Detection:
from the Dark Ages to the X-ray Detectors for future SR and FEL Photon Sources

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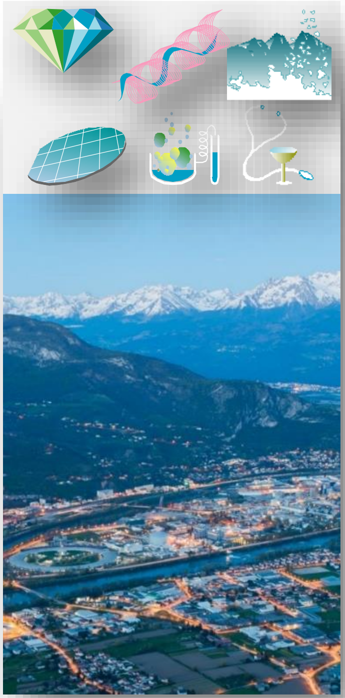
OUTLINE OF THE PRESENTATION



- Definitions
- X-ray detectors: from Röntgen to SR and FEL
  X-ray sources in a nutshell
- The future of SR and FEL sources
- My trivial reflections
- Are ATTRACT and/or LEAPS the solution?
- Conclusions

LET US MAKE SURE THAT WE TALK ABOUT THE SAME THING

detector

/dɪˈtɛktə/

noun

a device or instrument designed to detect the presence of a particular object or substance.

British Dictionary definitions for detector

detector

/dɪˈtɛktə/

noun

1. a person or thing that detects
2. any mechanical sensing device
3. (**electronics**) a device used in the detection of radio signals

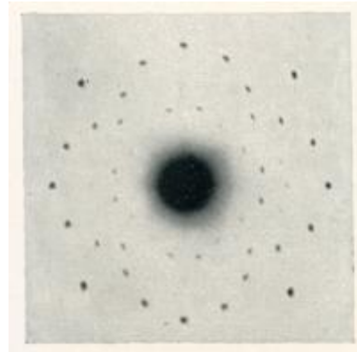
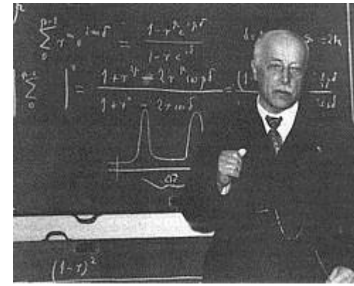
Word Origin and History for detector

n.

1540s, from Latin *detector* "uncoverer, revealer," agent noun from *detectus*, past participle of *detegere* (see detect).

X-RAY SCIENCE: A LONG SUCCESS STORY WHICH STARTED IN 1895

Wilhelm Conrad Röntgen (1845-1923)

Max von Laue (1879-1960)

1947: First observation of synchrotron radiation at General Electric (USA).

..followed by decades of parasitic use of Synchrotron radiation on high-energy machines

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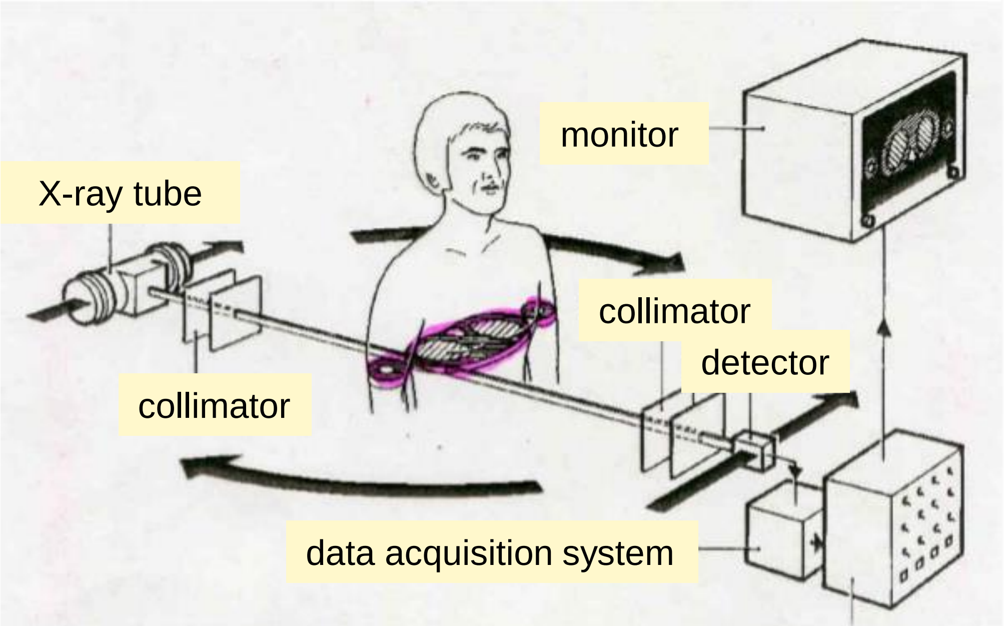
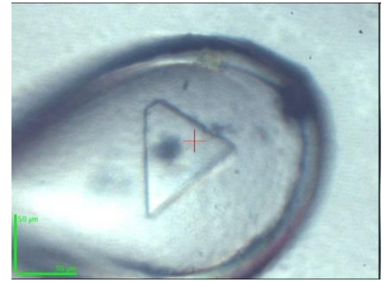
X-RAY IMAGING – X-RAY RADIOGRAPHY

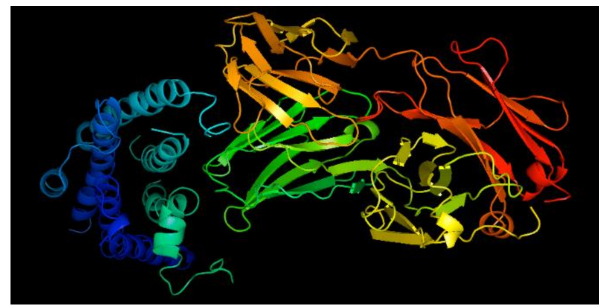


X-ray radiography: the oldest X-ray imaging technique
(see hand of Röntgen's wife)

