



INDUSTRIAL COMPACT FREE ELECTRON LASERS

AND LASER-DRIVEN ACCELERATORS

CATALIN C. NEACSU

(on behalf of the people who
actually do the work)

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AGENDA

TAU SYSTEMS - **THE WHO & WHERE**

GOALS - **THE WHY**

PRODUCT LINES - **THE WHAT**

SERVICE CENTER - **THE TAU LABS**



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COMPANY OVERVIEW

FOUNDED IN JULY 2021

BELLA HTU-FEL FACILITY BERKELEY, CA

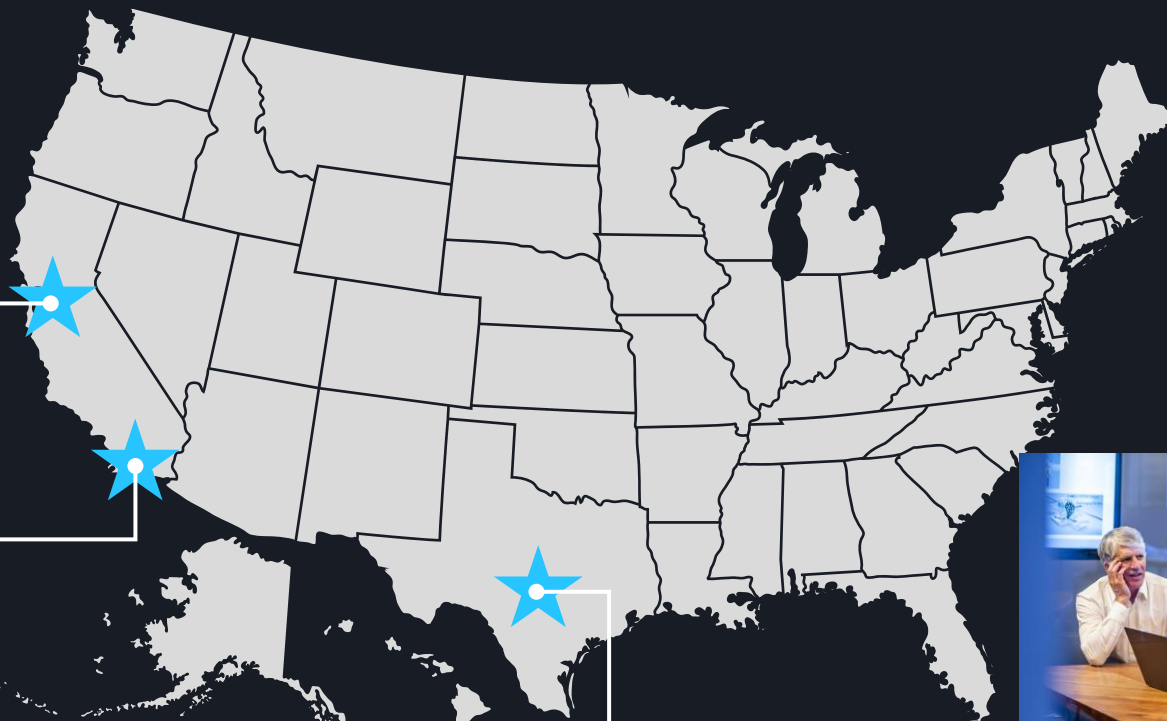
- SPP/CRADA with Lawrence Berkeley National Laboratory
- Personnel: 4-5 TAU

TAU LABS SAN DIEGO, CA

- Next generation laser & accelerator prototype development
- Personnel: 6 TAU

HEADQUARTERS AUSTIN, TX

- Main office
- Joint TAU/UT Austin R&D Facility @ UT Austin campus: accelerator, x-ray, neutron, diagnostics, & control systems R&D
- Personnel: 15 TAU / 5 UT





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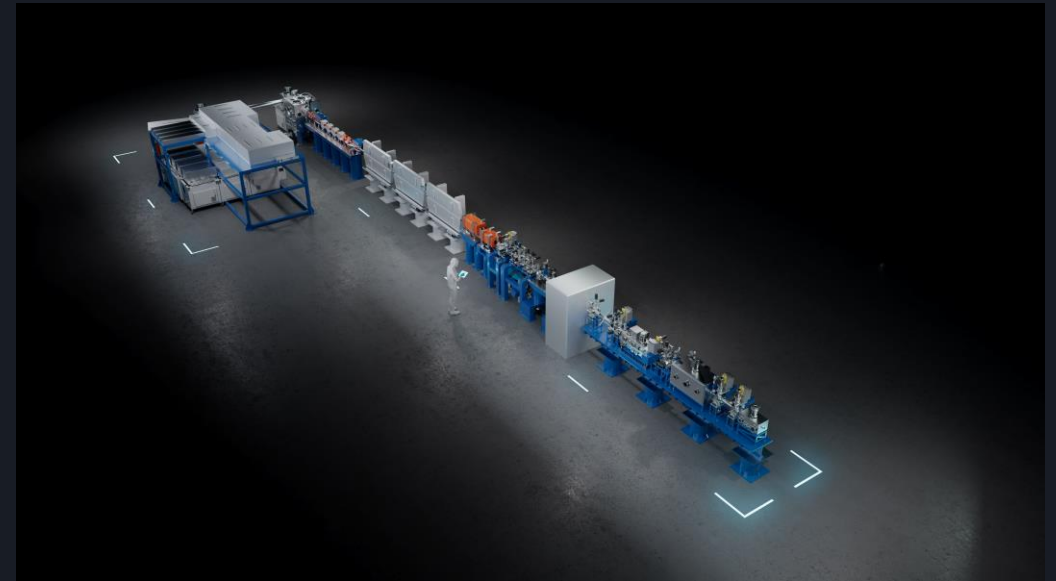
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ADVANCING THE LARGE LIGHT SOURCES BY PROVIDING COMPACT LASER-PLASMA ACCELERATOR AND FEL

