ALICE 3 SC magnet project

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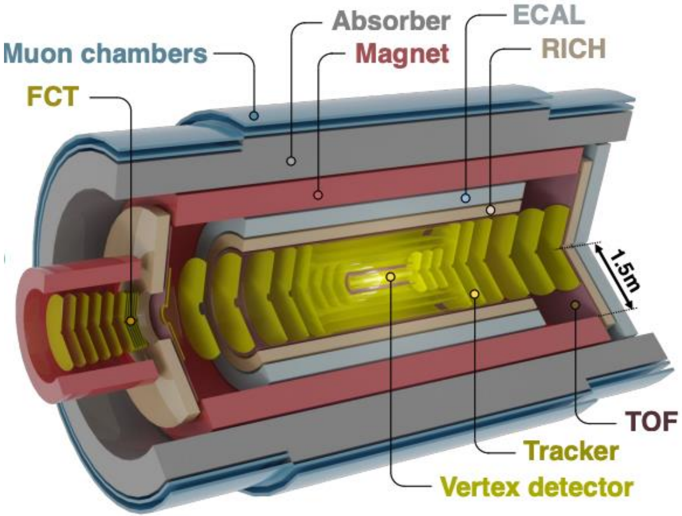
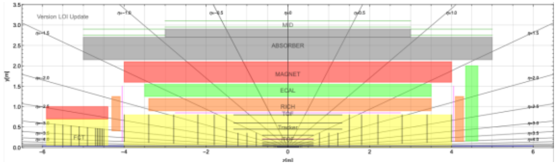
8.10.2024

