CERN

Beam Transfer at CERN's Accelerator Complex.

Septa magnets for injection and extraction, state-of-the-art and future plans

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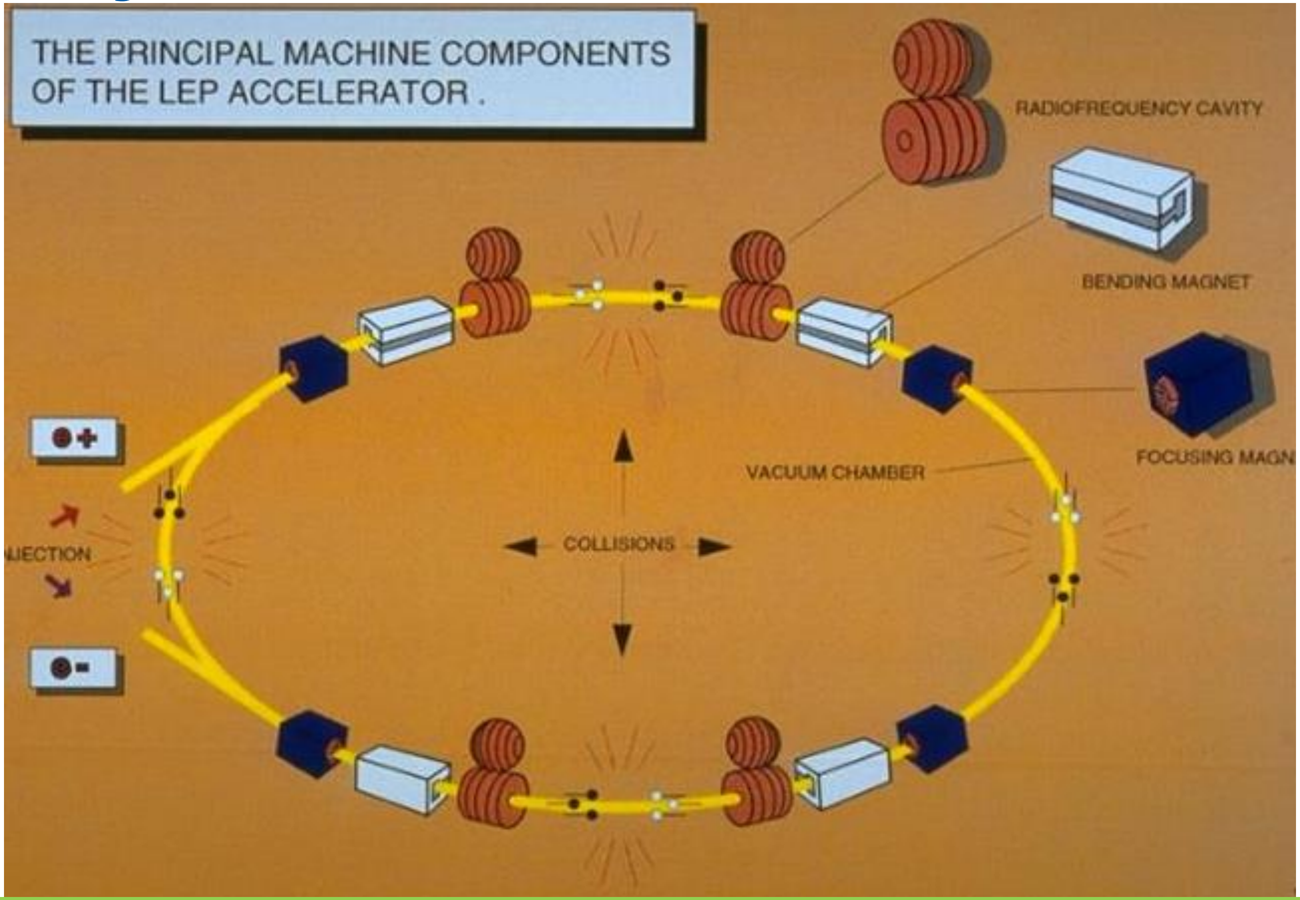
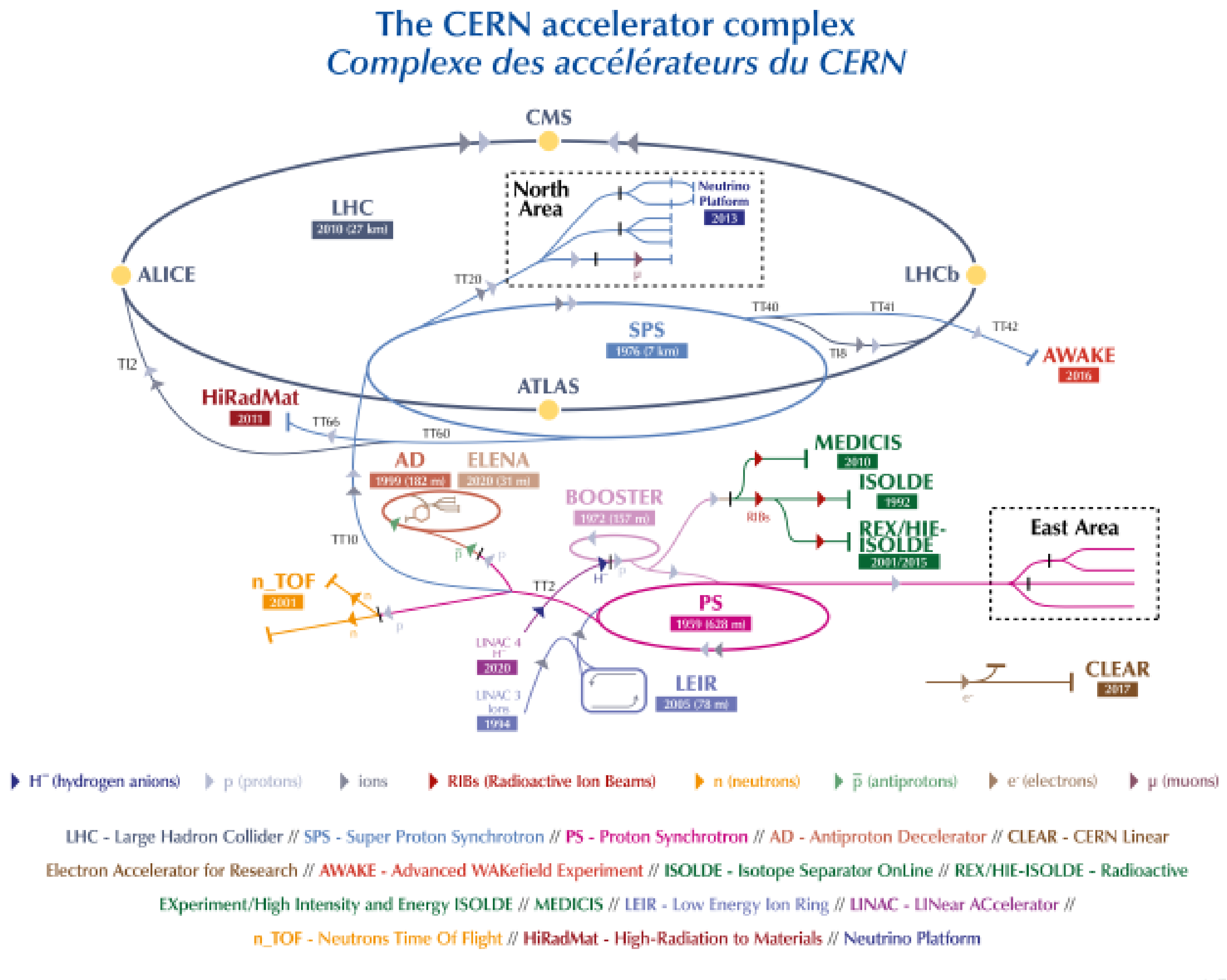
The synchrotron



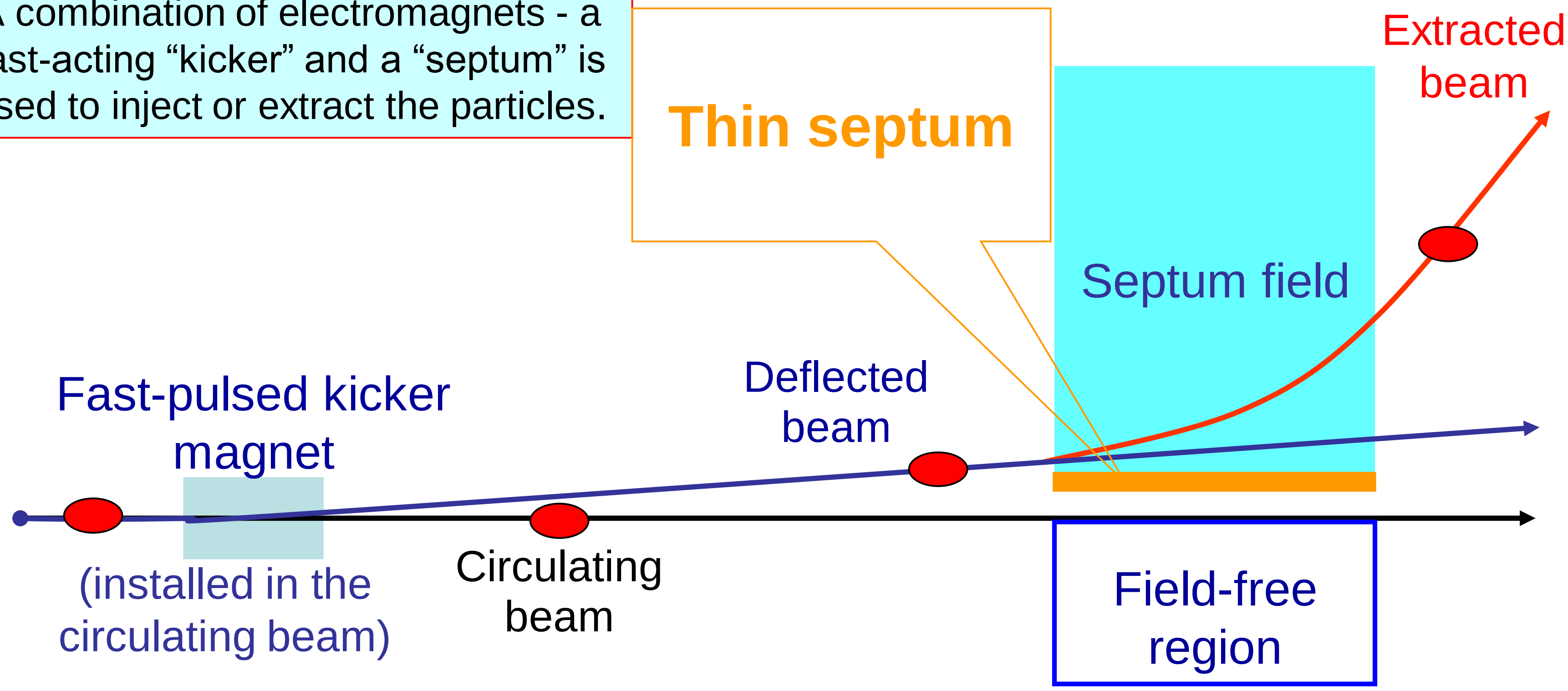
Charged particles are kept in circular trajectories using dipole magnetic fields, which are synchronised with the accelerating (or decelerating) electric fields, in such a way, that for every increase of the particle energy, there is a corresponding increase of the bending magnetic field, such that the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



- 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.

