FRIB Project Update

DOE/NSF Nuclear Science Advisory Committee Meeting
December 8, 2010

Thomas Glasmacher
FRIB Project Manager and Project Director

MICHIGAN STATE UNIVERSITY

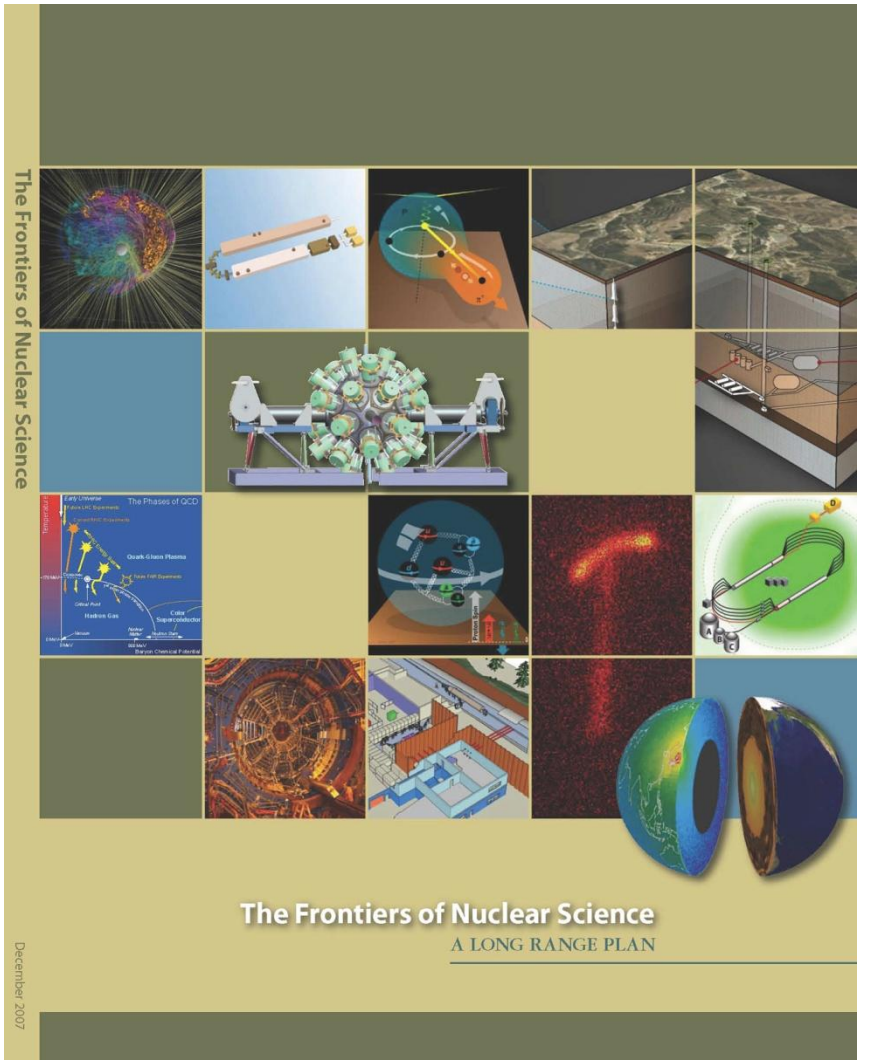
U.S. DEPARTMENT OF ENERGY | Office of Science

FRIB Project Overview Outline

- FRIB in the context of the 2007 Long Range Plan
- FRIB in the context of the National Academies
- FRIB Key Performance Requirements
- DOE Office of Science – Michigan State University partnership governed by Cooperative Agreement for Financial Assistance
- FRIB Key Performance Requirements
- CD-1 Preferred Alternative approved in September 2010
- Working with the best in the nation and the world
- Preliminary Performance Baseline
- FRIB Users Engaged
- Outlook

FRIB in the Context of the 2007 LRP – [1]

- Recommendation II
  - "We recommend construction of the Facility for Rare Isotope Beams (FRIB), a world-leading facility for the study of nuclear structure, reactions, and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society."

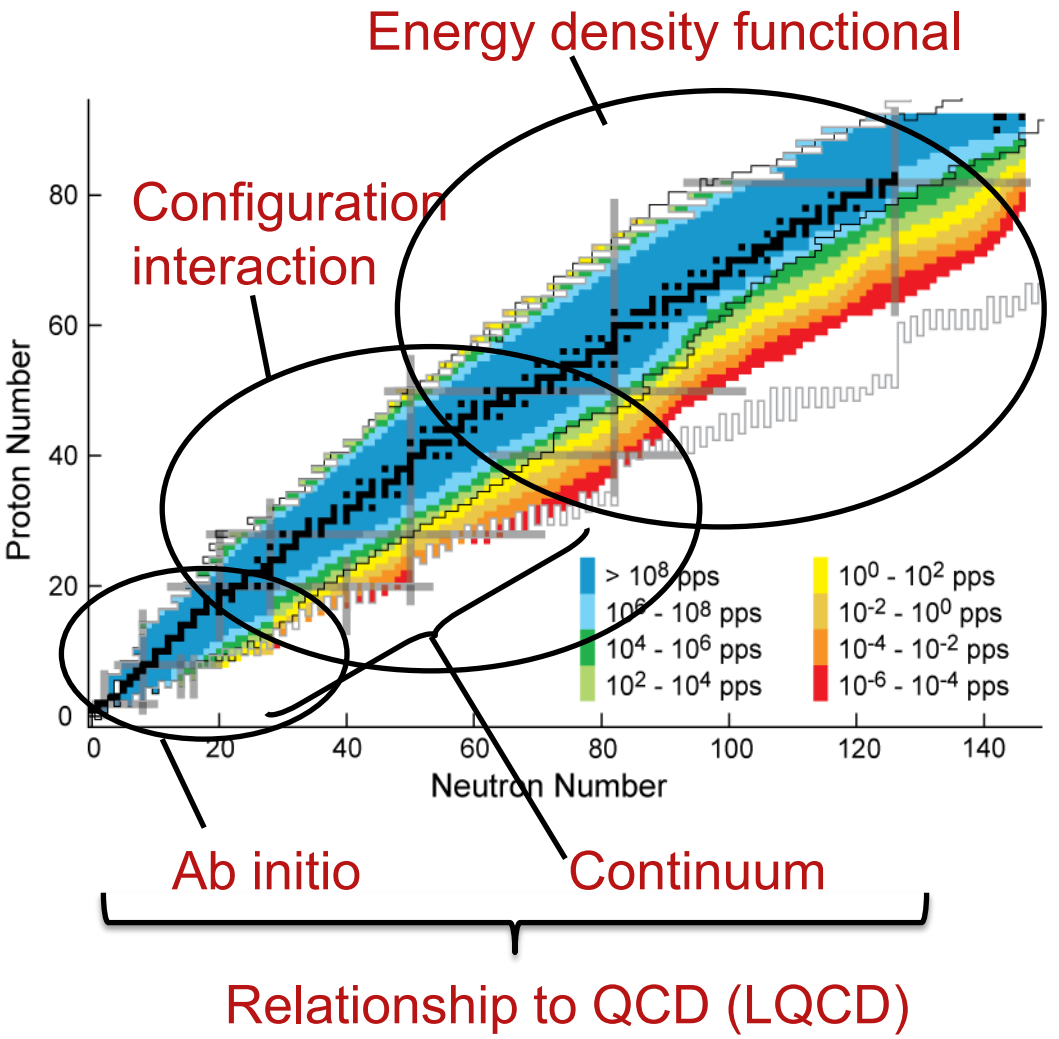


FRIB in the Context of the 2007 LRP – [2]

- The 2007 Long Range Plan poses a number of fundamental questions that the field of nuclear science should address
- FRIB is needed to answer all of these
  - What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
  - What is the origin of simple patterns in complex nuclei?
  - What is the nature of neutron stars and dense nuclear matter?
  - What is the origin of the elements in the cosmos?
  - What are the nuclear reactions that drive stars and stellar explosions?
- Other LRP themes where FRIB contributes
  - Tests of Nature's Fundamental Symmetries
  - Applications to Societal Needs
- Sample of interesting isotopes from FRIB and their uses

What is the Nature of the Nuclear Force that Binds Protons and Neutrons?

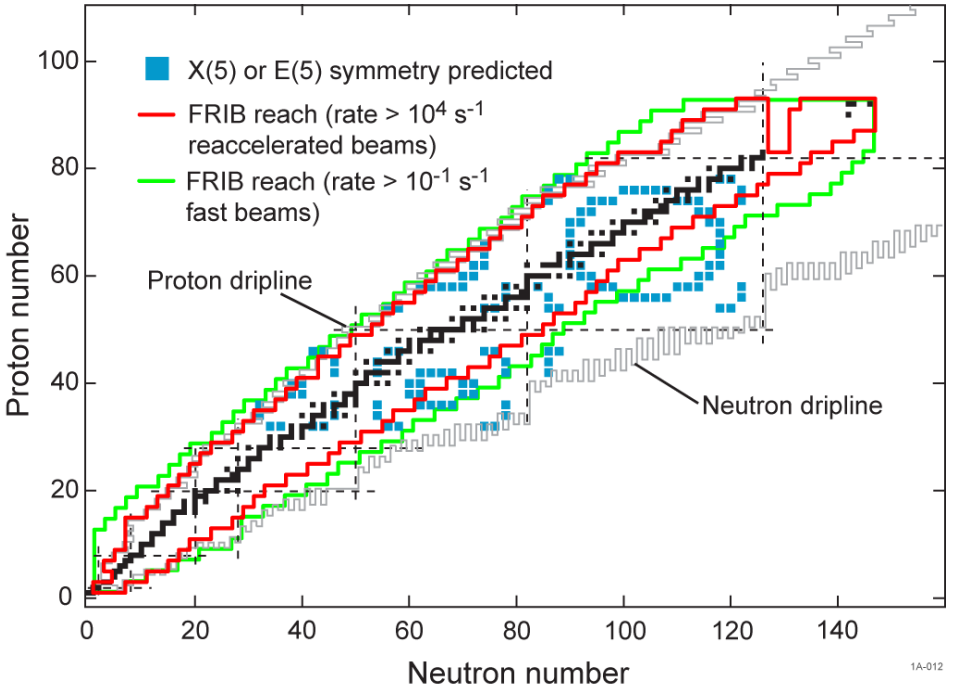
- Theory Road Map – comprehensive description of the atomic nucleus
  - Ab initio models – study of neutron-rich, light nuclei helps determine force to use in models (measurement of sensitive properties for *N* = 14,16 nuclei)
  - Configuration-interaction theory; study of shell and effective interactions (study of key nuclei such as 54Ca, 60Ca)
  - The universal energy density functional (DFT) – determine parameters (broad view of mass surface, BE(2)s, BE(4)s, fission barrier surface, etc.)
  - The role of the continuum and reactions and decays of nuclei (halo studies up to A ~100)
- IMPORTANT: Understand and select the most sensitive measurements (role for theory)



What is the Origin of Simple Patterns in Complex Nuclei?

