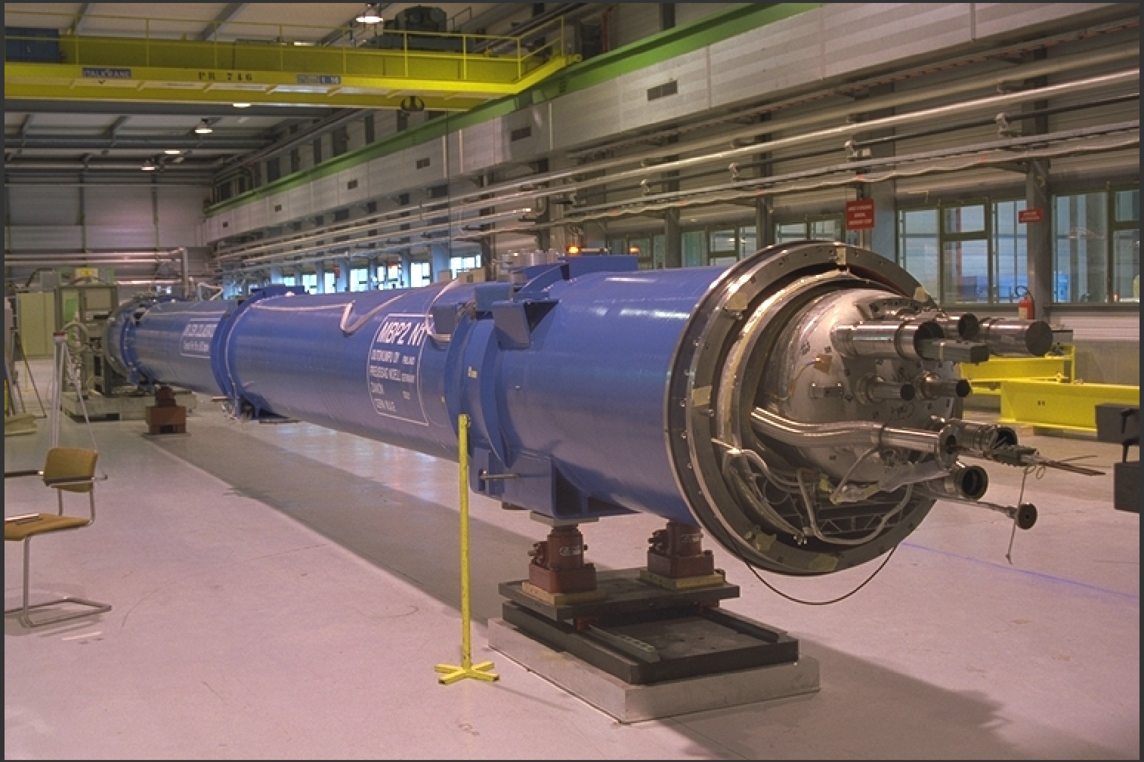
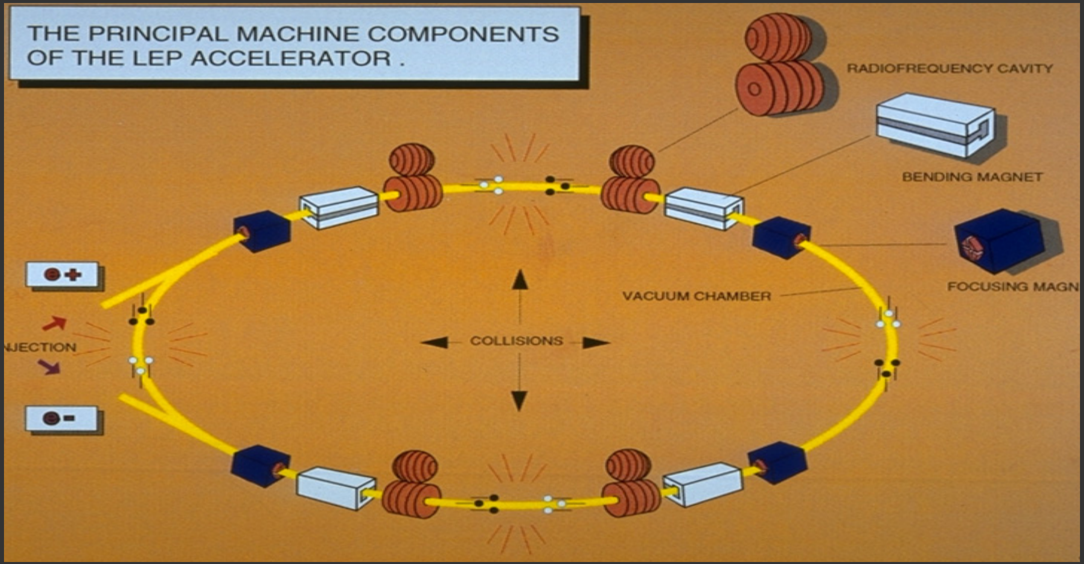


Trip to CERN
-
Magnets at the LHC

Depasse Antoine

25 Février 2025

Accelerator concept



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

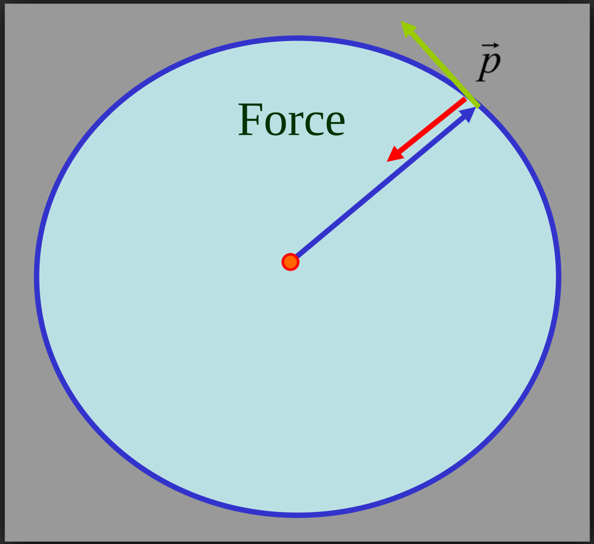
- Guiding: Dipole magnets
- Focusing: Quadrupole magnets
- Accelerating: RF cavities

