LUXE

Overview

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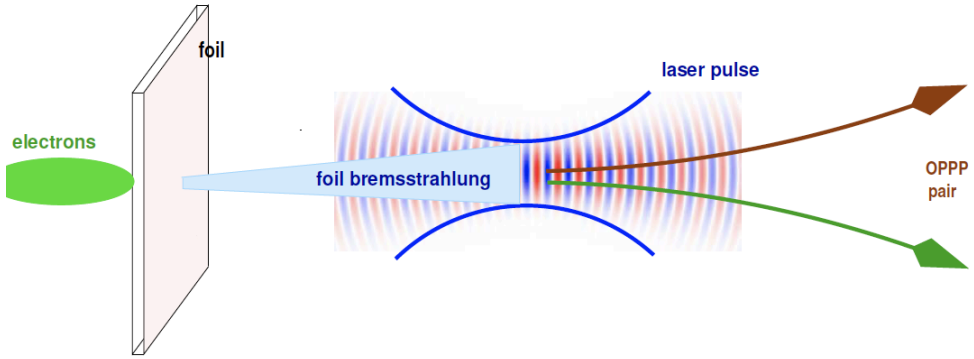
INTRODUCTION

- **Goal: Develop new experiment at European XFEL to test quantum physics in unexplored regime using high intensity laser**
  - Electron+Laser: $e + n\omega \rightarrow \gamma e^-$ or $e + n\omega \rightarrow e^- e^+ e^-$
  - Photon+laser: $\gamma + n\omega \rightarrow e^+ e^-$
- **Relevant to many phenomena, e.g**
  - Astrophysics: Hawking radiation, surface of neutron stars, early Universe (e.g. inflation)
  - Condensed matter and atomic physics (e.g. dielectric breakdown)
  - Accelerator physics: high energy e^+e^- colliders
  - Testing theoretical predictions in novel regime => gain deeper understanding of quantum physics
- **Schwinger field has never been reached experimentally in clean environment**
  - Exciting to be the first to explore this … we might be surprised what we find!

LASER AND PHOTON BEAM

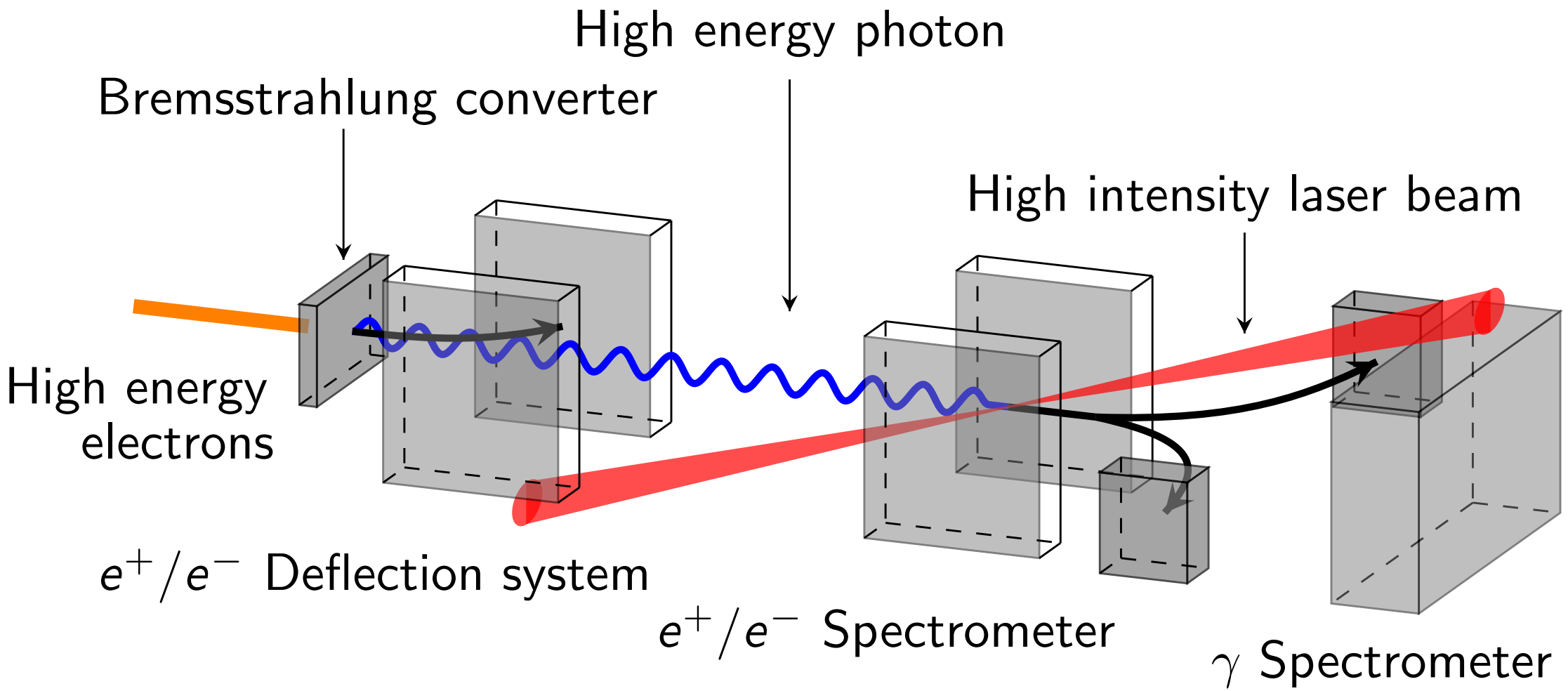
- **Use Laser to generate electric field**
- **Use high energy electron beam to create high-energy photons**

$$\xi = \frac{eE_L}{m_e \omega_L c} \qquad \chi \approx \gamma \frac{\varepsilon}{\varepsilon_S} \propto \gamma \sqrt{E_L}$$

