Workshop on High Energy Density Physics with BELLA-i

Berkeley, Jan 20-22, 2016

Wim Leemans, Thomas Schenkel, Eric Esarey, Sven Steinke, Stepan Bulanov, Qing Ji

BELLA-i workshop structure

- **workshop charge: what high impact science is uniquely enabled by BELLA-i ?**

- four working group topic areas (with somewhat fluid boundaries)
- five workshop sessions (roughly aligned with working group areas)
- working group leaders/session chairs
  - steer the discussions
  - collect input for the brief workshop report

1. **laser-ion acceleration, ...**
   - chairs: B. Manuel Hegelich (U Texas, Austin) and Sven Steinke (LBNL)
2. **secondary radiation generation, high harmonics, ...**
   - chairs: Félicie Albert (LLNL) and Jeroen van Tilborg (LBNL)
3. **nQED, high field physics, nuclear-plasma, ...**
   - chairs: Jonathan Wurtele (UC Berkeley) and Stepan Bulanov (LBNL)
4. **facilities, ...**
   - chairs: Ronnie Shephard (LLNL) and Qing Ji (LBNL)

- invited talks 35 min, contributed 20 min, including Q&A
- ample time for discussions at the end of each day

- capacity of our conference room 71-264 is 55
- overflow room with live stream: 71-233 (just around the corner)
- a ZOOM remote streaming option is also set up: https://lbnl.zoom.us/j/976865653

BELLA-i - a facility for high energy density physics and discovery plasma science at Berkeley Lab

BELLA-i	1	2	3
peak intensity (W/cm^2)	2×10^{19}	3×10^{21}	3×10^{21}
pulse length	30 fs	30 fs	30 fs
peak pulse energy	40 J	40 J	40 J
laser spot size	55 µm	5 µm	5 µm
peak repetition rate	1 Hz*	1 Hz*	1 Hz
contrast (ns)	10^{-10}	10^{-10}	$>10^{-14}$
diagnostics (details to be determined)	• optical spectrometers • ion and electron spectrometers • …	• optical pump- probe • betatron x-rays • MeV protons • …	• same as 2 • beamline for experiments with laser accelerated ions • …
1st access (estimates)	2017-2018	2018-2019	2019-2020

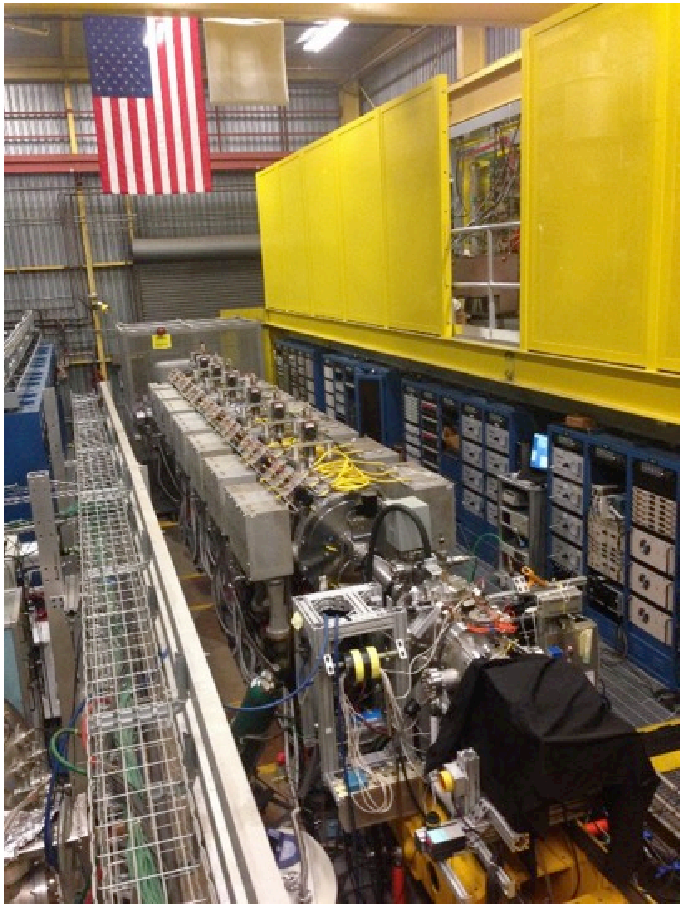
1. experiments with the existing, long focal length BELLA beamline in the existing cave
2. experiments in the existing BELLA cave with a new dual-beam line
    - * shielding in the BELLA cave limits the repetition rate for experiments with generation of intense pulses of >20 MeV protons
3. experiments in a new cave with improved shielding and with a beam line for laser accelerated ions
    - * improved shielding in a three-times larger experimental area for continuous operation at 1 Hz

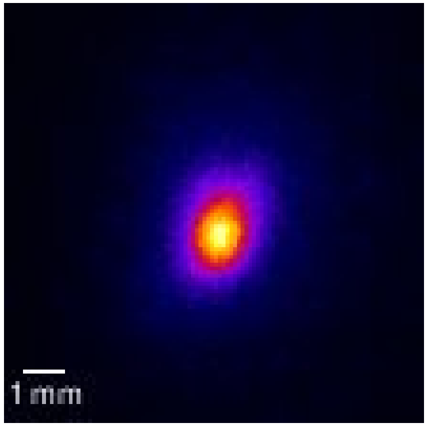
- contact: WPLeemans@lbl.gov; http://bella.lbl.gov/

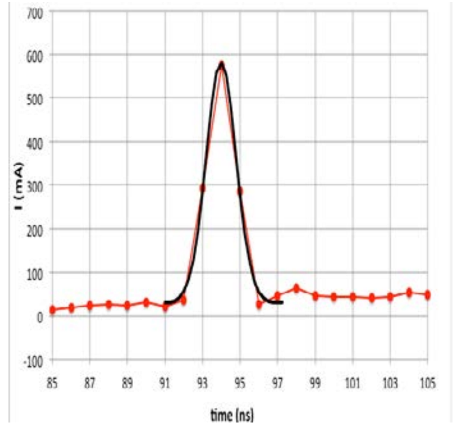
Context for BELLA-i in our division and at Berkeley Lab

