PETRA III

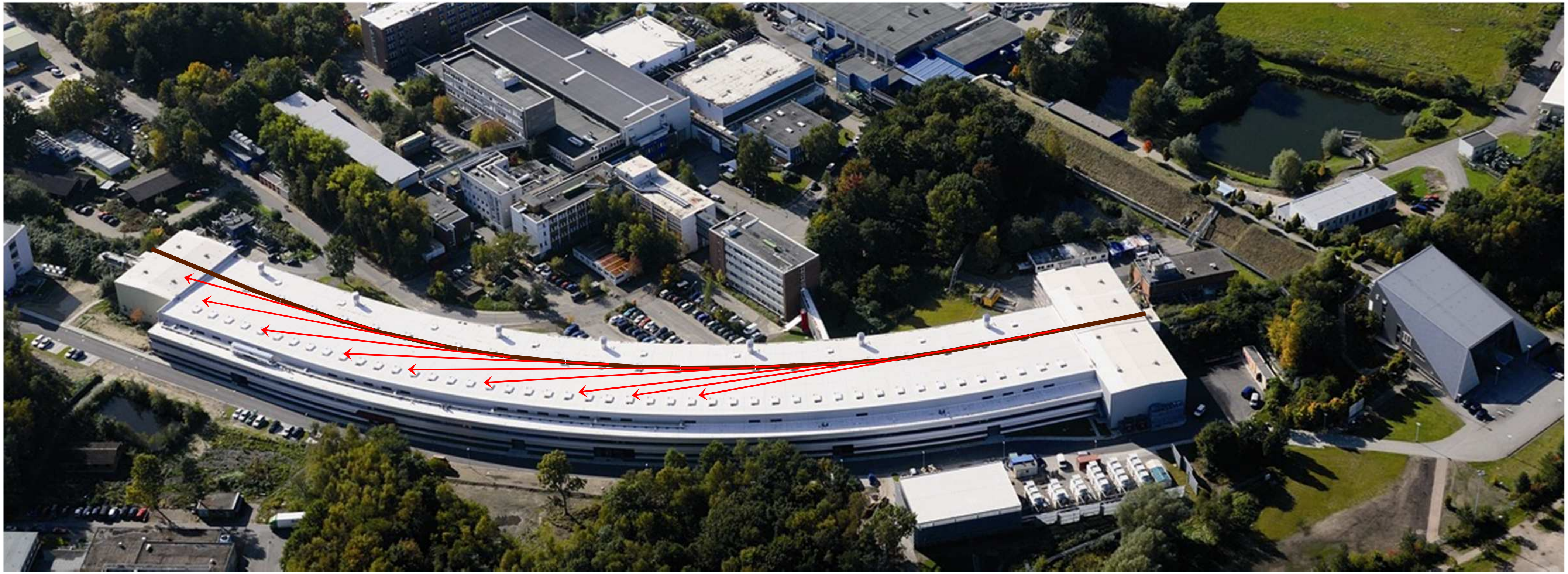
Materials science opportunities

Hermann Franz
DESY/KEK Meeting
March 20 2012

HELMHOLTZ
GEMEINSCHAFT

DESY

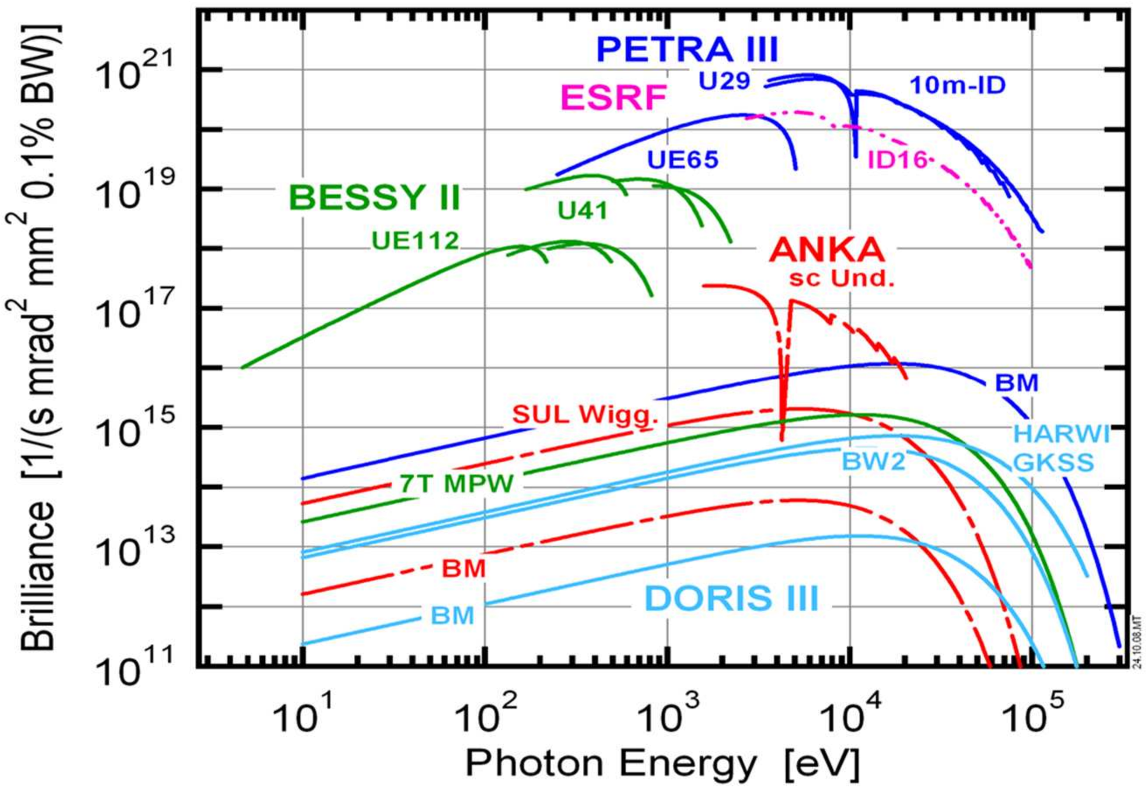
PETRA III: DESYs brilliant X-ray source



- particle energy:	6 GeV
- stored current:	100 mA (top-up)
- emittance:	1.0 nmrad
- circumference:	2304 m
- # of undulators:	14 (incl. canted)
- # of experiments:	30
- X-ray wavelength:	10 – 0.05 Å
- beamline length:	70-100 m
- annual operation:	5000 h

- built in 1978
- rebuilt as a synchrotron radiation source in 2007/2009
- commissioning since 2009
- user operation since 2010
- largest storage ring of its kind

PETRA III – a high brilliance machine



- coherent flux @12keV (B(λ/2)²):
  - 2m ID: ~ 4x10¹⁰ ph/s/0.01%BW
  - 5m ID: ~ 1x10¹¹ ph/s/0.01%BW
  - 20m ID: ~2.5x10¹¹ ph/s/0.01%BW

Main goal of PETRA III

Production and use of nanometre sized X-ray beams

Photon beam parameters at 12keV:

	β_x [m]	β_y [m]	σ_x [μm]	σ_y [μm]	$\sigma_{x'}$ [μrad]	$\sigma_{y'}$ [μrad]	ID-length [m]
low-β 5 m	1.3	3	35.9	5.7	28	5.0	5
high-β 5 m	20	2.38	141	5.2	8.6	5.2	5

Horizontal β-function of each straight section can be selected individually and is changeable (β_x= 1.3m or β_x = 20m)

PETRA III beamline list (phase I)

Number	Name	ID type	Energy range	Contact
P01	Dynamics beamline, IXS, NRS	10 m U32	5 - 40 keV	**H.-C. Wille, DESY**
P02	Powder and Extreme Conditions	2 m U23	20 - 100 keV	**H.-P. Liermann, DESY**
P03	Micro and Nano SAXS/WAXS	2 m U29	8 - 25 keV	**S. Roth, DESY**
P04	Variable Polarization XUV	5 m UE65 (APPLE II)	0.2 - 3.0 keV	**J. Viefhaus, DESY**
P05	Micro- and nano-tomography	2 m U29	8 - 50 keV	**A. Haibel, HZG**
P06	Hard X-ray nano probe, imaging	2 m U32	2.4 - 100 keV	**G. Falkenberg, DESY**
P07	High energy materials science	4 m U19 (IV)	50 - 300 keV	**N. Schell, HZG**
P08	High resolution diffraction	2 m U29	5.4 - 30 keV	**O. Seeck, DESY**
P09	Resonant scattering/diffraction, HAXPES	2 m U32	2.4 - 50 keV	**J. Strempfer, DESY**
P10	Coherence	5 m U29	4 - 25 keV	**M. Sprung, DESY**
P11	Bio imaging and diffraction	2 m U32	3 - 35 keV	**A. Meents, DESY**
P12	BioSAXS	2 m U29	4 - 20 keV	**M. Rößle, EMBL**
P13	Macro molecular crystallography I	2 m U29	5 - 35 keV	**M. Cianci, EMBL**
P14	Macro molecular crystallography II	2 m U29	5 - 35 keV	**G. Bourenkov, EMBL**

high beta section	**142 x 5 μm**
low beta section	**35 x 6 μm**

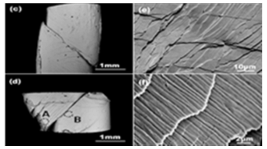
Main research topics

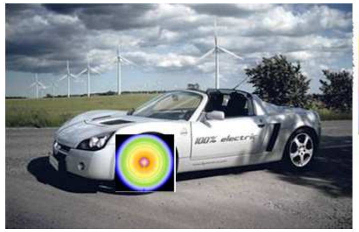
> Surface science

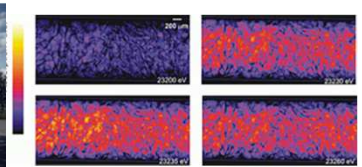
- Thin film technology (polymer-metal)
- Wetting phenomena
- Phase transitions
- NRS (P01), GISAXS (P03), XRR&GID (P08), XPCS (P10)