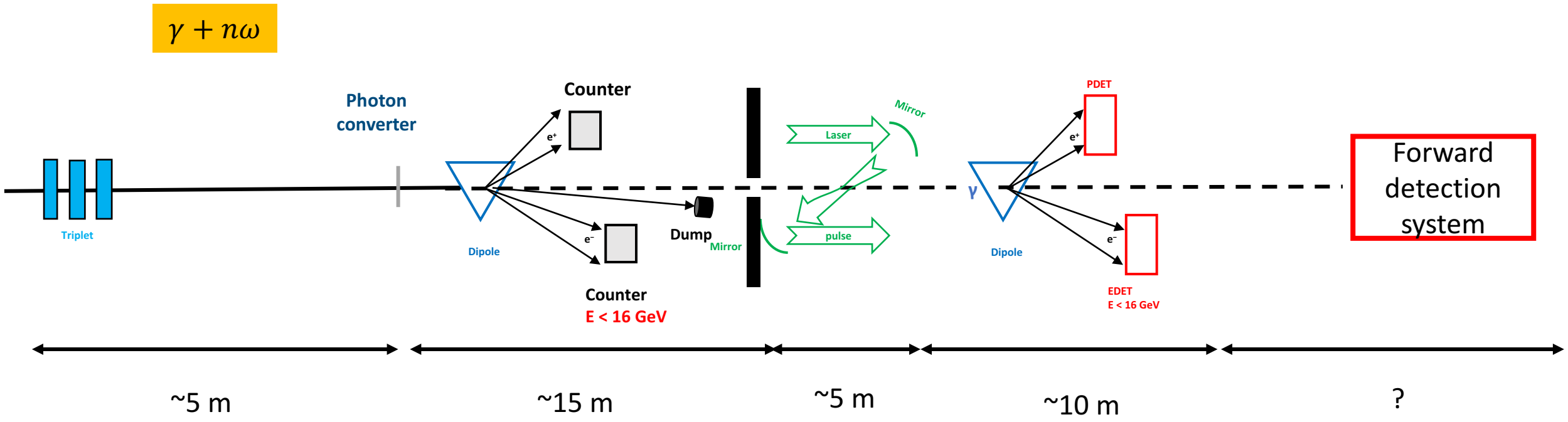


- **Laser power required to reach Schwinger field ($\chi_\gamma \sim 1$):**
  - Non-relativistic photons: $I = 2 \times 10^{29}$ W/cm^2 => Much beyond currently achievable values
  - EU.XFEL, $E_\gamma \approx 10$ GeV: $I \approx 10^{20}$ W/cm^2 => Can use well-tested laser technology
  - ELI-NP, $E_\gamma \approx$ GeV: $I \approx 10^{22}$ W/cm^2 => State-of-the-art laser needed

LUXE CONCEPTUAL DESIGN



PHOTON LASER COLLISIONS



Kicker and triplet to select single bunch and focus it

Dipole and detectors to remove e+e- pairs and monitor photon flux

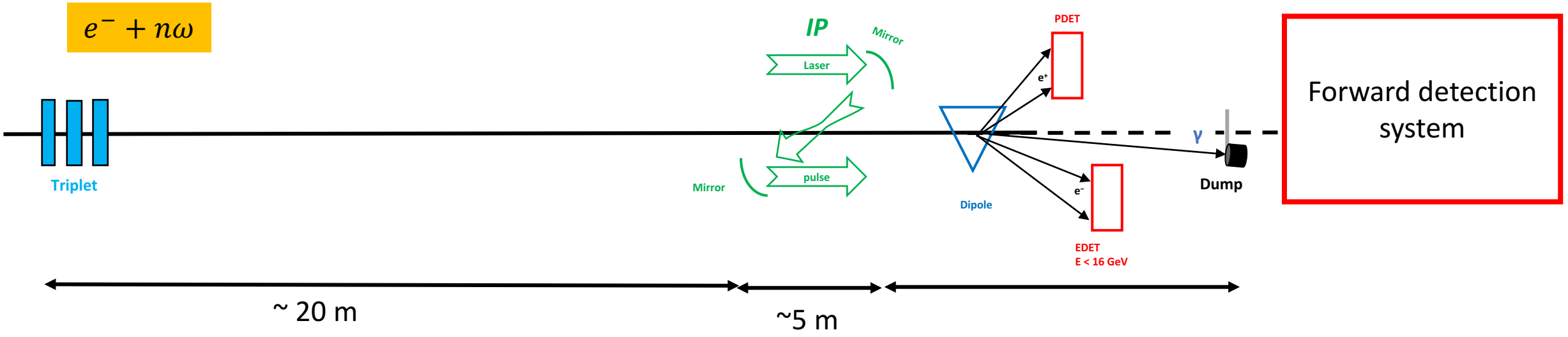
Photon- Laser interaction area

Dipole and detectors to observe e+e- pairs

ELECTRON LASER COLLISIONS

Plan to also study electron directly in laser field (ω is a laser photon):

