DIFFER

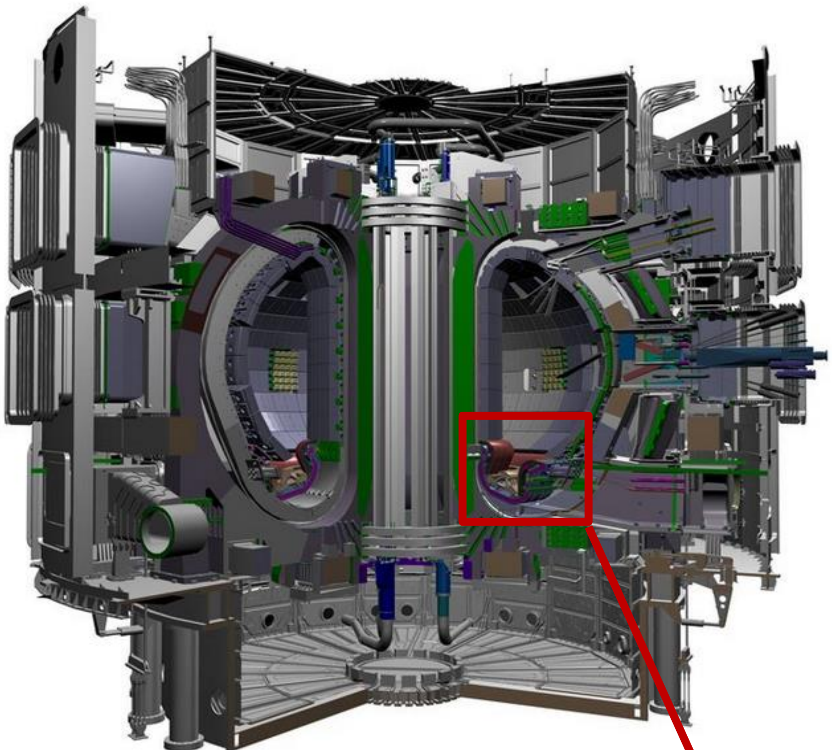
A 2.5 T, 1.25 m free bore superconducting magnet for the Magnum-PSI linear plasma generator

Hans van Eck

Fusion Facilities and Instrumentation

Dutch Institute for Fundamental Energy Research

Plasma-Surface Interaction in fusion



Understanding PSI is important:

- Erosion: lifetime and performance
- Retention: safety limits and fueling

No easy access in existing tokamaks

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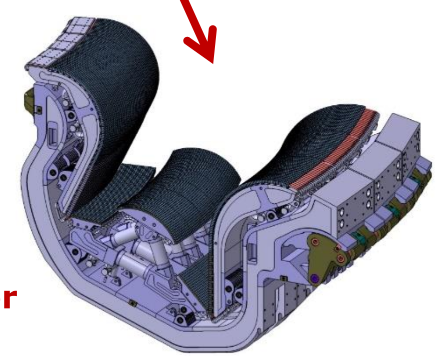
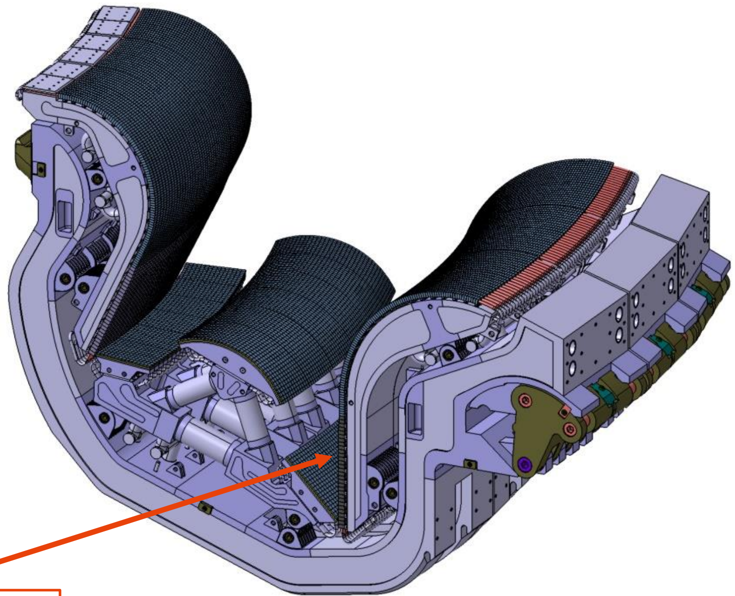
Need for linear machines



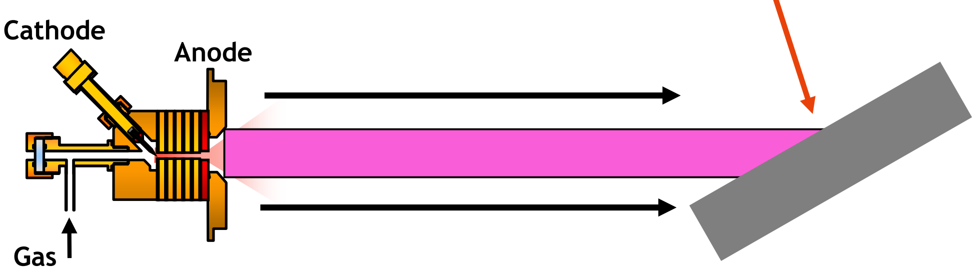
ITER divertor

Linear machines at DIFFER

- Recreate the fusion reactor environment
- Characterize and control plasma parameters
- Spacious enough to fit relevant size targets
- Good access (diagnostics + target exchange



