Pressure gauges with crystal cathodes

Summary of activities supported by EF 2019-2021 (ENR grant, ITER support by S1)

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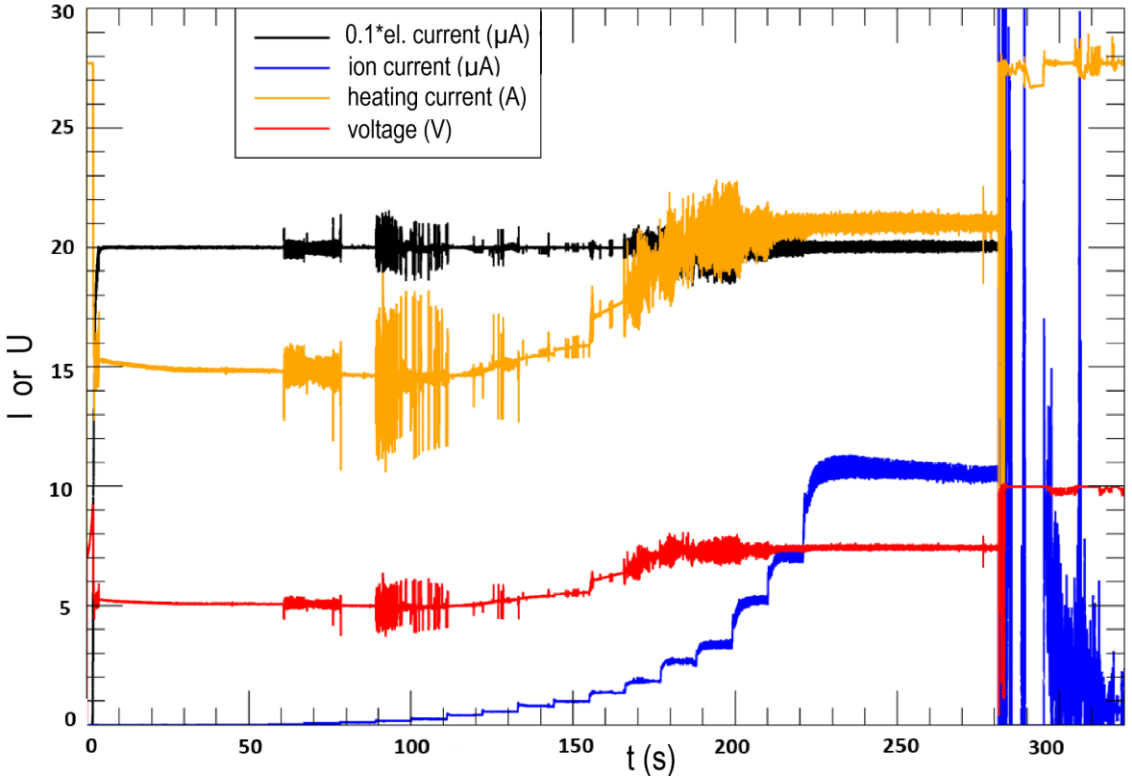
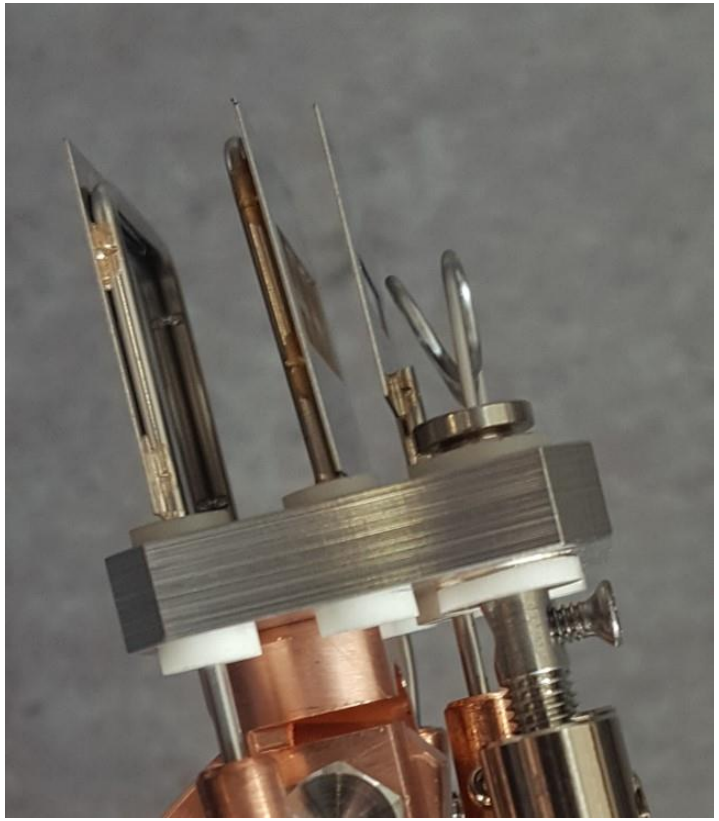
Intro 1 – Bad performance of APGs in W7-X

Temperatures of tungsten cathodes are often too high

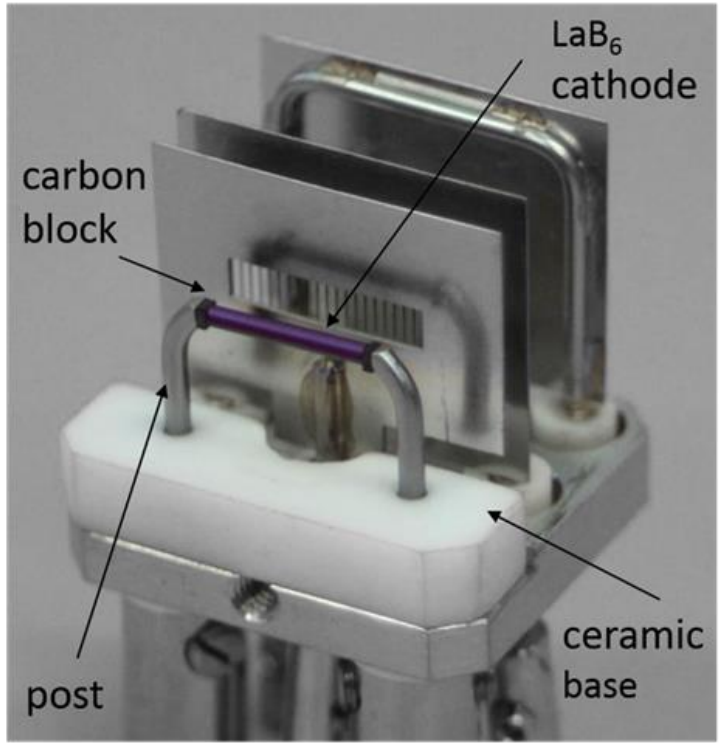
Cathodes can survive seconds but not 300 s …





.. and are subject of creeping deformations which result sooner or later to a short circuit

