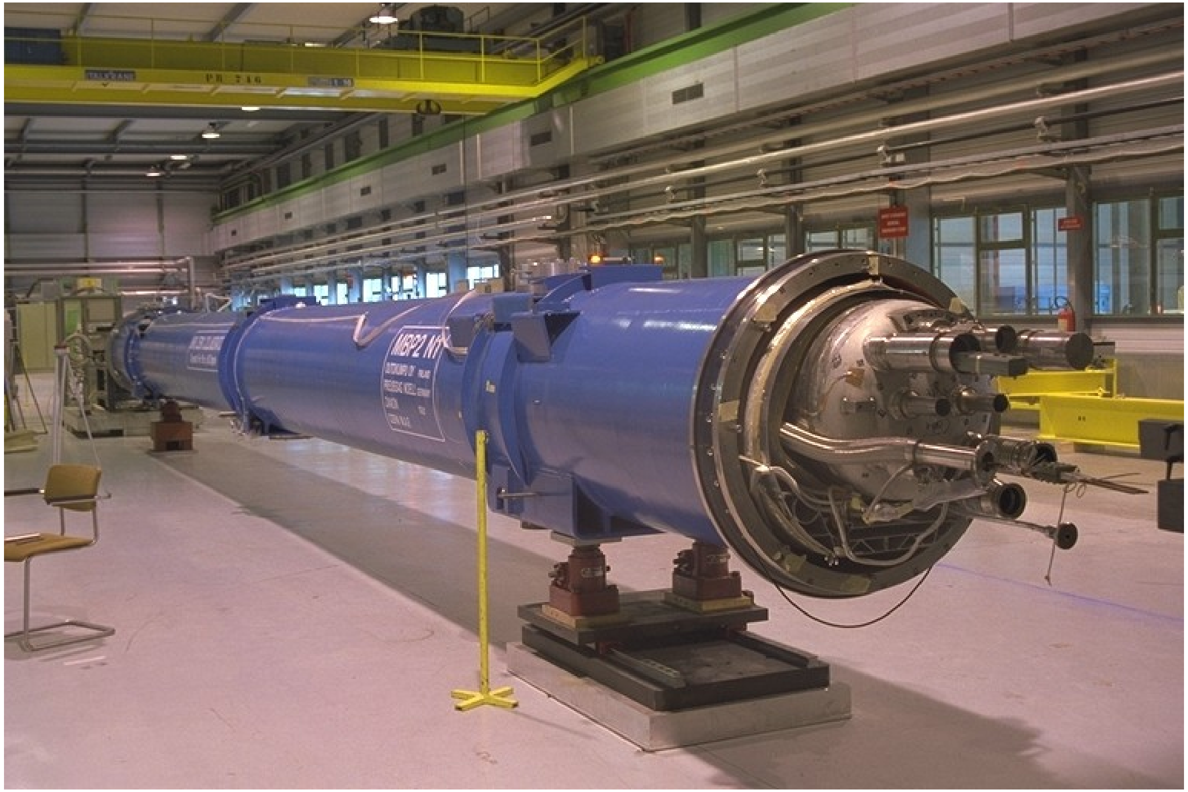
Magnets at the LHC and SM18



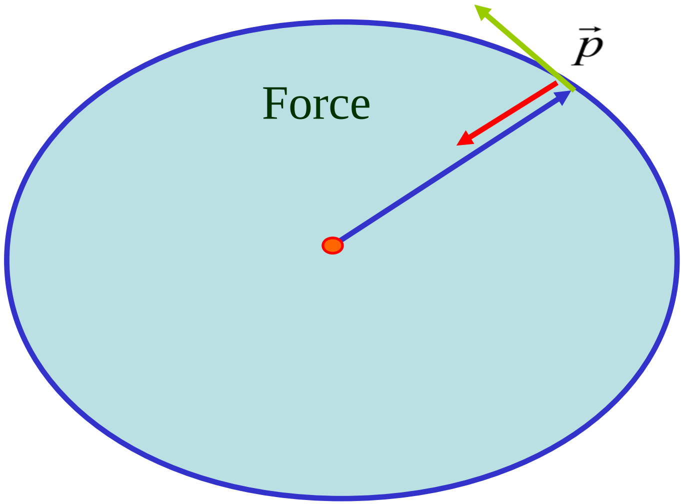
Florian Bury

Bending

Lorentz force $\vec{F} = e(\vec{v} \times \vec{B} + \vec{E})$

Magnetic rigidity $B\rho = \frac{mv}{e} = \frac{p}{e}$

LHC: ρ = 2.8 km given by LEP tunnel!



To reach p = 7 TeV/c given a bending radius of ρ = 2805 m:

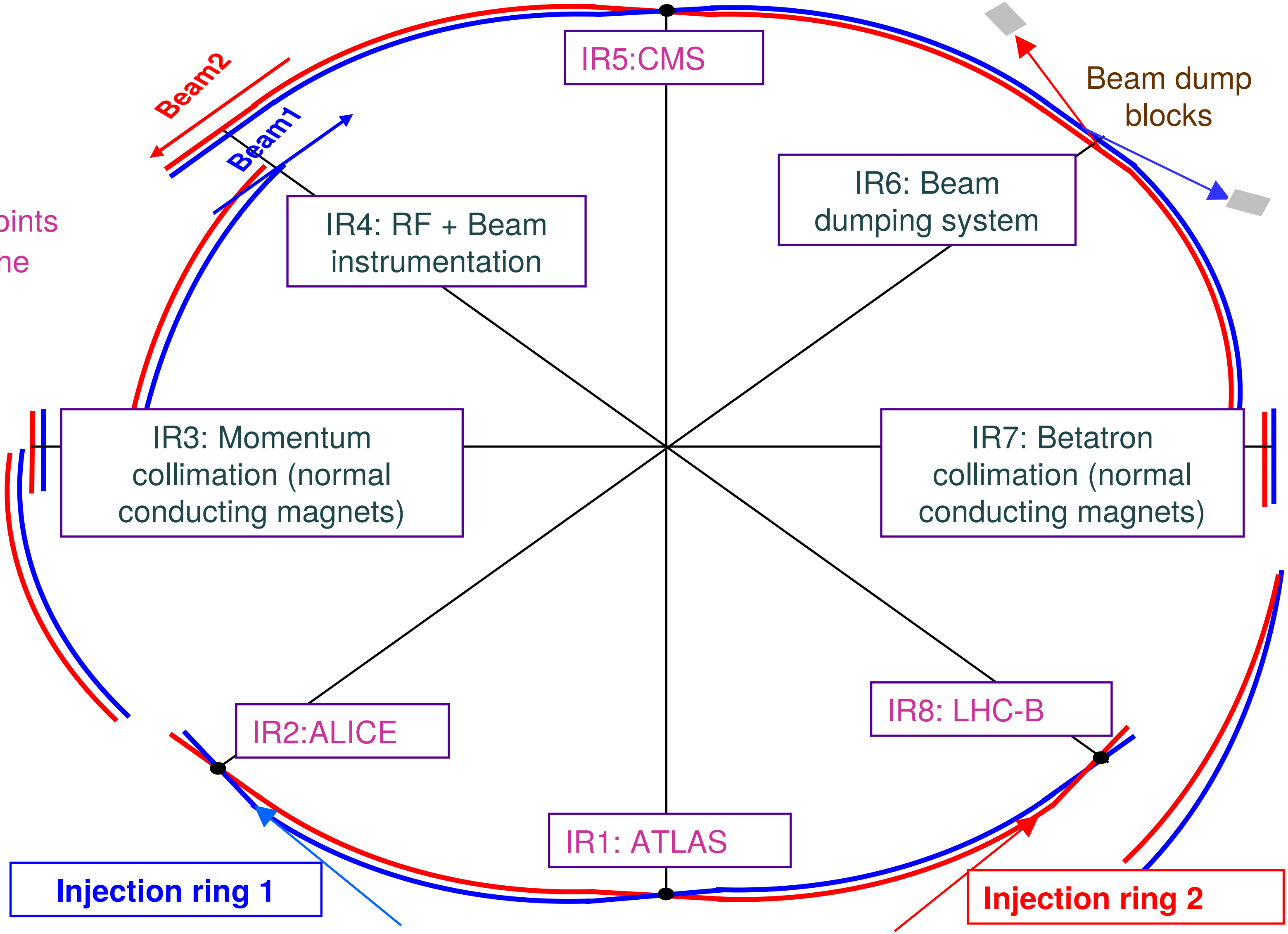
- Bending field : B = 8.33 Tesla
- Superconducting magnets