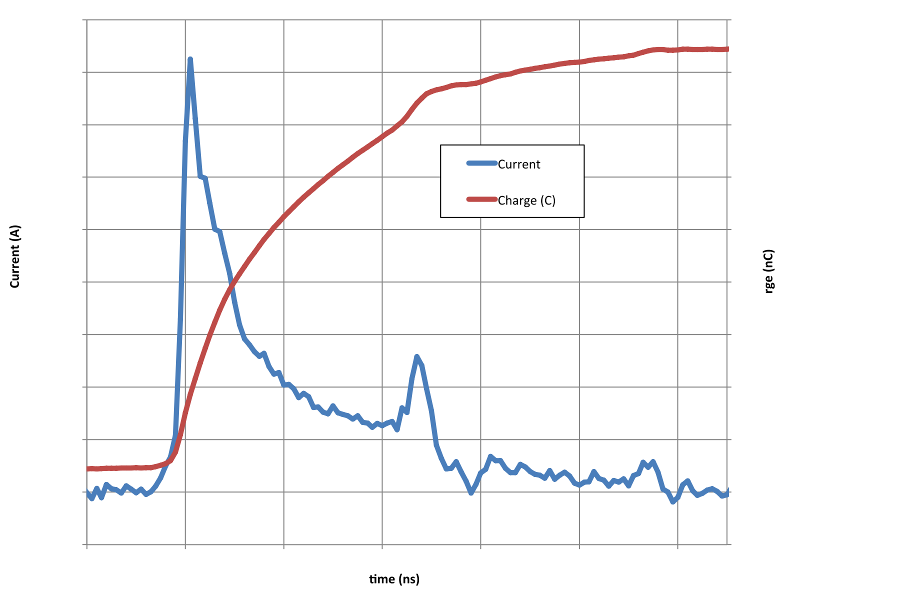
- BELLA center
- Fusion Science and Ion Beam Technology
  - NDCX-II, ...
- Berkeley Center for Magnet Technology
- Nuclear Science Division
- The Molecular Foundry
- National Energy Research Scientific Computing Center (NERSC)
- ...

NDCX-II, an induction linac, delivers intense ion pulses to targets, complementary to laser-ion acceleration





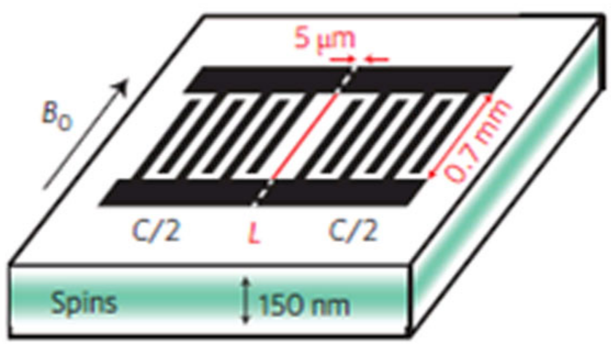




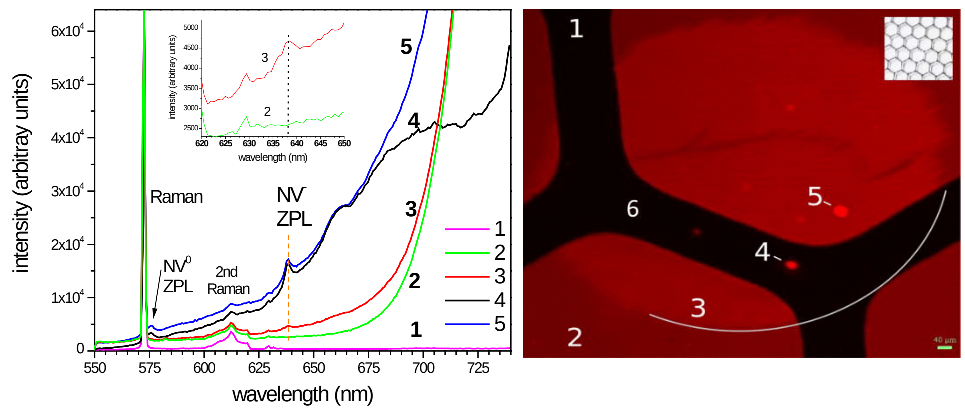
- 1.2 MeV He^{+}, few ns, 1 mm, 2/minute
- best to date: 10^{11} ions/pulse

With short ion pulses we gain access to the multi-scale materials physics of radiation damage, “extreme chemistry” and phase transition at the onset of warm dense matter

- Probes of multi-scale defect dynamics will inform the development of optimized materials and benchmark models and simulation codes
- New opportunities to tailor materials properties through “extreme chemistry”
- Very important for materials in high radiation environments, and opportunities to tailor e. g. spin properties for exploration of quantum information processing schemes

