The Berkeley Lab Laser Accelerator (BELLA): Commissioning and Safety Systems of a PW-class, 1 Hz Laser

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LOASIS/BELLA Program, LBNL, Berkeley, CA

LSO Workshop 2014, Livermore, CA, USA
Aug 19, 2014

Outline

- Laser Plasma Accelerators (LPA) at LOASIS & BELLA

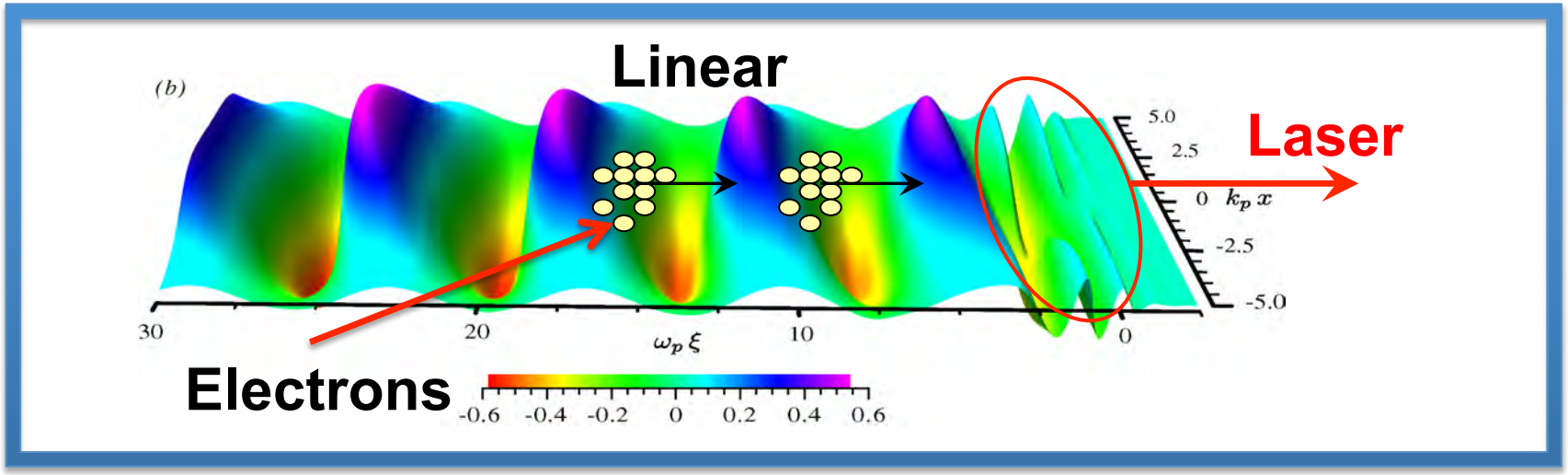
- BELLA Laser – Design and Key Parameters

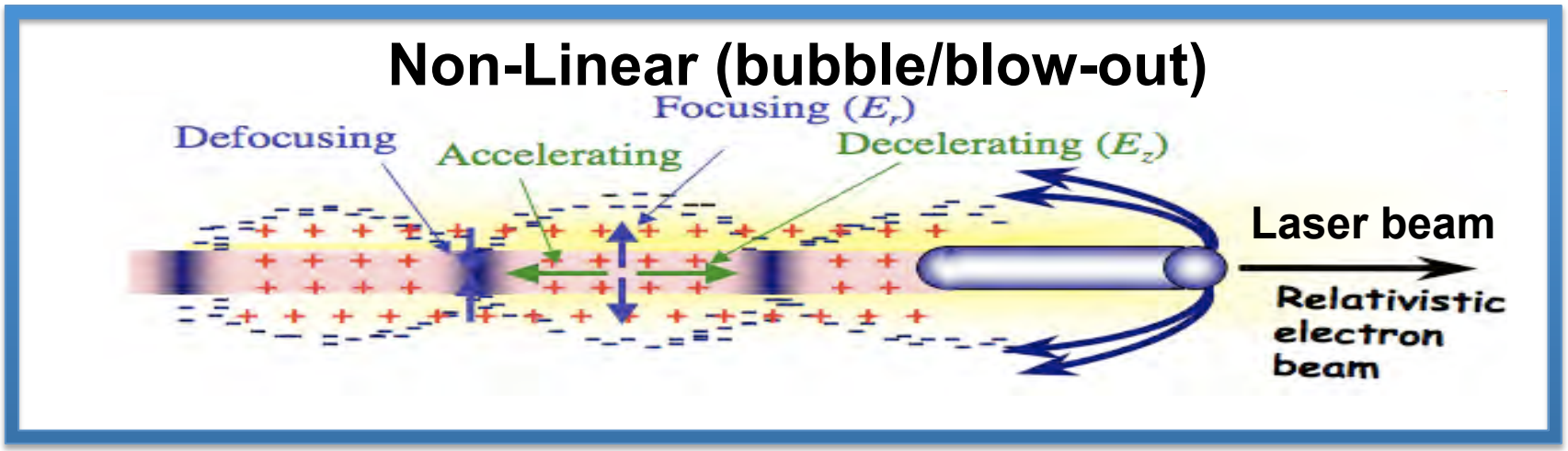
- Safety Systems and Commissioning

- Current Operations and Outlook

Principle of Laser-Plasma Accelerators

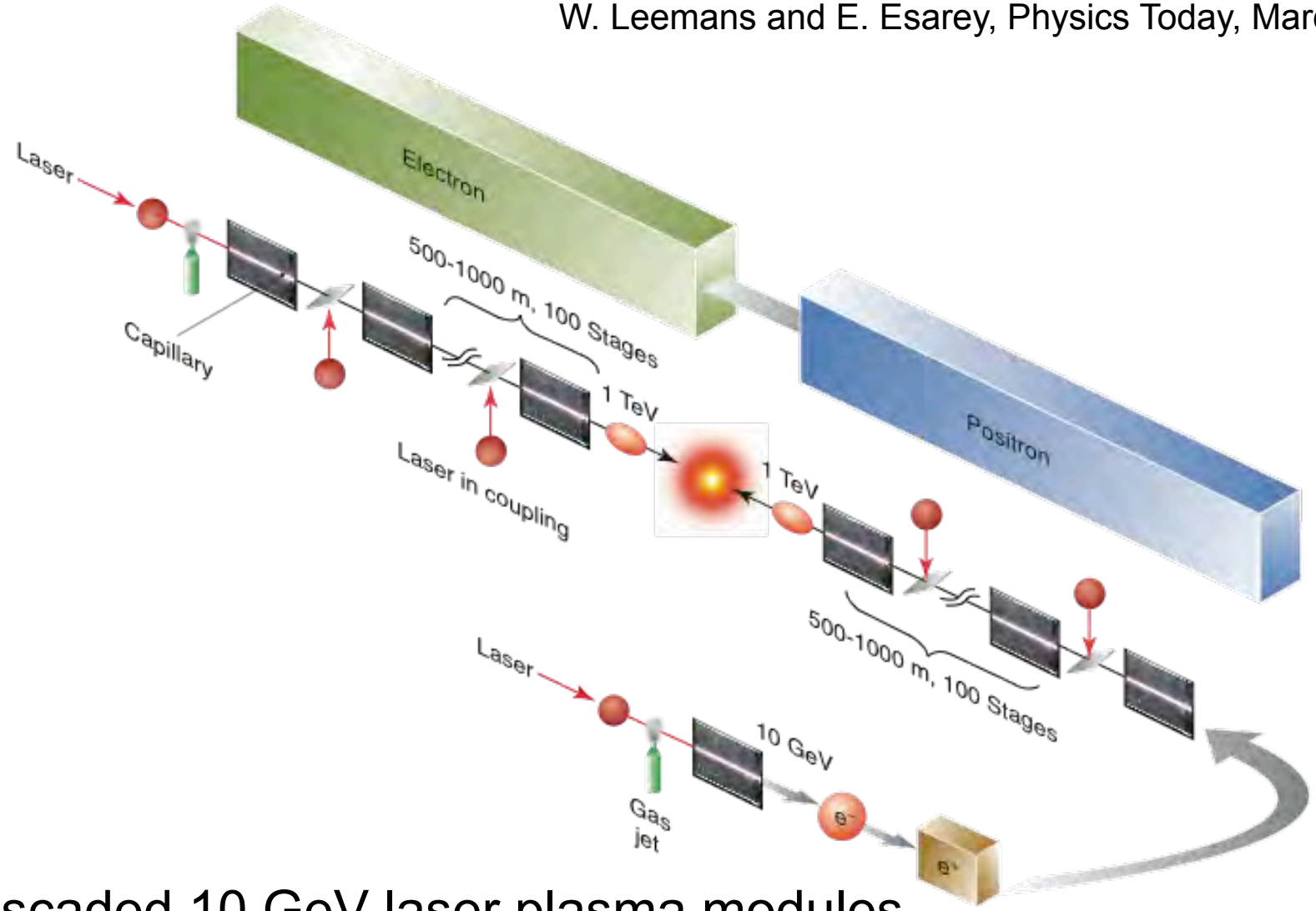
- E-fields: 10 – 100 GV/m => compact accelerators





Laser Plasma Accelerator Concept for a Laser Plasma Based Linear Collider

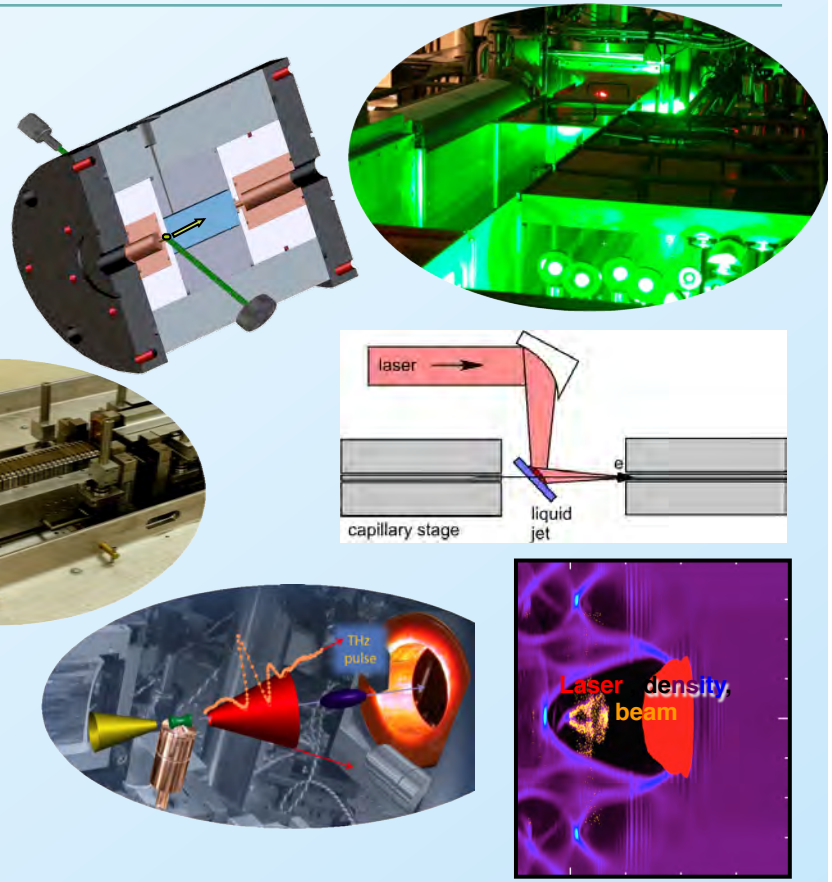
W. Leemans and E. Esarey, Physics Today, March 2009



- Cascaded 10 GeV laser plasma modules

BELLA = BErkeley Lab Laser Accelerator

- BELLA Project:
  - 1 PW, 1 Hz laser system and facility to house it in
- Laser Plasma Accelerator (LPA) R&D:
  - Diagnostics
  - Staged Accelerators
  - 10 GeV
  - Simulations



