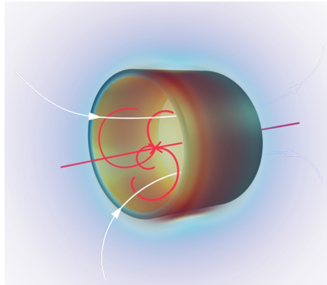
Updated, 2022-9-22



Summary and Discussions

Superconducting Detector Magnet Workshop for Future Colliders & Physics Experiments

Co-chairs : *Matthias Mentink (CERN) and Toru Ogitsu (KEK)*

Local Organizing Committee: *Nikkie Deelen and Connie Potter (CERN)*

Program Committee: *Benoit Cure (CERN), Lionel Quettier (CEA), Renuka Rajput-Ghoshal (JLab), Vadim Kashikhin (Fermilab), Ken-ichi Sasaki (KEK), Yasuhiro Makida (KEK), and Akira Yamamoto (Chair, KEK/CERN)*

Summarized and discussed, on 14 Sept. 2022

https://indico.cern.ch/e/sdmw

Executive Summary (1/3)

- **Superconducting Detector Magnet Workshop o**rganized by CERN and KEK, hosted at CERN
  - in hybrid format, with 90 participants (57 on-site, 33 online) from 36 institutes and companies,
  - opening with the welcome address given by Prof. J. Mnich, CERN's Director of Research and Computing.
- **Aiming at :** :
  - **Addressing the issue of** commercial availability of Al-stabilized superconductor technology for future superconducting detector magnets,
  - **Informing the community** of on-going and future projects, to exchange ideas, concepts, best practices, and to advance superconducting detector magnet technology, and fostering collaboration,
  - **Bringing together the physics community, the magnet designers and the industry** to exchange about the future needs and efforts to be achieved in research and development to build the next magnet generations of the Future Colliders and Beyond Collider Physics Experiments developed by collaborative Institutes.
  - **Understanding the industrial capacities and their availabilities,** with the foreseen prospects and plans, with presentations made by representatives of industry working on all aspects of superconducting detector magnet were invited.

Executive Summary (2/2)

Agenda:

- **Report from Projects:** EIC, ALICE-3, ILC-ILD, -SID, CLIC, FCC-ee, FCC-hh for colliders, and BabyIAXO, MadMax, Mu2e, Comet, AMS100 for beyond collider physics
- **Reports from Industry:** Furukawa E., Toly E., Techmeta, Hitachi, Toshiba, Mitsubishi E., Bilfinger-Noel., ASG, Sigma-Phi,
- **Discussions:** Advanced SC for detector magnets, Al-stabilized SC w/ EBW/Soldering, CICC, HTS?

Outlook:

- Al-stabilized superconductor/magnet technology needs to be resumed,
- Industrial cooperation anticipated and strongly encouraged, in particular,
  - "Co-extrusion technology" of Al-stabilizer and NbTi/Cu-conductor to be resumed and widely available, and
  - "Hybrid-structure technology" by using electron beam welding (EBW) or by other approaches, to maximize the performance of Al-stabilized SC (Ni or Cu/Mg doped) combined with ultimately high-strength Al-alloy structure.
- Laboratory's leading effort will be very important to advance the technology to be openly transferred to the industry.

Remarks:

- It will be important to investigate/seek for backup solutions such as soldering technology of NbTi/Cu conductor with Cu stabilizer, Cu-coated Al-stabilizer, and/or CICC. In long-term future,
- Al-stab. HTS stabilized will provide important potential in specific detector magnet applications.
- The next workshop will be planned to be held in 1 ~ 2 years, based on the R&D advances expected.

Some Background for the Workshop:
SnowMass White Paper Submission

arXiv > physics > arXiv:2203.07799

Search...

Help | Advanced S

Physics > Instrumentation and Detectors

[Submitted on 15 Mar 2022]

Superconducting detector magnets for high energy physics

Matthias Mentink, Ken-ichi Sasaki, Benoit Cure, Nikkie Deelen, Alexey Dudarev, Mitsushi Abe, Masami Iio, Yasuhiro Makida, Takahiro Okamura, Toru Ogitsu, Naoyuki Sumi, Akira Yamamoto, Makoto Yoshida, Hiromi Iinuma

Various superconducting detector solenoids for particle physics have been developed in the world. The key technology is the aluminum-stabilized superconducting conductor for almost all the detector magnets in particle physics experiments. With the progress of the conductor, the coil fabrication technology has progressed as well, such as the inner coil winding technique, indirect cooling, transparent vacuum vessel, quench protection scheme using pure aluminum strips and so on. The detector solenoids design study is in progress for future big projects in Japan and Europe, that is, ILC, FCC and CLIC, based on the technologies established over many years. The combination of good mechanical properties and keeping a high RRR is a key point for the development of Al-stabilized conductor. The present concern for the detector solenoid development is to have been gradually losing the key technologies and experiences, because large-scale detector magnets with Al-stabilized conductor has not been fabricated after the success of CMS and ATLAS-CS in LHC. Complementary efforts are needed to resume an equivalent level of expertise, to extend the effort on research and to develop these technologies and apply them to future detector magnet projects. Especially, further effort is necessary for the industrial technology of Al-stabilized superconductor production. The worldwide collaboration with relevant institutes and industries will be critically important to re-realize and validate the required performances. Some detector solenoids for mid-scale experiment wound with conventional copper-stabilized Nb-Ti conductor require precise control of magnetic field distribution. The development efforts are on-going in terms of the magnetic field design technology with high precision simulation, coil fabrication technology and control method of magnetic field distribution.

Comments: 35 pages, 35 figures, 8 tables, contribution to Snowmass 2021
Subjects: Instrumentation and Detectors (physics.ins-det); Accelerator Physics (physics.acc-ph)
Cite as: arXiv:2203.07799 [physics.ins-det]
(or arXiv:2203.07799v1 [physics.ins-det] for this version)

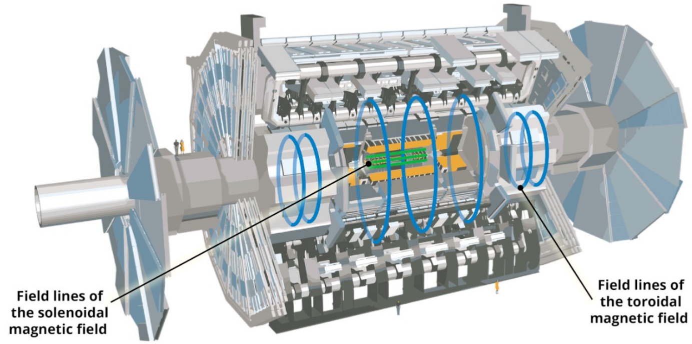
Historical experiences of the ATLAS and CMS magnet projects

Very large superconducting detector magnet projects!

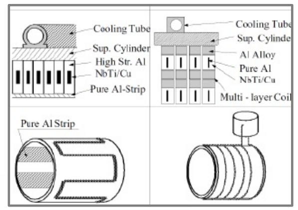
- Time-scale for engineering design and validation effort, the construction, and the commissioning: More than 15 years each
- Production of components (conductor, coils, support structure, etc) in industry, and subsequent assembly at CERN
- Designed, constructed, commissioned, and maintained with strong support from multiple institutes:
    - ATLAS: CEA-Irfu, KEK, INFN-LASA, RAL, NIKHEF, JINR-Dubna, IHEP-Protvino, ITAM Novosibirsk, CERN
    - CMS: CEA-Irfu, ETH Zurich, INFN Genoa, University of Wisconsin, Fermilab, ITEP Moscow, CERN

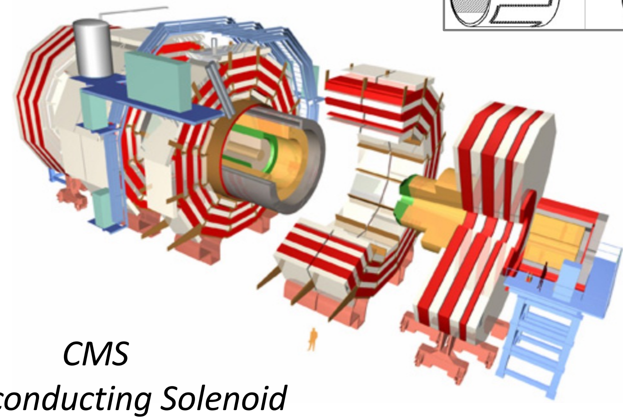
Important lessons:

- For large superconducting detector magnets a long-term strategy is needed
- **The historical importance of collaboration is evident**



ATLAS
Superconducting magnets





CMS
Superconducting Solenoid

Report of the Workshop

Agenda:

Day 1, Report from Projects:

- EIC, ALICE-3, ILC-ILD, -SID, CLIC, FCC-ee, FCC-hh for colliders, and
- BabyIAXO, MadMax, Mu2e, Comet, AMS100 for beyond collider physics

Day 2, Reports from Industry:

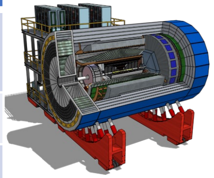
- Furukawa E., Toly E., Techmeta,
- Hitachi, Toshiba, Mitsubishi E., Bilfinger-Noel., ASG, Sigma-Phi,

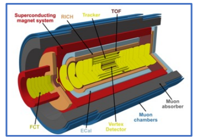
Day 3, Discussions:

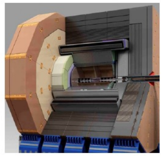
- Advanced SC for detector magnets,
  - Al-stabilized SC w/ EBW/Soldering, CICC, HTS/MgB_2 ?

Day 1: Reports from Project Plans and Requirements

Subject / Project	Presented by
Welcome Address	**J. J. Mnich, (CERN Director for Physics and Computing)**
Opening Address	M. Mentink (CERN), T. Ogitsu (KEK)
Program Overview	A. Yamamoto (KEK-CERN)
The Electron-Ion Collider (EIC)	R. Rajput-Ghoshal (JLab)
International Linear Collider –ILD (ILC-ILD)	K. Buesser (DESY), Y. Makida (KEK)
International Linear Collider - SiD (ILC-SiD)	T. Markiewicz (SLAC)
Compact Linear Collider (CLiC)	B. Cure (CERN)
Leptron Future Circular Collider (FCC-ee)	N. Deelen (CERN)
Hadron Future Circular Collider (FCC-hh)	M. Mentink (CERN)
Circular Electron Positron Collider (CEPC)	F. Ning (IHEP)
A Large Ion Collider Experiment 3 (ALICE-3)	W. Riegler (CERN)
Muon to Electron (Mu2e)	M. Lamm (Fermilab)
Muon Experiments in Japan	K. Sasaki and M. Yoshida (KEK)
antiProton ANihilation at DArmstadt (PANDA)	L. Schmitt (GSI-Helmholtzzenter)
Baby International Axion Observatory (BabyIAXO)	U. Schneekloth (DESY)
MAgnetized Disc & Mirror Axion eXp. (MADMAX)	W. A. Maksoud (CEA)
Alpha Magnetic Spectrometer 100 (AMS-100)	T. Mulder (CERN), S. Schael (Rheinish Westfaeli…)


EIC


ALICE-3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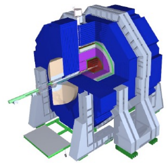
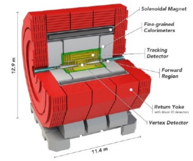
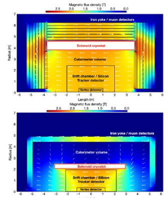
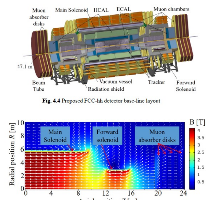
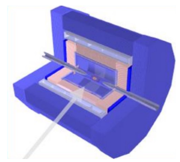

-SiD


CLIC


FCC-ee


FCC-hh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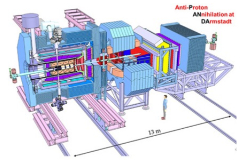
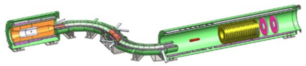
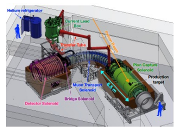
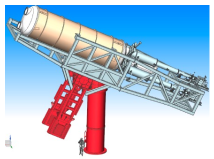
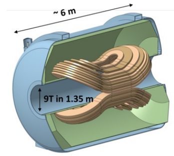
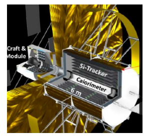

PANDA


Mu2e


Comet


BabyIAX0,


MadMax


AMS100

Future Colliders Proposed

COMET, Mu2e

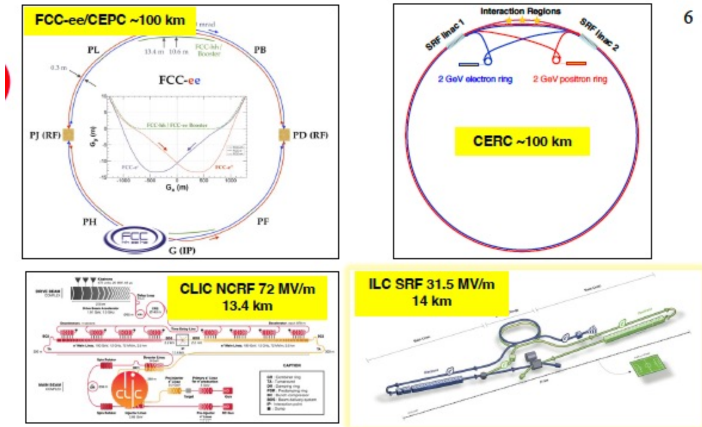
2007 ～ 2022

from LDG Accelerator R&D Report, CERN 2022-001

< 2030	2030-2035	2035-2040	2040-2045	> 2045
SPS fixed target Other fixed target; FAIR (hep) Belle II ALICE LS3 PIP-II/DUNE/Hyper-K	ALICE 3 LHCb (≥ LS4) EIC LHeC	ILC	FCC-ee CLIC	FCC-hh FCC-eh Muon Collider Plasma Collider

Other phys. Experiments: Mu2e, G-2 (fnal), Comet, G-2)J-Parc), BabyAXIO, AXIO (desy)

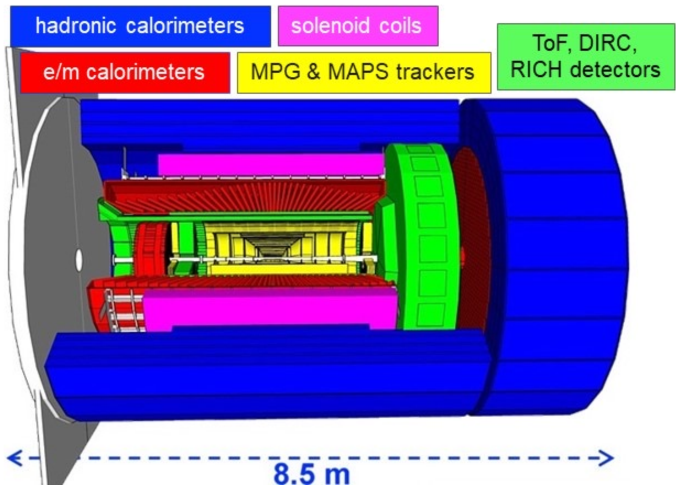
- **Colliders:** ILC, CLIC, FCC-ee, -hh, -eh,
- EIC, MC, and others (CEPC, SPPS, …)
- **Non-Colliders;** Panda, Muon Beam Experiments, Axion-Observatory (BabyIAXO), and others (….)
- Others ?



