THE GÉRARD MOUROU
CENTER FOR ULTRAFAST
OPTICAL SCIENCE
UNIVERSITY OF MICHIGAN

Zettawatt-Equivalent Ultrashort Pulse Laser System

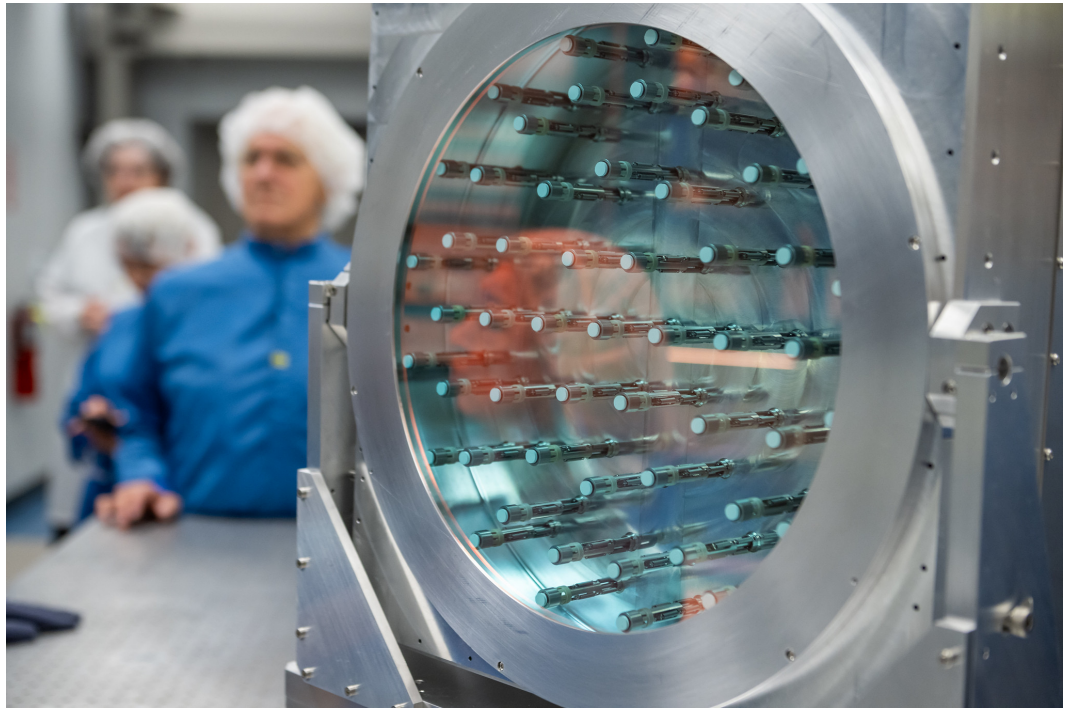

# ZEUS townhall

November 20, 2023

## FACILITY COMMISSIONING, STATUS, FY25 CALL FOR PROPOSAL

NSF

# ZEUS Facility Townhall



- ZEUS laser system
- ZEUS target areas and science
- ZEUS commissioning & status
- FY2025 capabilities
- Accessing the ZEUS facility
- Proposal process


Mid-scale Research – Award # 2126181

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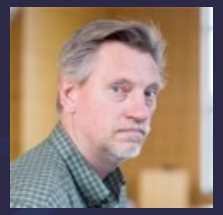
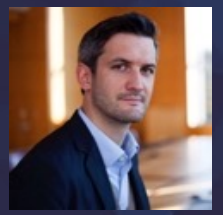
Zettawatt-Equivalent Ultrashort Pulse Laser System

# The ZEUS team



Karl Krushelnick (PI)
Director

Louise Willingale
Associate Director



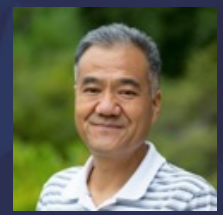
Alec Thomas
*Co-PI*

Igor Jovanovic
*Co-PI*

Carolyn Kuranz
*Co-PI*

Anatoly Maksimchuk
*Experimental Manager*

John Nees
*Laser Manager*



Bixue Hou
*Engineering Manager*

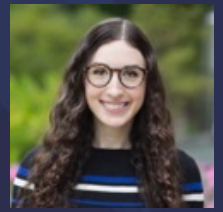
Franko Bayer
*ZEUS Project Manager*

Yong Ma
*Link Scientist*

Paul Campbell
*Link Scientist*

Milos Burger
*Laser Scientist*

Galina Kalinchenko
*Laser Engineer*



Lauren Weinberg
*Laser Engineer*

Qing Zhang
*Data Scientist*

Sallee Klein
*Target Fabrication*

Elizabeth Oxford
*Outreach Coordinator*

Amy Brooks
*Research Administration Manager*

External Advisory Board:
*Prof Chan Joshi (chair), Prof Stefan Karsch, Prof Ritchie Patterson, Dr Rajeev Pattathil, Dr Csaba Toth, Prof Jon Zuegel*

