The BELLA PW iP2 & 2BL Upgrades

Radiation and Laser Safety considerations and implementations for safe and efficient user experiments

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BELLA Center, ATAP, LBNL

20th Advanced Accelerator Concepts Workshop (AAC'22)
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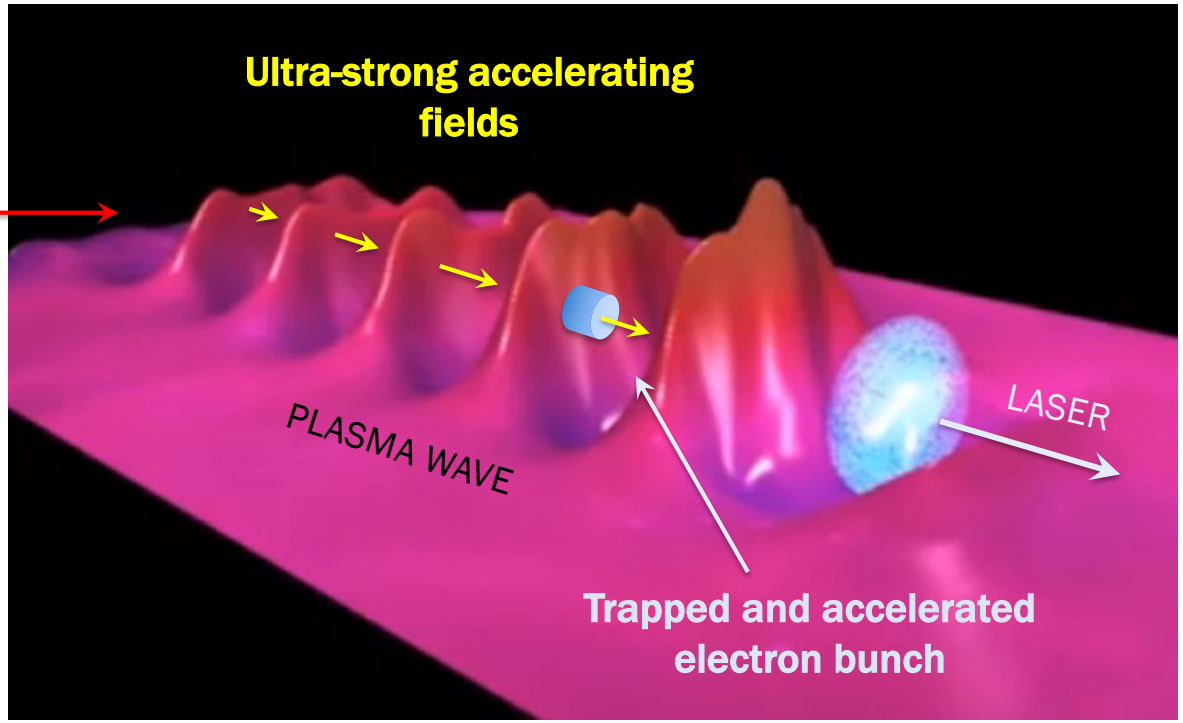
Outline

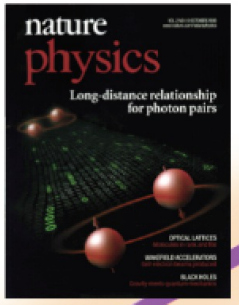
- **Science motivation of PW upgrades for extended LPA studies**
  - Laser Plasma Accelerator (LPA) science and previous results
  - Upgrade #1: Staging of electron acceleration modules to go beyond 10 GeV **(PW-2BL)**
  - Upgrade #2: Ion acceleration in solid-target experiments **(PW-iP2)**
- **Safety at the BELLA PW LPA Facility**
  - Existing radiation shielding, combined laser and radiation interlock systems
  - Analysis of new hazards, hazard mitigation strategies:
    - ✓ design of new shielding components
    - ✓ radiation field monitoring via interlocked radiation detectors
    - ✓ laser beam shutter systems
- **Operational practices**
  - Conditions for low- and high-energy operations (LAM vs. HEM)
  - Lessons Learned, On-the-Job Trainings (OJTs), safety culture

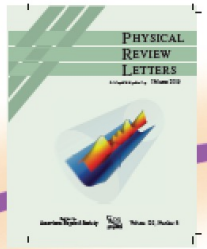
In Laser Plasma Accelerators (LPAs) a small portion of background plasma electrons are injected into the wake, generated by the laser pulses

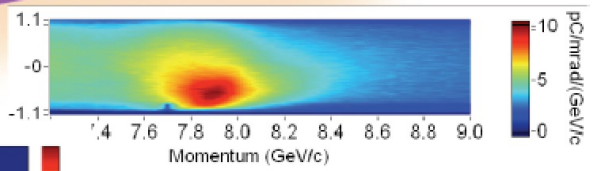
See any earlier LPA or LWFA review talks at this workshop



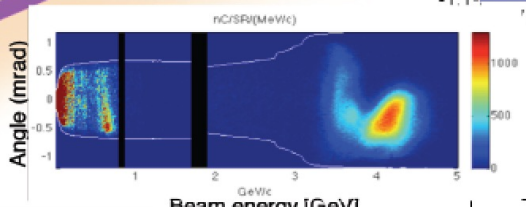
BELLA Center: pushing energy from 86 MeV to 1 GeV, and with BELLA-PW laser, from GeV to beyond 8 GeV



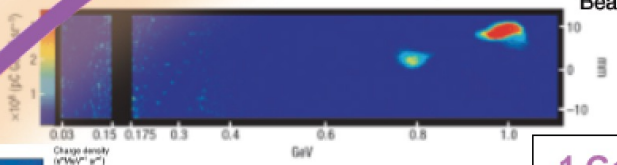




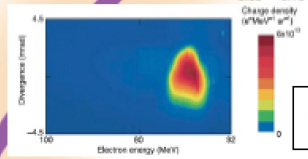
8 GeV



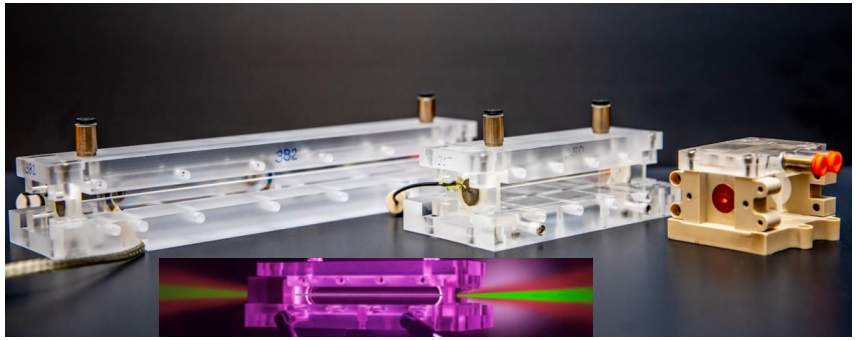
4.2 GeV



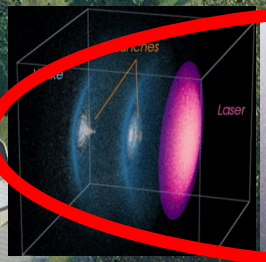
1 GeV



86 MeV



The BELLA Center houses multiple laser facilities addressing laser, accelerator, and light source R&D and applications

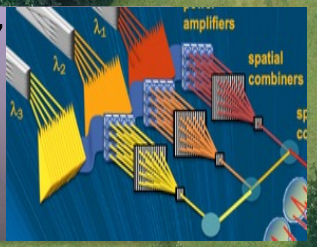


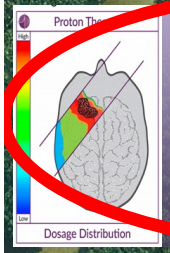
BELLA-PW 1st and 2nd beamlines
40 Joule in ~30fs (1 PW @ 1Hz)
- multi-GigaVolt e- acceleration
- high-brightness LPAs

