AF7-Magnets
Summary Report overview

Community Summer Study – Seattle, July 19, 2022

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(Snowmass'21 AF7-Magnets Conveners*)*

Working group goals and process

- The AF7-Magnets working group goals:
  - address the potential contributions of magnet technology to future HEP facilities
  - evaluate the R&D required to enable these opportunities
  - estimate the time and cost scales of these efforts
  - assess the needs for associated fabrication infrastructure and test facilities
- Following a series of meetings to introduce the program goals and process, the LoI were solicited.
- By October 2020, 50 LoI have been submitted.
- A pause from January until fall 2021.
- In fall 2021, a call for WPs on technical progress and opportunities in specific areas, as well as recommended plans and priorities for the next decade.
- In March 2022, 21 WPs have been received (one WP still need to be submitted to arXiv) providing good foundation for the Summary report.

Introduction

- This report addresses the working group goals, summarizes the status of accelerator and detector magnet technologies, and discuss ideas and plans to push this key area of the US and international HEP to new horizons.

WP	pages	refs
MWP1	42	84
MWP2	19	41
MWP3	8	15
MWP4	4	1
MWP5	9	9
MWP6	6	15
MWP7	16	34
MWP8	23	103
MWP9	16	21
MWP10	10	13
MWP11	22	59
MWP12	10	18
MWP13	18	38
MWP14	10	16
MWP15	7	23
MWP16	4	25
MWP17	13	56
MWP18	7	27
MWP19	35	67
MWP20	9	14
MWP21	62	292
	350	46

350p=>33p

Contents

33p=>3p ES

2 HEP accelerator magnet programs overview

2.1 United States

- 2.1.1 HL-LHC Accelerator Upgrade Project
- 2.1.2 US Magnet Development Program - [MWP1]
- 2.1.3 Directed R&D - [MWP2]

2.2 Europe [MWP4]

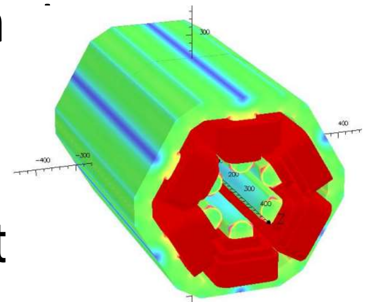
2.3 Japan [MWP6]

