

# New X-ray Analysis Methods Utilizing Microfluidics Devices: Concepts and Applications in BioMedical Research

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**FS – SCS** Structural Dynamics in (bio)Chemical Systems

Deutsches Elektronensynchrotron DESY, Hamburg,

Göttingen Research Campus: Göttingen University and

Max Planck Institute for Biophysical Chemistry

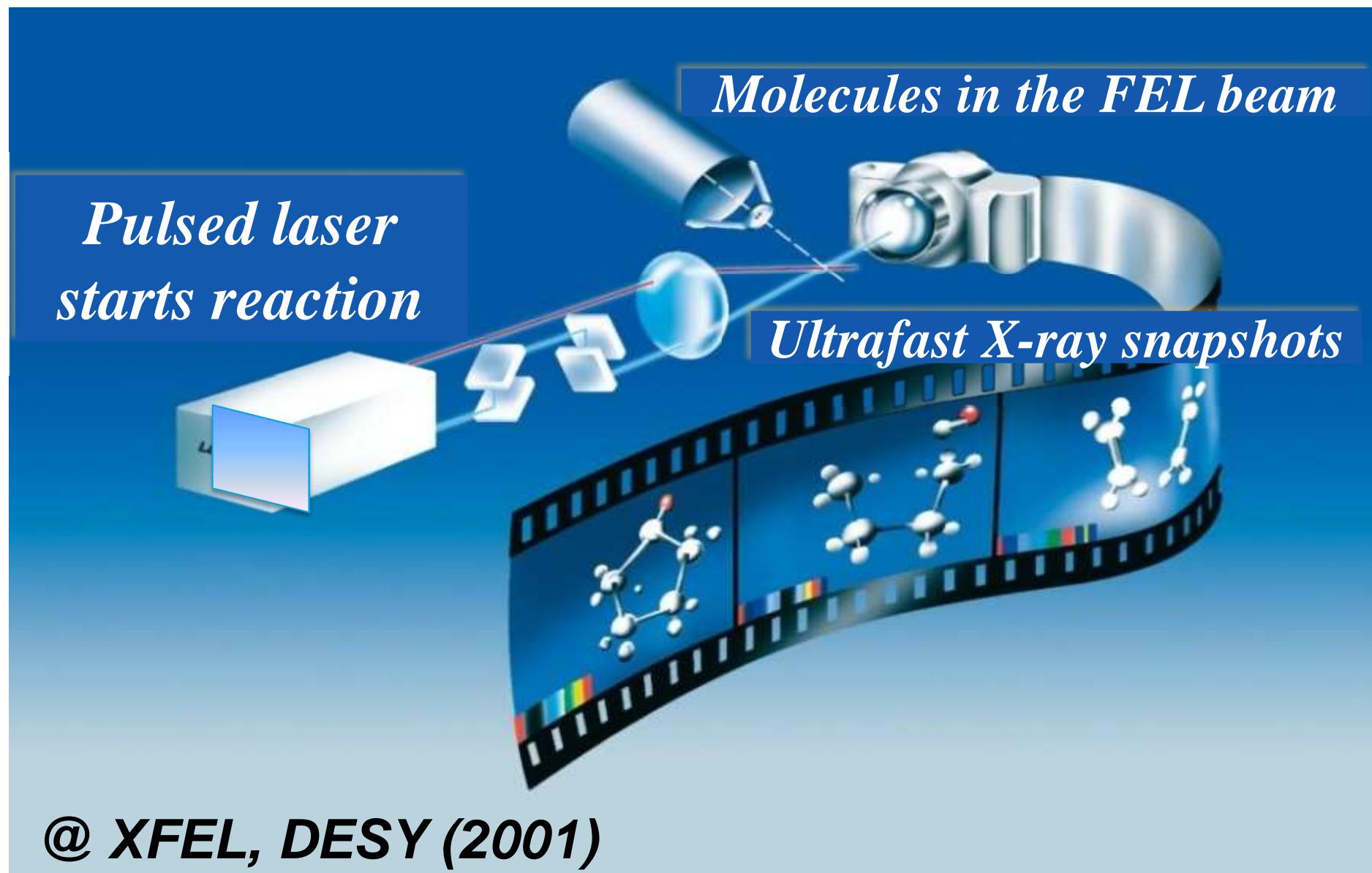


# Introduction

- Reactions out-of-equilibrium: life cellular processes
- Example: molecular transport through membranes such as blood cleaning (kidney)
- Applications to medical research: hemodialysis, peritoneal-dialysis etc.
- The growth of cellular cancer also involves transport processes: between nucleus and the intracellular environment
- Investigation method: microchannel devices coupled to X-ray sources

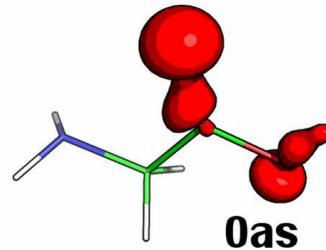


# Filming the „Molecular Movie“

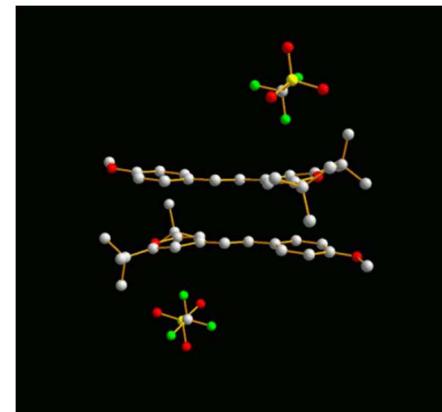


# Time Scales of Dynamics in Biosystems

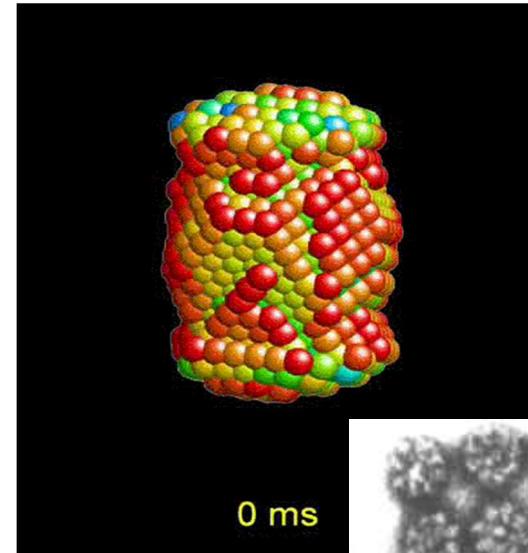
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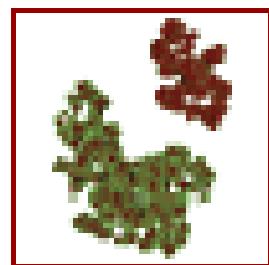
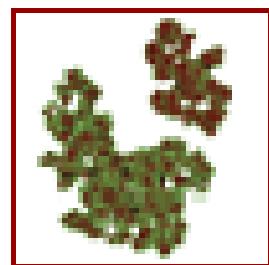
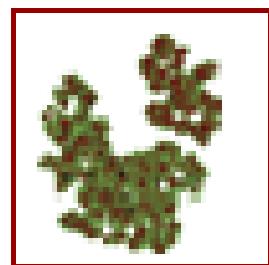
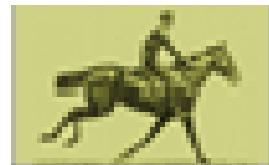
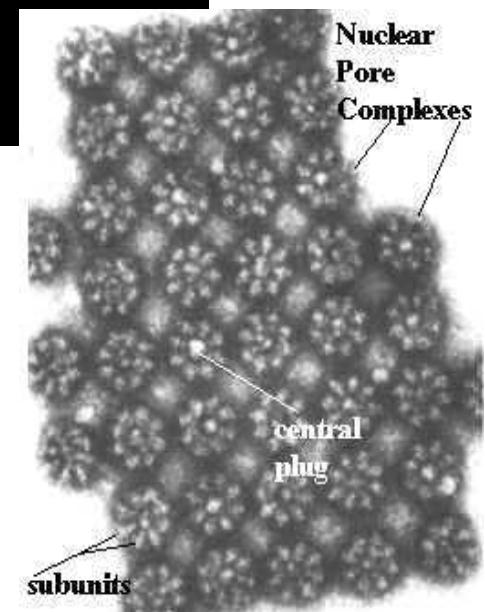
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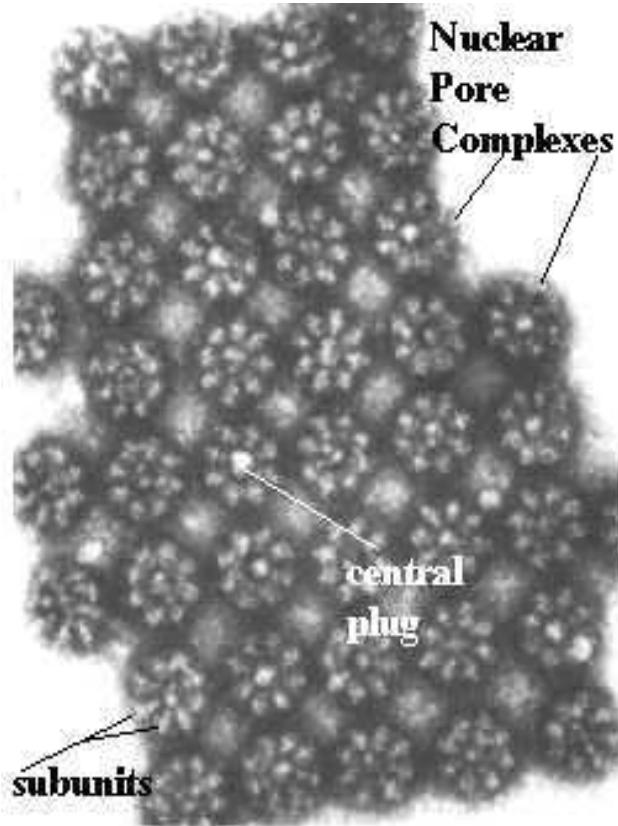
**0.01sec**



**0.1-1sec**



# X-ray Investigations of the Pore Proteins' Dynamics

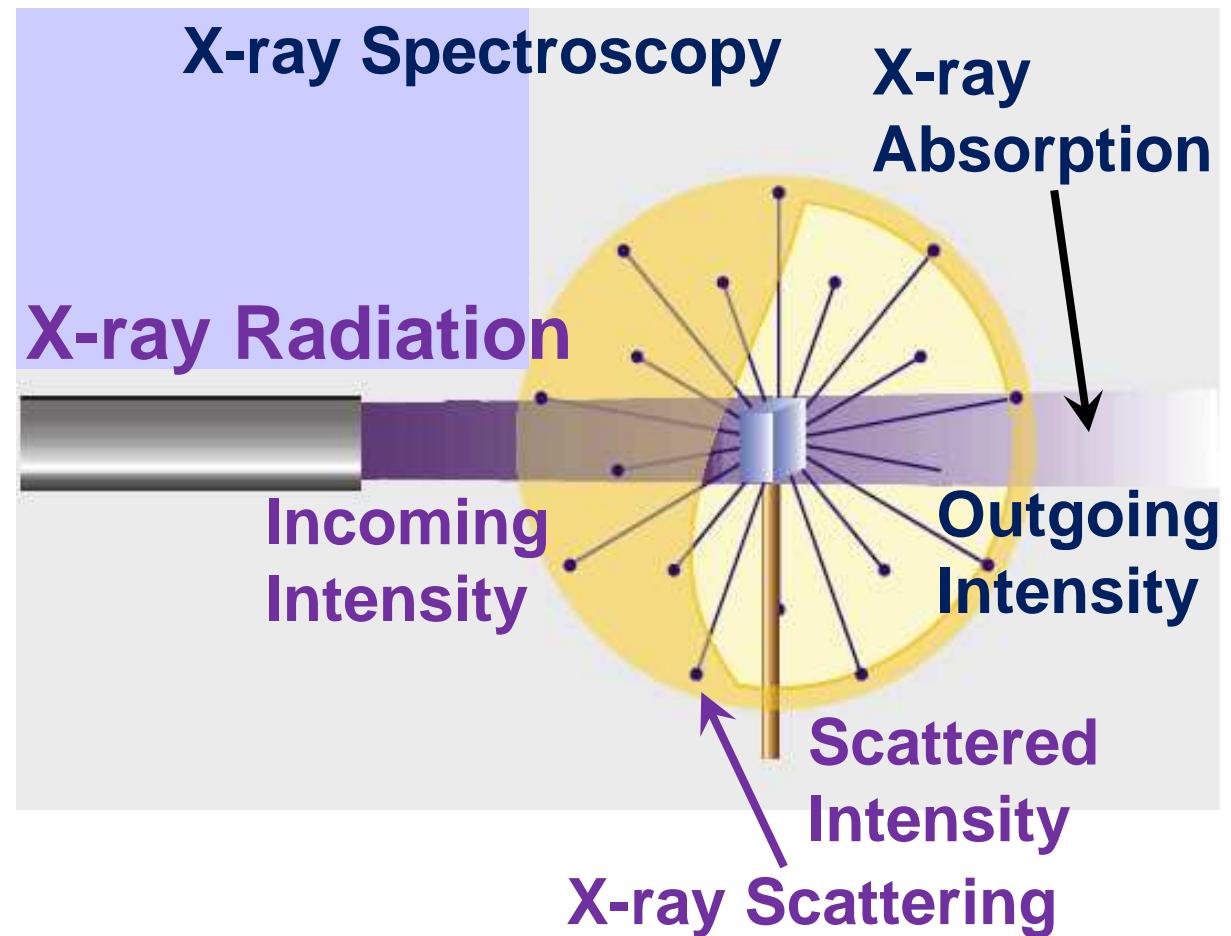


- How do the non-structured proteins look like?
- Which dynamics do they follow?

