Les Journées Thématiques AFF-CCS au CERN
Cryogénie et Supraconductivité pour le LHC et ses détecteurs

Organisées par l'Association Française du Froid
Commission de Cryogénie et de Supraconductivité

La distribution électrique et les amenées de courants du LHC

Amalia Ballarino

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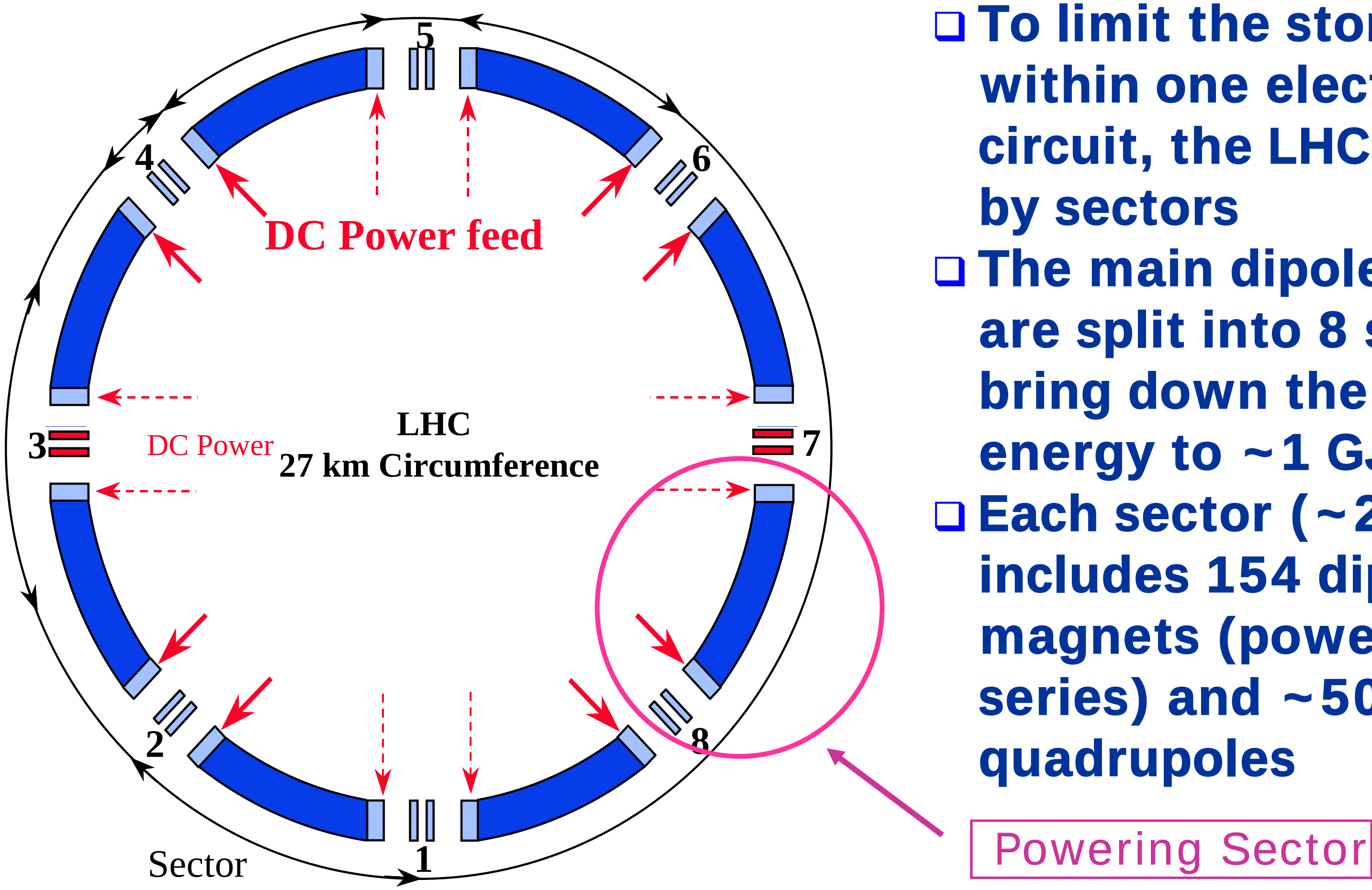
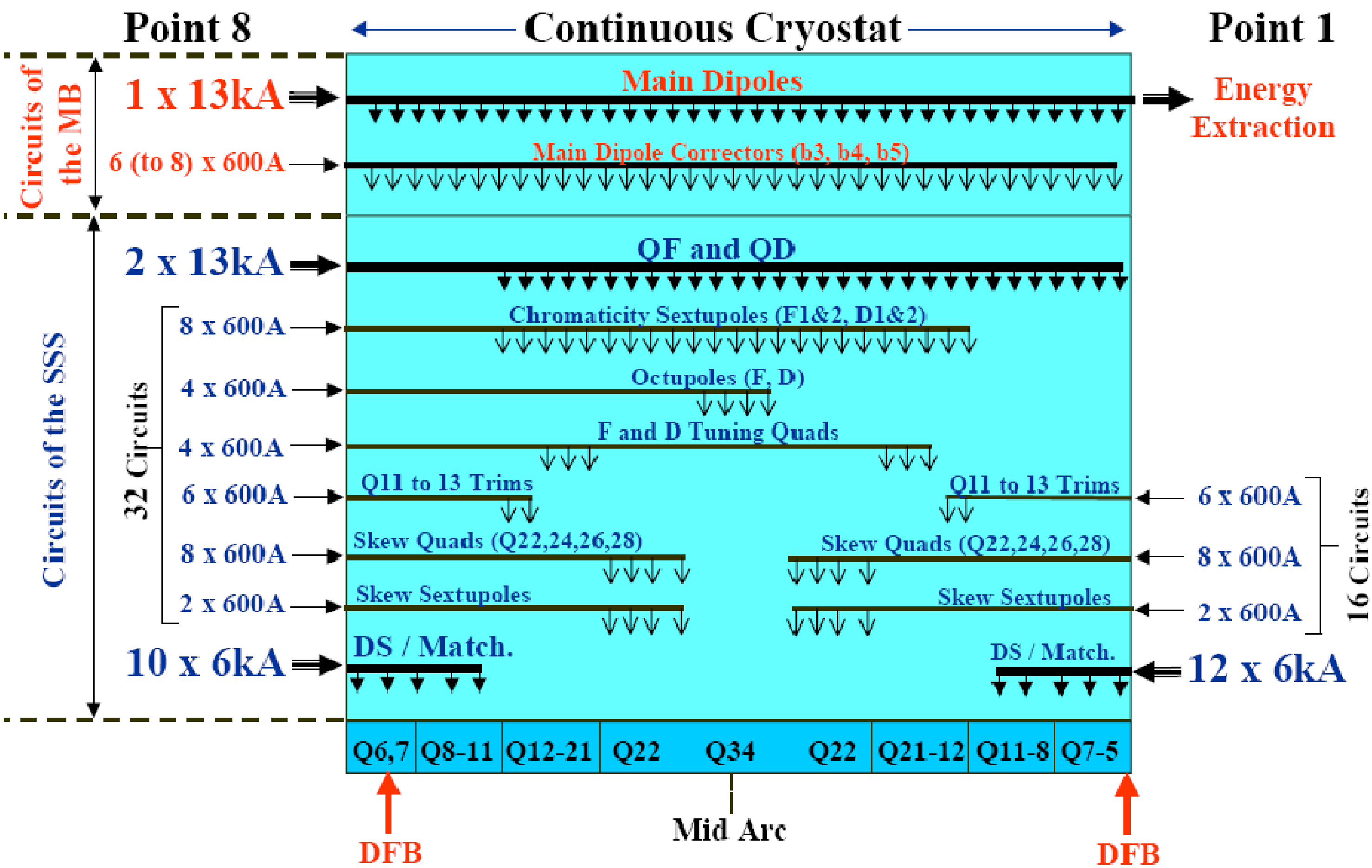
LHC Powering in Sectors



