Lund Circuit Design Workshop

Status and Future Plans for the MAX IV Light Sources

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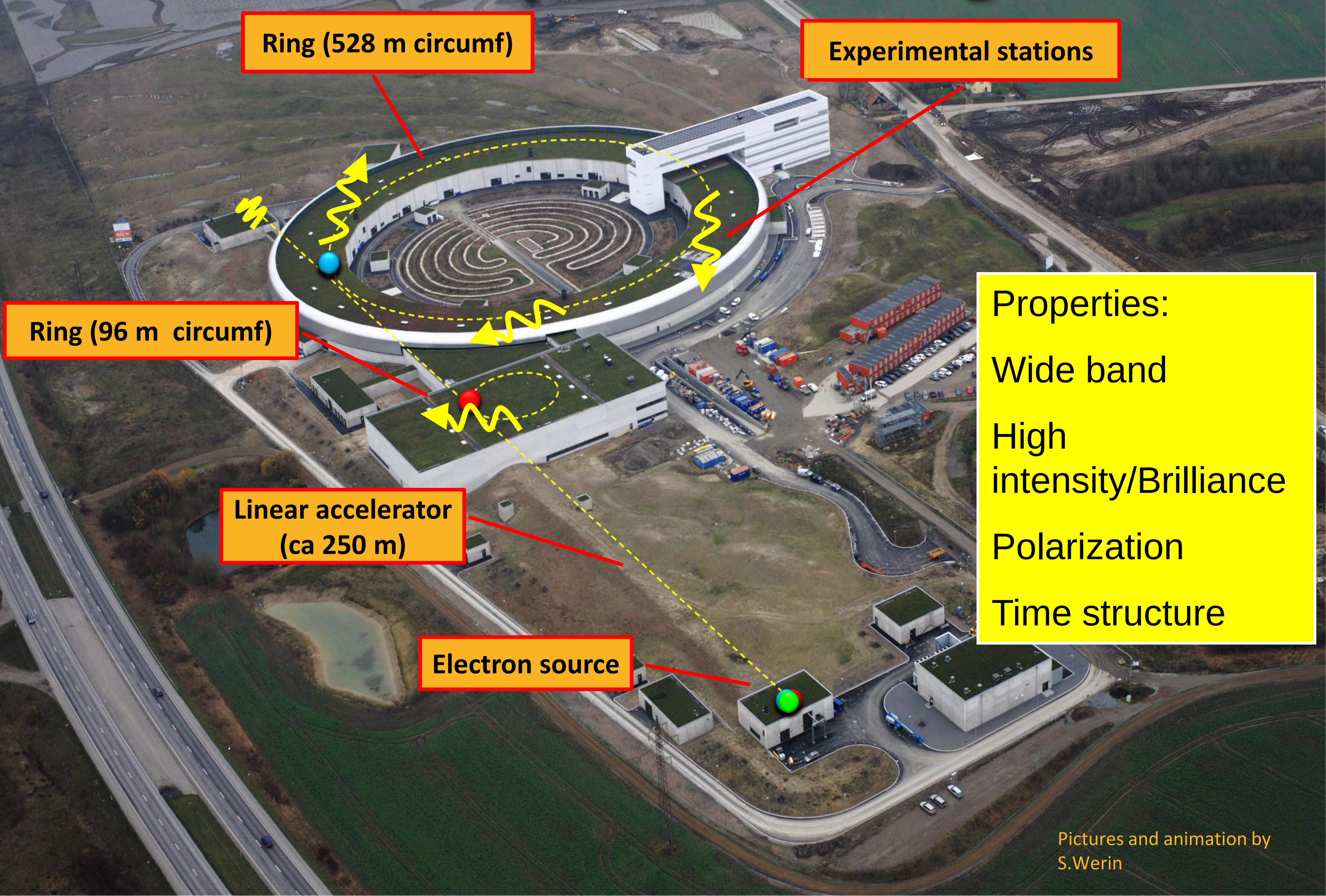
MAX IV Laboratory

MAX IV

Summary

- What is Synchrotron Radiation ?
- Why Synchrotron Radiation ?
- The MAX IV Light Sources: Status and Commissioning Highlights
- Future Perspectives

What is Synchrotron Light ?



Properties:

Wide band

High intensity/Brilliance

Polarization

Time structure

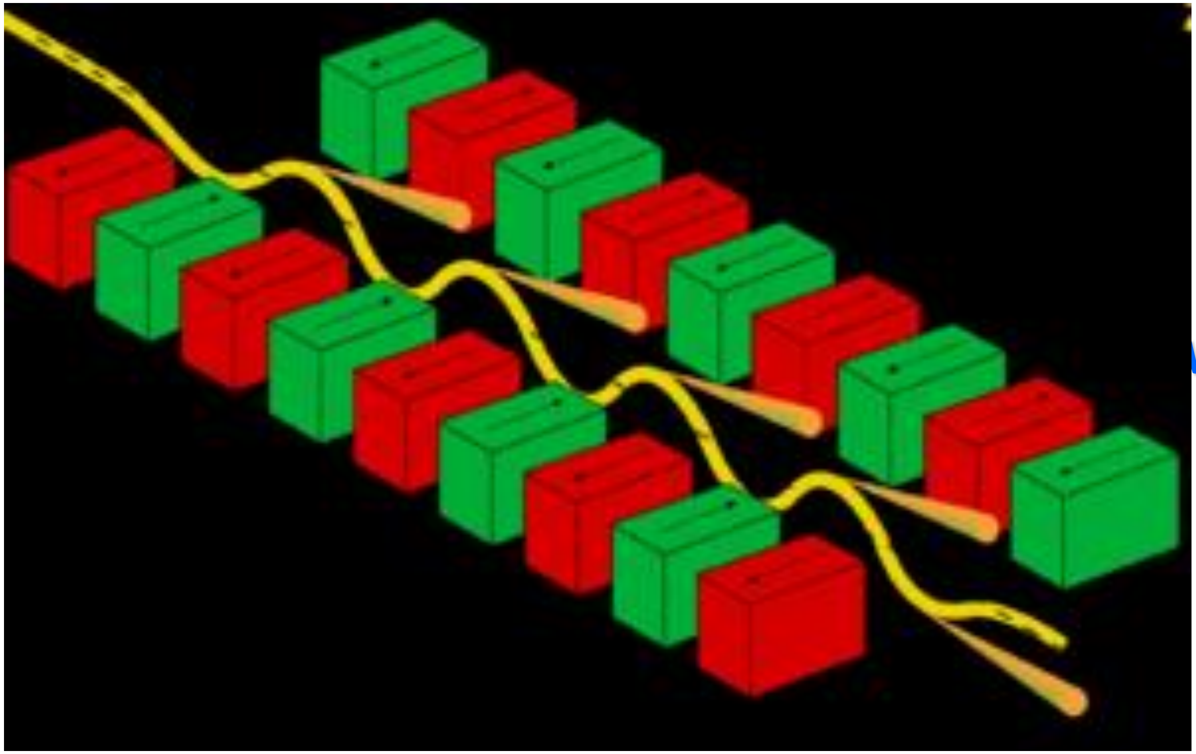
Pictures and animation by S.Werin

Insertion Devices

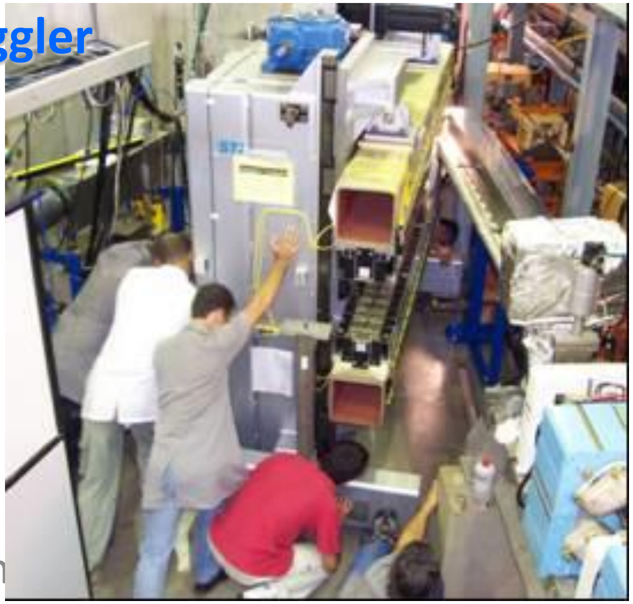
Undulator


Photo E.Wallen

Periodic arrays of magnets cause the beam to “undulate”



Wiggler

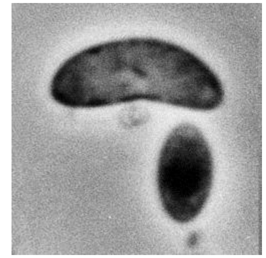


www.lightsources.org

Using Light To Understand the World

Anton van Leeuwenhoek

1632-1723



Why Synchrotron Light ?