## Studies Possible with Mixing Devices



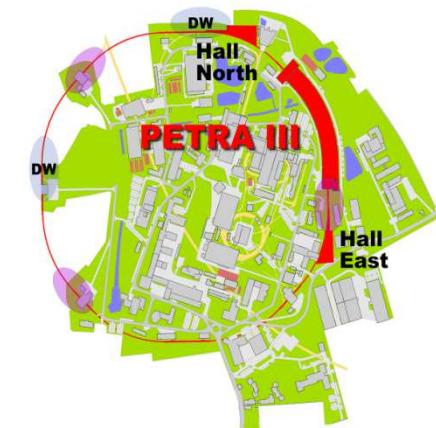
# Two Basic X-ray Interactions



# X-ray Investigations at Large Scale Facilities

## DESY Campus: Deutsches Elektronensynchrotron

### PETRA Synchrotron at DESY

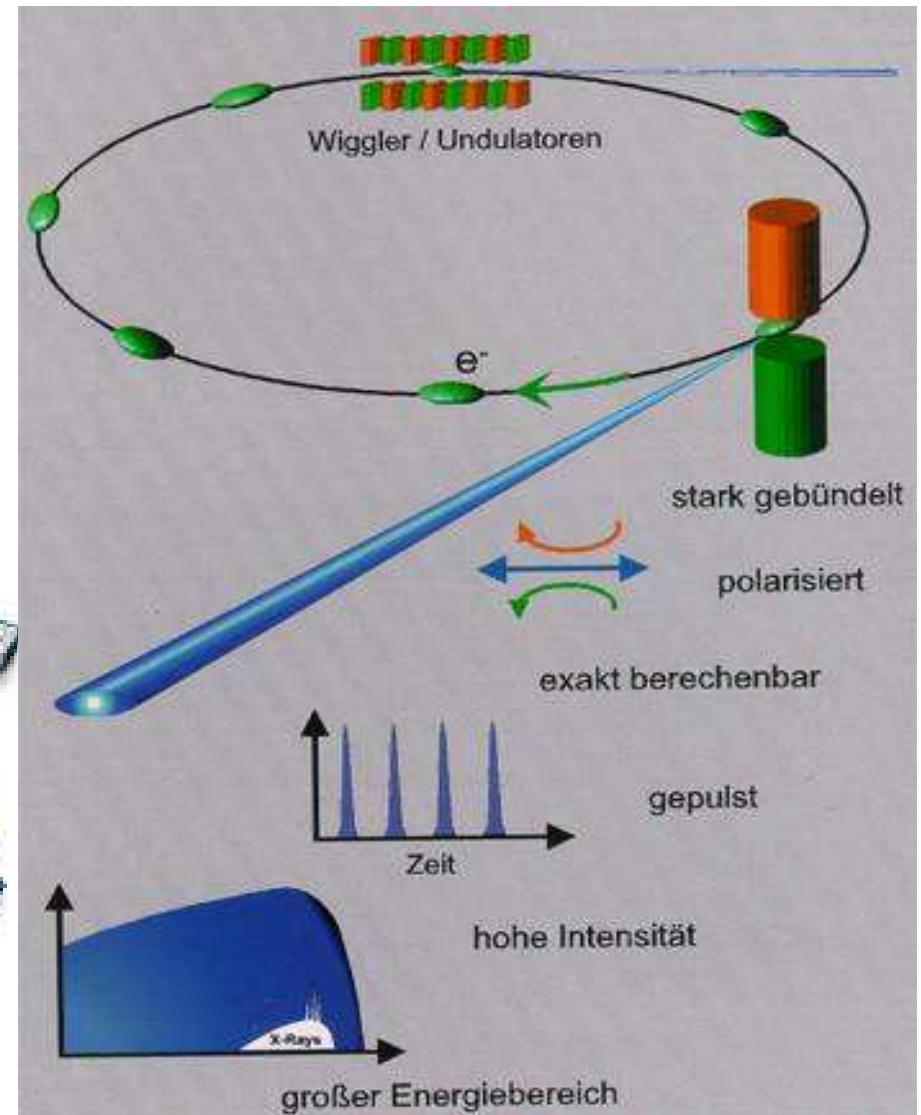
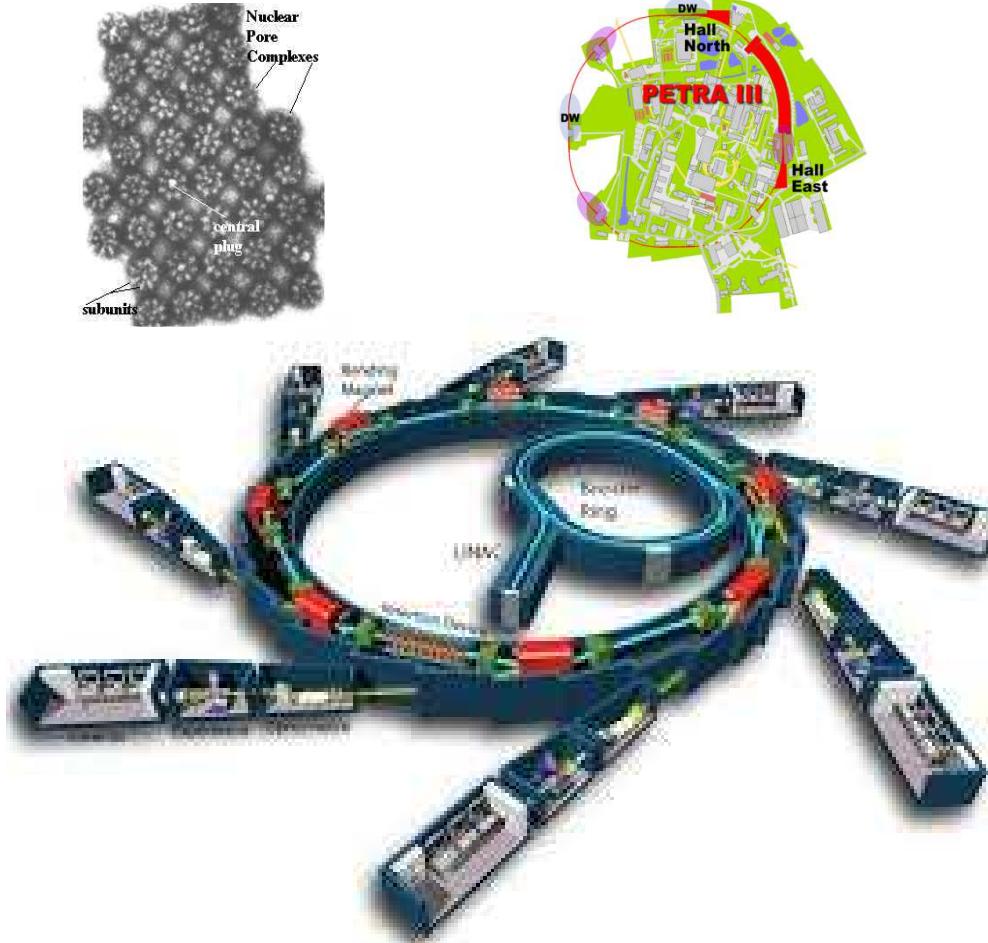


### FLASH Free Electron Laser at DESY



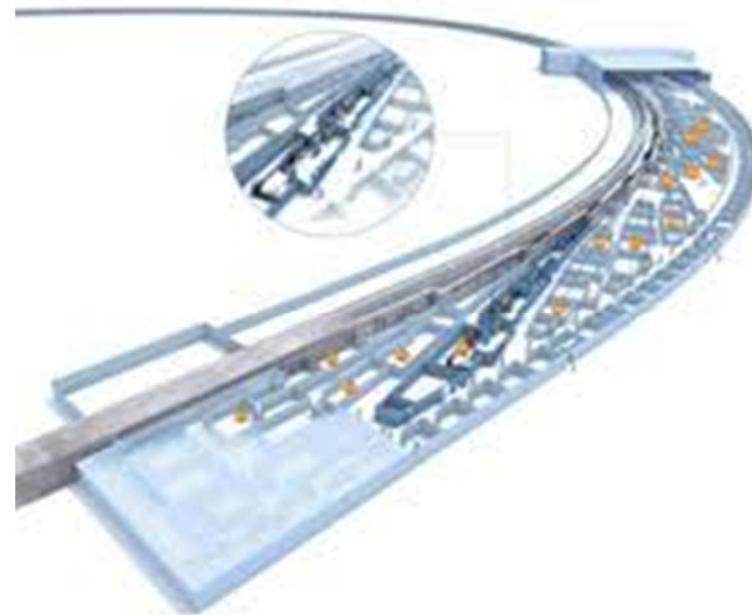
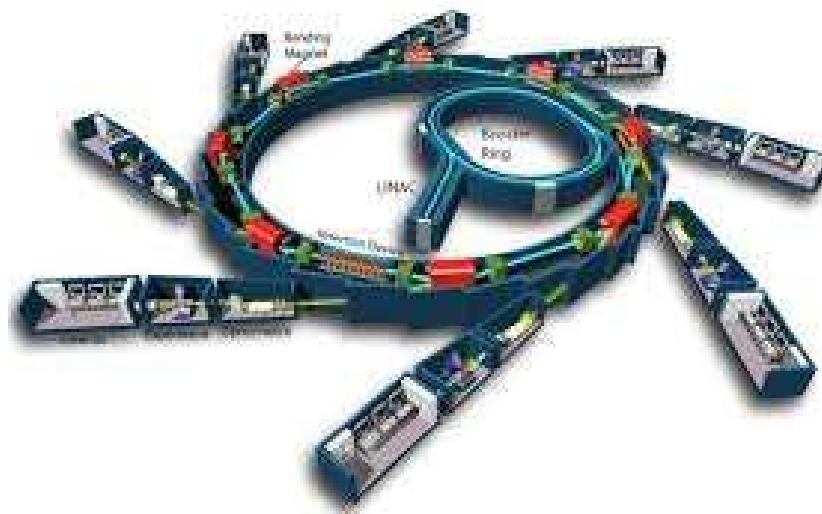
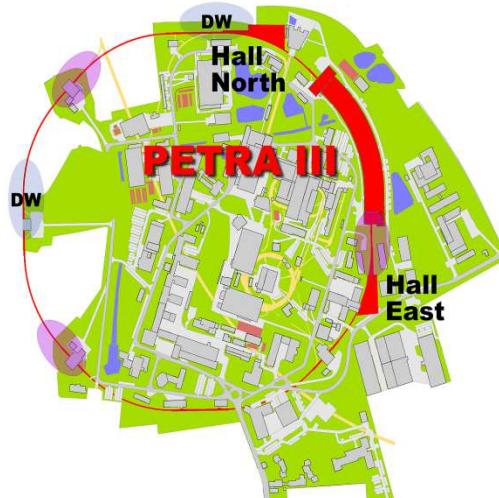
# PETRA Synchrotron X-ray Radiation

## PETRA Synchrotron at DESY

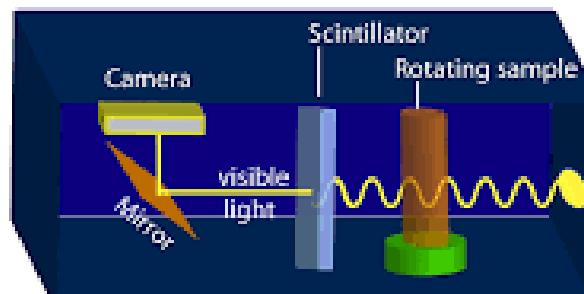
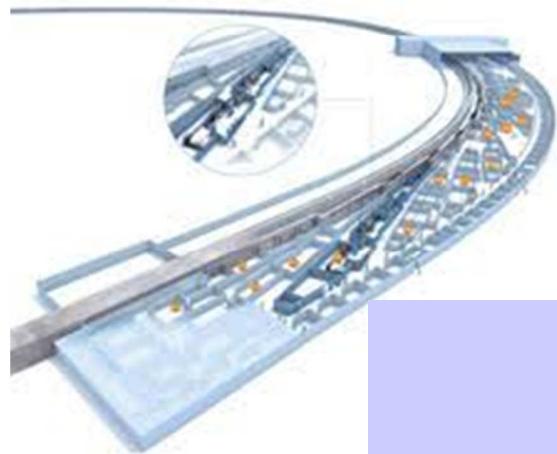