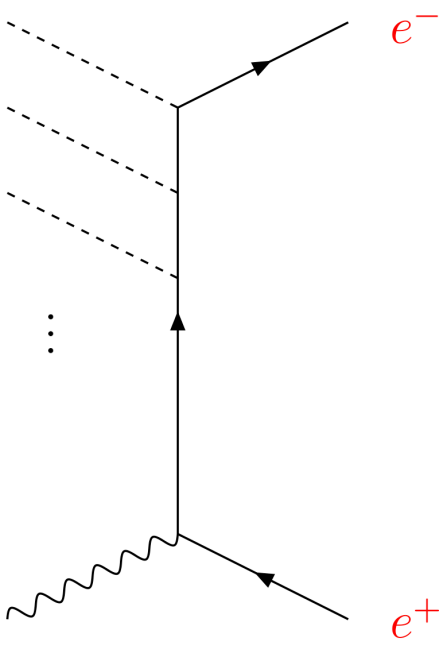
- **Study Compton process:** $e^- + n\omega \rightarrow e^- + \gamma$
- **Study "trident" process:** $e^- + n\omega \rightarrow e^- e^+ e^-$

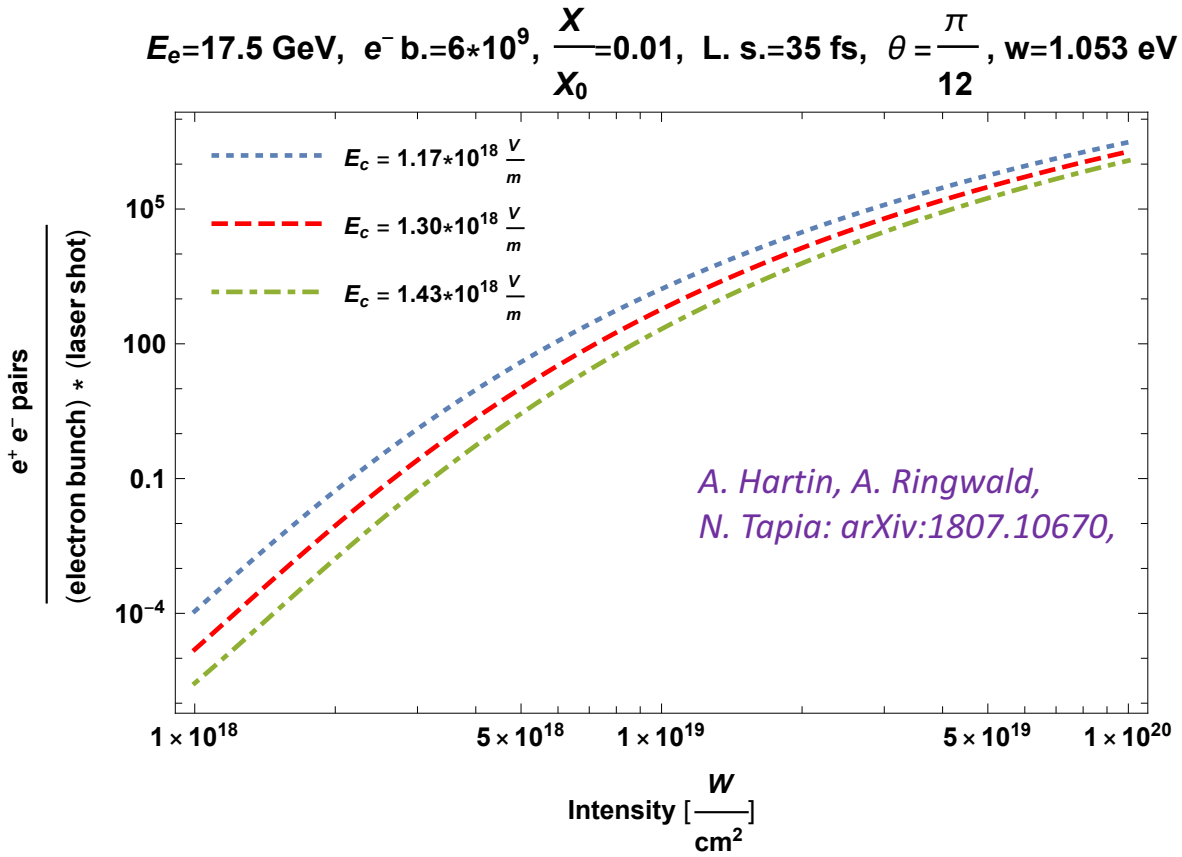


ABSORBING LIGHT WITH LIGHT

Low-energy photons from laser γ_L

High-energy (relativistic) photon γ





Predictions for rate

- Pair production positron rate: depends on adiabacity

$\xi \ll 1$: $R_{e+} \propto \xi^{2n} \propto I^n$ ☚ Strong rise, follows power-law

$\xi \gg 1$: $R_{e+} \propto \chi^2 \exp\left(-\frac{8}{3\chi}\right)$ ☚ Non-perturbative regime: departure from power-law