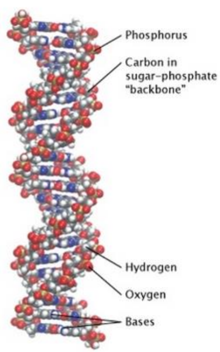
X-RAY DIFFRACTION- FROM DNA TO G-PROTEIN COUPLED RECEPTORS



tiny crystals



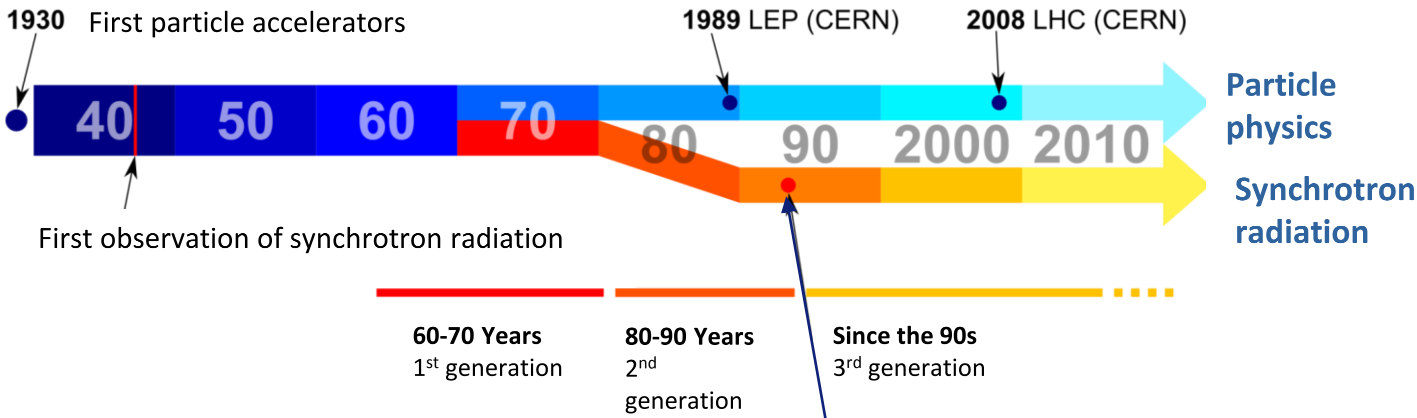
very complex structure



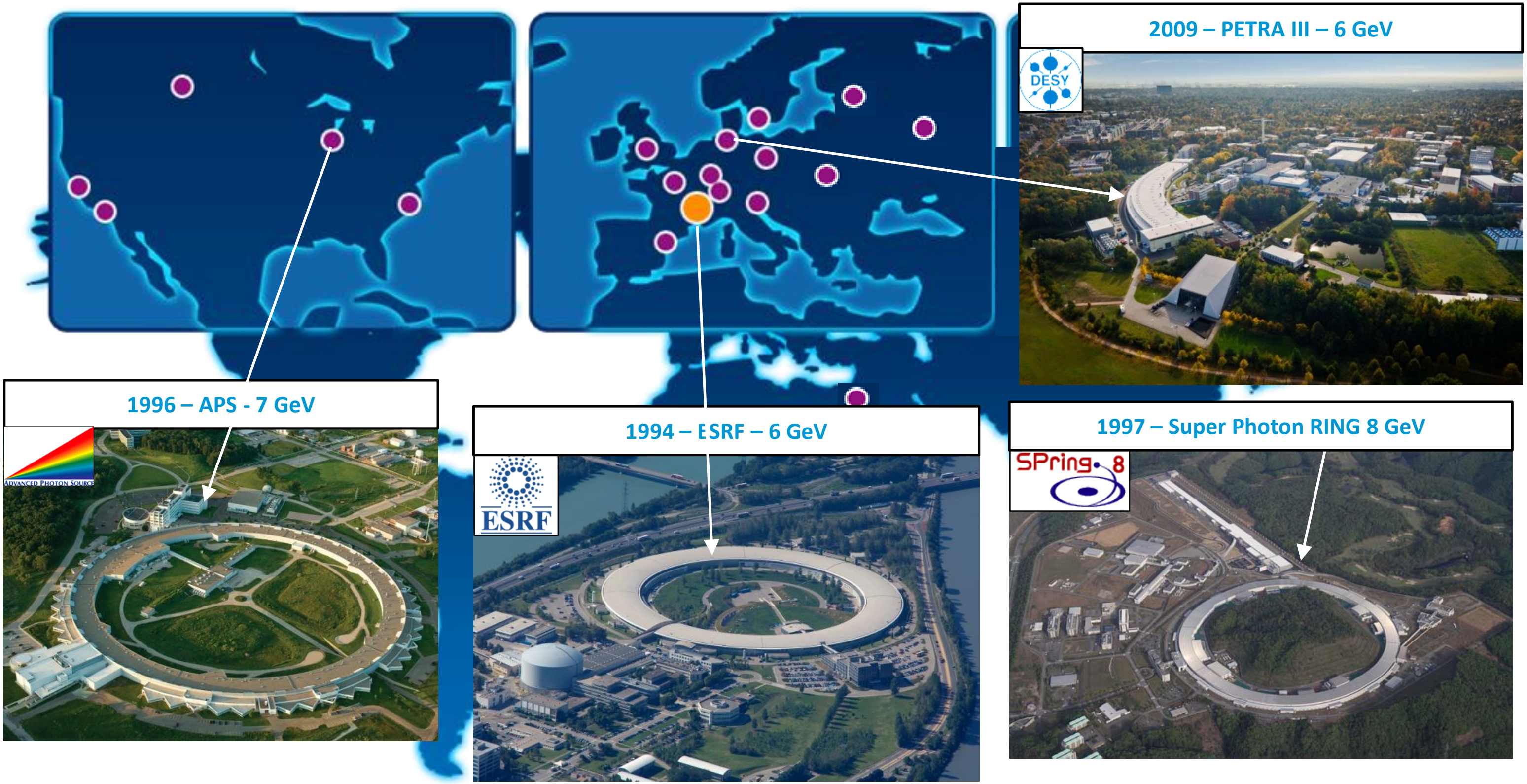
J. Watson, F. Crick,
R. Franklin, M. Wilkens
(1953)

Modern X-ray sources
Modern X-ray detectors

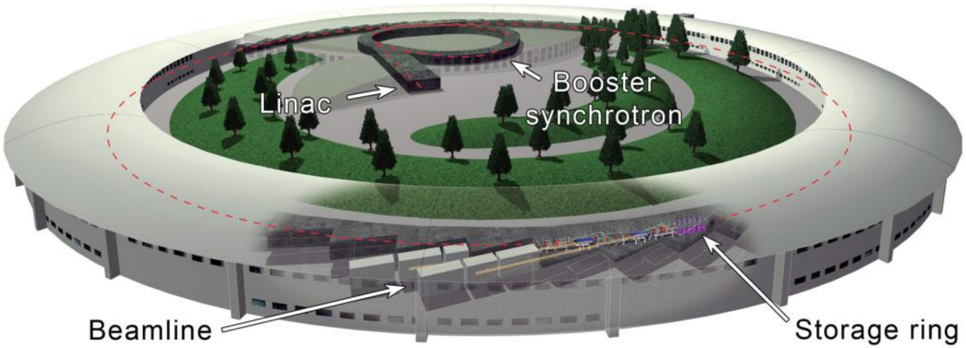
HISTORY OF SYNCHROTRON RADIATION SOURCES

