Approaching the Schwinger Critical Field with the LUXE experiment.

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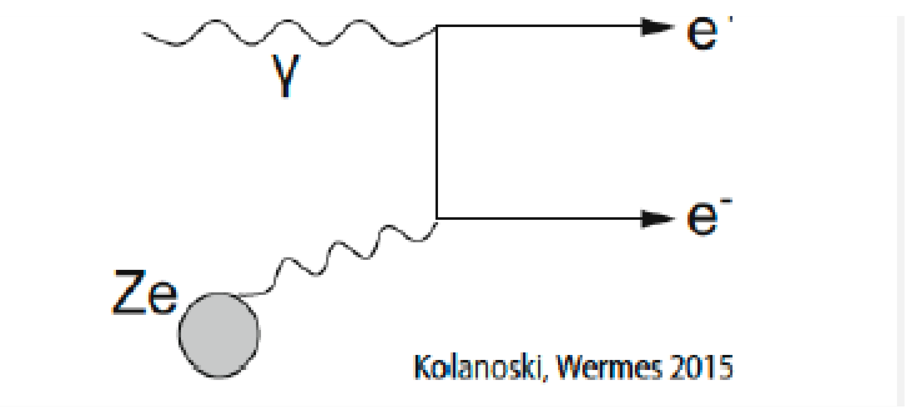
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

LUXE

DESY.

Introduction and Motivation

Hawking radiation and the Schwinger limit

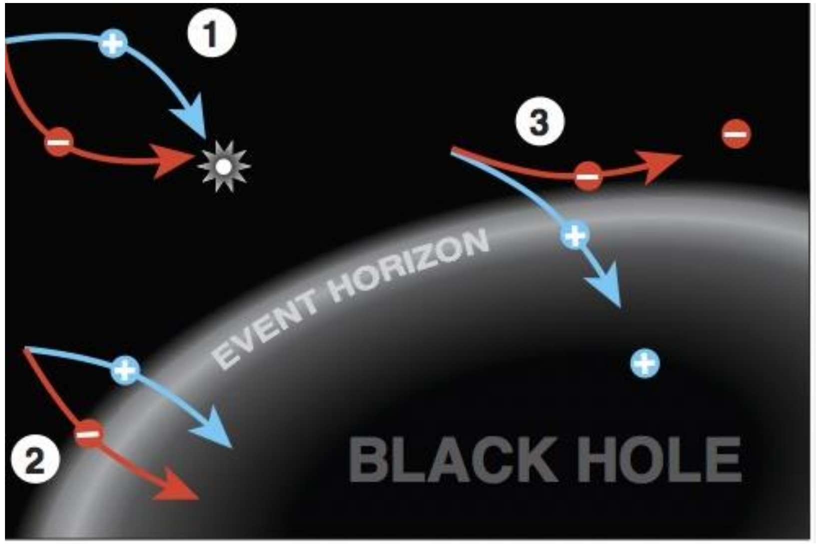


Pair Production by a single photon decay

- Impossible in vacuum -> violation of energy/momentum conservation
- Needs an external field, for example the presence of atomic nuclei

From quantum fluctuations into real pairs

- If an external field in vacuum is strong enough, it should be able to separate virtual e^+e^- pairs from quantum fluctuations
- Famously: Hawking Radiation possible if: $\frac{\hbar c^3}{4G_N M} > 2mc^2$



- Substitute gravitational field with an electric field: $\frac{\hbar e\varepsilon}{mc} > 2mc^2 \Longrightarrow \varepsilon > \frac{2m^2c^3}{\hbar e} = 2\varepsilon_{Schwinger} = 2 \text{ x } (1.3 \text{ x } 10^{18})$ V/m