BELLA-HTT
3 Joule in 30fs (100 TW @ 5Hz)
- Mono-chromatic gamma rays
- Pump-probe X-rays
- Medium-intensity p+ acceleration

Future kBELLA: 100TW, operation at 1kHz

BELLA FIBER "mini kBELLA"
100s mJ in <100fs (>1kHz)
- Laser R&D
- LPA & light at >1kHz

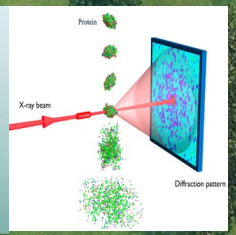




BELLA-iP2 at BELLA-PW
40 Joule in 30fs (1 PW @ 1Hz)
- High-intensity p+ acceleration
- Strong-field physics

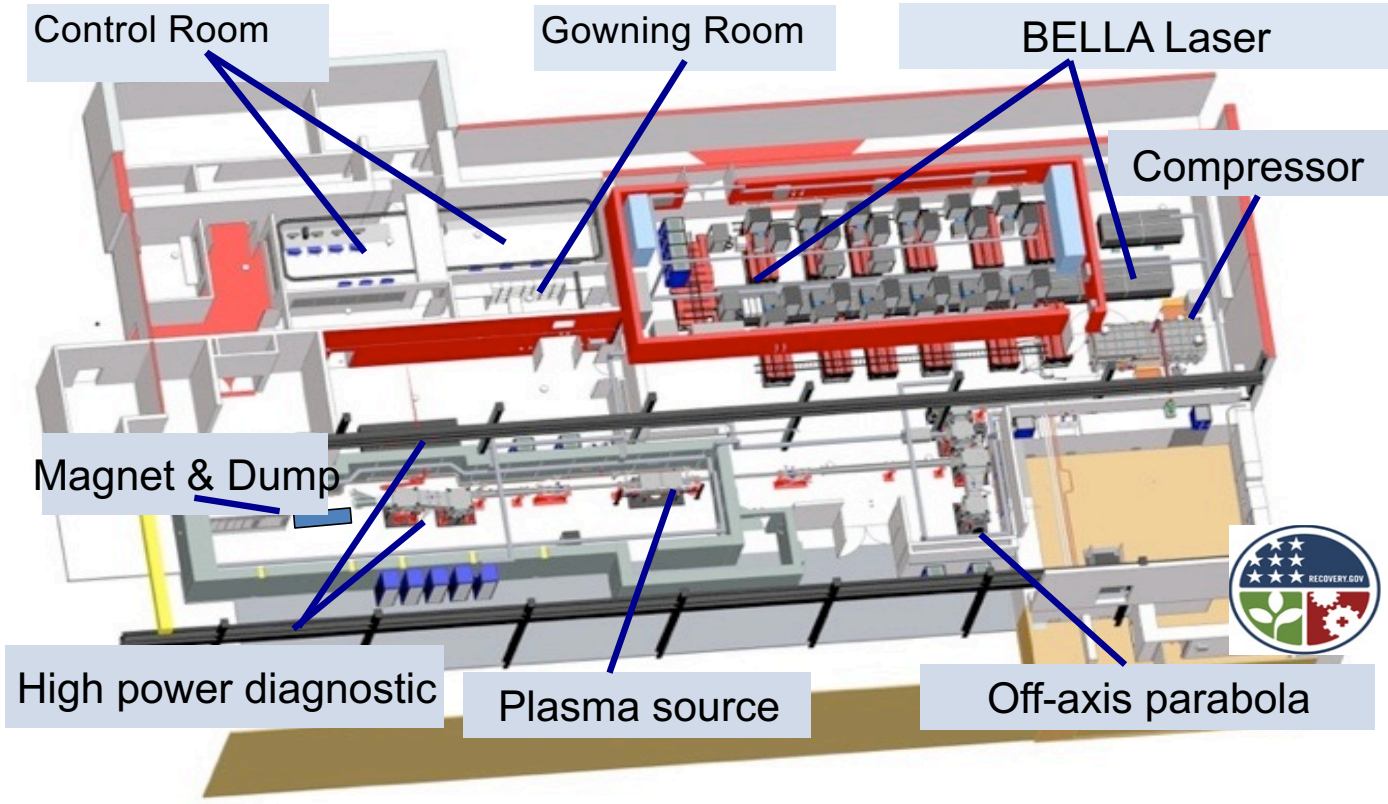
1TW-kHz, 4mJ Joule in 4fs (1 TW @ 1kHz)
- Few-MeV electrons & X-rays
- Medical & detection

BELLA-HTU,
3 Joule in 30fs (100 TW @ 5Hz)
- Electron transport line
- Undulator X-rays

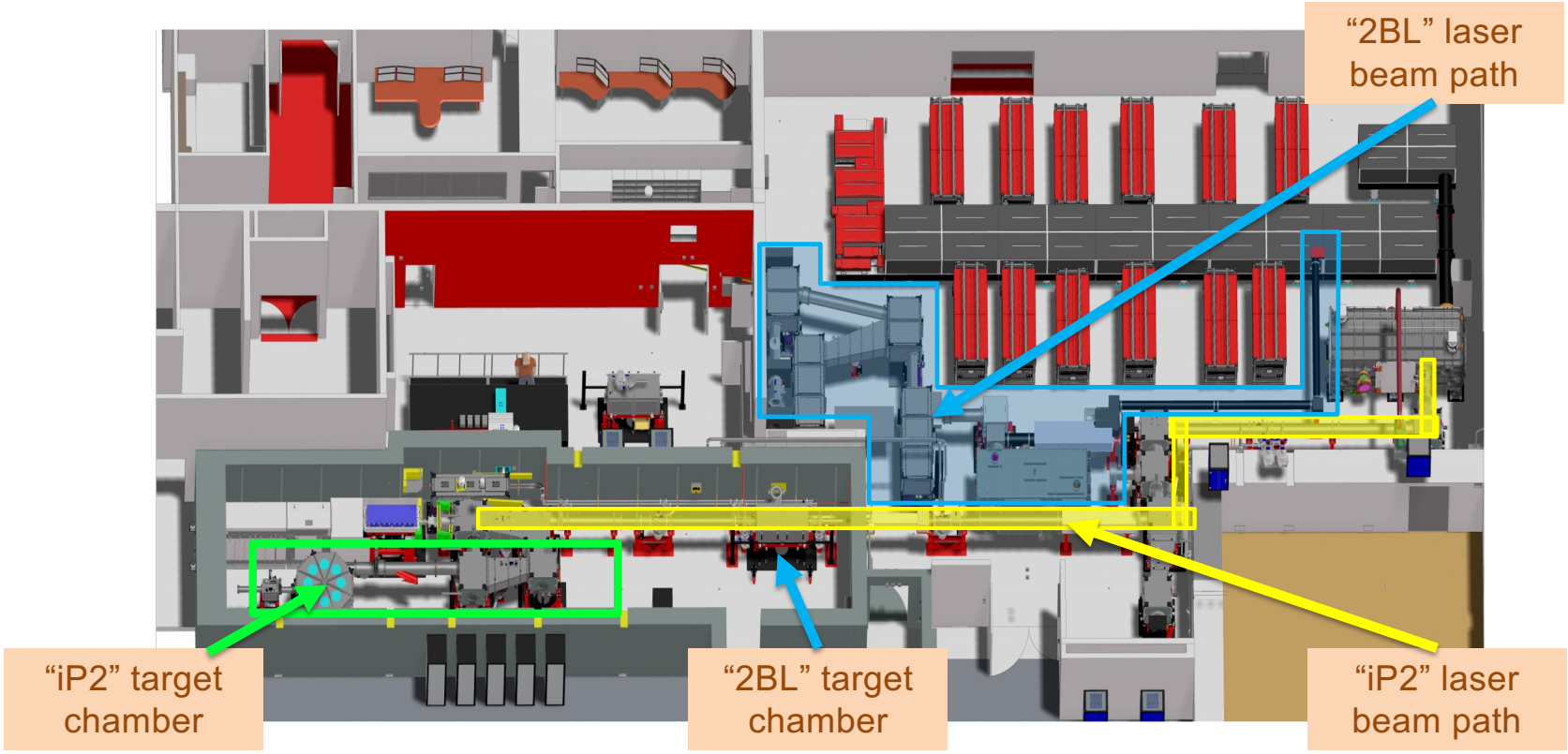


The original BELLA PW facility houses a 1 Hz, PW CPA laser for laser plasma accelerator (LPA) science