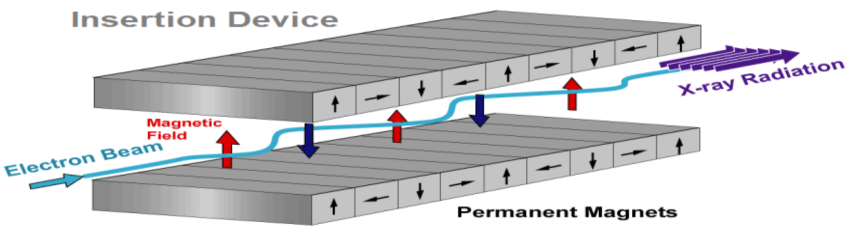


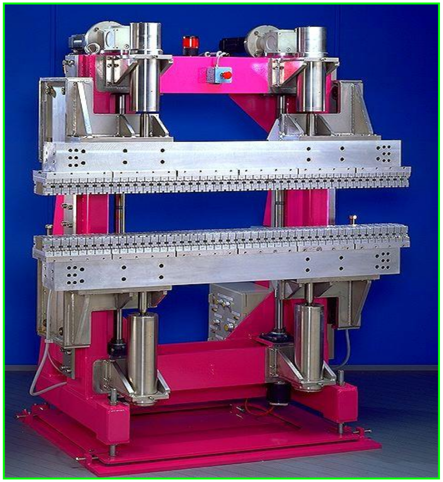
MAJOR THIRD GENERATION SYNCHROTRON FACILITIES WORLDWIDE

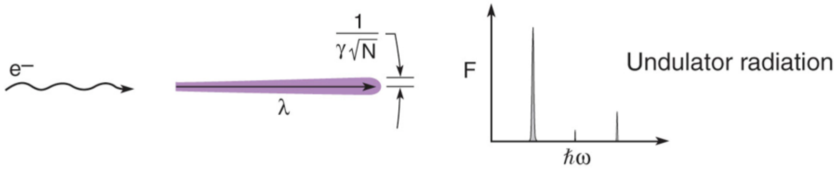


OPERATION OF A SYNCHROTRON SOURCE









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EVOLUTION OF X-RAY BRILLIANCE

SR X-rays:

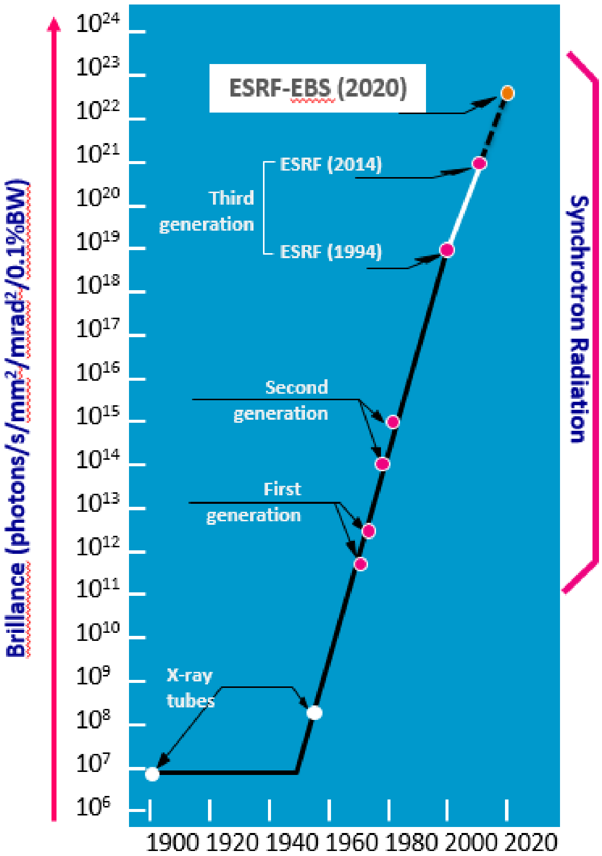
Large energy tunability
(infrared -> γ-rays)

Polarisation tunability

High spatial coherence

Pulsed emission
(e^- bunches):

Single bunch time resolution:
100 picoseconds
ΔT = 2.8 ns - 176 ns – 2.8 ms



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Fundamental and applied studies on materials and living matter

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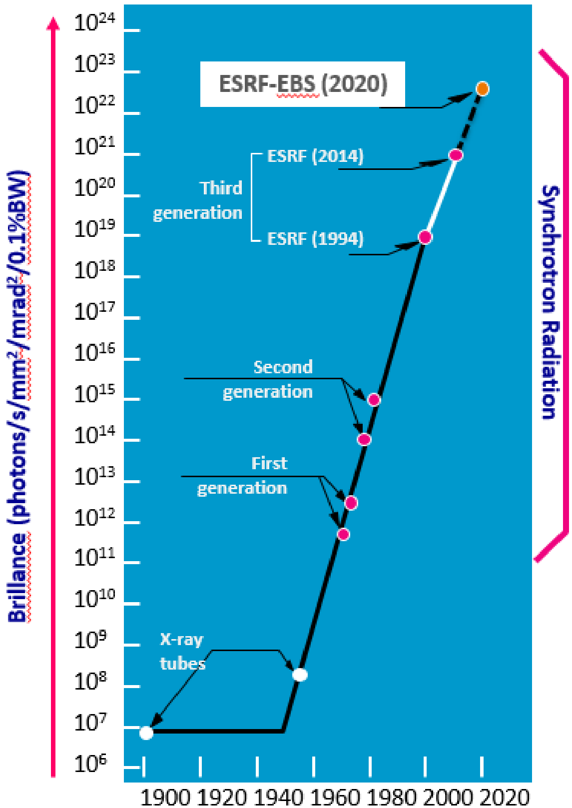
ESRF UPGRADE PROGRAMME – ESRF EBS (2015-2022)

