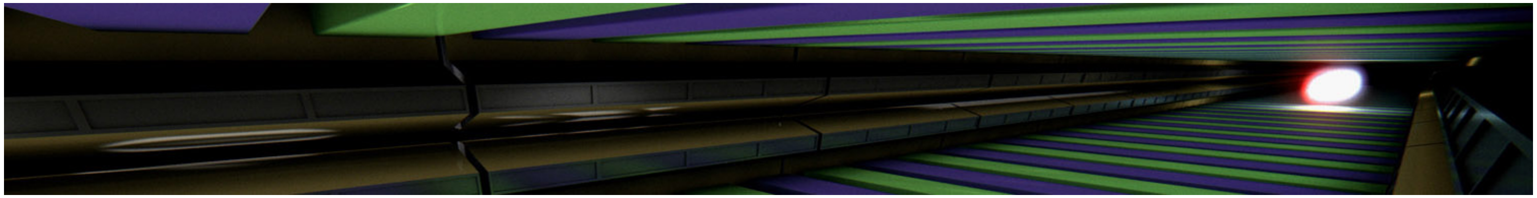
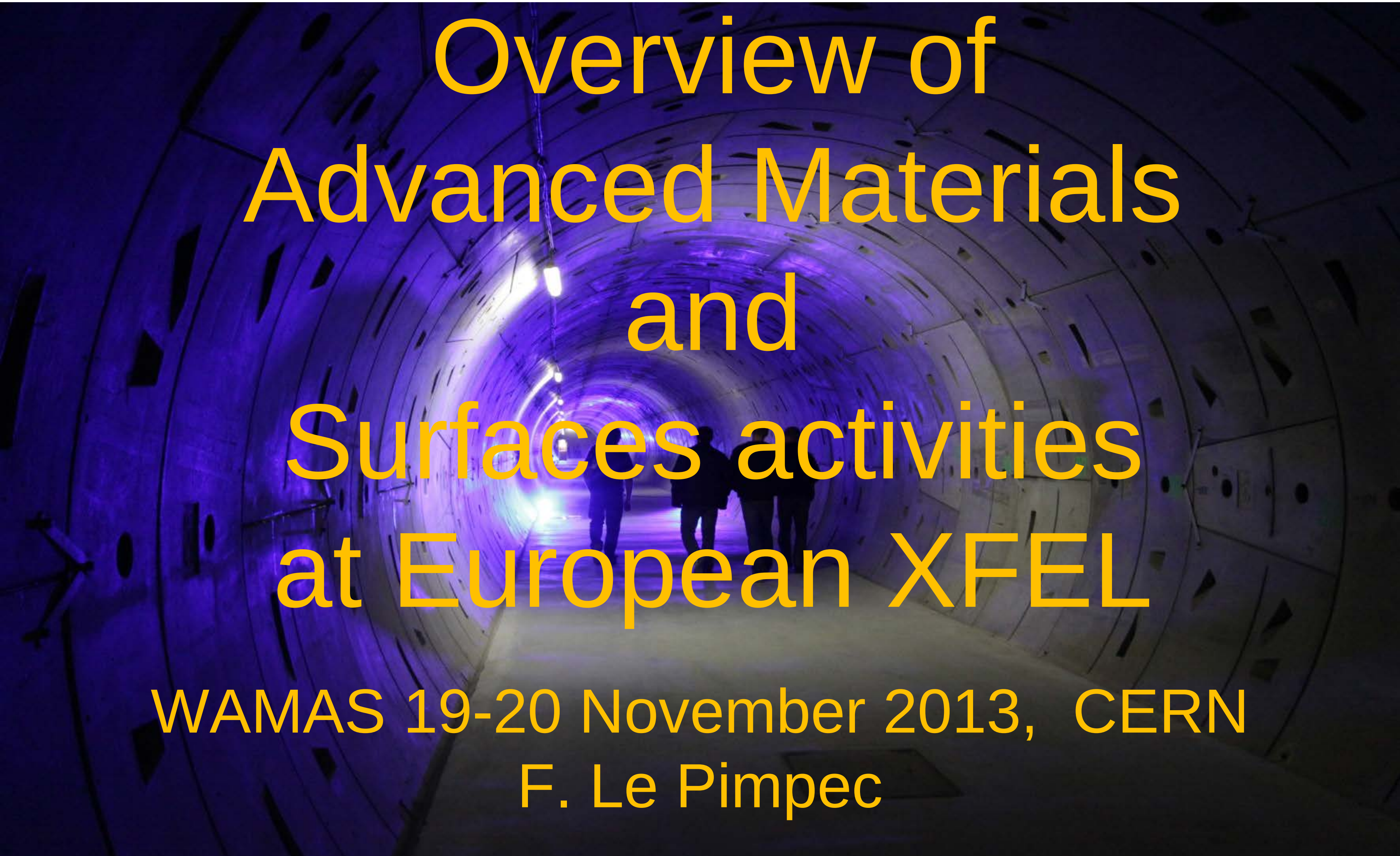


