Probing new physics at the LUXE experiment

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on behalf of the LUXE Collaboration
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Outline

1. Introduction to LUXE.
2. The LUXE Physics and Experimental Setup.
3. New Physics at the Optical Dump (NPOD).
4. Summary

More talks on LUXE: by Yan Benhammou and Shan Huang.

LUXE CDR

Conceptual Design Report for the LUXE Experiment

H. Abramowicz[1], U. Acosta[2,3], M. Altarelli[4], R. Aßmann[5], Z. Bai[6,7], T. Behnke[5], Y. Benhammou[1], T. Blackburn[8], S. Boogert[9], O. Borysov[5], M. Borysova[5,10], R. Brinkmann[5], M. Bruschi[11], F. Burkart[5], K. Büßer[5], N. Cavanagh[12], O. Davidi[6], W. Decking[5], U. Dosselli[13], N. Elkina[3], A. Fedotov[14], M. Firlej[15], T. Fiutowski[15], K. Fleck[12], M. Gostkin[16], C. Grojean[*5], J. Hallford[5,17], H. Harsh[18,19], A. Hartin[17], B. Heinemann[†5,20], T. Heinzl[21], L. Helary[5], M. Hoffmann[5,20], S. Huang[1], X. Huang[5,18,20], M. Idzik[15], A. Ilderton[21], R. Jacobs[5], B. Kämpfer[2,3], B. King[21], H. Lahno[10], A. Levanon[1], A. Levy[1], I. Levy[22], J. List[5], W. Lohmann[‡5], T. Ma[23], A.J. Macleod[21], V. Malka[6], F. Meloni[5], A. Mironov[14], M. Morandin[13], J. Moron[15], E. Negodin[5], G. Perez[6], I. Pomerantz[1], R.Pöschl[24], R. Prasad[5], F. Quéré[25], A. Ringwald[5], C. Rödel[26], S. Rykovanov[27], F. Salgado[18,19], A. Santra[6], G. Sarri[12], A. Sävert[18], A. Sbrizzi[§28], S. Schmitt[5], U. Schramm[2,3], S. Schuwalow[5], D. Seipt[18], L. Shaimerdenova[29], M. Shchedrolosiev[5], M. Skakunov[29], Y. Soreq[23], M. Streeter[12], K. Swientek[15], N. Tal Hod[6], S. Tang[21], T. Teter[18,19], D. Thoden[5], A.I. Titov[16], O. Tolbanov[29], G. Torgrimsson[3], A. Tyazhev[29], M. Wing[5,17], M. Zanetti[13], A. Zarubin[29], K. Zeil[3], M. Zepf[18,19], and A. Zhemchukov[16]

LUXE CDR: 2102.02032

LUXE NPOD paper

DESY 21-111

LUXE-NPOD: new physics searches with an optical dump at LUXE

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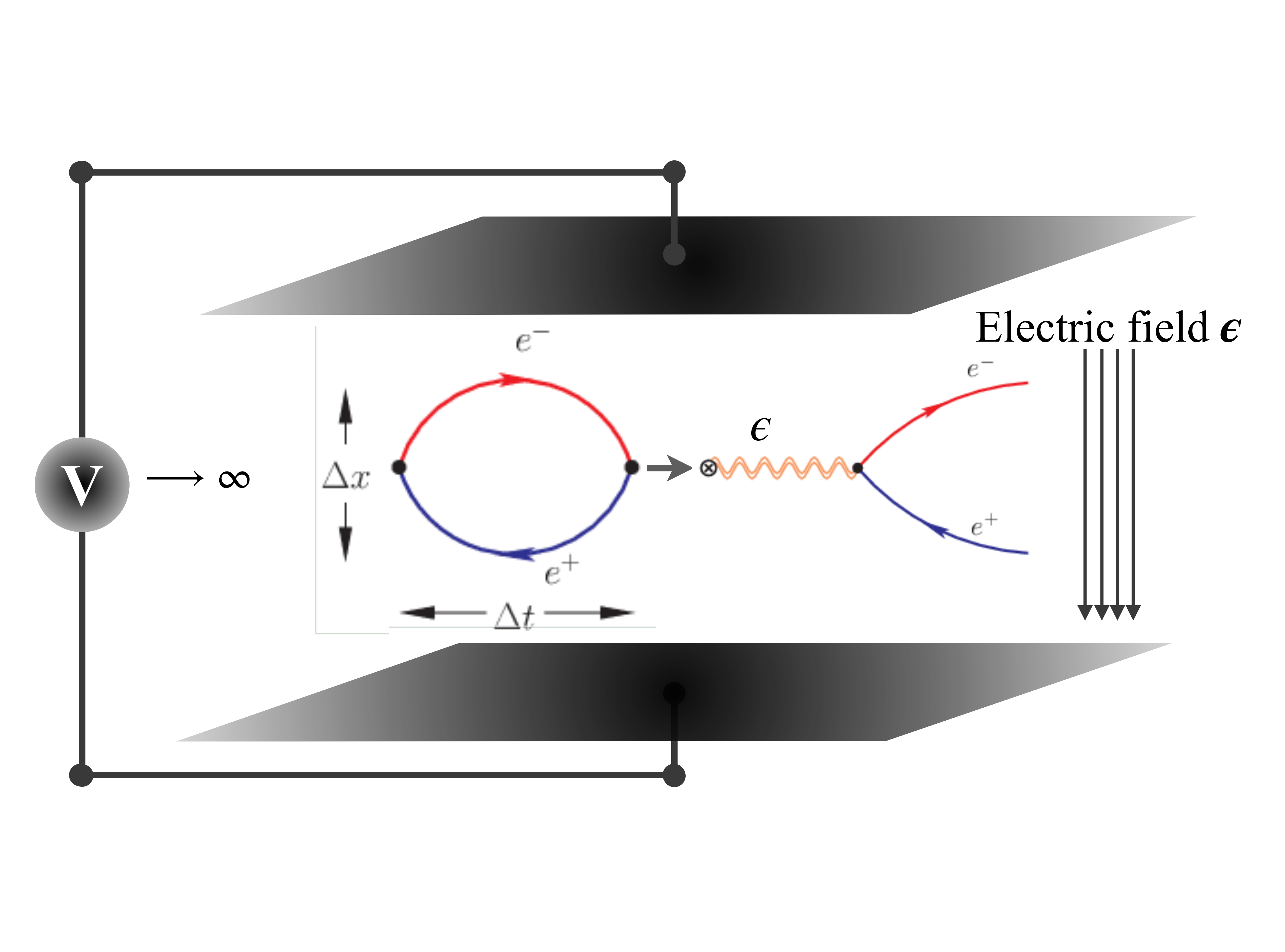
We propose a novel way to search for feebly interacting massive particles, exploiting two properties of systems involving collisions between high energy electrons and intense laser pulses. The first property is that the electron-intense-laser collision results in a large flux of hard photons, as the laser behaves effectively as a thick medium. The second property is that the emitted photons free-stream inside the laser and thus for them the laser behaves effectively as a very thin medium. Combining these two features implies that the electron-intense-laser collision is an apparatus which can efficiently convert UV electrons to a large flux of hard, co-linear photons. We further propose to direct this unique large and hard flux of photons onto a physical dump which in turn is capable of producing feebly interacting massive particles, in a region of parameters that has never been probed before. We denote this novel apparatus as "optical dump" or NPOD (new physics search with optical dump). The proposed LUXE experiment at Eu.XFEL has all the required basic ingredients of the above experimental concept. We discuss how this concept can be realized in practice by adding a detector after the last physical dump of the experiment to reconstruct the two-photon decay product of a new spin-0 particle. We show that even with a relatively short dump, the search can still be background free. Remarkably, even with a 40 TW laser, which corresponds to the initial run, and definitely with a 350 TW laser, of the main run with one year of data taking, LUXE-NPOD will be able to probe uncharted territory of both models of pseudo-scalar and scalar fields, and in particular probe natural of scalar theories for masses above 100 MeV.

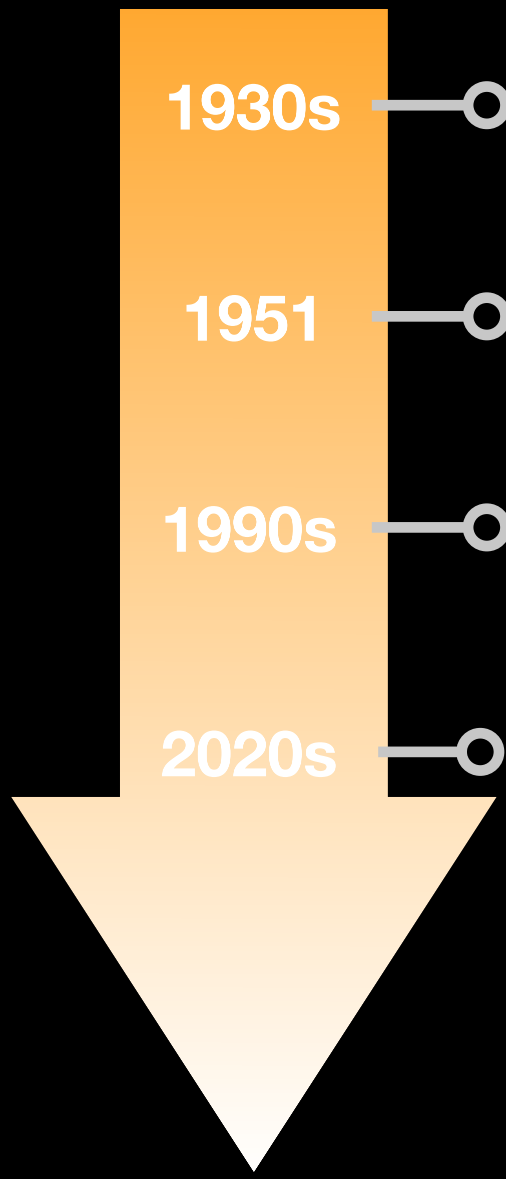
LUXE NPOD paper: 2107.13554

LUXE: tests of strong-field QED

- Schwinger critical field: $\epsilon_S = m_e^2 c^3 / e\hbar \simeq 1.32 \cdot 10^{18}$ V/m.
  - Not achievable in terrestrial laboratories.
  - May use lasers — in certain rest frames the field of lasers can be enhanced by the system's boost.



The probability to materialize one virtual e^+e^- pair from the vacuum:
$P \sim \exp(-a\frac{\epsilon_s}{\epsilon})$, a numeric constant, non-perturbative when $\epsilon \to \epsilon_s$



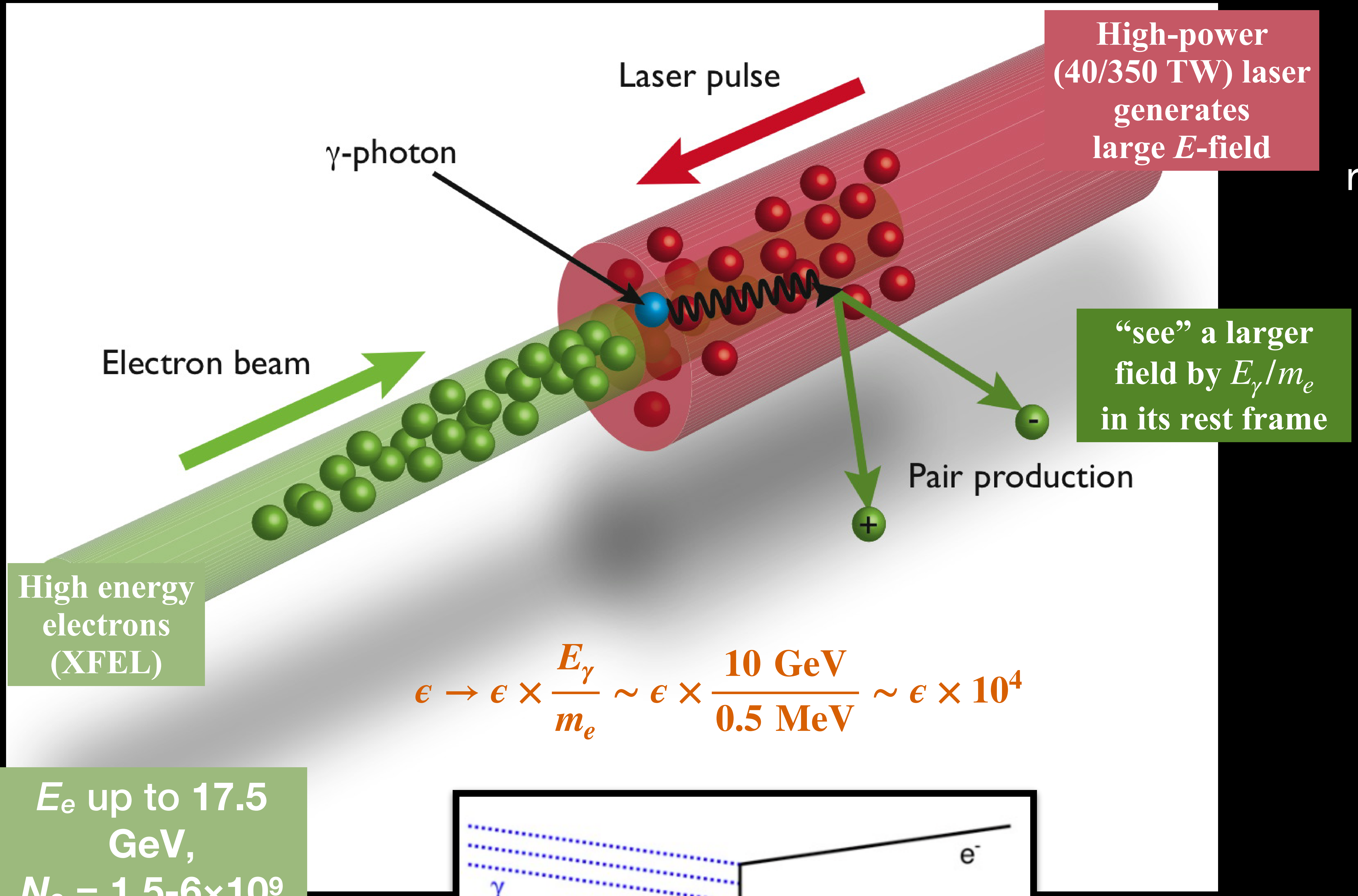
- **1930s:** **First discussions by Sauter, Heisenberg & Euler**
- **1951:** **First calculations by Schwinger: ϵ_S**
- **1990s:** **E144 at SLAC first to approach ϵ_S (reached $\epsilon \to \epsilon_S/4$)**
- **2020s:** **LUXE: reach ϵ_S and beyond**

- **Goal of LUXE experiment:**
  - Effort to reach ϵ_s and beyond
  - Test basic predictions of novel Quantum Mechanics
  - Search for BSM Physics enhanced by the strong field

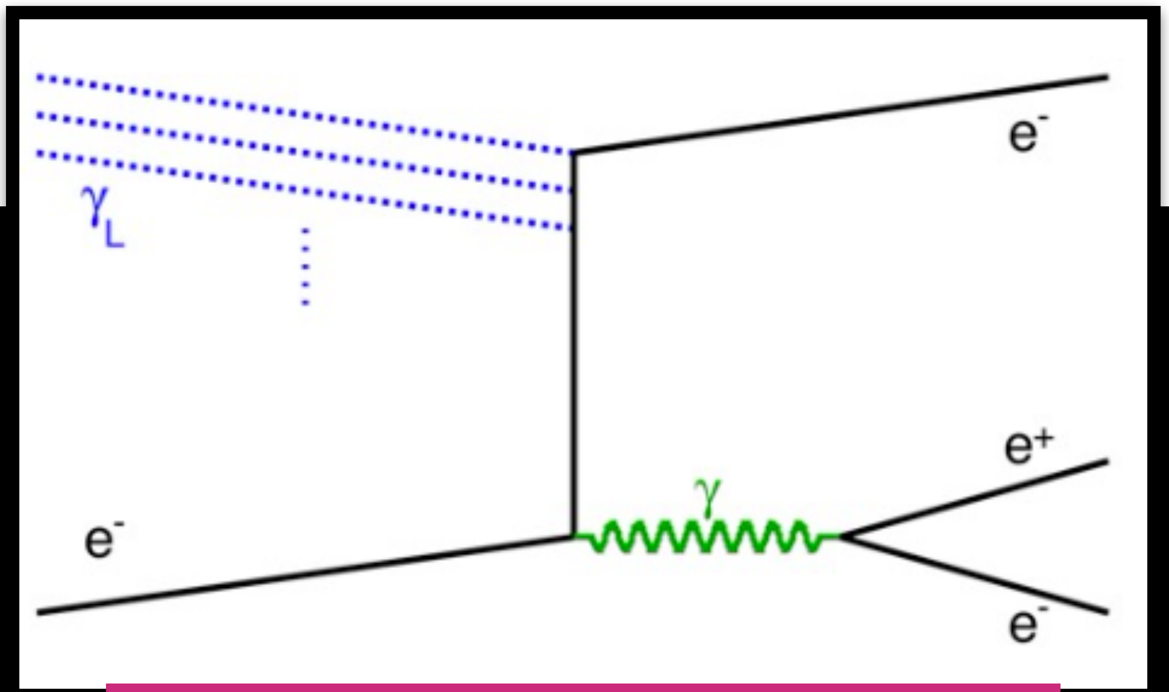
A Brief Idea about the LUXE physics

Laser Und XFEL Experiment

More details about LUXE: The Conceptual Design Report



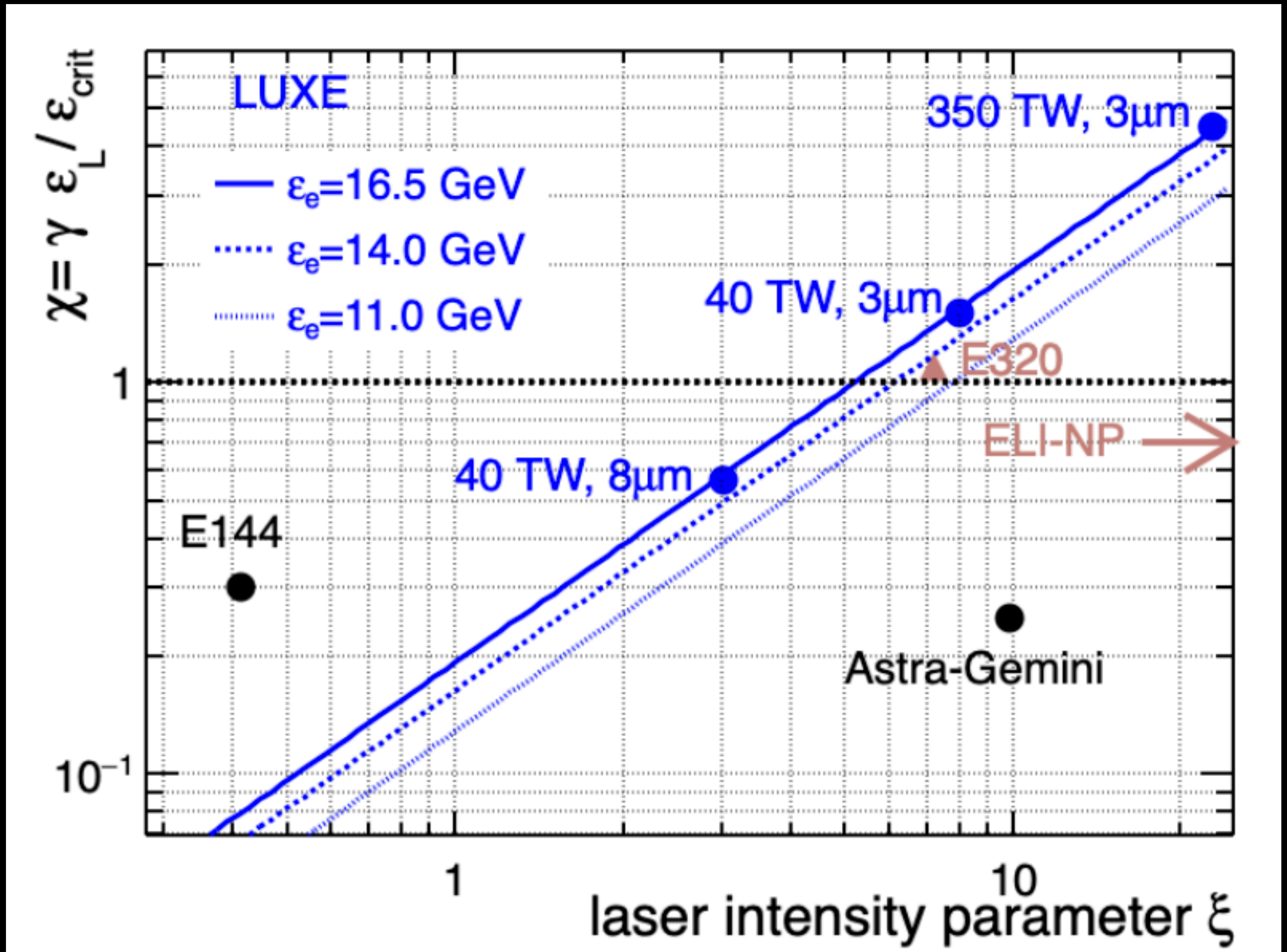
E_e up to 17.5 GeV,
N_e = 1.5-6×10^9 e^-/bunch



Compton process followed by Breit-Wheeler process

The rate of laser assisted one photon pair production asymptotically resembles to that of the spontaneous pair production in vacuum.