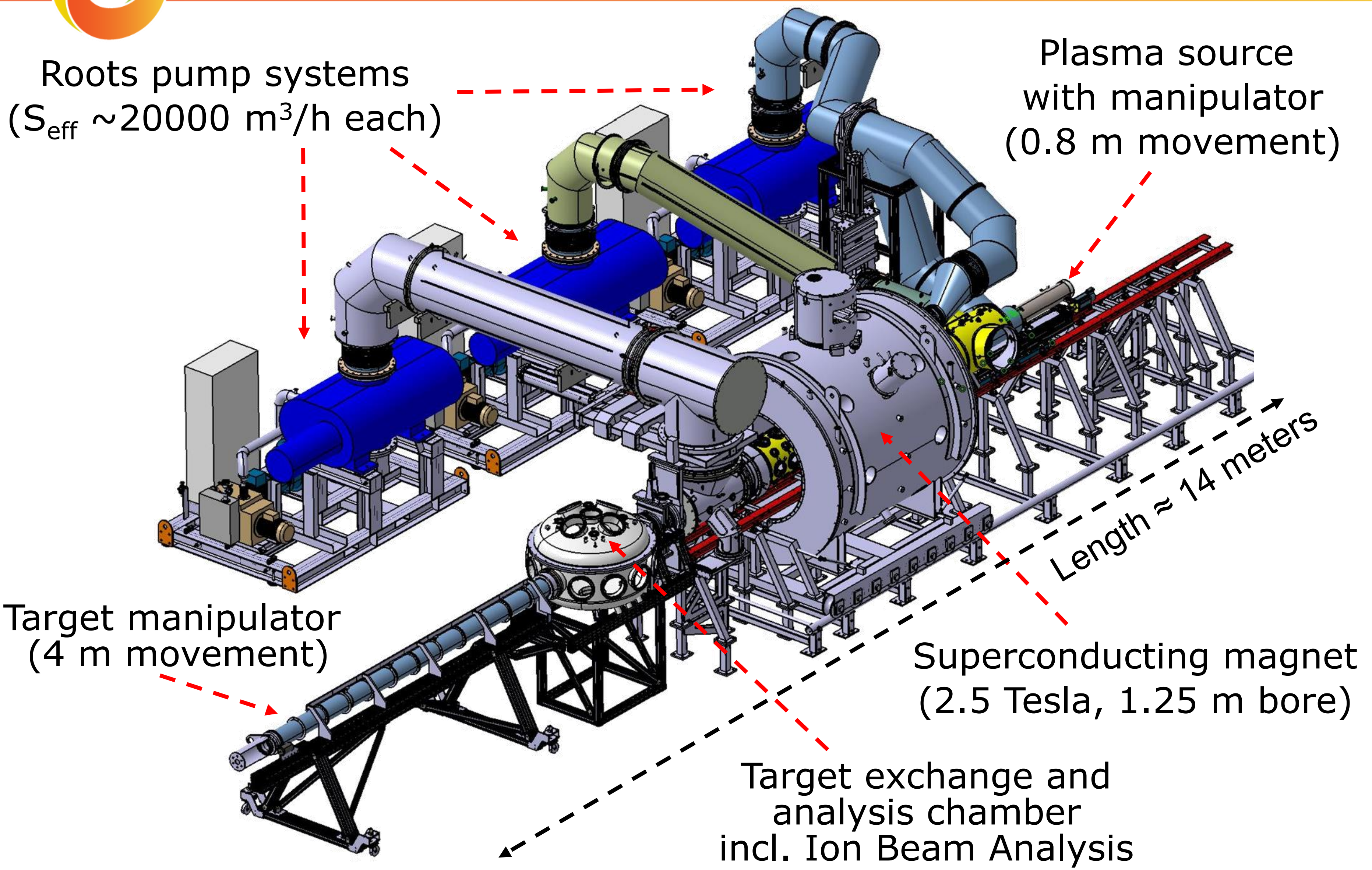
Similar PSI conditions



Source B field Target

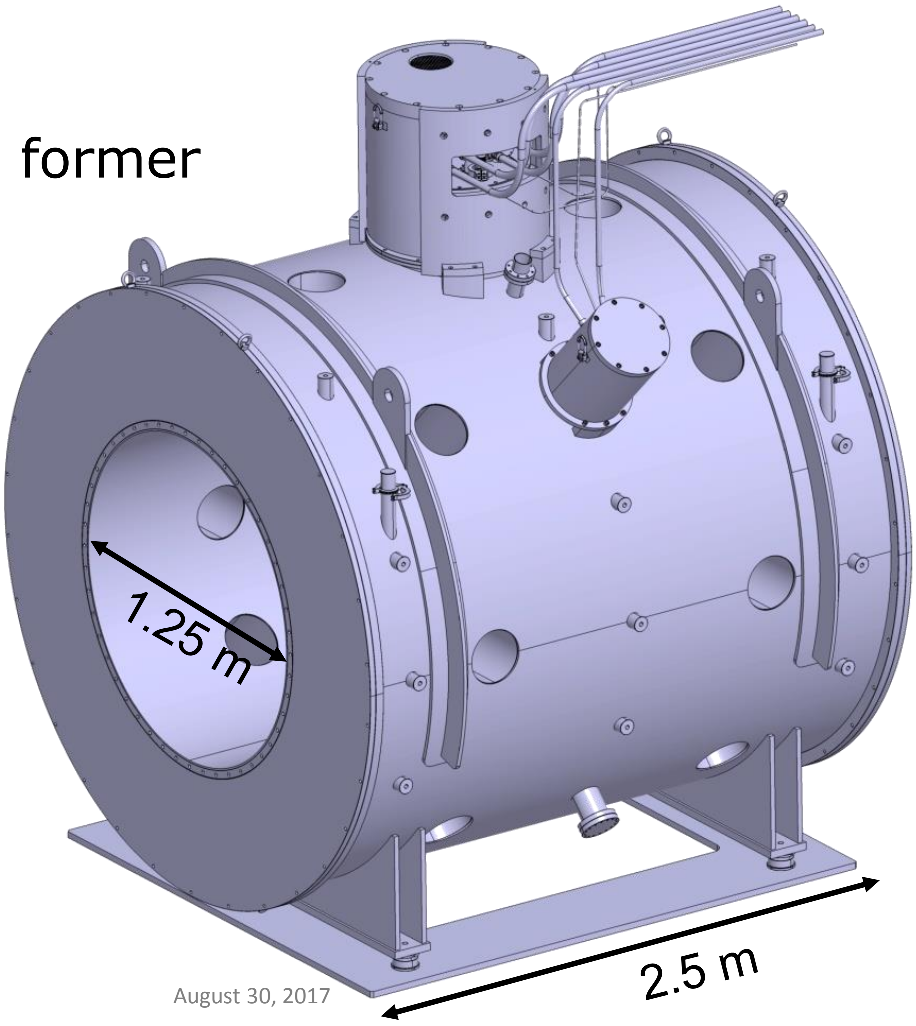
- High density ~10^{20} - 10^{21} m^{-3}
- High flux ~10^{24} particles $m^{-2}s^{-1}$
- High fluence (integrated flux)
- Plasma T ~1 - 5 eV
- High power load ~10 MW m^{-2}

