Accelerator Perspectives in the Americas

Andrew Hutton

Jefferson lab

Overview of Projects

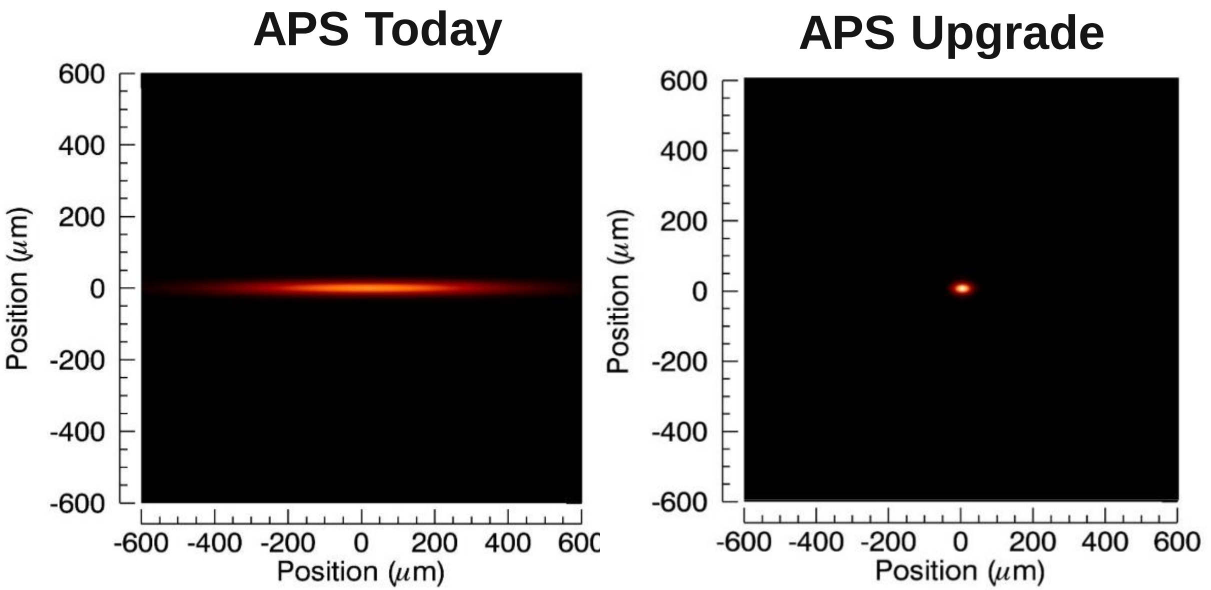
- Projects under construction
  - APS-U at Argonne National Lab
  - C-Beta at Cornell University
  - FRIB at Michigan State University
  - LCLS-II at SLAC, Stanford
  - PIP-II at Fermilab
  - Sirius, Campinas, Brazil
- Projects planned (not all will be approved!)
  - ALS-U at Lawrence Berkeley Lab
  - eRHIC at Brookhaven National Lab
  - JLEIC at Jefferson Lab
  - MARIE at Los Alamos National Lab
  - SNS-U at Oak Ridge National Lab

APS Upgrade Project Progress

The APS Upgrade: Building the world's leading high-brightness hard x-ray synchrotron facility

The APS Upgrade is a **next-generation** facility:

- Optimized for hard x-rays
- Incorporating advanced beamlines, optics and detectors
- 'Round' source ideal for imaging



APS-U exceeds the capabilities of today's storage rings by **2 to 3 orders of magnitude** in brightness, coherent flux, nano-focused flux

Powers the **entire beamline suite** to meet the needs of APS' community of >5,000 unique users per year

World's brightest storage ring light source above 4 keV

APS Upgrade Project Scope

New storage ring
- 6 GeV MBA lattice
- 200 mA current
- Improved electron/photon stability

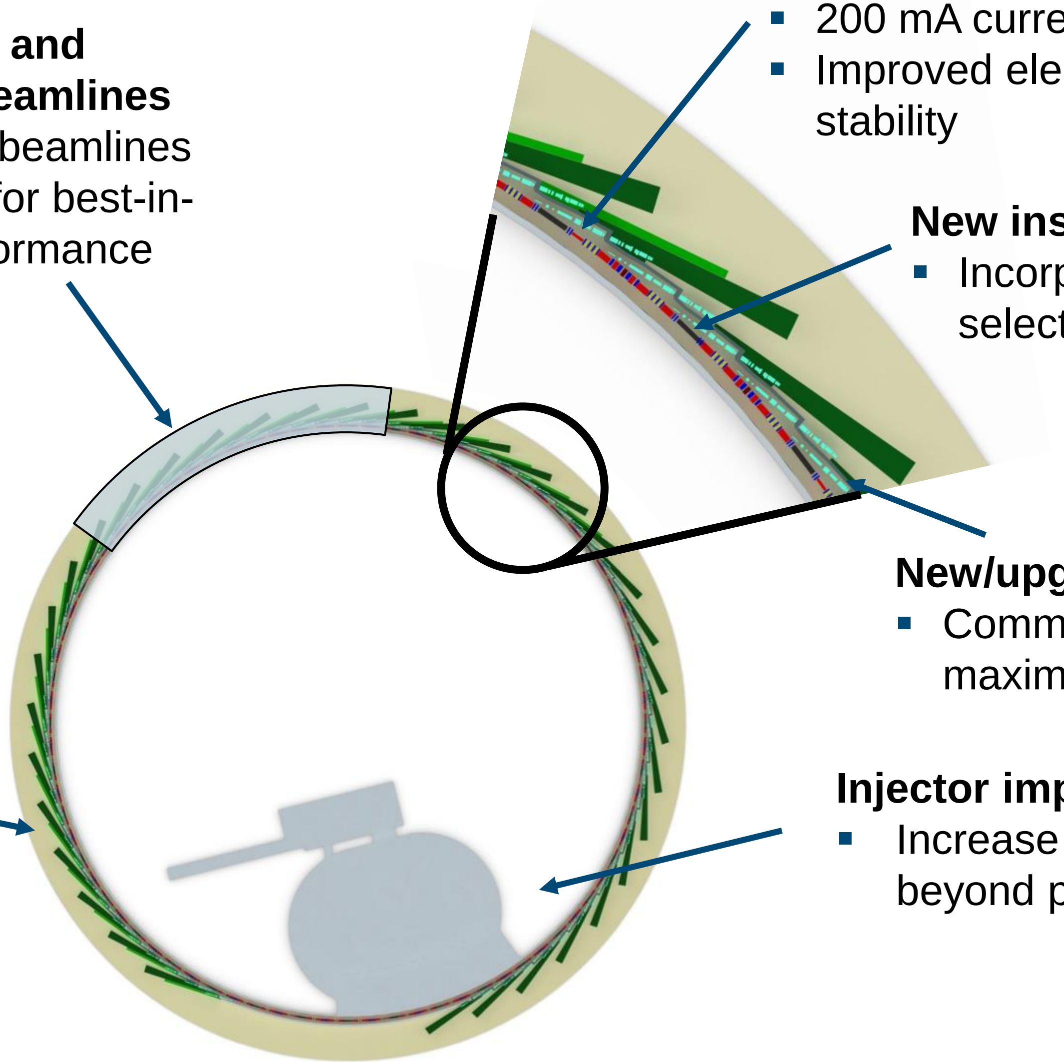
New, rebuilt and upgraded beamlines
- Suite of 8 beamlines designed for best-in-class performance

New insertion devices
- Incorporate SCUs on selected beamlines

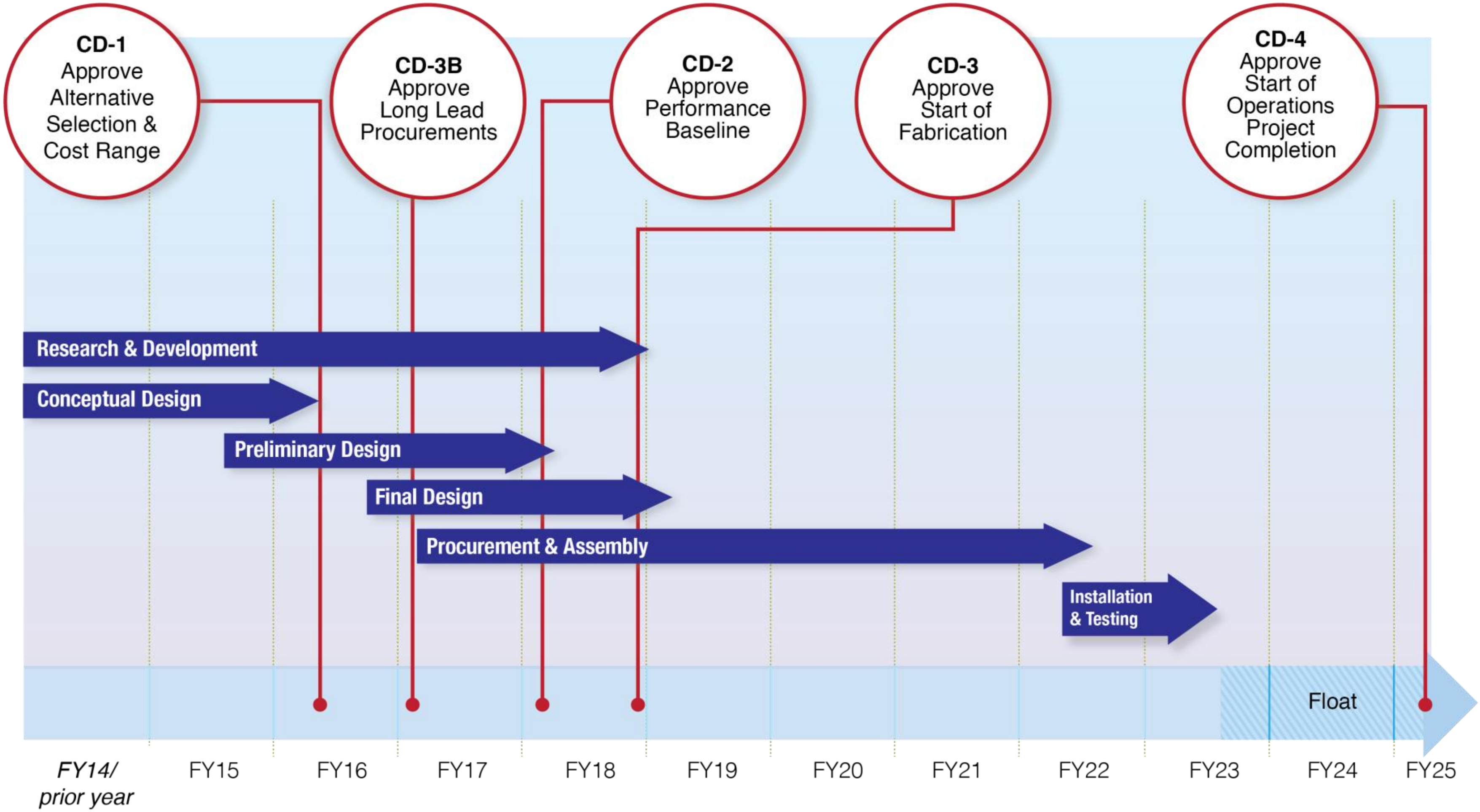
Beamline Enhancements:
- Improvements to make all beamlines 'Upgrade Ready'

New/upgraded front-ends
- Common design for maximum flexibility

Injector improvements
- Increase performance beyond present capability



APS Upgrade Project Schedule



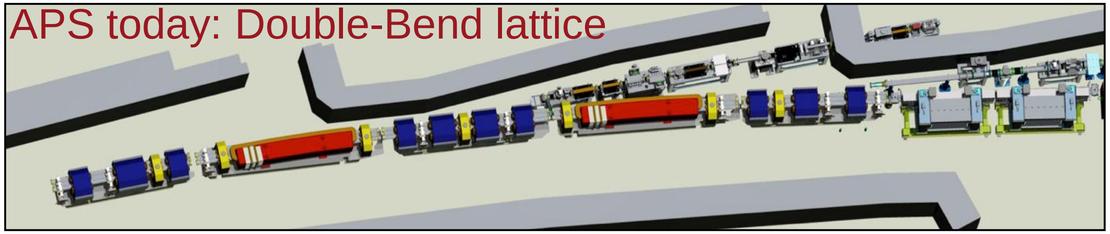
This schedule is based on proposed funding profile

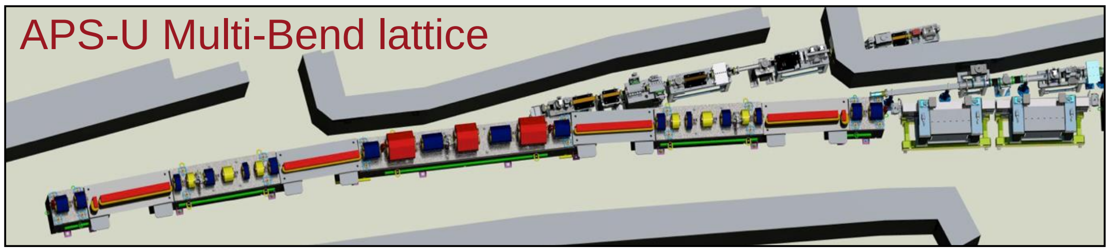
From the technical point of view the project is ready to proceed more rapidly

