The LUXE experiment

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FLC Group Meeting
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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

LUXE

Introduction and Motivation

Probing the Schwinger limit

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

QED becomes non-perturbative if field strength of an electric field exceeds Schwinger limit:

$$\varepsilon_{Schwinger} = \frac{{m_e}^2 c^3}{\hbar e} = 1.3 \times 10^{18}\ \text{V/m}$$

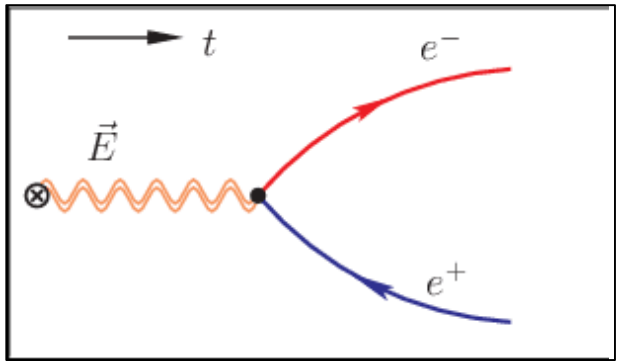
Pair production in vacuum possible if

$$\boldsymbol{\varepsilon > 2 \times \varepsilon_{Schwinger}}$$

not measured in experiment

pair production by a single photon decay

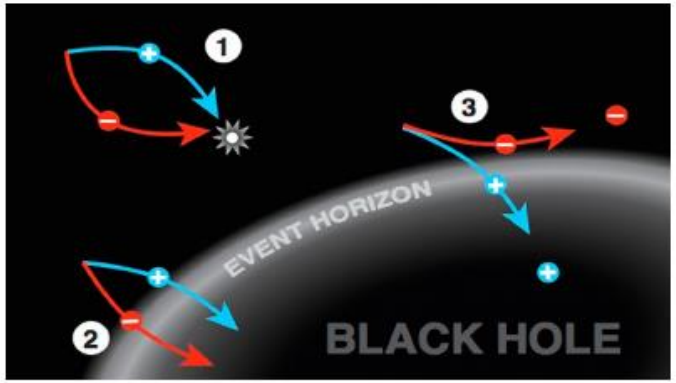
- Impossible in vacuum → violation of energy/momentum conservation
- possible in presence of a strong field



not measured in controlled environment

Introduction and Motivation

Why is this Interesting?



hawking radiation

Energy needed to create on-shell e^+e^- pair: $\Delta E = 2mc^2$

Grav. Field near the event horizon: $F = \frac{G_N M m}{r_s^2}$

Schwarzschild radius $r_s = \frac{2G_N M}{c^2}$**. =>** $F = \frac{mc^4}{4G_N M}$

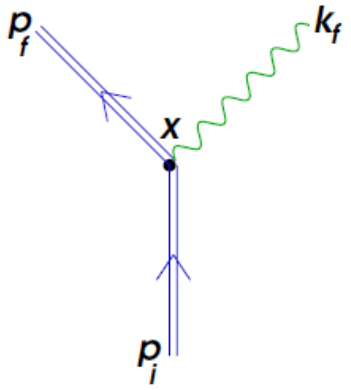
Energy to separate pair: $E = F d_{min} = \frac{mc^4}{4G_N M} \times \frac{\hbar}{mc} = \frac{\hbar c^3}{4G_N M}$

Hawking radiation possible if virtual pair becomes real, i.e. $\frac{\hbar c^3}{4G_N M} > 2mc^2$

Other physics areas where strong fields are of interest

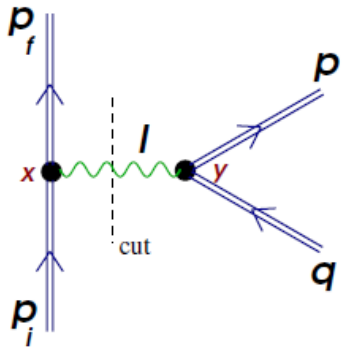
- neutron stars
- Condensed matter physics (dielectric breakdown)
- future e^+e^- colliders

Physics processes at LUXE

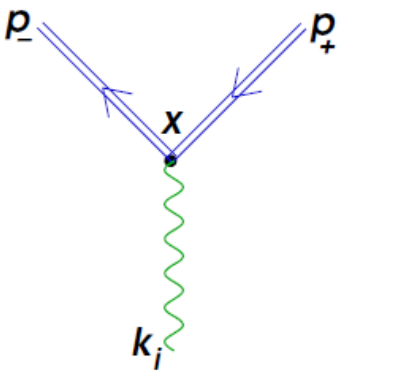


High intensity Compton scatttering (HICS)

Electron-Beam + Laser-field

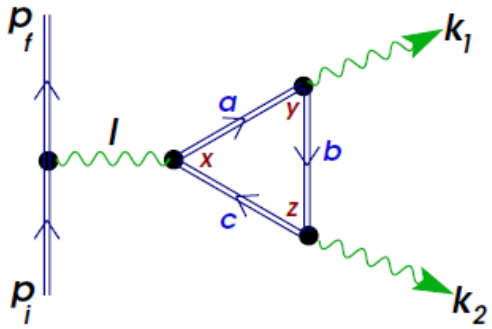


Trident process (one step and two step)



One photon pair production (OPPP)

Photon-Beam + field



Photon splitting (vacuum birefringence)

By A. Hartin, LUXE Workshop Talk

Introduction and Motivation

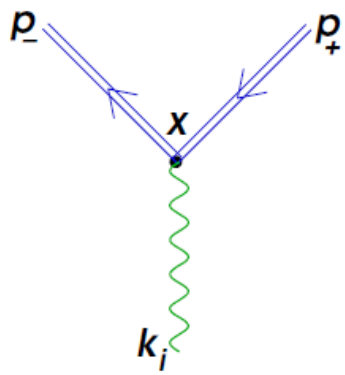
Probing the Schwinger limit with a high energy photon beam

- 1.3×10^{18} V/m not reachable with current technology (lightning in air: 3×10^{6} V/m)
- to probe the schwinger limit:
  - high intensity laser field
  - high energy photon (or electron) beam

Non-relativistic photons: $I_L = 2 \times 10^{29}$ W/cm^2

European XFEL: E_γ = O(10 GeV); $I_L \geq 10^{20}$ W/cm^2

First experiment to reach the critical field



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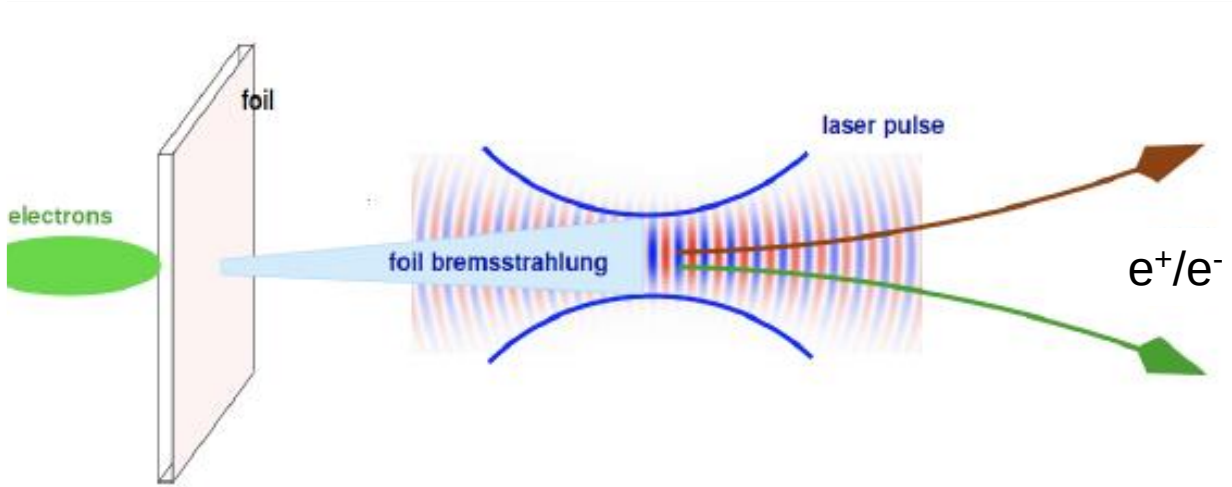
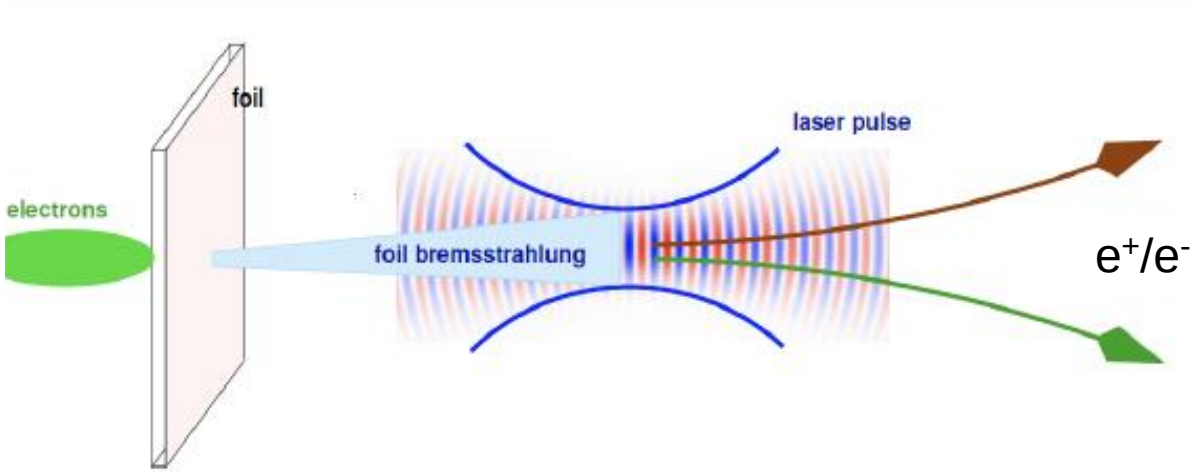


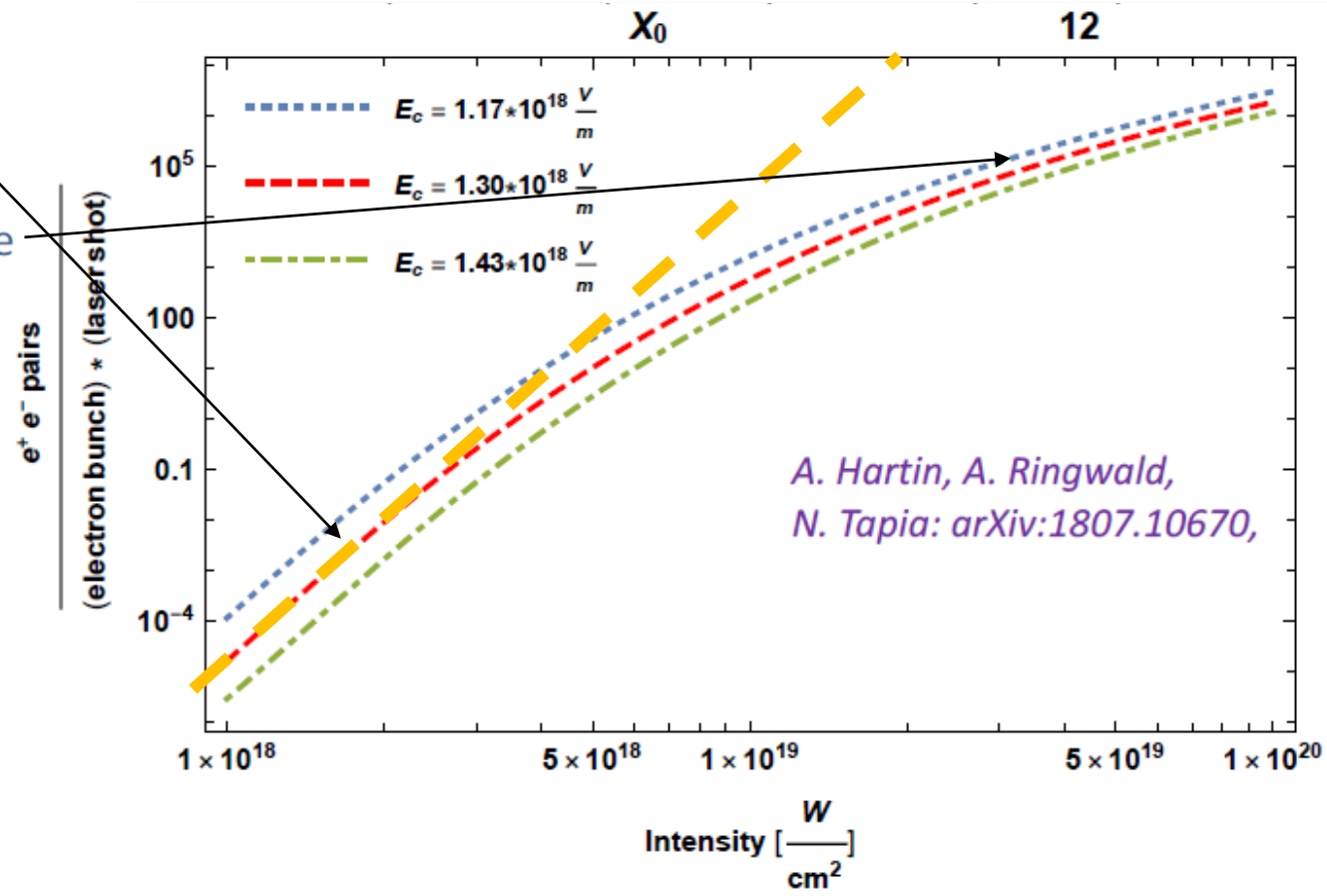
Introduction and Motivation

OPPP in principle allows the measurement of the schwinger critical field value



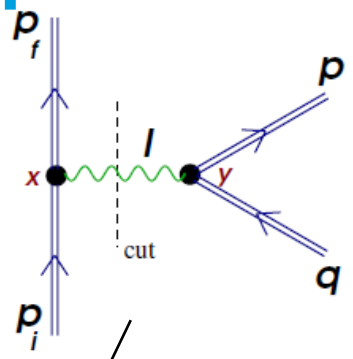
$\xi \ll 1: \; R_{e^+} \propto \xi^{2n} \propto I^n$ ☚ Strong rise