LOASIS Program – TREX/Godzilla/Chihuahua

BELLA Project - PW laser

plus BELLA

FY08 FY09 2010 2011 2012 2013 ----------2018

YEARS

Outline

- Laser Plasma Accelerators (LPA) at LOASIS & BELLA
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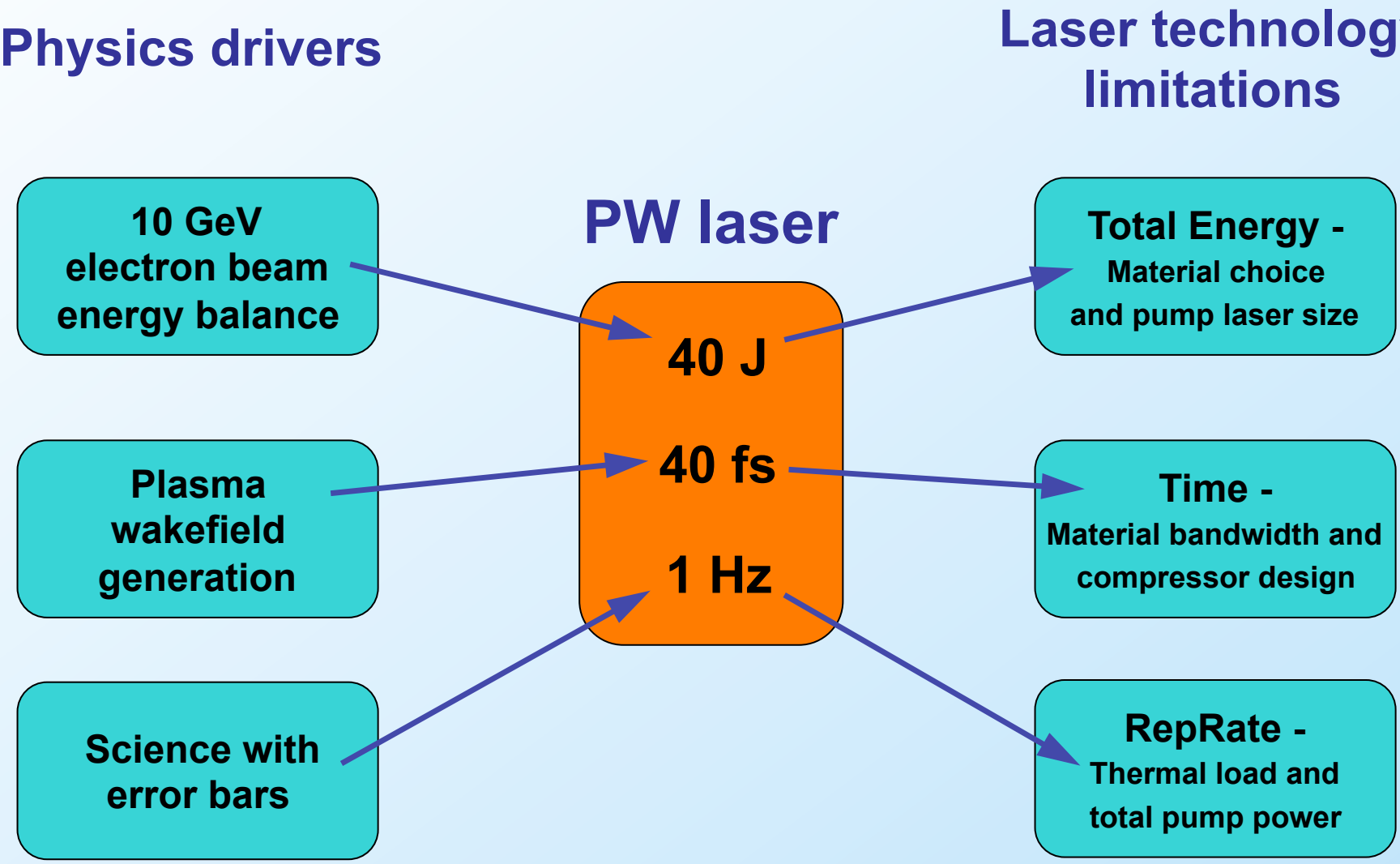
BELLA Laser Specification determined by 10 GeV needs and technology limitations



BELLA Project

- 1 PW, 1 Hz Laser System (40 J, 40 fs on target)
  - Laser specs determined based on physics and LOASIS expertise
  - Laser procurement from commercial vendor
  - Laser system commissioning and validation
- Ancillary systems:
  - Diagnostics to verify CD-4 goals
- Conventional Facilities
  - New clean room for laser bay
  - New radiation shielded area
  - New control room
- Site and Systems integration
  - Ensuring conventional facility is ready and works together with laser and ancillary systems

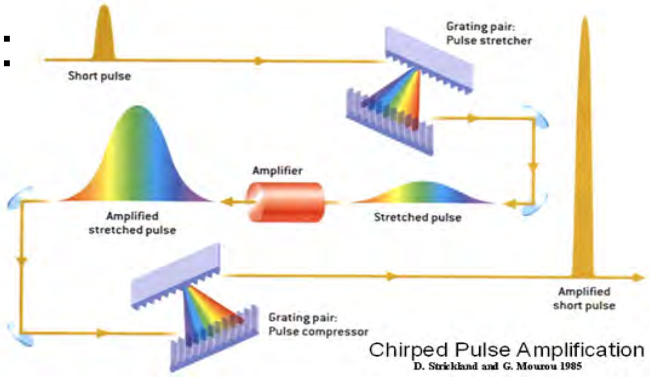
PW Laser System Architecture

- Seed oscillator → multiple booster amplifier stages

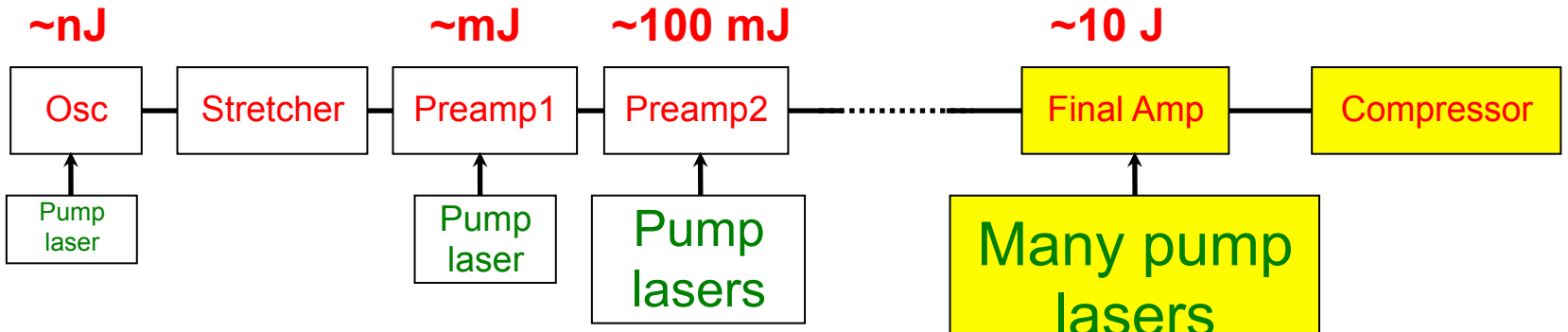
  To avoid optical damage during amplification:

  expansion → amplification → compression

  both in space and time



- Ti:sapphire active material - **800 nm**
- Pumped with SHG of Nd:YAG lasers - **532 nm**



Delivered operating commercial systems up to 200 TW

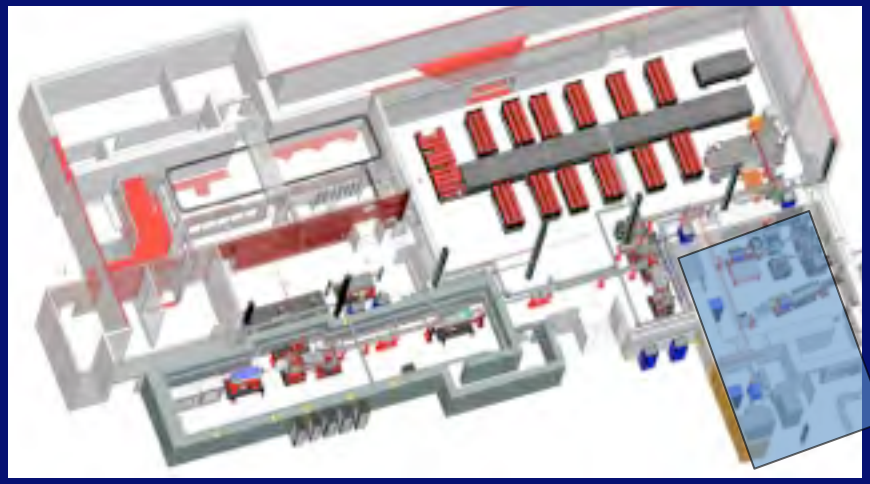
High energy components here

BELLA PW Laser - Baseline Parameters

SPECIFICATIONS	VALUE	NOTES
MAIN DESIGN GOAL PARAMETERS		
Wavelength	820 ± 20 nm	Typical Ti:sapphire wavelength
Spectral bandwidth	>40 nm FWHM	Needed to support final compression < 40 fs
Energy on target	>40 J	To reach 10 GeV in plasma accelerator
Pulse duration	<40 fs FWHM	Needed to reach peak intensity and provide flexibility for chirped pulse and 40-400 fs parameter studies
Repetition rate	1 Hz	Needed to scan multidimensional parameter space
Peak power	>1 PW	Simulation and theory predict: PW range needed to reach 10 GeV in plasma accelerator
CONTRAST AND STATISTICS		
Contrast at 1 ns and at 5 ps	$>10^{10}$, $>10^{6}$	Needed for prepulse-free experiments at high peak power
Pointing stability	< 2.5 μrad rms	Plasma interactions in capillary are sensitive to pointing
M^2 of focused beam	<1.3	Laser beam quality determines e-beam quality
Focus size fluctuation	2.5% rms on a 80 μm spot	Determines peak intensity and plasma wake parameters
Pulse duration fluctuation	<5%	Determines peak intensity and plasma wake parameters
Pulse energy fluctuation	<2.5%	Determines peak intensity and plasma wake parameters

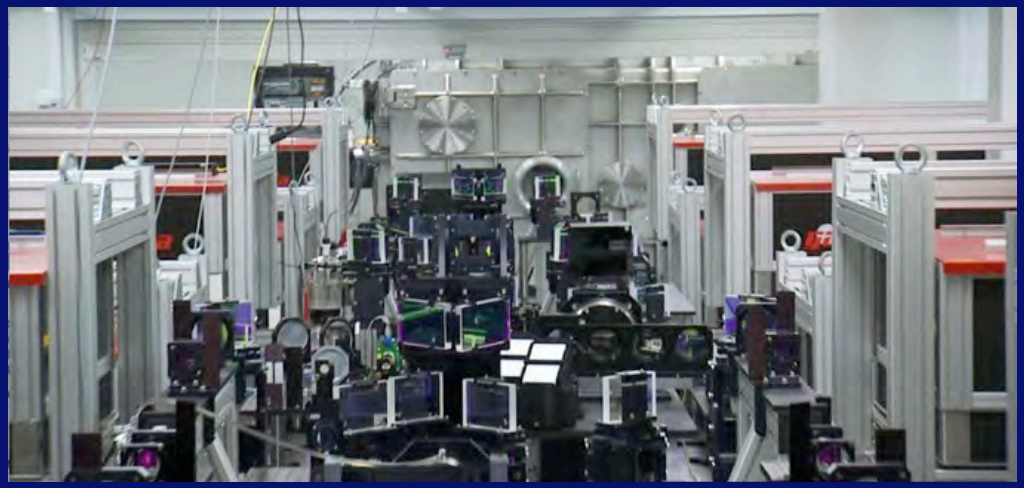
BELLA project is organized into four main areas

