Radiation Safety Aspects of LCLS-II Project at SLAC

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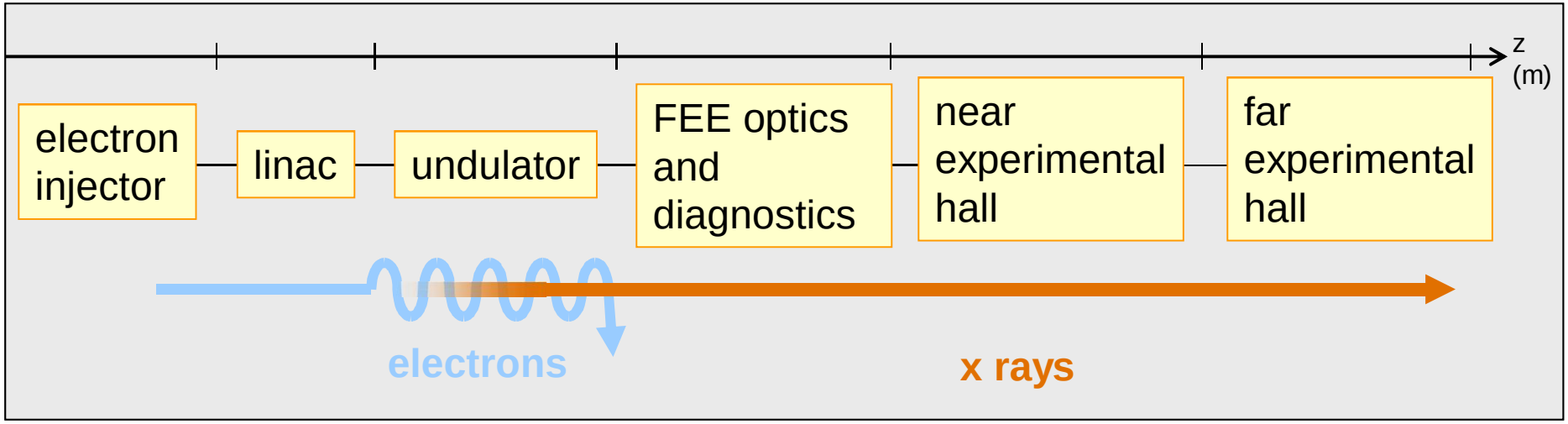
Outline

- Overview of LCLS
- Description of LCLS-II
- Radiation protection for LCLS-II
- Radiation sources in LCLS-II
- Examples of shielding studies
- Lessons learned from LCLS-I
- Summary

Overview of LCLS



- Like a synchrotron light source LCLS generates x-rays from high-energy electrons
- LCLS uses a one pass linac, rather than a storage ring
  - Self Amplified Stimulated Emission
- The linac creates a much brighter, shorter electron pulse than a storage ring can, allowing the *free-electron laser effect* to produce intense x-rays in the 120 m long undulator

Overview of radiation safety issues

Personnel access to experimental areas located near zero-degree with respect to the electron beam direction

- Proper containment of electron beam (ultimate top-off mode!)
- Electron beam interactions ➔ bremsstrahlung pointing to the Experimental Hall (EH)➔ muons and high-energy neutrons generated close to the EH
- Higher electron beam energy, higher average beam power, higher critical energy than synchrotron Facilities

Containment of FEL beam

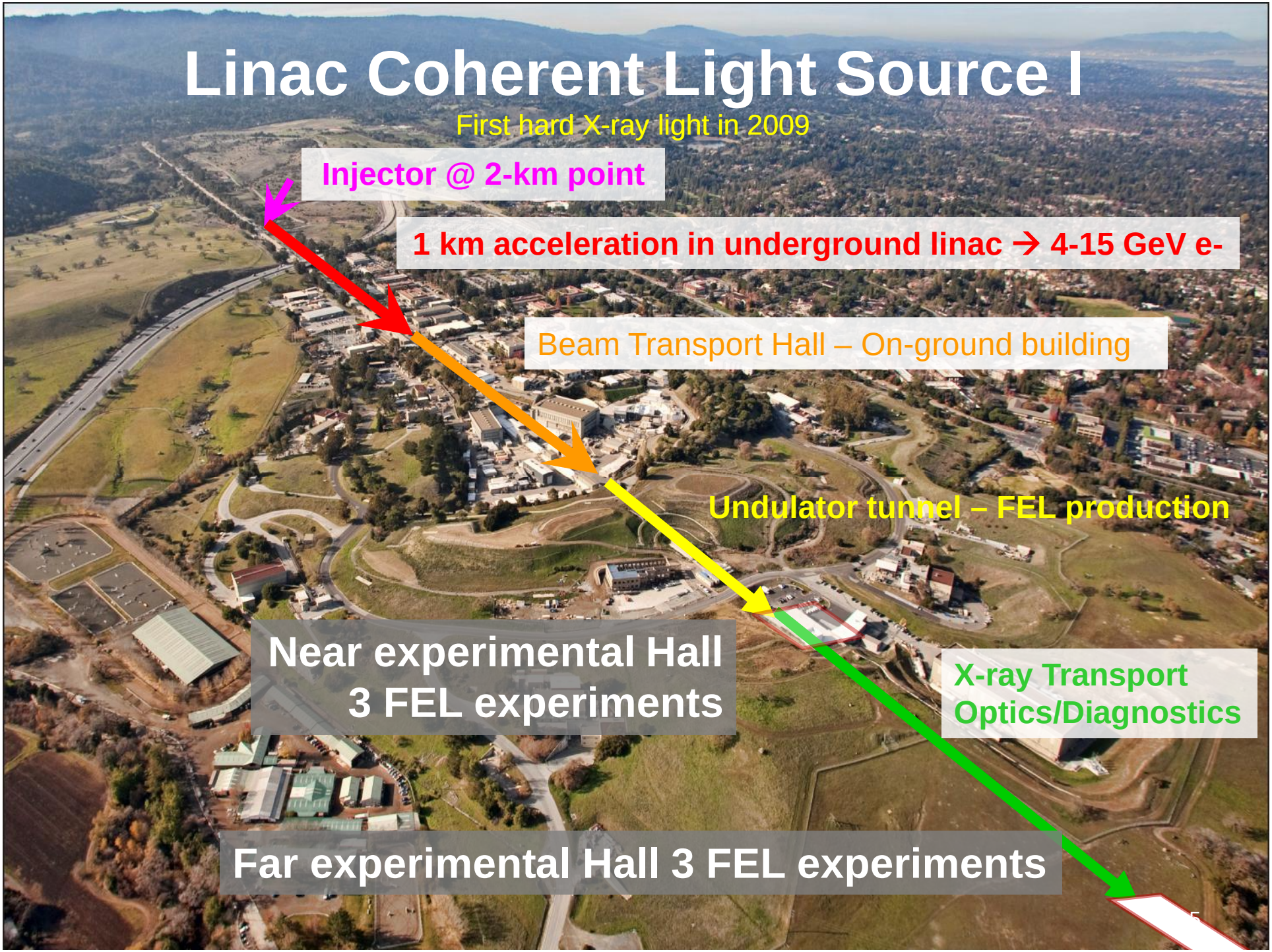
- FEL beam can damage (ablate) most materials due to its high peak energy density per pulse (J/mm^2)
- Use of B4C, air collimators, water dumps, ….

