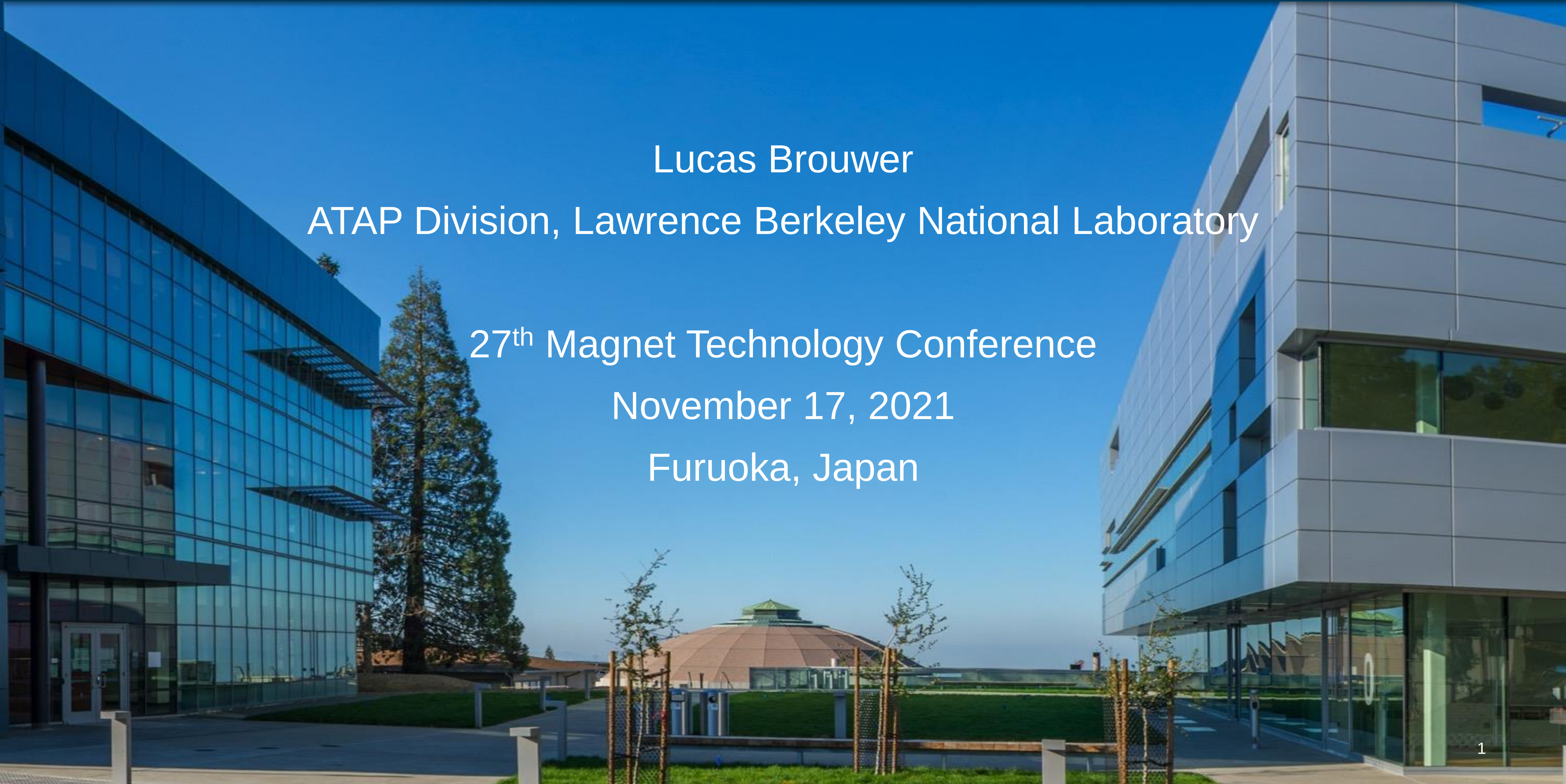
Coupling superconducting magnet technology with large momentum acceptance beamlines to enable lightweight, high performance gantries for ion beam cancer therapy



