Working with Faculty and students at Magnet Systems Department

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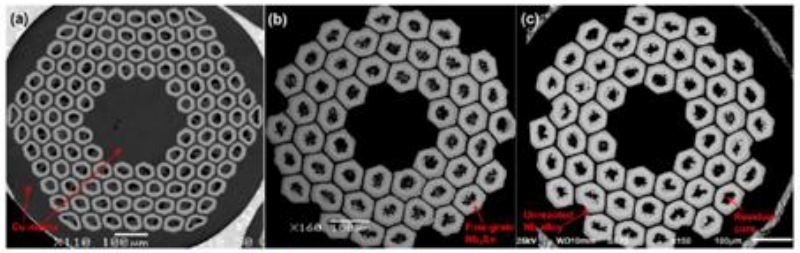
FermiFusion Workshop: Uniting Minds for Scientific Advancement

Background

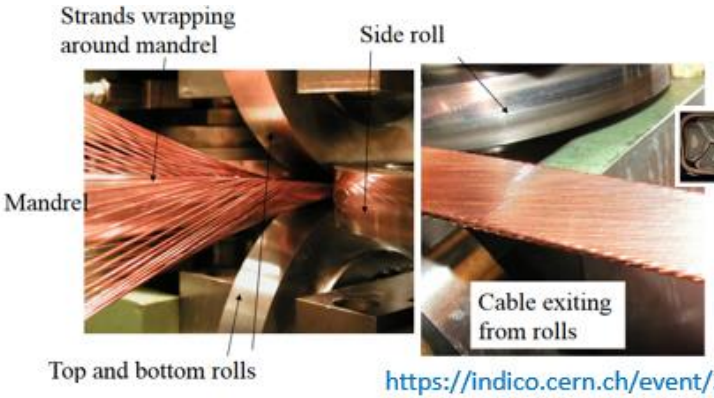
- I am a Deputy Department Head of Magnet Systems Department (MSD)
- I know Nick Pohlman (NIU) from previous work on magnets for the PIP-II project – years back
- For the last few years, MSD were offering temporary positions to students vetted by NIU professors (facilitated by prof. Pohlman)
  - ✓ Maybe it is more appropriate to say we were working with Professors to identify common interests and for them to identify proper students
  - ✓ Positions (5-6 in total) were primarily in the R&D area
- Our cooperation was not excellent because we could hardly provide direct support to NIU
- But we provided support in the form of identifying funding sources together with NIU, and helping them apply (DOE and NSF both offer Funding Opportunities for Universities)
- Eventually, an application was successful!
- But wait, are there so many magnet experts at NIU to work with us and all of them are interested?

Highlights from a previous presentation to students/Faculty

Structure of wires/strands of ~1 mm diameter



https://www.osti.gov/biblio/1971789



Cross-section of a cable

https://indico.cern.ch/event/355818/contributions/840361/attachments/706603/970083/2014_12_10_MQXF_magnet-international-review_design-overview_final.pdf

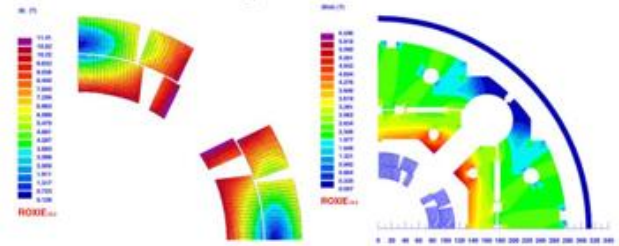
https://indico.cern.ch/event/338963/contributions/797867/attachments/664275/913133/MQXF_Cable_for_Q1-Q3_Final.pdf

Fabricated coil

... and test-magnet

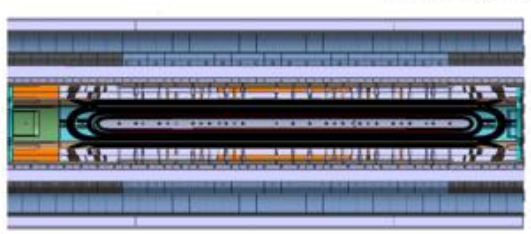
https://inspirehep.net/files/732cb48cbdc3e7736342e5da4cae00bb