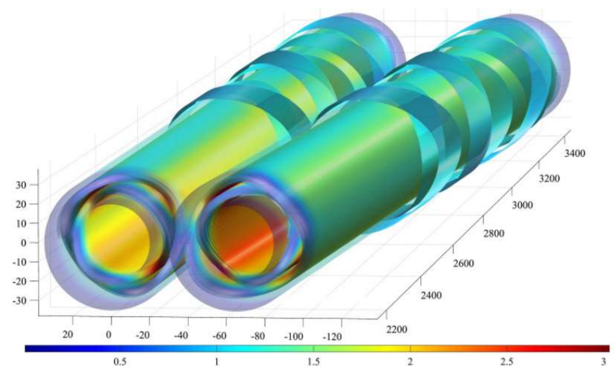
2.4 China

3 HEP Accelerator Magnets Status and Future (1)

3.1 Electron Collider Magnets

3.1.1 FCC-ee magn

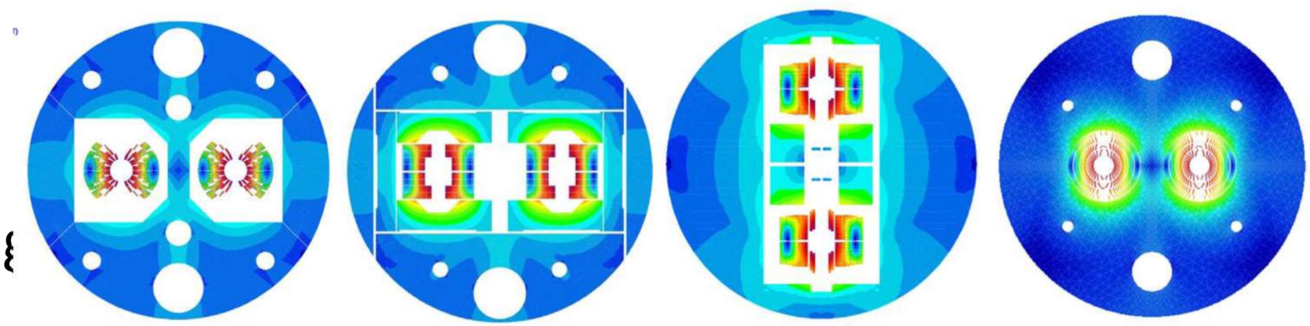




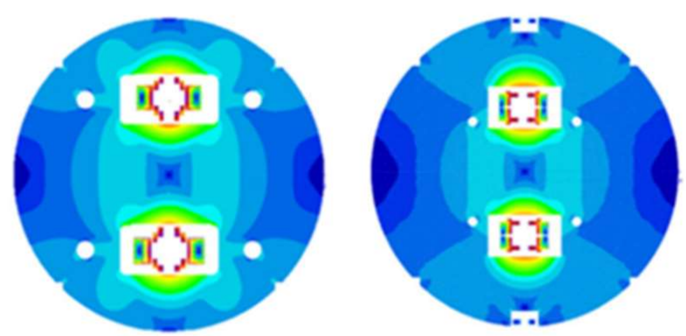
3.1.2 CEPC magnet

3.2 High-Field Proton Collider Magnets

3.2.1 FCC-hh ma



3.2.2 SPPC magnets



3 HEP Accelerator Magnets Status and Future (2)

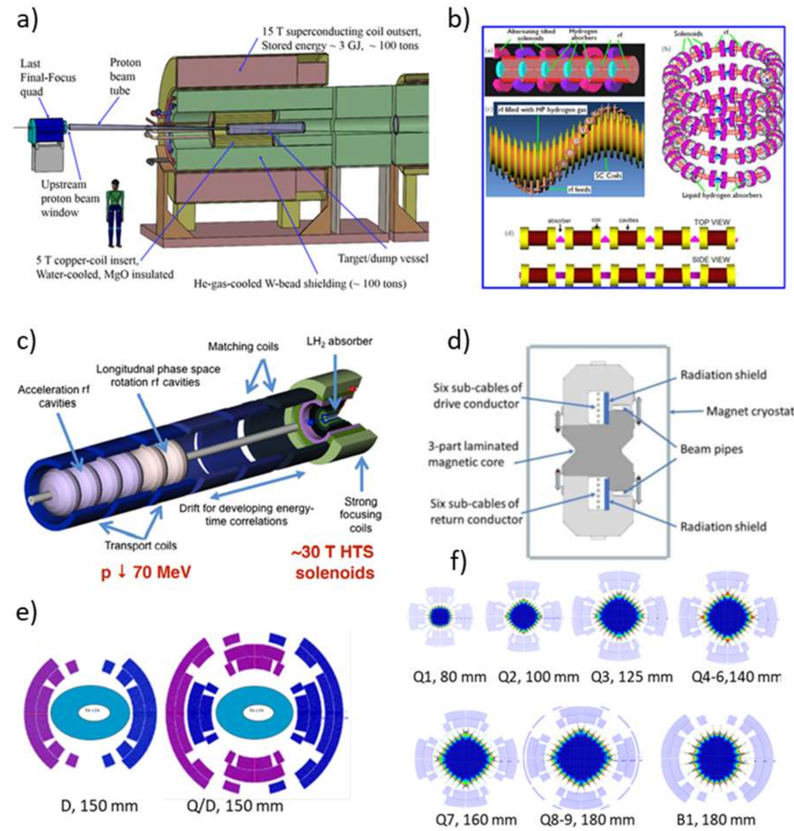
Snowmass 2021

3.3 Muon Collider Magnets (4 WPs)

- Muon Collider (MC) magnet needs and challenges are discussed in [MWP5].

3.3.1 Muon collider magnet system
3.3.2 Muon production
3.3.3 Muon cooling
3.3.4 Acceleration

- A practical opportunity to build fast-cycling dipole magnets using second generation HTS is discussed in [MWP20]



3.3.5 Collision

- The results of 3 TeV c.o.m. MC studies and a design concept of the 6 TeV c.o.m. MC optics, the SC magnets, and a preliminary analysis of the protection system to reduce radiation loads on the magnets and particle backgrounds in the MC detector are discussed in [MWP9].
- A low-energy medium-luminosity MC as a possible Higgs Factory (HF) has been also studied and is discussed in [MWP10].

