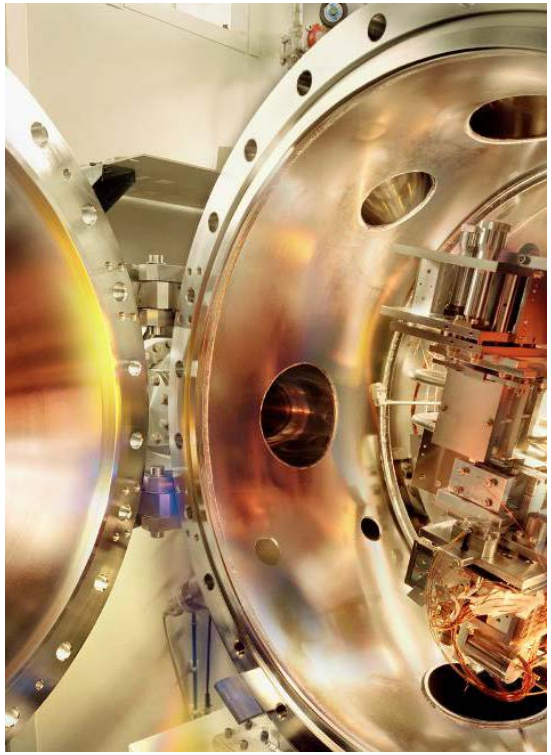
ESRF | The European Synchrotron



The ESRF Upgrade Phase II

The instrumentation roadmap

A presentation on strategy and challenges rather than a scientific/technical report

Jean Susini
Instrumentation Services and Development Division
European Synchrotron Radiation Facility

ULTRA-LOW EMITTANCE SOURCES: THE MISSING LINK TOWARDS DLSR

Janus: the god of beginnings, transitions and doorways

Past

Third generation storage rings

New Science Drivers

Innovative Instrumentation

Present

Ultra-low emittance storage rings

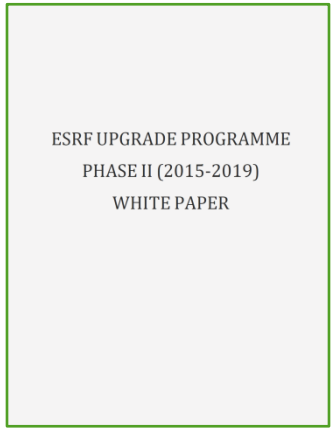
Future

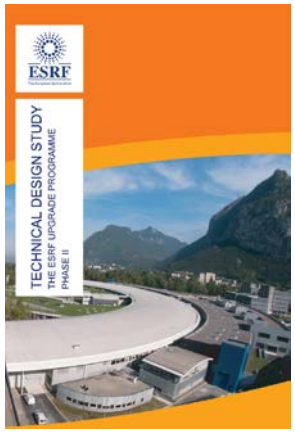
Diffraction Limited Storage Rings

New Science Drivers

Innovative Instrumentation

THE ESRF UPGRADE: MILESTONES





2007 **2009** **2013** **2014** **2015** **2016** **2023**

Phase I
Definition - Preparation

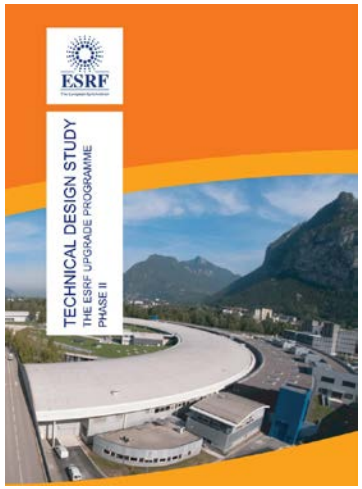
Phase I
Implementation

Phase II
Definition

Phase II
Implementation

ESRF UPGRADE: SCIENTIFIC DRIVERS

Vision for 2009 to 2022 mapped out in Purple and Orange Books



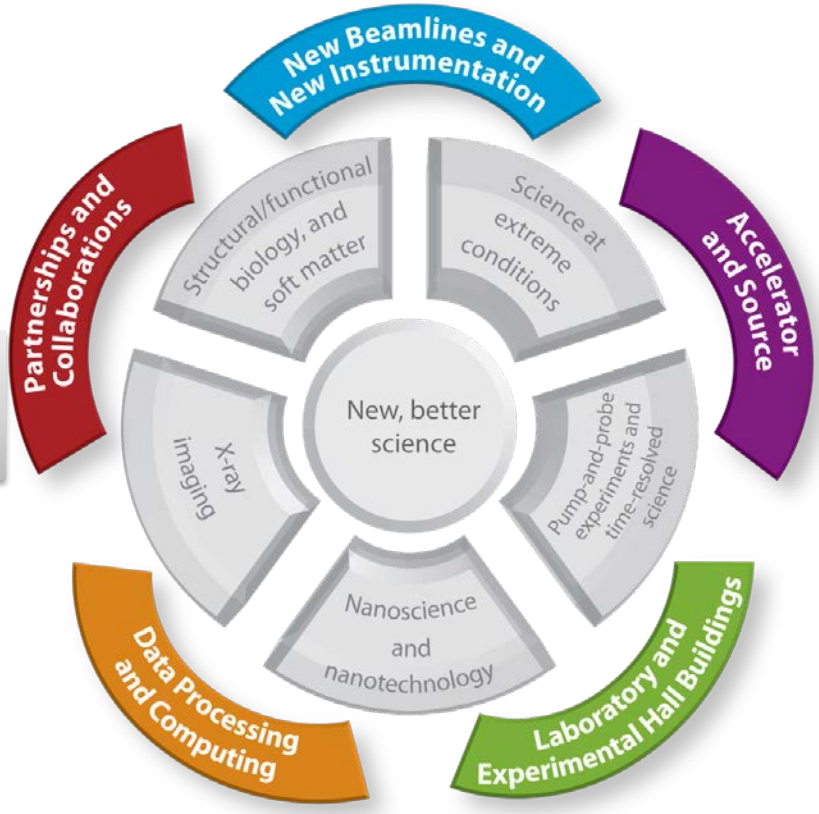
H. Reichert's talk tomorrow am

http://www.esrf.eu/AboutUs/Upgrade

PHASE I (2009-2015) DELIVERABLES

Renewed Beamline Portfolio
(19 new/upgraded beamlines)

New partnerships
Science Building

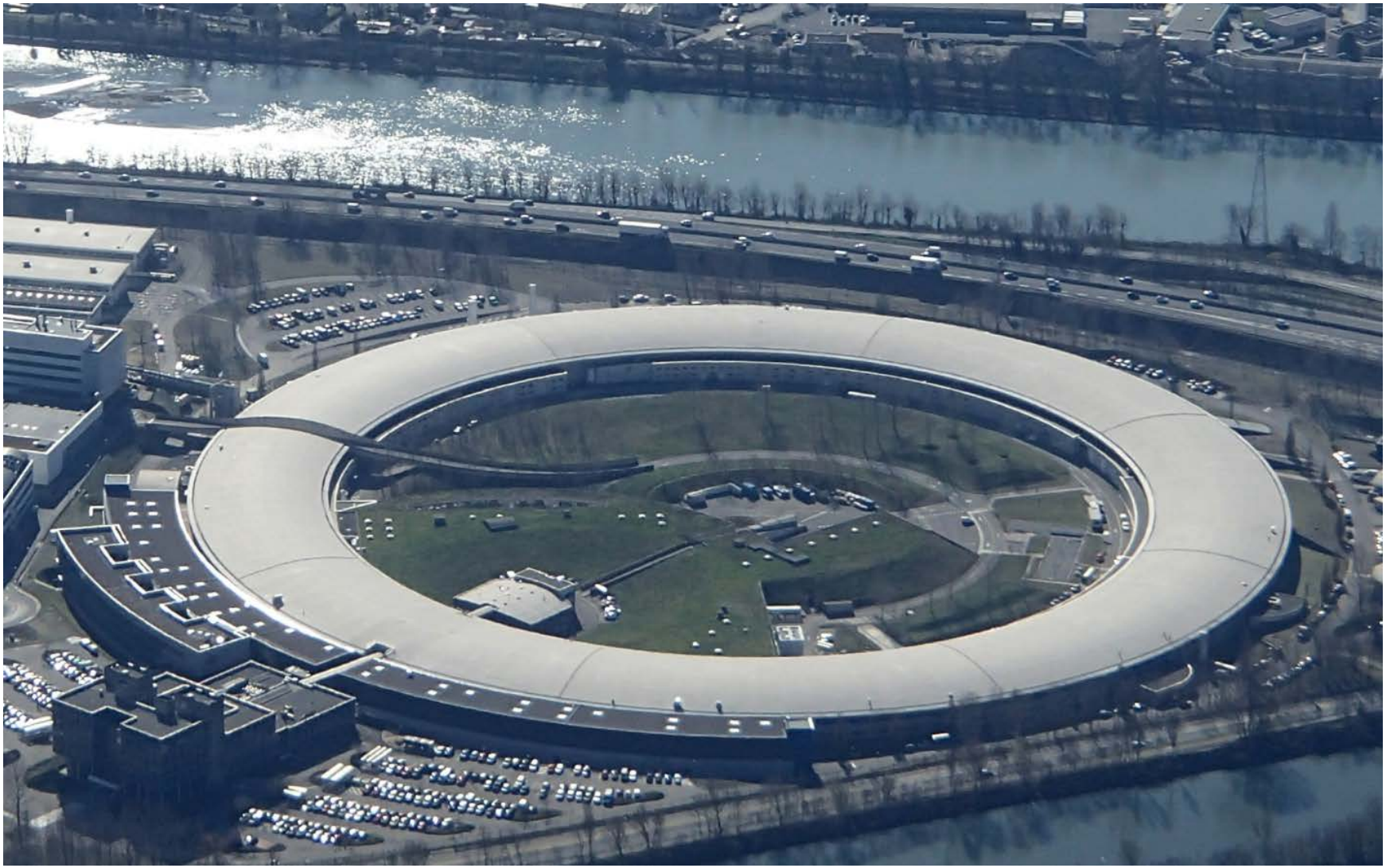


Accelerator Upgrade
- *straight sections*
- *canting sections*
- *orbit correction system*
- *Top-up*
- *RF cavities*
- *…*