Introduction and Motivation

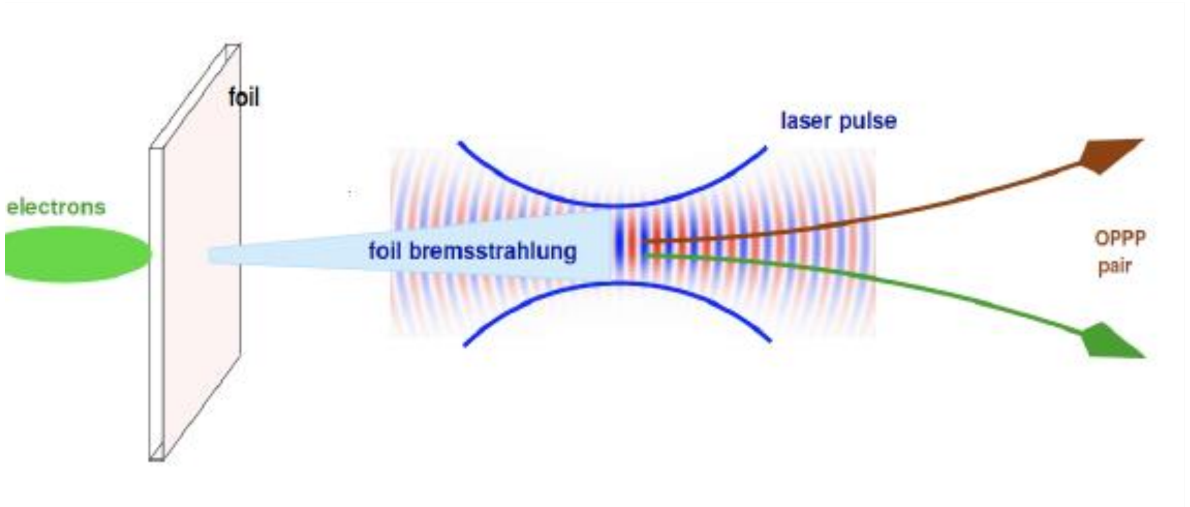
Measuring the Schwinger critical field

$$\varepsilon_{Schwinger} = 1.3 \; x \; 10^{18} \text{ V/m}$$

J. Schwinger
On Gauge Invariance and Vacuum Polarization
Phys. Rev. 82 (1951) 664

Reasons to be interested

- Astrophysics: Hawking Radiation, Neutrons stars, early universe
- Condensed matter (dielectric breakdown)
- Effects in high energy e^+e^- colliders
- Last but not least: Be the first to test Schwingers prediction for the critical field value



How to reach such field strength

- $1.3 \; x \; 10^{18}$ V/m not reachable with current technology
- Solution: Produce high energy photons, which enhances the field strength by γ
  (High Energy Electron Beam needed)

⇨

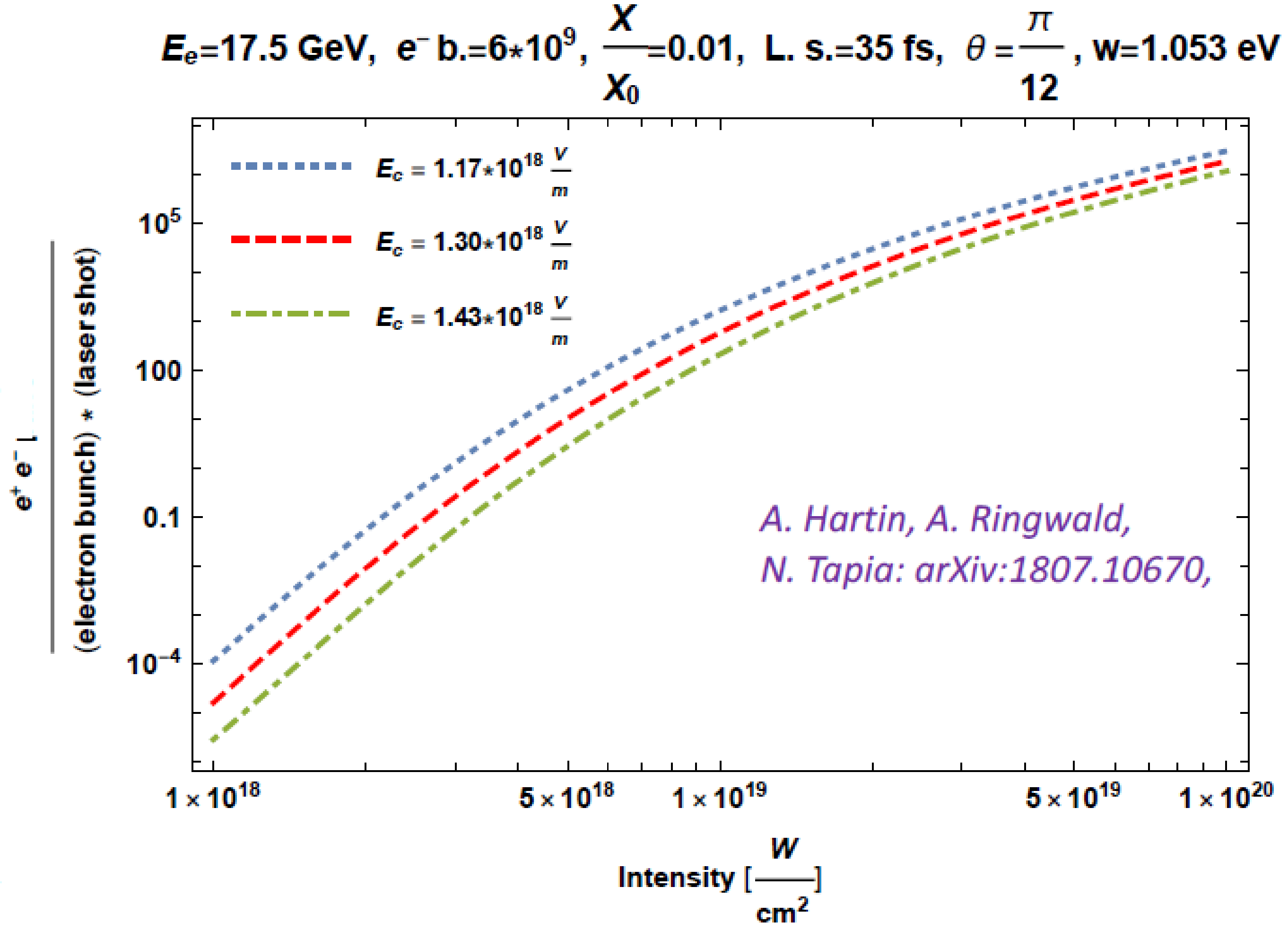
Non-relativistic photons: I_L=2x10^{29}W/cm2

