Status and Plans of Aluminium Stabilized Conductor R&D at CERN for Detector Magnets

Benoit CURE

05.10.2023

Context

Future Physics Experiments anticipated :

- **Colliders:**

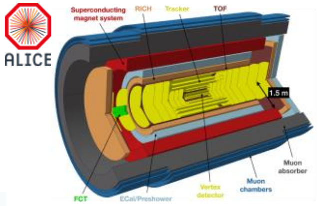
  Alice3 (CERN), FCC-ee -hh –he (CERN), CLIC(CERN), Muon Collider (CERN), ILC (IDR,SLAC), CEPC (IHEP), Panda (GSI/Fair), EIC(BNL, J-Lab).

- **Non-Colliders:**

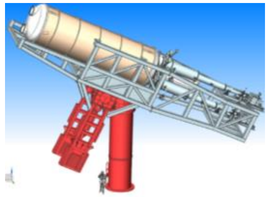
  Babylaxo (Desy), SHiP (CERN), Muon Beam Experiments (Comet-KEK, Mu2e-Fermilab), MadMax (Desy), AMS100 (RWTHAAchen)

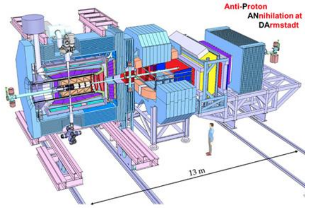
→ **More than 15 projects**, either:

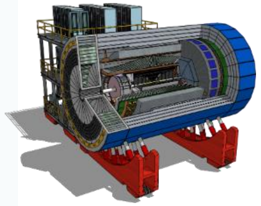
- Under construction,
- Design phase,
- Conceptual phase.