Richard Anthony
*Engineer*

Gregg Sucha
*Engineer*

Richard Van Camp
*Engineer*

Gaylene Opal-Deitering
*Administration Assistant Sr.*

https://zeus.engin.umich.edu/

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# ZEUS Facility Overview

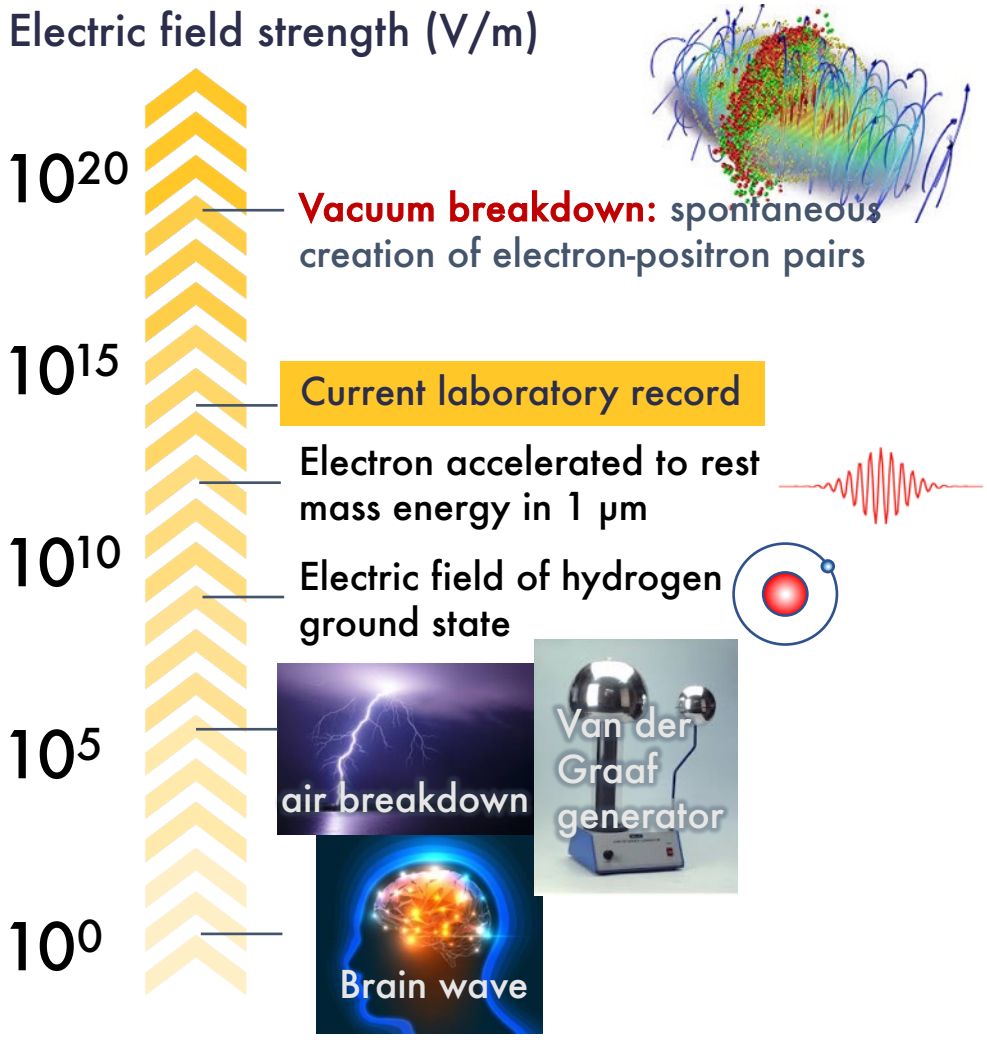
**Z**ettawatt = $10^{21}$ W

**E**quivalent

Critical field
$E_c \sim 10^{18}$ V/m

**U**ltrashort pulse laser

**S**ystem



# ZEUS Facility Overview

**Z**ettawatt = $10^{21}$ W

**E**quivalent

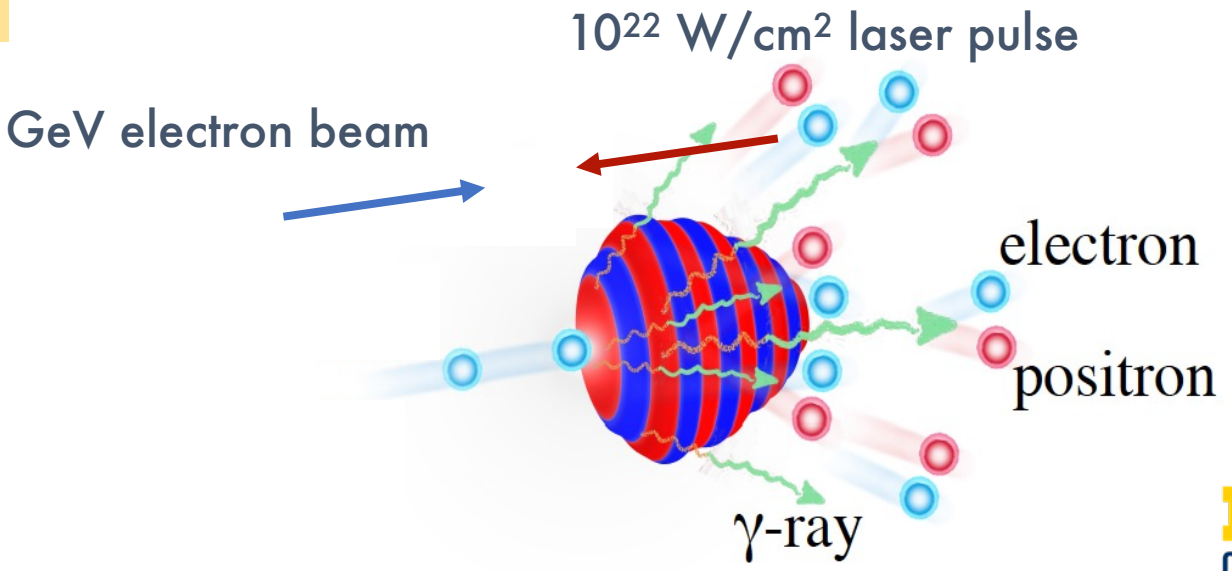
Critical field
$E_c \sim 10^{18}$ V/m

**U**ltrashort pulse laser

**S**ystem

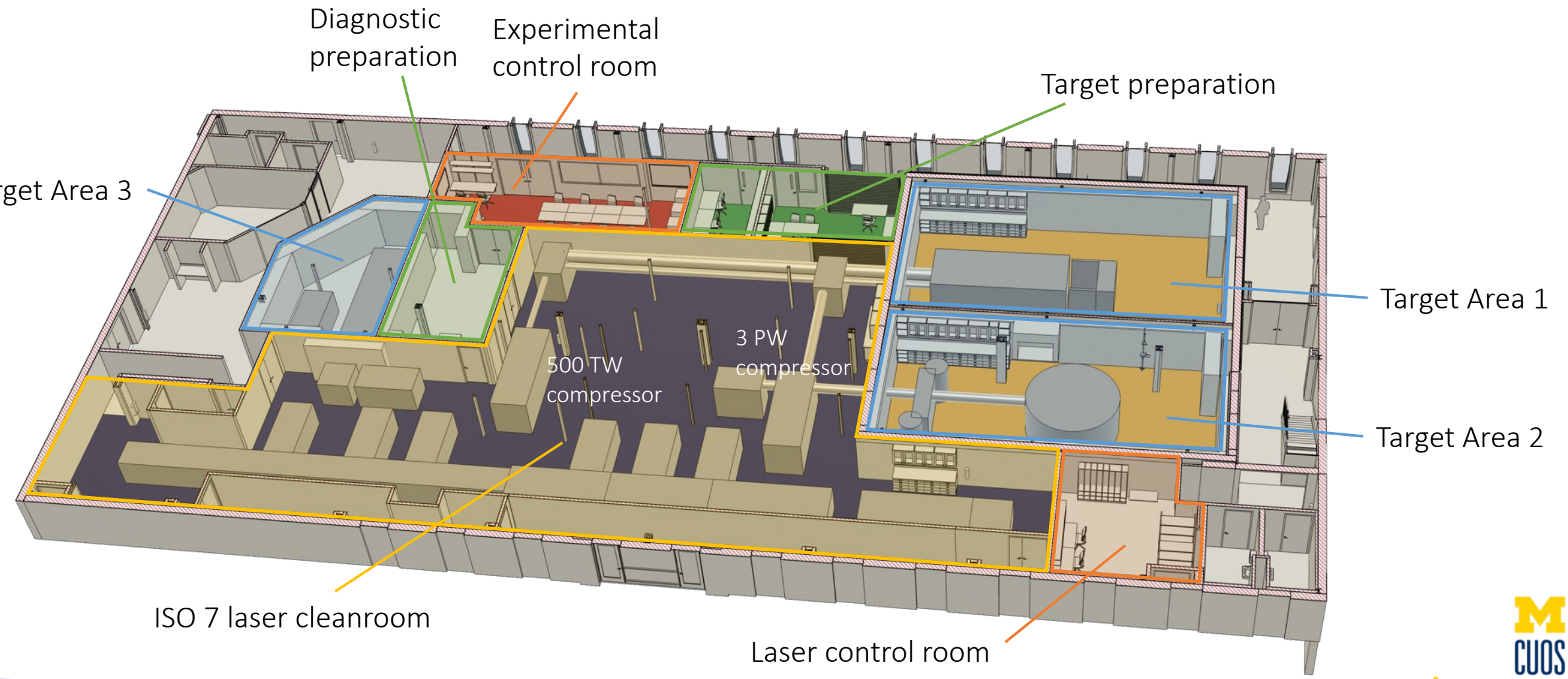
ZEUS power = 3 PW = 3 x $10^{15}$ W
(Highest power laser in the USA)

The intensity experienced by a GeV electron beam in the rest frame of reference will be equivalent to a Zettawatt power pulse!



# ZEUS Grand Opening

# ZEUS Floor Plan





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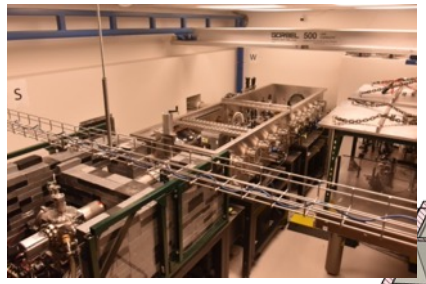
# ZEUS Floor Plan



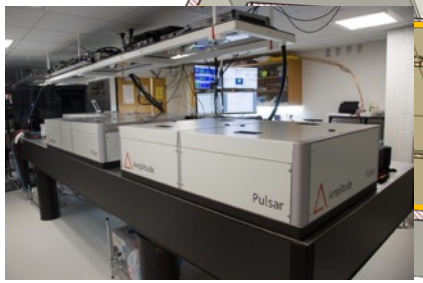
Target Area 3

Diagnostic preparation

Experimental control room

Target preparation

Target Area 1




Target Area 2

ISO 7 laser cleanroom

Laser control room



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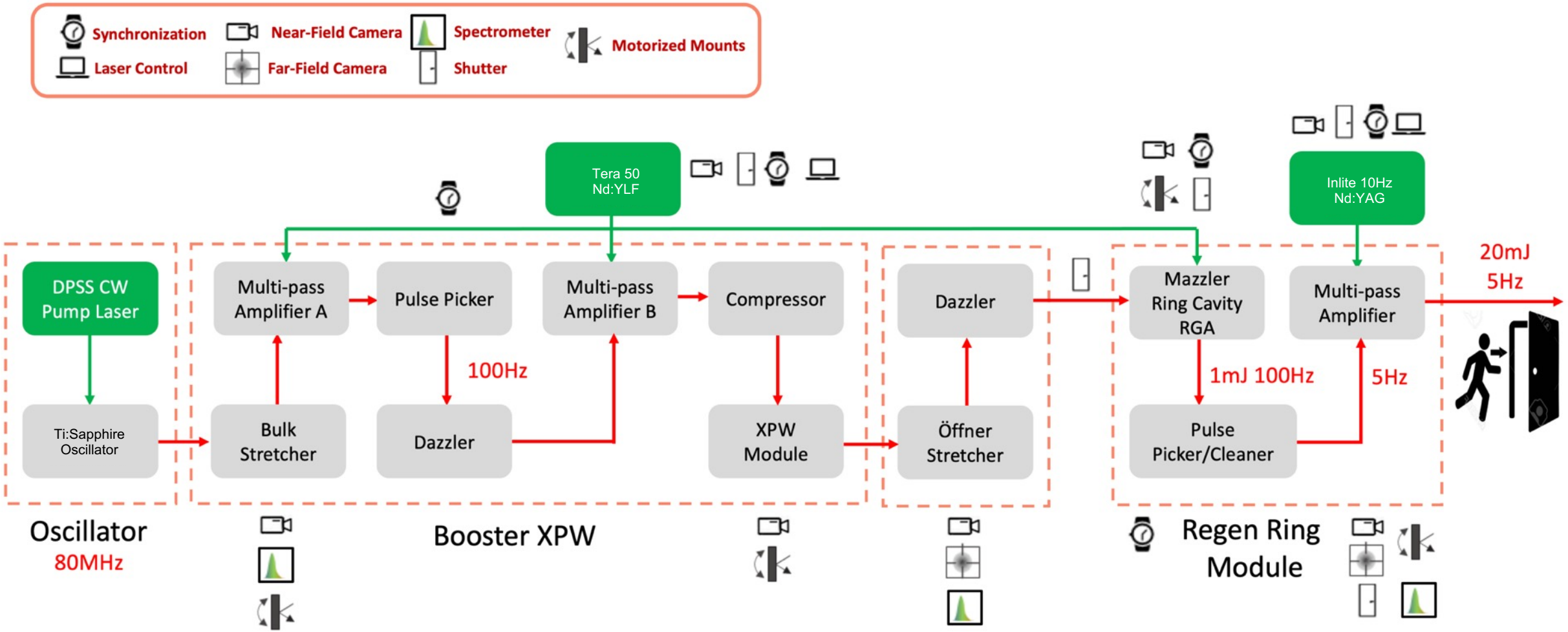
# ZEUS FRONT END




Front end supplied by Amplitude Technologies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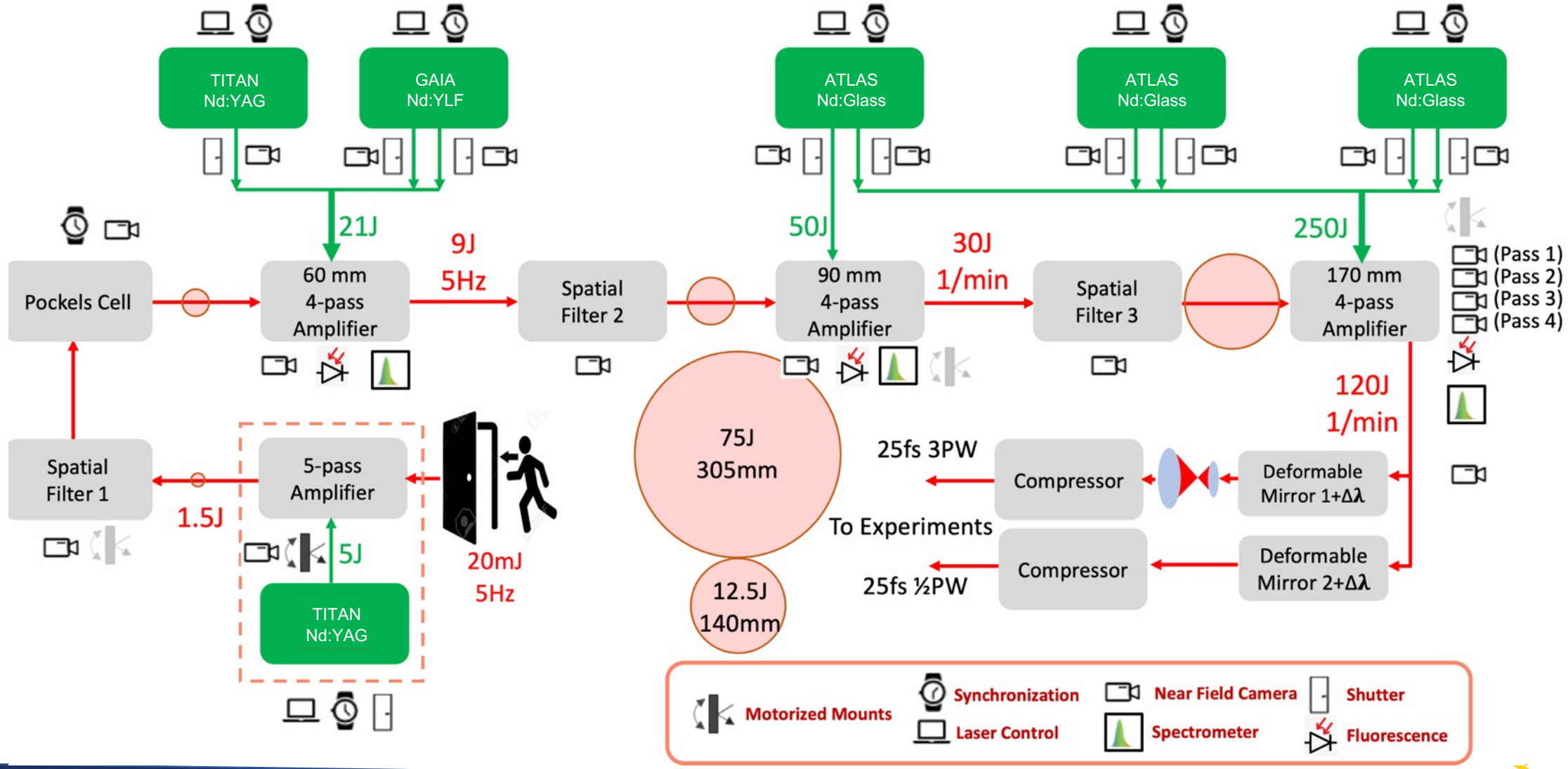
# ZEUS Amplifier Chain





