TRISHUL: Petawatt Laser Science Facility at TIFR-Hyd

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HYDERABAD

29th November 2024, TIFR-Hyderabad

EPICS India Collaboration Meeting 28–29 November 2024

Acknowledgement: Ultrafast intense laser group at TIFR-Hyderabad

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Ratul Sabui

Niladri

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Tamanna

Sourabh

Mukesh

Acknowledgement: UPHILL group at TIFR-Mumbai

UPhill

ULTRASHORT PULSE
HIGH INTENSITY LASER LABORATORY

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- Prof. G. Ravindra kumar
- Prof. M Krishnamurthy
- Dr. Amit D Lad
- Dr. Jagannath Jha.
- Yash Ved.
- Aparajit, Ankit, Anandam
- Ameya, Deepak, Kiran,
- Niladri, Rakeeb, Sagar

High energy (MeV scale) Science

with

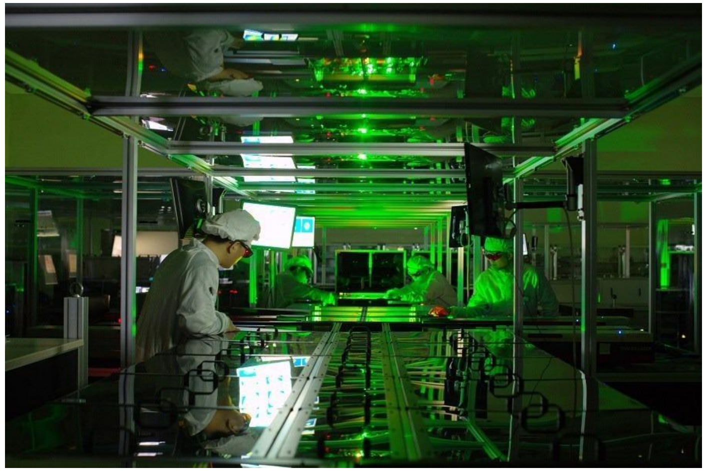
weak (eV) light pulses

Evolution of Intense lasers: from millisecond (kilowatt) to femtosecond (Petawatt)

Year: 1960

- $First\ laser\ (3\ kW)$: $E = 3\ Joule, \lambda = 694.3\ nm,\ \boldsymbol{\tau = 1ms, r_0 = 10\mu m, I = 5 \times 10^8 Wcm^{-2}}$

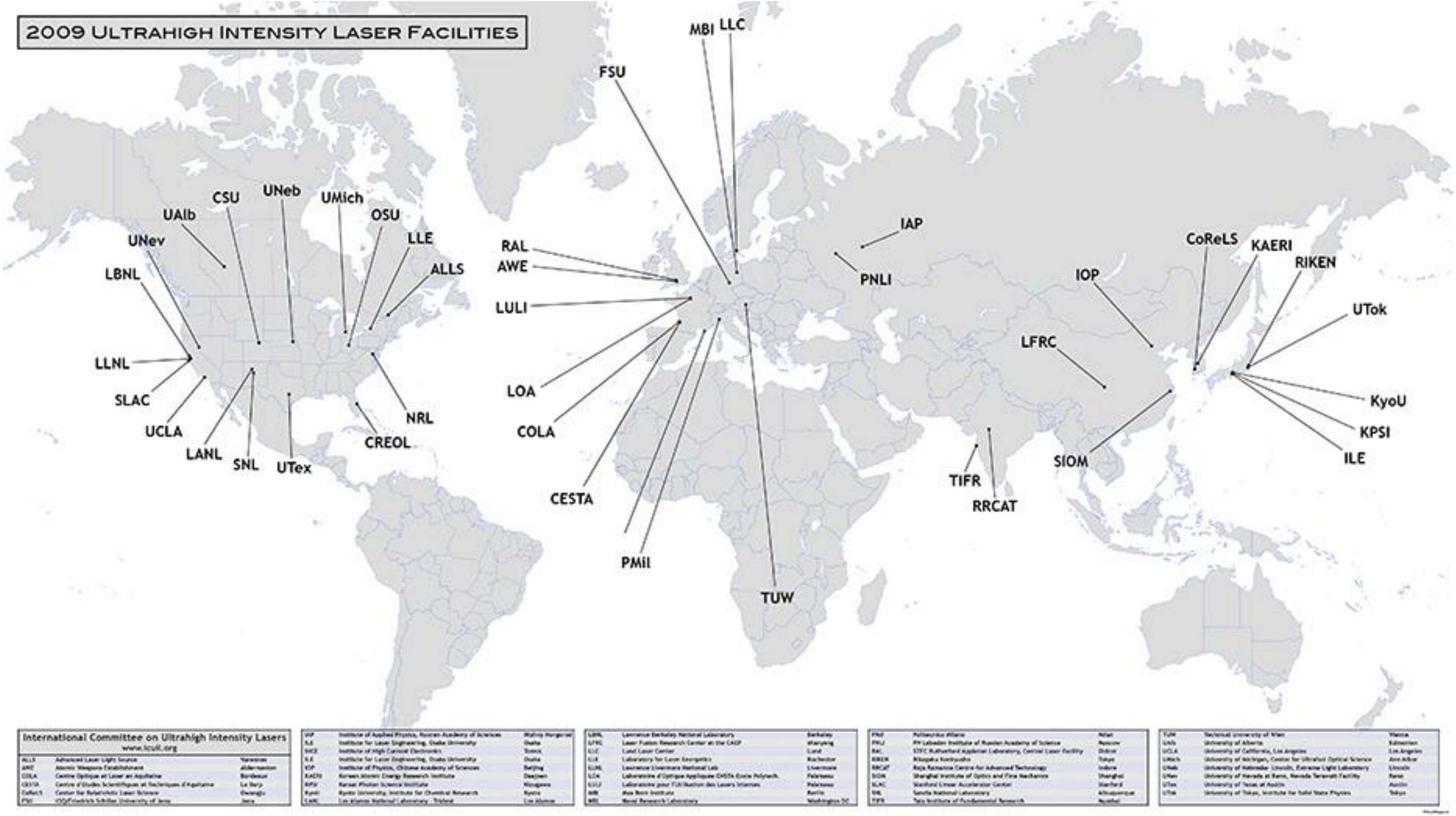
Year: 2023



- $CoReLS\ 4\ PW\ laser$: $E = 100\ Joule, \lambda = 800\ nm,\ \boldsymbol{\tau = 20fs, r_0 = 1.2\mu m, I = 1 \times 10^{23} Wcm^{-2}}$

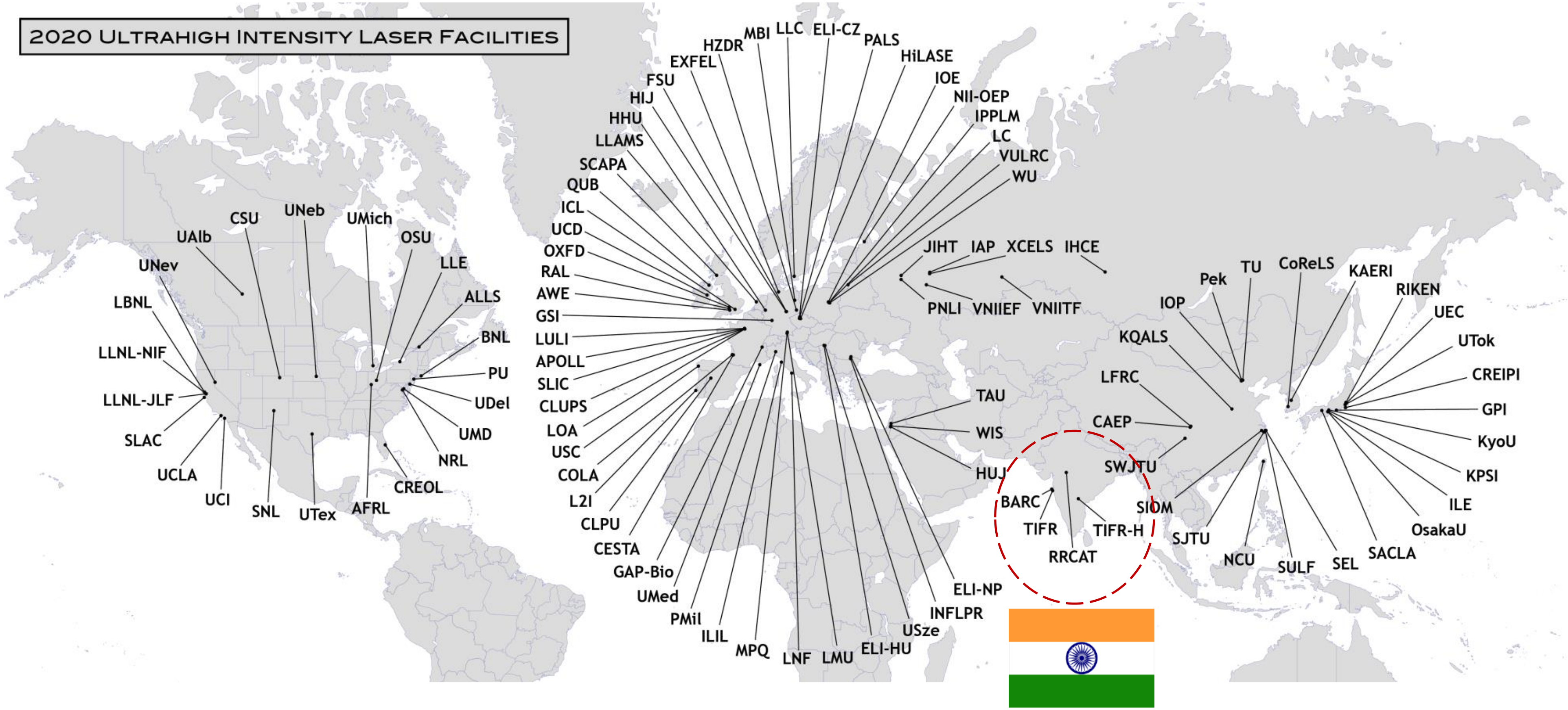
- In 6 decades the peak laser intensity has gone up by factor of $\boldsymbol{10^{14}}$!!

