Workshop: Positron Studies of Defects, Praha, September 2008

Progress of the Intense Positron Beam Project EPOS

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A Positron Study of Hydrogen Ion-Cutting of GaN

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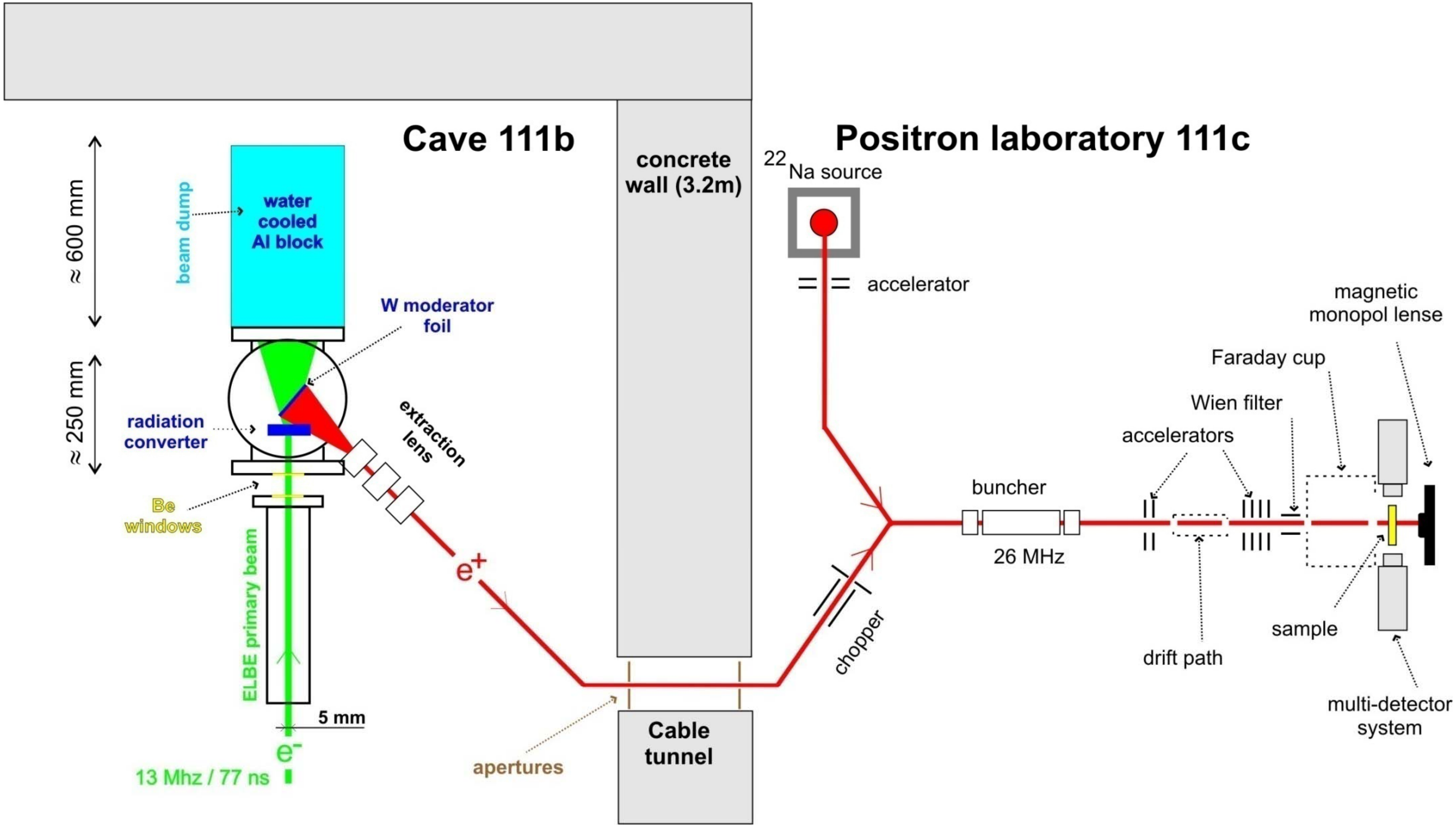
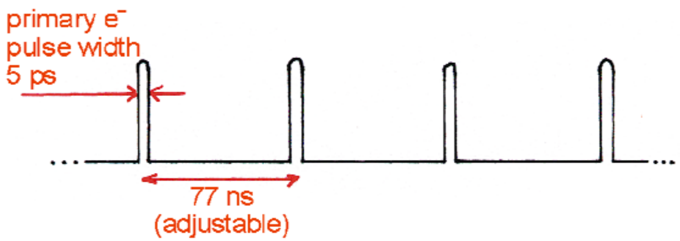
EPOS scheme

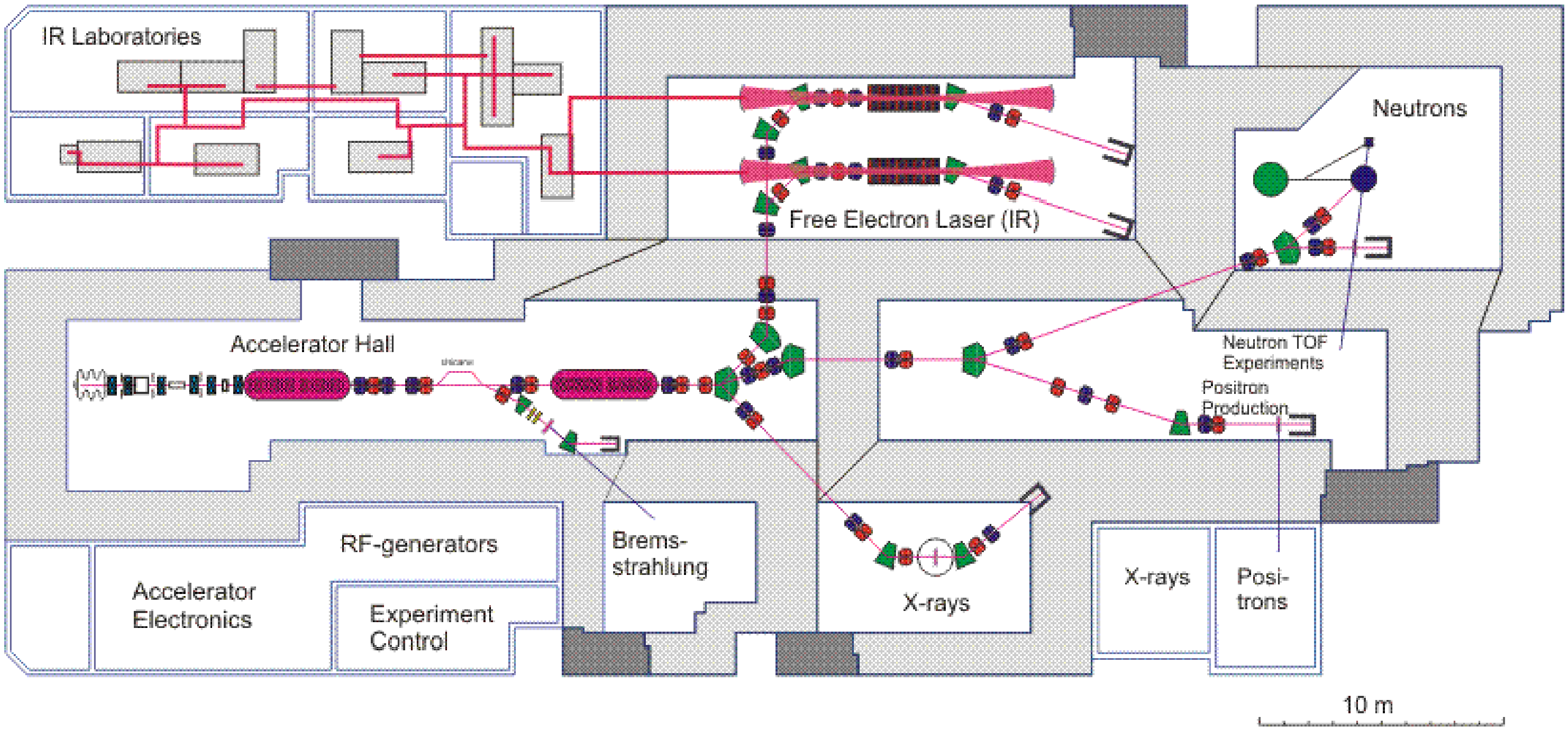


Cave 111b
Positron laboratory 111c
concrete wall (3.2m)
≈ 600 mm
≈ 250 mm
beam dump
water cooled Al block
W moderator foil
radiation converter
extraction lens
Be windows
ELBE primary beam
5 mm
e-
13 Mhz / 77 ns
e+
apertures
Cable tunnel
chopper
22Na source
accelerator
buncher
26 MHz
accelerators
drift path
Wien filter
Faraday cup
magnetic monopol lense
sample
multi-detector system

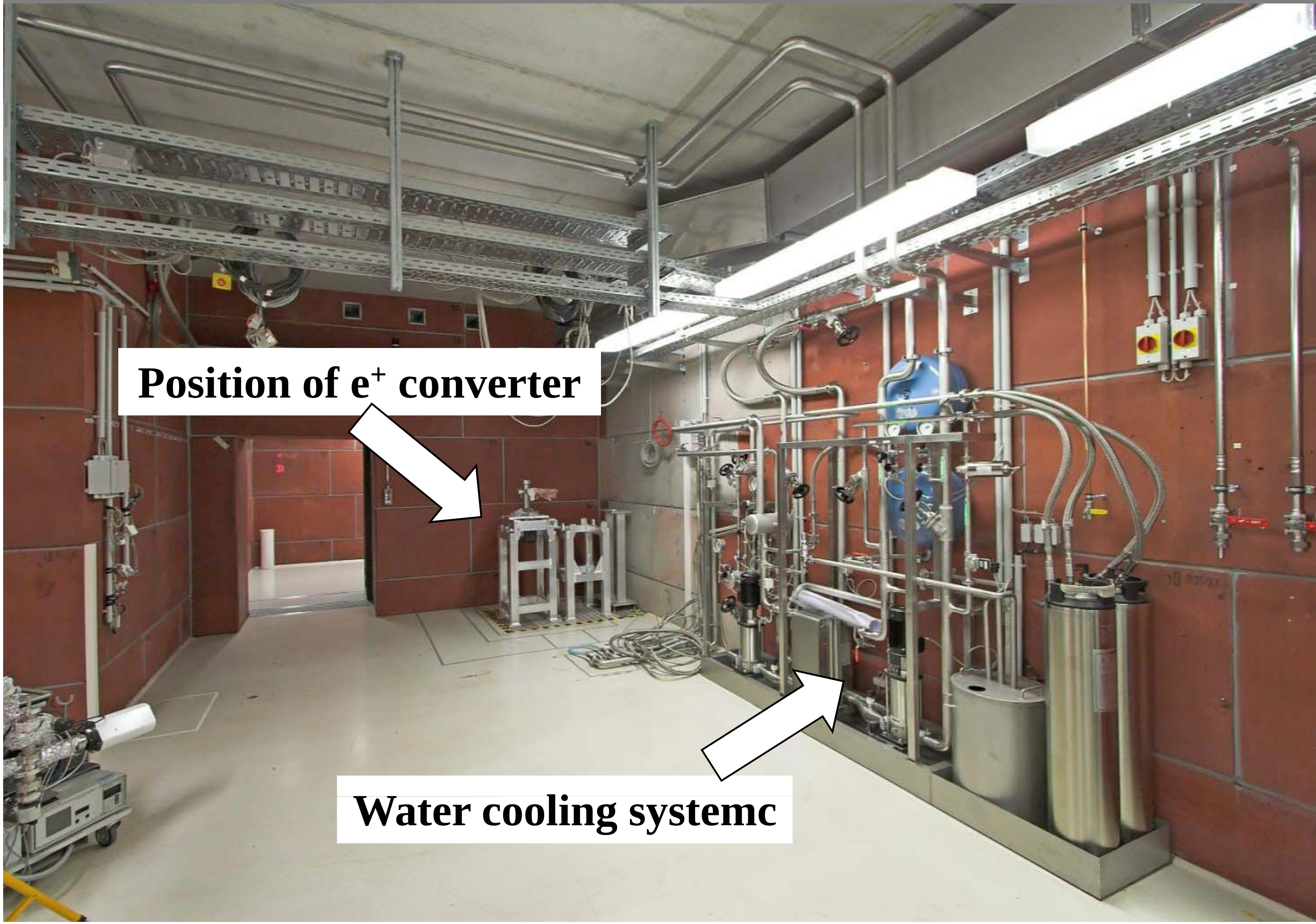


primary e-
pulse width
5 ps
77 ns
(adjustable)