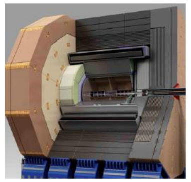


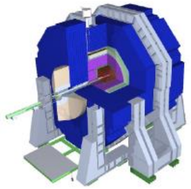
Alice-3

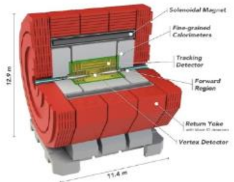

BabyIAXO

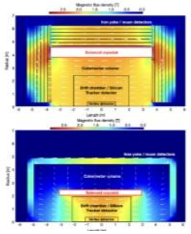

PANDA

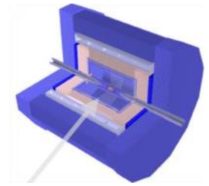

EIC

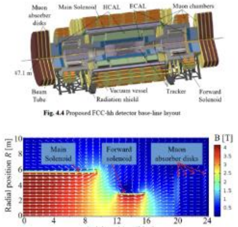

ILC-ILD

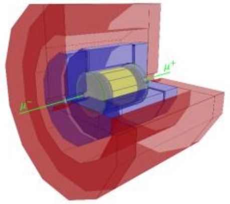

ILC-SiD

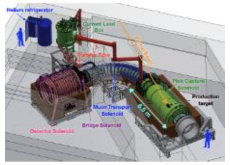

CLICdp


FCC-ee

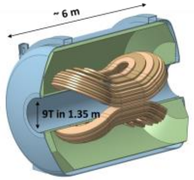

CPEC


FCC-hh

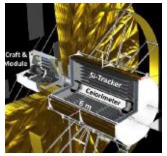

iMuC


Comet


Mu2e



MadMax

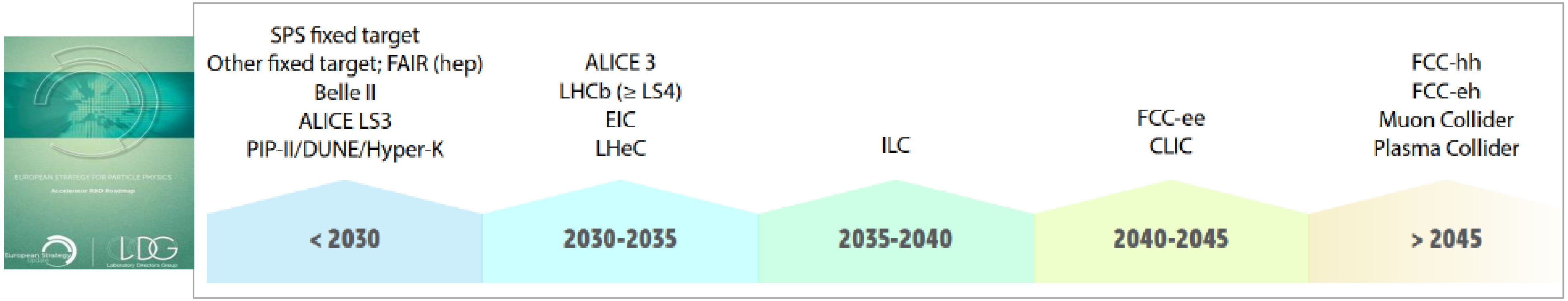

AMS100

High Energy Physics projects timeline

Short term (within ~ 5 - 8 years):

4 identified projects: Babylaxo , Alice3 , Panda, EIC.

Long(er) term :



Future proposed particle physics experiments being studied: from LDG Accelerator R&D Report, CERN 2022-001

Next generation of Detector Magnets for HEP

Detector magnet designs:

- **Typical field range 2 T ~ 4 T,**
- **Thin coils** within the calorimeter volume, as transparent as possible for particles,
- **Large coils** with high stored energy (**up to GJ**) and magnetic forces,
- **Large bore** (several meters) **and lengths** .

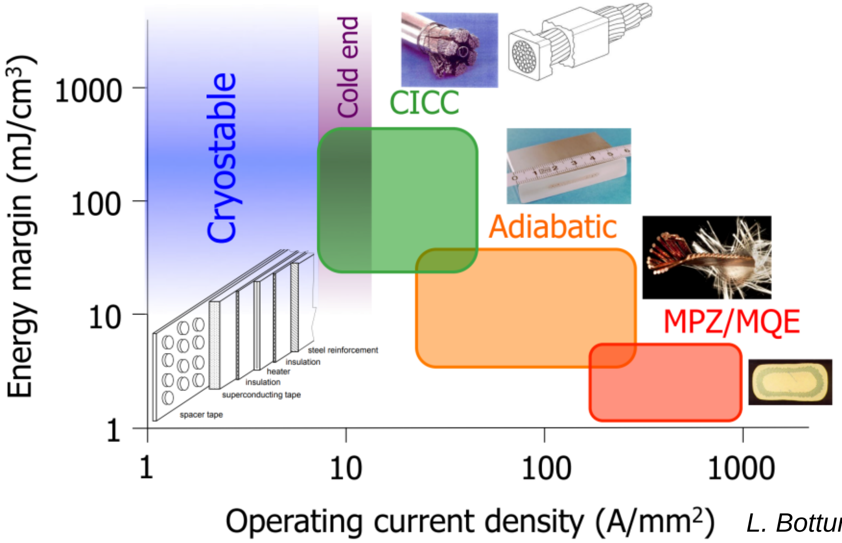
Need of well proven and sturdy technologies:

- **No magnet pre-series**, no spare, each magnet is one-of-a-kind, any repair hinders strongly physics program.
- With **reduced complexity** for conductor and coil manufacturing,
- Based on **enthalpy stabilization** + energy extraction for quench protection, indirect cooling.

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.