Control over beam line configuration

Complex Access Control modes, work in an up beam area

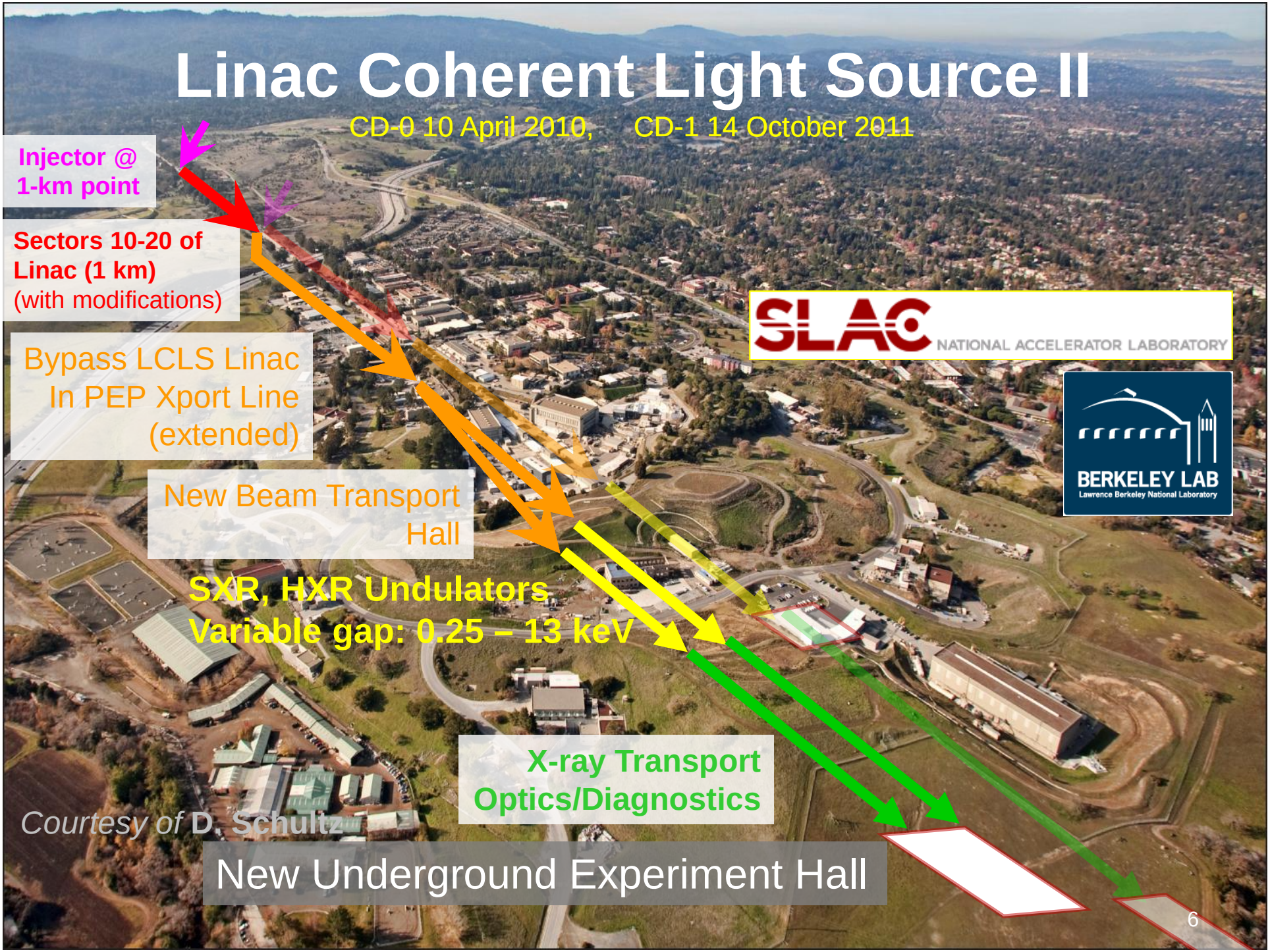
Linac Coherent Light Source I

First hard X-ray light in 2009



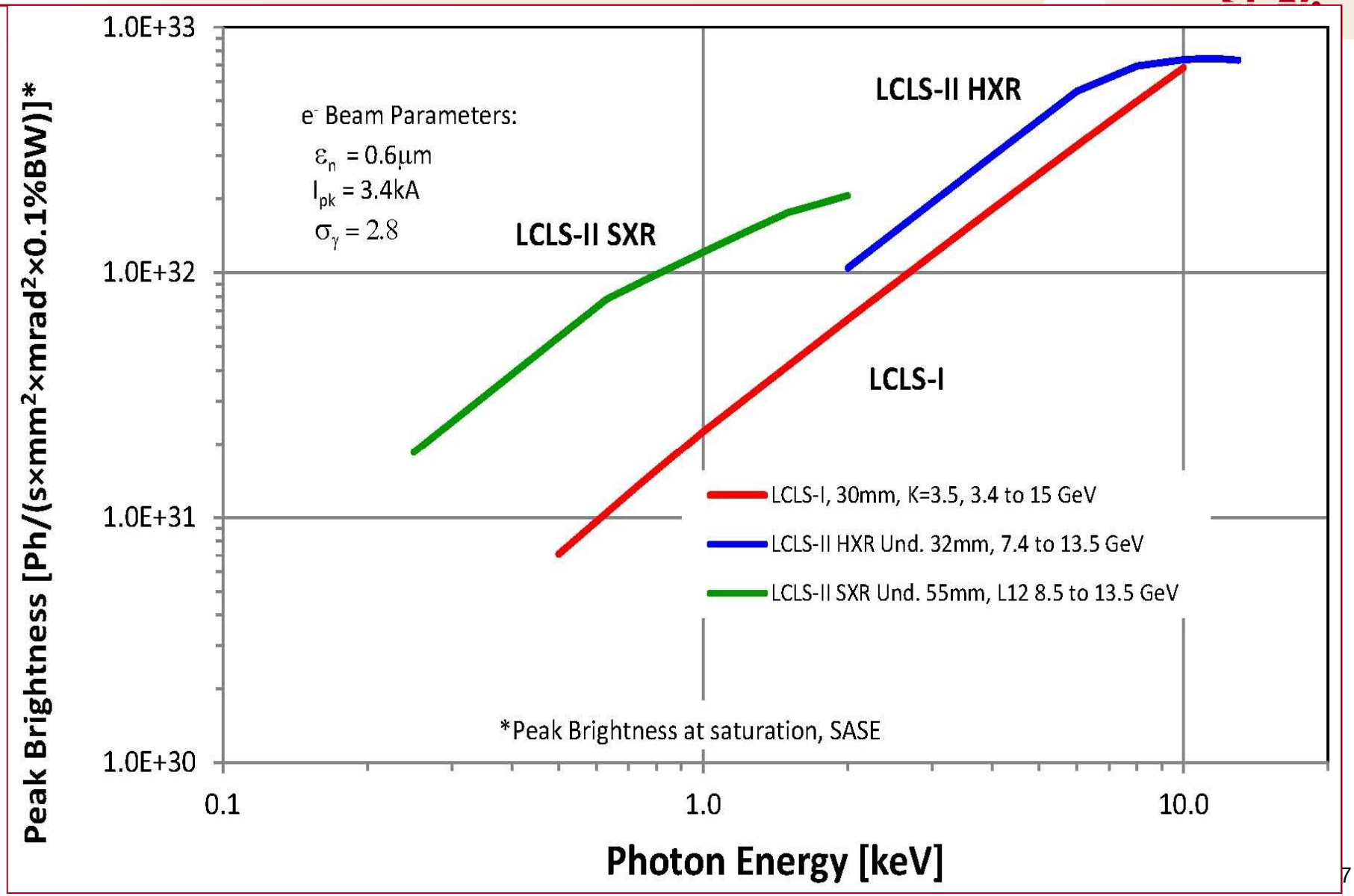
Linac Coherent Light Source II

CD-0 10 April 2010, CD-1 14 October 2011



Courtesy of D. Schultz

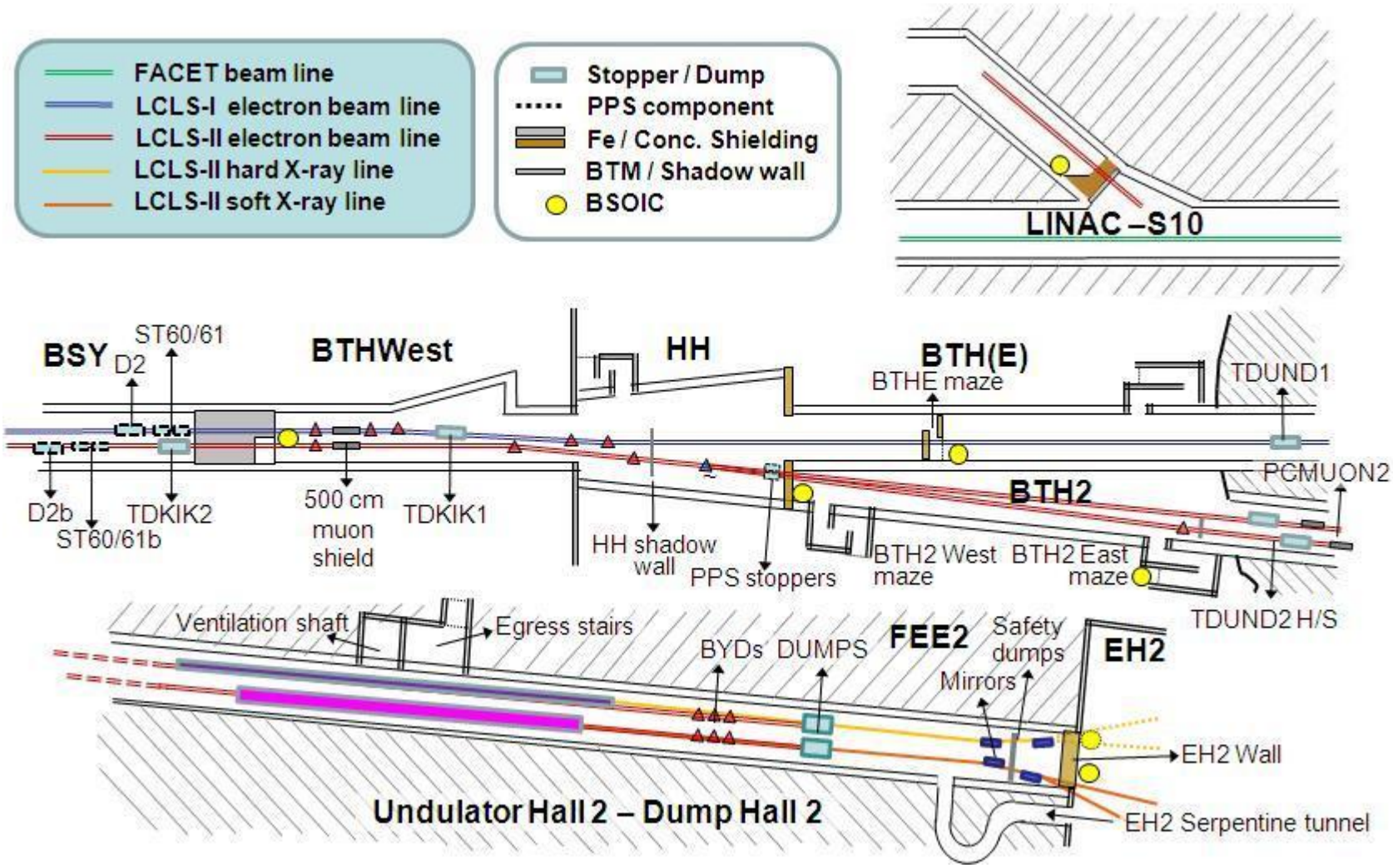
Greater capability and capacity



LCLS-II project description

- A new, independent electron injector
- Use of existing accelerator, sectors 10-20 (2nd km of the SLAC Linac)
- Use of existing PEP-II by-pass lines
- Redesign of muon shield
- New Beam Transport Hall
- Tunnel to house two new undulator sources
  - Hard X-ray (2-13 KeV)
  - Soft X-ray (250-2,000 eV)
- Beam dump Hall, X-ray front end
- A new experiment hall with capacity for six experiment stations
