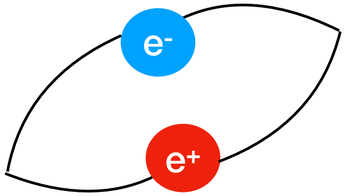
LUXE: A NEW EXPERIMENT TO STUDY NON-PERTURBATIVE QED

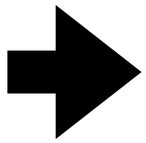
LOUIS HELARY

LUXE - T20 KICKOFF MEETING, NOVEMBER 12TH 2021

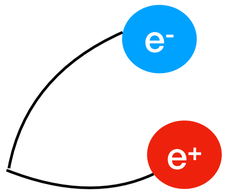
INTRODUCTION: QED, VACUUM AND STRONG FIELD QED

- If one apply a strong electromagnetic field on a vacuum:
  - $W_{field} < 2\ m_e$





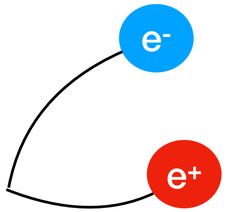
$W_{field} > 2\ m_e$, with: $W_{field} = \frac{\varepsilon e}{m_e}$ and $\varepsilon_{crit} = \frac{m_e^2 c^3}{\hbar e} \simeq 1.3 \cdot 10^{18}\ \mathrm{V/m}$

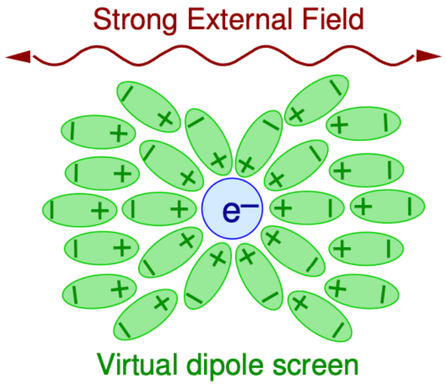


←above Schwinger-limit

  - Quantum ElectroDynamics becomes non perturbative → Strong field QED (SFQED)!

- Experimental consequences:
  - **Field-induced ("Breit-Wheeler") Pair Creation**
  - **Modified Compton Spectrum.**





- Non-perturbative and strong field QED have never been reached in laboratory, accessible by LUXE!
  - Experimentally reached by colliding highly boosted electrons with high-intensity laser!

- Main Luxe scientific goals:
  - Pioneer new regime of quantum physics.
    - Measure positron rate as a function of laser intensity.
    - Measure Compton edges.
  - Study BSM physics.

- LUXE results will have effect over future accelerators, astro- and particle physics and atomic physics!