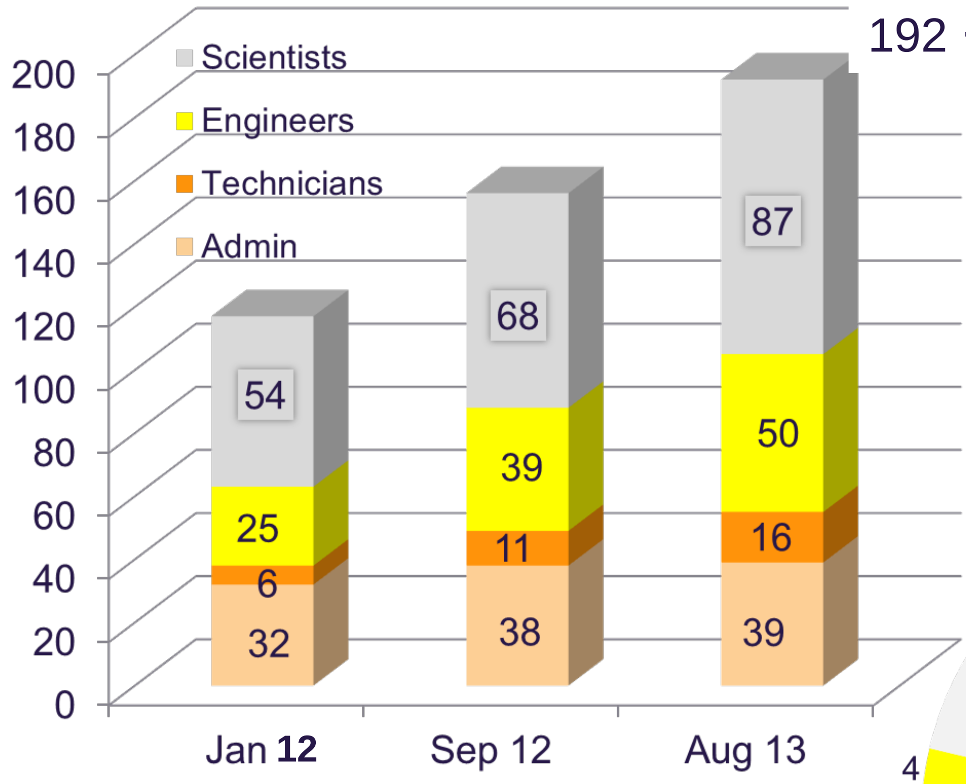


Overview of Advanced Materials and Surfaces activities at European XFEL

WAMAS 19-20 November 2013, CERN

F. Le Pimpec

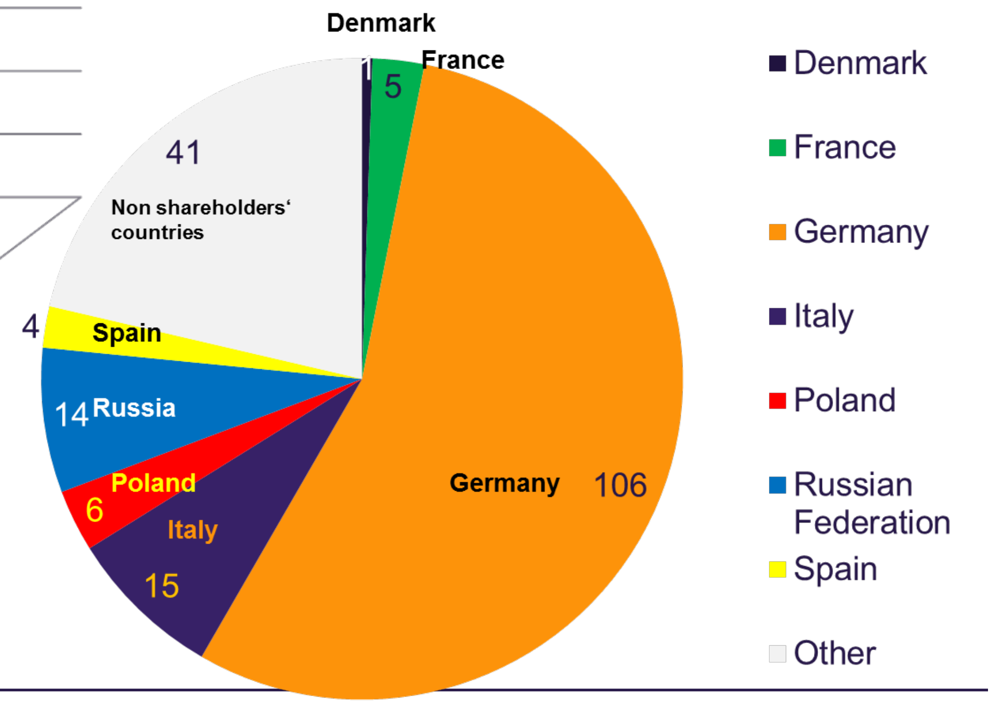
European XFEL GmbH (2009) (Staff In Brief)