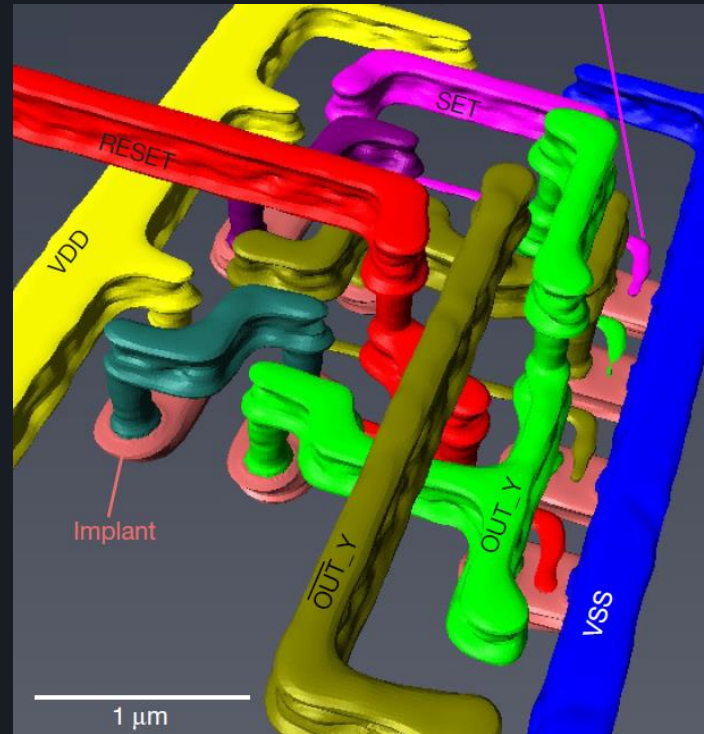


Miles to meters - billions to millions.
Industrial grade. Economically viable.

3D-STACKED SEMICONDUCTOR CHIPS QUALITY CONTROL: DEEPER, SMALLER, FASTER

**SEMICONDUCTOR
CHIPS ARE NOT ONLY
GETTING EVER SMALLER
BUT ALSO ARE NOW
INCREASINGLY 3D
STRUCTURES**

3D rendering of an ASIC chip obtained by X-ray tomography using the Swiss Light Source synchrotron

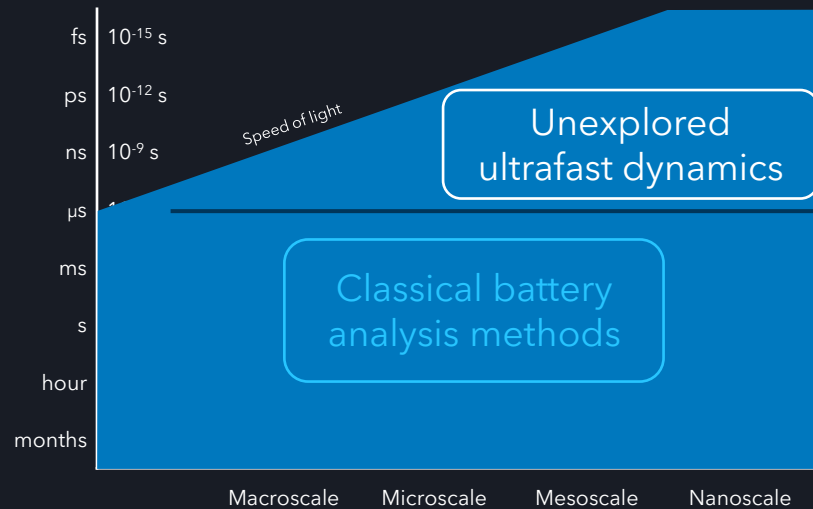


Finding defects in the most advanced 3D-stacked semiconductor chips requires:

- Higher energy X-rays to penetrate deep into the layers of the chip
- Shorter wavelength X-rays to detect smaller features
- Smaller X-ray source dimension for higher imaging resolution
- High photon flux for faster measurements

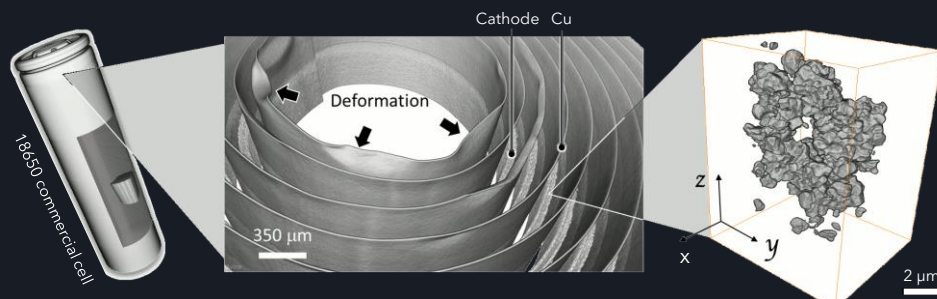
BATTERY CELLS QUALITY CONTROL: DEEPER, SMALLER, FASTER

**BATTERY CELL
DEVELOPMENT AND
QUALITY CONTROL
REQUIRE EXPLORATION
OF SMALL FEATURES,
DEEP IN THE CELL, ON AN
ULTRASHORT TIME SCALE**



Finding defects in ever bigger battery cells requires:

- Higher energy X-rays to penetrate deep into the cell
- Shorter wavelength X-rays to detect smaller defects
- Smaller X-ray source dimension for higher imaging resolution
- High photon flux for faster measurements
- Ultrashort X-ray pulses to detect ultrafast dynamic effects





TODAY:

Advanced Photon Source (APS) synchrotron at Argonne NL.



The sources of choice for ultra-high resolution and in-depth imaging are [synchrotrons](#) - very large, very expensive, & very few.

The only X-ray sources for production environments are based on [X-ray tubes](#) and [small linear accelerators](#) - limited photon energy and brightness

The time has come to have compact and affordable X-ray sources that industry needs to progress.



