LUXE

Lighter than GeV

Probing for Light New Particles with the LUXE experiment

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speaking for the LUXE Collaboration [luxe.desy.de]

IFIC INSTITUT DE FÍSICA CORPUSCULAR CSIC VNIVERSITAT DE VALÈNCIA

SUSY 2024 Theory meets Experiment

Financiado por la Unión Europea NextGenerationEU

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Plan de Recuperación, Transformación y Resiliencia

GENERALITAT VALENCIANA Conselleria de Educación, Universidades y Empleo

GVANEXT Fondos Next Generation en la Comunitat Valenciana

Laser und XFEL Experiment

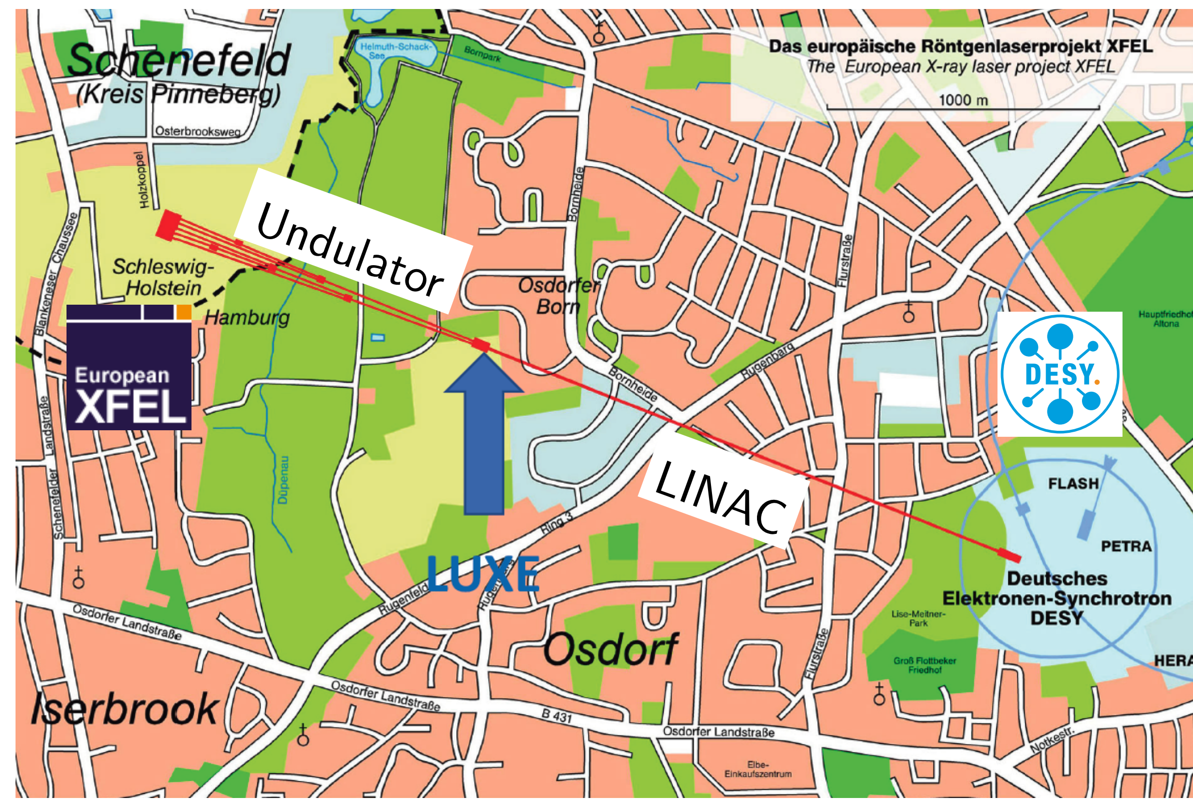
- An asymmetric photon-electron/photon collision experiment between
  - 1.5 eV highly dense photon beam (provided by a 40 or 350 TW laser) and
  - 16.5 GeV electron/photon beam (provided by the XFEL)

Physical quest: non-perturbative QED

- Uncharted regime of the physics of critical EM field/highly dense photons
- "Background" survey for the future colliders/FIPs on the intensity frontier

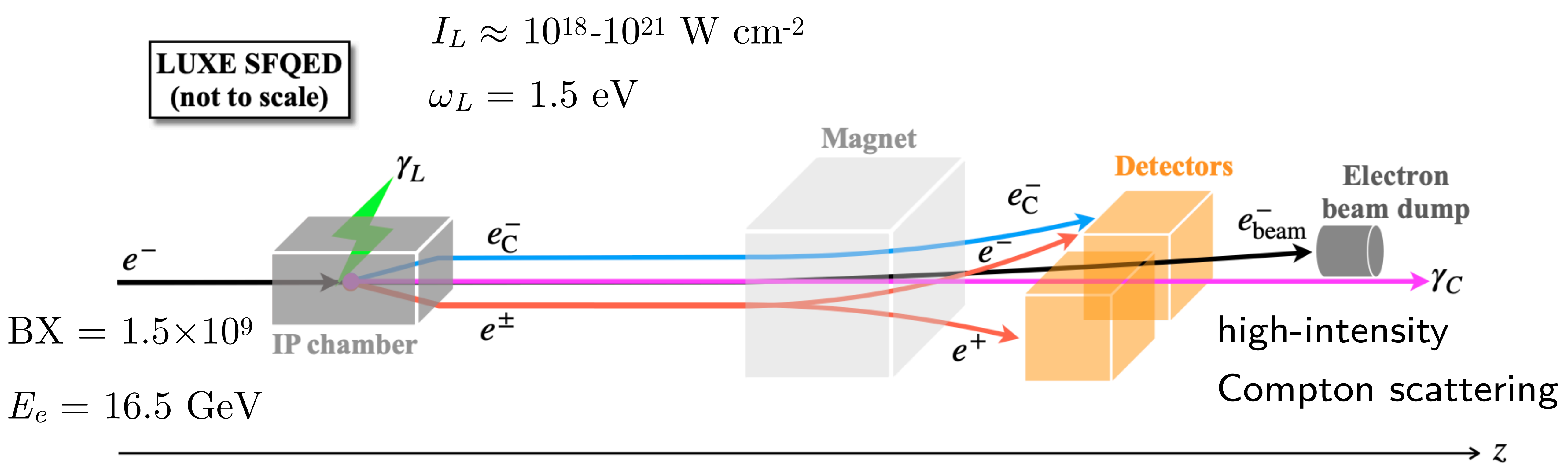
This talk: "New Physics" at LUXE

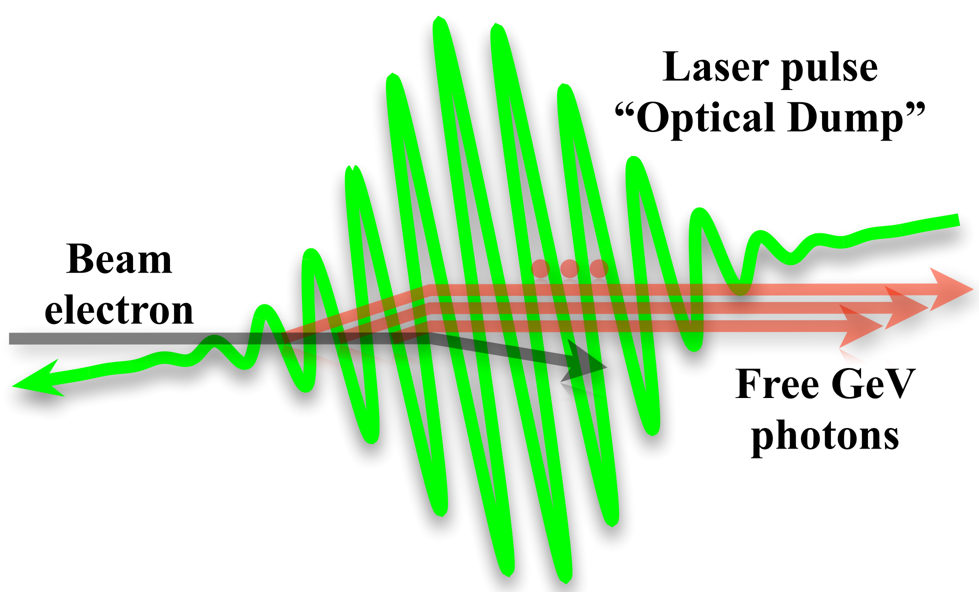
- LUXE NPOD, PRD 106 115034 (2022)
- Recent progresses on background studies, detector searching, and event reconstruction



LUXE LoI: arXiv 1909.00860
LUXE CDR: EPJ ST 230 2445 (2021)
LUXE TDR: arXiv 2308.00515 (accepted)

LUXE electron-laser mode

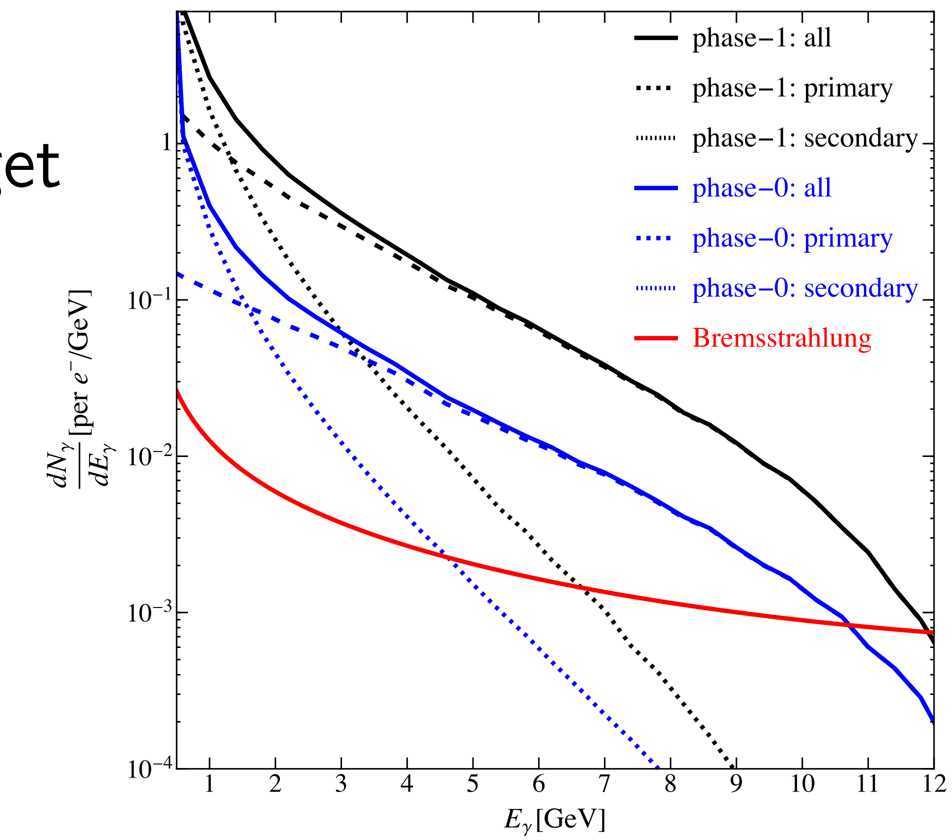


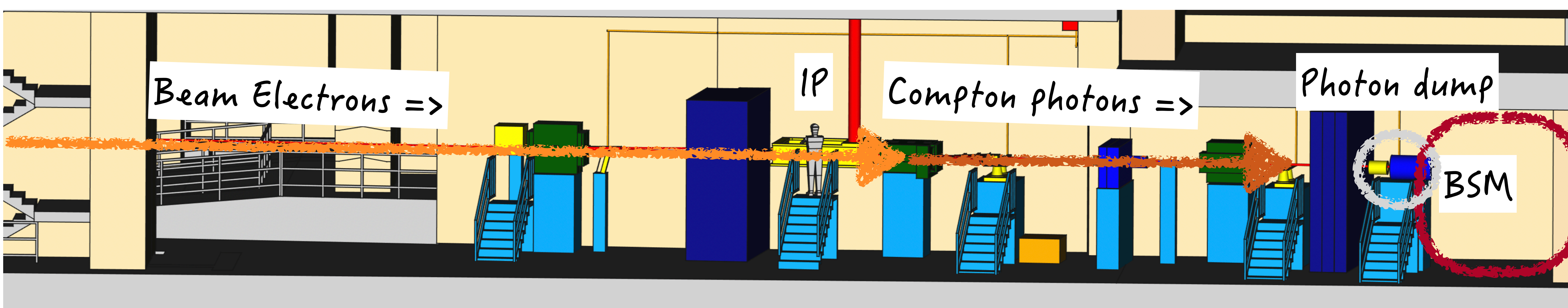


- High-intensity laser converts electrons into GeV photons like a dump
- GeV photon flux falls into a 5 cm radius (95%) on the photon dump at IP+13 m