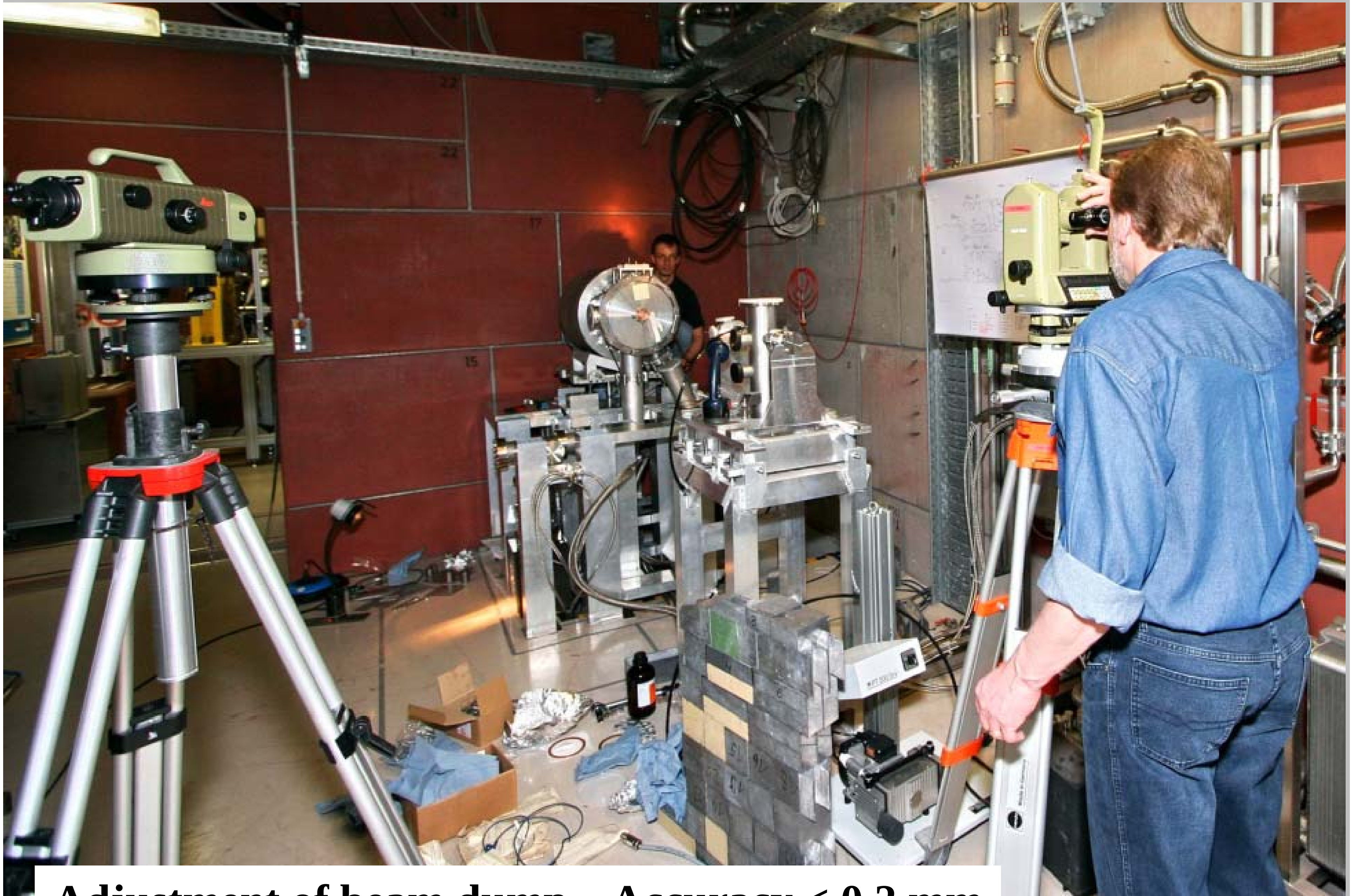
Ground plan of the ELBE hall



Cave 111b



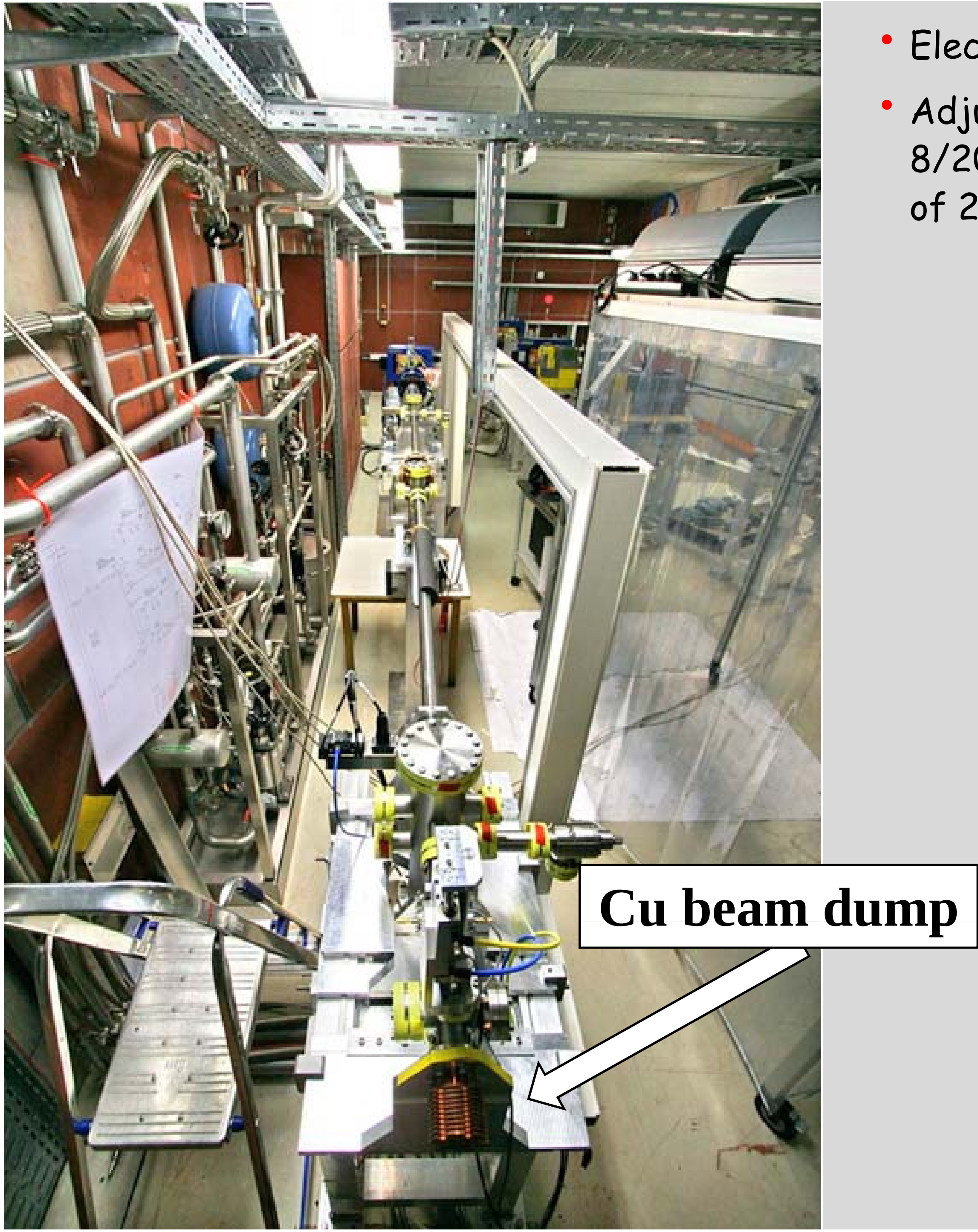
Beam dump



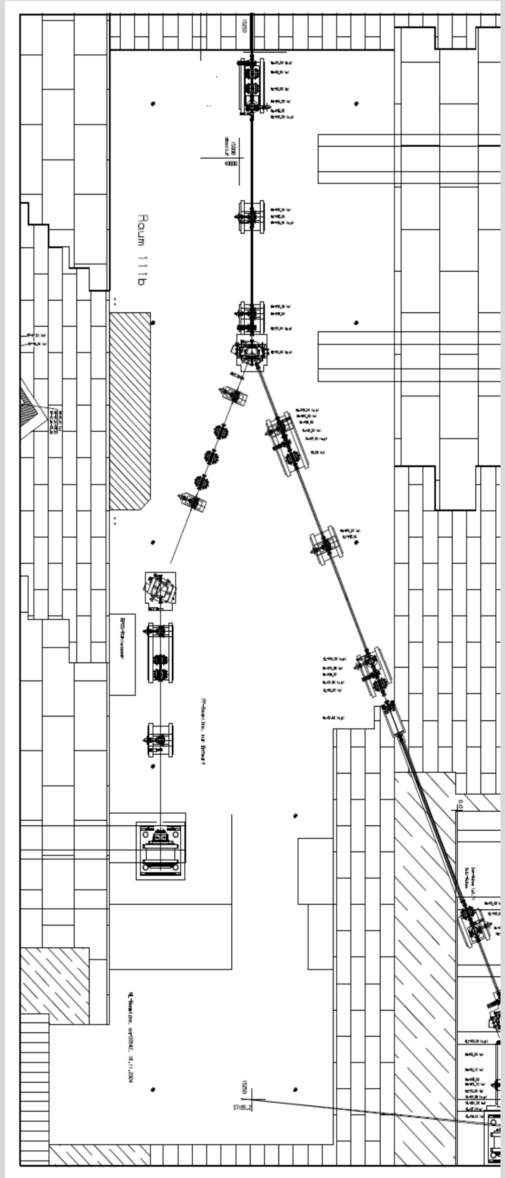
Adjustment of beam dump – Accuracy < 0.2 mm

Radiation screening

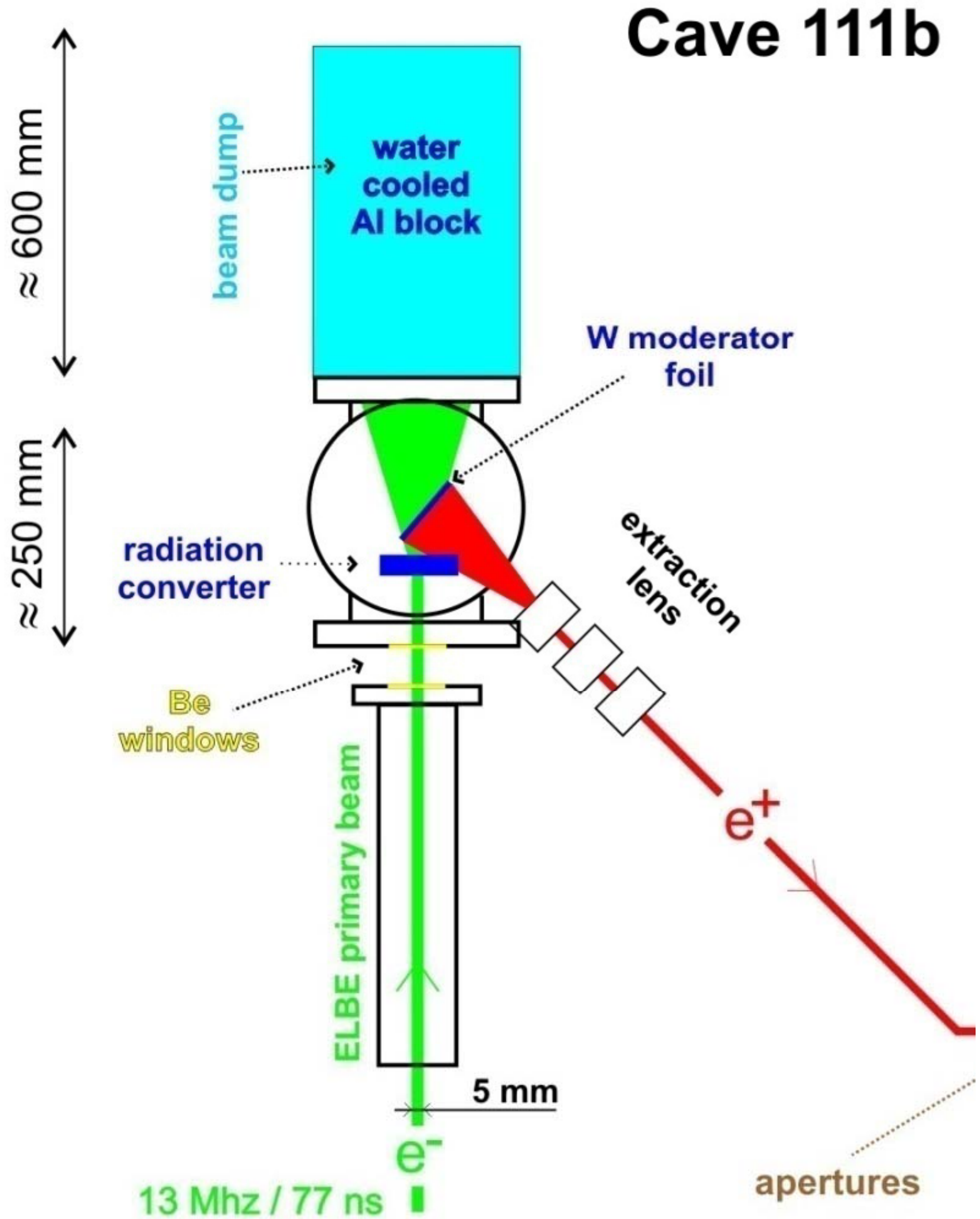
Screening consists of lead blocks and heavy concrete



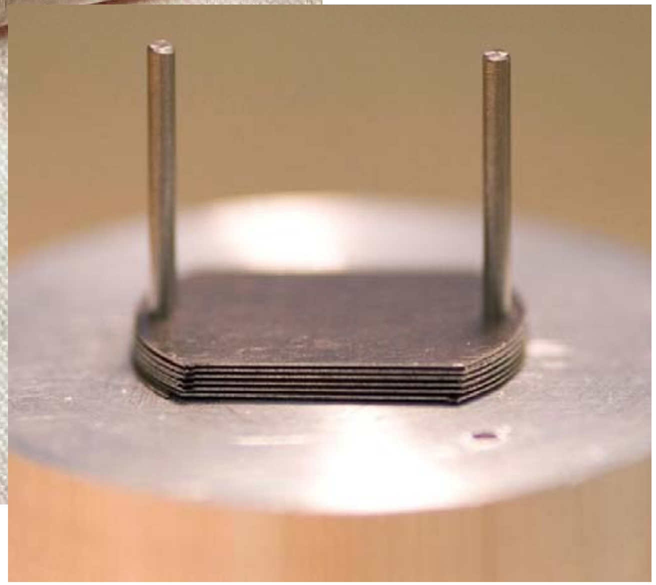
- Electron beam line
- Adjustments finished in 8/2008 using beam power of 200W



