Defect Study of Hydrogen Ion-Cutting of GaN

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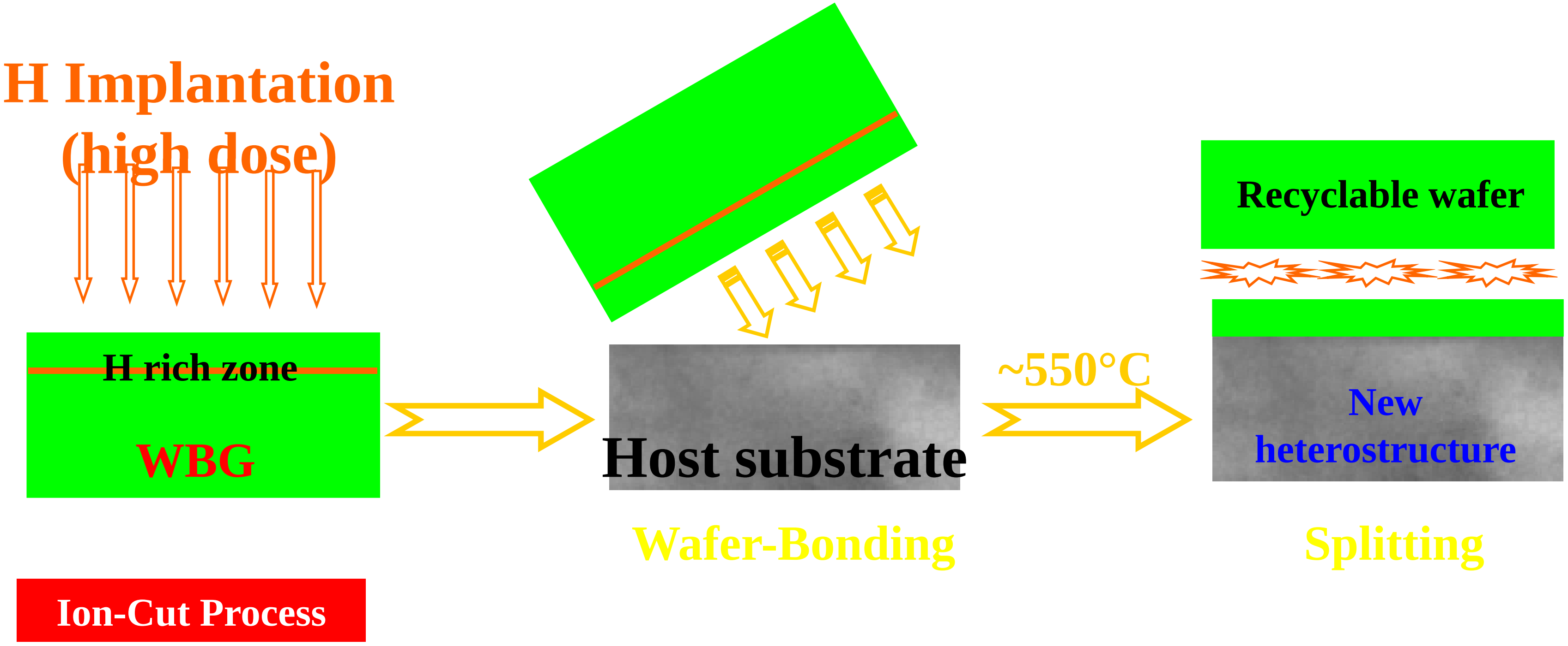
Motivation: Cheap & easy Heterostructures of wide-band gap materials (GaN, ZnO, AlN)

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

Experimental Techniques:

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;

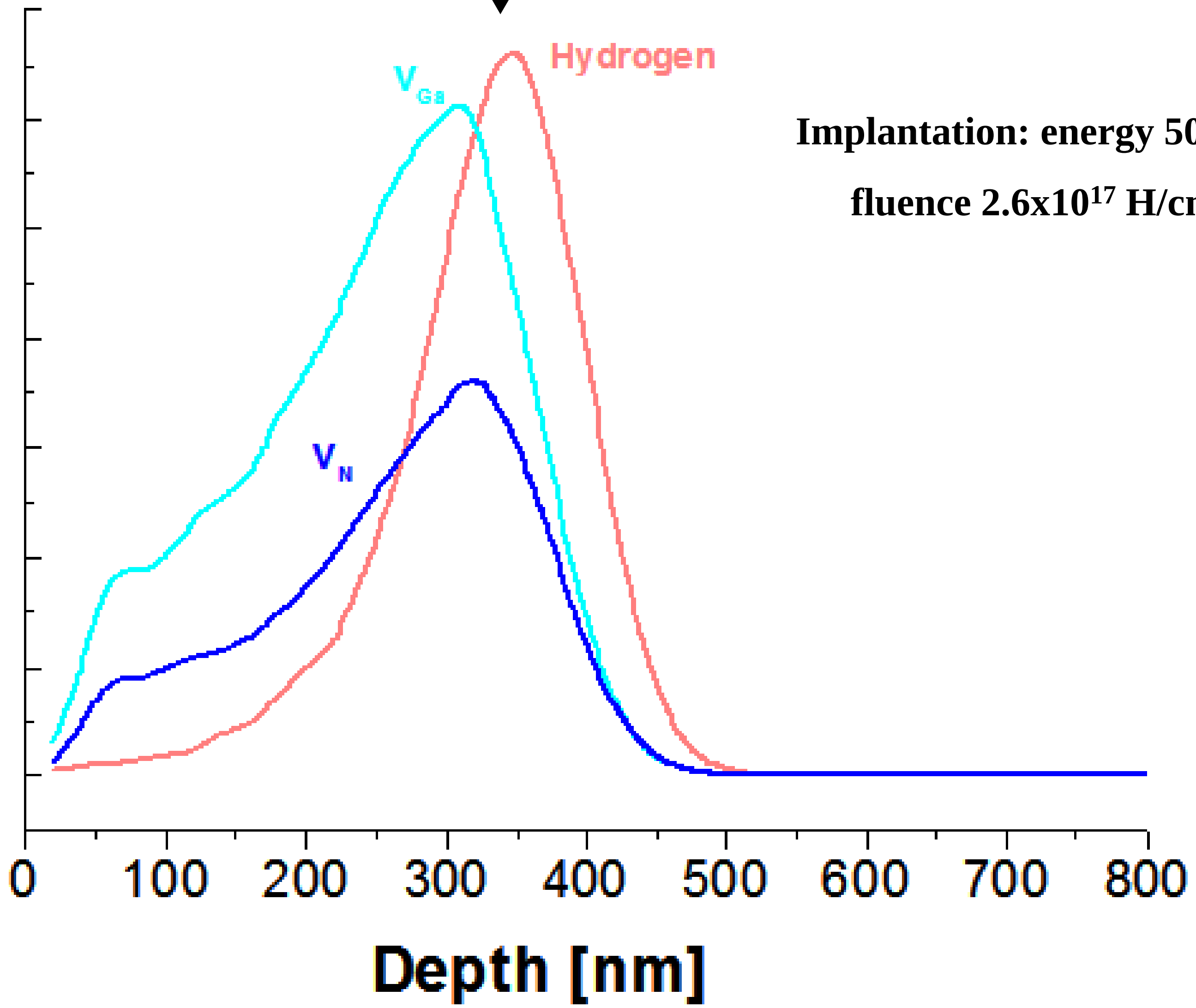
4- **Fourier Transform Infrared Spectroscopy**: Identification of H-defect complexes induced by H implantation and their evolution during sub-surface cleaving process.