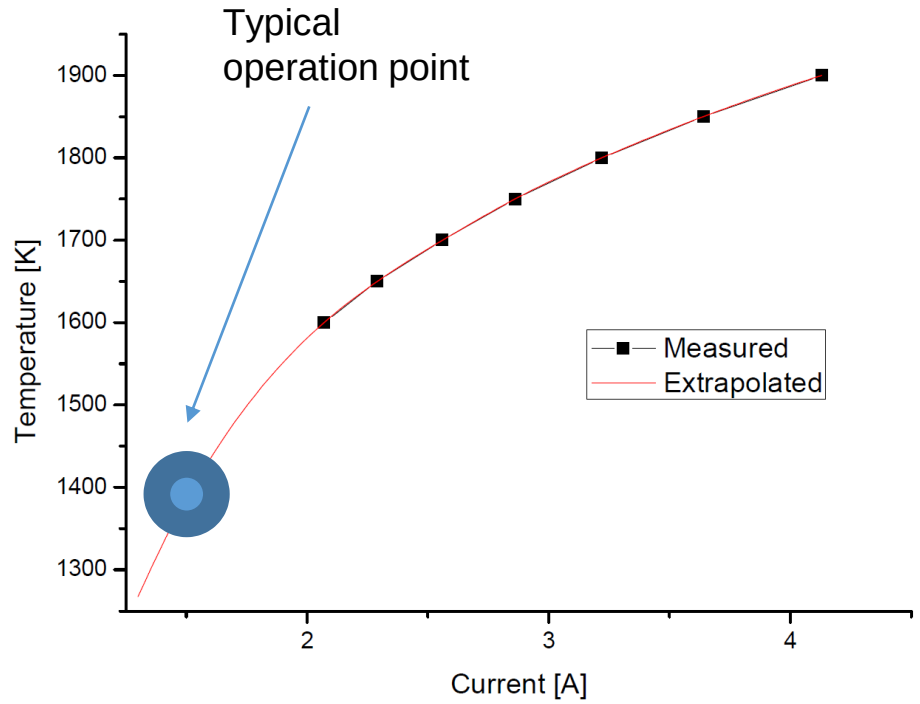
Intro 2: New design of the cathode with LaB_6 crystals



Typical heating current 1.5 A at 1400 K

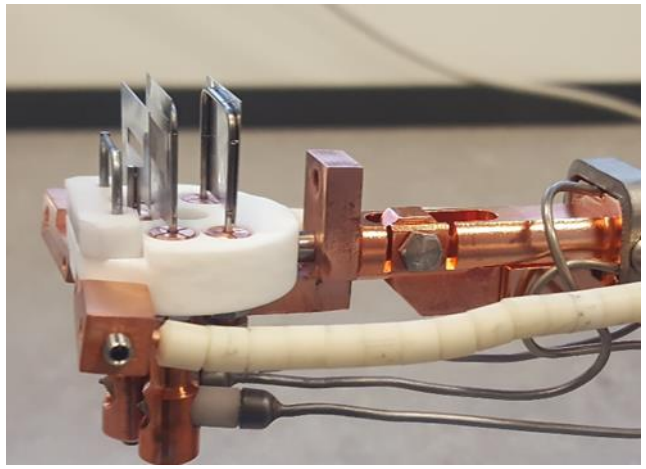
No creep

Large operation space up to 4 A

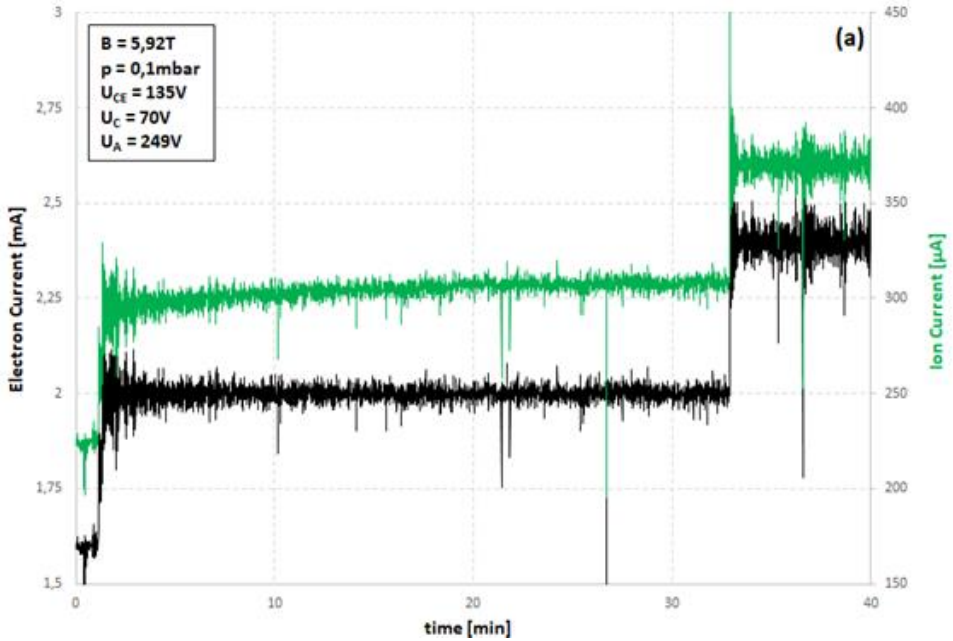


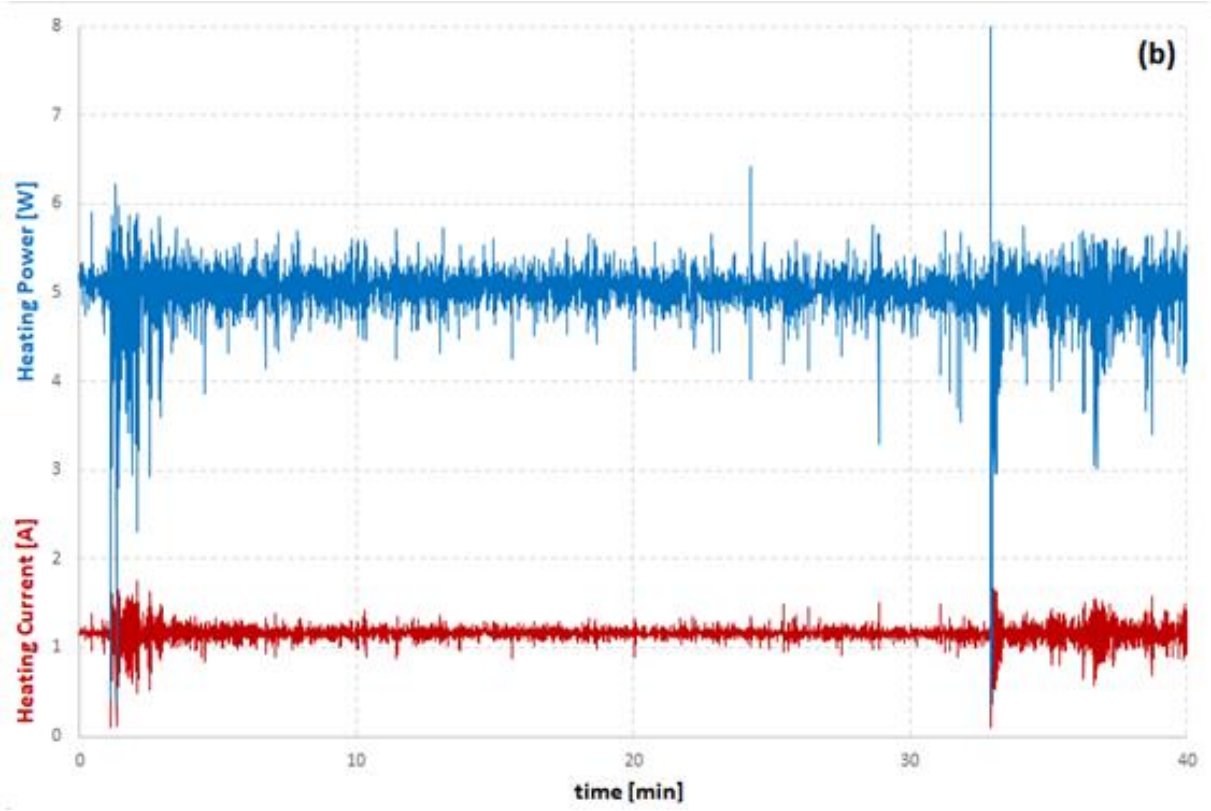
With the massive financial support from EUROFusion, we developed this concept further and tested it in W7-X and LHD. For lab tests we build a test stand with a superconducting magnet up to 6 Tesla (D-MAG).