To collide two counter-rotating proton beams, the beams must be in separate vaccum chambers (in the bending sections) with opposite B field direction.

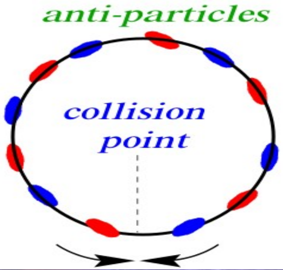
→ There are actually **2** LHCs and the magnets have a 2-magnets-in-one design!

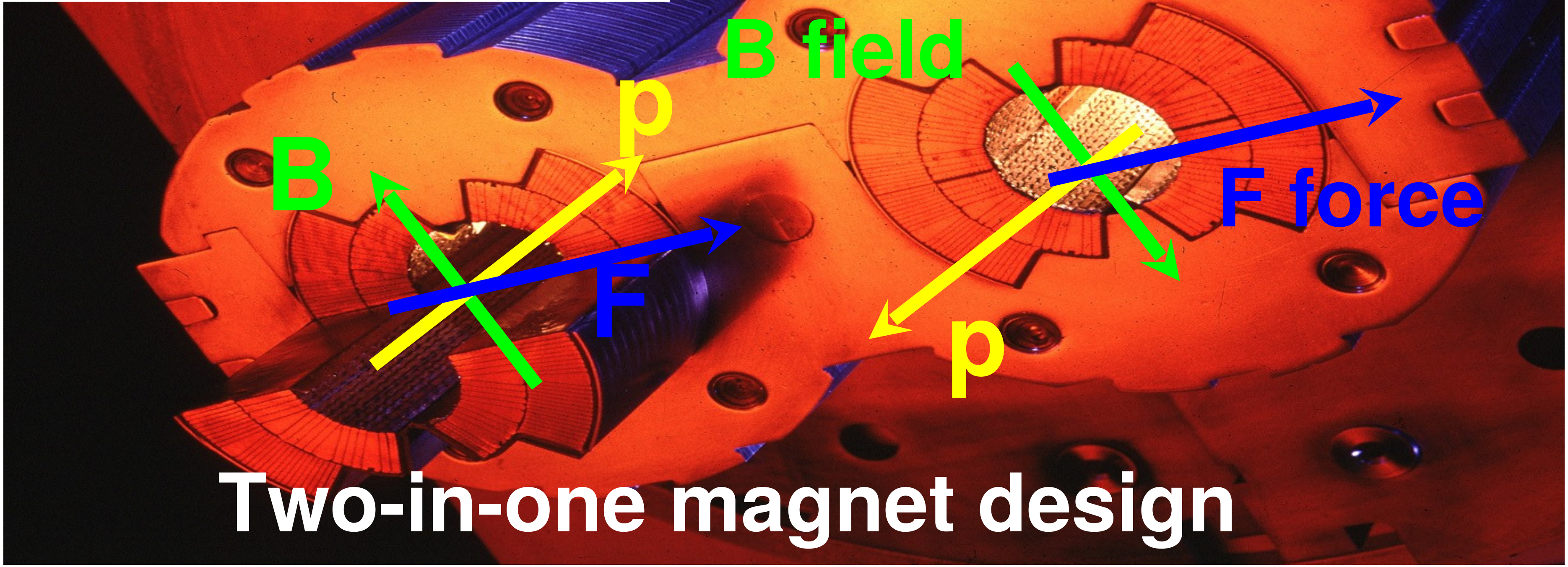
LHC Layout

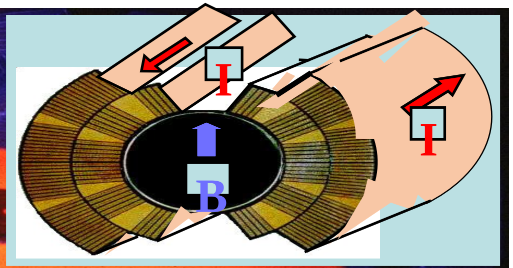
- 8 arcs.
- 8 straight sections (LSS), ~ 700 m long.
- The beams exchange their positions (inside/outside) in 4 points to ensure that both rings have the same circumference !



