



PIP-II Status

Lia Meringa
HEPAP Meeting
2 November 2021

A Partnership of:
US/DOE
India/DAE
Italy/INFN
UK/STFC UKRI
France/CEA, CNRS/IN2P3
Poland/WUST



PIP-II Mission

PIP-II is an essential upgrade to Fermilab accelerator complex to enable the world's most intense beam of neutrinos to LBNF/DUNE, and a broad physics research program for decades to come.

PIP-II Capabilities

Beam Power

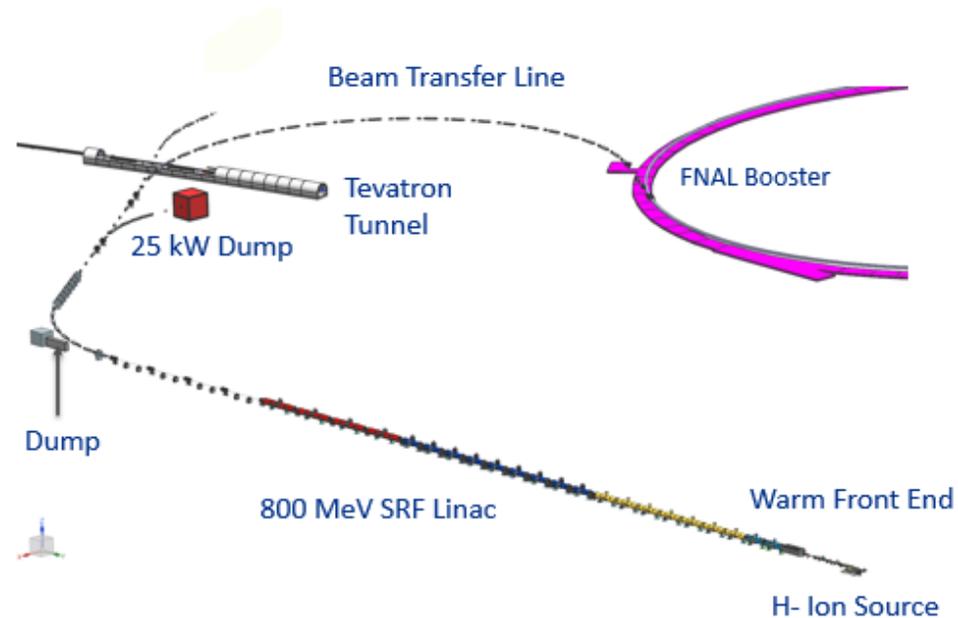
- 1.2 MW proton beam
- Upgradeable to multi-MW