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

defect layer at about 350 nm



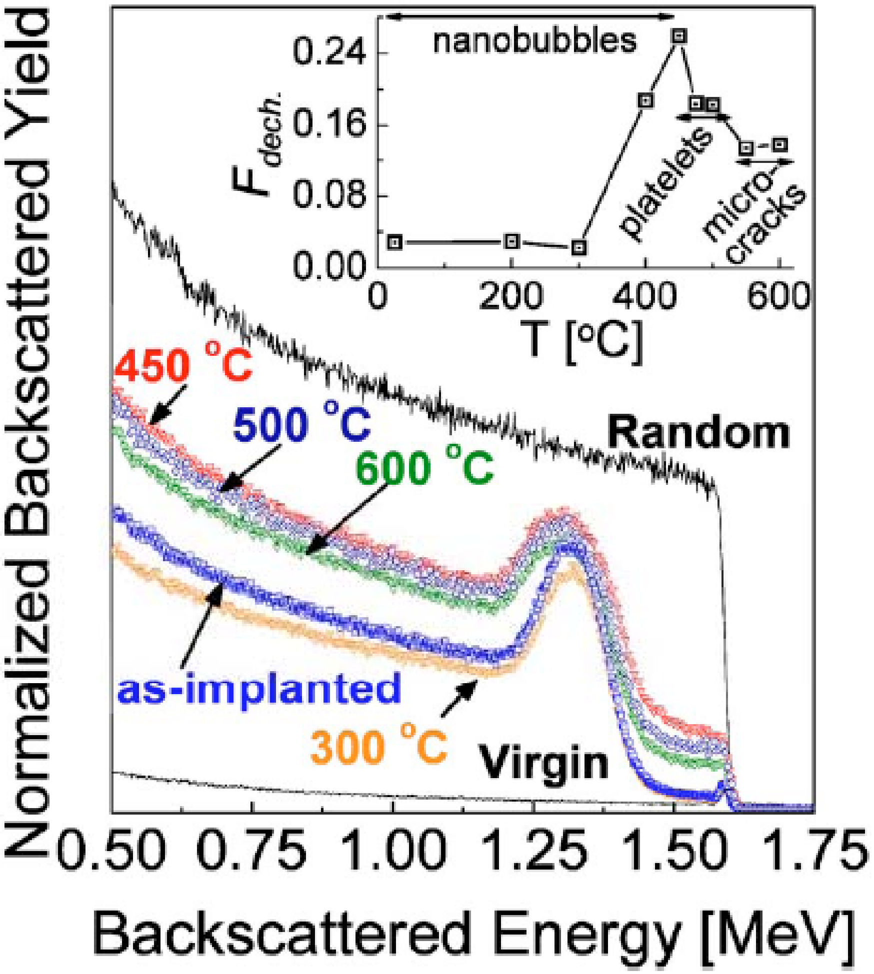
Implantation: energy 50 keV,

fluence 2.6×10^{17} H/cm^2

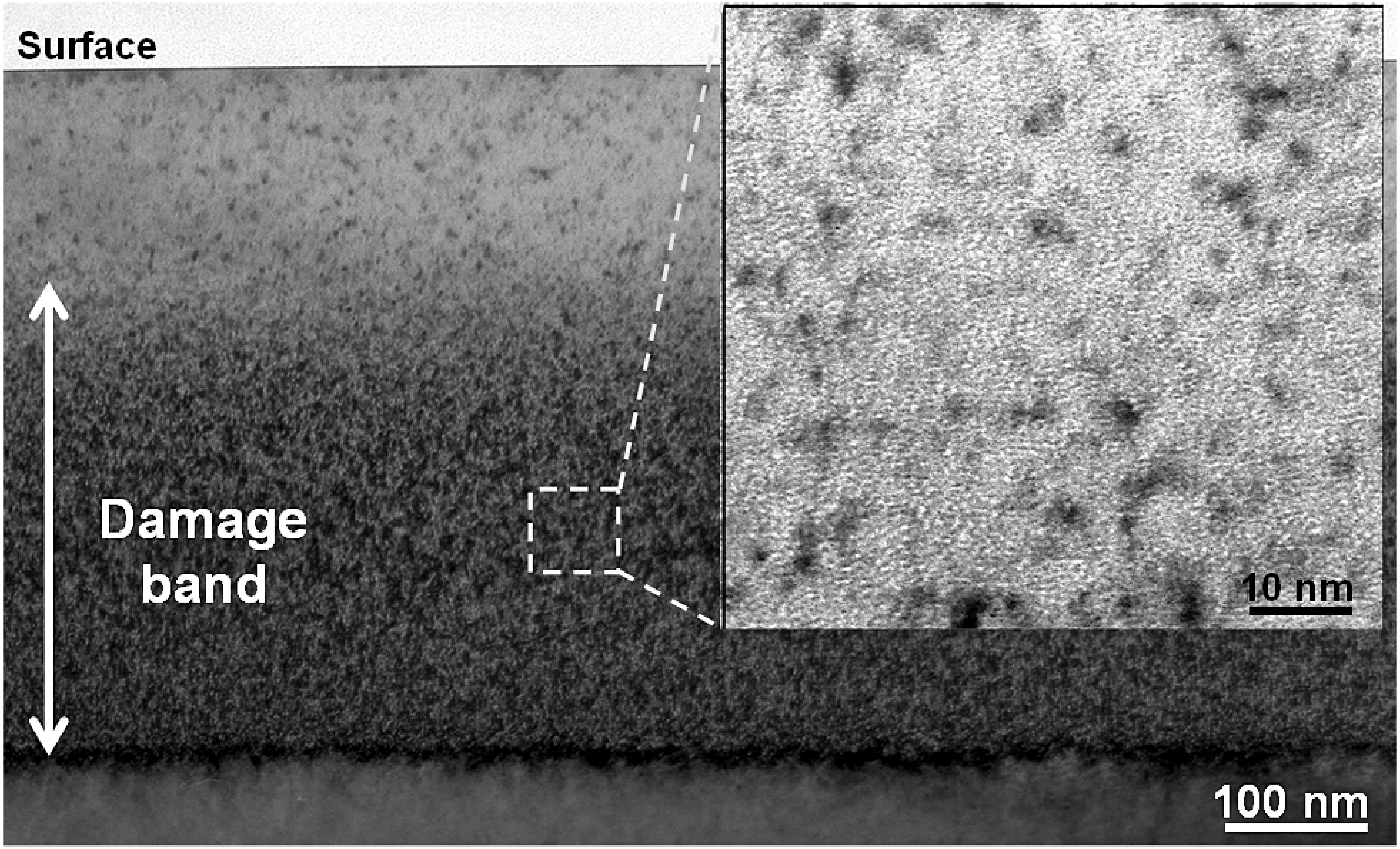
Rutherford Backscattering

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

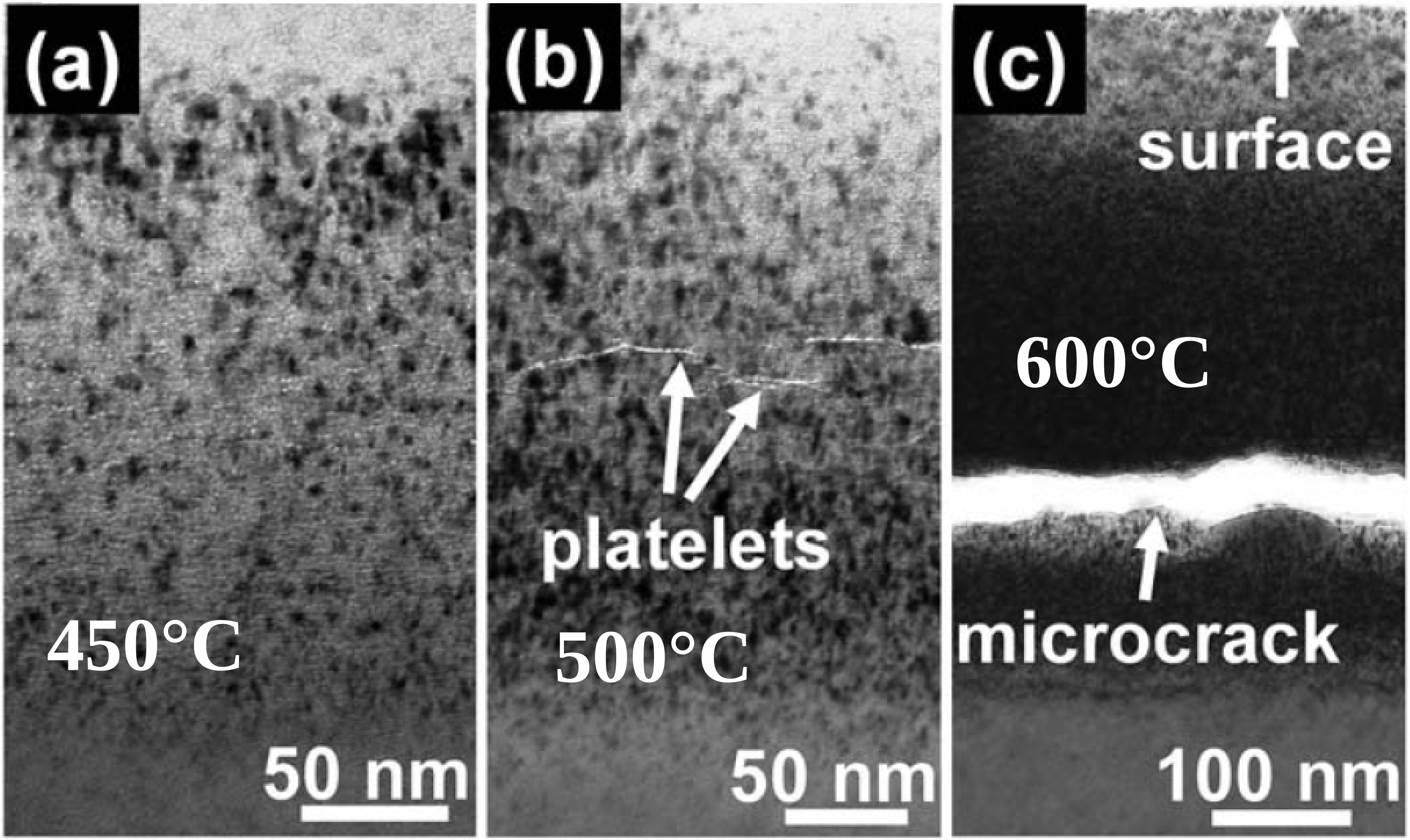
Implantation: energy 50 keV, fluence 2.6×10^{17} H/cm^2