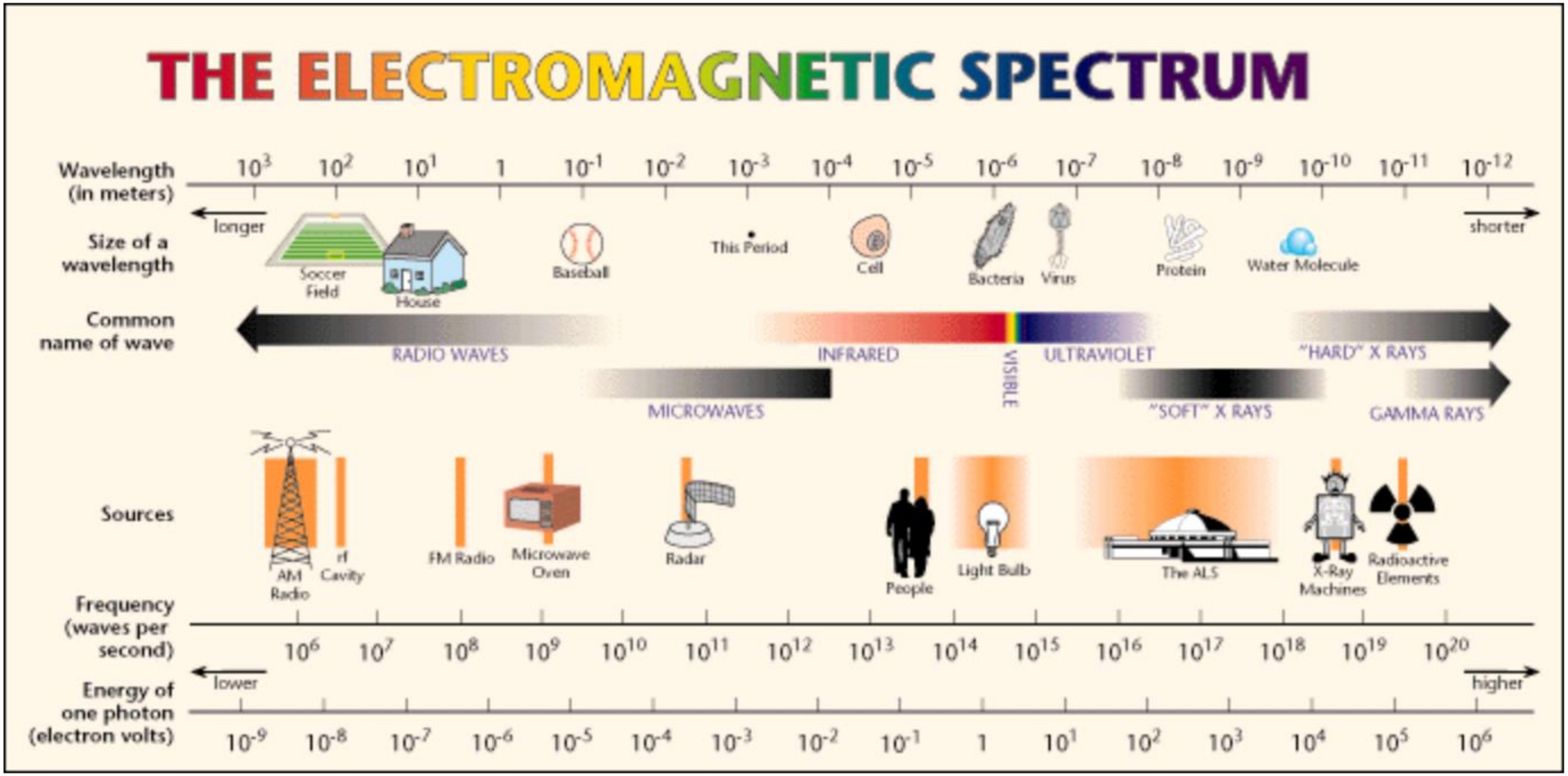
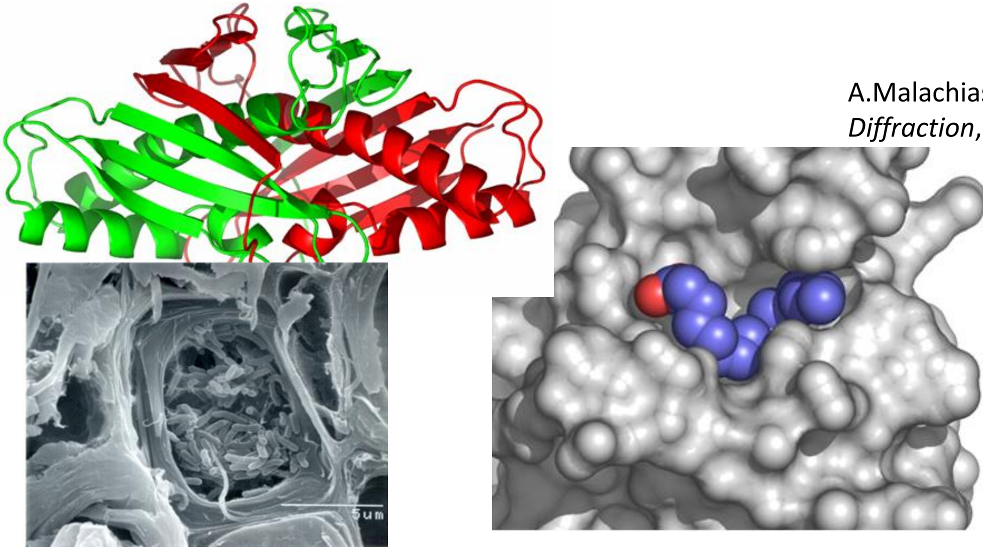
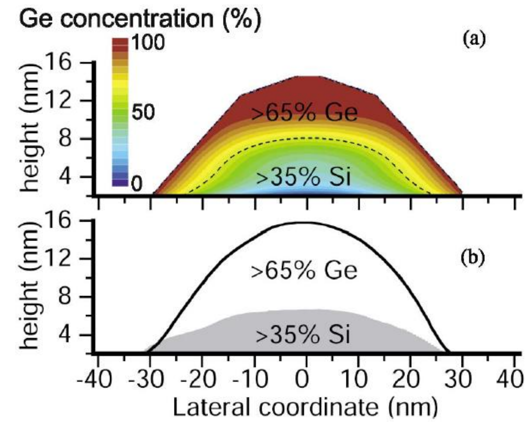


Image: Lawrence Berkely Lab

Why Synchrotron Light ?



A.Malachias et ak, *3D Composition of Epitaxial Nanocrystals by Anomalous X-Ray Diffraction*, PRL **99,** 17 (2003)



OLIVEIRA, M. A. et al. *Crystallization and preliminary X-ray diffraction analysis of an oxidized state of Ohr from Xylella fastidiosa.* Acta Crystallographica. Section D, Biological Crystallography, v. D60, p. 337-339, 2004

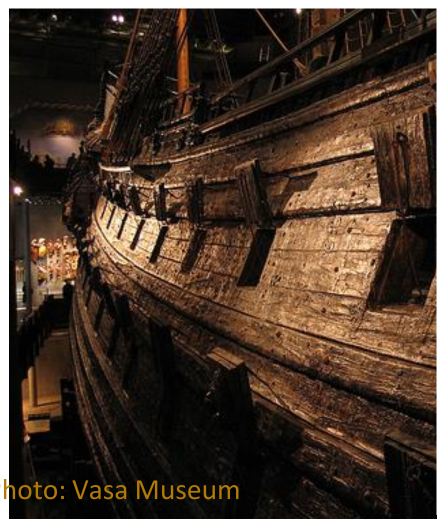
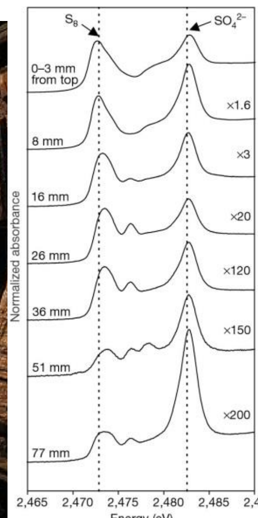
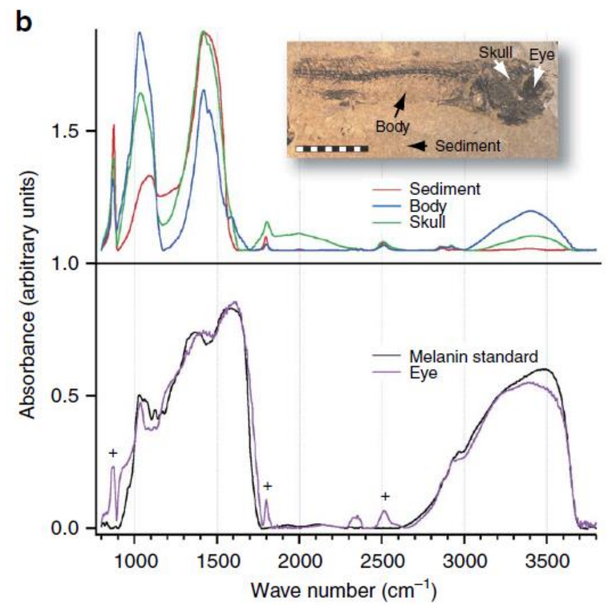


