Experimental possibilities in Jülich – an update

15th June 2016

| M. Köppen
| A. Allouche, F. Aumayr, D. Borodin, J. Bröder, T. Dittmar, K. Dobes,
| P. Dollase, J. Du, Y. Ferro, A. Kreter, J. Linke, Ch. Linsmeier, D. Matveev
| C. Pardanaud, B. Spilker, B. Unterberg, T. Weber

Outline

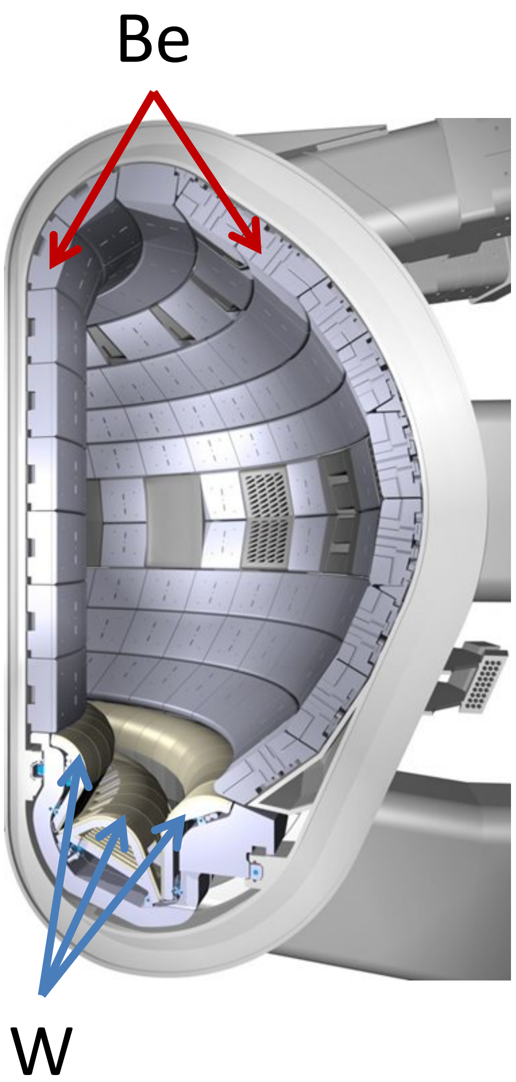
1. Motivation

2. Update on experiments
   - XPS
   - Raman
   - ARTOSS
   - FREDIS
   - JULE-PSI
   - JUDITH 1 & 2

3. Concluding Remarks

Motivation

- ITER material mix: Be and W
  - 700 m² Be
  - W in divertor region
- Plasma impurities
  - Seeding gas, e.g. Nitrogen
  - Contaminations, e.g. Oxygen
- Material transport by:
  - Erosion
  - Plasma transport
  - Re-deposition



Why is compound formation of interest?

- Elevated temperatures and ion irradiation lead to solid state reactions
  - e.g. Be_2W alloy formation in divertor region

- Be-based mixed materials have new properties compared to Be:
  - Isolating / different conductivity
  - Altered hydrogen retention
  - Co-deposits
  - Ammonia formation

- Physical and Chemical Data needed as input data for e.g. ERO, SOLPS, WallDyn to predict first wall properties for future devices

	Be	BeO	Be_3N_2	W	WO_2	WO_3
Melting Point [K]	1551	2780	2473	3683	1773	1746
$\Delta_f H°$ [kJ mol^{-1}]	--	-609	-558	--	-590	-843

Multi-method approach: Solutions

Be-mixed materials

Chemical analysis:
- XPS, ARXPS
- RBS
- NRA
- CRDS
- TDS

Erosion and implantation yields:
- QMB-experiments
- SDTrim.SP
- TDS

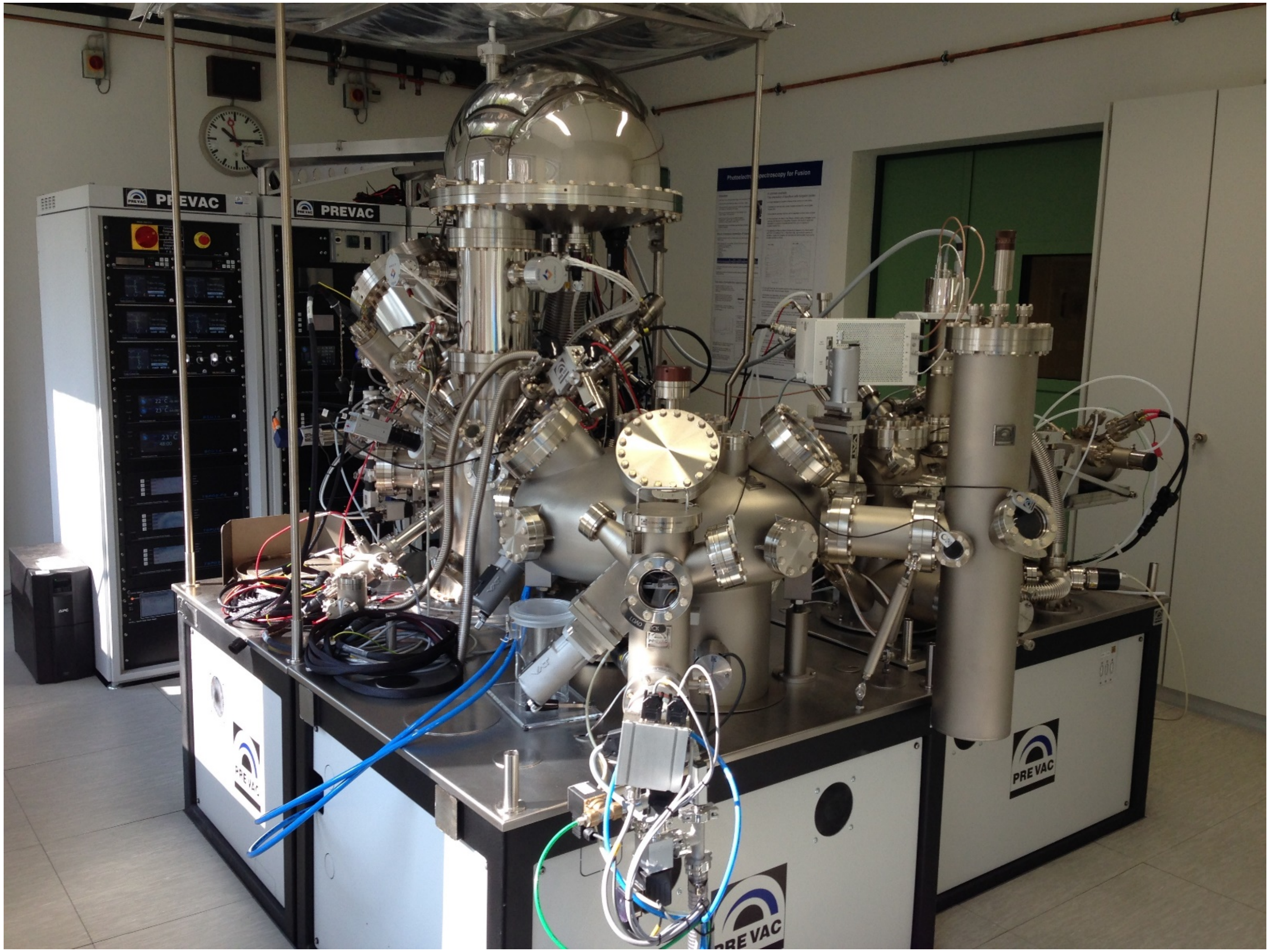
Hydrogen retention and release:
- NRA
- TDS
- DFT
- EELS