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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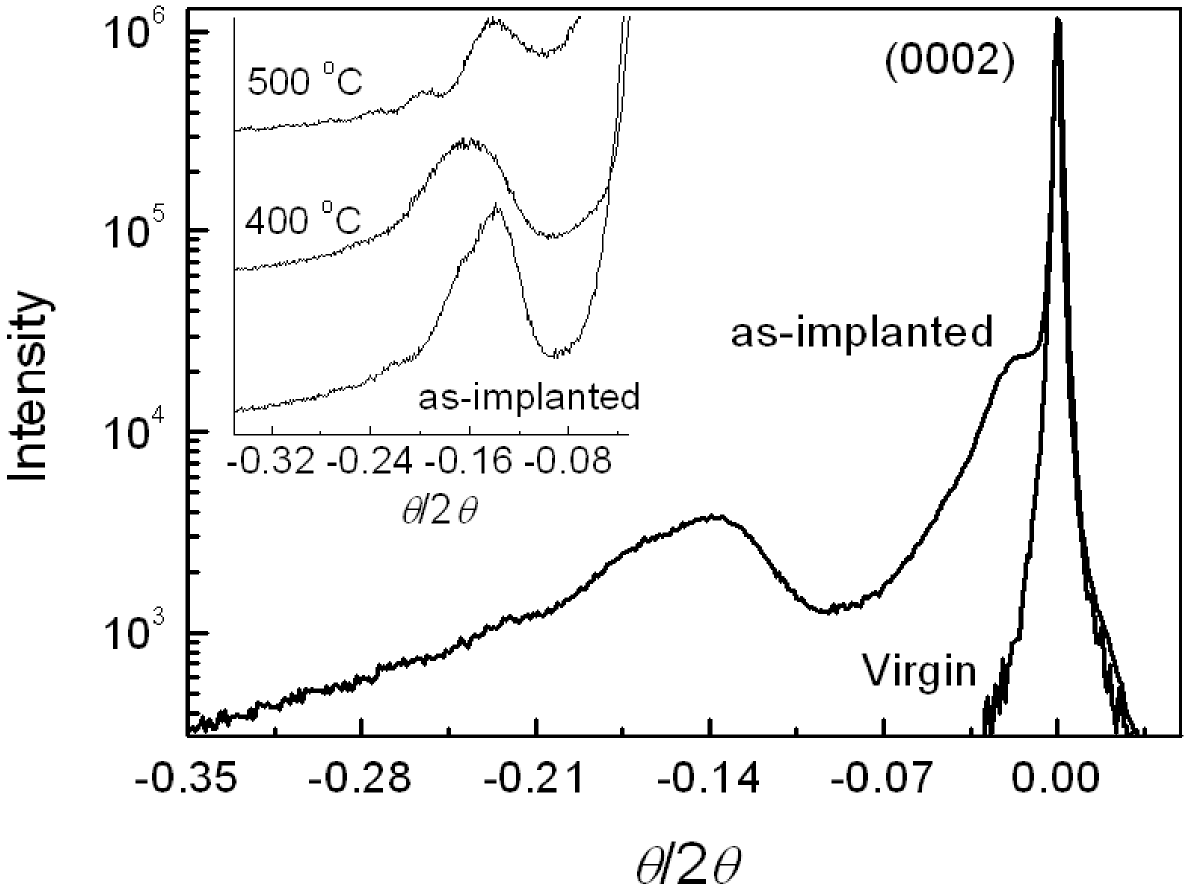
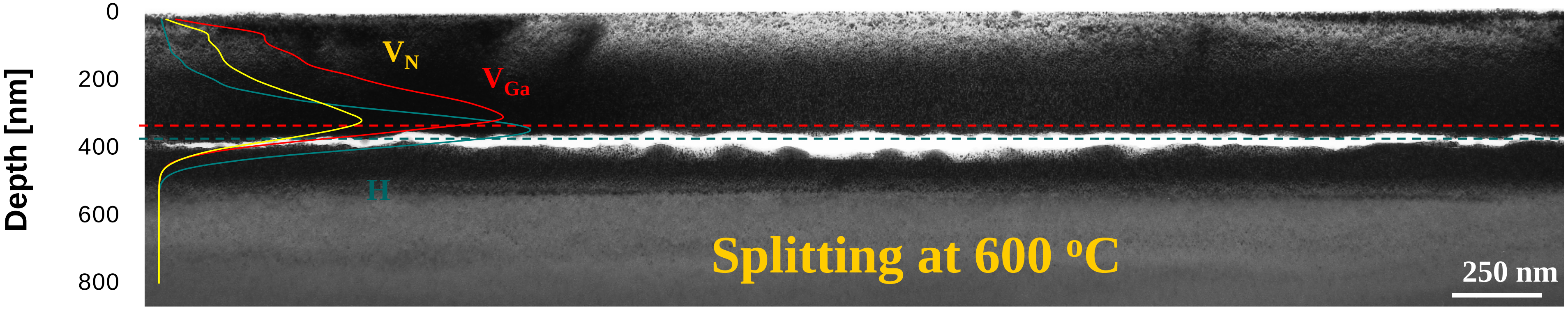
X-ray line form analysis

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



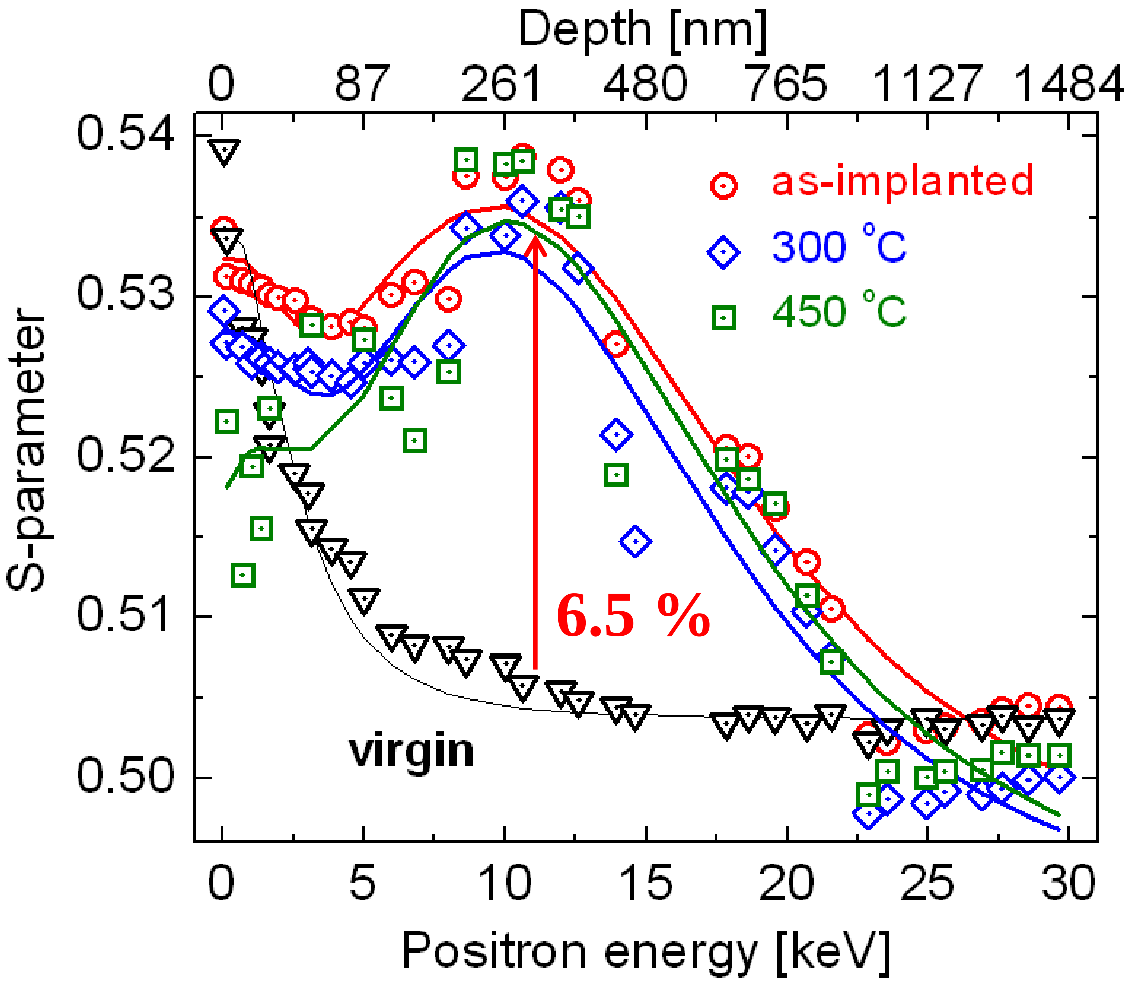
Understanding basic mechanisms of ion-cut process