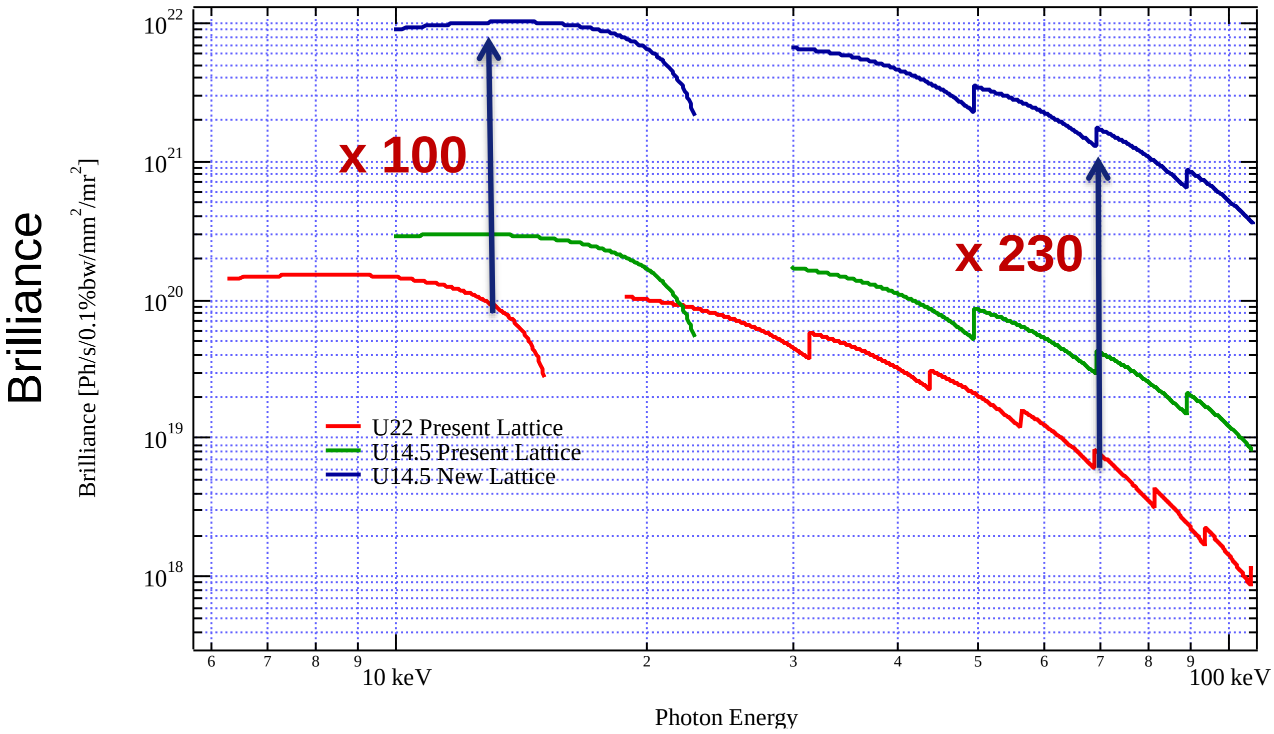


DESIGN OF A NEW LOW-HORIZONTAL-EMITTANCE LATTICE

(from 4 nm to ~0.15 nm)

ESRF EBS AND NEW UNDULATORS

IVUN22 min. gap 6 mm, K_{max}=1.7
CPMU14.5 min. gap 4 mm, K_{max}=1.7



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ESRF EBS AND NEW UNDULATORS

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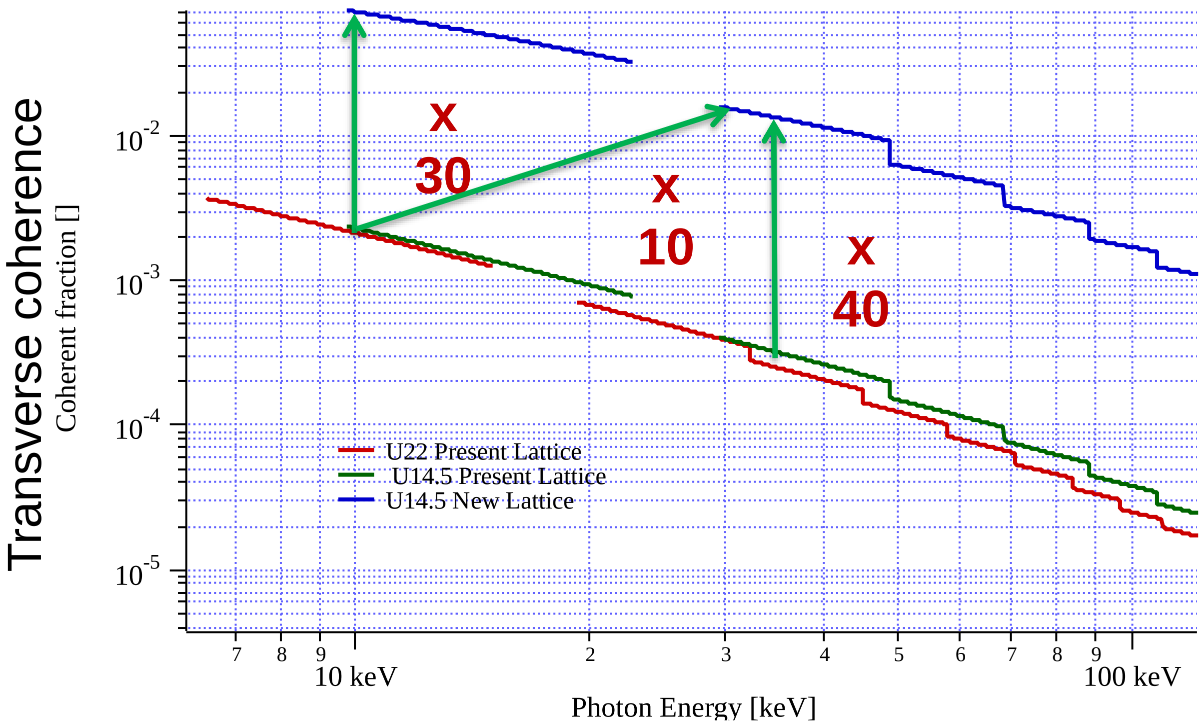
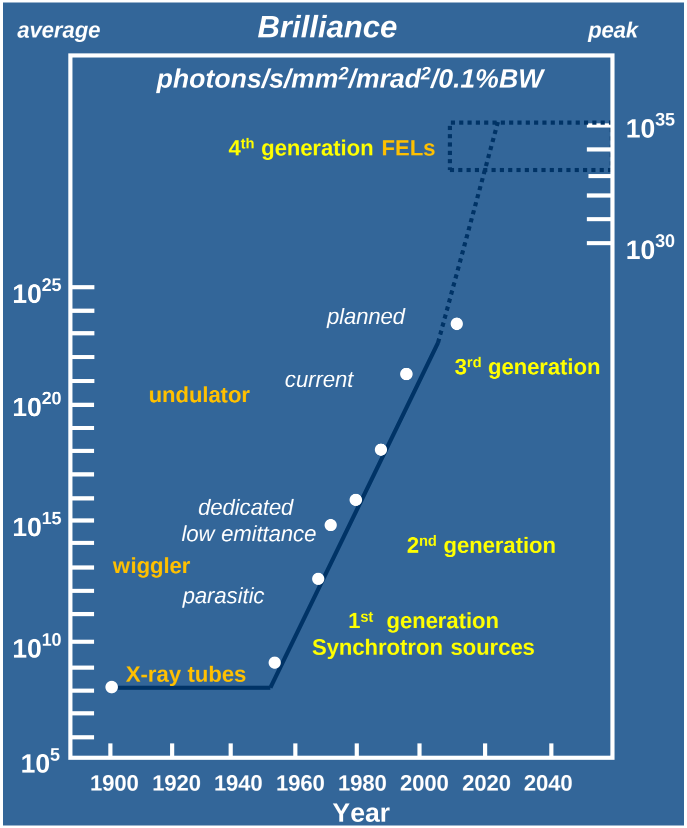