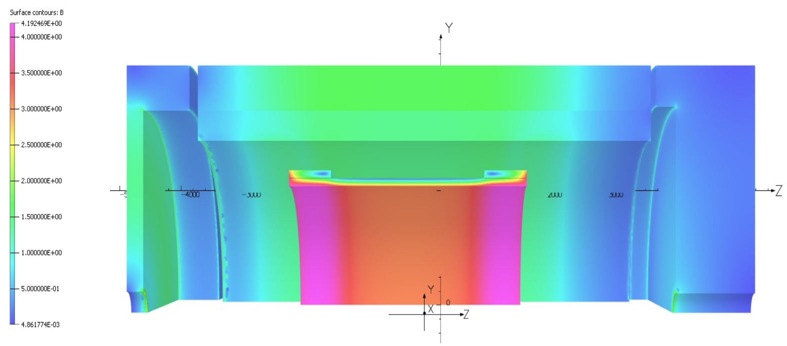
The Electron-Ion collider

	Detector solenoid #1	Detector solenoid #2
Warm bore diameter [m]	2.8	3.2
Cold mass length [m]	3.5	3.6
Magnetic field in the centre [T]	2.0	3.0
Stored magnetic energy [MJ]	46	~150

Magnet parameters



Detector solenoid #1



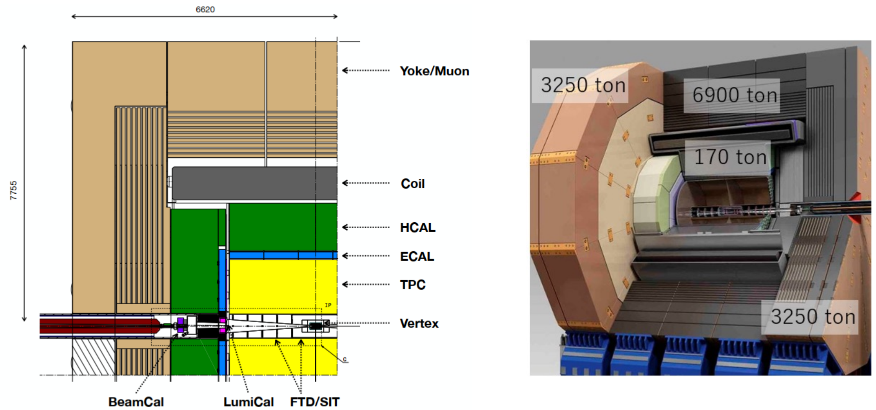
Detector solenoid #2

- Presentation by R. Rajput-Ghoshal (Jefferson Lab)
- For the Electron-Ion Collider project to be hosted at BNL, with full project finalization foreseen by 2034
- Two superconducting detector solenoids, for two interaction points:
  - #1: 2 T in solenoid with a 2.8 meter warm bore diameter and a 3.5 meter cold mass length
  - #2: 3 T in solenoid with a 3.2 meter warm bore and a 3.6 meter cold mass length
- Conductor:
  - Solenoid #1, initial preference for reinforced aluminum-stabilized Nb-Ti/Cu, but copper-stabilized conductor can work as well
  - Solenoid #2, a reinforced aluminum-stabilized Nb-Ti/Cu conductor is foreseen

International Linear Collider, ILC-ILD

	Detector solenoid
Warm bore diameter [m]	6.9
Cold mass length [m]	7.35
Magnetic field in the centre [T]	4.0
Stored magnetic energy [MJ]	2300

Magnet parameters



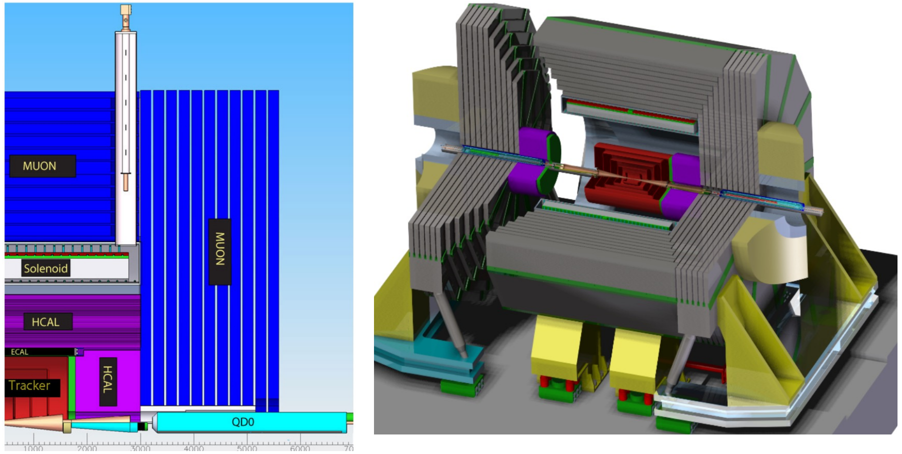
ILC-ILD detector featuring a 4 T superconducting solenoid

- Presentations by K. Buesser (DESY) and Y. Makida (KEK)
- For the International Linear Collider project, proposed to be hosted in Japan
- Featuring a superconducting solenoid, with 4 T over a 6.9 m warm bore diameter, and a 7.35 m cold mass length, stored magnetic energy of 2300 MJ
- With optional "Detector-Integrated-Dipole" coil wound on top of the solenoid
- Conductor: Foresees to use a reinforced aluminum-stabilized Nb-Ti/Cu conductor

International Linear Collider, ILC-SiD

	Detector solenoid
Warm bore diameter [m]	5.2
Cold mass length [m]	5.6
Magnetic field in the centre [T]	5.0
Stored magnetic energy [MJ]	1590

Magnet parameters



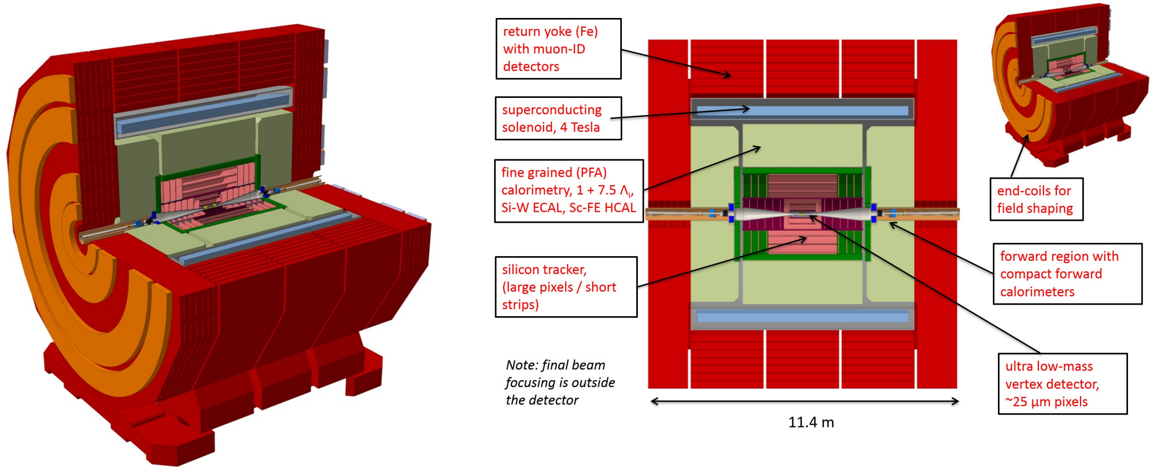
ILC-SiD detector featuring a 5 T superconducting solenoid

- Presentation by T. Markiewicz (SLAC)
- For the International Linear Collider project, proposed to be hosted in Japan
- Featuring a superconducting solenoid, with 5 T over a 5.2 m warm bore diameter, and a 5.6 m cold mass length, stored magnetic energy of 1590 MJ
- Conductor: Proposal to use a reinforced aluminum-stabilized Nb-Ti/Cu conductor with same dimensions as was used for CMS

Compact Linear Collider (CLiC)

	Detector solenoid
Warm bore diameter [m]	7.0
Cold mass length [m]	7.8
Magnetic field in the centre [T]	4.0
Stored magnetic energy [MJ]	2400

Magnet parameters



CLiC detector featuring a 4 T superconducting solenoid

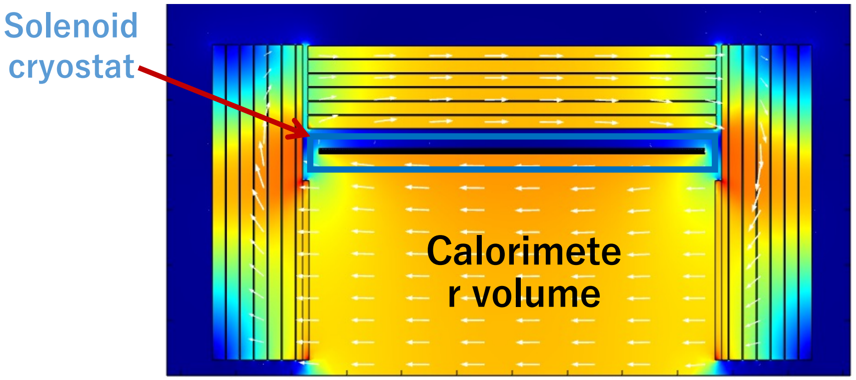
- Presentation by B. Cure (CERN)
- For the Compact Linear Collider linear collider, proposed to be hosted at CERN
- Large superconducting solenoid, with 4 T over a 7.0 m warm bore diameter, and a 7.8 m cold mass length, stored magnetic energy of 2400 MJ
- Conductor: Foresees to use a reinforced aluminum-stabilized Nb-Ti/Cu conductor

FCC-ee: IDEA and CLD

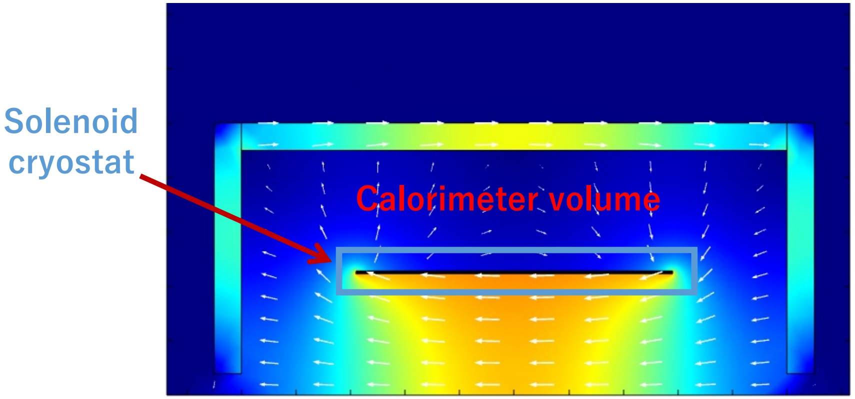
	Detector Solenoid #1	Solenoid #2
Warm bore diameter [m]	8.0	4.0
Cold mass length [m]	7.0	5.8
Magnetic field in the centre [T]	2.0	2.0
Stored magnetic energy [MJ]	600	170

Magnet parameters

- Presentation by N. Deelen (CERN)
- For the FCC-ee project, proposed to be hosted at CERN, with operation foreseen to start in 2045, featuring electron-position collisions
- Two solenoid types (For “IDEA” and “CLD”) detectors
  - One solenoid, featuring 2 T over a free bore of 8.0 meters, and a cold mass length of 7.0 meters, no transparency requirement
  - One solenoid, featuring 2 T over a free bore of 4.0 meters, and a cold mass length of 5.8 meters, with transparency requirement
- Conductor: Reinforced aluminum-stabilized Nb-Ti/Cu conductor



CLD detector, featuring a 2 T solenoid



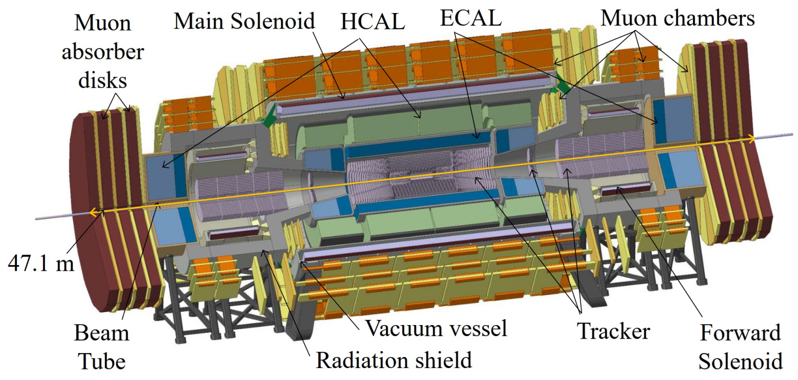
IDEA detector, featuring a transparent 2 T solenoid

FCC-hh

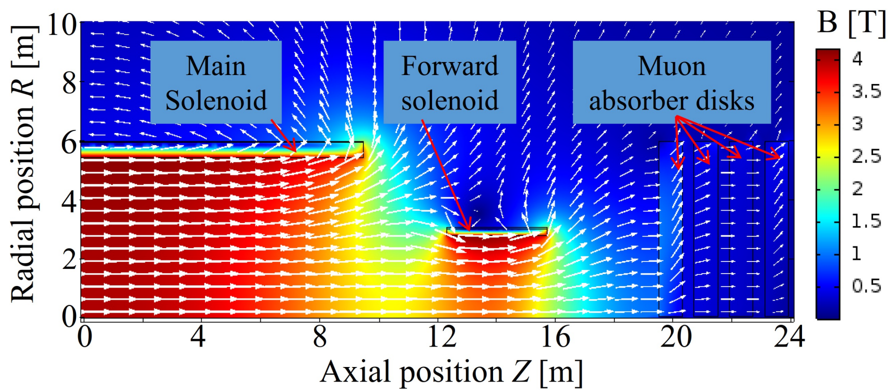
	Detector solenoid #1	Detector solenoid #2
Warm bore diameter [m]	10	5.2
Cold mass length [m]	19	3.4
Magnetic field in the centre [T]	4.0	3.2
Stored magnetic energy [MJ]	13800	

Magnet parameters

- Presentation by M. Mentink (CERN)
- For the FCC-hh project, proposed to be hosted at CERN, with operation foreseen to start in 2070, featuring hadron-hadron collisions
- Featuring three superconducting solenoids in close proximity, where the two forward solenoids enhanced bending power for high pseudo-rapidity particles
  - Main solenoid, warm bore: 10 meters, cold mass length 19 meters
  - Forward solenoids, warm bore: 5.2 meters, cold mass length: 3.4 meters
- Conductor: Requires very large reinforced aluminum-stabilized Nb-Ti/Cu conductors



FCC-hh detector, featuring three 4 T superconducting solenoids



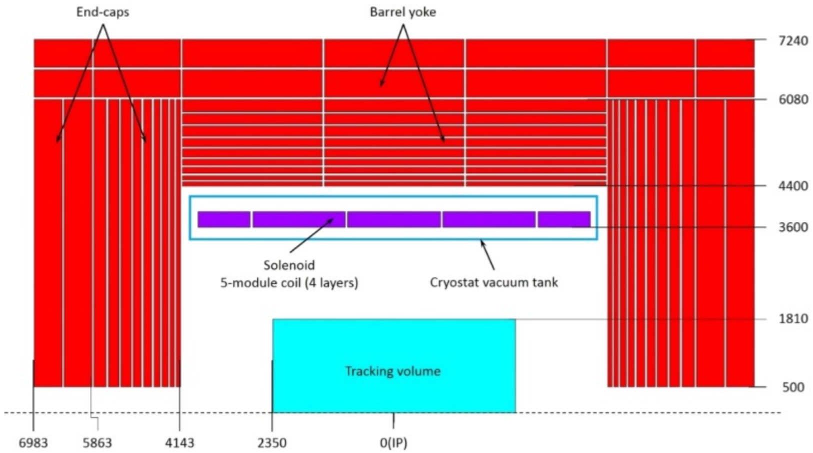
Magnetic configuration

CEPC

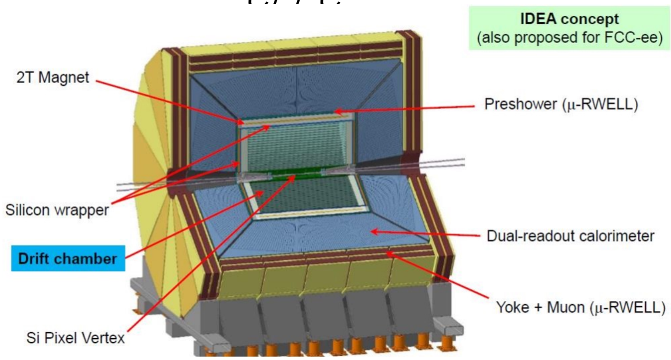
	Detector solenoid
Warm bore diameter [m]	~6.8
Cold mass length [m]	7.6
Magnetic field in the centre [T]	3
Stored magnetic energy [MJ]	1300

Magnet parameters

- Presentation by N. Feipeng (IHEP)
- For the Circular Electron-Position Collider project, proposed to be hosted in China
- Featuring multiple proposed superconducting detector magnets, including an IDEA-like transparent solenoid, and a large 3 T solenoid with return yoke
- Reinforced aluminum-stabilized conductor R&D ongoing (~foreseen for another 3 years)
    - Featuring both LTS (=Nb-Ti) and HTS (=ReBCO) conductor research
    - In collaboration with Chinese industry (Wuxi Toly Electric Works)