> Materials science

- Catalysis, joining technology
- Magnetism, superconductivity
- Metallic glasses, Battery research
- HEMS (P07), RXRD & HAXSPES (P09), NRS (P01), XRD (P02), IXS (P01,P04)

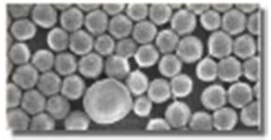






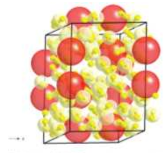
> Soft matter research

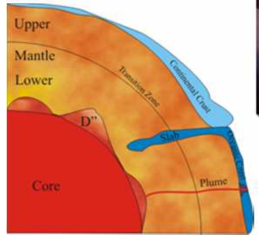
- Properties of colloids, glass transition
- NRS (P01), Diffraction (P08&P09), SAXS (P03), XPCS&Rheology (P10)



> Earth science

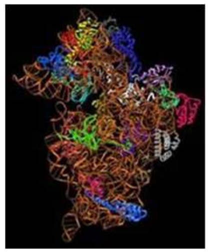
- High pressure research, Geophysics, Mineralogy
- Trace element analysis
- Extreme conditions (P02), IXS&NRS (P01), Diffraction (P08&P09)

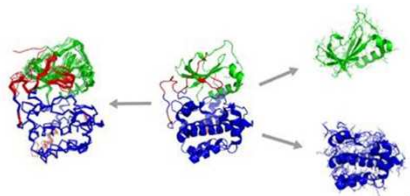




> Life science

- Protein structures
- Drug development
- BIOSAXS (P12), MX (P11,P13, P14), Imaging (P11)





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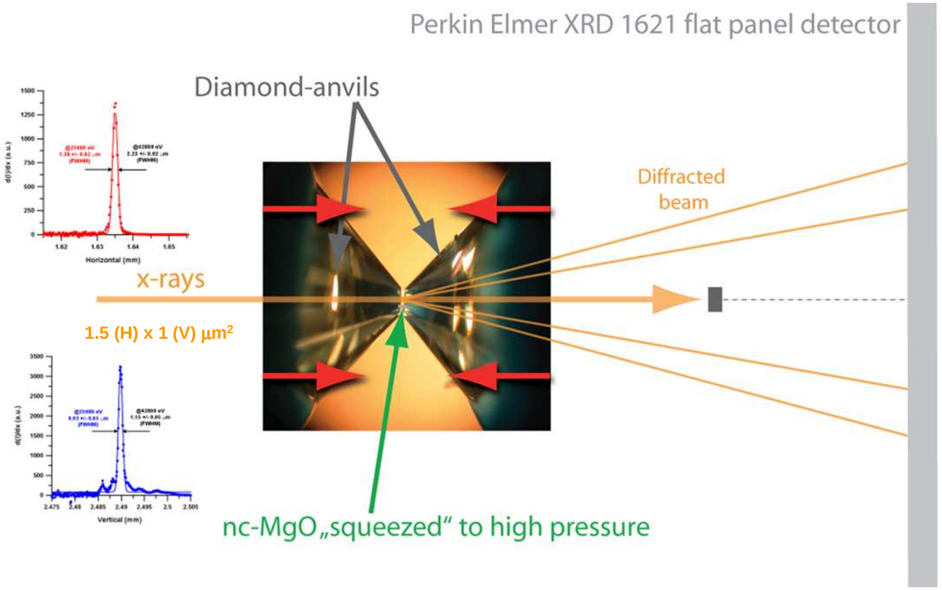
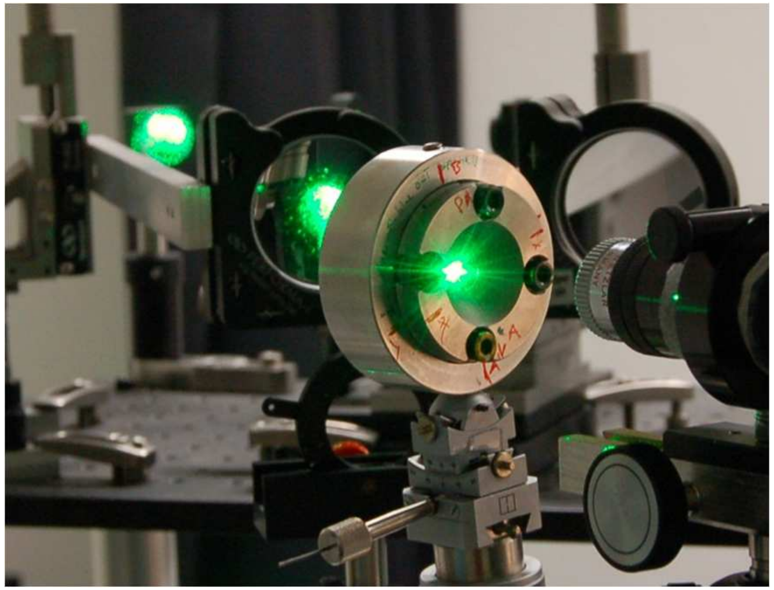
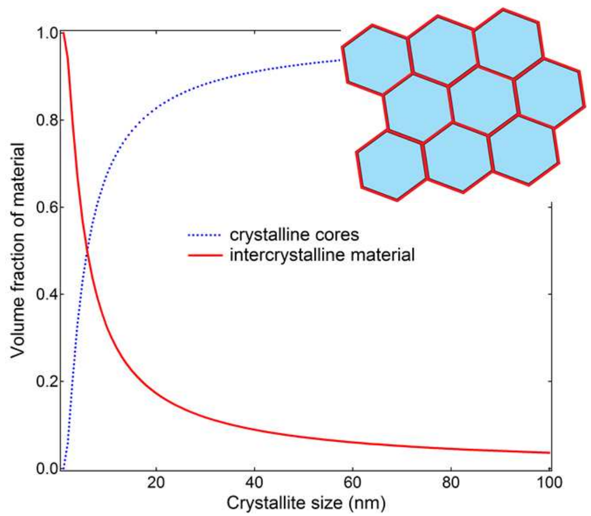
Hard X-ray Diffraction & Brillouin Spectroscopy at P02