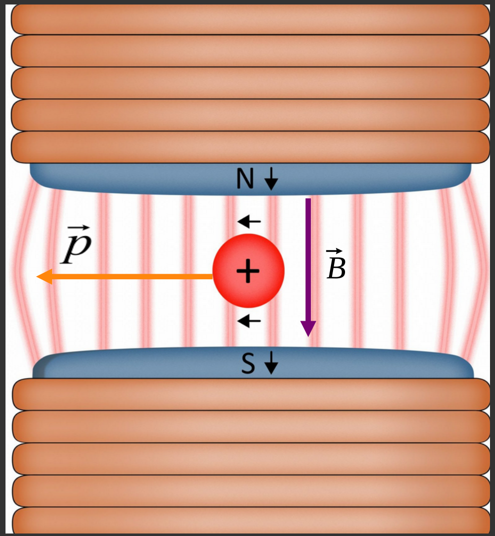
Guiding with Dipole Magnets

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

Circular Motion $F = \frac{m v^2}{r}$

Magnetic rigidity $B r = \frac{m v}{e} = \frac{p}{e}$

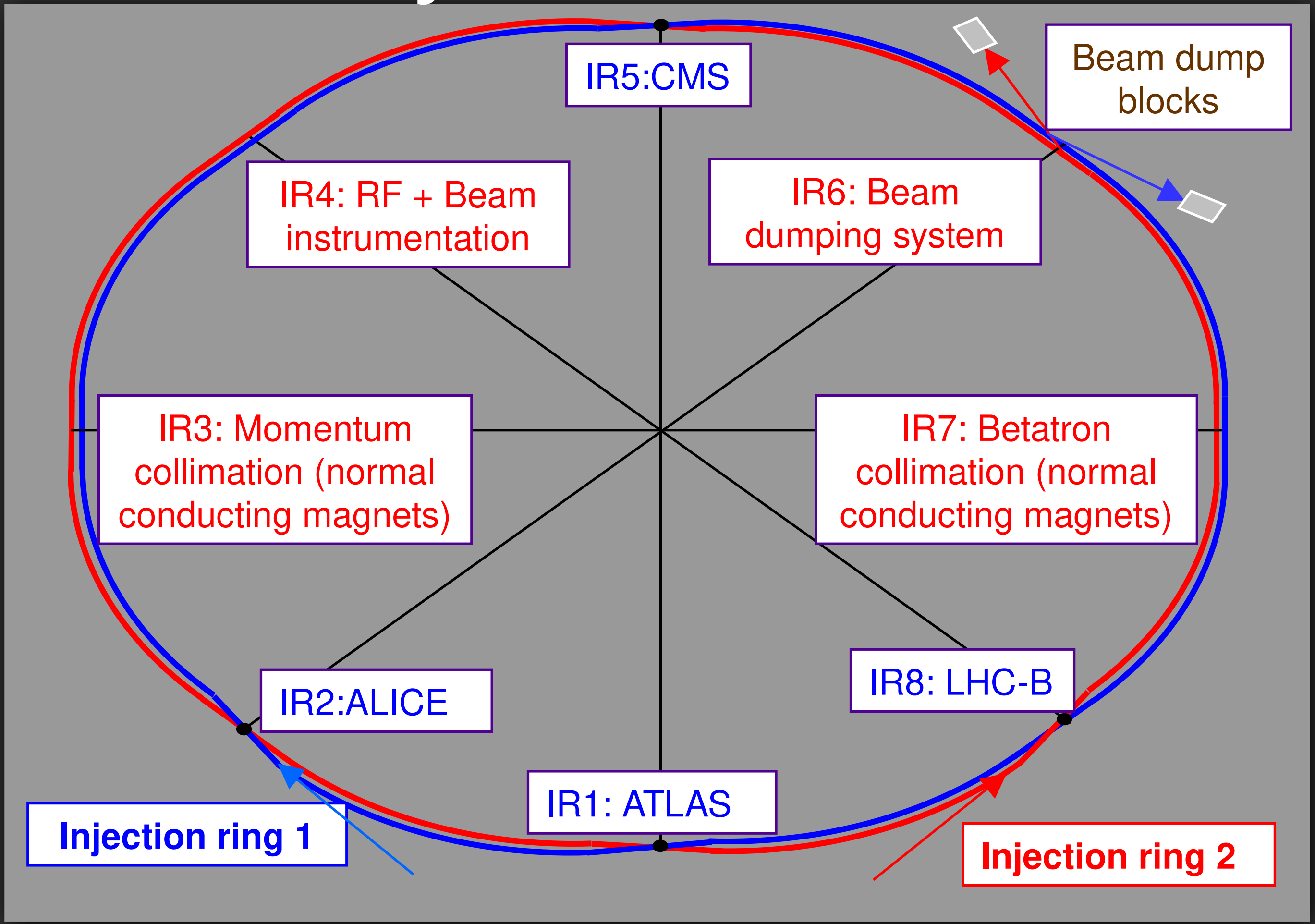




LHC: r = 2.8 km given by LEP tunnel!
To reach p = 7 TeV/c with a bending radius of r = 2805 m:
Bending field : B = 8.33 Tesla
Two counter-rotating proton beams : beams in separate vacuum chambers with opposite B field direction.