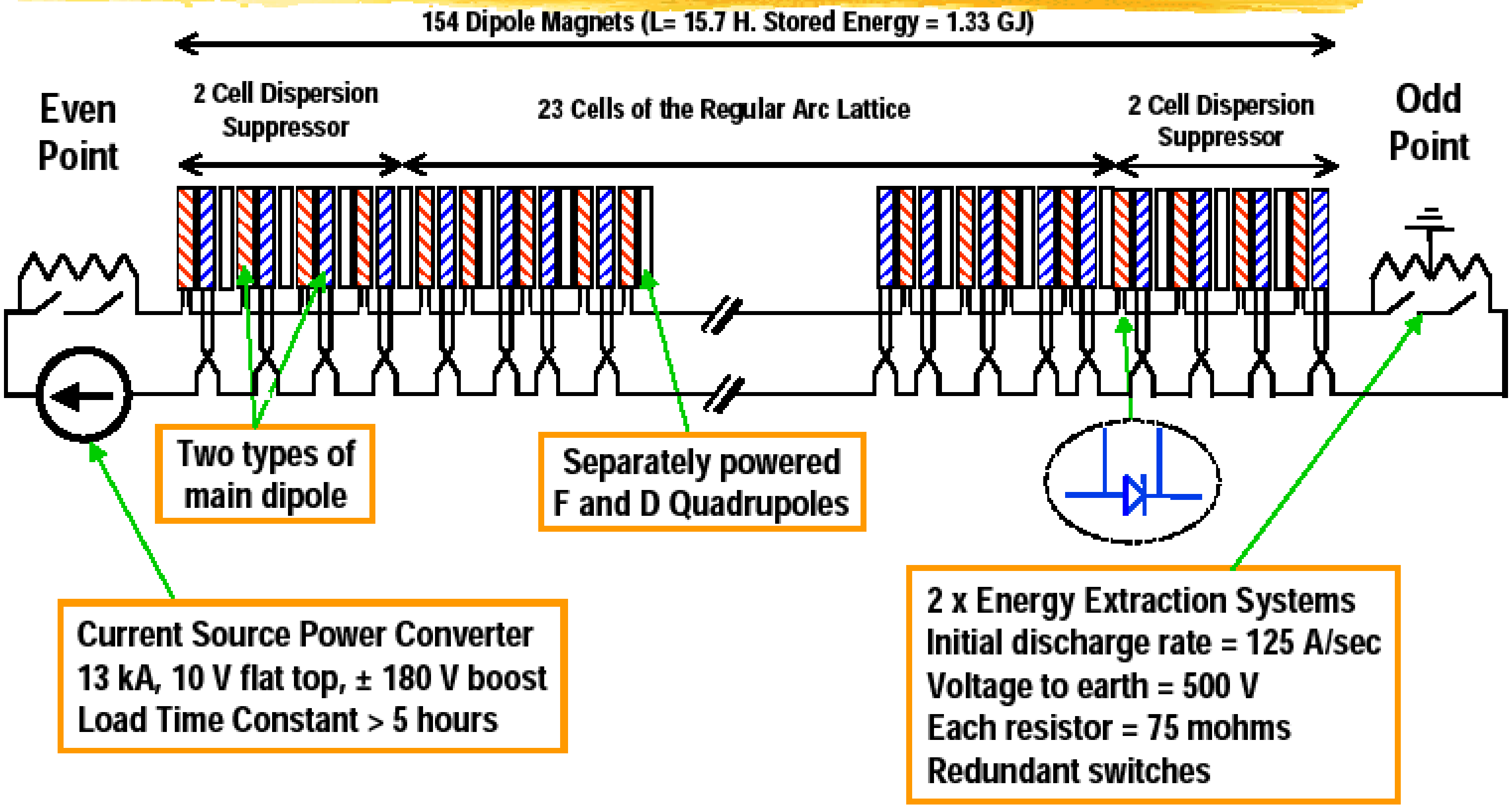
- To limit the stored energy within one electrical circuit, the LHC is powered by sectors
- The main dipole circuits are split into 8 sectors to bring down the stored energy to ~1 GJ/sector
- Each sector (~2.9 km) includes 154 dipole magnets (powered in series) and ~50 quadrupoles

Layout of one LHC Sector

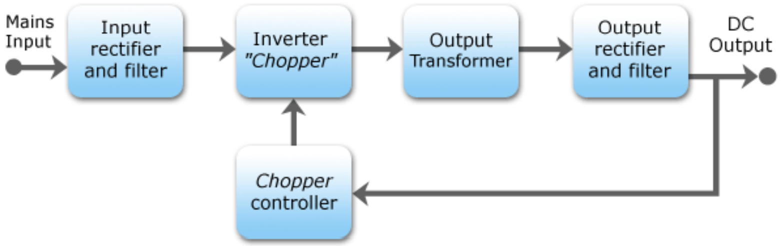


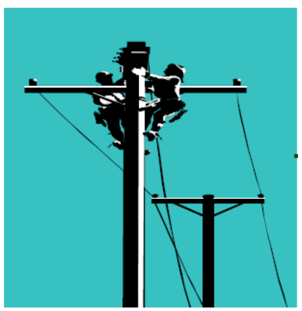
Main Dipole circuit

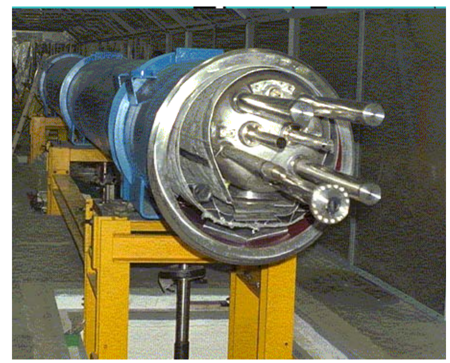
Main Dipole Powering Scheme for one sector (1/8 of LHC)

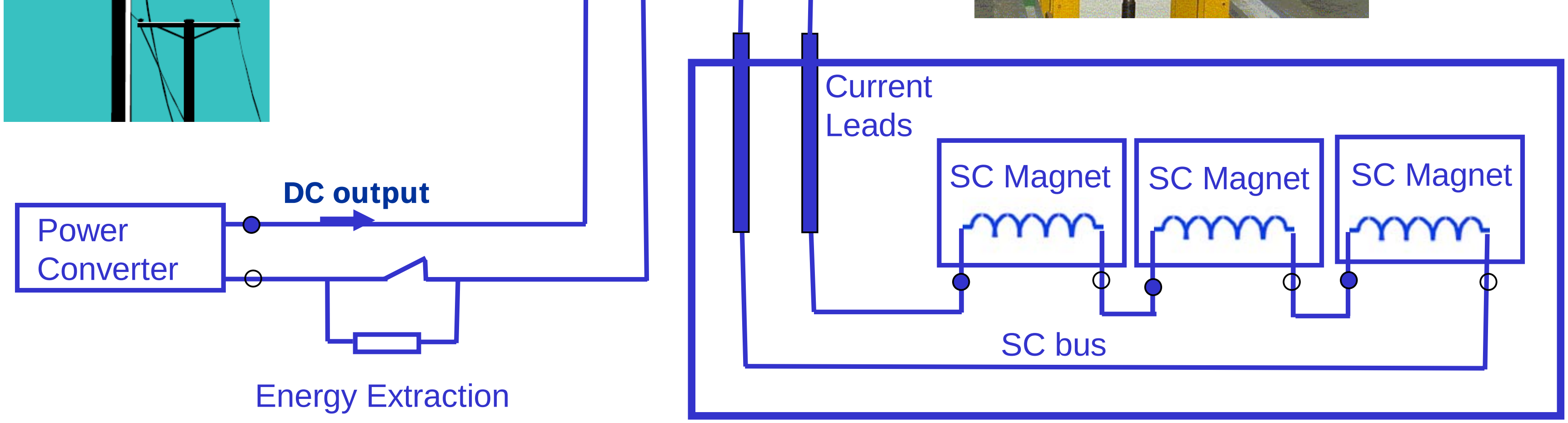


Electrical circuit









From the room temperature source…

High current – Low voltage power converters installed in the underground areas:

- ❑ **Reduced volume,**
- ❑ **High precision (< 10 ppm),**
- ❑ **High efficiency (> 80 %),**
- ❑ **High reliability**