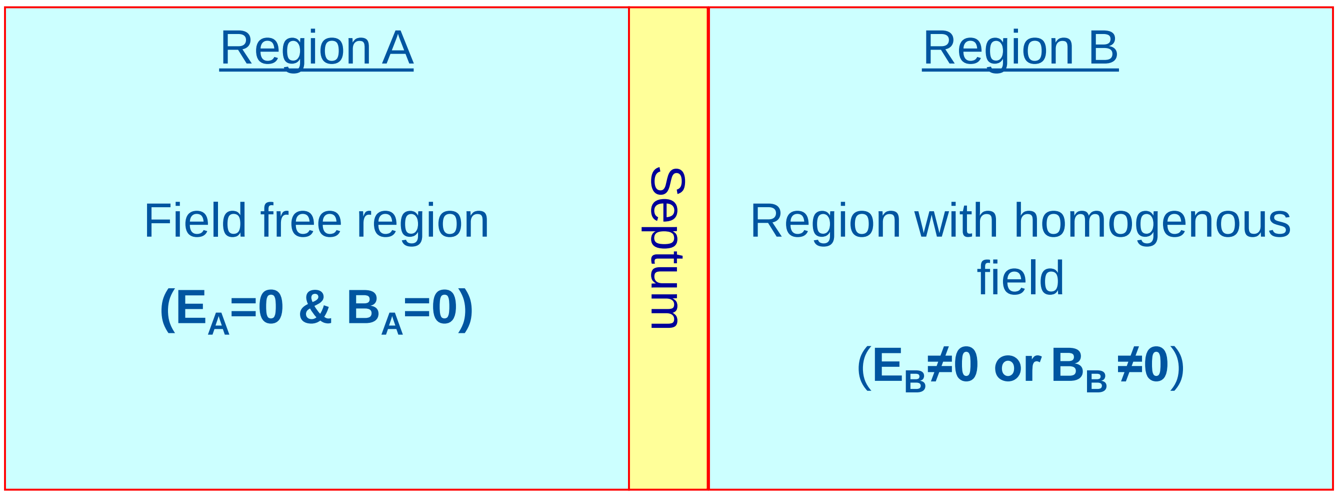
Accelerator Beam Transfer group

The ABT group covers:

- Beam Transfer Physics (BTP)
- Kicker Magnets (KSC)
- Kicker Generators (PPE)
- Controls (software, slow controls, fast controls) (BTC and BTE)
- **SEpta** section:
  - Electrostatic Field Devices (incl. septa)
  - Magnetic Septa
  - Extraction Protection Devices

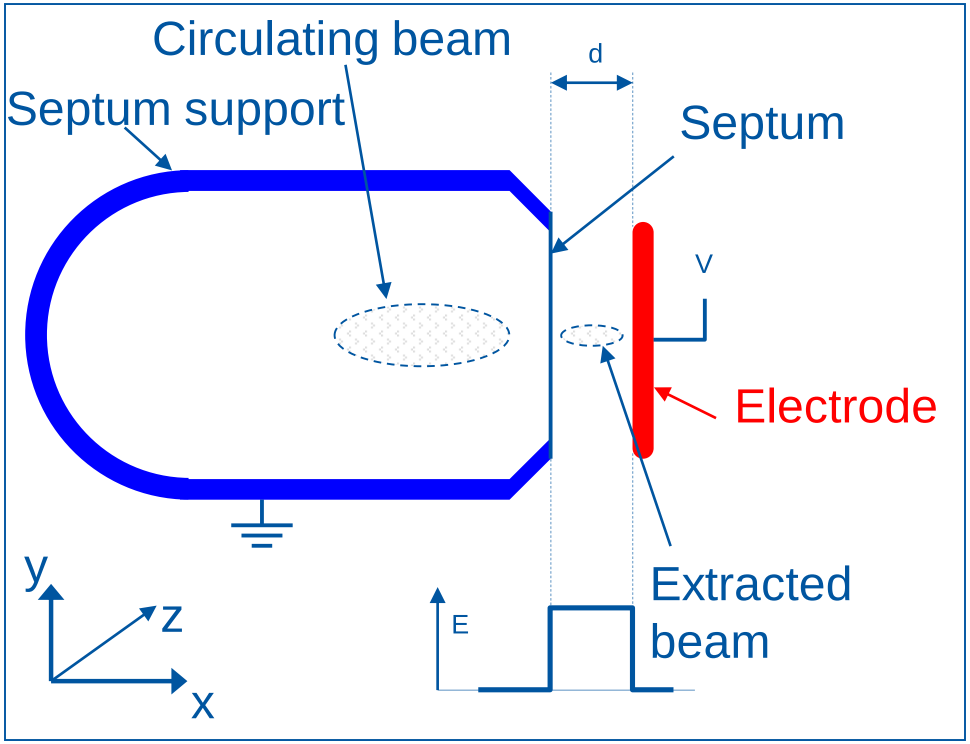
Septa

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 a passing beam is not perturbed), and the presence of a homogenous field in the other region (for the required deflection of the other beam). The septum thickness should be as thin as possible in order to reduce the strength of the highly complex kicker magnet.

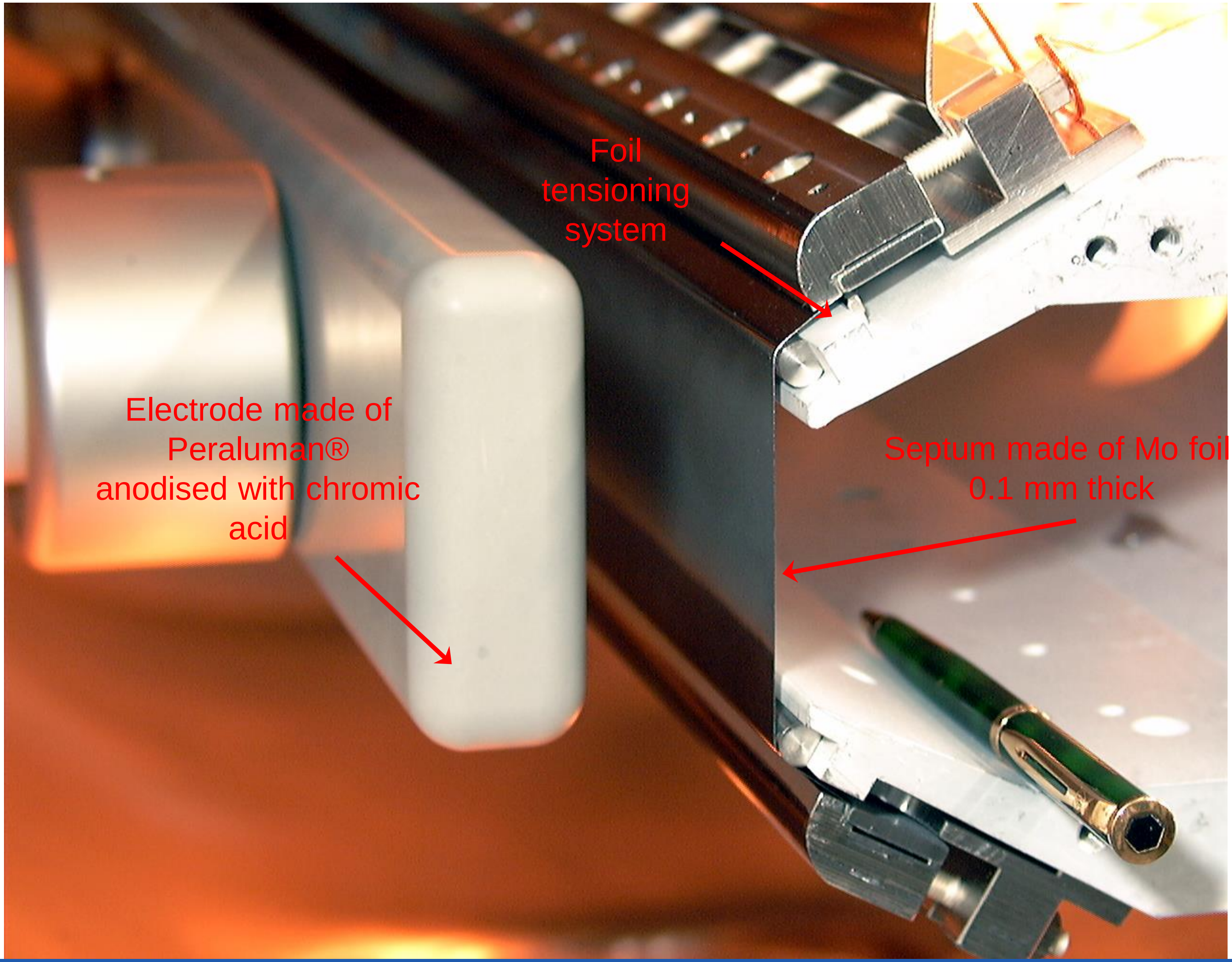
Electrostatic septum



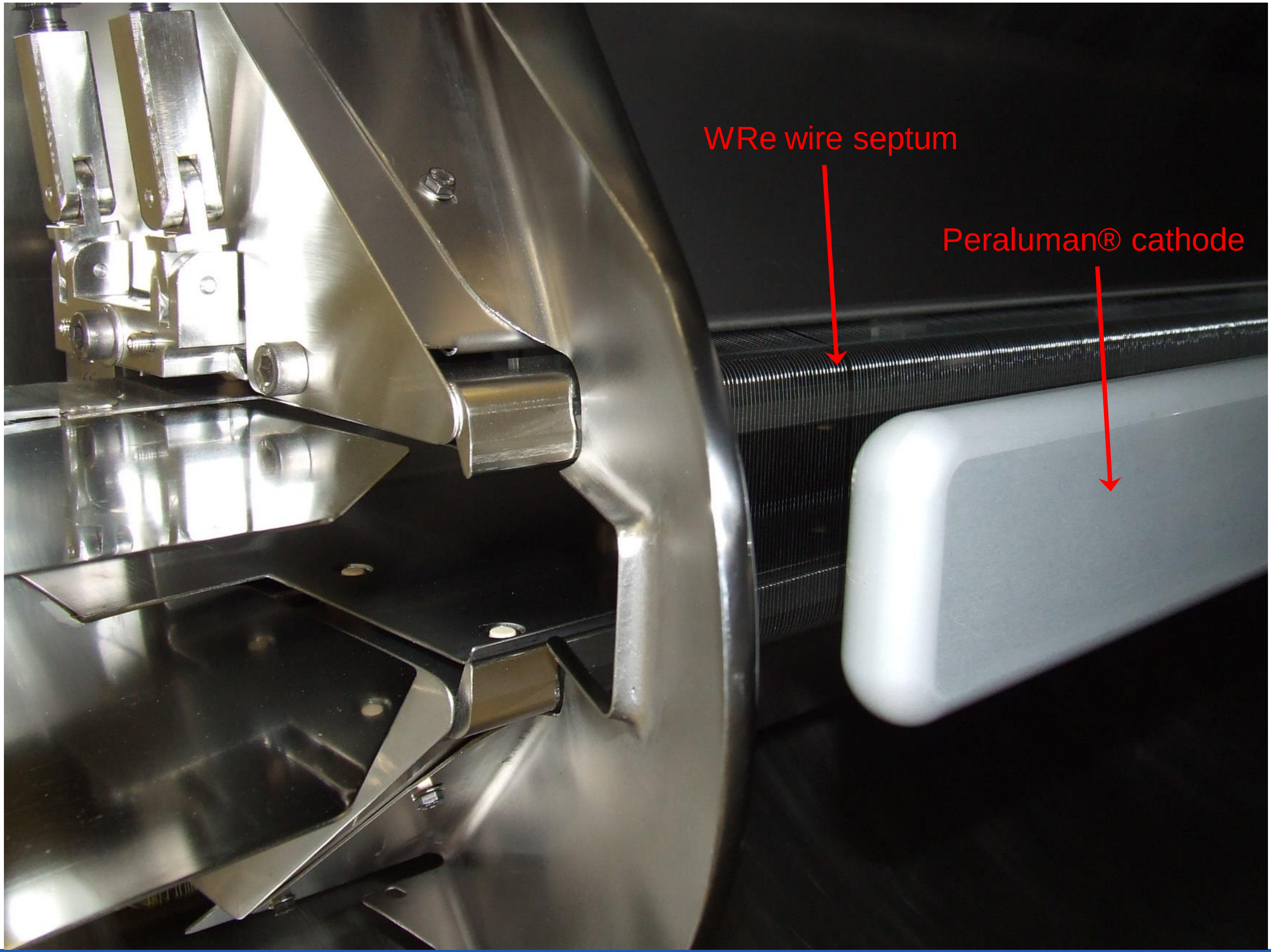
Typical parameters:

- 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 strength 10 MV/m;
- Septum made of Mo foil or WRe wires;
- Electrode made of anodised aluminium, stainless steel or titanium;
- Bake-out up to 300 ºC for achieving ultra-high vacuum up to 10^{-12} mbar;