Flexibility, multi-user capability

- CW-compatible
- Customized beams
- Multi-user delivery

Reliability

- Modernizes Fermilab accel complex



PIP-II Scope

800 MeV H⁻ SRF linac

CW RF Operations

Linac-to-Booster transfer line

Accelerator Complex Upgrades

Booster

Recycler

Main Injector

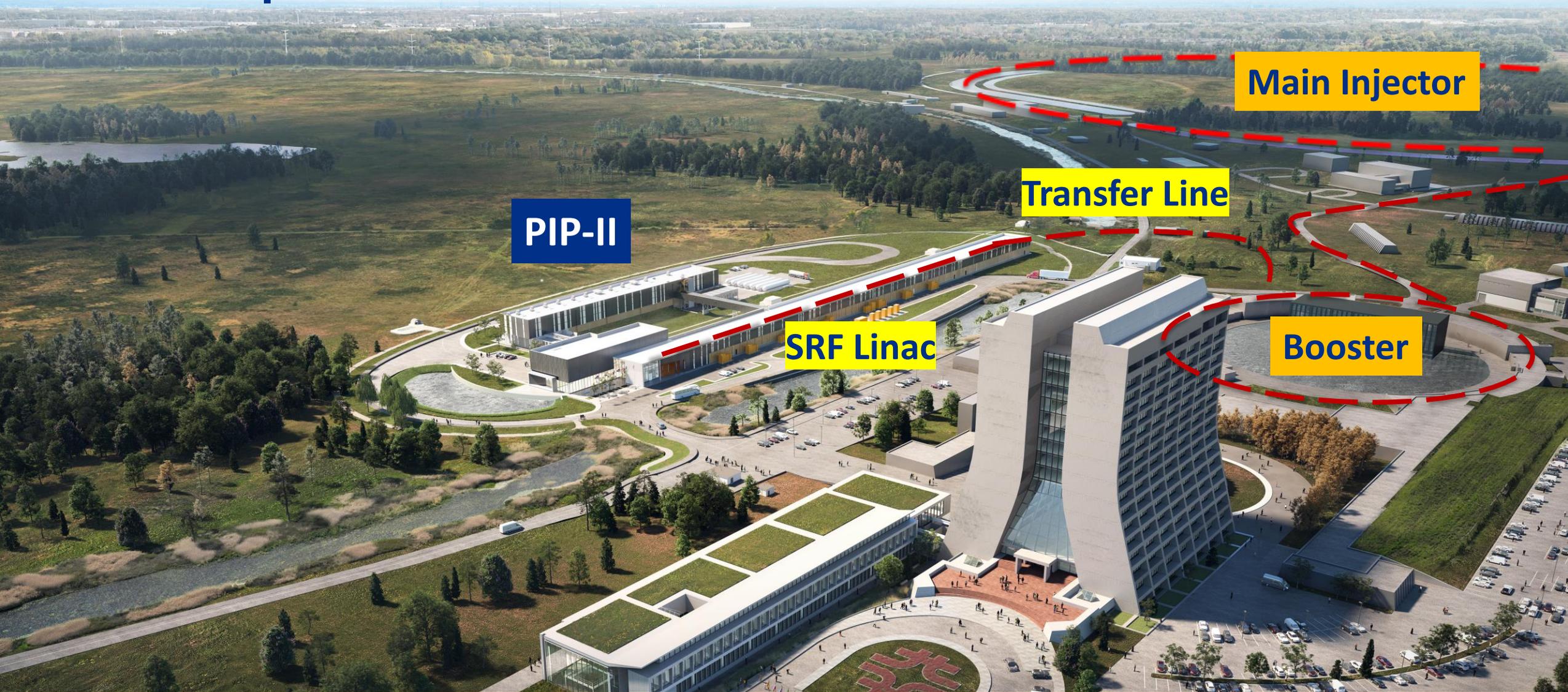
Conventional Facilities

Space reserved for two CMs
for 1 GeV Upgrade



The PIP-II scope enables the accelerator complex to reach 1.2 MW proton beam on LBNF target

PIP-II Scope



PIP-II will provide a highly capable, reliable, upgradeable and expandable scientific infrastructure with significant savings to DOE

PIP-II International Partners, Expertise and Capabilities



India, Department of Atomic Energy (DAE) (started 2009)
BARC, RRCAT, VECC; also IUAC

Substantial engineering / manufacturing experience; Superconducting magnets for LHC; 2 GeV synch light source



Italy, INFN (started 2016)

Internationally recognized leader in superconducting RF technologies
SRF cavity and cryomodule fabrication for XFEL; SRF cavities for ESS



UK, STFC UKRI (started 2017)

Substantial engineering and manufacturing experience; Construction, operation of synch light & neutron sources SRF cavity processing and testing for ESS



France, CEA, CNRS/IN2P3 (started 2017)

Internationally recognized leader in large-scale CM assembly
CM assembly for European XFEL and ESS; SSR2 cavities and couplers for ESS



Poland, WUST, WUT, TUL (started 2018)

Substantial engineering / manufacturing experience; CDS, LLRF, QC for XFEL, ESS



PIP-II is the U.S. first accelerator project to be built with major international contributions; benefits from world-leading expertise, capabilities.