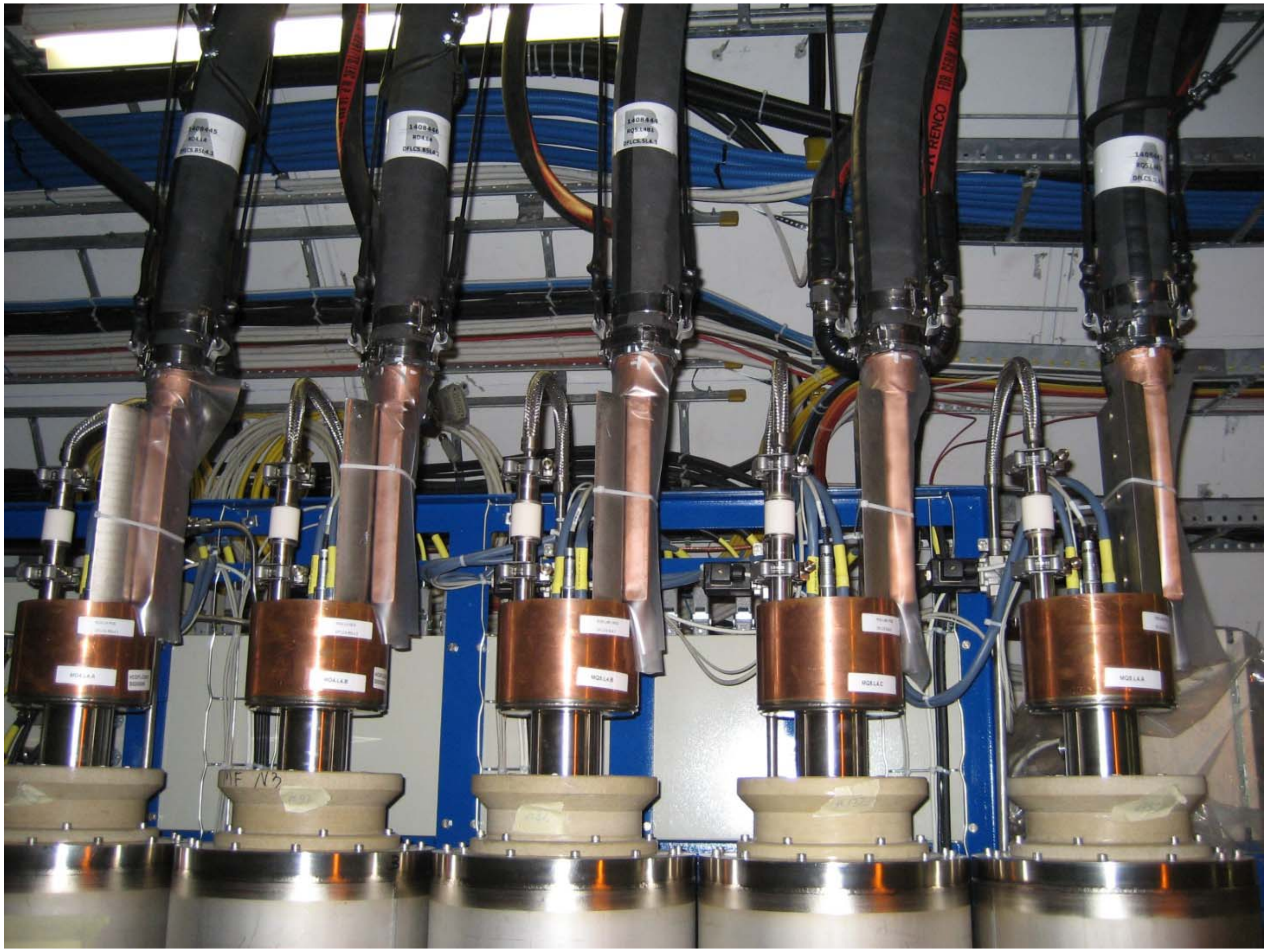
~ 1900 Power converters

➢ **3000 Warm power cables (water cooled for I > 600 A)**

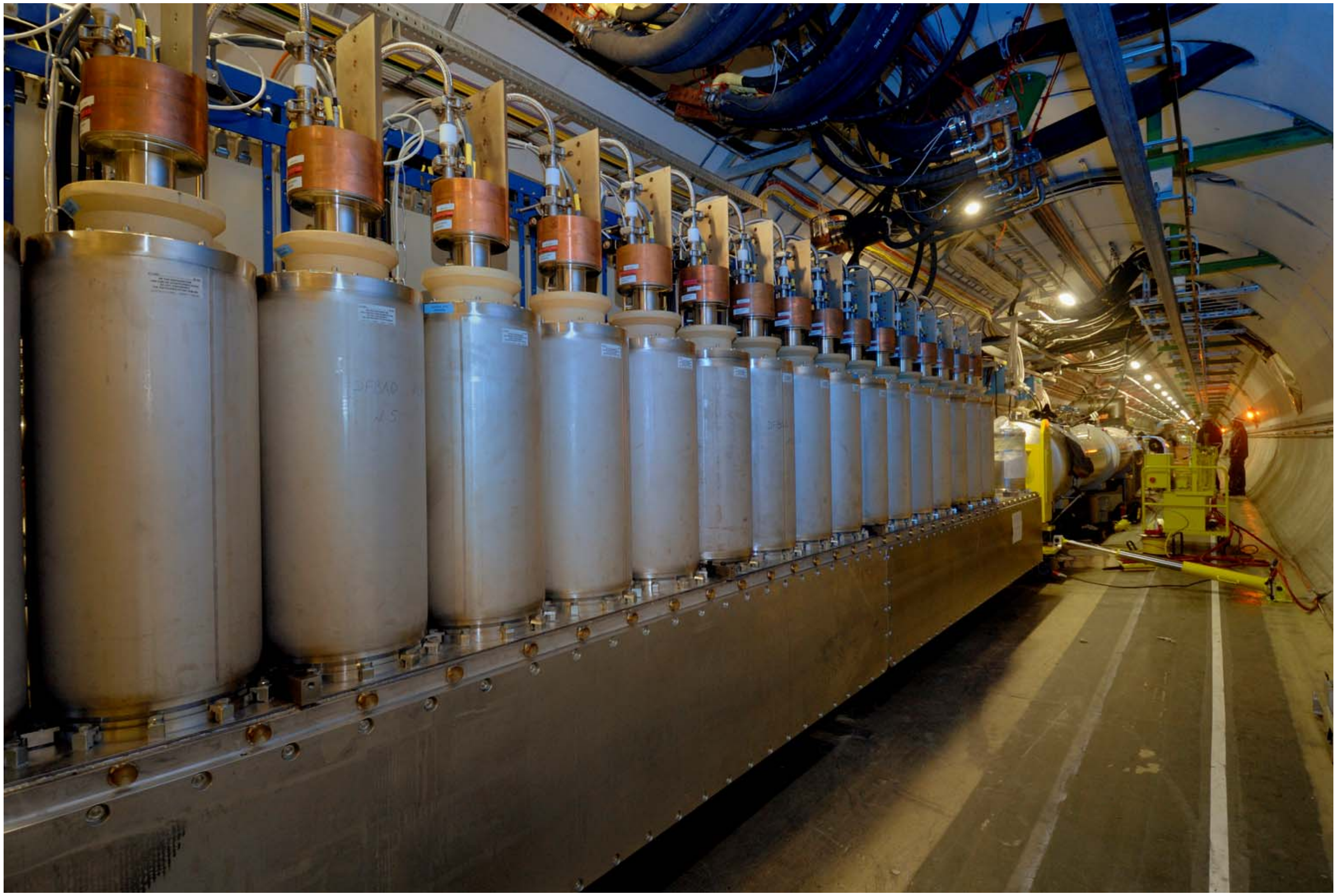
…via the RT electrical devices

Dump Resistors for the LHC main dipoles (1 GJ of stored energy).

…to the warm end of the leads



…into the cryogenic environment



…into the cryogenic environment

What needs to be powered

- 3 MA of current from/to liquid helium environment
- ~ 8000 Superconducting magnets
  - 1232 Main Dipole magnets (8 circuits 13000 A)
  - 392 Main Quadrupole magnets (16 circuits 13000 A)
  - 124 Insertion magnets (186 circuits ~ 6000 A)
  - 6340 Corrector magnets (1460 circuits from 60 A to 120 A)
  - 112 Warm magnets (38 circuits from 600 A to 900 A)
  - SC RF Cavities
- 1732 Electrical circuits

LHC Current Leads

3286 Current leads rated at currents ranging from 60 A to 13000 A

Number of leads	Current rating (A)	
64	13000	Main dipoles/quadrupoles
298	6000	Insertion magnets
820	600	Corrector magnets
2104	60-120	Corrector magnets