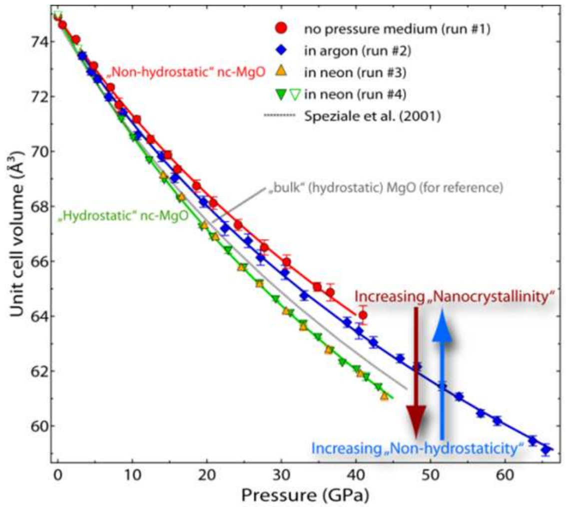


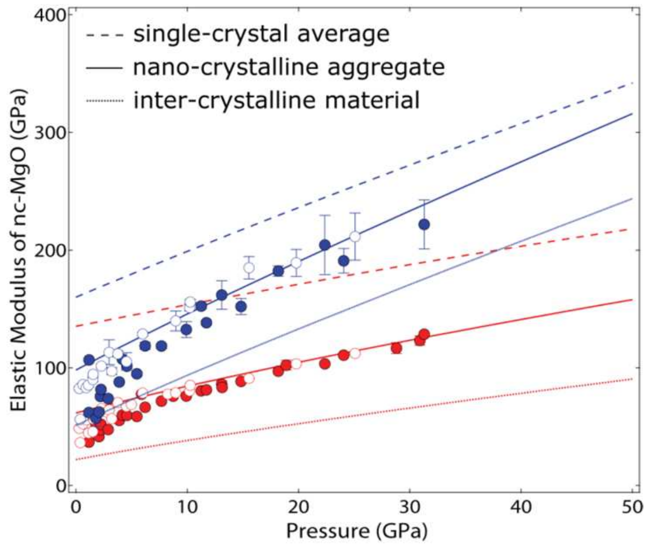
+



Nanomaterials (MgO) are "softer" then their bulk counterparts





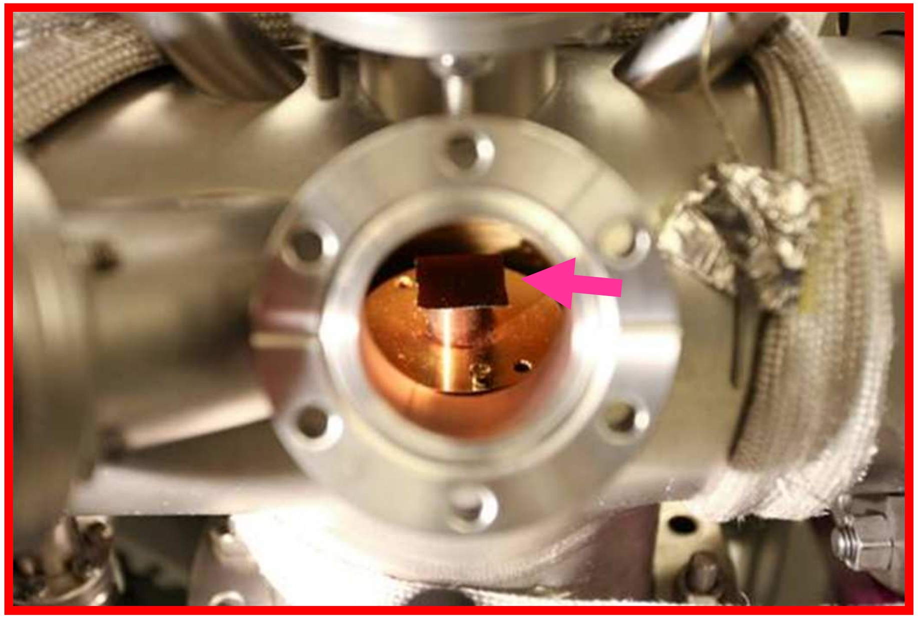


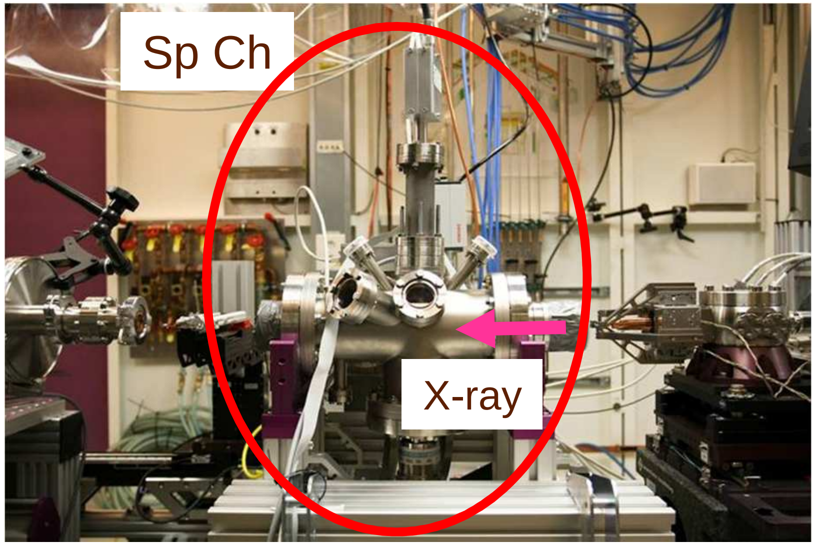
GFZ Helmholtz-Zentrum POTSDAM

DESY

P03: Micro and nano Small-angle scattering

- **In-situ sputter deposition & thin films**
- **Nano-structured polymer thin film**
- **Metal sputter deposition**
  - **Rate: (0.23±0.03)nm/s**
  - **d_{final}=35nm**
- **Beam size: 38x19µm^2 (SAXS)**
- **Temporal resolution 15 ms**





DESY: Roth, Schwartzkopf, Buffet, Abul-Kashem, Herzog, Gehrke, Perlich, Röhlsberger, Rothkirch, Schlage, Benecke (*DESY/MPI Golm*)
TU München: Müller-Buschbaum, Metwalli, Körstgens

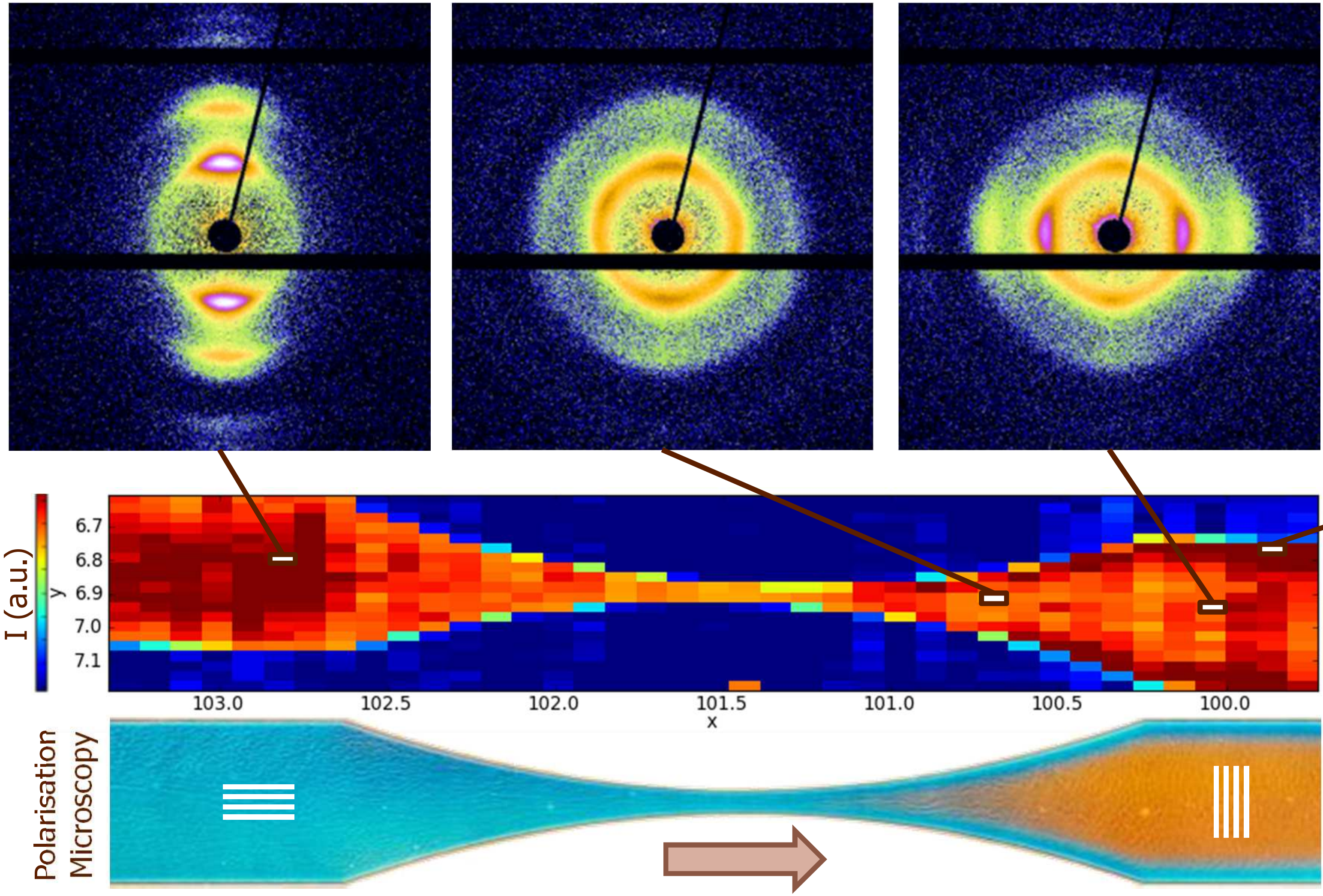
Shear-induced orientation of cylindrical micelles: model system to understand injection molding