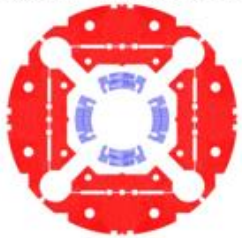
Modeling and simulations

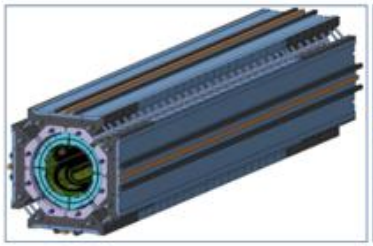


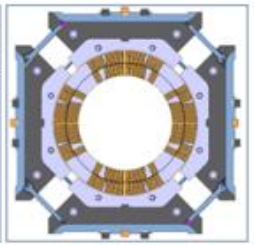
https://arxiv.org/ftp/arxiv/papers/2203/2203.06723.pdf

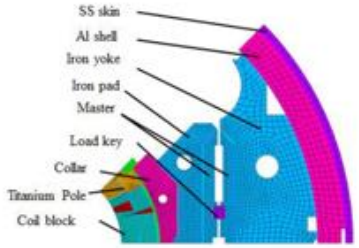
Modeling and simulations









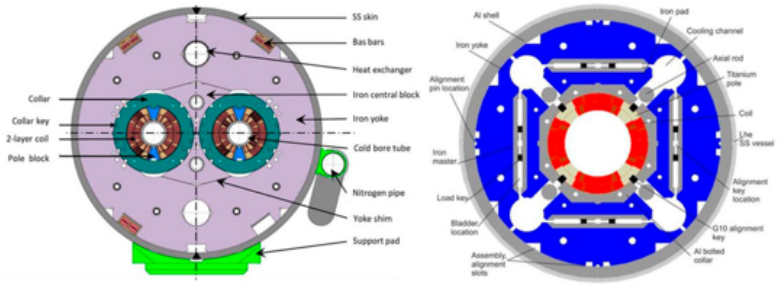


<u>Bottom line</u>: there are various and distinct areas within "magnet development" (I am not even showing "data analysis" here)

Highlights from a previous presentation to students/Faculty

Superconducting accelerator magnets

- You need a good superconductor to start with → **Material science, chemistry, physics**
- You need to protect it from itself – superconductors are usually very bad conductors (in the non-superconducting state) and the current through them, even for a short time, will burn them (energy is dissipated as heat); one way out – use it along with a good normal conductor → **Material science, mechanical engineering, electrical engineering, physics**
- Copper is an excellent conductor and material and is often used together with a superconductor to create a wire, or a tape, or a cable, that can be wound into a coil
- To keep the coil in shape while working on it you may have to use some "glue" → **Material science, chemistry**
- NbTi is a good superconductor and excellent material – very strong, easy to work with
- Nb_3Sn is very brittle – easily breaks, difficult to work with; and is more expensive
- Different processes are employed to build magnets from them → **Mechanical engineering, electrical engineering**



(and there is a big push for **high temperature superconductors /HTS/**
I don't have time to even start to talk about)

Highlights from a previous presentation to students/Faculty

Superconducting accelerator magnets (2)

- In fact, often wires/cables contain the chemical ingredients, properly "placed", to make Nb_3Sn, but are first wound into a coil, and only after that the coil is "heat treated" which create conditions for chemical reactions to form the brittle Nb_3Sn - clever, ah?
  → **Material science, chemistry**
- And then you have to use some "filler", like epoxy, to make the coil a strong enough single object
  → **Material science, chemistry, mechanical engineering, physics**
- I didn't mention you have to properly design your coil (and magnet) before doing any hardware work. Obviously. A lot of modeling and computer simulations.
  → **Mechanical engineering, electrical engineering**
  → **Engineering, computing**
- The above coil, which is a mix of materials with interfaces at this point, will have to be placed in some structure together with other coils to form a proper magnet (10^{-4} accuracy of magnetic field, remember)
  → **Mechanical engineering, physics**
- This coil, will run at high current and high magnetic field and the two generate the Lorentz force that can create a substantial pressure – 200 MPa and more
  → **Mechanical engineering, physics**
- So, both the coils and the structure should be able to sustain that pressure without breaking (at low temperature where many materials become more brittle.. like epoxy…)
  → **Material science, chemistry, mechanical engineering**
  → **Cryogenic engineering**

Highlights from a previous presentation to students/Faculty

Superconducting accelerator magnets (3)

- OK, you have built a magnet, does it do what you want?
- Magnetic field properties?
- Performance, stable operations?
- Can you build more with the same properties (reproducibility)?
- Does it perform the same if it is bigger?
  (scaling up; usually you start with a small "prototype")
- What did you say the cost was? Can you bring it down?
- What if you find a problem or you want improvements (yeah, you do) –
  go back to square one and repeat as necessary based on what you learned
  (but what did you say the cost *for that* was; plan better)

Data acquisition and Analysis:

- engineering,
- physics,
- electronics,
- chemistry,
- material science,
- computing,
- statistics/mathematics,
- management,
- entrepreneurship
- ...