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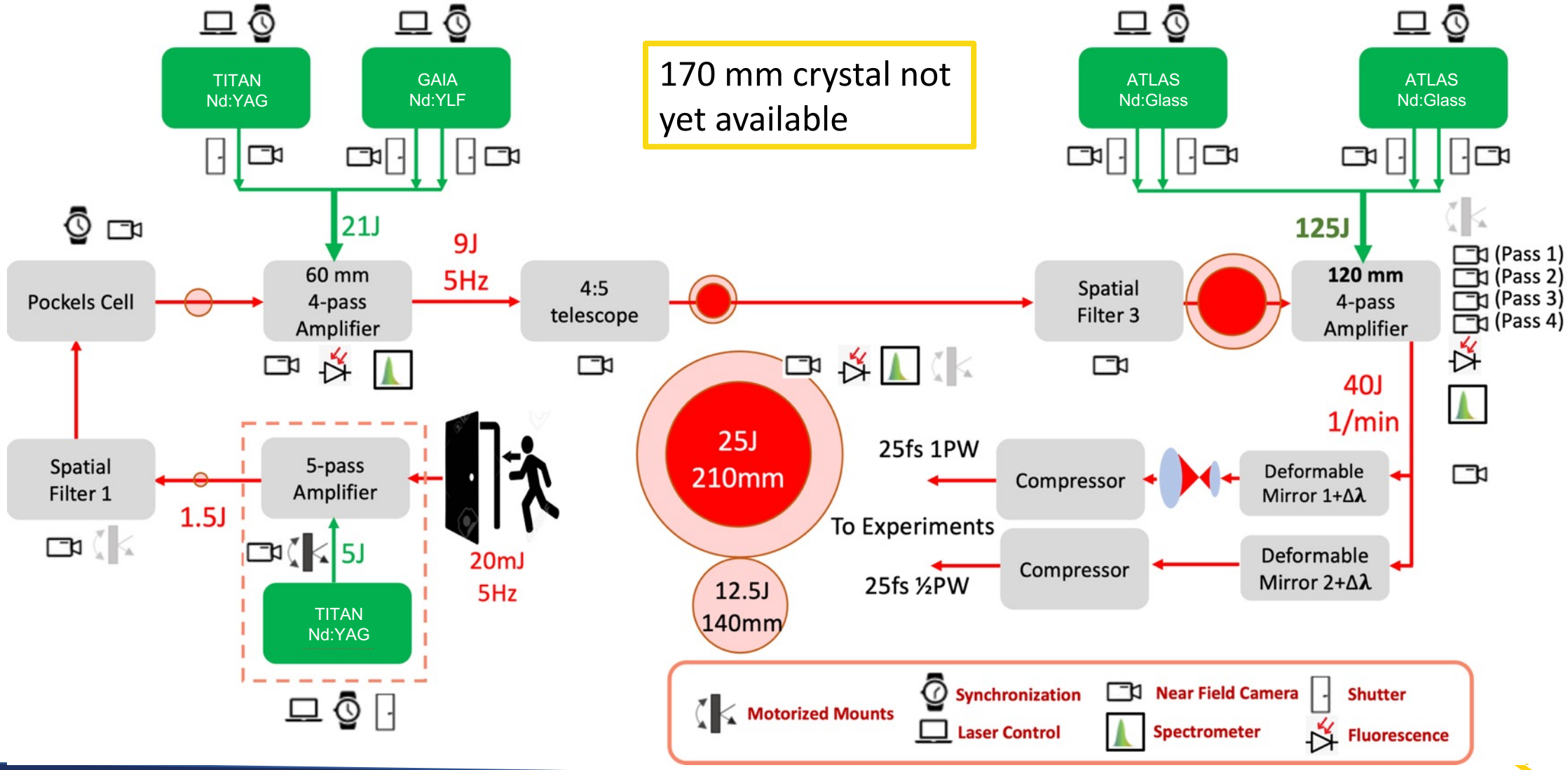
# ZEUS Amplifier Chain – Year 1





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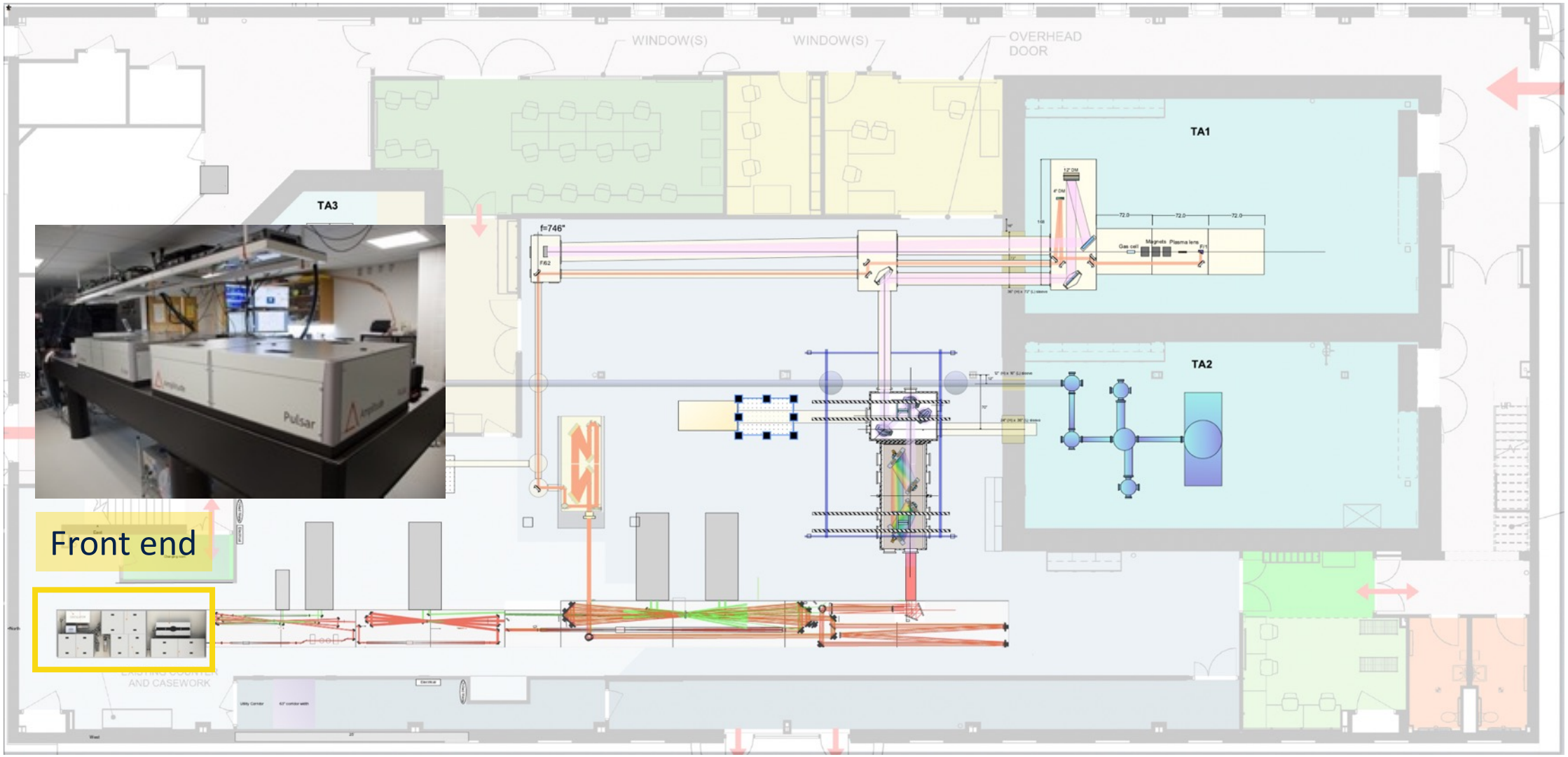
# ZEUS Facility Layout



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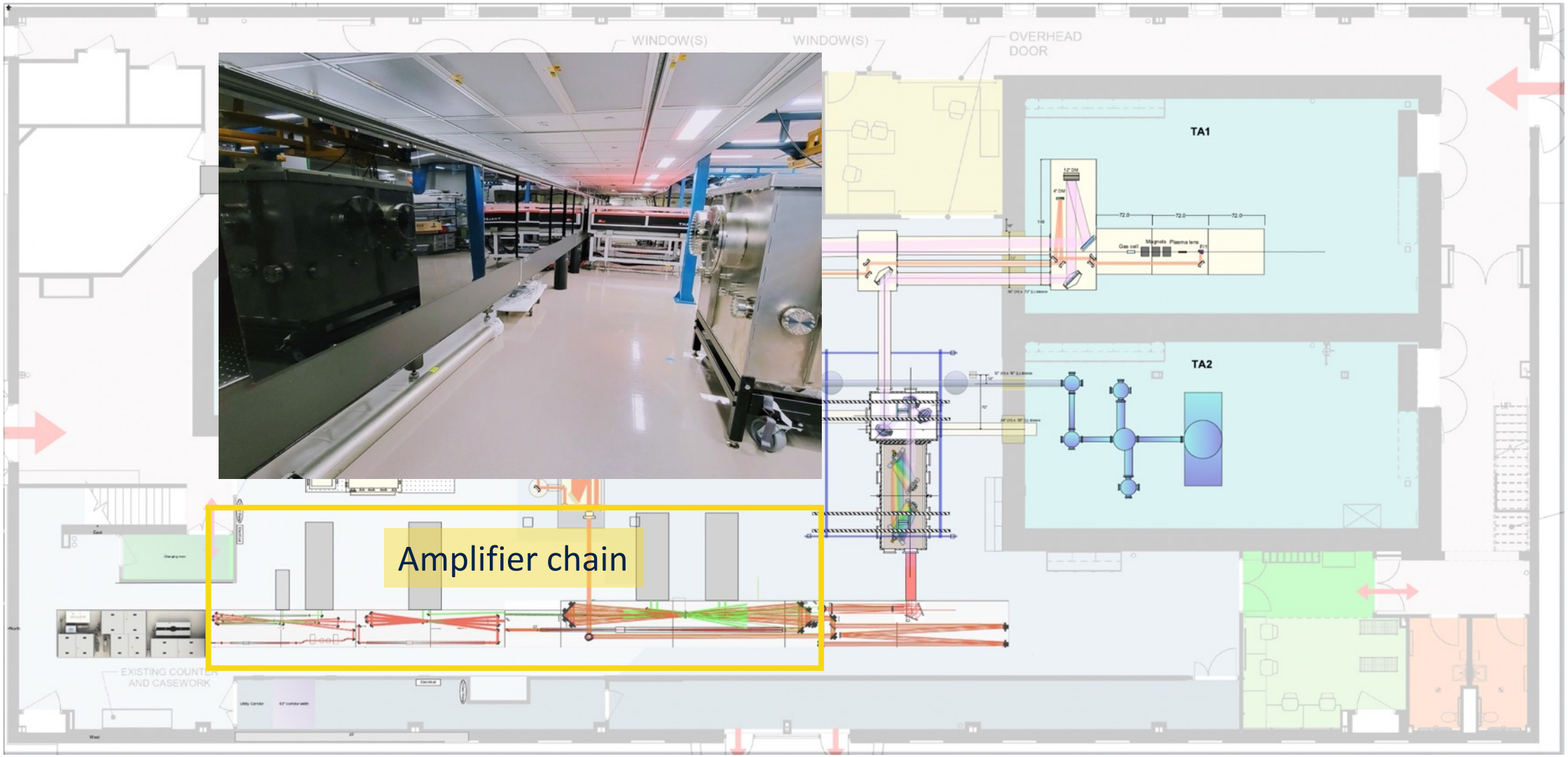