- New Access Control Systems, Beam Containment system, Area Monitors

LCLS-II layout for radiological overview



Radiation sources in LCLS-II

Electron Beam up to 15 GeV, 5 kW. 5 W beam loss at any other point, 200 mW of Bremsstrahlung at forward angle

B **Beam halo interaction with collimators**

- 5 W lost in jaws with 0.1 [mrad] grazing angle

B **Beam losses on bending dipoles (BYD) in the dump line**

- 20 W grazing with 0.1 [mrad] → **100 mW bremsstrahlung**

Full beam into main electron dumps (DUMP1 + DUMP2)

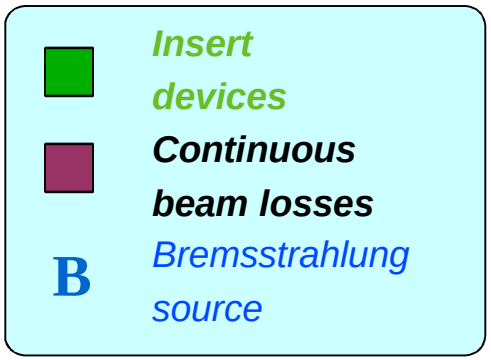
- 5000 W

Beam is stopped by the tune-up dumps

- 420 W (10 Hz) on each of the dumps

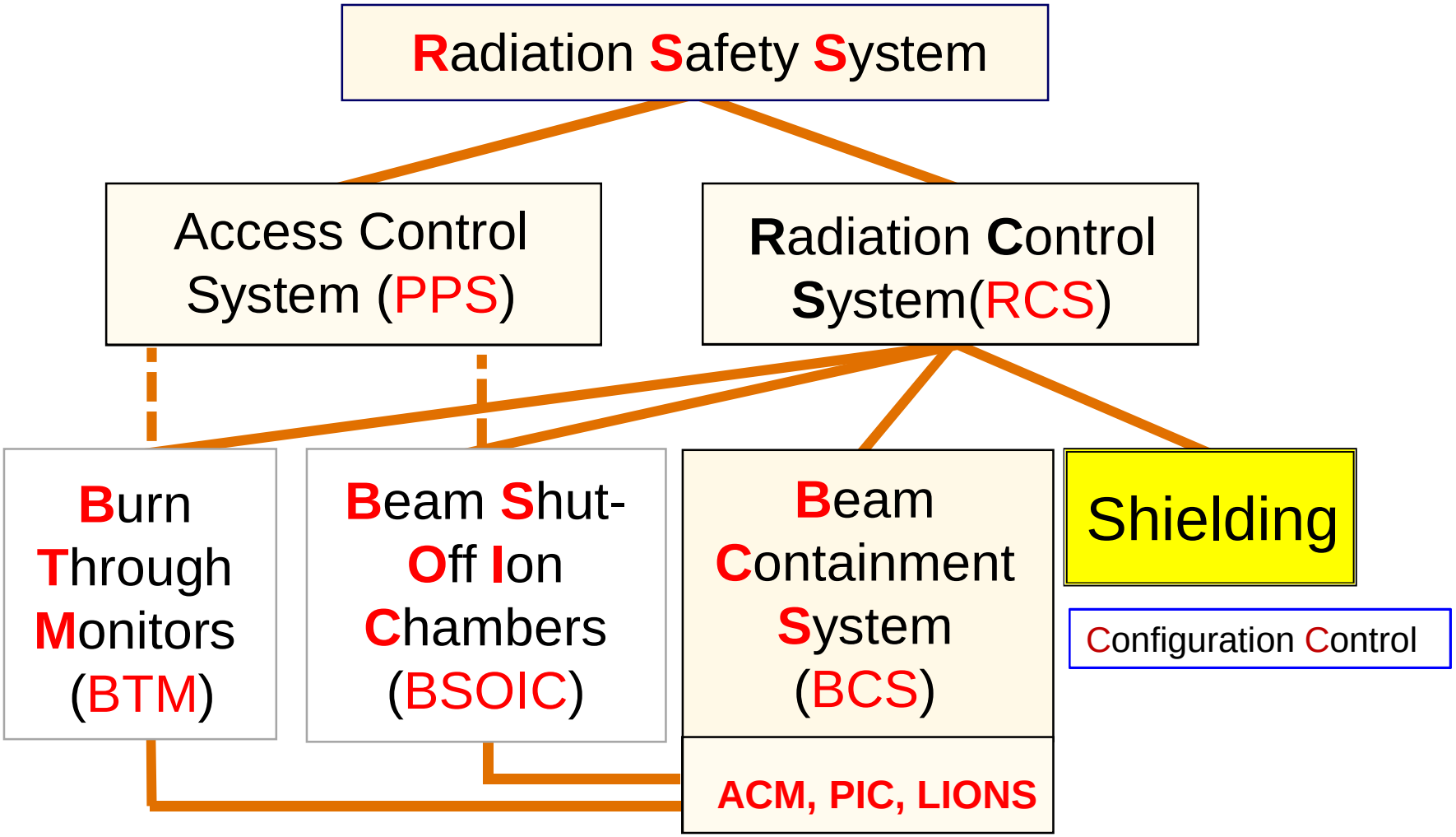
B **Beam goes through wire scanner**

- 42 W crossing a 40 micron carbon wire



REF: J. Welch, *'LCLS-II Electron Beam Loss and Maximum Credible Beam Power'*, LCLS-II PRD, SLAC-I-060-103-005-00-R001