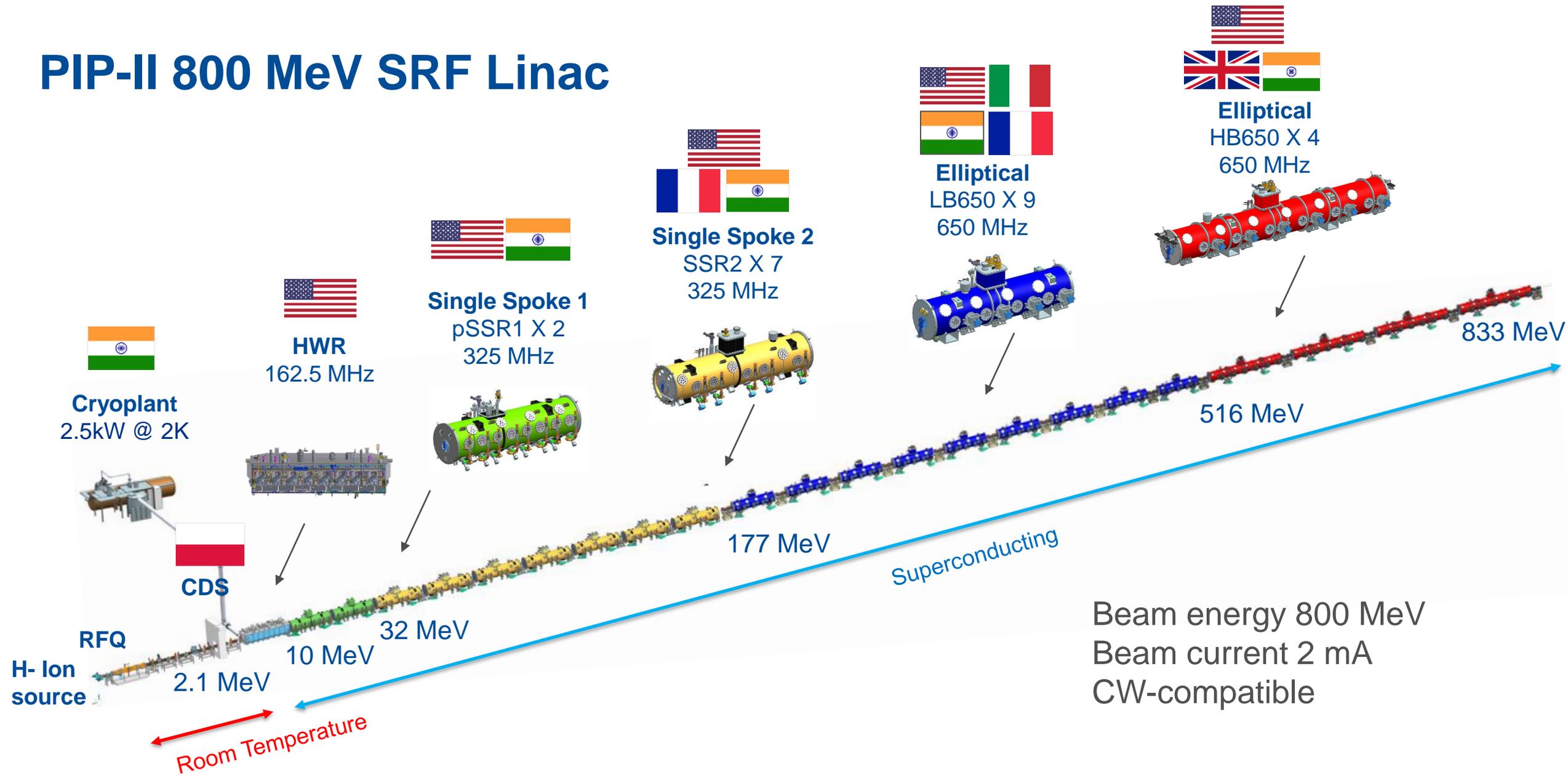
Bottom Line Up Front – PIP-II Status

- ▶ In the past ~year, three Critical Decisions (CD) were approved
 - ▶ CD-2/3 of Early Conventional Facilities (ECF) subproject – **Jul 2020**
 - ▶ CD-2 Performance Baseline – **Dec 2020**: TPC \$978M (+\$310M IKC), Early CD-4 Dec 2028
 - ▶ CD-3a for Long Lead Procurements – **Mar 2021**
- ▶ Beam tests at PIP2IT successfully completed, critical technologies demonstrated
- ▶ Cryogenic plant building construction is 85% complete
- ▶ International partners strongly engaged: **DAE/BARC cryogenic plant contract under execution**
- ▶ Developing a diverse workforce and engineering pipeline: **ASPIRE Fellowship launched**
- ▶ CD-3 DOE review – Start of Construction/Execution: date set 1-3 March 2022
 - ▶ Project is ready for execution: Exceptional team incl. partners complete, ensuring stability of requirements and interfaces, maturing technical designs, streamlining processes

IKC: In-Kind Contributions

***PIP-II is blazing a new trail in major accelerator projects
in DOE/SC with international partners***

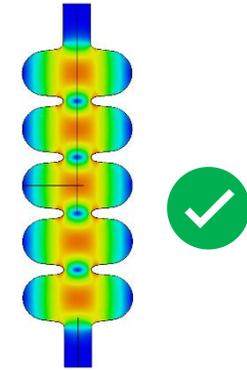
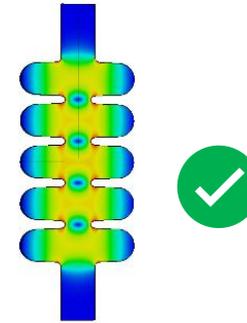
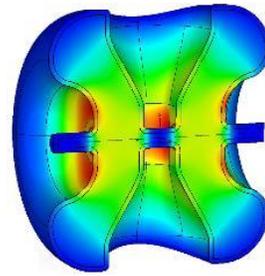
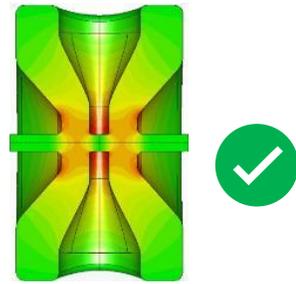
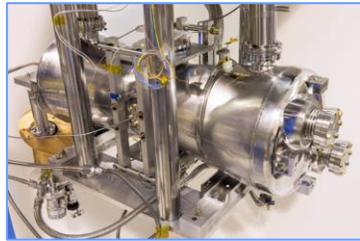
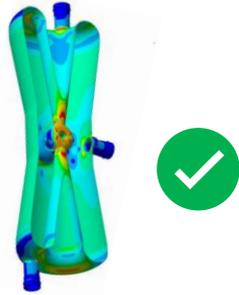
PIP-II 800 MeV SRF Linac



PIP-II is the world's highest energy CW RF proton linac



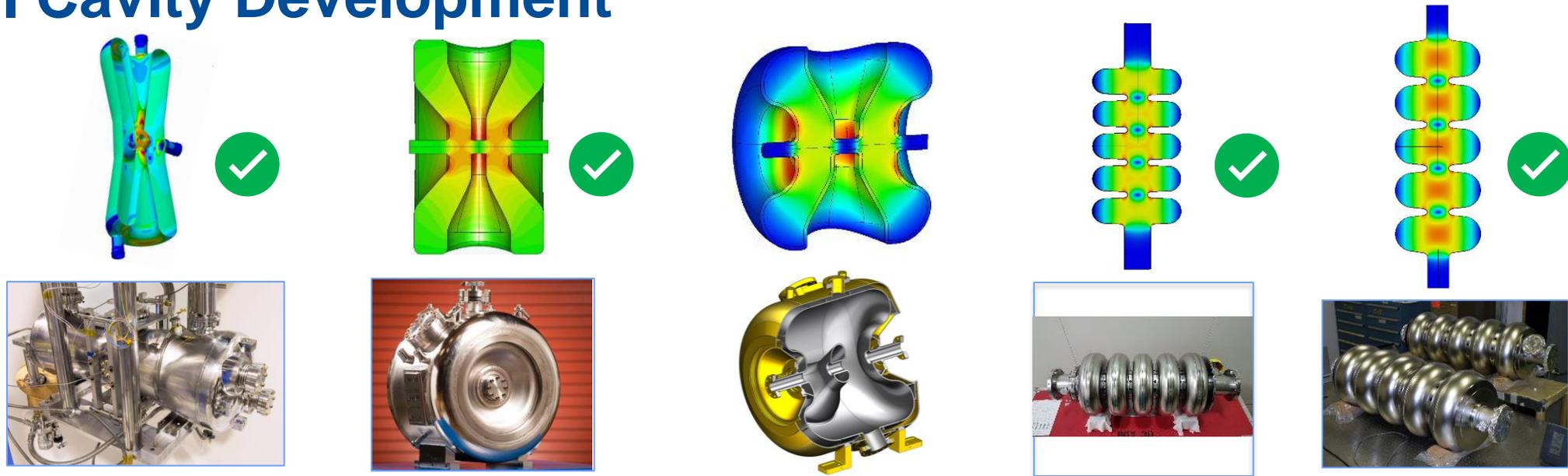
PIP-II Cavity Development



Name (Qty.)	HWR (8)	SSR1 (16)	SSR2 (35)	LB650 (36)	HB650 (24)	Units
Type	Half-Wave	Single Spoke	Single Spoke	Elliptical	Elliptical	
β	0.11	0.22	0.47	0.61	0.92	
Frequency	162.5	325	325	650	650	MHz
Q_0	$8.5 \cdot 10^9$	$8.2 \cdot 10^9$	$8.2 \cdot 10^9$	$2.4 \cdot 10^{10}$	$3.3 \cdot 10^{10}$	
Gradient	9.7	10	11.5	16.8	18.7	MV/m
N-doped	No	No	No	Yes	Yes	