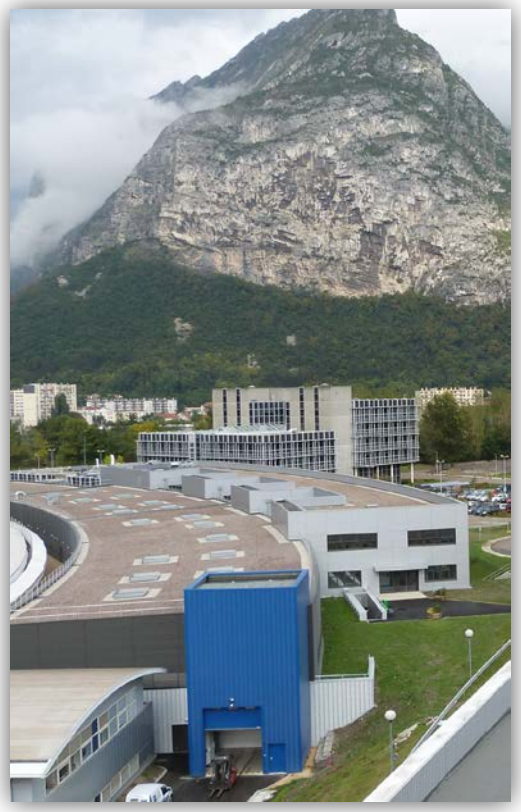
H. Reichert's talk tomorrow am

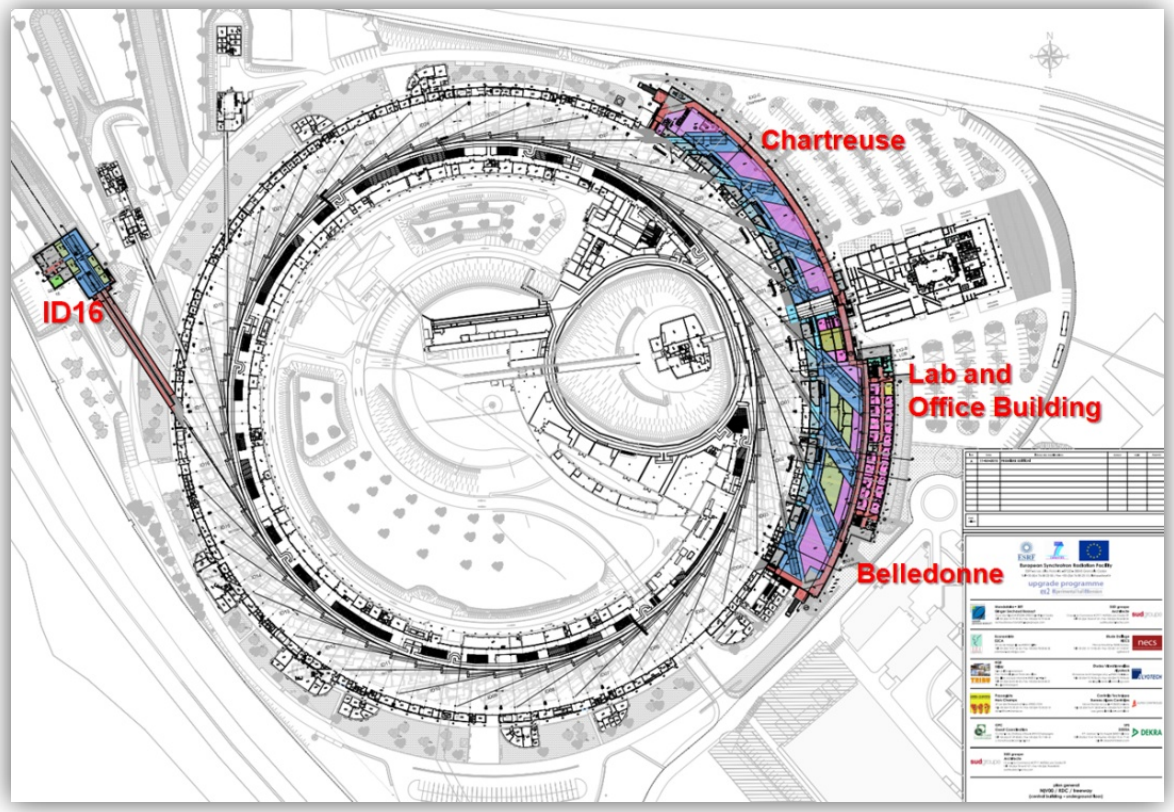
New Building Infrastructure
New Data Center

THE ESRF TODAY

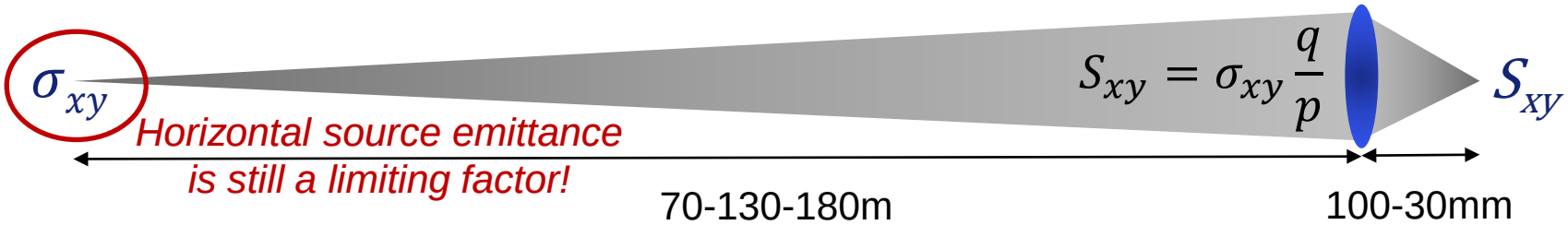


ESRF-UP PHASE I: EXPERIMENTAL HALL EXTENSION





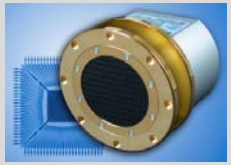
Long beamlines = Large demagnification = Nanoprobes + long working distances



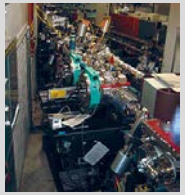
THE FOUR PILLARS OF THE ESRF UPGRADE PHASE II

Ultra-low emittance SR

New X-ray detectors



4 new beamlines



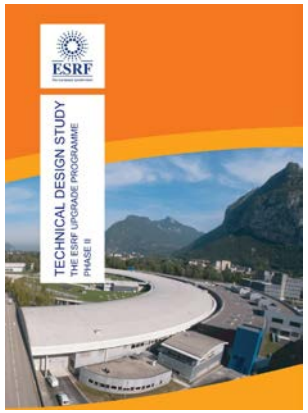
Data Analysis and IT

Phase II

2015 - 2022

Orange book

Technical Design Study



- Content endorsed by ESRF Council (Spring 2014)
- Publicly available from Jan 2015

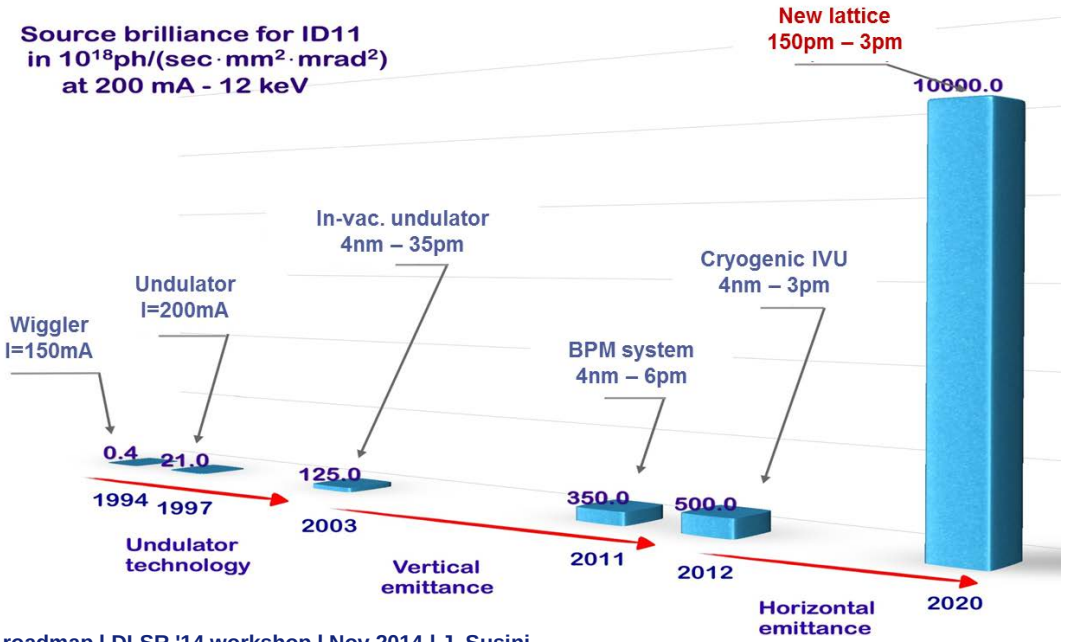
ESRF-UP-II: A NEW LOW HORIZONTAL EMITTANCE STORAGE RING

Current double-bend achromat (DBA) lattice

ε_x= 4 nm

Future hybrid seven-bend achromat (HMB) lattice

ε_x= 0.15 nm

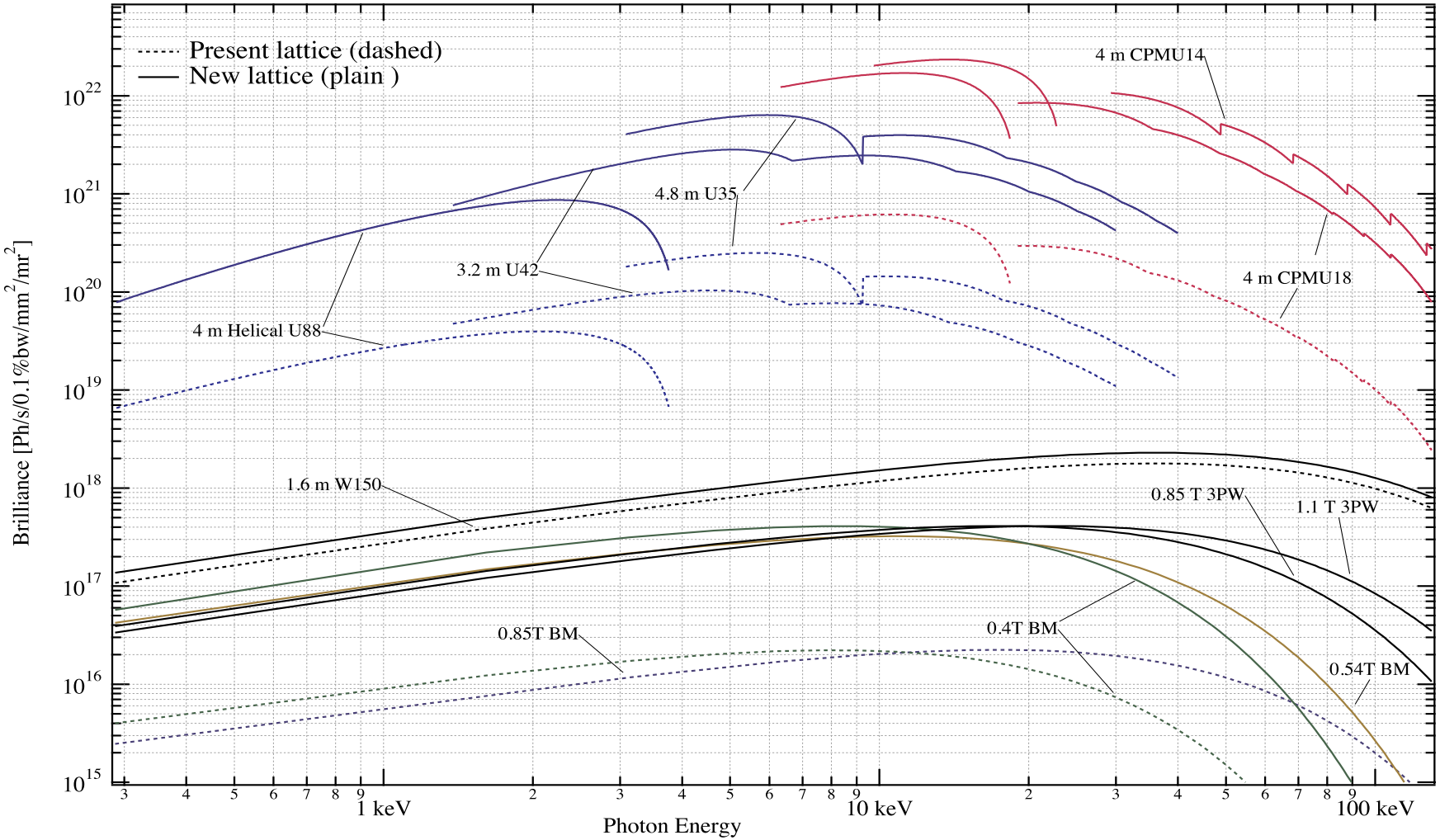


Higher Brightness

?