# PETRA Synchrotron X-ray Radiation

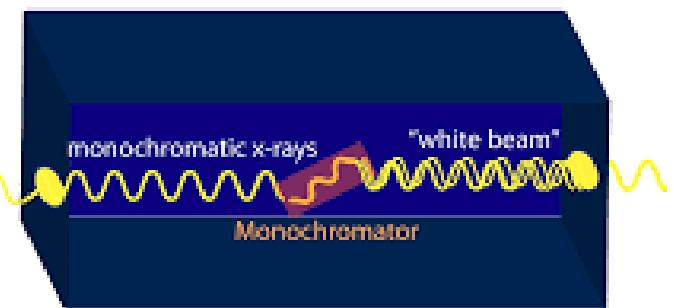
## PETRA Synchrotron at DESY



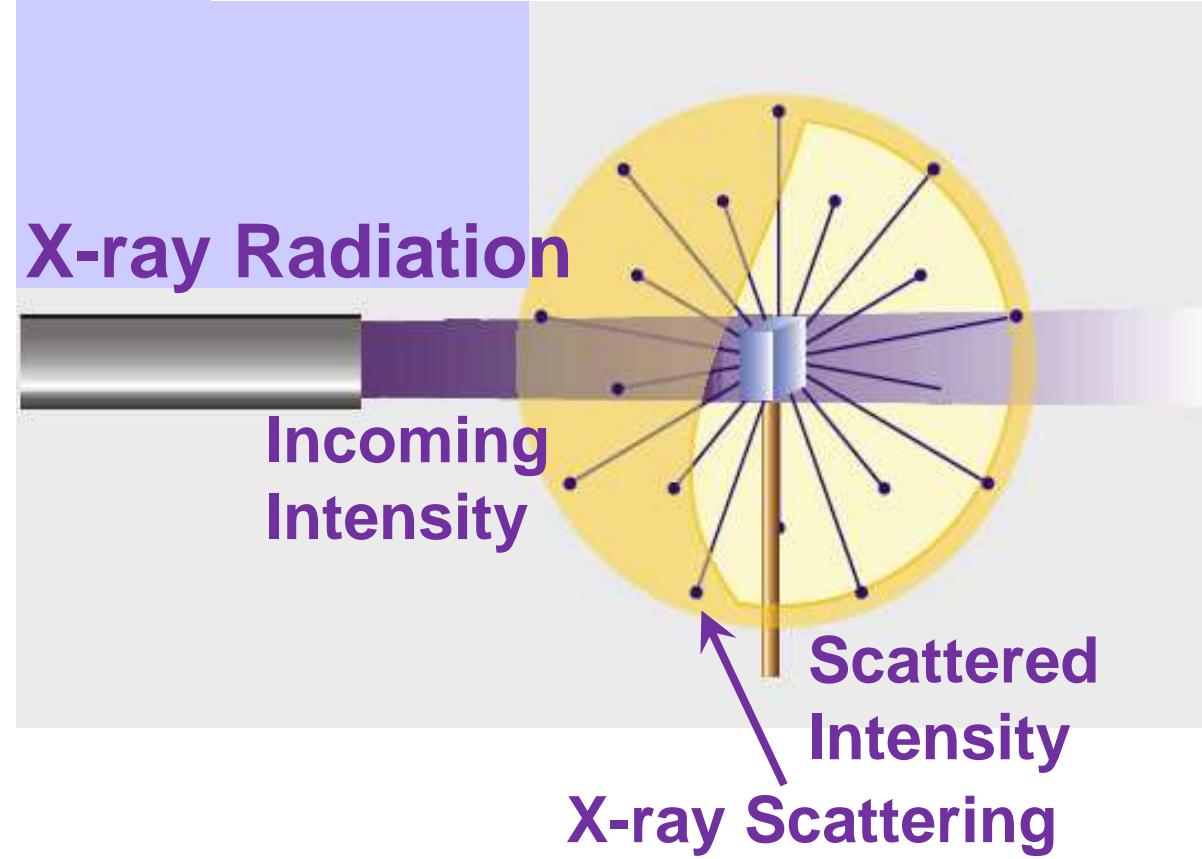
# Mixing Endstation at the PETRA Synchrotron: X-ray Diffraction



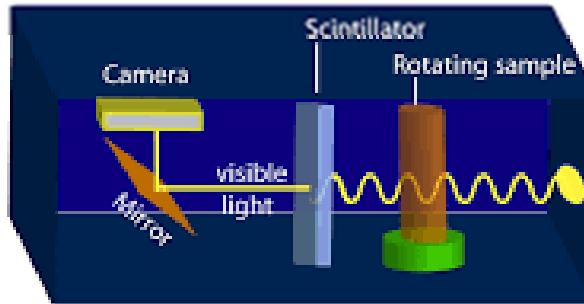
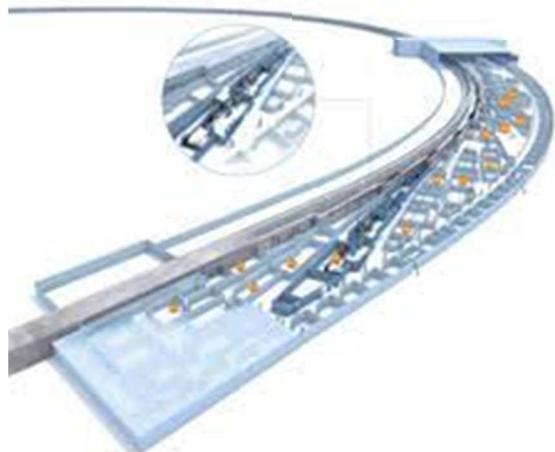
Experimental Hutch



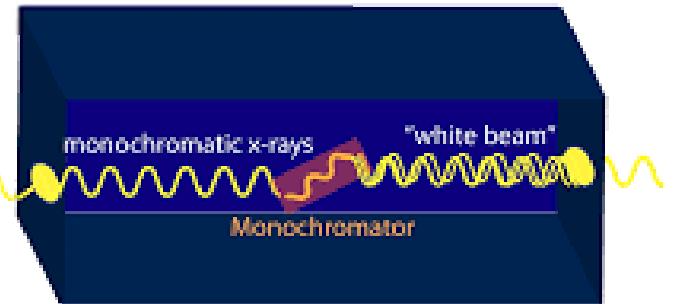
Optics Hutch



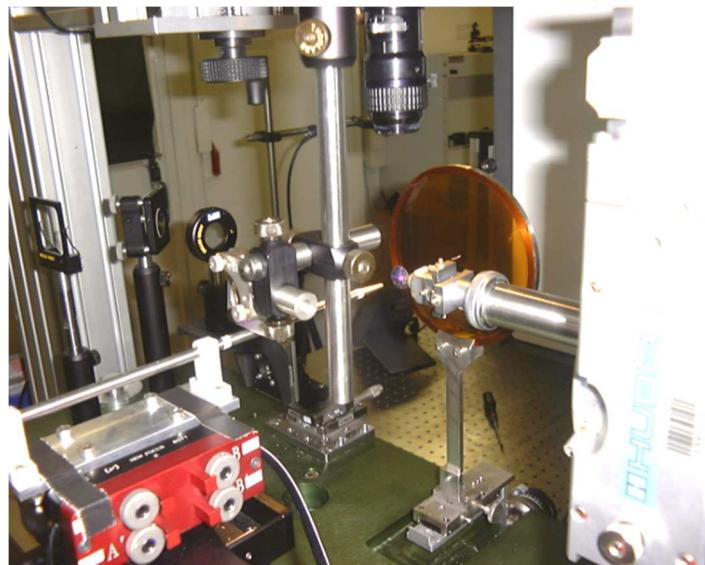
# Mixing Endstation at the PETRA Synchrotron: X-ray Diffraction



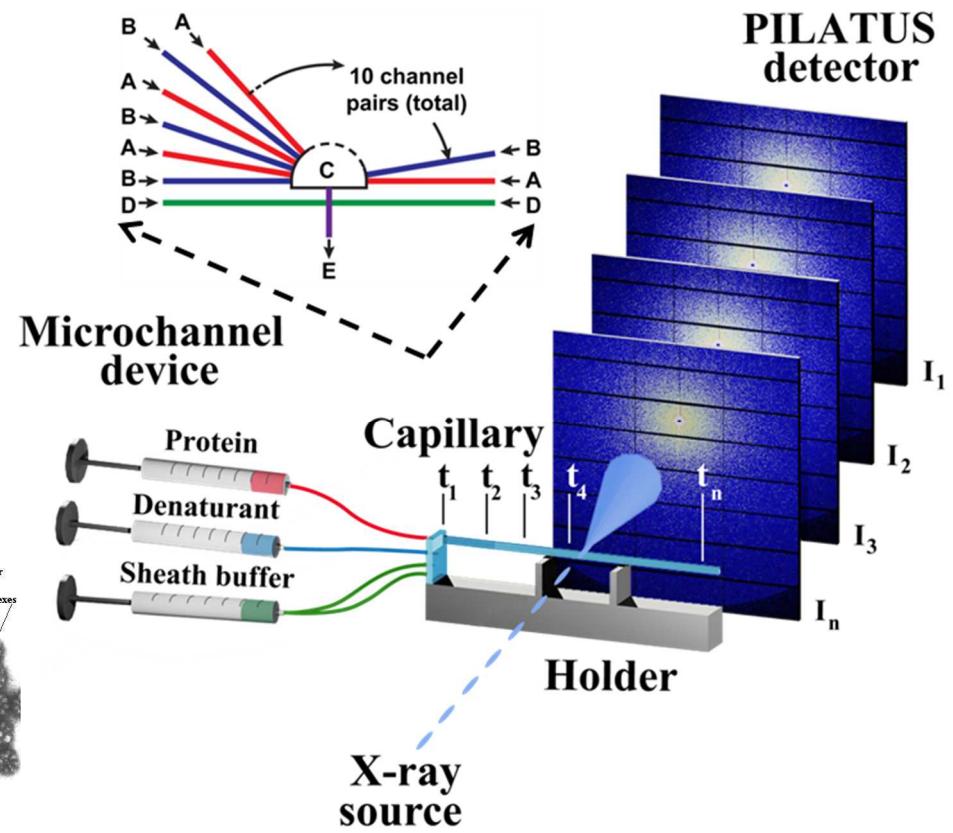
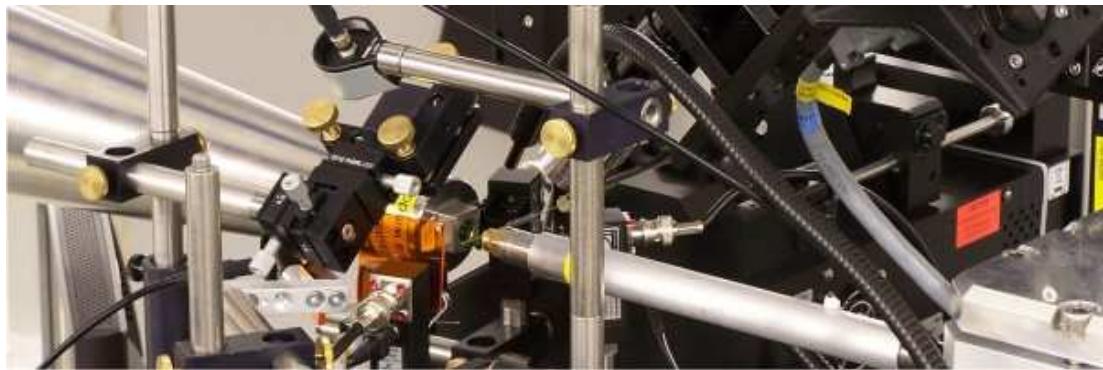
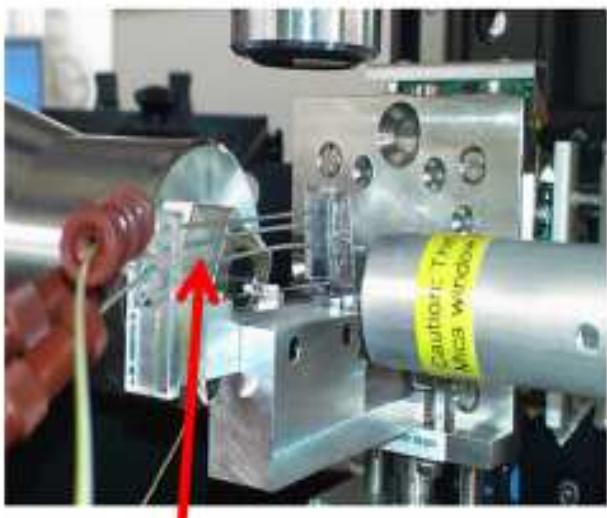
Experimental Hutch