Positron extraction electrodes

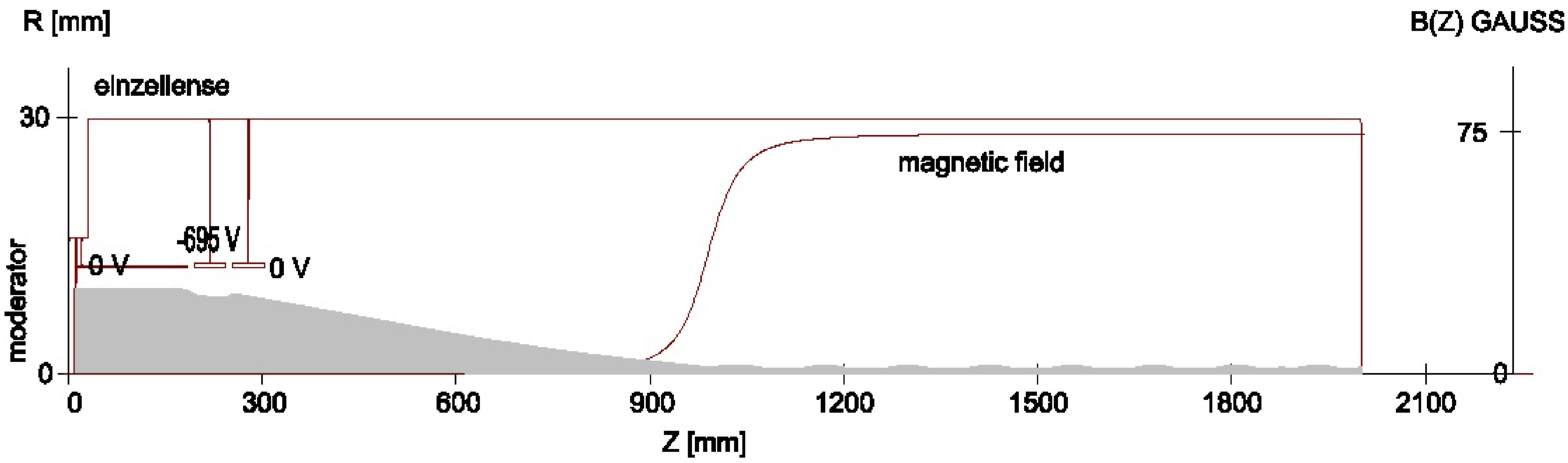


Directly water-cooled Electron-Positron Converter



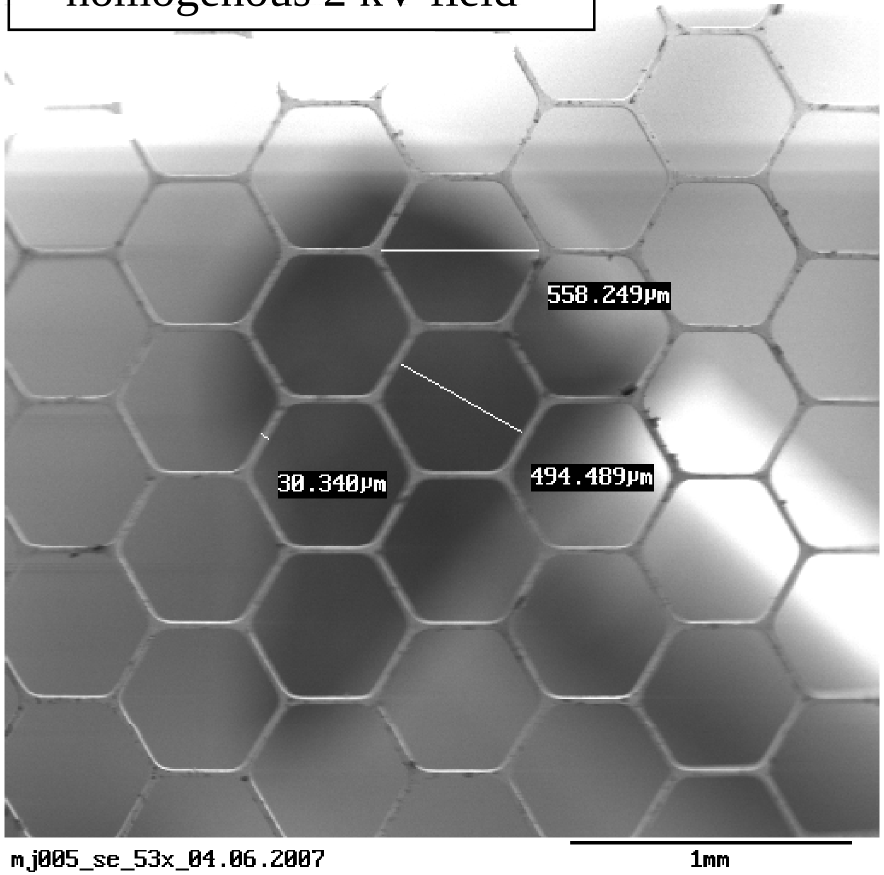
Simulation of positron extraction

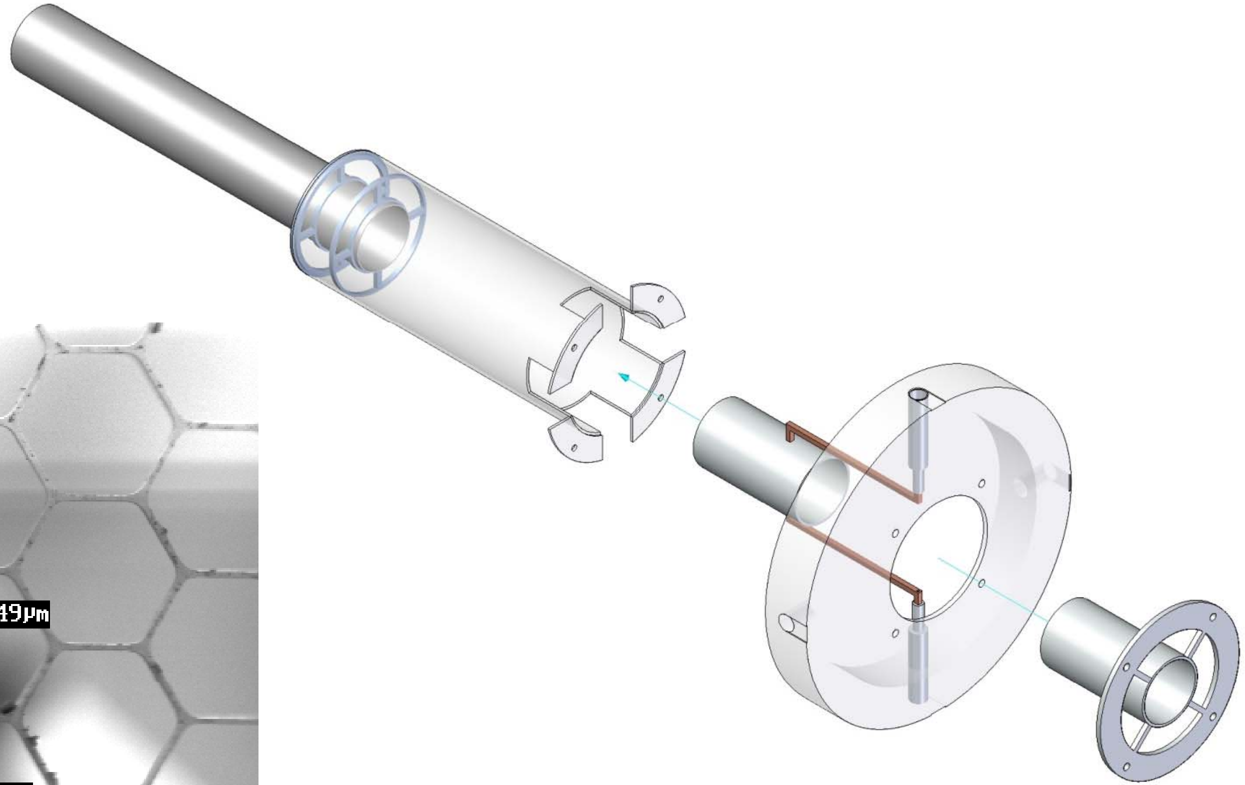
- simulation done by EGUN
- area of 20 mm diameter at moderator is used and squeezed to about 2 mmc



Positron extraction electrodes

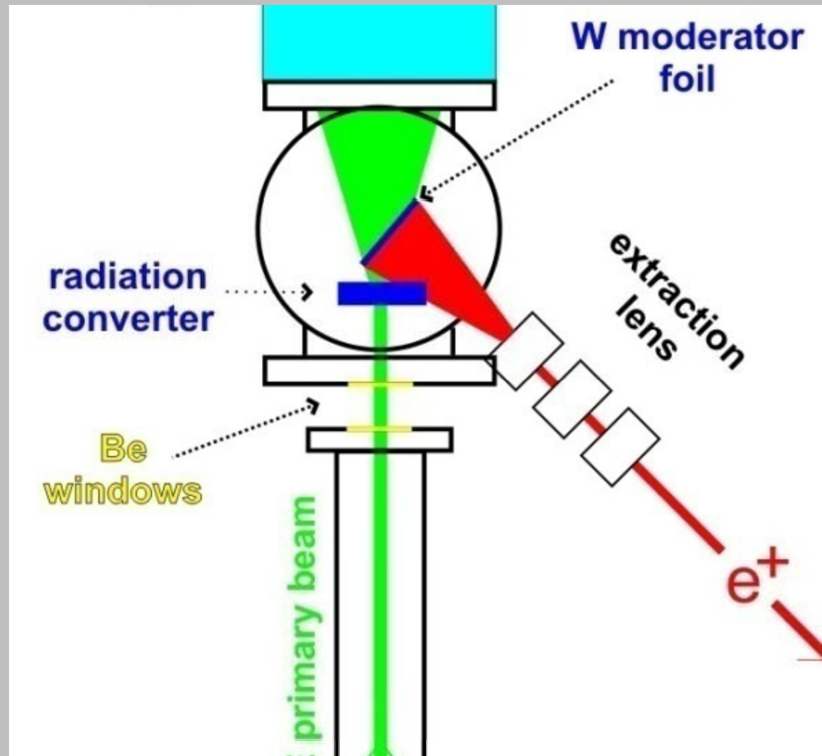
- stainless steel mesh
- 90% opening
- in front of Einzel lens
- provides very homogenous 2 kV-field