Bottom line: one can contribute substantially without having the tag "magnet expert" attached to them (to start with)

Funding opportunities exists for Universities (DOE/NSF/…)

Funding Opportunity Announcement (FOA) by DOE

DEPARTMENT OF ENERGY (DOE)
OFFICE OF SCIENCE (SC)
HIGH ENERGY PHYSICS (HEP)

REACHING A NEW ENERGY SCIENCES WORKFORCE FOR HIGH ENERGY PHYSICS (RENEW-HEP)

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER:
DE-FOA-0002949

FOA TYPE: INITIAL
CFDA NUMBER: 81.049

FOA Issue Date:	**January 9, 2023**
Submission Deadline for Letters of Intent:	**February 21, 2023 at 5:00 PM Eastern Time** **A Letter of Intent is optional/encouraged**
Submission Deadline for Applications:	**March 31, 2023 at 11:59 PM Eastern Time**

Project application (awarded later)

RENEW: Accelerating Underrepresented Engineering Careers through Accelerator Innovations

Institution:
Northern Illinois University

Principal Investigator:
Nicholas Pohlman
Professor, Department of Mechanical Engineering

Co-Principal Investigator:
Barton Sharp
Professor, Management

Undergrads work at MSD/FNAL/ and some “post-grad” work

Those below are part of the NIU-RENEW efforts

High Temperature Superconductors (HTS):

- Finite element analysis of stress concentrators in REBCO superconducting cables
- Characterization of REBCO stack for fusion coils

Magnet protection (for HTS):

- Novel quench detection system for HTS magnets (work on fiber optics)

Conductor development:

- Heat treatment oven calibration and machine modeling

Magnetic measurements:

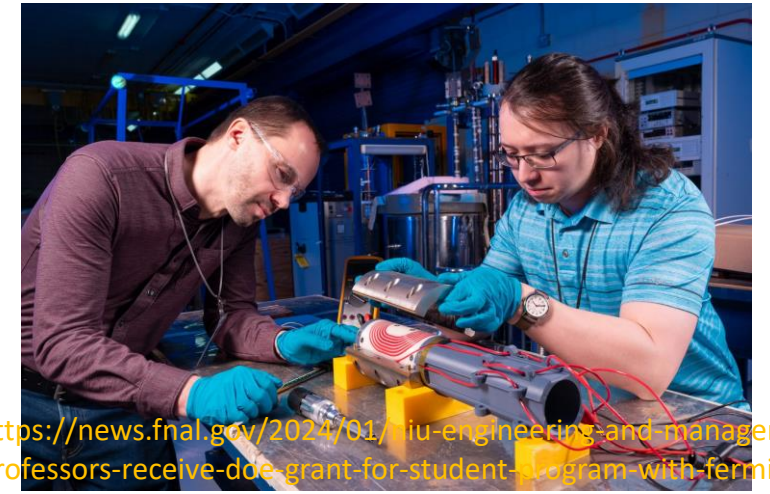
- Development of a sagless probe to measure the magnetic field of curved dipole magnets

Machine Learning/Artificial intelligence:

- Analysis and algorithm development
- Databases development

(each sub-topic is for a separate student; they are seven now)

A former NIU-student working with a FNAL researcher on HTS magnet development (small prototypes)



https://news.fnal.gov/2024/01/niu-engineering-and-management-professors-receive-doe-grant-for-student-program-with-fermilab/

NIU-RENEW undergrad with her Supervisor working on optical fibers

Highlights of efforts at MTD*/MSD

- Work for large projects (HL-LHC/CERN, PIP-II/FNAL,…)

- Supporting the FNAL accelerator complex and helping other Labs
  (conventional and superconducting magnets – development, testing, refurbishment,…)

- Design of high field accelerator magnets, including novel designs and approaches
  - ✓ Prototypes testing

- Development of superconductors and materials
  - ✓ Quality improvements
  - ✓ High temperatures superconductors

- Diagnostics and data analysis
  - ✓ New sensors and measurement probes
  - ✓ New methods
  - ✓ Machine learning methods (as a special effort)

- Work with Universities/students

- Expansion of efforts
  - ✓ Fusion!
  - ✓ HTS!