192 → 250

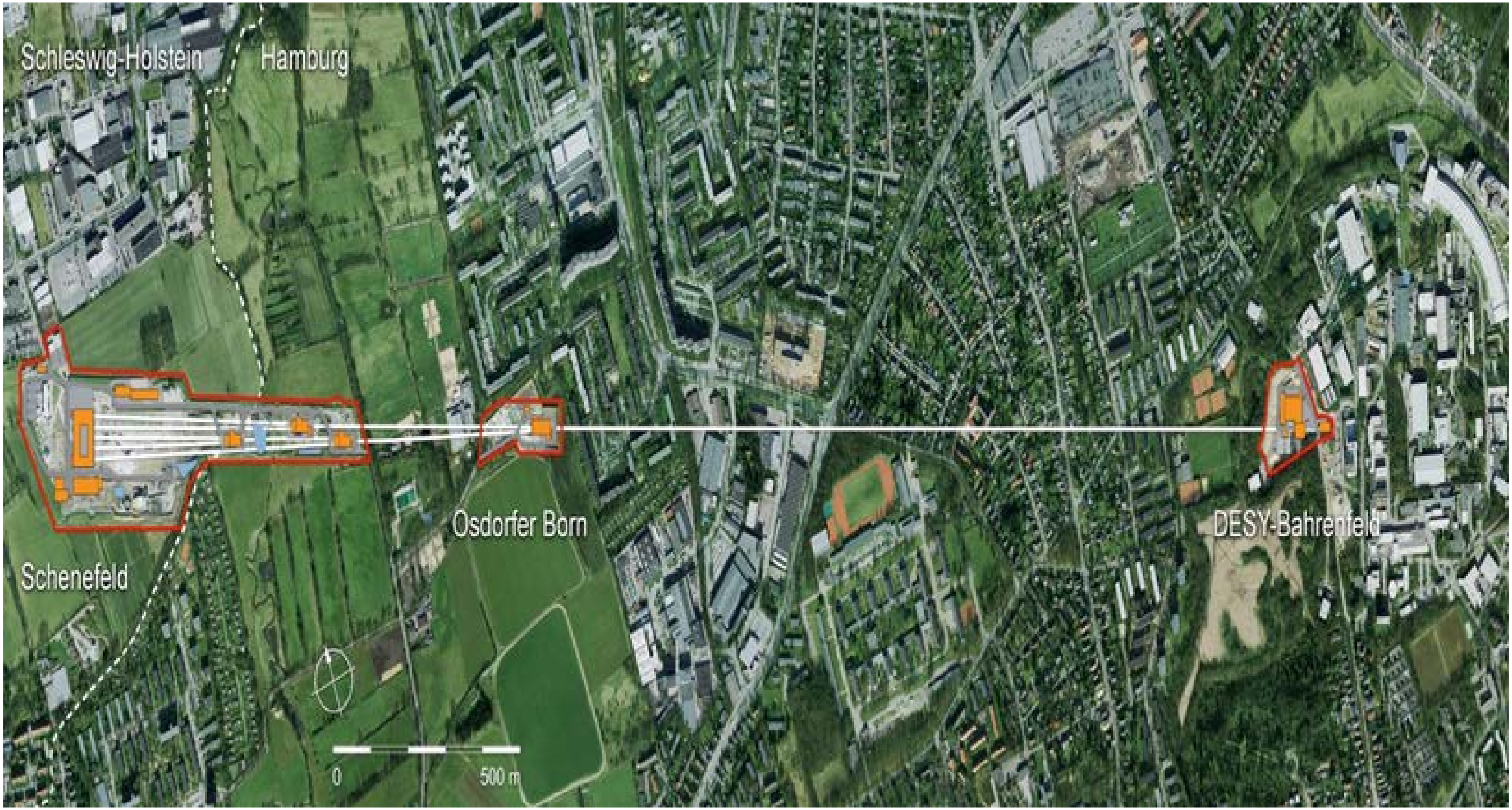
12 Partners

https://www.xfel.eu/organization/company/shareholders/



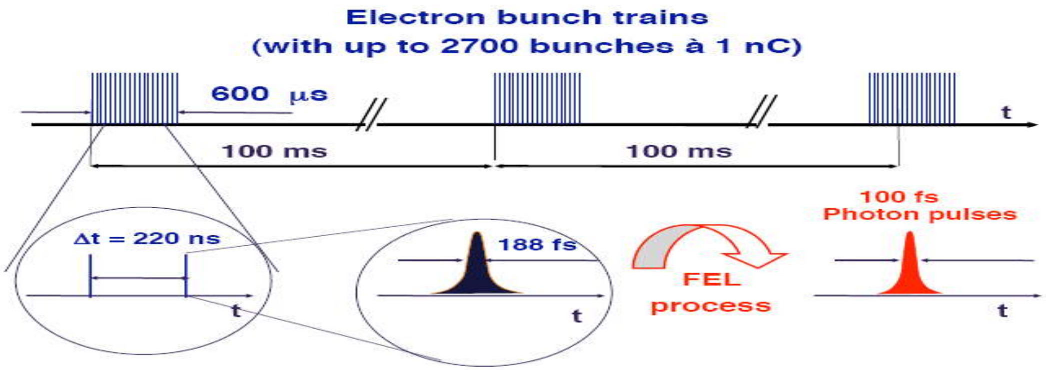
29 Nationalities

European XFEL Construction



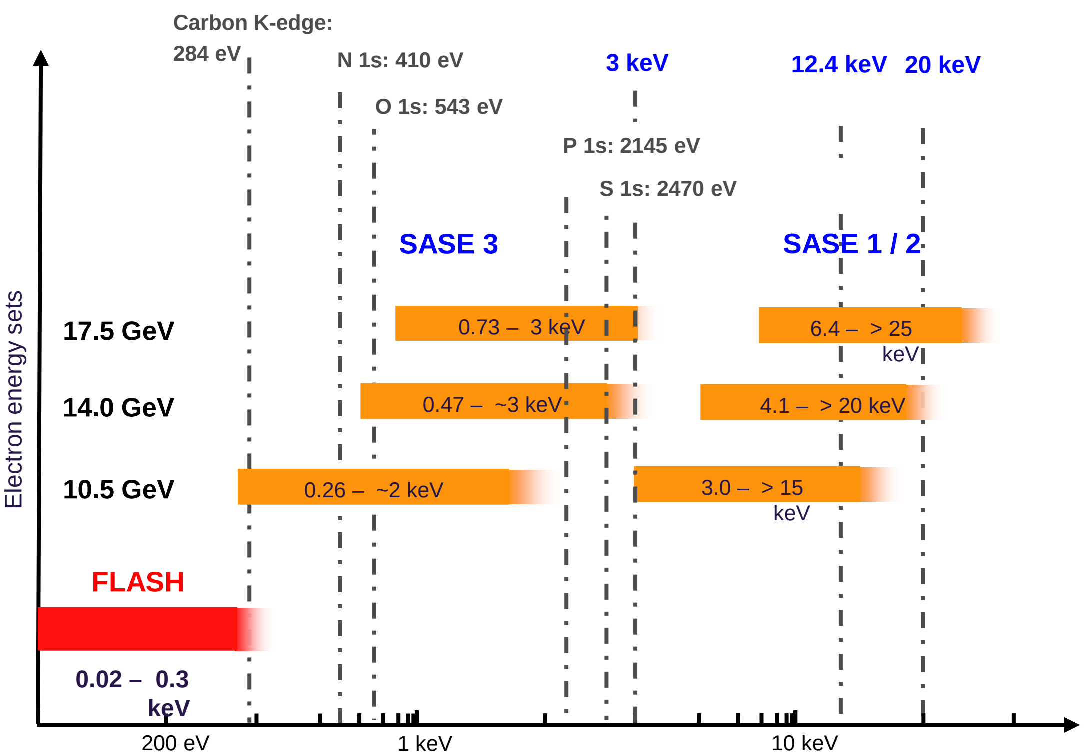
3.4 km long   5.8 km of tunnels excavated

European XFEL Parameters Photons and Electrons



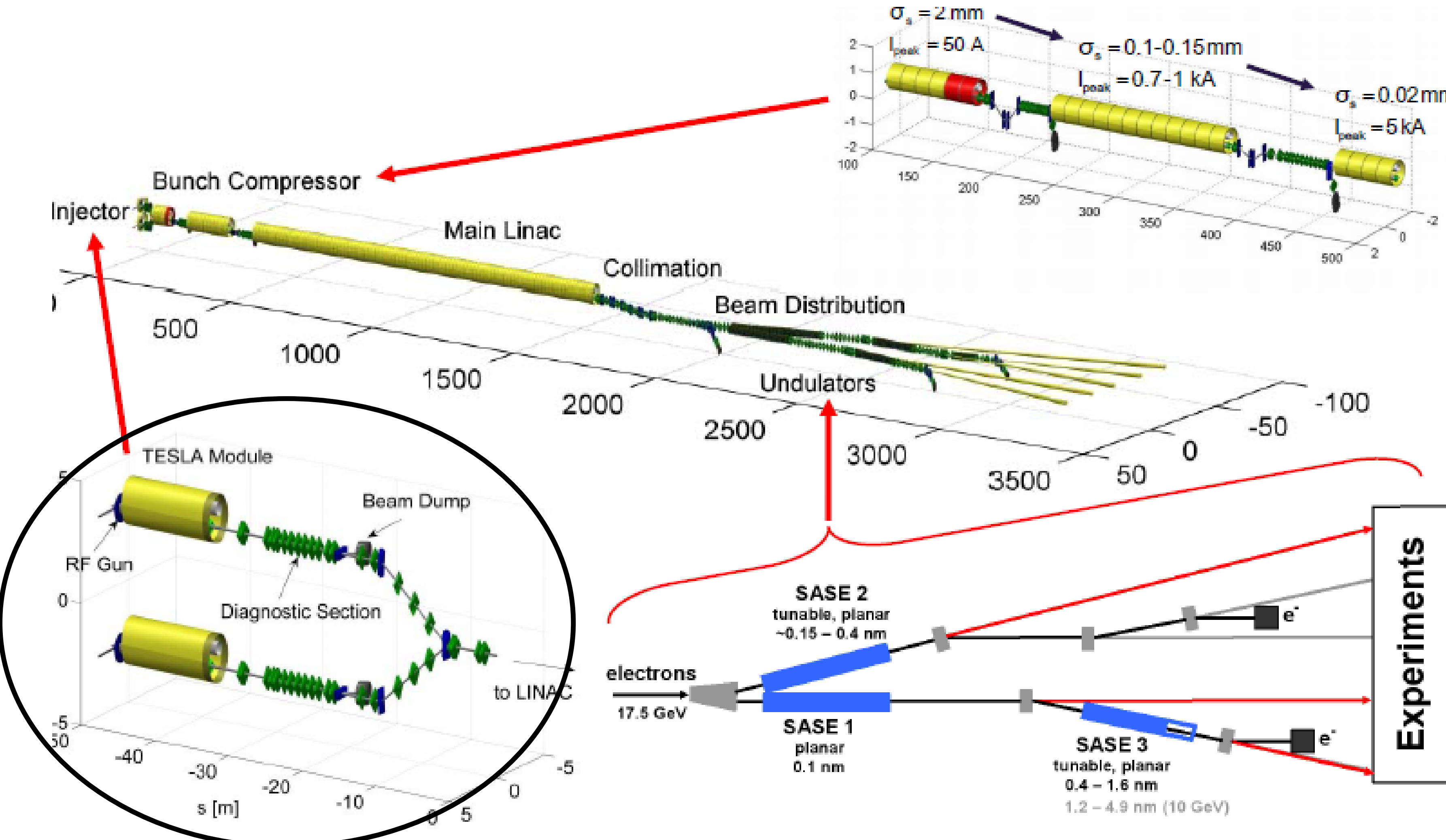
Superconducting LINAC (2 K)
800 RF structures – 100 Modules