Photo: Vasa Museum

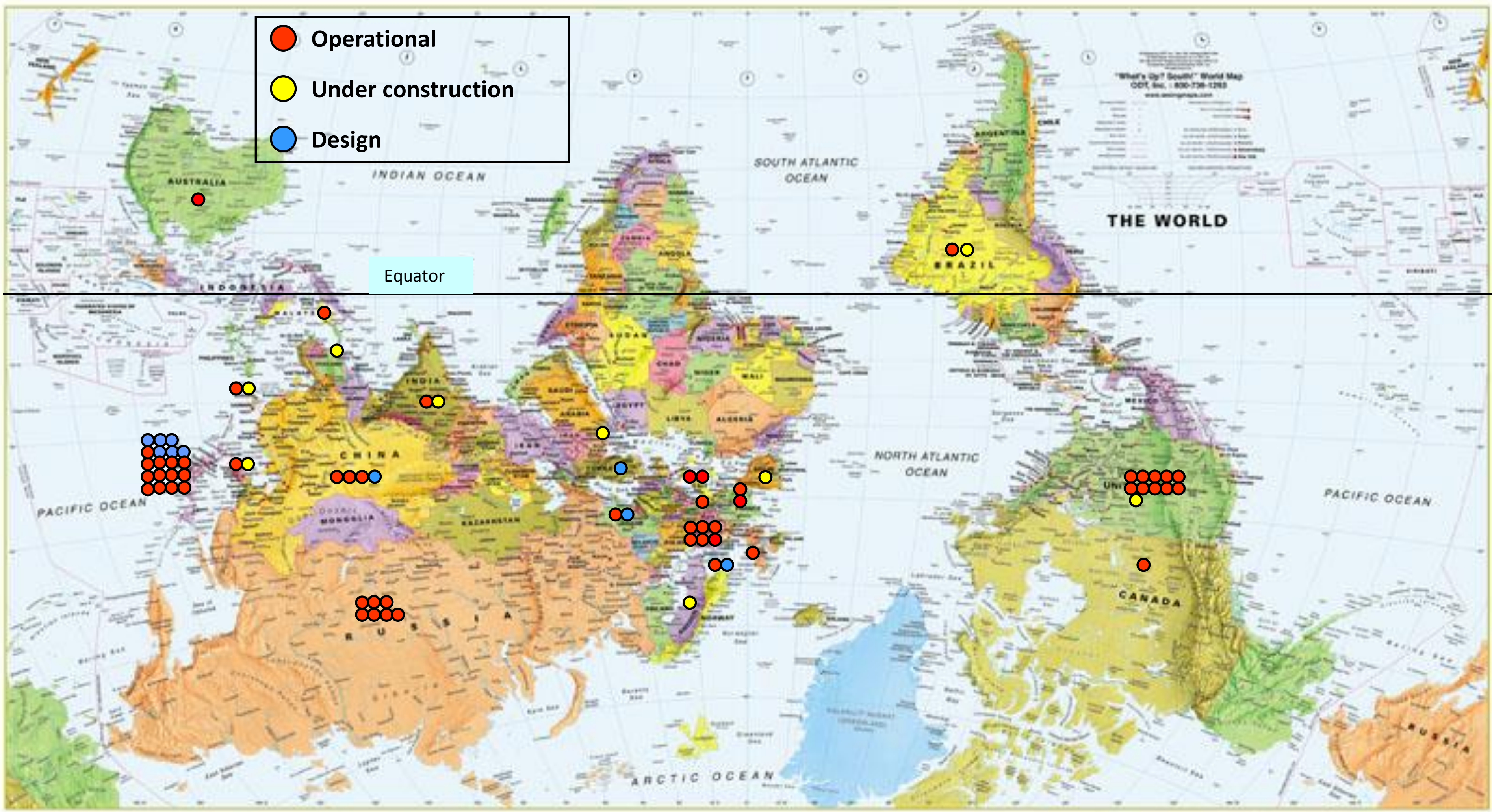




Sandstrom, M. *et al*. **Deterioration of the seventeenth-century warship vasa by internal formation of sulphuric acid**. *Nature* **415,** 893 - 897 (2002)

J.Lindgren et al, **Molecular preservation of the pigment melanin in fossil melanosomes**, Nature Communications DOI: 10.1038/ncomms1819 (2012)

SR Light Sources WorldWide



Conceptual Basis of the MAX IV Design

- **Scientific Case calls for high brightness radiation over a wide spectral and time range: IR to Hard R-rays, Short X-Ray Pulses.**
- **Need for high brightness: low emittance and optimized insertion devices.**

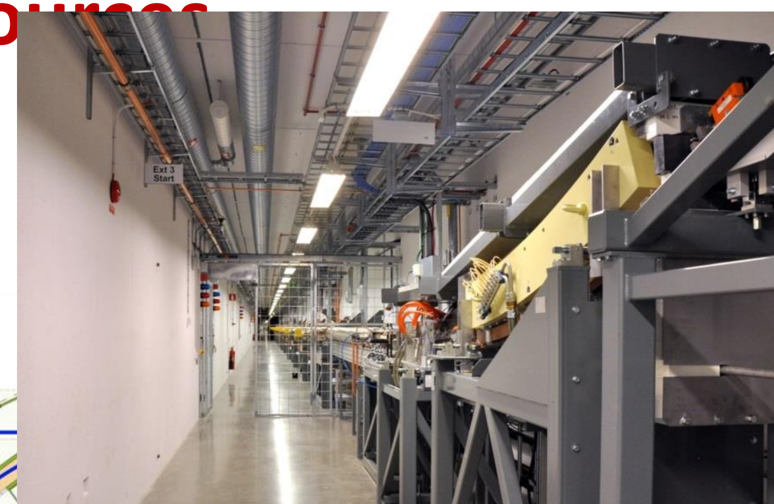
- **This is hard to achieve in a single machine:**
- **higher electron beam energy → harder photons**
- **lower electron beam energy → softer photons**

One size does not fit all !

The MAX IV Approach

- **Different machines for different uses:**
  - A high energy ring with ultra-low emittance for hard X-ray users.
  - A low emittance low energy ring for soft radiation users
  - A LINAC based source for generating short pulses and allowing for future development of an FEL source.