Ultra-intense lasers around the world (peak power > 10 TW)



- *Map of high – intense laser facilities in* 2009.

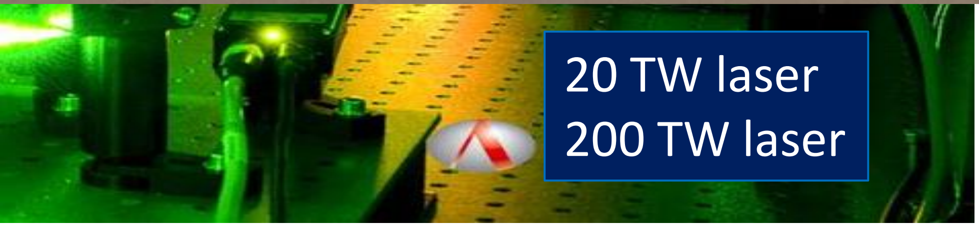
Ultra-intense lasers around the world (peak power > 10 TW)



- Several High power laser facilites are coming up (ELI – Pillars in Europe)
- Exciting time for high-field science activities in India ..!

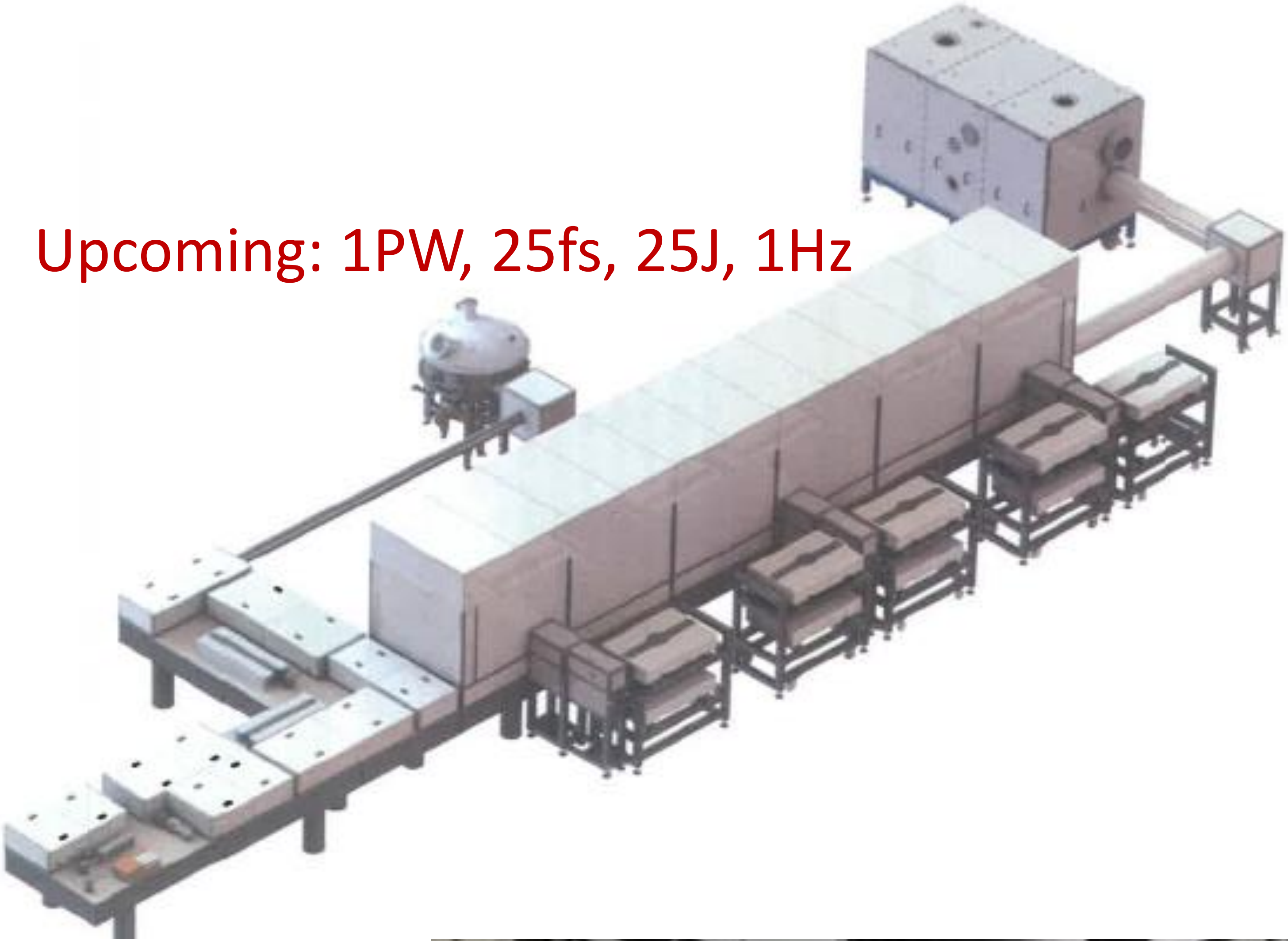
Intense laser drivers in TIFR-Mumbai and TIFR-Hyderabad

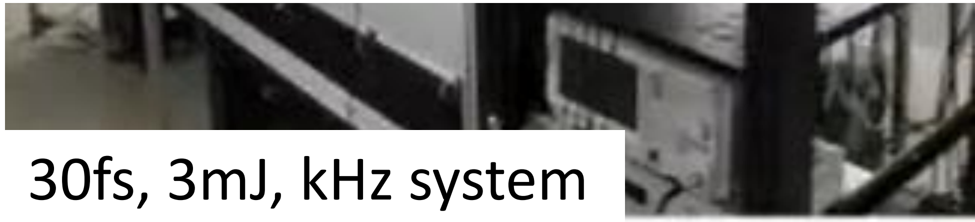
TIFR-Mumbai



20 TW laser
200 TW laser

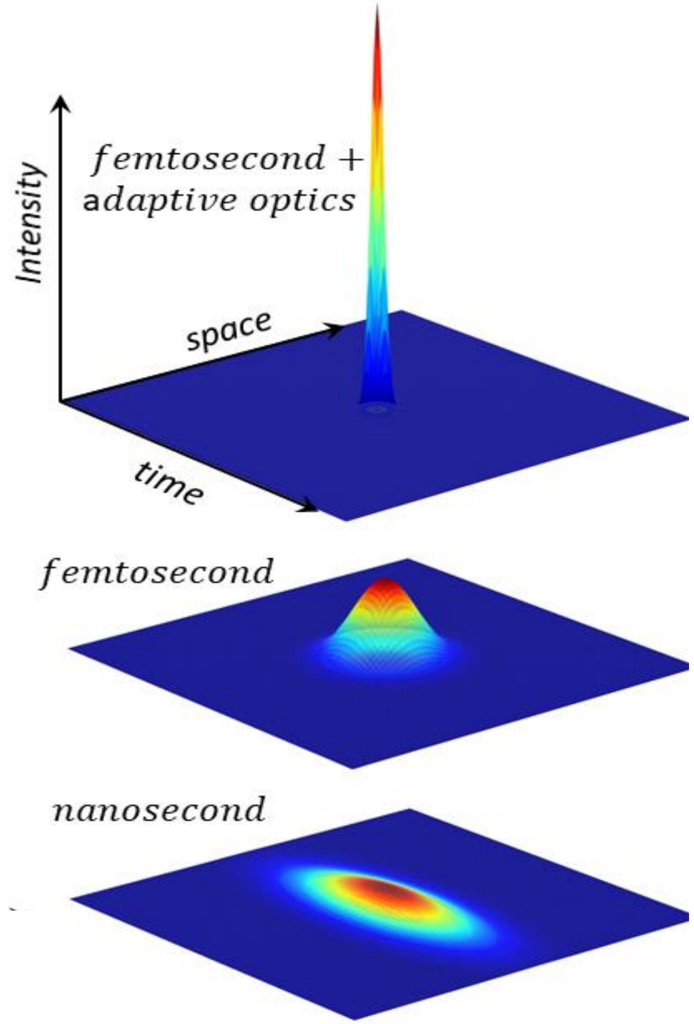
Upcoming: 1PW, 25fs, 25J, 1Hz





30fs, 3mJ, kHz system

Maximization of laser intensity: 3-d confinement of light (2-d space & 1-d time)