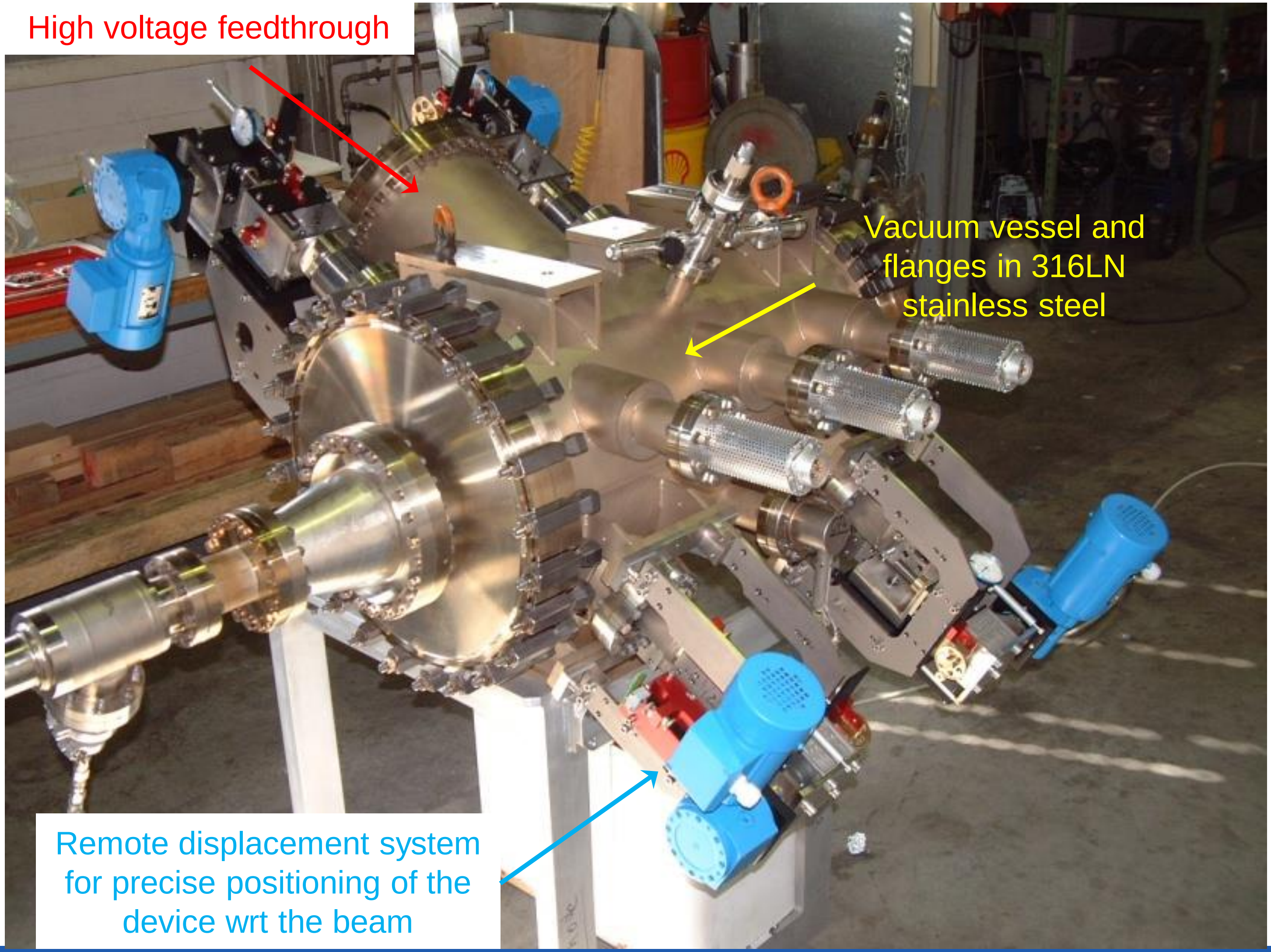
Electrostatic septum (SEH23 in PS)



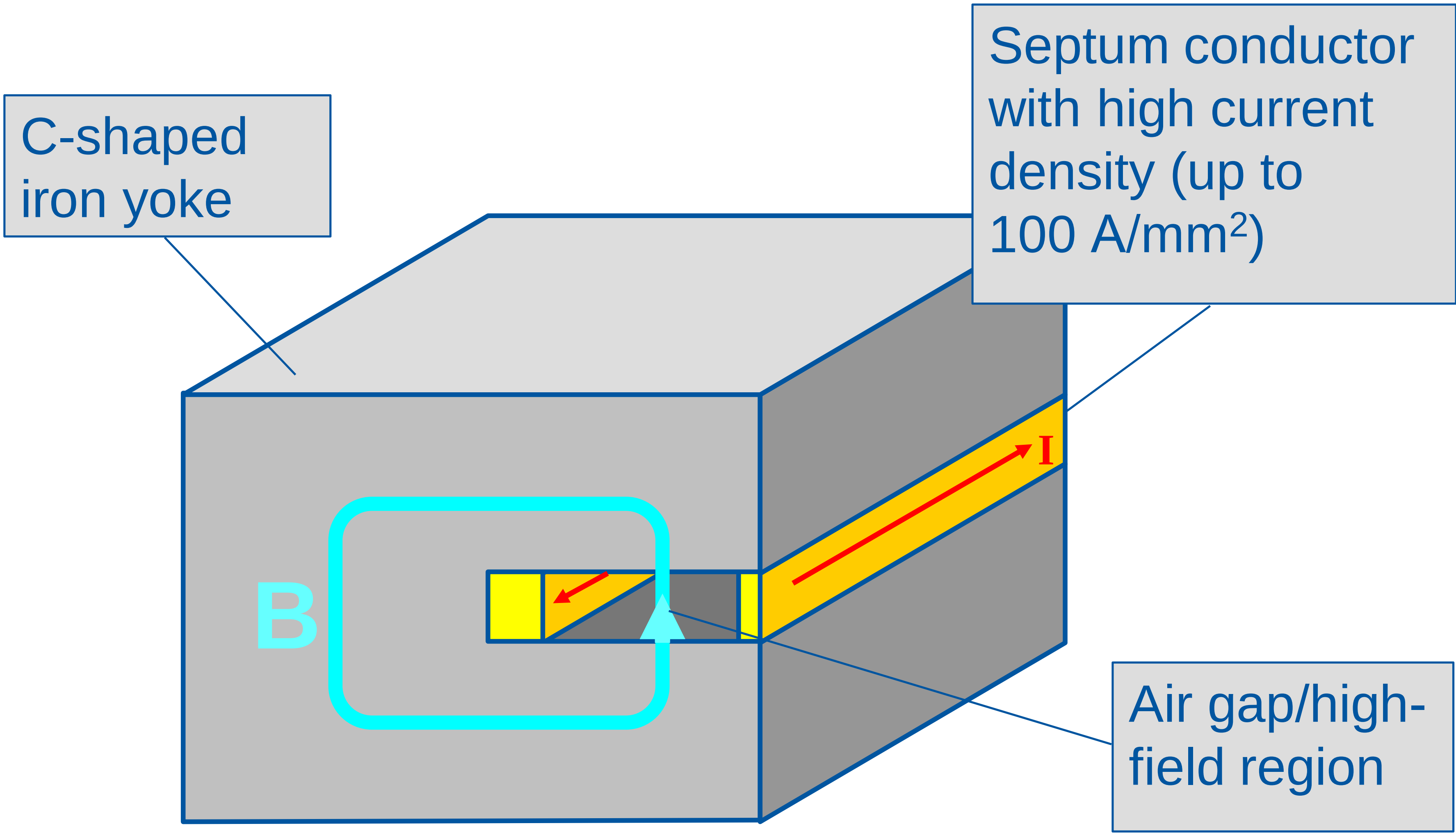
Electrostatic septum (ZS in SPS)



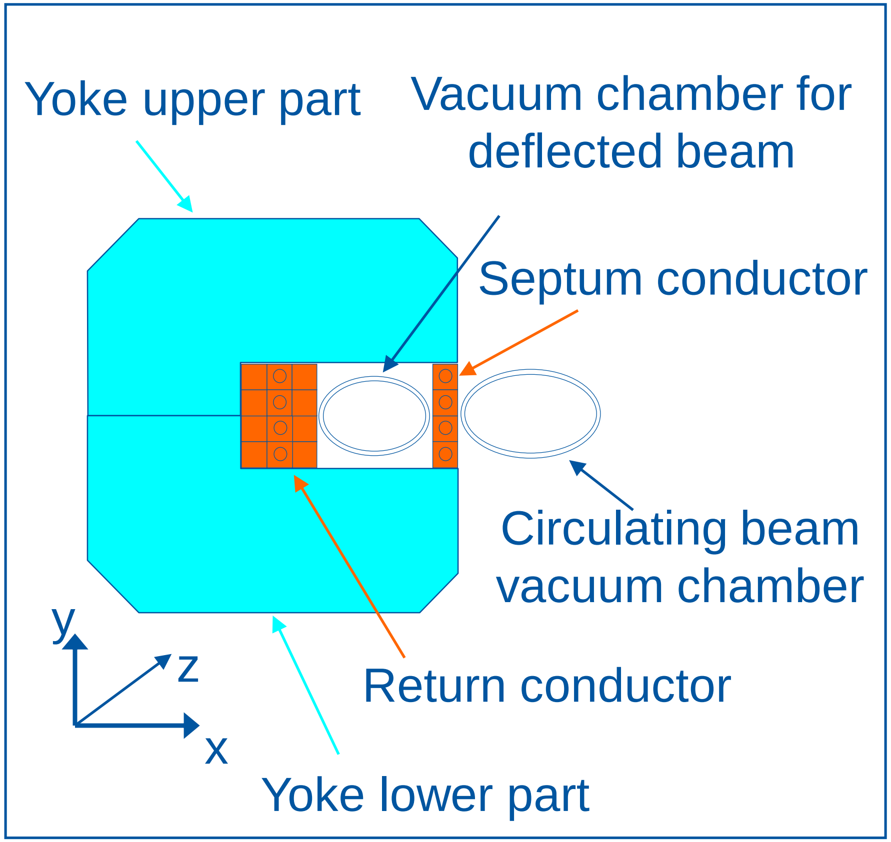
Electrostatic septum (SEH10 in LEIR)



Magnetic septum



DC magnetic septum



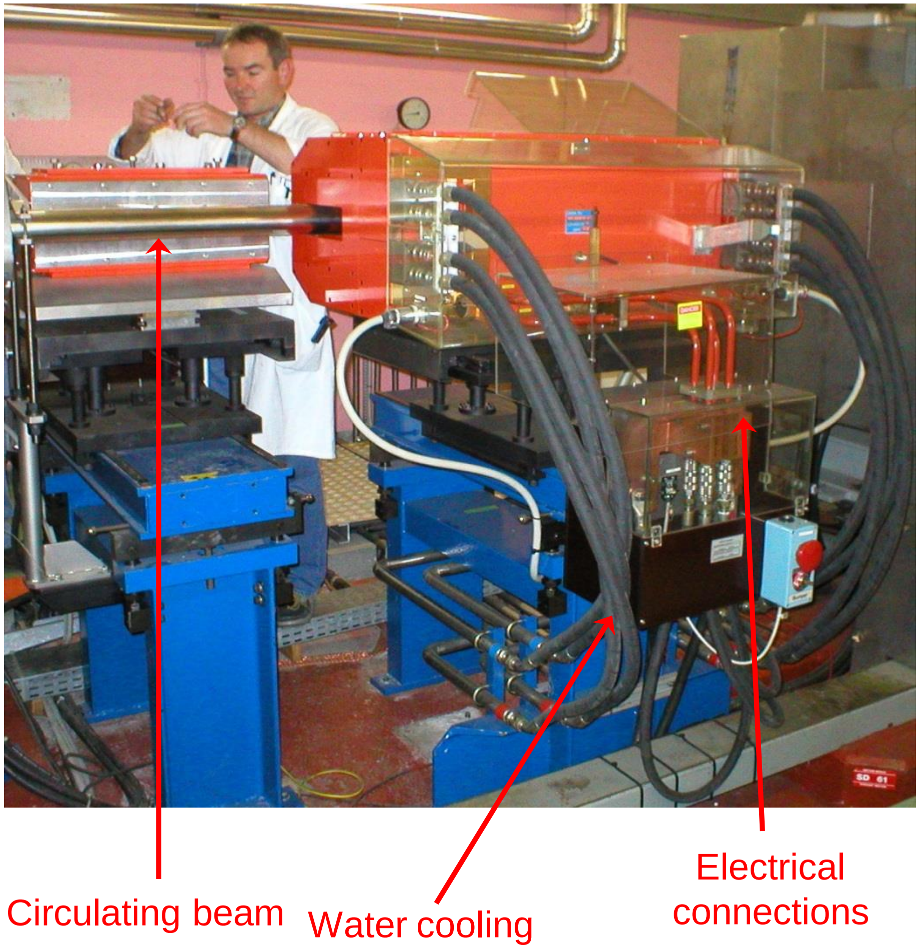
DC powered (up to 10 kA).

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.