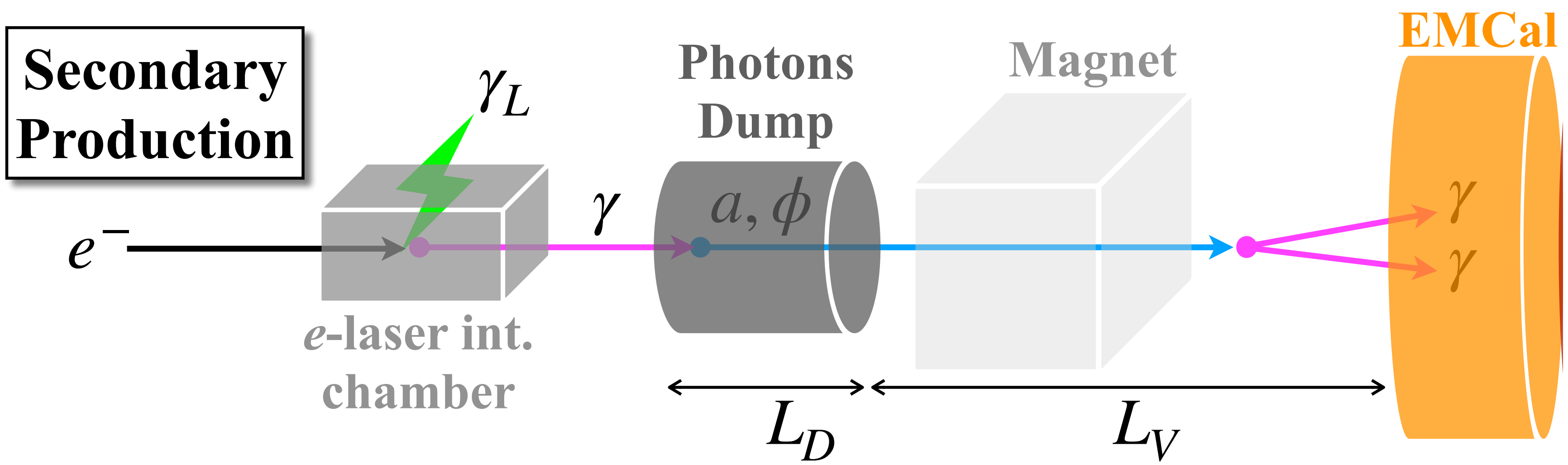
Optical Dump

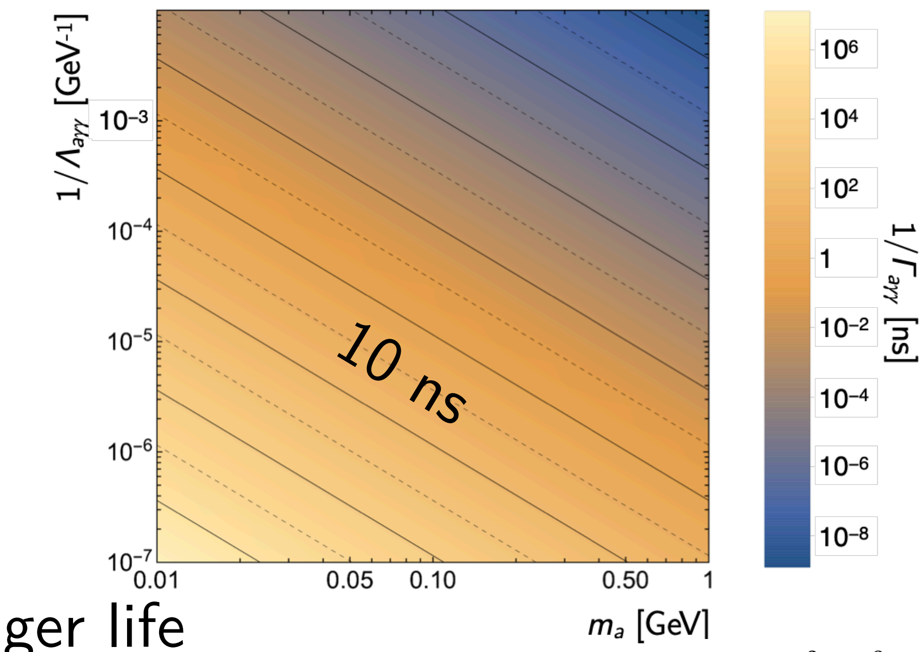
- The optical dump creates more photons than actual "dump" of a $0.01X_0$ Bremsstrahlung target
- Photon number over 1 GeV per BX
  - Phase-1: 2.5 x 10^9
  - Bremsstrahlung: 10^8
- The high intensity Compton scattering produces enough amount of photons for the study of new physics, such as ALP-photon coupling at GeV



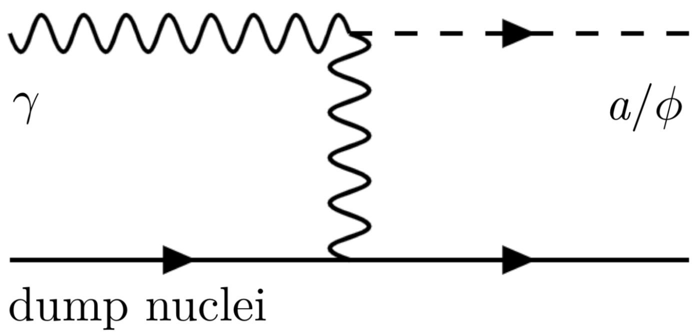


Photon Regeneration





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



$$\mathcal{L}_{a,\phi} = \frac{a}{4\Lambda_a} F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{\phi}{4\Lambda_\phi} F_{\mu\nu}F^{\mu\nu}$$

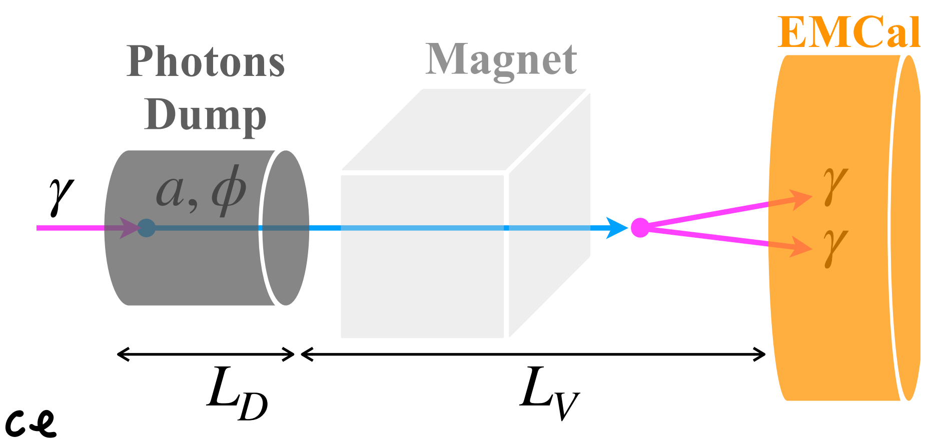
- Light-shinning-through-wall/photon regeneration scheme
- Part of the Compton photons convert into FIPs (e.g. ALPs) at the photon dump; the other photons are exhausted by the dump
- ALPs (of lifetime L_X/c) decay back to pairs of photons
- Photon pairs are picked up by BSM detector

Photon Regeneration

Luminosity cross-section Geometry

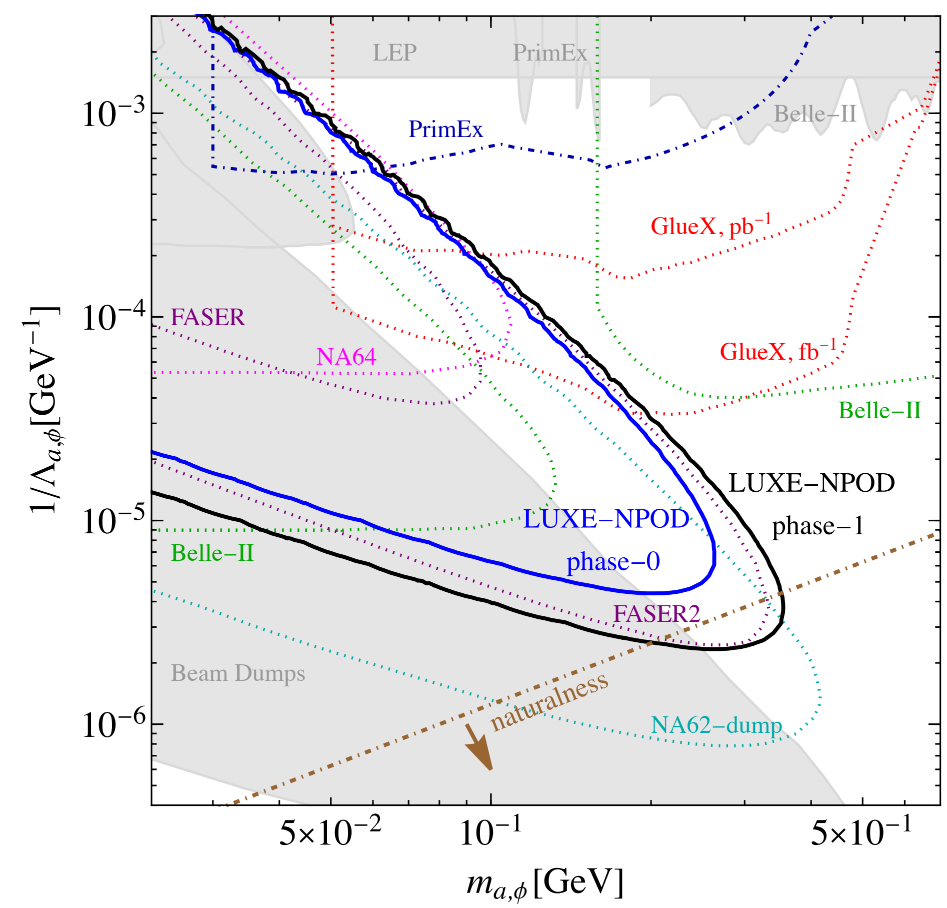
$$N_X \approx \mathcal{L}_{\text{eff}} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \sigma_X(E_\gamma) \left(e^{-\frac{L_D}{L_X}} - e^{-\frac{L_V + L_D}{L_X}} \right) \mathcal{A}$$

Photon spectrum Detector acceptance

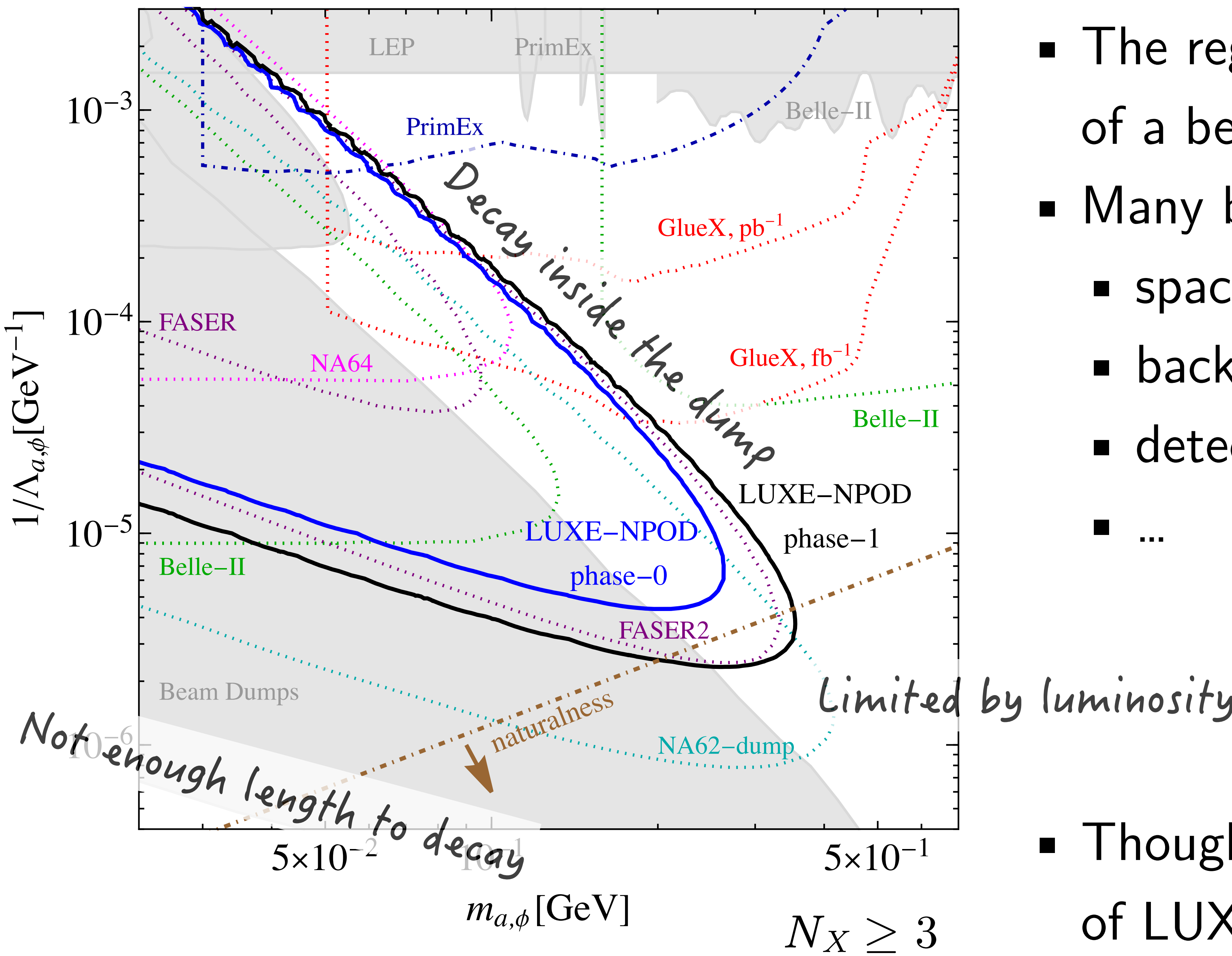


- Luminosity is proportional to photon rate, and relates to the dump material (density, radiation length)
- Cross section depends on ALP parameters (one example in the back up)
- Acceptance mainly depends on detector size
- Geometry, specifically the lengths of the dump and the decay volume, is a key player

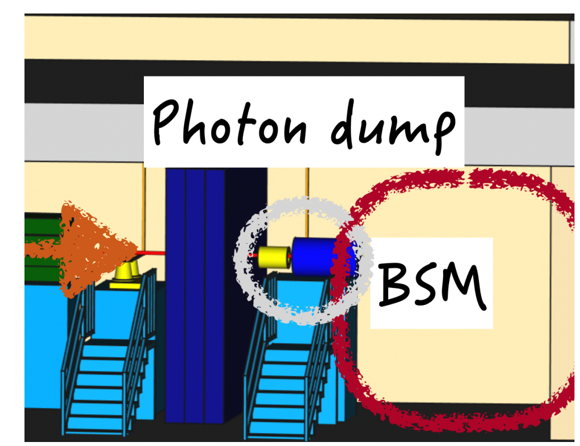
Sensitivity $(N_X \geq 3)$



Sensitivity



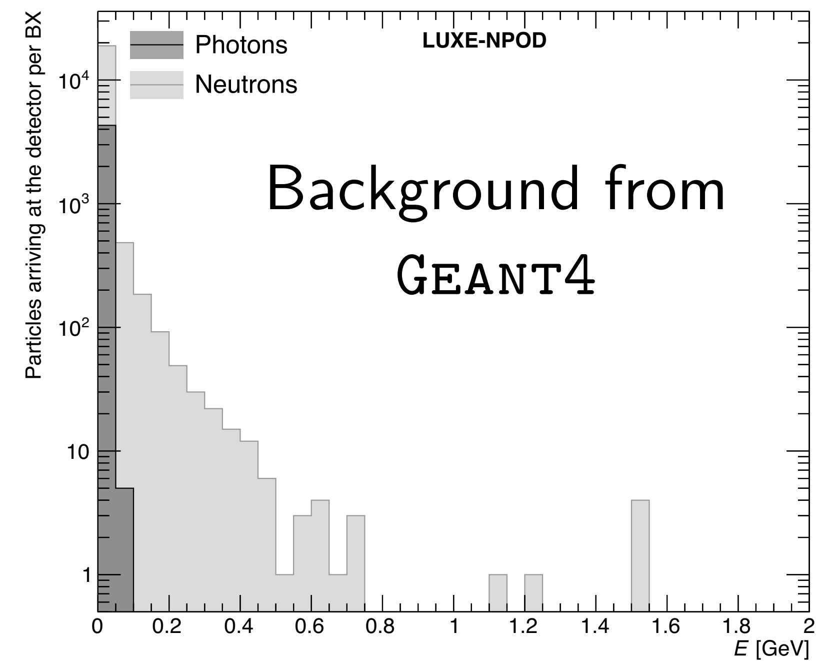
- The region has the typical shape of a beam-dump type experiment
- Many bargaining between:
  - space limit of the experiment
  - background suppression
  - detector size
  - ...

