Summer Lecture Series Schedule

Date	Speaker	Topic
Now	Maurice Ball	Mechanical Engineering
Thurs, June 12	Eric Prebys	Accelerators
Tues, June 17	Mary Convery	Muon Campus
Tues, June 24	André de Gouvêa	Exploring the unknown
Thurs, June 26	James Hoff	Electrical Engineering
Tues, July 1	Mark Pankuch	Cancer Therapy
Tues, July 8	No talk scheduled at this time	
Thurs., July 10	Don Lincoln	Higgs Boson & the LHC
Tues, July 15 Curia II	Hugh Lippincott	Searching for Dark Matter
Tues, July 22 Curia II	Brian Nord	Cosmic Acceleration
Tues, July 29	Amitoj Singh	Computer Engineering
Thurs, July 31	Jinyuan Wu	Rotations: The moon, MRI, g-2, etc.
Tues, Aug. 5	Tia Miceli	Neutrinos: Ghosts of the Universe
http://ed.fnal.gov/interns/lectures/ **There may be last-minute changes, so check this web site for the current schedule**		

Mechanical Engineering at Fermilab

Maurice Ball

Summer Student Lecture Series

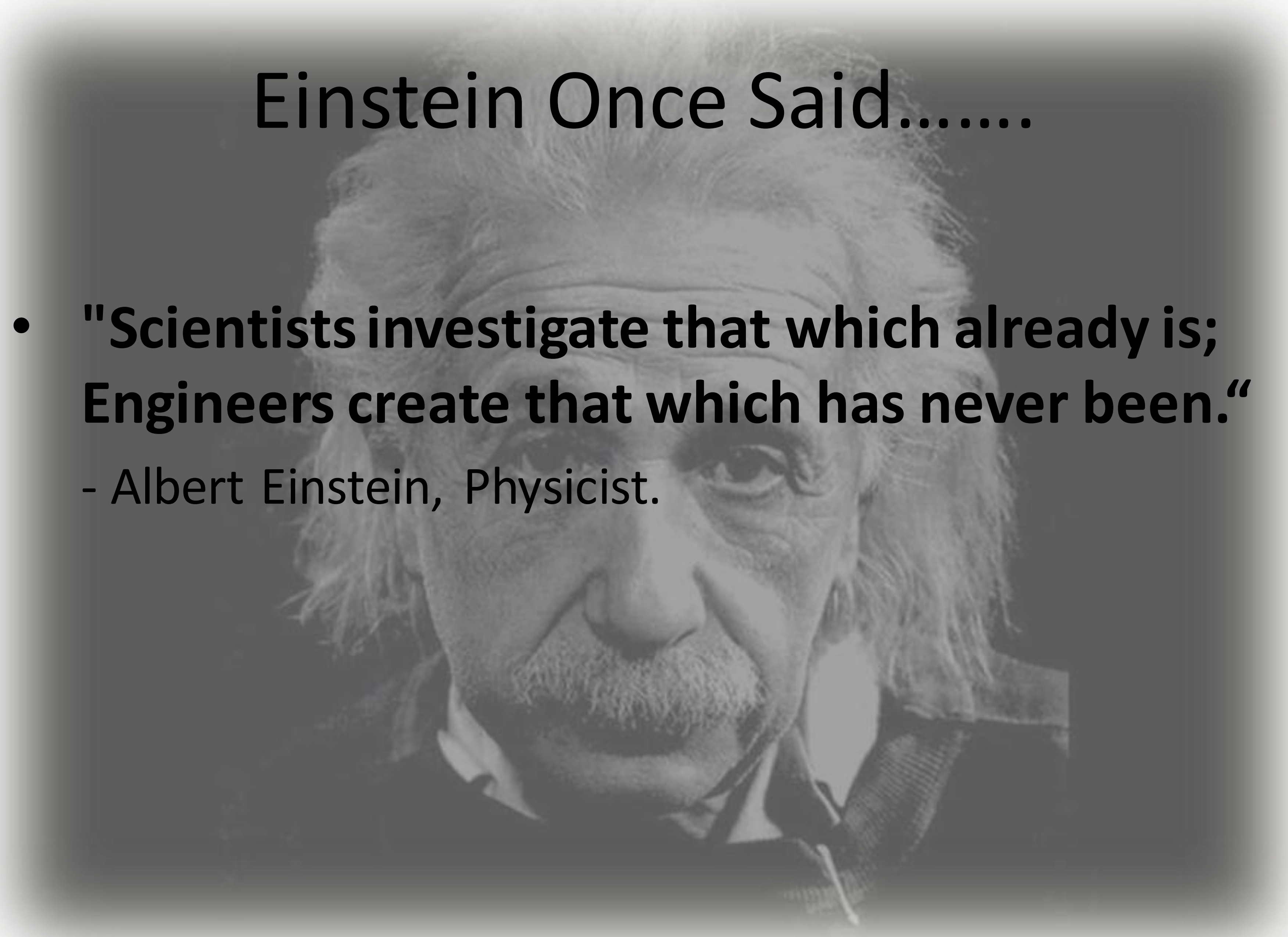
June 10, 2014


HIGH VACUUM COMPONENTS
TEV I SEPTUM & VAC SYST
TEV I P̄ WATER
P BAR RING TEMP DATA C.U.P
1991 IEEE PARTICLE ACCELERATOR CONFERENCE

Einstein Once Said…….

- **"Scientists investigate that which already is; Engineers create that which has never been.“**

  - Albert Einstein, Physicist.



Outline

- Introduction
- What is Engineering?
- What is Mechanical Engineering?
- What is Fermilab?
- Where/How are Mechanical Engineers Used at Fermilab
- Summary
- Closing Thought

What is Engineering?

- **Engineering** is the discipline, art, skill and profession of acquiring and applying scientific, mathematical, economic, social, and practical knowledge, in order to design and build structures, machines, devices, systems, materials and processes that safely realize improvements to the lives of people.
- Engineering is the art of solving problems!
- **Turning Ideas Into Reality!**

What is Mechanical Engineering

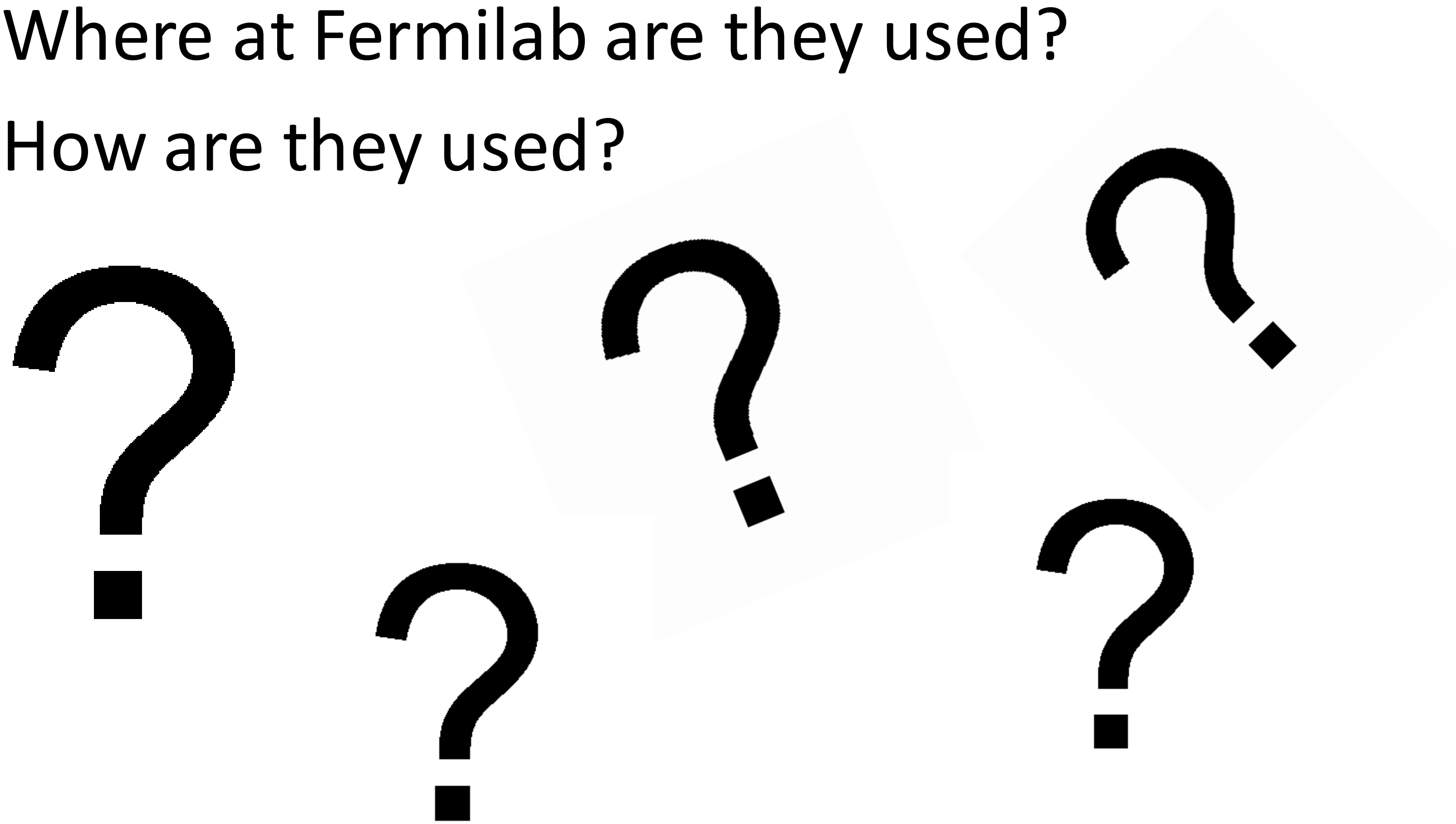
- Is a branch/discipline of engineering
- Applies the principles of physics and material science for analysis, design, manufacturing and maintenance of mechanical systems
- Involves the production and usage of heat and mechanical power for the design, production, and operation of machine, tools, and structures
- is one of the oldest and broadest engineering disciplines
- Uses core concepts and principles including mechanics, kinematics, thermodynamics, materials science, structural analysis, heat transfer, fluid mechanics, and computer aided design, and product life-cycle principles

What is Fermilab

- Fermilab is America's particle physics and accelerator laboratory.
  - Our vision is to solve the mysteries of matter, energy, space and time for the benefit of all. We strive to:
  - lead the world in neutrino science with particle accelerators
  - lead the nation in the development of particle colliders and their use for scientific discovery
  - advance particle physics through measurements of the cosmos
- Our mission is to drive discovery by:
  - building and operating world-leading accelerator and detector facilities
  - performing pioneering research with national and global partners
  - developing new technologies for science that support U.S. industrial competitiveness

The Mechanical Engineers and Their Fermilab Footprint

- Where at Fermilab are they used?
- How are they used?