Bonding mechanisms:
- UPS
- XPS
- Raman
- DFT

XPS setup

Investigation of Be-based mixed materials

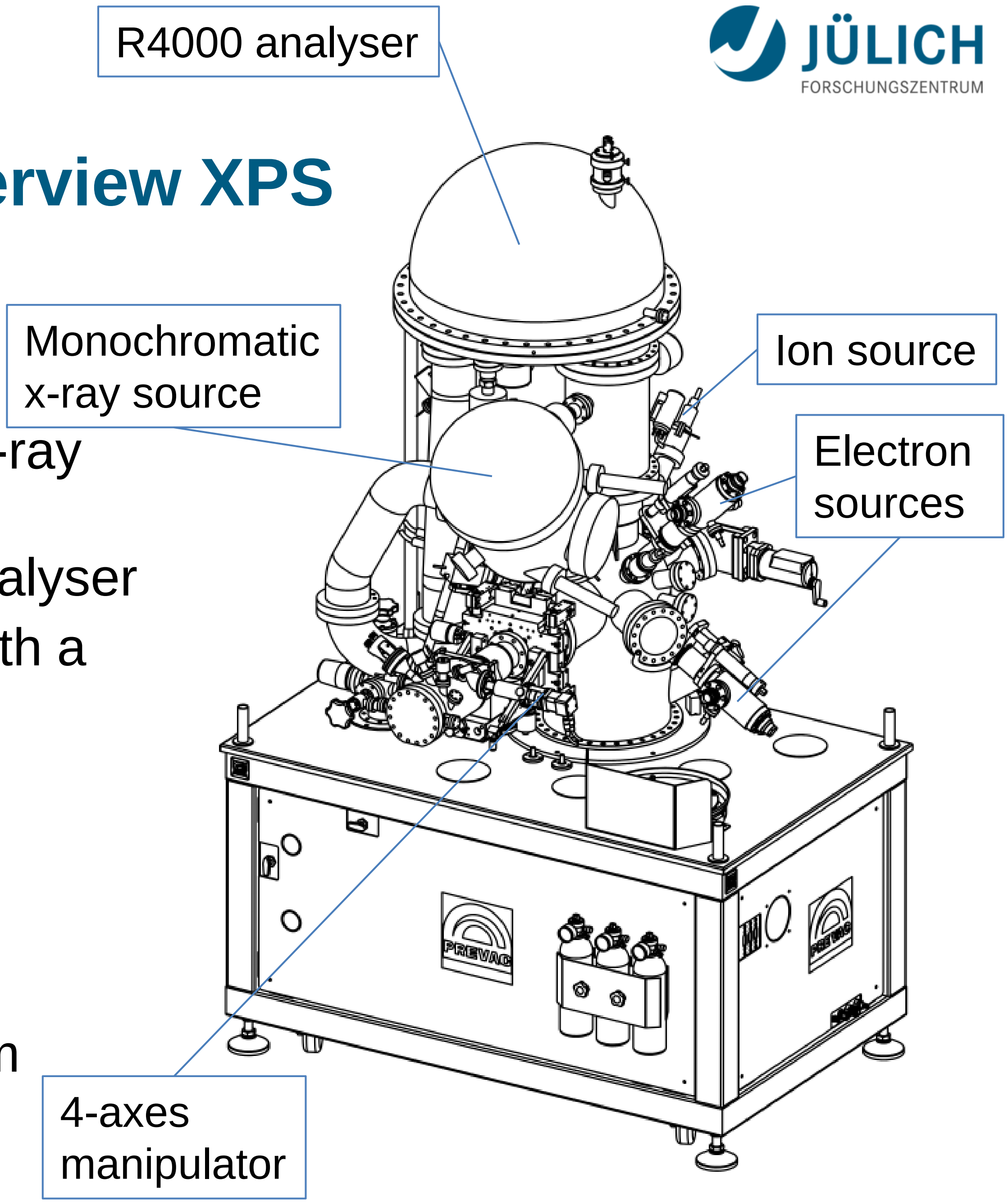
Experimental Setup



Experiments: Overview XPS

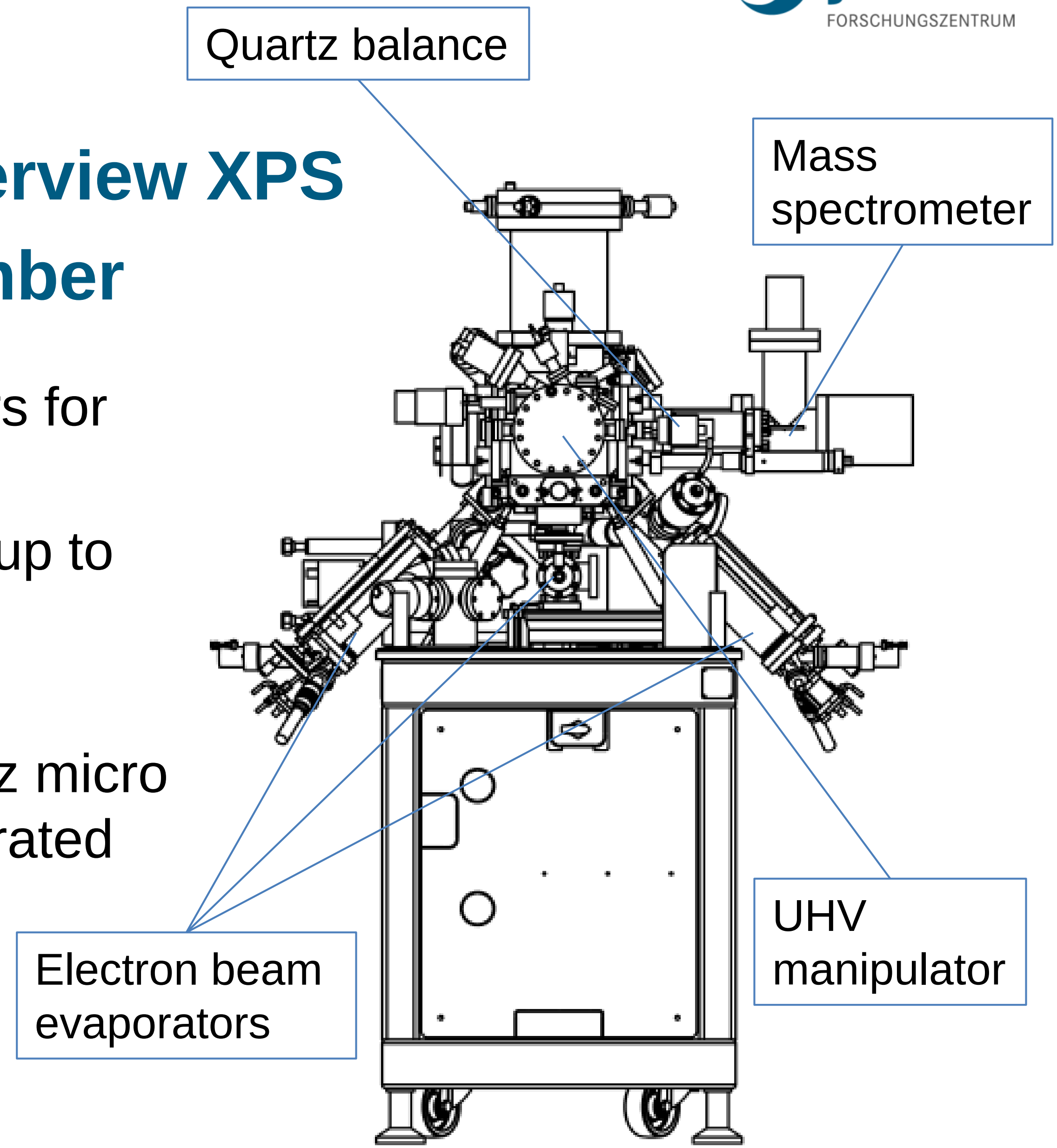
Main chamber

- XPS
  - Monochromatic x-ray source
  - Hemispherical analyser
- 2 ion sources, one with a Wien Mass Filter
- 2 electron sources
- UV source
- Sample size:
  - heating: 2,5 cm
  - Non-heating: 5 cm

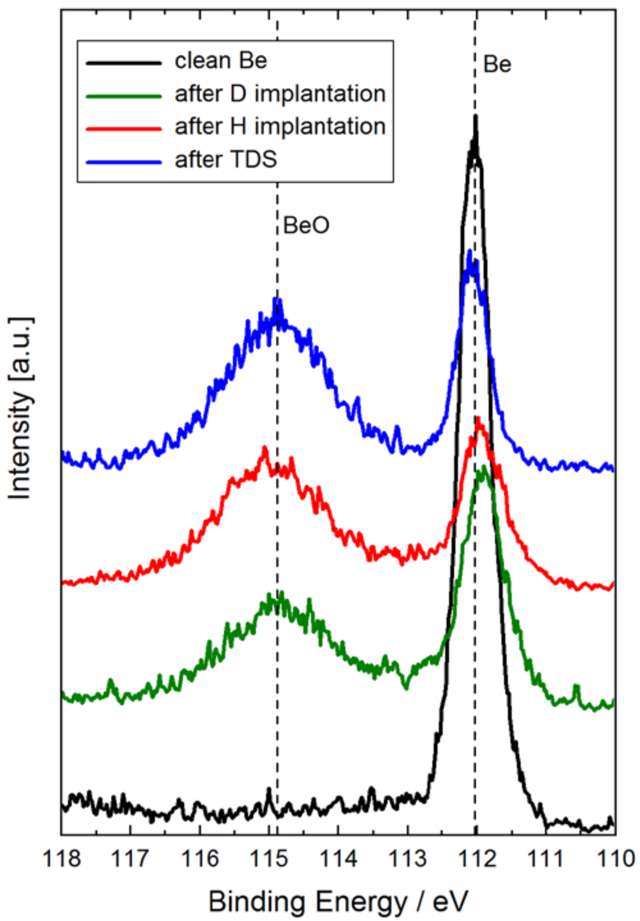


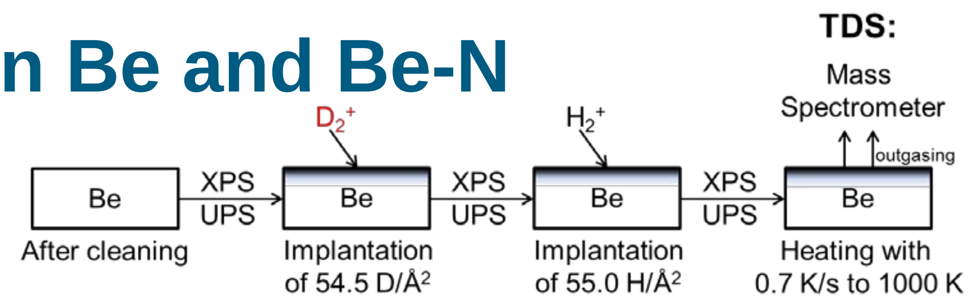
Experiments: Overview XPS Preparation Chamber

- 3 electron evaporators for W, C, Be
- Manipulator, heating up to 2500 °C
- Mass spectrometer
- High-resolution quartz micro balance can be integrated

