Teilchenquellen
Charged Particle Sources

Thorsten Kamps (HZB)

kamps@helmholtz-berlin.de

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Disclaimer

This presentation gives a very broad overview on the topic of charged particle sources relevant for accelerator physics for radiation sources.

It can only serve as a starting point for a discussion among stakeholders (users, beam physicists, labs, universities, funding agencies) on goals and measures for charged particle sources.

I want to thank (in no particular order) Jochen Teichert, Anke-Susanne Müller, Daniel Krieg, Serena Barbanotti, Peter Spätke, Oliver Boine-Frankenheim, Axel Neumann, Luca Cultrera, John Smedley, Julius Kühn, Tobias Eggert, Maximilian Herbert, Simon Friederich, Fernando Sannibale, Klaus Tinschert, Caterina Cocchi

Outline

What are the scientific and technical needs for particle sources?

What advances are possible and what are the influences?

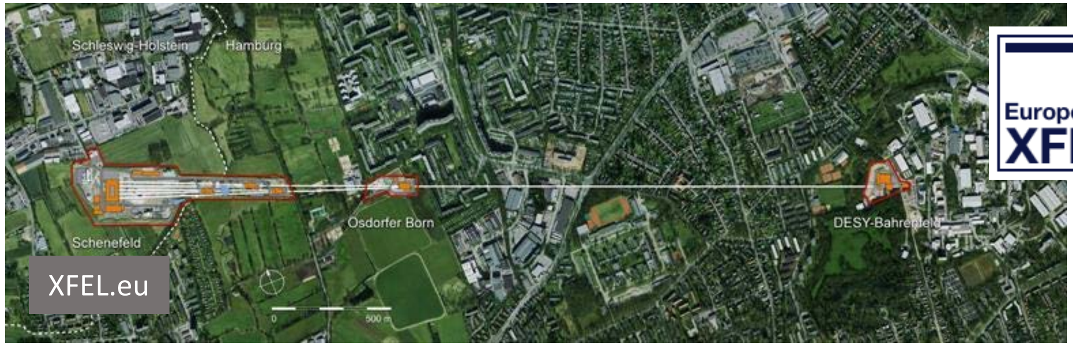
Which directions have the highest potential and thus need a strong push?

Scientific Needs

Scientific Needs - X-rays from Free Electron Lasers (FELs)

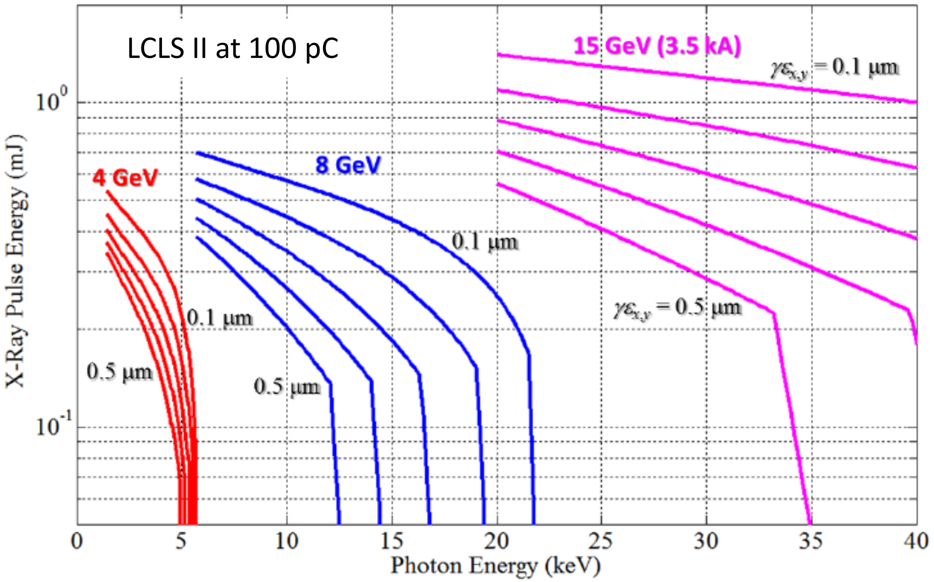
- X-rays from **FELs** are required to study atomic structure dynamics, electronic and nuclear coupling in biological and chemical processes, and energy materials in situ.
- Extend scientific capabilities of exisiting and future FEL light sources with **brighter electron source.**
- Higher photon energy and higher peak intensity through **reduced emittance.**
- **CW operation** improves user operation with regards to time structure, higher average brilliance and improved stability.