Argonne NATIONAL LABORATORY

APS-U design concept

~50-fold reduction in horizontal emittance





$$\varepsilon_x = C_L \frac{E^2}{N_D^3}$$

E = Beam energy
N_D = Number of dipoles per sector

– J. Murphy, BNL-42333

APS Upgrade Features

- 4th generation storage ring based on multi-bend achromat lattice
- Design for high-brightness, ultra-low emittance: ε_x < 75 pm goal (objective KPP)
- Diffraction limited vertical emittance to 15 keV, horizontal emittance to 2 keV
- Flexible operation: High-brightness and timing modes, round and flat beams
- Reuse existing infrastructure valued at $1.5B
- World leading experimental capabilities with a suite of new/rebuilt/heavily-upgraded state-of-the-art beamlines included in the project
- 35 ID straight sections with full suite of ~69 operating beamlines in APS-U era
- One-year dark period is a key project deliverable

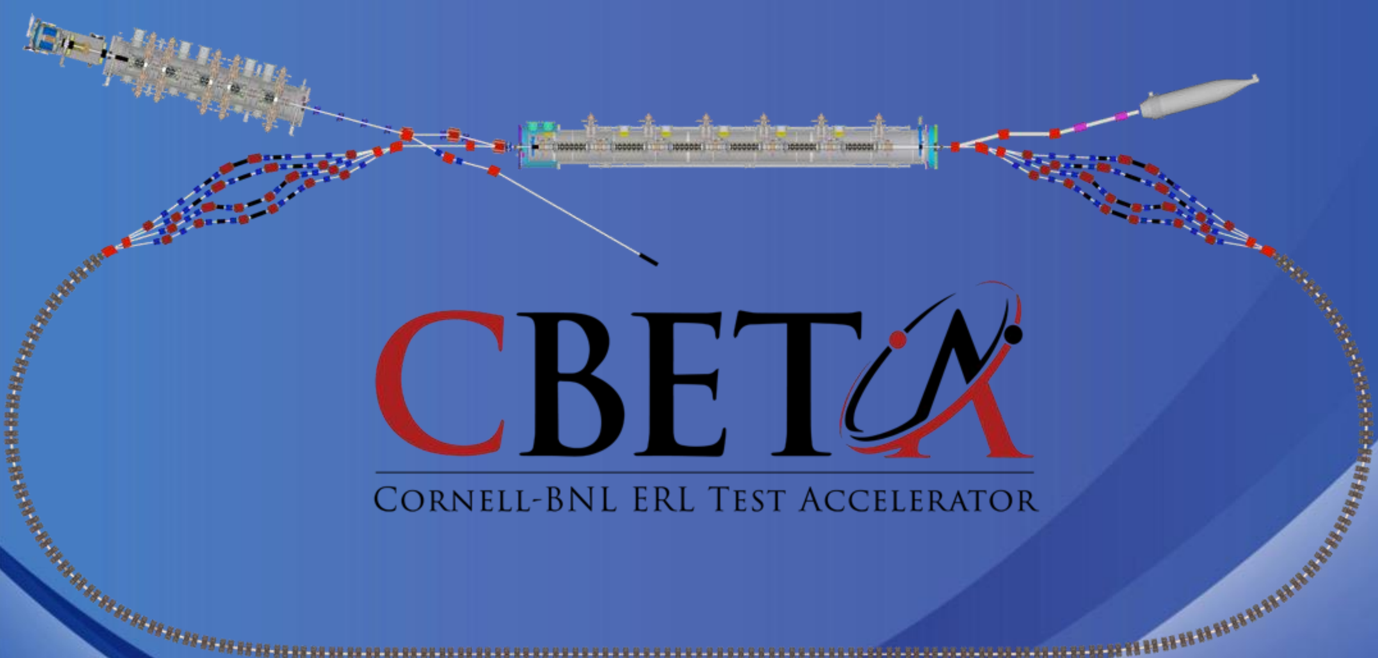
Components

- The total project cost is $770M (US accounting)
  - Approximately 2/3rds estimated for production hardware components
- 1320 resistive magnets
- 1.1 km storage ring vacuum system
- 120 plinths, support plates and associated mounting systems
- Approximately 35 complete front-end systems (masks, vacuum systems)
- Beam diagnostics:
  - >500 BPMs
  - ~40 X-ray BPM systems

The Cornell/BNL FFAG-ERL Test Accelerator: CBETA

A 4-turn SRF ERL with FFAG return arc

Georg Hoffstaetter (Cornell)



BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

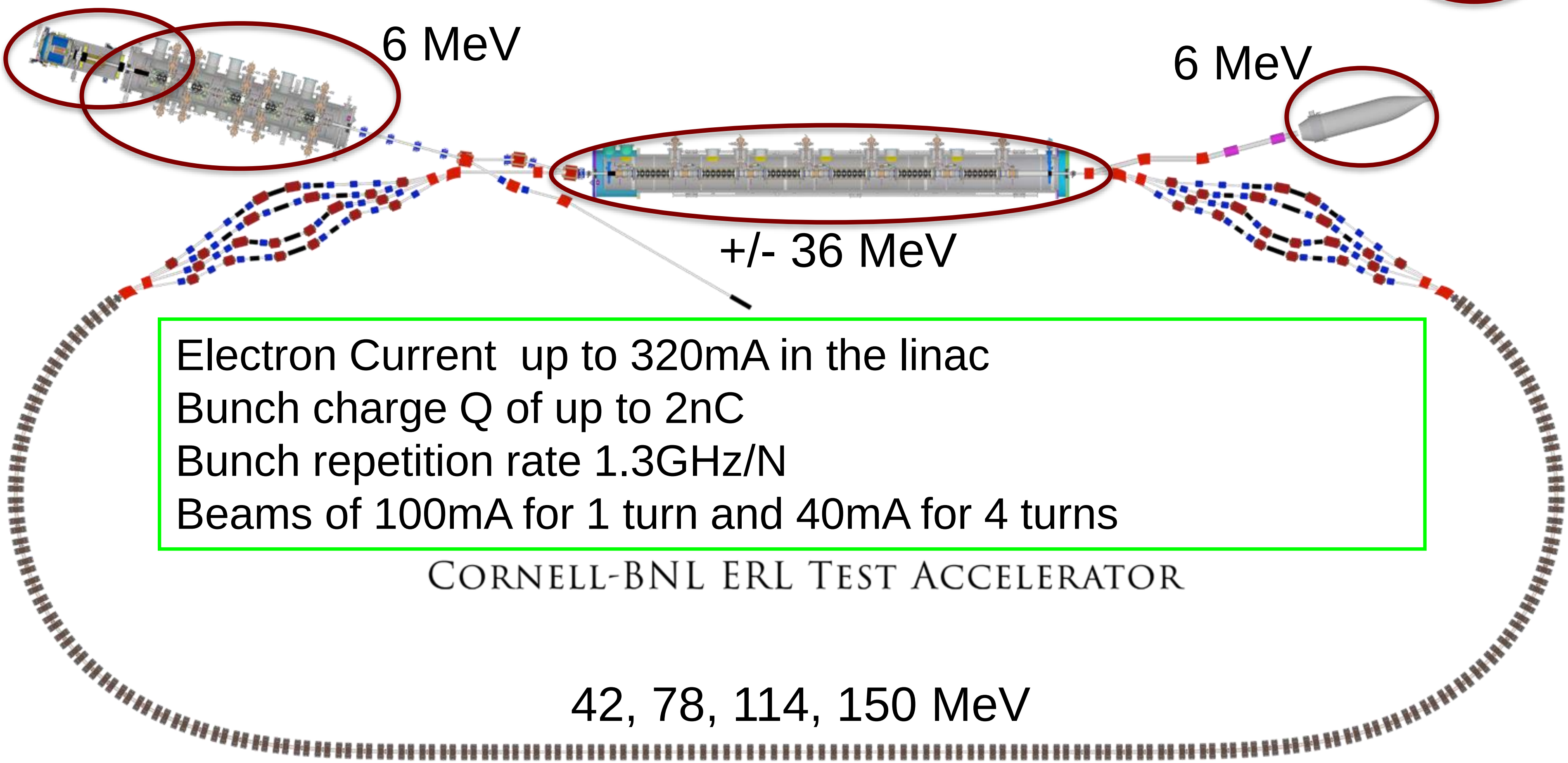
Office of Science
U.S. DEPARTMENT OF ENERGY

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

The test ERL in Cornell's hall LOE

- Cornell DC gun
- 100mA, 6MeV SRF injector (ICM)
- 600kW beam dump
- 100mA, 6-cavity SRF CW Linac (MLC)

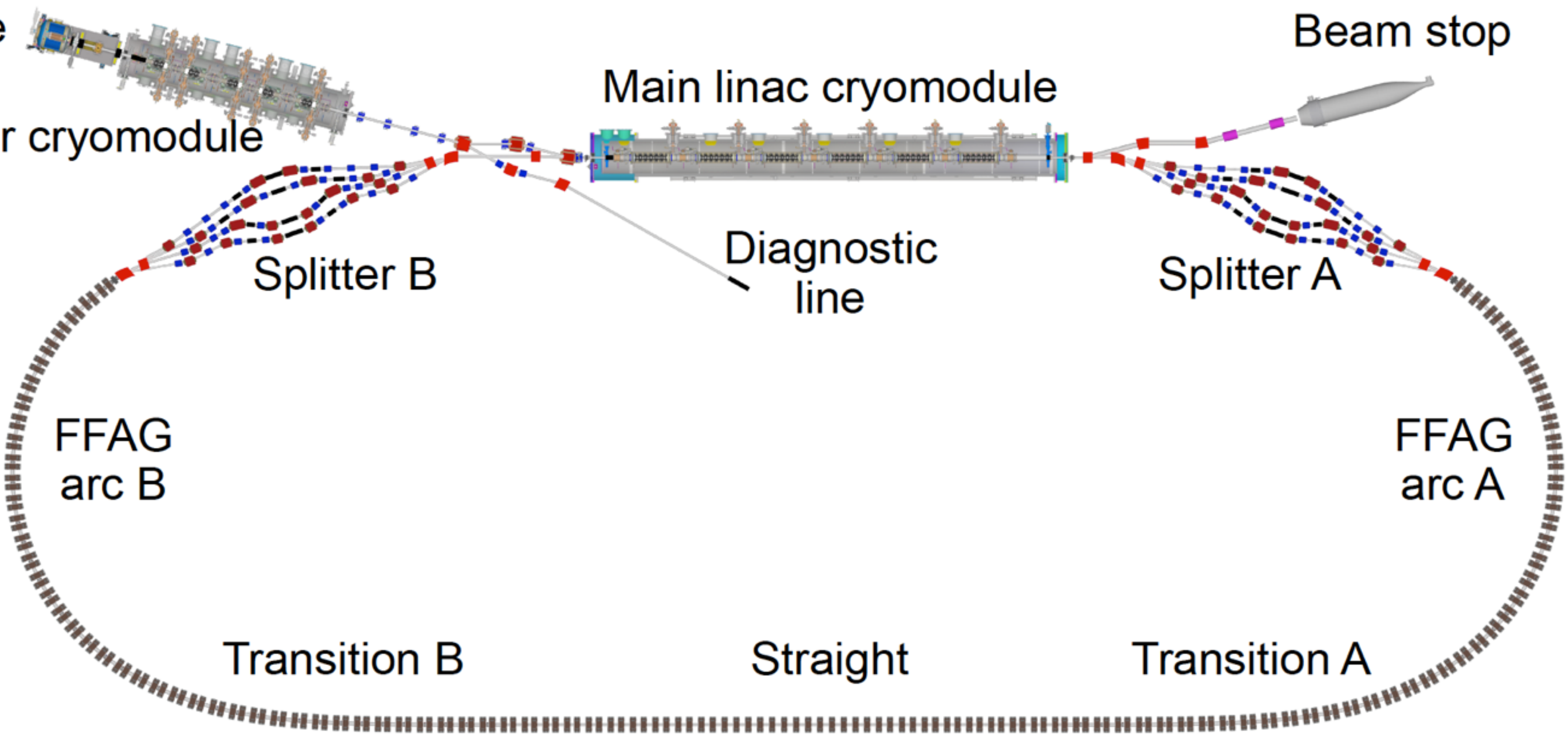
Existing components at Cornell



Electron Current up to 320mA in the linac
Bunch charge Q of up to 2nC
Bunch repetition rate 1.3GHz/N
Beams of 100mA for 1 turn and 40mA for 4 turns

Existing & new equipment

CBETA



Much equipment & infrastructure exists — 32 M$

Major new equipment:

- 2 splitters (electromagnets & tables)
- FFAG arc permanent magnets
- Diagnostics, power supplies etc.