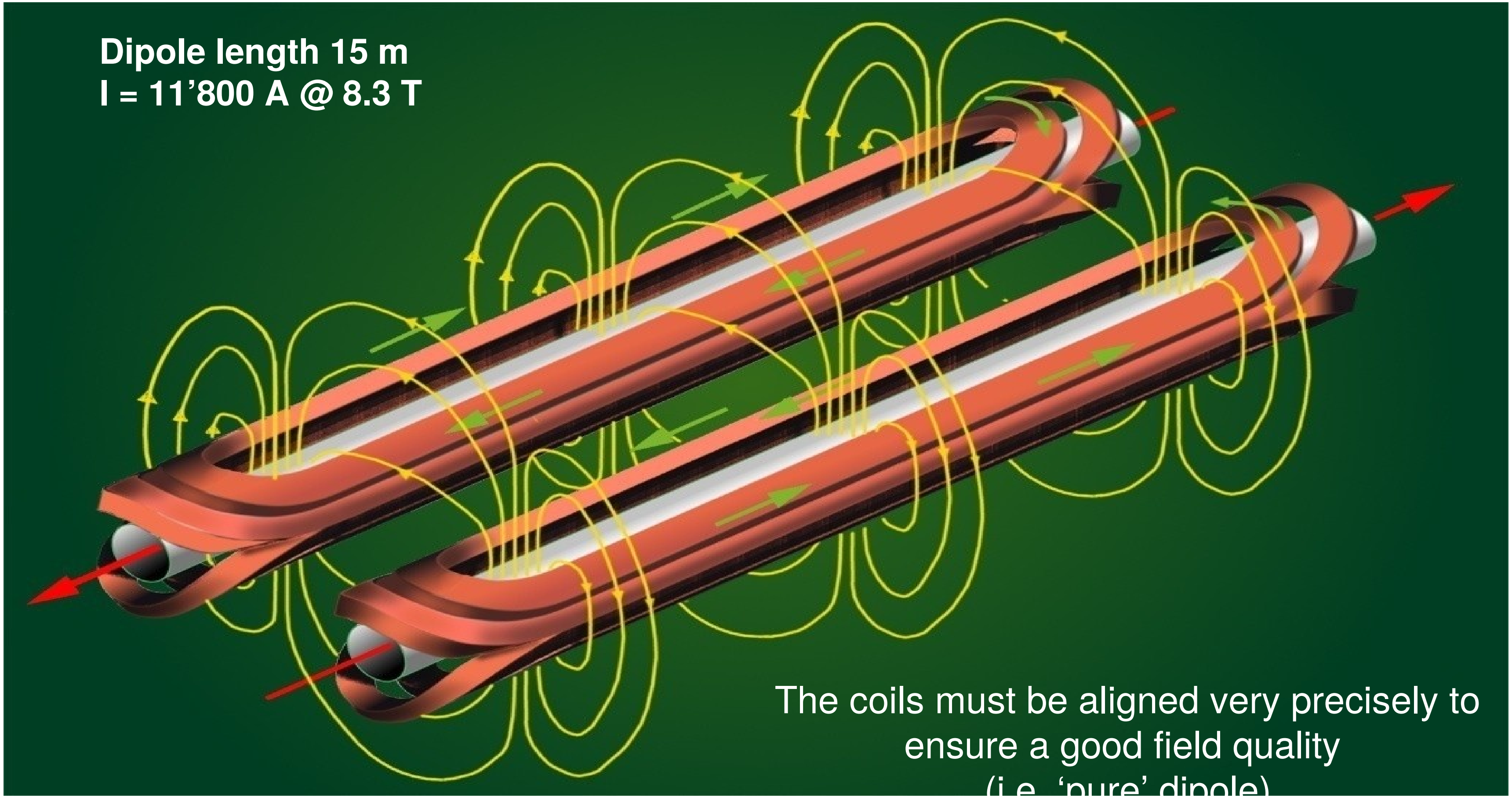
Bending Fields







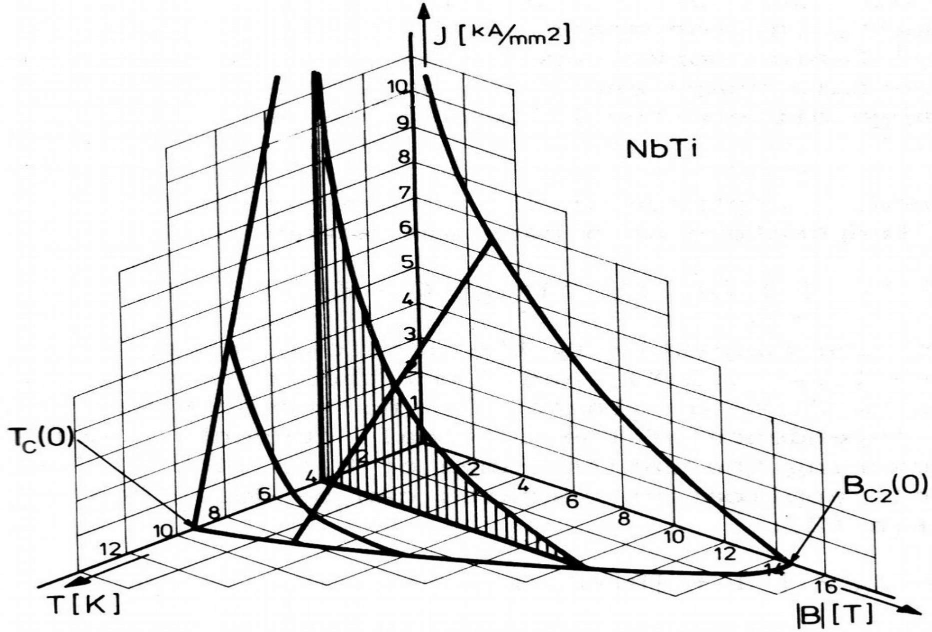
Coils for dipoles

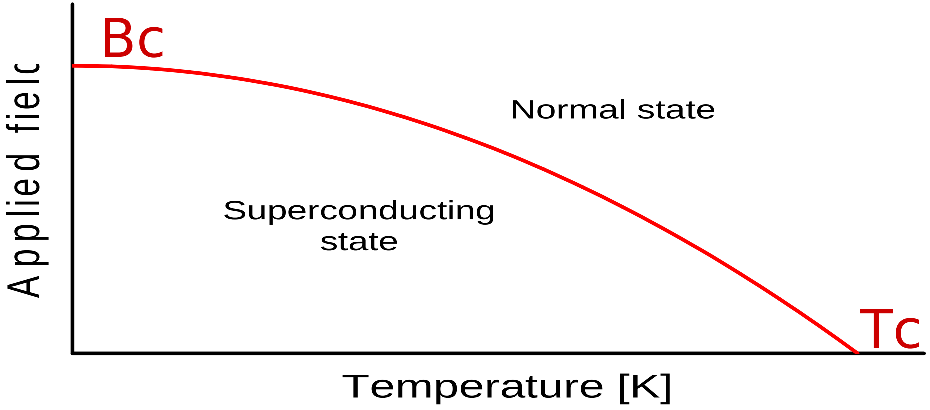


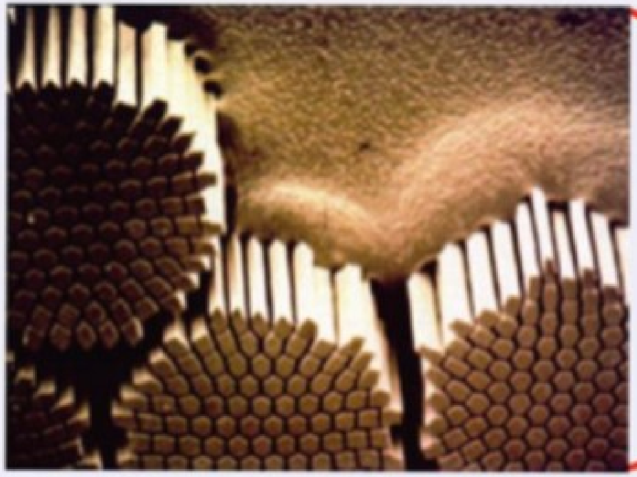
The coils must be aligned very precisely to ensure a good field quality (i.e. ‘pure’ dipole)

Superconductivity

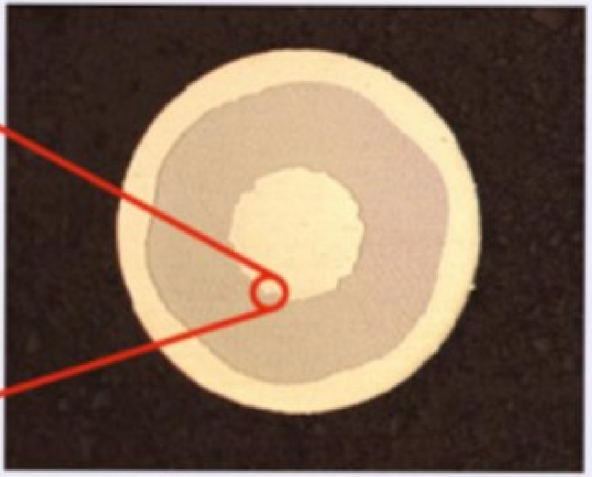
- The very high DIPOLE field of 8.3 Tesla required to achieve 7 TeV/c can only be obtained with superconducting magnets !
- The material determines:
  - **Tc** critical temperature
  - **Bc** critical field
- The cable production determines:
  - **Jc** critical current density
- Lower temperature ⇒ increased current density ⇒ higher fields.
- Typical for NbTi @ 4.2 K
  - 2000 A/mm2 @ 6T
- To reach 8-10 T, the temperature must be lowered to 1.9 K – superfluid Helium !