- Measurements
  - Level structures and transition probabilities as a function of proton and neutron number
    - » Pre-term: ^{122}Pd and ^{96}Kr
    - » Short-term: Neutron-rich Ba
    - » Mid-term: Ni and Zr isotopes
    - » Long-term: High-*Z*, neutron-rich nuclei
- The answer to this question requires access to a broad range of the nuclear chart to produce key nuclides
- FRIB provides the broadest reach for exploring the evolution of nuclear symmetries and for developing the understanding of their origin

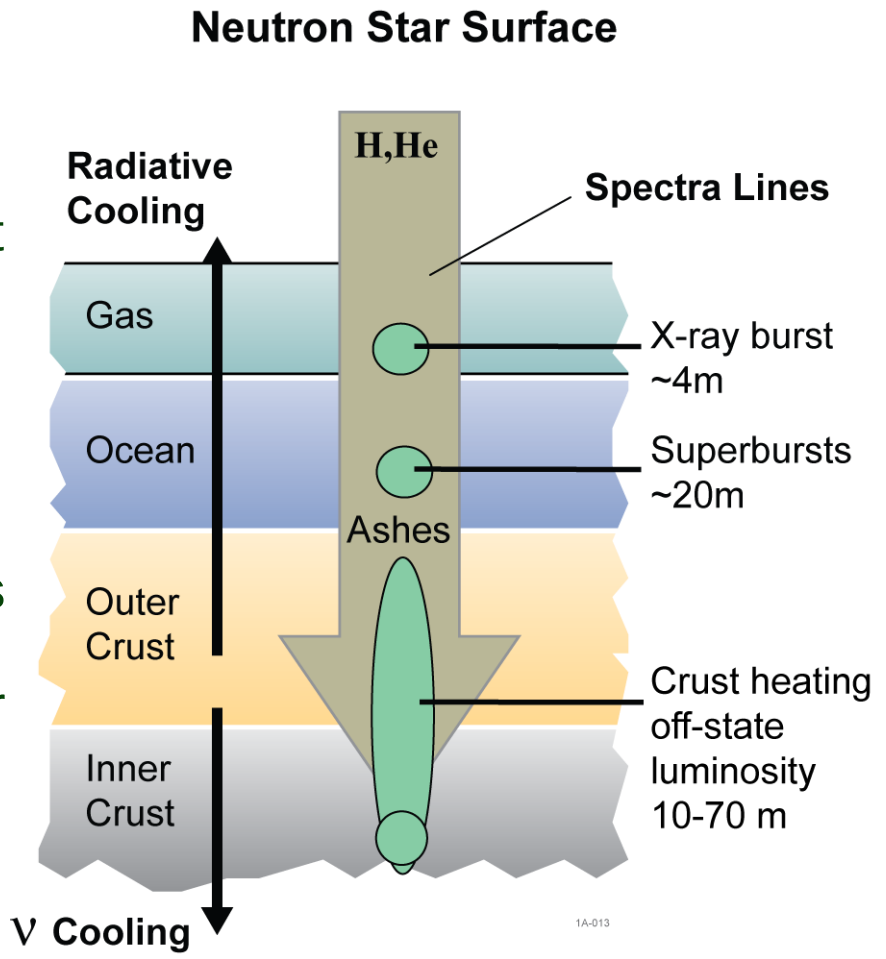
Highlighted regions of potential critical point symmetries



Approach: Verify or refute the persistence of critical-point symmetries at the extremes of the nuclear chart

What is the Nature of Neutron Stars and Dense Nuclear Matter?

- Key: Relate models to neutron-star observables
- FRIB will allow the study of all proton and alpha capture reactions needed to model the surface regions and interpret X-ray burst light curves
- FRIB will allow us to measure or determine the electron capture reactions and drip lines to models process in the outer crusts
- Reactions of neutron-rich beams will allow us to probe the symmetry energy (away from normal nuclear density) of the neutron-matter equation of state
- Properties of exotic, neutron-rich nuclei are related to the symmetry energy at normal nuclear density

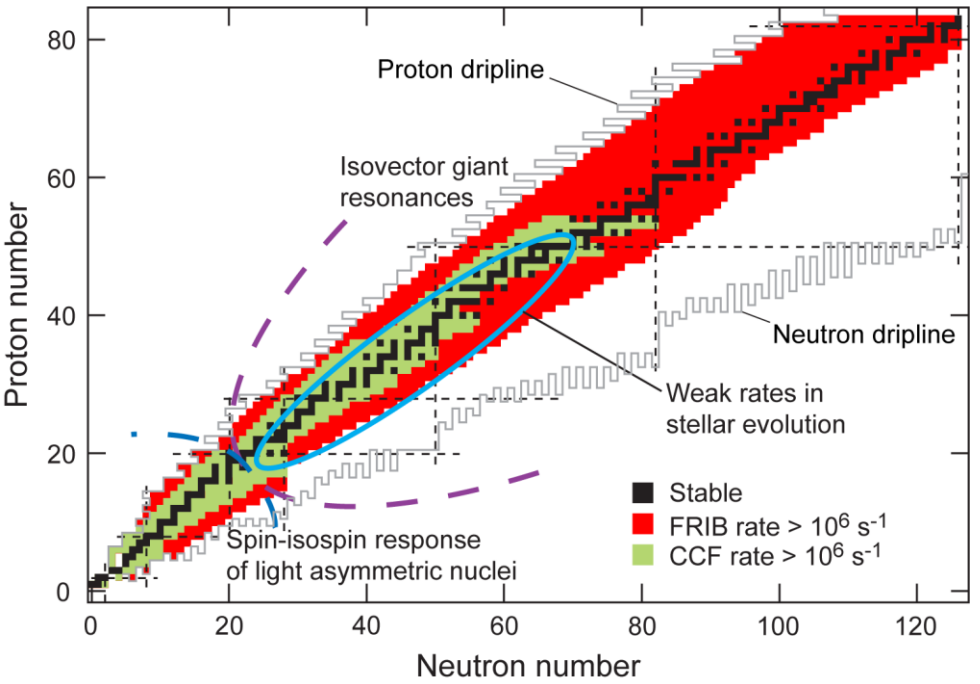


What are the Nuclear Reactions that Drive Stars and Stellar Explosions?

- FRIB will allow the exploration of the weak interaction rates needed to model pre-supernovae core evolution and type Ia explosions
- FRIB will allow the key (p, γ) and (α,γ) reactions on unstable nuclei to be measured in order to model novae and X-ray bursts
- FRIB will allow production of most of the isotopes needed to model r-process nucleosynthesis and thereby connect nucleosynthesis models to astronomical observations of element abundances in stars
- FRIB will help lead to a comprehensive theory for nuclear properties and how they react

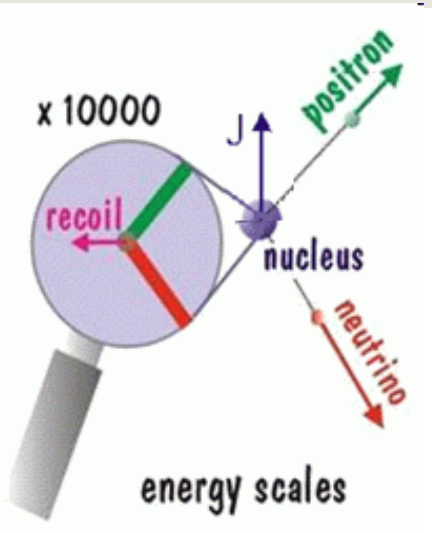
> "FRIB will be required to address this challenge and will enable the systematic study of weak interaction strength on most of the relevant unstable nuclei using charge exchange reactions with rare-isotope beams."
>
> —LRP 2007

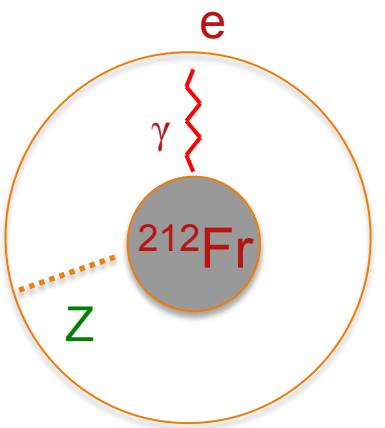
1A QB-012

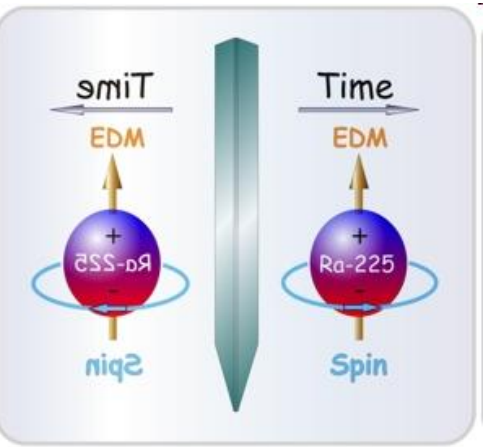


Other LRP Themes: Tests of Nature's Fundamental Symmetries

- Angular correlations in β-decay and search for scalar currents
  - Mass scale for new particle comparable with LHC
  - ^{6}He and ^{18}Ne at 10^{12}/s
- Electric dipole moments
  - ^{225}Ac, ^{223}Rn, ^{229}Pa (30,000x more sensitive than ^{199}Hg; ^{229}Pa > 10^{10}/s)
- Parity non-conservation in atoms
  - weak charge in the nucleus (francium isotopes; 10^{9}/s)
- Unitarity of CKM matrix
  - V_{ud} by super allowed Fermi decay
  - Probe the validity of nuclear corrections





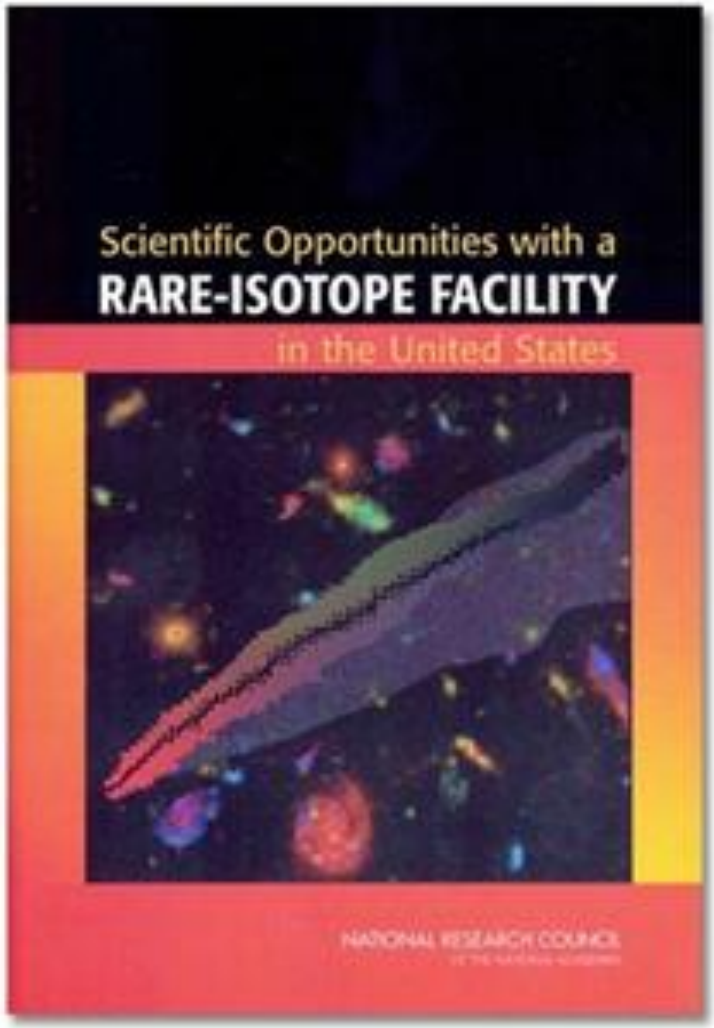


$$\begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix}$$

FRIB in Context of the National Academies

NRC Rare Isotope Science Assessment Committee, RISAC

"The committee concludes that the science addressed by a rare-isotope facility, most likely based on a heavy ion linac driver, should be a high priority for the United States."