- The most expensive items still to be purchased are:
- Six 1.3GHZ, 5kW solid-state amplifiers
- About forty 2m long girders form precision magnet alignments
- About 80m of vacuum system
- About 50 small (up to about 40cm long) electro magnets with associated power supplies and cabling
- About two hundred Halbach magnets of about 20cm diameter

12 proof-of-principle magnets (6 QF, 6 BD) have been built as part of CBETA R&D.
Iron wire shimming has been done on 3 QFs and 6 BDs with good results.


PoP BD

PoP QF


PoP magnet series

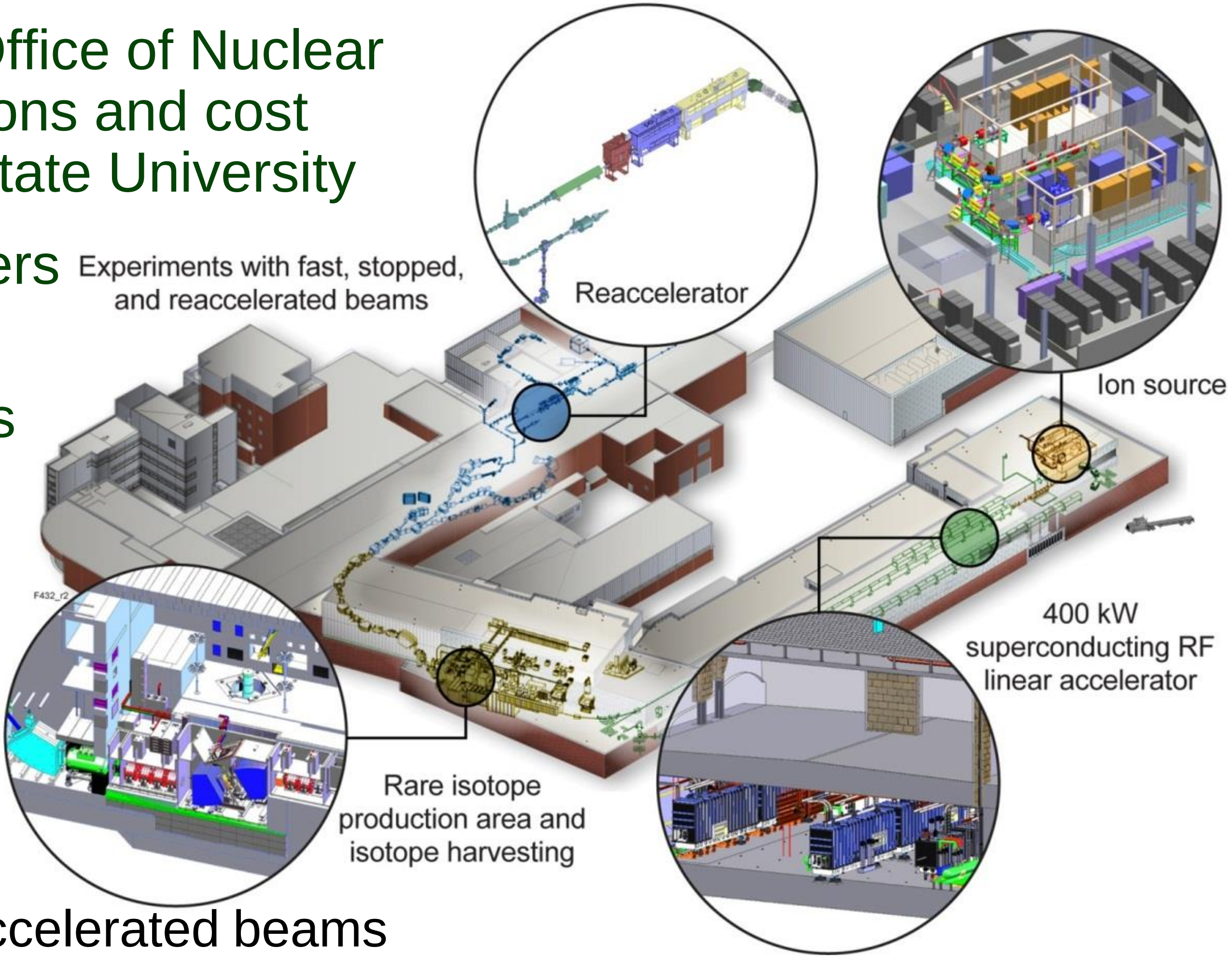
Iron wire shims

FRIB Project Overview

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Facility for Rare Isotope Beams
A Future DOE-SC National User Facility

- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University
- Serving over 1,300 users
- Key feature is 400 kW beam power for all ions (e.g. 5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - All elements and short half-lives
  - Fast, stopped, and reaccelerated beams



Civil and Technical Construction on Track

- June 2009 – DOE-SC and MSU sign Cooperative Agreement
- September 2010 – CD-1 approved, DOE issues NEPA FONSI
- August 2013 – CD-2 approved (baseline), CD-3a approved
- March 2014 – Start civil construction
- August 2014 – CD-3b approved (technical construction)
- FY2021 – Early completion goal
- June 2022 – CD-4 (project completion)
- Recent milestones
  - September 2016 – Beam from Room Temperature ECR Ion Source
  - February 2017 – Fabrication of 3 low-beta cryomodules completed
  - March 2017 – Beneficial occupancy of FRIB buildings

- $730M Total Project Cost (TPC)
  - $635.5M DOE outlay
  - $94.5M MSU cost share
- $306.6M contributions
  - Outside of project baseline
  - Monitored for schedule and performance, all critical items complete

22 March 2017

Successfully Delivering Technical Scope

Major procurements progressing well:

- Accelerator Systems ($124M): 91% costed/committed
- Experimental Systems ($24M): 81% costed/committed

Cold iron quadrupole magnets

Accelerator Systems:

- Linac cryomodules (4 types) – 46 + 3 spares
  - Cavities – 324 + 16 spares
  - Solenoids – 69 + 5 spares
- Room temperature magnets – 151
- Superconducting dipole magnets – 4
- Solid-state RF amplifiers (5 types) – 220
- Cryogenic transfer lines – 49
- Network switches – 164
- Room temperature magnet power supplies – 314
- Superconducting magnet power supplies – 278
- High voltage power supplies – 74
- Diagnostics – 608 total devices
  - Beam position monitors – 150
  - Fast thermometry for beam loss - 240
- 4 K and 2 K Cryogenic plants
- Radio Frequency Quadrupole
- Charge state stripper
- Low- and high-level controls

Experimental Systems:

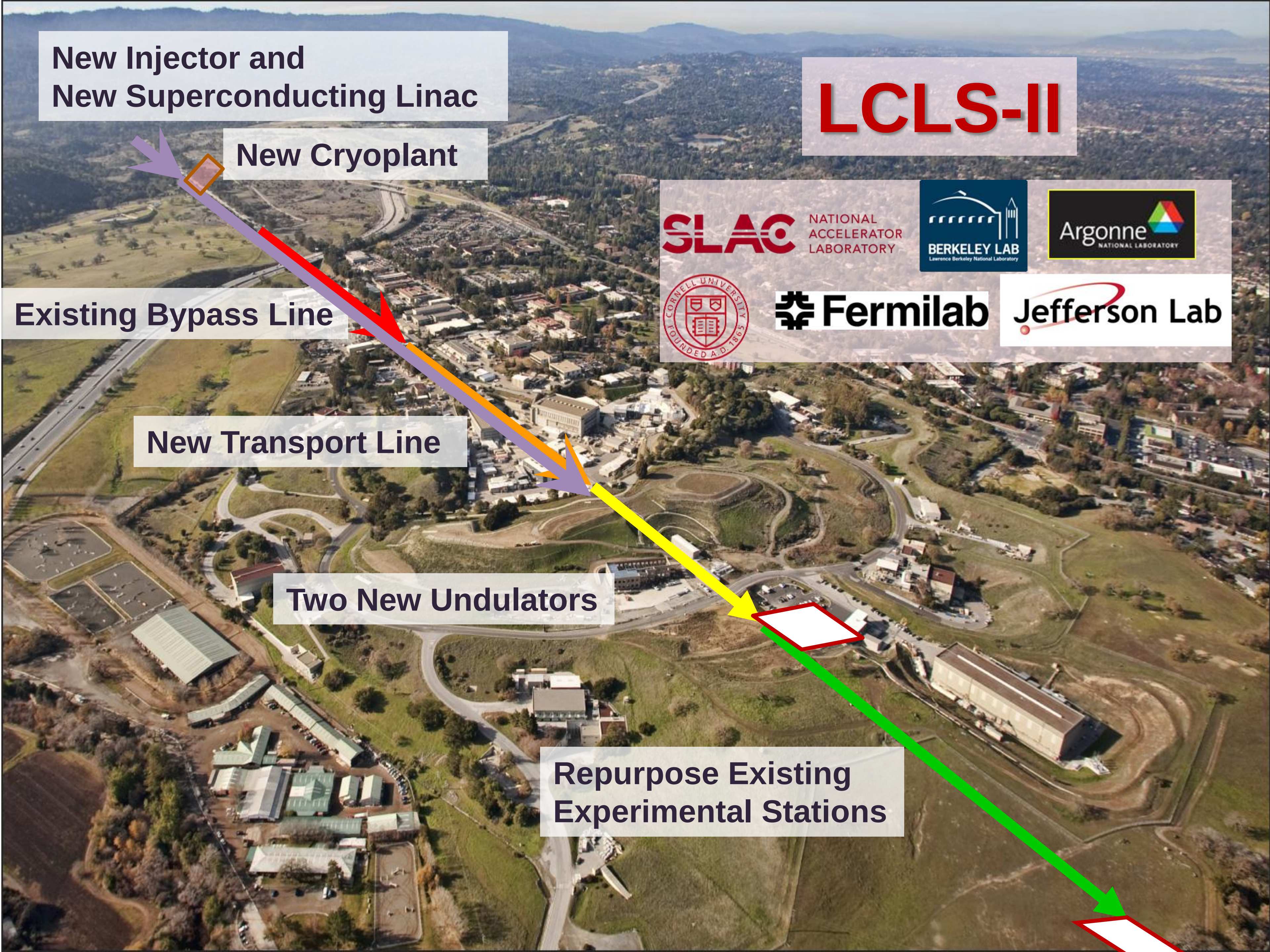
- Preseparator magnets
  - Superconducting dipoles – 4
  - Superconducting cold iron quads – 4
  - Superconducting warm iron quads – 4
  - Room temperature magnets – 2
- Large vacuum vessels – 3
- Remote handling gallery
- Target, beam dump, and wedge
- Cooling water processing loops – 2

Wedge vacuum vessel

4K cold box

Radio frequency quadrupole

Beta=0.041 cryomodule



LCLS-II
New Injector and
New Superconducting Linac
New Cryoplant
Existing Bypass Line
New Transport Line
Two New Undulators
Repurpose Existing
Experimental Stations
SLAC NATIONAL ACCELERATOR LABORATORY
BERKELEY LAB
Argonne NATIONAL LABORATORY
Fermilab
Jefferson Lab

SLAC Relies on Highly Capable Partners with Unique Competencies to Deliver LCLS-II

Fermilab

- Cryomodule engineering/design
- Manufacture 50% of cryomodules: 1.3 GHz
- Design and manufacture 2 Cryomodules: 3.9 GHz
- Design and acquisition of helium distribution
- Processing for high Q (FNAL-invented gas doping)

Jefferson Lab — EXPLORING THE NATURE OF MATTER

- Manufacture 50% of cryomodules: 1.3 GHz
- Design and acquisition of two 4 kW Cryoplants
- Processing for high Q

Berkeley Lab

- Undulators
- e^- gun & associated injector systems

Argonne National Laboratory

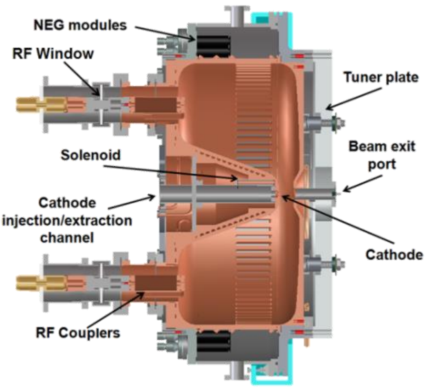
- Undulator R&D: vertical polarization prototype
- Undulator Vacuum Chamber
- Also supports FNAL w/ SCRF cleaning facility