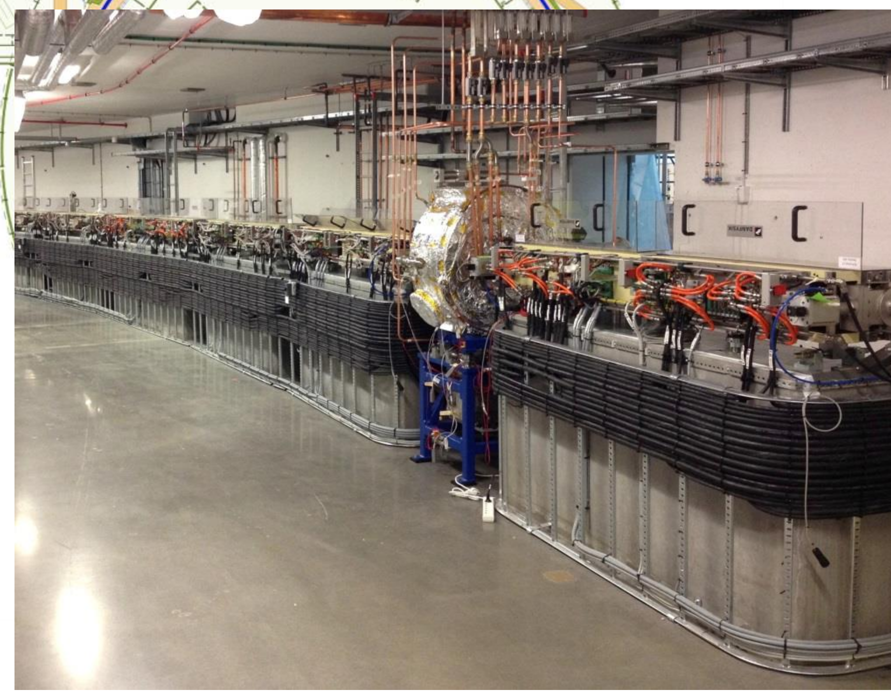
The MAX IV Light Sources

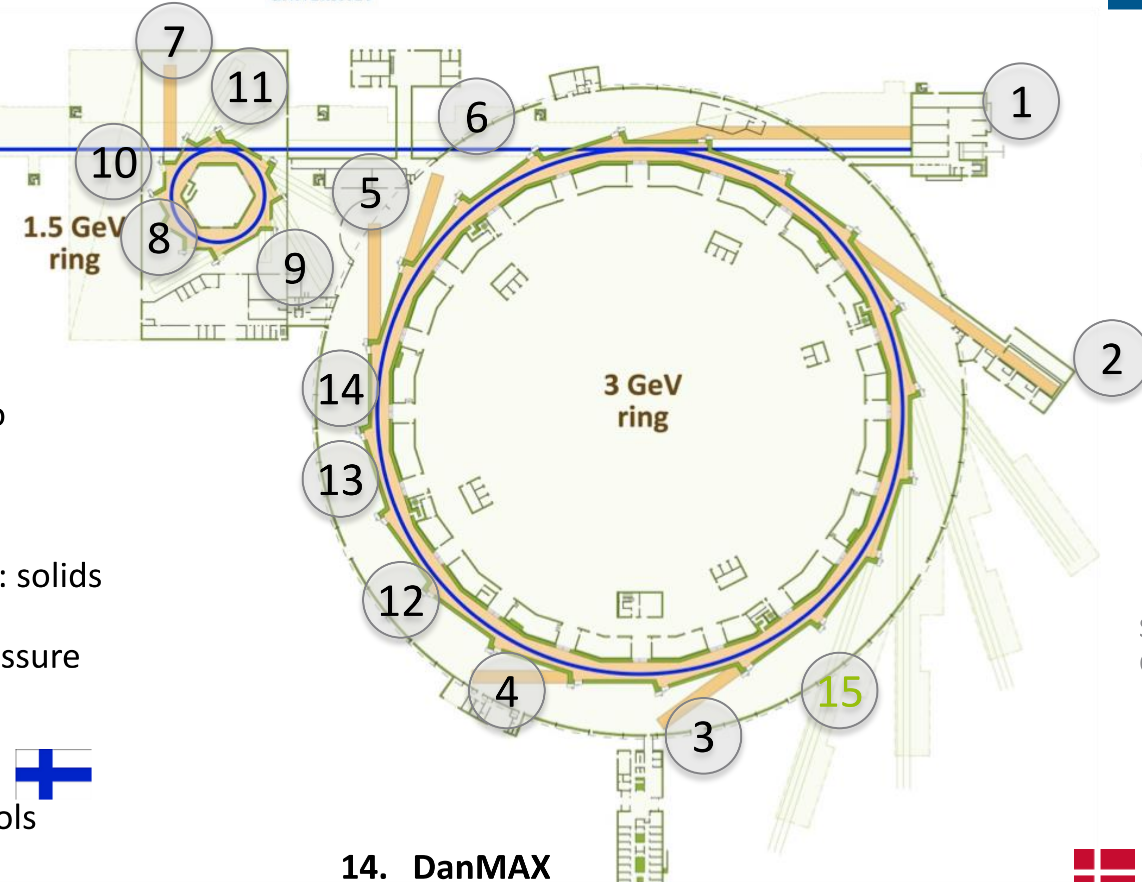


3 GeV LINAC

250 m

100 Hz to SPF





Vetenskapsrådet

1. **FemtoMAX**
   fs dynamics in solid
2. **NanoMAX**
   Nano-imaging & - spectroscopy
3. **BALDER**
   Chemical spectroscopy: operando
4. **BioMAX**
   Protein crystallography
5. **Veritas**
   Electronic & magnetic excitations: solids
6. **Hippie**
   Photoemission: near ambient pressure
7. **ARPES**
   Electronic structure: solids
8. **FinEstBeaMS**
   Electronic structure: gases, aerosols
9. **SPECIES**
   Electronic & magnetic excitations: surfaces
10. **Transfer_PEEM**
    Microscopy: surfaces
11. **Transfer_XPS**
    Electronic structure: surfaces & gases
12. **CoSAXS**
    Geometric structure & correlation: (bio) liquids
13. **Soft*i*MAX**
    Microscopy & method development
14. **DanMAX**
    Powder diffraction & imaging: materials science
15. **ForMAX**
    Wood & paper: structure & processing
16. **MicroMAX**
    Most relevant (difficult) protein structures
17. **DiffMAX**
    Crystal structure of bulk & surface
18. **iMAX**
    Imaging of engineering materials

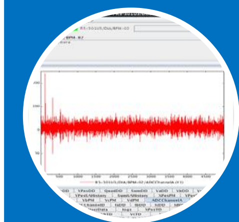
Slide by C. Quitmann

MAX IV Project Timeline

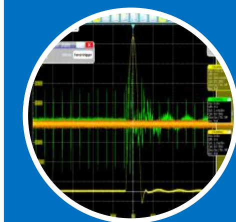
- 2002 – First technical design note
- 2005 – Scientific Case/Conceptual Design Report
- 2009 – Funding secured
- 2010 – Detailed Design Report – Funding released
- Spring 2015 – Linear accelerator commissioned
- Autumn 2015 – 3 GeV ring commissioning
- June 2016 – Inauguration
- Autumn 2016 – 1.5 GeV ring commissioning

3 GeV Ring Commissioning Timeline

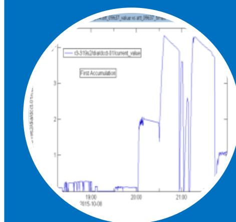
Beam in TR3
Aug 11
2015



First Turn
Aug 25
2015



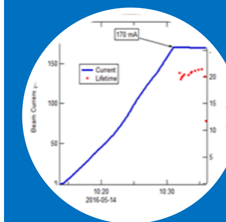
Stored Beam
0.1 mA
Sep 15
2015



Stacking
4 mA
Oct 08
2015

First Light
Nov 2
2015

Feb&March 2016
First IVUs



198 mA
July 9, 2016

Future Perspectives
Higher Brightness and Coherence

Full Delivery of the DDR Parameters – User operations

LINAC	3 GeV Ring	1.5 GeV Ring
• Soft X Ray FEL (proposal User Community) • Hard X Ray FEL	• Brightness Improvements: current lattice and Ids (150 pm rad) • Brightness Improvements: additional focussing (100 pm rad) • **Completely new lattice (diffraction limit at 10 keV)**	• Timing modes (requested by User Community)

Light Source Figures of Merit

Intensity/spectral range → Brightness/Flux Density

Coherence

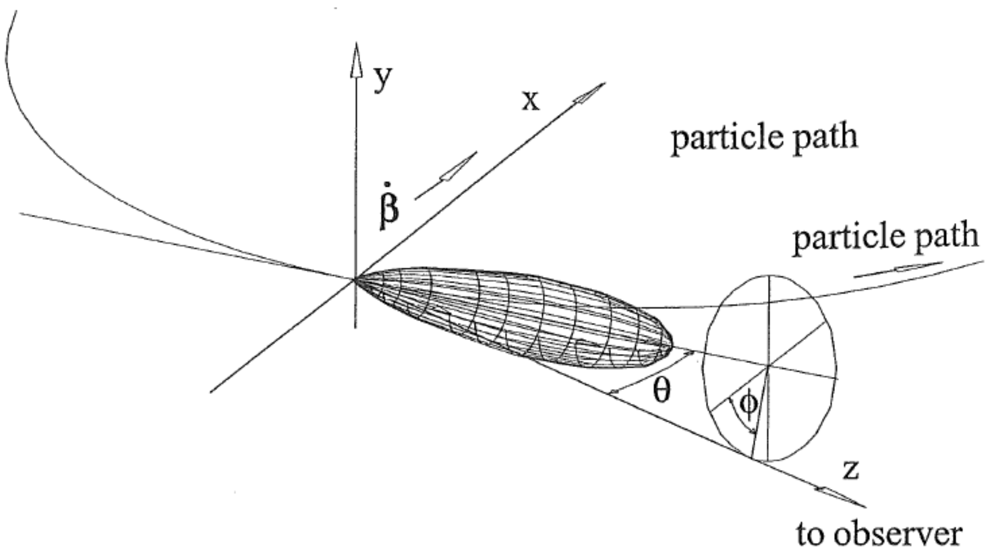
Time structure → Average vs Peak Values

Polarization

Stability

How do photon beam performance goals translate into electron beam performance requirements ?