Machine Parameter	Unit	Value
Electron energy	**GeV**	**17.5**
Accelerating gradient	**MV/m**	**22.9**
Bunch charge	**nC**	**1**
RF pulse repetition rate	**Hz**	**10**
Electron bunch repetition rate during RF pulse	**MHz**	**4.5**
Max. number of electron bunches per RF pulse		**2700**
Duration of electron bunchtrain	**µs**	**600**
Average electron beam power	**kW**	**570**
Normalized slice emittance (rms)	**mm mrad**	**0.8**
Electron energy spread (rms)	**MeV**	**< 1**



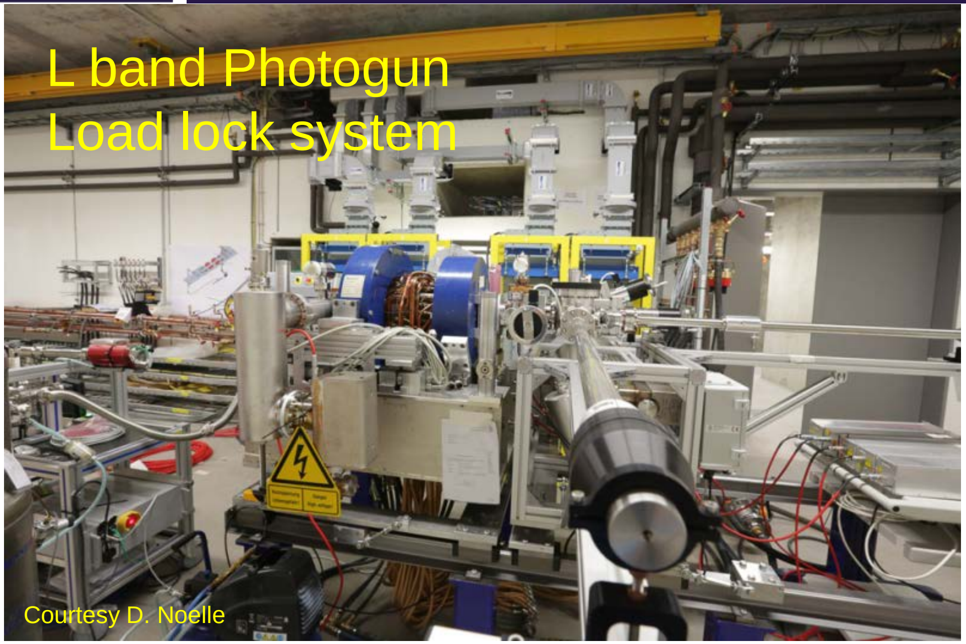
Self **A**mplified **S**pontaneous **E**mission

The European XFEL machine



(start-up version)

The Source : RF photogun and Cathode



- Achieving high Brilliance by producing high Brightness e- beam
  - A lot of charges (QE) – short bunches – small emittance
- Achieving short wavelength
  - (K parameter / energy)

$$\bar{B}_n = \frac{2I}{\pi^2 \varepsilon_{nx} \varepsilon_{ny}}$$ Normalized Brightness

$$\lambda_l = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \qquad K = \frac{eB\lambda_u}{2\pi m_e c}$$

The (obviously) most important Photocathode Properties

- **Quantum efficiency**
  - High QE at the longest possible wavelength → Cheaper Laser system
  - Fast response time: <100 ps → follow laser impulse
  - Uniform emission
    - Non-uniform emission seeds emittance growth due to transverse, space charge expansion
  - Easy to fabricate, reliable, reproducible
  - Low dark current, field emission. → roughness, ion back bombardment roughening (CsI)

- **Intrinsic emittance**
  - Low as possible
    - Atomically flat: ~few nm p-p, to minimize emittance growth due to surface roughness and space charge → might be true but not necessarily
  - Tunable, controllable with photon wavelength
    - May need to "chase" the work function: $\varepsilon_{\text{intrinsic}} \propto \sqrt{\hbar\omega - \phi_{\text{eff}}}$
  - Better at cryogenic temperatures?

- **Lifetime, survivability, robustness, operational properties**
  - Require >1 year of operating lifetime
    - reasonable vacuum level: 10^{-10} Torr range → Effect of gases on surfaces ?
  - Easy, reliable cathode cleaning or rejuvenation or re-activation
  - Low field emission at high electric fields
    - needs to be very flat: ~few nm p-p → crystallographic defects (Single crystals)
  - Reliable installation and replacement system (load lock)

D. H. Dowell -- EuroFEL Workshop

Atomically clean - Atomically flat

Vacuum : Desorption

What is a good vacuum Surface ?

An atomically clean surface !

What about a surface with an outgassing rate = 0 ?!