Magnum-PSI design



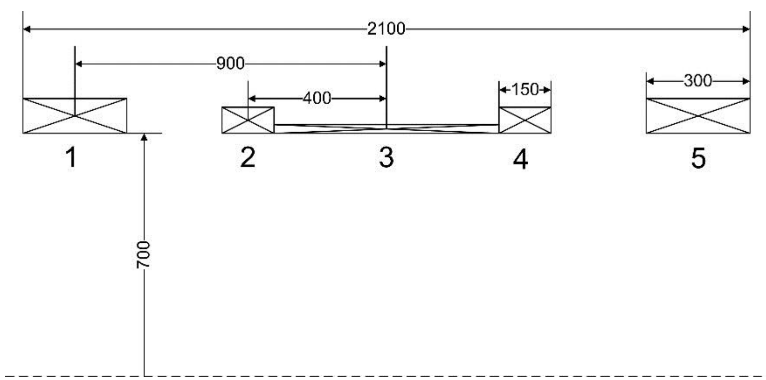
2.5 T superconducting magnet

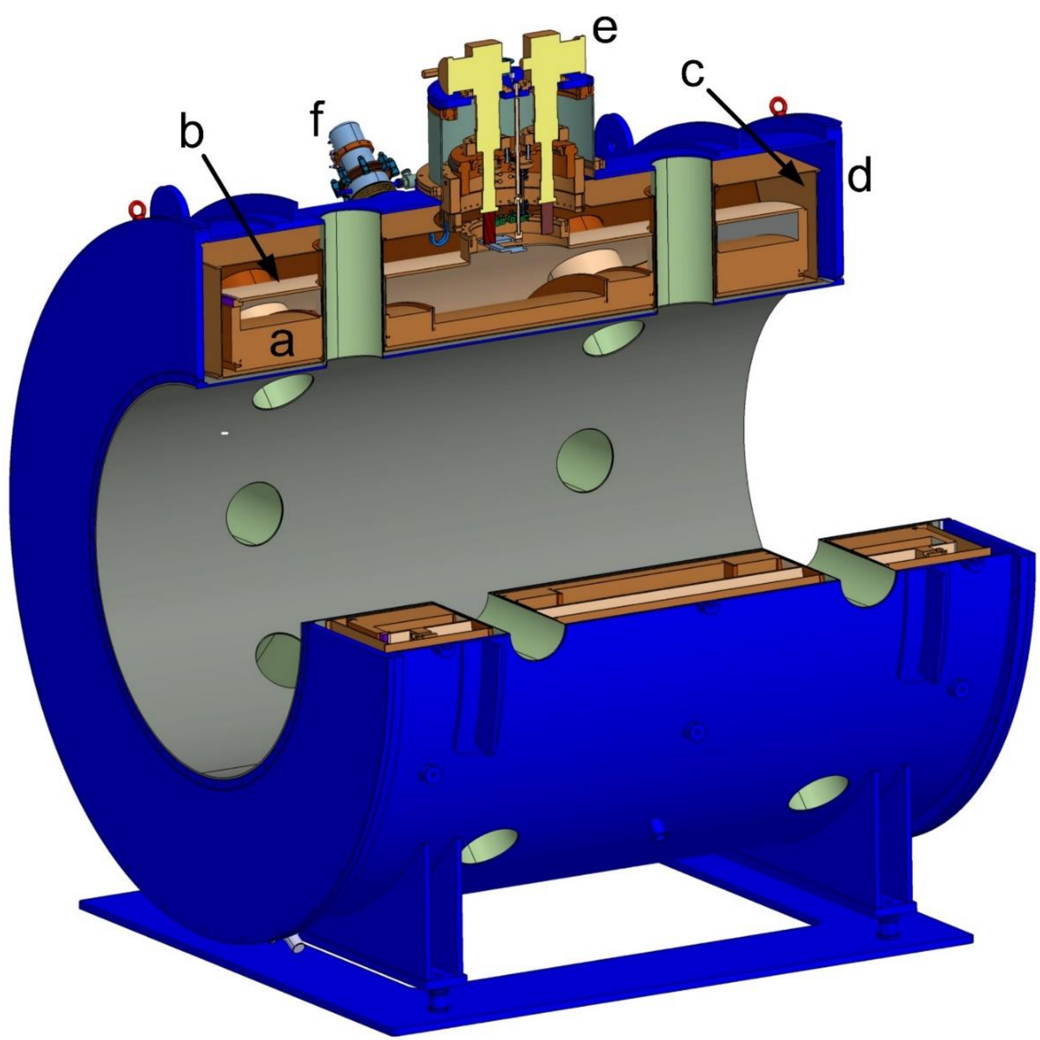
- Standalone superconducting magnet system in liquid He
- Recondensing cooling method
- 5 solenoids wound on one coil former
- Total stored energy: 16.3 MJ
- Passive stray field shielding
- 16 radial access ports
- Induction: 492 H
- Weight: 15 tons