K. Nakamura et al., IEEE J. Quantum Electron. 53, 1200121 (2017).

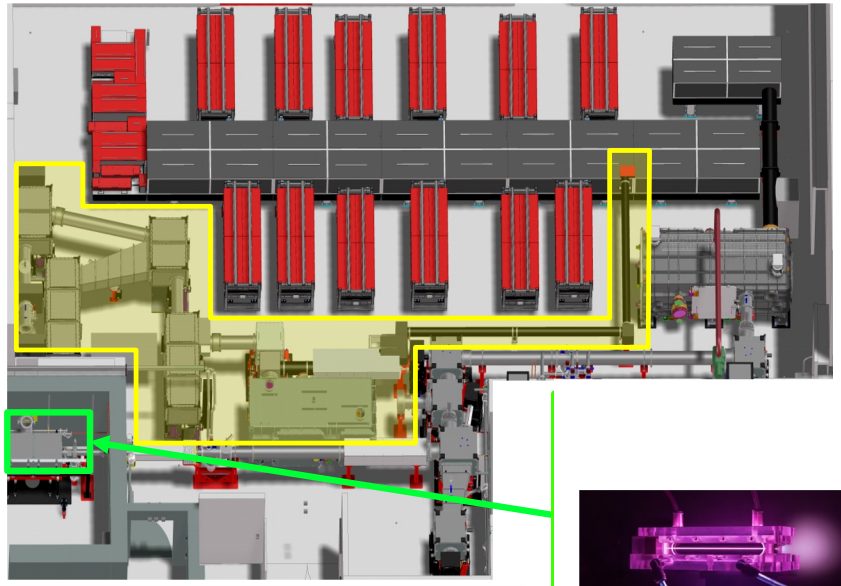


BELLA PW upgrades - iP2 & 2BL beamlines



BELLA PW 2nd beamline designed for Laser Plasma Accelerator (LPA) staging

- Problem: single laser & single structure can only drive an LPA stage to max limit
- Solution: Staging (two laser pulses & two plasma structures, independently tuned)
- Staged LPAs offer potential for high-gradient, efficient colliders. **On DOE roadmap**



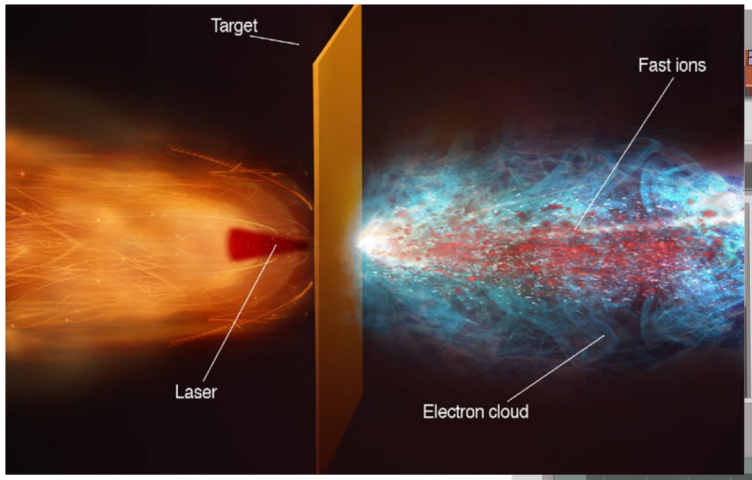
C. B. Schroeder et al., PRSTAB 13, 101301 (2010); S. Steinke et al., Nature 530, 190 (2016)

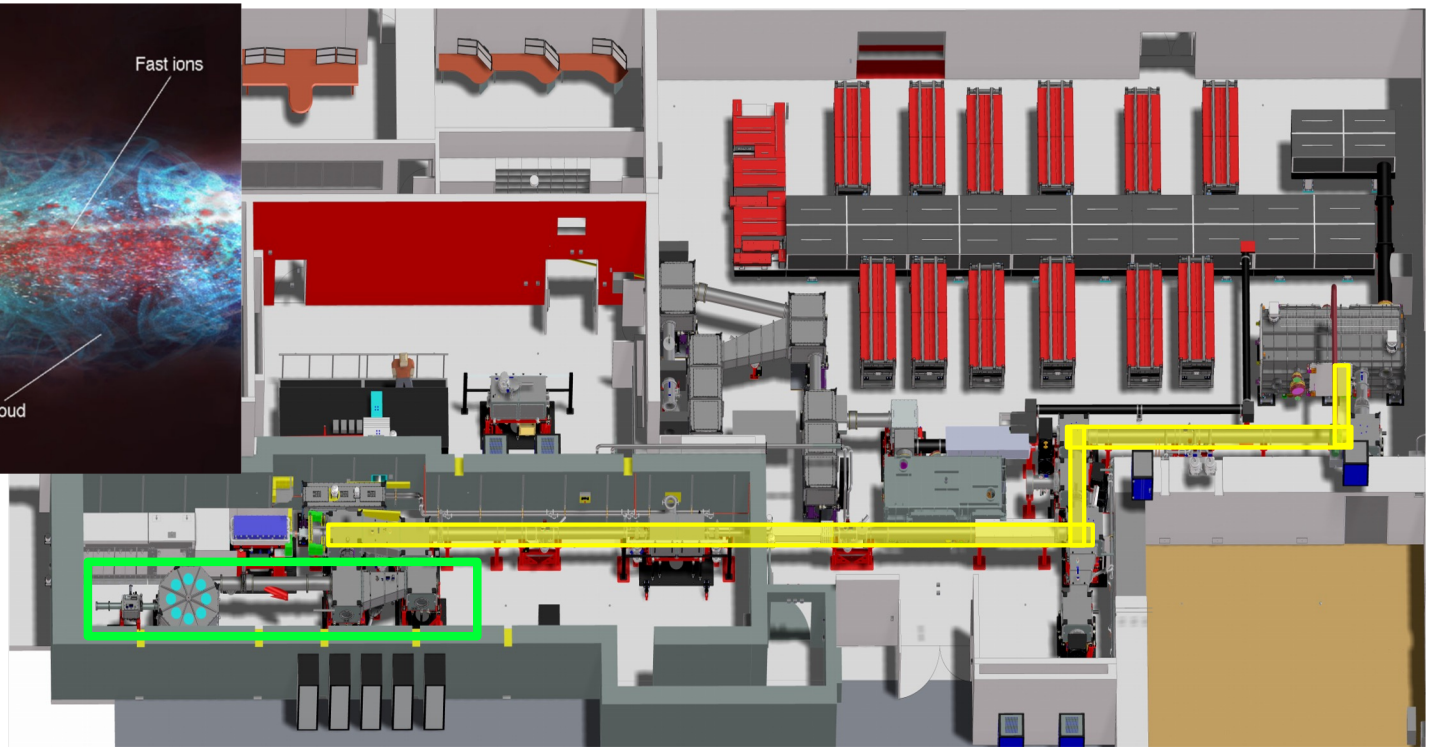
2021	2023	2025	2027
Staging 2.0: demonstration of 5GeV+5GeV			

Present	Goals
0.1 GeV boost	5 GeV
Few pC, 4% captured	100pC, >90% captured
>5 GV/m	>5GV/m
Emittance growth	Emittance preserved

See also talk by A. Picksley – WG1&8 – WED pm

BELLA PW ‘interaction Point #2’ (iP2) beamline for high-laser-field experiments (e.g. proton beams)





See also talk by S. Hakimi – WG6 – WED pm

Pre-2021 BELLA PW (still first target chamber “plasma1”, iP1): intensity 2×10^{19} W/cm^2
BELLA PW iP2: shorter focal length OAP: intensity up to 1×10^{22} W/cm^2 - higher energy protons!