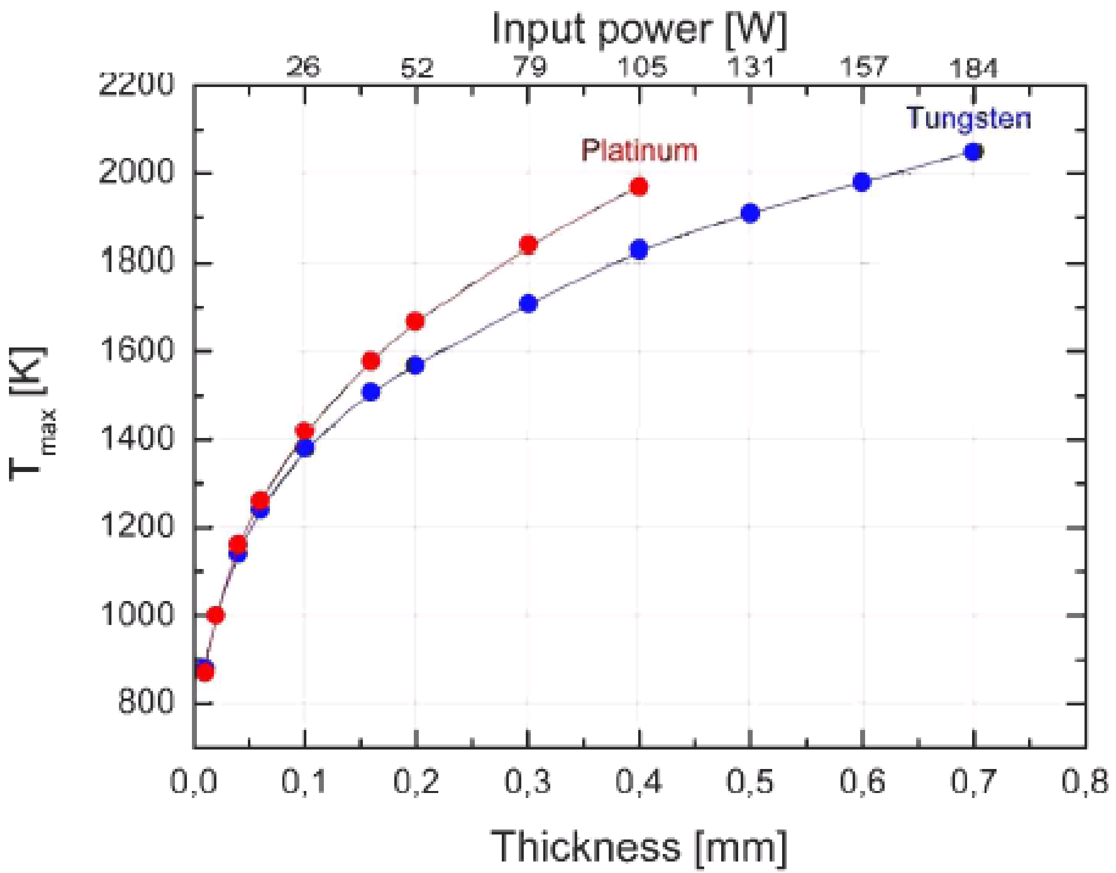


Einzel lens for extraction

Assembled lens



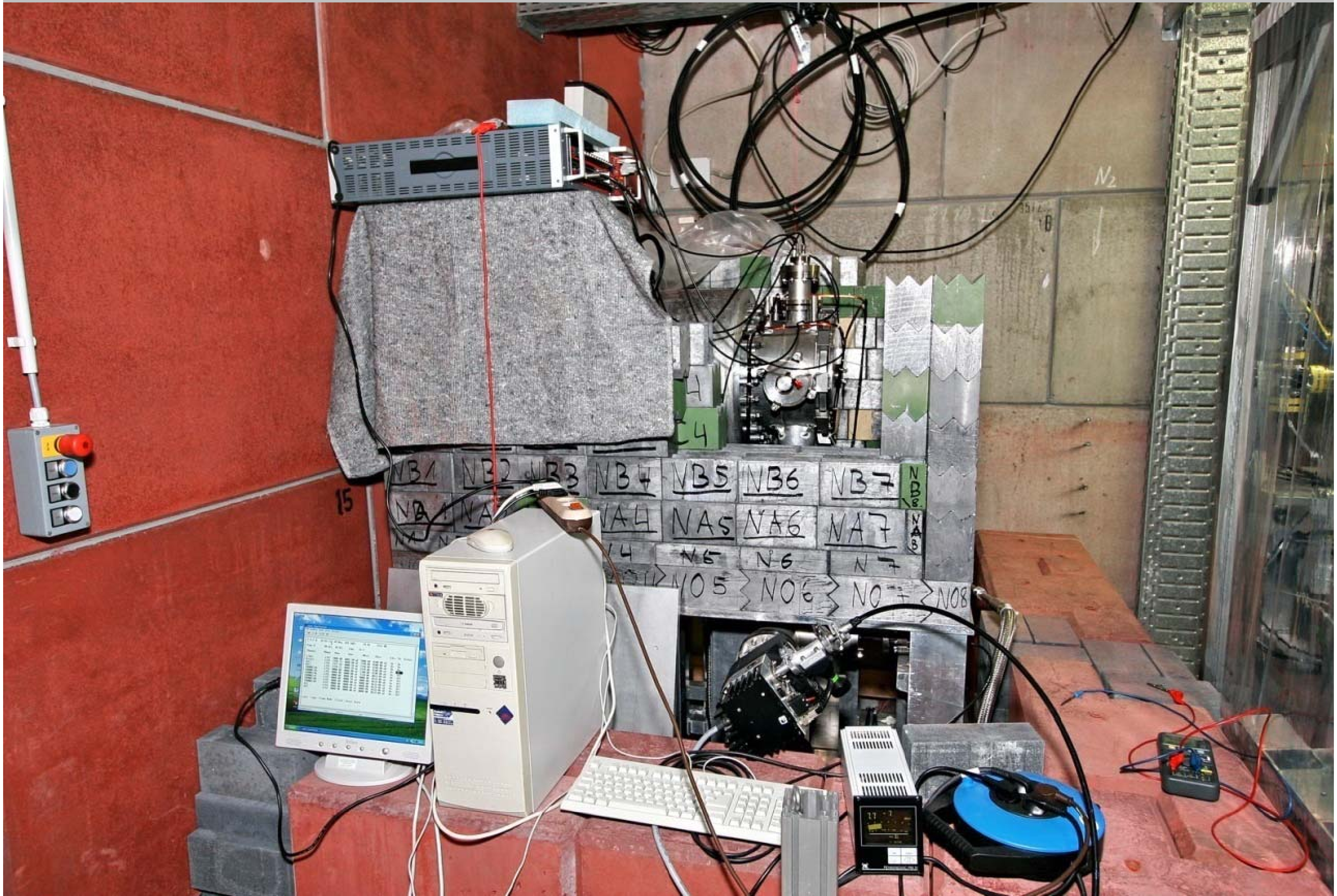
Thermal simulation



- Thermal simulation using finite elements
- Radiation and heat conduction considered
- Result: lens must be thinned to wall thickness of 50 μm
- Moderator can be annealed in-situ by choosing depth of foil

Lens mounted in converter chamber


Electron gun mounted instead of lens

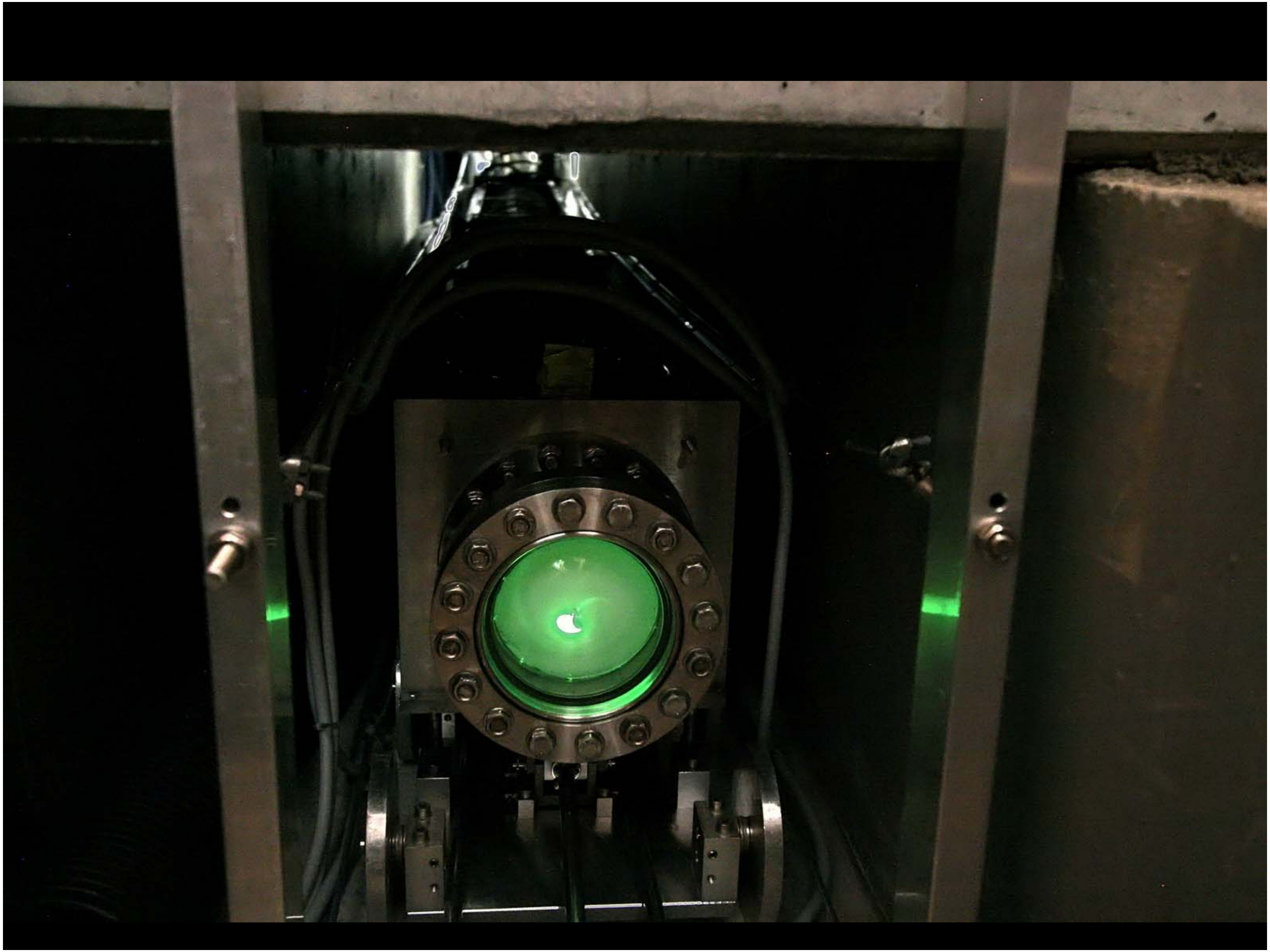


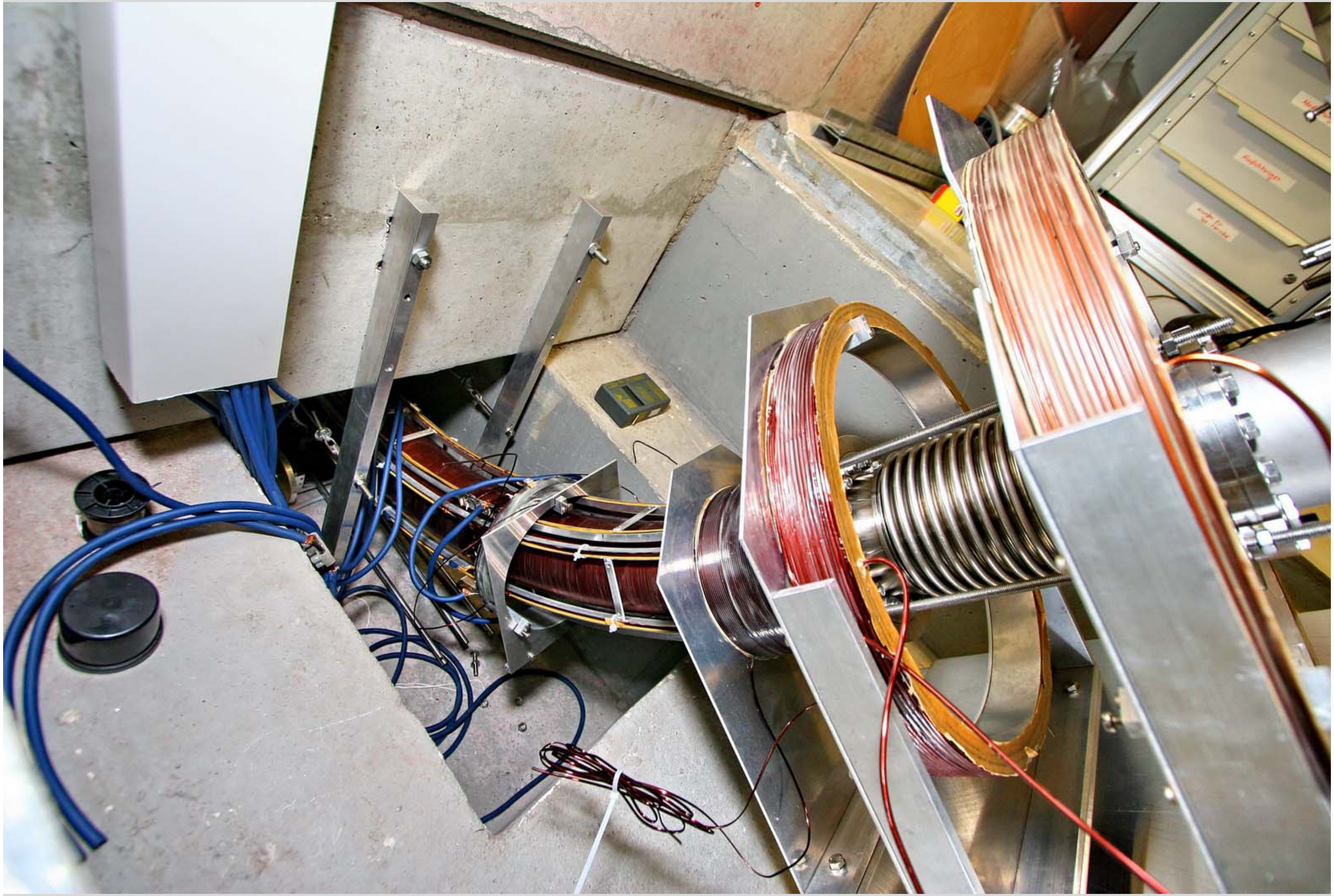
NB1
NB2
NB3
NB4
NB5
NB6
NB7
NA4
NA5
NA6
NA7
NO5
NO6
NO8
C4
15