R. Brinkmann, et al., NIM A 768 (2014) 20-25



European XFEL

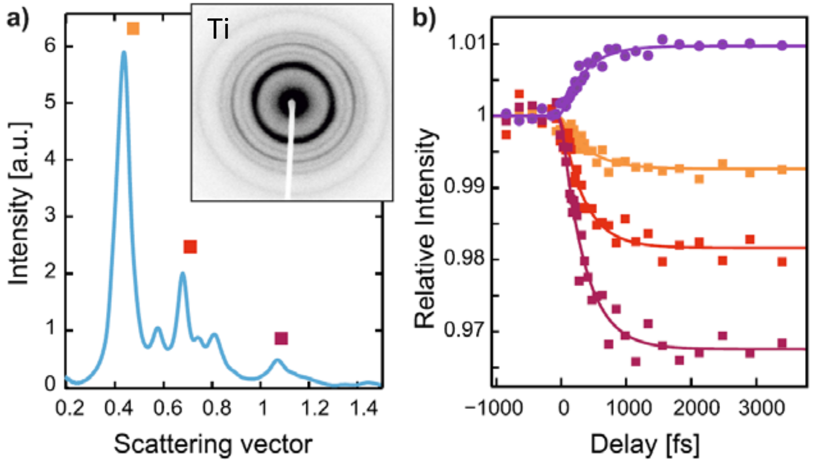
HXR (λ_u = 26 mm) with SCRF Linac (red, blue) and Cu-Linac (magenta) and emittance of 0.1, 0.2, 0.3, 0.4, and 0.5 μm



P. Emma, DOE BES Future Electron Sources White Paper, 2016

Scientific Needs - Electrons for Ultra-Fast Science

- Explore **ultra-fast structural dynamics** (electron-lattice-spin coupling) in a university-scale lab
- Probing matter with electrons ideal for surfaces, thin films and gas samples, complementary to FEL
- The source comes to your lab: Relativistic electron pulses for scattering: Ultra-Fast Diffraction and Microscopy (UED/UEM)
- **Fast-growing community** in Germany with high demand from user side (MPG-FHI Berlin, MBI, DESY, CFEL, U Duisburg-Essen, TU Dortmund, HZB, JGU Mainz, …)
- Require electron pulses with **ultra-fast pulse length** and **high transverse coherence** (meaning low emittance and small spot at sample).



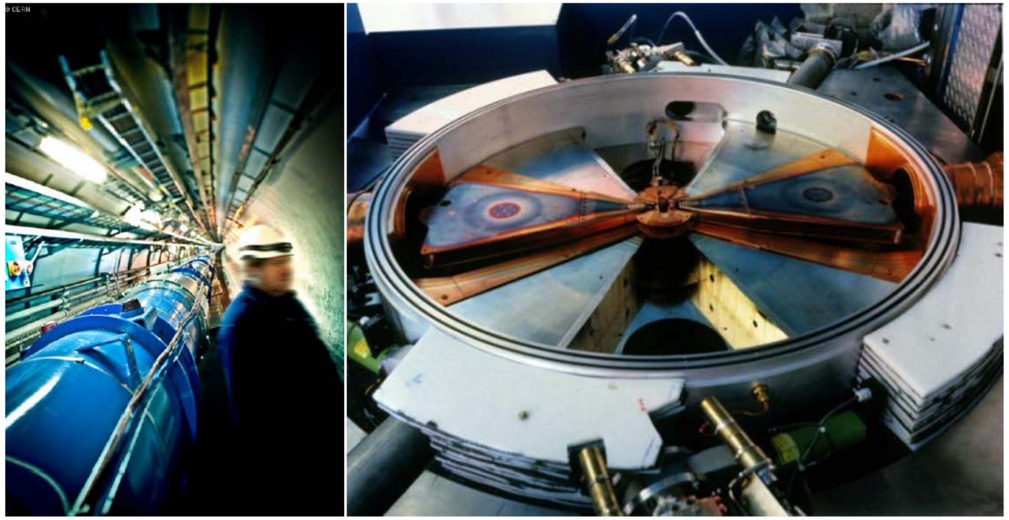
Waldecker et al., J. Appl. Phys 117, 044903 (2015)

