EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
eXCELLENCE IN
APPLICATIONS

EuPRAXIA-LPA – A EuPRAXIA Construction Site Based on Laser-Driven Plasma Acceleration

Maria Weikum[1]

On behalf of Ralph Assmann and the EuPRAXIA Collaboration

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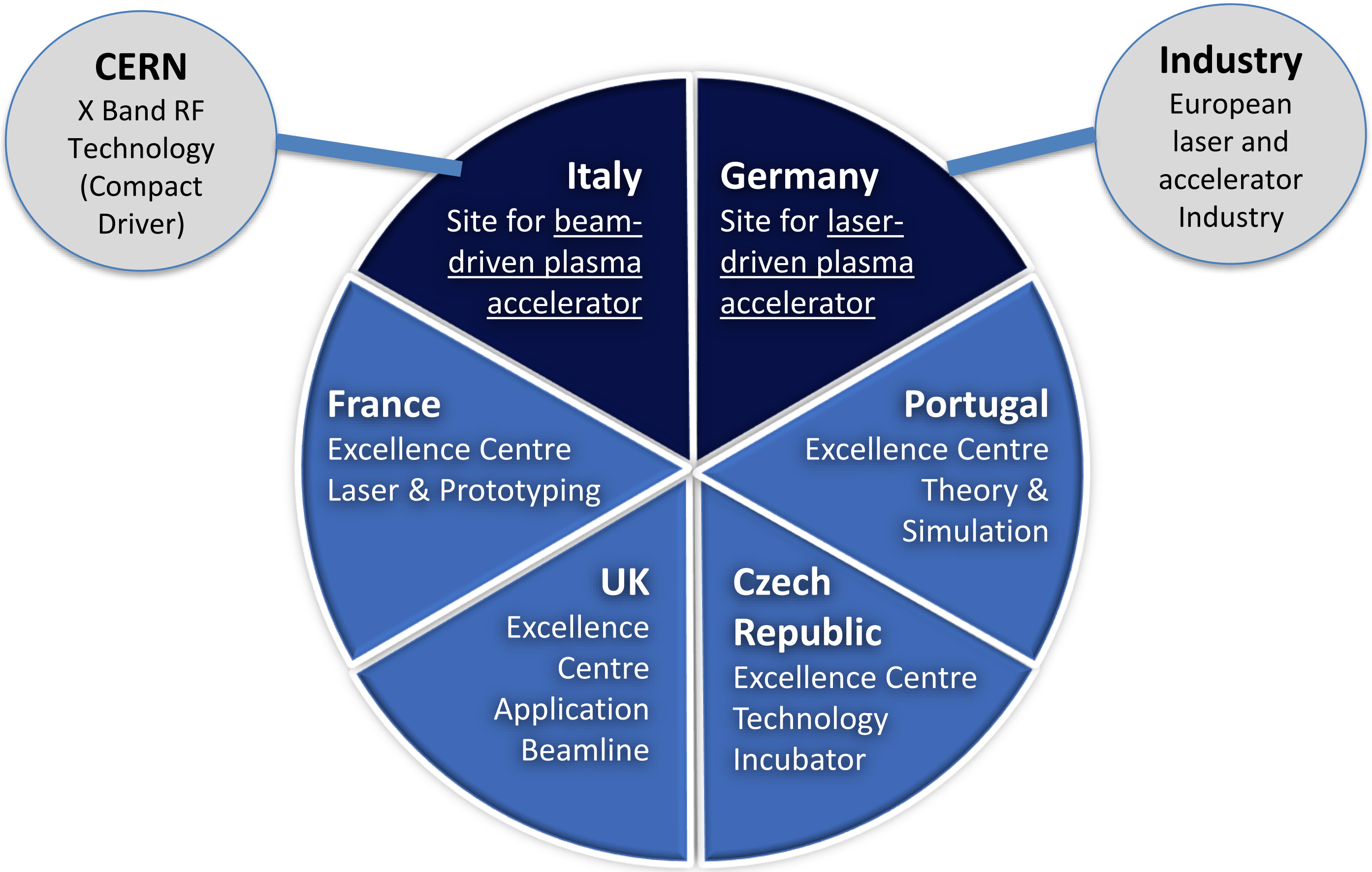
EuPRAXIA FEL Pilot User Application Workshop
17th June 2019 – Rome, Italy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

A Construction Site Based On LWFA



CERN
X Band RF Technology (Compact Driver)

Italy
Site for beam-driven plasma accelerator

Germany
Site for laser-driven plasma accelerator

Industry
European laser and accelerator Industry

France
Excellence Centre Laser & Prototyping

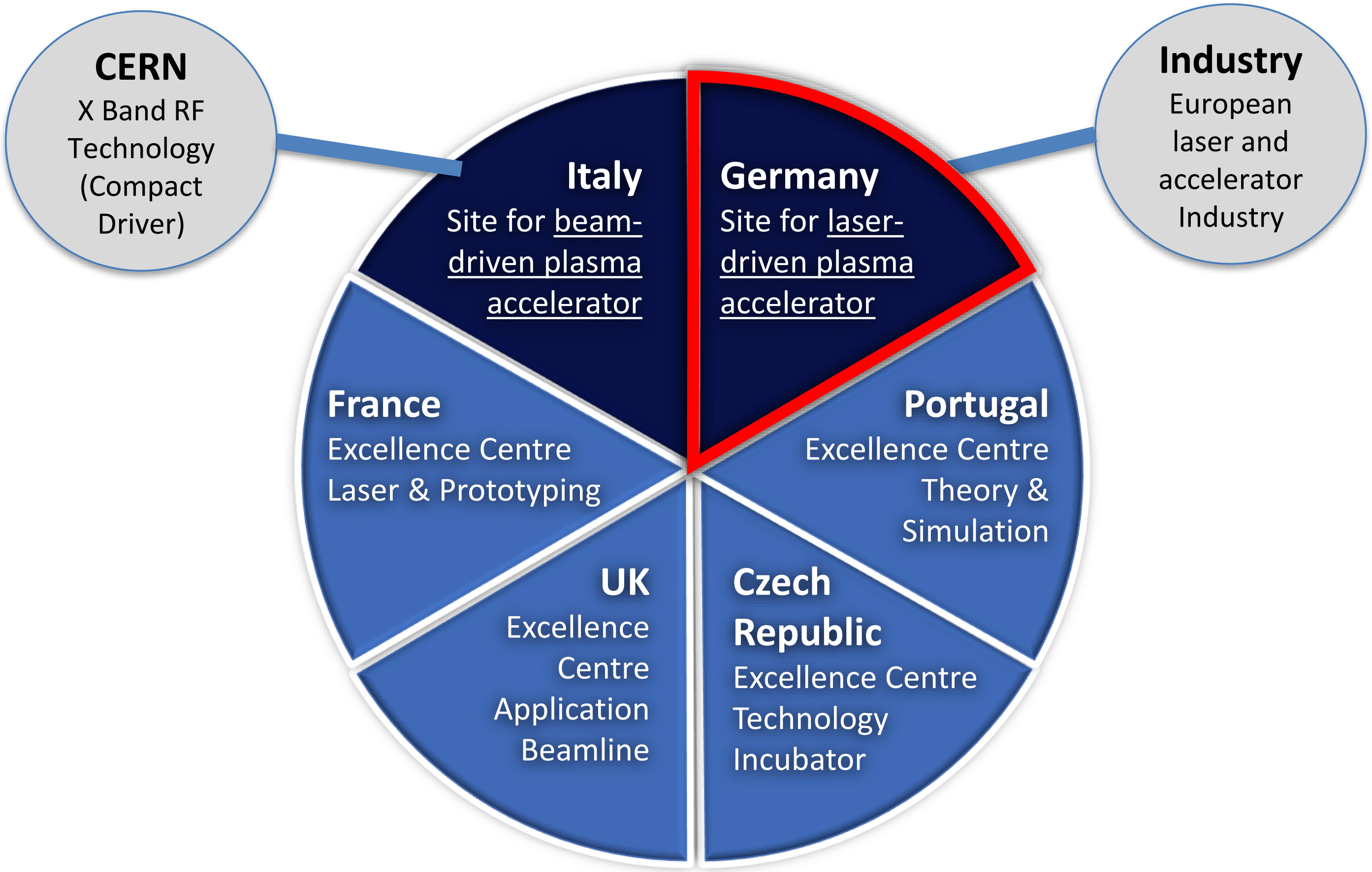
Portugal
Excellence Centre Theory & Simulation

UK
Excellence Centre Application Beamline

Czech Republic
Excellence Centre Technology Incubator

PRELIMINARY

A Construction Site Based On LWFA



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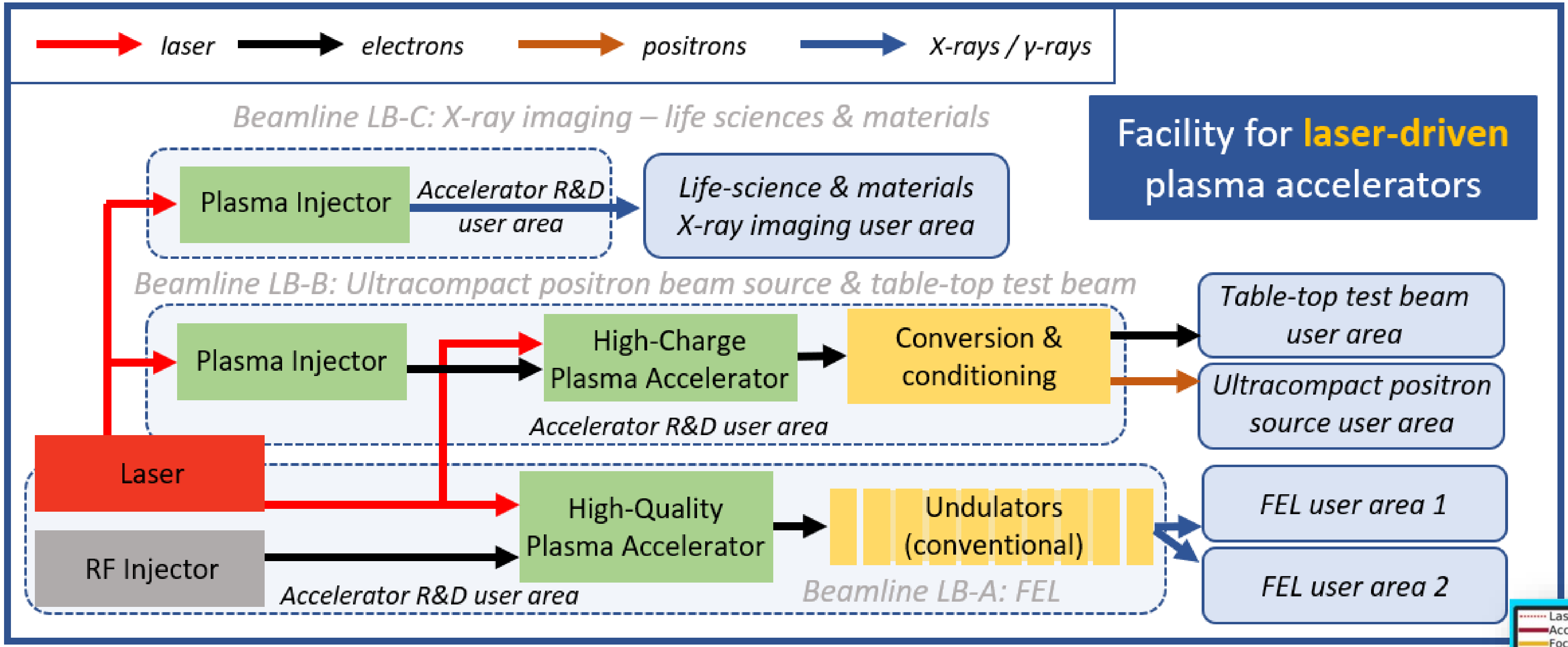
PRELIMINARY