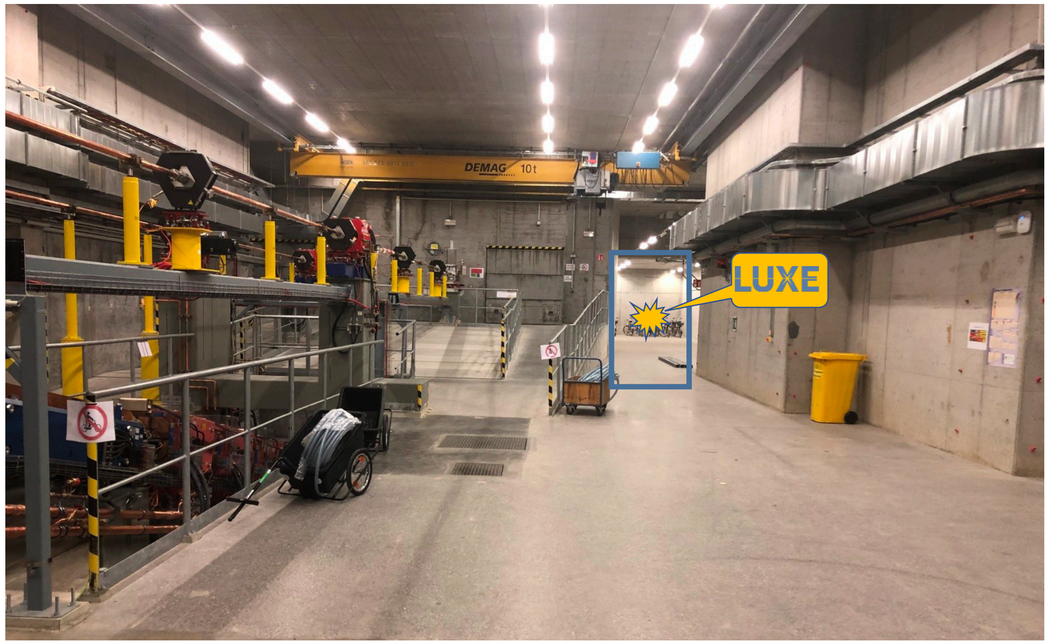
LUXE@EUROPEAN XFEL

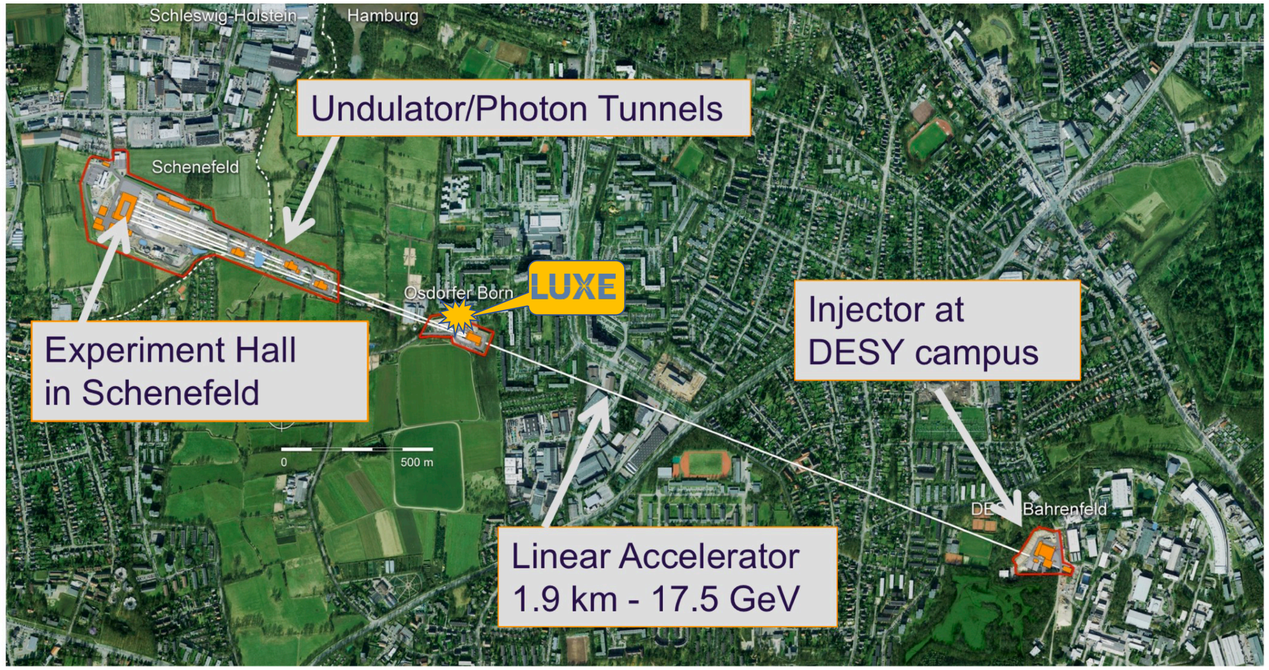
- Experiment will be located in annex of XS1 shaft building in Osdorfer Born.

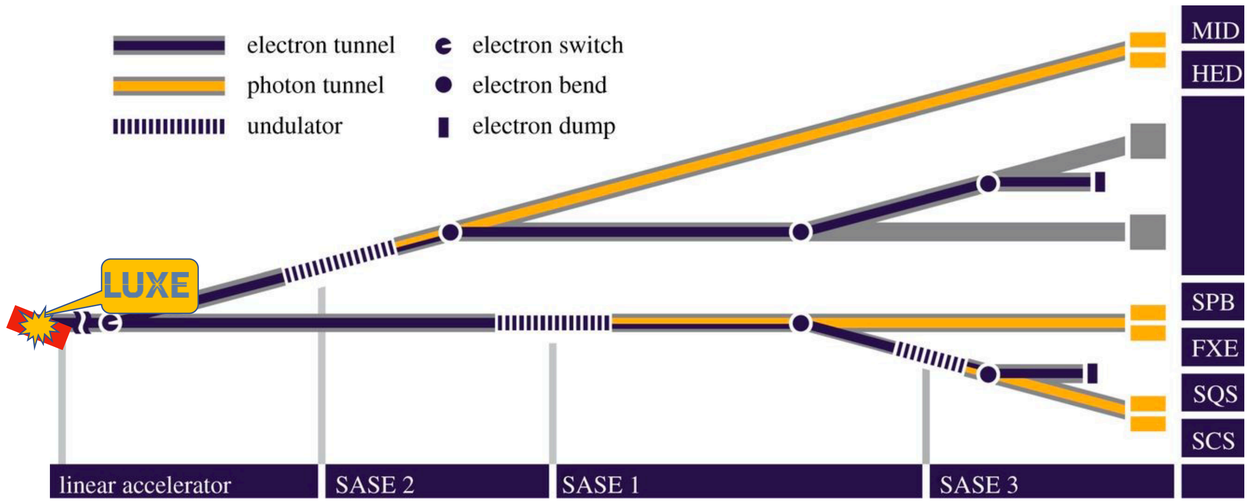
- Beam parameters for LUXE:

Parameter	Max	Typical
Beam Energy [GeV]	17.5	14
Bunch Charge [nC]	1	0.25
Bunch length (RMS) [fs]	80	20
Beam Size [mm]	variable	10
Repetition Rate [Hz]	1-10	13500 (in 10 Hz bursts)

- Experiment designed to have no impact on photon science!







LUXE FOOTPRINT IN XS1 BUILDING

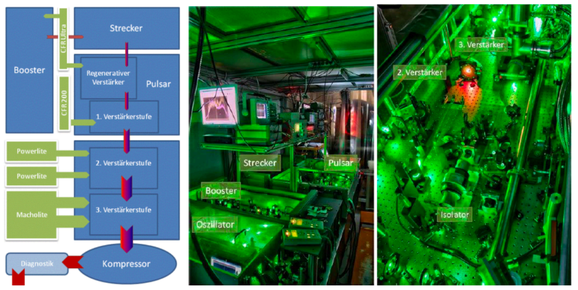
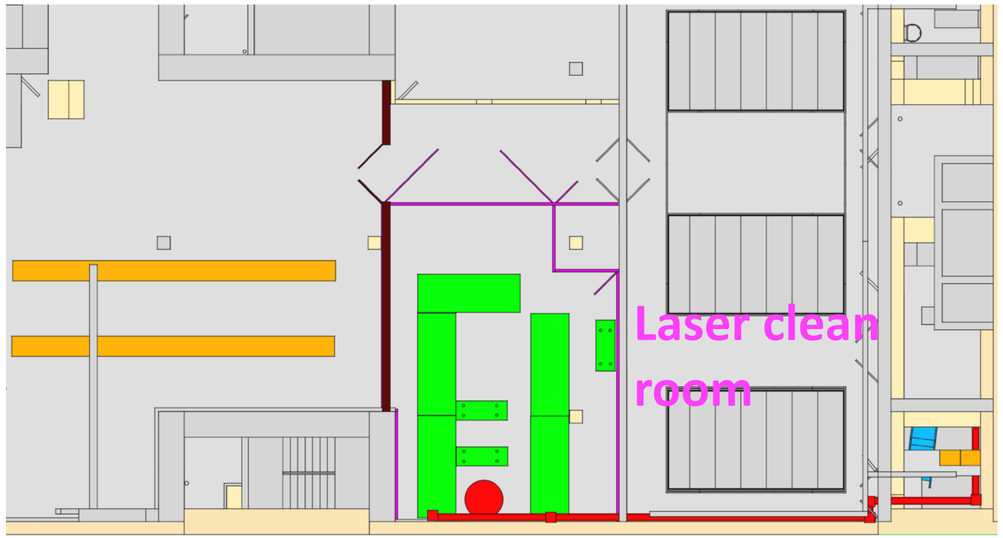