Hartin et.al. Phys. Rev. D 99, 036008 (2019)

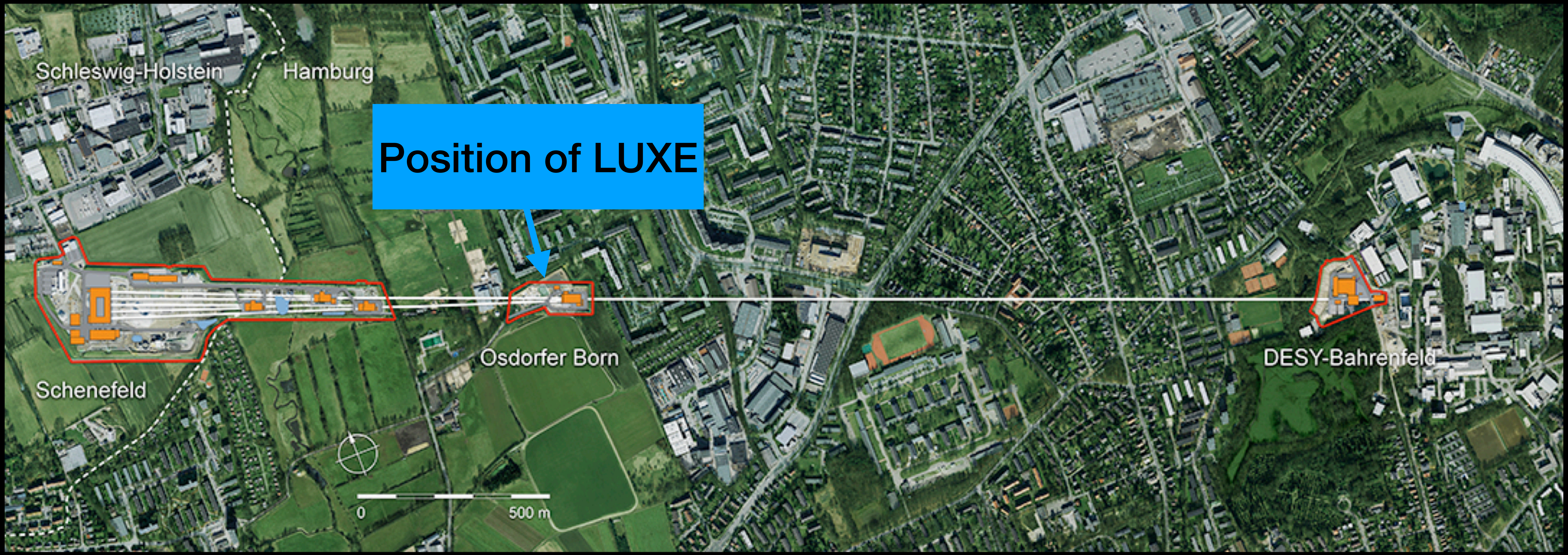


Laser intensity parameter: $\xi \propto \epsilon/\epsilon_s$.

Quantum parameter: $\chi_{e,\gamma} \propto (E_{e,\gamma}/m_e)\xi$, describes the interaction.

Non-perturbative when $\xi > 1$

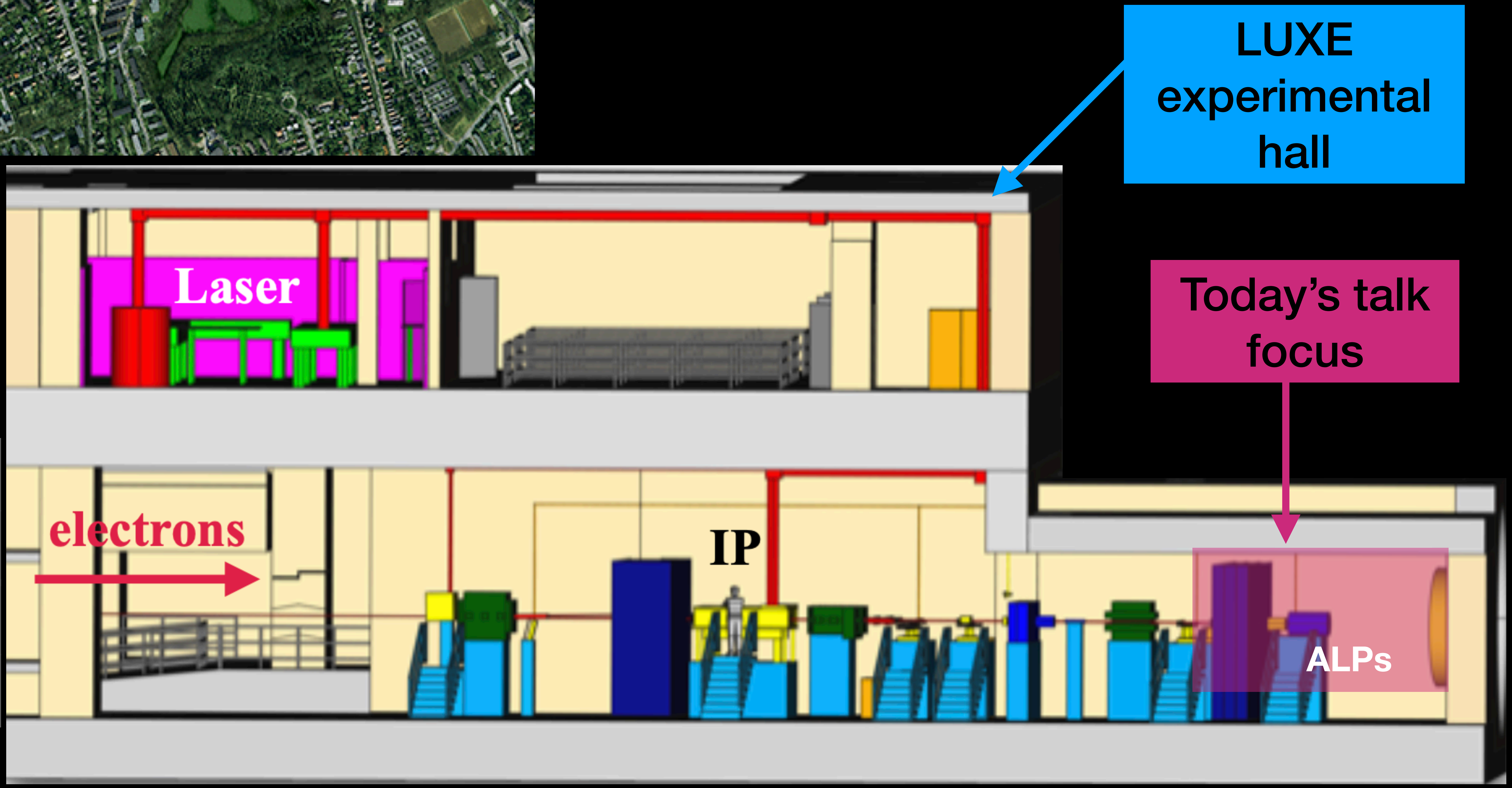
LUXE at the EU.XFEL



- ★LUXE will start running from 2024.
  - ★Run up to 2029 in two phases.
  - ★First physics result around 2025/2026.
- ★Critical Decision 0 from DESY received.

XFEL: Running since 2017

Electrons	E_e up to **16.5 GeV**, with N_e **= 1.5×10^9 e^-/bunch** and a bunch charge up to 1.0 nC,	
	1/2700 bunches/train, ~1+9 Hz (collisions+background), spot r_{xy}=5 μm, l_z=24 μm	
Laser	Ti-Sapphire, 800 nm, **40/350 TW**, up to ~10 J, ~10 Hz repetition, 60% losses	
	~30-200 fs pulse length, down to 3×3 μm^2 FWHM spot with up to I~10^{21} W/cm^2	



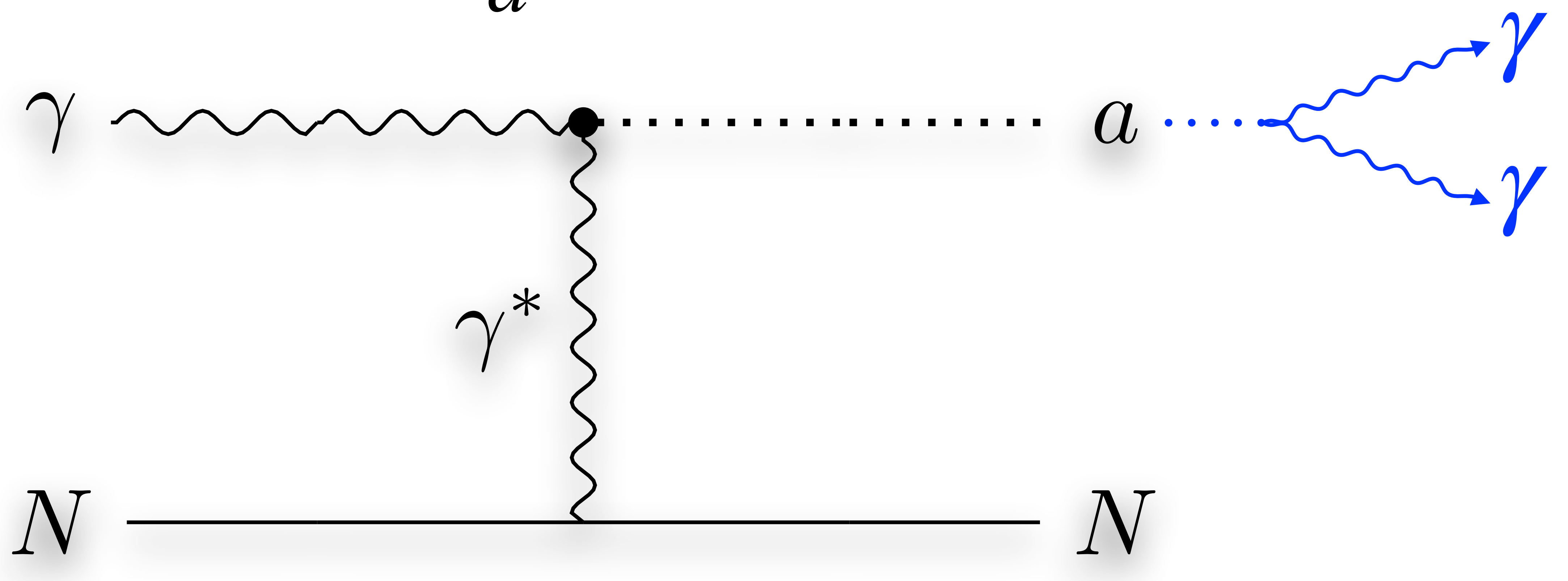
New Physics @ LUXE

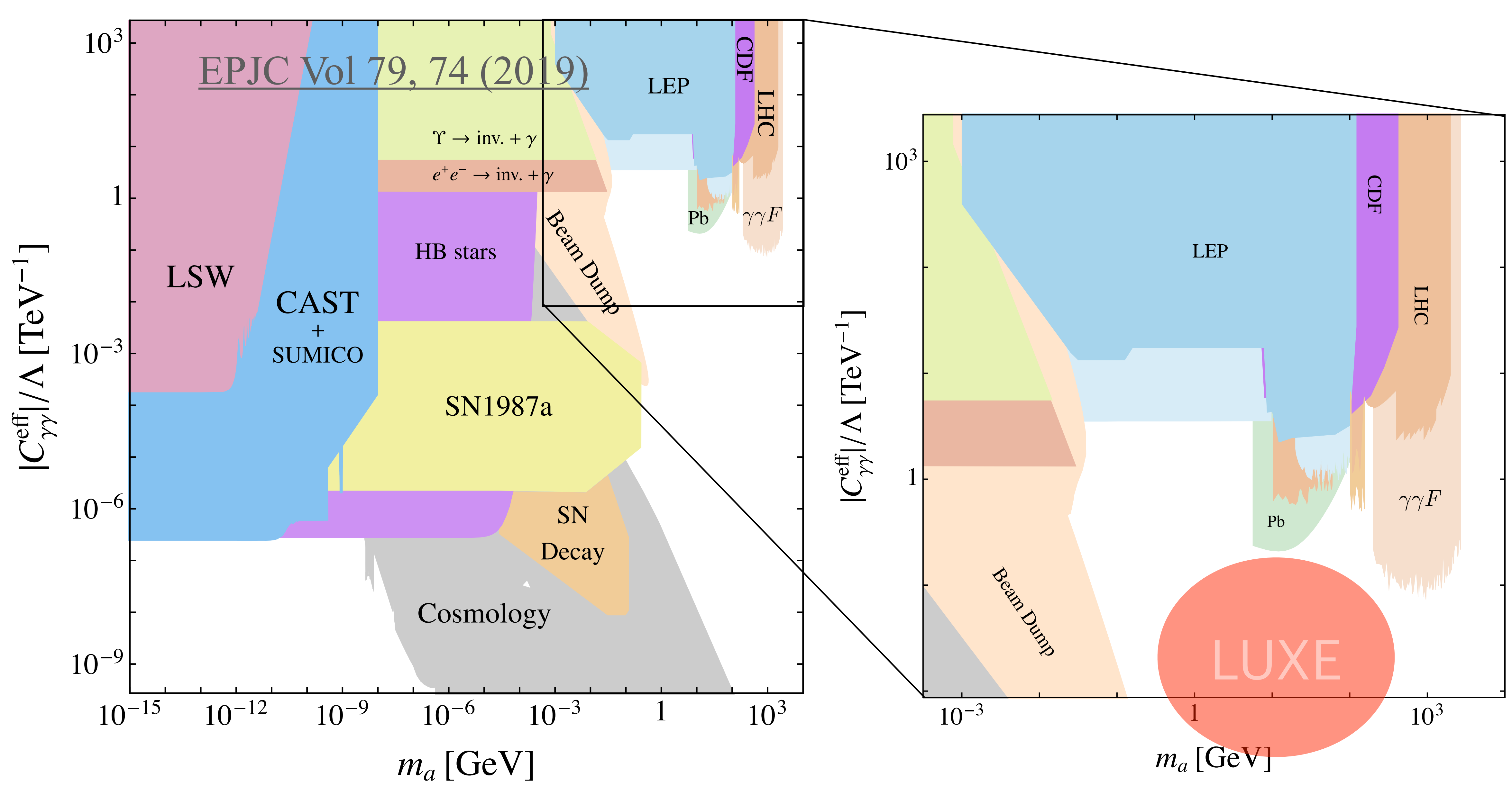
Focus on axion-like-particles (ALP)

- Well motivated BSM scenario
  - The axions propose as a solution to strong CP problem.
  - If very light, it is a dark matter candidate.
  - Light ALPs arise in variety of models motivated by Goldstone theorem.
- Focussing on the Primakoff production
  - Displaced decay of ALPs to 2 hard photons
- Everything applies to scalar with:
  - $a \rightarrow \phi, \tilde{F}_{\mu\nu} \rightarrow F_{\mu\nu}, i\gamma^5 \rightarrow 1$

ignore today

$$\mathcal{L}_a = \frac{a}{4\Lambda_a} F_{\mu\nu}\tilde{F}^{\mu\nu} + i\cancel{g_{ae}} a\bar{e}\gamma^5 e$$