Scientific Needs – Ions for therapy… to …rocket science

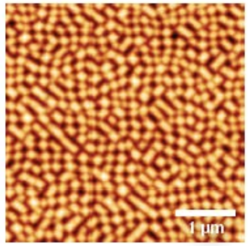
- **Pulsed and dc ion sources** for broad spectrum of applications from material analysis and modifications to rocket science and medical applications
- For high charge state production **Electron Cyclotron Resonance Ions Source (ECRIS) is a** highly developed method

  Growing demand for **higher intensity, higher brightness and higher stability** of ion beams
- Beams from **laser based proton sources** are promising tools for radiotherapy of cancer.

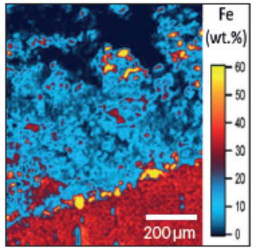
  Reliability and compactness



R. Scrivens, CAS Ion Sources 2012

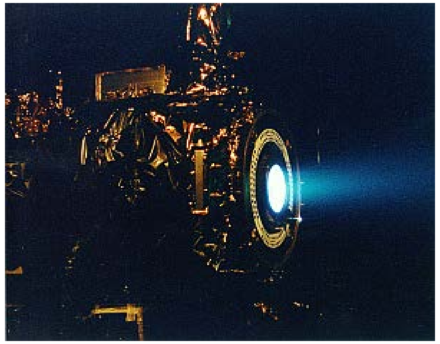


Crystalline nanostructures: Checkerboard pattern on Ge after LEI irradiation at 300°C



Iron distribution of a sample from an underwater volcano rock obtained by micro-PIXE

Ion Beam Center at HZDR

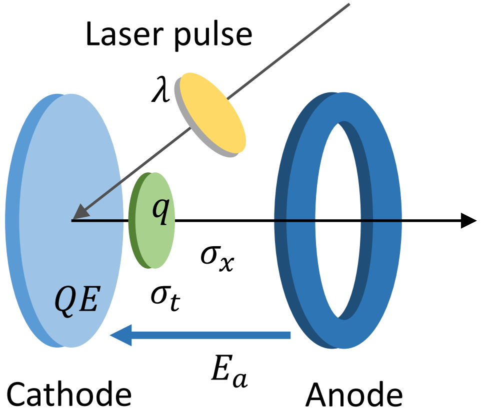


NASA

How to we get brighter beams?

How to we get brighter beams?

For photoemission sources: Embed a photocathode with high quantum efficiency in an accelerating gap with high electric field and illuminate it with short laser pulses …

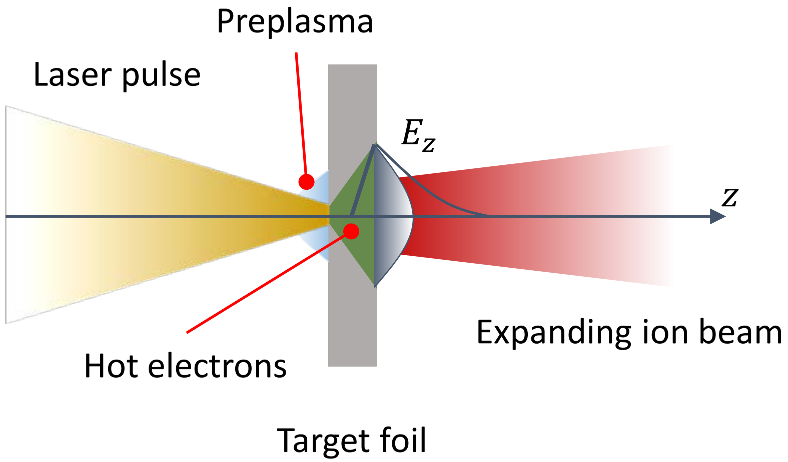


$$B_{pk} = \frac{2q}{\pi^2 \epsilon_{n,x} \epsilon_{n,y} \sigma_t \sigma_E}$$

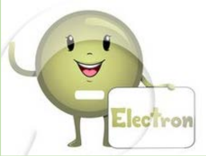
$$B_{pk} \propto \frac{E_a}{\mathrm{MTE} \cdot \sigma_t \sigma_E}$$

