Cryostats for superconducting magnets

Délio Ramos, CERN, Technology Department

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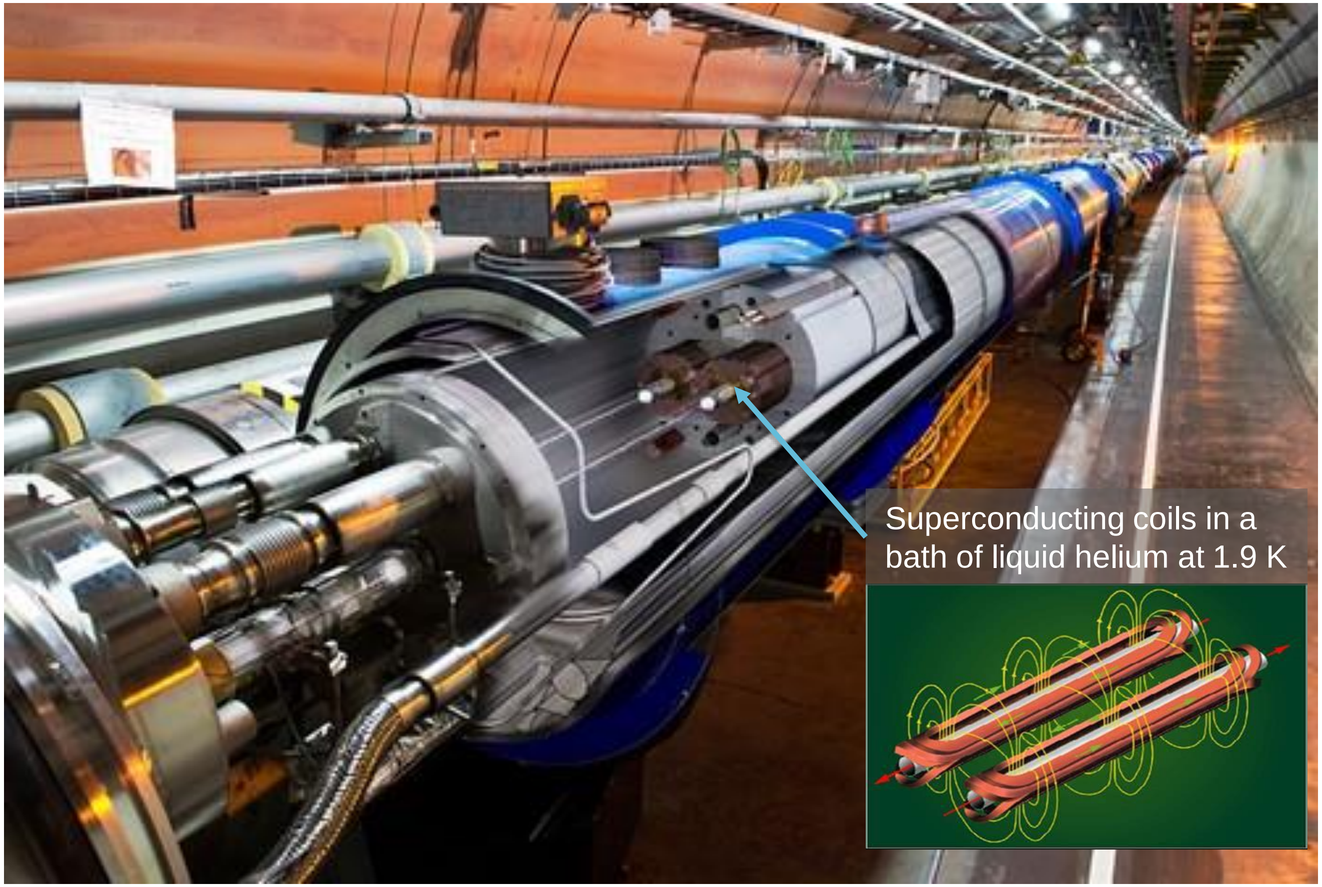
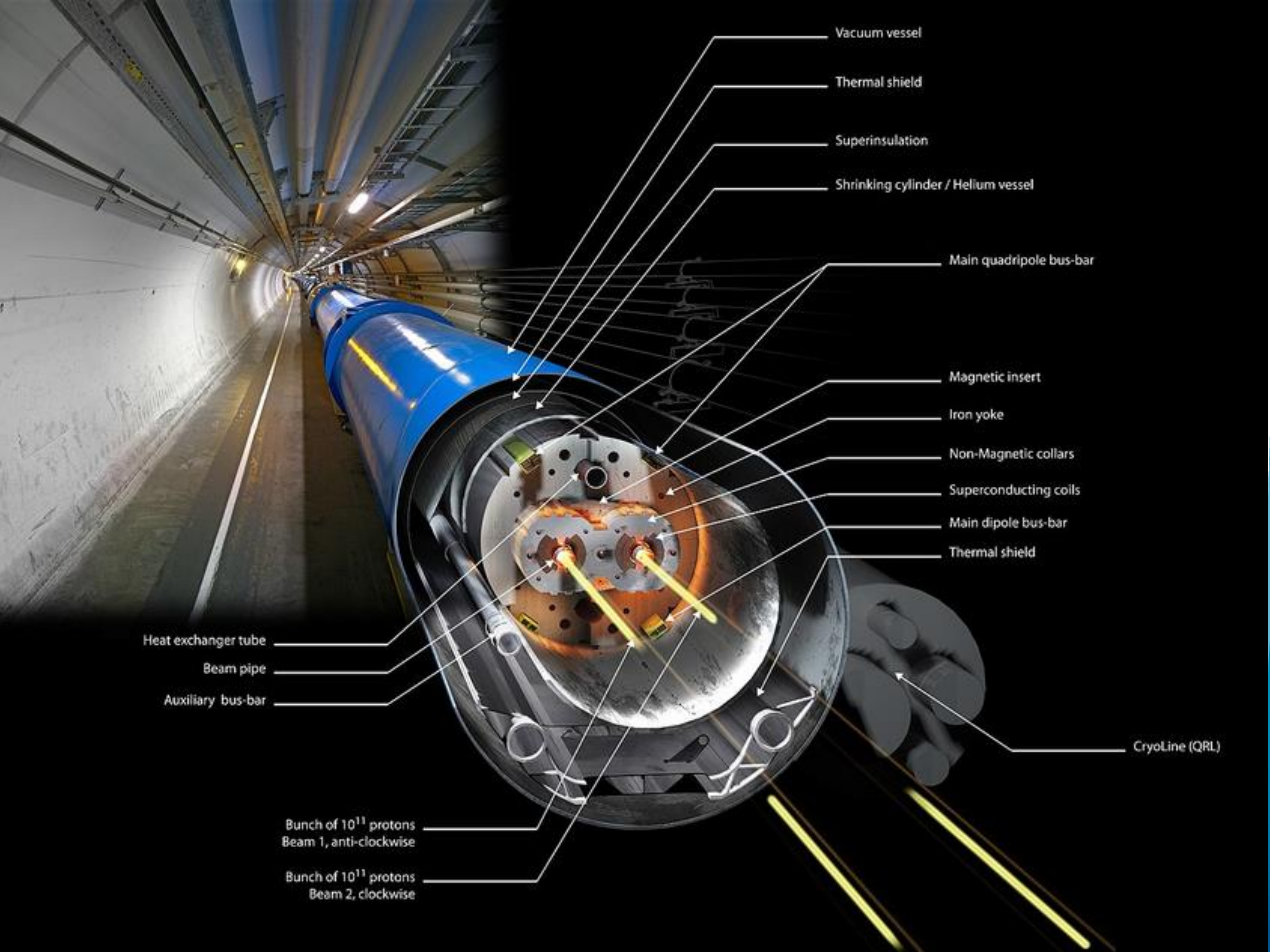
A typical magnet cryostat in the LHC



