Elliptic aperture, combined function SC magnets for fixed-field accelerators

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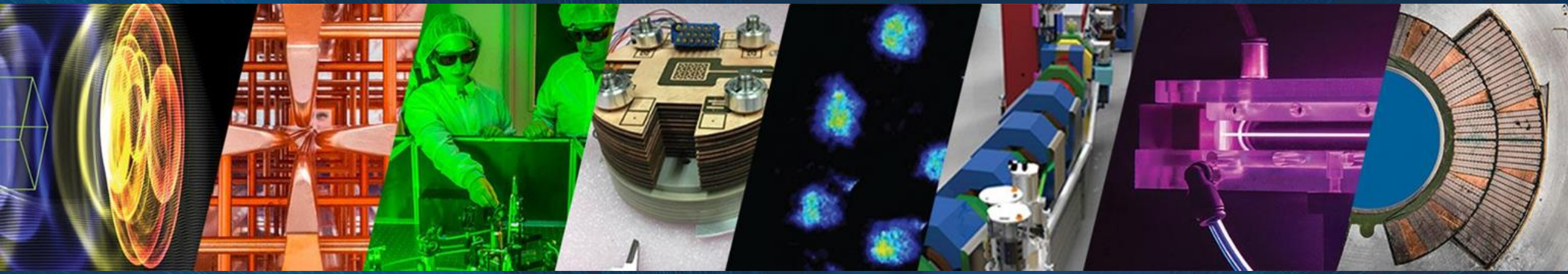


International Muon Collider Magnets Working Group
July 25th, 2024

BERKELEY LAB
ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION ATAP
U.S. DEPARTMENT OF ENERGY | Office of Science

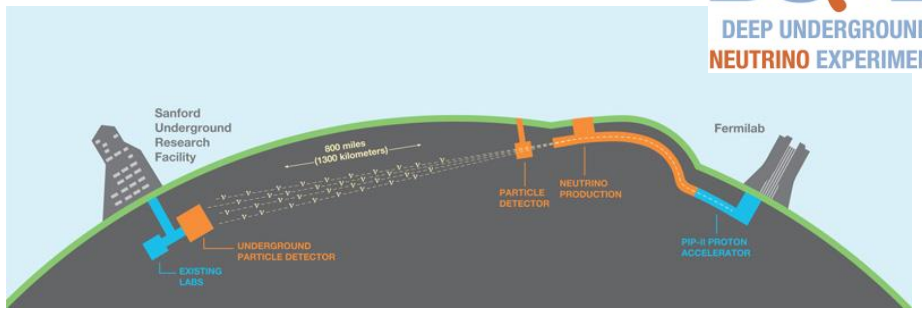
Outline

- Motivation for elliptic bore, combined function SC magnets — **Lucas**
- Design/analysis tool development for elliptic CCTs — **Yufan**
- Windability (tests, theory, tilted channels…) — **Yufan**
- Initial design and prototyping for a ~5 T demonstrator magnet — **Yufan**

Future HEP experiments require high-power, rapid accelerators

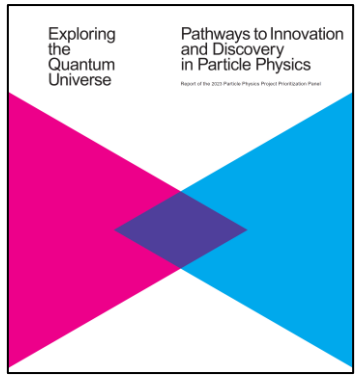
High-power proton drivers for neutrino experiments