Cornell University — Founded A.D. 1865

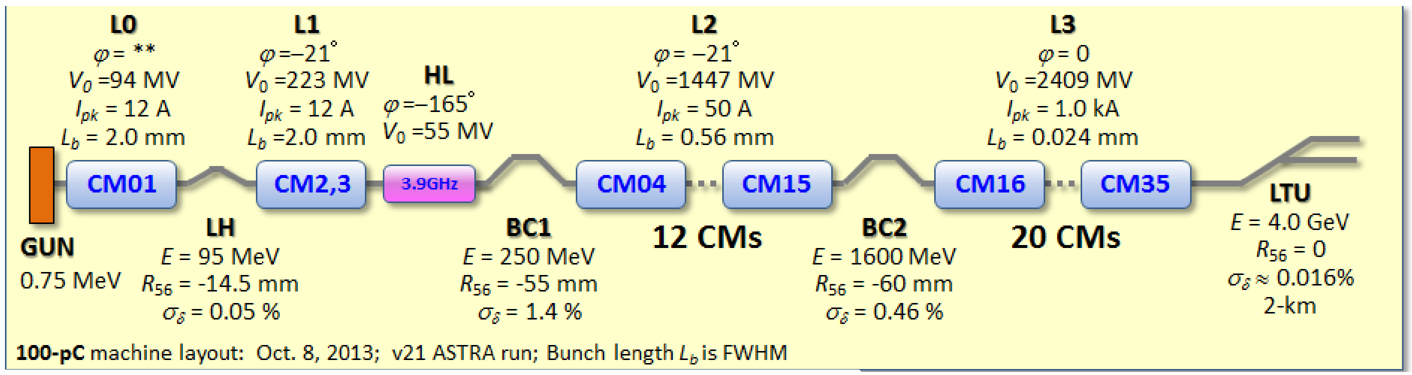
- R&D planning, prototype support
- processing for high-Q (high Q gas doping)
- e^- gun option

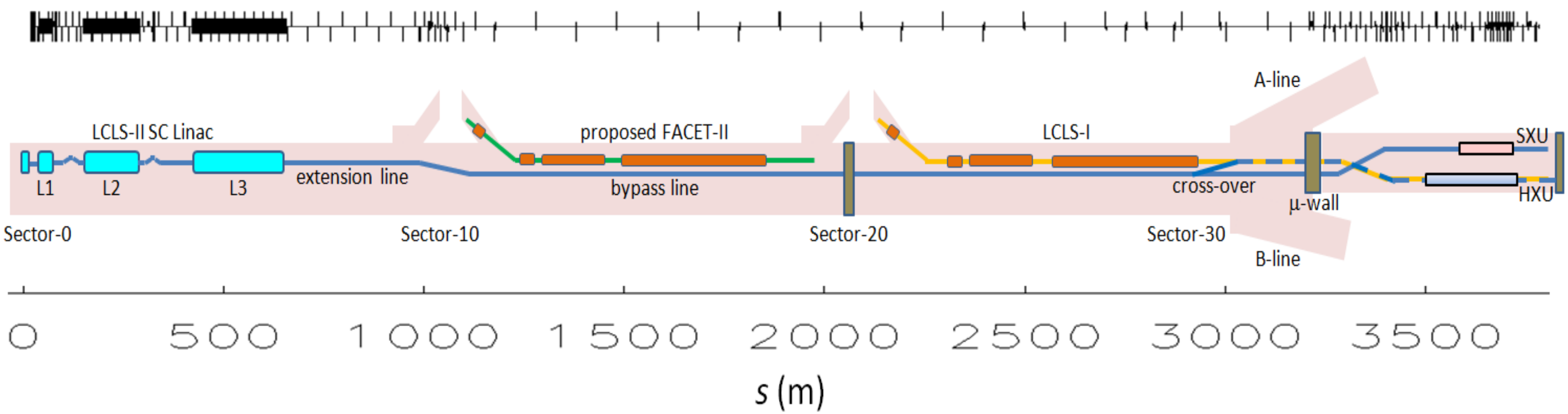
Electron source, linac and transport Scope

186 MHz CW gun,
Cs_2Te photocathode



4 GeV linac:
1.3 GHz: 35 cryomodules, 8 cavities/module, 9 cells/cavity
3.9 GHz: 2 cryomodules, 8 cavities/module, 9 cells/cavity





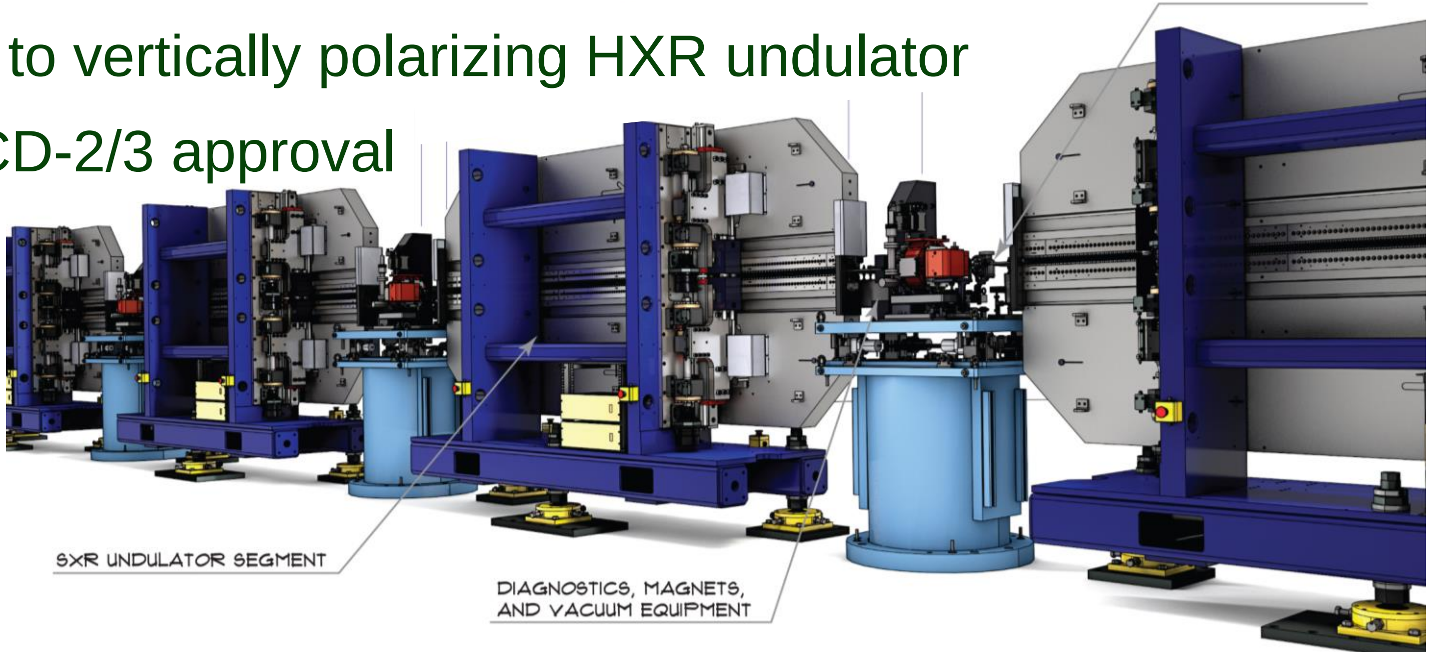
Cryogenic Systems Scope

Component	Count	Parameters
Linac	4 cold - segments	35 each 8 cavity Cryomodules (1.3 GHz) 2 each 8 cavity Cryomodules (3.9 GHz)
1.3 GHz Cryomodule	8 cavities/CM	13 m long. Cavities + SC Magnet package + BPM
1.3 GHz 9-cell cavity	280 each	16 MV/m; Q_0 ~ 2.7e10 (avg); 2.0 K; bulk niobium sheet - metal
Cryoplant	2 each	4.5 K / 2.0 K cold box system; 18 kW @ 4.5 K equivalent
Cryo Distribution	260 m vacuum-jacketed line, 2 each distribution boxes, 6 each feedcap / 2 each endcap	

- Closely based on the ***European XFEL / ILC / TESLA*** Design
  - 20 year old design with ***> 1000 cavities*** built
  - SC Cavities use ***Nitrogen Doping***
- ***CEBAF-12 GeV Upgrade Cryoplant*** adapted

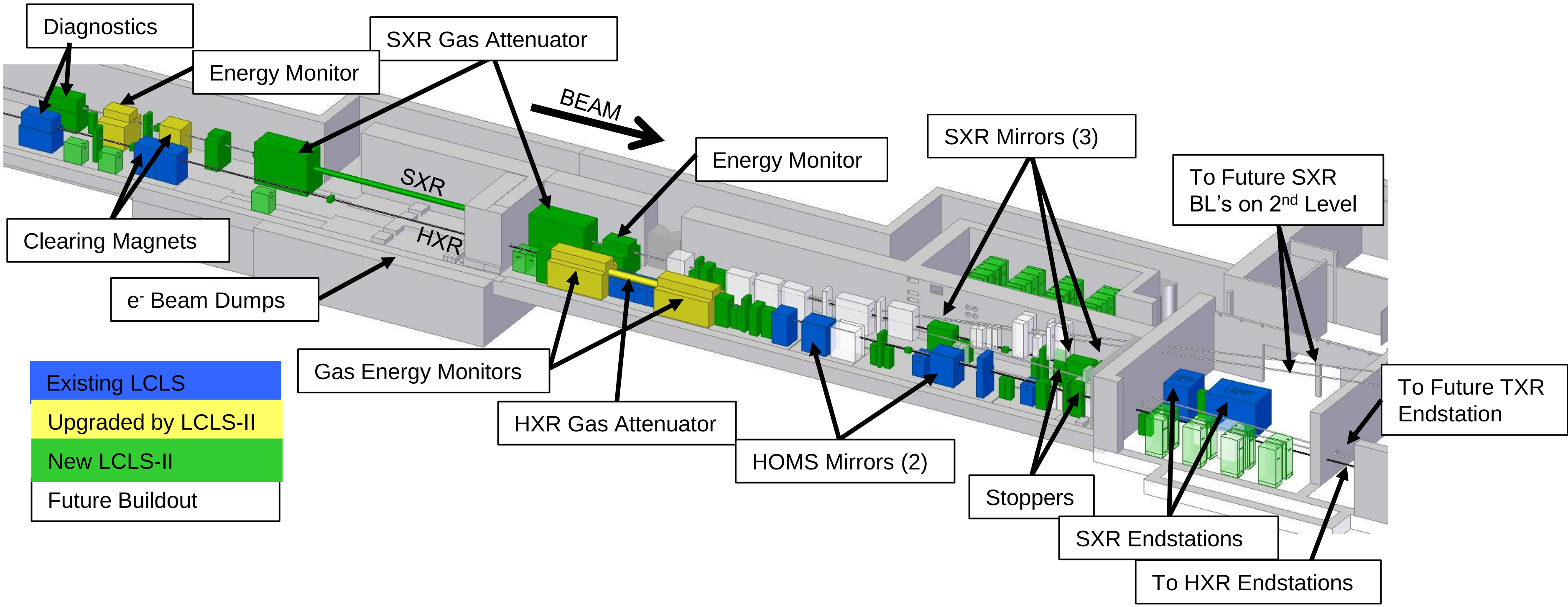
Undulators Scope

- Two Horiz. Pol. variable gap undulator systems
  - HXR 1 to 5 keV w/ SC Linac, 1 to 25 keV w/ Cu Linac
  - SXR 0.2 to 1.3 keV w/ SC Linac
- The LBNL horizontally polarizing undulators are at final design
- Self-seeding
  - HXRSS 4 to 12 keV w/ existing system
  - SXR 0.2-1.3 keV w/ system for high rep-rate
- Change to vertically polarizing HXR undulator
  - before CD-2/3 approval

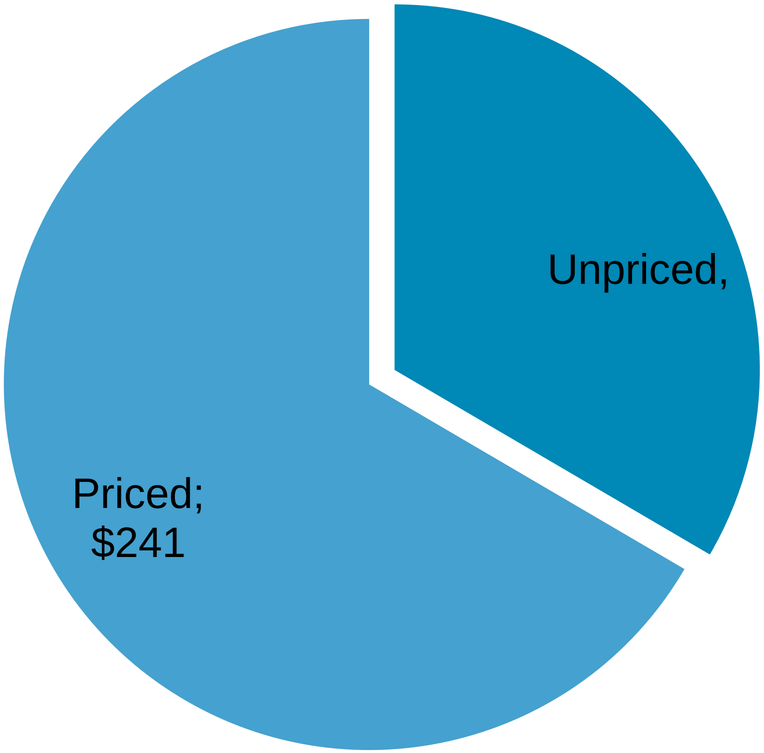


Scope - X-ray Transport & Experimental Systems (XTES):