Conventional facilities



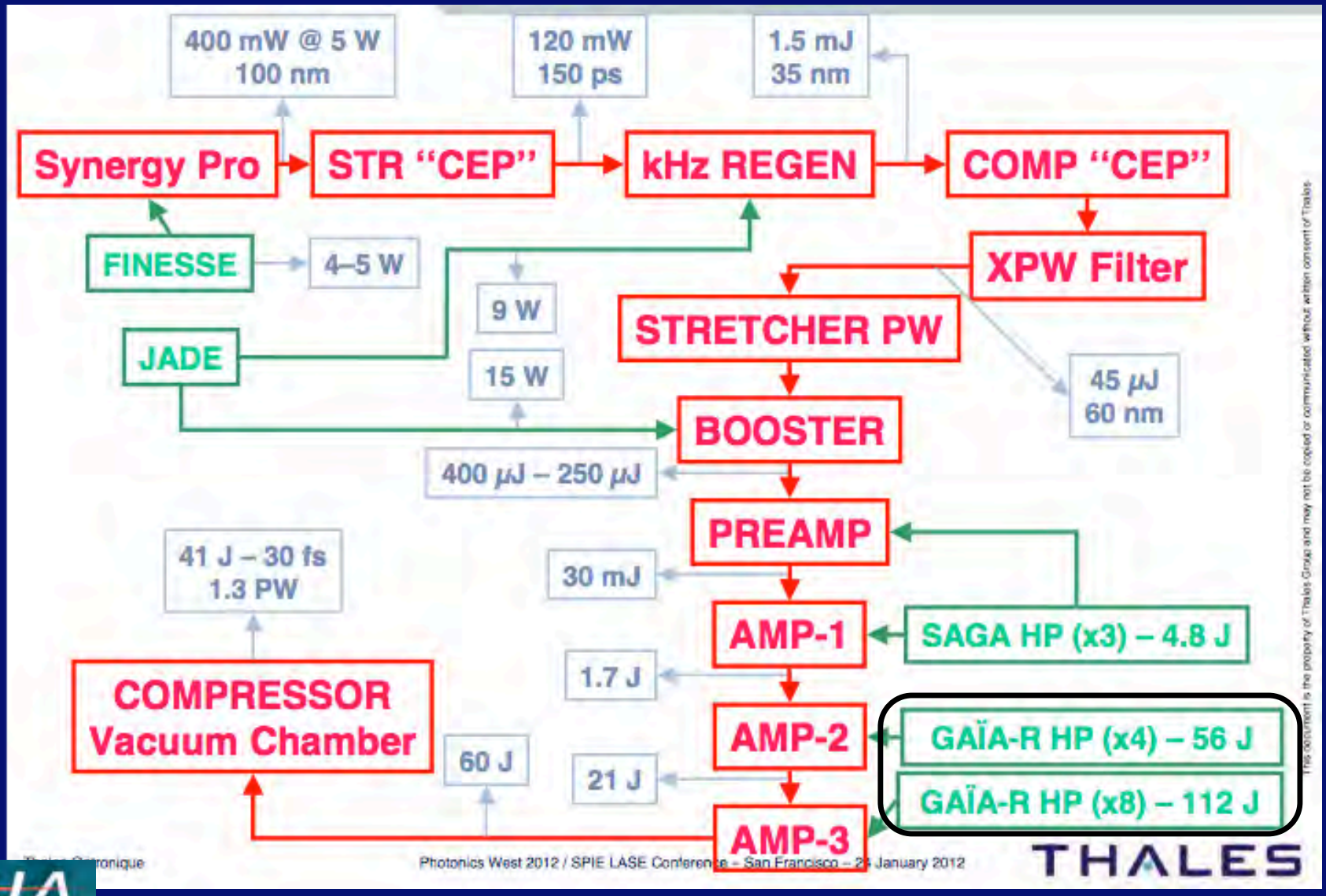
Ancillary systems

Laser system



Site & system integration

BELLA follows classic master oscillator-power amplifier design but required new generation of pump lasers at 1 Hz



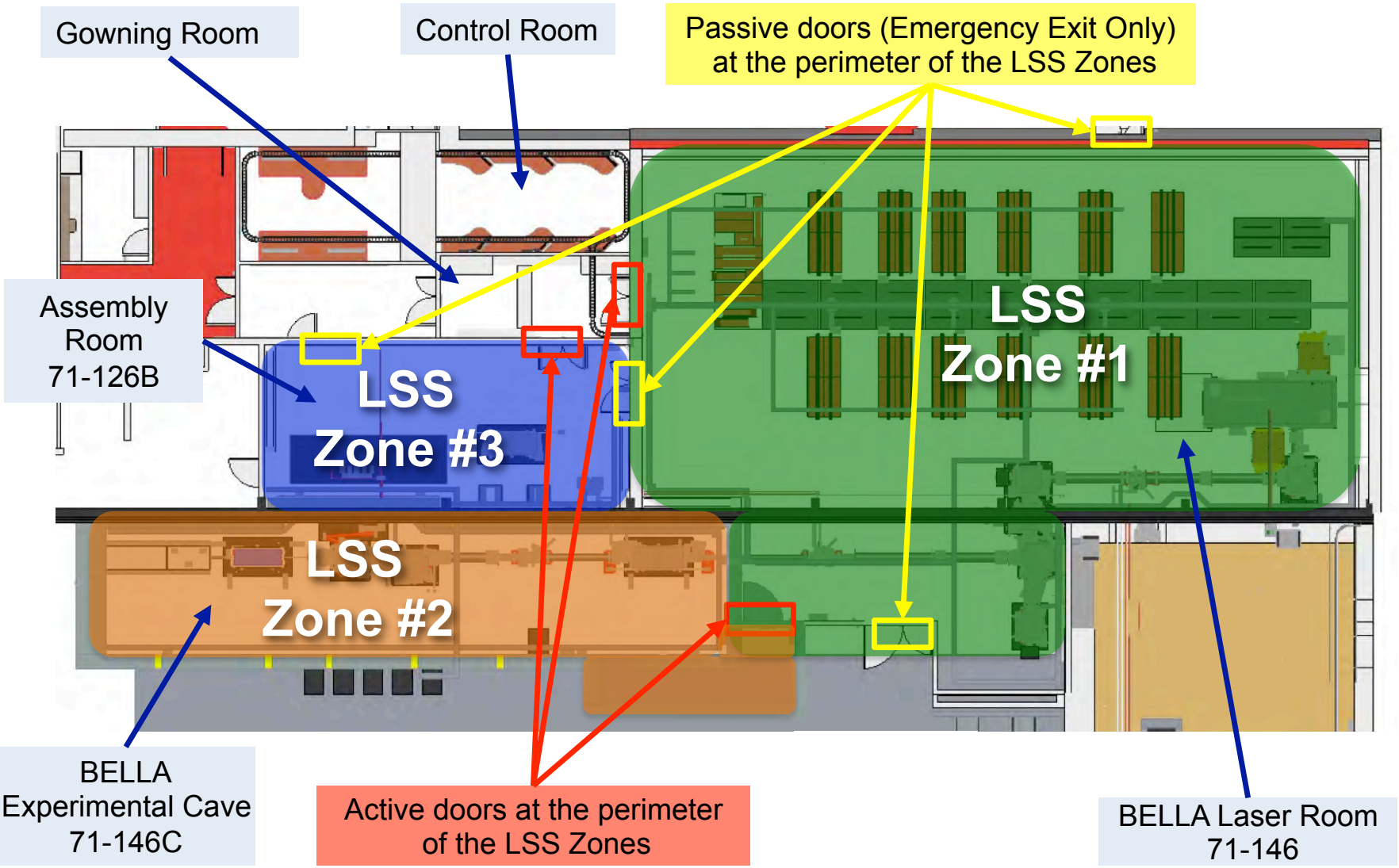
All laser system hardware was built by THALES and first installed at THALES factory

BELLA system at LBNL

Outline

- Laser Plasma Accelerators (LPA) at LOASIS & BELLA
- BELLA Laser – Design and Key Parameters
- **Safety Systems and Commissioning**
- Current Operations and Outlook

BELLA Laser Interlock Zone Layout for AHD

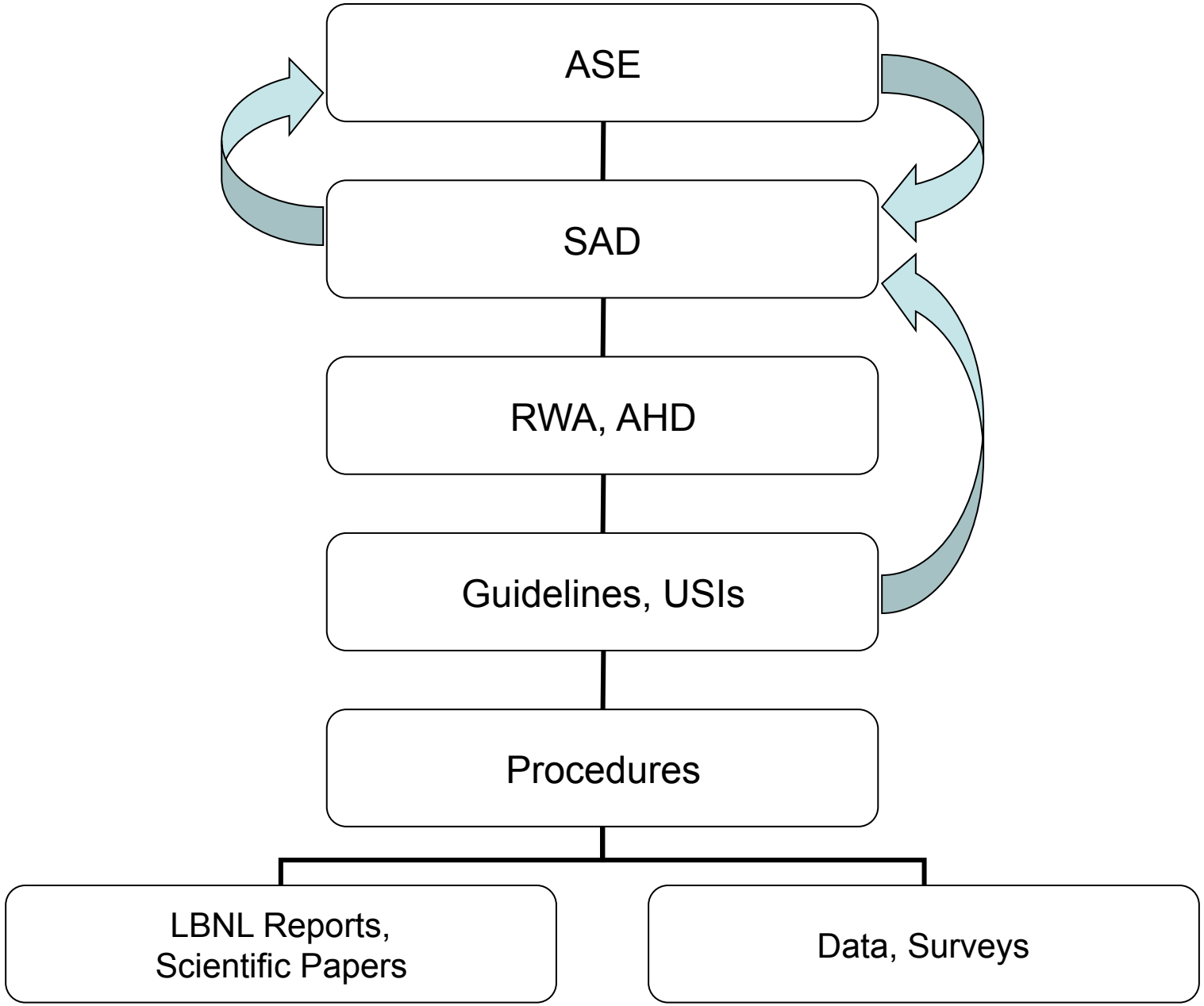


The LOASIS/BELLA LPA facility traditionally equipped with comprehensive rad shielding and monitoring systems

- **Radiation shielding** designed to protect workers and environment during exploratory research -> combined with continuous 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)
- "Parasitic" **activation measurements** help to understand e-beam properties outside of the normal observation areas of the dedicated diagnostic devices: e-beam magnetic spectrometer, beam positioning monitors (BPMs), phosphor screens, betatron- and THz-emission detectors, etc.)