converging flow: **parallel**

end of tapering: **transition**

diverging flow **perpendicular**

wall shear: **parallel**

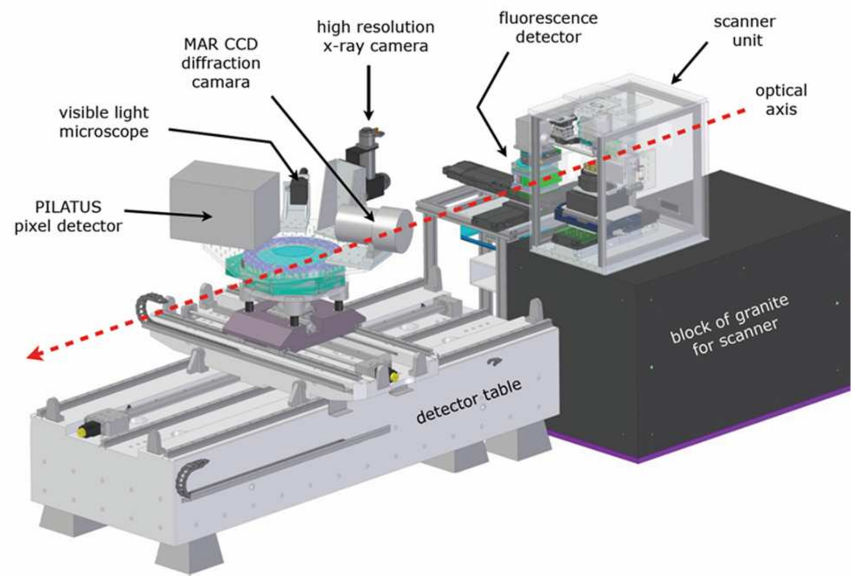


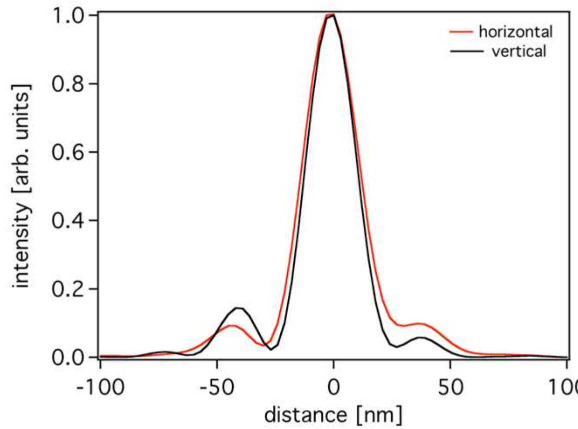
500 µm x 67 µm
(**7.5:1** ratio)
flow 300 µL/h
PB-PEO cyl. mic.
(30% w/w, water)
Blue: = to X
Yellow: = to Y

M. Trebbin, G. Benecke, S. With, S.V. Roth, S. Förster et al. **2012**, *in preparation*.

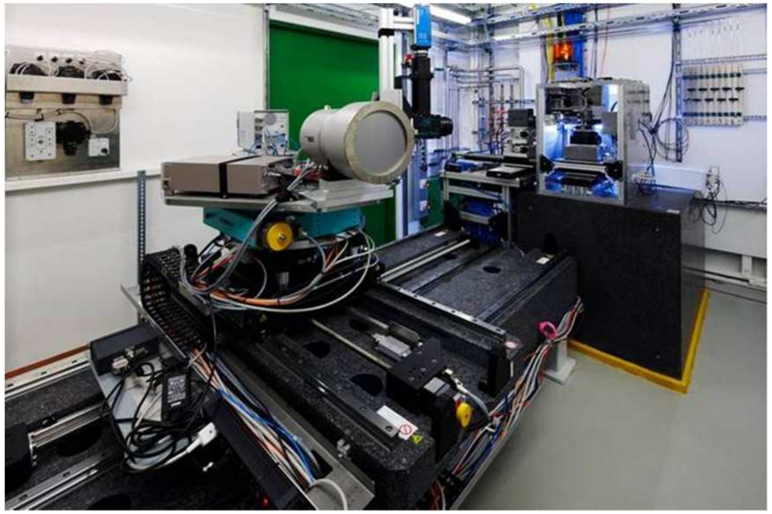
P06: hard X-ray nano- and micro-probe

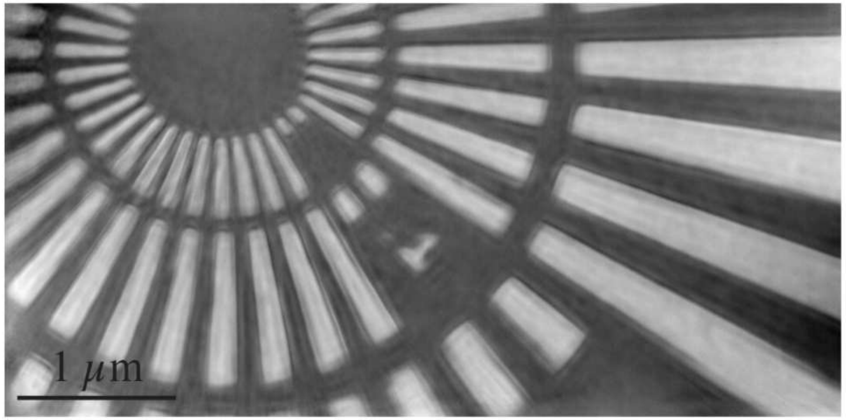
- Scanning fluorescence microscopy
- Nano-diffraction
- Ptchography
- Tomography
- 5 – 50 keV
- NFLs
- KB system
- FZP





Zone plate focus: (25 nm)²



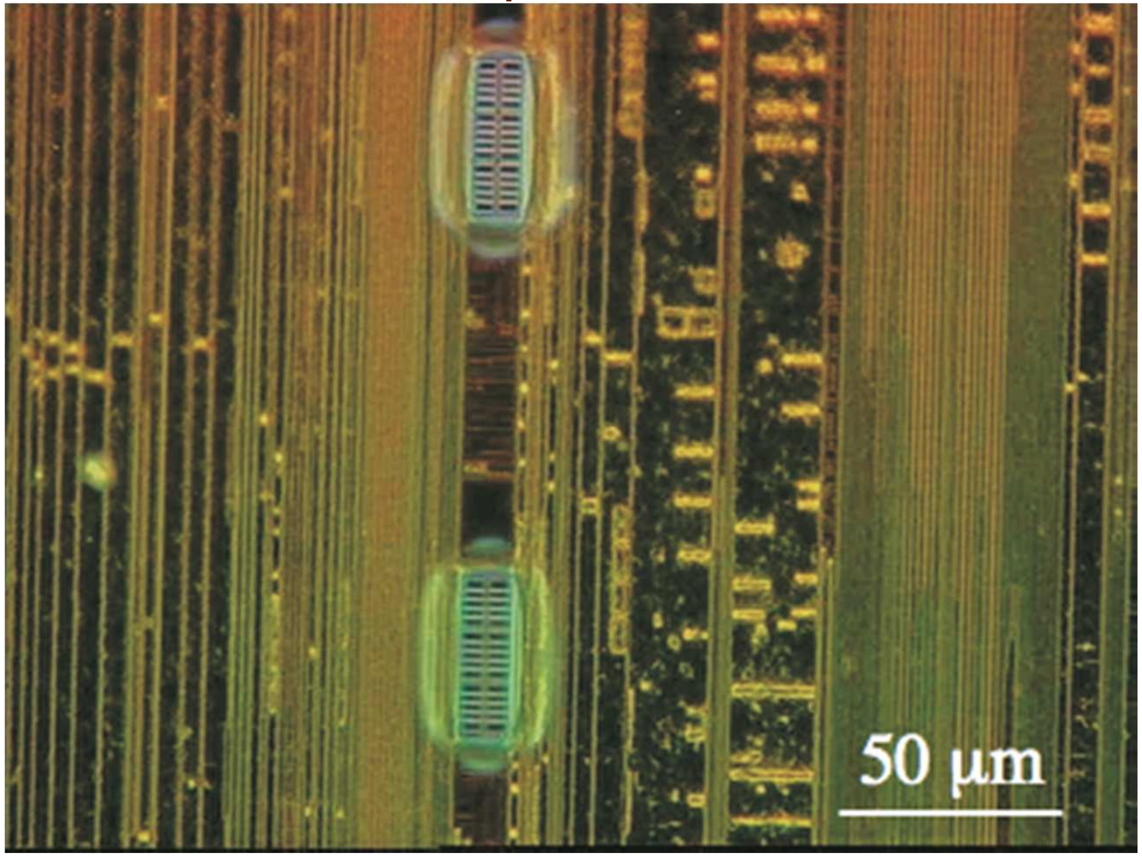


Ch. Schroer et al (TU Dresden), Ch. David (PSI)

P06 Example: Qimonda storage chip

Ptychographic Imaging of Qimonda storage chip

Shared sense amplifier



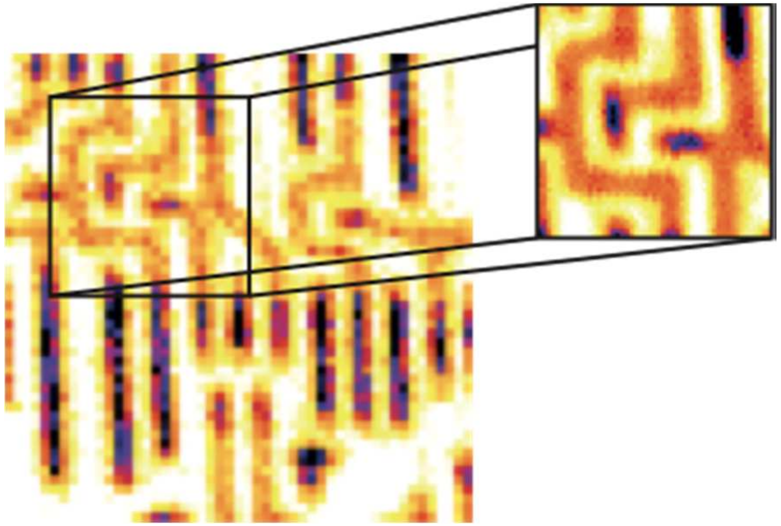
No sample preparation: passivated chip (thickness:>100 µm)