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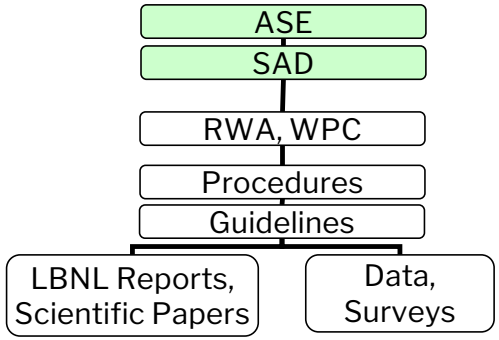
The LPA facilities of the BELLA Center traditionally equipped with comprehensive radiation shielding and monitoring systems

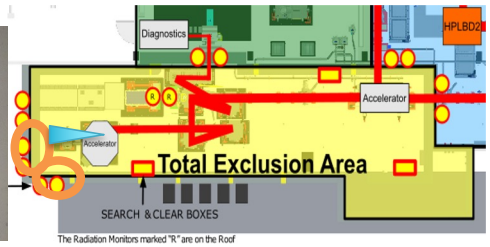
The design and operation of the safety system follow the **DOE Accelerator Safety Order ASO 420.2C** -> including the development and maintenance of a Safety Assessment Document (SAD), Accelerator Safety Envelope (ASE), established **Credited Controls** and a continuous Safety Assurance process

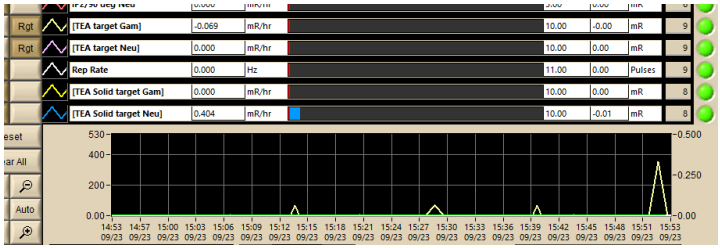
Radiation shielding designed to protect workers and environment during exploratory research -> combined with continuous radiation field monitoring

Monitoring radiation INSIDE and OUTSIDE of target caves during all runs by strategically positioned gamma and neutron detectors

Online telemetry -> working in close collaboration with Radiation Protection Group (RPG)

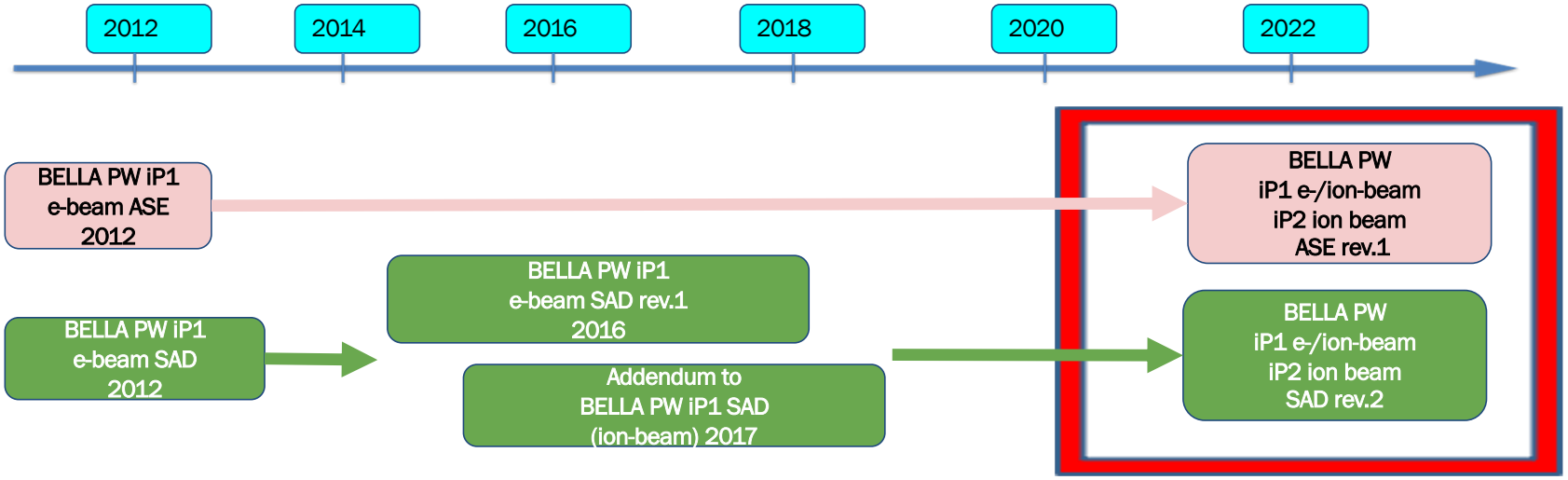






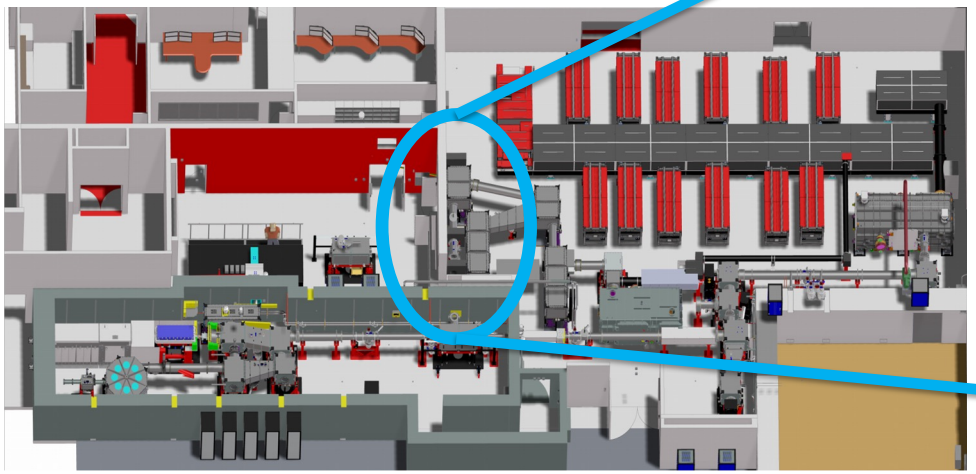
Credited Controls are identified based on the SAD and ASE process