"The committee concludes that nuclear structure and nuclear astrophysics constitute a vital component of the nuclear science portfolio in the United States. Moreover, nuclear structure-related research provides the scientific basis for important advances in medical research, national security, energy production, and industrial processing."

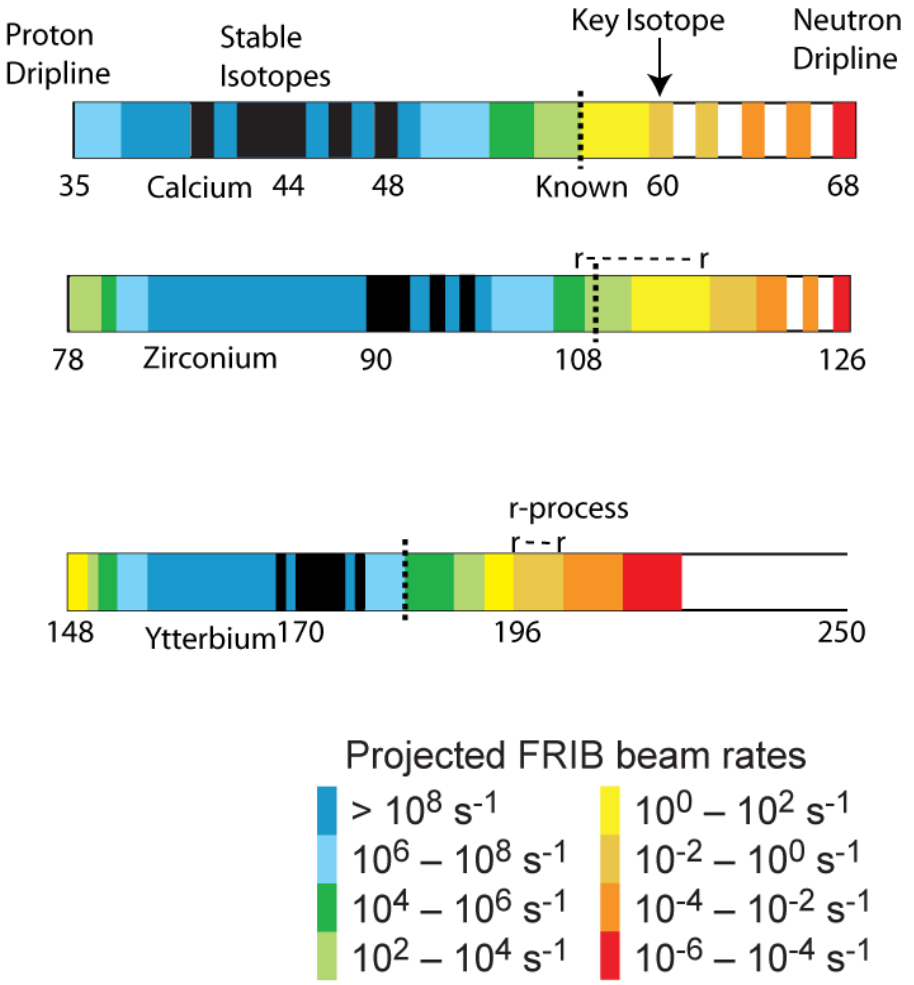
"The Gathering Storm report argued that strong public support of basic research can help fuel the national economic engine… While it is nearly impossible to argue that any one specific investment is critically necessary to maintain the future health of the enterprise, the committee does recognize the value of a U.S. FRIB as one element of a much broader portfolio in the physical sciences."

—Scientific Opportunites with a Rare Isotope Facility, December 2006

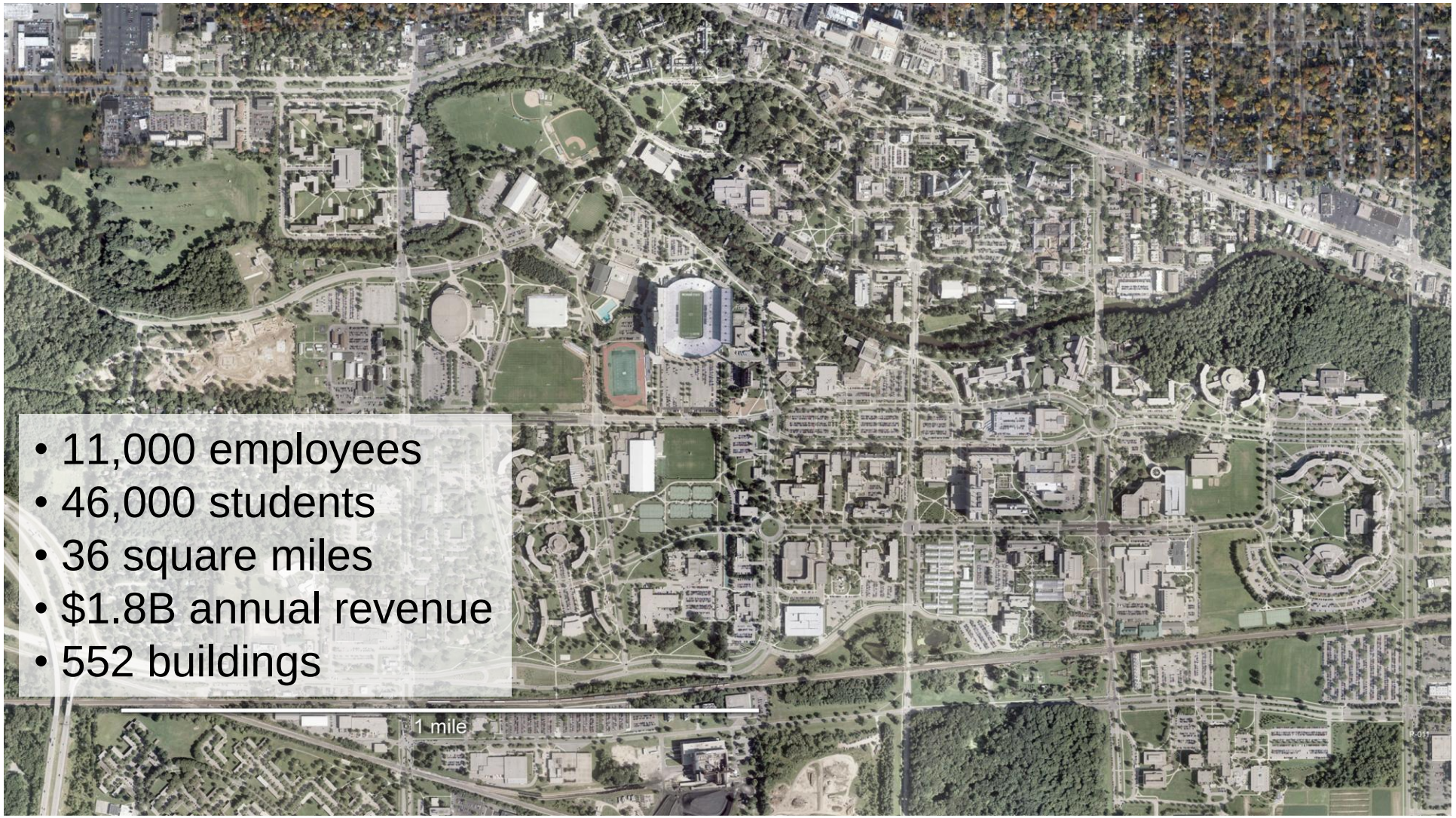
1A QB-002

RISAC Science Drivers

- Nuclear Structure
  - Explore the limits of existence and study new phenomena
  - Possibility of a broadly applicable model of nuclei
  - Probing neutron skins
  - Synthesis of superheavy elements
- Nuclear Astrophysics
  - The origin of the heavy elements
  - Explosive nucleosynthesis
  - Composition of neutron star crusts
- Fundamental Symmetries
  - Tests of fundamental symmetries
- Other Scientific Applications
  - Stockpile stewardship, materials, medical, reactors