ECFA Roadmap 2021

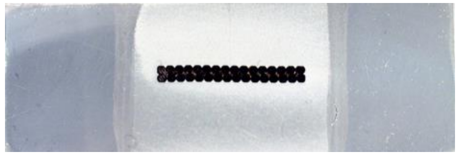


L. Bottura, CAS 2013

Next generation of Detector Magnets for HEP

Aluminium gives the strong performance needed (heat capacity, electrical and thermal conductivity at low T, strong mechanical properties with Al-doped or Al-alloy)

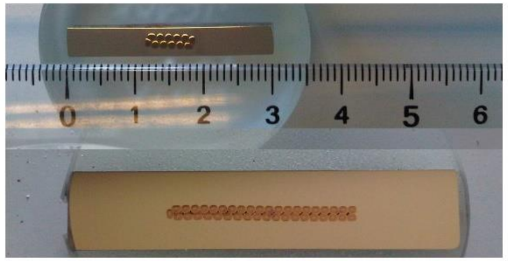
Aluminium stabilized reinforced conductor is the preferred technology today.



CMS conductor

Aluminium Co-extrusion is also preferred to other technologies (CICC, WIC, soldering)

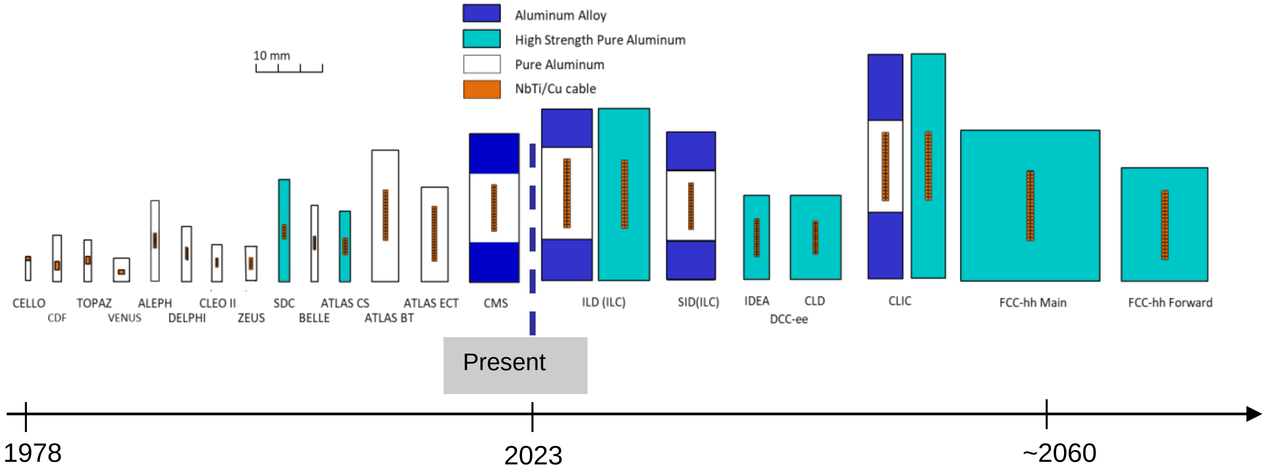
Successfully used in many (most of) past and on-going detector magnets.



ATLAS conductors

→ **Baseline design** **for all future detector magnets:**

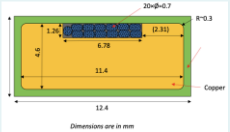
Reinforced Co-extruded Al-stabilized SC, with NbTi/Cu Rutherford cable



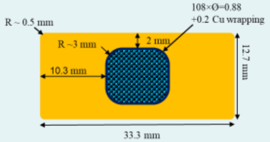
Courtesy Prof. A. Yamamoto, KEK

Exceptions: copper, but as back-up solution, when possible

- **EIC** plans to use Cu-stab SC for solenoid #1, in case of **the Al-stabilized SC not be available within time**. Al-stabilized SC needed for solenoid #2.
- **MADMAX** is planning to use Cu-based CICC SC because other conductor types are presently **not commercially available.**



EIC



MADMAX

Production past experience

This press used for CMS and Atlas BT has been dismantled

Courtesy Nexans-Cortaillod,CH, 2003

Example: ATLAS BT and CMS

- aluminium stabilized SC cables were produced in industry by cable manufacturers
- Active collaboration between Collaborating Institutes and cable manufacturer (e.g. materials, testing, metrology)
- Collaborative development through prototyping then fabrication.