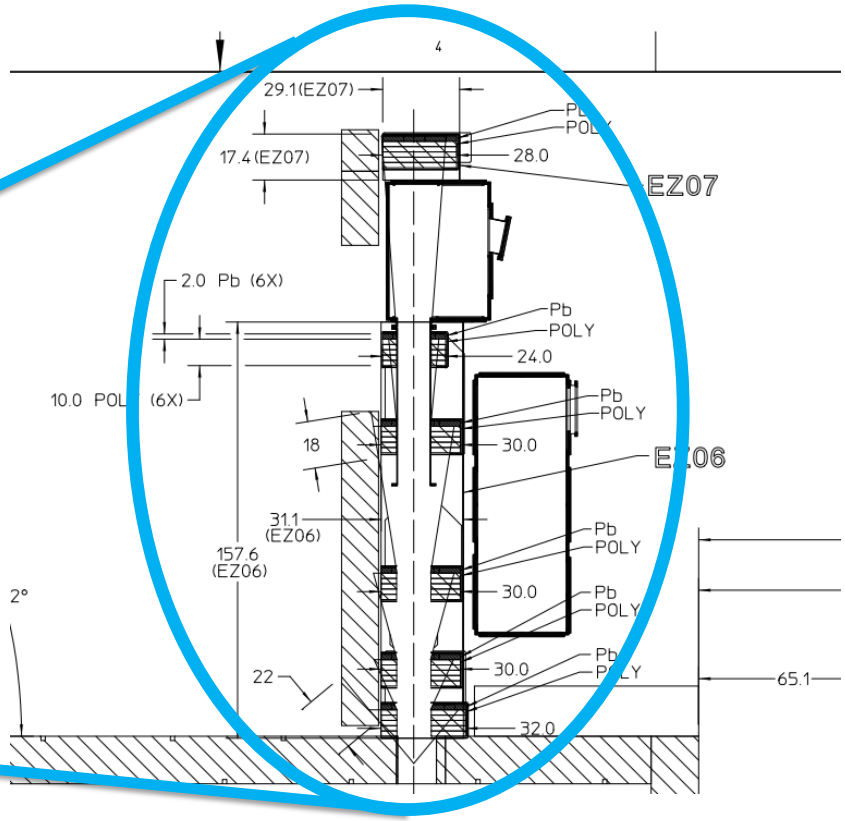
(1) Beam Line Design: Accelerator beams are contained inside the Total Exclusion Area (TEA) at all times.
(2) Radiation Shielding: The Total Exclusion Areas (TEA) shall have permanent shielding in place to protect personnel from exposure to radiation above permissible limits.
(3) Personnel Protection System: The TEA has a Personnel Protection System to protect personnel from exposure to radiation above permissible limits.
(4) Approved Search and Secure procedure: must be carried out for the TEA prior to high power, on-target, laser operations to ensure that all personnel are excluded.
(5) Electron and Ion Beam Parameter Limits:



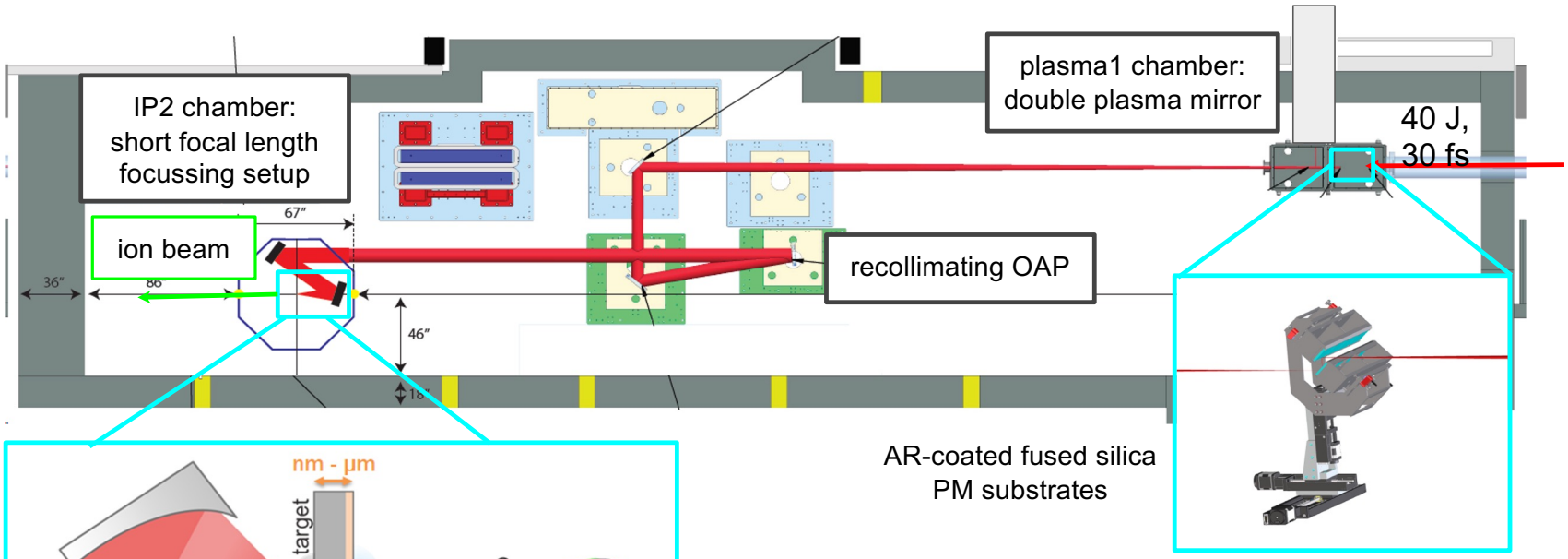
The 2BL Hazard Analysis resulted in the requirement of installing new shielding components around the new 2BL beamline

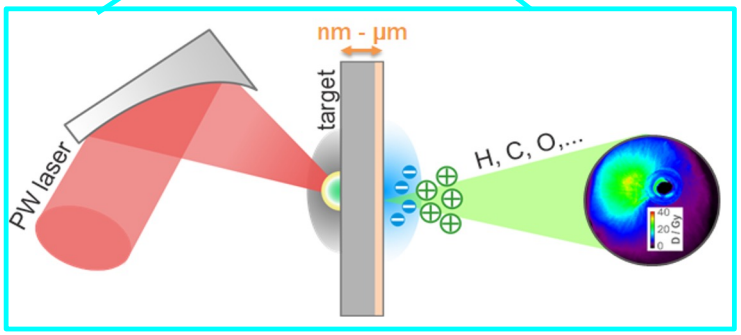
- As the PW 2nd beamline represented a new potential local loss beam area, the equivalent of 10-inches of polyethylene, and 2-inches of lead was installed on the 2nd beamline in the form of collars and a backstop, consistent with the existing shielding for the 1st Beamline penetration area
- Figure is showing the 2BL laser beam tube penetration area toward the TEA (on the bottom if this drawing)





The design of the new iP2 beamline maintains the arrangement that the particle beams contained inside the TEA at all times (Credited Control -1)

