Research Activities at UW for TTC

Günter Müller
Physics Department, University of Wuppertal, Germany
gmueller@uni-wuppertal.de

- **Motivation**
- **DC Field Emission Scanning Microscopy on Nb Samples**
- **High Resolution SEM/EDX for Field Emitter Identification**
- **Surface Roughness Measurements with OP/AFM on Nb**
- **Photo-induced FE for High Brightness Electron Sources**
- **Outlook and acknowledgments**

Motivation

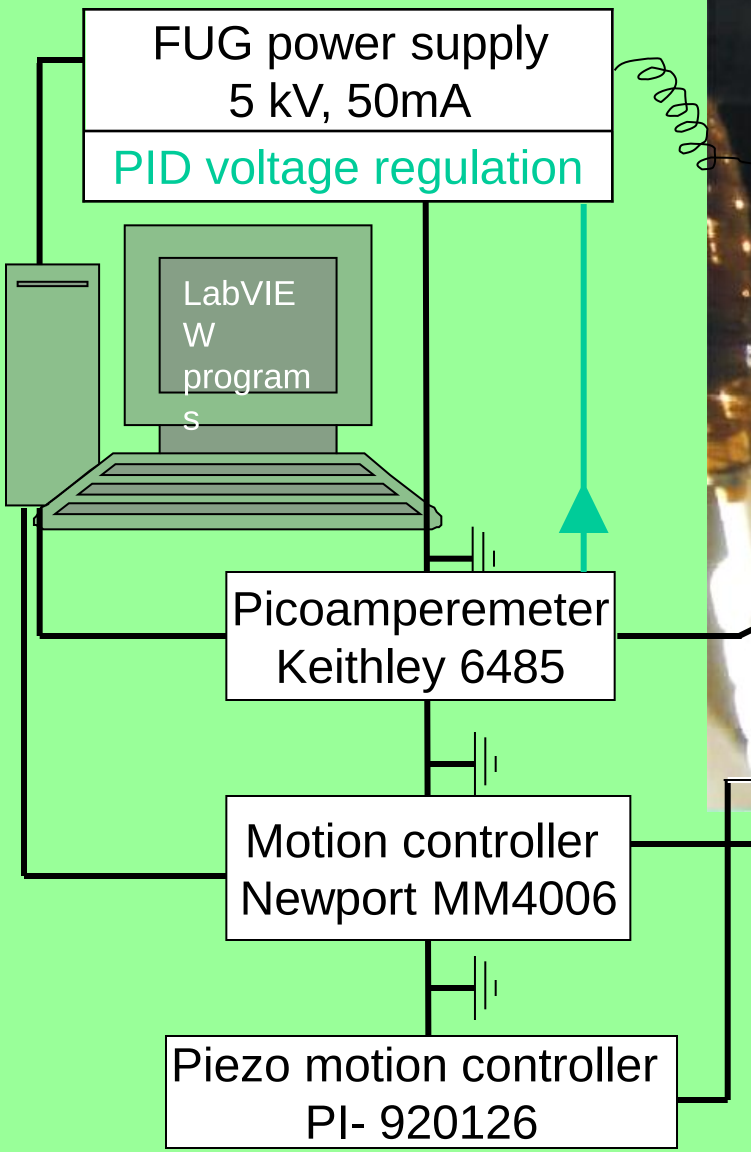
Further progress of superconducting electron linacs towards fundamental limits requires advanced material science which can be provided by universities.

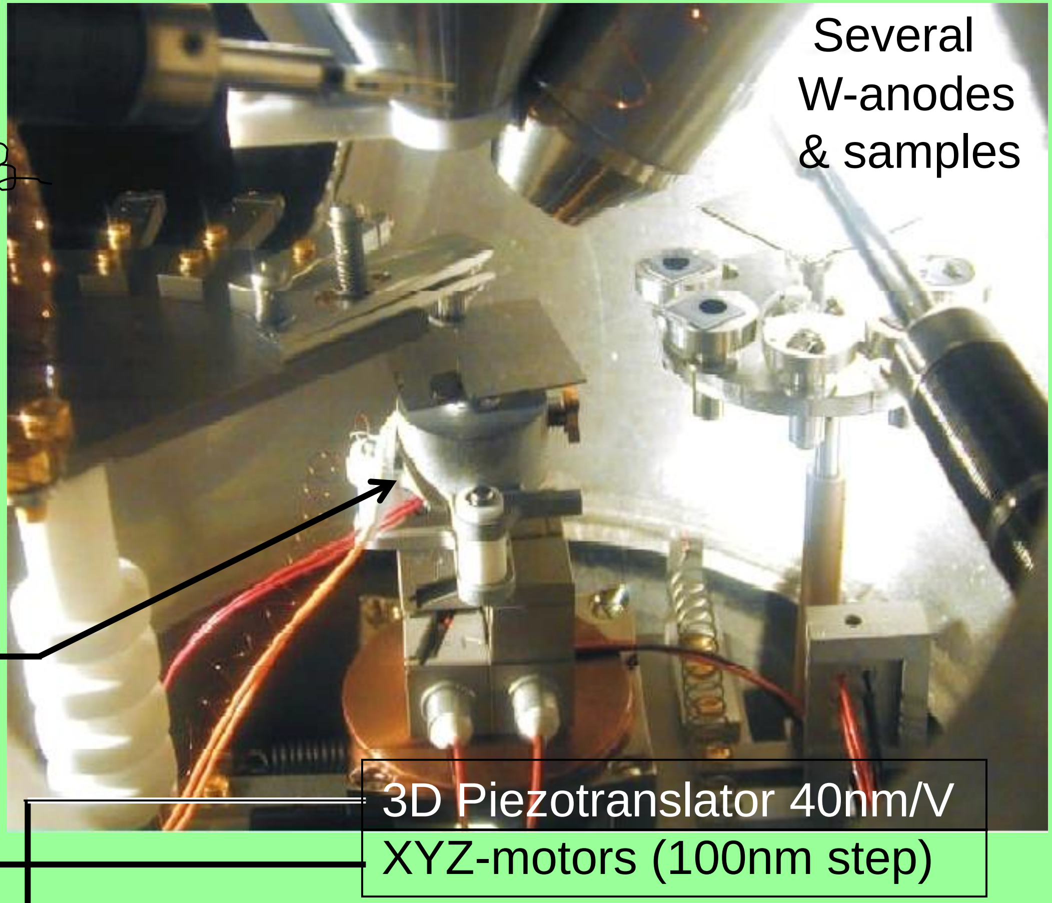
Enhanced field emission (EFE) from imperfect surfaces is a major limitation for achievable accelerating gradients in Nb cavities (E_p = *50-120 MV/m* !). ⇒ In order to avoid EFE reliably, its physical origin must be understood, e.g. by means of localisation and idenfication of emitters on samples.