Michigan State University



Experimental Nuclear Physics at MSU

1958 MSU hires first accelerator expert

1961 NSF approves sector focused K50 cyclotron

1965 Research with K50; single turn extration

1975 NSF approves superconducting cyclotron magnet prototype

1977 NSF approves K500 cyclotron

1978 NSAC recommends national user facility at MSU

1982 Research with stable beams from K500

1989 Research with stable beams from K1200

1990 Research with fast rare isotope beams from A1200

1996 NSF approves coupled cyclotron facility (CCF)

2001 Research with fast rare isotope beams from CCF

2002 Infrastructure for SRF linac R&D

2005 Research with trapped rare isotope beams

2006 MSU funds ReA3 reaccelerator project

2008 DOE selects MSU to establish FRIB

2011 Research with reaccelerated rare isotope beams from ReA3

2020 FRIB operations

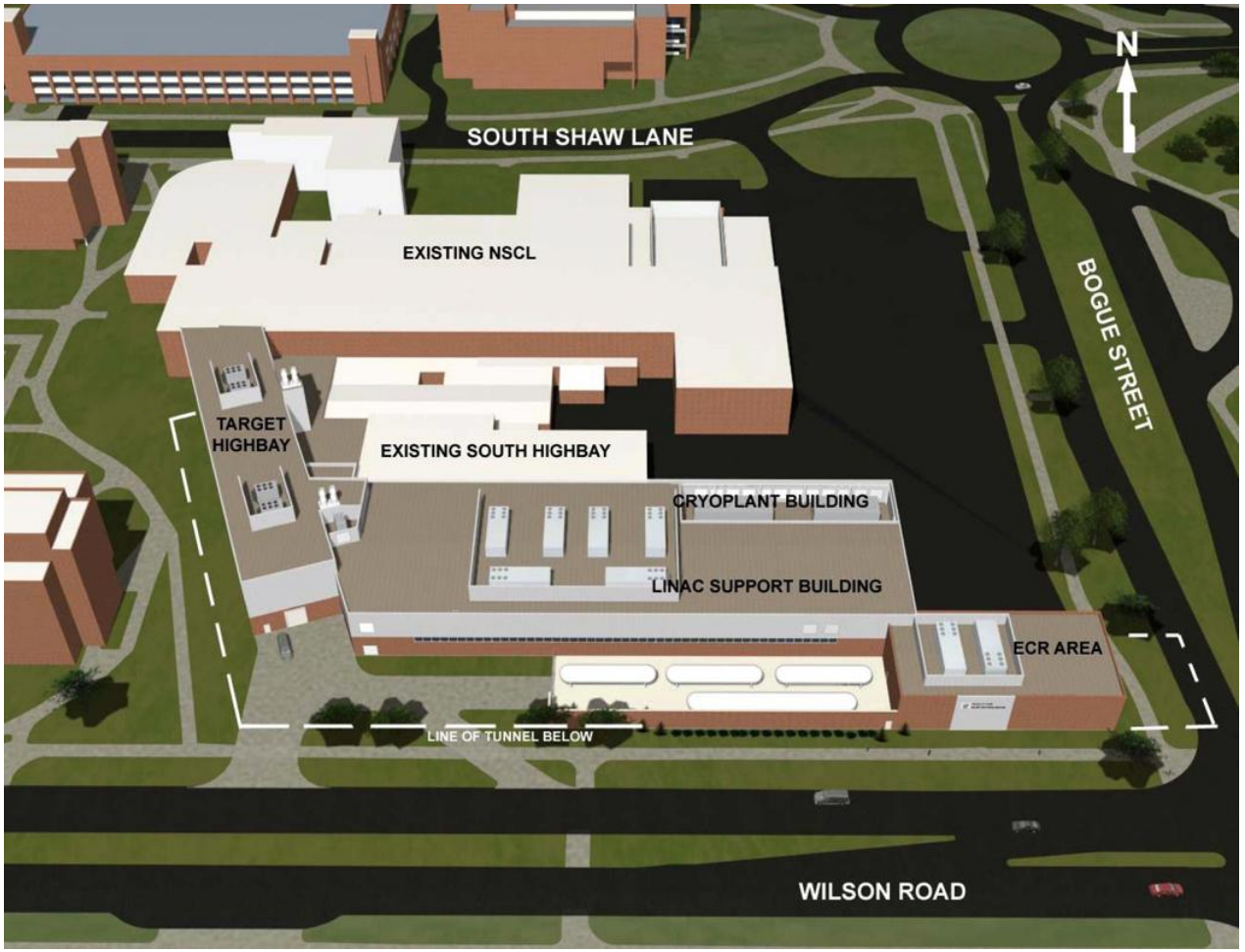
DOE-MSU FRIB Partnership Governed by Cooperative Agreement for Financial Assistance

- Similar to grant, but DOE retains significant involvement based on programmatic interests
- FRIB project management system based on DOE and industry best practices and follows DOE O 413.3A principles
  - Project management system will be captured in Preliminary Project Execution Plan (was approved at CD-1)
- External regulation
  - Michigan OSHA (agreement state since 1973); Nuclear Regulatory Commission (through amendment to existing MSU NRC Broad Scope License); State of Michigan Department of Community Health
- Management systems
  - ISO 14001-registered Environmental Management System; OHSAS 18001-registered ISMS; ISO 9001-registered Quality Management System
  - EVMS will meet ANSI 748
- Oversight by DOE-SC Nuclear Physics Program (SC-26), Office of Project Assessment (SC-28) and MSU

FRIB Key Performance Requirements

- ≥ 200 MeV/u, 400 kW superconducting heavy ion driver linac
- Initial capabilities should include fragmentation of fast heavy ion beams combined with gas stopping and reacceleration
- Capable of world-class scientific research program at start of operation
- Accommodate 100 users at a time, 400-500 per year

CD-1 Preferred Alternative Approved September 1, 2010



- TPC $614.5M
  - $520M DOE
  - $94.5M MSU
- CD-4
  - Q2 FY2020
  - Early finish goal Q4 FY2018
- Lowest-cost configuration that meets FRIB Key Performance Requirements
- Upgradable
  - Can increase beam energy
  - Can add ISOL
  - Can add light-ion driver
  - Can add multi-user

CD-1 Conceptual Design – [1]

CD-1 design maintains Key Performance Requirements

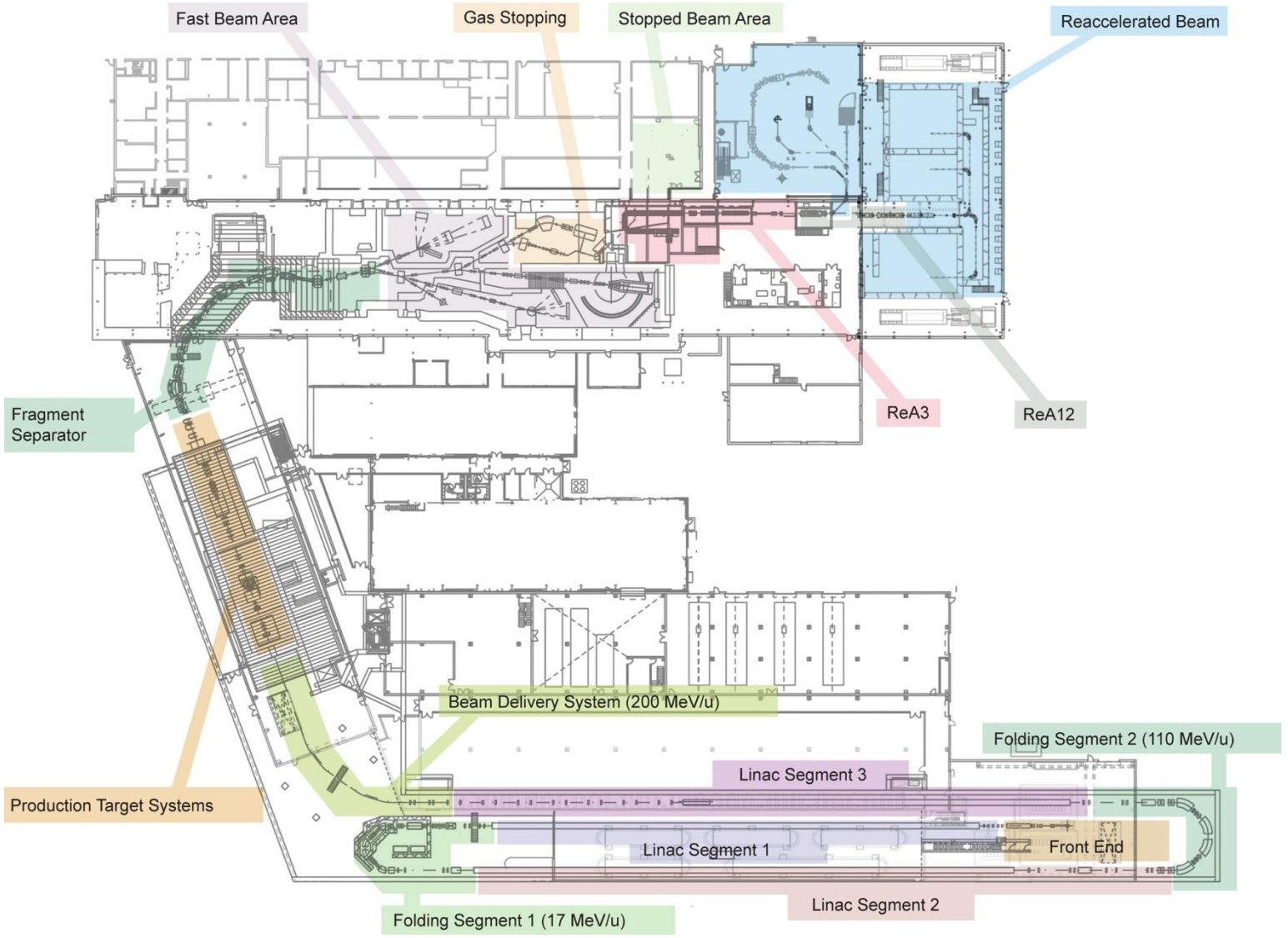
- TPC cost to <$615M (then year)
  - Achieved by value engineering – largely by reducing civil facility cost by modifying driver linac geometry
- Facility performance
  - Driver beams with ≥200 MeV/u and up to 400 kW beam power
  - Rare isotopes produced (particle fragmentation), selected (fragment separator), and utilized at production velocity (fast beams), at rest (stopped), or low velocity (reaccelerated)
- Ready for world-class science program at start of operations
- Upgrade potential
  - Substantial (2x) expansion of experimental areas
    (fast, stopped or reaccelerated beams – depends on science needs)
  - Driver beam energy increase to ≥400 MeV/u
    (assumes 35% cavity performance increase over baseline performance for β=0.53 half wave cavities)
  - Isotope Separation On Line (ISOL) capability by addition ISOL target
  - Multiuser capability by addition of light ion injector

CD-1 Conceptual Design – [2]

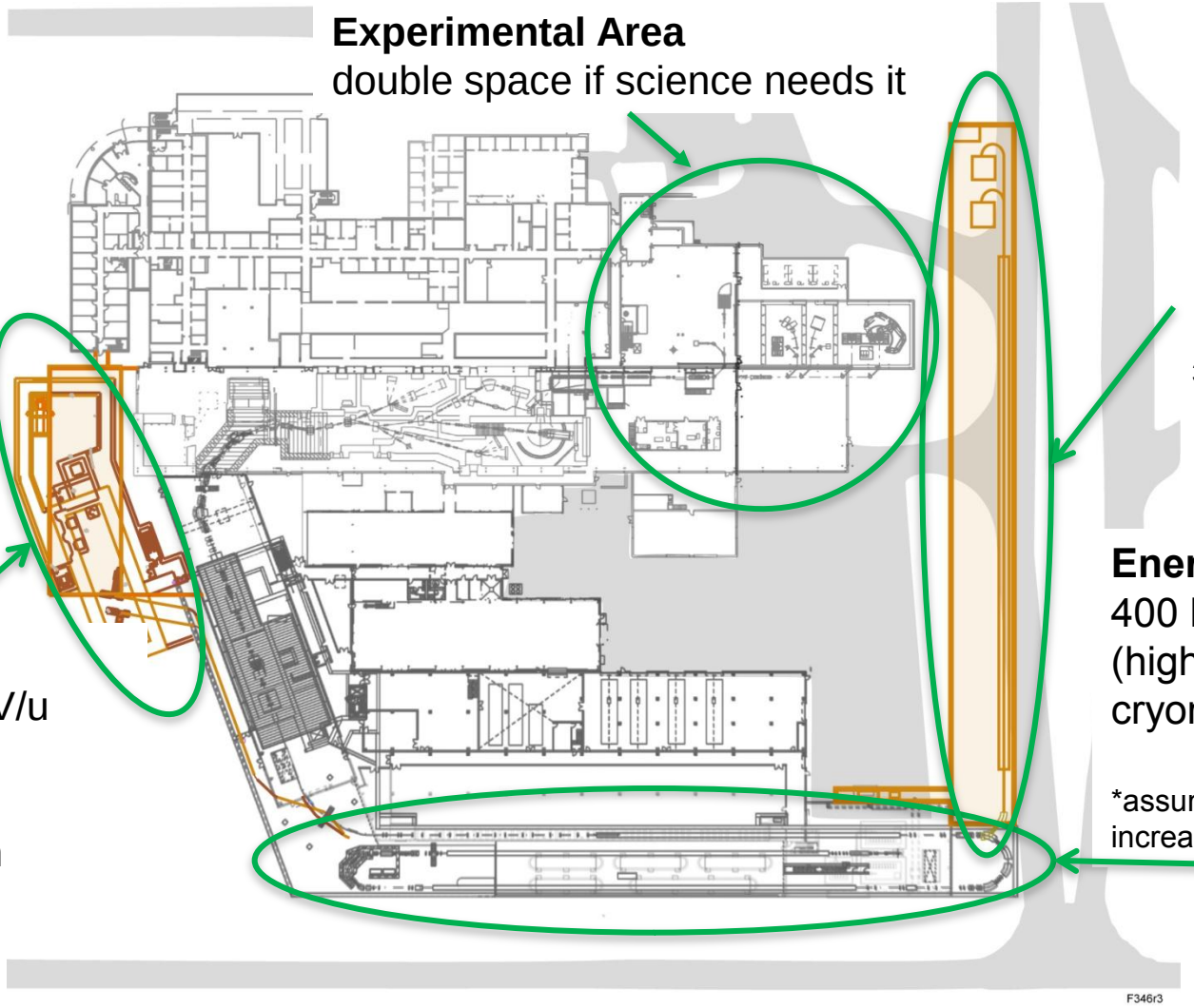
Risks indentified and mitigation developed