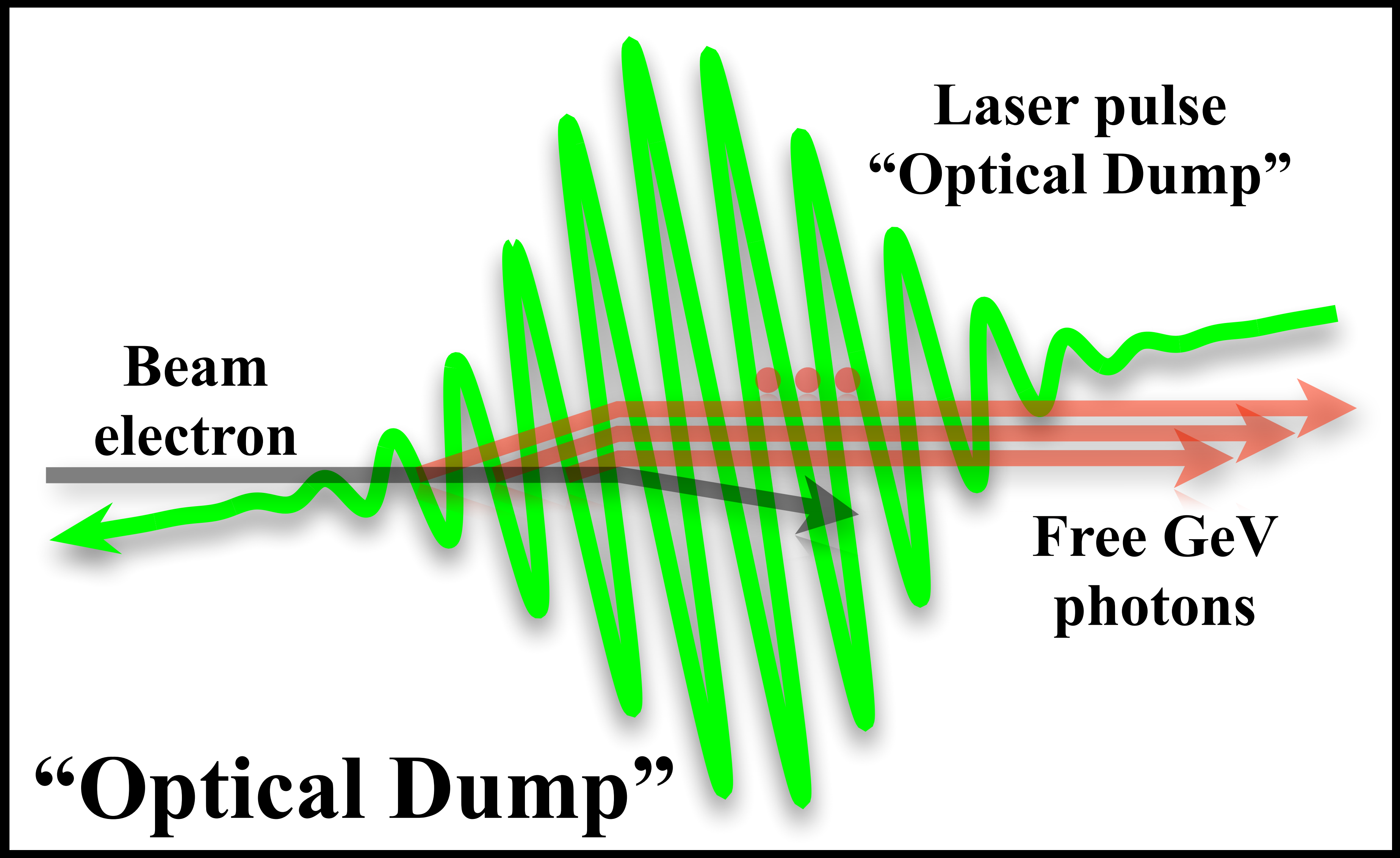
Concept of Optical Dump

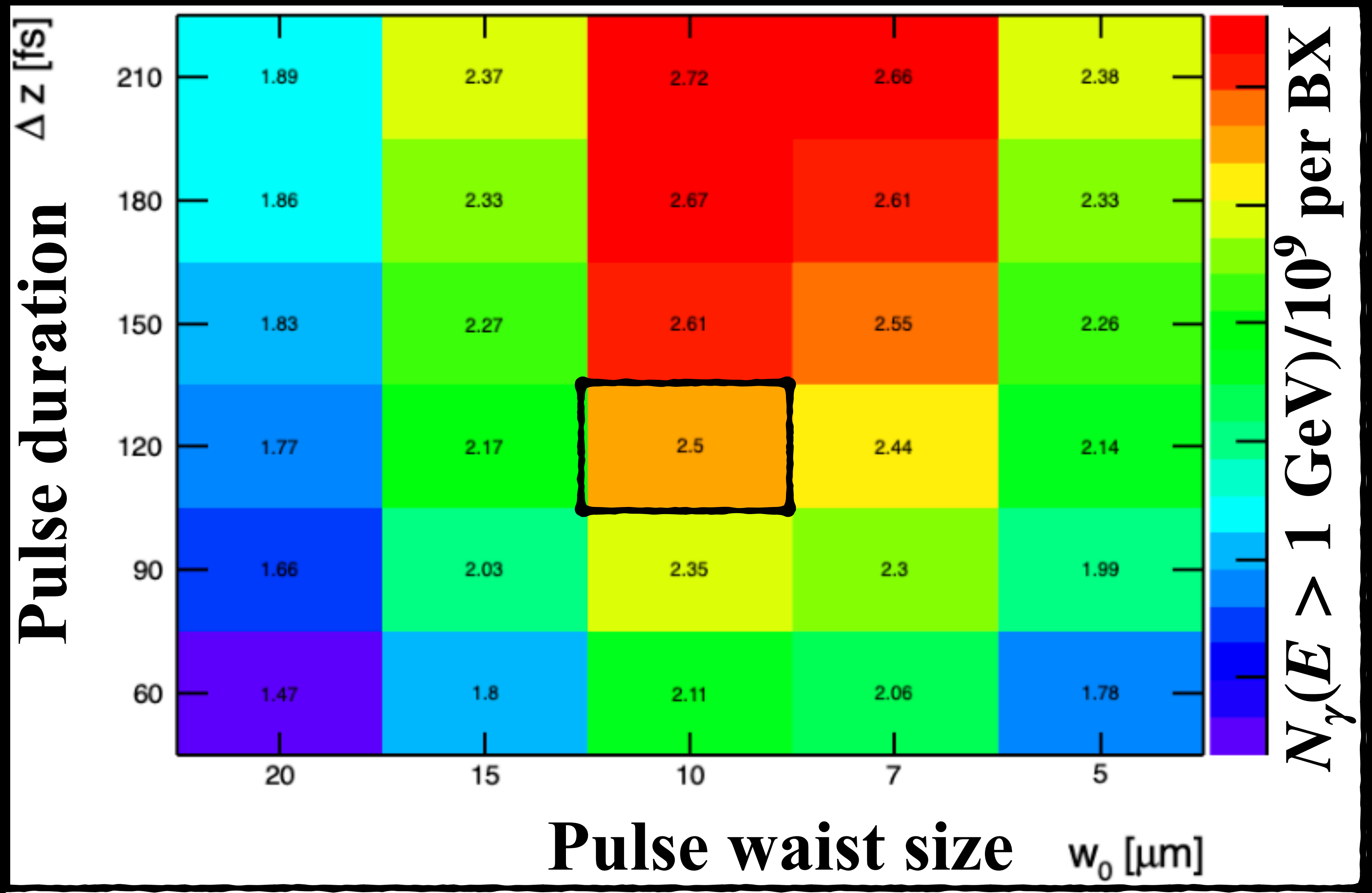
- High flux of GeV photons emitted from the LUXE's electron-laser interaction region.

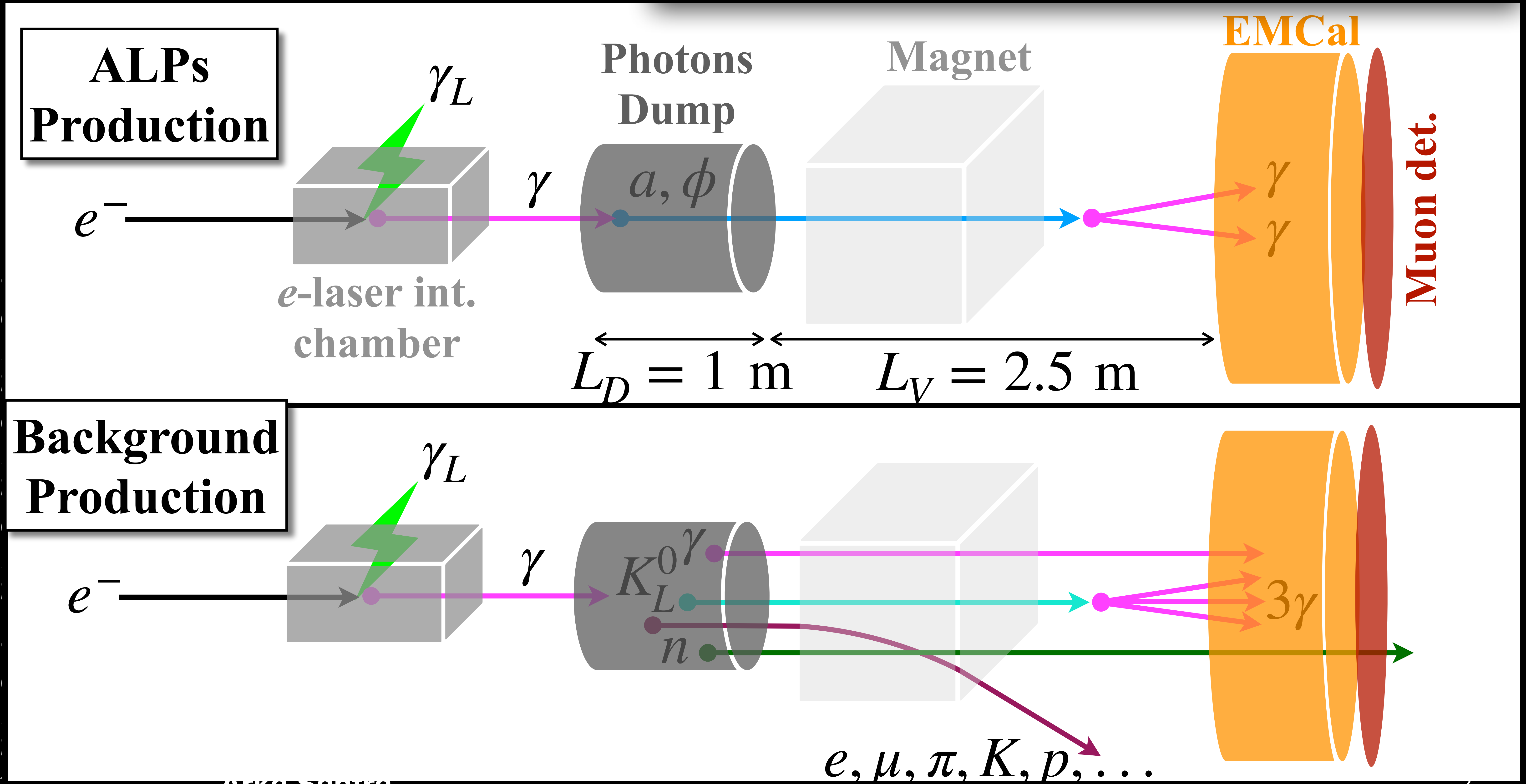
- $N_a \approx \mathscr{L}_{\text{eff}} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \sigma_a(E_\gamma, Z) \left(e^{-\frac{L_D}{L_a}} - e^{-\frac{L_V + L_D}{L_a}} \right) \mathscr{A}$

Time scales: $\omega_L^{-1} \ll \tau_\gamma \lesssim t_L \ll \tau_{ee}$

$\ast 1/\omega_L \sim 0.4$ fs: good to use laser as a background field to a leading order.
$\ast \tau_{ee} \sim \mathscr{O}(10^4 - 10^6)$ fs: treat the photons in the laser as free streaming.
$\ast \tau_\gamma \sim \mathscr{O}(10)$ fs and $t_L \sim \mathscr{O}(20 - 120)$ fs.
  $\ast$laser behaves as a thick target for electrons.

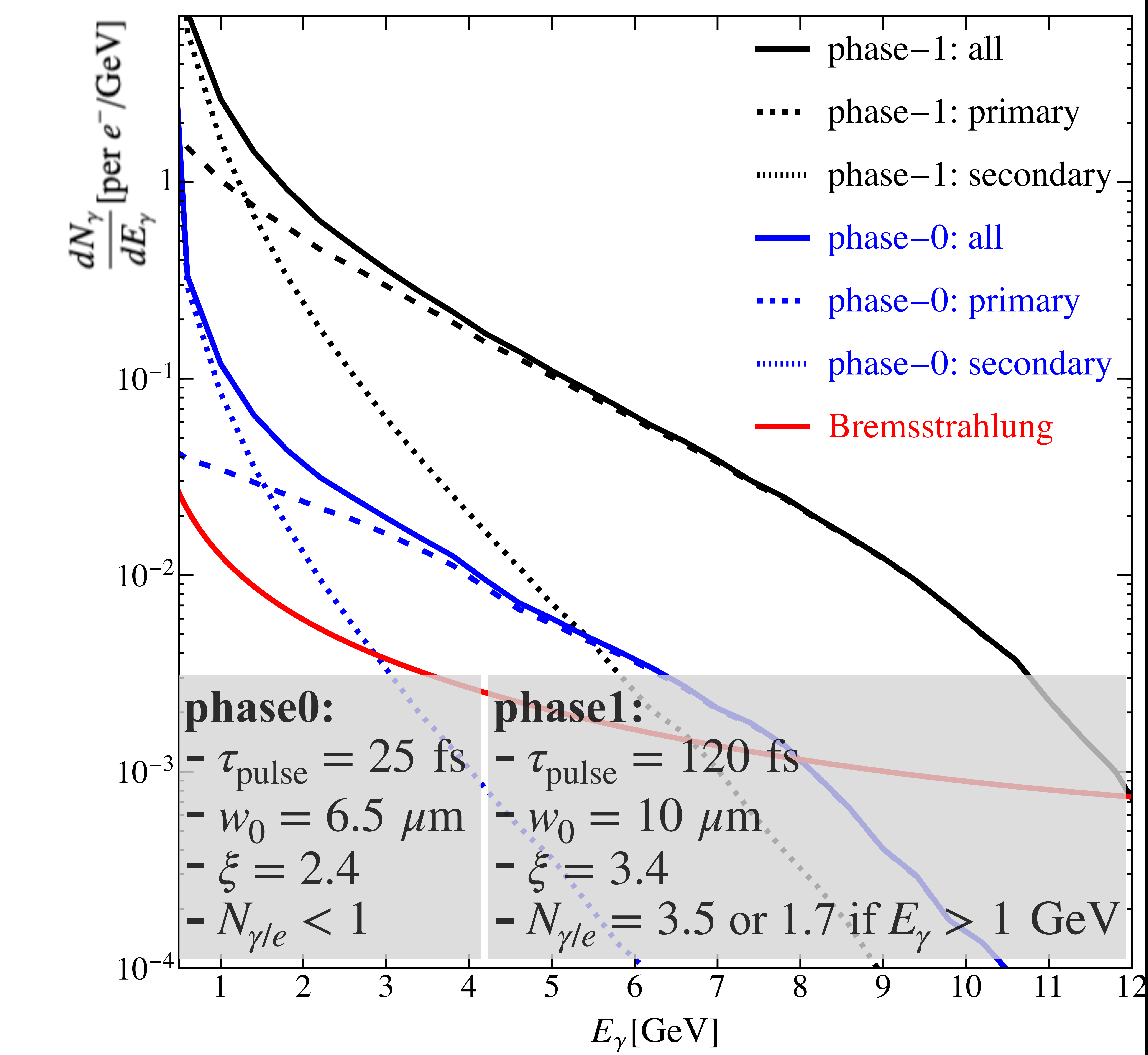






Photon spectra for ALPs production

- Spectra of photons per initial electrons
  - Primary photons from the interaction point
  - Secondary photons from the shower in the dump
- For phase I, there are many photons per initial electron
  - $\sim$3.5 photons for $E_\gamma > 0$ GeV
  - $\sim$1.7 photons for $E_\gamma > 1$ GeV
- More photons if the electron beam is sent directly to the dump
  - More signal, but at the cost of much more background.



Background Estimation:

- SM particles produced in the dump during the shower
    - Charged particles: electrons, muons and hadrons.
        - Can be bent away from the detector surface by a magnetic field.
    - Fake photons: mostly neutrons.
    - Real photons: EM/hadronic interactions from the close to the end of the dump or from meson decay.

✳Background estimated from the Geant4 simulation

✳Got 0 photons and 10 neutrons (with $E > 0.5$ GeV) in the 2 BX simulated for the 1 m long dump.

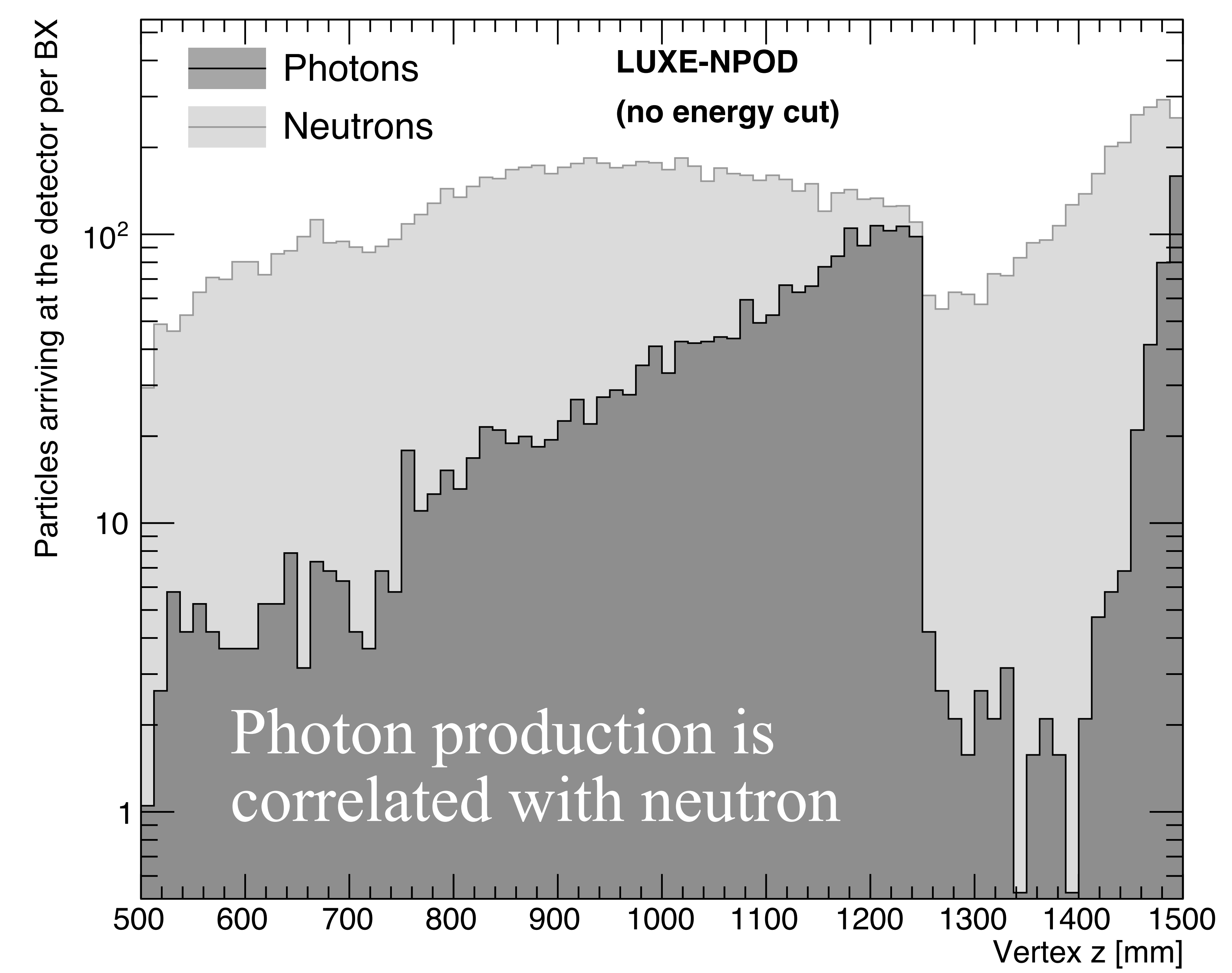
✳Photons can be statistically limited here.