Video camera at the end of vacuum beam line

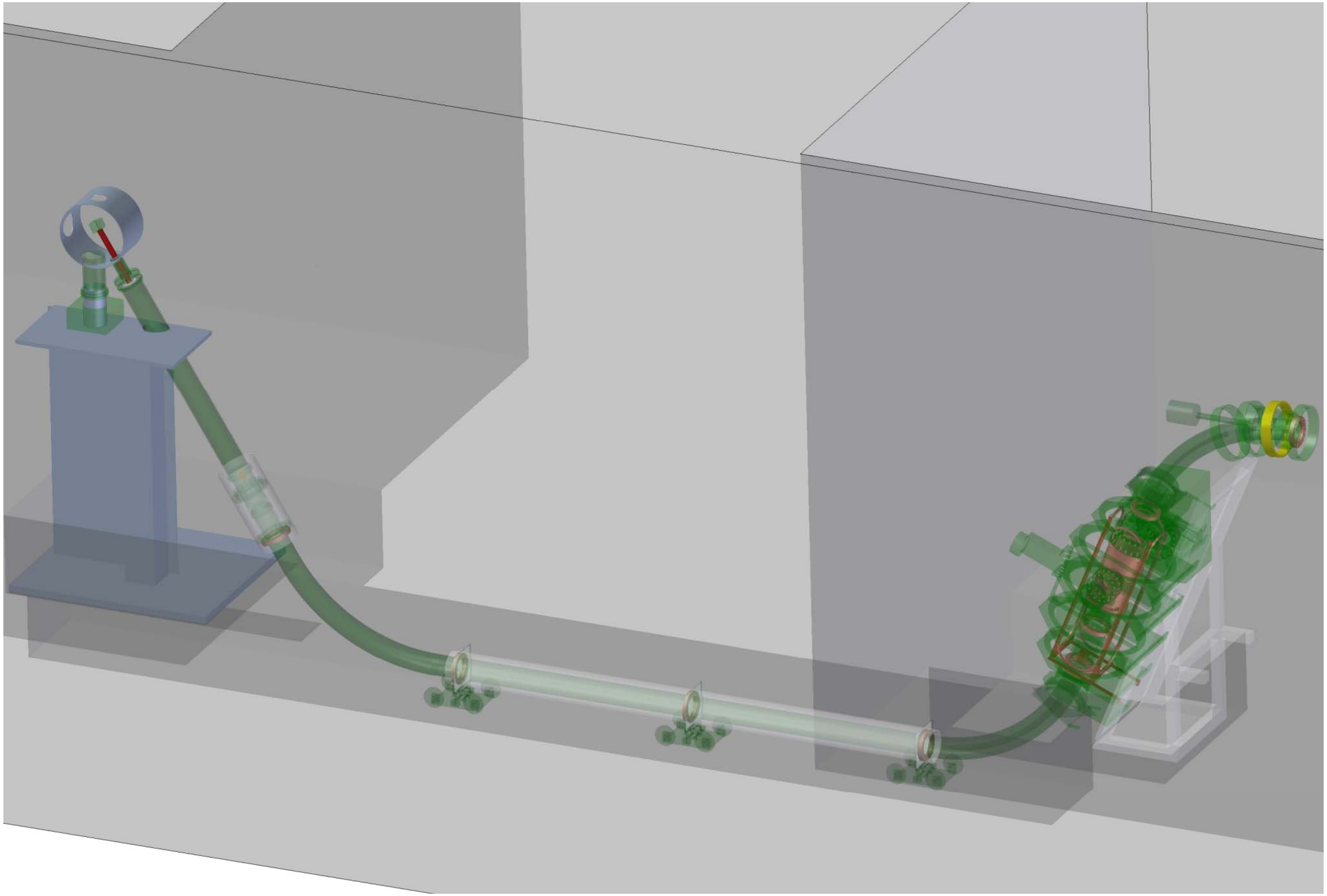
- 14 steering coils were to be adjusted
- We were lucky: job done after 10 min

Labview control of the steering coils

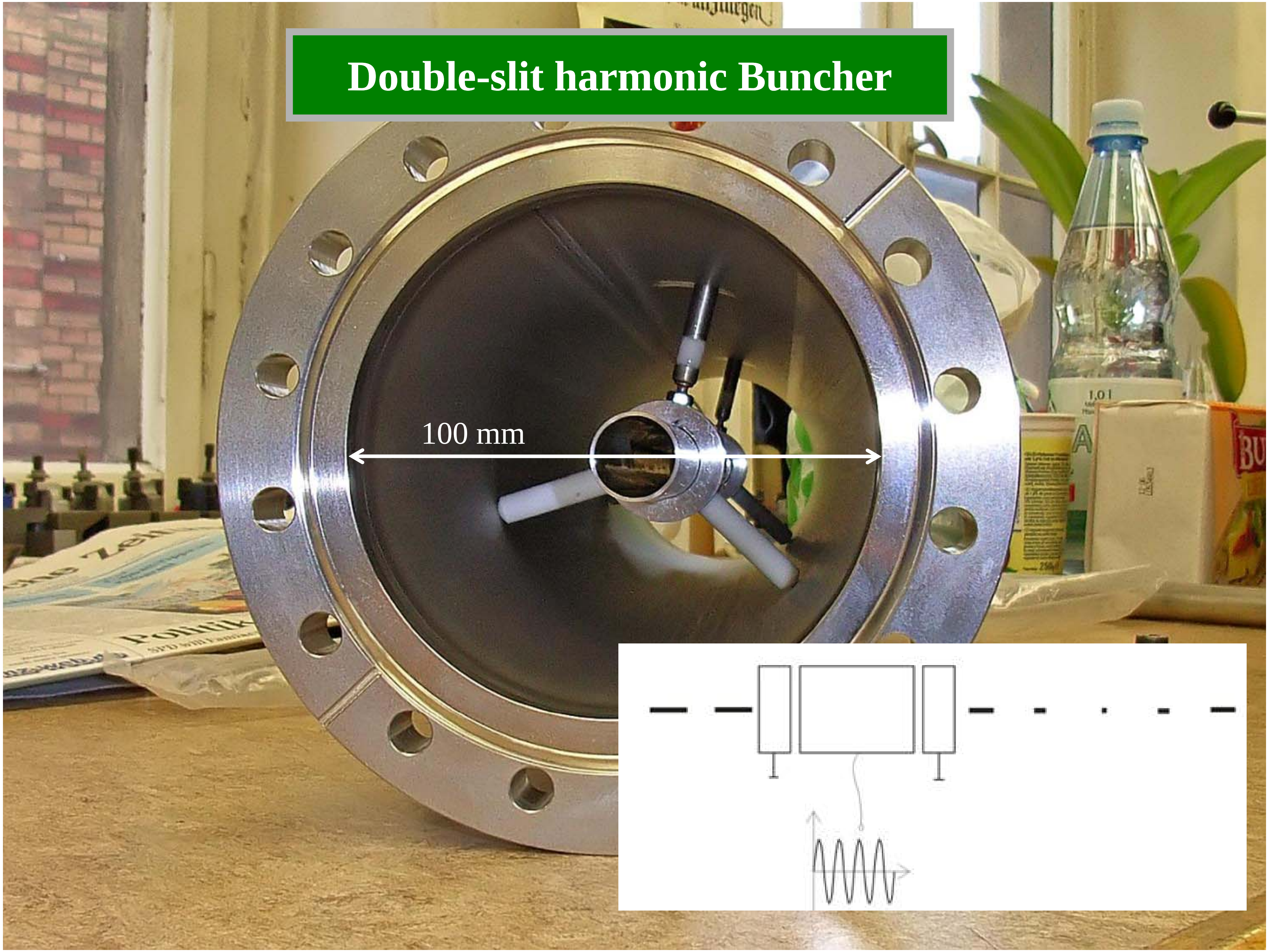




Magnetic Beam Guidance System

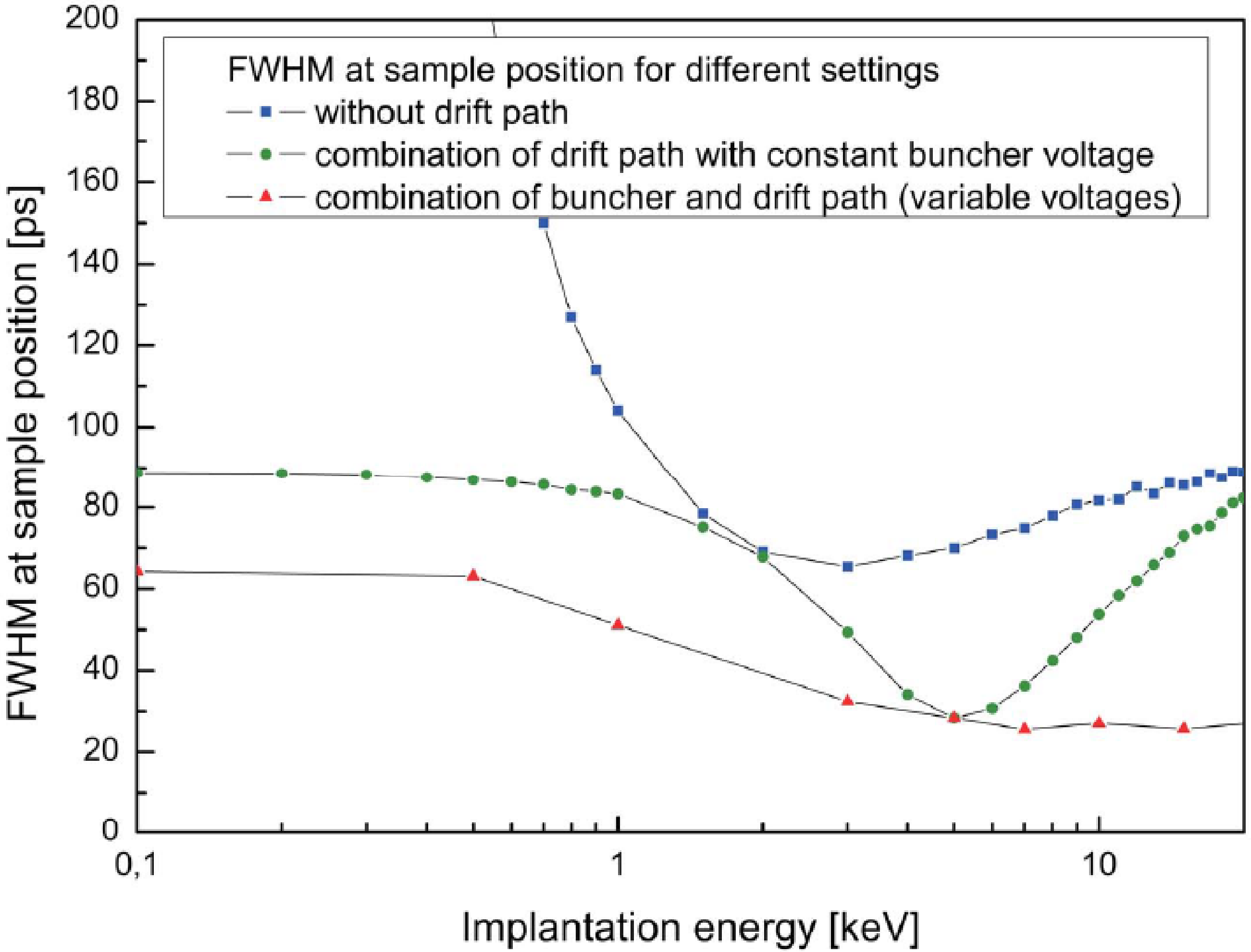


Double-slit harmonic Buncher



Simulations of Bunching

- Time focus must be at sample position at all beam energies
- Combination of Buncher RF adjustment and DC driven drift path necessary



