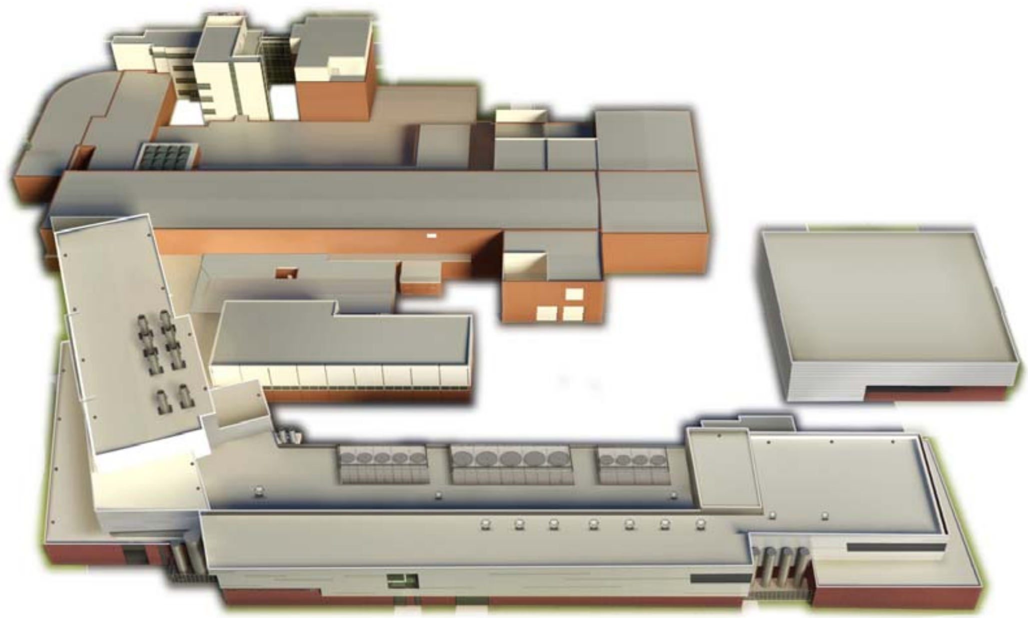
Facility for Rare Isotope Beams – FRIB
Strategic Partnership “FRIB-Materials under Extreme Conditions” MatX