512 Mb DDR2 RAM
80 nm technology

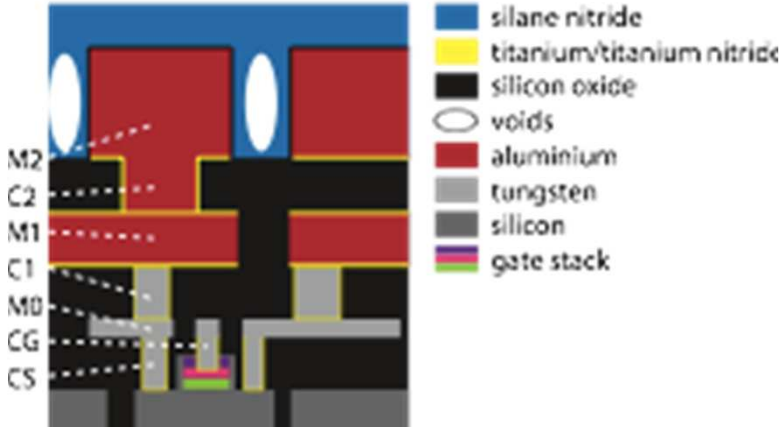
A. Schropp, et al., J. Microscopy, 241(1), 9 (2011)

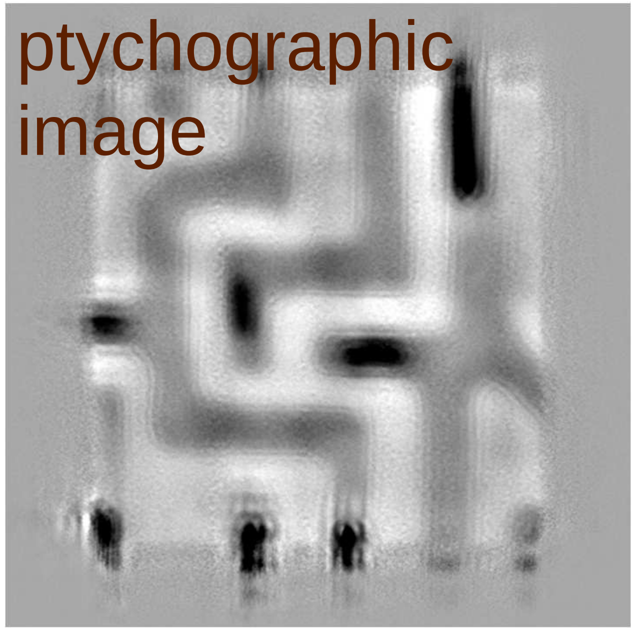
P06 Example: Qimonda storage chip

W-fluorescence map



vertical stacking scheme





- E= 15.25 keV
- 200nm wide conducting paths

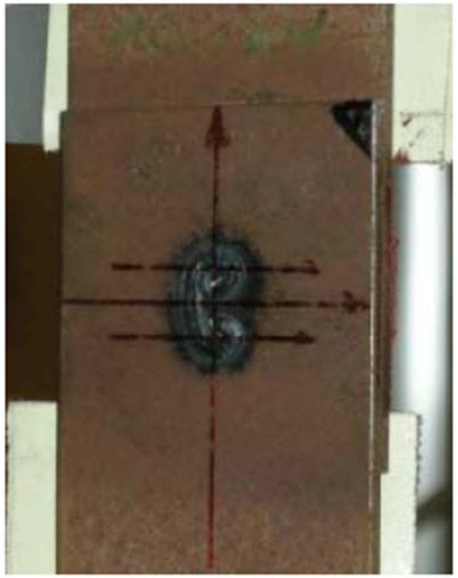
contrast:

- W in SiO_2
- voids

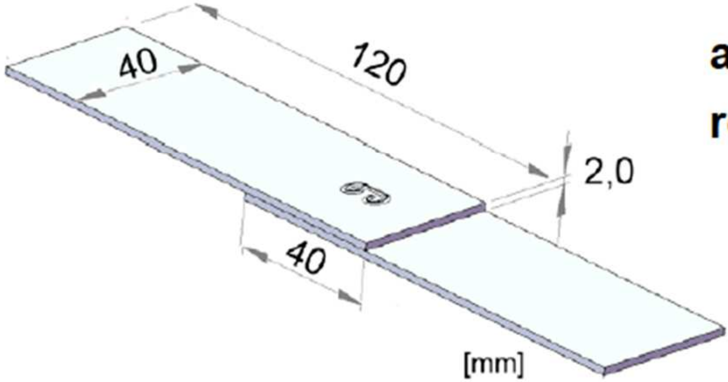
quantitative information:

- thickness via: 90 nm
- two stacked plugs: 570 nm

P07: residual stress in laser spot welds



Residual stress distribution in laser beam welded overlap spot welds (e.g. steel sheets of car bodies) influences fatigue properties.

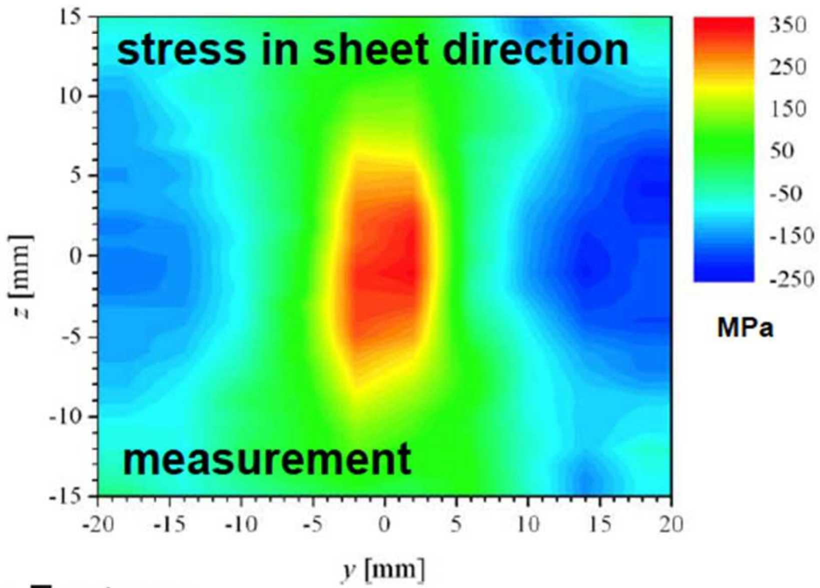


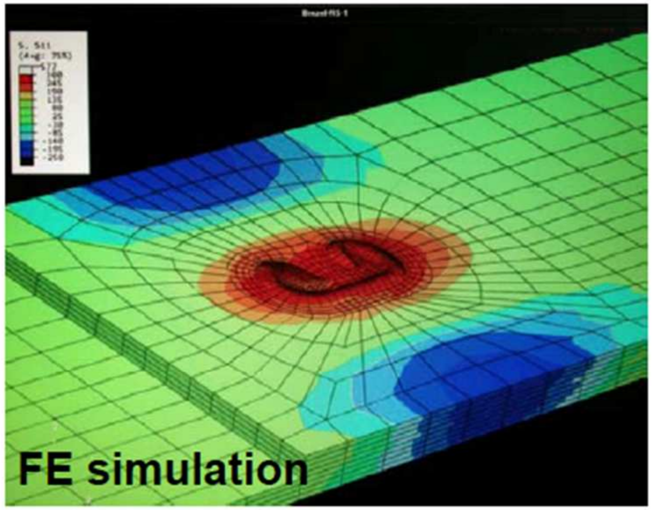
aim: **evaluation of FE simulation**

result: **good agreement**

53.6 keV, 1 x 1 mm², MAR345

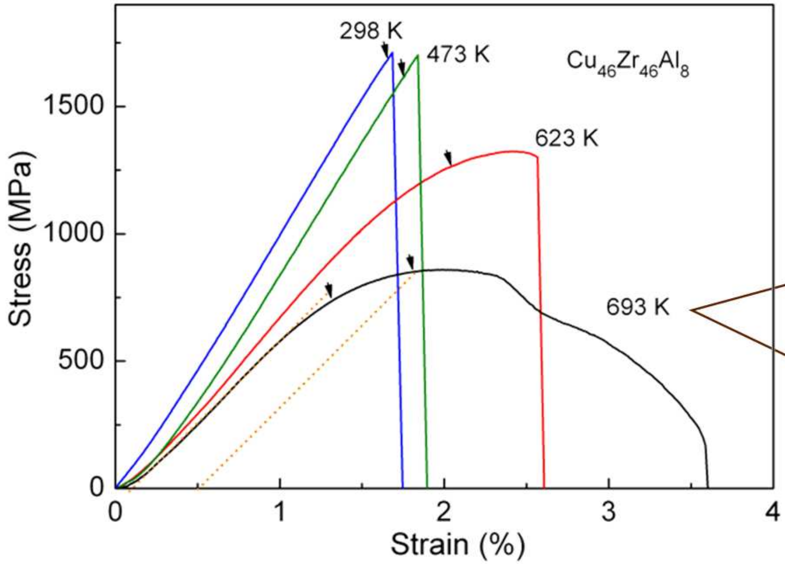
tensile stresses in the weld, balanced by compressive stresses near the sample edges