Development of barrier diffusion thin films and thin film NEGs

Photocathode : Emittance

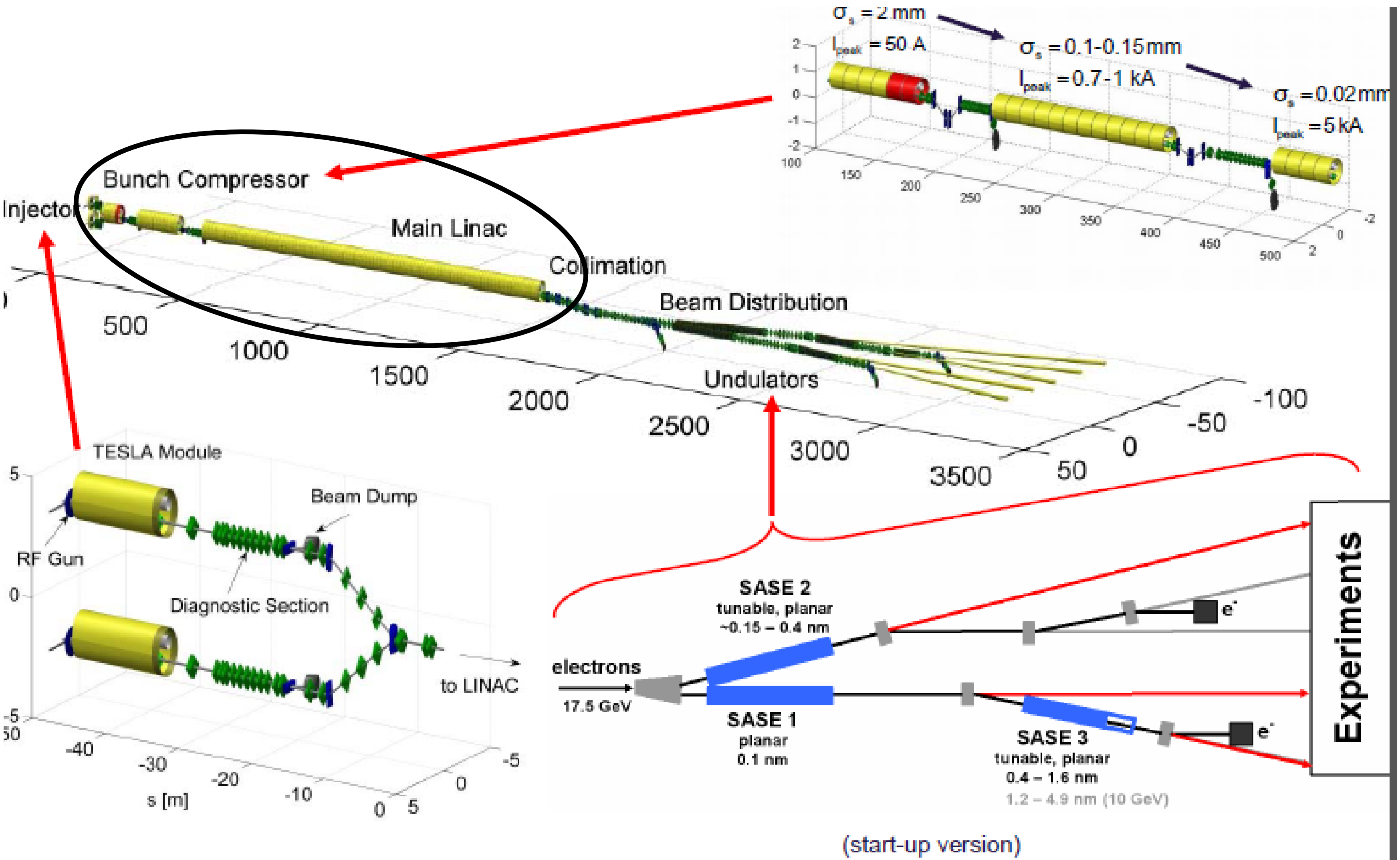
What is a good Photocathode Surface ?

An atomically flat surface !

What about a surface which emits electron with $P_{\perp} = 0$?!

Emission mechanism of electrons from a material ???
Create the *Emittonium*

The European XFEL machine



European XFEL

The Accelerator: Niobium based accelerating structures

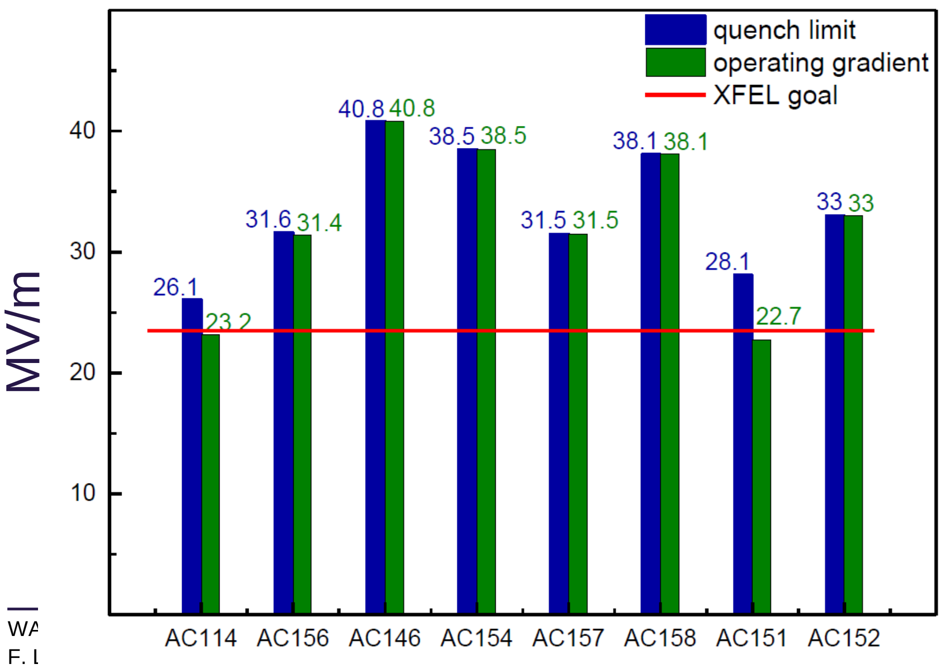
Superconducting LINAC (2 K)
800 RF structures – 100 Modules

