CERN

Beam transfer systems at CERN’s accelerator complex.

Design, construction and operational considerations of normal conducting magnets and electrostatic deflectors in high vacuum and high radiation environments

Miroslav Atanasov TE-ABT

Acknowledgements M. Barnes, B. Goddard, J. Borburgh, M. Hourican, T. Masson, S. Gibson

13.07.2017

Contents

- The Lorentz force
- The CERN accelerator complex
- Beam transfer
- Septa devices
  - Electrostatic
  - Magnetic (DC or pulsed)
- Protective absorbers
- Mechanical and electromagnetic design

Lorentz force

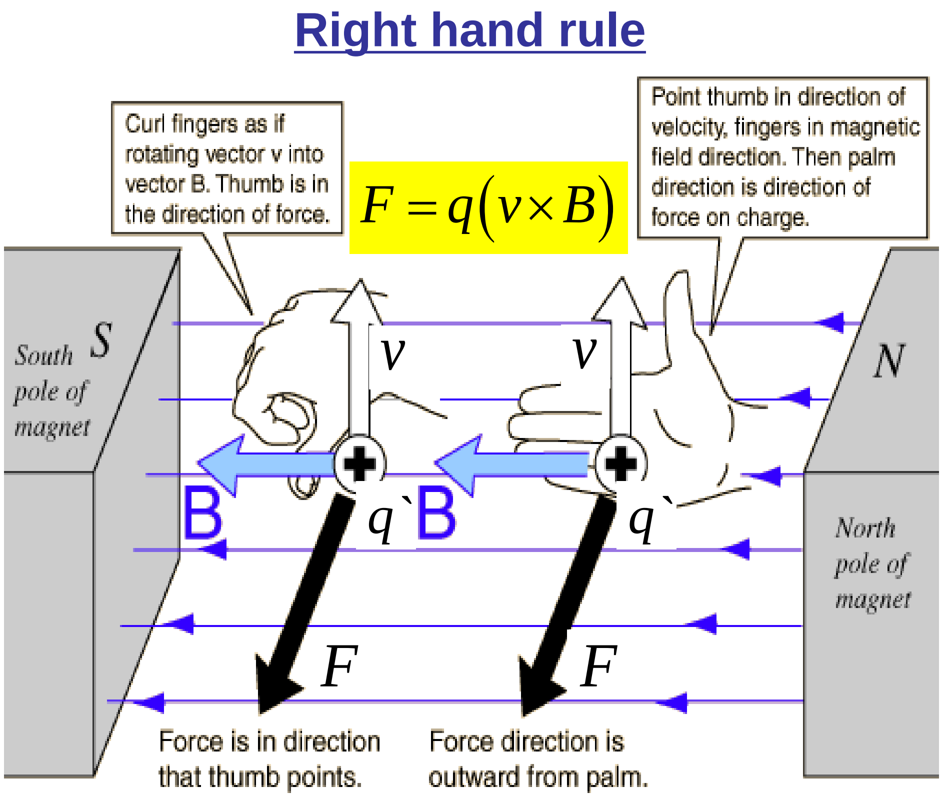
- Describes the interaction between charged particles and electromagnetic fields.

$$F = q\left[E + \left(v \times B\right)\right]$$

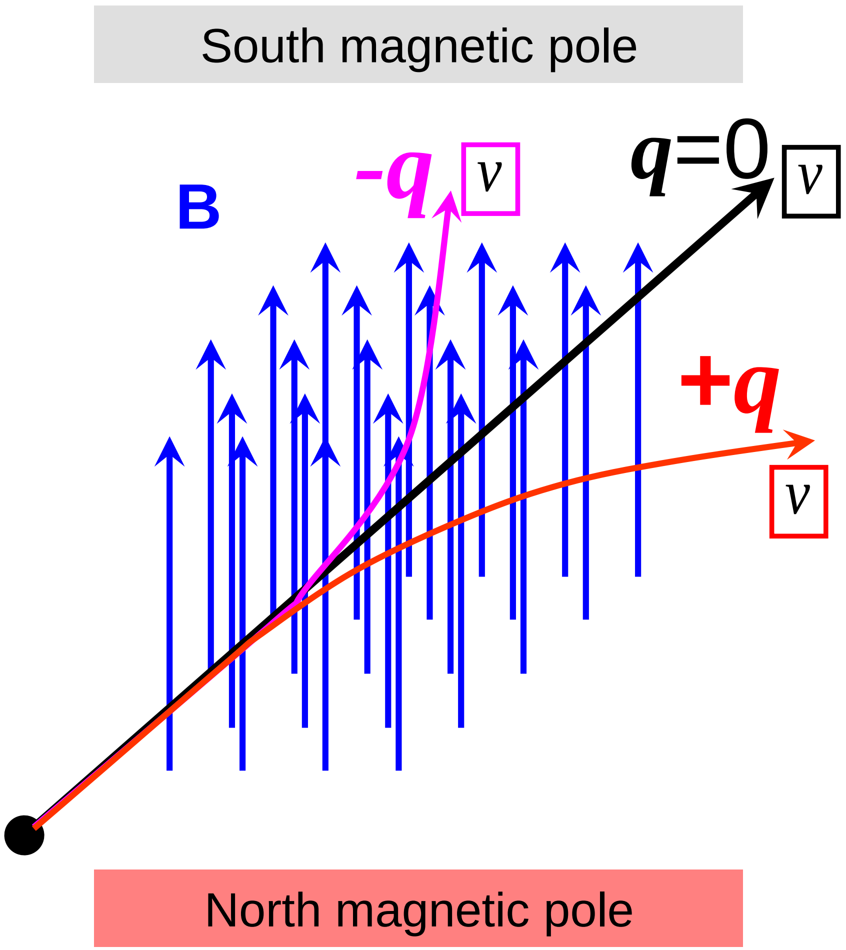
- F is the force vector;
- E is the electric field intensity (volt/metre);
- B is the magnetic flux density (tesla);
- q is the charge (coulomb);
- v is the particle velocity (metre/second);
- X is the vector cross-product.

Conclusion: The vector cross-product shows that the **magnetic** component of the force does not change the particle energy, but only the trajectory. The **electrical** component acting transversely leads to a change of trajectory, and acting longitudinally leads to a change in kinetic energy. Its contribution to the change of particle energy does not depend on the particle velocity.

Magnetic component

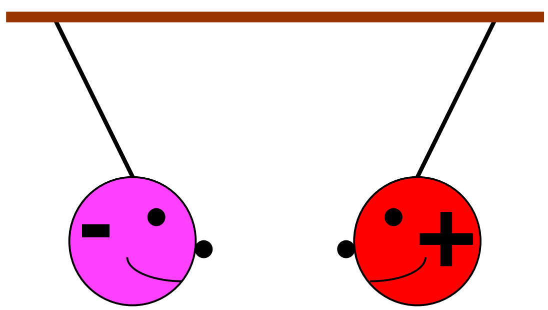


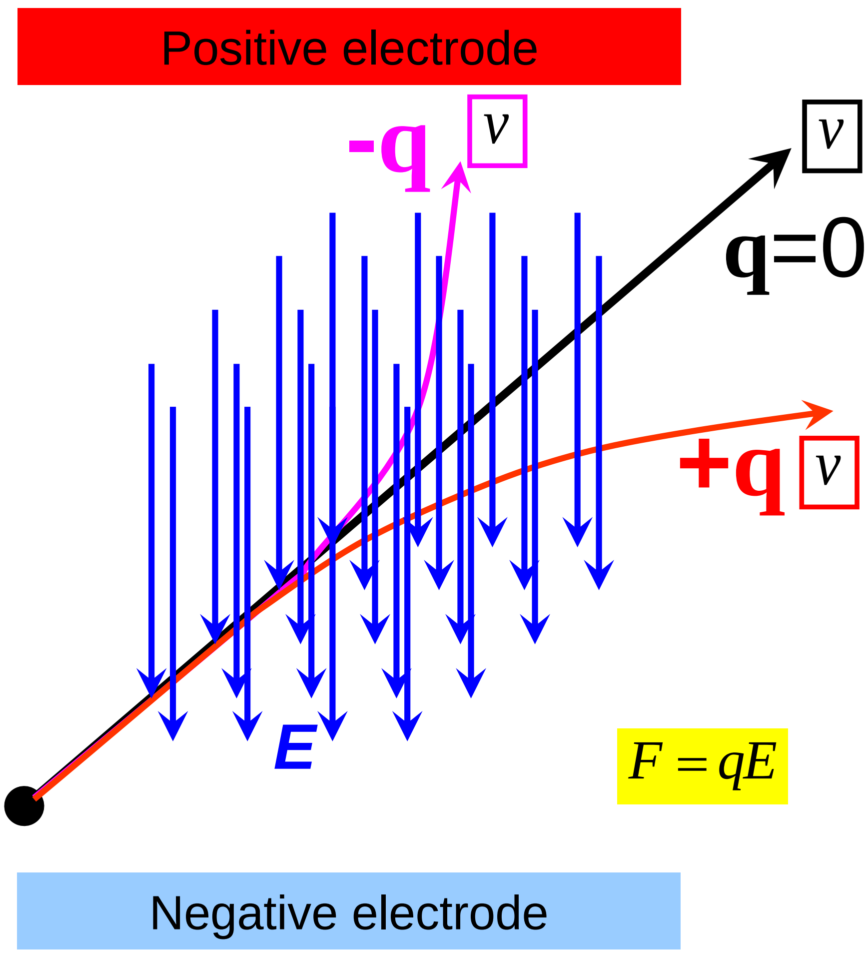
Ref: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magfor.html



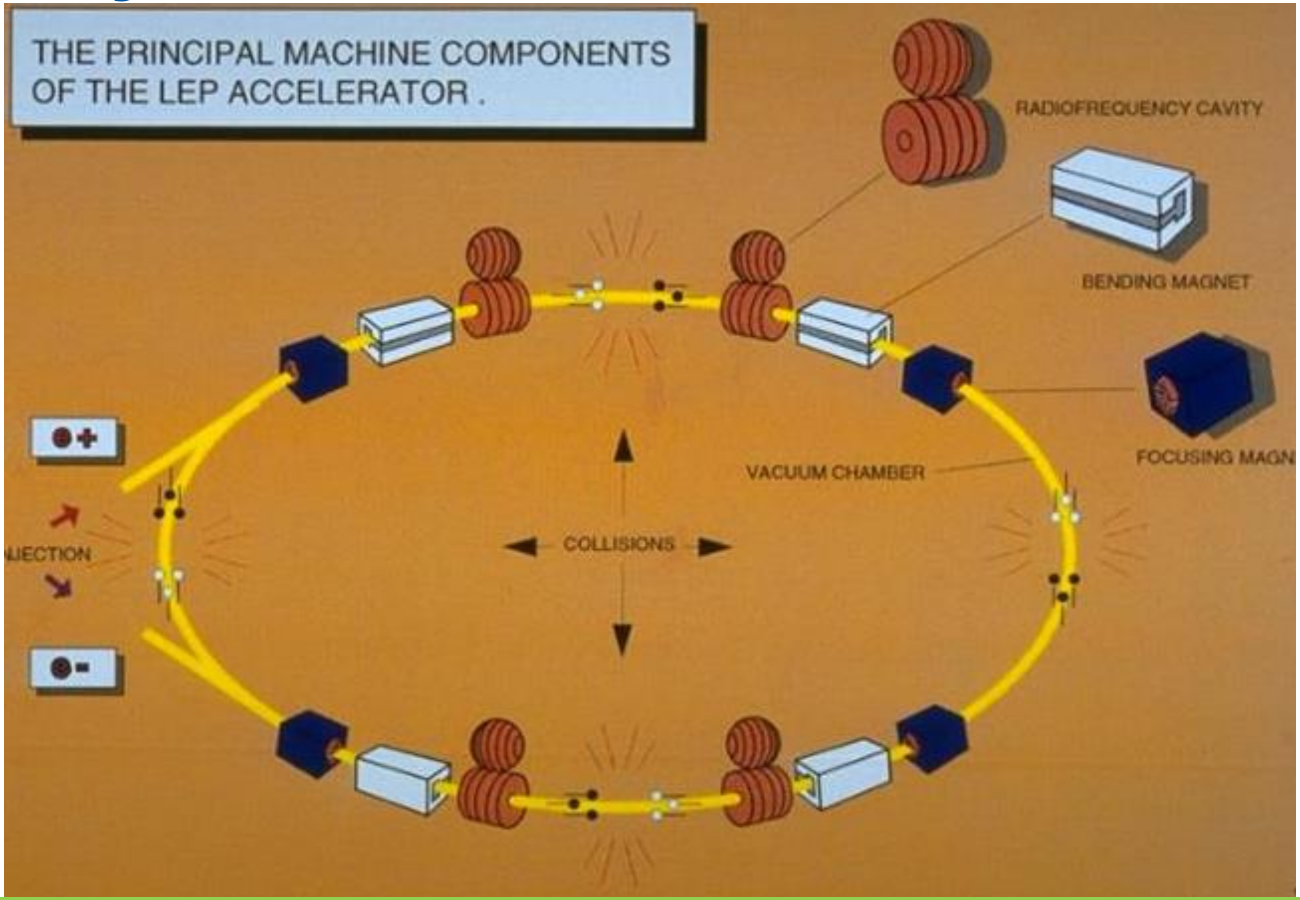
Electric component

Opposites attract!