Innards of Magnum-PSI magnet

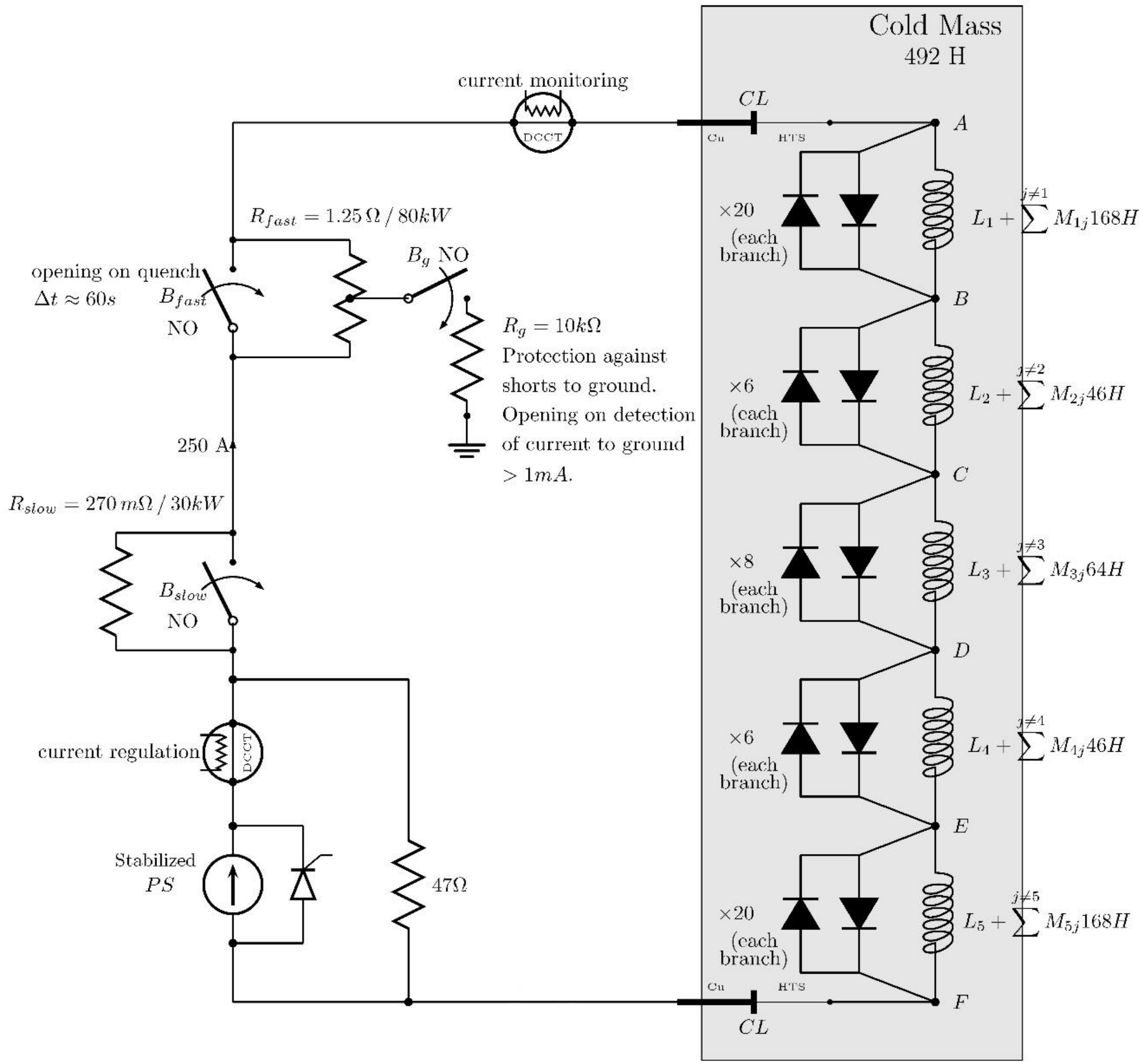
a) Coils
b) Helium vessel
c) Radiation shield
d) Vacuum vessel
e) Turret with cryocoolers
f) Shield cryocooler





Protection circuit

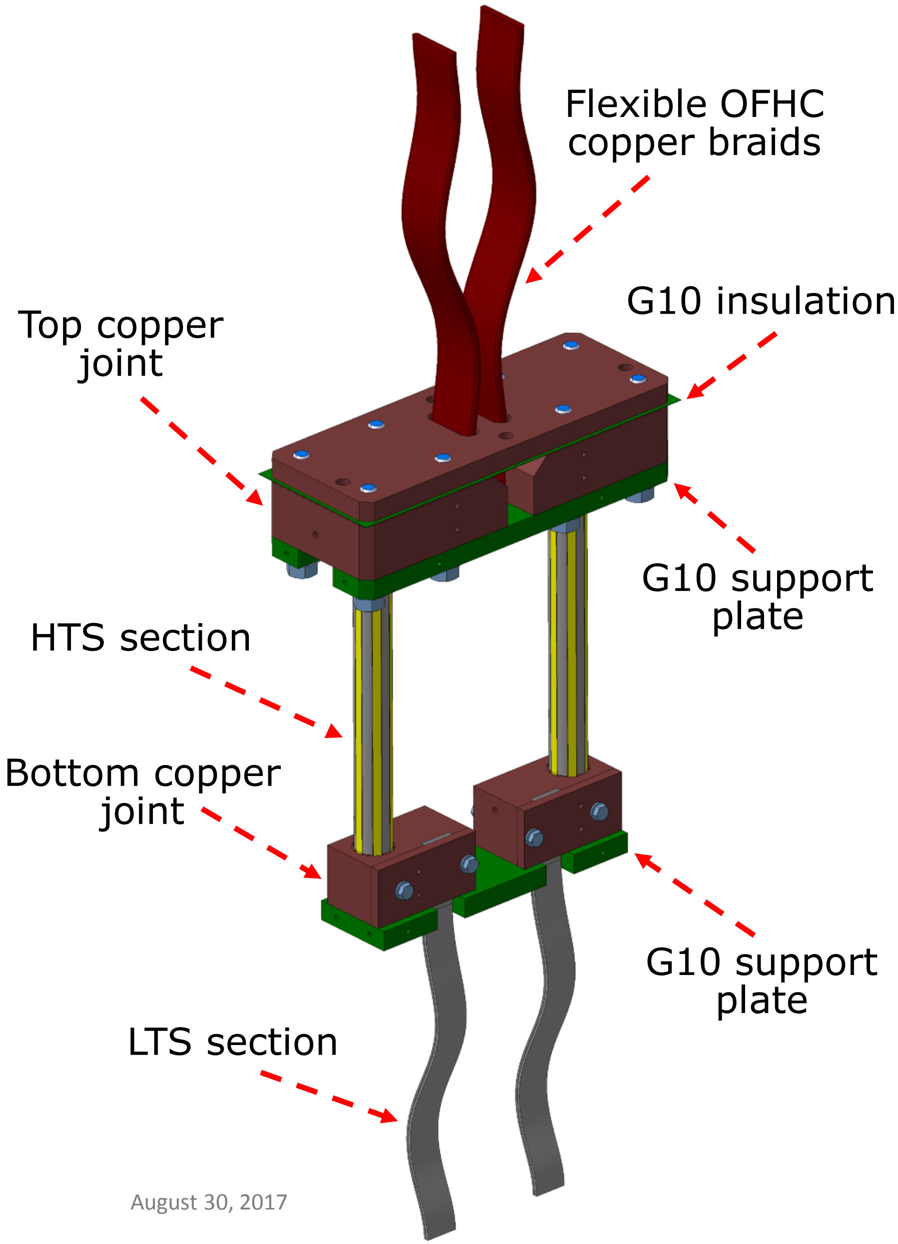
- Passive protection with cold diodes
- Each diode is connected to 793 gram Cu heat sink
- Each coil equipped with quench heaters
- Slow dump resistor for power failure
- Fast dump resistor to quickly remove current from circuit