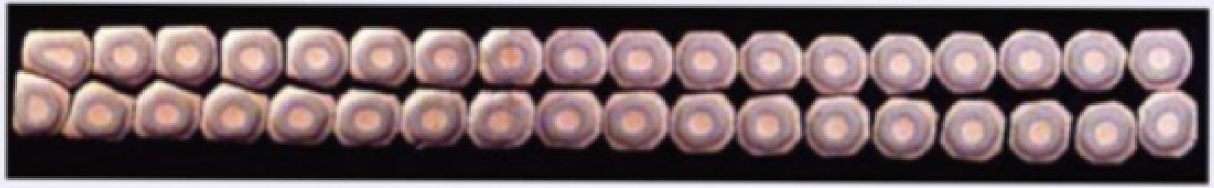




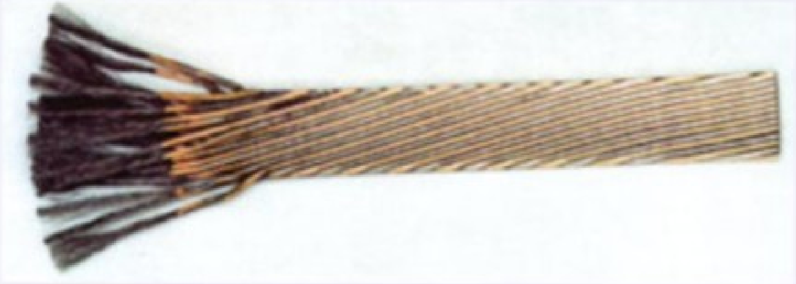
Fine filaments of Nb-Ti in a Cu matrix



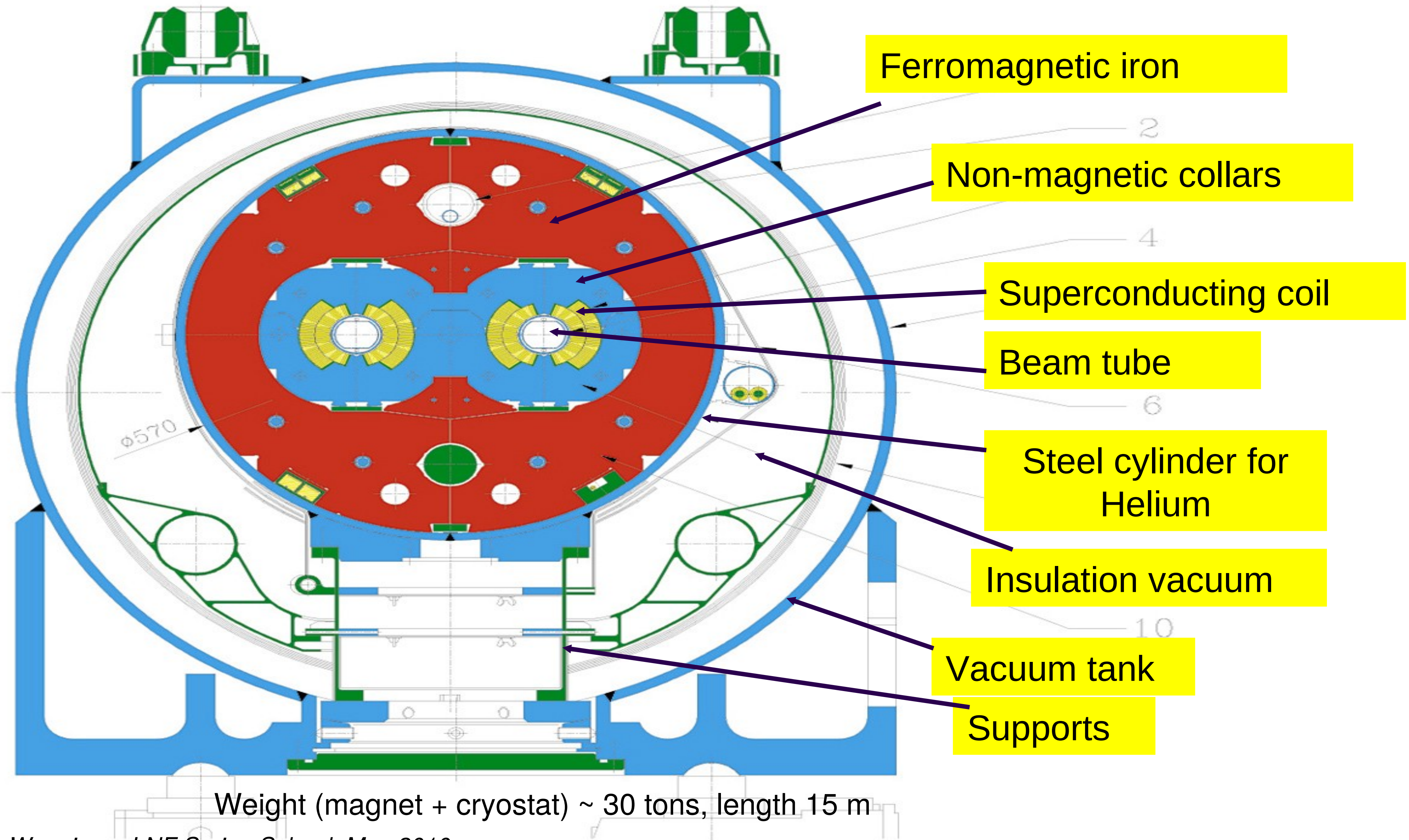
Full cross-section



Rutherford cables: cross-section

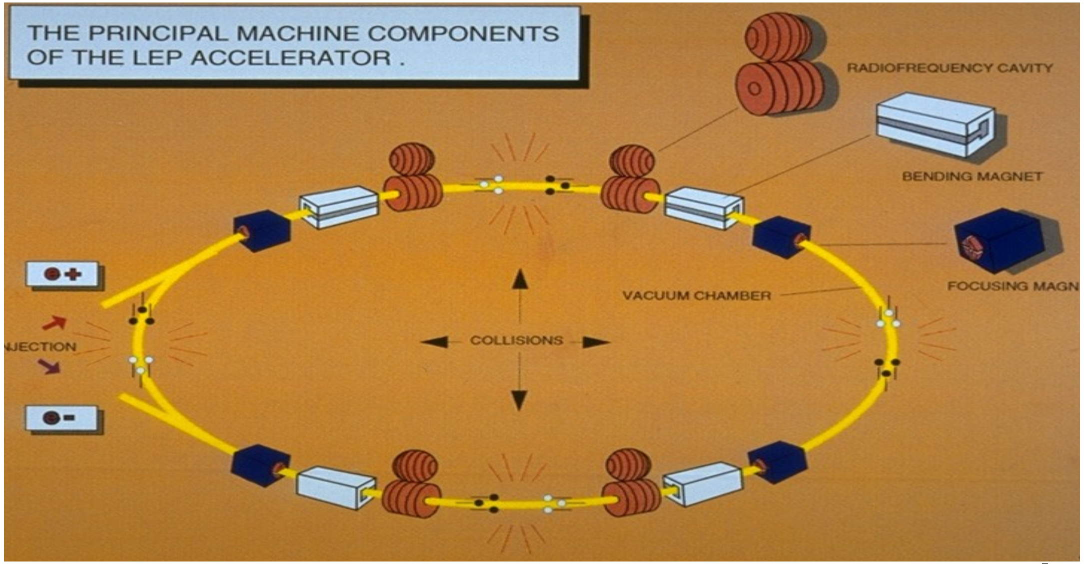


View of the flat side, with one end etched to show the Nb-Ti filaments



Weight (magnet + cryostat) ~ 30 tons, length 15 m

Accelerator concept



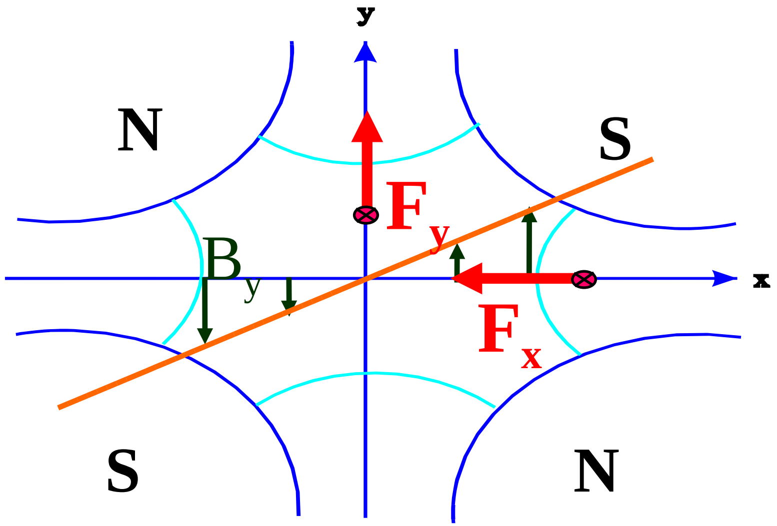