Spectral Brightness



Photon Phase Space

$$B(E,\phi,\theta,x,y) = \frac{dN}{dt\,d\delta\,d\theta\,d\phi\,dx\,dy}$$

Density in photon phase space

In an ideal optical transport system, brightness is conserved – a property of the source.
Several derived quantities are often used

Central Brightness

$$B_0 = \frac{dN}{dt\,d\delta\,d\theta\,d\phi\,dx\,dy}\Big|_{x=y=\theta=\alpha=0}$$

Angular density of flux

$$F_0 = \int B\,d\phi\,dx\,dy$$

H.Wiedemann, Part.Acc.Phys, Vol II

Brightness from a real beam

Convolute the angular distribution of radiation from a single electron with the electron beam transverse spatial and angular distributions

For the nth harmonic of an undulator of length L

Spectral flux (E,I,B,n)

$$B_{0n} = \frac{F_n}{(2\pi)^2 \sigma_{Tx}\sigma_{Ty}\sigma_{Tx'}\sigma_{Ty'}}$$

Effective source size and divergence

Electron beam

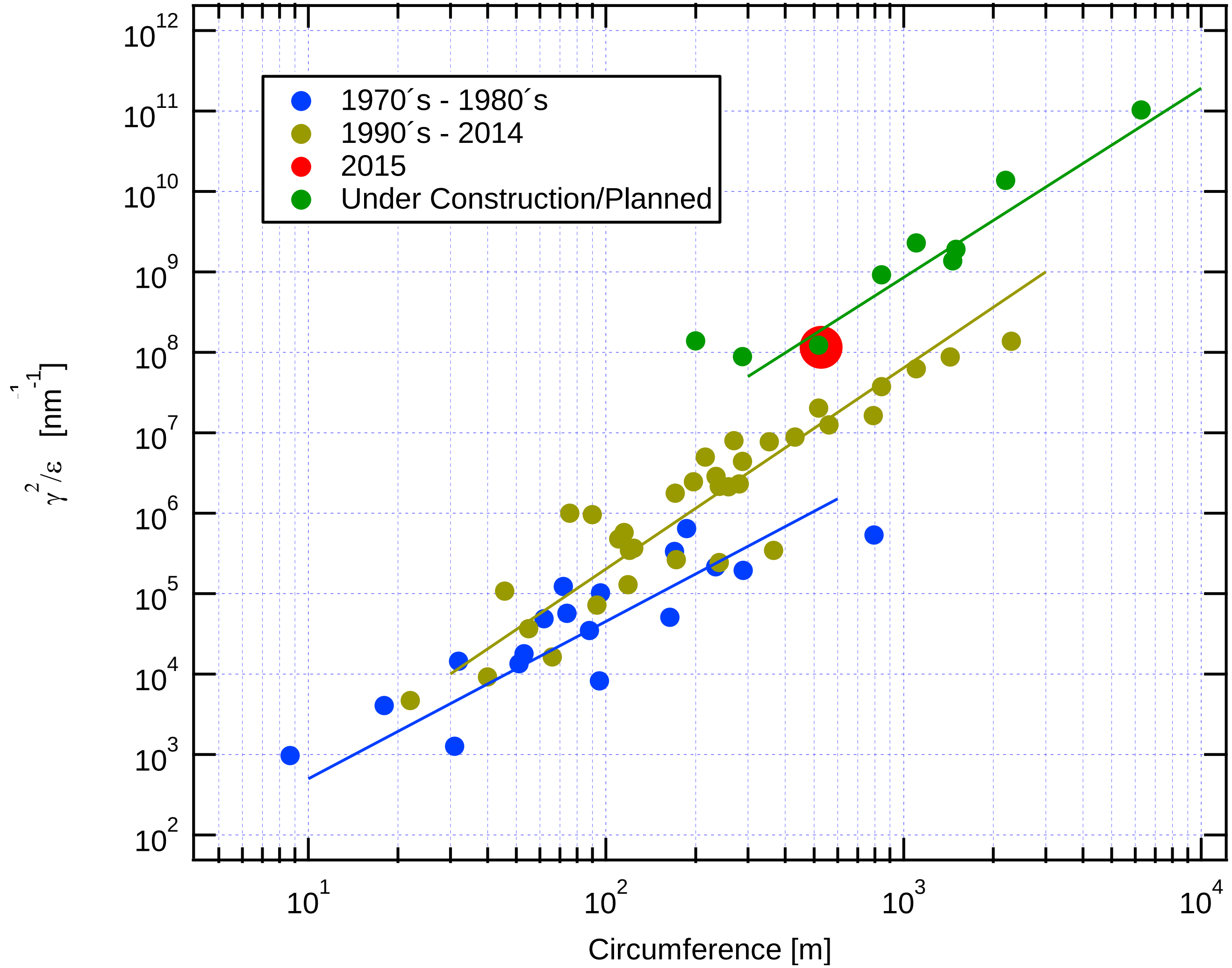
$$\sigma_{Tx} = \sqrt{\sigma_x^2 + \sigma_r^2} \qquad \sigma_r = \frac{1}{4\pi}\sqrt{\lambda L}$$

$$\sigma_{Tx'} = \sqrt{\sigma_{x'}^2 + \sigma_{r'}^2} \qquad \sigma_{r'} = \sqrt{\frac{\lambda}{L}}$$

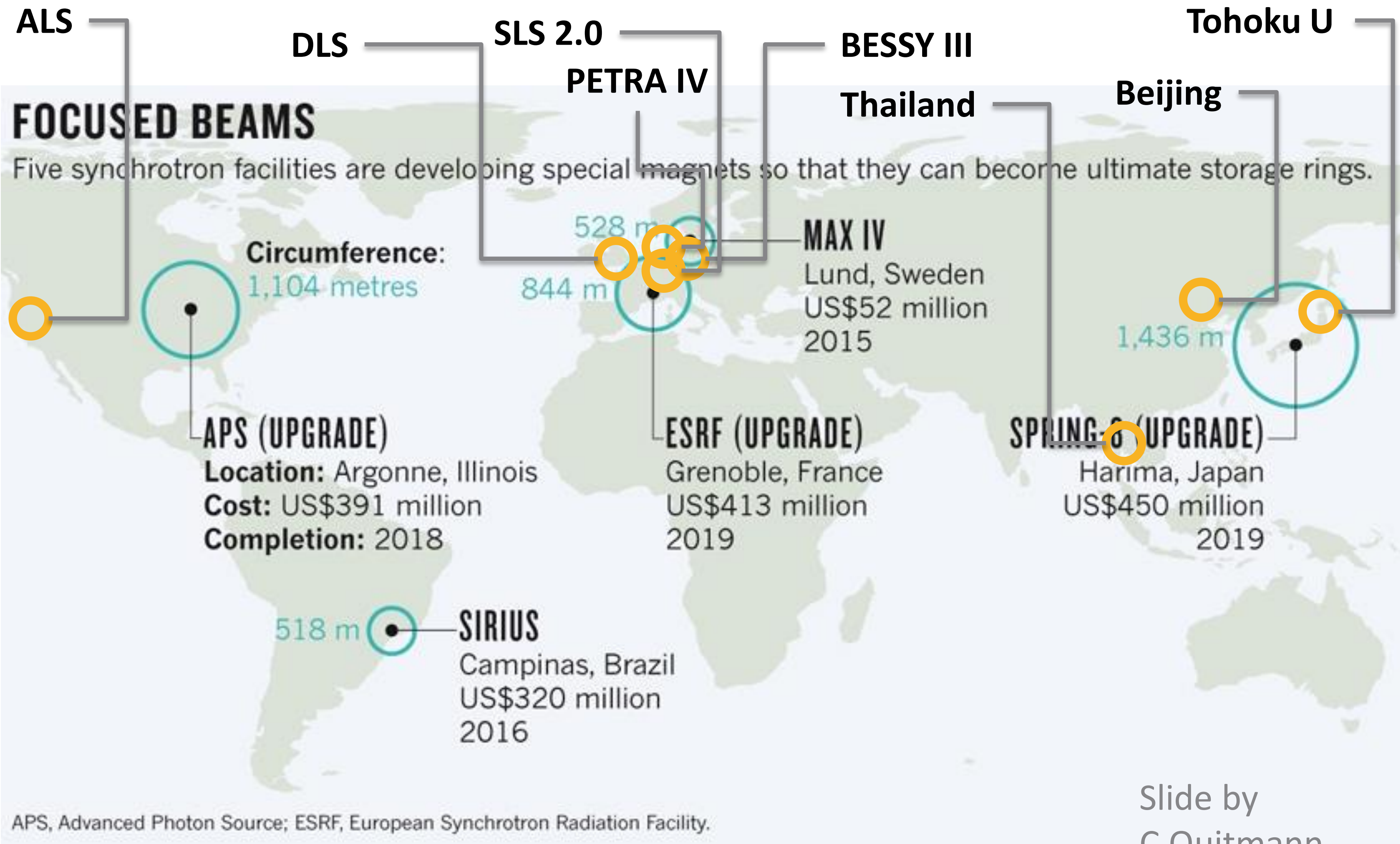
Diffraction Limit: $\sigma_r \sigma_{r''} = \frac{\lambda}{4\pi}$