$$\text{Intensity} = \frac{\text{Energy}}{(\text{area} \times \text{time})}$$

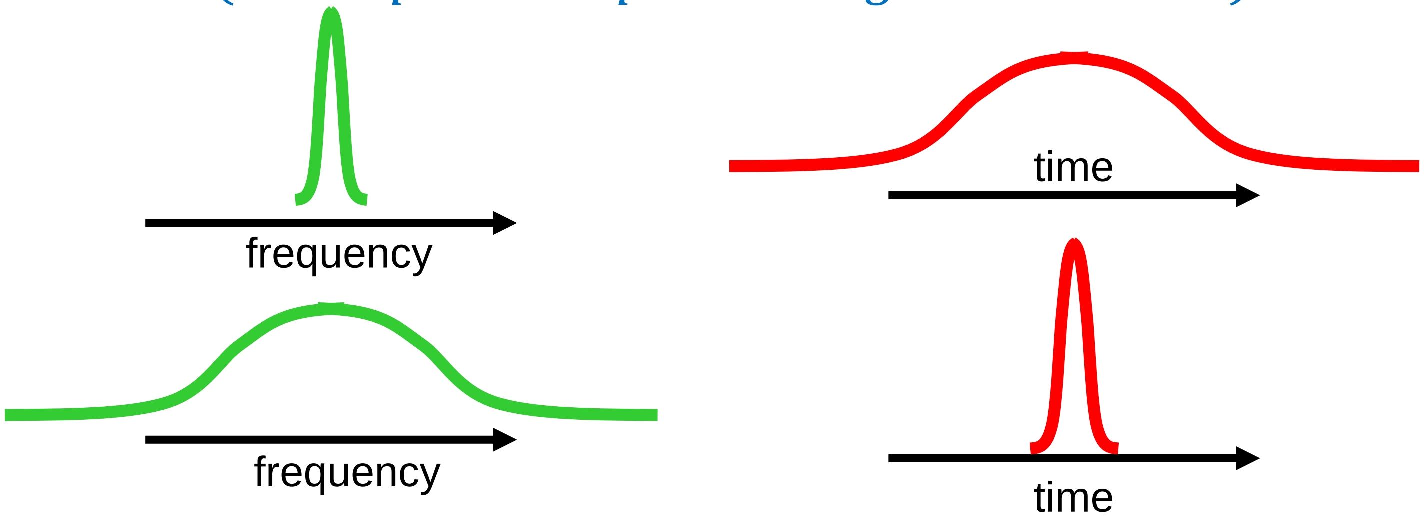
- Power of 3D confinement:
- towards few femtosecond (temporal squeez)
- towards few micrometer ~λ (spatial squeez)

Time-domain: Going down to single optical cycle, few femtosecond lasers

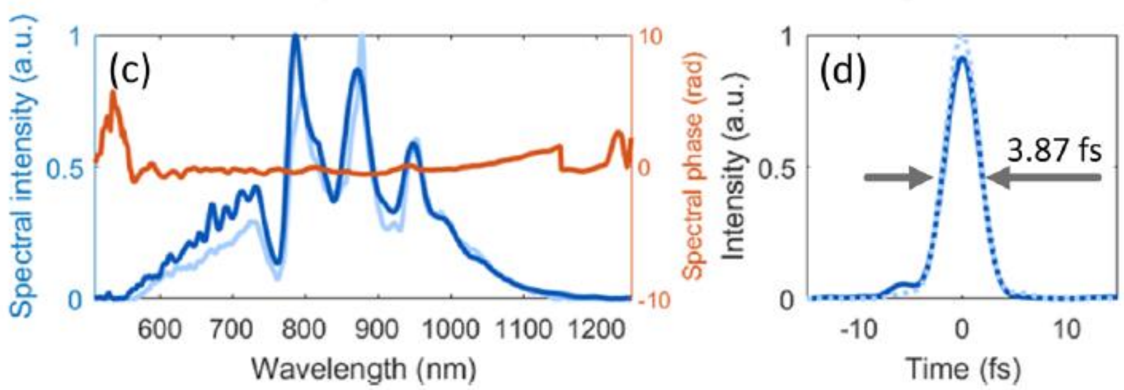
- Uncertainty principle: $\Delta\vartheta \times \Delta\tau \approx 1$ (*short pulse requires large bandwidth*).

Long pulse

Short pulse



➢ Go for spectral broadening: Gas cell/ thin plates



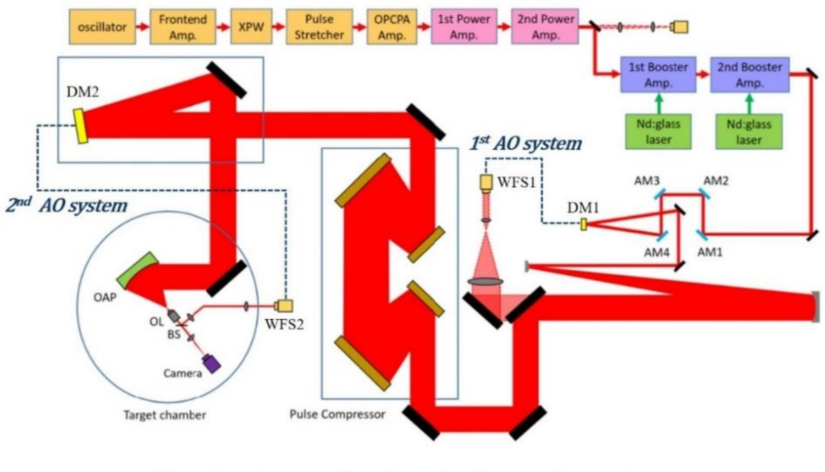
State of the art: 3.9 fs

at multi-TW level!

S. Toth, Optics Letter, **48**, 57, (2023)

- In pursuit of single cycle **NIR pulses** are becoming **white light!**

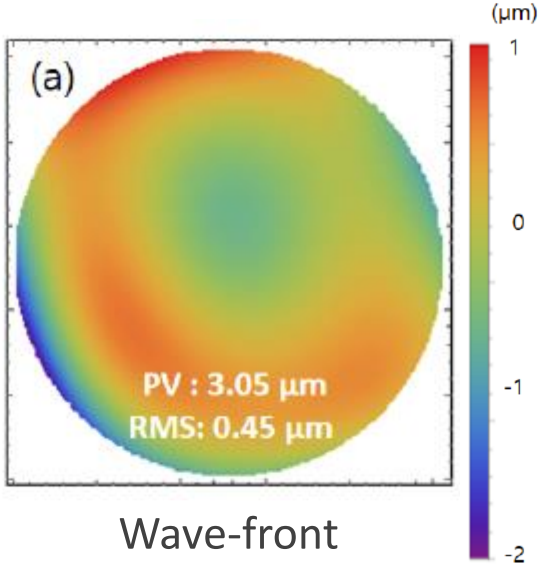
Adaptive Optics for wave-front Correction of intense laser pulses.



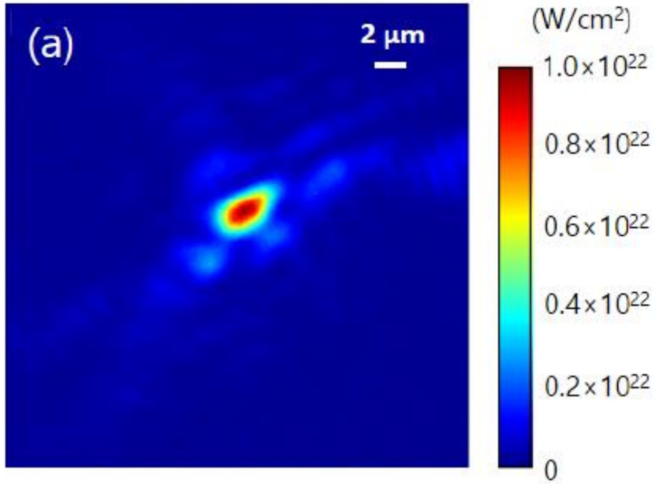
Wavefront correction by adaptive optics systems

Laser wave-front gets aberrated after passing through multiple amplifier stages and large size (500mm) optics.

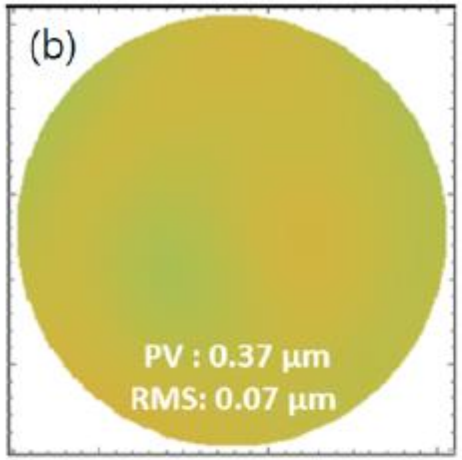
J. W. Yoon, et al, Opt. Express **27**,20412(2019).



