New (and future) facilities for fusion research

Gianluca Gregori (University of Oxford)

With contributions from:
Gilliss Dyer (SLAC)
Rip Collins (LLE / University of Rochester)
Ulf Zastrau (Eu.XFEL)

Imperial College
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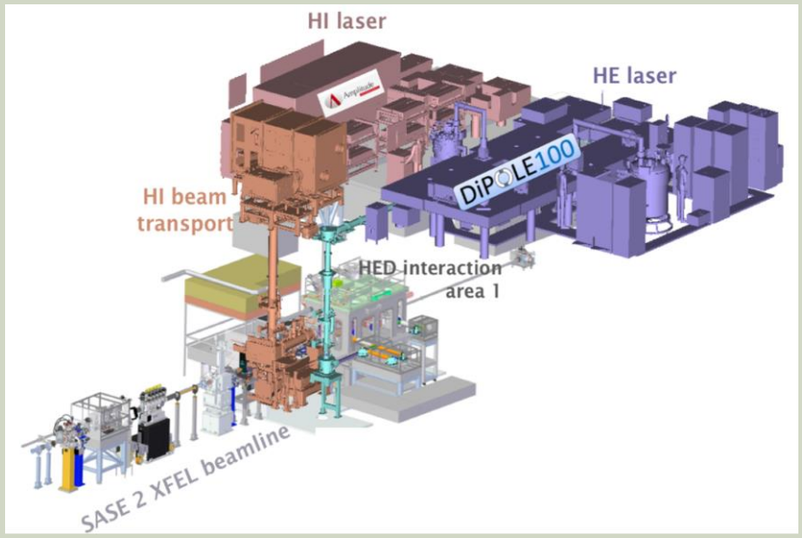
Combination of different technologies (laser/X-ray/particles) is bringing new perspectives

HiBEF (EuXFEL) MEC-U (LCLS)

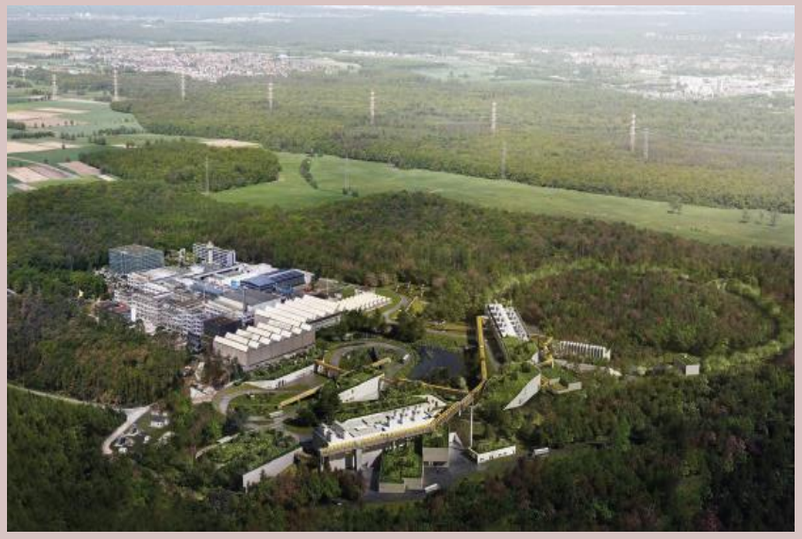


- HiBEF consortium (at EuXFEL) is commissioning a multi-purpose facility (XFEL, High-rep rate optical laser, High-intensity laser, Pulse magnet).
- Similar facility is been planned for MEC-U.

ECOS (LLE)

- Inverse Compton Scattering source.
- Provide high-energy X-ray probe for ICF plasmas.
- Prototype being developed by U Rochester.

FAIR (GSI)



- Facility for Antiproton and Ion Research (FAIR).
- Homogeneous energy deposition of heavy ions in mesoscopic targets.
- EOS / stopping power in Warm Dense Matter.

Exciting new physics will be accessible with these facilities

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Physics of Clean and Limitless Energy

