DEPFET detectors for the Molecular Movie

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Max Planck Institute for Structure and Dynamics of Matter

mpsd

CFEL SCIENCE

Center for Free-Electron Laser Science

Centre for Free-Electron Laser Science

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

MAX-PLANCK-GESELLSCHAFT

- Condensed Matter Department (Prof. Andrea Cavalleri)
- Atomic Resolution Department (Prof. R. J. Dwayne Miller)
- Division 3
- Division 4
- Division 5 (Theory)

mpsd
Max-Planck-Institut für
Struktur und Dynamik der Materie

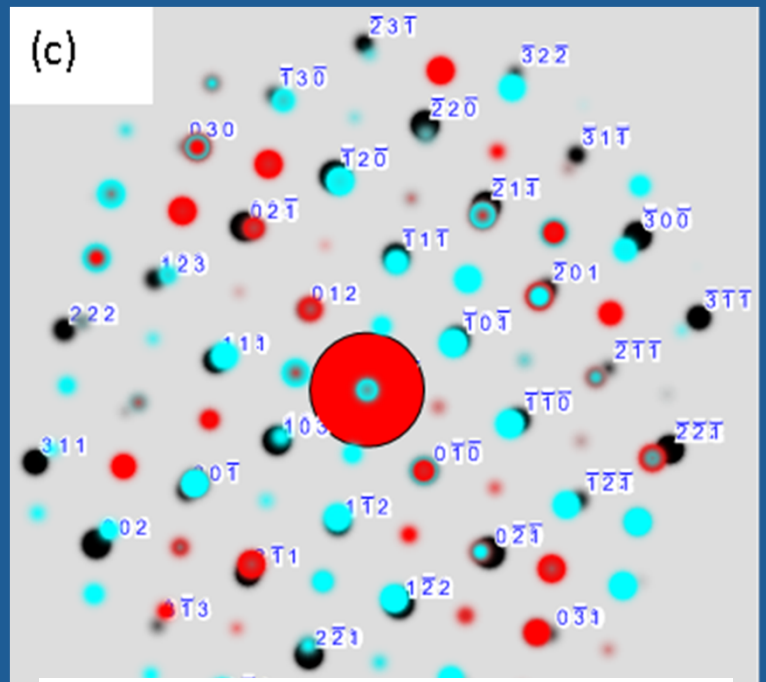
Feb. 2013

rchitekten

Electron diffraction

The wave-particle duality of particle beams

- We exploit the wave nature of the electron
- Need to detect electrons
  - direct-hit detector
  - in-direct hit detector



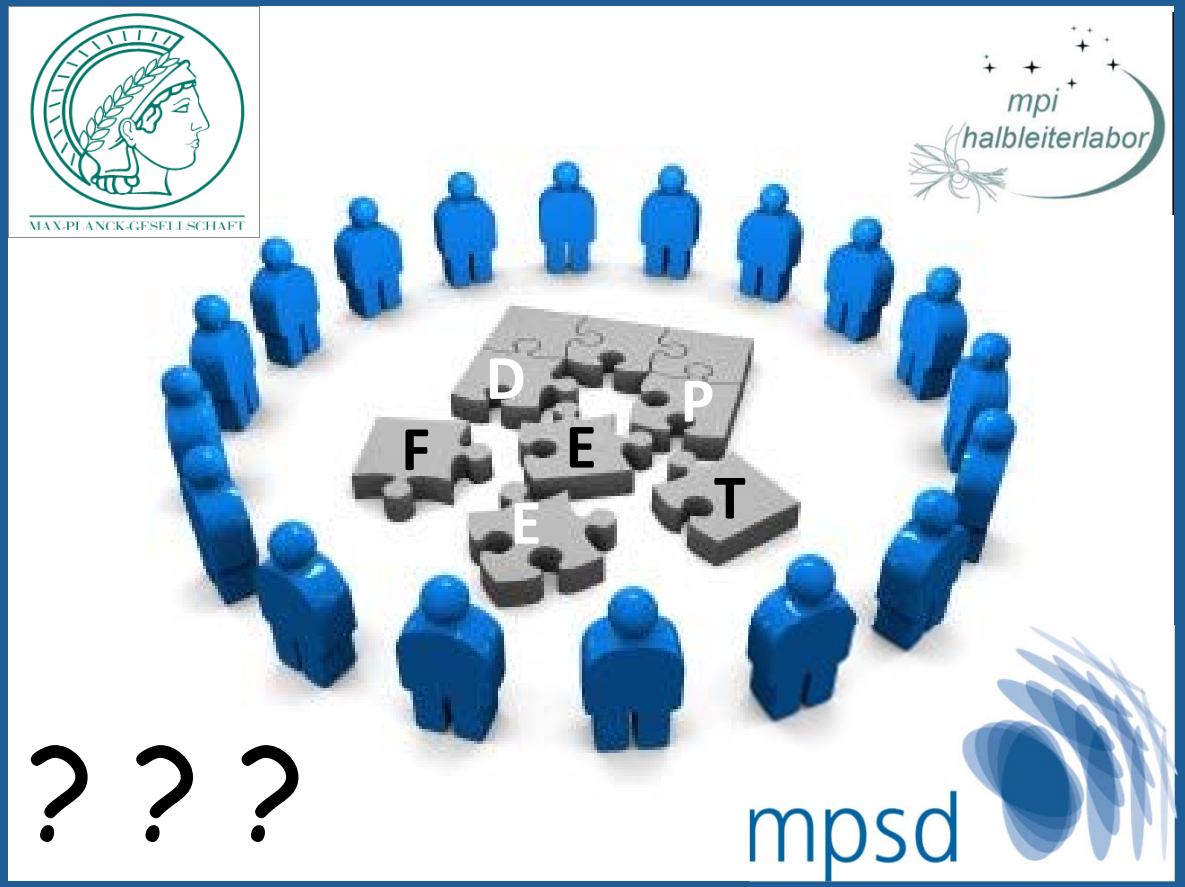
Diffraction out to less than 0.2Å!

$$\lambda_{dB} = \frac{hc}{\sqrt{2E_{kin}E_0 + E_{kin}^{\ 2}}} < 0.1\ \dot{A}$$

- 0.1 A corresponds to 100 keV X-rays

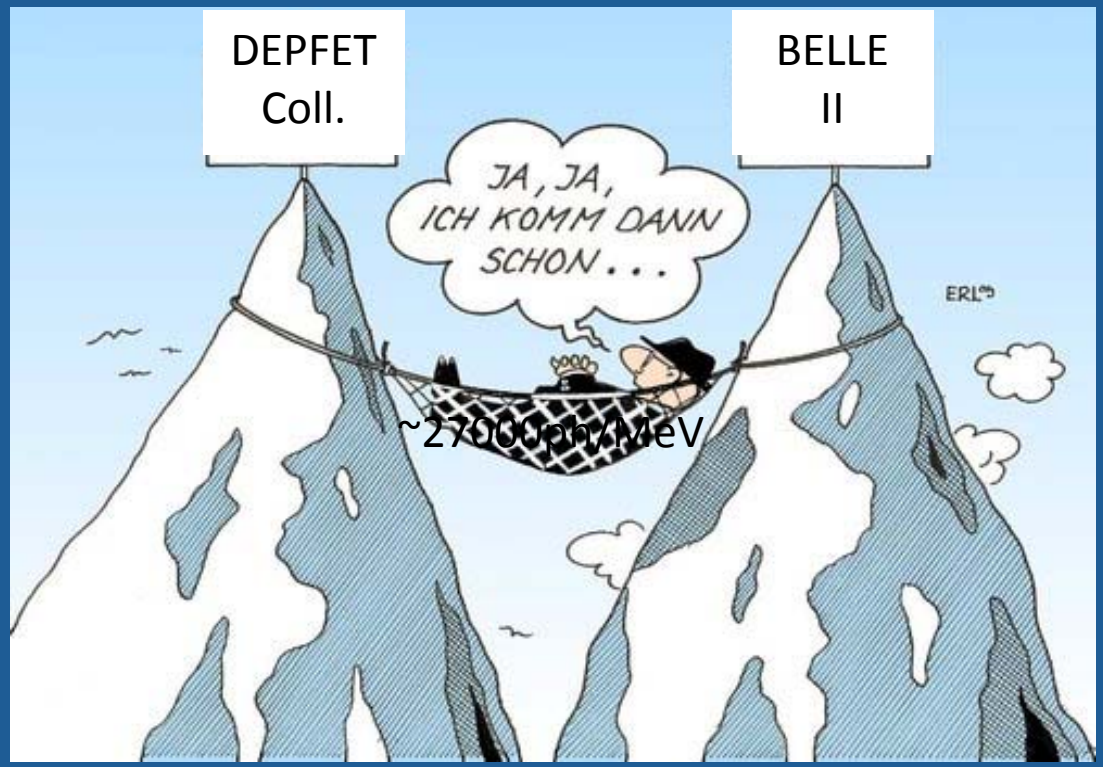
We seek for help!

Join the team…!



We seek for help!

Join the team…!



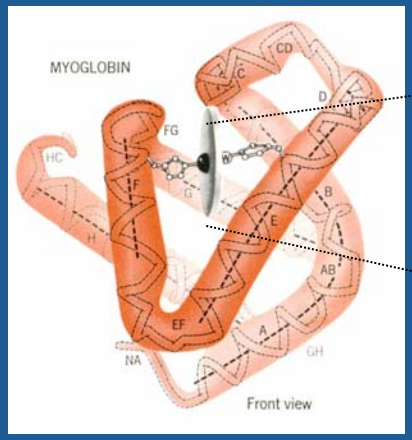
- Want to use existing technology whenever possible
- Presently, it seems this plan could work…….

Outline

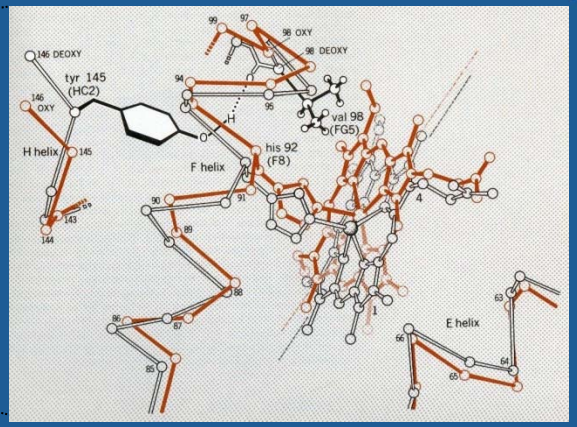
- Motivation & Introduction
  - Molecular Movie
  - How to record it
  - Time scales
- Our experimental setups
  - Diffraction
  - Imaging
  - Requirements for detectors
- Detector concept (present status)

The "Molecular Dance"

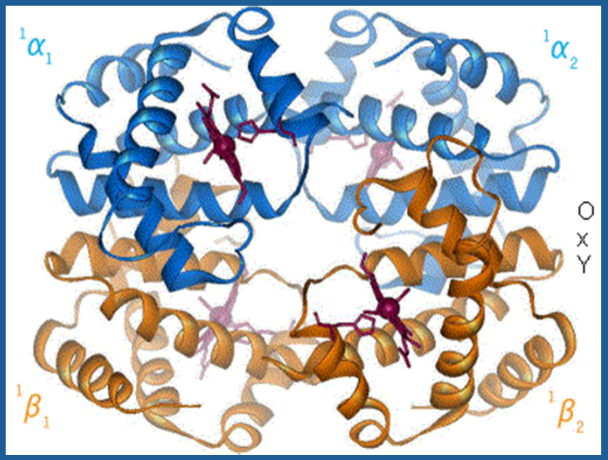
Functionally important protein motions

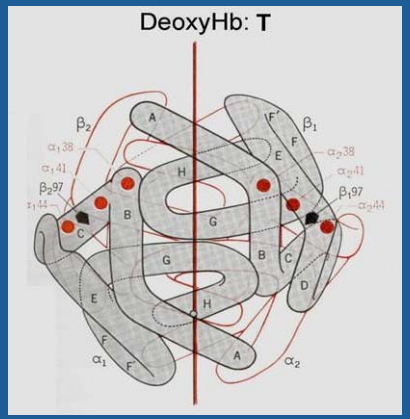


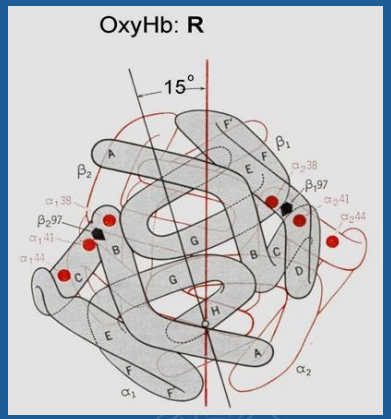
Myoglobin (single subunit)



Hemoglobin





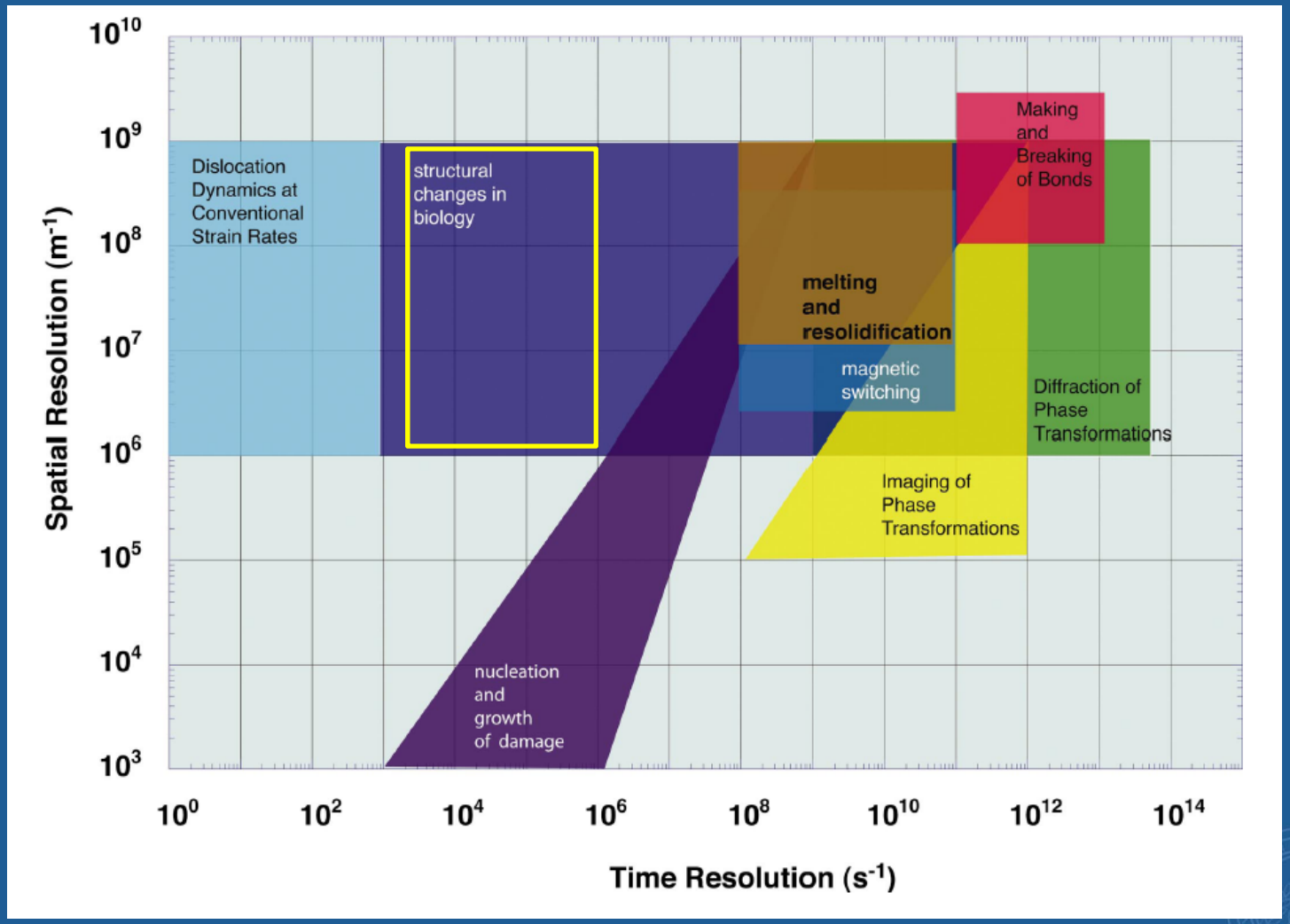


What is the mechanism of correlated atomic displacements?