Optics Hutch



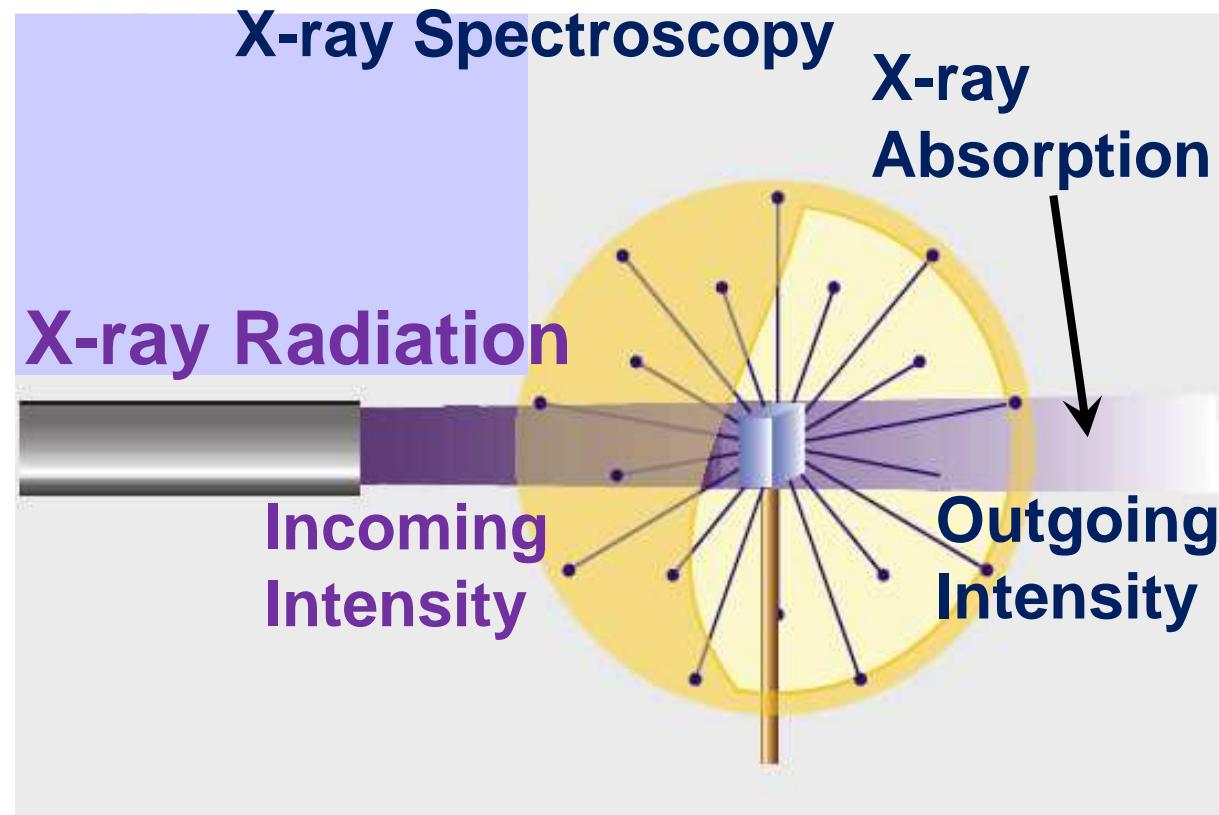
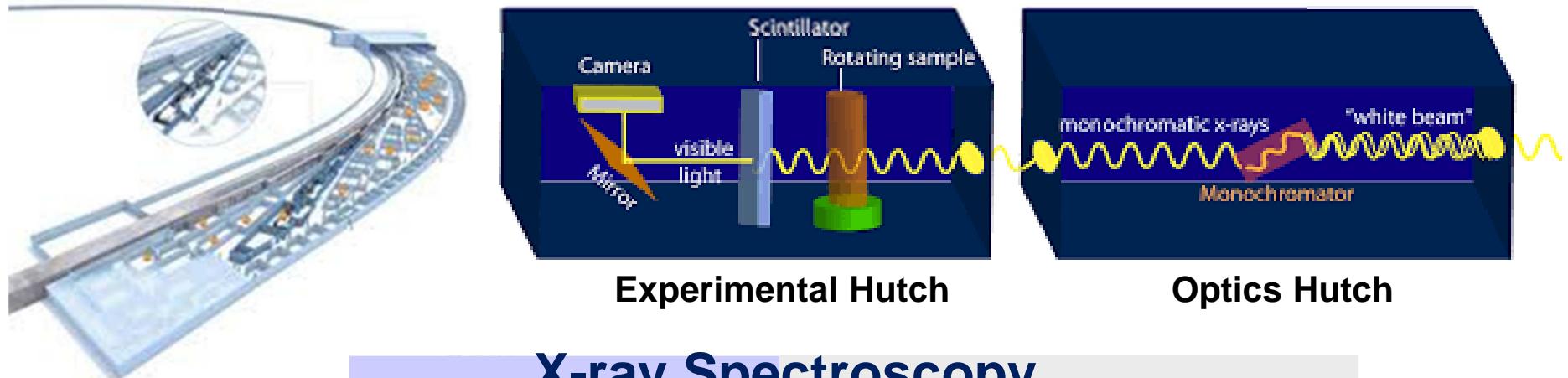
# Mixing Endstation at the PETRA Synchrotron: X-ray Diffraction



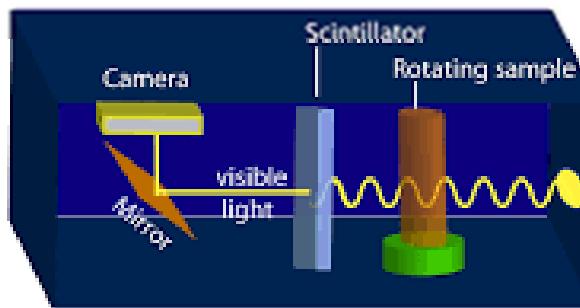
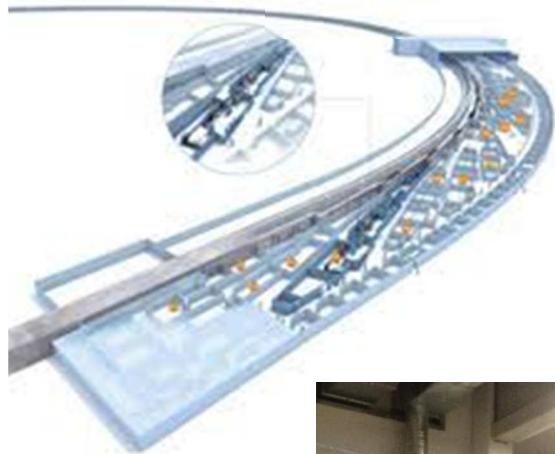
Jain et al. *Eur. Phys. J.* (2013).



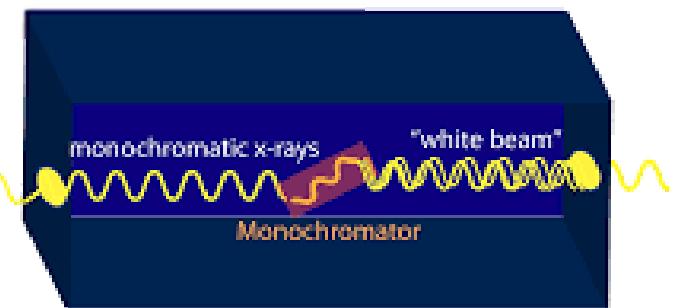
# Mixing Endstation at the PETRA Synchrotron: X-ray Spectroscopy



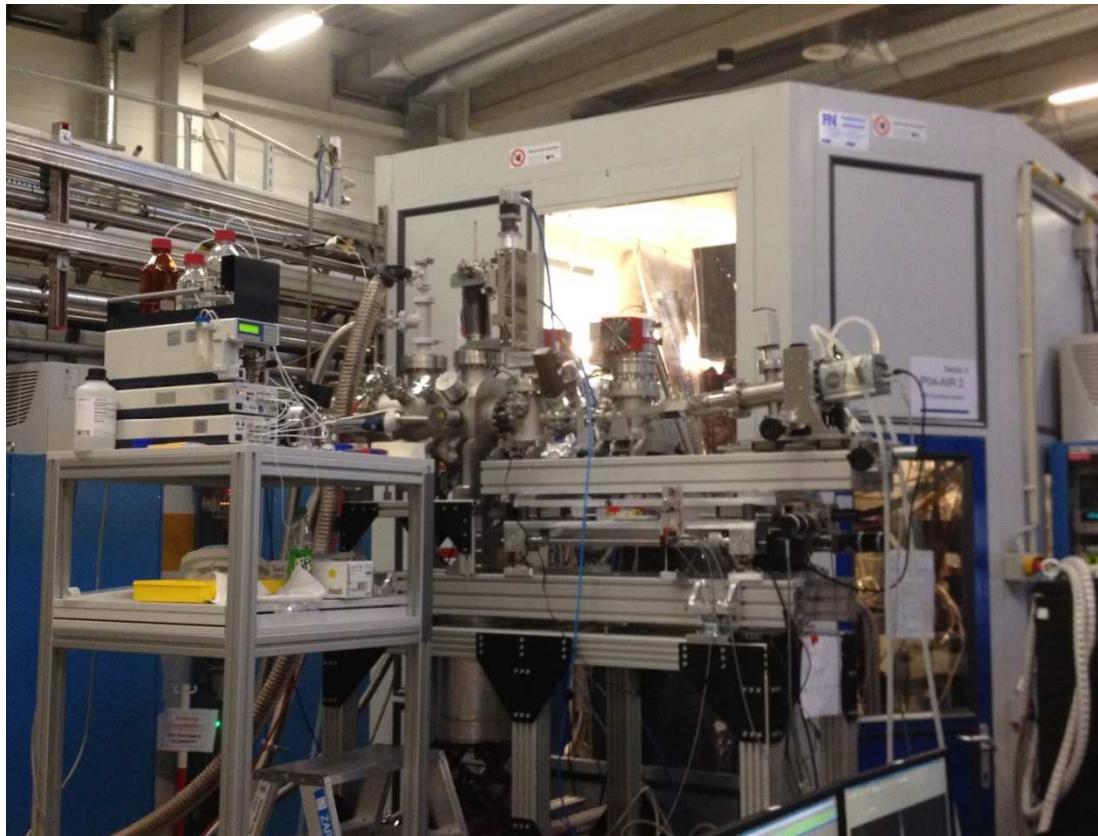
# Mixing Endstation at the PETRA Synchrotron: X-ray Spectroscopy



