ESRF | The European Synchrotron

Science at synchrotrons and the ESRF EBS

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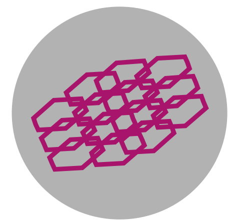
X-ray science and tomorrow's challenges

Challenges and Objectives of Storage Ring and XFEL sources:

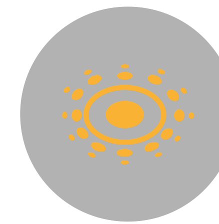
- Explore from the extremely fast:
  FEMTO-SECOND SCALE
- Explore from the extremely small:
  NANO-WORLD
- New tools to investigate condensed and living matter, bridging gaps and complementing optical and electron microscopies
- News tools to answer the pressing technological, economic, health and environmental challenges facing Society.

New, better science



New and innovative materials

Health & life sciences



Energy and Environment

- A new paradigm for beamlines and source: **ESRF Upgrade Programme and ESRF-EBS**

ESRF UPGRADE PROGRAMME: AN AMBITIOUS PROGRAMME TO PREPARE THE FUTURE

Purple Book January 2008

Orange Book January 2015

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI ROADMAP 2006-2016
IN TIME – WITHIN BUDGET

- 19 new beamlines, many specialised on *nano*-beam science
- Upgrade and renewal of facilities and support laboratories

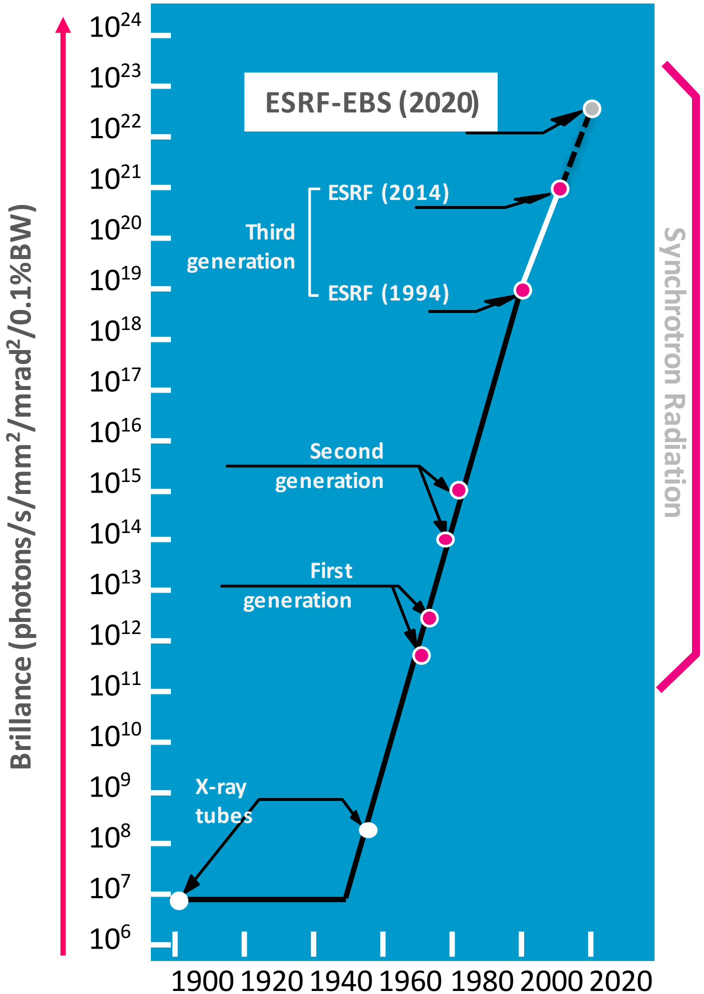
ESRF-EBS
Extremely Brilliant Source
150 M€ (2015-2022)
ESFRI LANDMARK (2016)

revolutionary design
for a new generation of synchrotron
source storage rings

ESFRI

European Commission

ESRF UPGRADE PROGRAMME



ESRF Upgrade Programme

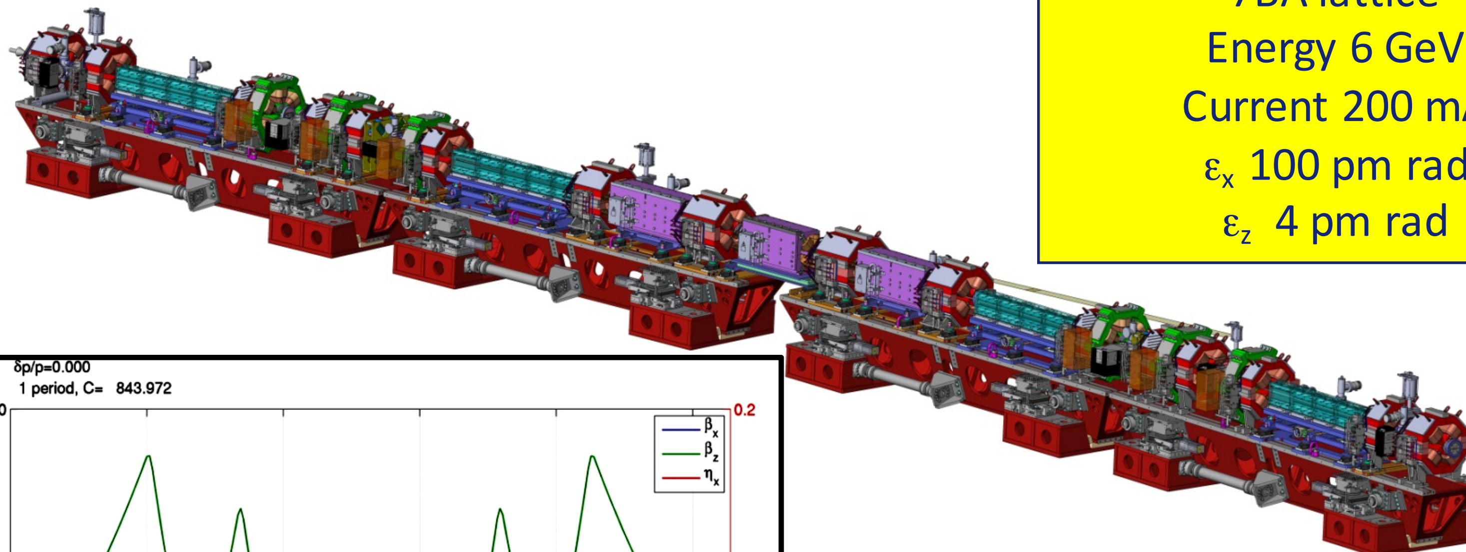
- A factor of ~100 increase in brillance and coherent flux of the X-ray source
- A conceptually new storage ring
- A complete renewal of the « beamline » portfolio and of the users' support facilities adapted to the new research opportunities

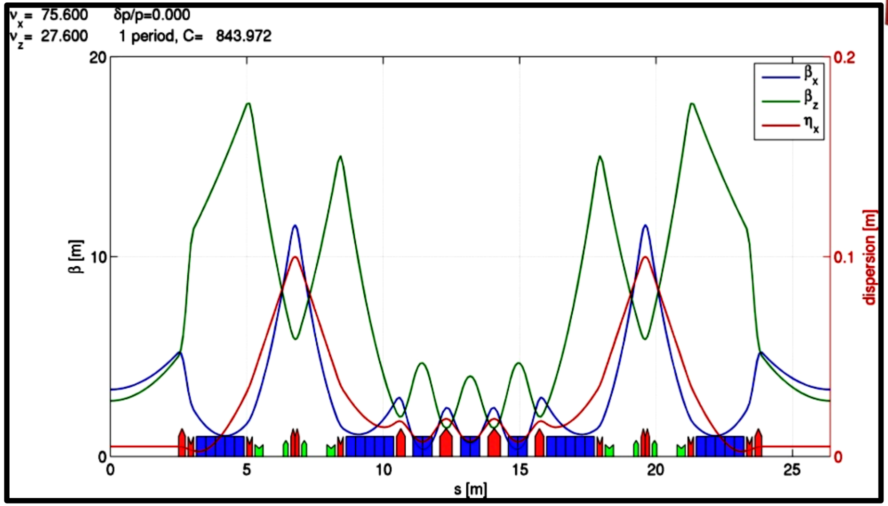
But also:
MAX IV, SIRIUS
And soon
SPRING8-II, APS, DIAMOND-II, etc.

NEW ESRF LATTICE: 7BA – SEVEN BENDS ACHROMAT LATTICE (RAIMONDI LATTICE)

Key Paramaters

7BA lattice
Energy 6 GeV
Current 200 mA
ε_x 100 pm rad
ε_z 4 pm rad

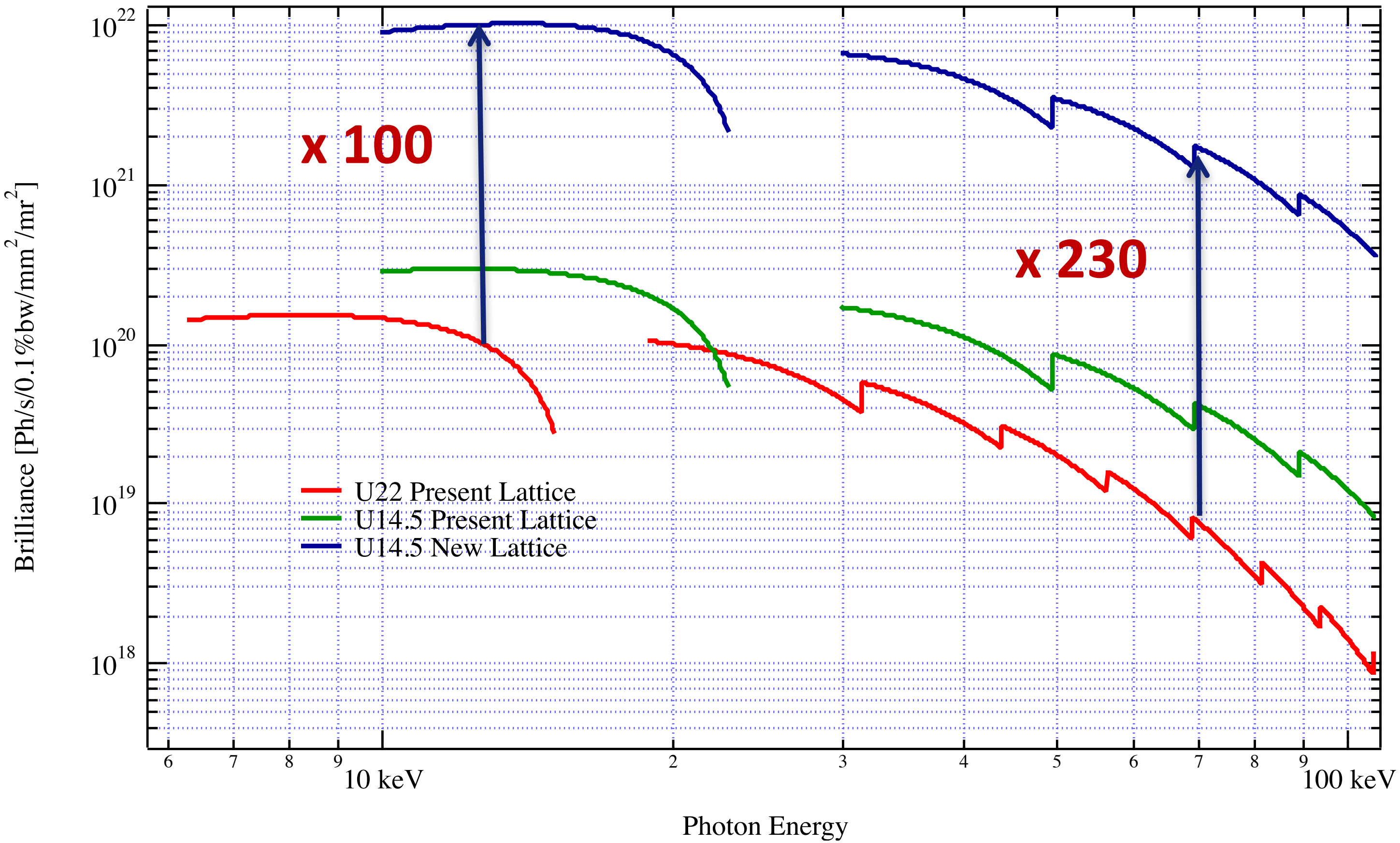




2 M IVUS & CPMUS

IVUN22 min. gap 6 mm, K_{max}=1.7

CPMU14.5 min. gap 4 mm, K_{max}=1.7



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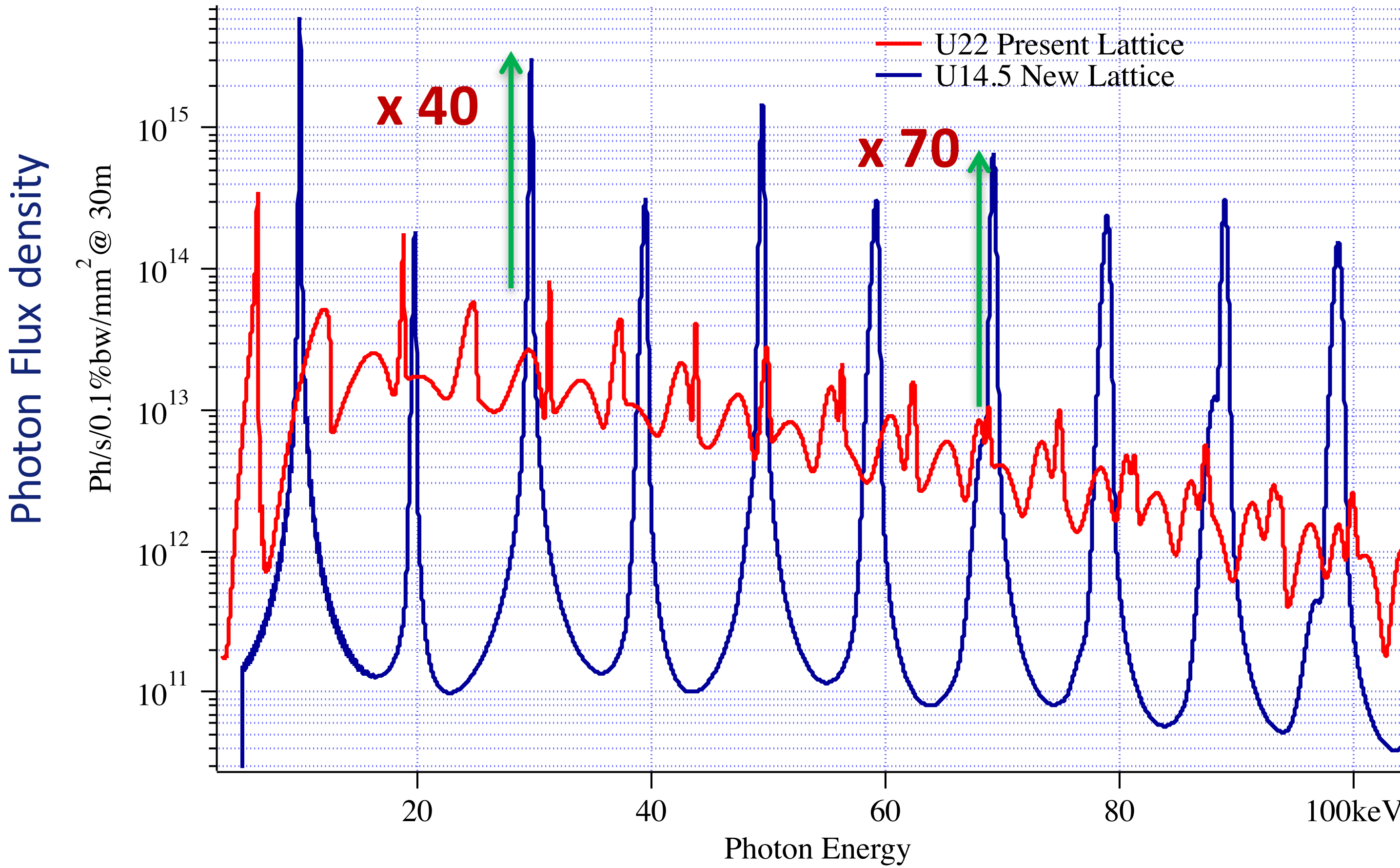

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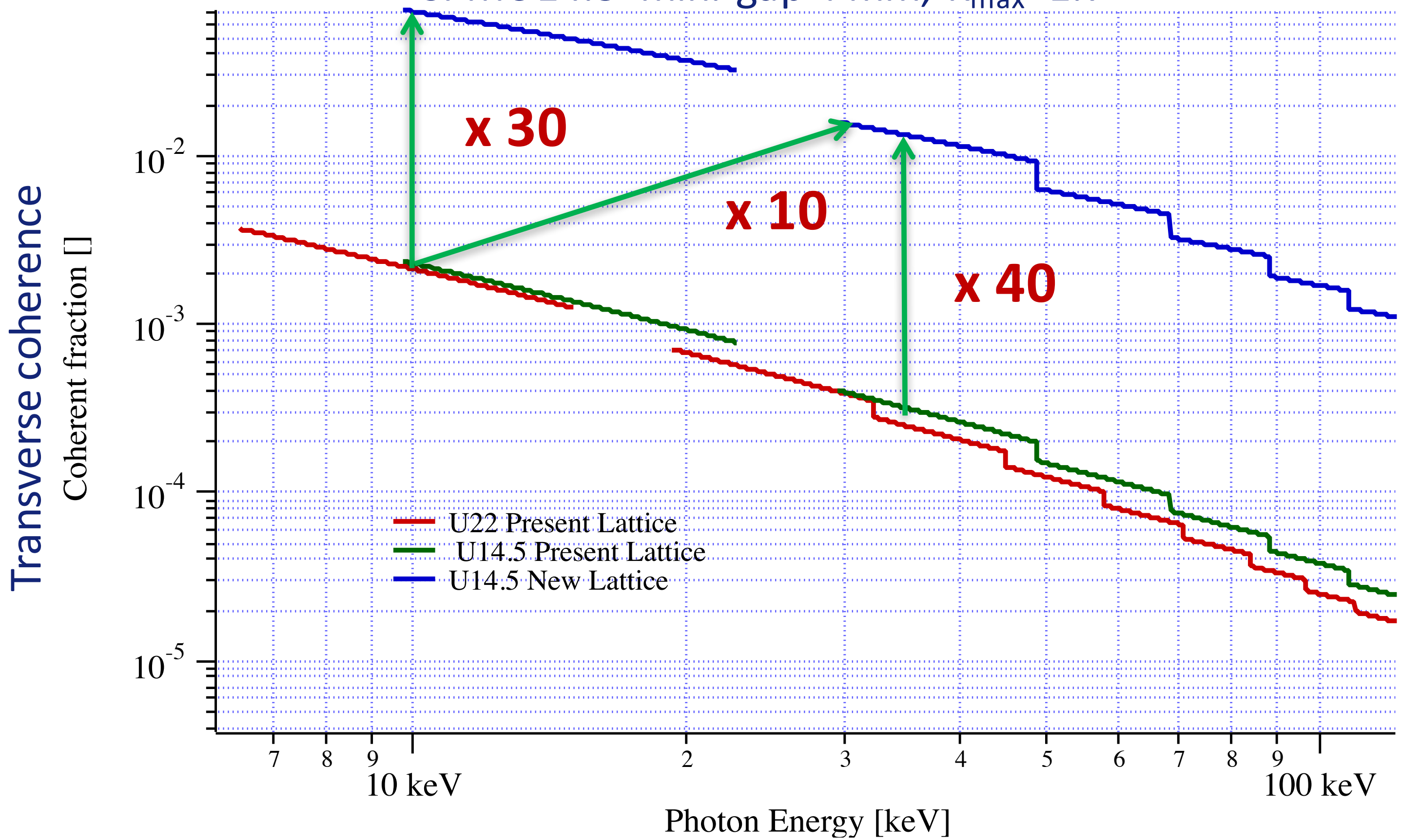
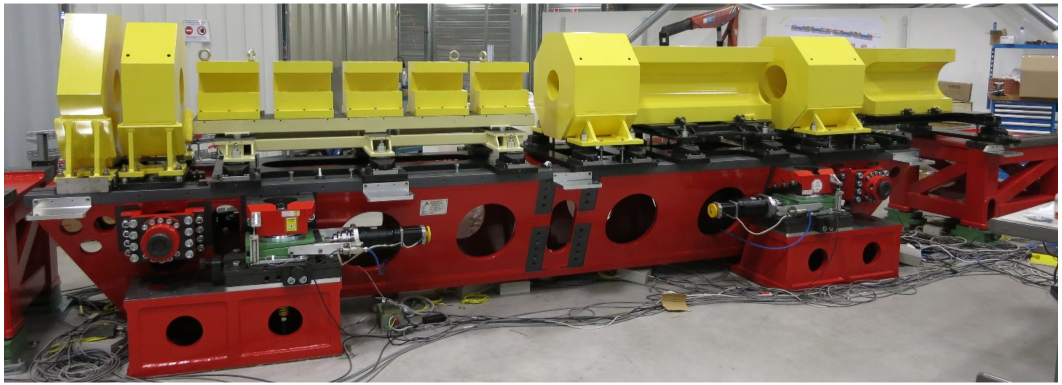
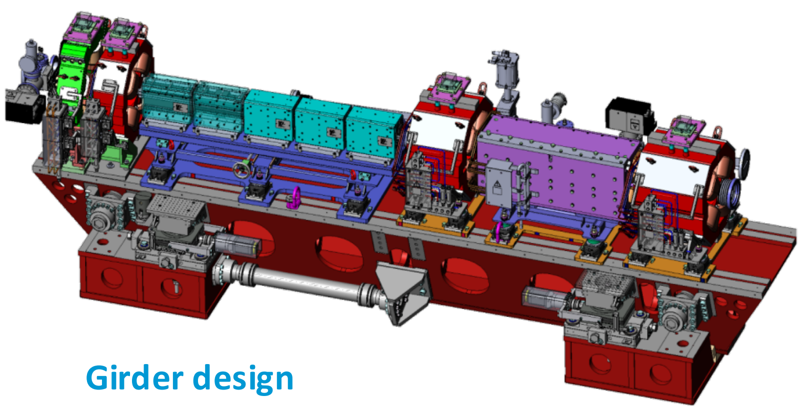