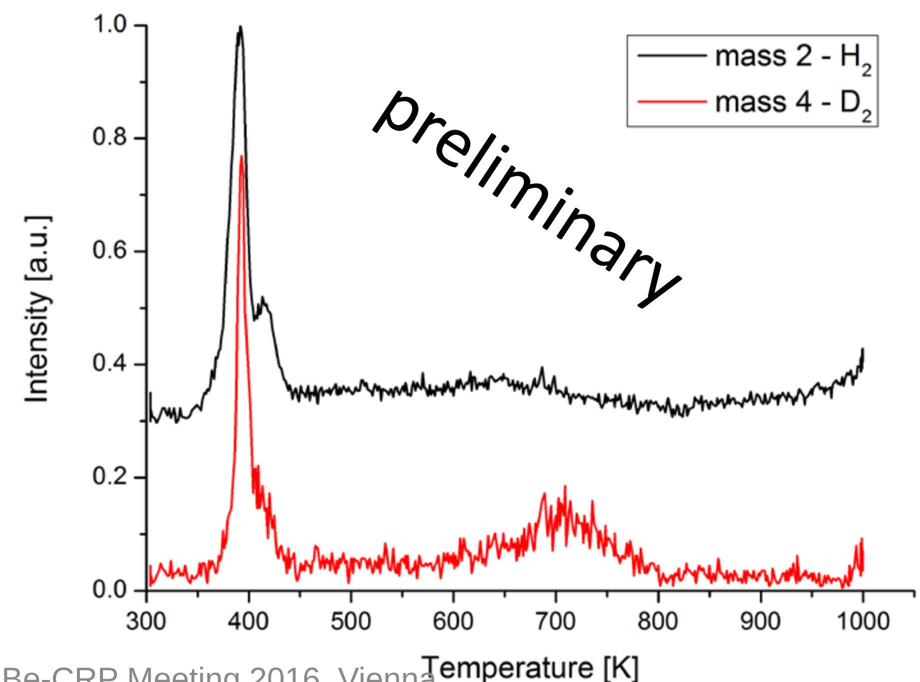


Isotope exchange on Be and Be-N

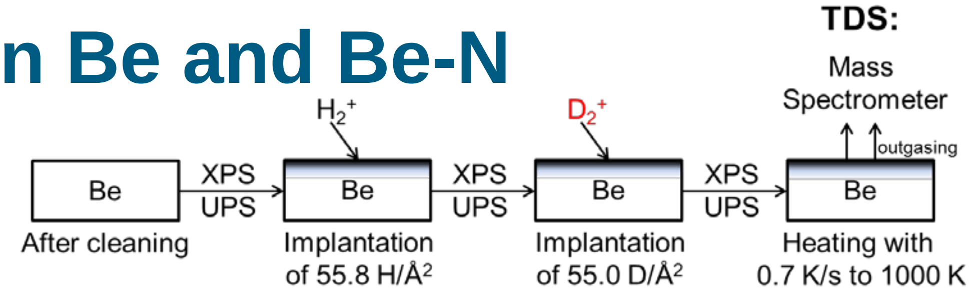




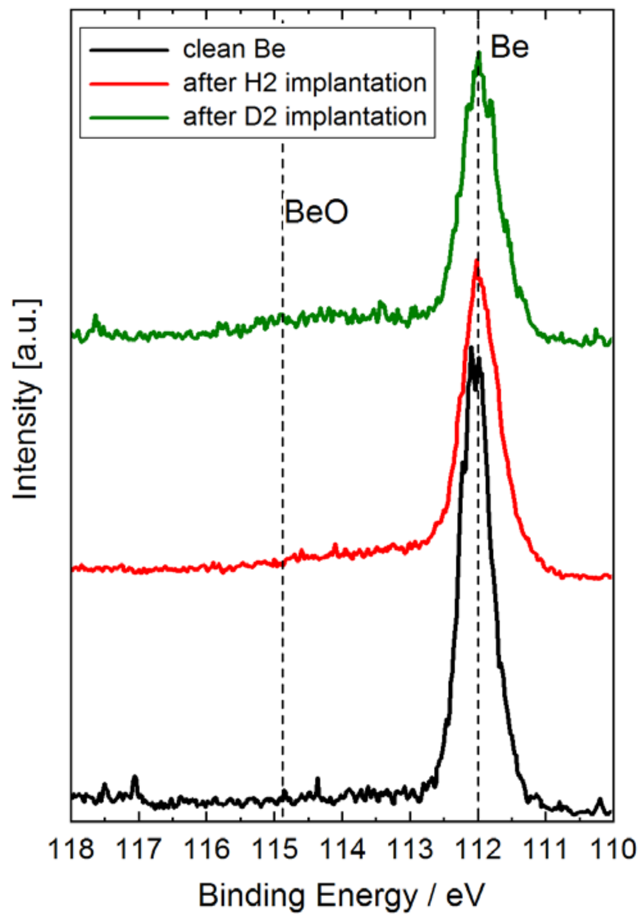
Implantation conditions: 3 kV → 1.5 keV/D or H
Area: 2.5 x 2.5 mm^2; Sample current: 0.6 – 1 μA

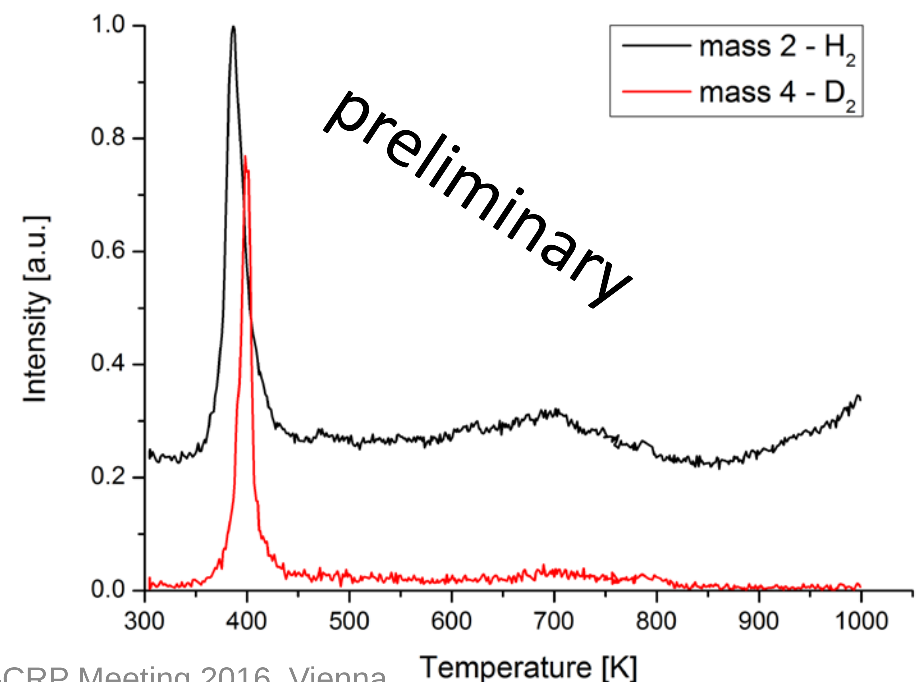


Isotope exchange on Be and Be-N

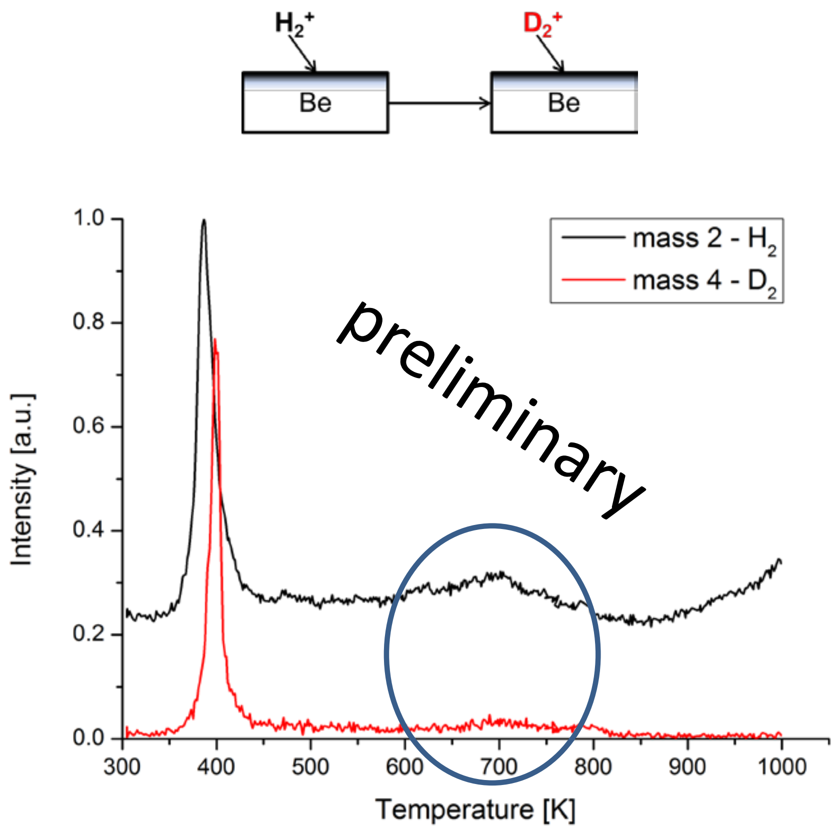


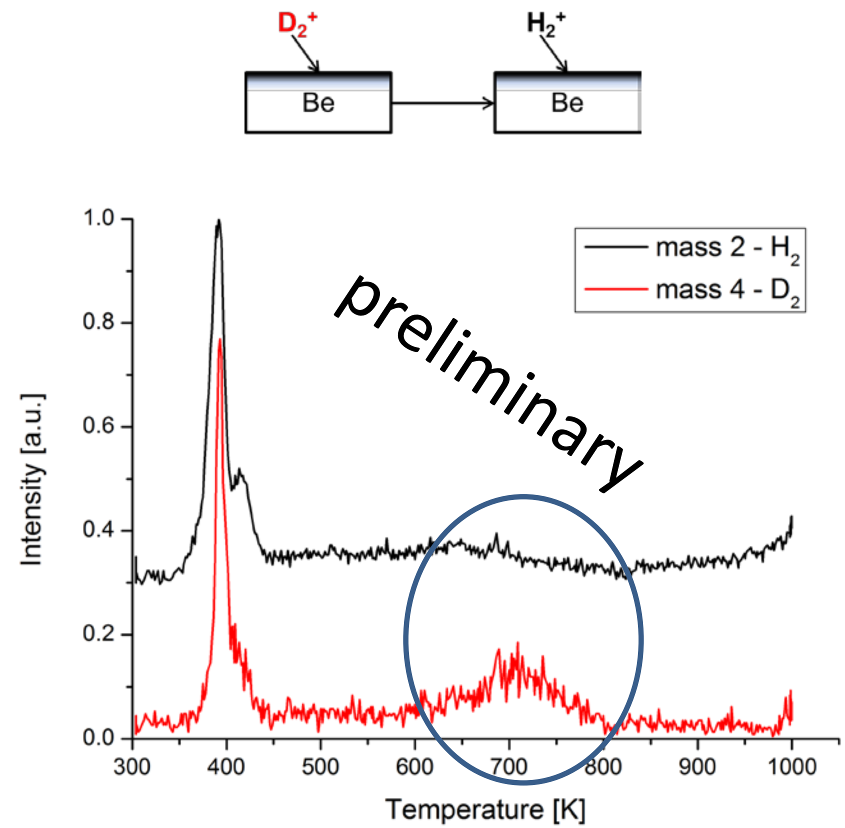
Implantation conditions: 3 kV → 1.5 keV/D or H
Area: 2.5 x 2.5 mm²; Sample current: 0.6 – 1 μA