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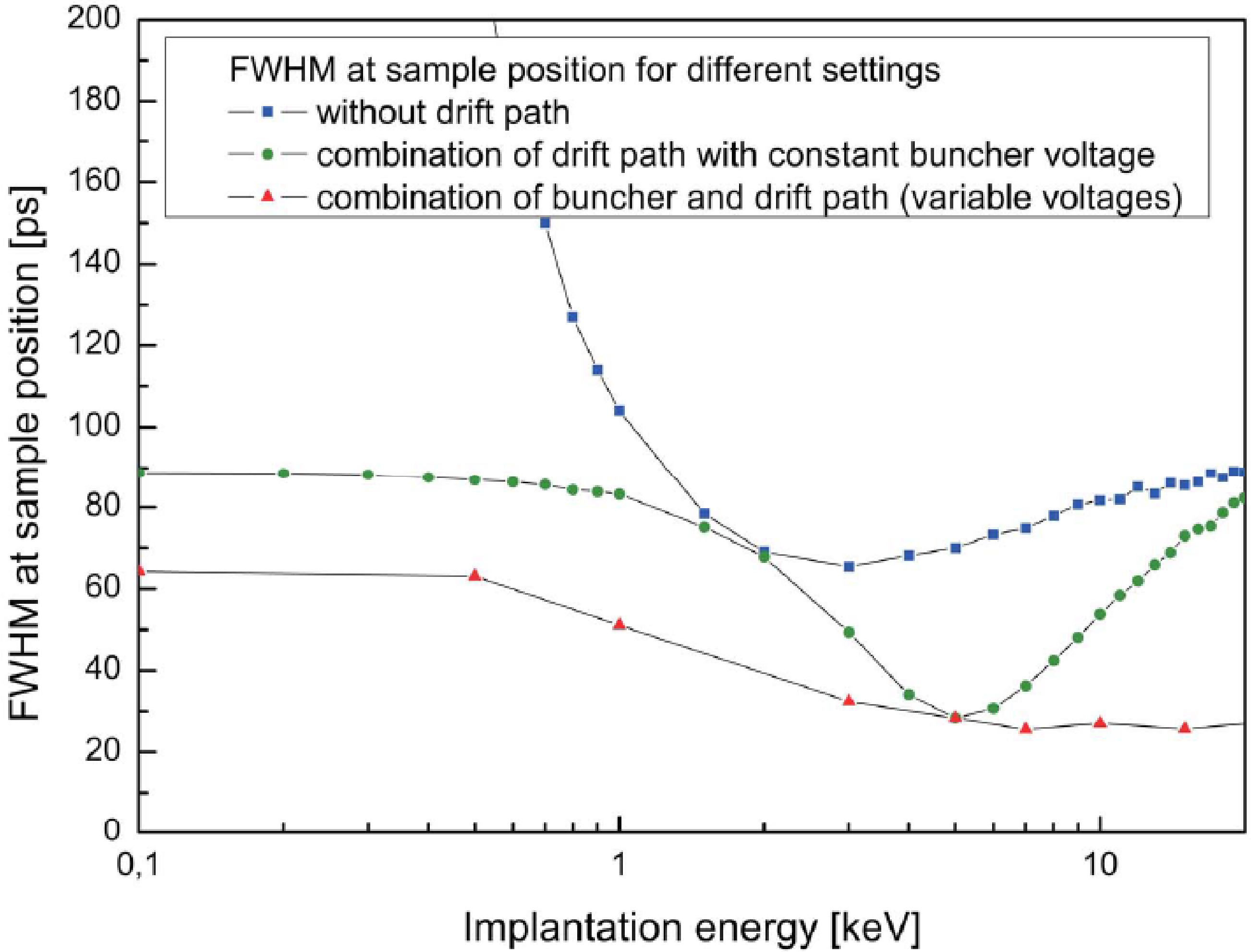
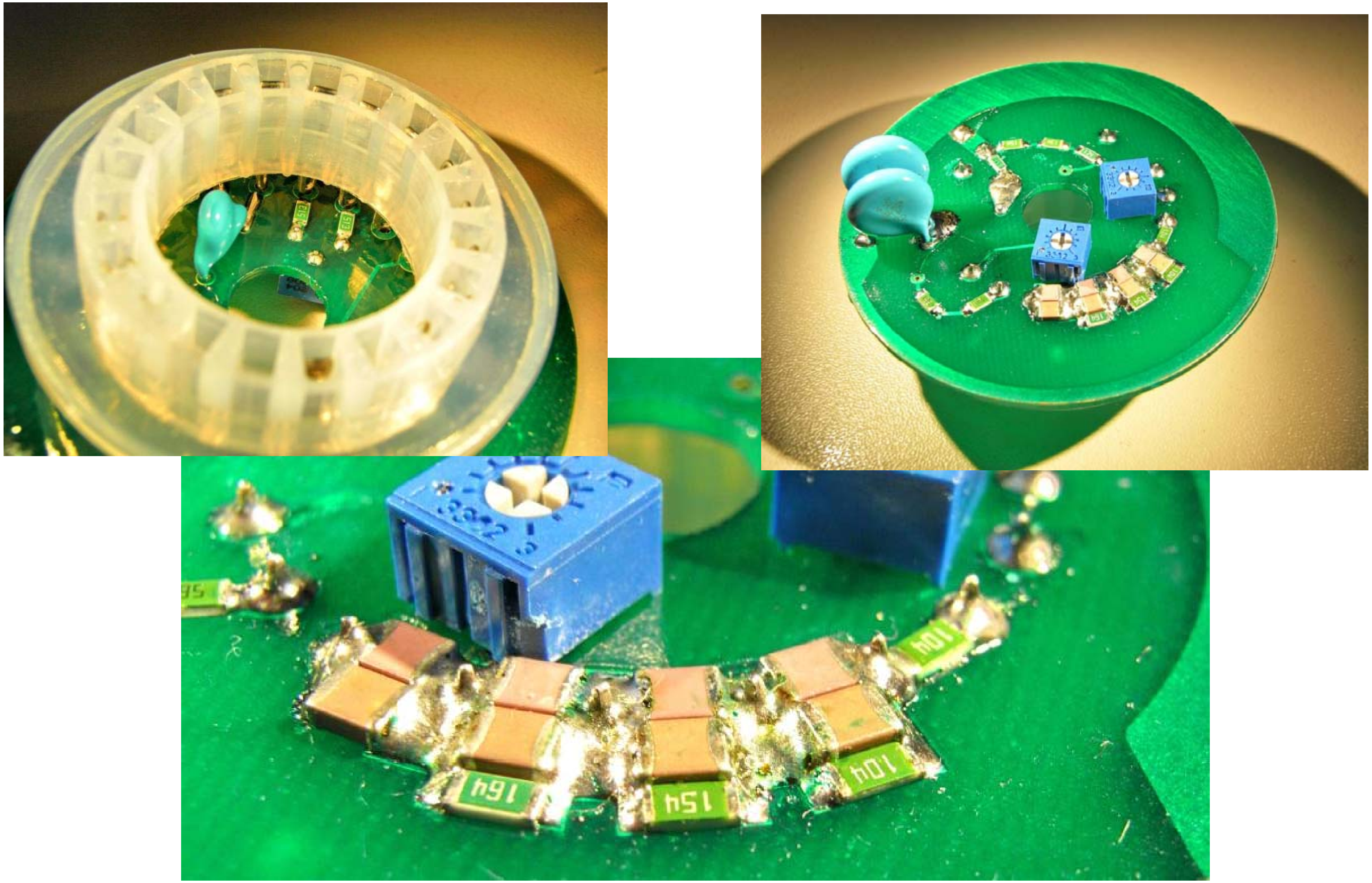


PMs and Scintillators

- SMD socket for new XP20Z8 for throughput of high frequencies



Future Plans

- Electron gun until the end of the vacuum tube
- 22-Na beam source with moderator should be built in instead of electron-positron converter (save ELBE beam time)
- ELBE-beam time in December: Generating positrons by ELBE electron beam in low-power mode (diagnostic mode)
- Measure energy and time spread of positron bunches
- Finish sample chamber design
- Further improvement of digital lifetime and Doppler measurement
- Test scintillators (LSO, ZnO, ...)

A Positron Study of Hydrogen Ion-Cutting of GaN

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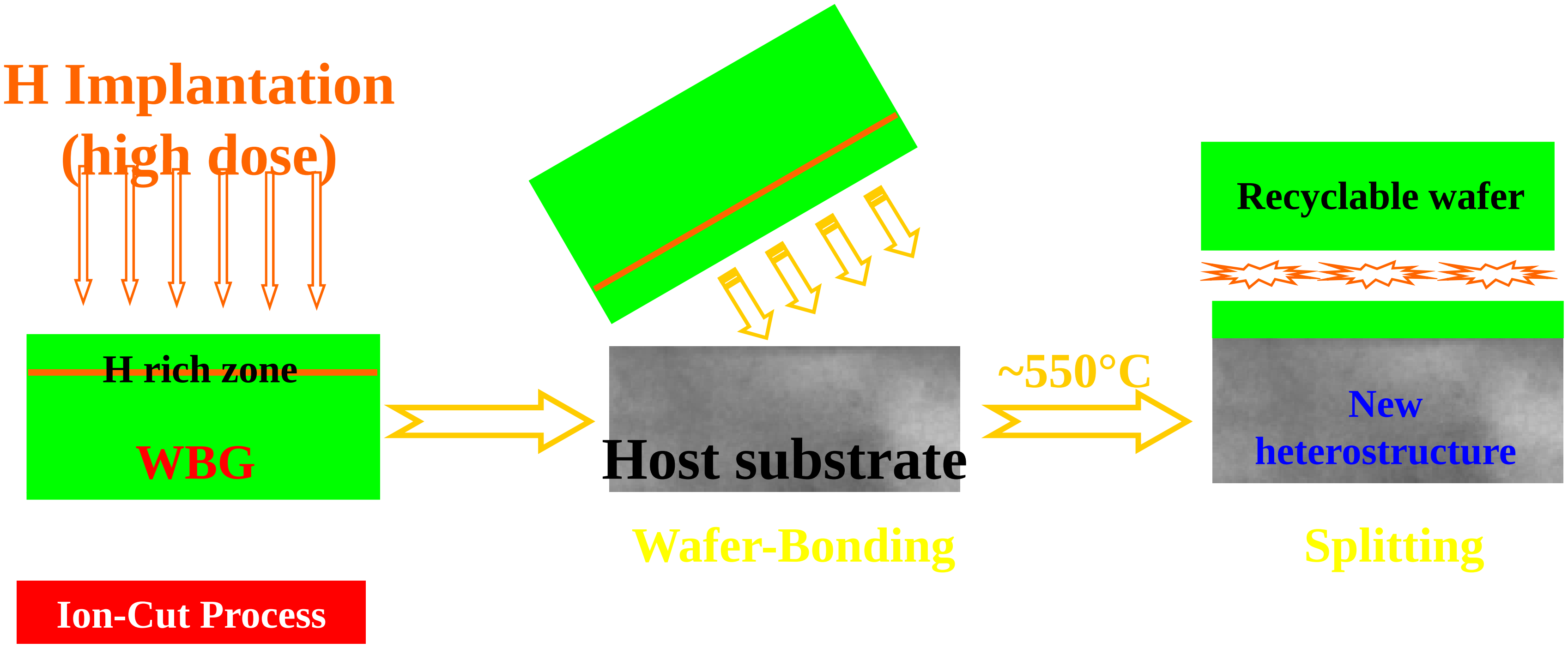
Motivation: Cheap & easy Heterostructures of wide-band gap materials (GaN, ZnO, AlN)

Technological context: Hetero-epitaxial growth of WBG materials on foreign substrates leads unavoidably to the formation of growth-related defects such as dislocations, stacking faults and twins that occur to relax the strain which significantly limits the quality of the grown structures with undesirable impact on devices performance.

What to do? Direct wafer bonding in combination with hydrogen ion-cutting is a promising stratagem to integrate bulk quality thin layers onto various host materials achieving a wide variety of heterostructures sometimes inconceivable by epitaxy. Having bulk properties, these new materials are very promising for a low cost fabrication of WBG-based devices such as phosphorous-free white LED and high performance laser diodes.



Methodology

We are using a wide variety of experimental techniques in order to address different aspects of H-defect interactions leading to extended internal surfaces

<u>Experimental Techniques:</u>

1- Cross section **transmission electron microscopy**: Study of post-implantation structural and morphological changes (blisters)

2- **Rutherford backscattering spectrometry** in channeling mode: Characterization of displacement fields and strain build-up induced by thermal annealing of implanted substrate;

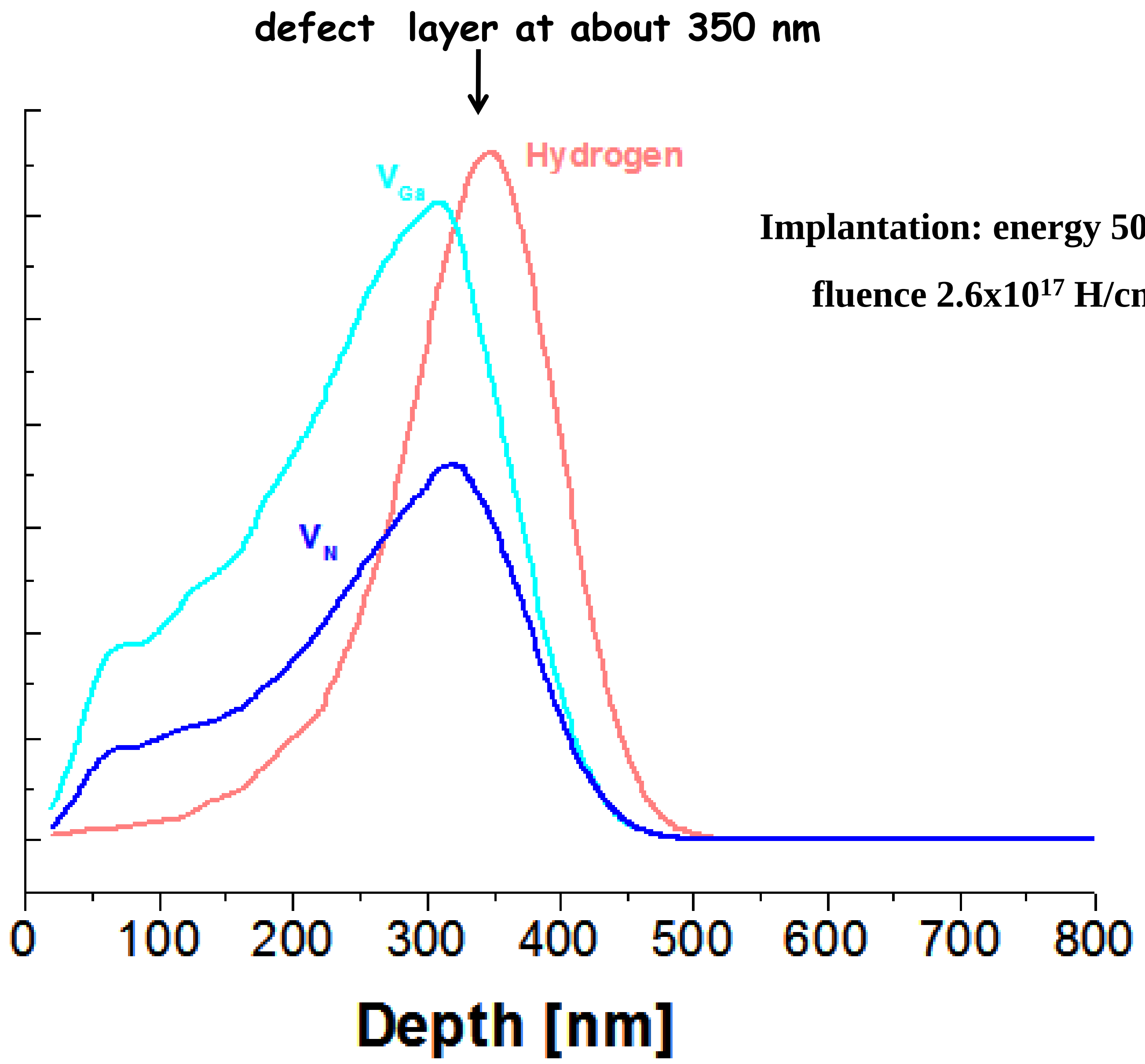
3- **Elastic recoil detection analysis**: Implanted gas depth profile and quantification of its amount as a function of thermal annealing;

4- **Fourier Transform Infrared Spectroscopy**: Identification of H-defect complexes induced by H implantation and their evolution during sub-surface cleaving process.

5- **Positron annihilation spectroscopy**: To probe open volumes and vacancy clusters induced by H implantation and their thermal evolution.