Structure - Function Correlation ⇒ resolve atomic motions on timescales faster than the onset of diffusive motions…..observe force correlations

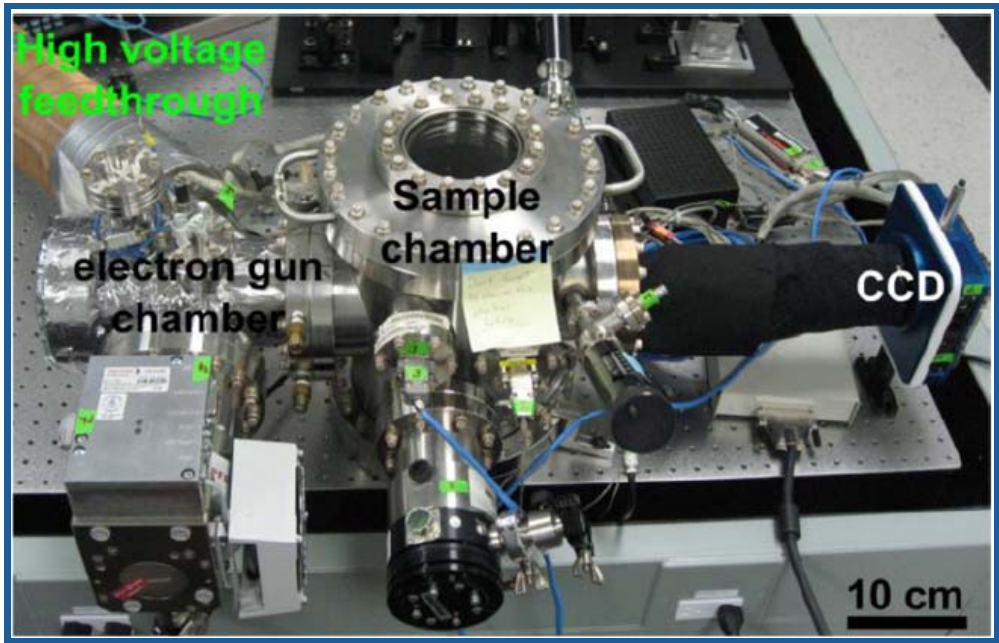
Static & Dynamic

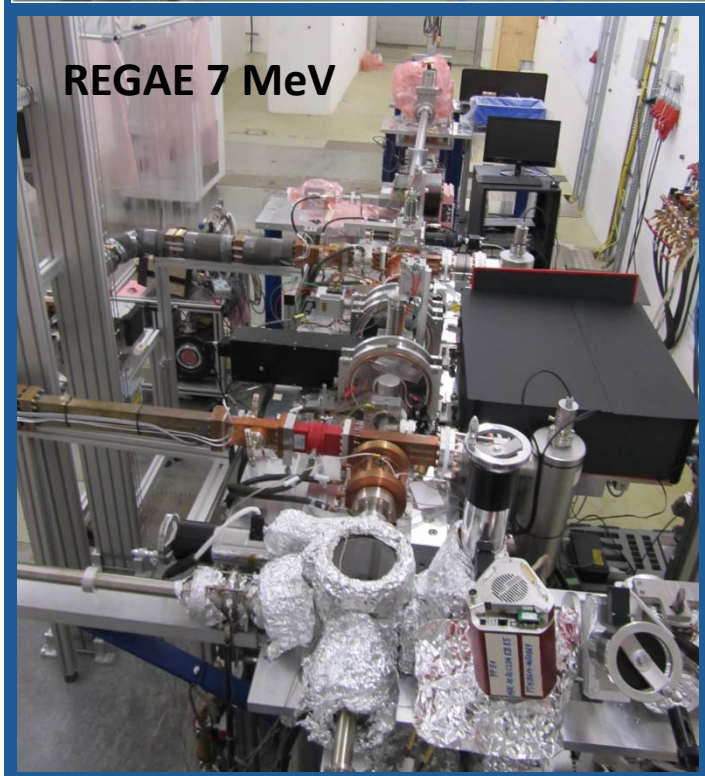
Time scales



Experiments

Large scale



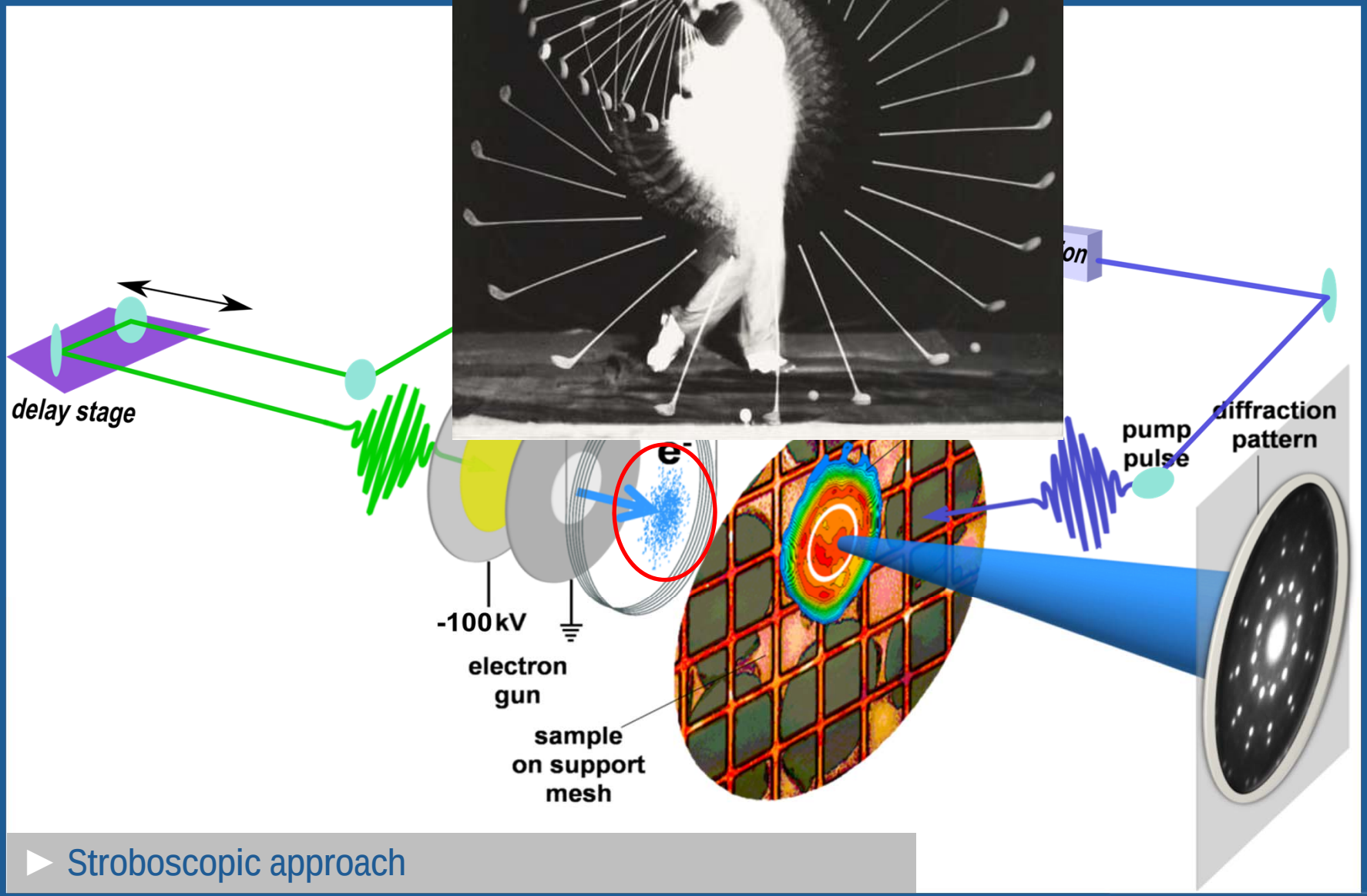


Experiments

Small scale & with e-

- keV FED – solid state
- keV FED – liquid phase
- keV FED – gas phase
- REGAE Diffraction
- keV time-resolved TEM
- REGAE Dynamic RTEM

Femto



► Stroboscopic approach

γ versus e-

No winner

FED

DC compact e-guns
200-300 fs
10^3-10^4 e/pulse (10^8-10^9 ph/pulse)

New DC e-gun designs
100-300 fs
10^4-10^5 e/pulse (10^9-10^{10} ph/pulse)

RF-compression e-guns
~100 fs (300-400 fs)
10^5-10^6 ph/pulse (10^{10}-10^{11} ph/pulse)

Relativistic e-guns (MeV)
~100 fs
10^6-10^8 ph/pulse (10^{10}-10^{12} ph/pulse)

fs X-ray

SLS—3rd generation LS, slicing
200 fs
200 ph/pulse

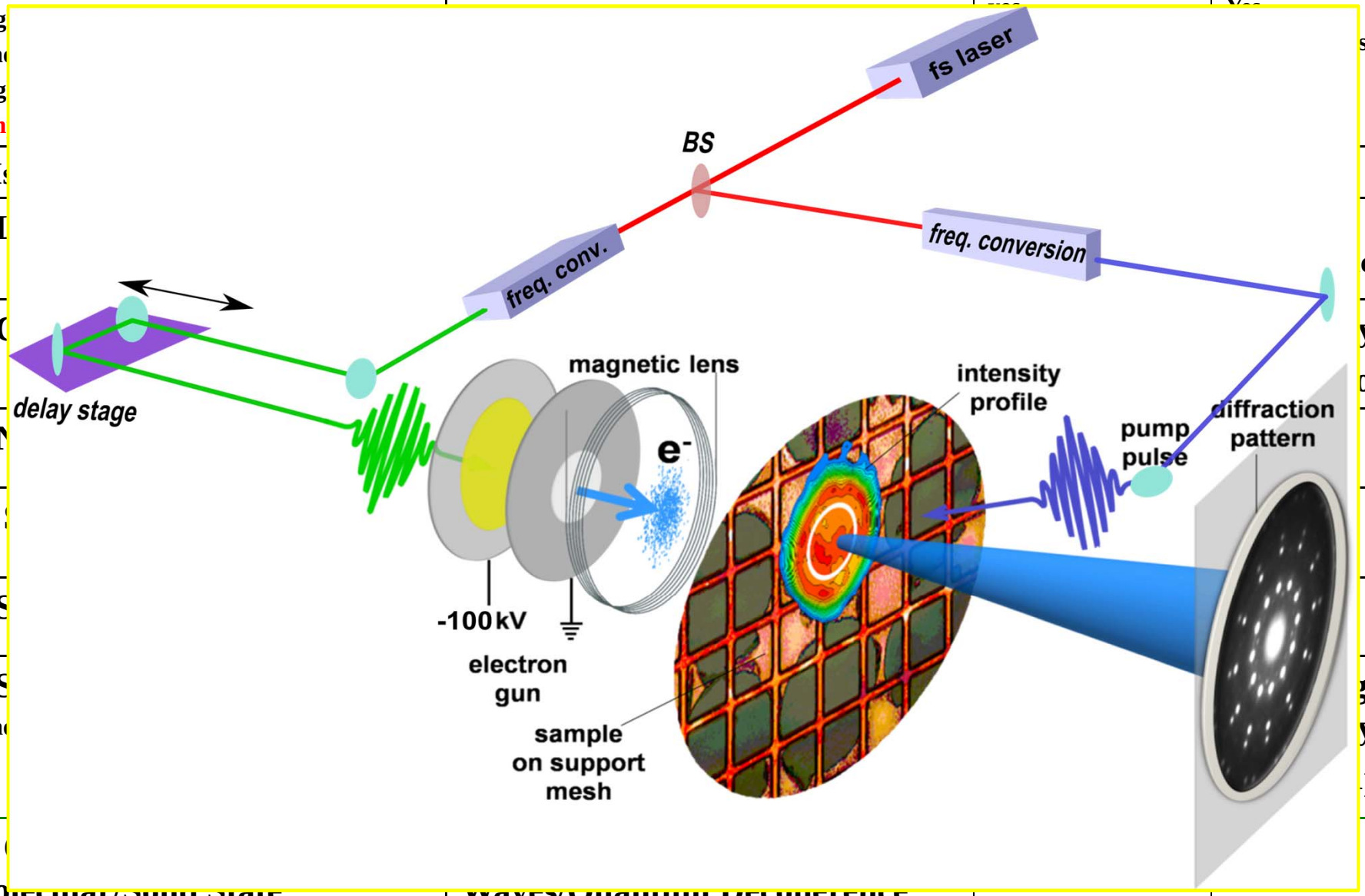
Plasma sources
~100 fs
10^3 ph/pulse @ 1 kHz (5 mJ)
$10^{4\text{-}5}$ ph/pulse @ 10 Hz (100 mJ)

SPPS, LCLS 2003-2009
~100 fs (time stamping/single shot)
10^6 ph/pulse

4th generation light sources.
sub-100 fs (200 fs, timing jitter)
10^{12} ph/pulse (LCLS) **2009 -**

X-FEL/REGAE COMPARISON

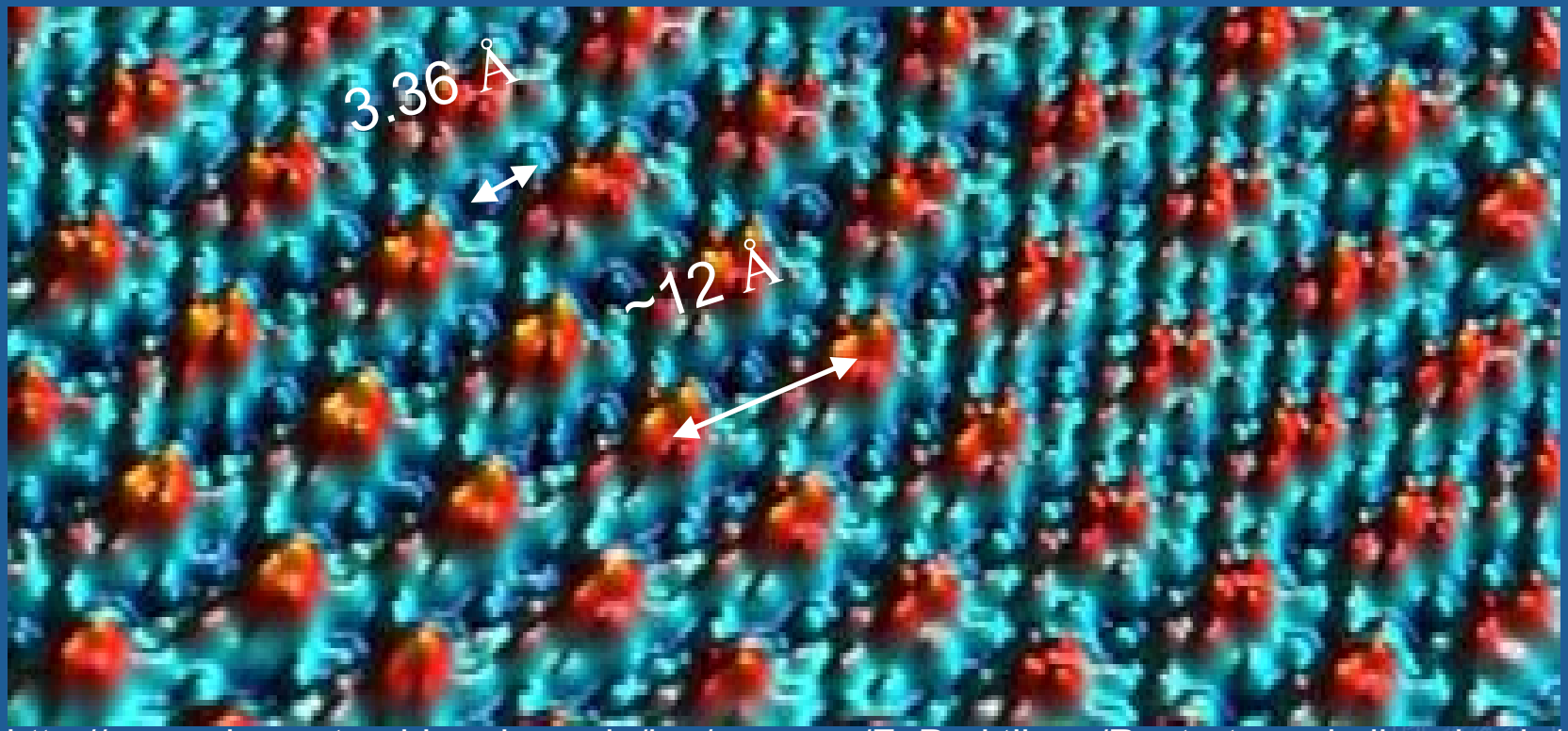
EXPERIMENT	SCIENTIFIC CASE	X-FEL/LCLS	REGAE
1. Molecular Movie Sing Time Sing Sam	**Direct Obs. of Transition States**		ss)
2. I			
3. I			cs
4. C			y ol.
5. N			
6.			
7. S			
8. S Time			gh y ps
9. Molecular/Solid State	Waves/Quantum Decoherence		



