The US High Field Magnet Program

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Outline

- Context for high field accelerator magnet R&D
  - P5 and ARD Subpanel
- Grand challenges and program goals
- Current status of US program
- Implementing a coordinated US magnet program

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Energy frontier in the US – P5

The P5 report states, "A very high-energy proton-proton collider is the most powerful future tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window."

The report also says, "The U.S. is the world leader in R&D on high-field superconducting magnet technology, which will be a critical enabling technology for such a collider." In light of these observations, the P5 strategic plan endorses medium-term R&D on high-field magnets and materials in the context of its recommendation 24:

"Participate in global conceptual design studies and critical path R&D for future very high-energy proton-proton colliders. Continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs."

P5 set high expectations

- "The future of particle physics depends critically on transformational accelerator R&D to enable new capabilities and to advance existing technologies at lower cost. "

- "The program is driven by the physics goals, but future physics opportunities will be determined by what is made possible."

- "Going much further, however, requires changing the capability-cost curve of accelerators, which can only happen with an aggressive, sustained, and imaginative R&D program."

- "Primary goal, ... build the future-generation accelerators at dramatically lower cost. For, example, the primary enabling technology for pp colliders is high-field accelerator magnets, . . ."

- "Strengthen national laboratory-university R&D partnerships, leveraging their diverse expertise and facilities."

Accelerator R&D Subpanel reinforced the P5 recommendations

- Recommendation 5. Participate in international design studies for a very high-energy proton-proton collider in order to realize this Next Step in hadron collider facilities for exploration of the Energy Frontier. Vigorously pursue major cost reductions by investing in magnet development and in the most promising superconducting materials, targeting potential breakthroughs in cost-performance.

- Recommendation 5a. Support accelerator design and simulation activities that guide and are informed by the superconducting magnet R&D program for a very high-energy proton-proton collider.

- Recommendation 5b. Form a focused U.S. high-field magnet R&D collaboration that is coordinated with global design studies for a very high-energy proton-proton collider. The over-arching goal is a large improvement in cost-performance.

Accelerator R&D Subpanel recommendations

- Recommendation 5c. Aggressively pursue the development of Nb_3Sn magnets suitable for use in a very high-energy proton-proton collider.

- Recommendation 5d. Establish and execute a high-temperature superconducting (HTS) material and magnet development plan with appropriate milestones to demonstrate the feasibility of cost-effective accelerator magnets using HTS.

- Recommendation 5e. Engage industry and manufacturing engineering disciplines to explore techniques to both decrease the touch labor and increase the overall reliability of next-generation superconducting accelerator magnets.

Accelerator R&D Subpanel recommendations

- Recommendation 5f. Significantly increase funding for superconducting accelerator magnet R&D in order to support aggressive development of new conductor and magnet technologies.

- Recommendation C1a. Ramp up research and development of superconducting magnets, targeted primarily for a very high-energy proton-proton collider, to a level that permits a multi-faceted program to explore possible avenues of breakthrough in parallel. Investigate additional magnet configurations, fabricate multi-meter prototypes, and explore low cost manufacturing techniques and industrial scale-up of conductors. Increase support for high-temperature superconducting (HTS) materials and magnet development to demonstrate the viability of accelerator-quality HTS magnets for a very high-energy collider.

Grand Challenges aligned with the Subpanel recommendations

Magnets

- Achieve a field of 16T in a bore of at least 50mm
- Focus on simple, manufacturable designs (the cost goal)
- Understand training of Nb_3Sn magnets and develop ways to reduce or eliminate it
- Produce an HTS (Bi-2212/YBCO) insert with a self-field of > 4T and measure the field quality