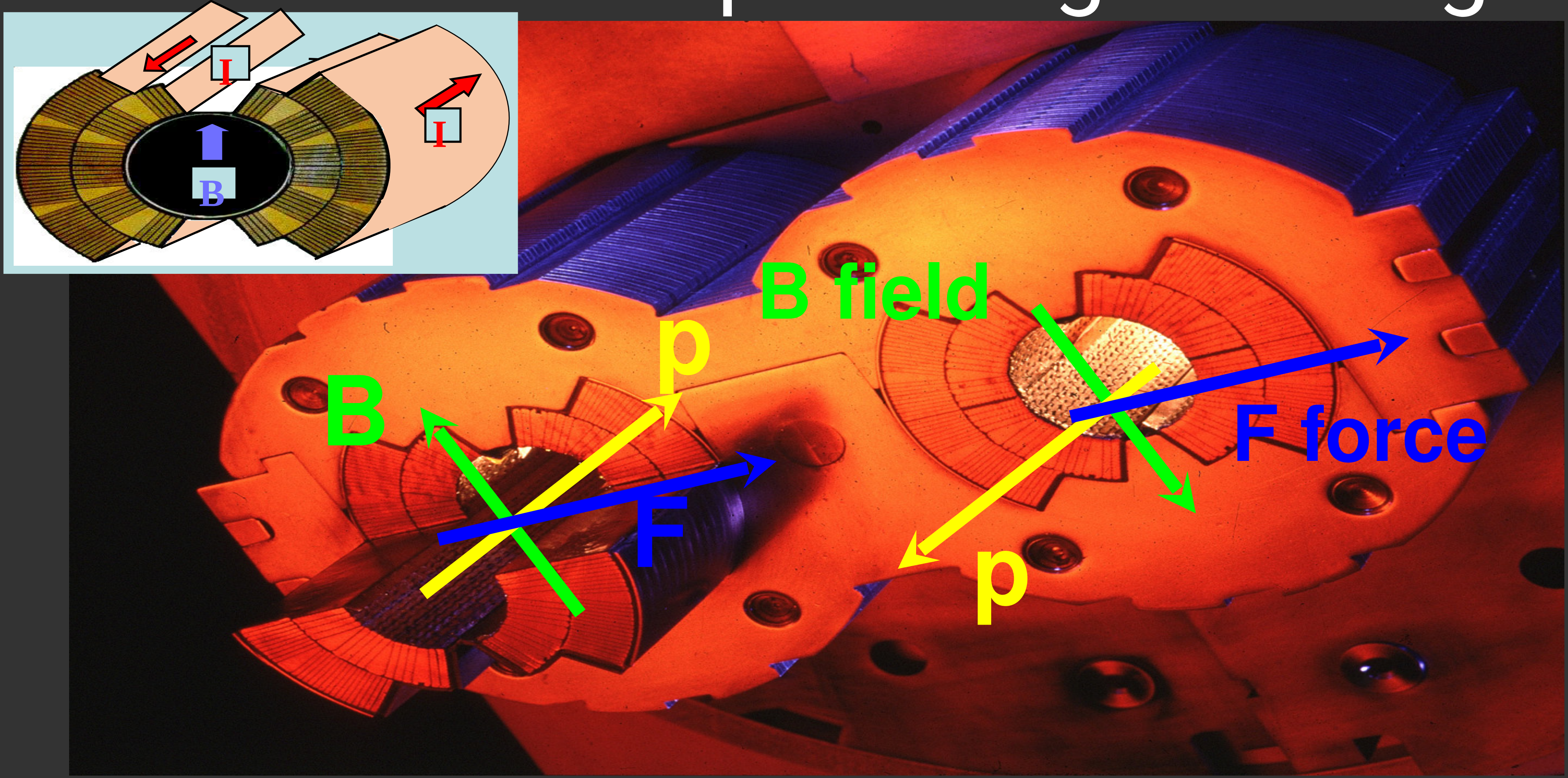
LHC Layout

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

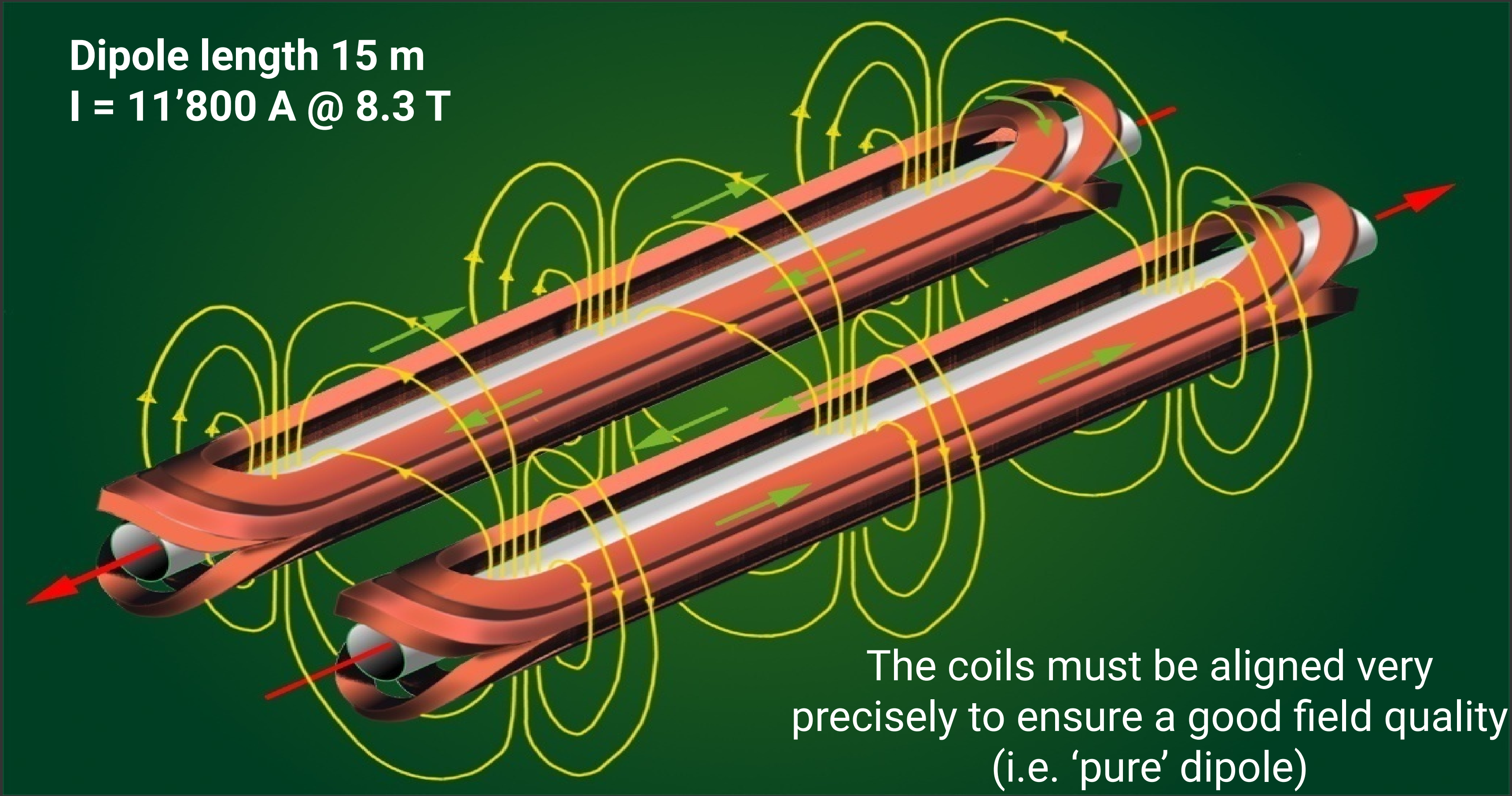


J. Wenninger LNF Spring School, May 2010

Two-in one dipole magnet design



Coils for dipoles



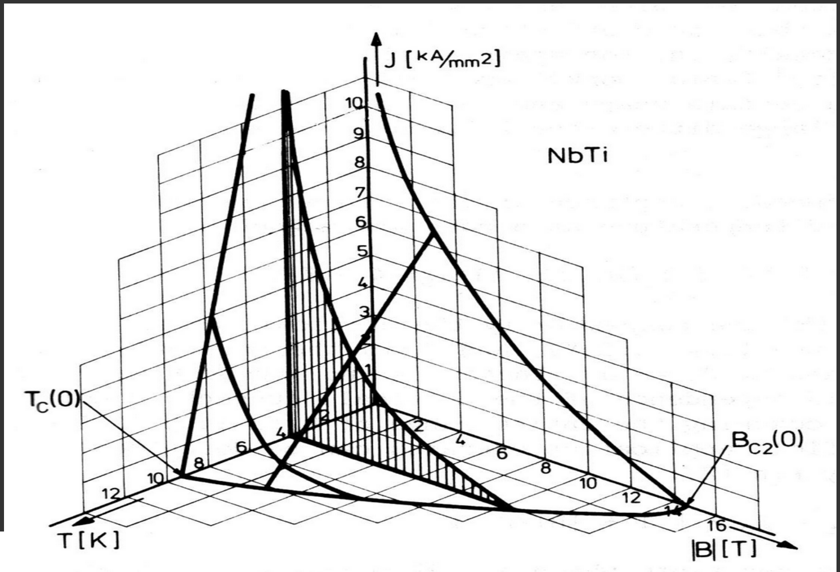
Dipole length 15 m
I = 11’800 A @ 8.3 T