Outline

- Construction site overview
  - Accelerator beamlines
  - Non-X-ray applications
  - Betatron X-ray source
  - FEL source
- Possible site location
- Conclusion and open points

Construction Site Layout



laser → electrons → positrons → X-rays / γ-rays

Facility for **laser-driven** plasma accelerators

Beamline LB-C: X-ray imaging – life sciences & materials

Plasma Injector → *Accelerator R&D user area* → *Life-science & materials X-ray imaging user area*

Beamline LB-B: Ultracompact positron beam source & table-top test beam

Plasma Injector → High-Charge Plasma Accelerator → Conversion & conditioning → *Table-top test beam user area* / *Ultracompact positron source user area*

Accelerator R&D user area

Laser

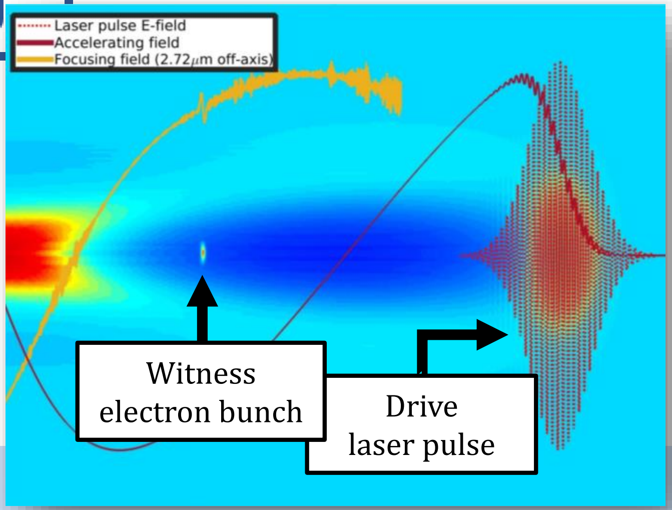
RF Injector → High-Quality Plasma Accelerator → Undulators (conventional) → *FEL user area 1* / *FEL user area 2*

Accelerator R&D user area

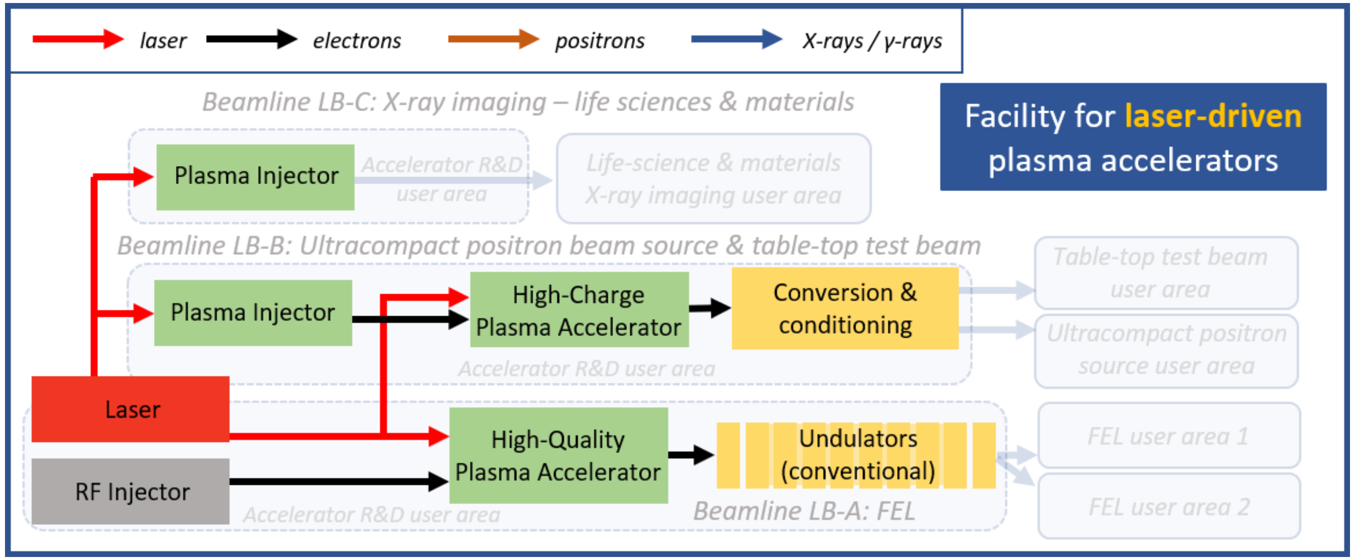
Beamline LB-A: FEL

***LWFA** = **L**aser **W**ake**f**ield **A**cceleration (i.e. plasma acceleration with a high-power laser pulse driving the accelerating wakefield)*

- ☐ Based on laser-driven plasma acceleration (LWFA)
- ☐ Three beamlines, eight user areas
- ☐ Three types of beams: electrons, positrons, X-rays



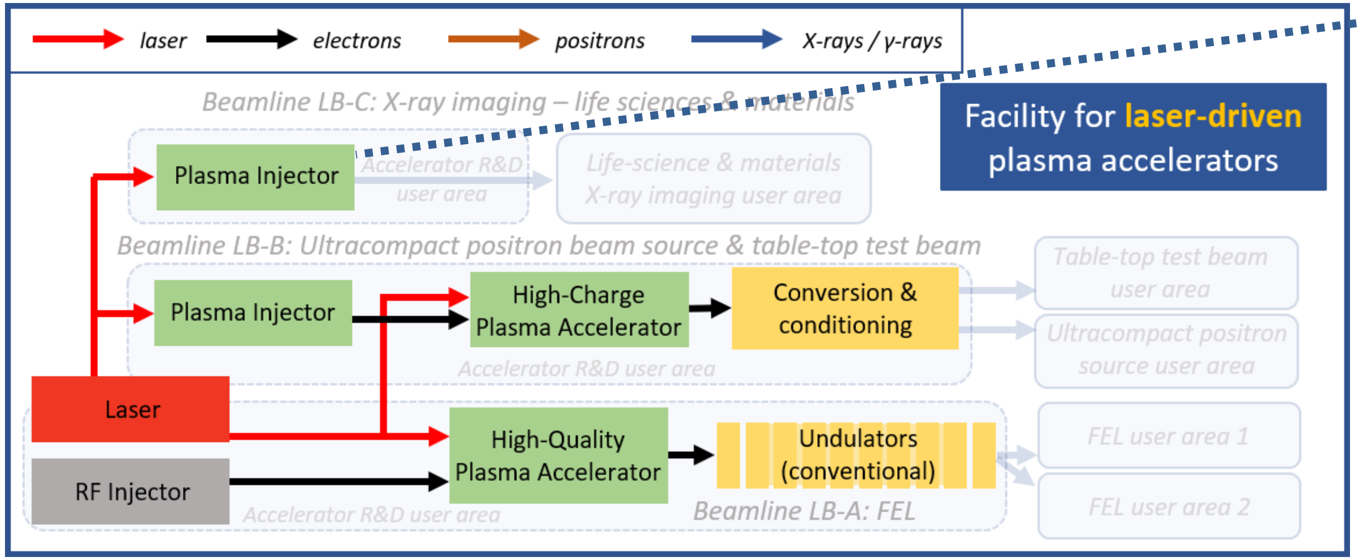
Site Layout – Accelerator Beamlines



EuPRAXIA

Site Layout – Accelerator Beamlines

Horizon 2020



laser electrons positrons X-rays / γ-rays

Beamline LB-C: X-ray imaging – life sciences & materials

Plasma Injector

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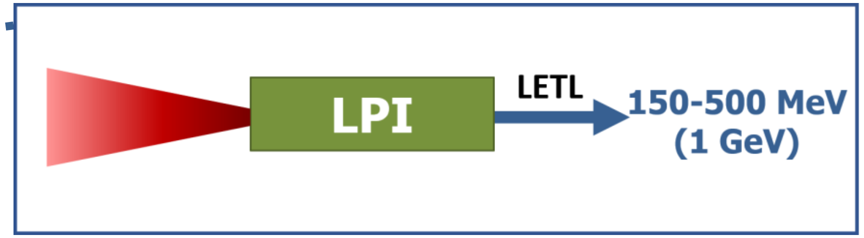
Beamline LB-A: FEL

FEL user area 1

FEL user area 2

Facility for **laser-driven** plasma accelerators



LPI

LETL

150-500 MeV (1 GeV)

LPI	= *Laser-Plasma Injector*	⊓	= *Chicane*
RFI	= *RF-Injector*	***LETL***	= *Low-Energy Transport Line*
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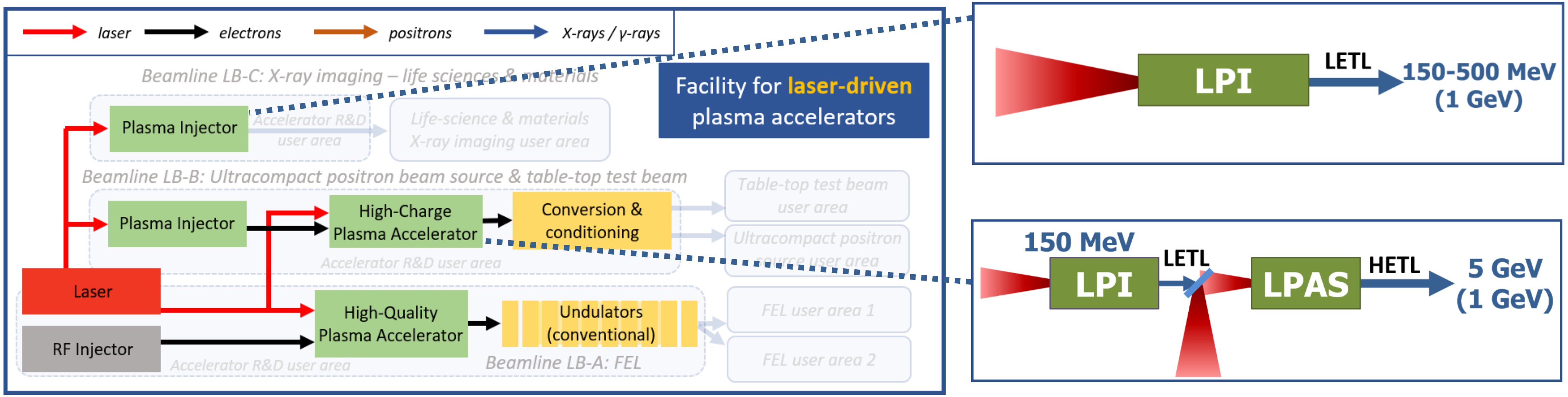

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LPI
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150-500 MeV (1 GeV)

150 MeV
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LPAS
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5 GeV (1 GeV)