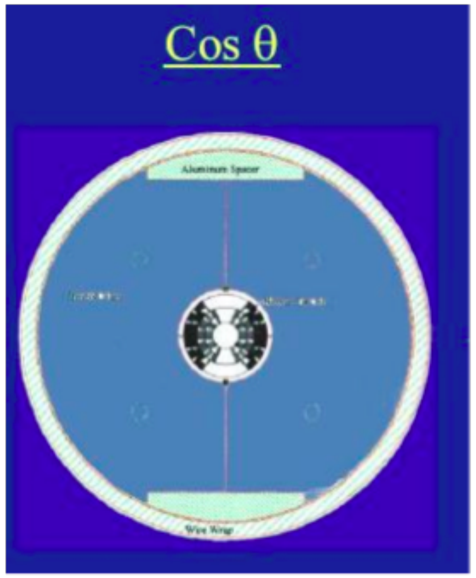
Conductor

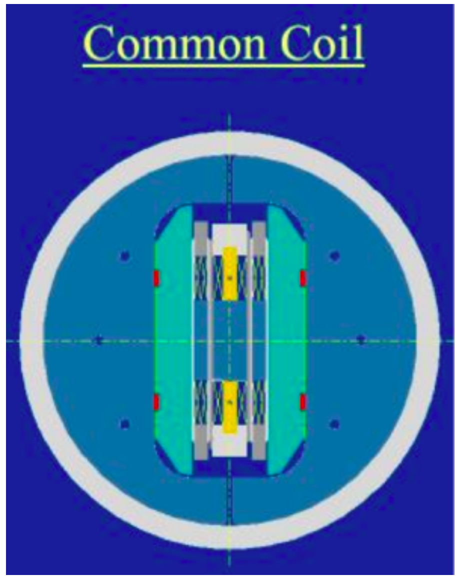
- Focus on magnets as technology drivers
- Reduce cost and improve performance of Nb_3Sn
- Increase the current density by 30% with a scalable sub-element structure
- Aim for a cost per kg the same as NbTi
- HTS conductor development with clear performance targets

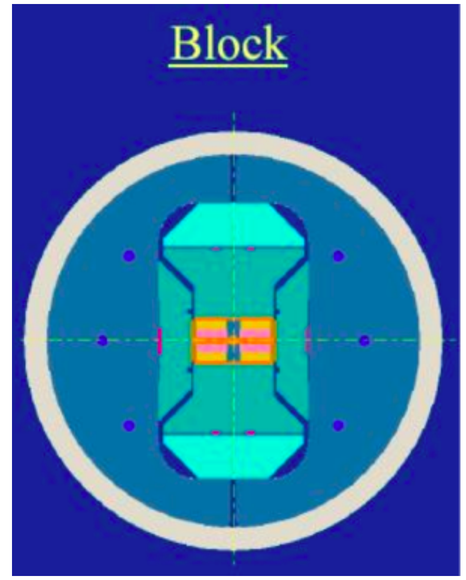
Questions as drivers for an aggressive generic Superconducting Magnet and Materials Program

- **Is operation at 16T feasible and economically justified?**
- **What are the drivers and optimal operation margin for accelerator magnets?**
- **What are the key magnet cost drivers?**
- **Do we need to operate at 1.8K?**
- **What is the nature of training? Can we reduce or eliminate it?**
- **Can we provide accelerator quality magnets in the range of 16T?**
- **Can we improve quench protection?**
- **Can we build practical accelerator magnets with HTS conductor(s)?**
- **Where is the LTS to HTS transition?**
- **Is there an alternative to Rutherford cable for high field magnets?**
- **What are the near and long-term goals for HTS conductor development?**