Test in D-MAG at 6 T and 10 Pa over 40 min



5 mm
LaB6
crystal



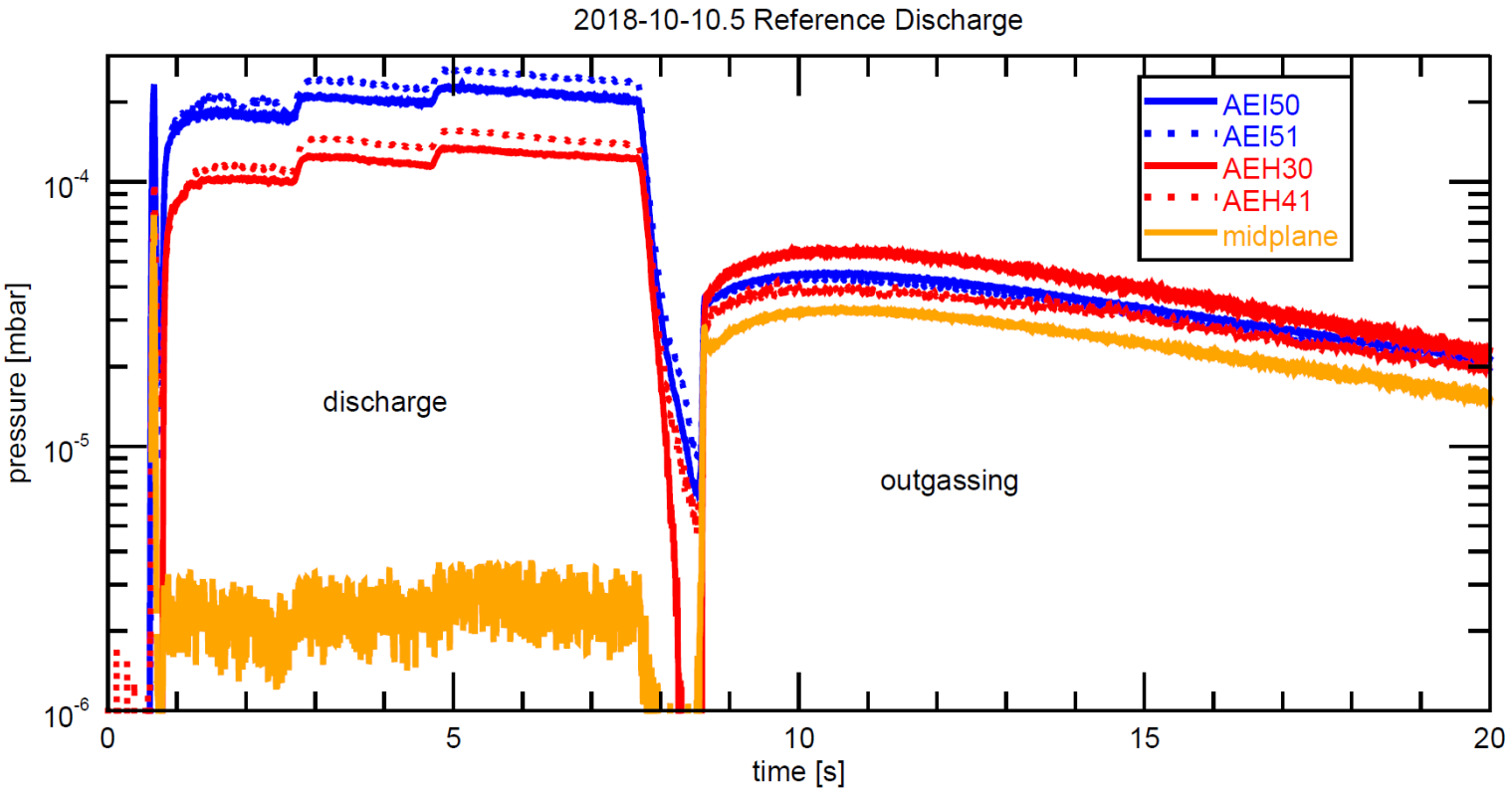


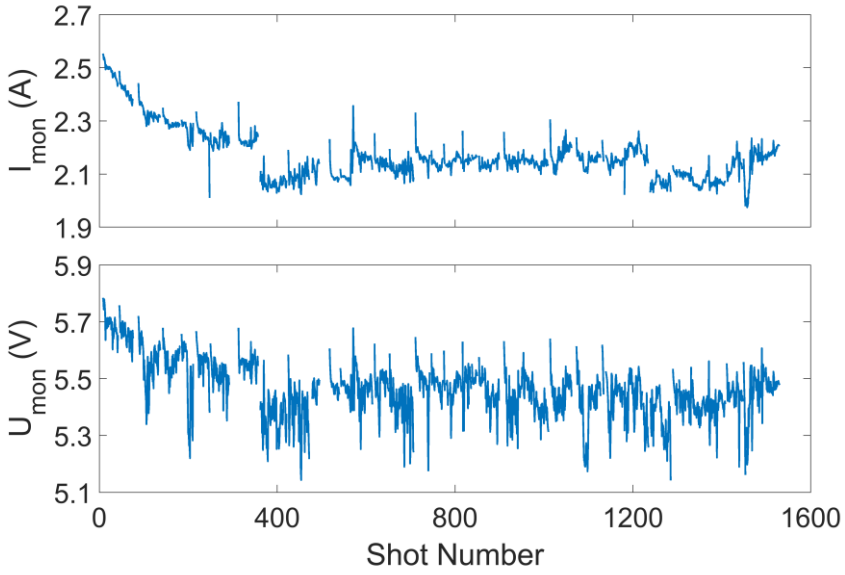
Low current (1.1A) and power consumption (5 W)

Very good performance in Wendelstein 7-X (OP1.2b)

We operated 9 LaB6 gauges and 9 tungsten gauges

All LaB6 gauges were functional without any problems.