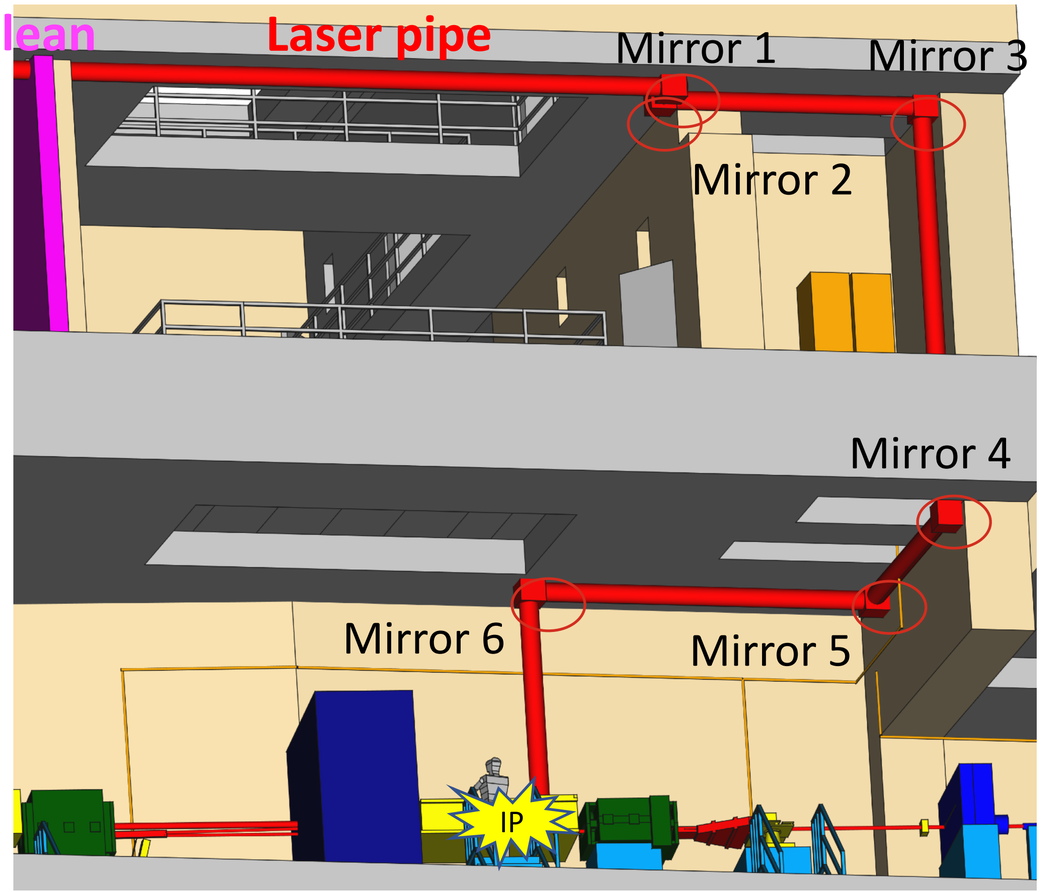
Figure 22. Schematic of the JETI system highlighting major assemblies. Current Installation of JETI-40 at the University of Jena. Front-end is shown in centre and power amplifiers right.

LASER

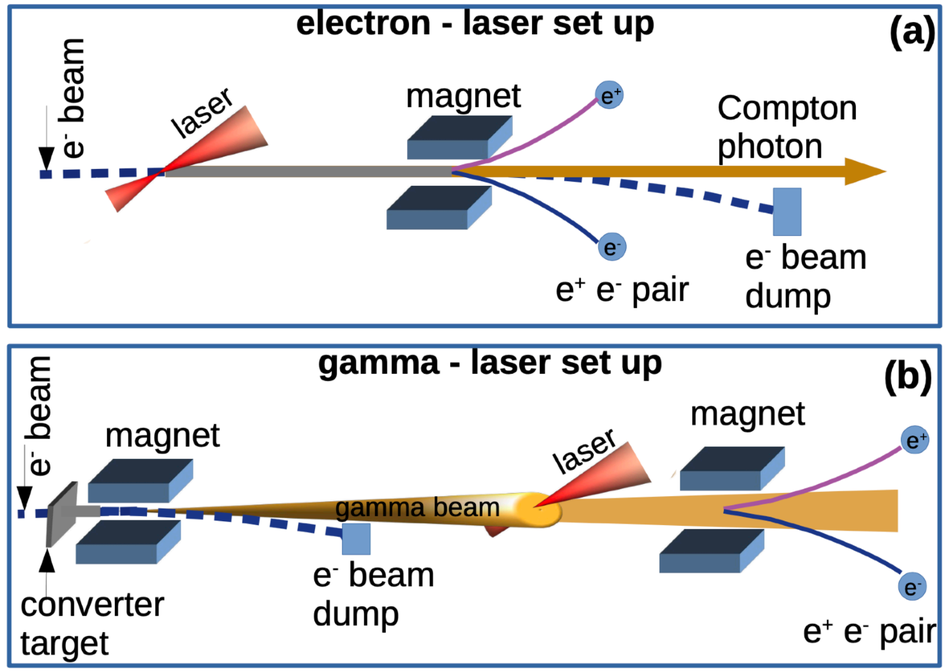
- Use Ti-Sa laser, with CPA technique
  - Peak wavelength at 800nm
- Staged installation
  - Start from a 40 TW laser (that can be the JETI40 or a new system)
  - Then move to commercial 350 TW system.
- Installation planned in UG02 laser to interaction point (IP) with 40m long vacuum pipe.
- Dedicated IP vacuum chamber.
- Could share space and more with ChirpTaper project.
  - Potentiality to share up to laser front end (being discussed).
- Summary, main characteristics of clean room
  - Volume clean-room 300m^3
  - Temperature in the clean-room: 21± 0.5 °C
  - Humidity in the clean-room: 40 ± 5%