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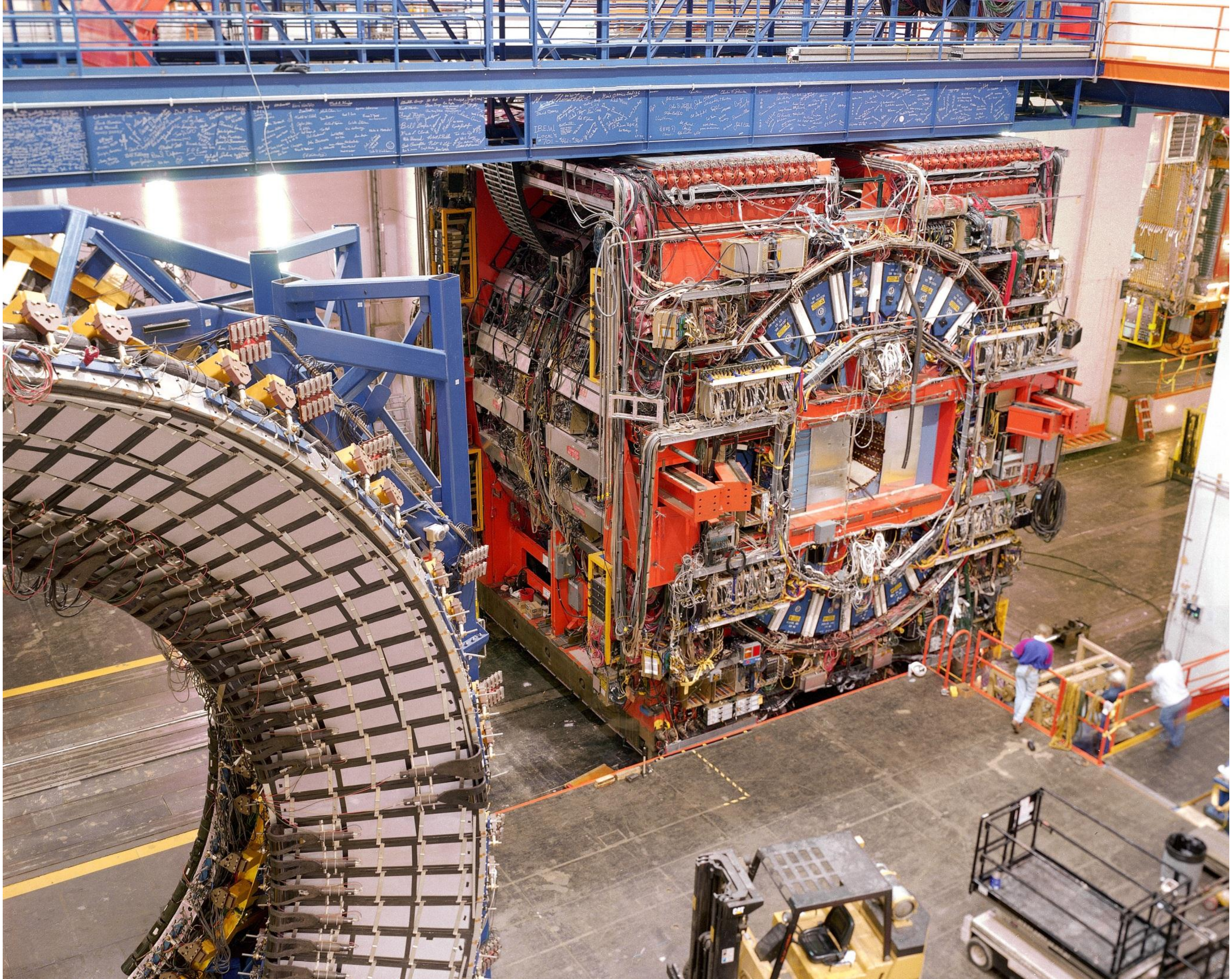
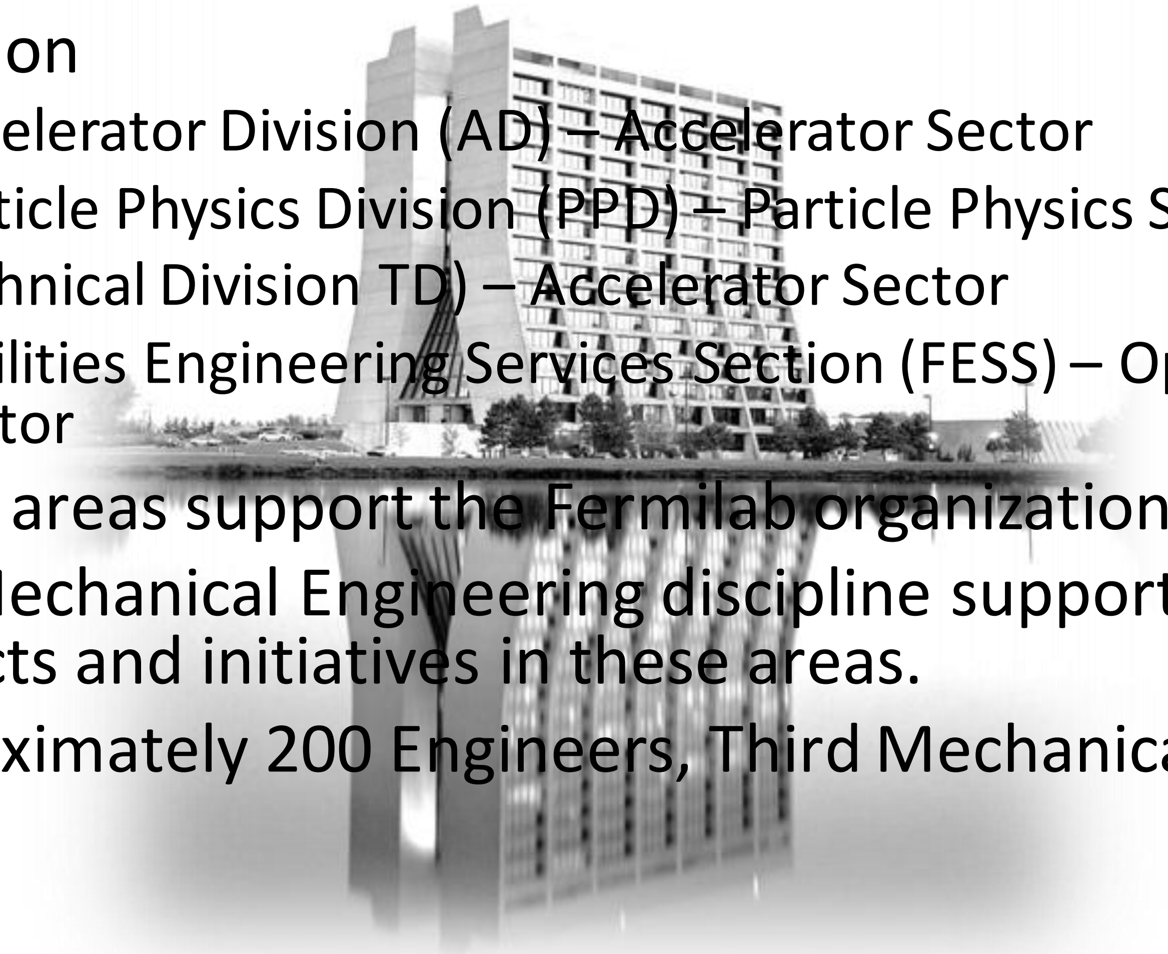


The Different Departments at Fermilab

- First you need a lesson on the [Fermilab Organization]
- Focus on
  - Accelerator Division (AD) – Accelerator Sector
  - Particle Physics Division (PPD) – Particle Physics Sector
  - Technical Division TD) – Accelerator Sector
  - Facilities Engineering Services Section (FESS) – Operations Sector
- These areas support the Fermilab organization.
- The Mechanical Engineering discipline supports all projects and initiatives in these areas.
- Approximately 200 Engineers, Third Mechanical