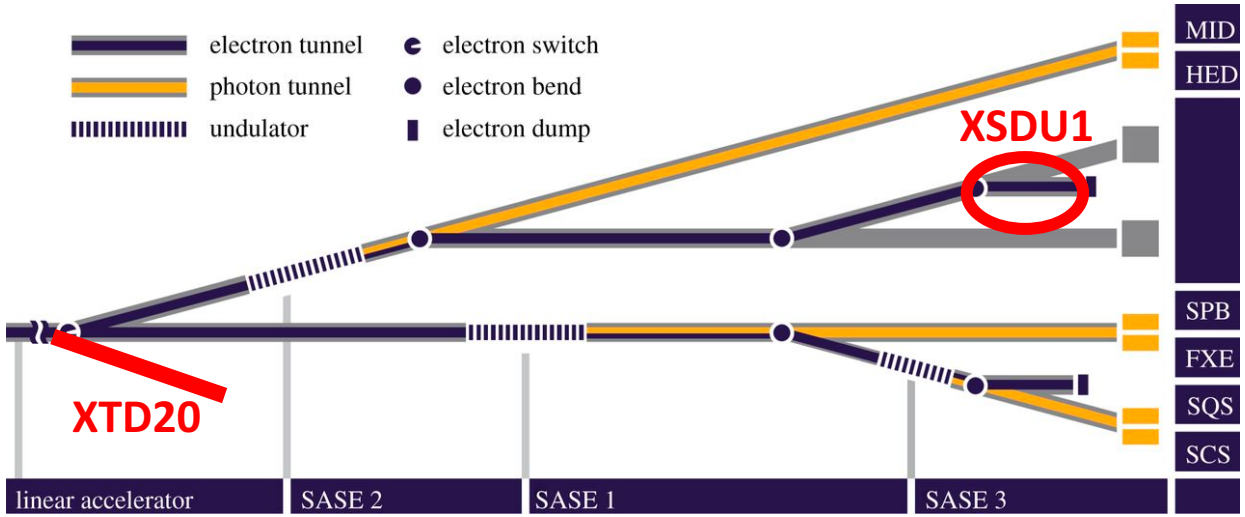
LOCATIONS IN EU.XFEL TUNNEL

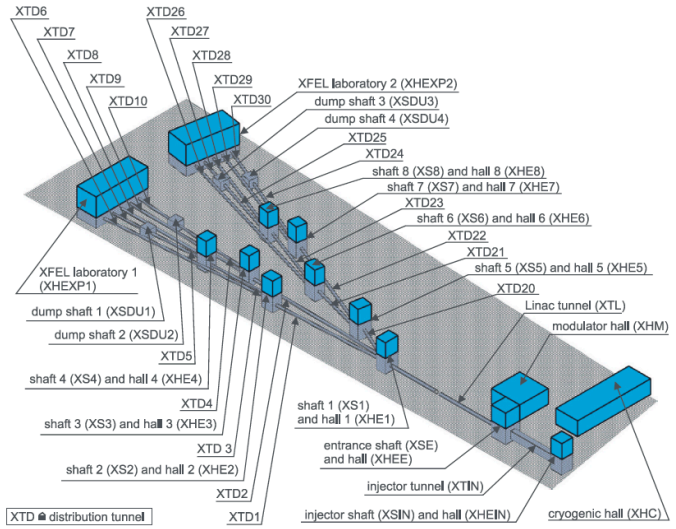
Location in XFEL: two options being explored

1. XSDU1: right before the beam dump (after all undulators)
2. XTD20: At the start of the 2nd EU.XFEL FAN
   - Would imply early construction of extraction for 2nd EU.XFEL fan

Design aims to have no impact on photon science programme

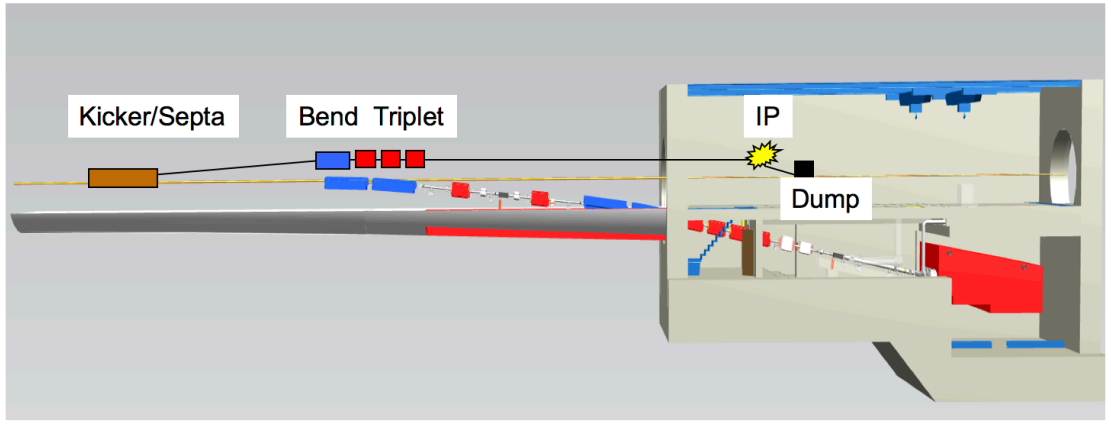
- Use only 1 of the 2700 bunches in bunch train (kicked out by kicker)