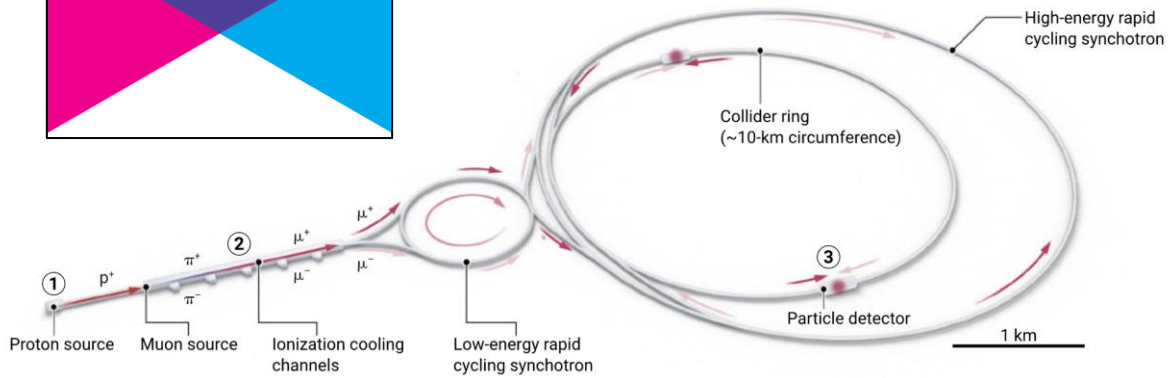
DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT



PIP-II

Rapid acceleration for a 10 TeV parton center-of-momentum muon collider





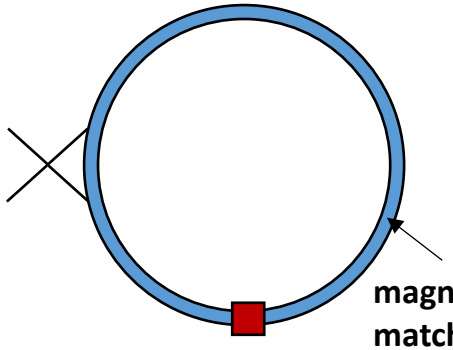
https://www.science.org/content/article/muon-collider-could-revolutionize-particle-physics-if-it-can-be-built

Fixed-field accelerators (FFA's) potentially enable rapid, high-power acceleration with a reduced number of costly SRF cavities, but require complex magnets

Linacs

similar to linac: efficient use of cavity cycles (+speed, +power)

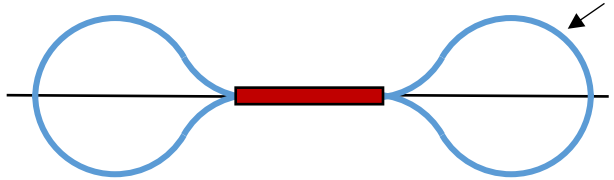
Rapid Cycling Synchrotron (RCS)



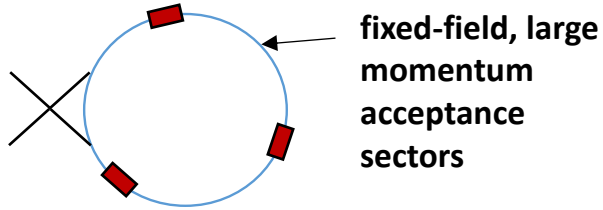
similar to RCS: reuse of costly SRF cavities (+cost reduction)

Fixed-Field Accelerators (FFA's)