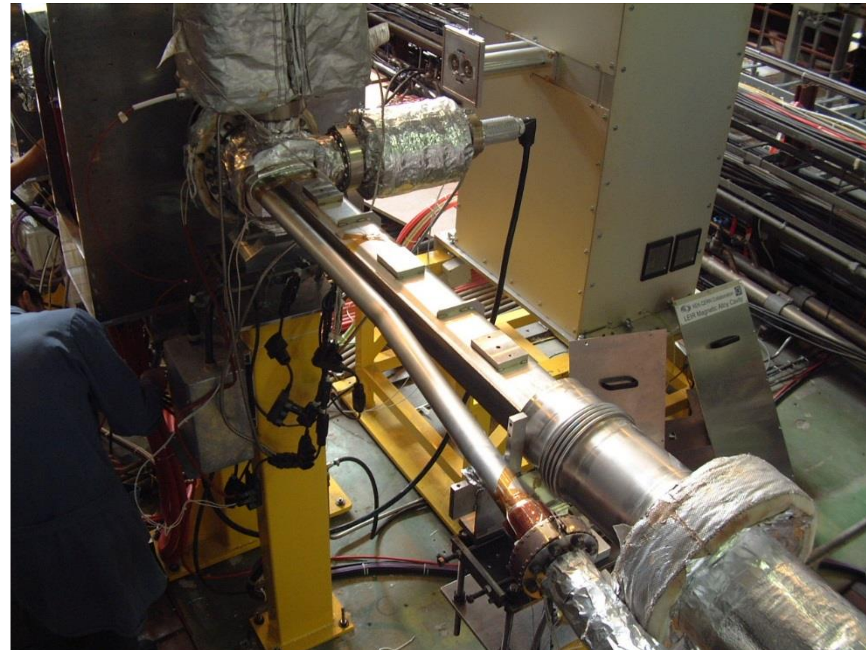
Magnetic septum (SMH61 in PS)

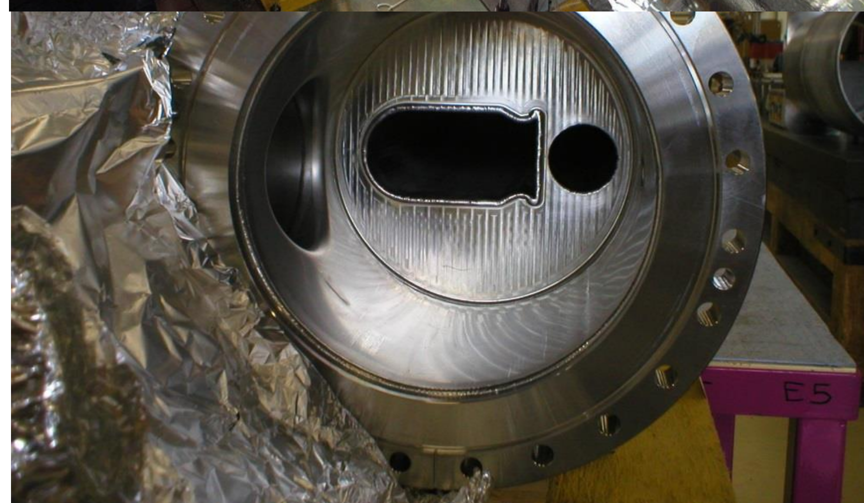


Typical parameters:

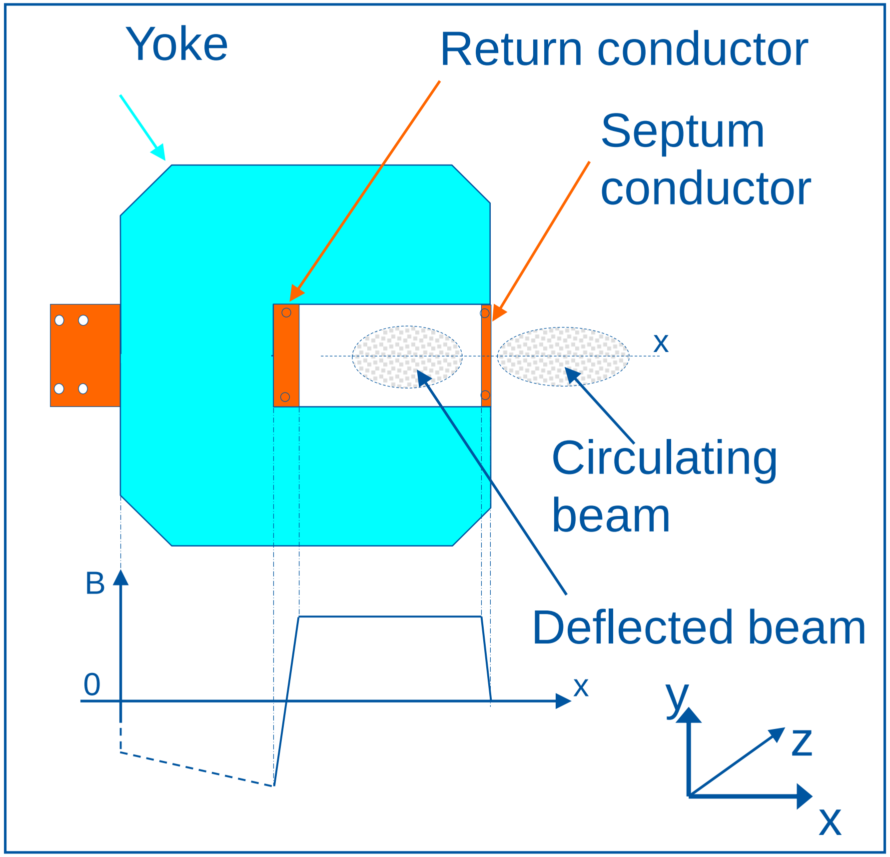
- Yoke length: 400 - 1200 mm;
- Air gap: 25 - 60 mm;
- Septum thickness: 6 - 20 mm;
- Installed outside vacuum;
- Laminated steel yoke;
- Water-cooled multi-turn coil (12 - 60 l/min);
- Rated current: 1 - 10 kA;
- Power supplied by controllable rectifier;
- Power consumption: 10 - 100 kW !

Septum vacuum chamber (SMH40 in LEIR)



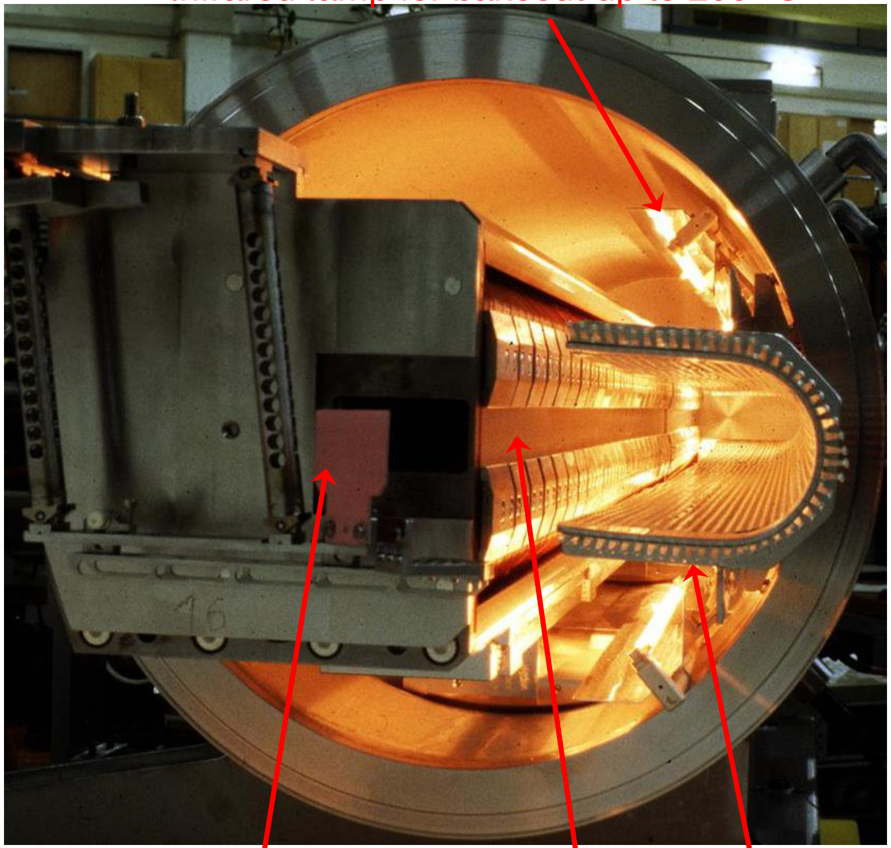


Pulsed magnetic septum



- Pulsed with a half sine over 3 ms.
- Single turn coil to reduce self-inductance.
- Transformer between power convertor and magnet.
- Often 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.

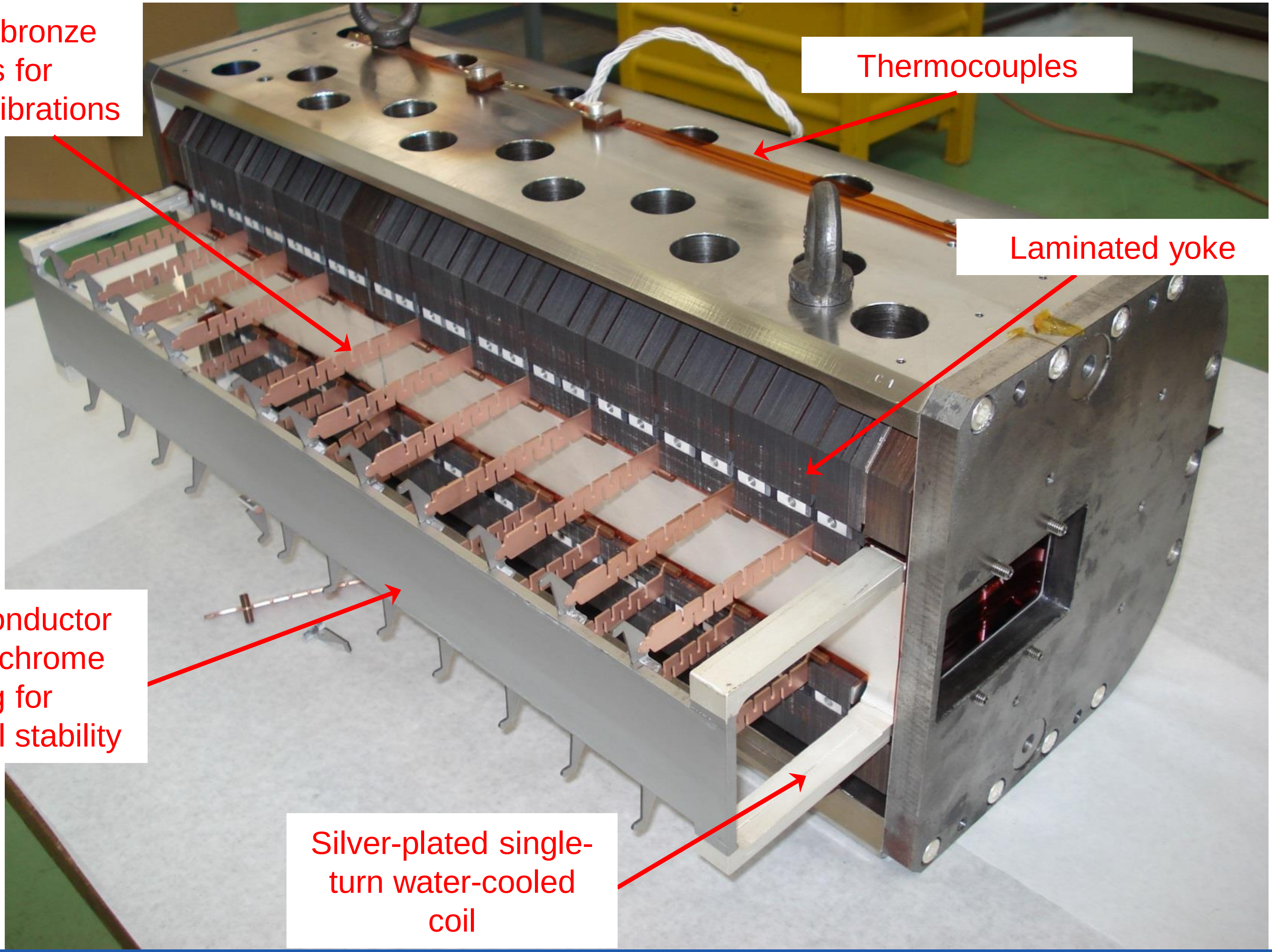
Pulsed magnetic septum (SMH16 in PS)