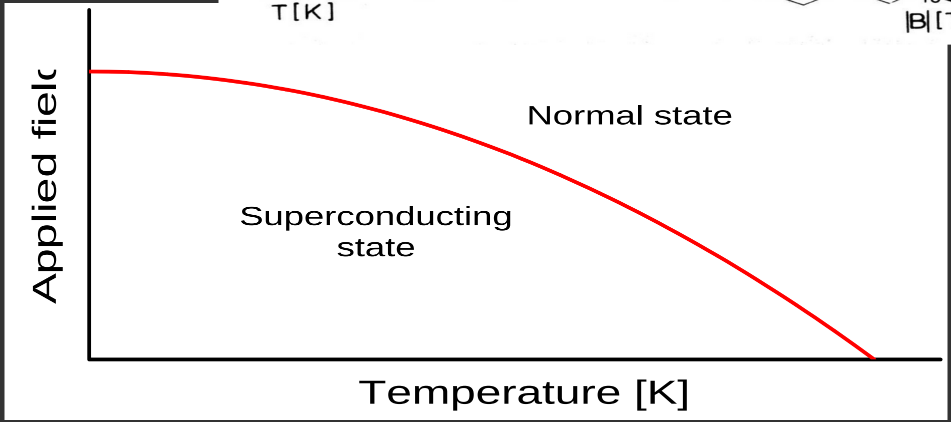
The coils must be aligned very precisely to ensure a good field quality (i.e. ‘pure’ dipole)

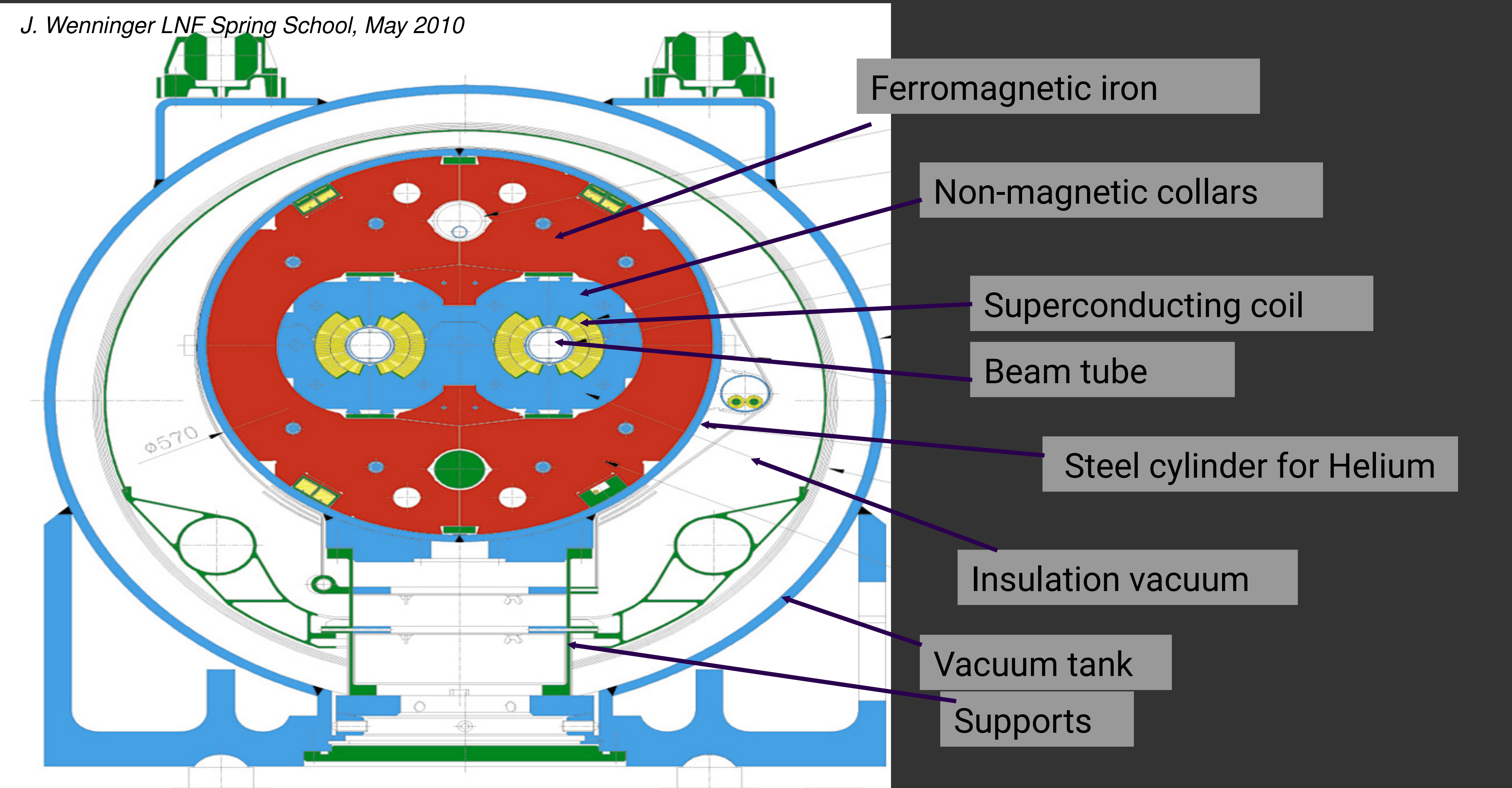
J. Wenninger LNF Spring School, May 2010

Superconductivity

- Stable dipole field of 8.3 Tesla 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 !