Charged particles are accelerated, guided and confined by **electromagnetic fields**.

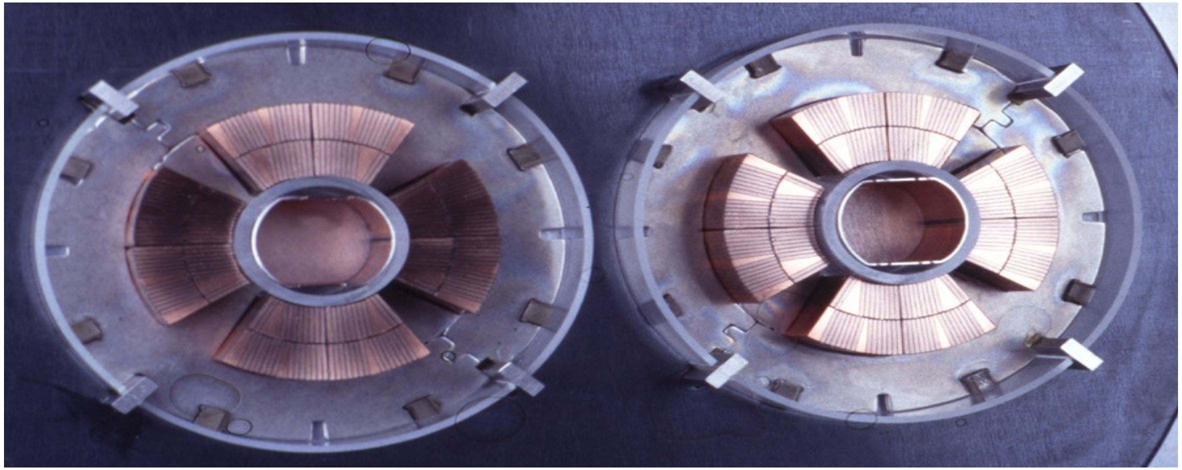
- Bending:	Dipole magnets
- Focusing:	Quadrupole magnets
- Acceleration:	RF cavities

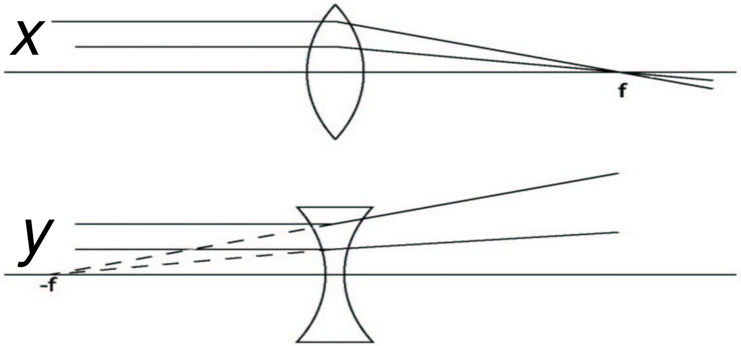
In synchrotrons, they are ramped together synchronously to match beam energy.

- Chromatic aberration:	Sextupole magnets

Focusing





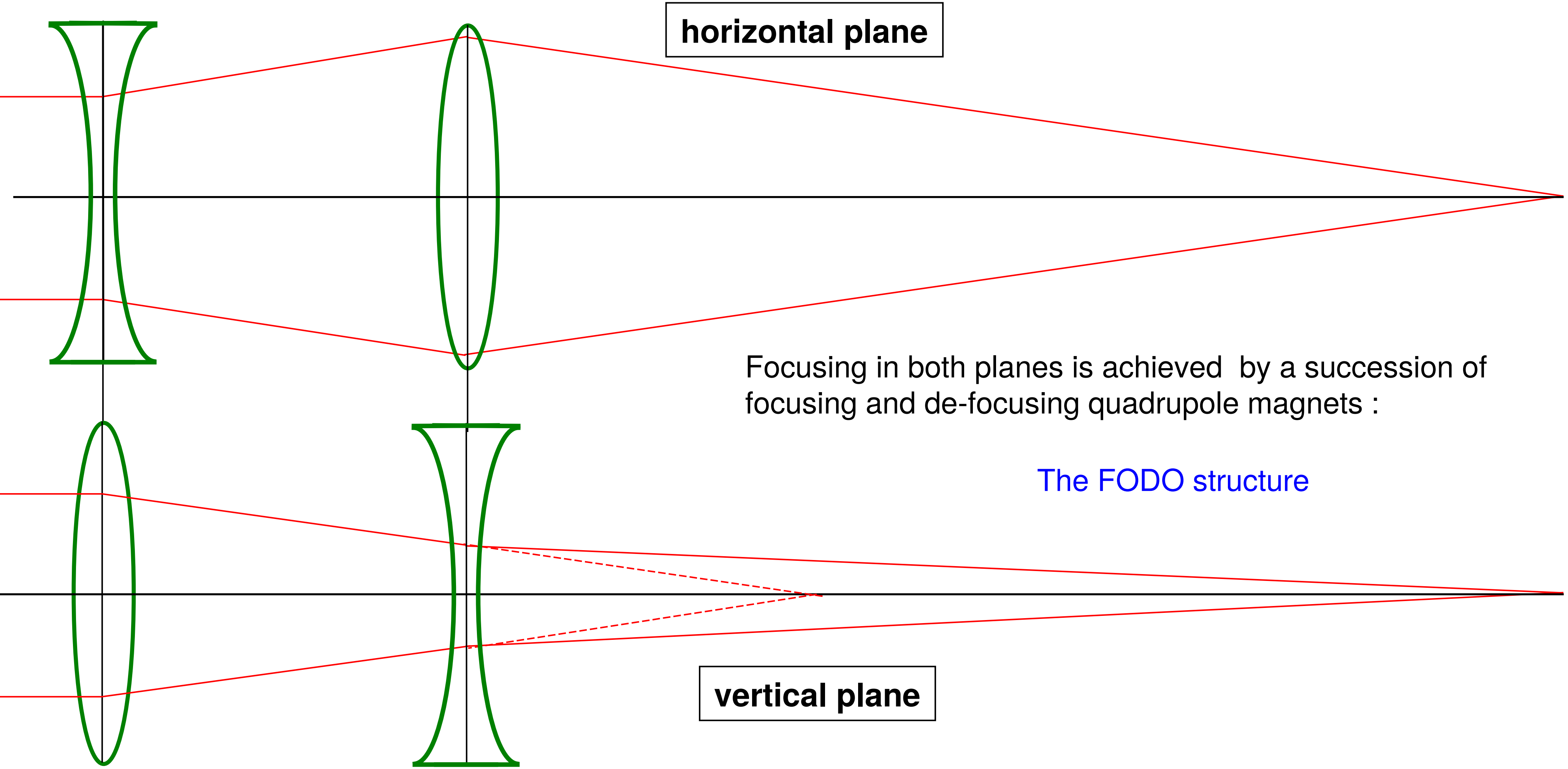


Transverse focusing is achieved with **quadrupole magnets**, which act on the beam like an optical lens.