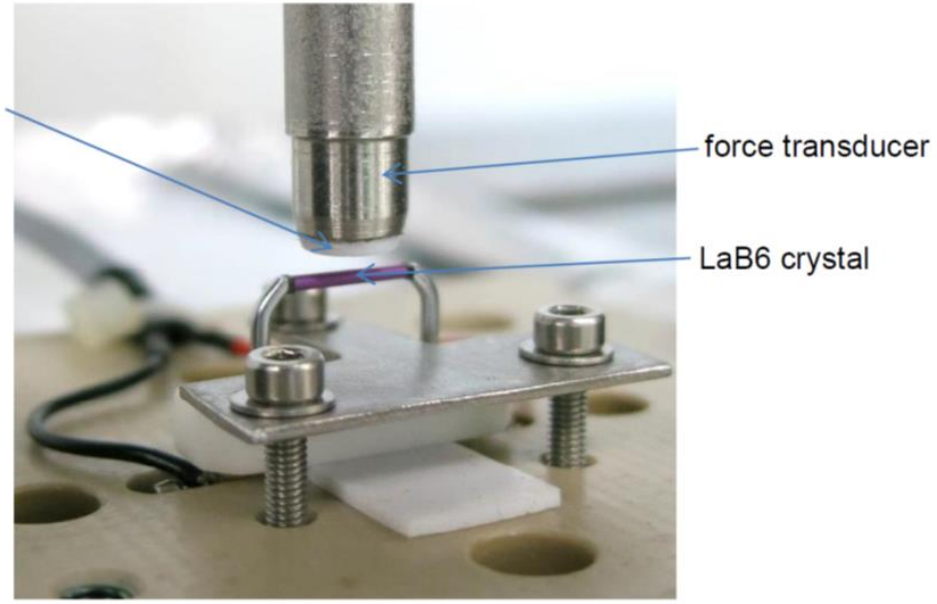


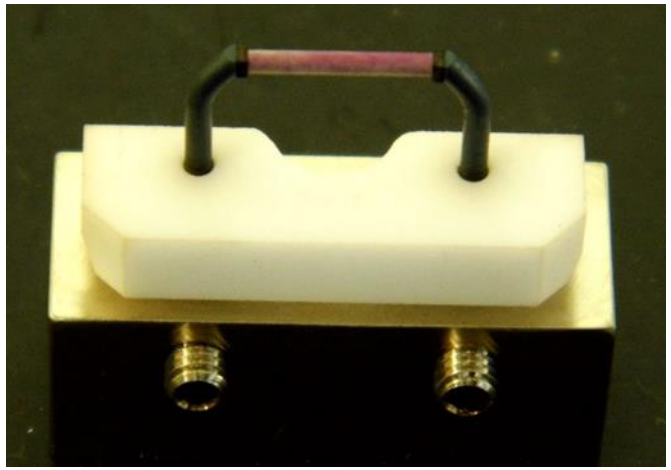
Stable power consumption of the cathodes over the campaign

Clamped design has good stability

- Stability in the magnetic field: Static force of 4 N is needed to pull-out the crystal (equivalent to 60 T at 2A)
- Can survive accelerations of 17000 g during disruptions.
- Survived the steam test in KIT
- Boron 10 has a large cross section for neutron capture.

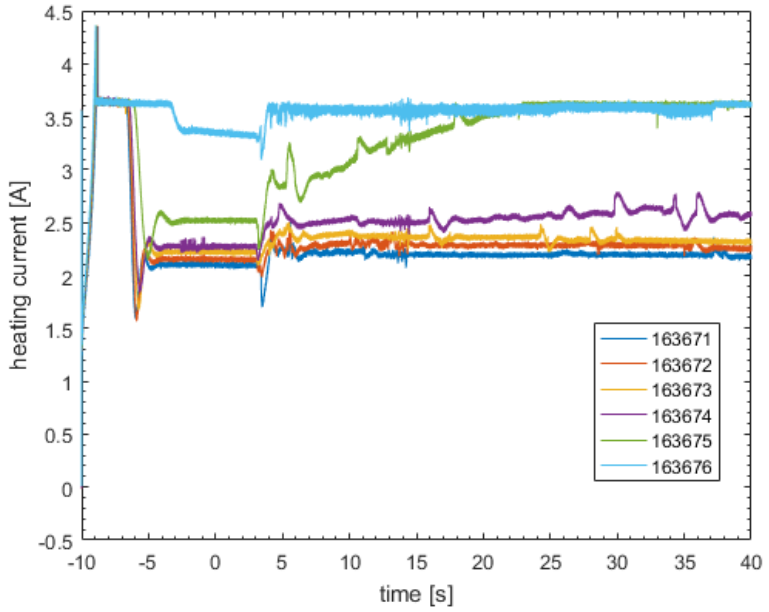
Test of the structural stability by the ITED group in a nuclear reactor. After an ITER relevant radiation dose the LAB6 crystal was not broken due to the clamping force of 400 bar as feared.



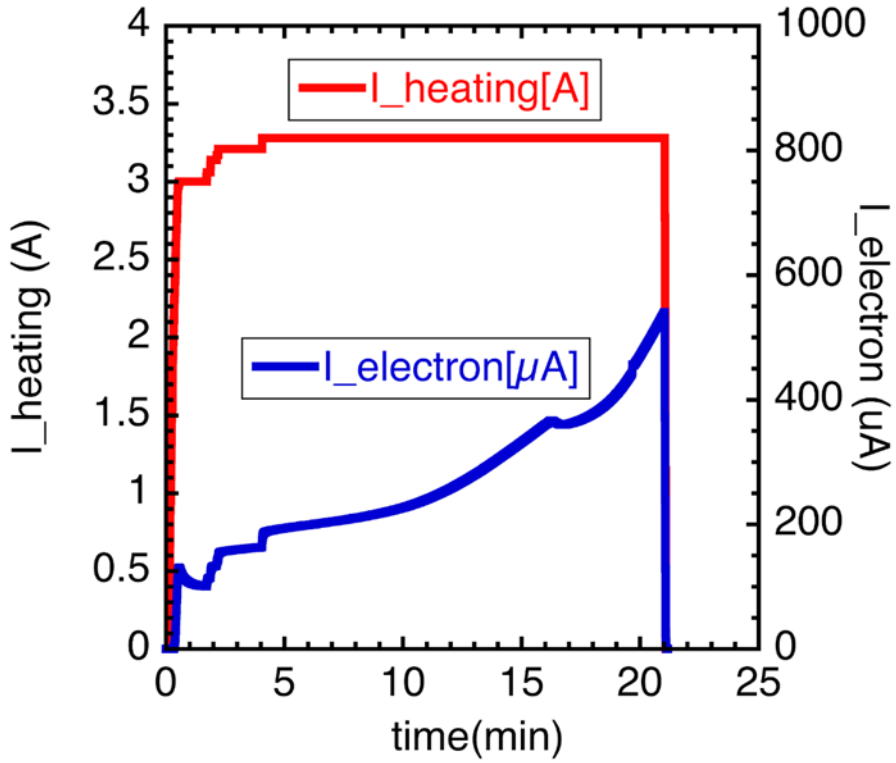


Test in the LHD during deuterium operation 20/21

2 CCPGs in the LHD:
midplane and divertor position



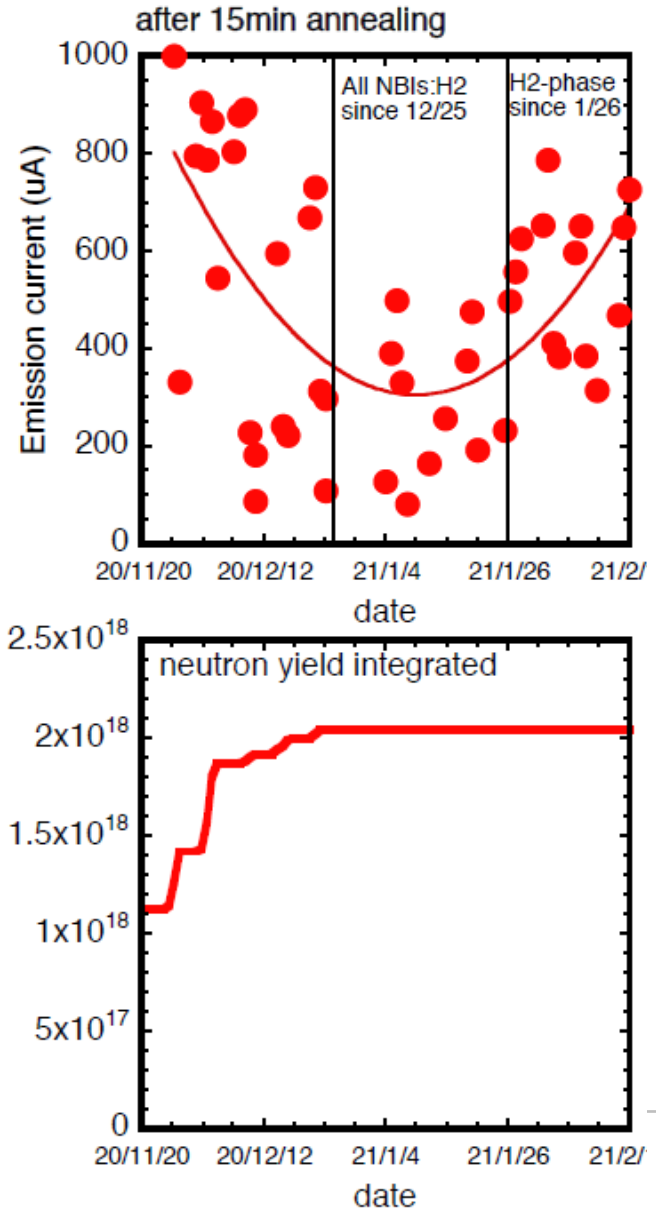
CCPG was heated every morning for recovery