3 T solenoid with return yoke for CEPC

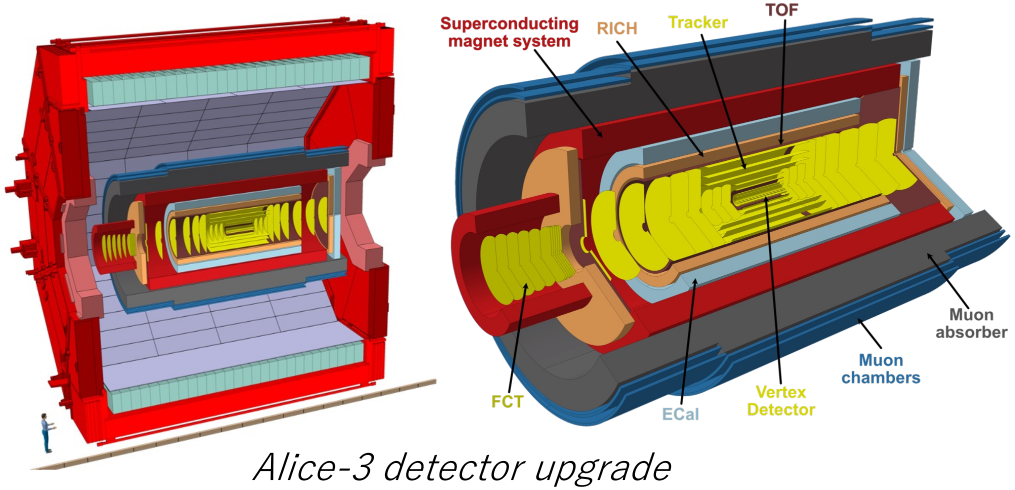


IDEA-like detector concept for CEPC, featuring a transparent 2 T superconducting solenoid

Alice-3

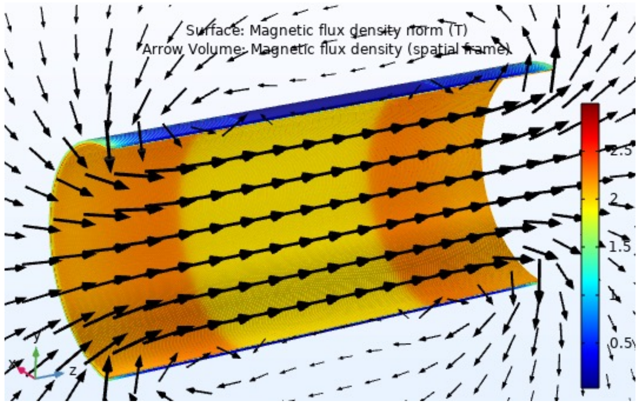
	Detector solenoid
Warm bore diameter [m]	3
Cold mass length [m]	7.5
Magnetic field in the centre [T]	2
Stored magnetic energy [MJ]	130

Magnet parameters



Alice-3 detector upgrade

- Presentation by W. Riegler (CERN)
- Planned to be installed by LS4 (which is currently foreseen to start in 2033)
- Featuring a superconducting solenoid, with 2 T in the center and additional windings at the end to augment bending power for high-pseudo-rapidity particles
- Also featuring a forward (superconducting) dipole
- Conductor: Proposal to use a reinforced aluminum-stabilized conductor

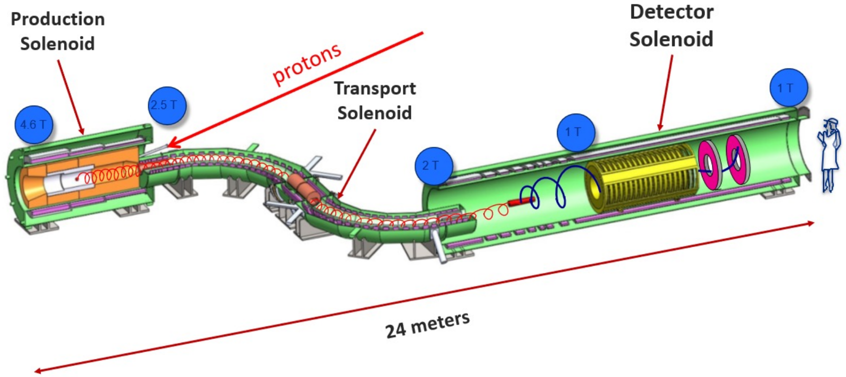


Magnetic field configuration

Mu2e

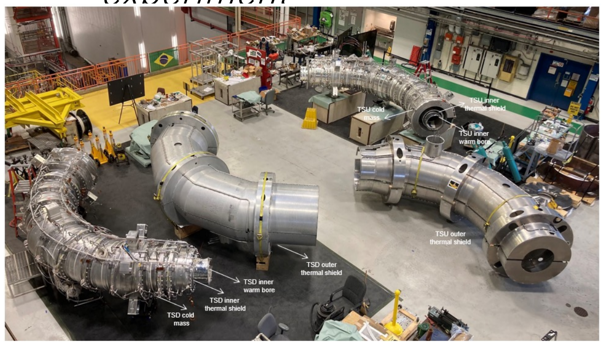
	Production solenoid	Transport solenoid	Detector solenoid
Warm bore diameter [m]	1.5	0.5	1.9
Cold mass length [m]	4	13	10
Magnetic field in the center [T]	2.5 – 4.6	2 – 2.5	1 - 2

Magnet parameters



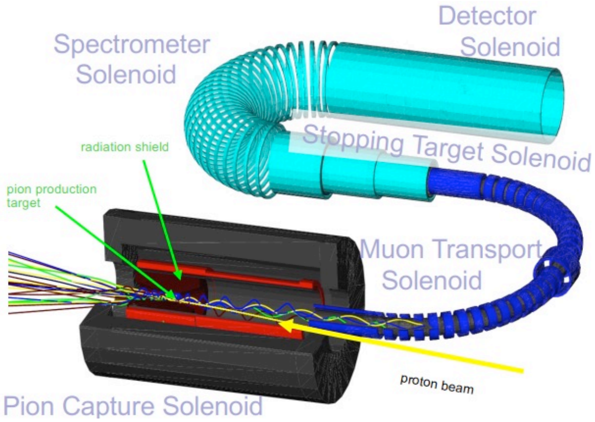
Magnet layout of the Mu2e experiment

- Presentation by M. Lamm (Fermi-lab)
- Mu2e experiment, to be hosted at Fermi-lab, for studying charged Lepton Flavor Violation to probe physics beyond the Standard Model
- Construction is on-going, and commissioning is foreseen to start in 2025
- Featuring three solenoids: Production solenoid, transport solenoid, and detector solenoid
- Conductor: Aluminum-stabilized Nb-Ti/Cu conductor technology, previously received from industry when it was still commercially available

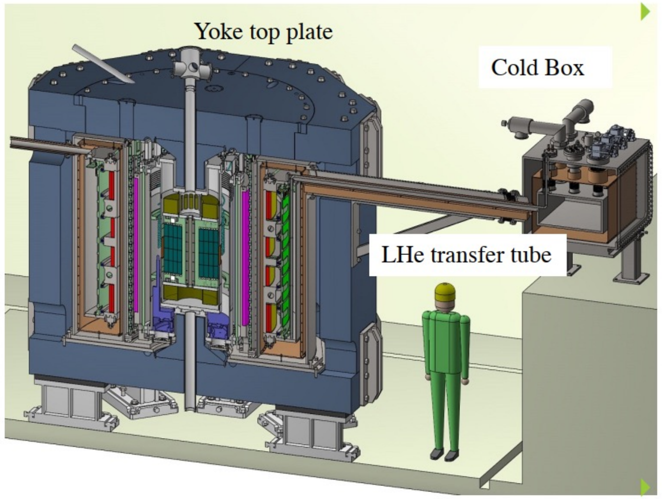


Assembly at Fermi lab

COMET and J-PARC g-2/EDM



Superconducting solenoids for COMET



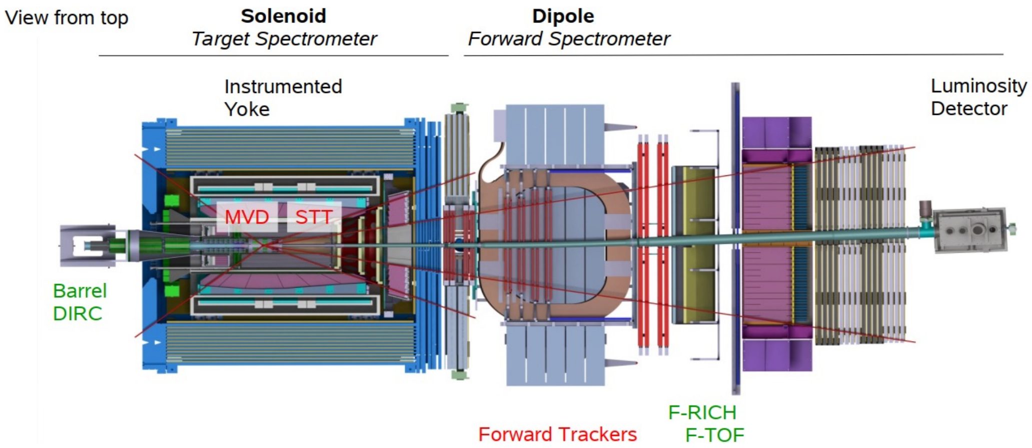
Muon storage solenoid for J-PARC g-2/EDM

- Presentation by K. Sasaki (KEK)
- COMET experiment for muon physics at KEK
  - Featuring several superconducting solenoids
  - Construction currently underway, with magnet commissioning foreseen by 2024
- J-PARC g-2/EDM
  - Featuring a superconducting muon storage solenoid
  - Design on-going, with physics run foreseen by 2027, pending approval and funding
- Conductor: Nb-Ti single wire conductors (relatively small magnets)

The PANDA detector

	Target spectrometer solenoid
Warm bore diameter [m]	1.8
Cold mass length [m]	~3.1
Magnetic field in the centre [T]	2
Stored magnetic energy [MJ]	22

Magnet parameters



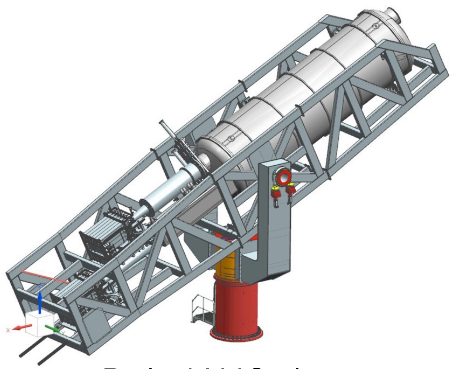
The PANDA detector layout

- Presentation by L. Schmitt (GSI)
- For fixed-target anti-matter physics at FAIR, foreseen to start operation by 2029
- With strong involvement of various Russian institutes, including the Budker Institute of Nuclear Physics
- Featuring a 2 T superconducting solenoid, with a stored magnetic energy of 22 MJ
- Conductor: Aluminum-stabilized Nb-Ti/Cu conductor technology, under development through a R&D effort by Russian institutes and industry (BINP, VNIINM Bochvar, VNIIKP, SARKO)

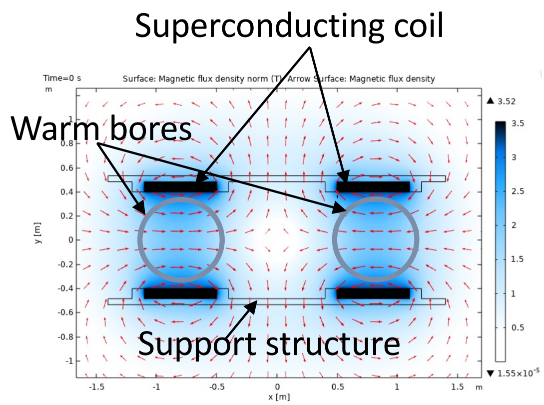
BabyIAXO

	Detector dipole
Warm bore diameter [m]	2x 0.7
Cold mass length [m]	11
Magnetic field in the centre [T]	2.0
Stored magnetic energy [MJ]	40

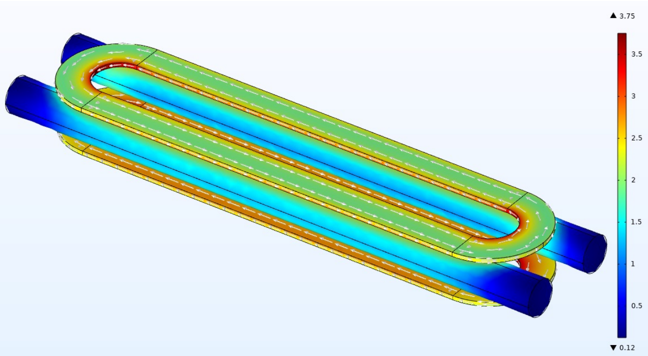
Magnet parameters



BabyIAXO detector



Magnetic field in cross-section



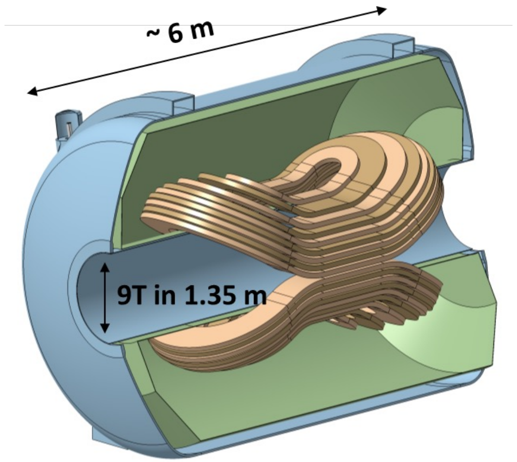
Common-coil dipole, with counter-flowing current in two superconducting race-track coils

- Presentation by U. Schneekloth (DESY)
- BabyIAXO detector, for studying axions emanating from the sun
- Featuring a superconducting common-coil dipole with a 2 T transverse magnetic field in two 0.7 meter warm bores of 11 meters length
- Conductor: Featuring an aluminum-stabilized Nb-Ti/Cu conductor

MadMax

	Detector dipole
Warm bore diameter [m]	1.35
Cold mass length [m]	~4
Magnetic field in the centre [T]	9.0
Stored magnetic energy [MJ]	480

Magnet parameters



Magnet layout

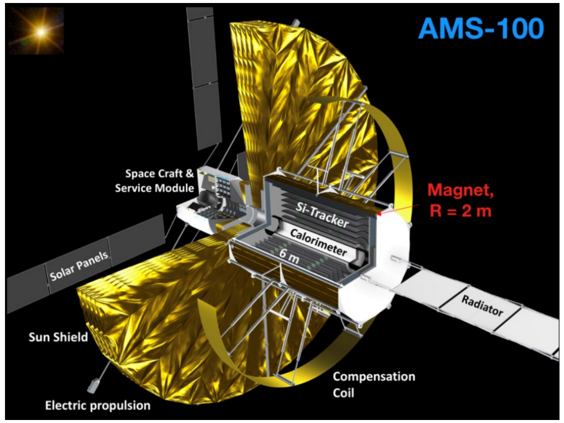
- Presentation by W. Maksoud (CEA)
- MadMax superconducting dipole for Axion physics, proposed to be hosted at DESY
- Superconducting dipole featuring a high magnetic field (9 T) over a 1.35 m bore, under development in a collaboration between CEA and Bilfinger Noell
- Conductor: Reinforced copper-based Nb-Ti cable-in-conduit (CICC) technology
- Operation at 1.9 K (superfluid helium), featuring both helium inside the conductor and in the surrounding bath

CEA MadMAX team

AMS-100

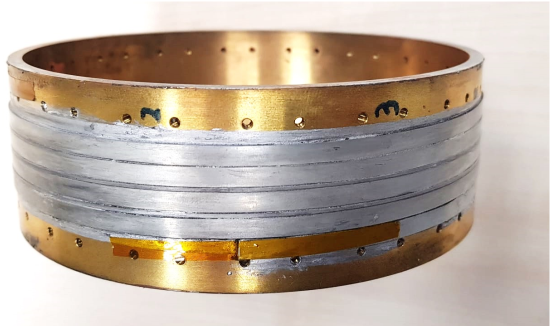
	Detector solenoid	Compensation solenoid
Warm bore diameter [m]	4	8
Cold mass length [m]	6	1.5
Magnetic field in the centre [T]	0.5	0.5
Stored magnetic energy [MJ]	14.3	