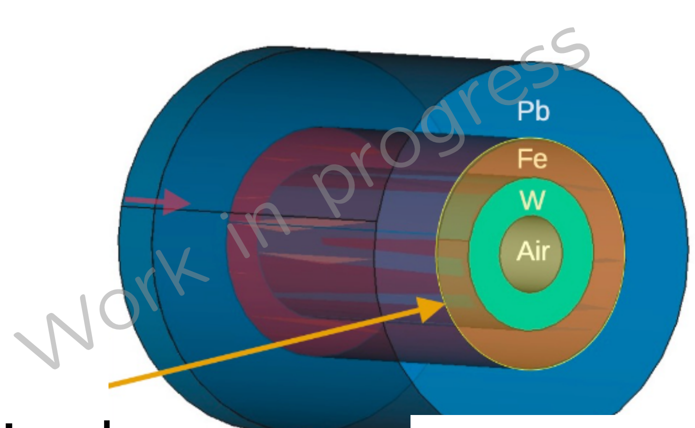


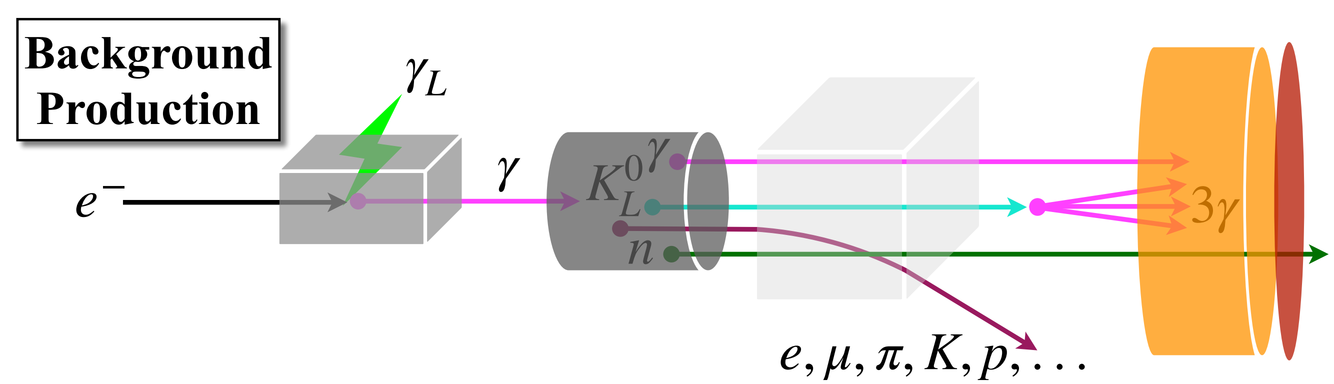
- Though with limits, the sensitivity of LUXE NPOD can compete with FASER2 and even NA62

Background

- Backgrounds come from
  - Charged particles: mostly bent out by magnet
  - Neutral particles:
    - leaked neutrons,
    - photons from other interactions, and
    - other long lived particles
- Background has been studied with GEANT4
  - 10 neutrons per BX (>0.5 GeV)
  - photon number estimated as 10^{-2}







Magnetised

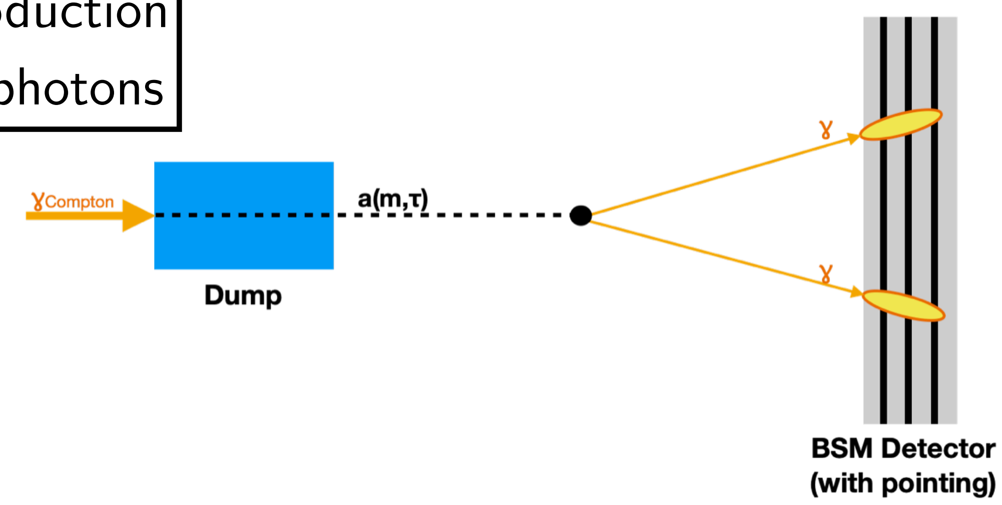
Credit: Oleksandr Borysov

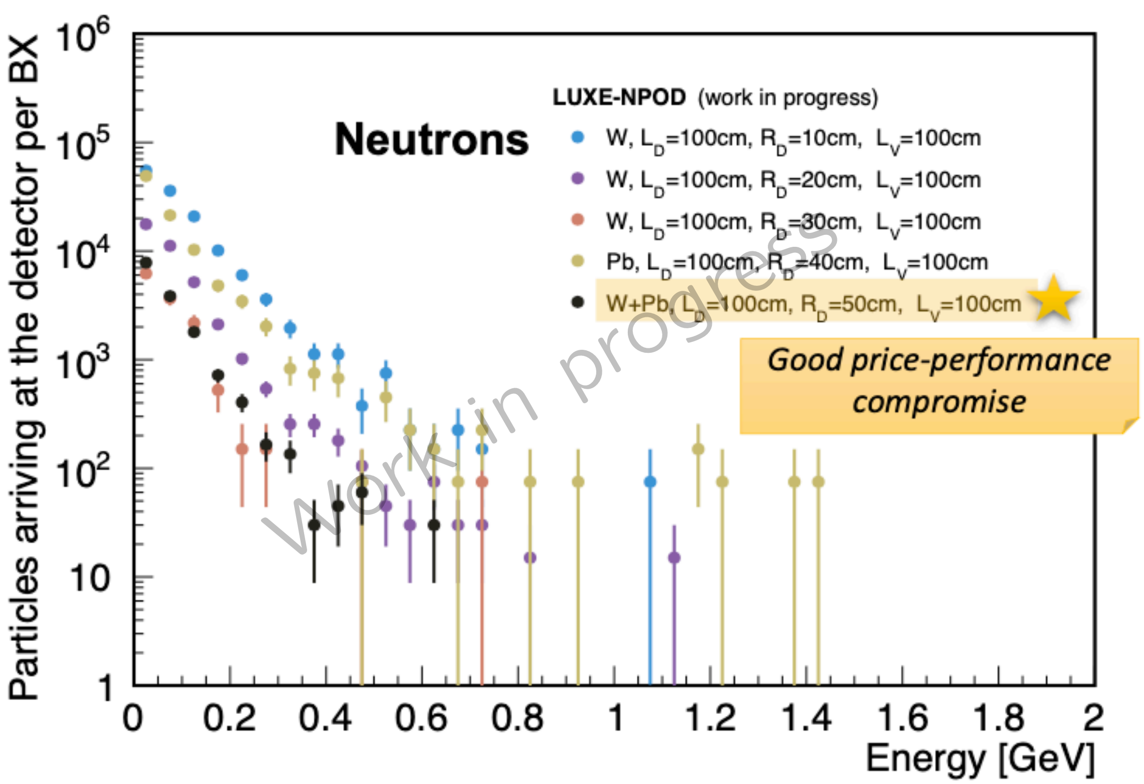
Background

- Time cut to improve the discrimination
  - Low energy neutrons fly much slower (ns)
- Take only events of two photons
- First estimate gave <1 background event of one year (10^7 BX @ 1 Hz) data taking

	Background rejection ~[%]				Signal efficiency [%] for m_a:1/Λ_a		
Δt [ns]	γ	n	p	K_L	130:1e-4	200:e-5	416:e-5
0.1	57	99.9	99.9	87	99.6	84	46
0.5	16	96	94	52	100	100	99
1.0	0	80	70	13	100	100	100

Signal Production with two photons





- More detailed studies ongoing to find out the best dump and geometric composition

Credit: Raquel Quishpe, et al

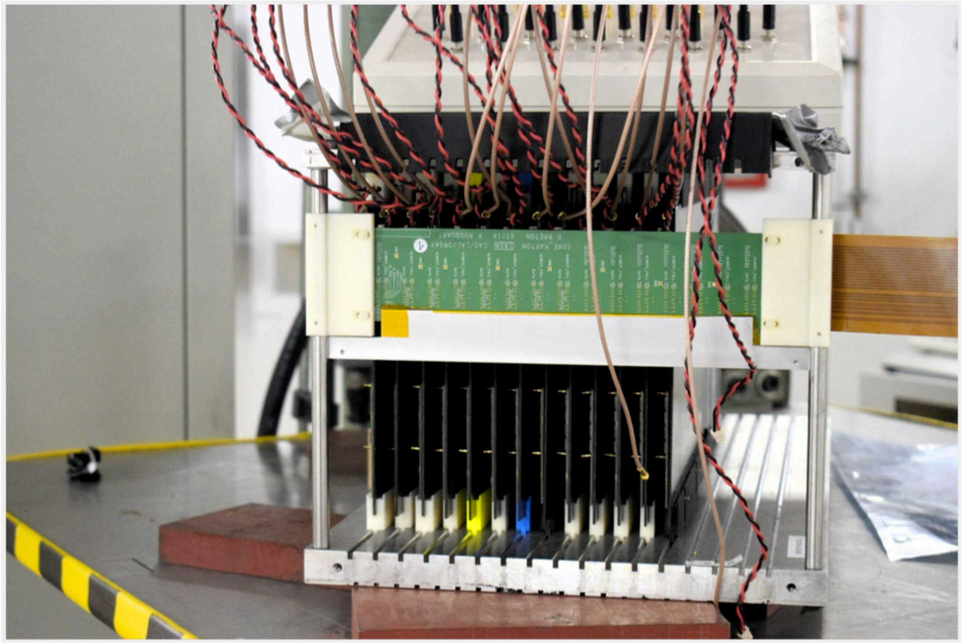
Detector hunting

Criteria for a good NPOD detector

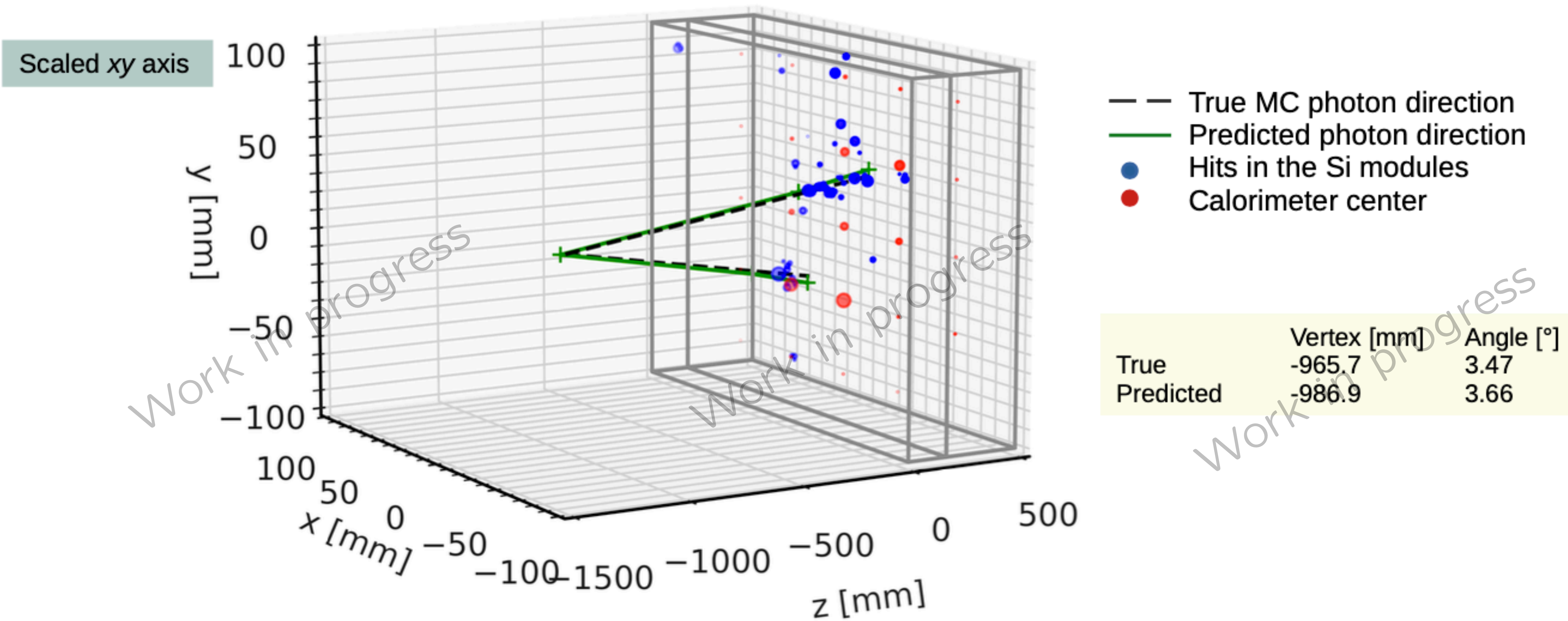
- Being able to efficiently reconstruct the invariant mass and the vertex of a signal candidate
  - Shower separation for two incoming photons
  - Angular resolution to find the vertex
  - Suitable energy resolution in sub GeV
- Being able to suppress the background
  - Time resolution better than 1 ns
  - PID