On 26.11.2020 the heating current of the CCPG in the divertor run against the technical limit (3.7 A)
Electron current was reduced from 200µA to 50µA but this did not solve the problem:

.. but without permanent success

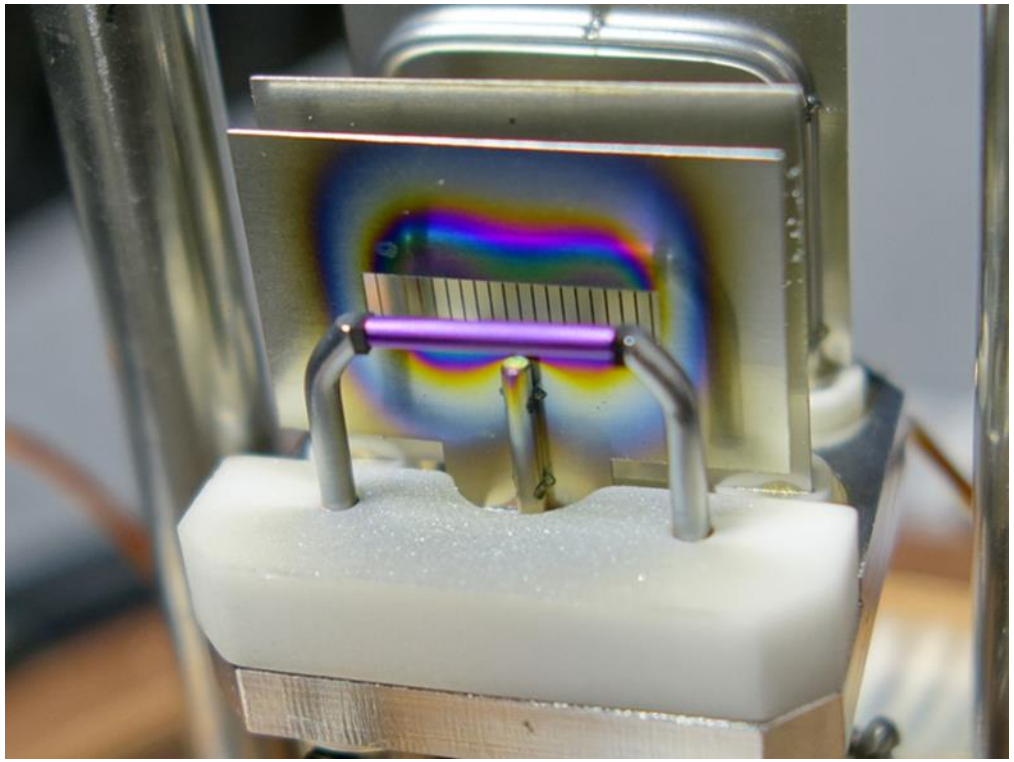
Now the LaB_6 cathode had to be heated daily in the morning



Performance after 15 min of annealing

Slow recovery after the neutron phase

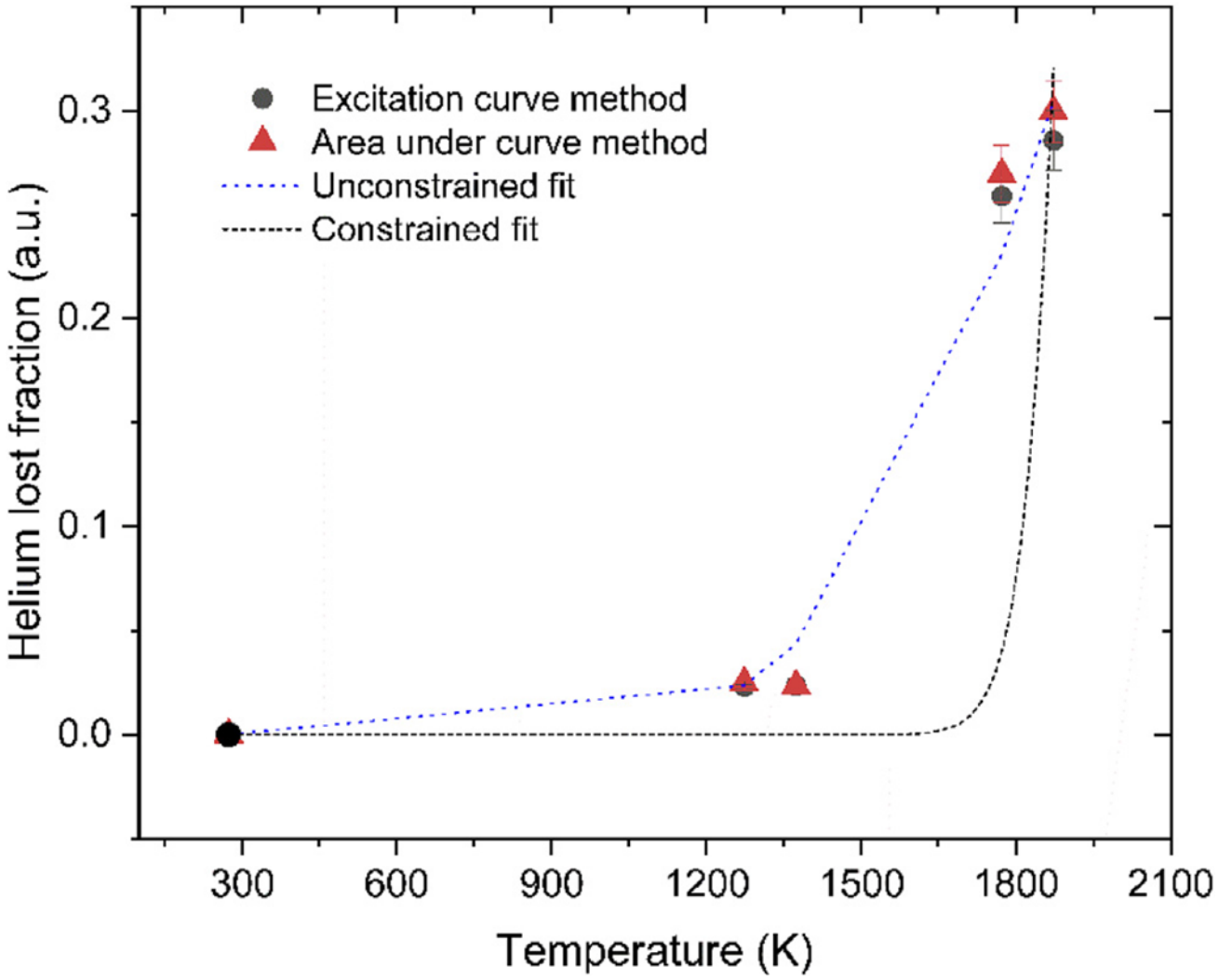
With neutrons LaB6 is in some way sensitive to deuterium gas. Gas can be removed by heating but the problem remains.