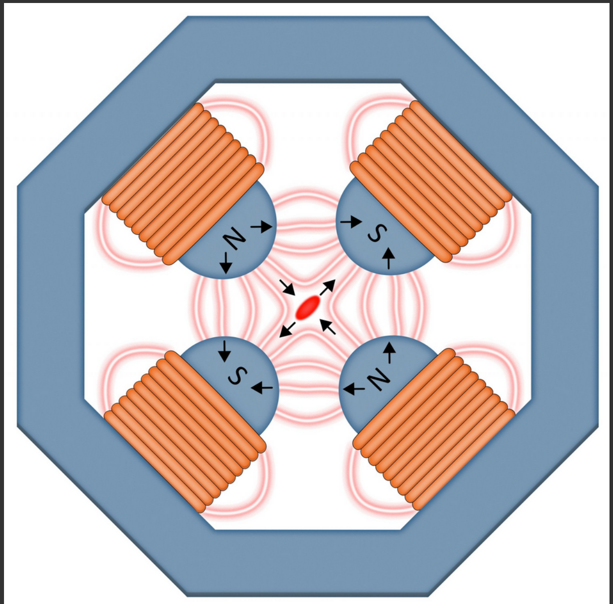


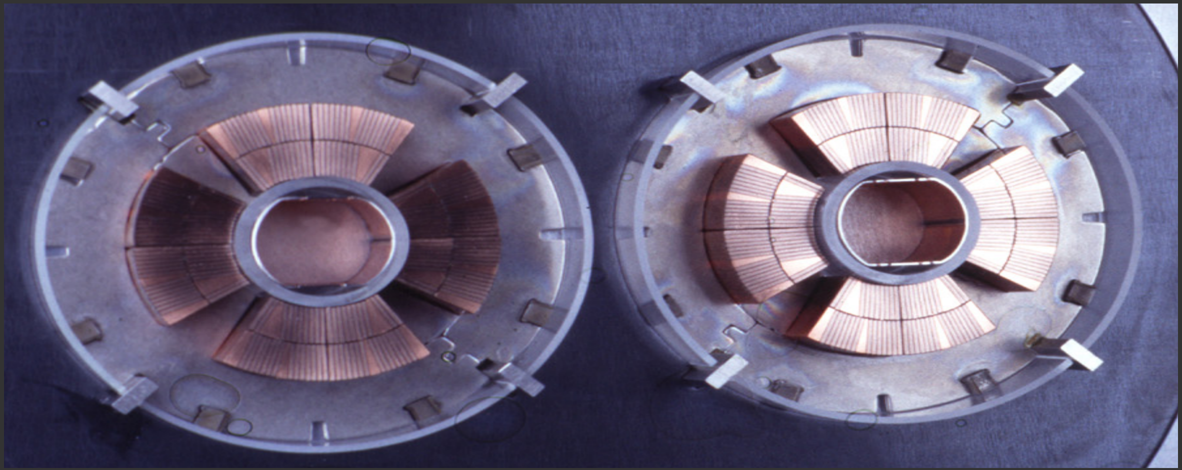


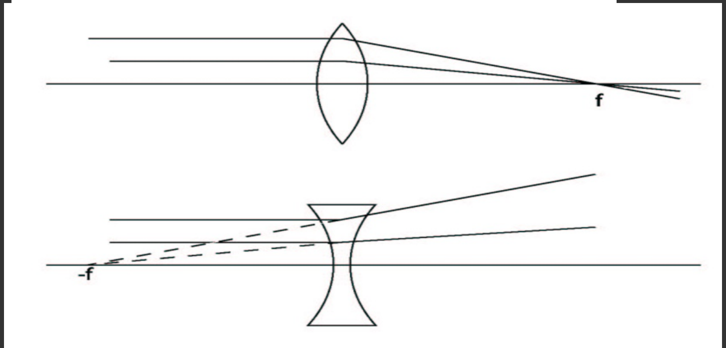


Weight (magnet + cryostat) ~ 30 tons, length 15 m

Focusing with Quadrupoles

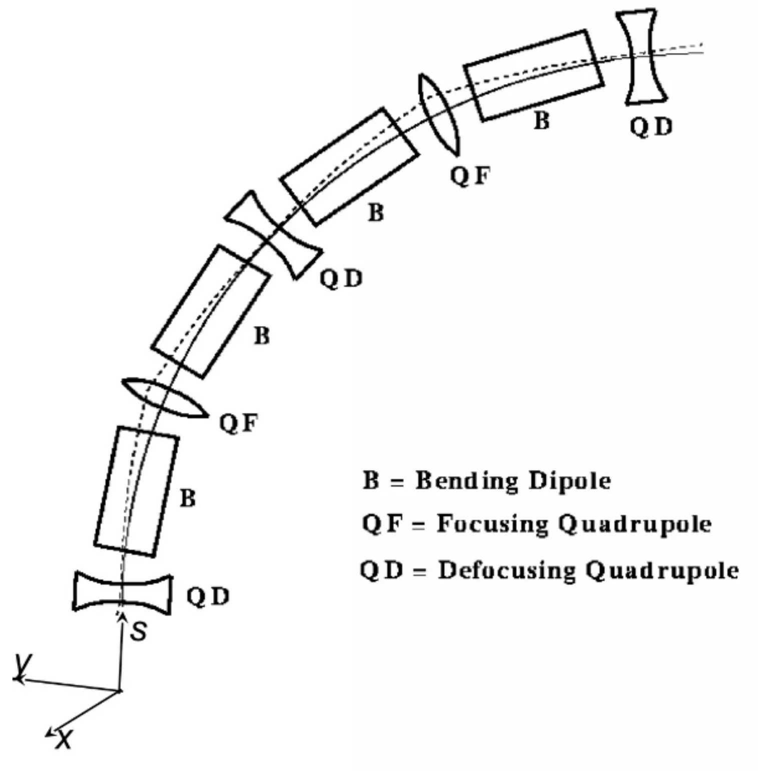




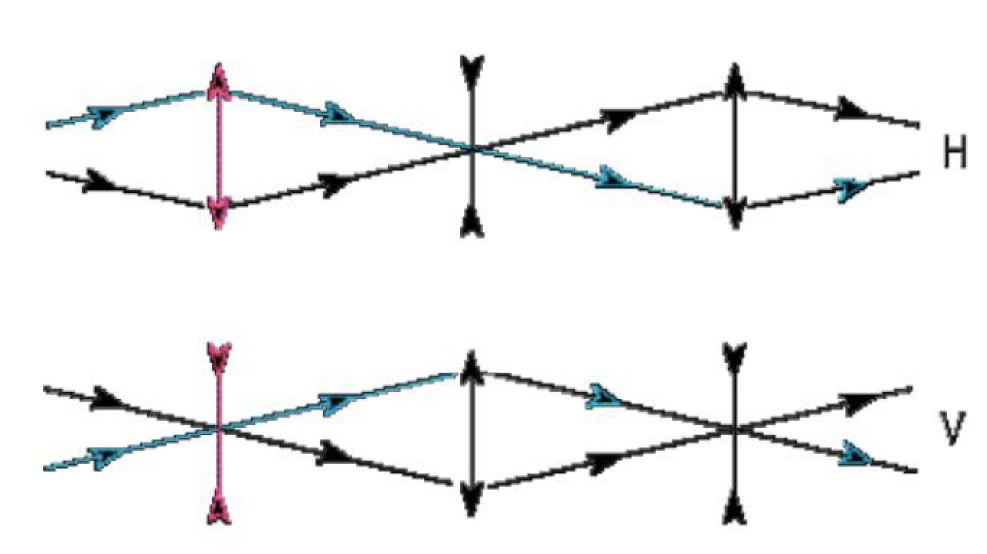


- Transverse focusing is achieved with **quadrupole magnets**, which act on the beam like an optical lens.
- Linear increase of the magnetic field along the axes (no effect on particles on axis).