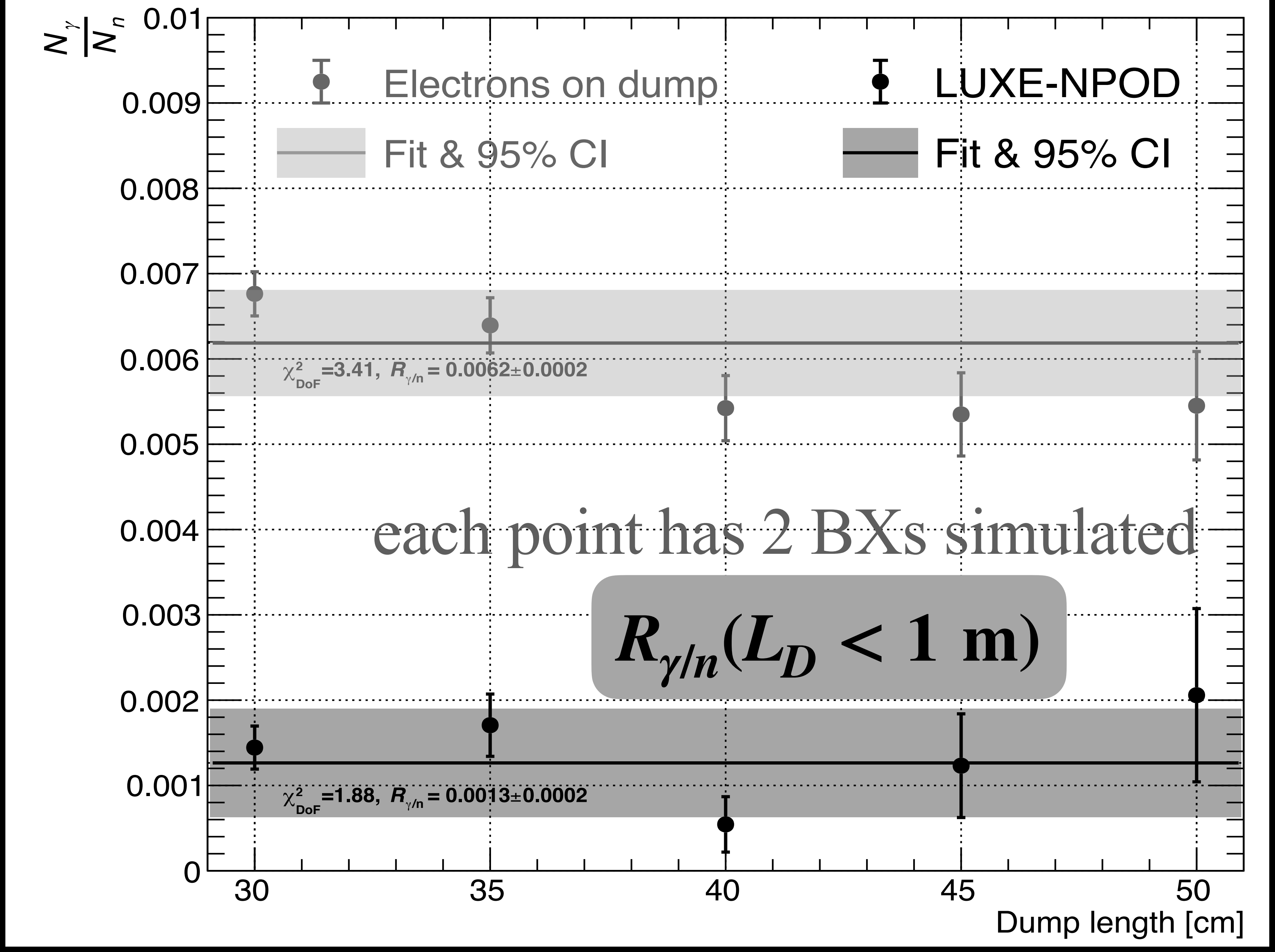
✳Unfortunately simulation is computationally expensive.

★ Way out: photon production is correlated with neutron production in hadronic processes

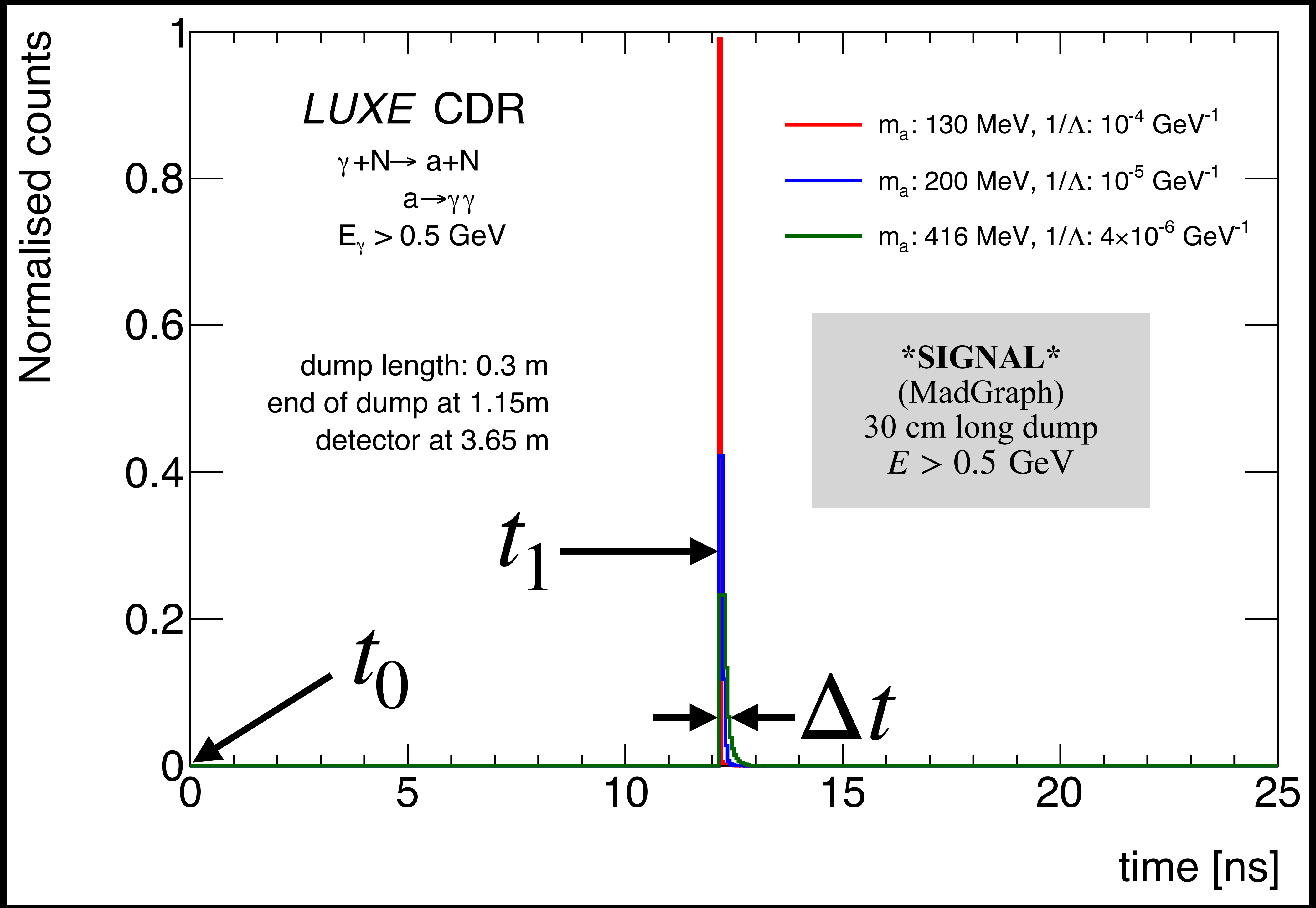
★ The number of photons can be estimated from the photons to neutron ratio at the shorter dump where there are more number of photons.

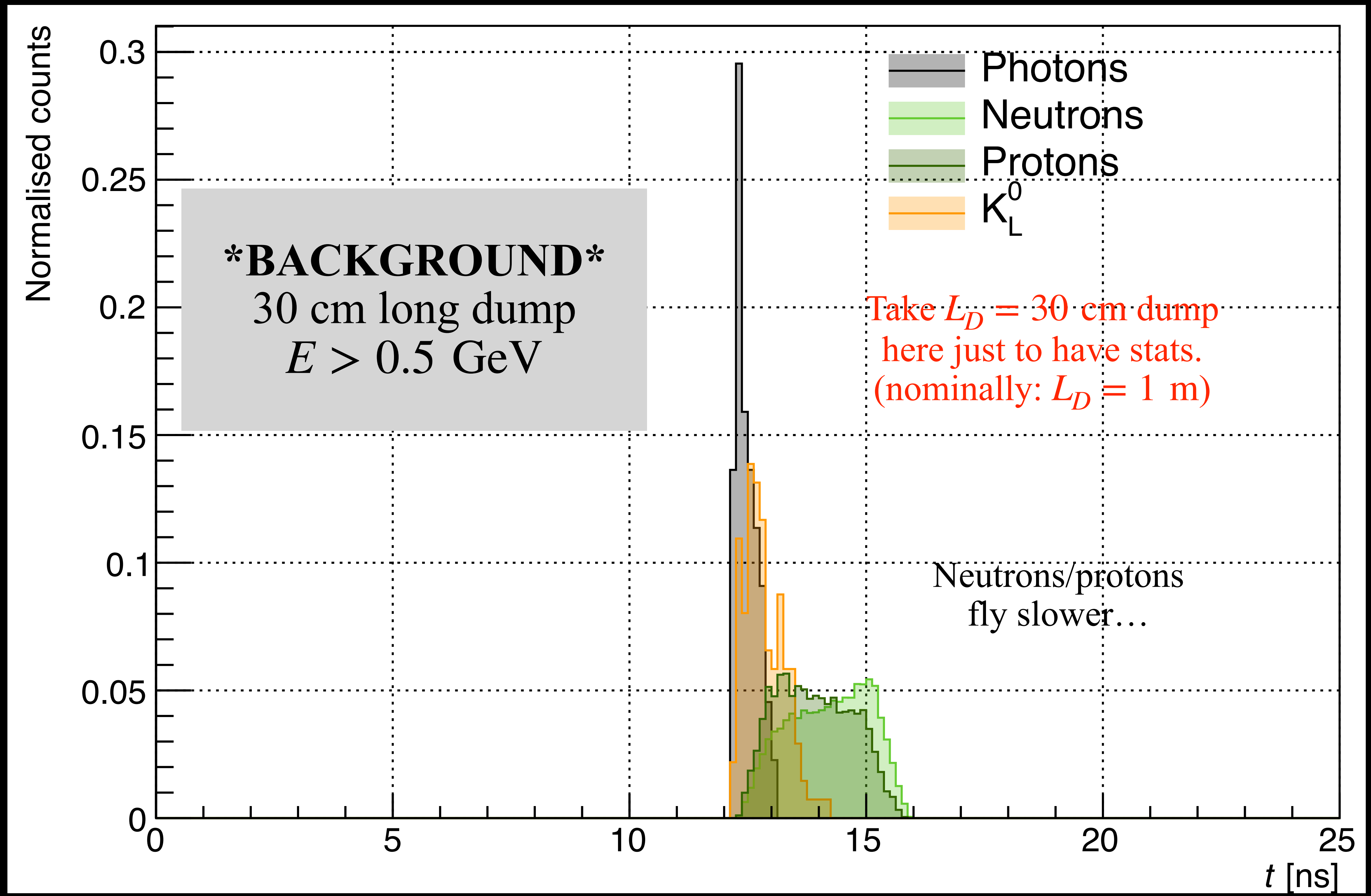
★$N_\gamma \sim N_n(L_D = 1m) \times R_{\gamma/n}(L_D < 1m)$





Use of timing information





- ★Signal and background particles take different time to travel the distance between the dump and the detector face.
  - ★Signal ALPs are faster than background neutrons/protons.
- ★Trigger at t_0 (Eu.XFEL clock) and then open a short time window Δt.
  - ★Most signal and background photons will arrive within $\Delta t \sim 0.5$ ns
  - ★Almost all hadrons will arrive after that.
- ★Background rejection $\lesssim 10^{-3} - 10^{-4}$ from kinematics and timing.
- ★Neutron to photon fake rate $\lesssim 10^{-3} - 10^{-4}$
- ★Considering one year of data taking ($10^7 s$), the number of total background is < 1.

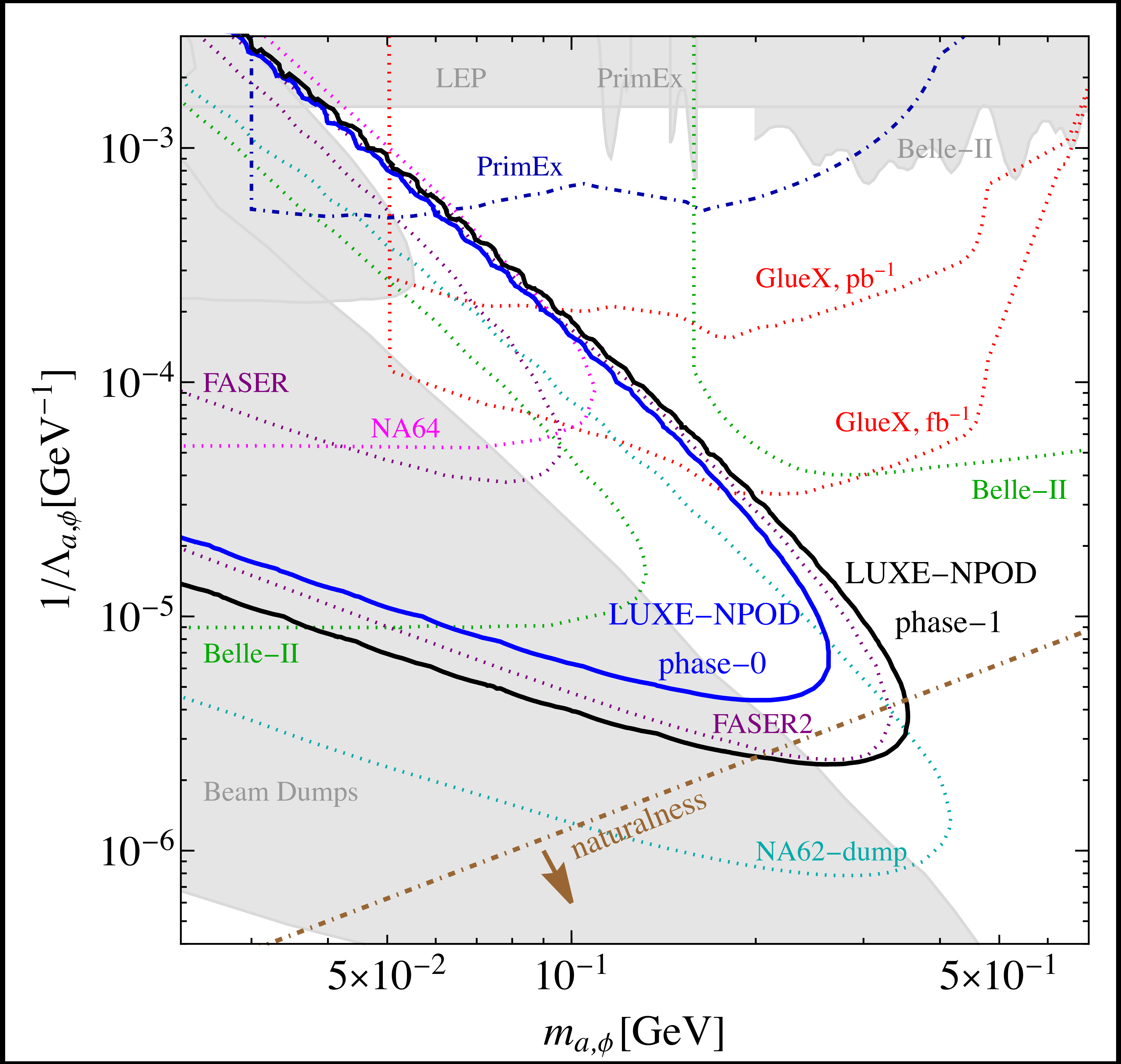
	Background rejection ~[%]				Signal efficiency [%] for m_a:$1/\Lambda_a$		
Δt [ns]	γ	n	p	K_L	130:1e-4	200:e-5	416:e-5
0.1	57	99.9	99.9	87	99.6	84	46
0.5	16	96	94	52	100	100	99
1.0	0	80	70	13	100	100	100

$R_{\text{sel}}^{\text{neutrons}} \sim 10^{-3}$

Summary

- LUXE is a new experiment with baseline plan of testing strong field QED.
    - Regions never been explored in a clean environment.
    - Plan to start taking data by 2024/2025.
- Search for new physics
    - Using optical dump feature of this experiment
    - Proposal is easily added to the experiment with essential background free search.
- The reach of LUXE is comparable with NA62 (with dedicated run) and FASER (end of HL-LHC).
    - LUXE reach in the mass 40 MeV to 350 MeV above $1/\Lambda > 10^{-6}$ GeV^{-1}.