New science

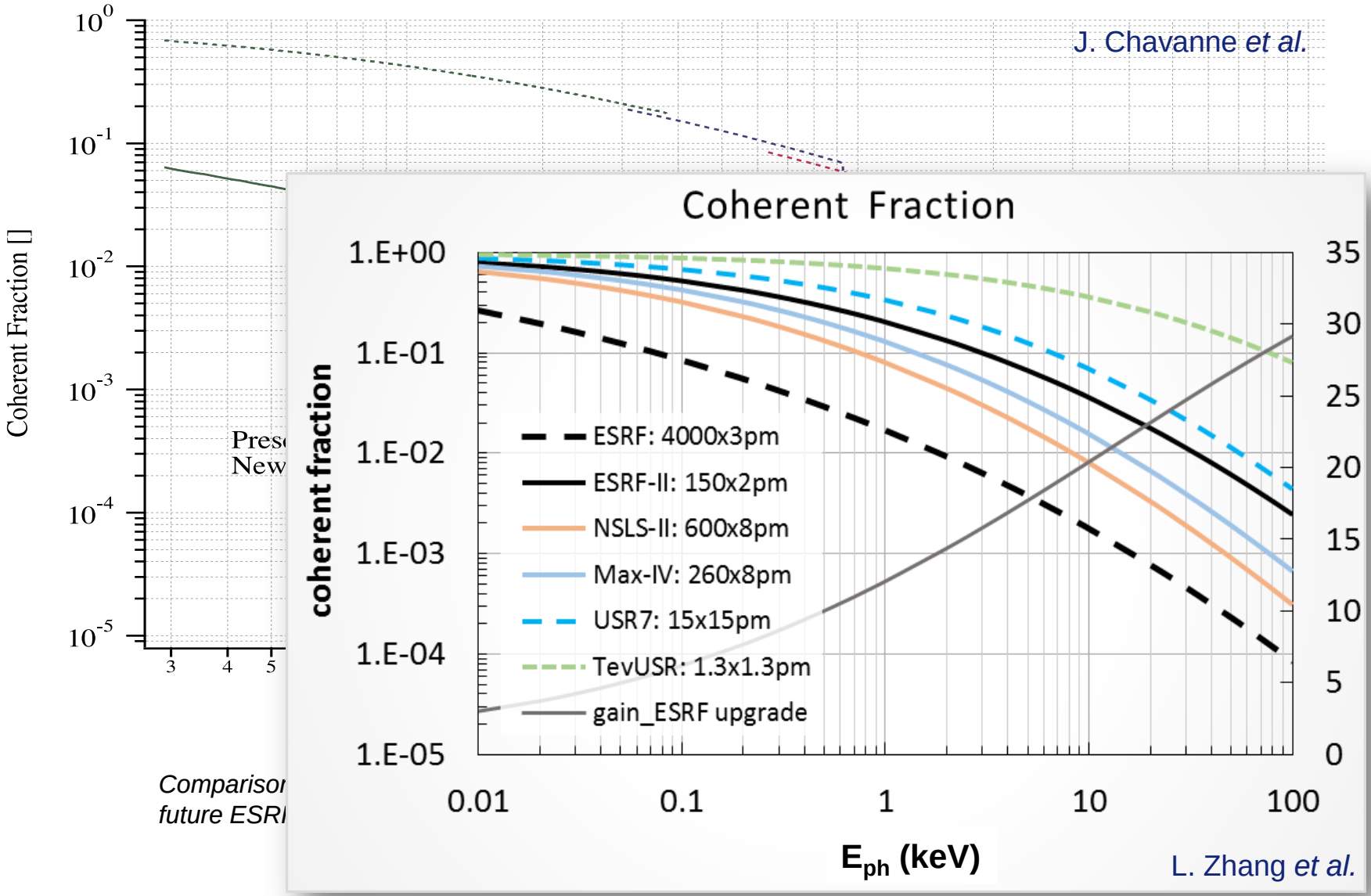
NEW ESRF LATTICE = INCREASED BRILLIANCE (x 25 @ E> 10KEV)



Conventional devices operated with a minimum gap of 11 mm, short period small gap (5 mm) in-vacuum type Undulators such as Cryogenic Permanent Magnet Undulators (CPMUs)

J. Chavanne et al.

NEW ESRF LATTICE = GAIN (x10-30) IN COHERENT FRACTION



Comparison
future ESRF

SCIENTIFIC INSTRUMENTATION: ESRF-UP-II DRIVERS & OBJECTIVES

Some key experimental drivers

- Small source size → nanoprobe based techniques
- Less x/y asymmetric photon source/beam → more efficient use of the beam
- Transverse coherence length → coherence based techniques
- Longitudinal coherence length → scattering and absorption techniques
- High brightness/flux → fast acquisition & time resolved techniques
- High energies → Imaging & Diffraction/Scattering techniques

Ultra Low Emittance Storage Rings provide all parameters together

Generic challenges

- Preservation of the photon beam properties (coherence)
- Transfer of the (coherent) brightness/flux to the sample

And also,

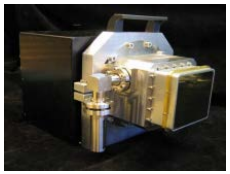
- Optimum conversion of brightness/flux into high-quality data
- Scientific discoveries from the recorded data

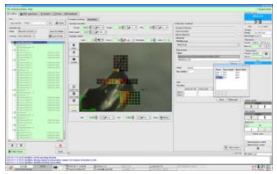
Some practical considerations for ESRF

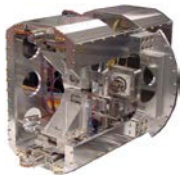
- Optimum use of the 18-month shutdown (Fall 2018-Spring 2020)
- Capitalization on UP-Phase I investments

SCIENTIFIC INSTRUMENTATION: ESRF-UP-II CHALLENGES & DELIVERABLES

- Transfer of the brightness/flux to the sample
- Preservation of the photon beam properties (e.g. coherence)
- Optimum conversion of brightness/flux into high-quality data
- Scientific discoveries from the recorded data







X-Ray Source

→ Beam Transfer

→ Sample Manipulation

→ Detection Systems

→ Data Processing & Analysis

Need for a fully optimized experimental chain

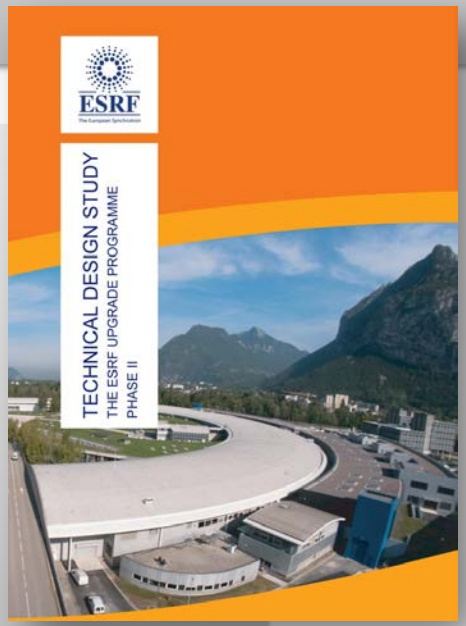
SCIENTIFIC INSTRUMENTATION : ORANGE BOOK-CHAPTER 4

Content

- a comprehensive overview of ESRF's strategy for the development of this instrumentation, driven by the new storage ring's performances
- a vision for the future ESRF beamline instrumentation across entire beamline portfolio
- planned human and financial resources

Outline

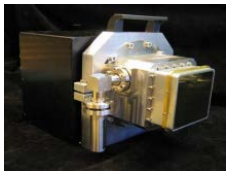
- Beam transport and conditioning
- End-station integration
- X-ray detectors
- Beamline control
- Data analysis
- Computing infrastructure

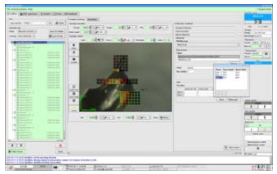


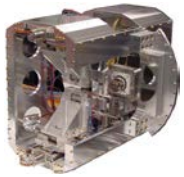
Main contributors of chapter 4: J. Susini, R. Barrett, P. Fajardo, P. Marion, Y. Dabin, T. Mairs, N. Janvier, L, Zhang, A. Goetz, C. Ferrero and many others…

SCIENTIFIC INSTRUMENTATION: FOUR MAJOR PROGRAMS

- Transfer of the brightness/flux to the sample
- Preservation of the photon beam properties (e.g. coherence)
- Optimum conversion of brightness/flux into high-quality data
- Scientific discoveries from the recorded data







1. A new detector programme with consolidation of ongoing projects on enabling technologies and development of two new 2D detector systems
2. IT and computing infrastructure: control system modernisation and data analysis platforms
3. Development of new expertise in mechatronics and on-line metrology
4. Development of advanced metrology tools and methods for X-ray optics

ONE EXAMPLE OF SUB-PROGRAMME STRUCTURE

4.1 - Beam transport and conditioning

	#	Technology	Development objectives	Type	Phase II
Engineering	BT1	Power management	Cooling schemes matching top-up conditions	G	
	BT2	Photon beam diagnostics	On-line tools for measuring and optimising performance of optical systems	A	
	BT3	Vacuum technologies and related phenomena	Improved optics longevity	G	
	BT4	Choppers and shutters for controlling time structure and sample dose	Control of X-ray pulse time structure and exposure.	A	✓
X-ray optics	BO1	Optical modelling	Unified tools for modelling of incoherently, partially-coherently and coherently illuminated X-ray optical systems	G	
	BO2	Coherence/brightness/wave-front preservation	Reduction of phase error to optical imperfections	A	✓
	BO3	Mirror technologies	Opto-mechanical mounting methods Corrective figuring Surface metrology	G	✓
	BO4	Multilayer technologies	Optimisation of deposition methods for high-energy applications Precise deposition control for short optics and alternative focusing technologies	G	✓
	BO5	Refractive lens technologies	Optics in front-end Lens manufacture	G	✓
	BO6	Crystal monochromator systems	High performance fixed-exit double crystal monochromator for fast energy scanning applications	G	