Magnet parameters



Detector layout

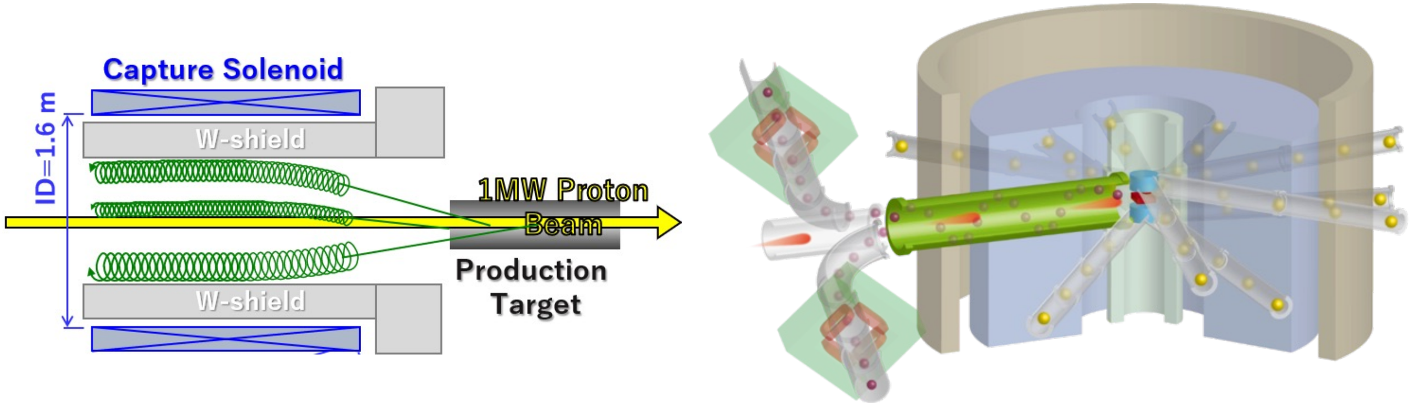
- Presentation by T. Mulder (CERN)
- To be hosted at Lagrange-point 2, for probing high energy cosmic rays, in particular anti-protons and anti-deuterons (proposal by RWTH Aachen University)
- Featuring a compensated ultra-transparent superconducting solenoid
- Cooled by back-ground thermal radiation to space, with operation at 50-60 K (Main solenoid) and 30 K (Compensation solenoid)
- Conductor technology: Reinforced aluminum-stabilized HTS-based conductor, currently under development



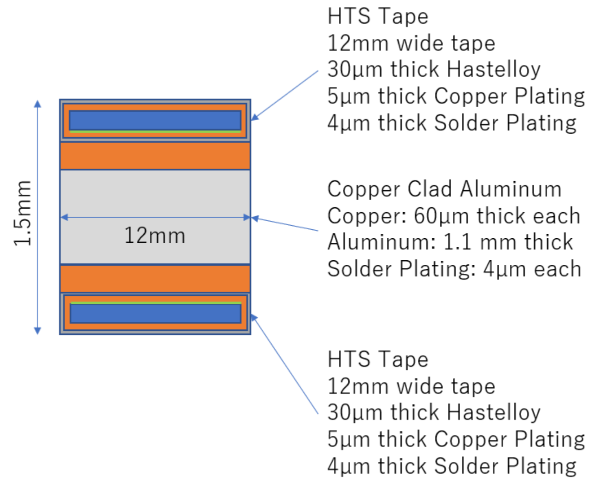
AMS-100 demonstrator coil, developed at RWTH Aachen university

RWTH AACHEN UNIVERSITY FH AACHEN UNIVERSITY OF APPLIED SCIENCES EPFL CERN UNIVERSITÉ DE GENÈVE

J-PARC MLF 2nd Target station



Proposed HTS-based solenoid



Proposed conductor concept

- Presentation by T. Ogitsu (KEK), on 3rd day
- Proposed for the J-PARC MLF 2nd Target Station, for a variety of applications, including muon spectroscopy, muon clairvoyance, muSR, muon physics
- Featuring a superconducting solenoid exposed to heavy neutron radiation
- Proposal:
  - To utilize an HTS-based ReBCO aluminum-stabilized conductor
  - For operation at 20 K for combined cryogenic operation with the Neutron Moderator

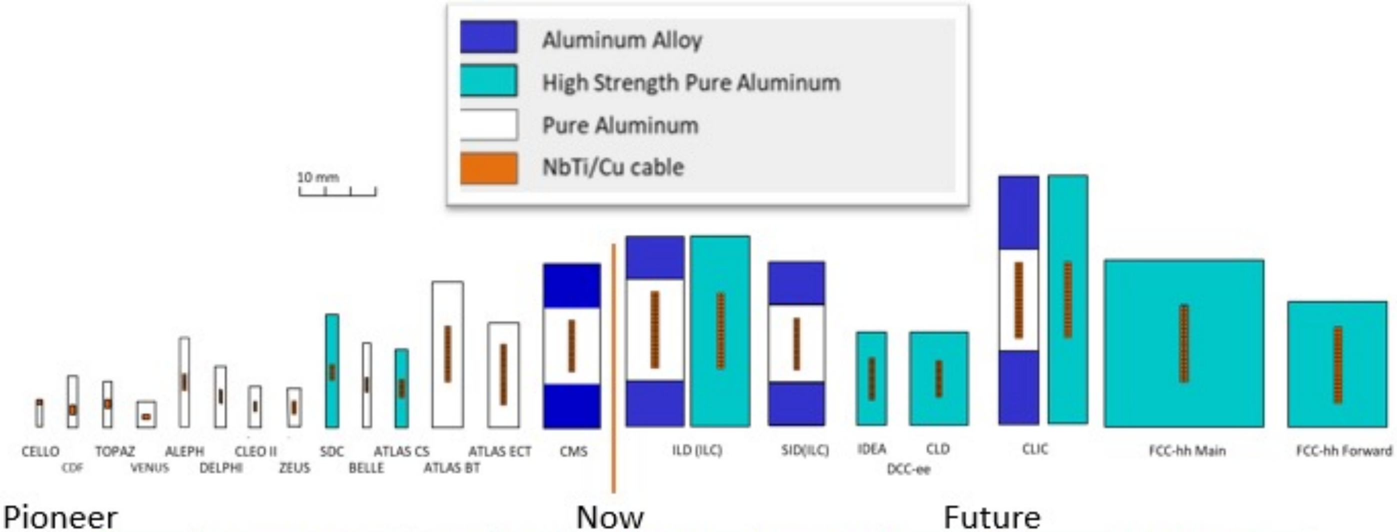
Overview

Courtesy: Y. Makida

	Experiments	Site	B [T}	Size, ID x L [m]	Note	Fabrication Expected
Colliders	EIC-Detector	BNL	1.5~3	2.5~3.2 x 8.5	Solenoid	2025 ~
	ILC-ILD	Japan	4	6.88 X 7.35	Solenoid	2030 ~
	ILC-SiD	Japan	5	5 X 5	Solenoid	2030 ~
	CLIC-ILD	CERN	4	6.8 X 8.3	Solenoid	2035 ~
	CLIC-SiD	CERN	5	5.4 X 6.5	Solenoid	2035 ~
	CLIC	CERN	4	7 X 8.3	Solenoid	2035 ~
	FCC-ee IDEA	CERN	2	4.2 X 6.0	Solenoid	2035 ~
	FCC-ee CLD	CERN	2	7.4 X 7.4	Solenoid	2035 ~
	FCC-hh	CERN	4	10 X 20	Solenoid	2060 ~
	ALICE-3	CERN	2	3 x 7.5	Solenoid	2027 ~
Others	M2e	Fermilab	5 ~ 2.5	1.5 X 4	Production	Under construction
	Muon-g-2	Fermilab	1.473	0.09 X 14.22 ▪ π	Storage solenoid	Reuse after BNL
	COMET	J-PARC	5 ~ 3	1.3 X 1.6	Capture Sol.	Under const.
	Muon-g-2	J-PARC	3	0.66 X 0.33	Solenoid	2025 ~
	BabyIAXO	DESY	2	0.7 X 10	D. Racetrack	TBD
	IAXO	DESY	5 - 6	5 X 25	Toroid	TBD
	Panda	GSI	2	1.8 x 3.1	Solenoid	TBD
	Madmax	DESY	9	1.35 x 1.2	Dipole	TBD

Aluminum-stabilized Nb-Ti/Cu conductor types

Courtesy: Y. Makida



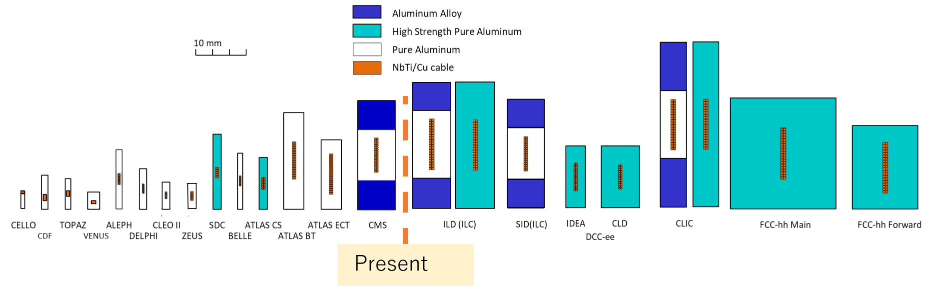
	Experiments	Site	B	Size ID x L	Energy (MJ)	Note	Fabrication Expected
Collider	EIC-Detector	BNL	1.5~3	2.5~3.2 x 8.5	45.7		2025 ~
	ILC-ILD	Japan	4	6.88 X 7.35	2300		2030 ~
	ILC-SiD	Japan	5	5 X 5	1400		2030 ~
	CLICdet	CERN	4	7 X 8.3	2320		2035 ~
	FCC-ee IDEA	CERN	2	4.2 X 6.0	170		2035 ~
	FCC-ee CLD	CERN	2	7.4 X 7.4	600		2035 ~
	FCC-hh	CERN	4	10 X 20	13800		2040 ~
Others	BabyIAXO	DESY	2	0.7 X 10	38	Racetrack	

Day 1 Reports from Projects: Summary

Subject / Project	Presented by
Welcome Address	**J. J. Mnich, (CERN Director for Physics and Computing)**
Opening Address	M. Mentink (CERN), T. Ogitsu (KEK)
Program Overview	A. Yamamoto (KEK-CERN)
The Electron-Ion Collider (EIC)	R. Rajput-Ghoshal (JLab)
International Linear Collider –ILD (ILC-ILD)	K. Buesser (DESY), Y. Makida (KEK)
International Linear Collider - SiD (ILC-SiD)	T. Markiewicz (SLAC)
Compact Linear Collider (CLiC)	B. Cure (CERN)
Leptron Future Circular Collider (FCC-ee)	N. Deelen (CERN)
Hadron Future Circular Collider (FCC-hh)	M. Mentink (CERN)
Circular Electron Positron Collider (CEPC)	F. Ning (IHEP)
A Large Ion Collider Experiment 3 (ALICE-3)	W. Riegler (CERN)
Muon to Electron (Mu2e)	M. Lamm (Fermilab)
Muon Experiments in Japan	K. Sasaki and M. Yoshida (KEK)
antiProton ANihilation at DArmstadt (PANDA)	L. Schmitt (GSI-Helmholtzzenter)
Baby International Axion Observatory (BabyIAXO)	U. Schneekloth (DESY)
MAgnetized Disc & Mirror Axion eXp. (MADMAX)	W. A. Maksoud (CEA)
Alpha Magnetic Spectrometer 100 (AMS-100)	T. Mulder (CERN), S. Schael (Rheinish Westfaeli…)

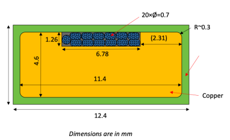
The most of projects:

- Assuming to Al-stabilized superconductor (SC) to be available.
- Expecting the Al-stabilized SC technology to be urgently resumed.

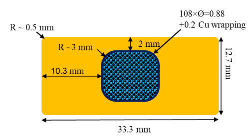


EIC and Madmax:

- **EIC:** planning to use Cu-stabilized superconductor, in case of the Al-stabilized SC not be available within time.
- **Madmax:** planning to use Cu-based CICC superconductor after their extensive investigation showed that other conductor types are presently not commercially available



EIC



Madmax

Day 2: Reports from Industry, Experience and Prospect

Reports from 10 (+3) leading companies (according to agenda order):

- **Furukawa Electric**, Japan: ……………………………*Al-Stabilized NbTi Conductor for Detector Solenoid at Furukawa*
- **European Industrial Status** on superconductor manufacturing ……………. *introduced by A. Ballarino (CERN)*
- **Wuxi Toly Electric Works Co.,Ltd.**, China: ………………………………*Development of Al-stabilized superconductor*
- **Techmeta**, France: …………………...*Continuous EB-Welding of the reinforcements of the CMS Superconductor*
- **Status Report on Co-extrusion Facilities in Europe** for Detector Magnet SC …. *Introduced by B. Cure (CERN)*
- **Hitachi, Ltd.**, Japan: ………………………..*Development of Superconducting Magnets for Accelerators in Hitachi*
- **Toshiba Energy Systems & Solutions Corporation**, Japan: …………….*Superconducting Technology in Toshiba*
- **Mitsubishi Electric corporation**, Japan: ……………………………………*Manufacturing of Superconducting Magnet*
- **Bilfinger Noell**, Germany: ………………………..……………….*Presentation of the activity in the field of SC magnets*
- **ASG Superconductors**, Italy: …………………………*Superconducting detector magnets at ASG Superconductors*
- **SAES Group**, Italy: …………………………………..*Fabrication of the High Order Corrector Magnets for Hi-Lumi LHC*
- **Sigmaphi**, France: …………………………………………………………………………*Sigmaphi presentation*

○ ← Highlighted

Presenting past or on-going development and manufacturing capacities :

- Superconductor (with Al or Cu stabilizer),
- Coil winding and magnet assembly, including cryostating,
- Specific technology.

Day 2: Reports from Industry
Furukawa Electric

Report from	Presented by
Furukawa Electric	**H. Sakamoto**
European Industrial SC manufacturing	A. Ballariono (CERN)
Wuxi Toly Electric	Y. Chao
Co-extrusion Machine manufacturing	B. Cure (CERN)
TECHMETA	P. Oving
Hitachi	T. Semba
Toshiba	S. Takami
Mitsubishi Electric	H. Horii
Bilfinger Noel	P. Revilak
ASG	A. Pellecchia
SAES RIAL	C. Santini
Sigma-Phi	F. Forest
MgB2	R. Musenich (INFN)

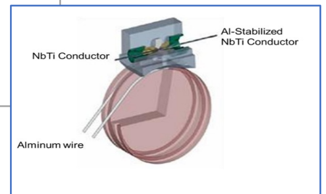
History of Al-stabilized NbTi conductor at FEC

FURUKAWA ELECTRIC

- FEC has many experiences for producing Al-stabilized NbTi conductors.
- FEC had contributed many detector solenoid projects.

Project	Lab.	Completion	Dim. of NbTi Strand (mm)	No. of strands	Stranded Cable	Stabilizer	Conductor	Quantity (m)
Mu2e PS	FNAL	2016	1.47	30	2.3*23.7	Ali-Ni	5.6*30	10,720
Mu2e DS	FNAL	2015	1.47	12	2.3*7.9	Al	5.3*20.1	9,900
SMES R&D Coil	NIFS	2004	0.823	8	1.55*	Al	5.8	14,000
SRC Main Coil	RIKEN	2000	1.15	10	2.15*	Al-Ni	8*15	77,680
ATLAS Thin Solenoid for LHC	KEK	1998	1.22	12	2.3*7.4	Al-Ni	4.2*30	6,500
SRC Trim Model Coil	RIKEN	1997	1.25			Al-Zn	2.9*3.6	4,600
SRC Main Model Coil	RIKEN	1997	1.25	10	2.35*	Al-Zn	8*15	15,400
BESS	KEK	1996	0.77			Al	1.2*1.8	7,000
SDC Prototype SSC	KEK	1993	1.277	10		Al-Zn-Si	4.37*43.8	6,000
TOPAZ	KEK	1983	1.8*3.3			Al	3.6*18	2,300

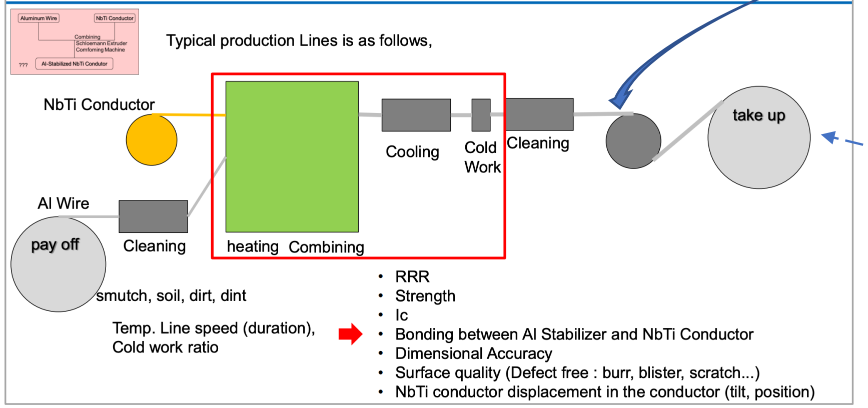
Subsidiary ⇧ ⇩ In house

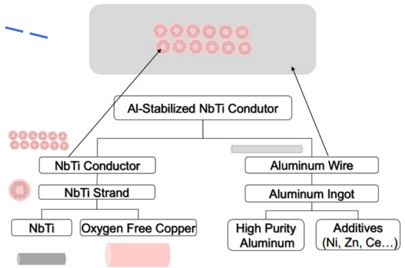


Schematic view of conforming machine
https://bwe.co.uk/conklad/

Al-stabilized NbTi conductor production

FURUKAWA ELECTRIC





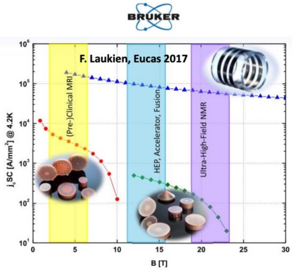
Day 2: Reports from Industry
Eu Industrial SC Manfucturing