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



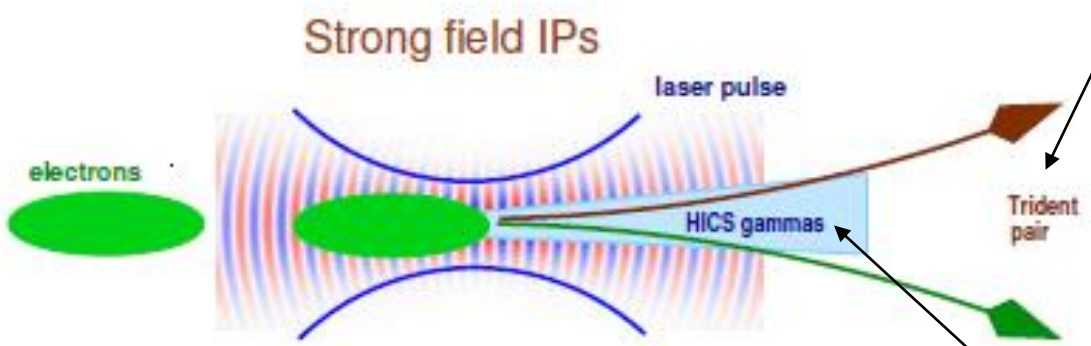
Introduction and Motivation

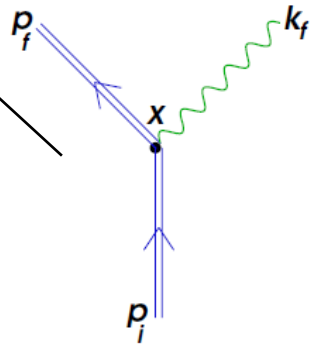
Electron beam laser Interaction



O(10) pairs per Interaction

Trident process (one step and two step)





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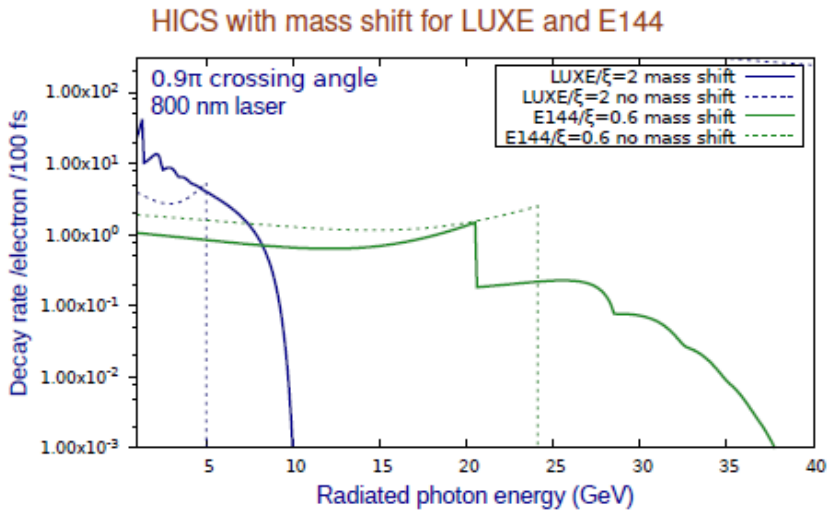


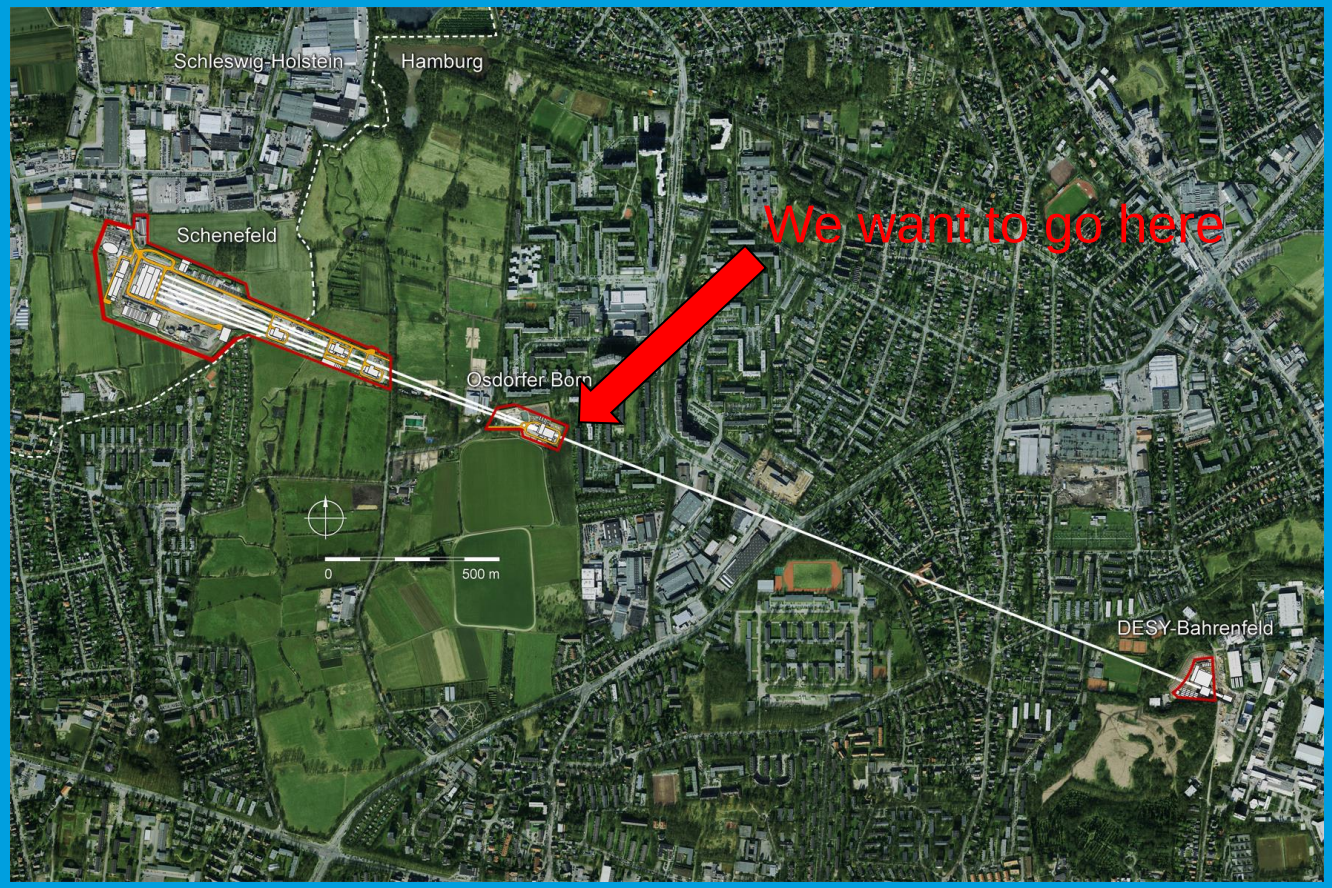
By A. Hartin

LUXE

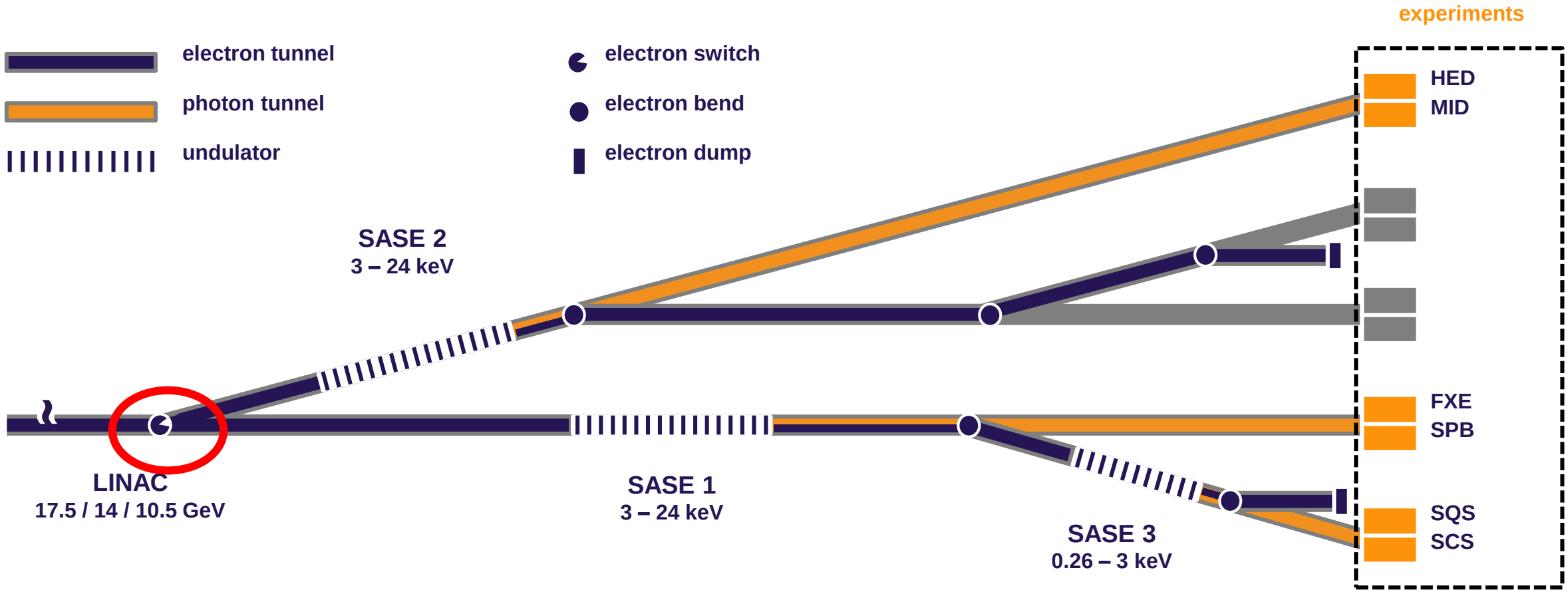
“Laser Und European XFEL Experiment“

European XFEL facts:

- 3.4 km long facility
- 17.5 GeV
- highest energy electron accelerator in operation worldwide



