Superconducting Links

for accelerator technology

Eucard’13, CERN

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CERN, TE-MSC-SCD

With contributions from the SCD SL Team (B.Bordini, S.Giannelli), the Columbus Superconductors team and T. Taylor

Outline

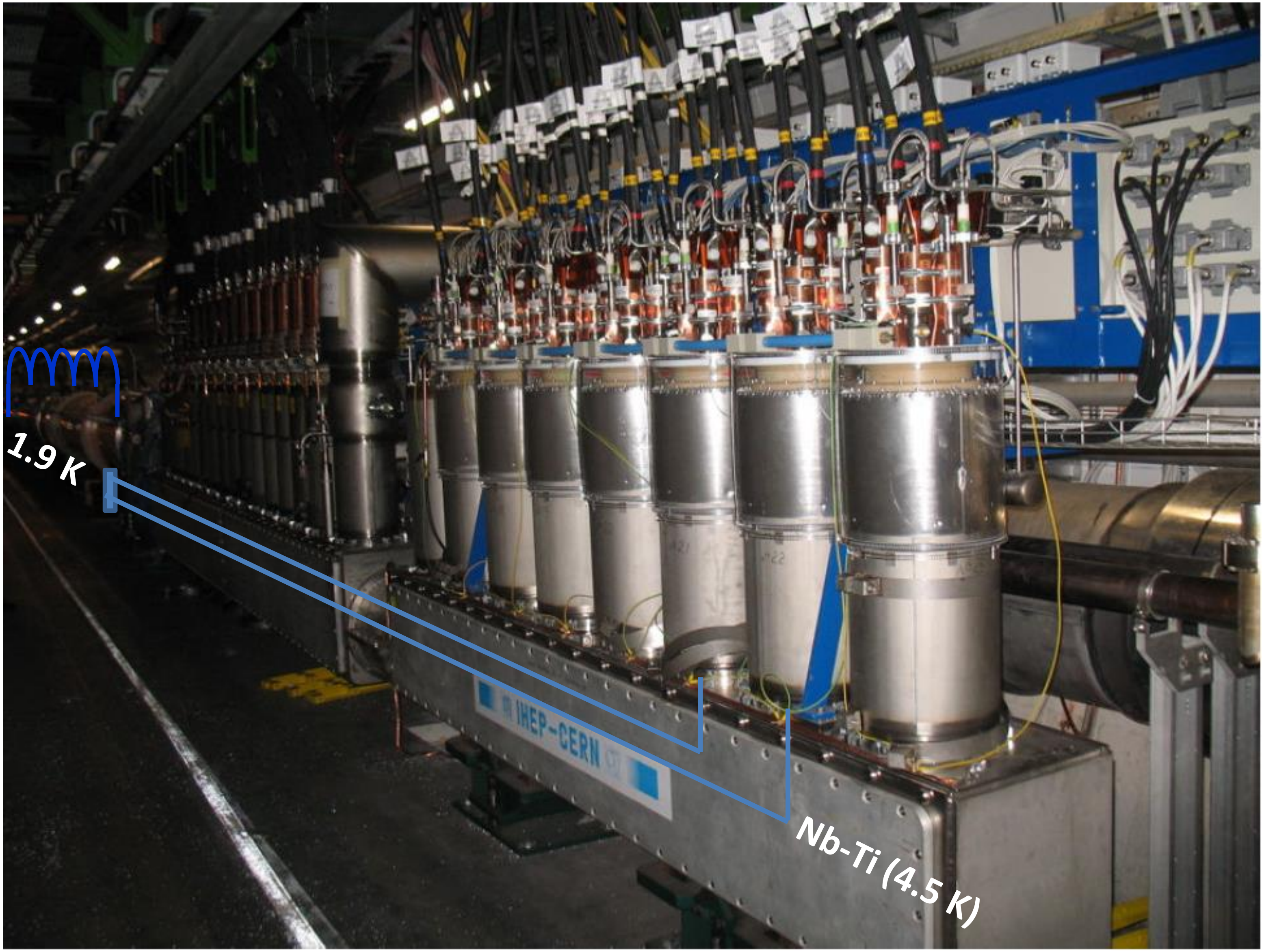
- When/how did the development for LHC start
  - Eucard 1 Task 7.5, LHC P7
  - Hi-Luminosity Upgrades, LHC P1 and P5
- Development for LHC Upgrades
- Potential applications to accelerator technology
  - High Current bus-bars, Experiments, Magnets
- Conclusions

Superconducting Links for LHC

Original proposal (2009)*: development of a technology enabling the **remote powering of the LHC magnets** using novel HTS conductors:

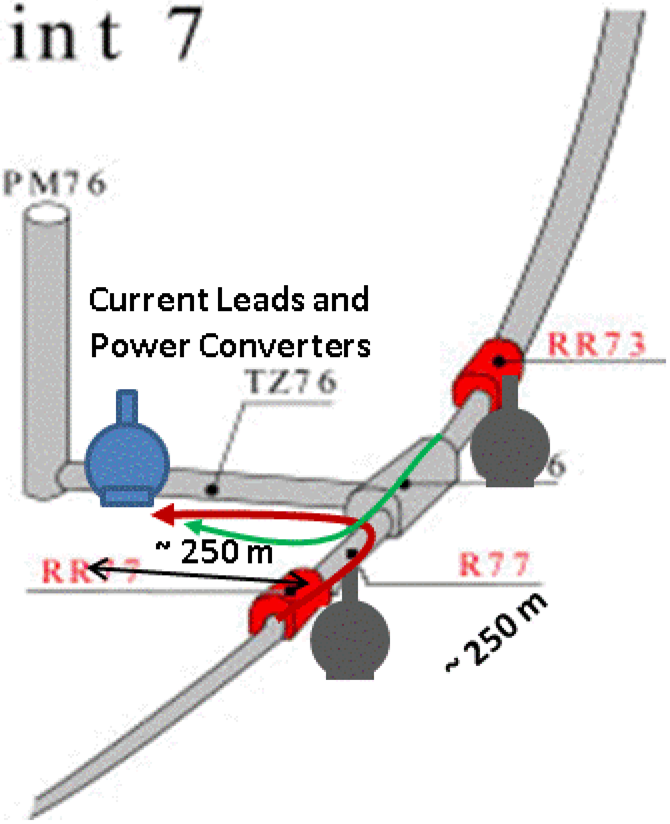
- higher Tc $\rightarrow$ operational temperature margin;
- safer access of personnel in the tunnel;
- shorter time for interventions in the tunnel;
- free space in the LHC ring;
- safer long-term operation of powering equipment located in radiation-free environment.

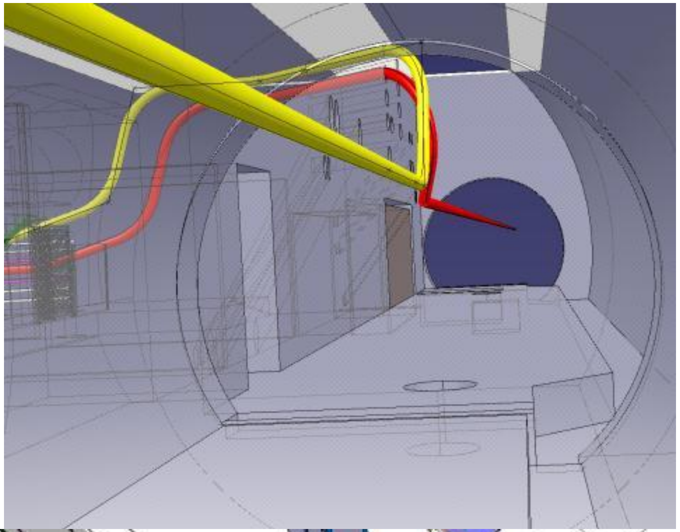
*Eucard 1, Task 7.5, A. Ballarino. Underground installation at **LHC Point 7**