THE ADVENT OF THE FREE-ELECTRON LASER FACILITIES



LCLS

SACLA

FERMI

European XFEL

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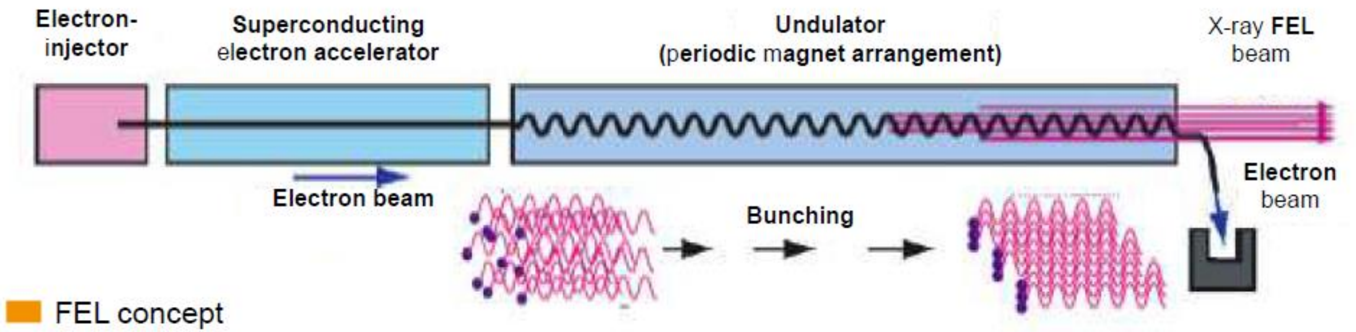
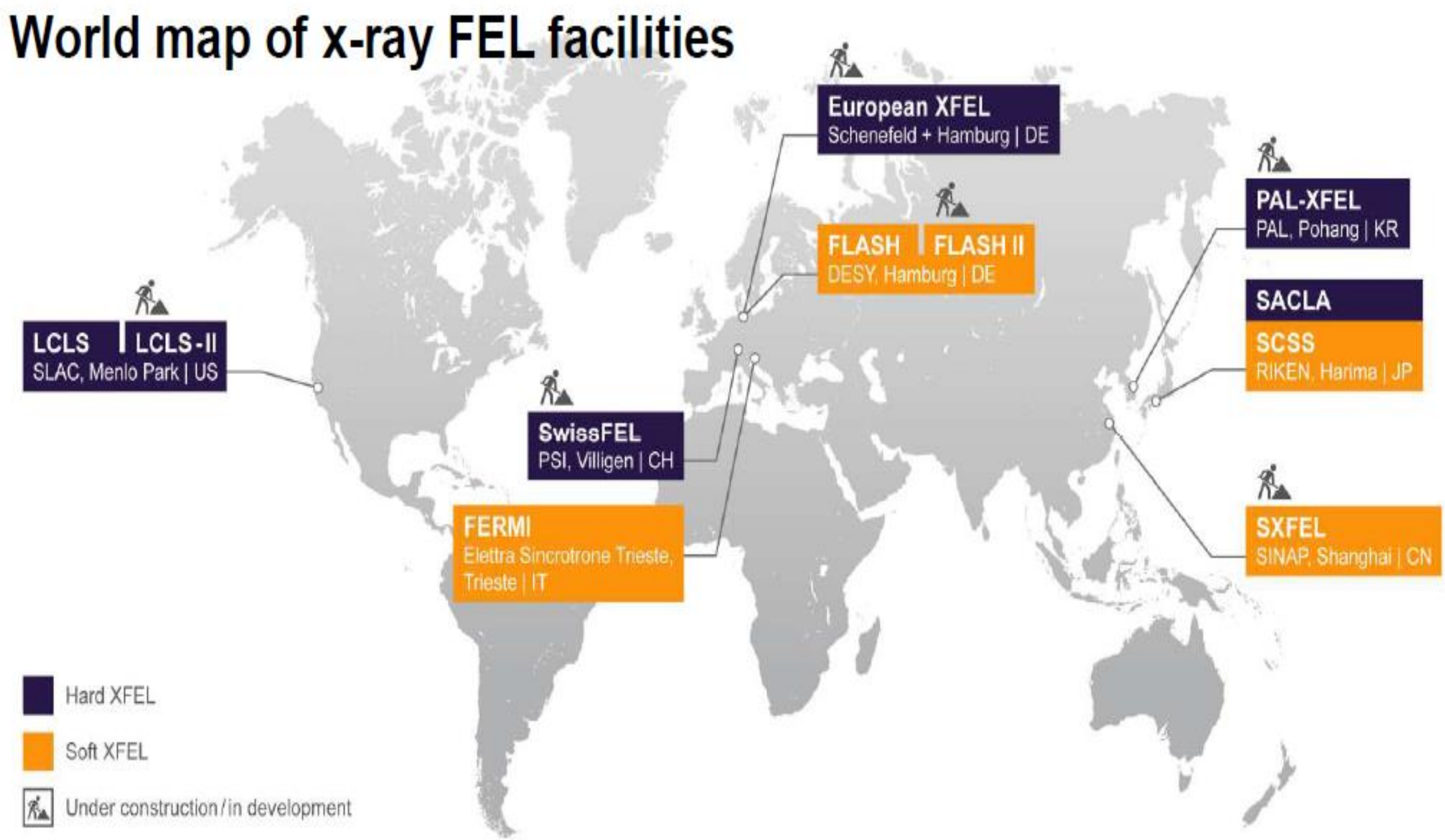
PRINCIPLE OF FREE-ELECTRON LASERS



Self-Amplified Spontaneous Emission (SASE) principle:
electrons produce spontaneous undulator radiation in the first section of a long undulator magnet which then serves as seed radiation in the main part of the undulator.