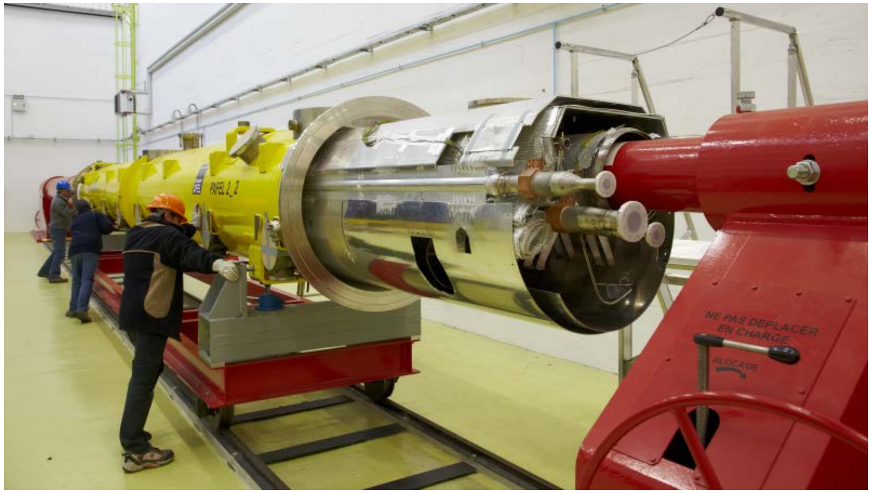
Large grain Nb cavities

Surface cleaning : HPWR

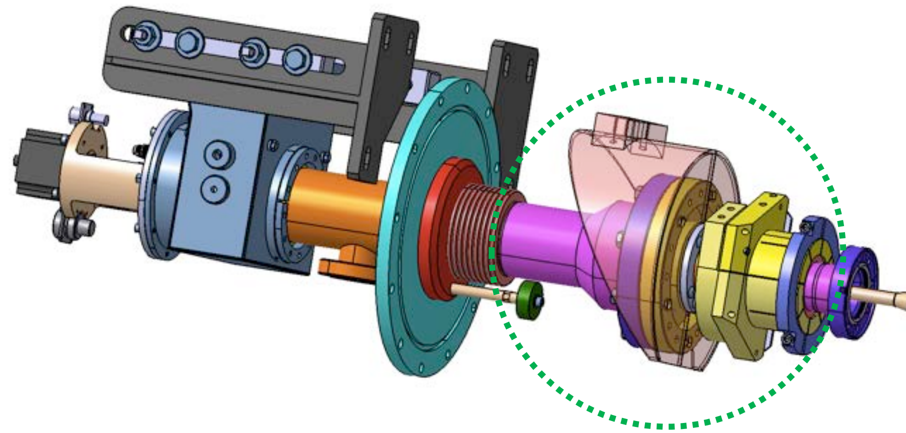
2 talks – Electropolishing
– new materials

XM-3 module – RF testing Cold





RF couplers for SC cavities Cu plating (a lost technology?)



Warm to Cold transition

Cu Platting (reduce RF power loss)

1 coupler / cavity

Specification :

- Thickness
- Residual Resistivity Ratio (RRR)

OLD technology (200 yrs old) / Science 1950+

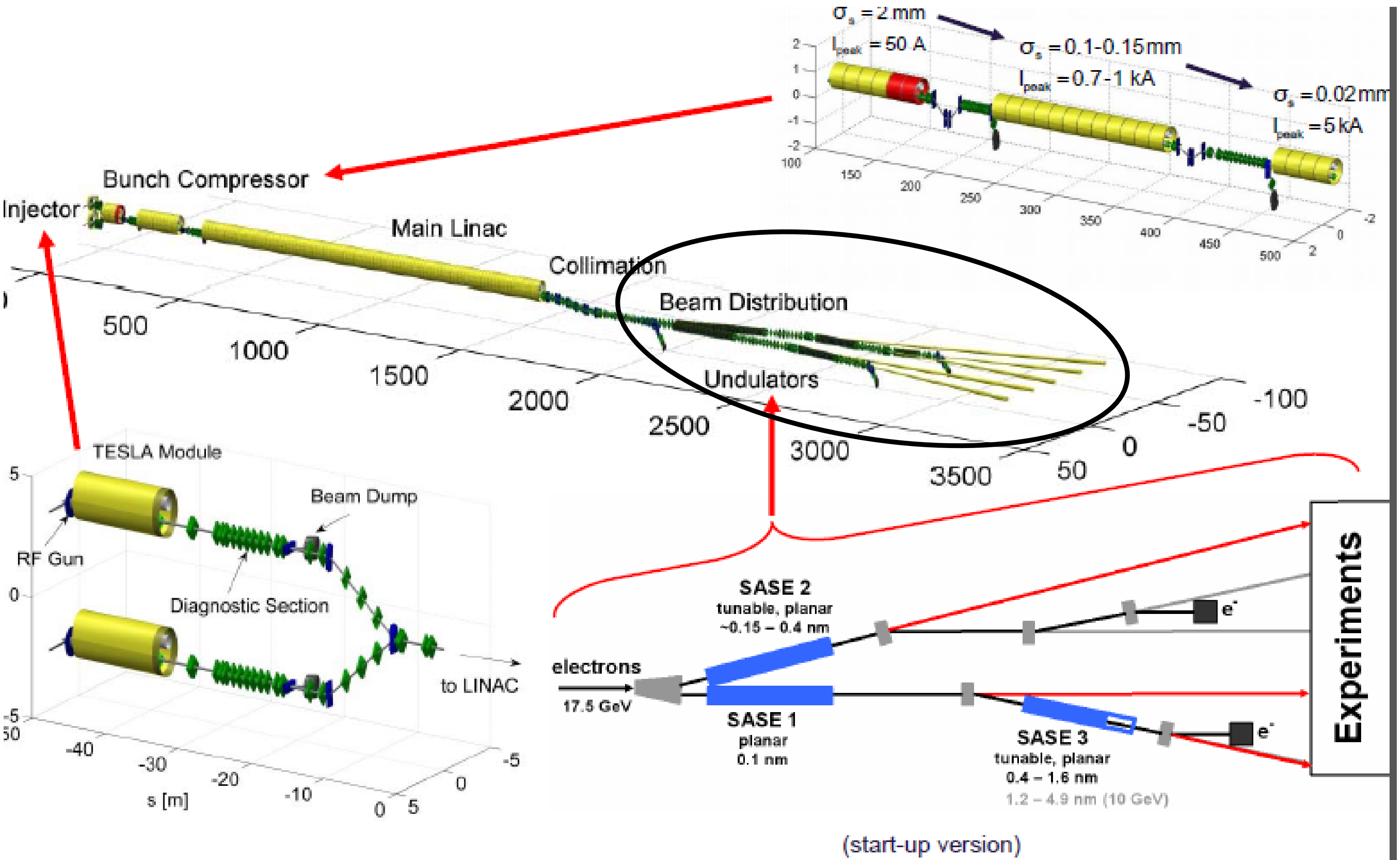
- FLASH commissioned 2004

Problem:

- Blistering of the plating
- Uneven thickness
- Residual Resistivity Ratio (RRR)