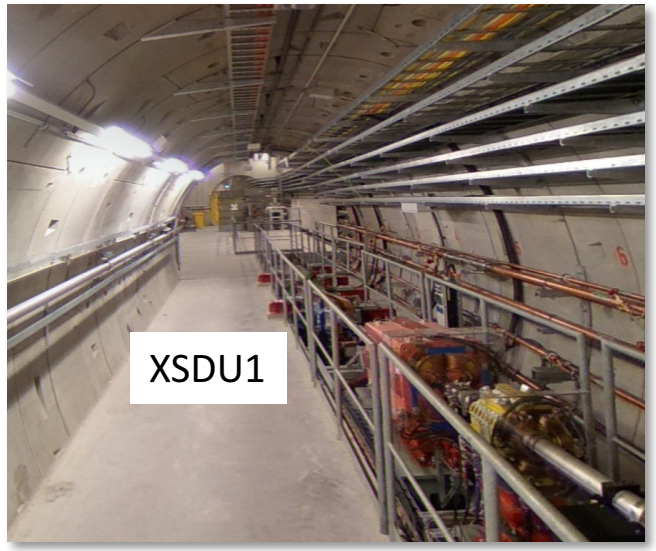




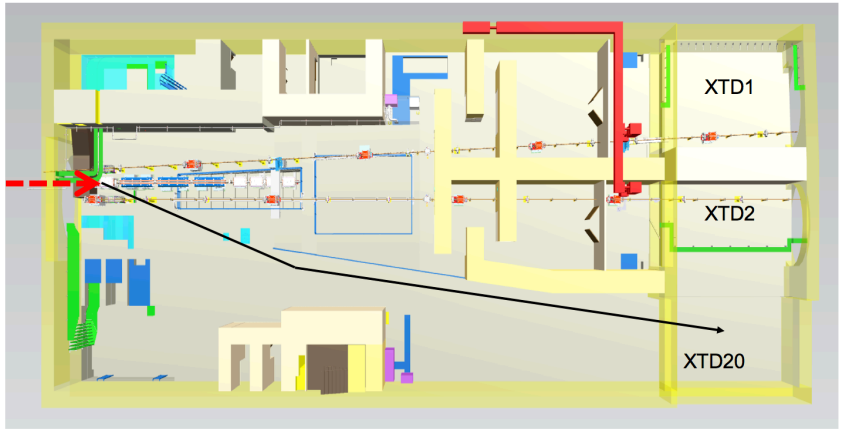
LOCATIONS IN THE EU.XFEL TUNNEL

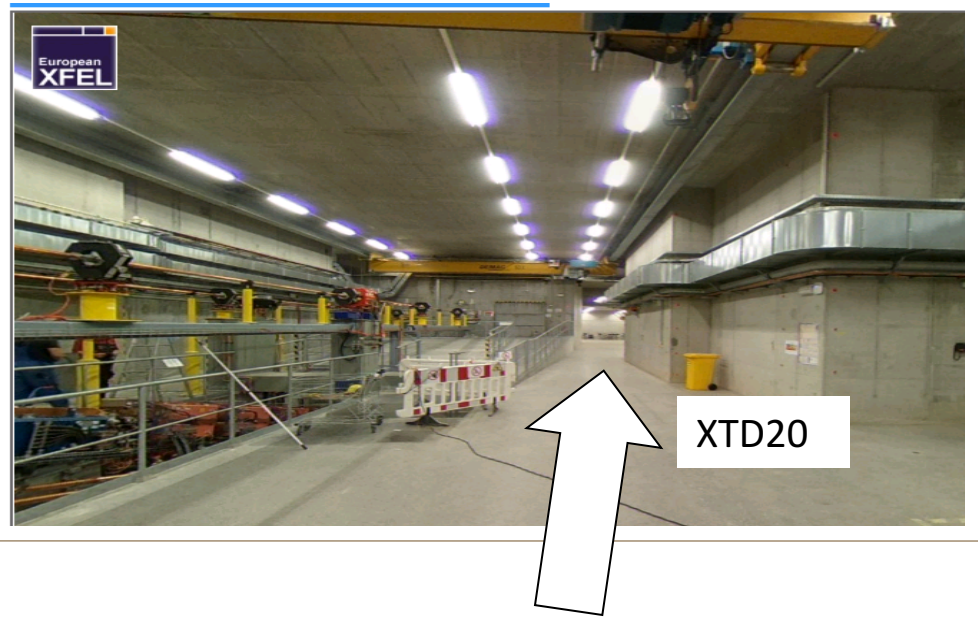
XSDU1 location





XTD20 location





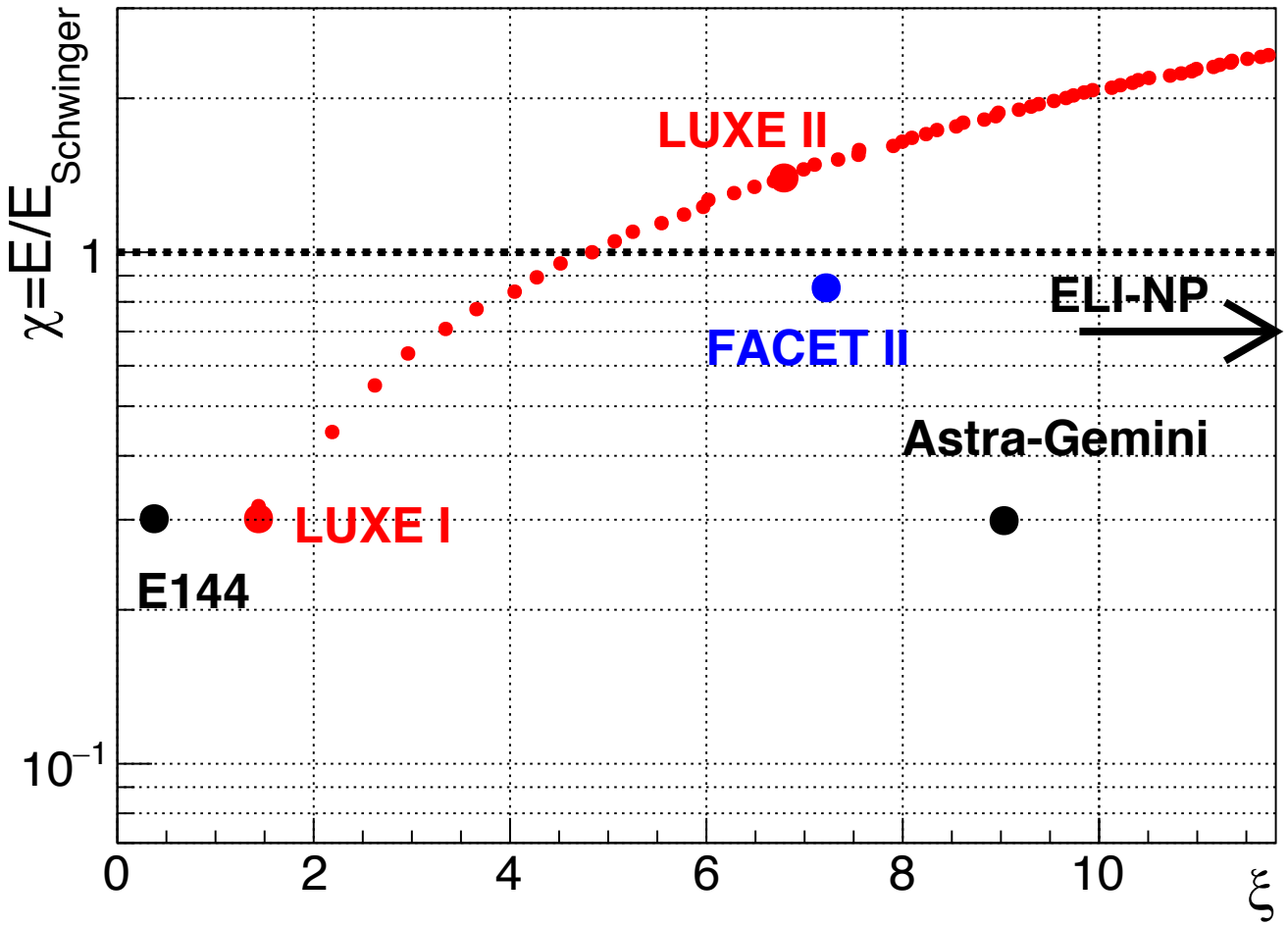
LUXE LASER PARAMETERS

Ti:Sapphire technology
Pulse length: 35 fs
Wavelength: 800 nm
Focal length: 1m
Focus area: 100 μm^2
Frequency: 1-10 Hz

	STAGE 0	STAGE 1
Energy [J]	0.35	7.0
Power [TW]	10	200
Intensity [W/cm^2]	10^{19}	$2x10^{20}$
ξ Parameter	1.5	6.8
χ Parameter	0.3	1.4

- Initial Stage (stage 0):
  - proof of principle, less costly, smaller laser
  - similar to E144 but higher precision
- Design Stage (stage 1):
  - Reach critical field strength => pioneering new territory of quantum theory