- ~1000 W of electrical power per 1 W extracted at 1.9 K: Extreme thermal insulation is a must!
- Thermal contraction of stainless steel ~3 mm/m length i.e. 45 mm over a 15 m dipole magnet; ~80 m over the whole LHC!
- Precise and stable alignement of large and heavy structures: tight fabrication tolerances



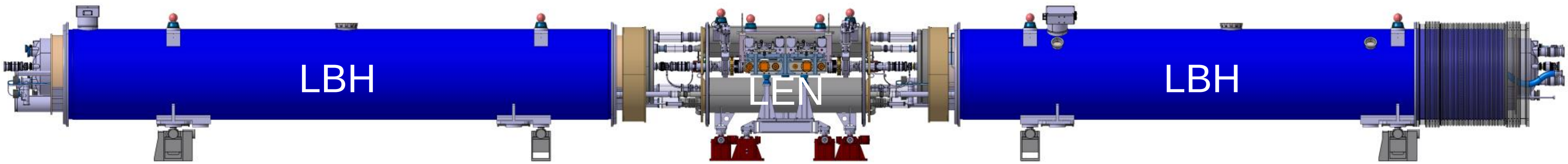
Vacuum vessel
Thermal shield
Superinsulation
Shrinking cylinder / Helium vessel
Main quadripole bus-bar
Magnetic insert
Iron yoke
Non-Magnetic collars
Superconducting coils
Main dipole bus-bar
Thermal shield
Heat exchanger tube
Beam pipe
Auxiliary bus-bar
CryoLine (QRL)
Bunch of 10^{11} protons
Beam 1, anti-clockwise
Bunch of 10^{11} protons
Beam 2, clockwise

Some guidelines for the design and construction

Issue	Solution	Some requirements/ specifications
Convection heat transfer	Vacuum (~10^{-6} mbar)	Leak tightness is critical, especially on large cryostats like the LHC Qualification of welding procedures and welders Material compatibility Cleanliness
Conduction heat transfer	Insulating support materials (ex. GFRE)	Stifness and strength Repeatability of material properties and dimensions Layout taking into account thermal displacements
Thermal radiation	Reflective surfaces (Multi-layer insulation)	Avoid openings Low compactness Proper assembly techniques to prevent thermal bridges Film material and coating properties
Thermodynamic efficiency	Intercept heat at intermediate temperatures (ex. thermal shield at 50-65 K)	High conductivity materials Avoid poor thermal contacts

For installation in 2019-2020: 11 T magnets

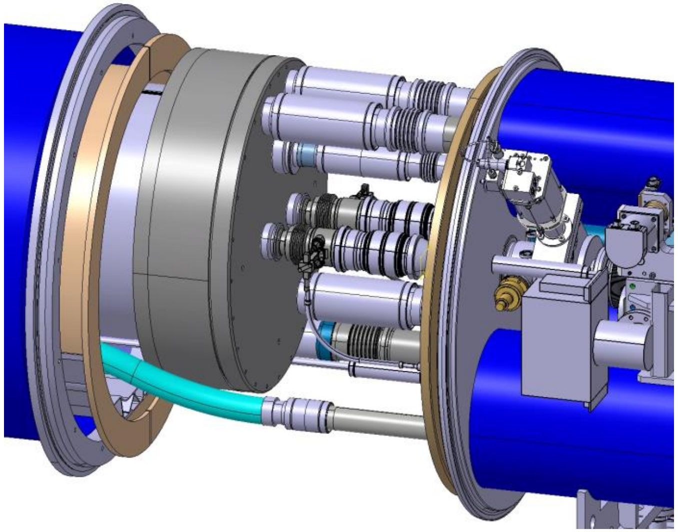
First Nb_3Sn high field magnets in a particle accelerator will create space for installation of new collimators

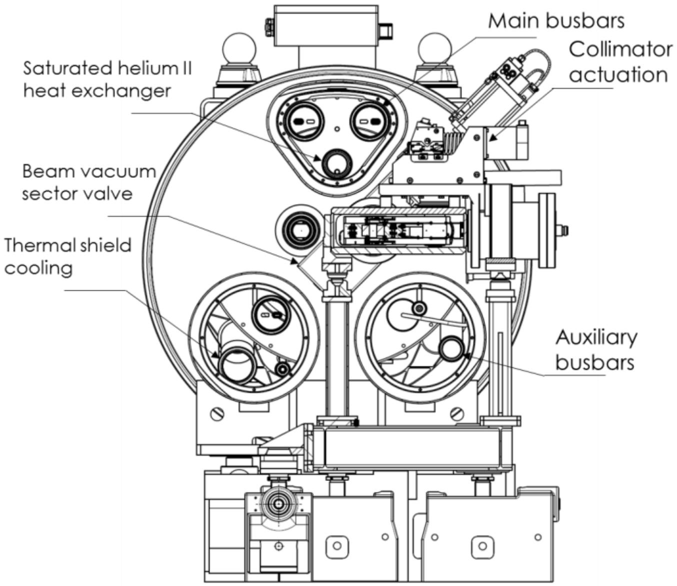


- On-going integration study for trim current leads
- Specification drawings for bottom trays being prepared

- Drawings controlled
- Procurement started

- Prototype under fabrication
- QA documents being prepared
- Tooling design nearly finished