For ECRIS sources: For higher intensities generate stable high plasma density → need higher frequencies and higher magnetic field

Explore alternative paths like laser generated ion sources → need intense laser sources



Pushes from photocathode R&D for lower MTE and from SRF and DC gun technology for higher fields



Pushes from advanced modeling, microwave technology, supercon-ducting coils, intense laser sources

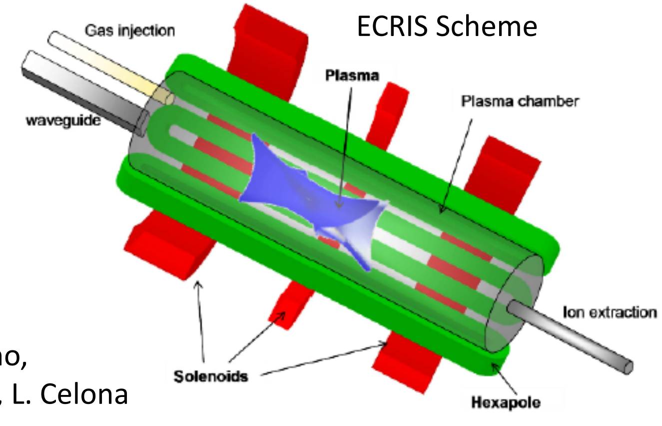
Advances

Advances in ion sources

- ECRIS: Increase operating frequency beyond 28 GHz and peak magnetic field beyong 1 T.

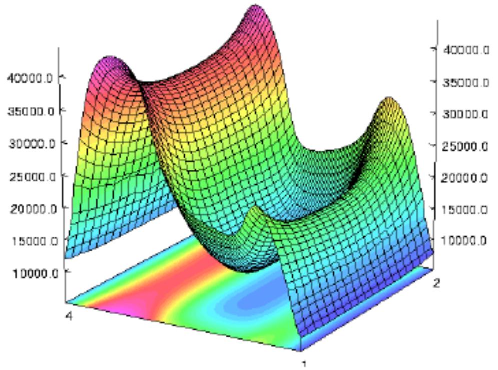
→ Impact of **microwave and superconducting tech**. Better comprehension of plasma formation and heating is needed.