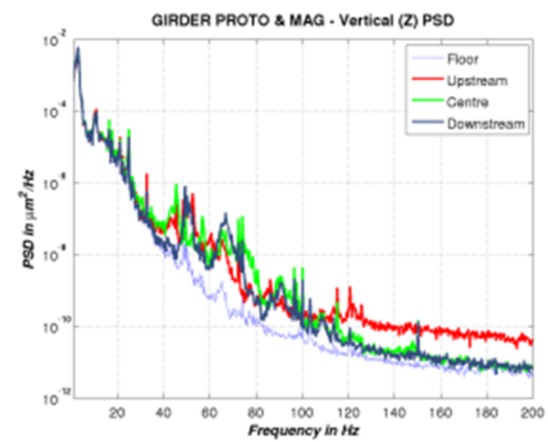
Girder prototype tests: 128 girders construction started



Girder prototype with dummy magnets for mechanical tests



Girder design

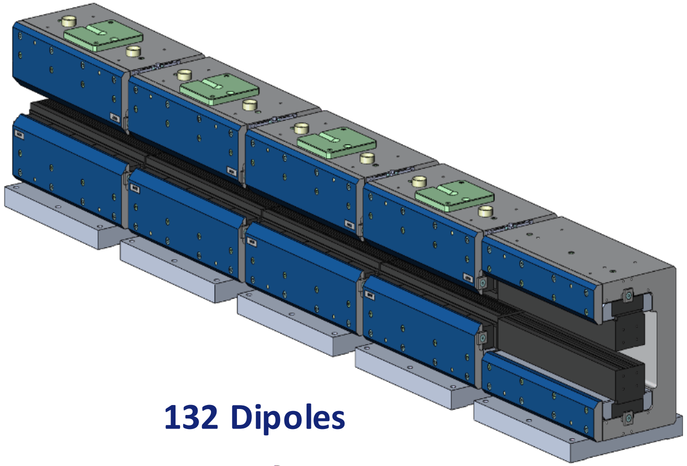


First vibrational mode at 40 Hz

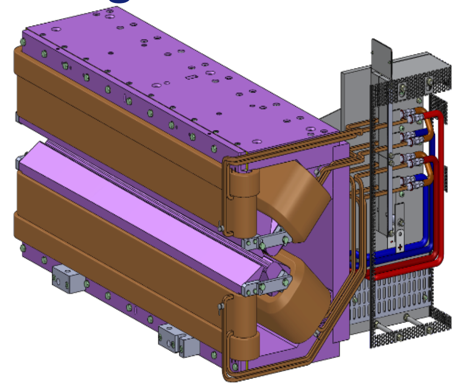
Virtually no amplification of natural ground motion

ESRF UPGRADE PROGRAMME – ESRF EBS (2015-2022)

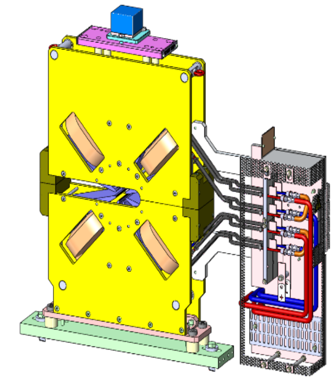
Magnets: more than 1 000 magnets construction started



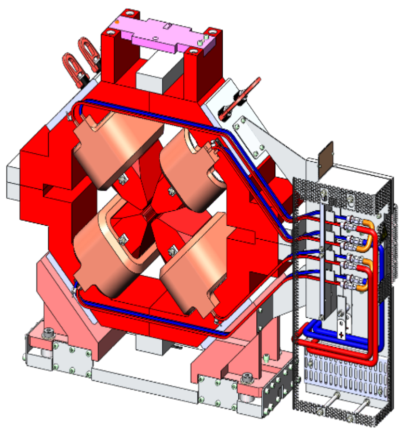
132 Dipoles



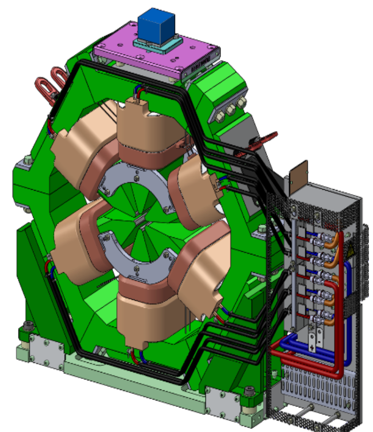
98 Dipole-quadrupoles



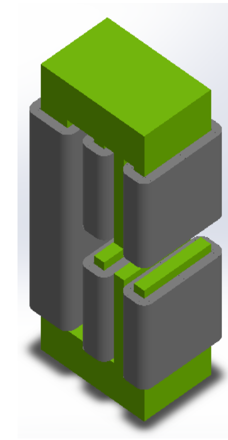
66 Octupoles



526 Quadrupoles



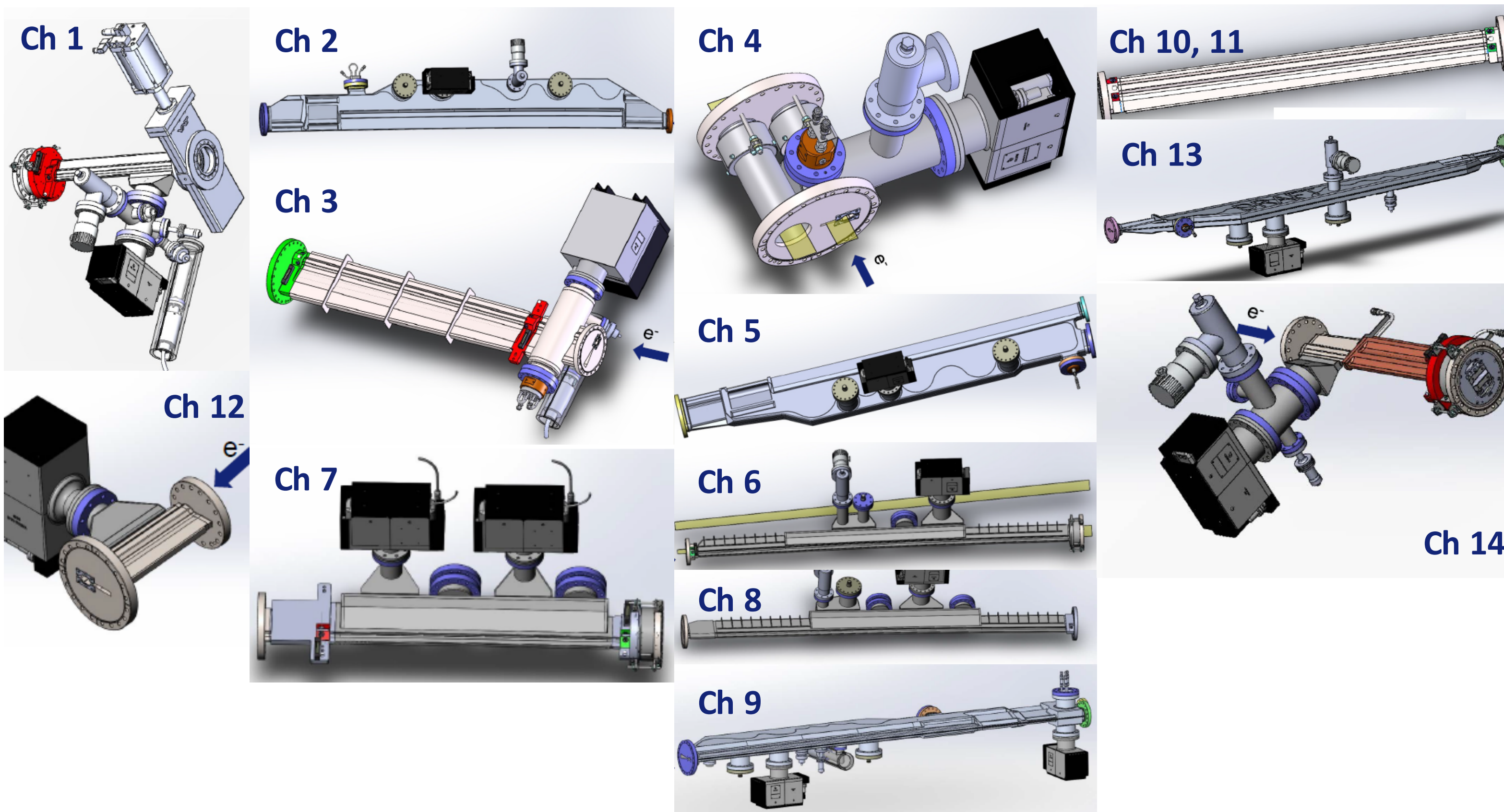
196 Sextupoles



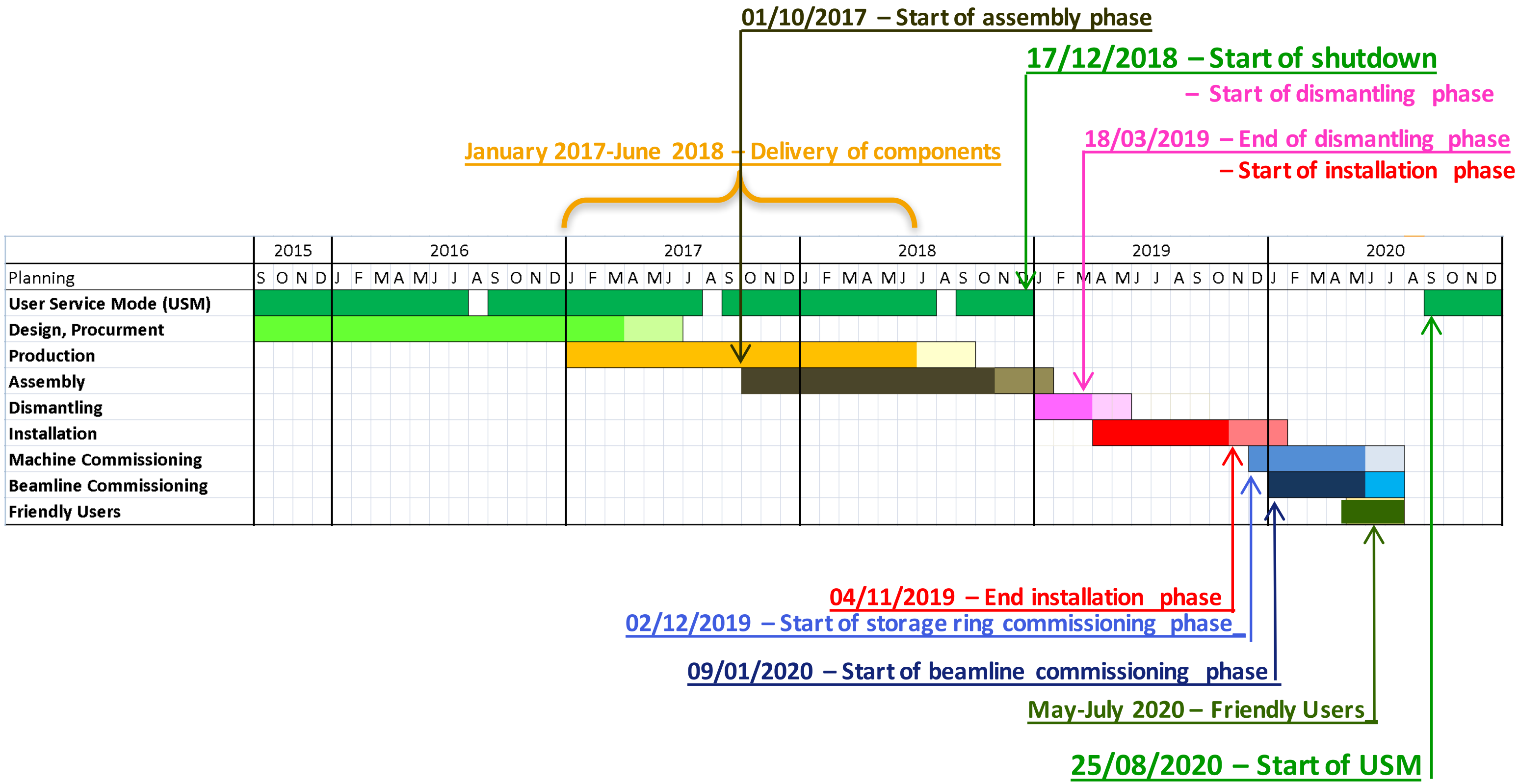
98 Correctors

ESRF UPGRADE PROGRAMME – ESRF EBS (2015-2022)

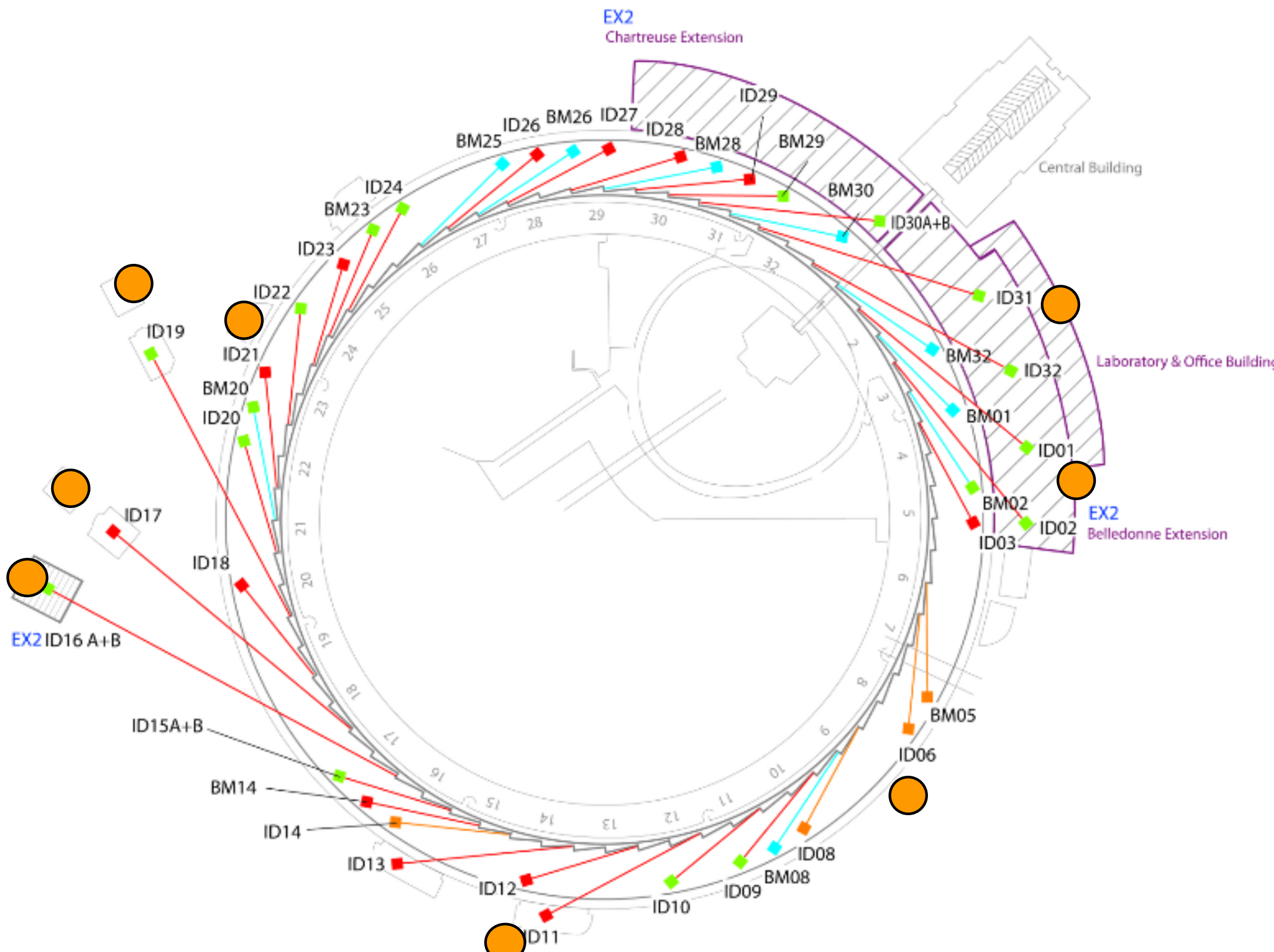
Vacuum chambers: more than 450 chambers construction started



Accelerator Master Plan and Major Milestones



EBS ON ESRF BEAMLINE PORTFOLIO: IMAGING BEAMLINES



The European Synchrotron | ESRF

Main Conclusions

Imaging beamlines mostly on low-β straights

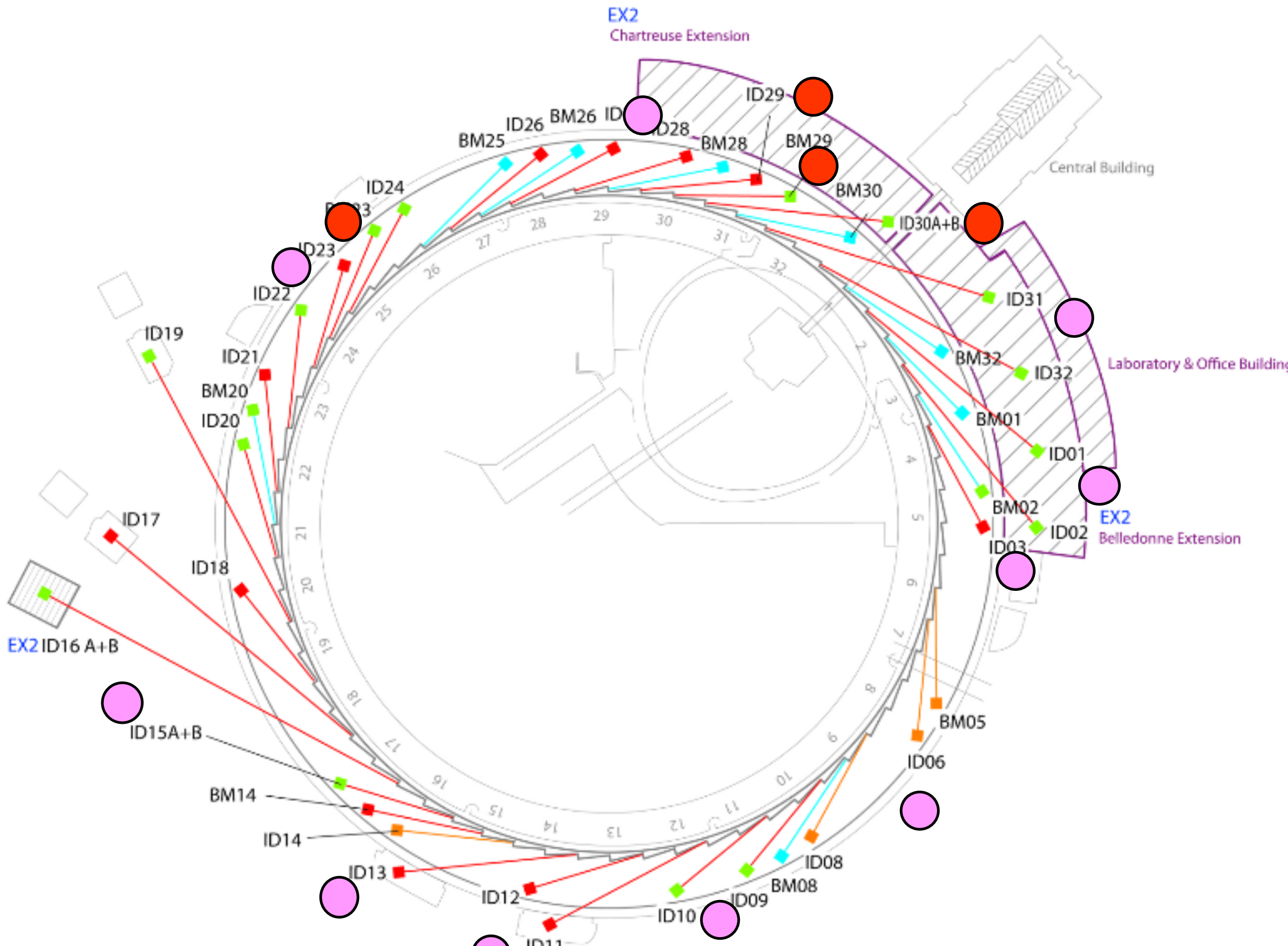
(wiggler and undulator sources)