Linear increase of the magnetic field along the axes (no effect on particles on axis).

Focusing in one plane, **de-focusing** in the other!

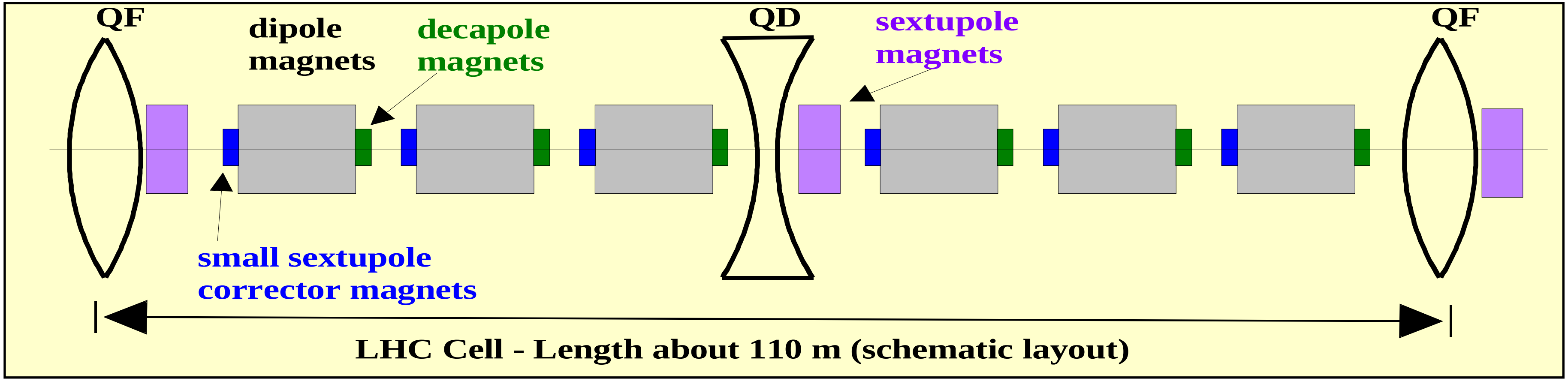
Accelerator lattice



Focusing in both planes is achieved by a succession of focusing and de-focusing quadrupole magnets :

The FODO structure

LHC arc lattice

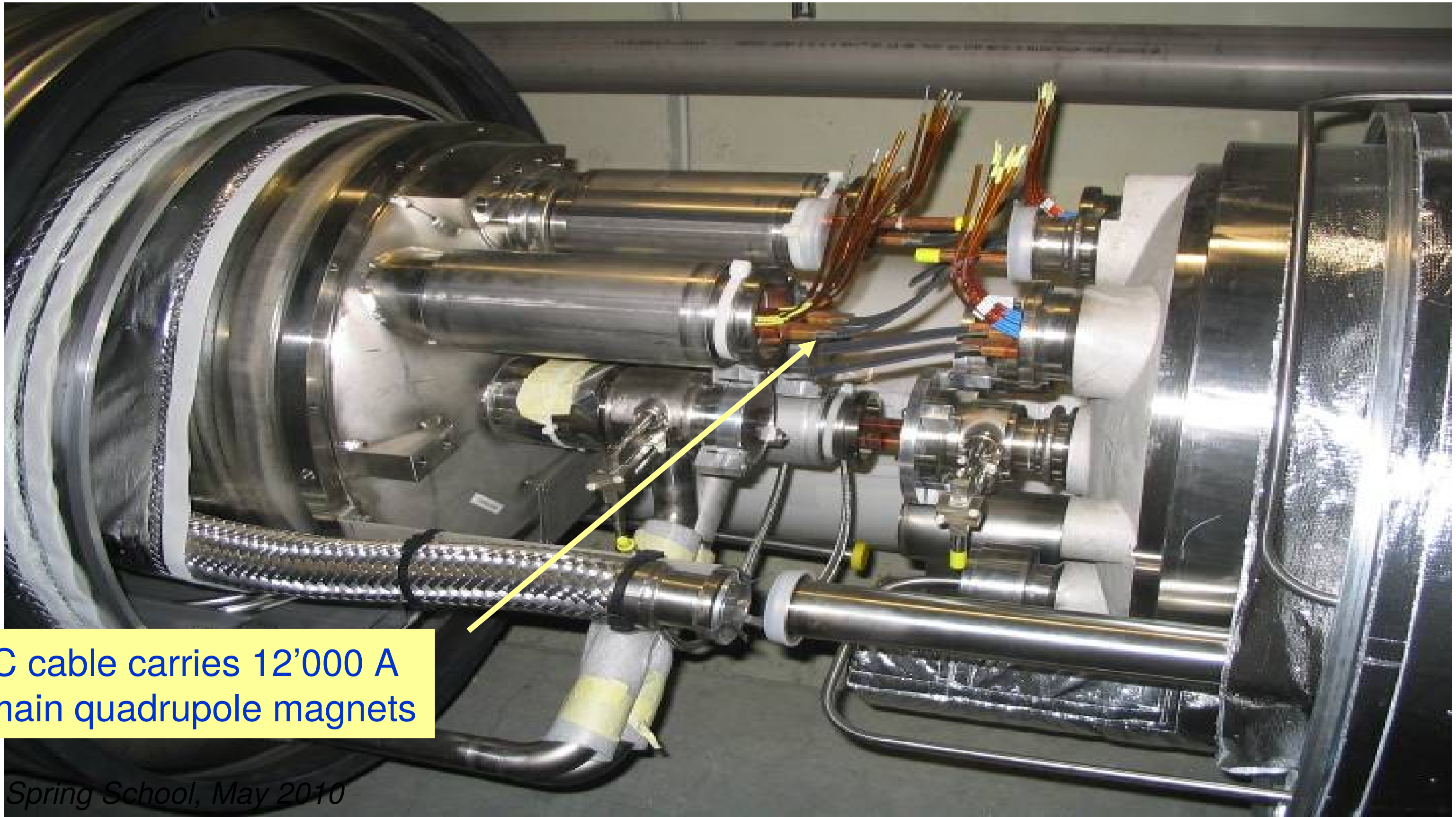


- Dipole- und Quadrupol magnets
  - Provide a stable trajectory for particles with nominal momentum.
- Sextupole magnets
  - Correct the trajectories for off momentum particles (‚chromatic' errors).
- Multipole-corrector magnets
  - Sextupole - and decapole corrector magnets at end of dipoles
  - Used to compensate field imperfections if the dipole magnets. To stabilize trajectories for particles at larger amplitudes – beam lifetime !