European XFEL: E_γ = O(10 GeV); $I_L \geq 10^{20}$ W/cm2

Measuring the critical field…

…by counting positrons

The total number of pairs produced depends on the critical field strength: (plot for EU.XFEL parameters)



$\xi \ll 1$: $R_{e^+} \propto \xi^{2n} \propto I^n$ — Strong rise

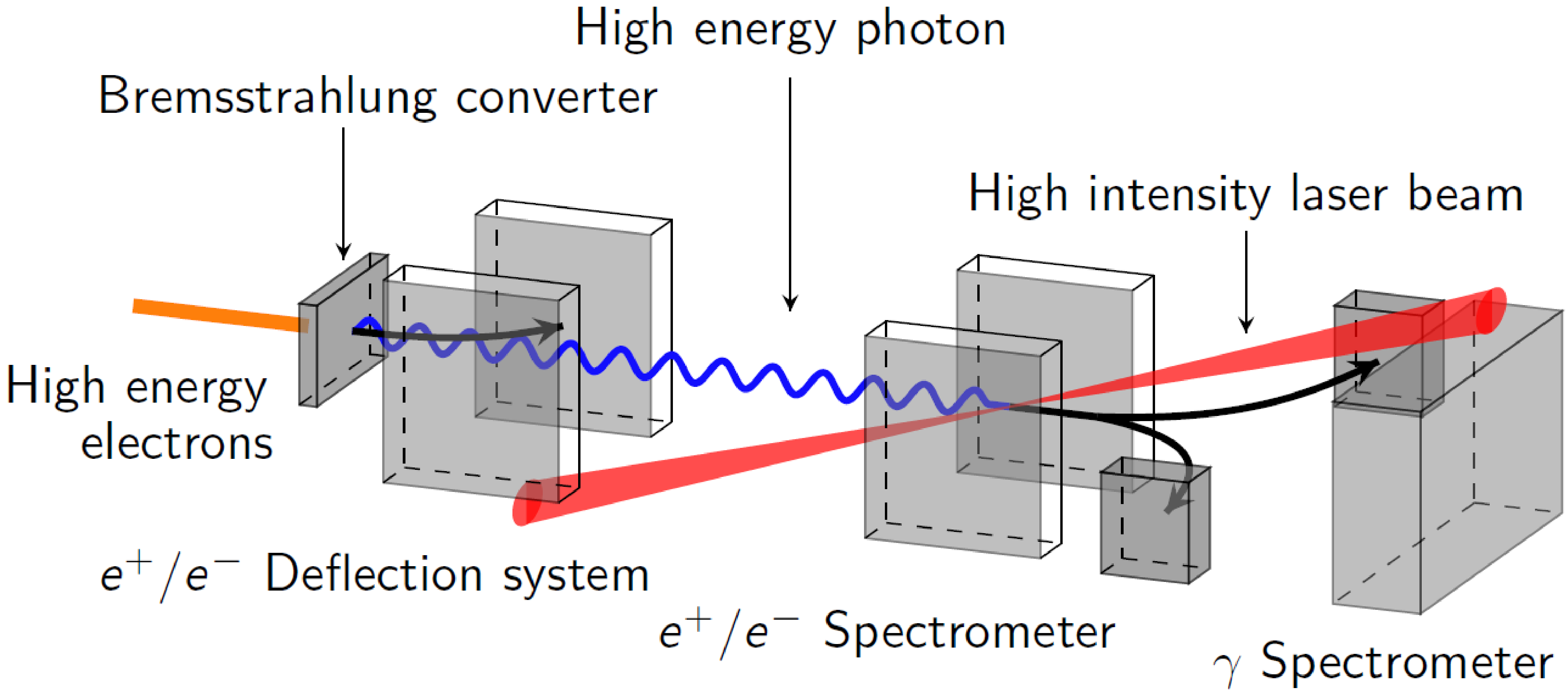
$\xi \gg 1$: $R_{e^+} \propto \exp\left(-\frac{8}{3\chi}\right)$ — Non-perturbative regime