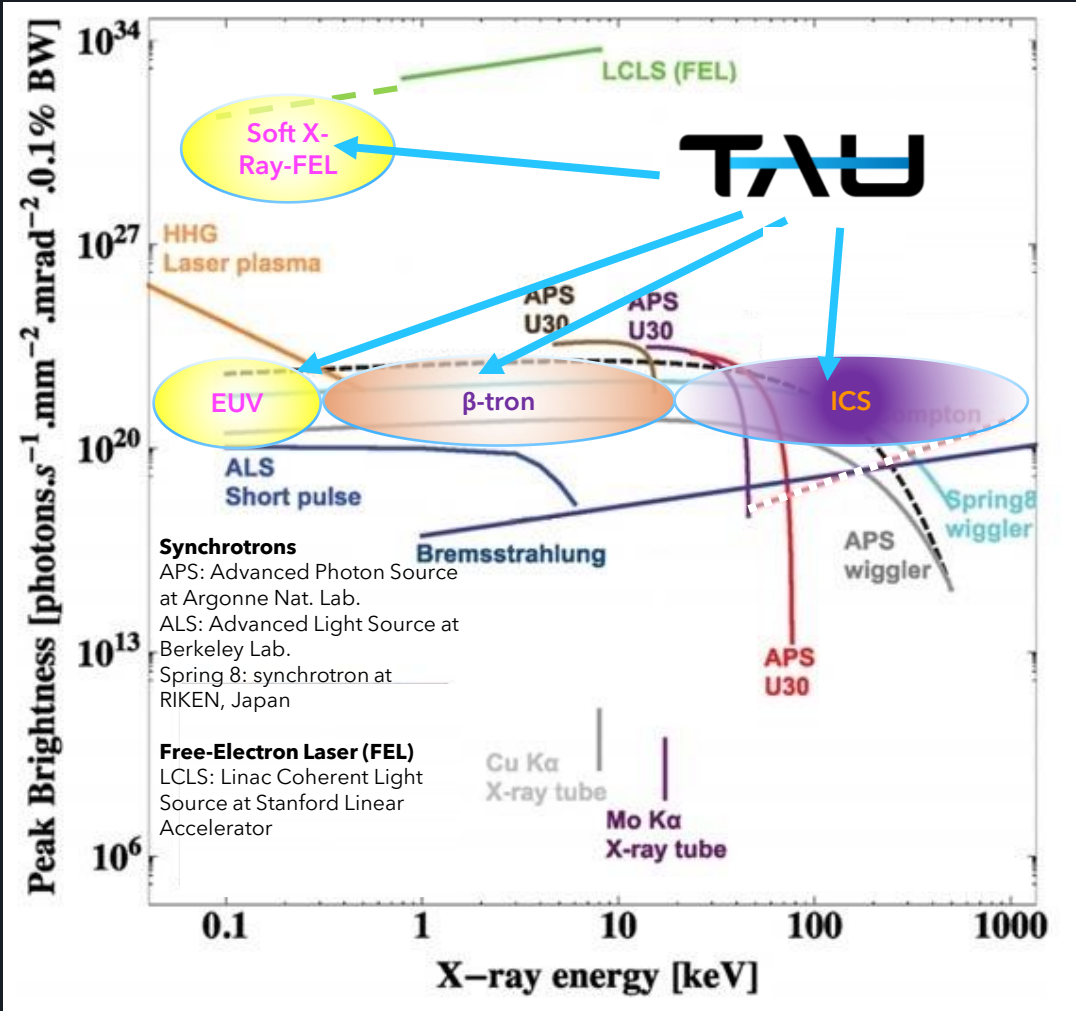
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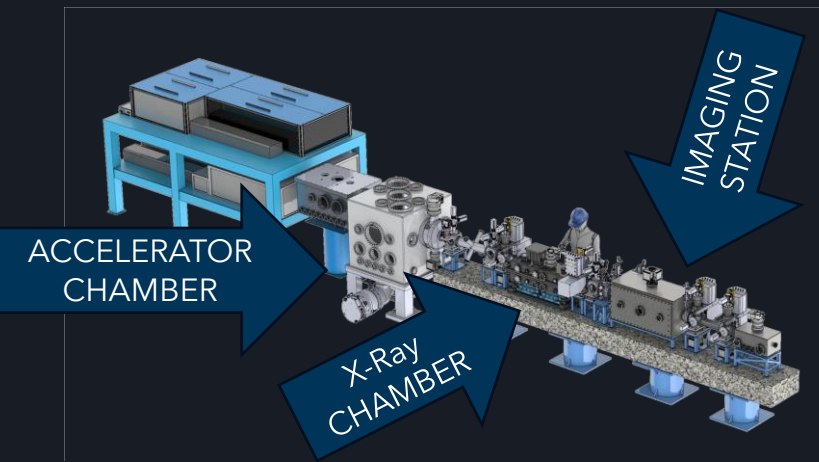
BETTER X-RAY SOURCES... AT 1/100 OF THE COST

TAU's new type of industrial grade X-ray sources:

- High X-ray energy: 100s keV
- High peak brightness: $>10^{20}$ photons.s⁻¹.mm⁻².mrad⁻².0.1% BW
- Very small source size for high imaging resolution: $\sim 1 \mu\text{m}$
- Ultrashort pulses: less than 25 fs

Industrial grade.
Economically viable.

TAU X-100+: HIGH POWER TABLETOP SYNCHROTRON



TAU X-100+: X-ray light source at 100 Hz repetition rate

COMPACT SYNCHROTRON FOR X-RAY METROLOGY & R&D

TAU WILL HAVE A FIRST X-RAY LIGHT SOURCE OFFERED AS A PRODUCT AND OPERATING AS A SERVICE CENTER BY 2025.

Specs, to start with:

Ti:Sapphire Laser:

Pulse duration: 25 fs

- Pulse energy: 1 J and higher
- Repetition rate: 100 Hz and higher

X-rays

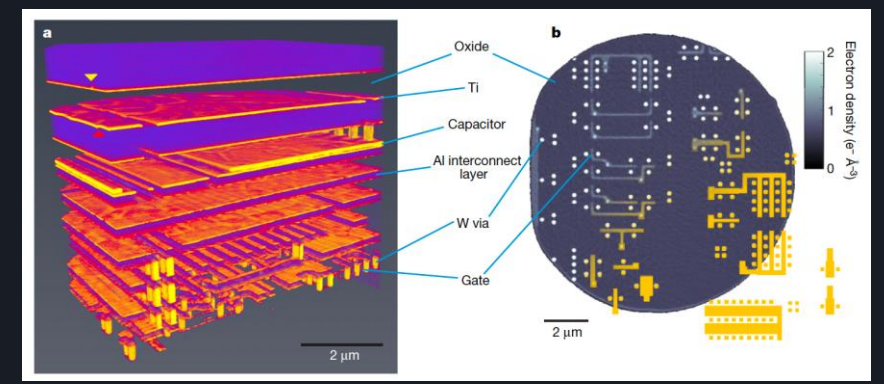
- X-ray energy: 1-25 keV
- X-ray flux: $>10^{10} / 10^{12}$ photons/sec

Applications:

Semiconductor and battery metrology

- Nano CT
- Resonant soft X-ray Scattering (RSoXS)
- Lithography R&D
- X-ray ptychographic computed tomography
- Critical Dimension Small Angle X-ray Scattering (CD-SAXS)

High Signal to noise ratio needed... and rep. rate is what it takes.



