X-RAY FREE ELECTRON LASER AT FREIA: WORK IN PROGRESS

Anatoliy Opanasenko, Kevin Pepitone, Dragos Dancila, Marek Jacewicz, Akira Miyazaki, Maja Ovegård, Roger Ruber, Jan Rusz, Georgii Shamuilov, Peter Salen, Zoltan Tibai, Hermann Durr, Vitaliy Goryashko

May 4th 2020, Uppsala

Towards a compact FEL: ASU concept

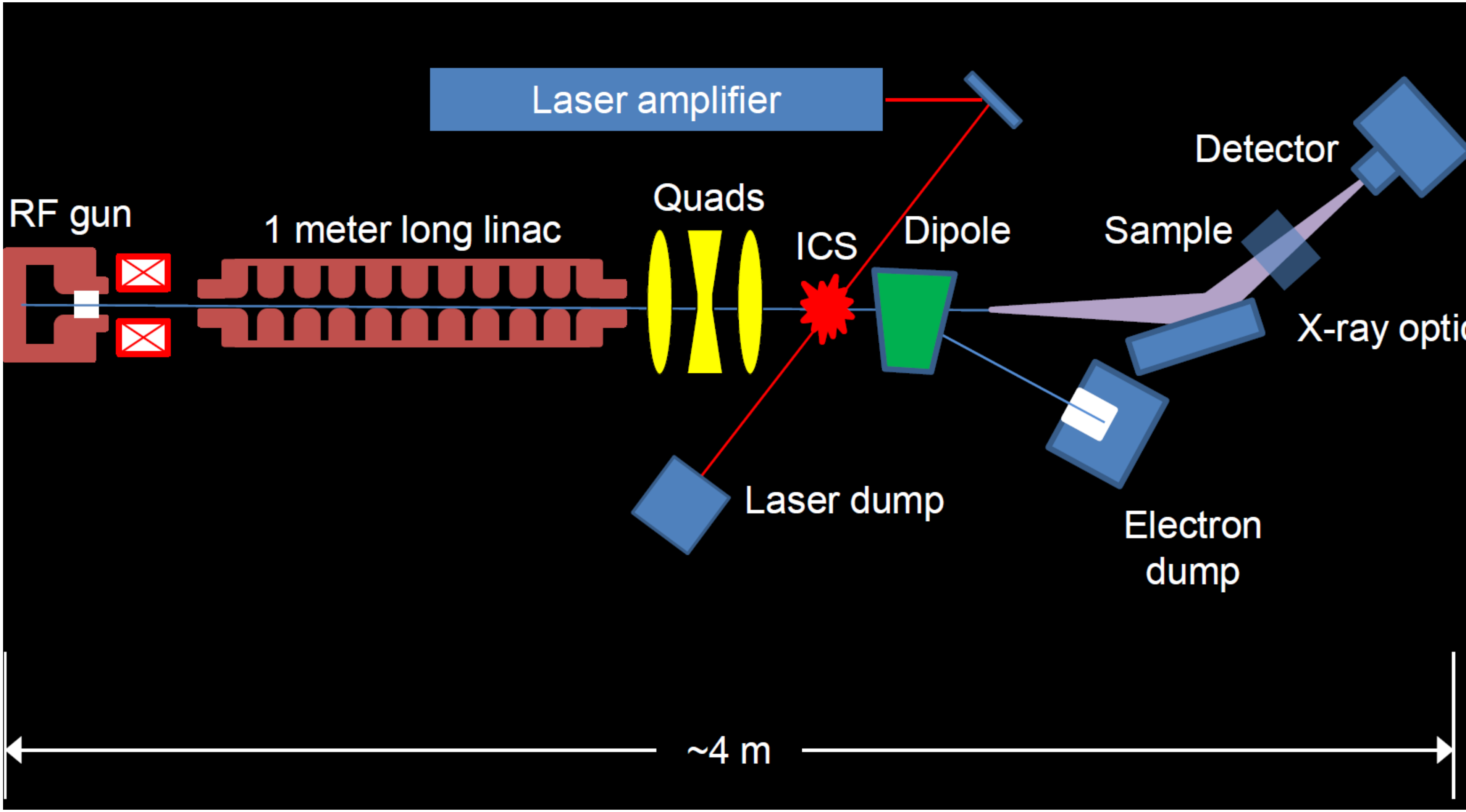
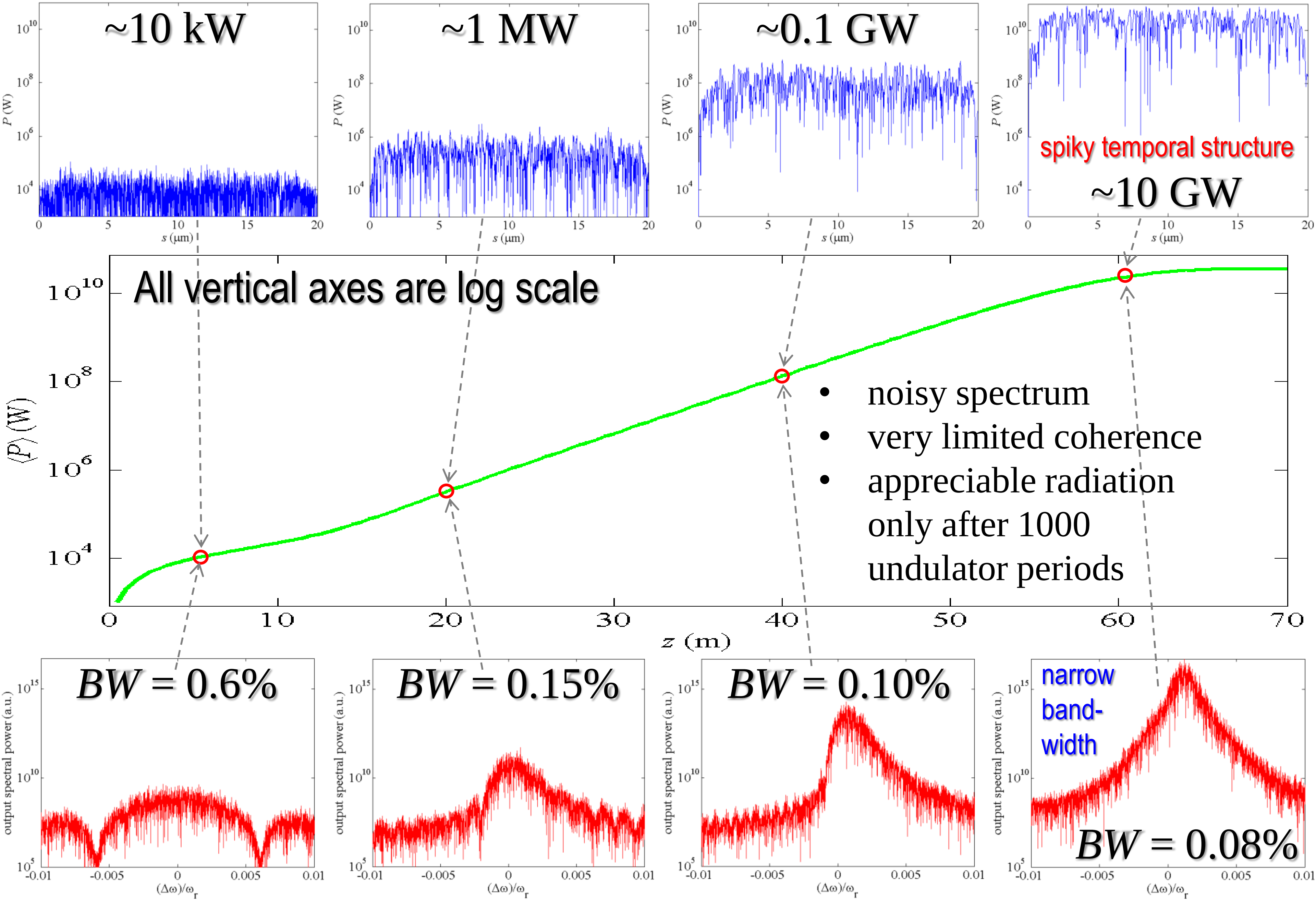