Laser parameters: $\xi = \frac{eE_L}{m_e \omega_L c}$ $\quad \chi \approx \gamma \frac{\varepsilon}{\varepsilon_S} \propto \gamma\sqrt{E_L}$

Depending on Schwinger-critical field

Introducing LUXE

“Laser Und European XFEL Experiment”

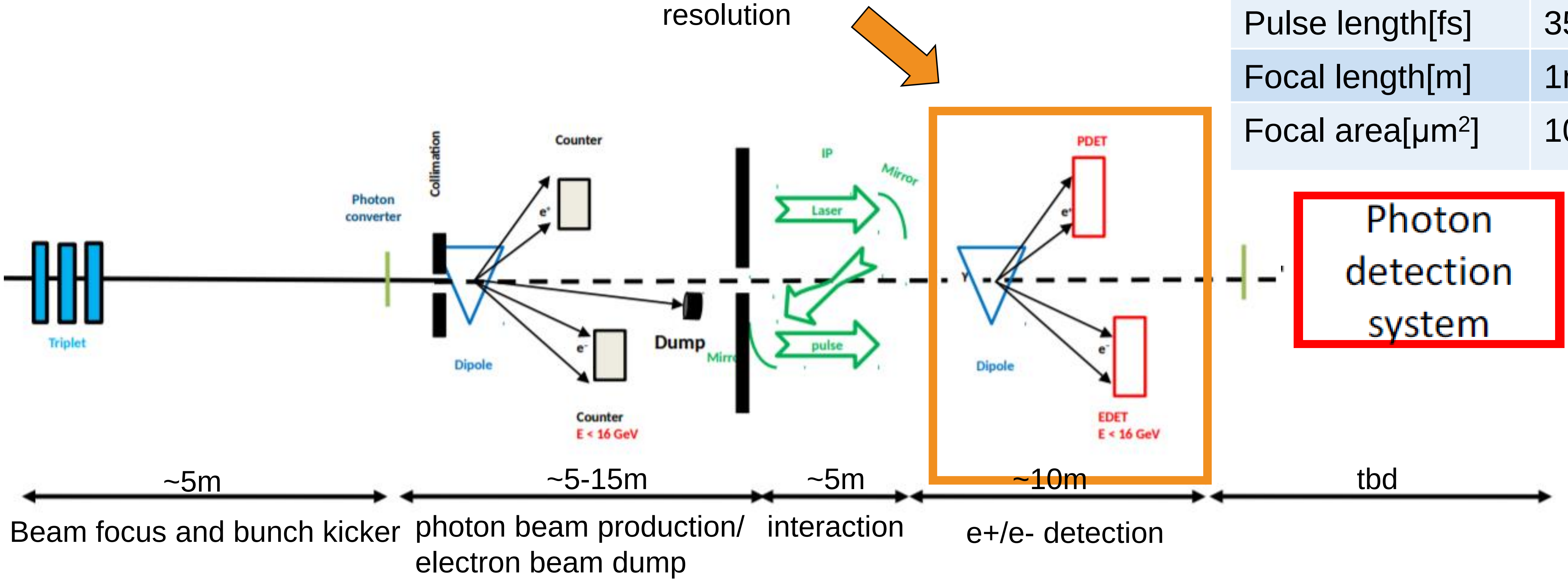


LUXE Setup and Parameters

Design of the experiment

Lots of parameters to optimise:
Magnets,
Distances,
Detector size,
type,
resolution