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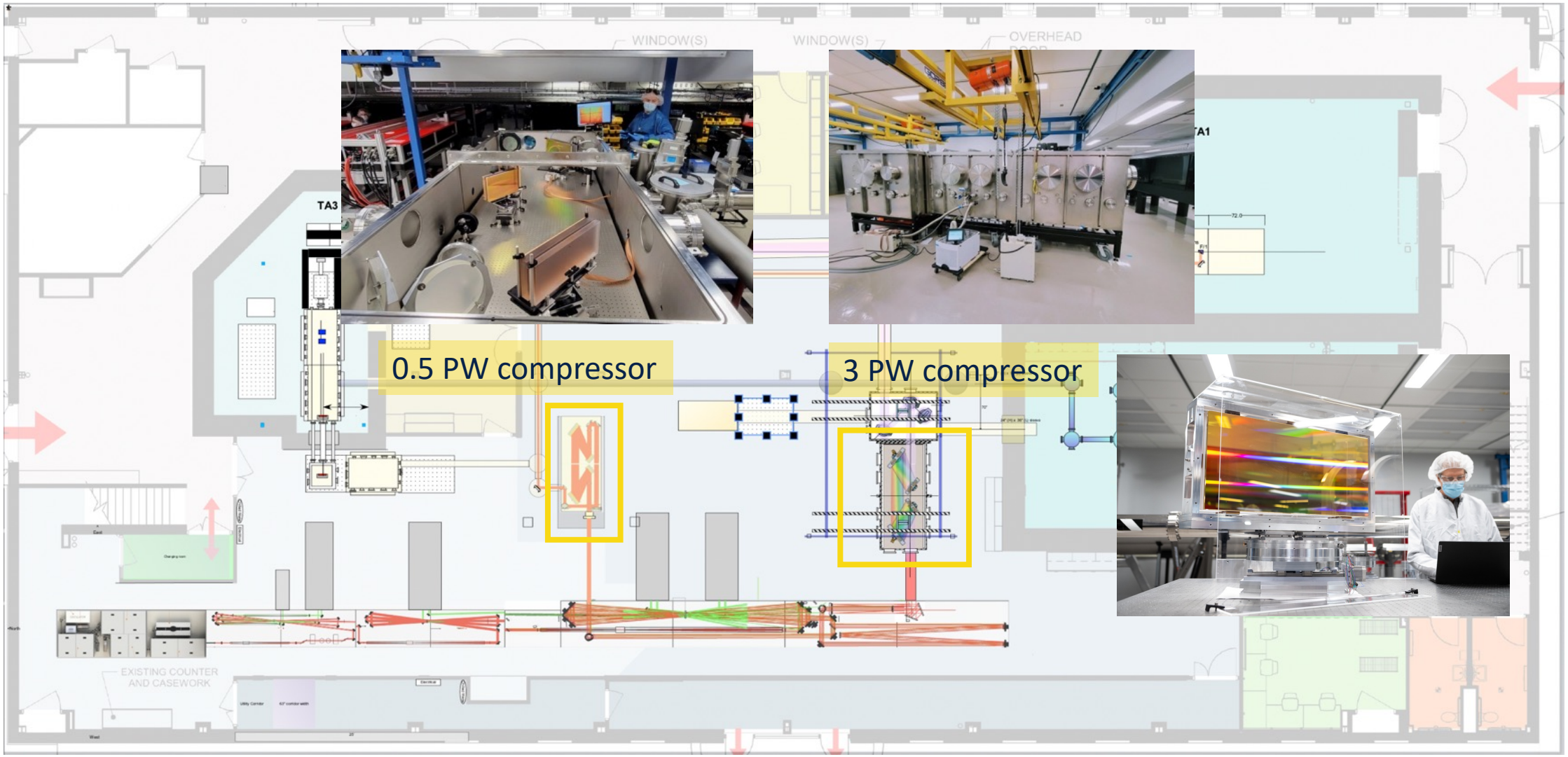
# ZEUS FACILITY LAYOUT





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# ZEUS Laser Diagnostics



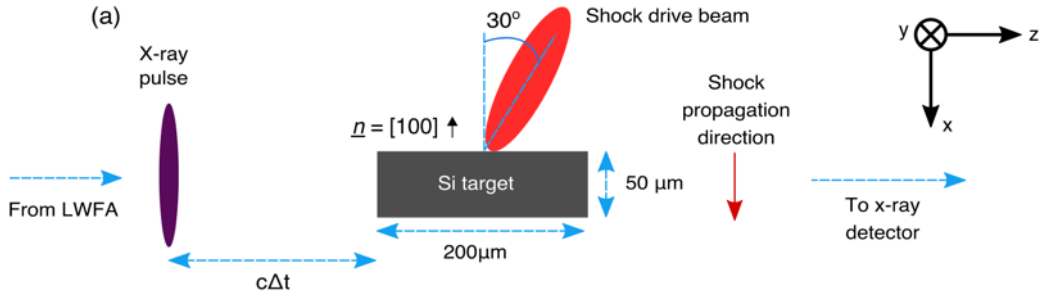
- Shot-ID (time stamps)
- On-shot laser energy (photo-diode)
- On-shot beam profile before and after compressor (leak-through)
- On-shot laser focus (leak-through)
- Off-shot pulse duration with Auto-correlator, Frog and Self-ref spectral interference
- Off-shot laser spectrum
- 2 DMs in air (before and after compressor)
- Off-shot laser focus and wavefront (TA3)

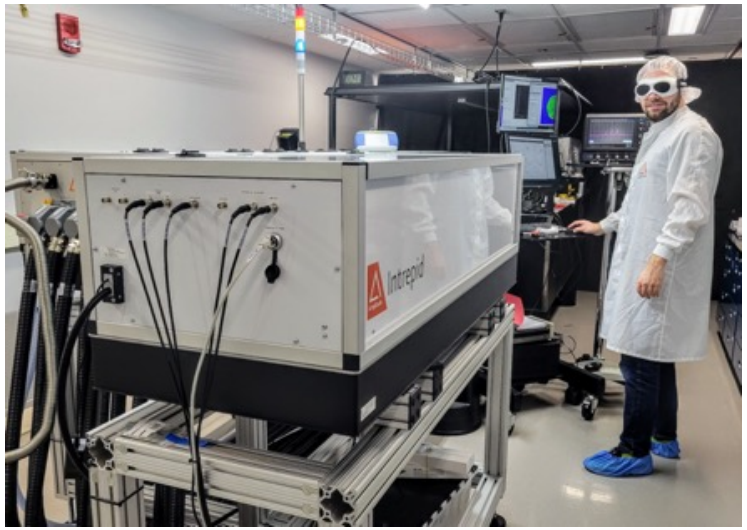
# ZEUS LONG PULSE CAPABILITY

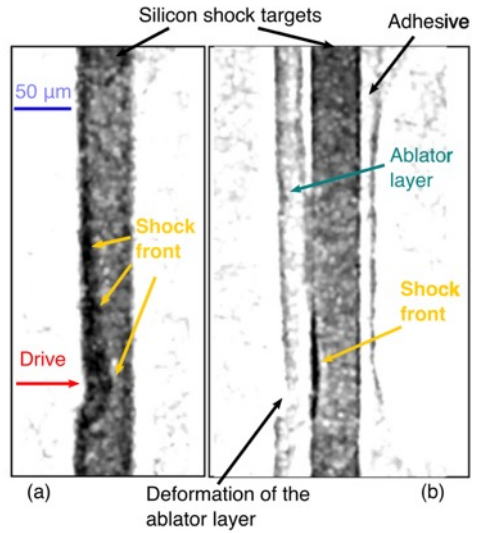
A “shock-driver” laser will be available in TA2 (FY25)

Amplitude Intrepid:

- Nd:glass system, $\lambda = 1054$ nm (or 527 nm)
- 1 shot per minute rep rate
  - 110 J (75 J) at 10 ns duration
  - 46 J (35 J) at 1.5 ns duration