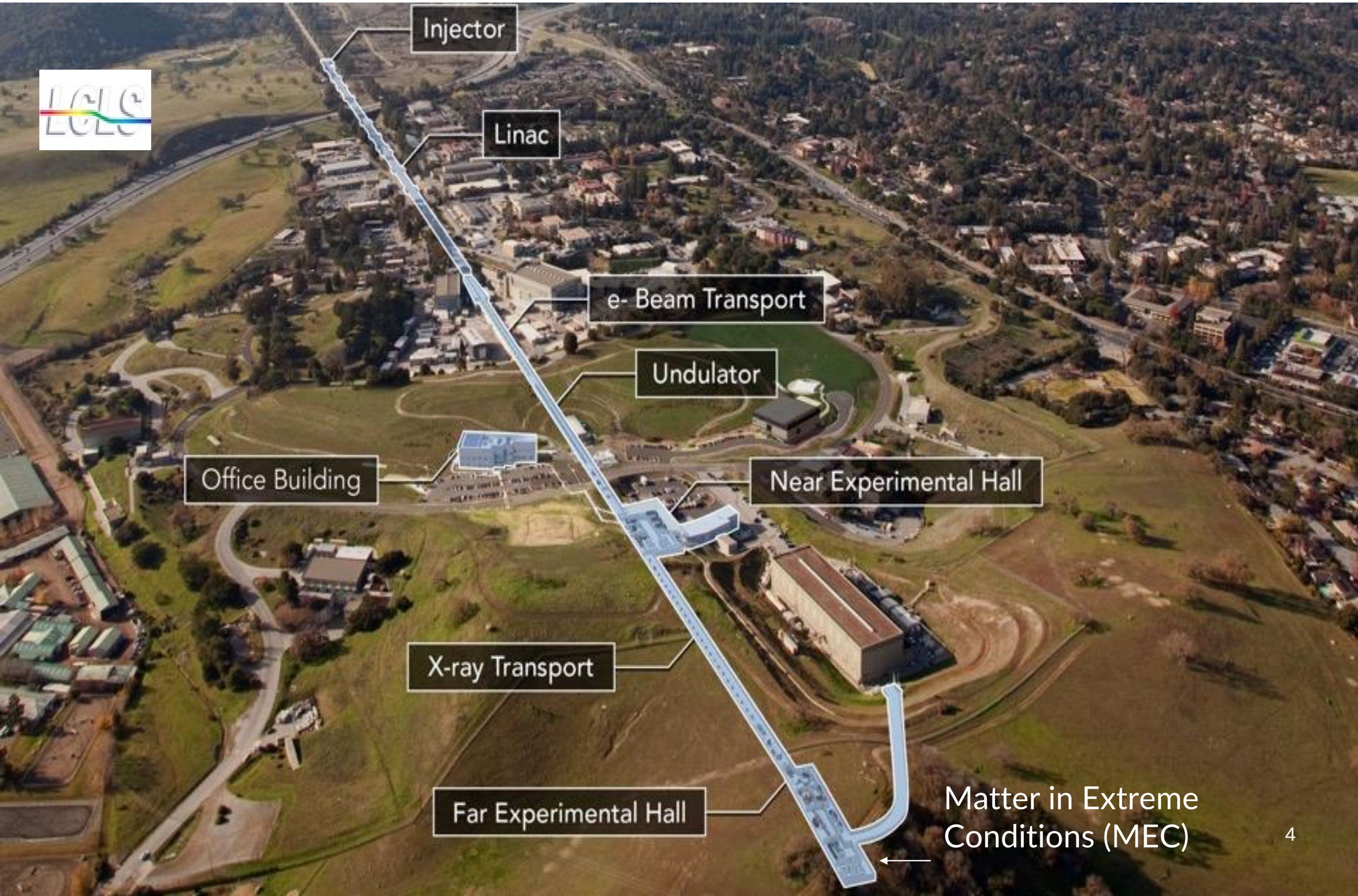
The physics of impact events

MEC-U
HiBEF

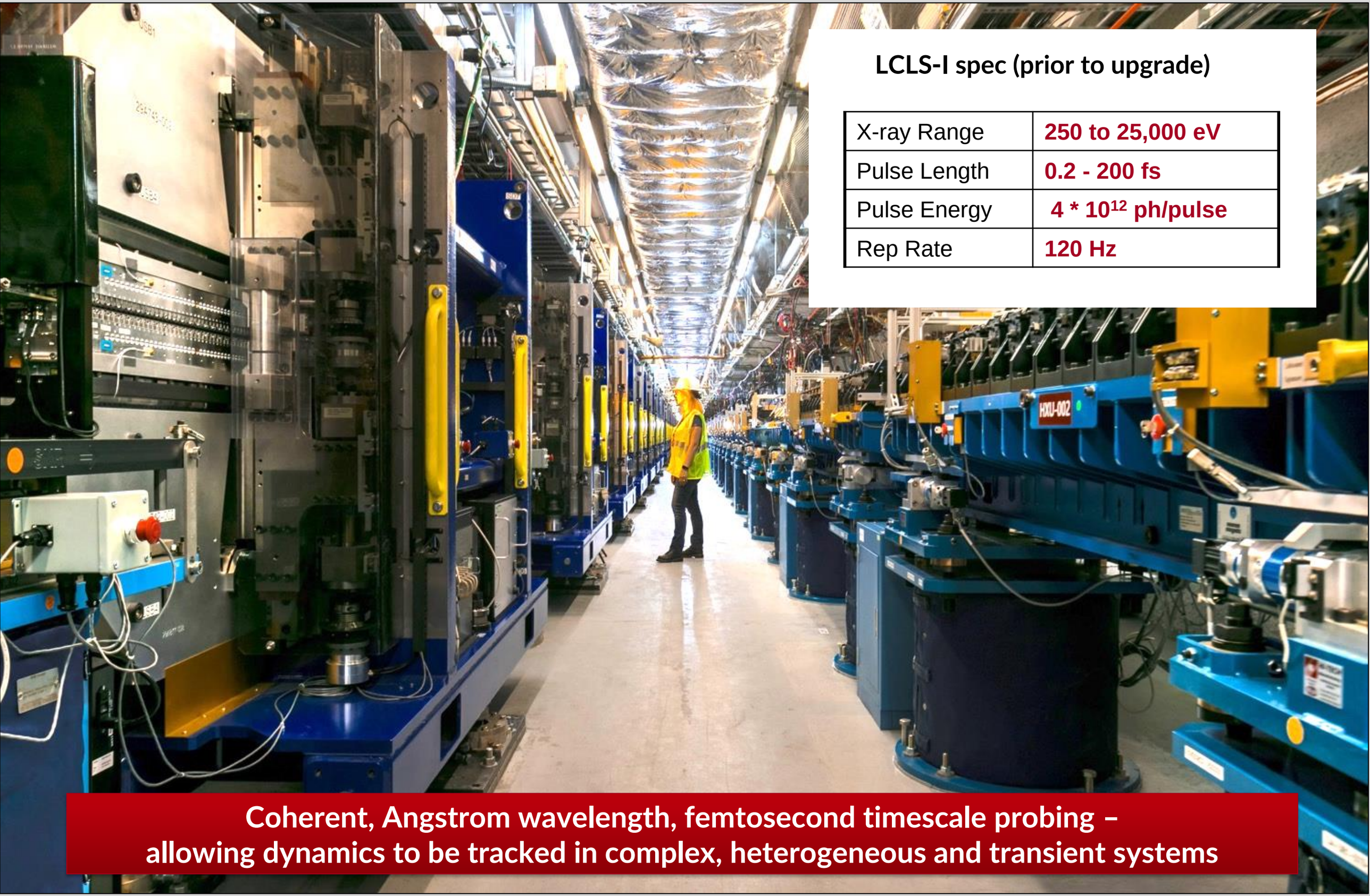
Exoplanet Interiors and Habitability

Cosmic Ray Origins as a Window in Time

LCLS: the first X-ray FEL has provided unprecedented brightness to users



LCLS performance was a game-changer
>10^9 increased brightness



LCLS-I spec (prior to upgrade)