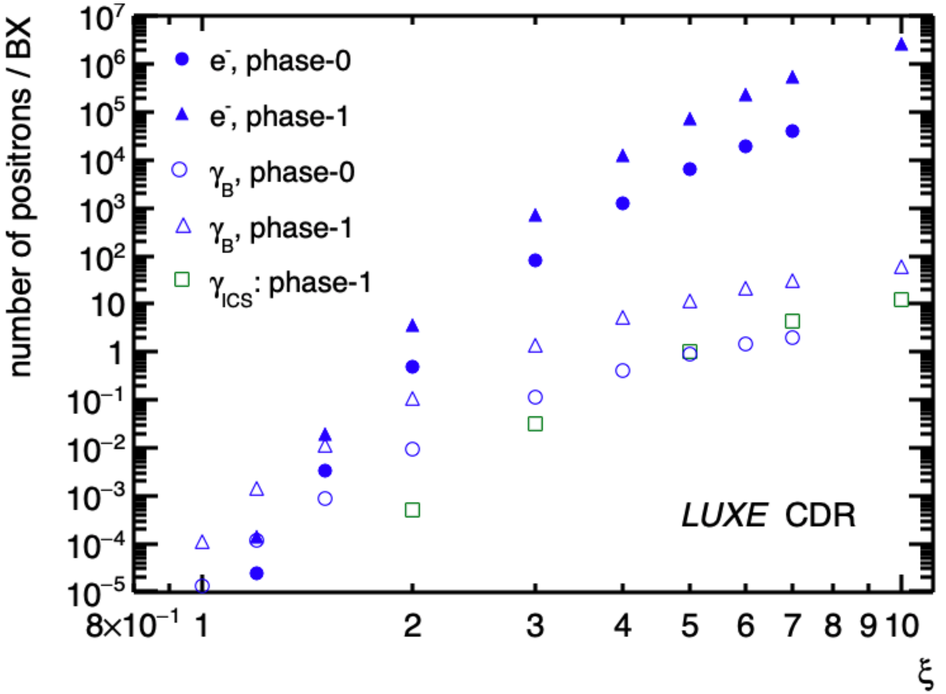
Parameter	Phase 0		Phase 1
Laser Power [TW]	40		350
Laser energy after compression [J]	1.2		10
Percentage of Laser in focus [%]	50		
Laser focal spot size w_0 [μm]	> 8	> 3	> 3
Peak intensity in focus [$\times 10^{19}$ Wcm^{-2}]	1.9	13.3	120
Peak intensity parameter ξ	3.0	7.9	23.6
Peak quantum parameter χ for E_e = 16.5 GeV	0.56	1.50	4.45

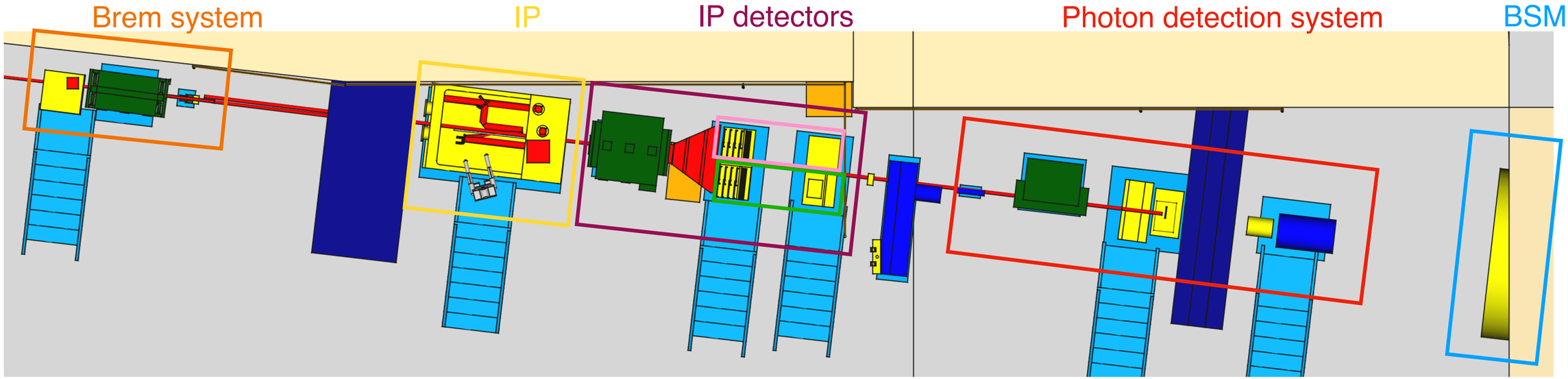




EXPERIMENT


electron - laser set up
(a)
e⁻ beam
laser
magnet
e⁺
Compton photon
e⁻
e⁺ e⁻ pair
e⁻ beam dump
gamma - laser set up
(b)
e⁻ beam
magnet
laser
magnet
e⁺
gamma beam
e⁻ beam dump
converter target
e⁻
e⁺ e⁻ pair


number of positrons / BX
e⁻, phase-0
e⁻, phase-1
γB, phase-0
γB, phase-1
γICS: phase-1
LUXE CDR
ξ