  Focusing in one plane, **de-focusing** in the other!

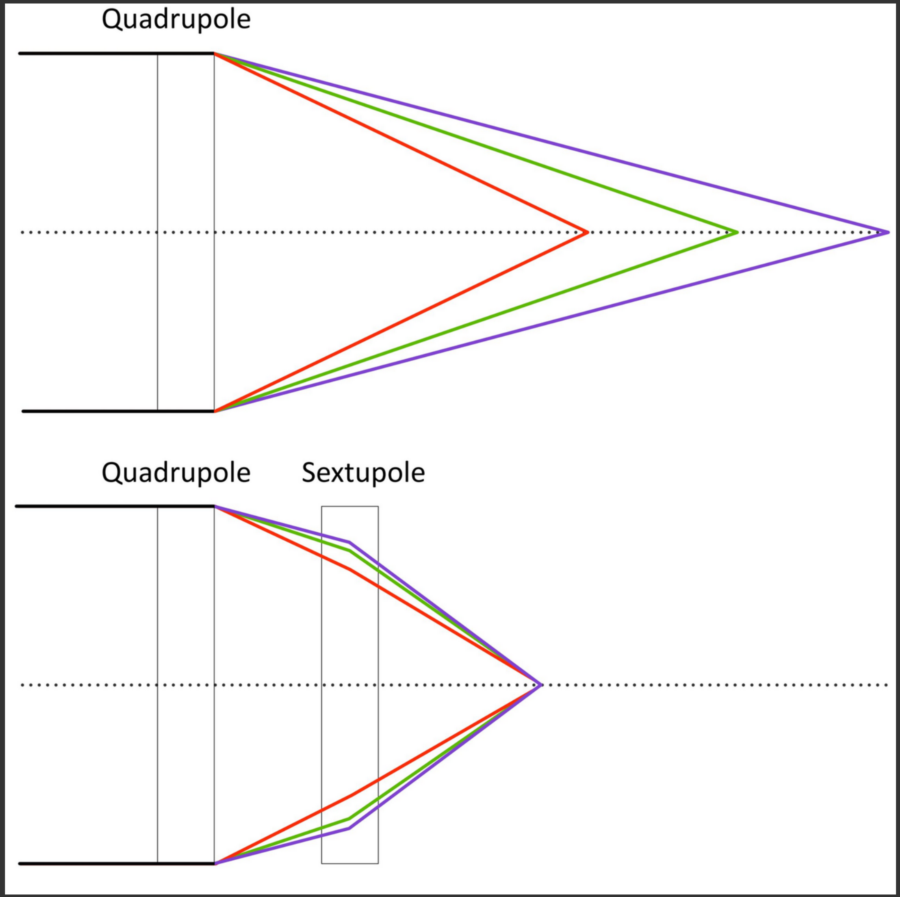
Alternating gradient lattice



- Dipoles keep particles on track
- Alternating Quadrupoles create net focussing in both planes.

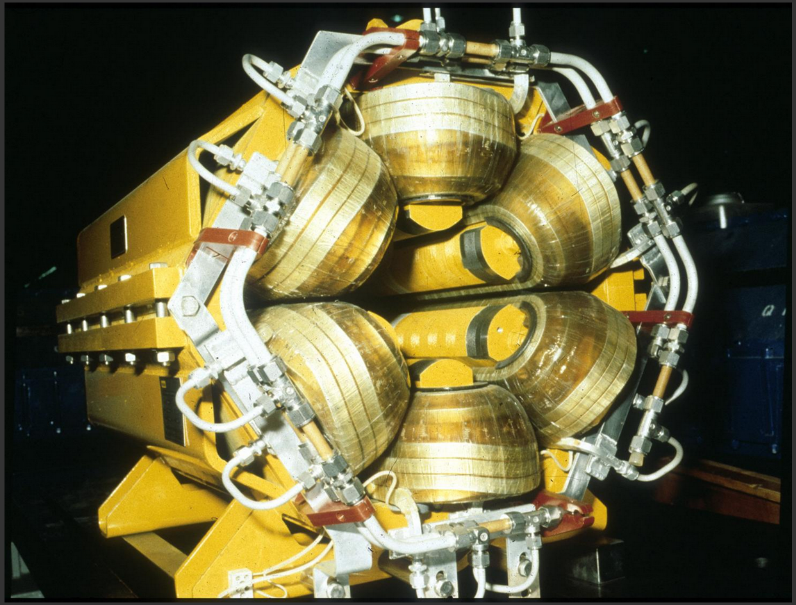


Chromatic Correction with Sextupoles



- Particles with different energies react differently in quadrupole magnets → «Chromatic Aberration »