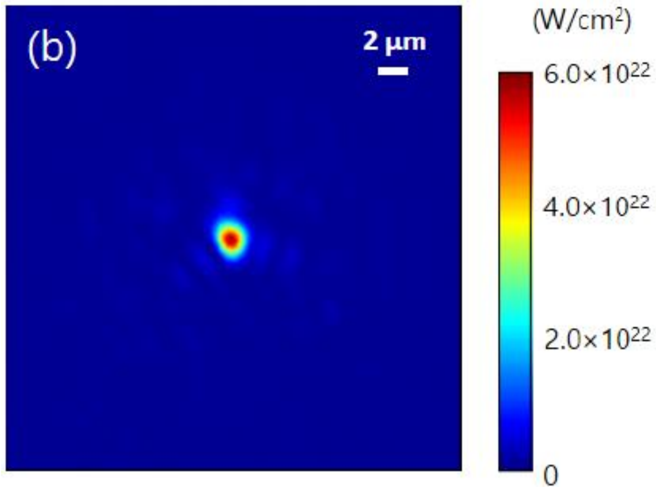
Wave-front
before correction



Focal spot
before correction



Wave-front
after correction

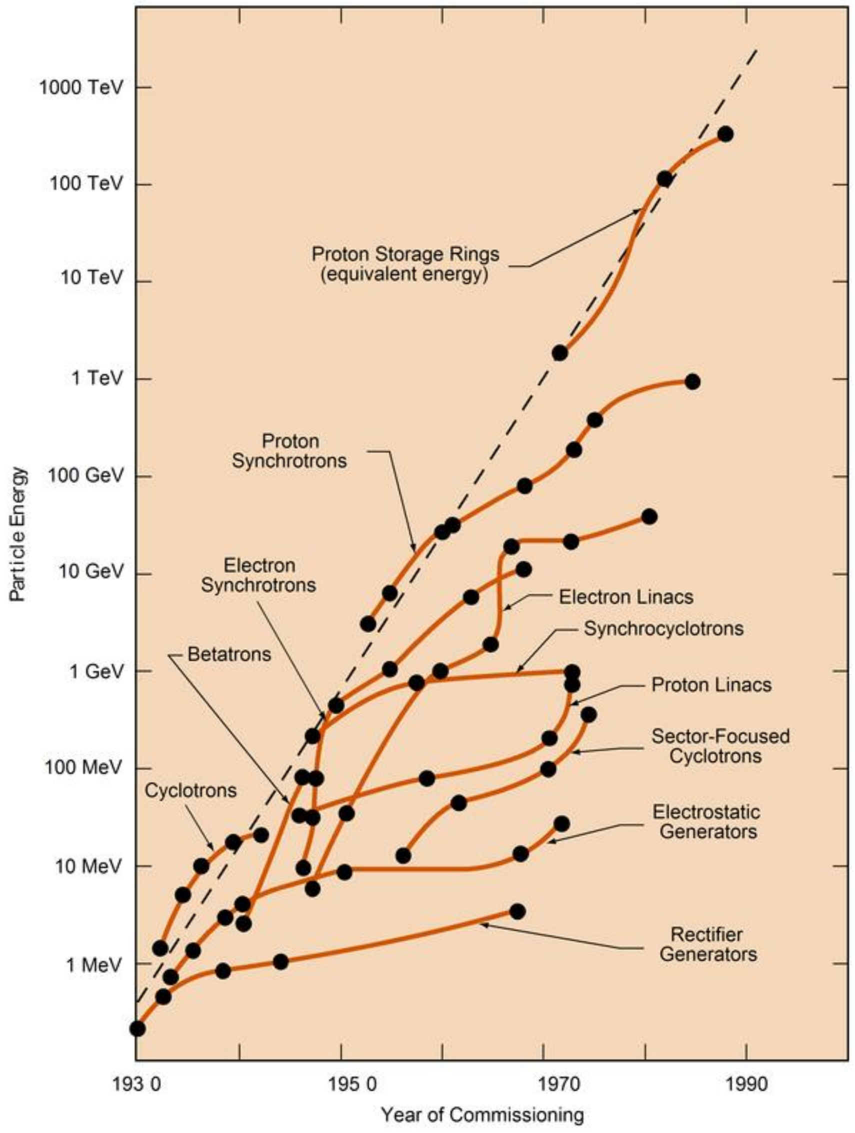


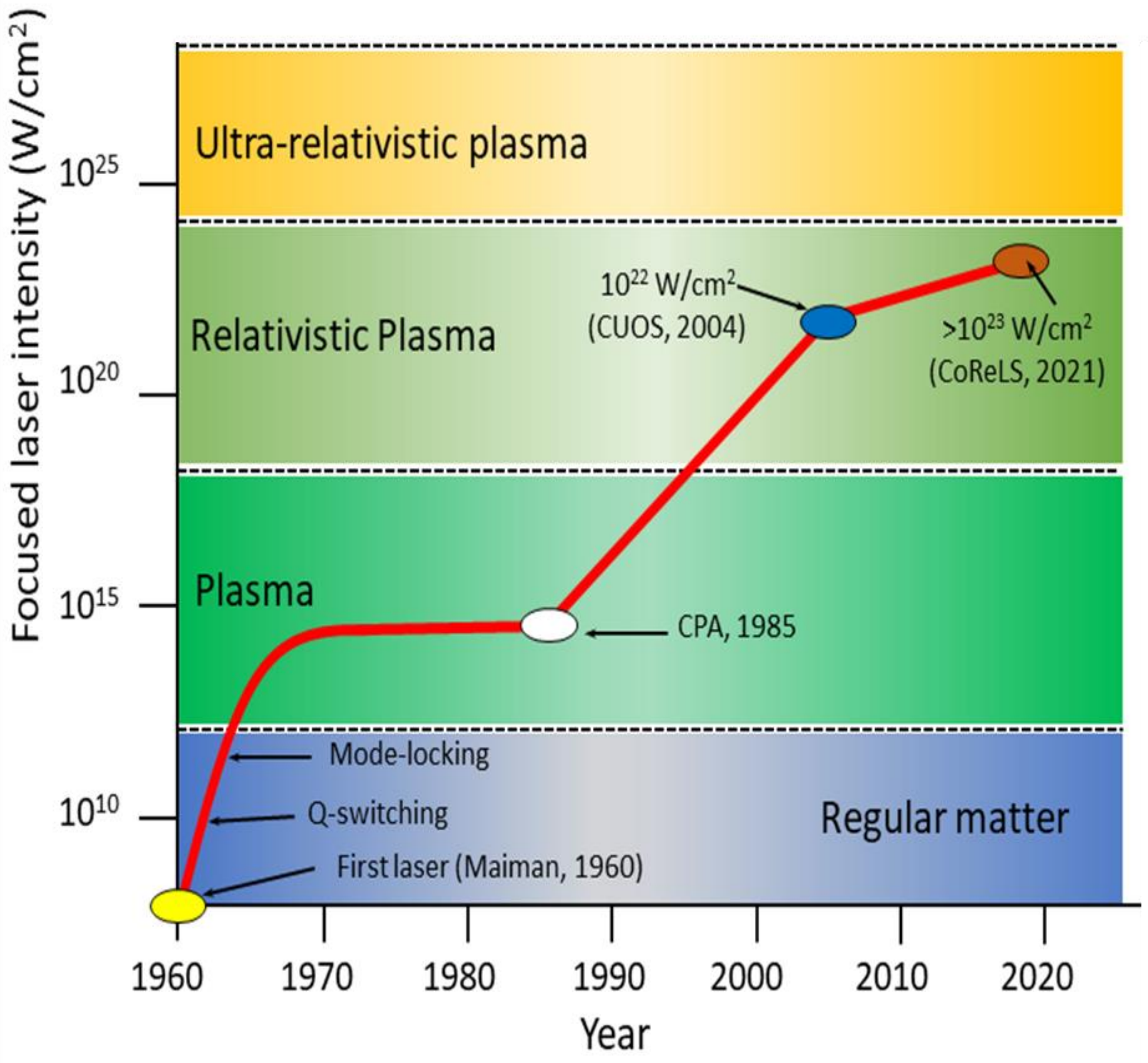
Focal spot
after correction

- Adaptive correction helped in getting 6 times more laser intensity!

Livingston plot equivalent for intense laser plasmas

- Evolution of different generation of particle accelerator have pushed the high − energy − physics frontier.