- Superconducting Rutherford cable provided by Collaborating Institutes, supplied from industry: NbTi/Cu + cabling

Nowadays also cabling capacities in institutes (CERN, LBNL, FNAL).

Production capacities

Last production:

- LHC experiments Atlas (BT, CS, ECT), CMS (1999~2004)
- Comet, Mu2e (2007~2022)

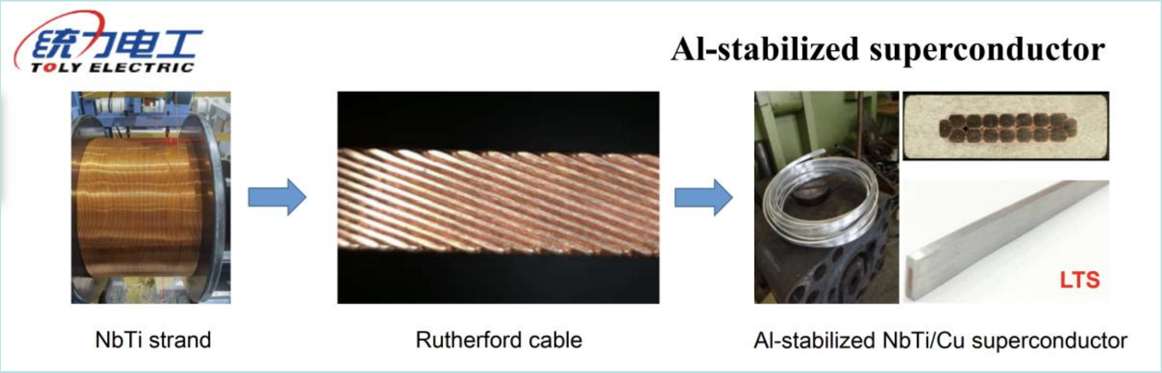
None of the past production sites are any longer available or interested in producing these conductors.

Today only one site identified for R&D and production of Al-stabilized superconductors:

Wuxy Toly Electric Works, China:

- Several 1.5km lengths for Experimental Muon Source (EMuS), China.
- R&D with HTS Rebco for CPEC with IHEP Beijing.

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



Courtesy Wuxy Toly Electric Works Co., Ltd, PRC

Production needs

Detector magnet conductors:

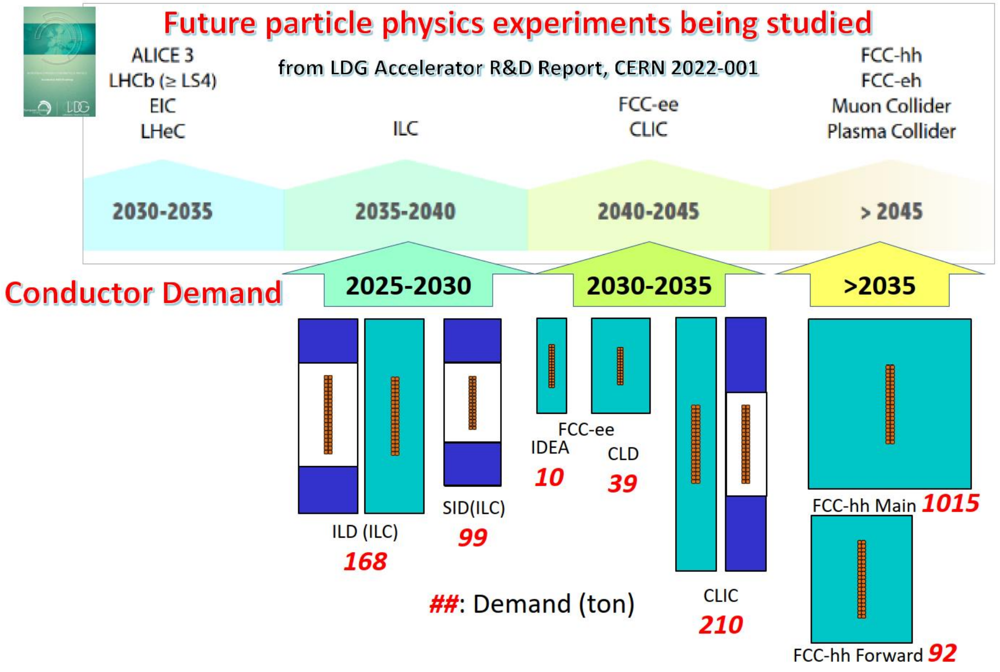
- **Low volume production compared** to the volumes handled in the cable industry.
- **Production not regular, scheduling only case by case**: detector magnet projects do not follow one another on a regular basis.
- **Need to keep production capacity over the years** (sustainability of production tools).