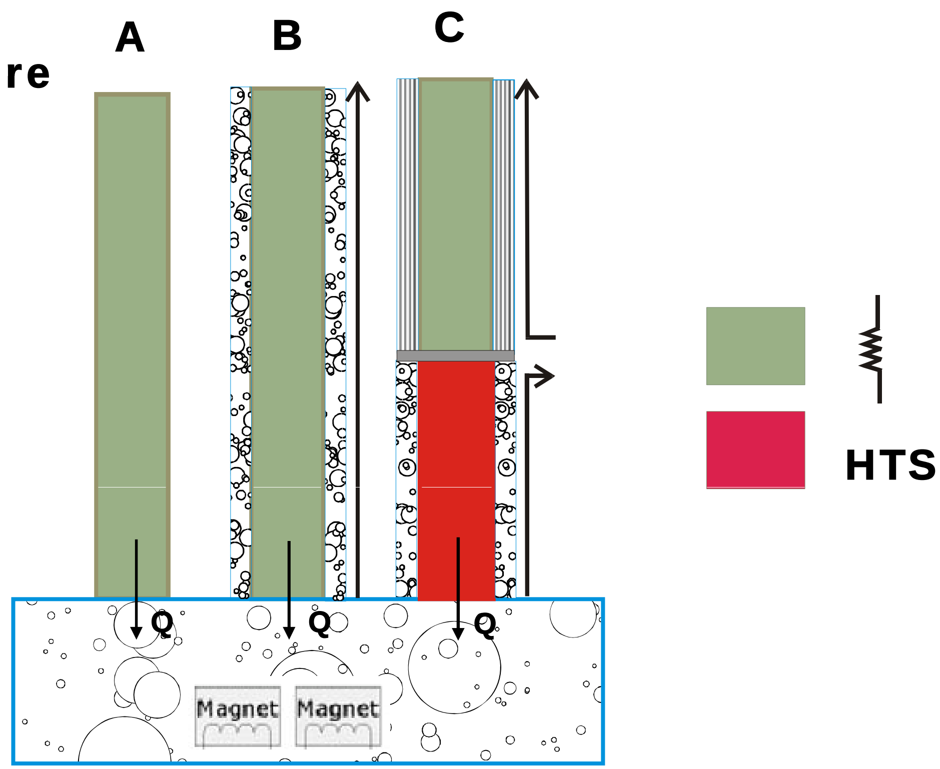
HTS Current leads

Resistive Current leads

From RT to LHe

Room temperature

LHe temperature

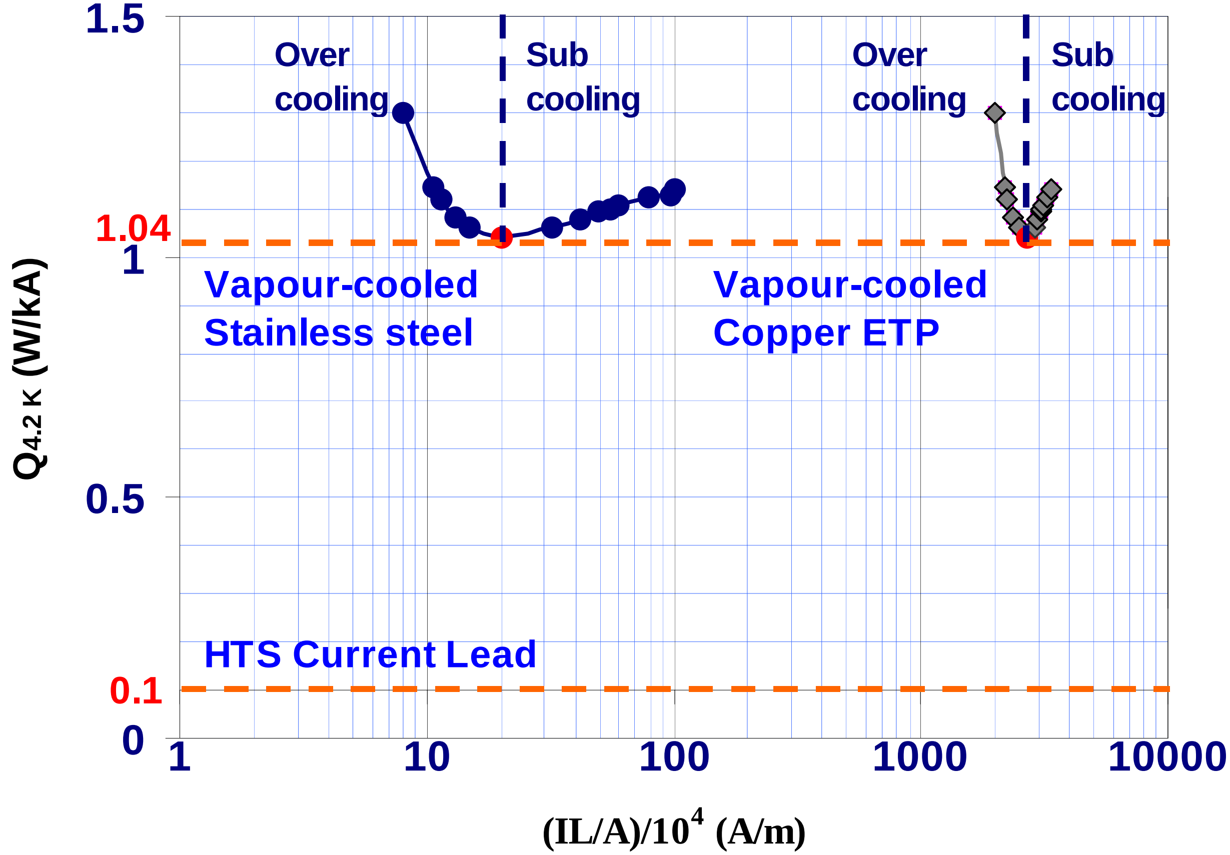


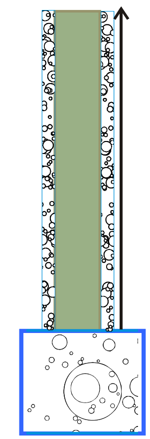
QA = 47 W/kA

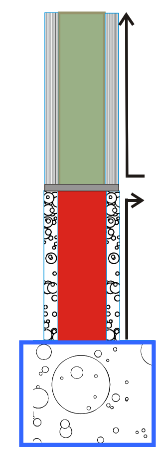
QB = 1.04 W/kA

QC = ?