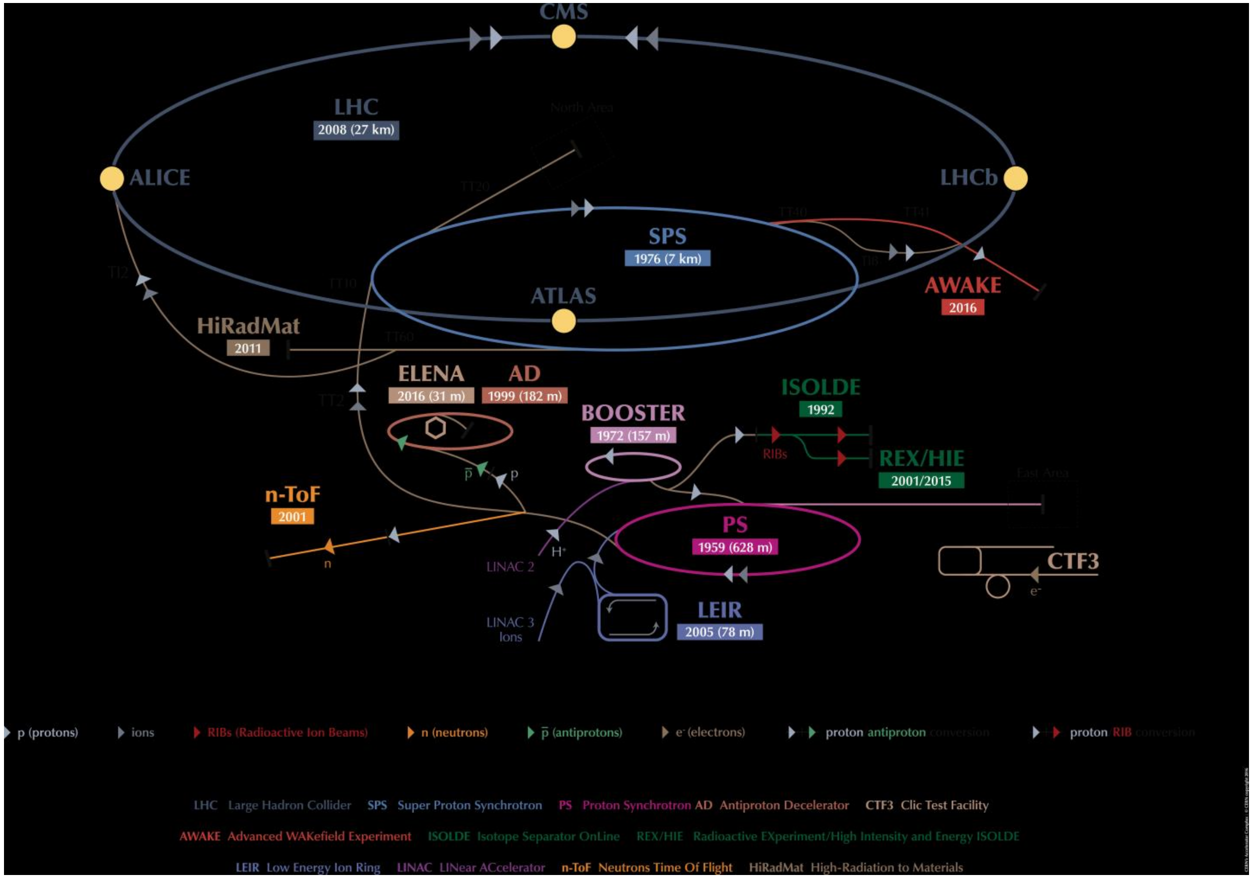


The synchrotron



Charged particles are kept in circular trajectories using dipole magnetic fields, which are synchronised with the accelerating (or decelerating) electric fields, in such a way, that for every increase of the particle energy, there is a corresponding increase of the bending magnetic field, such that the particle trajectory remains unchanged.

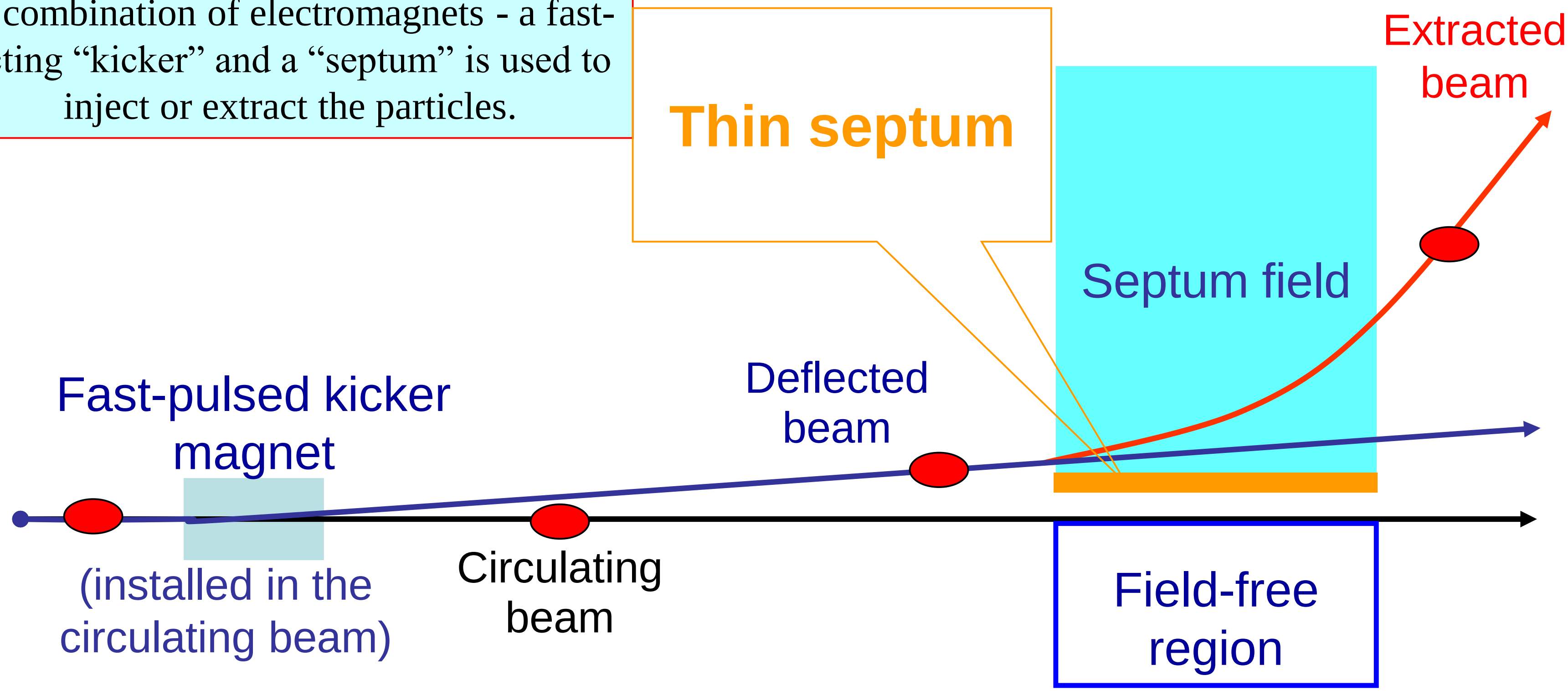
Beam transfer at CERN's complex



- Each accelerator has a limited dynamic range;
- A chain of accelerators is required in order to reach high energies;

Beam transfer

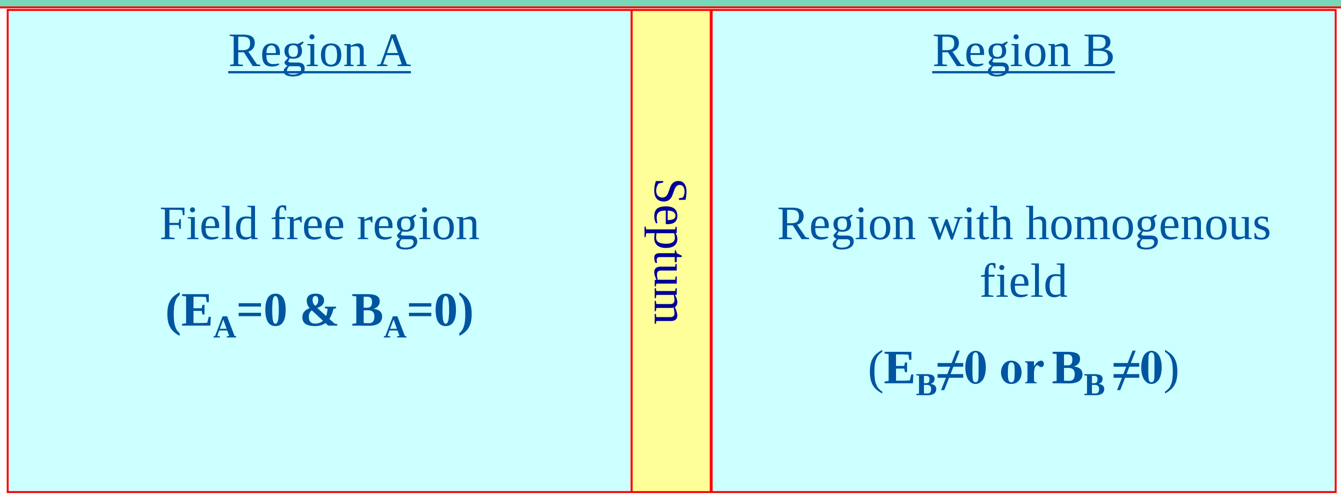
A combination of electromagnets - a fast-acting "kicker" and a "septum" is used to inject or extract the particles.



- Kicker – a fast-pulsed electromagnet giving a small initial deflection of the beam trajectory (a few mrad or less) into the high field region of the septum;
- Septum – produces a magnetic field strong enough for the final deflection of the beam into the accelerator (injection), or the transfer line or fixed-target experiment (extraction), without perturbing the circulating beam.

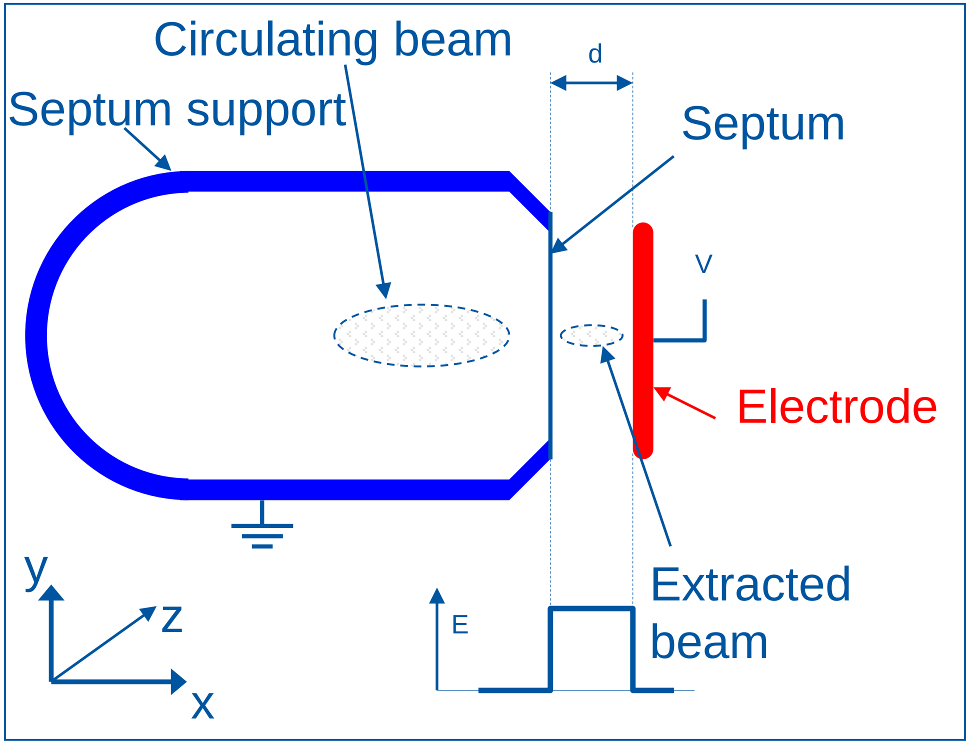
Septa

Septum (pl. septa) is a partition separating two cavities or regions (in medicine, for example – the part between the nostrils).
In a particle accelerator a septum is a device that separates two field regions:



The important features of septa devices are the absence of field in one region (so that circulating beams are not perturbed), and the presence of a homogenous field in the other region (for the required deflection of the beam). The septum thickness should be as small as possible in order to reduce the strength of the highly complex kicker magnet.