Local quenches and enhanced losses in high magnetic surface field regions ($H_p \rightarrow H_{crf}$) should depend on the local and average surface roughness of Nb. ⇒ The final surface quality resulting for poly/single crystalline EP & BCP Nb should be measured systematically and correlated to EFE & Quenches.

Actual photocathodes used in rf guns (e.g. FLASH) provide short bunches but also high transverse emittance and have a short lifetime even under UHV. ⇒ Photo-induced field emission (PFE) from flat metallic or semiconducting cathodes could lead to robust high brightness rf guns (e.g. XFEL).

DC Field Emission Scanning Microscope (FESM)





UHV system typically at $2 \cdot 10^{-7}$ Pa

LabVIEW automated scans of U(x,y) for 1 nA

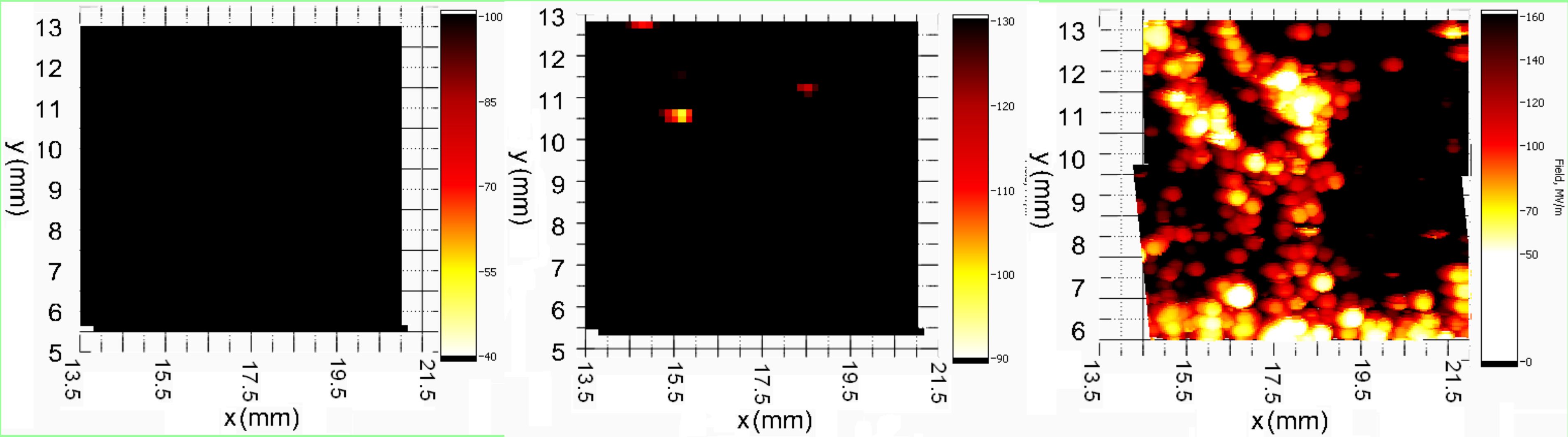
Scanning speed: (100×100) pixels in 1 hr

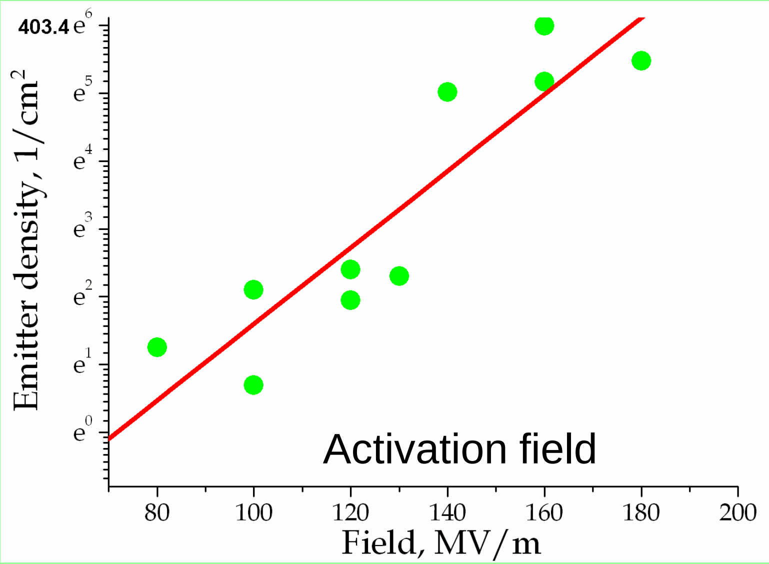
I/V curves and localization of stable emitters

FESM results on typical polycrystalline HPR-Nb from DESY

Regulated $E_{on}(x,y)$ maps for I = 1nA at $\Delta z \approx 50$ µm of the same area at

100 MV/m 130 MV/m 160 MV/m





- ⇨ Emitter density increases exponentially with field
- ⇨ **Activation** of emitters occurs at $E_{act} = (2\text{-}4)\ E_{on}$ probably due to burning of conducting channels into the surface oxide or removal of adsorbates.