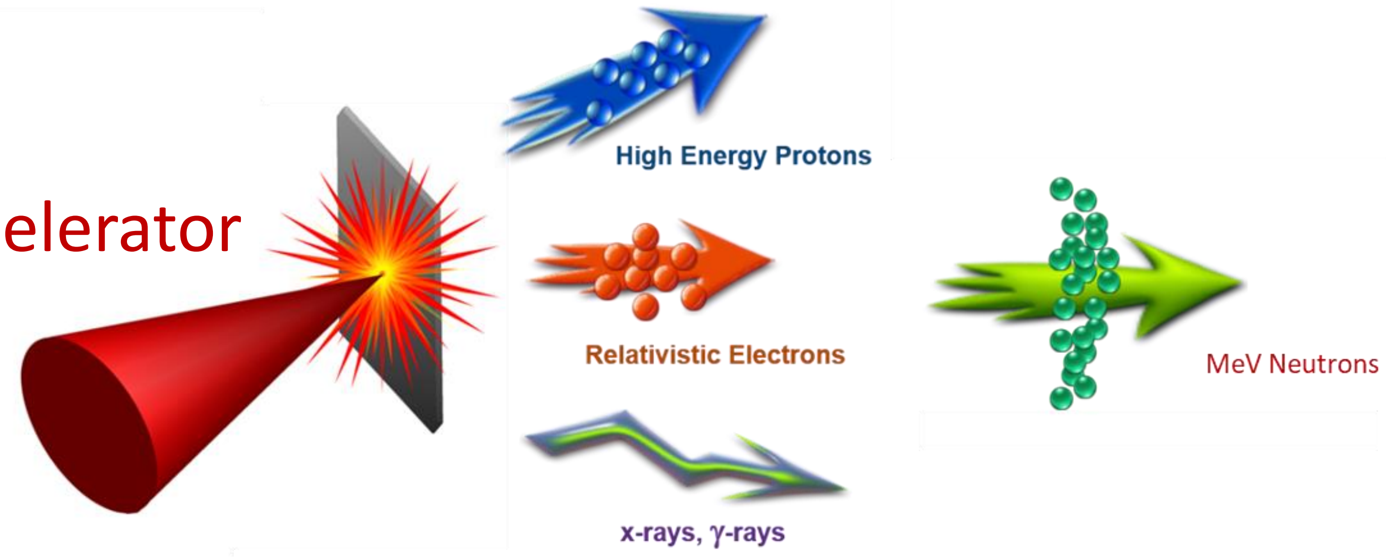




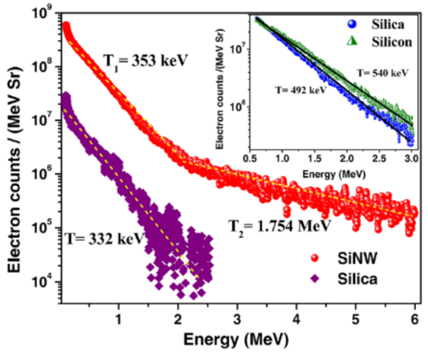
- *New regimes of laser intensity opens new ways of exploring extreme science*!

Converting 1 eV visible photon to MeV electrons, Ions, Neutrons, and X-rays

- Optical Particle accelerator

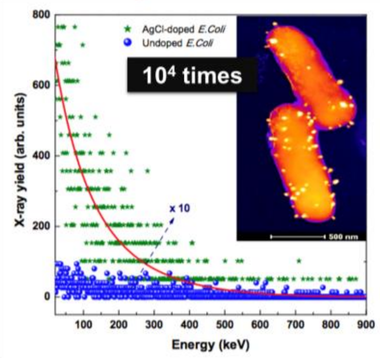


MeV Electrons



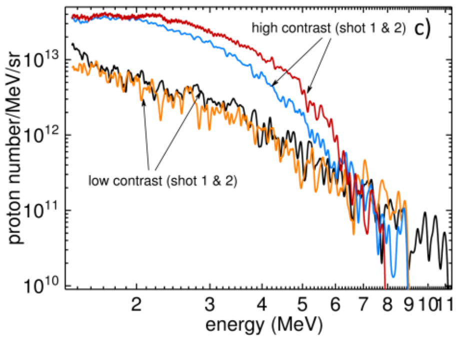
P. K. Singh et al, APL (2012)

MeV X-rays



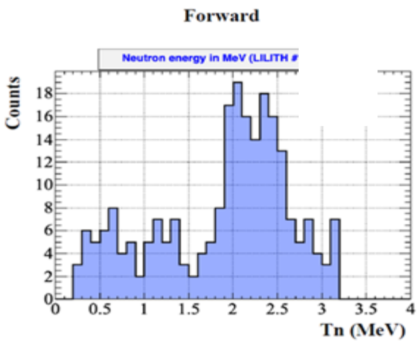
Patented; Opt. Exp. (2015); Sci. Rep (2016)

MeV Protons



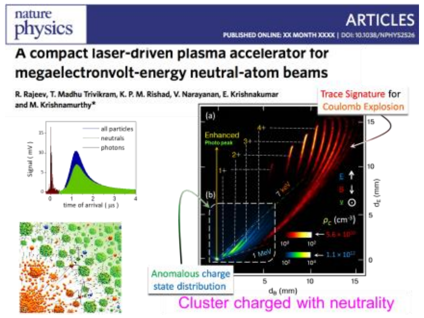
P. K. Singh et al, PoP (2018)