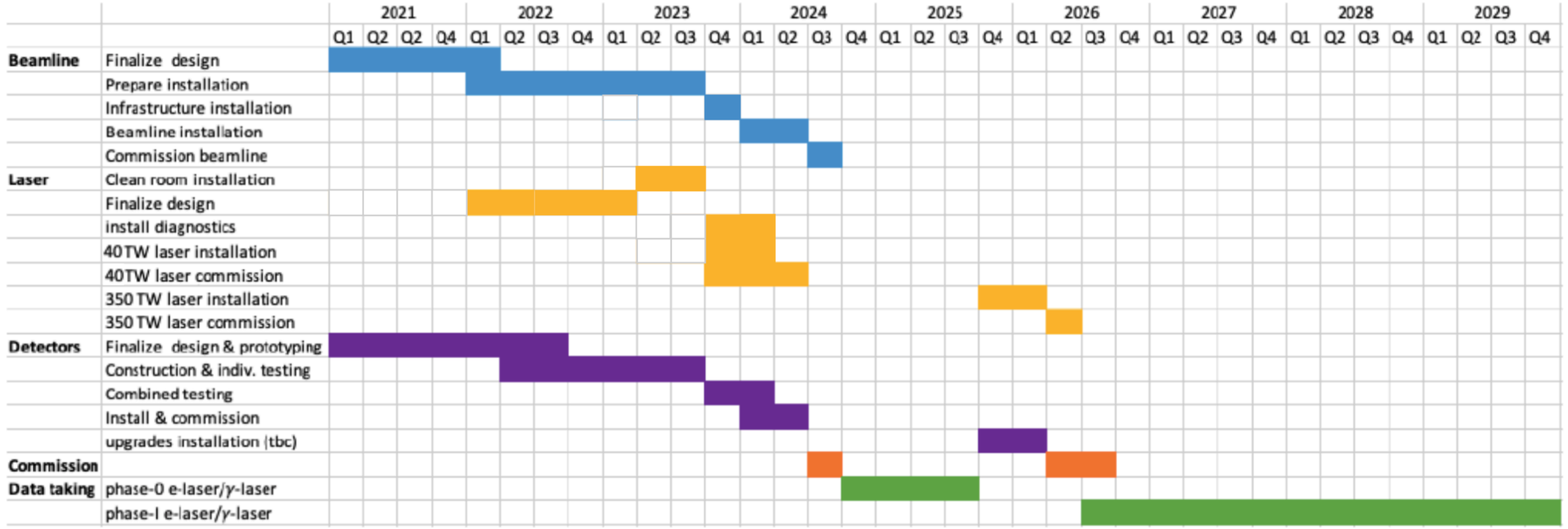

Brem system
IP
IP detectors
Photon detection system
BSM detector

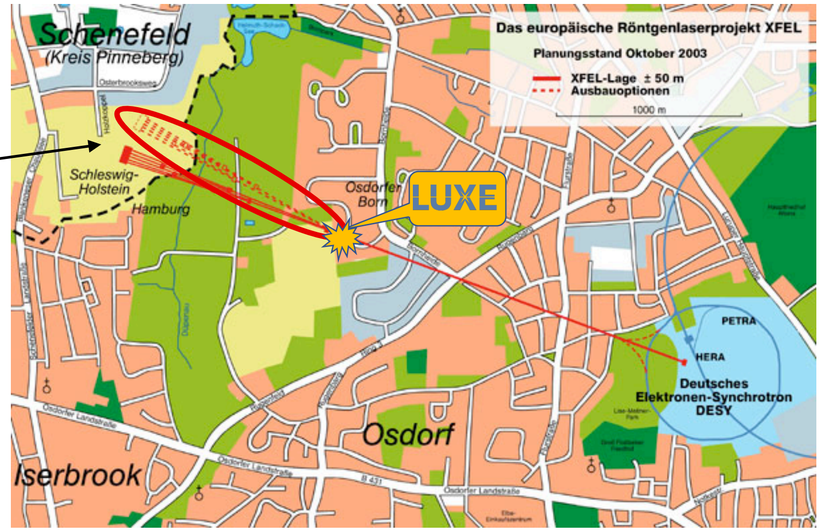
ONE WORD ON THE PLANING

- CDR recently released.
  - Now working toward TDR for 2022.

- Experiment now decoupled from beam-line planing.
  - With the caveat that to start data-taking experiment need beam-line.
  - Would be nice if most of experiment can be installed in 2024.
    - Long shutdown of the XFEL.
  - Baseline:
    - Data taking to start in 2024.
      - Start with e-laser.
      - γ-laser to start in 2025.
      - Laser upgrade (350 TW) in 2026.
      - Run until XFEL want to construct new fan (2029 for now).
  - Working on alternative scenario where missing pieces of the experiment could be installed in regular shutdown of the XFEL.

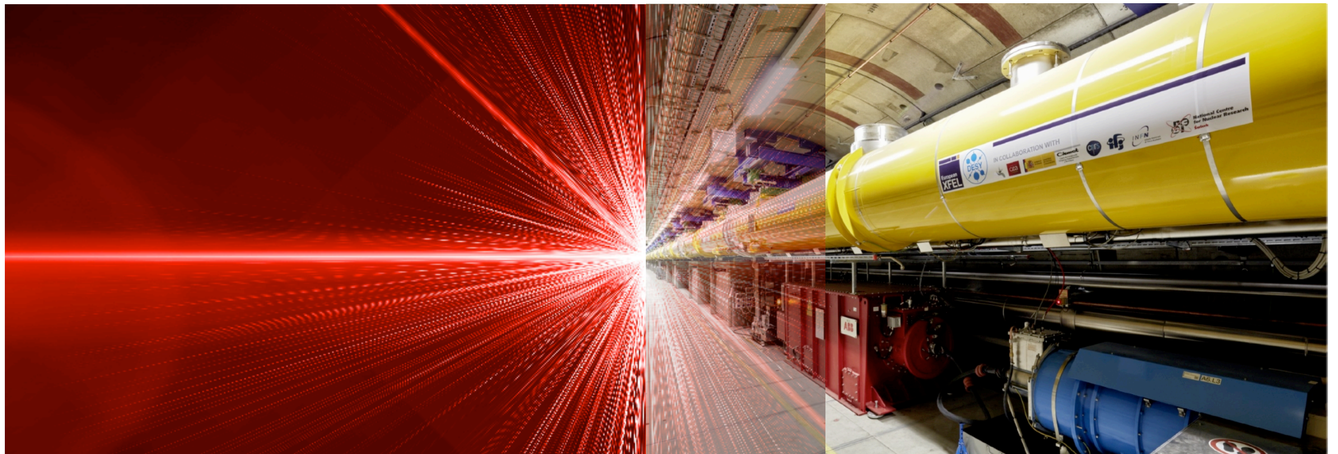
- In parallel of review continue detector R&D, and experiment planification.
  - Plan to perform multiple test-beam campaign in the future.