XTD-20, at the end of the linac



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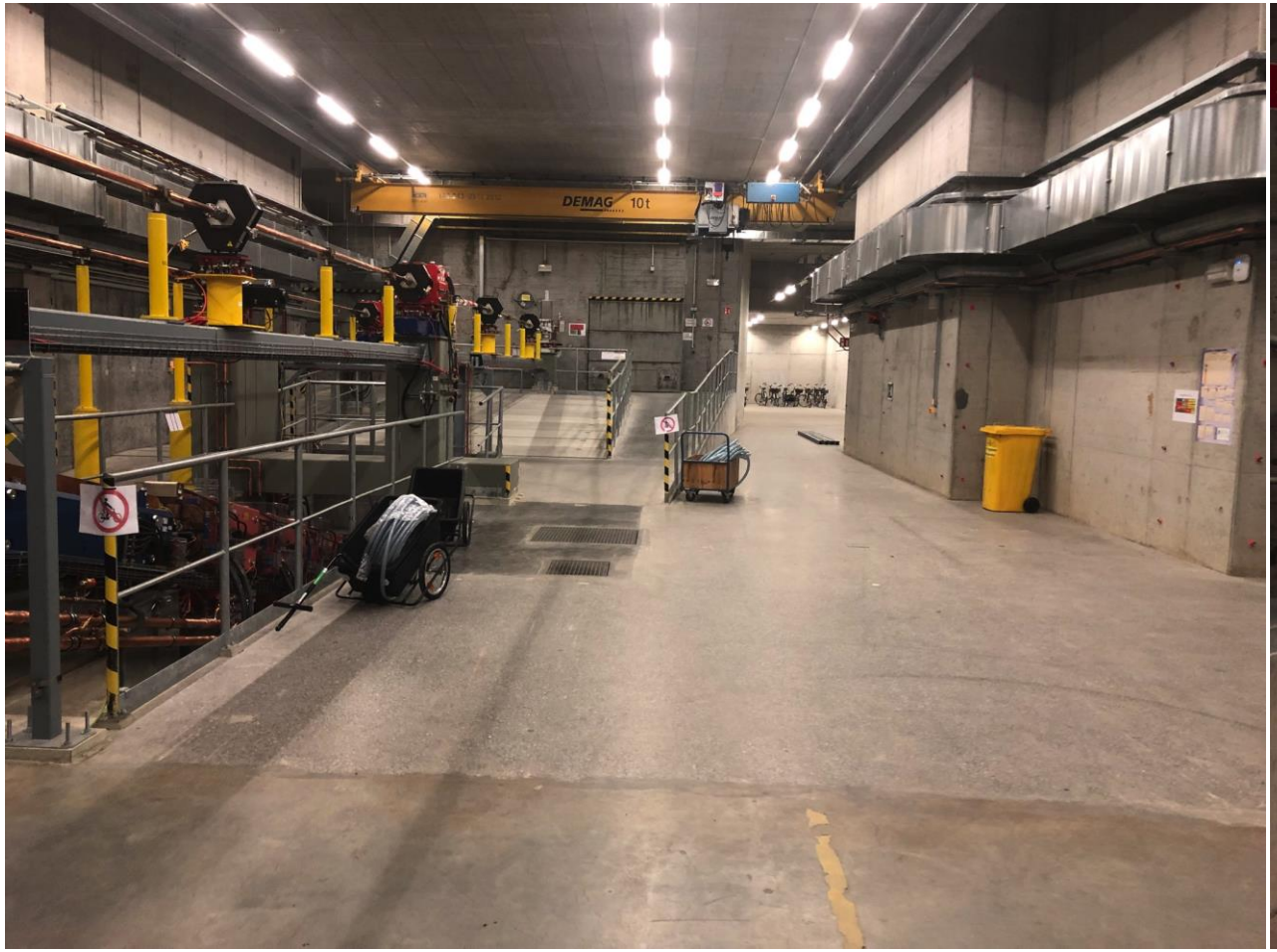
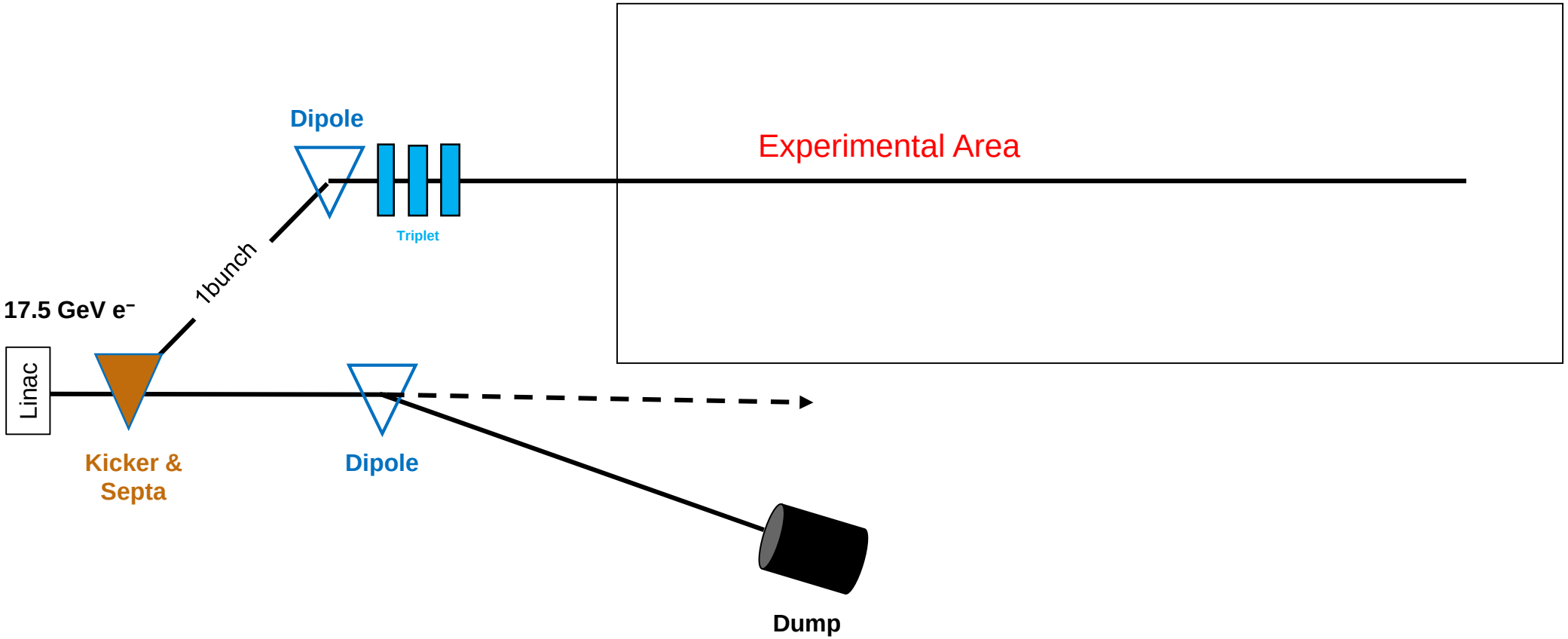


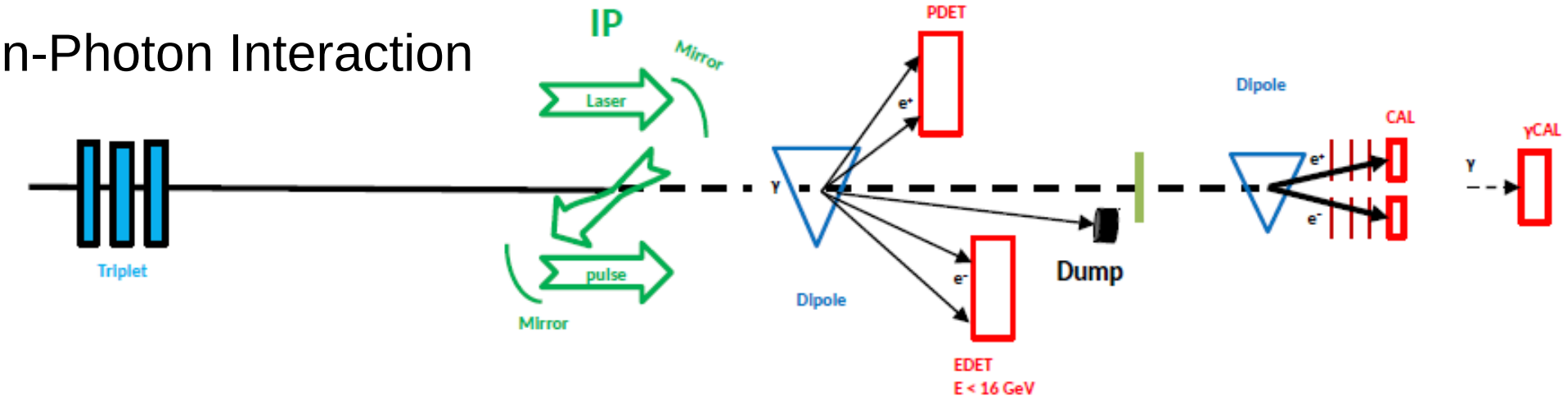
General Layout



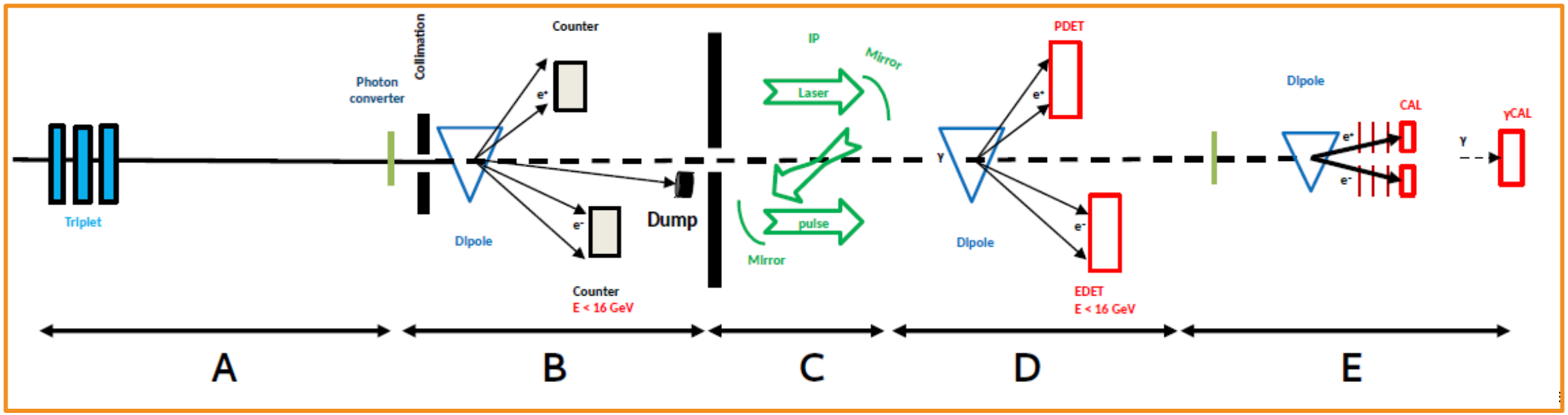
Kick out **one** bunch and send it to the experimental area.

LUXE – Experimental Layout

Electron-Photon Interaction



Photon-Photon Interaction



The LUXE - Team

At FLC and beyond

FLC: Jenny List, Oleksandr (Sasha) Borysov, Marina Borysova, Marius Hoffmann
M: Florian Burkart, Winfried Decking, Evgeny Negodin
Theory: Andreas Ringwald

ATLAS: Beate Heinemann

Noam Hoad

Matthew Wing, Anthony Hartin

Halina Abramowicz, Aharon Levy

Andreas Maier

Massimo Altarelli

Nina Elkina, Christian Rödel, Harsh Harsh,
Felipe Salgado, Thomas Teter, Matt Zepf

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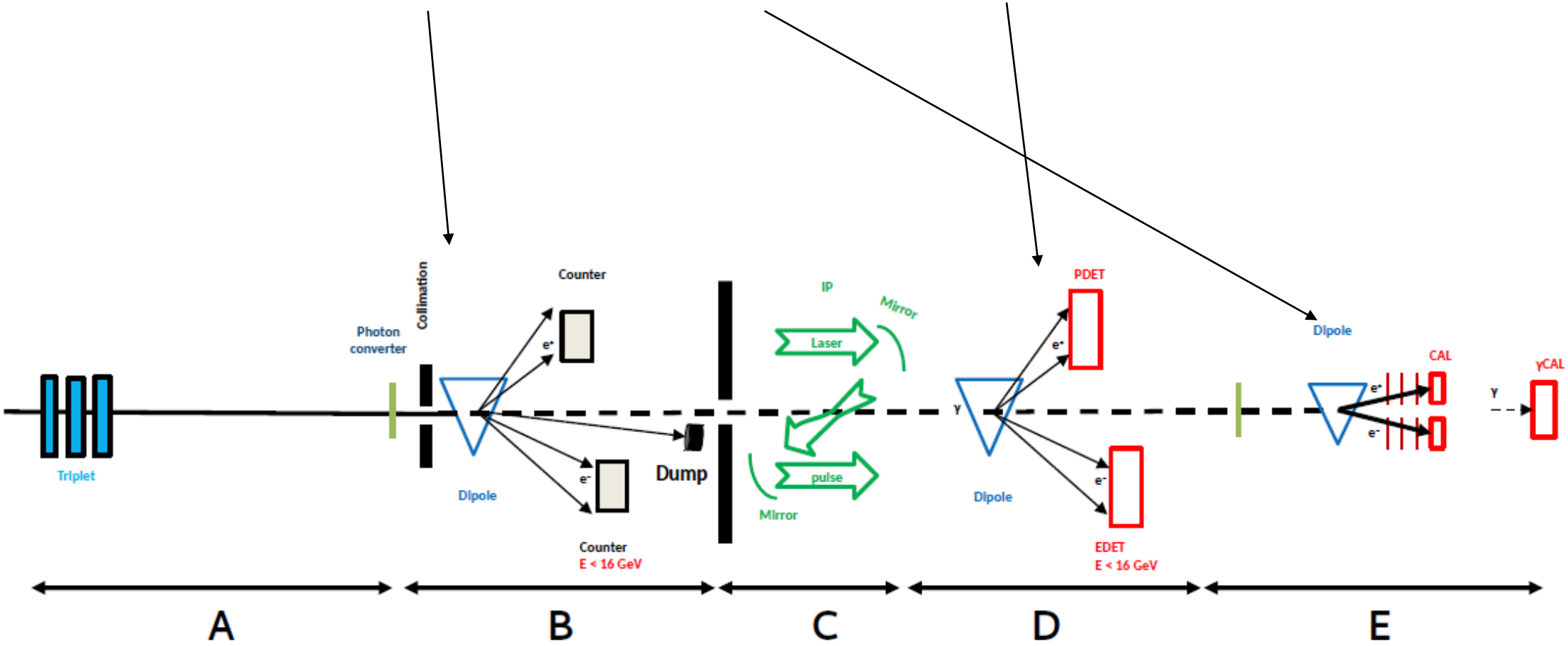
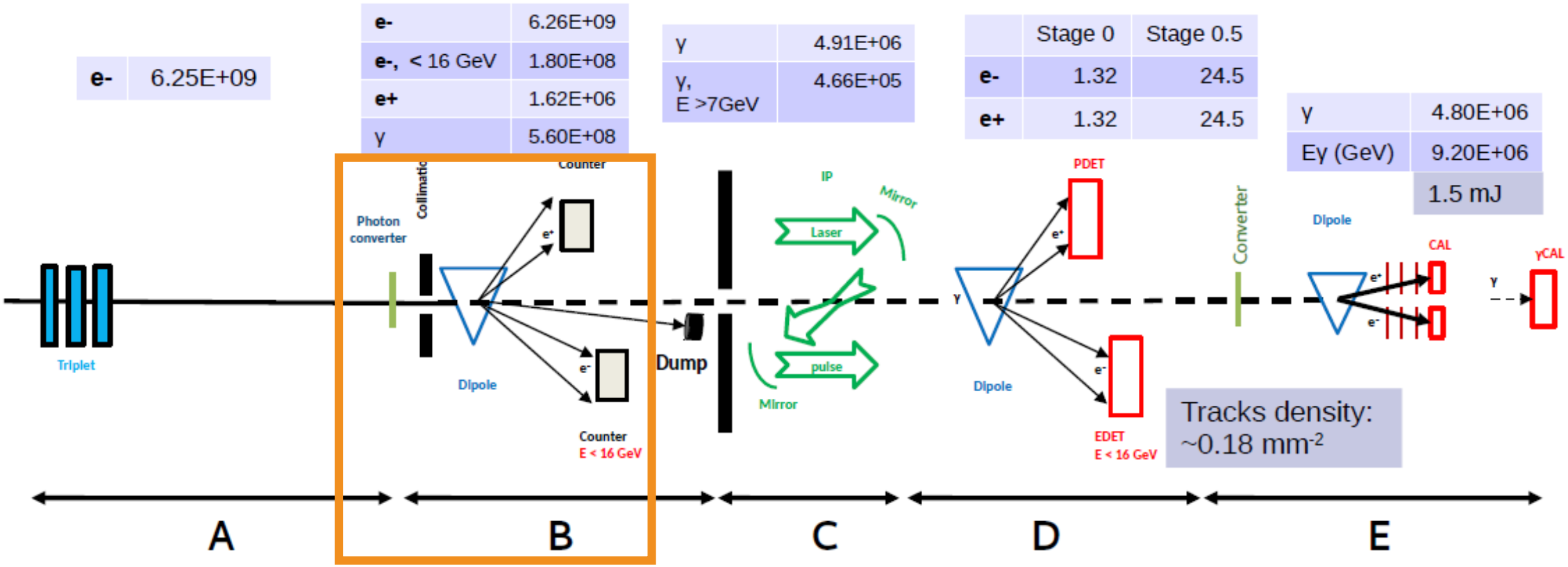