JC Wood, et al., Scientific Reports, **8**, 11010 (2018)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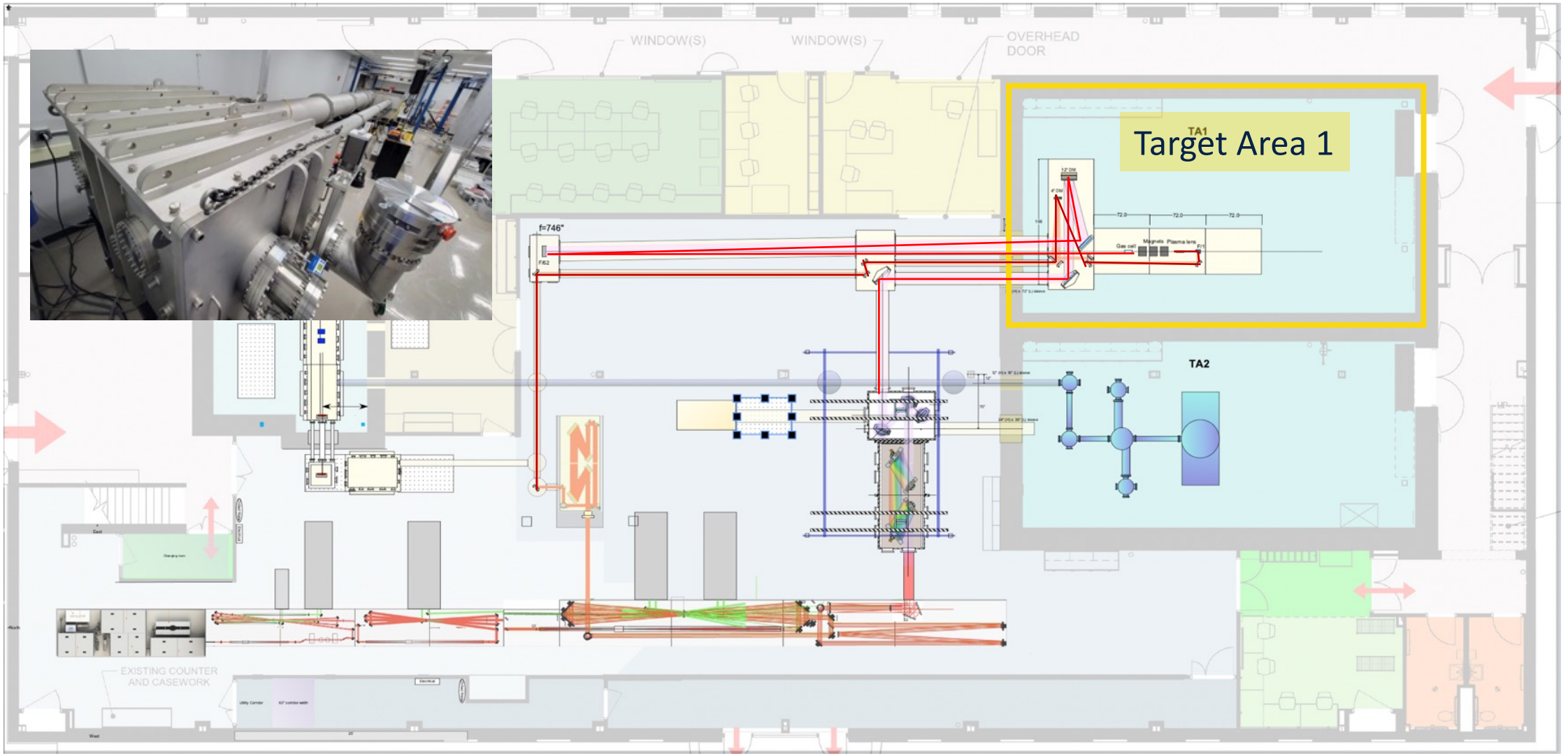
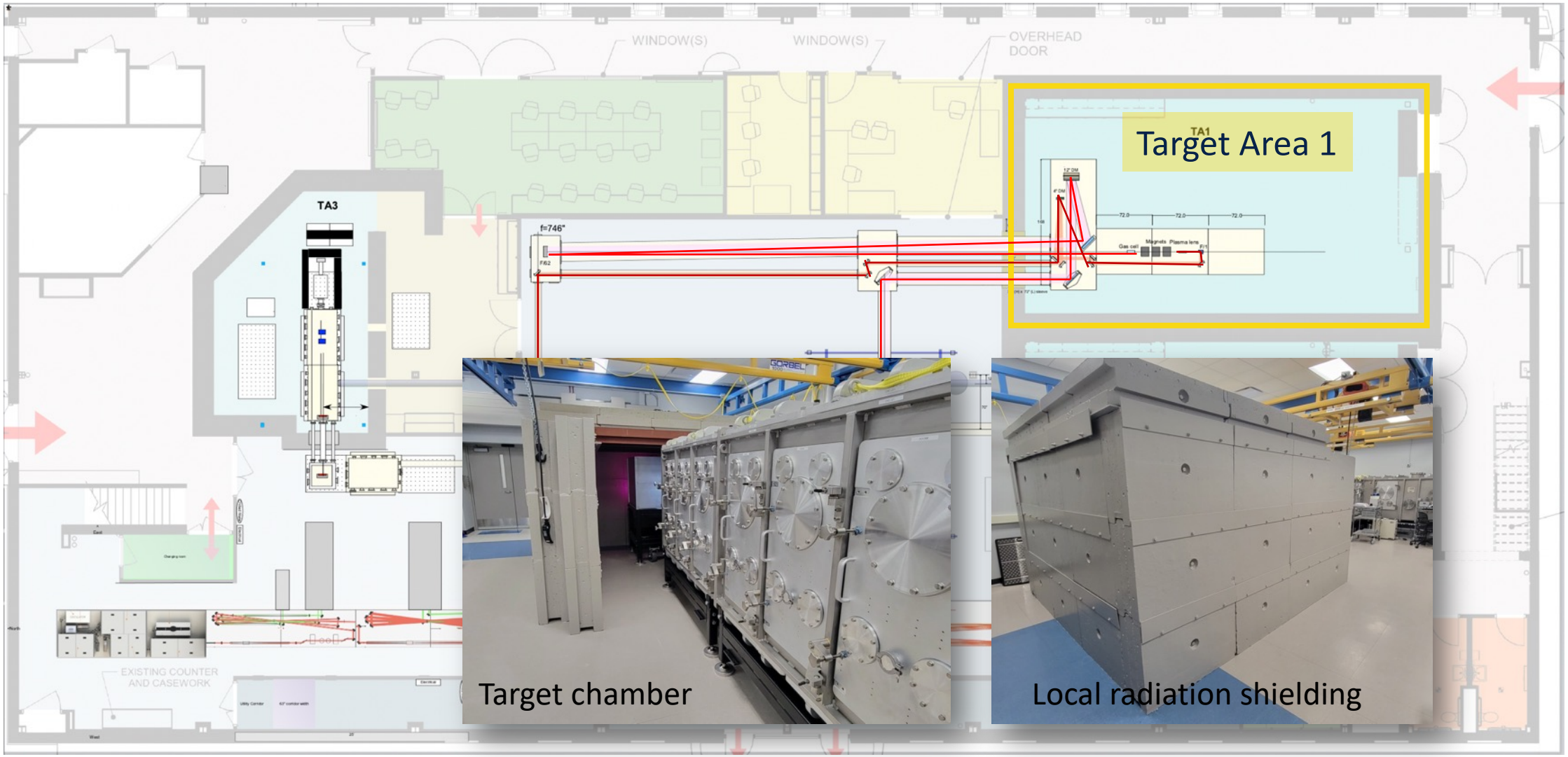
# ZEUS Facility Layout



# ZEUS Facility Layout





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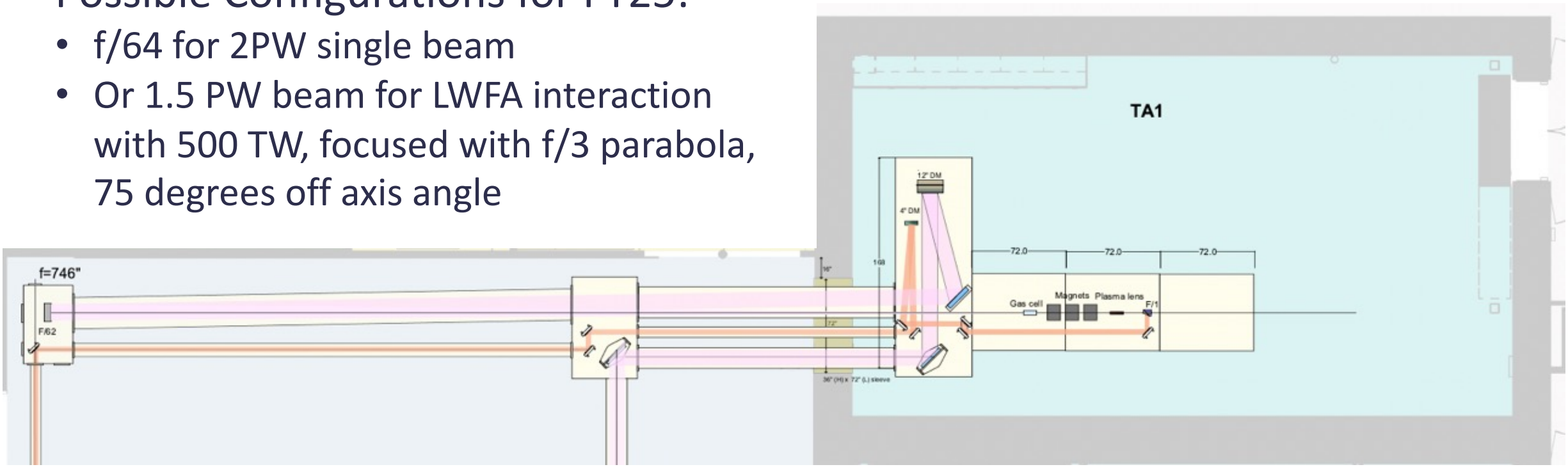
# Target Area 1 (TA1)

## Possible Configurations for FY25:

- f/64 for 2PW single beam
- Or 1.5 PW beam for LWFA interaction with 500 TW, focused with f/3 parabola, 75 degrees off axis angle




## Semi-permanent diagnostics

- Triple magnet electron spectrometer
- Optical probe beam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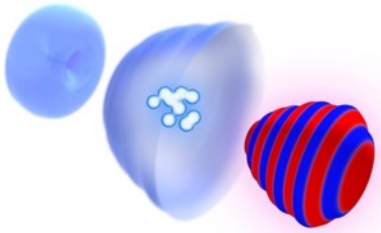
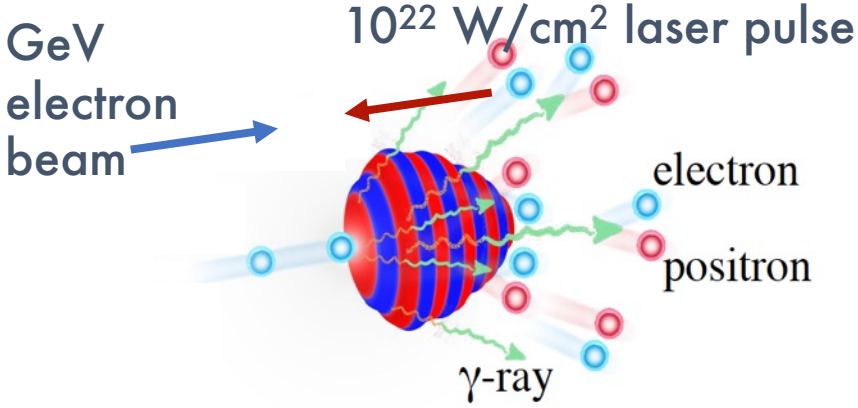
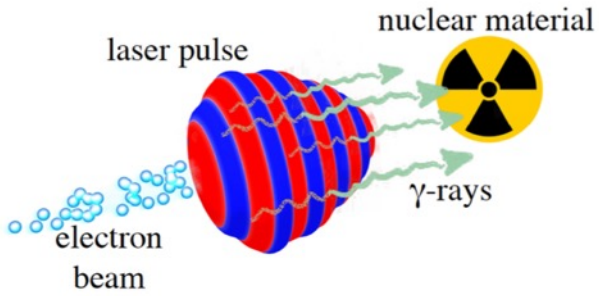
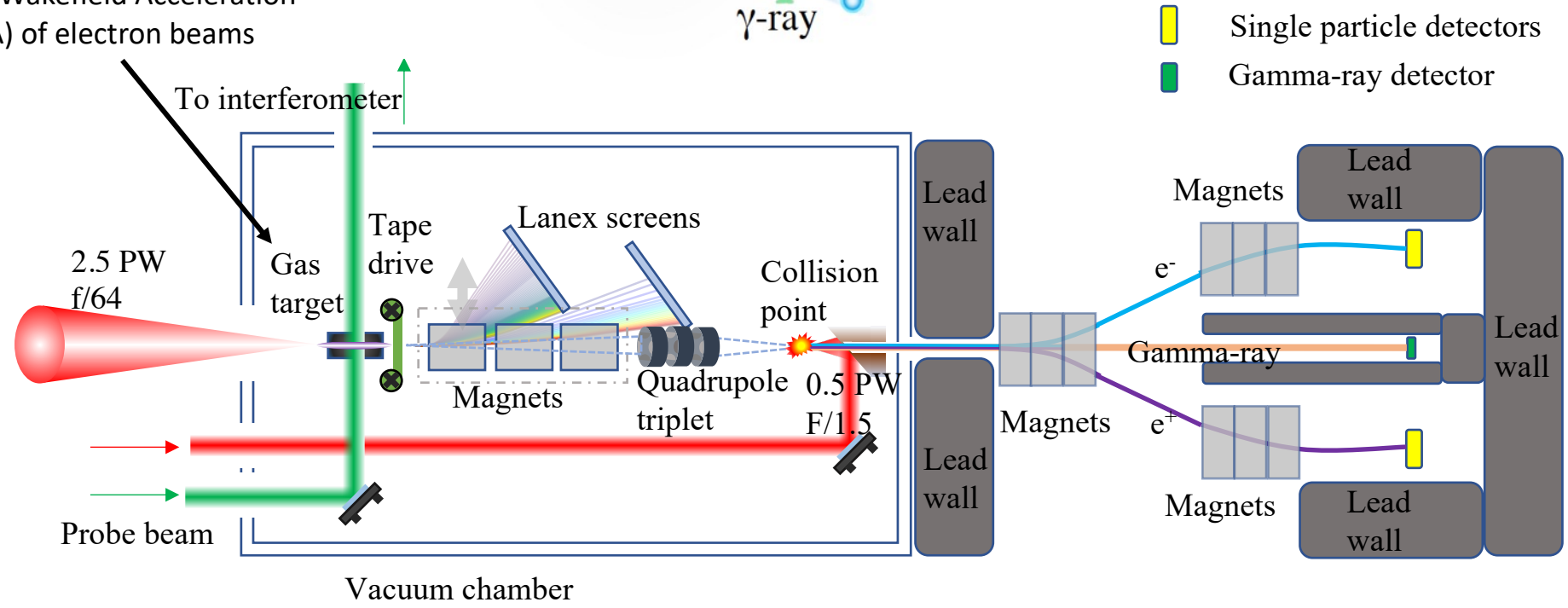
# TARGET AREA 1 (TA1): SCIENCE