G: Generic R&D

A: Application specific

✓ Phase II funded

SOME BASIC CONSIDERATIONS ABOUT THE EFFICIENT USE OF THE “GOOD” PHOTONS

The New ESRF Lattice merits:

A great combination of high and low beta section assets: small σ_x+ low $\sigma_{x'}$

+

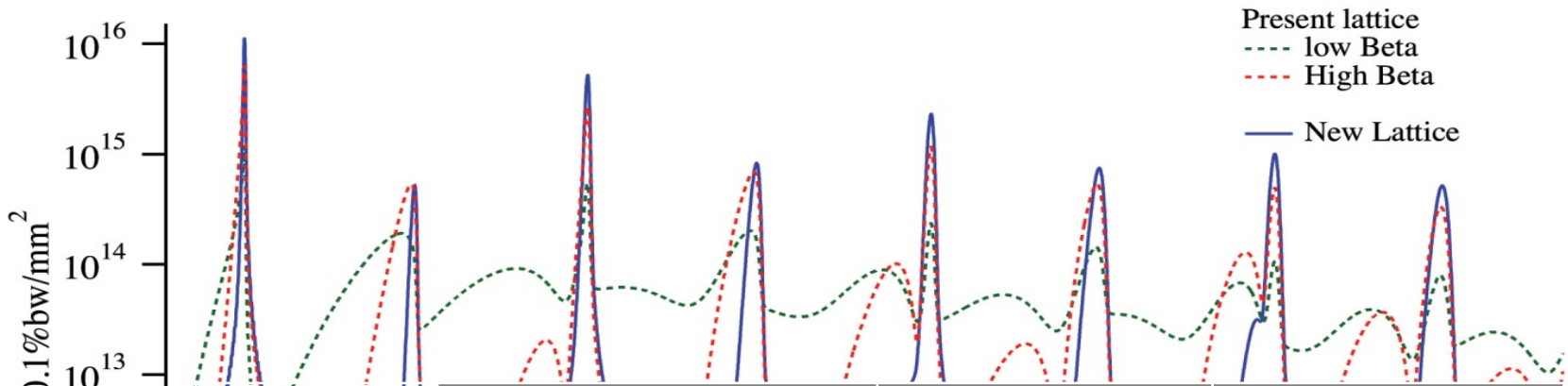
Higher circular symmetry of the photon source & beams

+

Top-up

- High brightness → power density and heat load manageable ?
- Higher degree of coherence (2D) → optics performances ?
- Smaller horizontal beam → shorter optics ?
- Symmetric beam → new options for optical design ?
- Narrow spectral bandwith → new options for (pre) monochromators ?

POWER MANAGEMENT IS NOT REALLY AN ISSUE BUT…

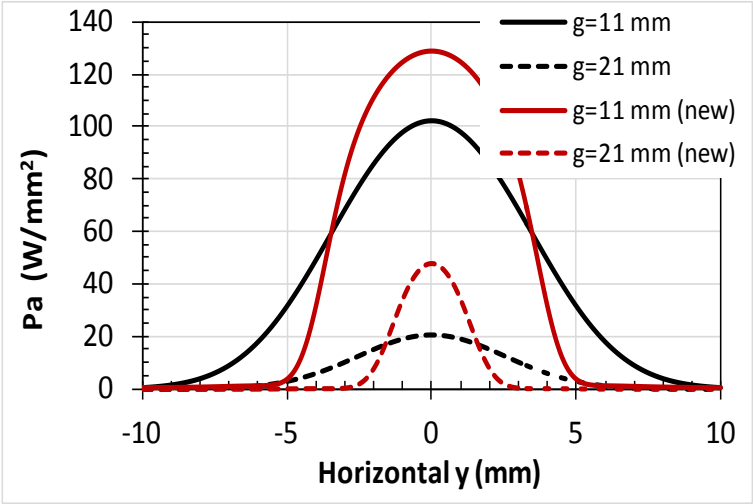


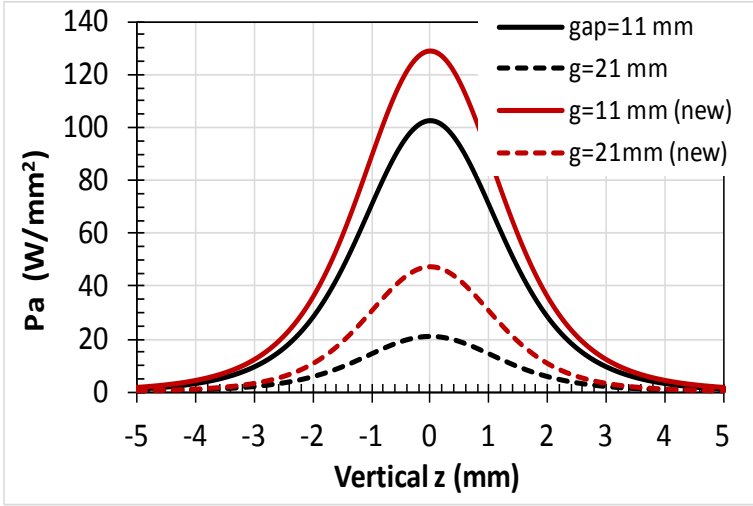
	RMS Photon beam size at 30m (µm)		Integrated Power (W)	Integrated Power in 0.1% BW (W)
Lattice	H	V		
Low β	3100	150	180	0.77
High β	530	150	42	0.77
New lattice	220	150	17	0.77

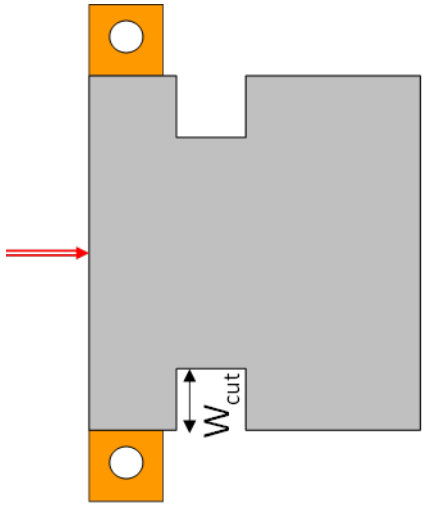
Straight section equipped with a 4m-long, 18mm-period undulator at 10keV.
The integrated power refers to the total power integrated over a surface equal to the RMS beamsize.

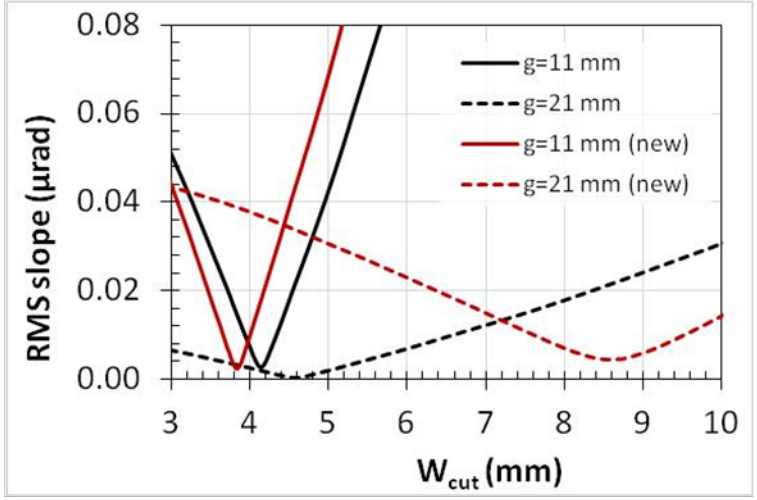
J. Susini *et al.*, JSR, 21, 2014

COOLING OPTIMISATION IS MORE CHALLENGING WITH SHARPER UNDULATOR PEAKS





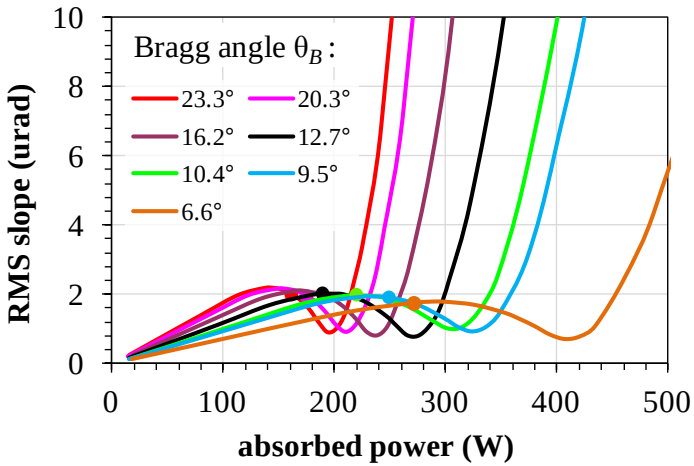


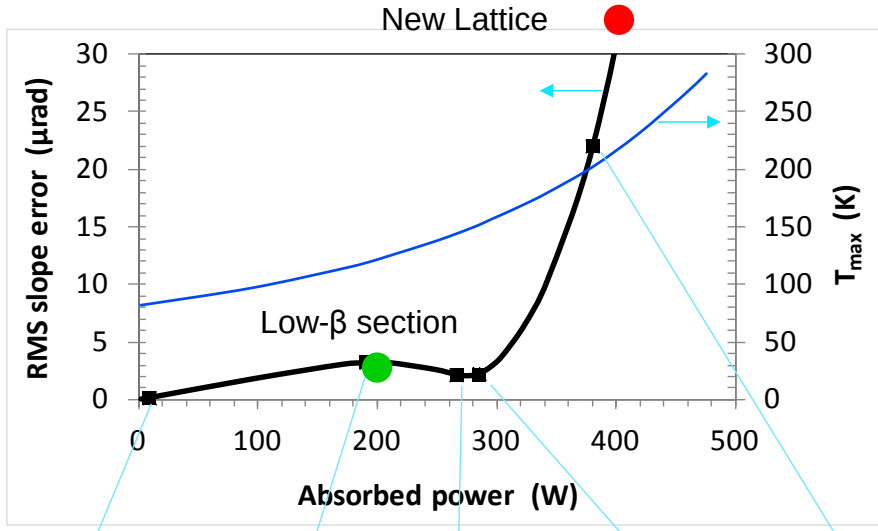


L. Zhang et al., J. of Physics, 425, 2013

J. Susini *et al.*, JSR, 21, 2014

RE-TUNING LN2 COOLING OF SILICON MONOCHROMATOR





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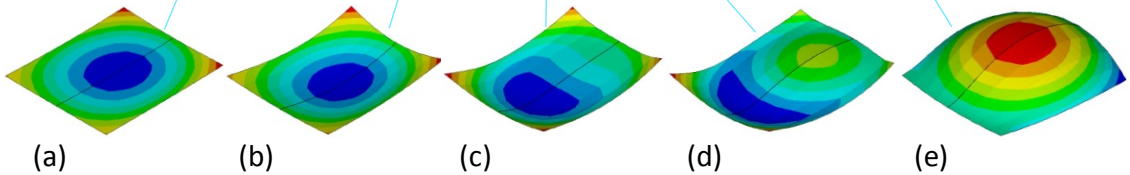


New Lattice

- Power absorbed by crystal increased by a factor of ~ 2
- Working point changed
  - focusing elements to be re-tuned
  - white beam mirror to be inserted ?