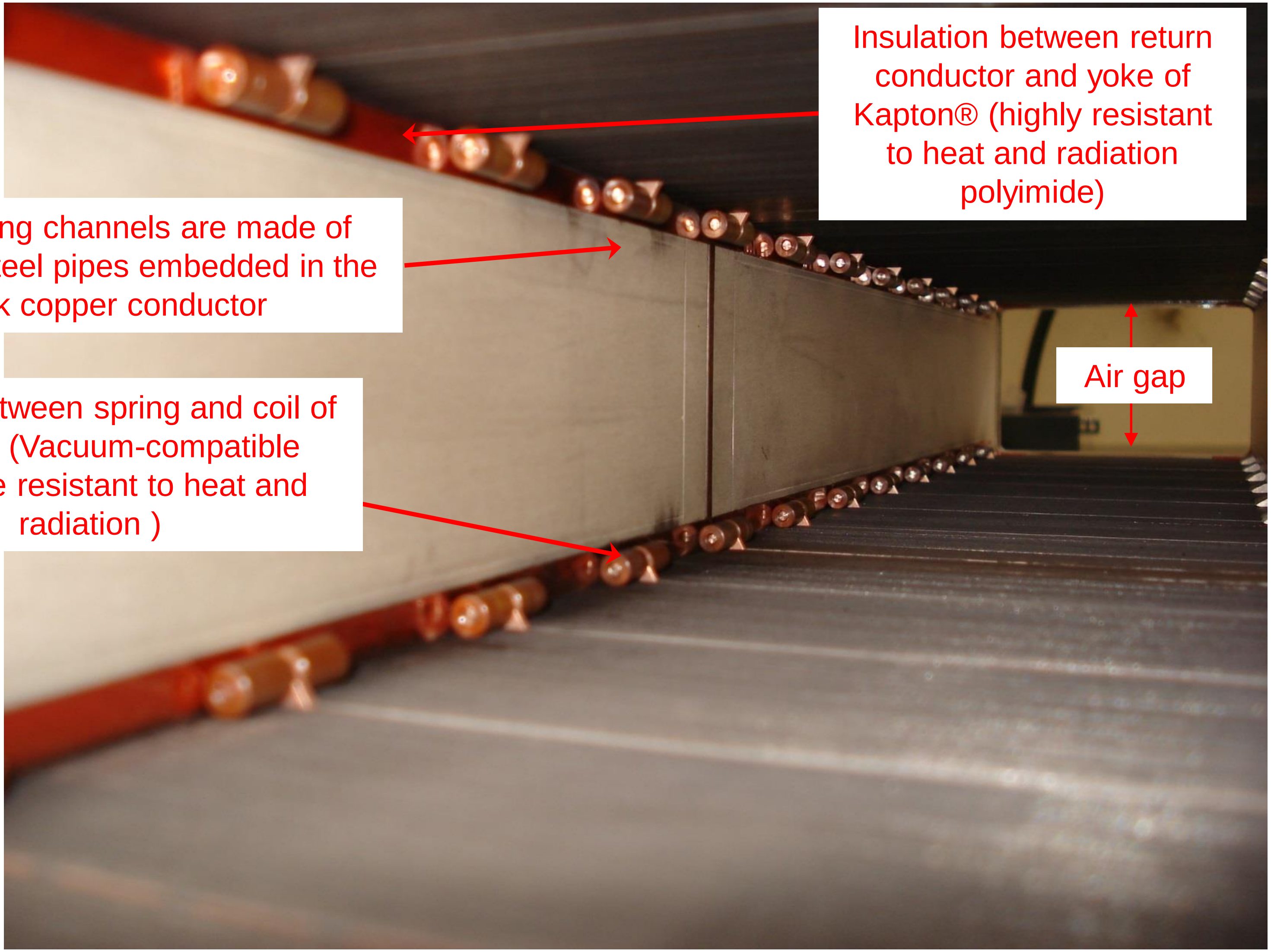
<u>Typical parameters</u>

- 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;

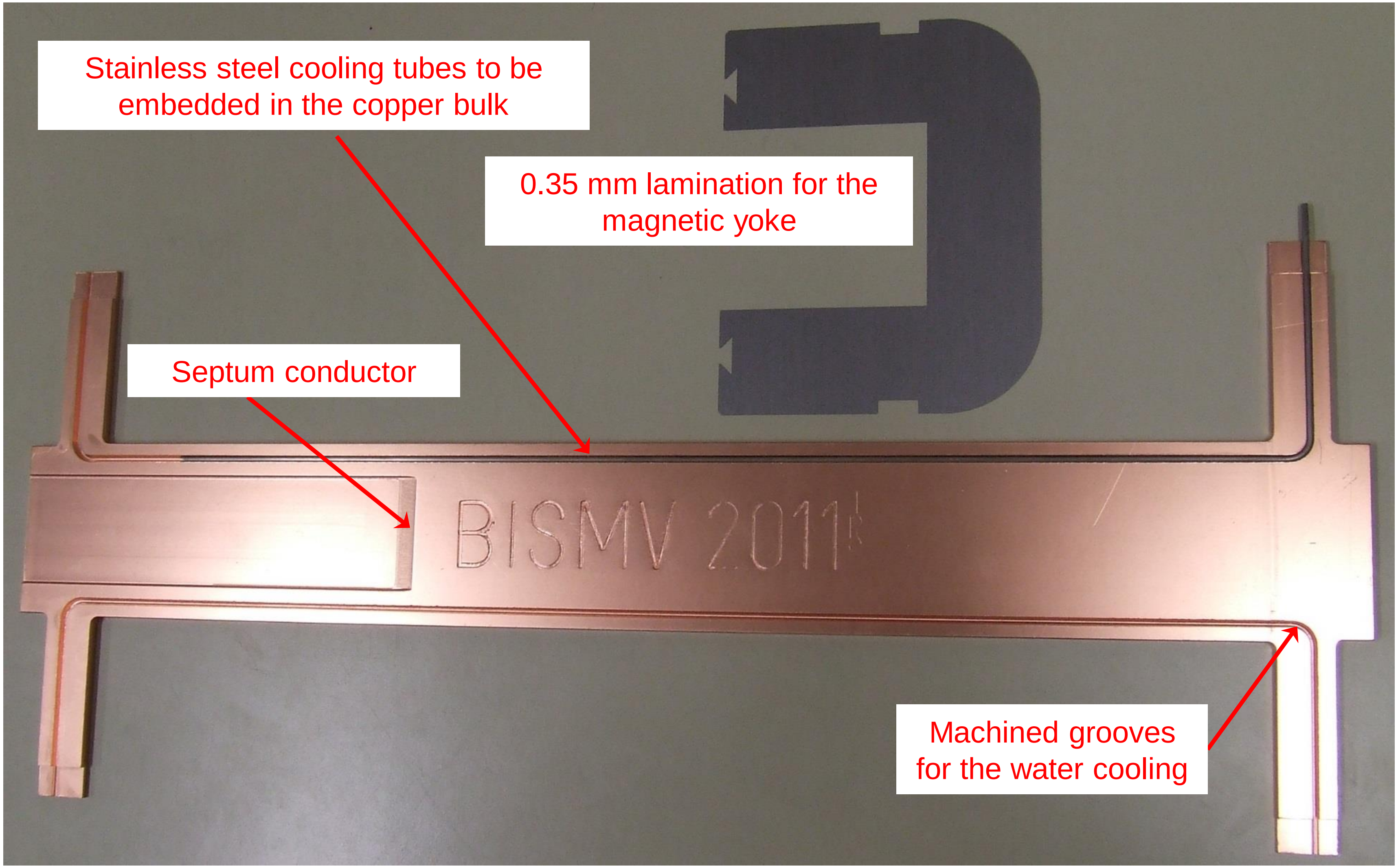
Pulsed magnetic septum (SMH42 in PS)