HTS current leads

- HTS section: 12 ReBCO tapes on a stainless-steel tube
- LTS section: 2 NbTi/Cu LHC type 2 cables
- Heat flow to top copper joint: 14 W w/o current and 26 W with current
- Heat flow to 4K: 180 mW

Contribution from ATLAS magnet group at CERN

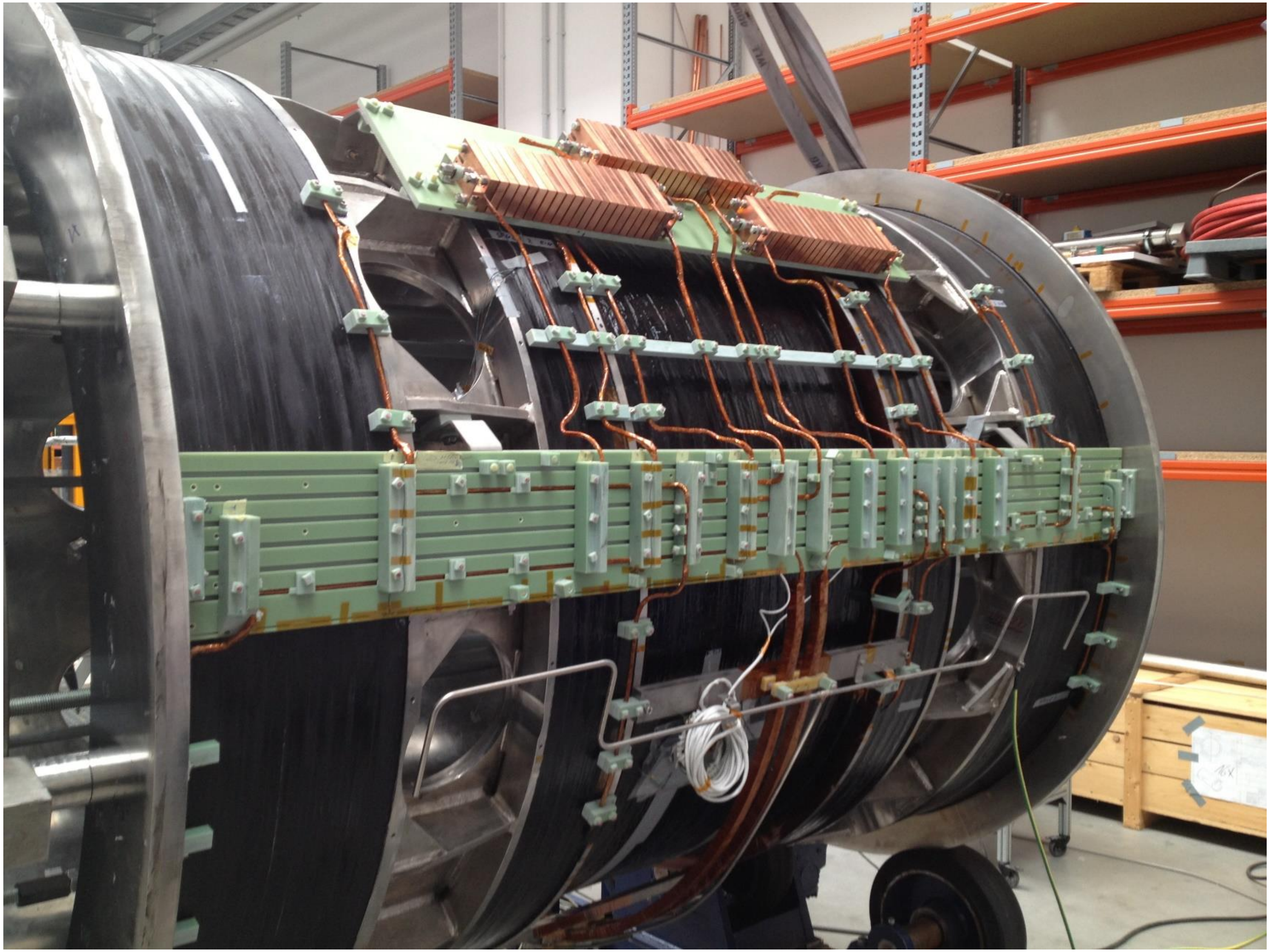


Cryogenics

- Designed as zero boil off system
- 2 Sumitomo RDK-415D two stage cryocoolers (3 W @ 4 K)
- 1 Leybold 250 MD one stage cryocooler on radiation shield
- Excess power used to re-condense evaporated helium
- Calculated average shield temperature: 60 K

	Heat load on shield at 60 K [W]	Heat load on 4 K level with shield at 60 K [W]
Radiation	88	1.11
Conduction	20	0.76
Current leads	26	0.18
Total	**134**	**2.05**