  - Requires about 100 m^2 space for laser

FUNDING AND INTERNATIONAL LANDSCAPE



International landscape:

- Several (in part complementary) efforts world-wide proposed to reach Schwinger field
- RF beam at EU.XFEL very well suited
- FACET II should achieve similar sensitivities

MONTE CARLO SIMULATION

Files available for both processes

- Thanks to Tony Hartin!!
- For photon-initiated process, use photons produced by Geant (Sasha Borysov)

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)

Corresponding values:

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

LUXE: EVENT RATE VS LASER INTENSITY

M. Hoffmann

Stage-0:

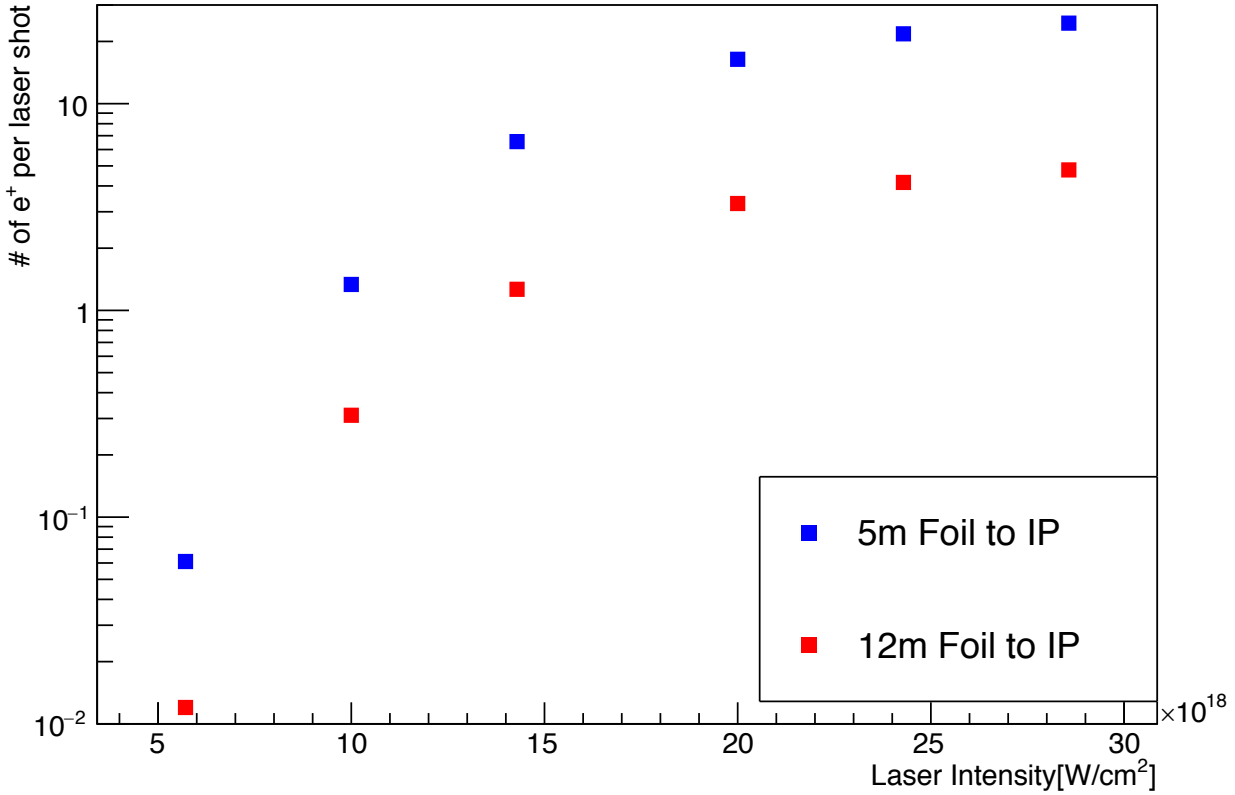
- Laser intensity: $1\text{x}10^{19}$ W/cm^2
- Observe steep rise of rate $\propto \xi^{2n}$