→ moderate to very high gain - no gain on wiggler sources

high gain in flux and flux density (undulator sources)

very high gain in coherence $F_c \sim B$

EBS ON ESRF BEAMLINE PORTFOLIO: DIFFRACTION BEAMLINES



Main Conclusions

Diffraction beamlines mostly on low-β straights

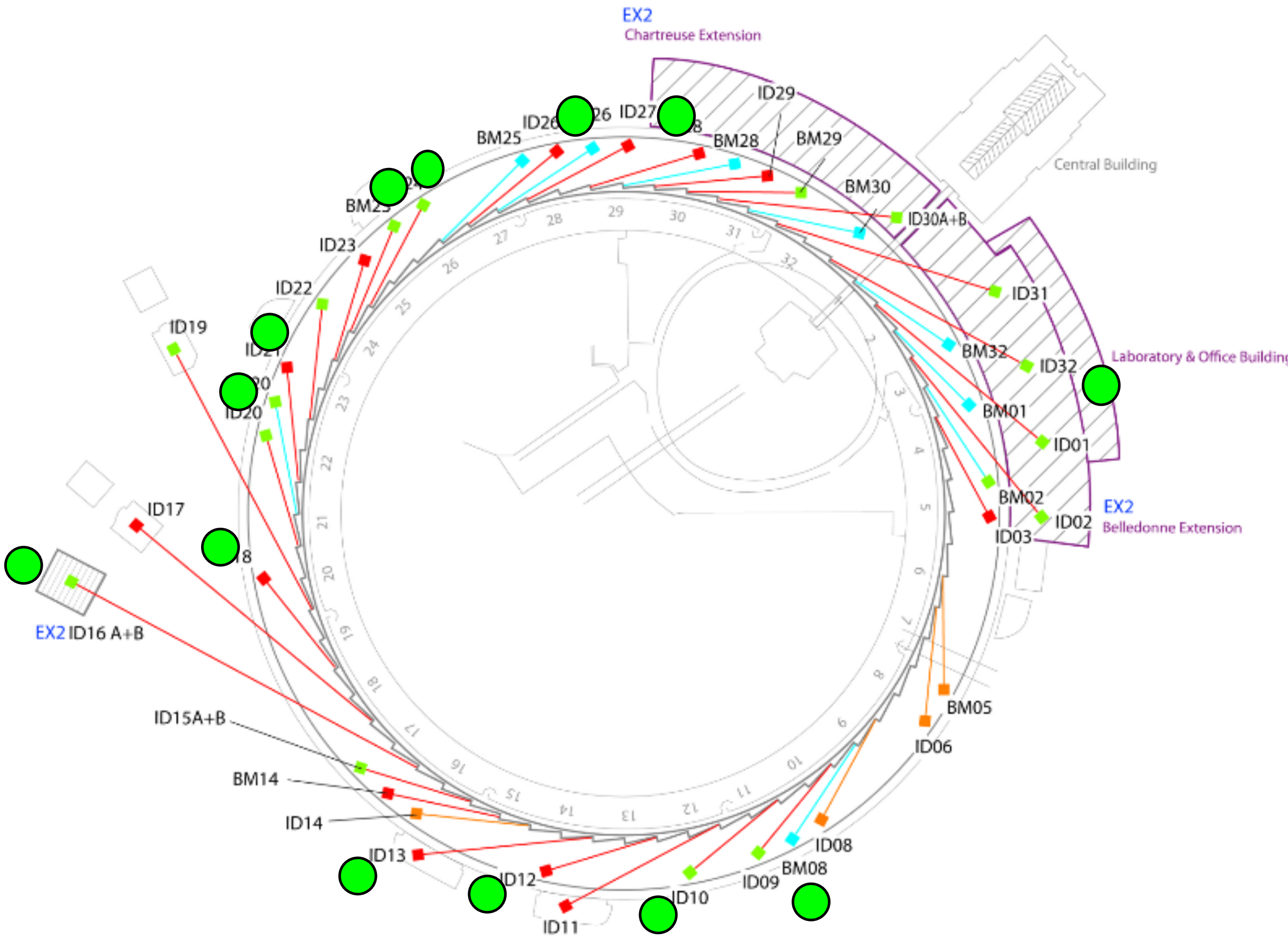
→ very high gain

high gain in flux and flux density

very high gain in coherence $F_c \sim B$

ideally suited for the production of *nano*-beams

EBS ON ESRF BEAMLINE PORTFOLIO: SPECTROSCOPY BEAMLINES



Main Conclusions

Spectroscopy beamlines mostly on high-β straights

→ moderate to high gain

moderate gain in flux

moderate to high gain in flux density

ideally suited for the production of *nano*-beams

SUMMARY EBS ON ESRF BEAMLINE PORTFOLIO:

Today, limitations in:

• Brightness ➡ ~95% loss in *nano*-beams

• Coherence ➡ 0.2% at 10 keV

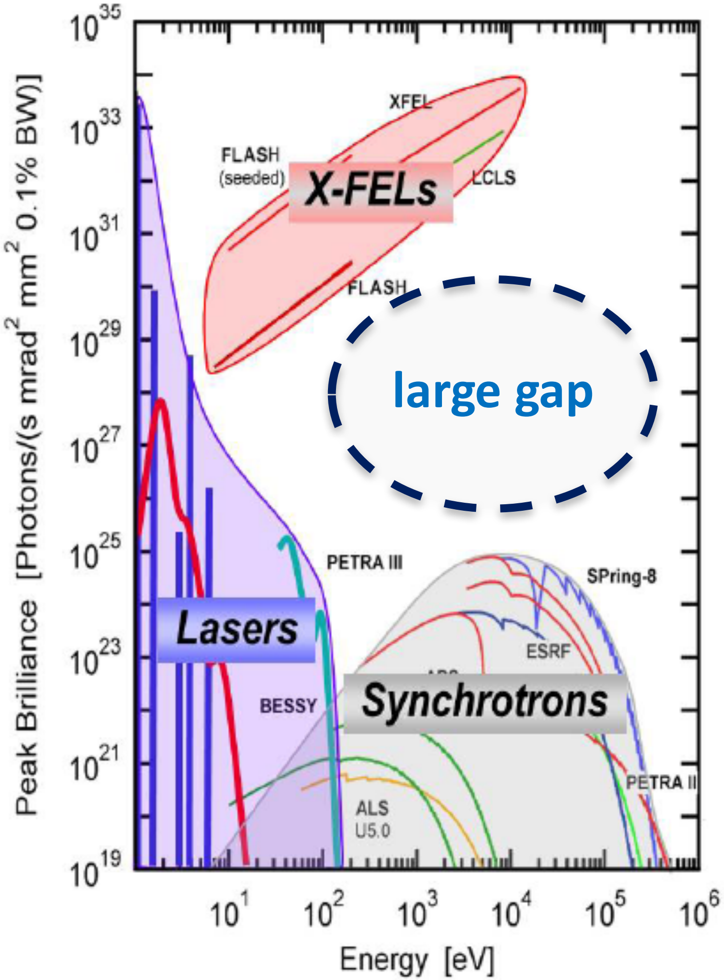
Increased brightness and coherence:

- Smaller source size
- Larger working distance for given beam size
- Resolution beyond the limits of beam size

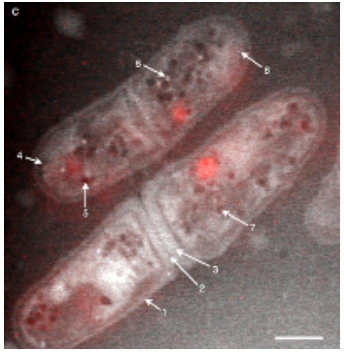
Increased flux and flux density

- Higher time resolution

Light



STEM in liquid

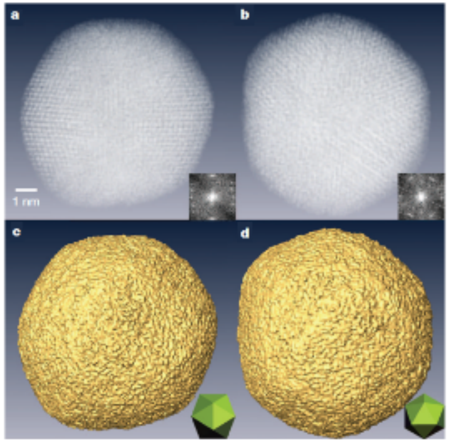


Peckys et al, *Biophys. J.* 100, (2011)

Electrons

Limitations in imaging & spectroscopy for d > 100nm

TEM



"Electron tomography at 2.4 Å resolution", Scott et al., *Nature*, (2012)

Tremendous gain in brilliance, flux, and coherence!

ID10: **x 40** in coherent flux (soft matter BL)

ID16: **x 30** in flux at ultimate 10nm focus (imaging BL)

ID29: **x 10^5** in flux density at the sample (MX BL)

ID31: **x 10^3** in focused high E beam (materials processing BL)

....

We are starting to fill that gap……

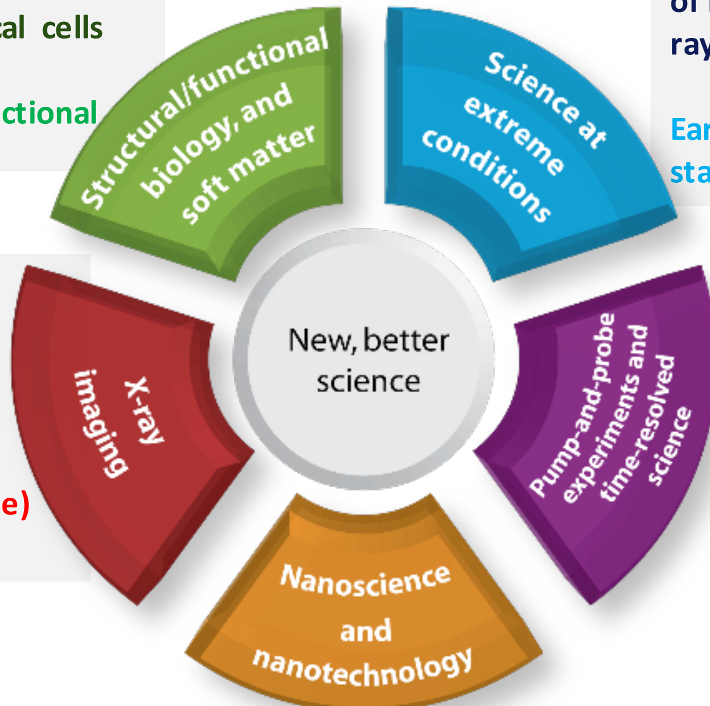
ESRF UPGRADE PROGRAMME: SCIENCE CASE

Revolutionizing life sciences at the ESRF: from serial crystallography to molecular machines in functional biological cells

Structure and Dynamics of Functional Biological Units

Revealing the hidden treasures of Nature with a diffraction-limited X-ray Source

Earth & Planetary Science, Novel states of matter

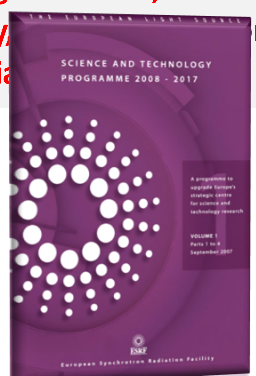


Time-resolved bio-response of organisms to exogenous materials

Bio-regeneration, Evolutionary Biology, ... mposite) Materia...

Diffraction-limited sources: opportunities for in-situ studies

Energy S... Catalysis ... Material...



Purple Book January 2008

5D diffraction imaging of electronic devices and nanostructures

Nanotechnology, Information technology, Quantum computing

Orange Book January 2015

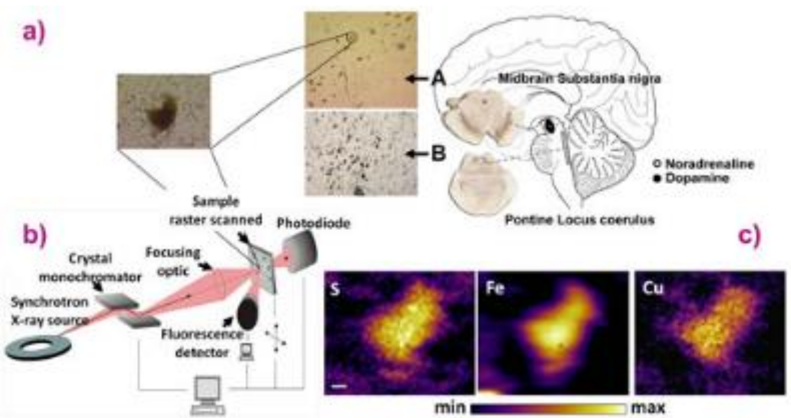
Opportunities in biological systems

- Probing the bioresponse to exogenous materials with ultimate sensitivity and resolution
- Multiscale analysis of heterogeneous materials
- Low-dose *in vivo* tomography of living organisms

One of the big challenges for our aging societies: Degenerative diseases

Alzheimer's disease, Parkinson's disease

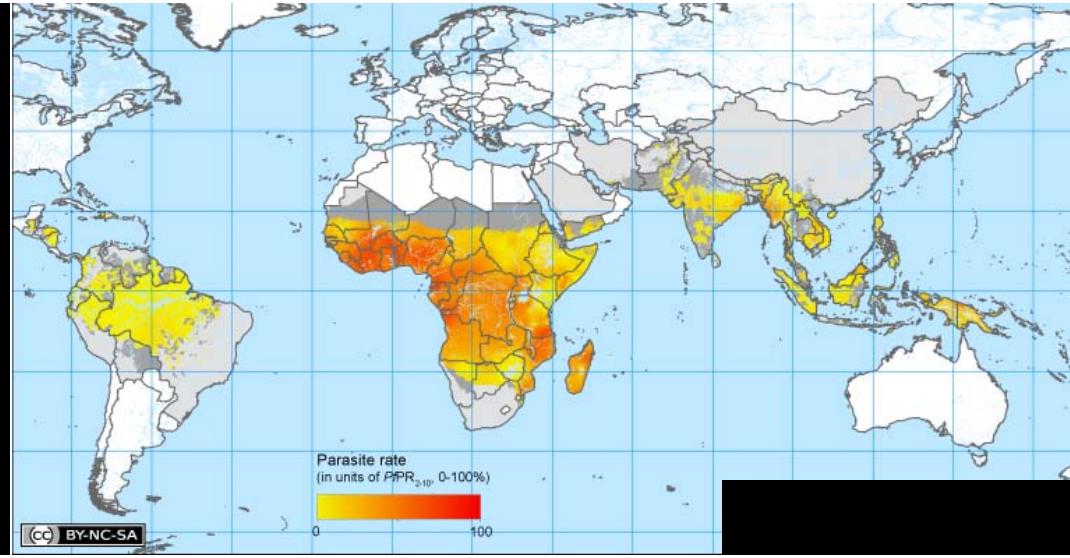
Copper pathology in vulnerable brain regions in Parkinson's disease



Davis *et al.* 2014, Neurobiology of Aging

Limitations	Solution
spatial resolution	higher brightness
detection limit	higher brightness
radiation damage	better detectors
data analysis	IT and software

Sub-cellular label-free localization of anti-malarian drugs



CJL Murray et al., Lancet 2012; 379: 413

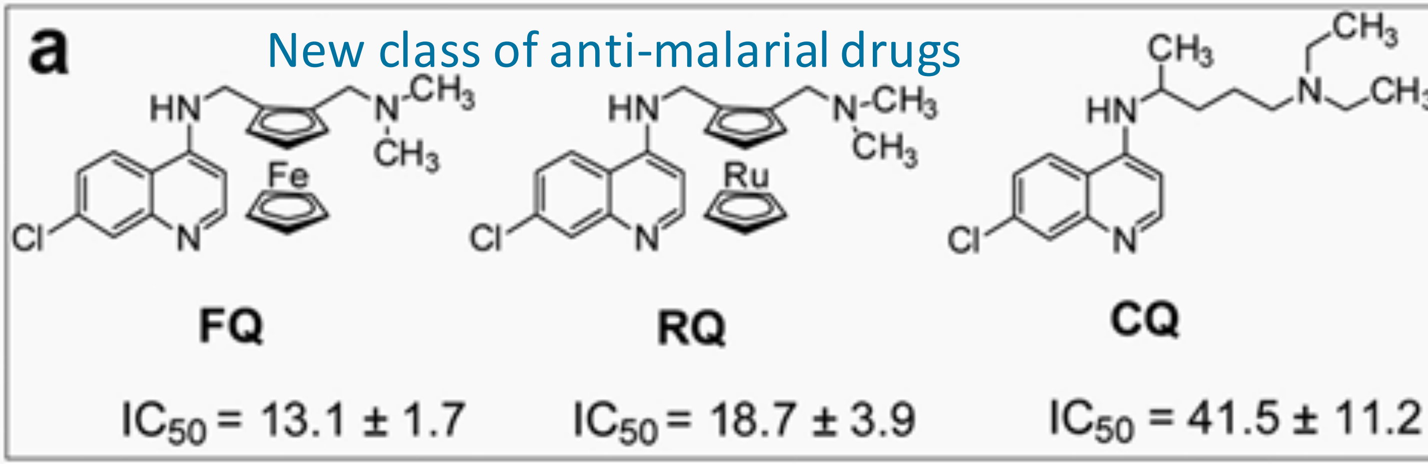
Malaria:

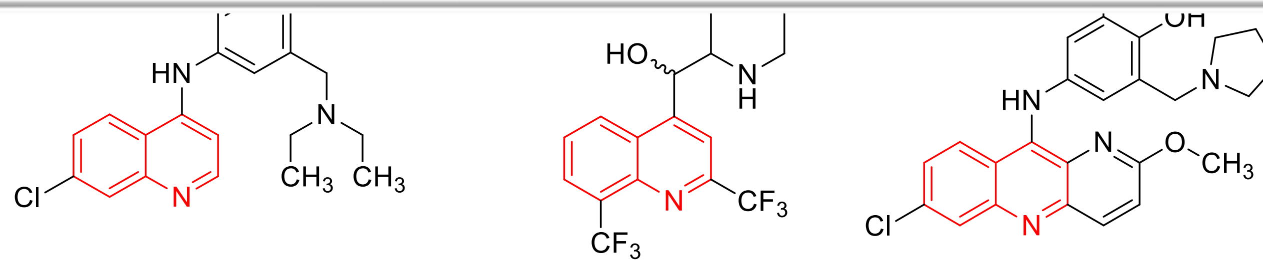
- 3-500 million clinical cases per year
- ~1.2 million deaths (mostly children under five)

- Resistance of main parasite to existing drugs
- Essential to constantly develop new anti-malarian drugs

Inserm Institut national de la santé et de la recherche médicale | Institut Pasteur de Lille | CNRS | Université Lille Nord de France | SANOFI

Quinine | Primaquine | Chloroquine



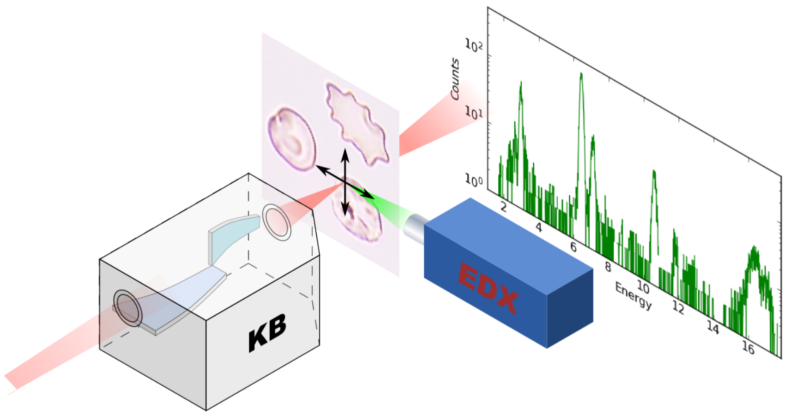


1948-1980

1977-1982

SUB-CELLULAR LABEL-FREE LOCALIZATION OF ANTI-MALARIAN DRUGS

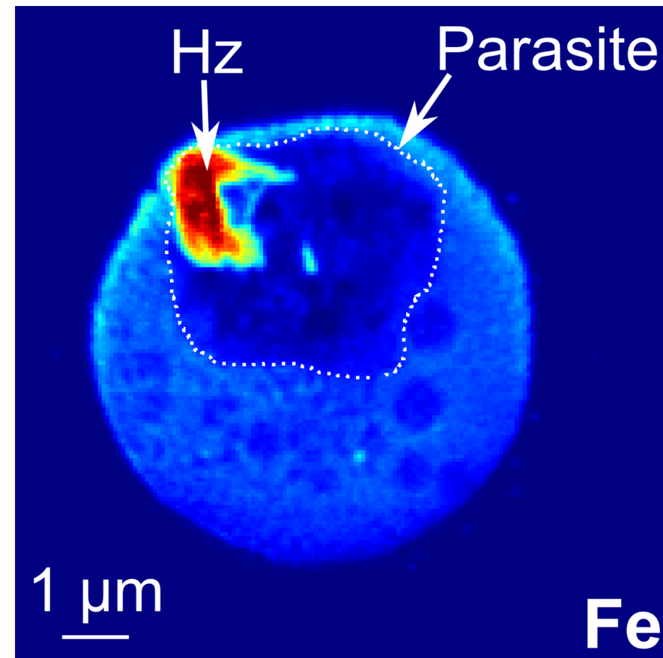
Synchrotron *nano*-probe techniques contribute to the localization of new drugs and to the elucidation of their action mechanisms.