2025 - 2030

Typical cross sections	Panda	Babylaxo	Alice 3
Rutherford NbTi/Cu cable	5.3 x 2.5 mm^2	12 x 2.5 mm^2	7.8 x 2.5 mm^2
Superconductor with aluminum cladding	12.3 x 8.9 mm^2	20 x 4.5 mm^2	26.1 x 8.6 mm^2
Total superconductor weight (metric ton)	3	9	12
Total length (km)	8	22	21

Future Colliders and Conductor Demand

Courtesy: Y. Makida



Motivations for R&D

Issue raised during the **Superconducting Detector Magnet Workshop (**CERN, Sept. 2022)

- **The coextrusion technology for Al-stabilized superconductors has to be resumed and more widely available,**
- **A leading effort by Institutes is needed for an R&D program to advance the technology of Al-stabilized SC, to be openly transferred to the industry.**

References:

- Superconducting Detector Magnet Workshop, Sept. 2022, https://indico.cern.ch/event/1162992/
- A.Yamamoto, M. Mentink, B. Curé, Summary of the Superconducting Detector Magnet Workshop for Future Colliders & Physics Experiments, CERN Detector Seminar, https://indico.cern.ch/event/1200637/.

ECFA Roadmap – Detector Research and Development Themes (DRDTs) 8.1

Short list of key technologies needed for magnets of collider experiments :

- Al-stabilized high-yield strength Rutherford cable superconductors,
- Ultra-Thin conductors Al/Cu/NbTi,
- Long term: development of high temperature superconductors for coils and current leads.

Reference: ECFA Detector R&D Roadmap Process Group, Geneva : CERN, 2020. - 248 p., DOI: 10.17181/CERN.XDPL.W2EX

Program objectives

Restoring industrial availability of Aluminium co-extruded superconductors:

- to maintain R&D and production capacity,
- not only relying on one supplier as of today for future R&D and production.

- **Scope**:

  Produce sample lengths in view of scaling up to production for future detector magnet conductors.

Set up a coextrusion + coldworking line for aluminum-stabilized superconductors, to perform :

1. Prototyping with production of short demonstrator length (with NbTi/Cu),
2. Further potential developments and applications (e.g. Al-stab HTS).
3. Future production of superconductors for detector magnets,

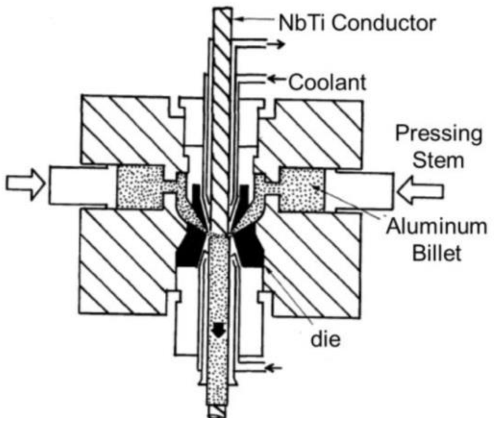
- Target a **sustainable** and lasting solution, available for the detector magnets of future projects, to avoid repeating the re-establishment of an R&D and production line for each magnet project.
- Provide for the possibility of **internalizing** all or part of the development line within a participating Institute, if an industrial partner(s) decide to withdraw from the project.