Report from	Presented by
Furukawa Electric	H. Sakamoto
European Industrial SC manufacturing	**A. Ballariono (CERN)**
Wuxi Toly Electric	Y. Chao
Co-extrusion Machine manufacturing	B. Cure (CERN)
TECHMETA	P. Oving
Hitachi	T. Semba
Toshiba	S. Takami
Mitsubishi Electric	H. Horii
Bilfinger Noel	P. Revilak
ASG	A. Pellecchia
SAES RIAL	C. Santini
Sigma-Phi	F. Forest
MgB2	R. Musenich (INFN)

Manufacturer of Nb-Ti Wire – Bruker

Bruker EAS/OST

- Different types of round and rectangular Nb-Ti wires, bare or insulated (braided or varnish)
- Bruker production for **LHC: Nb-Ti wire** for MB and MQ and for other magnets (LHC Type 5 a and Type 6 wire for insertion quadrupoles), cable for ATLAS, **BSCCO 2223 HTS** for current leads



Manufacturer of Nb-Ti Wire - Luvata

Luvata USA/Luvata Pori (EU)

- Enameled monolithic wires in round and rectangular configurations
- Wire-in-channel or cable-in-channel integrated conductors
- Luvata Pori production for **LHC**: 1/8 of MB+MQ Nb-Ti outer cables/wire

Other non-European Manufacturers of Nb-Ti Wire

- SuperCon (USA)
- TVEL (Russia) – Production at Chepetsky Mechanical Plant (Glazov)
- KAT (Korea)
- Furukawa, Jastec, Hitachi (Japan)
- Supercon (USA)
- WST (China)

Thanks to MRI and NMR applications, Nb-Ti wire production is maintained at the industrial level

Rutherford cabling in industry

Rutherford cabling machines at:

- Brugg, Switzerland, 40-strand;
- Tratos cavi, Italy, > 60-strand (recent installation);
- Furukawa, Japan
- New England Wire Technology, USA, 36-strand
- ASIPP, Hefei, China

A **"sufficiently" large project** – with medium term definition of production requirements – could **attract** again **interest of industry.**
R&D on novel cables (superconductor/layout) is **more effective at the laboratory** level.
Series production (if sufficiently large) can be **industrialized.**

Day 2: Reports from Industry
Eu Industrial SC Manfucturing

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NbTi:

- NbTi/Cu wire manufacturers:
    - Bruker, Luvata (Europe)
    - TVEL (Russia)
    - KAT (Korea)
    - Furukawa, Jastec, Hitachi (Japan)
    - Supercon (USA) • WST (China)
- Excellent electrical and mechanical properties
- Assembled in different cable configurations
- Used in magnets up to ~9 T @ 4.2 K and up to ~ 10 T @ 1.9 K
- available at affordable price Reference cost: ~ 1 Euro/kA m*
  *before the recent increase of cost of raw materials
- Thanks to MRI and NMR applications, Nb-Ti wire production is maintained at the industrial level

Nb_3Sn:

- A complex material: used only when field requirements reach performance limits of Nb-Ti
- Production by several manufacturers for HL-LHC and ITER.

Day 2: Reports from Industry
Wuxi Toly Electric
Al Co-extrusion Technology under development

Report from	Presented by
Furukawa Electric	H. Sakamoto
European Industrial SC manufacturing	A. Ballariono (CERN)
Wuxi Toly Electric	**Y. Chao**
Co-extrusion Machine manufacturing	B. Cure (CERN)
TECHMETA	P. Oving
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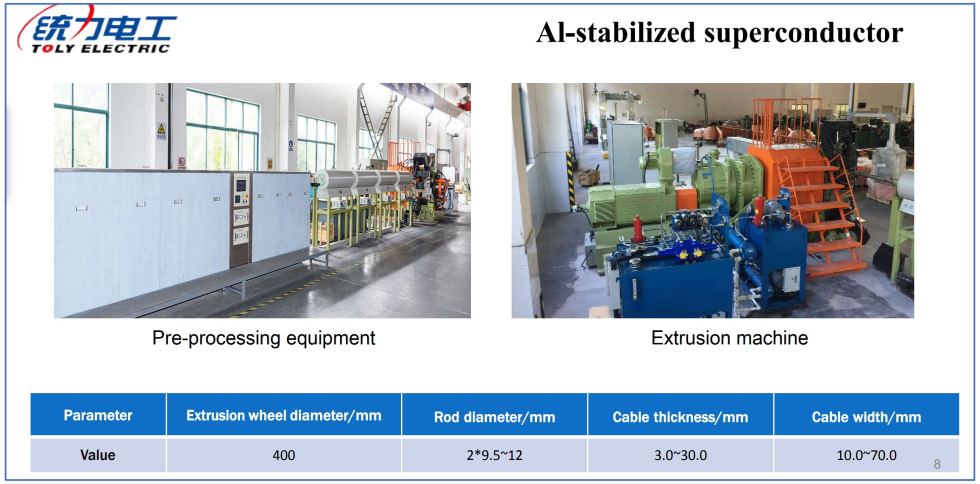
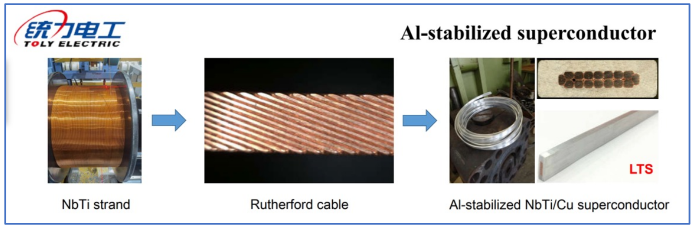
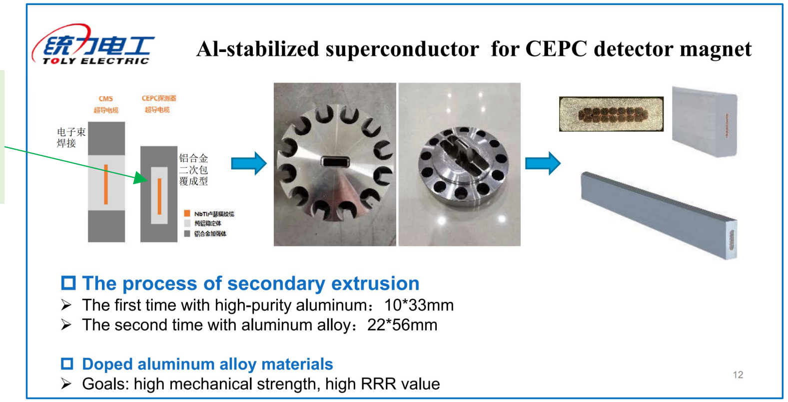


Parameter	Extrusion wheel diameter/mm	Rod diameter/mm	Cable thickness/mm	Cable width/mm
Value	400	2*9.5~12	3.0~30.0	10.0~70.0



Future Potential:
Secondary Extrusion
Study in Progress



Day 2: Reports from Industry
Co-extrusion Machine manufacturing

Report from	Presented by
Furukawa Electric	H. Sakamoto
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Sigma-Phi	F. Forest
MgB2	R. Musenich (INFN)

Companies that performed coextrusion for the LHC detector magnets

ATLAS Conductors:

Barrel and End cap toroids:
- VAC Vacuumschmelze , Hydro aluminium (Seneffe, B) (later EAS). *Facility closed in 2014.*
- Alcatel Cable Suisse (later Nexans). *Facility dismantled (2022). Expert left company in 2016.*

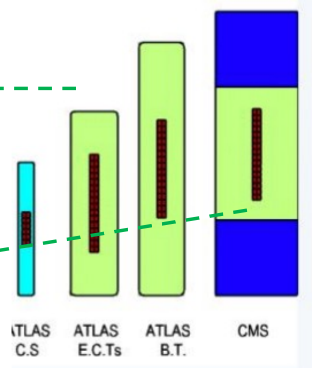
No more contact or information available.

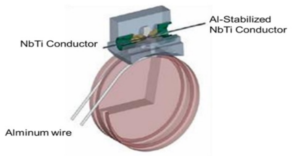
Central Solenoid: (Japan)
- Furukawa Electric Co. Ltd,
- Hitachi Cable Co. Ltd.

Ref: H. H. J. Kate, "ATLAS superconducting toroids and solenoid," in IEEE Transactions on Applied Superconductivity, vol. 15, no. 2, pp. 1267-1270, June 2005, doi: 10.1109/TASC.2005.849560.

CMS Conductor:
- Alcatel Cable Suisse (later Nexans). *Facility dismantled (2022). Expert left company in 2016.*

Ref: B. Blau et al., "The CMS conductor," in IEEE Transactions on Applied Superconductivity, vol. 12, no. 1, pp. 345-348, March 2002, doi: 10.1109/TASC.2002.1018416.





Schematic view of conforming machine
https://bwe.co.uk/conklad/

Status of communication to date

Investigation on other potential suppliers:

About the Conklad™ process: machinery for cladding or sheathing wires and cables with aluminium (e.g. cladding copper wire with aluminium).

BWE Ltd, Beaver Industrial Estate, Ashford, Kent, TN23 7SH, England

Commercialized by **BWE Ltd, UK** (formerly Babcock Wire Equipment)
- BWE Ltd is a British engineering company specialising in **continuous rotary extrusion** (CRE) machines for many different applications and cold pressure welding machines for the cable and wire industry.
- This company owns the registered names **Conform™ , Conklad™ and SheathEx™** together with a number of critically important patents associated with the processes and their development.
- **In 1976** the Company was awarded the first licence to develop, manufacture and supply Conform™ Continuous Rotary Extrusion Machines, by the inventors, the United Kingdom Atomic Energy Authority.
- **In the 1980's BWE pioneered the development of cladding and sheathing** using the Conform continuous rotary extrusion (CRE) method. This work led to the introduction of **Conklad™**, which has become the industry standard for many applications.

Source: bwe.co.uk

Conclusion

- Looking for coextrusion facilities in industry, available for prototyping and production, according to the schedules of the various project.
- No new manufacturer identified yet, references are needed.
- Alternative solutions have to be looked at, with dedicated studies and prototyping.

Report from Industry - Day 2

Co-extrusion
Machine Availability in Industry

Report from	Presented by
Furukawa Electric	H. Sakamoto
Industrial SC manufacturing	A. Ballarino (CERN)
Wuxi Toly Electric	Y. Zhao
Co-extrusion manufacturing	**B. Cure (CERN)**
TECHMETA	P. Oving
Hitachi	T. Semba
Toshiba	S. Takami
Mitsubishi Electric	H. Horii
Bilfinger Noel	P. Revilak
ASG	A. Pellecchia
SAES RIAL	C. Santini
Sigma-Phi	F. Forest
MgB2 (INFN-ASG)	R. Musenich

European companies that did the coextrusion of Al stabilized superconductors **stopped the activity or even closed definitevely** (e.g. ATLAS and CMS conductors).

Two ways of cladding SC Rutherford cable with aluminum:

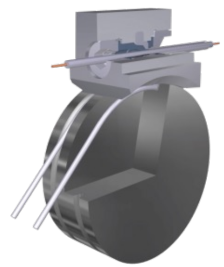
- ➢ Schloemann extrusion process (billet-on-billet)
- ➢ Conform™ cladding process = Conklad™ process (continuous)

Conklad™ machinery manufacturer in Europe : BWE, UK

- ➢ **Contacted by CERN Detector Magnet Team.**

- Further contacts CERN-BWE to discuss about feasibility and prototyping.
- Looking for coextrusion facilities in industry available for prototyping and production.

Source: bwe.co.uk



Day 2: Reports from Industry

Techmeta:

EBW Technology experienced

Report from	Presented by
Furukawa Electric	H. Sakamoto
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Wuxi Toly Electric	Y. Chao
Co-extrusion Machine manufacturing	B. Cure (CERN)
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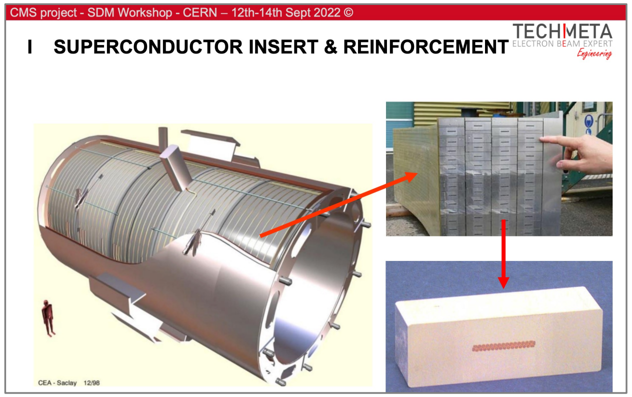

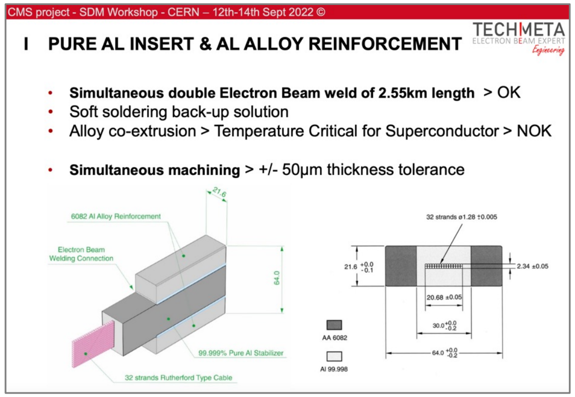

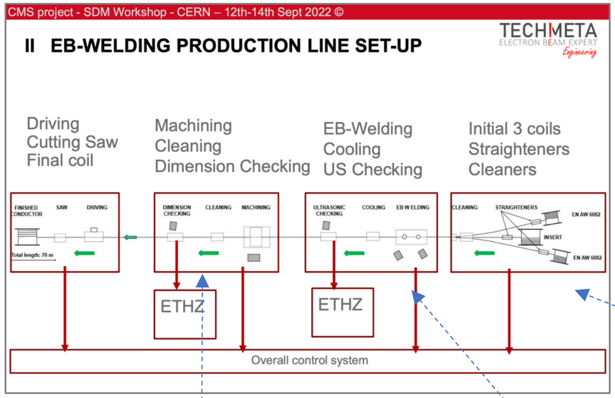

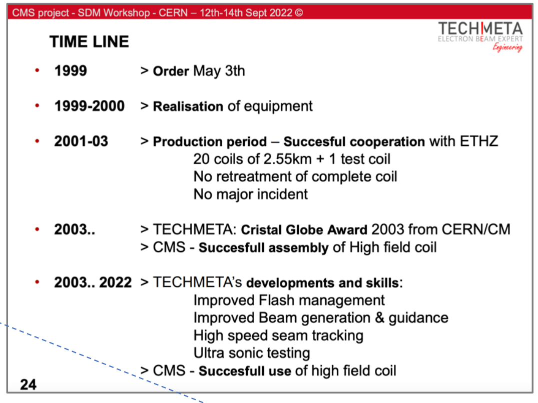

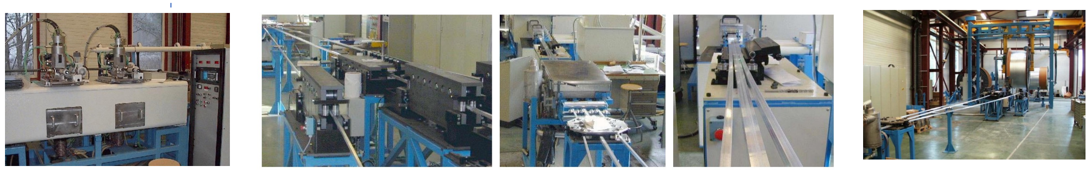

Report from Industry - Day 2

Hitachi, Toshiba, and Mitsubishi (JP):
Detector Magnets experienced

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Industrial SC manufacturing	A. Ballarino (CERN)
Wuxi Toly Electric	Y. Zhao
Co-extrusion manufacturing	B. Cure (CERN)
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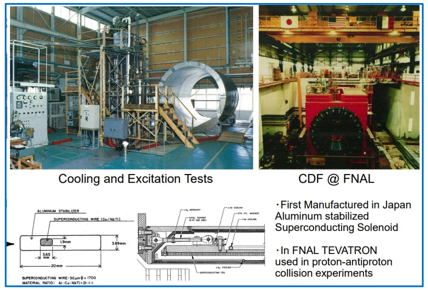