LUXE: Setup

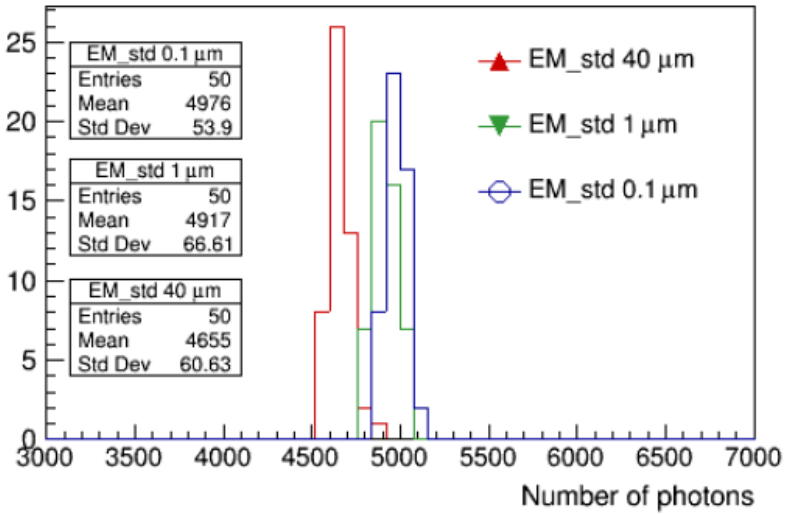

e- 6.25E+09
e- 6.26E+09
e-, < 16 GeV 1.80E+08
e+ 1.62E+06
γ 5.60E+08
γ 4.91E+06
γ, E >7GeV 4.66E+05
Stage 0 Stage 0.5
e- 1.32 24.5
e+ 1.32 24.5
γ 4.80E+06
Eγ (GeV) 9.20E+06
1.5 mJ
Triplet
Photon converter
Collimator
Counter
Dipole
Counter E < 16 GeV
Dump
IP
Mirror
Laser
pulse
Mirror
PDET
Dipole
EDET E < 16 GeV
Converter
Dipole
CAL
γCAL
Tracks density: ~0.18 mm-2
A
B
C
D
E

Photon Beam Generation with GEANT4

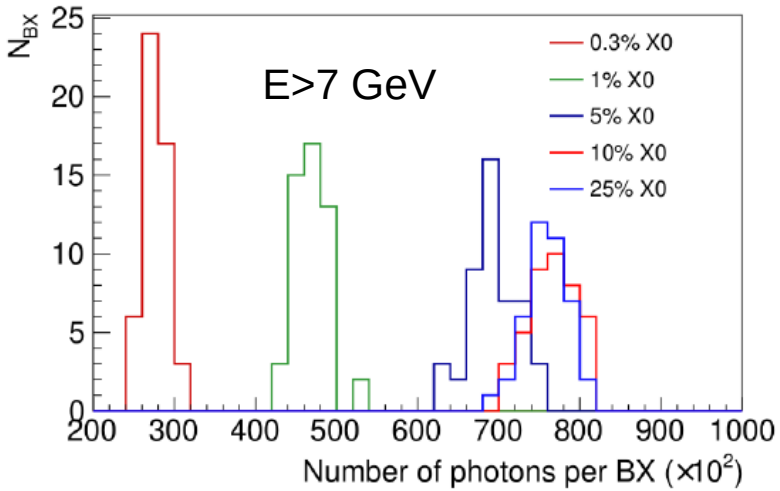
Sasha

- For now assuming gaussian beam
- Tungsten Target 35 µm (= 1% X0)
- Foil 5m in front of Laser Interaction Point (IP)
- At Laser IP: Photons inside an area of 25 x 25 µm around the IP

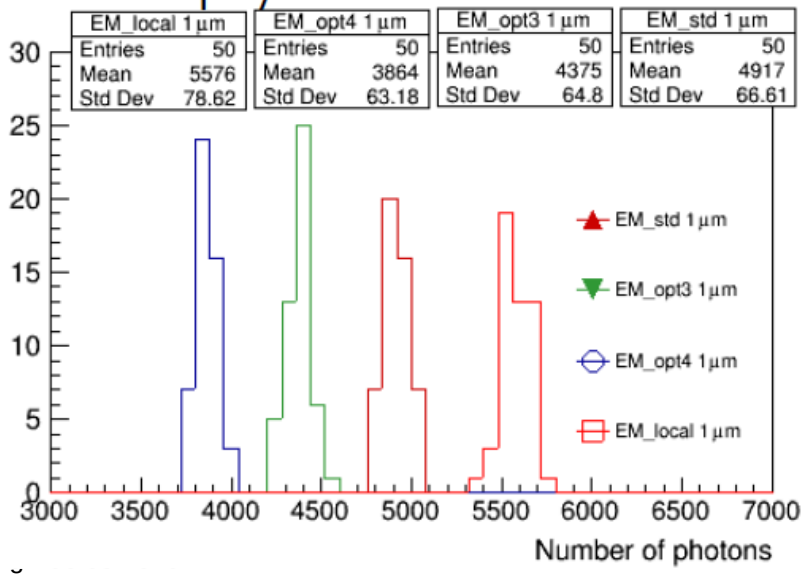
Different step



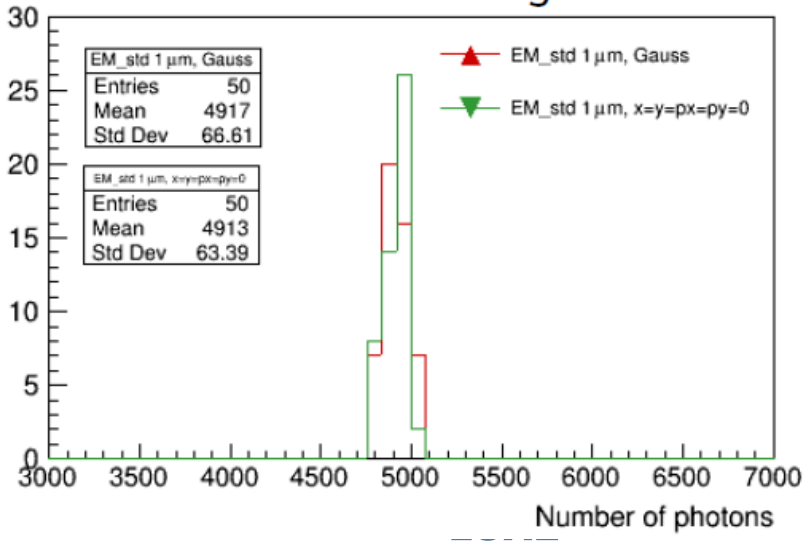
Different Target Thickness



Different physics lists



Different beam settings



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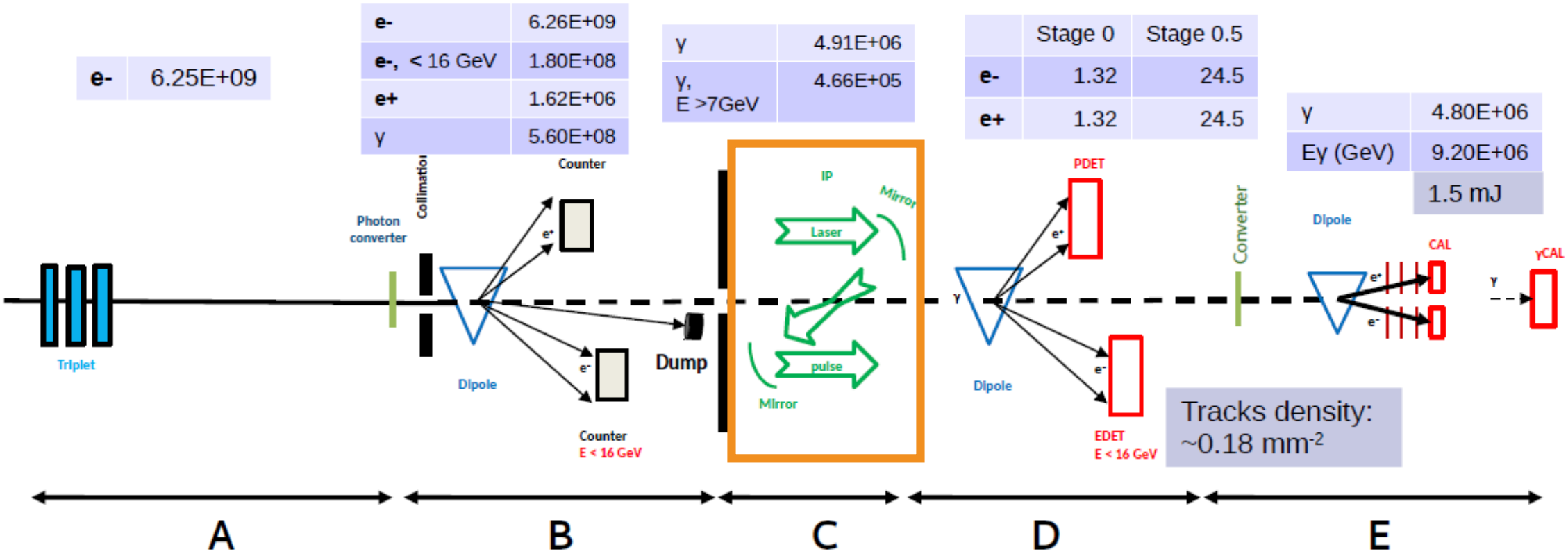
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Dipole
Dipole
CAL
γCAL
Tracks density: ~0.18 mm-2
A
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C
D
E

Monte Carlo Simulation of Beam Interactions

Tony Hartin

- Monte Carlo PIC code for both Electron-Photon and Photon-Photon Interaction
- Input: XFEL Electron Beam / GEANT4 Photon Beam
- Output: all generated and propagated photons/electrons/positrons
- Data for stage 0 of OPPP, while stage 1 is still not possible

Parameter	value
E_e [GeV]	17.5
Laser Energy [J]	5 values: 0.2, 0.35, 0.5, 0.7, 1.0
Pulse length [fs]	35 (gaussian)
Pulse width [um]	5
Beam width [um]	5
#e/bunch	6.25e9
Xing angle	0.3 radians (17 degrees)

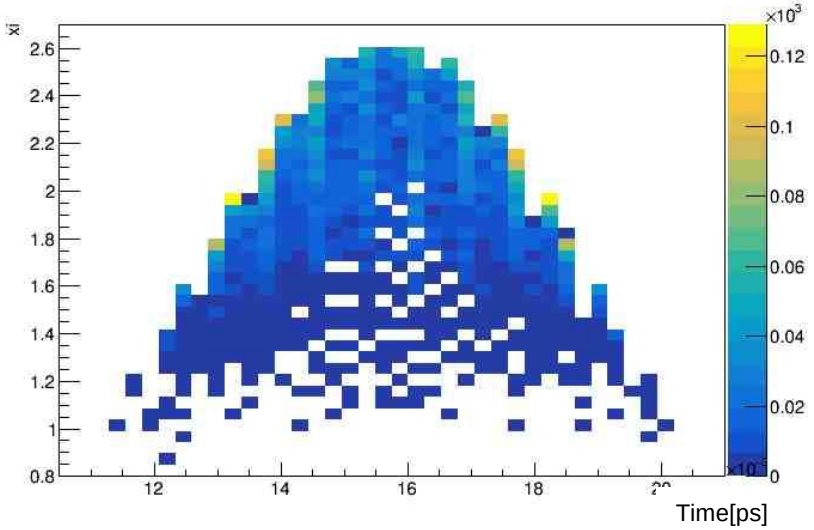
Design Laser Parameters		
Energy[J]	0.35	7.0
Power[TW]	10	200
Intensity[W/cm^2]	10^{19}	2×10^{20}
ξ	1.5	6.8
χ	0.3	1.4