Recirculating Linac



Fixed-Field Alternating Gradient Ring

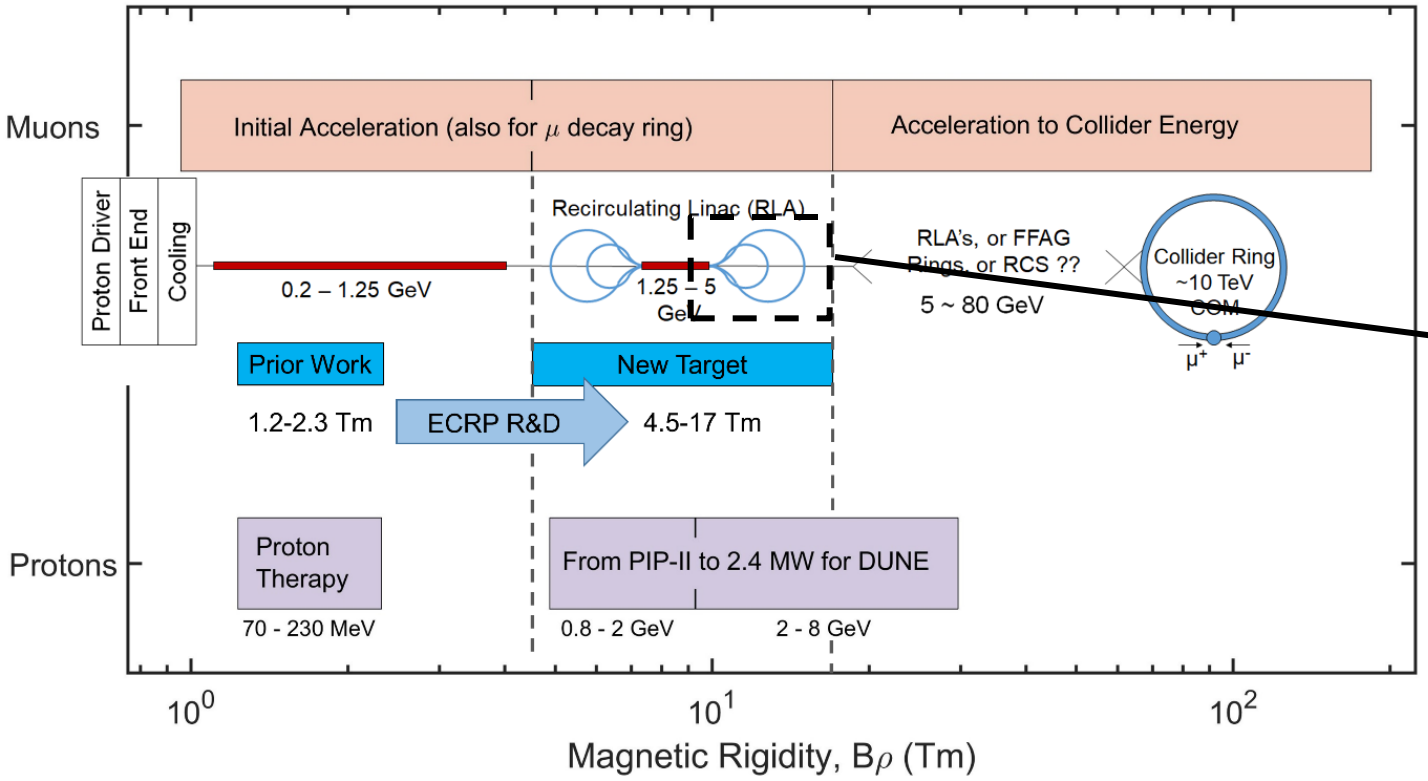


Challenges for FFA's

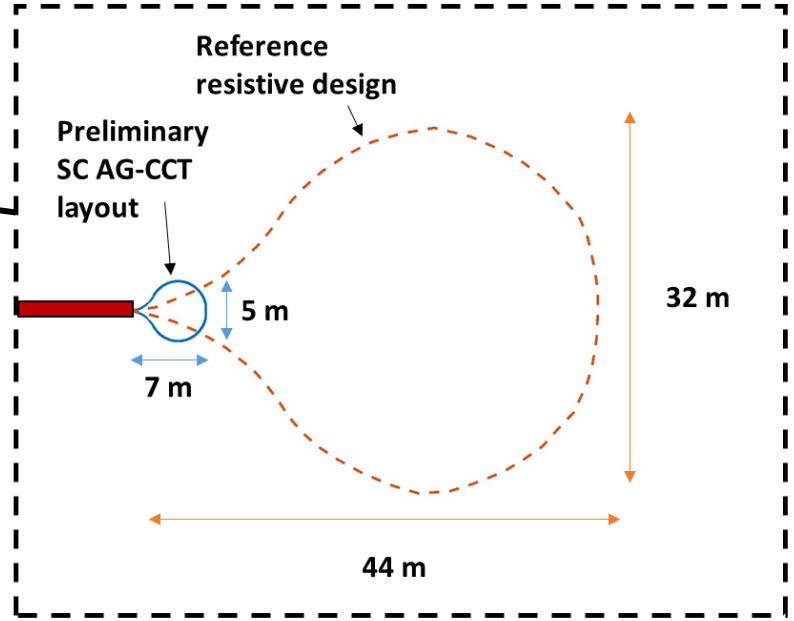
accelerator physics: design of large momentum acceptance beamlines for multiple passes with fixed field, tune shift, successful demonstrations so far are for low-energy electrons (e.g. EMMA, CBETA)

accelerator magnet technology: combined function (e.g. dipole and quadrupole fields in the same aperture) and non-circular bores