Main candidate:

- LUXE ECAL-e by CALICE, J NIMA 2019 162969
- Also open to other options



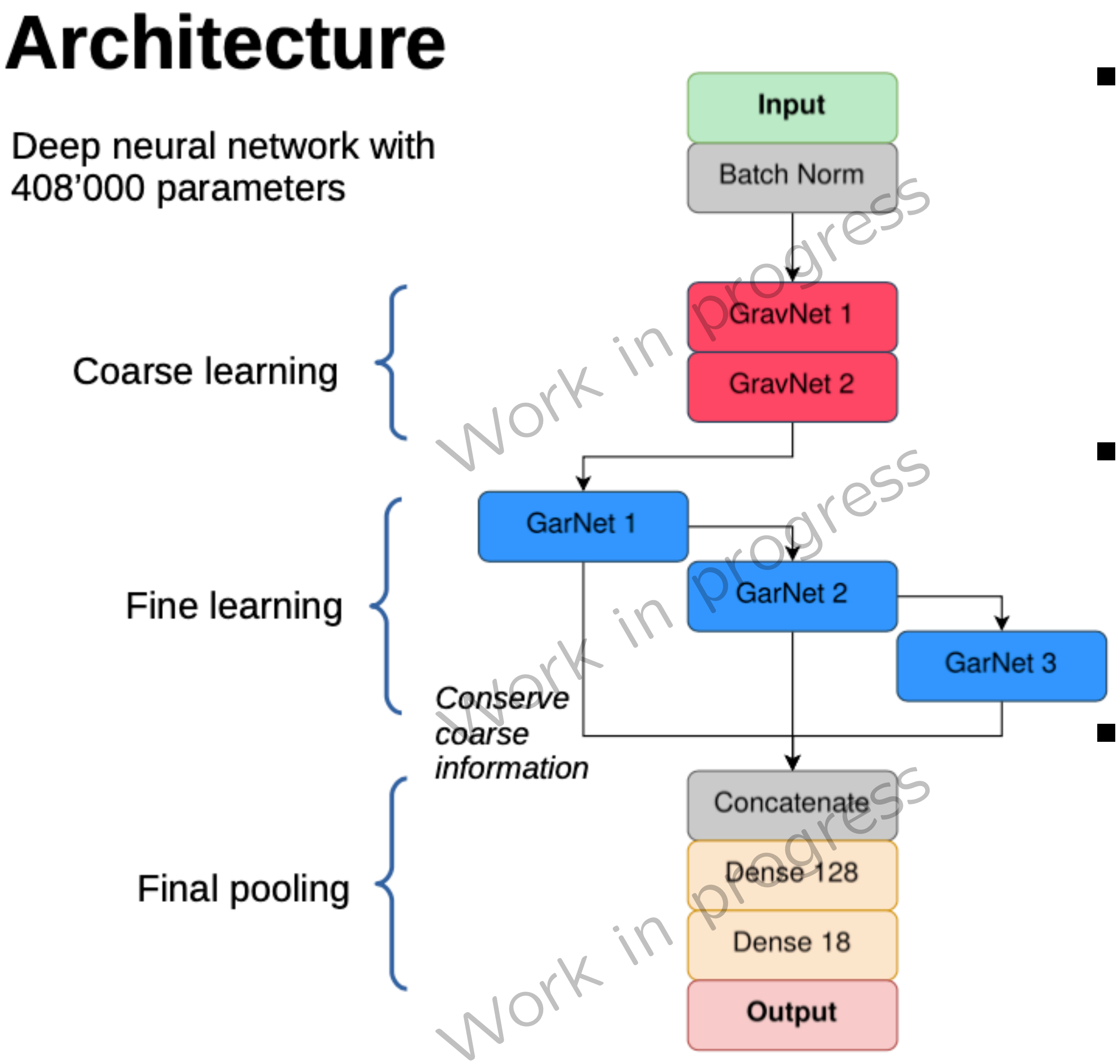
Reconstruction



	Vertex [mm]	Angle [°]
True	-965.7	3.47
Predicted	-986.9	3.66

Credit: Kylian Schmidt

Reconstruction

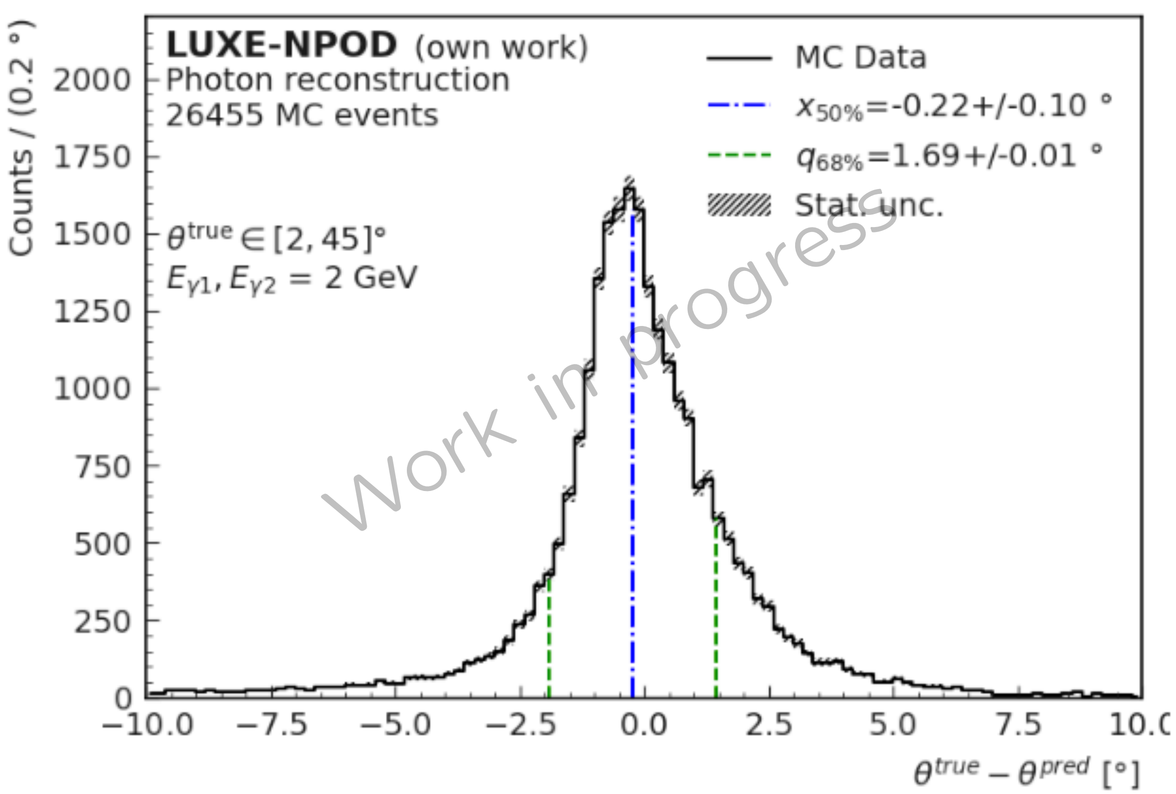


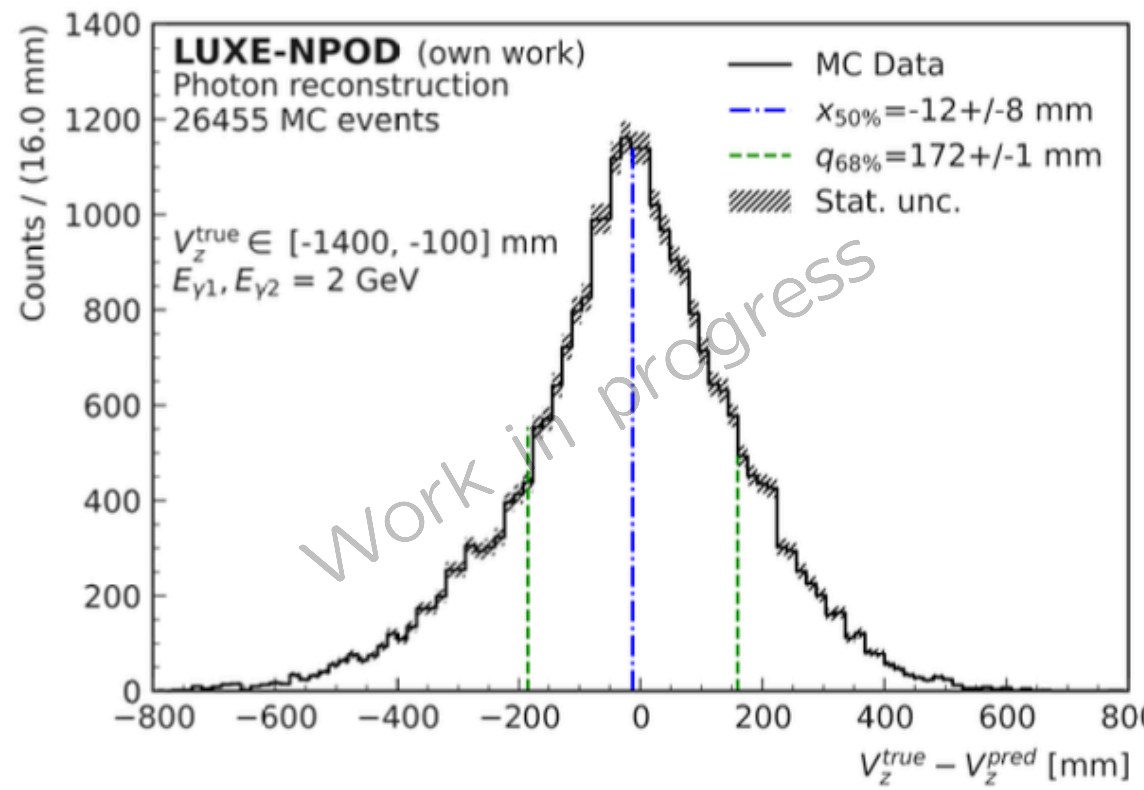
Credit: Kylian Schmidt

- A proof of concept work has been conducted to test the power of graph neural network (GNN) to reconstruct the signal from the calorimeter image
- The GNN clusters the input image into two separate showers, while rejects the background
- The GNN is flexible to the change from the dummy detector to other candidate detectors in test

Reconstruction

- The GNN shows almost no bias and good resolution on opening angle and longitudinal vertex position
- Further benchmarking and testing are ongoing

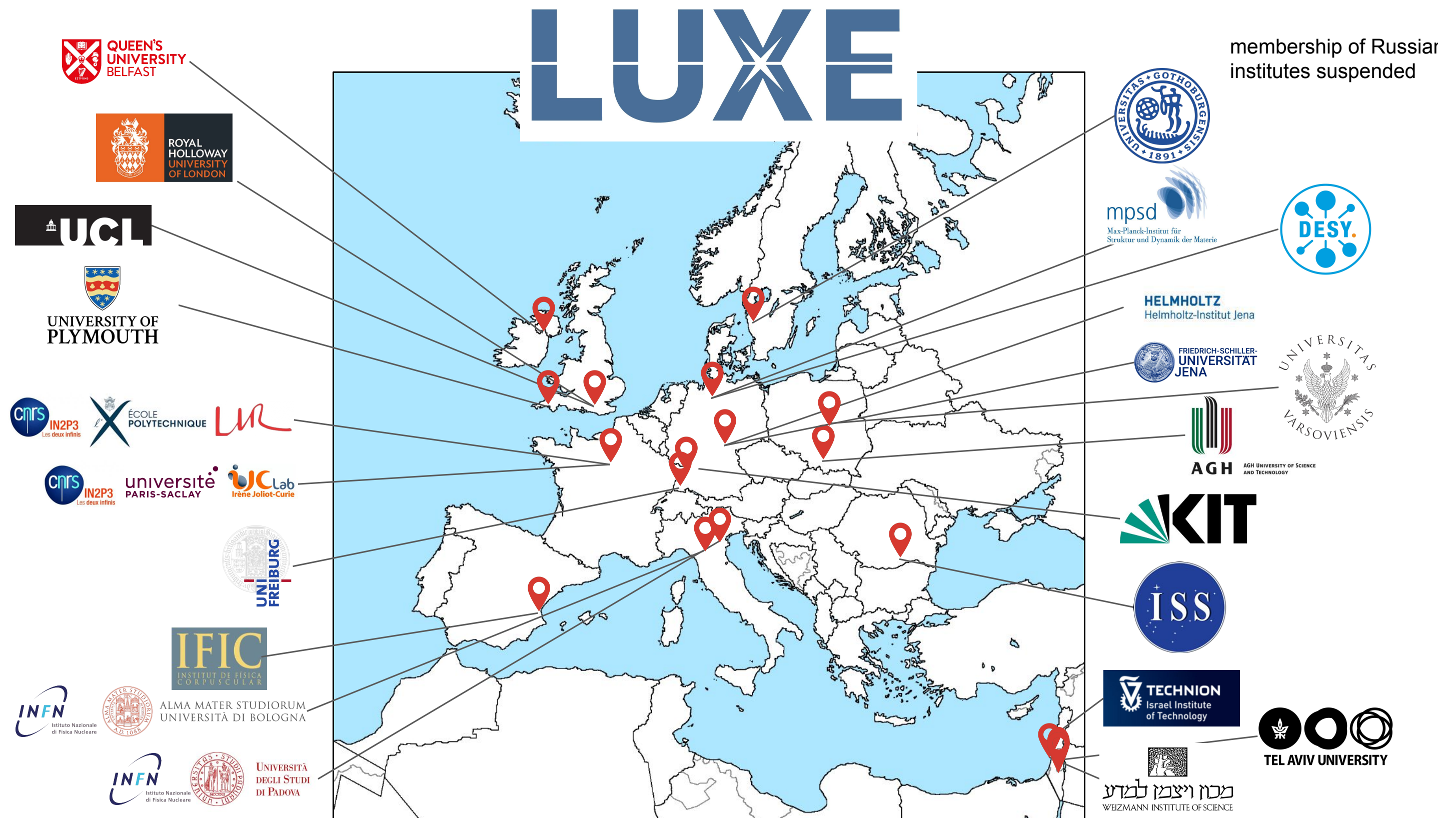




Credit: Kylian Schmidt

Summary

- LUXE: One of the groundbreaking experiments for non-perturbative QED
- High-intensity Compton scattering provides a GeV photon flux better than a physical dump. The photon beam is suitable for ALP search, and more!
- The result is comparable to FASER2 and NA62
  - m_a: 50-350 MeV; $1/\Lambda_a$: $6\text{x}10^{-6}$-10^{-3} GeV^{-1}
- First estimate found background free during a one-year data taking. More detailed studies are ongoing to optimise the dump/decay geometry
- LUXE NPOD is also searching for suitable detector. Studies with current candidates are ongoing
- Reconstruction with machine learning algorithm has found good proof-of-concept results
- Looking for other possibilities on BSM with high flux photons