ESRF *nano*-probe ID22NI-ID16B
50 nm pixel, flux ~ 5 10^{11} ph/s
E_0 = 17 keV, 100 ms dwell-time

Simultaneous acquisition of the **fluorescence signature of most elements of biological interest**

Fe fluorescence
in malaria infected red blood cell

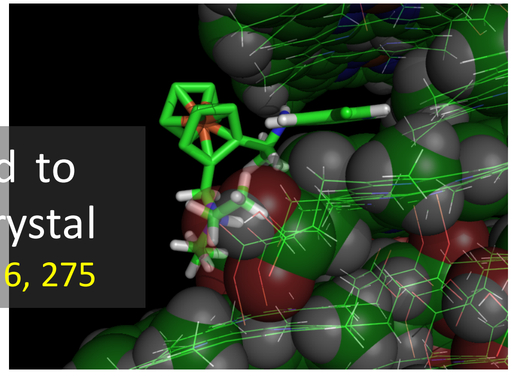


F Dubar et al., Chem. Comm. 48, 910 (2012)

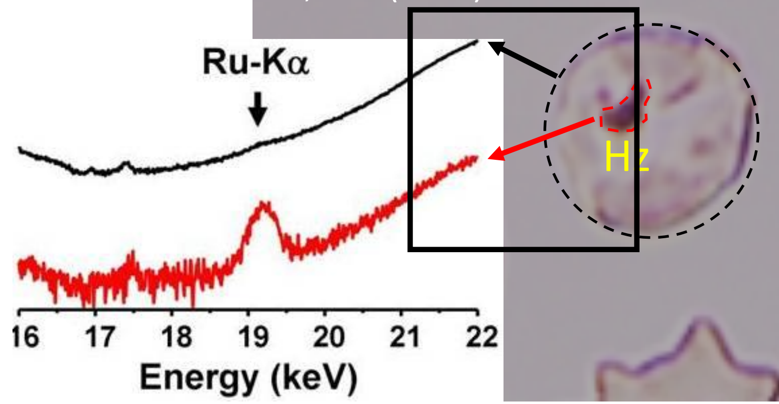
SUB-CELLULAR LABEL-FREE LOCALIZATION OF ANTI-MALARIAN DRUGS

Localization of a new drug candidate
Ruthenoquine (Ferroquine equivalent)

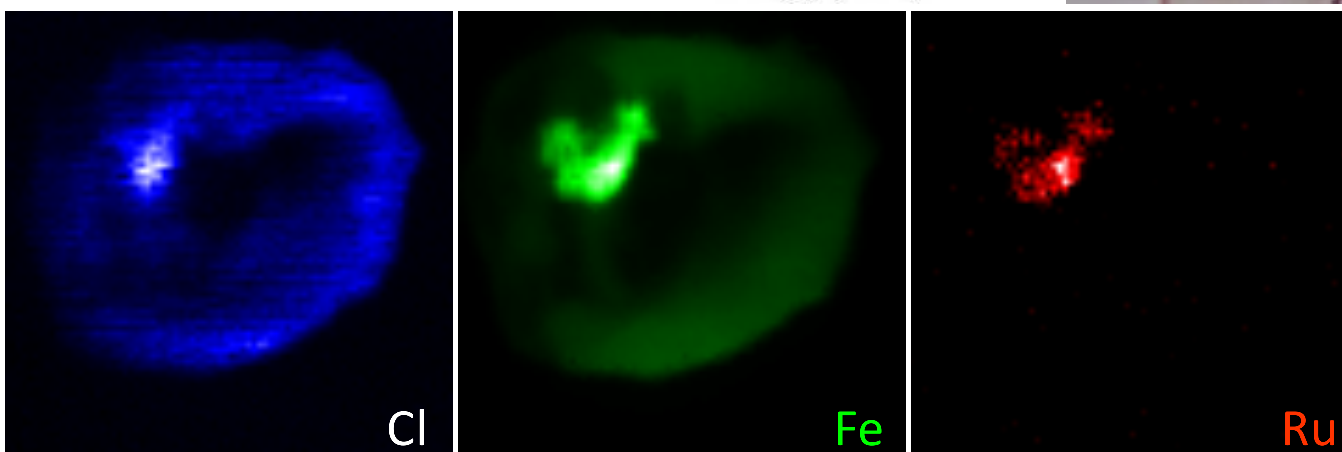
Ferroquine bound to Hemozoin (Hz) crystal
ACS Chem Biol, 2011, 6, 275



F Dubar et al., Chem. Commun. 48, 910 (2012)



E_0=29 keV



Opportunities at cellular and molecular levels

- *Ab initio* crystal structure determination of large protein complexes
- Room temperature serial protein crystallography of microcrystals
- High resolution imaging of cells and probing protein structural dynamics during physiological activity

Body

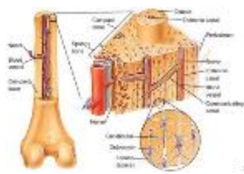
Tissues

Cells

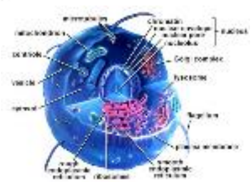
Organelles

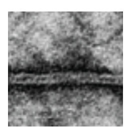
Large complexes

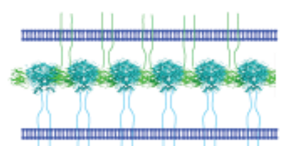
Proteins



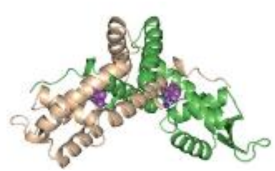
X-rays







TEM



X-rays

Limitations	Solution
spatial resolution	coherence
radiation damage	better detectors
data analysis	IT and software

WHY SX?

Serial crystallography (SX):

Assembly of a complete dataset from multiple images or sub-datasets, usually from many crystals

- **Much higher effective doses possible**
- **Less optimisation of crystal size**
- **No crystal harvesting :**

Harvesting (without a robot) is a significant bottleneck

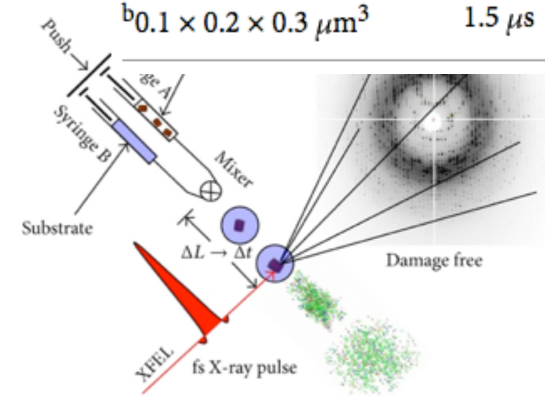
Handling can damage crystals

- **Kinetics: optical pump probe and stopped flow**
- **Microcrystals are better for:**

Soaking – diffusion through small crystals is much faster

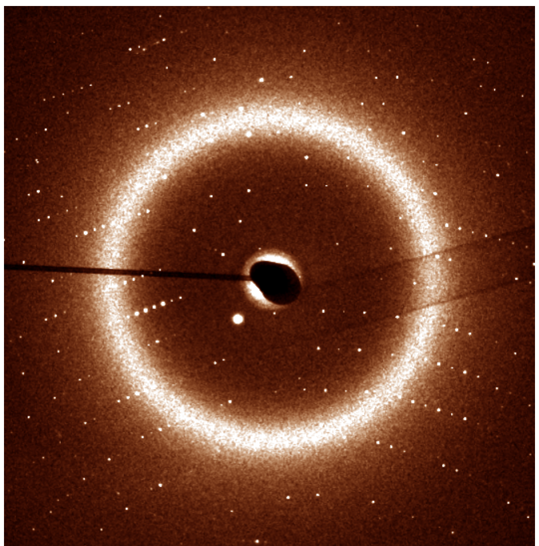
Optical penetration depth

Crystal size	τ_D
$400 \times 400 \times 1600\ \mu m^3$	16 s (3) 24 s [60] <1 min [59]
$300 \times 400 \times 500\ \mu m^3$	9.5 s
$10 \times 20 \times 30\ \mu m^3$	15 ms
$3 \times 4 \times 5\ \mu m^3$	1 ms
[a]$1 \times 2 \times 3\ \mu m^3$	150 μs
$0.5 \times 0.5 \times 0.5\ \mu m^3$	17 μs
[b]$0.1 \times 0.2 \times 0.3\ \mu m^3$	1.5 μs



Schmidt, M., "Mix and Inject: Reaction Initiation by Diffusion for Time-Resolved Macromolecular Crystallography", *Adv. Condens. Matter Phys.* ***2013, e167276 (2013).***

SX AT THE ESRF



Membrane-Protein

Serial Micro-Crystallography

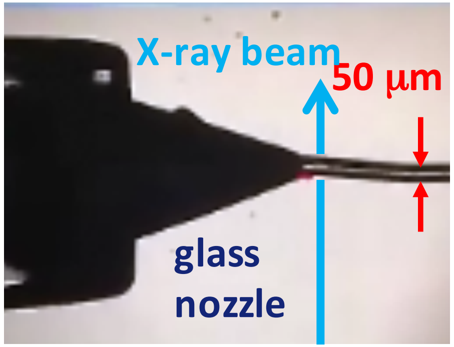
using

Synchrotron Radiation

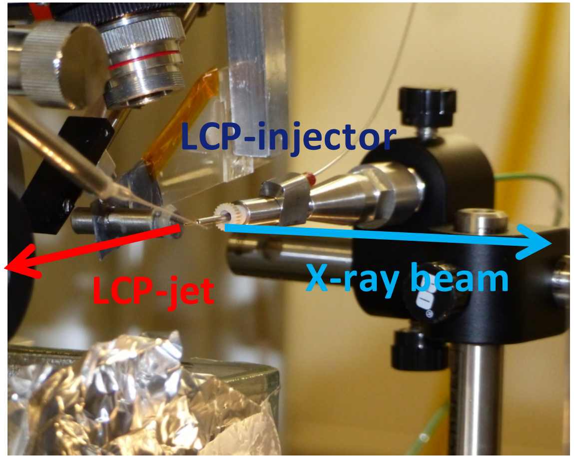
and a

Liquid Cubic Phase Injector

MICRO-BEAM LCP-INJECTOR SETUP AT ID13



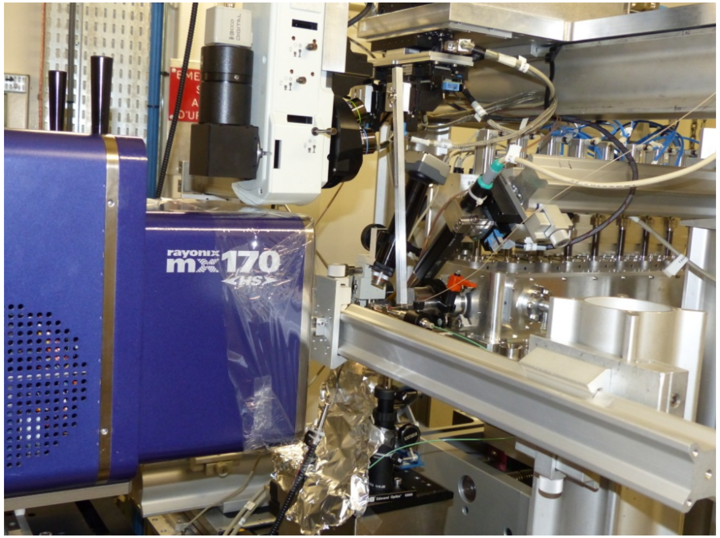
micro-beam 13 keV, 8x10^{11} ph/sec
3x2 μm^2 (FWHM HxV)



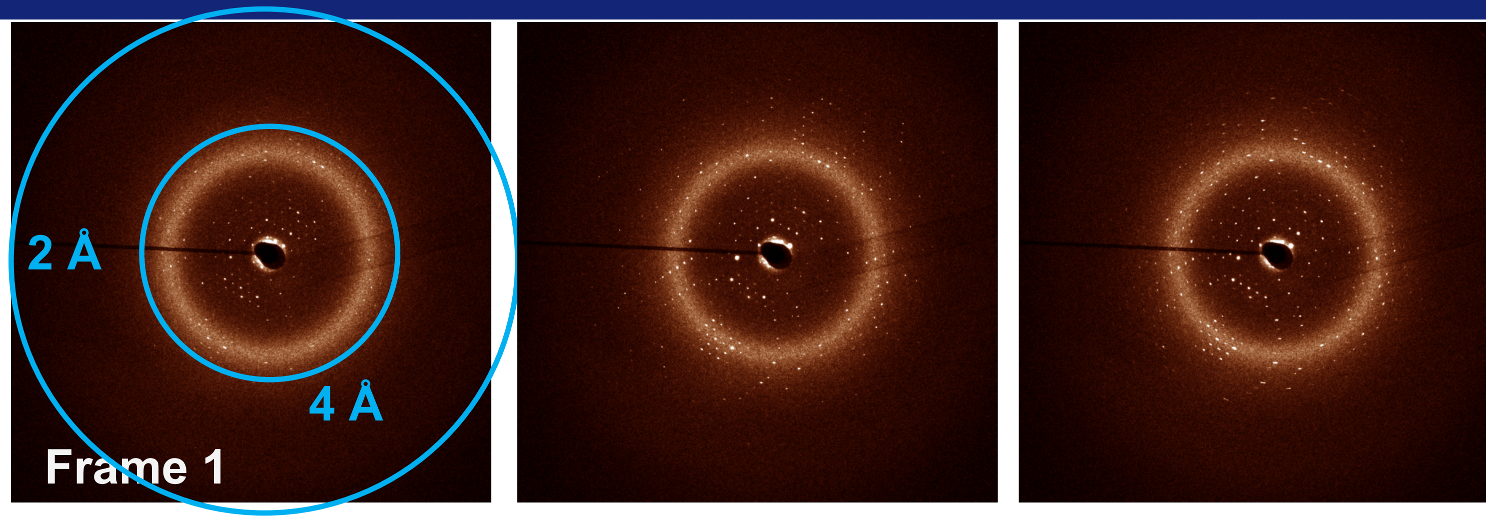
liquid cubic phase (LCP) injector in operation

- pressurized via HPLC pump
- helium mantle stream
- LCP-jet with 50 mm diameter
- velocity of LCP-jet: 100 mm/sec

Weierstall et al.: Nature Communications (2014) 5, 3309



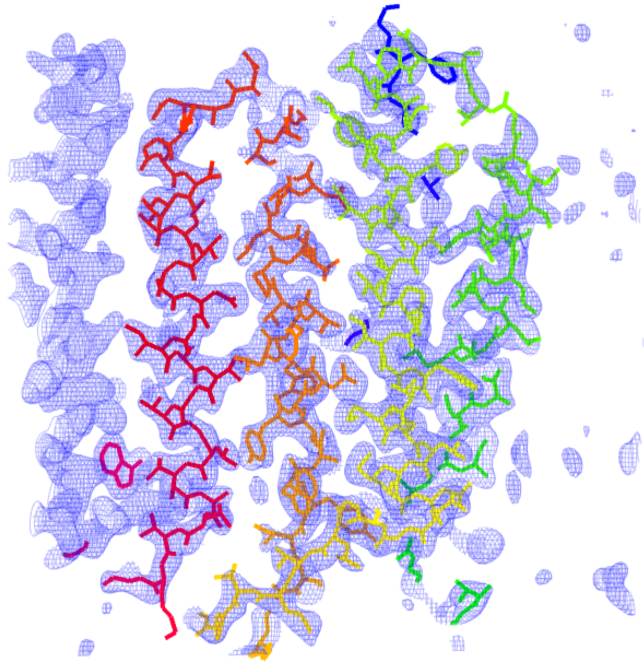
BACTERIORHODOPSIN MICRO-CRYSTAL FLY-BY IN 3 SUBSEQUENT FRAMES

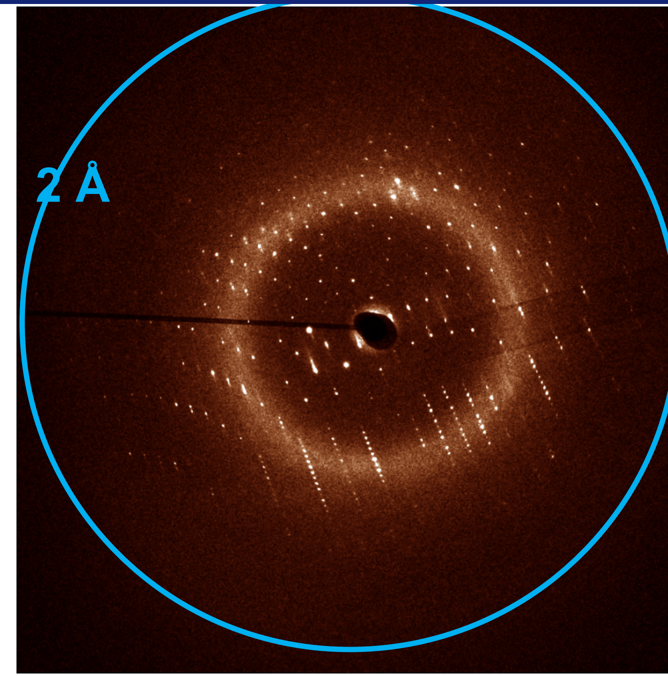


Average travel per 25 ms exposure: 2.5 µm
Crystal detected in 3 subsequent frames
>> crystal size ~ 30 µm
(preliminary evaluation:
Typical hit rate in the percent range limited by overhead and crystal concentration)

Foreseen for Summer 2016 at ID13:
EIGER 4M pixel array detector for quasi-continuous exposure @ 750 Hz
80-90 % of the sample could be used
ESRF storage ring upgrade << µs exposure possible

BACTERIORHODOPSIN STRUCTURE REFINEMENT FROM SERIAL DATA





Preliminary data analysis and structure refinement of **Bacteriorhodopsin** membrane protein test crystals from synchrotron LCP-jet serial data at ID13 (electron density map current resolution 2.7 Å)

Acknowledgement:

R. Neutze (Gothenburg unniv., S):

I. Moraes (Imperial college, Diamond Light Source, UK),

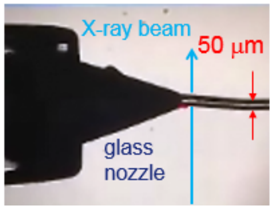
Weierstall et al. (Arizona State University, USA): LCP-injector

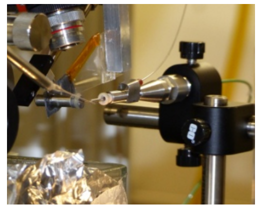
G. Schertler, J. Standfuss et al. (PSI, CH),

H. Chapman, T. White T., et al (Desy/Petra/C-FEL , D)

SYNCHROTRON SERIAL CRYSTALLOGRAPHY (SSC) EFFORTS AT THE ESRF

Liquid cubic phase injector

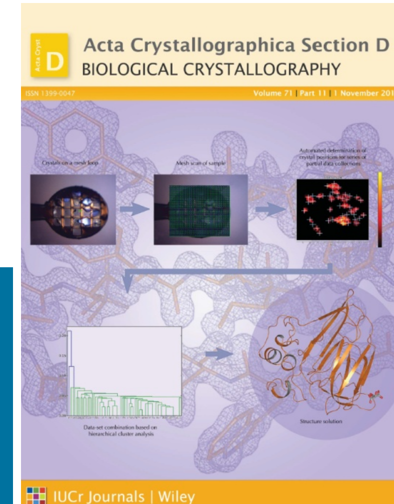




Injectors

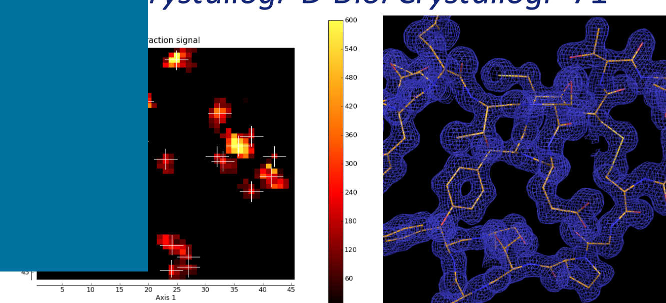
Nogly, et al., (2015), IUCrJ 2, 168-176, (ID13)

Multi-crystal workflows



r, et al., (2015).

rystallogr D Biol Crystallogr 71



Current

- Mini oscillation techniques (Zander *et al.*, 2015)
- Capillaries (Stellato *et al., 2014*)
- Si "Sandwiches" (Coquelle *et al*, 2015)
- Cubic lipidic phase injector (Nogly *et al.*, 2015)
- Grease Injector (Botha *et al.*, 2015)

Future

- Fluidic chips (Heymann *et al.*, 2014)
- In vacuum (Warren *et al.*, 2015)

SYNCHROTRON VS. XFEL VS CRYOEM

	FEL	Synchrotron SX	CryoEM
Mol. Weight (Da)	1->mega	1->mega	~100 kD->mega
Resolution	+++	+++	+
Crystal size	Nano-micro Eventually: NA (single particle)	Micro	NA: No crystallization necessary
Pump probe time resolution	fs	ms, μs	NA
Maximum dose	Up to GGy/position?	Up to 20 MGy per position at cryo (less at ambient)	~20MGy, cryo

SYNCHROTRON VS. XFEL VS CRYOEM

	FEL	Synchrotron SX	CryoEM
Experiment length	Fixed target: minutes Jet: hours	Fixed target: minutes Jet: hours	Hours
Pump probe time resolution	fs	ms, µs	NA
Detector maturity	+	+++	++
Sample preparation	Difficult: Crystallisation	Difficult: Crystallisation	Difficult: Grid prep, freezing
Instrument cost and availability	+++	+	++
Phasing	In development	Highly mature	Optical phases
Sample consumption	Jet: high	Jet: high	low
Required compute resources	++	+	+++

SPECIFIC AREAS FOR IMPROVEMENT IN SYNCHROTRON AND XFEL SX

Flux – EBS!