From RT to LHe





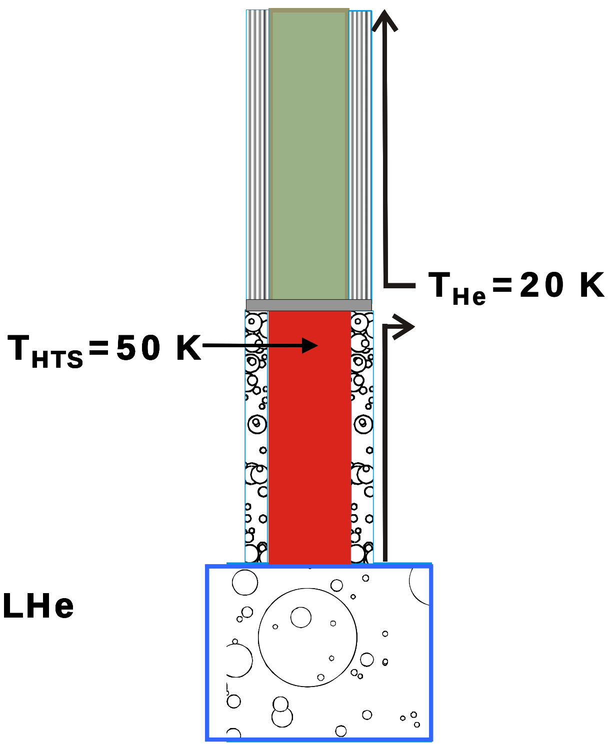


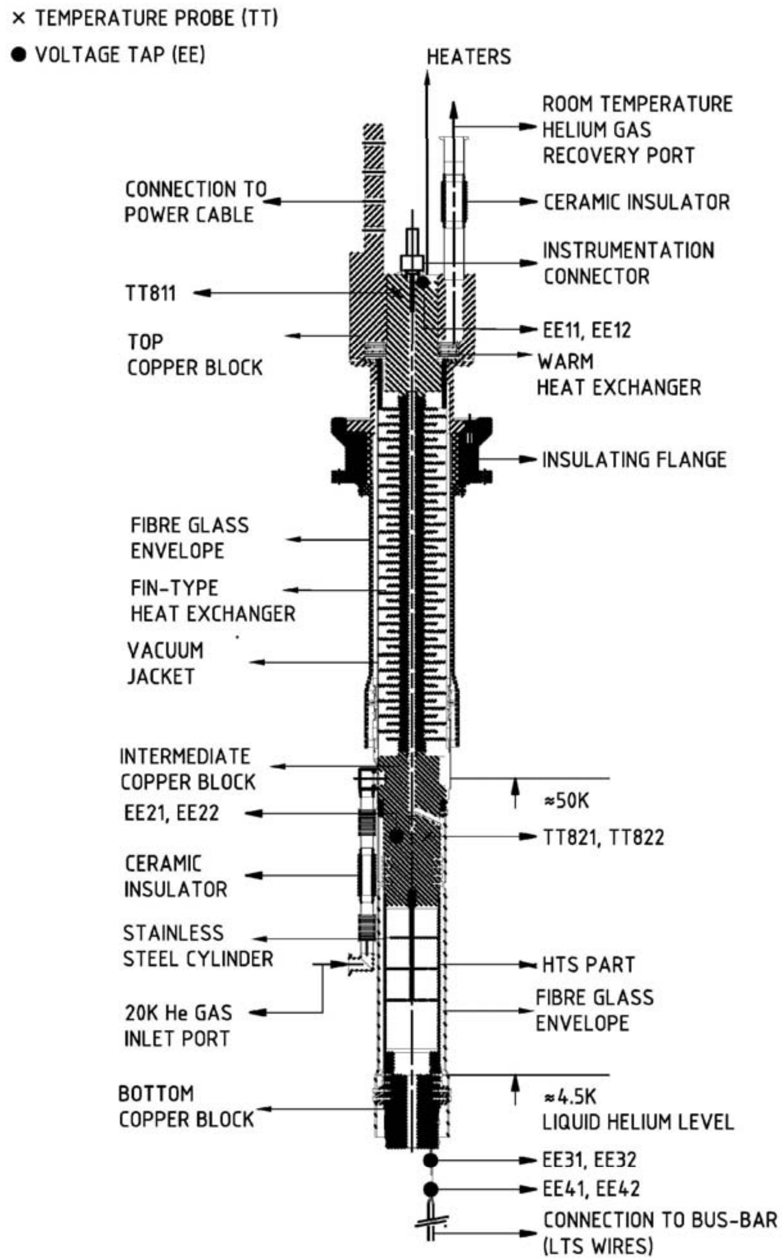
Conventional leads compared to HTS leads

LHC: 3 MA of current

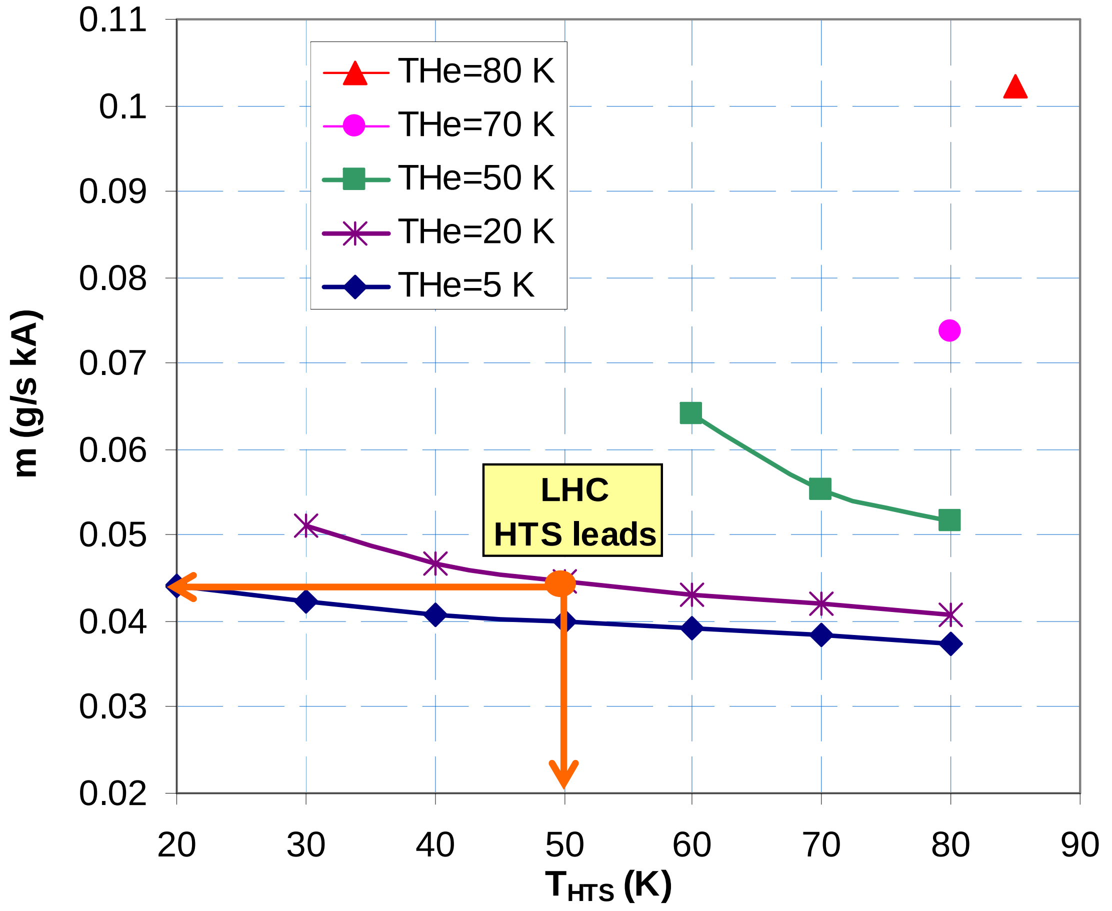
	Conventional leads	HTS leads
Heat load into LHe	1.1 W/kA	0.1 W/kA
Exergy consumption	430 W/kA	150 W/kA
Exergy consumption (% conv. lead)	100	35
Total exergetic power	1290 kW	450 kW
Total saving for LHC cryogenics (%)	-	~ 10