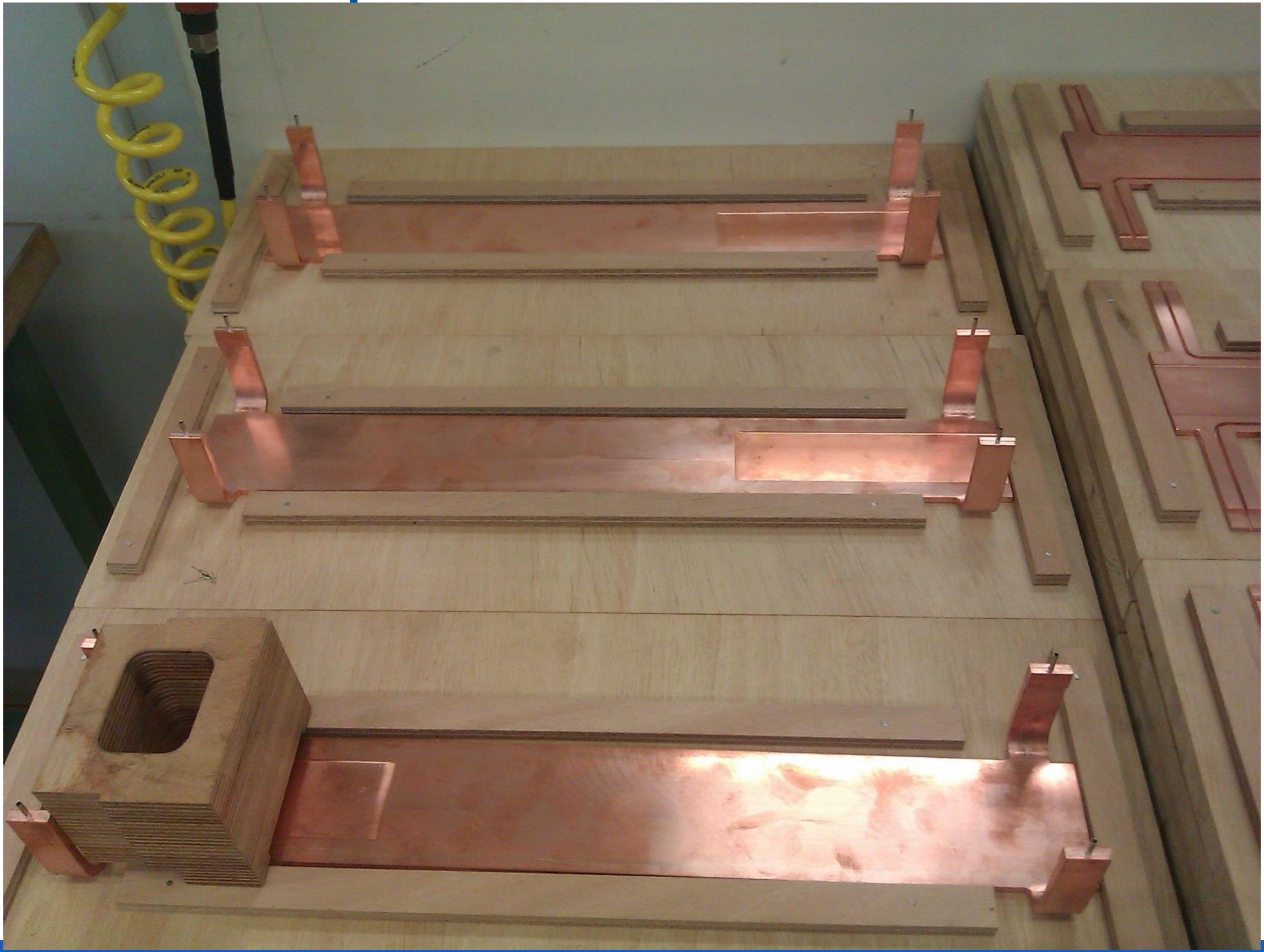
Pulsed magnetic septum magnet gap



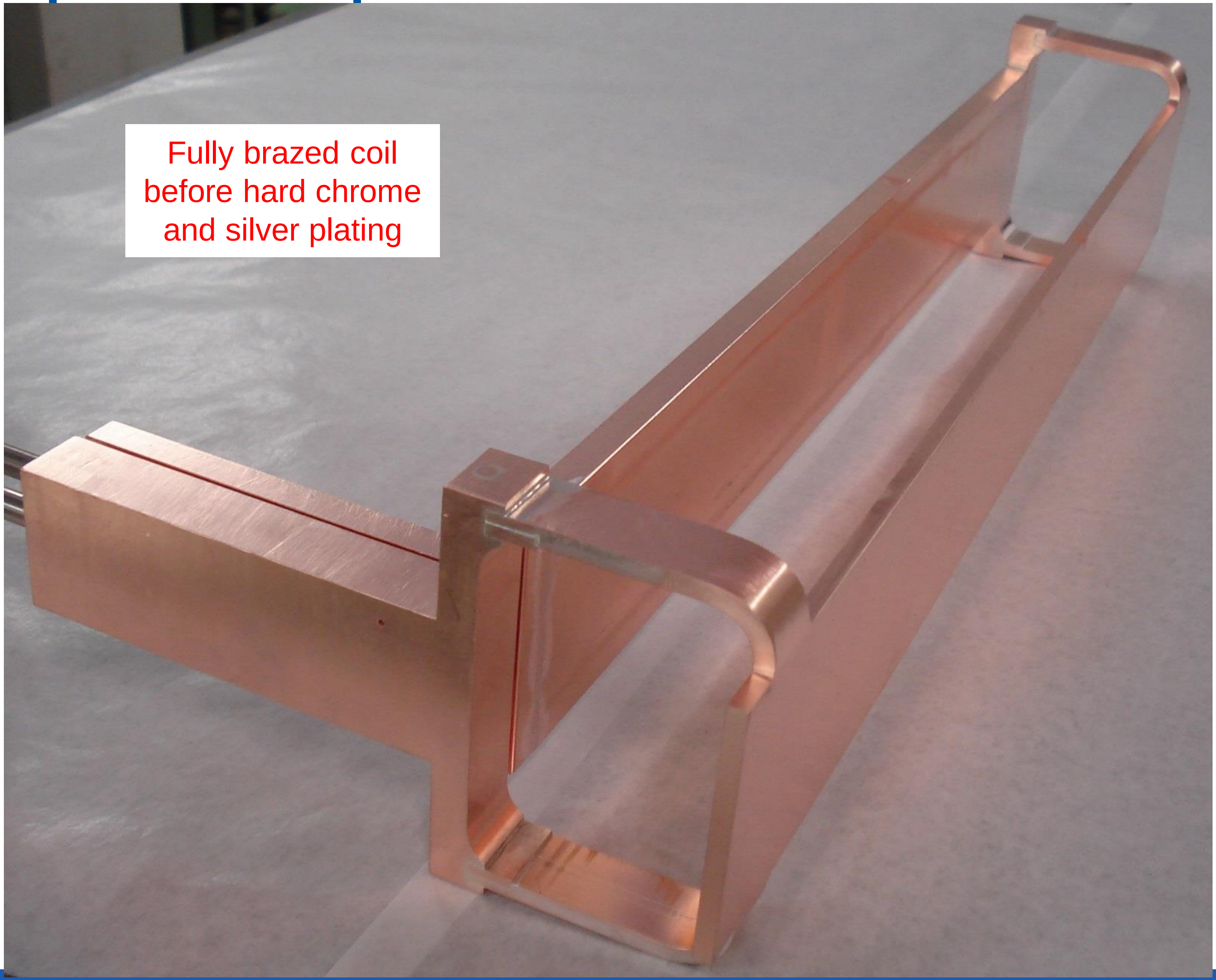
Pulsed magnetic septum conductor



Finished septum blade

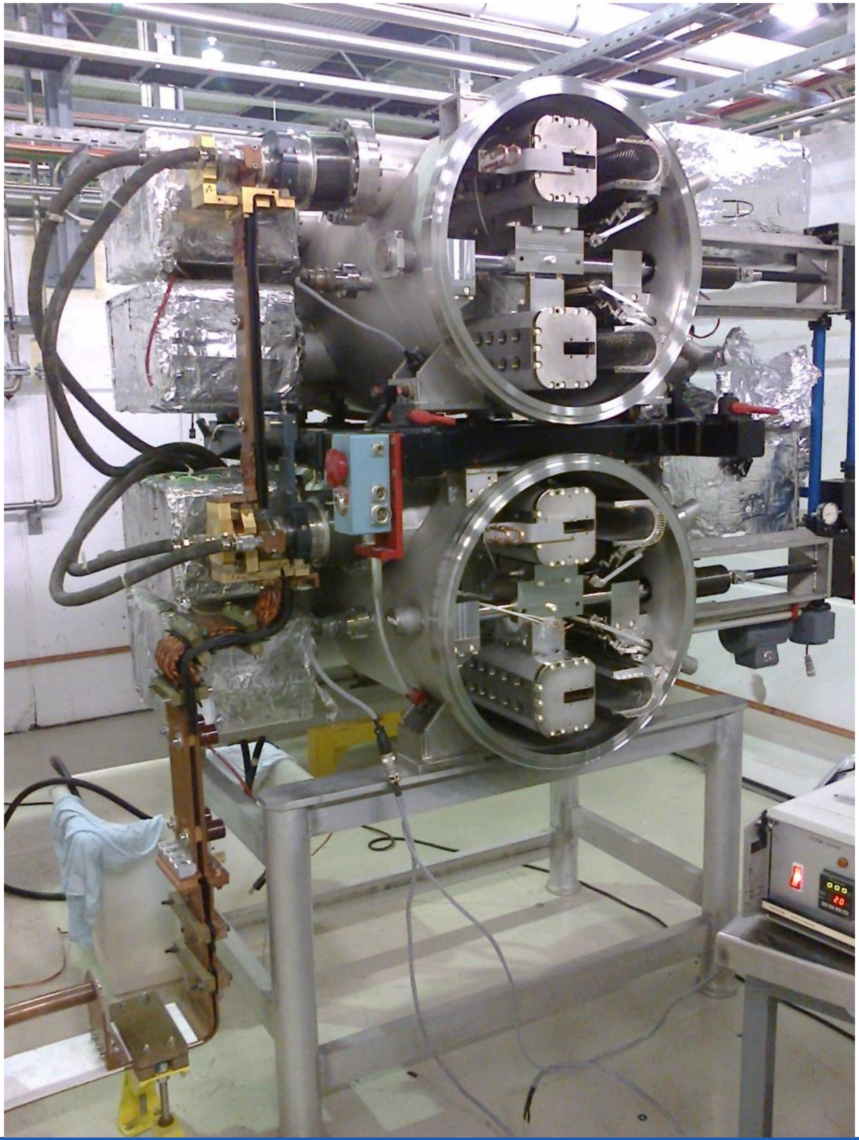


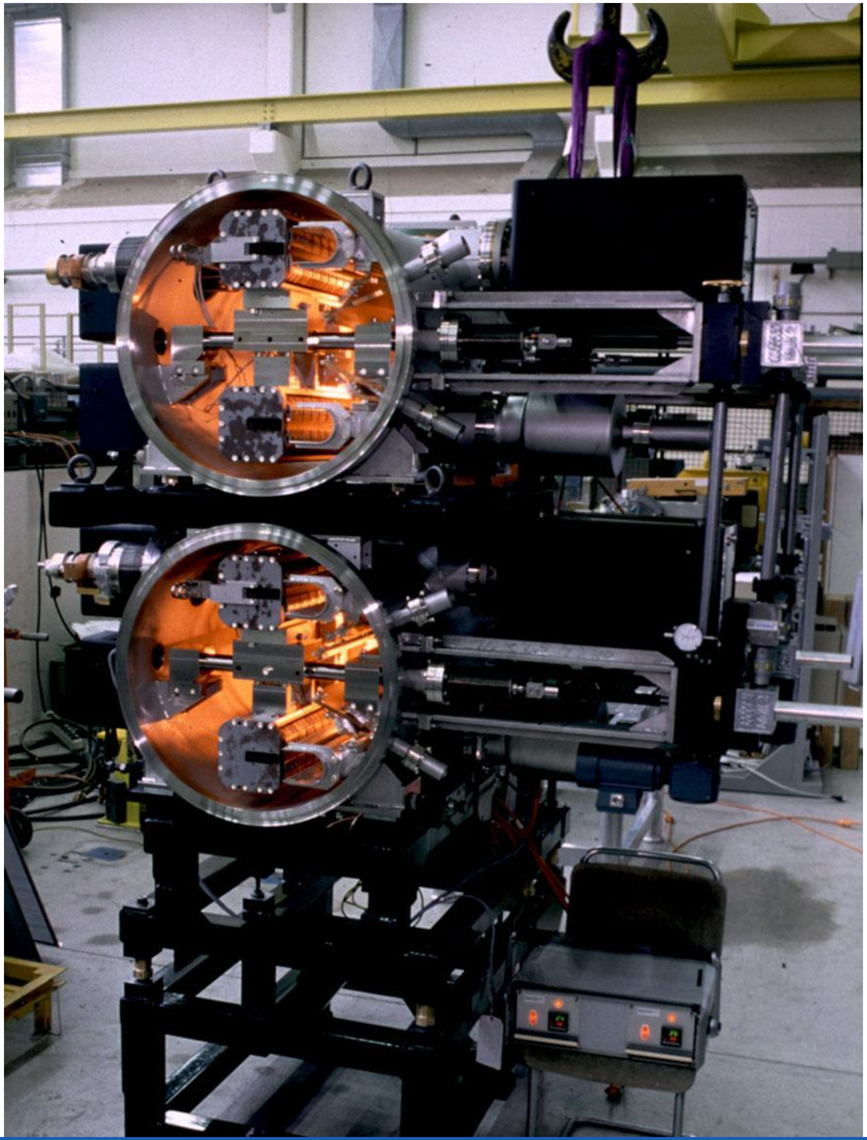
Complete septum coil



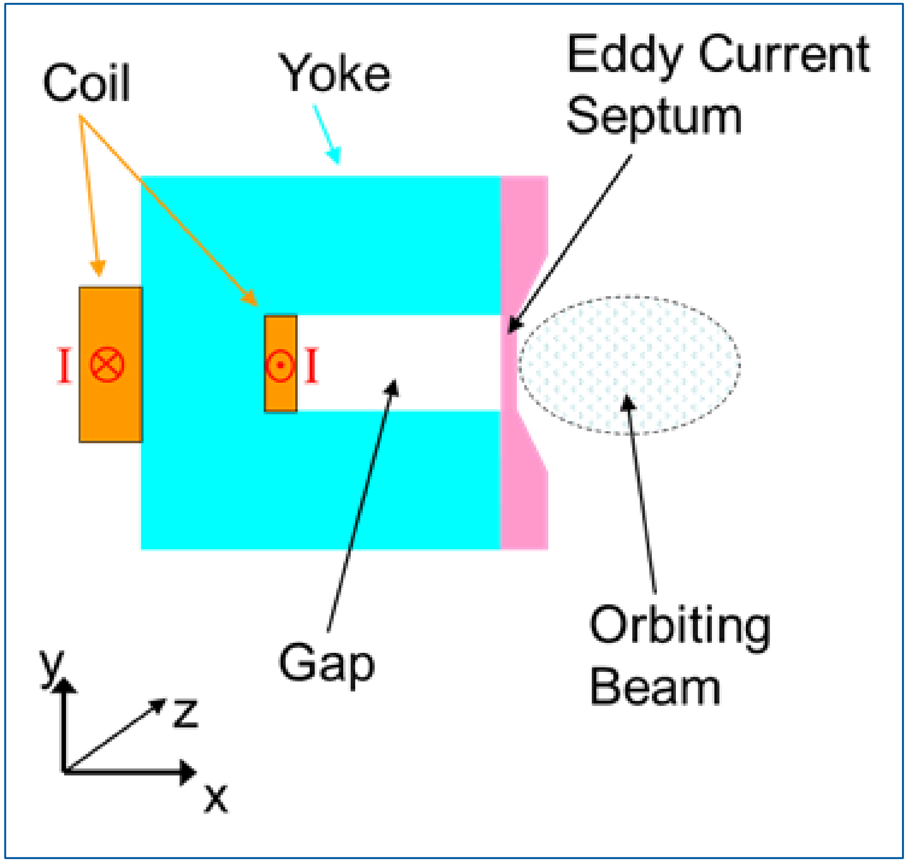
Fully brazed coil
before hard chrome
and silver plating

Pulsed magnetic septum (BE.SMH in PSB)