Impact for SRF cavities:

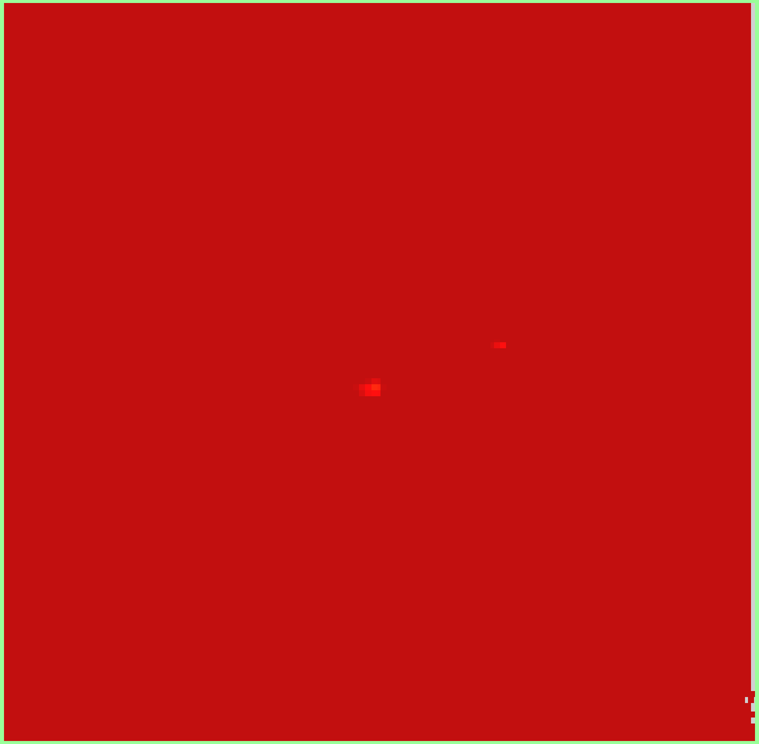
Heating [1] or **rf power** might activate emitters

[1] E. Mahner, Part. Acc. 46, pp.67-82 (1994)

FESM results on single crystalline BCP/HPR-Nb from DESY

Regulated U(x,y) maps for 1 nA for scanned areas of 7.5×7.5 mm^2
with flat W-anode Ø$_a$ = 100 µm at anode voltage U = 4800 V

electrode spacing Δz = 32 µm | Δz = 24 µm

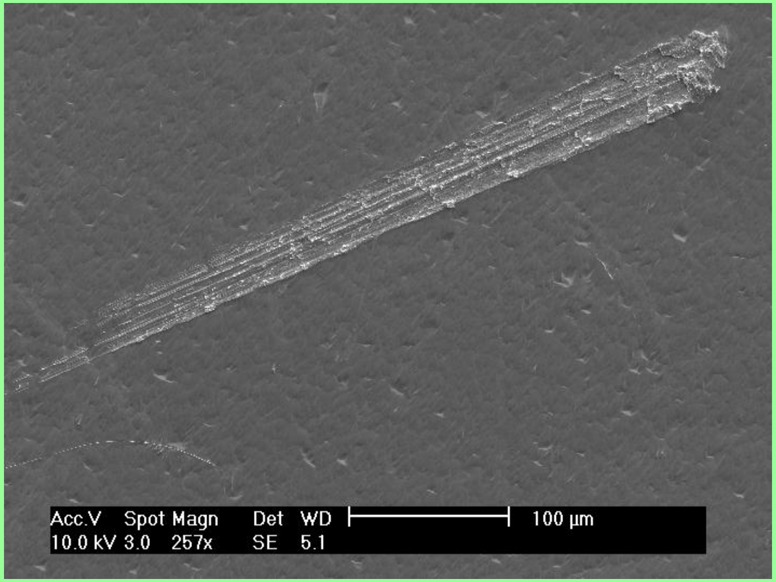


mirror-like surfaces show no emission @ 120MV/m

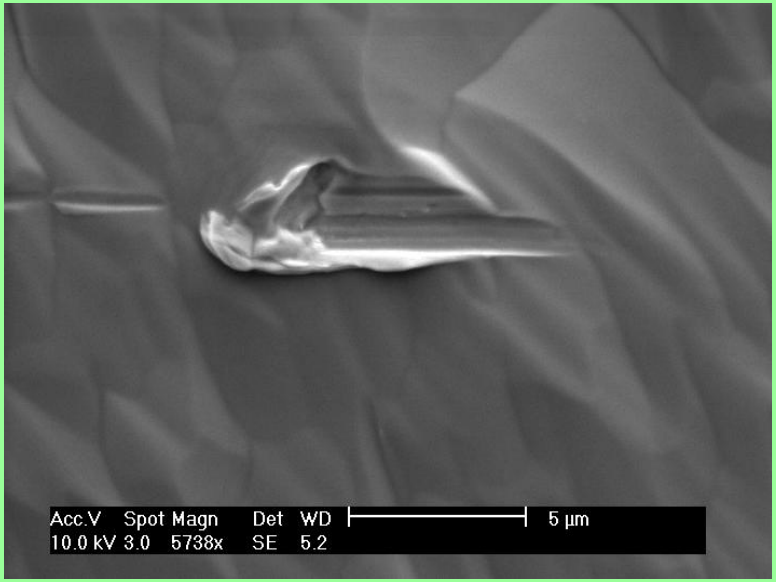
2 emitters @ 150MV/m | 5 emitters @ 200MV/m

⇒ **best FE performance of all Nb samples measured yet**

SEM images of protrusion emitters (EDX ⇒ only Nb (+ O?))