Example for UED

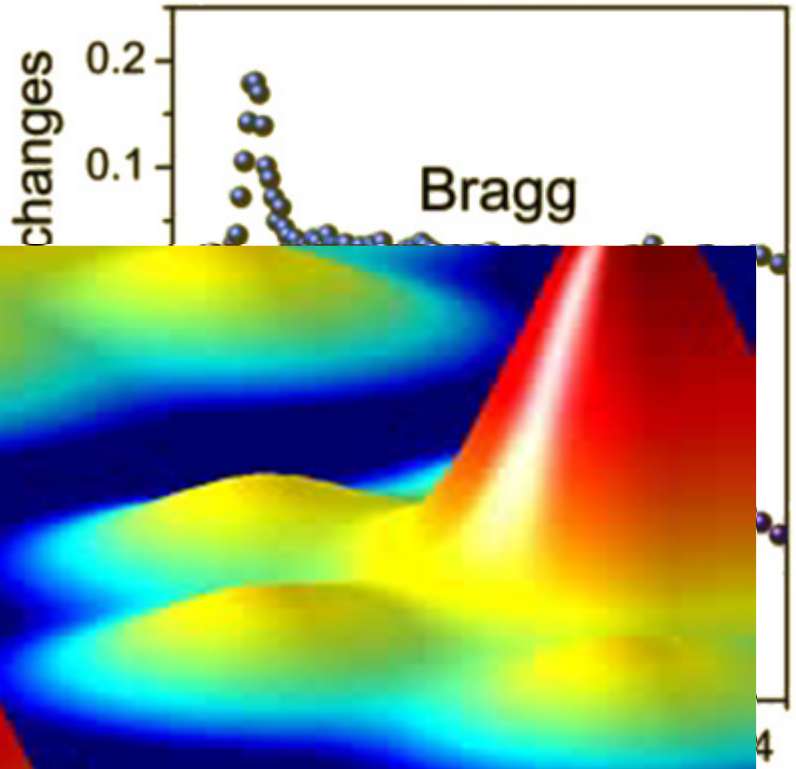
Superlattices in 2-D systems

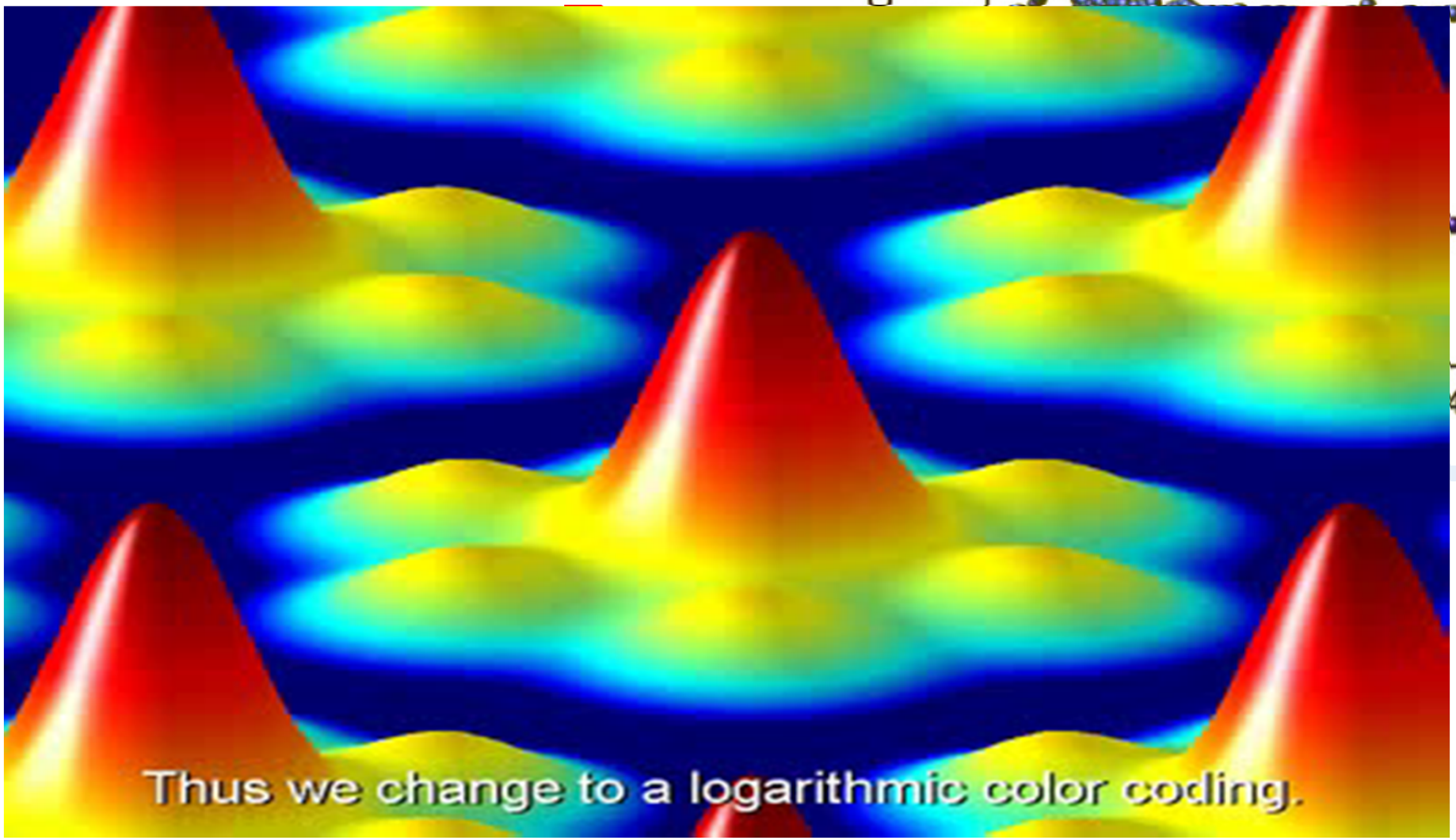
Charge density waves (CDW), definition:
A possible ground state of a metal in which the electron charge density is sinusoidally modulated in space.



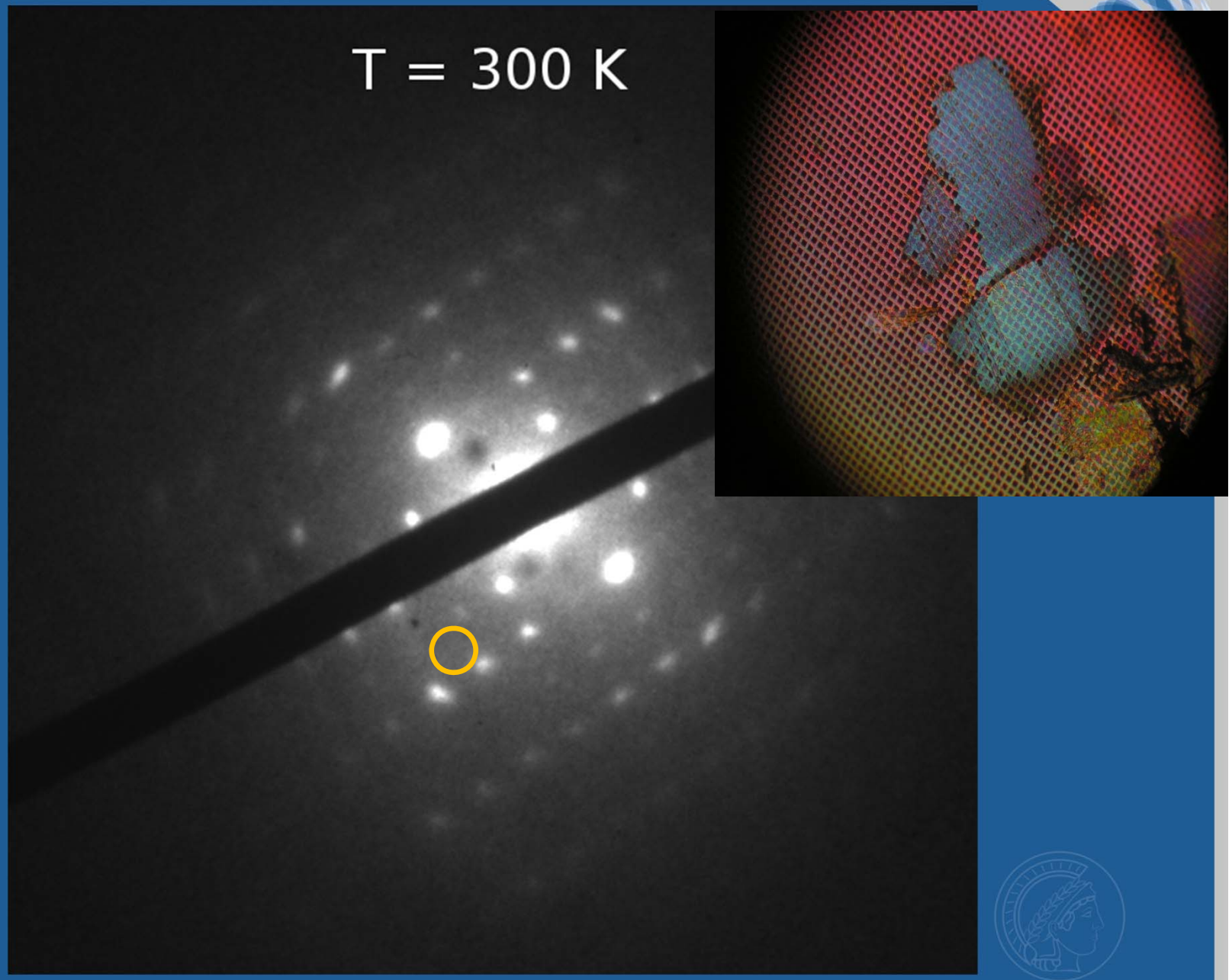
http://www.physnet.uni-hamburg.de/iap/group_g/F_Praktikum/Rastertunnelmikroskopie/

Direct Observa
Structural



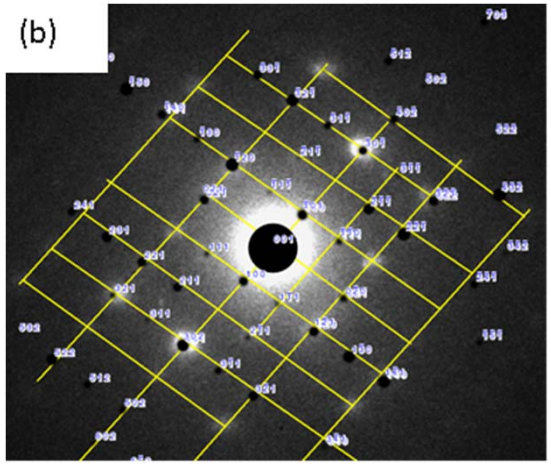


Eicherberger, Sciaini et al, Nature 2010

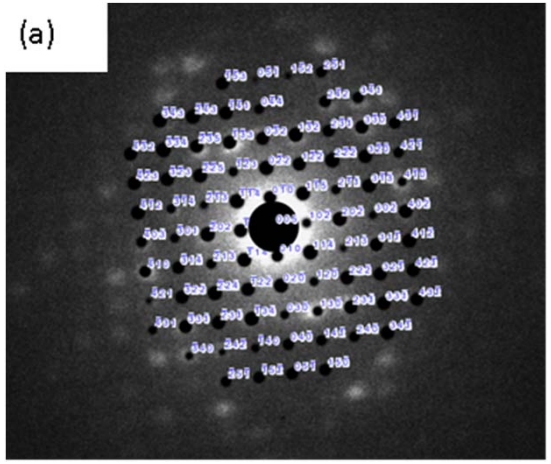

T = 300 K

Static Diffraction

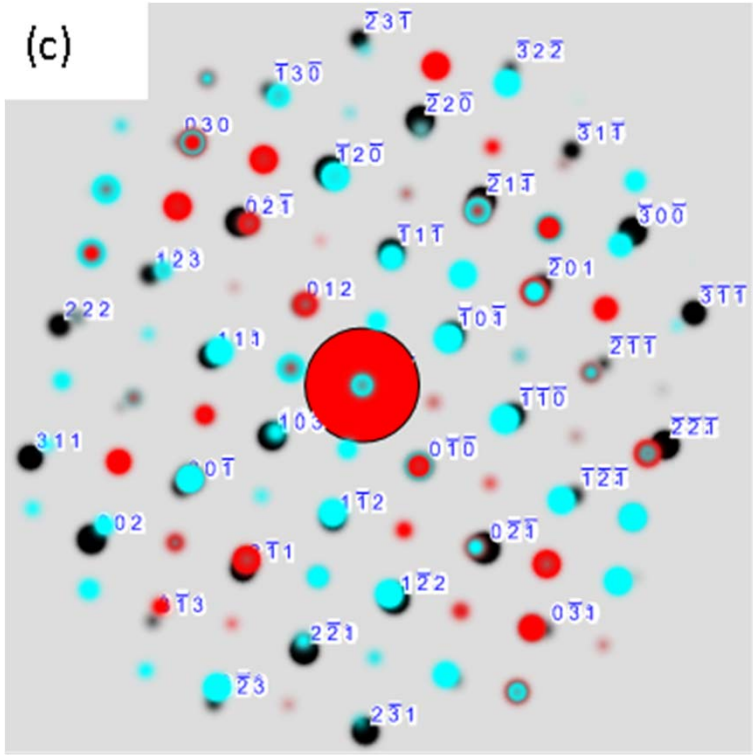
Rm Diffraction



200K Diffraction



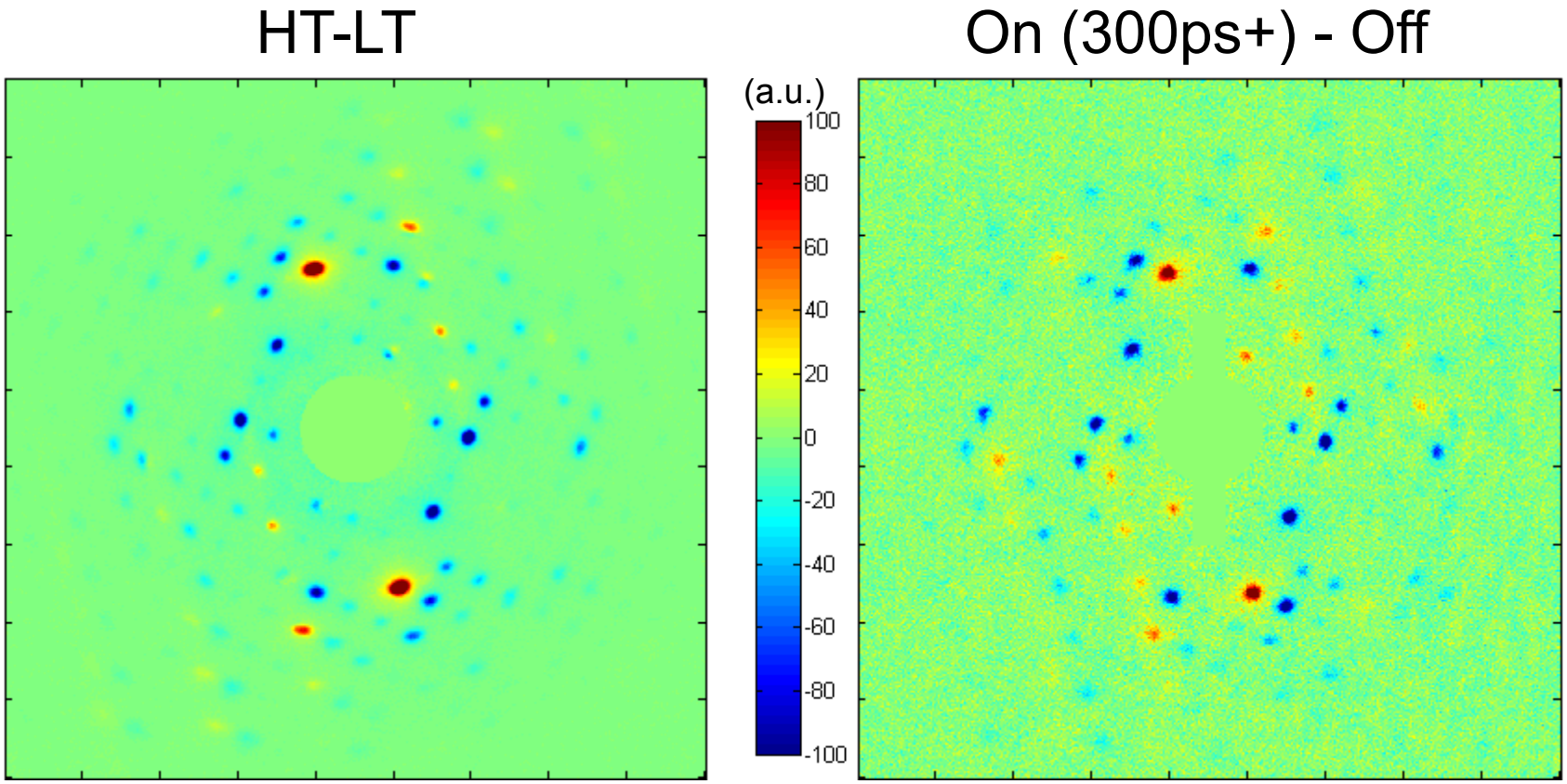
Difference (rm-200K)



Hundreds of diffraction orders for structure refinement

Diffraction out to less than 0.2Å!