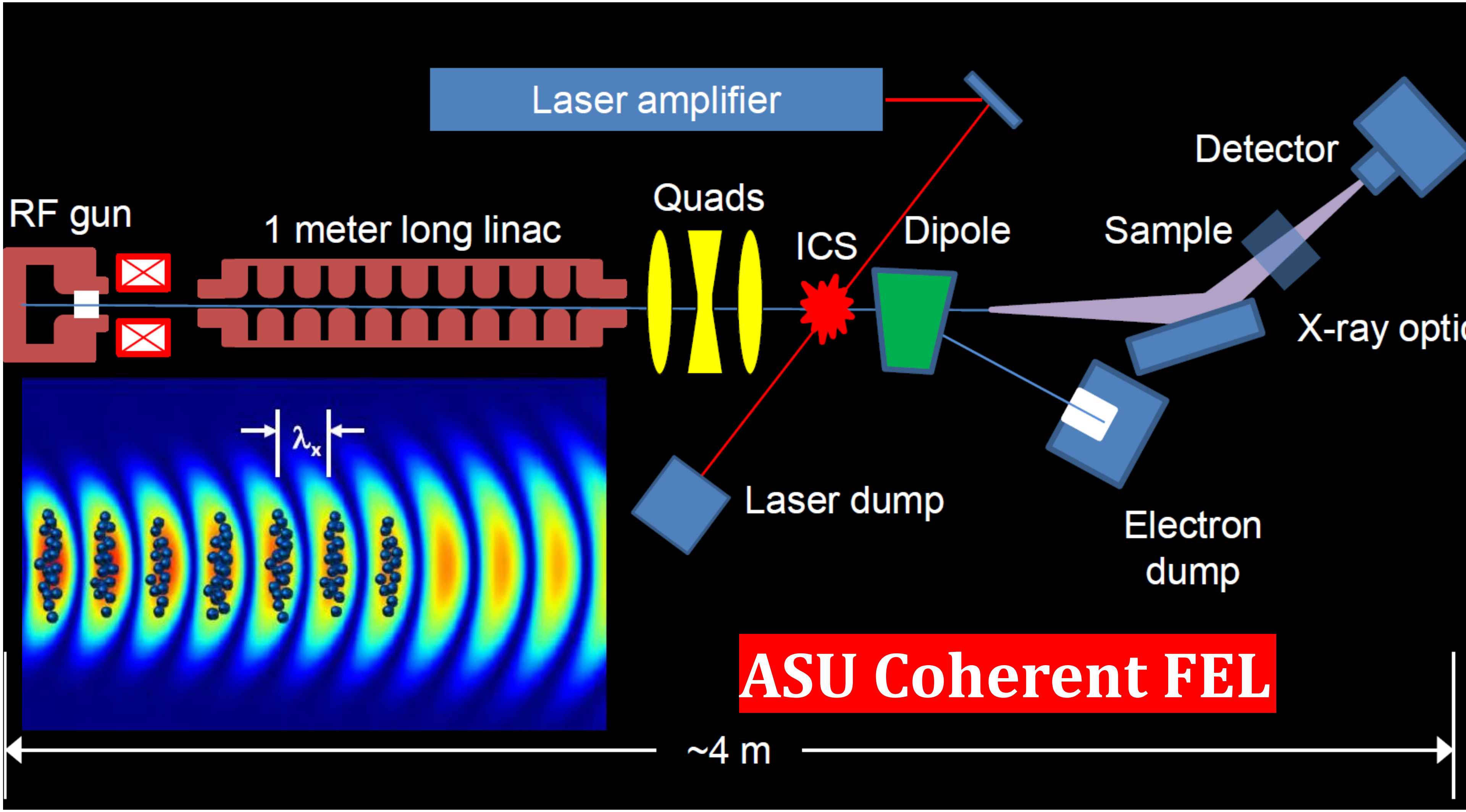
Table-top FEL is a very old idea but there is a strong renewed interest.
It is an incoherent source because of shot noise of the electron beam.