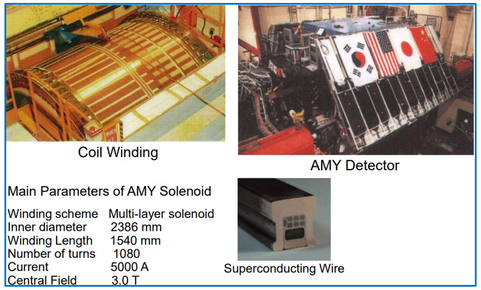

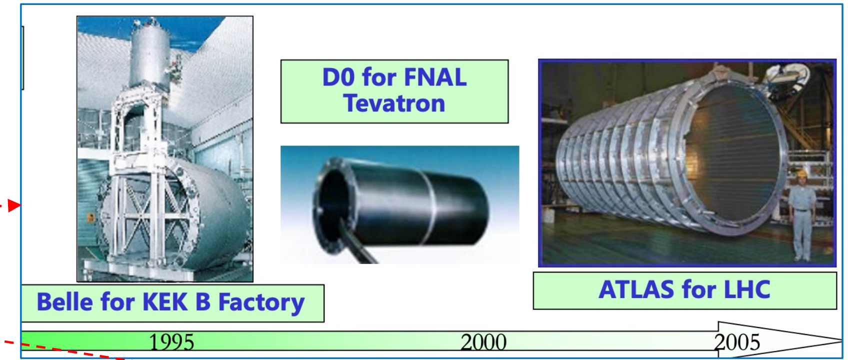

Report from Industry - Day 2

Bilfinger-Noel, ASG, SAES-RIAL, Sigma-Phi (Eu)
Detector & Accelerator Magnets experienced

Report from	Presented by
Furukawa Electric	H. Sakamoto
Industrial SC manufacturing	A. Ballarino (CERN)
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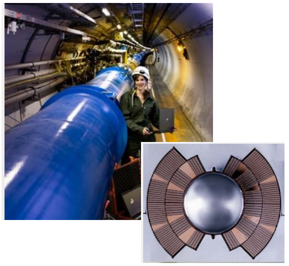
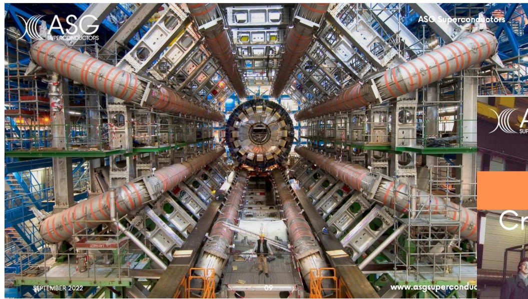




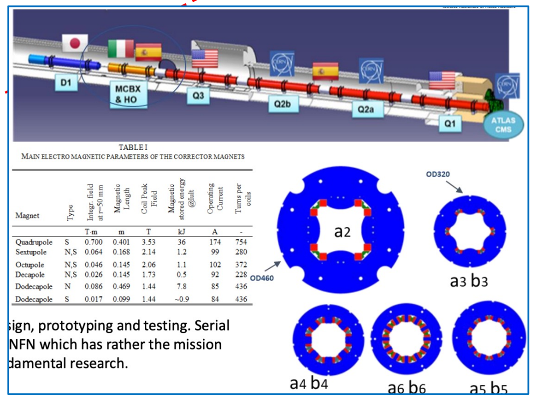


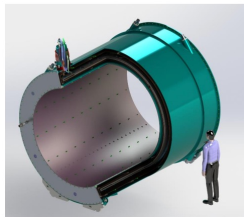
TABLE I
MAIN ELECTRO MAGNETIC PARAMETERS OF THE CORRECTOR MAGNETS

Magnet	Type	Integr. field at r=50 mm	Magnetic Length	Coil Peak Field	Magnetic stored energy @Iult	Operating Current	Turns per coils
		T·m	m	T	kJ	A	-
Quadrupole	S	0.700	0.401	3.53	36	174	754
Sextupole	N,S	0.064	0.168	2.14	1.2	99	280
Octupole	N,S	0.046	0.145	2.06	1.1	102	372
Decapole	N,S	0.026	0.145	1.73	0.5	92	228
Dodecapole	N	0.086	0.469	1.44	7.8	85	436
Dodecapole	S	0.017	0.099	1.44	~0.9	84	436

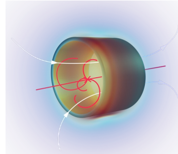
sign, prototyping and testing. Serial
NFN which has rather the mission
damental research.

Superconducting Solenoid P2 for Gutenberg Univ. Mainz

NbTi – 725 A – 0.7T – Cryostat OD 3309 mm x L 3840 - Aperture 2400 mm
Helium bath - Coils & cryostat weight 15 tons



Report from Lab and Industry - Day 2



INFN-Genova / ASG Cooperation

MgB_2 for future Space Magnets

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Wuxi Toly Electric	Y. Zhao
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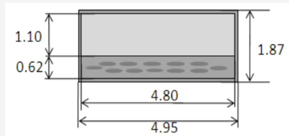
Sigma-Phi	F. Forest
MgB2 (INFN-ASG)	R. Musenich

SR2S Space Radiation Superconducting Shield

EU FP7 project to study superconducting shields to protect astronauts from space radiation

Conductor: Titanium clad MgB_2 tape + Aluminium strip

Ti/MgB_2 ratio 2.7/1.
75 μm thick insulation.
Total conductor cross section: 9.25 mm^2.
Average mass density : 3000 kg/m^3.



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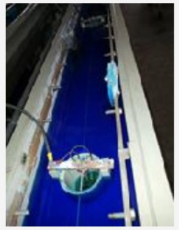
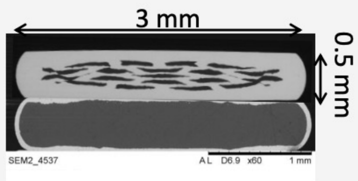


Ti-MgB_2 tape during copper plating

copper plated Ti-MgB_2 tape



Cu-Ti-MgB_2 tape

Day 2: Reports from Industry: Summary

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MgB2	R. Musenich (INFN)

Feasibility of Al-stabilized superconductor production based on the experience integrated in past 20 years:

- **NbTi/Cu SC & Cable production**: multiple companies available
  - SC strand: Fufukawa, Luvata, Bruker …?
  - Cable: Furukawa, CERN, LBNL, and …?
- **Co-extrusion of Al-NbTI/Cu**: a company getting active
  - Most of industrial facilities have been closed/dismantled, However,
  - Toly E. (in China) active in development for the CEPC detector solenoid..
  - The technology needs to be widely available.

    → Lab's leadership to be important
- **Reinforcing EBW Work**: a company keeping technology
  - The technology well established at TECHMETA (in France).
  - The production facility may be re-established under appropriate coordination

Day 3: Strategic Discussions for Future

Subject	Speaker
Advanced Al-stabilize SC : Part 1	S. Sgobba
Advanced Al-stabilize SC : Part 2	B. Cure
Summary of Al-stabilize SC requirements	Y. Makida
Comment from Furukawa	H. Sakamoto
Comment and Advice on EBW work from TECHMETA	P. Oving
Comments on alternate technology: Soldering	C. Berriaud
Discusssion on alternate technology: CICC	N. MItchell
Discussion on HTS	T. Ogtsu
Progress in Al-stabilized HTS	A. Vaskuri
Challenge of HTS for Future Accelerator Magnets	A. Ballarino
General Discussions	A. Yamamoto
Closing Remark	T. Ogitsu

Al-stabilized SC:

- No industrial production available, as current status,
- Development to be resumed
  - Urgent requests from EIC, BabyIAXO, …
- Laboratory-Industry cooperation inevitable. For
  - **Co-extrusion** + EBW technology and/or
  - Soldering technology as backup

Alternate SC:

- **CICC**
  - It may be applicable in most detector solenoid design, if no request of "transparency".
  - A proposal to apply CICC to ILC-SiD, with no request for "transparency.
  - It is Important to study the feasibility, and to learn experiences integrated in the ITER project.
- **HTS**
  - HTS application proposed by AMS-100,
  - The feasibility to be investigated.

Day 3: Strategic Discussions

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Context: next generation HEP detector magnet

Next detector magnets for collider and non-collider experiments (list non-exhaustive):

- **Thin coils** within the calorimeter volume, as transparent as possible for particles.
- **Large coils** with high stored energy and magnetic forces

All future coils need the use of **aluminum reinforced conductors.**

High purity aluminum stabilizer alone cannot be used (yield strength ~ 30MPa at 4K)

Accelerator	Detector	B [T]	R[m]	L[m]	I [kA]	E [GJ]	comment
LHC	CMS	4	3	13	20	2.7	scaling up
LHC	ATLAS solenoid	2	1.2	5.3	7.8	0.04	scaling up
FCC-ee [Ch8-1]	CLD	2	3.7	7.4	20-30	0.5	scaling up
	IDEA	2	2.1	6	20	0.2	ultra light
CLIC [Ch8-2]	CLIC-detector	4	3.5	7.8	20	2.5	scaling up
FCC-hh [Ch8-3]	main solenoid	4	5	19	30	12.5	new scaling up
	forward solenoid	4	2.6	3.4	30	0.4	scaling up
IAXO [Ch8-4]	8 coil toroid	2.5	8x0.6	22	10	0.7	new toroid
MadMax [Ch8-5]	dipole	9	1.3	6.9	25	0.6	large volume

Table 8.1: Examples of magnets for future experiments that represent the engineering and R&D challenges. The dimensions and fields refer to the free bore. The magnets for ATLAS and CMS are given for reference.

Source ECFA DRD Roadmap 2021

Day 3: Strategic Discussions

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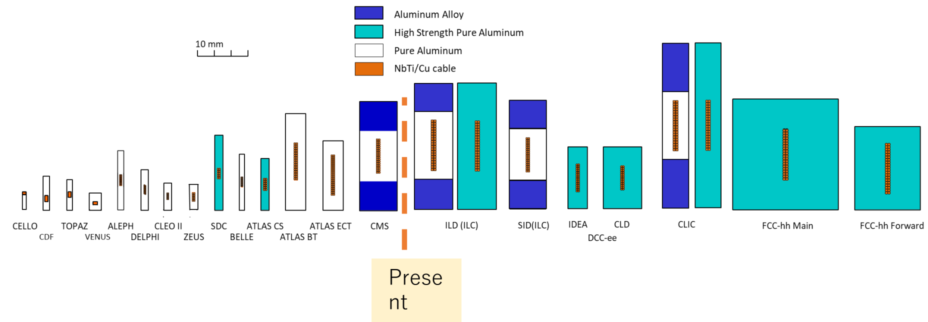
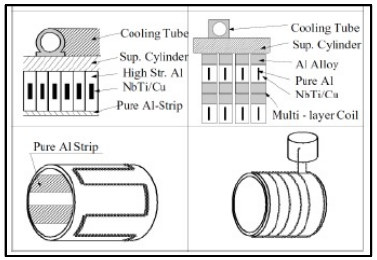
	Experiments	Site	B	Size ID x L	Energy (MJ)	Note	Fabrication Expected
Collider	EIC-Detector	BNL	1.5~3	2.5~3.2 x 8.5	45.7	Cu only	2025 ~
	ILC-ILD	Japan	4	6.88 X 7.35	2300		2030 ~
	ILC-SiD	Japan	5	5 X 5	1400		2030 ~
	CLICdet	CERN	4	7 X 8.3	2320		2035 ~
	FCC-ee IDEA	CERN	2	4.2 X 6.0	170		2035 ~
	FCC-ee CLD	CERN	2	7.4 X 7.4	600		2035 ~
	FCC-hh	CERN	4	10 X 20	13800		2040 ~
Others	BabyIAXO	DESY	2	0.7 X 10	38	Racetrack	~2024





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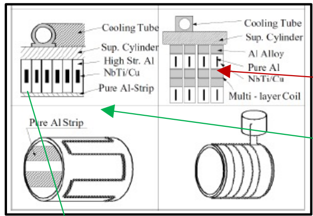
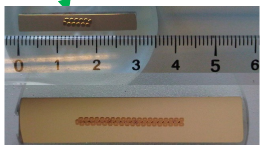
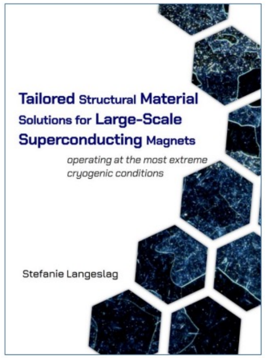
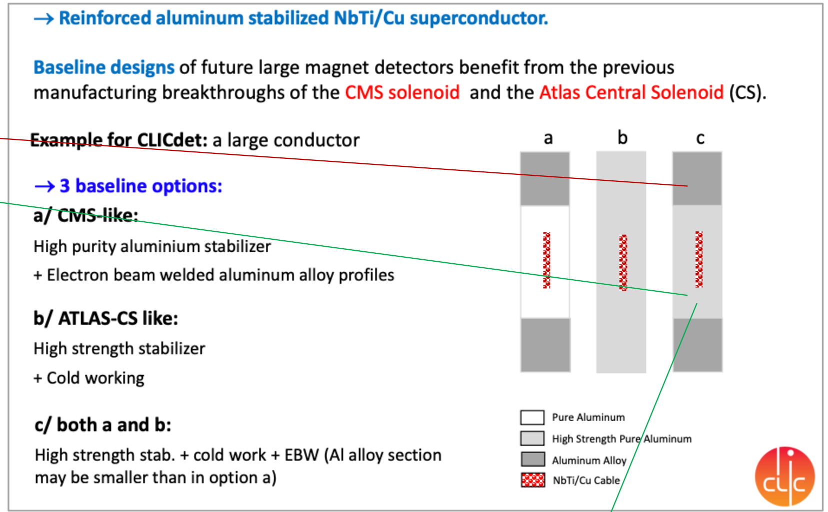


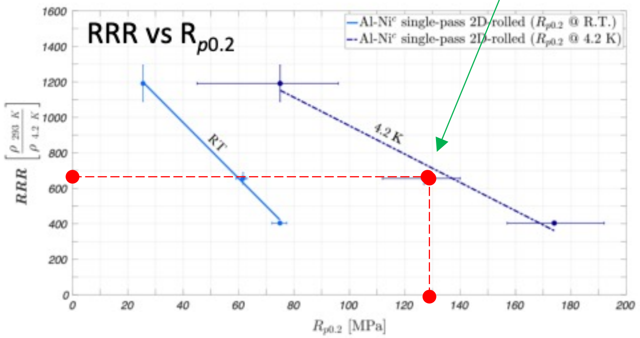




Ph. D. thesis, 28th May, 2020, University of Twente, The Netherlands

ISBN: 978-94-028-2052-2





RRR plotted against $R_{p0.2}$, for the various cold-worked states, at both room temperature and 4.2 K. Notice the large increase in $R_{p0.2}$ at 4.2 K compared to room temperature.