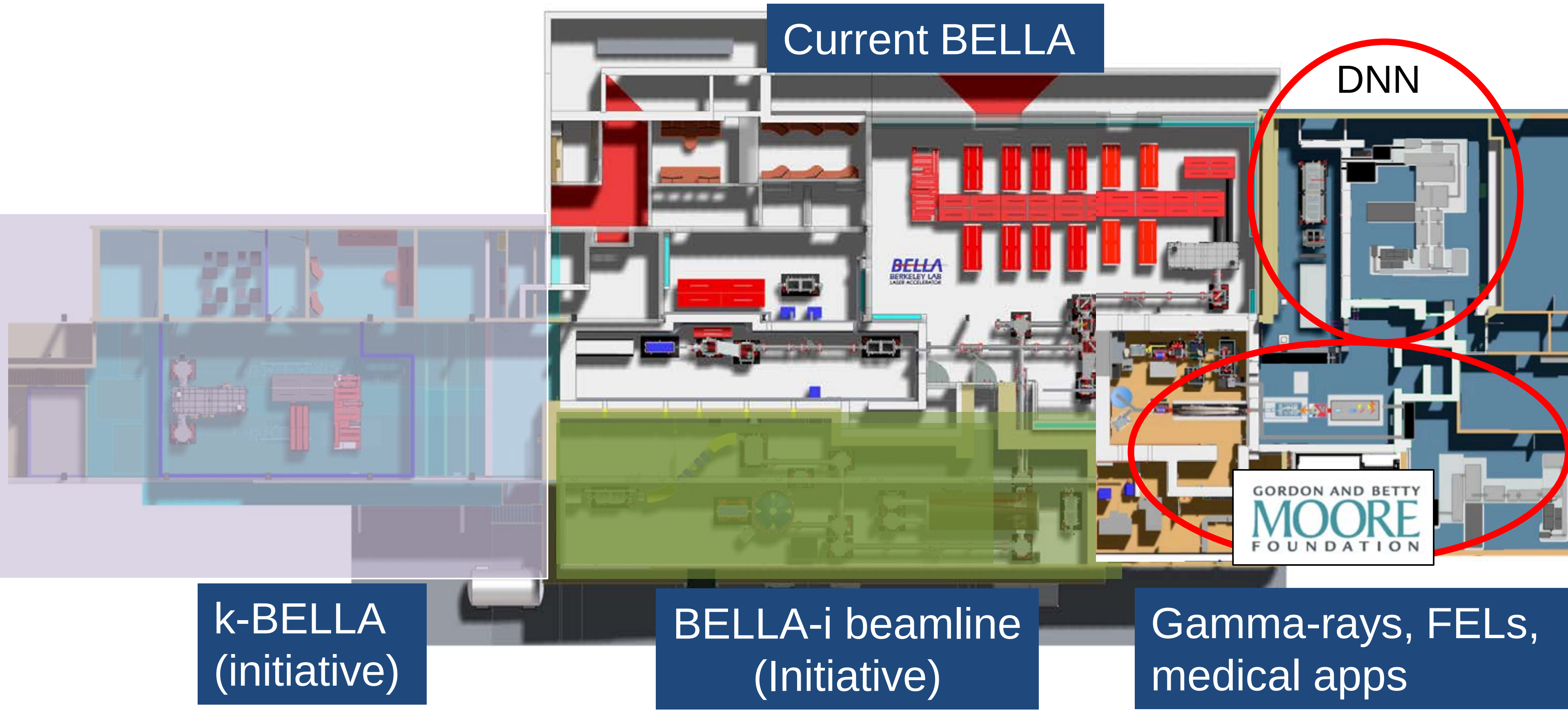


“Reaching the quantum limit of sensitivity in electron spin resonance”, A. Bienfait, J. J. Pla, Y. Kubo, M. Stern, X. Zhou, C. C. Lo, C. D. Weis, T. Schenkel, M. Thewalt, D. Vion, D. Esteve, B. Julsgaard, K. Mølmer, J. Morton, and P. Bertet, Nature Nanotechnology, online Dec. 14 (2015)

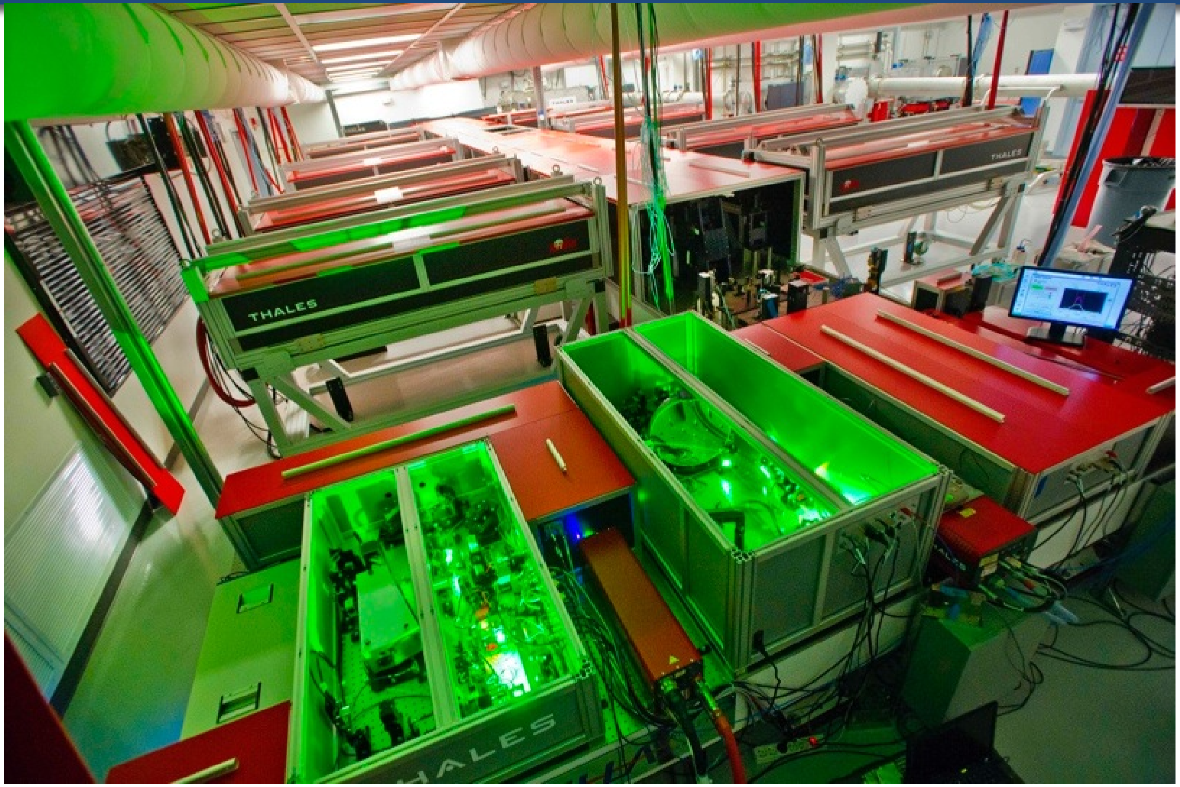


“Local formation of nitrogen-vacancy centers in diamond by swift heavy ions”, J. Schwartz, S. Aloni, D. F. Ogletree, M. Tomut, M. Bender, D. Severin, C. Trautmann, I. W. Rangelow, and T. Schenkel, J. Appl. Phys. 116, 214107 (2014)

BELLA Facility is designed for laser plasma accelerator R&D and expanding toward ultra-high intensity laser-matter experiments



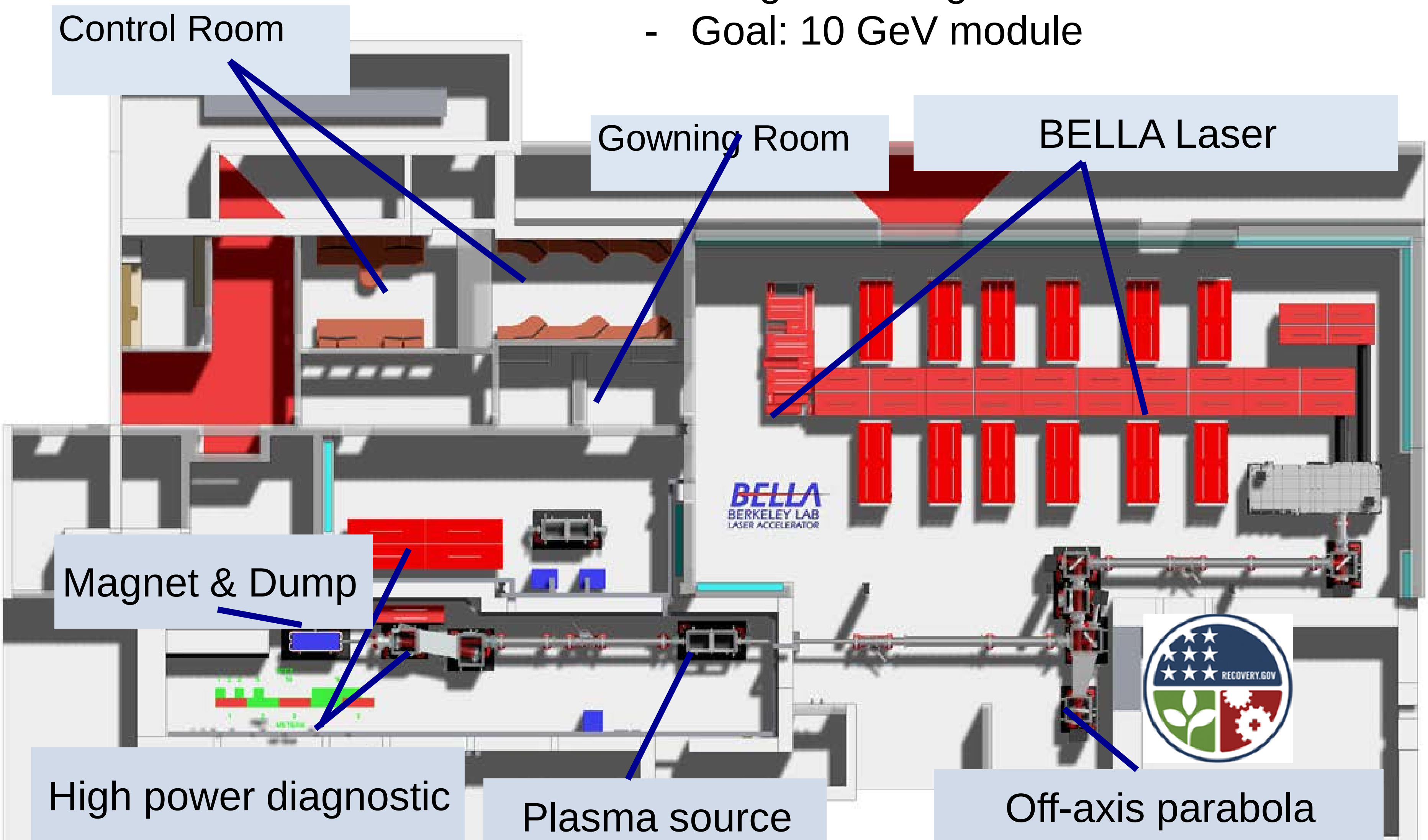
BELLA laser operates at ~ 1.4 PW, 1 Hz allowing high intensity laser plasma acceleration experiments