- 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



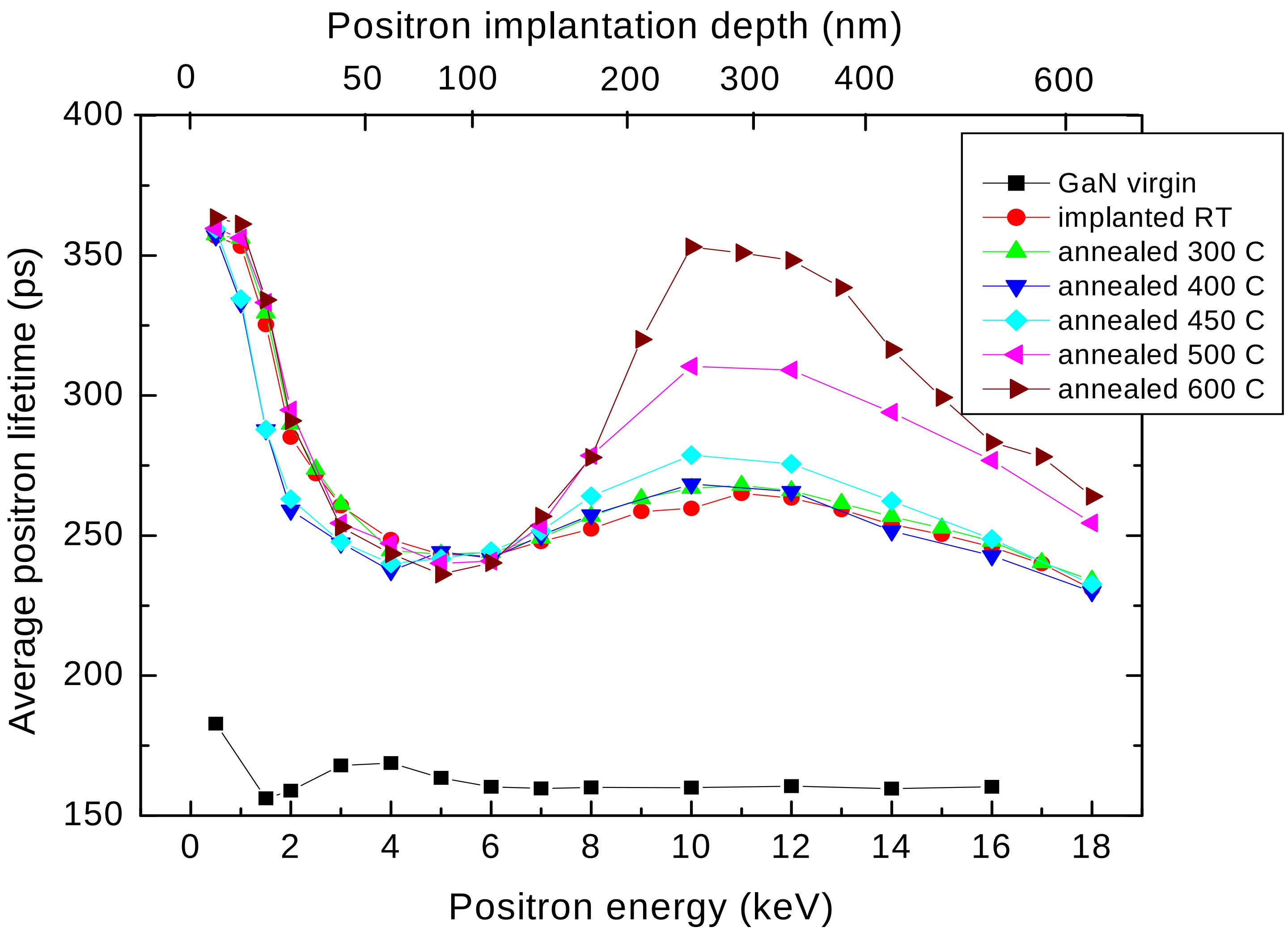
Positron Doppler Broadening Measurements