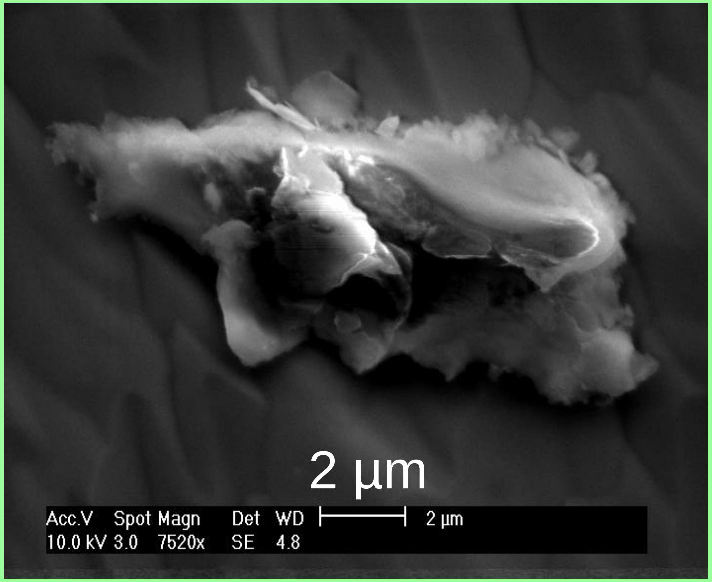
E_{on}(2nA) < 60 MV/m
~500 µm long scratch
(mishandling of sample)



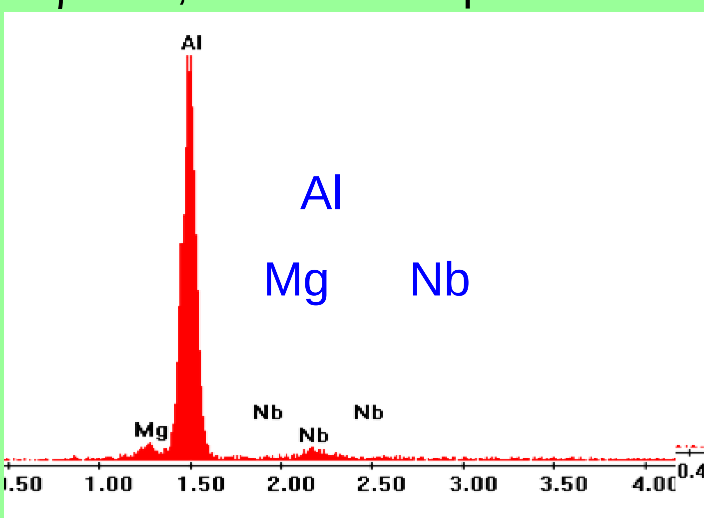
E_{on}(2nA) = 90 MV/m
~5 µm long groove
$\beta = 71$, $S = 2.3\cdot10^{-6}\ \mu m^2$

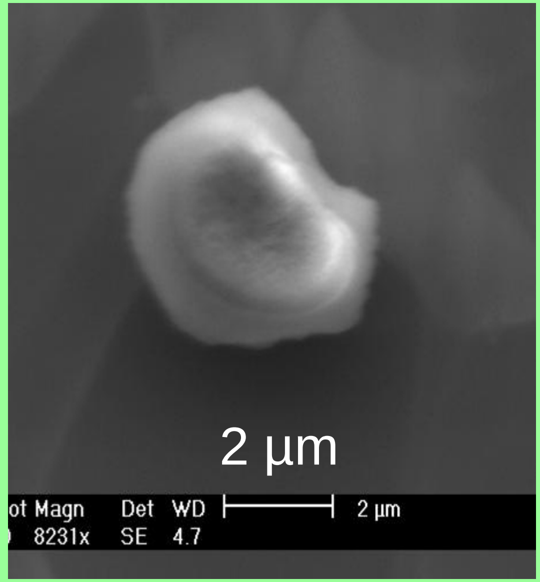
E_{on}(2nA) > 140 MV/m
~1 µm small defect
$\beta = 59$, $S = 7\cdot10^{-8}\ \mu m^2$

SEM/EDX of typical particulate emitters with impurities

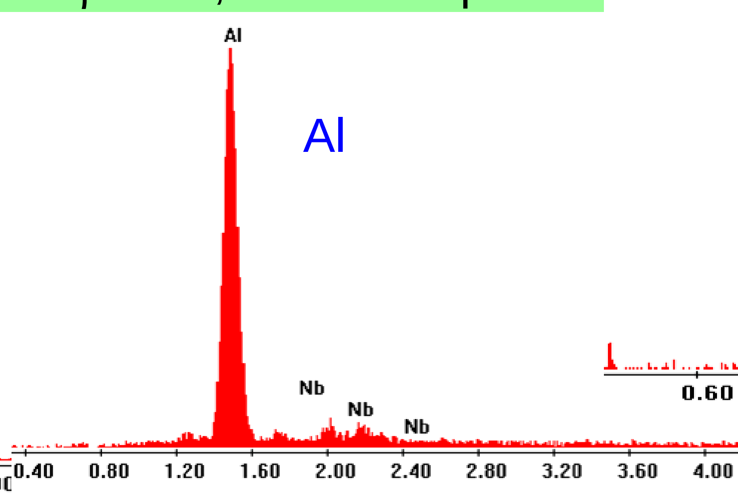


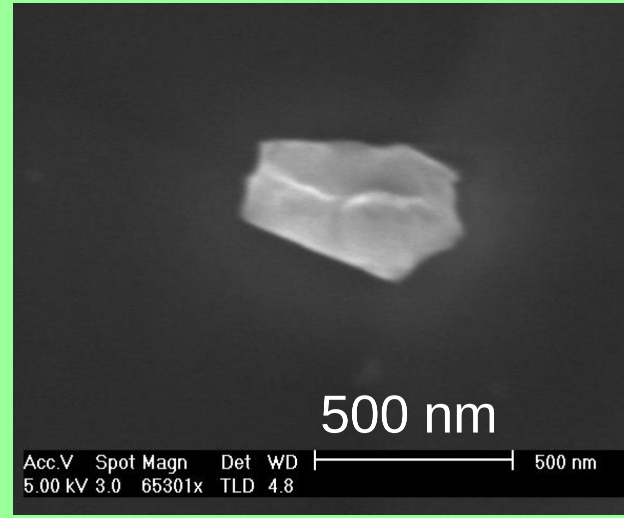
E_{on}(2nA) =140 MV/m
β= 31, S = $6.8\cdot10^{-6}$ µm²