Setting the number of observed signal-like events to $N_a = 3$, the 95 % CL equivalent for background free search



LUXE

More than 90 scientists, 29 institutes, 9 countries

Royal Holloway University of London

Queen's University Belfast

UCL

University of Plymouth

DESY.

mpsd
Max-Planck-Institut für Struktur und Dynamik der Materie

Helmholtz
Helmholtz-Institut Jena

Technische Universität Darmstadt

université Paris-Saclay

Uni Freiburg

Alma Mater Studiorum Università di Bologna

INFN
Istituto Nazionale di Fisica Nucleare

Università degli Studi di Padova

Universitas Gothoburgensis 1891

Skoltech
Skolkovo Institute of Science and Technology

MEPhI
National Research Nuclear University • Moscow Engineering Physics Institute

HZDR
Helmholtz Zentrum Dresden Rossendorf

Technische Universität Dresden

AGH
AGH University of Science and Technology

Національна Академія Наук України 1918

Technion
Israel Institute of Technology

Tel Aviv University

מכון ויצמן למדע
Weizmann Institute of Science

National Research Tomsk State University

Tomsk, Russia

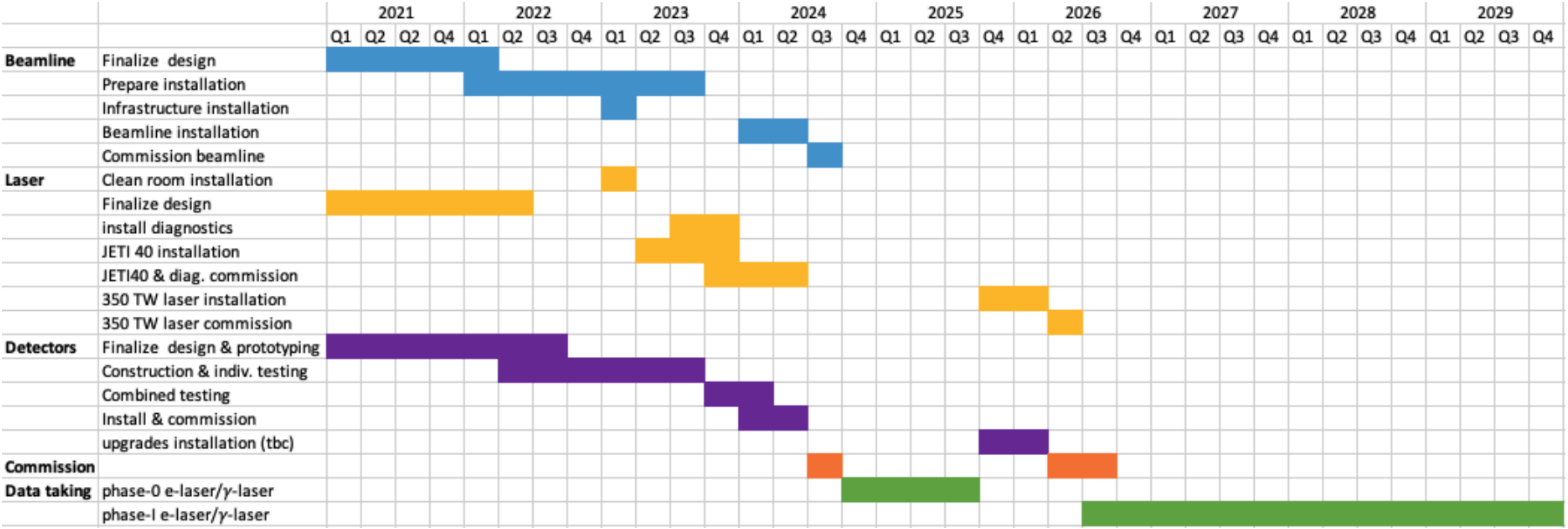
SUSTech
Southern University of Science and Technology

Shenzhen, China

Thank you!

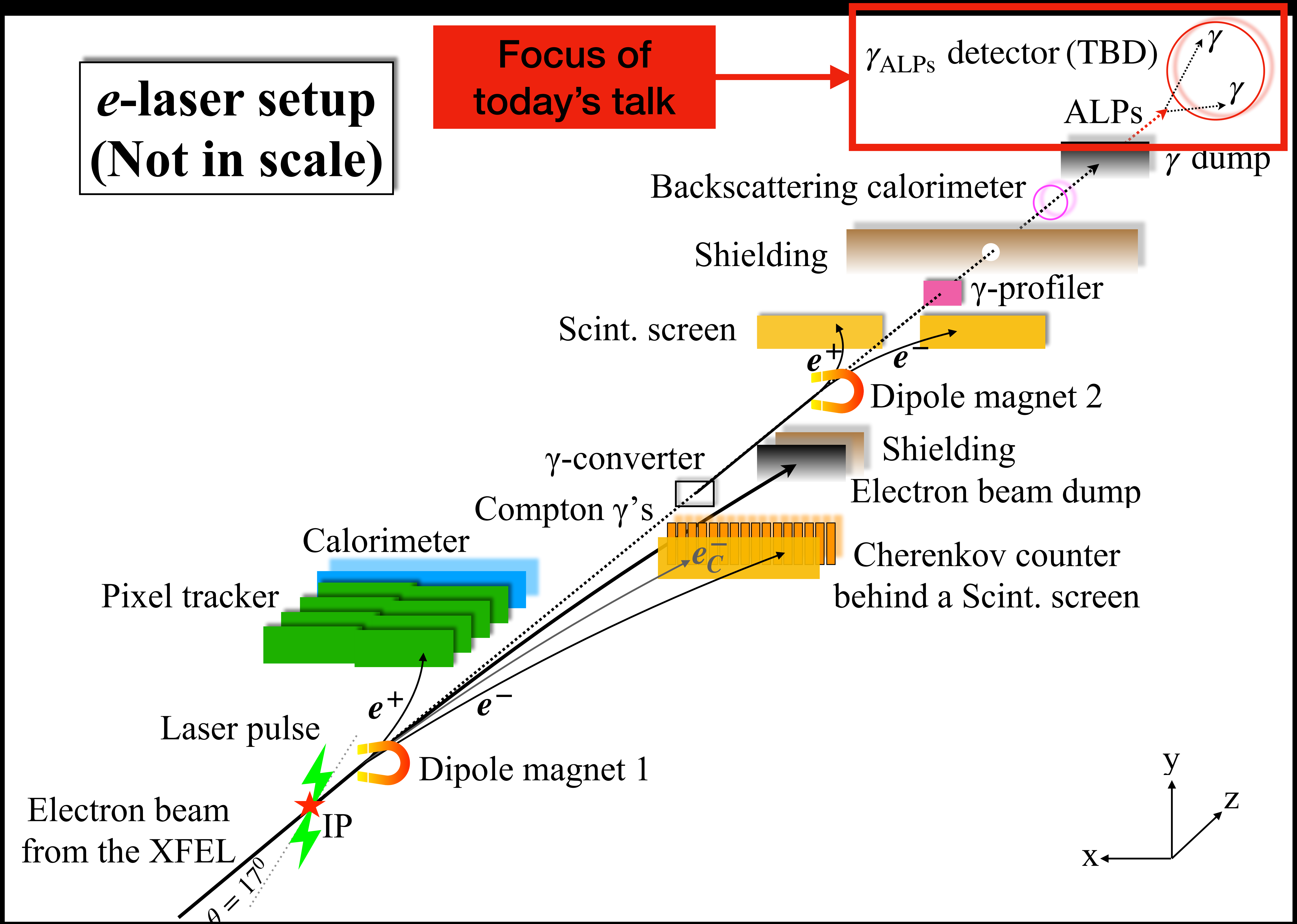
Back up

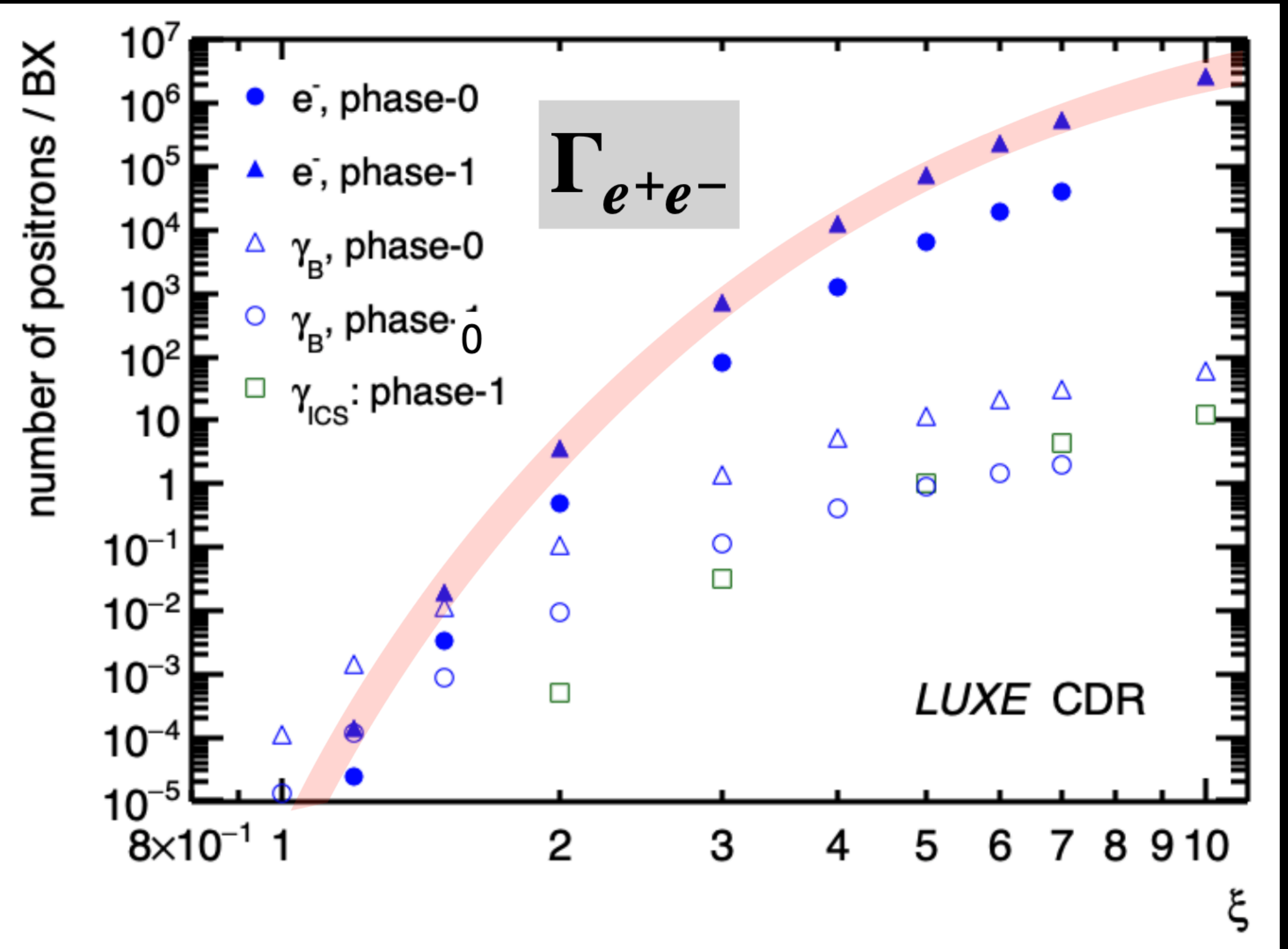
LUXE Planning

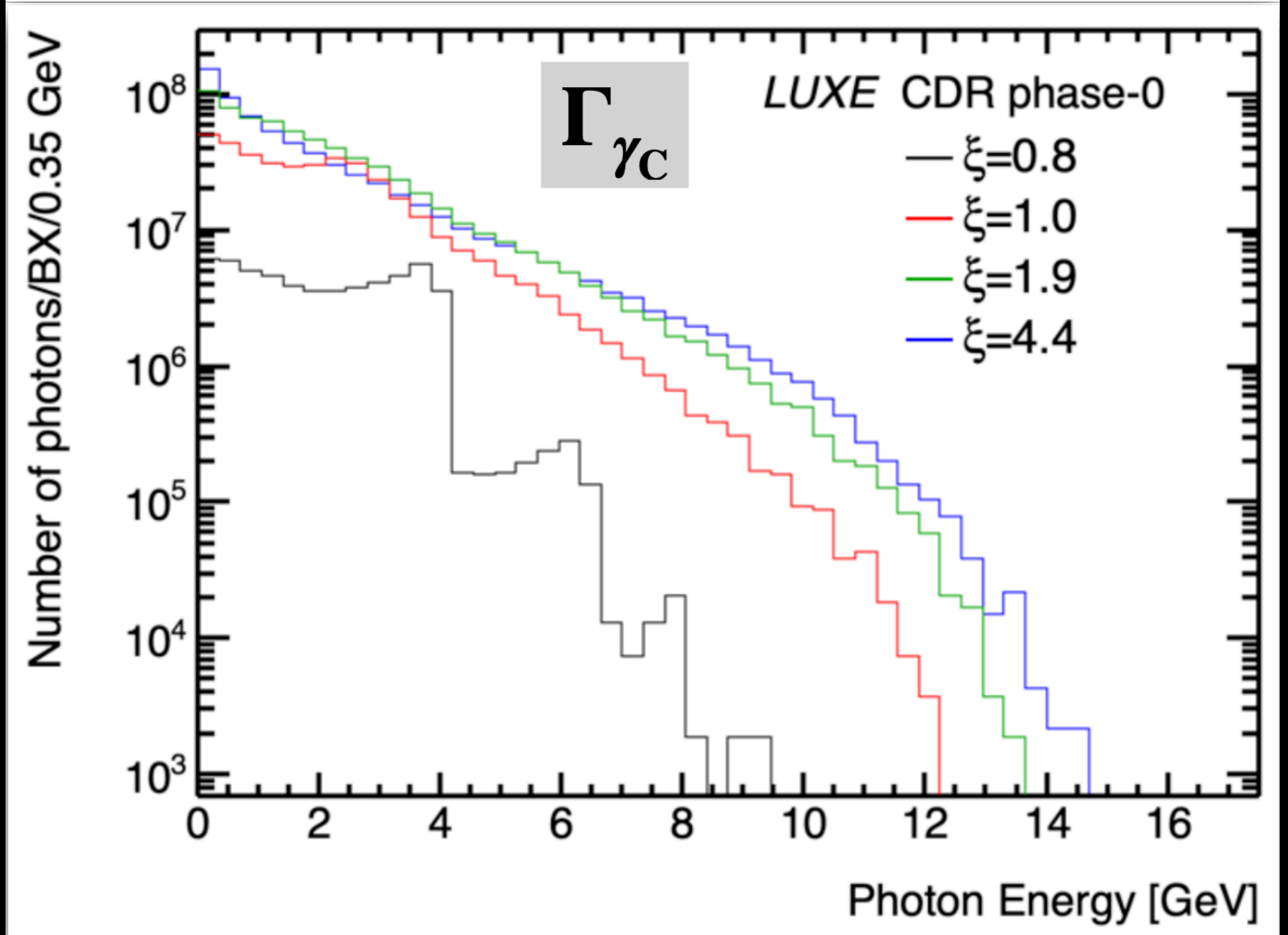


- CDR released in Feb 2021 & passed an international review. Now working toward TDR for 2022
- Experiment must be installed by 2024 during the long shutdown of the Eu.XFEL
- Phase-0: data taking in 2024 with the 40 TW laser in e-laser mode and move to γ-laser in 2025
- Phase-1: upgrade laser to 350 TW in 2026 and run until the Eu.XFEL needs the tunnel (~2029)