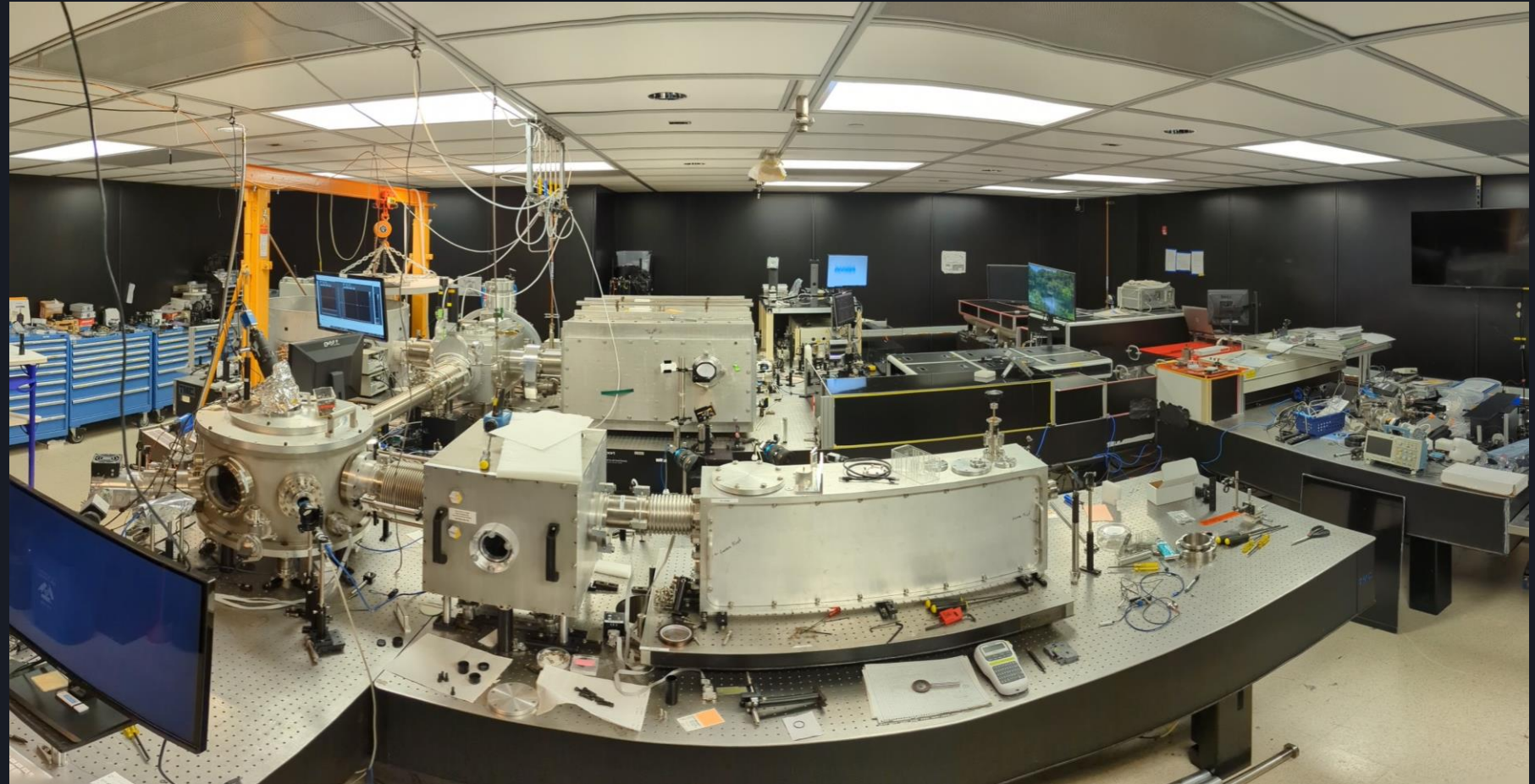


UT-TAU JOINT R&D FACILITIES

Agreement for shared use in
collaboration with Prof. Downer

Finished UT³ laser upgrade:

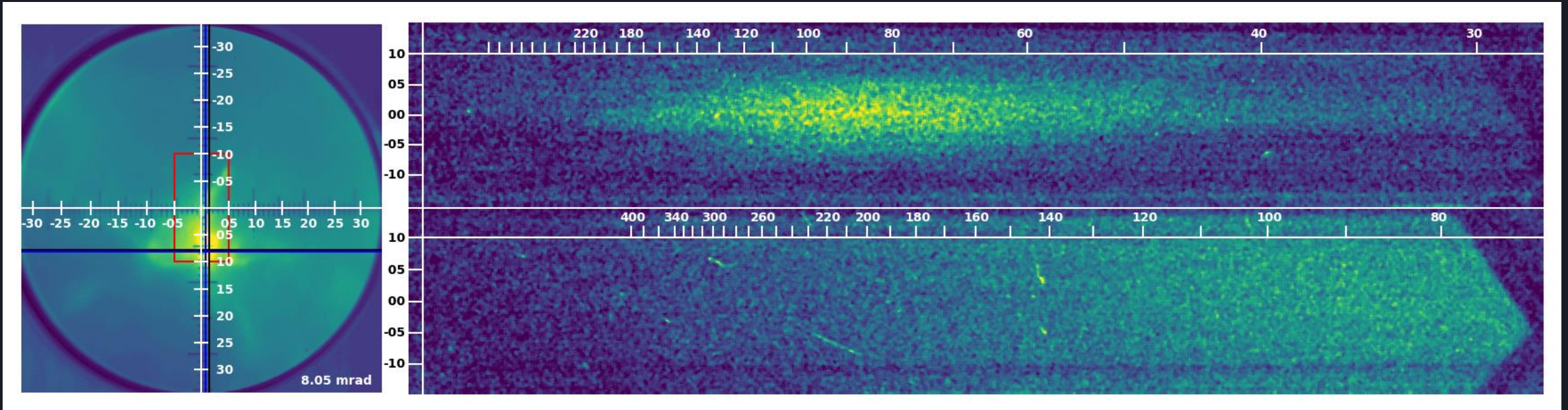
- Laser refurbishment
- 1 J , 30 fs pulse, 10 Hz
- LWFA/x-ray beamline
- Probes, diagnostics