Georg Bollen
FRIB/MSU

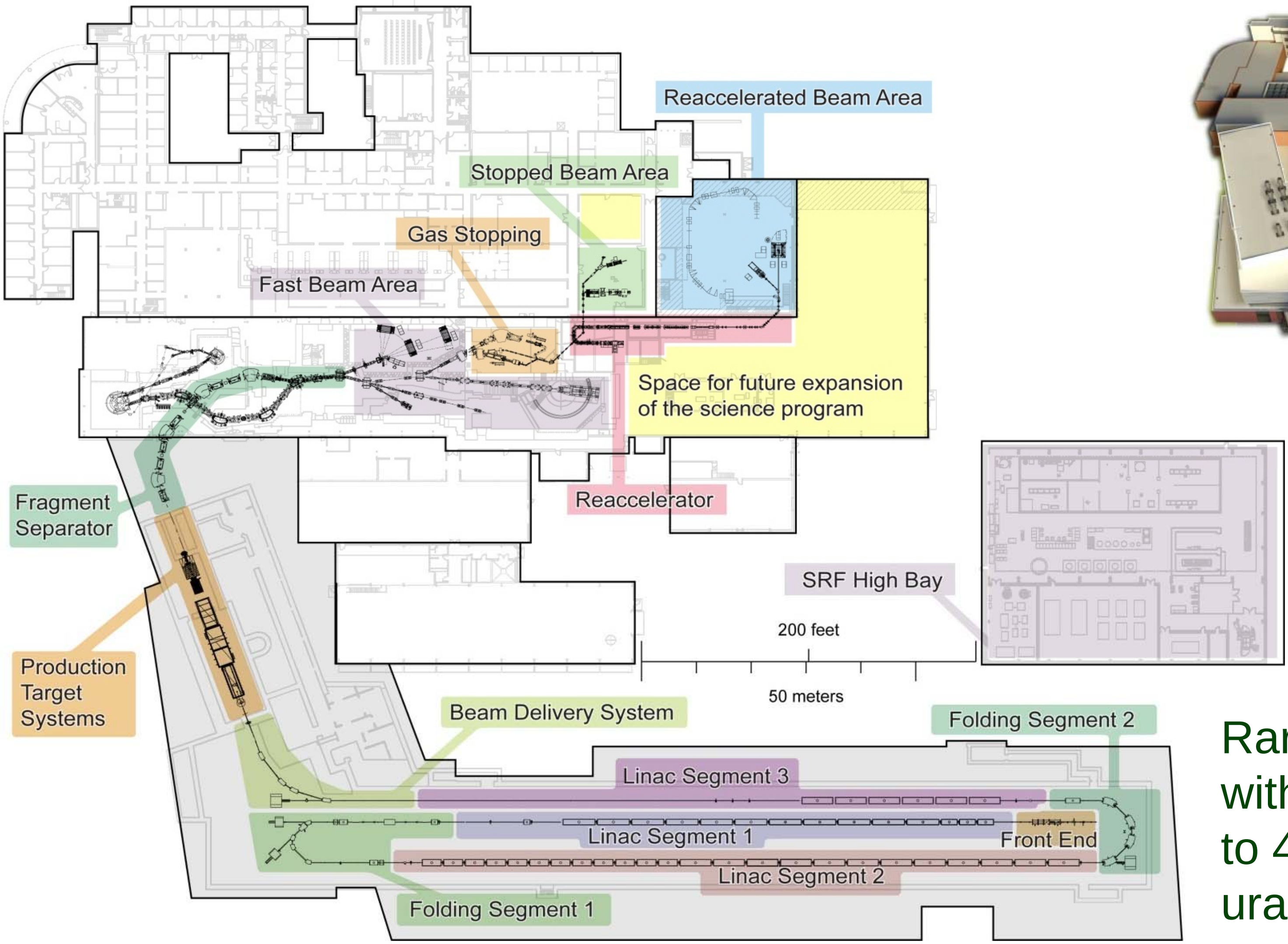


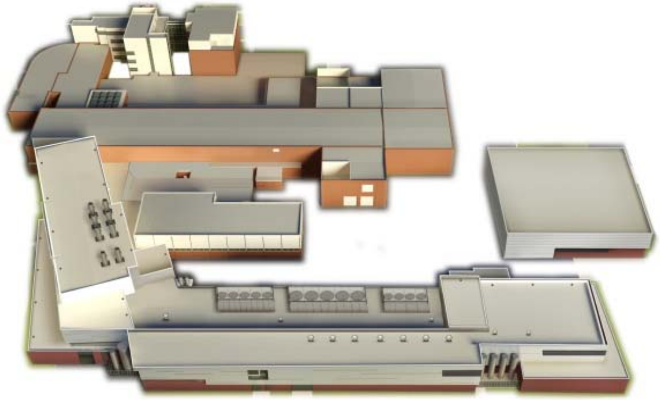
RaDIATE Meeting March 20, 2013

<u>MSU Attendees:</u>

- Georg Bollen: Experimental System Division Director
- Frederique Pellemoine: FRIB Target Systems Group Leader
- Reg Ronningen: FRIB Radiation Transport Group Leader