Lucas Brouwer

ATAP Division, Lawrence Berkeley National Laboratory

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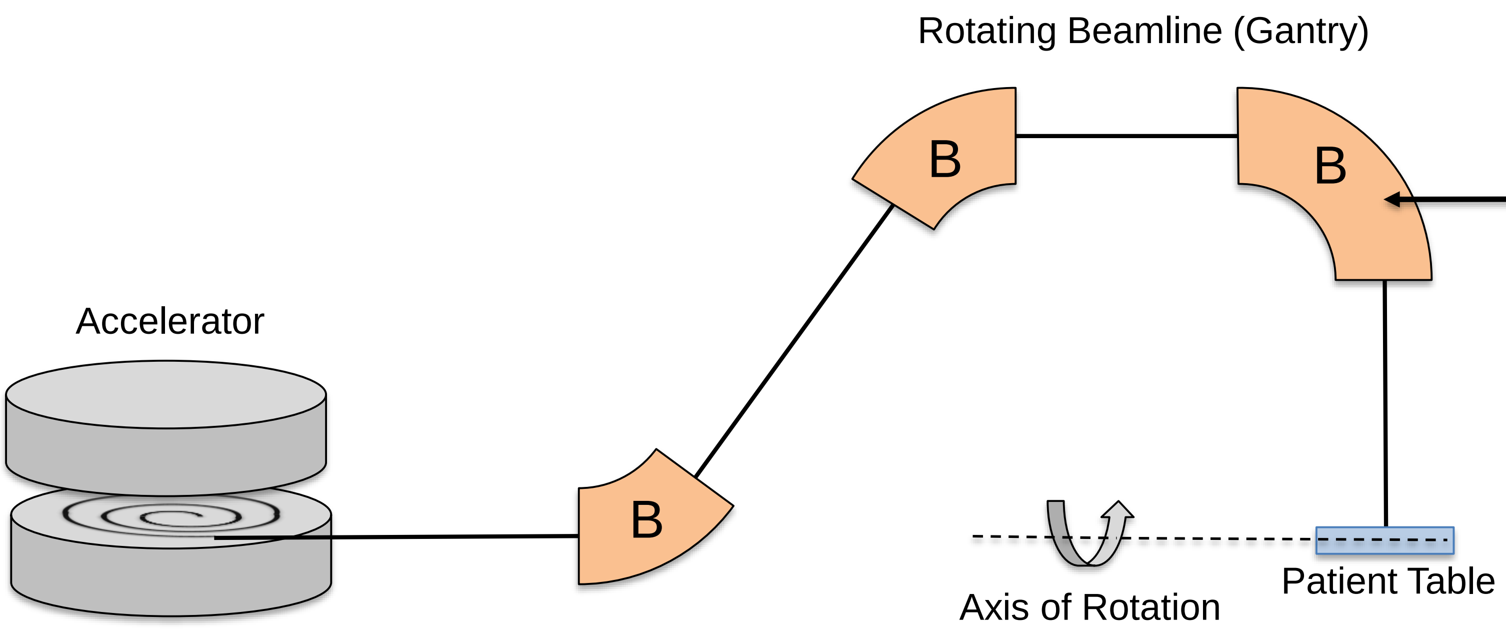
Furuoka, Japan

Rotating Gantries for Ion Beam Cancer Therapy are Large and Heavy, Contributing to High Facility Cost



Proton Gantry-2 at the Paul Scherrer Institute, Switzerland

https://www.psi.ch/en/protontherapy

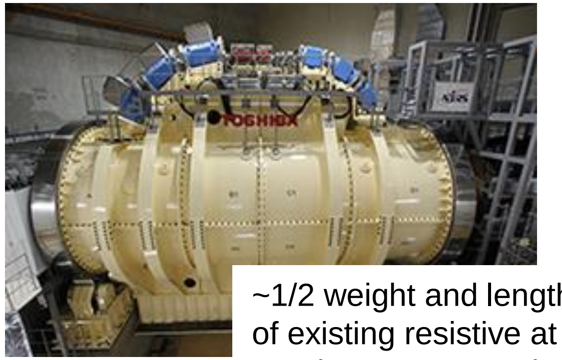
Superconducting Magnets can Reduce the Size and Weight of Gantries

Both carbon and proton gantries with superconducting magnets are now treating patients!