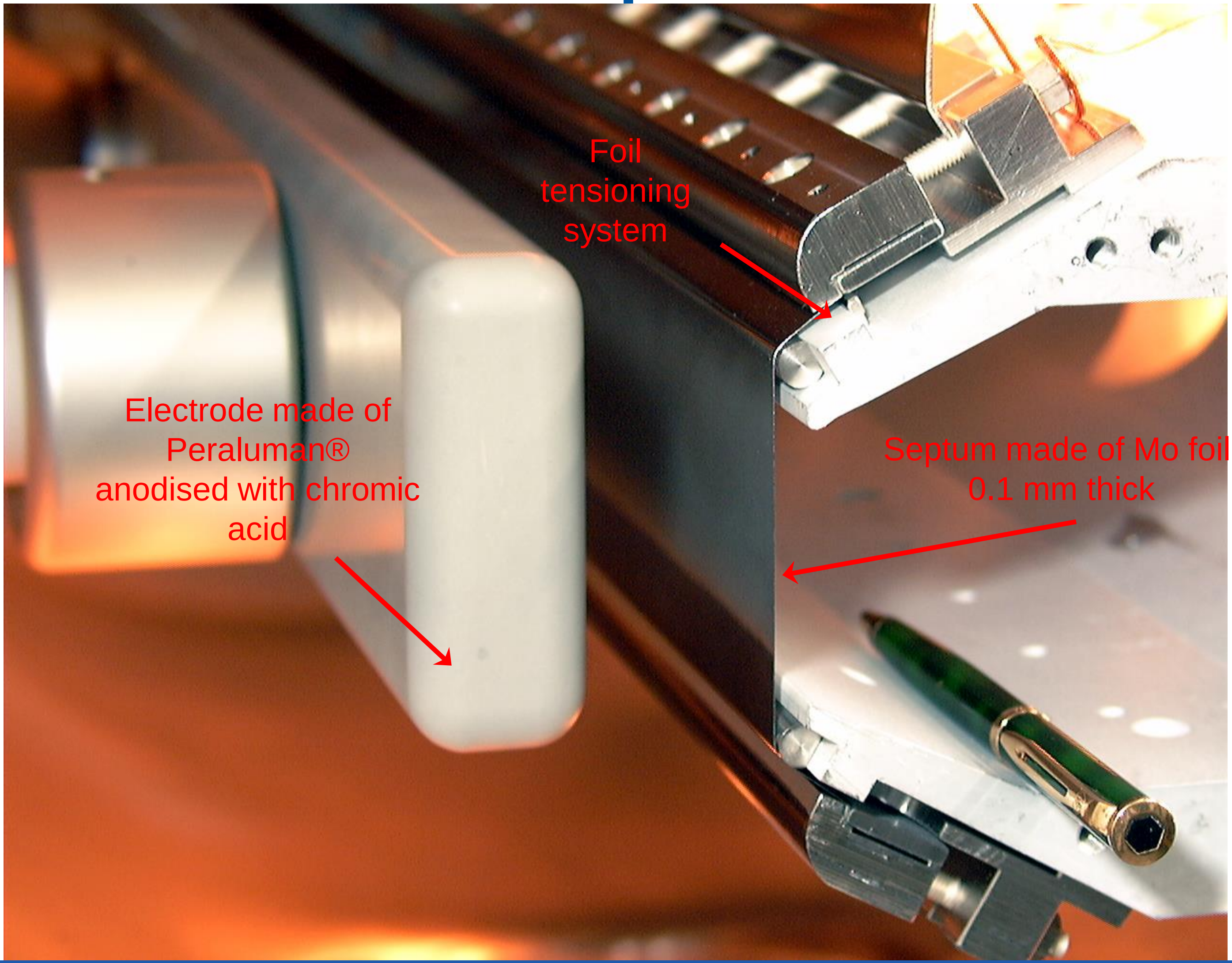
Electrostatic septum



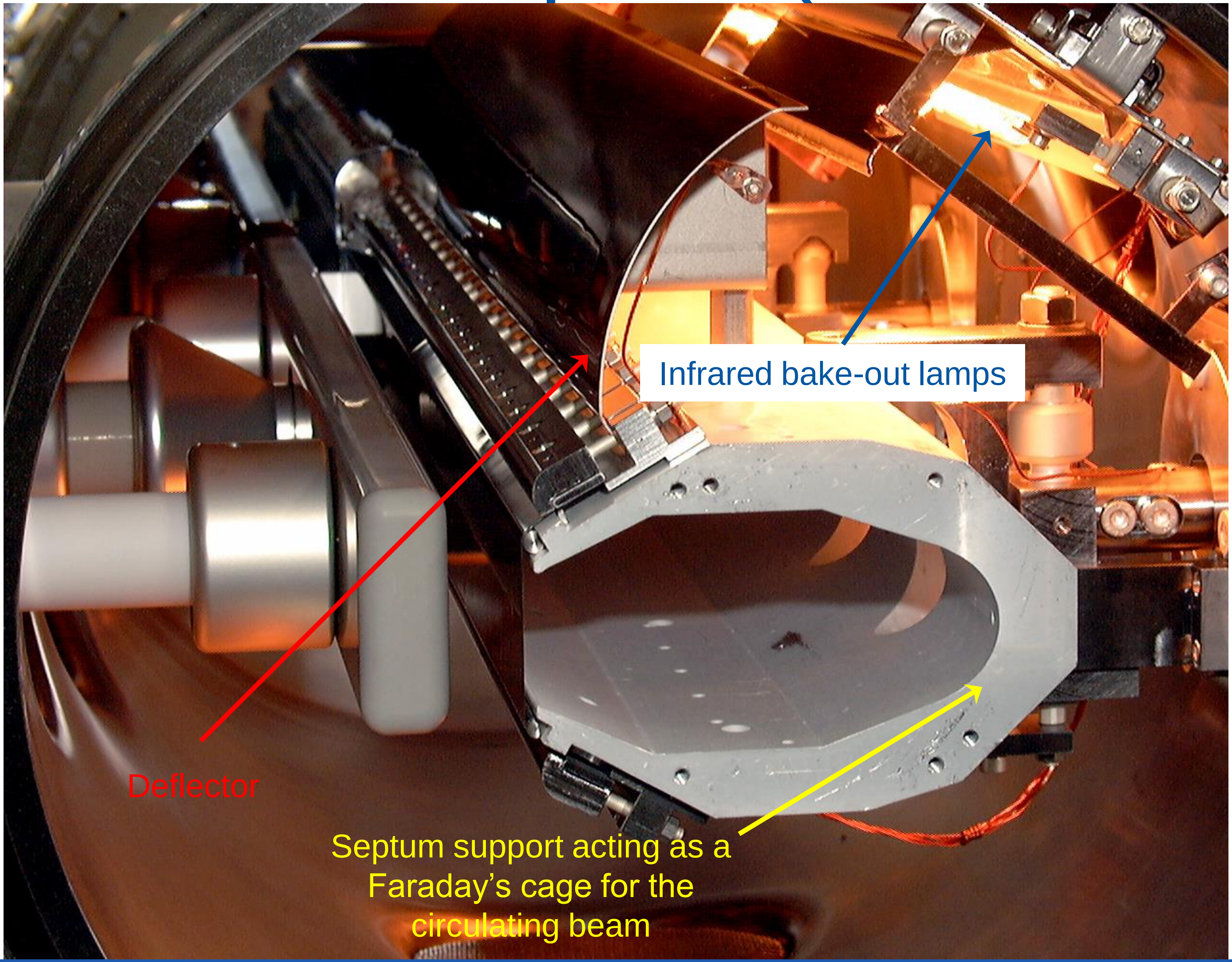
Typical parameters:

- Electrode length: 500 – 3000 mm;
- Variable gap width (d): 10 - 35 mm;
- Septum thickness: <=0.1 mm;
- Vacuum (10^{-9} to 10^{-12} mbar);
- Voltage: up to 300 kV;
- Electric field strength10 MV/m;
- Septum made of Mo foil or WRe wires;
- Electrode made of anodised aluminium, stainless steel or titanium for ultra-high vacuum;
- Bake-out up to 300 ºC for achieving ultra-high vacuum up to 10^{-12} mbar;

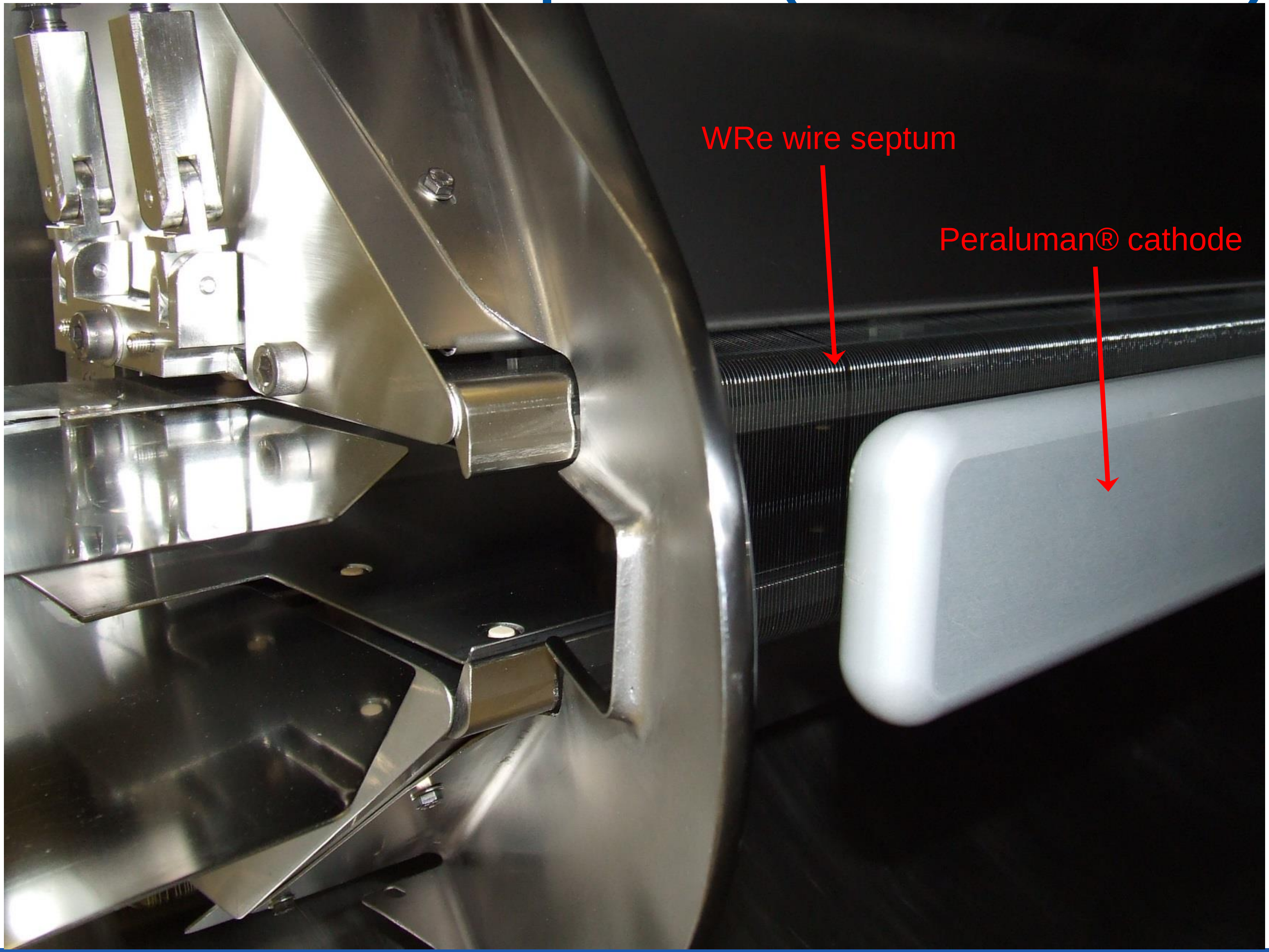
Electrostatic septum



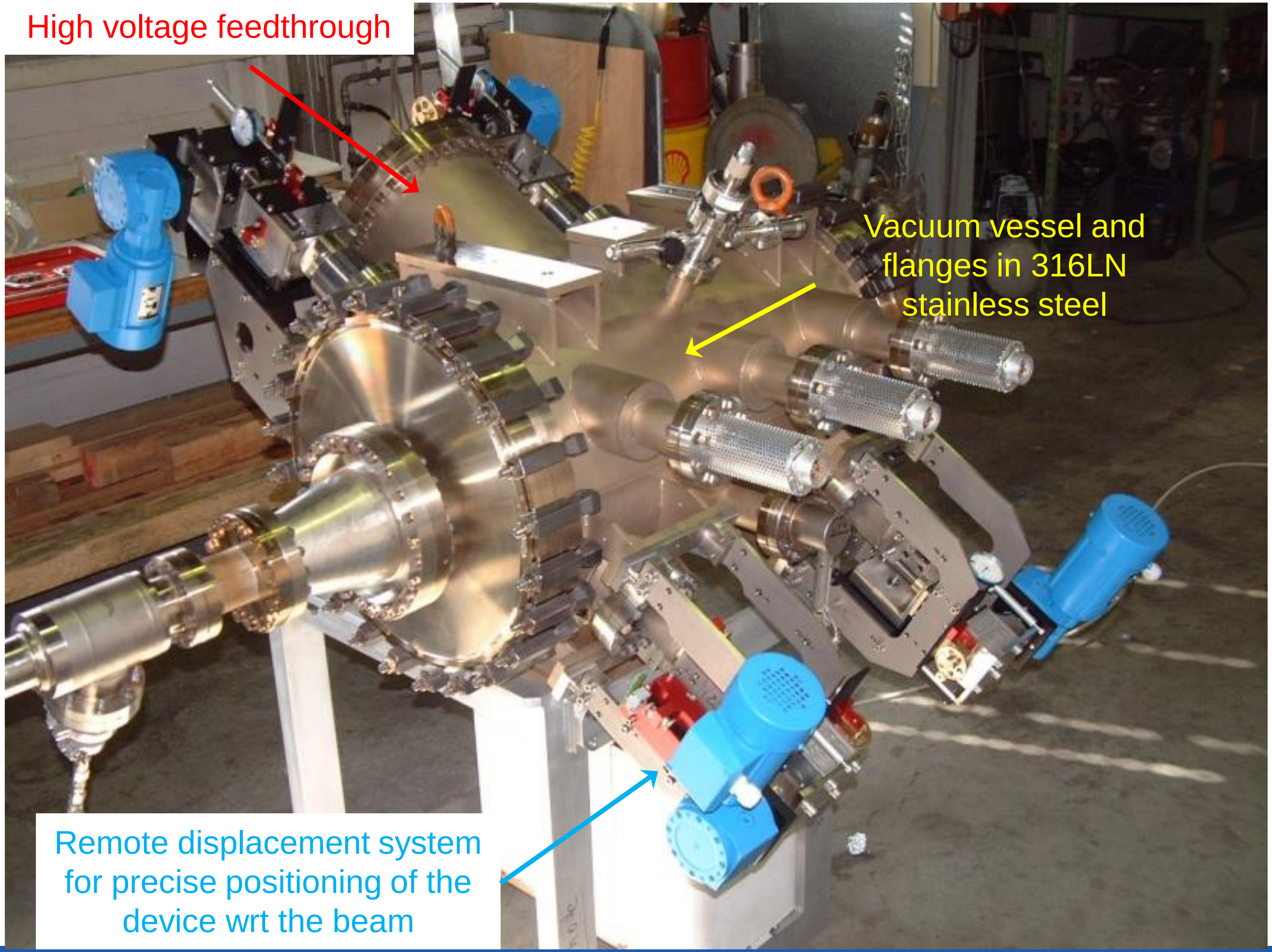
Electrostatic septum (SEH23 in PS)