MeV Neutrons



K. Osvay, P.K. Singh *et al.*
Sci. Rep (2024)

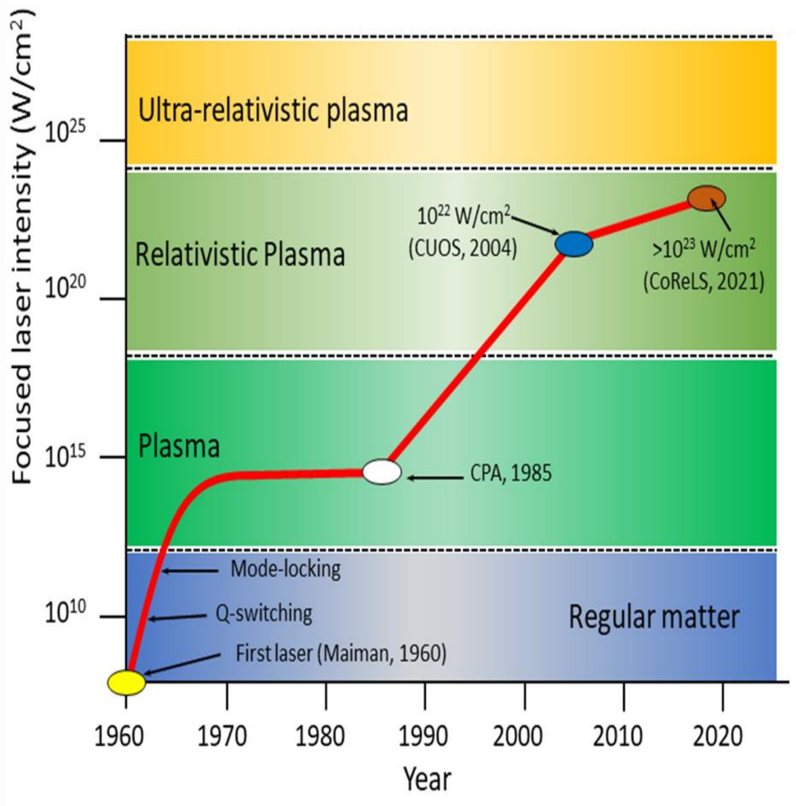
MeV Neutrals



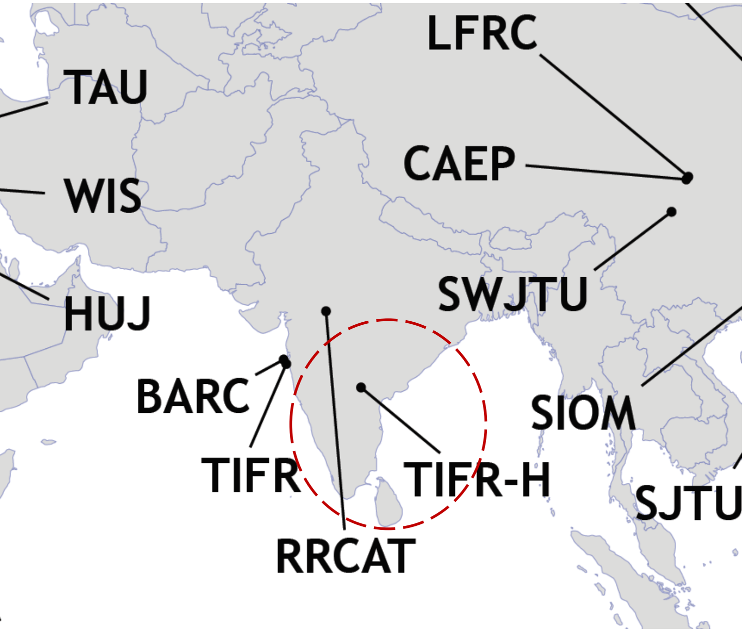
R. Rajeev *et al.*
Nature Physics

- *Different types of Particle and Photon sources can be generated.*

Future pathways for Relativistic Laser-plasma Science

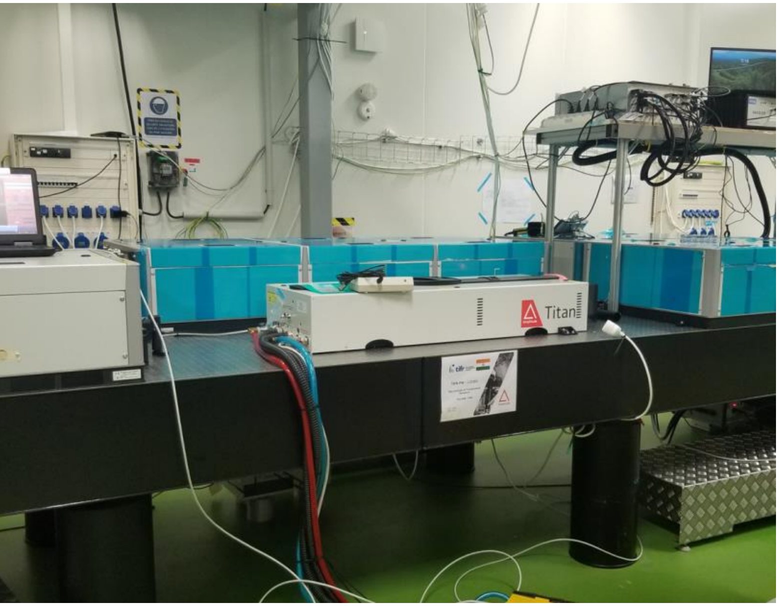


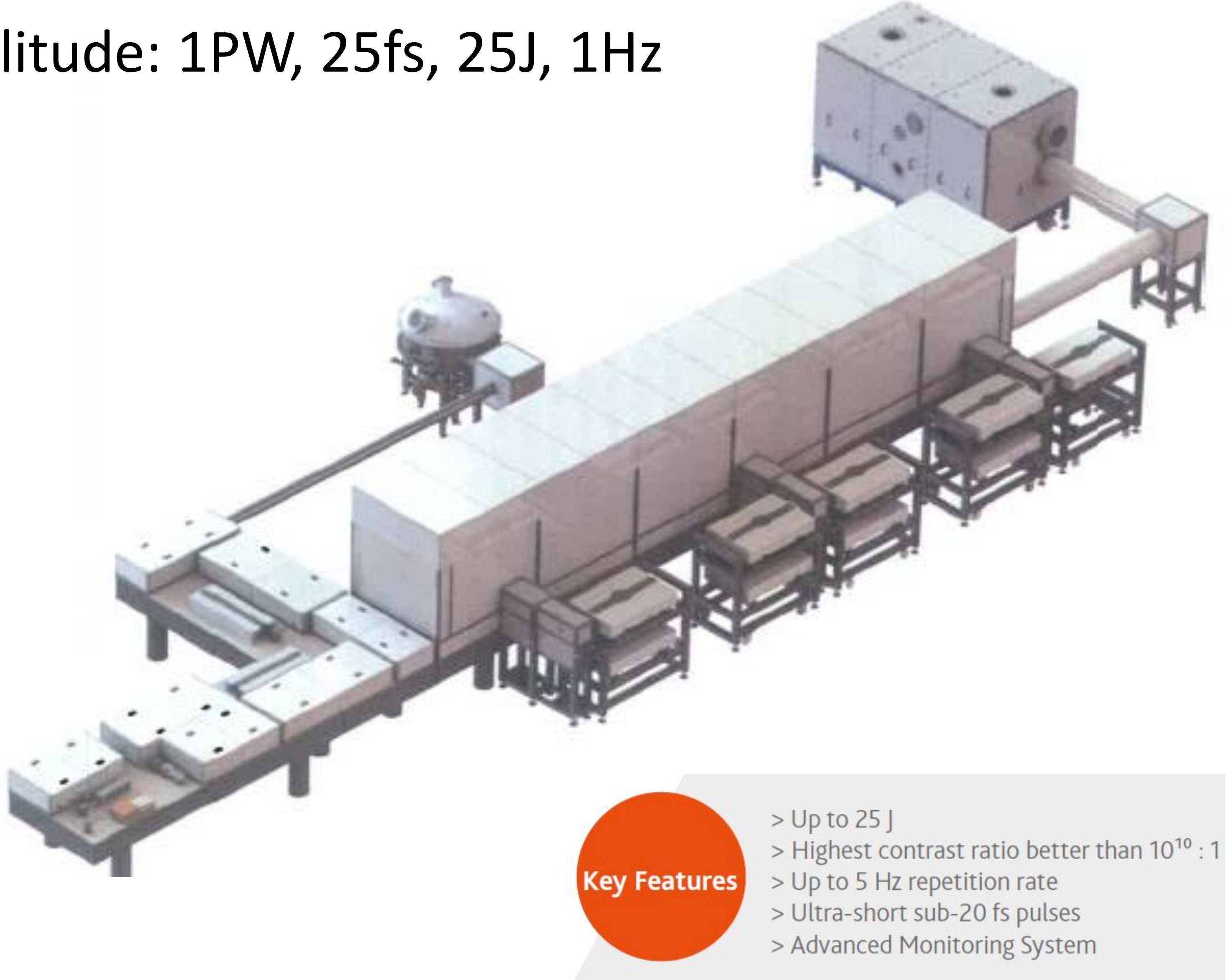
Upcoming Petawatt laser facility at TIFR-Hyderabad