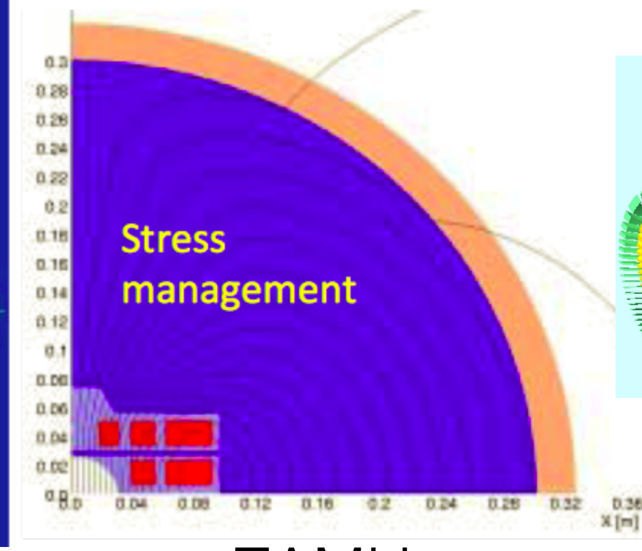
Starting point for magnet technology



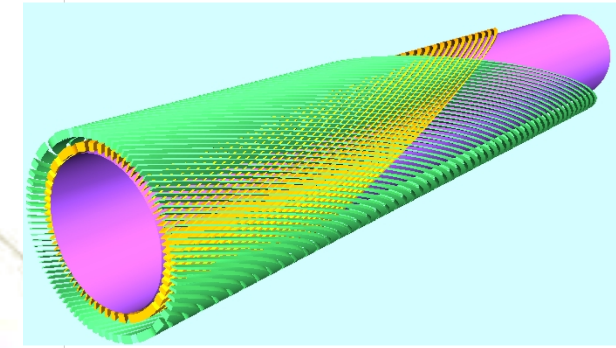




LBNL



TAMU



CCT

4.5T

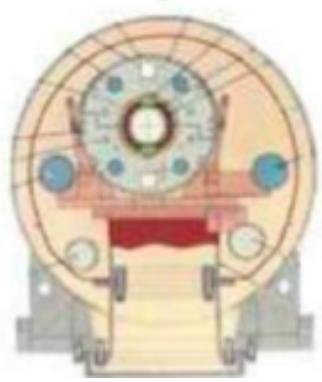
Tevatron,
6 m, 76 mm
774 dipoles

5.3T

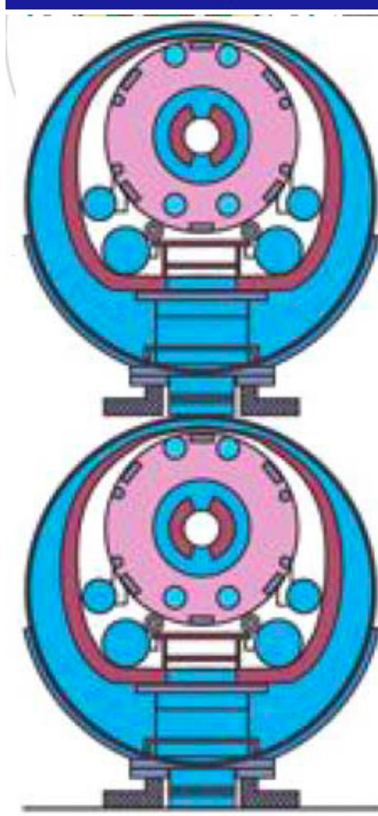
HERA,
9 m, 75 mm
416 dipoles

3.5T

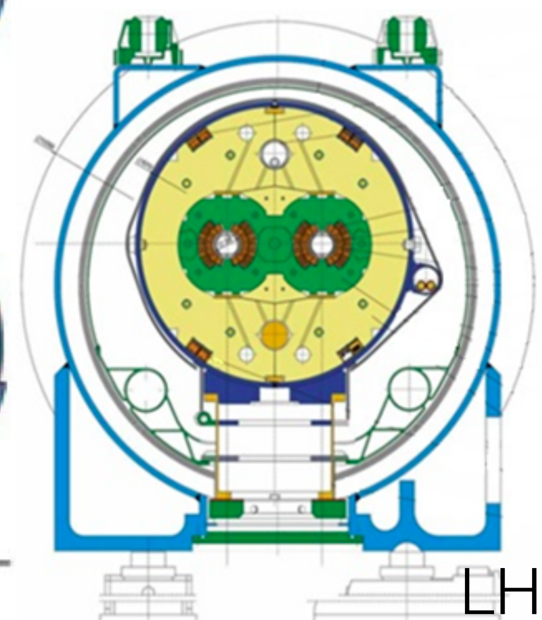
RHIC,
9 m, 80 mm
264 dipoles



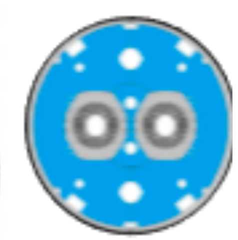
Shiltsev/Zlobin, (FNAL)



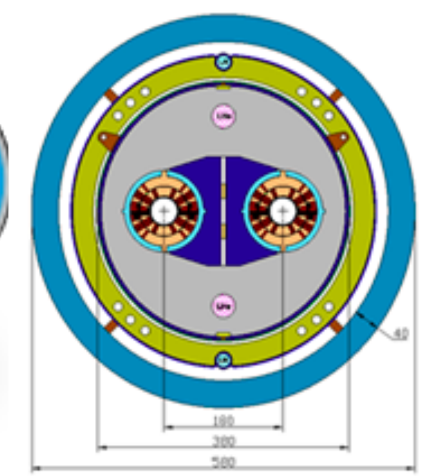
SSC, 50mm
6.6T, 4.3K



LHC, 56mm
8.3T, 1.9K



LHC, 60mm
11T,1.9K
FNAL/CERN

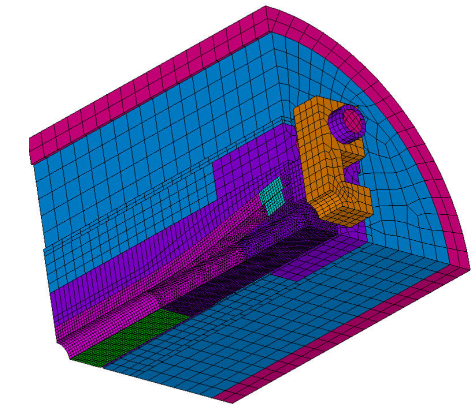


VLHC, 43mm
10T, 4.5K

We have built a strong R&D platform and are ready to launch an aggressive new program that will meet the P5 and Subpanel challenges