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

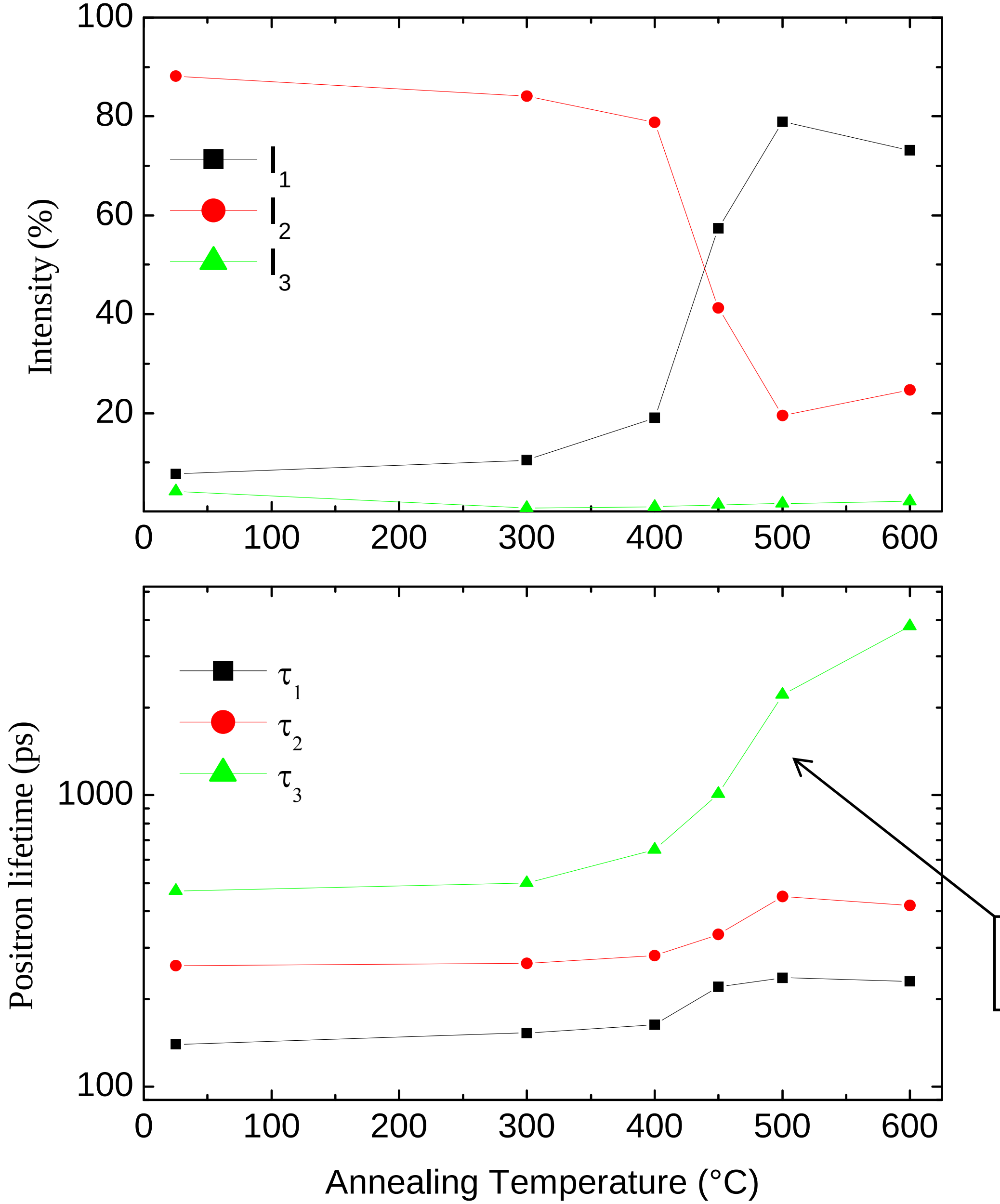


nanovoids

Positron Lifetime Experiments at PLEPS @ FRM-II



3-component decomposition of lifetime spectra



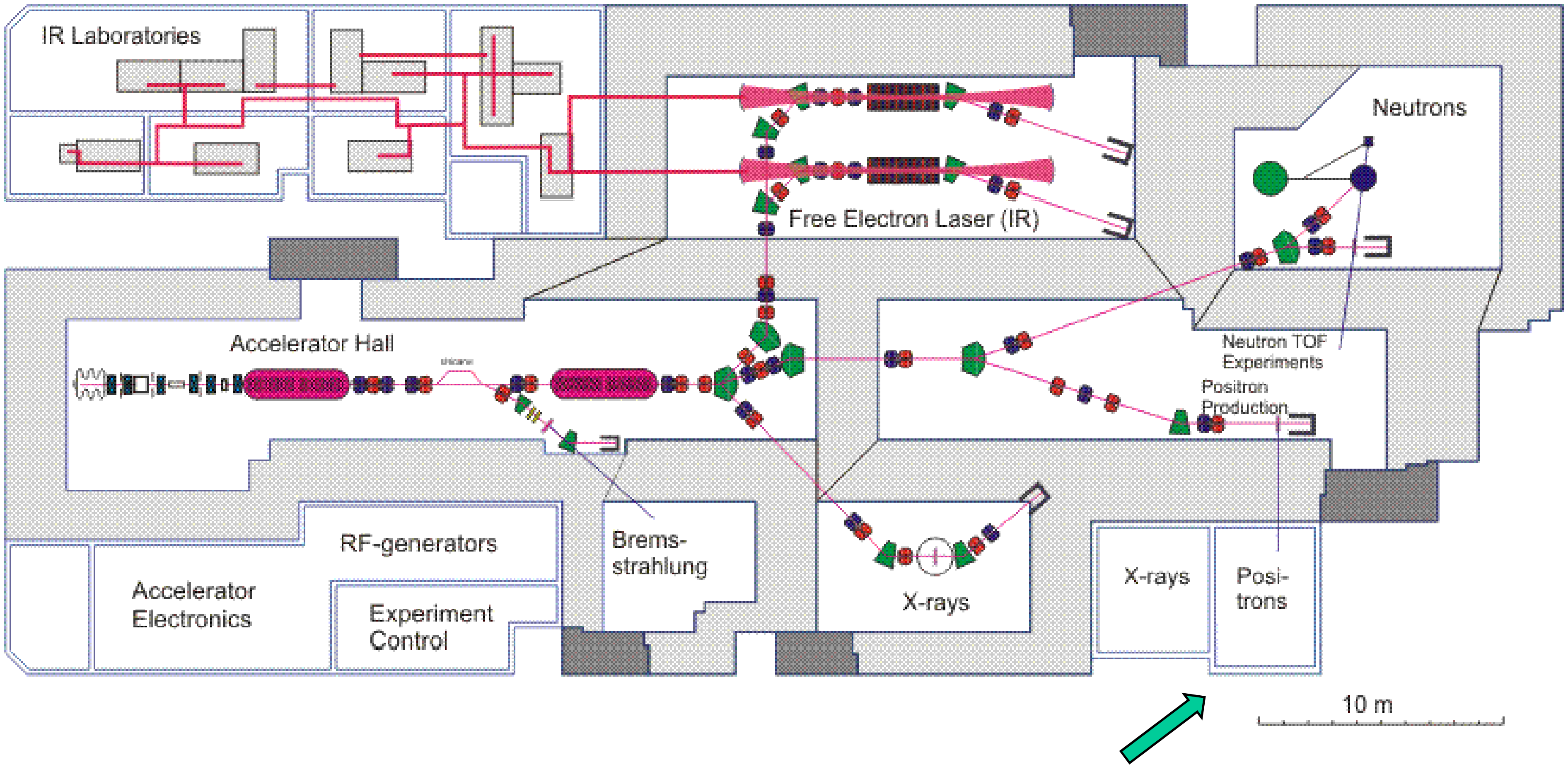
- Spectra at 10 keV correspond to depth of about 250 nm
- 3 components necessary for analysis:
  - Point defects
  - Small vacancy clusters
  - Large voids

Positronium Formation!

Conclusions

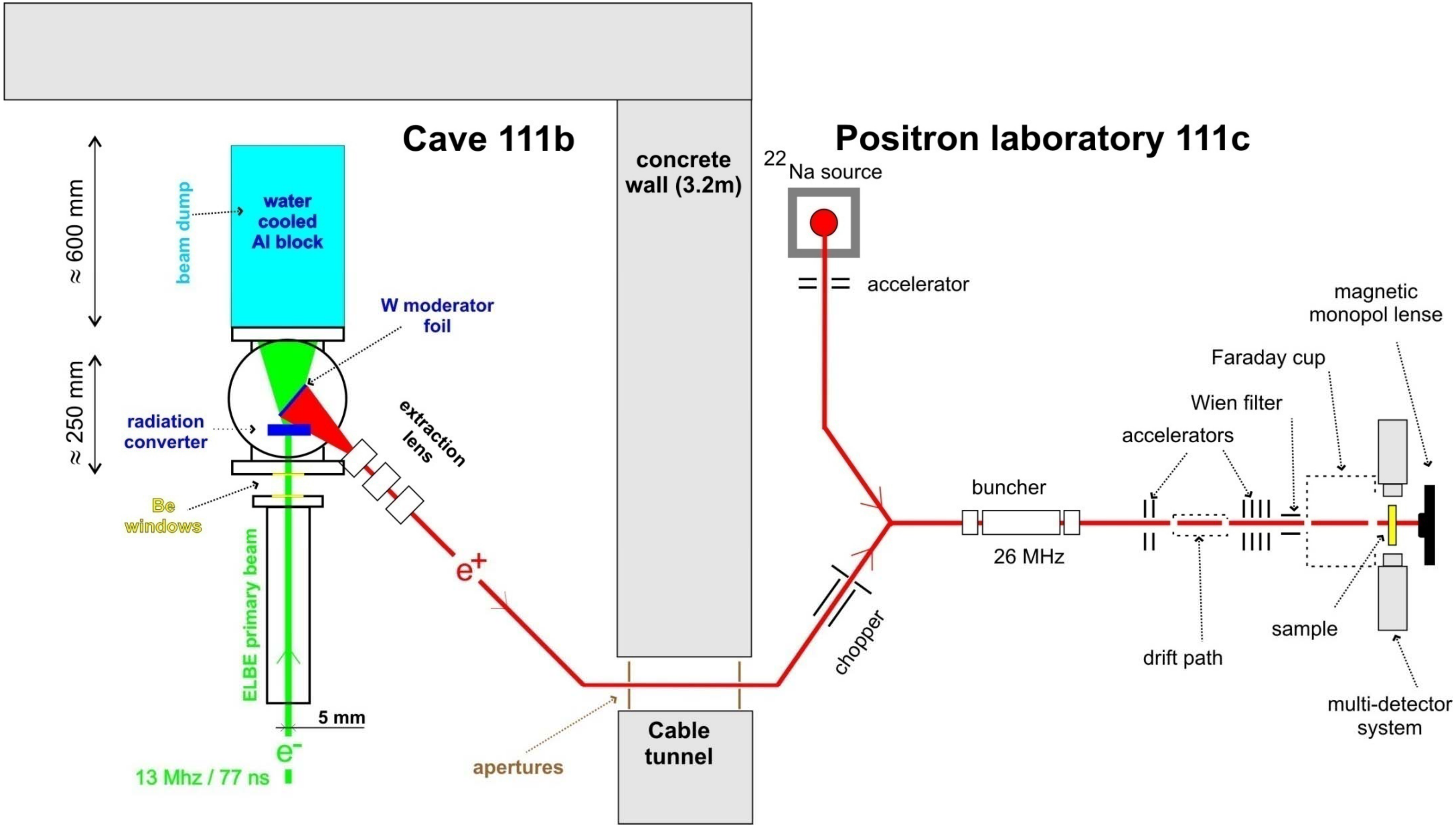
- structural study of ion splitting of GaN by H implantation
- vacancy clustering during the implantation: 1–2 nm nanobubbles
- further clustering during annealing
- 300–450 °C: strong enhancement of strain-induced lattice distortion
- formation of platelets: partial relief of the strain
- extended internal surfaces develop around 550 °C
- leading to splitting of 340-nm-thick GaN layer