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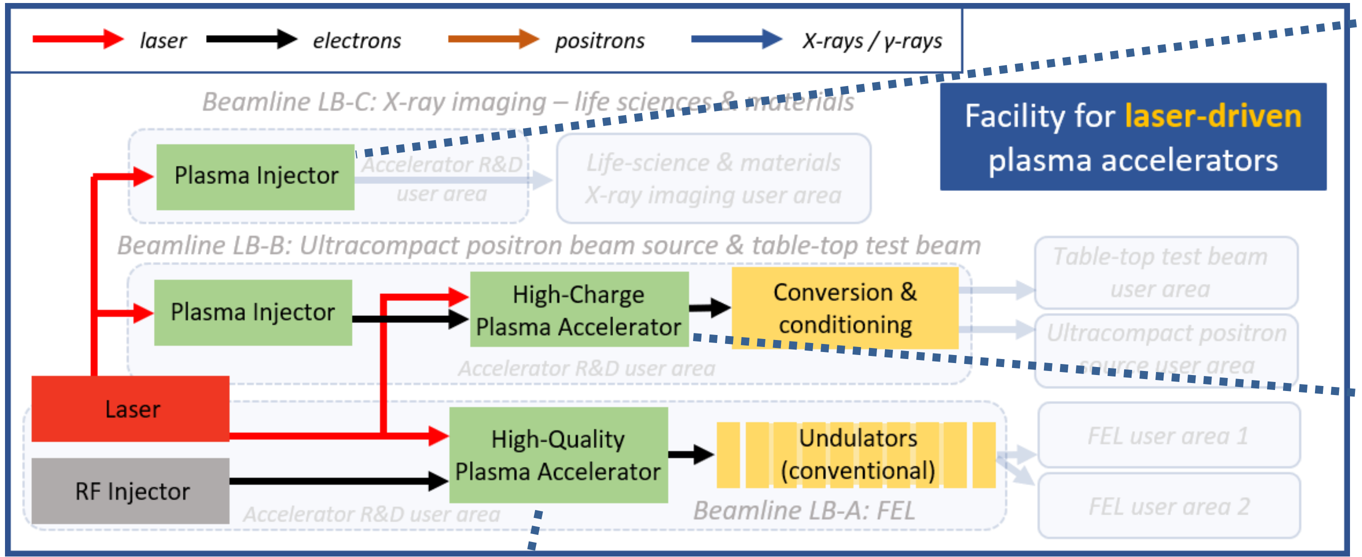
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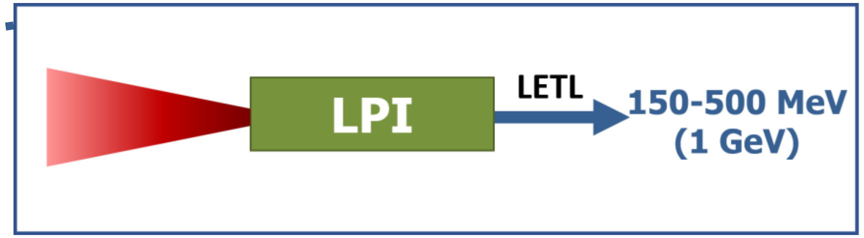

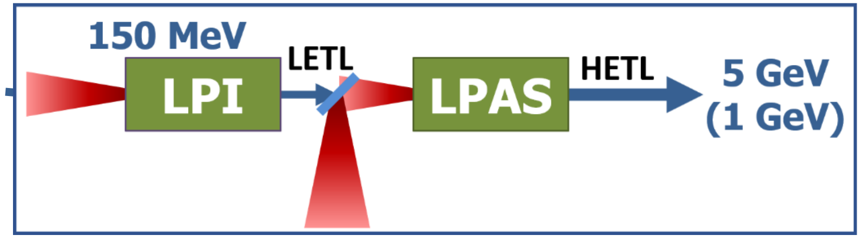

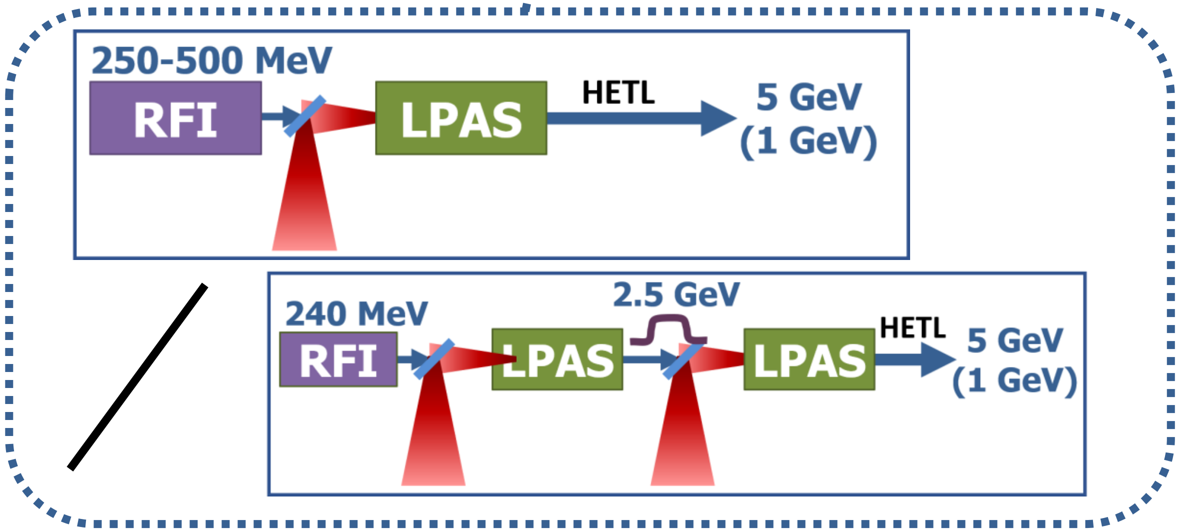

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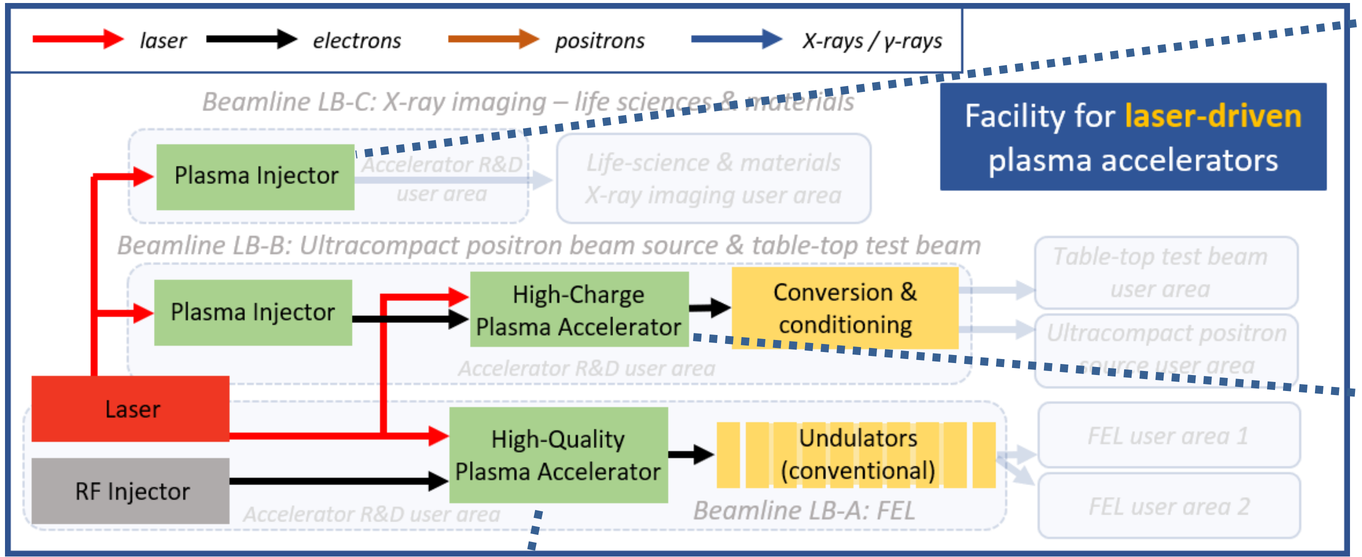