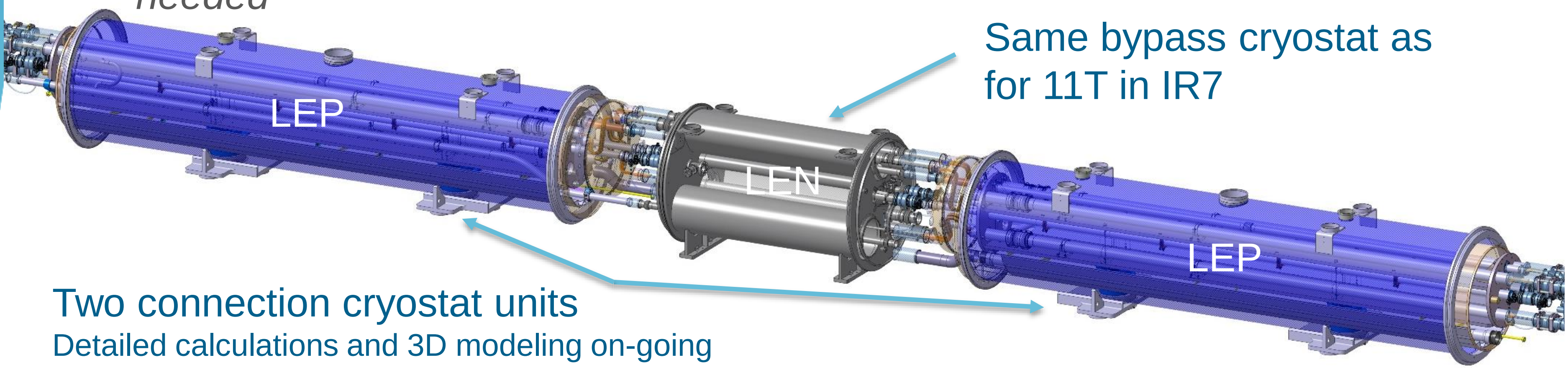




Overal integration length: 15660 mm

For installation in 2019-2020: Connection cryostats

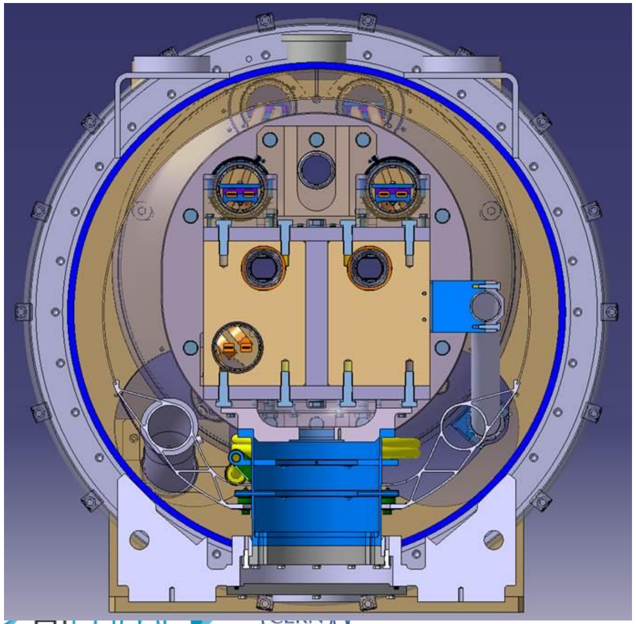
New collimators installed in a location without magnets but new cryostats needed

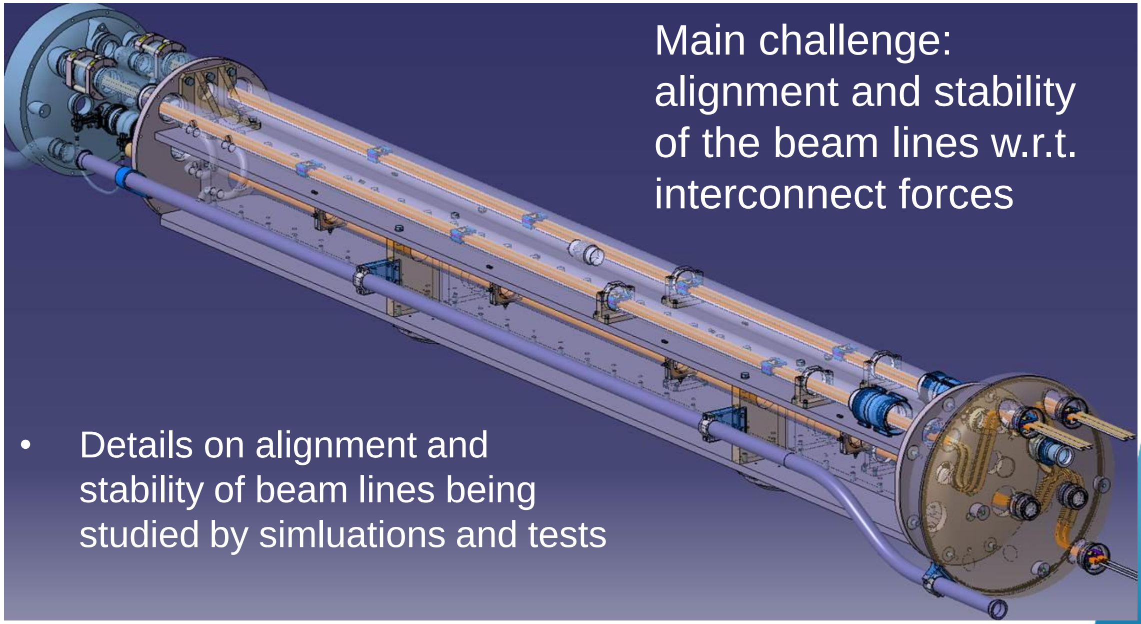


Same bypass cryostat as for 11T in IR7

Two connection cryostat units

Detailed calculations and 3D modeling on-going





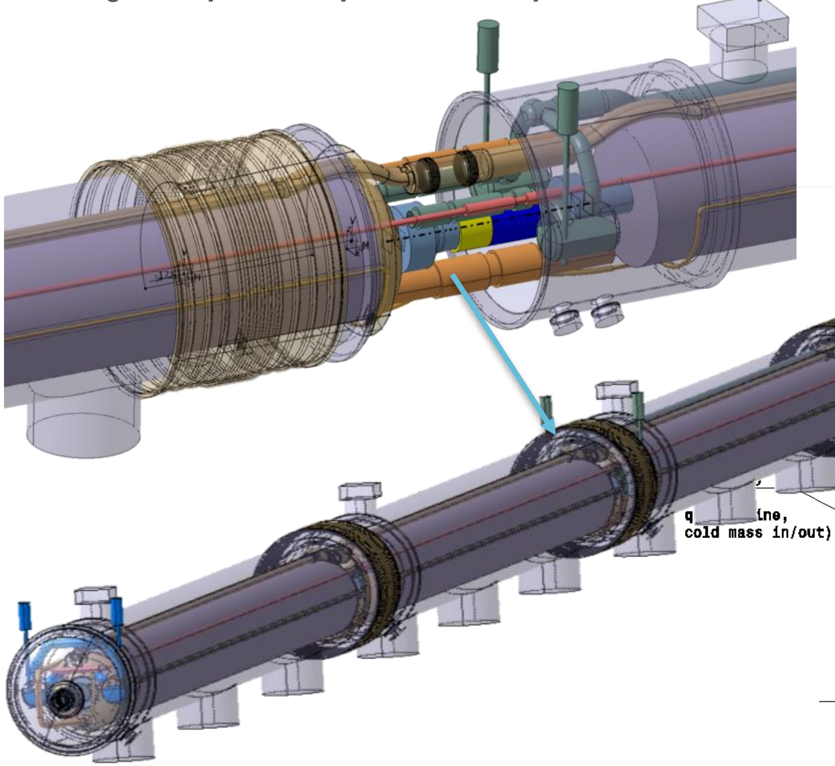
Main challenge: alignment and stability of the beam lines w.r.t. interconnect forces