X-ray Range	**250 to 25,000 eV**
Pulse Length	**0.2 - 200 fs**
Pulse Energy	**4 * 10^{12} ph/pulse**
Rep Rate	**120 Hz**

**Coherent, Angstrom wavelength, femtosecond timescale probing –
allowing dynamics to be tracked in complex, heterogeneous and transient systems**

MEC combines high-power lasers with LCLS to study extreme states of matter

125+ publications since 2014
>20% High-Impact: Science, Nature, PRL, APL

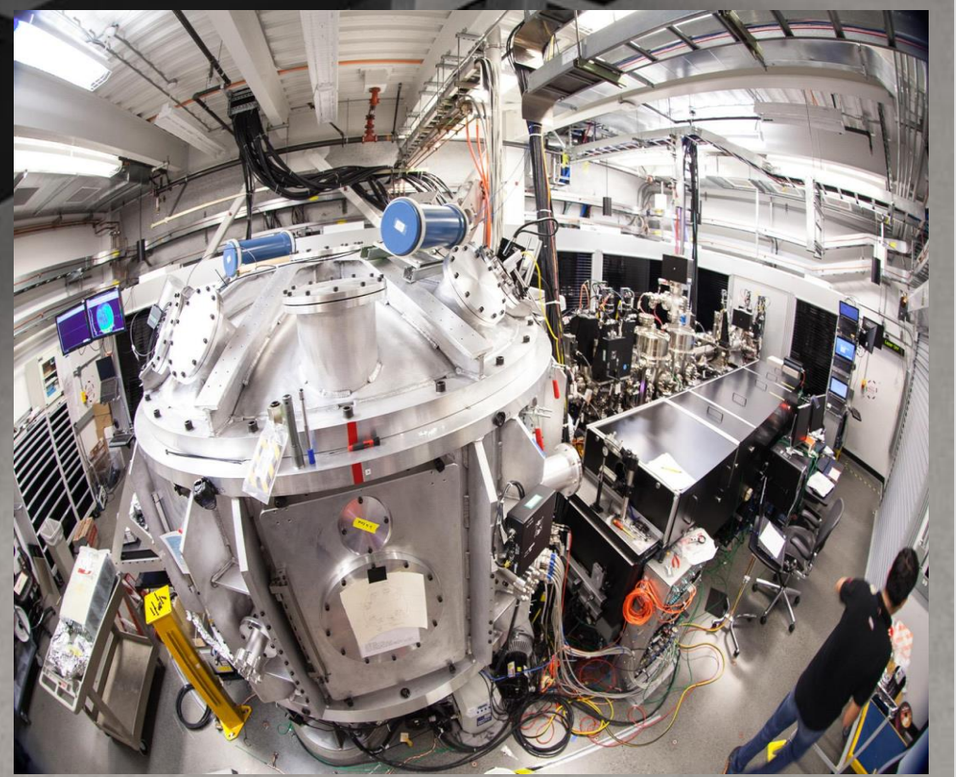
ns, 60 J shock driver

fs, 25 TW plasma driver

LCLS HXR beam

Spacious, versatile target chamber and experimental area

- Atomic resolution in small volumes
- Femtosecond x-ray probing
- Extreme x-ray brightness
- Coherent imaging
- Unprecedented signal-to-noise
- Multi-pulse capability
- Precise photon energy tuning
- High rep rate