ECRIS Scheme



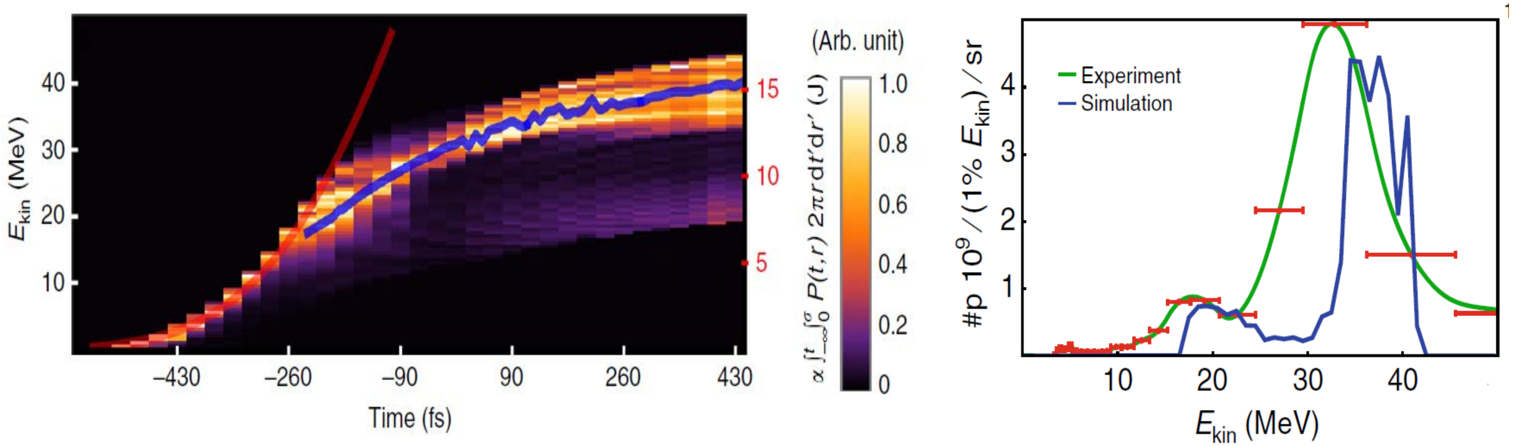
S. Gammino,
D. Mascali, L. Celona

Magnetic field in module



3D PIC Simulation of Acceleration Process

EXP vs SIM



P. Hilz, et al., Nature Communications 9 423 (2018)

- **Laser driven ion sources** have large potential for ion beam production

→ Investigation into **laser-plasma interaction** and impact of target properties.

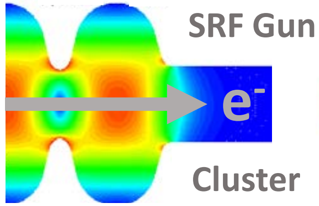
Pushing SRF Gun Development

- SRF technology has potential for **very high accelerating field** (30 to 40 MV/m)
- **CW** operation at 100% duty cycle
- Need more experimental setups to **optimize performance** with cavity/cathode interface
- **SRF Gun Cluster (DESY, HZB, HZDR)**

→ **Transfer best practices** from accelerating XFEL cavities to gun cavities

→ Setup of a **modular system kit** (Baukasten) for SRF guns

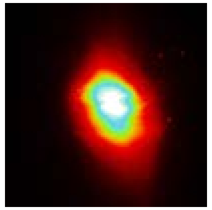
→ Case study **XFEL CW SRF gun,** benefits also **bERLinPro, ELBE, DALI, LCLS II**



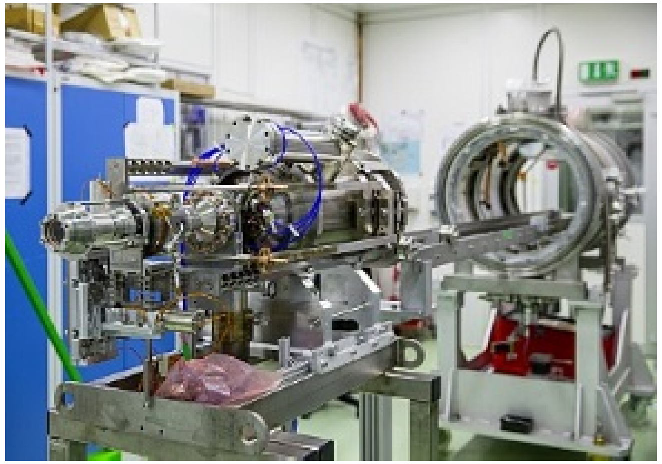
DESY.