Day 3: Strategic Discussions

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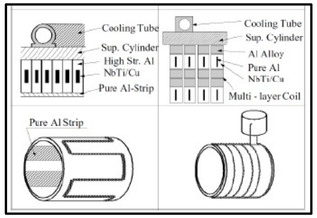
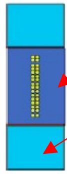
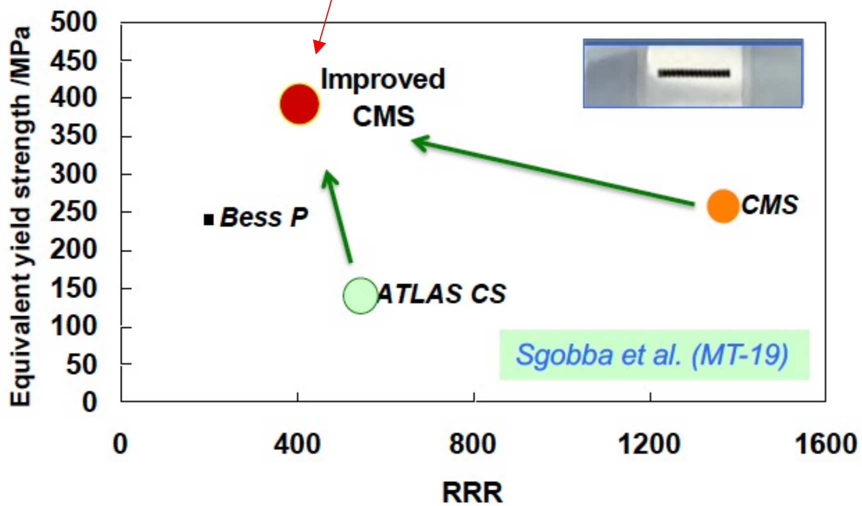




	Rein-force	Feature	Al Y. S. (MPa)	Full cond. Y.S.	Full cond. RRR
ATLAS-CS	Uniform	Ni-0.1% Al	110 MPa	146 MPa	590
CMS	Hybrid	Pure-Al & A6082-T6	26 / 428	258	(1400)
Future	**Hybrid**	**Ni-Al & A6082-T6**	**110 / 428**	**300**	**400**
Future	**Hybrid**	**Ni-Al & A7020-T6**	**110 / 677**	**400**	**400**



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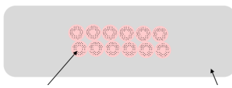
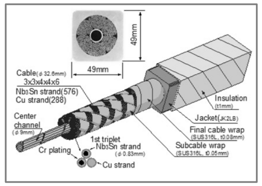
Possibility

FURUKAWA ELECTRIC

Items	Co-extrusion	CICC	WIC
Combining Process	Detector Outside	Fusion (ITER) Outside?	MRI etc In house ?
Stabilizer	high purity Al-Ni	Conduit ? Al wire ?	Cu-clad high purity Al ? Cu ?
Ic	X	X	X
RRR	X	High purity Al ?	High purity Al ? Cu?
Strength	Cold work	?	?
Bonding	Diffusion	?	Soldering
Dimension	Drawing	Conduit	Channel
Surface Defect			

3





Day 3: Strategic Discussions

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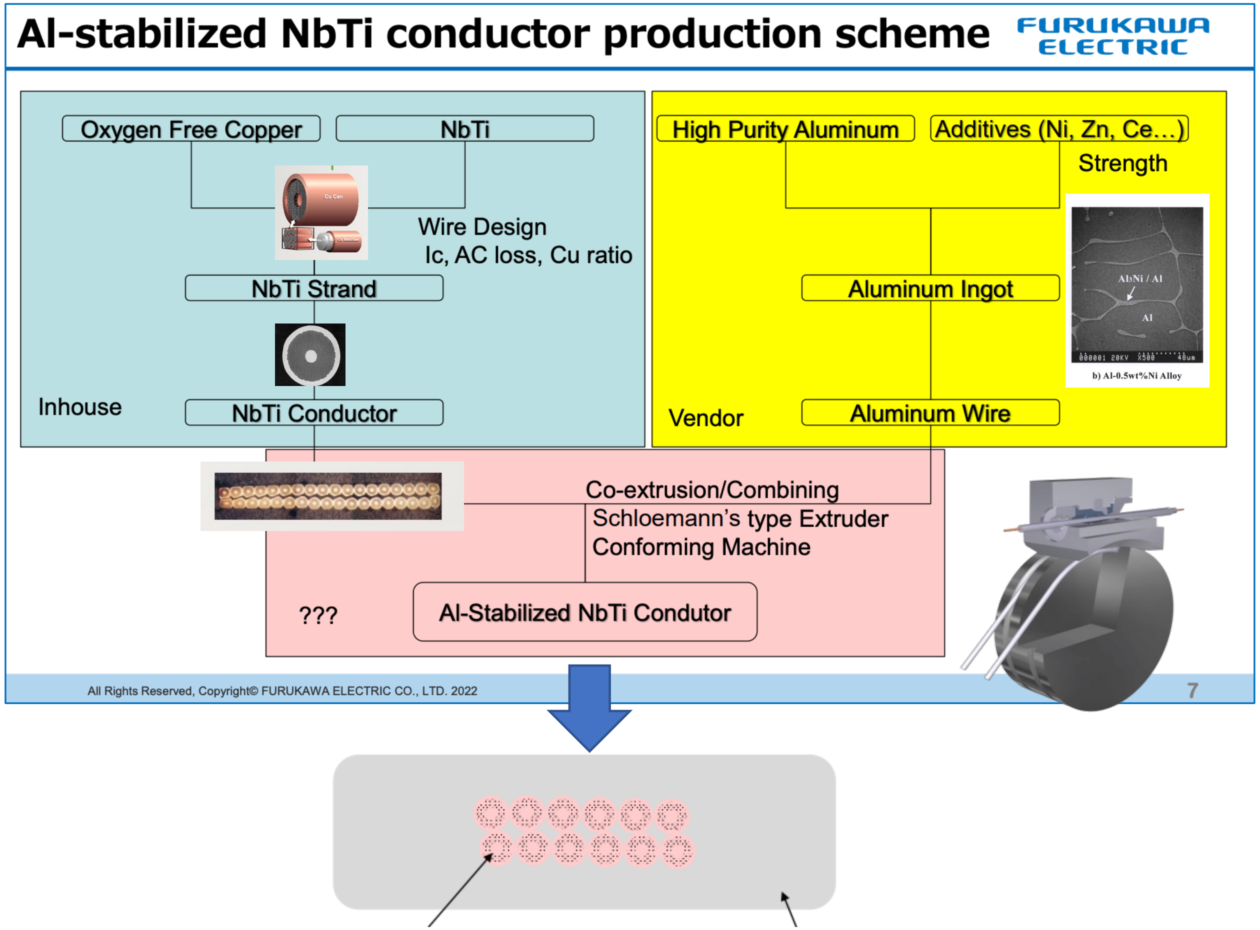

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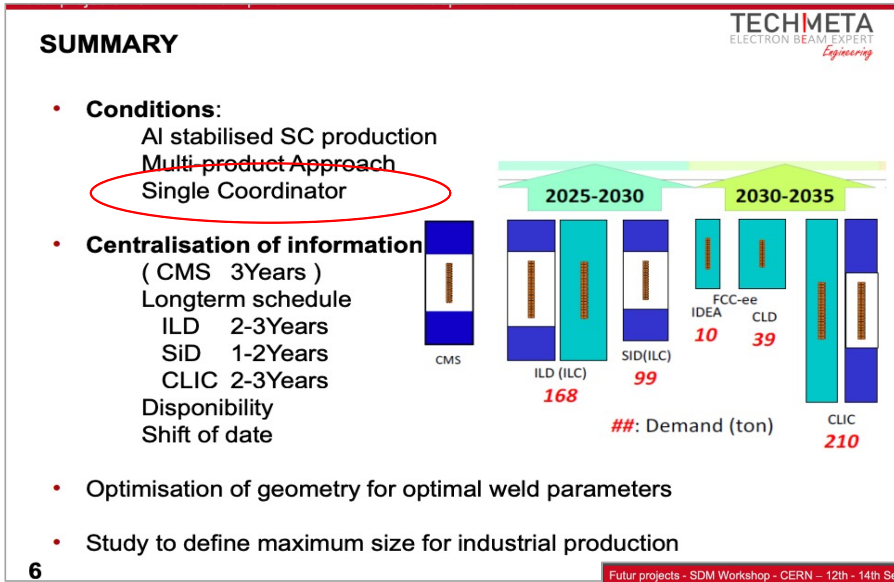

Day 3: Strategic Discussions

Reliable Al Soldering Technology
to be advanced with Cu-coated Al technology

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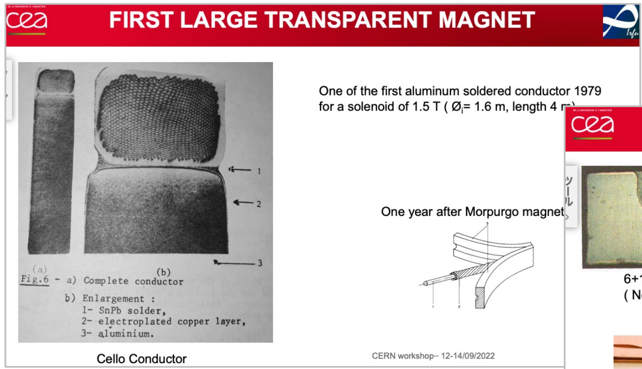

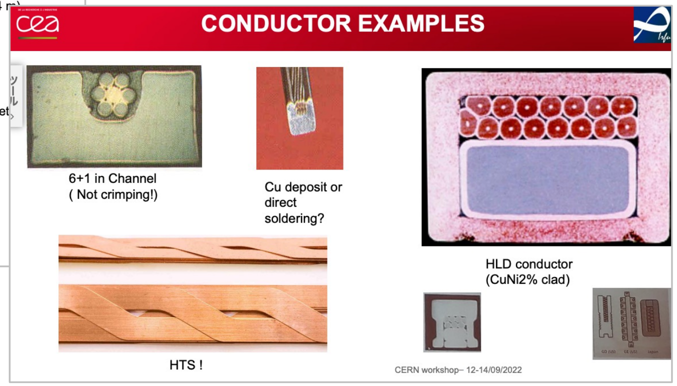

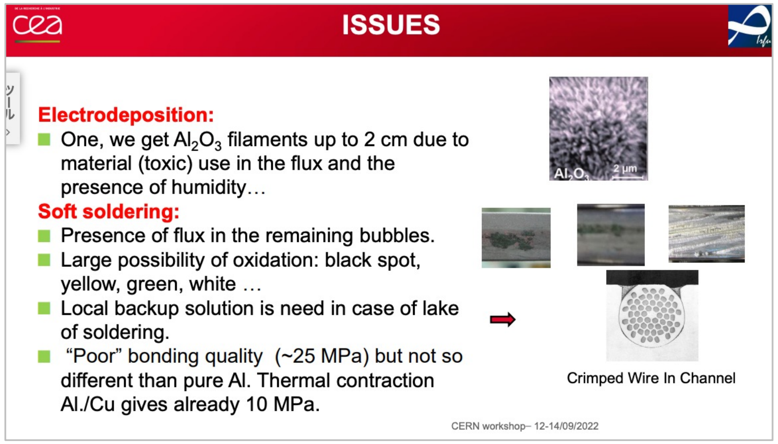

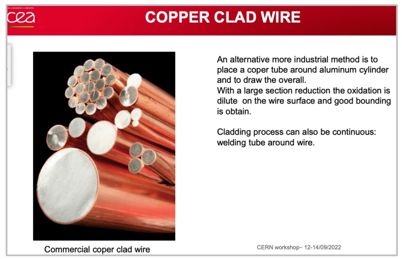

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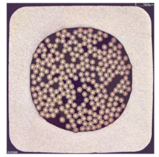
CICC Appplications in HEP Detector Magnet?



Conclusions 1

HEP Application 1: *Al stabilised low(ish) field for transparent applications*

ISSUE	HOW CICC COULD PERFORM	Improvement over conduction-cooled Al-stabilized Cond/Coil?
Conductor fabrication tooling: availability and cost (including strands)	Tooling (cabling and jacketing) can be simple (easy to make complicated too....) using standard manufacturing sub-steps, tooling available. Much flexibility to adapt composition with materials	Yes
Manufacturing process of the magnet (coil winding)	Conventional, CICC has more flexibility to choose X sections and aspect ratio. Even locked hexagonal shape! And X section can vary (with joints)	=
Operational performance of the conductor	Normally more stable than Rutherford cable due to He, more resistant to local damage. Issue is what is required, HEP generally low disturbance	Maybe more compact
High-voltage sustainability	W&(R)&I route would be conventional insulation. More scope for more insulation with convection cooling, scope for shaped conductors to reduce insulation loads	Maybe
Cooling scheme during pre-cooling and in steady state	CICC could have very low in-channel flow and be substantially conduction cooled, or use intermediate He inlets to increase convection cooling	More complex, likely better performing
Physical envelope including cooling path and joints of conductors	Cooling paths can be separated from electrical paths which allows design flexibility. Experience (ITER CS Nb3Sn) on very compact in line joints	More complex, likely better performing
Quench protection	Fast discharge based similar, probably higher internal propagation with convective cooling. Maybe more scope to embed quench triggers in cable	=

Advantage: Stability because of Direct He contact

Issue: Cooling system complexity

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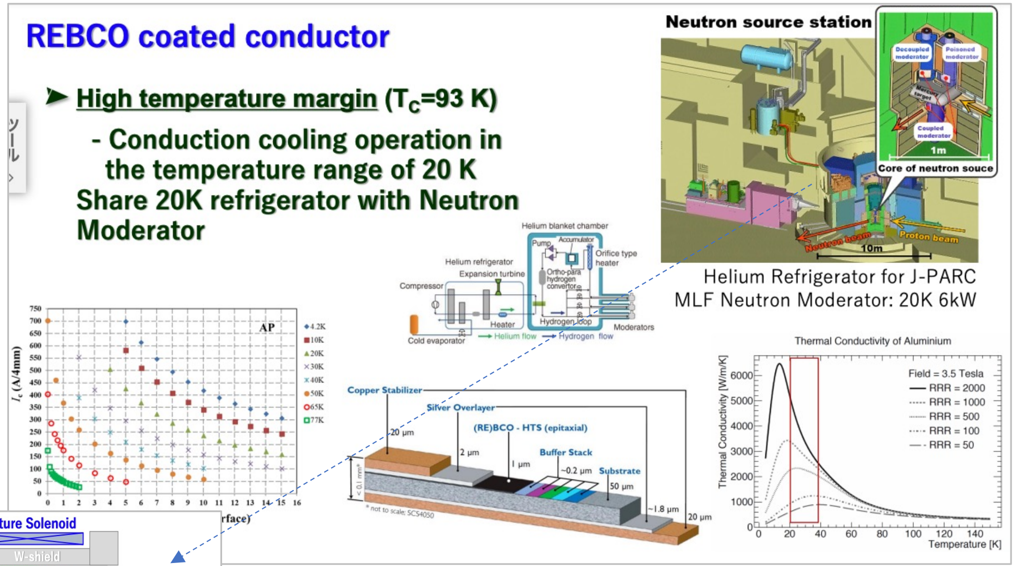
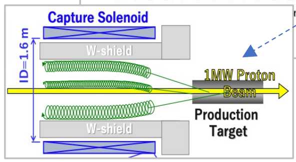
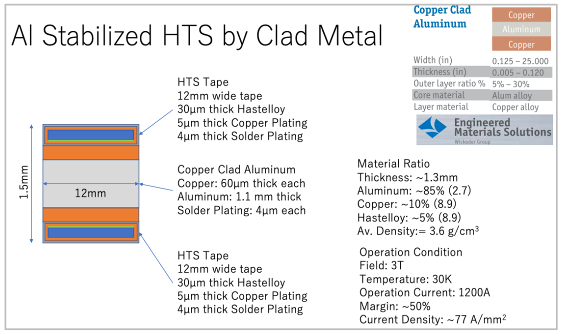
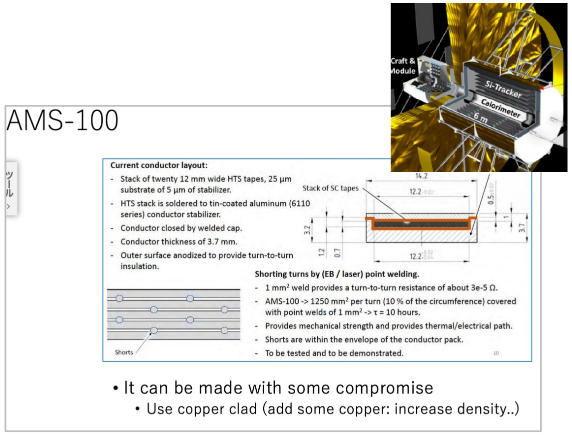
Al-stabilized HTS applications in Future









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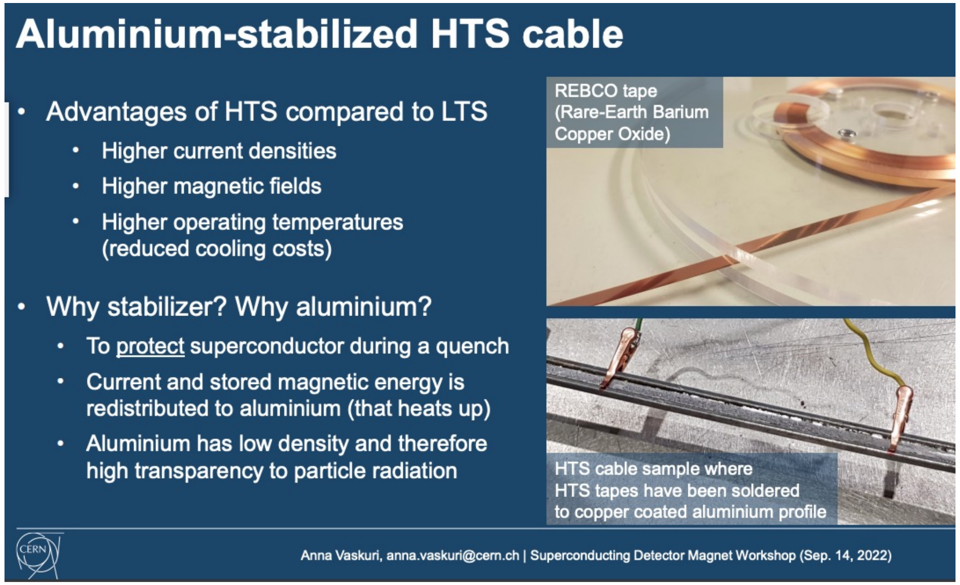
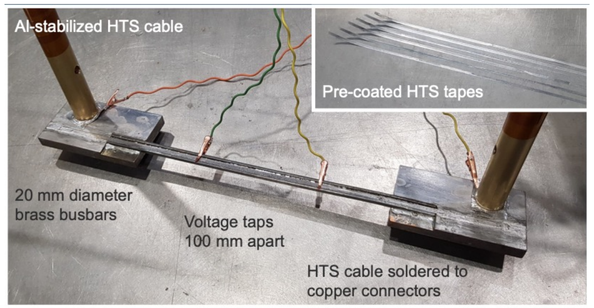
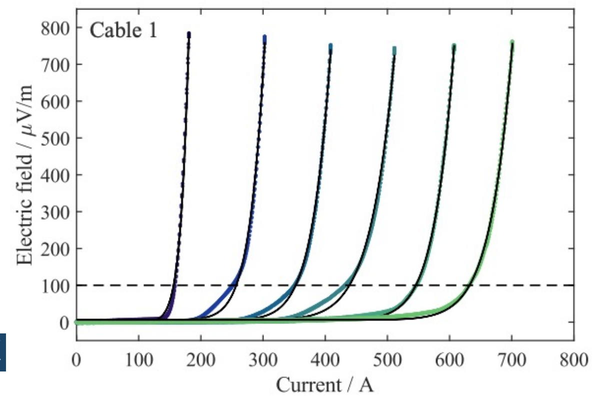