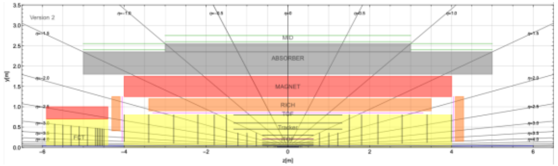


Recap magnet and conductor options

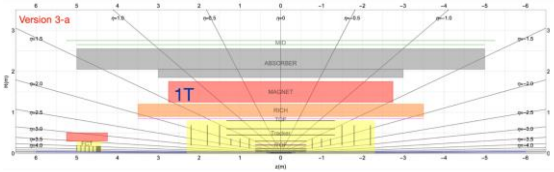
Magnet options



V1 (LoI): r=1.6m, l=7.5m
B=1–2 T

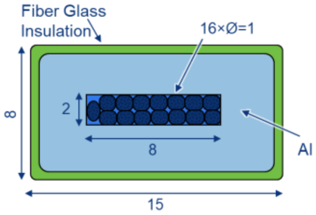


V2 r=1.25m, l=7.5m
B=1–2 T

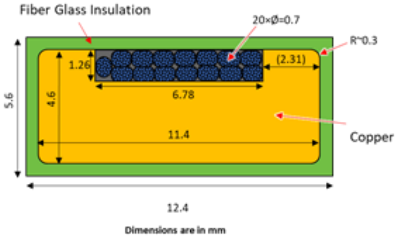


V3: r=1.25m, l=5.5m
B=1T

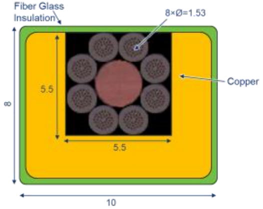
Conductor options



Aluminum-stabilized Nb-Ti/Cu



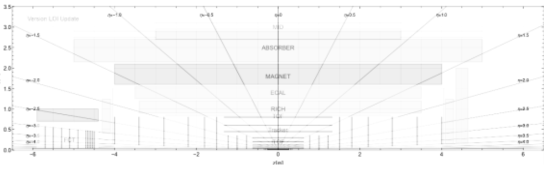
Copper-stabilized Nb-Ti/Cu



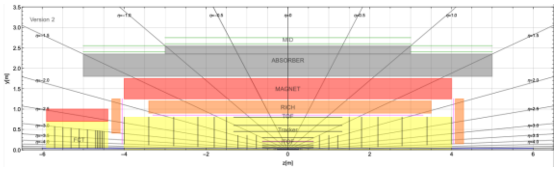
Copper-stabilized MgB2

Design choice

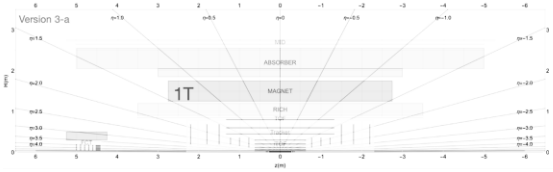
Magnet options



V1 (LoI): r=1.6m, l=7.5m
B=1–2 T

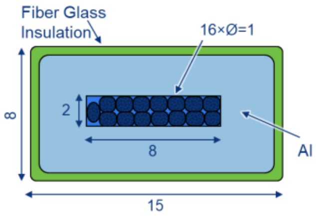


V2 r=1.25m, l=7.5m
B=1–2 T

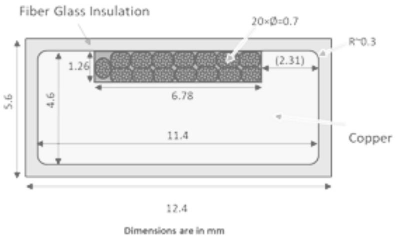


V3: r=1.25m, l=5.5m
B=1T

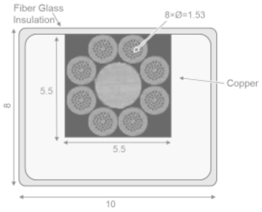
Conductor options



Aluminum-stabilized Nb-Ti/Cu



Copper-stabilized Nb-Ti/Cu

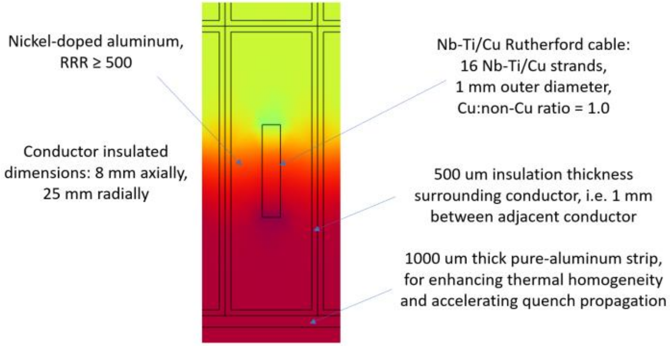


Copper-stabilized MgB2

Design choice

- Quite several scoping options (geometry x field x cable type) → studies focused on **V2-2T** geometry and aluminum-stabilized Nb-Ti/Cu for engineering, adaptable to future decisions.

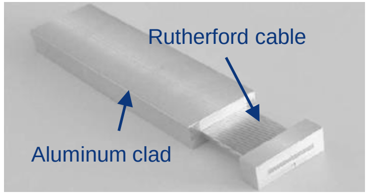
	V1_2T	V1_1.5T	V1_1T	V2_2T	V2_1.5T	V2_1T
B0 [T]	2	1.5	1	2	1.5	1
Rfree [m]	1.6	1.6	1.6	1.25	1.25	1.25
Rmag [m]	1.8	1.8	1.8	1.45	1.45	1.45
Layer	3	2	1	3	2	1
I [A]	6613	7728	9902	6771	7616	10154
Bp [T]	2.83	2.39	2.02	2.73	2.29	1.92
E [MJ]	121.5	68.9	30.2	74.7	42	18.6
L [H]	5.0	2.2	0.9	3.1	1.31	0.6
L conduct [km]	21.7	14	7.2	16.5	11	5.5



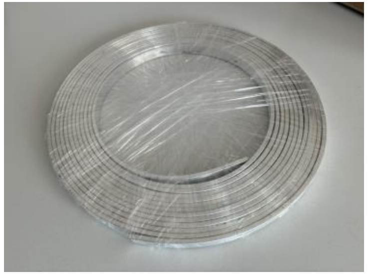
Example of conductor layout

News on the conductor

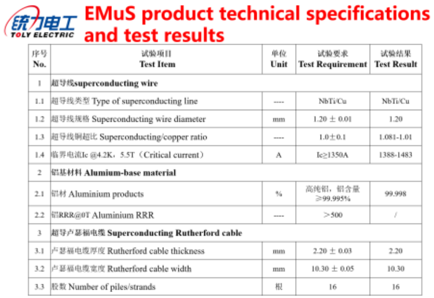
- **Baseline → CERN R&D program:** tender early 2025 to set up a development line for coextrusion and coldwork.
- **Since availability of the conductor remains an issue, we decided to design a magnet starting from an available conductor, rather than following the conventional process, i.e. magnet design → conductor design.**
- The Chinese company **Wuxi-Toly** provided specs and a **10m sample** of a cable, which they produced in the past for the **Experimental Muon Source (EMuS)** magnet:
  - A bit **smaller** than our nominal design: 4.7 x 15 mm^2.
  - Coextruded with **pure Al**.
- We asked **M. Mentink** (CERN EP) to studiy a cold-mass concept based on this cable → see next slide.



Al-coextruded cable

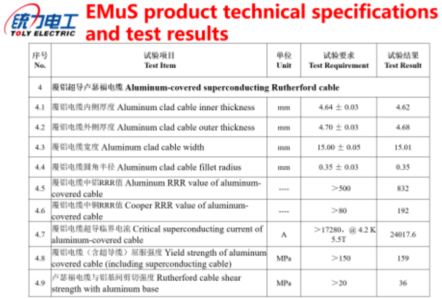


EMuS conductor sample



EMuS product technical specifications and test results

序号 No.	试验项目 Test Item	单位 Unit	试验要求 Test Requirement	试验结果 Test Result
1	**超导线superconducting wire**			
1.1	超导线类型 Type of superconducting line	----	NbTi/Cu	NbTi/Cu
1.2	超导线规格 Superconducting wire diameter	mm	1.20 ± 0.01	1.20
1.3	超导线铜超比 Superconducting/copper ratio	----	1.0±0.1	1.081-1.01
1.4	临界电流Ic @4.2K，5.5T（Critical current）	A	Ic≥1350A	1388-1483
2	**铝基材料 Alumium-base material**			
2.1	铝材 Aluminium products	%	高纯铝，铝含量≥99.995%	99.998
2.2	铝RRR@0T Aluminium RRR	----	＞500	/
3	**超导卢瑟福电缆 Superconducting Rutherford cable**			
3.1	卢瑟福电缆厚度 Rutherford cable thickness	mm	2.20 ± 0.03	2.20
3.2	卢瑟福电缆宽度 Rutherford cable width	mm	10.30 ± 0.05	10.30
3.3	股数 Number of piles/strands	根	16	16