Control electrode had a layer of evaporated LaB6

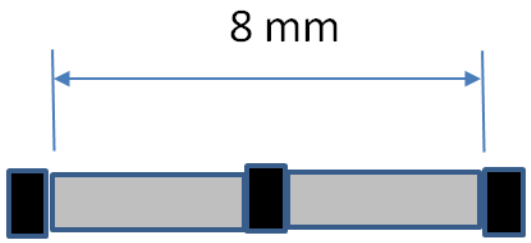
Use of another cathode material - ZrC

- A simple replacement by the ZrC rod did not work.
- Hollow profile of temperature due to lower heat conductivity
- Very sensitive to helium gas up to deactivation, i.e. no electron emission at all.
- Reason is possibly the helium retention
- Cathode must be operated with 1900 K or more



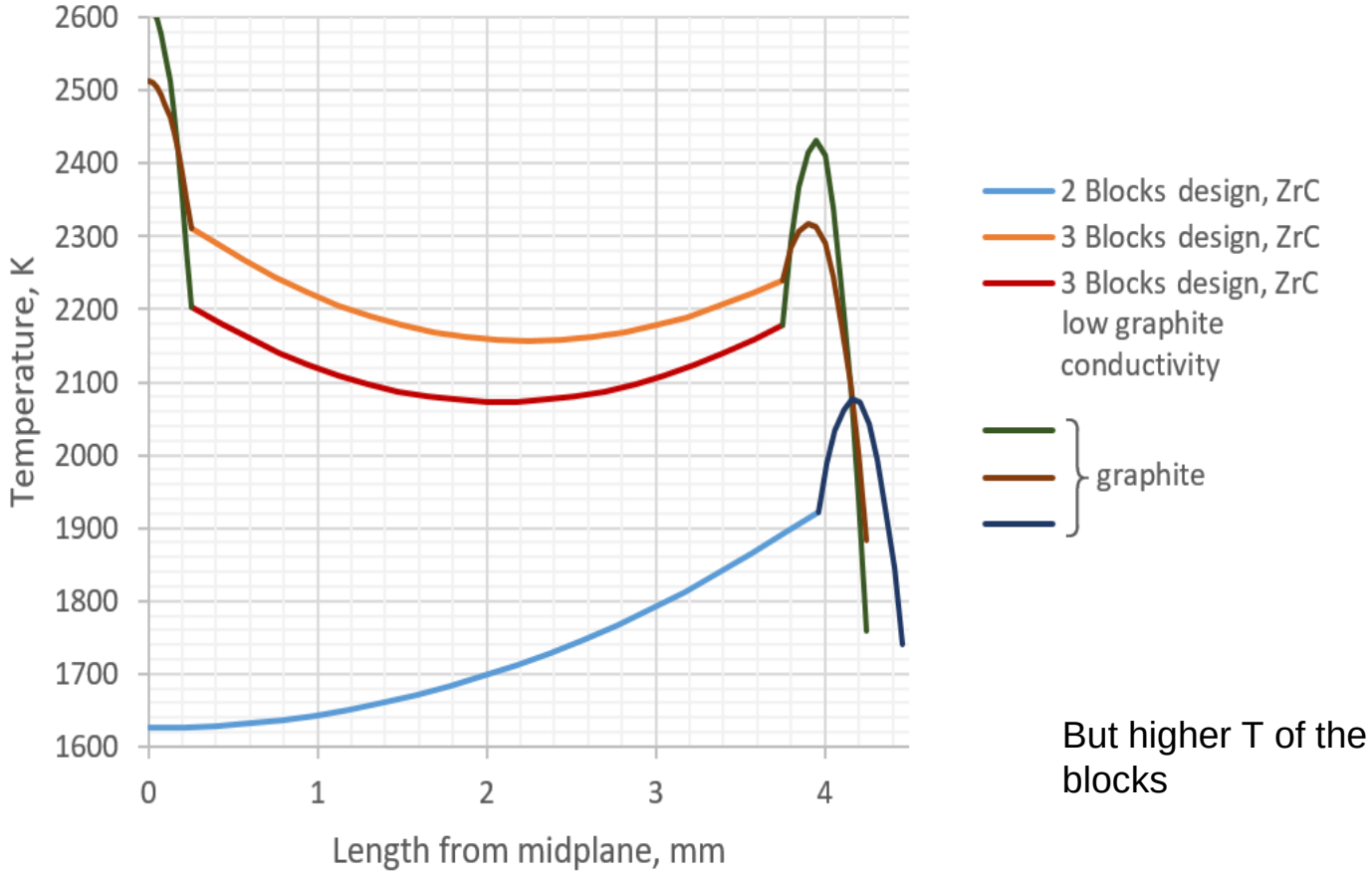
3-block design with ZrC

Flat profile with a 3rd central block



Heating current is 3.4 A.

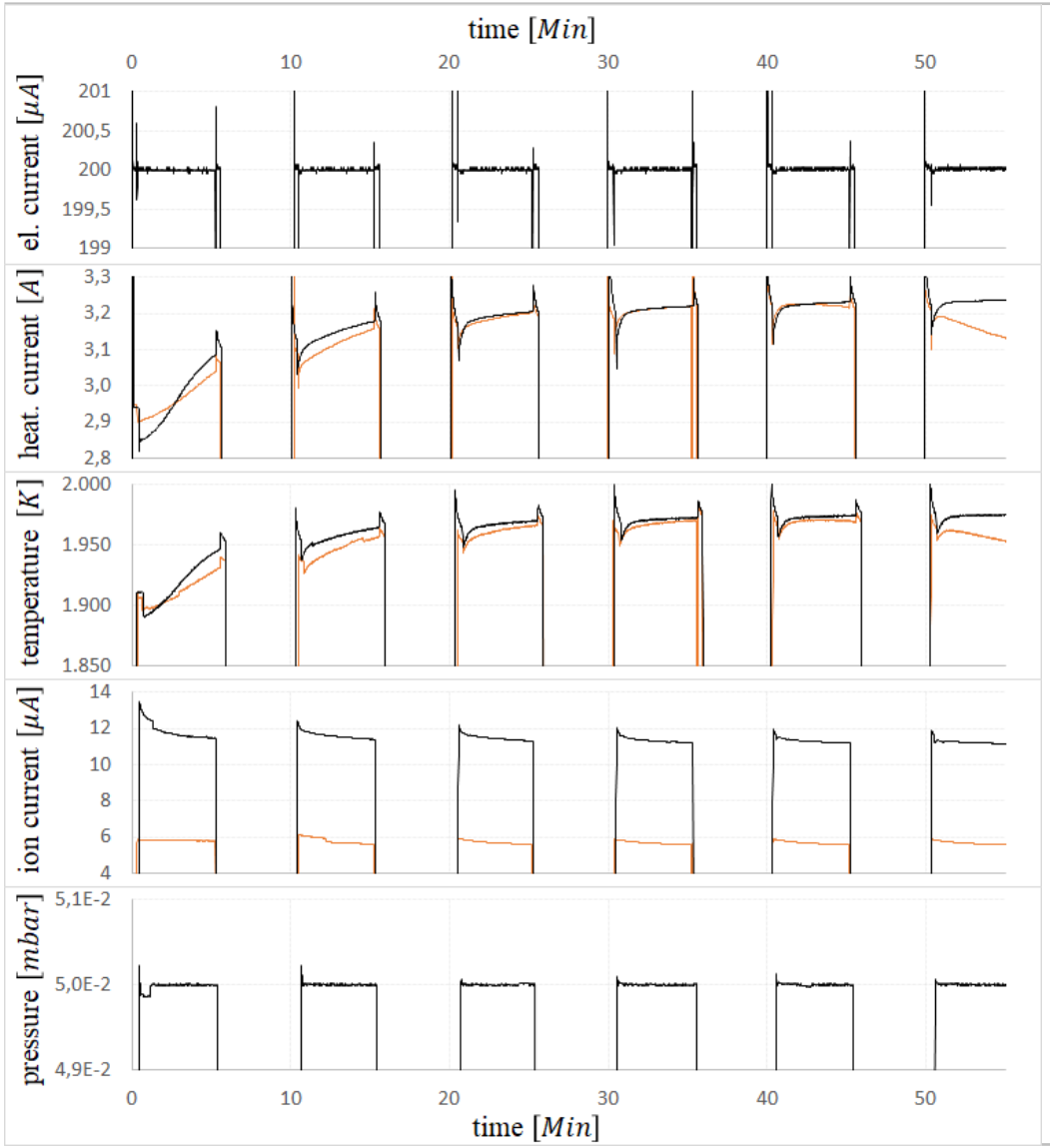
Higher temperatures everywhere, also of the outer blocks. Lower operation limit.