- Layout accommodates LCLS build out plans
- X-ray transport and diagnostics to 5 existing HXR stations
  - Use existing upgraded HOMS mirrors in front end
- X-ray transport and diagnostics to new SXR station
  - Distribution and focusing mirrors, controls and DAQ
  - Designed to use existing LCLS experimental chambers



LCLS II Procurement Status, $362 Mil Total Scope (raw $)



- 66% ($241 Mil)of Procurement baseline priced
- Most Cryoplant, Cryomodule, Undulators, and Linac equipment (SSA, Waveguide) all under contract
- Some ancillary cryoplant equipment (2K coldboxes, dewars, etc.) is still in pre-solicitation
- Most remaining contracts are related to installation at SLAC
  - Cryoplant installation
  - Accelerator and Cryomodule installation
  - Controls and Cable Installation

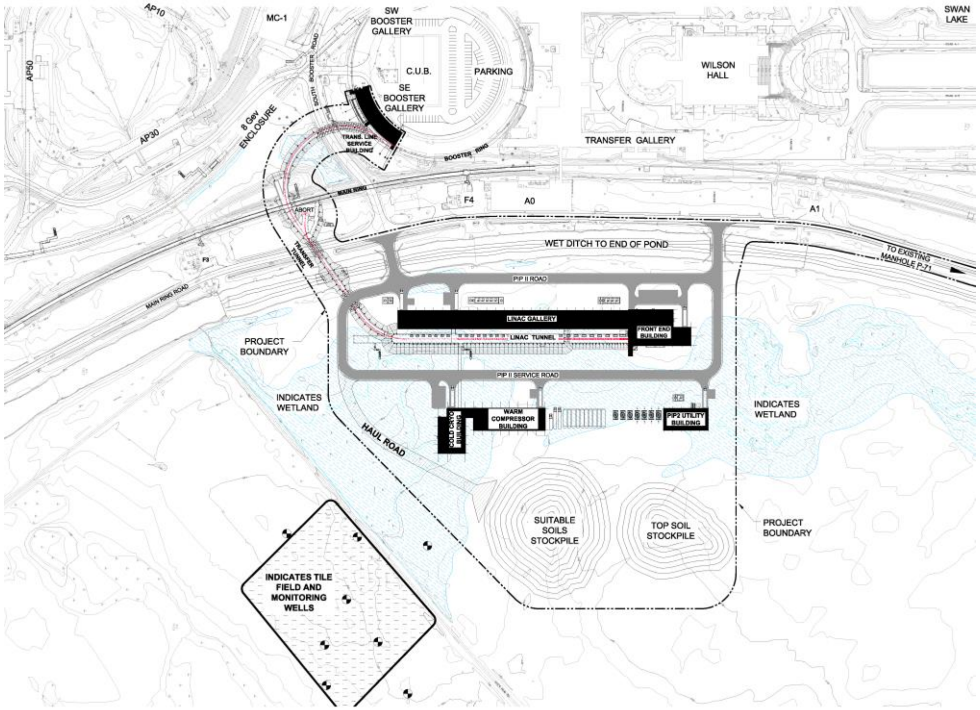
PIP-II Overview

Steve Holmes

What is PIP-II?

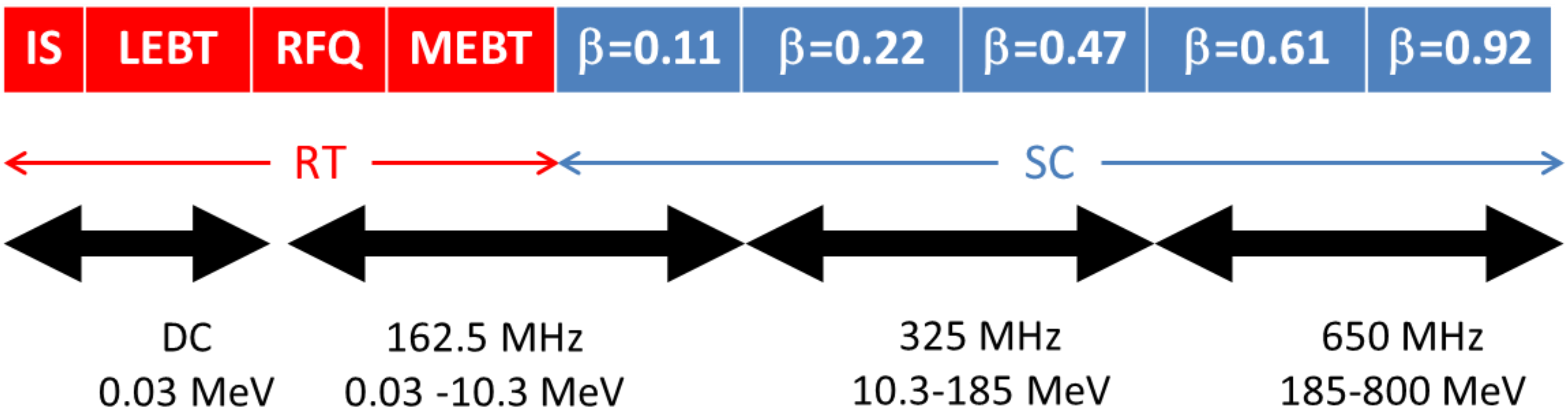
Proton Improvement Plan-II (PIP-II) is a Fermilab-based accelerator project

- Deliver world-leading beam power to the U.S. neutrino program (1.2-2.4 MW)
- Provide a platform for future development of the Fermilab accelerator complex based on high-intensity proton beams
- Based on replacing the existing 400-MeV room temperature linac with a new 800-MeV superconducting proton linac



Fermilab PIP-II

PIP-II Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_g=0.61)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_g=0.92)	650	500-800	24/8/4	5-cell elliptical, doublet*

*Warm doublets external to cryomodules

All components CW-capable

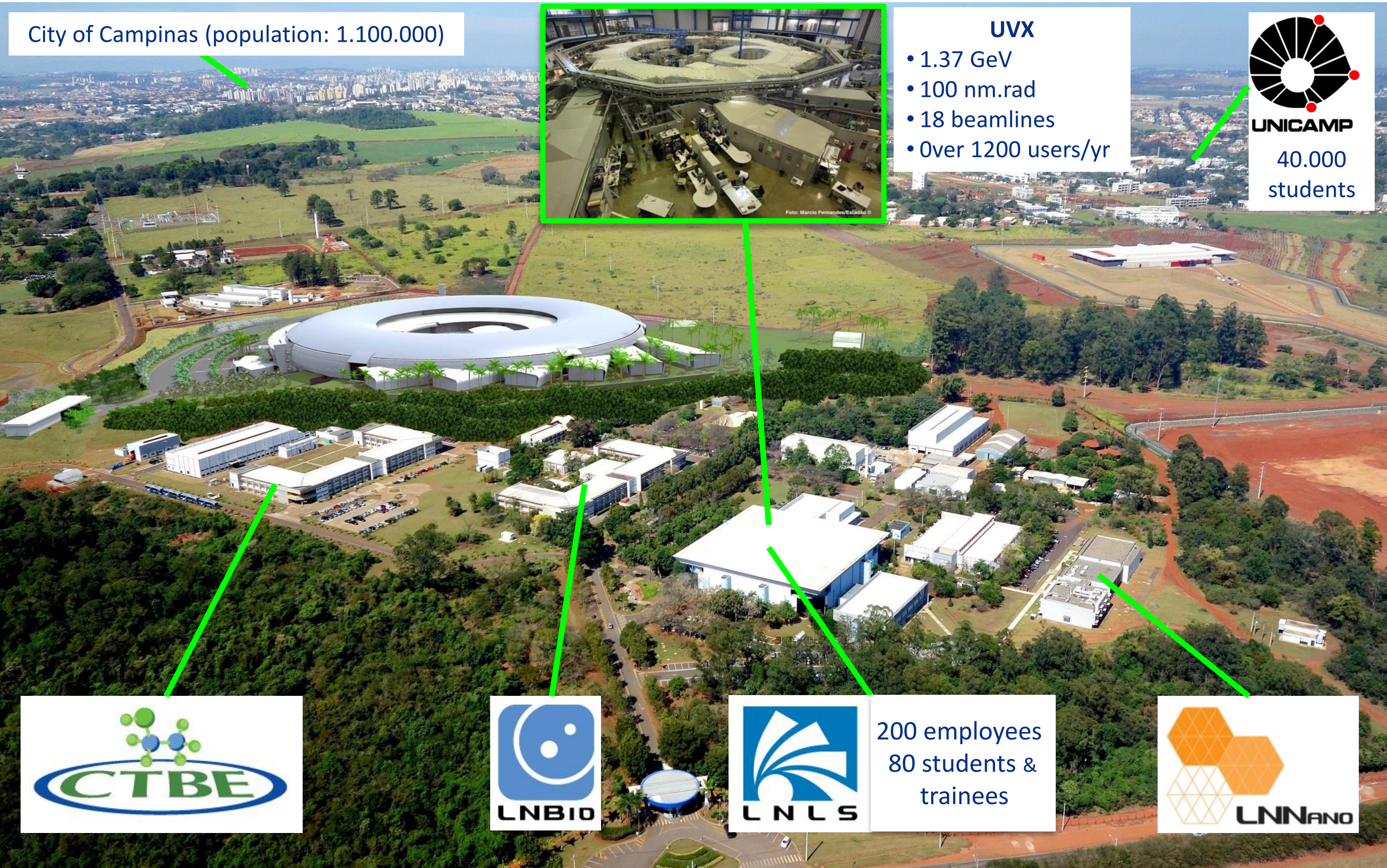
Technical Components

- RF accelerating structures
  - 116 superconducting cavities (+ spares) of five different types
  - Assembled into 25 cryomodules
- RF Sources
  - 116 RF sources from 162.5 MHz to 650 MHz/7 to 70 kW
  - Solid state amplifiers are assumed
- Magnets + Power Supplies
  - Linac: 37 superconducting solenoids and 40 normal-conducting quadrupoles; 20 2-plane correction dipoles
  - Beam transfer line: 42 dipoles, 57 quadrupoles, 56 1-plane correction dipoles
- Cryoplant
  - 1900 W at 2K
- Instrumentation for the above

Project Status

- Mission Need Statement/CD-0 approved November 2015
  - Draft Conceptual Design Report is available
  http://pip2-docdb.fnal.gov/cgi-bin/ShowDocument?docid=113
- Construction period (MNS): FY2019-FY2025
- Cost range (MNS): $465-$650M
  - Cost to U.S. DOE after international contributions
- Significant international in-kind contribution is likely
  - India/DAE (authorized) and Italy/INFN (in discussion)
- R&D program underway focusing on
  - Front end development (0-25 MeV): PIP-II Injector Test
  - SRF Development
  - Undertaken with DAE and INFN

CNPEM Campus



Sirius building construction

First beam 2018 – Open in 2019

Budget

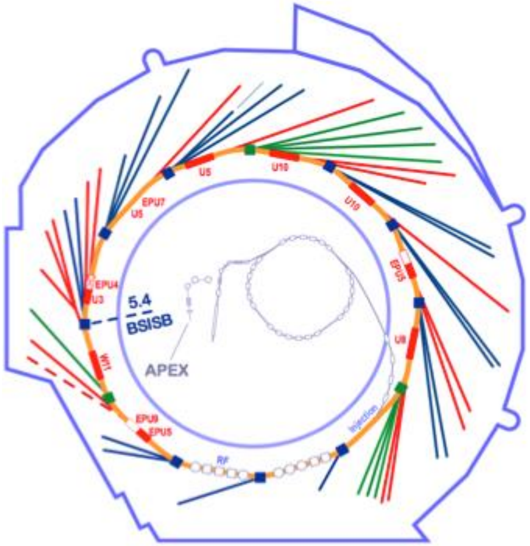
• Accelerators	100 M US$
• 13 beamlines	140 M US$
• Building	213 M US$
• Human Res	57 M US$
• Total	510 M US$