ON-CAMPUS LABS UNIVERSITY OF TEXAS AT AUSTIN

Technology development for laser acceleration, X-ray, gamma, and neutron sources, control systems, imaging

TAU TABLE-TOP ACCELERATOR FIRST RESULTS @ AUSTIN LABS



Drive Laser : UT³ Ti:Sapphire

700 mJ @ 10 Hz, 35 fs

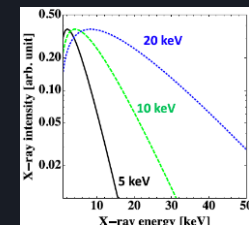
ELECTRON ACCELERATION

~90 MeV peak

Up to 200 MeV tail

X-RAYS

... to come

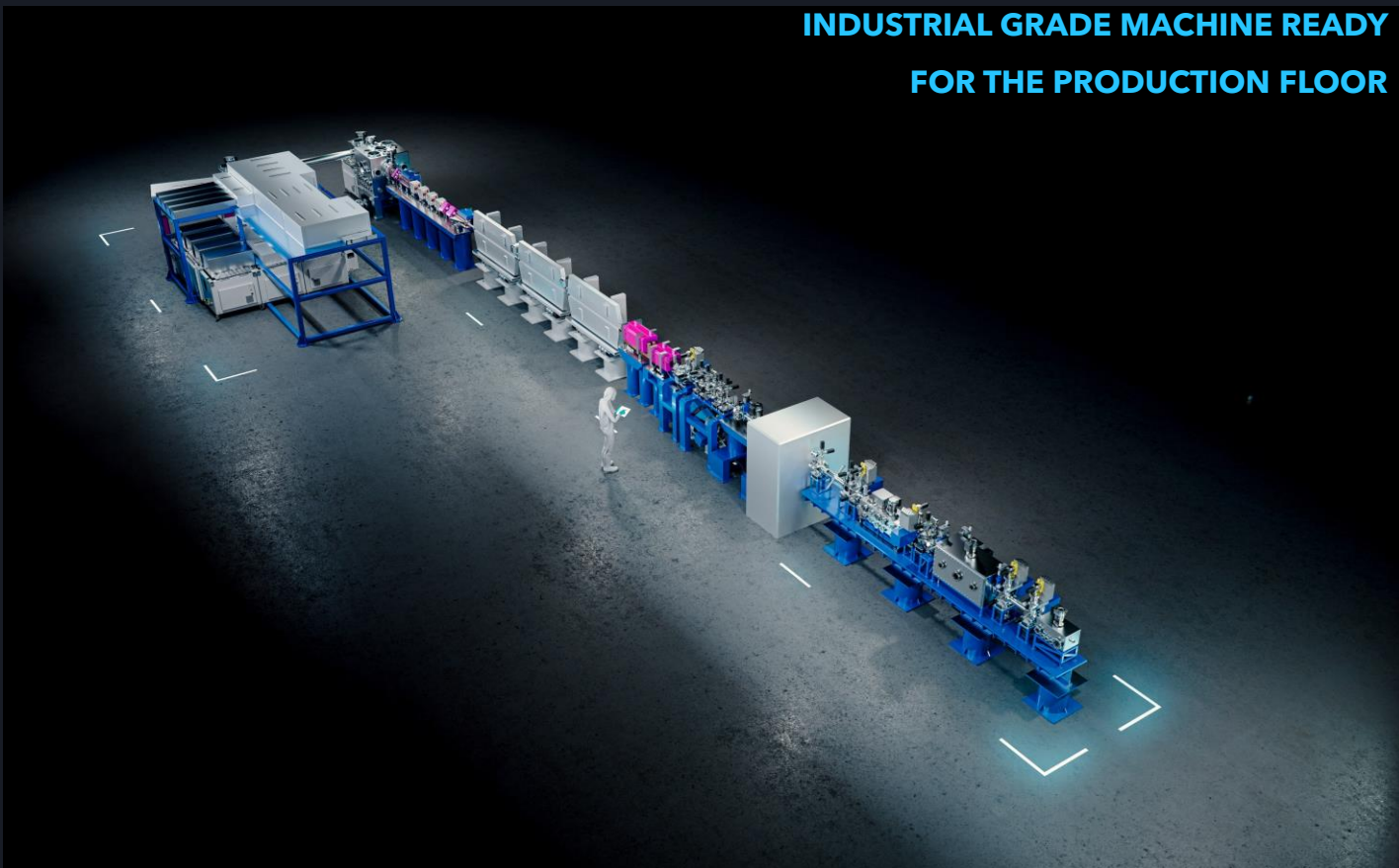


*Phys. Plasmas 30,
050902 (2023);*



TAU EUV-FEL: LASER-DRIVEN EUV FREE ELECTRON LASER

**INDUSTRIAL GRADE MACHINE READY
FOR THE PRODUCTION FLOOR**



TAU EUV-FEL	
Drive Laser	
Drive energy (J)	1-10 J
Repetition rate (Hz)	1-10s kHz
X-ray Source	
Energy (keV)	0.01- 1
Flux (ph/sec)	$>10^{17}$
Pulse duration (fs)	1
Average Brightness (ph/s.mm ² .mrad ² .4% BW)	$>10^{27}$

Time is Money in production... and rep rate is what it takes.



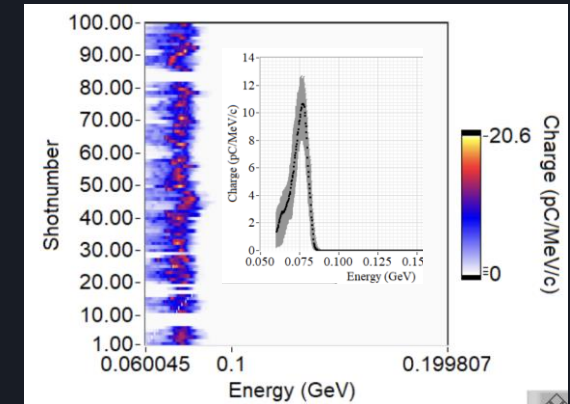
COLLABORATION WITH LBNL ON LWFA-FEL EXPERIMENTS IN BERKELEY SHOWS FIRST GAIN

Collaboration agreement with LBNL to develop laser-driven EUV-FEL

TAU funds half the operating cost of the BELLA Hundred Terawatt Undulator facility