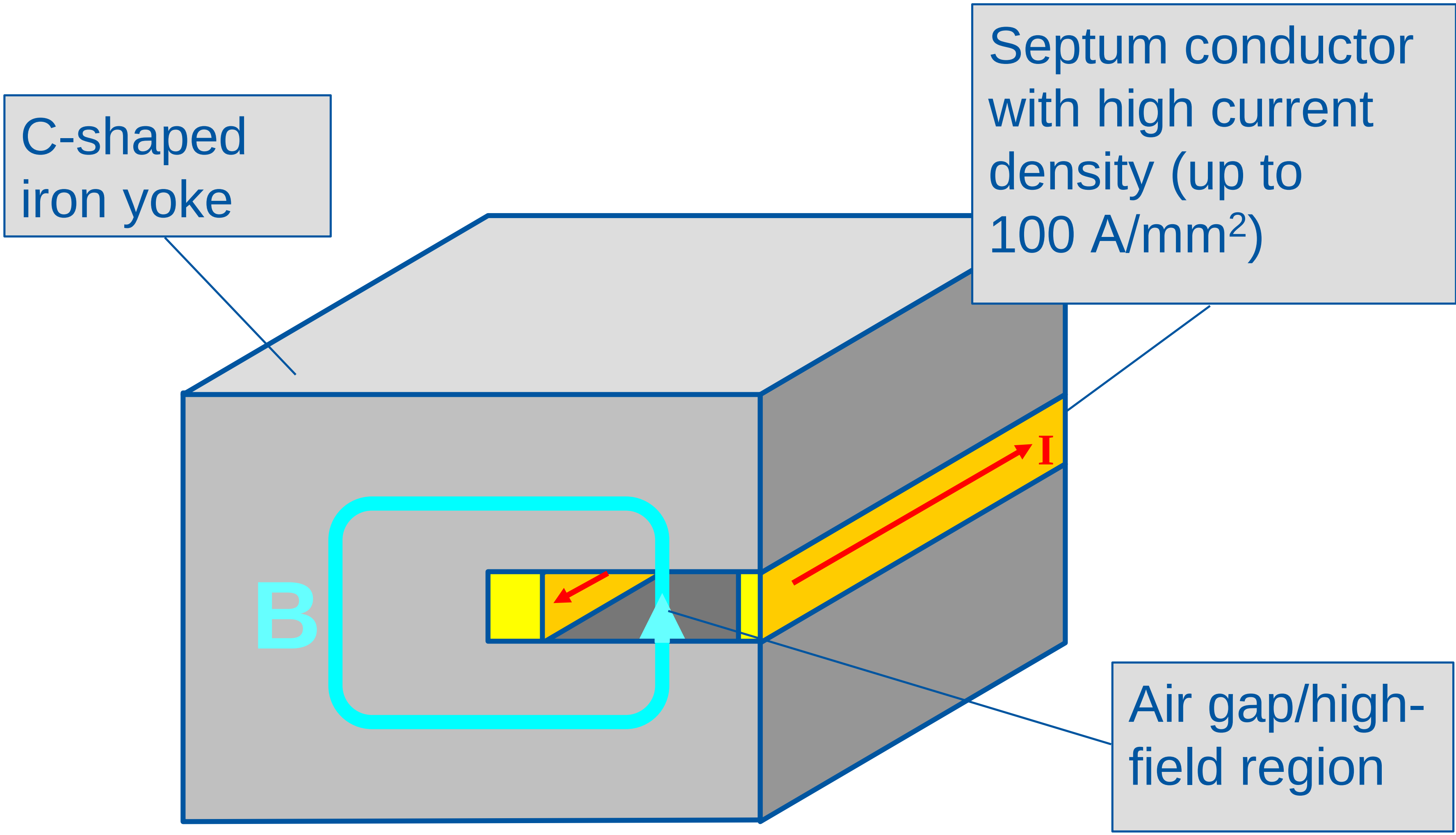
Electrostatic septum (ZS in SPS)



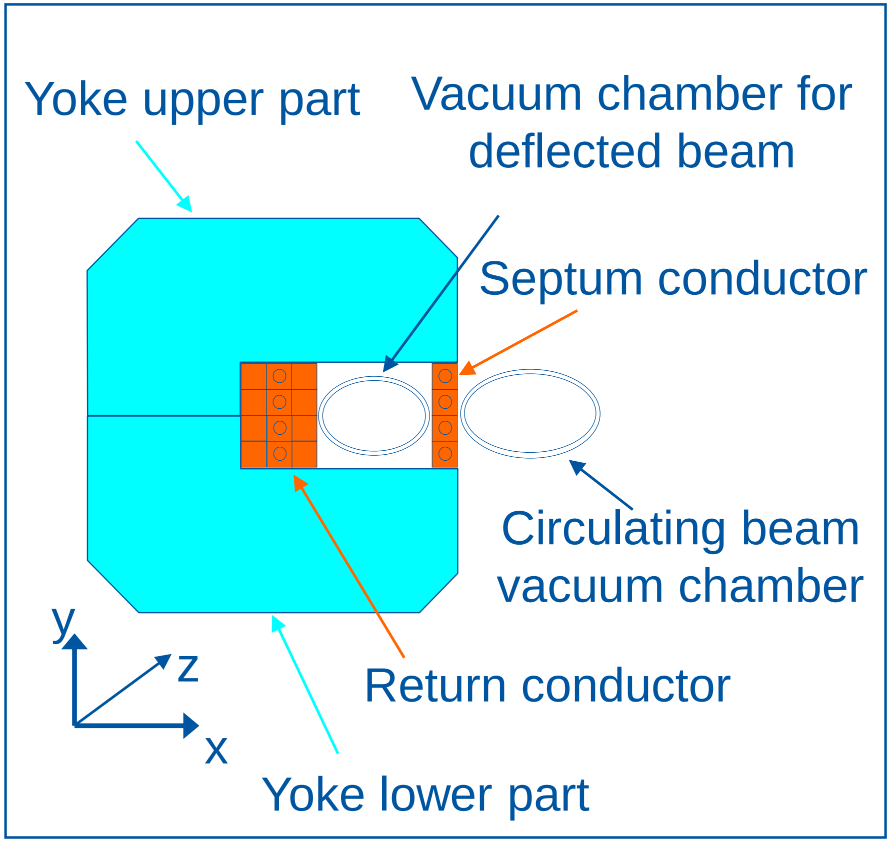
Electrostatic septum (SEH10 in LEIR)



Magnetic septum



Magnetic septum



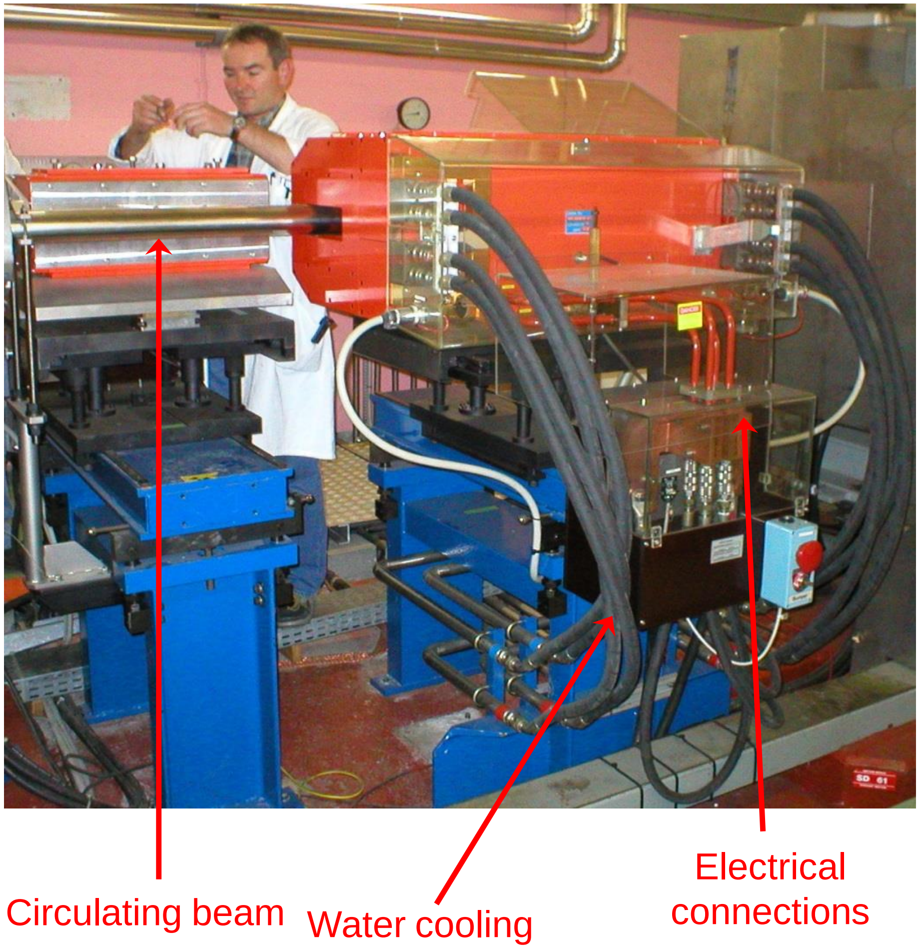
DC powered (up to 10 kA).

Usually a multiturn coil to reduce the current.

The yoke and coil are made of two parts to allow "splitting" of the magnet for installation of the vacuum chamber.

Rarely under vacuum.

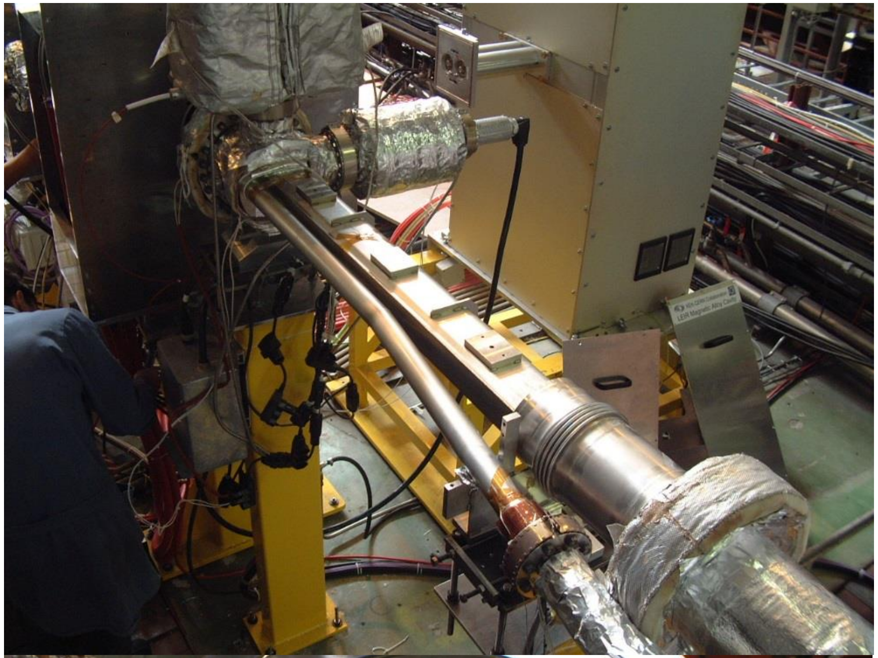
Magnetic septum (SMH61 in PS)

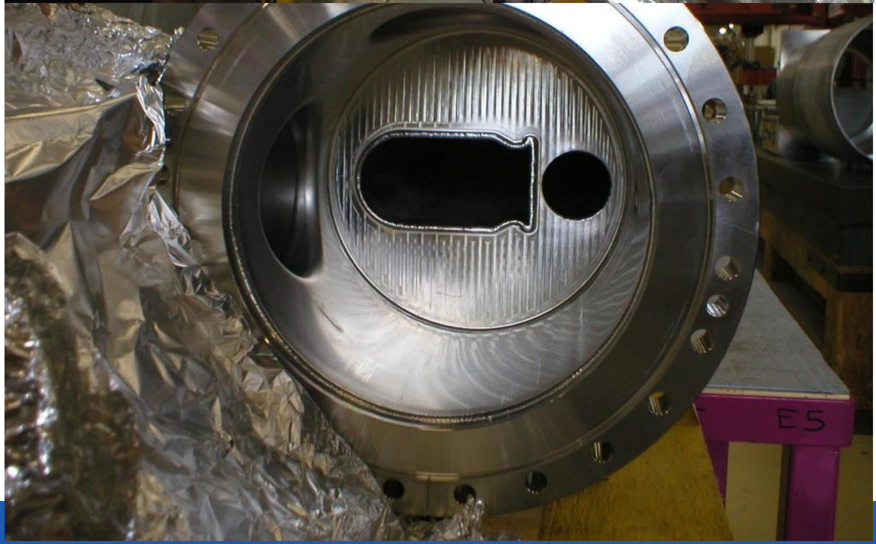


<u>Typical parameters:</u>

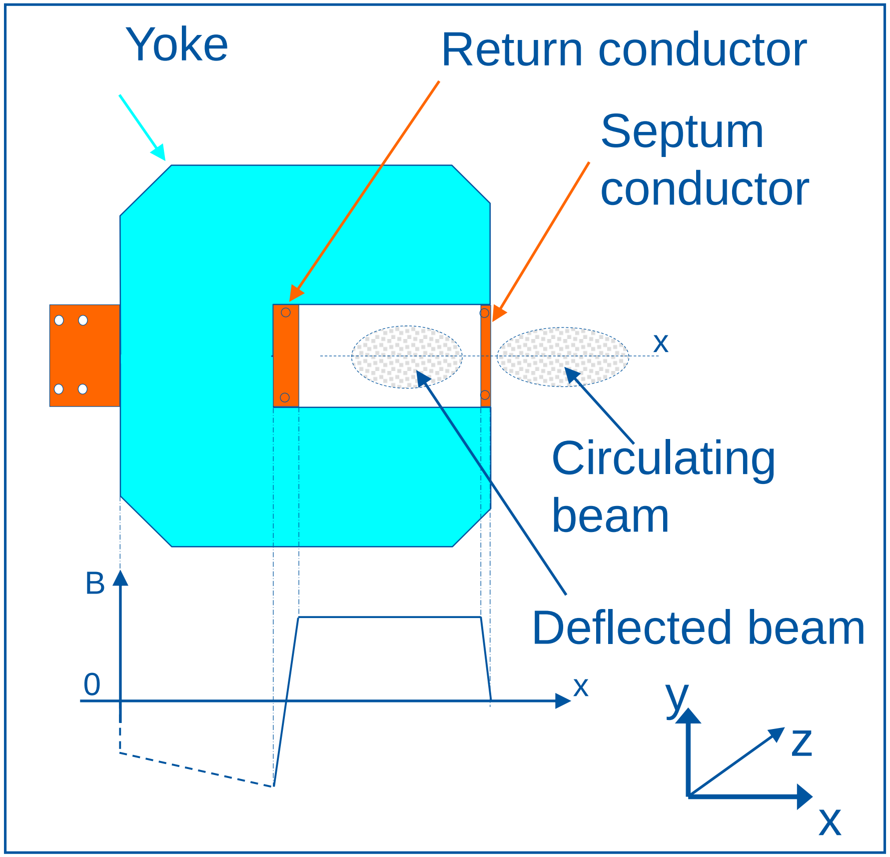
- Yoke length: 400 - 1200 mm;
- Air gap: 25 - 60 mm;
- Septum thickness: 6 - 20 mm;
- Installed outside vacuum;
- Laminated steel yoke;
- Water-cooled multi-turn coil (12 - 60 l/min);
- Rated current: 1 - 10 kA;
- Power supplied by controllable rectifier;
- <u>Power consumption: 10 - 100 kW !</u>

Septum vacuum chamber (SMH40 in LEIR)