¡MUCHAS GRACIAS!

y Buen apetito

BACKUP

LUXE

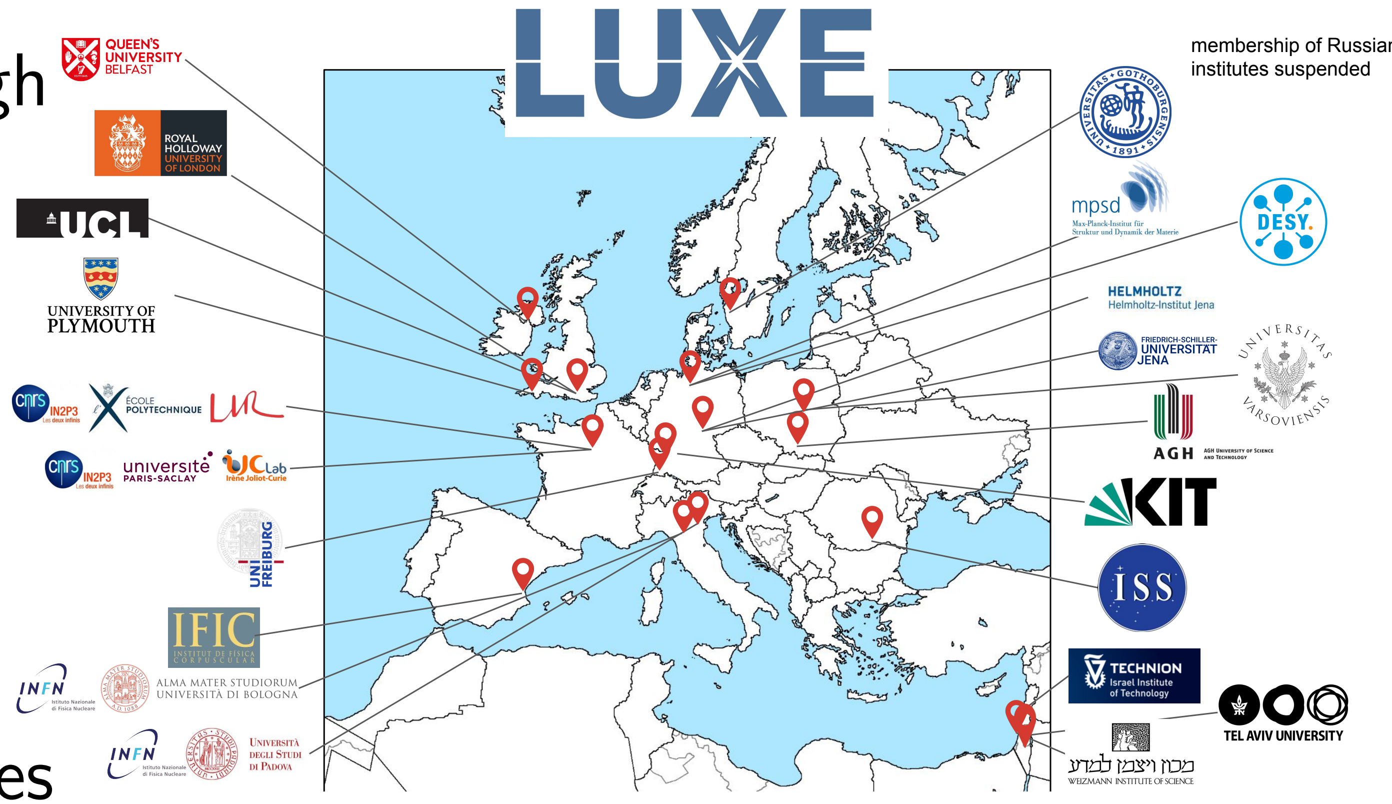
Why non-perturbative QED? Why LUXE?

- “It is precisely the fact that everything is supposed to be known that makes it interesting”—Ulrik Uggerhøj, NA63, CERN Courier 51(4) 15 (2011)
- Uncharted regime of the physics of critical EM field/highly dense photons
- “Background” survey for the future colliders/FIPs on the intensity frontier
- Application of high power laser in particle physics: unique chance at DESY

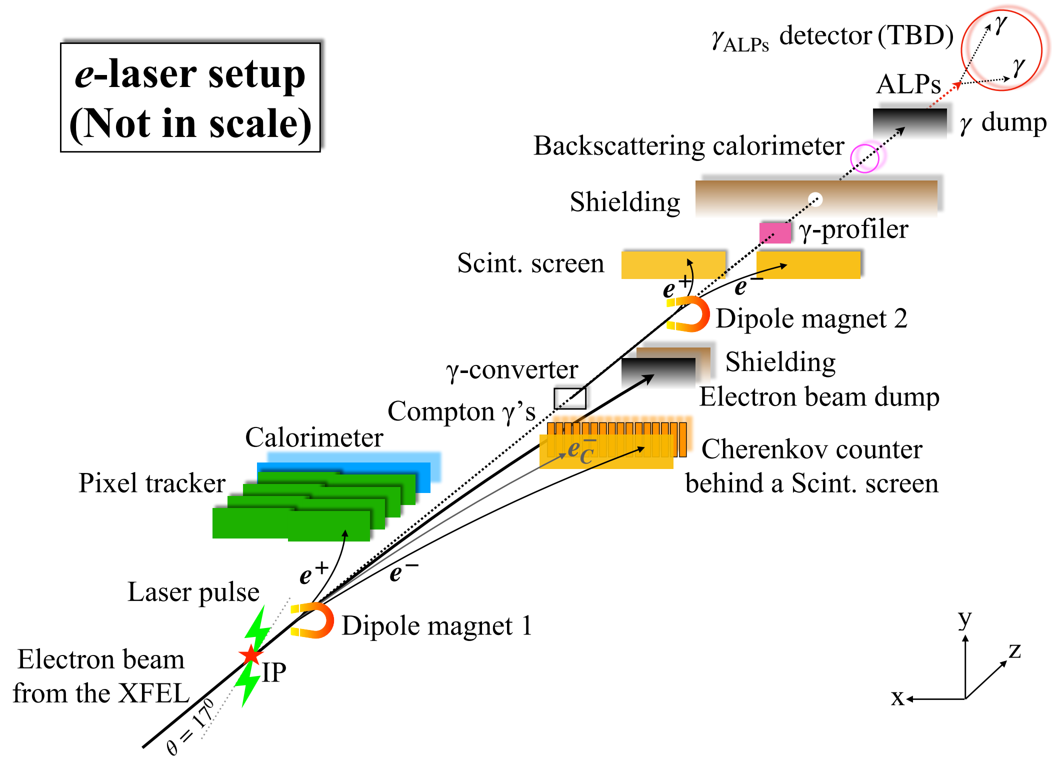
Synergy among the communities of high energy (density) physics

An international collaboration

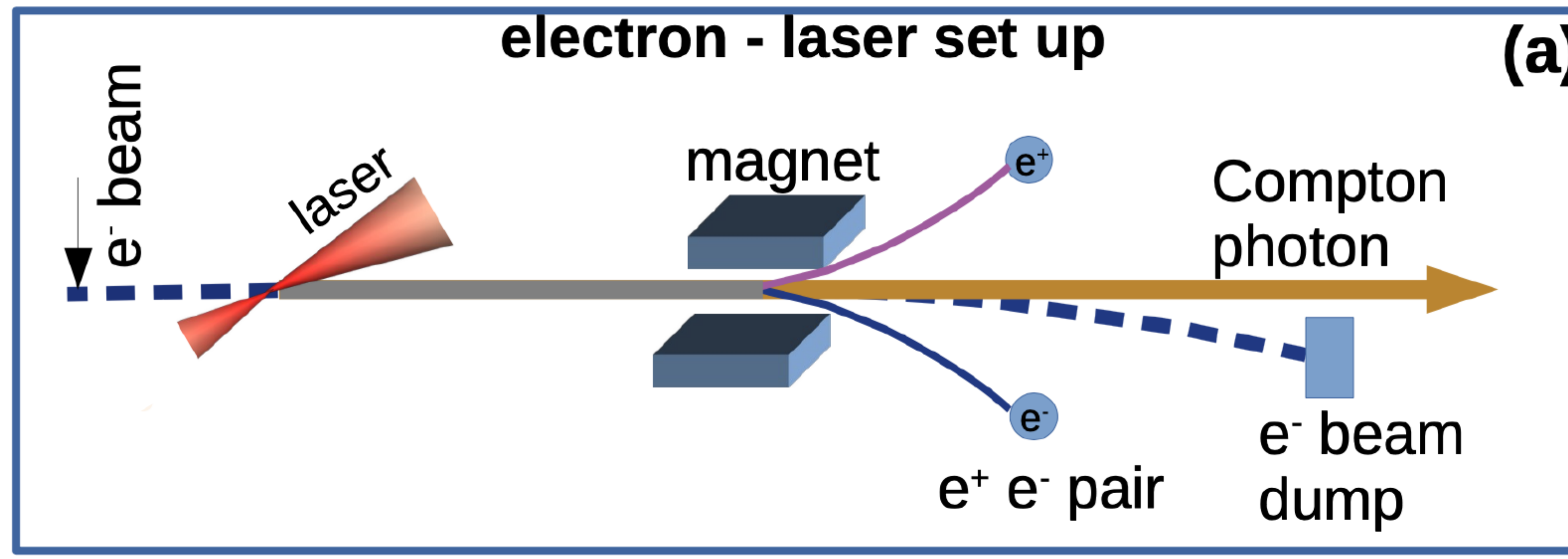
- Hosted by DESY
- 91 (CDR) ⇉ 132 (TDR) contributing scientists
- Over 20 active collaborating institutes