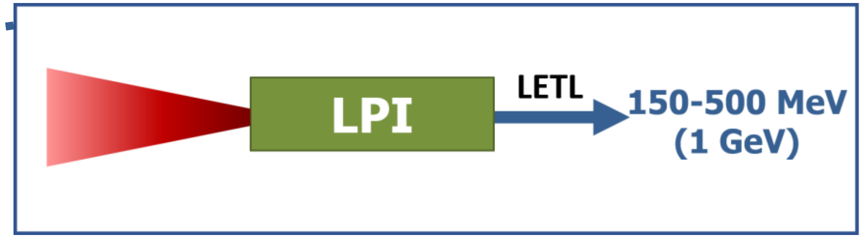

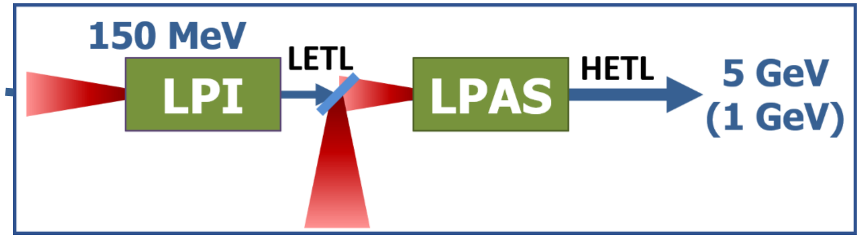

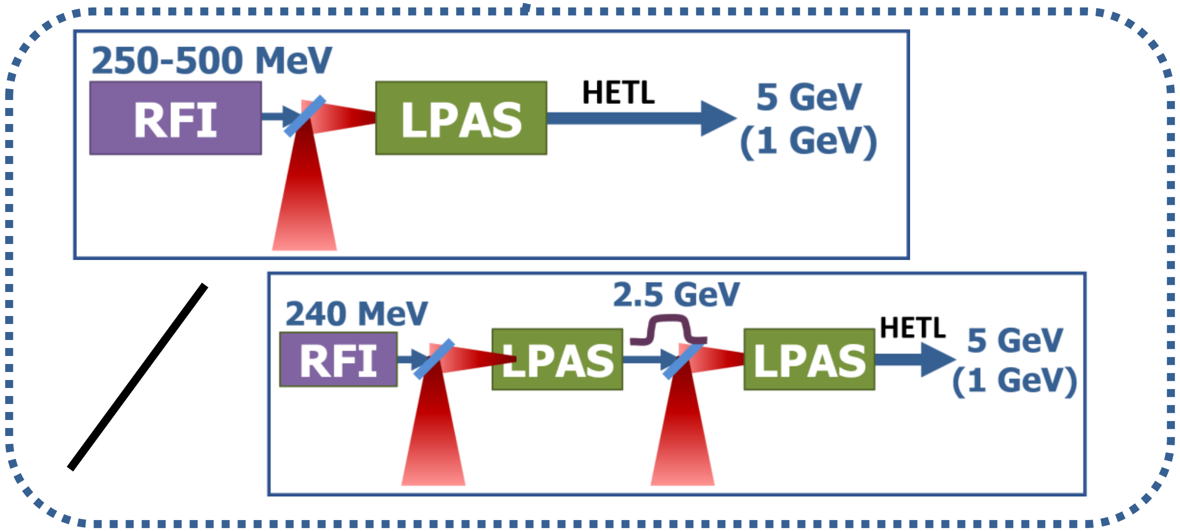

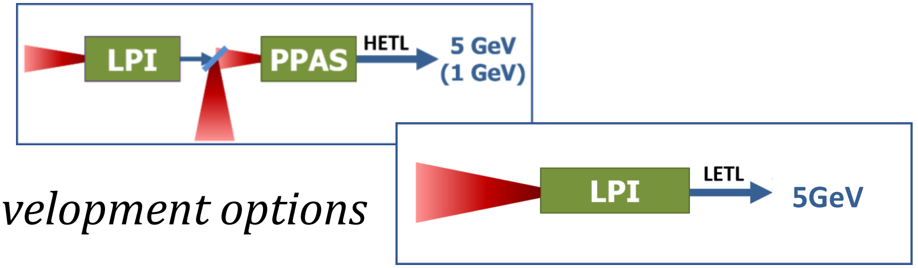

+ future development options

LPI	*= Laser-Plasma Injector*	⊓	*= Chicane*
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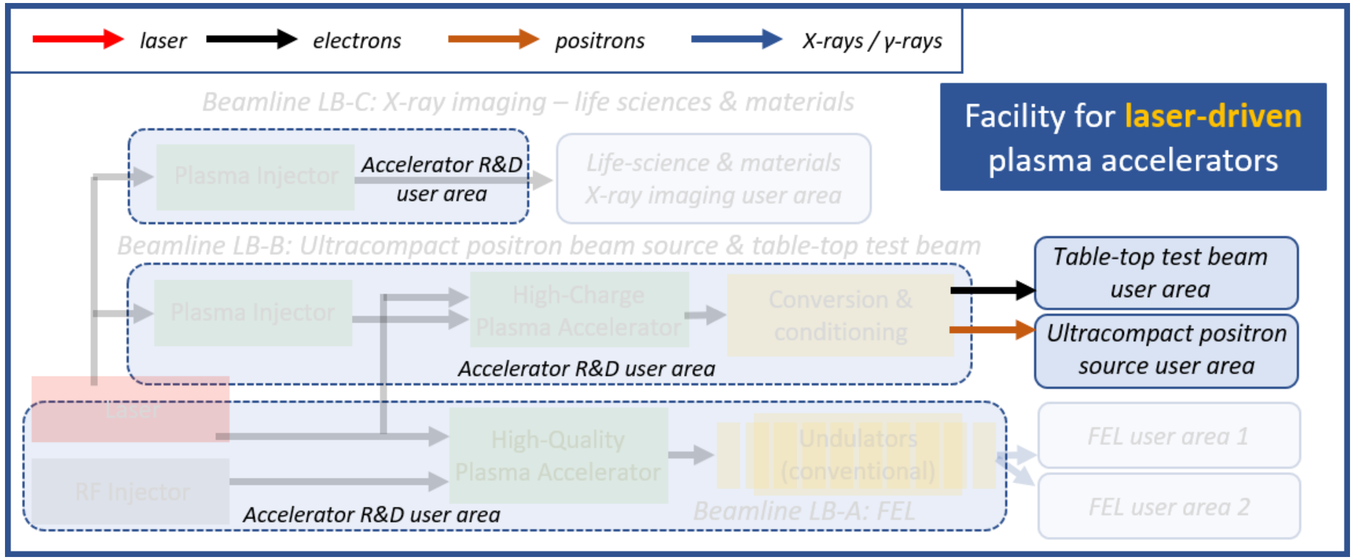

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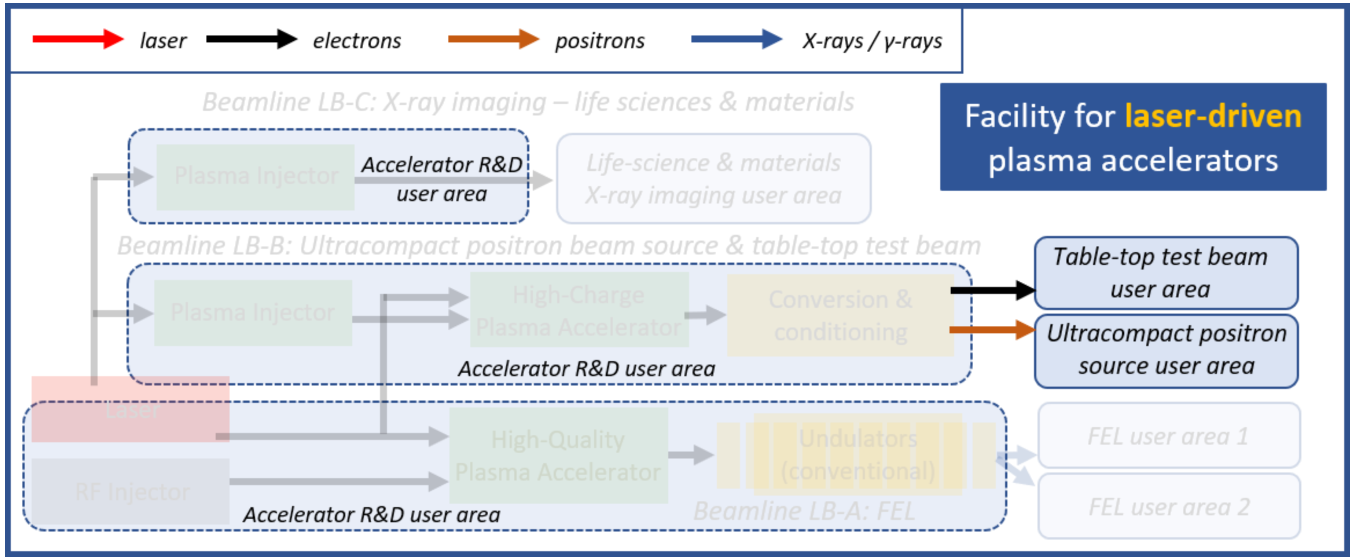
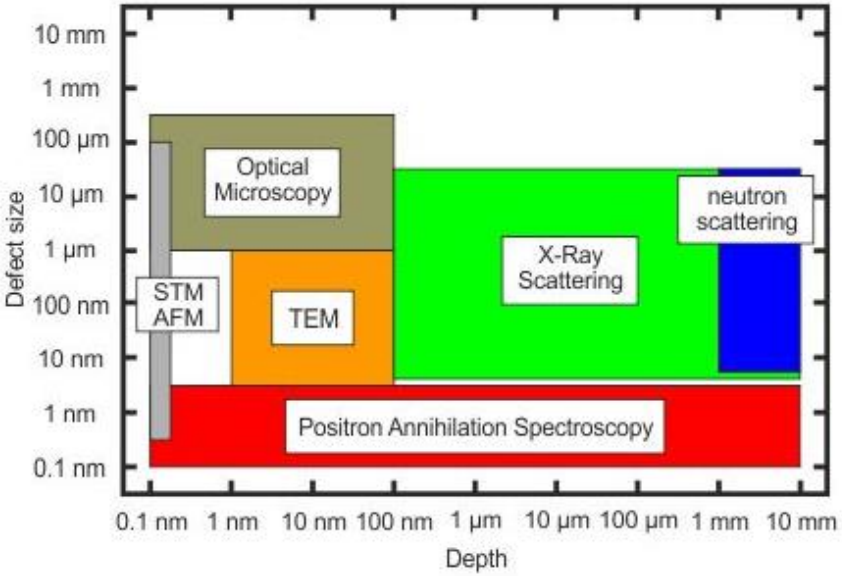


Table-top test beams

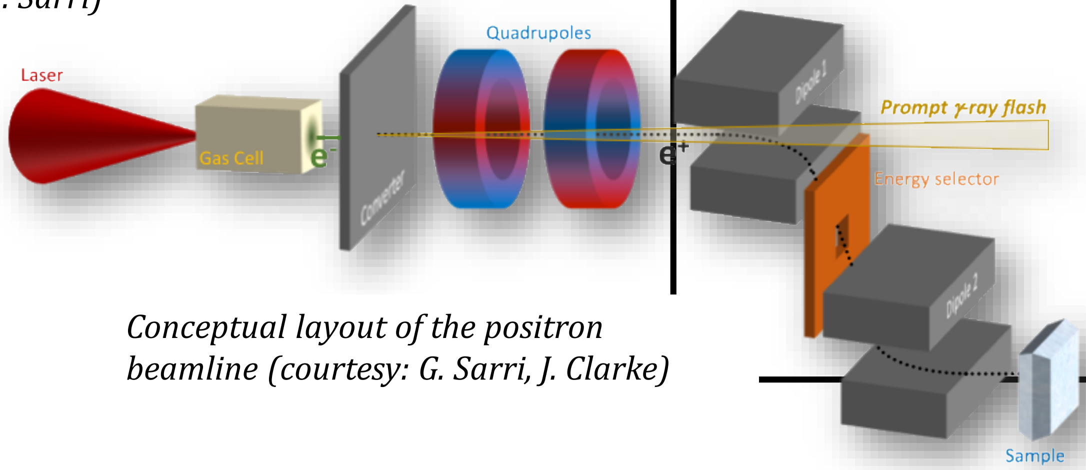
- GeV energy, controlled bunch charge / momentum / duration selection
- Potential application for HEP detector or diagnostics testing

Ultracompact positron source

- Properties: ~0.1-5MeV, ~100keV bandwidth, >10^8 positrons/s, 10s ps duration, ~ mm mrad emittance



PALS working regime compared to other techniques (courtesy: G. Sarri)

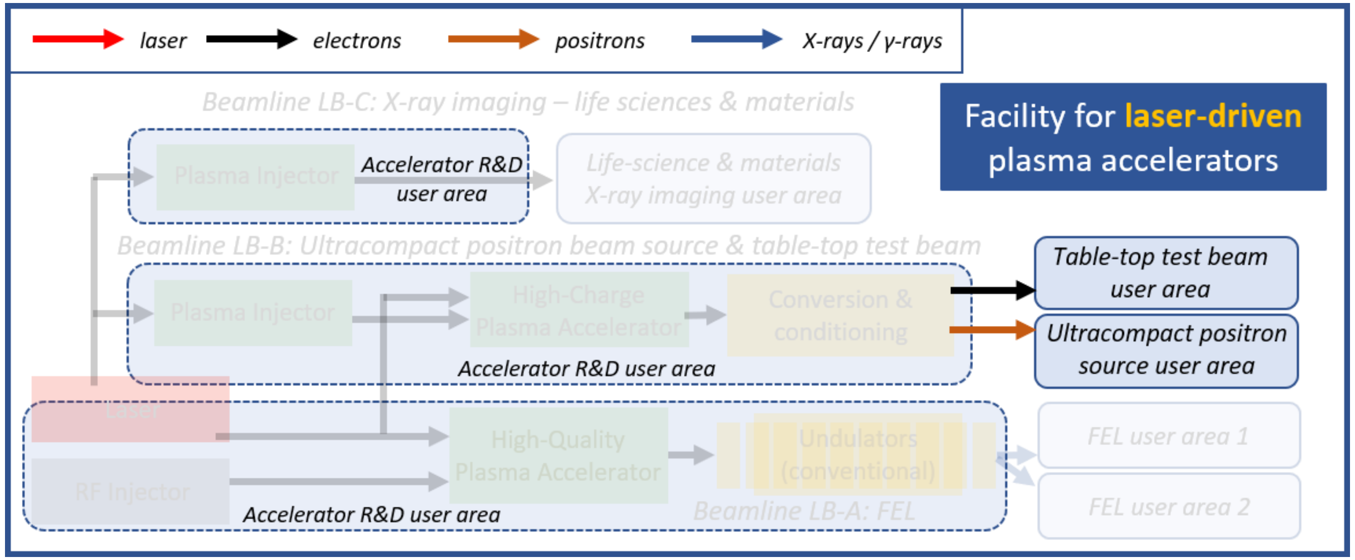


Conceptual layout of the positron beamline (courtesy: G. Sarri, J. Clarke)