MEC-U: Flagship facility for Fusion Plasma Science

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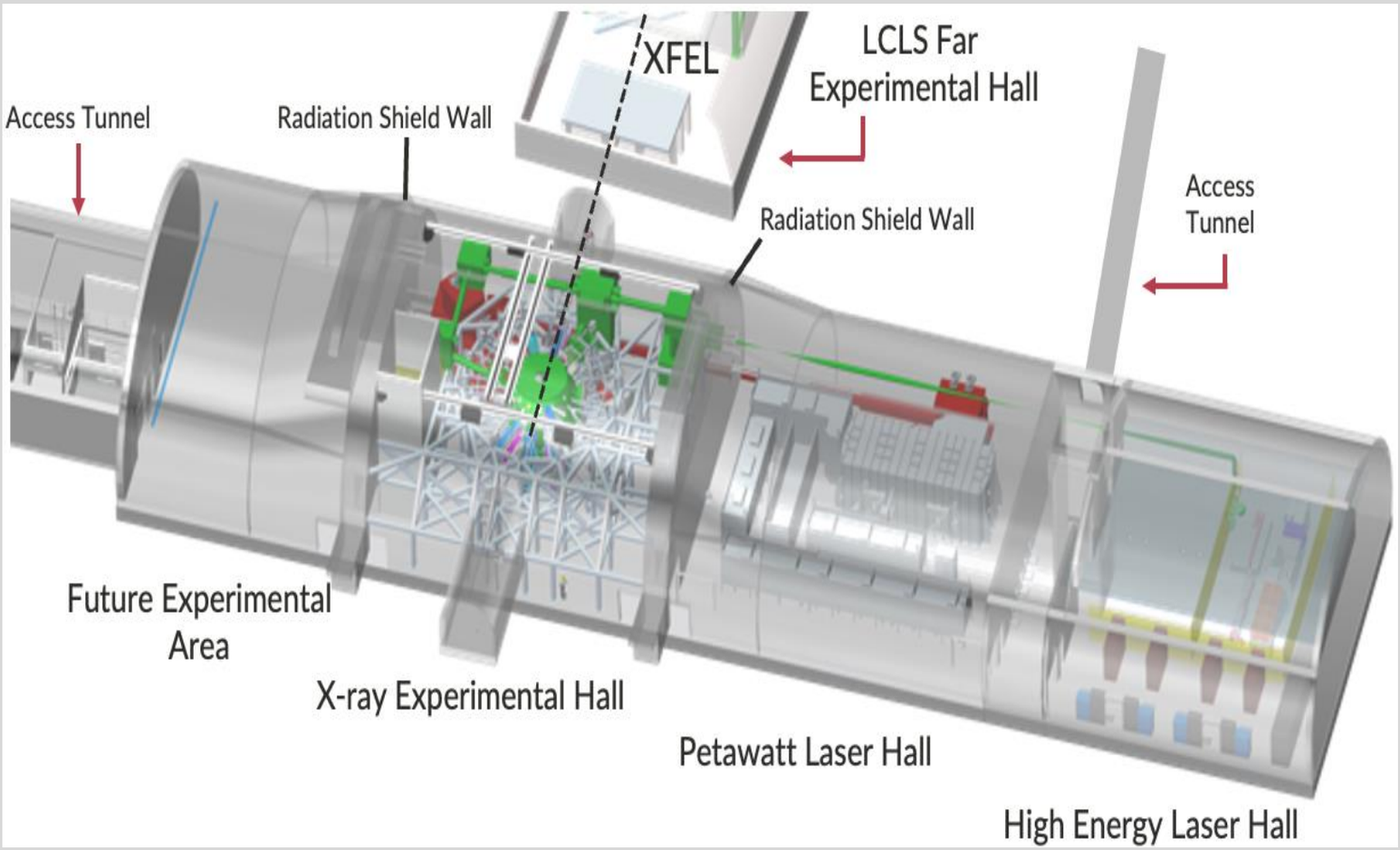
Lawrence Livermore National Laboratory | LaserNetUS | UR LLE

Stanford University | U.S. DEPARTMENT OF ENERGY



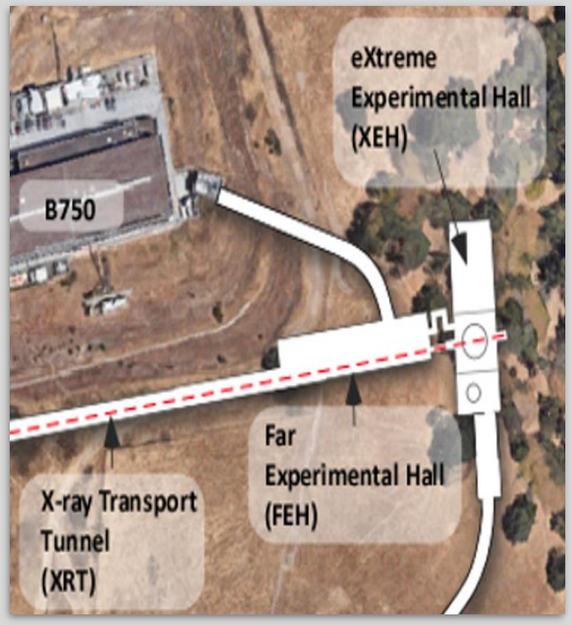
World-Leading Technical Specifications

Unique laser capabilities combined with XFEL

- 10x higher power @ 10 Hz (Petawatt)
- 10x higher energy laser (kilojoule)
- Versatile target chamber for HED science