6- **X-ray line shape analysis**: internal strain

SRIM Simulations

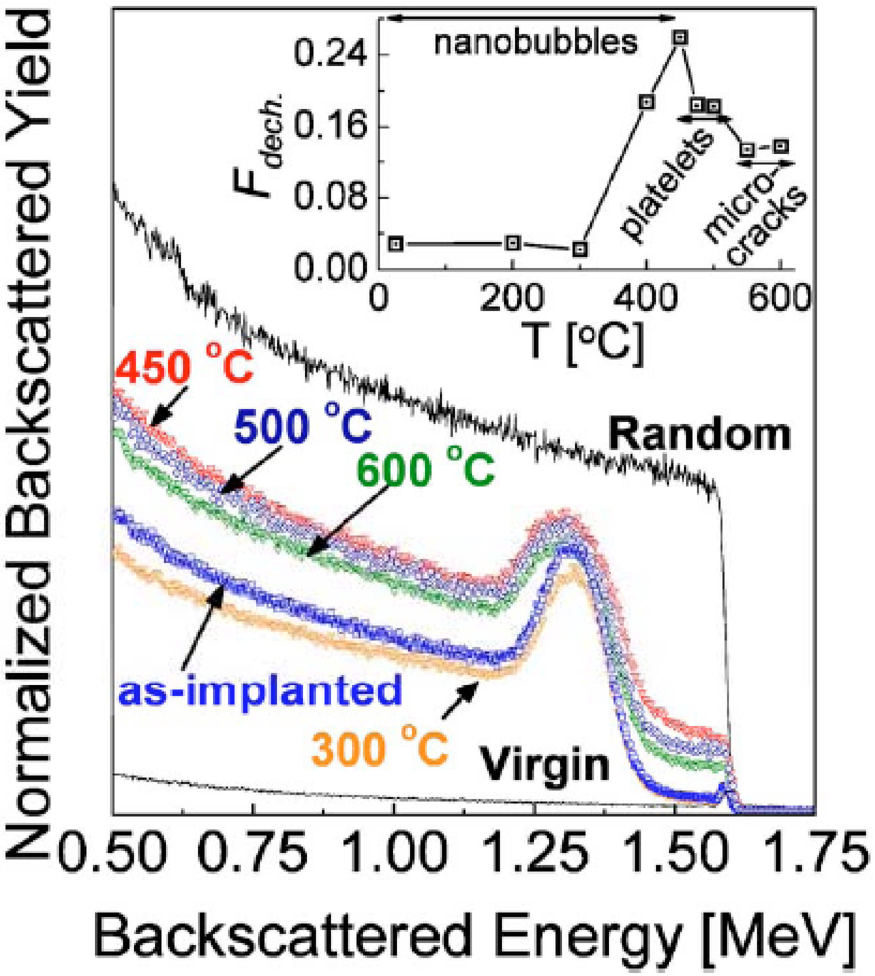


Implantation: energy 50 keV, fluence 2.6×10^{17} H/cm^2

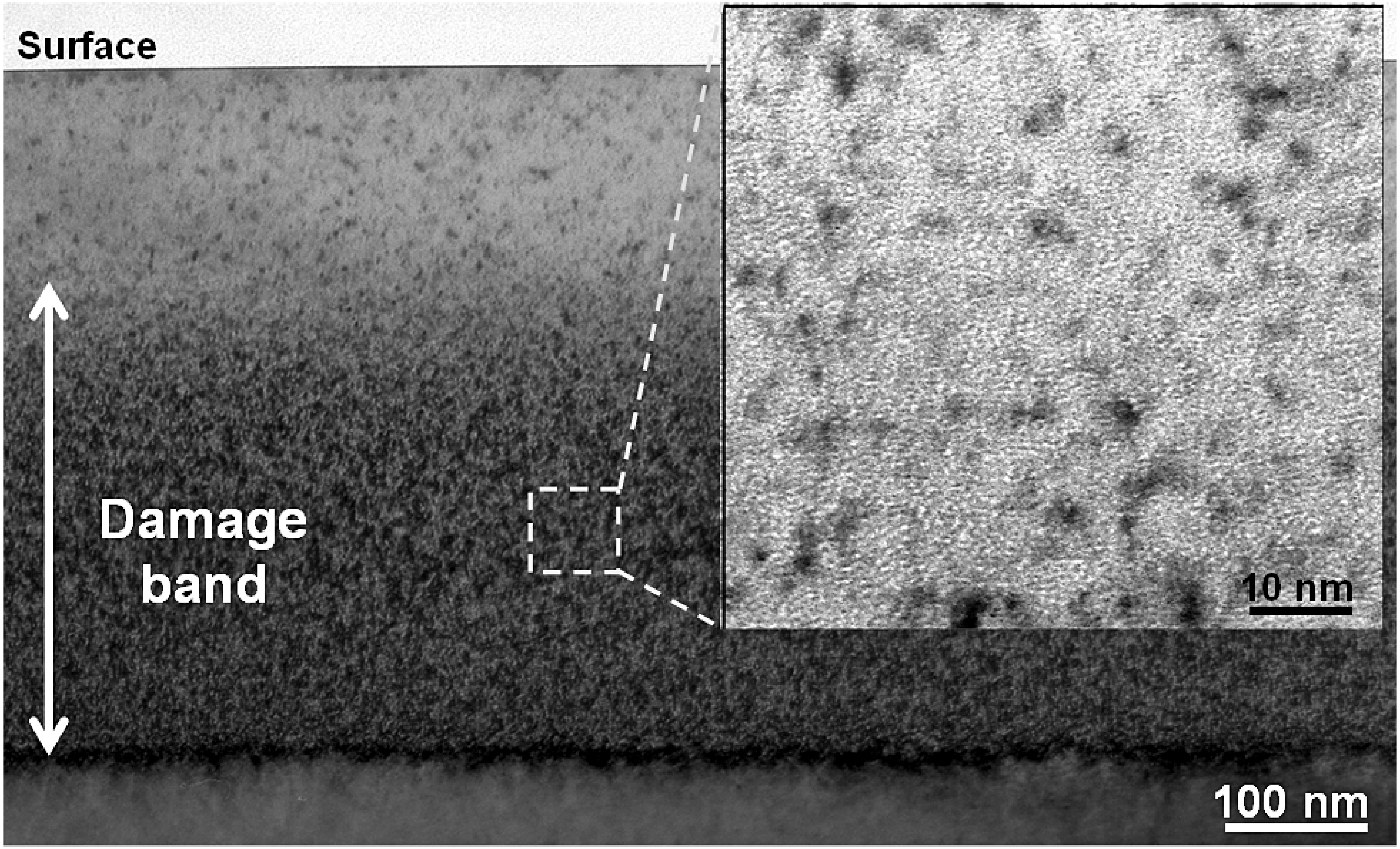
Rutherford Backscattering

An annealing Rutherford backscattering was performed and can be compared to PALS.

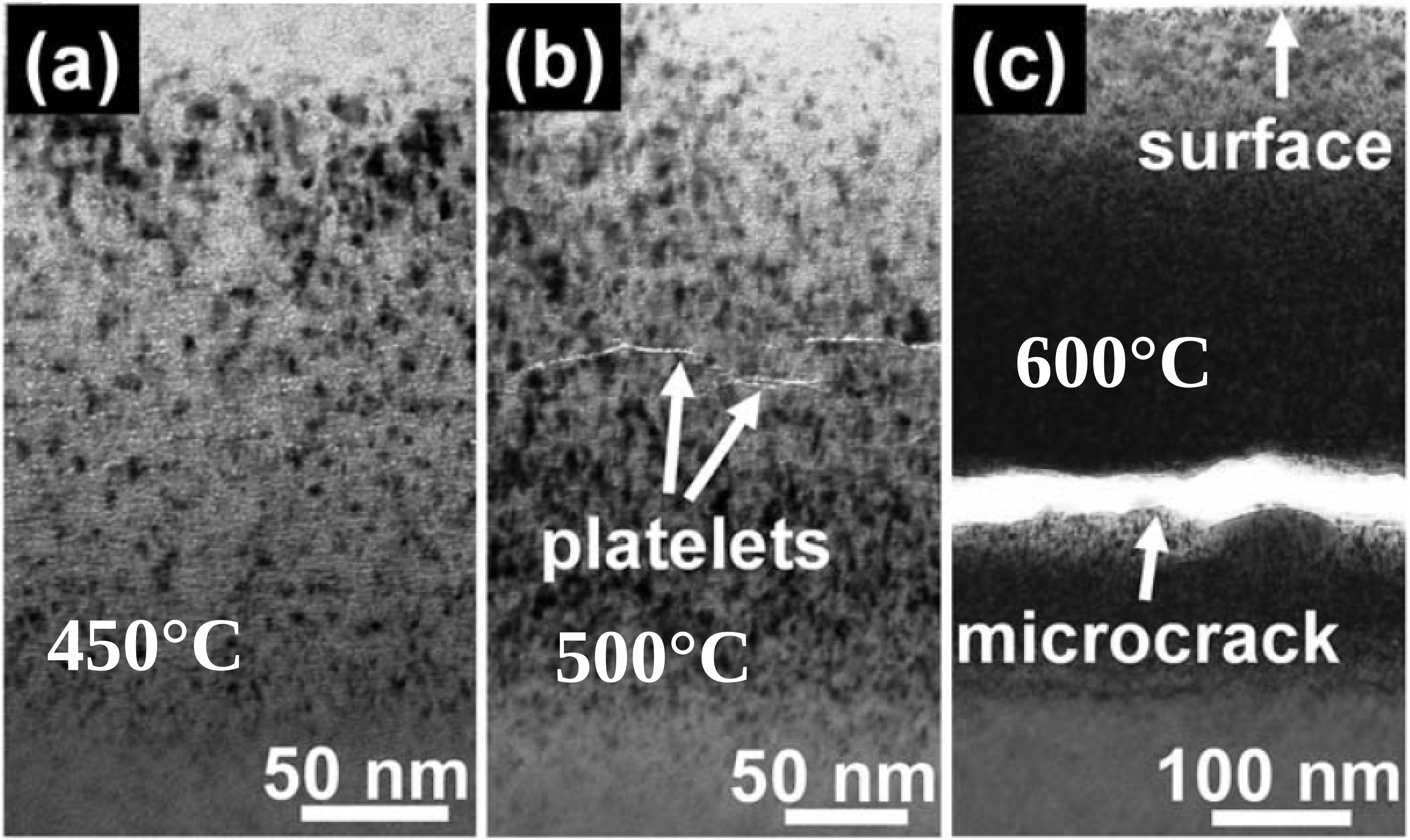
Implantation: energy 50 keV, fluence 2.6×10^{17} H/cm^2



During implantation: nanobubbles 1-2 nm are formed



XTEM micrographs of H-implanted GaN annealed at different temperatures: 450 °C (a), 500 °C (b), and 600 °C (c).



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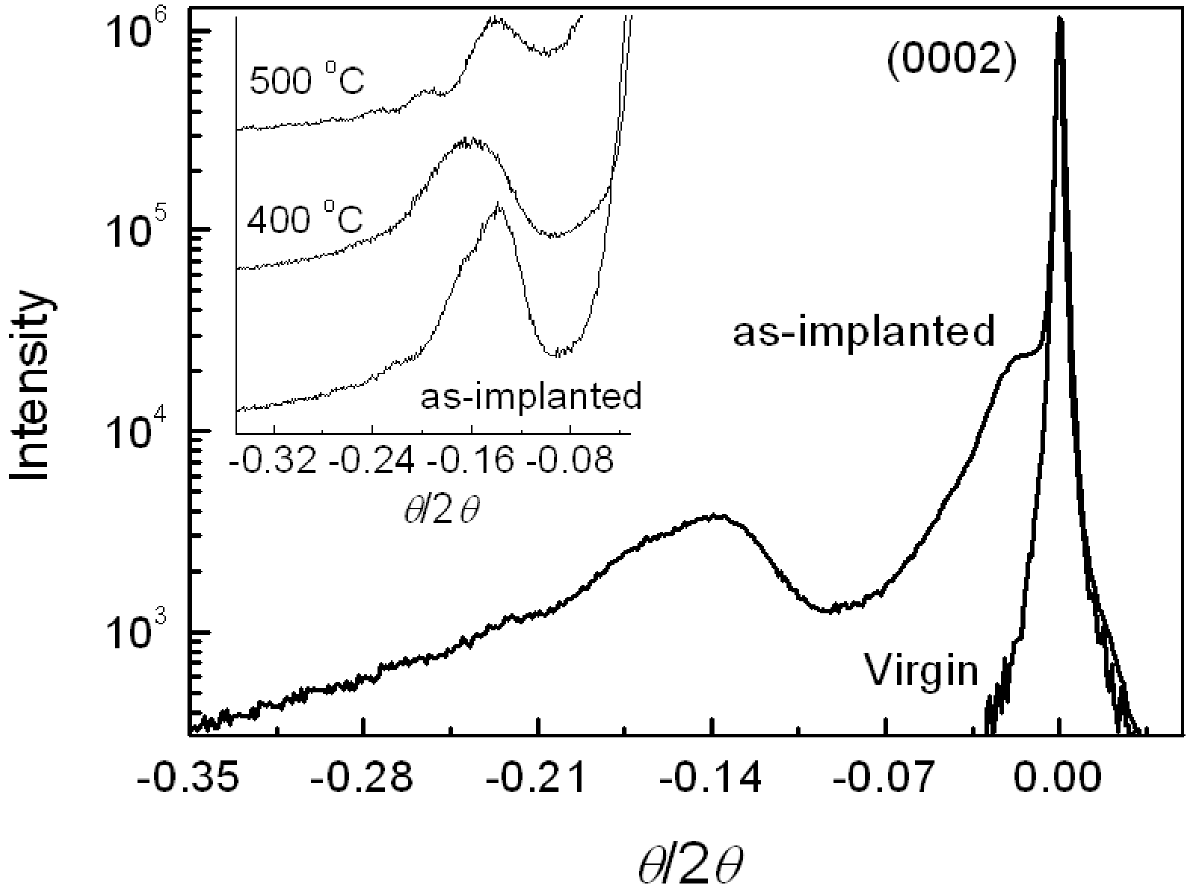
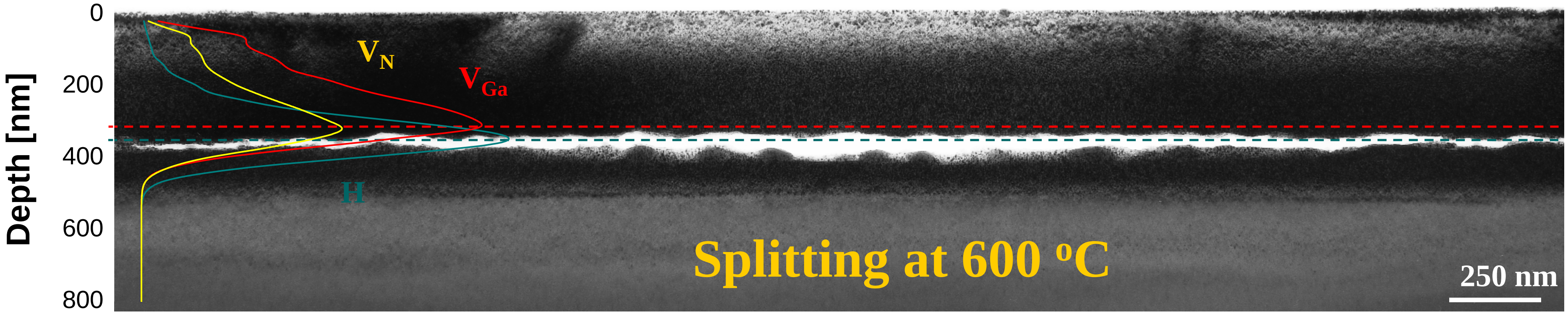
X-ray line form analysis