EMuS product technical specifications and test results

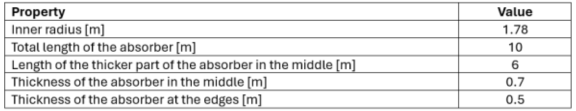
序号 No.	试验项目 Test Item	单位 Unit	试验要求 Test Requirement	试验结果 Test Result
4	**覆铝超导卢瑟福电缆 Aluminum-covered superconducting Rutherford cable**			
4.1	覆铝电缆内侧厚度 Aluminum clad cable inner thickness	mm	4.64 ± 0.03	4.62
4.2	覆铝电缆外侧厚度 Aluminum clad cable outer thickness	mm	4.70 ± 0.03	4.68
4.3	覆铝电缆宽度 Aluminum clad cable width	mm	15.00 ± 0.05	15.01
4.4	覆铝电缆圆角半径 Aluminum clad cable fillet radius	mm	0.35 ± 0.03	0.35
4.5	覆铝电缆中铝RRR值 Aluminum RRR value of aluminum-covered cable	----	＞500	832
4.6	覆铝电缆中铜RRR值 Cooper RRR value of aluminum-covered cable	----	＞80	192
4.7	覆铝电缆超导临界电流 Critical superconducting current of aluminum-covered cable	A	＞17280，@ 4.2 K 5.5T	24017.6
4.8	覆铝电缆（含超导缆）屈服强度 Yield strength of aluminum covered cable (including superconducting cable)	MPa	＞150	159
4.9	卢瑟福电缆与铝基间剪切强度 Rutherford cable shear strength with aluminum base	MPa	＞20	36

Overview of properties of the EMUS conductor (Wuxi Toly)

Cold-mass concept based on EMuS conductor 1/2

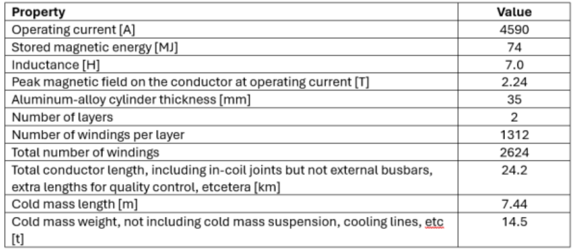
- Preliminary investigation of using this conductor “as-is” for the ALICE 3 superconducting magnet (v2-2T):
    - **Very stable conductor** with **large operating margin**.
    - The **shear stress** at the interface between the conductor to the support cylinder is modest, with a peak of 1.1 MPa.
    - **Quench protection:** with an energy extraction resistance of 150 mΩ, the adiabatic hotspot temperature may be kept below 100 K, provided quench detection and validation occurs within 1.5 s.

- **Conclusions: the conductor might be used as-is**, even if **it would preferable if the amount of aluminum were increased, while reducing the fraction of Nb-Ti.** Quench protection would be more straightforward if the conductor cross-sectional area were larger (i.e. **more aluminum**).



Property	Value
Inner radius [m]	1.78
Total length of the absorber [m]	10
Length of the thicker part of the absorber in the middle [m]	6
Thickness of the absorber in the middle [m]	0.7
Thickness of the absorber at the edges [m]	0.5

Table 2. Considered geometrical properties of the ferromagnetic absorber



Property	Value
Operating current [A]	4590
Stored magnetic energy [MJ]	74
Inductance [H]	7.0
Peak magnetic field on the conductor at operating current [T]	2.24
Aluminum-alloy cylinder thickness [mm]	35
Number of layers	2
Number of windings per layer	1312
Total number of windings	2624
Total conductor length, including in-coil joints but not external busbars, extra lengths for quality control, etcetera [km]	24.2
Cold mass length [m]	7.44
Cold mass weight, not including cold mass suspension, cooling lines, etc [t]	14.5

Table 3. Considered solenoid geometry

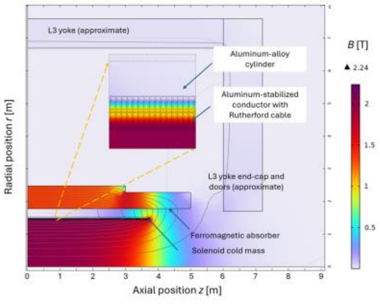
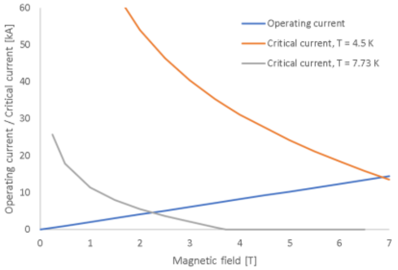
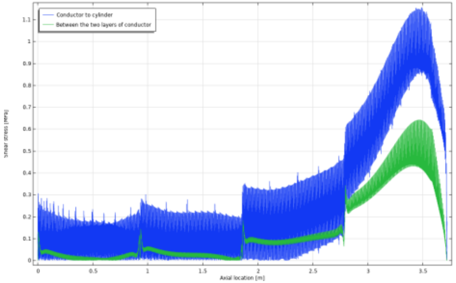


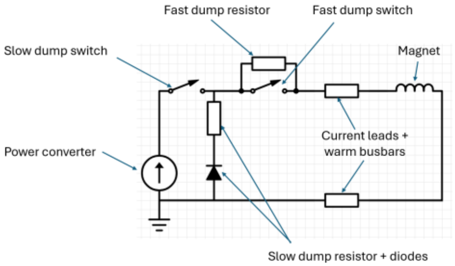
Fig. 1. Considered Alice-3 geometry



Load-line plot of the EMuS conductor



Von Mises stress (peak is at 1.1 MPa)