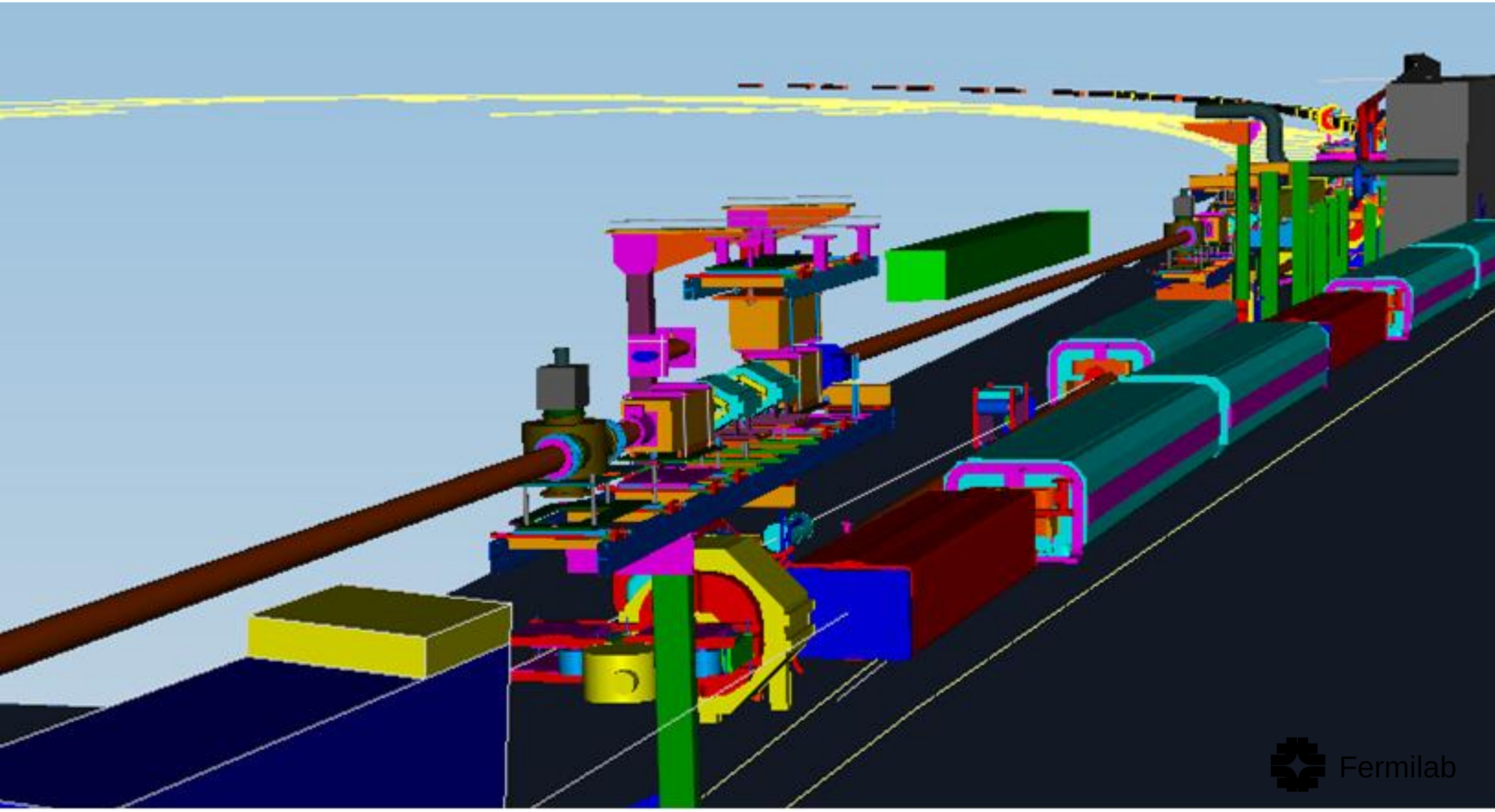
How are Mechanical Engineers Used at Fermilab?

Accelerator Technologies
Abort Systems
Compressed Gas
Computer Aided Design (CAD)
Cryogenics
Finite Element Analysis (FEA)
Fluid Temperature Control Systems
Instrumentation
Magnet Design
Project Engineering and Management

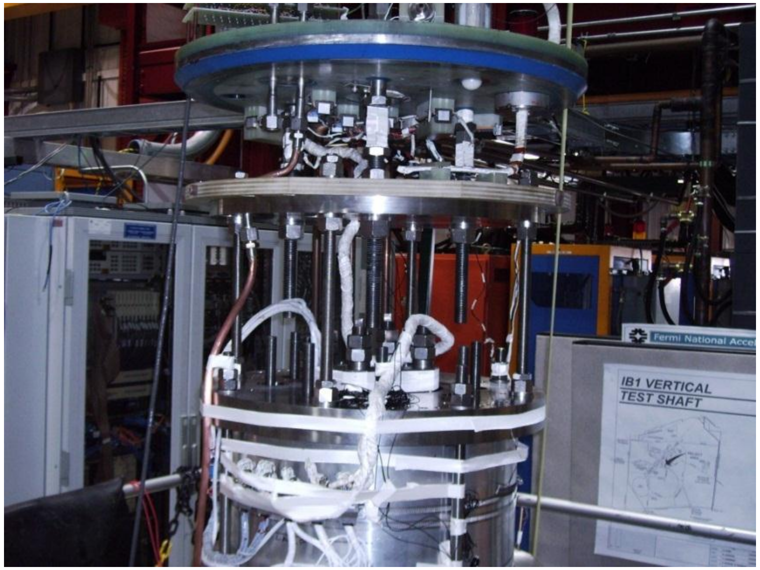
Superconducting Radio Frequency (SRF)
2D, 3D, and Solid Modeling
Support Stands
Target and Horns
Vacuum
Vibrations

Just to name a few !!!!!

Mechanical Systems

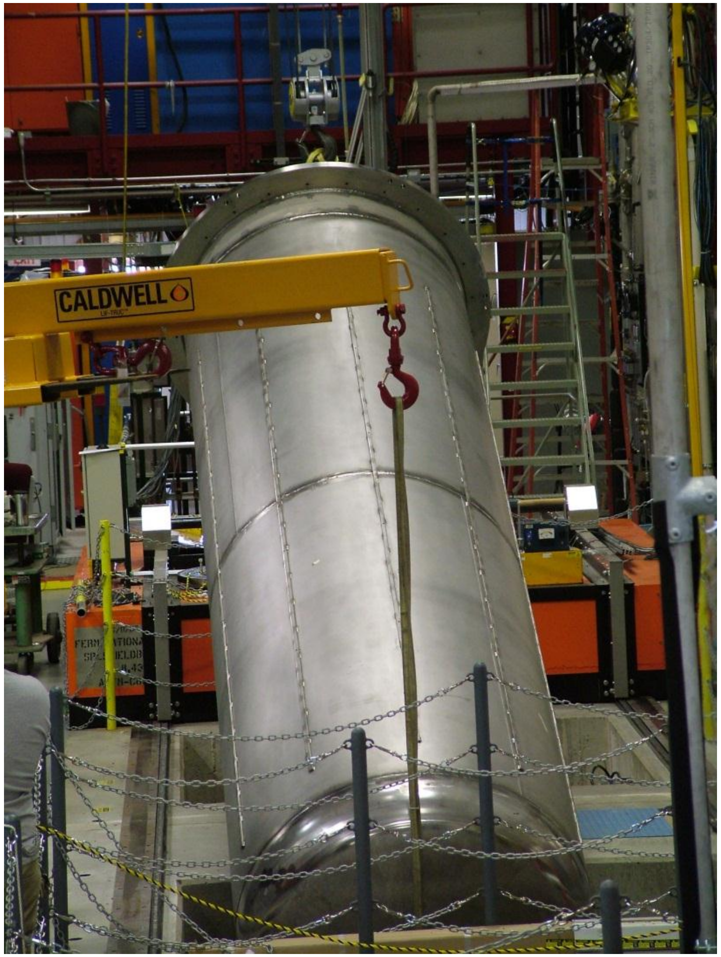


Magnet Suspension System



The Fixture for tilting the Magnet was provided by LBNL (collaborator)

Cryostat for SRF Multiple SRF Cavity Testing



Helium Purifiers

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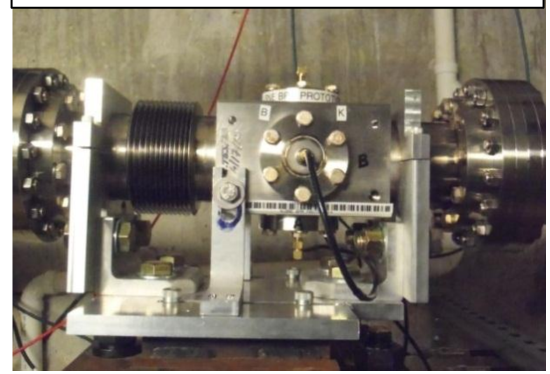
Beam Diagnostics/Instrumentation

Allison Emittance Scanner

Beam Diagnostics/Instrumentation (continued)

Beam Position Monitor



Ionization Profile Monitor

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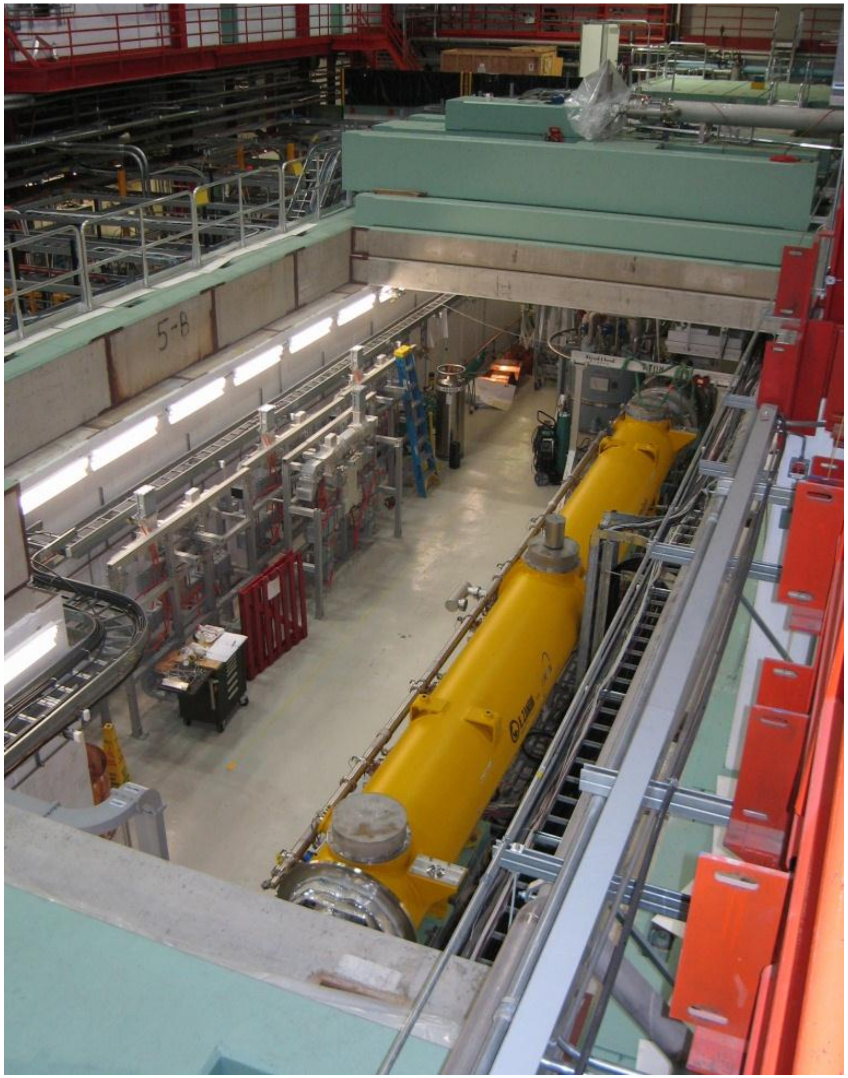
Vacuum Systems Engineering