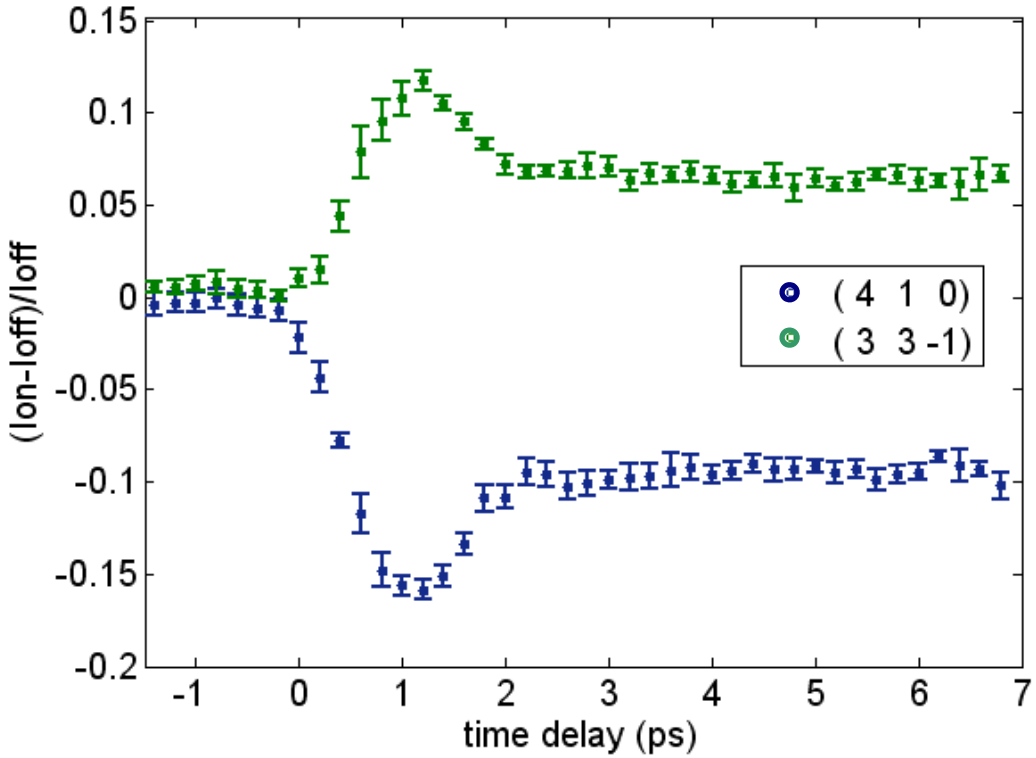
Comparison of “difference ediff pattern” HT-LT vs. optically induced

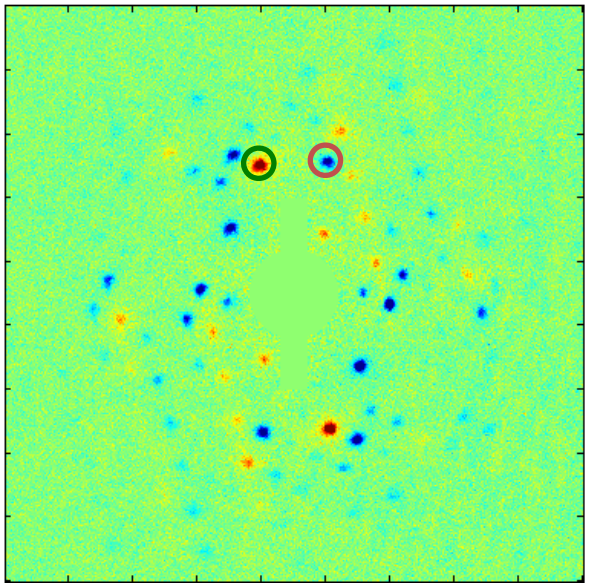


note: qualitatively similar for the majority of peaks

FED results – fs ultrafast dynamics, Observation of Transient State

Typical time-resolved change in diffraction intensity – early dynamics – shared (qualitatively) by several peaks (~50%)

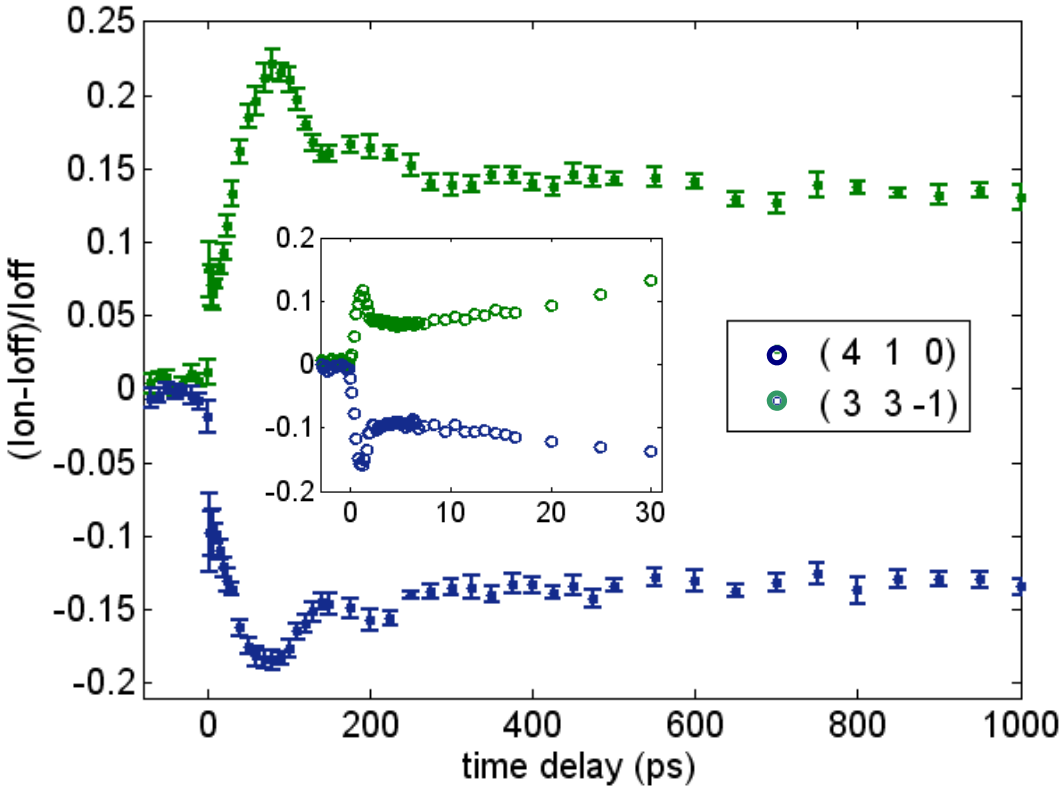


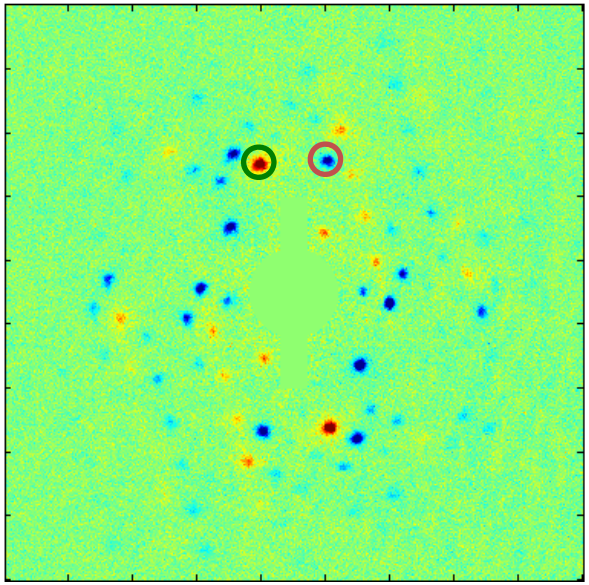


note: this ps rise/drop varies from 20 to -35% for different peaks

FED results – ps/ns dynamics
Evidence for transient state

Typical time-resolved change in diffraction intensity – long dynamics – shared (qualitatively) by several peaks (~50%):



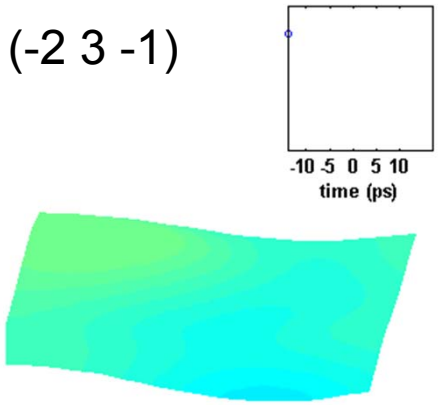


Clear observation of a cooperative intermediate state

…..**"Hidden Phase"**

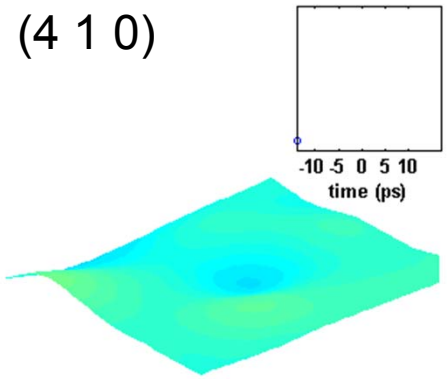
Movies (live…)

(-2 3 -1)



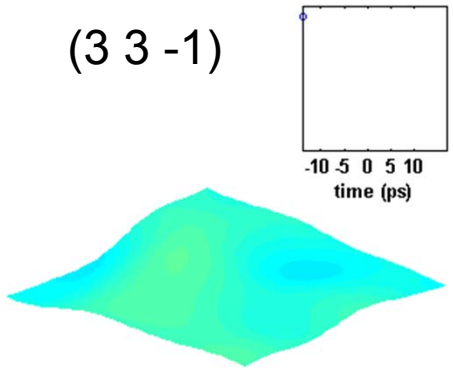
-14000 fs

(4 1 0)

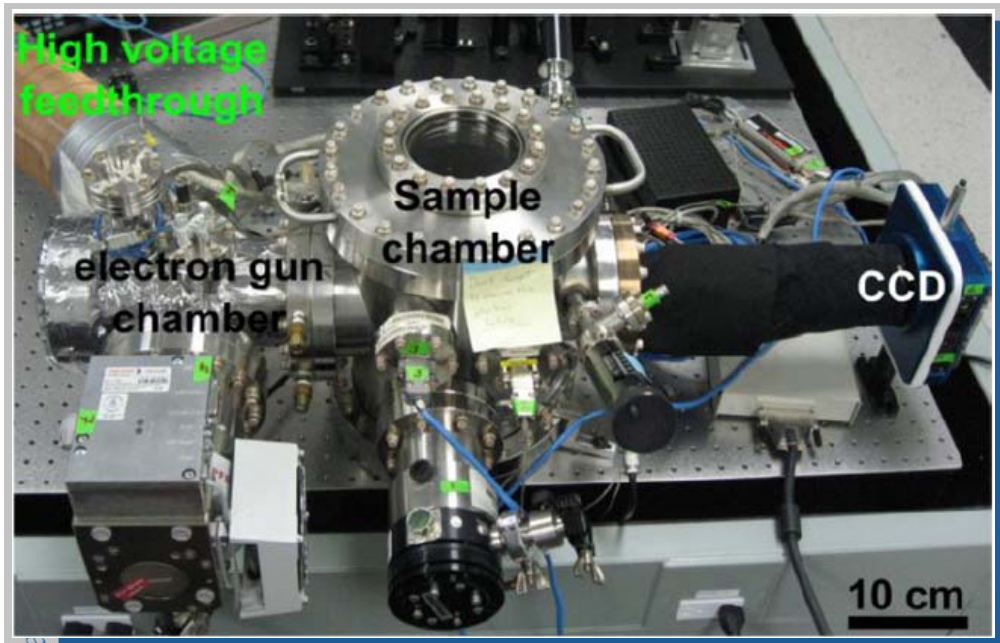


-14000 fs

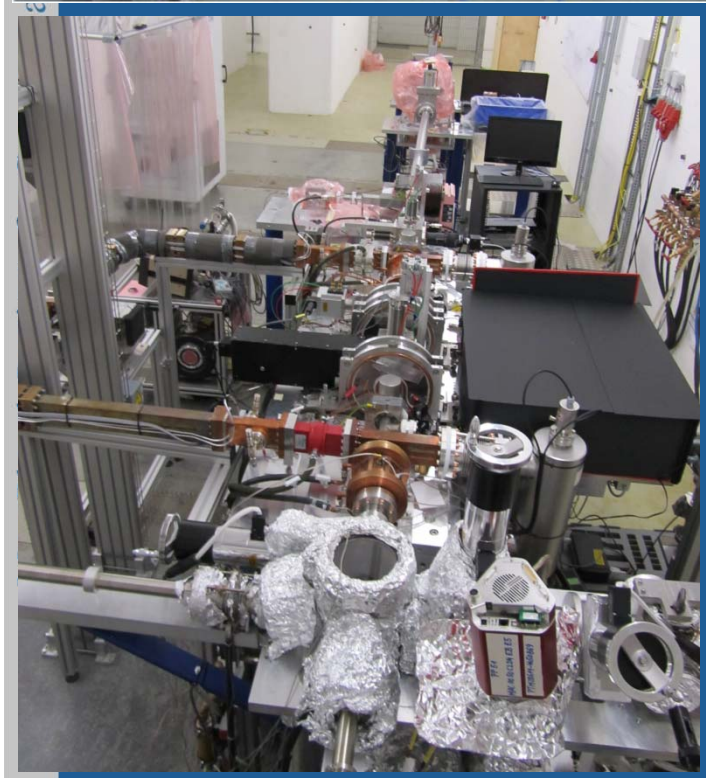
(3 3 -1)



-14000 fs



psd



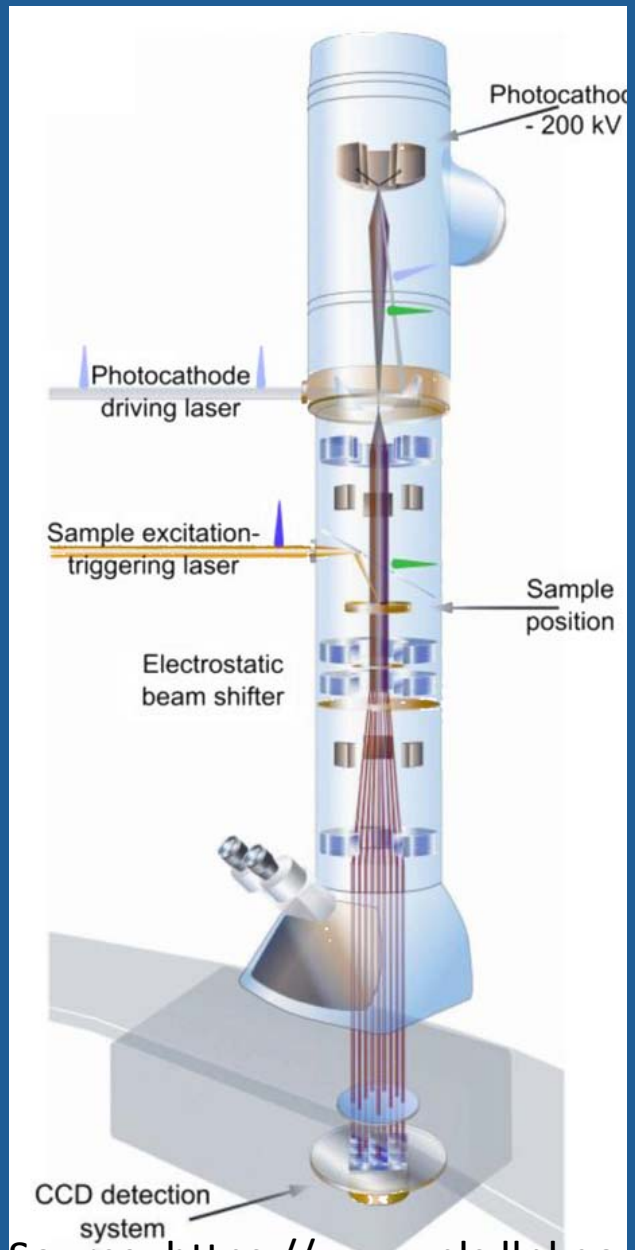
Experiments

Small scale & with e-

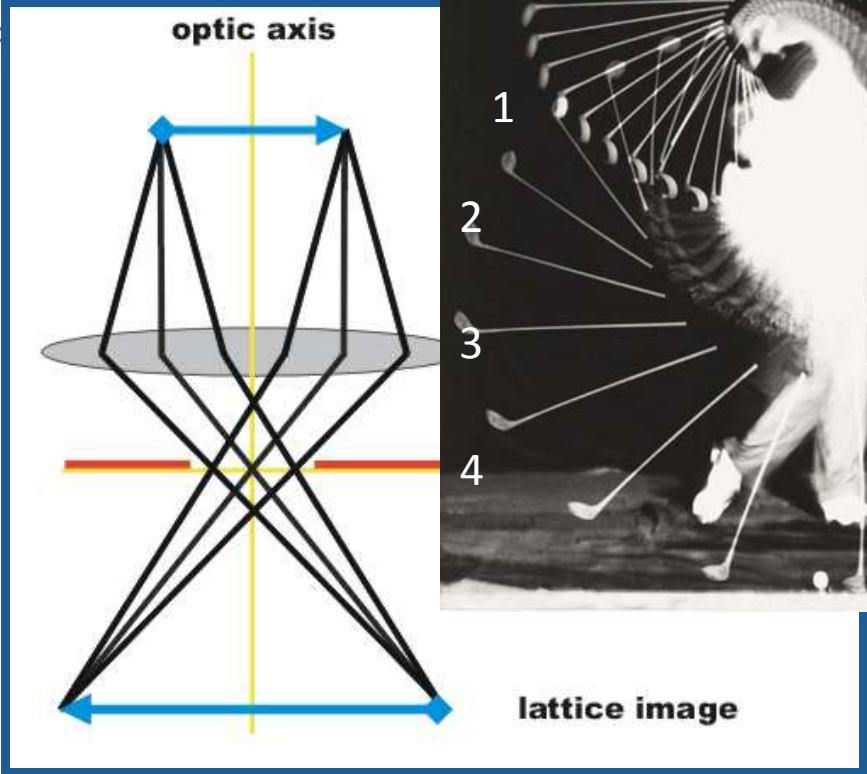
- keV FED – solid state
- keV FED – liquid phase
- keV FED – gas phase
- REGAE Diffraction
- keV time-resolved TEM
- REGAE Dynamic RTEM