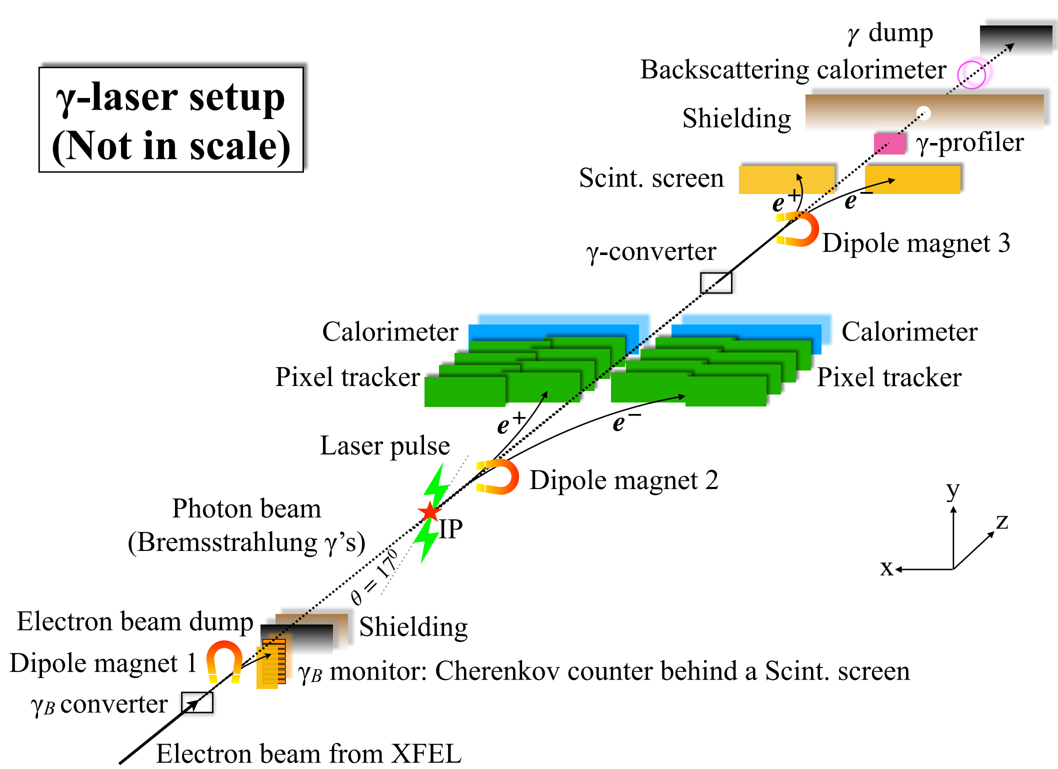
LUXE setups



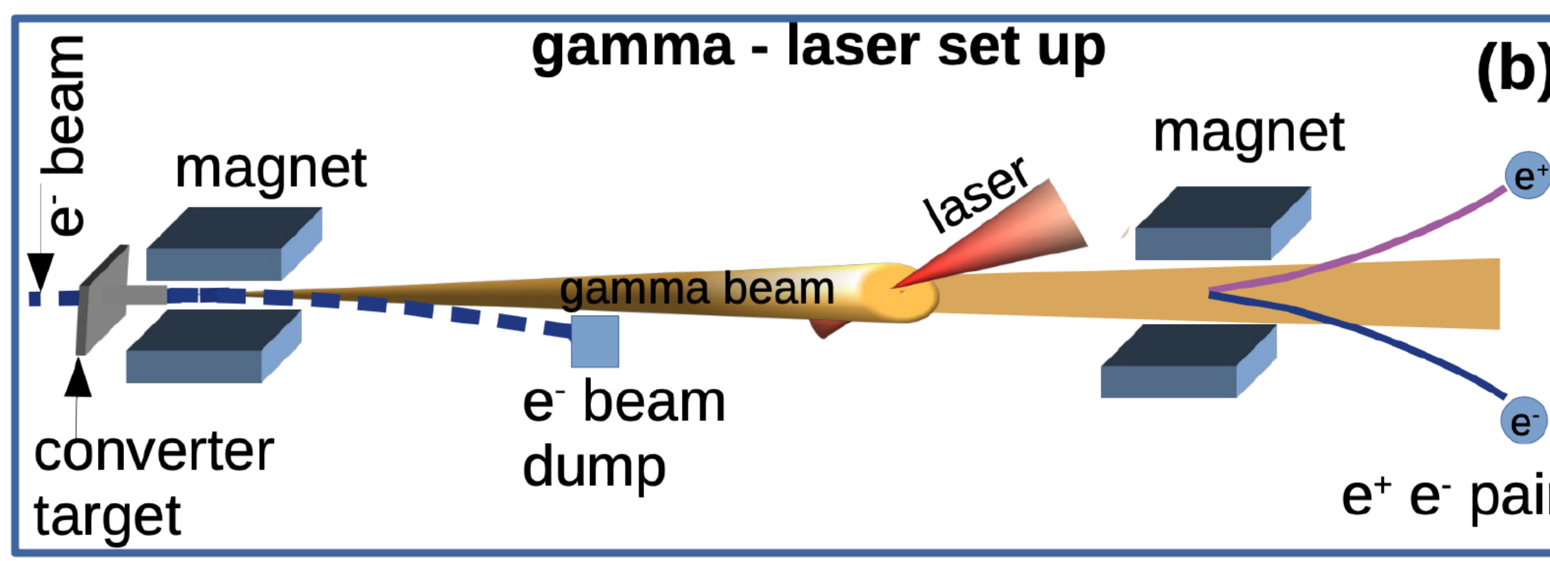
e-laser setup
(Not in scale)
γ_{ALPs} detector (TBD)
γ
γ
ALPs
γ dump
Backscattering calorimeter
Shielding
γ-profiler
Scint. screen
e^+
e^-
Dipole magnet 2
γ-converter
Shielding
Electron beam dump
Compton γ's
Calorimeter
e_C^-
Cherenkov counter
behind a Scint. screen
Pixel tracker
e^+
e^-
Laser pulse
Dipole magnet 1
Electron beam
from the XFEL
IP
$\theta = 17^0$
y
z
x



electron - laser set up
(a)
e^- beam
laser
magnet
e^+
Compton
photon
e^-
e^+ e^- pair
e^- beam
dump

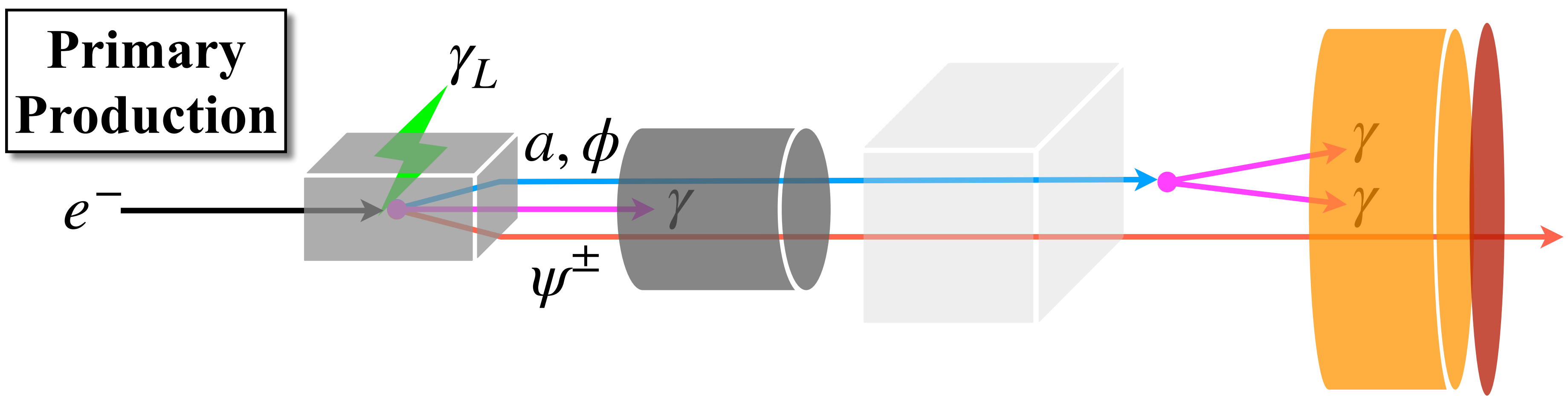


γ dump
Backscattering calorimeter
γ-laser setup
(Not in scale)
Shielding
γ-profiler
Scint. screen
e^+
e^-
Dipole magnet 3
γ-converter
Calorimeter
Calorimeter
Pixel tracker
Pixel tracker
e^+
e^-
Laser pulse
Dipole magnet 2
Photon beam
(Bremsstrahlung γ's)
IP
$\theta = 17^0$
y
z
x
Electron beam dump
Shielding
Dipole magnet 1
γ_B monitor: Cherenkov counter behind a Scint. screen
γ_B converter
Electron beam from XFEL

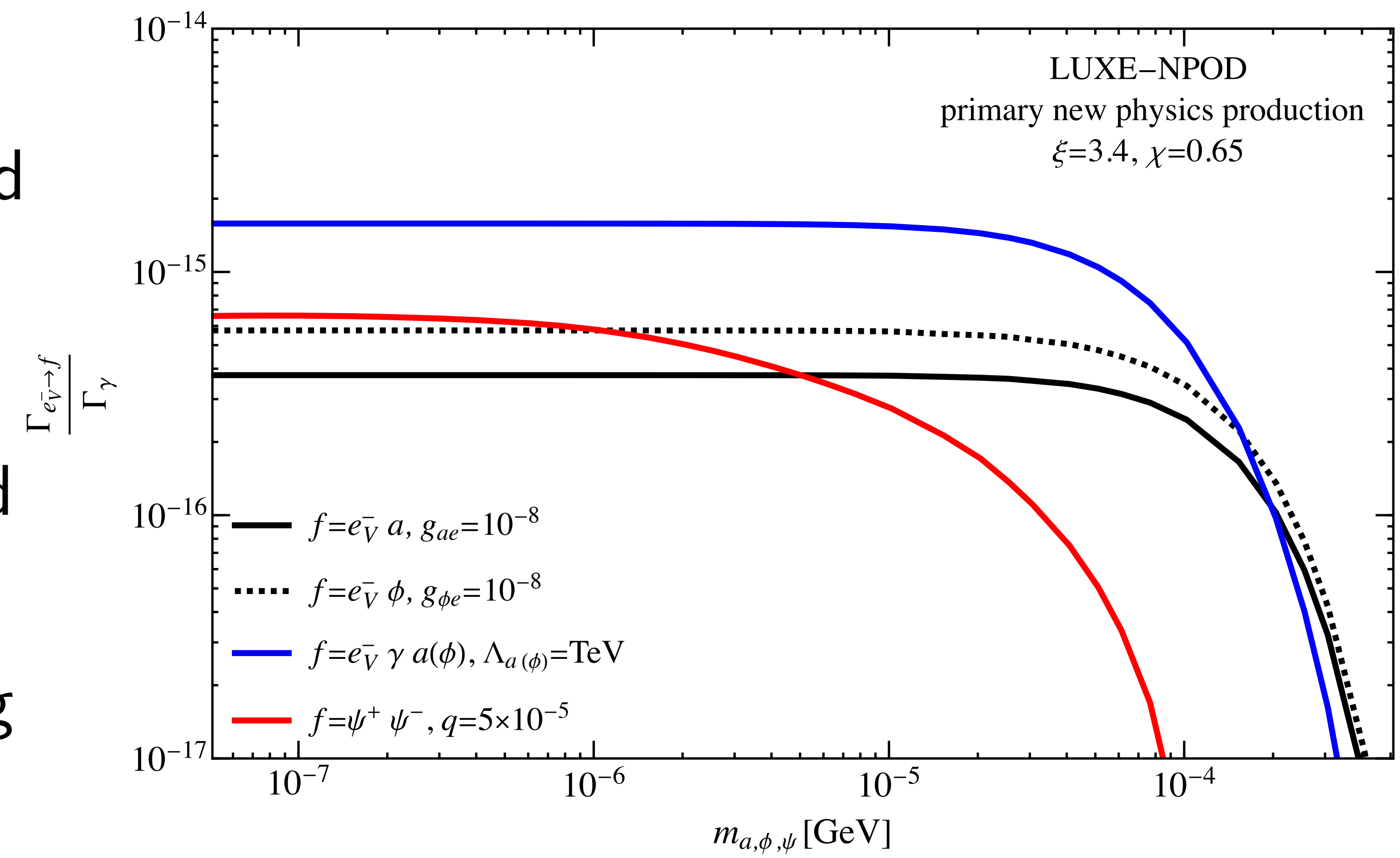


gamma - laser set up
(b)
e^- beam
magnet
laser
magnet
e^+
gamma beam
e^-
converter
target
e^- beam
dump
e^+ e^- pair

Other NP scenarios



- Three types of processes have been calculated at eV scale:
  - ALP-electron under laser field
  - ALP-electron-photon
  - Photons into mCP pairs
- Production rates are normalised by HICS rates
- Further estimations are ongoing

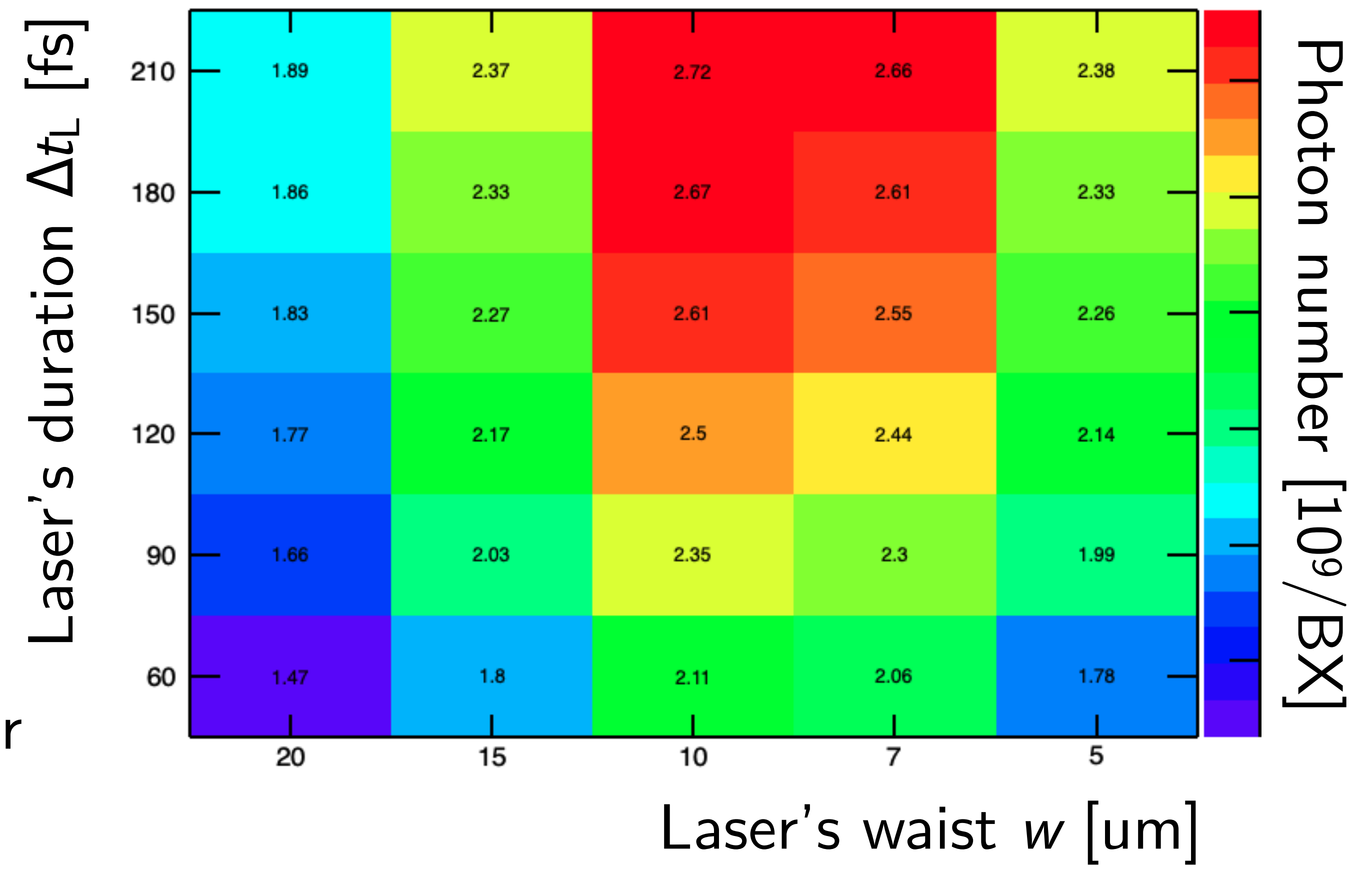


Luminosity

- A year's run will produce 10^7 BXs
  @ 1 Hz x 8 hours per day
- To create as many Compton photons as possible, laser's profile needs to match electron beam's characters
- The LUXE primary goal requires a short and narrow laser beam
  - Phase-1: 2.5×10^9
- Benchmarked with a W disk dump
  - 1 m in length
  - $>$ 10 cm in radius