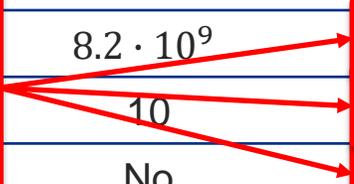
 Prototypes validated

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N-doped	No	No	No	Yes	Yes	

State of the art



Prototypes validated



PIP-II Cryomodule Development: HWR, SSR1 Prototypes Demonstrated, HB650 Prototype in Fabrication



5.9 m

5.3 m

6.5 m

5.5 m

9.9 m

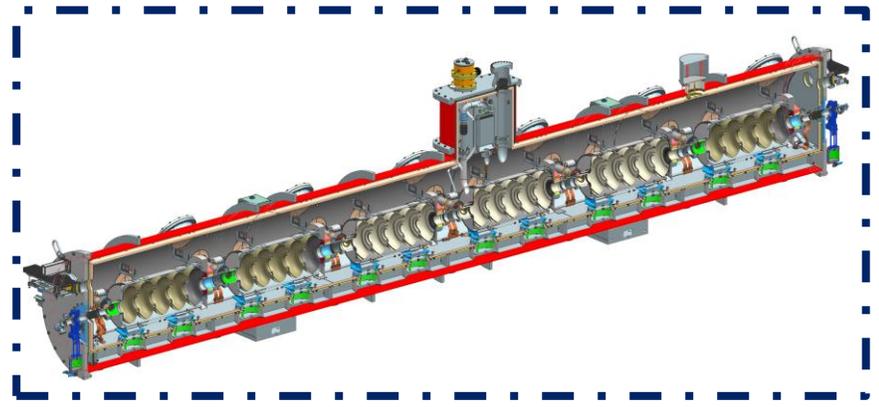
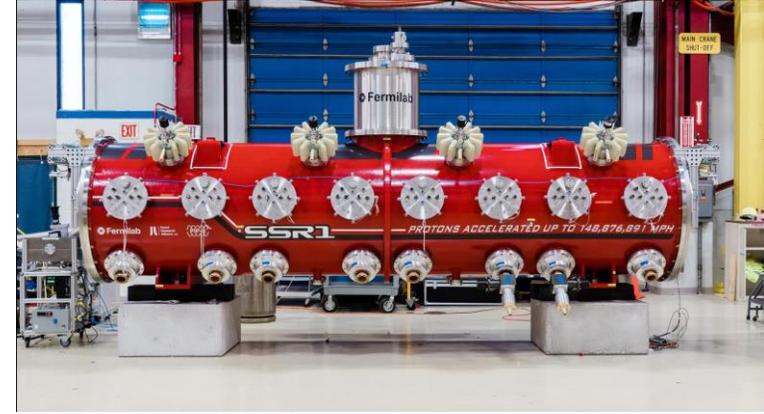
HWR ✓