Energy [J]	0.2	0.35	0.5	0.7	1.0
Intensity [10^{18} W/cm^2]	5.7	10	14	20	29
a0 or ξ	1.1	1.5	1.8	2.2	2.6
χ	0.24	0.32	0.38	0.45	0.54

MC simulated Interaction

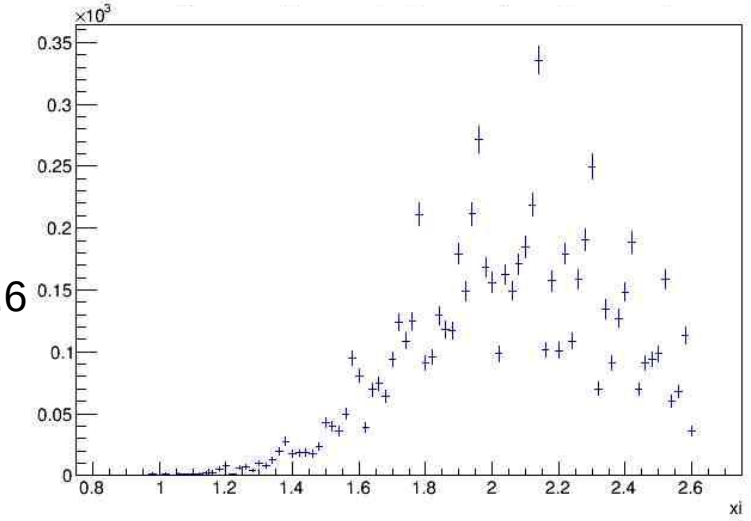
Average of 1000 bunch crossings | 1.0J

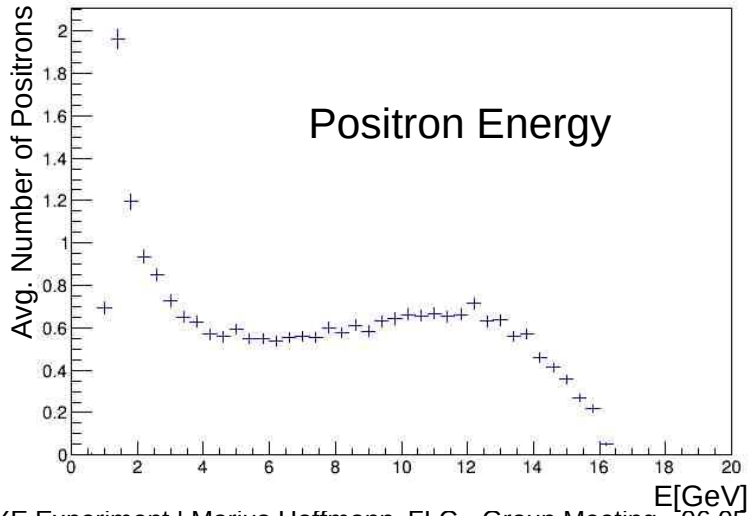
Input:
Monte-Carlo generated
laser-photon interactions
(A. Hartin)



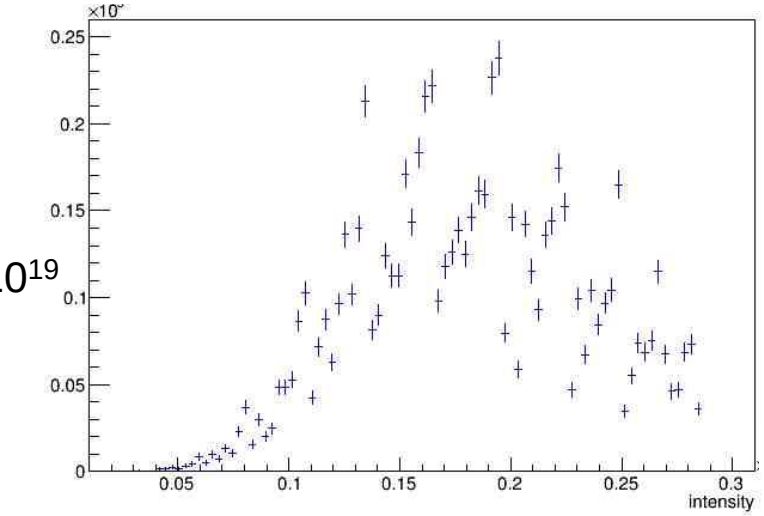
Time vs. xi

Xi profile
Nom. xi = 2.6





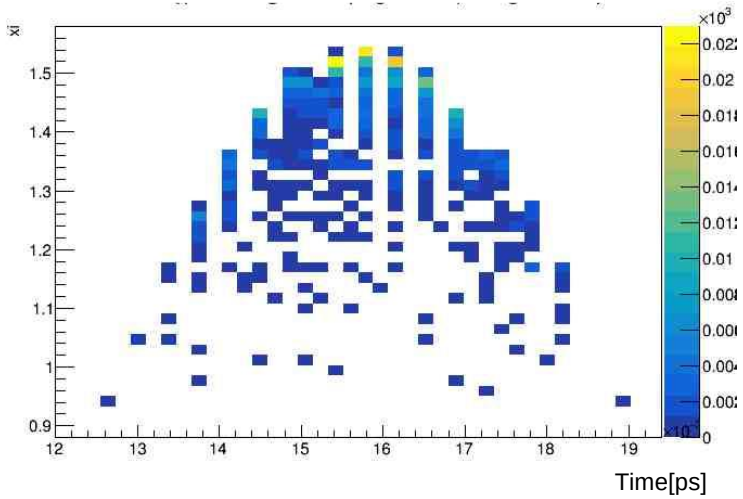
Laser Intensity
Nom. Int 2.9 × 10^{19}



MC simulated Interaction

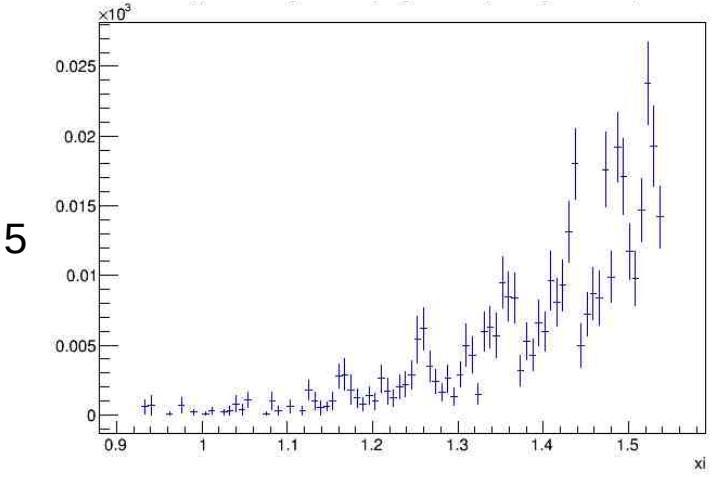
Average of 1000 bunch crossings | 0.35J

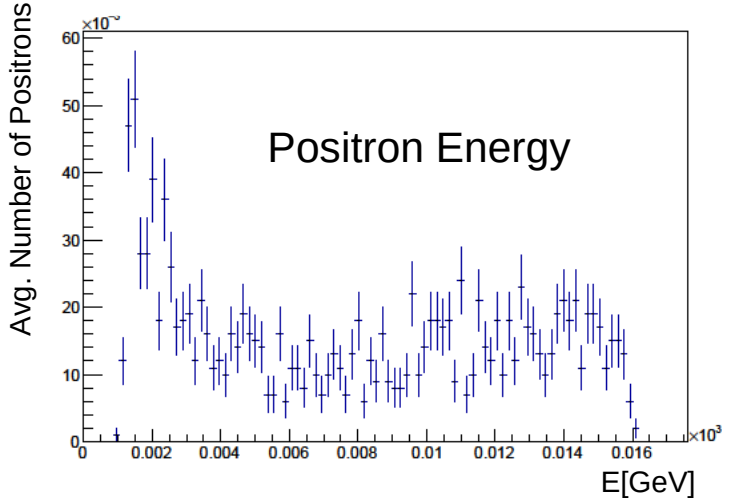
Input:
Monte-Carlo generated
laser-photon interactions
(A. Hartin)



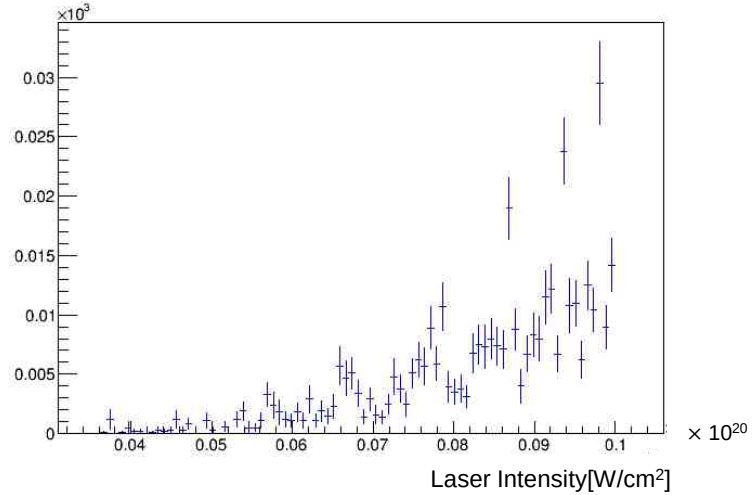
Time vs. xi

Xi profile
Nominal xi = 1.5

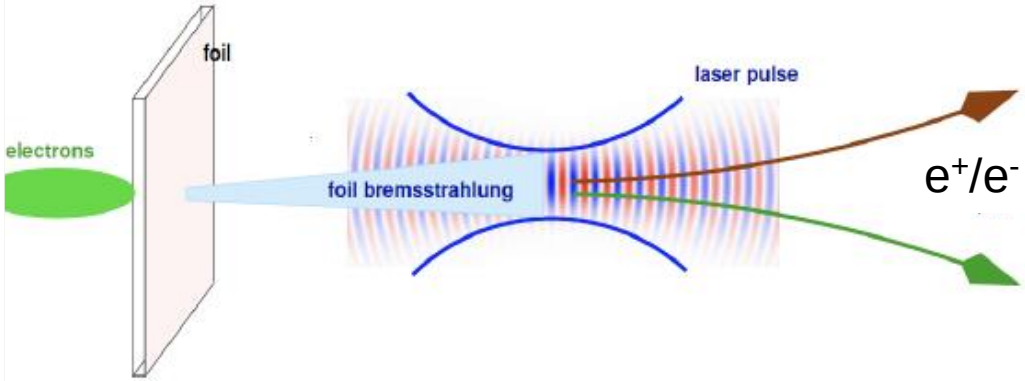




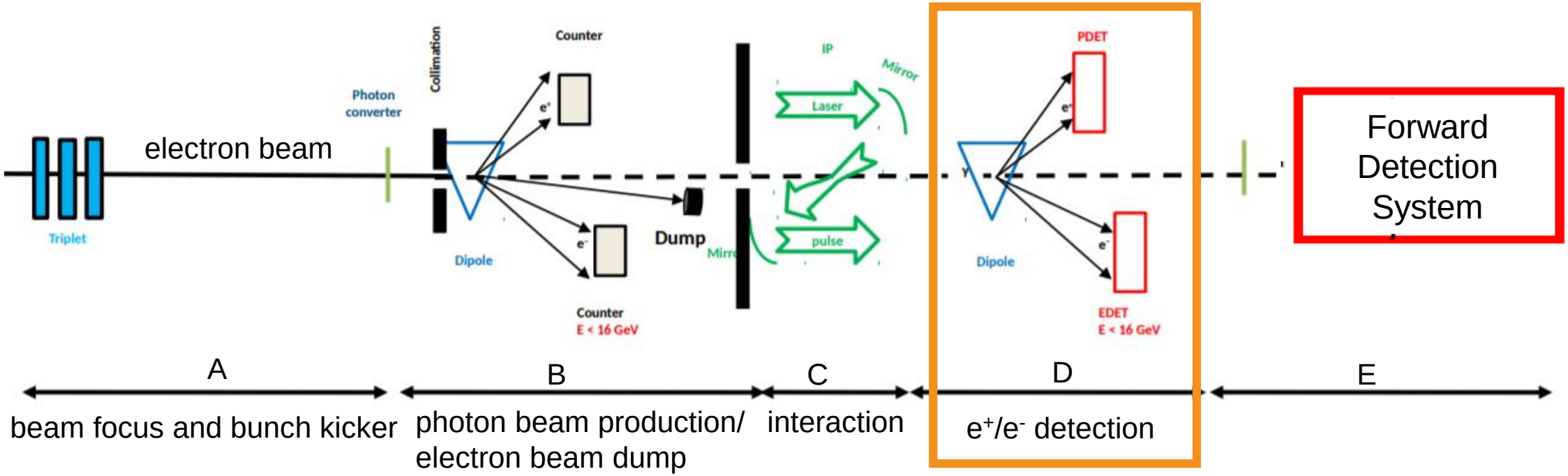
Laser Intensity
Nominal Int. 1×10^{19}



LUXE: Setup



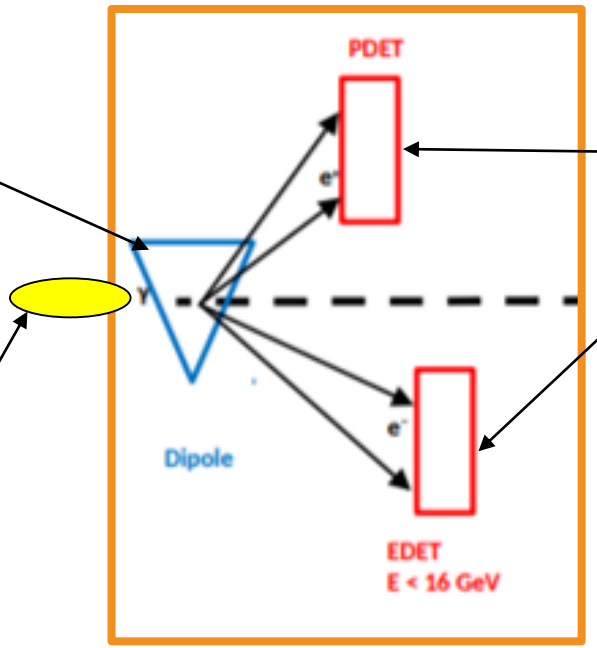
Electron/Positron
Detector System



The pair detection system

Marius

Magnet
- Aperture
- Field strength
- size



Detector system
- Pixel Silicon Trackers
- Multiple Layers
- Calorimeters
- Cherenkov Counters