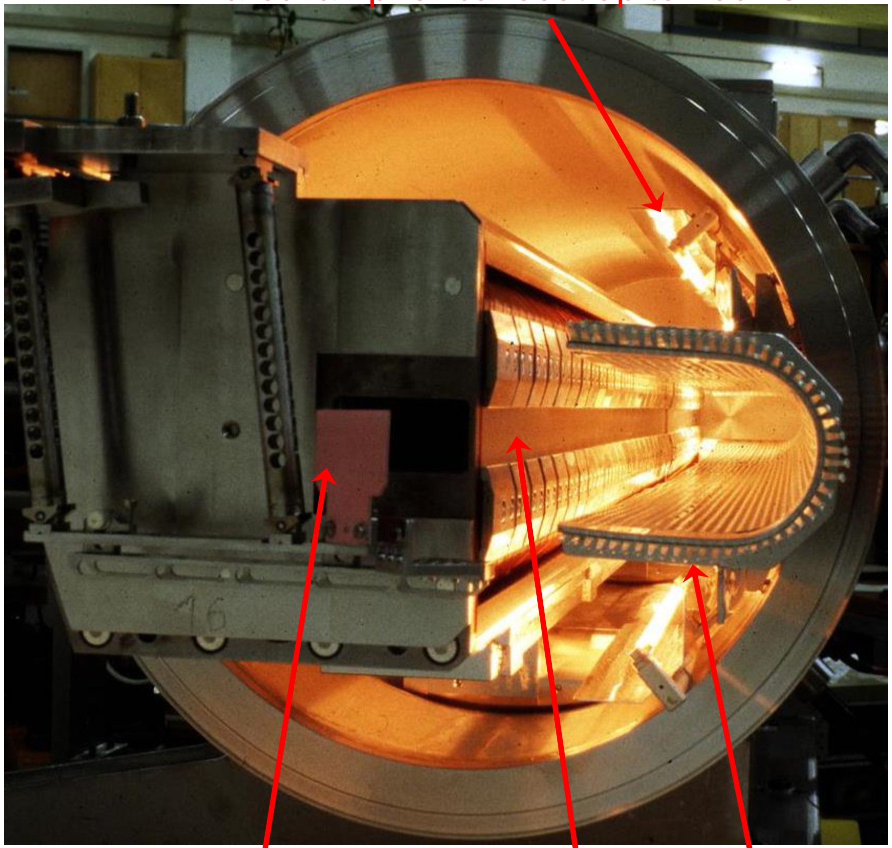


Pulsed magnetic septum



- Pulsed with a half sine over 3 ms.
- Single turn coil to reduce self-inductance.
- Transformer between power convertor and magnet.
- Installed under vacuum to reduce the effective septum thickness.
- Remote displacement system for precise positioning wrt the circulating beam.
- Large forces between conductors – require a special coil fixation and retention system to absorb vibrations and reduce fatigue.

Pulsed magnetic septum

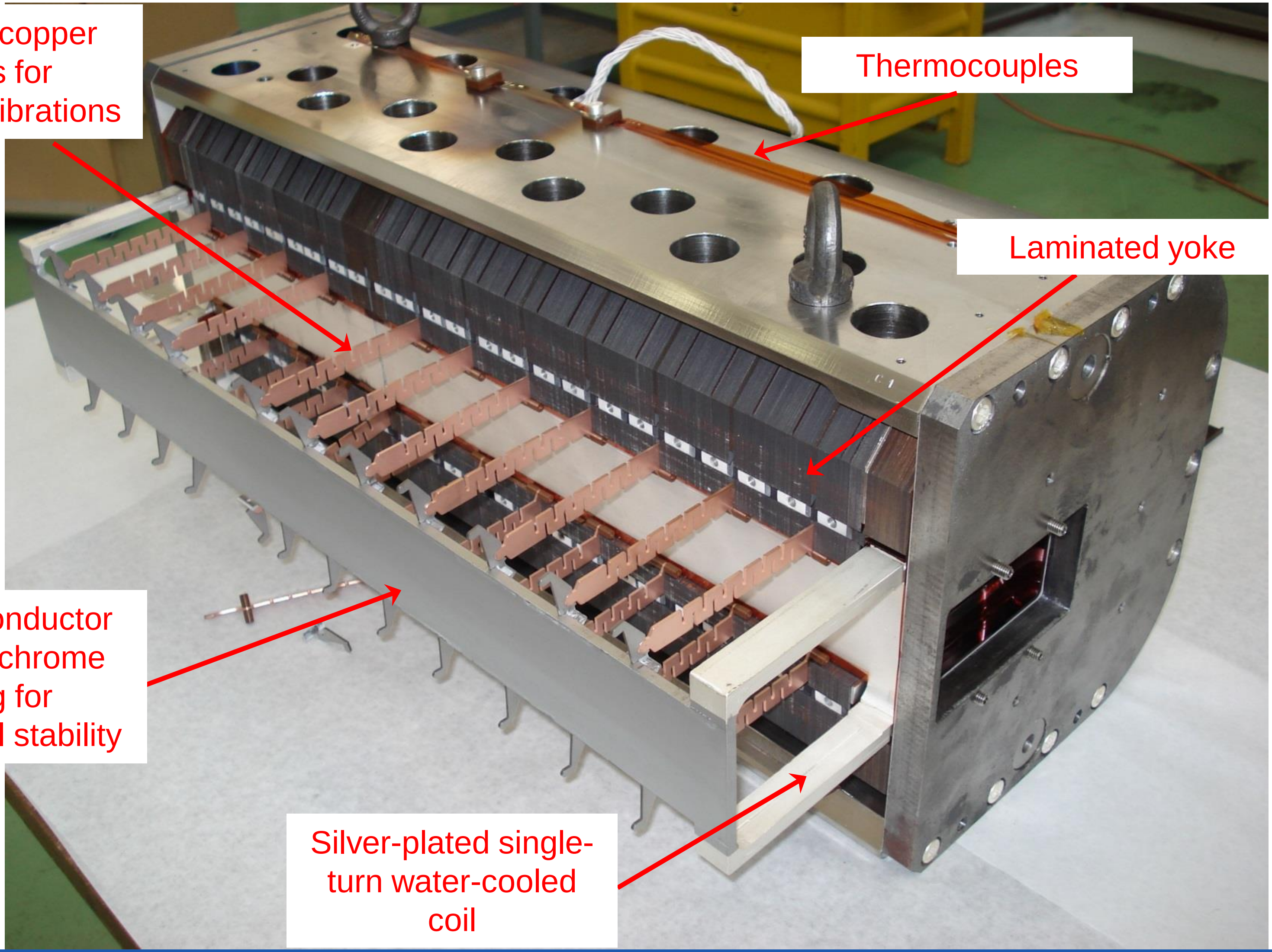


SMH16 in PS

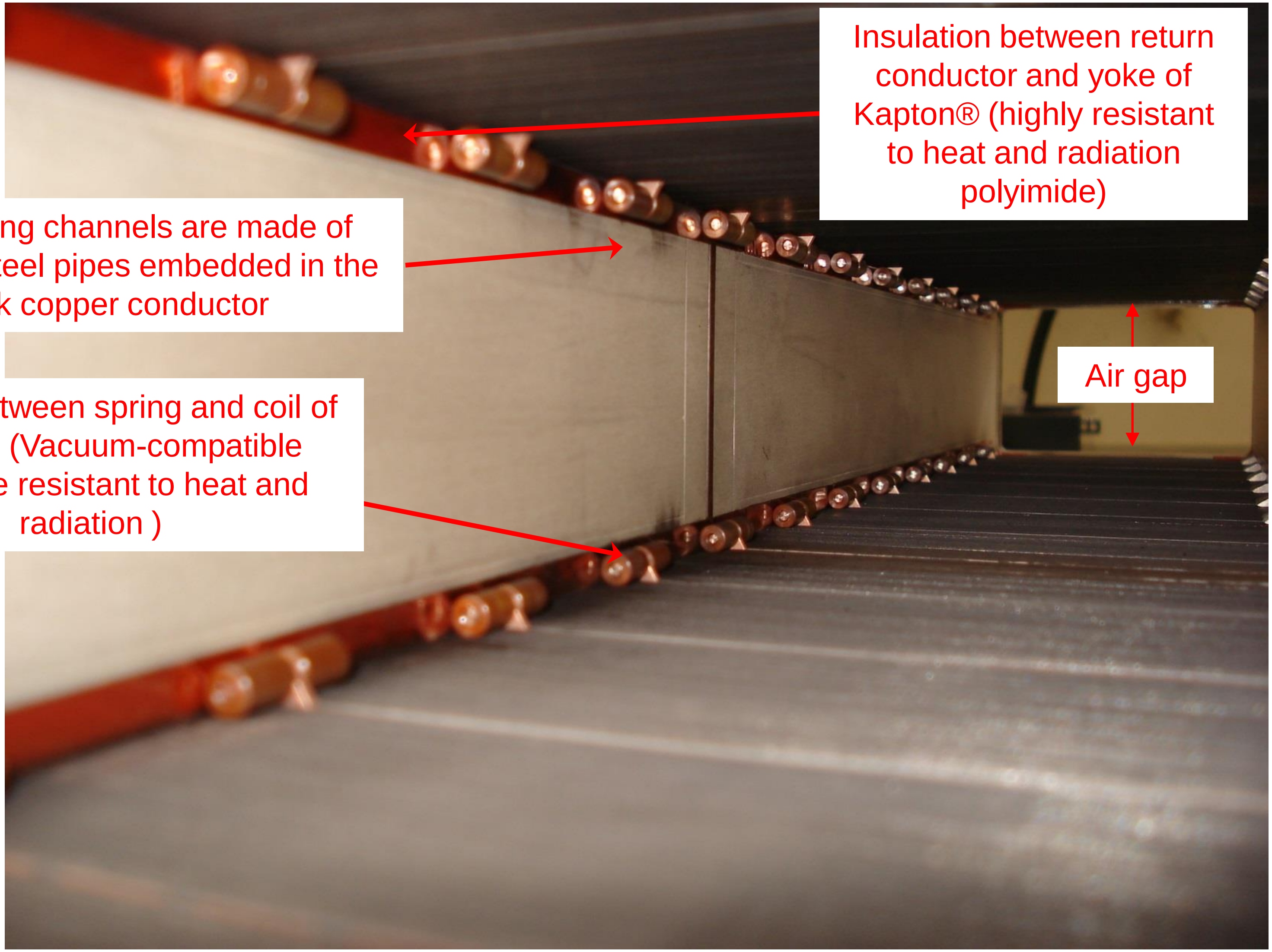
Typical parameters

- Yoke length: 300 – 1200 mm;
- Air gap: 18 - 60 mm;
- Septum thickness: 3 - 20 mm;
- Vacuum levels (~10^{-9} mbar);
- Laminated steel yoke (0.35 - 1.5 mm);
- Water-cooled single-turn coil (1 - 80 l/min);
- Current (half sine): 7 - 40 kA;
- Powered by a capacitor discharge unit and a superposition of a 1st and 3rd harmonic + active filters for increased waveform stability;

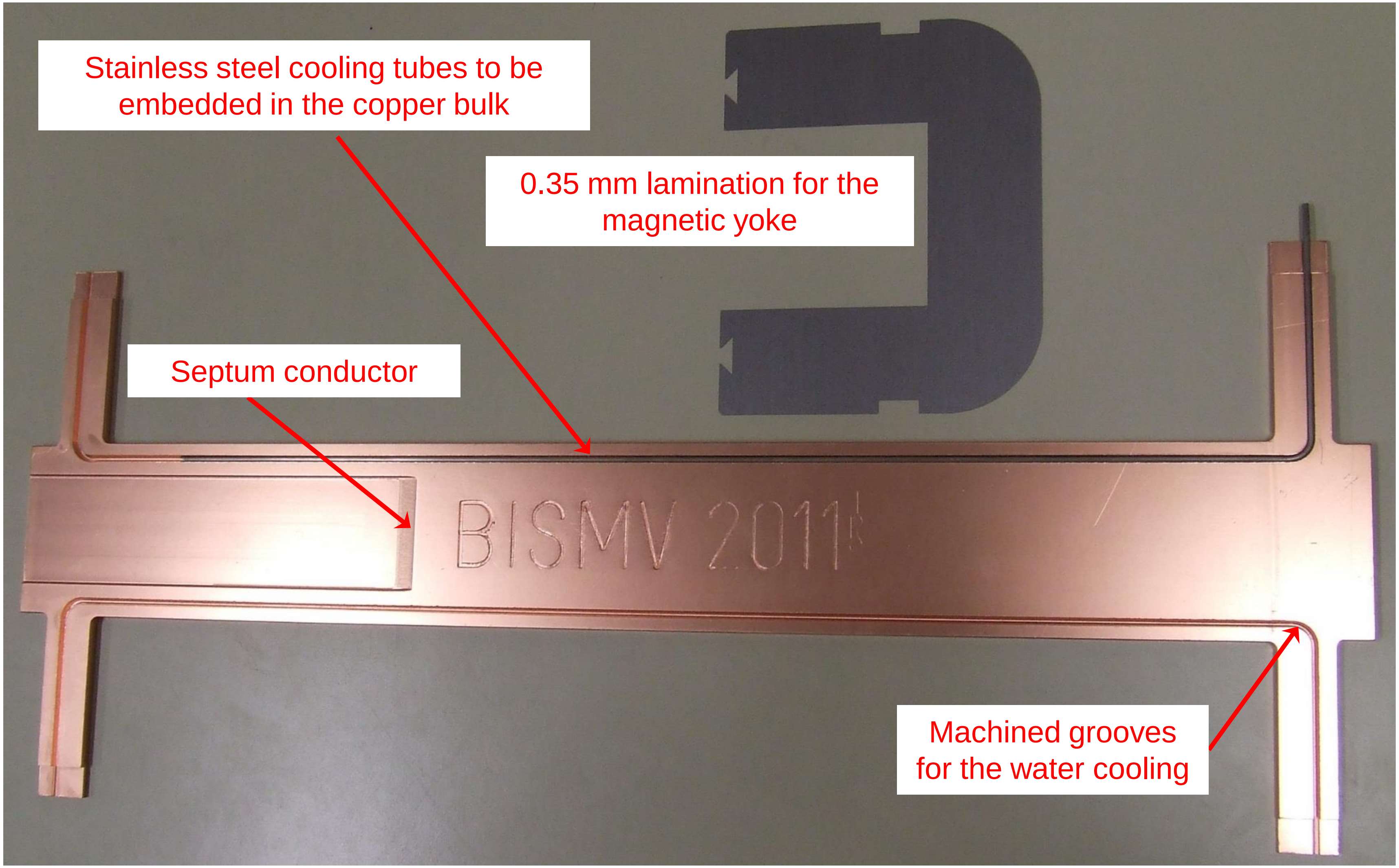
Pulsed magnetic septum (SMH42 in PS)