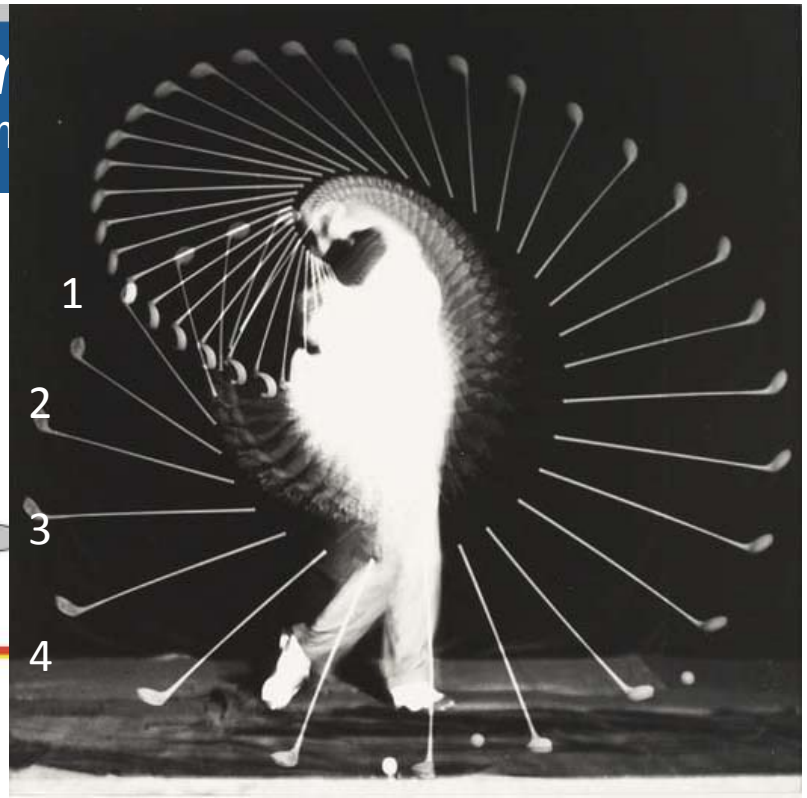
TEM real space im

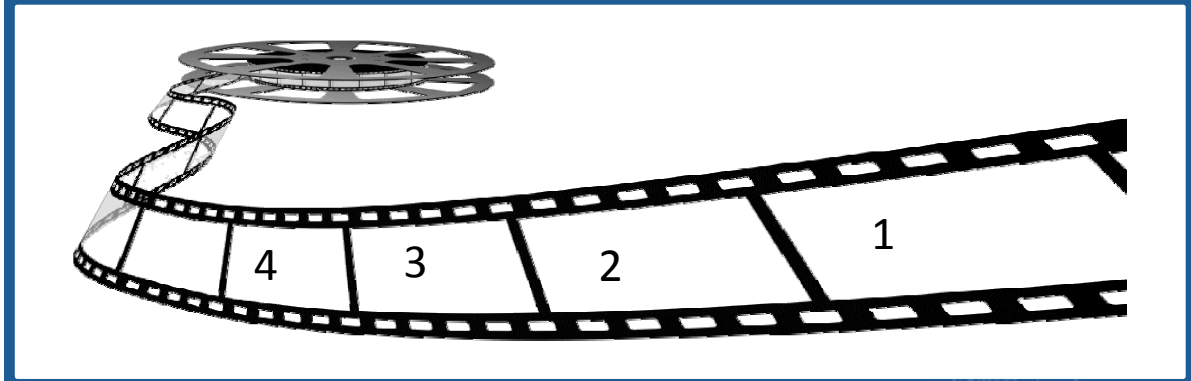
A movie like in cinem



Source: https://www-pls.llnl.gov

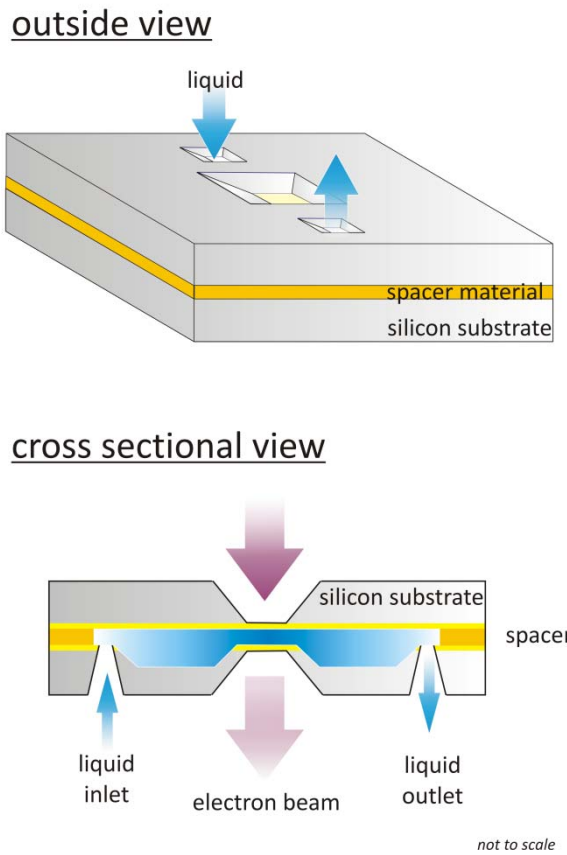






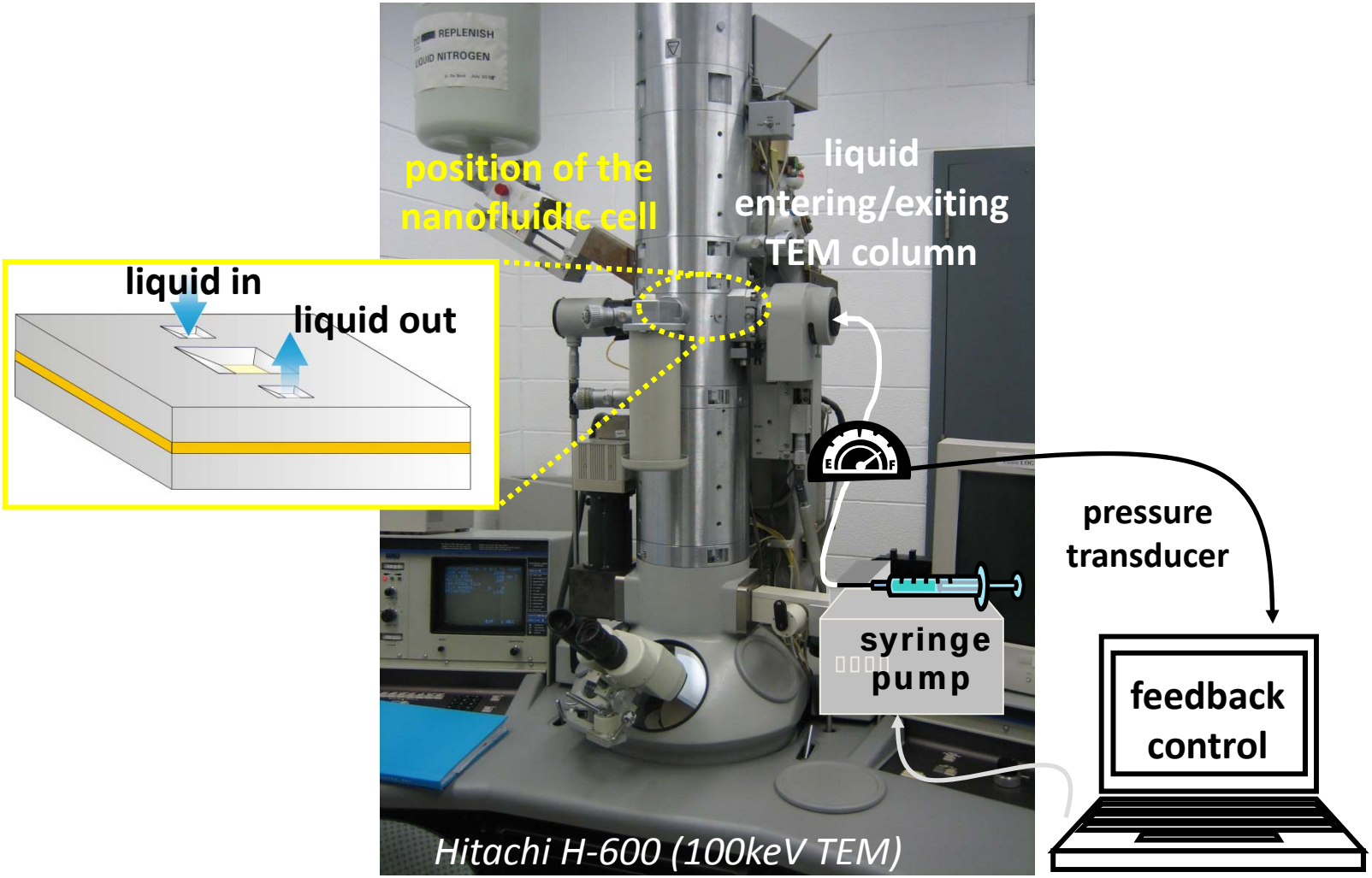
Further Evolution in atom gazing: ……Solution Phase Dynamics

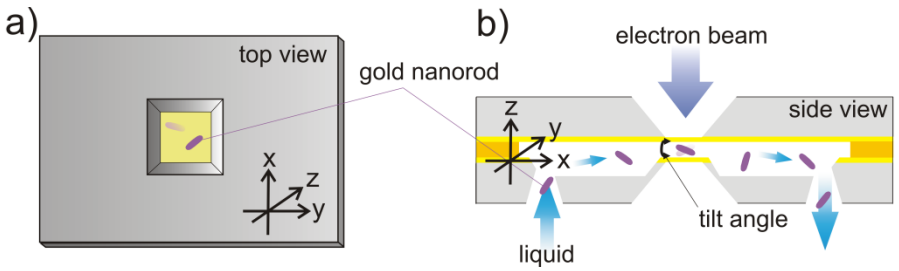
TEM nanocell with flow!

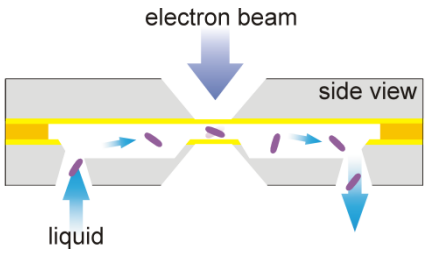


Christina Müller, U Toronto

Setup schematic: MRS proceedings 2013, submitted





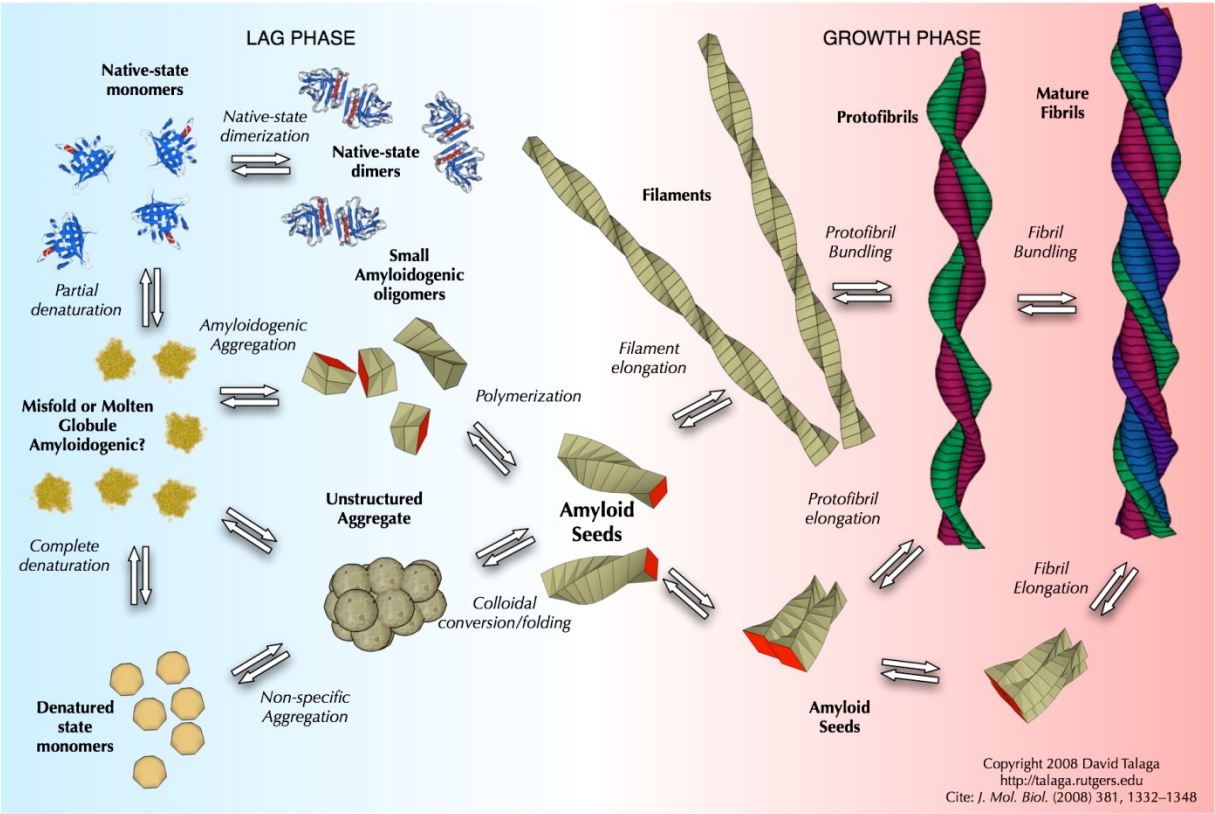


useful notes:
- viewing area 50x50um
- flow rates in the uL per hour range (low sample need)
- automated syringe pump used
- 100/125/200keV TEM and 200keV STEM used

first results: biomedical applications
- amyloid fibrils -

responsible for many diseases such as Alzheimers, Diabetes, Parkinson….

extra-cellular depositions of protein fibrils with characteristic appearance in TEM and x-ray, spectroscopy etc.



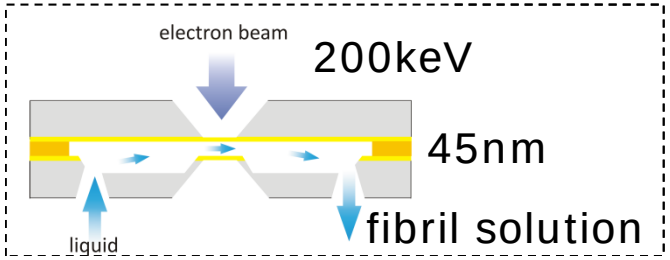
P. Fraser, *Biochem.* **2000**, 39, 13269.
M. Faendrich, *Cell. Mol. Life Sci.* **2007**, 64, 2066.