- First commercial Petawatt laser operating at > 42 J in ~30 fs
- Energy stability <0.5 % rms fluctuation
- Pointing stability < 1.2 micro-rad
- Long focal length mirror: ~55 micron spots on target

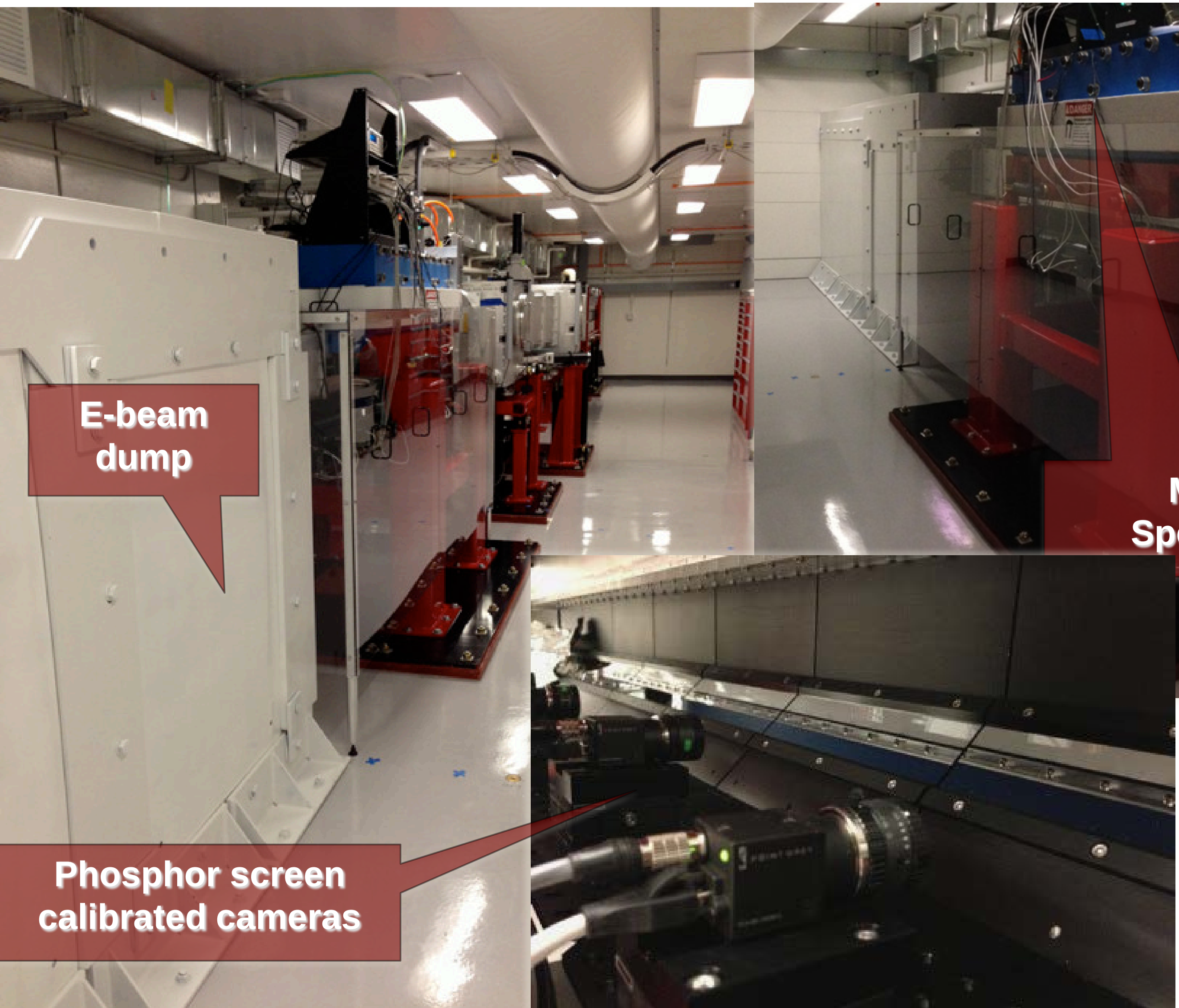
1. Present BELLA PW laser and long focal length beamline