Design Laser Parameters	
Energy[J]	7.0
Power[TW]	200
Intensity[W/cm^2]	2×10^{20}
ξ	6,8
χ	1,4
Pulse length[fs]	35
Focal length[m]	1m
Focal area[μm^2]	100



Fast Simulation of the Detector

Using idealised magnets and detectors for design studies

Assumptions:

- No detector losses (e+/e- only)
- Homogenious magnetic field

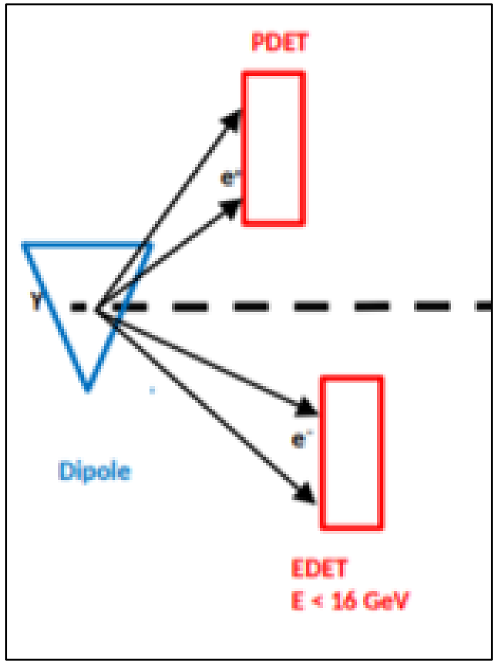
Goal of Optimisation:

- Close to no losses of e^+ and e^-

from detector layout

- space for laser system
- reasonable detector size

Input:
1k Monte-Carlo generated Laser-Photon Interactions for different Laser Parameters (MC Gen. not yet published)



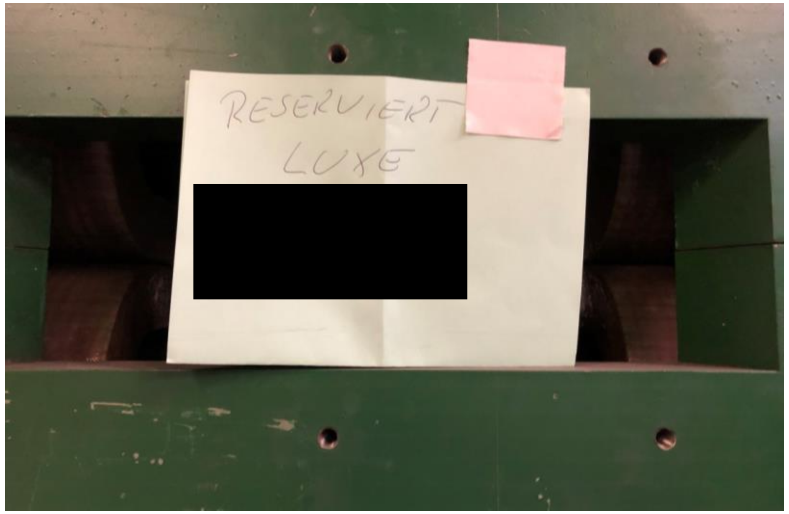
Magnet?

Benefits of doing the experiments at DESY

Taking a look into the storage space

And we find:

A fitting Magnet from old DORIS accelerator



Fast Simulation of the Detector

Using idealised magnets and detectors for design studies

Assumptions:

- No detector losses (e+/e- only)
- Homogenious magnetic field

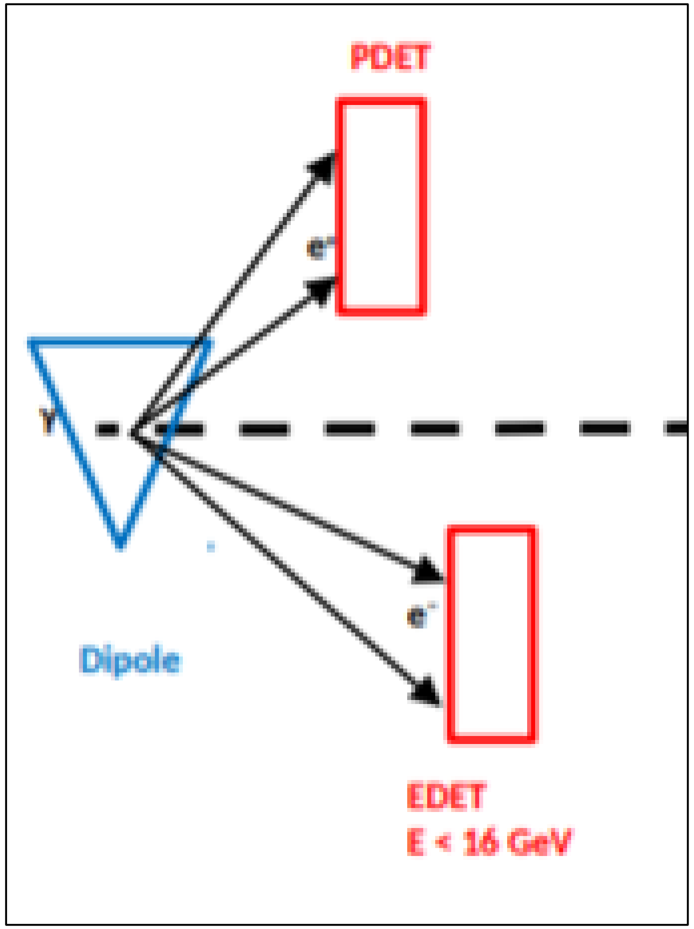
Goal of Optimisation:

- Close to no losses of e^+ and e^-

from detector layout

- space for the laser system
- small detector size

Input:
1k Monte-Carlo generated Laser-Photon Interactions for different Laser Parameters (MC Gen. not yet published)



Magnet

- Aperture
  - Horizontal: 0.6m
  - Vertical 0.3m
- Field strength up to 2.24 T
- 1m long

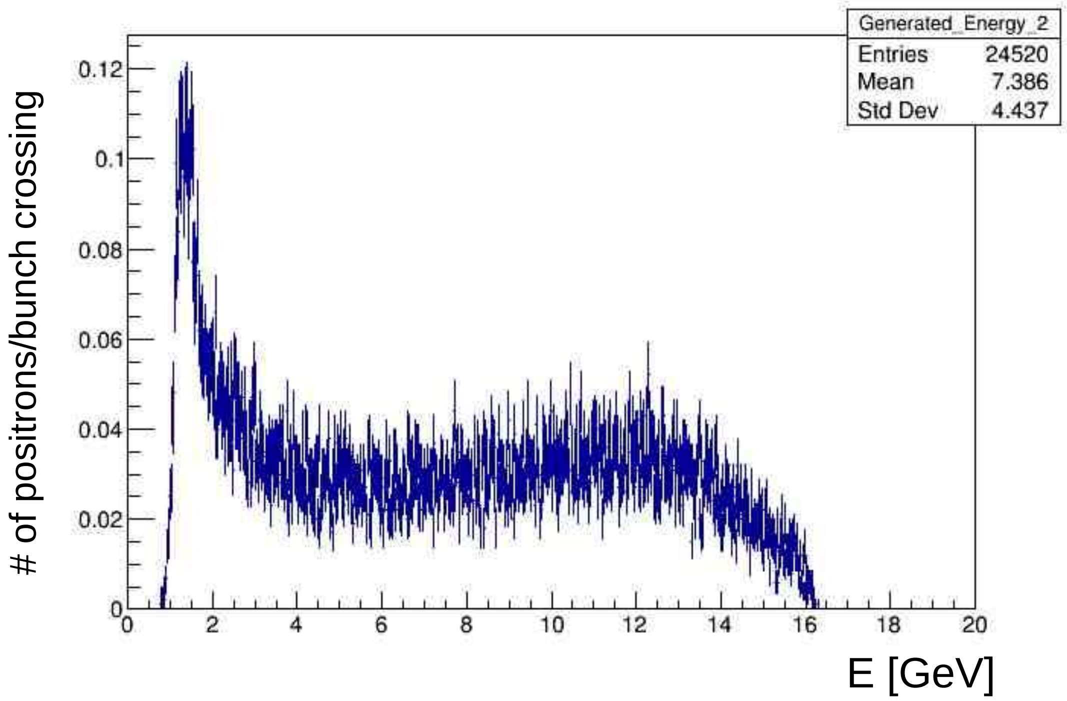
Detector

- Size
  - Max. 1m horizontal
  - Arbitrary vertically
- Min. Pixel size: 50 µm
- Min. distance from Magnet: 1m