$$PV = nRT$$

Where:

n = number of moles

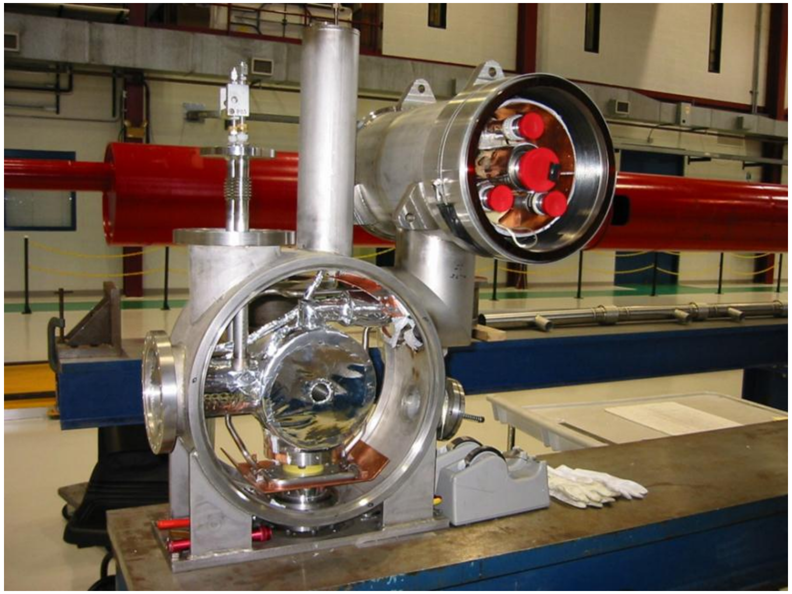
P = pressure

V = Volume

R = Universal Gas Constant

T = temperature

Magnet Design Engineering



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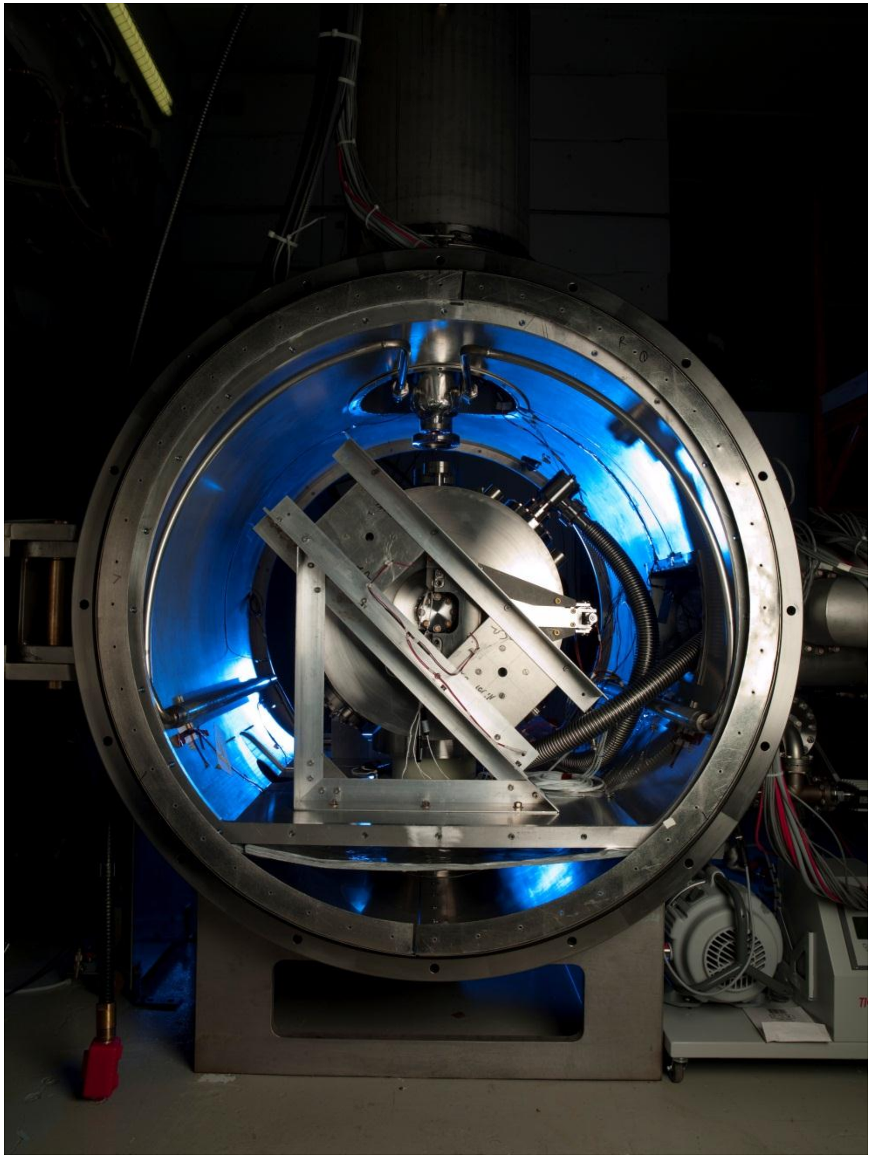
Fluids Engineering

Bernoulli's Therorem

$$z_1 g + \frac{p_1}{\rho} + \frac{v_1^2}{2} = Z_2 g + \frac{p_2}{\rho} + \frac{v_2^2}{2} + h_L$$

Where:
z = Elevation
v = Velocity
p = Pressure
Rho(ρ) = density
g = gravity

Cryogenics Systems Engineering



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Cryogenic Systems Engineering (continued) - Super Fluid Cryogenic Plant Cold Box at CMTF

$Q = \frac{kA(T_h - T_c)}{L}$ where

Q: Heat conduction [W]

k: Average thermal conductivity [W/m-K]

A: Cross sectional area for conduction [m^2]

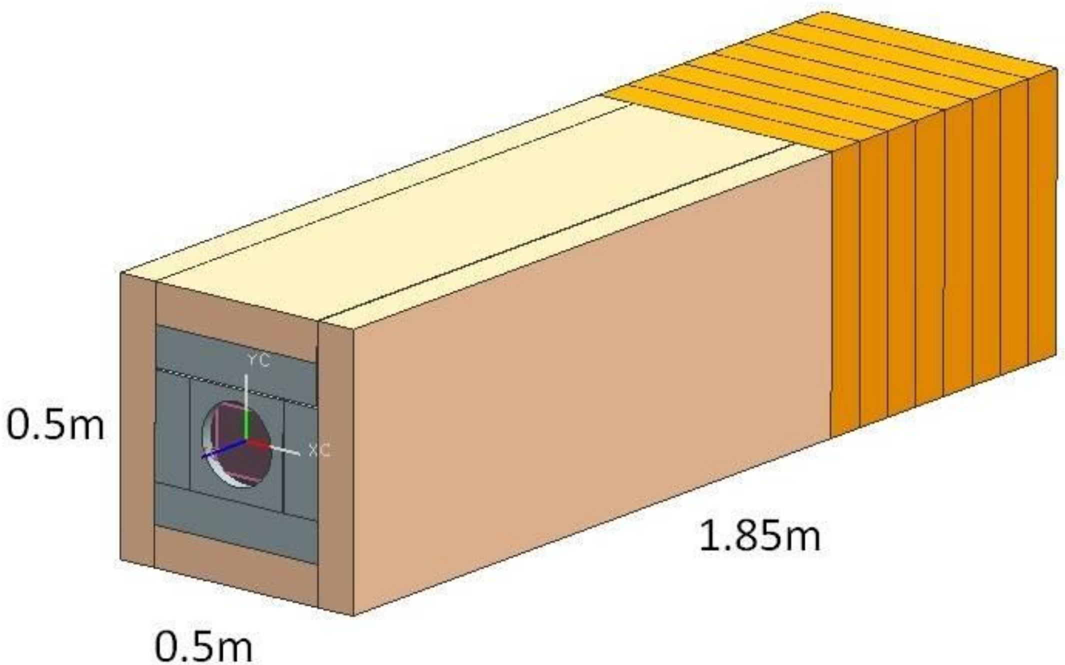
T_h: Hot end temperature [K]

T_c: Cold end temperature [K]