*W.P. Leemans et al., Phys. Plasmas **8**, 2510-2516 (2001)*

Safety Documents at the BELLA

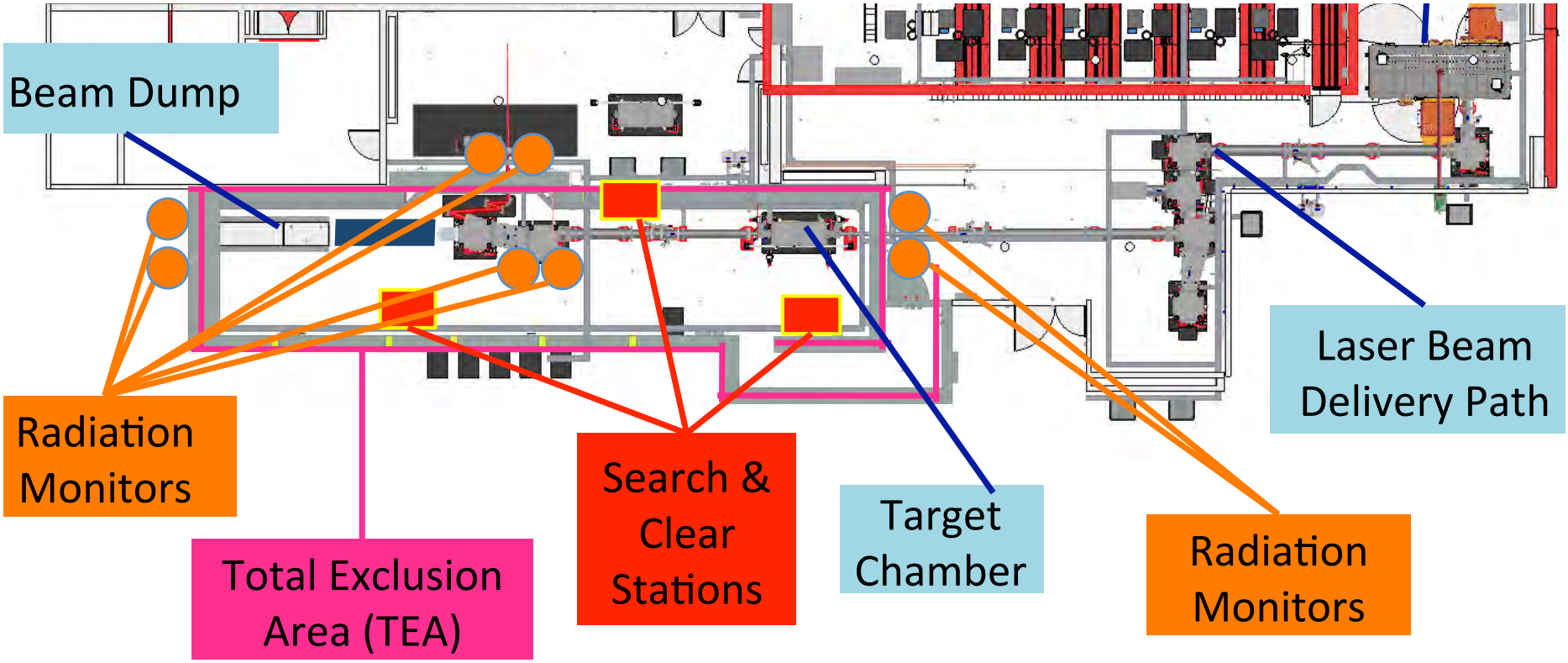


DOE Order 420.2C

OBJECTIVE: To establish accelerator-specific safety requirements which, when supplemented by other applicable safety and health requirements, will serve to prevent injuries and illnesses associated with Department of Energy (DOE) or National Nuclear Security Administration (NNSA) accelerator operations.

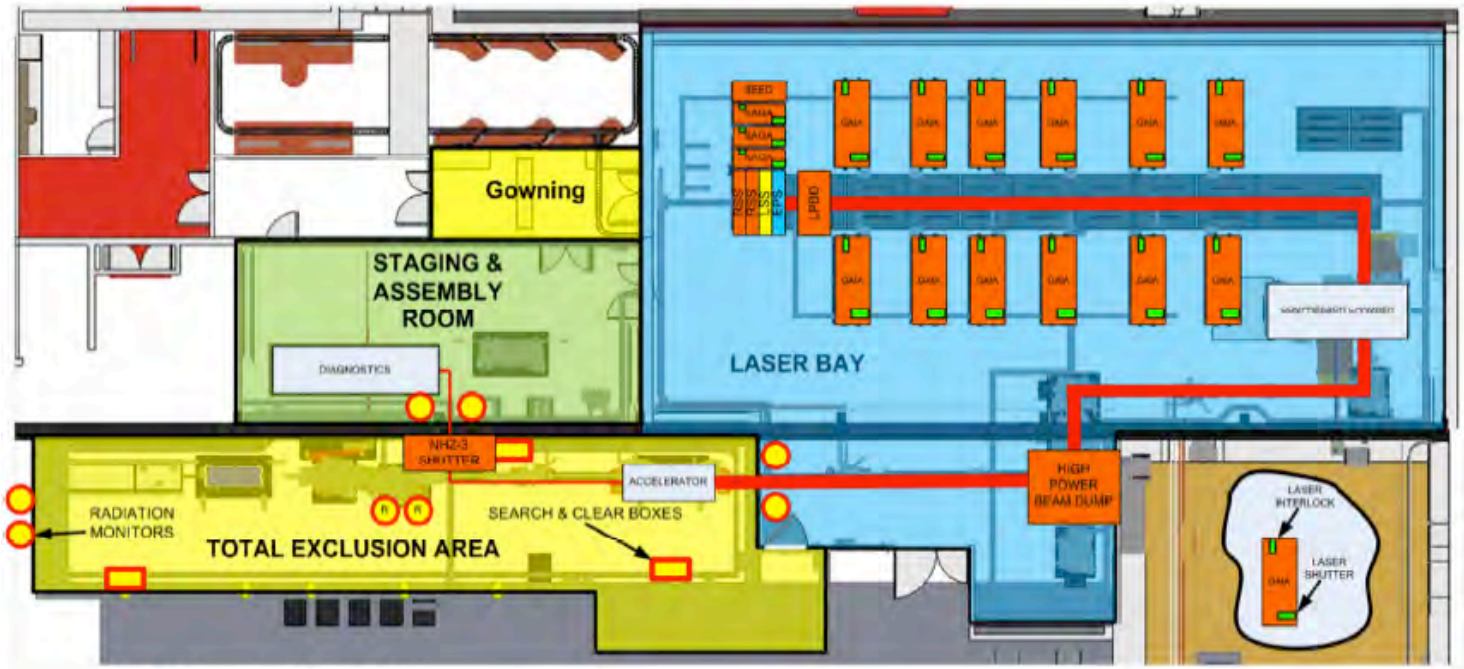
- Requirements
  - Safety Assessment Document (SAD)
  - Accelerator Safety Envelope (ASE)
  - Accelerator Readiness Reviews (ARRs)
  - Training and Qualification requirements
  - Written Procedures
  - Internal Safety Review System
  - Shielding Policy

Beam Line Design and Radiation Shielding



Personal Protection System (LSS & RSS)

- PPS is a redundant interlock system that prevents entering TEA when beam is delivered
- Consists of: Interlock access door position sensing devices, key control panels, the relay logic devices and the diagnostics displays associated with each component of the PPS safety systems.
- If one or any component fails the interlock system will disable the laser plasma accelerator system

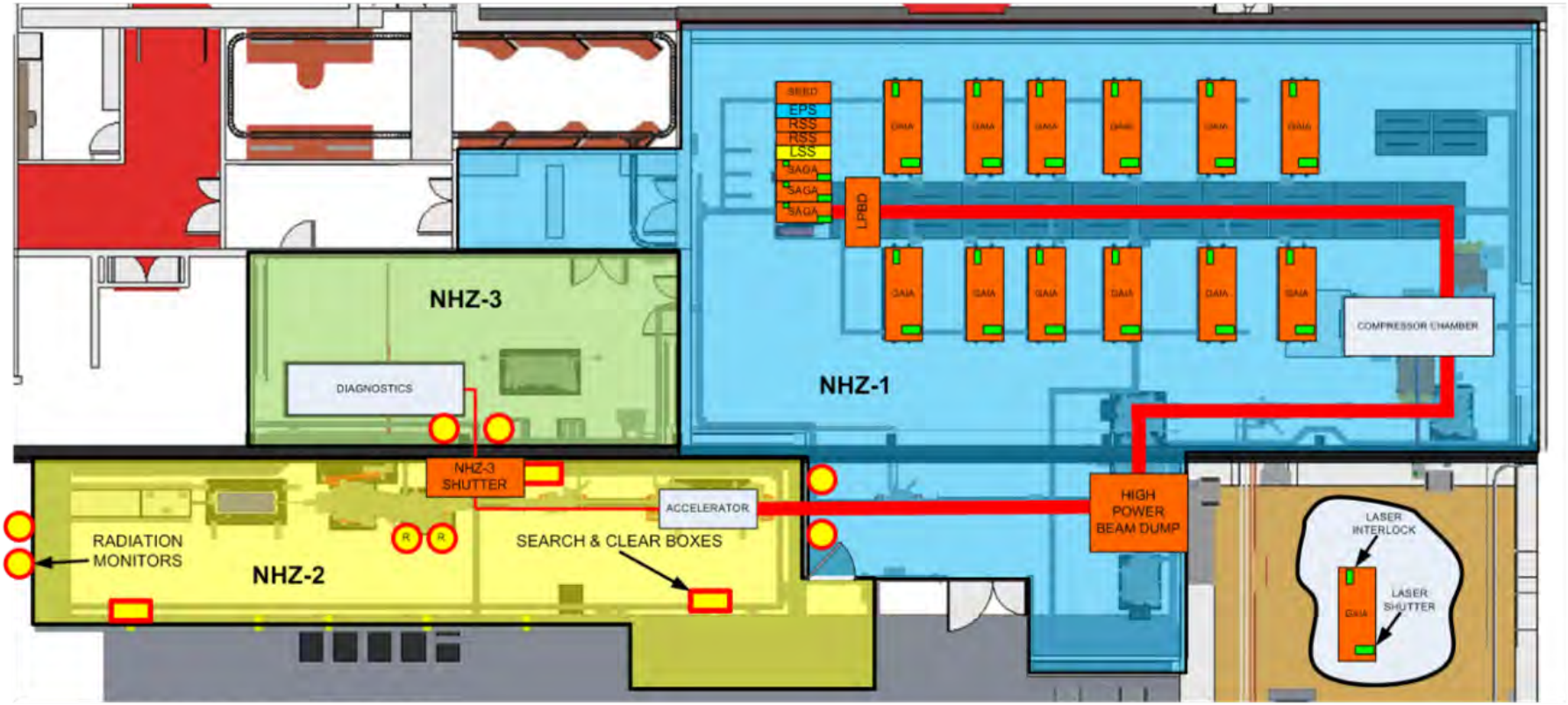


PPS Accelerator Readiness Review

- The BELLA PPS is an interlock system that integrates the laser interlocks and radiological interlocks in one logic controller.
  - Laser Safety System
  - Radiation Safety System
- The requirement for the PPS was developed by LBNL
- The interlock system was designed by DSI based on the LOASIS interlock system that they previously designed

PPS → LSS

- The LSS is divided into 3 Nominal Hazard Zones (NHZ)
- Each zone has specific requirements for allowing laser operation within the zone.



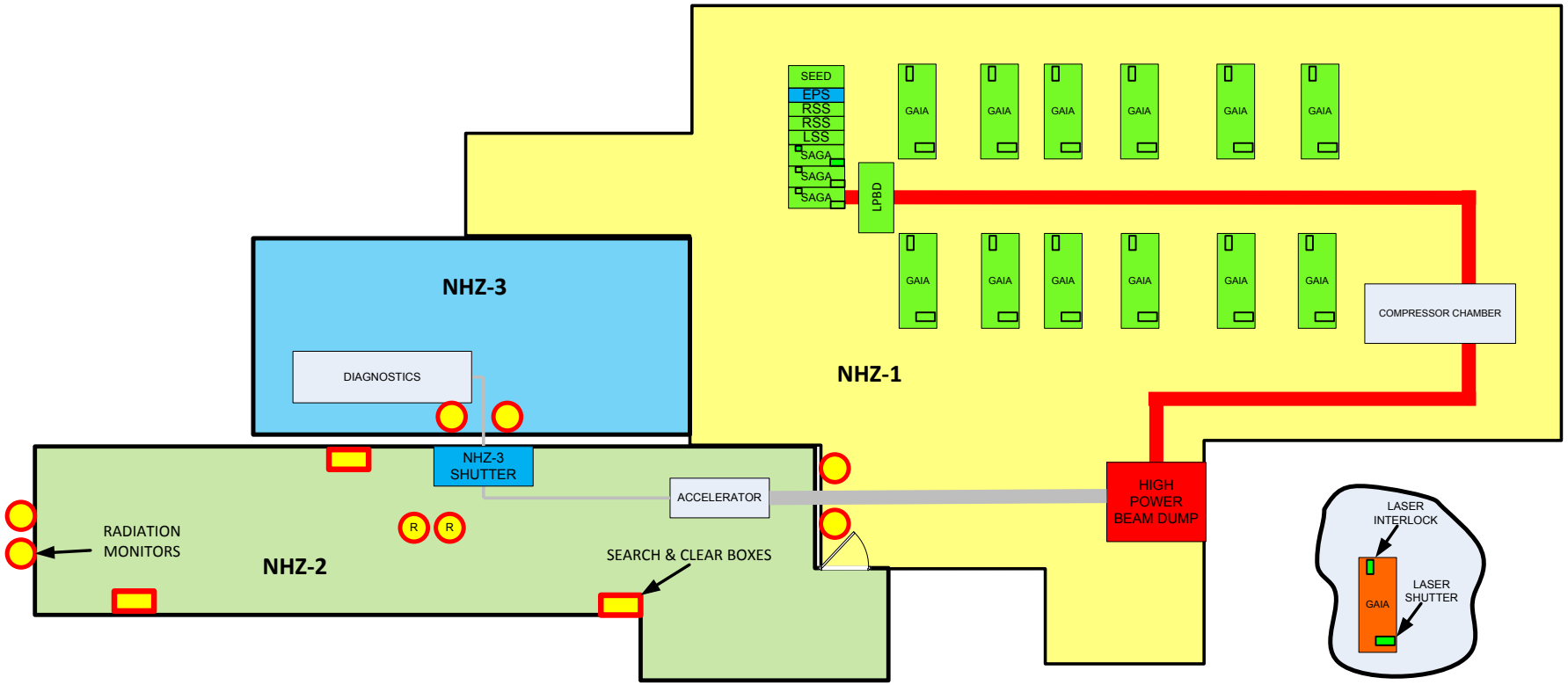
The Radiation Monitors marked "R" are on the Roof.