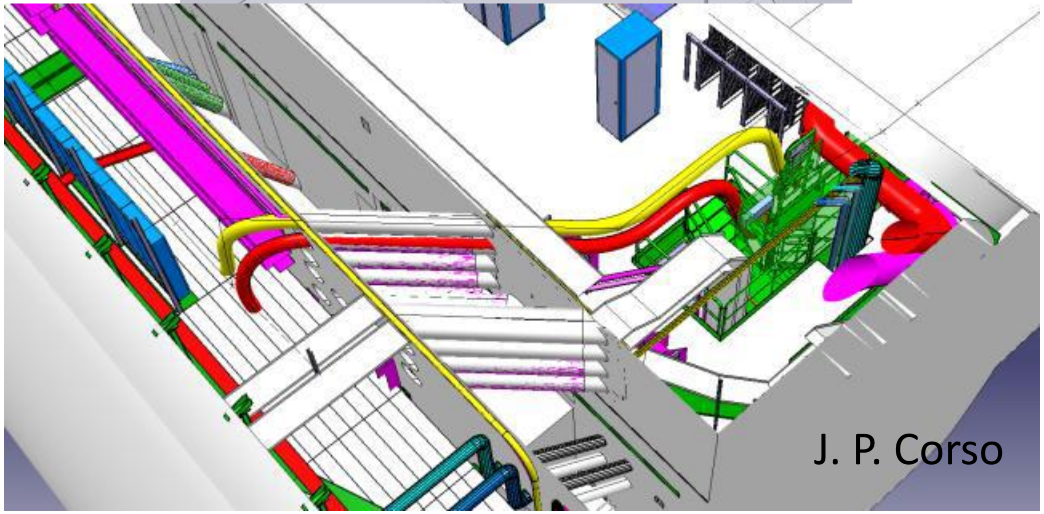


Distribution Feed Box in LHC tunnel

Point 7







50 Cables Rated at 600 A

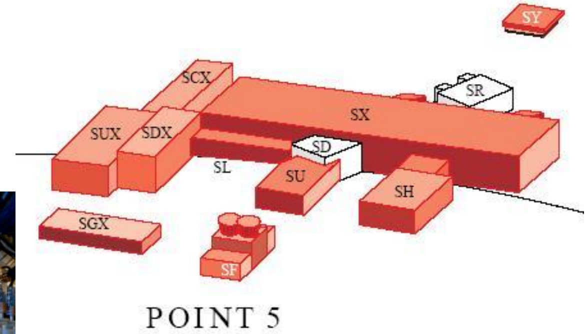
Superconducting Links for LHC

While Eucard 1 was on-going:

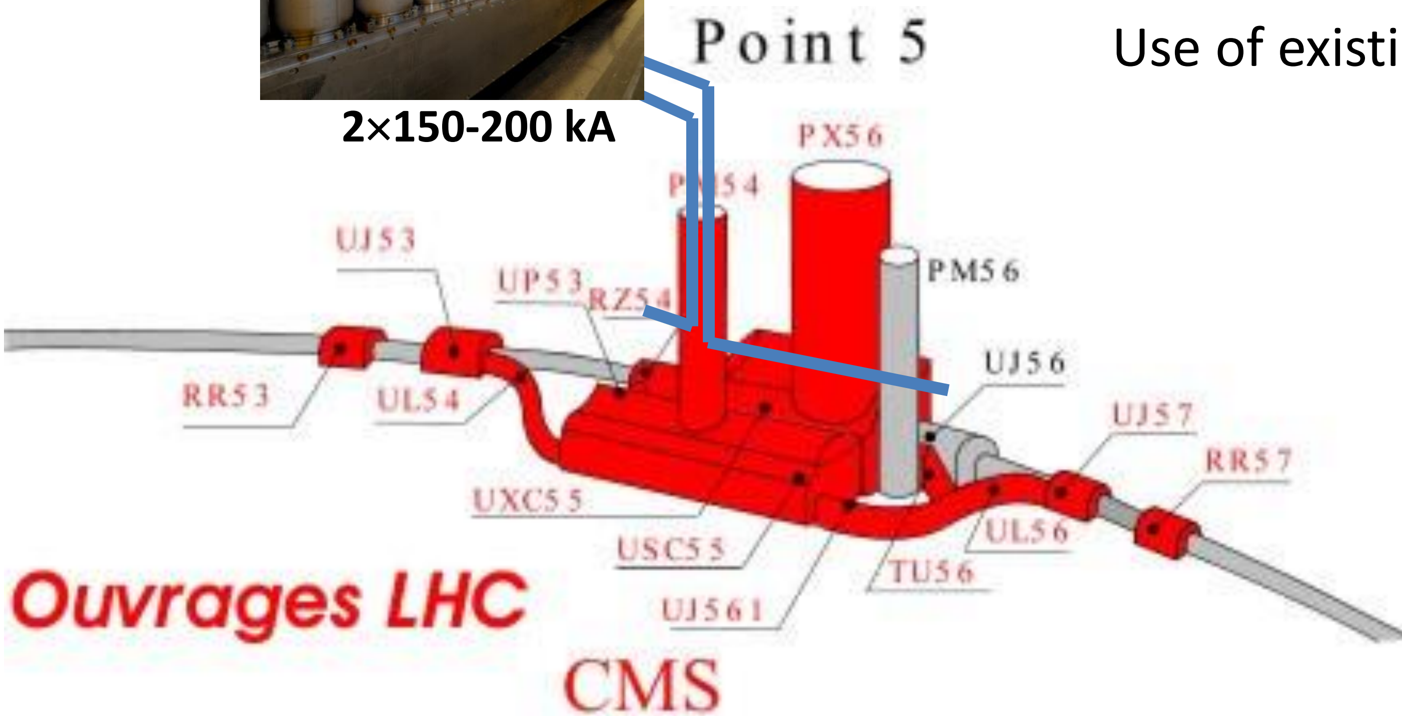
- single event effects on electronics of power converters: risk for the reliable running of the LHC machine in particular at high luminosities;
- additional equipment to be installed in the LHC ring;
- adoption of superconducting links for the powering of the new high-luminosity magnets (Triplets and Matching Sections) at **LHC P1** and **P5** – in addition to **P7**