SLAC Radiation Safety System (RSS)



Design goals, criteria

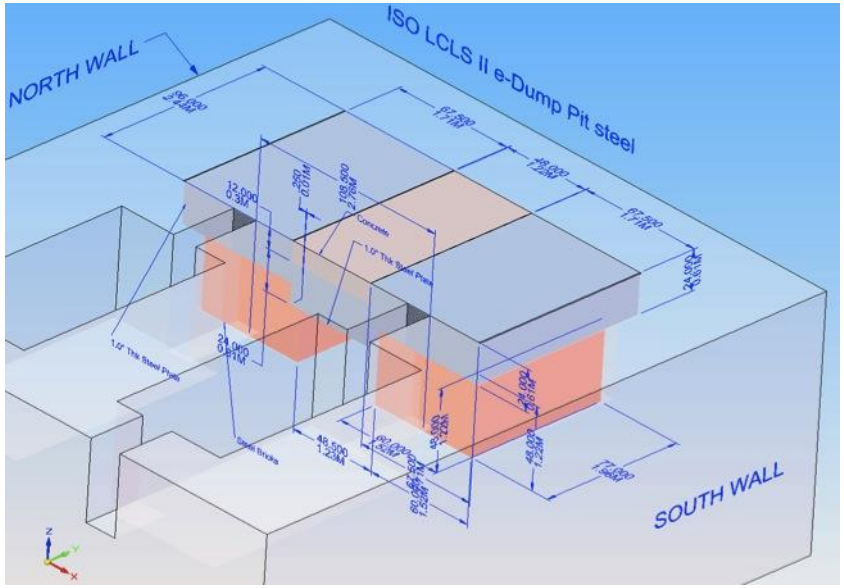
- **Protect workers, users, general public, and the environment on-site and off-site from radiation of accelerator and beam operations**

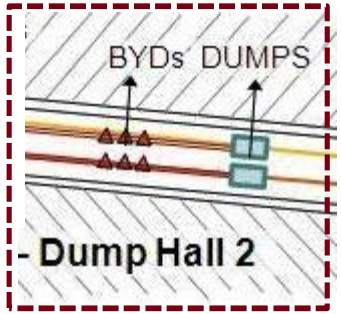
  - Bulk shielding 5 μSv/hr (0.5 mrem/hr)
  - Experimental hutch 0.5 μSv/hr (0.05 mrem/hr)
  - Site boundary dose 50 μSv/yr (5 mrem/y)
  - Ground water activity 740 Bq/L for ^{3}H (20 nCi/L)
  - Air activation dose 1 μSv/yr (0.1 mrem/y)

- **Maintain doses as low as reasonably achievable (ALARA)**

Shielding of the main dump hall

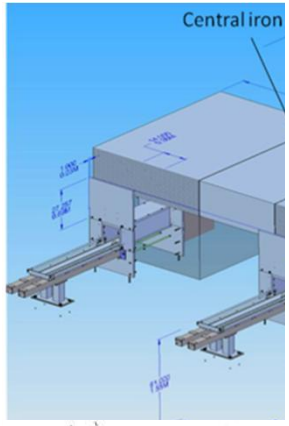
- Two main dumps in the same pit.
- Each dump can take up to 5 kW.
- The tunnel above the dumps must be accessible 1 h after beam off (50 [*μSv*/h])
- The tunnel and shielding around the dumps is sufficient to limit **environmental impact**
- The dump shielding and soil coverage over the tunnel contain the **prompt dose** to the public (0.5 [*μSv*/h])

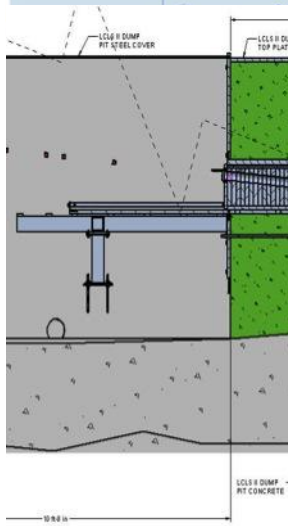


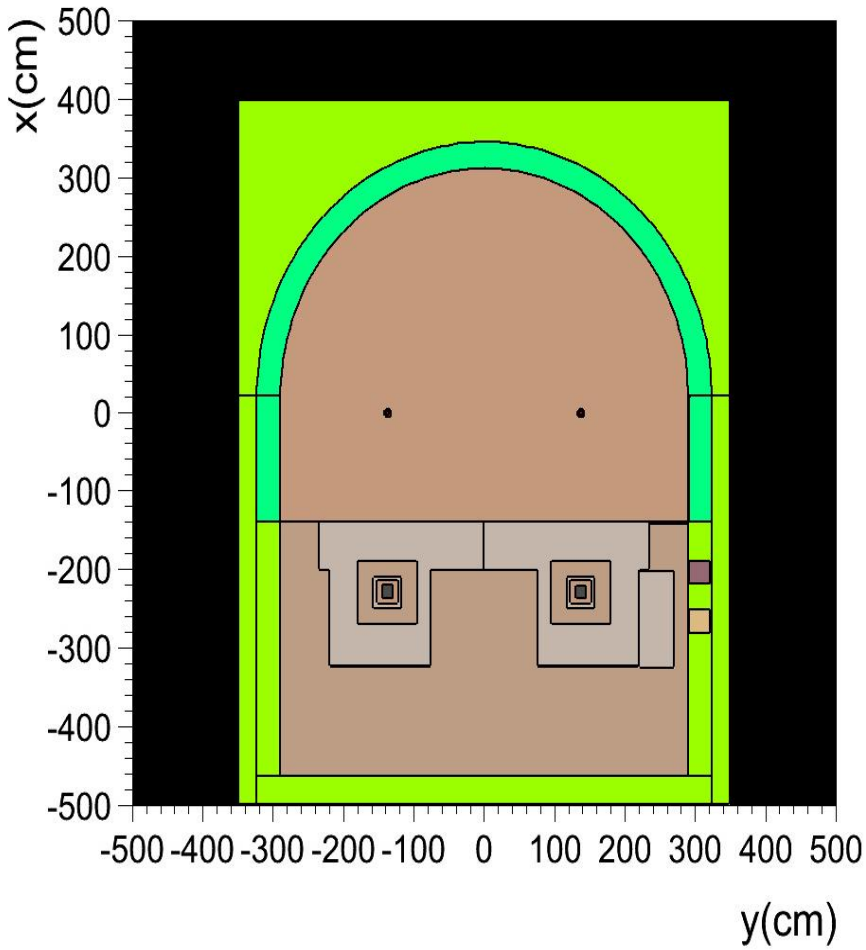


Shielding of the main dump hall – residual dose shielding

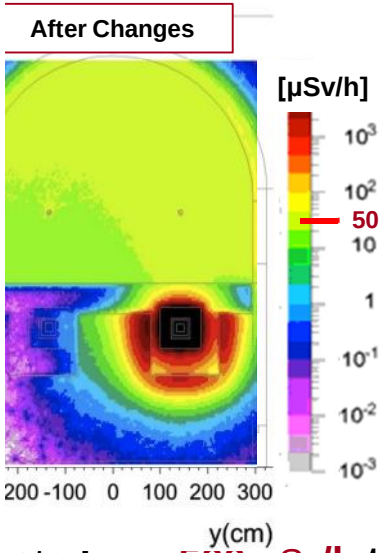
Changes required to
view and elevation v