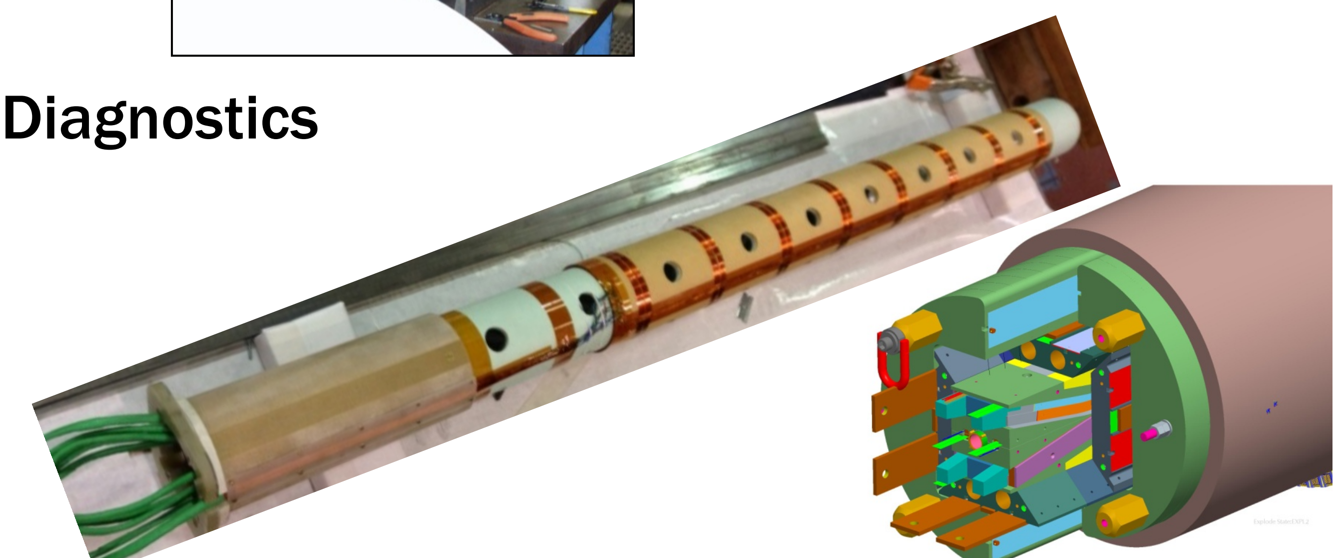
Experience with a variety of geometries

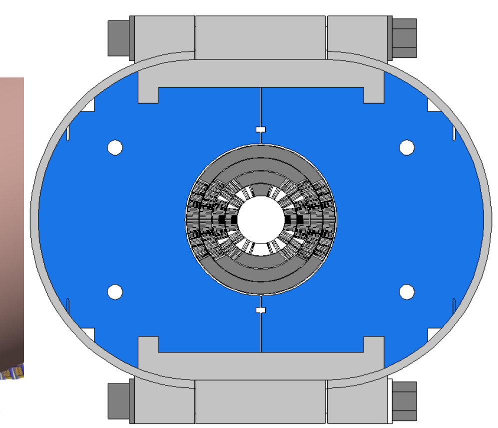
- ○ Cos-Theta – D20 and more recently, LARP
- ○ Common Coil
- ○ Block
- ○ Sub-scale racetracks
- ○ Some Canted-Cos-Theta



We have the tools and experience required for success

- ▪ Analysis tools
- ▪ Unique Instrumentation and Diagnostics
- ▪ Infrastructure
  - ○ Fabrication
  - ○ Testing