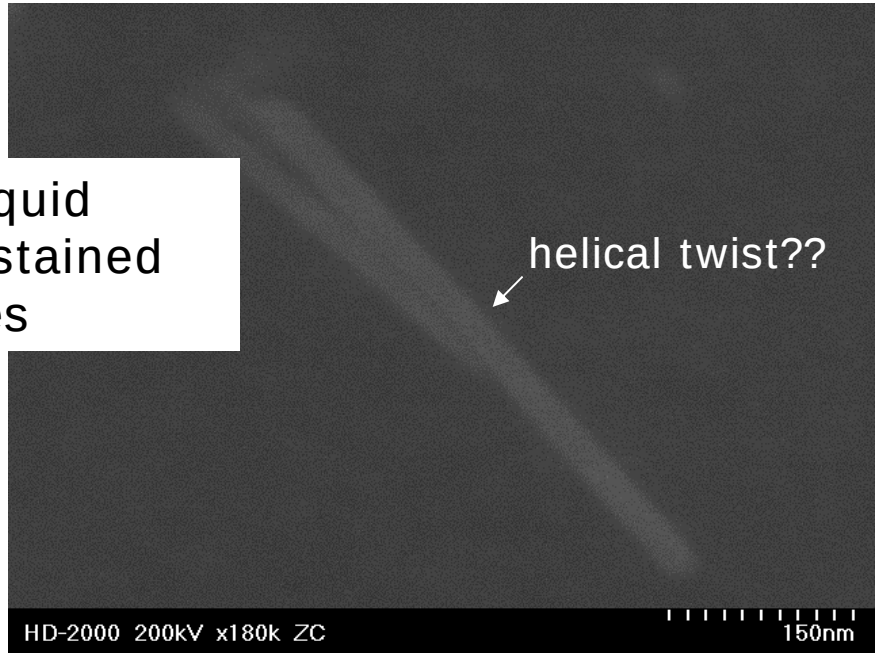
http://talaga.rutgers.edu/research/amyloid.php

amyloid fibrils

- fragments of the initial amyloid fibrils
- solvent here: DMF/water (destruction of the fibril structure)

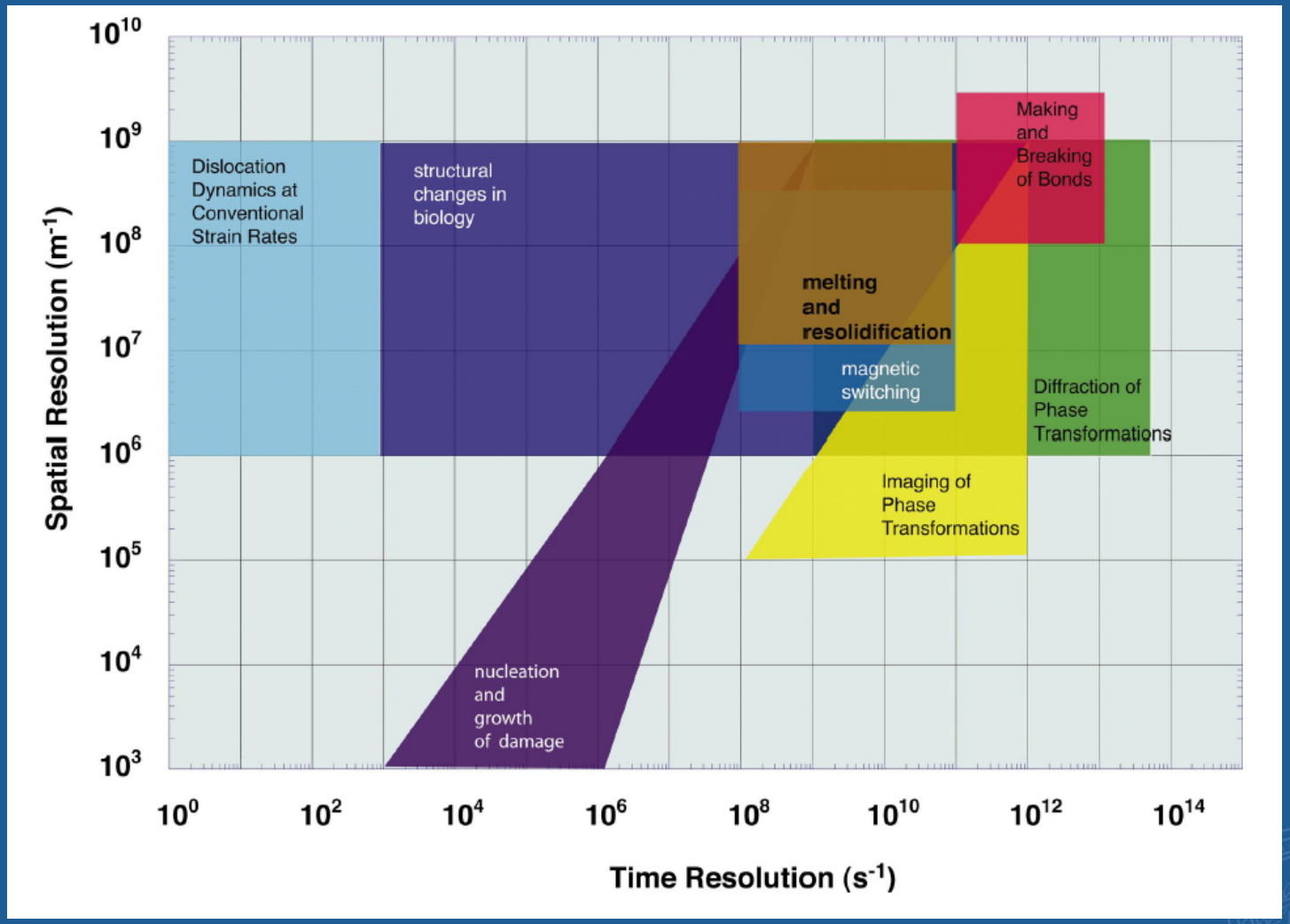
<u>remarkable:</u> in liquid imaging of NON stained biological samples





Static & Dynamic

Time scales



Detector requirements

Experiment	Energy / MeV	# Pixels	Single-shot Dynamic range	Frames per second read out
REGAE relativistic electron diffraction (static & time-resolved)	3 – 5	1k x 1k (1M)	10^3 (up to 10^4)	100 Hz
REGAE relativistic TEM[1] mode	3 – 5	2k x 2k (4M)	100	100 Hz
time-resolved TEM[1] (adapted commercial TEM[1])	0.1 – 0.3	1k x 1k (1M)	100	*ca.* 1-10 MHz
keV UED[2] – solid state samples	0.1 - 0.3	1k x 1k (1M)	10^3 (up to 10^4)	1 kHz
keV UED[2] – liquid phase samples	0.1 – 0.3	1k x 1k (1M)	100	1 kHz
keV UED[2] – gas phase samples	0.1 – 0.3	1k x 1k (1M)	>3	1 kHz

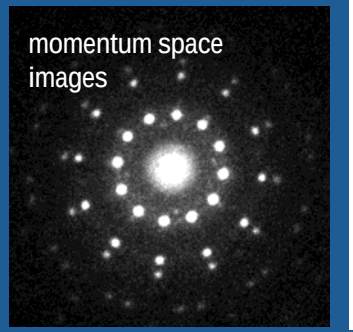
Table 1: Most demanding requirement to a detector system for the various types of experiments performed at MPSD. The most demanding requirements are indicated in red.
([1]transmission electron microscope [2]ultrafast electron diffraction)

Can one single system serve all requirements?

Principally yes, but we make two different systems!

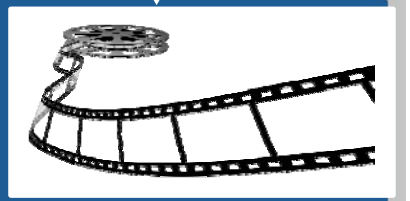
Detector specifications

Two different detector systems

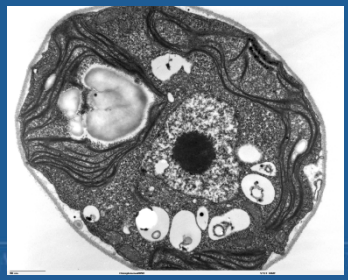


	Direct hit detector	Ultrafast detector
Sensor active area	(50 x 50) mm^2	
Sensor size in pixel	1000 x 1000	
Physical pixel size	50 µm (subject to change)	50 µm (subject to change)
Detection principle	DEPFET direct e- hit	DEPFET with scintillator
Read out mode	rolling shutter 4x	
Read out speed	>1000 Hz full frame rate (continuously)	~0.1 MHz full frame rate for 100 frames
Electronic noise contribution	100 e-	
Sensor thickness	50 µm (down to 30 µm possible)	450 µm
Pixel well depth (TCH)	60 000 (improvement is part of work package #1)	
Operating temperature	ambient temperature	
Radiation hardness (pixel)	10Mrad	protected
Primary e- energy range	80 keV-5 MeV	80 keV-350 keV
Range of Ø num. secondary e-	between 5k-12k	typically 1000 per 0.1 MeV

Table 2: Detector specifications.



Real space images



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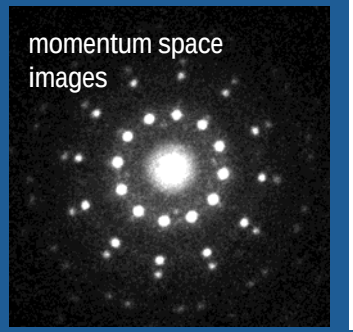
mpsd

Detector specifications

Two different detector systems



	Direct hit detector	Ultrafast detector
Sensor active area	(50 x 50) mm^2	
Sensor size in pixel	1000 x 1000	
Physical pixel size	50 µm (subject to change)	50 µm (subject to change)
		or
		for
Elec		
P		
O		
Rad		
Pr		
Rang		leV

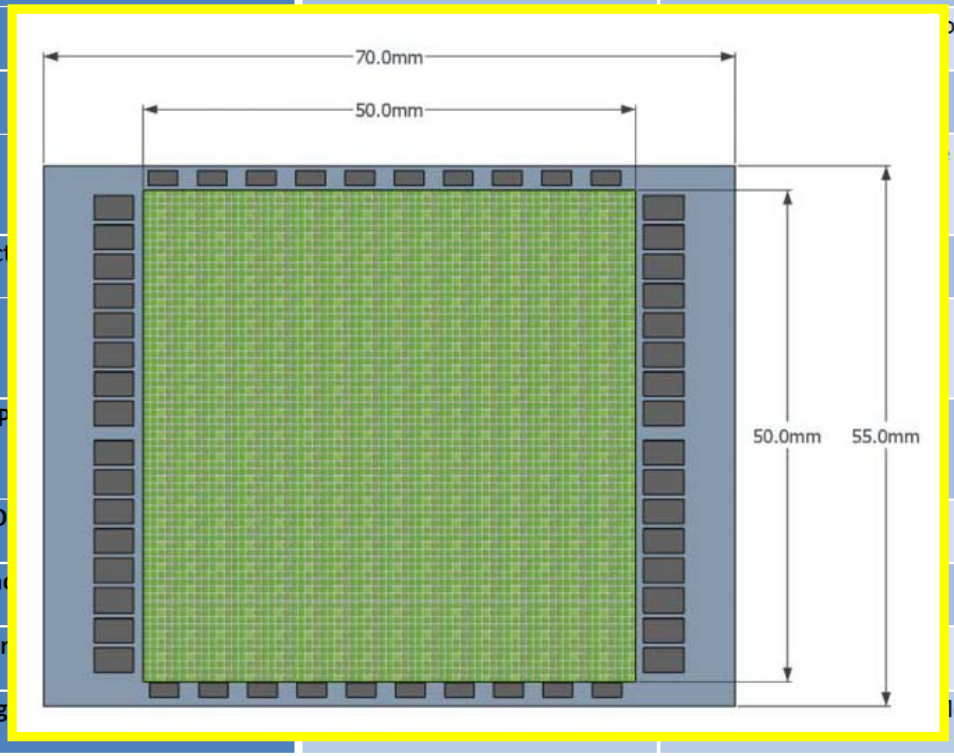
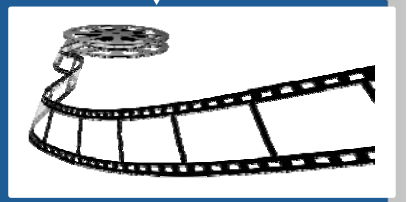
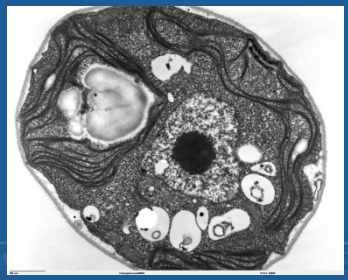


Table 2: Detector specifications.



Real space images



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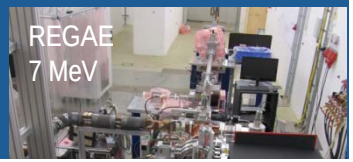
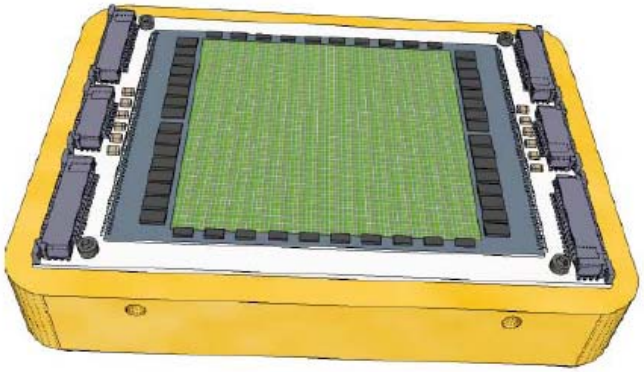
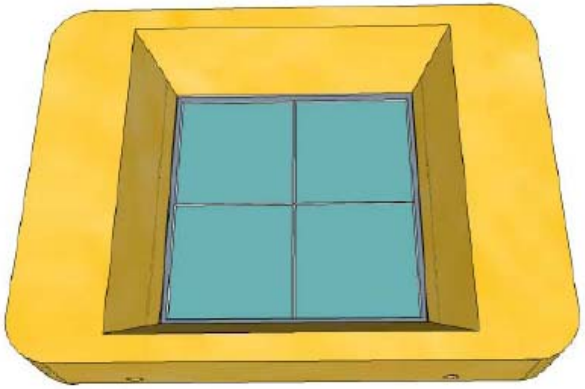
Detector specifications

Two different detector systems

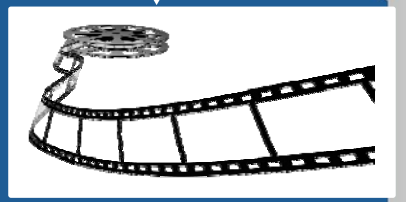


	Direct hit detector	Ultrafast detector
Sensor active area	(50 x 50) mm^2	
Sensor size in pixel	1000 x 1000	
Physical pixel size	50 µm (subject to change)	50 µm (subject to change)
Detection principle	DEPFET direct e- hit	DEPFET with scintillator
Read out mode	rolling shutter 4x	
Read out speed	>1000 Hz full frame rate	~0.1 MHz full frame rate for