Superconducting magnets enable ultra-compact FFA layouts



Scoping with superconducting magnets leads to a compact layout for a 1-5 GeV/c muon RLA (1.7 T, 87 T/m, 100 mm aperture)

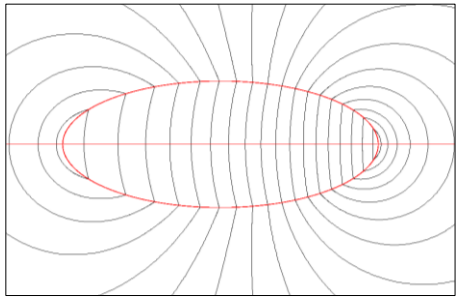


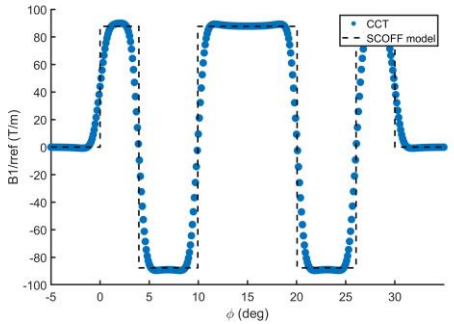
SC magnets reduce footprint with higher field and a novel configuration achieving large momentum acceptance with minimal reverse bending

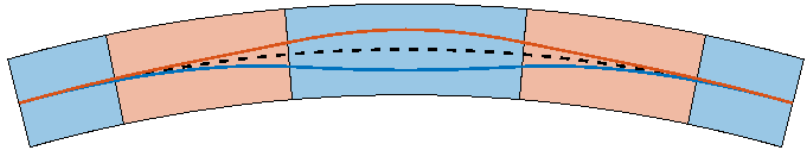
Fixed-field accelerators (FFA's) potentially enable rapid, high-power acceleration with a reduced number of costly SRF cavities, but require complex magnets

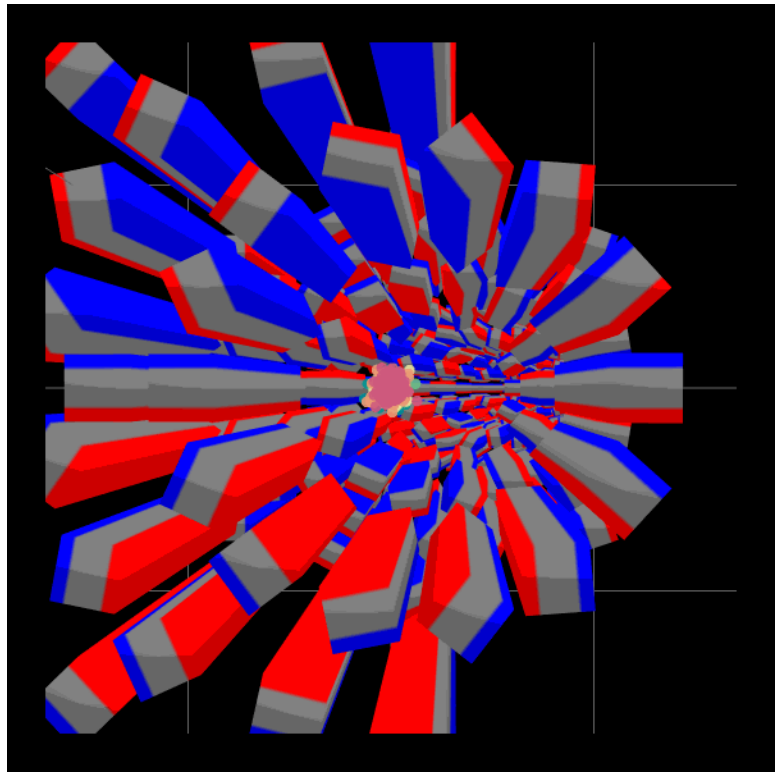
Challenging SC magnets are desired for fixed-field arcs