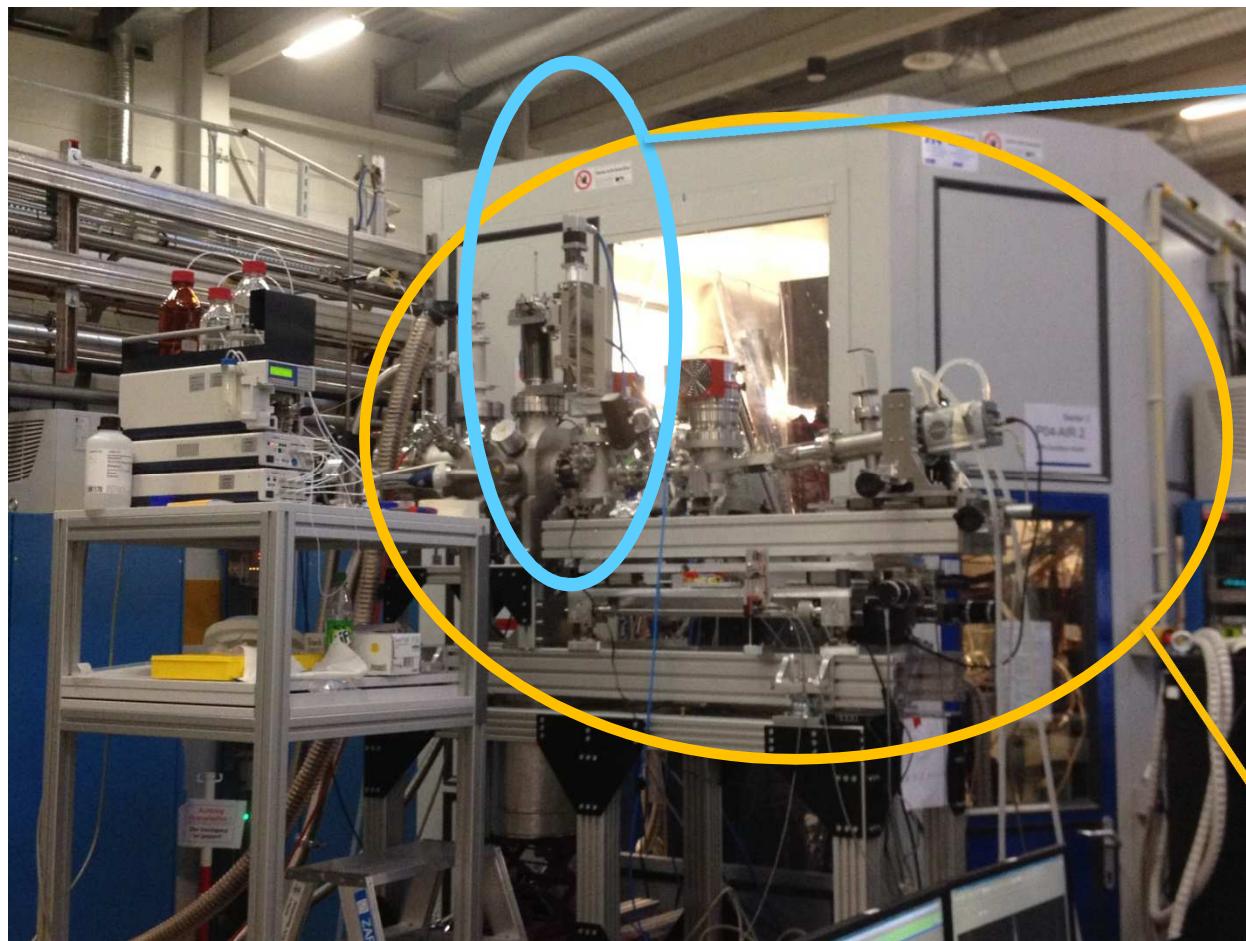
Experimental Hutch



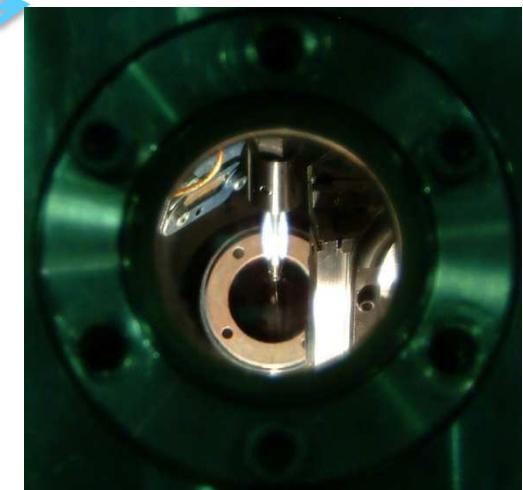
Optics Hutch



# Mixing Endstation at the PETRA Synchrotron: X-ray Spectroscopy



Liquid target holder

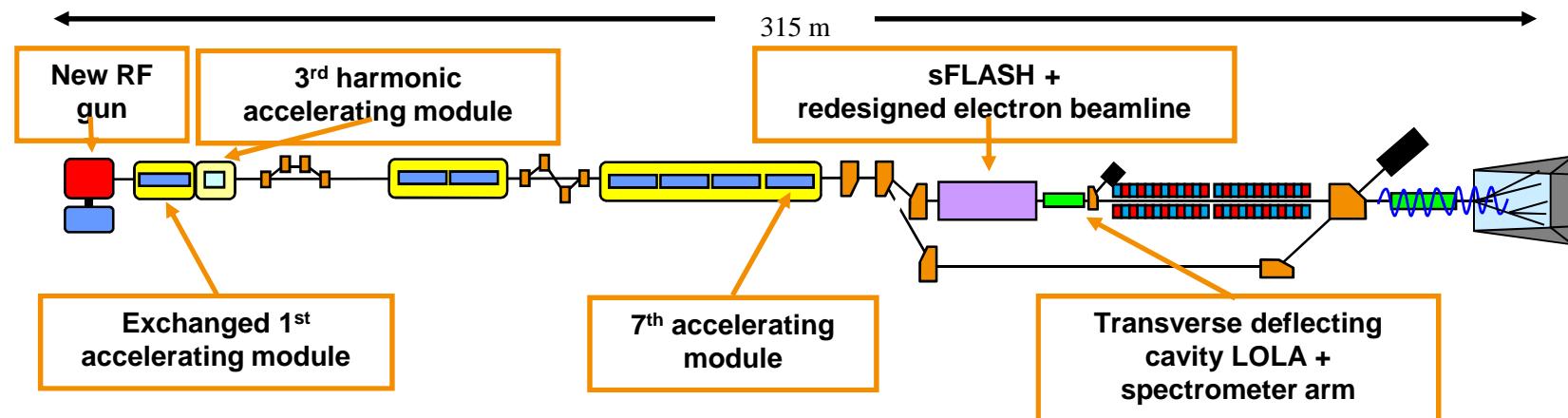
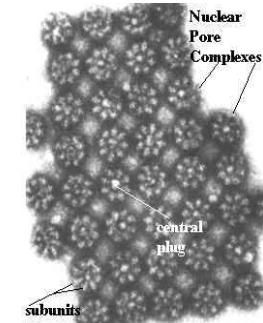


X-ray  
Spectrometer

Energy range from 210 eV – 1230 eV (1 – 6 nm)

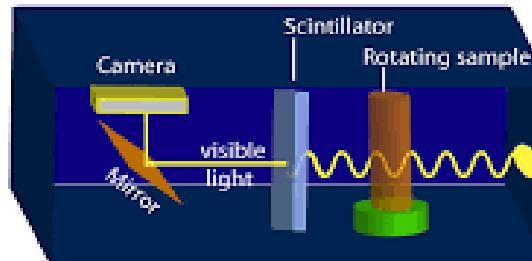
# FLASH Free Electron Laser XUV Radiation

## FLASH Free Electron Laser at DESY

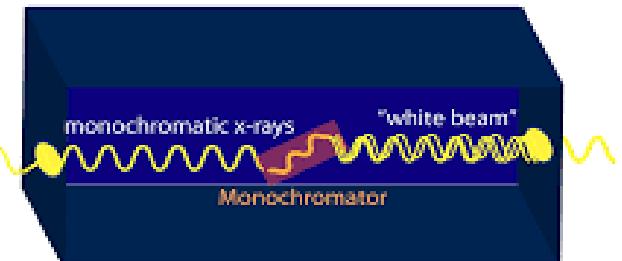


# FLASH Free Electron Laser XUV Radiation

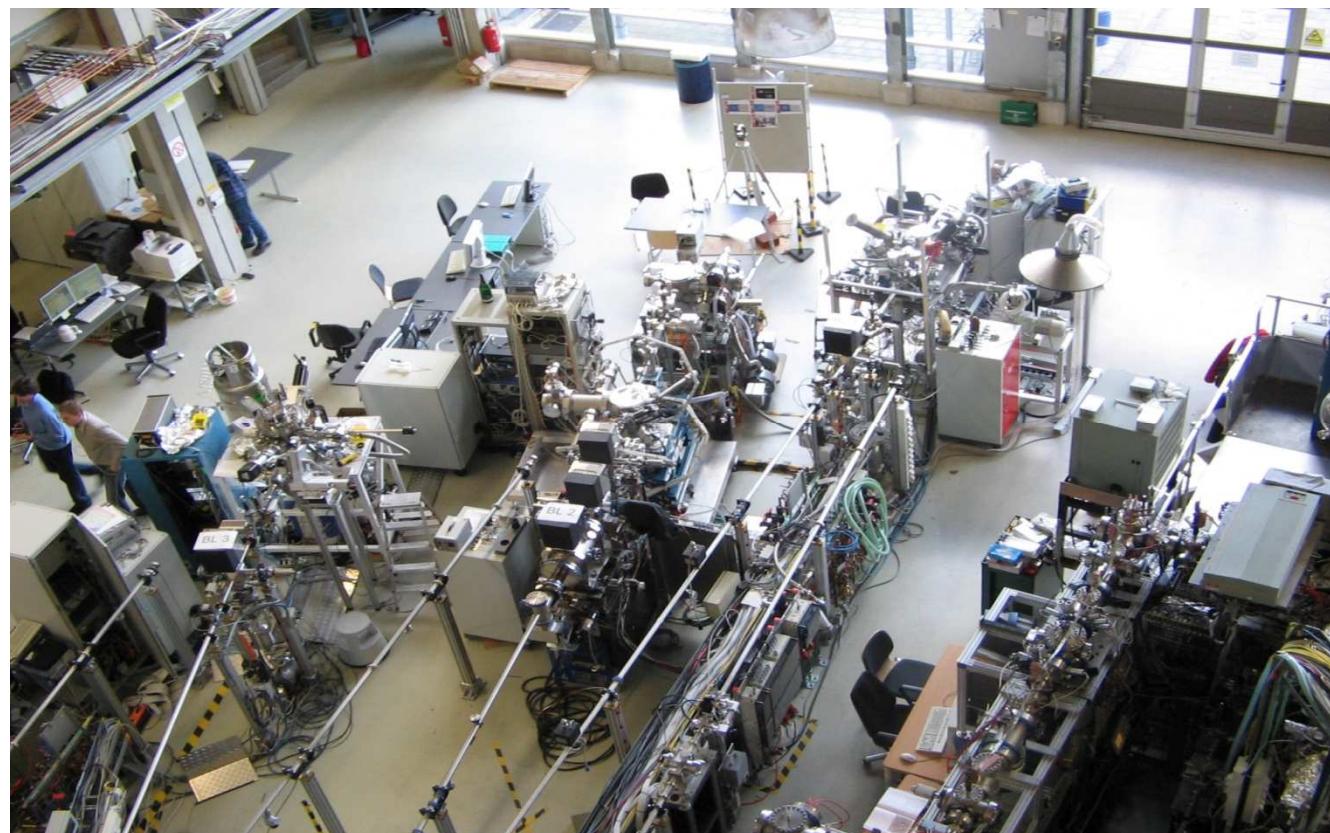
## FLASH Free Electron at DESY



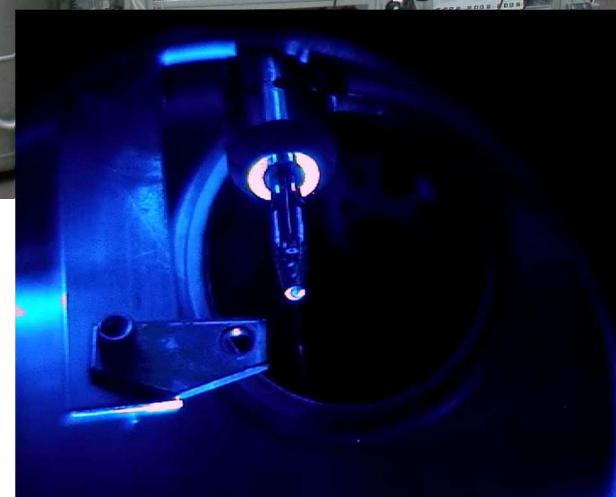
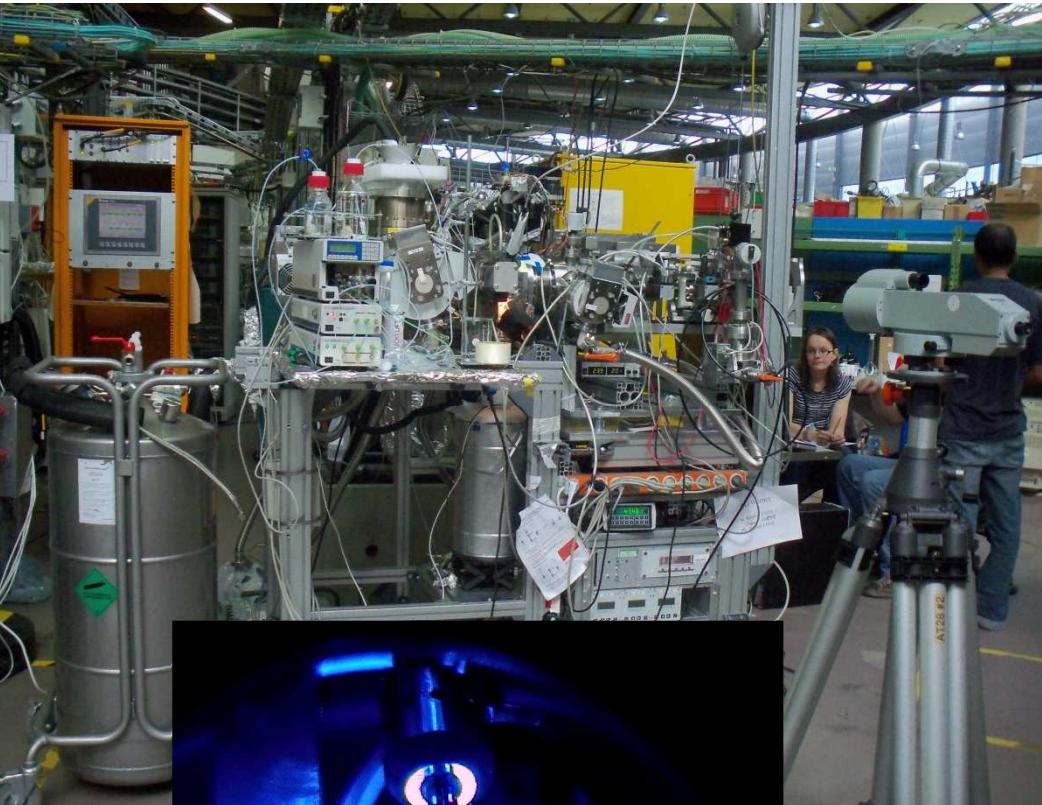
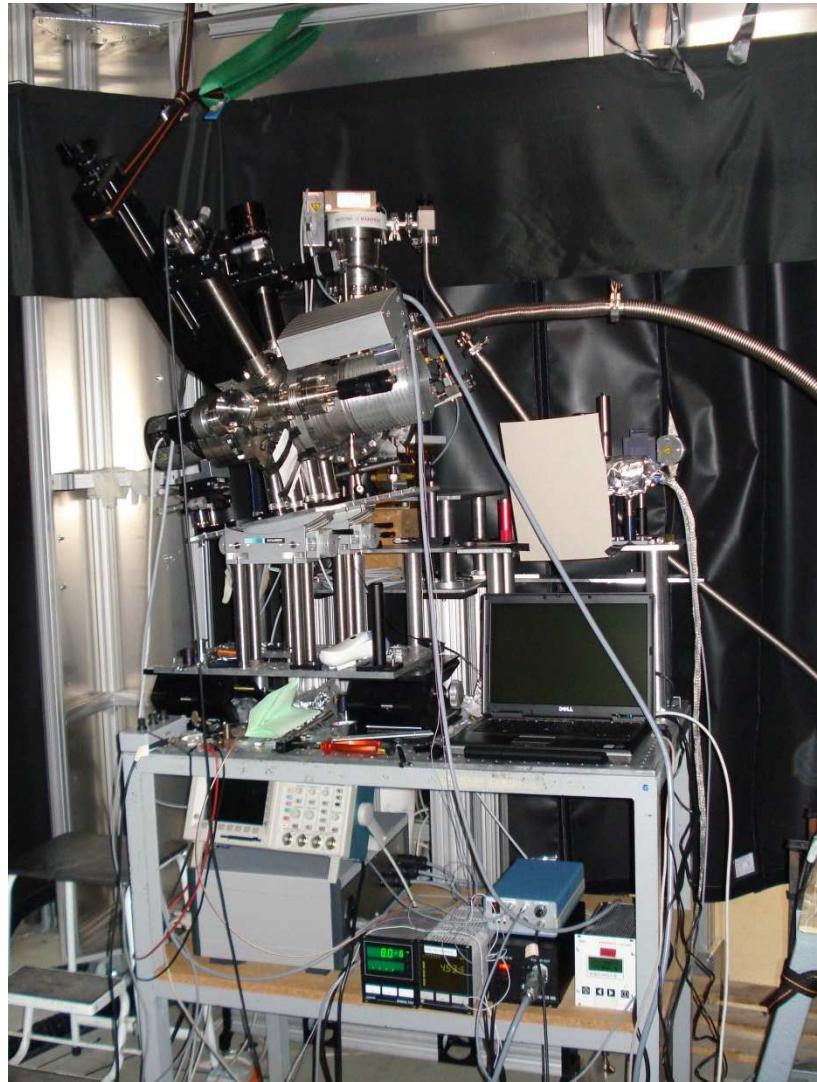
Experimental Hutch