- During course of annealing: X-ray lines broaden
- Internal stress increases during annealing



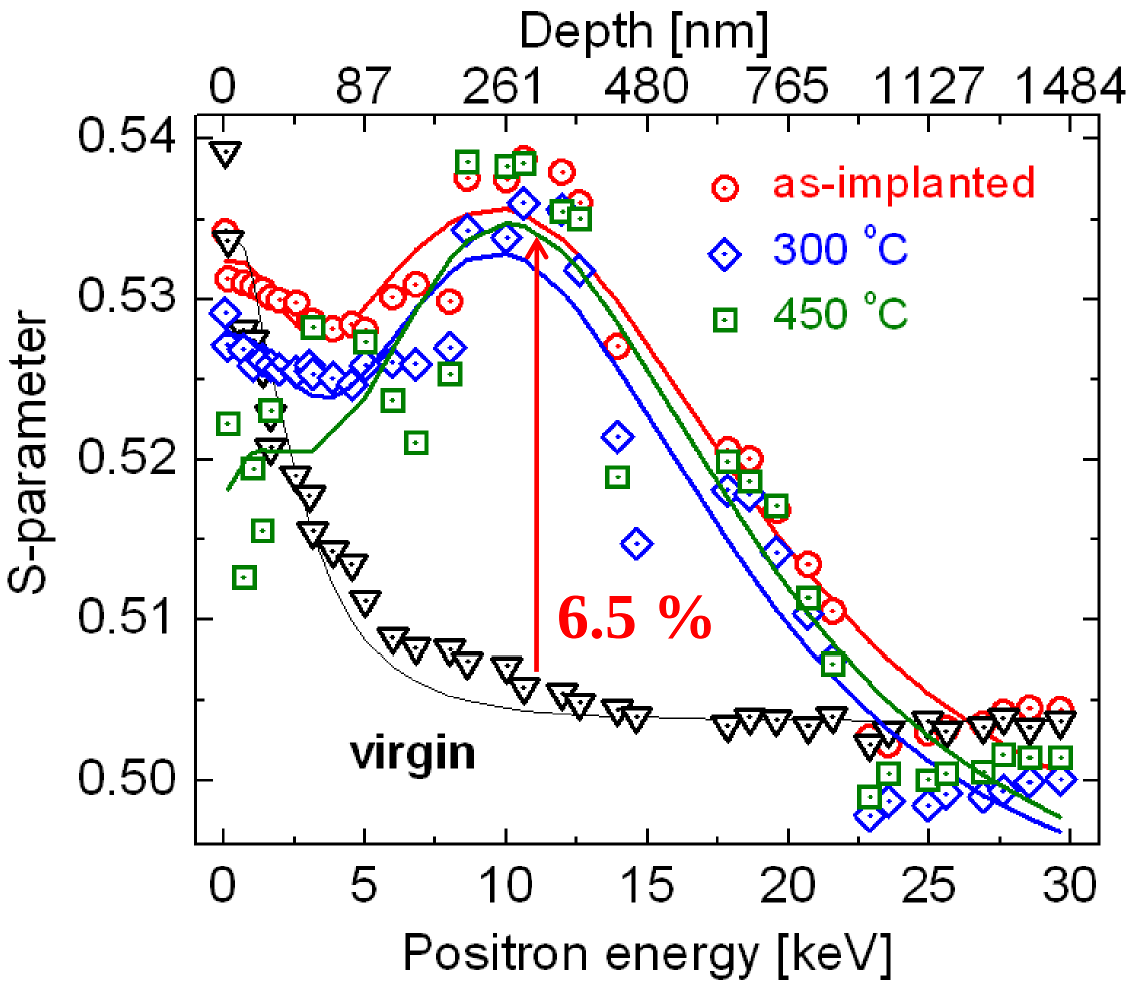
Understanding basic mechanisms of ion-cut process

- In order to draw a precise mechanistic picture of H-induced splitting of WBG materials a deep investigation thermal evolution of H-defect complexes is required
- Simulated defect concentration fits to position of platelets



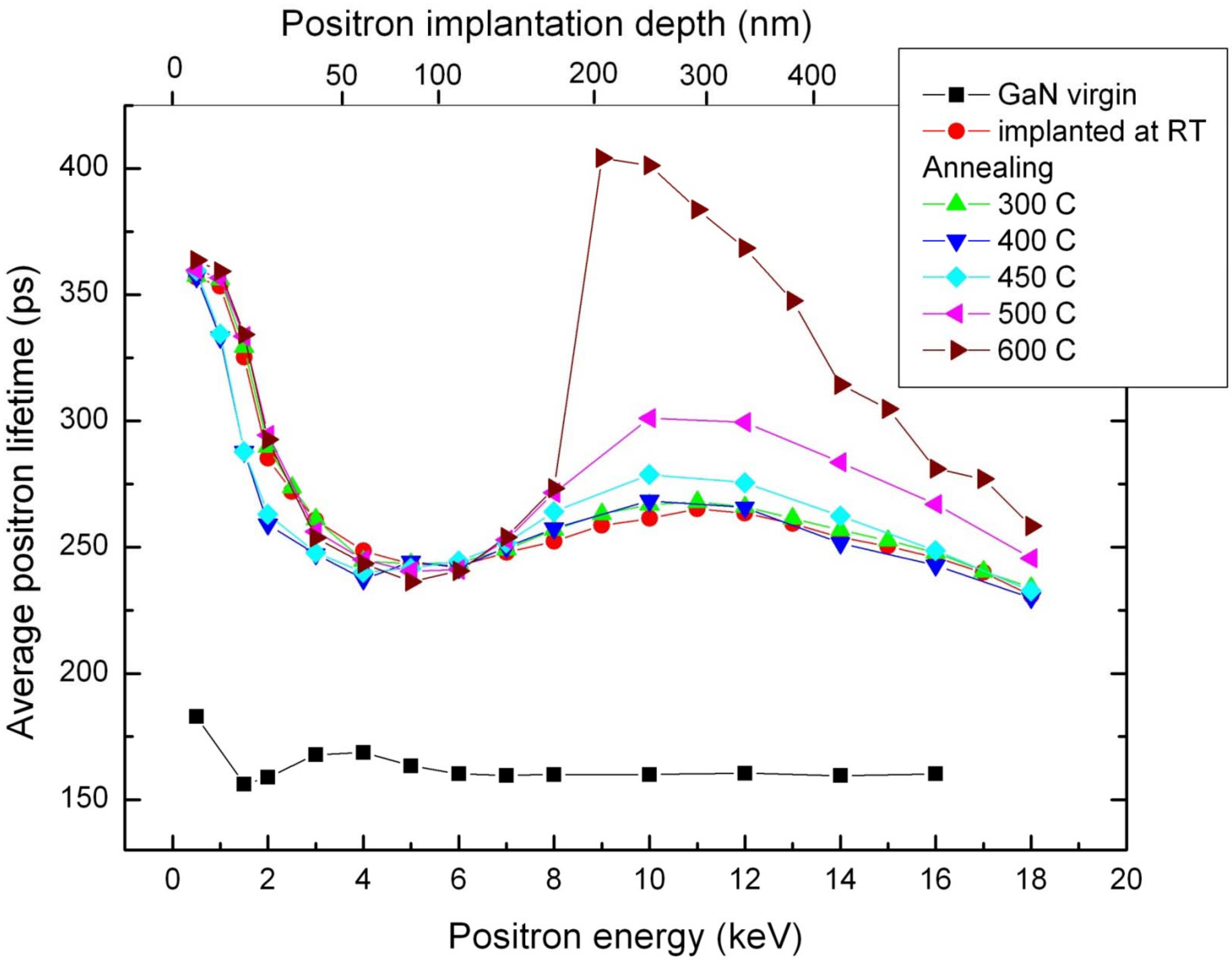
Doppler Broadening Measurements

- Slow positron DOBS of implanted GaN sample: results show strong defect signal
- 50 keV protons and 2.6×10^{17} H/cm^2

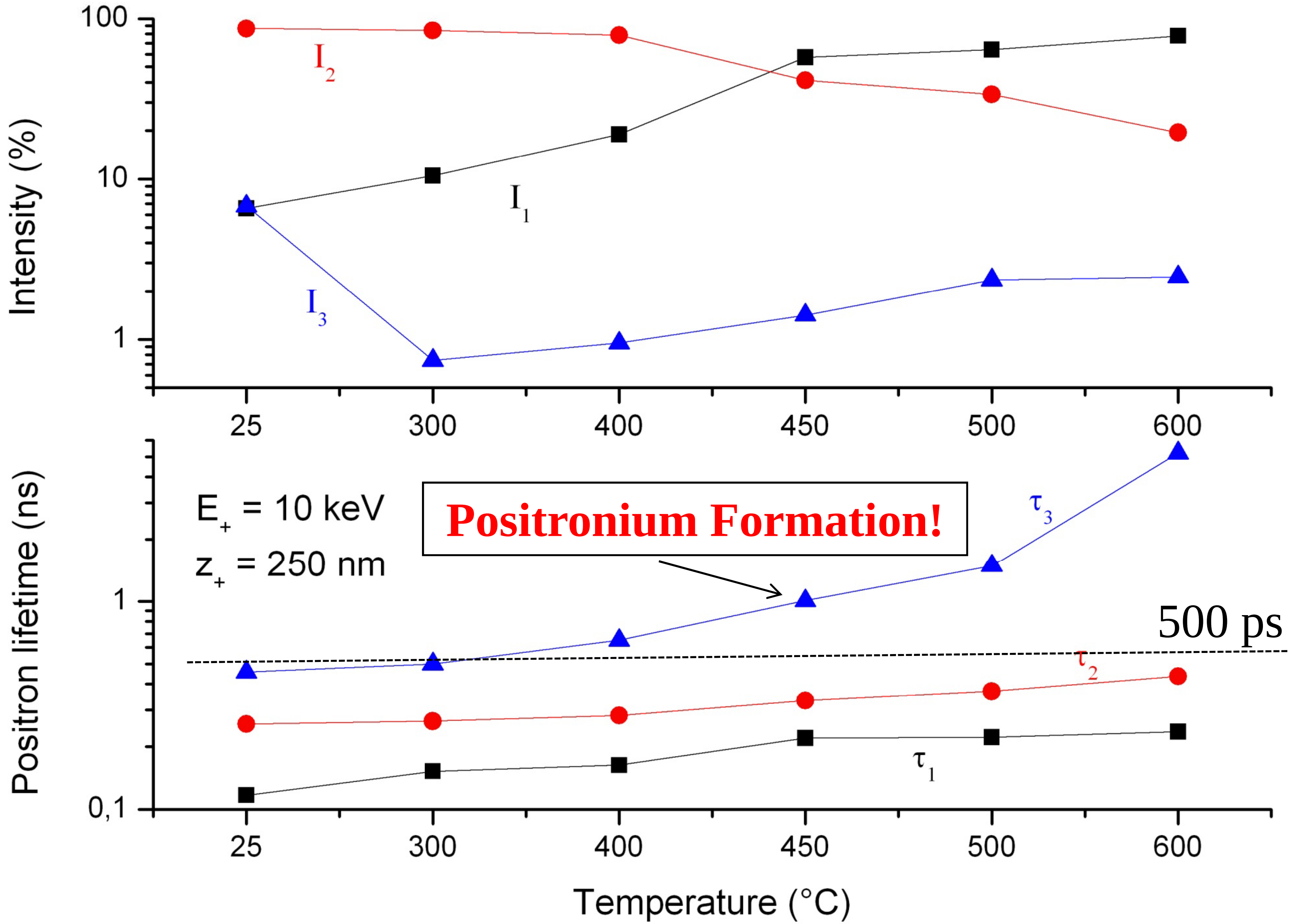


nanovoids

Positron Lifetime Experiments at PLEPS @ FRM-II



3-component decomposition of lifetime spectra



Conclusions

- structural transformations studied of splitting of GaN by H implantation
- vacancy clustering during the implantation: 1–2 nm nanobubbles
- 300–450 °C: strong enhancement of strain-induced lattice distortion
- formation of platelets: partial relief of the strain
- extended internal surfaces develop around 550 °C
- leading to splitting of 340-nm-thick GaN layer
- can be seen be by positrons: Ps formation – up to 5 ns lifetime