Incoming particles
- Energy Distribution
- Number
- Spatial distribution

Spacial constraints
- Tunnel

XSDU1 tunnel ~2m diameter, European XFEL

Proposed Magnet

Taken from the DESY storage

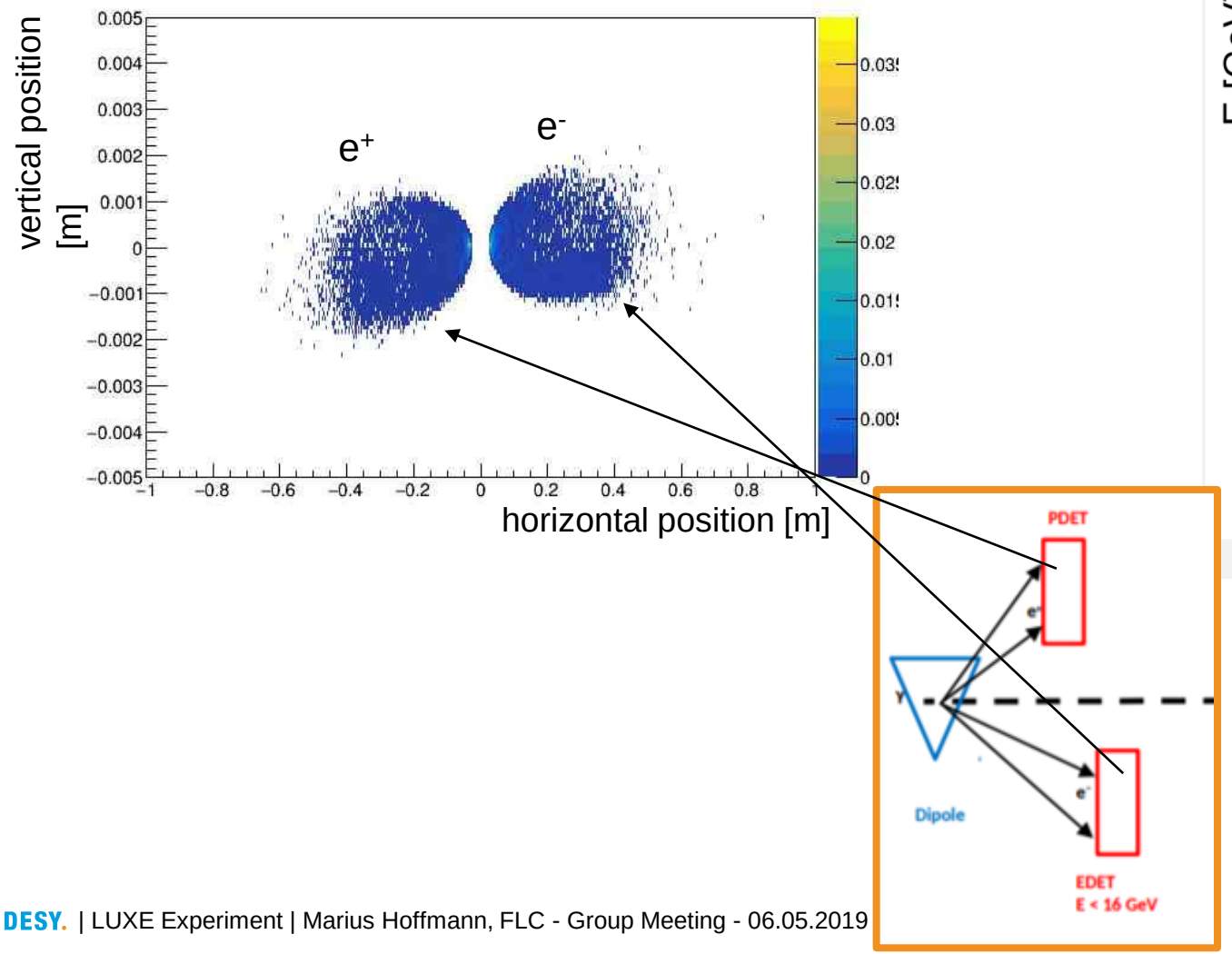
suitable magnet from old DORIS accelerator

Doris Dipole	
Length	1.029m
Aperture horizontal	0.6m
Aperture vertical	0.1m
Max. Field strength	2.24T

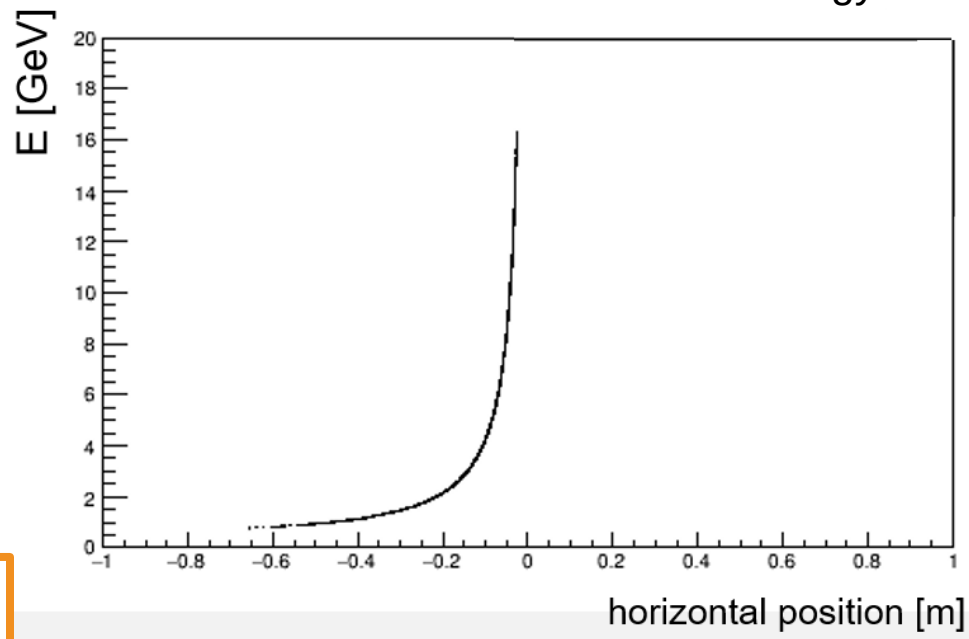
Simulation of Magnetic Spectrometer

Modifying HERA spectrometer simulation code by Jenny

Particle Position

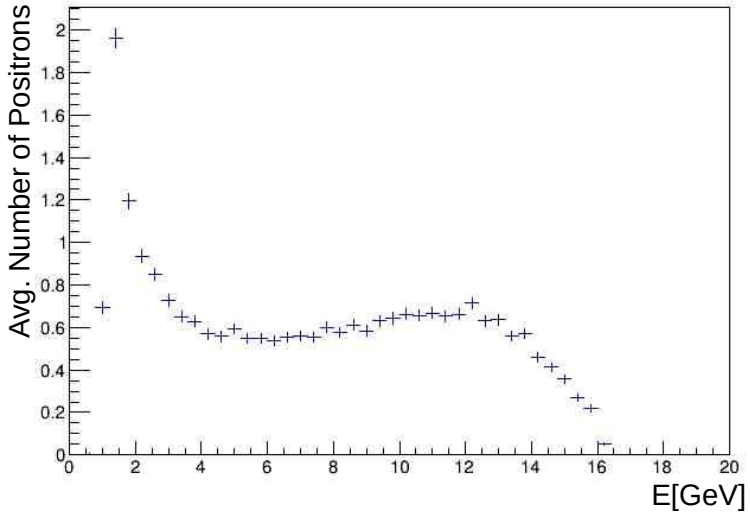


Positron Position vs. Energy



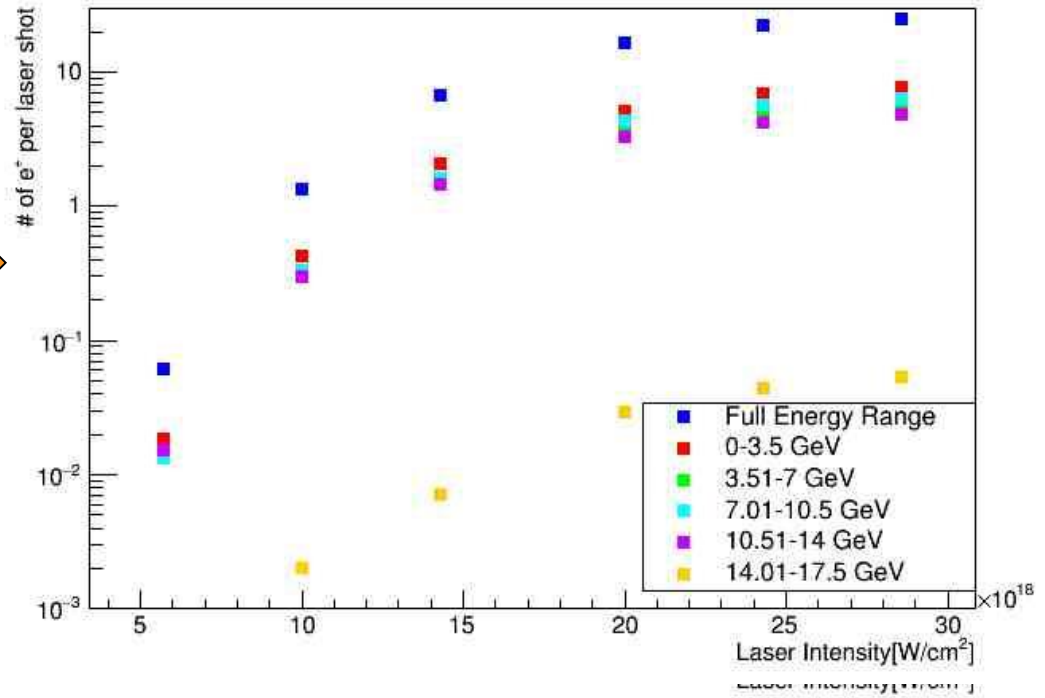
e^+e^- numbers after interaction

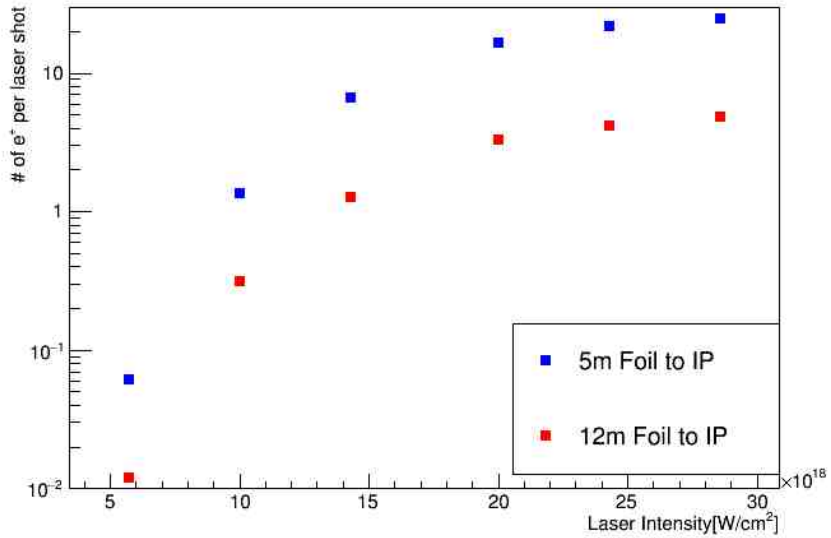
Energy spectrum of positrons



Slope is independent of Energy range

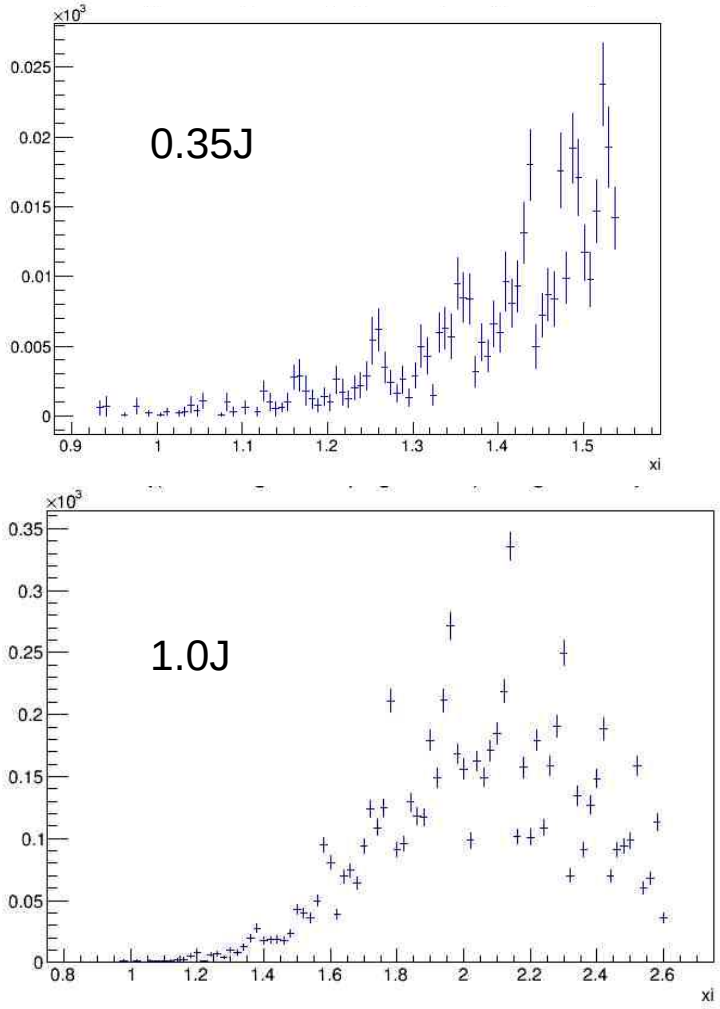
Number of positrons produced for Foil-IP 5m