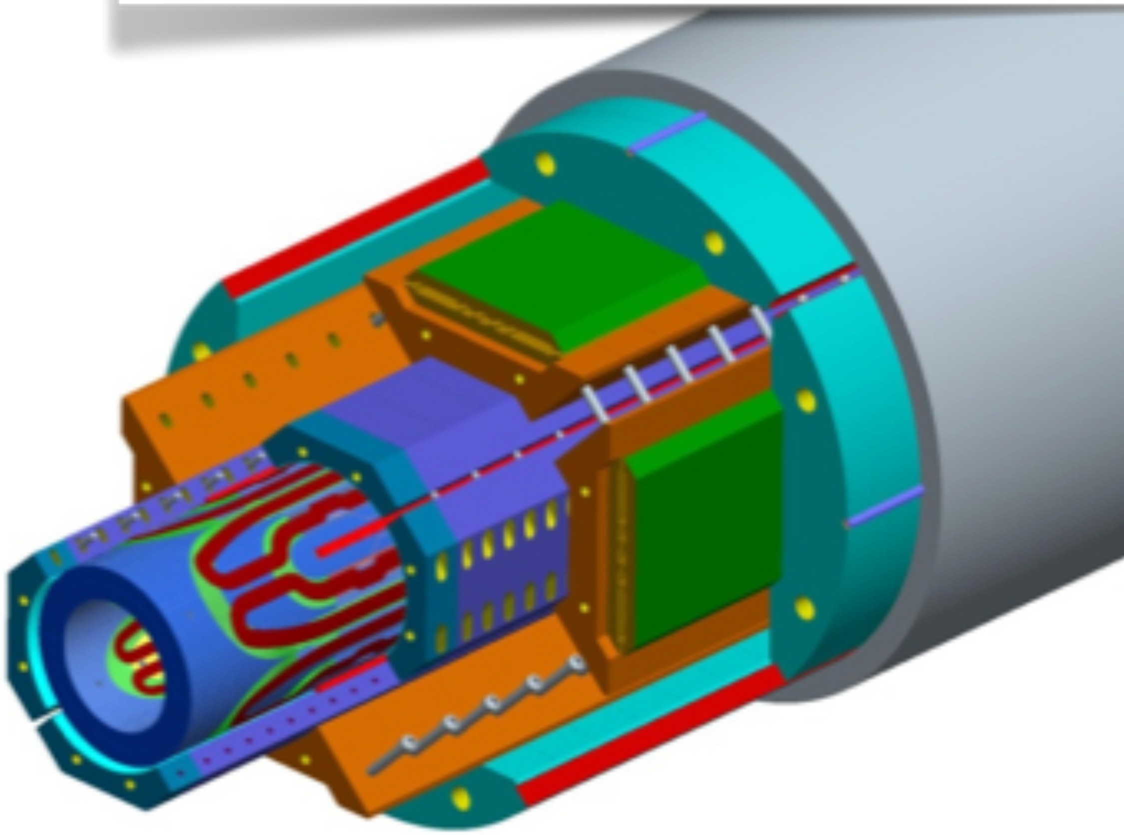


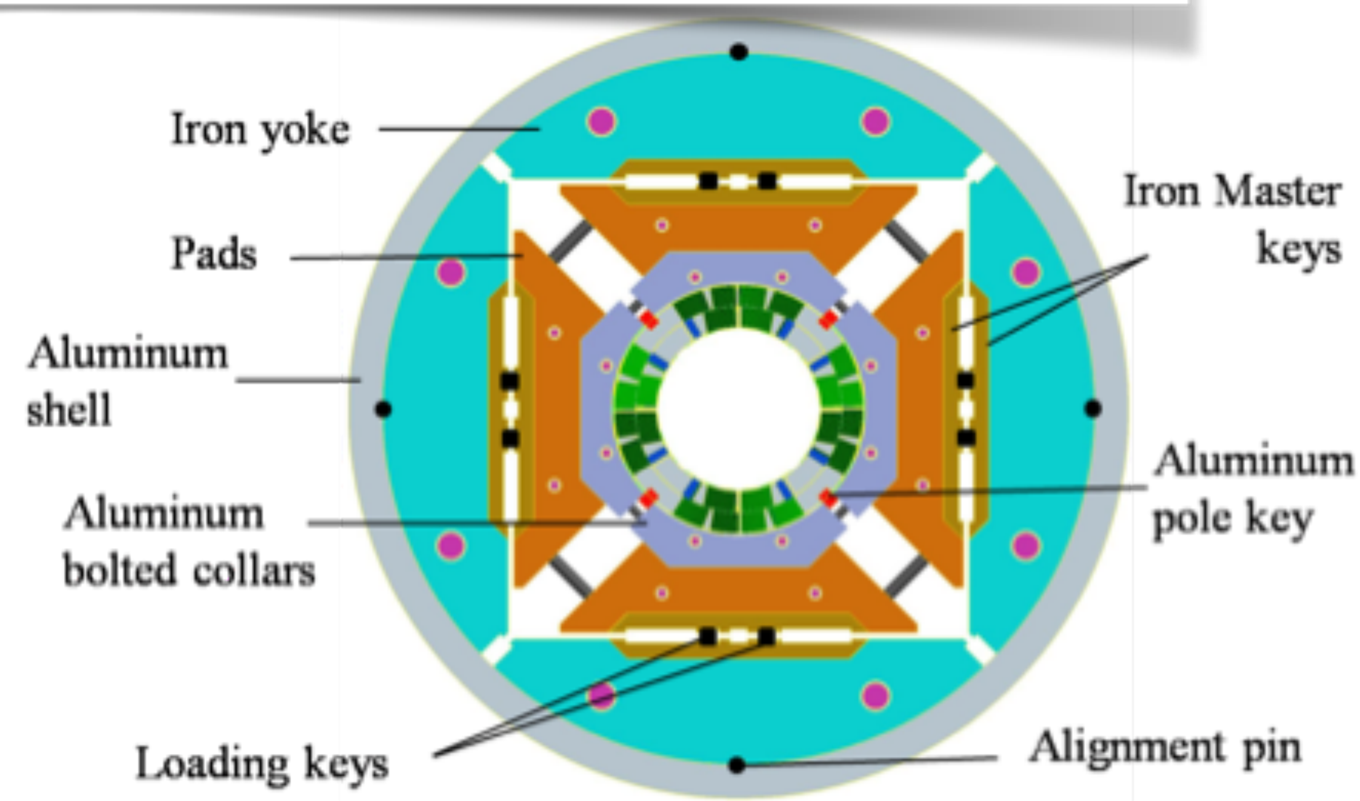


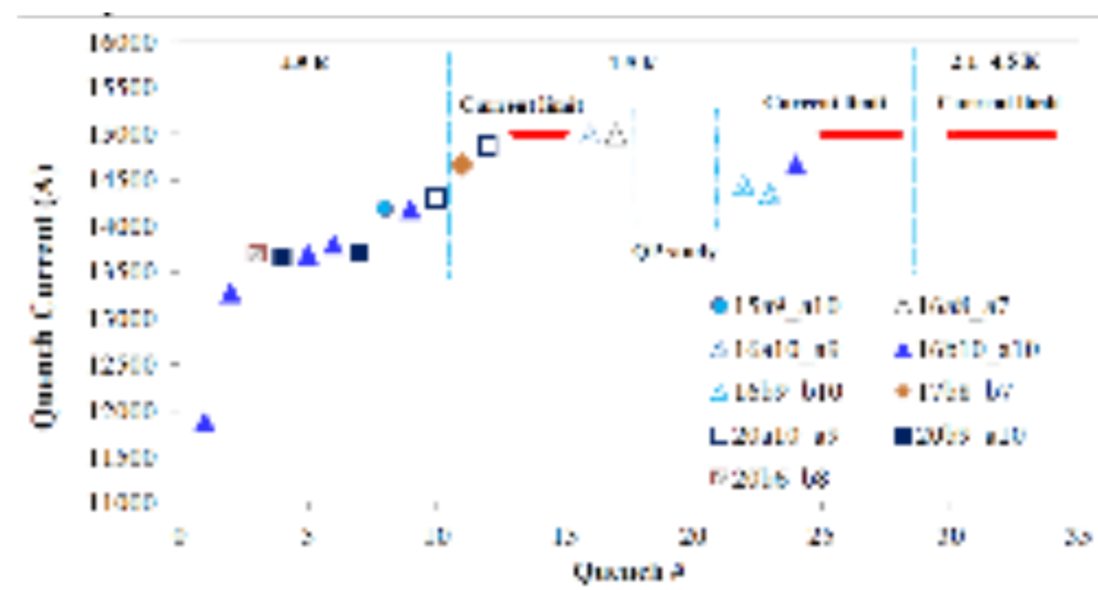
We have time but not that much time. And we need to substantially raise the level of expectation for magnet performance.

Nb_3Sn technology is being readied by LARP:
HQ ➠QXF ➠ Hi-Lumi upgrade

Design, fabrication, and test results from LARP: FNAL, LBNL, BNL







Current Status of the US Magnet Program

Funding for R&D Programs is at an all-time low

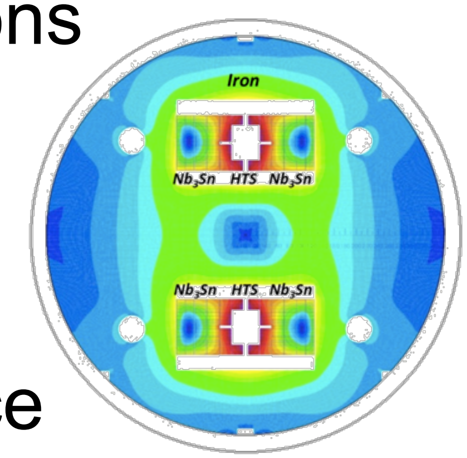
Heavily involved in Hi-Lumi (the top priority)

New US strategy (P5 and HEPAP Accelerator R&D Subpanel) strongly support Magnet R&D and participation in future pp colliders.