4 Detector Magnets Progress and Requirements

- The detector solenoids design study is in progress for future big projects in Japan and Europe - ILC, FCC and CLIC [MWP19].
- The proposed design parameters for each solenoid are summarized in Table 4.1.

Project	Magnet	B_c (T)	R_{in} (m)	Length (m)	E/M (kJ/kg)	Stored Energy (GJ)
FCC-ee	IDEA	2	2.24	5.8	14	0.17
	CLD	2	4.02	7.2	12	0.6
FCC-hh		4	5	20	11.9	13.8
CLIC		4	3.65	7.8	13	2.3
ILC	ILD	4	3.6	7.35	13	2.3
	SID	5	2.5	5	12	1.4

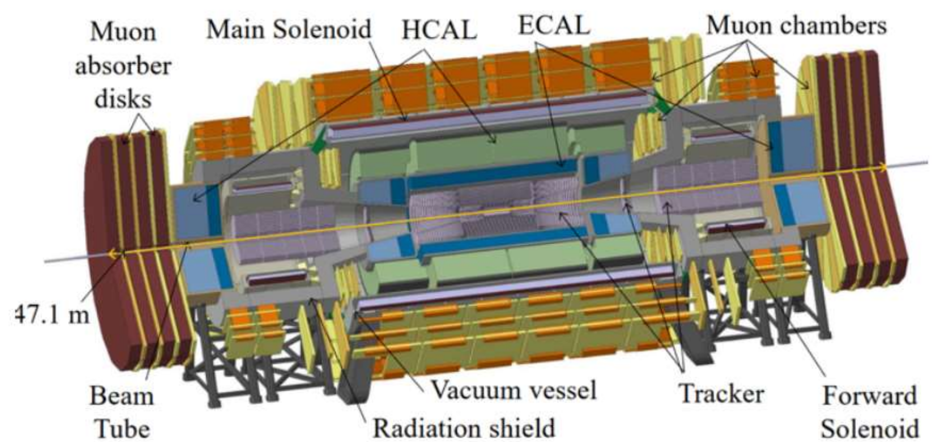
Details in

4.1 FCC-ee

4.2 FCC-hh

4.3 CLIC

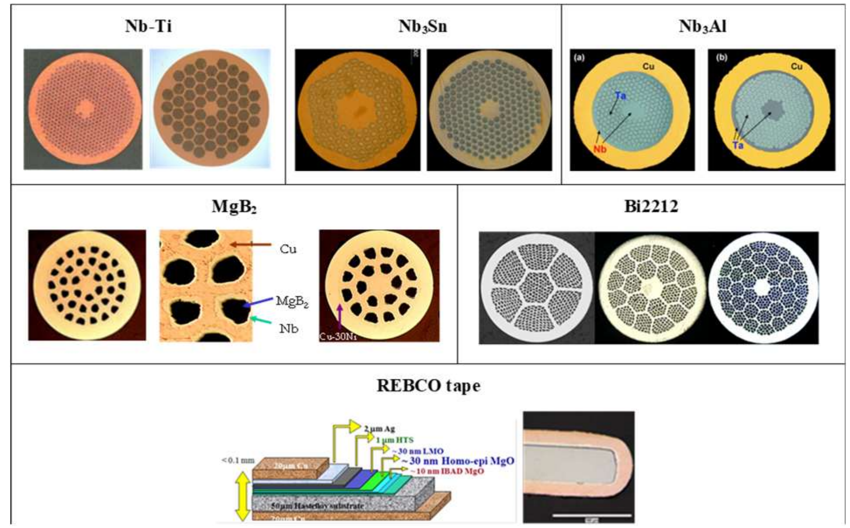
4.4 ILC-ILD and ILC-SID



5 Magnet technology R&D for HEP (1)

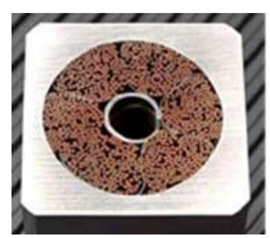
- 5.1Superconducting composites (WP tbs)