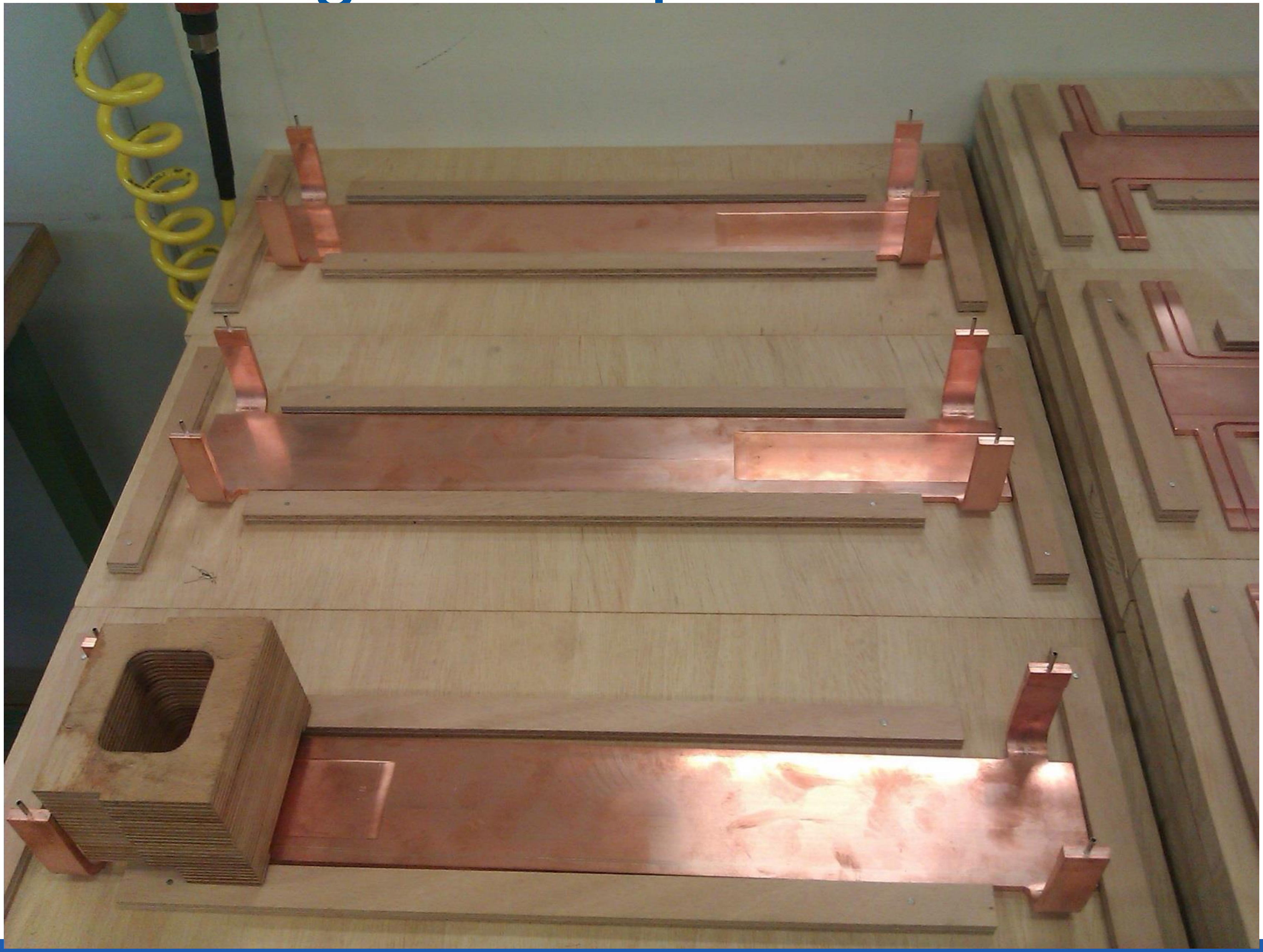
Pulsed magnetic septum



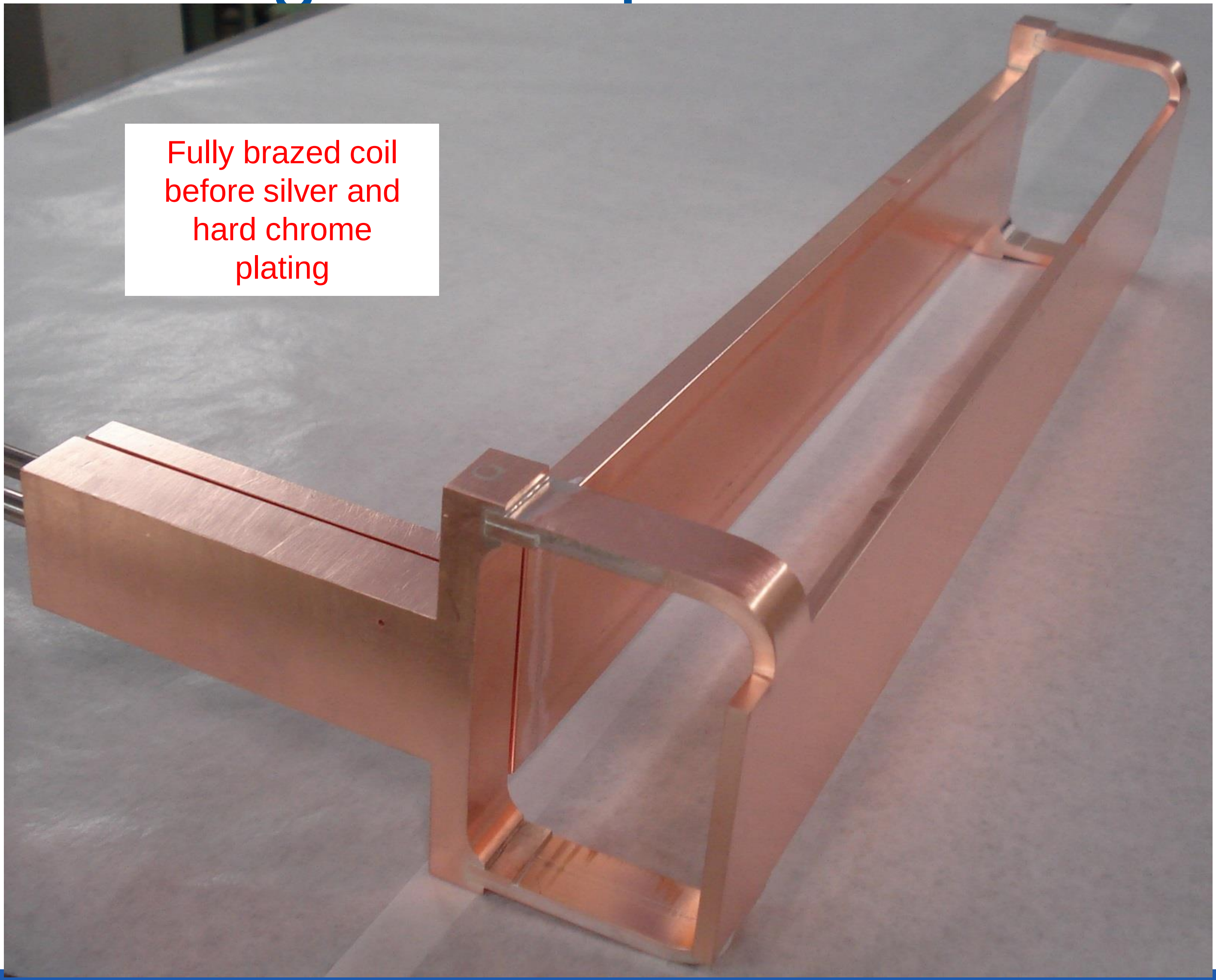
Pulsed magnetic septum



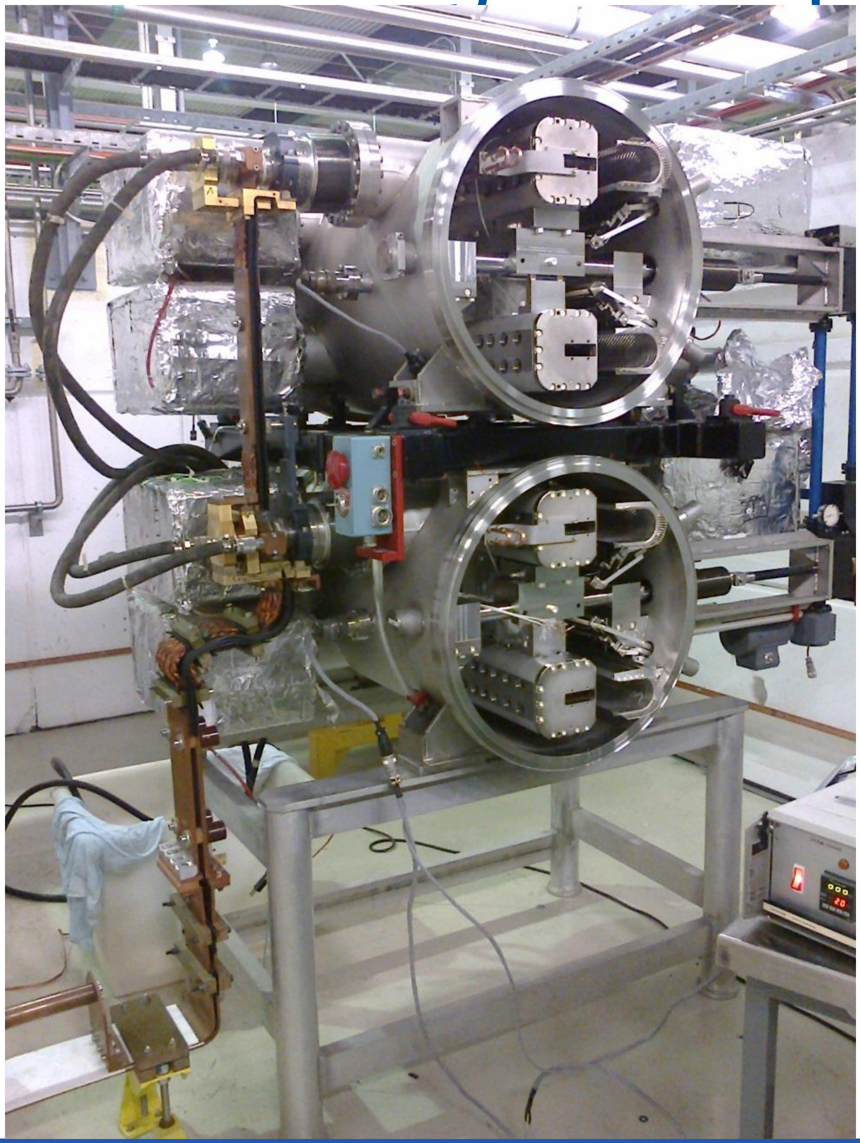
Pulsed magnetic septum

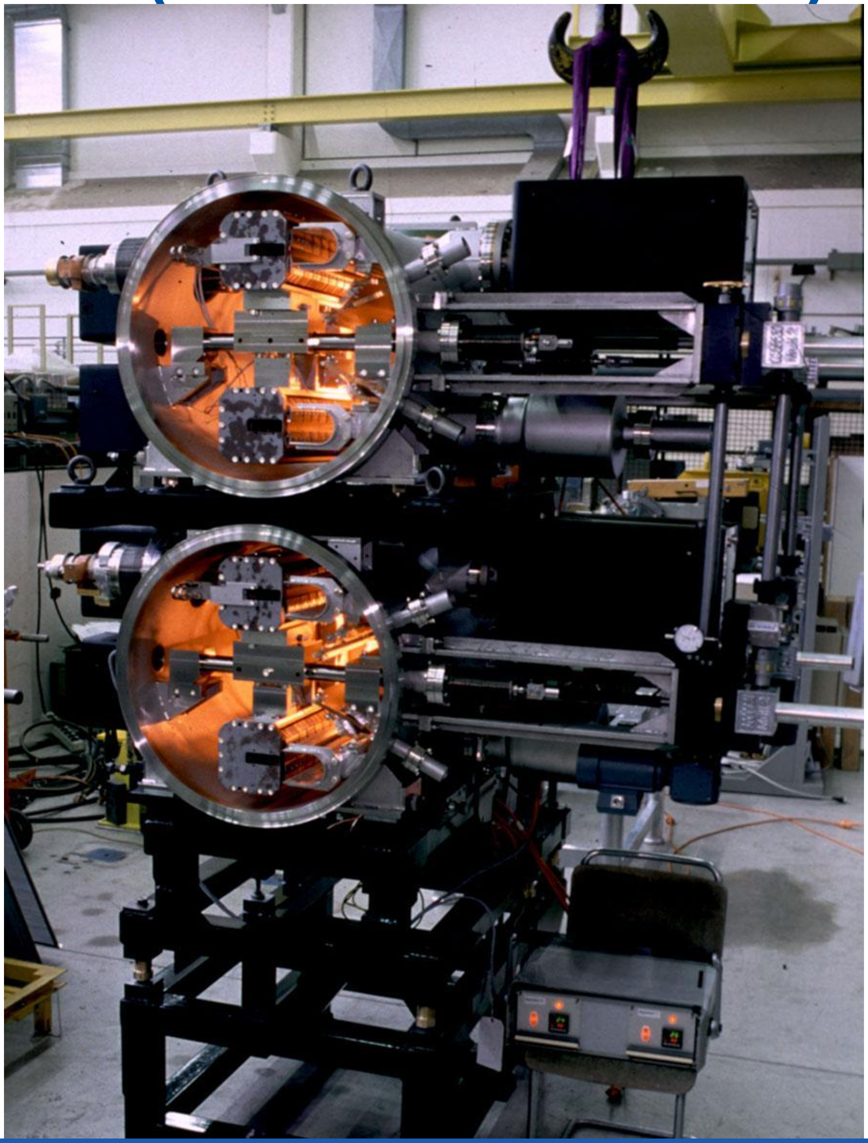


Pulsed magnetic septum

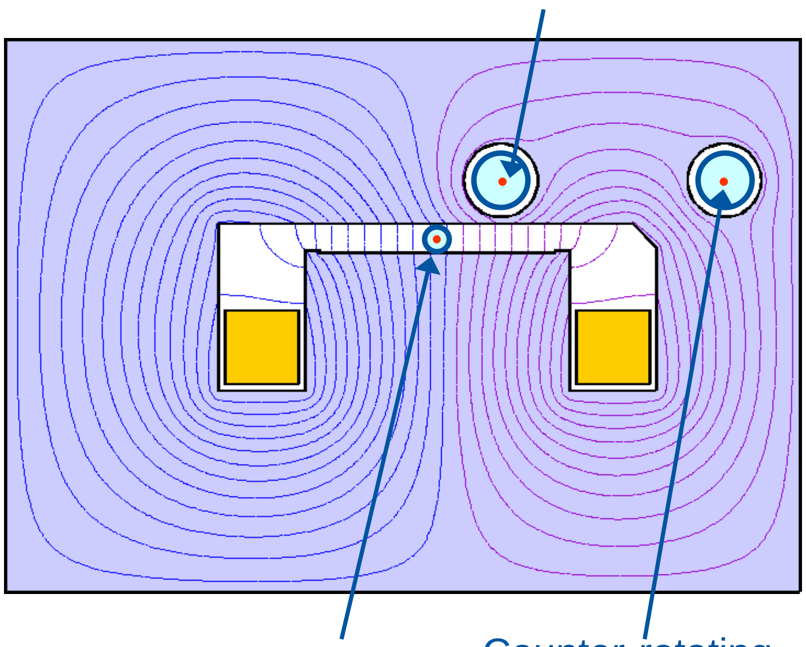


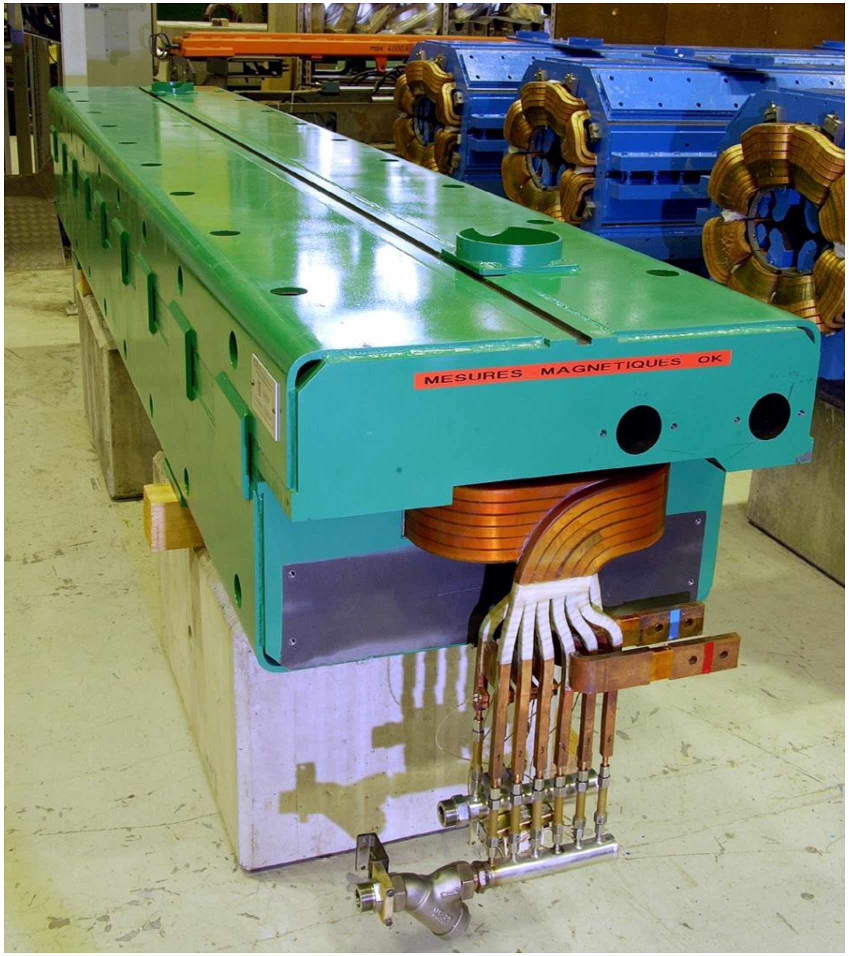