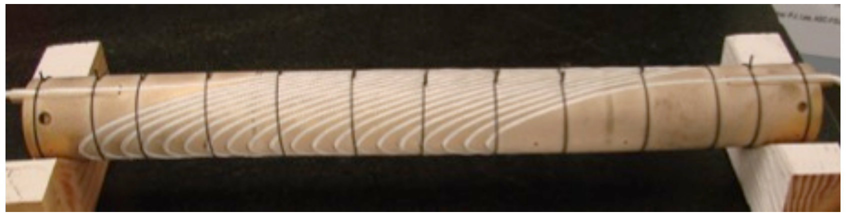
- In the process of forming a coordinated US Program

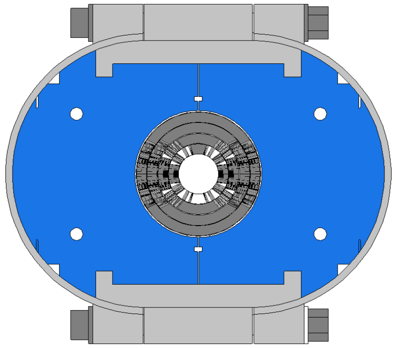
Participating programs offer a broad approach

Minimal breadth with focus on answering the driving questions



- BNL – 16T Nb_3Sn Common Coil, 10T insert test facility
- FSU/NHMFL – Conductor R&D, 32 T NMR Solenoid, OP furnace
- FNAL – 16T small-aperture demonstrator based on (BCT)
- LBNL – Development of CCT design for Nb_3Sn and HTS, technology development via version of subscale program
- TAMU – CIC-based high field dipole





Philosophy: Raise the Bar on Expectations and Implement an Aggressive Approach

- **Leverage through collaboration**
- **Shoot for the moon – high risk, high payoff**

  Aim for the highest dipole fields

  New ideas for simplicity

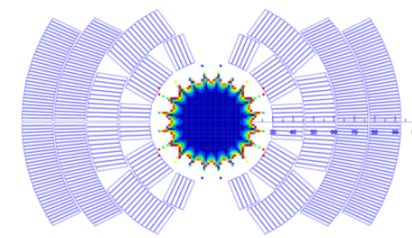
  Explore the limitations of materials and structures
- **Implement a technically driven program that strives for one test at least every 3 months. i.e. make our mistakes quickly and learn from them**

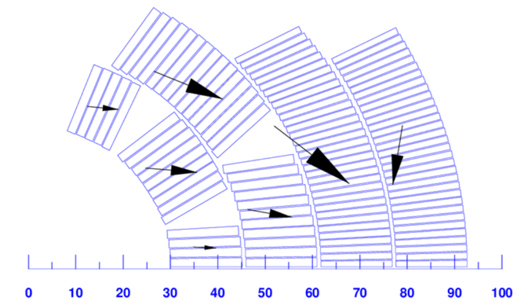
Outcomes are . . .

We need to build magnets!

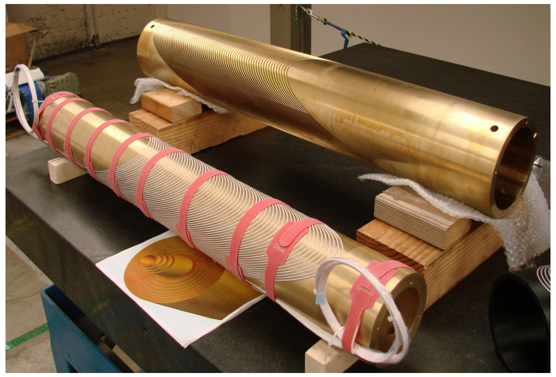
- **New record dipole fields**
- **A discontinuity in superconducting magnet technology**
- **A platform that can be used to design and build magnets for a variety of applications with optimal field, coil configuration and bore size**
- **Significant increase in performance/cost ratio**