TDS Results



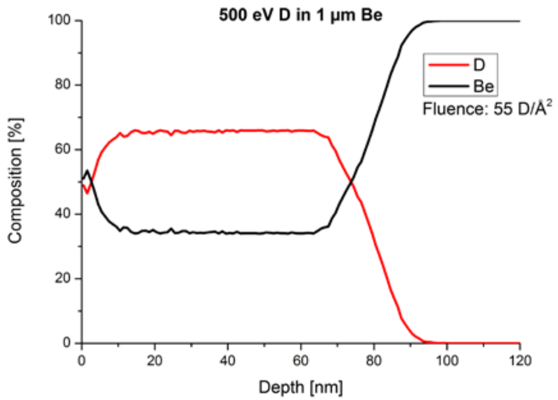


First implanted species occupies energetically favoured trap sites

Isotope exchange: Status & Outlook

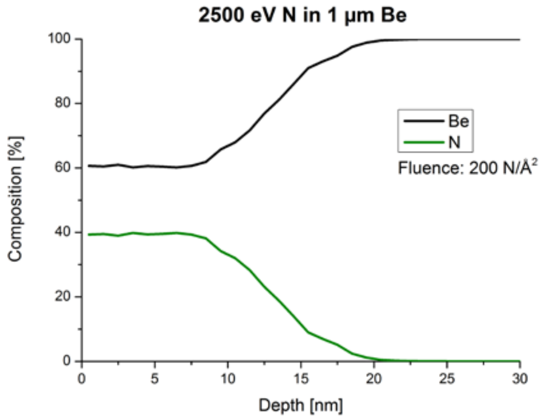
Done:

- Construction, installation and commissioning of the experimental setup
- First experiments for deuterium/hydrogen isotope exchange on beryllium



To do:

- Further experiments with the ion source with Wien filter
- Use different implantation enegies (500 eV to 5,000 eV)
- Do the same experiments on Be_3N_2

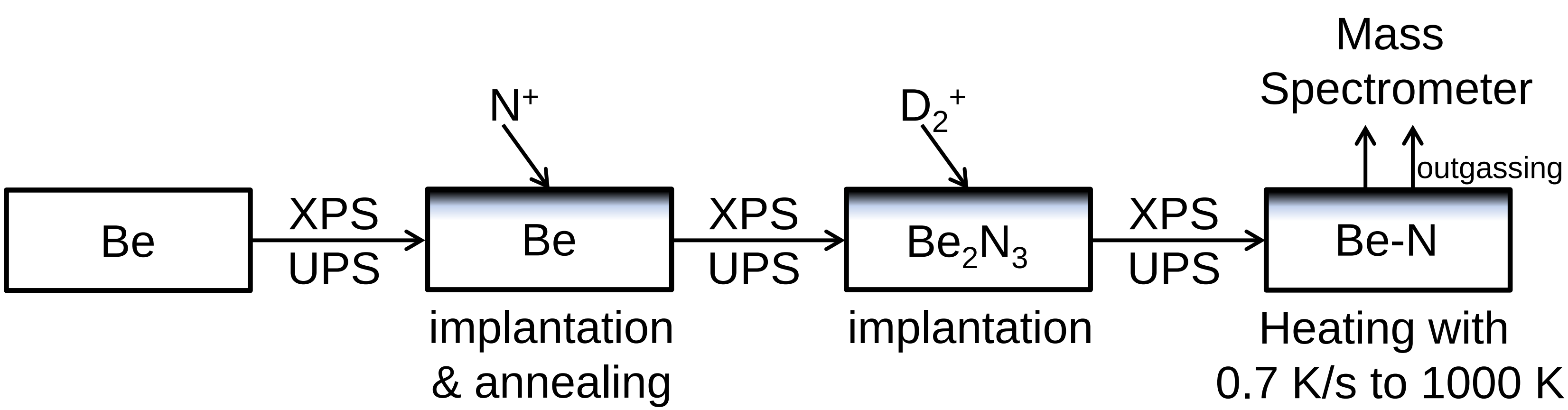


Outlook: Ammonia formation on Be-N

Exposure of thin Be-N films to hydrogen ions & gas under:

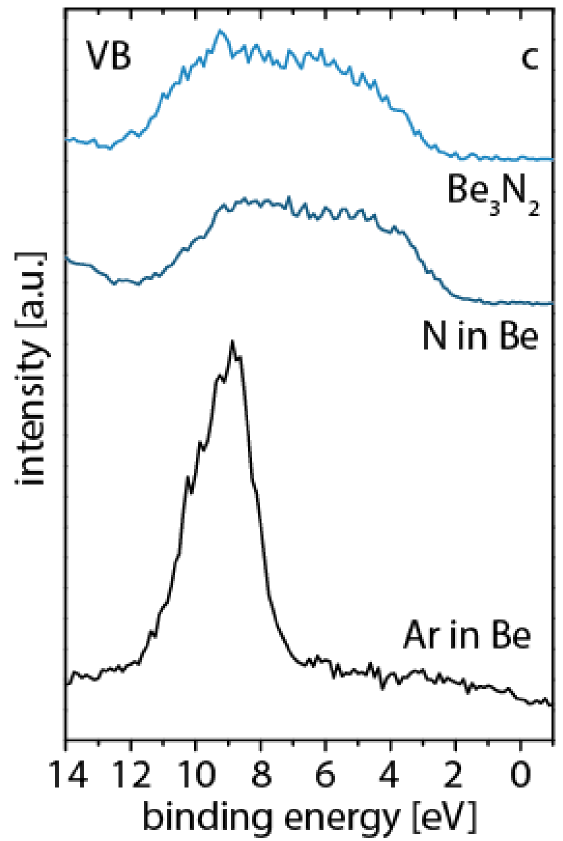
- Different surface temperatures (ions & gas)
- Different hydrogen partial pressures (gas)

=> Address the issue of mobilized tritiated ammonia



Outlook: Interaction of Be and noble gases

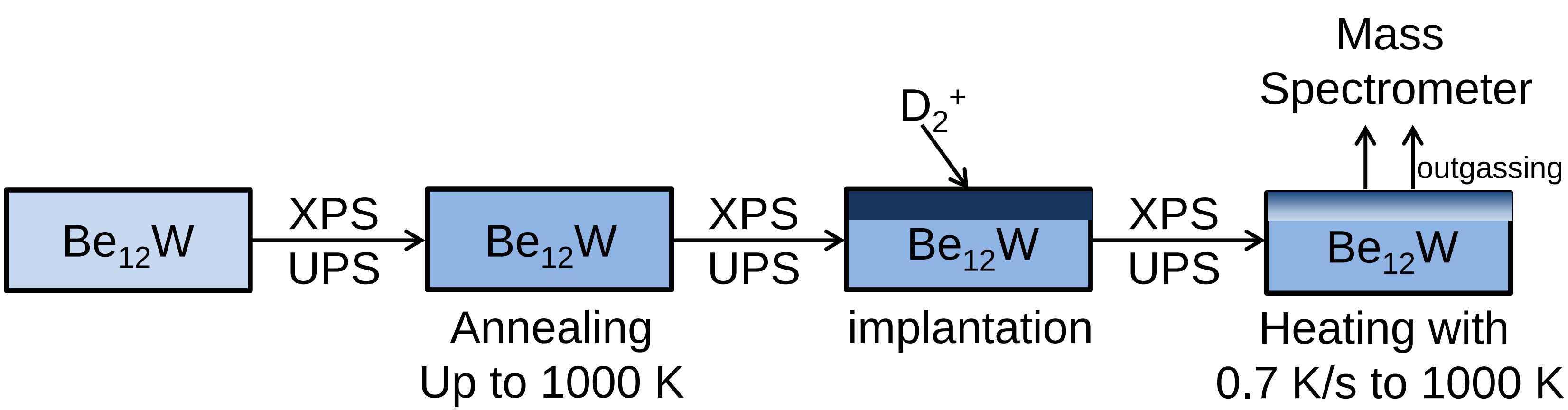
- Influence of noble gas ion bombardment on:
  - Be and its electronic structure (UPS and maybe DFT investigation)
  - H-retention behaviour
  - Noble gases to investigate: He, Ne, Ar, Kr, Xe



See Allouche et al., 2015

Beryllides

- Understanding beryllides is important as they are used in the breeding blanket
- DFT study on beryllides performed
- Experiments on thermal behaviour and H-retention of beryllides start in october 2016
- Beryllides: $Be_{12}Cr$, $Be_{12}Ta$, $Be_{12}W$, $Be_{12}Ti$, $Be_{12}V$