SC material	T_c, K	B_{c2} @4.2K, T	Mech. Prop.	Billet or batch mass, kg	Annual production scale, Tons	Relat. Cost	Final cost /material cost
Nb-Ti	9.2	11	ductile	200-400	>100	1	3
Nb_3Sn	18	26	brittle	45	1–10/1*	5/8*	5-7
Nb_3Al	18	26	brittle	45	1	8	?
MgB_2	39	20	brittle	20	< 1	2	?
Bi2212	85	100	brittle	20	< 1	20–50	~10
REBCO	92	>120	brittle	10	< 1#	20–50	>>10



  – A practical plan to make the IBS into a much cheaper, higher stability, round, twisted and effectively isotropic multifilament conductor for 16-20 T magnets is discussed in [MWP7]

- 5.2High-Current Cables



5 Magnet technology R&D for HEP (2)

5.3 Magnet Development and Test Technologies

5.3.1 Approaches and Status of high-field Nb3Sn accelerator magnet R&D

5.3.2 The 12-14 T operation field range for large scale deployment

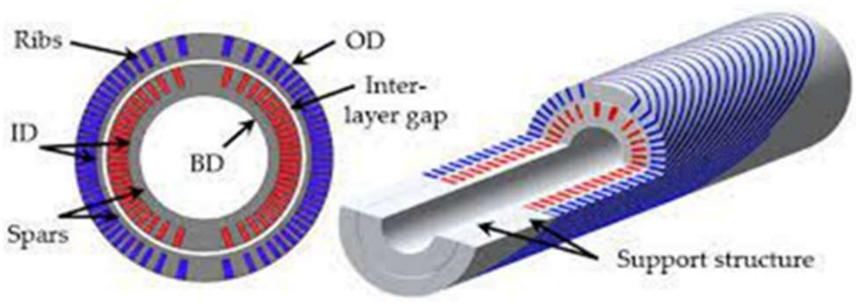
- The R&D will explore designs and technologies to identify design options for the field level targeted. In Europe, the program includes the construction and test of short and long model magnets [MWP4].
- [MWP3] discusses the development and demonstration of new technologies for next generation of Nb3Sn accelerator magnets with operation fields of 12-14 T. The main goal is to reduce magnet cold-mass cost at least by a factor 2 with respect to the present Nb3Sn magnets produced in the US by AUP for the HL-LHC upgrade.
- This program is proposed as self-standing program, or it may be part of the Leading-Edge technology And Feasibility-directed (LEAF) Program [MWP2] aimed at the demonstration of magnet technology readiness for Energy Frontier Circular Colliders (hadron, muon) by the next decade.

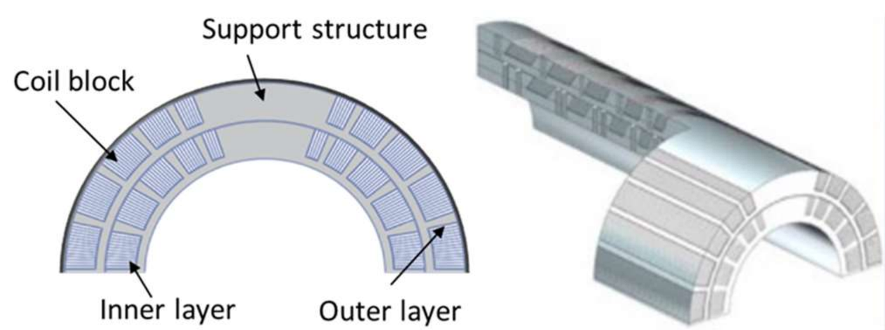
5 Magnet technology R&D for HEP (3)

5.3.3 Accelerator magnets in the 14-16 T operation field range

5.3.3.1 Coil stress management

- To reduce conductor stress, the US MDP program [MWP1] is focused on stress-management approaches introduce internal structures and additional interfaces when compared to more traditional magnet designs.