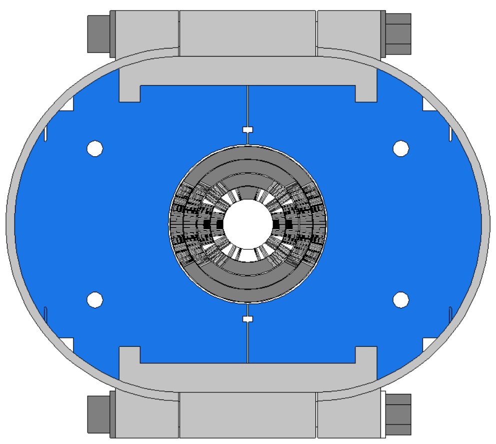
Initial Program Elements

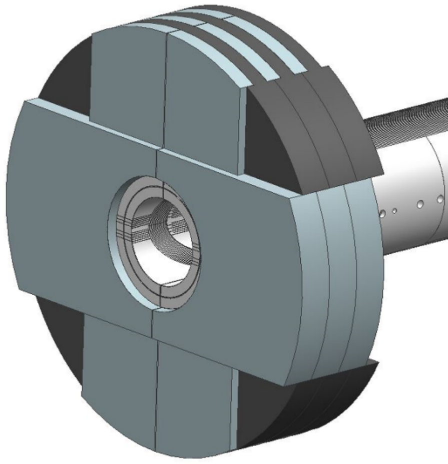

Graded block-cos-theta coil



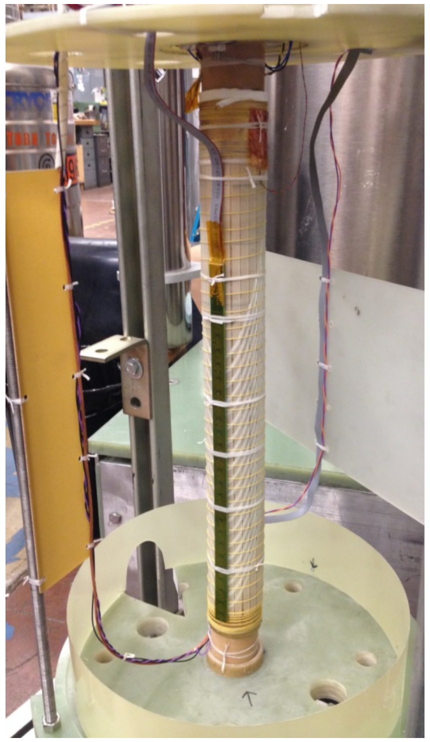
- **Demonstrate feasibility of 16 T operating field with Nb_3Sn**
  - Combination of high risk, high payoff and extrapolation of existing technology
  - 16T Canted-Cosine-Theta (CCT) and a 16T Block Cosine-Theta (BCT)
- **Parallel technology development**
  - Reduce development time via sub-scale studies
  - Materials
  - Manufacturing techniques
  - Quench protection
  - Training studies


5T NbTi





- **HTS (relatively small fraction of program)**
  - Build HTS accelerator magnets (feasibility at some level)
  - Try to develop market drivers outside HEP to lower cost and maintain R&D
- **Continued conductor development**
  - Scalable sub-element structures for Nb3Sn scale-up
  - Performance improvement of both Nb_3Sn and HTS
- **Development of facilities and intellectual infrastructure**
  - Integrate design and analysis tools - Filament to structure
  - Diagnostics/instrumentation for design feedback and fundamental understanding
  - Cost reduction engineering (engage industry and universities)



Taking steps toward program integration

Initially form teams in common technical areas

- **Consolidate design and analysis**

  LBNL to help FNAL with BCT Structure and FNAL to help with CCT

- **Consolidate manufacturing and testing**

  Integrate teams, work together to develop instrumentation
  Possible test of FNAL BCT in larger LBNL cryostat
  Possible test of LBNL CCT at 1.8K at FNAL

- **Coordinated conductor R&D activities (already doing this)**
- **Develop an active technology development program utilizing university resources and students**
- **Annual workshop in conjunction with LTSW is being discussed**

Going forward, what are the challenges and opportunities?

- **Funding profile**

  Demanding and expensive technology vs dwindling funding
  Denies pursuit of a technically-driven program in the near term
  Become LARP-scale ASAP and grow as program demonstrates need and success

- **Resources (in the next decade)**

  Hi-Lumi will dominate substantial fraction of facilities at FNAL, BNL and CERN for the next decade but also makes available a broad range of resources, thus highly leveraging R&D funding

- **Availability of conductor (HTS and Nb_3Sn)**

  Can't build magnets without conductor and it is expensive

Conclusions

- **Accelerator quality dipoles with an operating field of 16T are feasible**
- **Making them affordable is a challenge and will take time and require more resources than we have now. It will be a world-wide effort.**

Very important

- **Program has to be integrated (AP, cryo, etc) and take into account ancillary problems, e.g. SR heat load**
- **HTS has many issues to understand and overcome in order to be a viable option**

We need to prove feasibility, which could be demonstrated within the next year or two, then we can worry about the cost.

The US has an opportunity to make a critical and unique contribution to a future high-energy proton-proton collider