LHC HTS Leads

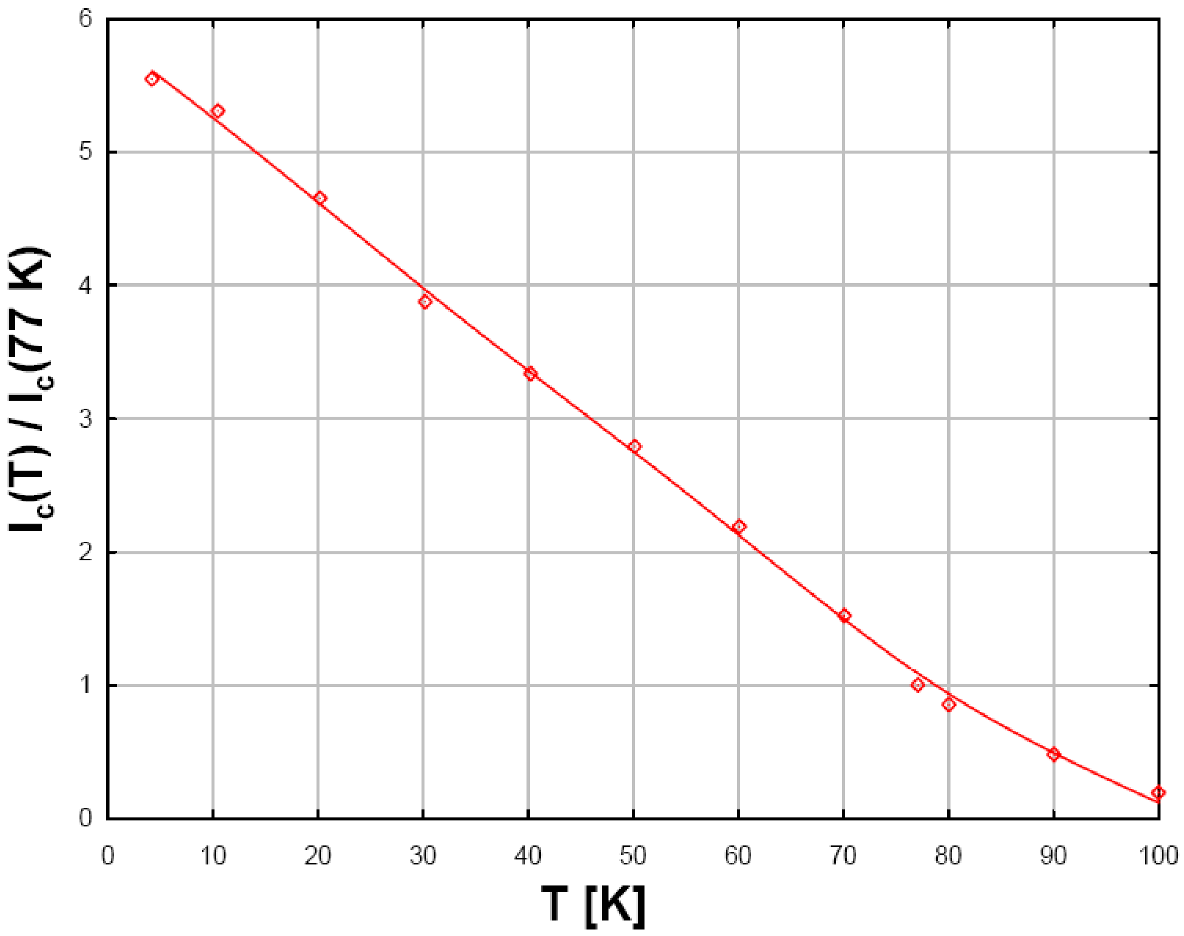




Resistive part of HTS leads

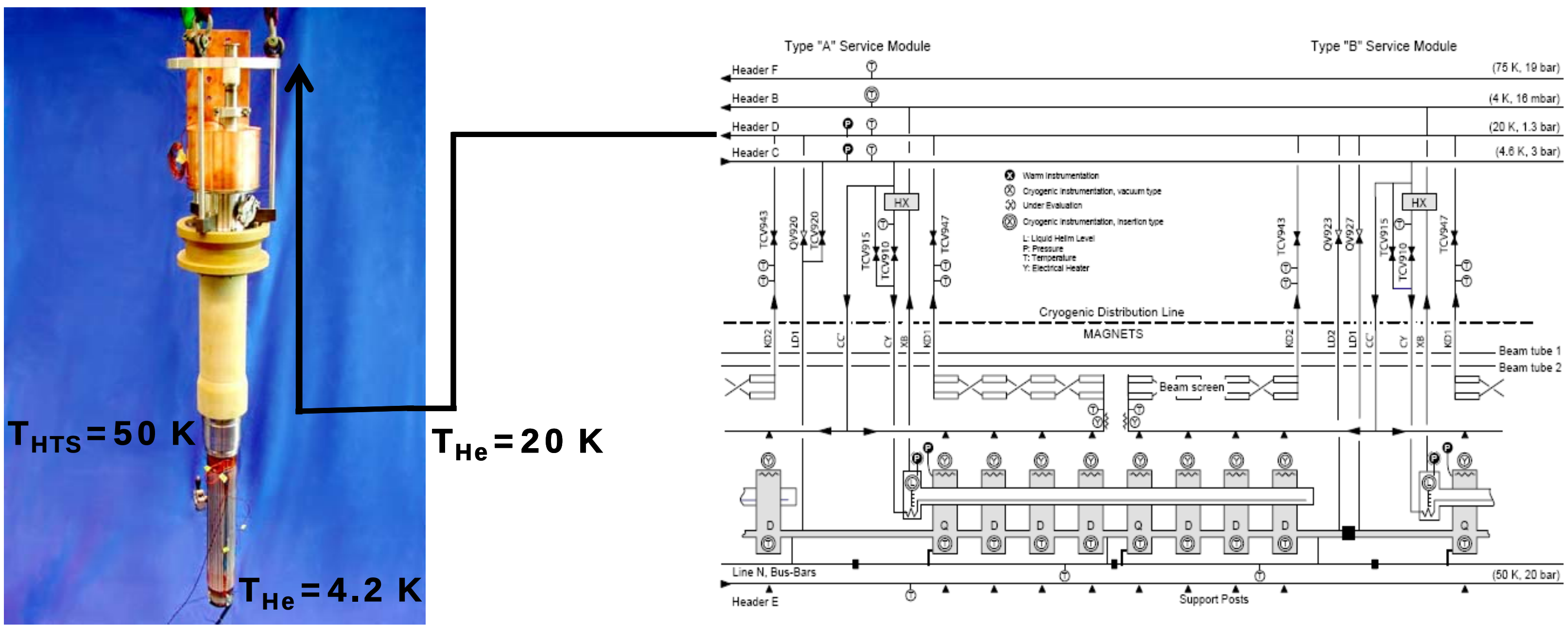


Superconducting part of HTS leads



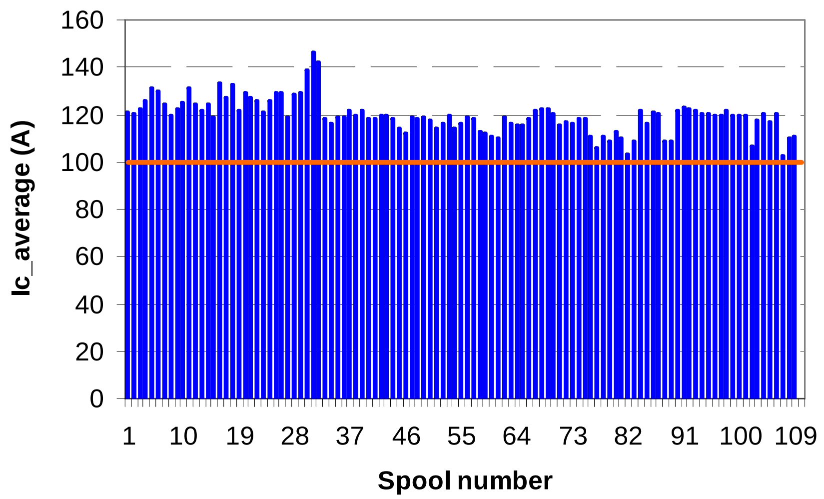
Cooling of LHC HTS leads

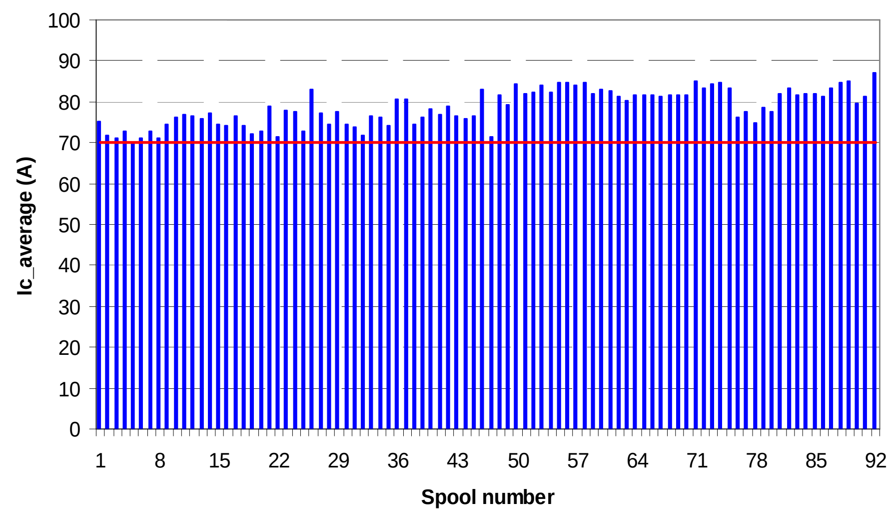
20 K-1.3 bar He gas : comfortable temperature margin, best fitted to the system and best potential power saving



HTS material in LHC leads

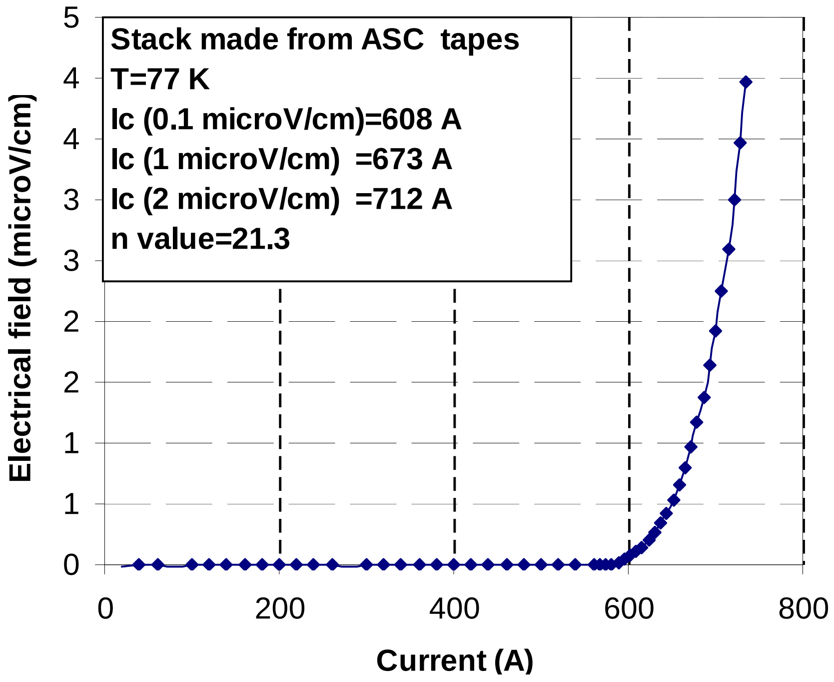
- 31 km of Bi-2223 tape (Ag 5.3%wt Au) delivered to CERN on spools in convenient lengths of 100-200 meters
- Tape supplied by AMSC (US) and EHTS (D)