- Plans proposed to reduce risks to schedule – critical path candidates
  - Conventional Facilities – plan to expedite implementation
  - Accelerator Systems cryogenic facility – will implement early acquisition
  - Accelerator Systems cryomodules – acquisition strategy proposed
- R&D plans proposed to reduce technical risks
  - Accelerator Systems
    - » SRF cavity performance
      - 3 of 4 cavity types prototyped
      - Capitalize on early production experience from MSU reaccelerator project
    - » Driver linac charge stripping system – **biggest technical challenge** – R&D plans evolved with new information
      - Carbon foil found not viable
      - Liquid lithium pursued with ANL & gas pursued with BNL, RIKEN, and Texas A&M
  - Experimental Systems - form/fit/function known – development at detailed level
    - » High-power production target & fragment separator beam dump & radiation resistant magnets

CD-1 Conceptual Design – [2]



Upgrade Options for CD-1 Preferred Alternative



Experimental Area
double space if science needs it

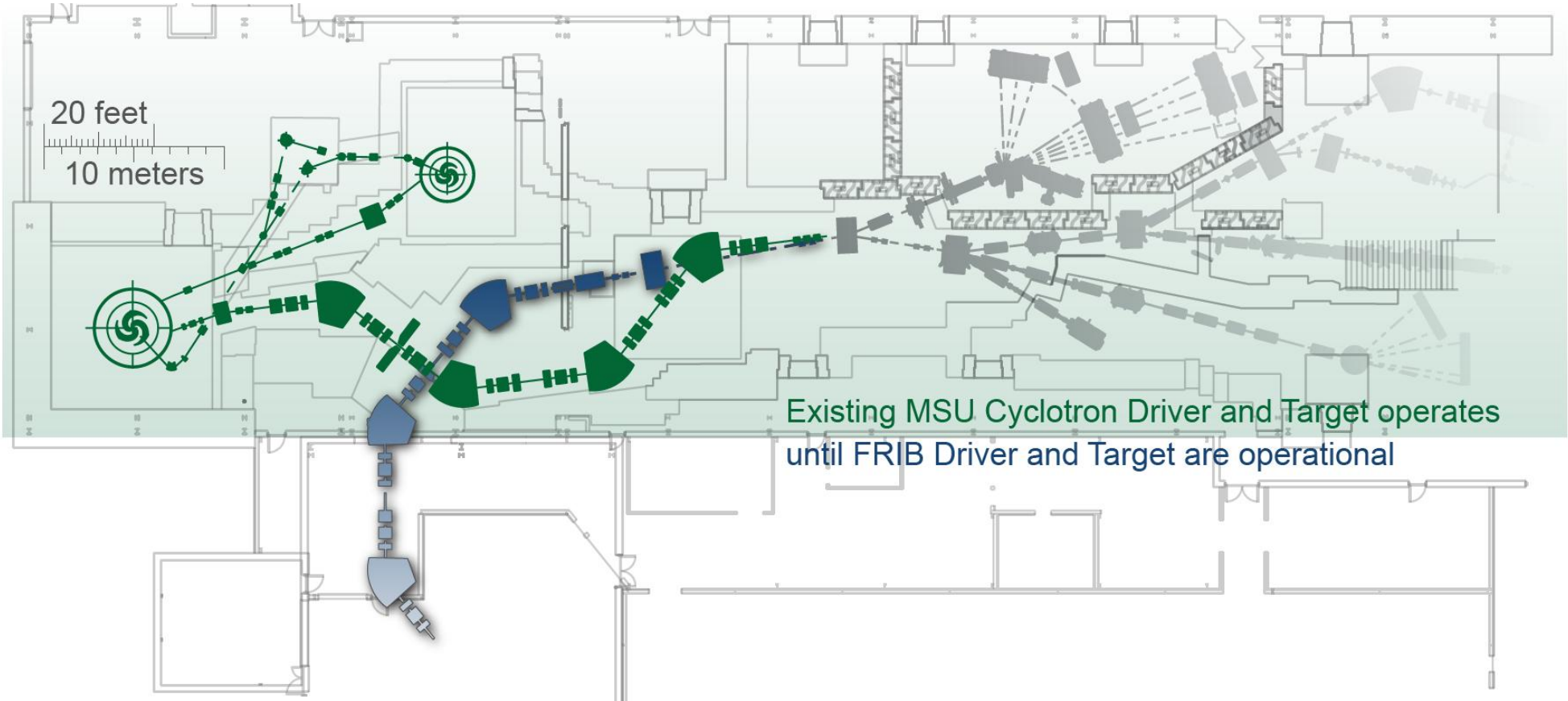
Light ion injector upgrade
$^{3}He^{+}$, 195 MeV/u

Energy upgrade to ≥ 400 MeV/u for all ions (high performance* λ/2 cryomodules)

*assumes 35% performance increase over baseline design

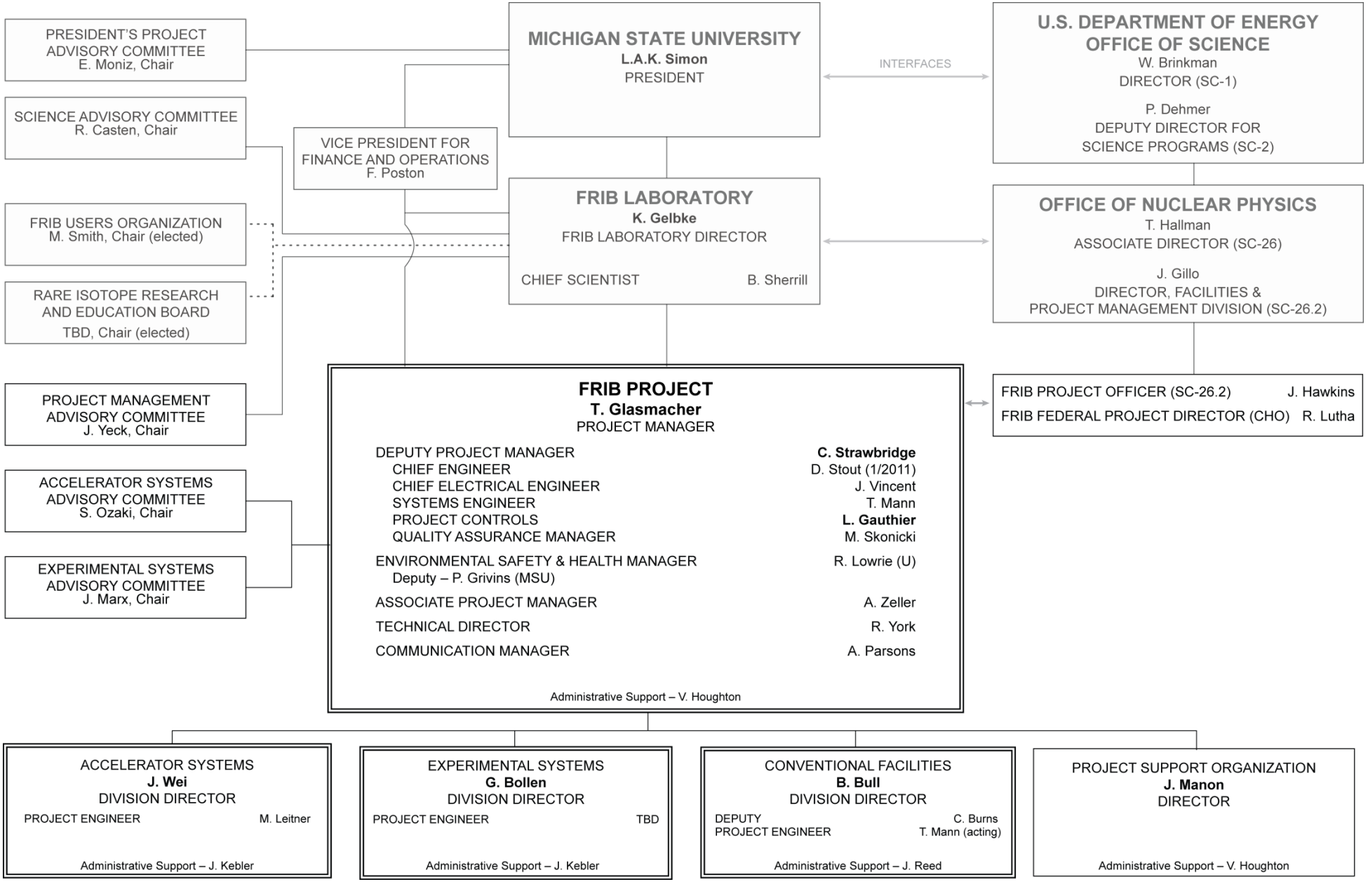
ISOL targets
^{3}He, 400 MeV/u
Multiuser capability with light ion injector