Facility for Rare Isotope Beams

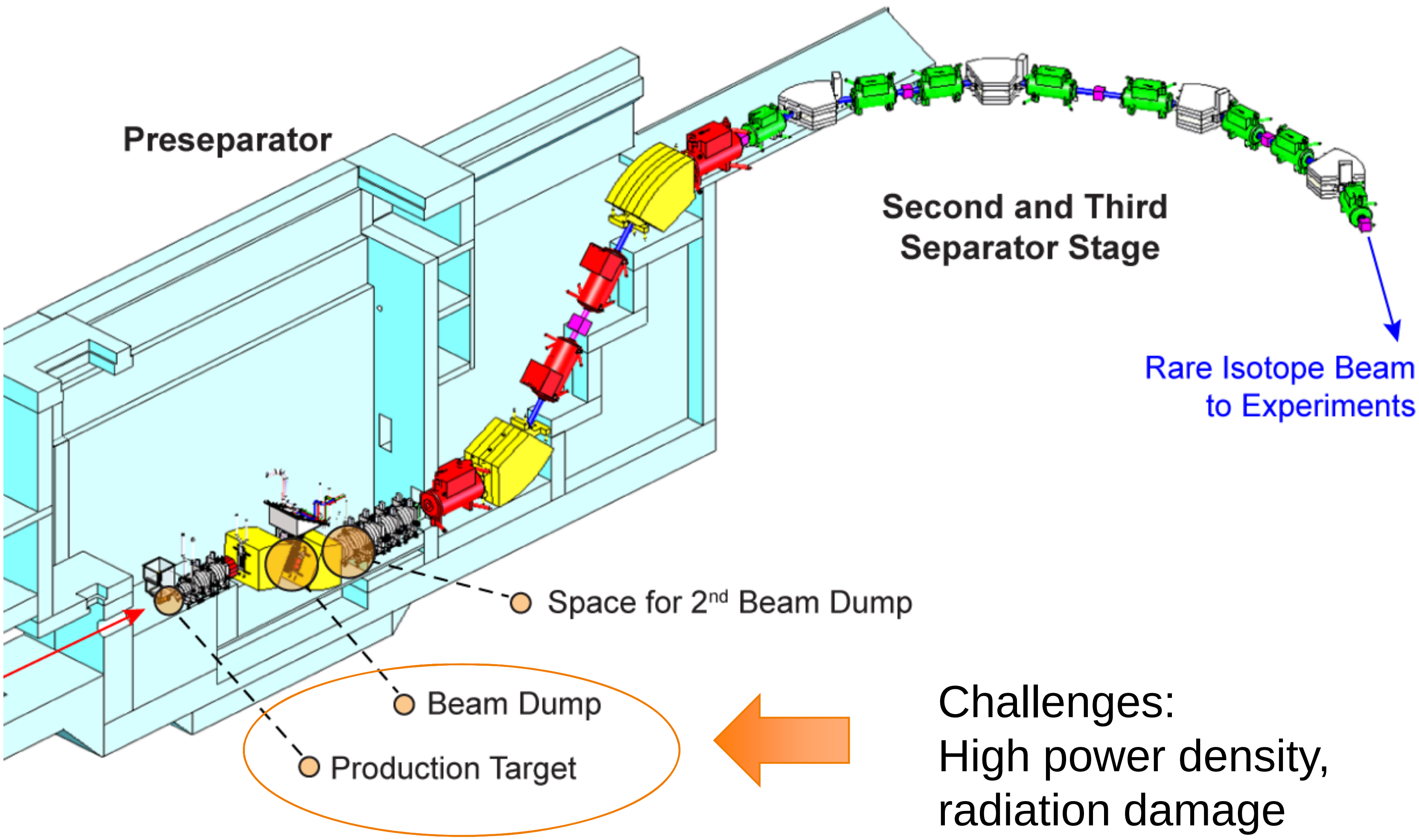




Rare isotope production with primary beams up to 400 kW, 200 MeV/u uranium

FRIB Rare Isotope Production

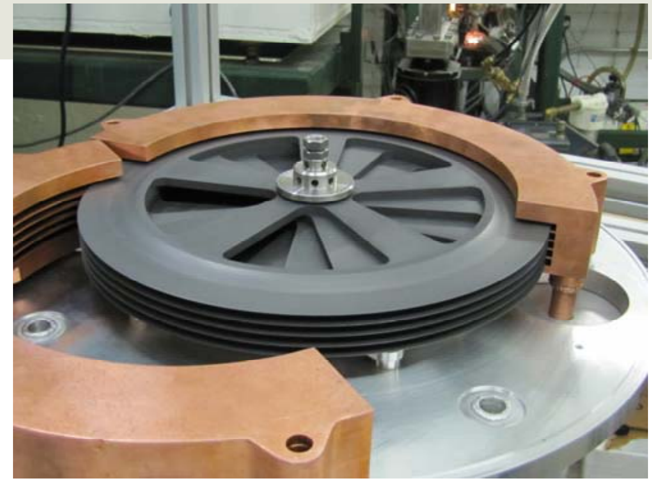
- Rare isotope production with primary beams up to 400 kW, 200 MeV/u uranium



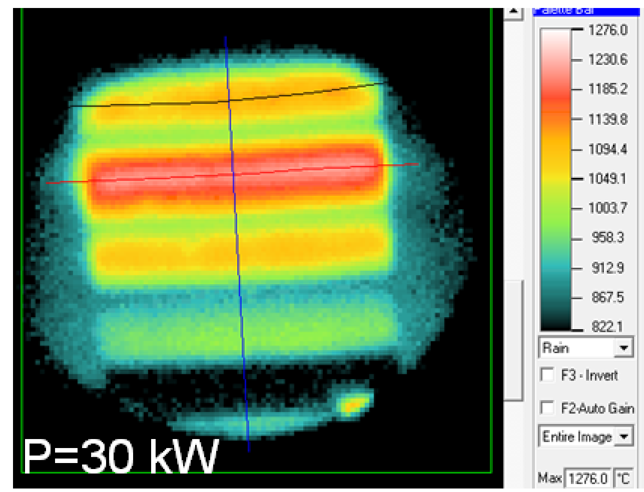
Challenge: Detectors for high beam rates