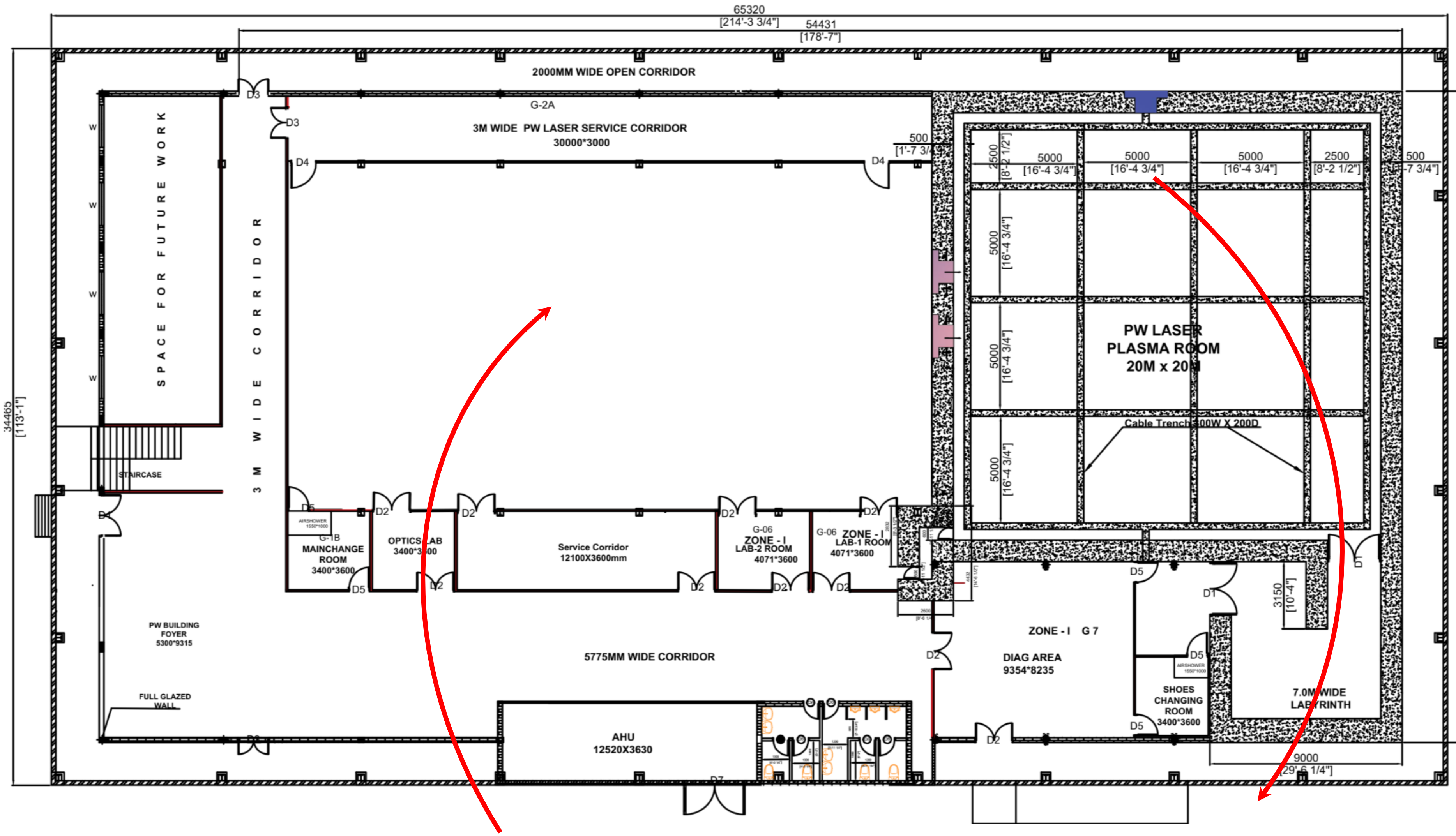
Upcoming Petawatt laser at TIFR-H

Amplitude: 1PW, 25fs, 25J, 1Hz





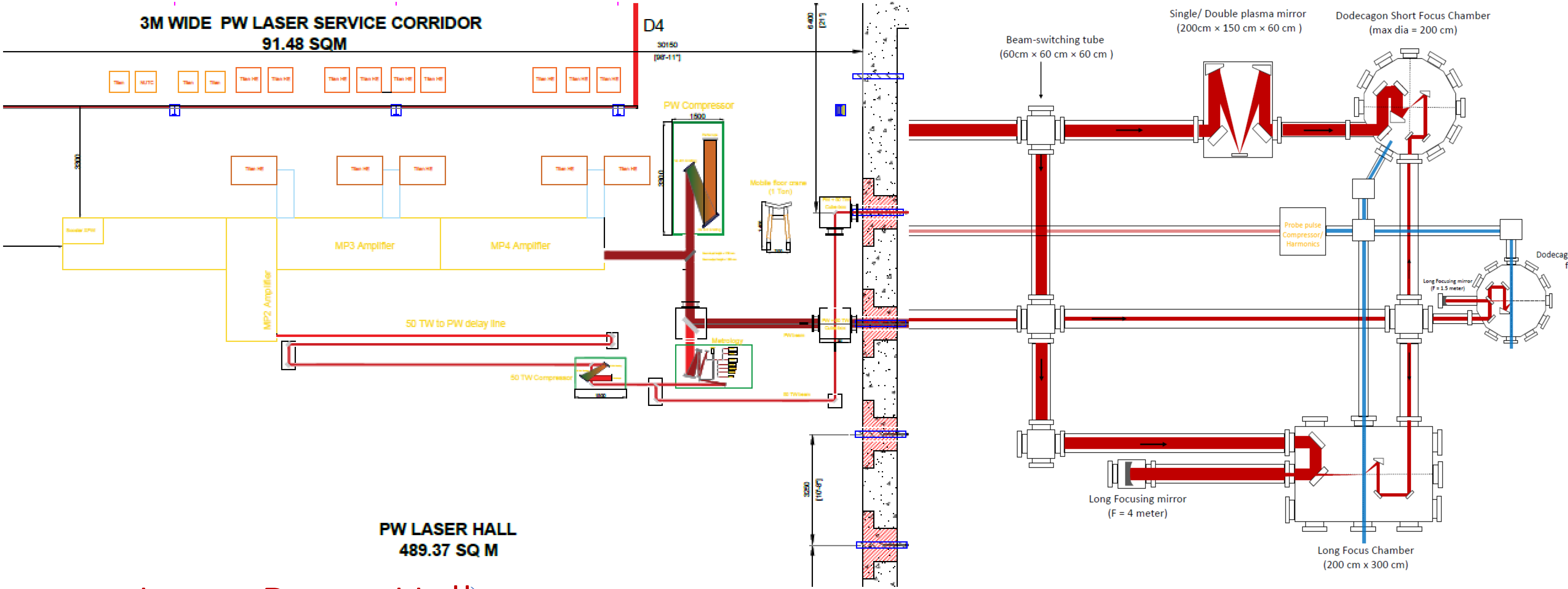
Petawatt Laser and Experimental Hall



- $30m \times 16\,m$ *Laser Hall*
- *ISO 7 (Class 10000, isolated floor slab)*

- $20m \times 20\,m$ *experimental Hall*
- *Concrete Wall 1 meter thickness*

Upcoming Petawatt laser at TIFR-H



- Laser Beam Hall
- Experimental Hall
- Control Room

EPIC using EPICS for TRISUL...........

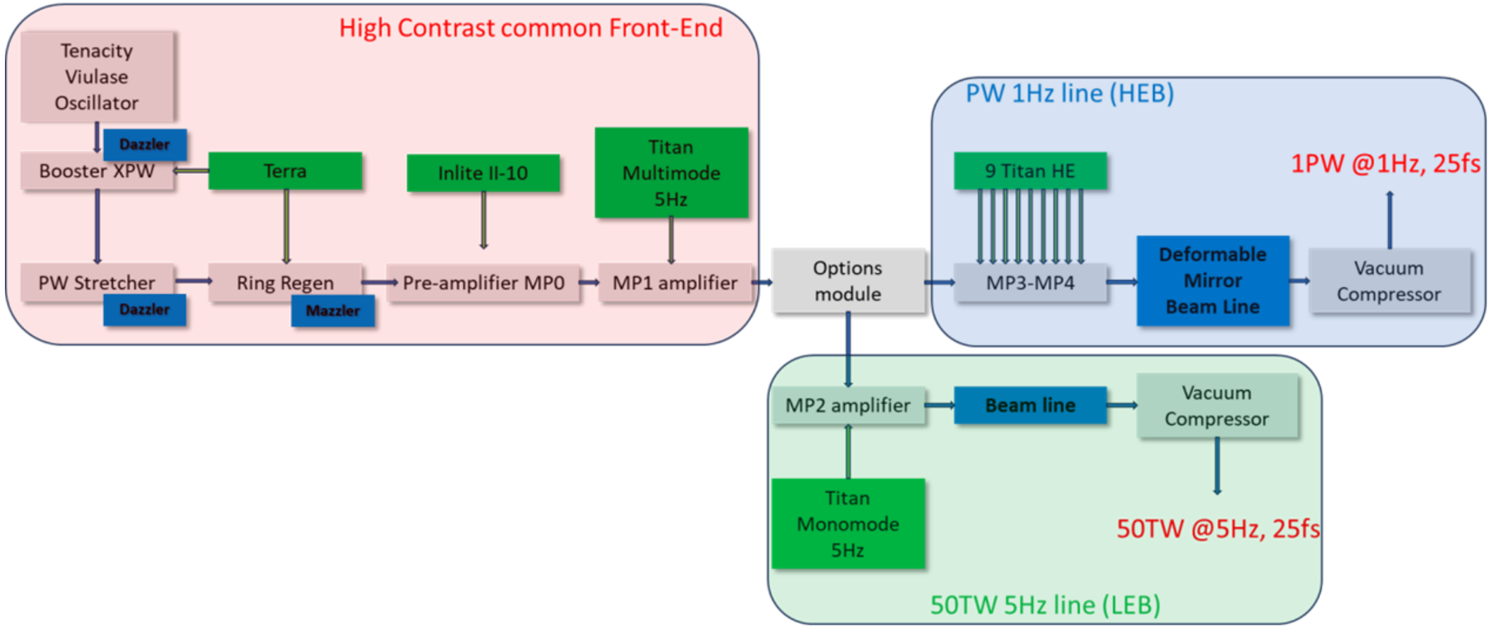
- Extreme Photonics Innovation Centre (EPIC) Software development team is tasked for the complete solutions of control system development of TRISHUL.

- Control System will be based on EPICS framework.

- EPIC team expertise in Software development process. In Past team has delivered software services for multiple laser facilities at CLF, UK.

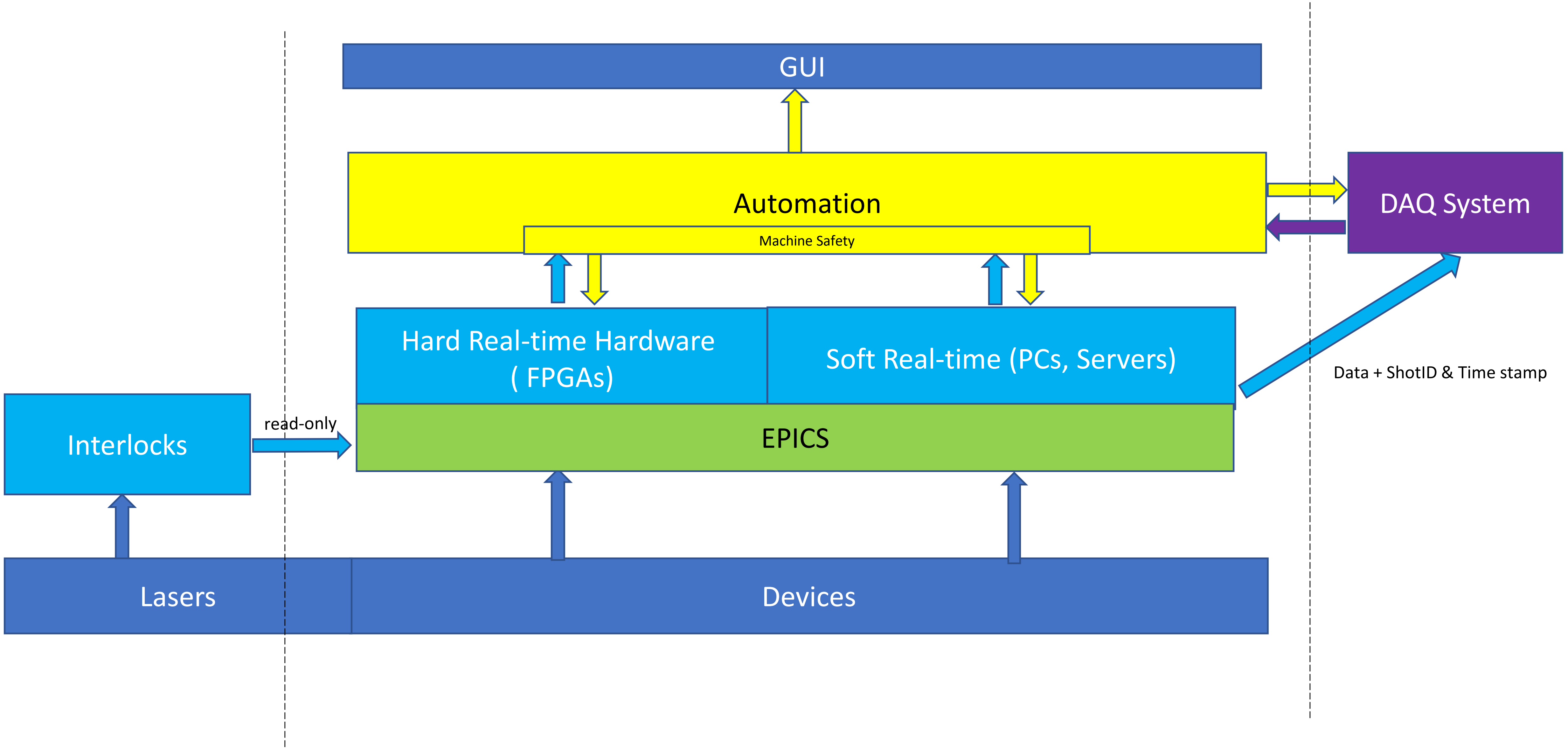
- TRISHUL repetition rate is **1Hz/5Hz**. However, the EPIC team has demonstrated the CS development for the Lasers running at ***10Hz.***