- transport of multipole energy passes simultaneously with unique, alternating focusing structures
- **non-circular aperture due to orbit offset**
- **combined function fields (dipole + quad, + sextupole + ..)**









From: Adam Steinberg, Design of a Closed-Dispersion Arc with a Large Energy Acceptance for the TURBO Project, FFA23

We have a new five-year program to demonstrate the unique superconducting magnet technology for fixed-field-accelerators (leveraging our larger CCT program)

US-MDP CCT dipole magnet program

U.S. MAGNET DEVELOPMENT PROGRAM

https://doi.org/10.1109/TASC.2022.3155505

high field design and analysis techniques, fabrication methods, Nb_3Sn, impregnation materials

ARDAP project for proton therapy

BERKELEY LAB

VARIAN medical systems

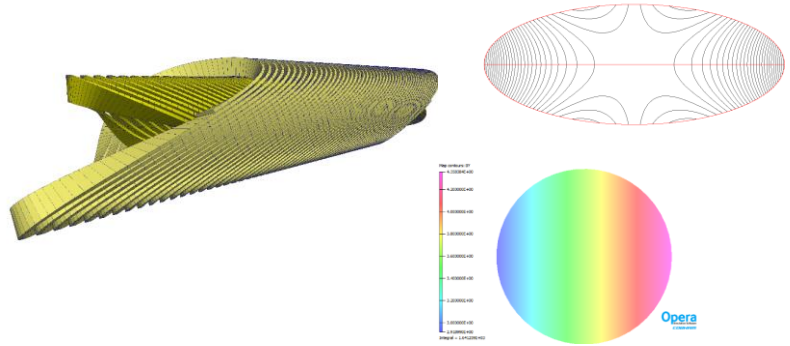
PAUL SCHERRER INSTITUT PSI

https://doi.org/10.1016/j.nima.2020.163414

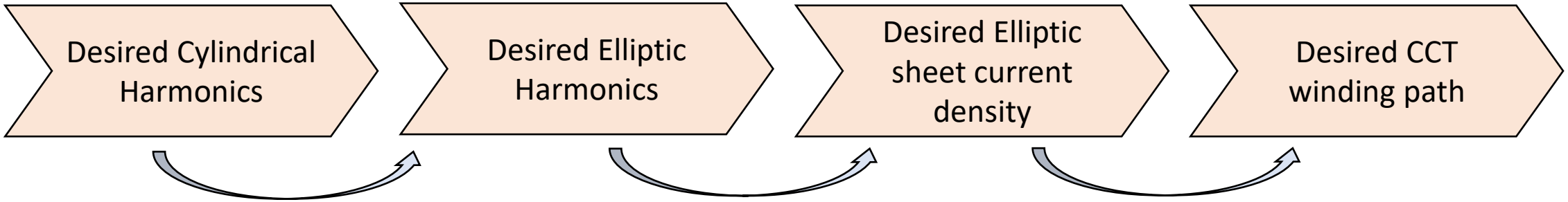
large momentum acceptance designs, combined function, curvature, coupled beam dynamics and magnet design