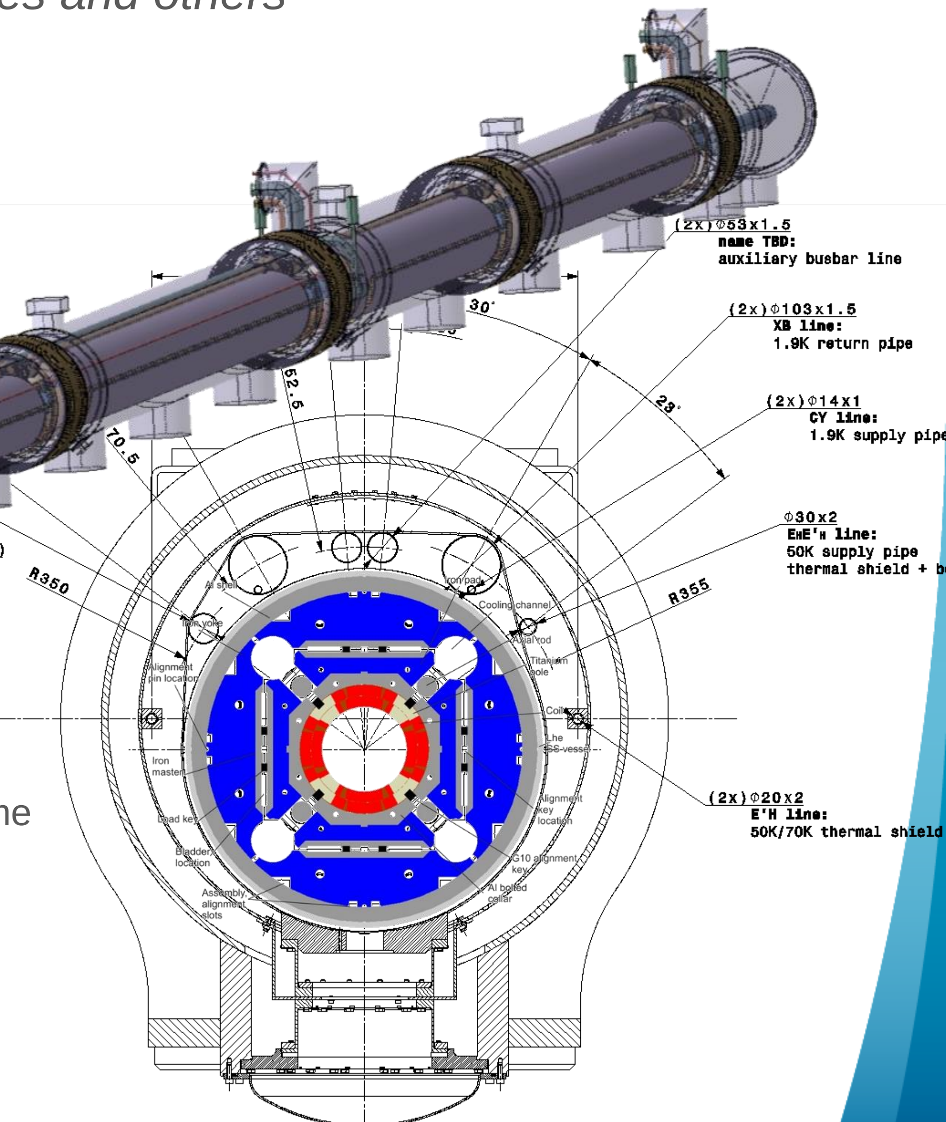
- Details on alignment and stability of beam lines being studied by simluations and tests

Overal integration length: 12774.7 mm

For installation in 2024-2025: Insertion regions

Nb_3Sn quadrupoles, separation dipoles and others





- Larger magnet diameters but cryostat of same diameter because of tunnel size restrictions: compact design
- New support system
- Complex interconnect and pipework
- Under design

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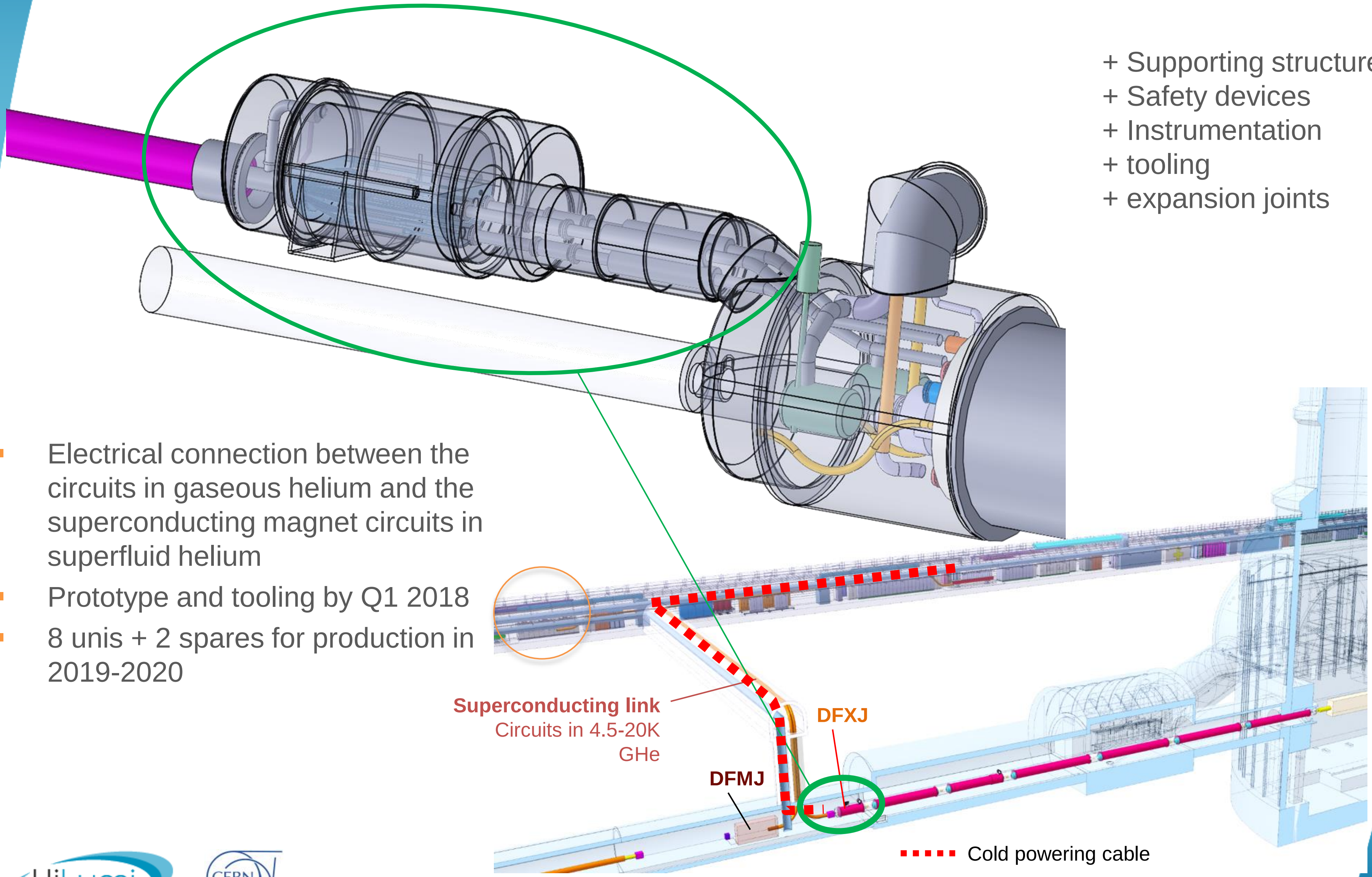
For installation in 2024-2025: Cryostats for interfaces with cold powering