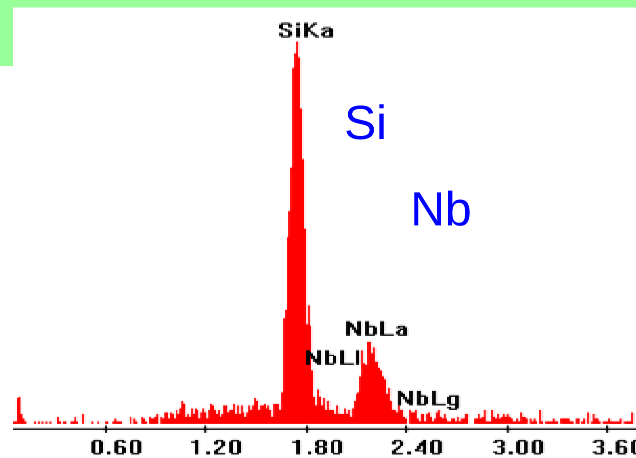


E_{on}(2nA) = 132 MV/m
β = 27, S = $7\cdot10^{-5}$ µm²





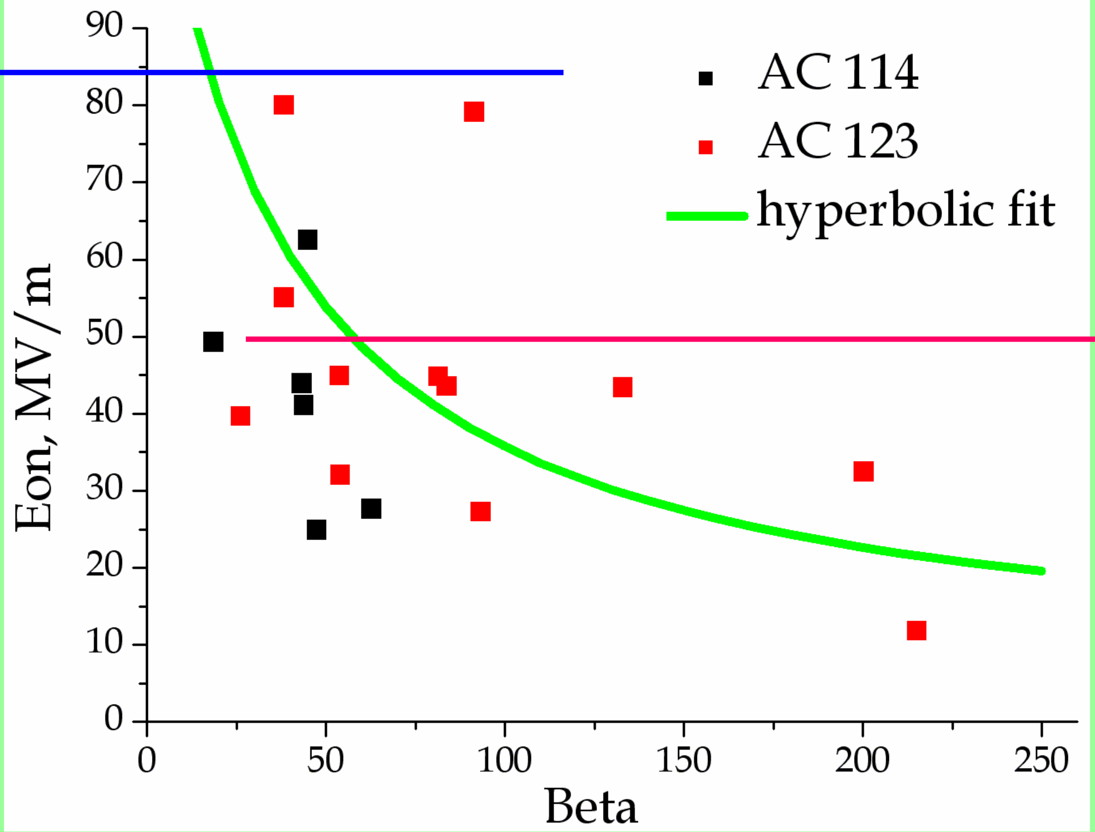
E_{on}(2nA) > 120 MV/m
β = 46, S = $6\cdot10^{-7}$ µm²