PPS → RSS

- **Five modes of operation**
  - Safe Mode
  - Diagnostic Mode
  - Alignment Mode
  - High-E Mode
  - Crash (Emergency Off State)

Safe Mode

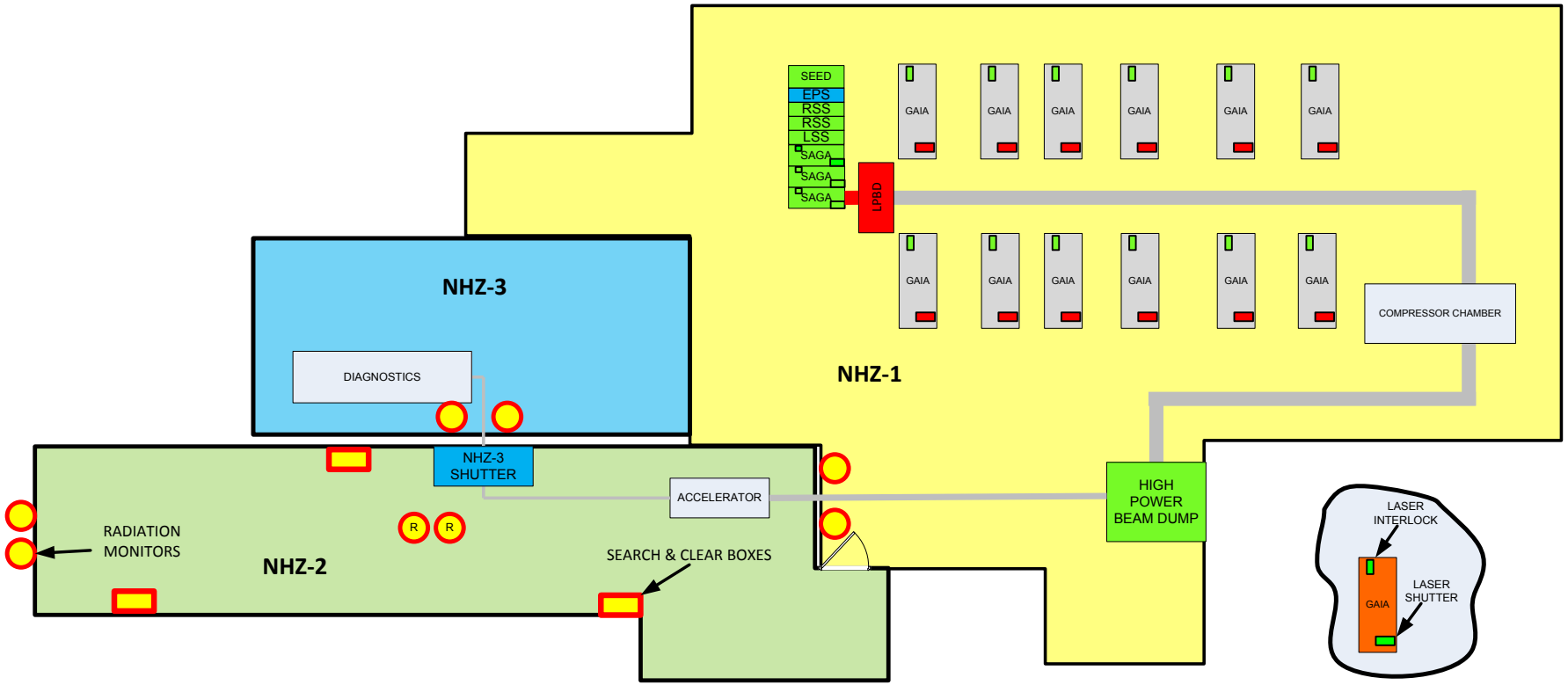
- High Power Beam Dump closed



The Radiation Monitors marked "R" are on the Roof.

Diagnostic Mode

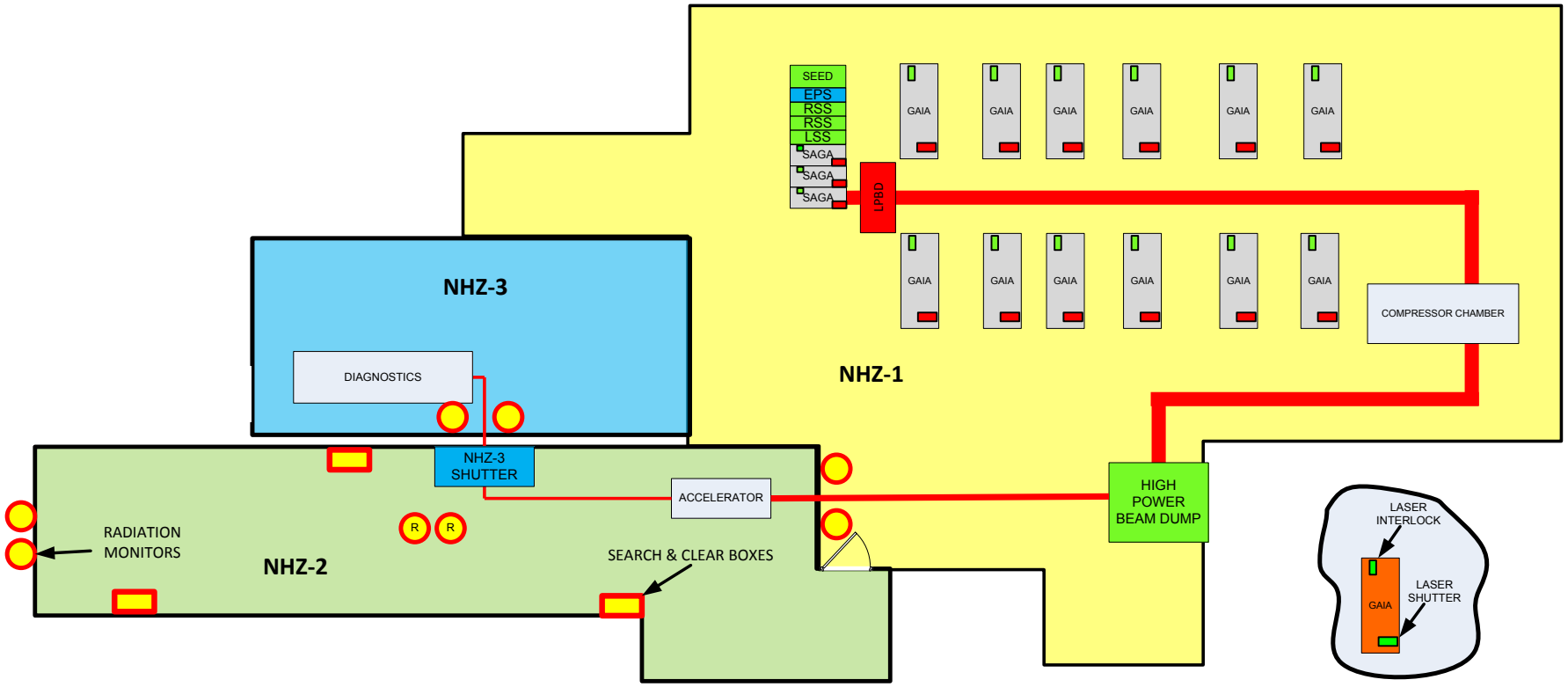
- Low Power Beam Dump closed



The Radiation Monitors marked "R" are on the Roof.

Alignment Mode

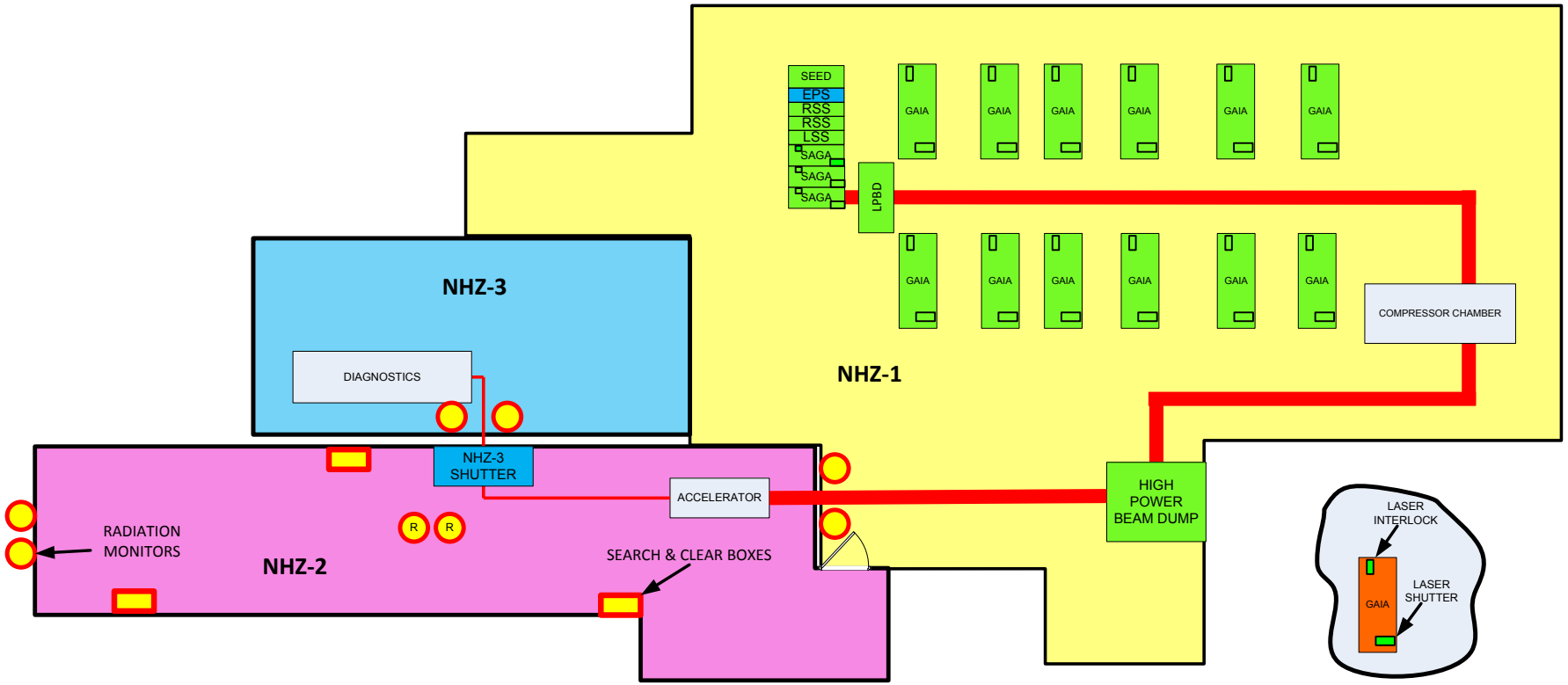
- SAGA and GAIA laser shutters closed



The Radiation Monitors marked "R" are on the Roof.