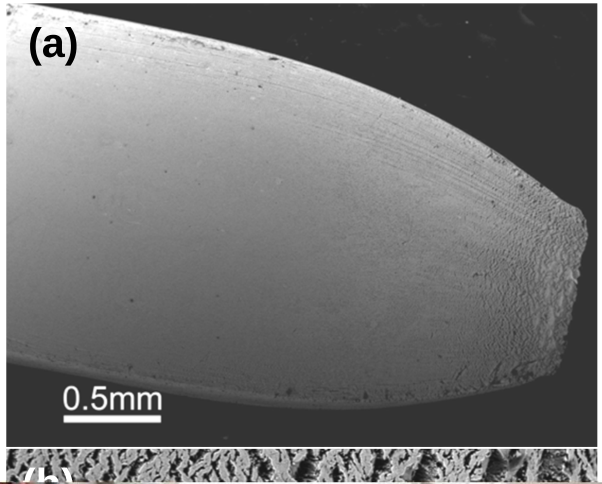


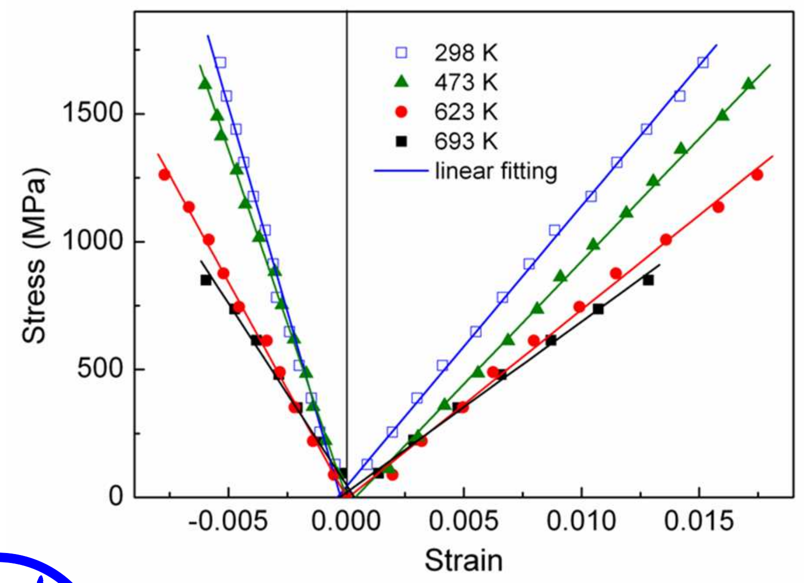


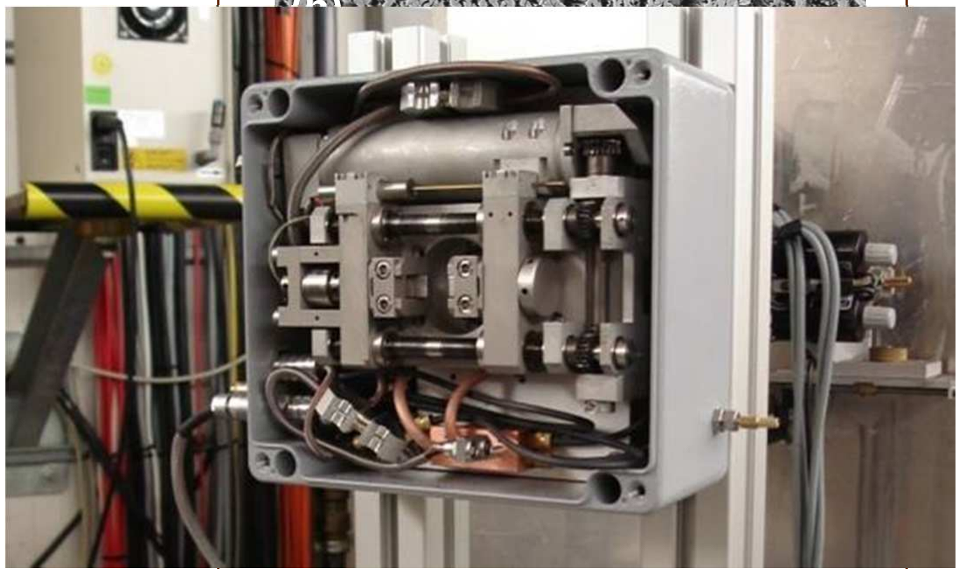
Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

P07: Deformation of CuZrAl bulk metallic glass





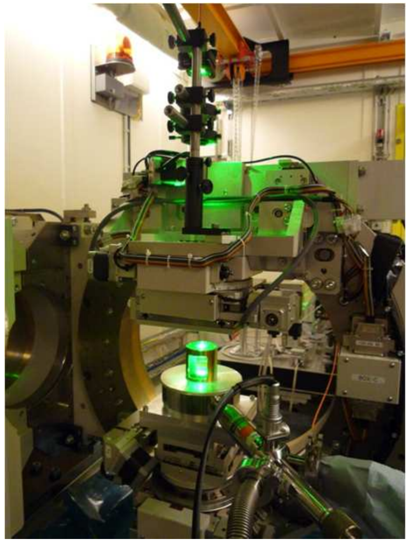


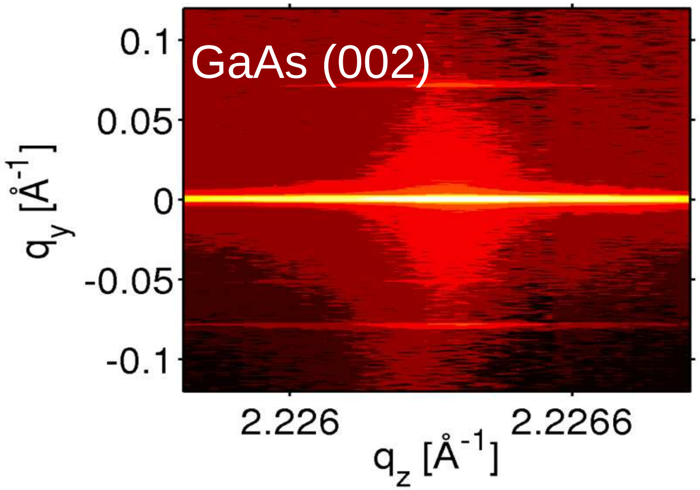


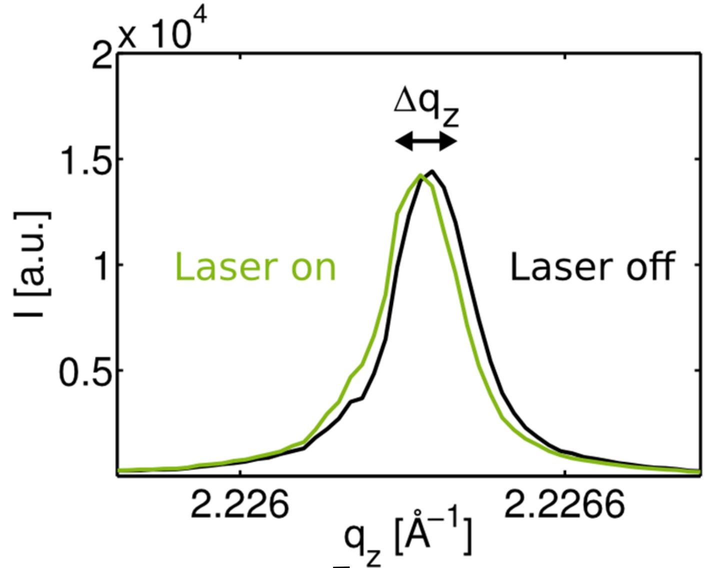
X.D. Wang et al. 2010

P08: Laser-induced anisotropic strain in optically excited InAs/GaAs quantum dots