Superconducting coils and diode blocks



Helium vessel

Radiation shield

Vacuum vessel

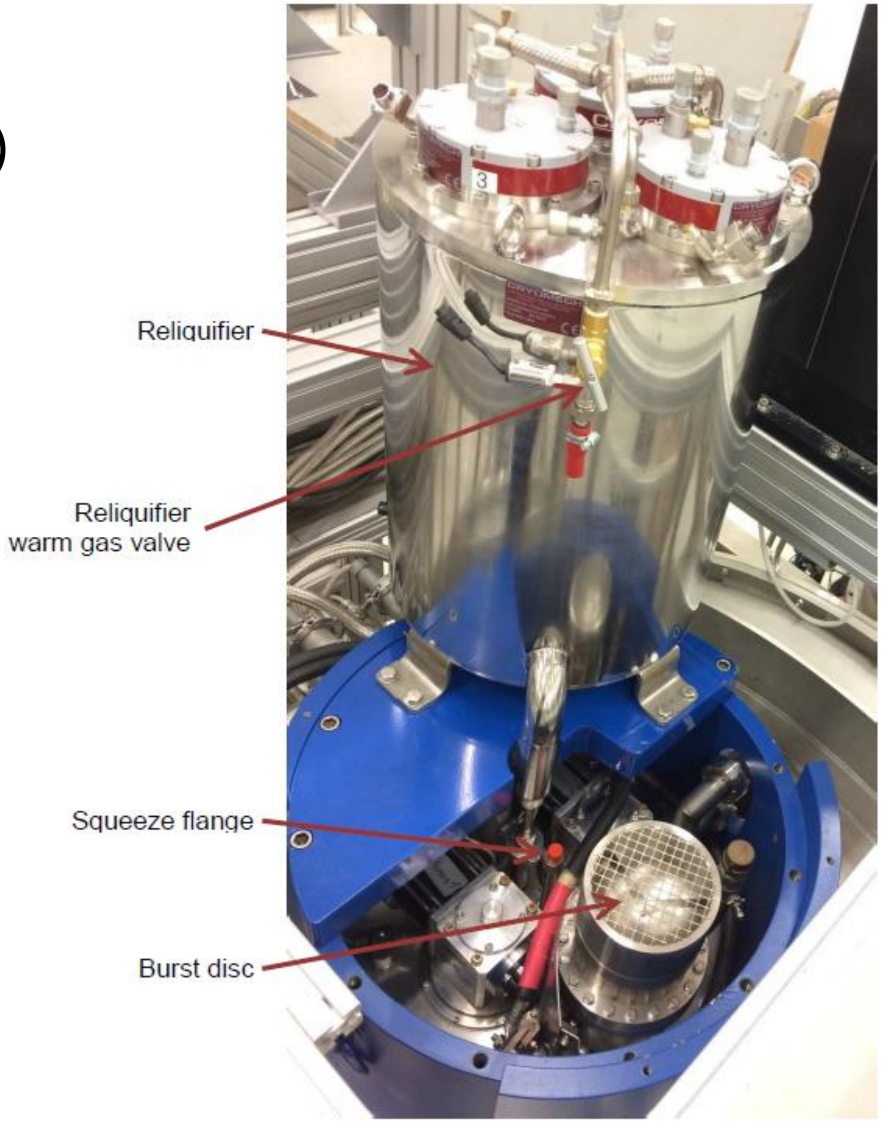
Factory acceptance tests

- FAT in 2010: erratic quench behavior due to incomplete clamping and insufficient stabilization of wires
- FAT in 2011: damage to wiring plate and outer layer of coils by two electrical arcs due to weak points in the local insulation on one of the bus bars
- FAT in 2016 after rewind of coils and new wiring board:

  - No zero boil off due to too high average radiation shield temperature: 80 K instead of 60 K
  - Magnetic field profile well within specifications

Cryogenic situation

- Average radiation shield temperature: 80 K (I/O 60 K)
- Probable cause: bad connection between radiation shield and cryocooler
- Installation of Cryomech HeRL45 reliquefier on top of magnet was chosen as most robust and low risk solution
- Zero boil off: pressure in helium vessel controlled by heater (~2 W excess power)