Schedule

• Jan.2015	start of building construction
• Oct.2017	start of machine installation
• Jul.2018	start of SR commissioning
• Sep.2018	phase 1 operation (20mA, NCC)
• Feb.2019	phase 2 operaton (100mA, SCC)

The Advanced Light Source

- Optimized for the production of bright soft x-Ray light
  - Very bright source of infrared, ultraviolet, soft and hard x-Ray light
- Useful for studying matter on the scale of atoms, molecules, and cells
- About 2500 users each year
- Very successful enabling breakthroughs in materials, chemistry, biology, and environmental science
- In operation since 1993



~40 beamlines

BERKELEY LAB

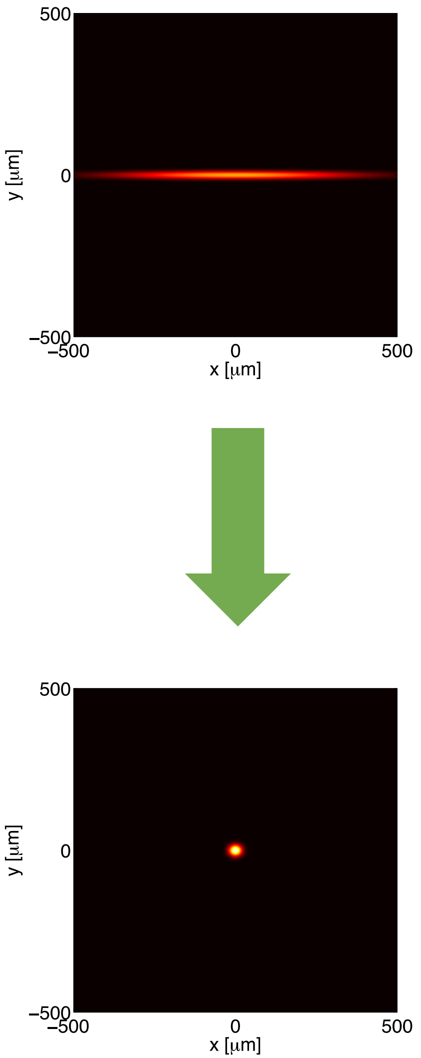
ALS-U
ADVANCED LIGHT SOURCE

The Advanced Light Source Upgrade

ALS is now the most productive source in the world for soft x-ray science.

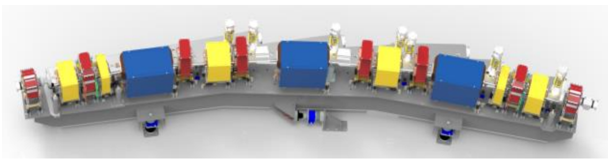
ALS-U will provide orders of magnitude more brightness and coherent flux.

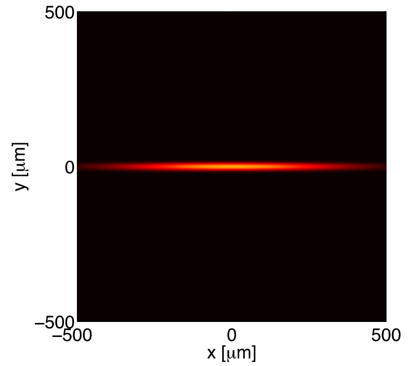
- The ALS-U design is based on the multibend achromat (**MBA**) lattice that is being adopted by all new and upgraded facilities.
- High brightness and coherent flux will make it possible to resolve nanometer-scale features and interactions and will allow real-time observation of chemical processes.



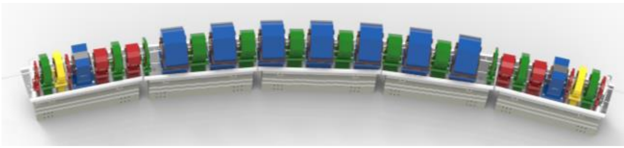
ALS-U Approach – Start with an Accelerator Upgrade using Multibend Achromat (MBA) Technology

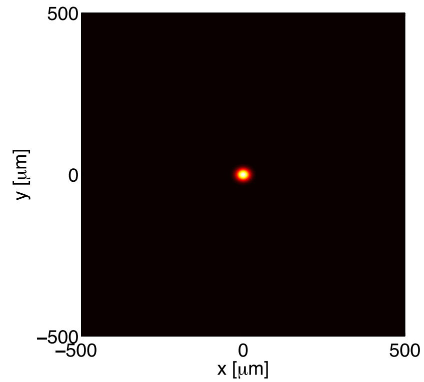
ALS today : triple-bend achromat





ALS-U: multi-bend achromat

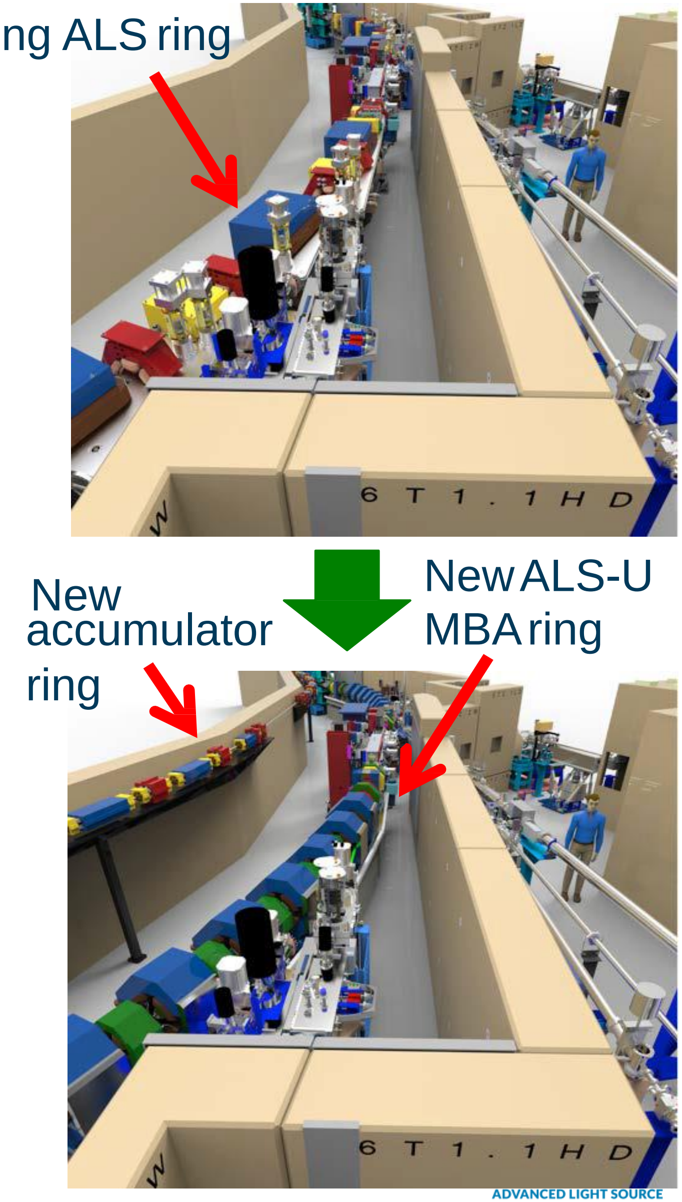




Large increase in brightness and coherent fraction and flux

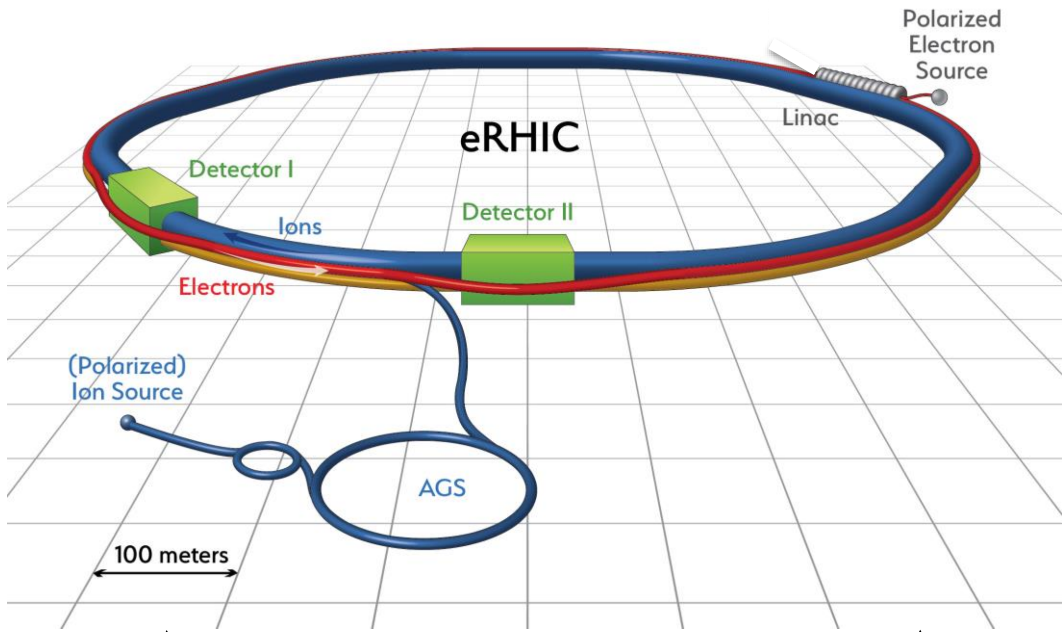
ALS-U Proposed Scope

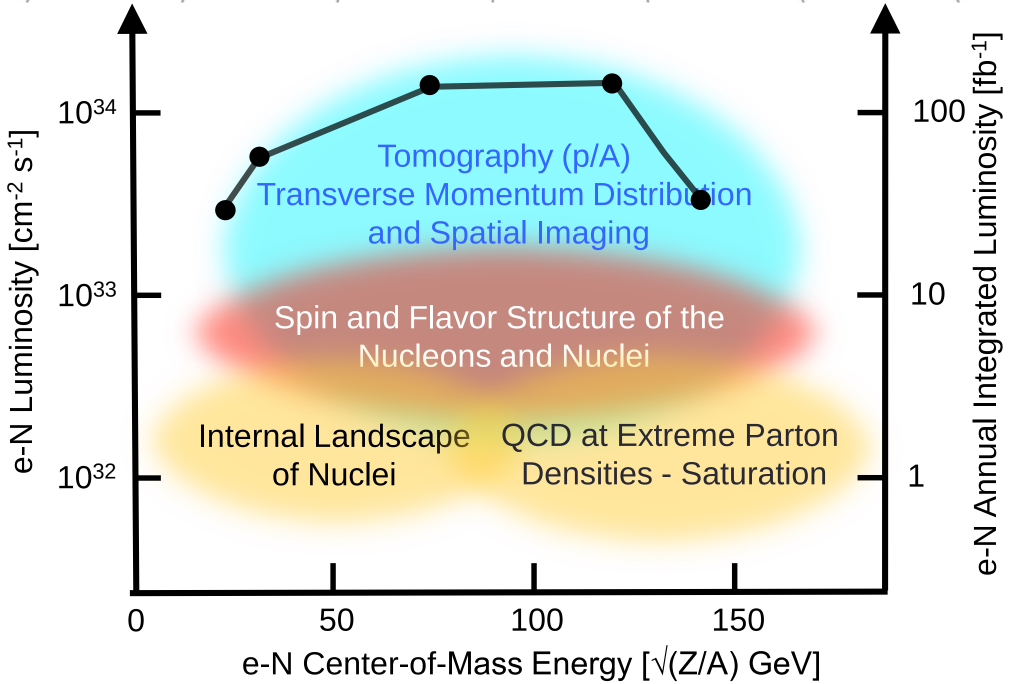
1. **Replacement of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multi-bend achromat.**
2. **Addition of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection using fast magnets.**
3. **Upgrade of the optics on existing beamlines and realignment or relocation of beamlines where necessary.**
4. **Addition of new undulator beamlines that are optimized for novel science made possible by the beam's high soft x-ray coherent flux.**