Carbon Scanning Gantry at Heidelberg University Hospital, Germany [1]

~600 tons, ~135 tons magnets

2017: superconducting carbon gantry at NIRS in Chiba, Japan [2]

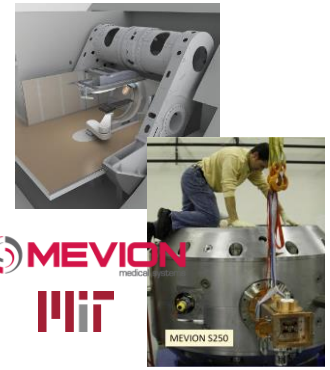


~1/2 weight and length of existing resistive at HIT (300 tons, 13 m)

curved, combined-function Nb-Ti magnets

Initial application in proton therapy

2013: superconducting proton Nb_3Sn accelerator on gantry from US company Mevion [3]



MEVION

MIT

2018: SC360 superconducting proton gantry from US company Pronova [4]

PRONOVA

PROVISION PROTON THERAPY CENTER

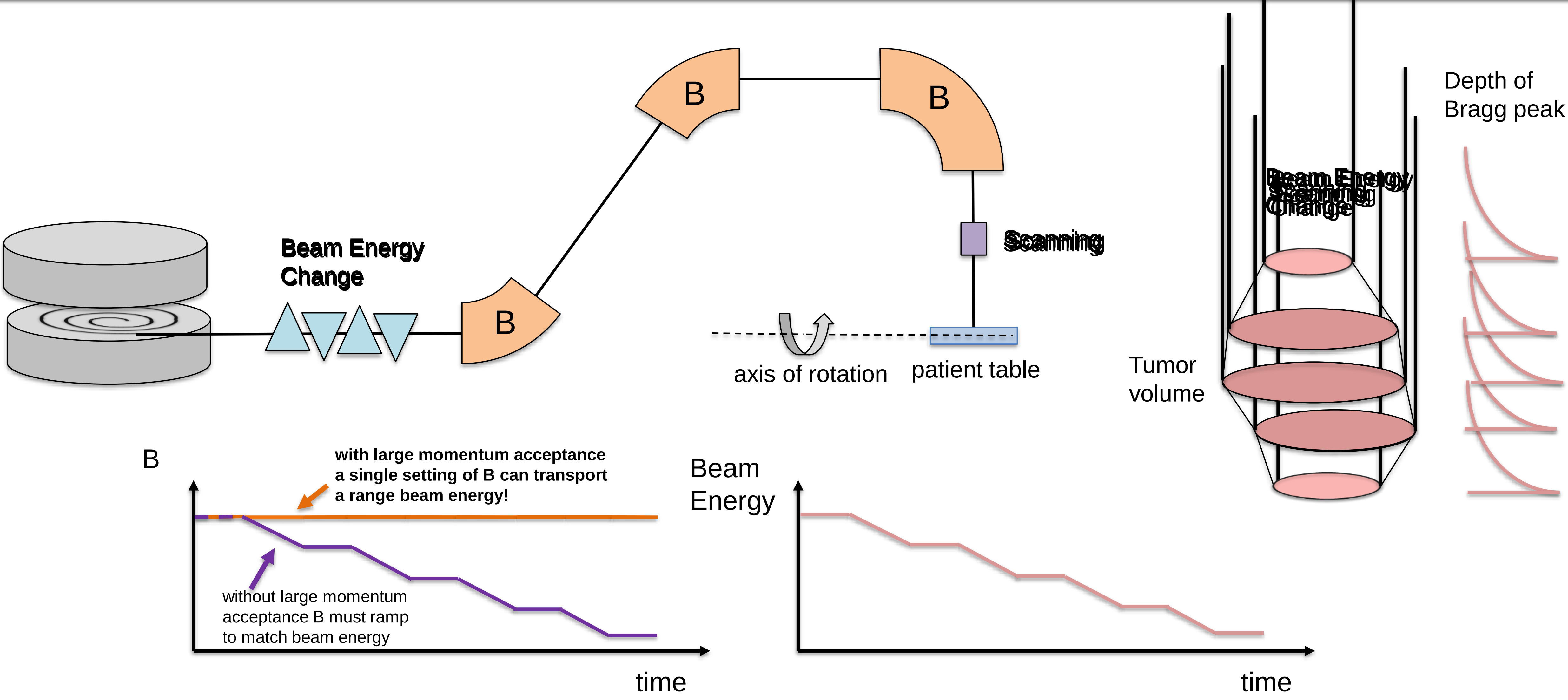
Widespread use requires further commercial adoption

challenged by
- cost
- complexity

conduction cooling
conductor cost
curved magnets
fast magnet ramping

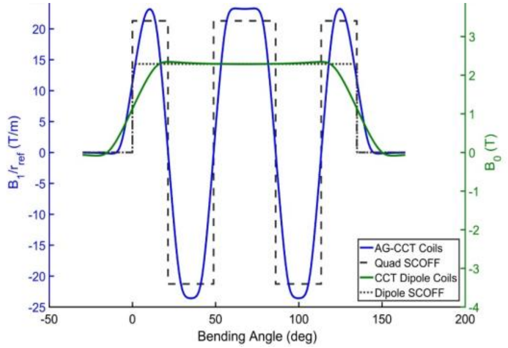
[1] https://www.heidelberg-university-hospital.com/diseases-treatments/cancer-and-tumor-diseases/proton-therapy-and-carbon-ion-therapy
[2] Iwata et al. IEEE TRANS. APPL. SUPERCOND., 28.3, 4400807, 2018
[3] https://www.mevion.com/products/mevion-s250-proton-therapy-system
[4] https://provisionhealthcare.com/about-us/innovative-solutions/proton-therapy-system/