SSR1 ✓

SSR2

LB650

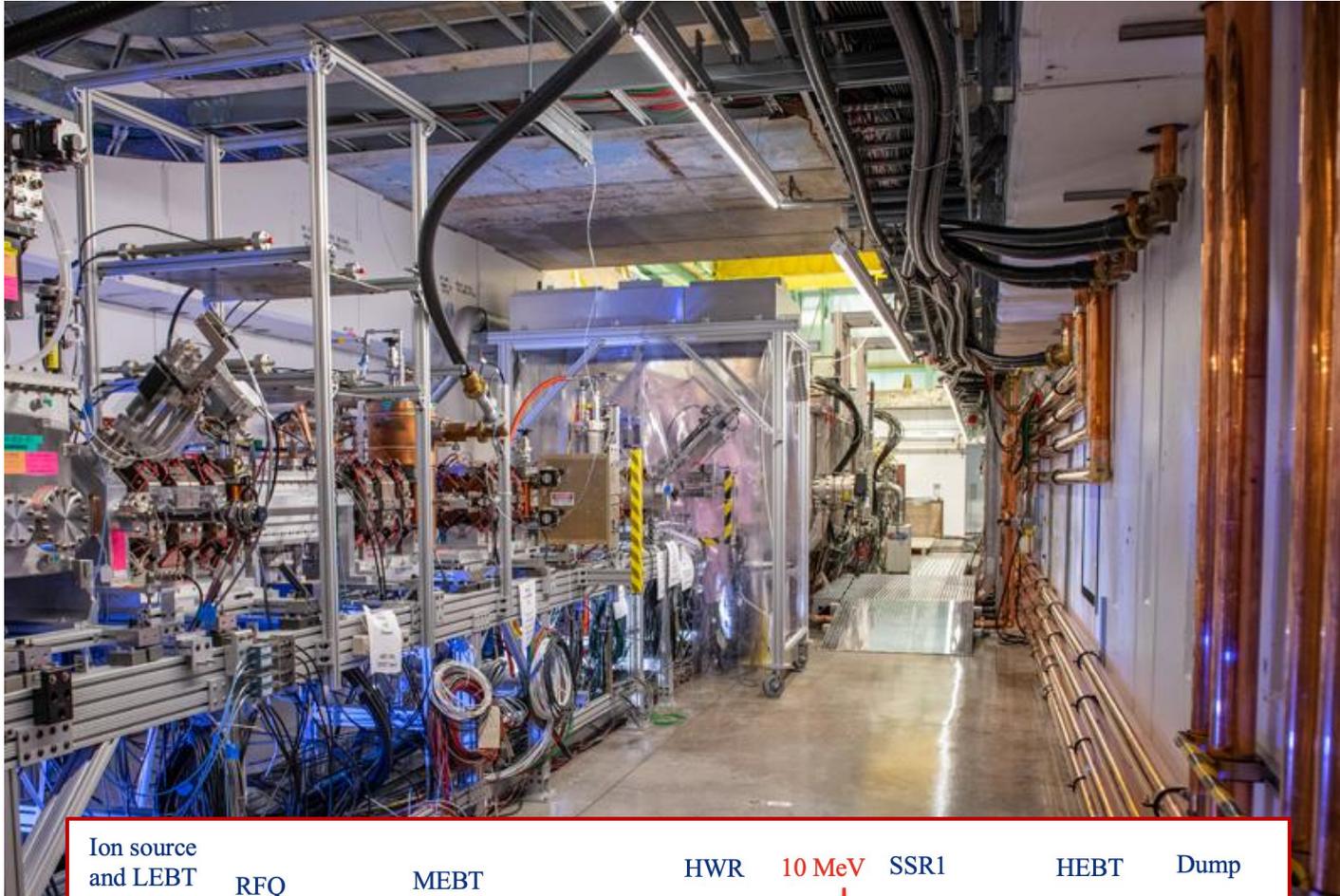
HB650



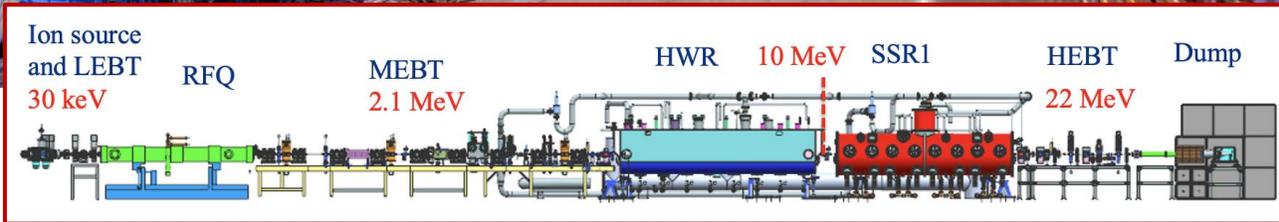
✓ Prototypes validated



PIP-II Injector Test (PIP2IT) – Testbed for PIP-II Technologies



- PIP2IT was a near full-scale Front End of PIP-II, incl. first two cryomodules and IKC from partners
- Last April a very successful multi-year beam test program concluded
- Conversion to a **PIP-II 2-Cryomodule Test Stand** in progress - new cryo distribution, RF amplifiers, fully EPICS
- Test Stand on track to enable RF testing of proto HB650 cryomodule



DAE Solid-State Amplifiers Powered Beam Tests



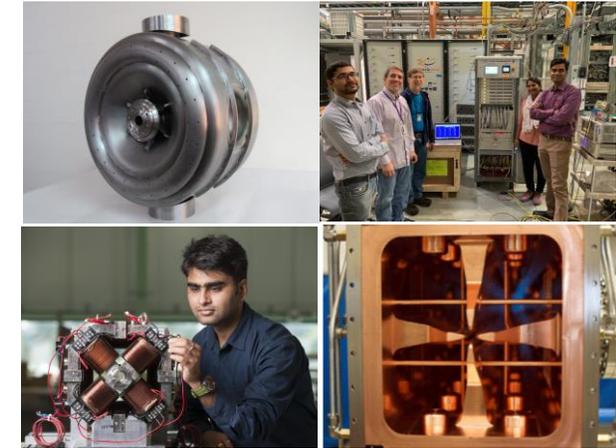
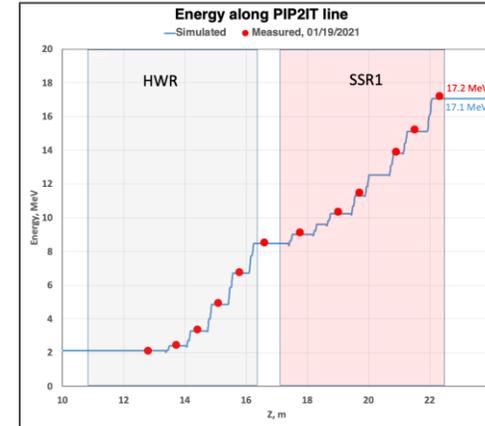
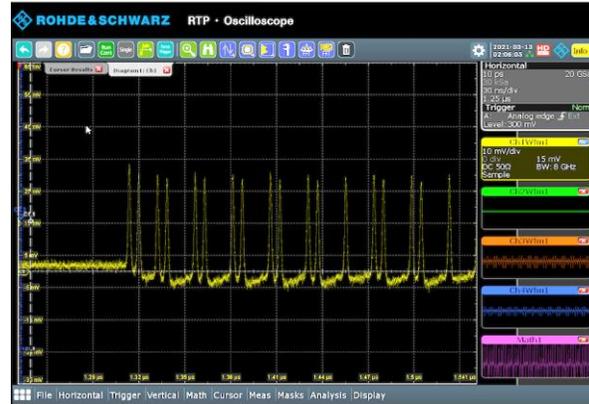
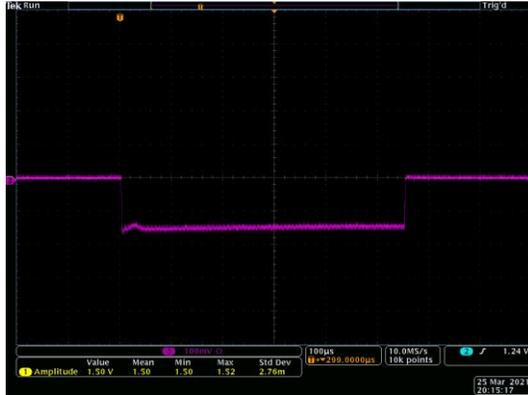
ECIL/BARC 7 kW 325 MHz amplifiers powered SSR1 cavities during beam testing at PIP2IT