Challenges:
High power density, radiation damage

Material Challenge #1 - Production Target



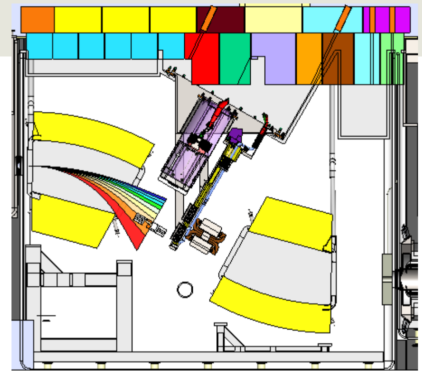
- Target requirements
  - 400 kW beam power requirement
    - » 100 kW power loss in a ~ 0.3 - 8 g/cm2 target
  - Optics requirements
    - » 1 mm diameter beam spot
  - Desired lifetime 2 weeks
- Technical Risk
  - High power density: ~ 20 - 60 MW/cm3
  - Radiation damage
- Design for FRIB baseline
  - Rotating radiation-cooled multi-slice **graphite** target
  - 5000 rpm, 30 cm diameter



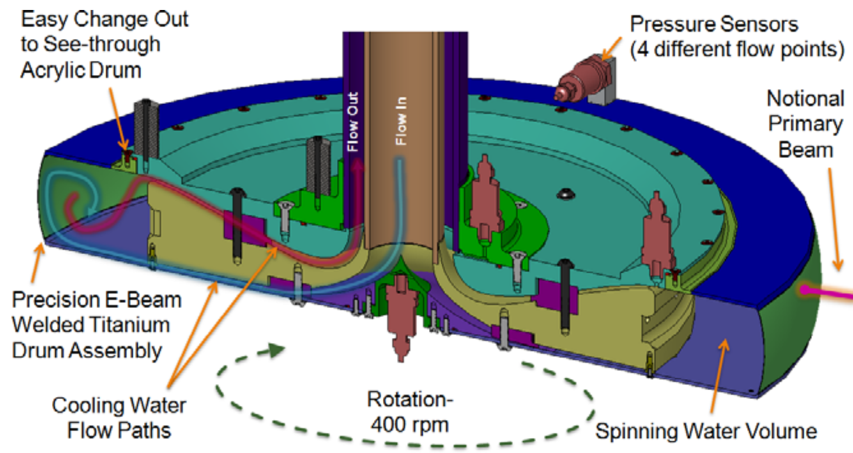
- Heavy-ion induced radiation damage annealing and high-power density capability demonstrated
  - Heavy-ion irradiation tests at GSI
  - Electron-beam tests at SOREQ, Sandia, BINP

F. Pellemoine, W. Mittig

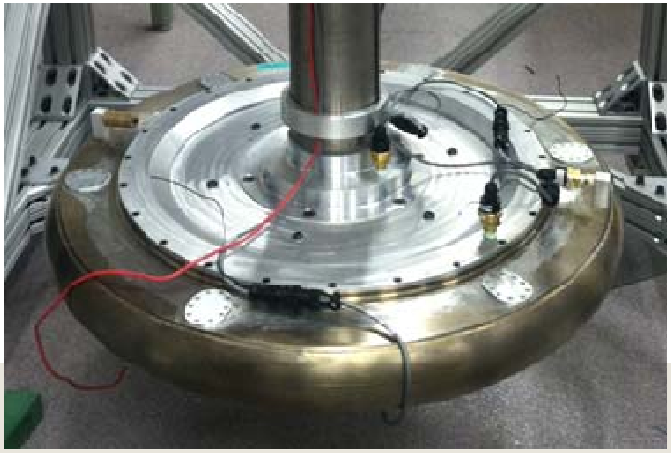
Material Challenge #2 – Primary Beam Dump