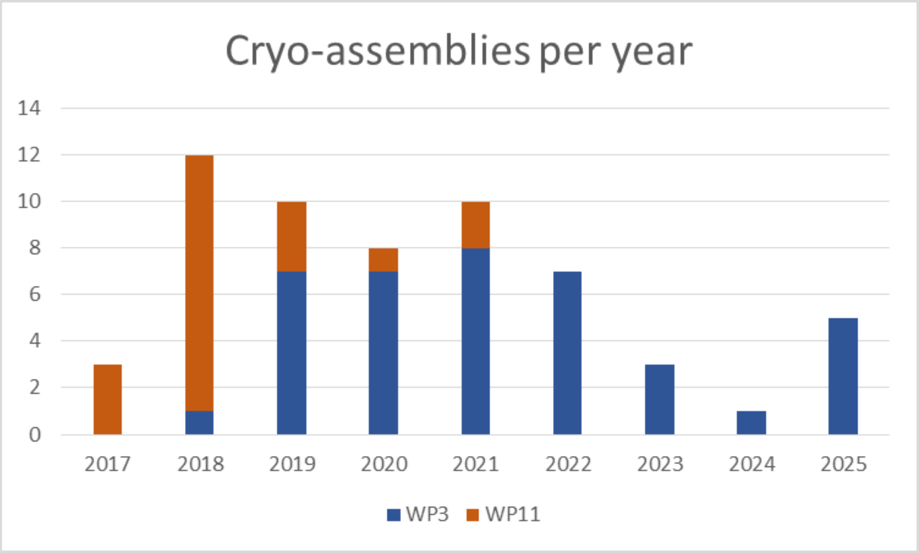
+ Supporting structure
+ Safety devices
+ Instrumentation
+ tooling
+ expansion joints



- Electrical connection between the circuits in gaseous helium and the superconducting magnet circuits in superfluid helium
- Prototype and tooling by Q1 2018
- 8 unis + 2 spares for production in 2019-2020

In a few numbers

- 77 cryostat units | 70 procured by CERN, incl. prototypes and spares
- Diameter ~1 m
- Unit lenghts vary from 2 m up to 15 m
- Roughly 500 m of new cryostats to be installed in the LHC
- Carbon steel, stainless steel, aluminium, glass fiber composites…
- Production from now until 2025