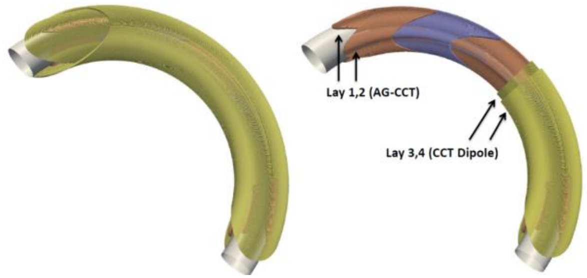
Without large momentum acceptance, fast field ramping is required to match beam energy changes during treatment, complicating the SC magnet and cryogenics ($$$)



Large momentum acceptance is not a new idea for gantries, with many efforts worldwide, here are two concepts from our HEP stewardship collaboration (LBNL+PSI+Varian)

Curved, Nb-Ti, canted-cosine-theta magnet with 20% momentum acceptance

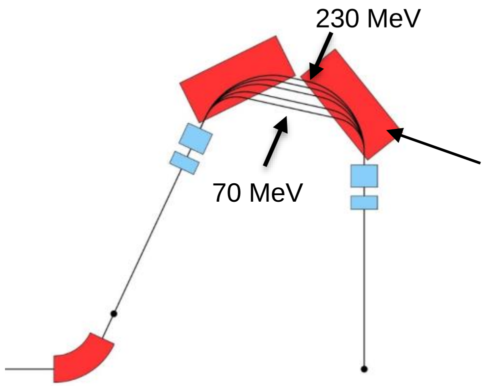




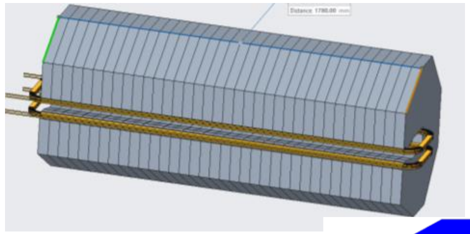
<1 ton coldmass

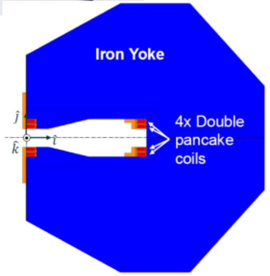
2.5 T prototype of the CCT dipole magnet layers successfully tested in 2019

Straight, Bi-2223 (HTS) racetrack design with full acceptance, achieving fixed-field in the superconducting magnets



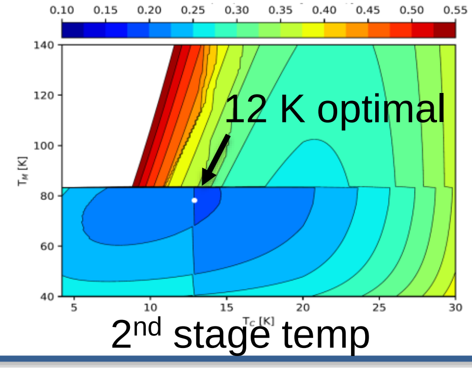
simple, straight, flat racetrack coils embedded in iron yoke allow for implementing HTS at fixed-field operation point [1]





cost of the HTS material (2223) is offset by lifetime savings due to operating efficient conduction-cooled cryogenics near 12 K [2,3]

1st stage temp



Contours = cost of conductor + cryocoolers + 20 yrs electricity

Wan et al, PRSTAB,18, 103501, 2015
Brouwer et al, NIMA, 957, 163414, 2020

[1] Brouwer, Huggins, and Wan, IJMPA,34.36, 1942023, 2019 [2] Godeke et al, SUST, 33.6, 064001, 2020
[3] Teyber et al, SUST, 33.10, 105005, 2020

Summary

Momentum acceptance allows for implementing lightweight superconducting magnets without fast field ramping

Enables HTS and other novel designs → Enables cost-effective, stable cryogenics which balance the cost of HTS

Challenge, can we as magnet engineers demonstrate this!