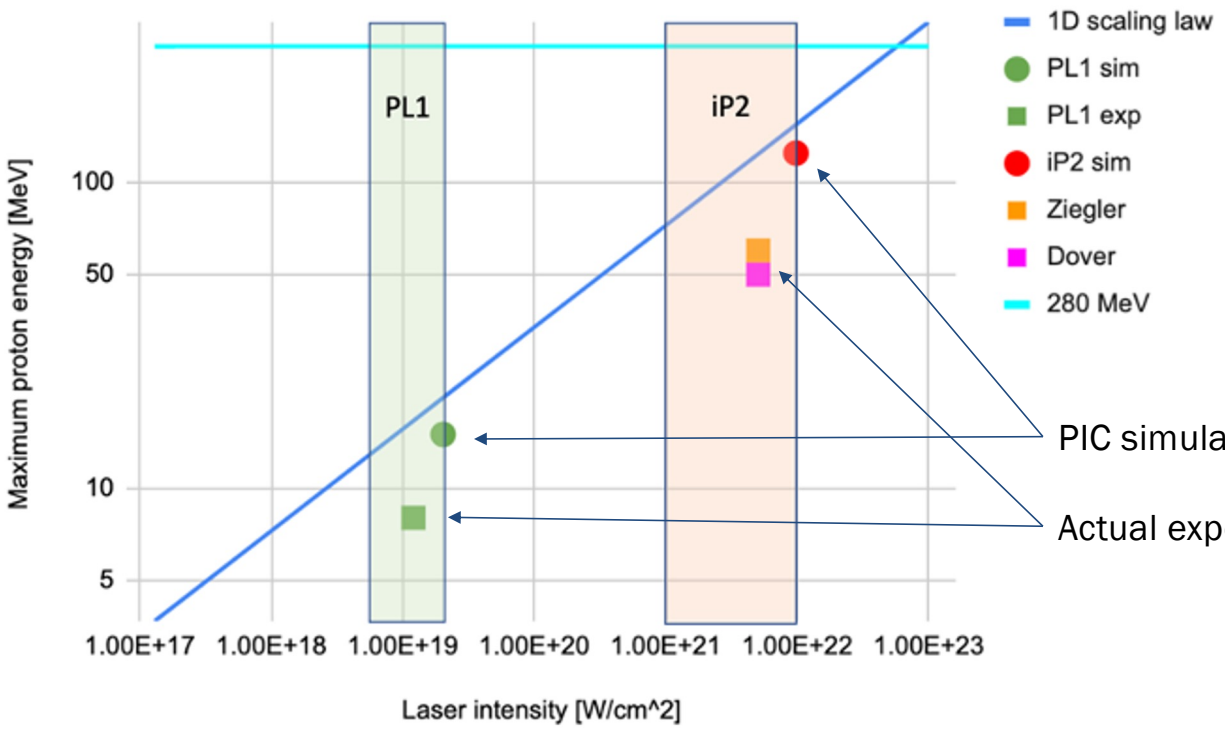




→ 50 - 100 MeV peak proton energy expected

old (iP1) laser focus	new (iP2) laser focus
spot radius ~ 50 micron	spot radius ~ 2 micron
intensity 2×10^{19} W/cm^2	intensity up to 1×10^{22} W/cm^2

Highly conservative ion beam spectrum was used as input for the shielding requirements calculation by RPG (MCNP6, RP-07 memo)



Ziegler et al., Scientific Reports 11 (2021) 7338.
Dover et al., High Energy Density Physics 37 (2020) 100847.

PIC simulation results with ideal laser pulses

Actual experimental results.

Figure 3.2-7: Maximum proton energy E_{max} as a function of the laser intensity

The existing shielding of the TEA still appropriately protects personnel from exposure to radiation beyond allowable limits (Credited Control -2)

- Gamma / Neutron yields investigated and documented in RP-07 RPG Memo
  - Location study
  - Impacts from Collimators including material selection
  - Impacts from Carbon ion beam
  - Impacts from an extended high-energy cut-off
  - Impacts from hot electrons

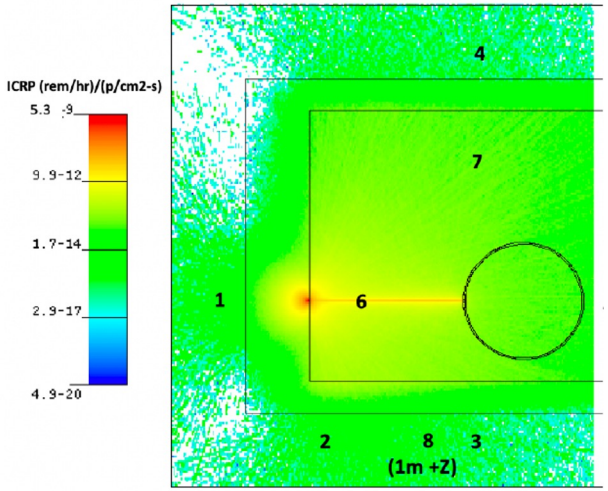


Figure 10. Neutron dose rates (rem/hr/(p/cm2-s) by location

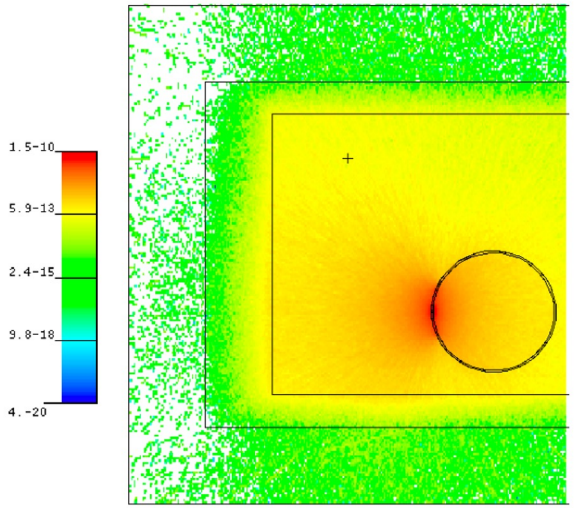


Figure 11. Neutron dose rates (rem/hr/(p/cm2-s) for diverging 175 mrad source

Two extreme cases of "pencil-like" and "broad divergence" ion beams were considered in MCNP6 simulations

The integrity of the shielding is regularly checked based on the 18-month checklist (BC's Configuration Control Policy)

The upgraded combined “laser & radiation” Personnel Protection System (PPS) includes new interlocked gamma/neutron monitors and a new laser shutter

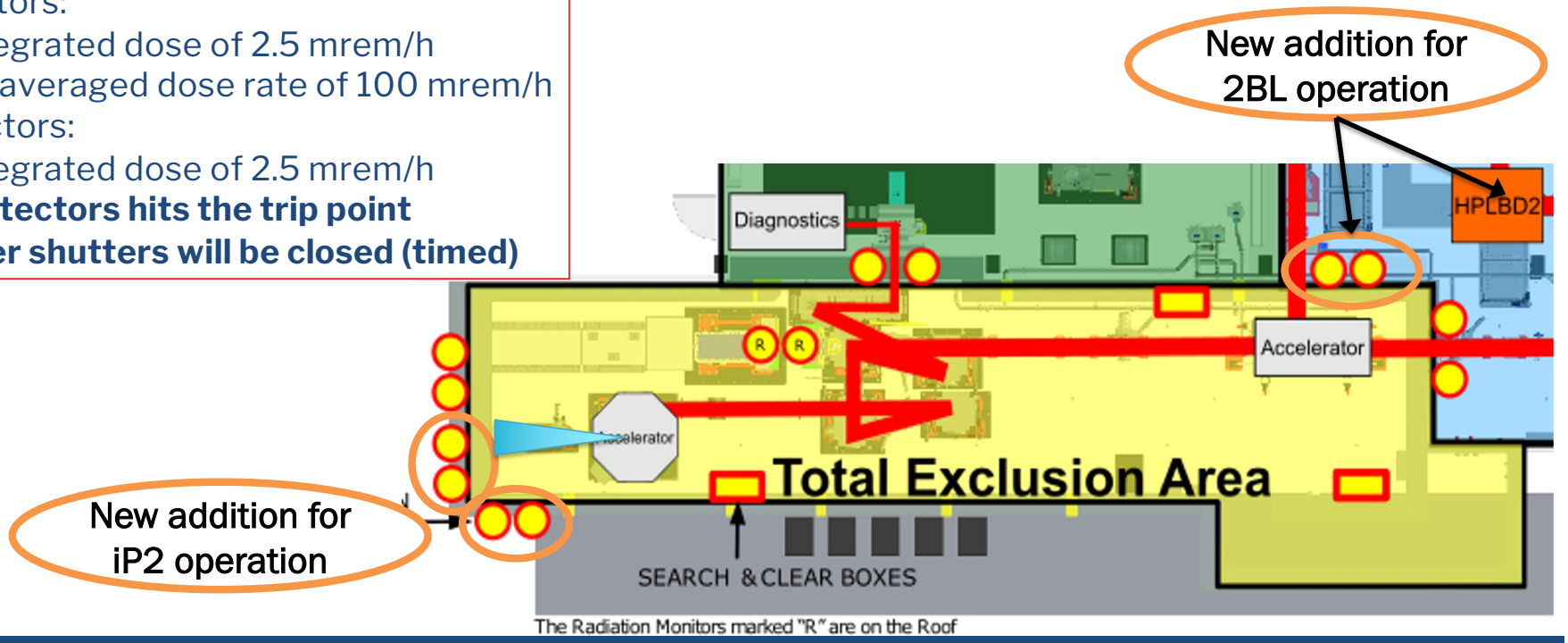
Regulation limit: 5 mrem/h

Detector trip point (**BOP-21**)
Gamma detectors:
- 1-hour integrated dose of 2.5 mrem/h
- 4-second averaged dose rate of 100 mrem/h