Co-extrusion

We need access to a coextrusion line

Targeted technology: conforming process (continuous rotary extrusion) for small to medium cross sections, continuous, small machine size.

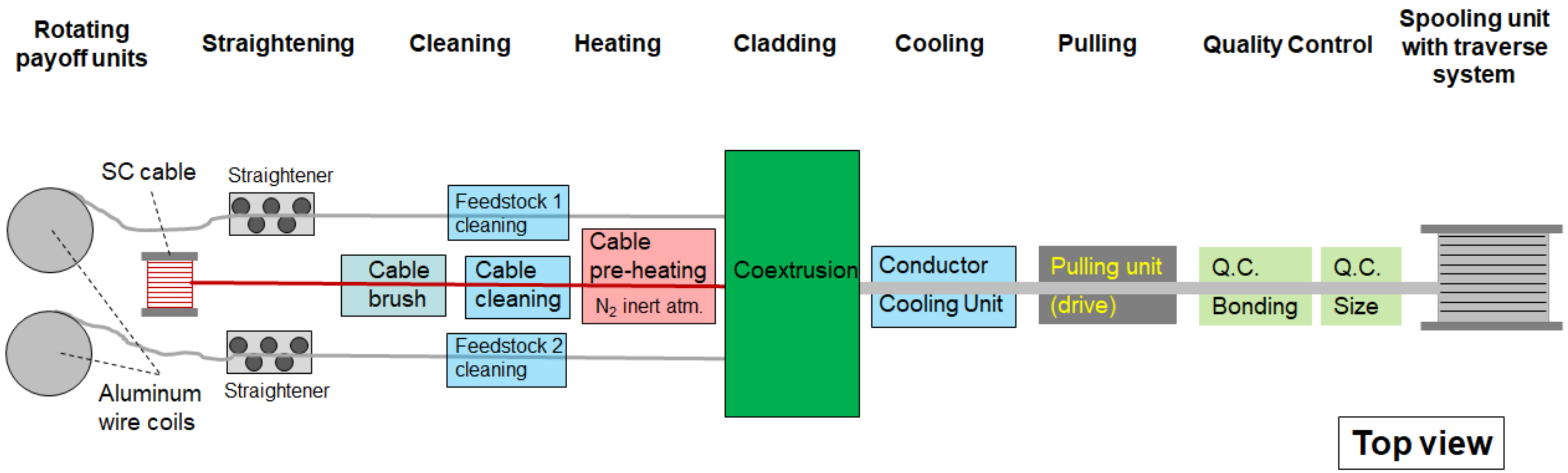
Other technology: Schloemann's process for large cross sections, billet-on-billet, large machine size (most used not continuous).

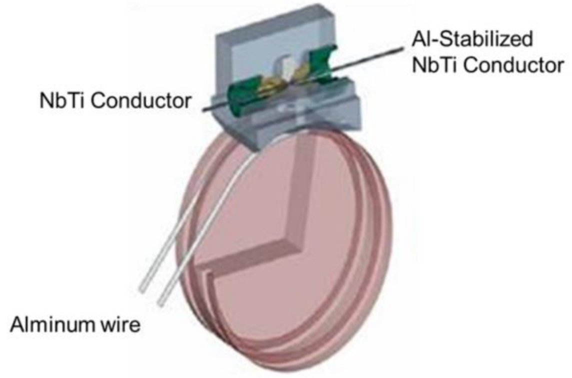


Schematic view of Schloemann's cable cladding press

K.Saito et al., J.JILM, Vol. 35, No. 5 (2020), 297-303

Typical sketch of a coextrusion line (conform process)





Schematic view of conforming process

https://bwe.co.uk/conklad/

Cold-working

We also need access to a cold-working facility,

for conductors with structural aluminium stabilizer AND to reach the dimensional accuracy of the conductor.