Early Science Opportunities with Fast, Stopped, and Reaccelerated Beams

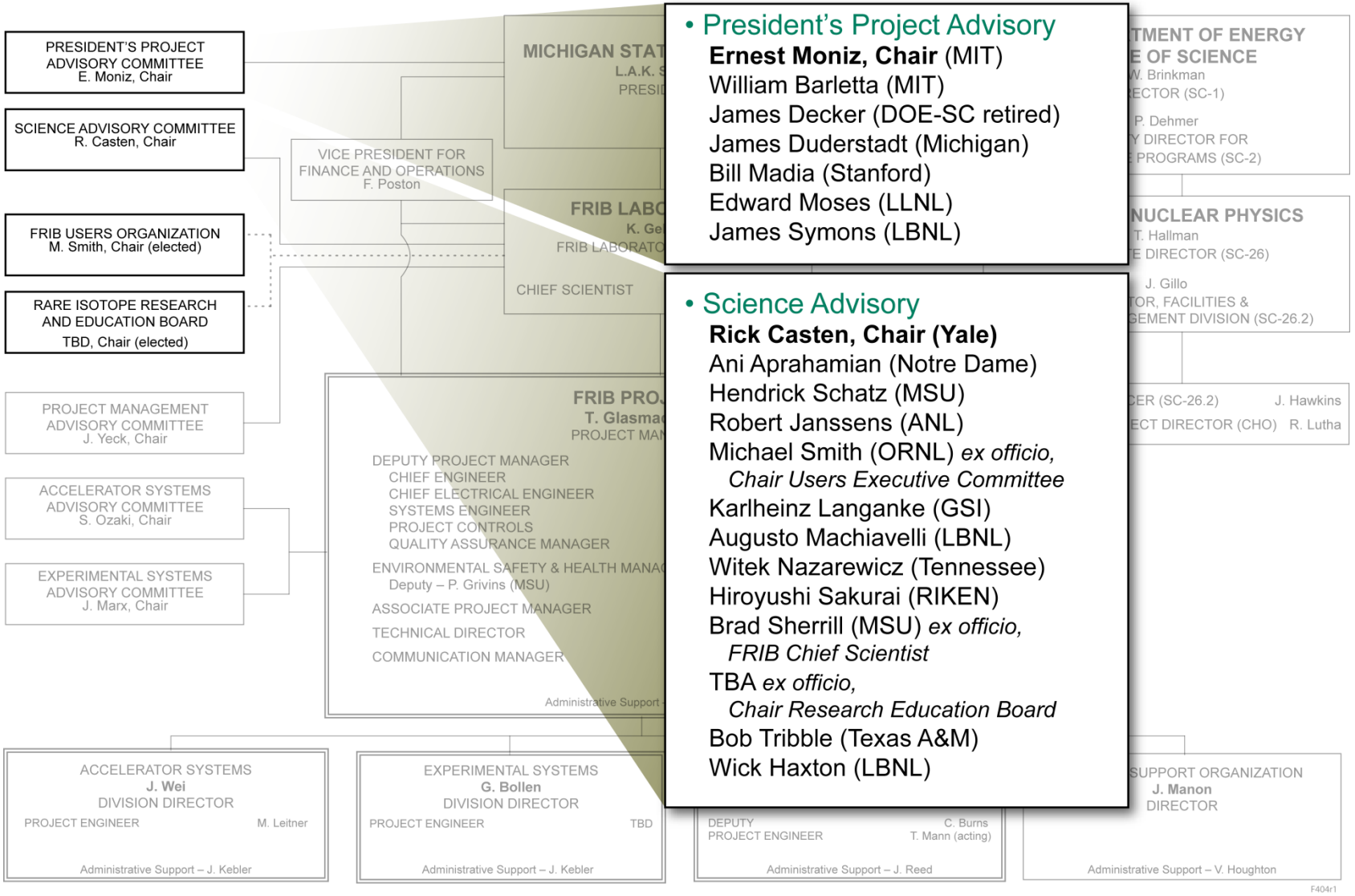


- Collaborations form early while FRIB is being constructed
- Post-production elements commissioned before FRIB driver linac complete
- Ensures world-class scientific research program at start of FRIB operation

DOE-MSU FRIB Project Team



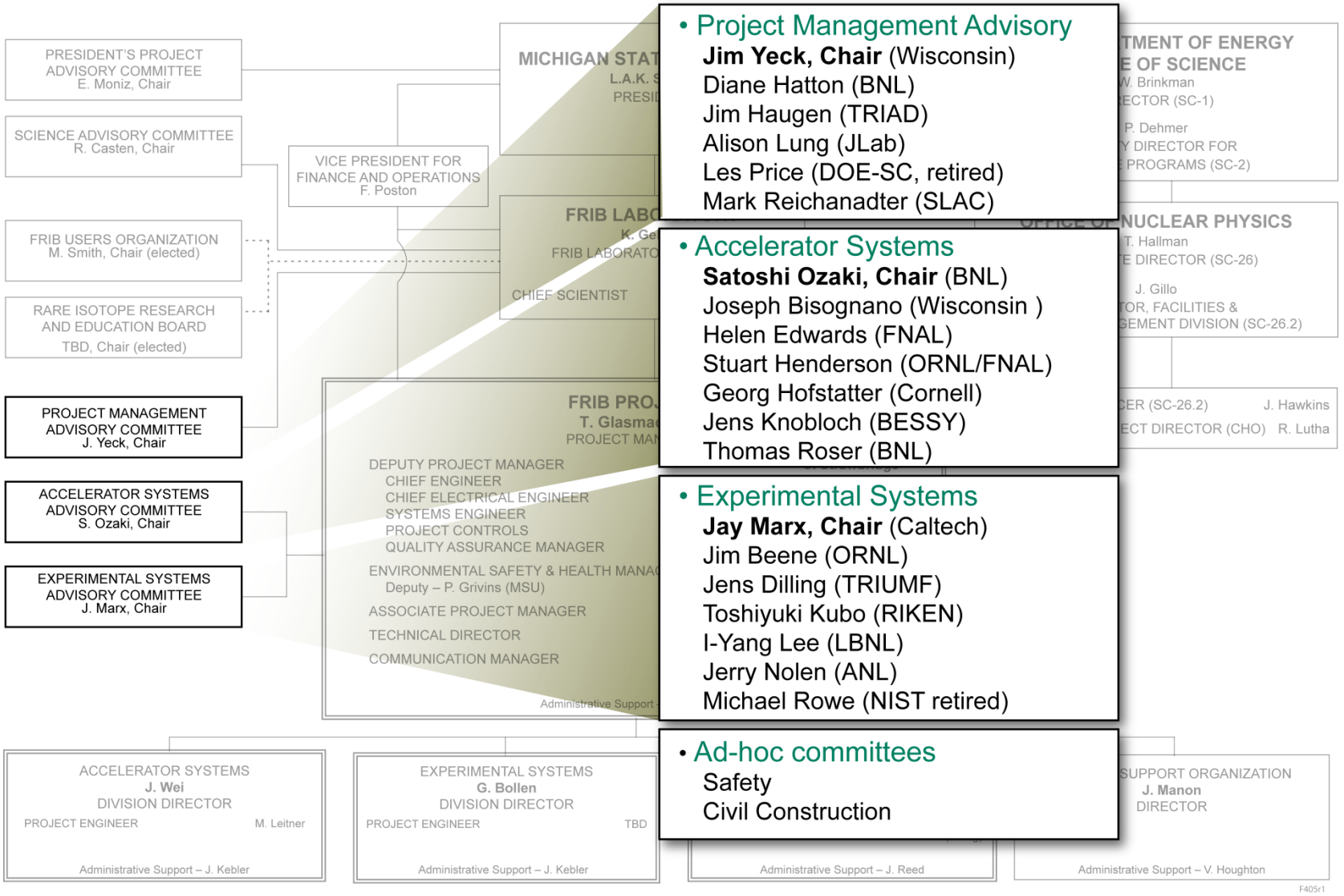
MSU and FRIB Laboratory External Advisory Groups



- President's Project Advisory
  - **Ernest Moniz, Chair** (MIT)
  - William Barletta (MIT)
  - James Decker (DOE-SC retired)
  - James Duderstadt (Michigan)
  - Bill Madia (Stanford)
  - Edward Moses (LLNL)
  - James Symons (LBNL)

- Science Advisory
  - **Rick Casten, Chair (Yale)**
  - Ani Aprahamian (Notre Dame)
  - Hendrick Schatz (MSU)
  - Robert Janssens (ANL)
  - Michael Smith (ORNL) *ex officio, Chair Users Executive Committee*
  - Karlheinz Langanke (GSI)
  - Augusto Machiavelli (LBNL)
  - Witek Nazarewicz (Tennessee)
  - Hiroyushi Sakurai (RIKEN)
  - Brad Sherrill (MSU) *ex officio, FRIB Chief Scientist*
  - TBA *ex officio, Chair Research Education Board*
  - Bob Tribble (Texas A&M)
  - Wick Haxton (LBNL)