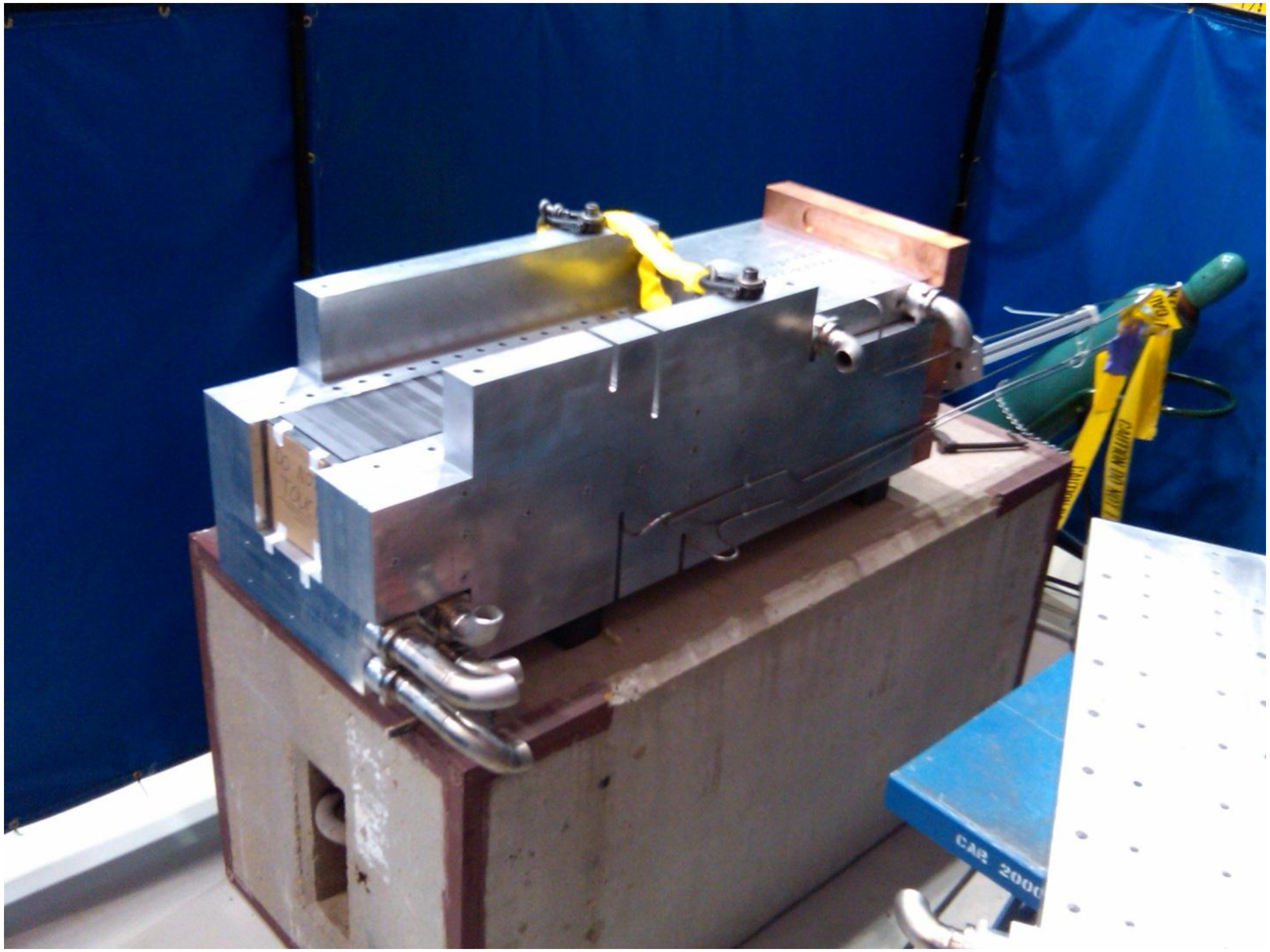
L: Conduction length [m]

Mechanical Systems – Beam Dump

Absorber Core Configuration



Mechanical Systems – Beam Dump (continued)

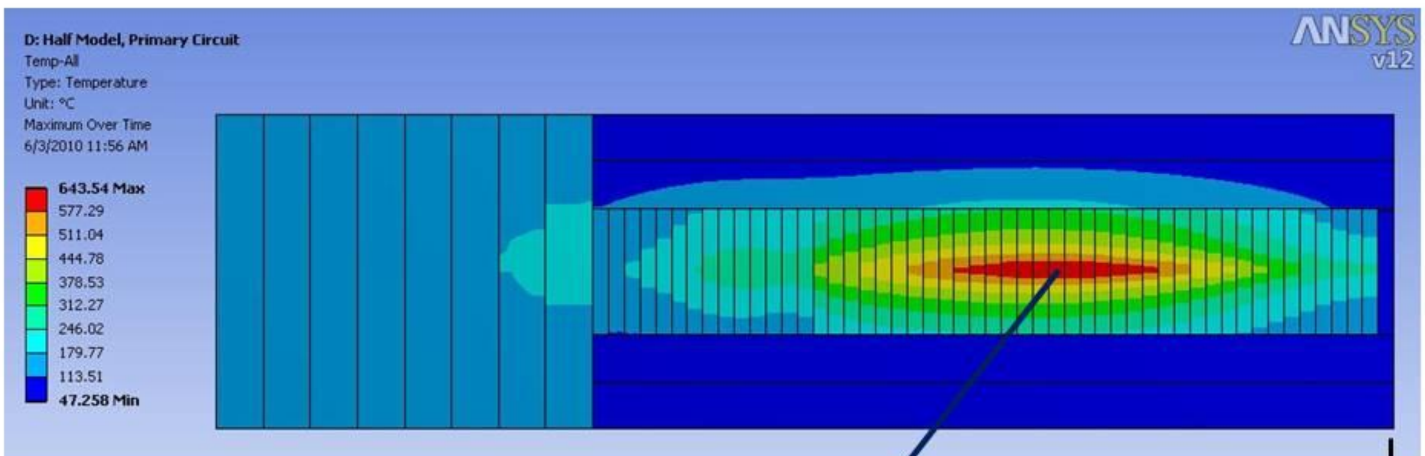


Mechanical Systems – Beam Dump (continued)

System Model Steady State

Centered Beam @BOL

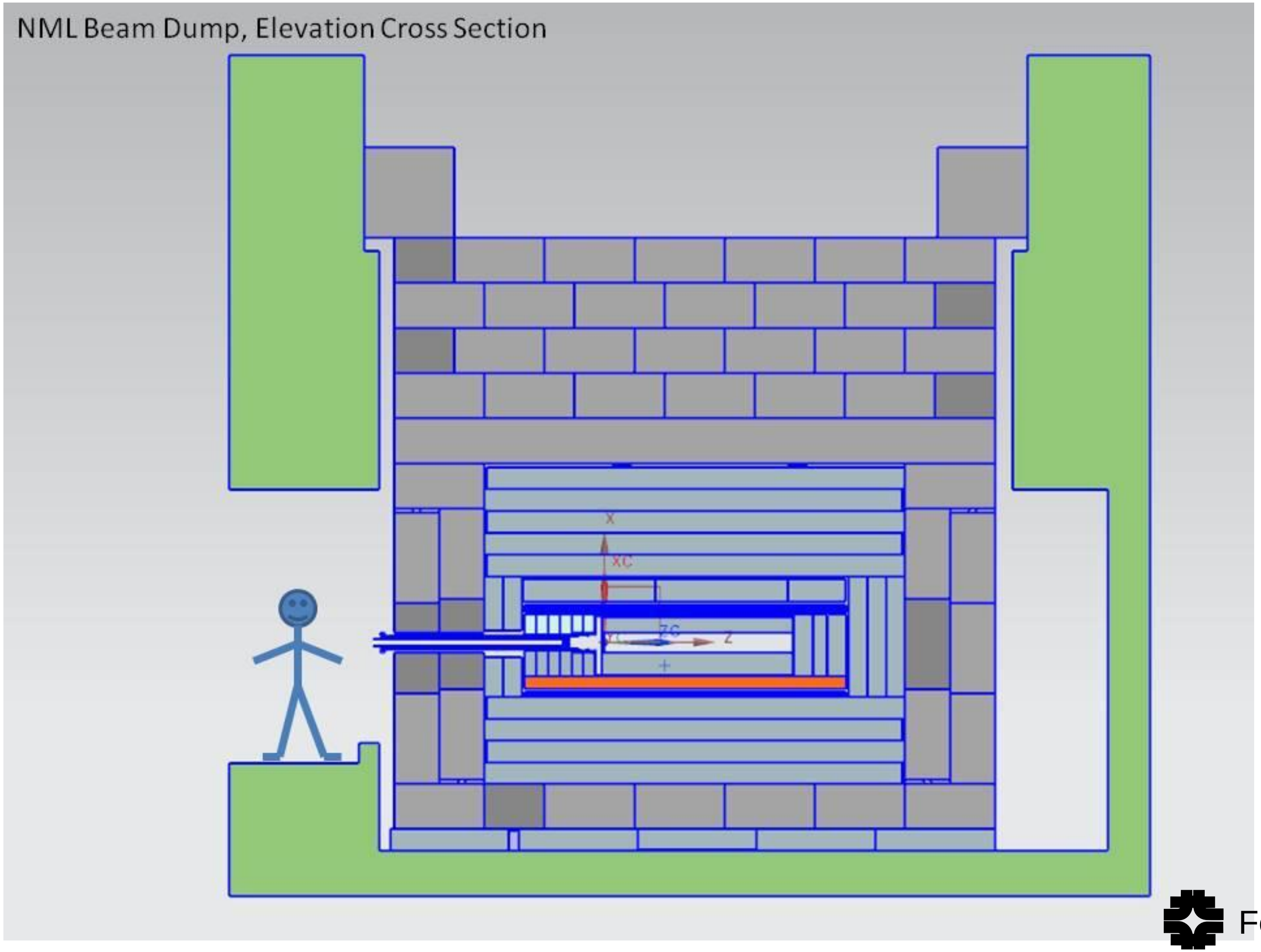
Maximum temperature in graphite and system



Z

Max Temperature in Graphite
643°C @ Z=.482m

Mechanical Systems – Beam Dump (continued)