High-E Mode

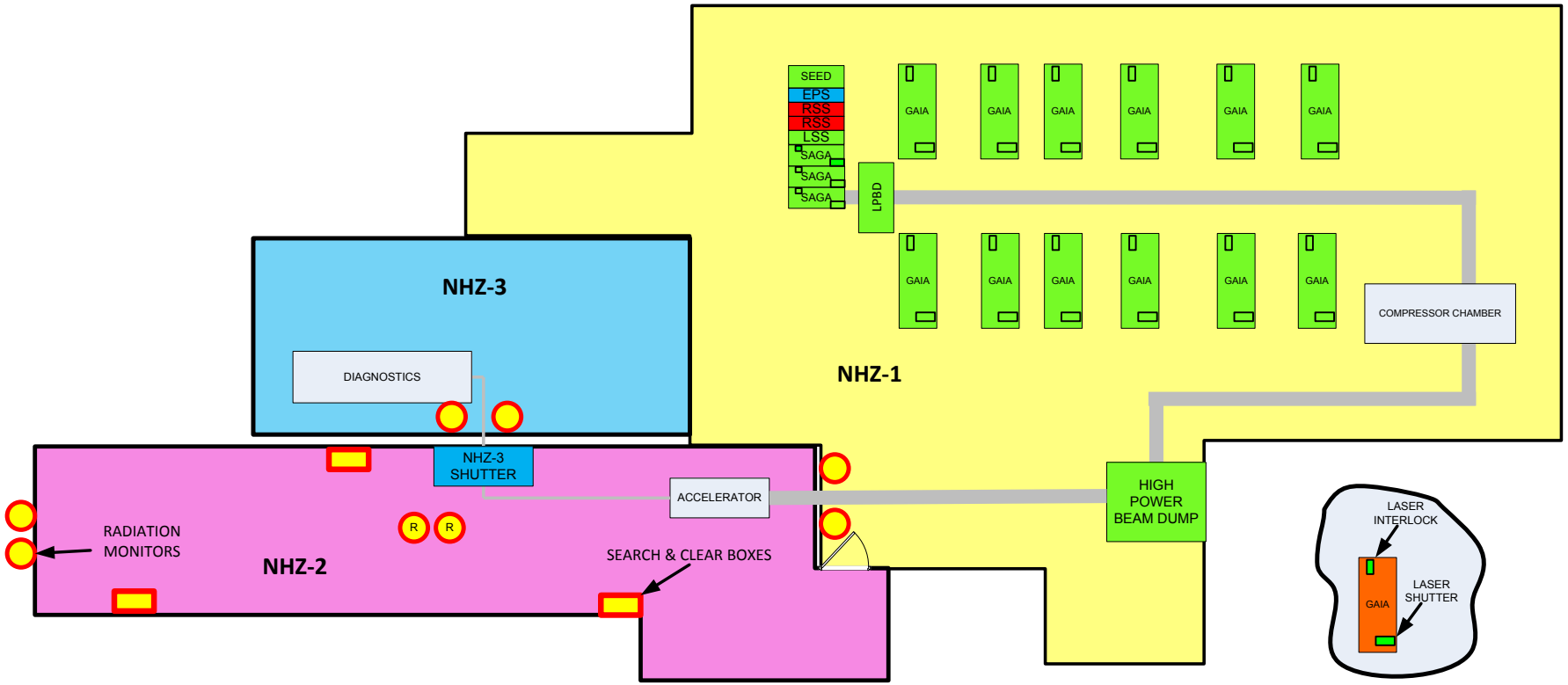
- Enclosure Searched & Secure for operation



The Radiation Monitors marked "R" are on the Roof.

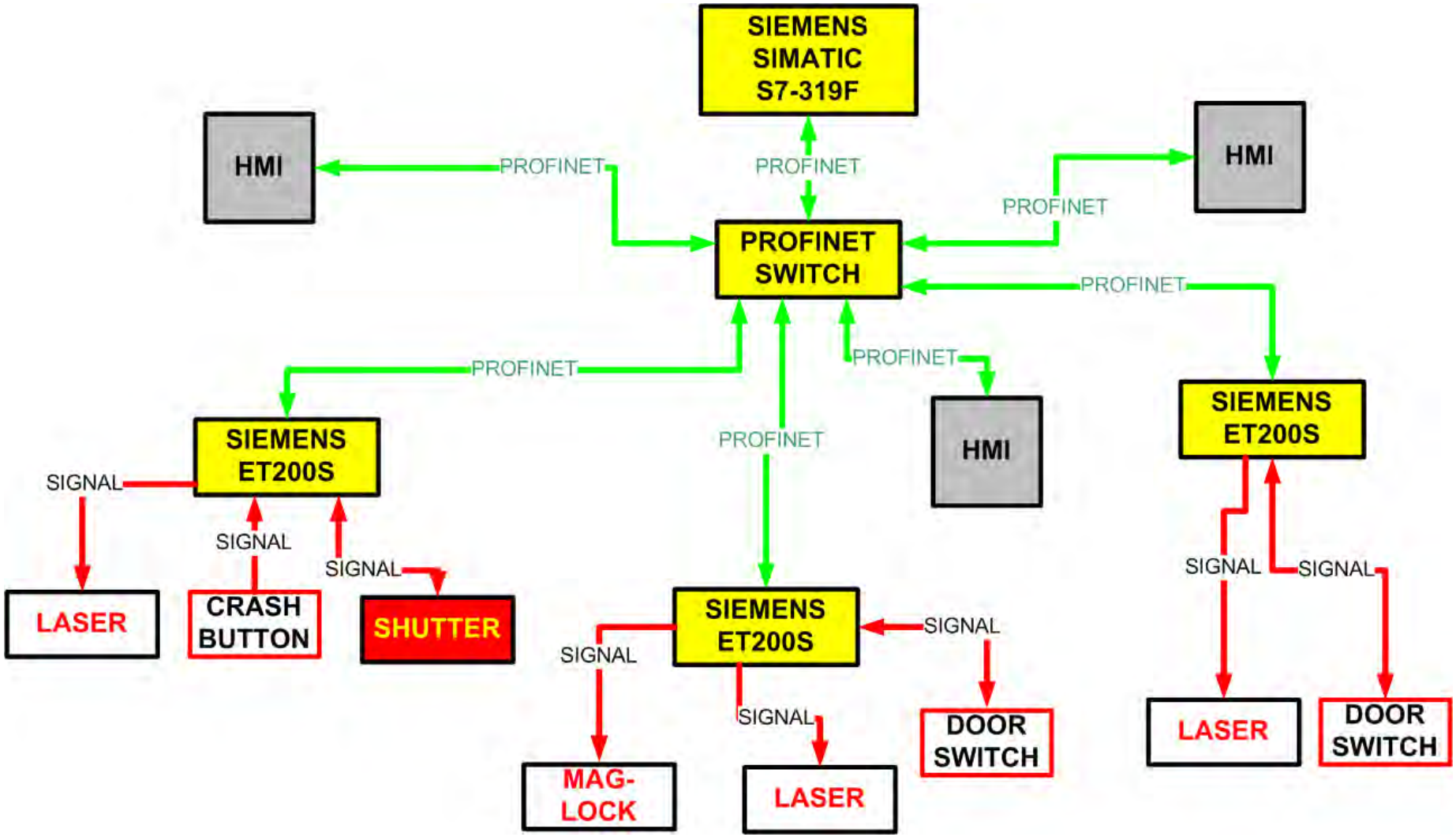
Radiation Monitor Fault

- Redundant RSS shutters closed



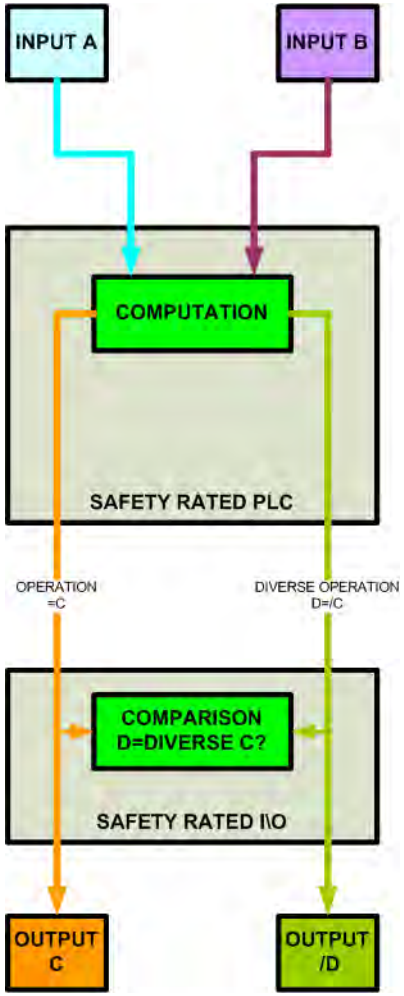
The Radiation Monitors marked "R" are on the Roof.

LSS CONCEPT DIAGRAM



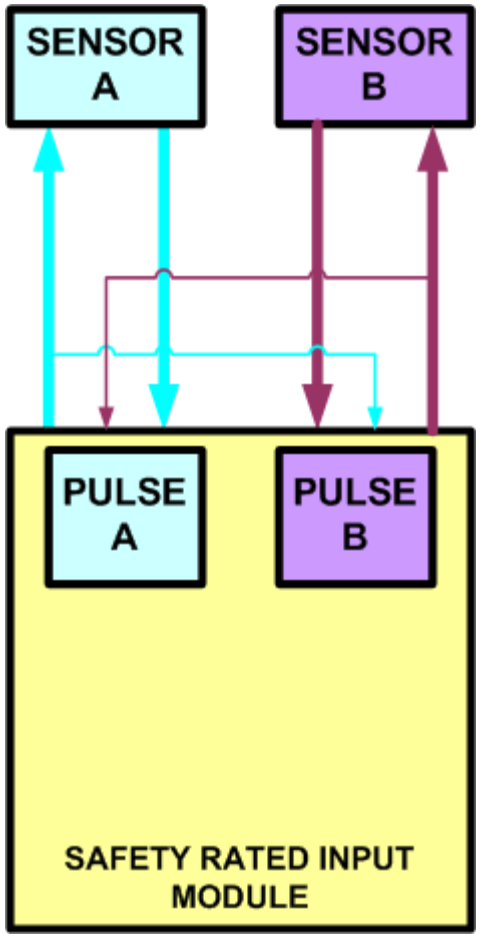
DETERMINISM OF PLC SYSTEM

- Inputs A, B entered as operators
- Computation of the operation resultant, failsafe CPU calculates diverse operation resultant
- Safety rated output module has own CPU that checks diverse operation resultant against the original operation resultant
- Check good = operation executed



DETERMINISM OF I/O

- Failsafe I/O modules detect:
  - Open/broken wire connection
  - Crossed wire connection
  - Shorted/grounded wire
- Fails safe in the event of loss of connection to PLC
- Input A monitors Input B to determine wire crosses or shorts
- Input A pulses supply to sensor, expecting response on return



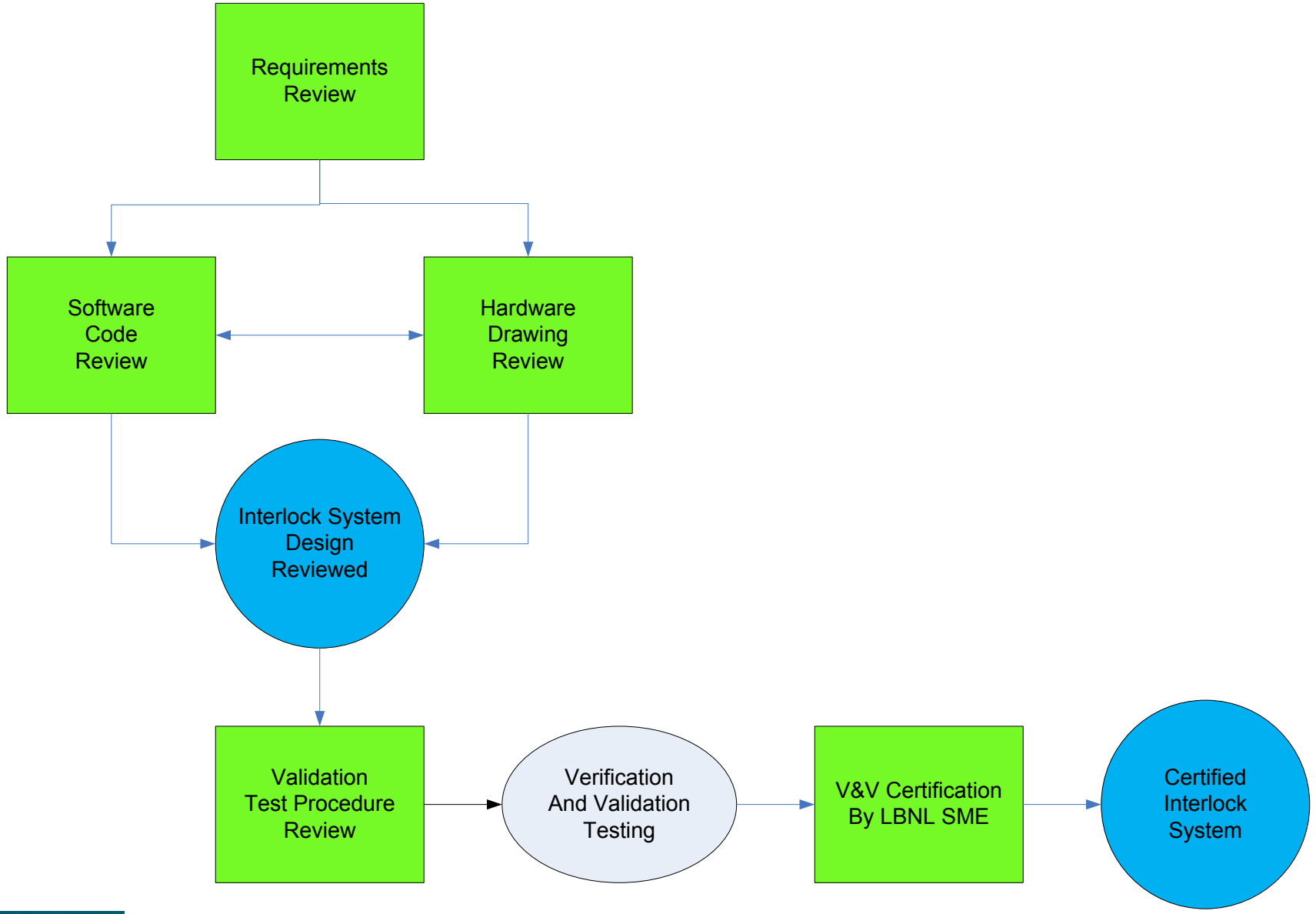
LSS USER INTERFACES

- Based on Siemens touch screen HMI
- Located in each LSS Laser Zone
- Give operator control of laser permission for that zone
- Gives status of other laser zones