- Beam dump to absorb unreacted primary beam
  - High power capability up to 325 kW
    - » Heavy ions → high power density: ~ 10 MW/cm^3
    - » For comparison 0.4 kW/cm^3 for 1 MW SNS target (protons!)
  - Desired lifetime one year



- Technical Risk
  - High power density: ~ 10 MW/cm^3
  - Radiation damage, sputtering
- Design: water-filled rotating drum beam dump
  - 0.5 mm **titanium alloy** shell
  - 400 rpm, 70 cm diameter, 60 gpm waterflow
- Mechanical and waterflow tests underway
- Titanium alloy heavy-ion irradiation tests planned

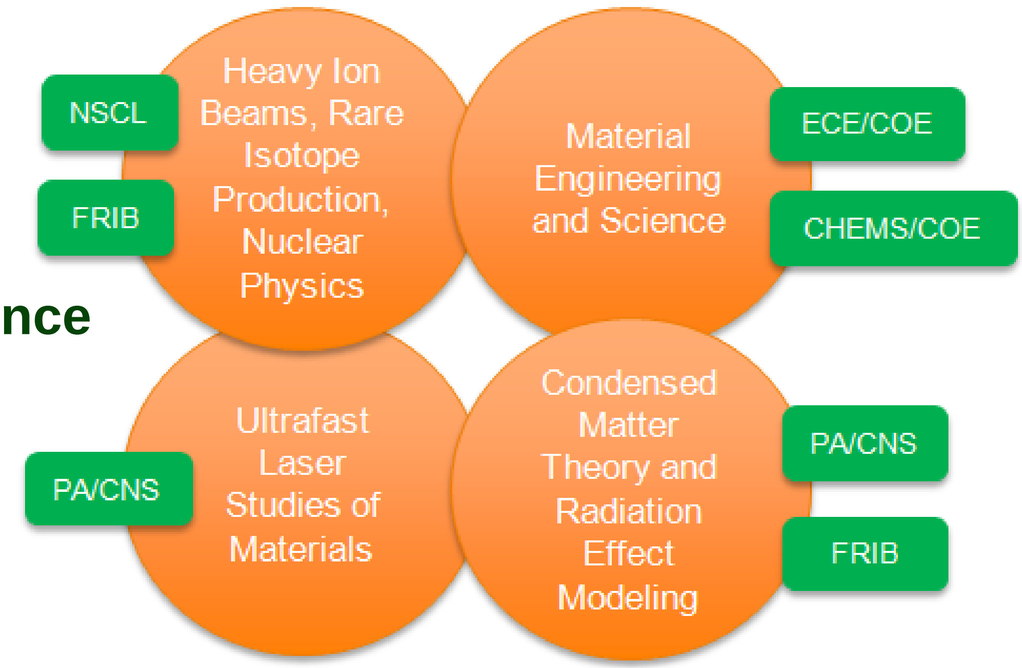


F. Pellemoine, R. Ronningen,
Collaboration with ORNL

MatX - Strategic Partnership
“FRIB-Materials under Extreme Conditions”

SPG funded by MSU Foundation, 2012

- **Physics and Astronomy**
  - P. Duxbury, C.-Y. Ruan
- **Electrical and Computer Engineering**
  - T. Grotjohn
- **Chemical Engineering and Material Science**
  - C. Boehlert
- **National Superconducting Cyclotron Laboratory**
  - W. Mittig, A. Stolz
- **Facility for Rare Isotope Beams**
  - G. Bollen, F. Pellemoine, R. Ronningen



Focus on graphite, diamond and **Ti alloys** as representative extreme materials

Important for diverse applications (aerospace, nuclear, accelerators)
Important for NSCL and critical for FRIB mission