- ultrashort duration: fs – 200 fs
- very high pulse energies: 0.1 – 1 mJ
- full transverse coherence (<10 keV)
- limited longitudinal coherence
- single pass generation / fluctuations

FEL SOURCES OF THE WORLD



Courtesy T. Tschentscher, Hercules lecture

XXL VERSION OF LINEAR ACCELERATOR AND UNDULATORS

Super-conducting accelerator

- Worlds first long sc accelerator, 20 GeV, ~1000 m acc. length, 800 Nb cavities, 100 cryo-modules

X-ray FEL undulators

- 450 m total length, 5 m segments, 92 segments, 3.5 cm period → ~54.000 single magnets

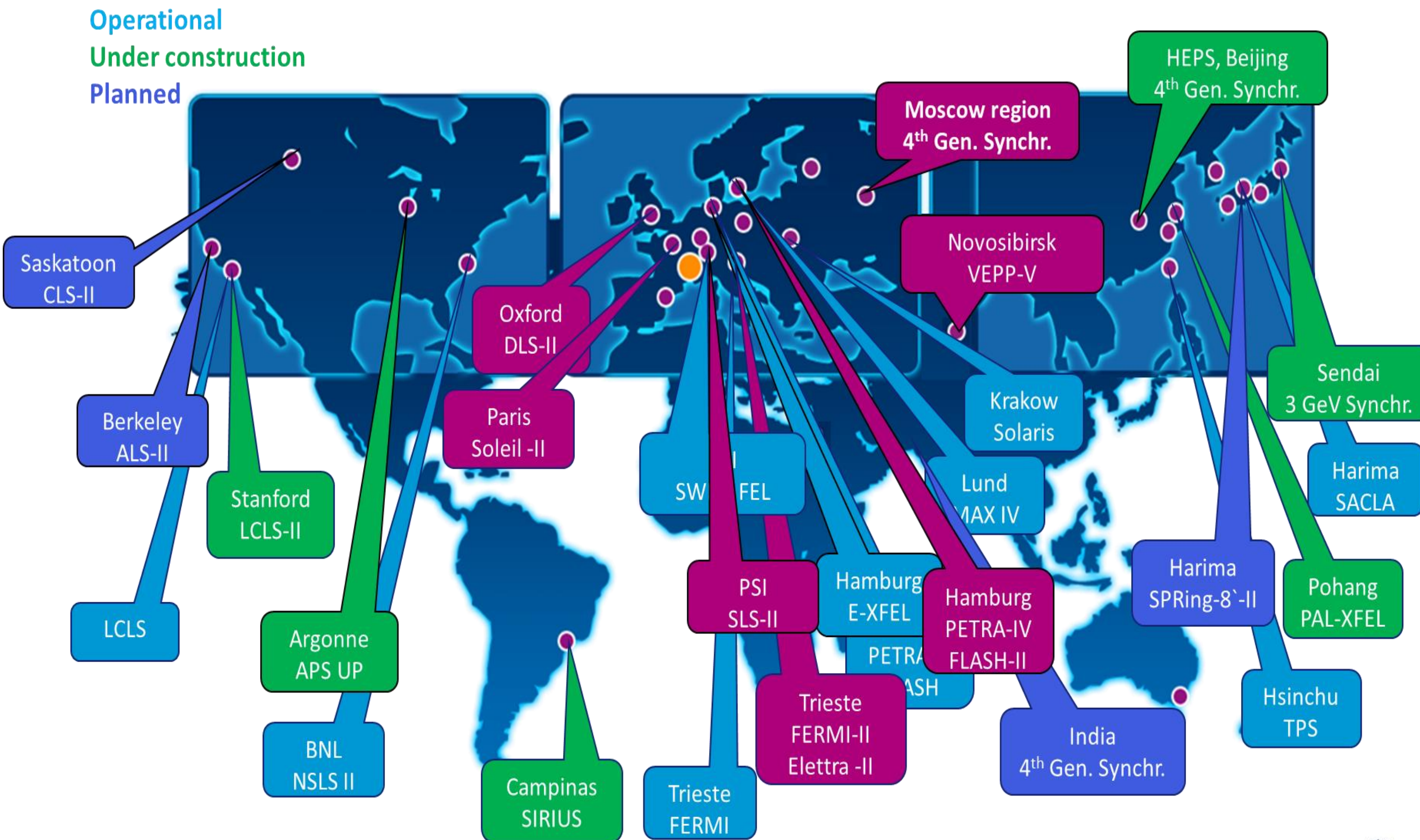
Courtesy T. Tschentscher, Hercules lecture

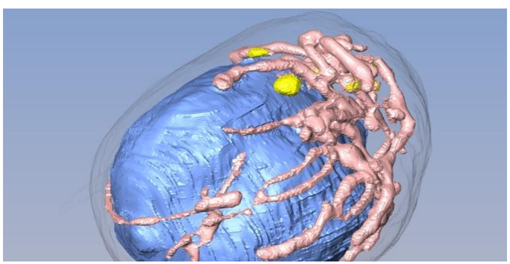
A rough comparison of hard x-ray FELs

Projekt	LCLS (USA)	LCLS-II CuRF	LCLS-II SCRF	SACLA (Japan)	SwissFEL (Switzerl.)	PAL-XFEL (Rep. Korea)	European XFEL
Max. elevtron energy (GeV)	14.3	15	4.5	8.5	5.8	10	17.5
Wavelength range (nm)	0.1–4.6	0.05–1.23	0.25–6	0.06–0.3	0.1–7	0.06–10	0.05–4.7
Photons/Pulse	~10^{12}	2 x 10^{13}	3 x10^{13} (soft X-rays)	2 x 10^{11}	~5 x 10^{11}	10^{11}–10^{13}	~10^{12}
Peak brightness	2 x 10^{33}	2 x 10^{33}	1 x 10^{32}	1 x 10^{33}	1 x 10^{33}	1.3 x 10^{33}	5 x 10^{33}
Pulses/second	120	120	10.000 – 100.000	60	100	60	27.000
No. of FELs	1	2	2	2	1	2	3
No. of end-stations	7	8	8	5	2	3	6
First FEL user beam	2009	2020	2020	2011	2018	2017	2017

Courtesy T. Tschentscher, Hercules lecture

SR SOURCES AND XFELS – MANY NEW PROJECTS OR MAJOR UPGRADES





EBSL3
A Beamline for High Throughput Large Field Phase-contrast Tomography

ESRF-EBS
EXTREMELY BRILLIANT SOURCE

- **Hard X-ray energy, high X-ray coherence, large field-of-view , high throughput tomography** is ideally suited to non-destructive study of large objects with sub-micrometre resolution
- **New perspectives** for research in palaeontology, archaeology and characterisation of engineered materials by providing the largest high-energy and high-coherence synchrotron beam worldwide for **hierarchical imaging** and automated tomography
- **3D-imaging research applications:**
  - materials for space, aeronautics, automotive, etc.
  - micrometre scale anatomy of entire organs
  - hierarchical imaging of large specimens, e.g. Mummies
  - 3D-virtual reconstruction of fossils and unique artefacts

The optimum detector for BM18 at the ESRF

20x20 microns CMOS pixel detector
40 x 4 cm area => 40 Mpixel
2 bytes per pixel, 80 Mbytes/frame
Frame rate up to 200 frames/sec
⇒16 Gbyte/sec
⇒58 Tbyte/h
⇒1.4 Tbyte/day

No way!!!!!