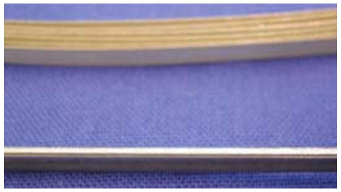


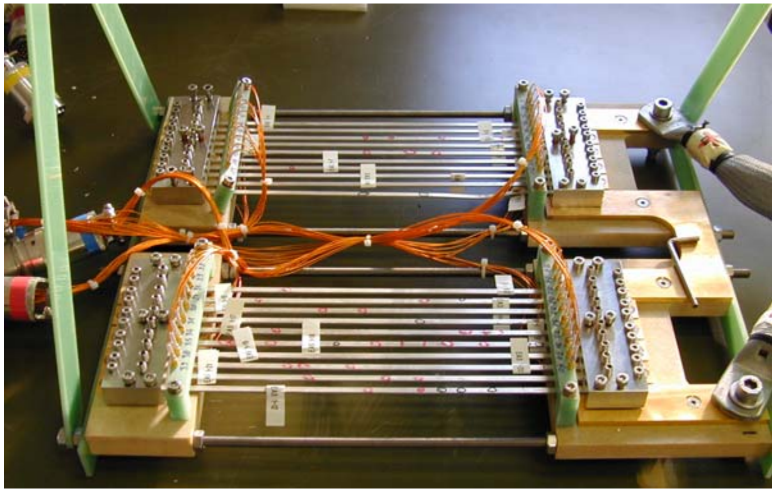


HTS Material in LHC leads

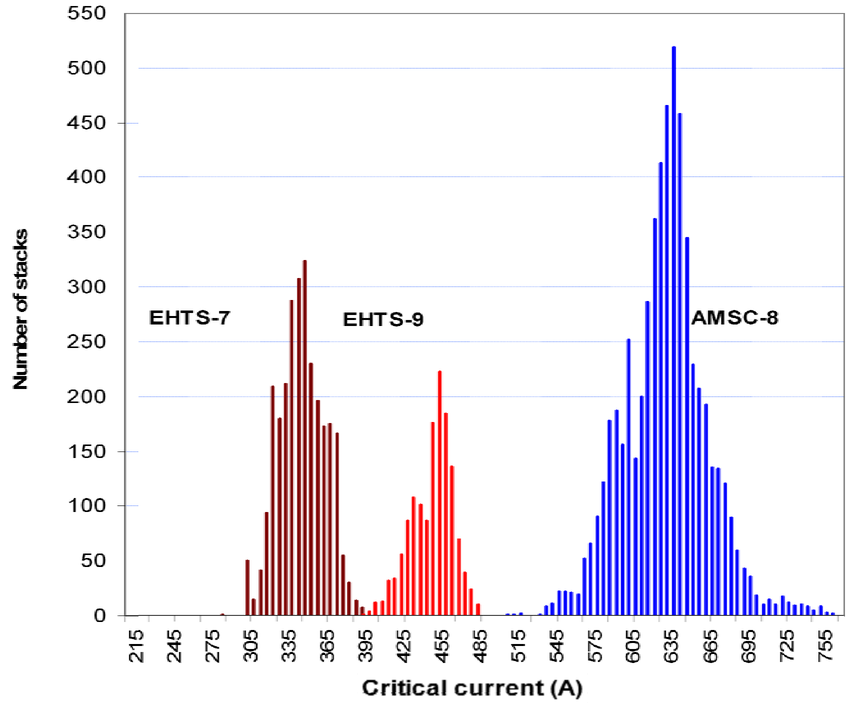
- The tapes were vacuum soldered into stacks at CERN
- More than 10000 stacks were produced and characterized in liquid nitrogen







HTS Material in LHC leads



	Ntot	Imin (A)	Imax (A)	Imean (A)	σ (A)
EHTS-7	2780	279	411	340	19
EHTS-9	1420	390	480	441	16
AMSC-8	5870	501	758	627	32

13000 A 600 A

1.5 m

0.5 m

1.5 m

Series production of HTS leads

- The design of the LHC leads was made at CERN, where prototype components were assembled and tested in nominal operating conditions

- The series production was made in CECOM-Rome (13000 A) and in BINP-Novosibirsk (6000 A and 600 A) on the basis of build-to-print designs

- All HTS leads were tested in nominal cryogenic conditions at ENEA-Rome (13000 A and 6000 A) and at the University of Southampton (600 A) prior to installation at CERN in the LHC cryostats.

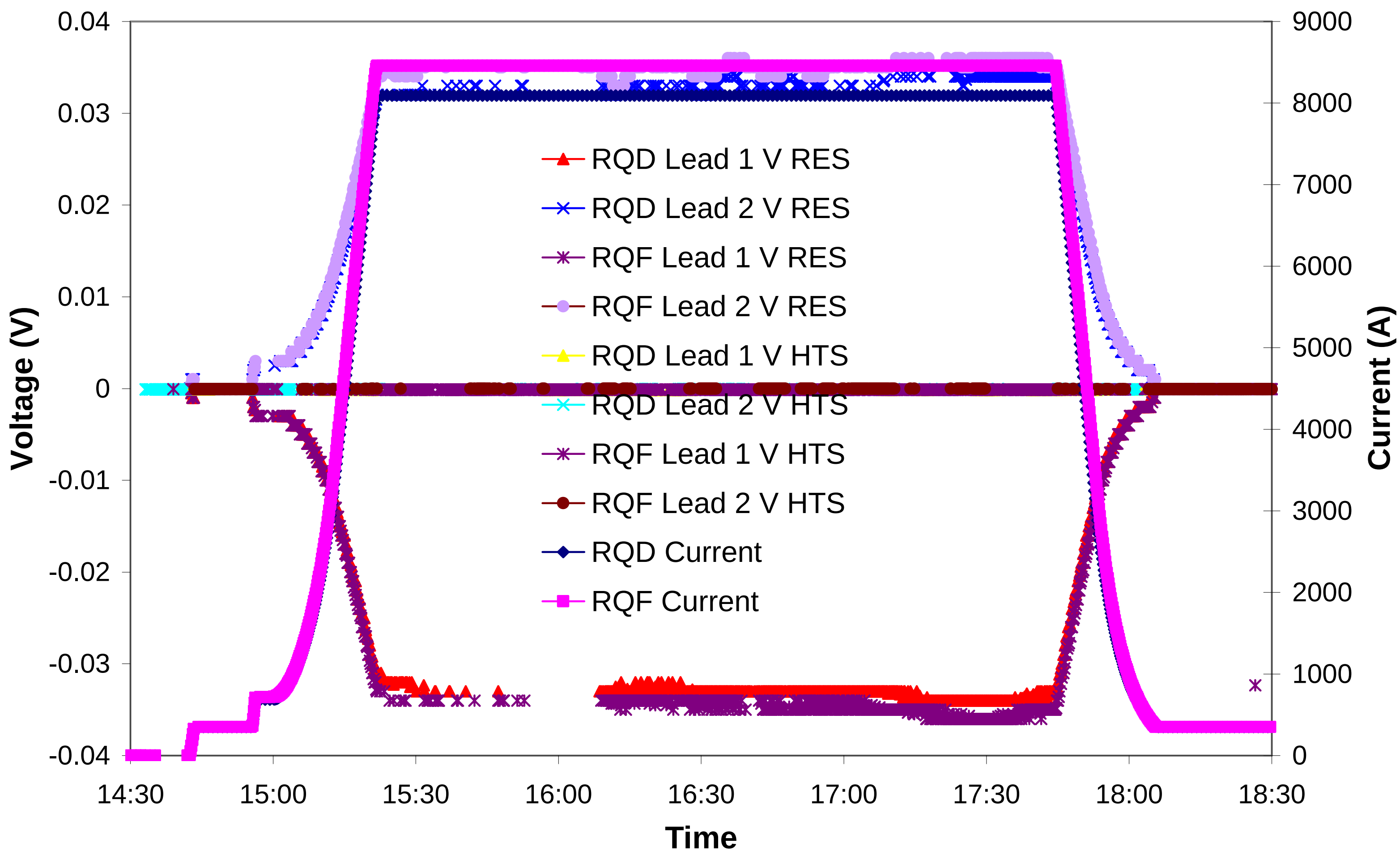
- The leads were installed in the cryostats at CERN on surface. The cryostats with the leads were lowered into the LHC tunnel according to the needs of the LHC installation schedule.