Stage-1

- Laser intensity: $2\text{x}10^{20}$ W/cm^2
- Well into non-perturbative regime
- Observe rate $\propto \chi^2 \exp\left(-\frac{8}{3\chi}\right)$

Real time required:

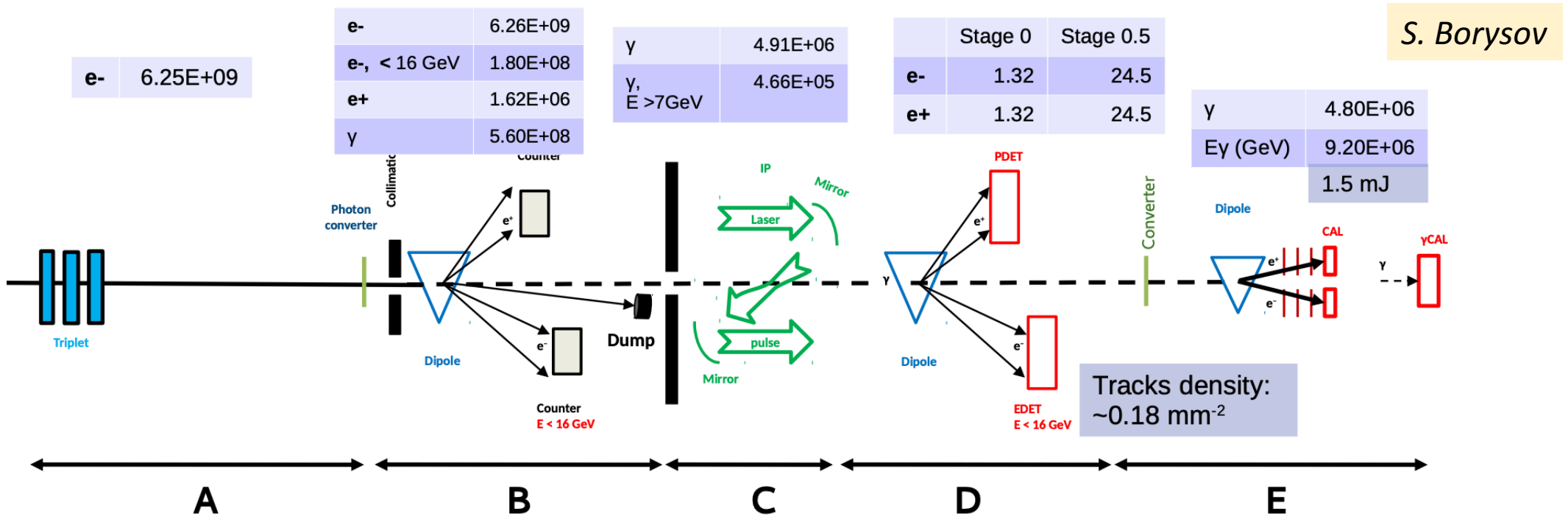
- Laser rate up to 10 Hz
- 1M laser shots ≈ 24 hours



(assumes $6\text{x}10^9$ electrons/bunch, E_e=17.5 GeV)

DESIGN OF DETECTORS

S. Borysov



Particle rates vary between ~10 to 10^9 => choose optimal detector technologies and magnets needed to

a) Count particles
b) Measure energies of particles

DRAFT TIME SCALE: PHASE-0

- **Summer 2019:**
  - Determine feasibility, work plan and possible time scales for the two locations in XFEL tunnel
- **October 2019:**
  - Publish letter of intent (?)
- **November 2019**
  - Application for ERC synergy grant (synergies of laser, particle physics and accelerator physics): for phase-0 “prototype” experiment
  - Obtain letter of support by management and council of EU.XFEL
- **Nov/Dec 2020**
  - Start of installation (?): May extend over two shutdowns (should know in summer 2019)
- **2021-2022 or 2022-2023: prototype experiment (stage-0)**
  - About 2-3 weeks per year likely sufficient but would try to take as much data as possible (if we can prove to be parasitic may be able to run much more)
- **2023/2024:**
  - Publish results of phase-0 experiment

DRAFT TIME SCALE: PHASE-1

- **2023/2024:**
  - Install more powerful laser (need to get money for it before)
- **2025-2027: Data taking with high-power laser (stage-1)**
  - Interesting to run at different energies, beam currents,… configurations
  - Plan to benefit from requirements of other experiments
  - Would like to run as much as possible

FUNDING

DESY

- strategy fund (~200k): ends end of 2019 => will reapply shortly
- The directorate of DESY has included in its financial planning support for the civil construction (for a volume of up to 3 M Euro) for the LUXE experiment, pending successful application of an ERC or other equivalent sources.

Helmholtz Innovation Pool (~500k)

- for laser developments
- Money has not quite arrived yet as far as I know

Grants in Israel (GIF, ISF, Minerva submitted, ~400K): news this summer?

ERC synergy grant (planned Nov. 2019, ~10M)

CONCLUSIONS

- Feasibility studies getting more and more advanced
- So far no show-stoppers identified
- Funding applications have generally been quite successful
- Positive feedback from XFEL.EU scientific advisory committee received
- A lot of things remain to be done!