Powering and quench protection circuit

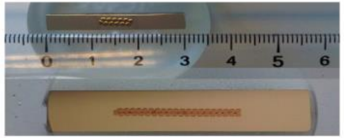
Cold-mass concept based on EMuS conductor 2/2

- We got a **quotation from Wuxi-Toly for a larger conductor** (5.75 x 20 mm^2):
  - The price is about 48 CHF/m → **0.8 MCHF for V2-2T.**
  - The cost of the **Rutherford cable**, which is not included in the offer, spans between 60 CHF/m (PRC) and 100 CHF/m (EU or JP) → **1-1.7 MCHF.**
  - The conductor is co-extruded with **pure Al.**

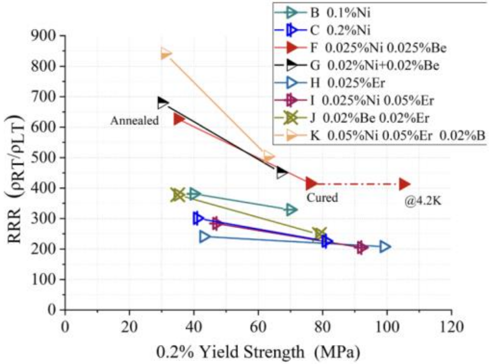
- The simulation shows that **doped Al might not be needed:**
  - Doping pure Al reinforces the conductor, guaranteeing reaching high **yield strength without penalising the RRR** (ATLAS/CMS values: yield strength > 105 MPa @ 4.5K and RRR > 500).
  - But **doped Al is expensive**: for our magnet we would need 7 ton (min order 10 ton, including 10% export taxes) → **1.35 MCHF.**

- **Next steps:**
  - Repeat Matthias' study for the **larger conductor.**
  - Cross-check conclusions with **different simulation code**.
  - Organise at CERN **independent tests** on the 10m sample received from China: RRR, tomography, critical current, bonding tests etc.

CMS conductor

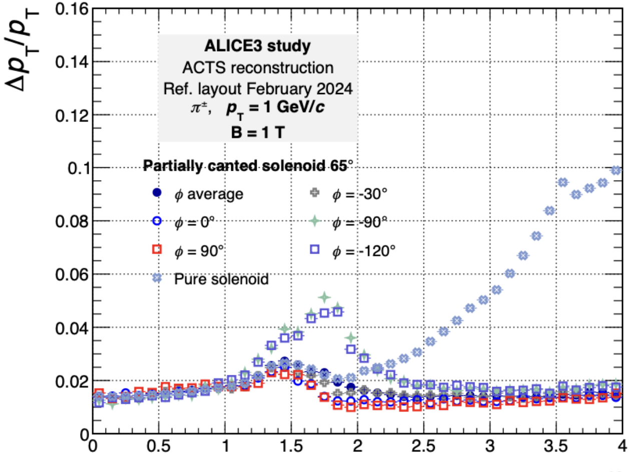


ATLAS conductor



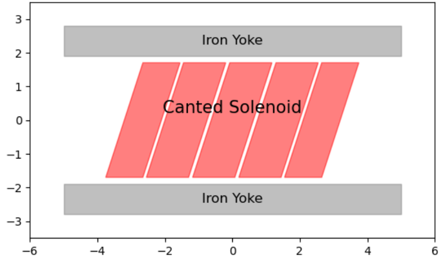
Follow-up on canted design options

- **Goal:** improve the momentum resolution at rapidity values $2<\eta<4$ (was investigated also in the LoI with dipoles).
- Field maps (1T magnet) produced for two different geometries: **canted** and **partially canted** and different **winding angles**.
- Field maps → pT resolution plots (see Pavel's talk).
- **Results:**
  - ☺ As expected, improved resolution in forward region $\eta>2.2$.
  - ☹ Large phi-asymmetry of pT resolution.
  - ☹ pT resolution in mid rapidity $1.3<\eta<2$ and over large fraction of azimuthal acceptance generally worse than pure solenoid (factor 3-5).
- These implementations present <u>added complexity and cost</u> → **probably more efficient to proceed directly with the 2T option?**