- Faster transit times for crystals, ms->μs
- Faster dynamics studies, ms->μs

Sample

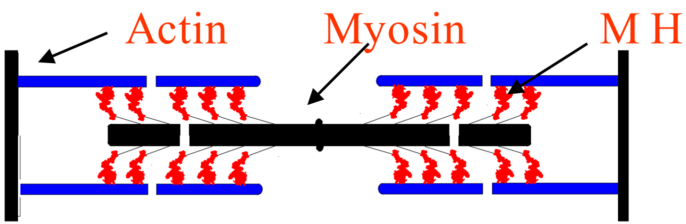
- High speed motorisation (
- In vacuum collection
- Optical pump probe setups, chemical mixing

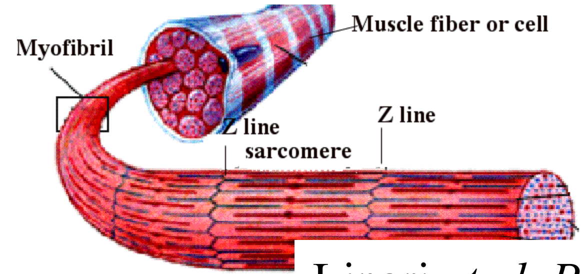
Detectors

- Readout rate
- "Hybrid" technologies with no count rate limitations
- Pixel size adapted to micro/nano crystals
- Improved dynamic range at high frame rate

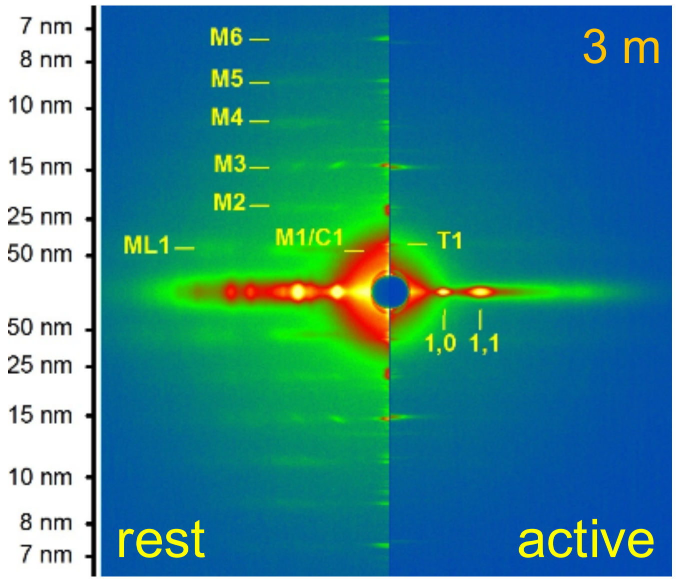
Many opportunities for common development efforts

DIFFRACTION FROM MUSCLE CELLS





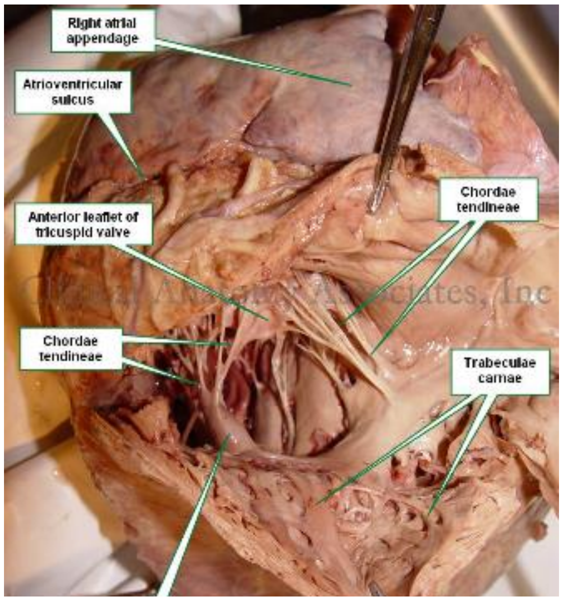
V. Lombardi *et al.*, Florence



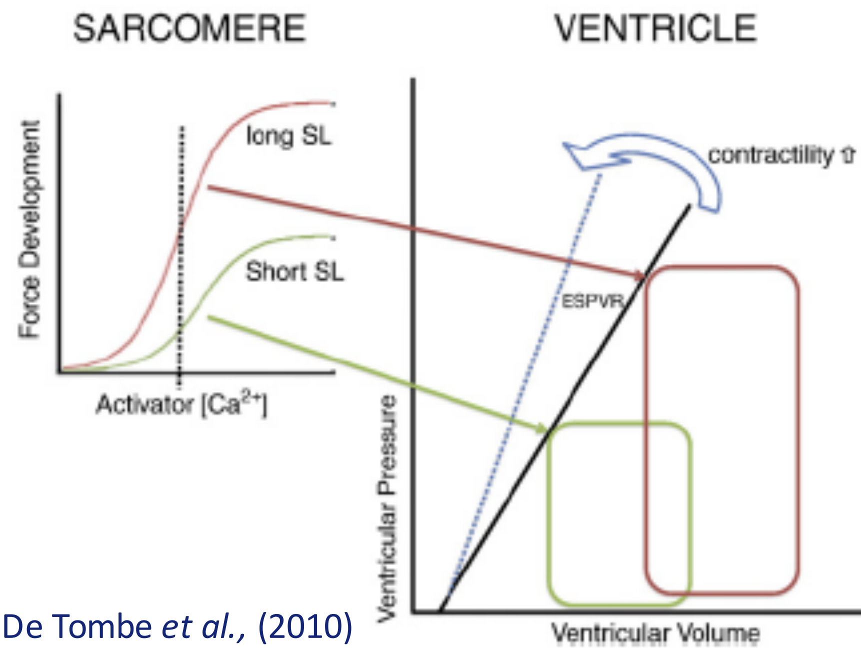
Linari *et al. PNAS*, **97**, 7226 (2000)
Piazzesi *et al. Nature*, **415**, 659 (2002)
Riconditi *et al. Nature*, **428**, 578 (2004)
Brunello *et al. PNAS*, **104**, 20114 (2007)
Riconditi *et al, PNAS,* **108**, 7236 (2011)
Linari *et al. Nature*, **528**, 276 (2015)

Interference fine structure: Time-resolved studies under physiological conditions

Frank-Starling Law of the heart: the force during contraction (systole) is adapted to the volume at the end of the relaxation (diastole)



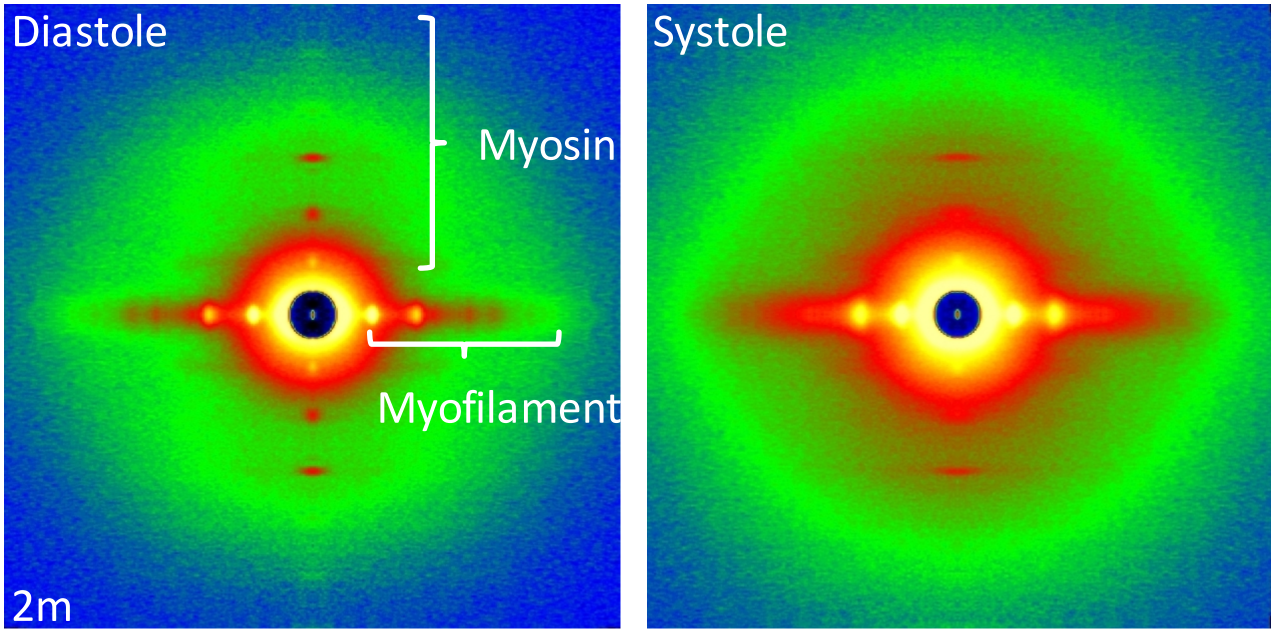
Picture of a mammalian heart showing the interior of the right ventricle.



P. De Tombe *et al.*, (2010)

Probing the molecular mechanism underlying this property of the heart

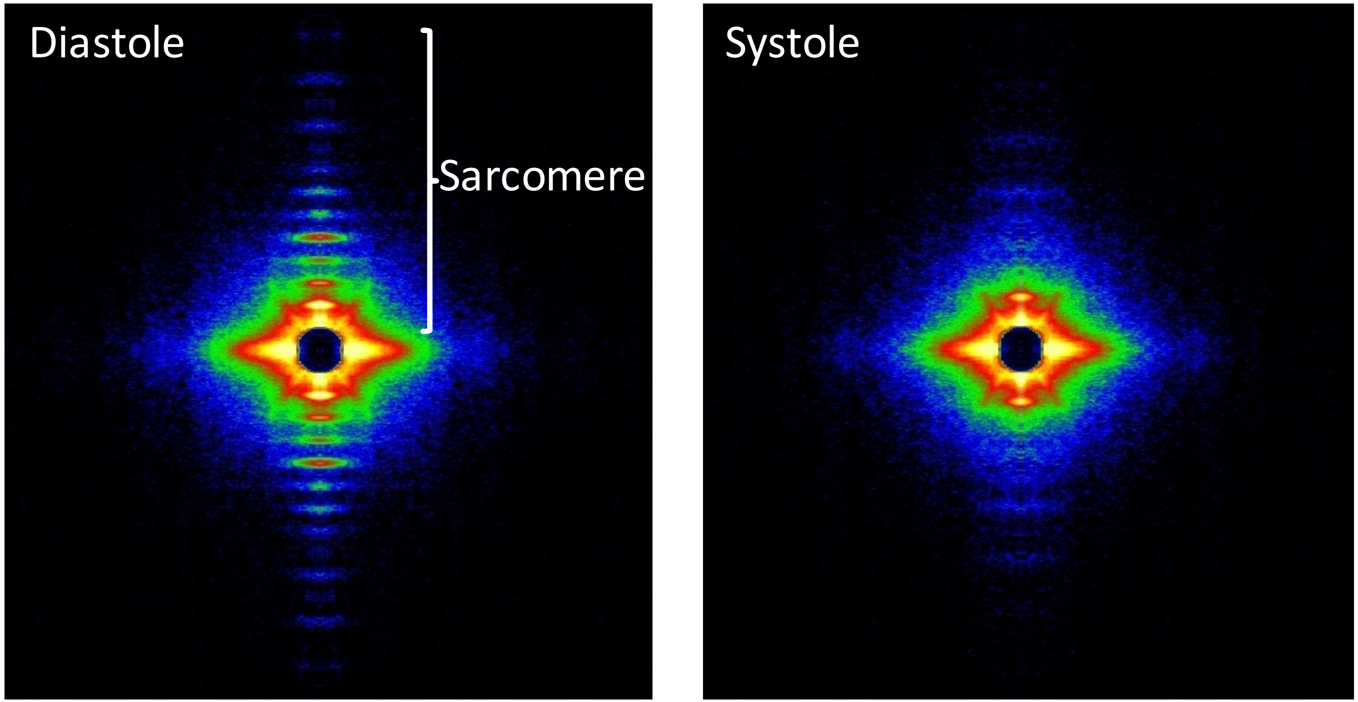
Small-Angle Diffraction from Cardiac Muscle Trabecula (~100 μm) of Rat



V. Lombardi (Florence), G. Stienen (Amsterdam), *et al.*

DIFFRACTION FROM THE CARDIAC MUSCLE

Ultra low angle diffraction reveals changes at the sarcomere (unit cell) during the activation and probe the supramolecular organization within



Allows to derive the force-sarcomere length relationship and to observe significant changes in the supramolecular organization

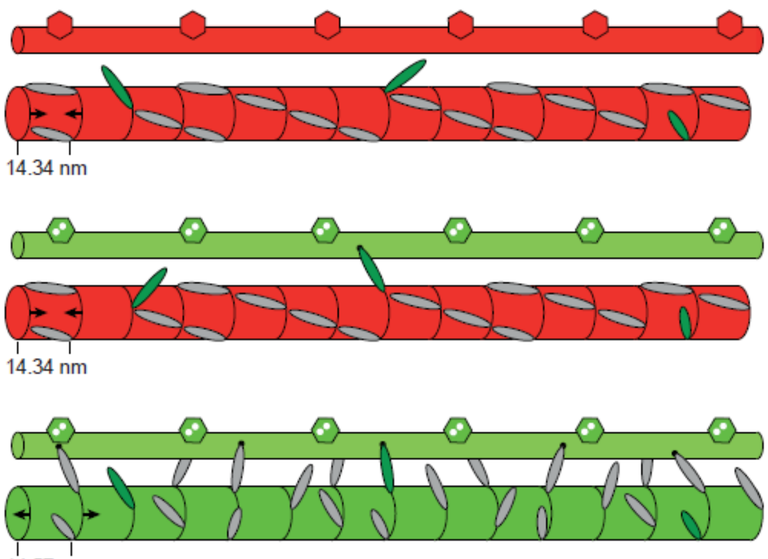
LENGTH DEPENDENT ACTIVATION OF THE CARDIAC MUSCLE

LETTER

Nature 2015
doi:10.1038/nature15727

Force generation by skeletal muscle is controlled by mechanosensing in myosin filaments

Marco Linari[1,2], Elisabetta Brunello[1]†, Massimo Reconditi[1,2], Luca Fusi[3], Marco Caremani[1], Theyencheri Narayanan[4], Gabriella Piazzesi[1], Vincenzo Lombardi[1] & Malcolm Irving[3]



Dual filament mechanism:

OFF/ON states of myosin motors

Mechanosensing action:

More motors turned on at high load

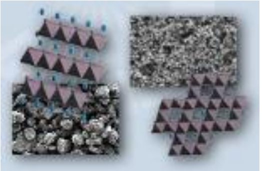
The same mechanism seems to work in the cardiac muscle

IN-SITU MATERIALS CHEMISTRY & MATERIALS PROCESSING

Opportunities in In-situ material chemistry

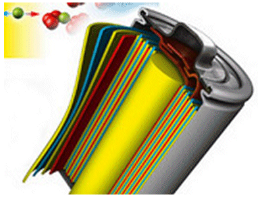
- Materials chemistry for devices to solve grand challenges in clean energy provision and transport
- A 'chemically resolved X-ray vision' on working catalysts and devices for a green energy economy
- Understanding and optimising complex devices on realistic time scales

Ni-Co-Mn compounds for electrodes



$LiFePO_4$ cathode material

new materials: characterisation



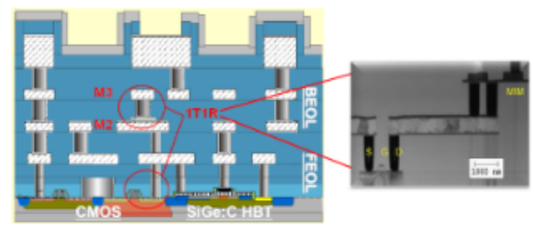
device development: in-situ studies

Limitations	Solution
spatial resolution	brightness
time resolution	brightness
penetration	high energy
data analysis	IT and software

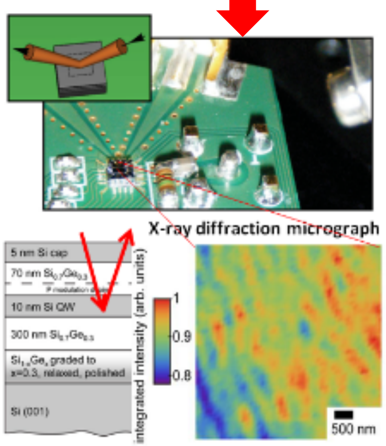
Opportunities

- *In situ* imaging of strain and chemical composition in biocompatible sensors
- Device imaging and failure analysis under operating conditions: from solar cells to quantum computers
- Three dimensional imaging of nano-electronic building blocks

Strategy for European Semiconductor Industry: more than Moore



Back-end of line integration of non volatile RRAM into a SiGe BiCMOS chip technology for system on chip solutions

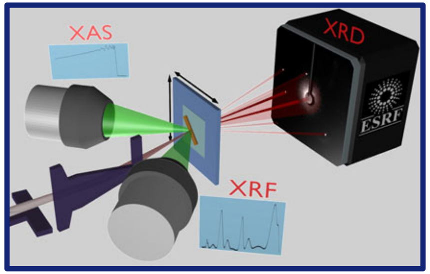


Quantum computing device
Evans et al. (2012)
Advanced Materials

Limitations	Solution
spatial resolution	coherence
strain resolution	coherence
time resolution	brightness
data analysis	IT and software

Beamline Synopsis:

ID16B is a versatile *hard X-ray nanoprobe* devoted to X-ray nano-analysis, consisting of the combination of X-ray fluorescence, X-ray diffraction, X-ray absorption spectroscopy and 2D/3D X-ray imaging techniques.