TAU retains intellectual property on its inventions and shares joint inventions

Data science and control systems



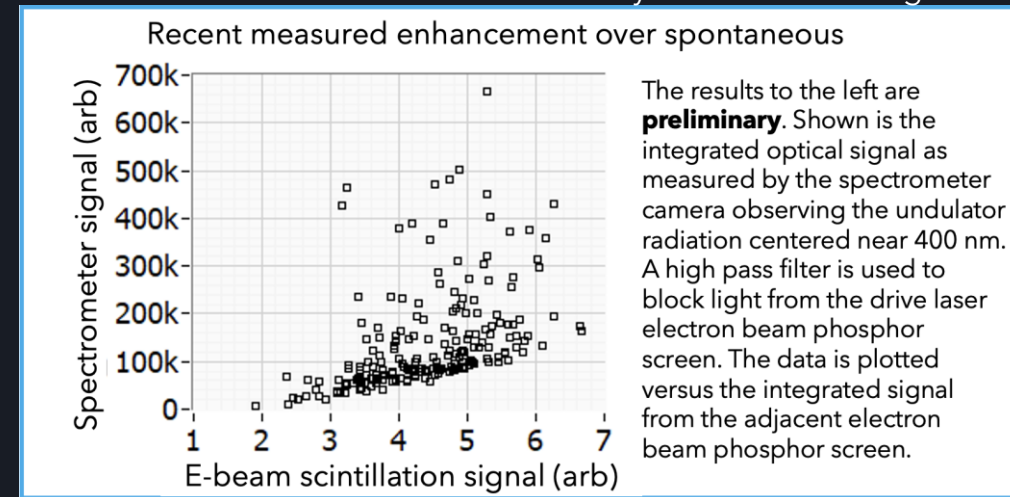
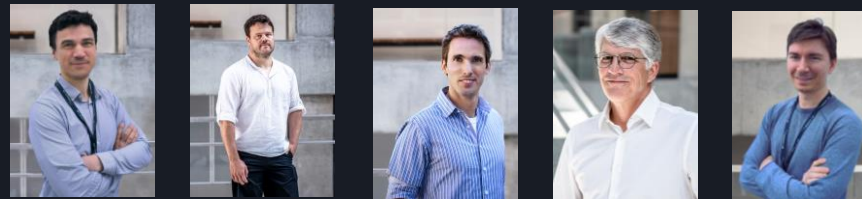
OBSERVATION FEL LASING @ 400NM

Beam energy stability improvement following systematic beam alignment

LBNL:
J. van Tilboerg, S. Barber



TAU:
G. Plateau, H. Smith, P. Walter, R. van Mourik, S. Milton





TAU DESIGN CAPABILITY

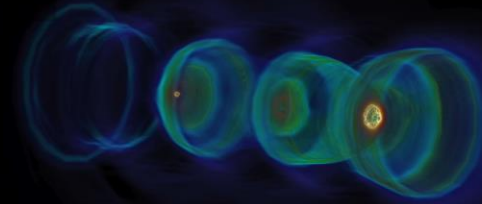
in house simulations to predict performance and support design of laser-plasma accelerator beamline:

- The PSC and PICTOR : PIC codes
- 3D cartesian & explicit cyl. grid with moving window & dyn. load-balancing
- Advanced PIC data post-processing and visualization
- HHG-SFA (in-house)
- elegant (beam transport)
- GENESIS 1.3 (FEL)
- GEANT4
- Zemax OpticStudio
- Fluent
- Comsol

TAU Electron Spectrometer & Software

- Fast routines for real-time feedback (<1 ms)
- High accuracy routines for offline post-processing
- Customizable statistical visualizations and analysis
- Complete uncertainty characterization

**REAL-TIME SPECTRUM
ANALYSIS IN LESS THAN A
MILLISECOND**



3D CYLINDRICAL LWFA SIMULATION

TAU free software release **TauOpt**

An automation and optimization code

<https://github.com/TAUSystems/TauOpt>

TauOpt is designed to automate simulations. With TauOpt, users can streamline their simulation processes, save time on manual parameter tuning, and benefit from faster results through optimized simulations.

If you want to try it & use it, reach out. It works & it's free.



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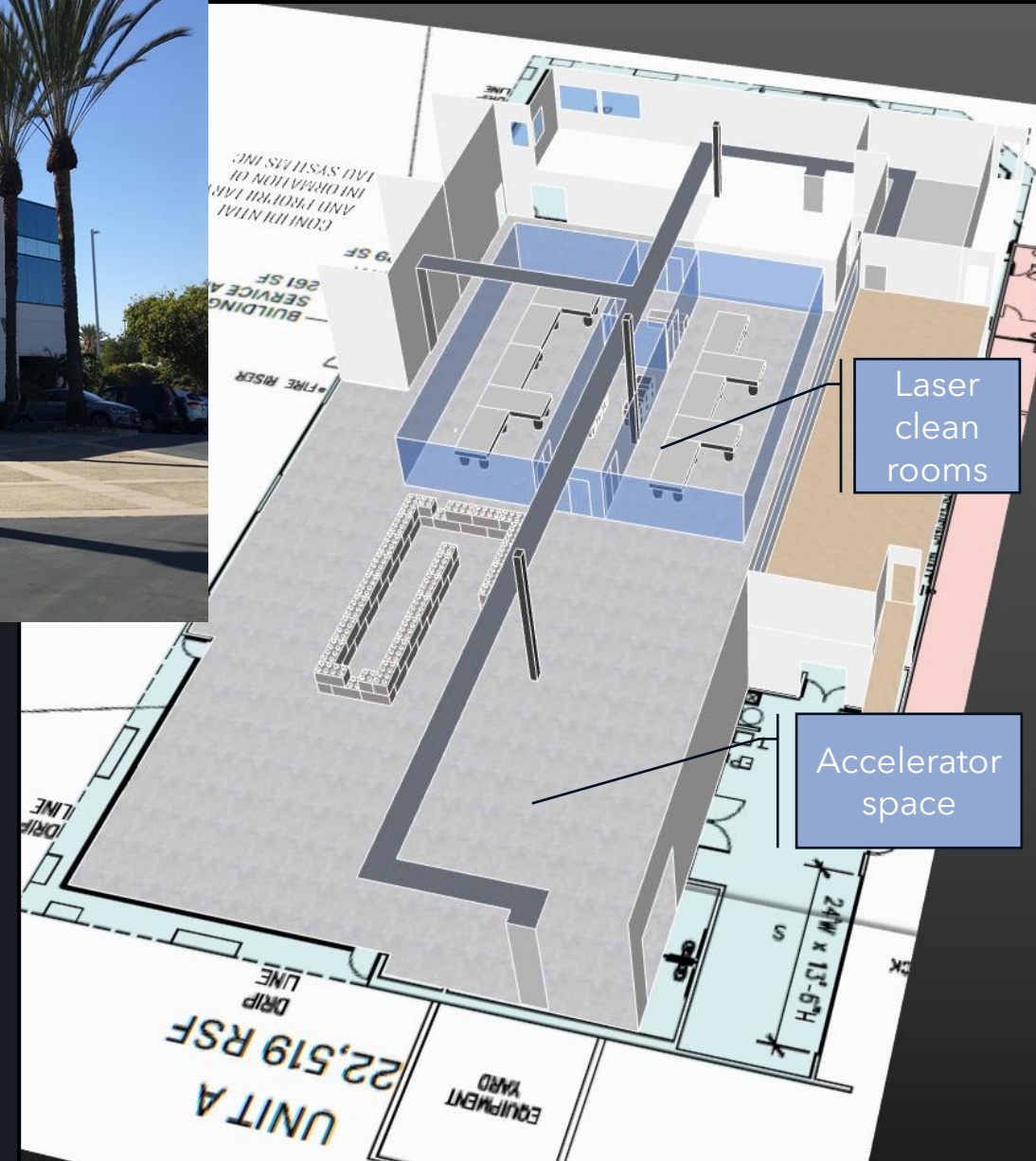
SERVICE CENTER - **THE TAU LABS**