Pulsed magnetic septum (BESMH in PSB)





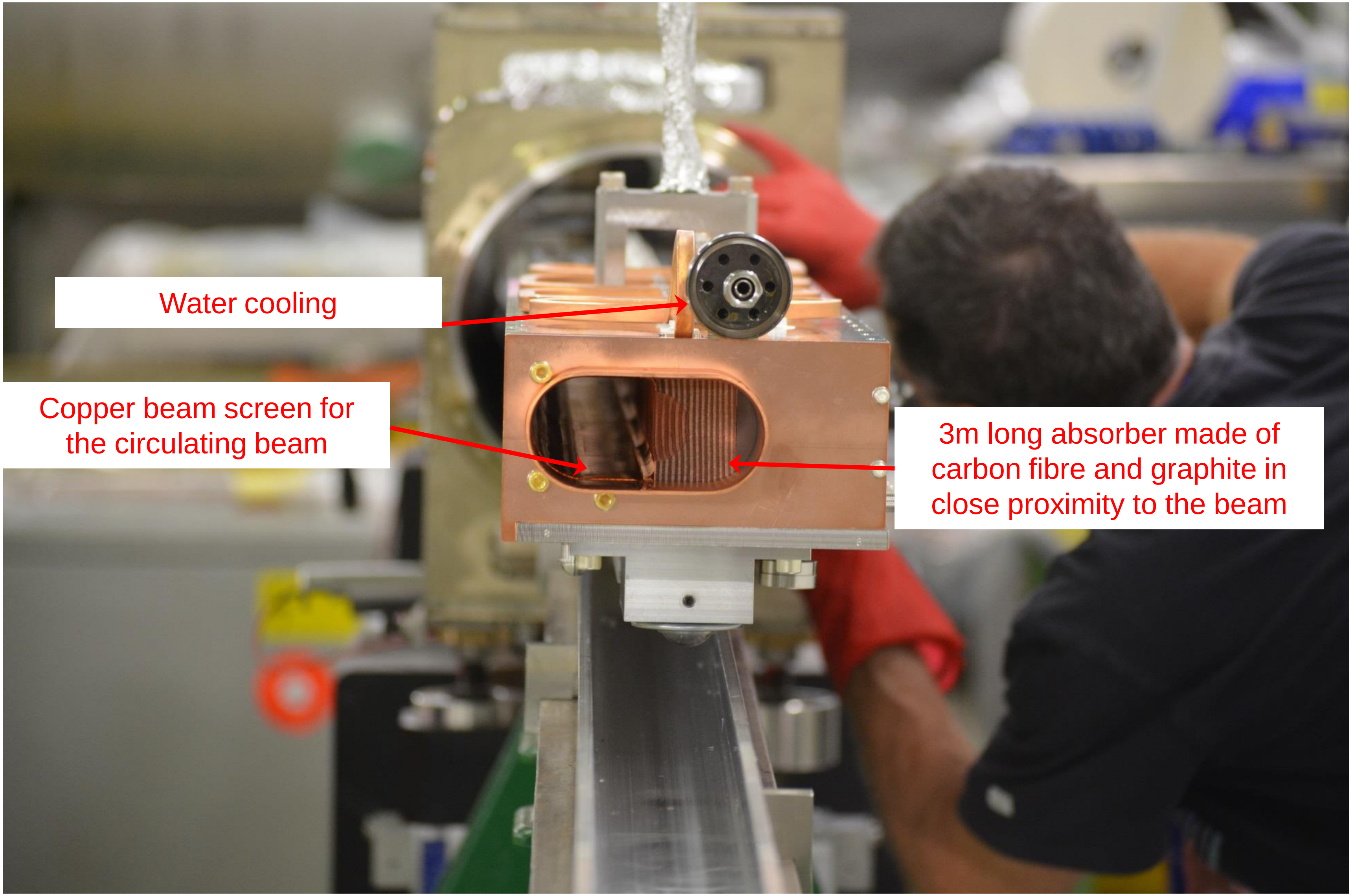
“Lambertson” septum for LHC injection (MSI)



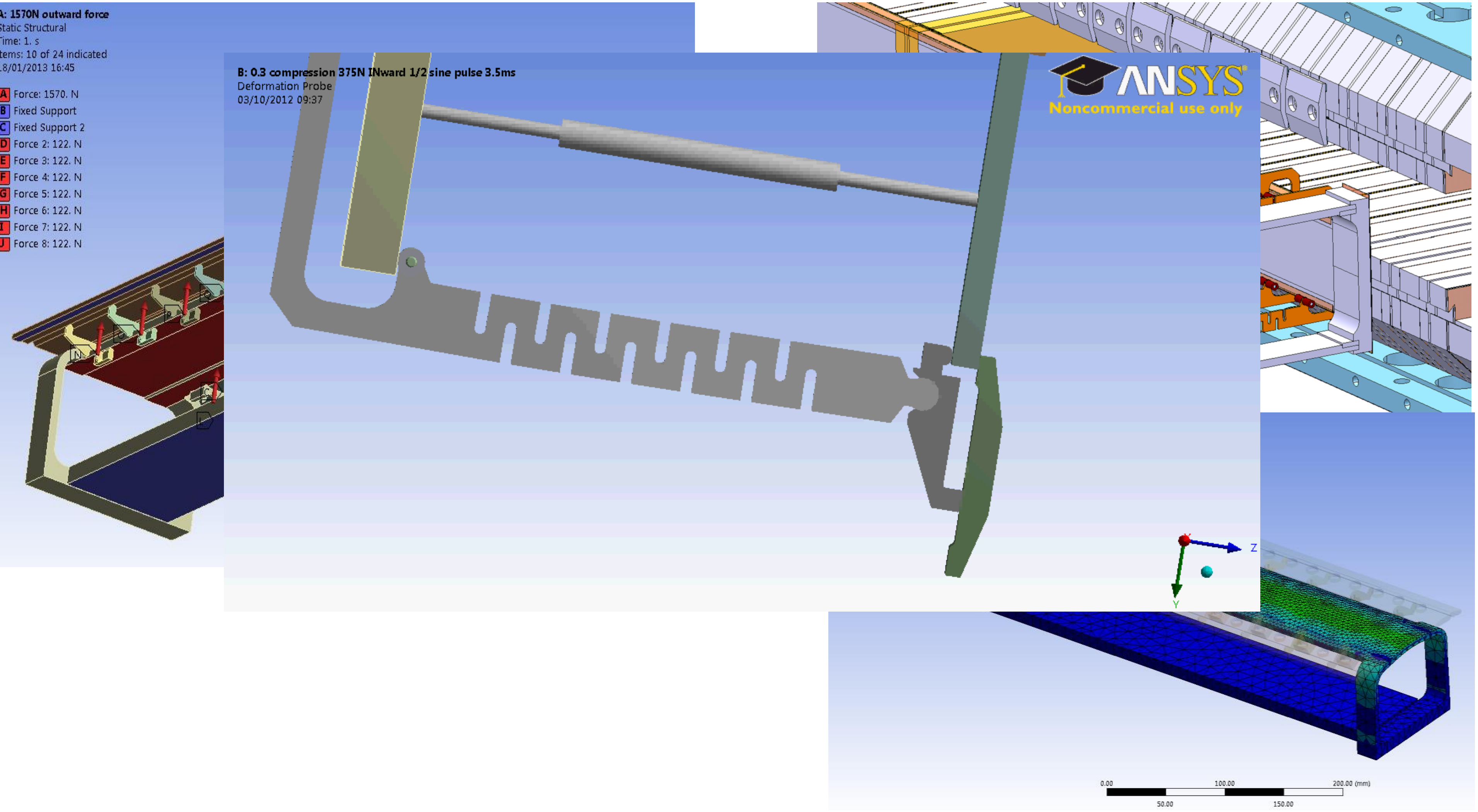


1. **The septum provides horizontal deflection towards the right;**
2. **The downstream kicker deflects vertically onto the central LHC orbit.**