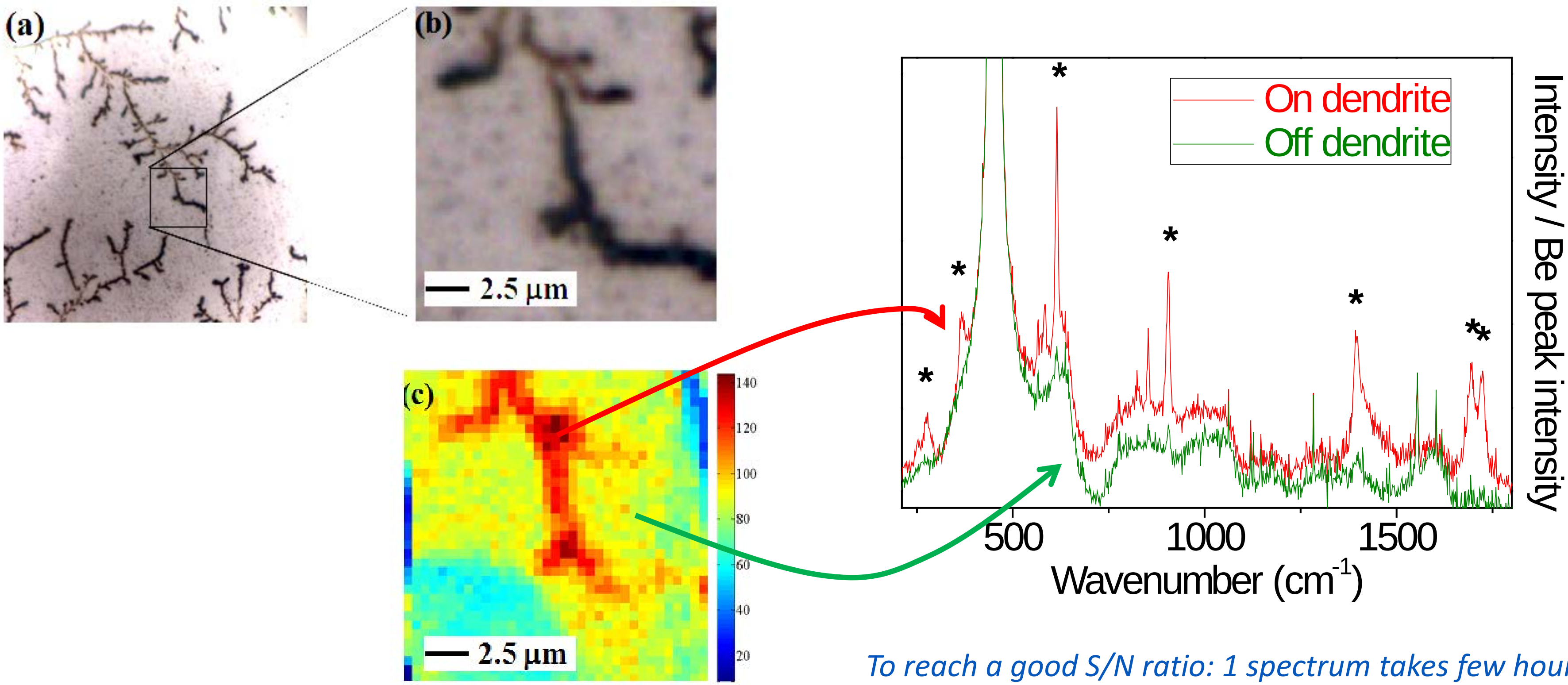


Raman Spectroscopy

Collaboration with Aix-Marseille Université

Example 3: Be implanted by D

($\phi > 2x10^{17}$ cm^{-2}, E_c=2 keV)



To reach a good S/N ratio: 1 spectrum takes few hours

Be-D vibrational modes evidenced on dendrites !

ARTOSS

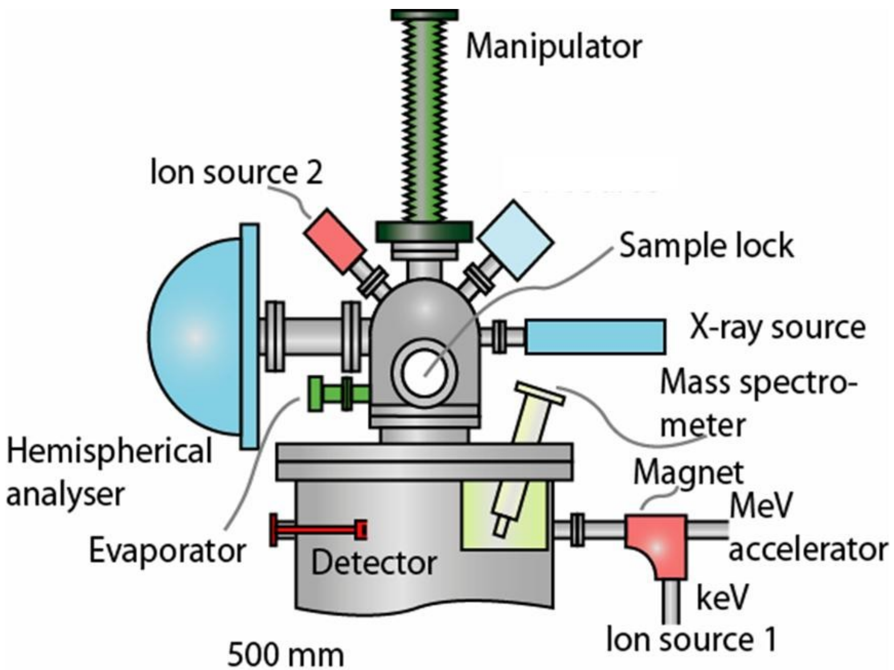
Dedicated to H-retention experiments

ARTOSS

- Ion beam analysis
  - Nuclear reaction analysis (NRA)
  - Rutherford backscattering spectroscopy (RBS)

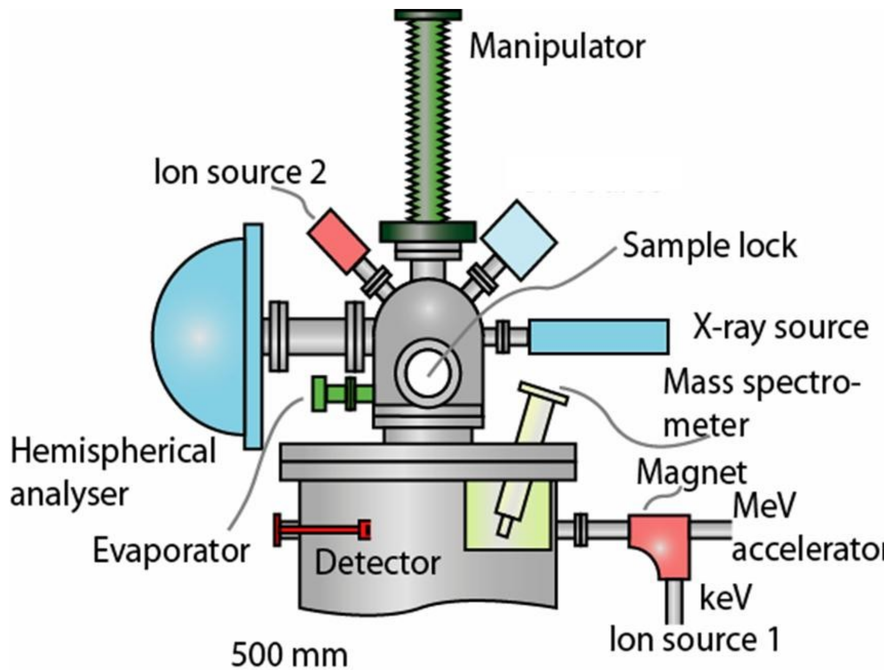
- Mass-spectrometer for thermal desorption spectroscopy (TDS)