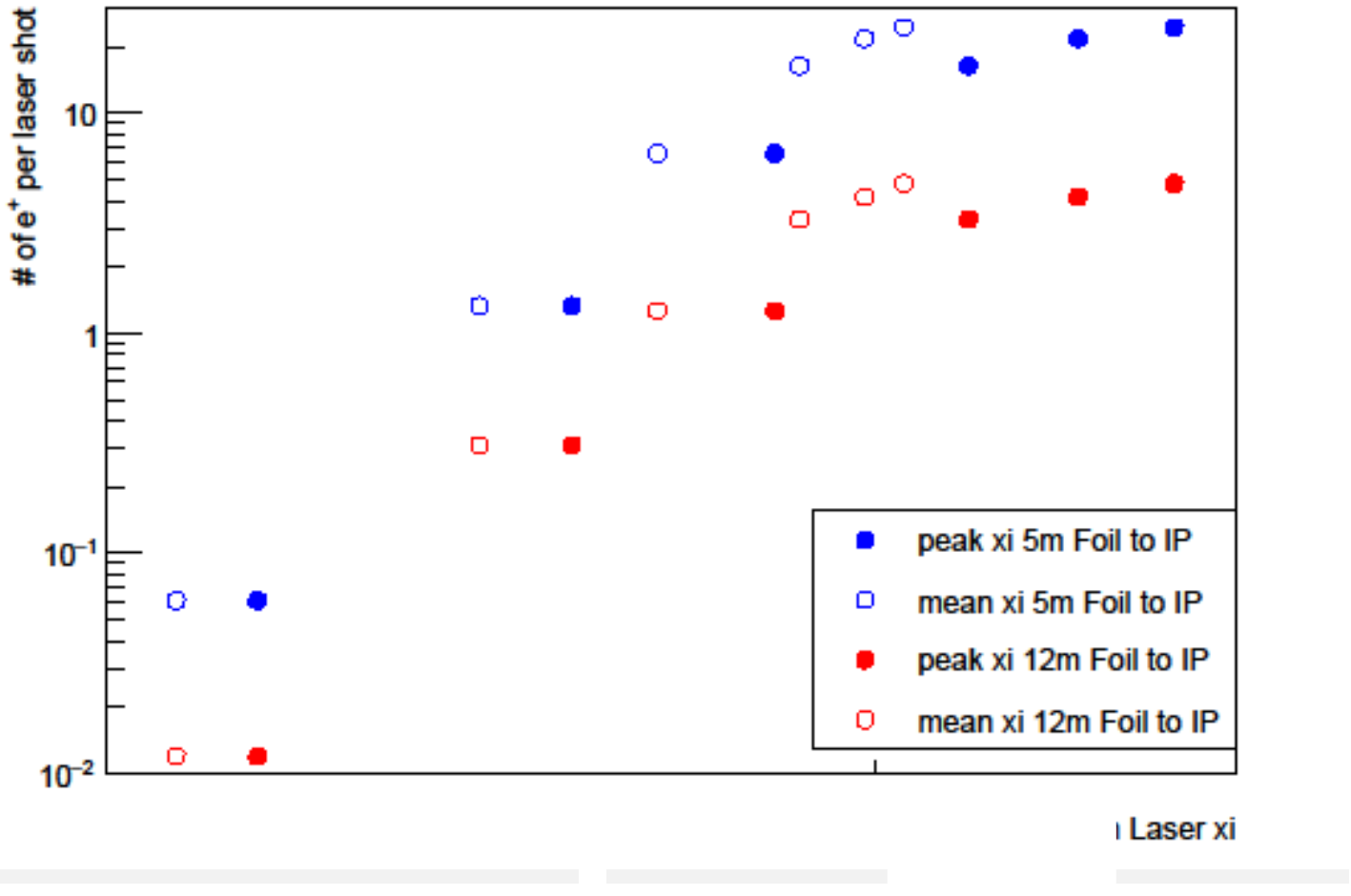




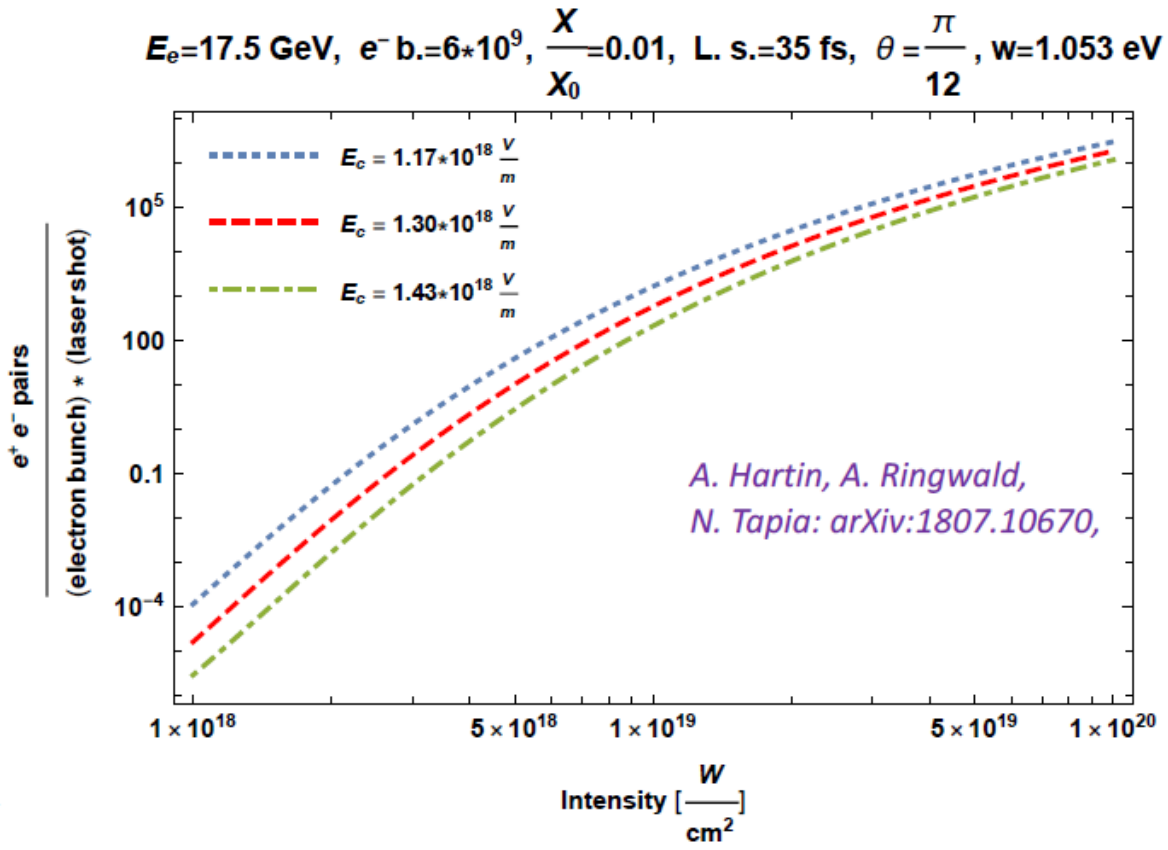
O(30) positrons for 1 J of laser energy
(Design Laser Energy = 7J)

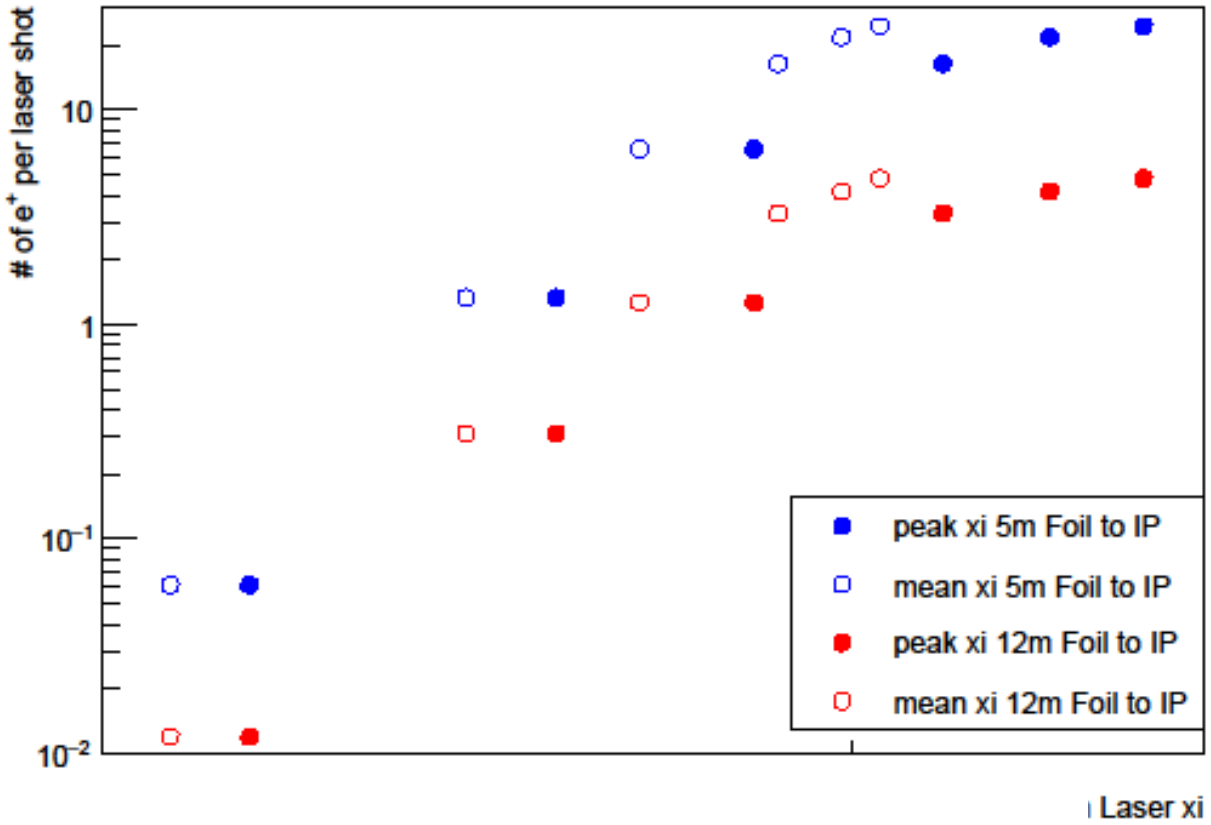
Mean or Peak ξ ?



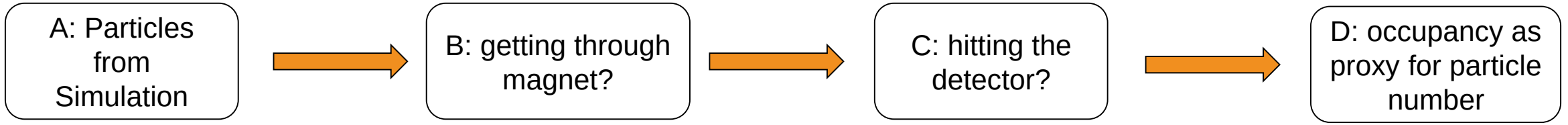


Mean or Peak ξ ?