First sample that was measured in LN_2 at 77 K



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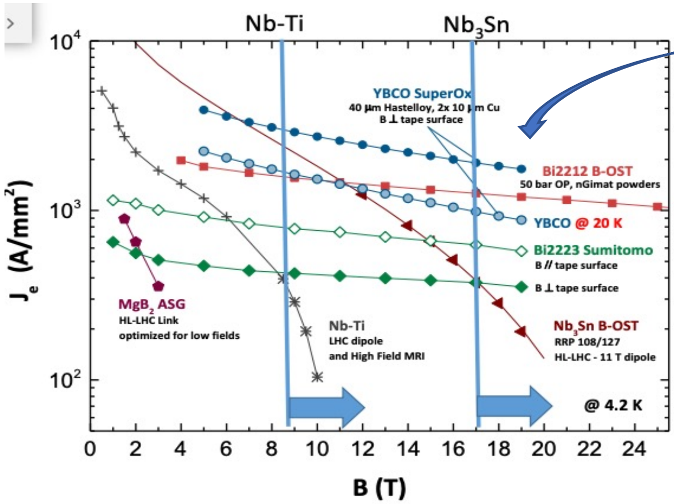
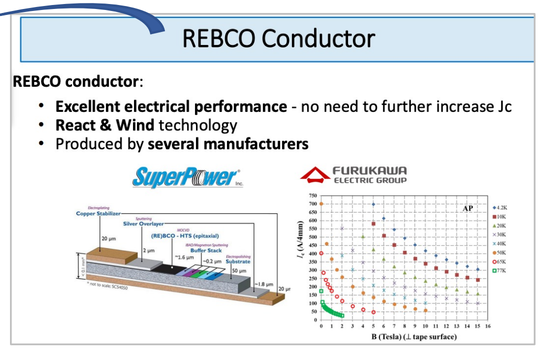
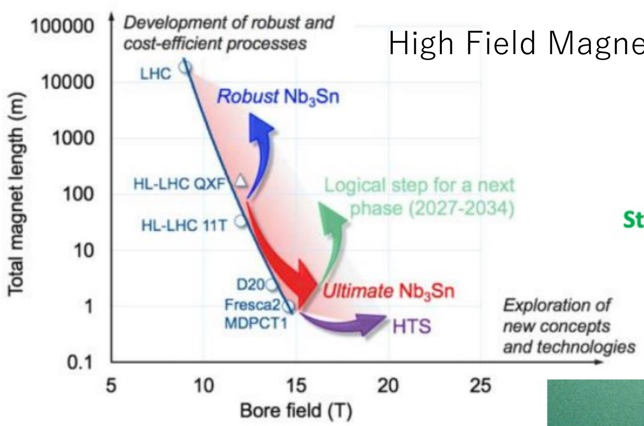




HTS: the only choice for
- B > ~16 T
- T-op > ~ 30 K



High Field Magnet Program - R&D Objectives

Phase 1: 2022 -2027

Phase 2: 2027 -2034

Study feasibility of 20 T dipoles

European Strategy Update | LDG Laboratory Directors Group

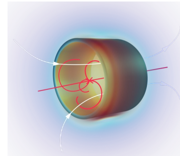
Day 3: Strategic Discussions

Outlook:

- Al-stabilized superconductor/magnet technology needs to be resumed,
- Industrial cooperation anticipated and strongly encouraged, in particular,
    - "Co-extrusion technology" of Al-stabilizer and NbTi/Cu-conductor to be resumed and widely available, and
    - "Hybrid-structure technology" by using electron beam welding (EBW) or by other approaches, to maximize the performance of Al-stabilized SC (Ni or Cu/Mg doped) combined with ultimately high-strength Al-alloy structure.
- Laboratory's leading effort will be very important to advance the technology to be openly transferred to the industry.

Remarks:

- Seek for common SC and magnet design concept, even part, for cost-effective development, as possible as we can
- Seek for worldwide cooperation among laboratory and industry
- It will be important to investigate/seek for backup solutions such as soldering/friction-welding technology of NbTi/Cu conductor with Cu stabilizer, Cu-coated Al-stabilizer, and/or CICC. In long-term future,
- Al-stab. HTS stabilized will provide important potential in specific detector magnet applications.
- The next workshop will be planned to be held in 1 ~ 2 years, based on the R&D advances expected.



Outcome from the Workshop (1/2)

We have looked into the possible approach for Al-stabilized Superconductor production, for each step:

- **Production of NbTi/Cu Rutherford Cable**
  - Industrial availability: **Multiple companies (+ Institutes)**
- **Co-extrusion of Al-stabilized SC cable**
  - Laborabory availability:
    - **to be launched for leading R&D/Prototyping and knowledge transfer**
  - Industrial availability: **Toly Electric ('single' as of today)**
- **Assembly with Aluminum alloy for reinforcement:**
  - EBW Industrial availability → **Techmeta**
  - Soldering → to be further investigated (as back-up)
  - Friction welding → to be investigated (no past experience with continuous welding of Al-stab SC)

Outcome from the Workshop (2/2)

Discussions for Future

Alternate Options as backup:

- CICC : NbTi + SUS/Al jacket
  - ➢ Benefit: He flow in Conductor Jacket contributes to "Stability"
  - ➢ Complexity: Sophisticated Cooling channels and connections, pre-cooling in parallel, etc

Future Extension:

- HTS + soldering of Aluminum stabilizer
- Cooperation with Accelerator High Field Magnet R&D program ?

Conclusion

What we need to resume / do next ?

Investigate multiple approaches for Al-stabilized SC

- Cooperation with industry
  - NbTi/Cu cable, Al-co-extrusion, Assembly with Al-reinforcement
  - Cost-effective approach need to be seriously investigated
- **Laboratory own effort**, in particular on
  - **Al-coextrusion facility and own R&D for leading technology advances**

Seek for common SC and magnet design concept, even part, for cost-effective development,

Seek for worldwide cooperation among laboratories and industry

Figure out Next meeting / workshop opportunity

- Based on sufficient progress, hopefully within 1 ~ 2 years to be held in Japan or the US, according the progress in the detector magnet technology advances.

Conclusion

Superconducting Detector Magnet Experts joined for a few days.

Following fruitful exchanges, experts now sharing a common understanding of the situation on the manufacture of detector magnets in the world.

Plans for resuming advanced R&D/prototyping (in view of production) with common approach to be drafted and proposed to Institute managements.

Special Thanks for Nikkie Deelen and Connie Potter, for the WS coordination !

Summary of the Workshop to be presented

at EP Seminar and Colloquia, Friday, 23 September

by Benoit Cure, Matthias Mentink

https://indico.cern.ch/event/1200637/

Detector Seminar

Summary of the Workshop on Superconducting Detector Magnets

by Benoit Cure (CERN), Matthias Mentink (CERN)

Friday 23 Sept 2022, 11:00 → 12:00 Europe/Zurich

40/S2-D01 - Salle Dirac (CERN)

Description A 'Superconducting Detector Magnets Workshop' took place at CERN from September 12-14, 2022, bringing together the physics community, magnet designers and industry with the purpose to exchange about the future needs and efforts to be achieved in research and development in order to build the next magnet generations for Future Colliders and Beyond Collider Physics Experiments.

The industrial capacities and their availabilities, with the foreseen prospects and plans, were addressed and representatives of industry working on all aspects of superconducting detector magnets were given. A topic of particular importance addressed was the availability of aluminium-stabilized Nb-Ti/Cu conductors.

The workshop provided a forum for the exchange of ideas, concepts, and best practices, to advance on superconducting detector magnet technologies and to foster collaboration.

In the seminar the key points coming out from the workshop will be summarised.

Superconducting D...

Organised by Burkhard Schmidt (EP-DT)

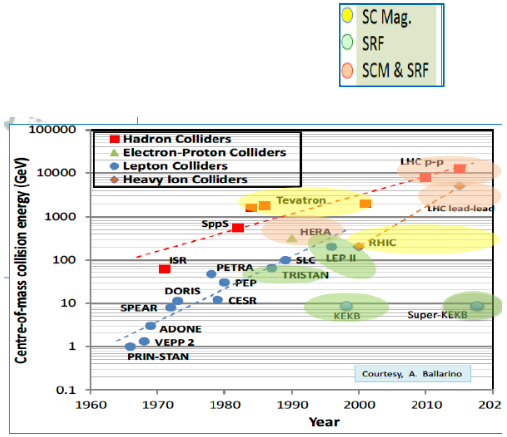
Videoconference Detector Seminar - 23 September Join

Webcast There is a live webcast for this event Watch

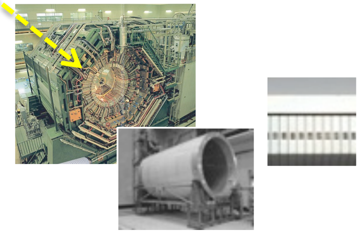
Contact ep-seminars.colloquia@cern.ch

Reserved

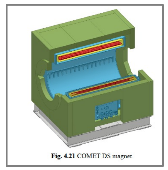
History of Detector Solenoids

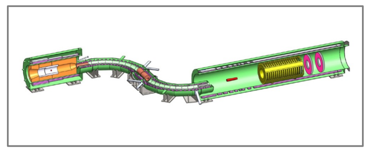


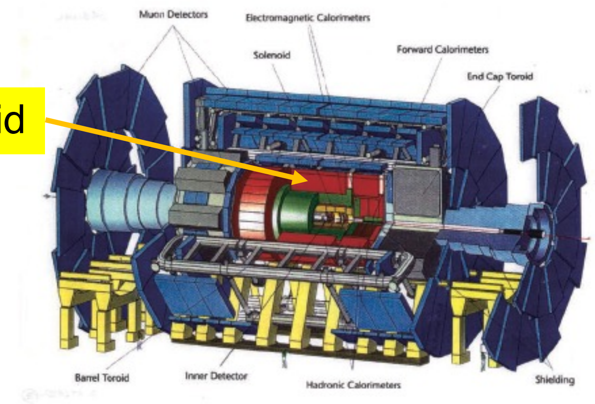
Experiment	Laboratory	R (m)	B (T)	I (kA)	X (X_0)	E/M (kJ/kg)	E (MJ)	Year
PLUTO	DESY	0.75	2.2	1.3	4.0	2.3	4.1	1972
ISR point 1	CERN	0.85	1.5	2	1.1	1.8	3.0	1977
CELLO	Saclay/DESY	0.85	1.5	3	0.6	5.0	7.0	1978
PEP4/TPC	LBL/SLAC	1.1	1.5	2.27	0.83	7.6	11	1983
CDF	KEK/FNAL	1.5	1.6	5	0.84	5.4	30	1984
TOPAZ	KEK	1.45	1.2	3.65	0.70	4.3	19	1984
VENUS	KEK	1.75	0.75	4	0.52	2.8	11.7	1985
AMY	KEK	1.2	3	5	N/A	N/A	40	1985
CLEO-II	Cornell	1.55	1.5	3.3	2.5	3.7	25	1988
ALEPH	Saclay/CERN	2.75	1.5	5	2.0	5.5	136	1987
DELPHI	RAL/CERN	2.8	1.2	5	1.7	4.2	110	1988
ZEUS	INFN/DESY	1.5	1.8	5	0.9	5.2	10.5	1988
H1	RAL/DESY	2.8	1.2	5	1.8	4.8	120	1990
BESS	KEK	0.5	1.2	0.38	0.2	6.6	0.25	1990
WASA	KEK/Uppsala	0.25	1.3	0.9	0.18	6	0.12	1996
BABAR	INFN/SLAC	1.5	1.5	6.83	0.5	N/A	27	1997
D0	FNAL	0.6	2.0	4.85	0.9	3.7	5.6	1998
BELLE	KEK	1.8	1.5	4.16	N/A	5.3	37	1998
ATLAS-CS	KEK/CERN	1.25	2.0	7.8	0.66	7.1	38	2001
BESS-polar	KEK	0.45	1.0	0.48	0.156	9.2	0.34	2005
CMS	CMS/CERN	3.0	4.0	19.5	N/A	12	2600	2007
BESIII	IHEP (China)	1.45	1.0	5	N/A	2.6	9.5	2008
CMD-3	BINP	0.35	1.5	1	0.085	8.2	0.31	2009



COMET (KEK) --- under construction, AL-stab. SC in 2013-2015
Mu2e (Fermilab) --- under construction, Al-stab SC in same time

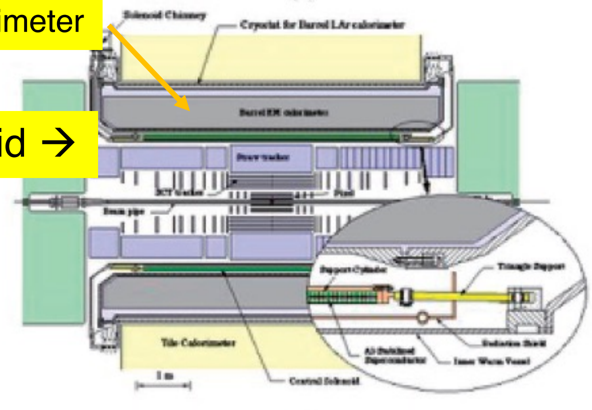






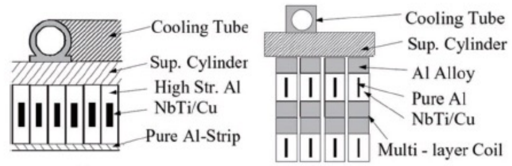
(a)

(b)



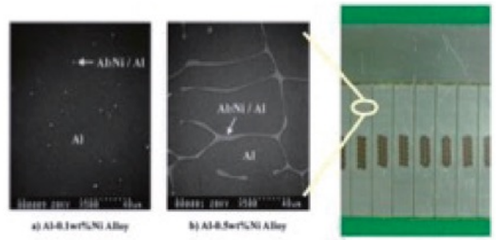
(c)

ATLAS-CS, placed inside Calorimeter



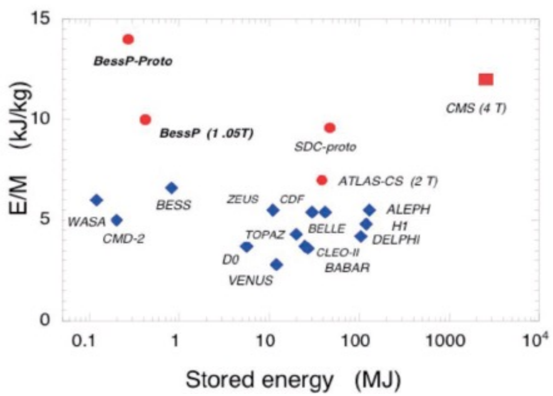
(a) (b)

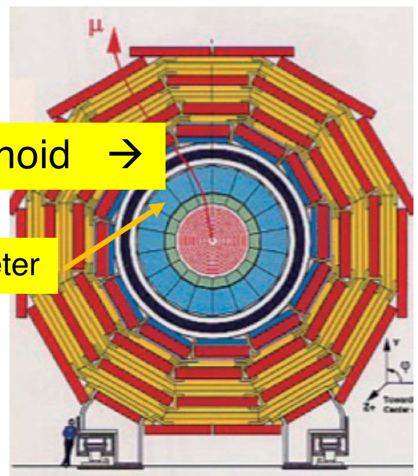
図 19 ATLAS および CMS 超伝導ソレノイドコイル断面図.



(a) (b) (c)

図 20 Ni 添加による Al-Ni 析出 ((a) 100 ppm, (b) 500 ppm), および ATLAS アルミ安定化超伝導コイル断面.





CMS Solenoid placed outside alorimeter