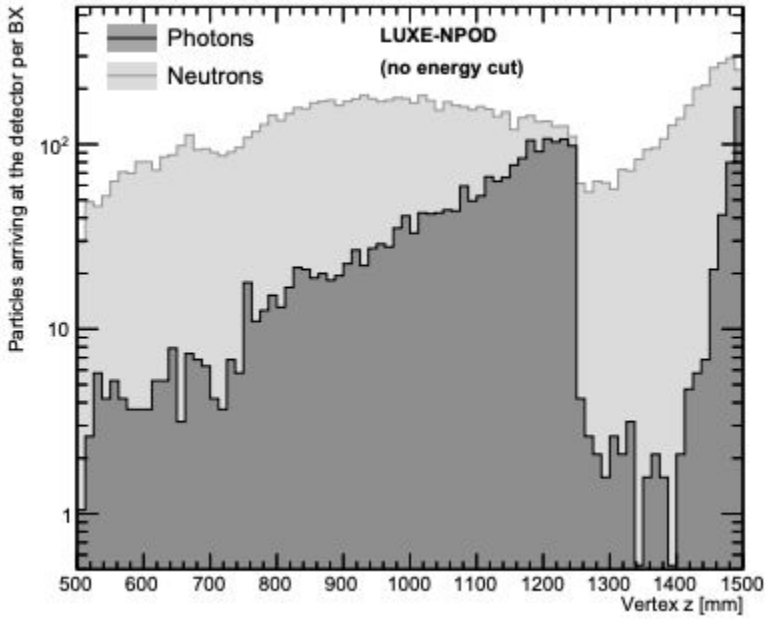
The detector requirements are known, and the development has just started.

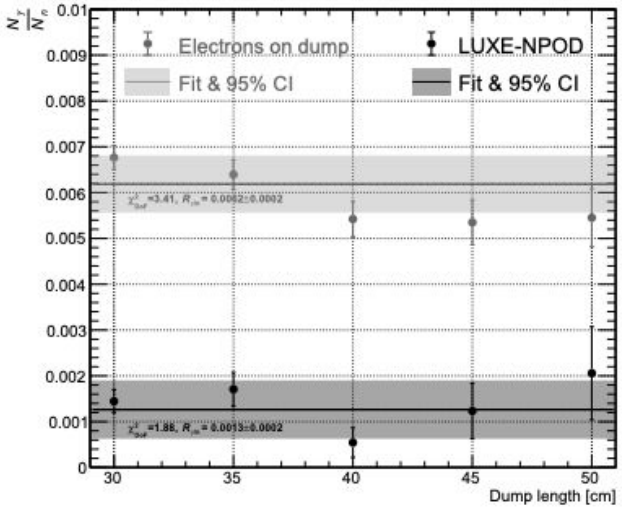
Plenty of space to experiment with new ideas!

Thank you!

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]