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An example mechanical engineering project: design of a beam exit window

- In many of our machines, beam must leave the high-vacuum of the beamline and go somewhere else (target, dump, etc.)
  - In this case a window is required
  - The beam interacts with the window, creating lots of engineering challenges

Window concept for ASTA

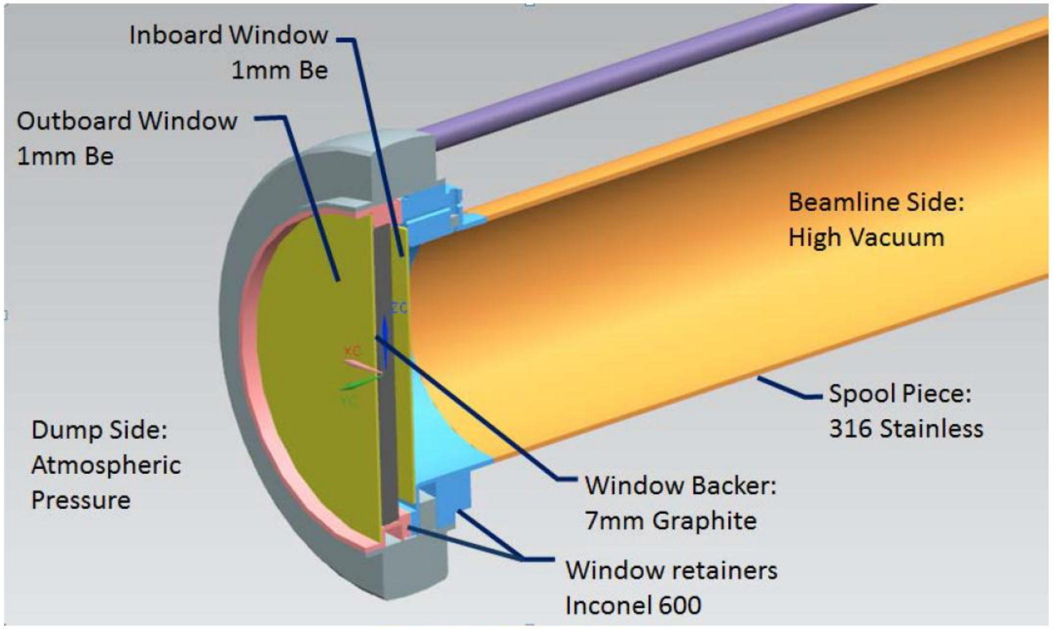


Figure 4: Beam Window Concept

Mechanical Engineer Responsibilities

- The mechanical engineer might
  - Work with scientists and/or radiation analysts to develop a concept
  - Perform thermal and stress analysis and optimization
  - Coordinate review of the design
  - Work with a designer to produce a final design
  - Work with the manufacturing engineer, shop and/or vendor to get it built
  - Define and execute a testing program
  - Work with safety to do it all safely
  - Work with technicians to assemble and install the window
  - Produce engineering documentation
  - Participate in commissioning to make sure it works

Mathematical Equation: Rough Estimate of Temperature Rise

During a short 1ms beam pulse, energy is deposited very quickly (as compared to the speed of thermal conduction in the material). A material will therefore experience a nearly-instantaneous temperature rise that depends only on the energy deposition, and specific heat. This temperature rise can be calculated as:

$$dT = \frac{EDpeak}{c}$$

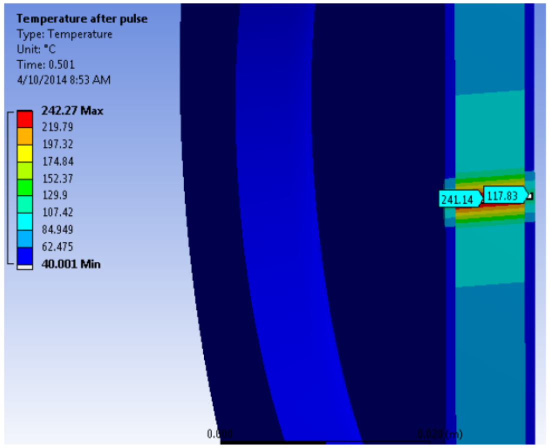
Where:

dT is the instantaneous temperature rise (over and above the time-average temperature)
EDpeak is the energy deposition at the peak of the beam profile (assumed Gaussian)
C is the specific heat of the material

A highly simplified thermal FEA analysis was done to estimate time-average temperatures in various window materials (i.e. the temperatures that would exist before a beam pulse). To these results, we can add the dT values to estimate the peak temperatures that a window would need to survive:

		Predicted Temperatures			Comparison Temperatures		
Material	**c J/g K**	**Tss °C**	**dT °C**	**Tmax °C**	**Tm °C**	**Trolloff °C**	**T50 °C**
Ti	0.528	311	304	615	1650	-	250
Al	0.9	114	178	292	600	175	205
Be	1.93	107	83	190		420	500
Inconel 600	0.5	478	288	766	1350	550	700
Graphite	0.550	106	121	227	2000	-	-
Mo TZM	0.272	145	473	618	1500	1000	1300

FEA Result: A better Estimate of Temperature Rise and Transients



oomed view of peak temperatures at the pulse location just after

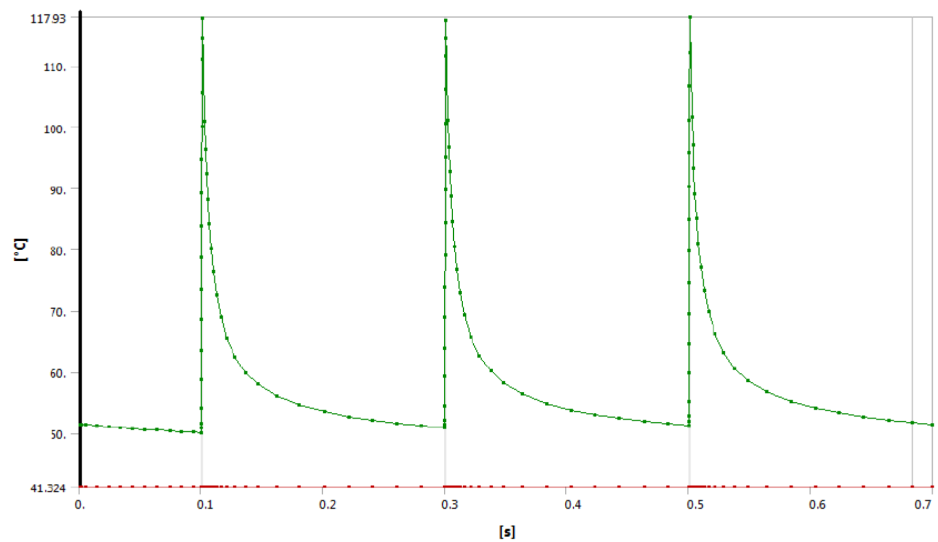


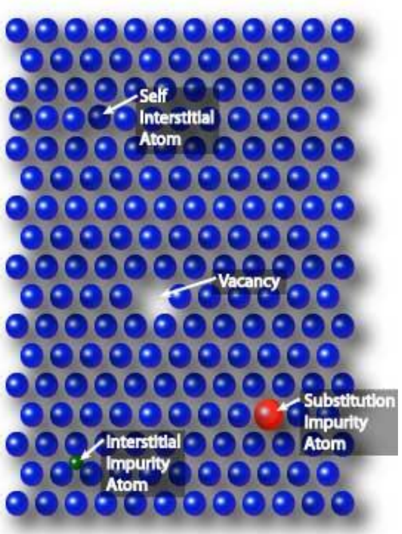
Figure 16: Maximum temperature (green) and minimum temperature (red) in the Be window through 3 beam pulses. At the center of the window, temperature cycles 50-118°C

The Real Hardware

Study of Radiation Damage Effects in Materials

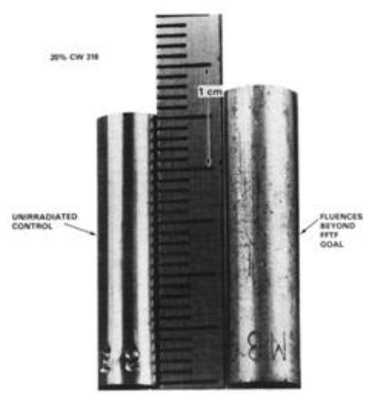
Radiation damage in accelerator components due to interaction with high energy particles

- Vacuum beam windows
- Targets for secondary particle production

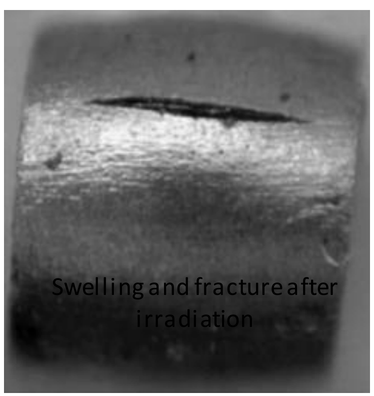


High energy particle interactions cause atom displacements in the material lattice, leading to vacancies and interstitials

Radiation damage effects in materials



Dimensional change after irradiation



Swelling and fracture after irradiation

Study of Radiation Damage Effects in Materials (Continued)

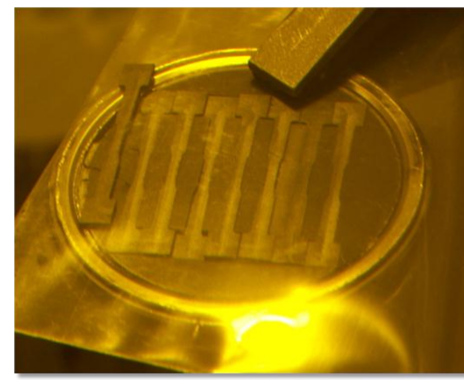
Radiation damage is a leading target facility challenge!