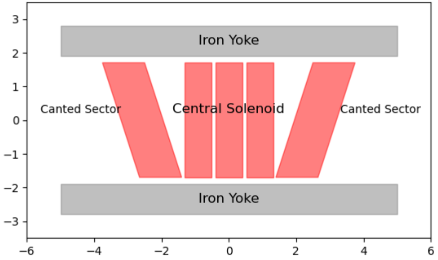


Partially canted

pT resolution → See Pavel's talk



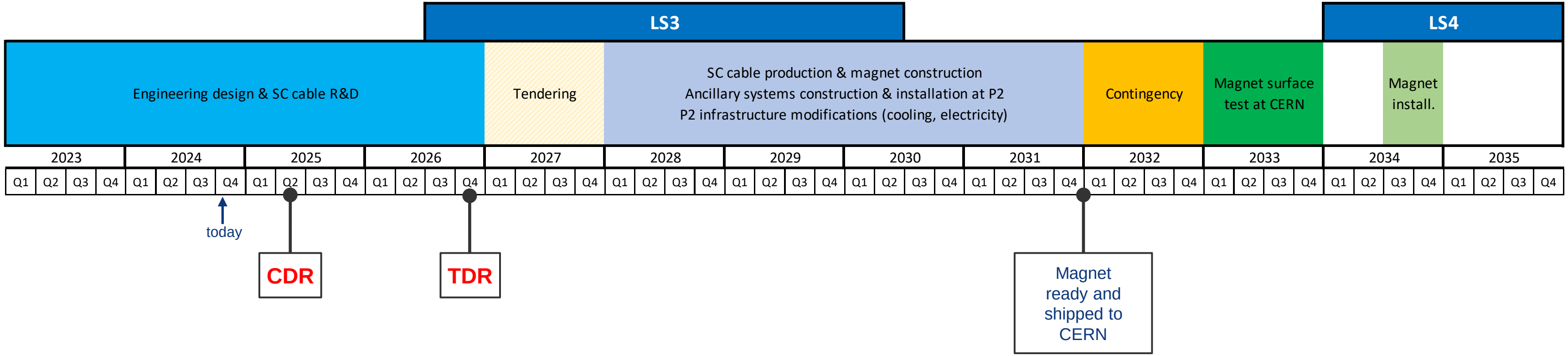
Canted solenoid



Patrially canted solenoid

Updated magnet timeline

- **LS4 shifted** by one year, now 2034-35 → everything kept as is and added 1-year contingency.
- **CDR (Q2 2025)** → detailed magnet system level design, based on R&D conducted at CERN/ASG. Decision on magnet technology.
- **TDR (Q4 2026)** → comprehensive description of the design, specifications, and implementation plan. Detailed engineering drawings, specifications, calculations, analysis results, test plans, quality assurance measures, and a finalized cost estimate.



LS3

LS4

Engineering design & SC cable R&D

Tendering

SC cable production & magnet construction
Ancillary systems construction & installation at P2
P2 infrastructure modifications (cooling, electricity)

Contingency

Magnet surface test at CERN

Magnet install.

2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035

Q1 Q2 Q3 Q4

today

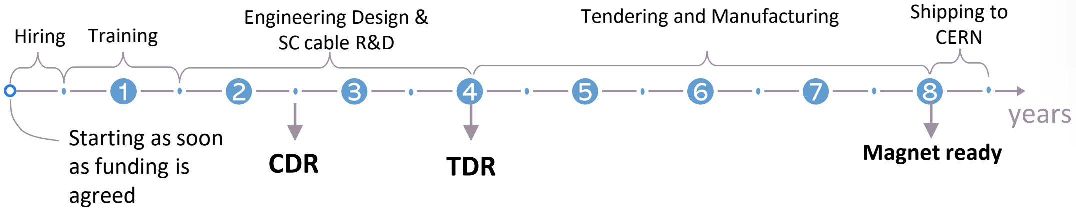
CDR

TDR

Magnet ready and shipped to CERN

News from Brazil

- **University of Sao Paulo (USP)** and **Brazilian Center for Research in Energy and Materials (CNPEM)** → reiterated interest in joining the ALICE 3 magnet project, with involvement in design and construction.
- **CNPEM’s Technology Unit** has proven expertise in accelerator design, manufacturing, and installation as demonstrated by the successful development of **Sirius**, a new light source accelerator lab in Campinas.
- They estimated the CDR phase will require **2.5 years** and **12 FTEs**, with an estimated cost of **1.4 M€** and **8.5 years** to build the magnet after funding is granted.
- They are also in touch with **Furukawa Brazil** to investigate about resuming the production of Aluminum-stabilized Nb-Ti/Cu cable.
- **CNPEM Director General, head of CNPEM TU and ALICE colleagues from USP will meet FAPESP on 10 October to discuss plans and funding.**


Hiring

Training

Engineering Design & SC cable R&D

Tendering and Manufacturing

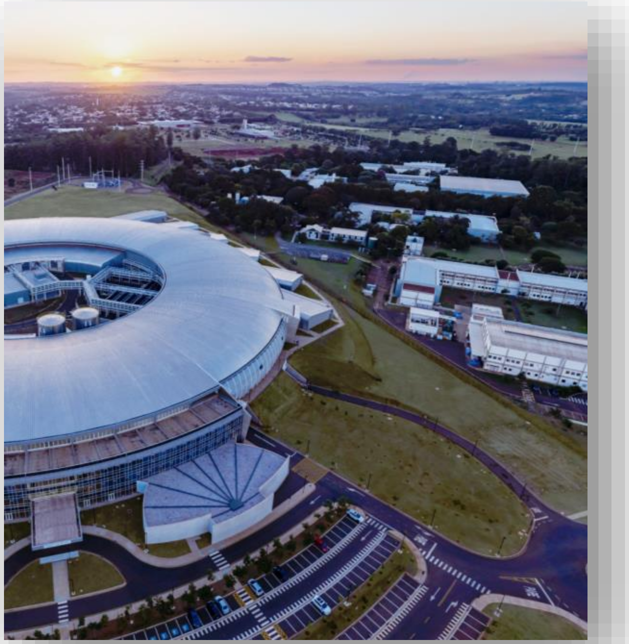
Shipping to CERN

Starting as soon as funding is agreed

CDR

TDR

Magnet ready



Interest from Pakistan (PAEK) 1/2

- We recently met representatives from PAEC → they are fully equipped to **manufacture large and heavy structures.**
- Heavy Mechanical Complex-3 (HMC-3), located in Taxila, one of the major Design & Manufacturing facilities of PAEC for the domestic design, manufacturing, testing, supply & installation of heavy mechanical equipment.
- In Taxila, they have CNC Turning, Milling, EDM, Wire Cut & CMM machines up to: 16 m diameter, 12 m length, 6.5 m height, 320 Tons weight, ±0.01 mm/m accuracy.