DETECTORS AND THE PHYSICS NOBEL PRIZE

1907		Albert Abraham Michelson	United States Poland	"for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid"[13] Astrophysics (LIGO, VIRGO)
1927		Arthur Holly Compton	United States	"for his discovery of the effect named after him"[32]
		Charles Thomson Rees Wilson	United Kingdom	"for his method of making the paths of electrically charged particles visible by condensation of vapour"[32] High-energy physics
1948		Patrick Maynard Stuart Blackett	United Kingdom	"for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation"[48] Astrophysics & High-energy physics
1950		Cecil Frank Powell	United Kingdom	"for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method"[50] High-energy physics

DETECTORS AND THE PHYSICS NOBEL PRIZE

1960		Donald Arthur Glaser	United States	"for the invention of the bubble chamber"[60] High-energy physics
1968		Luis Walter Alvarez	United States	"for his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using hydrogen bubble chamber and data analysis"[68] High-energy physics
1992		Georges Charpak	France Poland	"for his invention and development of particle detectors, in particular the multiwire proportional chamber"[92] High-energy physics
2002		Raymond Davis, Jr.	United States	"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"[102] Astrophysics
		Masatoshi Koshiba	Japan	
		Riccardo Giacconi	Italy United States	"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"[102]

DETECTORS AND THE PHYSICS NOBEL PRIZE

2009		Charles K. Kao	Hong Kong United Kingdom United States	"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"[109]
		Willard S. Boyle	Canada United States	"for the invention of an imaging semiconductor circuit – the CCD sensor"[109]
		George E. Smith	United States	
2017		Rainer Weiss	Germany United States	"for decisive contributions to the LIGO detector and the observation of gravitational waves"[117]
		Kip Thorne	United States	
		Barry Barish	United States	

Astrophysics

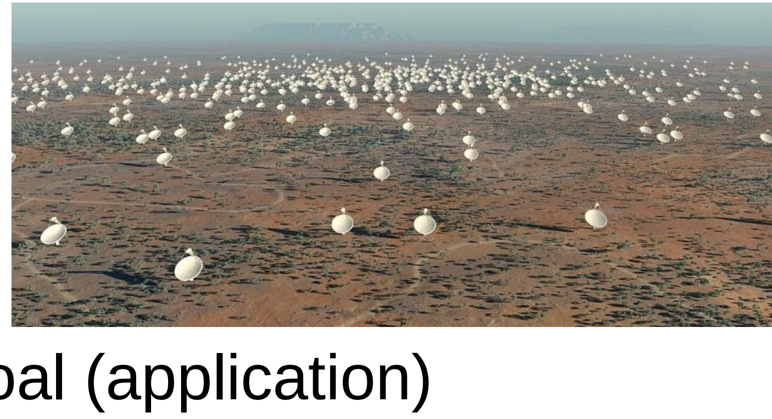
TRIVIAL REFLECTIONS

- Look what are the trends and developments in High-Energy Physics and Astrophysics

1x Data Analysis is mentioned =>

- It is not only about detectors

Data acquisition
Data transfer
Data storage
Data analysis



One detector – one goal (application)

versus

Many different detectors – for many applications

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THE WAY TO GO?: THE HUAIROU SCIENCE CITY

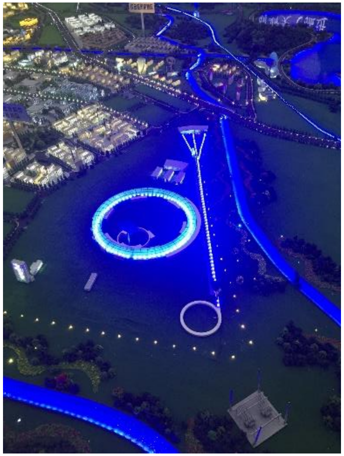
100 km^2 to build a centennium science city for study, research, living, and business

Physical and Matter Sciences
Space Sciences
Earth & Atmospheric Science

THE WAY TO GO?: THE HUAIROU SCIENCE CITY

Platform of advanced photon source technology R&D (PAPS)

High Energy Photon Source (HEPS)
Synergetic Extreme Conditions Facility
The Earth System Science Numerical Simulator Facility
Multimodal Trans-Scale Biomedical Imaging Facility
Ground-based Space Environment Monitoring Network
Beijing Materials Research and Analysis Center for Clean Energy
The platform of Materials Genome Research
Advanced vehicle and measuring technique platform
Test and Assurance Platform for Space Science Satellite Missions



From Open Science to Open innovation
A new paradigm to accelerate
breakthrough innovation in sensors and imaging technologies

Aalto University | CERN | eirma | EMBL | ESADE Universitat Ramon Llull | ESO | ESRF | European XFEL | ILL Neutrons for Science Institut Laue-Langevin

THE ATTRACT CONCEPT

A proposal for a dedicated, interdisciplinary program to co-develop with Research Infrastructures and industry breakthrough sensor & imaging technologies

The purpose is to address demanding challenges in both science and societal needs (e.g. health, sustainable materials and information and communication technologies)

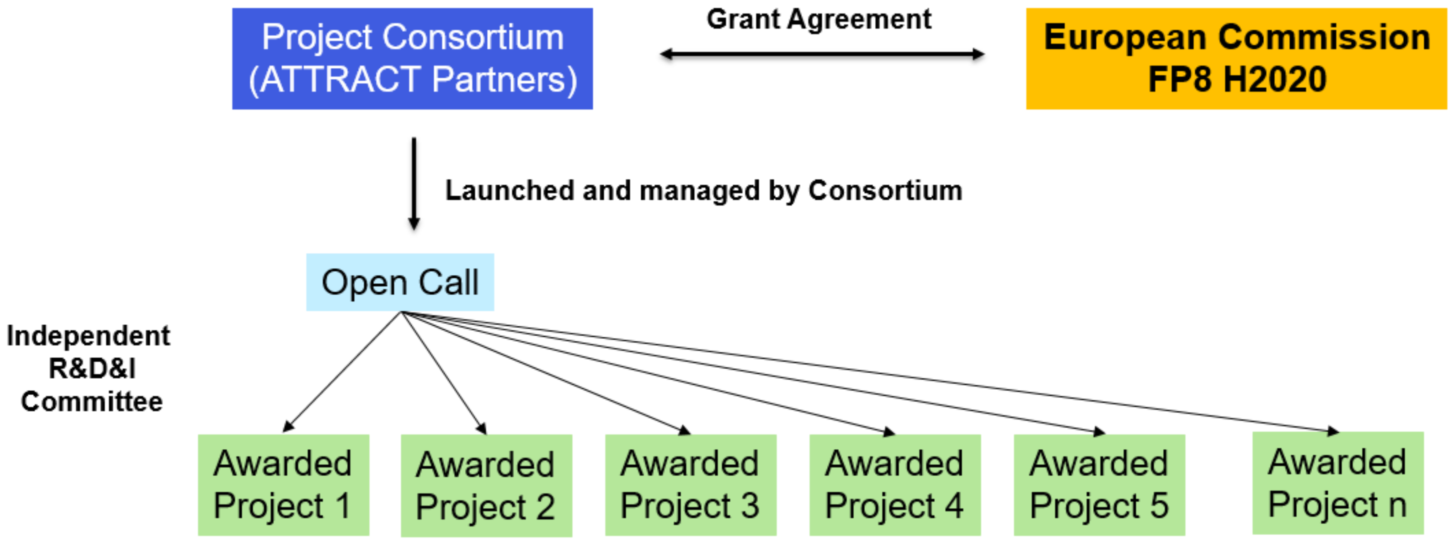
It shall involve the detector R&D community from many fields including e.g. biology, physics, astronomy, space exploration, nuclear engineering, medical sensing and imaging, related computing (ICT) and others