Mechanical properties that change:

- Strength
- Ductility
- Toughness
- Dimensional stability
- Thermal properties

Mechanical tests are required to quantify these changes

Study of Radiation Damage Effects in Materials (Continued)



Material tests in collaboration with Brookhaven National Laboratory*:

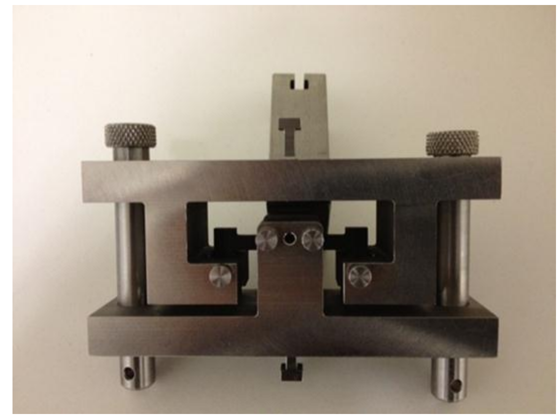
- Graphite specimens irradiated with proton prior to tests
- Transported to hot cell for mechanical and thermal tests

*work with Nick Simos at BNL

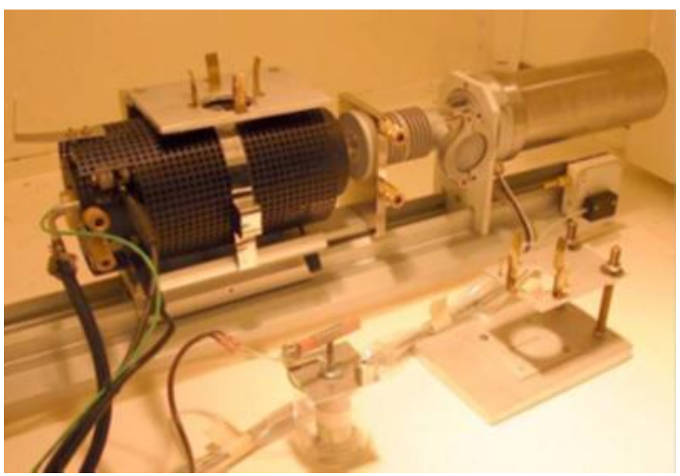
Study of Radiation Damage Effects in Materials (Continued)

Testing equipment

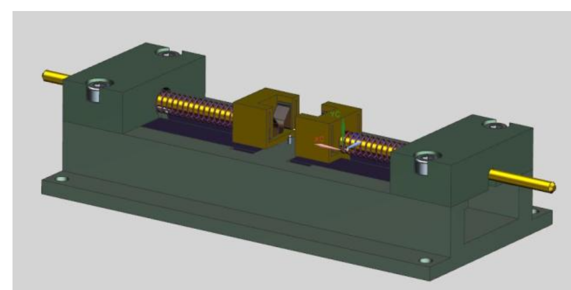
Tensile tests to measure elastic modulus and ultimate tensile strength



Bending tests to measure flexural strength



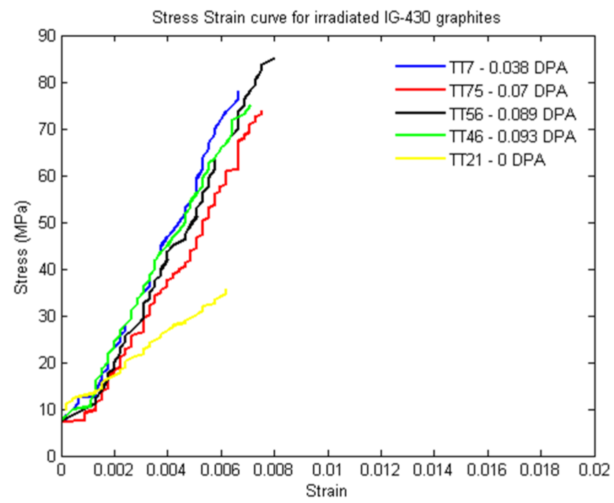
Dilatometer for thermal expansion measurement



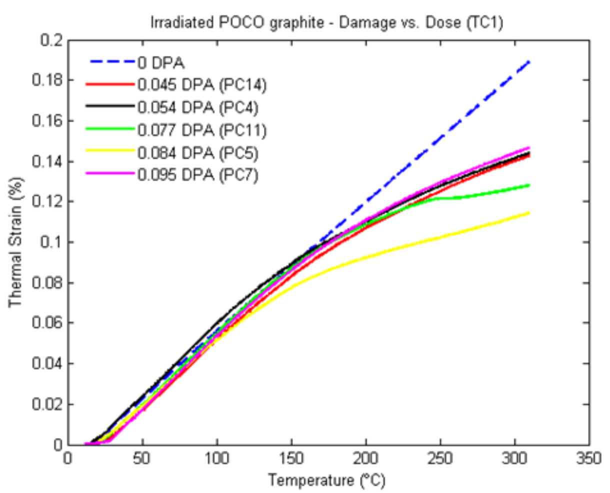
Resistivity fixture to measure the thermal conductivity of the specimens

Study of Radiation Damage Effects in Materials (Continued)

Some results…



Change in elastic modulus and ultimate strength of graphite as a result of proton irradiation



Change in thermal strain behavior after proton irradiation

Project Engineering

Ideal Gas Law:
$PV=nRT$

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Facilities Engineering

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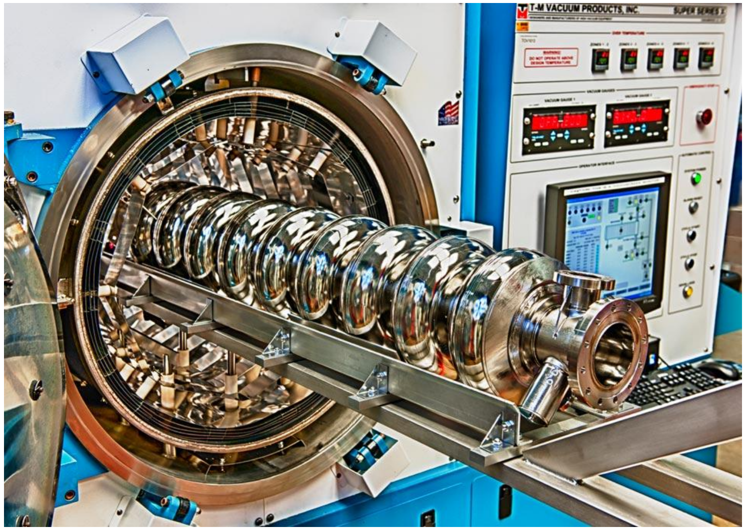
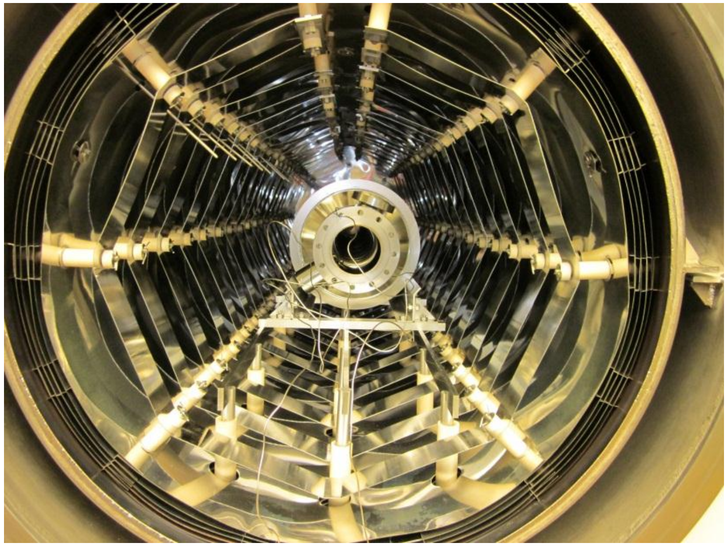
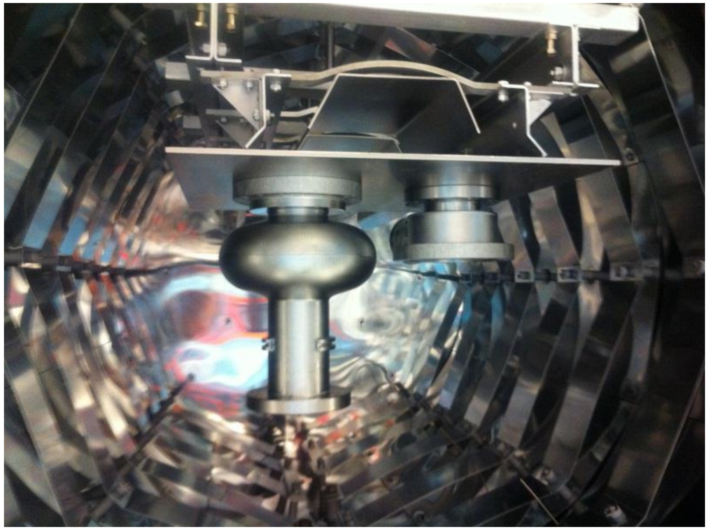
Facilities Engineering (continued)

Superconducting RF Cavity Fabrication and Processing







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Superconducting RF Cavity Fabrication and Processing (continued)

Vertical Test stand holding a 1.3 GHz 9-cell RF Cavity

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Superconducting RF Cavity Fabrication and Processing (continued) - Superconducting Single Spoke Resonator (SSR1) Cavity and Helium Vessel System

Summary

- Mechanical Engineers play a very important role at Fermilab.
- They are needed to help Physicists solve very complex physics problems.
- Without Mechanical Engineering, Fermilab would not be able to achieve its mission.