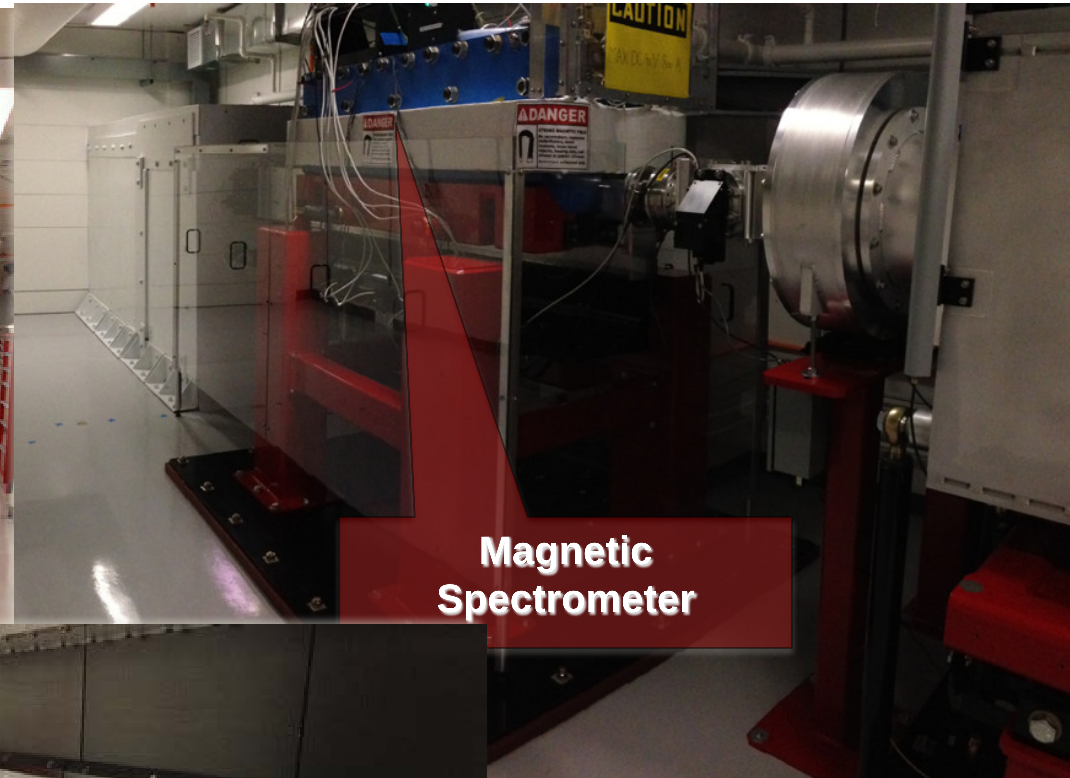
BELLA currently has one beamline
- Long focal length
- Goal: 10 GeV module



All major mechanical and electrical systems were installed and commissioned in 2012-2013

e-Beam diagnostics include energy, transverse profile and charge transformers



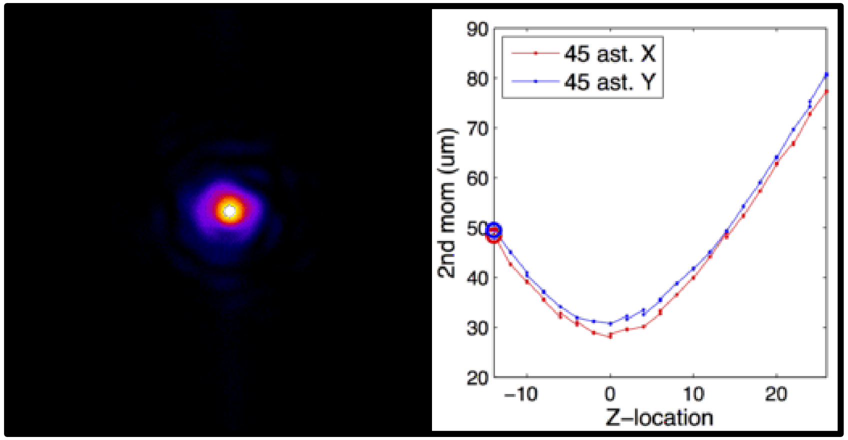


- Single shot
- 30 MeV-11 GeV
- Two ICTs
- Phosphor screen

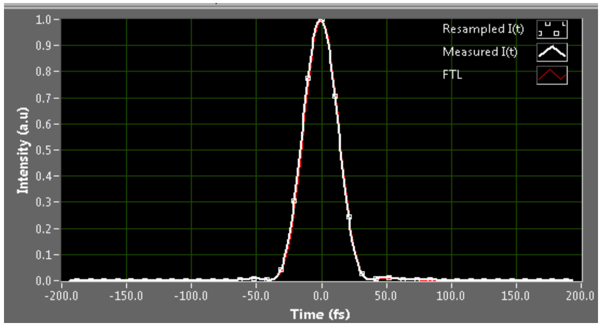
Laser beam quality from BELLA enables challenging experiments

Spatial Quality of Beam at Focus (uses deformable mirror)

- Supergaussian near field
- Gaussian focus
  - 0.8-0.9 Strehl Ratio
  - 30 nm wavefront error

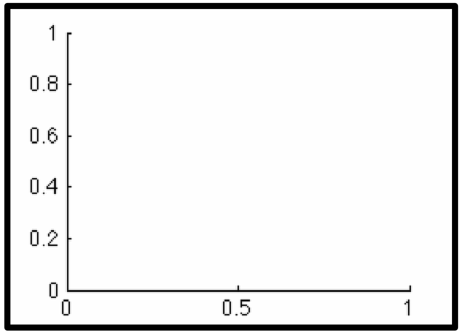


Temporal Shaping



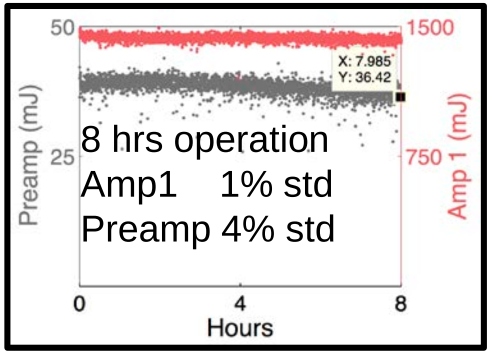
~30 fs FWHM
(with DAZZLER)

Pointing Stability



< 1.2 μrad rms

Energy Stability



< 0.5 % rms full amp

Contrast is sufficient for e-acceleration but we are planning for plasma mirrors to further improve contrast for ion acceleration

Current control:

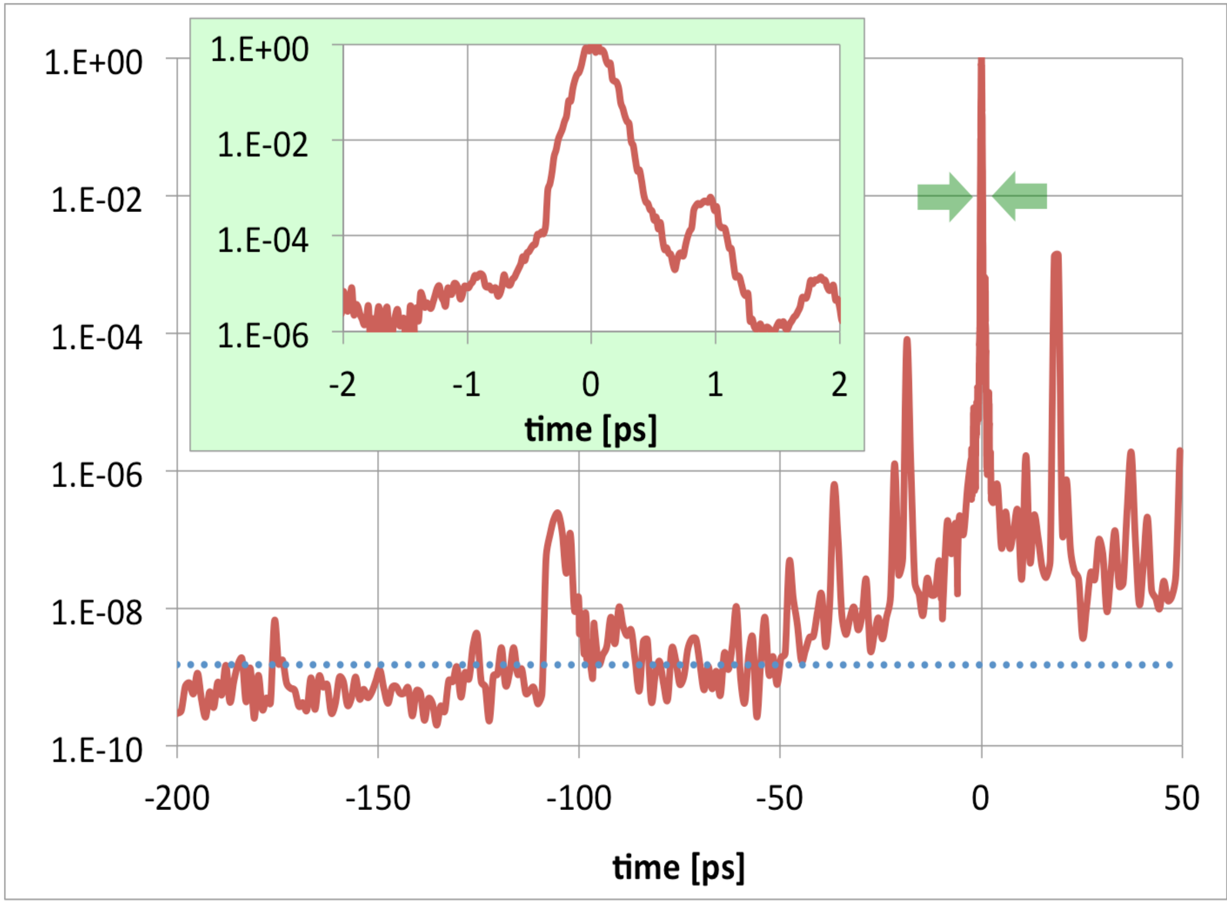
- XPW, Sequoia and planning single shot technique

Possible future Improvement:

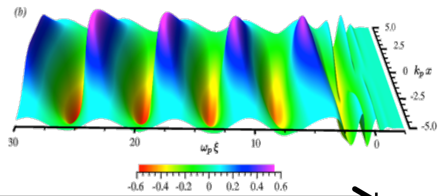
- Another XPW
- Saturable absorbers
- Regen. with different design.
- Major design mod. in amp. chain.
- Plasma mirrors:
  - o Tape based (currently used)
  - o Liquid film based (e.g.,

13 J on target

Contrast: 1×10^{-4} at 0.5 ps, 1×10^{-5} at 1 ps, 1×10^{-9} at 150 ps

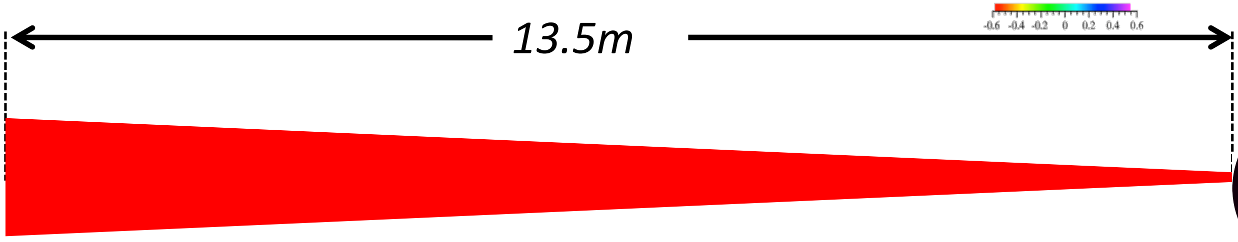


For electron acceleration, BELLA is focused with long focal length. We are planning to add short focal length optic and plasma mirrors

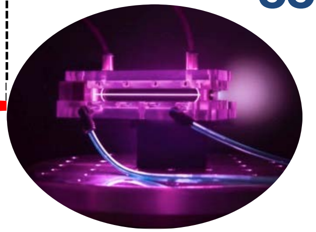


Intensity ~1.5x10^{19} Wcm^{-2}
Acc. fields ~10-50GV/m

Long focal length

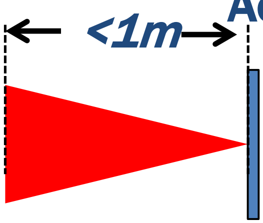


55 micron spot



Short focal length

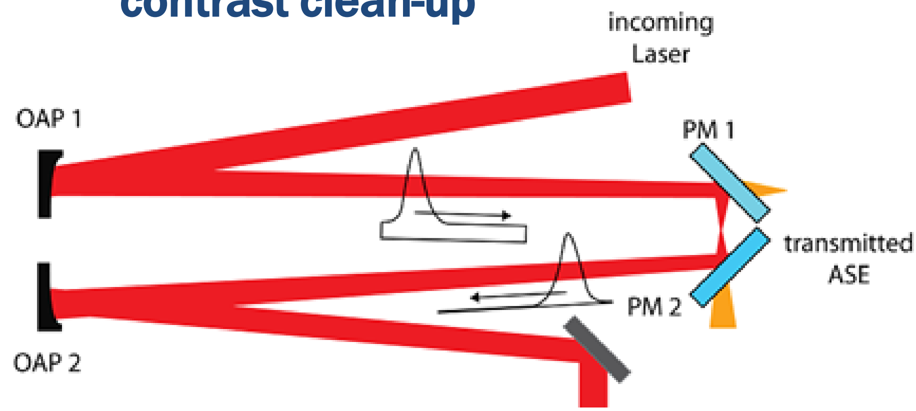
Intensity ~3-5x10^{21} Wcm^{-2}
Acc. fields ~TV/m