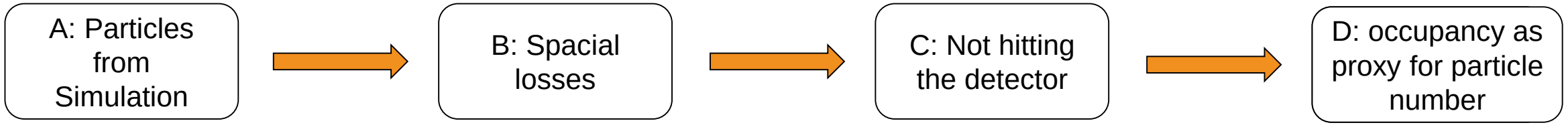
Occupancy vs. Detector Granularity



E>1 GeV		x_det < 1 m
x_magnet < 0.3 m	Aperture	y_det < 0.15m
y_magnet < 0.15m		

Pixel size
50 µm × 50 µm
100 µm × 100 µm
50 µm × 500 µm
50 µm × 50 µm
50 µm × 15000 µm (strip)
1000 µm × 1000 µm
10000 µm × 10000 µm
1M µm × 150k µm

Occupancy vs. Detector Granularity



Distance IP/Foil	A	B	C
5m	24.52 (100%)	99.7%	99.7%
12m	4.78 (100%)	99.7%	99.7 %

Pixel size [µm] IP/Foil)	50 × 50	100 × 100	50 × 500	100 × 15000 (strip)	1000 × 1000	10000 × 10000	1M × 150k
5m	98.6%	98.6%	98.5%	98.4%	97.8%	80.7%	4.0%
12m	99.6%	99.6%	99.6%	99.5%	98.7%	89.3%	20%

- **Granularity of up to 1mm**
- **Good granularity only needed in x plane**

Pixel size / comparison with other experiments

Pixel Technology readily available

High occupancy in electron-photon interaction will probably force cherenkov counter for electrons

Experiment	Pitch
ATLAS IBL	50 µm × 250 µm
CMS Pixel Upgrade	25 µm × 100 µm
LHCb	55 µm × 55 µm
ALICE	25 µm × 25 µm
CMS HGCAL	0.5 cm^2 hexagons

Next steps:

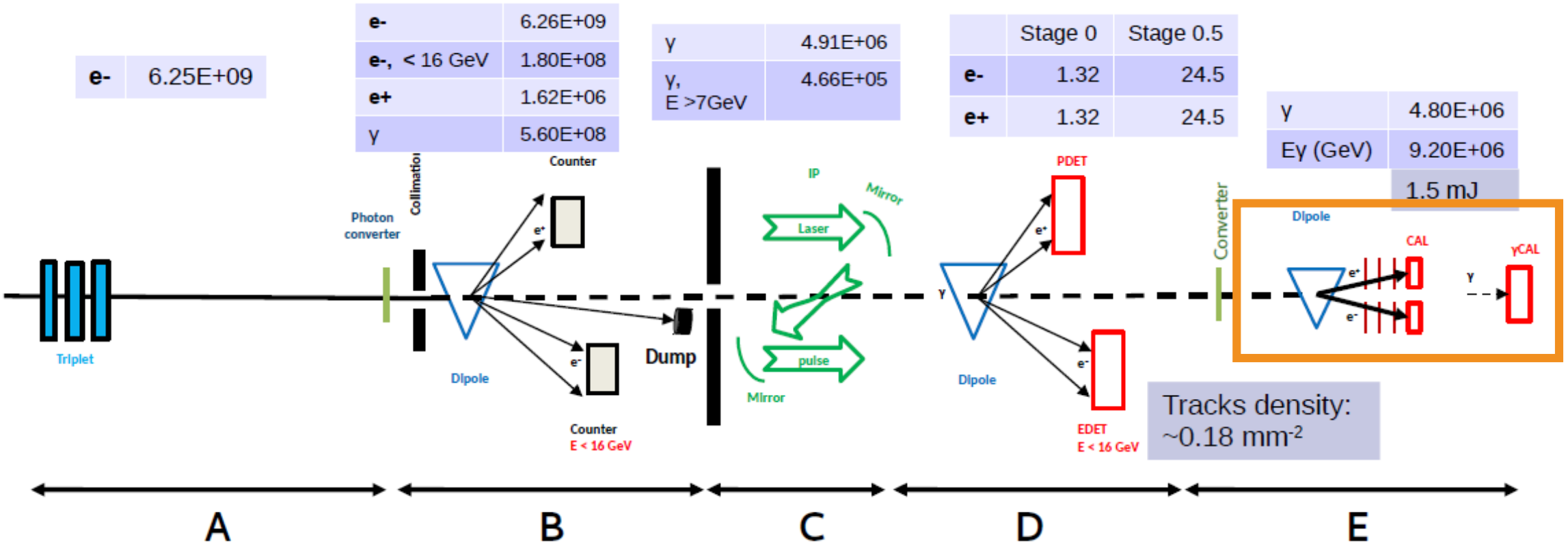
1. **Finalize design simulation studies**

- Study Impact of Laser Pulse Shape
- Include track fitting
- Increase realism of detector with help of Jenny and Mikhael (multiple layers, scattering etc.)

2. Implement final design Full simulation in GEANT4

3. DESY test beam runs for validation of photon production models

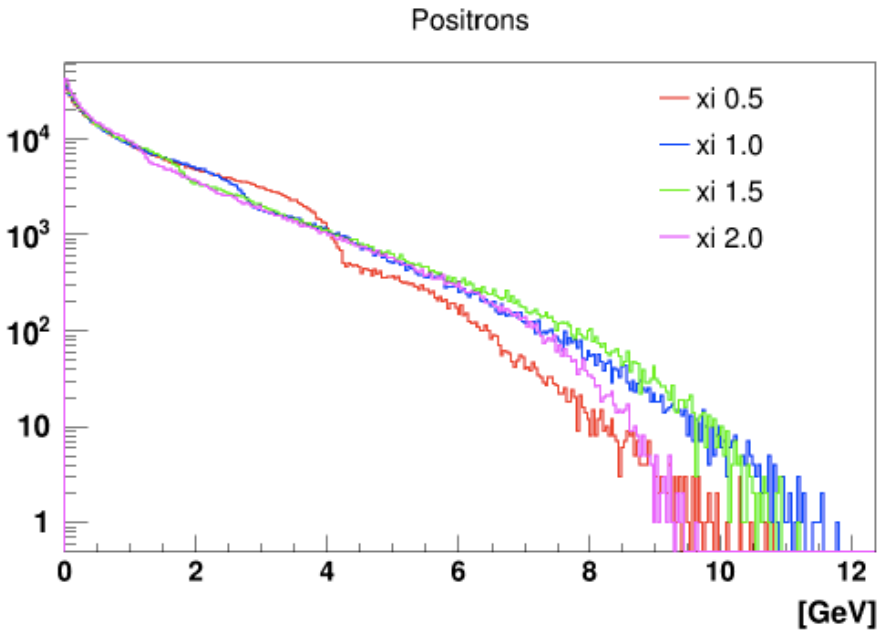
LUXE: Setup


e- 6.25E+09
e- 6.26E+09
e-, < 16 GeV 1.80E+08
e+ 1.62E+06
γ 5.60E+08
γ 4.91E+06
γ, E >7GeV 4.66E+05
Stage 0 Stage 0.5
e- 1.32 24.5
e+ 1.32 24.5
γ 4.80E+06
Eγ (GeV) 9.20E+06
1.5 mJ
Triplet
Photon converter
Collimation
Counter
Dipole
Dump
IP
Mirror
Laser
pulse
Mirror
Counter E < 16 GeV
PDET
Dipole
EDET E < 16 GeV
Converter
Dipole
CAL
γCAL
Tracks density: ~0.18 mm-2
A
B
C
D
E

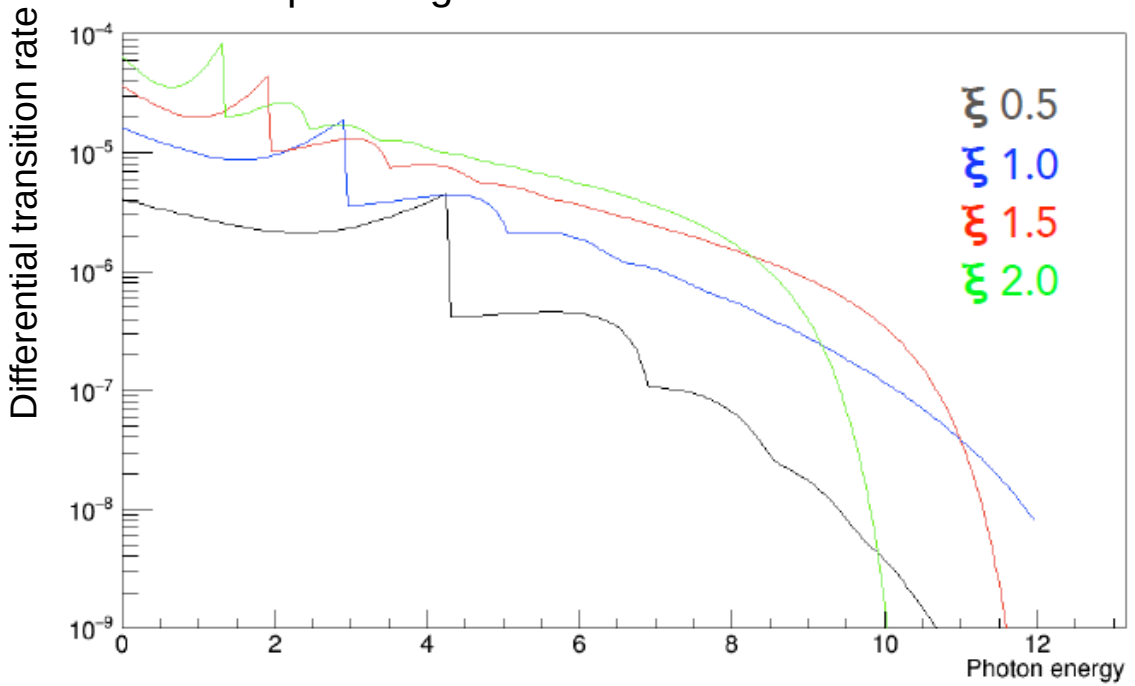
The Forward Photon Detector

Marina

- Detecting the Compton Edges in Electron-Photon Interaction
- Very high rates of photons
- Conversion to electron/positron pairs in foil/wire
- Challenging to any current detector technologies
- Searching for possibilities to decrease number of photons
- Reconstruct compton edges from electron/positron spectra



Compton edges for different Laser Intersities



ξ	1e 35 fs (1BX)	Nγ
0.5	2.39	1.49255E+10
1	8.43	5.26758E+10
1.5	16.29	1.01825E+11
2	24.41	1.52579E+11

How LUXE is proposed to continue

Our Timetable

- August 2019: Publish letter of intent
- Winter 2020 and 2021: Installation of accelerator components
- 2022+2023: prototype experiment (stage-0)
  - Commissioning, data taking and publication of results
- 2024 upgrade to strong laser
- 2025-2027 Data Taking in the final experiment

Thank you for your Attention

Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

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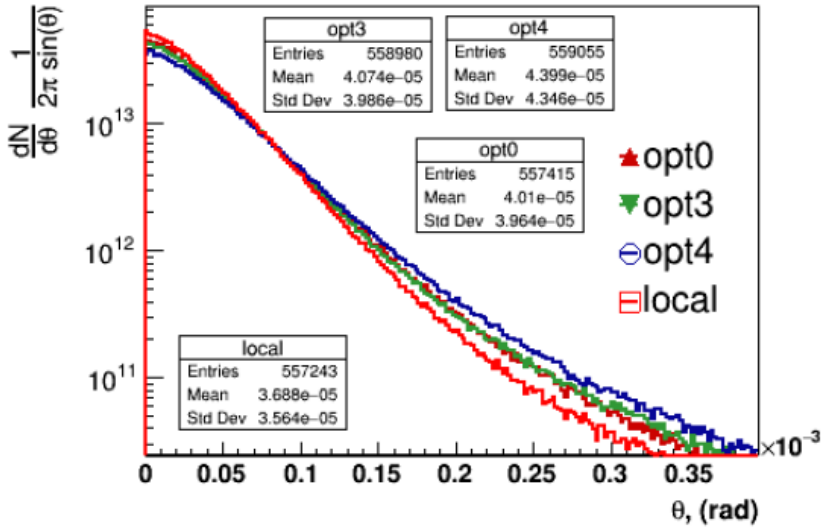
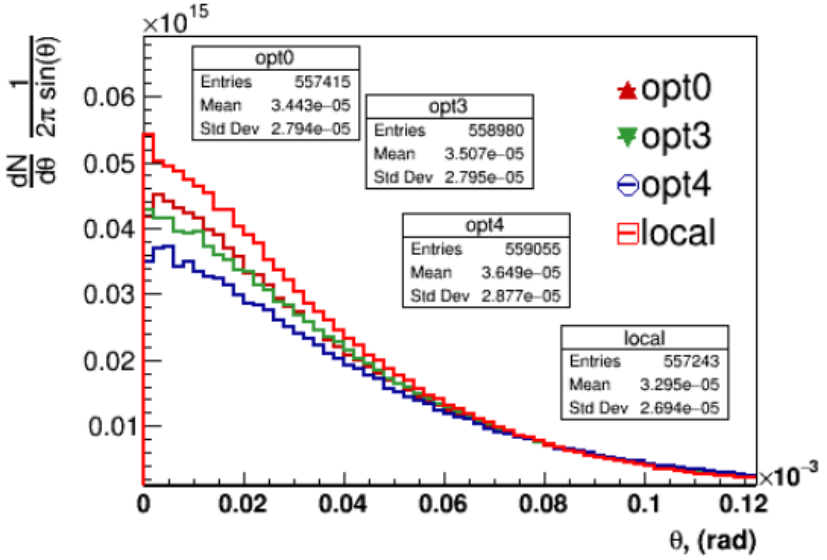
Backup

γ angular distribution for different physics lists





- Angular distribution is the widest for option_4 physics list.
- The difference in angular distribution explains the observed difference in the number of photons at IP.
- Total number of photons in forward region is identical for all physics lists.

Number of photons inside
|x|<1.5 m and
|y|<1.5 m