RRCAT 40 kW 650 MHz prototype amplifiers under testing at Fermilab. Will power 650 MHz cryomodule testing at PIP2IT



PIP2IT Tests Successfully Completed



PIP-II design beam parameters demonstrated

Energy = 16 MeV

Pulse beam cur = 2 mA

Pulse length = 550 μ s

Pulse rep rate = 20 Hz

Chopped beam pattern

Bunch-by-bunch chopping pattern required for LBNF demonstrated

MEBT chopper is critical for PIP-II operations, capable of removing individual bunches, provides arbitrary bunch pattern capability

Critical technologies demonstrated

Beam accelerated to 17 MeV

HWR and SSR1 Prototype cryomodules performance validated with beam

ML algorithm applied successfully to align orbit

Partner deliverables seamlessly integrated

Eight 7 kW amplifiers

SSR1 Cavity

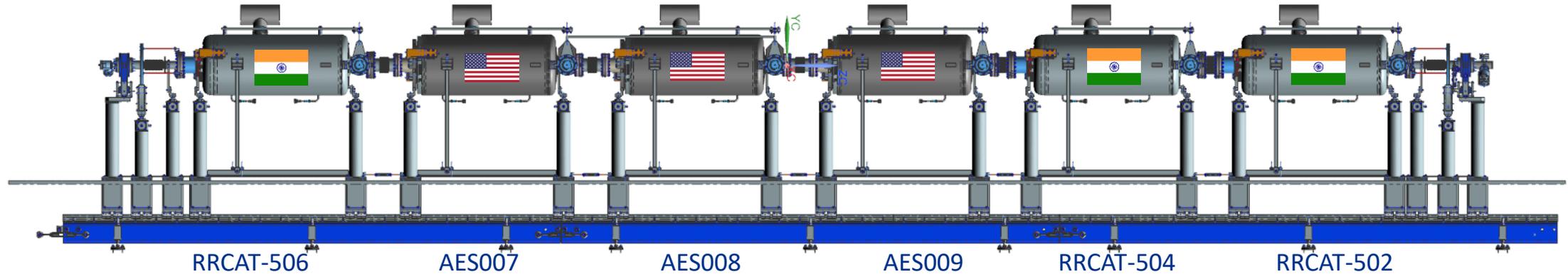
RF MEBT magnets

Radio frequency quadrupole

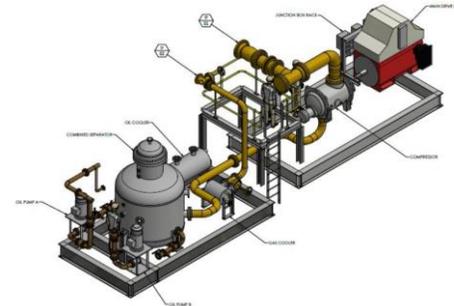
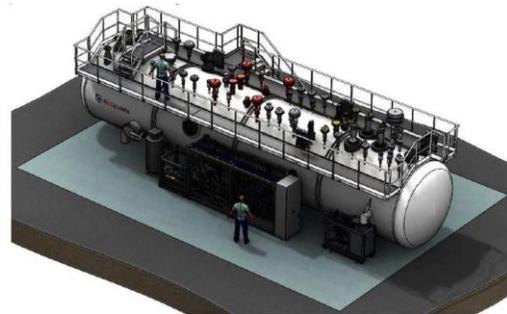
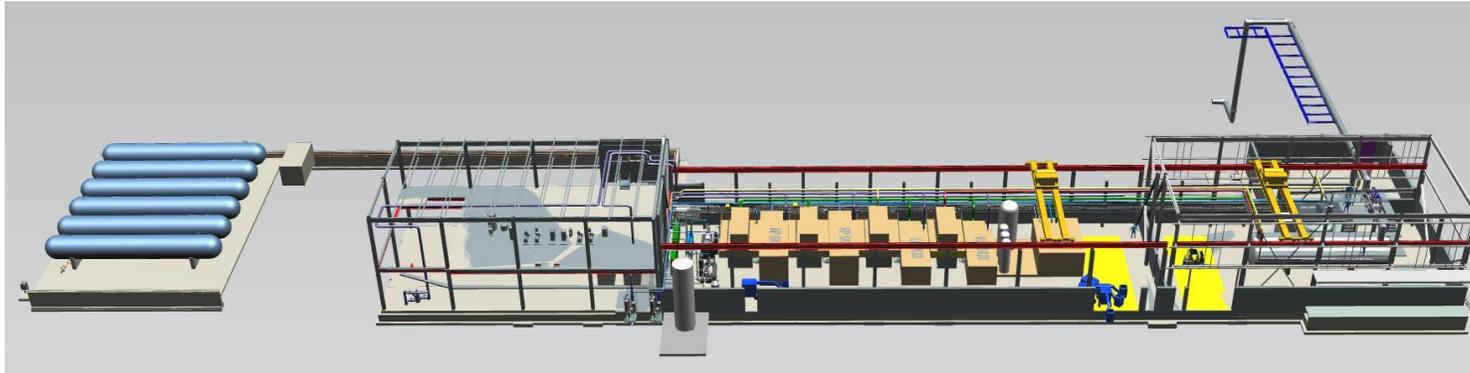
Half Wave Resonator cryomodule