Such a process was successfully applied to **Atlas CS conductor** (KEK, Furukawa, Hitachi - JP) with **doped Aluminium structural stabilizer**.

- Contact through CERN (S. Sgobba et.al.) with ENEA, Italy, to access to a test facility.
- **Possible to perform testing on short samples, in a first stage**.
- Sample cold work tests were done in 2013.

S. A. E. Langeslag et. al., "Characterization of a Large Size Co-Extruded Al-Ni Stabilized Nb-Ti Superconducting Cable for Future Detector Magnets," in *IEEE Trans. on Applied Superconductivity*, vol. 23, no. 3, June 2013, Art no. 4500504

Example of equipment (Criotec, ENEA - IT):

- 50-ton, actively driven, four-roll Turks head mill (DEM SpA),
- Used for production of the ITER cable-in-conduit [Della Corte et al., 2013].

CERN organization for Detector Magnets

Steering committee set up at CERN in March 2023

Decision taken by AT and RC CERN Directors and Department Heads EN, EP & TE, on a cooperation between the Accelerator and the Research sector on experiments magnets.

Co-leaders: Said Atieh (EN/MME), Benoit Curé (EP/CMX)

Cooperation at CERN between the Accelerator and the Research sectors on experiments magnets.

It concerns in particular the issue of non-availability of Alu-stab SC.

Working Group (initiated following the SDMW)

Members from: - **CERN** EN, EP, TE departments.

- **KEK.**

The WG is now working on establishing a program on coextrusion process for Al-stab SCs with institutional and industrial partner(s).

CERN organization for Detector Magnets

R&D program in CERN/EP

EP R&D program on detector technologies

- R&D program for new experiments and detector upgrades beyond LHC phase II.
- First phase launched in 2020.
- Continuation plan until 2028 approved.

WP8 on Detector Magnets

- New sub-WP8.2 included for Al-stab superconductor, **starting 2023**.
- **WP8.2 priority on Al-Stab NbTi/Cu superconductors**, as a first step.

Activities on Al-stab SC

Options considered for a coextrusion line:

1. Use an **existing facility** in industry
   - Now on-going,
   - Exploring industry capabilities, aiming first at demo lengths production.

2. **New set up** with an **industrial partner**
   - Business case to be validated by industry.
   - Partnership, larger budget than option 1.
   - Production volume low if only application with detector magnets.

3. **New set up** in an Institute
   - As a backup solution if none of the 2 options above succeeds.

Option 2 and 3 would need extra funds.

Option 1 now on existing CERN/EP funds, for the prototyping phase, with EN and TE support.

Activities on Al-stab SC

Contacts with industry

In CERN member states.

Market Survey done :

- June 2023, by the CERN Procurement Team (**Request For Interest**).

- CERN ILOs contacted : a presentation made on 23rd June.

- Sent to about 15 identified companies.

Results: 5 answers only

- **One company qualified with equipment available,**
- Others not qualified.

Activities on Al-stab SC

Next steps:

- **Place a contract to industry to produce demonstrator lengths.**
  - Sample testing for qualification at CERN with EN/TE expertise and support.
  - Priority on Al-Stab NbTi/Cu superconductors, as a first step.
  - Benefit from available expertise within the working group to set up the coextrusion and coldwork process.

- **If successful, this could give a possibility to :**
  1. Extend the R&D to coextruded Al-stabilized HTS.
  2. Develop, and potentially produce, with dedicated funds, conductors needed for future projects.

ep-rnd.web.cern.ch