Surface Installation

Superconducting Links for LHC



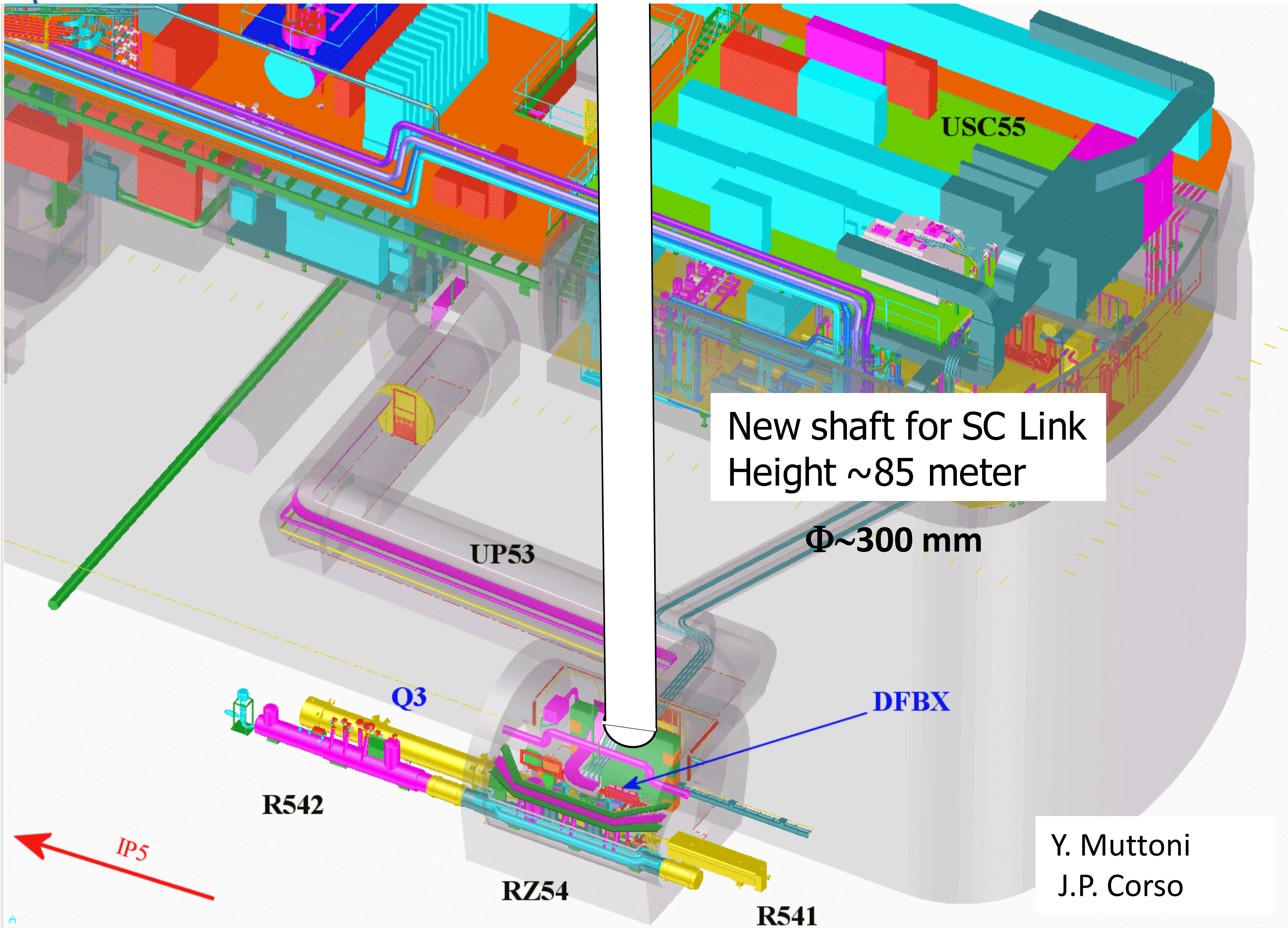
2×150-200 kA



Use of existing shafts

High-current cables (up to 20 kA)

Superconducting Links for LHC



Superconducting Links for LHC

Number of links:

2 SC Links at LHC P7, each ~ 500 m long
|Itot|~ **30 kA/link**
50 cables rated at **600 A**

4 SC Links at LHC P1, each up to ~ 300 m length
4 SC Links at LHC P5, each up to ~ 300 m length
|Itot| up to **150-190 kA/link**
Up to **50 cables** rated at **120 A, 600 A, 3000 A, 6000 A, 13000 A** and **20000 A**

Superconductors

		Φ (mm)	W (mm)	Th (mm)	Tmax (K)	Ic [‡] (A)
[†] MgB_2	wire	< 1	-	-	25	≥ 400
MgB_2	tape	-	3.7	0.67	25	≥ 400
YBCO	tape	-	4	0.1	35	≥ 400
BSCCO 2223	tape	-	4	0.2	35	≥ 400

[†] bending radius $R_B \leq 80$ mm
[‡] at applied field $B \leq 0.5$ T

Ltot ~ 1000 km of conductor for series production

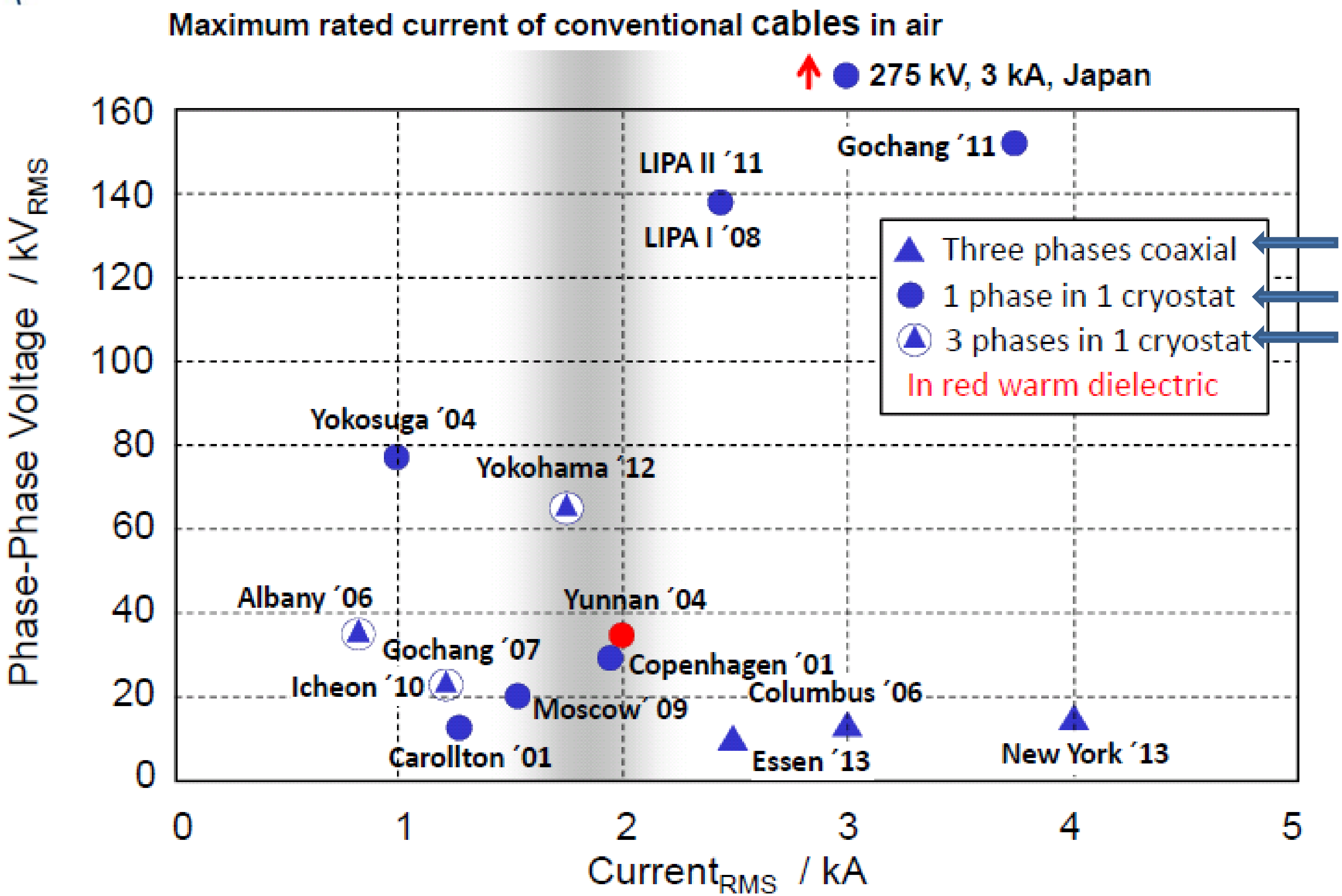
Superconducting Links for LHC

Complexity much greater than that that of “conventional” transfer lines developed (for power transmission in the least years with first (BSCCO 2223) and second generation (YBCO) HTS conductors

- **High current cables** (I up to 20 kA)
- **Multi-cable assemblies** ($|I| > 150$ kA)
- **Vertical transfer** ($\Delta H \sim 80$ m). Weight of cable ~ 1 ton

Cost of conductor is an important factor – in particular in view of the large quantity of conductor required for the final application

HTS Power Transmission Lines



M. Noe, CAS, Erice, 1st May 2013

HTS Power Transmission Lines

Nexans Cable

Multi-layer helical winding of HTS tape-shaped HTS Conductor (Bi-2223 of YBCO) around a cylindrical and flexible former

Cryostat diameter = 150-200 mm (LN_2, no active shielding)