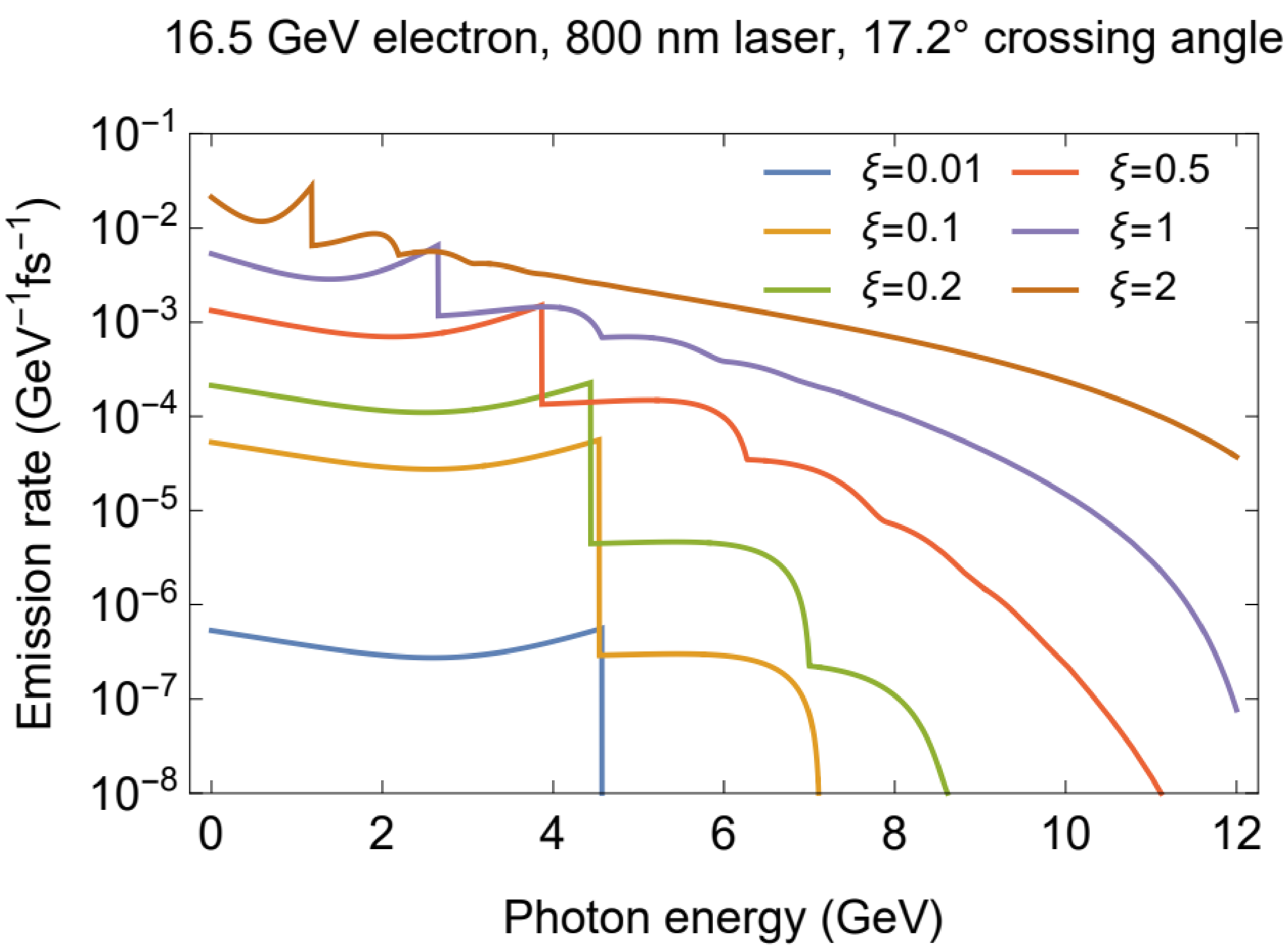
LUXE Electrons from XFEL.EU

Energy	16.5 GeV
Charge	0.25 nC
Spotsize (IP)	5 μm
Bunch length	30-50 μm = 100-130 fs
Norm. emittance	1.4 mm mrad



Phase-1 350 TW laser

Luminosity



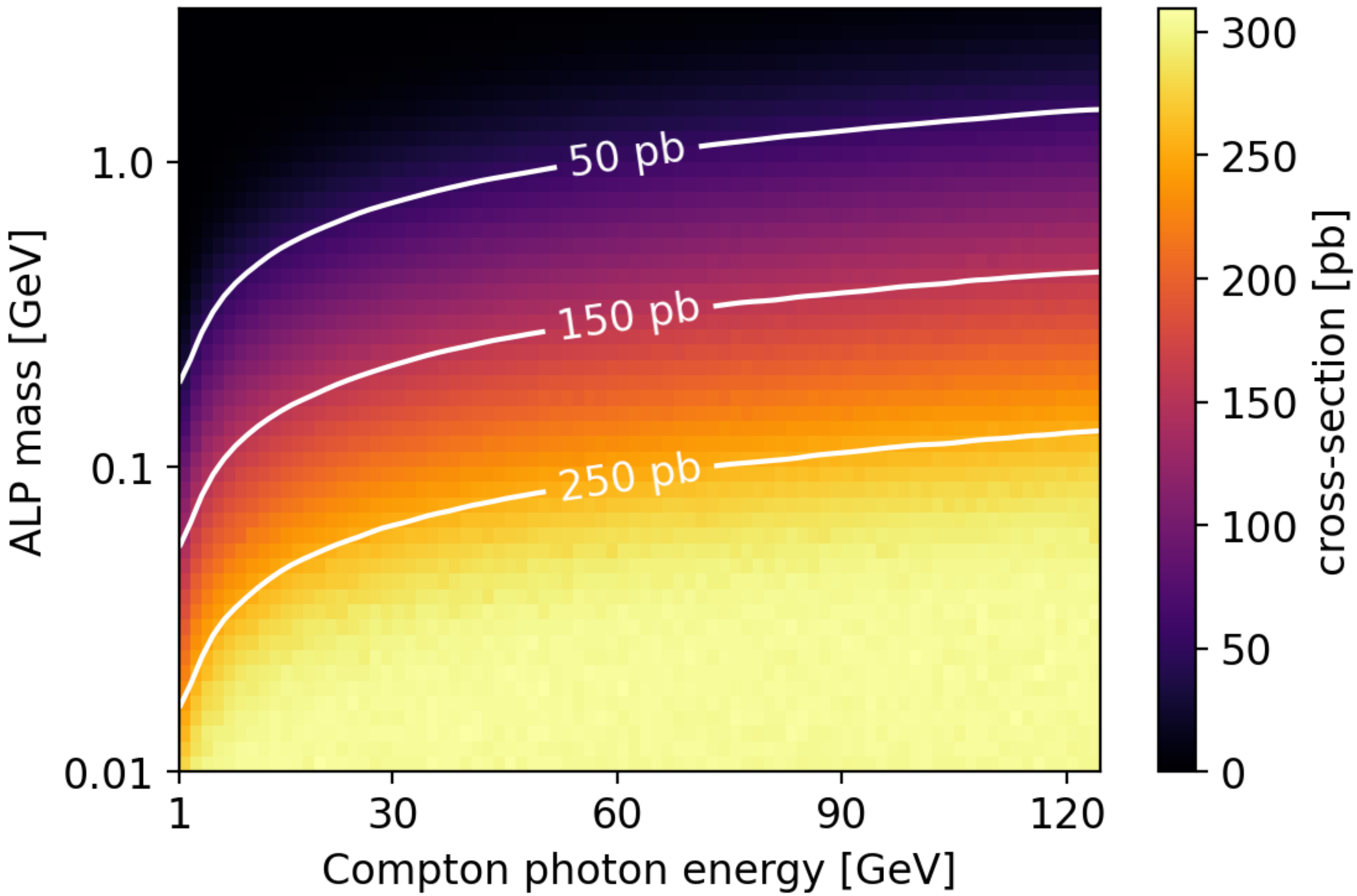
$$\xi \propto I_L^{1/2} \propto (\Delta t_L)^{-1/2} w^{-1}$$

Optimal laser parameters for NPOD

Phase-0 40 TW laser: $\xi = 2.4,\ \Delta t_L = 25$ fs

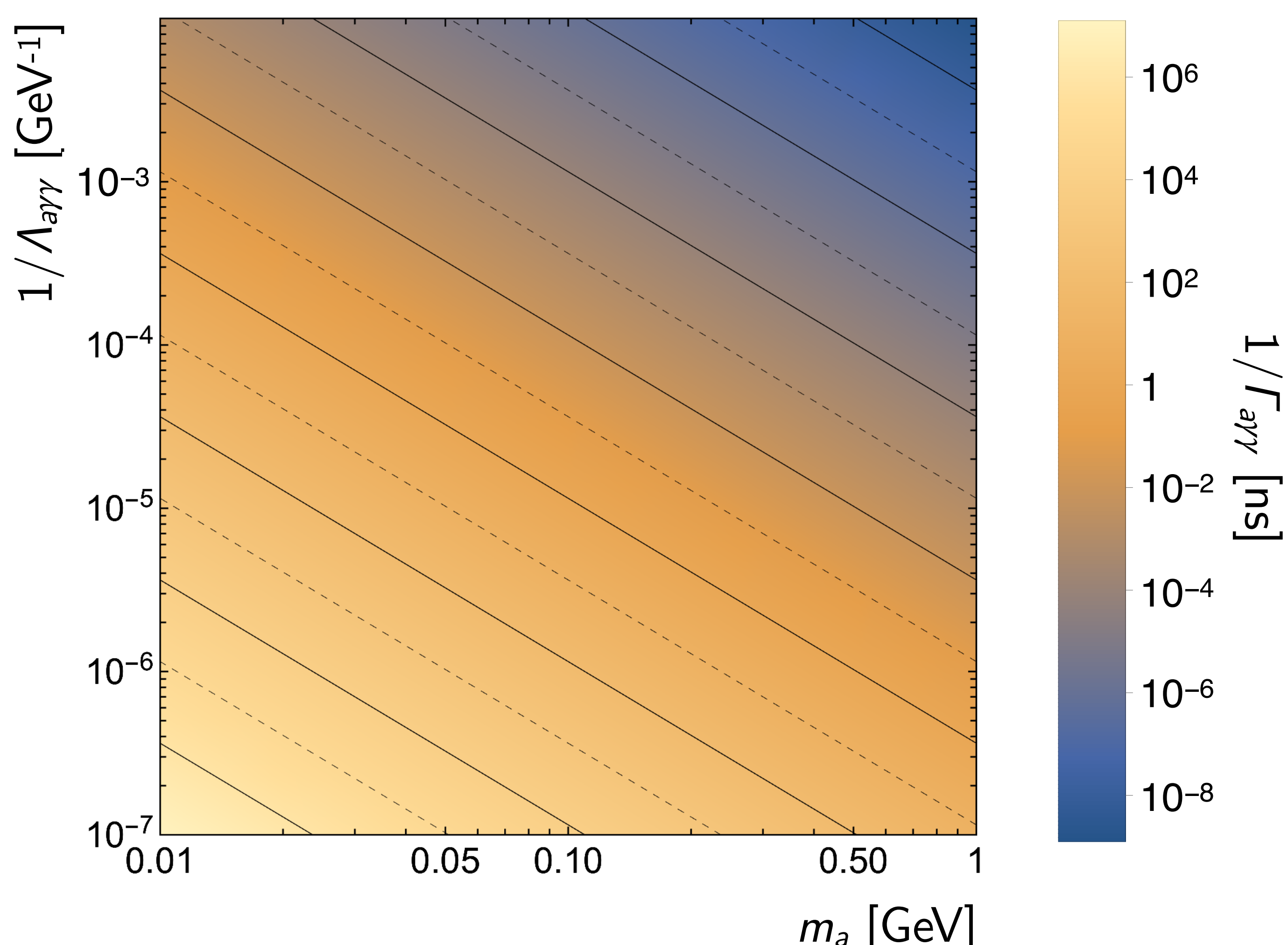
Phase-1 350 TW laser: $\xi = 3.4,\ \Delta t_L = 120$ fs