Beamline Team:

Gema Martinez-Criado

Julie Villanova

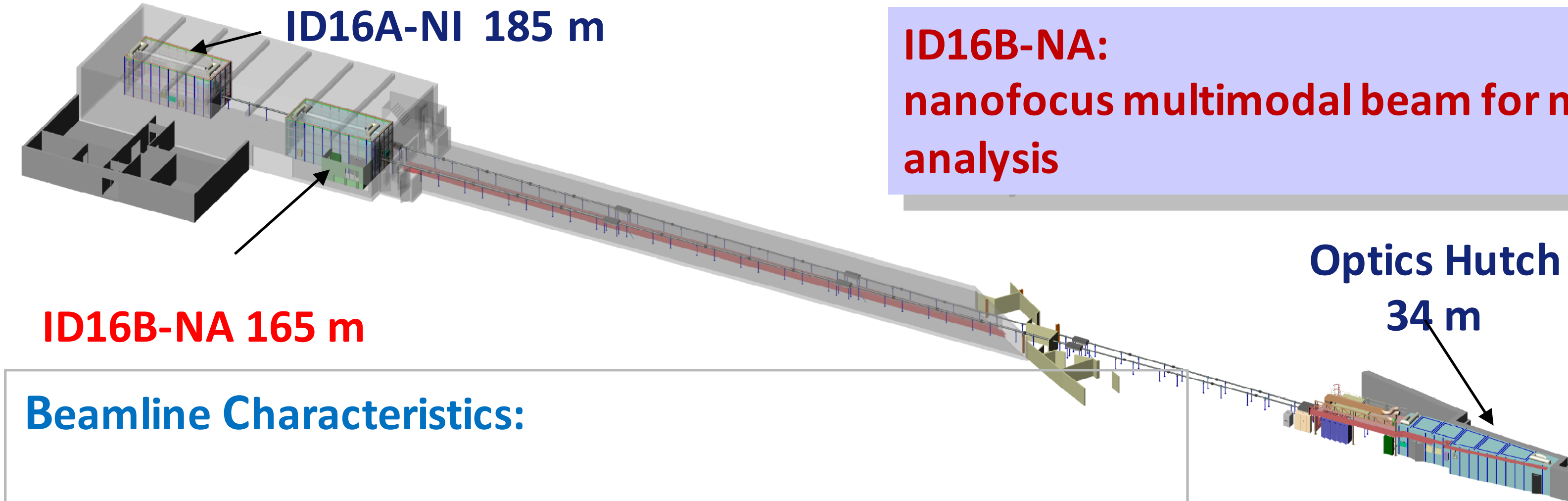
Remi Tucoulou

Sylvain Laboure

Damien Salomon

Jussi-Petteri Suuronen

ID16 NANOPROBE



ID16B-NA:
nanofocus multimodal beam for nano-analysis

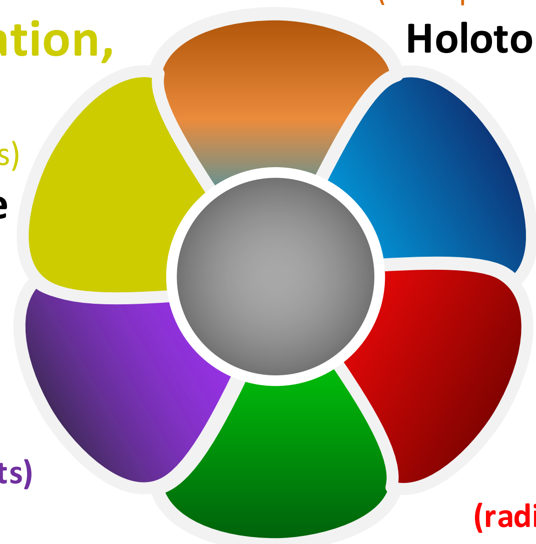
Beamline Characteristics:

- Beam size: 50 x 50 nm^2
- Energy range: 5 – 65 keV
- Photon flux: 10^9 – 10^{11} ph/sec
- $\Delta E/E$: 10^{-2} – 10^{-4}
- Beam operation modes: pink and monochromatic
- Techniques: XRF, XRD, XRI, XAS, XEOL, XBIC
- Studies: *in-situ, in –operando* & time-resolved experiments

ID16B METHODS

Microstructure
(multiphases, porous size)
Holotomography

Quantitative Information, Homogeneity
(Impurity content, clusters)
X-Ray Fluorescence



Oxidation States
(polytypes, mixed valence)
XANES

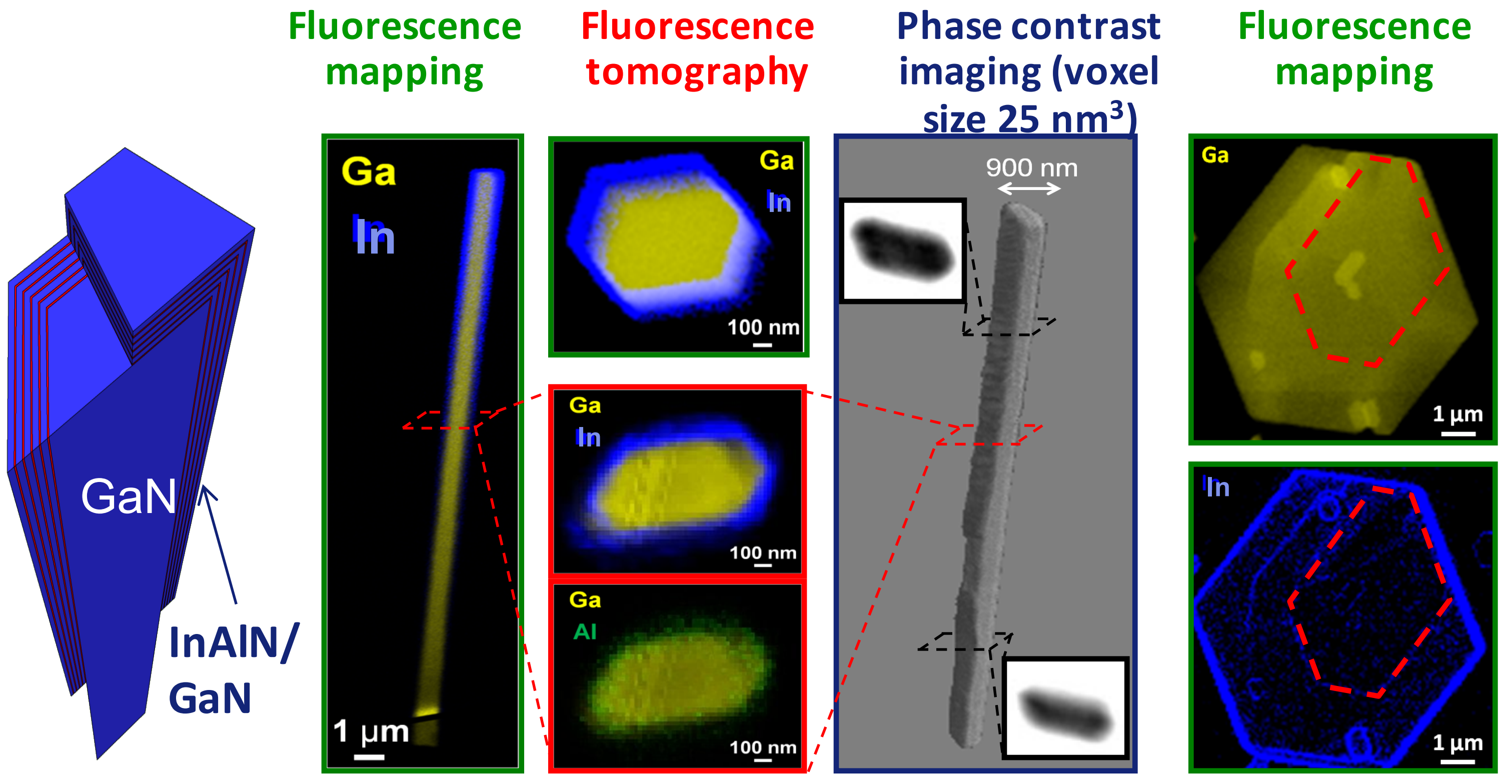
Long Range Order
(structure, grain size, strain effects)
X-Ray Diffraction

Optical transitions
(radiative recombinations, gap states)
X-Ray Excited Optical Luminescence

Local Structural Order
(interatomic distance, coordination)
EXAFS

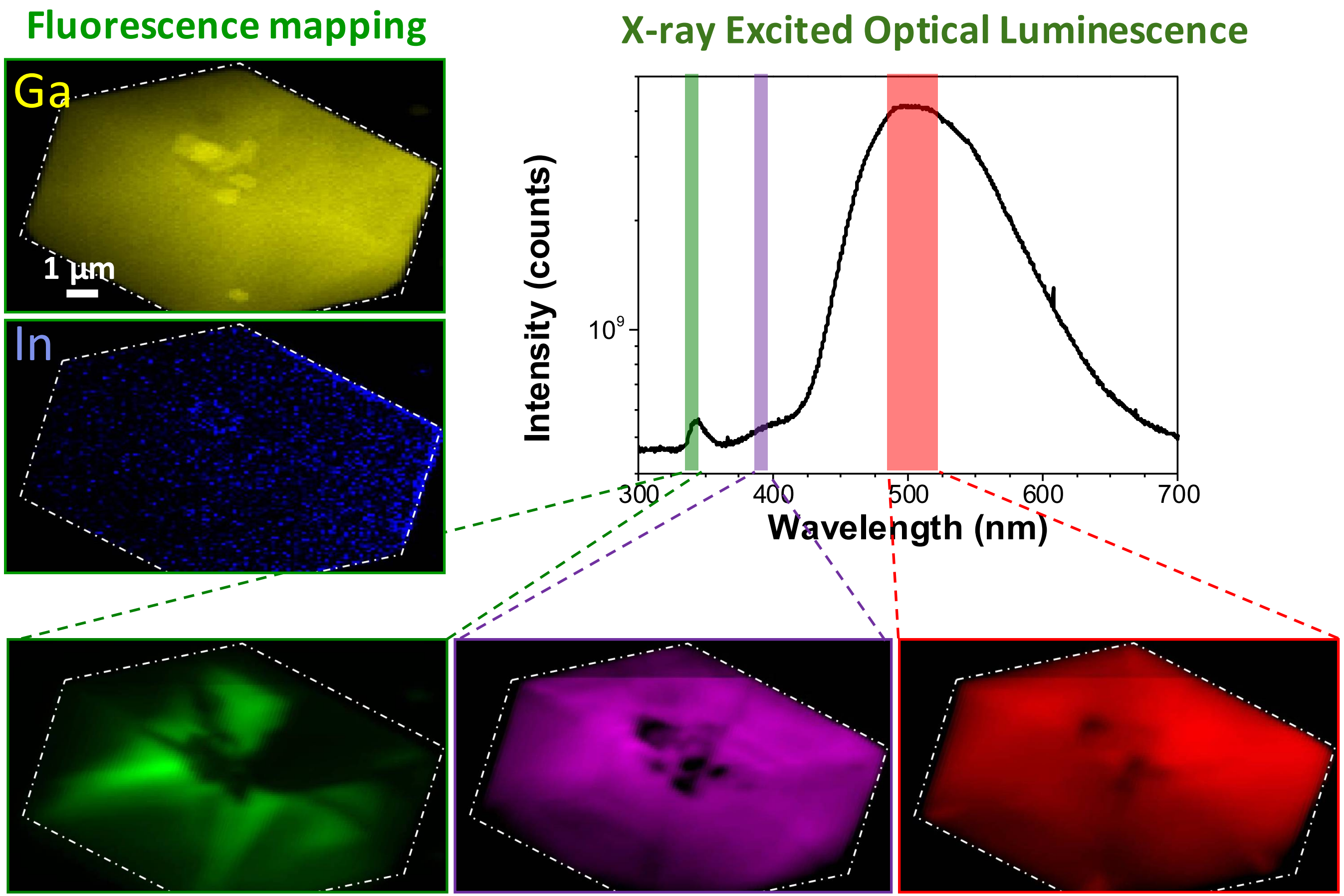
ID16B: COMBINATION OF DIFFERENT TECHNIQUES

GaN: the heart of the Nobel's Led

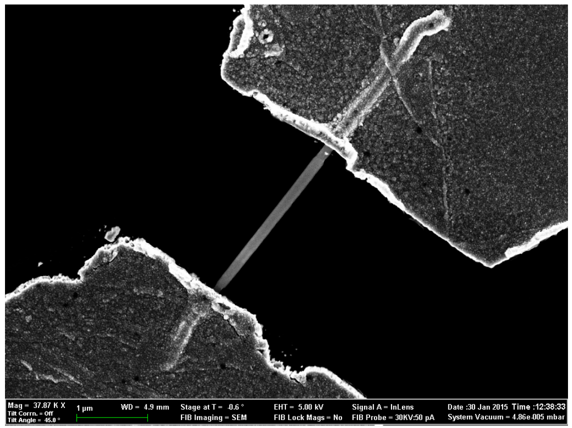


Akasaki, Amano & Nakamura: 2014 Physics Nobel Laureates

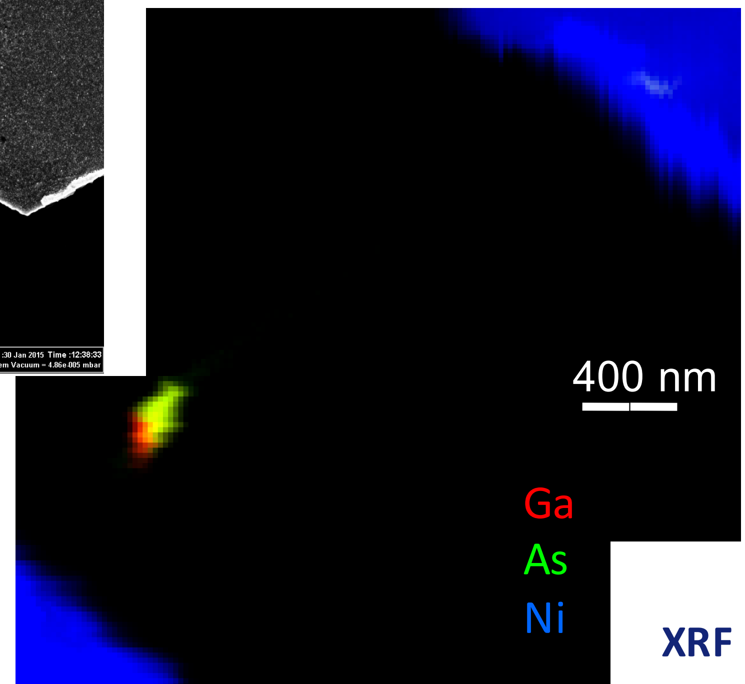
NANO-XEOL OF GAN



A GaAs quantum dot in a Si nanowire!



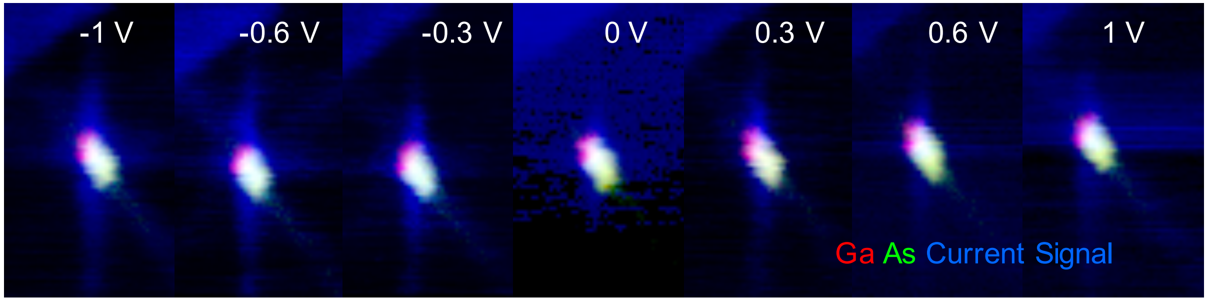
SEM



XRF

NANO-X RAY BEAM INDUCED CURRENT: XBIC VERSUS VOLTAGE

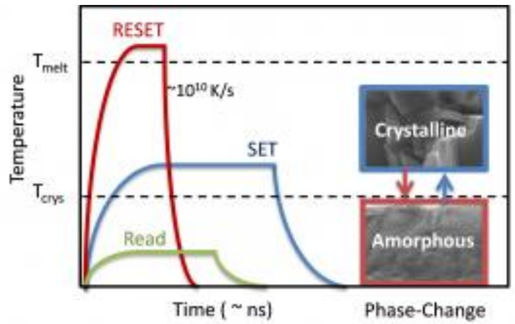
- current measured while scanning the X-ray nanobeam on contacted wire
  - blue-to-white: current signal (on log colour scale)
  - red: Ga, green: As (from fluorescence mapping)
- bias voltage on contact
- current signal
  - intense at the hetero-junction
  - the vertical and horizontal lines are from the beam
  - the top-left to bottom-right diagonal is from current induced in the Si wire
  - in the top left corner is the contact

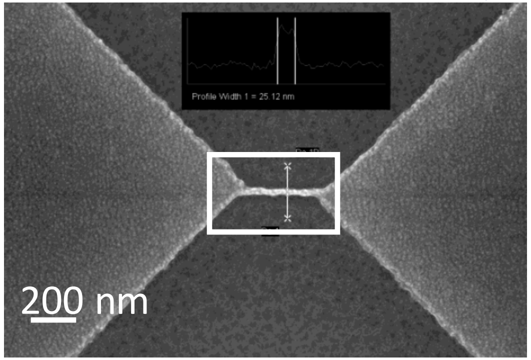


Phase–Change Memories (PCM)

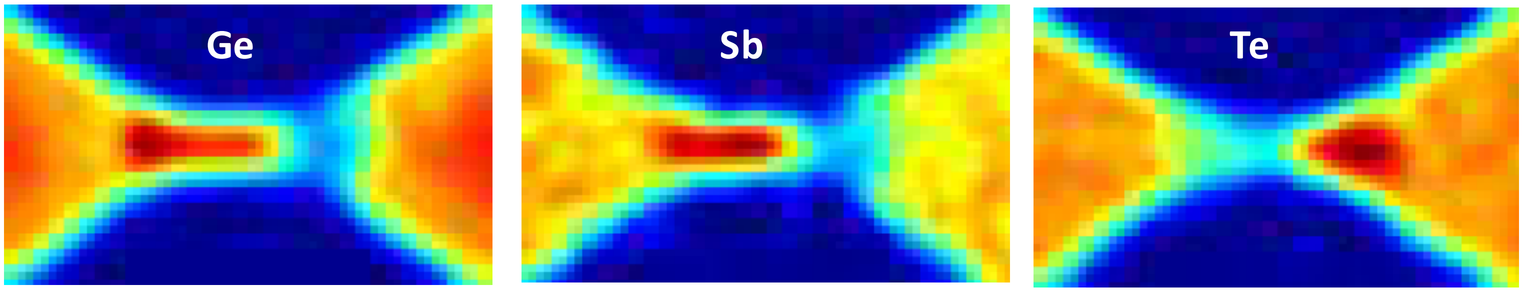
By Gisuseppe D-Arrigo *at al.* Institute of Microelectronics and Microsystems, CNR, Catania, Italy

Ge2Sb2Te5 system



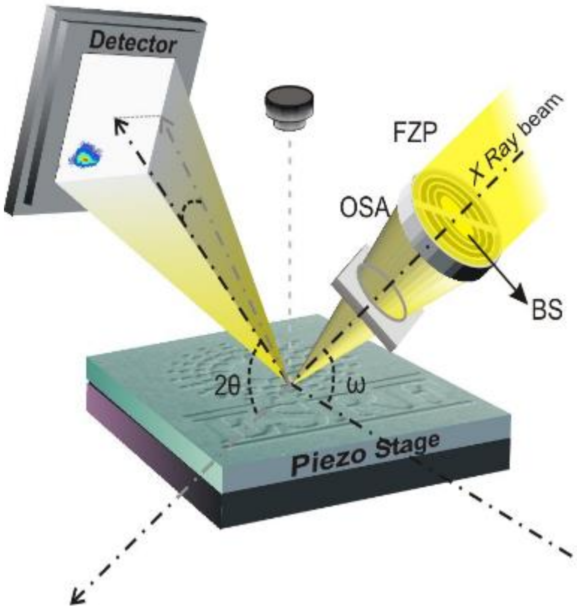


Single GST line



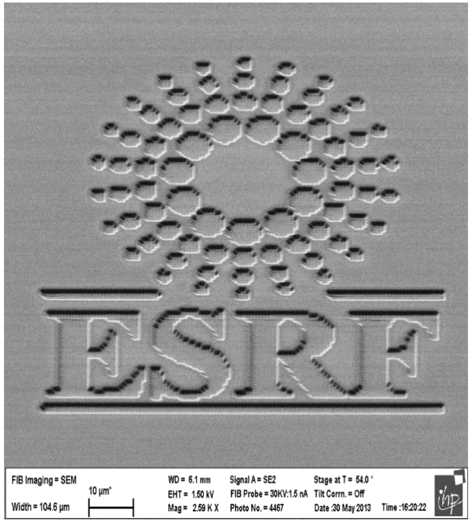
Iterations of SET and RESET: segregation effects, ions migration, etc.