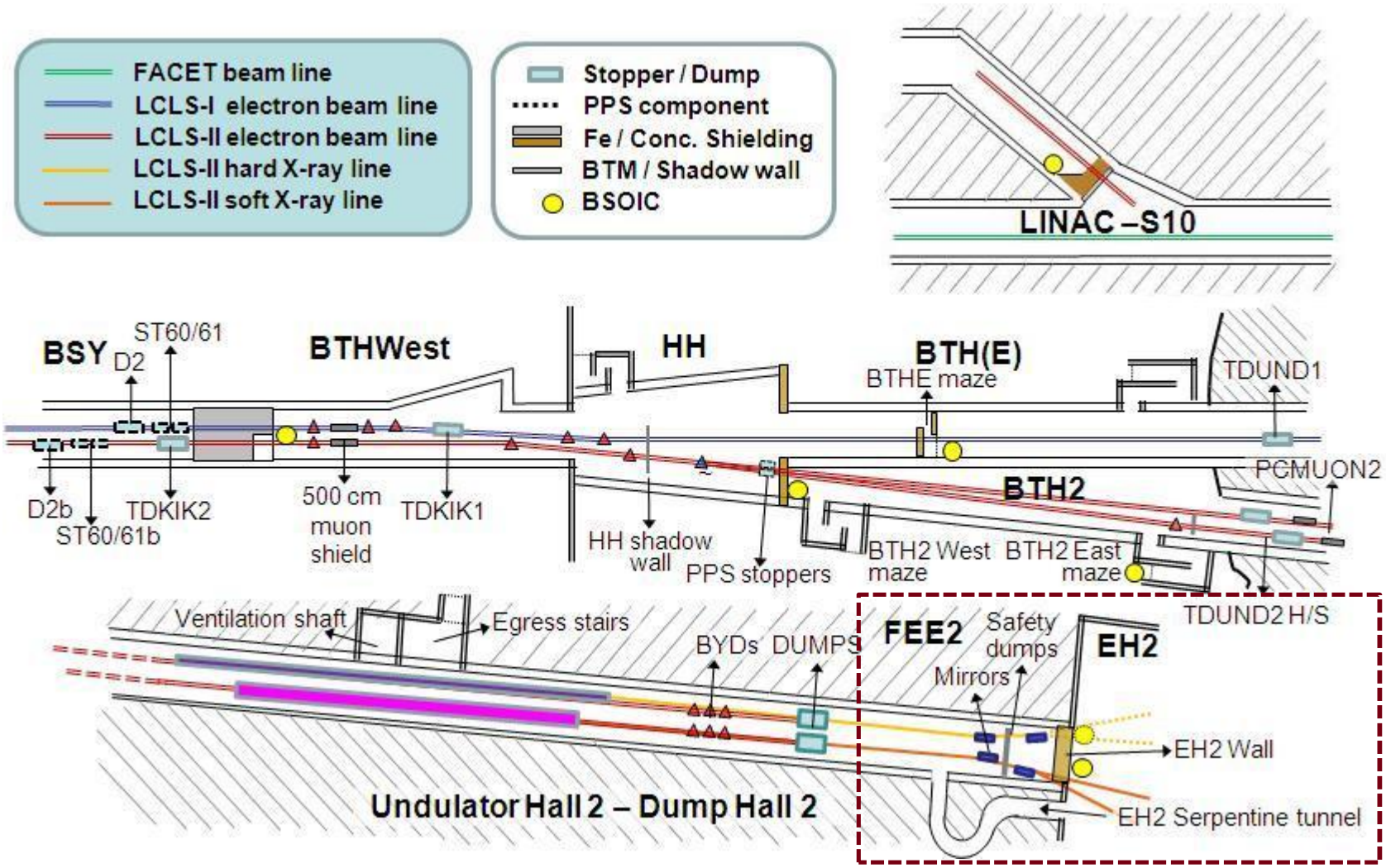
ıp or T_i=30 days, T_c=1h, 5kW



rate **from 500 *μSv*/h to 50**
as achieved by:

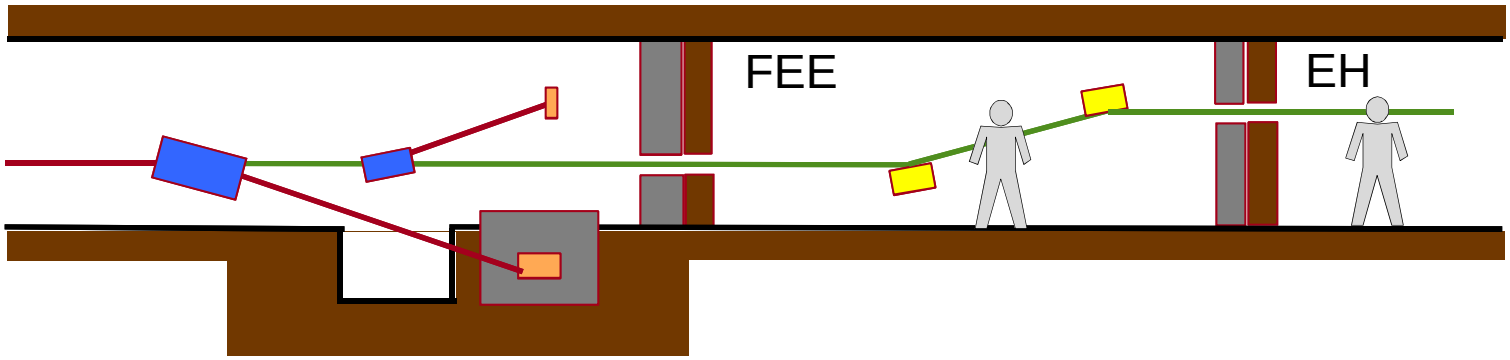
:e shell around the dump:
core lowering activation of

Shielding of the FEE2 (XTOD)

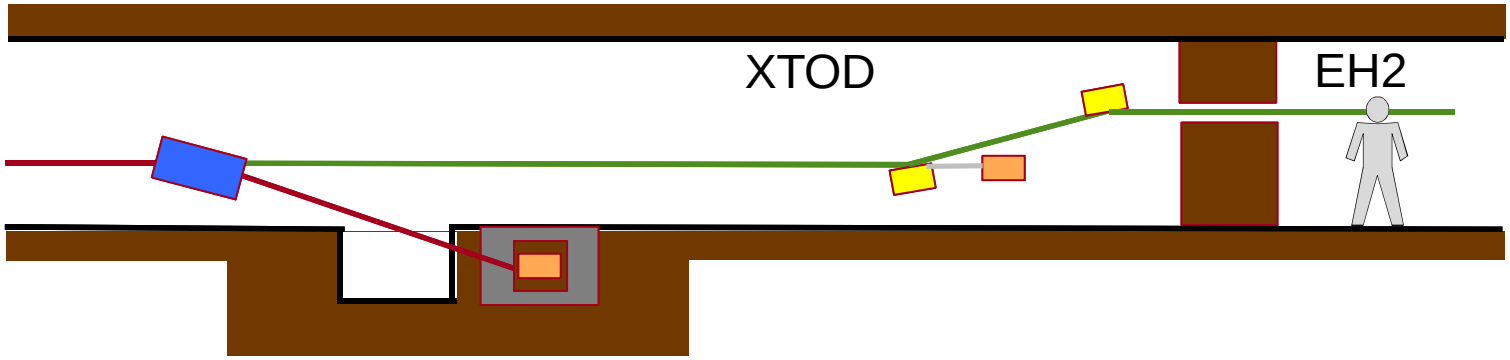


Shielding of the FEE2 (XTOD)