Installation at DIFFER Eindhoven

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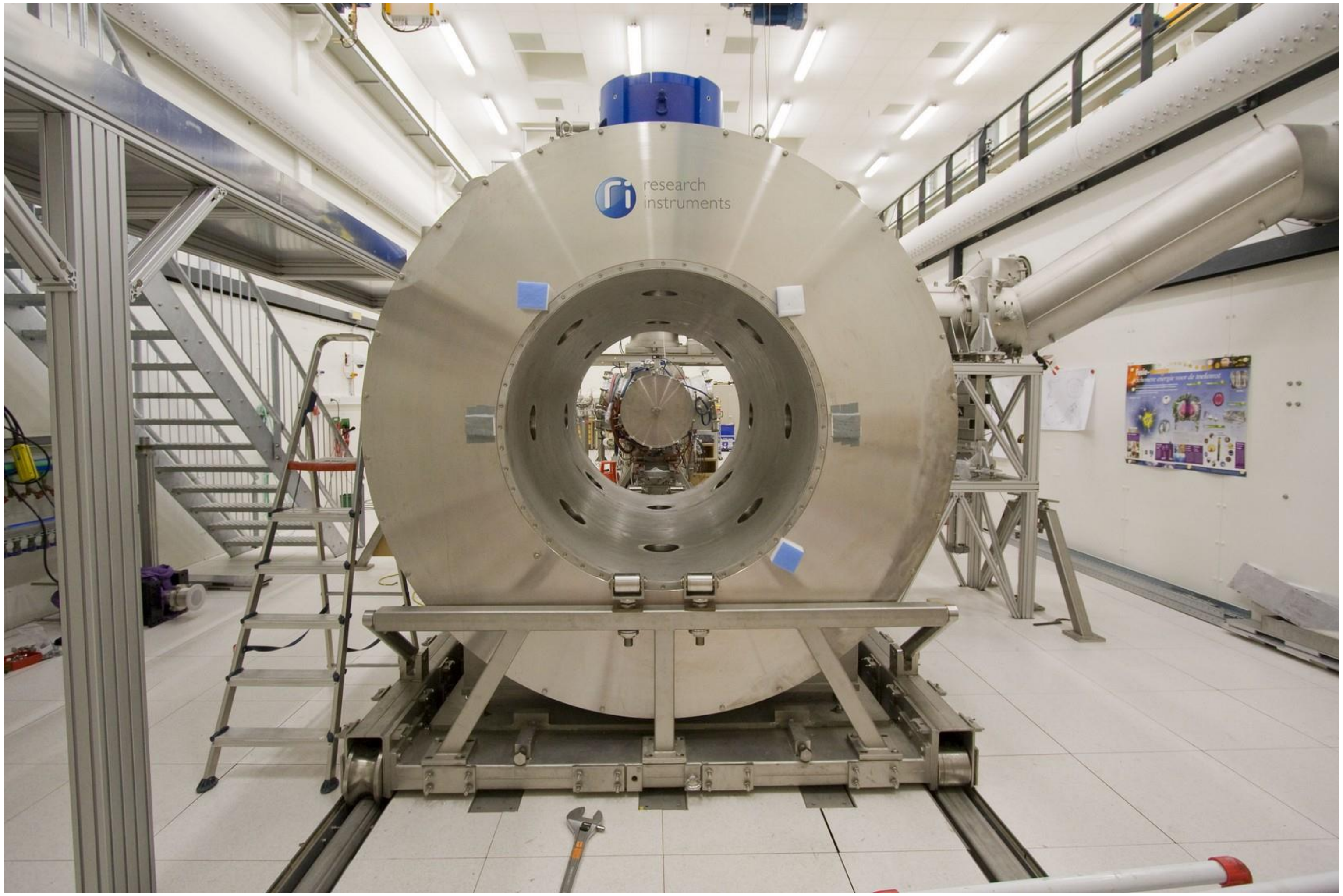
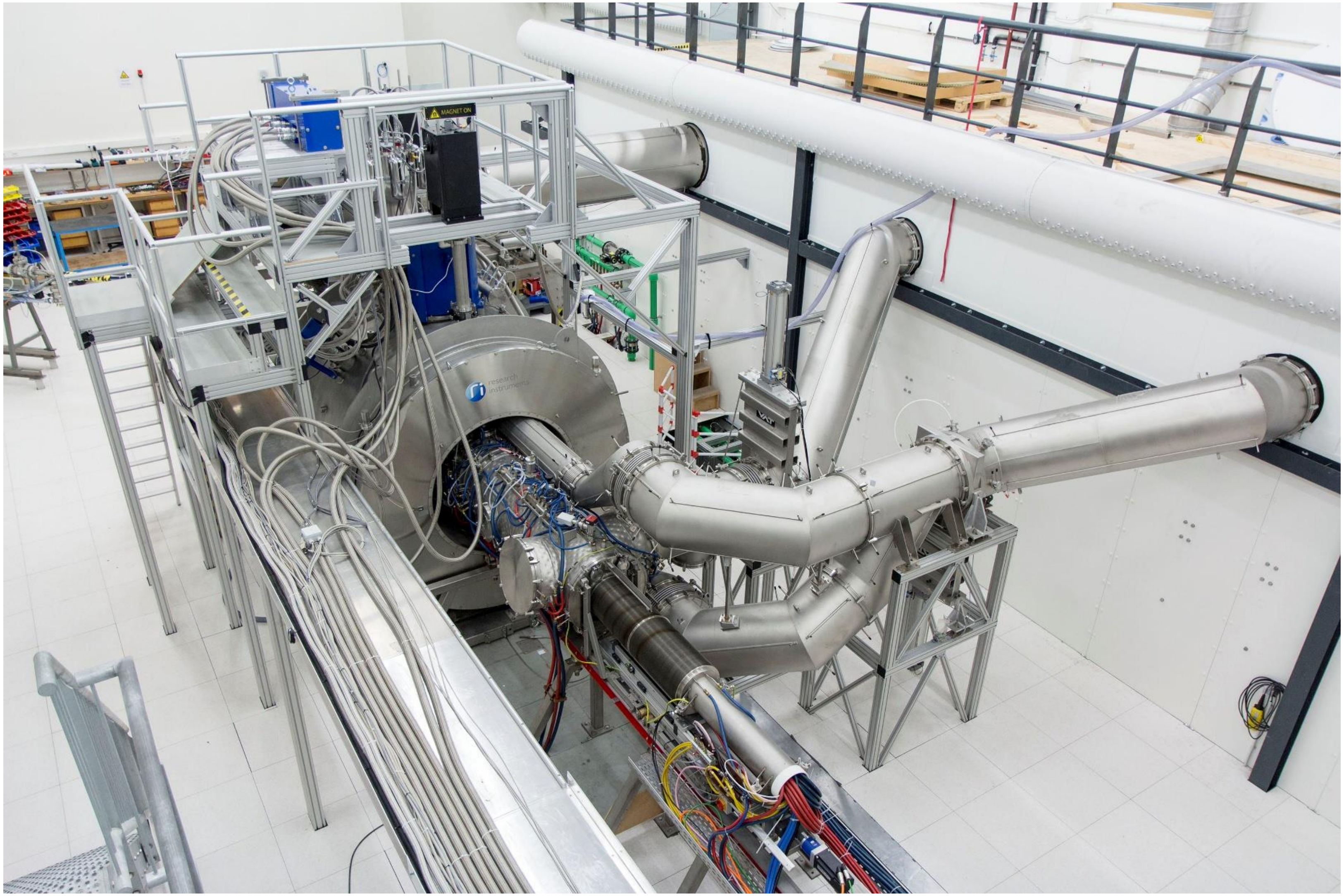
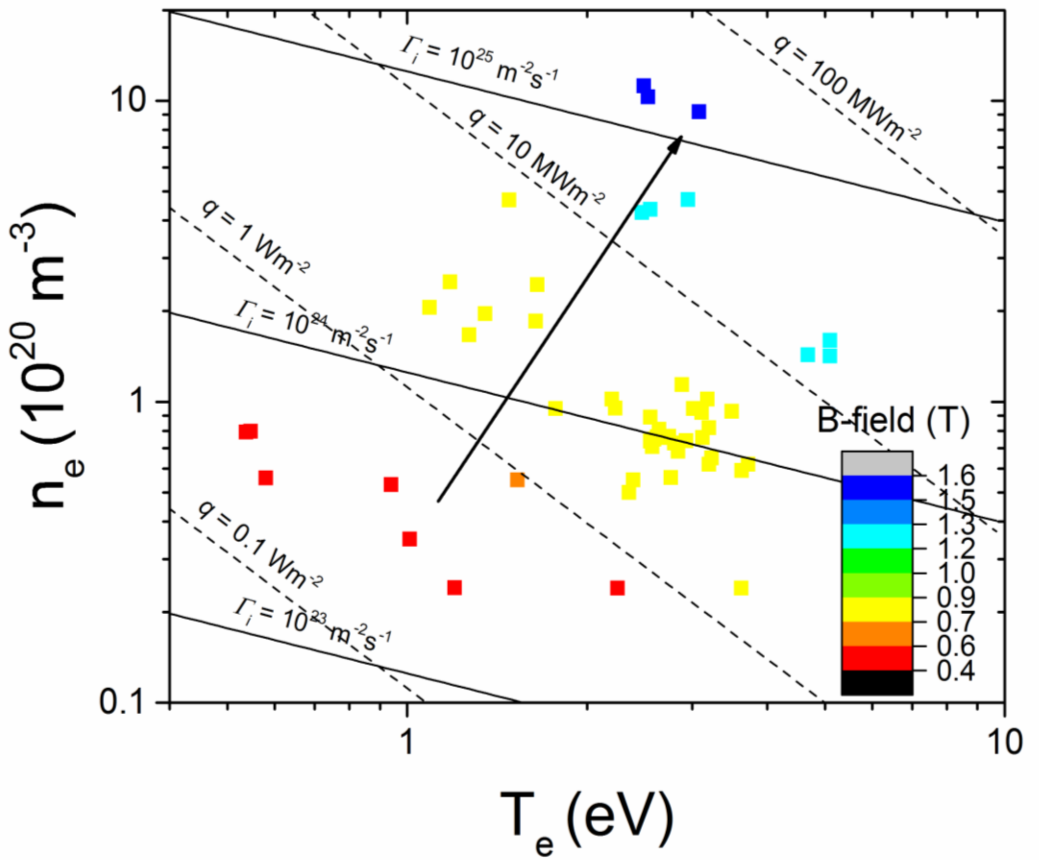