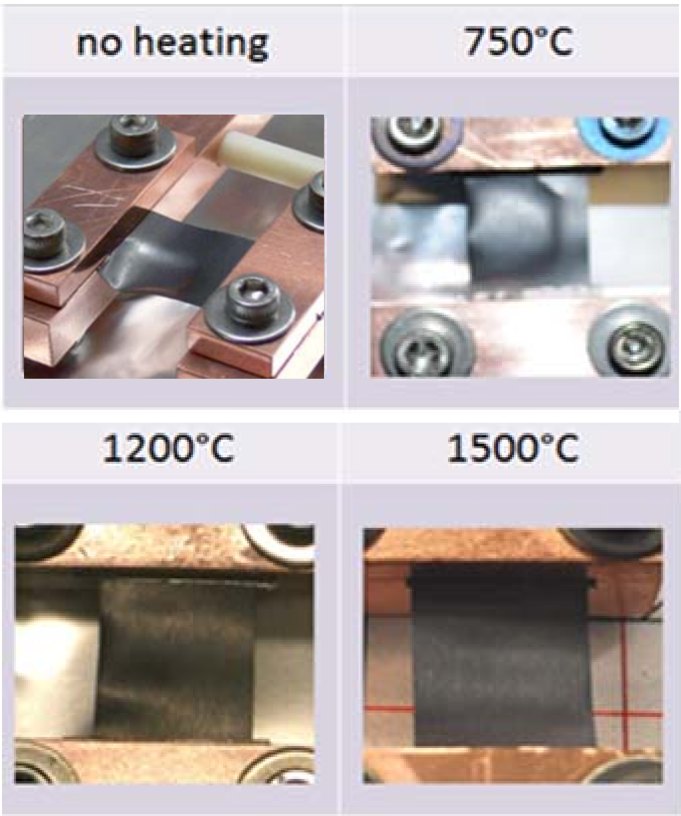
Key Material 1: Graphite – improving lifetime in high radiation environments

Motivation

- **Fuel containing material in nuclear reactors**
- **Material for high temperature applications**
- **Chosen material for FRIB production target**

Examples of planned studies

- NSCL swift heavy ion (SHI) irradiation at different temperatures to test annealing of radiation damage - **Understand healing by annealing**
- Ultrafast laser (UL) irradiation and ultrafast electron diffraction (UED) to study **image initiation of damage at picosecond timescales** at different temperatures
- Atomistic theory to demonstrate **unifying physical principles of materials response under extreme SHI and UL radiation environments**



Healing by high-temperature in-situ annealing during radiation

C.-Y. Ruan, F. Pellemoine, W. Mittig

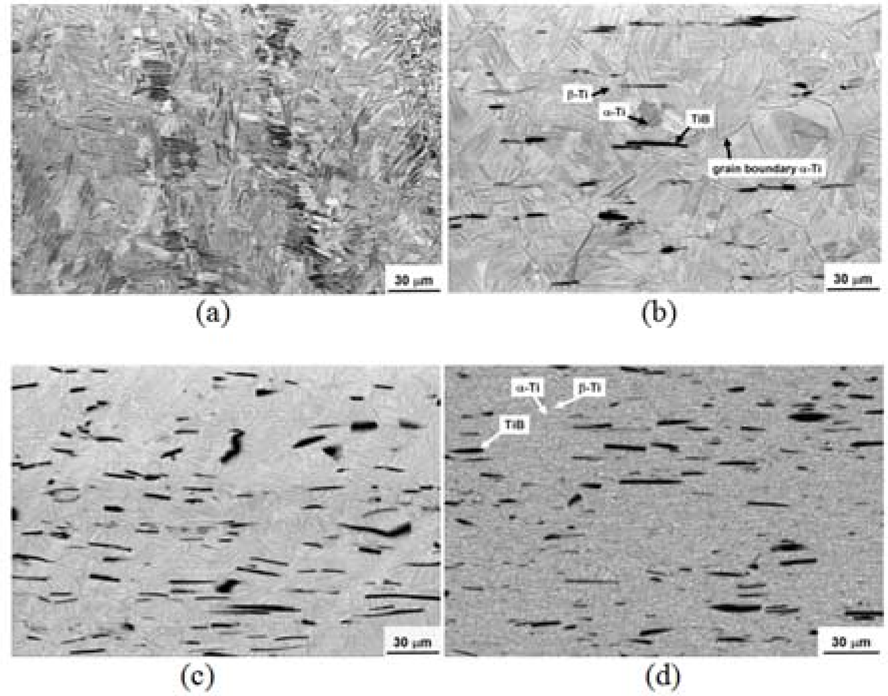
Key Material 2: Titanium alloys – improving resistance to high cycle fatigue and radiation dose

Motivation: Ti alloys (e.g. Ti – B) provide significant improvements relative to conventional alloys

- **Specific stiffness and strength up to 50% higher**
- **Reduced grain size enables improved processing and affordability**
- **Wide range of applications to high temperature and radiation environments (aerospace, nuclear, manufacturing)**
- **May be used in FRIB beam dump**

Examples of planned studies

- **In situ microscopy studies under high cycle fatigue conditions, pre and post irradiation with NSCL SHI beam**
- **Comparison with similar studies using UL/UED to probe ultra-short time mechanisms**