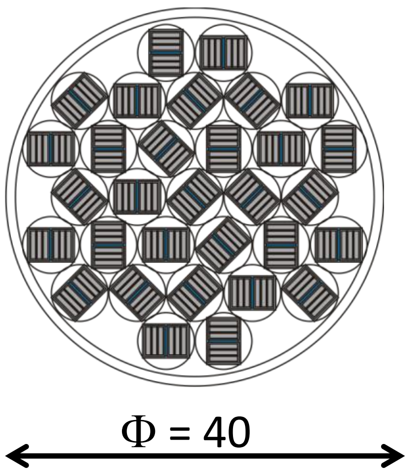
HTS Power Transmission Lines

NKT, Installation of Underground HTS Power Transmission Line

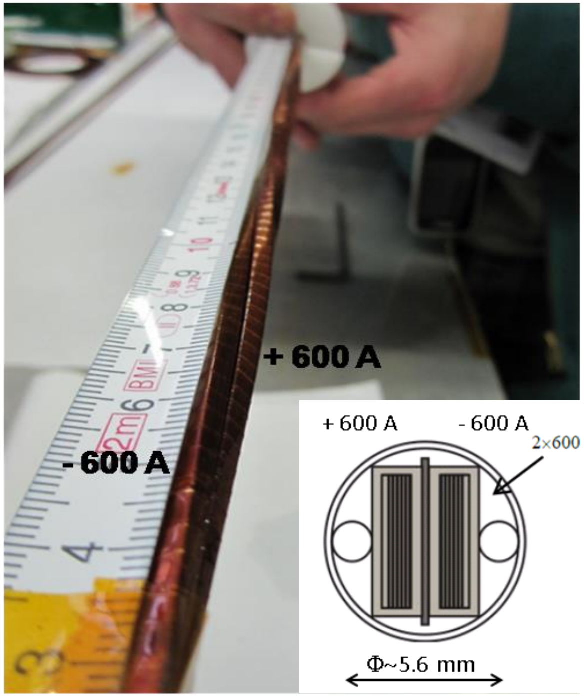
Superconducting Links for LHC
New high-current cable concepts