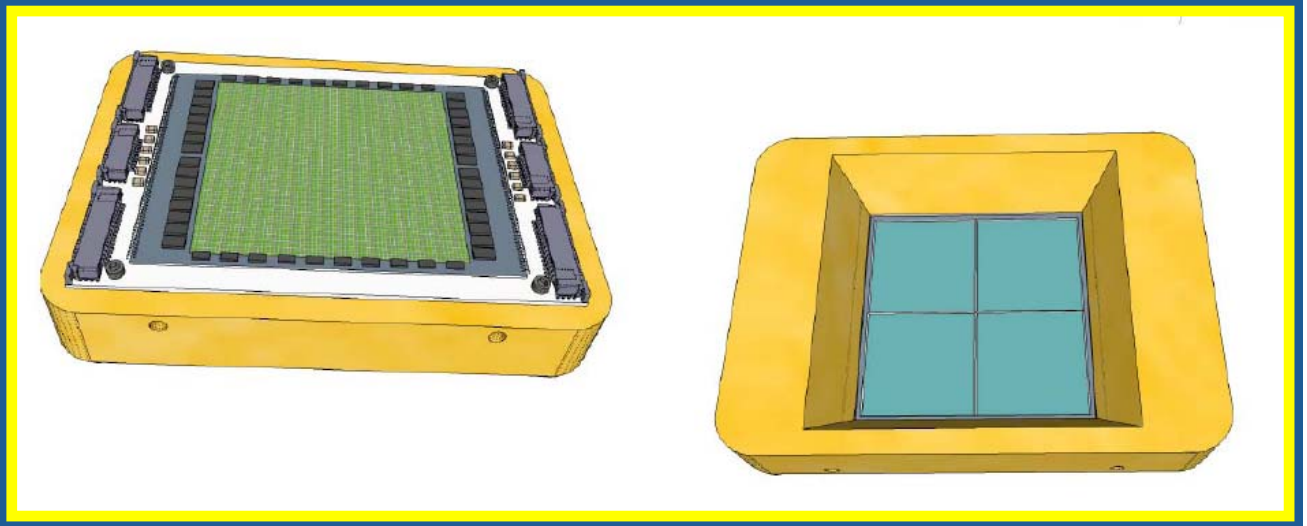
MeV

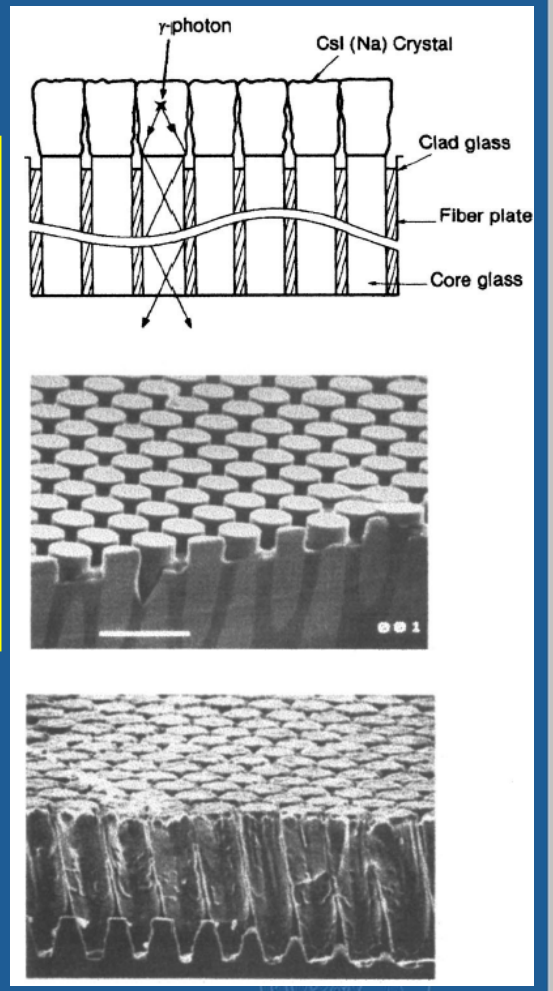


Real space images

Detector specifications

Fast detector; scintillator detector

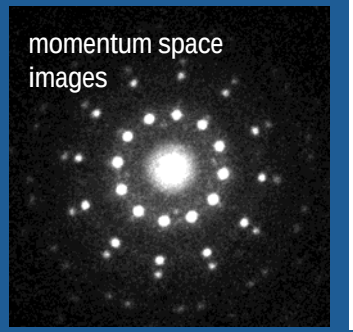




- High efficiency and low cross-talk with scintillator in fiber
- connection of fiber optical face plate to detector to be solved
- ~27000ph/MeV yield

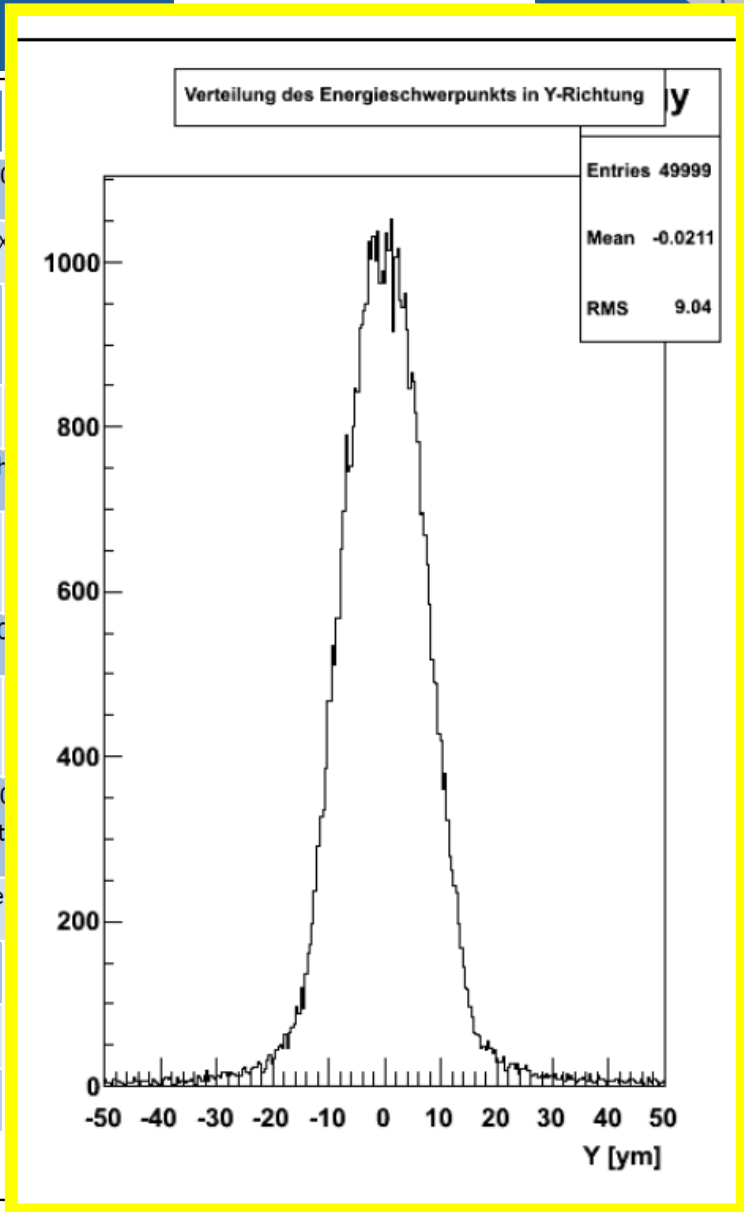
Detector specifications

Two different detector systems



	Direct hit detector
Sensor active area	(50 x 5
Sensor size in pixel	1000 x
Physical pixel size	50 µm (subject to change)
Detection principle	DEPFET direct e- hit
Read out mode	rolling sh
Read out speed	>1000 Hz full frame rate (continuously)
Electronic noise contribution	100
Sensor thickness	50 µm (down to 30 µm possible)
Pixel well depth (TCH)	60 ((improvement is part
Operating temperature	ambient te
Radiation hardness (pixel)	10Mrad
Primary e- energy range	80 keV-5 MeV
Range of Ø num. secondary e-	between 5k-12k

Table 2: Detector specifications.



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Detector specifications

Two different detector systems

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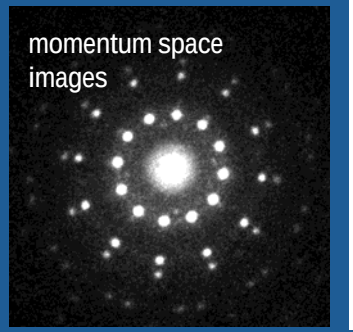
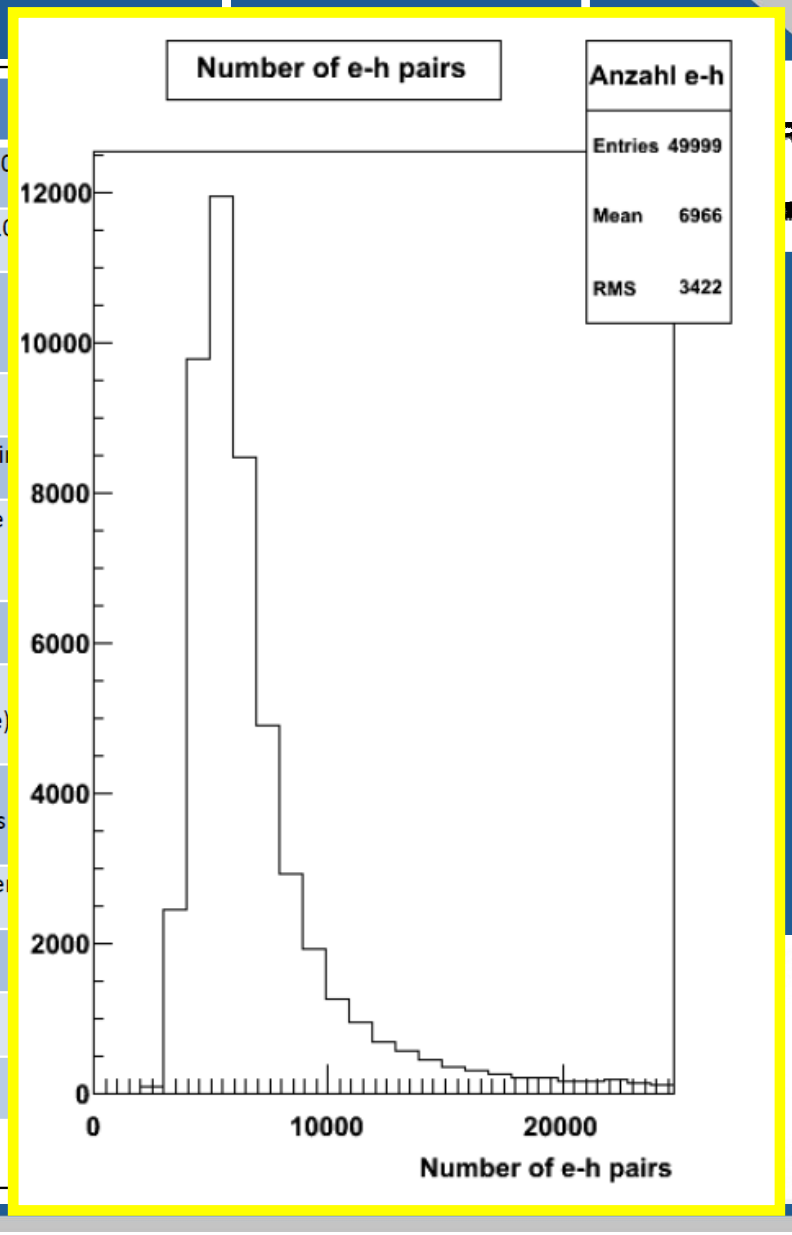


	Direct hit detector
Sensor active area	(50
Sensor size in pixel	10
Physical pixel size	50 µm (subject to change)
Detection principle	DEPFET direct e- hit
Read out mode	rolli
Read out speed	>1000 Hz full frame rate (continuously)
Electronic noise contribution	
Sensor thickness	50 µm (down to 30 µm possible)
Pixel well depth (TCH)	(improvement is
Operating temperature	ambie
Radiation hardness (pixel)	10Mrad
Primary e- energy range	80 keV-5 MeV
Range of Ø num. secondary e-	between 5k-12k

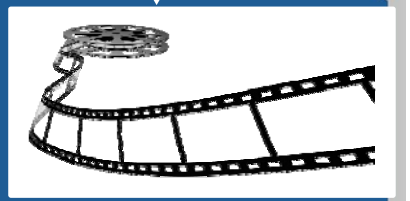
Table 2: Detector specifications.

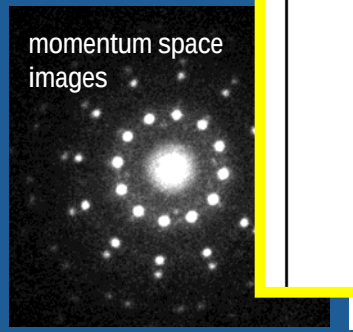


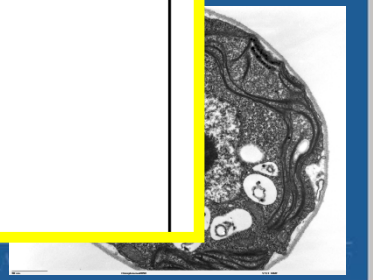
Detector specifications

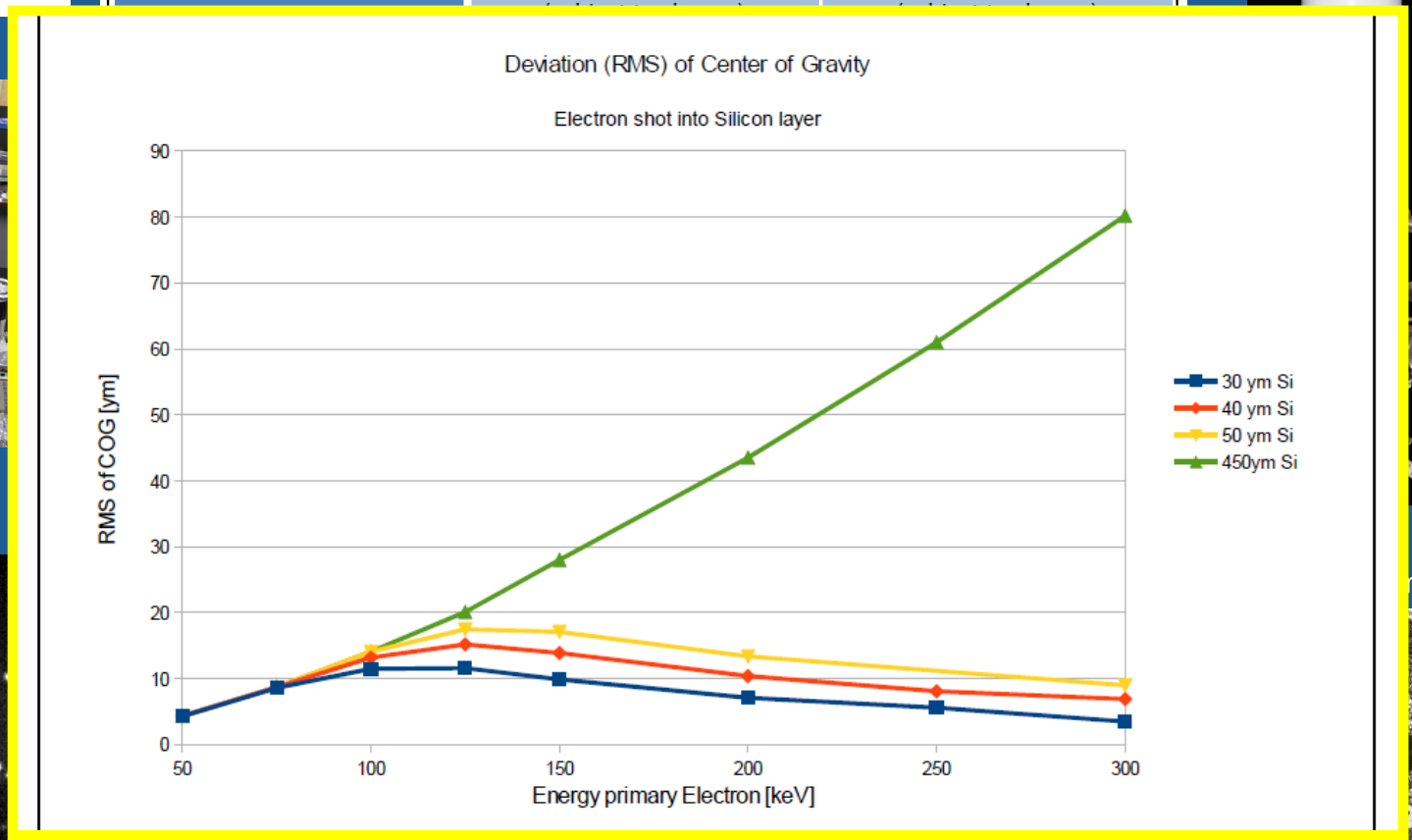
Two different detector systems

	Direct hit detector	Ultrafast detector
Sensor active area	(50 x 50) mm^2	
Sensor size in pixel	1000 x 1000	
Physical pixel size	50 µm	50 µm









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mpsd

Detector specifications

Two different detector systems

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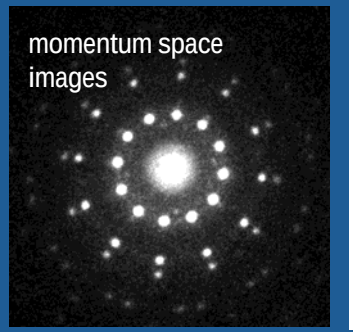
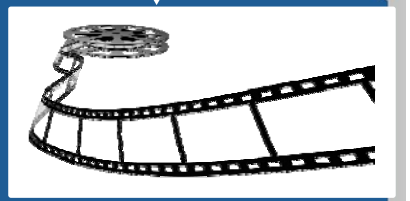


	Direct hit detector	Ultrafast detector
Sensor active area	(50 x 50) mm^2	
Sensor size in pixel	1000 x 1000	
Physical pixel size	50 µm (subject to change)	50 µm (subject to change)
Detection principle	DEPFET direct e- hit	DEPFET with scintillator
Read out mode	rolling shutter 4x	
Read out speed	>1000 Hz full frame rate (continuously)	~0.1 MHz full frame rate for 100 frames
Electronic noise contribution	100 e-	
Sensor thickness	50 µm (down to 30 µm possible)	450 µm
Pixel well depth (TCH)	60 000 (improvement is part of work package #1)	
Operating temperature	ambient temperature	
Radiation hardness (pixel)	10Mrad	protected
Primary e- energy range	80 keV-5 MeV	80 keV-350 keV
Range of Ø num. secondary e-	between 5k-12k	typically 1000 per 0.1 MeV

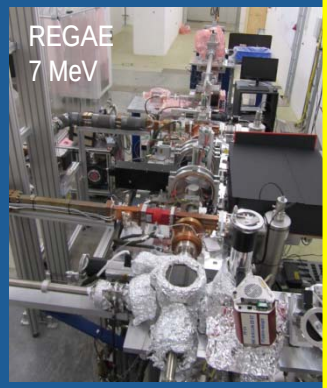
Table 2: Detector specifications.