Installation at DIFFER Eindhoven



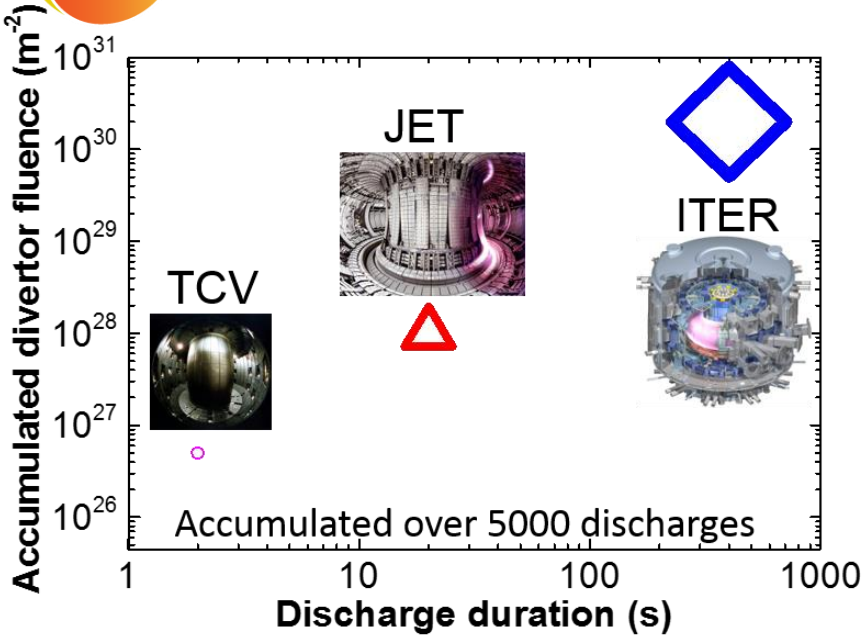
Operational space Magnum-PSI



Maximum plasma fluxes thus far achieved **41.6 MW m^{-2}**

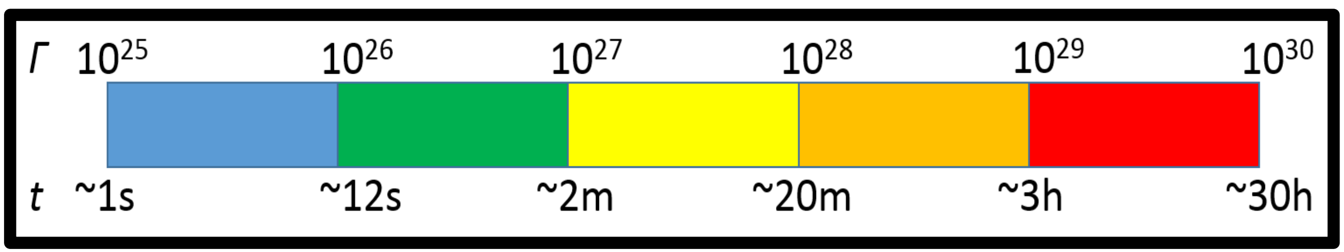
and **1.4x10^{25} particles m^{-2} s^{-1}**

Long fluence investigations now possible



Accumulated divertor fluence for different tokamaks [1] over 5000 discharges

High fluxes and steady-state performance are now achievable for the first time within a reasonable timeframe

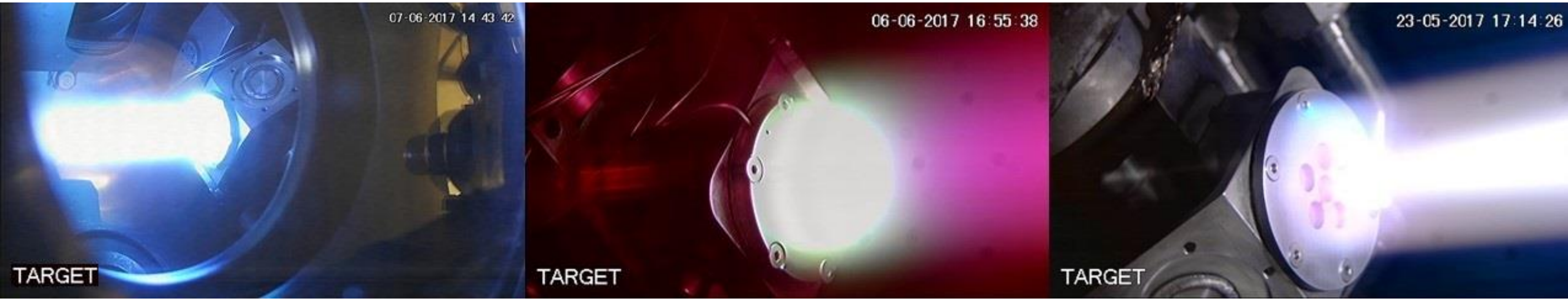


Time needed to reach a given fluence at q=10 MW m^{-2}
(T_e=1.0 eV, n_e=10.6x10^{20} m^{-3}, Γ=8.6x10^{24} m^{-2} s^{-1})

[1] G. De Temmerman et al. submitted to PPCF

Research program at DIFFER

- Assessing urgent plasma-surface interactions issues for ITER
- Potential of liquid metals as plasma facing materials for DEMO
- Plasma processing under extreme conditions



Conclusions

- Magnum-PSI is a unique research facility for Plasma Surface Interaction studies under extreme conditions.
- Construction of the 2.5 T superconducting magnet has been marked with many setbacks but is finally completed.
- Installation of this steady-state magnet has expanded the operational space with high fluence experiments.
- Experimental program started beginning 2017.
- Opportunity to visit DIFFER this Friday (Technical visit 3).