Neutron detectors:
- 1-hour integrated dose of 2.5 mrem/h

If any of 14 detectors hits the trip point
-> -> -> laser shutters will be closed (timed)

Interlocked radiation monitors



A series of formal safety and operations reviews for the BELLA PW iP2 & 2BL projects ensures appropriate hazard assessment and mitigation

• PPS [Personnel Protection System] Interlock Requirements review	June 9, 2021	iP2	2BL
• PPS [Personnel Protection System] Interlock Design review	July 26, 2021	iP2	2BL
• ARSC [Accelerator Radiation Safety Committee] review for iP2 – phase I	August 11, 2021	iP2	
• IRR [Instrument Readiness Review] of equipment, procedures, training – iP2	October 14, 2021	iP2	
• PPS [Personnel Protection System] Interlock Software review	November, 2021	iP2	2BL
• PPS [Personnel Protection System] Interlock Validation review	December 16, 2021	iP2	2BL
• BC [BELLA Center] & RPG [Radiation Protection Group] review Commissioning Procedures, finalize SAD [Safety Assessment Document] and ASE [Accelerator Safety Envelope]	Jan/Feb, 2022	iP2	2BL
• USI [Unreviewed Safety Issues] determination review for 2BL	February, 2022		2BL
• PPS [Personnel Protection System] Interlock Periodic Test Procedure	March/April, 2022	iP2	2BL
• ARSC [Accelerator Radiation Safety Committee] review for iP2 – phase II	May, 2022	iP2	
• BSO [Berkeley Site Office] reviews SAD/ASE for iP2	May, 2022	iP2	
• ARR [Accelerator Readiness Review] for iP2	July, 2022	iP2	
• IRR [Instrument Readiness Review] of equipment, procedures, training – 2BL	May 10, 2022		2BL

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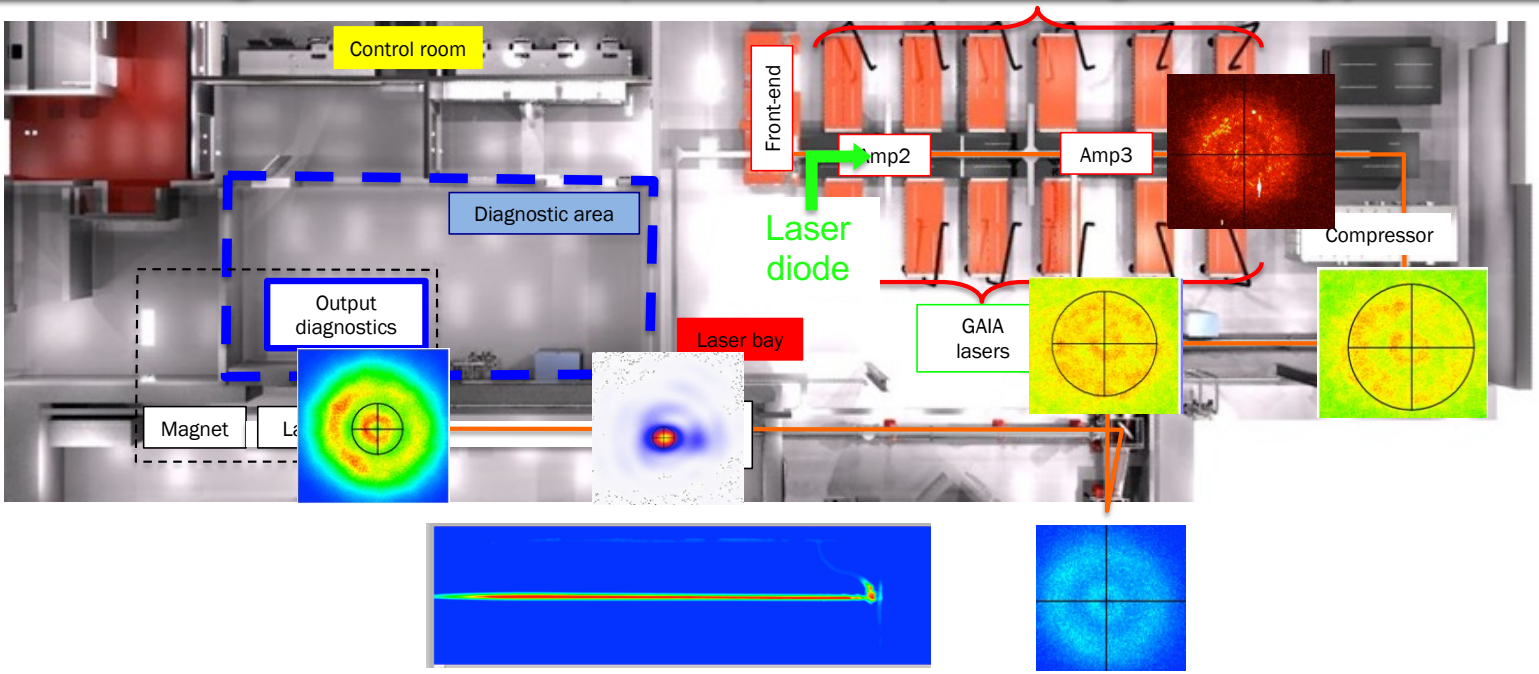
Insertable alignment laser is a critical tool allowing preparatory work in a Low Power Alignment Mode (LAM), as a pre-'high energy' mode (HEM)