Targeted Review Process

- The PPS was reviewed in a targeted approach
- The purpose of a targeted review process is to increase the number of hours spent analyzing a system by breaking the system into manageable study elements
- The reviews were parsed to provide a targeted study of each of the PPS elements
  - Requirements
  - Software
  - Hardware
  - Quality Assurance testing
- Each review was staffed with a small group of highly qualified personnel

Review Cycle



Certification

- DSI performs the Verification & Validation testing of the interlock system.
- The LBNL Interlock SME compares the completed V&V procedures against the requirements document to certify that the system was tested to perform as specified by the requirements.
  - 140 page procedure
  - 120 hour effort to certify

SAD/ASE Review Conclusions

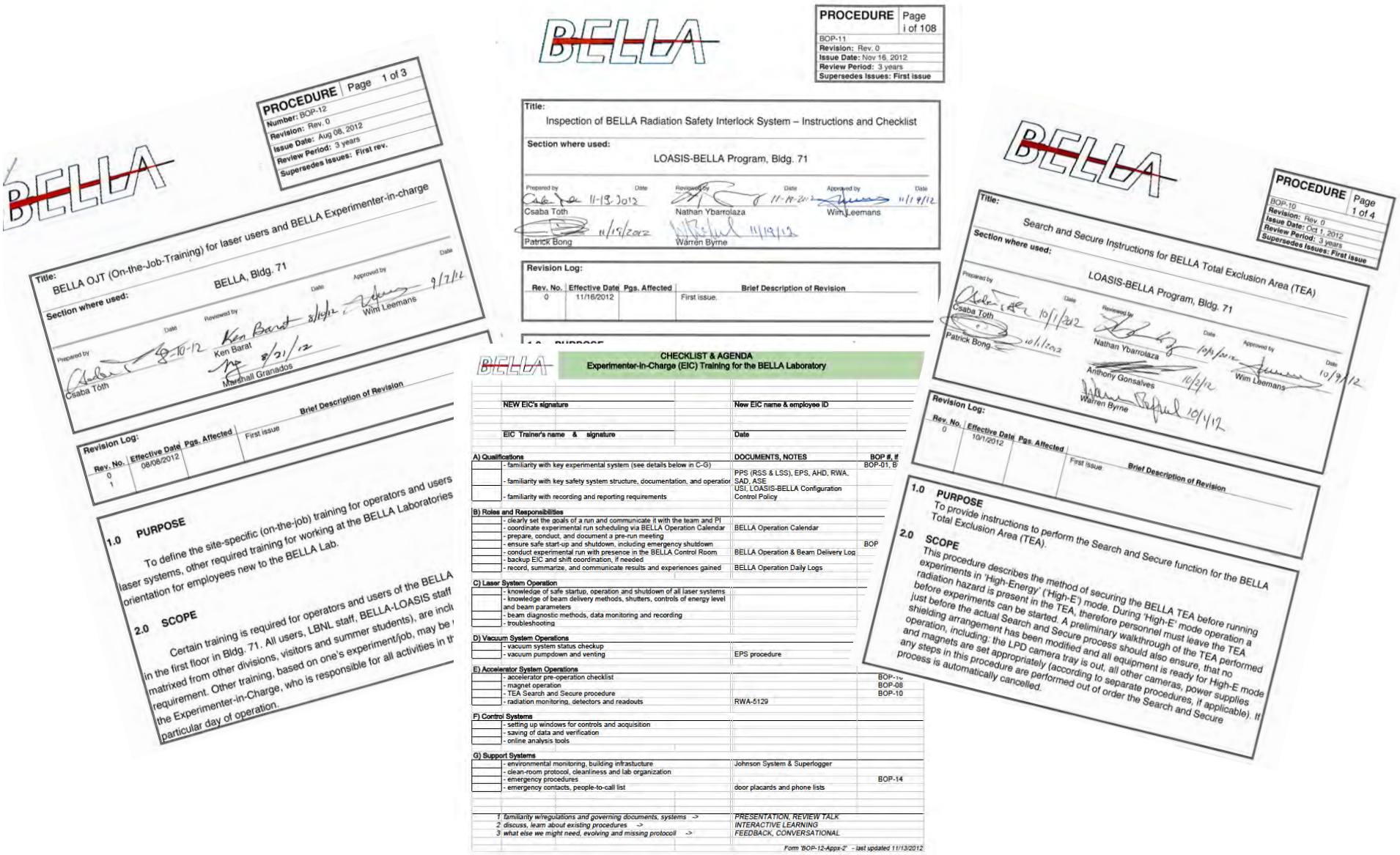
- Organization of the SAD conforms to the DOE O 420.2C
- Five Credited Controls have been evoked
- A thorough hazard analysis has been conducted
- ASE developed based on BELLA SAD, ARR Plan in place
- The BELLA interlocks are designed to comply with LBNL contract requirements:
  - 10 CFR 835, DOE o 420.2C
  - ANSI N43.2-2001, ANSI N43.3-2008, ANSI Z136.1-2007
  - NFPA 101

The operation of the BELLA does not compromise the safety of employees, the general public or the environment

Outline

- Laser Plasma Accelerators (LPA) at LOASIS & BELLA
- BELLA Laser – Design and Key Parameters
- Safety Systems and Commissioning
- Current Operations and Outlook

BELLA Procedures Control OJT, Interlock Testing and Search & Clear Protocol



PROCEDURE | Page 1 of 3
Number: BOP-12
Revision: Rev. 0
Issue Date: Aug 08, 2012
Review Period: 3 years
Supersedes Issues: First rev.

Title: BELLA OJT (On-the-Job-Training) for laser users and BELLA Experimenter-in-charge
Section where used: BELLA, Bldg. 71
Prepared by: Csaba Toth 8-10-12
Reviewed by: Ken Barat 8/10/12; Marshall Granados 8/21/12
Approved by: Wim Leemans 9/7/12

Revision Log:

Rev. No.	Effective Date	Pgs. Affected	Brief Description of Revision
0	08/06/2012		First issue
1			

1.0 PURPOSE

To define the site-specific (on-the-job) training for operators and users laser systems, other required training for working at the BELLA Laboratories orientation for employees new to the BELLA Lab.

2.0 SCOPE

Certain training is required for operators and users of the BELLA in the first floor in Bldg. 71. All users, LBNL staff, BELLA-LOASIS staff matrixed from other divisions, visitors and summer students), are incl requirement. Other training, based on one's experiment/job, may be the Experimenter-in-Charge, who is responsible for all activities in th particular day of operation.

PROCEDURE | Page i of 108
BOP-11
Revision: Rev. 0
Issue Date: Nov 16, 2012
Review Period: 3 years
Supersedes Issues: First issue

Title: Inspection of BELLA Radiation Safety Interlock System – Instructions and Checklist
Section where used: LOASIS-BELLA Program, Bldg. 71
Prepared by: Csaba Toth 11-19-2012
Reviewed by: Nathan Ybarrolaza 11-19-2012
Approved by: Wim Leemans 11/19/12
Patrick Bong 11/19/2012
Warren Byrne 11/19/12

Revision Log:

Rev. No.	Effective Date	Pgs. Affected	Brief Description of Revision
0	11/16/2012		First issue.

CHECKLIST & AGENDA
Experimenter-in-Charge (EIC) Training for the BELLA Laboratory

NEW EIC's signature | New EIC name & employee ID
EIC Trainer's name & signature | Date

		DOCUMENTS, NOTES	BOP #, if
A) Qualifications			
	- familiarity with key experimental system (see details below in C-G)		BOP-01, B
	- familiarity with key safety system structure, documentation, and operation	PPS (RSS & LSS), EPS, AHD, RWA, SAD, ASE	
	- familiarity with recording and reporting requirements	USI, LOASIS-BELLA Configuration Control Policy	
B) Roles and Responsibilities			
	- clearly set the goals of a run and communicate it with the team and PI		
	- coordinate experimental run scheduling via BELLA Operation Calendar	BELLA Operation Calendar	
	- prepare, conduct, and document a pre-run meeting		
	- ensure safe start-up and shutdown, including emergency shutdown		BOP
	- conduct experimental run with presence in the BELLA Control Room	BELLA Operation & Beam Delivery Log	
	- backup EIC and shift coordination, if needed		
	- record, summarize, and communicate results and experiences gained	BELLA Operation Daily Logs	
C) Laser System Operation			
	- knowledge of safe startup, operation and shutdown of all laser systems		
	- knowledge of beam delivery methods, shutters, controls of energy level and beam parameters		
	- beam diagnostic methods, data monitoring and recording		
	- troubleshooting		
D) Vacuum System Operations			
	- vacuum system status checkup		
	- vacuum pumpdown and venting	EPS procedure	
E) Accelerator System Operations			
	- accelerator pre-operation checklist		BOP-10
	- magnet operation		BOP-08
	- TEA Search and Secure procedure		BOP-10
	- radiation monitoring, detectors and readouts	RWA-5129	
F) Control Systems			
	- setting up windows for controls and acquisition		
	- saving of data and verification		
	- online analysis tools		
G) Support Systems			
	- environmental monitoring, building infrastucture	Johnson System & Superlogger	
	- clean-room protocol, cleanliness and lab organization		
	- emergency procedures		BOP-14
	- emergency contacts, people-to-call list	door placards and phone lists	
	1 familiarity w/regulations and governing documents, systems ->	PRESENTATION, REVIEW TALK	
	2 discuss, learn about existing procedures ->	INTERACTIVE LEARNING	
	3 what else we might need, evolving and missing protocoll ->	FEEDBACK, CONVERSATIONAL	

Form 'BOP-12-Appx-2' - last updated 11/13/2012

PROCEDURE | Page 1 of 4
BOP-10
Revision: Rev. 0
Issue Date: Oct 1, 2012
Review Period: 3 years
Supersedes Issues: First issue

Title: Search and Secure Instructions for BELLA Total Exclusion Area (TEA)
Section where used: LOASIS-BELLA Program, Bldg. 71
Prepared by: Csaba Toth 10/1/2012
Reviewed by: Patrick Bong 10/1/2012; Nathan Ybarrolaza 10/1/2012; Anthony Gonsalves 10/2/12
Approved by: Wim Leemans 10/9/12
Warren Byrne 10/4/12

Revision Log:

Rev. No.	Effective Date	Pgs. Affected	Brief Description of Revision
0	10/1/2012		First issue.