EFE status of actual polycrystalline HPR-Nb samples

Correlation between E_{on}(1 nA) and field enhancement factor β of emitters

ILC
E_{acc}= 35 MV/m
E_p/E_{acc}= 2.4

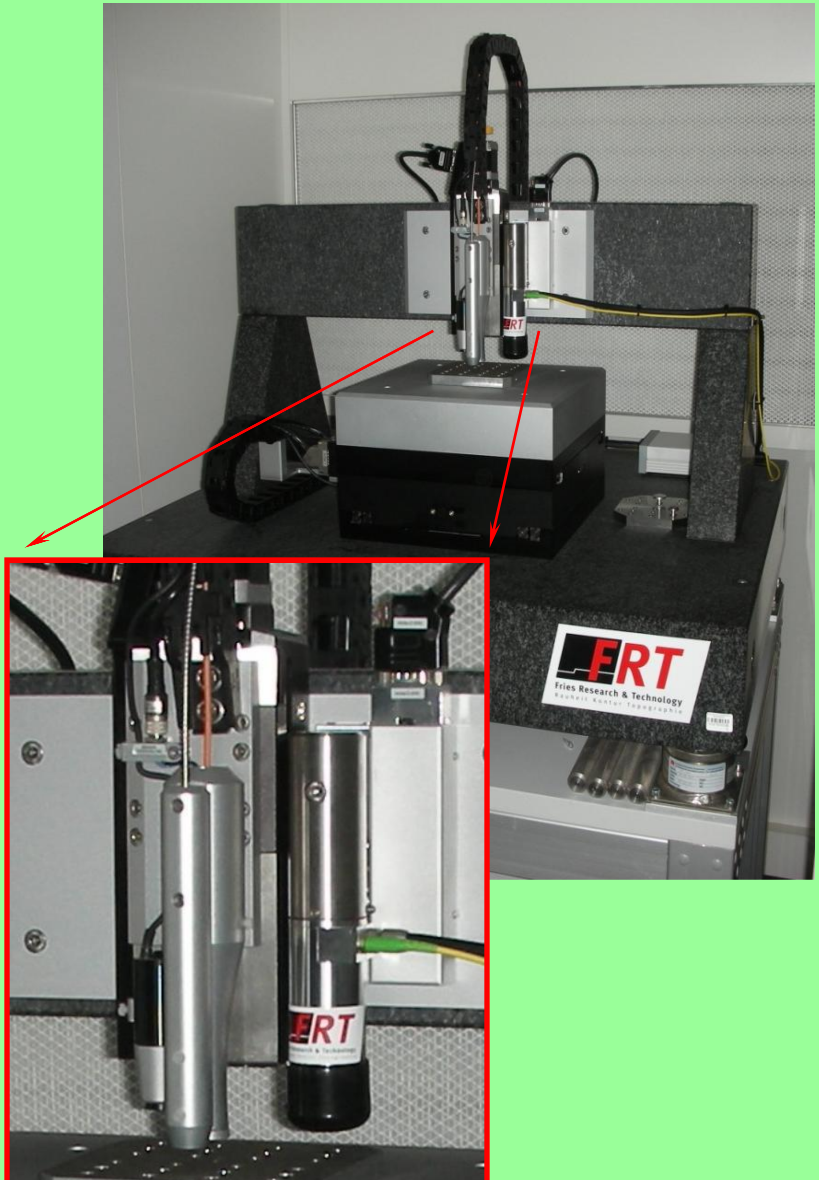


XFEL
E_{acc}=25 MV/m
E_p/E_{acc}= 1.98

Typical polycrystalline Nb samples show strong EFE due to activated emitters which are either particulates or scratches of µm height with nm sharp edges

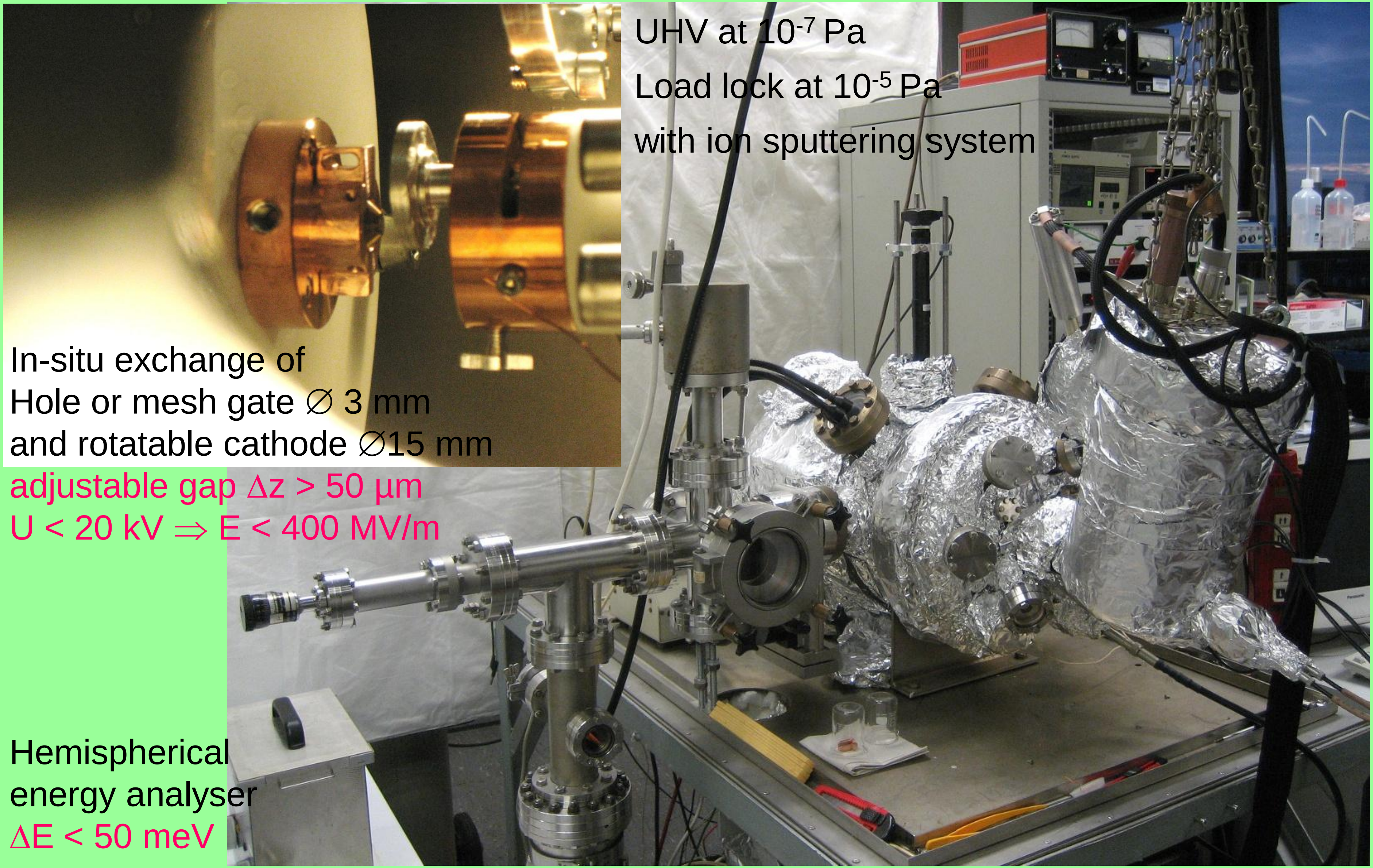
EFE requirements on surface defects: β < 50 for FXEL and β < 20 for ILC