- Standard-X-ray Source

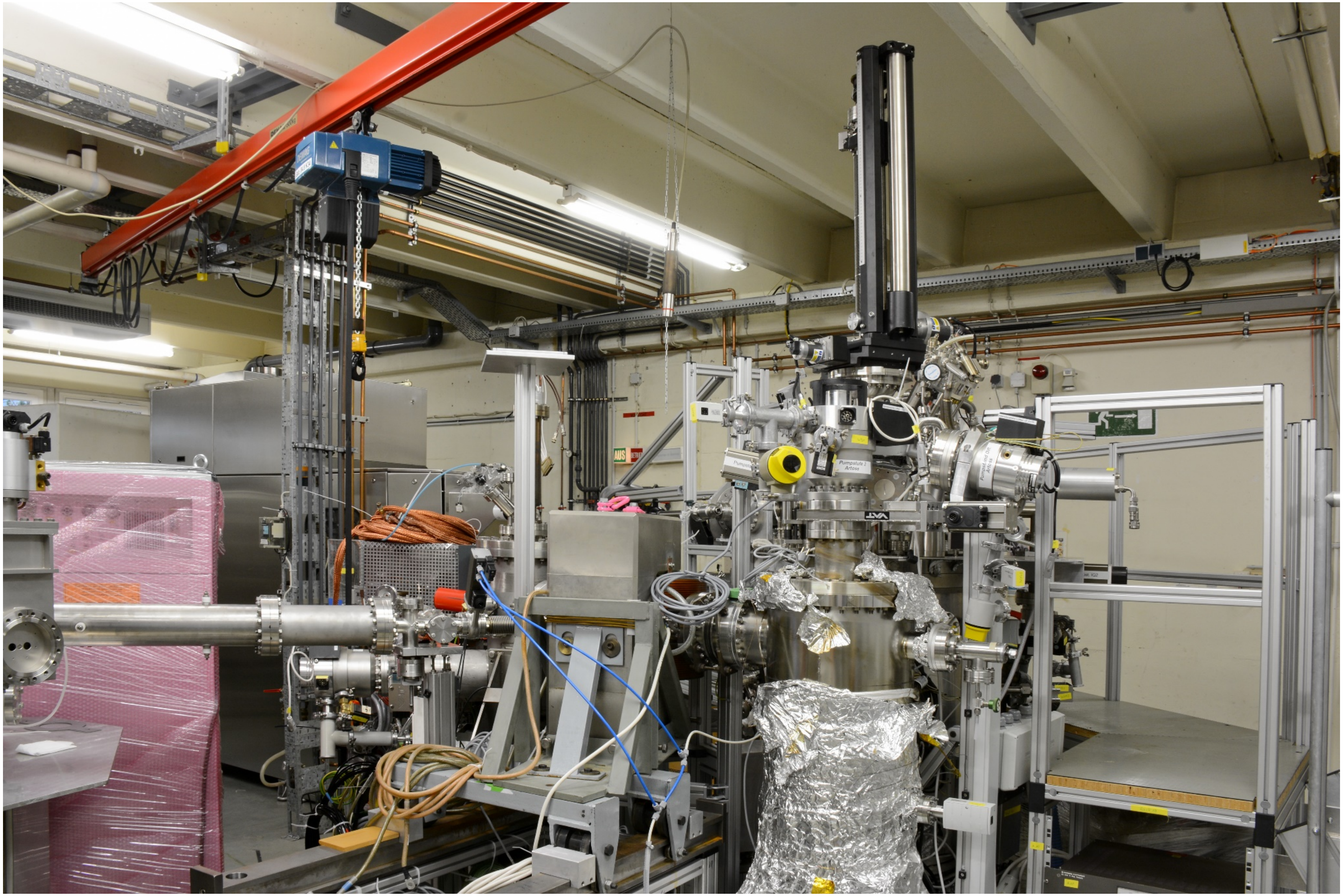


ARTOSS

- Mass-seperated low energy ion source (0.1-10 keV)
- Thermal atomic H-source
- Base Pressure: < 5×10^{-11} mbar
- Electron beam evaporator



ARTOSS

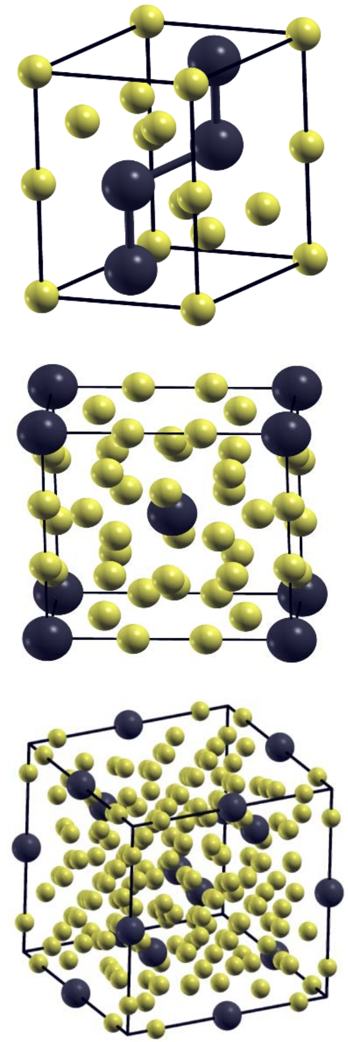


JÜLICH FORSCHUNGSZENTRUM

Achievements & Outlook

- ARTOSS commissioning is complete (without bake-out)

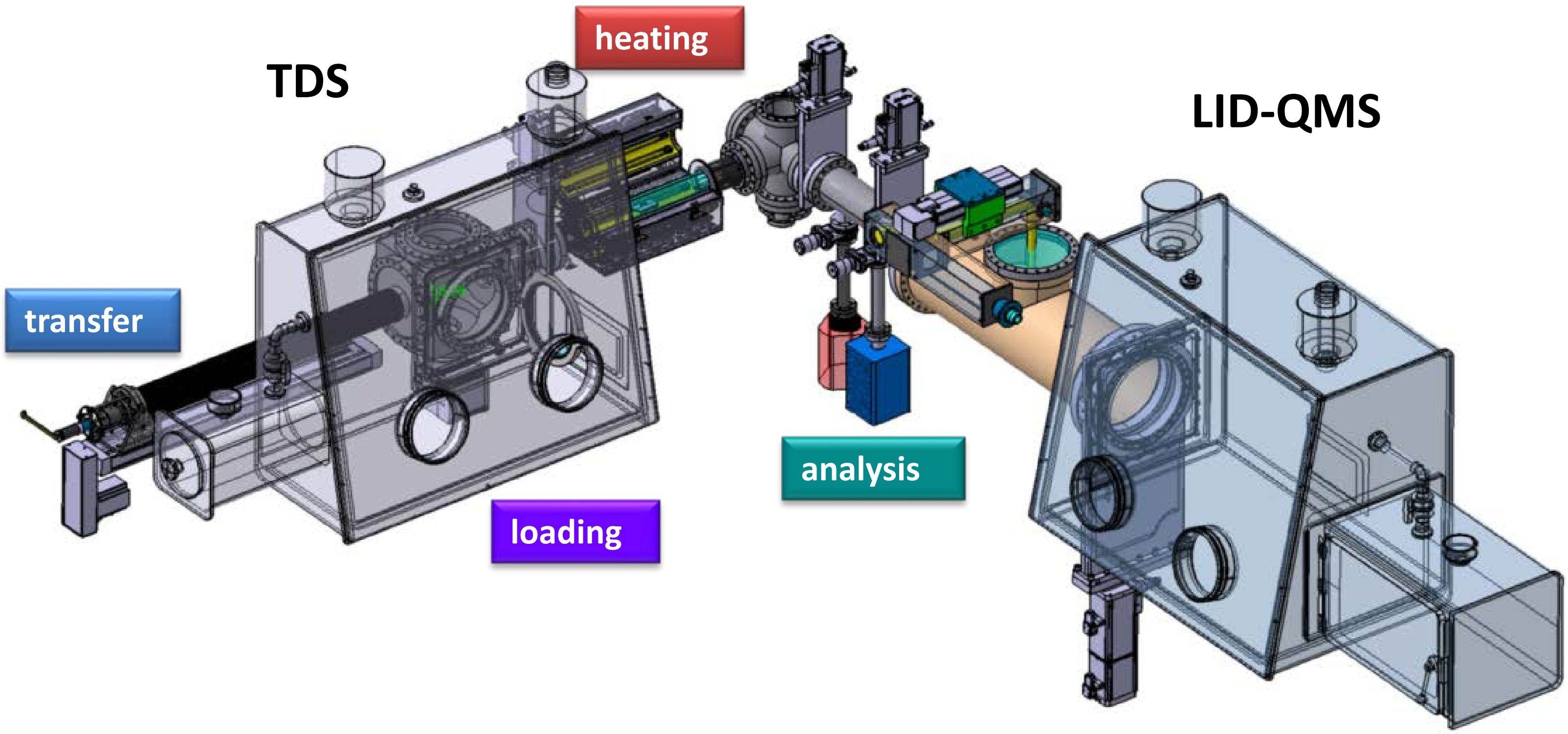
- Start with Beryllium phase:
  - Dedicated studies on the retention behaviour of the beryllium tungsten alloys Be_2W, $Be_{12}W$ and $Be_{22}W$
  - Comparison to DFT calculation by A. Allouche & L. Ferry and J. Bröder
  - Modelling with CRDS by D. Matveev



From Bröder 2015

FREDIS

FREDIS: Designed for JET-Tiles



- Combines classic TDS with laser-induced mass spectrometry (LID-QMS)

- Operation in hot materials lab => investigation of
  - Beryllium samples
  - Irradiated samples
  - Tritium-contaminated samples

FREDIS: Fuel Retention Diagnostic Set-up

Status & Outlook

Done:

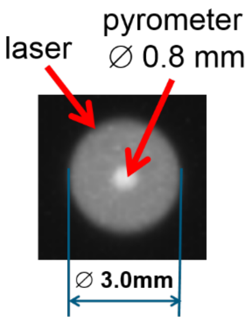
- Device tested outside HML
- First measurements on test samples were successful
- TDS: precise measurements up to 1400 K
- LID-QMS: Spatial resolved H release

To do:

- Transfer to HML & re-commissioning
- Comparison of TDS and LID-QMS

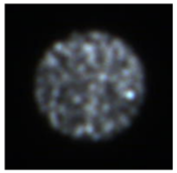
Test measurements using LID-QMS for large scale tiles outside of HML

JET CFC tile 246 × 142.5 × 26 mm³ loaded with deuterium by RF discharge in PADOS facility.