e-beam emittance $\varepsilon_x = \sigma_x \sigma_{x'}$

Emittance Evolution over 40 years

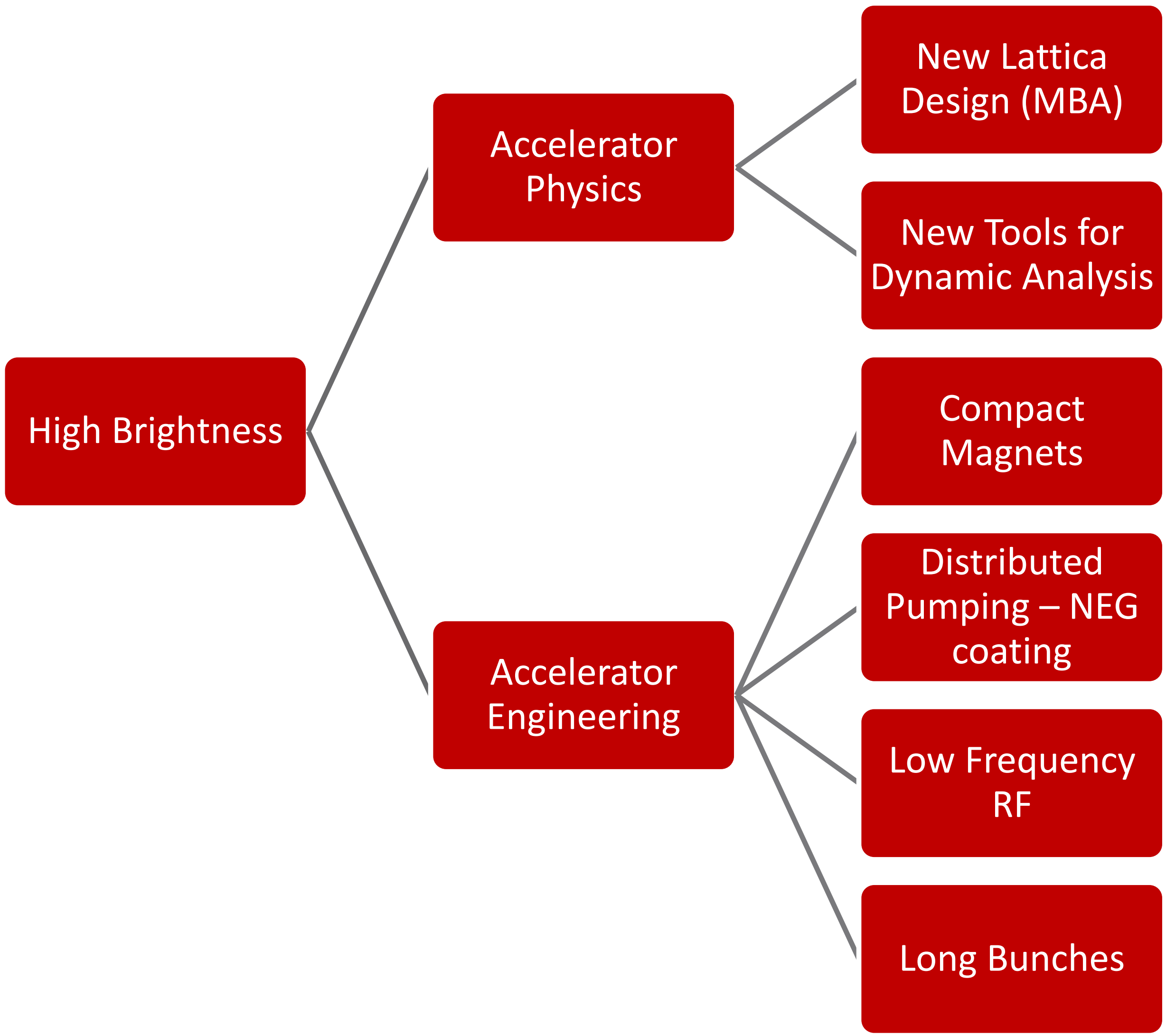


MAX IV: Forerunner of a new breed of accelerators

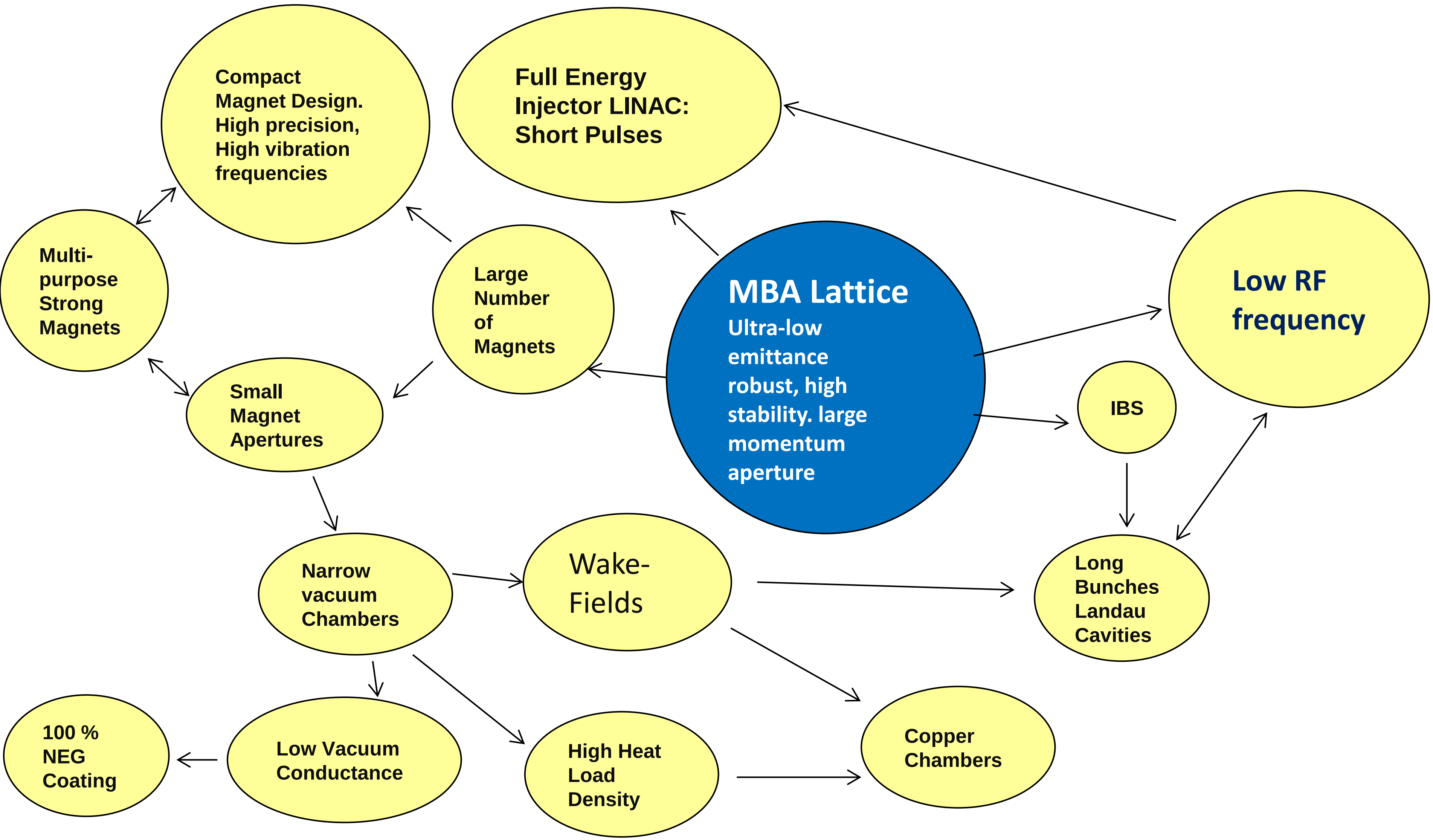


Slide by C.Quitmann

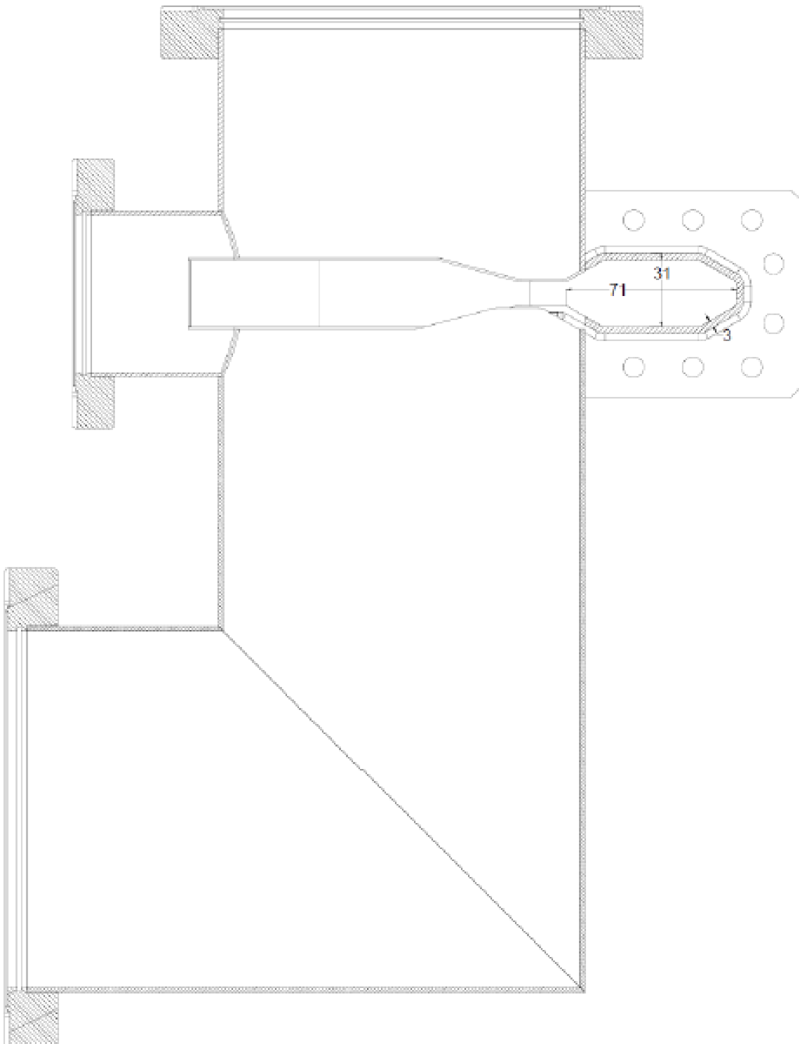
How did we go from third to fourth generation ?