Optics Hutch

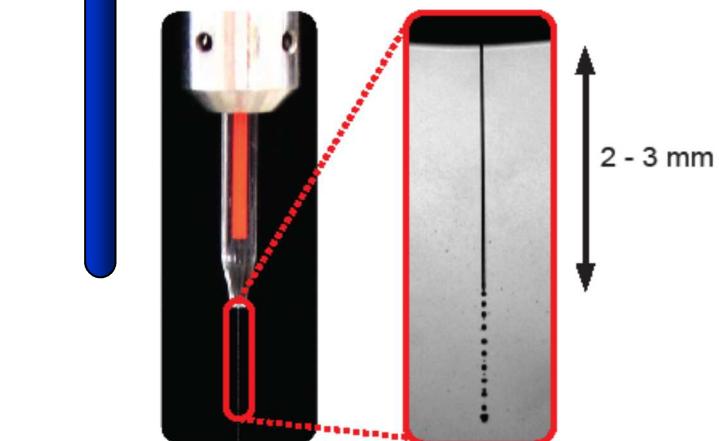
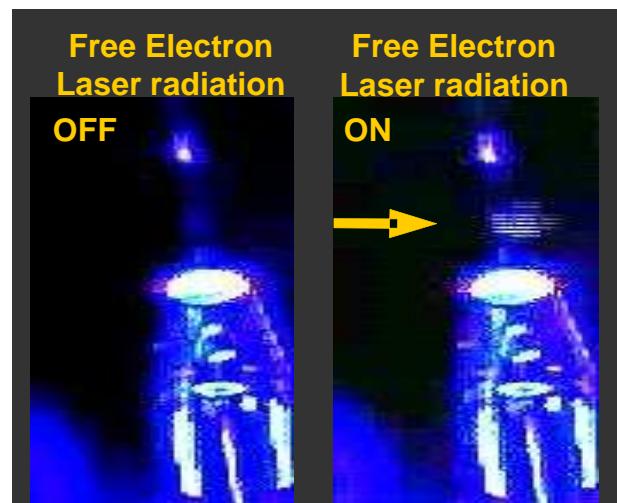
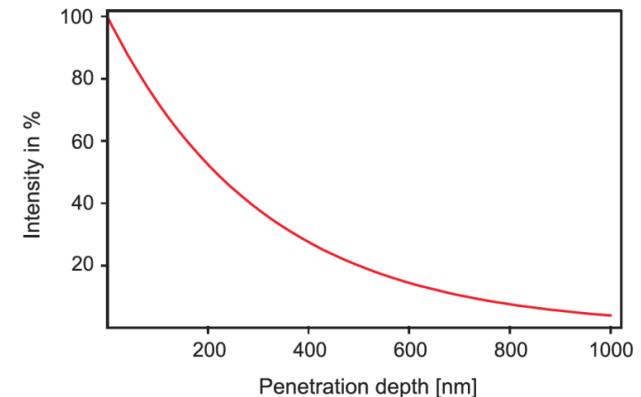
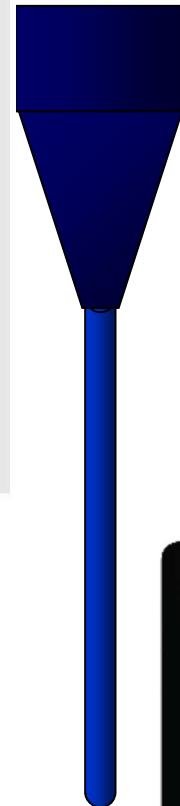
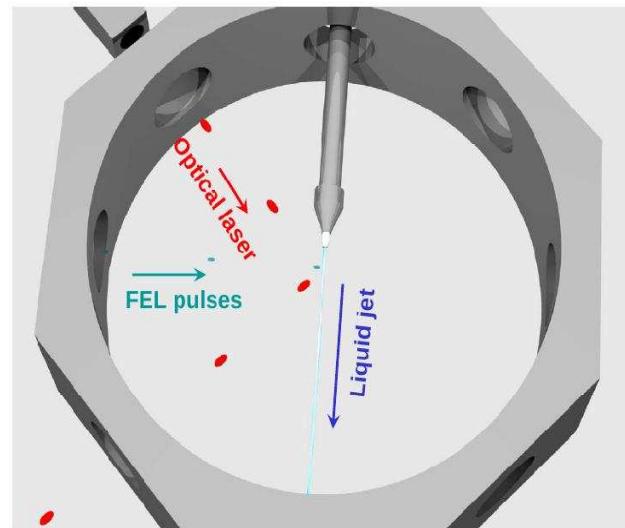


# Mixing Endstation at the FLASH Free Electron Laser: X-ray Diffraction and X-ray Spectroscopy



# Basics: Liquid Jets and Microchannel Devices

- Liquid is not stable under vacuum conditions
- X-ray radiation for static and time resolved experiments



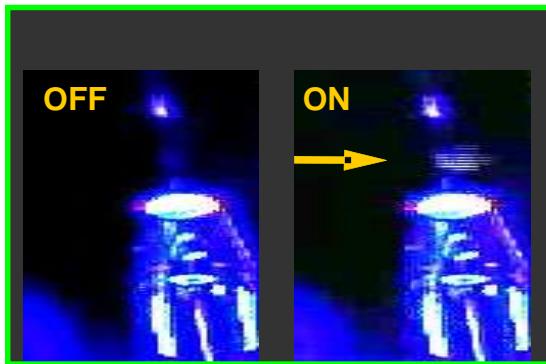
→ Penetration depth of 10 nm X-ray pulse in water bulk sensitiv!



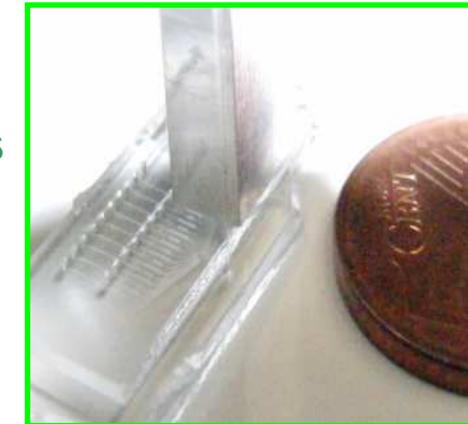
I. Rajkovic et al. Rev. Sci. Instr. 81, 045105 (2010); M. Faubel et al. Z. Phys. D, 269-277 (1988).



# Coupling of Jet to Microchannel Devices



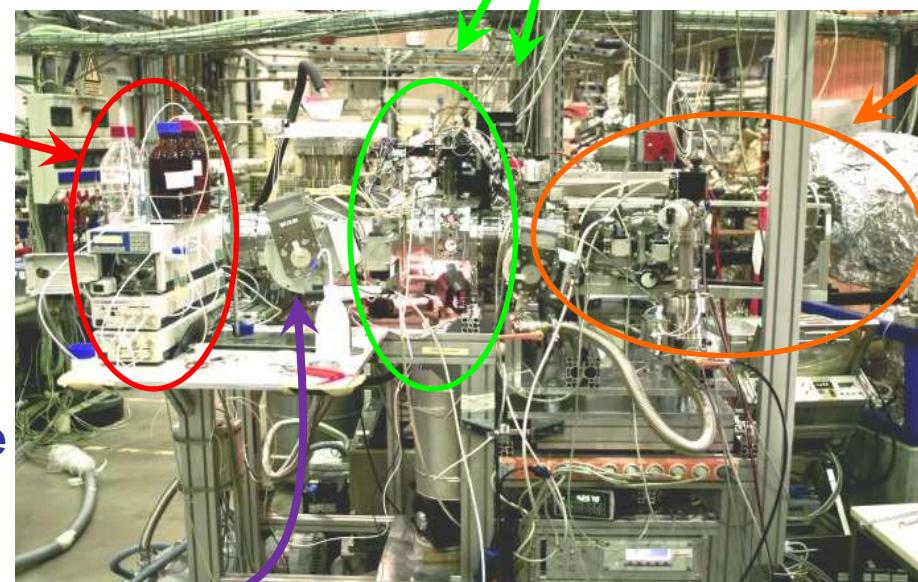
B) High throughput sample delivery:  
↳ liquid jet;  
microchannel devices



C) High pressure liquid chromatography pump system with autosampler



A) KB optics and optical components for pump/ probe experiments

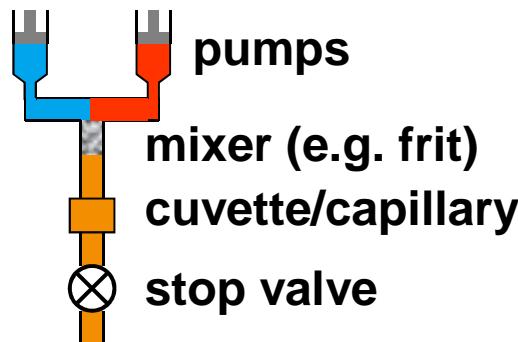


D) High resolution X-ray spectrometer / Diffraction unit

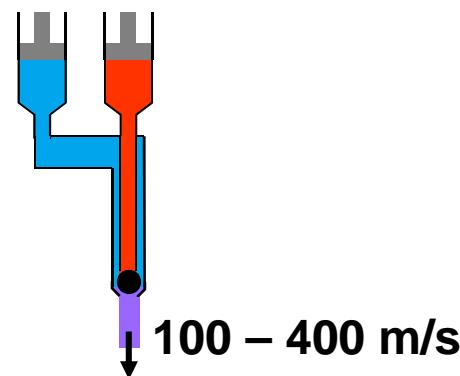


# Liquid Jets and Microchannel Devices

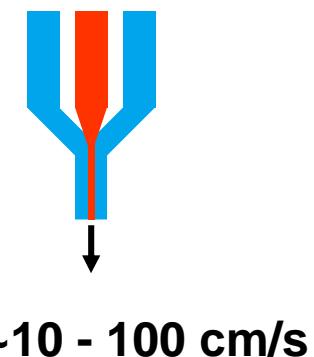
## Stopped-Flow (Turbulent Mixer)



## Continuous Flow, Turbulent



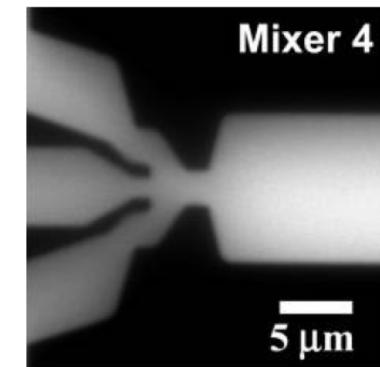
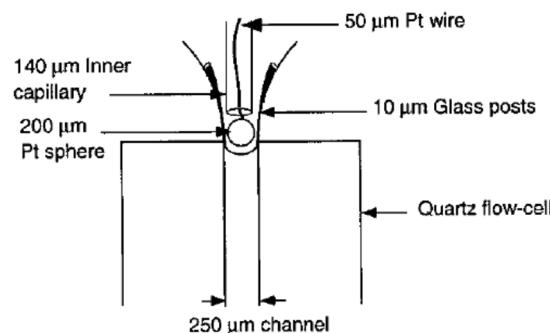
## Continuous Flow, Laminar



*Bio-Logic Inc.*



*Regenfuss, Clegg,...,  
Jovin, Rev. Sci Inst. (1985);  
Shastry, Luck, Roder,  
Biophys. J. (1998).*