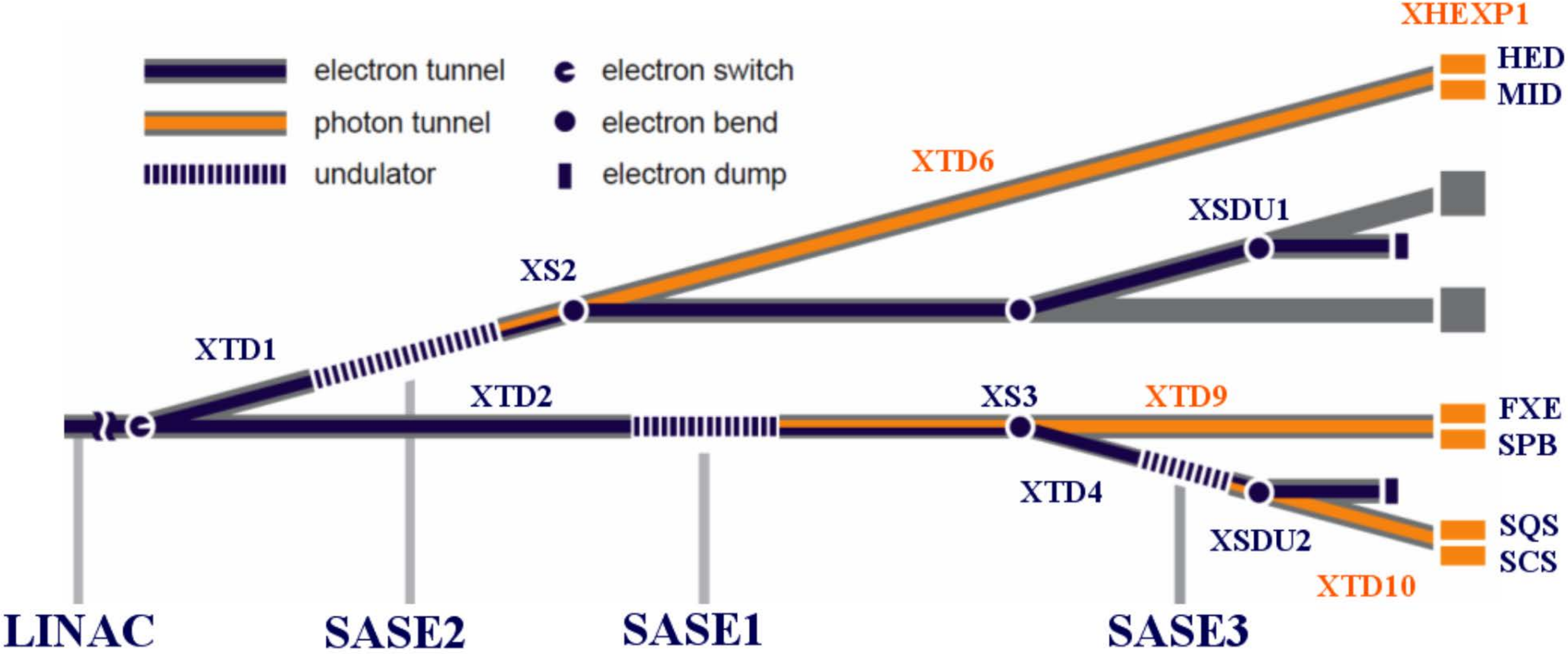
New developments ok keeping know-how

The European XFEL machine



XFEL Photon beam transport system

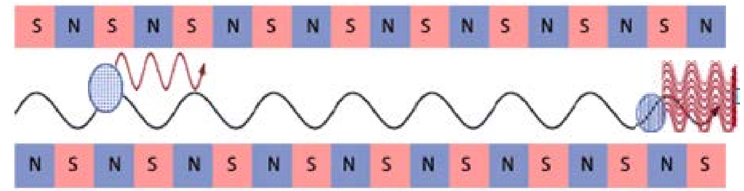
Undulator Segment	FEL radiation energy [keV]	Wavelength [nm]
SASE 1	3 - over 24	0.4 - 0.05
SASE 2	3 - over 24	0.4 - 0.05
SASE 3	0.27 - 3	4.6 – 0.4



Orange color: X-ray optics & Beam Transport

Mirrors and Transport System Challenges

- High Power flux on gratings and mirrors
- Flatness of the mirrors (2 types)
- New Coatings

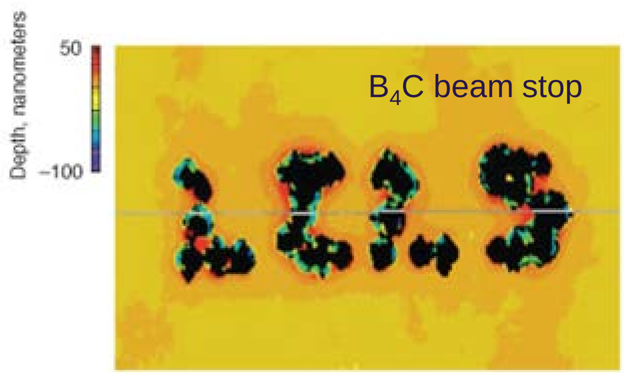


12 keV, 2-100 fs

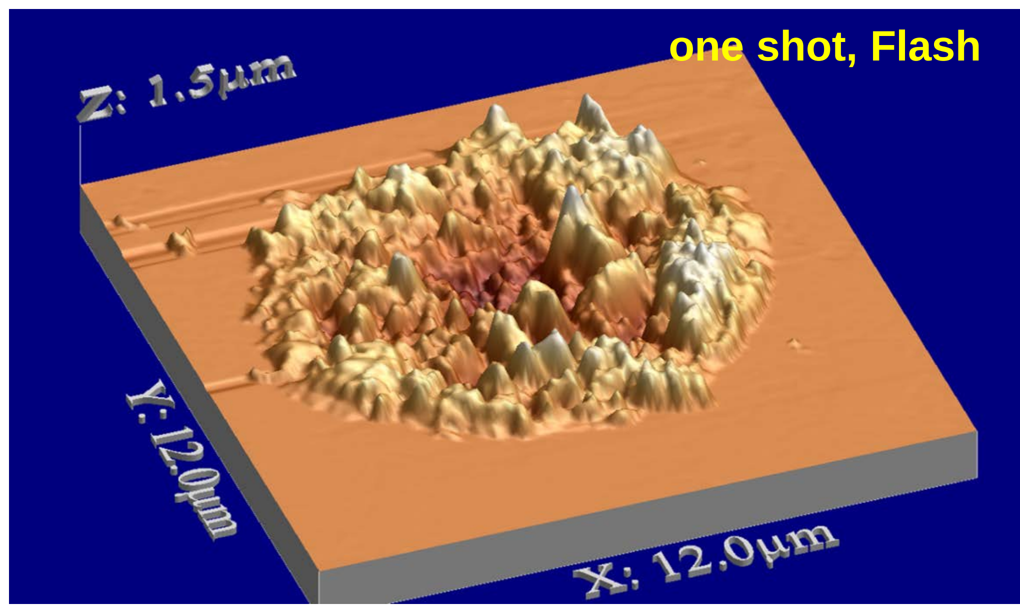
1 -10 mJ/pulse

Courtesy H. Sinn

10 micron LCLS beam (AMO station) on B_4C, 2009 Hau-Riege et al.