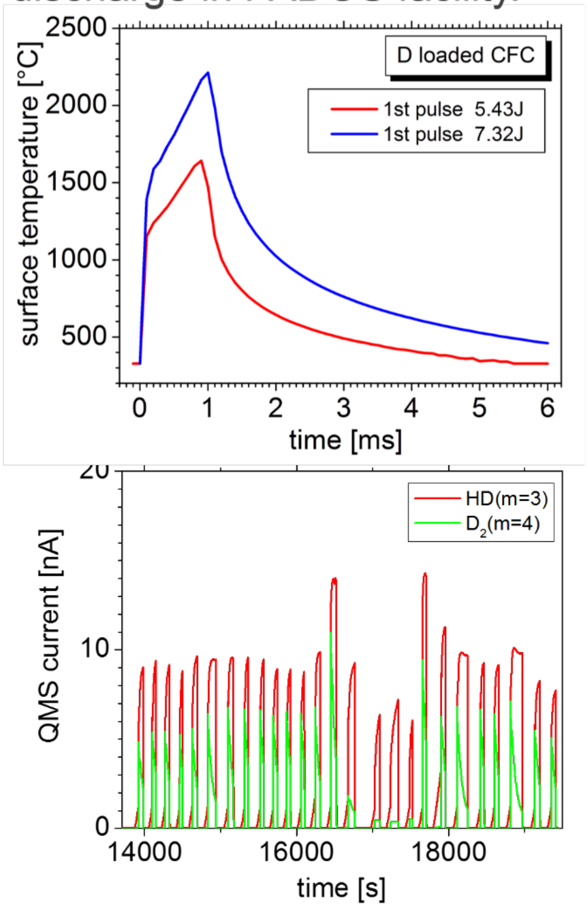


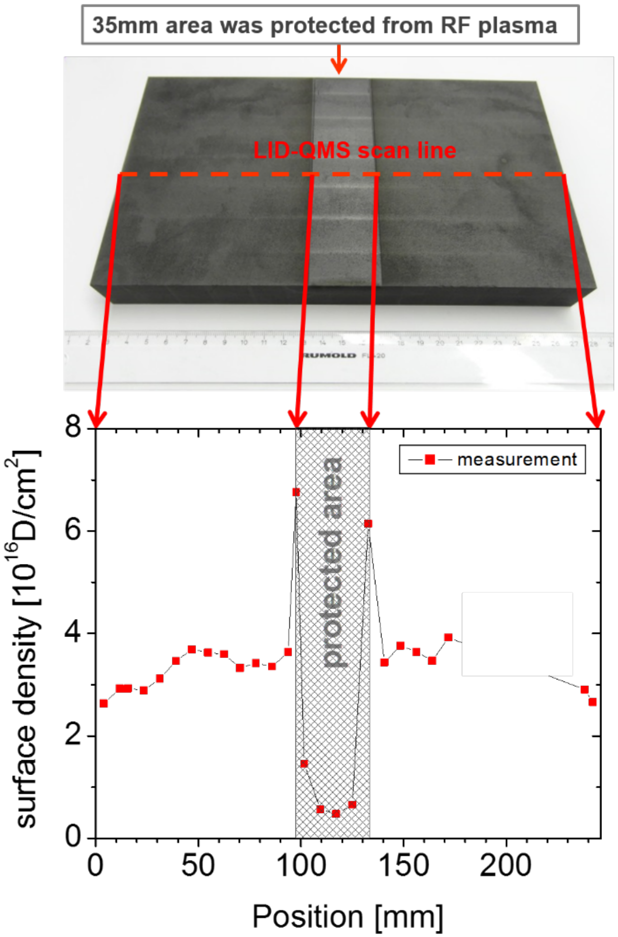
laser and pyrometer spots

$T_{max} \approx 2200°C$



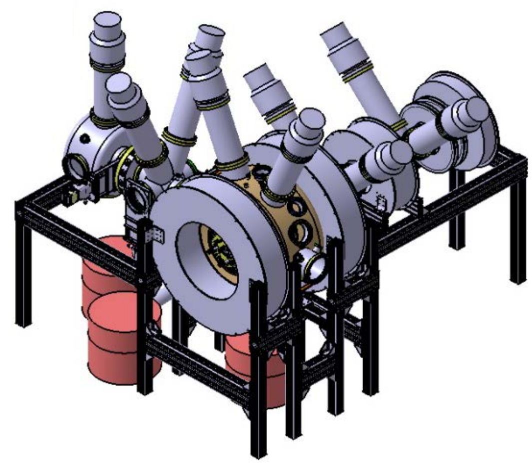
IR light from the laser spot (laser energy 7.3J)





JULE-PSI

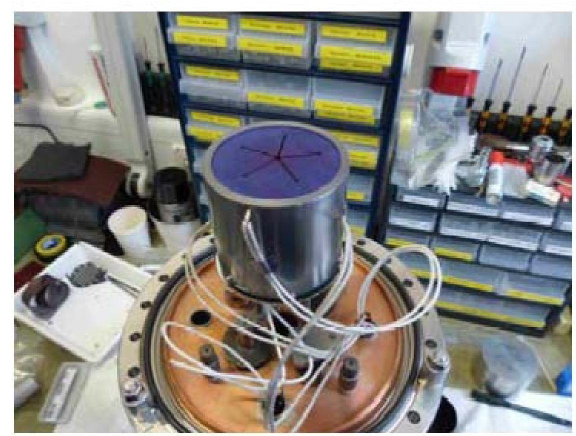
JULE-PSI – a new linear plasma device to investigate PSI processes with Be



Build to study erosion and fuel retention on Be and Be-based mixed materials

Status:

- Detailed feasibility study and design review finalized Feb. 2016
- JULE-PSI is currently being assembled outside of the controlled area
- first plasma operation expected for fall 2016 with a new plasma source following PISCES-B concept
- relocation to HML end of 2017



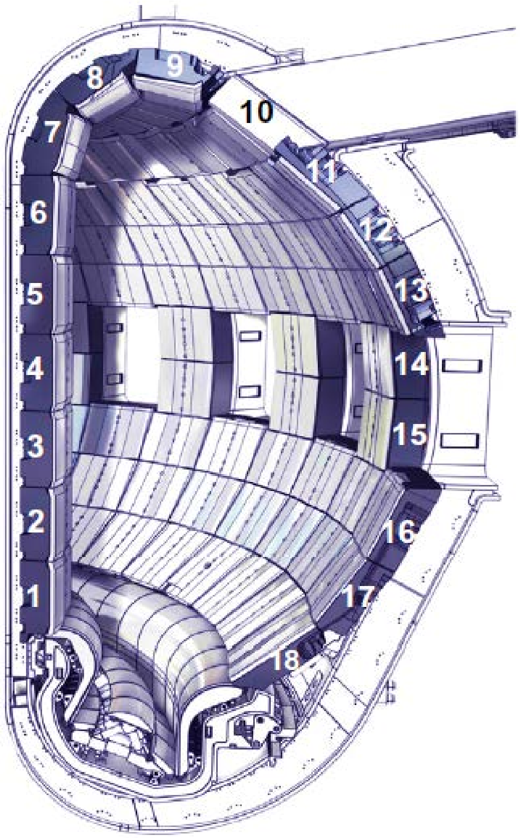
JULE-PSI: Tech Specs

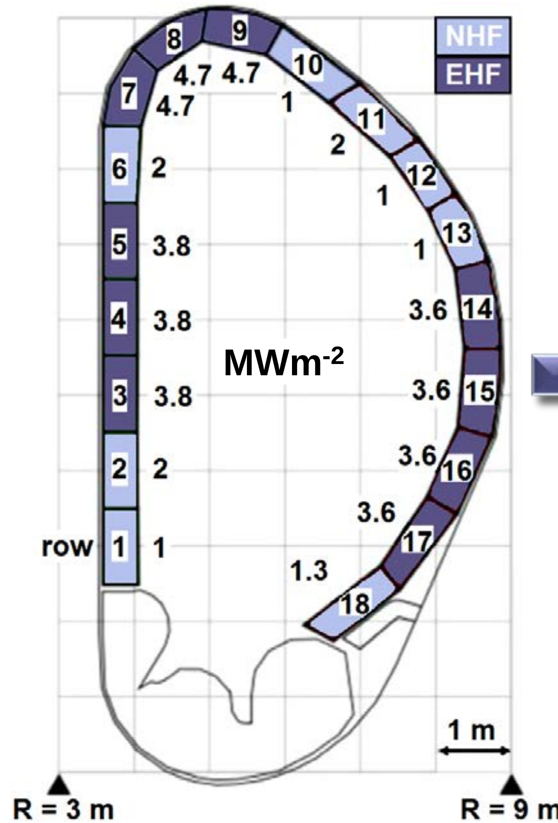
- Steady-state plasma exposure with plasma flux densities of 10^{21} – 10^{23} $m^{-2}s^{-1}$ and power flux densities of 0.1-2 MW m^{-2}
- Transient heat loads simulated by means of a Nd:YAG laser with pulse energies up to 100 J and pulse lengths 0.1-20 ms on top of the plasma load
- Measurement of fuel retention by LID-QMS, assessment of net erosion by weight loss measurements

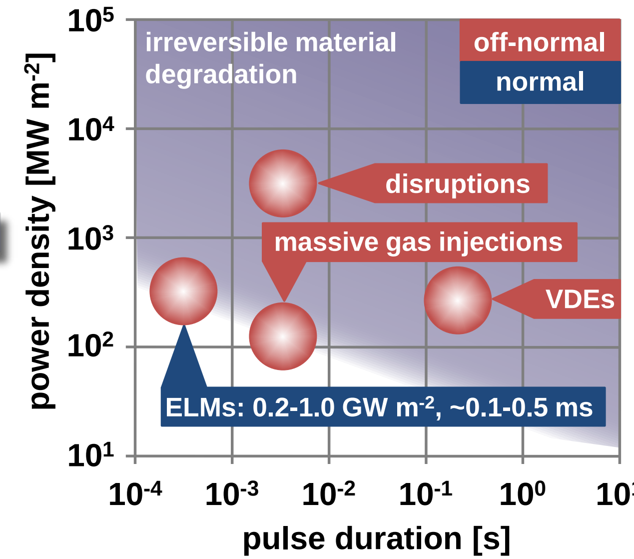
Judith 1 & 2

Behaviour of Be under ITER relevant cyclic heat fluxes

Introduction – Power loads to the FW







ITER first wall (FW): Be armour tiles

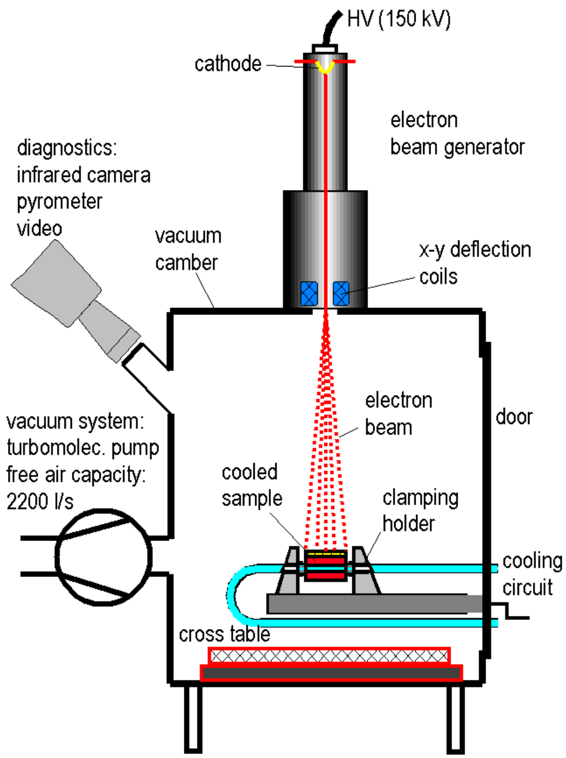
Expected maximum steady state power loads per row