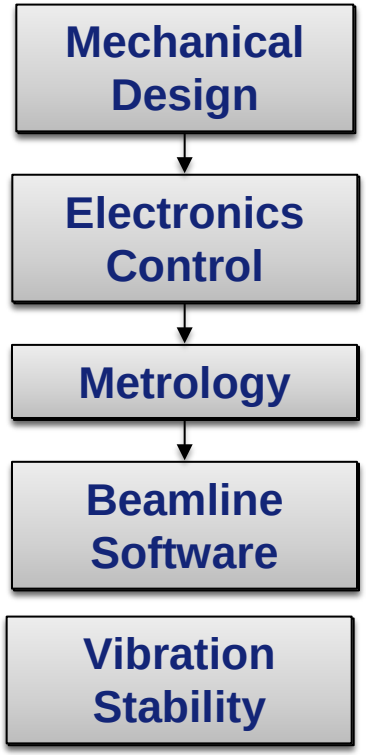
L. Zhang *et al.*, *JSR*, 20(4), 2013

The European Synchrotron | ESRF

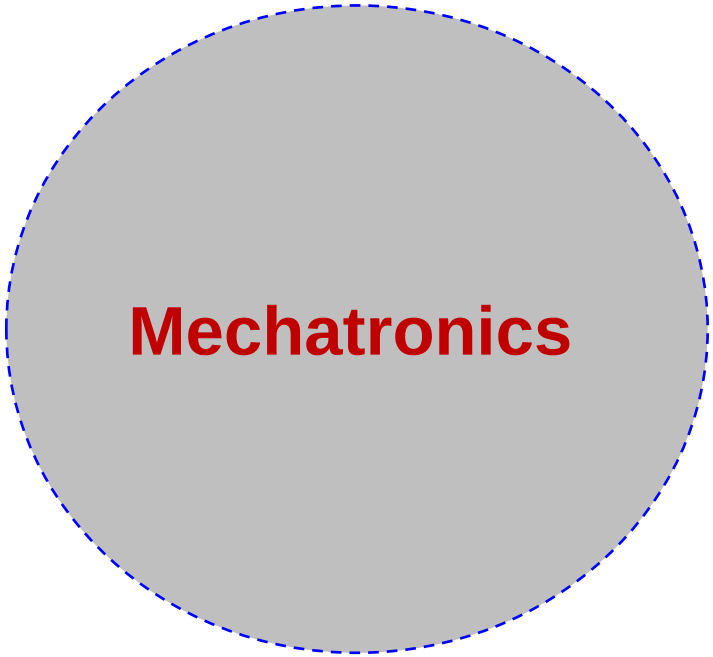
NANO-ENGINEERING AND MECHATRONICS

- Strong push for nano-probes with coupling of techniques and ultra fast acquisition
- Towards zero dead time experiments: on-the-fly acquisistion, automatic alignment,…
- Nano--engineering is a dynamics world → need for active/real-time corrections

Development paths often very ‘serial’
OK for engineering for micro-beams but not for nano-beam

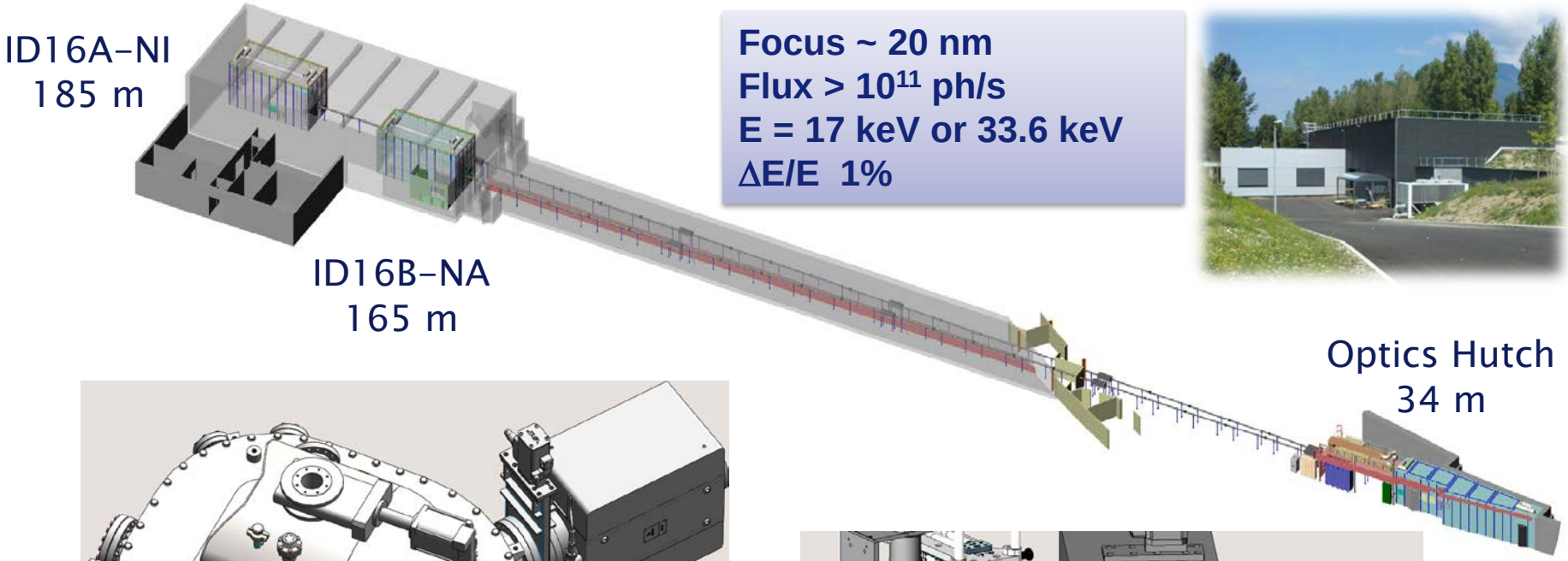


‘traditional’

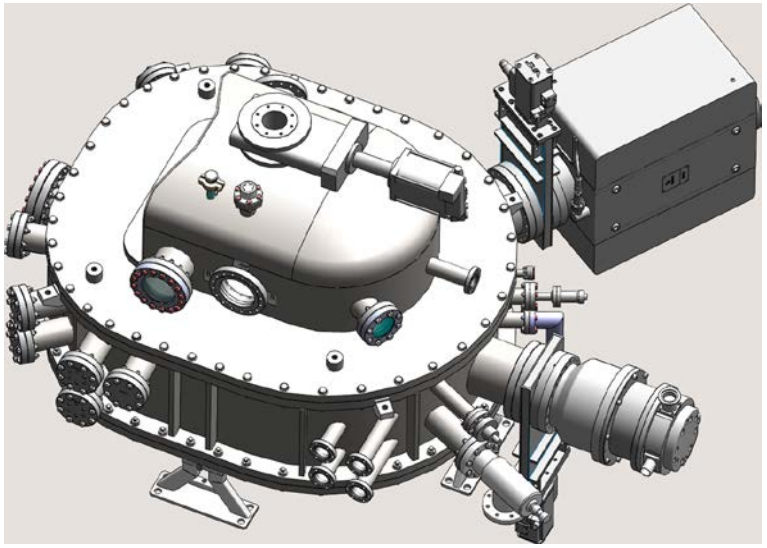


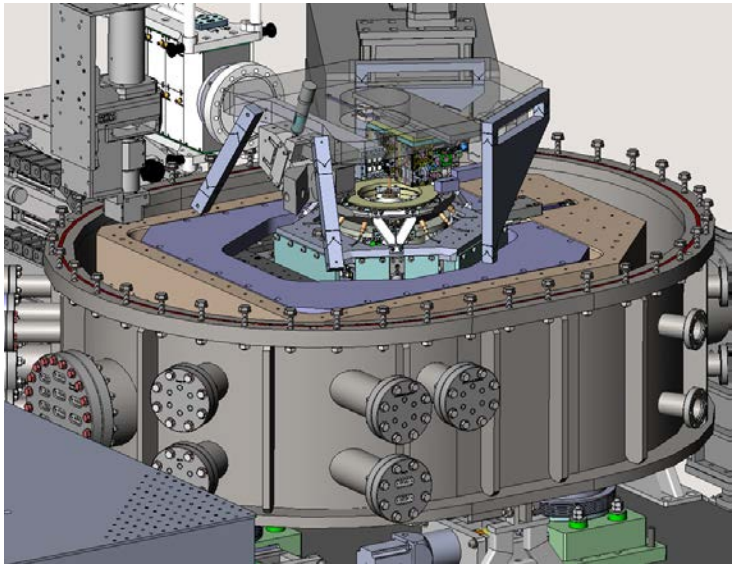
‘nano’

NANO IMAGING BL: A PIONEERING MECHATRONICS PROJECT AT THE ESRF



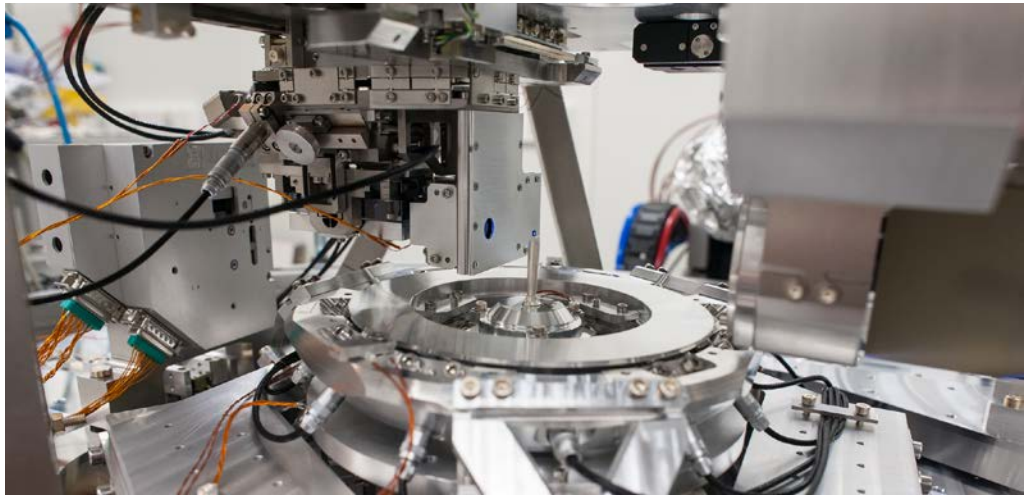
Focus ~ 20 nm
Flux > 10^{11} ph/s
E = 17 keV or 33.6 keV
$\Delta E/E$ 1%