ACCELERATE THE FUTURE

TAU LABS SERVICE CENTER

Opening 2024
Carlsbad (San Diego), CA



Secondary Radiation:

- Electrons
 - 30 - 250 MV
- X-rays
 - 1-250 keV
- Neutrons
 - MeV, 10^9 n/s



ACCELERATE THE FUTURE

TAU LABS SERVICE CENTER

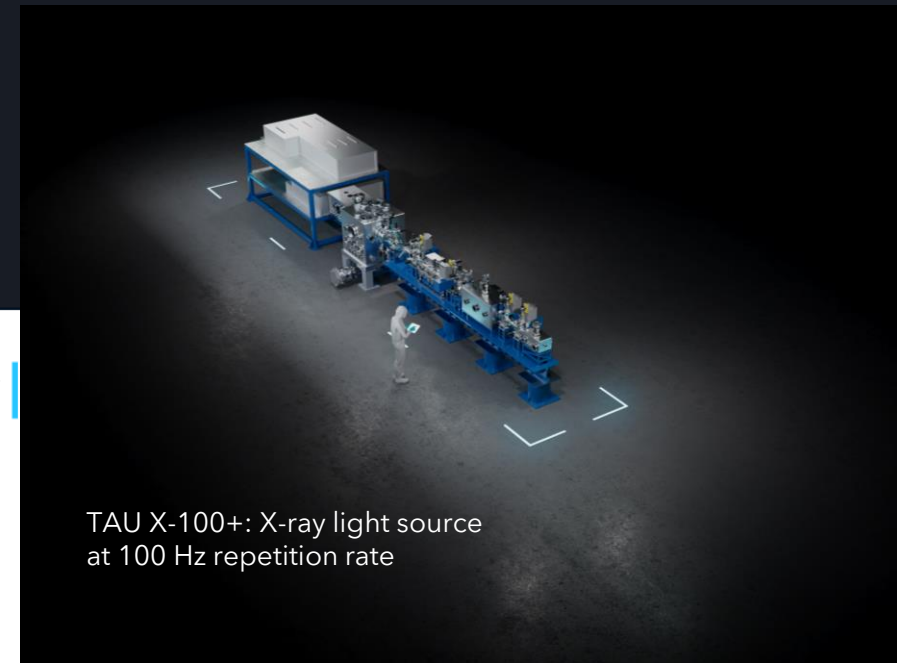
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APPLICATIONS

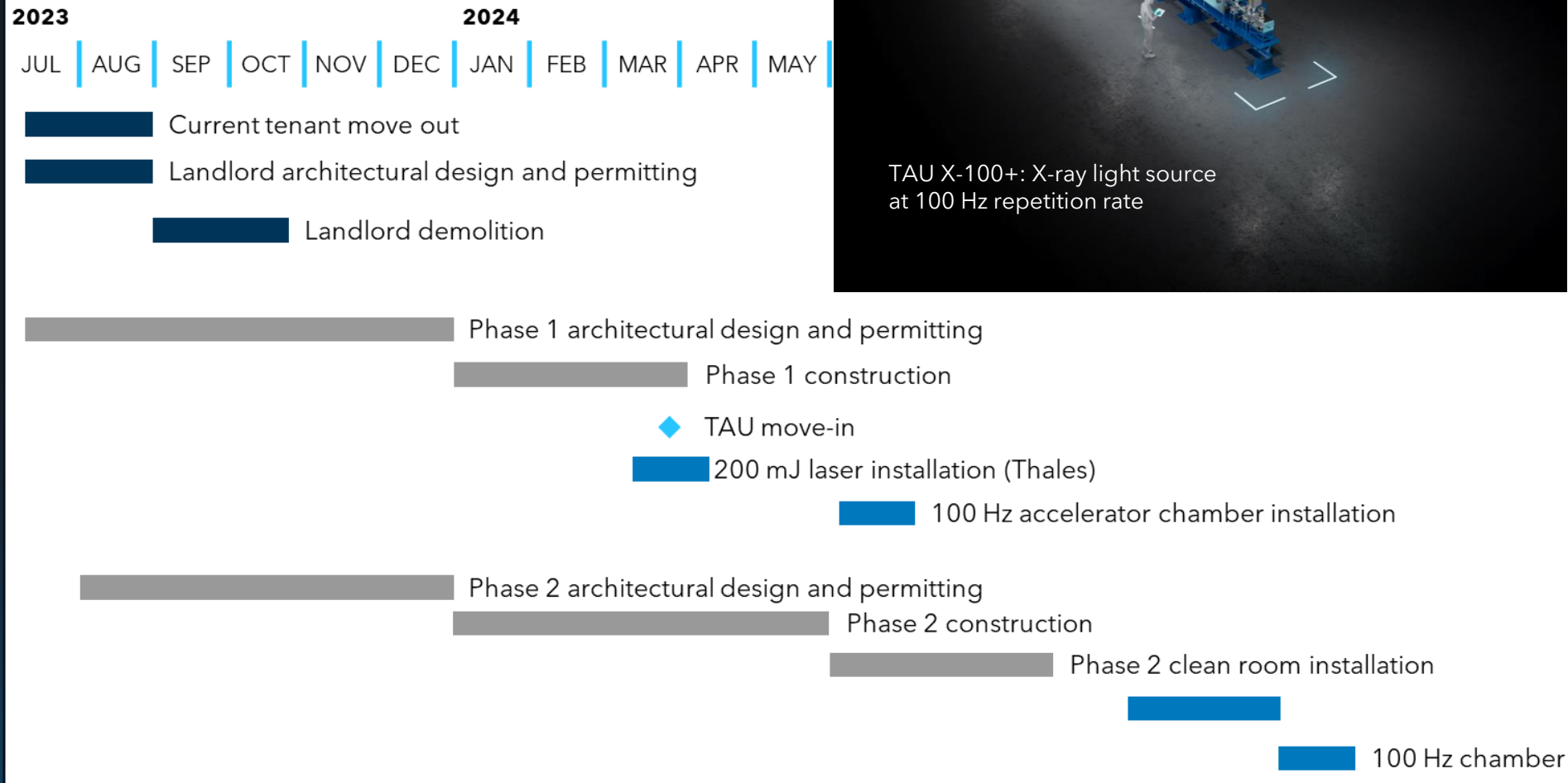
- Laser wakefield studies
- Attosecond science
- X-ray metrology/imaging
- Materials testing
- high rep rate diagnostic development
- optical component damage testing,
- campaigns for experimental preparedness