Surface roughness measurements on Nb samples



- Optical profilometer (OP)
  white light irradiation and spectral reflection
  - fast scanning speed (100×100 pixel per min)
  - samples up to 20×20 cm^2 and 5 cm height
  - 2 µm lateral and 3 nm height resolution
- atomic force microscope (AFM)
  operated in contact or non-contact mode
  - 2 µm positioning accuracy within OP scan
  - 34×34 μm^2 scanning range
  - 3 nm lateral and 1 nm height resolution
- CCD camera for positioning control
- granite plate with an active damping system for undisturbed measurement at nm scale
- clean laminar air flow from the back to reduce particulate contamination

Field emission spectrometer with UV irradiation of cathodes



UHV at 10^{-7} Pa

Load lock at 10^{-5} Pa

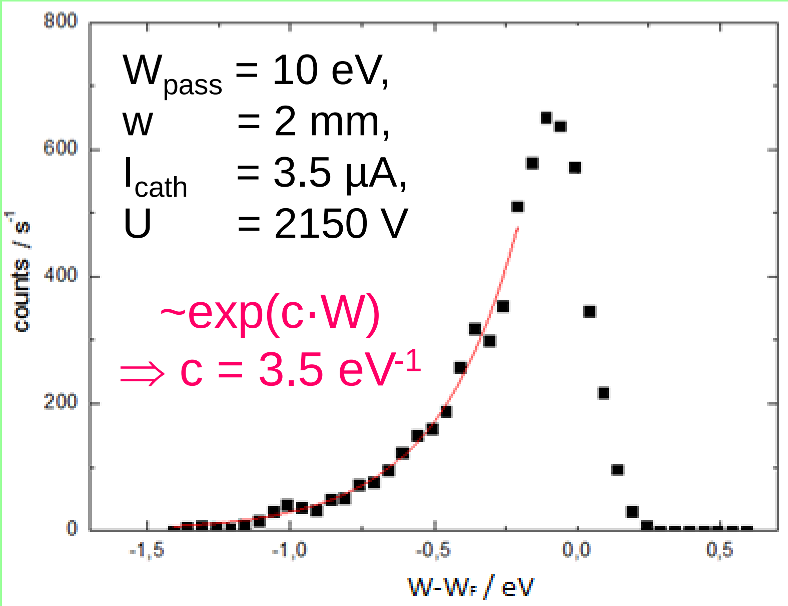
with ion sputtering system

In-situ exchange of
Hole or mesh gate ∅ 3 mm
and rotatable cathode ∅15 mm

adjustable gap $\Delta z > 50$ µm
$U < 20$ kV ⇒ $E < 400$ MV/m

Hemispherical
energy analyser
$\Delta E < 50$ meV

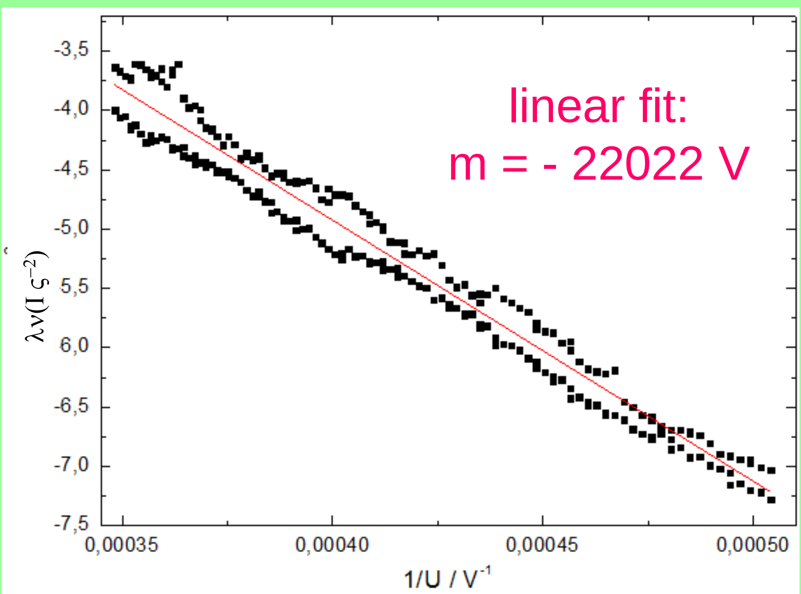
Determination of work function Φ and T of a W needle