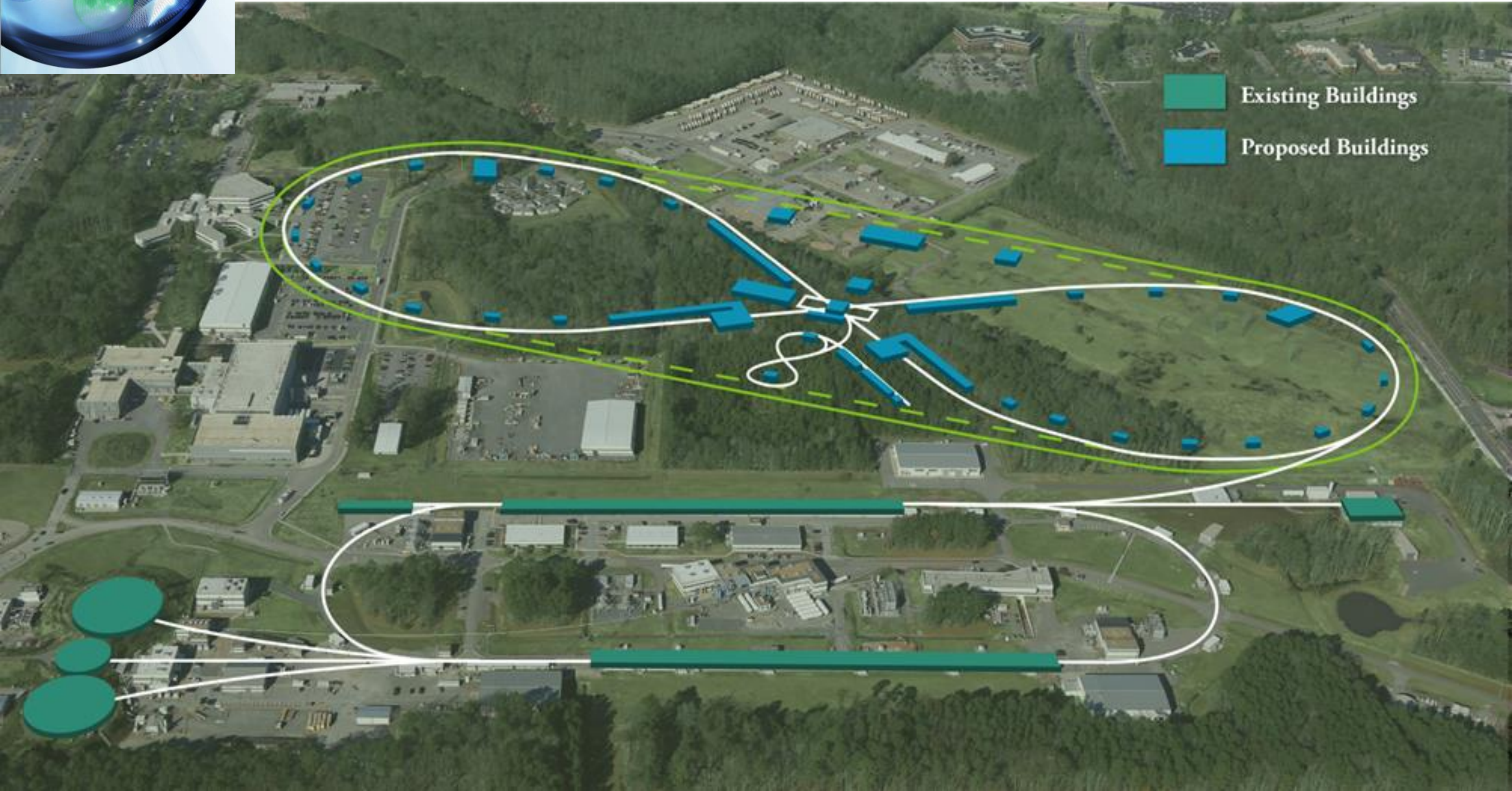
eRHIC Realization

- **Use existing RHIC**
  - Up to 275 GeV protons
  - Existing: tunnel, detector halls & hadron injector complex
- **Add 18 GeV electron accelerator in the same tunnel**
  - Use either high intensity Electron Storage Ring or Energy Recovery Linac
- **Achieve high luminosity, high energy e-p/A collisions with full acceptance detector**
- **Luminosity and/or energy staging possible**





Overview of JLEIC



JLEIC baseline

energy range:

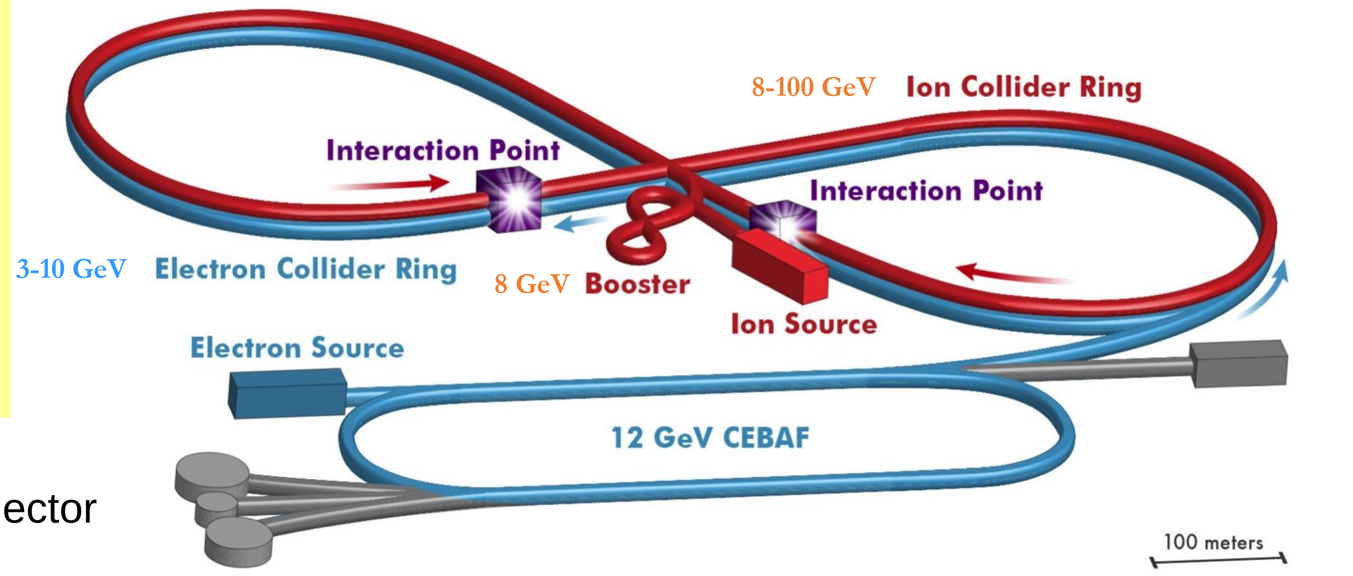
e-: 3-10 GeV

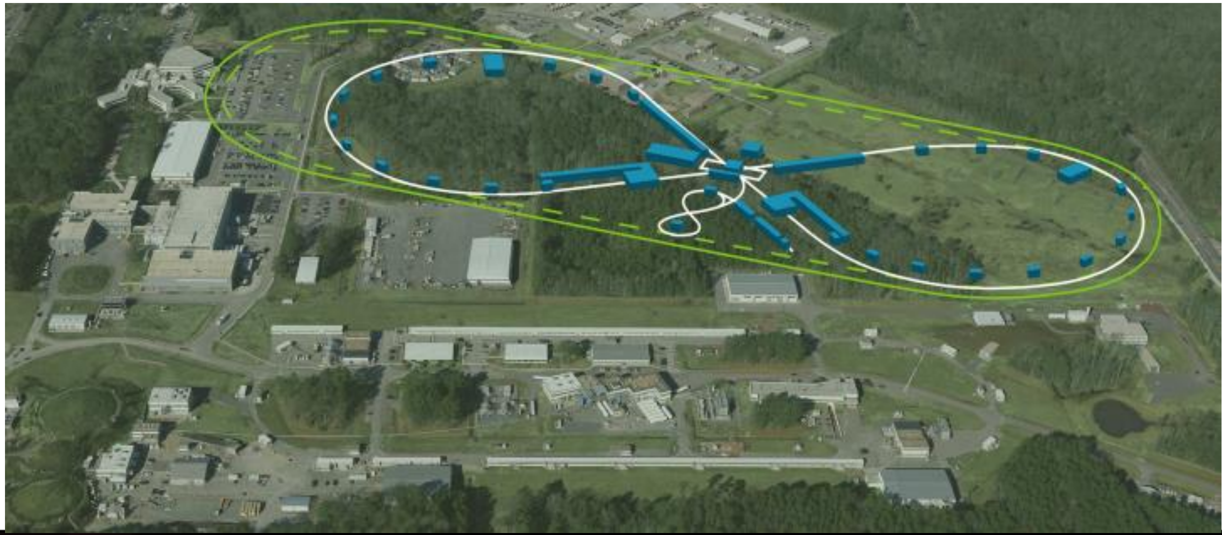
p : 20-100 GeV

√s: up to **65 GeV**

upgrade to √s=**100 GeV** possible

- **Electron complex**
  - CEBAF-full energy injector
  - Electron collider ring
- **Ion complex**
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring
- Fully integrated IR and **detector**
- DC and bunched beam **coolers**





System Elements

- 5.2 km of Beamline
- Magnets – dipoles, quadrupoles, sextupoles, correctors, and fast kickers
  - 1407 Normal-Conducting Magnets
  - 912 Superconducting Magnets
  - 659 BPMs
  - Additional diagnostics, vacuum system components
  - 2 Beam Dumps
- RF/SRF Cavities
  - 104 SRF Cavities
  - 10 Normal-Conducting Cavities
  - 23 MW RF Power

System Components

- Magnet Power
  - 63 major circuits with 10.5 MW, up to 15 kA for SC magnets
  - Cables and buss (water-cooled)
- Electrical Utilities: 49 MVA peak load
- Low Conductivity Water (LCW) for cooling of normal conducting magnets, power supplies, HPAs
- Cryogenics
  - 6.1kW @ 4.5K, 3.7 g/sec, 810 l/hr, 16kW shield
- 42 buildings with 68k sq ft
- 3.3 km of Shallow Tunnel

Magnets, Kickers, BPMs - Summary

Element	Type	Electron Complex	Ion Complex
Length of Beamline		2,439 m	2,629 m
Dipole Magnets	Normal-Conducting	270	12
	Superconducting	-	325
Quadrupole Magnets	Normal-Conducting	488	15
	Superconducting	7	292
Sextupole Magnets	Normal-Conducting	212	-
	Superconducting	-	156
Correctors Magnets	Normal-Conducting	405	-
	Superconducting	-	129
Solenoids Magnets	Superconducting	8	2
Kickers (RF)	Normal-Conducting	2	3
BPMs		405	254

Accelerating and Bunching – Summary

			#	Cavities per unit	Fwd Pwr per cavity (kW)
Electron Collider Ring	Acceleration		33**	1	500**
	Crab Cavities		2	2	13
Ion Injector/Linac	QWR and HWR		5	1	
	IIH-DTL with FODO		1	1	
	Heavy and Light Ion RFQs		2	1	
Booster	Acceleration		2	1	50
Ion Collider Ring	Bunch Ctrl (normal-conducting)		7	1	100
	Acceleration		7	5	75
	Crab Cavities		2	6	13
Electron Cooling	DC Cooler (Booster)		1	4	500
	Bunched Beam (Ion Collider Ring)	Injector	1	2	50
		ERL	1	6	50

** - PEP-II Cavities and HPAs

Excerpted from LA-UR-16-27709

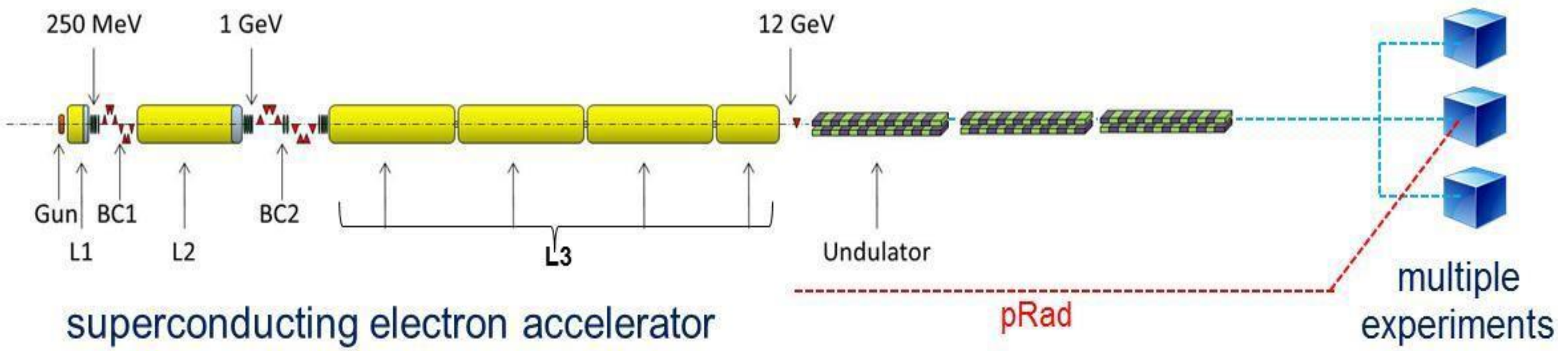
Status of the Los Alamos Multi-Probe Facility for Matter-Radiation Interactions in Extremes (MaRIE)