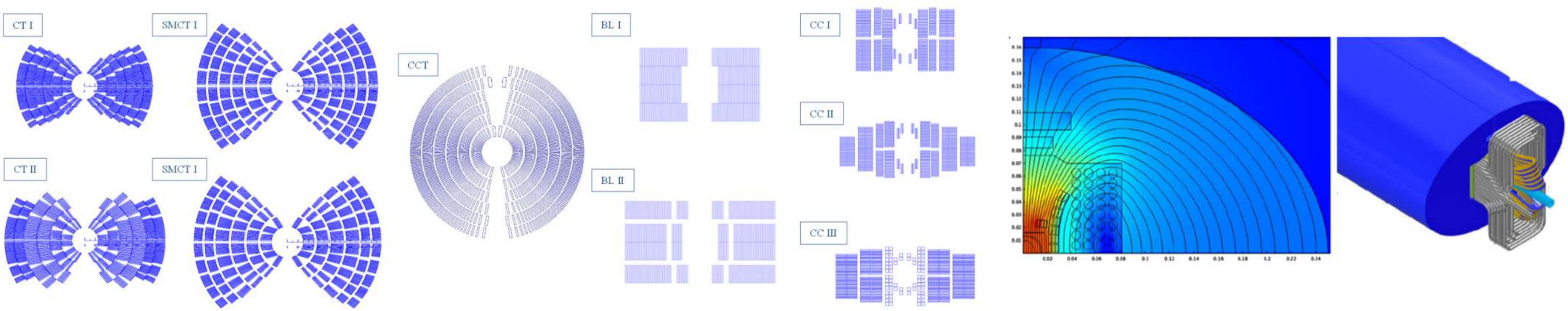




5 Magnet technology R&D for HEP (4)

5.3.4 Considerations for accelerator magnets beyond 20 T

- A 20 T hybrid magnet with a 50 mm bore by MDP ([MWP1] and [MWP12]), considering different layouts
- A tape-stack REBCO cable winding is presented and discussed in [MWP14]



- Bi2212 model magnet R&D program is discussed in [MWP13]
- REBCO model magnet R&D plan is discussed in [MWP11]

5 Magnet technology R&D for HEP (5)

- 5.3.5 Diagnostics and testing techniques, technology, advanced modeling
  - The main diagnostics and testing technique development plans are discussed in, [MWP15]-[MWP18].

- 5.3.6 Magnet Fabrication and Test infrastructures
  - In progress

- 5.4 Technologies for Detector Magnets
  - The development of technologies for detector magnets is discussed in [MWP19]
  - The main development item for future detector solenoids is Al-stabilized superconducting cable with both higher strength and high RRR
  - Future detector magnets will also take advantage of technologies such as coil winding inside the outer shell; indirect cooling to reduce materials used in magnet structure; pure aluminum strips as temperature equalizer in the steady operation and fast quench propagation; lightweight and high-transparency vacuum vessels.

Report Summary

- Superconducting accelerator magnets are the key enabling technology for present and future HEP particle accelerators
- All the present accelerators for decades use Nb-Ti magnets
  - practical field limit of this technology in accelerator magnets is 8-9 T
  - this technology continues to be the baseline for large detector magnets
- A new generation of accelerator magnets based on Nb_3Sn superconductor has shown in the last 2 decades a good progress in the USA, EU and Asia
  - maximum operation fields up to 15-16 T
  - within next 5 years, 11-12 T Nb_3Sn magnets will be implemented in HL-LHC
  - on the longer term, Nb_3Sn D and Q magnets with nominal operation fields up to 16 T are planned for FCC-hh and 3 TeV MC
  - several key technological issues need to be resolved
- More ambitious R&D towards 20+ T magnets, considered for SPPC and HE MC and based on HTS/LTS coils has also started recently
  - HTS materials promise higher fields and improved energy efficiency
  - much work needed to realize the HTS potential, starting from basic conductor characteristics through cable and magnet design, technology and quench protection, including their mass production and cost optimization

Next steps

- Report is open for discussion
- Send your comments/edits to conveners or put them in the excel spread sheet here https://docs.google.com/spreadsheets/d/1U8eNPECu4tRmTF97j4VMhyFiJTkW_7IJ/edit#gid=840849953

Acknowledgment

Thanks to all the colleagues who submitted WPs and to all of you for your participation in the discussion.