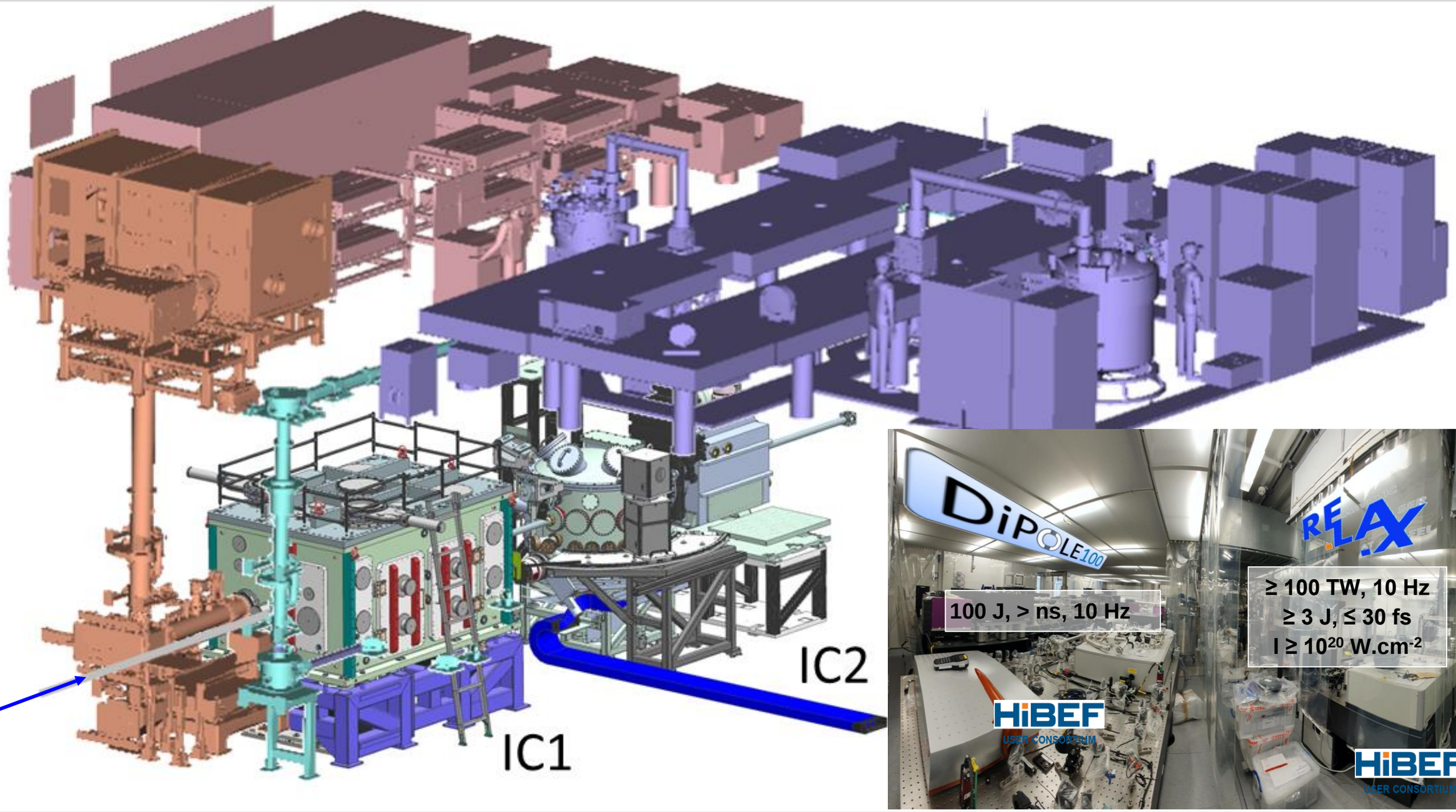
Focused fusion-relevant capabilities

- Rep-rate and hardened diagnostics
- High-throughput targets
- ML/AI optimized on physics measurements



MEC-U science capabilities were articulated in the framework of “flagship experiments” to drive design

HED/HiBEF is a similar project to develop equivalent capabilities with the EU



- DIPOLE 100X is the most powerful driver at any X-ray FEL facility
- Will allow data to be collected thousands of times faster than at any other comparable facility
- High photon energies (18-24 keV) available at EuXFEL provide much more detailed atomic structure information (Large q-space)

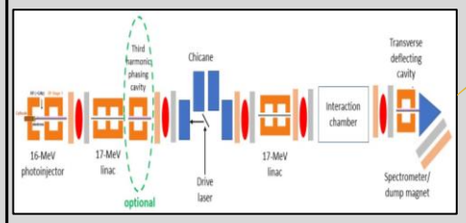
LANL's accelerator and LLE's laser expertise to produce the worlds first 1 shot - 50 KeV light source

X-ray source concept
(H. Rinderknecht, G. Bruhaug)

An electron-beam based Compton scattering x-ray source for probing high-energy-density physics

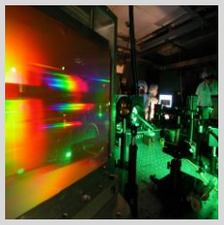
Hans G. Rinderknecht,[1,*] G. Bruhaug,[1] V. Muşat,[2] G. Gregori,[2] H. Poole,[2] and G. W. Collins[1,3,2]

Accelerator Design
(B. Carlsten, M. Furlanetto, E. Brown)