16 m Dia Vertical Lathe

Heavy Mechanical Complex-3 (HMC-3), located in Taxila

6 m Dia. Dish Forming Line

Light CNC Machining

30 m Annealing Furnace

12 m Milling & Boring Machine

Interest from Pakistan (PAEK) 2/2

- PAEK contributed largely to original construction of ATLAS and CMS magnets.
- Involved also in LS3 upgrade: **CMS HGCAL disks** and **support structure** and **ATLAS EIL4 TGC replacement structure**.

→ ALICE 3 involvement, beyond magnet project, such as absorbers and broader heavy infrastructure, definitely to be explored once we have clear plans of what we want to build.

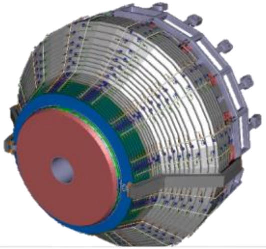

CMS collar shielding

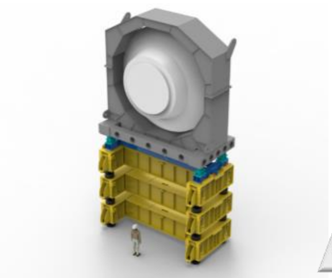
CMS magnet supports


ATLAS back cryostat supports


ALICE cooling pipes


CMS HGCAL disks






ATLAS EIL4 TGC Replacement

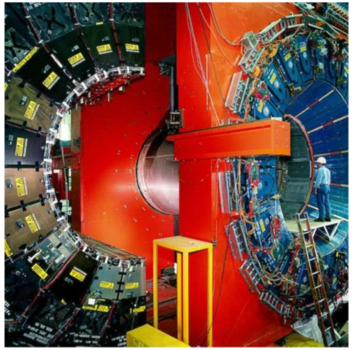
Follow-up on CDF magnet

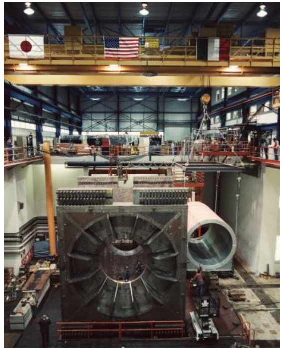
- Recuperation of the CDF magnet is our **backup plan** if we do not manage to build a new magnet.

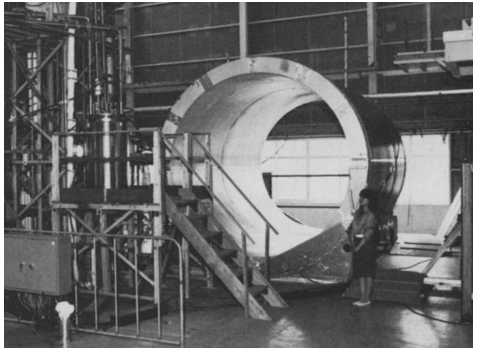
- A **complete verification at nominal temperature and current** would be beneficial to validate the characteristics of the coil, the instrumentation and the thermal insulation. It **requires transfer the magnet to CERN**. Although this is expensive, it is feasible.

- Plan to perform some **basic functionality tests** in the U.S., early next year:
  - HV and helium leak test
  - Coil electrical resistance measurement at room temperature
  - Verification of sensor cabling continuity (temperature, voltage and strain gages).
  - Verification of cable insulation to exclude radiation induced damage (presently a concern for the BaBar magnet, now relocated to sPHENIX).

- Simulations are needed to evaluate the compressive forces on the coil, the limitation on the current and on the maximum field when the CDF coil is replaced with the ALICE 3 absorber.







Conclusions

- We rely on CERN EP R&D to resume the Al coextrusion!
- INFN-Genova developed a 1T canted design with various winding angles. These solutions have degraded pT resolution in mid-acceptance region compared to the pure solenoid. Considering that the 1T canted design could be comparable in cost to the pure 2T solenoid version, it may be more efficient to proceed directly with the 2T option.
- We have a working concept for the ALICE 3 cold mass based on a commercially available SC cable!
- Brazil has expressed strong interest in participating in the ALICE 3 magnet development. They are actively seeking funding through FAPESP, the national funding agency.
- The CDF magnet remains a viable backup option. We are planning a test campaign in the U.S. early next year to further assess its suitability.
- Pakistan has demonstrated a keen interest in contributing to the ALICE 3 project. They possess the necessary expertise and infrastructure to produce the large and heavy structures required for our upgrade.

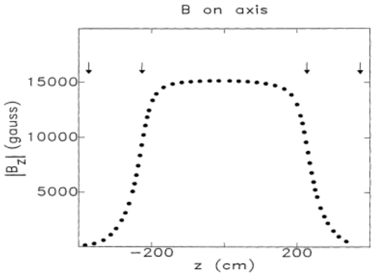

CERN
ALICE

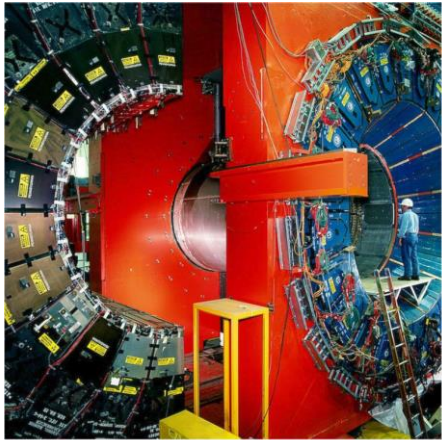
Possible alternative magnet option: CDF solenoid