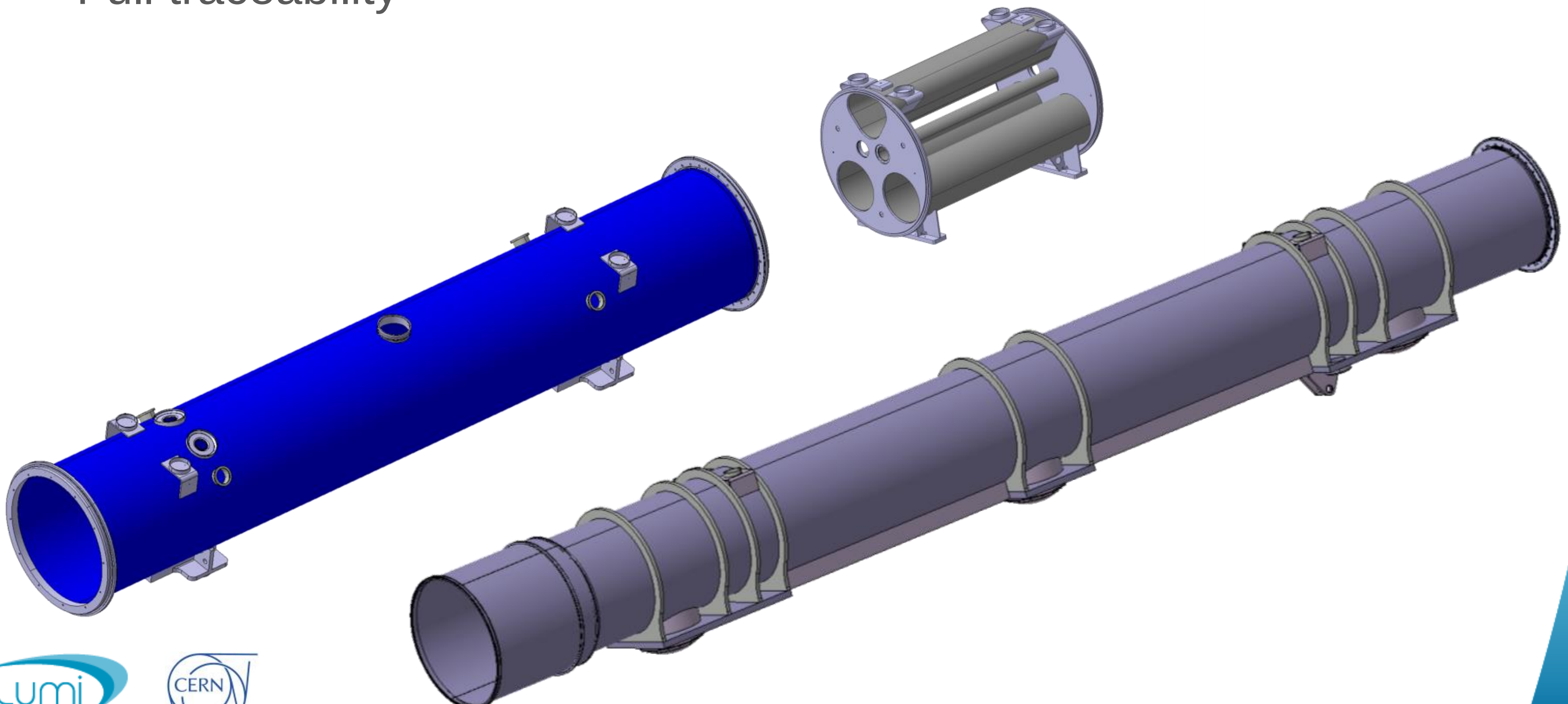
Assembly schedule at CERN

Strategy for construction

- Design done at CERN (internal design office with service contractor)
- Procurement of components in industry, mostly as “build-to-print” supplies according to CERN drawings and detailed specifications
- Assembly at CERN with on-site support of industrial contractors (ex.: mechanical assembly, welding, quality control)

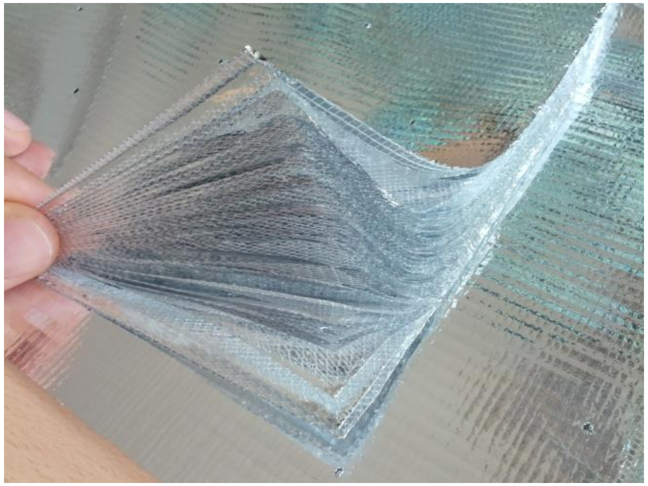
Vacuum vessels

- Cylindrical sections in carbon steel (certified for pressure applications at -50ºC) with flanges in stainless steel
- Precisely machined interfaces (large milling machines needed)
- Qualified welders and welding procedures
- Leak detection, welding NDT, 3D metrology
- Full traceability



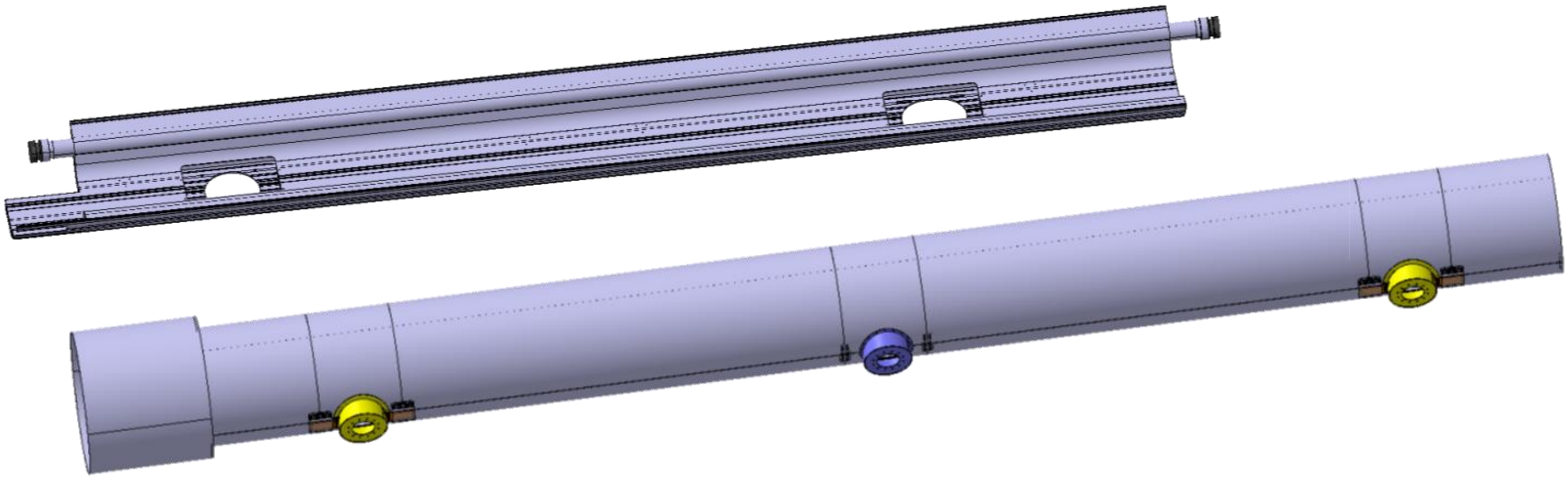
Multi-layer insulation

- Reflective sheets made from polyester film with aluminium thin coating on both sides
- Supplied in blankets of 10 or 15 reflective layers interleaved with insulating spacer layers made from polyester net
- Blankets joined with Velcro® tape
- Shape and size of the blankets to be designed by the manufacturer
- About 50’000 m^2 of reflective layer!