4-5 micron spot

+

Plasma mirror technology for contrast clean-up

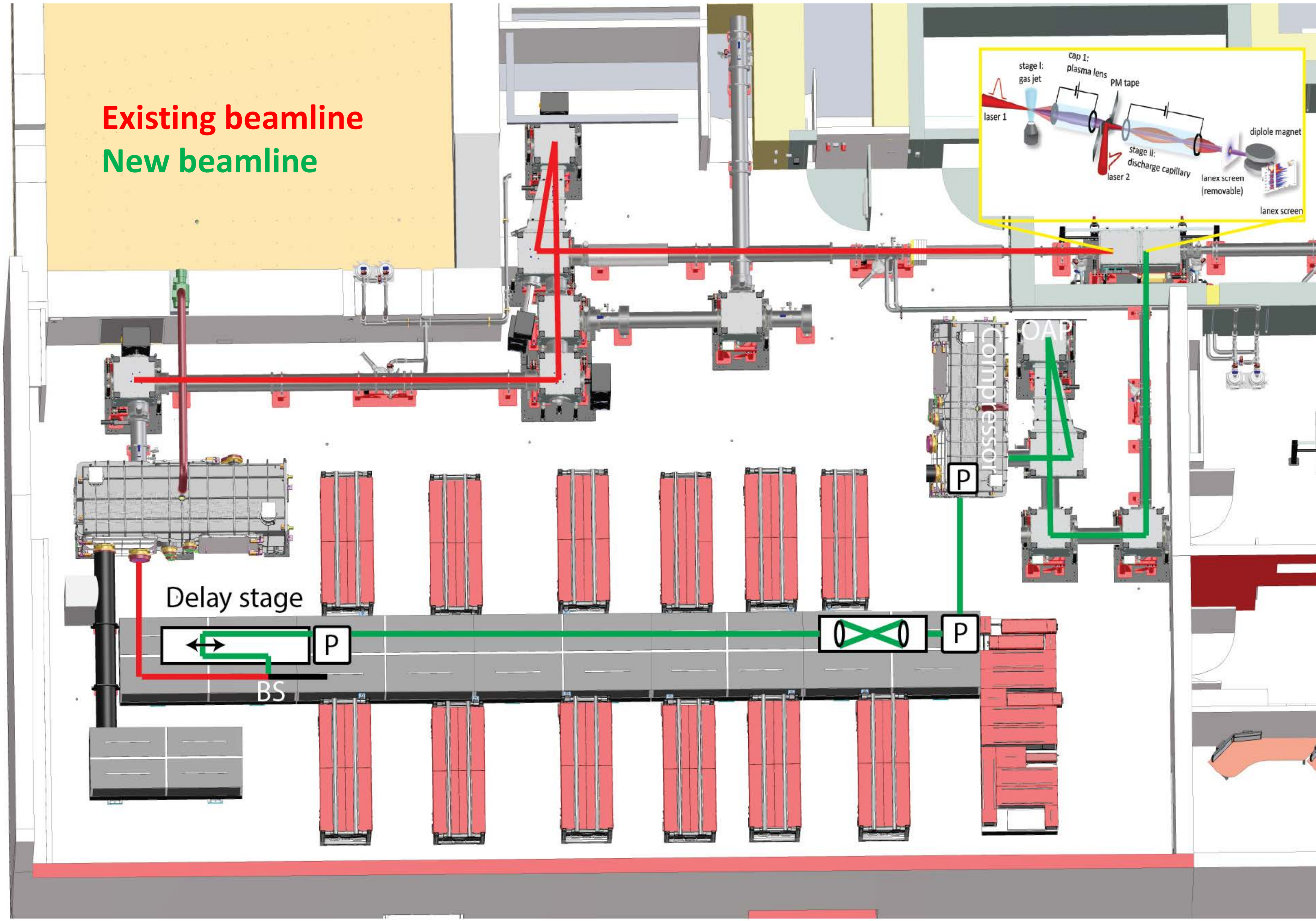


BELLA-i - a facility for high energy density physics and discovery plasma science at Berkeley Lab

BELLA-i	1	2	3
peak intensity (W/cm^2)	2×10^{19}	3×10^{21}	3×10^{21}
pulse length	30 fs	30 fs	30 fs
peak pulse energy	40 J	40 J	40 J
laser spot size	55 µm	5 µm	5 µm
peak repetition rate	1 Hz*	1 Hz*	1 Hz
contrast (ns)	10^{-10}	10^{-10}	$>10^{-14}$
diagnostics (details to be determined)	• optical spectrometers • ion and electron spectrometers • …	• optical pump- probe • betatron x-rays • MeV protons • …	• same as 2 • beamline for experiments with laser accelerated ions • …
1st access (estimates)	2017-2018	2018-2019	2019-2020

1. experiments with the existing, long focal length BELLA beamline in the existing cave

Phase 2: Upgrade BELLA experimental area to prototype the first two stages of an LPA based collider – AND to enable HEDP experiments