HZDR

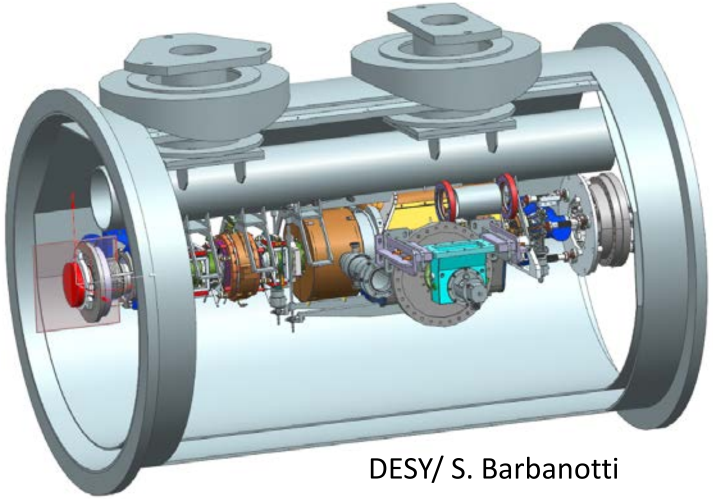
HZB Helmholtz Zentrum Berlin



HZB



HZDR



DESY/ S. Barbanotti

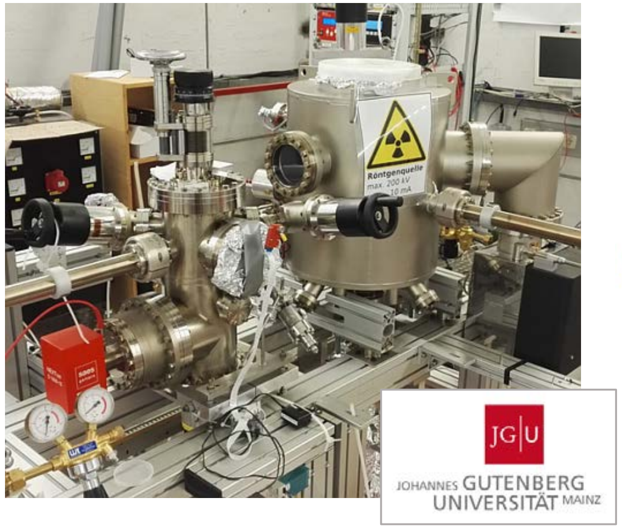
E. Vogel

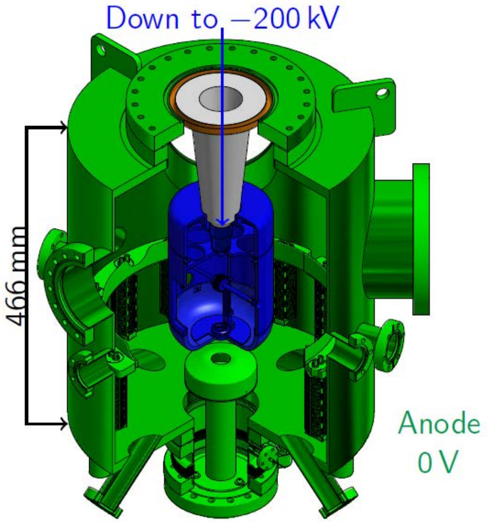
Innovative DC Guns

- **Well developed solution** for gradients up to 10 MV/m.
- Strong DC gun community in Germany (JGU Mainz, TU Darmstadt, U Bonn)
- Offers **excellent vacuum conditions for advanced, sensitive photocathode materials.**

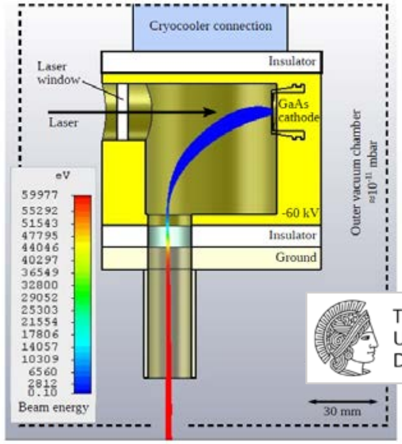
→ **Inverted gun** design to push high gradient, high voltage accelerating gap → **high brightness** beam generation

→ Implement **cryocooling** to improve vacuum and operational lifetime → benefits generation of **high average current**, polarized electron beam.





STEAM – S. Friederich



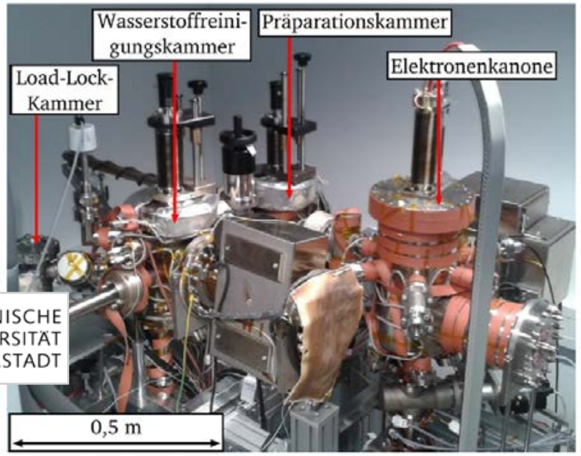


Photo-CATCH – T. Eggert, M. Herbert, M. Espig

Photocathode R&D – Material Science for Accelerators

- Use full arsenal of **material science** methods for preparation, analysis and computational modeling.