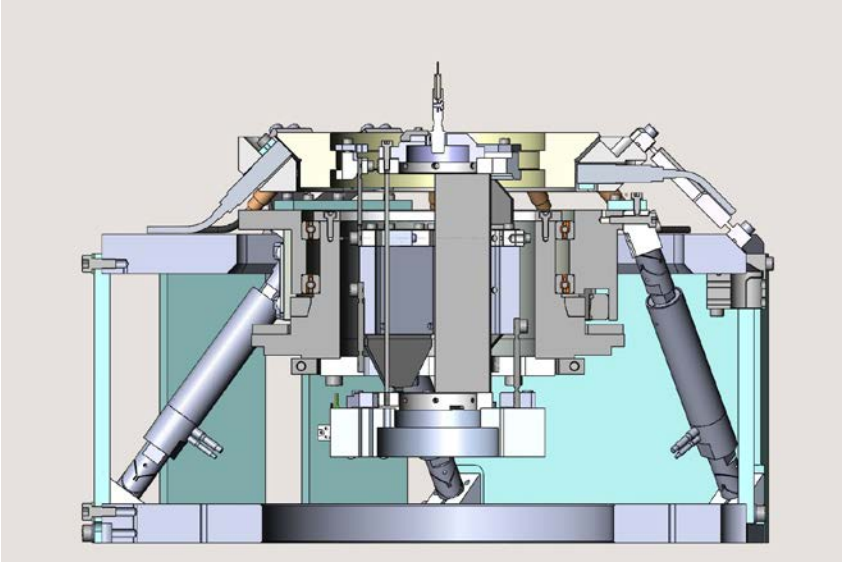
P. Cloetens, F. Villar,, A. Joita-Pacureanu, L. André, P. van der Linden, O. Hignette, R. Baker, C. Guilloud, J. Meyer.

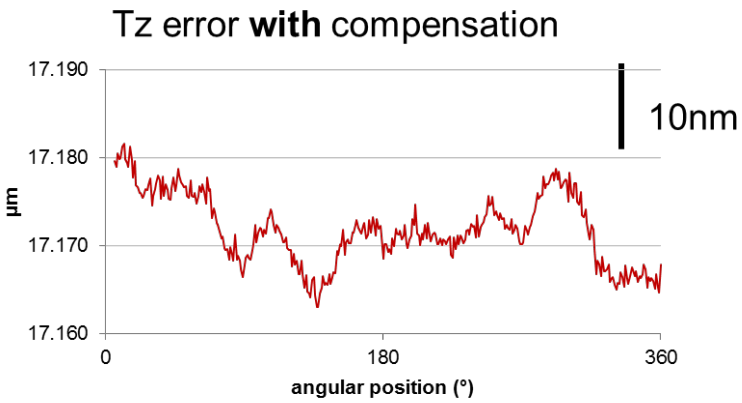
IN-VACCUM SAMPLE STAGE WITH DYNAMIC CORRECTIONS



Hexapod
+
12 capacitive sensors
=
6 degrees of freedoom
with nanometirc precision

F. Villar et al. MEDSI , 2014





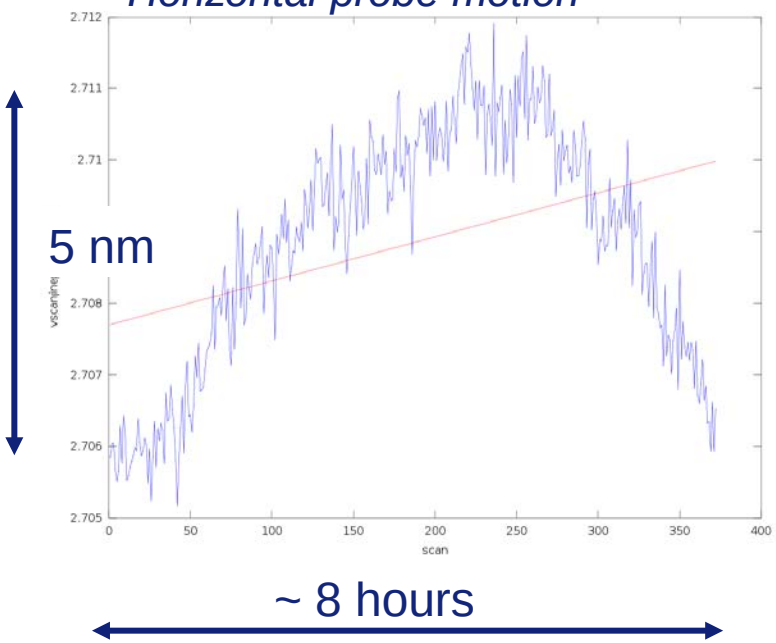
FIRST COMMISSIONING WITH X-RAY BEAM (OCT. 2014)

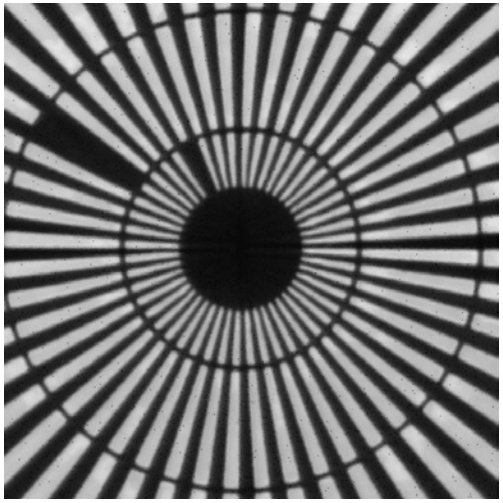
Compact KB (R. Baker, C. Morawe et al.)

20x37nm^2 focus – 17keV

Focus stability:
1 nm repeatability for successive knife-edge scans
Down to **6 nm** over 8 hours horizontally
Down to **30 nm** over 8 hours vertically

Horizontal probe motion





XRF 6hr scan

A. Pacureanu, Y. Yang, F. Fus, S. Bohic, P. Cloetens

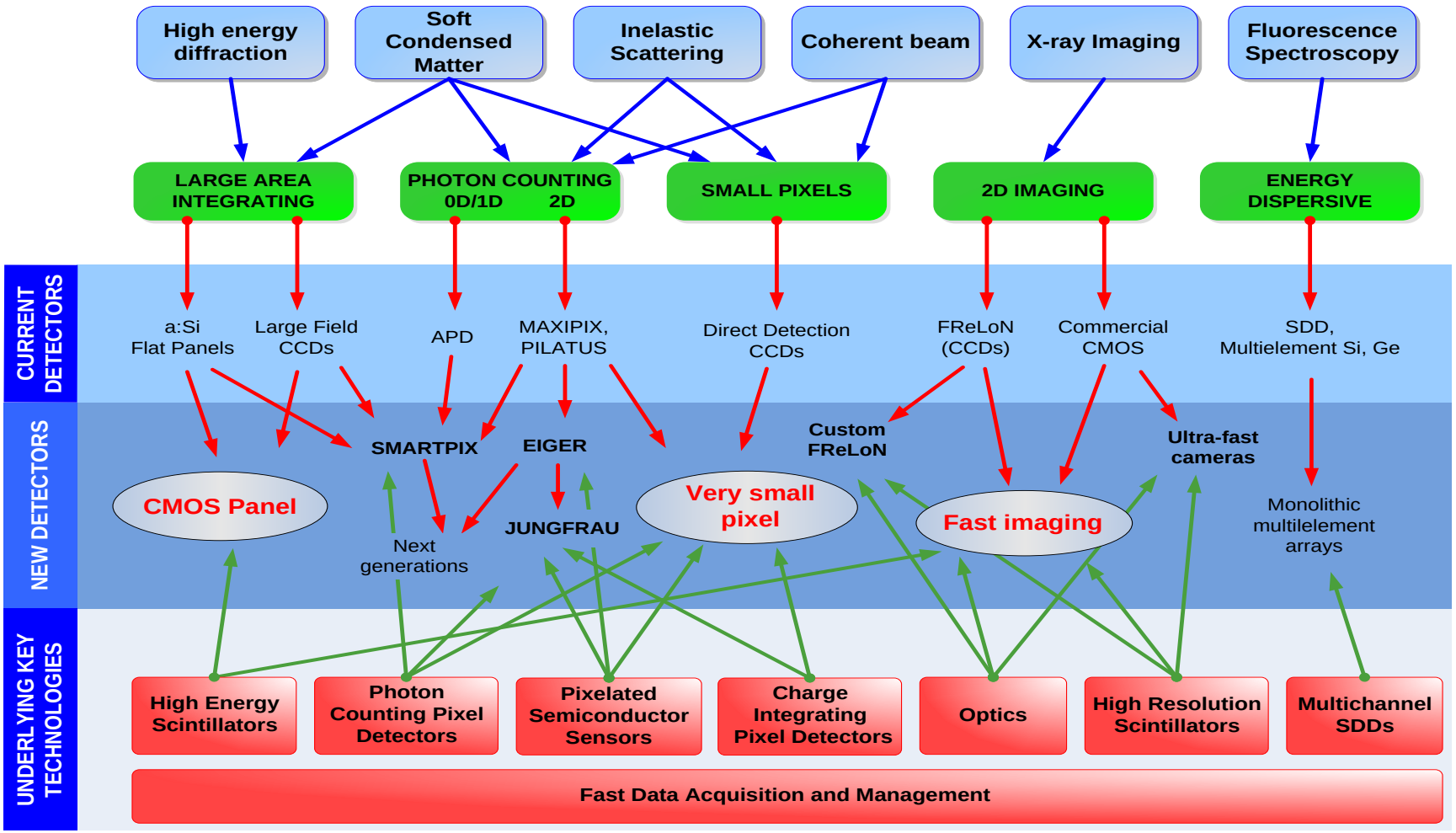
PHASE II NEW SOURCE: DETECTOR CHALLENGES

- **Management of higher photon fluxes and shorter exposure times:**
  - Detectors will require **extended dynamic range**
  - **Photon counting** detectors **will be challenged** by high fluxes
  - Better photon statistics = **shorter exposure times/high frame rates**

- **Improvement of detector efficiency for high energy X-rays:**
  - New source = a push towards **higher energies**:
    - *Reduction of sample radiation damage*
    - *Access to complex sample environments*

- **Combine high spatial resolution with single-photon sensitivity:**
  - Coherent scattering techniques will need **higher detection angular resolution**:
    - Increase of transversal coherence length will allow to image bigger samples
    - Coherent diffraction techniques at high photon energy (> 30keV) will become possible
  - Practical implementation will require detectors with **better spatial resolution**

ESRF DETECTORS ROADMAP



UP-PHASE II: TWO NEW DETECTOR PROJECTS

Selection criteria:

- Driven by the Phase II Science Case
- Not well covered today by other projects worldwide

high spatial resolution & single-photon sensitivity

high energy X-rays

higher photon fluxes shorter exposure times

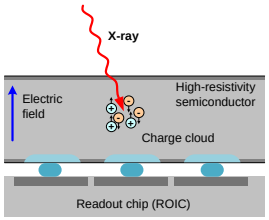
Coherent Scattering

High Energy Diffraction & Imaging

Noise–free small pixel 2D detector

Hybrid pixel detector

- Photon counting or charge integrating
- Silicon and high-Z semiconductors
- ~ 15µm pixel size
- ~ 20-40keV energy range



High dynamic CMOS sensors

Large format CMOS panel

- ~100 cm^2 module with 100µm pixel
- ~ 20 bits dynamic range:
- ~ 1000 frames per second

Fast X-ray imaging camera

- ~ 14 bits dynamic range:
- ~ µs dead-time
- ~ 500 fps for 2048 x 2048 pixels

DATA ANALYSIS IN PHASE II: A PARADIGM SHIFT

The Big Data challenge:

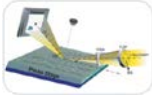
- More and more data
- Users cannot transport data home
- Data processing requires powerful computing infrastructure

The paradigm shift:

- Raw data will stay at ESRF as long as possible
- Provide users with reduced data to take home

Deliverables:

- ESRF data analysis platform
- Enhanced computing infrastructure
- Generic Data Analysis software frameworks
- User's Training



A typical example:

ID01 scanning XRD microscope

- 680 000 files
- 1 Terabyte in 3 hours
- 10 Terabytes in 24 hours

IMPACT:

ESRF will be more efficient and more user-friendly

THE PANDAAS H2020 PROPOSAL SUBMITTED TO THE EU COMMISSION

- 20 partners (all photon and neutron sources in EU)
- Based on a common need and vision: **DATA ANALYSIS AS A SERVICE**
- Pooling of resources and solutions
- Infrastructure will be cloud based
- Users will see a common solution
- Coordinated by ESRF (R. Dimper & A. Goetz)

THE SCIENTIFIC INSTRUMENTATION ROADMAP: AN INCREMENTAL STRATEGY

Critical review of instrumentation prog. UP-Phase I

Analysis of the impact of the source on the ESRF beamline portfolio

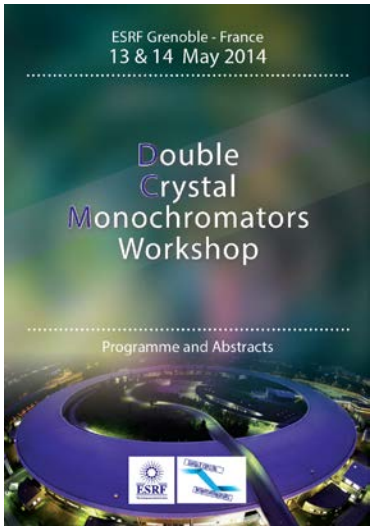
Projections on the Science Case

Expert Working Group (white beam mirror, XBPM, DCM…)

Topical workshops

Instrumentation Roadmap V1 (TDS)

In-house brainstorming meetings



See R. Barrett 's talk tomorrow pm

Partnerships

Advisory bodies' feedback

User's meetings

Extra resources (ANR, IRT, H2020…)

Proof of concept Feasibility studies

Instrumentation Roadmap refinement and consolidation

Janus: the god of beginnings, transitions and doorways

Past

ESRF
20 years of operation

Incremental evolution

Present

Upgrade Programme
Phase I

Near Future

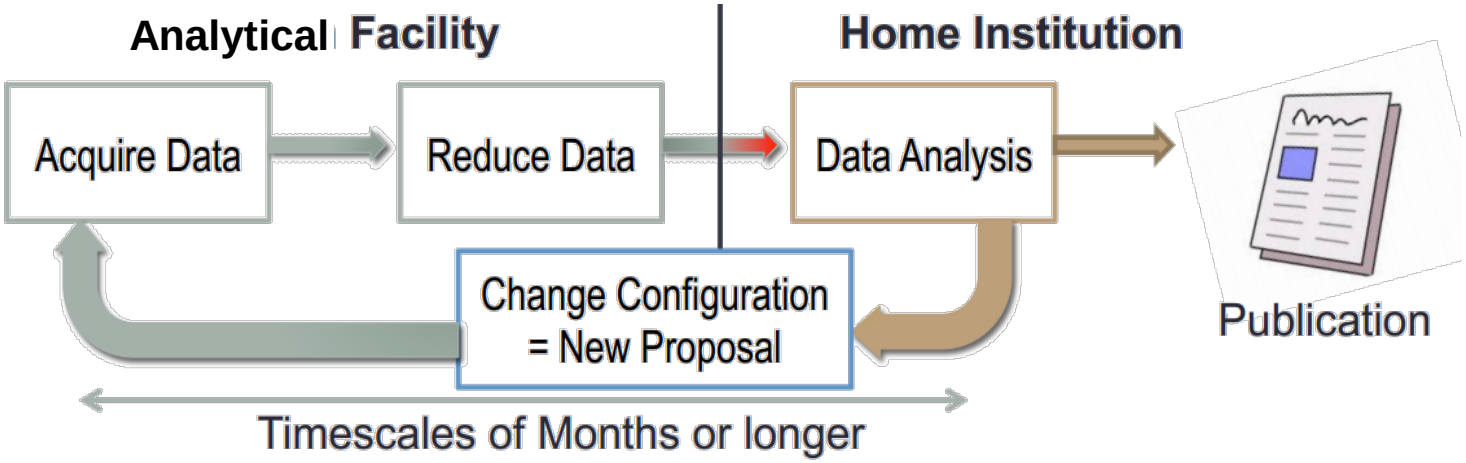
Upgrade Programme
Phase II

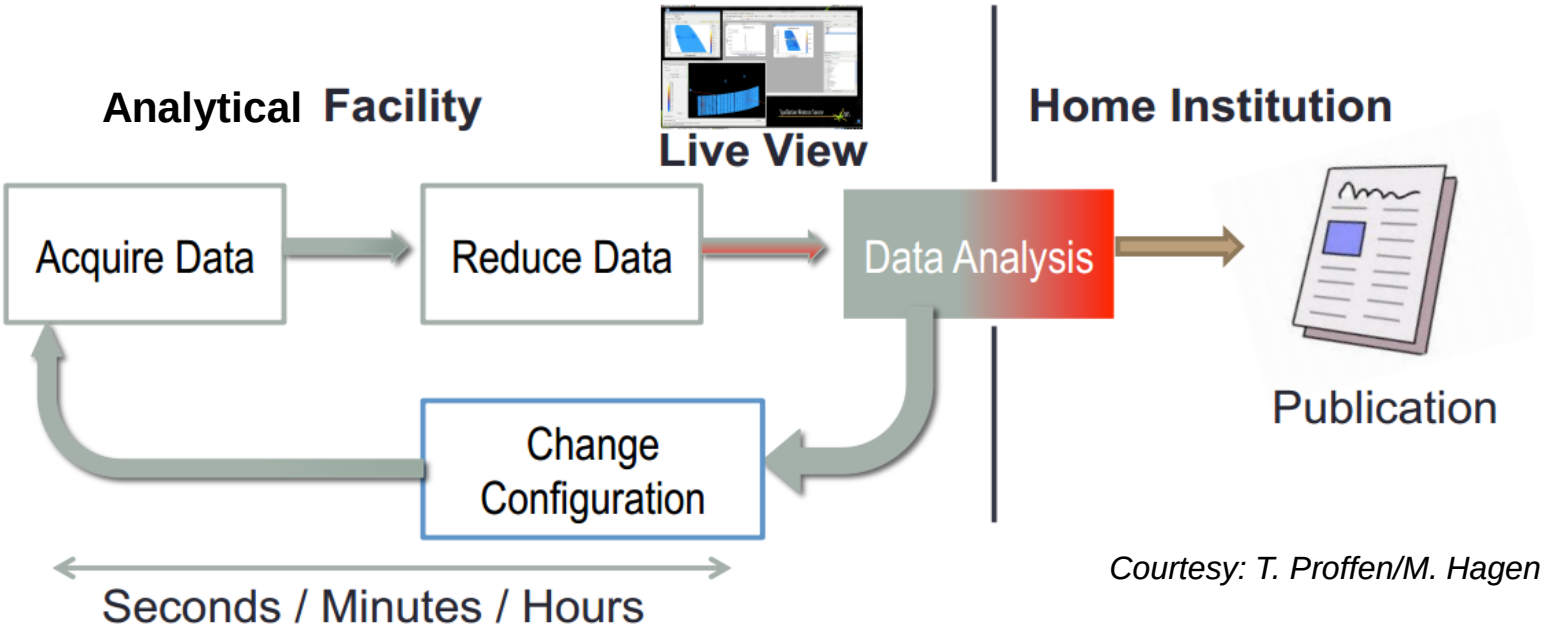
New source
New Science Drivers
Innovative Instrumentation

THANK YOU
for your attention!

ADDITIONAL MATERIAL

DATA ANALYSIS IN PHASE II: A PARADIGM SHIFT



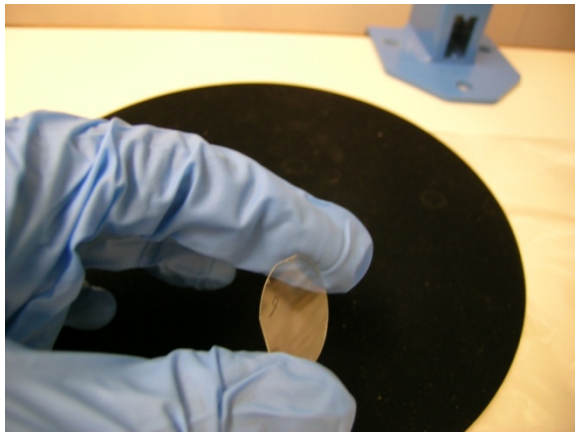


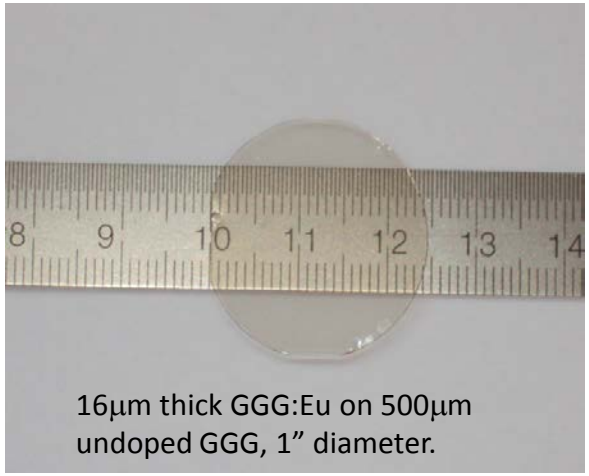
Courtesy: T. Proffen/M. Hagen

In-house LPE growth facility

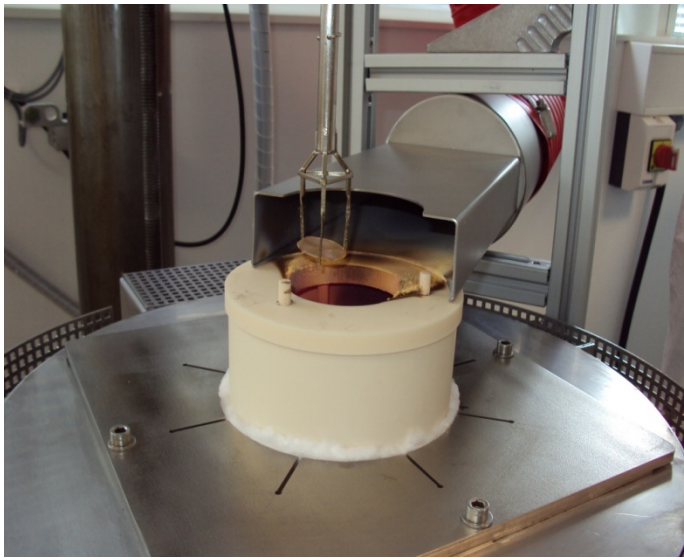
Continuous Improvement of thin crystal film scintillators:

- YAG:Ce ($Y_3Al_5O_{12}$)
- LAG:Eu,Tb ($Lu_3Al_5O_{12}$)
- LuGG:Eu ($Lu_3Ga_5O_{12}$)
- GGG:Eu , GGG:Tb ($Gd_3Ga_5O_{12}$)
- LSO:Tb (Lu_2SiO_5)

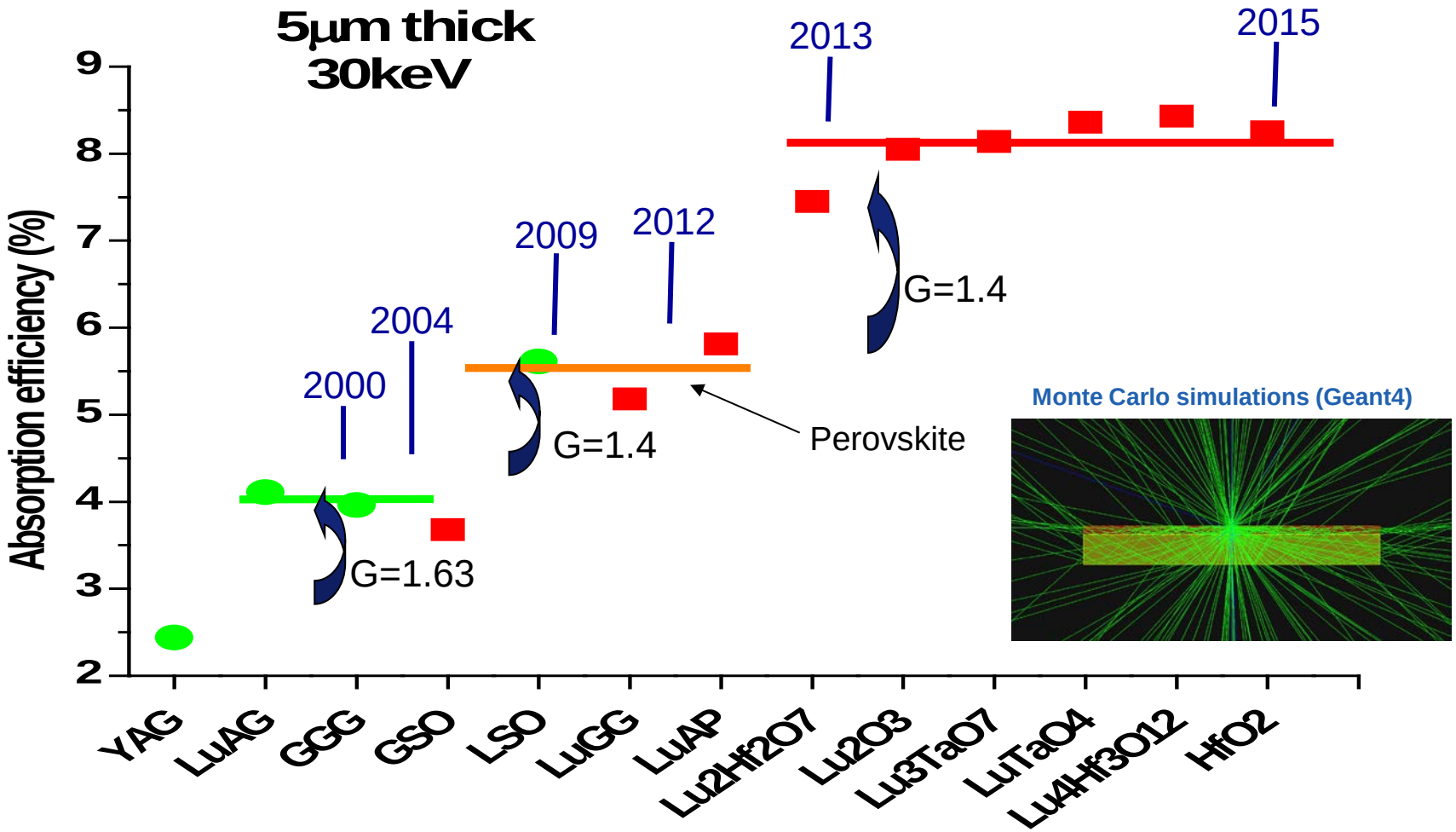




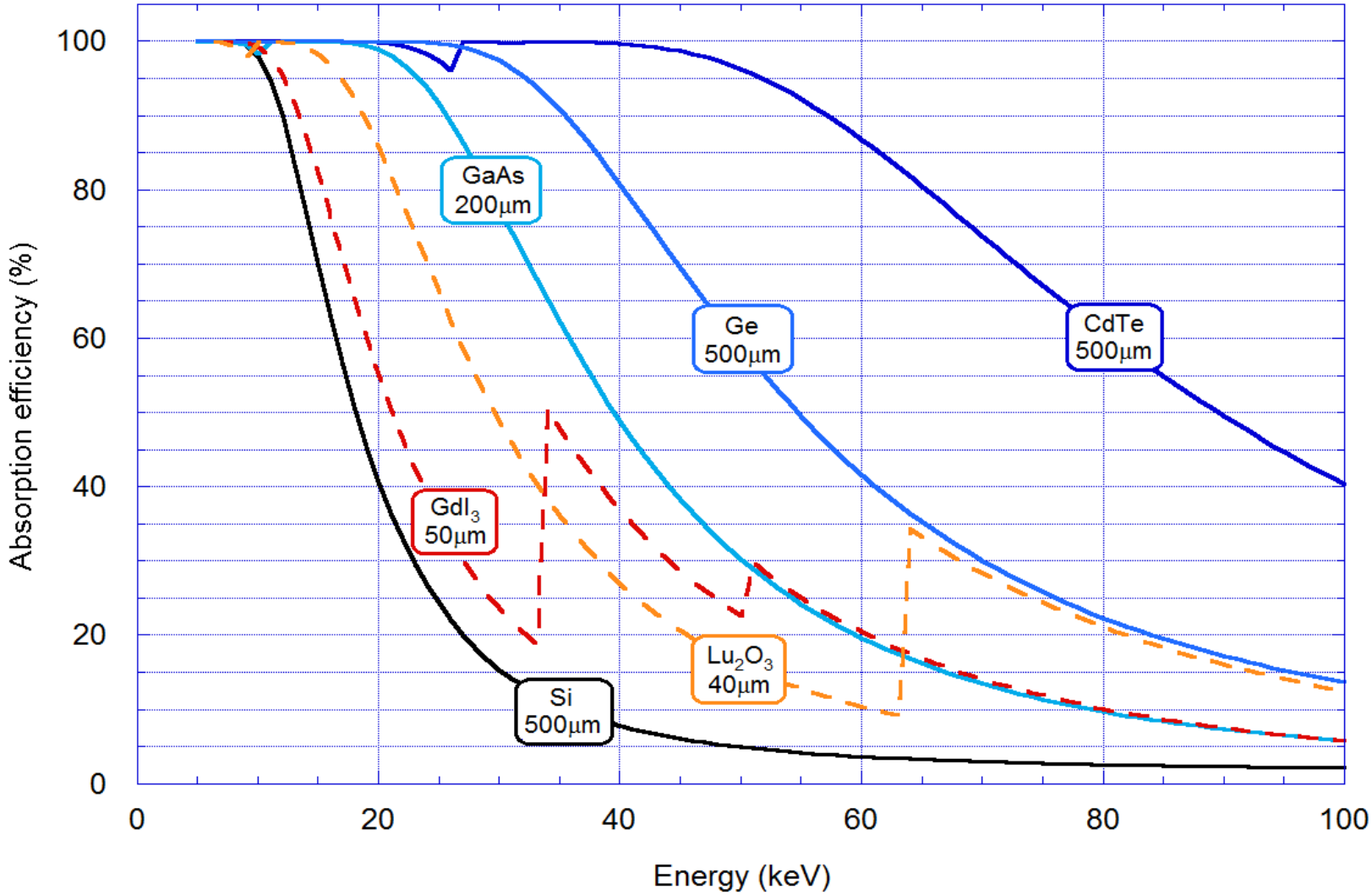
16µm thick GGG:Eu on 500µm undoped GGG, 1” diameter.



AN EXAMPLE OF EFFICIENCY GAIN



MATERIALS FOR HARD X-RAY DETECTION



efficiency calculated for various high stopping power X-ray sensor materials. The figure shows how high-Z semiconductors (GaAs, Ge, CdTe, in solid lines) and high density scintillators (GdI_3, Lu_2O_3, in broken lines) compare to 500 µm-thick silicon, typically used in pixel detectors today.

MAXIPIX: HIGH FRAME RATE HYBRID PIXEL DETECTOR

MPX2/Timepix photon-counting pixel readout chips

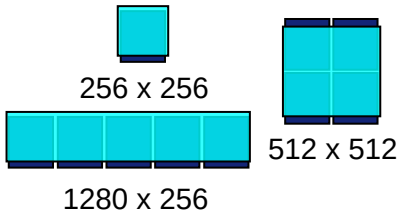
Si, CdTe, GaAs semiconductor pixel sensors

Flip-chip hybridizations

FPGA based readout interfaces

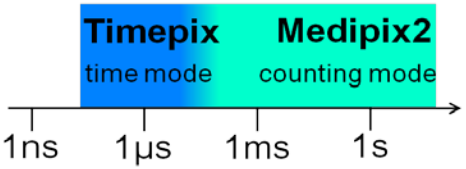
Fast data acquisition platforms

Detection geometries



- **55 x 55 μm²** pixel size
- 5-20 keV energy range
- > 10^5 counts/pixel/s
- **1400 frames per second**

Time domains



Coherent scattering

μ-SAXS

GISAXS

surface diffraction

inelastic scattering

PETRAIII DLS