Experimental setup

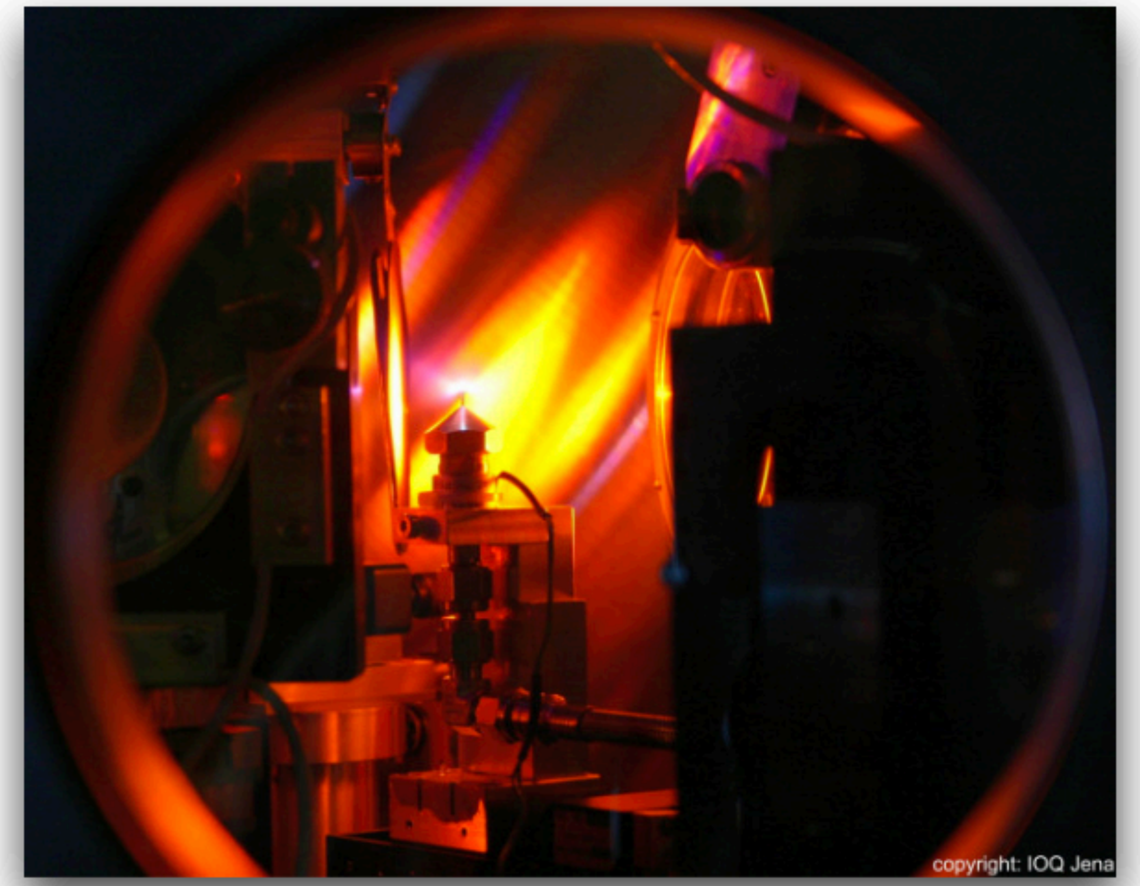


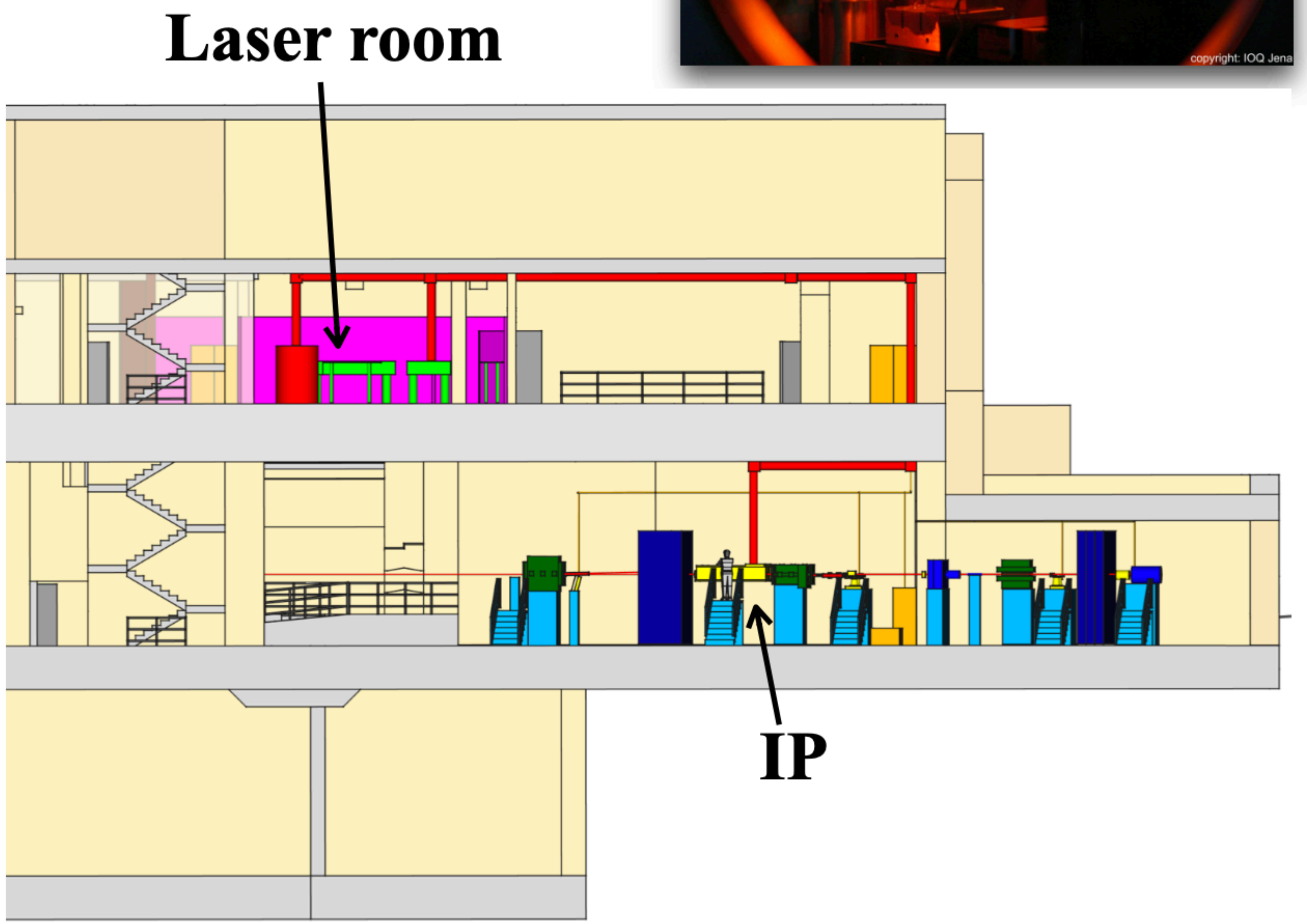




Laser

- Phase-I: the JETi40 40 TW laser loaned to LUXE by Helmholtz Institute Jena
- Phase-II: looking up towards a 350 TW laser with as small as 3×3 μm^2 spot size
- Challenge: exact knowledge of the intensity at the IP
    - with the laser being ~10's of meters away from it
    - and with a remote diagnostics system





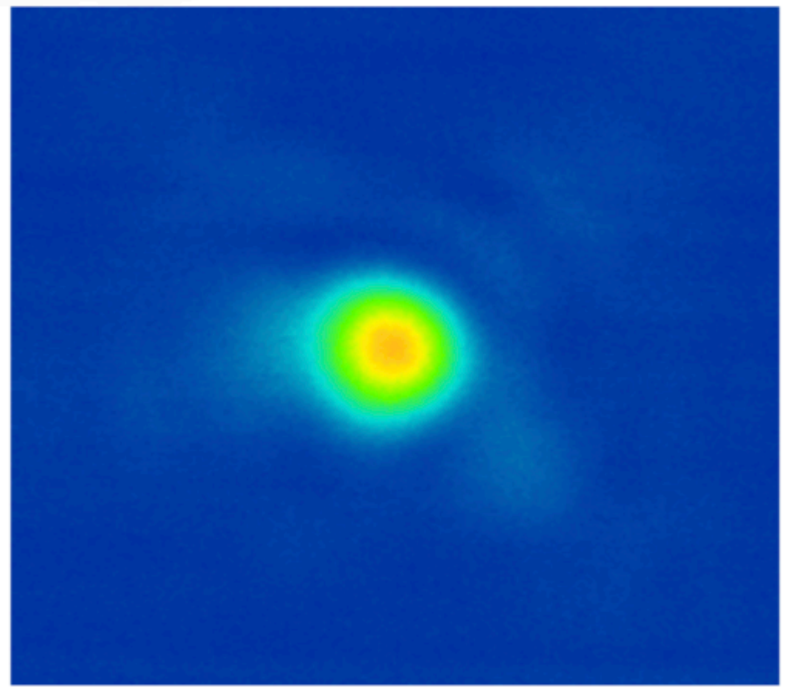
Laser diagnostics

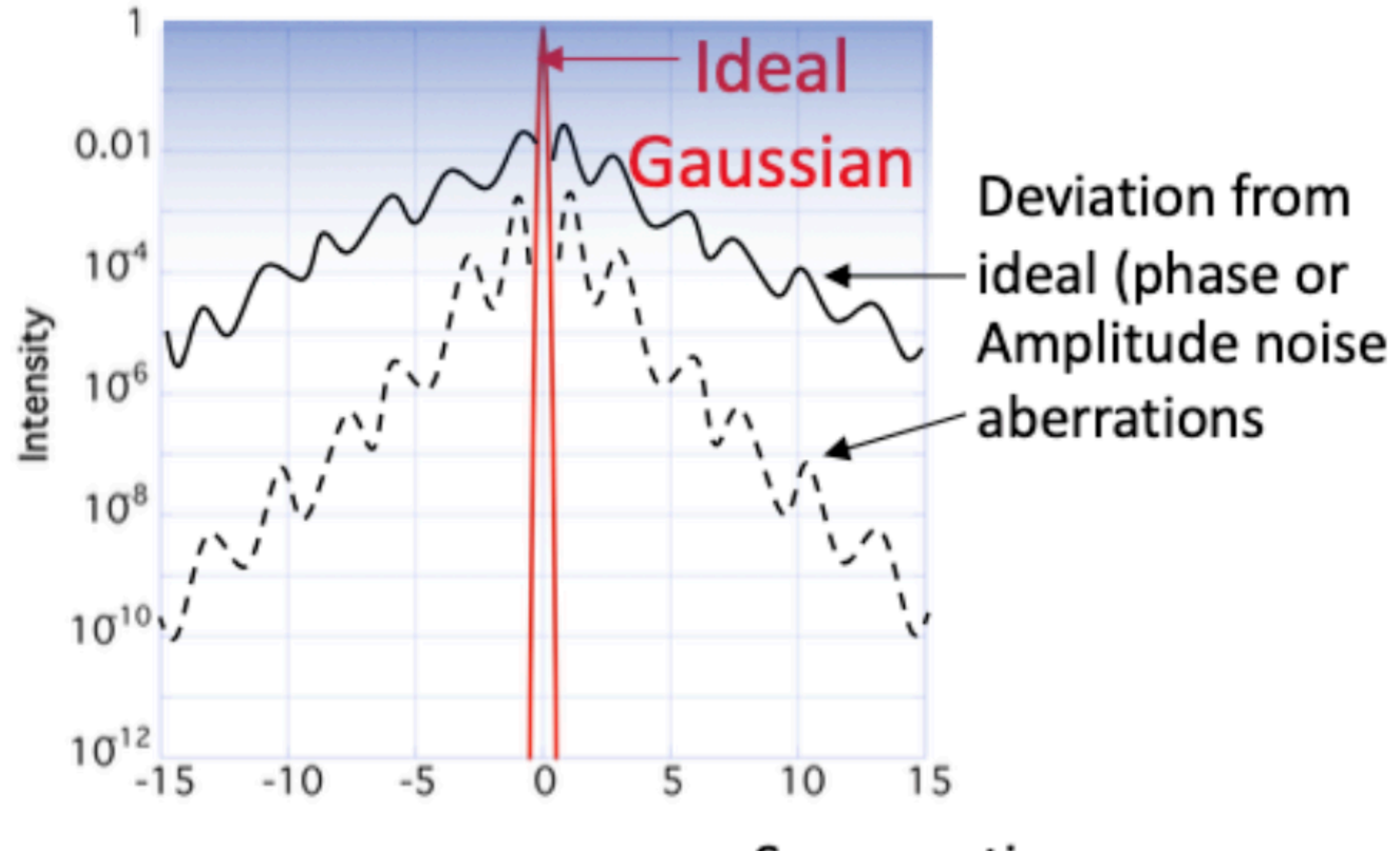
- Measure laser parameters to infer the intensity, I
  - can be indirect and direct, relative and absolute
- Small fluctuations in I lead to large rate fluctuations
  - air movement, vibrations, temp-drift, pump discharge variations, etc.
- The laser beam will be attenuated and imaged on the return path to the diagnostics 10s of meters away from the IP