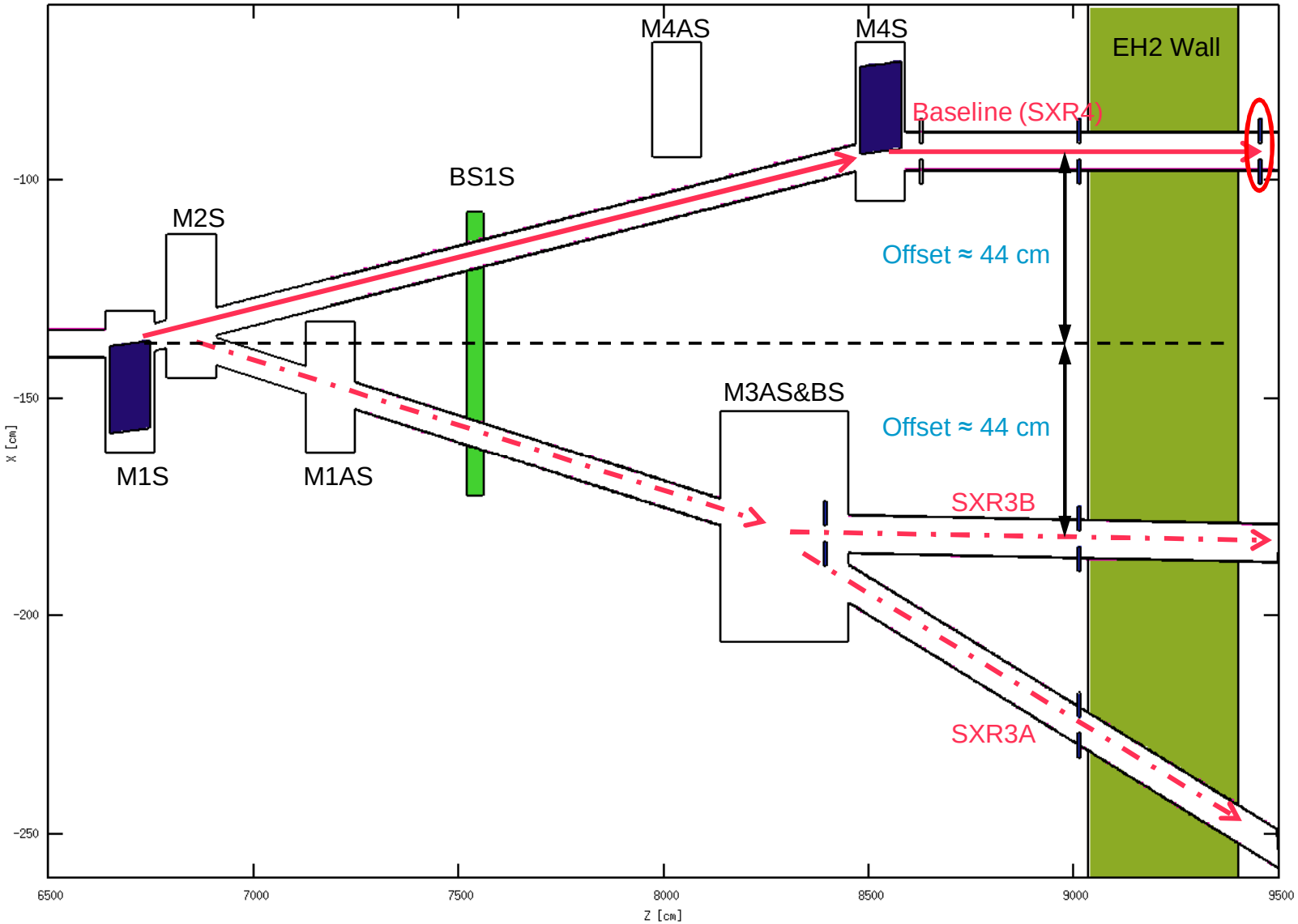
LCLS-I: Access to FEE requires thick shielding walls with iron to reduce muon dose from high-energy bremsstrahlung or from accident case



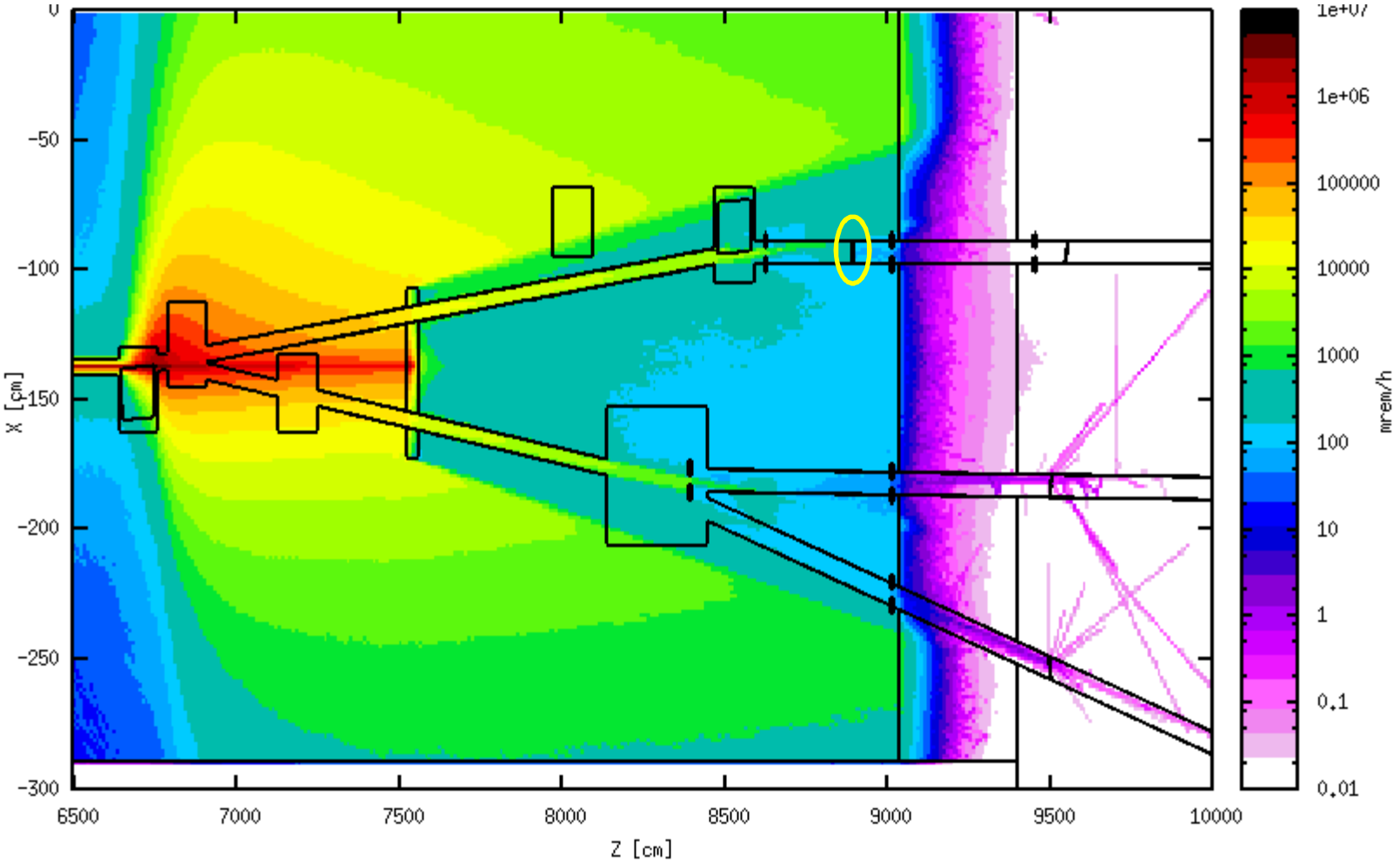
LCLS-II: NO access to XTOD. A safety stopper is located at the zero-degree line behind first FEL mirror to scatter bremsstrahlung radiation or un-steered electrons.