- Ideal for material testing, e.g. with Positron Annihilation Lifetime Spectroscopy (PALS)

Horizon 2020

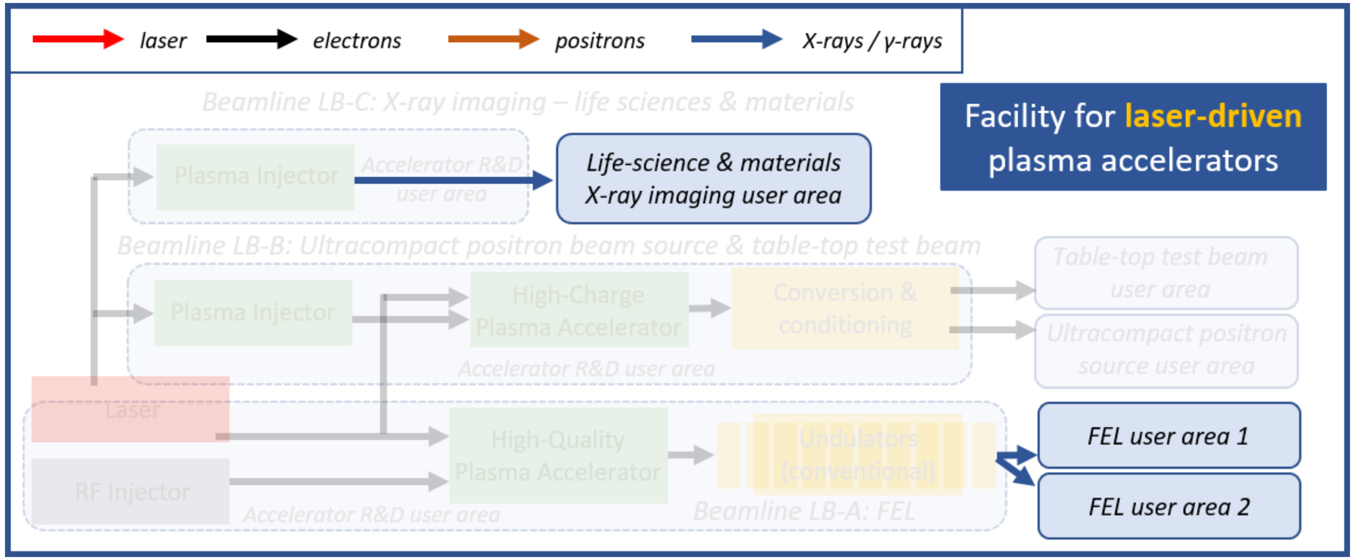
Site Layout – Non-X-Ray Applications



Accelerator R&D

- ○ Access to different types of beamlines with single- and multi-stage accelerators
- ○ Suitable for diagnostics development, experiments on plasma accelerator components and techniques, studies on accelerator stability

Site Layout – X-Ray Applications



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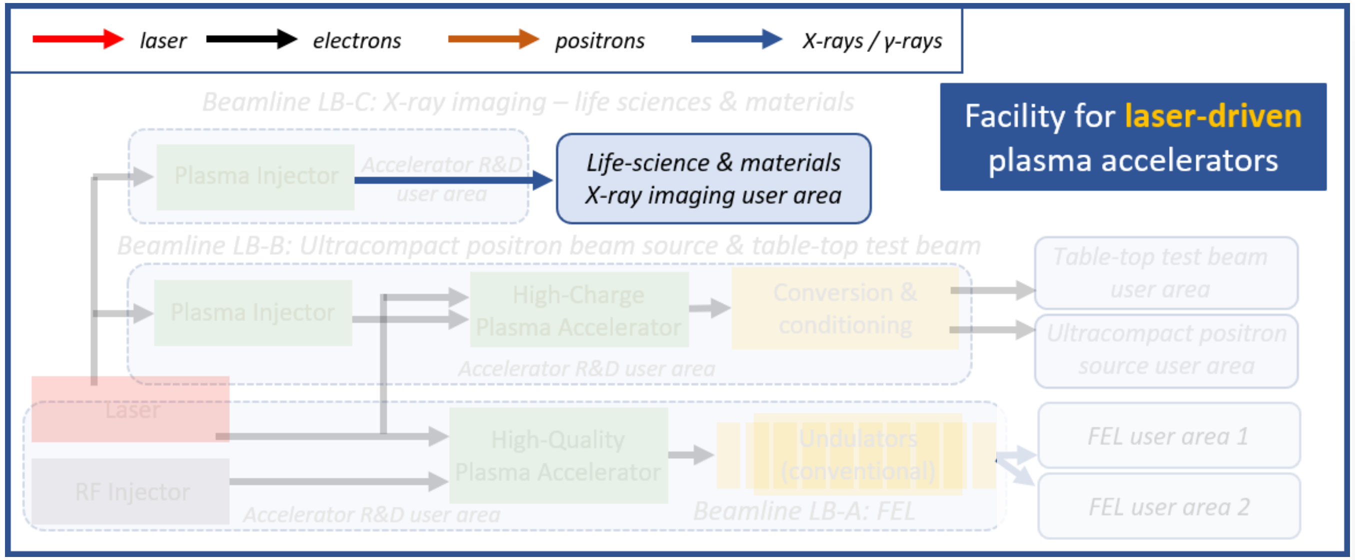
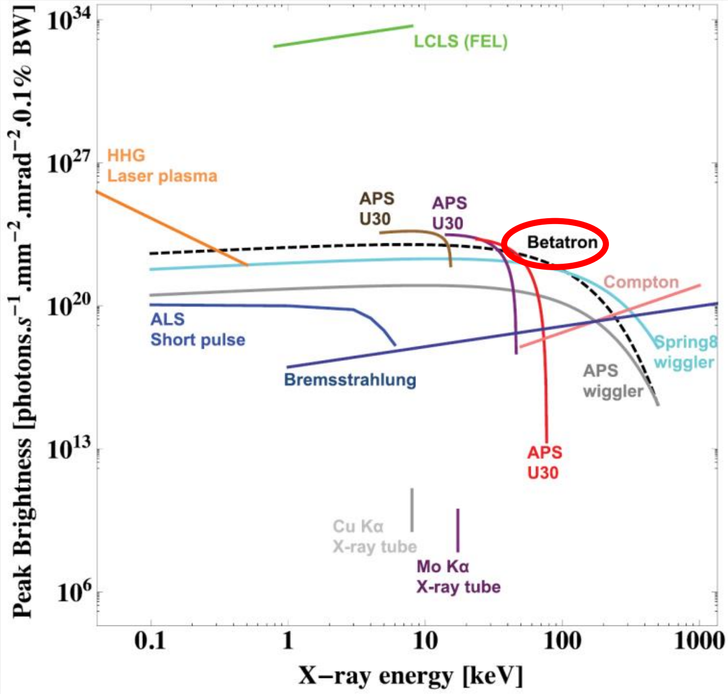
Beamline LB-A: FEL

FEL user area 1

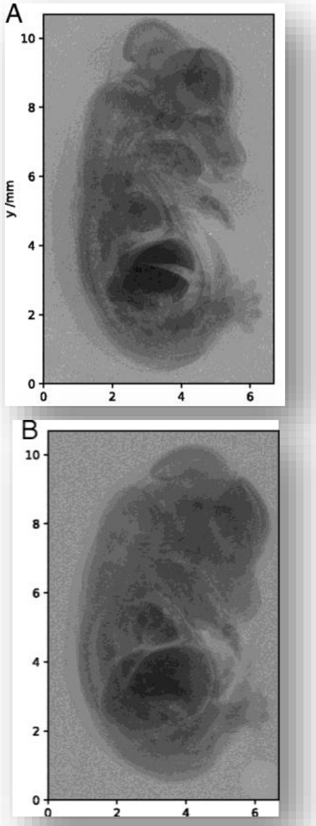
FEL user area 2

Site Layout – Betatron X-Ray Source





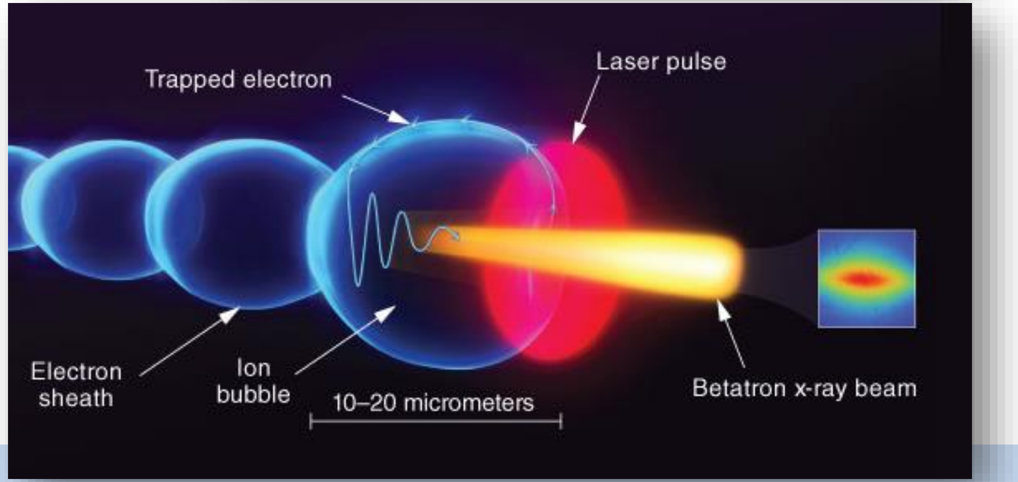
F. Albert & A.G.R. Thomas, 2016 Plasma Phys. Control. Fusion ***58*** *103001*



J.M. Cole et al., 2018 PNAS ***115*** *(25) 6335-6340*

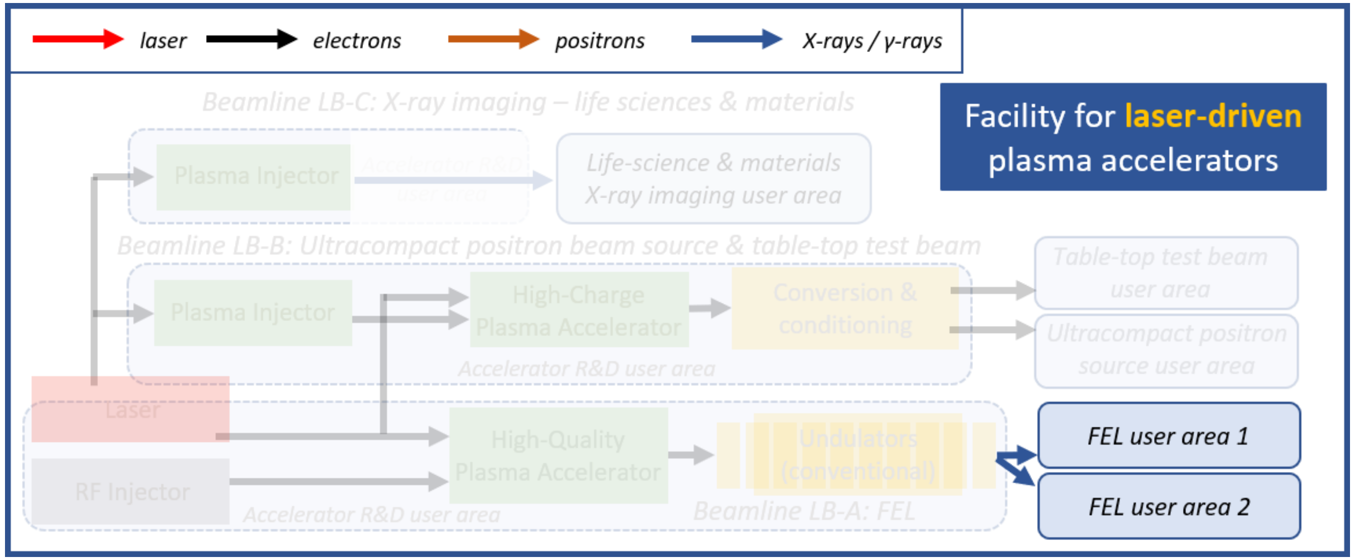
Life-science & materials X-ray imaging

- Compact, synchrotron-like radiation source (with, in principle, pump-probe capabilities)
- ≥10^{10} photons/shot, ~1-100keV energy, single to tens of fs duration, µm source size
- Beamline of approx. 10-15m length + large user area space