$$I = \frac{E}{A \times \tau}$$

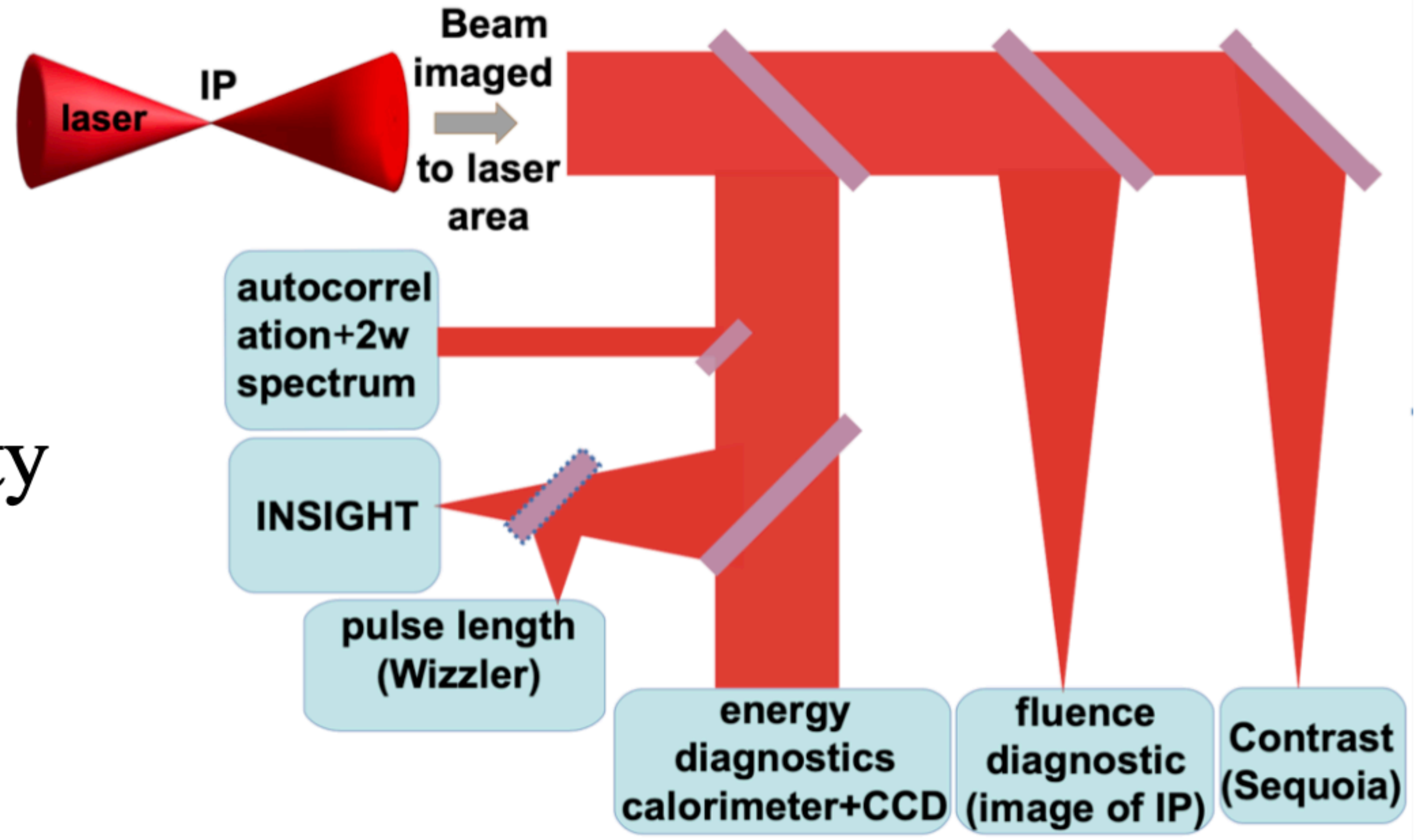
E ← pulse energy

$A \times \tau$ ← pulse spot size × duration



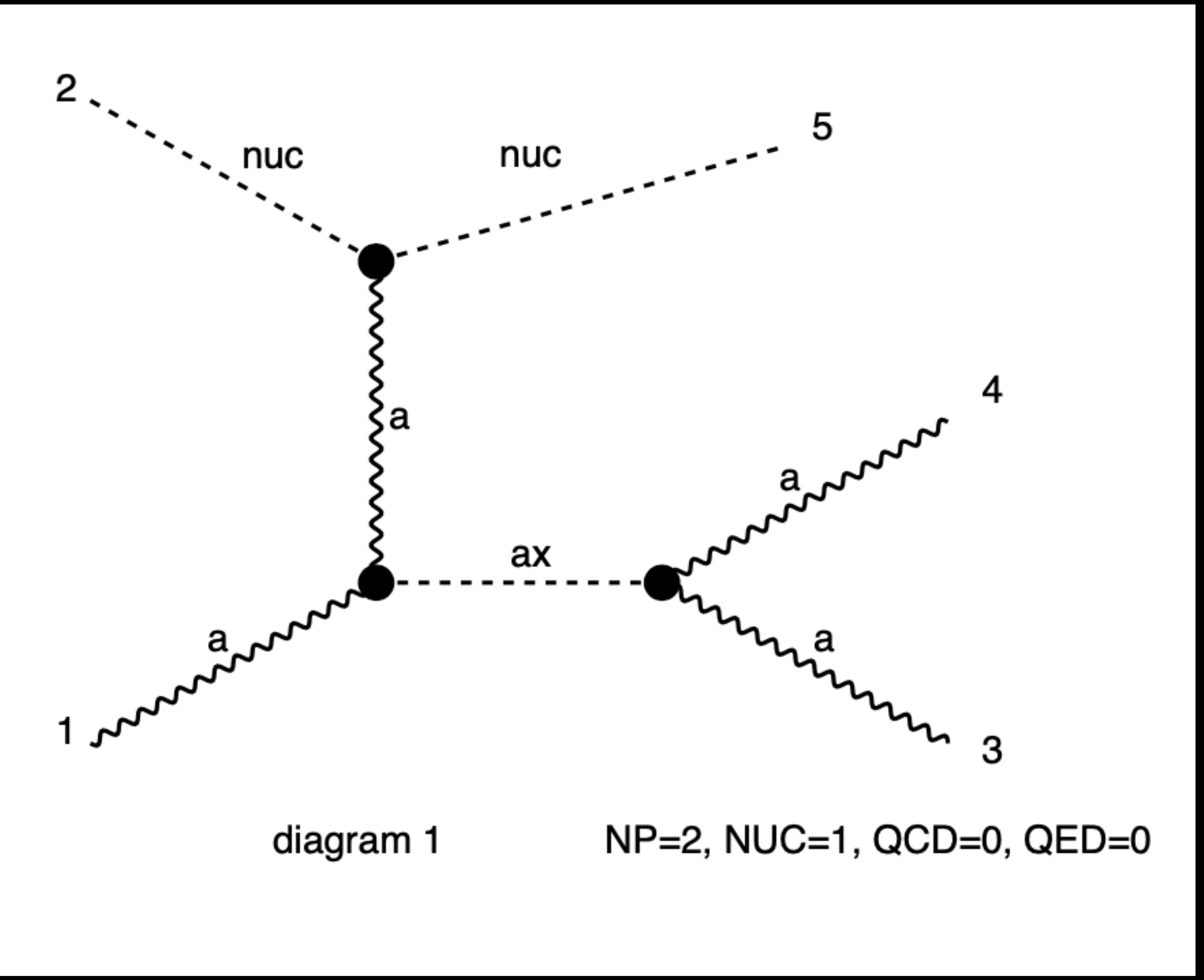


Diagnostics
- relative intensity
- pulse duration
- beam size

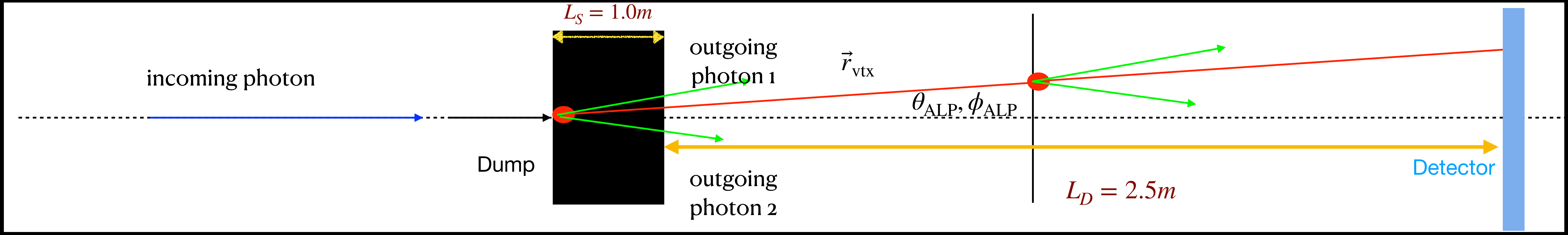


MadGraph settings

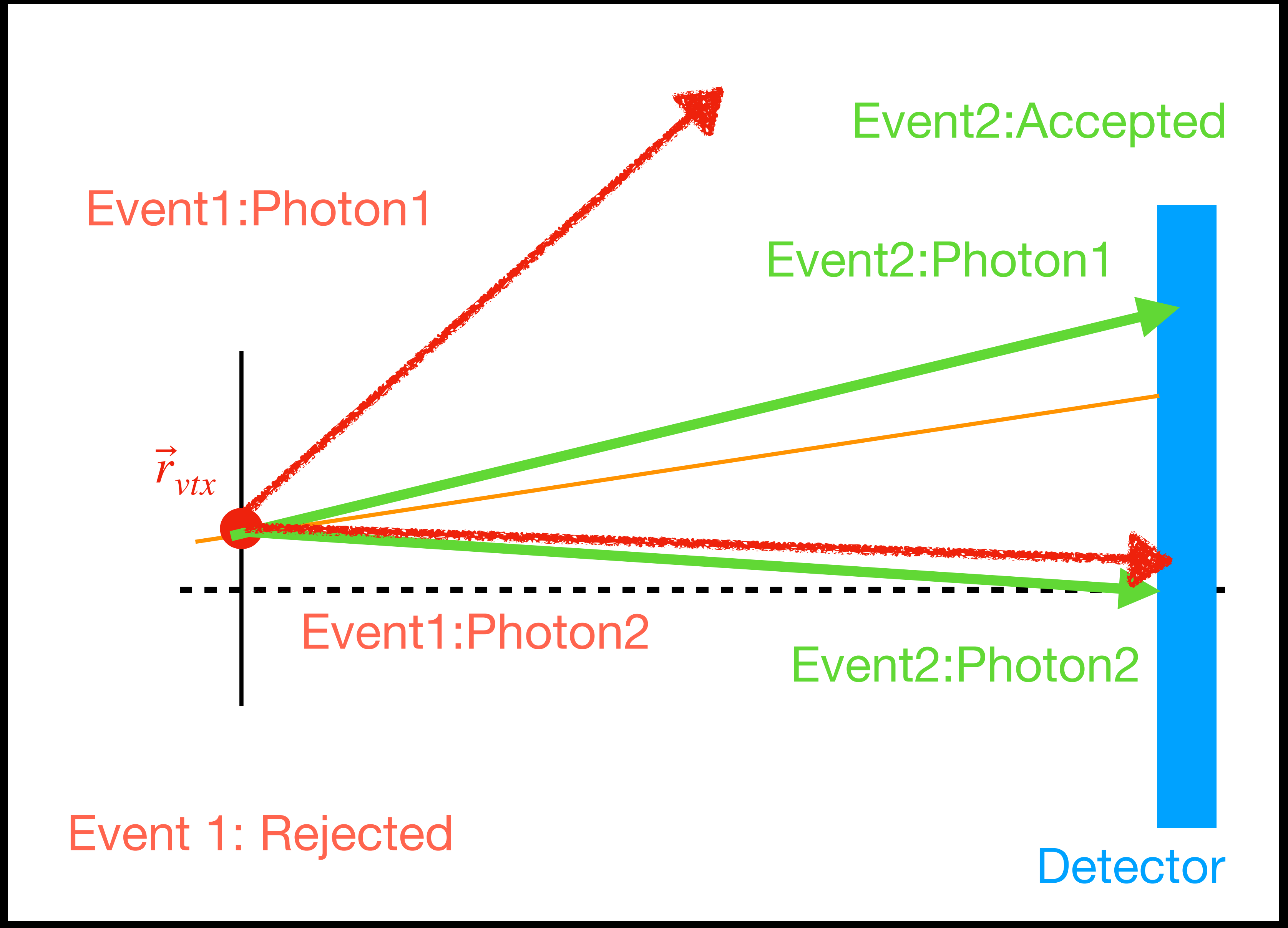
- Generate this process: a nuc -> ax nuc where a is photon, nuc is the nucleus of the tungsten dump and ax is the ALP (a BSM pseudoscalar particle).
  - Primakoff production mechanism.
  - The dump is stationary.
- The nuclear form factor was obtained from Iftah Galon and implemented in the model.
- The MadGraph generated output in the standard LHE file format.
  - Converted to root using ExRootConverter
- The root file contained these branches:
  - Particle four momentum, PDG, Status (incoming/outgoing) etc.
- MadGraph does not smear the vertex position, so all collisions happen at z=0, t=0.
  - Moreover MadGraph decays ALP instantaneously - so we have two photons in the final state.
  - The 2 photons are produced at z=0 and hence we need to displace them according to the ALP's lifetime



Acceptance Calculation



- The distance of decay (r_{vtx}) for each ALP is obtained by randomly drawing a length from the decay length distribution of the ALP.
    - Decay length is obtained using $L_A = c\tau_A p_A / m_{ALP}$.
    - r_{vtx} : randomly drawing a number from exp(-L_A).
    - The direction is determined by the momentum of ALP.
- Once the $\vec{r}_{vtx}$ is determined, photons are shifted to that position.
    - If $|\vec{r}_{vtx}|\cos(\theta_{ALP})$ is more than the dump length ($L_S = 1.0m$) and less than ($L_S + L_D = 3.5m$), then we proceed to next stage, other wise the event is rejected.
    - Given the opening angle of the photons and the distance still need to travel to detector, one checks if the photons are caught by the detector or not.
- If both the photons are caught by the detector (and E > 0.5 GeV), then that event is accepted.
    - If at least one photon has energy less than 0.5 GeV or/and at least one photon is outside geometric acceptance, the event is rejected.
- Acceptance $\mathscr{A}$ = events with both photons passing the energy cut and geometric constraints/total number of events generated.



ALPs production

$$N_a \approx \mathscr{L}_{\text{eff}} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \sigma_a(E_\gamma, Z) \left(e^{-\frac{L_D}{L_a}} - e^{-\frac{L_V + L_D}{L_a}} \right) \mathscr{A} \qquad \mathscr{L}_{\text{eff}} = N_e N_{\text{BX}} \frac{9\rho_W X_0}{7A_W m_0}$$

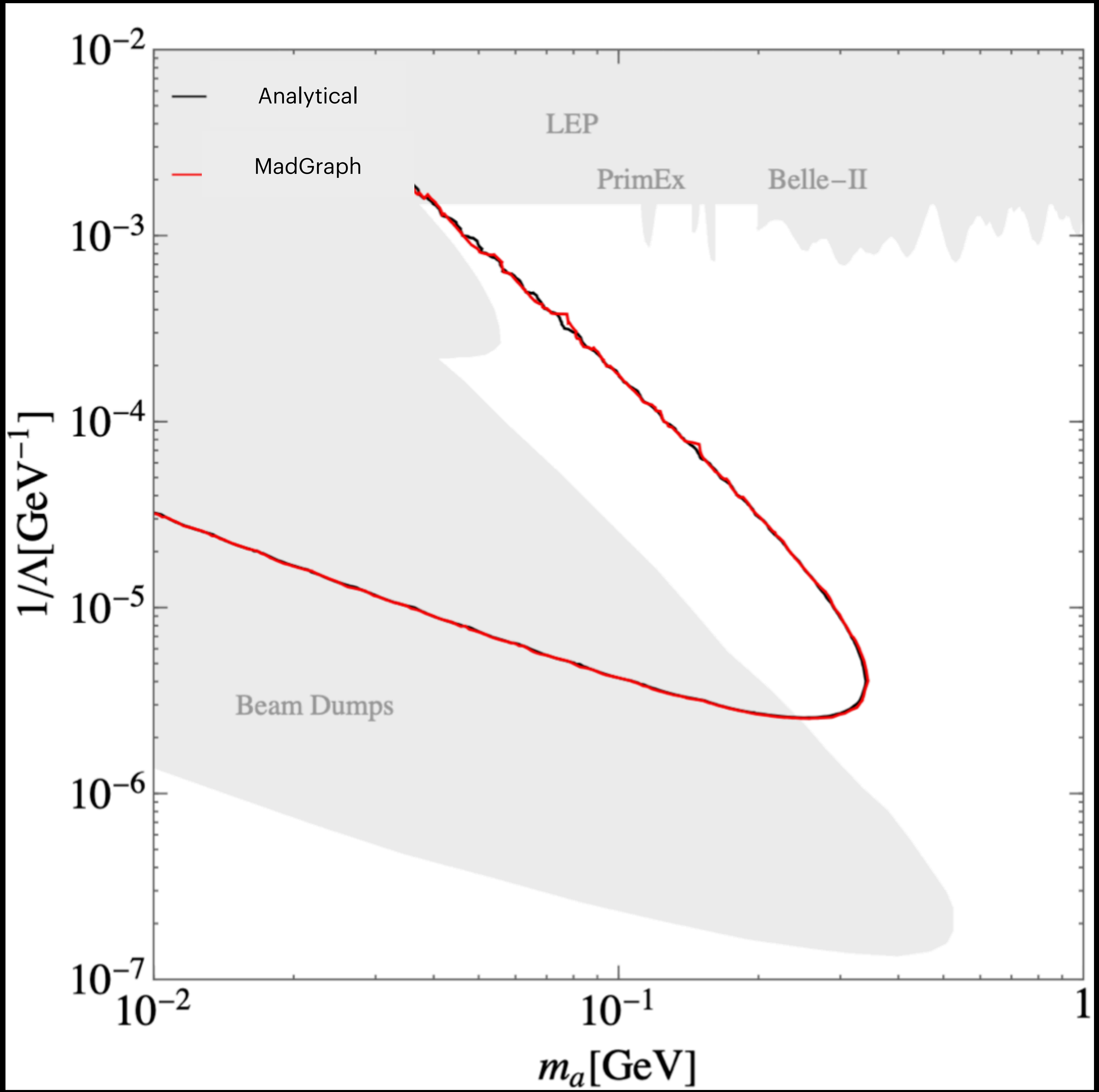
$$L_a = c\tau_a \frac{p_a}{m_a}$$

$$p_a \approx \sqrt{E_\gamma^2 - m_a^2}$$

- $N_e = 1.5 \times 10^9$ is the number of electron per bunch and $N_{\text{BX}}(=10^7)$ is the number of BXs assumed
- E_γ is the incoming photon energy
- $\mathscr{L}_{\text{eff}}$ is the effective luminosity, where ρ_W is the Tungsten density, A_W is its mass number and X_0 is its radiation length. $m_0 \sim 930\ \text{MeV}$ is the nucleon mass
- L_a is the ALP propagation length, where τ_a is its proper lifetime and p_a is its momentum
- $\sigma_a(E_\gamma, Z)$ is the Primakoff production cross section of the ALP in the dump
- $\mathscr{A}$ is the angular acceptance times efficiency of the detector
- dN_γ/dE_γ is the differential photon flux per initial electron, includes photons from the electron-laser interaction, as well as secondary photons produced in the EM shower which develops in the dump
- $L_D = 1\ \text{m}$ is the dump's length. The dump is positioned ~13 m away from the electron-laser interaction region
- $L_V = 2.5\ \text{m}$ is the length of the decay volume
- The decay rate of the ALP into two photons is $\Gamma_{a\to\gamma\gamma} = m_a^3/(64\pi\Lambda_a^2)$

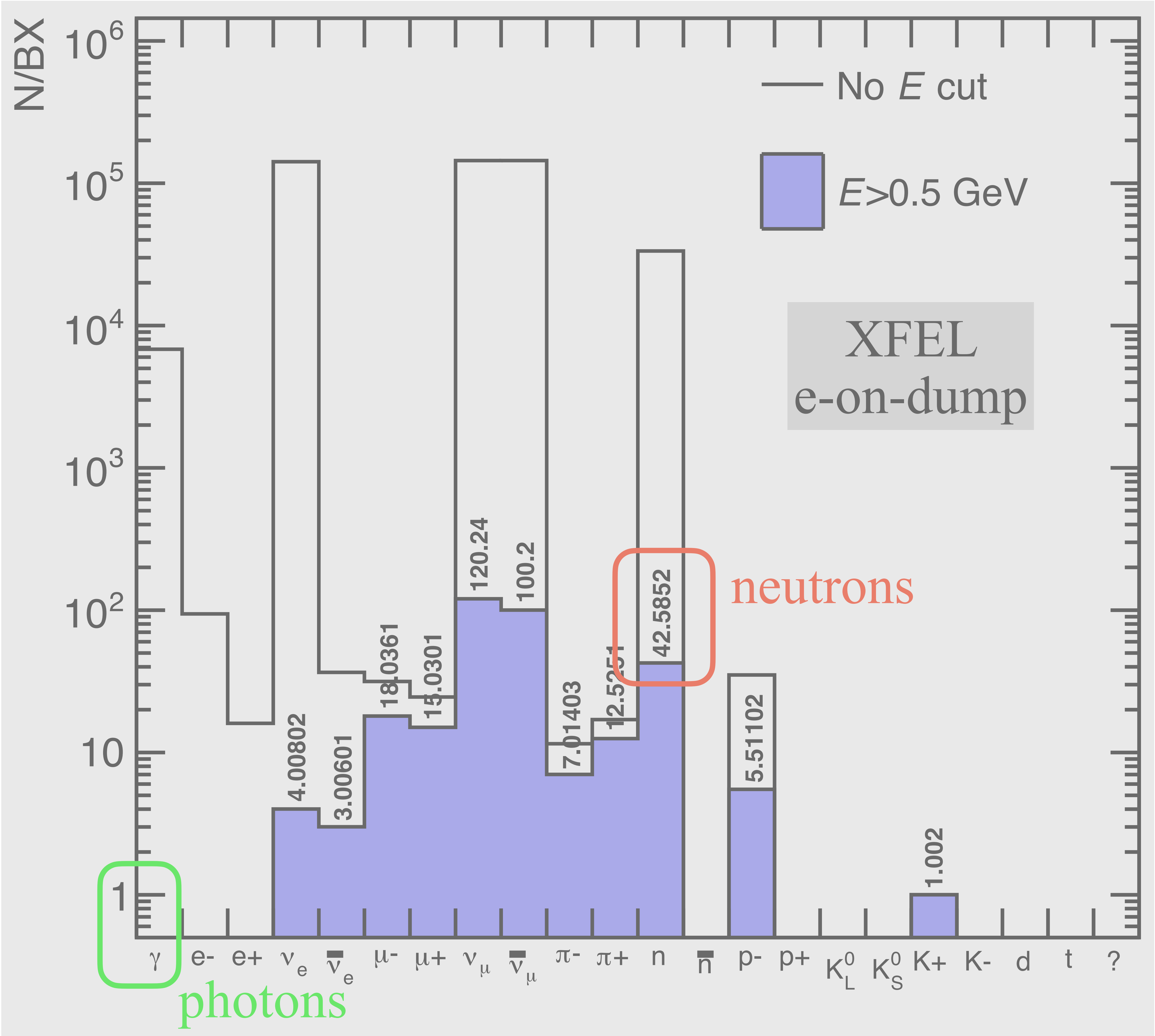
LUXE ALP reach:

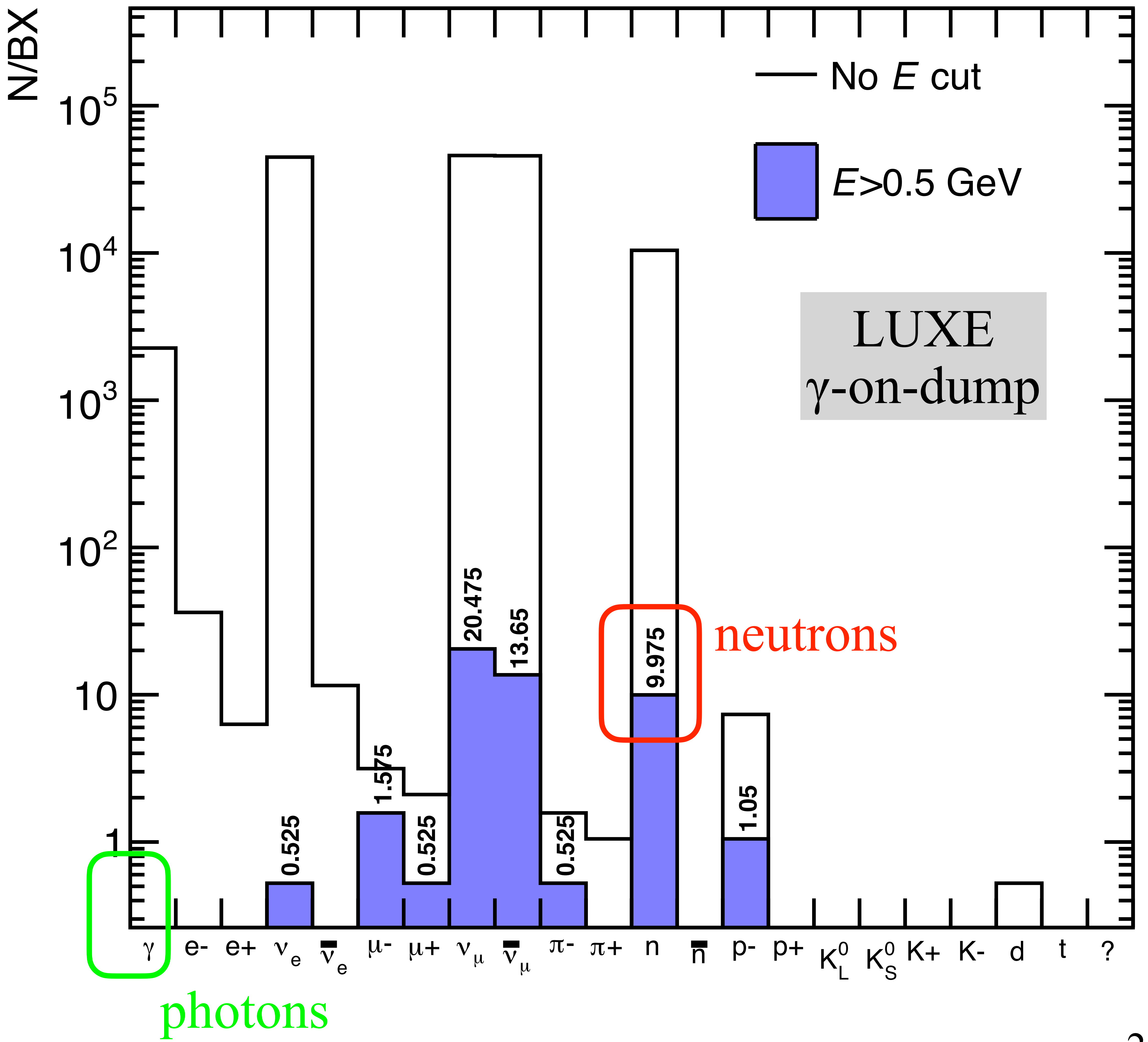
- The line is drawn where LUXE expects at least 3 ALP events.
- Result coming from phase 1 incoming photon distribution.
- Yotam Soreq obtained the result analytically, I got the same result using simulation.