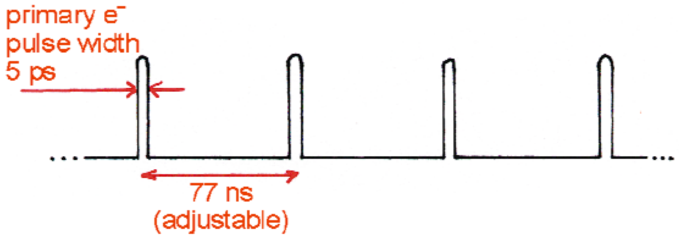
Ground plan of the ELBE radiation source at Research Center Dresden/Rossendorf

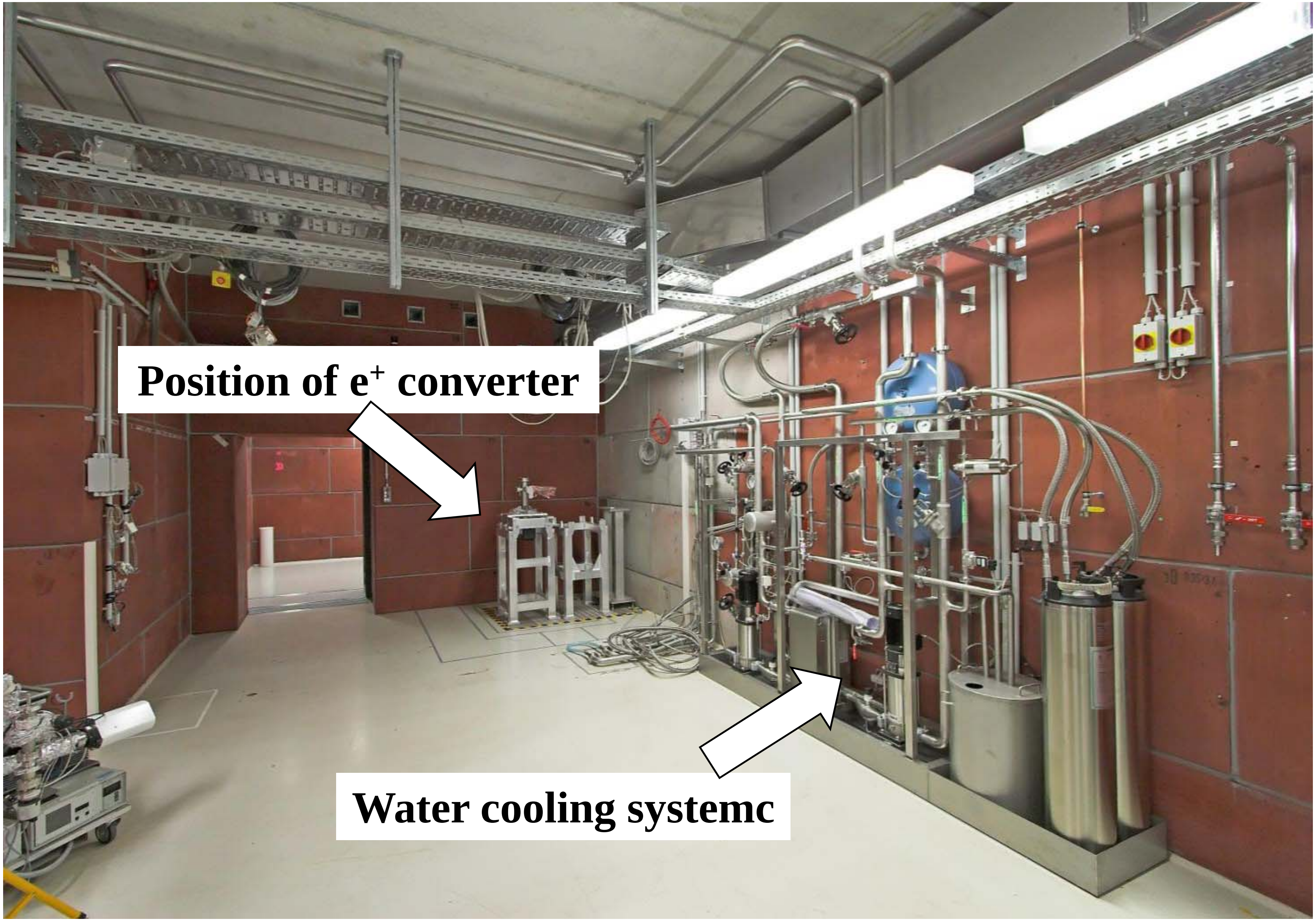


EPOS = ELBE Positron Source

EPOS scheme


Cave 111b
concrete wall (3.2m)
Positron laboratory 111c
^{22}Na source
accelerator
≈ 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
buncher
26 MHz
accelerators
Wien filter
Faraday cup
magnetic monopol lense
drift path
sample
multi-detector system

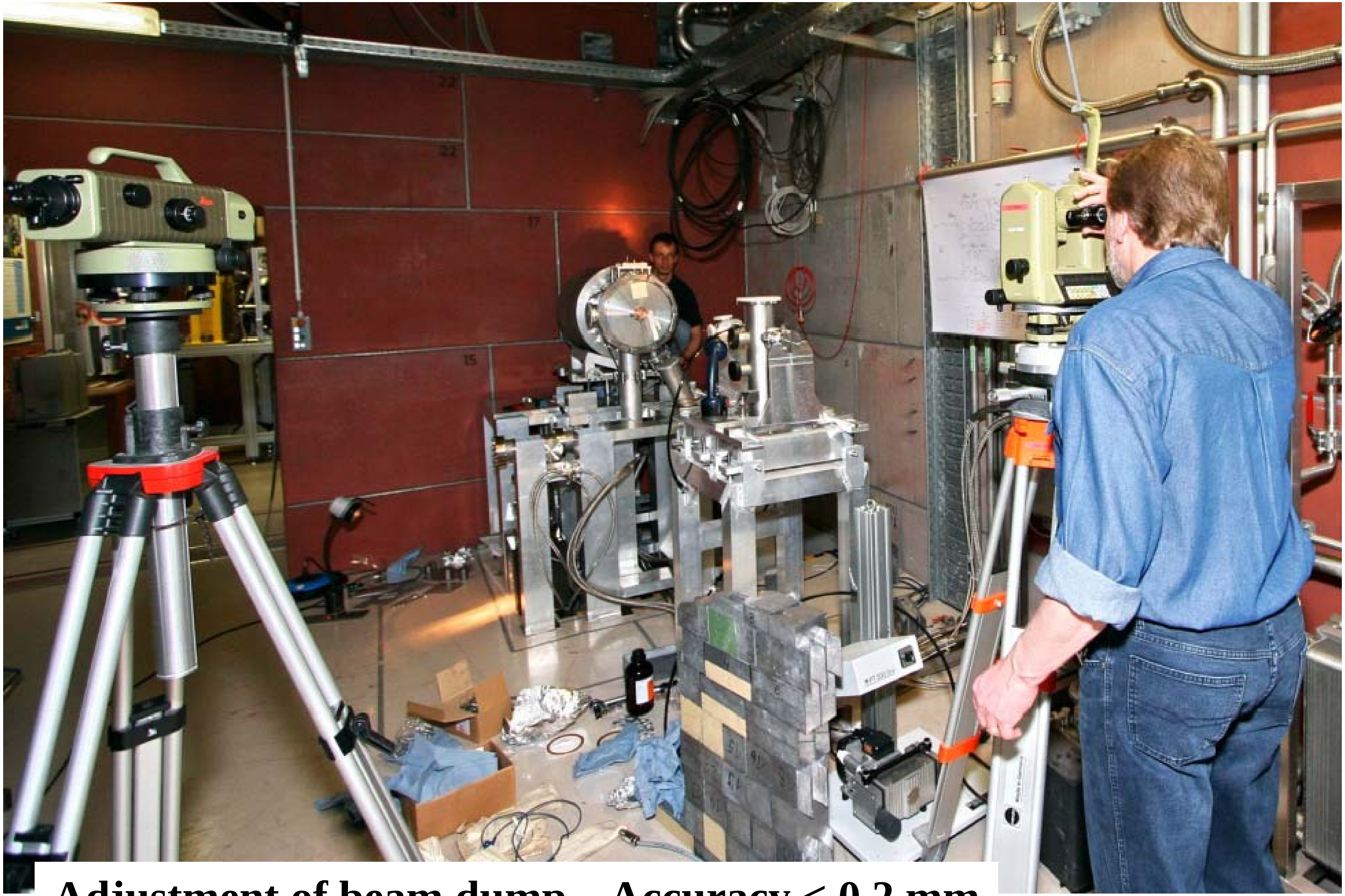

primary e⁻
pulse width
5 ps
77 ns
(adjustable)