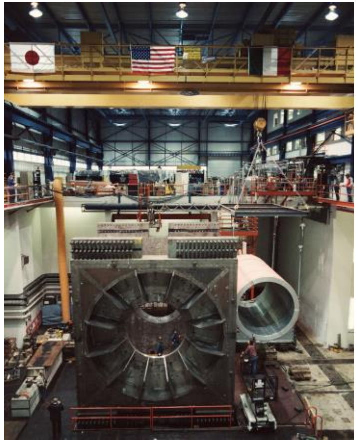
CDF magnet at Fermilab (Hitachi, 1984)

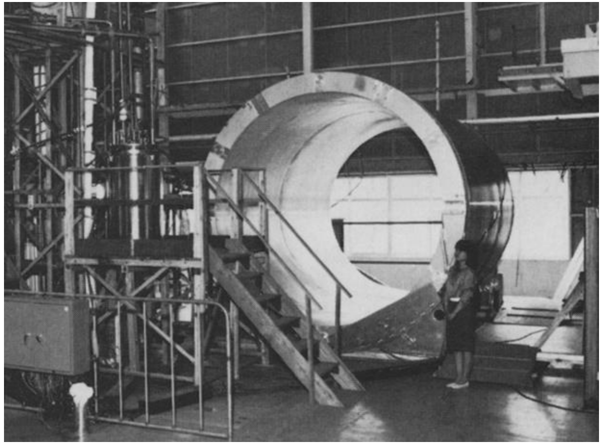
B=1.5 T, r_in=1.4 m, l=5 m

Operated at Fermilab until 2011, when Tevatron was shut down – still in place in experimental hall.









Possible alternative magnet option: CDF solenoid

Documentation and Testing:

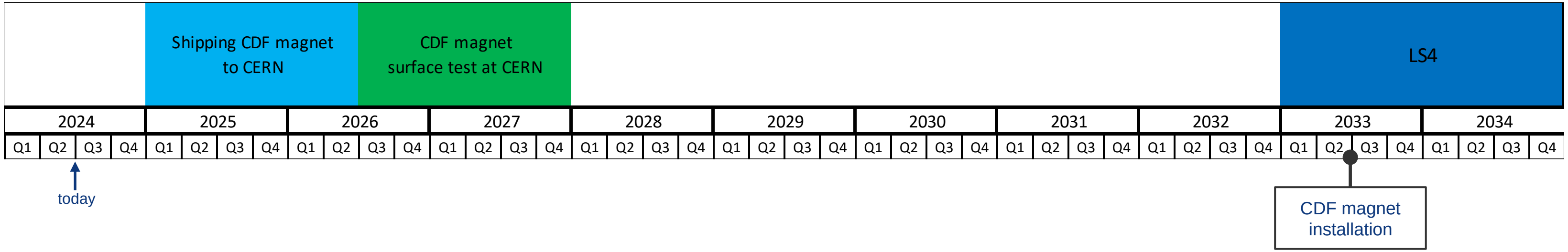
- **Contact with Fermilab:** we have received all relevant technical documentation about the magnet from J. Lewis at Fermilab.
- **Basic Tests:** initial functionality tests without cryogenics can be conducted at Fermilab.
- **Full Verification:** complete verification at nominal temperature and current requires transfer to CERN. Although this is expensive, it is feasible.

CDF magnet transportation from Japan to US (photo 1984)

Total Estimated Cost: 10 MCHF

- **Transportation, Refurbishment, and Tests: 5 MCHF**
- **Cryogenic and Powering Services: 5 MCHF**

Fallback Option: if tests at CERN fail and the magnet cannot be repaired, the backup plan is to use the existing L3 magnet (V3 version only). This option reduces costs by approximately **3 MCHF** (as 2 MCHF would be needed for a new L3 magnet PC).



Other magnet options

BaBar (ASG, 1998)

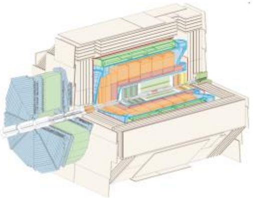
B=1.5 T, r_in=1.5 m, l=3.7 m

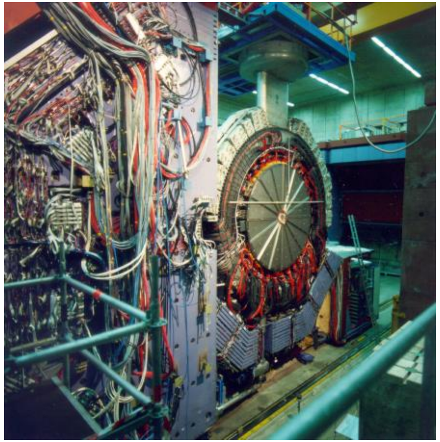
Built for SLAC, relocated to sPHENIX in 2015

H1 magnet (RAL, 1992)

B=1.15 T, r_in=2.6 m, l=5.75 m

Located at Desy





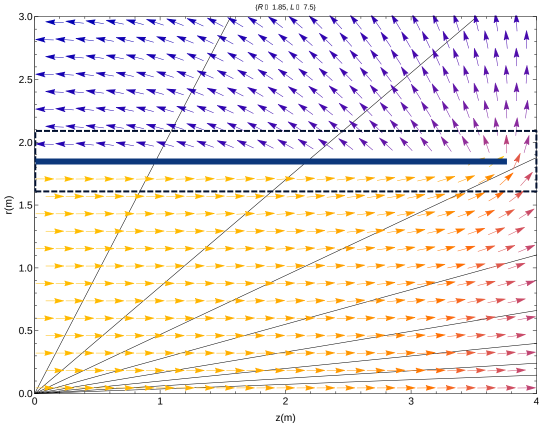
Delphi magnet (RAL, 1985)