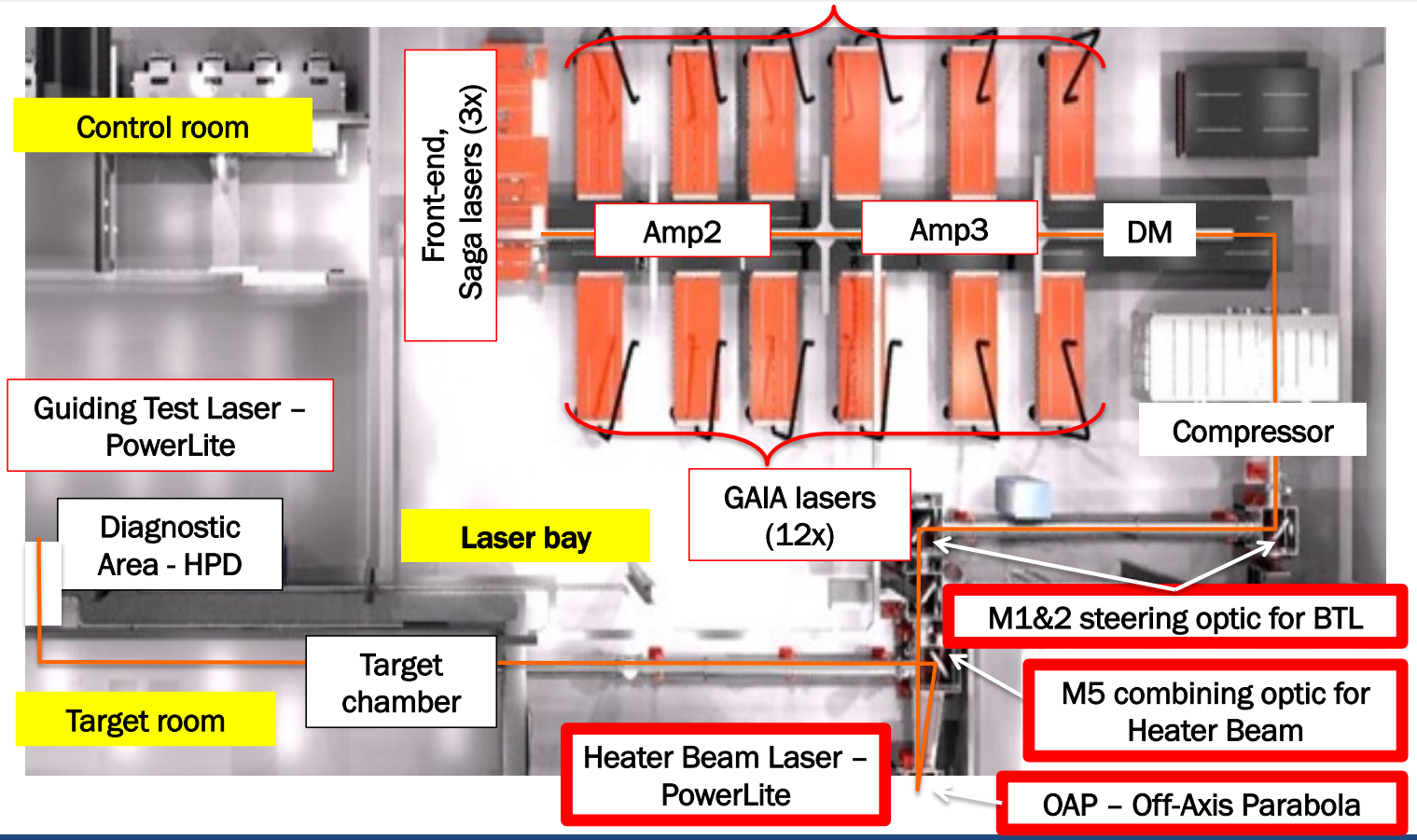


Capillary target pre-alignment

Automated alignment system with dedicated cameras for faster, precise, and consistent operation

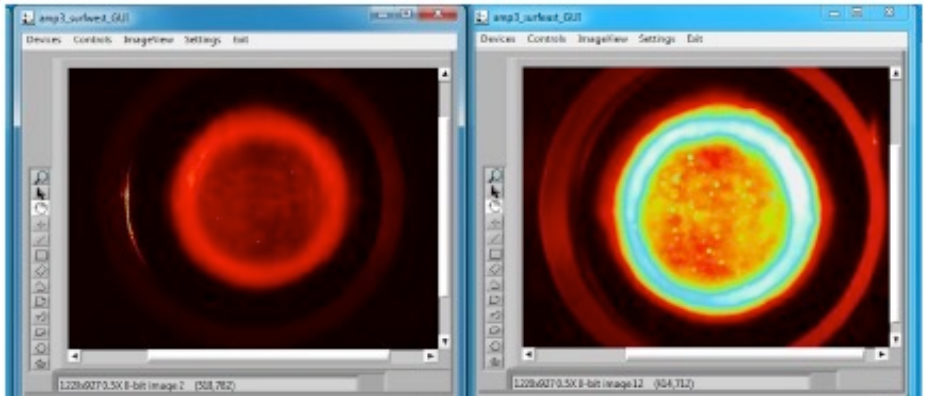
K. Nakamura et al., IEEE J. Quantum Electron. **53**, *1200121 (2017).*

Lessons learned #1 - Investment in critical spare laser components is important to maintain operability at the highest power level and quality

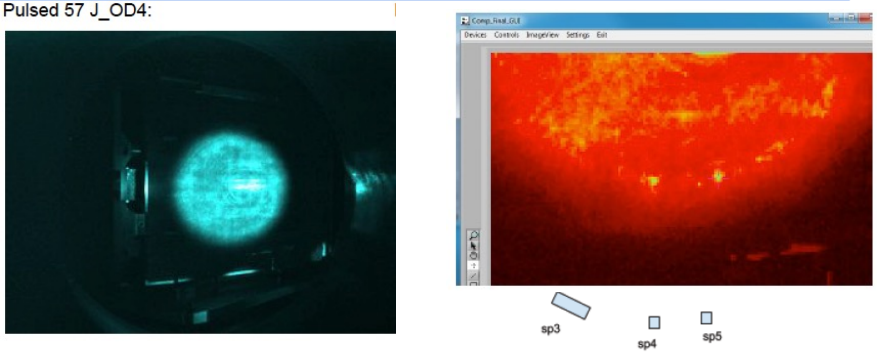


Lessons learned #2 – Continuous monitoring of critical surfaces of key optical components allows early detection of precursors of damages

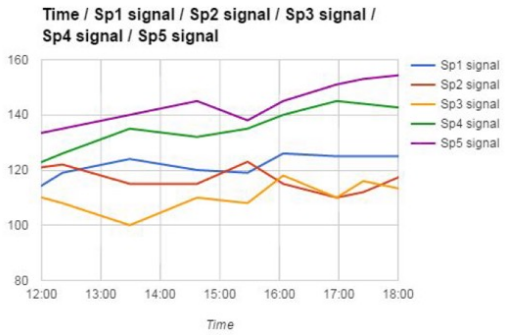
Continuous monitoring of fluorescence images of the final Ti:S amplifier's surfaces helps checking alignments and shows deterioration of AR coating early



Side-scattering images of final compressor grating show evolving hot-spots



Trending helps to predict catastrophic damages



Gradual training and continuing education in safe work practices are part of the BELLA Center's operation culture and policy

Steps of onboarding:

1. **Simple access to lab, no independent work**
2. **User training starts for lasers**
3. **User training for Rad Work (RWA/WPC)**
4. **Experimenter-in-Charge (EIC) training**

Methodologies:

- **Be trained on specific systems (detailed, area and equipment specific OJTs) given by the Area Leads based on BC's 'How-to-Guide'-s (HTGs)**
- **Continue to learn from, and cooperate with, other BC employees and EHS subject matter experts (SMEs) to work in the lab in a safe and efficient manner**
- **Become an authorized accelerator operator (EIC), based on demonstrated experience and training procedure**


BELLA

On-The-Job (Site-Specific) Training for the BELLA Center Laboratories CHECKLIST

User's signature

On-the-Job Trainer's name & signature

User's name & employee ID

Date

A) locate and explain site-specific properties and purpose of
- read and familiar with WPCS, room layout
- laser, safety goggles: selection and checking condition
- variety of shielding elements, beam blocks, beam dumps
- beam tubes
- irises, crosshairs
- mirrors, lenses, polarizers
- safety and control shutters
- mirrors, lenses: checking and blocking
- stray reflections: checking and blocking
- follow through all normal-operation beam-paths
- sending beams from room-to-room' protocol

B) demonstrate effects of various levels of laser light on
- fluorescent paper, white and black paper
- power meters, control of intensity levels
- burn papers, take a burn
- importance of plastic cover while taking burn
- noise effects of laser shots, signatures of damage, snap
- debris issues on crosshairs

C) other than laser hazards and their mitigation
- cleaning solvents (locations, sinks, protocols), PW Amp2&3 coolant
- high voltages (lamps, capacitors, Pockels-cells), QEW work-definition
- magnets
- vacuum pumps
- radiation safety
- fire extinguishers
- first aid kit
- stop work policy (unplanned events, new hazards)
- emergency shutdown
- contact persons, ways of reaching them

D) housekeeping standards, cleanliness issues
- booties, coats, hairnets, face masks, gowning protocol
- gowning area as buffer zone, no card board boxes
- green buttons for exit, 30 sec and flashing rule
- optics cleaning protocol
- handling and location of optics, filters, foils
- 'no-tear-only-cut' and 'no-speak-above-optics' policies
- vacuum tools, applicable materials in vacuum chambers
- toolboxes, building components
- equipment/parts borrowing etiquette
- logbook writing habits
- laser and vacuum system operation logs
- control systems, GoogleDoc and 'Server' basics
- location of safety and training documentation
- responsibility for visitors' protection, perception issues

Form: BOP-12-Appx-1 - last updated 9/29/2017

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