Laser Wakefield Acceleration (LWFA) of electron beams





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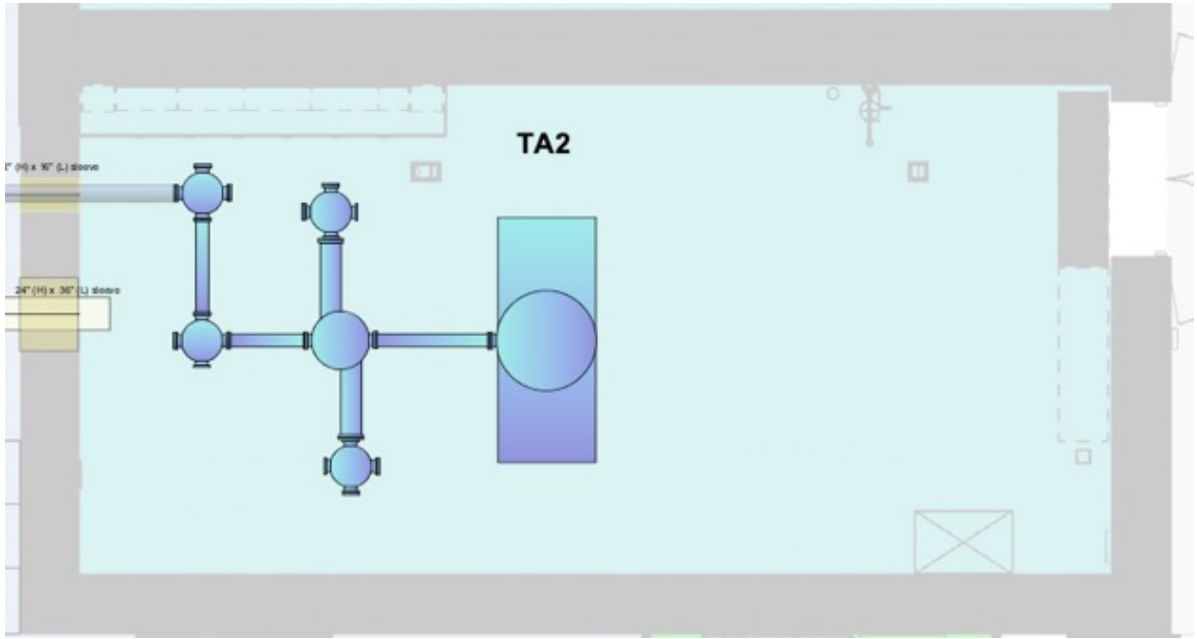
# Target Area 2 (TA2)



- 500 TW max for current chamber and upgrading to 3PW chamber in the future
- 2 ft thick concrete shielding
- Double plasma mirrors, deformable mirror and short focusing (f/2) configuration



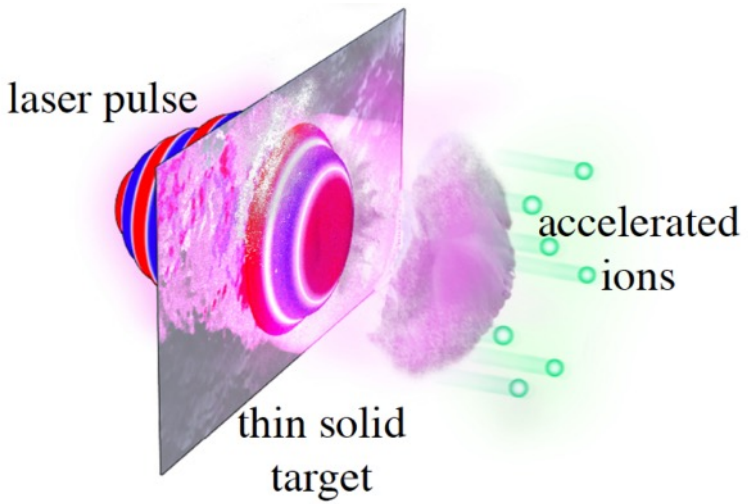

Semi-permanent diagnostics

- Thompson parabola ion spectrometer

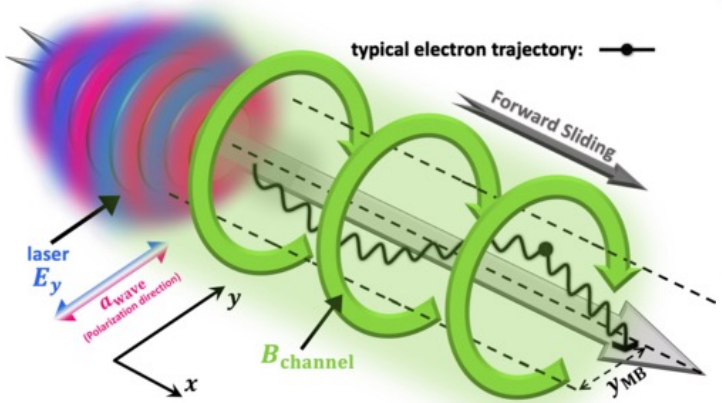
# Target Area 2 (TA2): Science

Plasma mirrors give excellent contrast to allow interactions with solid targets (without preplasma)
Short-focusing configuration gives the smallest focal spots and highest intensities

## Proton & ion beams
## Neutron sources

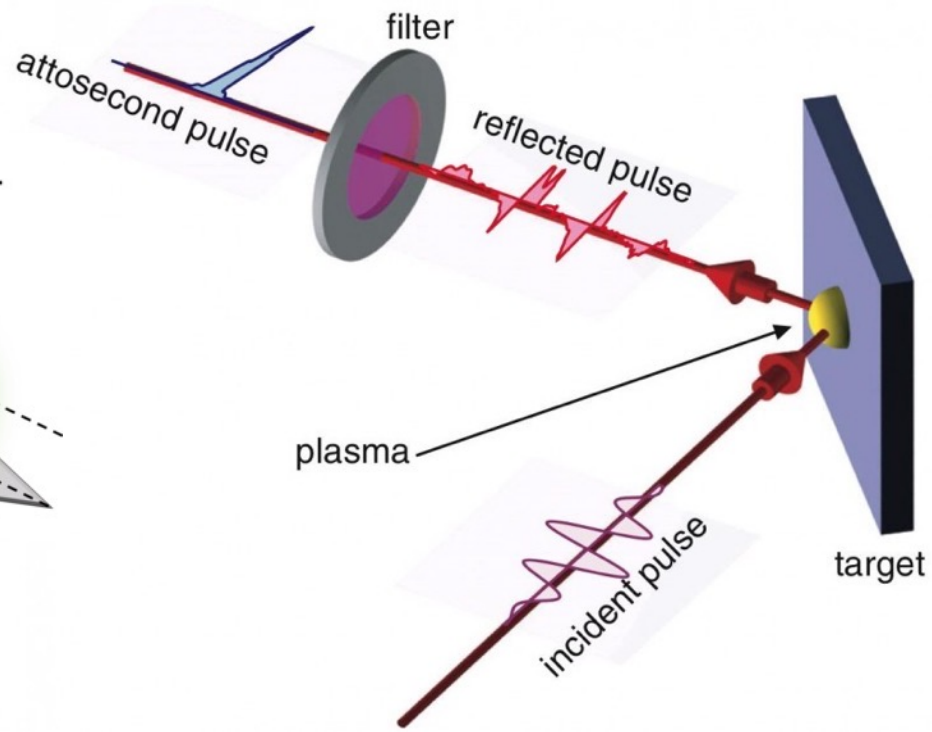



## Gamma beam generation

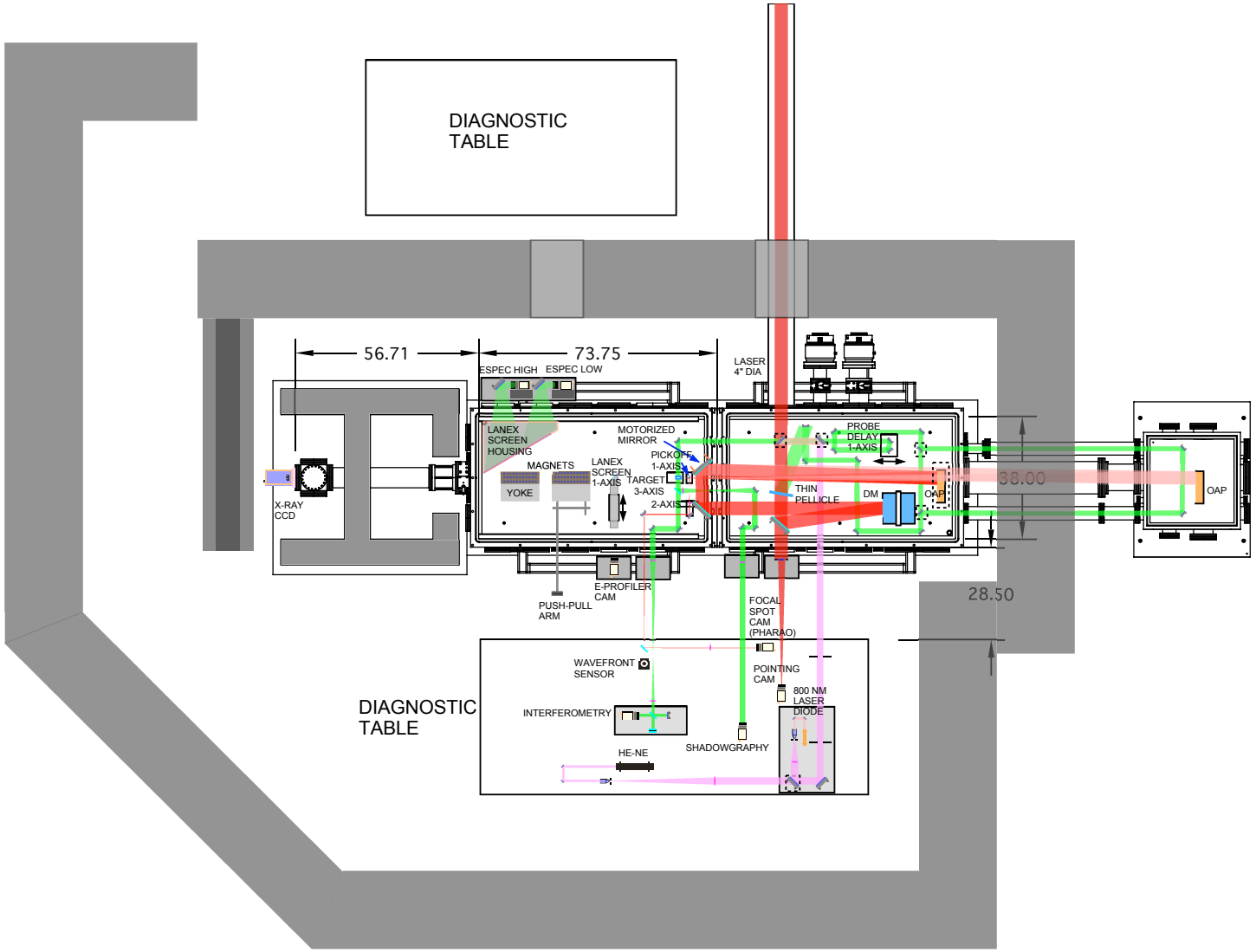



Z Gong, et al., PRE, **102**, 013206 (2020)