John Erickson

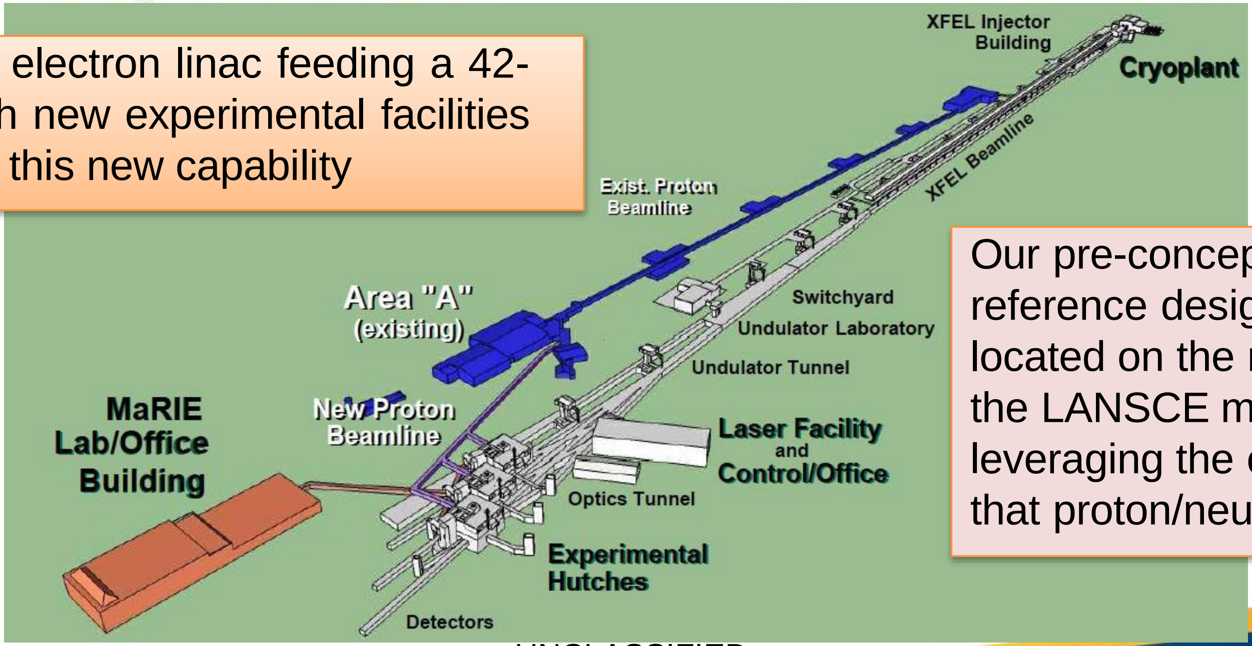
NAPAC16
Chicago, Illinois
October 9-14, 2016

UNCLASSIFIED

MaRIE at LANSCE would leverage existing proton and neutron capabilities to provide a next-generation, multi-probe facility



A 12-GeV SC electron linac feeding a 42-keV XFEL with new experimental facilities would provide this new capability



Our pre-conceptual reference design has the XFEL located on the north side of the LANSCE mesa, leveraging the capabilities of that proton/neutron facility

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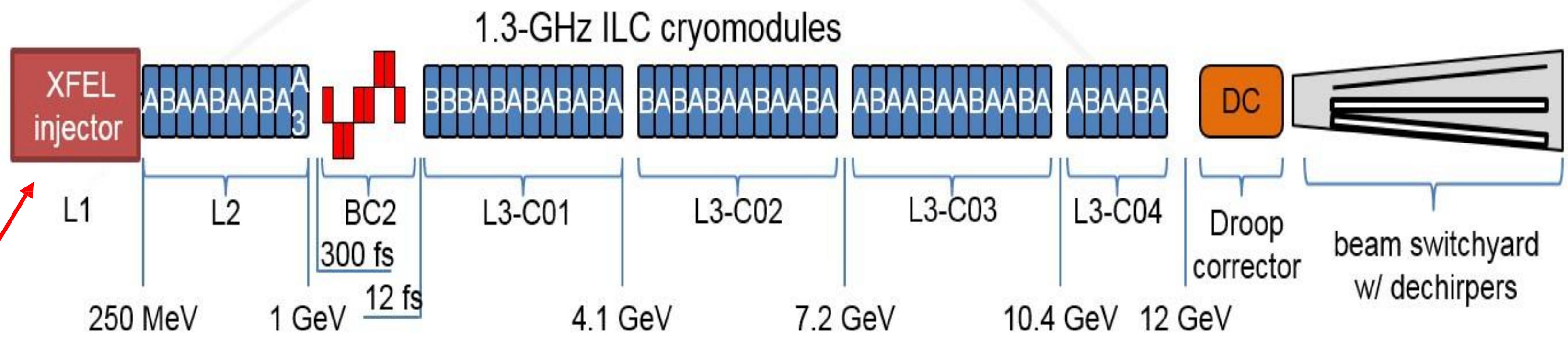
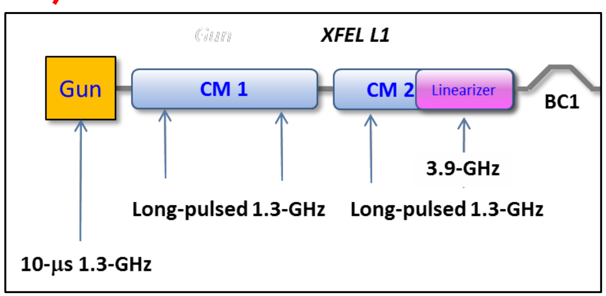
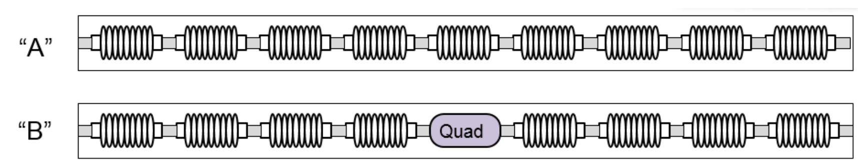
An XFEL pre-conceptual reference design that meets the MaRIE performance requirements has been developed as part of the CD-0 process





A 9-cavity ILC cryomodule, "A"-type

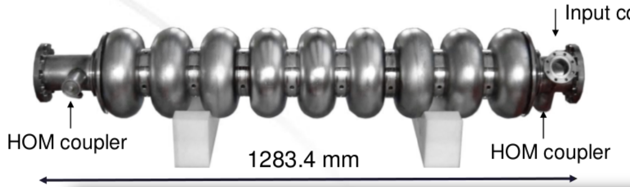
B 8-cavity ILC cryomodule, with quad / corrector / BPM, "B"-type

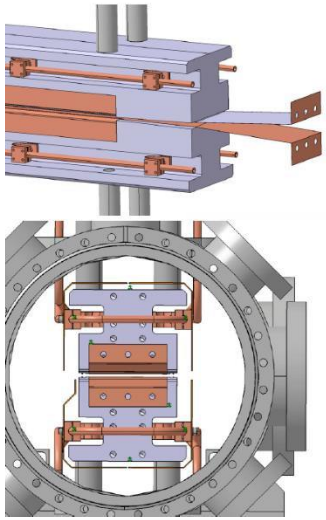


	1.3-GHz cavities	3.9-GHz cavities
L1 (X-FEL)	11	9
L1 (eRad)	11	9
L2	78	9
L3	360	0
Total	460	27

MaRIE pre-conceptual reference design is based on current technology.

- **Accelerating cavities and cryomodules based on 1.3-GHz ILC and DESY XFEL designs**
- **FLASH 3.9-GHz cryomodules to linearize the beam phase space**
- **Undulator design based on SwissFEL U15**





Courtesy of T. Schmidt

	Symbol	Value
Undulator period	λ_u	18.6 mm
Undulator magnetic field	B_0	0.7 T
rms (peak) undulator parameter	K_{rms} (K_{peak})	0.86 (1.22)
FEL resonance wavelength	λ_0	0.2934 Å
FEL (Pierce) parameter	ρ	0.0005
Calculated 3D gain length	L_G	2.6 m
Calculated 3D saturated power	P_S	9 GW
FEL pulse energy at saturation	W_p	0.3 mJ

MaRIE Status

- Project presently in the pre-conceptual planning phase
- We have a pre-conceptual accelerator/XFEL reference design
- Cost & Schedule estimate is based largely on current technology
- Following US Dept. of Energy, National Nuclear Security Agency (NNSA) guidance regarding submission of a large construction project
- Following DOE Order 413.3B requirements and process
- Beginning to initiate discussions with potential partner labs.

A.1 Proton Power Upgrade (PPU) Overview

J. Galambos

PPU Director

SNS-PPU to SNS-STS

SNS-PPU upgrades the existing accelerator structure

Increases neutron flux to existing beam lines

Provides a platform for SNS-STS

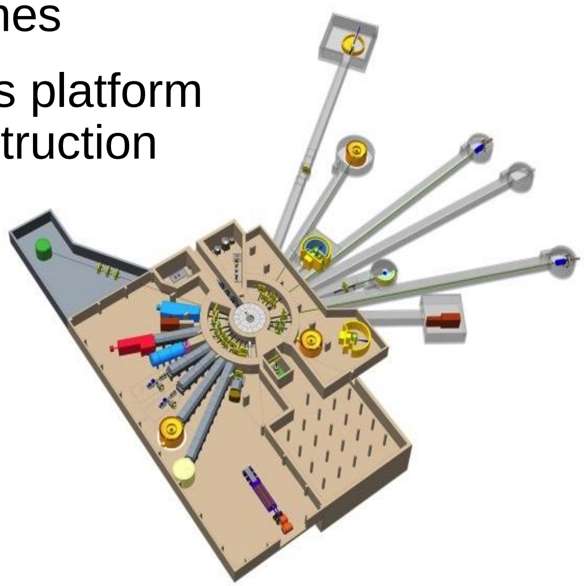
SNS-STS constructs a second target station with an initial suite of 8 beam lines

Mission need and science case for SNS-PPU and SNS-STS are the same

Upgrading SNS to a world-leading fourth-generation neutron source

SNS-PPU

- Increases power capabilities of existing 60 Hz accelerator structure from 1.4 MW to 2.8 MW
- Increases power delivered to first target station (FTS) to 2 MW
- Increases neutron flux on available beam lines
- Provides platform for construction of STS

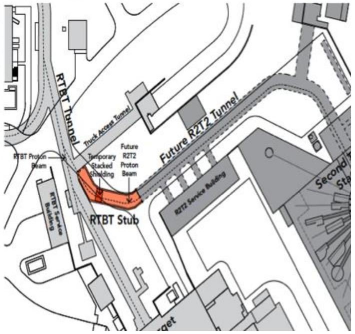


SNS-STS

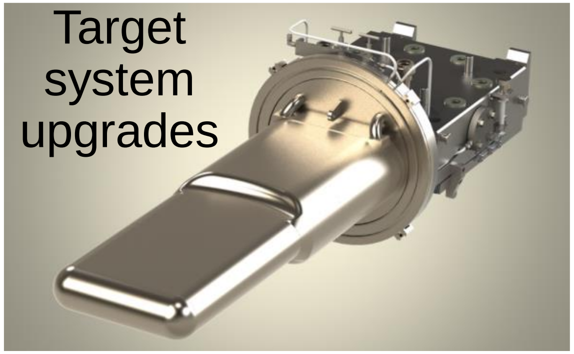
- Initial suite of 8 beam lines, with capacity to accommodate 22 beam lines
- 467 kW diverted to STS by additional accelerator systems
- 10-20 Hz repetition rate, enabling broad dynamic range
- World’s highest brightness short-pulse source optimized for cold neutrons
- 300,000 ft^2 of new infrastructure

PPU Technical Scope

Conventional Facilities



Basis for WBS Structure



Major Procurements

- Major procurements from industry:
  - 3 1MW average power High Voltage Convertor Modulators
  - 28 0.7 MW klystrons
  - ~28 SRF Cavities
- In addition, the existing modulators, klystrons etc. will be upgraded
- Major procurements from partner labs:
  - SRF cryomodules: ~ $40M
  - Ring magnets: $ 2-3M

Thanks

- **My thanks to everyone who provided information on the different projects**
- APS-U at Argonne National Lab – Jim Kerby jkerby@anl.gov
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- FRIB at Michigan State University – Paul Mantica mantica@frib.msu.edu
- LCLS-II at SLAC, Stanford – Mark Reichanadter reich@slac.stanford.edu
- PIP-II at Fermilab – Steve Holmes holmes@fnal.gov
- Sirius, Campinas, Brazil – Liu Lin liu@lnls.br
- ALS-U at Lawrence Berkeley Lab – Dave Robin DSRobin@lbl.gov
- eRHIC at Brookhaven National Lab – Thomas Roser roser@bnl.gov
- JLEIC at Jefferson Lab – Tim Michalski michalsk@jlab.org
- MARIE at Los Alamos National Lab – John Erickson jerickson@lanl.gov
- SNS-U at Oak Ridge National Lab – John Galambos galambosjd@ornl.gov