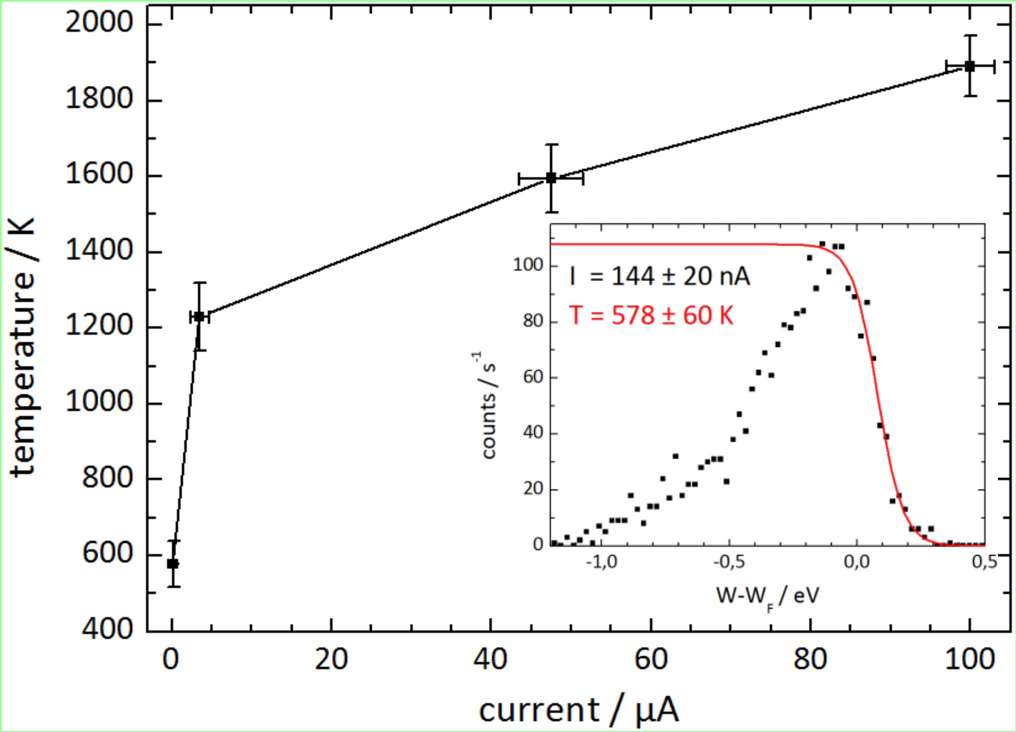


electron spectra for pass energy W_{pass} and slit width w combined with integral I-V curve

⇒ $\Phi_W = -1.5\ m\ c^{-1}\ U^{-1} = 4.39 \pm 0.3$ eV

(literature value: Φ_W = 4.55 eV)

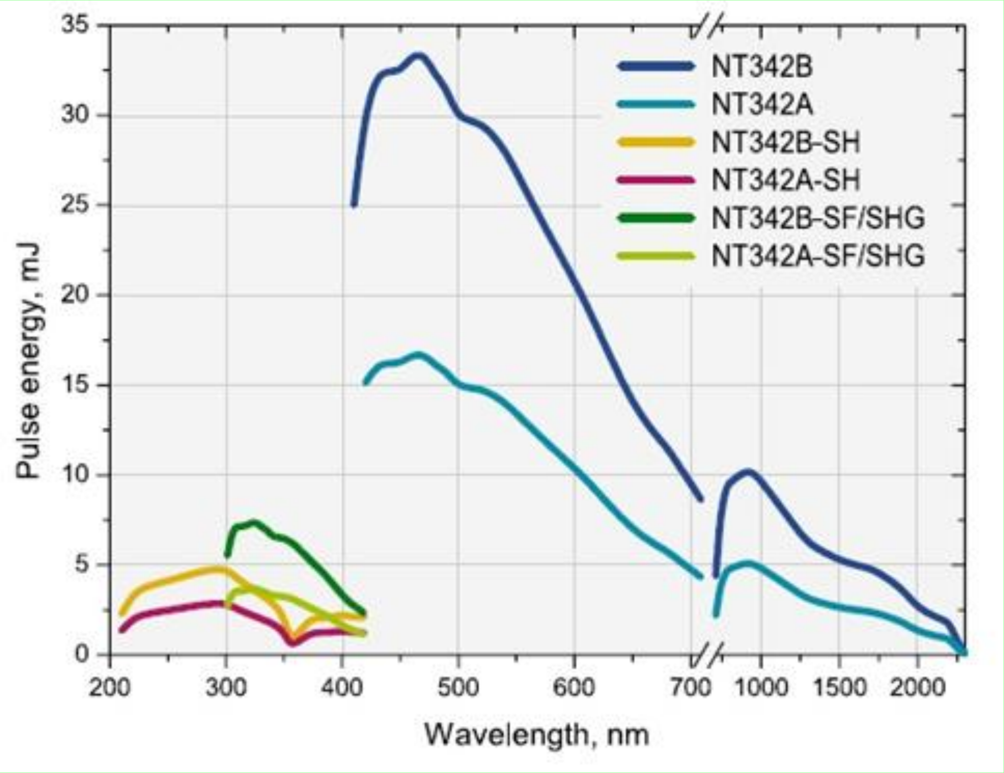


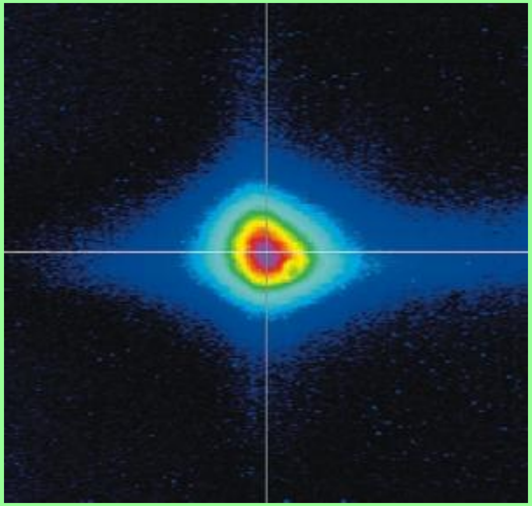


Fit of rigth slope to Fermi-Dirac-function

⇒ strong T increase of W-needle with I

Tunable OPO Laser for photo-induced FE investigations





- 210 nm < λ < 2300 nm, linear polarized
- E_{pulse} = 2-30 mJ, t_{pulse} = 3-5 ns
- f_{rep} = 10 Hz
- $ø_{beam}$ = 4 mm, divergence = 2 mrad

focussing optics under construction (optional λ/4-plate for spin polarization)

Outlook and Acknowledgments

- Systematic FESM and HRSEM/EDX investigations on actual Nb samples

  A. Navitski, S. Lagotzky (BUW), A. Matheisen, D. Reschke, X. Singer (DESY)

- Correlation studies between Nb surface roughness and EFE (tomorrow)

  A. Navitski, S. Lagotzky (BUW), J. Ziegler (DESY), P. Kneisel (TJNAF)

- PFES system ready for development of flat high brightness electron sources

  B. Bornmann, S. Mingels (BUW)

Actual Fundings: Helmholtz Alliance "Physics at the Terascale"
BMBF R&D projects on "SC Cavities" and "FLASH"