HB650 Prototype Cryomodule Integration

- HB650 proto cryomodule integration/testing a major FY21-22 technical goal
 - First High Beta CW cryomodule ever built!
- All six cavities qualified for string assembly
 - Excellent SRF cavity manufacturing capability at RRCAT



DAE-provided Cryogenic Plant Design Launched



- PIP-II Cryogenic Plant is the single largest in-kind contribution from DAE/India
- DAE/ALAT contract execution has started, Kickoff Meeting in October launched design

ALAT: Air Liquide Advanced Technologies

PIP-II Cryogenic Plant Building construction is 85% complete



https://app.truelook.com/?u=fc1599677013#tl_live
<https://app.truelook.com/?m=16002500832205565503647>



Inside of Cold Box Station

Linac Complex Design is Complete – Ready to Execute Civil Construction



Linac Complex design enables PIP-II multi-user capability and upgrade/expansion to 2 GeV linac in support of 2.4 MW program

International Partners are Strongly Engaged

- Legally binding agreements with all PIP-II International Partners are signed.
- Project Planning Documents (PPDs) in progress.



PPDs with UK are signed



PPDs with INFN are signed



WUST/Poland PPDs approved

ASPIRE Fellowship

Accelerator

Science

Program to

Increase

Representation in

Engineering

A banner for the ASPIRE Fellowship. On the left is a black and white photograph of a man in a white shirt and dark pants standing in a laboratory, looking at a piece of equipment. To the right of the photo, the text reads "ASPIRE Fellowship" in a large, blue, serif font, followed by "Accelerator Engineering Fellowship for Underrepresented Minorities" in a smaller, black, sans-serif font. Below the photo is a dark blue box with the word "ASPIRE" in white. To the right of this box is a light blue box with the text "Program Details >" in dark blue. At the bottom of the banner is a dark blue box with the URL "https://www.fnal.gov/pub/forphysicists/fellowships/aspire/" in white.

ASPIRE Fellowship
Accelerator Engineering Fellowship
for Underrepresented Minorities

ASPIRE

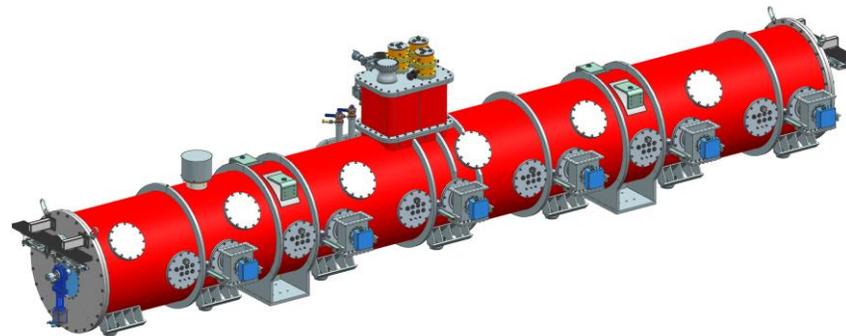
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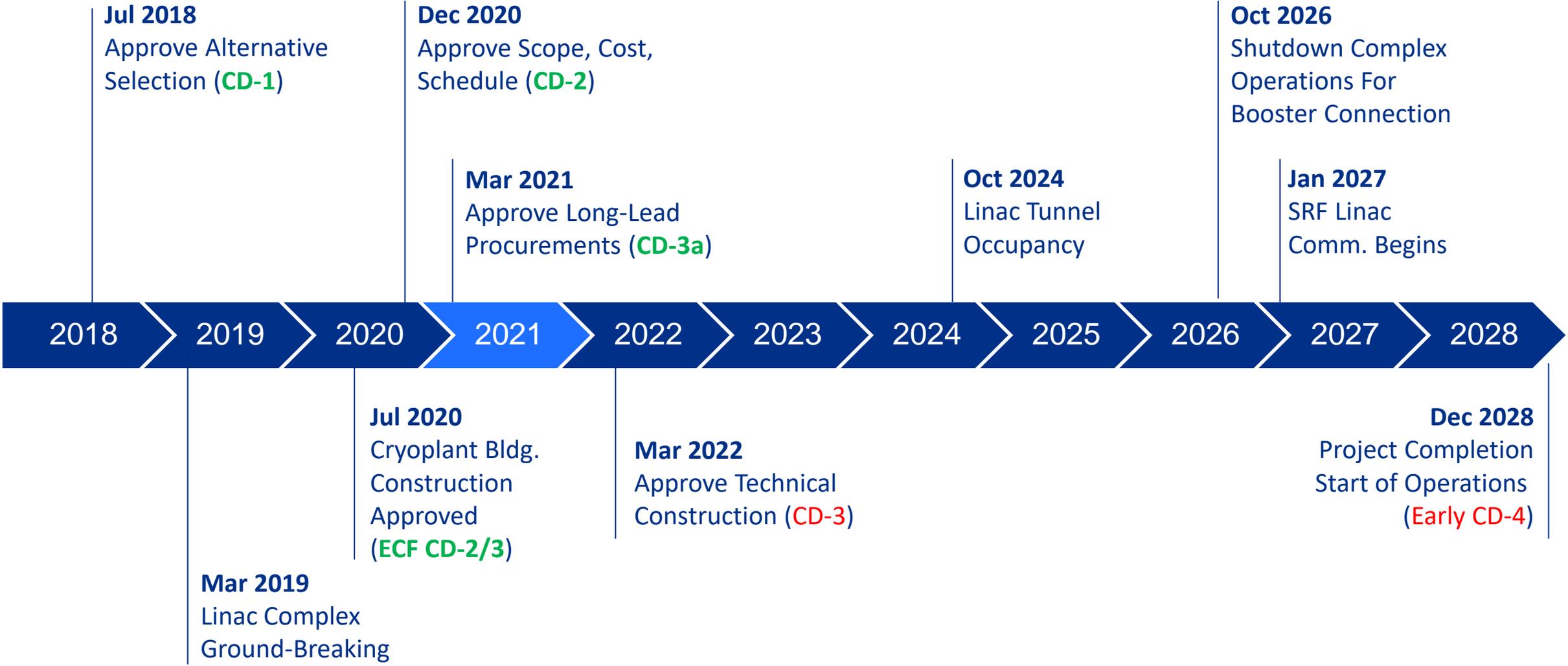
- ... is a Fermilab Fellowship for undergraduate and graduate (masters) students who are underrepresented in STEM disciplines, to develop the next generation of particle accelerator engineers.
- aims to further diversify PIP-II and Fermilab workforce and to meet the hiring needs in accelerator engineering disciplines.
-is a partnership between Fermilab and Midwest colleges and universities.