- Can be solved by Sextupoles magnets

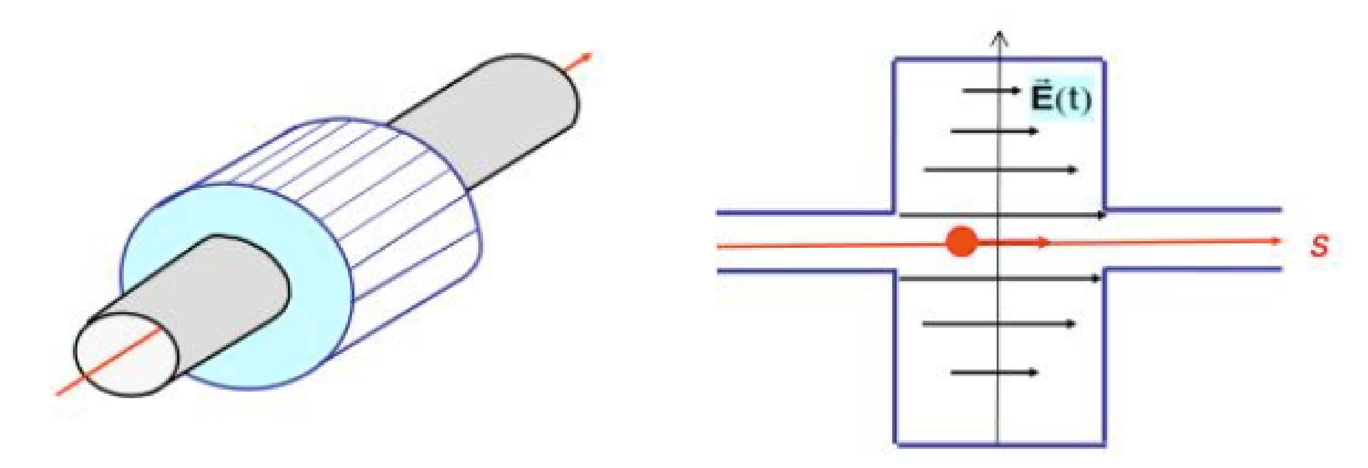


Acceleration with RF cavities

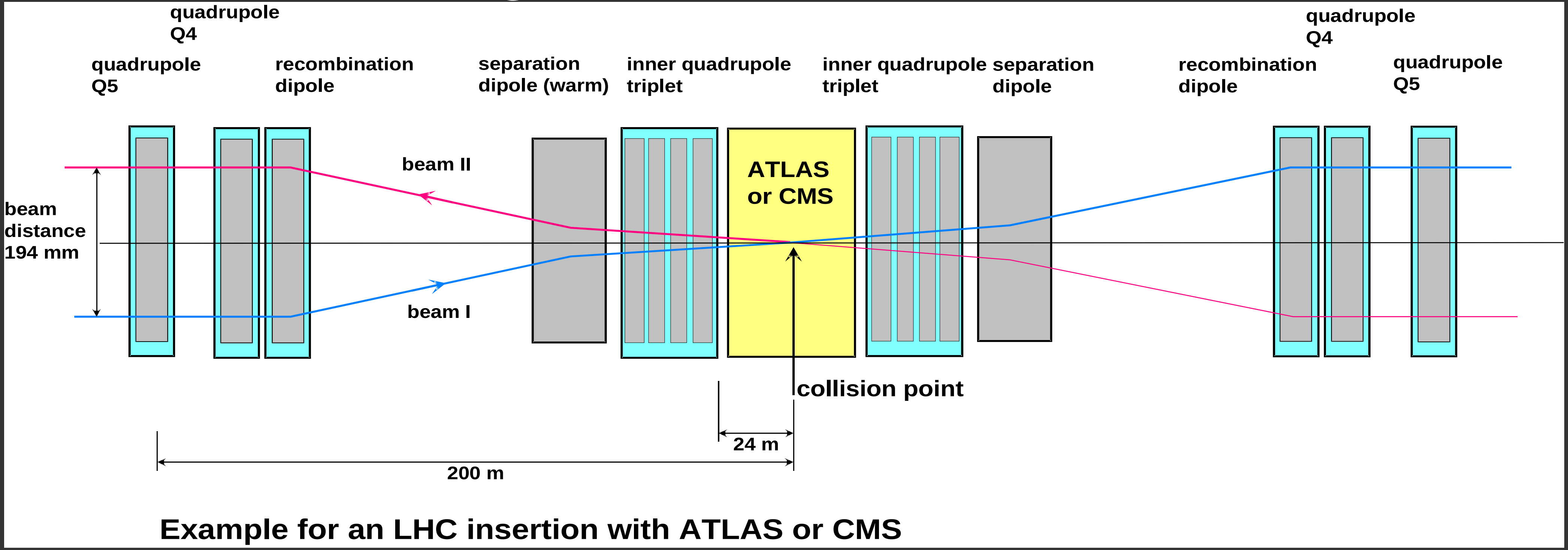
Acceleration with electric field in Radio-Frequency cavities.

In circular accelerators, the acceleration is done with small steps at each turn.

LHC : acceleration from **450GeV** to **7 TeV** lasts ~20 minutes, with an average energy gain of ~0.5 Mev on each turn.