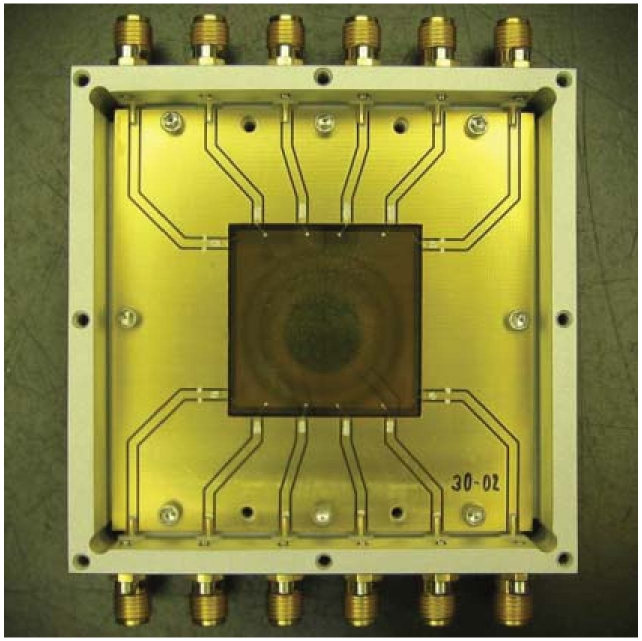
Scanning electron microscopy images of boron-modified Ti-6Al-4V alloys; (a) as-cast, (b) cast and extruded with 0.1wt.%B, (c) cast and extruded with 1 wt.%B, powder-metallurgy and extruded with 1 wt.%B. The Ti alloys with boron addition show significantly improved stiffness, strength, and fatigue resistance due to the creation of the Ti-B phase (dark).

C. Boehlert, F. Pellemoine

Key Material 3: Diamond – improving performance and detector lifetime in high radiation environments

Motivation

- **Diamond is very promising for particle detectors due to its: radiation hardness, high carrier mobility, high dielectric breakdown strength and low leakage current. Cost is a problem.**
- **Low cost diamond detectors with high performance would have a wide range of applications including: accelerators, space and military applications, medical diagnostics and treatments, and to the NSCL/FRIB.**



MSU developed high cost diamond detector

Examples of planned studies

- **Compare performance of high cost and low cost diamond detectors using commercial materials and materials grown at MSU Fraunhofer facility**
- **Use UL/UED to probe radiation damage mechanisms in diamond and explore possibility of healing by annealing, motivated by observations in graphite.**

T. Grotjohn, A. Stolz

Novel Method for Exploring Fundamental Mechanisms:

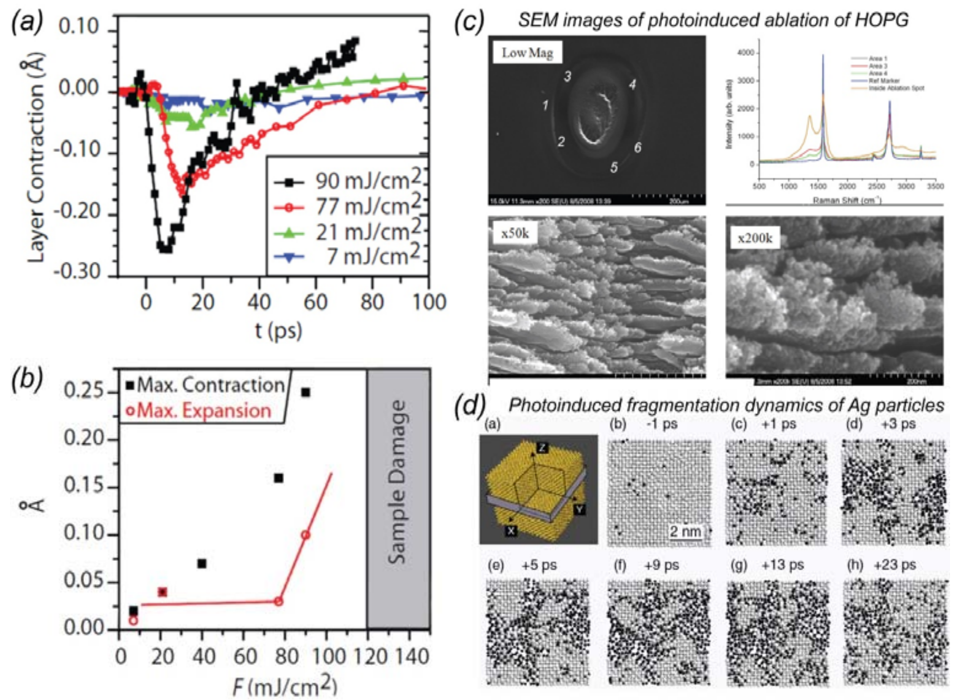
Developing UL-UED to probe microscopic, picosecond response of Graphite, Ti-alloys and Diamond to radiation