Major FY22 Milestones

- ▶ Complete HB650 prototype cryomodule assembly and RF, transportation testing
- ▶ Complete Cryogenic Plant Building Construction
- ▶ Receive CD-3 DOE approval - Start of Construction/Execution
 - ▶ CD-3 IPR date is set: March 1-3, 2022
- ▶ Award Linac Complex Construction Contract

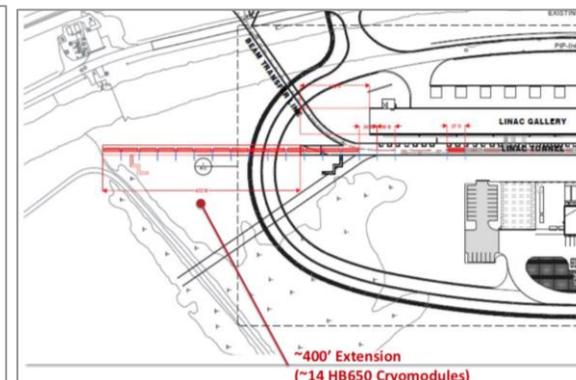
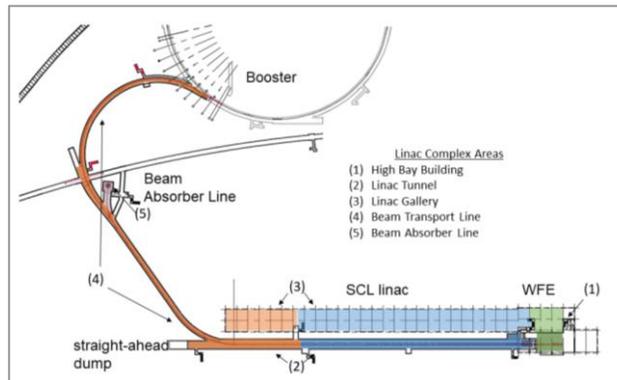
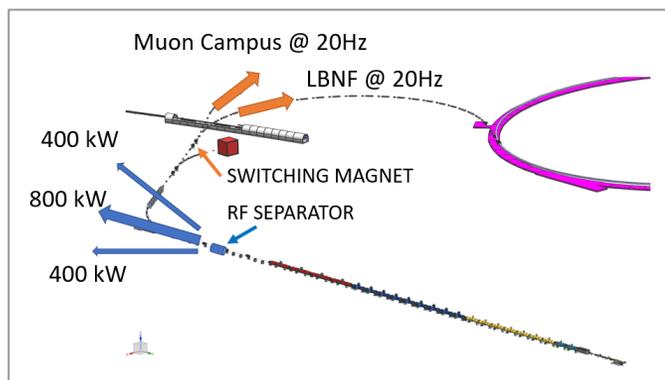


PIP-II Major Milestones



PIP-II Design Is Compatible With Future Science-Driven Upgrades

- PIP-II is designed for >1 MW over 60 – 120 GeV and 1.2 MW at 120 GeV
- Provides platform for upgrade to >2 MW
- Linac beam power of 1.6 MW (CW), programmable bunch patterns
- Facility enables multi-user, simultaneous, high beam power operations
 - Switch yard to provide beams to Muon Campus in multi-user mode with LBNF
- Linac tunnel includes space and infrastructure to reach 1 GeV and space to add RF separator for beam sharing
- Tunnel extension (by 120 m) compatible with energy ~ 2 GeV
- Beam current can be increased by a factor of ~ 4 -5 by upgrading amplifiers



Summary: Excellent Progress – Ready for Execution

- **A compelling mission**
 - PIP-II addresses the need for the most intense neutrino beam in the world, next 50 years of accelerator-based particle physics in the US
- **A unique capability to execute an ambitious project**
 - We have assembled a uniquely talented team across the laboratory and around the world
 - We are utilizing Fermilab's world leading expertise in SRF technology, accelerator science
- **State-of-the-art technology**
 - Excellent progress on state-of-the-art technology validation, civil construction, infrastructure
- **An international collaboration**
 - Outstanding, experienced international team is ready for execution
 - We are leveraging expertise and contributions of international partners to build a highly capable accelerator which secures US leadership in a key element of the global particle physics program

***PIP-II is a successful model for ambitious DOE accelerator mega-projects.
We greatly appreciate the commitment and strong support from the physics community,
Fermilab, DOE, and our International Partners!***

Thank you!