New concept proposed by CERN

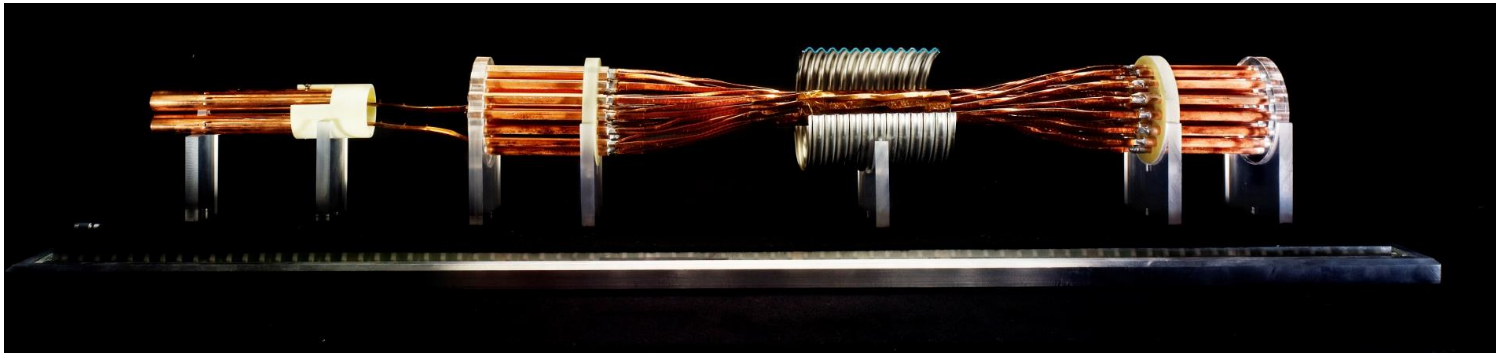
MgB_2, YBCO, BSCCO 2223



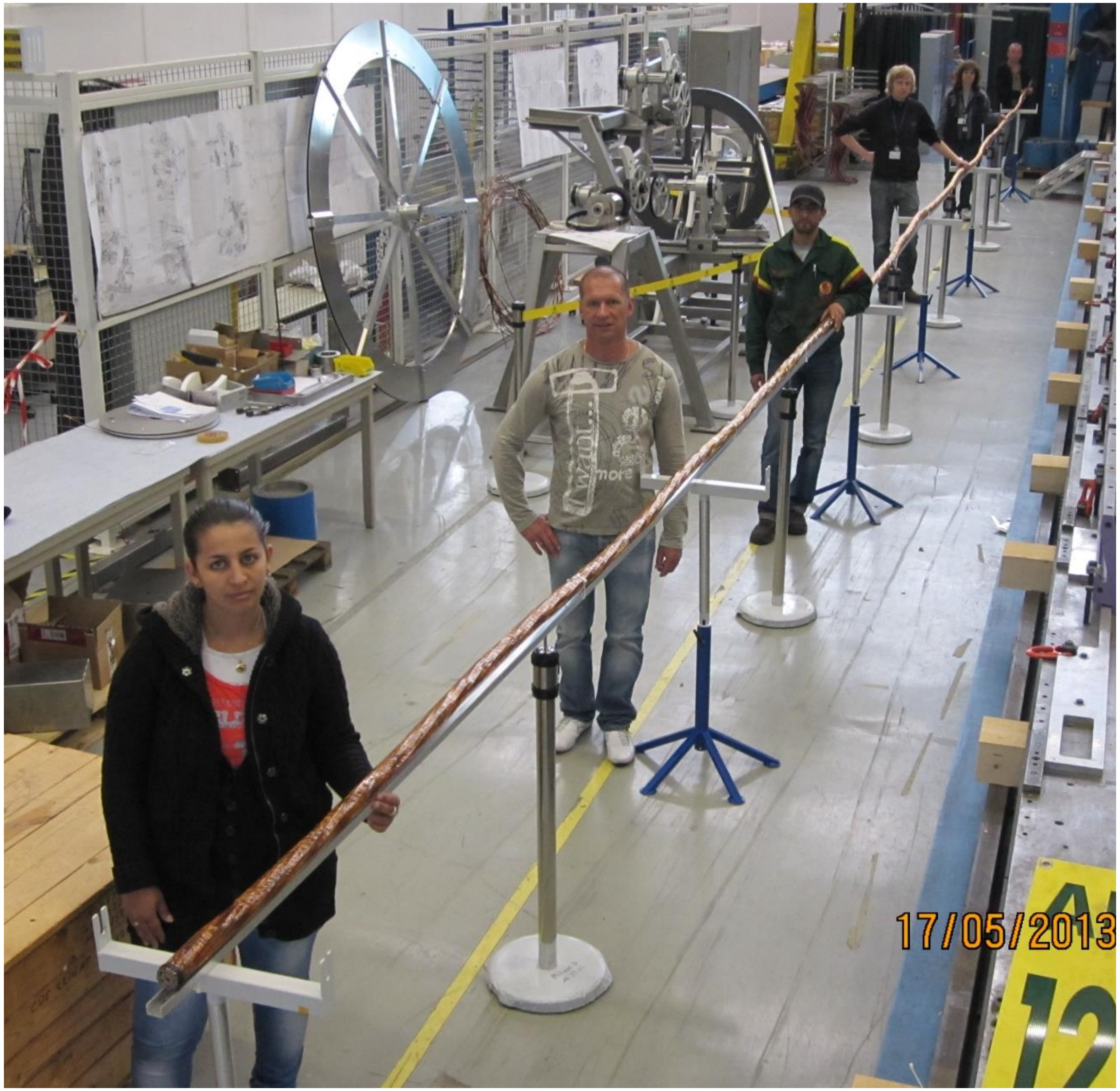
Ic >2.5 kA @ 20 K
Ic = 600 A @ T > 30 K



Mock-up by Julien Hurte, TE-MSC-SCD

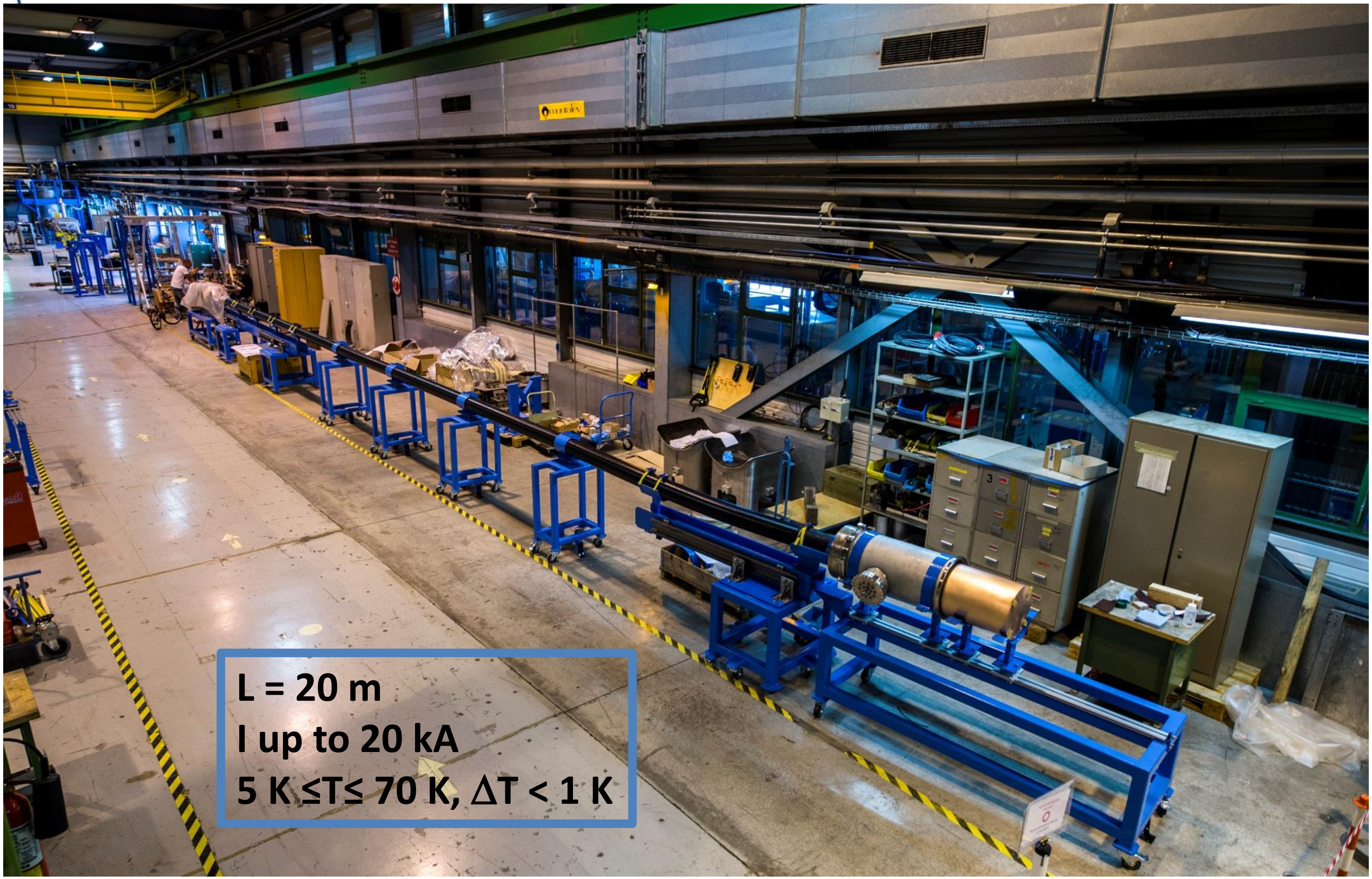


SC Link for LHC Point 7



Deliverable of Task 7.5, Eucard 1: 20 m long prototype (50 cables)

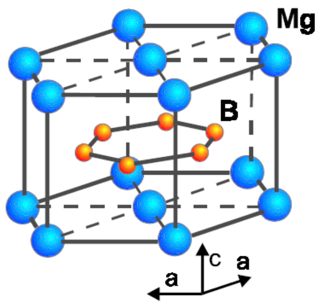
SC Link Test Station



MgB_2 Round Wires

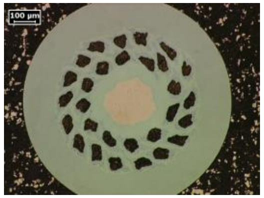
MgB_2 (Tc = 39 K)

- Simple hexagonal structure
- Low cost of raw materials and fabrication
- No weak link across gain boundaries
- Can be produced as round wire (Powder In Tube)



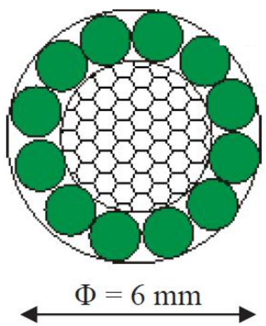
Development of **MgB_2 round wires** (**CERN/Columbus**) suitable for application to high-current cables. This development work took about 3 years. Cabling of conductor in reacted form, sufficient Ic and mechanical properties

Availability of round wire – that can be used in a a reacted form - is a **great advantage** for electrical applications