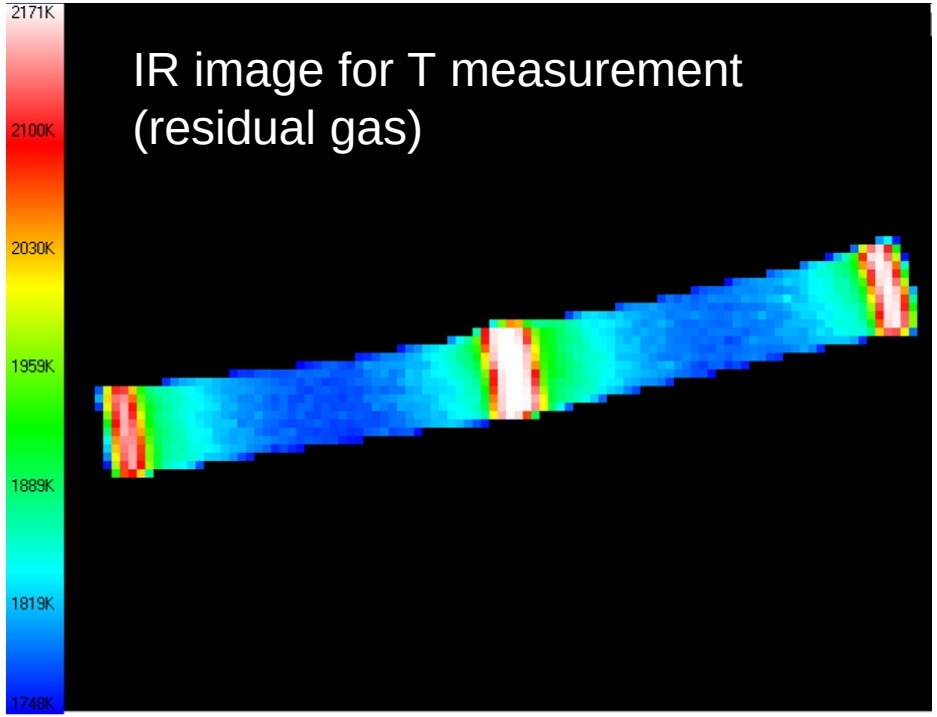


But higher T of the blocks

Simulation by Khokhlov, Zhu and Bykov (2020)

Successful operation of the 3-block-design at 5e-2 mbar (without B field)



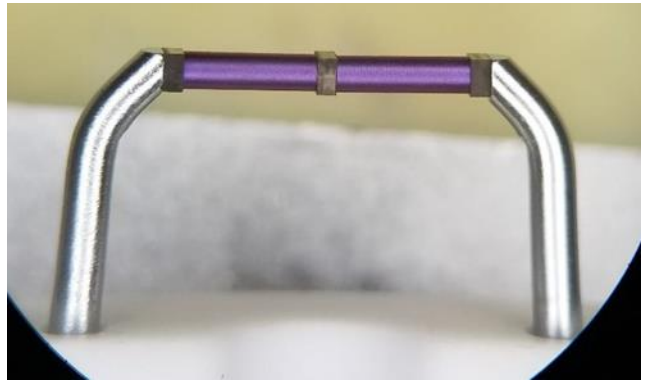


Increase of the heating current to 3.2 A
Safety limit is 3.5 A
High temperature of ZrC: 1960K
No differences between hydrogen and helium

Use of another cathode material - ZrC

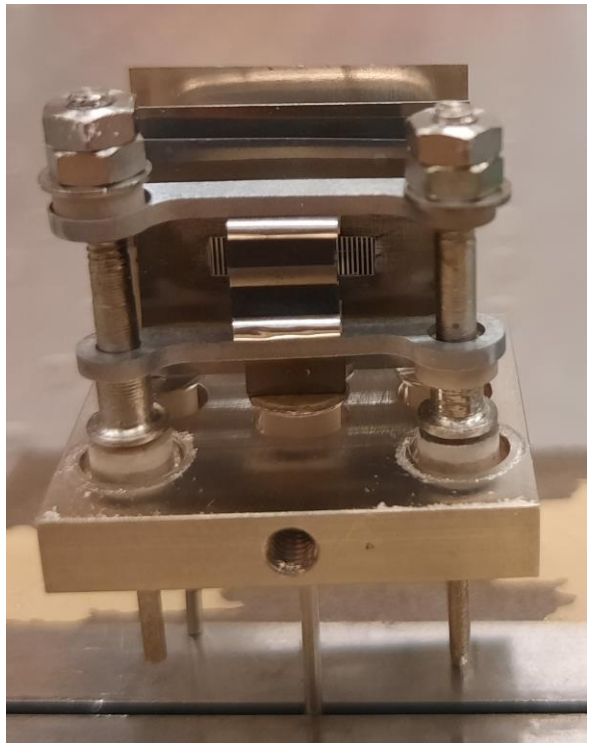
We have 2 alternative solutions for high-temperature cathodes

Central block (W7-X)



As with tungsten, operation in the lab only possible near the operation limit.
Nothing must happen in a fusion device, e.g. by neutrons.

vertical flow of the current (ITED)



Common understanding of LaB6 and ZrC

- Solids can take in gas and release gas during heating.
- The balance depends on neutral pressure and temperature
- Different retention properties explain the significant differences of LaB6 and ZrC

Problem by gas intake

- **The behaviour of LaB6 in the LHD can be explained by higher gas content in LaB6 modified by neutrons.**

Problem by retention

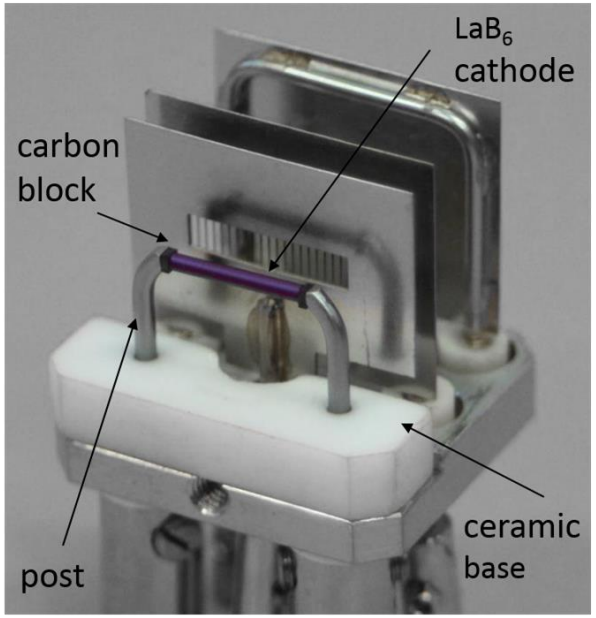
- **The deactivation of ZrC in helium at low temperatures can be explained by the high retention threshold of helium.**

