International
MUON Collider
Collaboration

Muon Collider Magnets

Introduction to Parallel Session

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Muon Collider Collaboration Meeting
CERN, 11-14 October 2022

Rationale

- What should be the (magnet) work of the coming four years, i.e. till the preliminary CDR ?
  - Define a coherent "**machine configuration**", starting from US-MAP and progressing beyond, based on advances on magnet technology (e.g. HL-LHC, HTS) as well as understanding of beam physics (e.g. 10 TeV)
  - Find the envelope of "**representative challenges**", the magnets that point to the main issues, and can provide focus for the specific R&D required to demonstrate feasibility. Address these main challenges through practical magnet design work

Machine configuration

Complex	Sector	Baseline	Magnet Type	Magnet technology	Field (T)	Gradient (T/m)	Aperture (mm)	Gap (mm)	Width (mm)	Length (m)	Number (-)	Ramp time (s)	Field rate (T/s) / (T/m/s)	Homogeneity (units)	Persistance (units/s)	Beam power deposition (kW/m)	Comments
Target and Capture	Target	baseline	solenoid	LTS	15		2400			2	1	21600	0.0007	100		1	baseline 15 T, 2.4 m bore design, assumes 6 hours ramp-up time and 5 kW deposited total power
		baseline	solenoid	NC	5		150			0.5	1	1	5.0000	100		100	baseline 5 T resistive insert
		option	solenoid	HTS	20		600			1.5	1	21600	0.0009	100		5	option based on a HTS cable, reduced bore and shielding, operating at 10…20 K
	Capture and decay channel		solenoid	TBD													
Cooling	Ionization Cooling	baseline	solenoid	TBD	2.2		600			2	66	21600	0.0001	100			cell A1
		baseline	solenoid	TBD	3.4		500			1.32	130	21600	0.0002	100			cell A2
		baseline	solenoid	TBD	4.8		380			1	107	21600	0.0002	100			cell A3
		baseline	solenoid	TBD	6		264			0.8	88	21600	0.0003	100			cell A4
		baseline	solenoid	TBD	2.2		560			2.75	20	21600	0.0001	100			call B1
		baseline	solenoid	TBD	3.4		480			2	32	21600	0.0002	100			call B2
		baseline	solenoid	TBD	4.8		360			1.5	54	21600	0.0002	100			call B3
		baseline	solenoid	TBD	6		280			1.27	50	21600	0.0003	100			call B4
		baseline	solenoid	TBD	9.8		180			0.806	91	21600	0.0005	100			call B5
		baseline	solenoid	TBD	10.5		144			0.806	77	21600	0.0005	100			call B6
		baseline	solenoid	TBD	12.5		98			0.806	50	21600	0.0006	100			call B7
		baseline	solenoid	TBD	13.6		90			0.806	61	21600	0.0006	100			call B8
	Final Cooling	baseline	solenoid	HTS	30		50			0.5	17	21600	0.0014			0	baseline design from US-MAP
		minimal option	solenoid	HTS	40		60			0.5	17	21600	0.0019	100		0	HTS NI option, including aperture margin
		target option	solenoid	HTS	60		60			0.5	17	21600	0.0028	100		0	HTS NI option, including aperture margin
Accelerator	RCS1		dipole	NC	1.8			30	100	8.08	432	7.35E-04	2448.980	10			
	RCS2		dipole	LTS	10		100			2.4	288	1000	0.010	10			
			dipole	NC	1.8			30	100	6.06	432	1.80E-03	1000.000	10			
	RCS3		dipole	LTS	10		100			2.6	288	1000	0.010	10			
			dipole	NC	1.8			30	100	5.05	432	1.80E-03	1000.000	10			
	RCS4		dipole	LTS	10		100			2.6	288	1000	0.010	10			
			dipole	NC	1.8			30	100	5.05	432	8.46E-03	212.716	10			
Collider	Arc		dipole	HTS	10	300	150					1000	0.010	10		0.5	
	IR		quadrupole	HTS		466.32	171.4			2	4	1000	0.000	10			IQF1
			quadrupole	HTS		376.93	212.2			2	4	1000	0.000	10			IQF1a
			quadrupole	HTS		300.71	266			2	4	1000	0.000	10			IQF1b
			quadrupole	HTS		191.41	417			13.6	4	1000	0.000	10			IQD1
			quadrupole	HTS		214.03	411.2			5	4	1000	0.000	10			IQF2

A first attempt, by no means complete, nor fully correct…

Proposal - **Configuration Meetings**

- Dedicate some of the mmWG slots (or other ?) to discussion of the “magnet specs”
- Proposed participants (initial, by specialty)
  - Solenoids: magnets, beam physics, target, radiation and loss, vacuum, cryogenics
  - Accelerators: converters and magnets, beam physics, RF
  - Collider: magnets, beam physics, radiation and loss, vacuum, cryogenics