Position of e^+ converter

Water cooling systemc

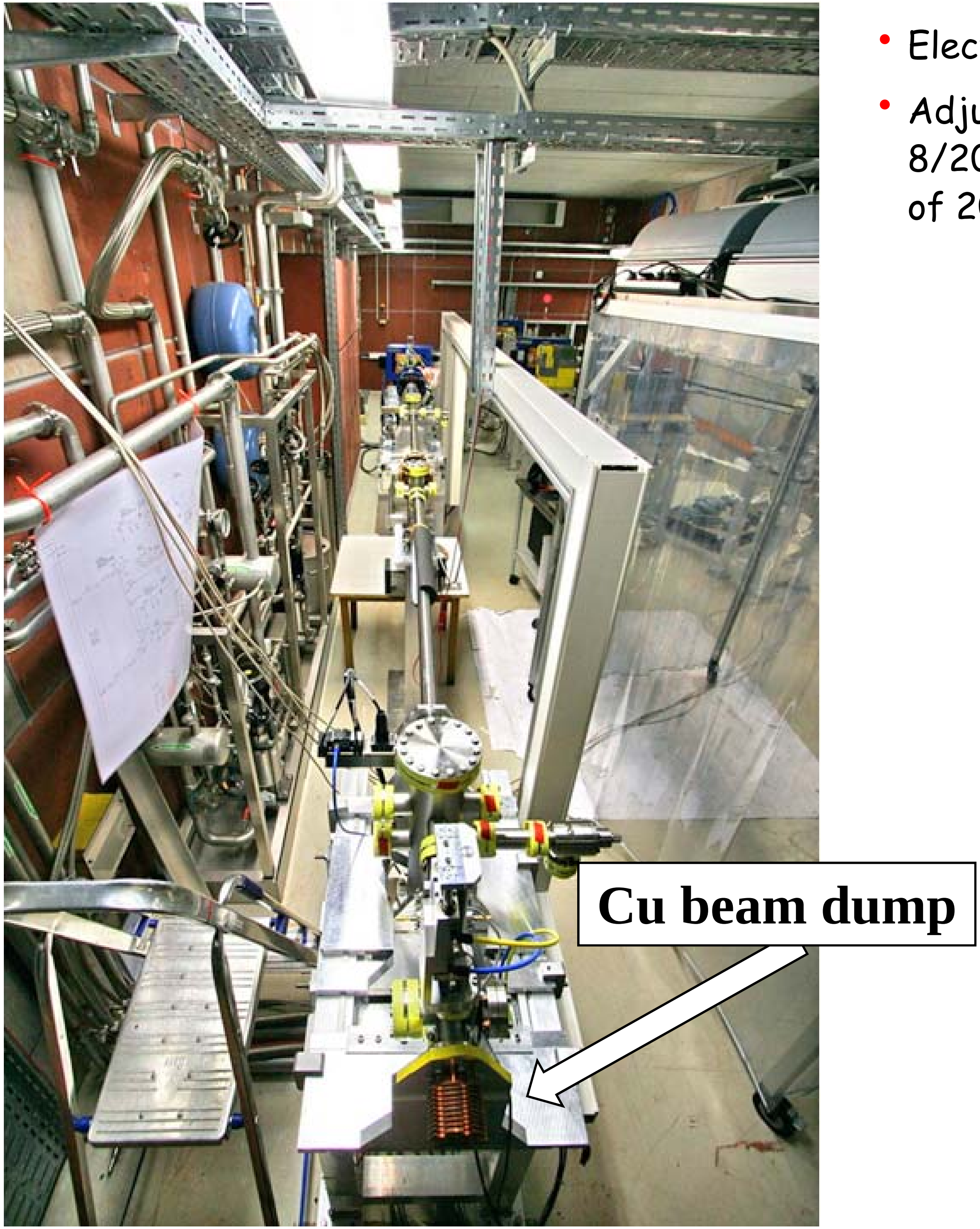
Beam dump



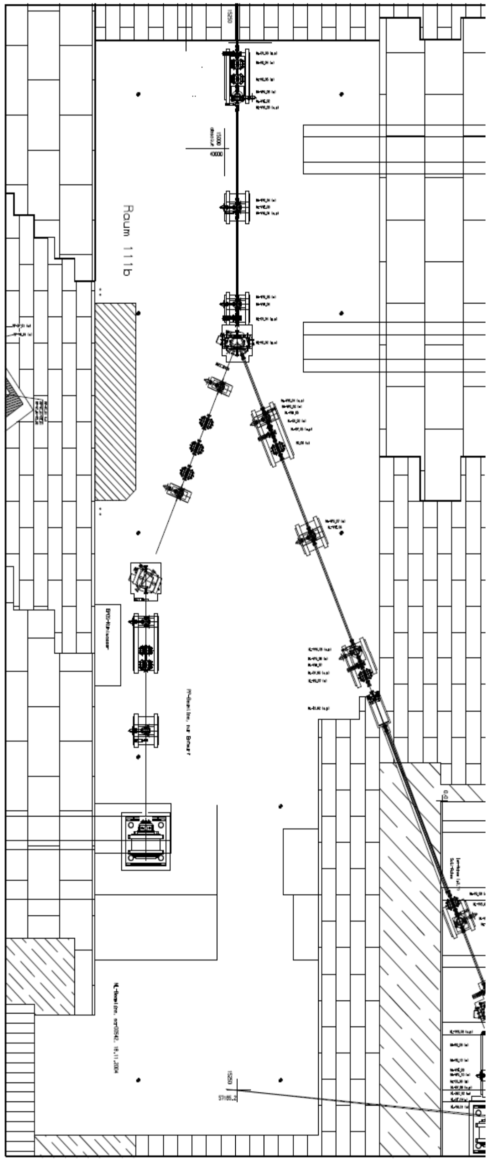
Adjustment of beam dump – Accuracy < 0.2 mm

Radiation screening

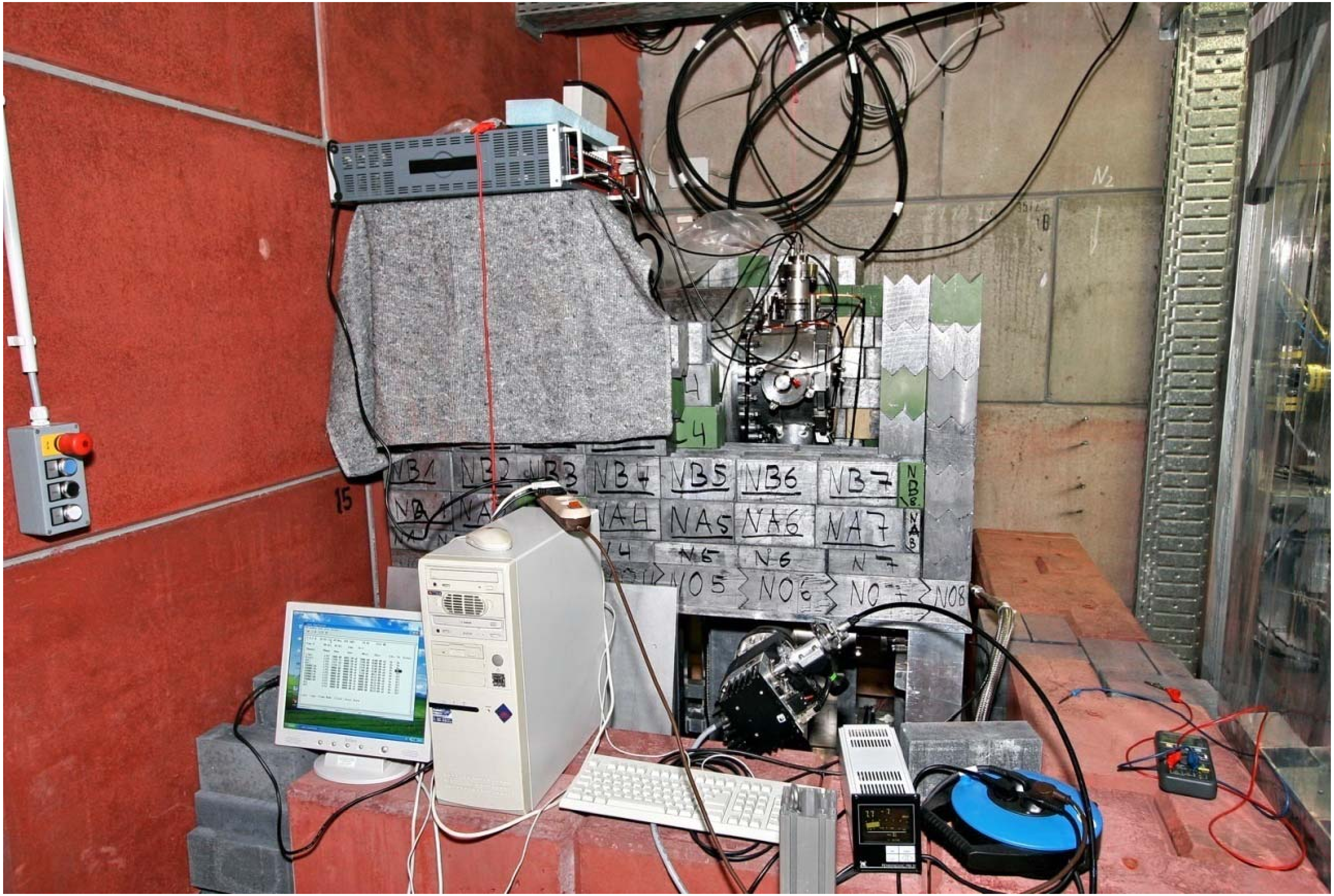
Screening consists of lead blocks and heavy concrete