Additional Websites

- Engineering at Fermilab
  - http://youtu.be/IBCw8ktqrSQ
- Engineering Physics at Fermilab
  - http://youtu.be/t48q7UWZlwg
- Cryogenic Module Installed at SRF Facility at Fermilab
  - http://youtu.be/L_Ko83KcgdY
- Scale of Universe
  - http://dk.filmomania.pl/j/Scale_of_Universe_In93570.swf

References and Acknowledgment

- Abhishek Deshpande, Mechanical Engineer, AD/Mechanical Support Department
- Albert Einstein, Physicist
- Alex Martinez, Mechanical Engineer, AD/Cryogenics Department
- Allan Rowe, Mechanical Engineer, TD/Superconductivity & RF Development Department
- Arkadiy Klebanar, Mechanical Engineer, AD/Cryogenics Department
- Ben Vosmek, Mechanical Engineer, AD/Mechanical Support Department
- Bradly Verdant, Mechanical Engineer, AD/Mechanical Support Department
- Charles Osgood, The Osgood File, CBS Radio Network
- Cory Crowley, Mechanical Engineer, AD/Mechanical Support Department
- Cosmore Sylvester, Mechanical Engineer, TD/Test & Instrumentation Department
- Curtis Baffes, Mechanical Engineer, AD/Mechanical Support Department
- Dave Pushka, Mechanical Engineer, PPD/Mechanical Department
- Emil Huedem, Mechanical Engineer, FESS/Engineering Department

- http://old.systemj.net/gallery/Physics/
- http://projectx.fnal.gov/
- http://filetraffic.eu/s/mechanical%20engineering%20description
- http://www.dedham-ma.gov/index.cfm?pid=12646

- Jerry Leibfritz, Mechanical Engineer, AD/Mechanical Support Department
- Karl Williams, Mechanical Engineer, AD/Mechanical Support Department
- Kevin Duel, Mechanical Engineer, AD/Mechanical Support Department
- Kurt Krempetz, Mechanical Engineer, PPD/Mechanical Department
- Lucy Nobrega, Mechanical Engineer, AD/Mechanical Support Department
- Marty Murphy, Photographer, AD/Operations Department
- Matt Slabaugh, Mechanical Engineer, AD/Mechanical Support Department
- Mike White, Mechanical Engineer, AD/Cryogenics Department
- Reidar Hahn, Photographer, Office Of Communication/Visual Media Services
- Tom Page, Mechanical Engineer, TD/Superconductivity & RF Development Department

- www.fnal.gov
- www.wikipedia.com

One Closing Note

Scale of Universe

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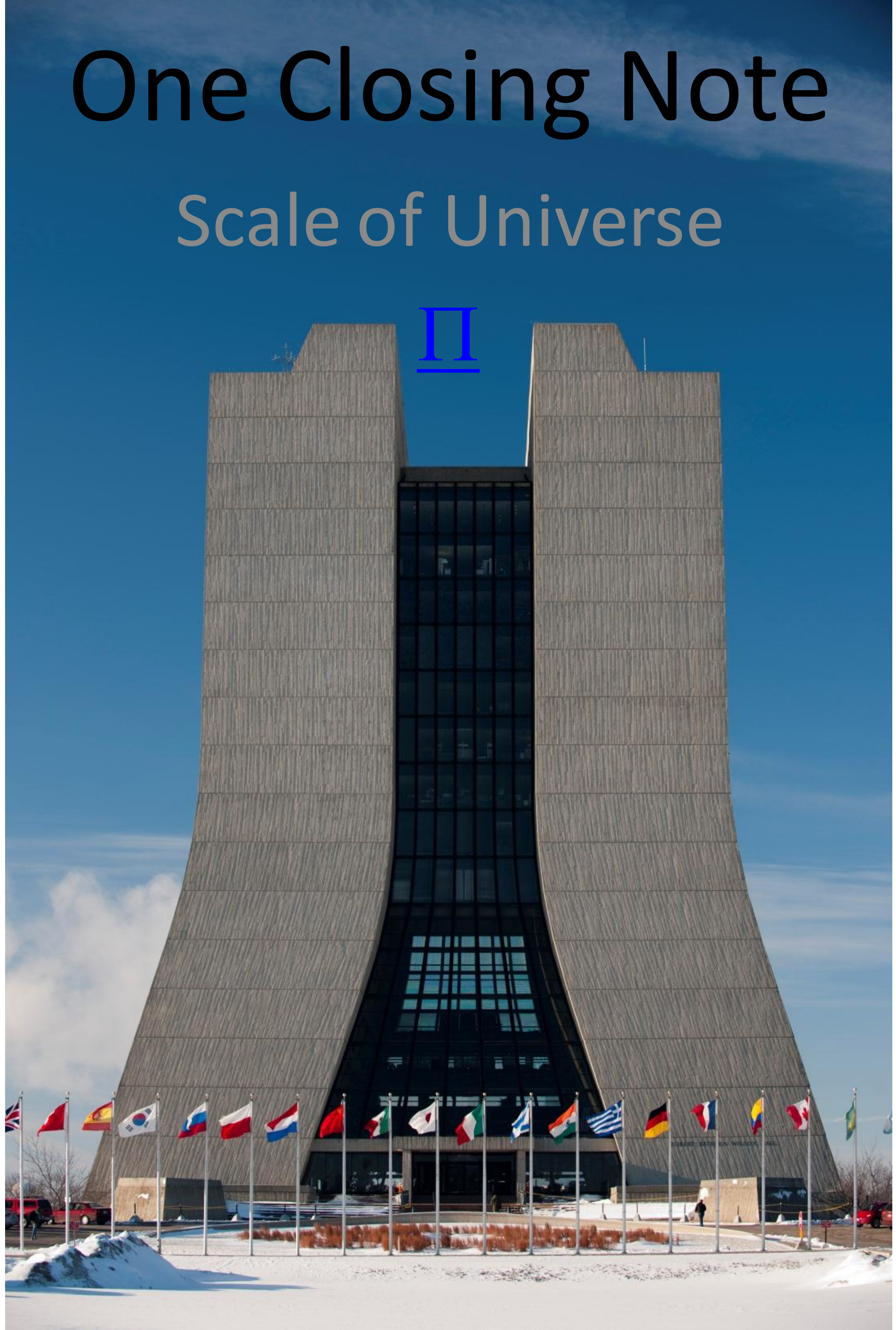

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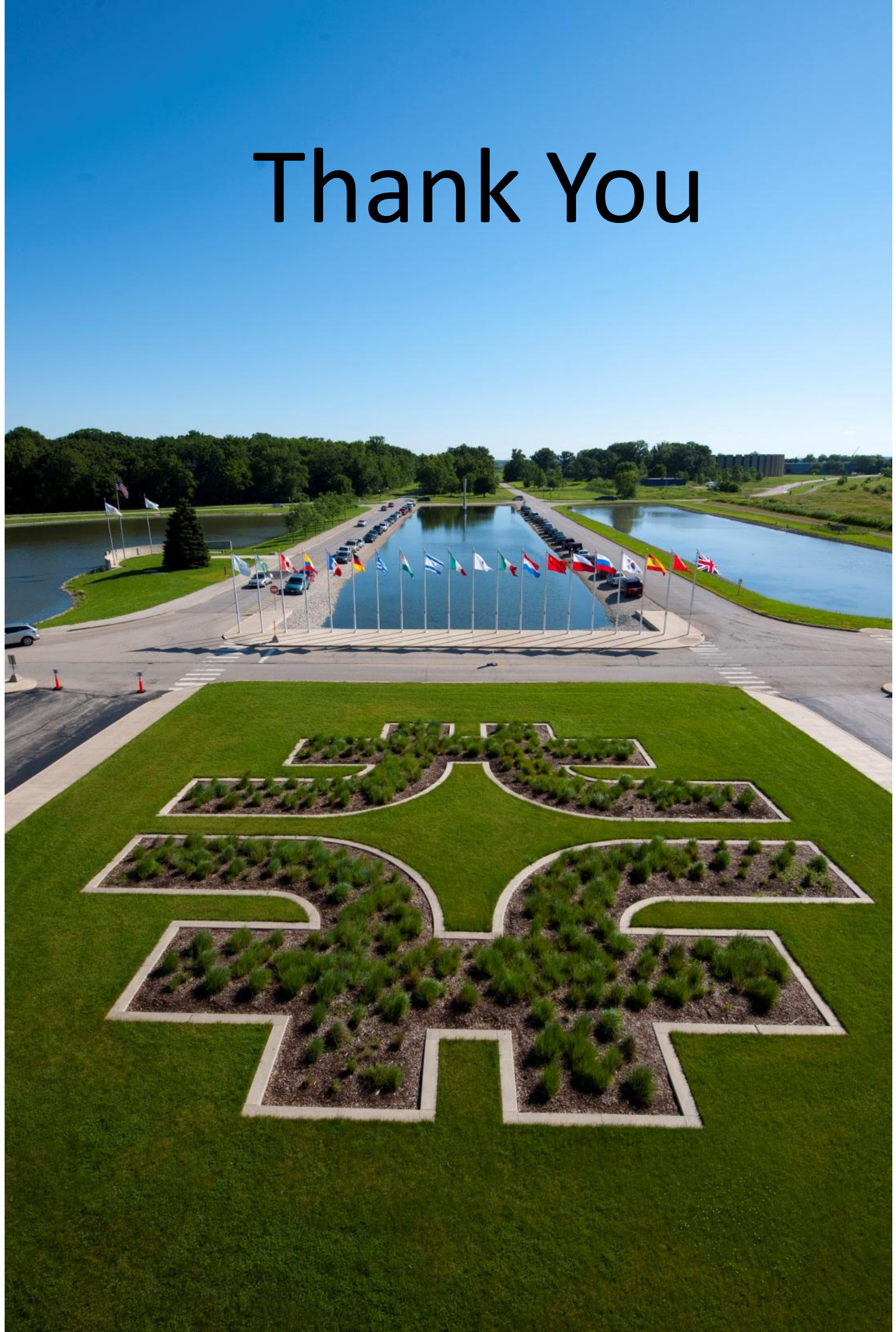
Thank You



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