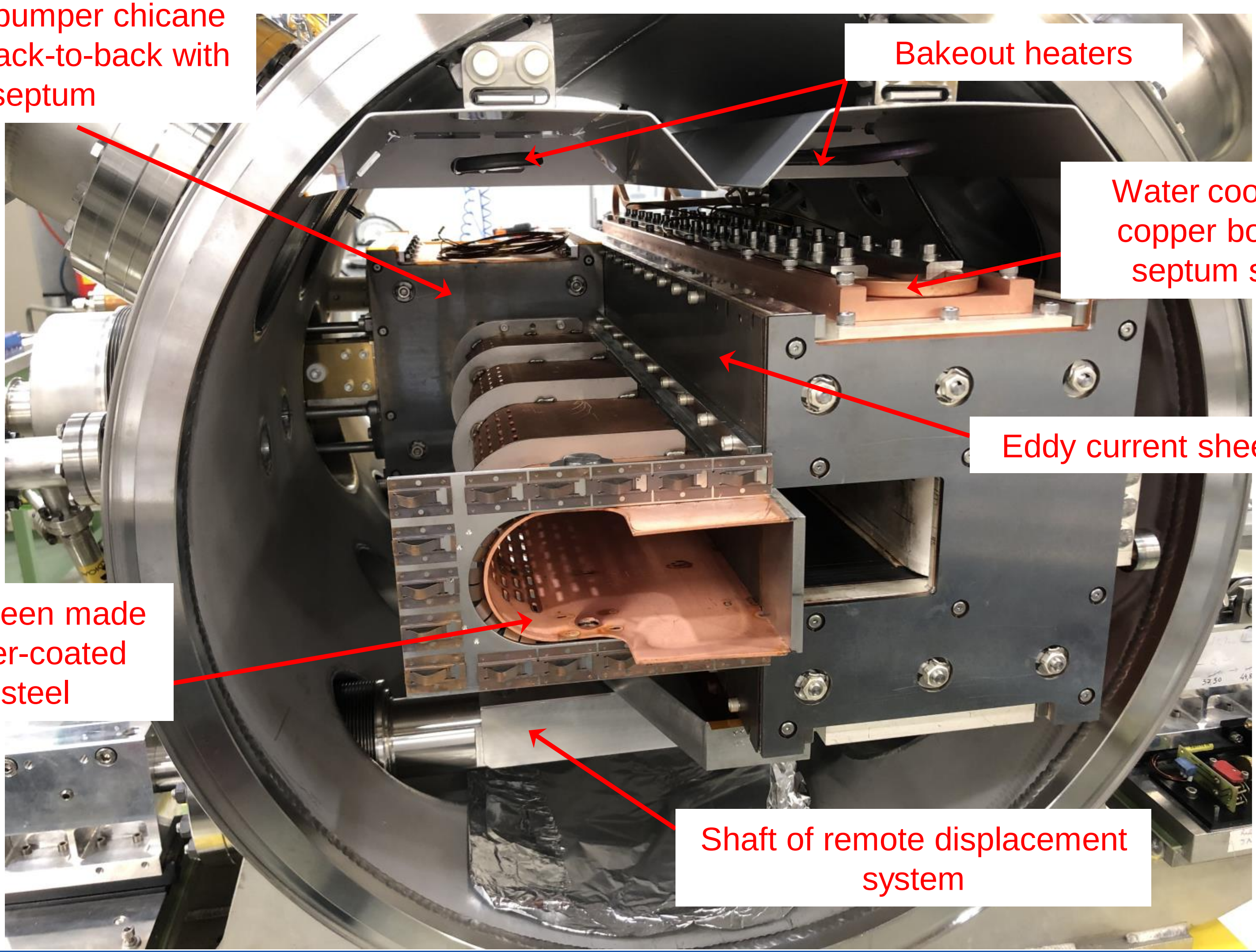


Eddy current septum



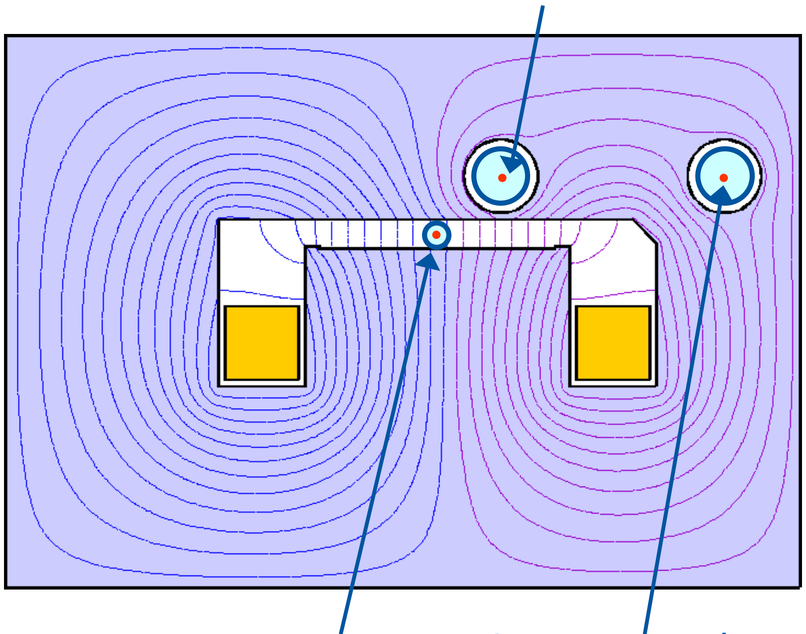
- Pulsed with a half sine or full sine.
- Single-turn coil is in the backleg of the yoke, exiting eddy currents into a thin eddy-current copper sheet.
- Current densities in this drive coil can be significantly reduced as compared to direct-drive pulsed septa.
- Increased mechanical robustness of coil -> increased lifetime.
- But: fast pulses (for example 400 μs full sine) lead to high voltages.
- Installed under vacuum

Eddy current septum (PS)



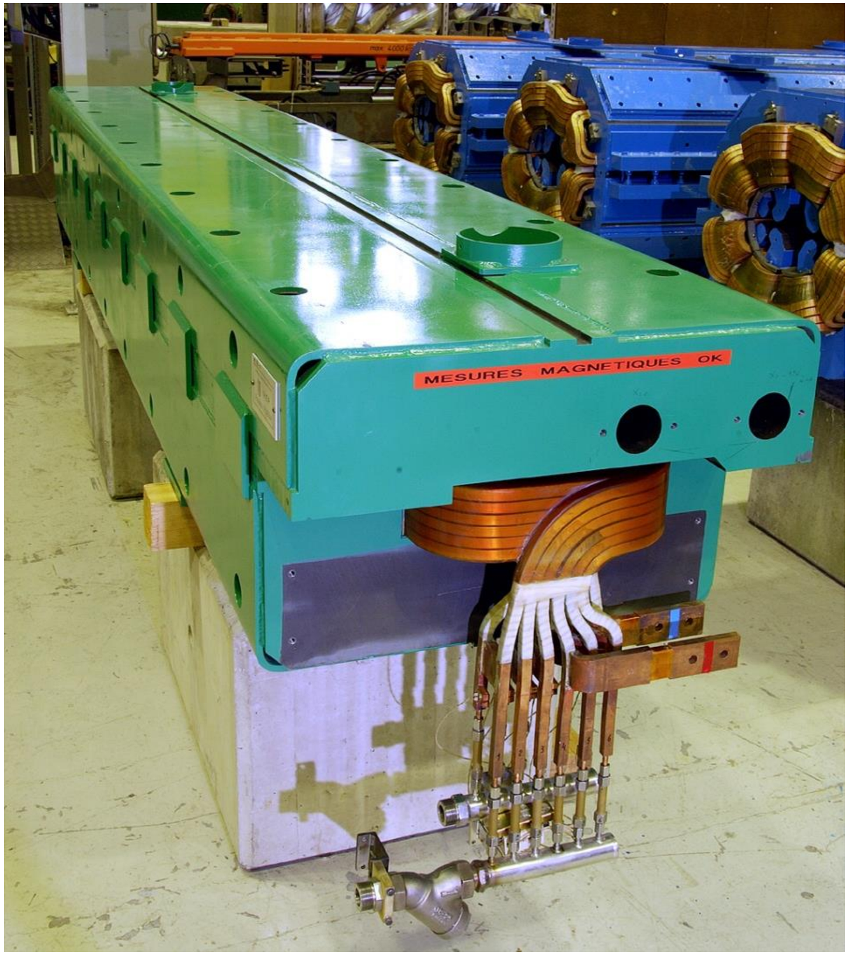
Lambertson septum for LHC injection (MSI)