Mechanism of betatron radiation generation (courtesy: LLNL, https://str.llnl.gov/january-2014/albert)

Site Layout – FEL Source

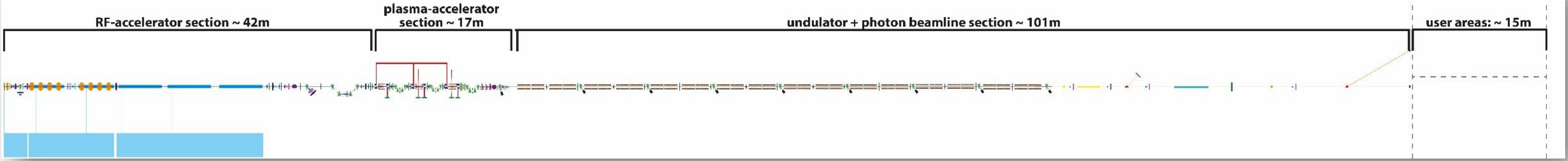


Plasma-based Free-Electron Laser

- Conventional undulators driven by multi-stage high quality plasma accelerator
- Naturally short pulse length and small spot size

Facilities / EuPRAXIA Designs	Accelerator length [m]		Total length [m]
	RF	Plasma	
EuPRAXIA - LWFA (1GeV)	42	16	135
EuPRAXIA - LWFA (5GeV)	42	17	175
FLASH (1.25GeV) [based on CDR]	144		315
SwissFEL (5.8GeV) [based on CDR]	440		720

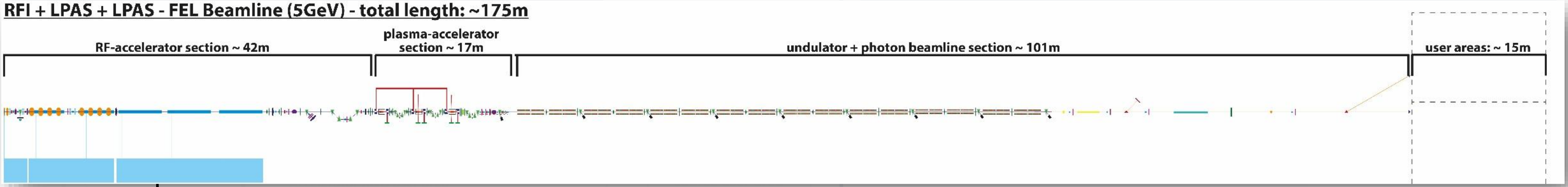
RFI + LPAS + LPAS - FEL Beamline (5GeV) - total length: ~175m

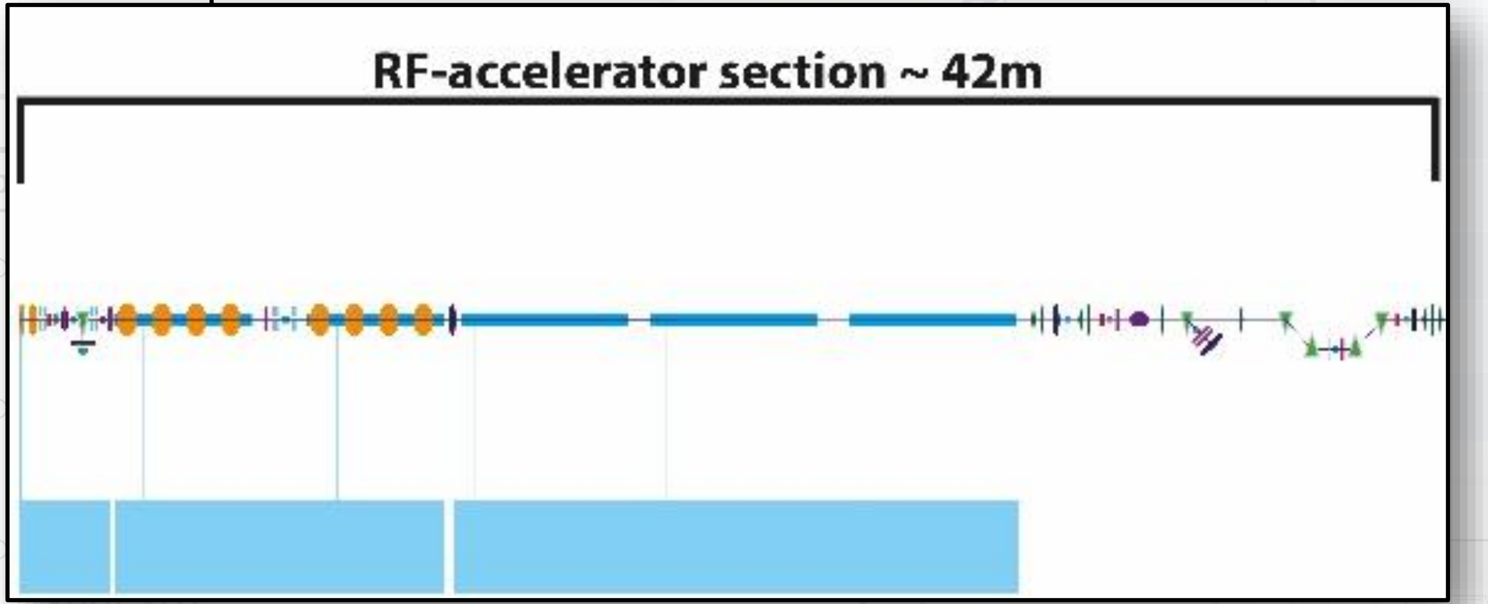


Site Layout – FEL Source

Expected FEL Performance (based on simulations

RFI + LPAS + LPAS - FEL Beamline (5GeV) - total length: ~175m



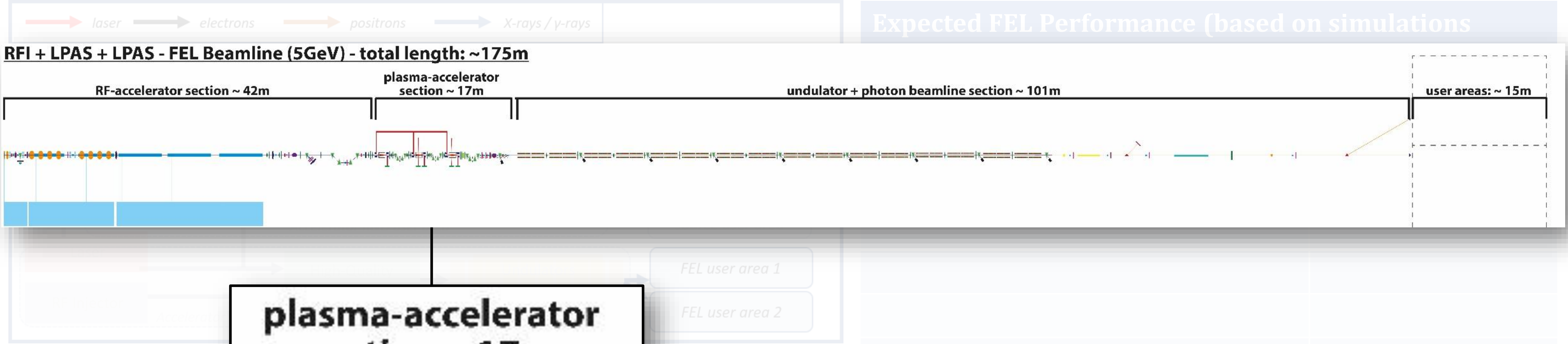


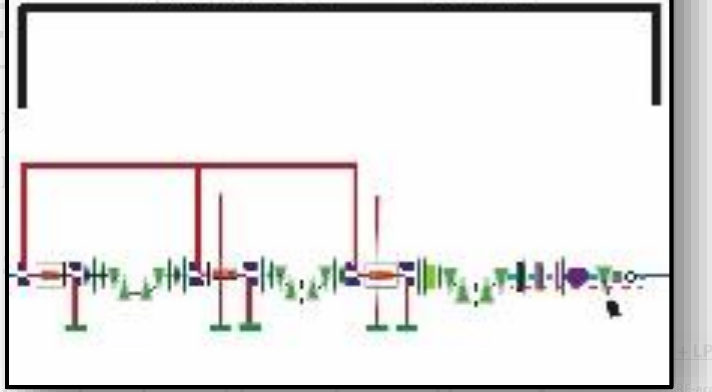
S-band electron injector + 3 travelling wave structures + bunch compressor:

- Final electron beam properties: 240MeV, 30pC, 7.5fs
- Hybrid compressor using velocity bunching + magnetic compression

Site Layout – FEL Source

Expected FEL Performance (based on simulations





Plasma-based F

- Conventional u
  stage high qua
- ?? parameters
  FELs
- Naturally short pulse length and small spot size

Staged plasma accelerator to 5GeV:

- Including plasma & electron diagnostics, a setup for laser-electron beam synchronisation and a dechirping mechanism
- Conventional transfer lines based on quadrupoles; more compact designs under investigation

Site Layout – FEL Source

laser electrons positrons X-rays / γ-rays

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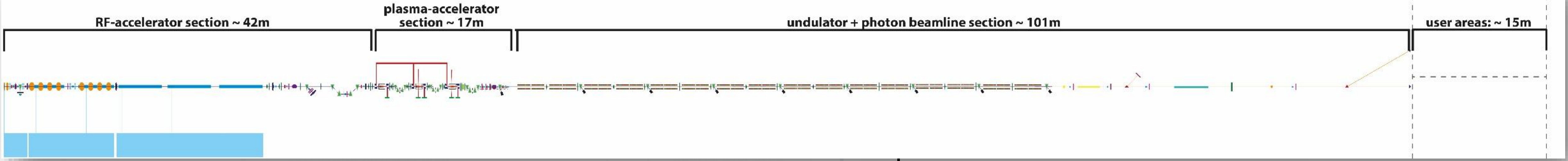


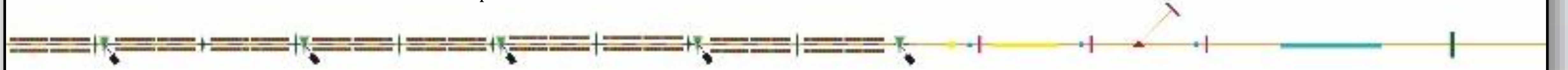
FEL user area 1

undulator + photon beamline section ~ 101m

Two undulator configurations:

Option 1: λ_u = 20mm, K = 1.5, B_{peak} = 0.81

Option 2: λ_u = 30mm, K = 4.36, B_{peak} = 1.56



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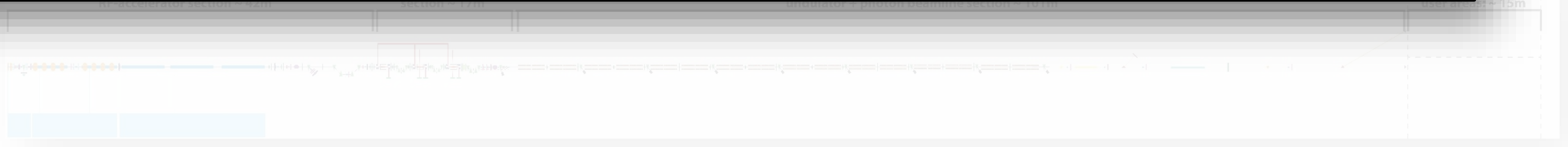

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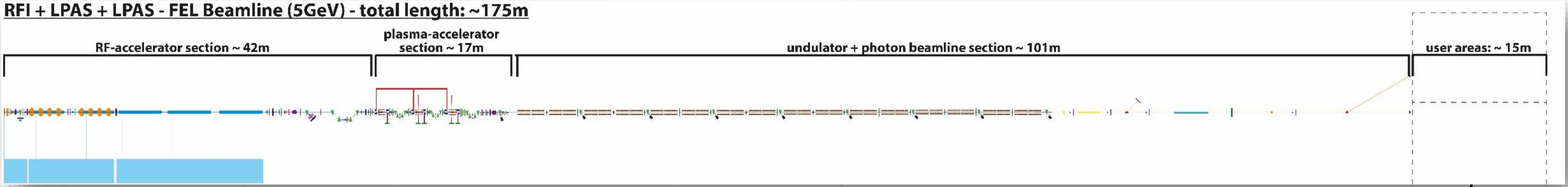
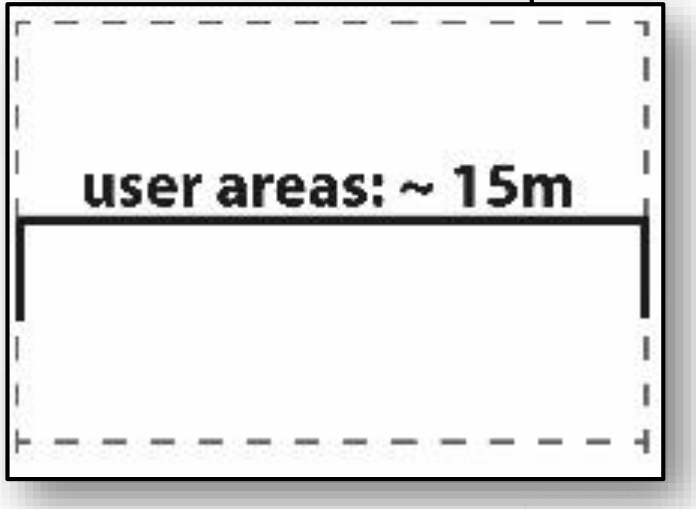




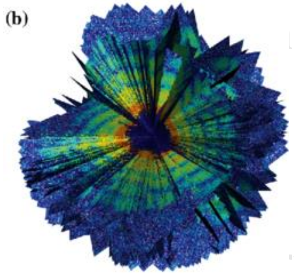
Make use of the strengths of plasma FEL performance:

+ fs-scale pulse duration

+ good pump-probe synchronisation

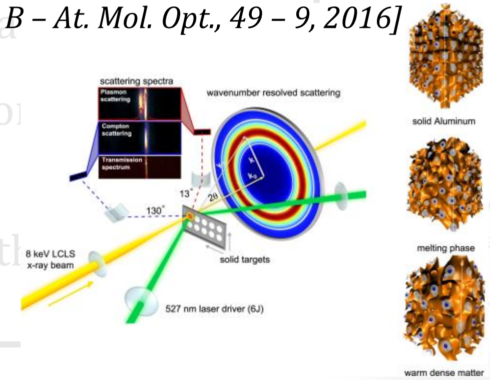
+ multiple beam species in one facility

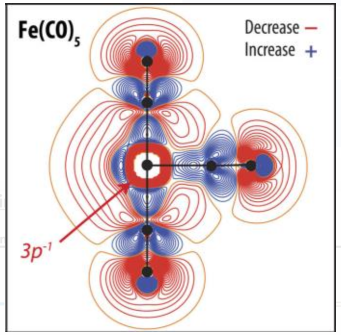
+ compact machine design



Single particle imaging *[T. Ekeberg et al., Phys. Rev. Lett. 114, 098102, 2015]*

Matter under extreme conditions *[S.H. Glenzer et al., J. Phys. B – At. Mol. Opt., 49 – 9, 2016]*





Time-resolved spectroscopy *[T. Leitner et al., J. Chem. Phys. 149, 044307, 2018]*

etc.

Site Layout – FEL Source

Expected FEL Performance (based on simulation results, not self-consistent) (courtesy: F. Nguyen)	
Electron beam energy [GeV]	5.0-5.4
Electron energy spread (slice) [%]	0.05-0.14
Electron beam charge [pC]	20-35
Electron beam emittance (slice) [mm mrad]	0.08-0.40
Beam duration [fs]	4-12
Repetition rate [Hz]	20-100
Radiation wavelength [nm]	1.4 – 1.65
Photons per pulse	$8\text{x}10^{11}$
Bandwidth (FWHM) [%]	0.273
Pulse duration [fs]	1.68

- **Phased setup with energy increase from 1 to 5GeV over time**
- **Possible future upgrades and developments:**
  - Repetition rate increase (to kHz level)
  - Improvement of FEL performance (wavelength, brilliance, etc.)
  - Ultrashort pulse generation (≤1fs)
  - Reduction in machine size

Possible Site Location

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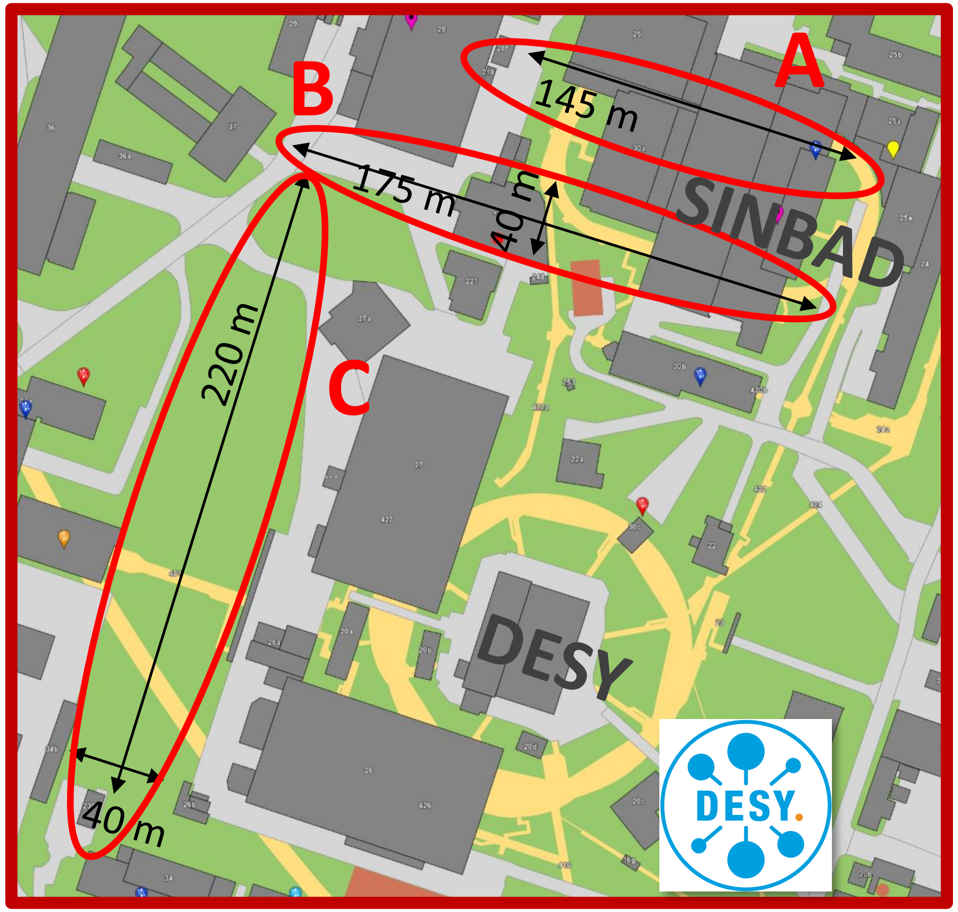
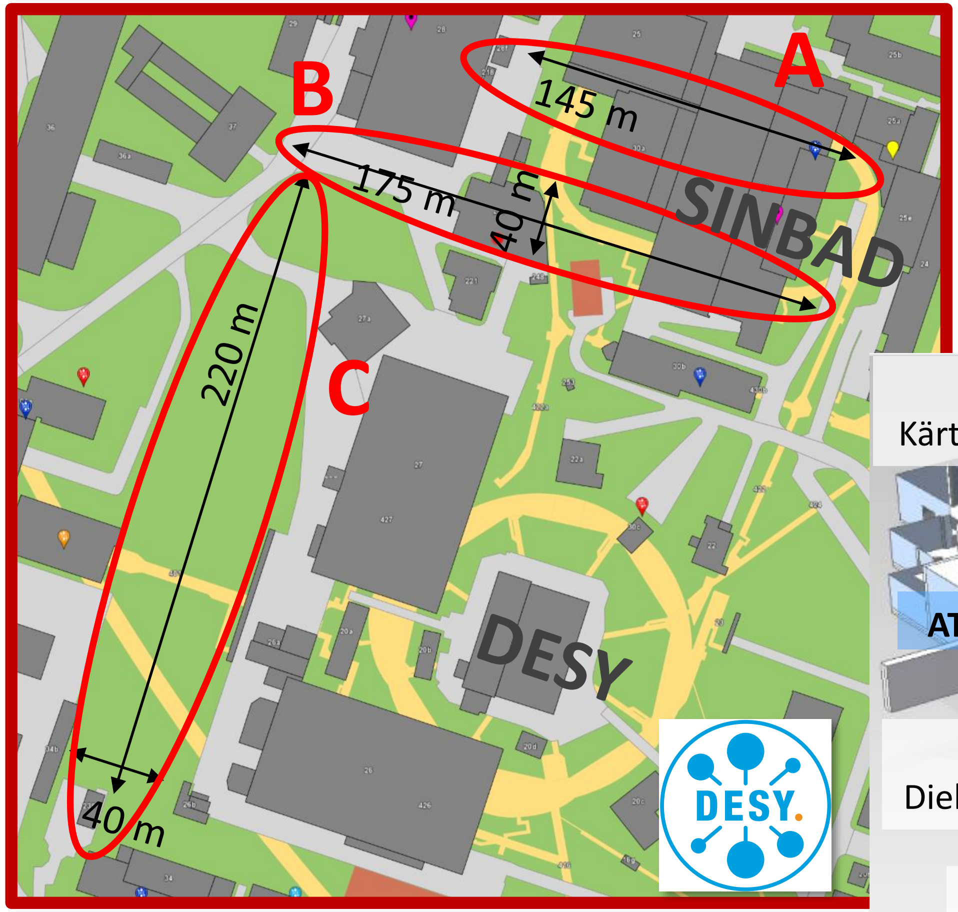