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



Electron gun mounted instead of lens


NB1
NB2
NB3
NB4
NB5
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NA8
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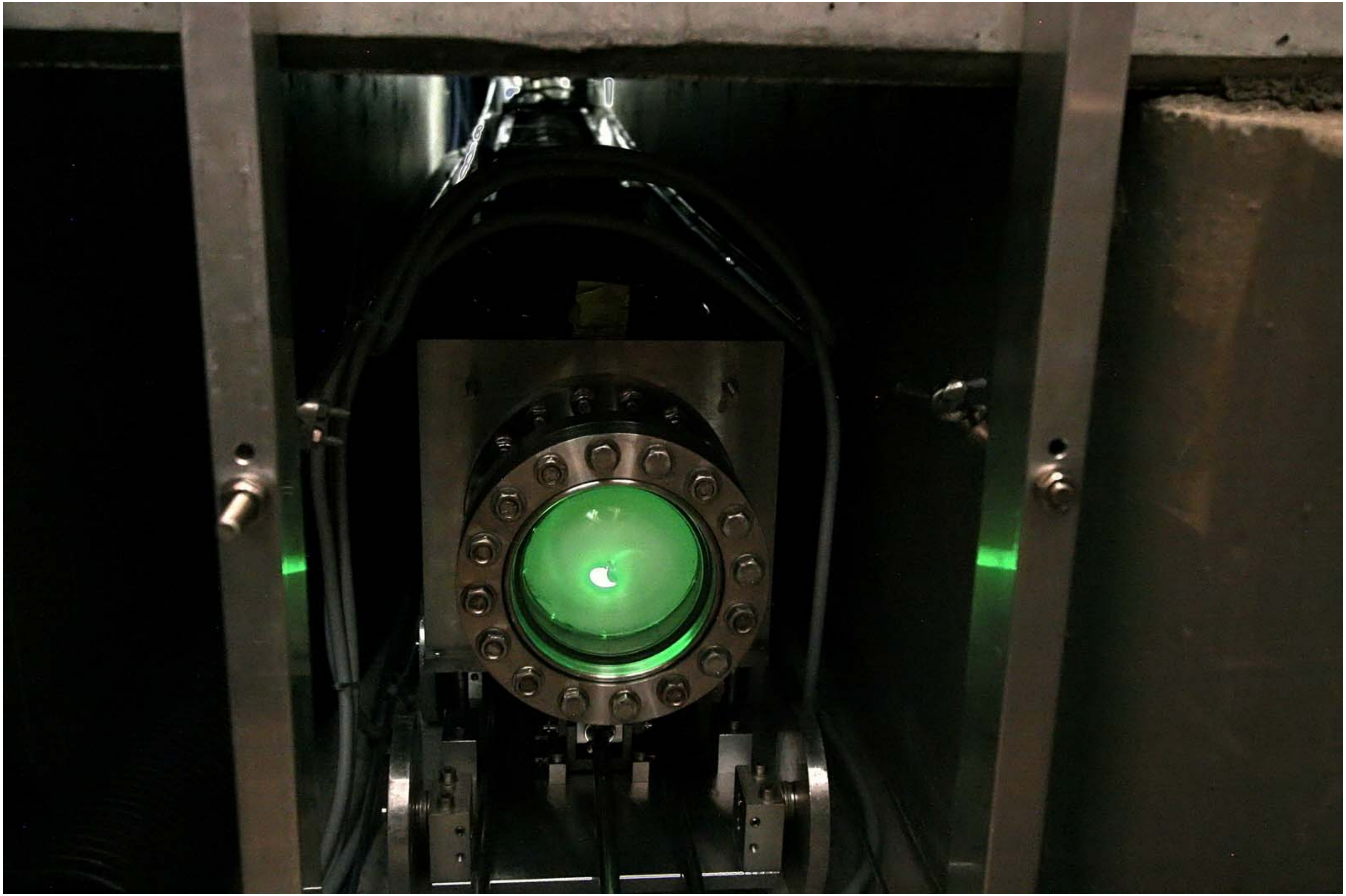
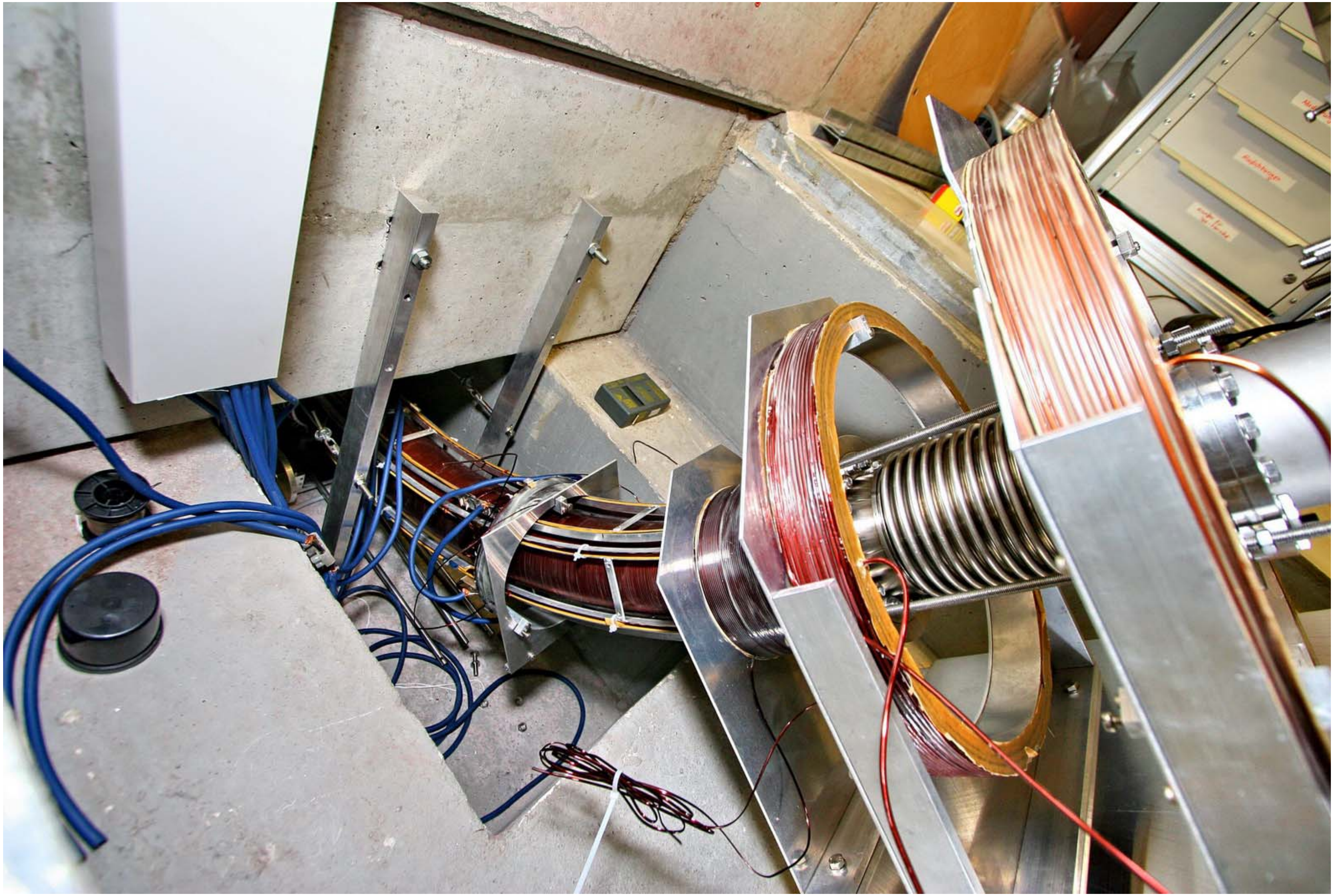
NO7
NO8
C4
N2
15





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 (14.-19.12.): 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, ...)
- System ready for use in about 12 month