- **ID01: nanofocused beam** (150 nm x 300 nm)

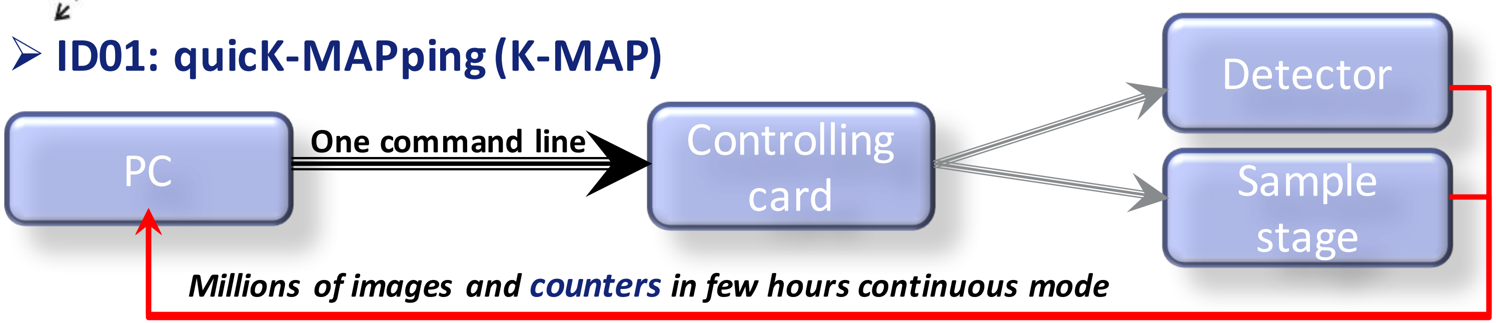


ESRF logo etched by FIB into a SiGe film on Si(001)

90 µm

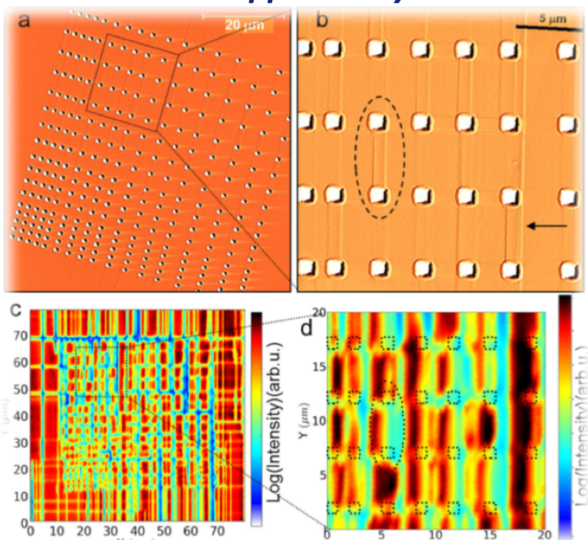


- **ID01: quicK-MAPping (K-MAP)**

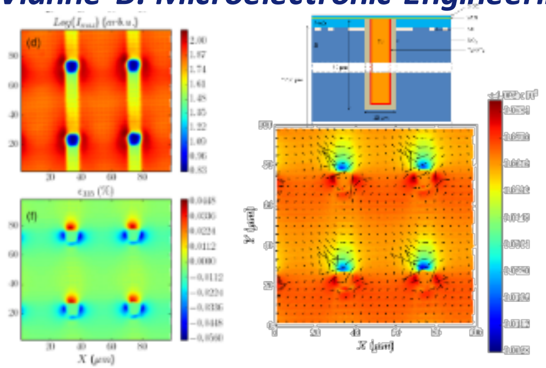


K-MAPPING FOR DEVICE COMMUNITY

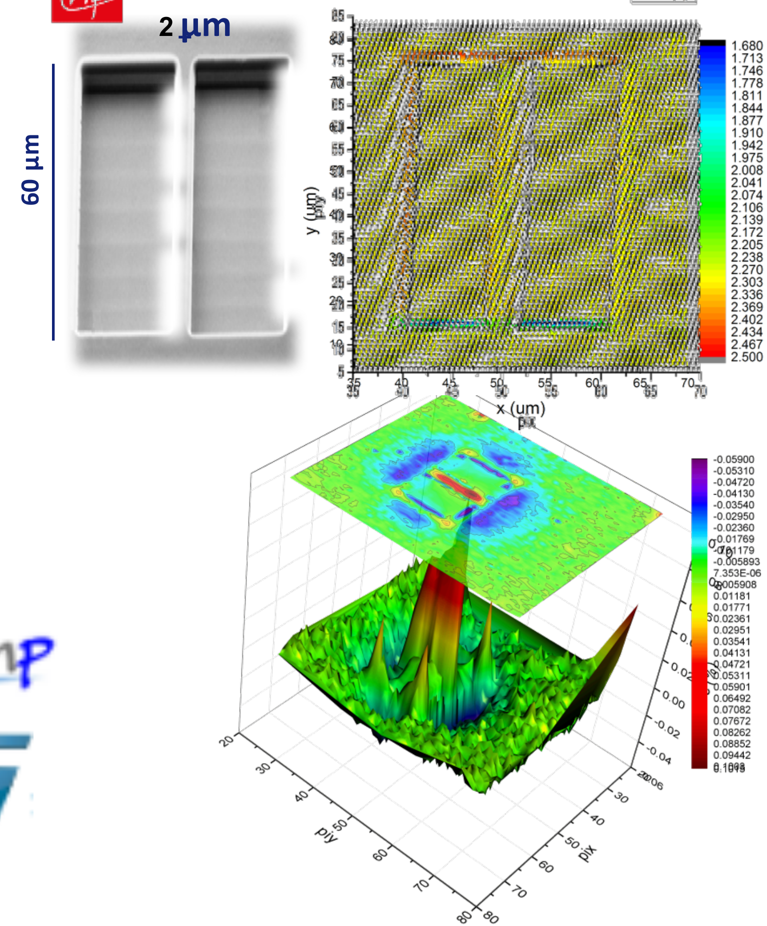
Mondiali et al. Applied Physics Letters



Vianne B. Microelectronic Engineering



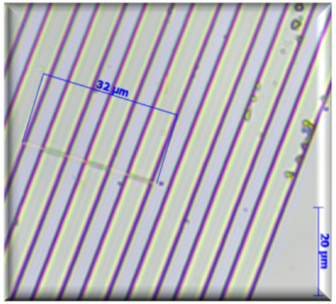
Capellini et al. J. Appl. Phys. (2013)



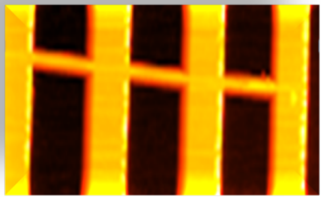
FIRST USER EXPERIMENT: *IN-SITU* BENDING OF AN AU NANOWIRE

➢ **Top view of Si (001) trenches and a Au NW (150 nm x 30 µm) with:**

ID01 optical microscope



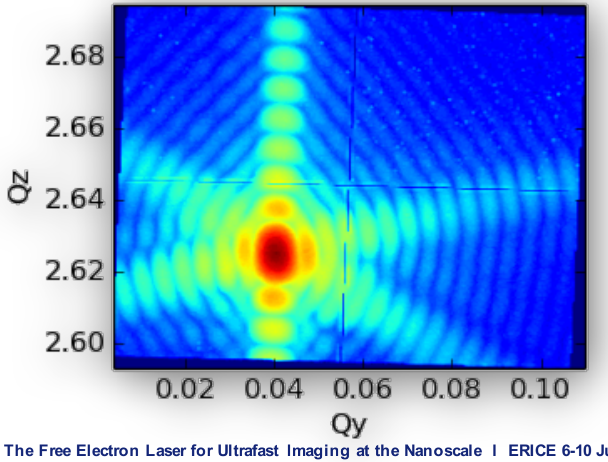
AFM mounted at the ID01 diffractometer



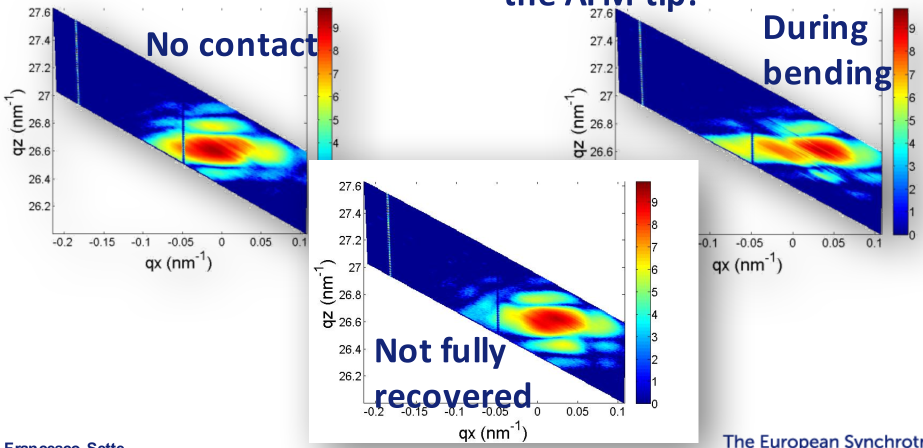
First measurements done by T. Cornelius, M.-I. Richard, G. Chahine, O. Thomas

➢ **Reciprocal space maps before, during and after *In-situ* bending:**

(111) Bragg peak of a suspended Au NW (~2s/frame):

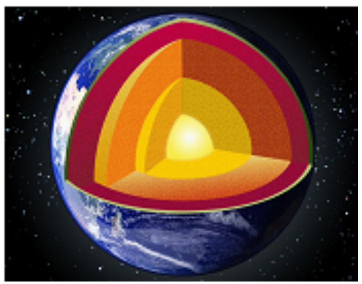


3D Bragg peak (energy scan ~100 eV) bending with the AFM tip:

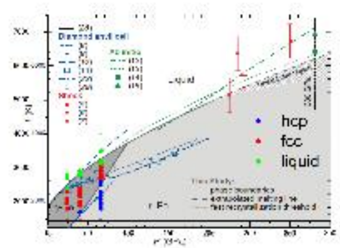


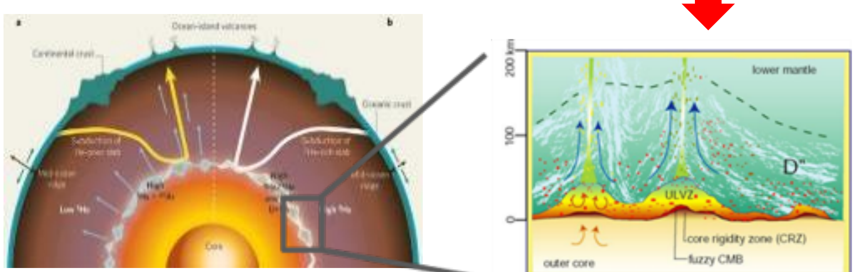
Opportunities

- Probing structural complexity and its relation to, e.g. superconductivity and quantum phenomena
- Imaging materials complexity in the TPa regime at the nanoscale
- Understanding the structure and dynamics of Earth's and Exo-planets deep interiors



Phase diagram



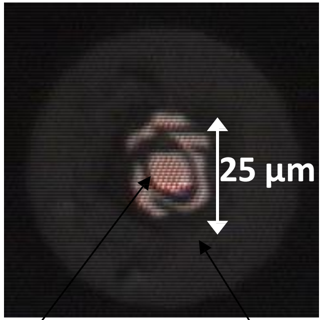


Creating thermodynamic conditions that exist only in a very small volume and/or for a very short time

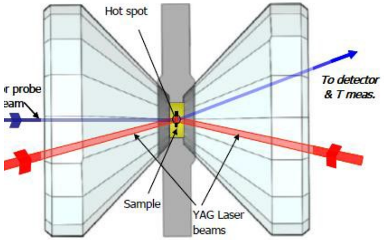
Limitations	Solution
beam size	brightness
time resolution	brightness
data analysis	IT and software

A STRONG COMMUNITY EFFORT AT ESRF

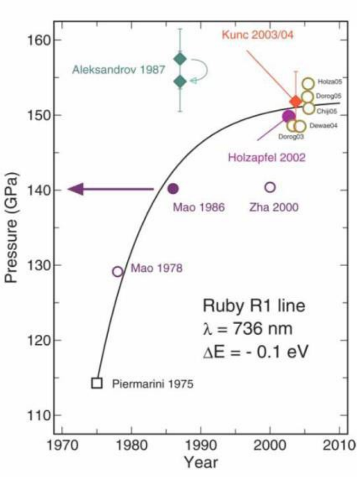
Samples +



H2 single crystal He



Metrology +



Accuracy of the P-T measurements
Ruby scale
Diamond or c_BN scale
Pyrometry

ESRF

Many techniques have been used.
Some dedicated beamlines.
XRD, XAS, IXS, NSR, XRI

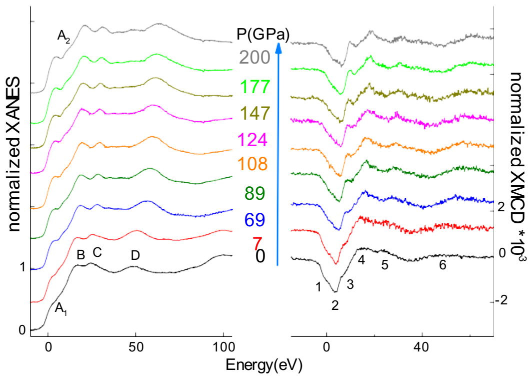
= interesting physics.

Study of a material at Mbars pressures completely and accurately as at ambient pressure

Major achievement of the HP field!

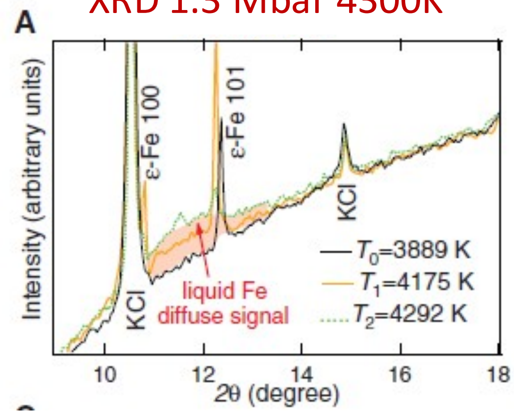
SOME RECENT HIGHLIGHTS

XMCD 2 Mbar



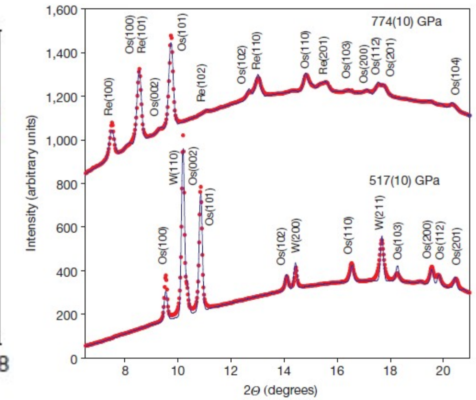
Torchio PRL 2011

XRD 1.3 Mbar 4300K



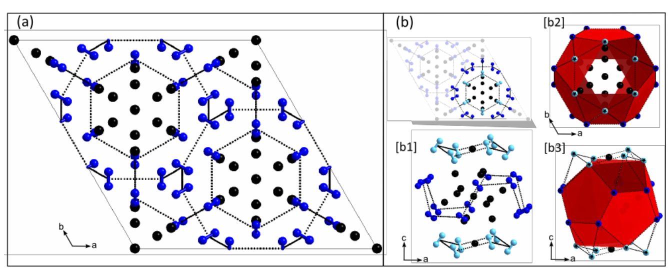
Anzellini Science 2013

XRD 7 Mbar



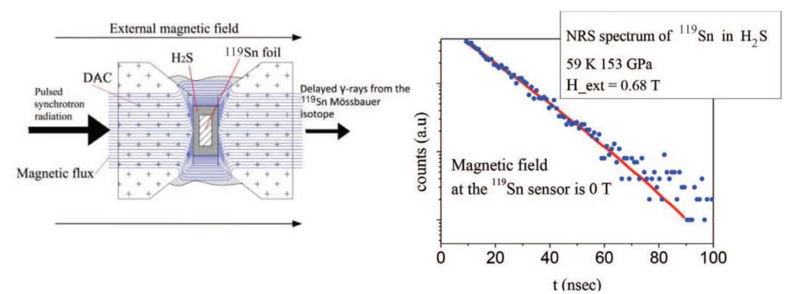
Dubrovinsky Nature 2015

Single-crystal XRD



Spaulding, Nature Comm. 2014

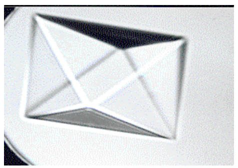
NRS

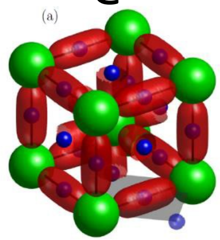


Troyan, Science 2016

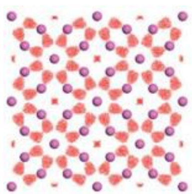
- **Go more extreme. TPa & eV** **WDM**

H20@1GPa → H30@ TPa



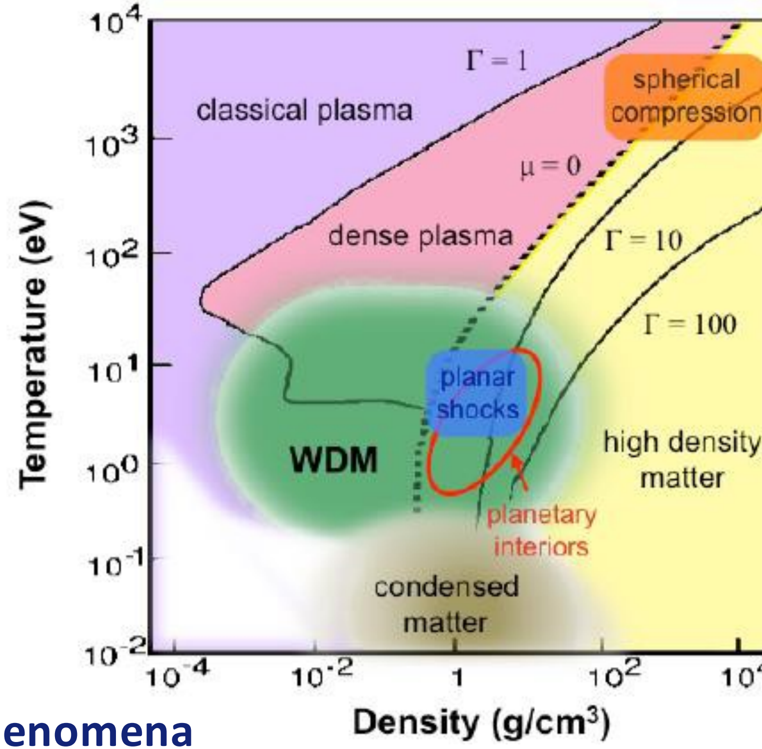


Tc>200K



Novel materials

Al@ 4 TPa: an electride (Pickard&Needs 2010)

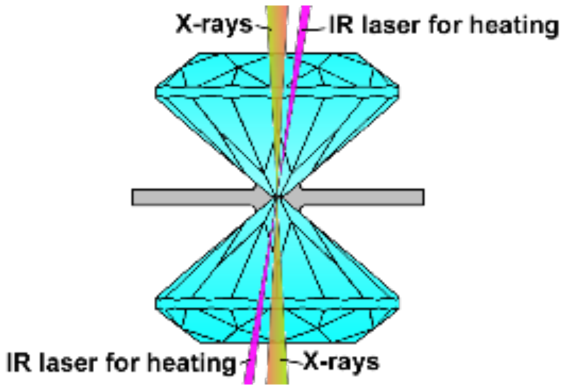


- **Explore the time scale of high pressure phenomena**

• Mechanism and nucleation of phase transitions.
• Yield strength (dynamics of dislocations).
• Nanostructuration; amorphisation; metastable phases.

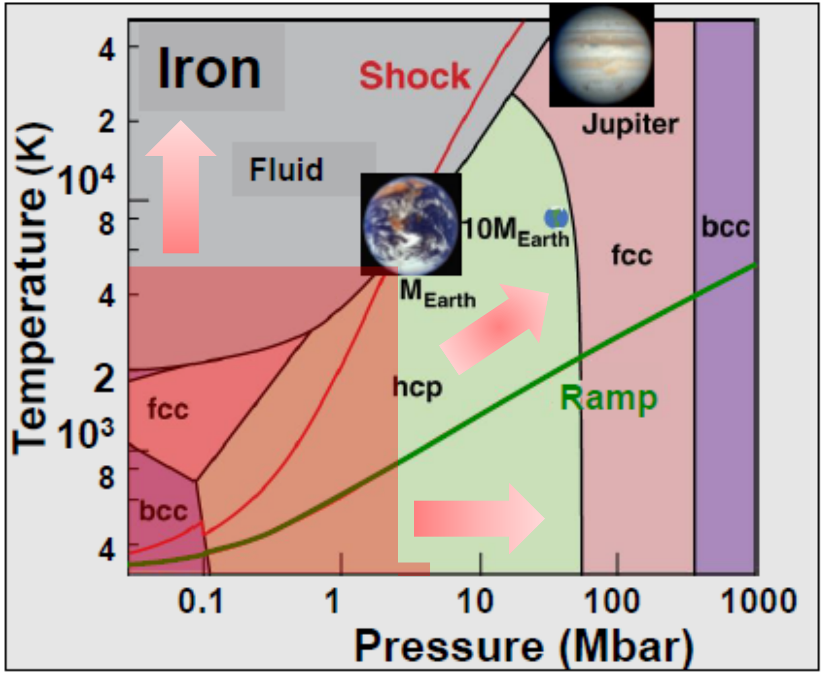
Go TPa & ns

GOING BEYOND THE LIMIT OF STATIC COMPRESSION



Static compression with LH–DAC covers Earth's core conditions

~ 360 GPa, 5500 K

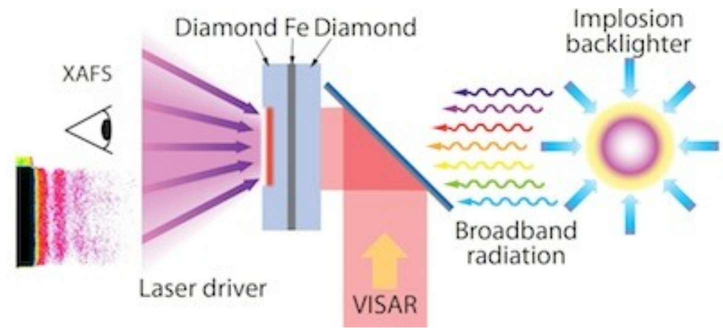


1. What is the stability limit of hcp phase in solid Fe ?
2. What is the local structure in the liquid ?
3. What is the nature of ion-ion correlations in the WDM regime ?