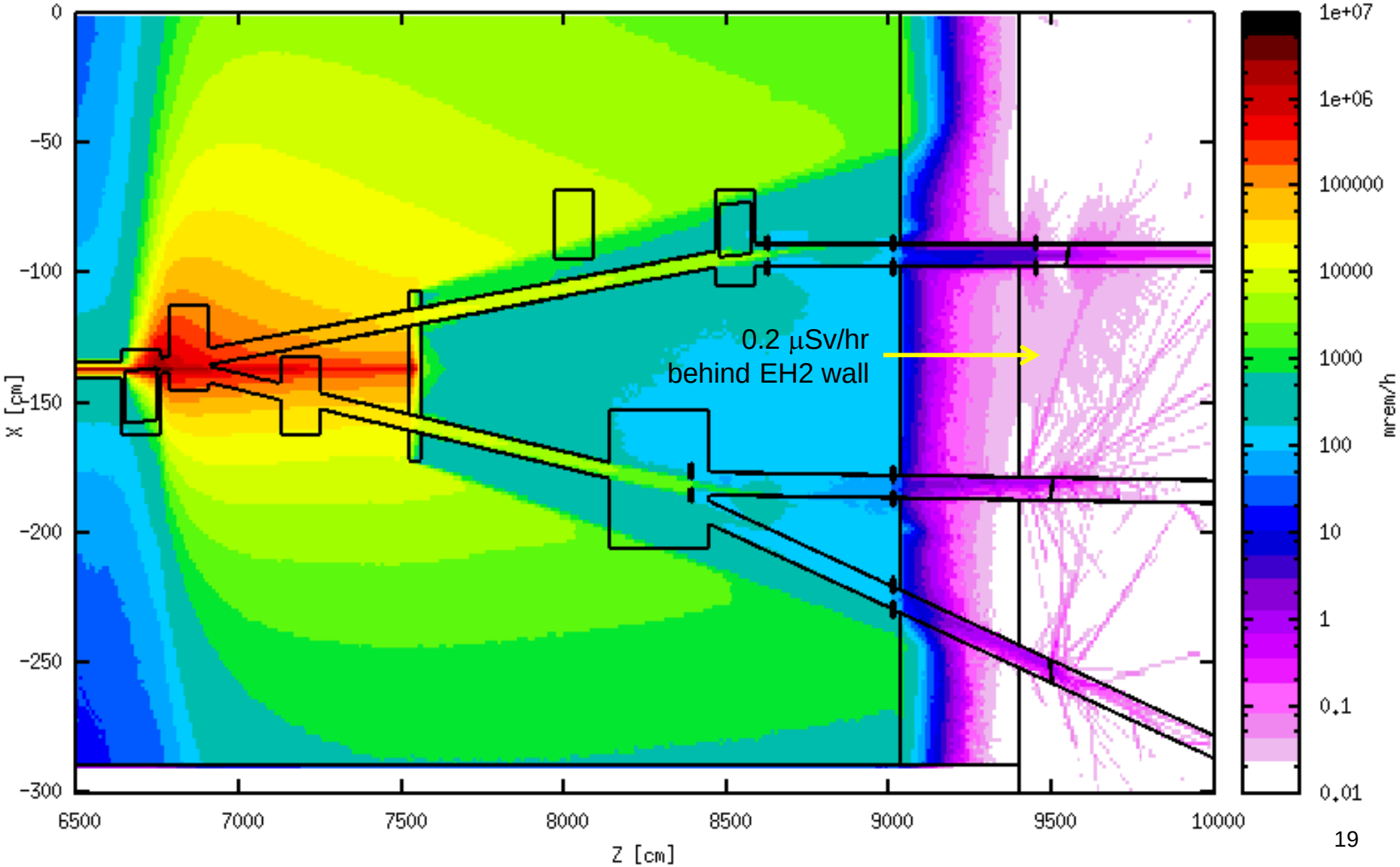
XTOD collimation, safety stopper



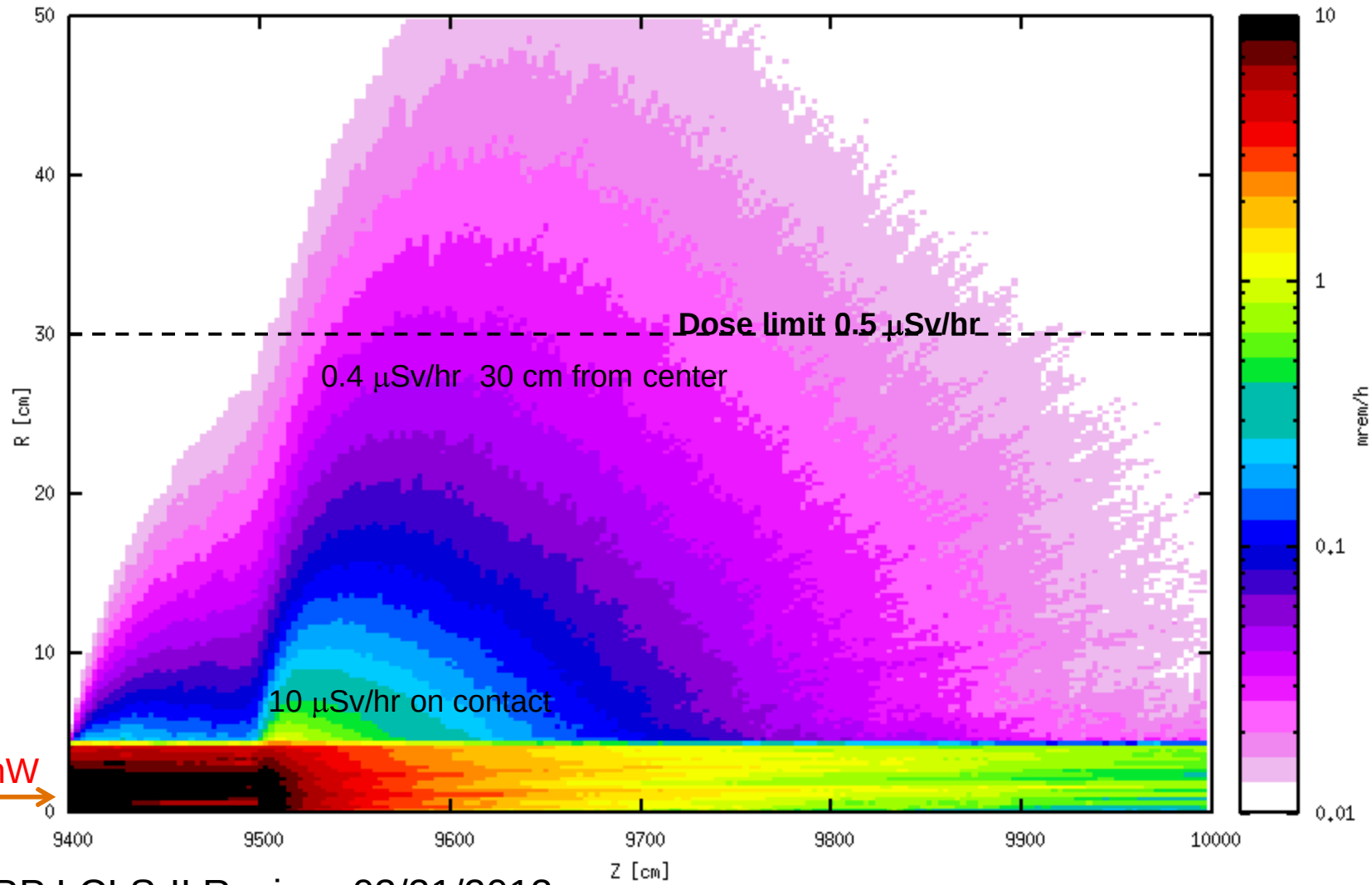
PPS shutter – closed



Plan view of total dose- normal operations

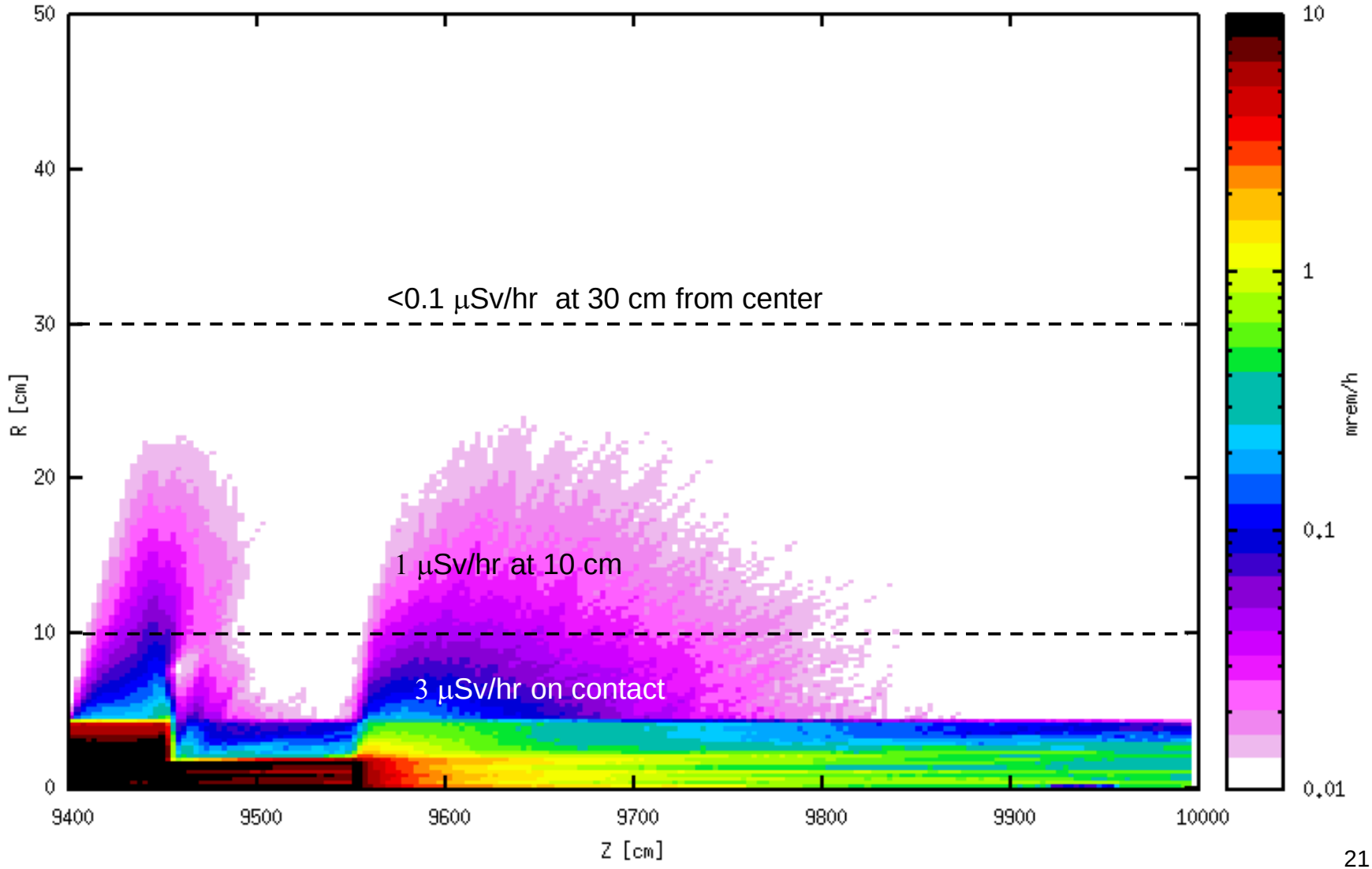


Total dose in EH2 from leakage

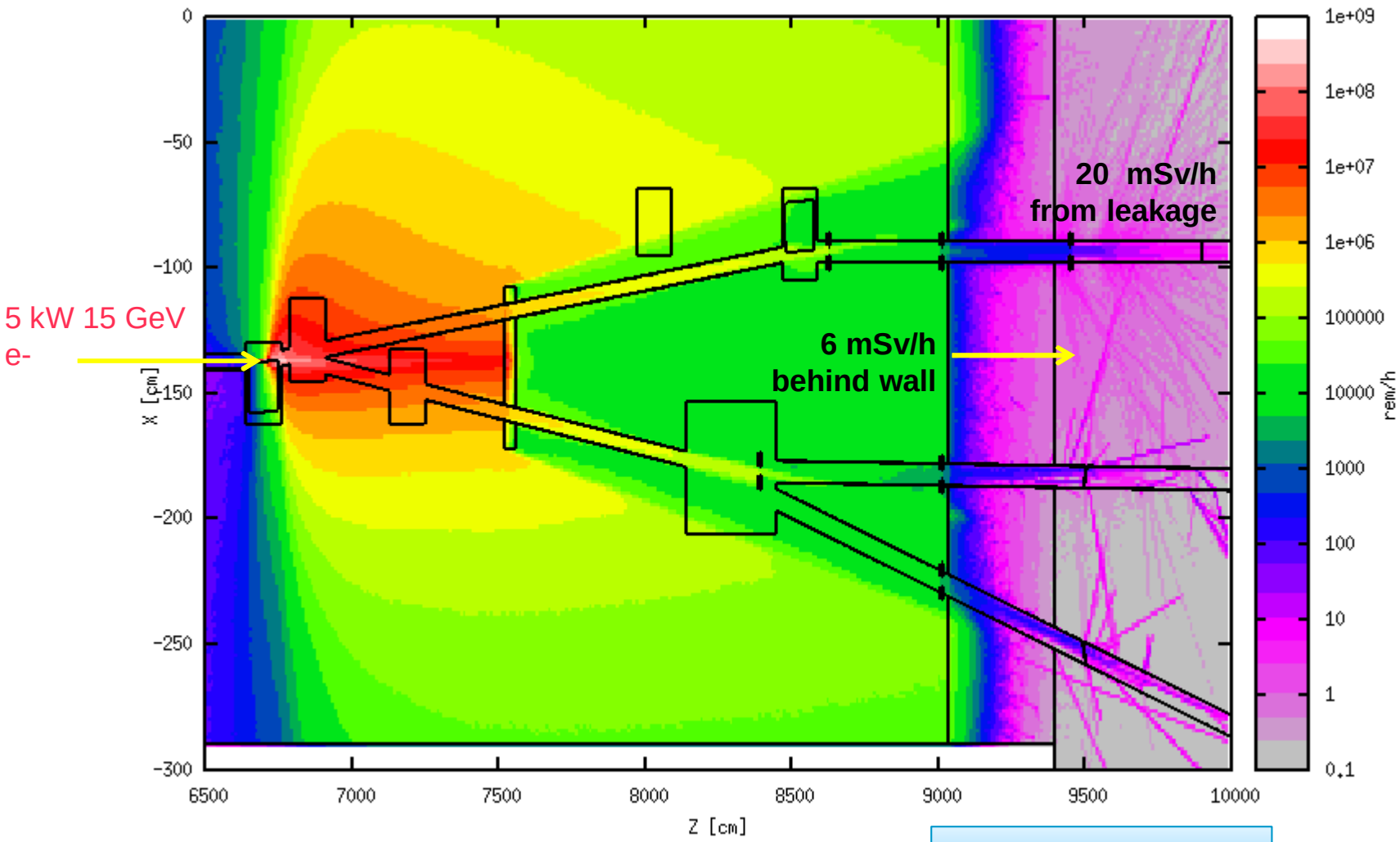


100 nW

Total dose in EH2 from leakage- after collimation



Radiation dose- failure mode



Direct shower on shielding

Lessons learned from LCLS-I

- Risks associated with zero-degree radiation are now better understood
- More accurate beam loss assumptions are available
- Experience with Beam Containment Systems in the critical areas of LCLS-I is a great advantage for LCLS-II design
  - No need for a dedicated FEE
- Electron beam containment analysis should address the beam line globally, not in sections
- Monte Carlo calculations and tools necessary for critical LCLS designs have been developed, benchmarked and optimized

Summary

- LCLS-II will expand the physics capabilities and help supply beam for the large user demand
- LCLS-II RP studies meet several challenges:
  - High energy, high power **beam points towards users**
  - **Complex access modes**: interaction between several accelerators (FACET, ESA, LCLS-I, LCLS-II) and beamlines, SXR, HXR
  - Underground tunnel (prevention of ground water activation) and also exterior building (lateral shielding, skyshine)
  - Several prompt radiation fields: high-energy muons, neutrons, photons and also wide spectrum of spontaneous and FEL radiation
  - Very aggressive project schedule

Summary

- The bulk RP studies for design of the shielding have been performed contributing to the success in the DOE design reviews
- Much work remains to have the first light in 2018
- Many thanks to the following for for their participations in various reviews of LCLS-II:
  - Alberto Fasso (SLAC/CERN)
  - Stefan Roesler (CERN)
  - Hee-Seock Lee (Pohang/FEL),
  - Rick Donahue (LBNL/NGLS)
  - Yoshihiro Asano (SPRING8/SACLA)

END