Sept 21 2023, EAAC23

Innitial full system 100 Hz capable: laser,
beamlines, accelerators, diagnostics, data handling



TAU X-100+: X-ray light source
at 100 Hz repetition rate



OUTLOOK

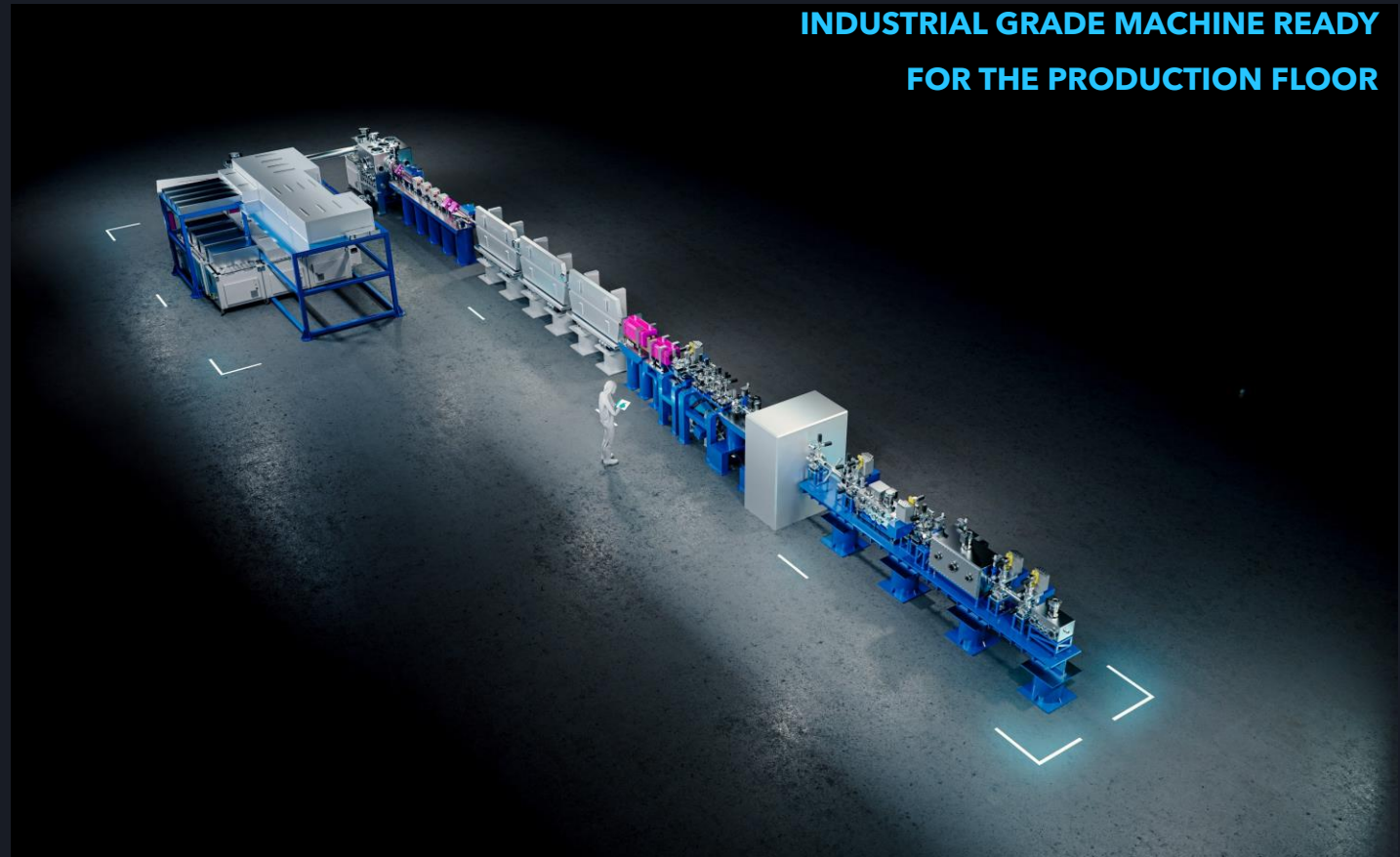
LASER TECHNOLOGY DEVELOPMENT NEEDED

The NEEDS:

- High energy: 1-10
- High repetition rate: 1 – 100 kHz needed
- Ease of use: closed box, alignment free
- Day-to-day reliability and repeatability

- The CHALLENGES:
- ... Well, just technology, specs and engineering 😊

INDUSTRIAL GRADE MACHINE READY
FOR THE PRODUCTION FLOOR



Tau is looking into several laser technologies & we are eager to learn about community's advances