CO-INNOVATION = "VALUE FOR MANY"

A simple way to understand it:

We all make the best fishing gear and then each one decides what to fish…

ATTRACT PROJECT CONCEPT



Attract Phase-1: 20 M€ (2018 – 2020, 24 months): seed funds (100 k€) for 180 projects

Topics: sensors, front- and back-end electronics, data acquisition systems, software and integration

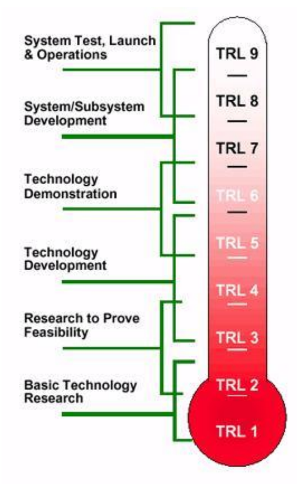
Eligibility criteria: legal entity within EU or H2020 associated countries, joint proposals of at least two entities

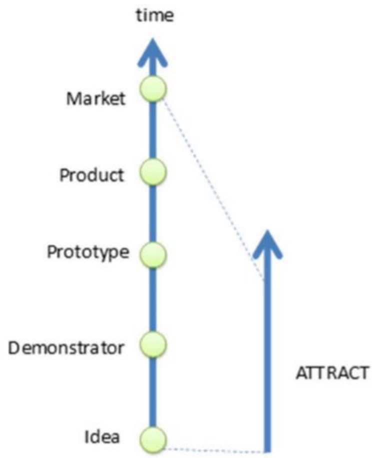
ATTRACT – THE FUTURE

Seed Funding | **Scale Funding**

Seed Funding | **Scale Funding**

Seed Funding | **Scale Funding**





THE LEAGUE OF EUROPEAN ACCELERATOR-BASED PHOTON SOURCES (LEAPS)

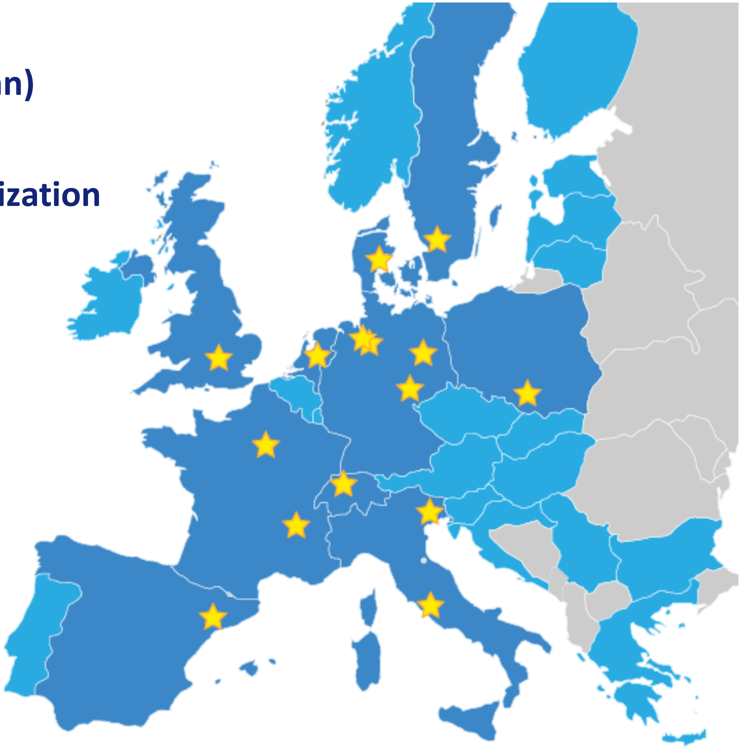
Launched: 2015

Chair: H. Dosch
(co-chairs A. Harrison, C. Quitmann)

Members: 15 Institutions in Europe
European Synchrotron User Organization

ESUO EUROPEAN SYNCHROTRON USER ORGANISATION

ALBA, DESY, diamond, Elettra Sincrotrone Trieste, ESRF, European XFEL, FELIX, HZB Helmholtz Zentrum Berlin, HZDR Helmholtz Zentrum Dresden Rossendorf, INFN Istituto Nazionale di Fisica Nucleare, MAX IV, ISA, Paul Scherrer Institut PSI, SOLARIS National Synchrotron Radiation Centre, SOLEIL Synchrotron



LEAPS GOALS

Secure European leadership in X-ray science for decades

Develop coherent Roadmap of all SR and FEL facilities in Europe

1) Enable excellent science
2) Serve a strong & diverse user community
3) Attract the next generation of scientists
4) Next generation light sources
5) Push & disseminate technology and innovation
6) Strive for integration & sustainability
7) Open Data
8) Implement best practice

LEAPS – PROPOSED DETECTOR DEVELOPMENTS

Ultra-high continuous frame rate imager (> 10^5 frames per second with >10^7 pixels)
Small pixel imager (< 10 micron pixels, with > 10^8 pixels)
Large format and high flux energy resolving imagers (≥ 500 cm2; DE/E < 0.04)
Soft X-ray imager (50 – 2000 eV photon range)
Tender X-ray imager (500 – 5000 eV photon range)
High-speed multi-element spectroscopy detector (> 100 elements, >10^6 cps/element)
Common Toolbox (back end electronics and interface with computing system)

EUROPE IS NOT ENOUGH!

A world-wide concerted effort is required


THANK YOU VERY MUCH FOR YOUR ATTENTION
….AND ENJOY THE WORKSHOP!!!