## High-harmonic generation



# Target Area 3 (TA3)




- 200 TW @ 1 Hz burst operation
- Or 500 TW @ 1 shot per minute
- 1.5 ft thick concrete shielding
- f/40 and f/20 configurations

## Semi-permanent diagnostics

- laser focal spot
- Laser wavefront measurement
- laser pointing
- Magnetic electron spectrometer
- electron beam profile
- X-ray CCD (Andor)
- Optical probe beam (interferometry and shadowgraphy)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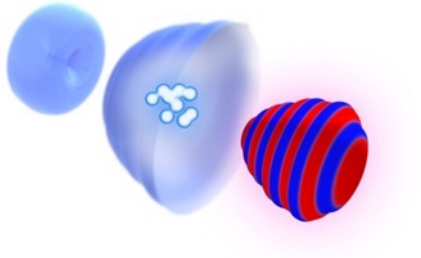
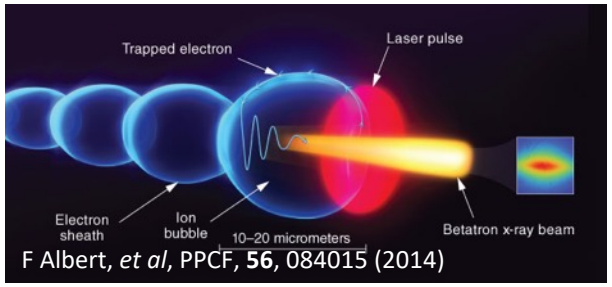
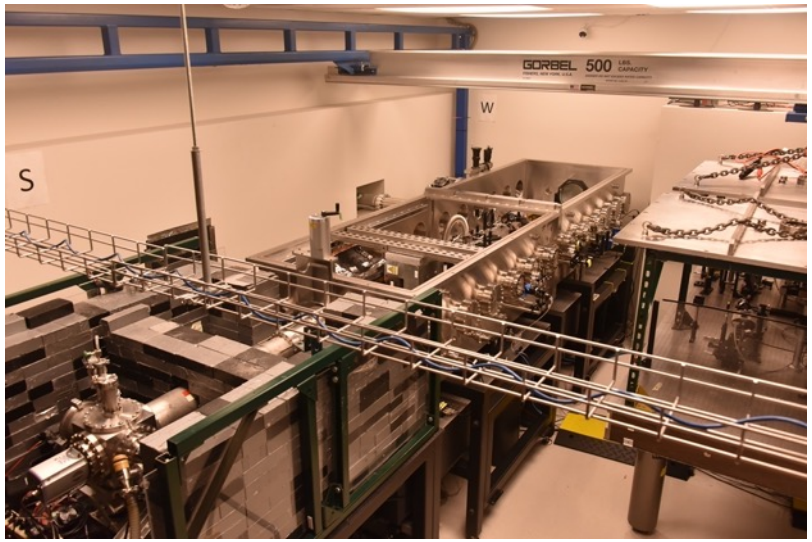
# Target Area 3 (TA3): Science

Laser wakefield acceleration of electrons & high-energy photon beam generation





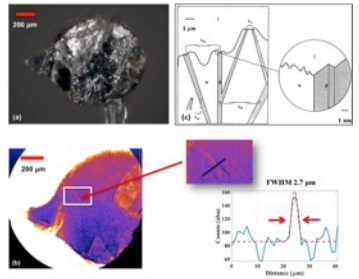
F Albert, *et al*, PPCF, **56**, 084015 (2014)

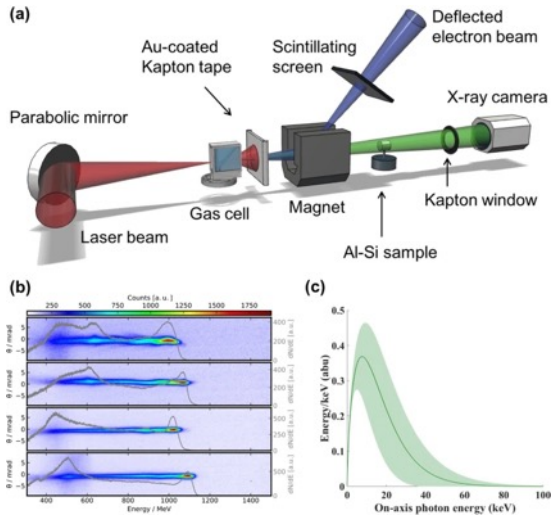



Probing applications (including for non-traditional high-power laser users)

Example: Material Science Applications

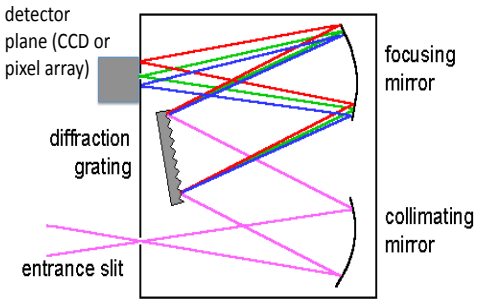
*A. E. Hussein, et al., Laser-wakefield accelerators for high-resolution X-ray imaging of complex microstructures, Scientific Reports, 9, 3249 (2019)*





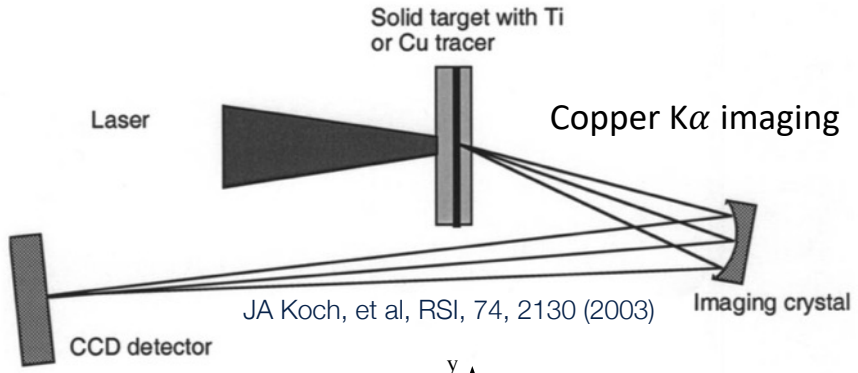
# DIAGNOSTICS

- Some semi-permanent and a broad selection of movable diagnostic will be available for use
- Information on each diagnostic will be available from a link on the ZEUS website (this is work in progress).
- The facility will work with external users to integrate their own diagnostics onto the system (assistance from mechanical and electrical engineering staff).
- Please speak with us if you have questions about the specifications or integration.

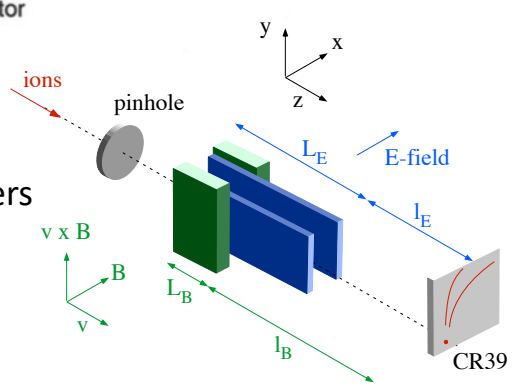


Grating spectrometer

CCD



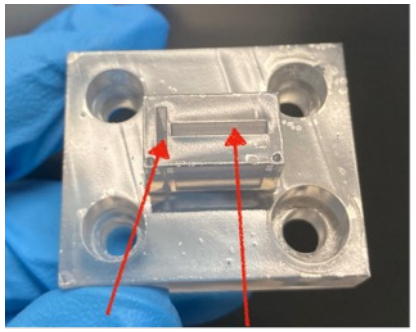

Magnetic spectrometers

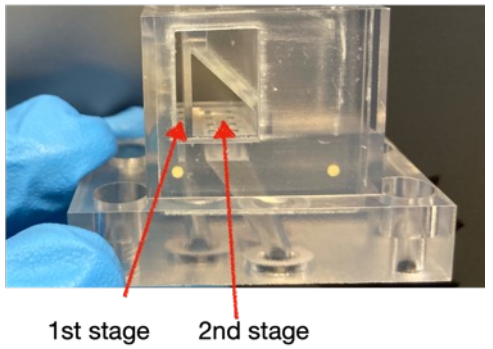


# TARGETS

- The ZEUS target fabrication engineer will assist with target preparation
- A suite of instruments for characterization will be located within the ZEUS facility.
- Basic targets will be available to users:
  - Flat foils
  - Gas jets or gas cells – variety of designs and gas types
    - 2-stage supersonic gas jets
    - 2-stage variable length gas cells
  - (Liquid jet target – but not first year)

Sallee Klein
(target fab engineer)



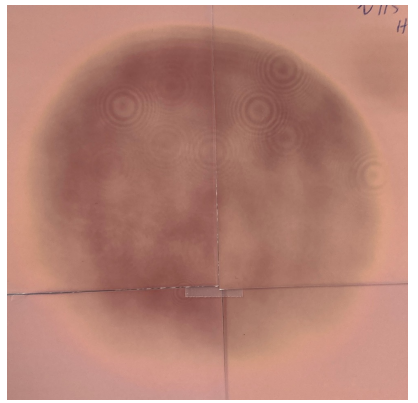

- Specialist targets may be fabricated using in-house machining, or outside vendors may supply some of the parts. Cost analysis and assessment will be necessary.

# COMMISSIONING STATUS

**Front End:** 1.5 J; 20 fs; 90 nm; 5Hz continuous

**Phase 1 >200 TW:**

- 6 J Compressed energy (92% per grating) (measured w/ Gentec-CM160)
- 26 fs FWHM pulse duration (38 fs autocorrelation)
- 80 nm spectral width (1/e^2) (bandwidth measured w/ Ocean Insight-Flame)
- ~80% Strehl ratio with DMs
- <2 fs Computed radial pulse delay
- Pointing jitter ~1 spot diameter
- 1 Hz Burst mode (5, 10, 20 pulses, etc.)