CONCLUSIONS

- The LUXE experiment will allow to measure QED in uncharted regime!
  - Might expect some surprises there!
- Experiment working toward being integrated in DESY-Roadmap.
- Installation planing of different elements is currently being investigated.
  - Laser as soon as possible, to allow early commissioning.
  - As much as possible of the TD20 line and experiment in 2024.
    - Rest in shorter shutdown.
- Experiment installation is highly stageable and adaptable with external constraints.
  - The sooner the data-taking can start the better for the physics.



Back up

NEXT STEPS

Beam Extraction

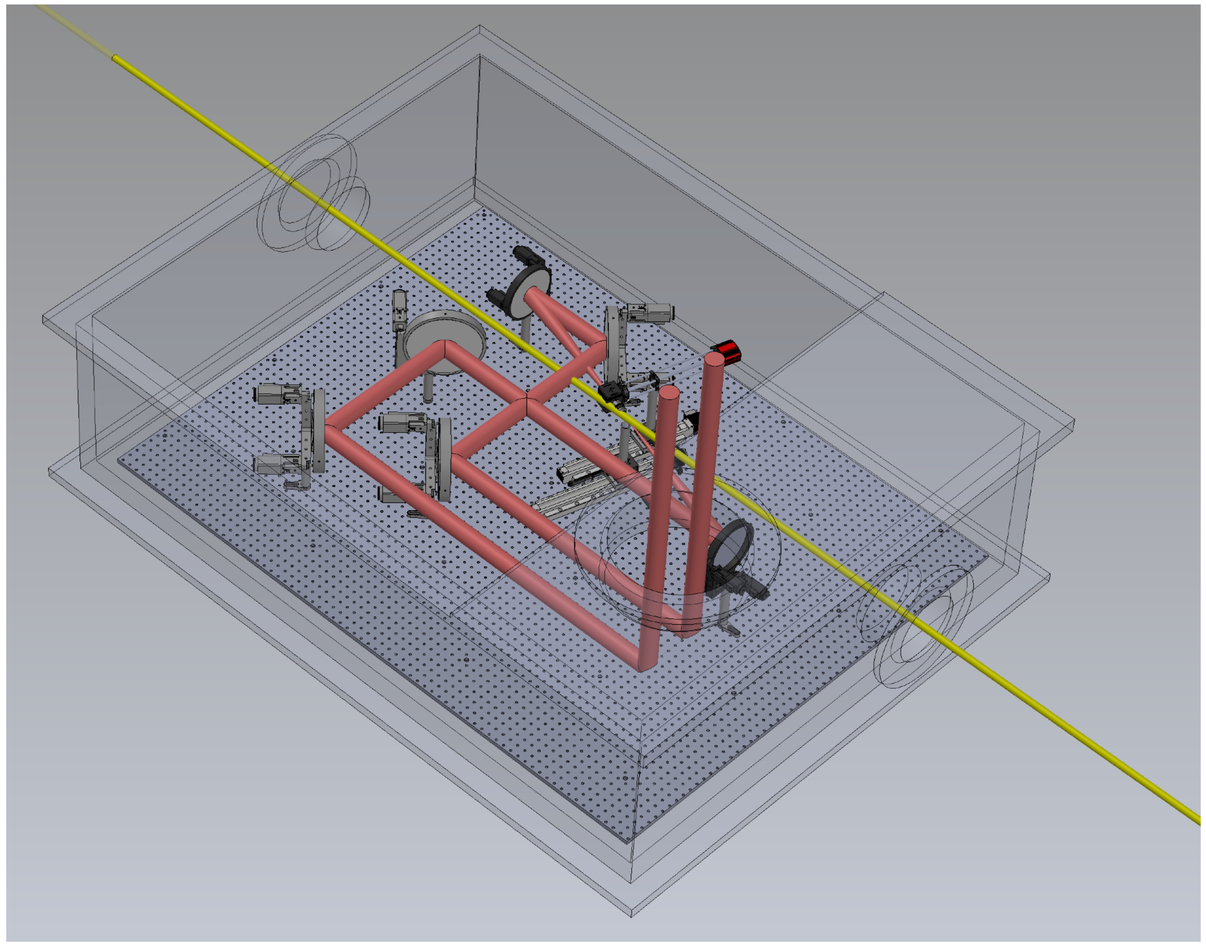
- **Oct. 2021:** Hire of additional technician/engineer at MEA and MVS
- **Oct. 2021:** Freeze of lattice for XFEL 2024 upgrade, including beam extraction to TD20 up to LUXE final focus triplet, internal review (Note: external review by MAC already in 2020)
- **Nov. 2021:** Full inventory for long lead items (magnets, power supplies, beam instrumentation) exists, start to prepare purchase
- **Nov. 2021:** Start of XS1 technical integration meetings to allocate and distribute space for technical and laser infrastructure in XS1/XHE1, including also requirements for SASE1/SASE2 chirp-taper projects, eventually hire additional personnel for MKK and MPC
- **Nov. 2021:** Start mechanical engineering for beamline integration and support (Note: engineering for beamline components does exist to a large extend); start vacuum engineering
- **Jan. 2022:** Purchase of long lead items (magnets, power supplies, auxiliaries)
- **Sep. 2022:** Finalise mechanical, vacuum and XS1 infrastructure engineering, internal review
- **Jul. 2023:** Last delivery of long lead items, quality check and pre-integration
- **Oct. 2023:** Finalise installation plan and resource requirements (integrated into XFEL2024 schedule), internal review