Representative challenges

- Target solenoid and capture channel
  - Large solenoid producing high field and submitted to high radiation load, target and shield integration
- *6D cooling solenoids*
- Final cooling solenoid
  - Ultra-high-field solenoid, absorber integration, taking bore field to the extreme
- Fast ramped synchrotron dipole
  - Management of field ramp, combining very high power and precision, in a magnet with minimal stored energy and suitable field quality
- Collider arc dipoles and IR quadrupoles
  - Large aperture, high field accelerator magnets, hosting muon decay shield, submitted to high radiation heat load and dose

Target solenoid and capture channel

Aim at **smaller SC bore** than US-MAP (factor 2) and running at 10...20 K to **reduce helium and consumption** (factor 2)

- Tentative specs
  - On-axis peak field: 20 T (same as US-MAP)
  - Bore(1): 1.2 m diameter (reduction by factor 2 w/r to US-MAP)
  - Magnetic length at peak field: 0.5 m (tentative)
  - Homogeneity: 1% (tentative)
  - HTS conductor technology, two options:
    - Large CICC cable ($J_E \approx 50$ A/mm^2) (e.g. EU-DEMO conductors)
    - NI stacks in supporting structure ($J_E \approx 500$ A/mm^2) (e.g. MIT/CFS R&D)
  - Operating temperature range(1): 10…20 K (gain factor 2…5 on COP)
- On-axis field along capture channel(2)

$$\frac{B_i B_f L_t^3}{B_i z^2 (3L_t - 2z) + B_f (L_t - z)^2 (2z + L_t)}$$

(1) Target and shield integration will modify the bore and operating temperature

(2) Hisham Kamal Sayed, J. Scott Berg, “Optimized capture section for a muon accelerator front end”, PRSTAB 17, 070102 (2014)

Final cooling solenoid

Aim at **higher field** (up to factor 2), and **compact winding** (500 A/mm^2)

- Tentative specs
  - On-axis peak field: 40 T minimum, 60 T target (study will determine maximum that can be achieved)
  - Bore(1): 60 mm diameter
  - Magnetic length at peak field: 0.5 m (tentative)
  - Homogeneity: 1 % (tentative)
  - HTS NI (and variants) conductor technology to achieve $J_E \approx 500$ A/mm^2 (compact windings are necessary to maintain forces and cost low(2))
  - Operating temperature range(1): 10…20 K (gain factor 2…5 on COP)

(1) Absorber integration may modify bore and operating temperature

(2) The solenoids of the 6D cooling cells will require compact windings for cost optimization reasons. Work on HTS NI will also profit these magnets

Fast Ramped Synchrotron Dipole

Fastest ramped dipole, **minimum stored energy** (TBD) per unit length and **minimum ramp losses** (TBD)

- Tentative specs
  - On-axis peak field: 1.8 T
  - Bore: 30 x 100 mm (gap x width)
  - Ramp-rate: 2500 T/s (linear)
  - Magnetic length: 8.1 m (tentative)
  - Homogeneity: 10 units (tentative)

Collider Arc Dipole

Combined function arc dipole, **field/aperture** (TBD), **dose tolerance** (TBD) and minimum **energy consumption** (TBD)

- Tentative specs
  - On-axis peak field(1): 10 T (TBD)
  - On-axis peak gradient(1): 300 T/m (TBD)
  - Bore(2): 150 mm (TBD)
  - Magnetic length: 15 m (tentative)
  - Homogeneity: 10 units (tentative)
  - LTS or HTS conductor technology(3)
  - Operating temperature range(2): 1.9/4.2 K (LTS) or 10 to 20 K (HTS)