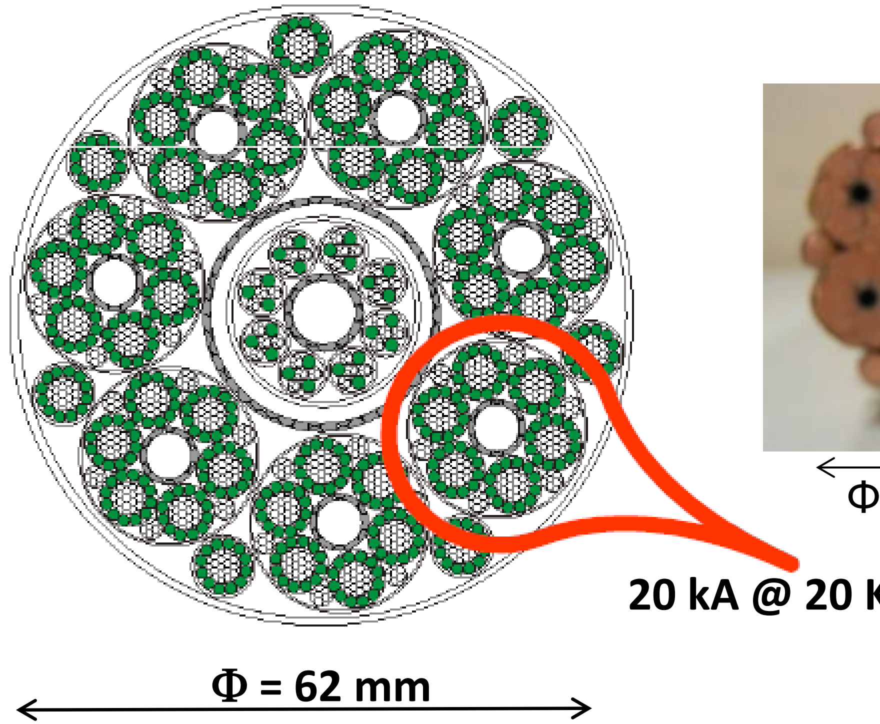


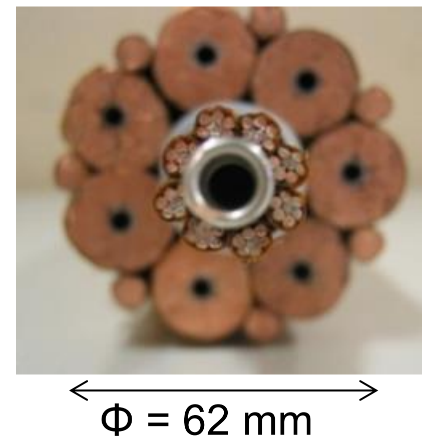
Φ = 0.85 mm

MgB_2 Cables from Round Wires



12 × MgB_2 wires
Ic > 3500 A @ 20 K





Operational temperature: 20 K- 25 K

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Transfer of 20000 A

Aluminium at Room Temperature*, L=100 m

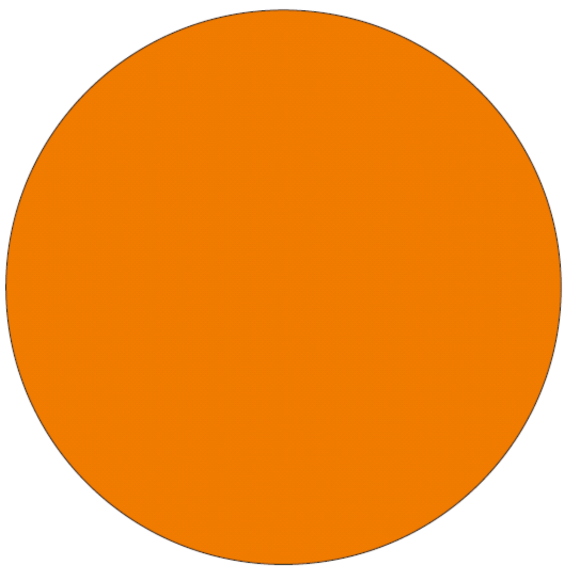
Water cooling – 5 m^3/h

P=880 W/m

A_cond= 9090 mm^2

W = 24.5 kg/m – 2.45 tons

Φext = 120 mm



*$\rho(RT) = 2 \cdot 10^{-8}\ \Omega$ m

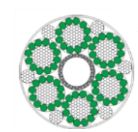
MgB_2 with copper stabilizer

He gas cooling, Tmax=25 K

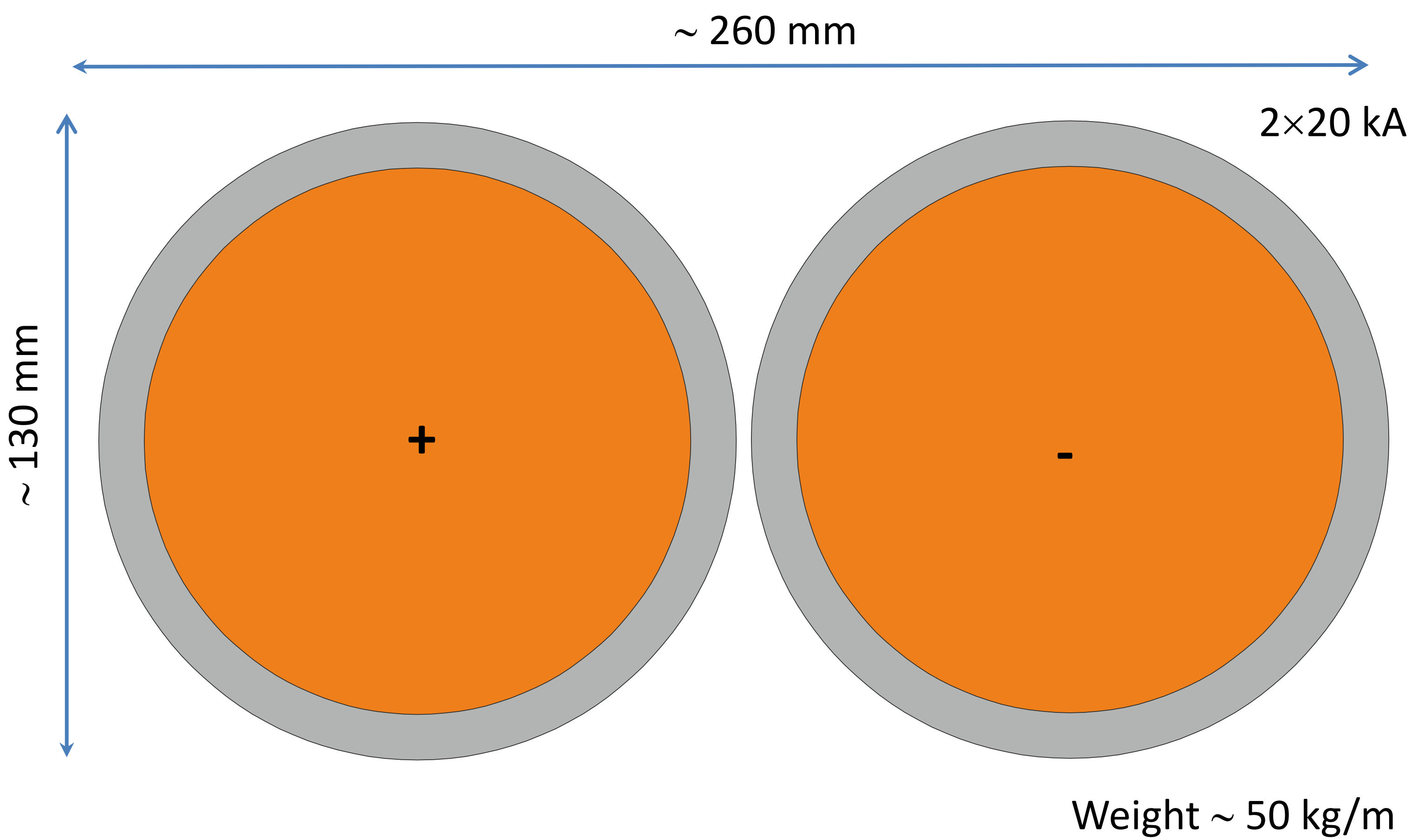
A_cond~ 100 mm^2

W ~ 1 kg/m – 100 kg

Φext=18 mm



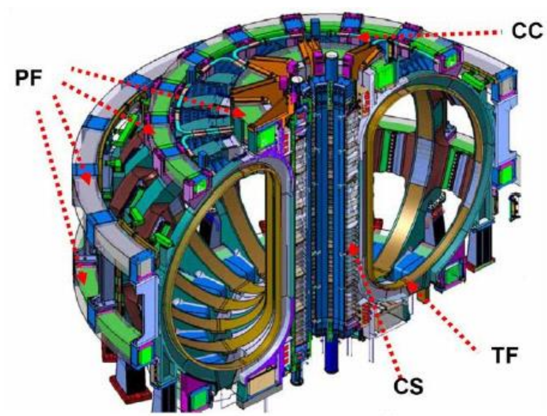
Transfer of 20000 A – Aluminium @ RT

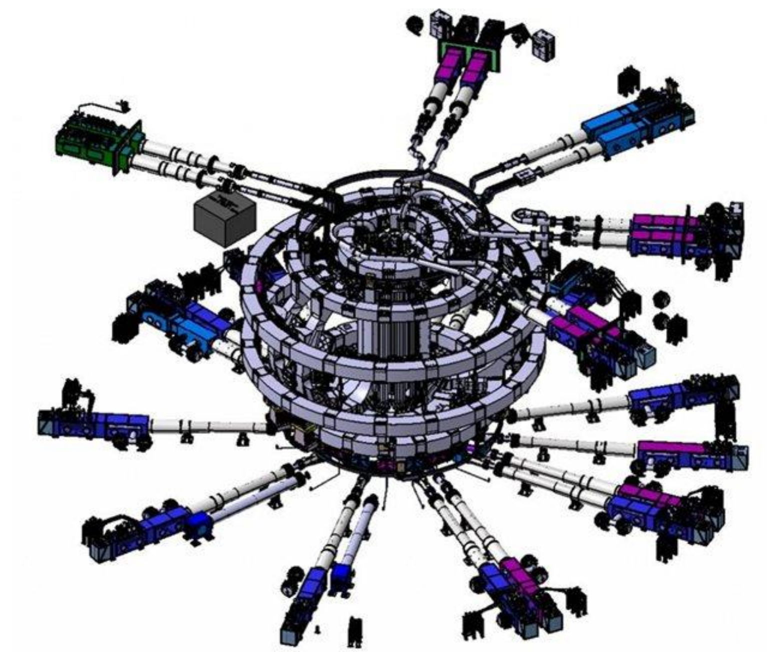


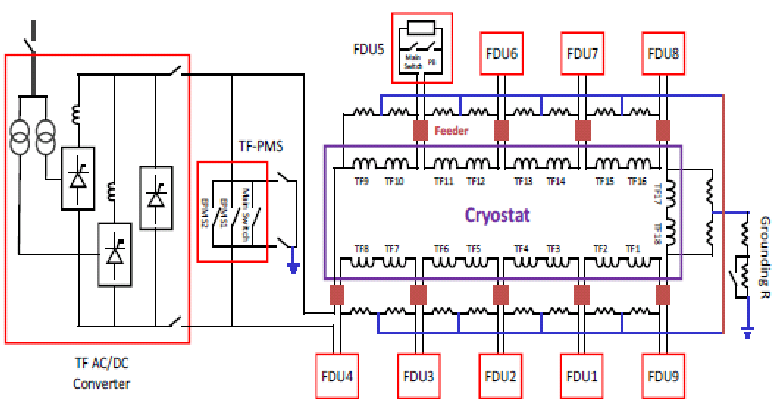
Φext = 220 mm, Cryostat with 150 kA multi-cable assembly for LHC