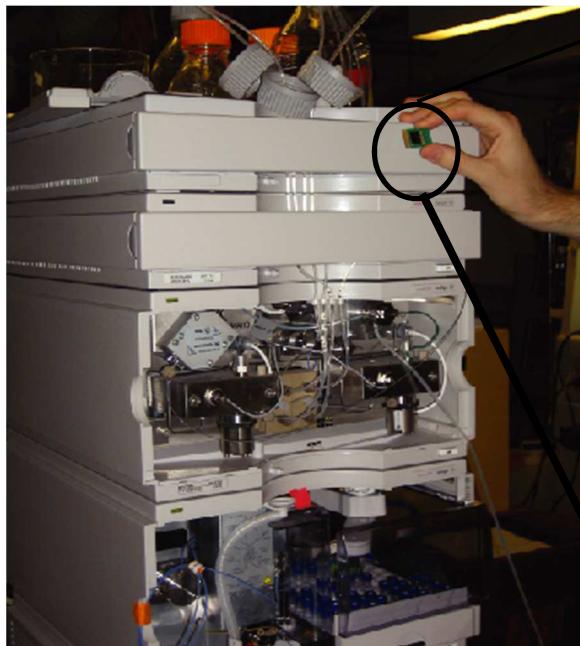


*Yao & Bakajin, Anal.  
Chem. (2007).*

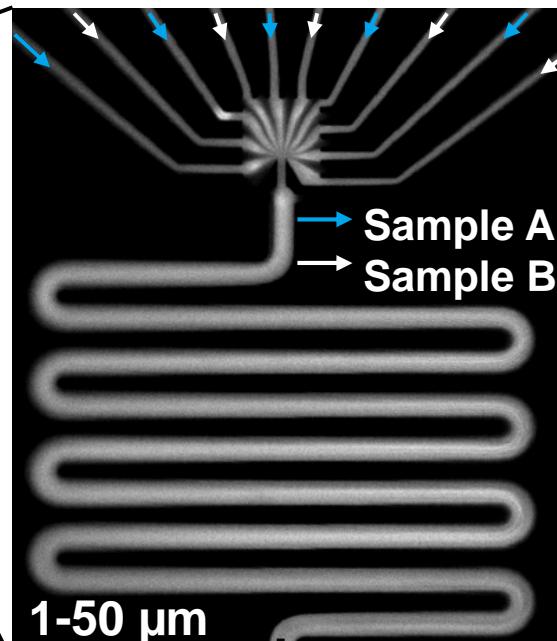
*courteously by T. Burg*



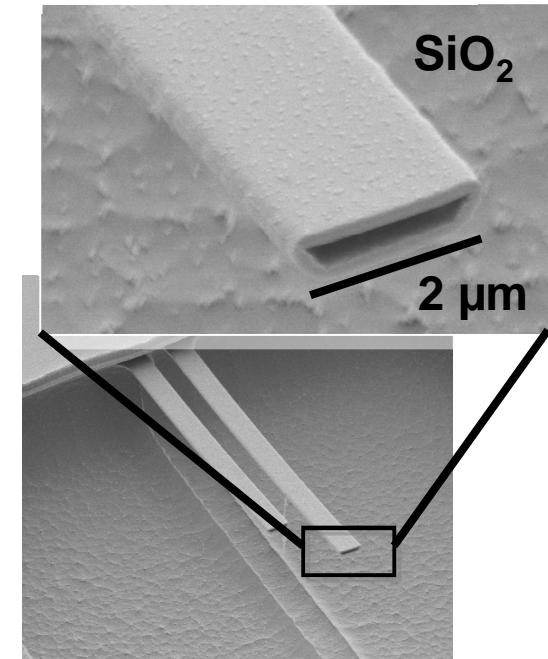
# Liquid Jets and Microchannel Devices



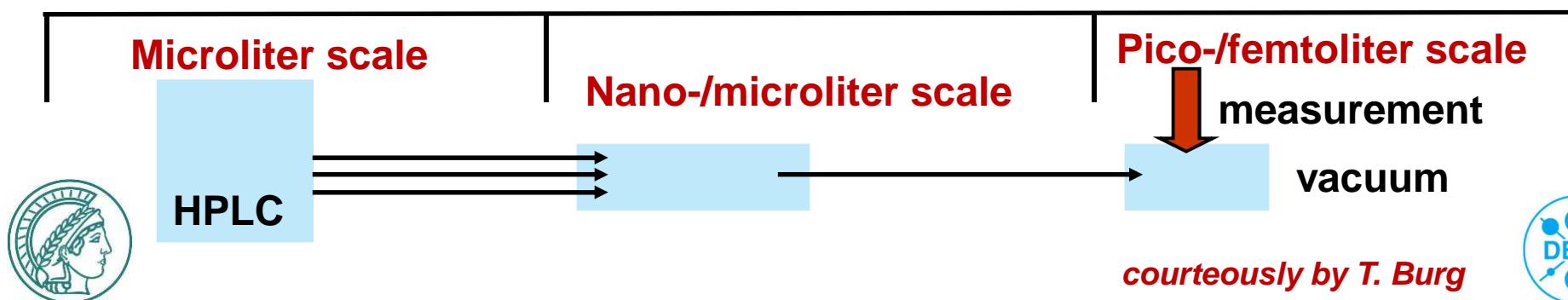
**Pumping System**  
 $10 \text{ nL/min} - 10 \mu\text{L/min}$



**Microfluidic Liquid Handling**  
Example: Fast mixing by hydrodynamic focusing



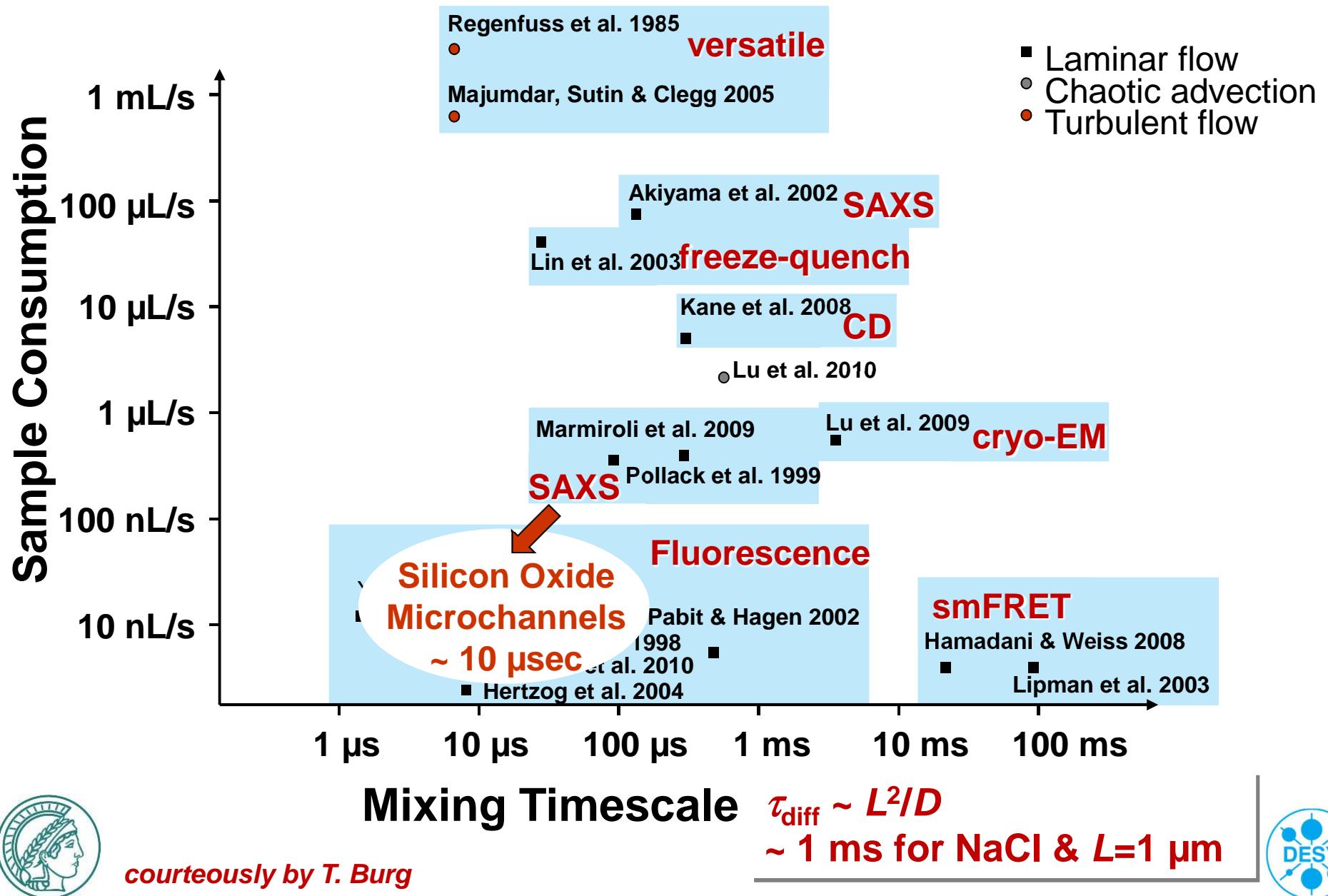
**Sample Delivery**  
Nanomechanical devices



courteously by T. Burg



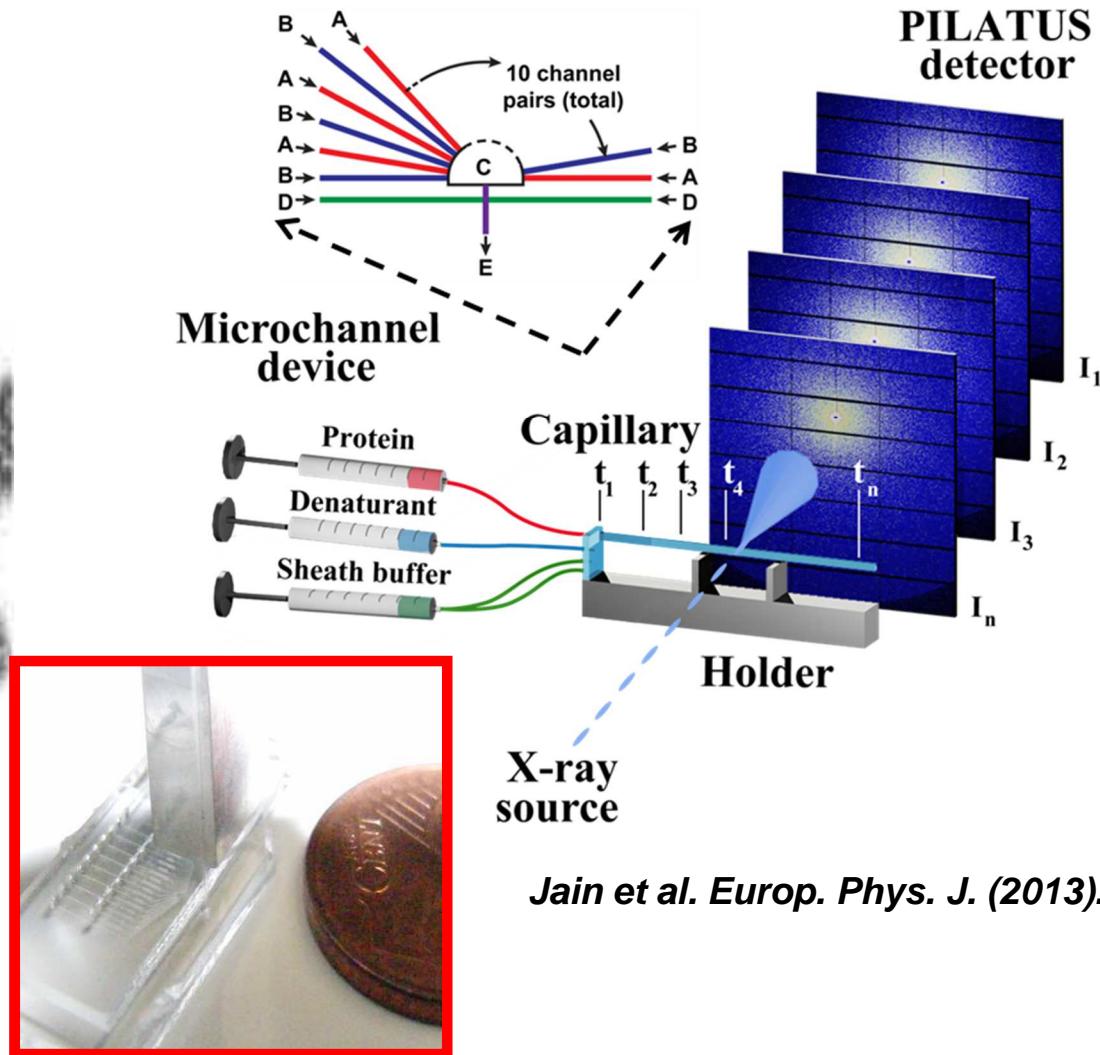
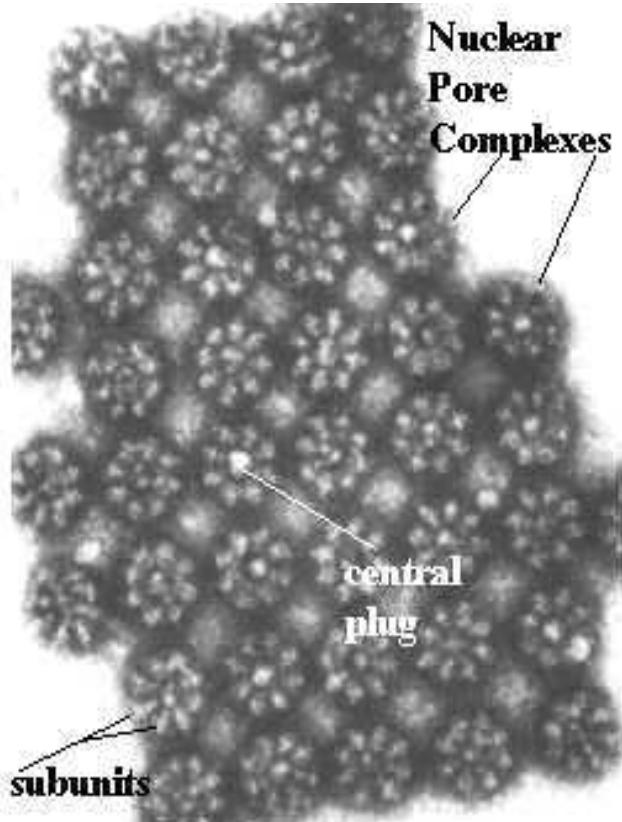
# Application of Liquid Mixing Technologies