This combination is not feasible

(1) Field and gradient are evolving with optics

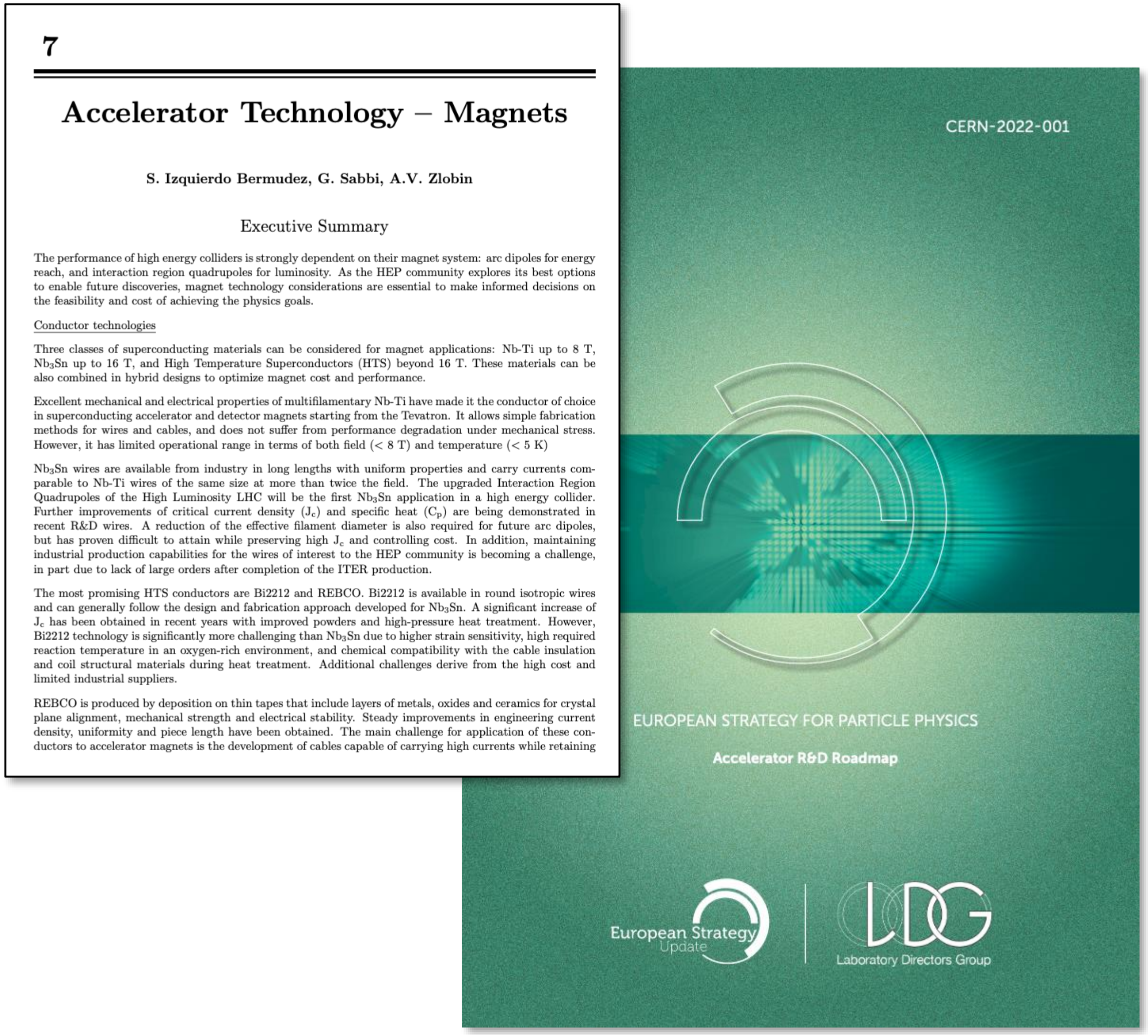
(2) Muon decay shield integration may modify bore and operating temperature

(3) Some of the technology choices are limited by the values of peak field and temperature

Important

- The point of the study is to produce a **credible and affordable** accelerator complex design (contain cost, energy efficient, sustainable operation)
- **Technology is a mean** not the end

Do not forget !



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Accelerator Technology – Magnets

S. Izquierdo Bermudez, G. Sabbi, A.V. Zlobin

Executive Summary

The performance of high energy colliders is strongly dependent on their magnet system: arc dipoles for energy reach, and interaction region quadrupoles for luminosity. As the HEP community explores its best options to enable future discoveries, magnet technology considerations are essential to make informed decisions on the feasibility and cost of achieving the physics goals.

Conductor technologies

Three classes of superconducting materials can be considered for magnet applications: Nb-Ti up to 8 T, Nb$_3$Sn up to 16 T, and High Temperature Superconductors (HTS) beyond 16 T. These materials can be also combined in hybrid designs to optimize magnet cost and performance.

Excellent mechanical and electrical properties of multifilamentary Nb-Ti have made it the conductor of choice in superconducting accelerator and detector magnets starting from the Tevatron. It allows simple fabrication methods for wires and cables, and does not suffer from performance degradation under mechanical stress. However, it has limited operational range in terms of both field (< 8 T) and temperature (< 5 K)

Nb$_3$Sn wires are available from industry in long lengths with uniform properties and carry currents comparable to Nb-Ti wires of the same size at more than twice the field. The upgraded Interaction Region Quadrupoles of the High Luminosity LHC will be the first Nb$_3$Sn application in a high energy collider. Further improvements of critical current density (J_c) and specific heat (C_p) are being demonstrated in recent R&D wires. A reduction of the effective filament diameter is also required for future arc dipoles, but has proven difficult to attain while preserving high J_c and controlling cost. In addition, maintaining industrial production capabilities for the wires of interest to the HEP community is becoming a challenge, in part due to lack of large orders after completion of the ITER production.