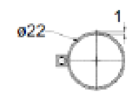
MAX IV - An integrated Solution



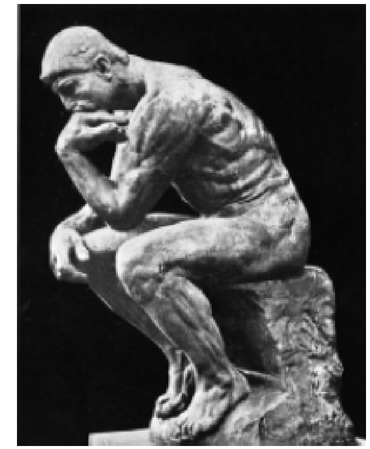
Compactedness is the key !



ALBA



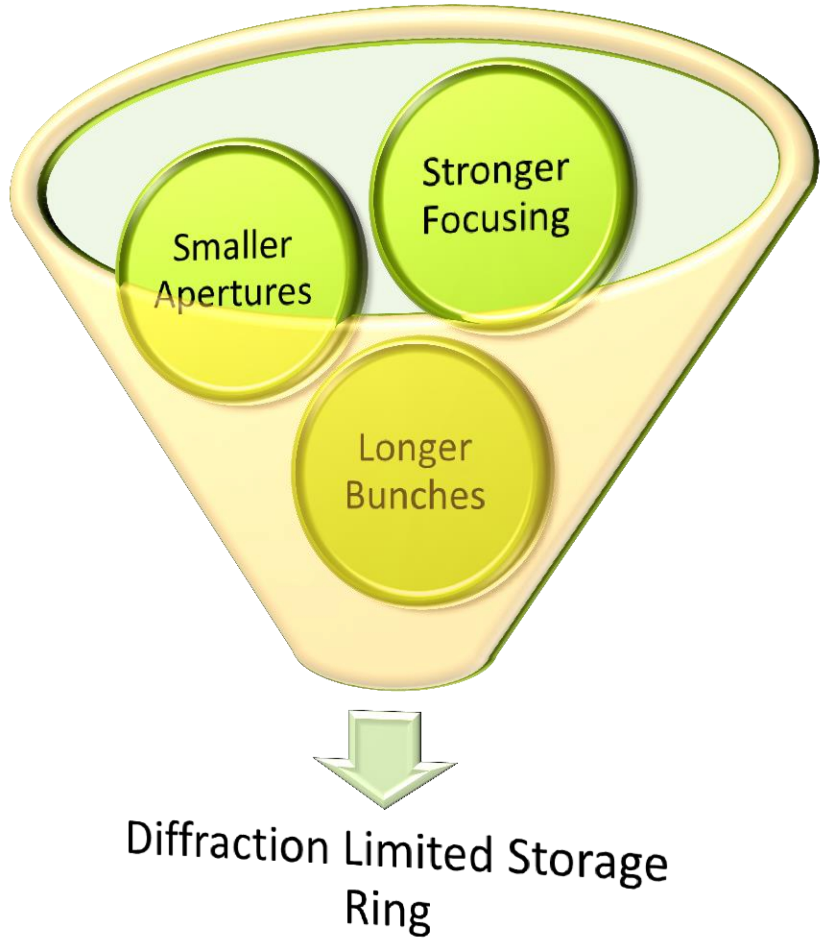
MAXIV



ALBA	MAXIV
St. steel	Copper
otch absorbers	Distributed absorbers
Ion pumps	NEG coating