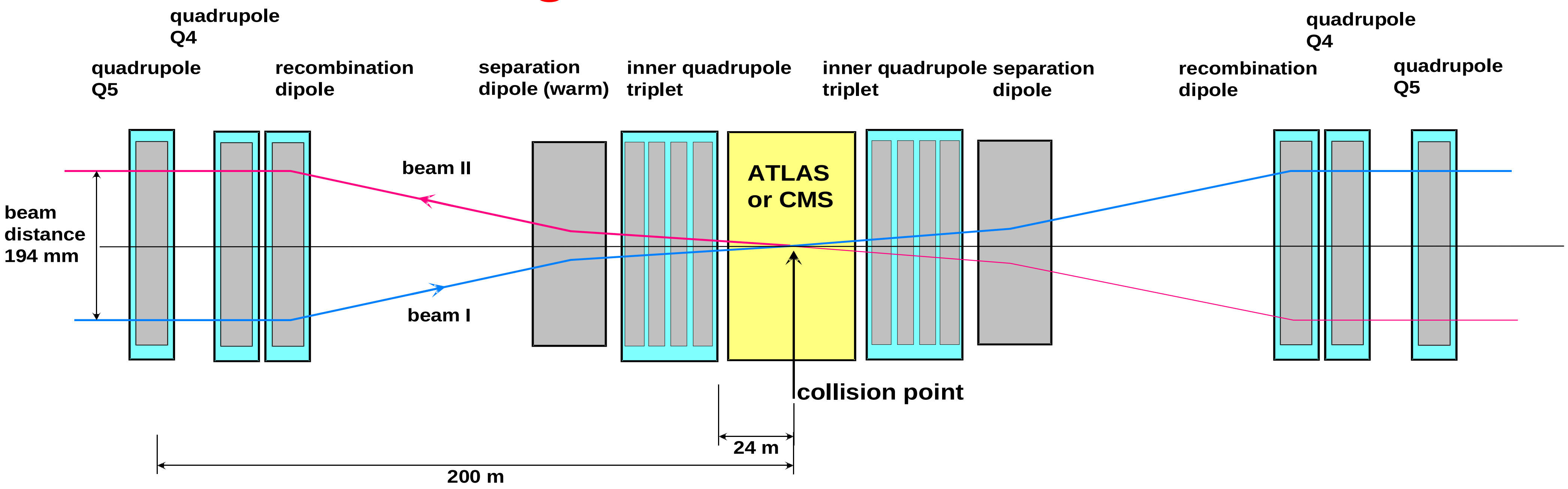
One rarely talks about the multi-pole magnets, but they are essential for good machine performance !

Complex interconnects

Many complex connections of super-conducting cable that will be buried in a cryostat once the work is finished.



Combining the beams for collisions

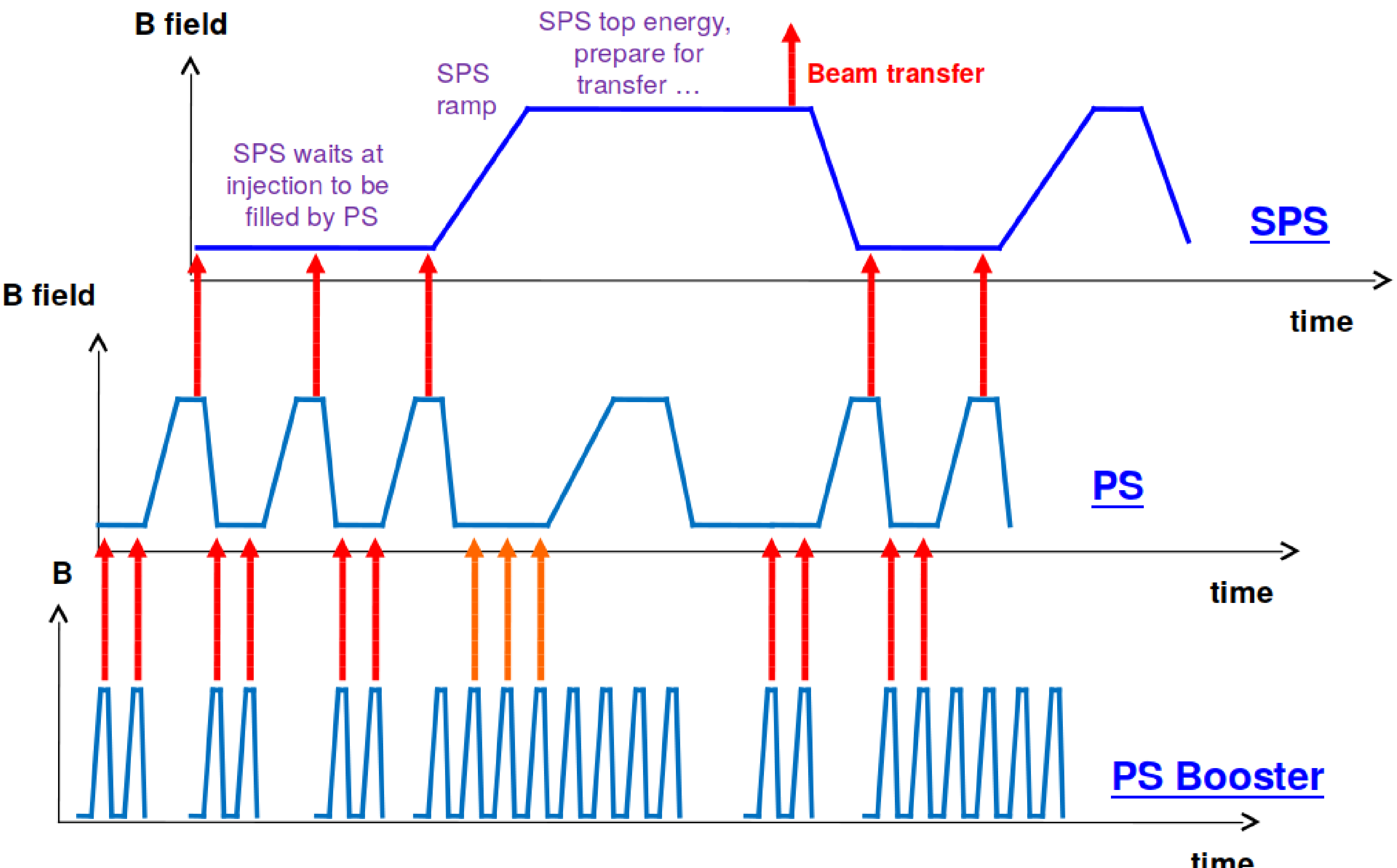


Example for an LHC insertion with ATLAS or CMS

- The 2 LHC beams must be brought together to collide.
- Over ~260 m, the beams circulate in the same vacuum chamber. They are ~120 long distance beam encounters in total in the 4 IRs.

Principle of injector cycling

The beams are handed from one accel. to the next or used for its own customers !