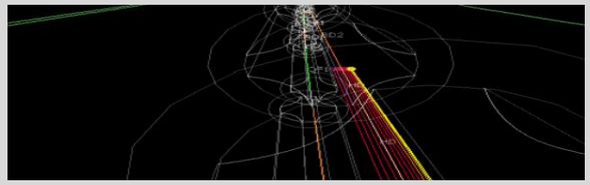


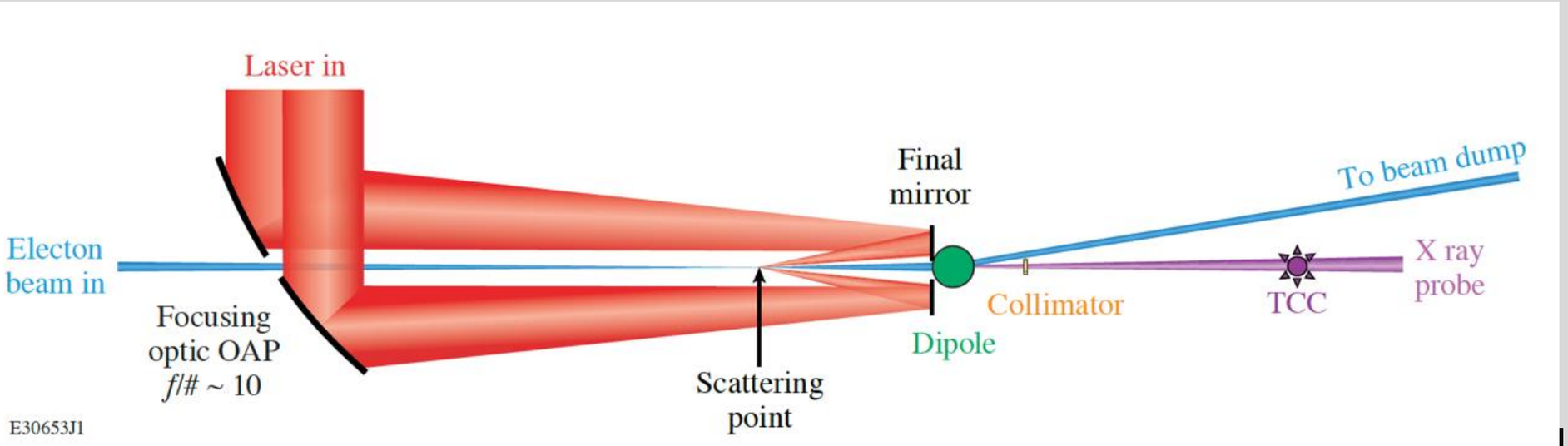
Los Alamos NATIONAL LABORATORY EST.1943

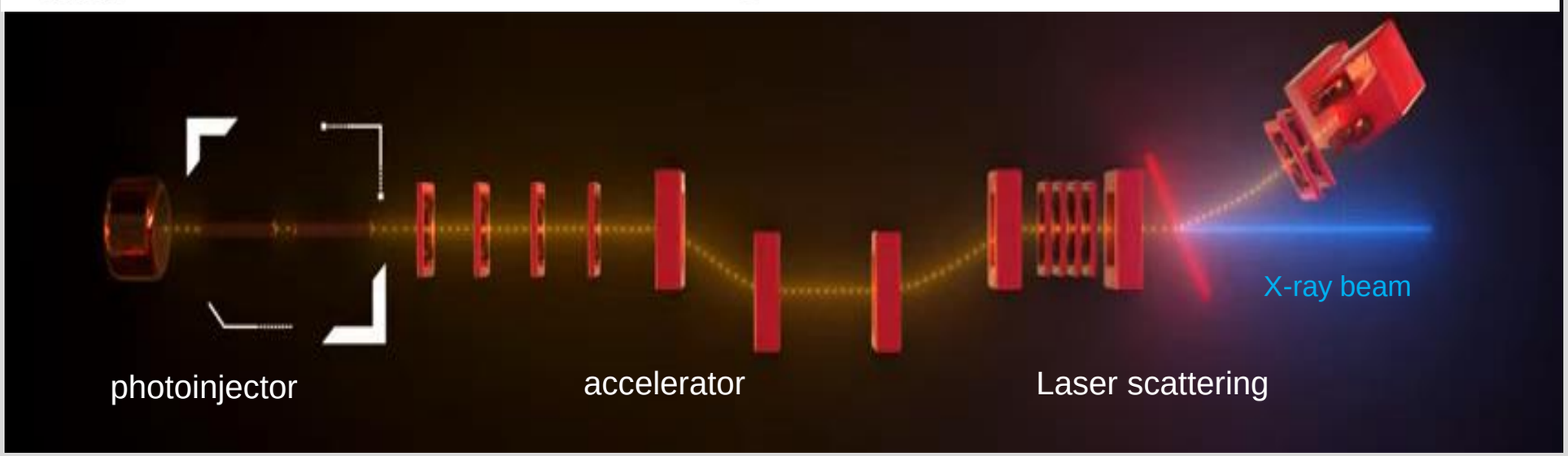
Laser Concepts
(J. Bromage, J. Zuegel, C. Deeney)



Brookhaven National Lab
(I. Pogorelsky, M. Fedurin)



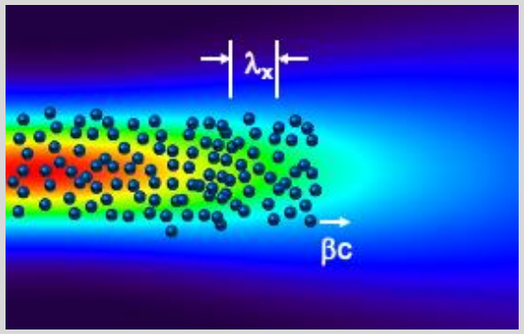




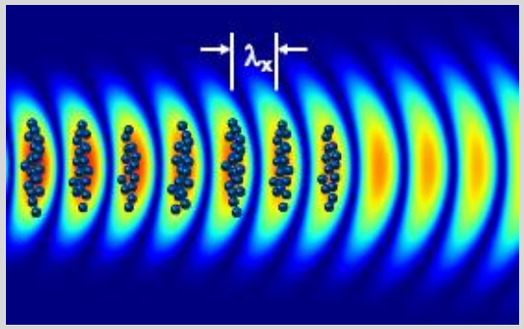
>10^{10} photons/pulse
10-50 KeV X-rays
Up to 100 Hz
~2% bandwidth
~2% divergence

And perhaps
>10^{11} photons/pulse
<0.1% bandwidth
and
<0.1% divergence

Bunching the electrons can enable >10^{10} *coherent* photons at 50 KeV



Incoherent:Random electron positioning for Undulator radiation with **GeV** electrons or Inverse Compton Scattering with **MeV** electrons

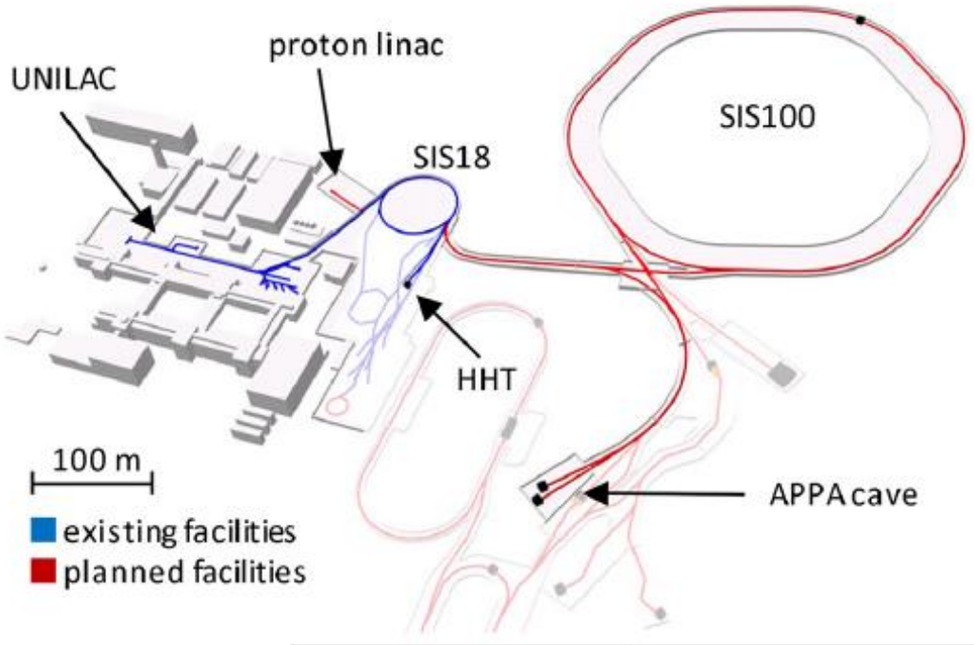


Coherently bunched electrons for **XFEL** radiation (GeV electrons) or Coherent ICS, compact **CXFEL** (MeV electrons)