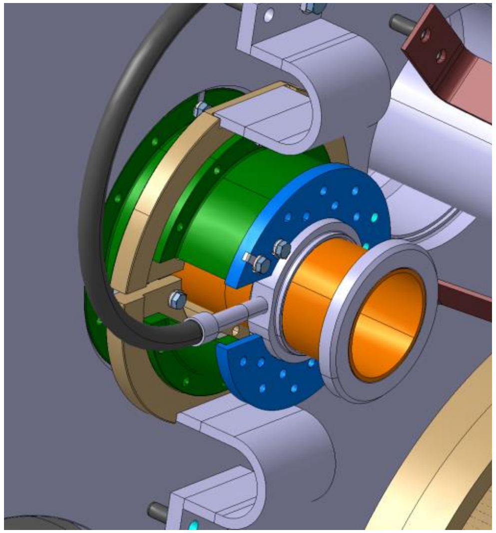
Thermal shields

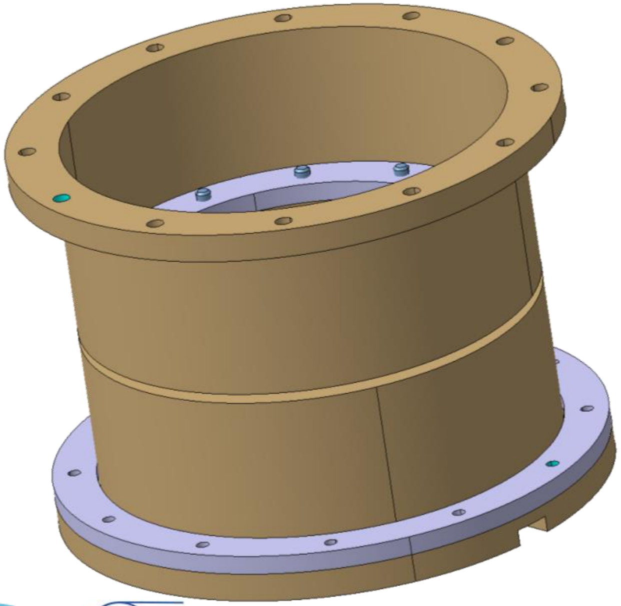
- Aluminium extrusions or roled sheets as structural elements
- Up to 14 m long
- Precise machining of support interfaces and extremities
- Aluminium to stainles steel transitons
- Leak tigth aluminium welds

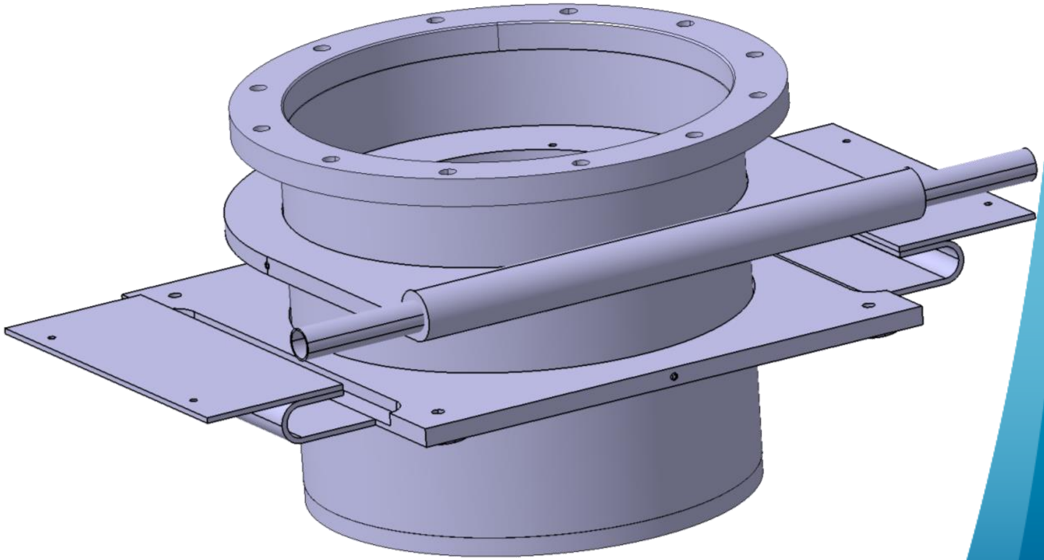


Cold supports

- Designed for stiffness and strength with minimum heat load
- **Glass fibre** reinforced epoxy
- Tight control of packing factor
- Equal and repeatable thermal contraction
- Finish machining after moulding

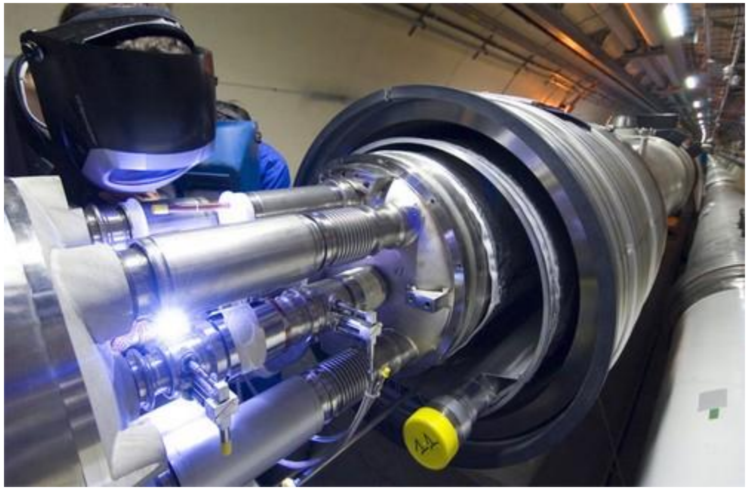


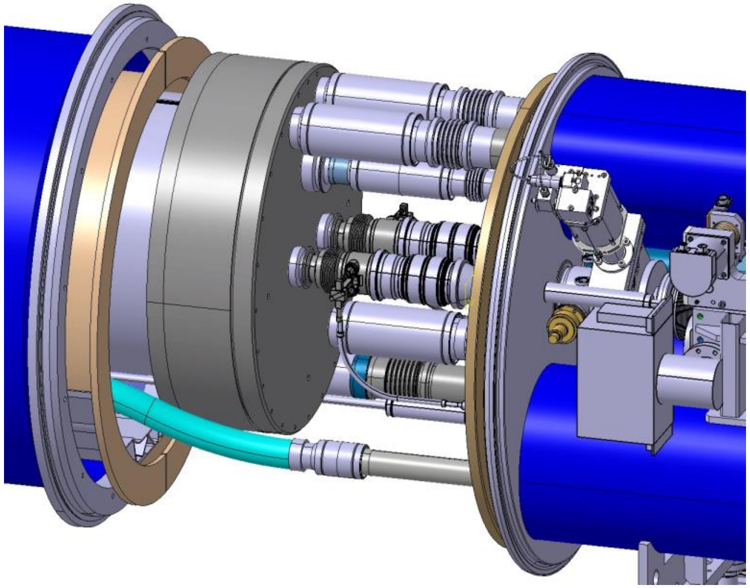




Expansion joints

- Compensation for thermal contraction during cooldown
- Reliability, leak tightness over the machine lifetime
- From vacuum to 20 bar
- EJMA, EN 13445
- Strict material specifications
- Full traceability of materials, manufacturing and QC
- ~500 units