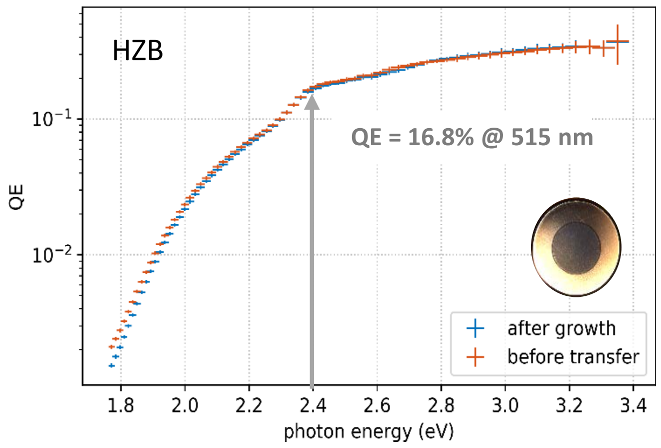
→ Implement **temperature control** for operation in harsh injector environment and to reduce MTE.

→ **Systems with long range order** to avoid physical and chemical surface roughness.

→ **Plasmonic and nanostructured emitters** to reduce mean transverse energy (MTE).

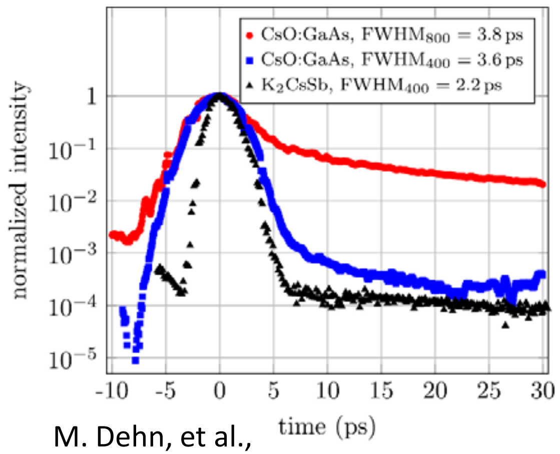
→ **Advanced model** for intrinsic emittance and QE (photocathode material library)

Spectral response CsK_2Sb photocathode P016



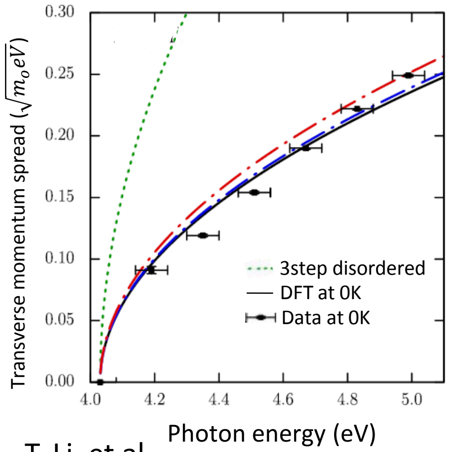
J. Kühn

Temporal response meas.



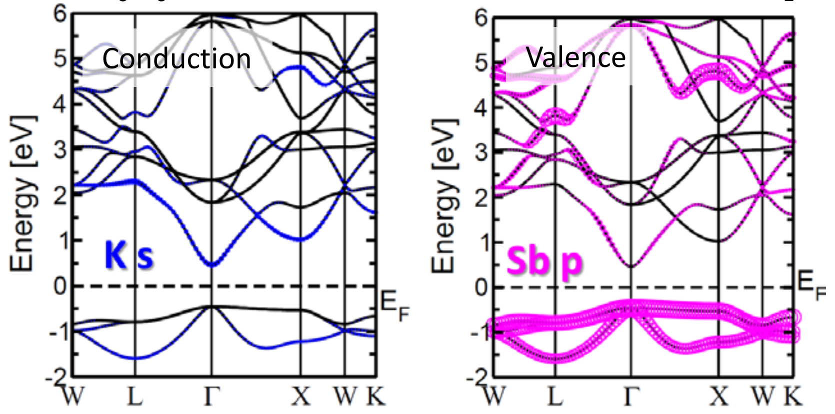
M. Dehn, et al.,
Appl. Phys. Lett. 111 132105 (2017)