Different layouts for a possible location of the site at DESY (courtesy: P. A. Walker)

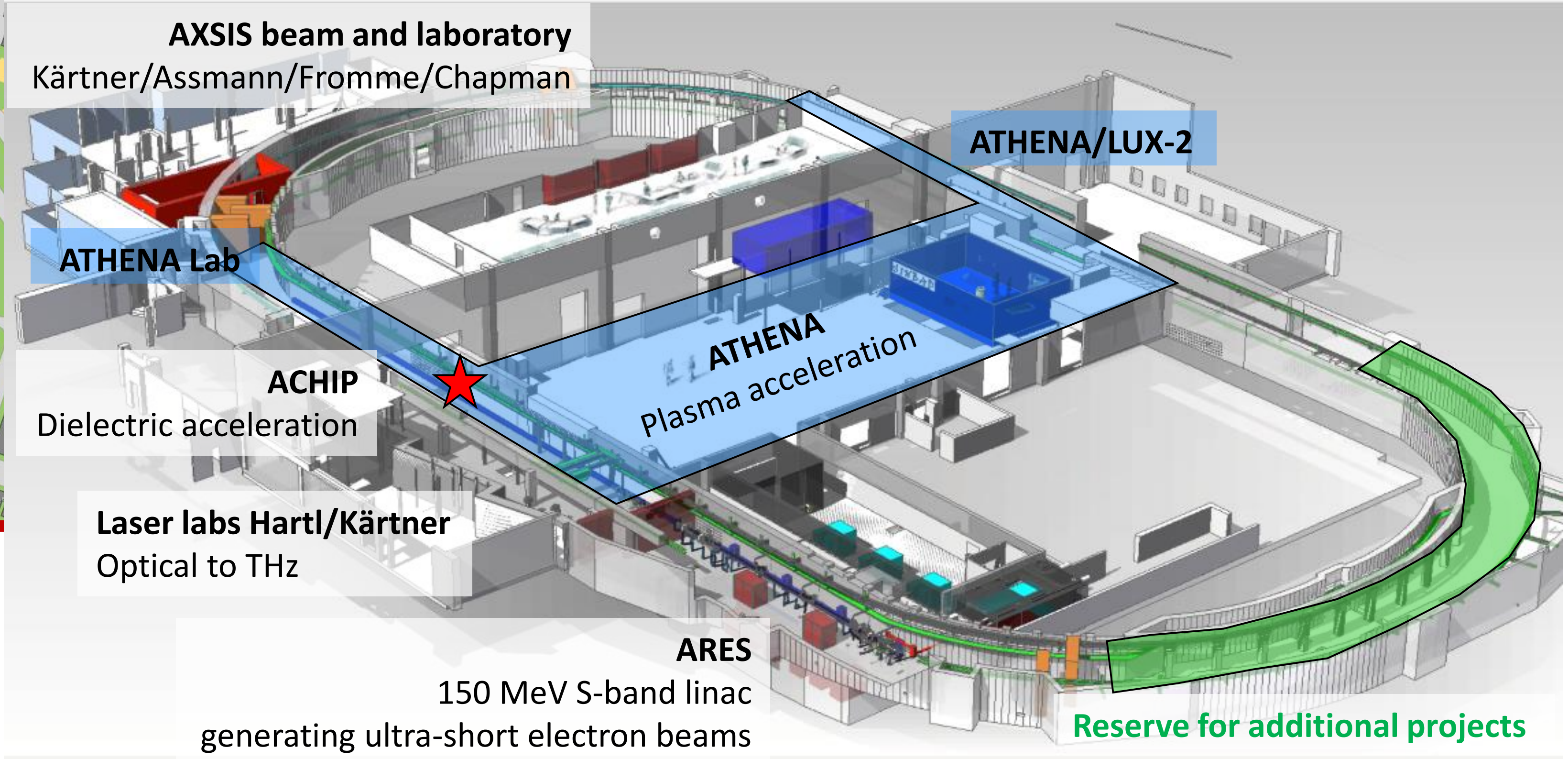
Possible Site Location



Different layouts for a possible location of the site at DESY (courtesy: P. A. Walker)

SINBAD

Short Innovative Bunches and Accelerators at DESY



Layout of SINBAD facility at DESY as one of the potential construction sites for EuPRAXIA

Conclusions & Open Points

- Construction site design with multiple beamlines, user areas and several types of particle & radiation beams conceptually well developed
- Many open points remain on user-related aspects to define during technical design, e.g.
  - What requirements should the user areas have?
  - What user operation modes (shift lengths, level of support, etc.) work best?
  - …

→ **Your feedback and discussions are extremely helpful!**

Acknowledgements

16 Participants

DESY
INFN
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cnrs
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IST-ID Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento
Science & Technology Facilities Council
SOLEIL SYNCHROTRON
MANCHESTER 1824 The University of Manchester
UNIVERSITY OF LIVERPOOL
ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development
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UHH Universität Hamburg
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(as of December 2018)

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KPSI Kansai Photon Science Institute
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Thank you for your attention!

Any questions?

EuPRAXIA‘s Main Technical Challenges

Note: This list is merely designed to give an overview, it is not comprehensive and does not cover any details of the proposed solutions.

Technical Challenge	Proposed Solution
Beam energy spread reduction	Optimisation of injection mechanisms Development of novel injection mechanisms External injection from RF accelerator Development and optimisation of dechirping techniques
Beam emittance reduction	Advanced beam control via transfer lines
Laser – e-beam synchronisation	Development of novel synchronisation schemes
Shot-to-shot stability	Advanced diagnostics Feedback & control system Tight control over laser tolerances
Operability & maintainability	Advanced diagnostics Feedback & control system
Increase in repetition rate	Development of heat control mechanisms in laser systems Differential pumping for vacuum systems
Accelerator staging	Advanced beam control via transfer lines Use of active plasma lenses for compact, strong focusing
Plasma-based FEL operation	Ongoing, large-scale „prototyping“ activities (e.g. LUX, COXINEL) Tight control of electron beam parameters and dynamics Development of novel FEL modes (e.g. decompression chicane, TGU)

Management Structure

Heads of Project and of Supervisory Boards

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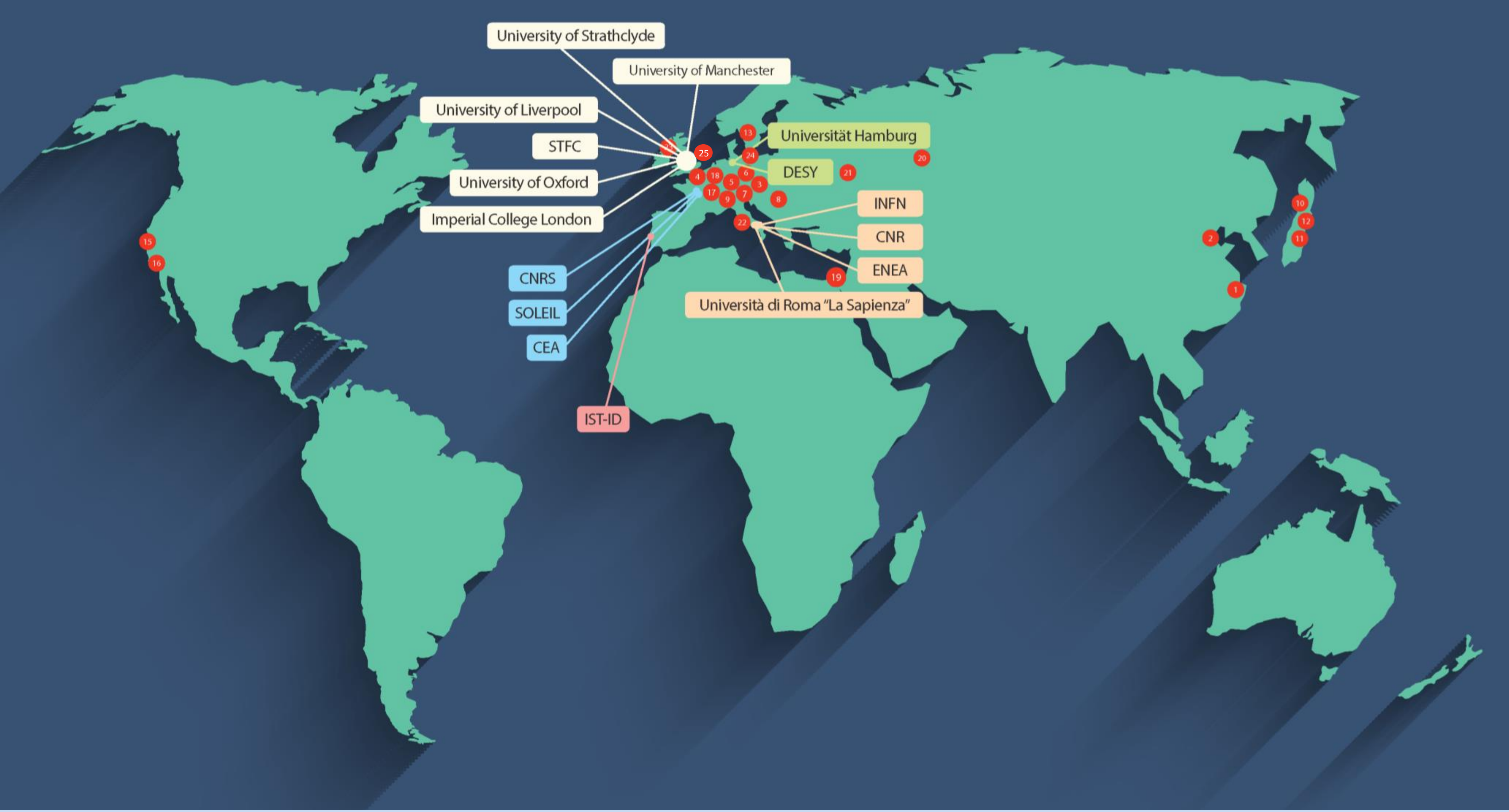
Steering Committee

- Collaboration board — Scientific advisory board
- Project coordinator — Management support team
- Steering committee
  - WP1: Project management and technical coordination
  - WP2: Physics and simulation
  - WP3: High-gradient laser-plasma accelerating structures
  - WP4: Laser design and optimization
  - WP5: Electron beam design and optimization
  - WP6: FEL pilot application
  - WP7: High-energy physics and other pilot applications
  - WP8: Outreach and liaison
  - WP9: Alternative e-beam driven plasma structures
  - WP10: Use of other novel technologies
  - WP11: FEL application prototyping
  - WP12: Accel. prototyping and experiments at test facilities
  - WP13: Alternative radiation generation
  - WP14: Hybrid laser-electron-beam driven acceleration

Participating Institutions



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2. Tsinghua University Beijing, China
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6. Helmholtz-Zentrum Dresden-Rossendorf, Germany
7. Ludwig-Maximilians-Universität München, Germany
8. Wigner Fizikai Kutatóközpont, Hungary
9. CERN – European Organization for Nuclear Research, International
10. Kansai Photon Science Institute/Japan Atomic Energy Agency, Japan
11. Osaka University, Japan
12. RIKEN SPring-8 Center, Japan
13. Lunds Universitet, Sweden
14. CASE – Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory, USA
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