B=1.23 T, r_in=2.6 m, l=7.4 m

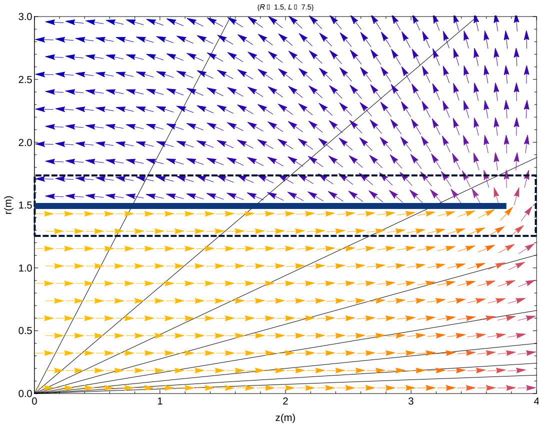
Located at LHCb

Close to impossible to take it out from LHCb.

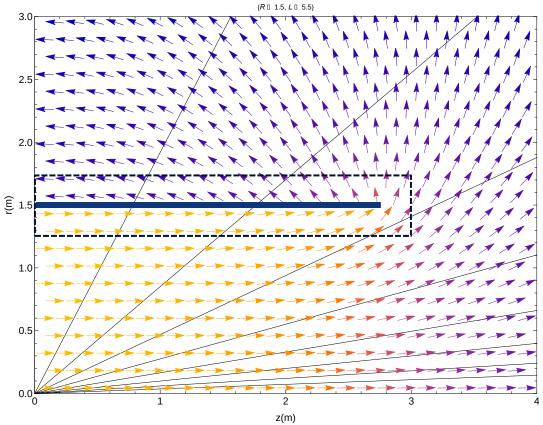
V1 (r_{in}=1.6m, l=8m)



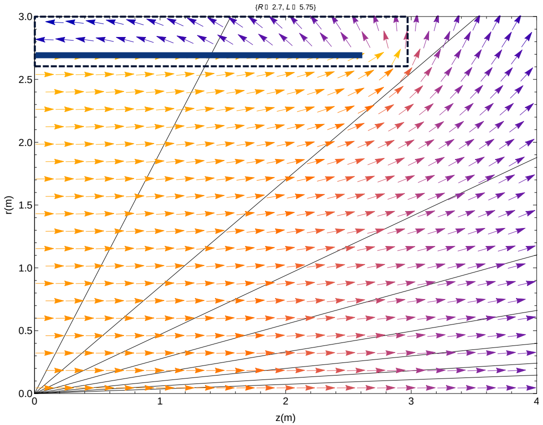
V2 (r_{in}=1.25m, l=8m)



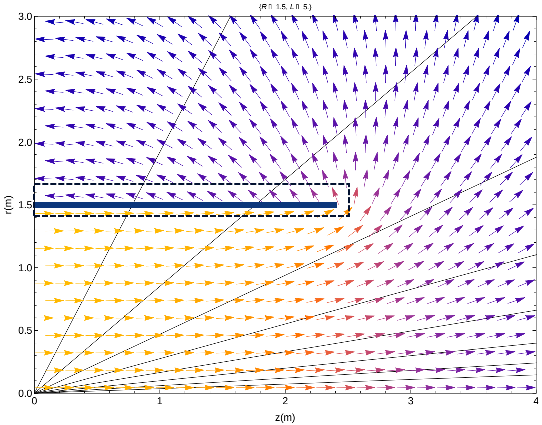
V3 (r_{in}=1.25m, l=6m)



H1 (r_{in}=2.6m, l=5.75m)



CDF (r_{in}=1.4m, l=5m)



Field maps → comparative evaluation of pT resolution among different magnets as a function of the central rapidity η

Magnet cost

System	V1-2T [MCHF]	V1-1T [MCHF]	V2-2T [MCHF]	V2-1T [MCHF]	Class	Description
Magnet (incl. cable)	25	18	20	15	C1	Quotation for **copper-stabilised Nb-Ti/Cu** cable
Cryogenics & vacuum	2.9	2.9	2	2	C1	Compressors, cold box, storage vessels, LHe intermediate dewar, cryogenic distribution lines and valve-box, control racks, vacuum pumps & controls for cryogenics, vacuum pumps & controls for cryostat, cryogenics fluids
Powering system	0.8	0.8	0.8	0.8	C1	Power converter, busbar extension inside UX25 cavern, Energy Extraction System, current leads
Control & quench detection	0.9	0.9	0.9	0.9	C1	Magnet Control System (MCS), Magnet Safety System (MSS), Vacuum Control System (VCS)
P2 cooling infrastructure	0.5	0.5	0.4	0.4	C1	Water cooling for cryogenics and vacuum pumps, water cooling plant for power converter and cold box
P2 electrical infrastructure	0.7	0.5	0.5	0.4	C1	Power for cryogenics, UPS, Diesel, power for the power converter and its cooling plant, power for vacuum valves
Surface test	0.3	0.3	0.2	0.2	C1	Temporary cryogenic piping, temporary busbar, temporary power for power-converter, cryogenics (cold-box), vacuum and MCS & MSS, temporary cooling for power converter, cryogenics and vacuum
Total cost [MCHF]	**31.1**	**23.9**	**24.8**	**19.7**	**C1**	
Reduction wrt V1-2T		**-23%**	**-20%**	**-36%**		

V3 not quoted yet