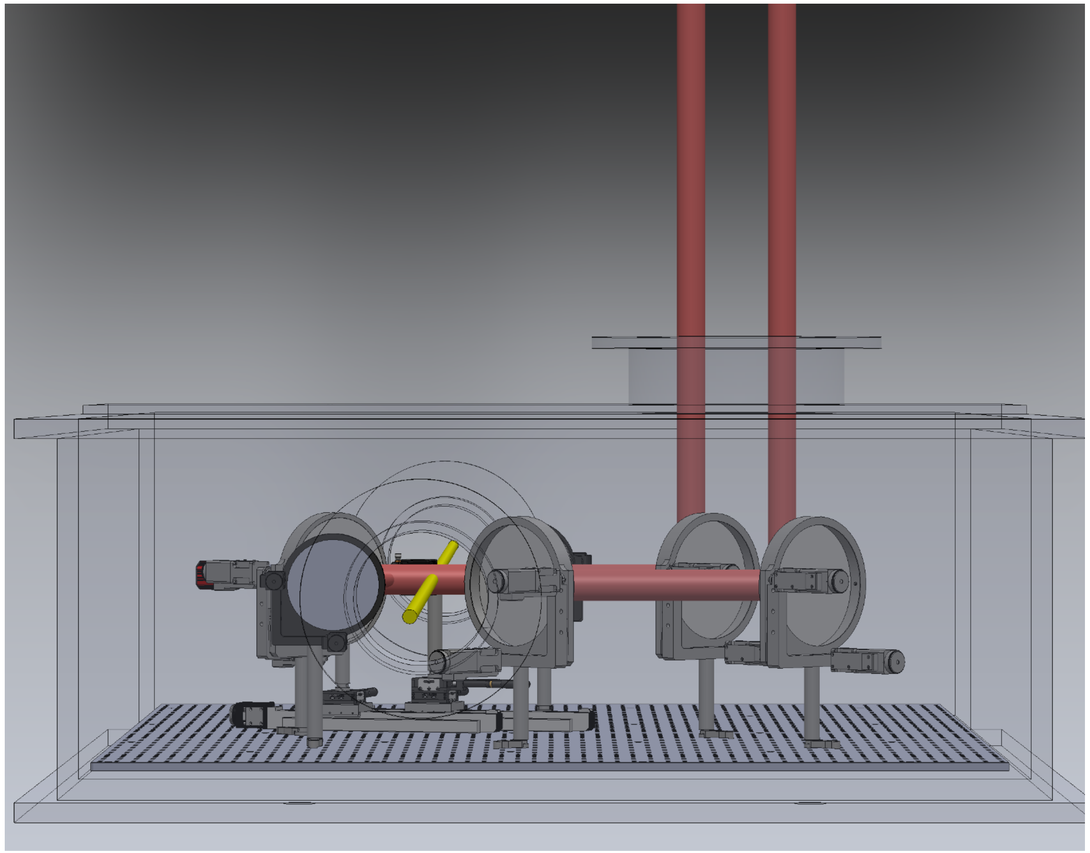
Experiment

- **Dec. 2021:** Draft installation plan ready => Goal install “as much as possible”during 2024 shutdown and the rest in shorter 2-4 week shutdowns.
- **Dec. 2021:** Start of ISO6 Laser clean-room technical specifications to prepare call for tender
- **Feb. 2022:** Start design supporting structure in experimental area, to prepare call for tender.
- **Mar. -May 2022:** Start Laser clean-room and support structures call for tender(3-6 months).
- **Jul. -Aug. 2022:** End call for tender Laser clean-room and support structures, company chosen start technical design and installation planing
- **Aug. 2022:** Start design of experiment counting room refurbishment.
- **Oct. 2022:** Finalise early installation plan and resource requirements.
  Dec. 2022: Early phase install: XS1-UG02: counting room and laser clean-room; XS1-UG03: Supporting structure.
- **Jan. 2023:** Install and commissioning JETI40 in XS1
- **Jul. - Oct. 2023:** Last delivery of long lead items (Magnets and Detectors), quality check and pre-integration
- **Oct 2023:** Finalise installation plan and resource requirements (integrated into XFEL2024 schedule), internal review

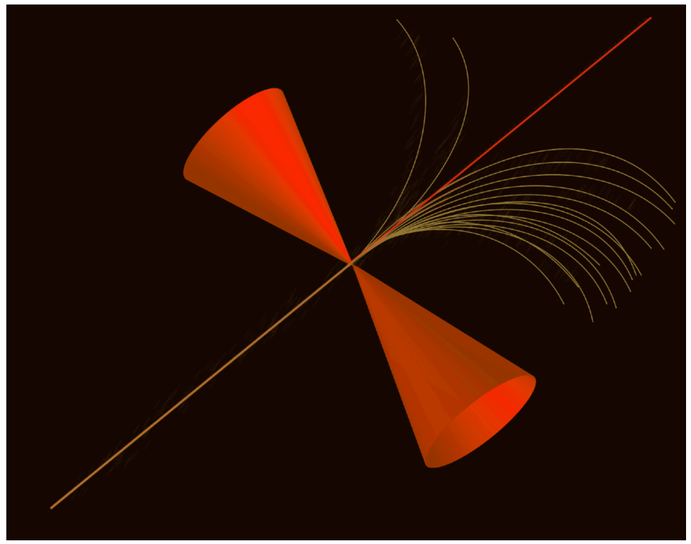
IP CHAMBER

- IP Chamber main characteristics:
  - Vacuum: 10^-6 mbar
  - Dimensions: 2m*1.m*0.4m





THANK YOU FOR YOUR ATTENTION!