FRIB Project
External Peer Advisory Groups

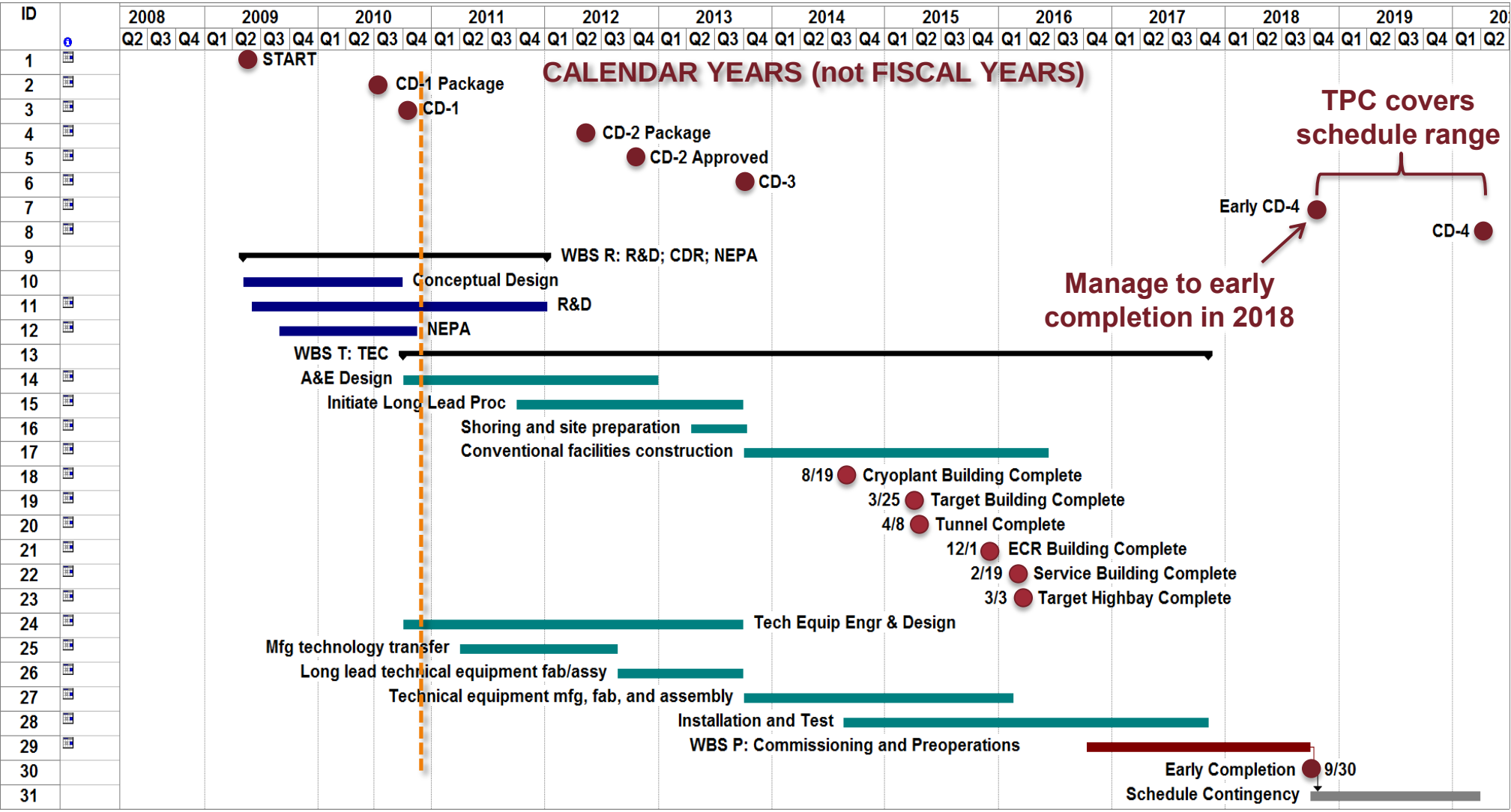


- **Project Management Advisory**
  - **Jim Yeck, Chair** (Wisconsin)
  - Diane Hatton (BNL)
  - Jim Haugen (TRIAD)
  - Alison Lung (JLab)
  - Les Price (DOE-SC, retired)
  - Mark Reichanadter (SLAC)
- **Accelerator Systems**
  - **Satoshi Ozaki, Chair** (BNL)
  - Joseph Bisognano (Wisconsin)
  - Helen Edwards (FNAL)
  - Stuart Henderson (ORNL/FNAL)
  - Georg Hofstatter (Cornell)
  - Jens Knobloch (BESSY)
  - Thomas Roser (BNL)
- **Experimental Systems**
  - **Jay Marx, Chair** (Caltech)
  - Jim Beene (ORNL)
  - Jens Dilling (TRIUMF)
  - Toshiyuki Kubo (RIKEN)
  - I-Yang Lee (LBNL)
  - Jerry Nolen (ANL)
  - Michael Rowe (NIST retired)
- **Ad-hoc committees**
  - Safety
  - Civil Construction

WFO Agreements and MOUs in Place

- Argonne National Laboratory
  - Liquid lithium charge stripper
  - Stopping of ions in gas
  - Fragment separator design
  - Beam dynamics (under discussion)
  - SRF (under discussion)
- Brookhaven National Laboratory
  - Radiation resistant magnets
  - Plasma charge stripper
- Lawrence Berkeley National Laboratory
  - ECR ion source
  - Beam dynamics
- Oak Ridge National Laboratory
  - Target facility conceptual design
  - Beam Dump R&D
- Jefferson Laboratory
  - Cryogenics
  - SRF (in preparation)
- Stanford National Accelerator Laboratory
  - Cryogenics (completed)
  - SRF multipacting
- Sandia
  - Production target
- Soreq (Israel)
  - Production target
- RIKEN (Japan)
  - Charge strippers
- GSI (Germany)
  - Production target
- GANIL (France)
- TRIUMF (Canada)
  - SRF
- Legnaro
  - SRF

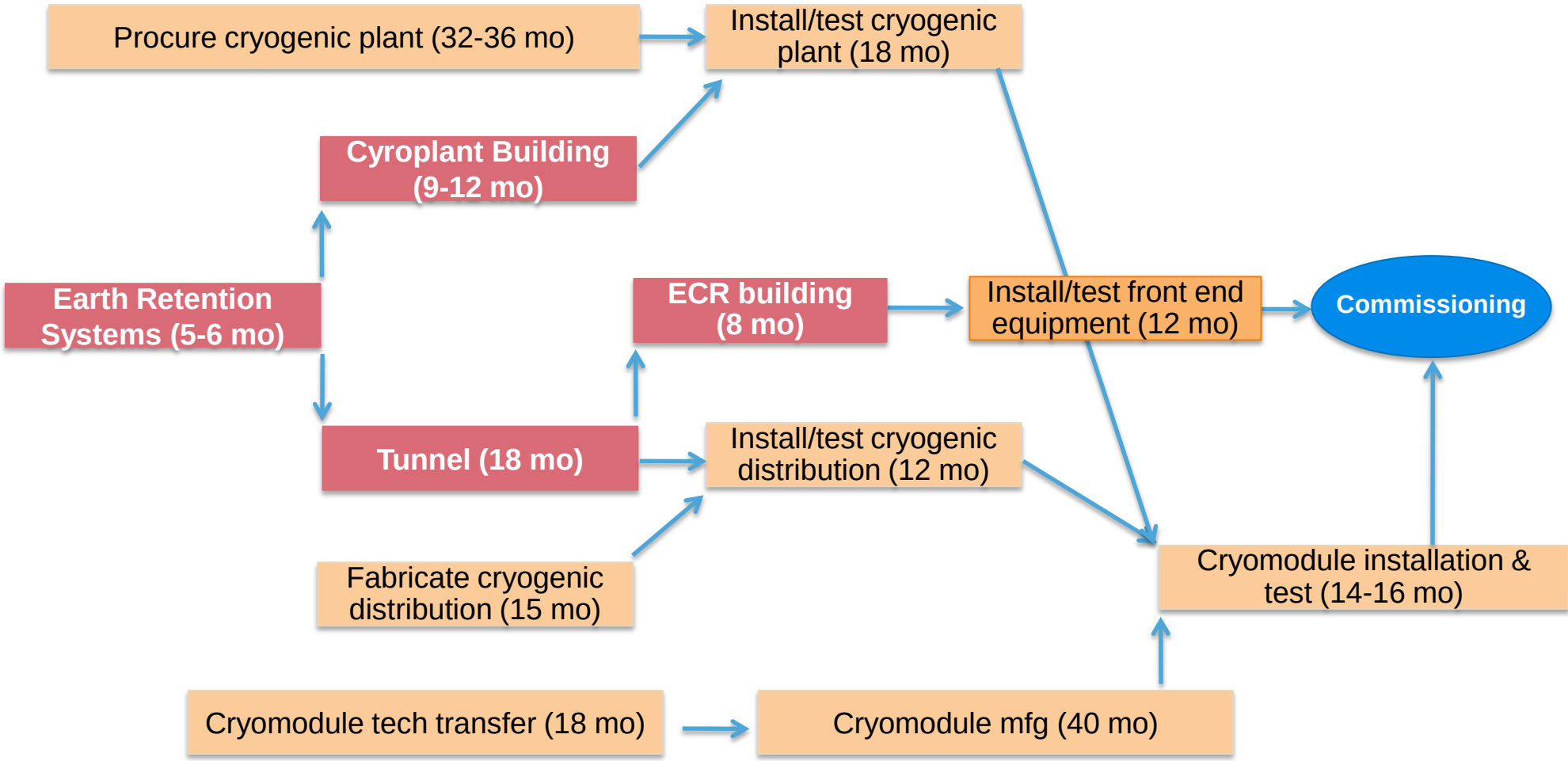
High Level Project Performance Schedule Approved at CD-1



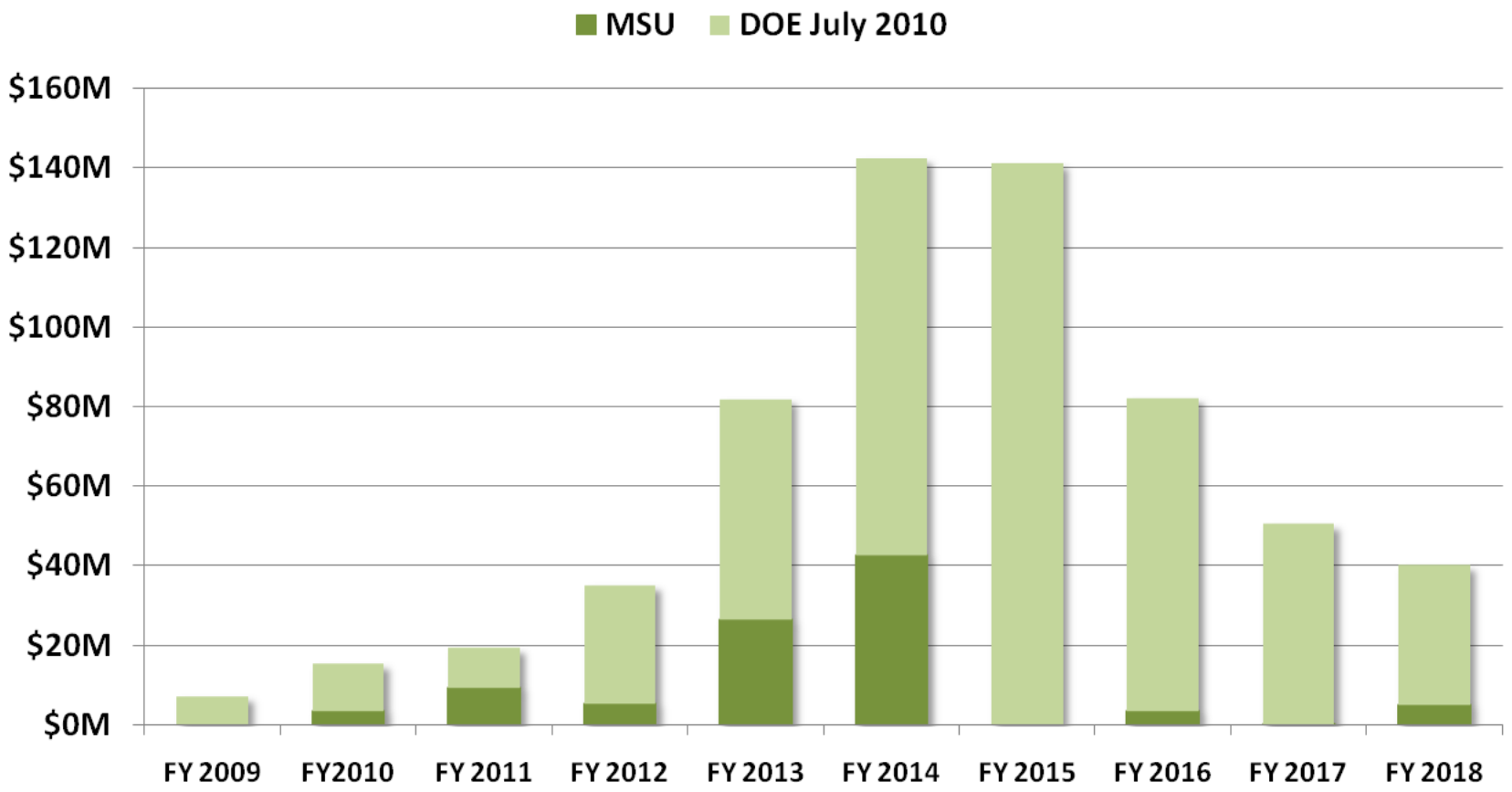
Paced by Funding Profile | Paced by Facilities | Paced by Installation & Test