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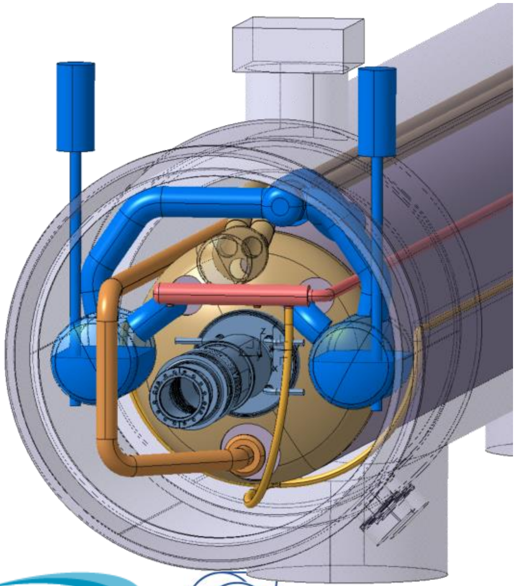
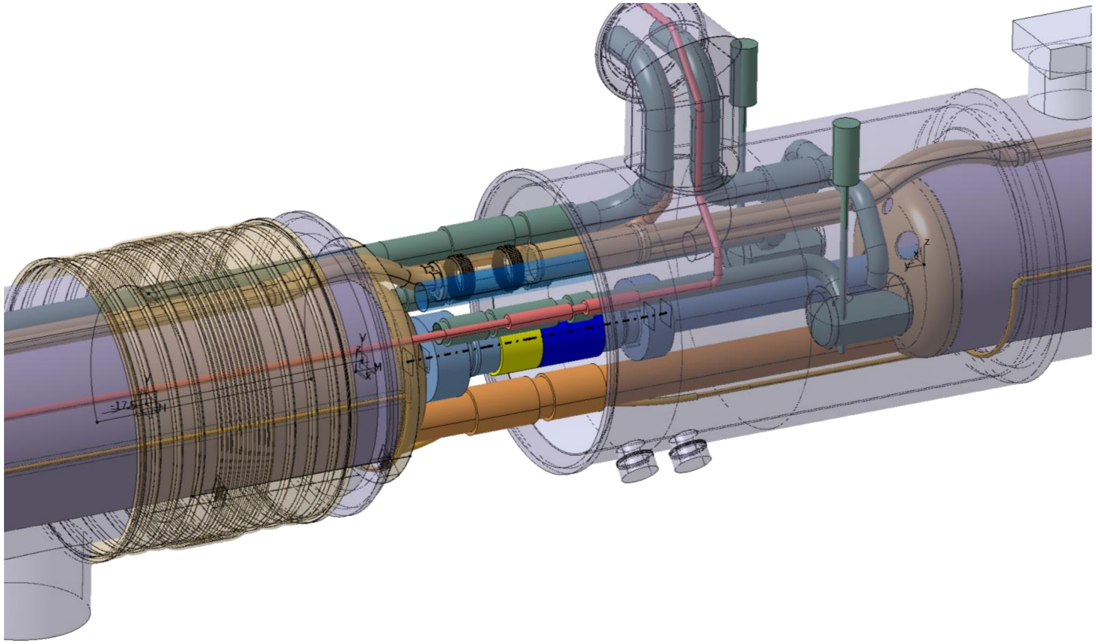
Piping and ancilliaries

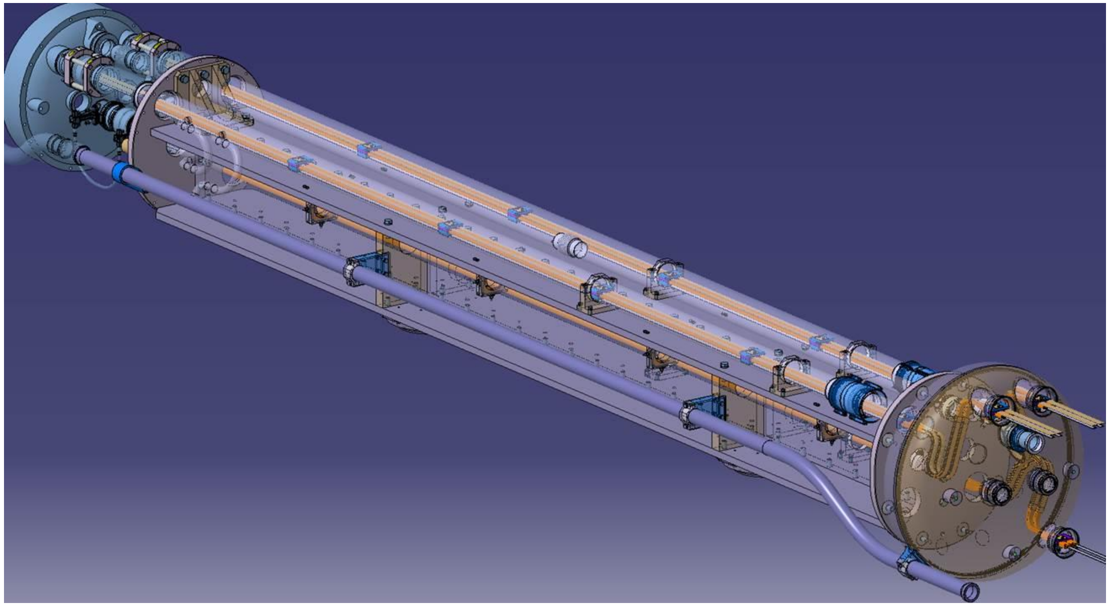
- Required inside most cryostats for helium distribution and routing of superconducting cables
- Pressurised up to 20 bar
- EN 13480
- Qualified welders and welding procedures
- Extensive welding QC





Cold mass for connection cryostats

- Used in cold parts of the accelerator without magnets, to route cryogenic services and superconducting cables
- Precise alignment
- Uniformity of temperature
- **Pressure vessel 20 bar**
- **EN 13458, EN 13445**
- **Stainless steel with cobalt content < 0.10%**
- 4 units plus 2 spares
- Assembly in 2018



Upcoming procurement contracts (main items)

Item	Quantity	Milestones	Status
Bypass proto vacuum vessel	1 unit	Order issued Oct 2016 Delivery April 2017	Contract adjudication
11T and Connection Cryostat series vacuum vessels	13 + 6 optional	Tendering process started Sep 2016 Finance committe and order issued June 2017 Delivery of first unit Nov 2017 Delivery of last unit end 2018	Market survey docs under preparation
Bypass series vacuum vessels	6 units	Tendering process starts Oct 2016 Order issued Jan 2017 Delivery of first unit June 2017 Delivery of last unit June 2018	Preparation of PE docs
Q1/3 proto, Q2 proto 1, Q2 proto 2	3 units + 1 optional	Start procurement procedure Mar 2017 Order issued Mar 2018 Delivery first unit Sep 2018 Delivery last unit Aug 2019	Planning
Q4 and Q10	8 + 2 optional	Start procurement procedure June 2017 Order issued Jun 2018 Delivery first unit Dec 2018 Delivery last unit Dec 2019	Planning
Q1/3 series, Q2 series, all CP, all D2		Start procurement procedure June 2018 Order issued May 2019 Delivery first unit Nov 2019 Delivery last unit Dec 2022	Planning

Thank you for your attention!