Particles from *e*/*γ*-beam on 1m *W* dump

Each simulation in the following is equivalent to about 2 BXs (i.e. 3e9 primary e's)
Showing the number of particles - only those which arrive at the detector surface





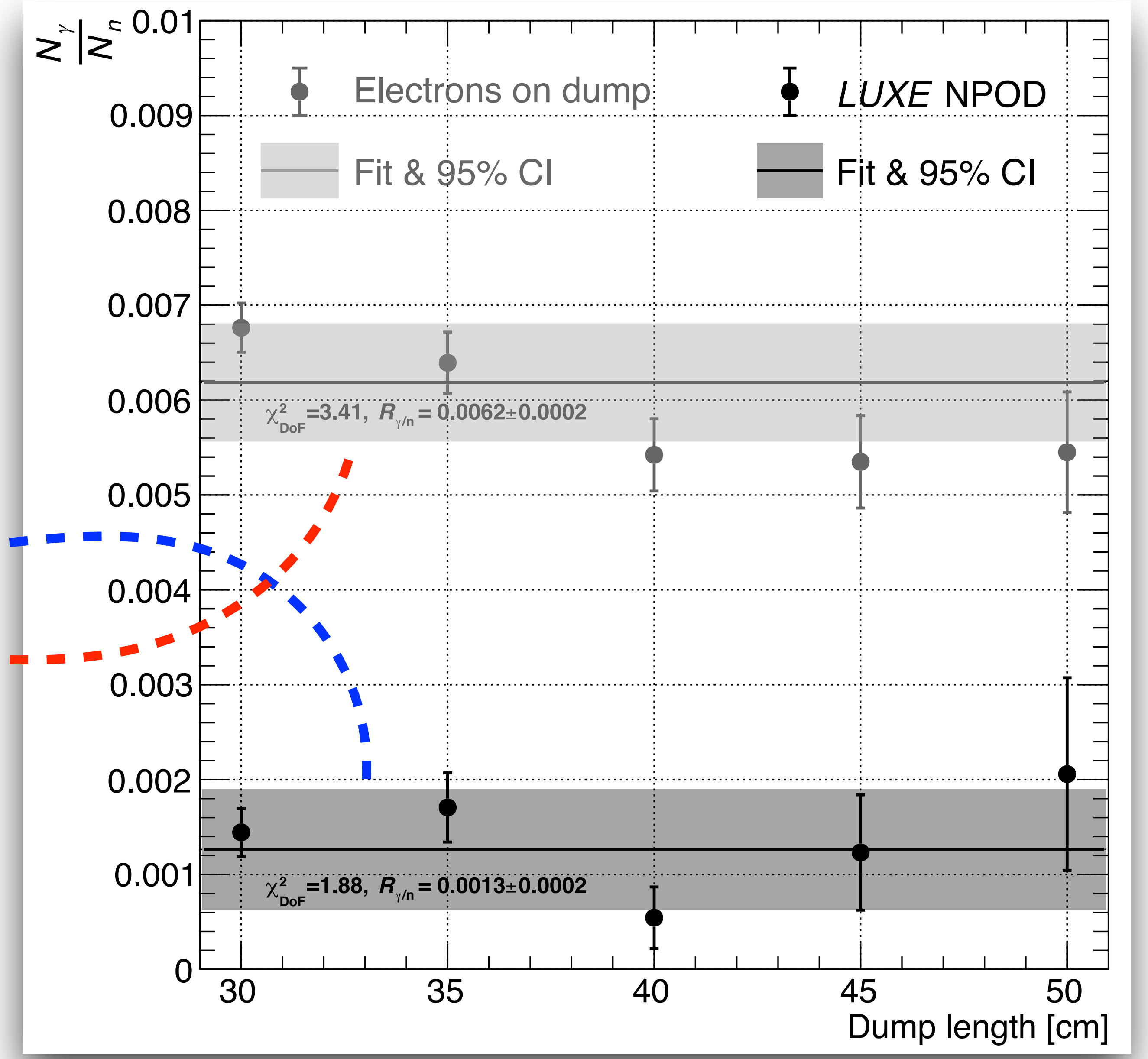
From Noam Tal Hod, WIS

Probability to get 2 real photons

- $$P_{m_\gamma} = \frac{\lambda_\gamma^{m_\gamma} e^{-\lambda_\gamma}}{m_\gamma!}$$

- $\lambda_\gamma = 0.013 \pm 0.004$ since the fit gives $R_{\gamma/n} = 0.0013 \pm 0.0002$ and since $N_n \simeq 10$, with $\lambda_\gamma = N_n R_{\gamma/n}\left(1 \pm \sqrt{\frac{1}{N_n} + \frac{\Delta^2 R_{\gamma/n}}{R_{\gamma/n}}}\right)$

  (or in the e-on-dump case: $\lambda_\gamma \simeq 0.26 \pm 0.04$ for $R_{\gamma/n} \simeq 0.0062 \pm 0.0002$ and $N_n \simeq 42.6$)



- $$P_{2\gamma} = \frac{\lambda_\gamma^2 e^{-\lambda_\gamma}}{2!} \simeq 8.34 \times 10^{-5}$$ (or in the e-on-dump case: 2.7×10^{-2})

Probability to get 2 fake photons

- $P_{n\to\gamma} = f_{n\to\gamma}$
- $\lambda_n = \lambda_n(1\ \mathrm{m}) = 10$ (or in the e-on-dump case: $\lambda_n \simeq 42.6$)
- $P_{2n\to 2\gamma} = \sum_{m_n=2}^{\infty} \frac{\lambda_n^{m_n} e^{-\lambda_n}}{m_n!} C(2, m_n, P_{n\to\gamma})$
- $P_{2n\to 2\gamma} = \sum_{m_n=2}^{\infty} \left(\frac{\lambda_n^{m_n} e^{-\lambda_n}}{m_n!}\right)\left(\frac{m_n!}{2!(m_n-2)!} P_{n\to\gamma}^2 \times (1-P_{n\to\gamma})^{m_n-2}\right) = \sum_{m_n=2}^{\infty} \frac{\lambda_n^{m_n} e^{-\lambda_n} \times P_{n\to\gamma}^2 \times (1-P_{n\to\gamma})^{m_n-2}}{2!(m_n-2)!}$
- $P_{2n\to 2\gamma} = \frac{P_{n\to\gamma}^2 e^{-\lambda_n} \lambda_n^2}{2}\left(1 + \lambda_n(1-P_{n\to\gamma}) + \frac{\lambda_n^2 (1-P_{n\to\gamma})^2}{2!} + \ldots\right) = \frac{P_{n\to\gamma}^2 e^{-\lambda_n} \lambda_n^2}{2}\left(\sum_{k=0}^{\infty} \frac{(\lambda_n(1-P_{n\to\gamma}))^k}{k!}\right) = \frac{P_{n\to\gamma}^2 e^{-\lambda_n} \lambda_n^2}{2} \underbrace{\sum_{k=0}^{\infty} \frac{x^k}{k!}}_{e^x}$
- $P_{2n\to 2\gamma} = \frac{P_{n\to\gamma}^2 \lambda_n^2 e^{-\lambda_n} e^{\lambda_n(1-P_{n\to\gamma})}}{2} = P_{n\to\gamma}^2 e^{-\lambda_n P_{n\to\gamma}} \frac{\lambda_n^2}{2} = 50 f_{n\to\gamma}^2 e^{-10 f_{n\to\gamma}}$ (or in the e-on-dump case: $\frac{42.6^2}{2} f_{n\to\gamma}^2 e^{-42.6 f_{n\to\gamma}}$)

From Noam Tal Hod, WIS

Probability to get 1 real + 1 fake photons

- For photons: $\lambda_\gamma = 0.013 \pm 0.004,\ P_{m_\gamma} = \dfrac{\lambda_\gamma^{m_\gamma} e^{-\lambda_\gamma}}{m_\gamma!} \Rightarrow P_{1\gamma} = \lambda_\gamma e^{-\lambda_\gamma}$

- For neutrons: $P_{n\to\gamma} = f_{n\to\gamma},\quad \lambda_n = 10 \pm 2.3,\quad P_{1n\to 1\gamma} = \displaystyle\sum_{m_n=1}^{\infty} \frac{\lambda_n^{m_n} e^{-\lambda_n}}{m_n!} C(1, m_n, P_{n\to\gamma})$

$$P_{1n\to 1\gamma} = \sum_{m_n=1}^{\infty} \left(\frac{\lambda_n^{m_n} e^{-\lambda_n}}{m_n!}\right)\left(\frac{m_n!}{1!(m_n-1)!} P_{n\to\gamma} \times (1-P_{n\to\gamma})^{m_n-1}\right) = \sum_{m_n=1}^{\infty} \frac{\lambda_n^{m_n} e^{-\lambda_n} \times P_{n\to\gamma} \times (1-P_{n\to\gamma})^{m_n-1}}{(m_n-1)!}$$

$$P_{1n\to 1\gamma} = P_{n\to\gamma} e^{-\lambda_n} \lambda_n \left(1 + \lambda_n(1-P_{n\to\gamma}) + \frac{\lambda_n^2 (1-P_{n\to\gamma})^2}{2!} + \ldots\right) = P_{n\to\gamma} e^{-\lambda_n} \lambda_n \left(\sum_{k=0}^{\infty} \frac{(\lambda_n(1-P_{n\to\gamma}))^k}{k!}\right) = P_{n\to\gamma} e^{-\lambda_n} \lambda_n \underbrace{\sum_{k=0}^{\infty} \frac{x^k}{k!}}_{e^x}$$

$$P_{1n\to 1\gamma} = P_{n\to\gamma} \lambda_n e^{-\lambda_n} e^{\lambda_n(1-P_{n\to\gamma})} = P_{n\to\gamma} e^{-\lambda_n P_{n\to\gamma}} \lambda_n$$

- For one neutron and one photon: $P_{n+\gamma\to 2\gamma} = P_{1n\to 1\gamma} \cdot P_{1\gamma} = \left(\lambda_n f_{n\to\gamma} e^{-\lambda_n f_{n\to\gamma}}\right) \cdot \left(\lambda_\gamma e^{-\lambda_\gamma}\right) \simeq 0.128 f_{n\to\gamma} e^{-10 f_{n\to\gamma}}$
  (or in the e-on-dump case: $1.12 f_{n\to\gamma} e^{-42.6 f_{n\to\gamma}}$)

Background estimation

- Assuming
  - one year of running with $T \sim 10^7$ live seconds, i.e. recorded BXs
  - rejection is $R_{\rm sel} \lesssim 10^{-3} - 10^{-4}$ from kinematics & timing
  - neutron-to-photon fake rate is $f_{n\to\gamma} \lesssim 10^{-3} - 10^{-4}$

- Number of bkg two-photon events is $\boldsymbol{N_{\rm bkg} = P_{\rm bkg} R_{\rm sel} T_{\rm operation}}$
  - $\text{bkg} = 2\gamma$
  - $\text{bkg} = 2n \to 2\gamma$ (sub-dominant)
  - $\text{bkg} = \gamma + n \to 2\gamma$

- The probabilities are given by Poisson and Binomial laws:

$$P_{N_\gamma} = \frac{\mu_\gamma^{N_\gamma} e^{-\mu_\gamma}}{N_\gamma!}$$

$$P_{N_n \to N_\gamma} = \sum_{k_n = N_n}^{\infty} \frac{\mu_n^{k_n} e^{-\mu_n}}{k_n!} \mathrm{B}(N_n, k_n, f_{n\to\gamma})$$

$$P_{n+\gamma\to 2\gamma} = P_{1n\to 1\gamma} \cdot P_{2\gamma}$$

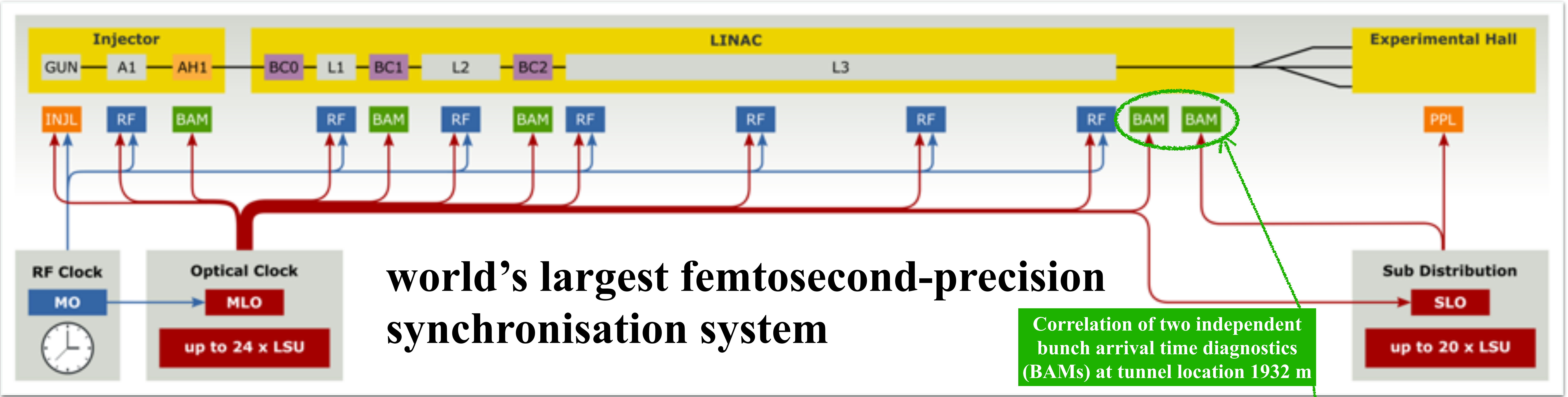
Assumptions	Value
$T_{\rm op}$	1E+07
$R_{\rm sel}$	5E-04
$f_{n\to\gamma}$	5E-04

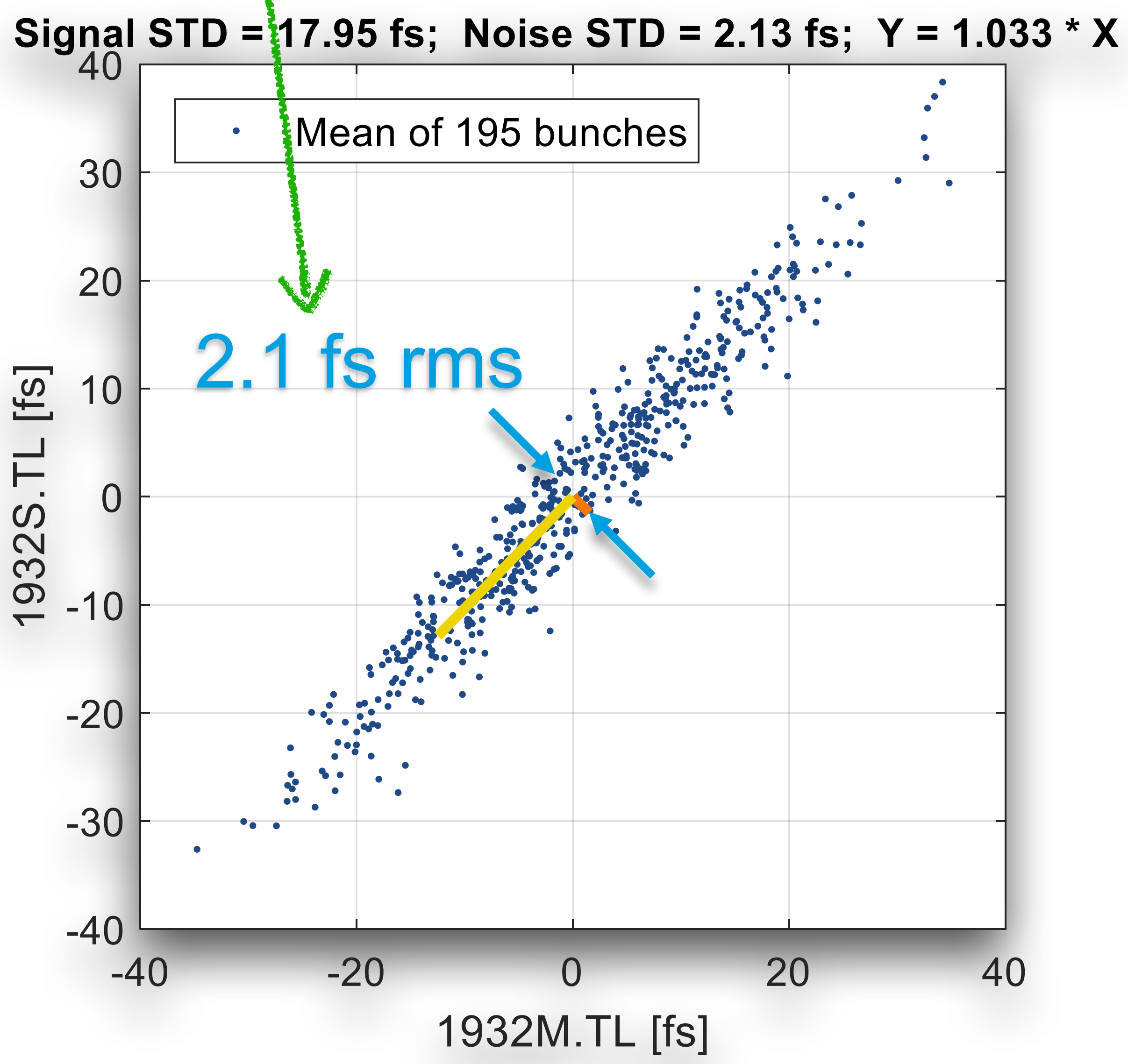
Parameter	LUXE NPOD	Electrons on dump
$R_{\gamma/n}$ (fit)	0.0013	0.0062
μ_n (count)	9.8	42.6
μ_γ (extrap.)	0.013	0.264

Max $N_{\rm bkg}$	LUXE NPOD	Electrons on dump
$N_{2\gamma}$	0.4	133.9
$N_{2n\to 2\gamma}$	0.1	1.1
$N_{\gamma+n\to 2\gamma}$	0.3	21.1

$N_{\rm bkg}^{\rm tot} < 1$

Synchronisation & Trigger





Synchronisation of the XFEL:

- Optical clock (master laser oscillator, MLO) provides stable pulsed optical reference (Phase-locked to radio frequency (RF) oscillator (MO))
- Optical reference distributed via length-stabilised optical fibre links for laser locking and RF re-sync

LUXE's laser oscillator:

- connected to the optical sync system, which will in turn trigger the detectors

From Noam Tal Hod, WIS