Amplified profile

Burn taken at compressor input



Mid-scale Research – Award # 2126181

ZEUS
Zettawatt-Equivalent Ultrashort Pulse Laser System

# CAPABILITIES FOR FY25

| Parameter | Target area 1<br>FY24 aim / FY25 aim [eventual] | Target area 2<br>FY24 aim / FY25 aim [eventual] | Target area 3<br>FY24 aim / FY25 aim [eventual] |
|---|---|---|---|
| Energy | **25 J** / **50 J** [75 J] | **5 J / 12.5 J** [ 75 J] | **5 J / 12.5 J** [12.5 J] |
| Pulse duration | **25 fs** | **25 fs** | **25 fs** |
| Power | **1 PW / 2 PW** [3 PW] | **<200 TW / 500 TW** [3 PW] | **200 TW / 500 TW** [500 TW] |
| Rep-rate | **1 shot per minute** | **1 shot per minute** | **200 TW 1 Hz burst mode / 500 TW 1 shot per minute**<br>[5Hz burst mode] |
| Split beam option | **No / 1.5 PW & 0.5 PW**<br>[2.5 PW & 0.5 PW] | **No** [No] | **No** |
| Plasma Mirror option | **No** | **Yes (double plasma mirror)** | **No** |
| Focusing | **f/64 / f/64 (2 PW) or f/64 (1.5 PW) and f/3 (0.5 PW)** [or (0.5 PW) or f/78 (0.5 PW] | **f/2** [f/2 or f/3] | **f/40 / f/40 or f/20** |
| Long pulse option | **No** / **No** [Yes] | **No / Yes** [ Yes] | **No / No** [Yes] |

# Accessing the ZEUS Facility



- Annual call for proposals
- Proposal Review Panel (PRP) is independent of the facility (No members from ZEUS facility or CUOS)
  - Access will be granted for fundamental research in Physics, medicine and engineering (rather than for industrial or commercial experiments)
  - No classified research will be conducted using ZEUS
- Successful proposals will be passed to the ZEUS facility for scheduling
  - Each experiment assigned a “link” scientist in initiate planning
  - Users connect with ZEUS user office to arrange training before arrival
- Users are expected to provide the facility with constructive feedback

# Experimental Planning



Meeting participants: Target area link scientist, PI and User team, Engineers, laser representative.

**- 3 months**

First planning meeting: Identify elements of experimental design that require development. Order targets.

**-1 month**

Second planning meeting: Finalize experimental design. Review for conflicts, design or operational problems.

**-2 weeks**

Third planning meeting: Finalize experimental design.

**Set up weeks**

External users arrive to prepare their experiment. Two weeks of access to the area prior to the beam time would be typical.

Register all users through the MyZEUSPortal.

Coordinate with User office to initiate travel plans and take required safety training before arrival.

# Typical Experimental Day

7 am – 2 technicians arrive, warmup laser systems, start alignment, maintenance

8 am – users arrive, morning meeting with TA Link scientist, technical staff

10 am – laser availability (first alignment beams, then high power beams)

12 pm – 2 laser technicians arrive

2 pm – afternoon meeting with TA Link scientist, technical staff

8 pm – end of laser operations, data available on user web-site

Note that preparatory work (without laser access) for future experiments in two other target areas will also be ongoing.


Mid-scale Research – Award # 2126181

# Second Call For Proposals (FY2025)



The 2nd annual call for proposals for access to the ZEUS facility will open this week.

- Announcement to the ZEUS user group email list and on ZEUS website

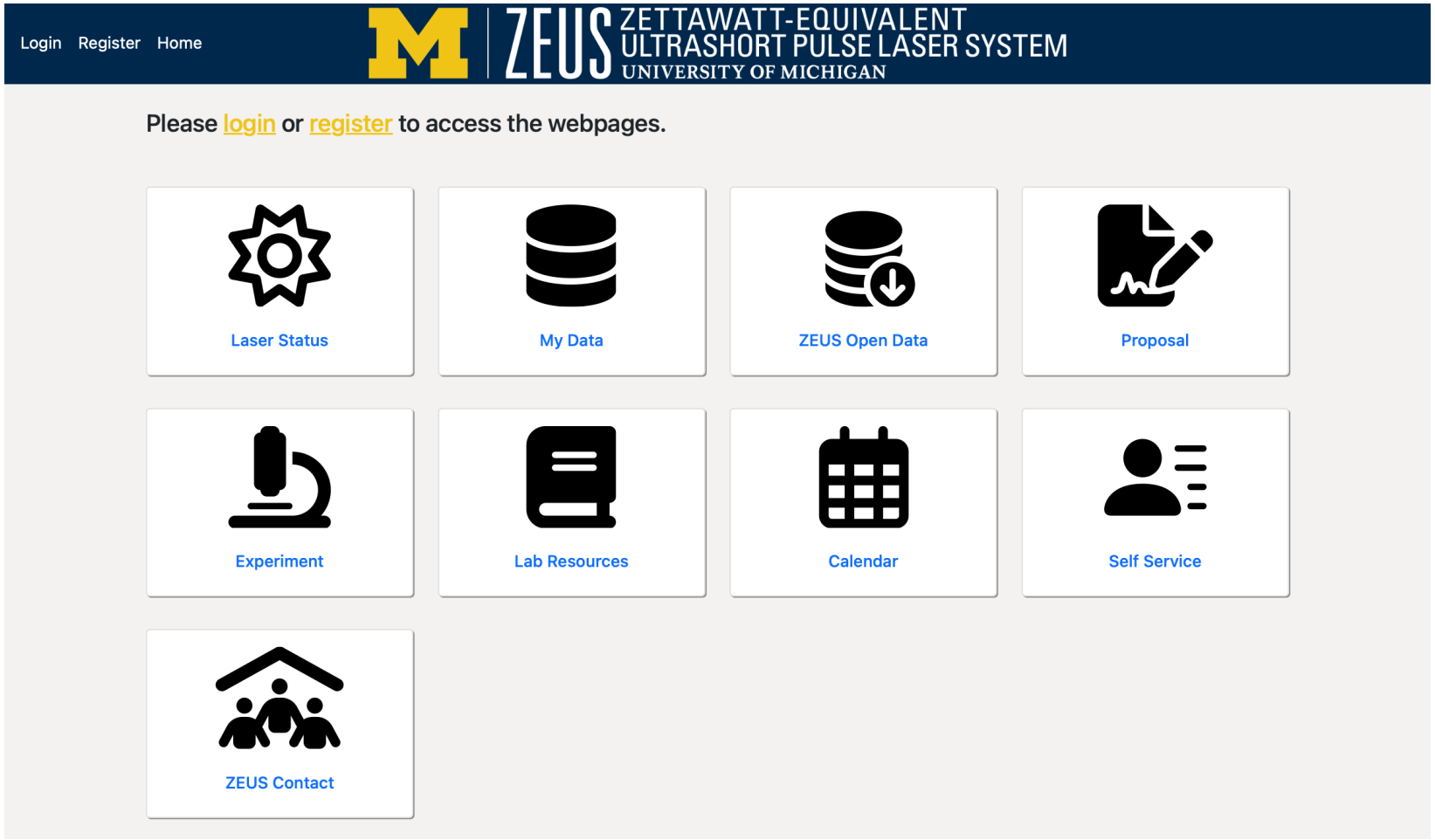
Proposals are due, through the online submission, by 5pm ET on 31st January 2024.

Expected capabilities of the ZEUS facility for the FY2025 cycle will be posted on the ZEUS website.

Approximately equal numbers of experiments will be scheduled in each of the three target areas, 30 weeks in total. Typical experiment would be 4 weeks (longer/shorter possible with justification).

**Eligibility criteria:** The ZEUS facility welcomes proposals from the whole scientific community, from within the plasma physics community and beyond, no restriction on your funding support. International researchers are welcome to submit proposals for the ZEUS facility.

# MyZEUSPortal




MyZEUSPortal is the web-based user interface with the facility.

Here you can submit a proposal, coordinate your experiment, find ZEUS info and resources, and view your experimental data.

MyZEUSPortal is work-in-progress so please let us know if you encounter bugs or problems.



Mid-scale Research – Award # 2126181

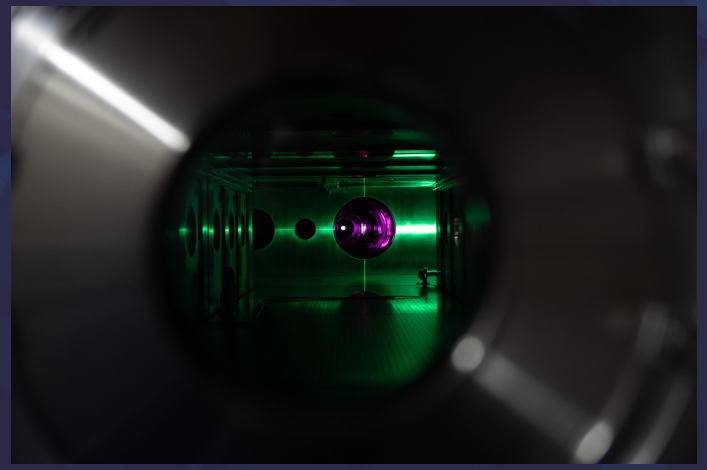
# How to Submit a Proposal

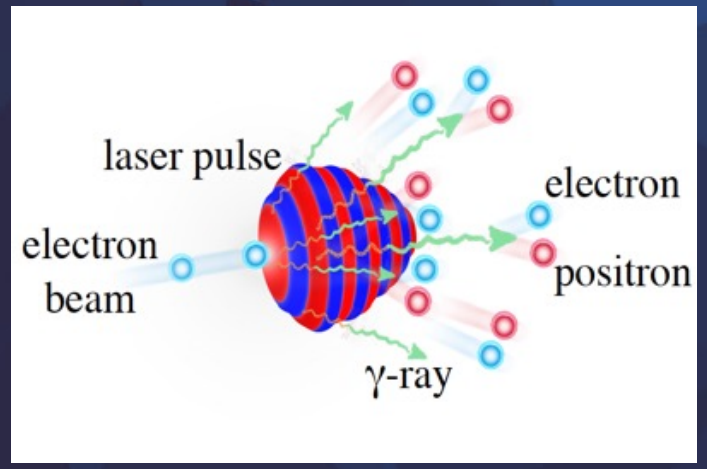


- Register for a user account on the MyZEUSPortal
- Prepare your proposal according to the requested proposal preparation guidelines, available on the ZEUS website.
- Contact ZEUS-users@eecs.umich.edu with any questions regarding the proposals.
- Or attend a Q&A virtual session to speak with the ZEUS team.
- Submit your proposal through the MyZEUSPortal before 31st January 2024, 5pm ET.

THE GÉRARD MOUROU
CENTER FOR ULTRAFAST OPTICAL SCIENCE
UNIVERSITY OF MICHIGAN

# The 3-PW ZEUS laser user facility







3 Petawatt power laser user facility

Experiments on:

- Testing extreme field physics
- Unique particle & photon sources
- Applications of sources across STEM

Commissioning late 2023 (now!)

User access through scientific merit-based proposal system

FY25 Call for proposals open
Deadline 31st January 2024

The ZEUS facility construction and operation is supported by the National Science Foundation under award 1935950 and 2126181, as well as by the AFOSR grant number FA9550-22-1-0118 and the University of Michigan.