Focused beam on sample



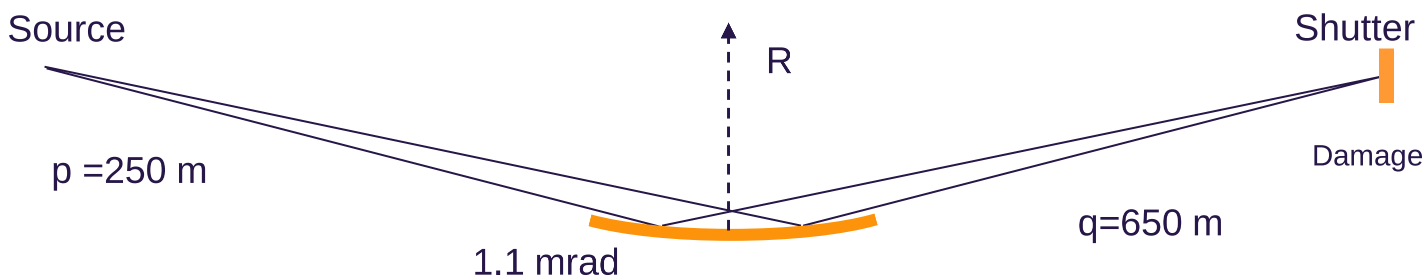
AFM picture of CVD diamond irradiated by FLASH pulse (hv=177 eV)

J.Gaudin, R. Sobierajski, L.Juha et al.

European XFEL

Transport Mirrors

- Photon beam to powerful at undulator exit – need to spread it
- Long photon beamlines at XFEL – reduce energy density on spot
- FLAT mirrors avoid focusing



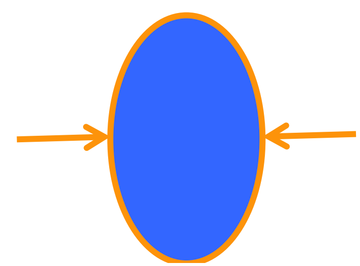
Focusing condition on shutter: 2/R = sin θ (1/p+1/q) → R ≥ 360 km

(currently fabrication limit for flat surfaces)

For an undistorted beam, we need much flatter mirror:

5% beam size variation: 6300 km bending radius (PV 12nm)

6371 km : earth radius



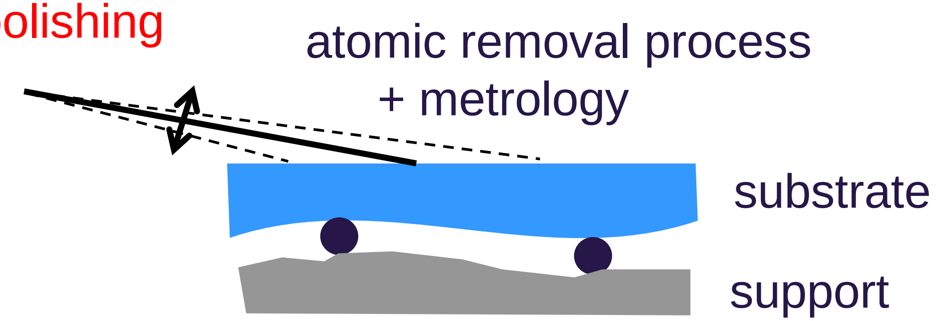
beam shape

Courtesy H. Sinn

Instruments' Focusing Mirrors

- Coherent beams require height-height correlation (absolute shape error) of less than 2 nm PV over entire length
- Storage rings: typical 1 µrad slope error, ~ µm height error
- Currently worldwide two suppliers with proven record of deterministic polishing to nm-scale
- Best mirror so far: 370 mm long substrate with 2 nm PV error
- Needed for XFEL: up to > 0.8 m long mirrors with same or better performance
- Focus beam to a few um size diameter

deterministic polishing



Courtesy H. Sinn

6 Instruments

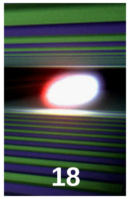
SASE 3

- SCS
- SQS

SASE 1-2

- FXE
- SPB
- MID
- HED

Scientific instruments



Hard x-rays

SPB : Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules

- Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.

MID : Materials Imaging & Dynamics

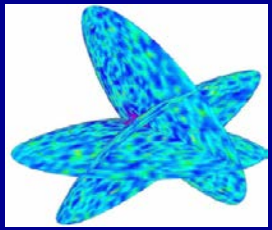
- Structure determination of nano- devices and dynamics at the nanoscale.

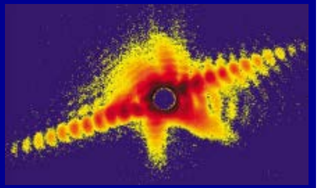
FXE : Femtosecond X-ray Experiments

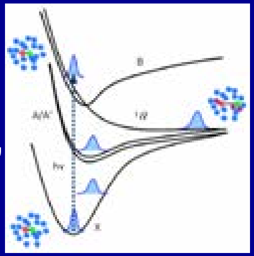
- Time-resolved investigations of the dynamics of solids, liquids, gases

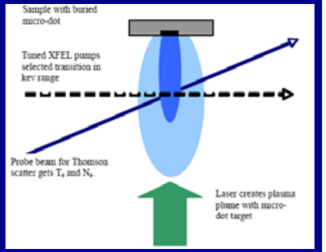
HED : High Energy Density Matter

- Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas









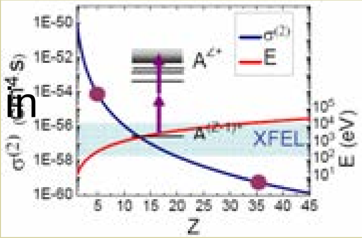
Soft x-rays

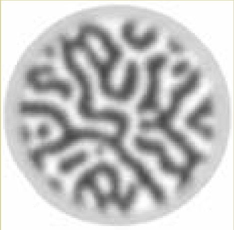
SQS : Small Quantum Systems

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

SCS : Soft x-ray Coherent Scattering/Spectroscopy

- Electronic and real structure, dynamics of nano-systems and of non-reproducible biological objects





Advanced Material Using XFEL Beam Fundamental studies

- Short pulse (dynamic & kinetic study, non-relaxed system)
- High coherence (transverse & temporal (seeded beam))
- High photon flux (reduce exposure time – RIXS)

- (De)magnetization
- Molecular data storage
  - Imaging experiment requires TB of storage
- Non ordered metal (Metallic glass)
- Dynamic at Interface (solid – liquid)
- http://www.xfel.eu/documents/technical_documents/ (TDR)

Material studies at XFEL (applied and fundamental) will also benefit the future machines

Acknowledgements

Definitely indebted to my colleagues from European XFEL and DESY (HH and Berlin) to have provided me with valuable info and pictures.

Thank you for your attention