Replacement of High-Current resistive bus-bar with SC lines

Ex. ITER TF Coils







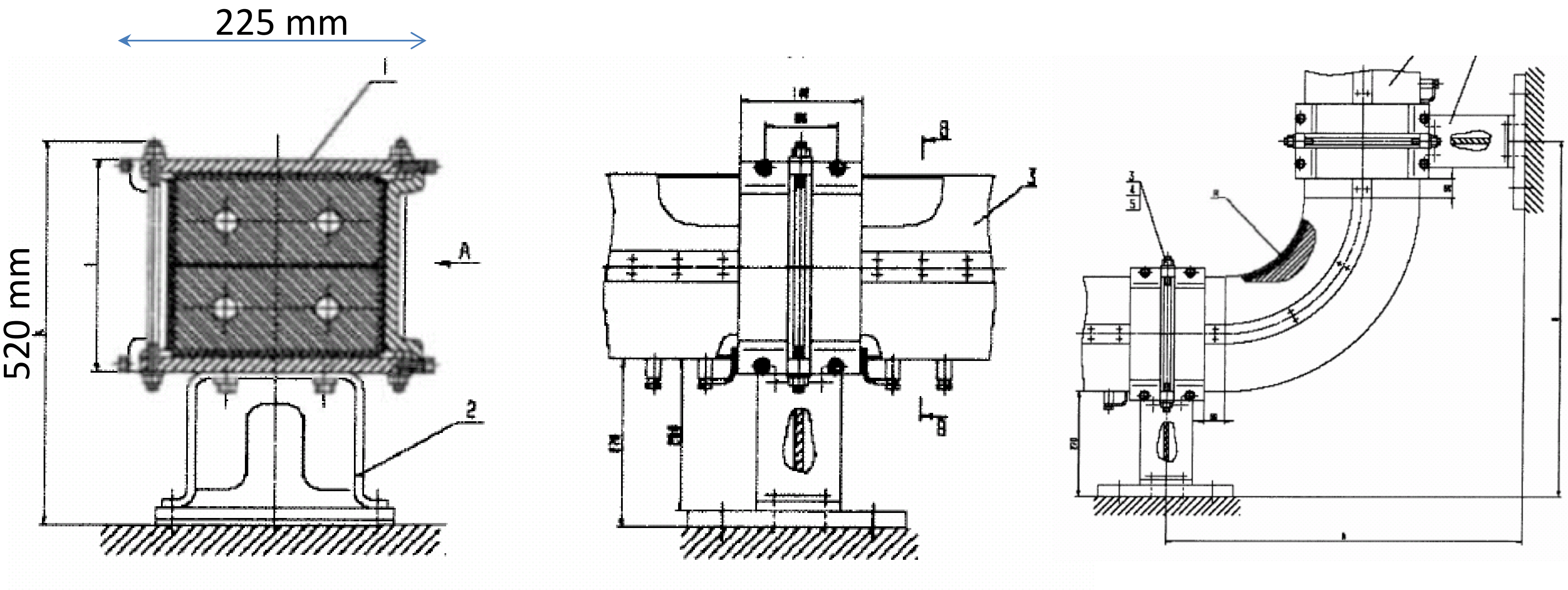
9 × 68 kA DC Circuits (18 Toroidal Field Coils)

Water cooled Aluminium bus-bar

ITER TF Coils

9 × 68 kA Circuits (18 Toroidal Field Coils)

9×2 × 50600 mm² of Al conductor (~ 225×225 mm²) – 150 kg/m

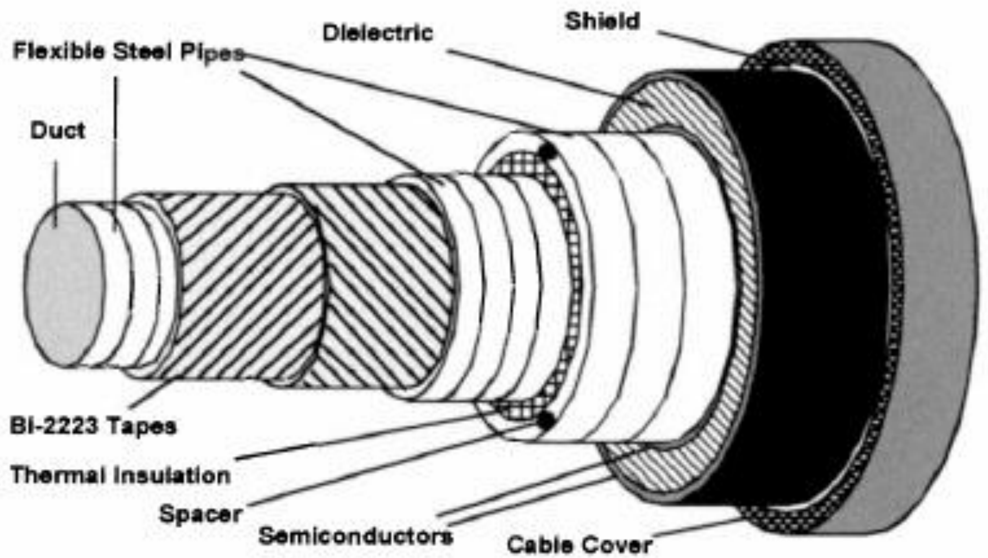


Maximum unit length = 10 m → Need for several joints

ITER bus-bar

EFDA study*: design of the **same type as that being developed for power transmission systems based on HTS tape conductor**

Φ = 152 mm - to be compared with **225×225 mm²** of the Al water cooled TF coils bus bar (68 kA)



*R. Wesche, R. Heller, W.H. Fietz, V.L. Tanna, G. Zahn, EFDA Ref. TW4-TMSF-HTSCOM, 2005

ITER bus-bar

Study commissioned by EFDA* of an alternative to Al bus-bar based on the use of **HTS – BSCCO 2223 Tape (**65 K)

This was found to **be attractive regarding space and weight**

BUT

Too expensive – even taking into account the power saving over 20 years of operation

MgB_2 High-Current Cables of the type being developed for LHC would be a viable option

*R. Wesche, R. Heller, W.H. Fietz, V.L. Tanna, G. Zahn, EFDA Ref. TW4-TMSF-HTSCOM, 2005

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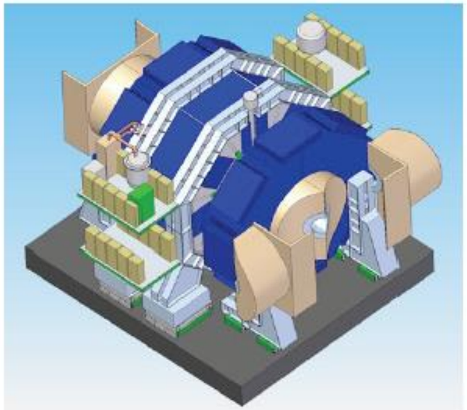
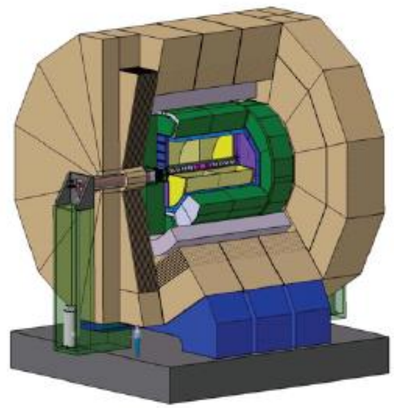
SC Links for "pull-push" experiments

In **CLIC/ILC** it is foreseen to install **2 experiments** that share the single interaction point on a **"push-pull"** basis

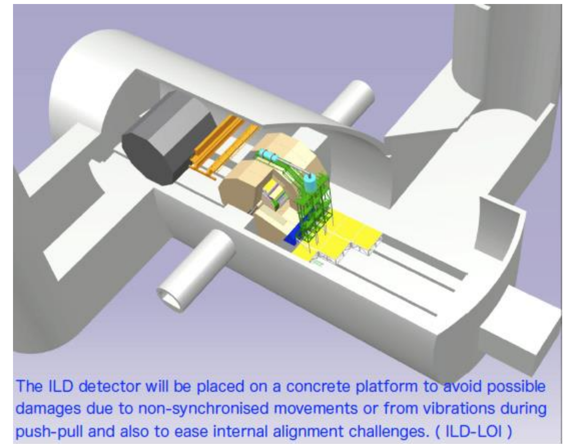


SiD with Platform

ILC



ILD with Platform



-det-1 BPL running	2 weeks + 1 week contingency for machine study and inefficiency
-push-pull+calib	1 week
-det-2 BPL running	2 weeks + 1 week contingency for machine study and inefficiency
-push-pull+calib	1 week