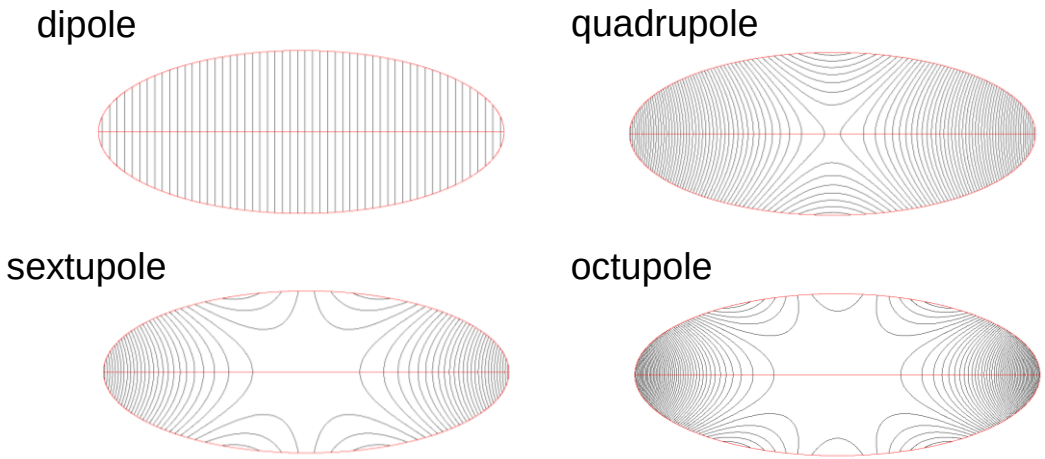
ECRP goal: first demonstration of CCT accelerator magnet technology with the new and challenging aspects desired for FFA's

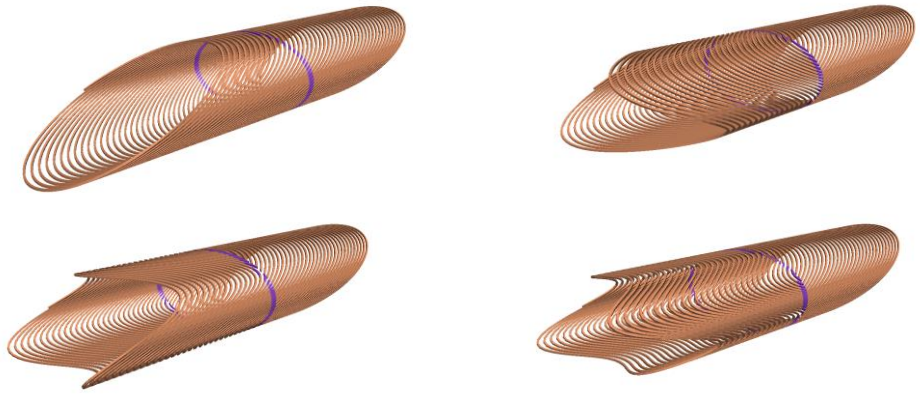
- combined function and higher order fields (e.g. dipole + quadrupole + sextupole in the same aperture)
- elliptic bore
- alternating fields along the axis integrated into a single coil



We developed an analytic method to go from a desired set of cylindrical harmonics in an elliptic aperture to a CCT winding path producing them