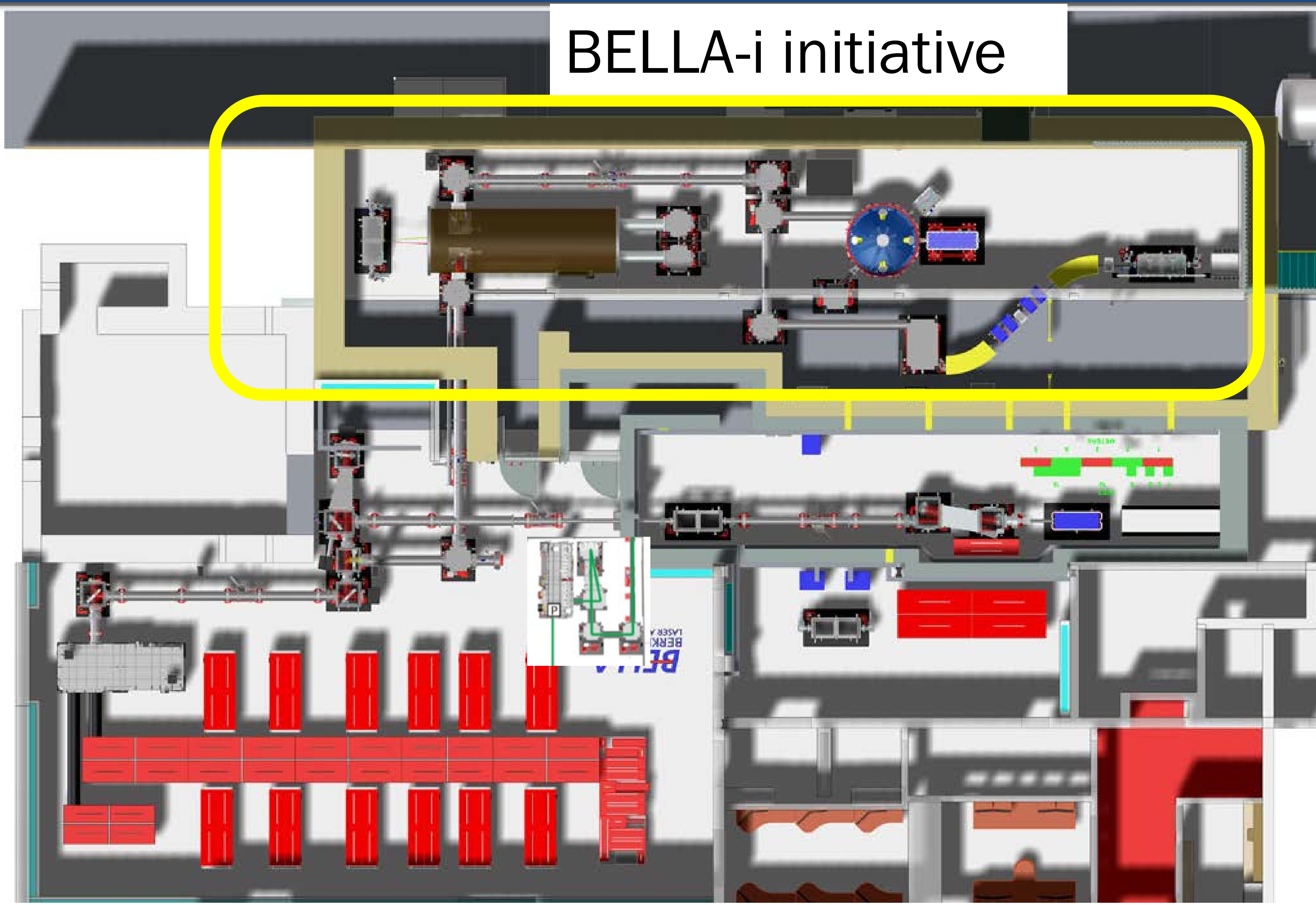


BELLA-i - a facility for high energy density physics and discovery plasma science at Berkeley Lab

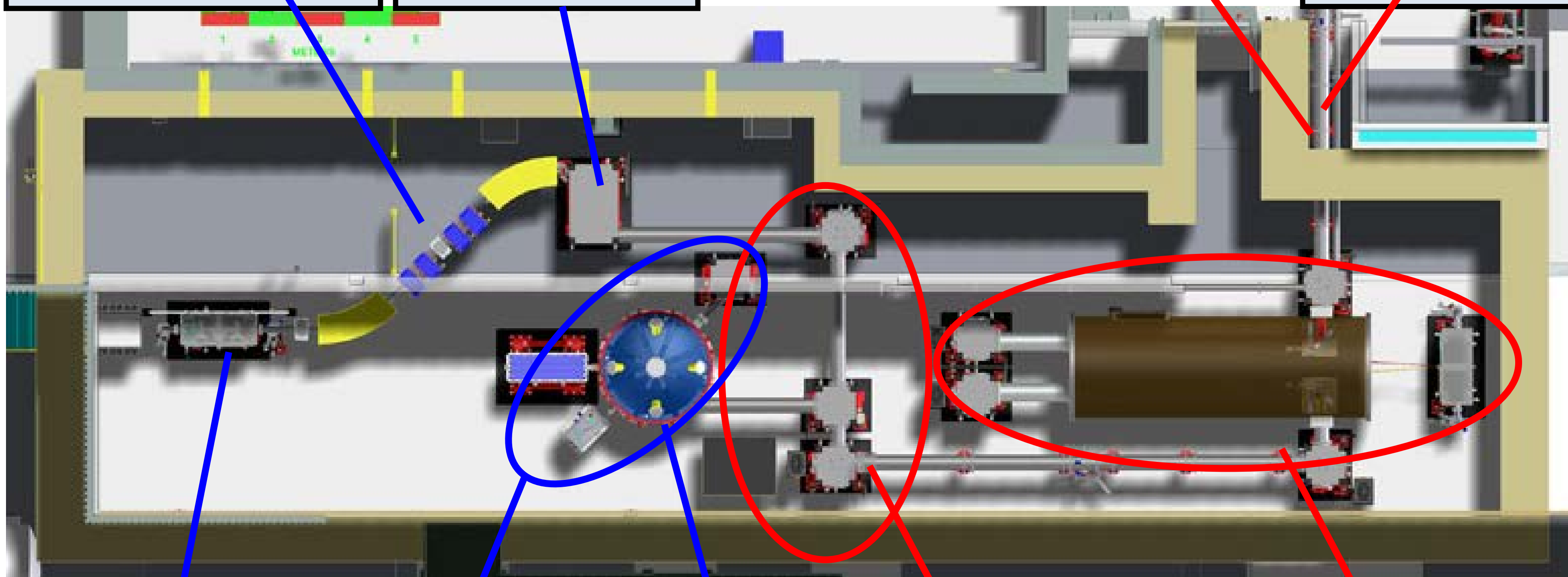
BELLA-i	1	2	3
peak intensity (W/cm^2)	2 x 10^{19}	3 x 10^{21}	3 x 10^{21}
pulse length	30 fs	30 fs	30 fs
peak pulse energy	40 J	40 J	40 J
laser spot size	55 μm	5 μm	5 μm
peak repetition rate	1 Hz*	1 Hz*	1 Hz
contrast (ns)	10^{-10}	10^{-10}	>10^{-14}
diagnostics (details to be determined)	• optical spectrometers • ion and electron spectrometers • …	• optical pump-probe • betatron x-rays • >10 MeV protons • …	• same as 2 • beamline for experiments with laser accelerated ions • …
1st access (estimates)	2017-2018	2018-2019	2019-2020

2. experiments in the existing BELLA cave with a new dual-beam line
    - * shielding in the BELLA cave limits the repetition rate for experiments with generation of intense pulses of >20 MeV protons

In Phase 3, we would build a new cave to add two new beamlines



3. We expand the facility by adding short focal length capability for ultra-high intensity



BELLA-i - a facility for high energy density physics and discovery plasma science at Berkeley Lab

BELLA-i	1	2	3
peak intensity (W/cm^2)	2 x 10^{19}	3 x 10^{21}	3 x 10^{21}
pulse length	30 fs	30 fs	30 fs
peak pulse energy	40 J	40 J	40 J
laser spot size	55 µm	5 µm	5 µm
peak repetition rate	1 Hz*	1 Hz*	1 Hz
contrast (ns)	10^{-10}	10^{-10}	>10^{-14}
diagnostics (details to be determined)	• optical spectrometers • ion and electron spectrometers • …	• optical pump- probe • betatron x-rays • MeV protons • …	• same as 2 • beamline for experiments with laser accelerated ions • …
1st access (estimates)	2017-2018	2018-2019	2019-2020

3. Experiments in a new cave with a beam line for laser accelerated ions
   - * improved shielding in a three-times larger experimental area for continuous operation at 1 Hz

BELLA-i will provide access to news regimes in High Energy Density Physics

- High field physics
- High pov
- Physics a
- High har
- Applicat
- Applicat
- Other, ...

- Leverage stitutions
  - Targ
  - Sup
  - Detectors → Nuclear Science and Physics Divisions, ...
  - Radiation effects on cells → Bio-sciences, ...

→Day 1 & flagship experiments at the three stages of BELLA-i

→let's discuss at this workshop