1.0 PURPOSE

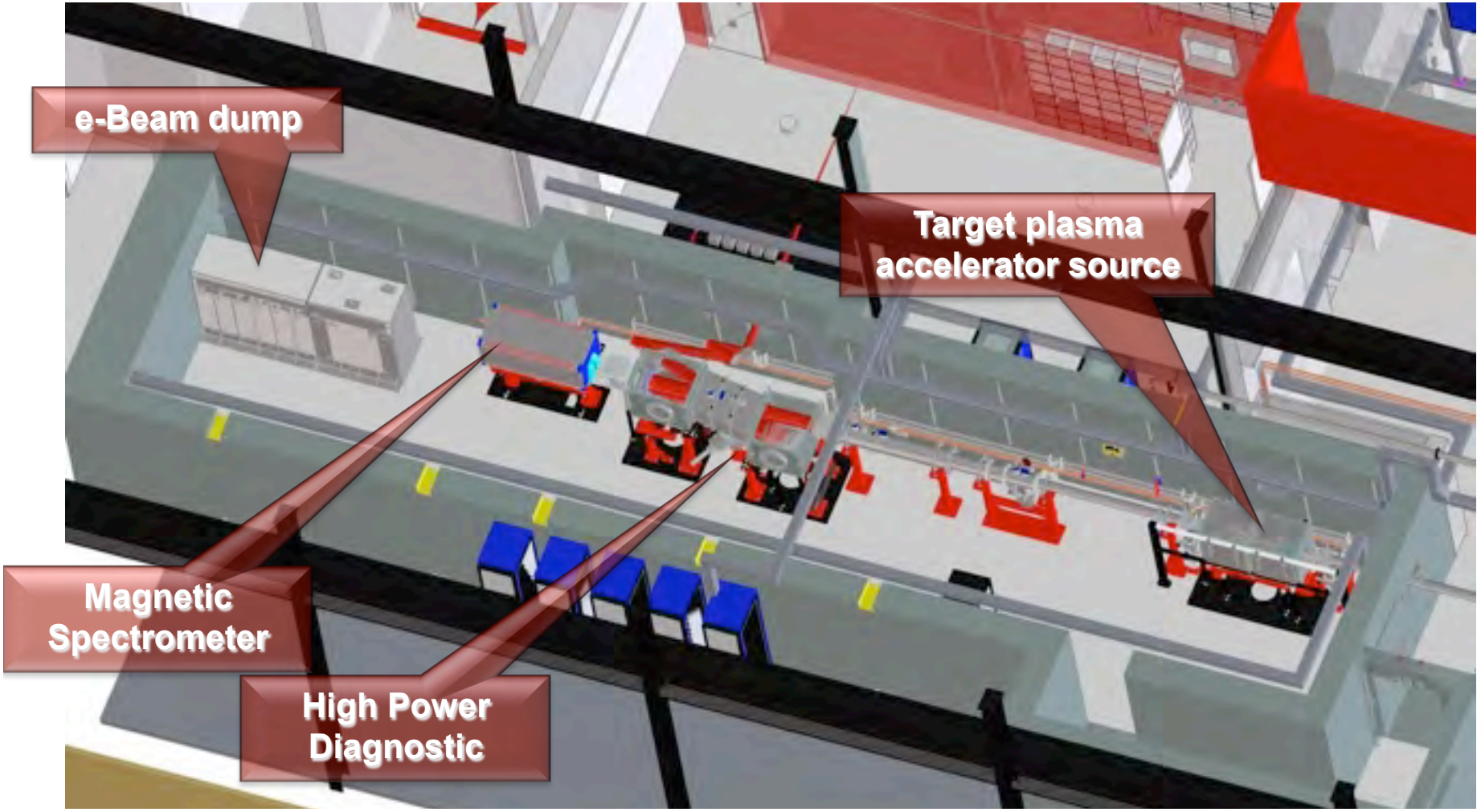
To provide instructions to perform the Search and Secure function for the BELLA Total Exclusion Area (TEA).

2.0 SCOPE

This procedure describes the method of securing the BELLA TEA before running experiments in 'High-Energy' ('High-E') mode. During 'High-E' mode operation a radiation hazard is present in the TEA, therefore personnel must leave the TEA before experiments can be started. A preliminary walkthrough of the TEA performed just before the actual Search and Secure process should also ensure, that no shielding arrangement has been modified and all equipment is ready for High-E mode operation, including: the LPD camera tray is out, all other cameras, power supplies and magnets are set appropriately (according to separate procedures, if applicable). If any steps in this procedure are performed out of order the Search and Secure process is automatically cancelled.

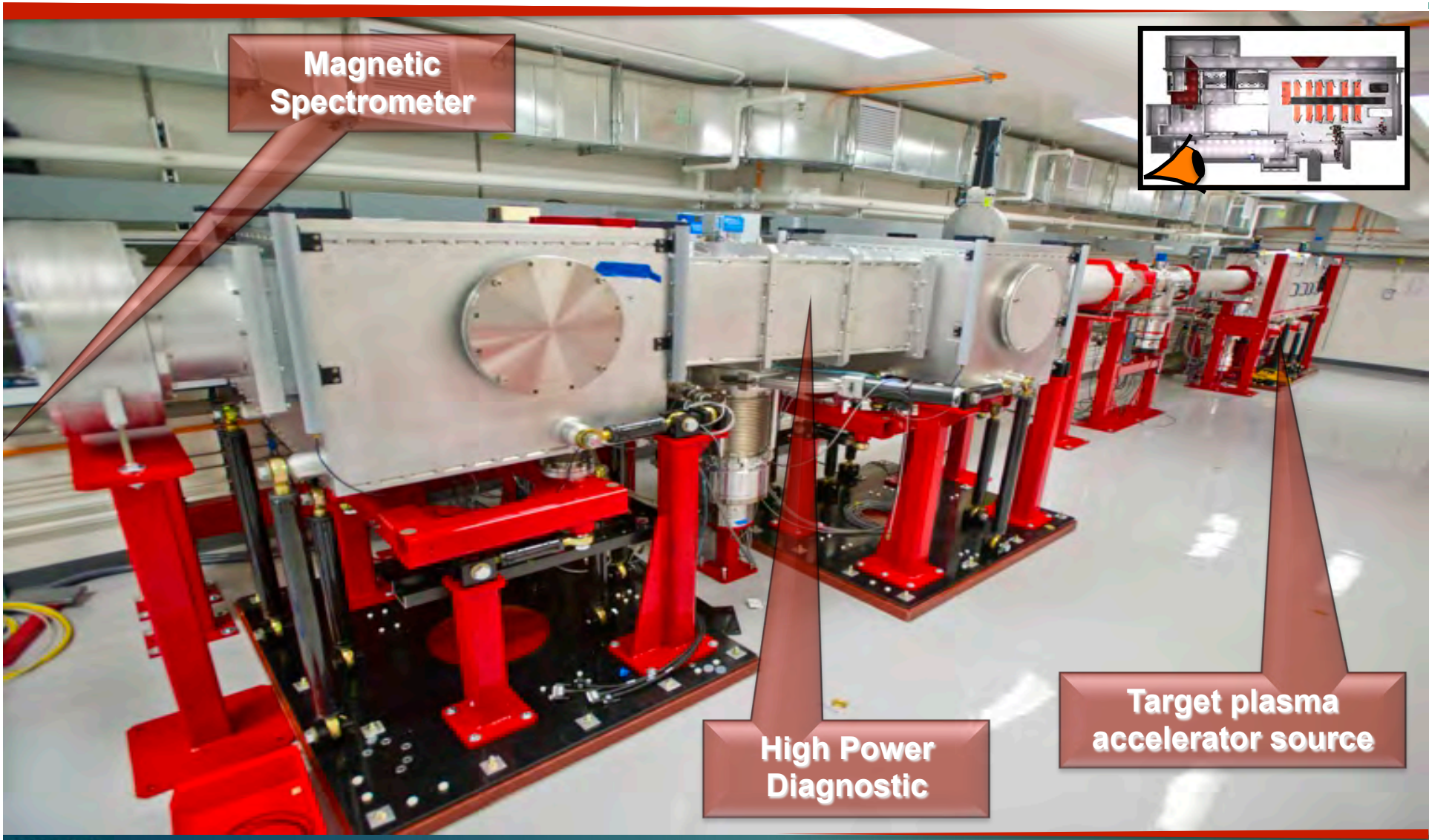
Installation and Integration of the Laser System is Complete

BELLA e-Beamline Installation: DESIGN



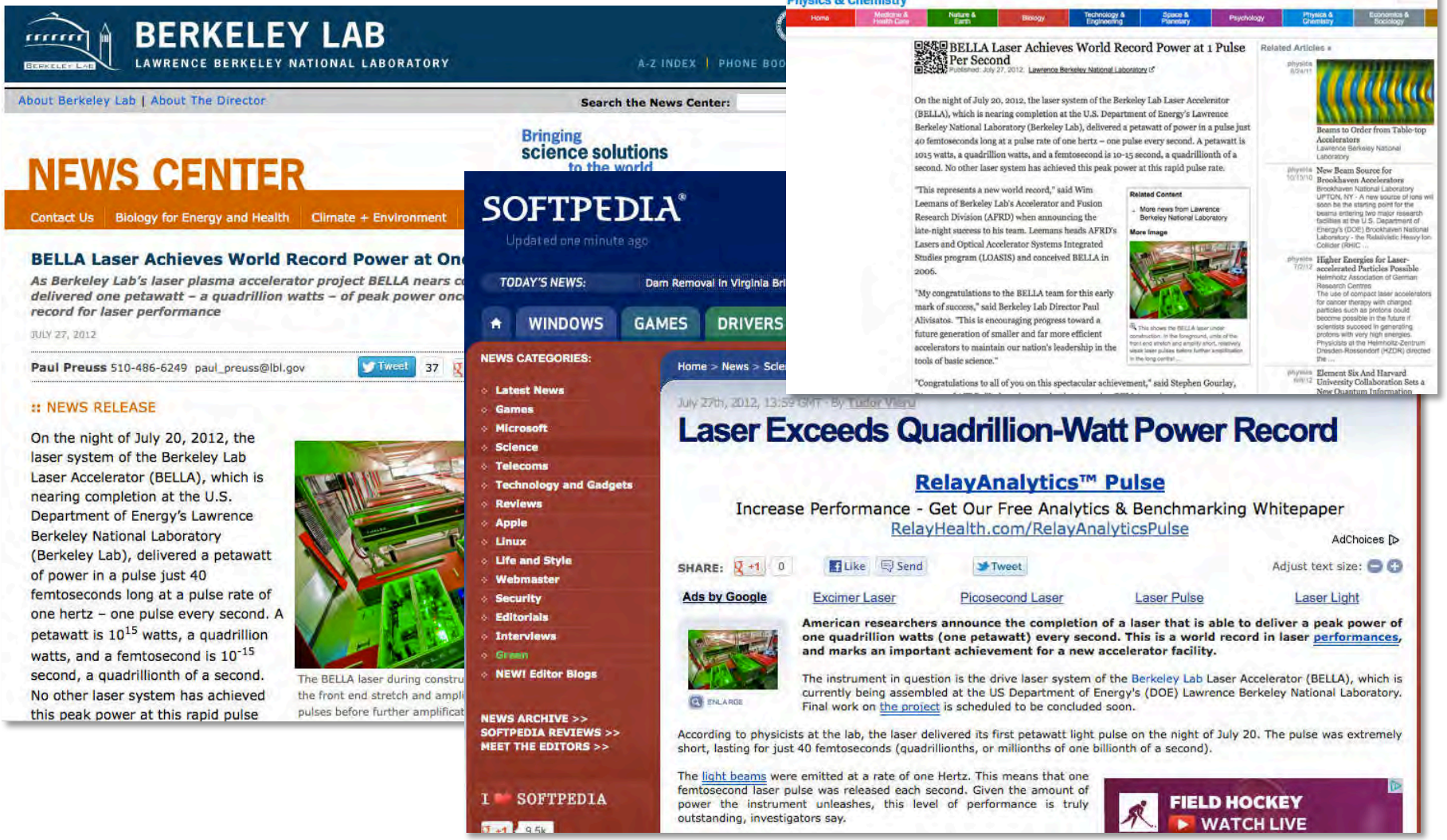
Installation and Integration of the Laser System is Complete

BELLA e-Beamline Installation: AS-BUILT



BELLA IS BREAKING WORLD RECORDS ALREADY

World firsts…

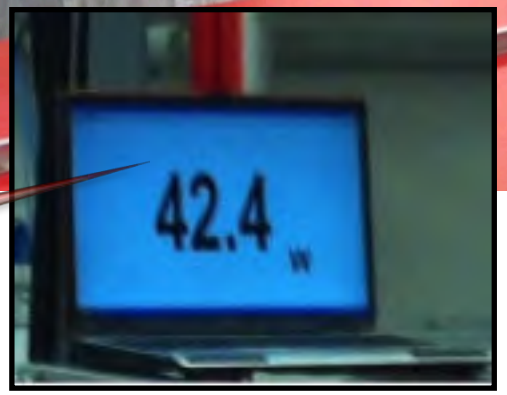


BELLA IS BREAKING WORLD RECORDS ALREADY

Historical moment for the BELLA team

Wim Leemans, Csaba Toth, Steve Fournier and the THALES team on 7/20/2012 @ 8h30pm

World record laser peak power @ 1 Hz



BELLA IS BREAKING WORLD RECORDS ALREADY

BELLA Laser TODAY

Outline

- Movie Time !