Can we create and probe WDM at the synchrotron, with data quality as "at ambient"?

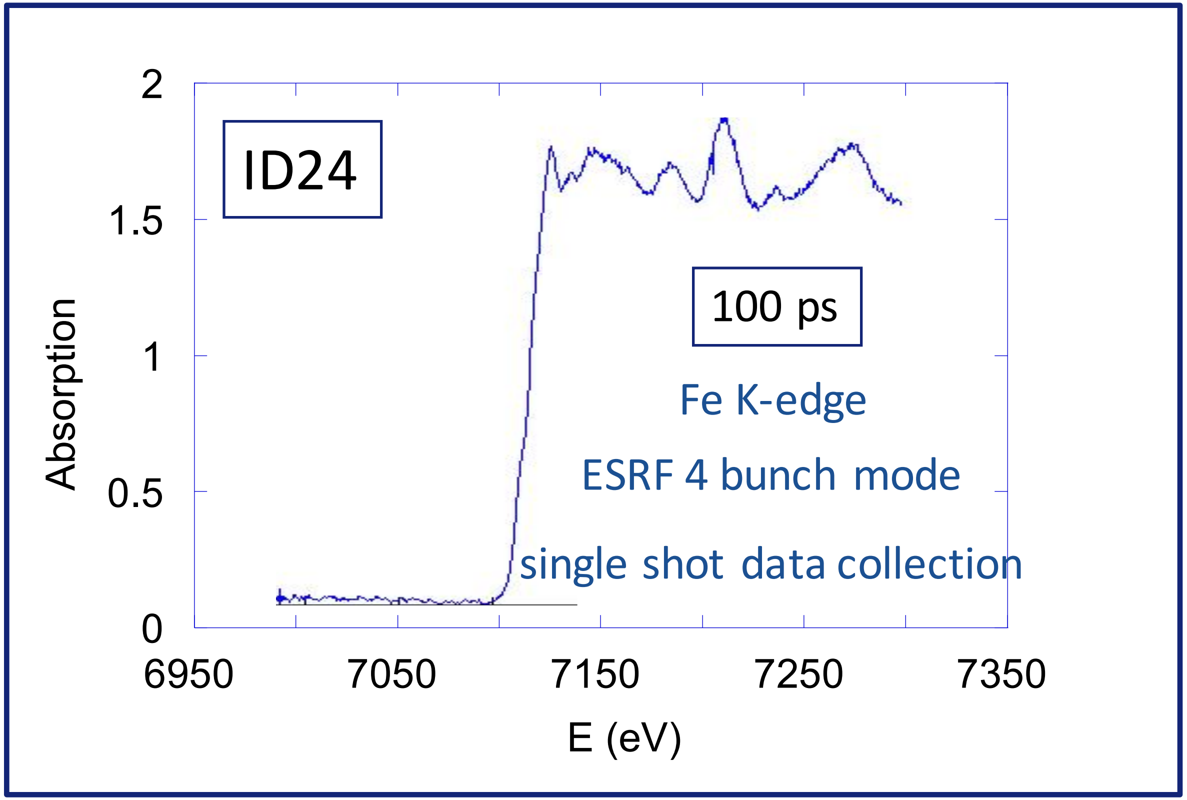
From macroscopic properties to atomic structure → X-ray diagnostics

High power laser facility + X-ray backlighter



- X-ray scattering, XRD, XAS, XES
- Phase transitions, new structures, WDM electronic and structure changes, etc…
- Test approximations used in theories

DETECTION LIMITS FOR SINGLE SHOT STUDIES: ED-XAS



data quality corresponds to 50 spectra before

Ge XH microstrip (STFC)

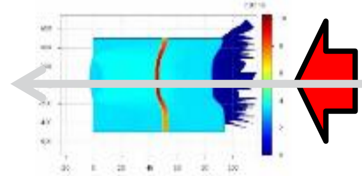
SINGLE SHOT EXAFS ON DYNAMICALLY COMPRESSED FE

ID24

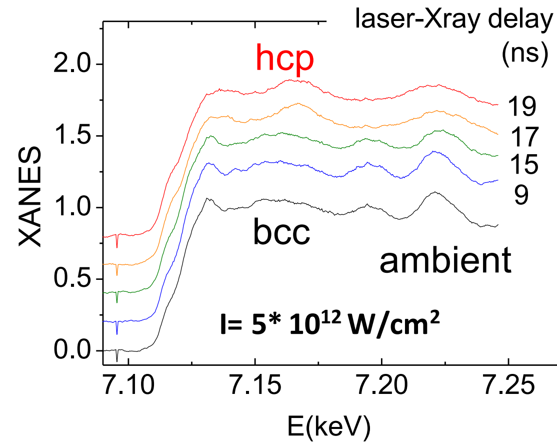
Institute of Shock Physics

cea

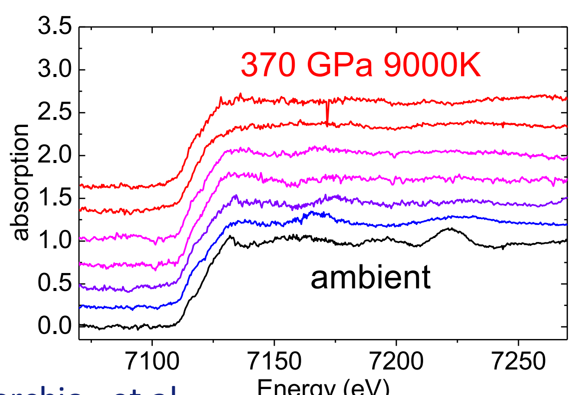
Science & Technology Facilities Council



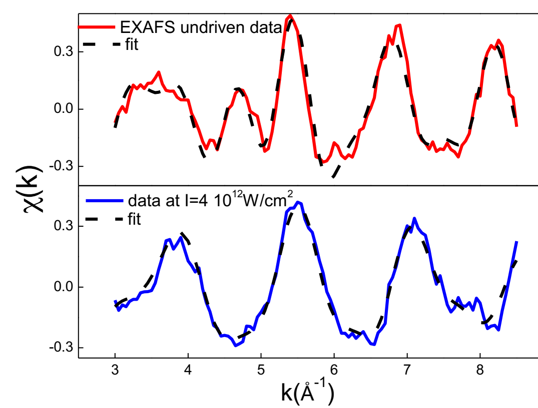
Single bunch XANES



I(W/cm^2)	P(GPa)	T(K)
1 10^{13}	160	2800
2 10^{13}	270	7000
3 10^{13}	320	8000
5 10^{13}	370	10000



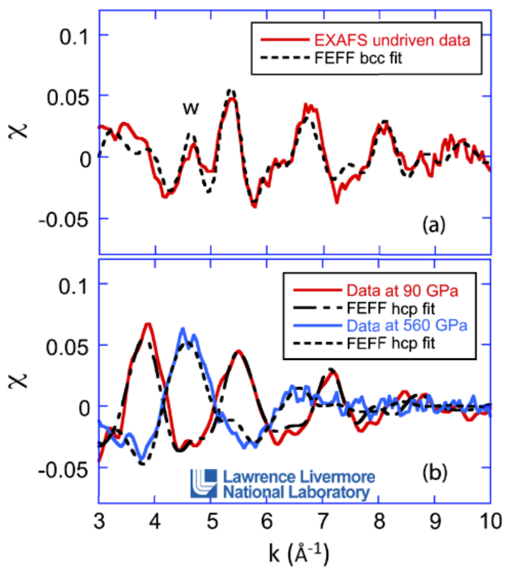
Single bunch EXAFS



F. Occelli, O. Mathon, A. Sollier, R. Torchio, et al.

XAS STUDIES ON LASER SHOCKED FE

High Power Laser Facility
OMEGA
single shot

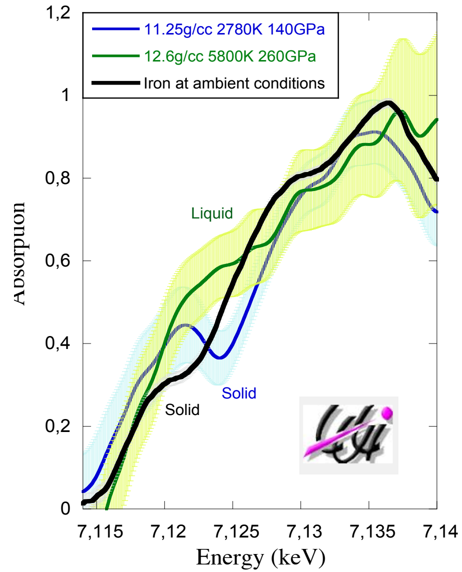


Only EXAFS region

Max 10 shots/day

Max 2 days/year

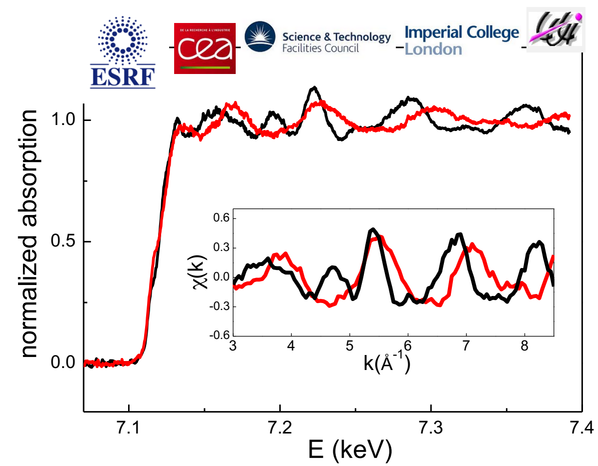
X-ray Free Electron Laser
LCLS
average over many shots



Only edge region

No. shots limited only by laser frequency

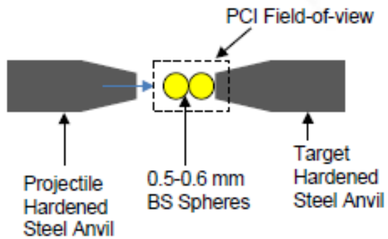
Synchrotron
ESRF
single shot

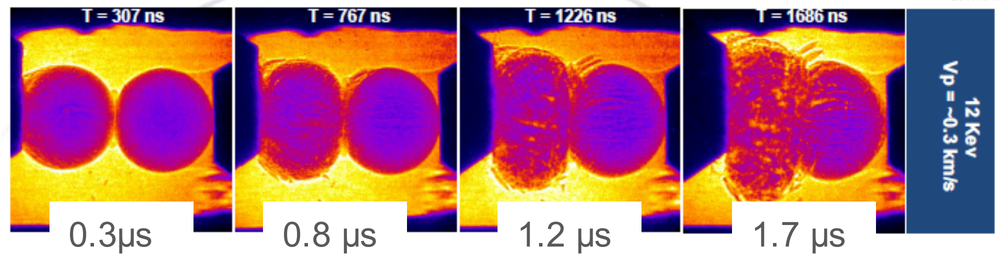


XANES and EXAFS

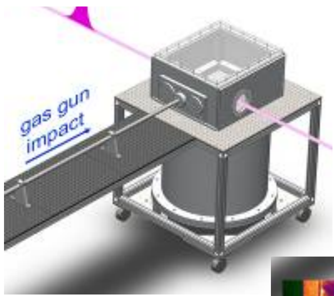
No. shots limited only by laser frequency

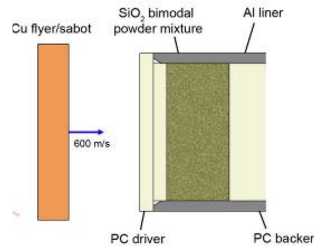
Mechanical properties, phase transitions and chemistry under high strain rates

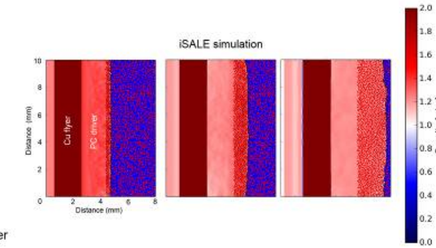


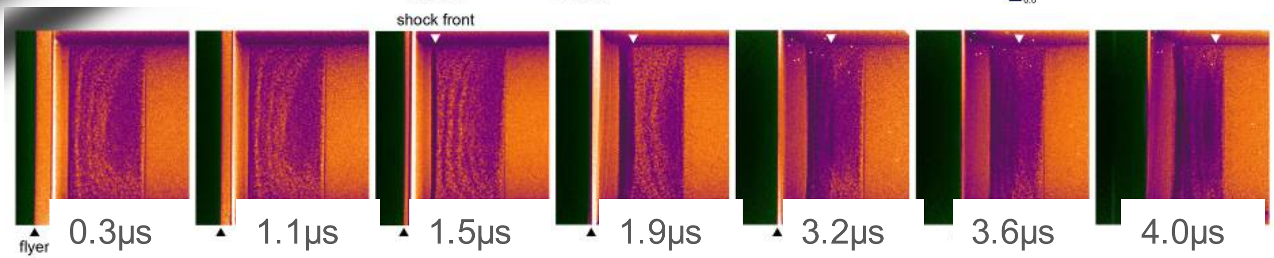


IMPULSE gas gun @ DCS, APS (Argonne, USA) - Courtesy B. Jensen, LANL









Imperial College gas gun @ ID19, ESRF - Courtesy A. Rack (ESRF)

UPBL7 on ID32

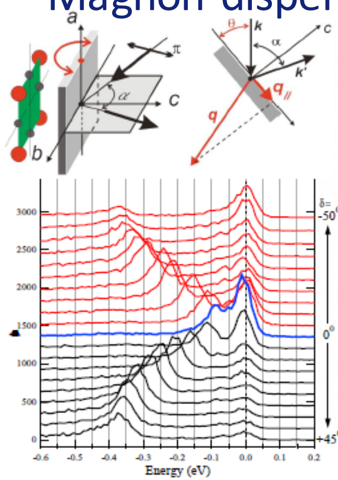
Nano-magnetism & Spectroscopy

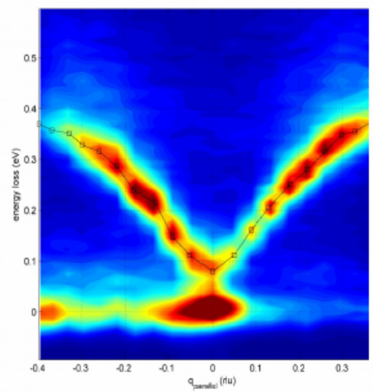
ID32

First Users: Early 2015

Magnon dispersion

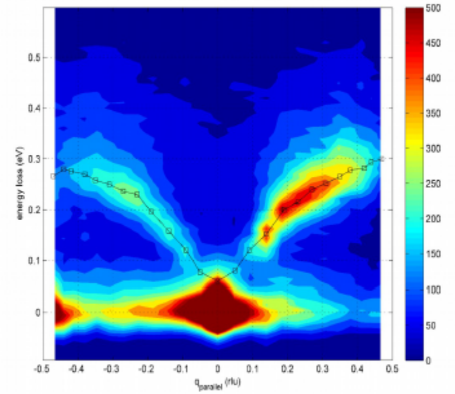
$CaCuO_2$

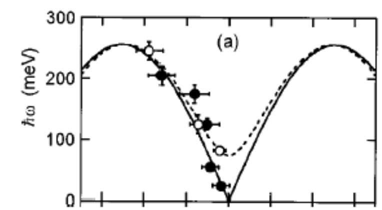




Ghiringhelli *et al.* Jul 2015

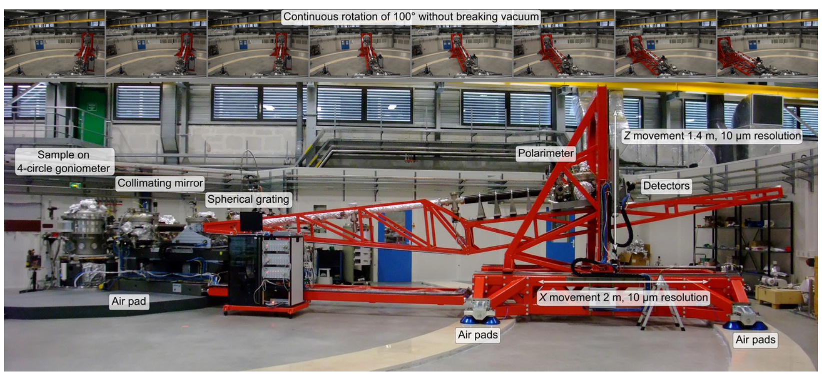
100nm film $Nd_{1.2}Ba_{1.8}Cu_3O_6$



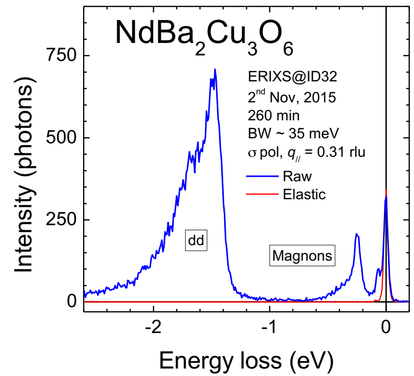


S. M. Hayden et al, PRB **54**

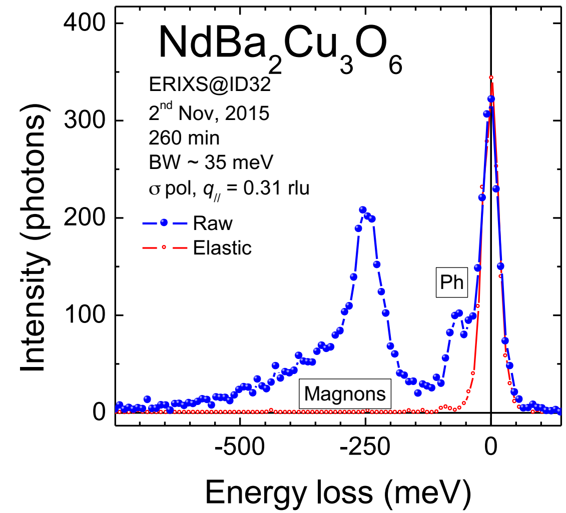
The sample used in INS was a single crystal of $YBa_2Cu_3O_{6.15}$ with mass 96 g.



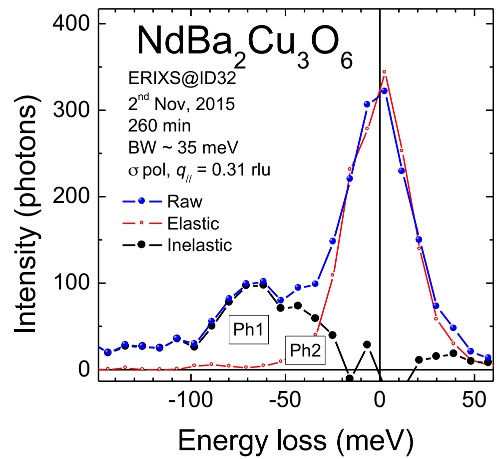
RIXS-ID32 : COMMISSIONING OF THE HIGH ENERGY RESOLUTION CONFIGURATION IN FALL 2015



magnons



Commissioning the High Resolution Set-up: November 2015



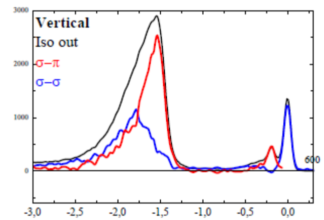
phonons

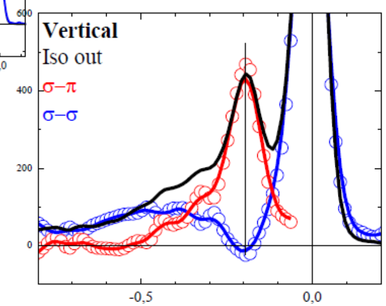
Polarimeter discriminating the σ–σ and σ–π scattering channels

- Excitations with or without spin/orbital –momentum flips
- Novel design conceived and realised at the ESRF by the joint PoliMi-ESRF Team

Neodimium-Barium-Cuprate parent compound of high Tc
Demo of polarimeter in ERIXS at ID32
Measured for 7 hours

NBCO antiferro, Normal emission, 2th=140, delta=-20, T=30K. q = --0.18 rec.latt.units





Incidence pol sigma i.e.
Vertical electric vector
Black spectrum without analysis of outgoing polarisation
Red crossed pol channel
(magnon + higher odd orders)
Blu non-crossed
(bimagnon + even higher orders)

April 2016, L. Braicovich, N. Brookes, G. Ghiringhelli and the ESRF-ID32/PoliMi Team

Thank you for your attention!