Conventional Facilities Drives Schedule

High Level PERT of Critical and Near-Critical Elements



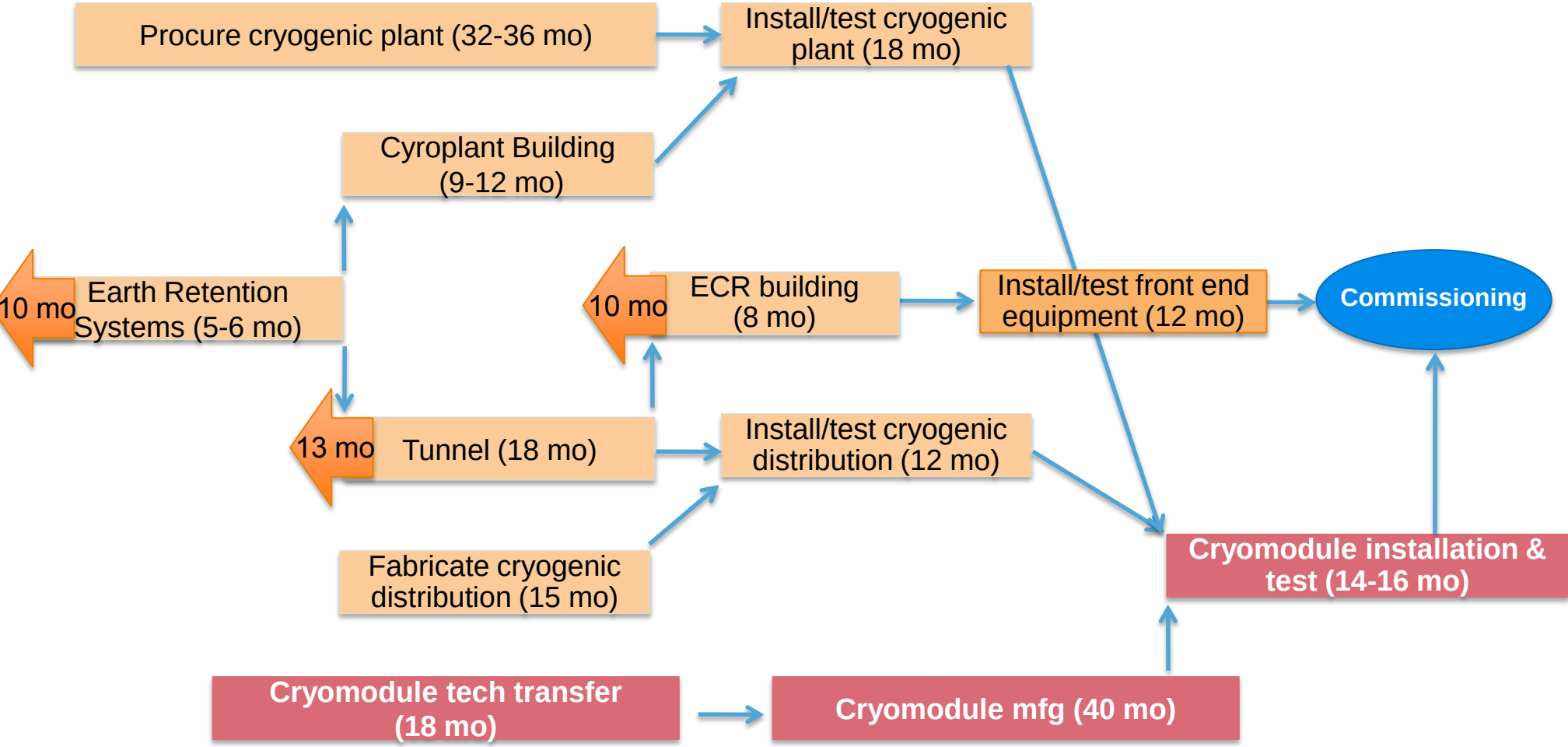
Funding Profile Agreed Between MSU and DOE Office of Science to supports CD-1 Plan



- Meeting between DOE-SC Deputy Director Dehmer and MSU President Simon (April 2010)
- MSU cost share front-loaded and optimized for project success

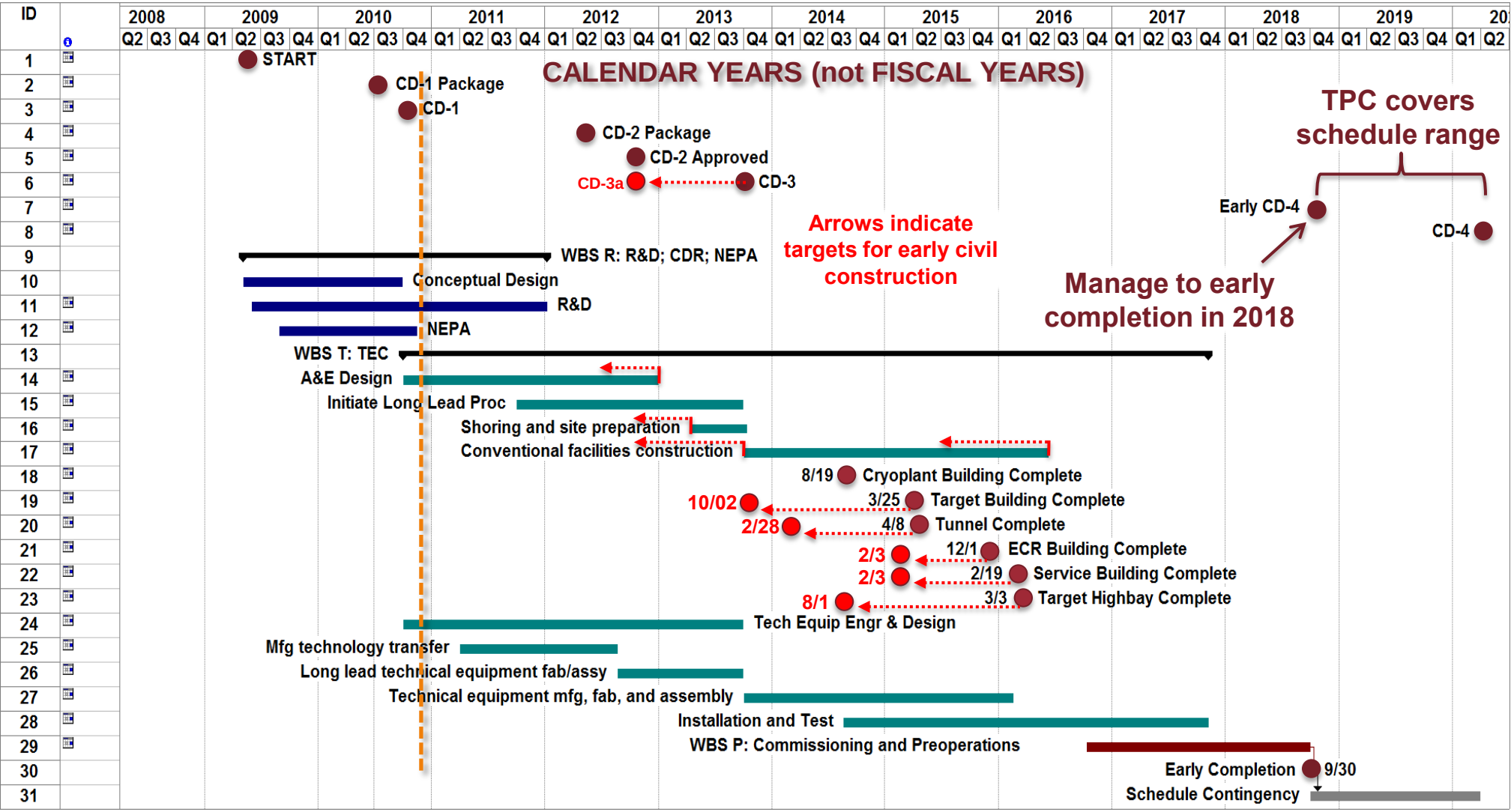
Accelerated Construction Reduces Risk: Project Evaluates CD2/3a in Spring 2012

High Level PERT of Critical and Near-Critical Elements



High Level Accelerated Civil Schedule

(Project is evaluating this, requires further frontloading of MSU cost share in FY12/13)



Key Activities for FY2011

- Technical R&D
  - Complete **SRF cryomodule** assembly
  - Complete 20 kW **prototype target** tests and design of 50 kW prototype target
  - Complete **Li-stripper** thickness and stability measurements
  - Complete **plasma stripper** stability measurements
  - **Gas stopper** delivered to FRIB
- Management and Support
  - Complete **Project Controls Manual**
  - Complete **EVMS** readiness assessment package
- Conventional Construction
  - **CM contract** awarded
  - A/E prelim design contract awarded
  - **CF prelim design 60%** complete
- Accelerator Systems
  - **Magnet** design
  - Complete **λ/2 cryomodule** PD
  - **Cryoplant** RFI and release RFP
  - Complete **utility distribution** PD
  - **Machine protection** system review
- Experimental Systems
  - Complete **preseparator** design
  - Complete **remote-handling** specs
- Global Systems
  - Complete **global safety system** specifications

Strong MSU Support for FRIB Project

- $94.5M cost share plus $212M in contributions
- Additional contributions beyond $212M
  - $6.3M (FY2010) contribution for site preparation
    - » Relocation of utilities to prepare site in progress
    - » Cost savings through combination with Plant Science construction and taking advantage of economic conditions
    - » Additional contribution has reduced TPC
    - » Eliminates critical scheduling dependency for FRIB construction
  - $5.5M (FY2011) Low-energy Experimental Area Expansion for ReA12
    - » Removed from FRIB scope to reduce TPC, needed for reaccelerated beam program with energies above Coulomb barrier
- $14.2M financing electrical feeder
  - Reduced TPC by $14.2M
- Significant frontloading of cost share
- $10M line of credit to mitigate Continuing Resolution in FY2011

FRIB Users Highly Engaged

www.fribusers.org – more than 800 registered users from 55 countries

- Isotope Harvesting at FRIB – held Sept. 29-Oct. 1 at Los Alamos National Laboratory
  - 30 participants identified examples of isotopes that would benefit fields from medicine to oceanography
- NUCL Symposium: Radiochemistry at FRIB – held Aug. 22-24 in Boston
  - Held in conjunction with 240th National Meeting of the American Chemical Society
- FRIB Equipment Workshop held Feb. 20-22, 2010 in East Lansing
  - 265 registered participants from 76 institutions in 15 countries
  - 18 working groups held sessions and presented summaries
  - meetings.nscl.msu.edu/frib-equipment-workshop2010/program.htm
- Prior workshop held May 30-31, 2009 at Argonne National Laboratory
  - "Step Forward to FRIB"
  - 210 registered participants from 47 institutions in 11 countries
  - www.fribusers.org/4_GATHERINGS/4_ARCHIVE/05_09/05_09.html

Summary

- Project on track for CD-2 (possibly CD-2/3A) in 2012
  - NEPA completed with Finding of No Significant Impact (Sept 2010)
  - CD-1 approved (Sept 2010)
  - Preliminary Design ongoing
- FRIB team highly energized and motivated for success
- Integrated cost and funding profiles collaboratively with DOE Office of Nuclear Physics for conceptual design total project cost of $614.5M (DOE $520M, MSU $94.5M) and project completion in 2020, early completion in 2018
- Effective working relationships in place with DOE Office of Nuclear Physics, Federal Project Director, Project Advisor, MSU senior administration and MSU support organizations
- Managing the project towards early completion