courteously by T. Burg



# Back to the Sample: X-ray Investigations of the Pore Proteins' Dynamics



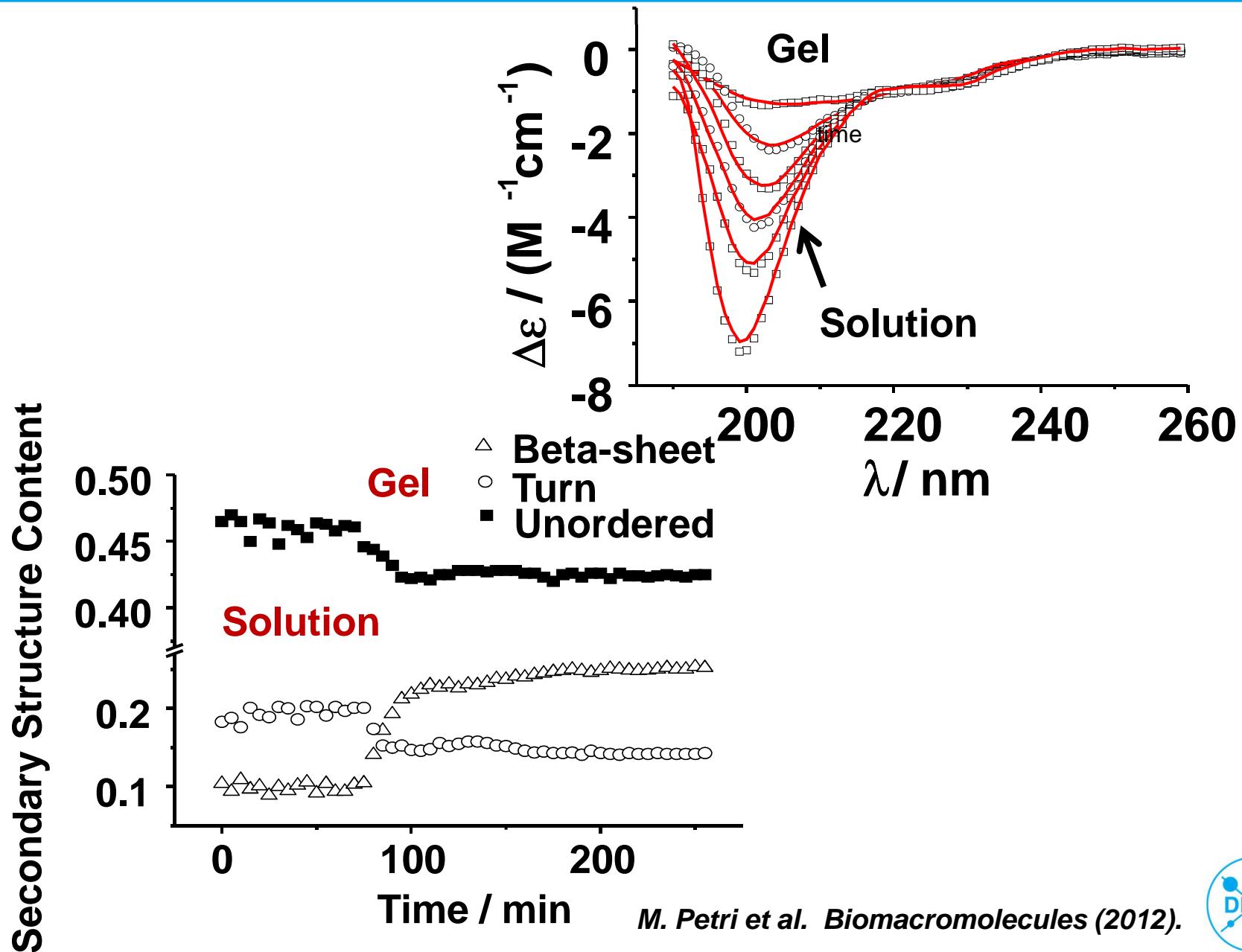
*Jain et al. Europ. Phys. J. (2013).*



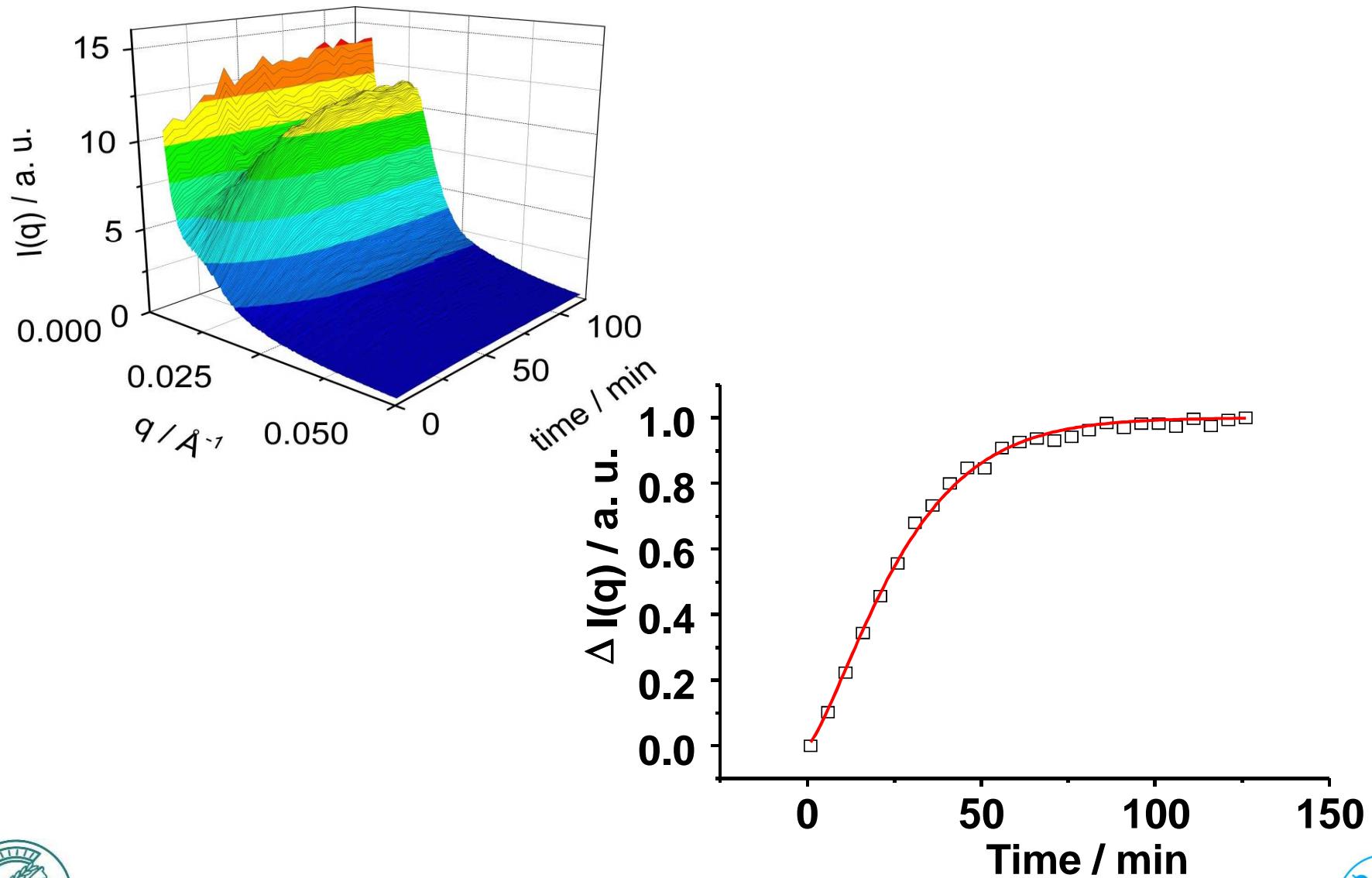
**Collaboration:**, S. Becker, C. Griesinger, T. Burg, MPIbpC, DESY



# Gelation Dynamics of Nuclear Pore Proteins



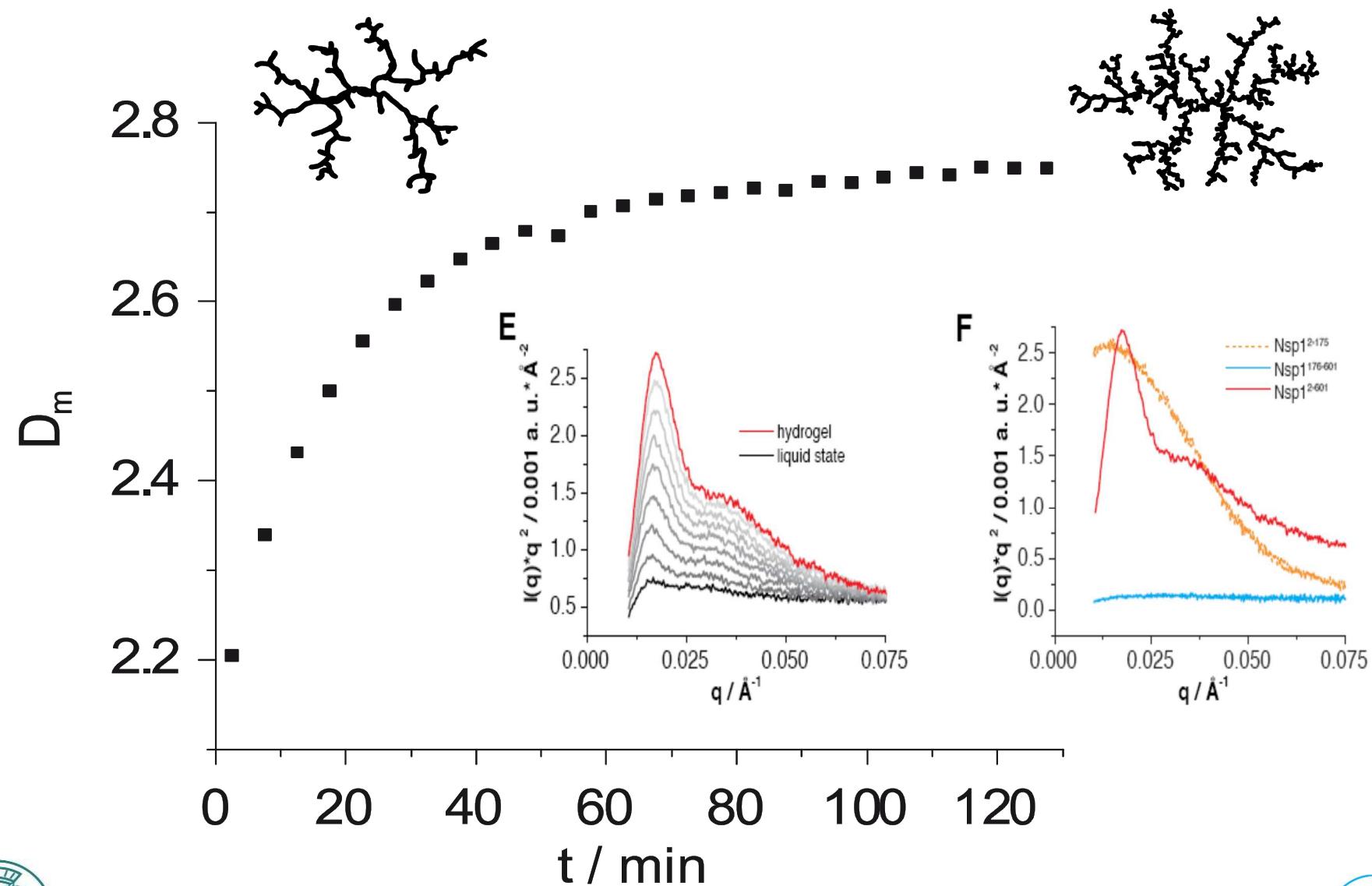
# Gelation Dynamics of Nuclear Pore Proteins



M. Petri et al. *Biomacromolecules* (2012).



# Fractal Dynamics of Nuclear Pore Proteins



M. Petri et al. *Biomacromolecules* (2012).



# Acknowledgement: DESY - Göttingen Campus

## Deutsches Elektronensynchrotron, Hamburg:

Dr. O. Bilani, O. Dreyer, Dr. L. Glaser, Dr. K. Idzik, Dr. K. Kubicek, D. Storozhuk, Dr. S. Thekku Veedu, Dr. Z. Yin;  
Dr. R. Boll, E. Saveljev, Dr. S. Bari, S. Dörner, K. Schubert, Dr. L. Schwob

## Göttingen Campus (Institute for X-ray Physics, Göttingen University, Max Planck Institute for Biophysical Chemistry):

G. Busse, L. Busse, P. Busse, Dr. R. Jain, Dr. D. Raiser, R. Patel, R. Schneider, Chemistry facility (J. Bienert, J. Schimpfhauser)

### DESY Campus



### IRP



### Göttingen Campus (GC)

### MPIbpC



*DFG-SFB 755 “Nanoscale Photonic Imaging”, DFG- SFB 1073 “Atomic Control of Energy Conversion Processes”, Helmholtz-viHZ “Multiscale Dynamics”, MPG-ASG, Max Planck Society, Helmholtz Society, Alexander von Humboldt Foundation, “Niedersachsen Vorab” – Volkswagen Foundation (AIMS Laboratory), Peter Paul Ewald Fellowship*