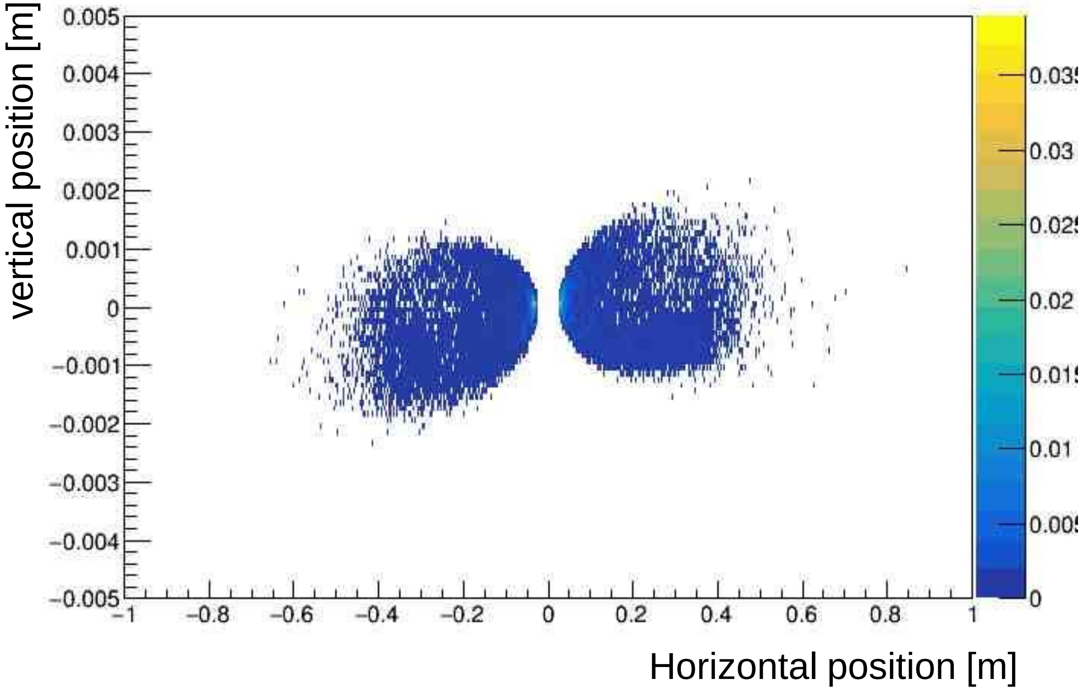
Fast Simulation

Particles in the Detector

$e^{+/-}$ with 1 < E < 16 GeV are detected
Very low average particle rates of <0.035/pixel per bunch crossing