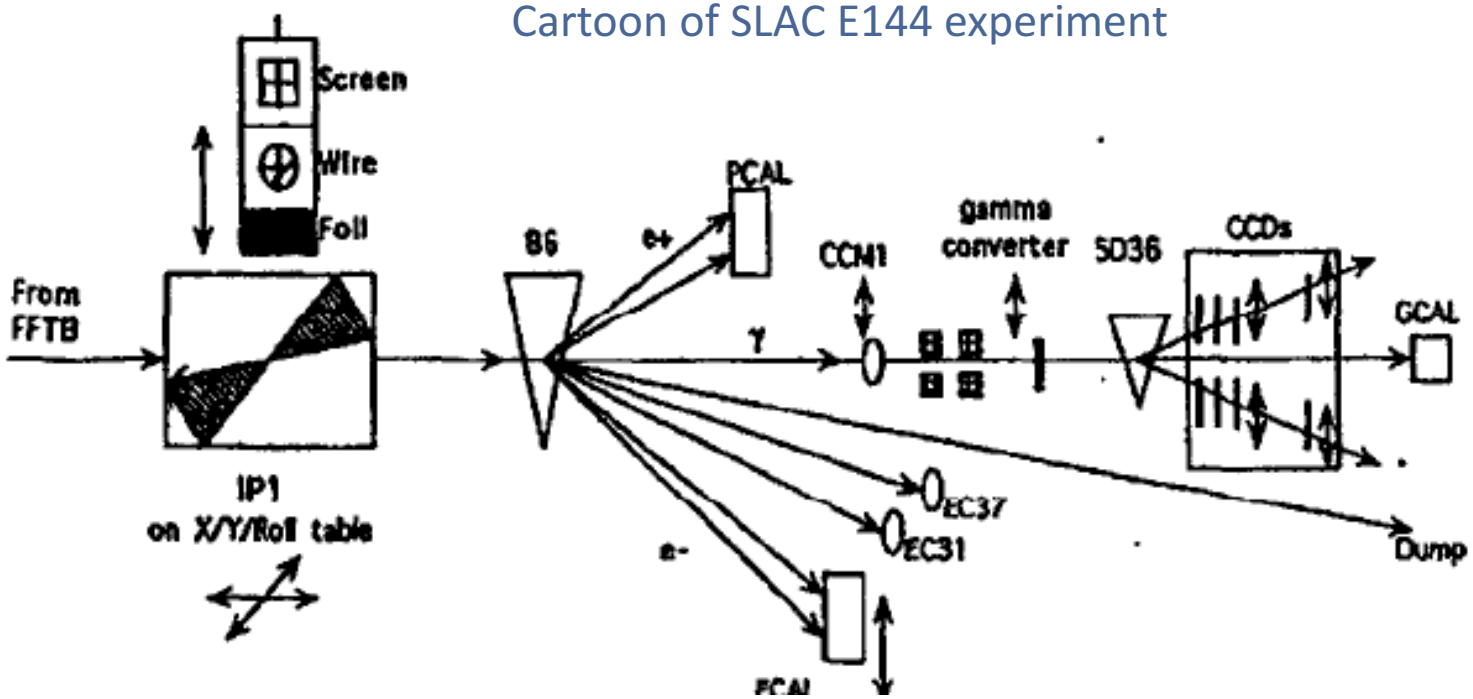
BACKUP SLIDES

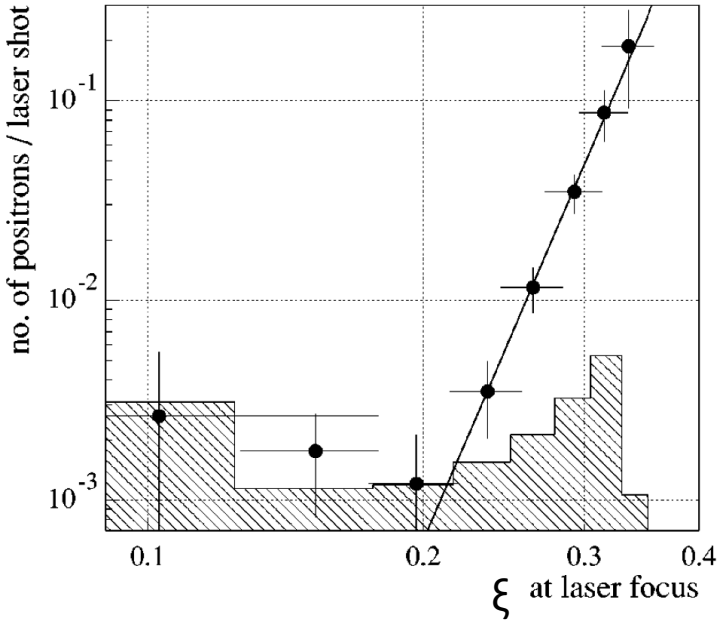
EXPERIMENT E144 AT SLAC

Experiment at SLAC in 1990s achieved $\chi \leq 0.25$

- Electron beam energy: 46.6 GeV
- Did observe the expected strong rise with ξ^{2n} but not the asymptotic limit

Cartoon of SLAC E144 experiment





[Bamber et al. (SLAC 144) '99]

DISCUSSIONS OF TWO LOCATIONS

XSDU1 (near beam dump)

- Modification of beam line
  - downtime to be evaluated.
- Potential delay due to legal situation
  - additional extraction/beam dump, beam line) → plan-approval procedure.
- Maybe radiation towards XTD7
  - additional shiedling required.
- New building at the surface
  - funded by DESY
- Background from beam dump for experiment?
  - Being evaluated

XTD20 (end of LINAC)

- Uses existing building and beam line design.
- Modification of extraction beam line
  - downtime to be evaluated.
  - Extraction and beam line already included in plan-approval.
- Laser beam line transport via XS1 shaft.
- Early implementation of the beam extraction for future XFEL upgrade (2nd XFEL fan) and/or test beam area.
- Additional demonstration of the flexibility of the facility.