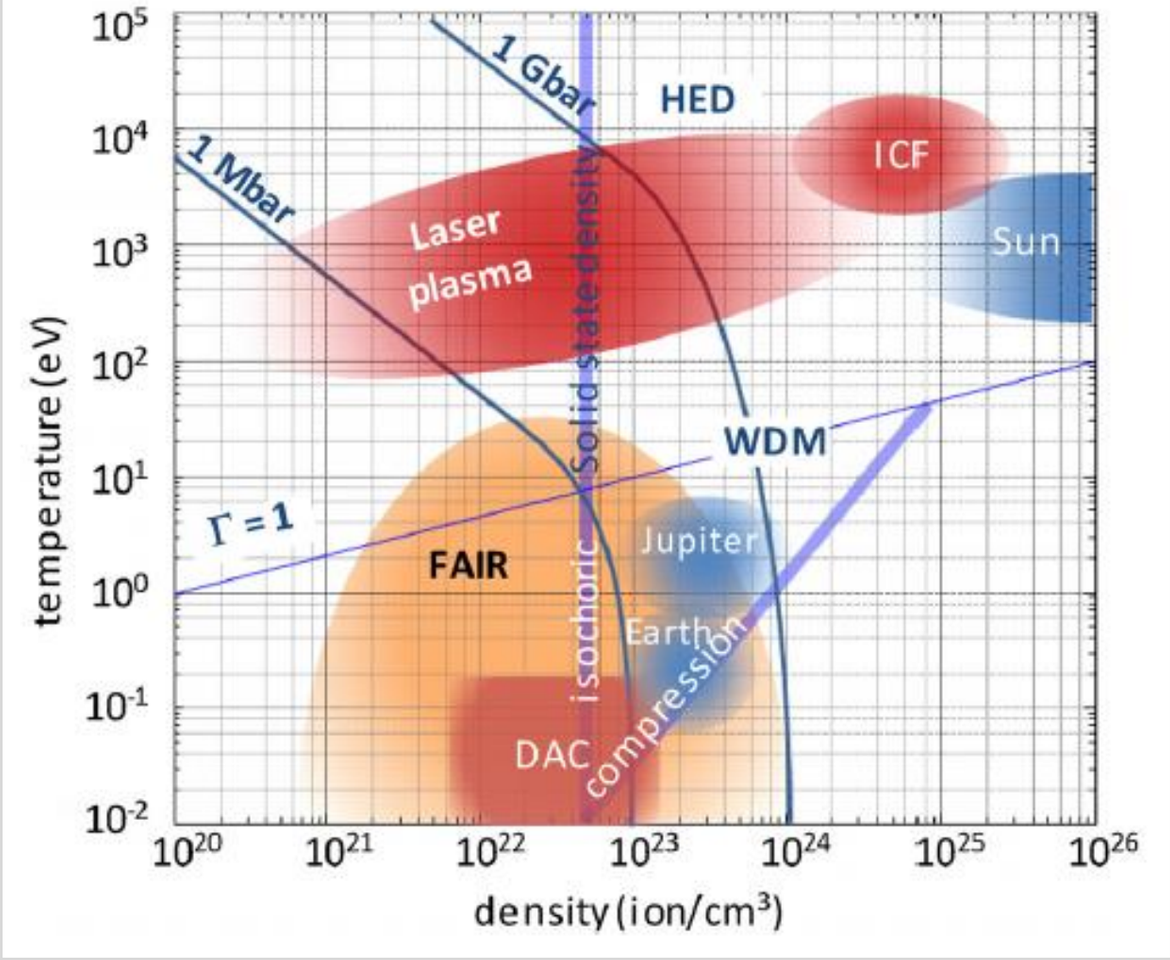
Light Source Attribute	LCLS	ECOS Incoherent ICS	LANL/LLE Coherent ICS
X-ray fundamental energy range	1-45 keV	**10-50 keV***	**10-50 keV***
Photons per image	$3x10^{10}$ @40 keV	**$3x10^{10}$ @50 keV/ pulse**	**> 10^{10} @50 keV/ pulse**
Number of closely spaced bunches within a fixed temporal window	8/0.6 μs	**tbd**	**tbd**
Energy Bandwidth (dE/E)	10^{-4}	**$2.5 x10^{-2}$**	**<10^{-4}**
Field of View	2 mm	**tbd**	**tbd**

FAIR facility is under construction at GSI

Schoenberg, K. *et al. Phys Plasmas* **27**, 043103 (2020)