Proposed running schedule (ILC) based on an 8-week cycle

It would be an advantage to keep cryogenics and busbars connected for such frequent movement . This could be achieved using semi-flexible cryostats containing MgB_2 based lines of the type being developed for LHC

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Transmission Line Magnets

Pipetron- type magnets

Use of **alternating gradient focusing pole tips** to focus the beam in the radial and in the vertical direction – no quadrupoles

Superferric magnets – field determined by iron core

Transmission Line-type cryostat – B < 1 T on the superconductor

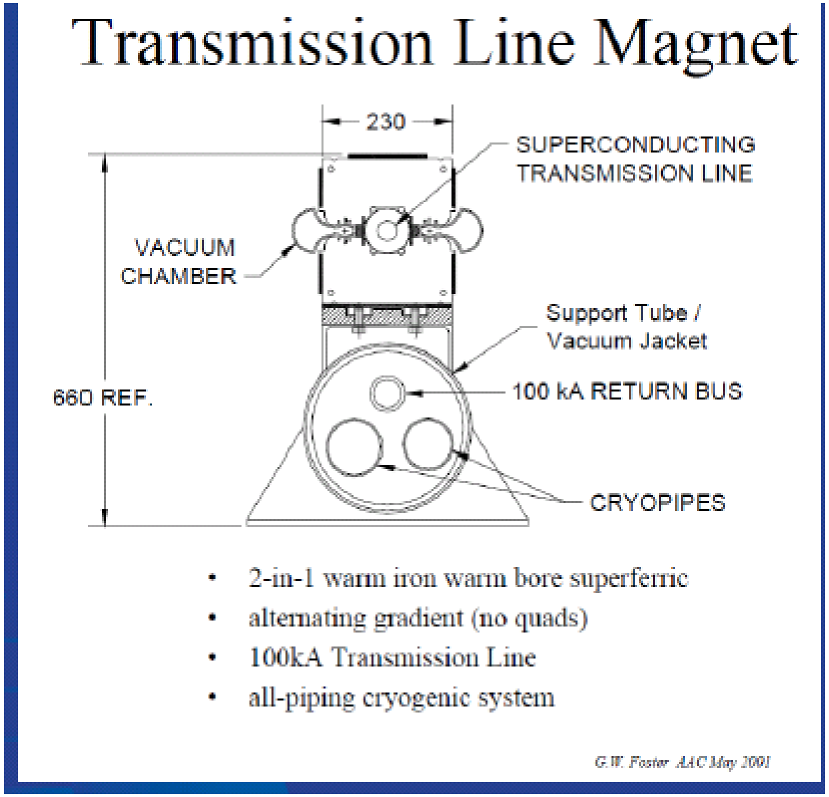
Initial proposal: use of **Nb-Ti** at about 6 K

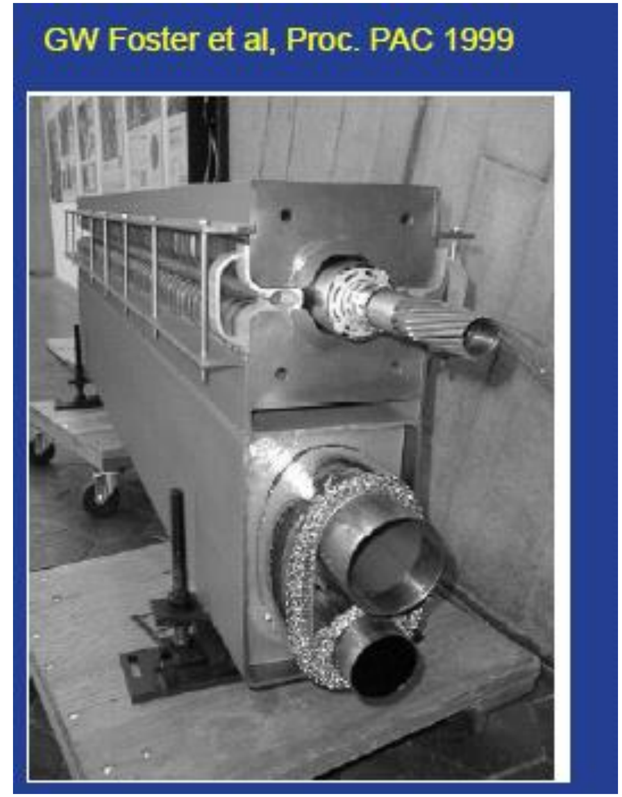
Studies on potential use of **HTS** at 20 K or possibly at 77 K

Test facility at FermiLab

Transmission Line Magnets

Combined-function lattice magnet for a collider with a very large tunnel





W. Foster, H. Piekarz

Nb-Ti, **100 kA @ 6.5 K** and **1 T**

Invar[TM] Transmission Line piping ($\Phi \geq 80$ mm)

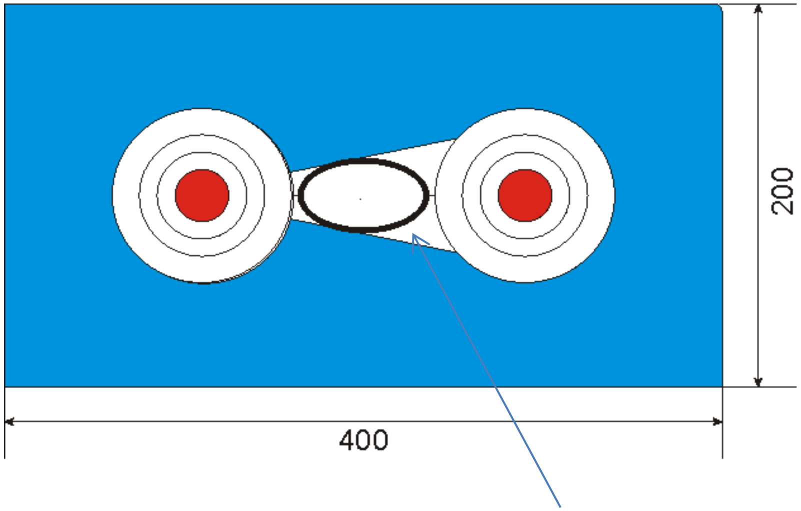
Lance Cooley, IASS Potsdam, 12-13 May 2011

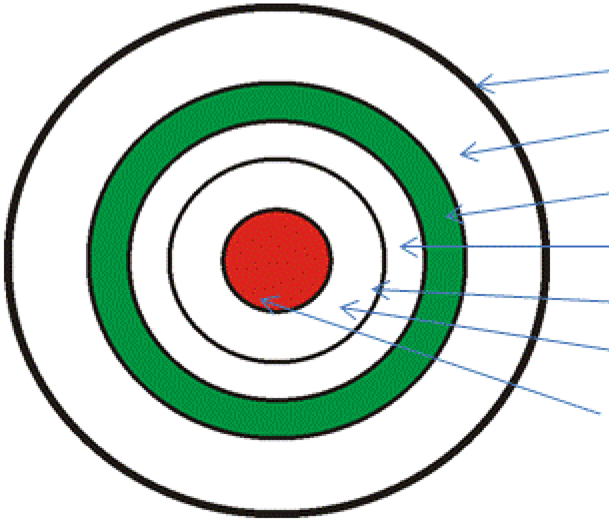
Transmission Line Magnets

Combined-function magnet for injectors in a proton machine

- Simple magnet
- Return line incorporated in the magnet - no stray field

MgB_2 could replace Nb-Ti in magnets for injectors for proton machines (B~1.6 T)





Conclusions

- HTS Superconducting Links became -rapidly- a baseline for the LHC Upgrades. Installation in the LHC is expected to take place according the LHC Upgrade plans (2018-2022)

- The development of the system can be of interest also for other applications to accelerator technology

- MgB_2 is an interesting candidate for accelerators with available He cryogenics because of its potential cost effectiveness. Today the conductor is suitable for low/medium field applications

- When cryogen at ≤ 25 K is not available, HTS is the choice. This is the case also for high-field magnet applications at 4.2 K , i.e. High Energy Upgrades of the LHC machine