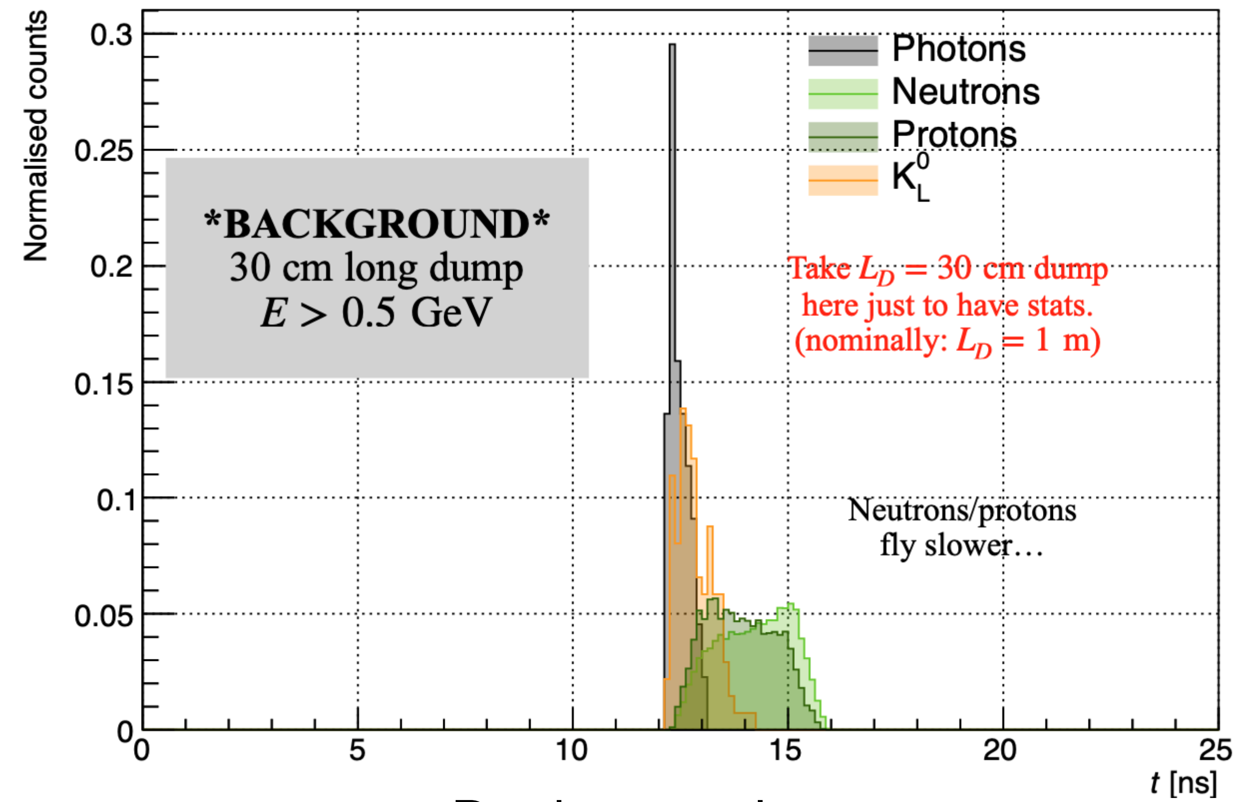
Cross section



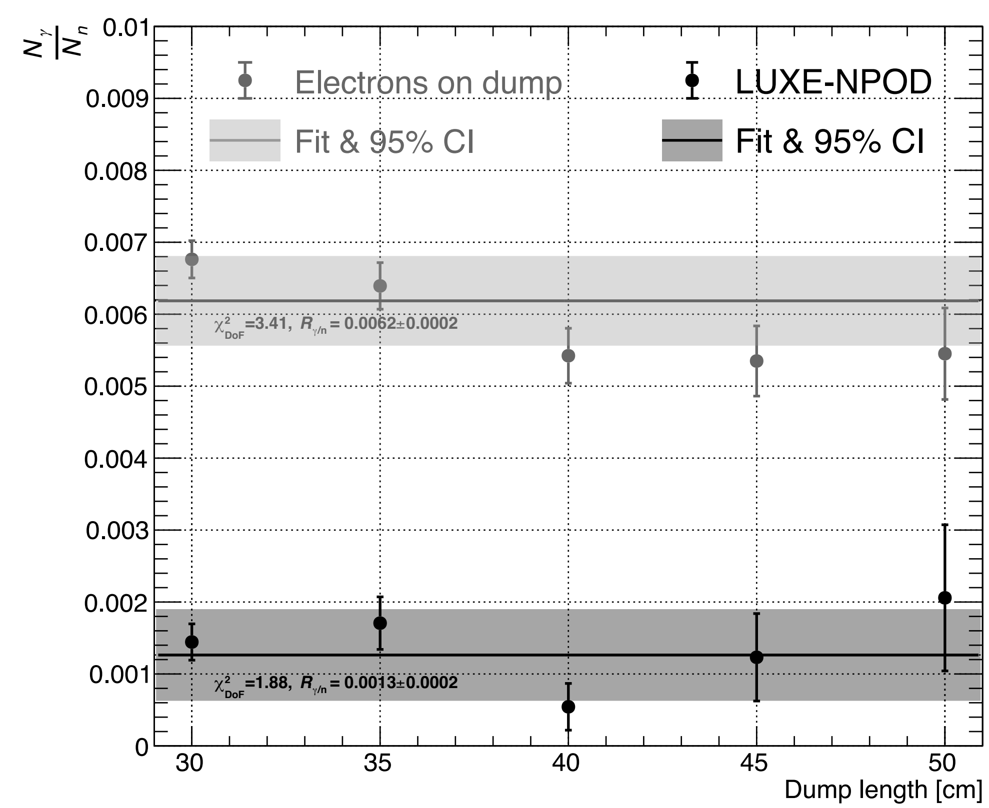
Credit: Ivo Schulthess

ALP lifetime

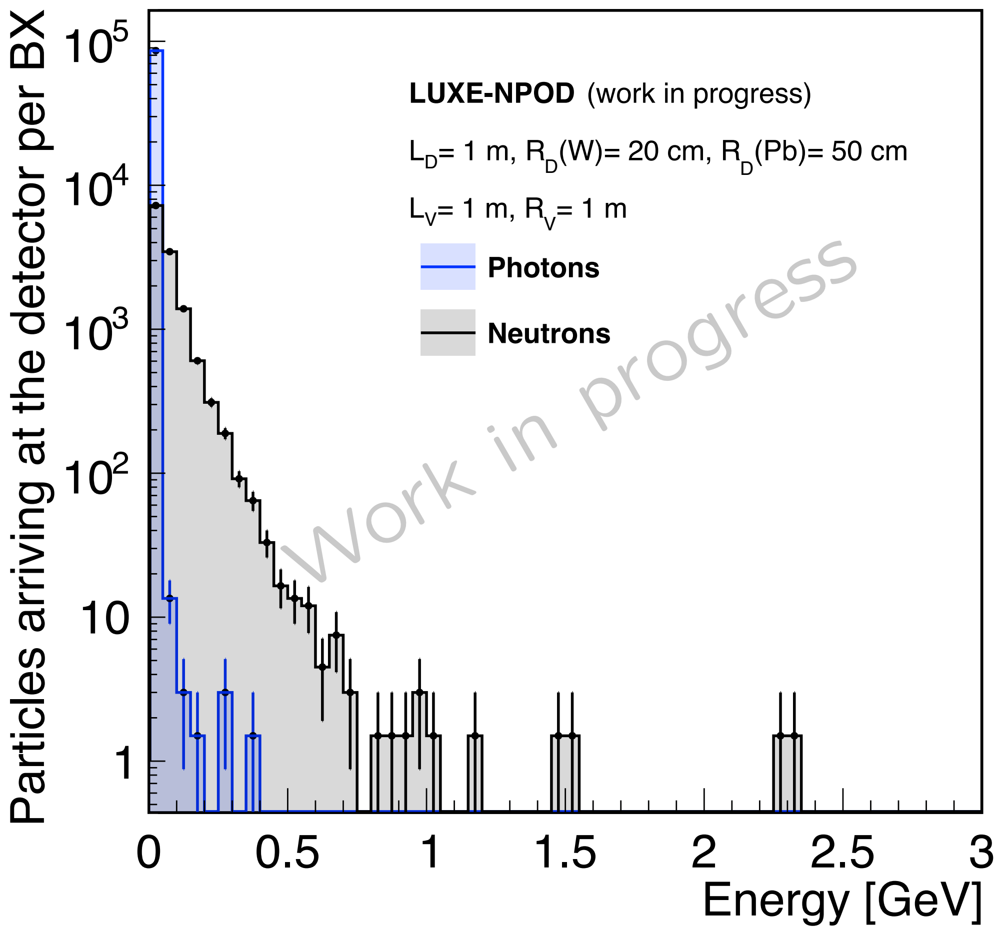


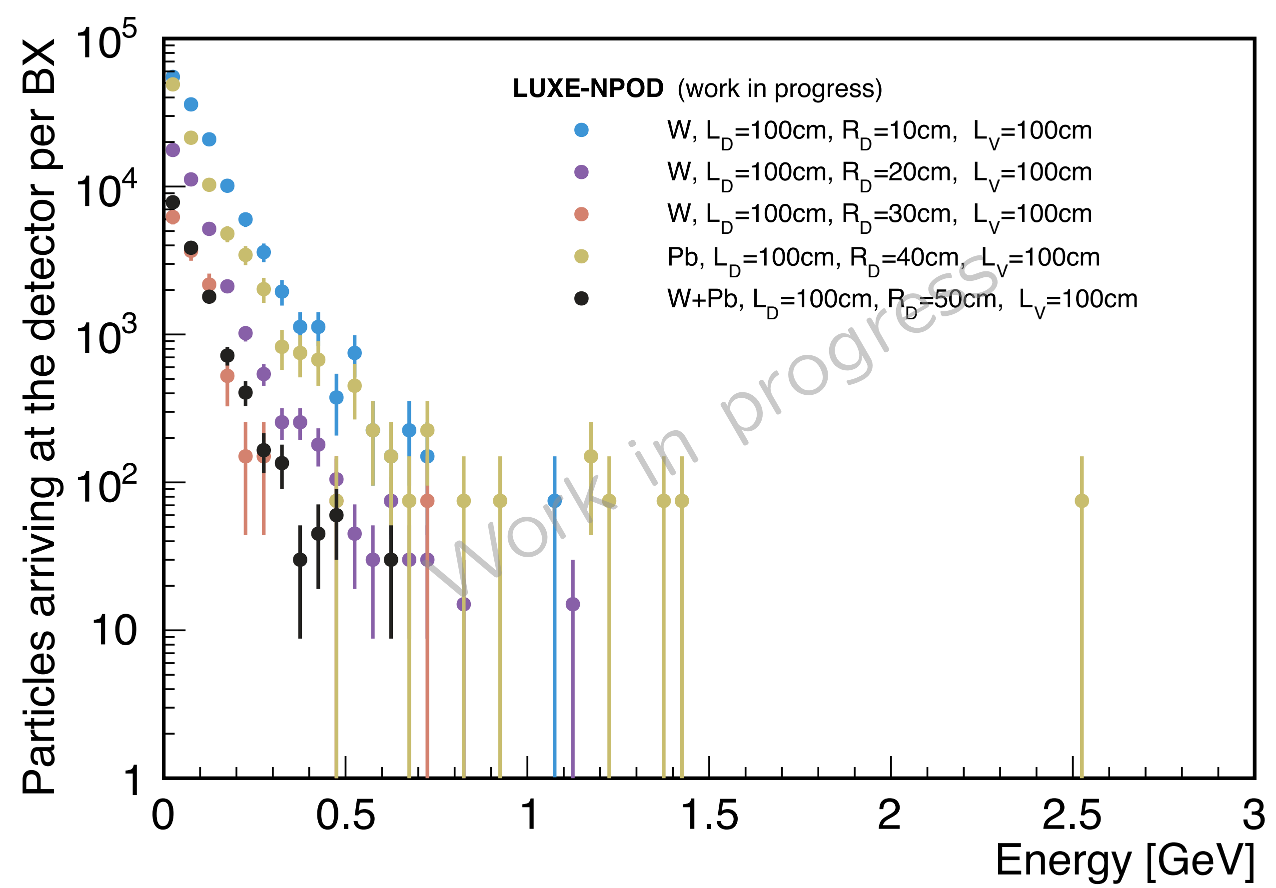


Background timing

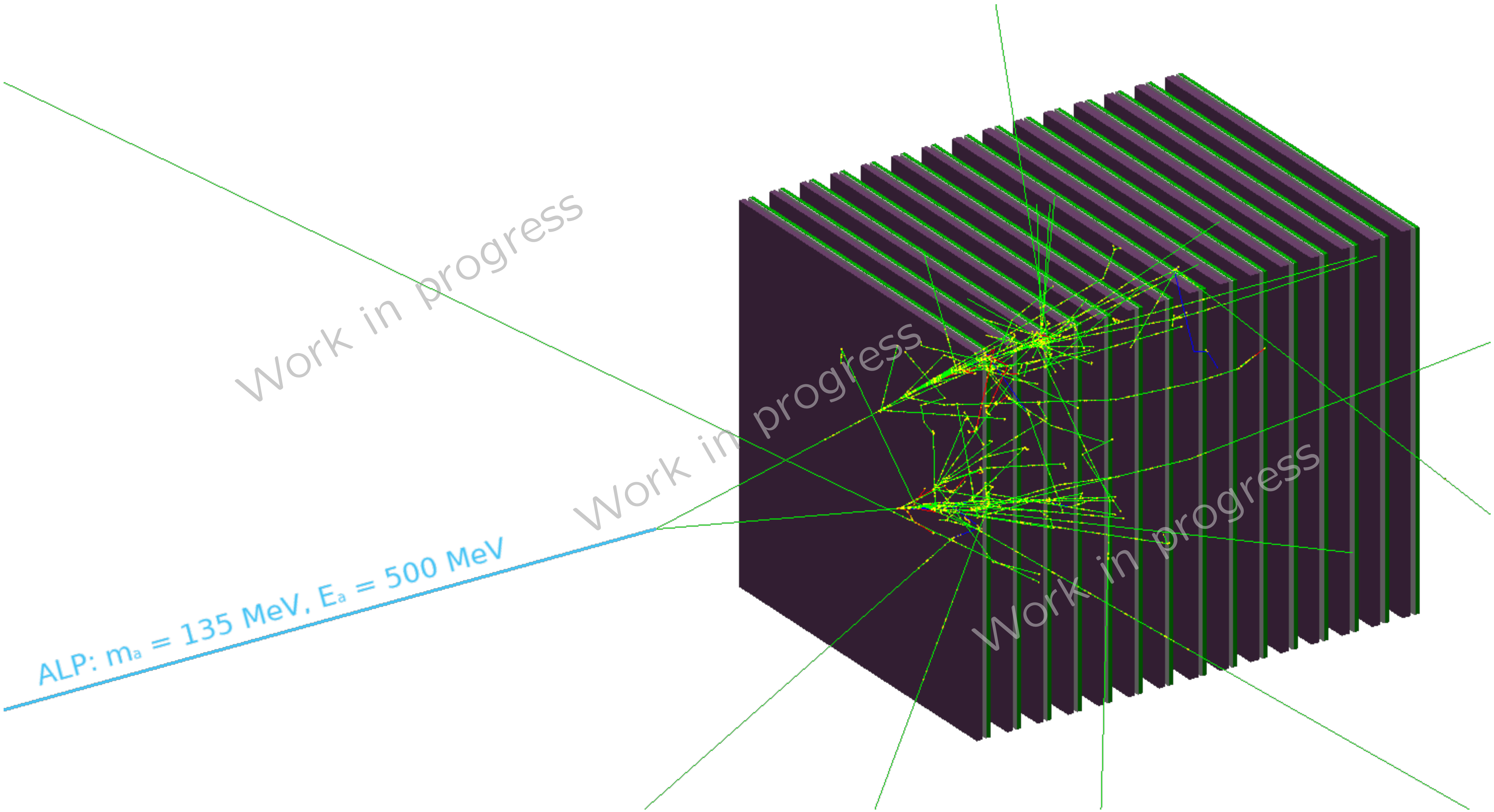


Neutron-photon correlation


LUXE-NPOD (work in progress)
L_D= 1 m, R_D(W)= 20 cm, R_D(Pb)= 50 cm
L_V= 1 m, R_V= 1 m
Photons
Neutrons
Work in progress
Particles arriving at the detector per BX
Energy [GeV]


LUXE-NPOD (work in progress)
W, L_D=100cm, R_D=10cm, L_V=100cm
W, L_D=100cm, R_D=20cm, L_V=100cm
W, L_D=100cm, R_D=30cm, L_V=100cm
Pb, L_D=100cm, R_D=40cm, L_V=100cm
W+Pb, L_D=100cm, R_D=50cm, L_V=100cm
Work in progress
Particles arriving at the detector per BX
Energy [GeV]

Simulation



Credit: Jesús Marquez Hernandez, Ivo Schulthess, *et al*