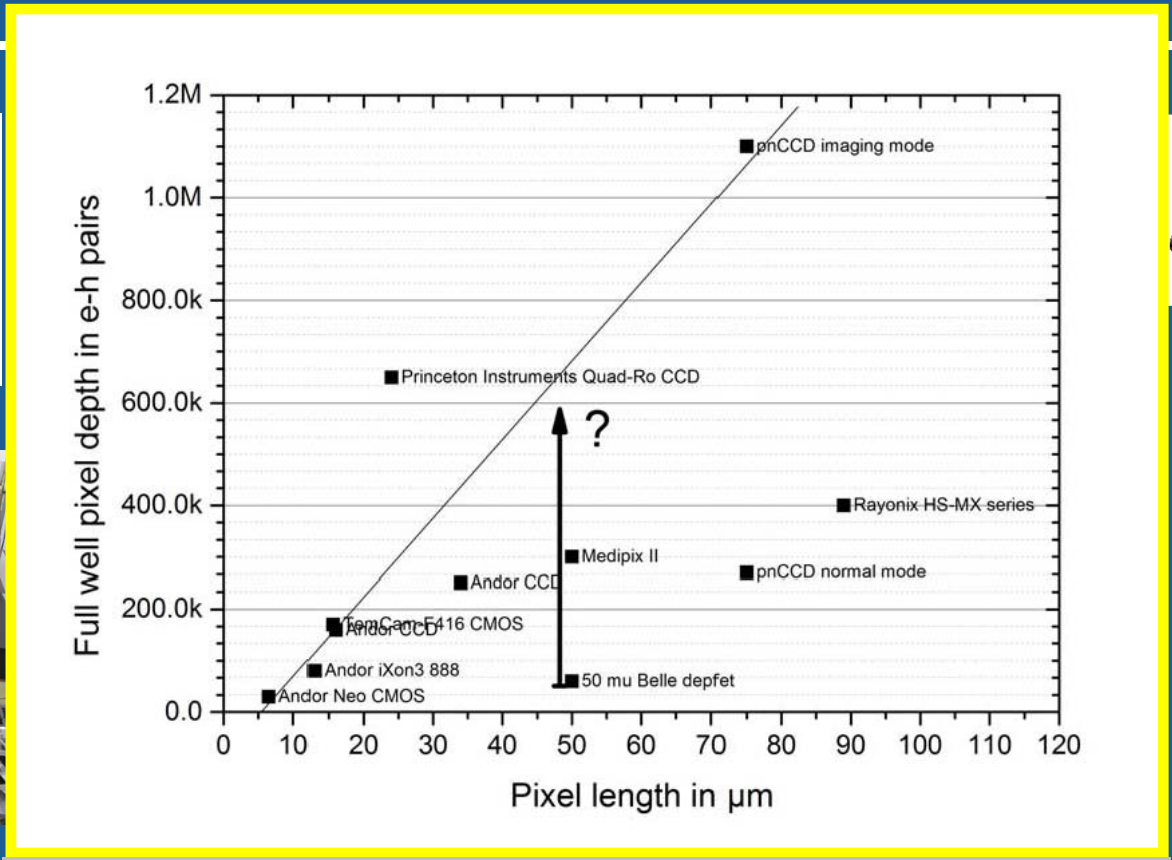


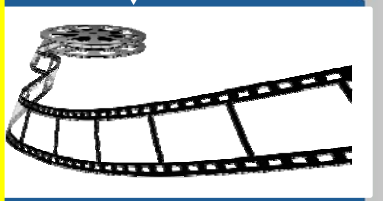
Real space images

Detector specifications

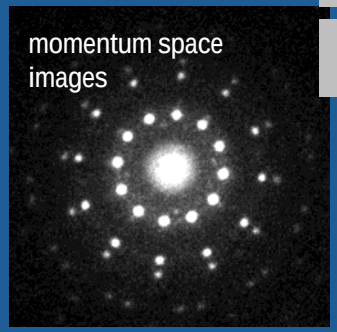
Two different detector systems







- Rainer Richter wants to do some VooDoo for Factor 5-10
- Might slow down the detector……



Operating temperature	ambient temperature	
Primary e- energy range	80 keV-5 MeV	80 keV-350 keV
Range of Ø num. secondary e-	between 5k-12k	typically 1000 per 0.1 MeV

Table 2: Detector specifications.

Real space images

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Detector specifications

Two different detector systems

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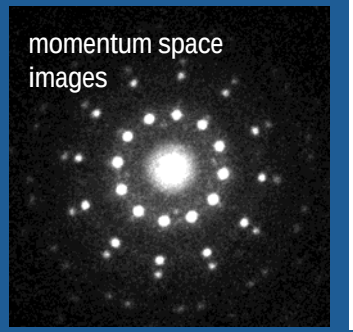

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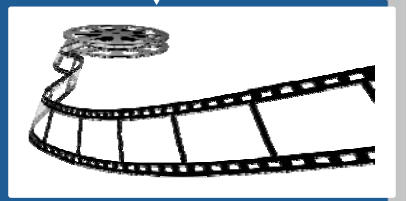
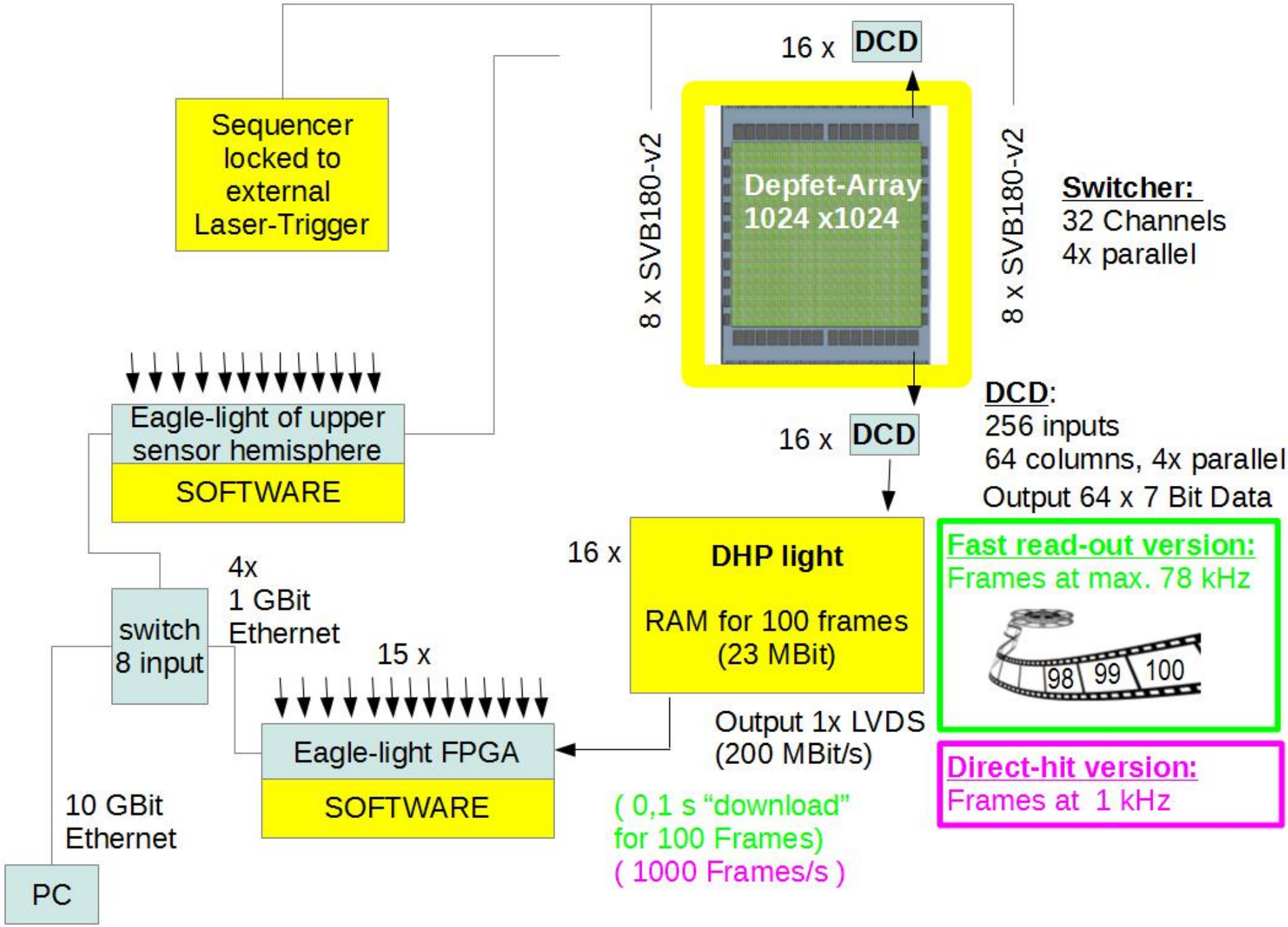


Real space images


Sequencer locked to external Laser-Trigger
16 x DCD
Depfet-Array 1024 x1024
8 x SVB180-v2
8 x SVB180-v2
Switcher:
32 Channels
4x parallel
Eagle-light of upper sensor hemisphere
SOFTWARE
16 x DCD
DCD:
256 inputs
64 columns, 4x parallel
Output 64 x 7 Bit Data
16 x
DHP light
RAM for 100 frames (23 MBit)
Fast read-out version:
Frames at max. 78 kHz
98
99
100
4x
1 GBit
Ethernet
switch 8 input
15 x
Eagle-light FPGA
SOFTWARE
Output 1x LVDS (200 MBit/s)
Direct-hit version:
Frames at 1 kHz
10 GBit
Ethernet
(0,1 s "download" for 100 Frames)
(1000 Frames/s)
PC

Work packages

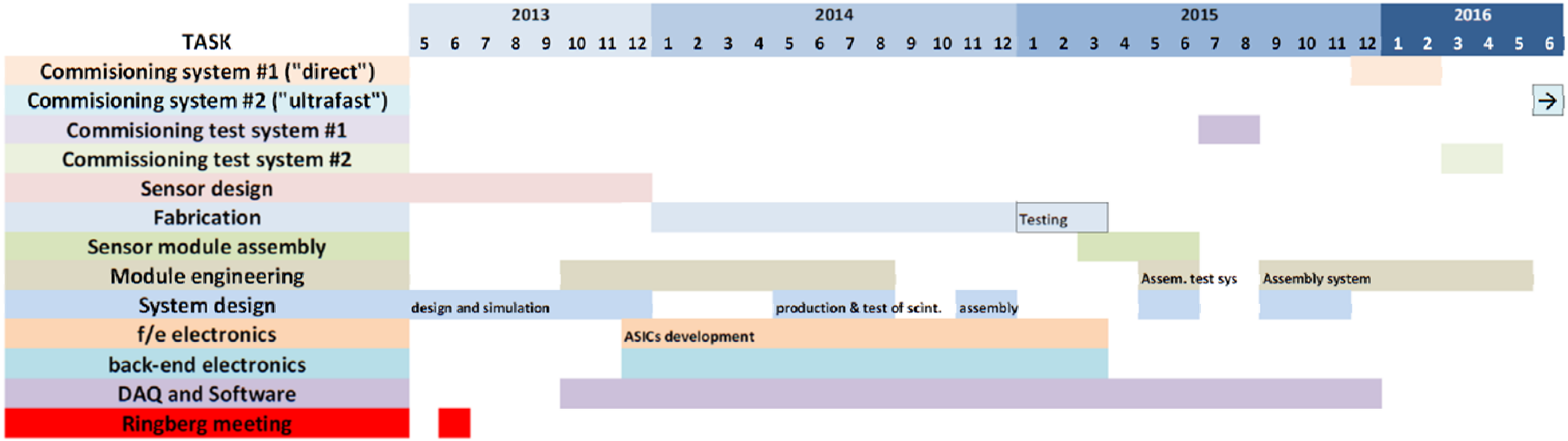
Responsibilities

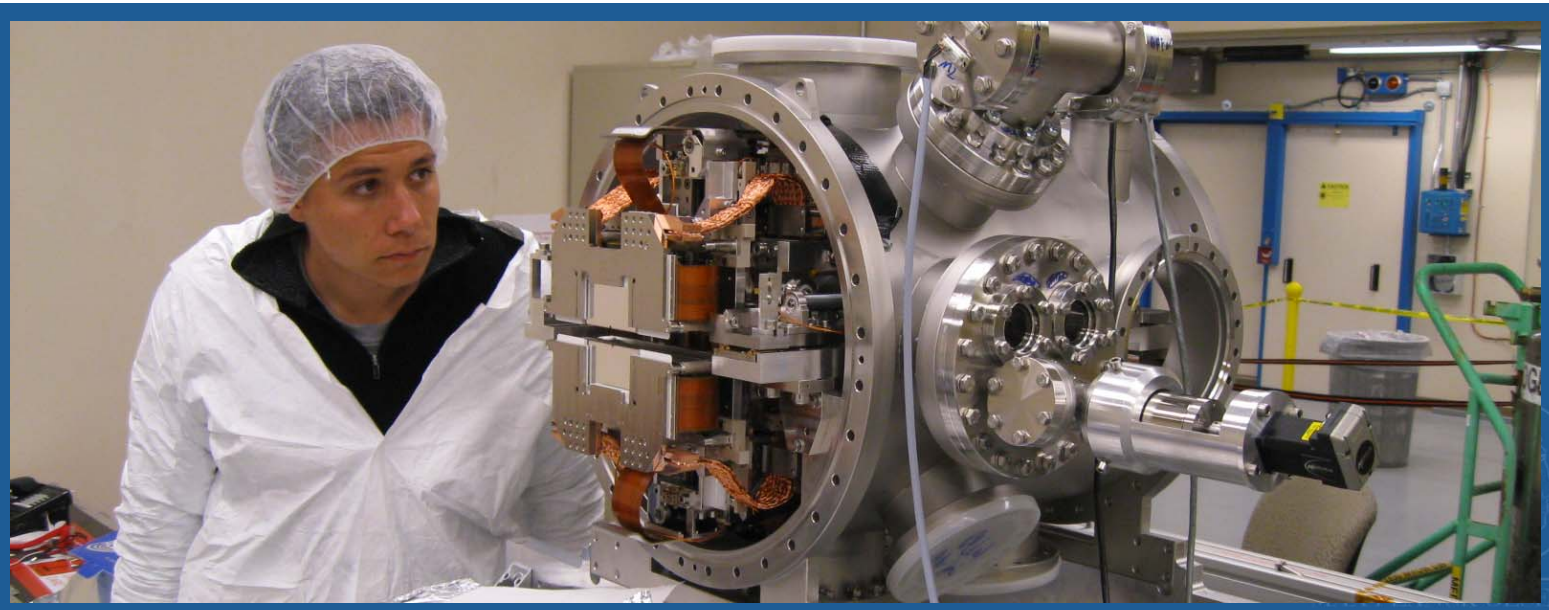
In total there are 8 work packages devoted to:

1. **Sensor design, fabrication and tests [HLL]:** pixel cell and technology, defining chip parameter, simulations, radiation hardness, layout of wafer for production, fabrication and processing of wafer, tests
2. **Sensor module assembly [HLL]**: definition of materials, assembly
3. **Module integration [MPI-SD]:** Thermal and electrical engineering and performance, definition of materials, fabrication of mechanical parts
4. **System design [MPI-SD]:** Scintillator optics, R&D for scintillator design, simulations, integration to sensor, definition and optimization of operation modes
5. **f/e electronics [?]**: ASICs design
6. **back-end electronics [?]:** FPGA system design, definition of protocols and interfaces between sensor and DAQ, Power supplies, slow control and housekeeping
7. **DAQ and Software [MPI-SD]:** definition of hardware, programming of user interface, data representation and analysis
8. **Commissioning [HLL, MPI-SD]:**

Timeline

Commissioning 2016……





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Present:U of T/U of H CFEL/DESY
German Sciaini
Hubert Jean-Ruel
Raymond Gao
Cheng Lu
Gustavo Moriena
Ryan Cooney
Dongfang Zhang
Julian Hirscht
Masaki Hada
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HLL:

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Rainer Richter
Laci Andricek
Florian Schopper
Andreas Wassatsch
Christian Koffmane

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Hossein Delsim-Hashemi
Kurt Mueller
Shyma Bayesteh
Jurgen Rossbach
Frank Mayet
Max Hachmann

Thank you !!!

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