3step vs DFT vs EXP



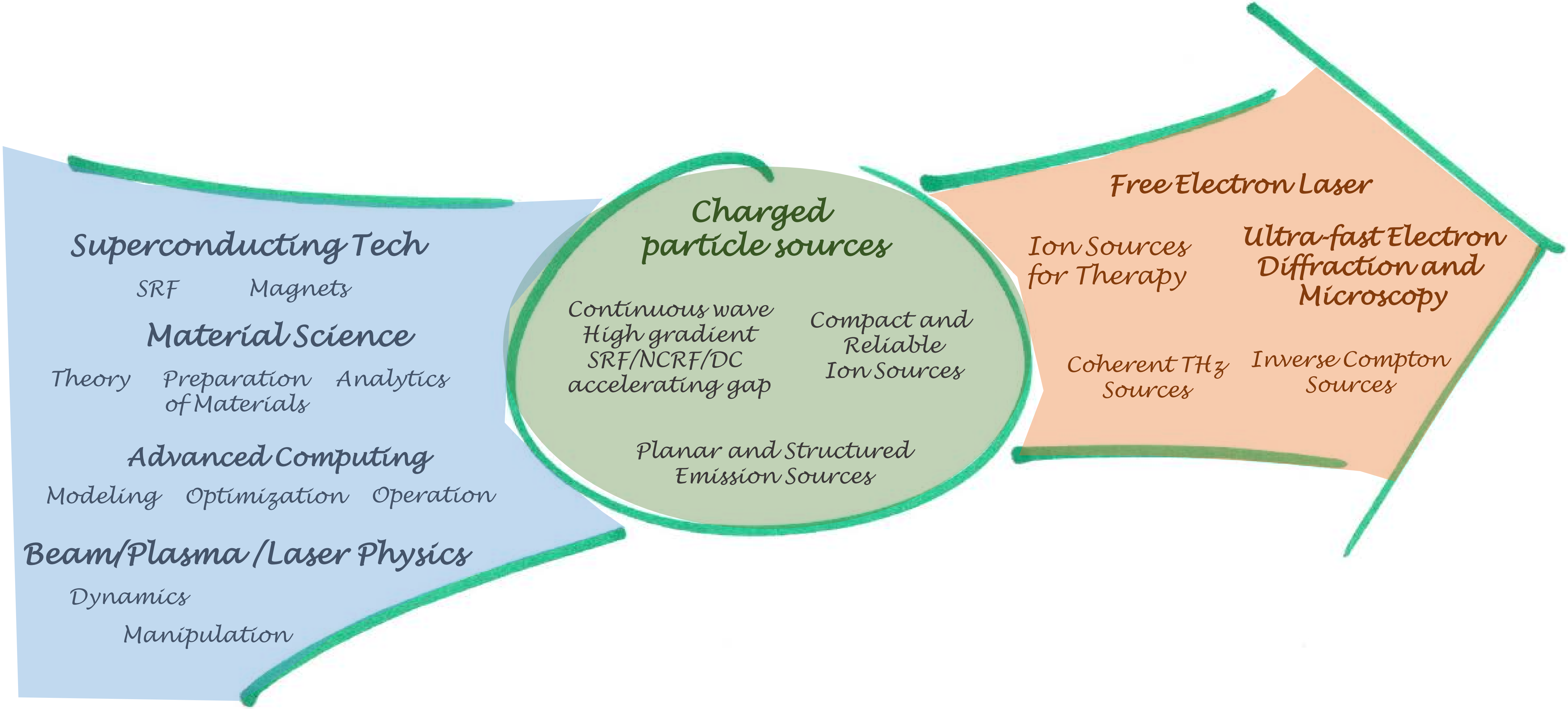
T. Li, et al.,
J. Appl. Phys. 117 134901 (2015)

DFT + G_oW_o band structure and atomic contribution for CsK_2Sb



Computation by C. Cocchi (HU Berlin)

Summary


Superconducting Tech
SRF
Magnets
Material Science
Theory
Preparation of Materials
Analytics
Advanced Computing
Modeling
Optimization
Operation
Beam/Plasma /Laser Physics
Dynamics
Manipulation
Charged particle sources
Continuous wave High gradient SRF/NCRF/DC accelerating gap
Compact and Reliable Ion Sources
Planar and Structured Emission Sources
Free Electron Laser
Ion Sources for Therapy
Ultra-fast Electron Diffraction and Microscopy
Coherent THz Sources
Inverse Compton Sources