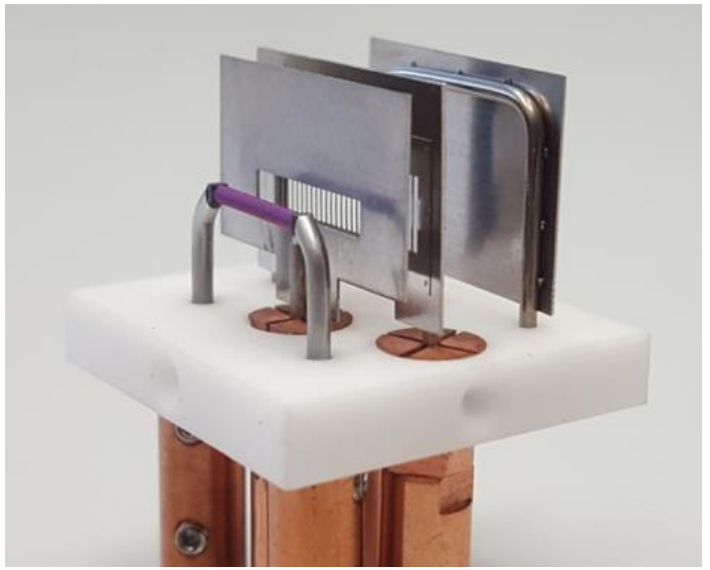
Summary

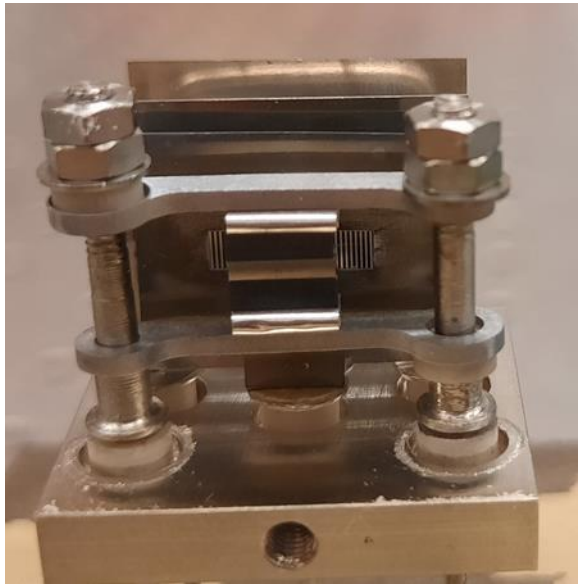
- The first design with an 8mm LaB6 rod worked very good in hydrogen. Cathode temperature is low. No problems with gas retention but it had problems in the LHD during the neutron phase probably due to enhanced storage of gas at high pressure.
- We developed different alternative designs with LaB_6 and ZrC. For ZrC, temperature must be high because of the high retention of helium (different to LaB_6).
- The new designs are stable in the lab but they were not yet tested in W7-X or in the LHD with neutrons.
- Support of Eurofusion for these activities will end in 2021. A part of the presented results were published in 3 articles in the Review of Scientific Instruments.
- Some activities will continue, however, on a lower level in W7-X, LHD and D-MAG.

Outlook 1 – Further tests in the LHD 2021/22

- Further tests in the LHD in the 2021/22 campaign with 3 CCPGs with LaB_6





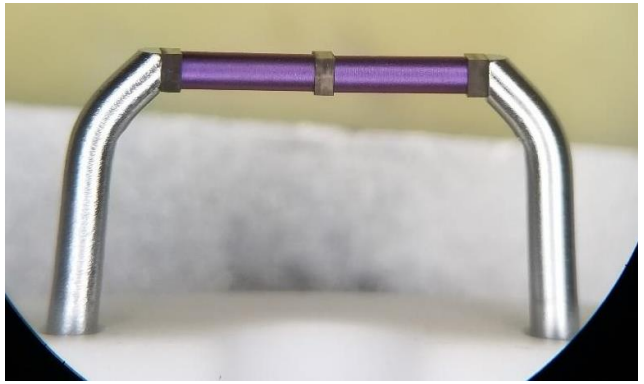


8 mm rod | 6 mm rod on ceramic plate | sandwich (from ITED)

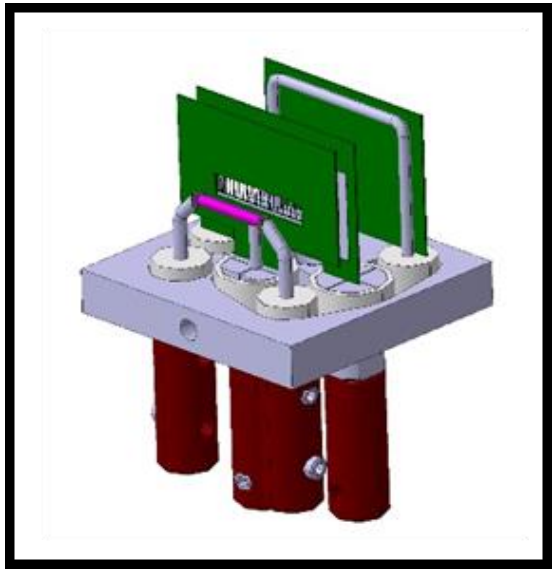
- All gauges are functional and calibrated in the B field.
- The sandwich-design with ZrC failed in the pretest in D-MAG und was not installed.

Outlook 2 – Operation in Wendelstein 7-X 2022/23

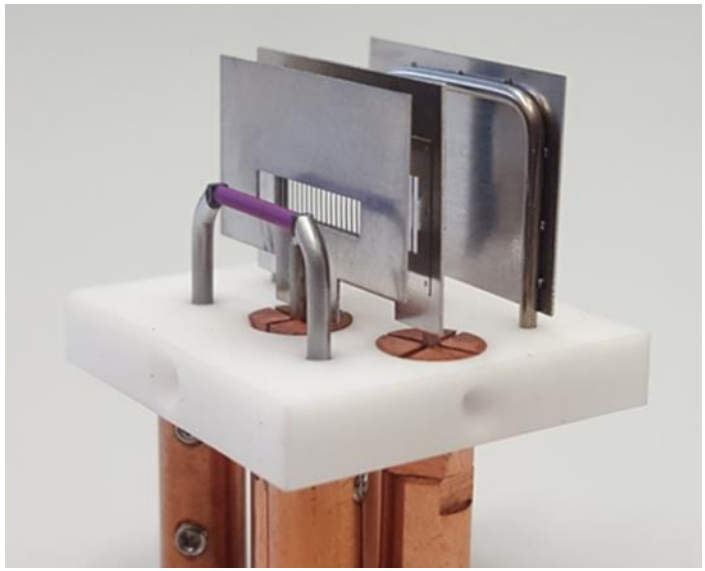
- Wendelstein 7-X: Full set-up with 18 LaB6 pressure gauges in different designs in the campaign 2022/23. Hydrogen operation. No problems expected.



3-block-design



metal base plate



ceramic base plate

- A test of the ITER DPG in Wendelstein 7-X was also planned for the campaign 2022/23. It was canceled in August this year by ITED.

Outlook 3 – D-MAG

- Test of the ITER DPG in D-MAG is planned for 2022. The financial basis of this test is not fully cleared.

TODO

- **A test of a ZrC pressure gauge in a fusion device with neutrons would be desirable. A very good experiment would be JET during the D/T campaign. We thought about this with Joao in the past, but there were no activities of refurbishment. Maybe a test is possible in LHD or, on a longer time scale, in an ITER companion.**