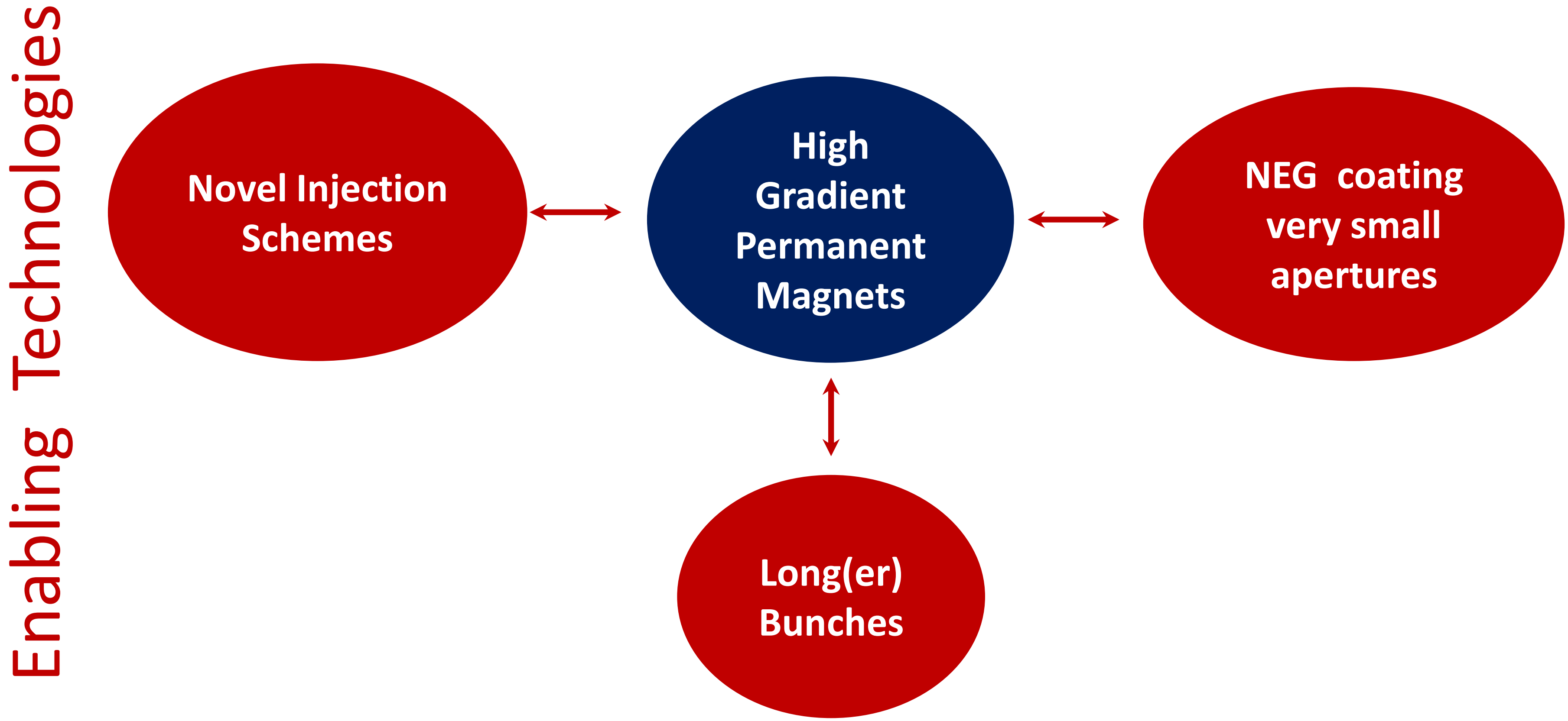
Picture by E. Aldmour

How can we go even further ?

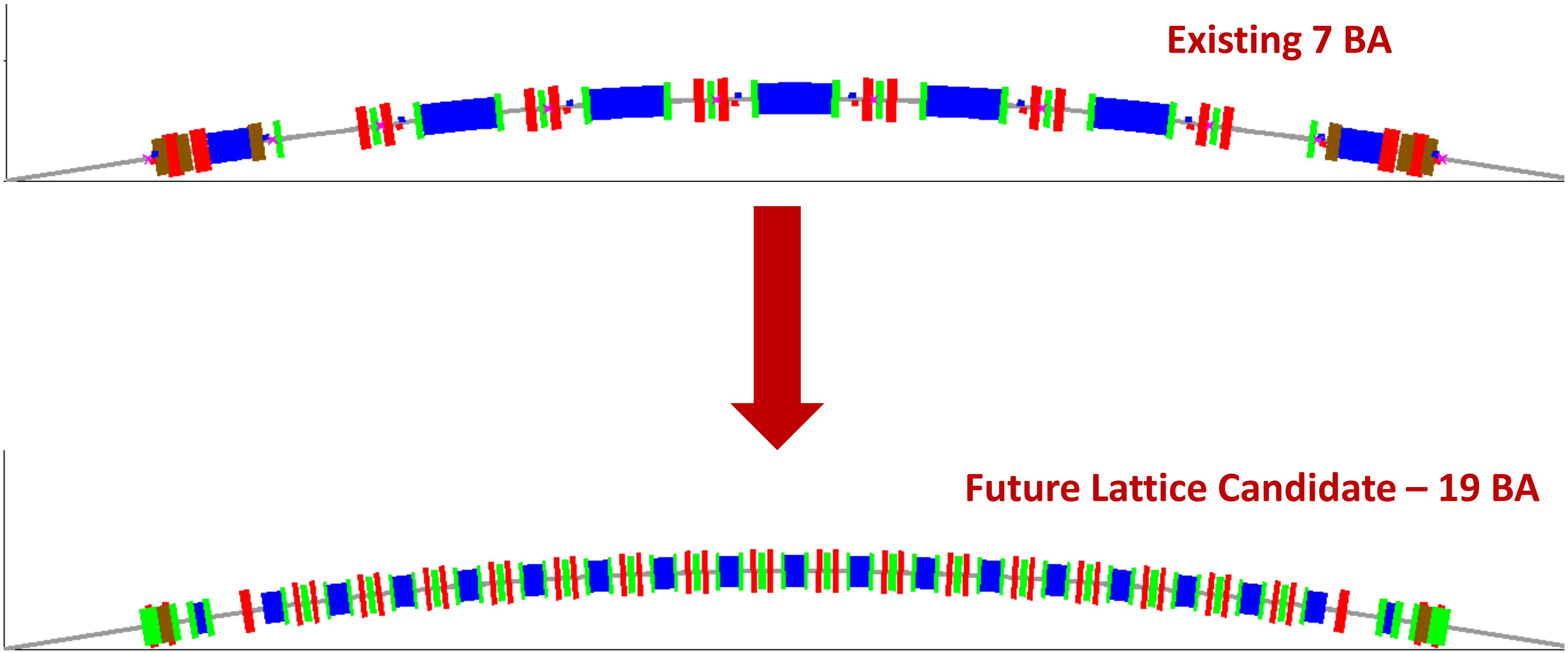


Diffraction Limited @ 10 keV within ~ 500 m

Compact Design – Small Aperture



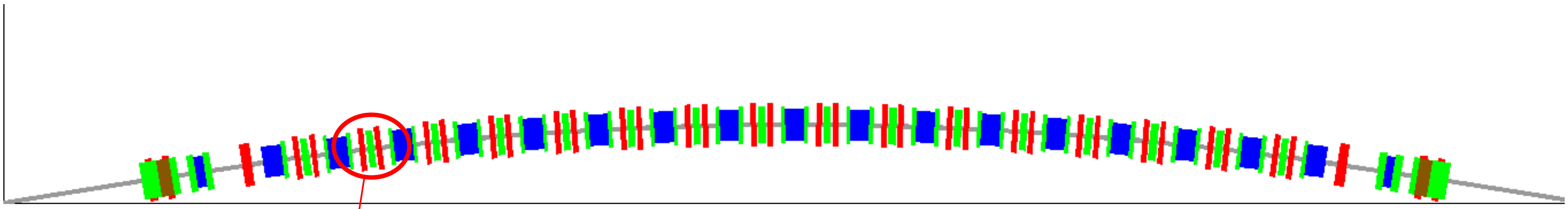
Beyond MAX IV – an exercise

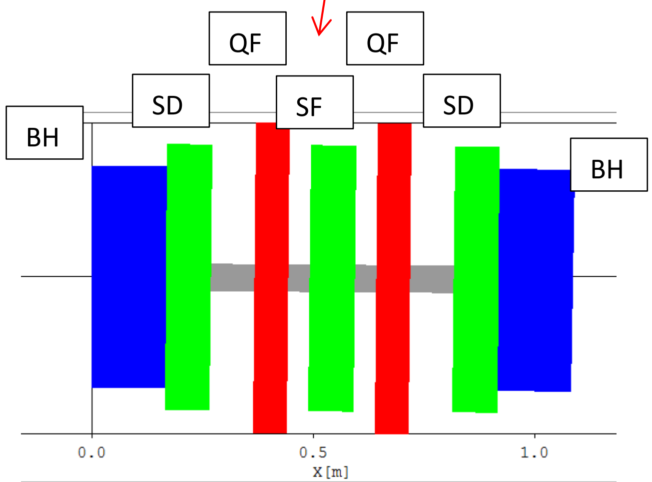


Beyond MAX IV – an exercise

Lattice design: OPA (A.Streun)
Elegant (M.Borland)

19-BA lattice in the MAX IV 3 GeV ring tunnel





Parameter	Value	Unit
Energy	3	GeV
Number of periods	20	
Circumference	528	m
Straight section length	5	m
Natural Emittance	16	pm.rad
Natural energy spread	0.09	%
Horizontal Tune	101.2	
Vertical Tune	27.28	
Natural horizontal chromaticity	-100.21	
Natural vertical chromaticity	-126.1	
Momentum compaction	5.30E-05	

Unit cell phase advances: $\Delta\mu_x = 2\frac{2\pi}{16}, \Delta\mu_y = \frac{\pi}{16}$

Conclusions

- A new generation of storage-ring based light sources has just come into operation opening a wide range of research opportunities.
- Many labs around the world are now following that trend.
- Future order-of-magnitude improvements in performance seem within reach if we just dare to go even further along the compactedness route.