Additional transient power loads (thermal shocks, TS)

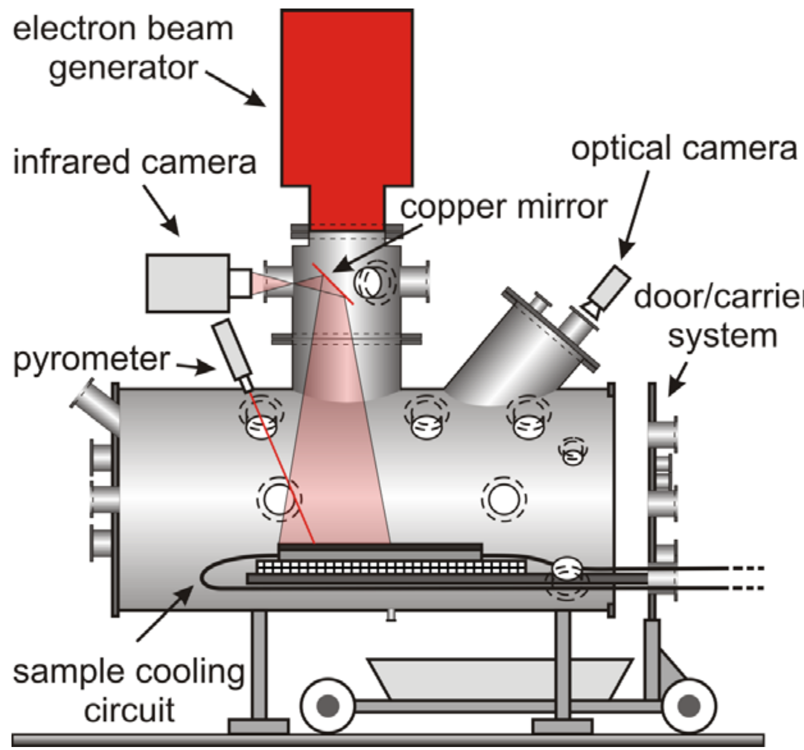
M. Kočan et al., J. Nucl. Mater. (2015), http://dx.doi.org/10.1016/j.jnucmat.2014.11.130
A.R. Raffray et al., Nucl. Fusion 54 (2014), 033004 (18pp)
A. Loarte et al., Phys. Scr. T128 (2007), 222-228

Electron beam facilities JUDITH 1 & 2

JUDITH 1



JUDITH 2



JUDITH 1 – machine parameters

Max. beam power:	60 kW
Acceleration voltage:	≤ 150 kV
Irradiation area:	4 mm^2 … 100 cm^2
Power density:	≤ 15 GW m^{-2}
Pulse duration:	1 ms – cont.
Licensed for materials:	toxic; radioactive

JUDITH 2 – machine parameters

Max. beam power:	200 kW
Acceleration voltage:	40 – 60 kV
Irradiation area:	40 × 40 cm^2
Power density:	≤ 2 GW m^{-2}
Pulse length:	5 µs – cont.

Scientific objectives

Last CRP (19.05.2014)

- **Influence of the surface finish on the cracking behavior / thermal shock performance of beryllium (polished is best up to 1000 pulses)**
  doi:10.1016/j.fusengdes.2015.10.028

Progress since then

1. Damage mapping for transient heat loads
doi:10.1088/0031-8949/T167/1/014024

2. Experimental simulation of massive gas injection induced heat loads

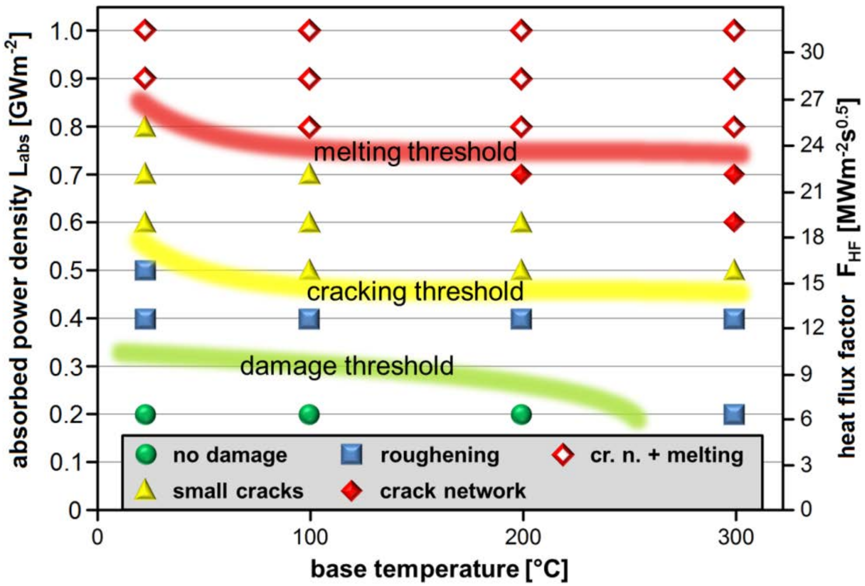
3. ITER/ELM relevant high pulse number experiments

4. Transient heat load induced oxide segregation

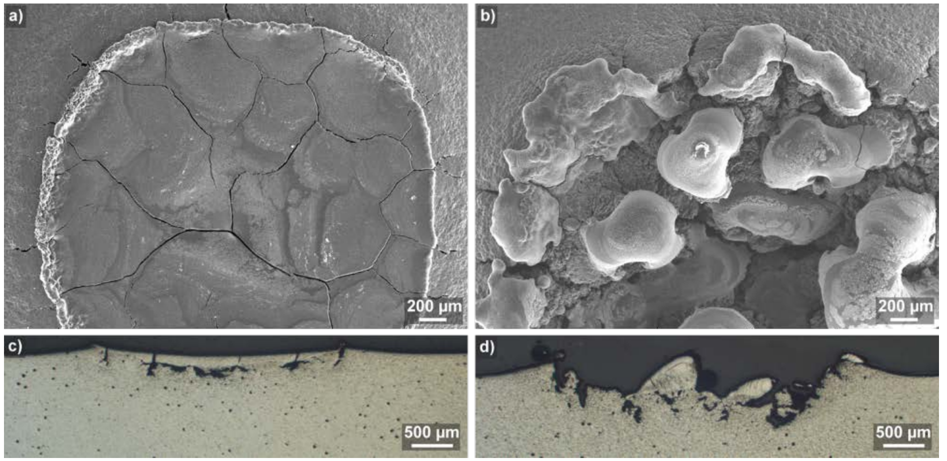
(5.) Planned: Transients simulated by laser (important and valuable comparison to e-beam, answering various open questions)

Scientific objectives

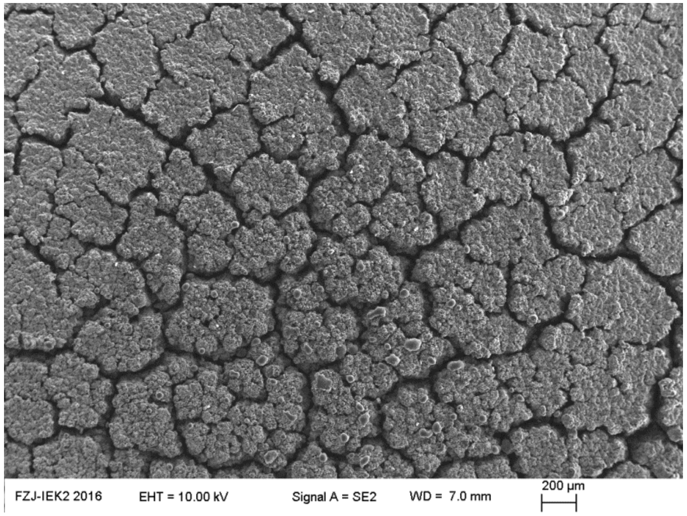
1. Damage mapping



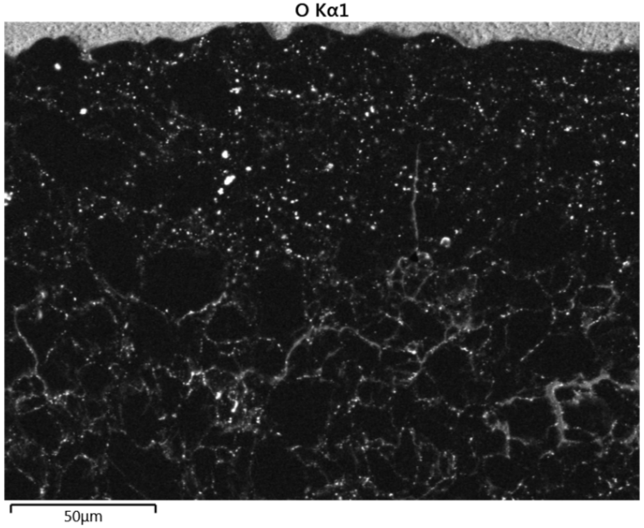
2. Massive gas injections



3. High pulse numbers



4. Oxide segregation



Conclusion

Conclusion

- JUDITH 1 & 2 work as expected

- ARTOSS will start operation soon
- XPS-Setup succesfully finished first experiments
- FREDIS & JULE-PSI are foreseen to start operation in hot materials lab in 2017

⇒ Most experimental setups are fully operational just now or will be operational soon

⇒ From my point of view, the Be-CRP should be prolonged to reap scientific results