Control System Development for TRISHUL



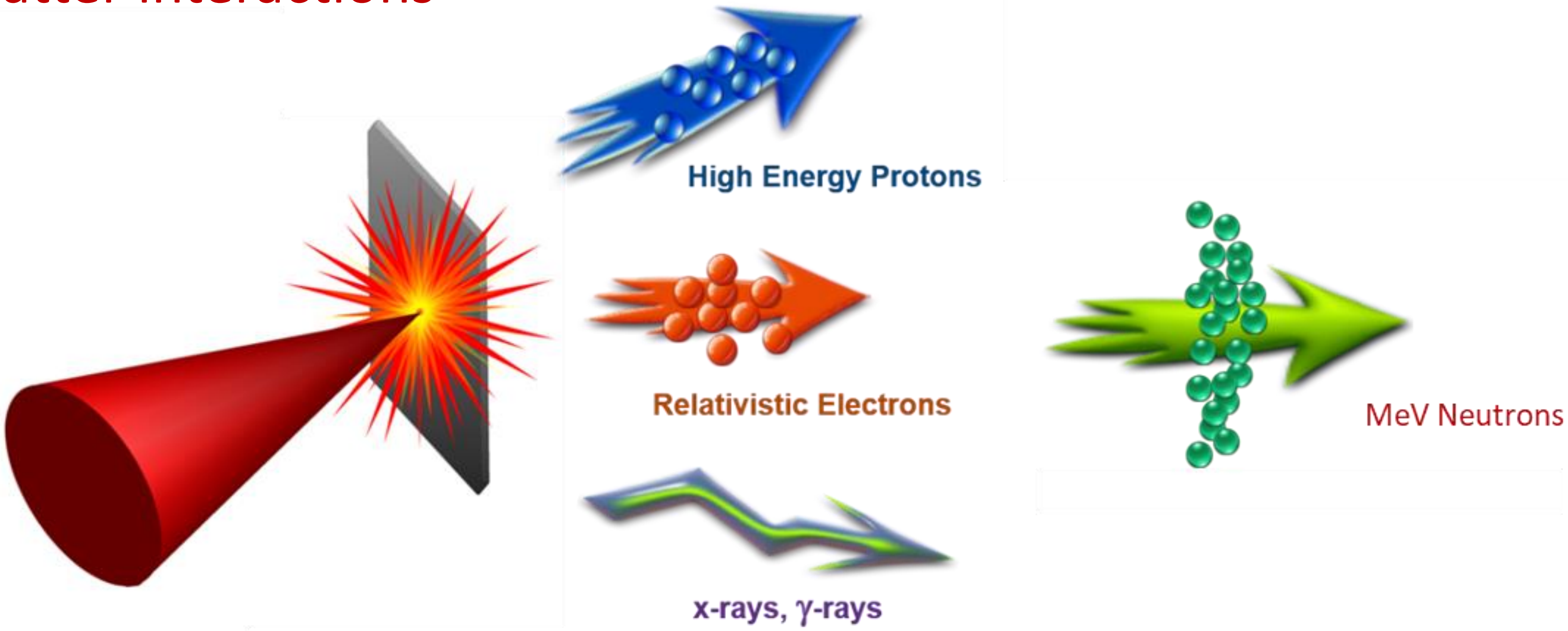
- **Integrating** various subsystems from **different manufacturers** into **central control systems**.
- Enabling user to **control hundreds of devices** on **single window** with ease.
- This significantly improves the **operational time** and better control and monitoring of the **whole facility**.

TRISHUL CS - Architecture Design



Converting 1 eV visible photon to GeV scale radiations

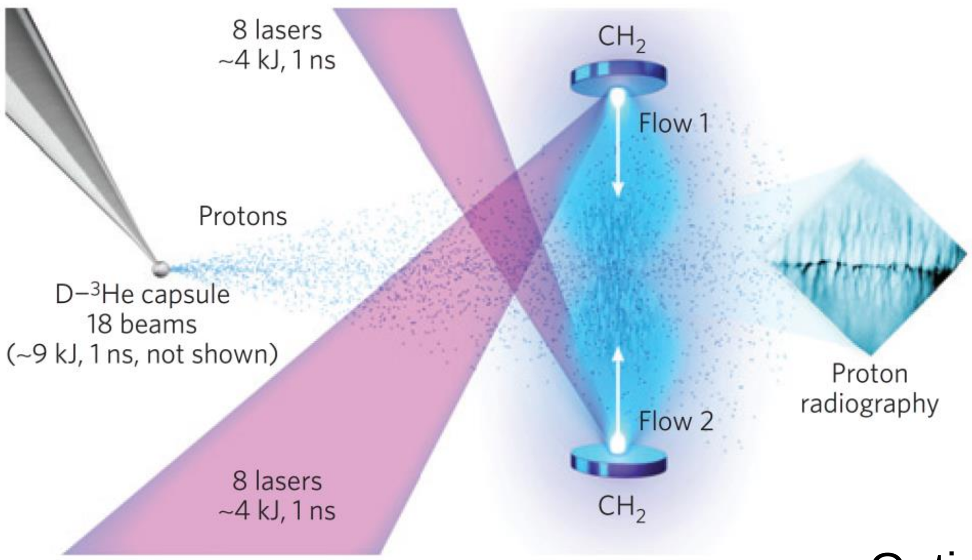
- PW laser-matter interactions



- *GeV level energy scales accesible with PW driven plasmas.*

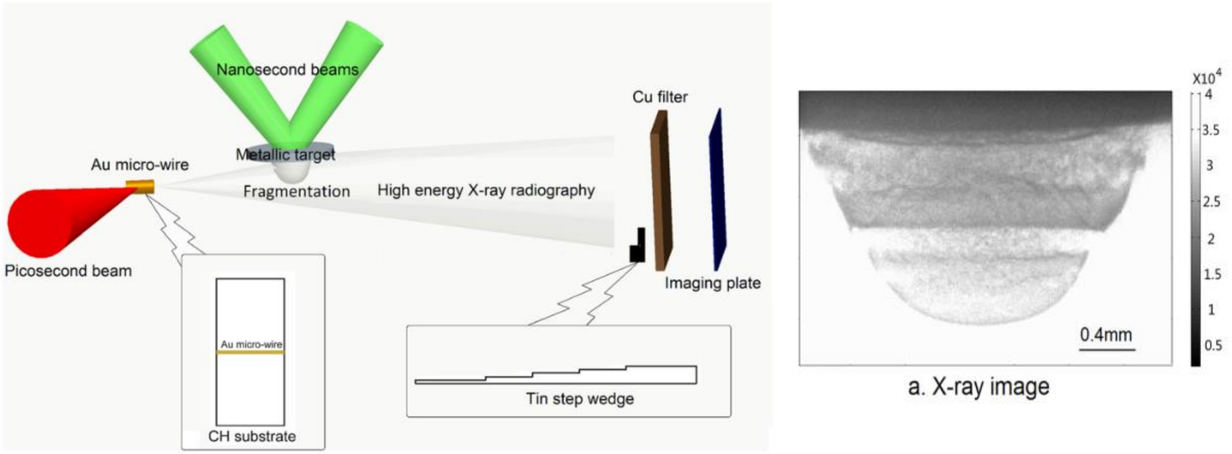
Multi-Probe radiography with Intense laser driven plasmas

Ultrafast electrons/ Proton radiography
(sensitive to EM field)



*C. M. Huntington et al, Nat. Phys. **11**, 173, (2015)

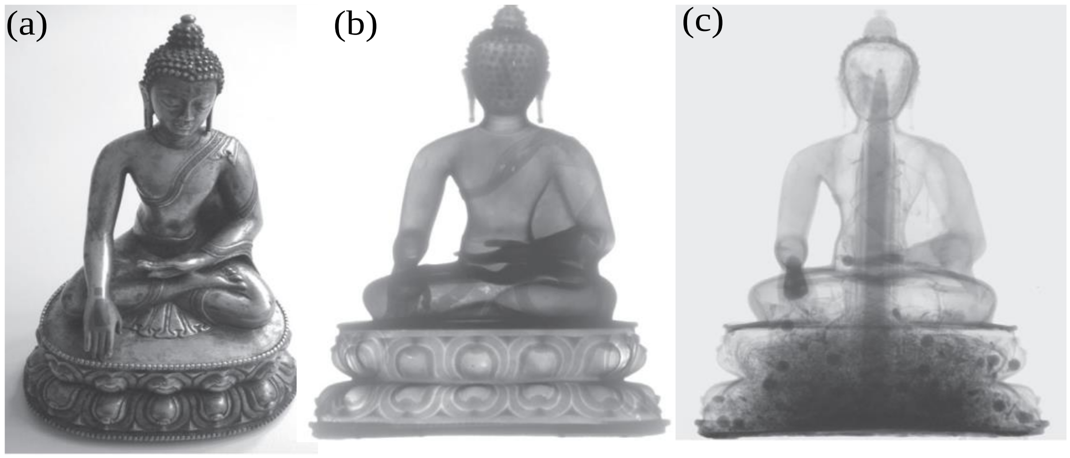
MeV Xray dynamic radiography



*G. Chu et al, Rev. Sci. Instrum. **89**, 115106 (2018)

Neutron & Xray radiography
(sensitive to low − Z opacity)

Optical Image X-ray Image Neutron Image



Buddha statue along with its x-ray (Fig. 1b) and neutron radiography (Fig. 1c) images performed at *Paul Scherrer Institut* (PSI), Switzerland.