Motivation

- **Fundamental radiation damage processes occur at femtosecond to nanosecond timescales. MSU UL/UED facility has the capability to image atomistic process at these timescales**
- **Understanding of fundamentals will guide development of improved materials and devices**

Example of planned studies

- **Use UL/UED to probe radiation damage mechanisms in Graphite, Ti-alloys and Diamond**



Ultrafast transitions probed using MSU UL-UED: (Top) Transient formation of diamond structure from graphite. (Bottom) transient structure change in a metal nanoparticle.

C.-Y. Ruan, P. Duxbury

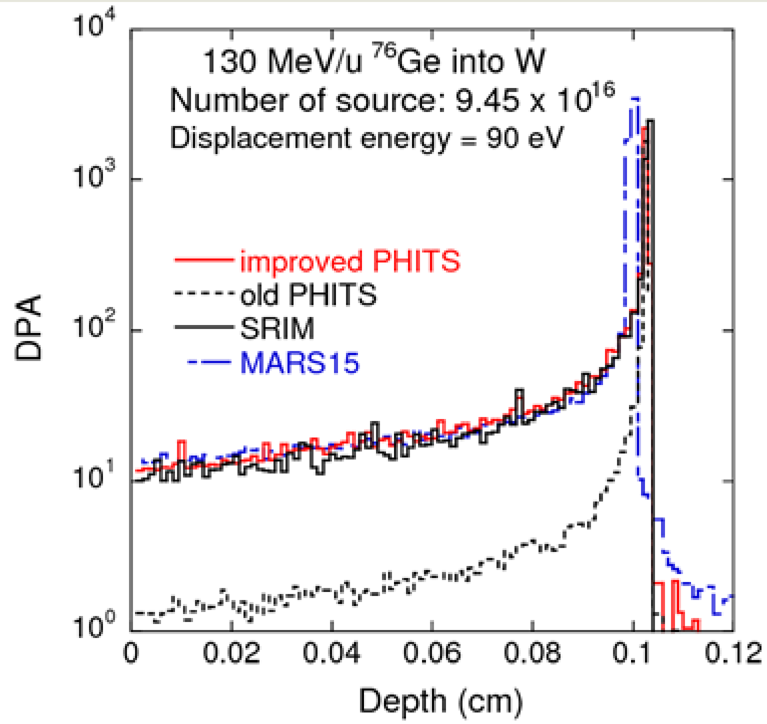
Theory and modeling: Software and methods to explore fundamental atomistic processes by combining nuclear transport codes with atomistic materials simulation methods

Motivation

- **Energy deposited by either swift heavy ions or ultrafast laser pulses mostly leads to high energy electrons**
- **Understanding the way in which highly excited electrons couple to nuclear motion can provide a unifying description of radiation effects (both UL and SHI) at ultrafast time scales**

Planned studies

- **Combine nuclear transport codes and atomistic materials simulations codes (e.g. Molecular Dynamics) to describe excited electron distributions and subsequent materials response**
- **Simulate radiation damage in Graphite, Ti-alloys and Diamond and compare with experiment**



Examples of typical nuclear transport codes that give the displacement per atom (DPA) which is related to the energy deposited, but are not sensitive to atomistic details such as electronic structure and crystal structure

P. Duxbury, R. Ronningen

Summary

- FRIB materials challenges will continue throughout the life of the facility
  - 400 kW beam power of heavy ions is unexplored territory
  - New extreme materials will benefit facility performance and science
  - FRIB can provide environment to test and develop new materials
- MatX - Strategic Partnership on “FRIB – material under extreme conditions”
  - Leverage unique MSU expertise and capabilities to address extreme materials problems of critical local and national importance
  - Develop synergies between MSU complex materials and the NSCL/FRIB materials focus areas
  - Build collaborations in the area of Extreme Materials Science