S. Tiemeyer, M. Bombeck, M. Paulus, C. Sternemann, M. Bayer, M. Tolan

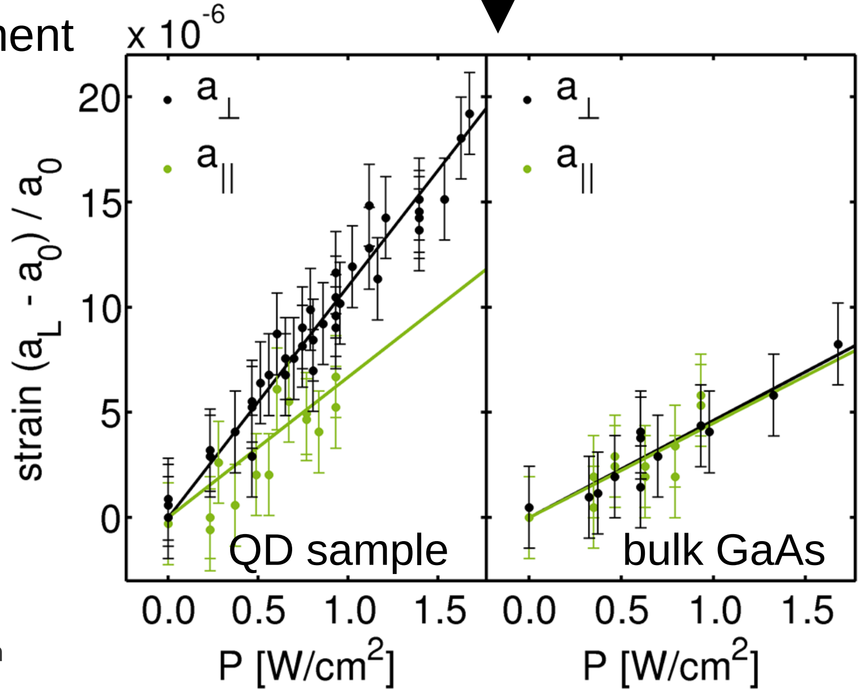




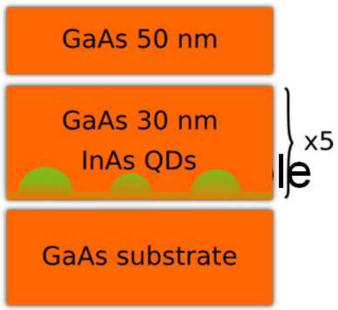


Known: Modification of density of state due to confinement (quantum dot)

Unknown: Modification due to additional heavy excitement with electrical field by LASER



High-resolution x-ray diffraction at P08, PETRA III



Nd:YAG laser 532 nm, max. 1 W

helium flow cryostat T = 100 K

Upcoming experiment will clarify the origin of the anisotropic strain

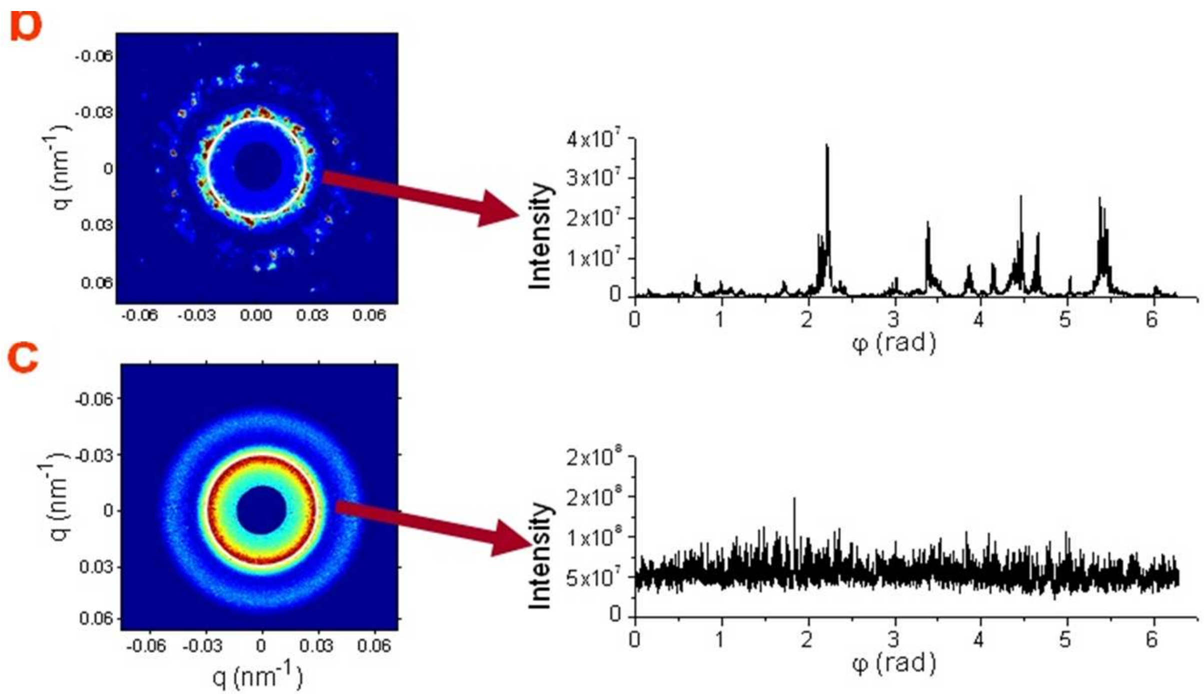
technische universität dortmund

Hermann

P10: Coherence beamline

- Coherent flux is given by the brilliance
- Coherence length by the source size and the length of the beamline
- Dedicated set-up for XPCS and coherent imaging
- Vertical SAXS set-up with Rheometer in plate-plate geometry

Glass transition of hard sphere colloidal systems

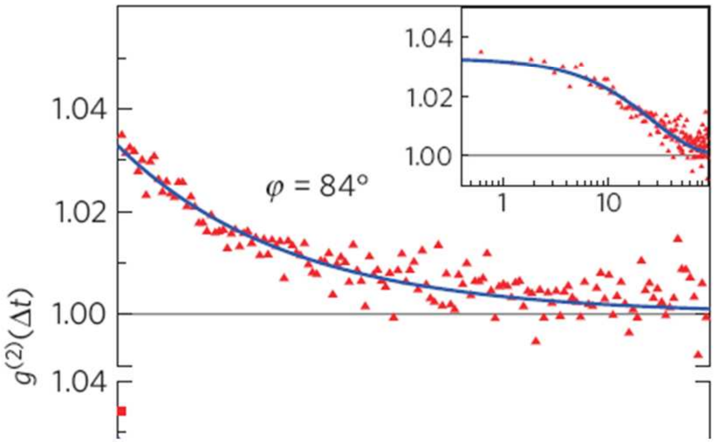


P10 Coherence beamline

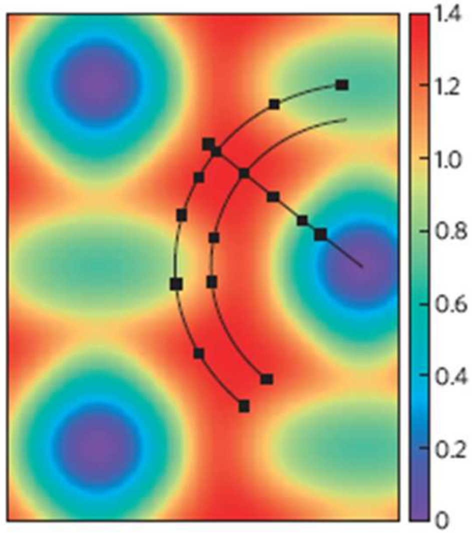
nature materials | LETTERS
PUBLISHED ONLINE: 26 JULY 2009 | DOI:10.1038/NMAT2506

Atomic diffusion studied with coherent X-rays

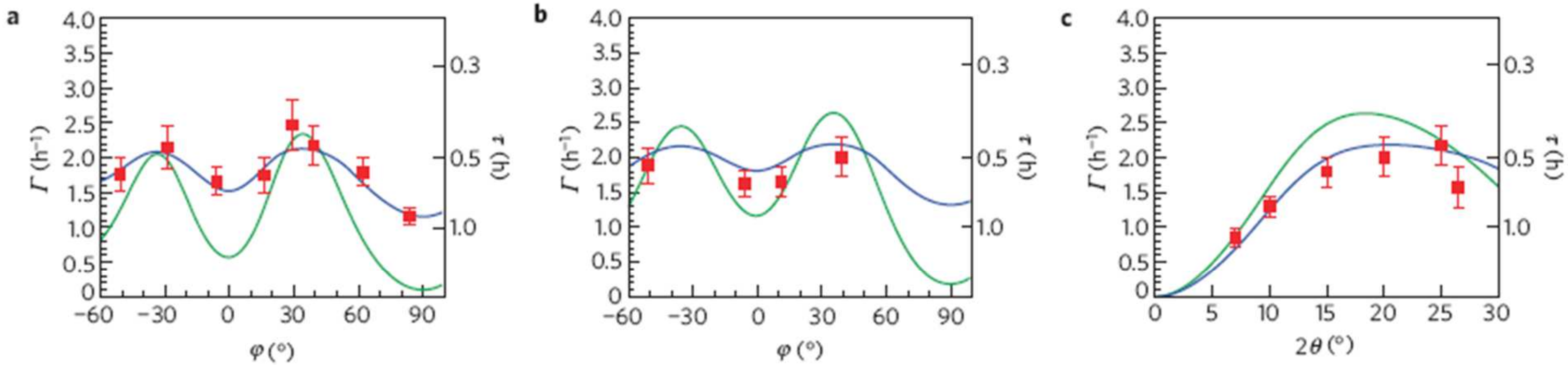
Michael Leitner[1]*, Bogdan Sepiol[1], Lorenz-Mathias Stadler[2], Bastian Pfau[3] and Gero Vogl[1]