Energy distribution of the positrons in the detector per bunch crossing

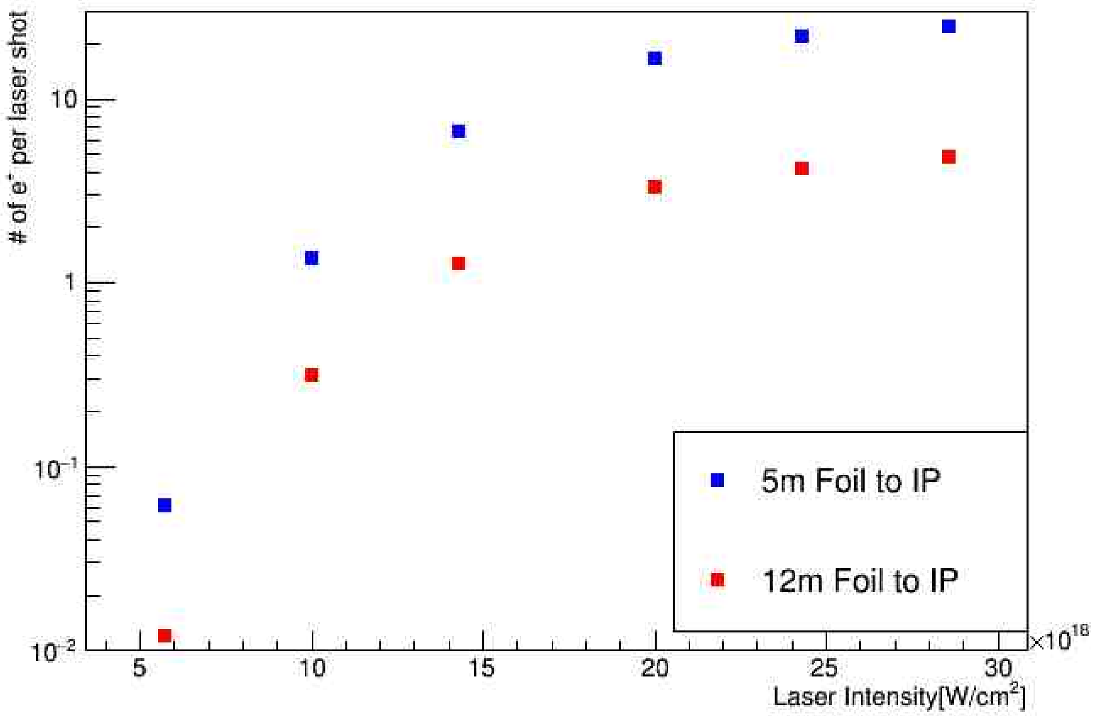


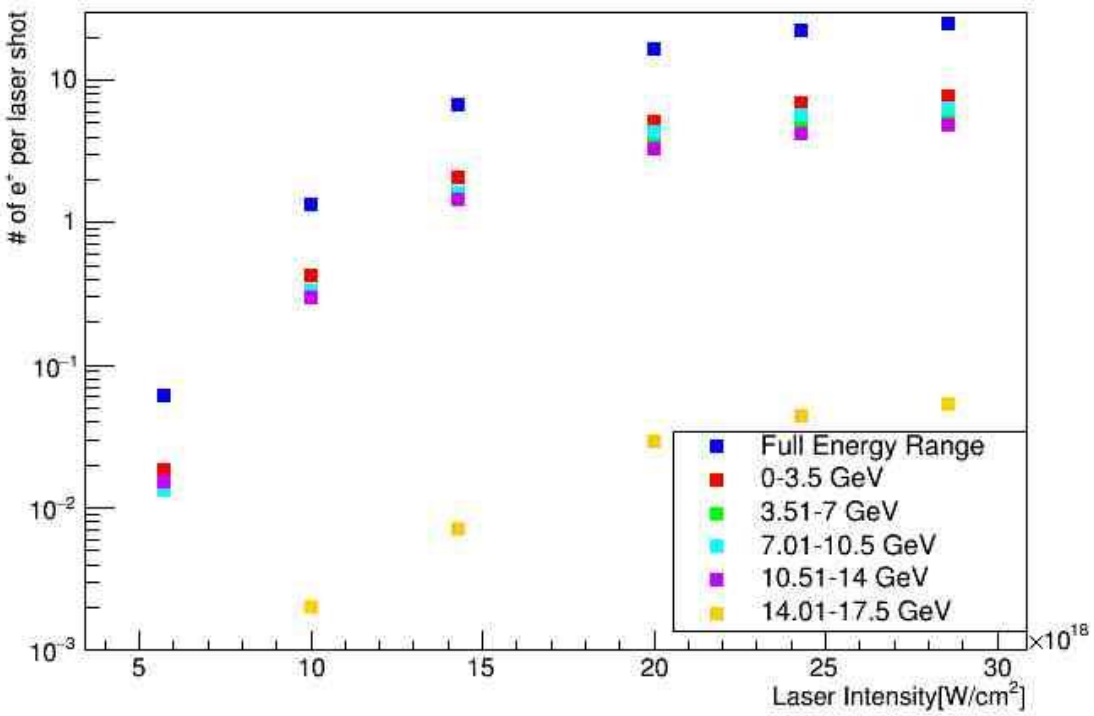
Parameters

- Magnetic Field 1.4T
- 5 m Distance from Laser Interaction
- 1m Distance Magnet – Detector
- Average over 1000 Laser-Photon bunch crossings
- $I_{Laser} = 2.8 \times 10^{18}$ W/cm^2

Fast Simulation 2

Non-perturbative effect in the Detector





Both assuming 10^9 bunches and 17.5 GeV

Outlook

How we want to continue

1. Finalize fast simulation optimization

- Derive final design for the photon Laser interaction scenario
- Test some prospects of vertexing in Laser diagnostics

2. Fast Sim Design studies for direct electron-photon interaction

3. Implement final design Full-Sim in GEANT4

4. DESY Test beam runs for validation of Photon production models

5. Start building the experiments in 2020/2021

Thank you for your Attention

LUXE

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Backup