DFB with leads transported in the tunnel

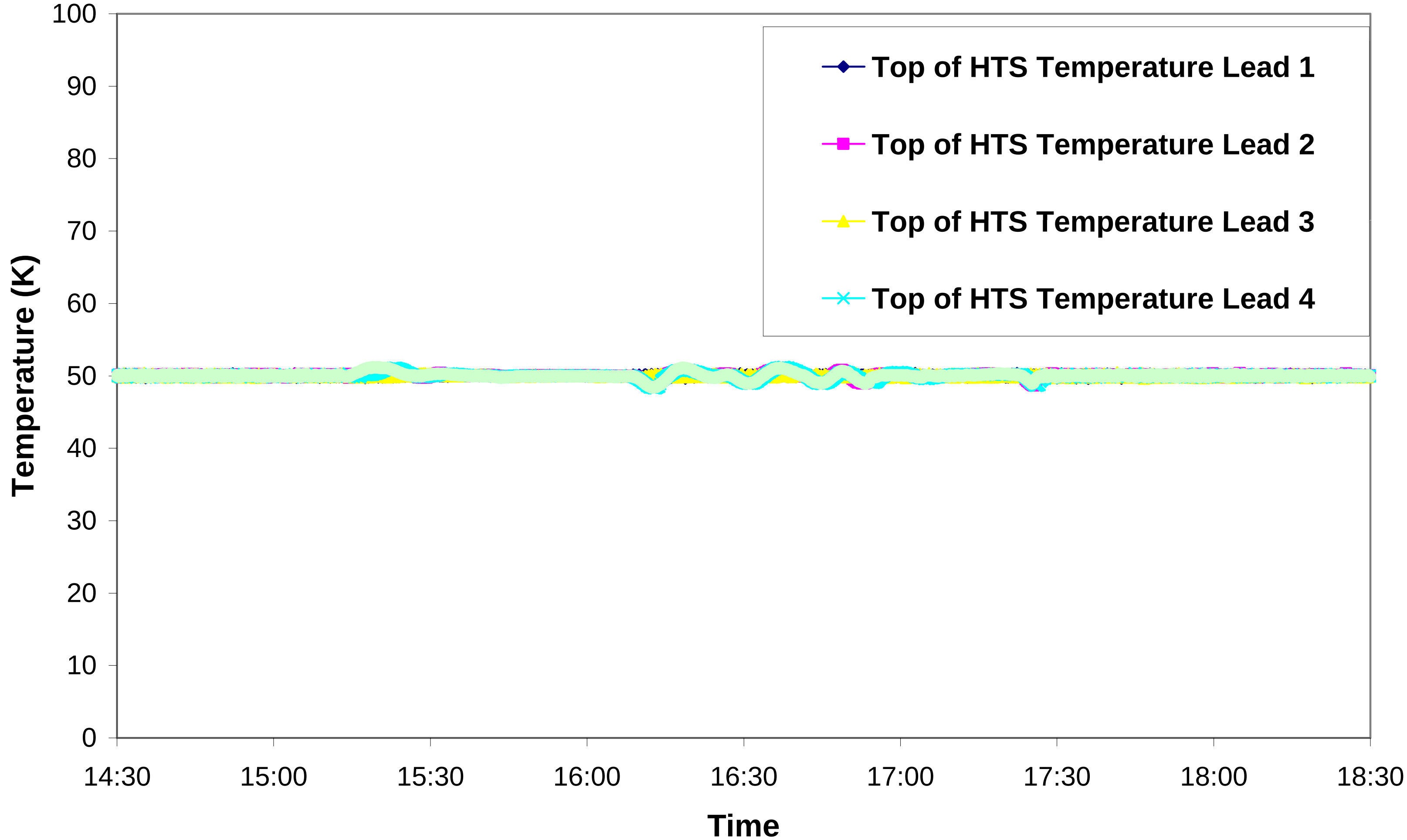
Commissioning of LHC leads

- As of today, all leads are installed in the LHC tunnel
- Hardware commissioning of the LHC machine is proceeding by cooling-down and testing individually each of the 8 Sectors
- The leads of two Sectors (~250 HTS and 600 resistive) have successfully undergone the pressure tests, the high-voltage insulation tests in warm and cold conditions, and the powering tests. This was the first time that the components were measured as part of the LHC accelerator, electrically connected to the magnet system. The cryogenic control system and the quench protection system (3 mV threshold for the HTS part) were also validated. A third Sector is being commissioned in these days

Powering of quadrupole circuits

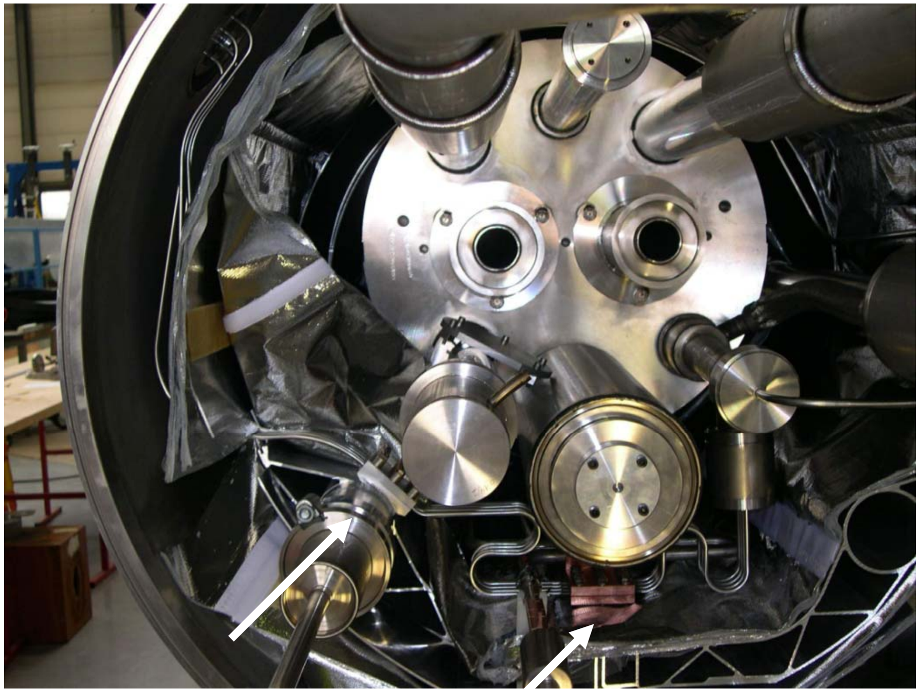


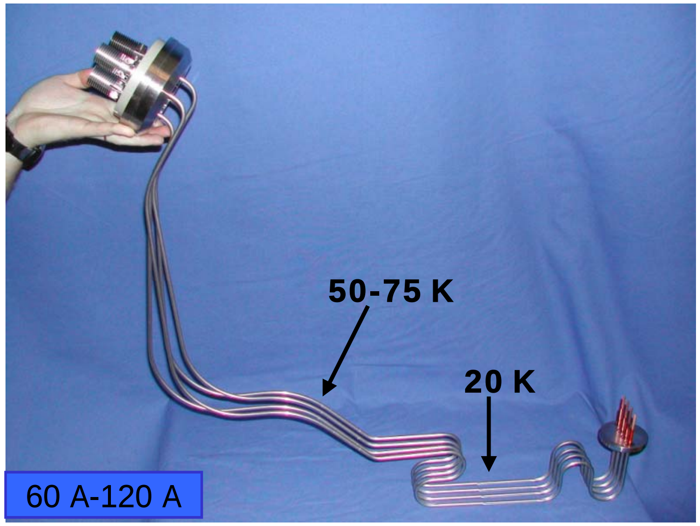
Powering of quadrupole circuits



Resistive 60 A-120 A leads

More than 2000 conduction-cooled current leads operating at 60 A, 80 A or 120 A.





Conclusions

- HTS leads offer the potential of enabling a considerable power saving in the cryogenic system
- The development of the LHC current leads has been a real technological challenge. The decision of going to HTS leads was taken in 1996: once decided, it would have been difficult to go back to conventional leads
- The incorporation of more a thousand units of HTS leads in the LHC machine has offered a unique opportunity for a real mission-oriented large scale application of HTS material. Experience from the cryogenic test of series units and LHC operation is positive, and provides the basis for increased confidence in this type of equipment