Data from ESRF



$$g^{(2)}(\mathbf{q},\Delta t) = \frac{\langle I(\mathbf{q},.)I(\mathbf{q},.+\Delta t)\rangle}{\langle I(\mathbf{q},.)\rangle^2}$$



Figu… in re…

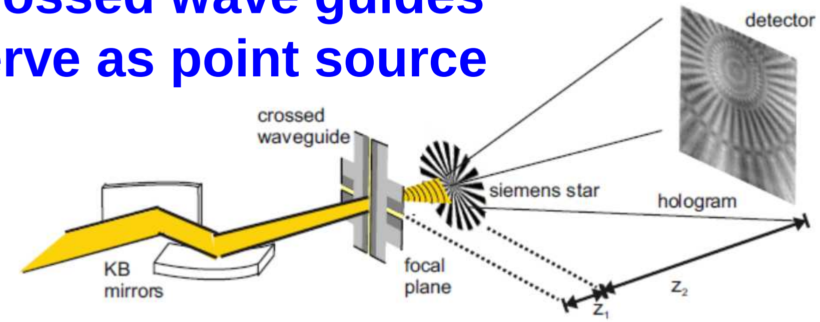
fixed scattering angle $2\theta = 25°$ and varying azimuthal angles $\varphi = 84°$ and $\varphi = 39°$ (for definition of the angles see Fig. 3) with fitted exponential decays. Although the modulus of the scattering vector is the same, the fitted correlation times (52±5 min for $\varphi = 84°$ and 28±4 min for $\varphi = 39°$, respectively) differ by a factor of two. The inset shows the measurement with $\varphi = 84°$ plotted on a logarithmic timescale.

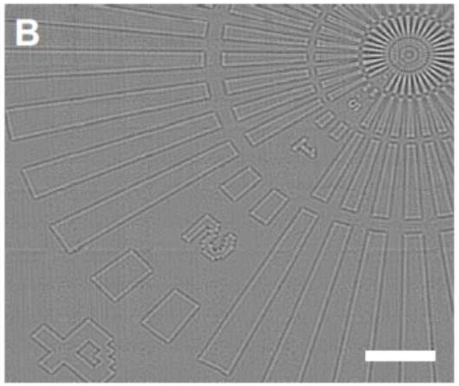
…stem

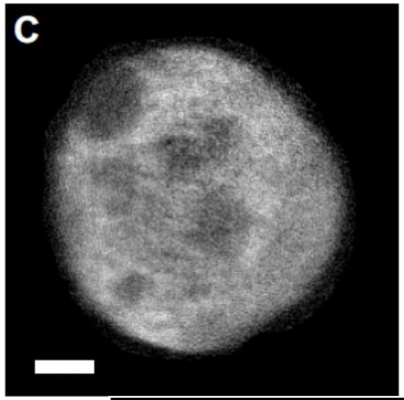
τ_0(T): time between (successful) jumps
denominator: contains jump mechanism

Imaging with a 10 nm beam at P10

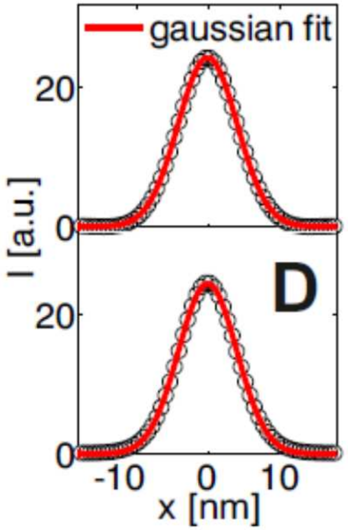
Crossed wave guides serve as point source







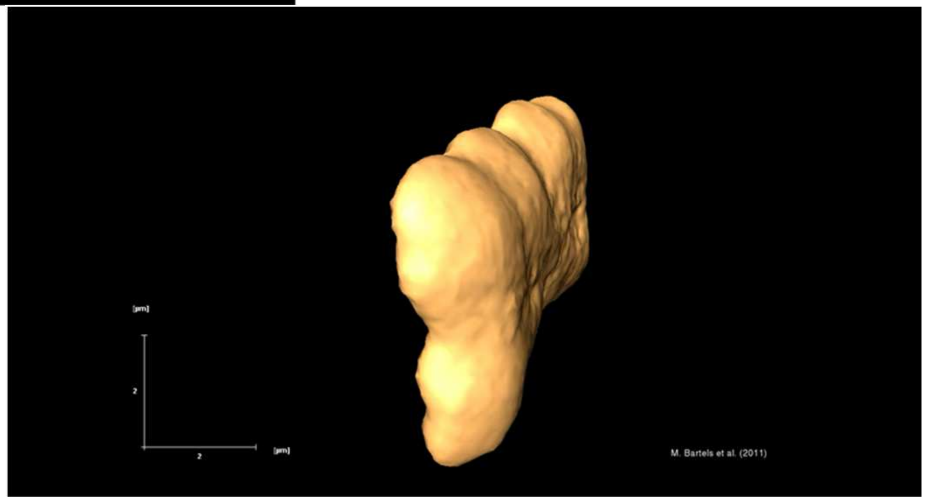
Beam profile reconstruction



M. Bartels, T. Salditt, M. Sprung et al: Göttingen end-station

Reconstructed image of **d.radiodurans using the 10nm beam as point source.**

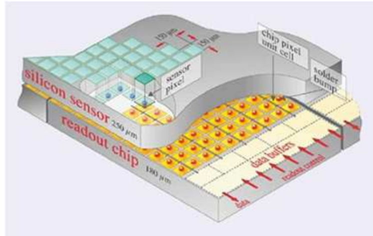
Resolution ca 70 nm



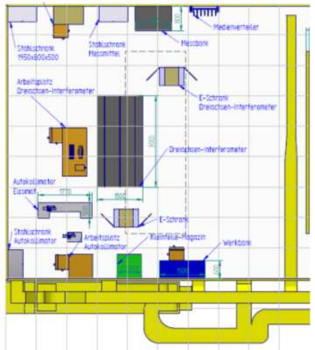
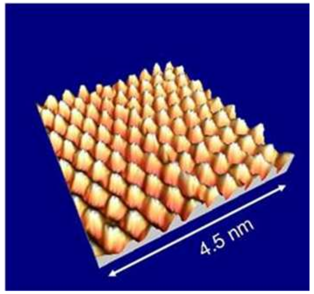
Auxiliary labs

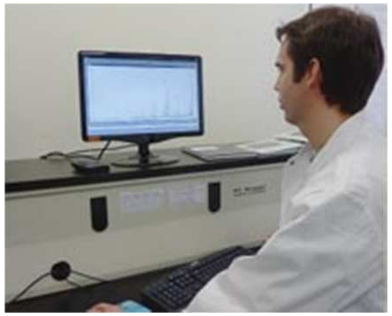
- **Detector pool**
- **Sample environment pool**
- **Chemistry lab**
- **Clean-room facilities**
- **Metrology lab**
- **AFM**
- **High pressure lab**
- **Laser labs (class 4)**
- **Wet-labs (with EMBL)**










New beamlines in hall North 2014+

- **P61 (damping wigglers)**
  P61.1 - **fixed-energy branch for PDF structure analysis**
  P61.2 - **high-energy engineering materials science station**
  (Helmholtz-Center Geesthacht, HZG)
  - extreme conditions station (large volume press)

- **P62 (mini-undulator)**
  X-ray micro fluorescence spectroscopy

- **P63 (mini-undulator)**
  small-angle X-ray scattering

- **P64 (2m undulator)**
  X-ray absorption spectroscopy: time-resolved and bio-XAFS

- **P65 (mini-undulator)**
  X-ray absorption spectroscopy

New beamlines in hall East 2014+

- o P21 (4m undulator & opt. wiggler)
  - High-energy X-ray material science (Swedish-German collaboration)
- o P22 (2m undulator)
  - "nano spectroscopy" working title (Indian-German collaboration)
- o P23 (2m undulator)
  - "nano diffraction" working title (Russian-German collaboration)
- o P24 (mini-undulator)
  - chemical crystallography
- o P25 (mini-undulator)
  - P25.1 - education, training, test beamline
  - P25.2 - fixed energy side station

Summary

- PETRA has reached all design goals within the first year of operation
  - 1.0 nm rad emittance and reliable top-up operation
  - Stability in the range of nm and nrad
  - Close to perfect undulators, no mutual influence

- Measured beam parameters are largely consistent with simulated values
  - High quality source and optics
  - Very efficient focussing
  - We are well ahead of our roadmap to achieve small, brilliant X-ray beams

- All PETRA beamlines open for user applications – regular or friendly users

Thank you for your attention