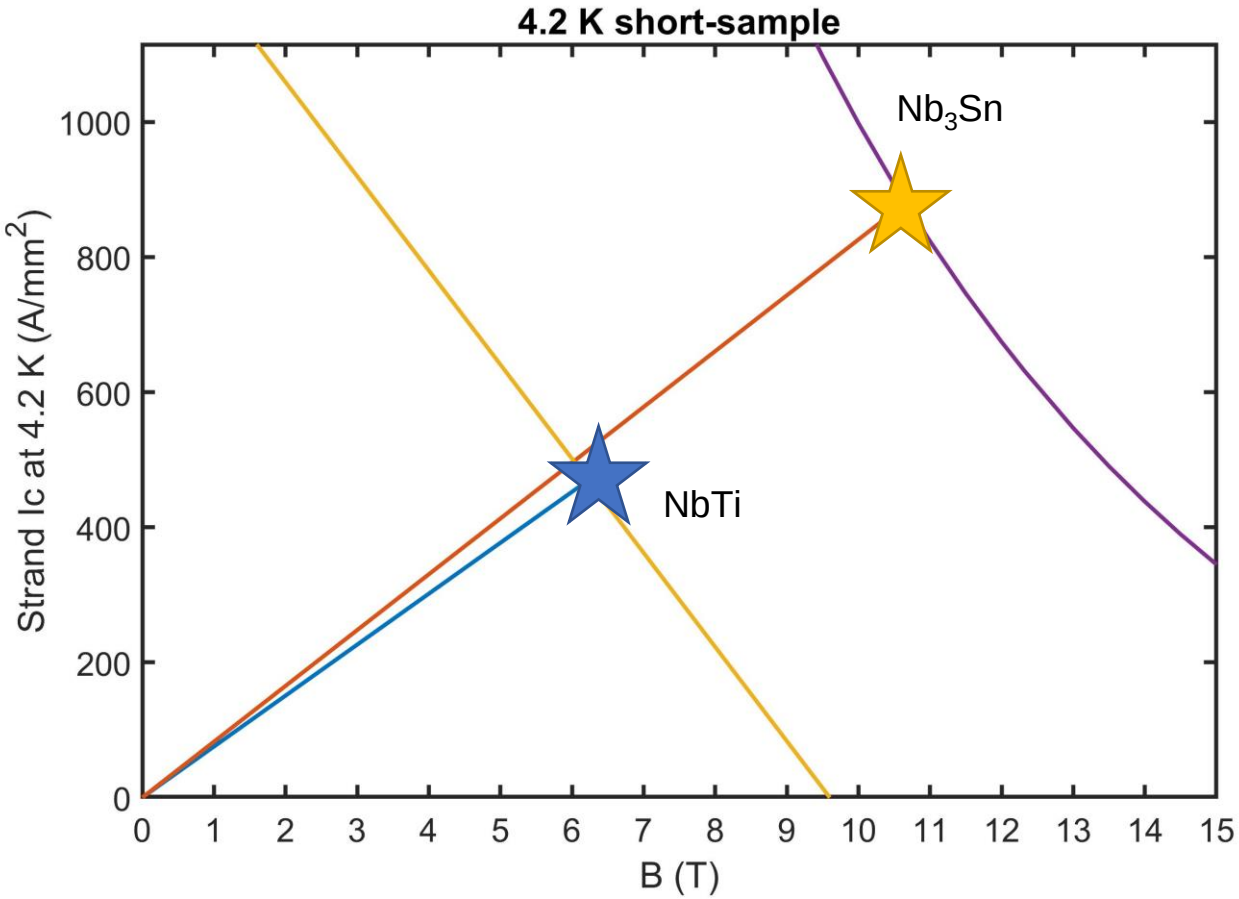




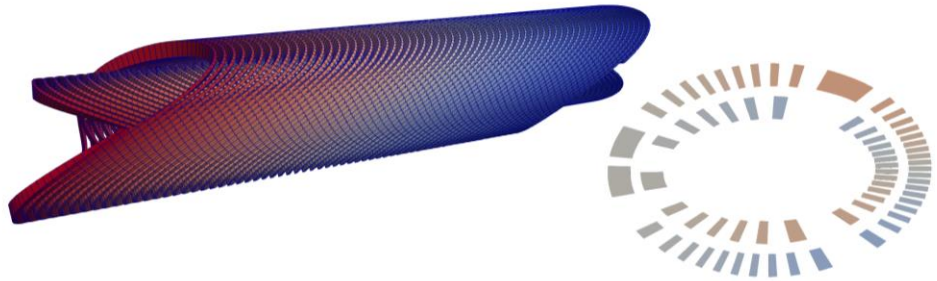


Brouwer, PRAB, 2024, 10.1103/PhysRevAccelBeams.27.022402

High level program goals



combined function CCT: 40 x 90 mm aperture, 500 mm length



Magnet #1: NbTi (~6 T cond, 2.8 T + 51 T/m)
- establish elliptic magnet fabrication techniques
- demonstrate performance and field quality for dipole + quadrupole combined function
- ~2 years from start (Fall 2025)

Nb_3Sn (~11 cond, 4.7 T + 87 T/m)
- work out Nb_3Sn compatibility
- demonstrate high field

Follows past LBNL development sequence for circular bore CCT dipole magnets (https://doi.org/10.1109/TASC.2022.3155505)