Injected beam



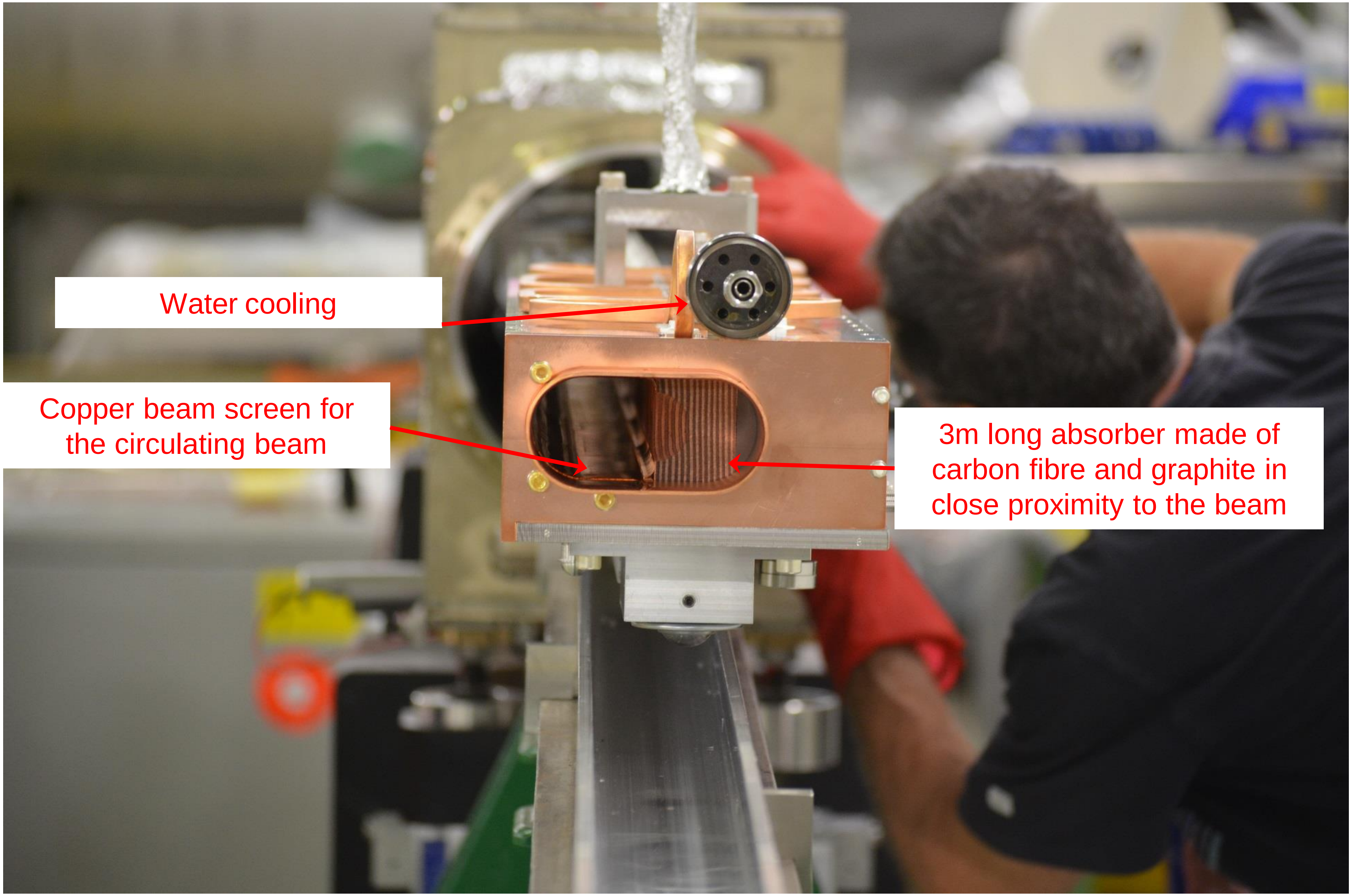
Incoming beam from SPS

Counter-rotating LHC beam

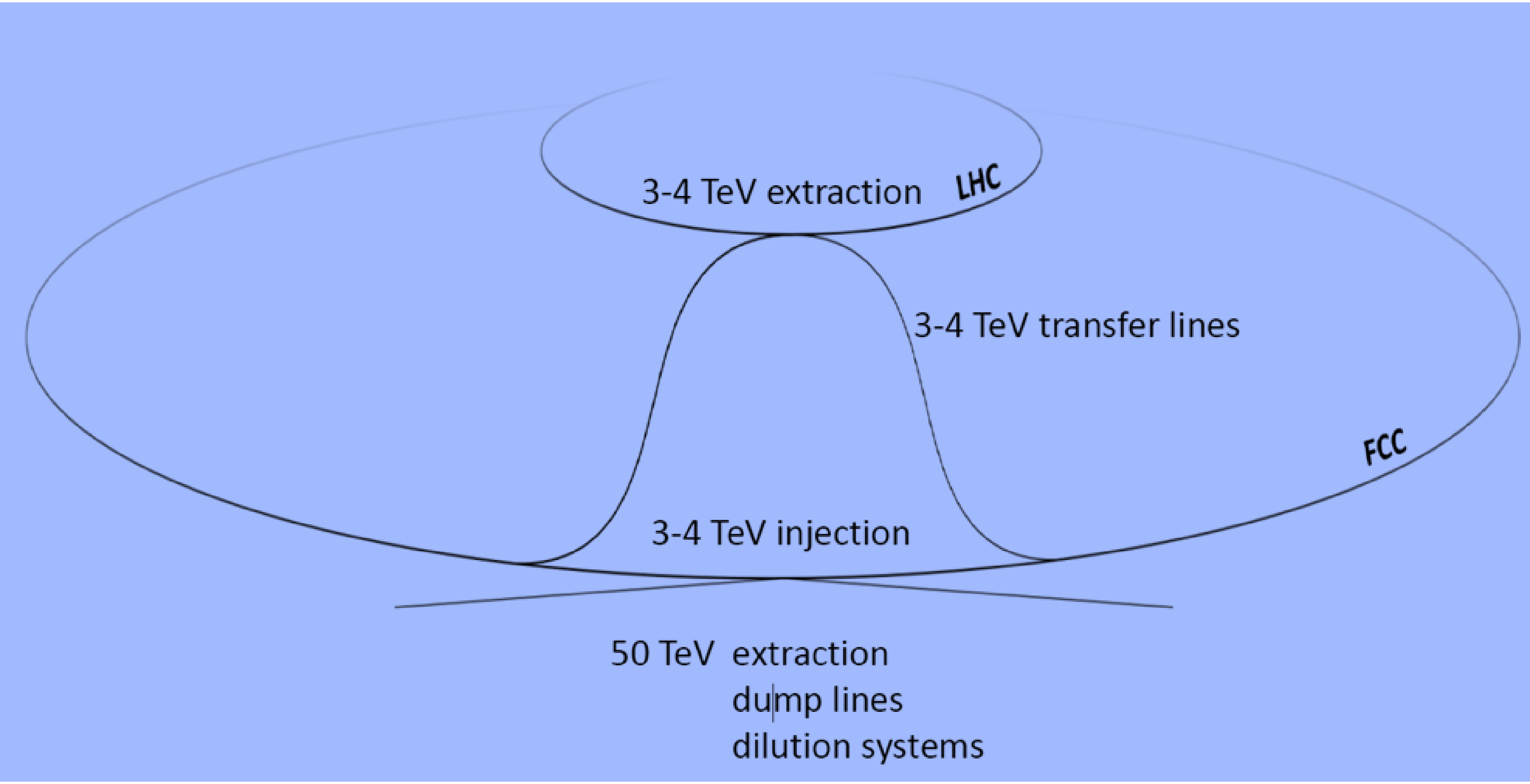


1. **The septum provides horizontal deflection towards the right;**
2. **The downstream kicker deflects vertically onto the central LHC orbit.**

Protective absorbers/diluters



The High Energy Frontier



The High Energy Frontier

Main parameters for FCC extraction

Beam parameters

Parameter	Unit	LHC	FCC
Kinetic Energy	TeV	7	50
Beam Rigidity	T.km	23.4	166.8
B.dl	T.m	56	400
Stored Beam Energy	GJ	0.36	**8.4**

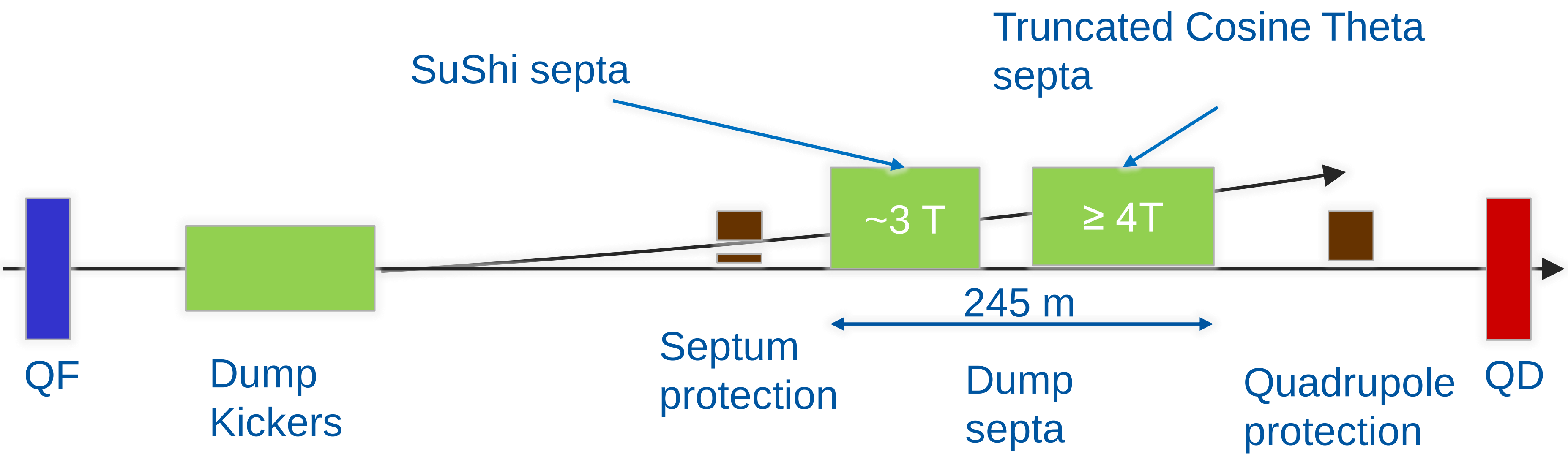
Septa parameters (scaled up from LHC)

Parameter	Unit	LHC	FCC
Magnetic Field	T	1	1
Deflection Angle	mrad	2.4	2.4
Number of Magnets	-	15	108
Total required length	m	73	**530**
Available length	m	74	245
Power Dissipation	MW	0.42	**3**

A simply scaled up version of the LHC Lambertson septa is unsuitable because of the required length as well as the power consumption.

The High Energy Frontier

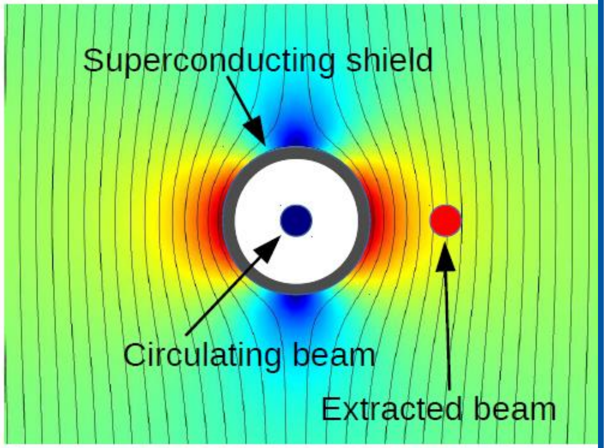
Pursued septa layout



The SuShi concept

A superconducting shield to create a field free region within a strong dipole field.

- Put a superconducting shield around the circulating beam
- Add a superconducting magnet around it
- Cool down below T_c in zero external field
- Ramp magnet up or down; shielding currents automatically follow the external field to cancel it inside.
- Principle similar to eddy current septa, but with persistent eddy currents – allows slow-ramp/DC mode

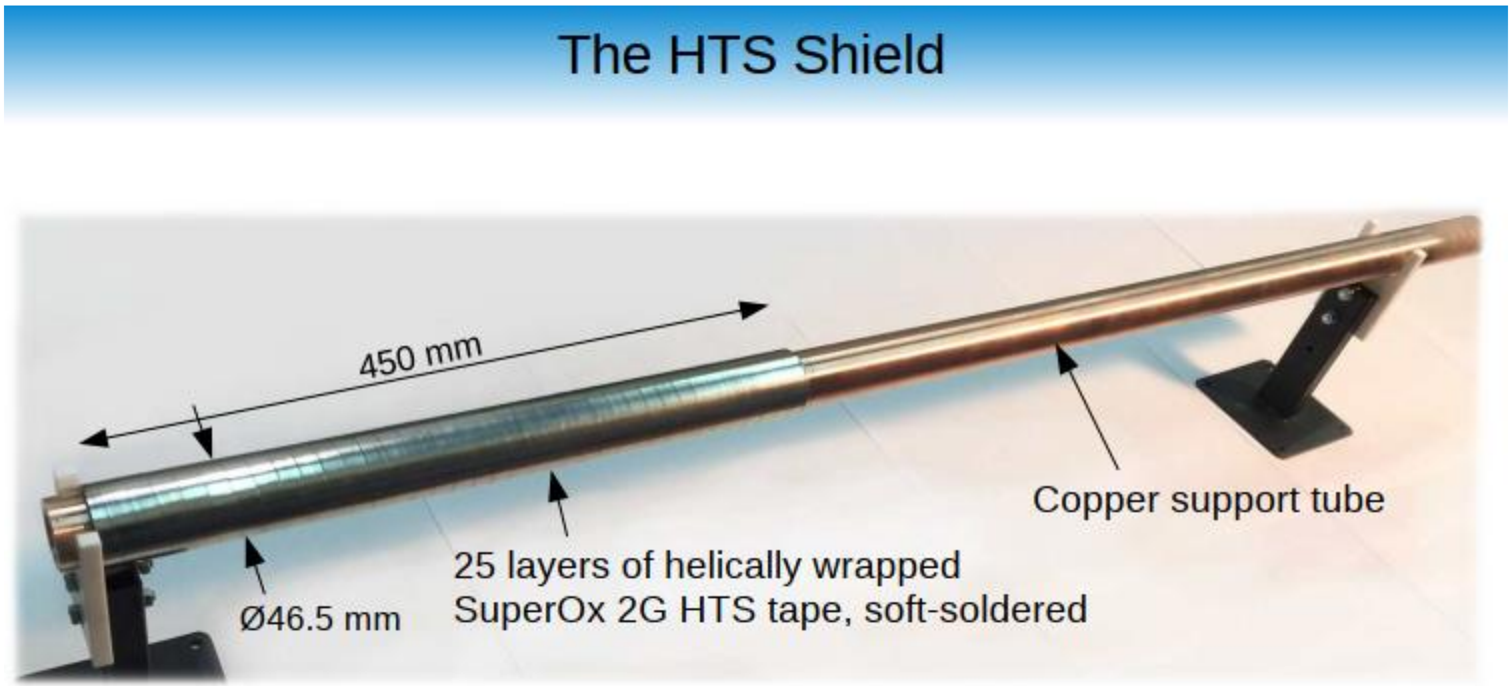


3 candidate technologies have been tested:

- HTS
- MgB_2
- NbTi multilayer sheet

HTS tape

- 25 layers of helically wrapped 2G HTS tape, 8.5 mm wall thickness

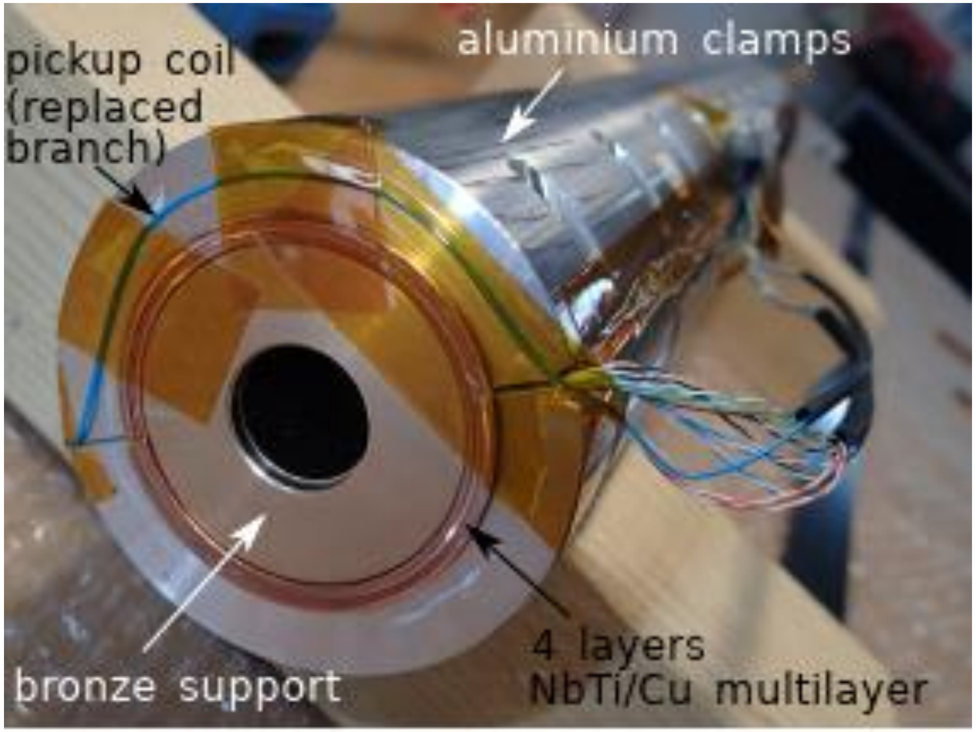


Bulk MgB_2

- Bulk MgB_2 - 8.5 mm wall thickness

Multilayer NbTi/Nb/Cu

- Multilayer NbTi/Nb/Cu, 3.2 mm wall thickness



Thank You!

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