*Magnet Technology Division

Challenges

- Superconducting cables are different types
  - ✓ HEP has different requirements than Fusion Sciences
  - ✓ It is not straightforward to make “universal” conductors

- Even within HEP, magnet designs serve different purposes
  - ✓ A muon accelerator is different than a hadron accelerator which is different that an electron accelerator

- There are unresolved problems in given directions/approaches
  - ✓ This is actually great for research
  - ✓ Difficult problems require time and efforts though

- Funding levels for research stagnate
  - ✓ This does urge us to search for synergies, external sources for support
  - ✓ Not all areas are equal, some see growth

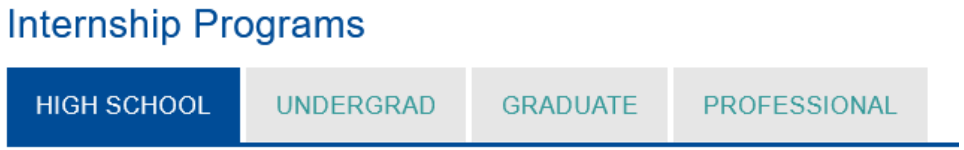
- Attracting people to the accelerator community is not easy
  - ✓ Not many universities “produce” magnet experts
  - ✓ “Mass production” of niche-experts is not feasible but the result is that there are no any (almost)
  - ✓ We are more likely to not find a person with given qualification than to have them unable to find jobs

- Introducing “new” people to the field (may be some of you? or your students?)
  - ✓ They have to want to be involved and need to have the proper support

Official programs at FNAL supporting students and Faculty

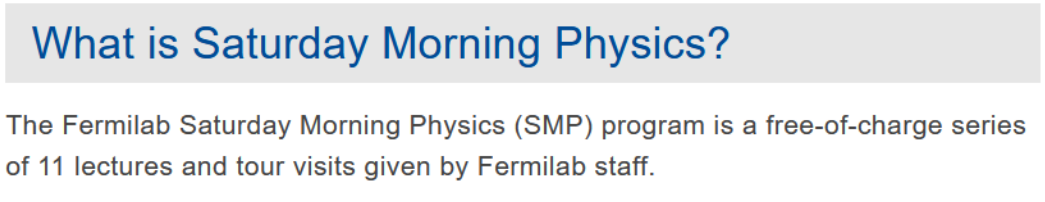
- Various levels of internships
  - Most are for students, but the Visiting Faculty Program is for Professors

https://internships.fnal.gov/



- Saturday Morning Physics

https://saturdaymorningphysics.fnal.gov/



The program's purpose is to further the understanding and appreciation of modern physics among **high school students**. The lectures are aimed at high school students who have no previous scientific knowledge.

- Organized and tailored on-site tours at request
  - ✓ It is great for "local" institutions but is a good opportunity in any case

https://diversity.fnal.gov/fswe/

Vision: By leveraging existing and emerging connections to collegiate groups, fSWE's Collegiate Pipeline Program (CPP) commits itself to inspire students to develop their STEM identity by building their careers through Fermilab's portfolio of internship opportunities.

If you would like to request an onsite visit to Fermilab for your college/university, please complete a fSWE Collegiate Pipeline Program (CPP) OnSite Visit Request Form

Summary

- Working on “magnets” is a versatile endeavor
  - ✓ Do be fair, that is true for most areas in Accelerator development
- There are many exciting topics for “newcomers”
  - ✓ You and your students can be involved if you (really) want to
- Challenges persists on various levels
  - ✓ Where is this not true
- Various DOE and NSF programs/funding opportunities exist to support your projects
  - ✓ But you have to look for them and apply for them
- FNAL also offers many opportunities for participation of students and Faculty in activities

Some reasons to get involved with “us” : you like research, you can handle challenges,
you prefer to work in collaboration, you have some time to dedicate to something new,
you want to expand your area of expertise or give your students more opportunities to do so