The most promising HTS conductors are Bi2212 and REBCO. Bi2212 is available in round isotropic wires and can generally follow the design and fabrication approach developed for Nb$_3$Sn. A significant increase of J_c has been obtained in recent years with improved powders and high-pressure heat treatment. However, Bi2212 technology is significantly more challenging than Nb$_3$Sn due to higher strain sensitivity, high required reaction temperature in an oxygen-rich environment, and chemical compatibility with the cable insulation and coil structural materials during heat treatment. Additional challenges derive from the high cost and limited industrial suppliers.

REBCO is produced by deposition on thin tapes that include layers of metals, oxides and ceramics for crystal plane alignment, mechanical strength and electrical stability. Steady improvements in engineering current density, uniformity and piece length have been obtained. The main challenge for application of these conductors to accelerator magnets is the development of cables capable of carrying high currents while retaining

CERN-2022-001

EUROPEAN STRATEGY FOR PARTICLE PHYSICS

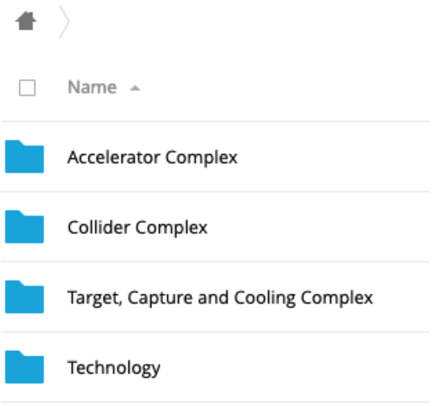
Accelerator R&D Roadmap

European Strategy Update

LDG Laboratory Directors Group

Many of our questions were asked and discussed already during the formation of the EU and US R&D plan

CERNbox repository of references and material



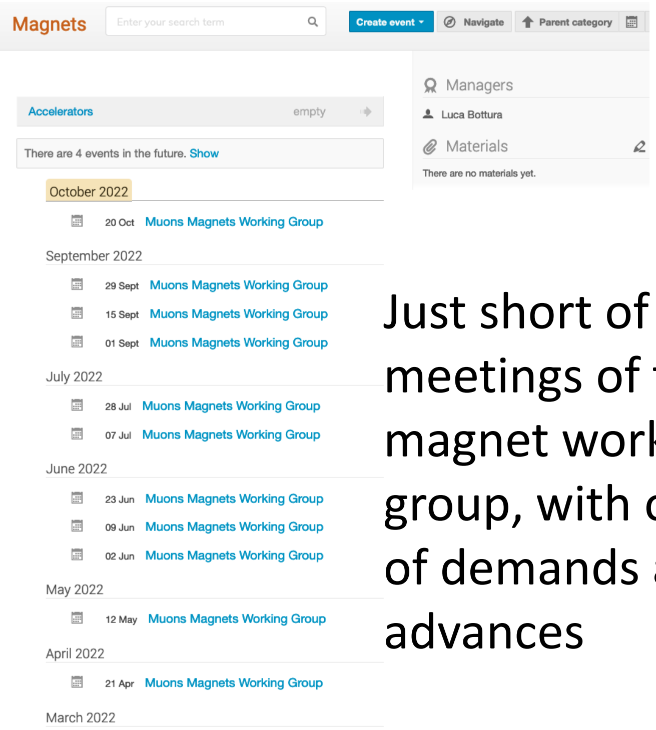
Accelerator Complex

Collider Complex

Target, Capture and Cooling Complex

Technology

https://cernbox.cern.ch/index.php/s/E7D5NDmIcelrkIe



Accelerators empty

There are 4 events in the future. Show

Managers

Luca Bottura

Materials

There are no materials yet.

October 2022

20 Oct Muons Magnets Working Group

September 2022

29 Sept Muons Magnets Working Group

15 Sept Muons Magnets Working Group

01 Sept Muons Magnets Working Group

July 2022

28 Jul Muons Magnets Working Group

07 Jul Muons Magnets Working Group

June 2022

23 Jun Muons Magnets Working Group

09 Jun Muons Magnets Working Group

02 Jun Muons Magnets Working Group

May 2022

12 May Muons Magnets Working Group

April 2022

21 Apr Muons Magnets Working Group

March 2022

Just short of 20 meetings of the magnet working group, with overview of demands and advances

https://indico.cern.ch/category/13958/