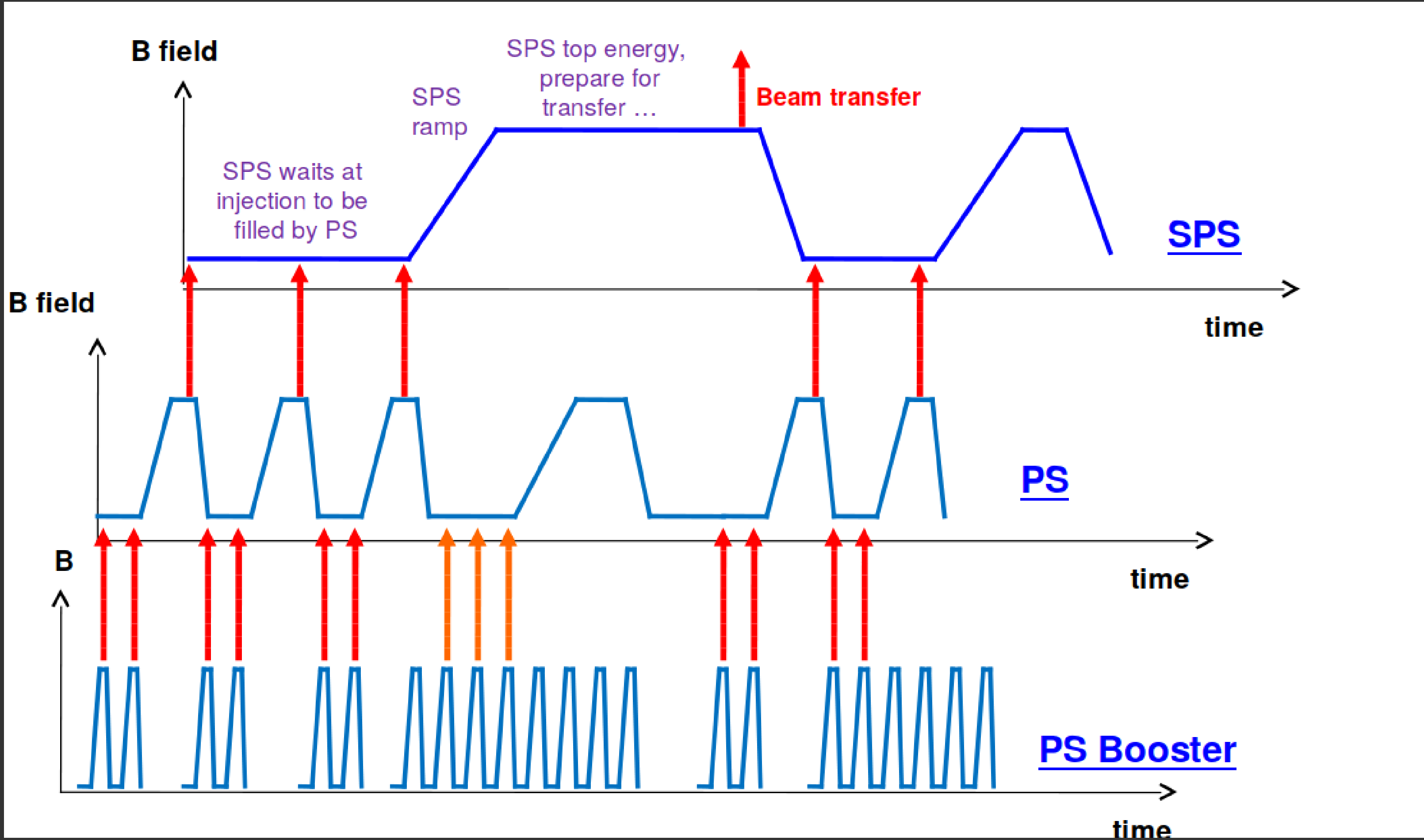


Combining the beams for collisions

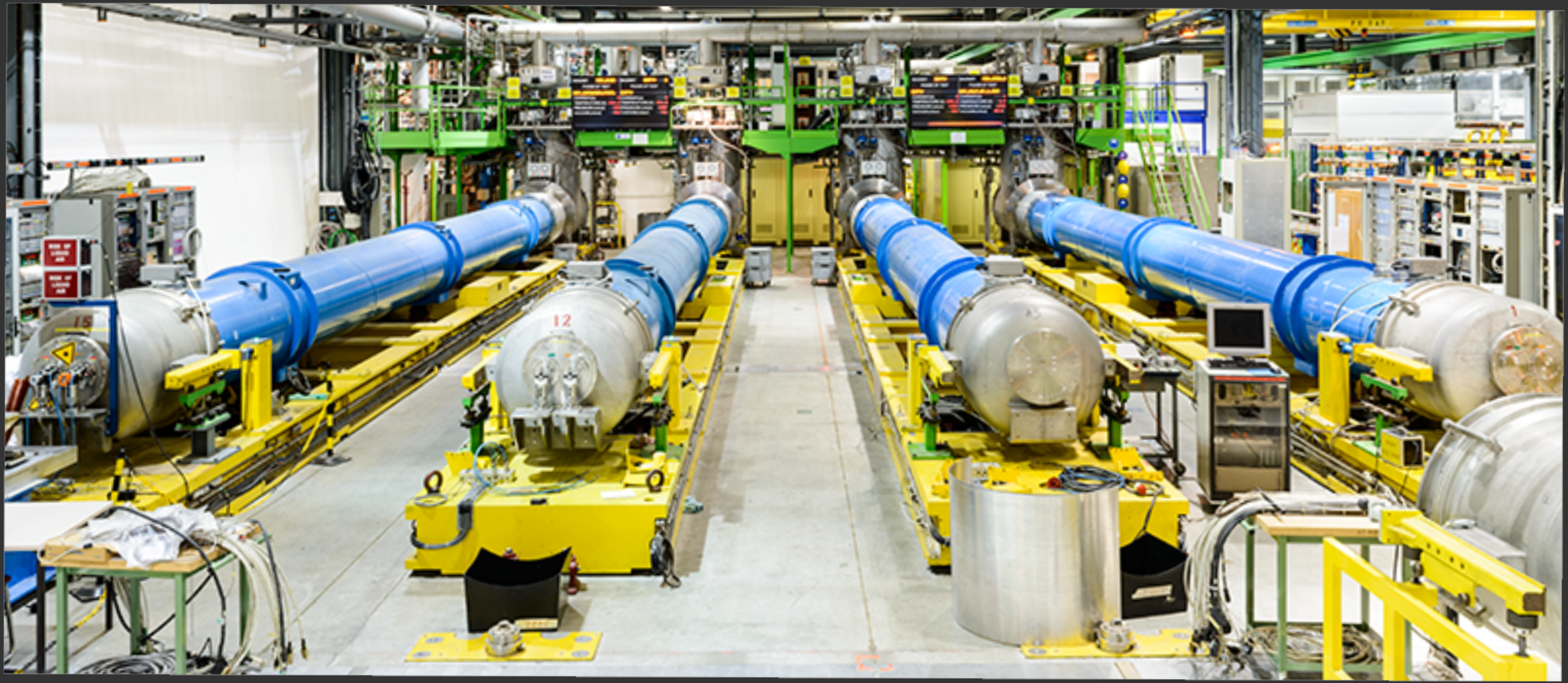


- The 2 LHC beams must be brought together to collide.
- Over ~260 m, the beams circulate in the same vacuum chamber.

Principle of injector cycling



SM18 : CERN Magnet testing facility



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 !

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

Damage at an LHC interconnect

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)