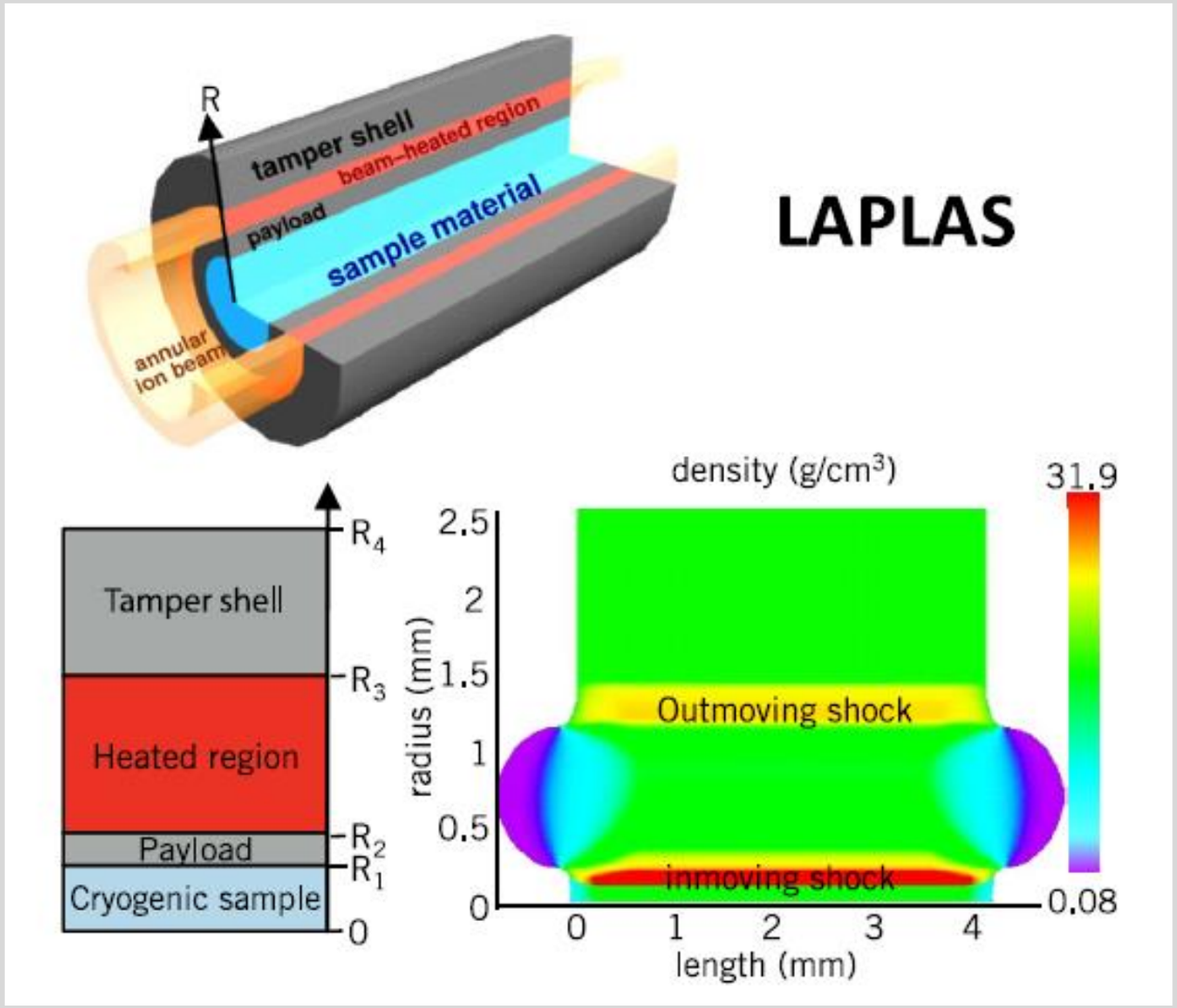
	Current performance		FAIR	
	Protons	U^{73+}	Protons	U^{28+}
Max. energy (GeV/u)	4.7	1	10	2.7
Particles/bunch	1×10^{10}	1×10^{10}	2.5×10^{13}	5×10^{11}

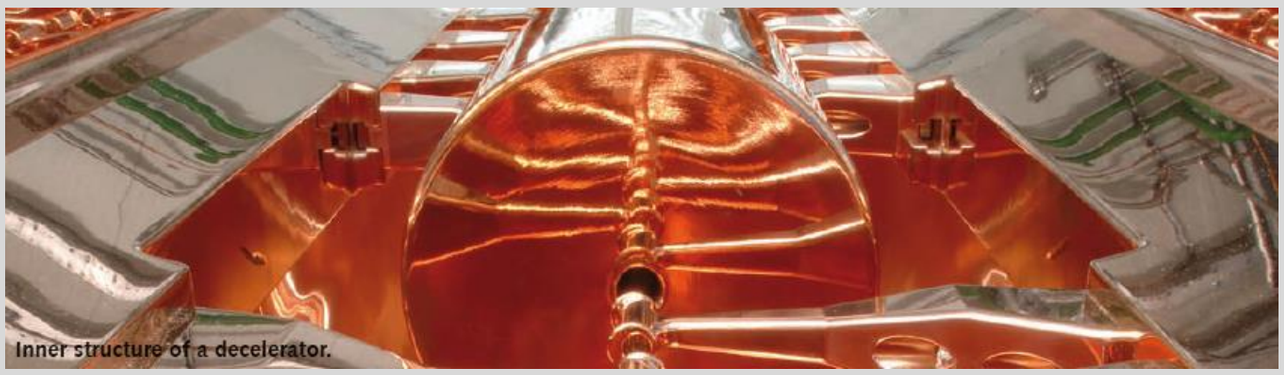


- The new heavy-ion beam synchrotron (SIS100) is a substantial upgrade over current facility.
- Ion beam used to heat matter isochorically under extreme conditions
- Access regimes in between Anvil Cells and Laser-plasma.

FAIR facility opens a wide parameter space for Warm Dense Matter studies

Schoenberg, K. *et al. Phys Plasmas* **27**, 043103 (2020)




Inner structure of a decelerator.

Science areas

- New fusion concepts.
- Properties of materials driven to extreme conditions of pressure and temperature.
- Strongly coupled plasma physics.
- Nuclear photonics.

Thank you for your attention!