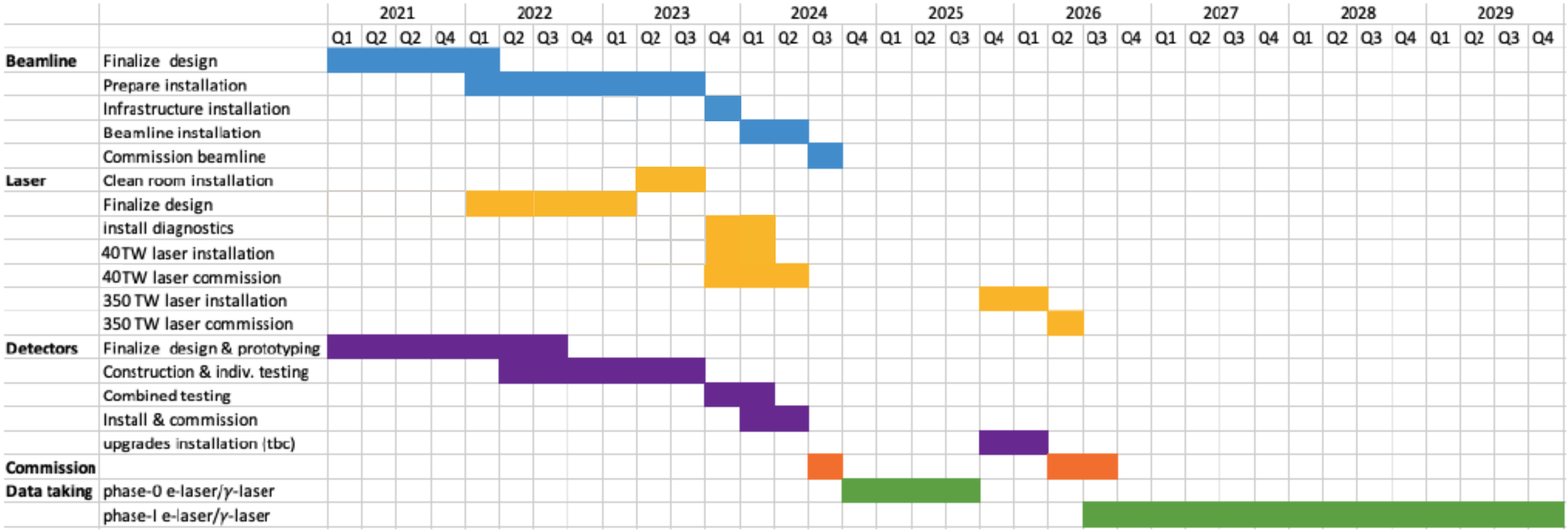


Conceptual Design Report for the LUXE Experiment

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[5,15,20], 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]

CDR, accepted by European Physics Journal ST:
https://arxiv.org/abs/2102.02032

[1]*Tel Aviv University, Tel Aviv, 6997801, Israel*
[2]*TU Dresden, 01062 Dresden, Germany*
[3]*Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany*
[4]*Max Planck Institute for Structure and Dynamics of Matter, 22761 Hamburg, Germany*
[5]*Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg, Germany*
[6]*Weizmann Institute of Science, Rehovot, 7610001, Israel*
[7]*Department of Physics, Southern University of Science and Technology, Shenzhen 518055, China*
[8]*University of Gothenburg, SE-41296 Gothenburg, Sweden*
[9]*John Adams Institute at Royal Holloway, Department of Physics, Royal Holloway, Egham, TW20 0EX, Surrey, UK*
[10]*Institute for Nuclear Research NASU (KINR), Kyiv, 03680, Ukraine*
[11]*INFN and University of Bologna, Bologna, Italy*
[12]*School of Mathematics and Physics, The Queen's University of Belfast, Belfast, BT7 1NN, UK*
[13]*INFN and University of Padova, Padova, Italy*
[14]*National Research Nuclear University MEPhI, Kashirskoe sh. 31, Moscow, 115409, Russia*
[15]*Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, Poland*
[16]*Joint Institute for Nuclear Research (JINR), Dubna 141980, Russia*
[17]*University College London, London, WC1E 6BT, UK*
[18]*Helmholtz Institut Jena, 07743 Jena, Germany*
[19]*Friedrich Schiller Universität Jena, 07743 Jena, Germany*
[20]*Albert-Ludwigs-Universität Freiburg, 79085 Freiburg, Germany*
[21]*University of Plymouth, Plymouth, PL4 8AA, UK*
[22]*Department of Physics, Nuclear Research Centre-Negev, P.O. Box 9001, Beer Sheva 84190, Israel*
[23]*Physics Department, Technion—Israel Institute of Technology, Haifa 3200003, Israel*
[24]*Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*
[25]*LIDYL, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91 191 Gif-sur-Yvette, France*
[26]*Institute of Nuclear Physics, TU Darmstadt, 64289 Darmstadt, Germany*
[27]*Skolkovo Institute of Science and Technology (Skoltech), Moscow 121205, Russia*
[28]*INFN Trieste, Trieste, Italy*
[29]*National Research Tomsk State University NI TSU, TSU, Russia*


2021
2022
2023
2024
2025
2026
2027
2028
2029
Q1 Q2 Q2 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Beamline
Finalize design
Prepare installation
Infrastructure installation
Beamline installation
Commission beamline
Laser
Clean room installation
Finalize design
install diagnostics
40TW laser installation
40TW laser commission
350 TW laser installation
350 TW laser commission
Detectors
Finalize design & prototyping
Construction & indiv. testing
Combined testing
Install & commission
upgrades installation (tbc)
Commission
Data taking
phase-0 e-laser/γ-laser
phase-I e-laser/γ-laser