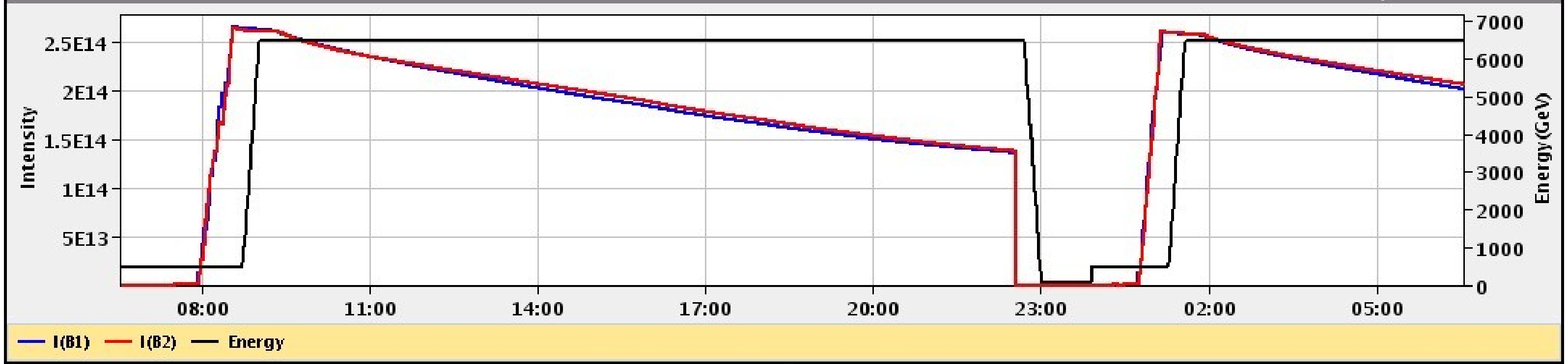


04-Aug-2018 06:32:54 Fill #: 7018 Energy: 6499 GeV I(B1): 2.01e+14 I(B2): 2.07e+14

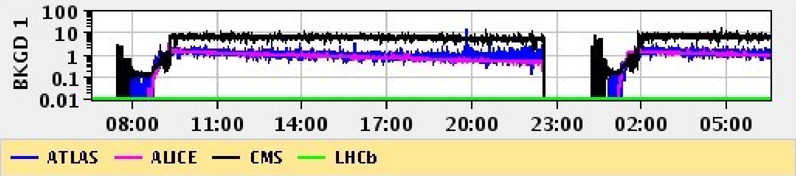
	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi [(ub.s)^-1]	10821.000	3.373	10320.197	426.903
BRAN Luminosity [(ub.s)^-1]	15294.5	3.2	14020.1	202.1
Fill Luminosity (nb)^-1	223876.000	56.739	210140.500	7280.120
Beam 1 BKGD	0.900	0.902	6.641	0.002
Beam 2 BKGD	0.715	0.104	6.665	0.028
Beta*	0.30 m	10.00 m	0.30 m	3.00 m
Crossing Angle (urad)	136(V)	200(V)	136(H)	-250(H)

LHCb VELO Position IN Gap: -0.0 mm | STABLE BEAMS | TOTEM: CALIBRATION

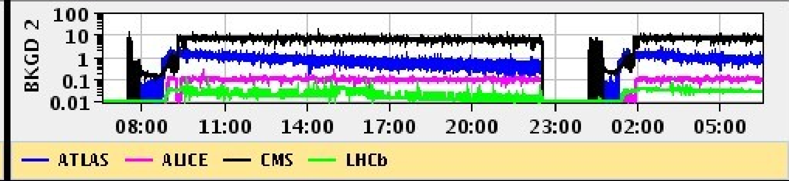
Performance over the last 24 Hrs Updated: 06:32:52



Beam 1 BKGD Updated: 06:32:53



Beam 2 BKGD Updated: 06:32:52



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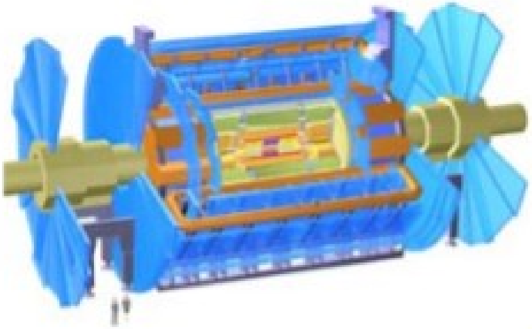
Destructive power of an uncontrolled quench

LHC dipole of 15m and 8.35T stores 8 MJ, which corresponds to melting 1.5L of copper, enough to evaporate 10cm of coil !

Damage at an LHC interconnect

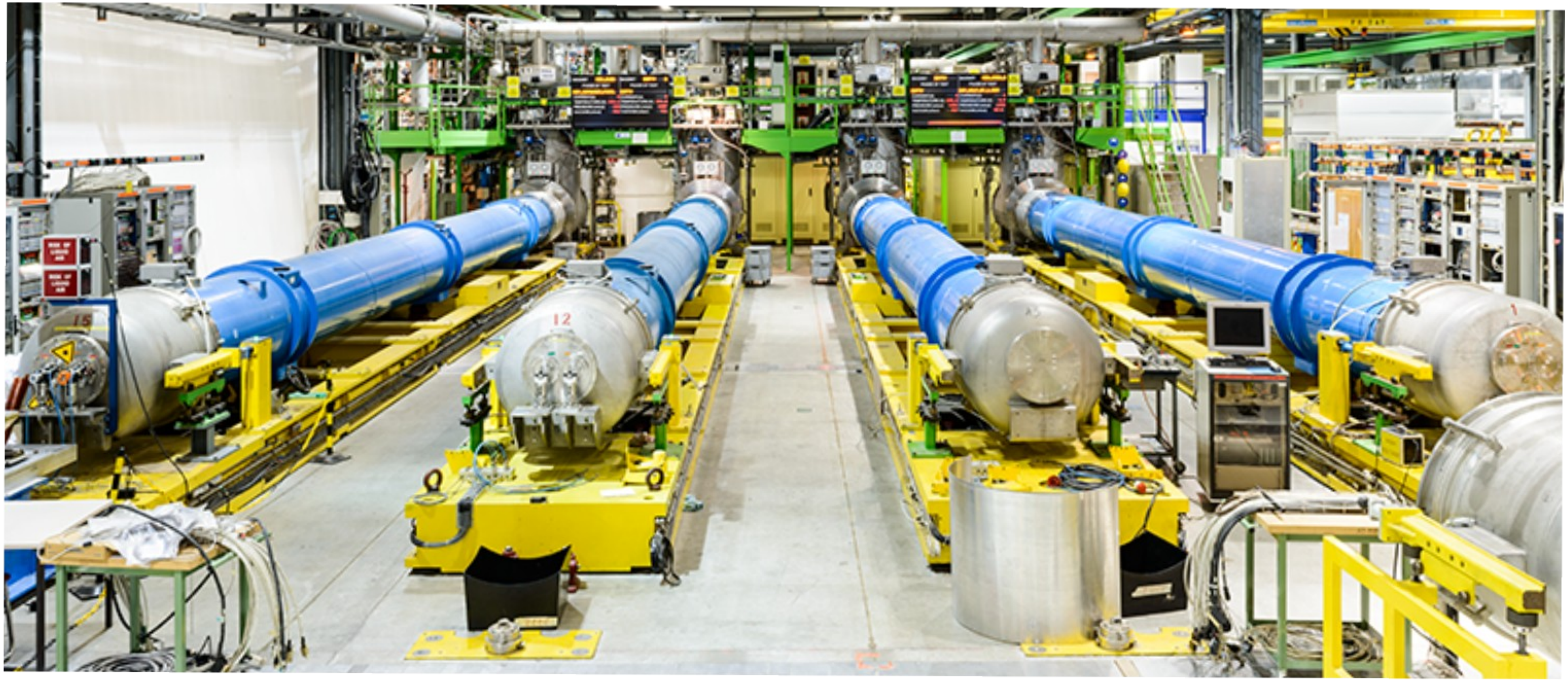
And we have seen in Sep 2008 what a few magnet quenches can do!

ATLAS detector toroid stores 1.6 GJ, good for 600L of melted copper, or equivalent to the collision energy of 100 trucks of 40 tons with speed of 100 km/h!



To be safe with equipment and personnel, Quench Protection has to cover all possible quenches in the entire electrical circuit from + to – terminal on the cryostat (current leads & bus connections & coil)

SM18 : CERN MAGNET TEST FACILITY



Training the dipoles