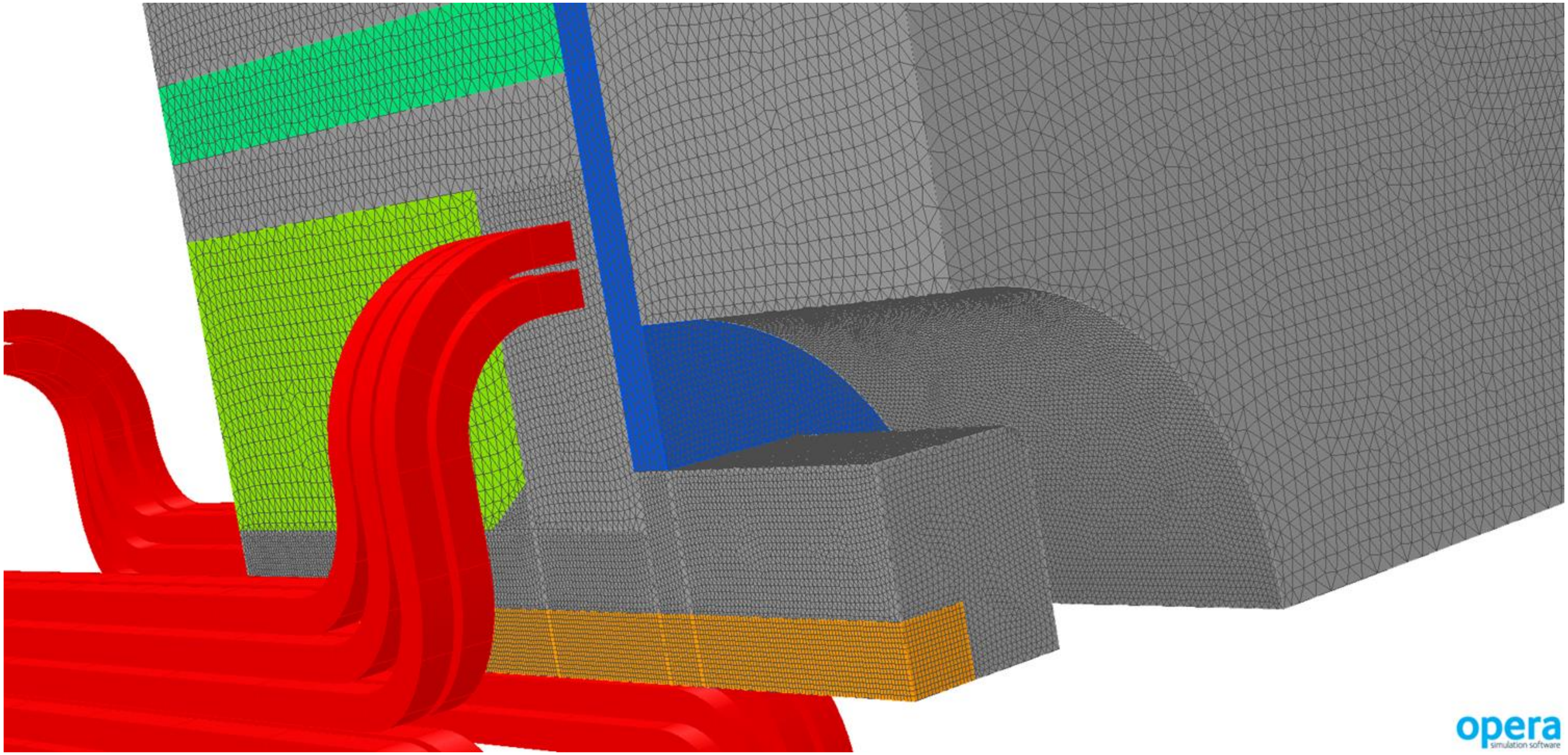
Protective absorbers/diluters



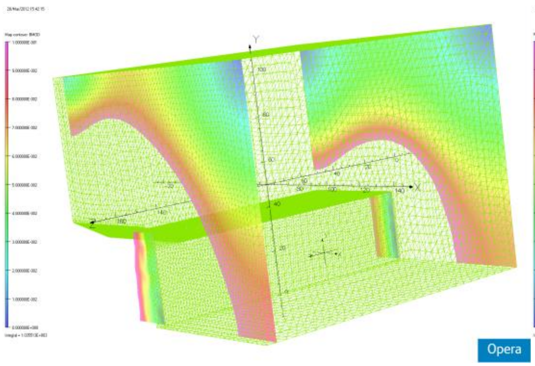
Mechanical design

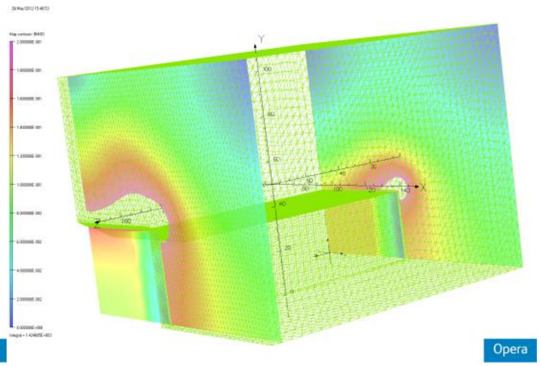


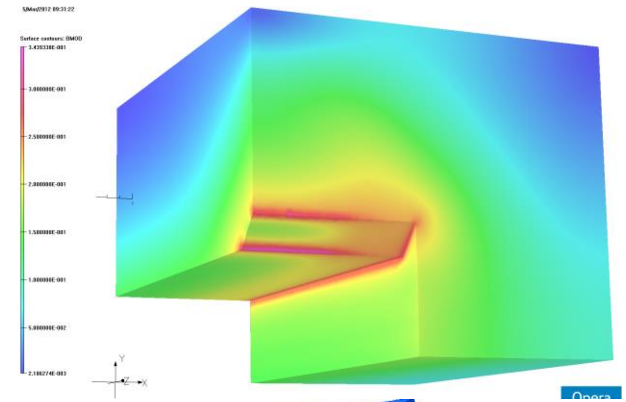
Electromagnetic design

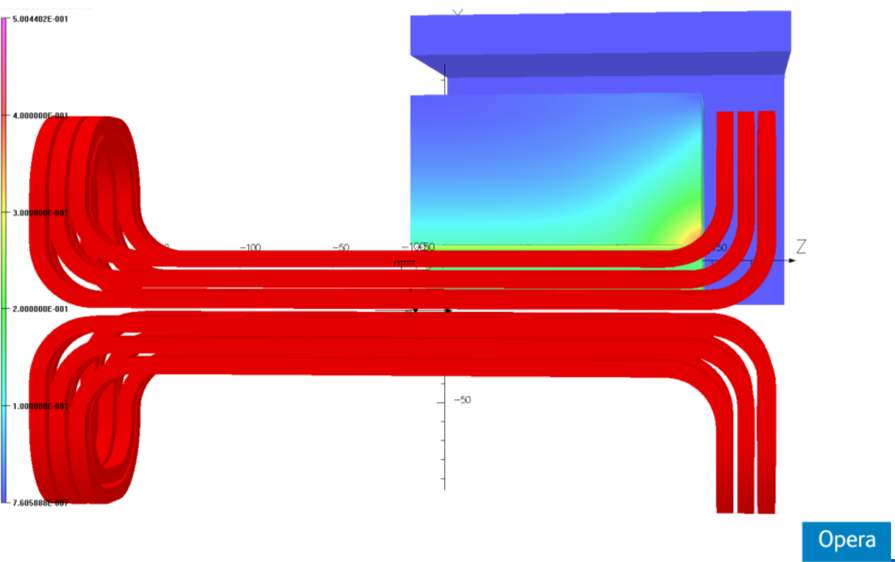


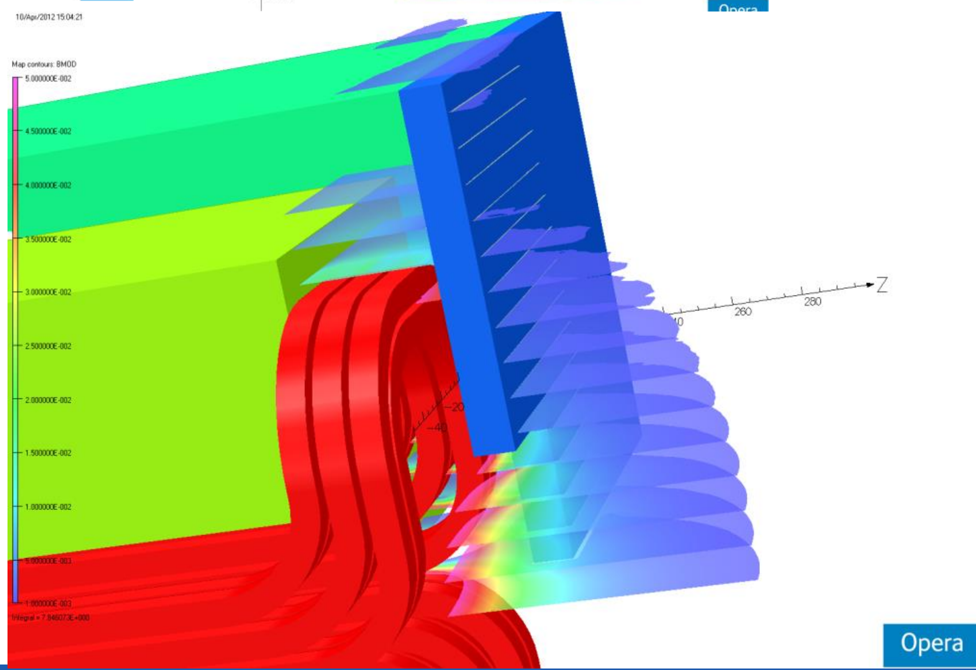
Electromagnetic design









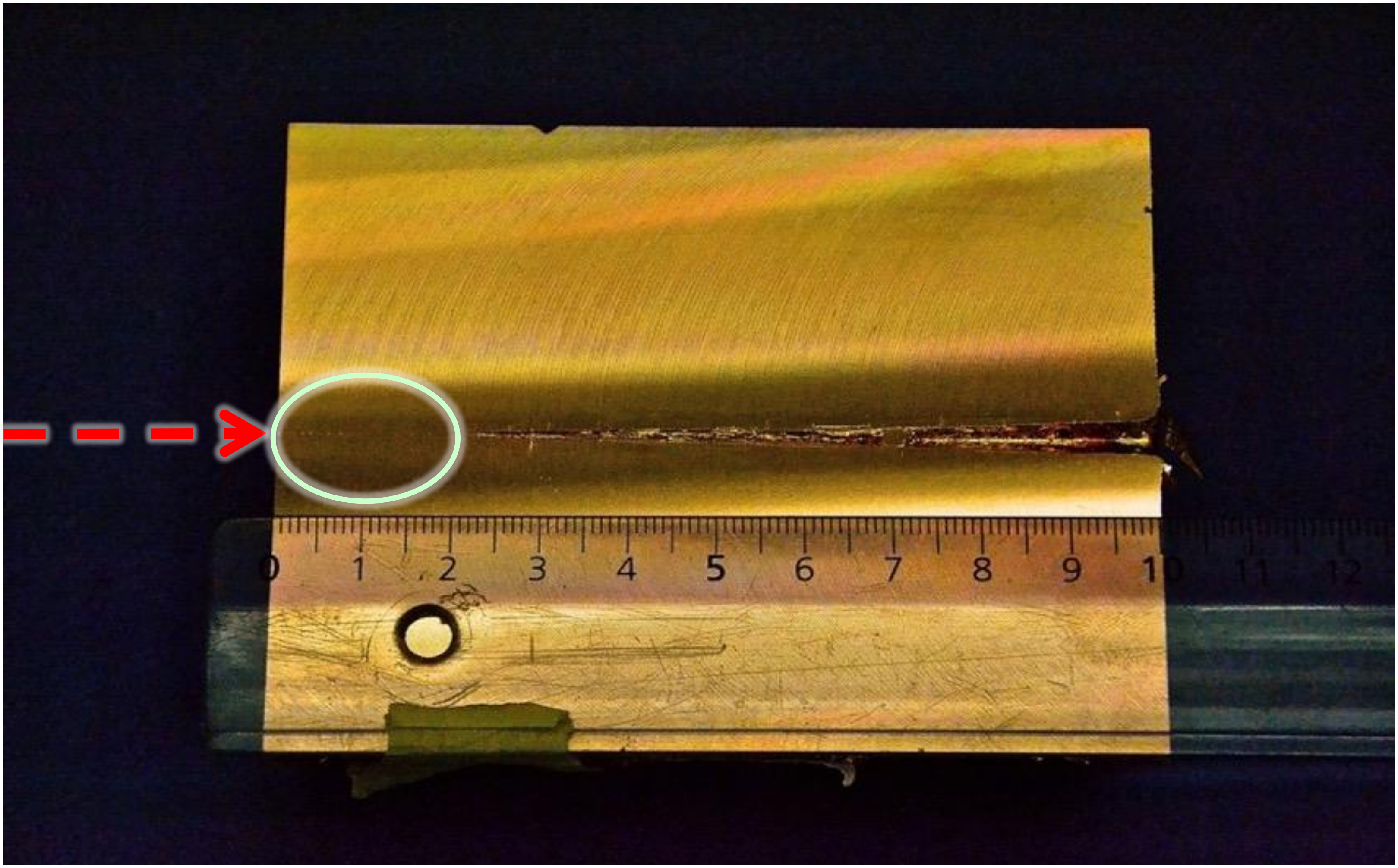


Thank You!

CERN

www.cern.ch

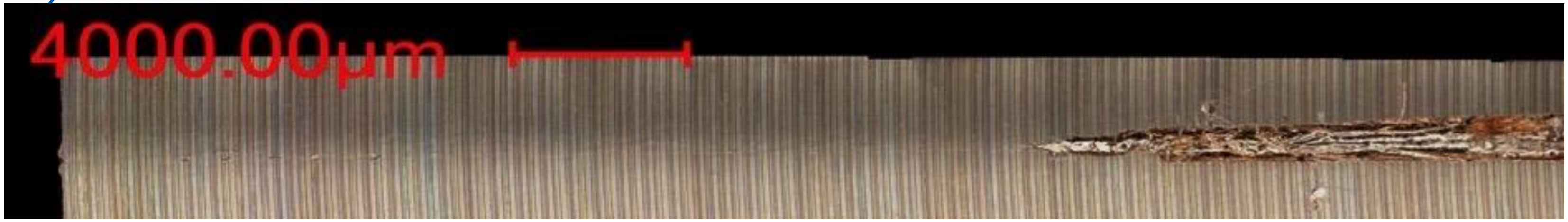
Extra slides – hydrodynamic tunnelling of the SPS beam into a copper target*



*HiRadMat experiment in SPS, photos courtesy F. Burkart

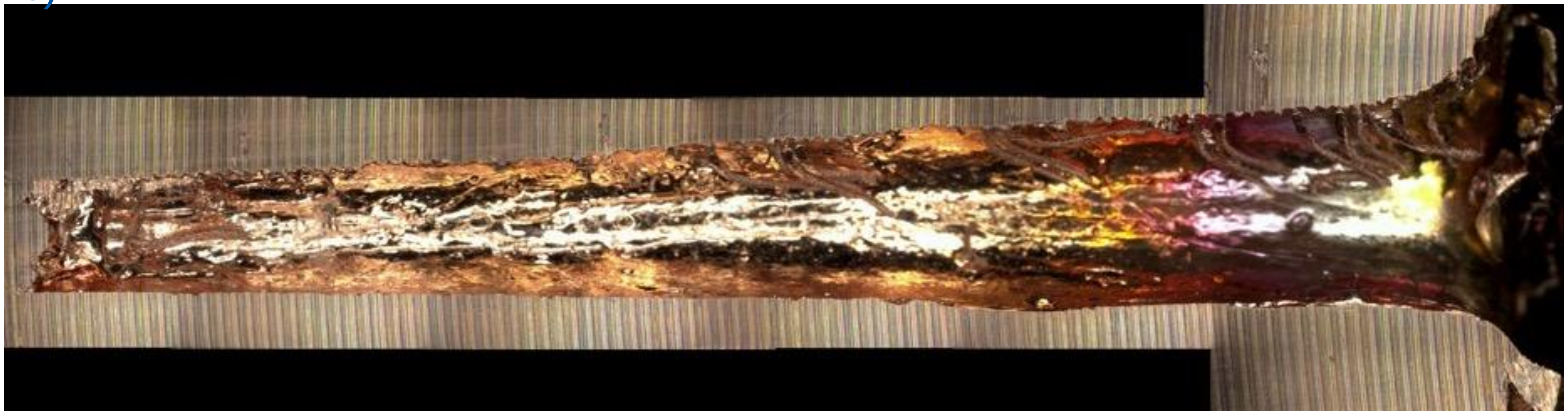
Extra slides – hydrodynamic tunnelling of the SPS beam into a copper target*

a)



b)

c)



*HiRadMat experiment in SPS, photos courtesy F. Burkart

Extra slides – hydrodynamic tunnelling of the SPS beam into a copper target*

*HiRadMat experiment in SPS, photos courtesy F. Burkart