FEL startup from e^- beam noise

Z. Huang



Towards a compact FEL: ASU concept



The electron beam is nanostructured to emit coherent radiation in an optical undulator driven by an external (IR) laser.

Towards Coherent FREIA FEL

Design target

- Stability
- Photon flux comparable to that of the synchrotron beamline
- Flexible time structure

Design challenge

- Beam bunching at the nanometer (nm) scale
- Beam emittance at the nm scale

Design strategies for beam structuring

- Beam structuring via electron diffraction + emittance exchange
- Beam structuring using plasmonic cathodes + emittance exchange
- Modulated beam from a cold electron source
- Beam modulation by an optical laser (*least promising*)

Design strategies for ultralow emittance

- Blow-out beam generation
- Collimation of a high-emittance beam
- Field emitters

Conceptual layout of the accelerator

1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression

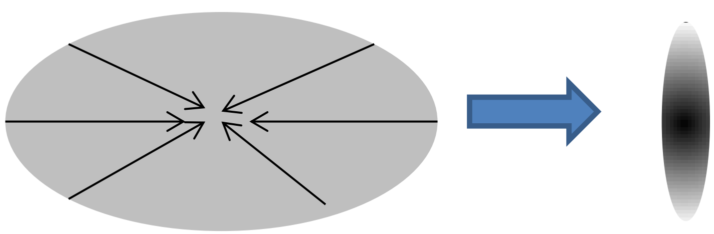
Conceptual layout of the accelerator

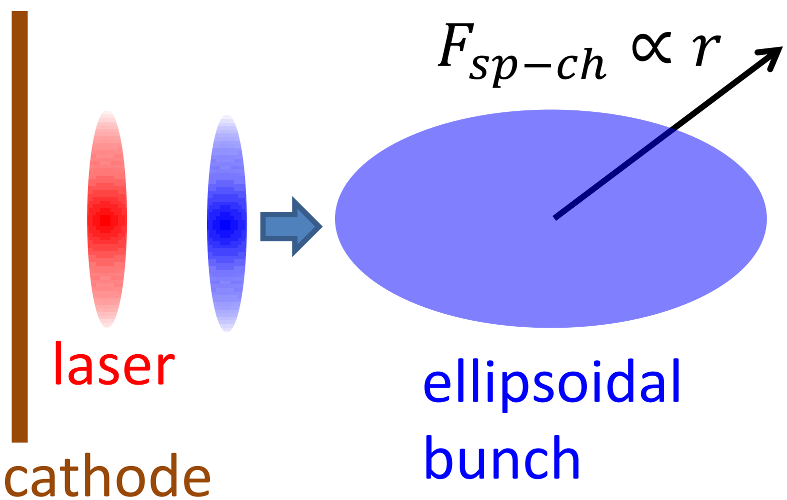
1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression





- The uniformly filled ellipsoidal electron bunch is a dream in beam physics.
- Space-charge field is linear.
- Difficult to realize in practice.
- Uniform prolate massive spheroid will collapse under its own gravitational field into a flat disk.
- $\rho(r,z) = \sigma_0 \sqrt{1-(r/R)^2}\,\delta(z)$
- A flat charged disk can blow out into a fully fledged ellipsoidal bunch, O.J. Luiten, PRL 094802 (2004).
- Density is limited by the image charge.

Conceptual layout of the accelerator

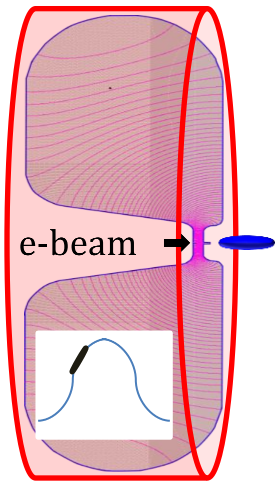
1. ellipsoidal bunches in blow-out regime

2. electron diffraction

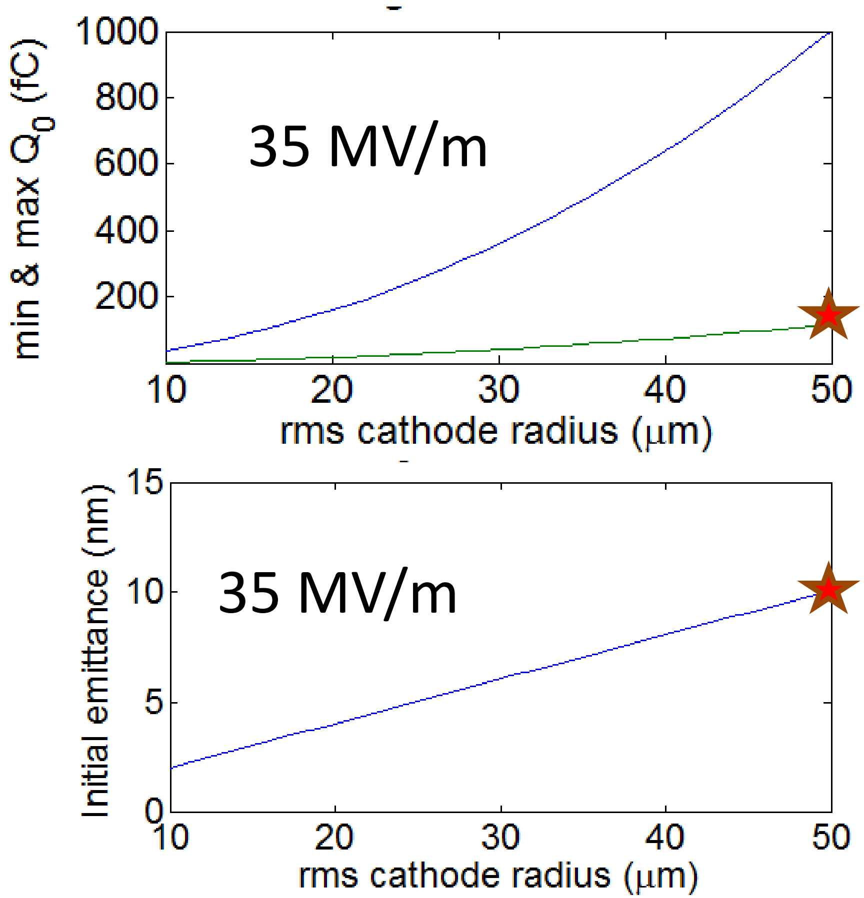
3. beam structuring: 4-f imaging

4. bunch compression

RF gun



325 MHz
CW, ~ 25 kW
420 keV



Initial beam:

- 50 um
- 30 fs
- 160 fC
- 10 nm emittance
- half-circular density distribution
- phase space based on "photoemitted Fermi-Dirac distribution"

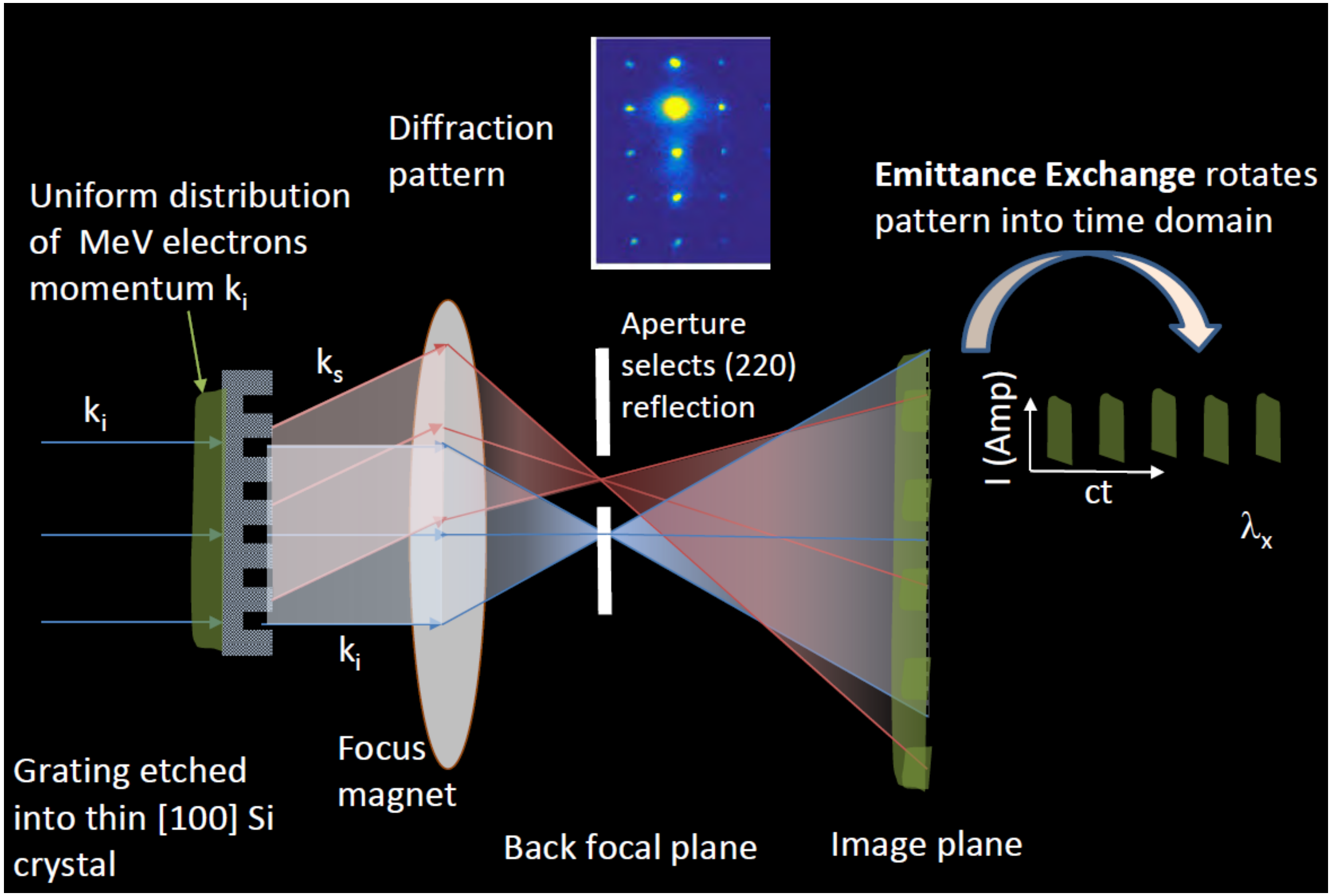
Conceptual layout of the accelerator

1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression



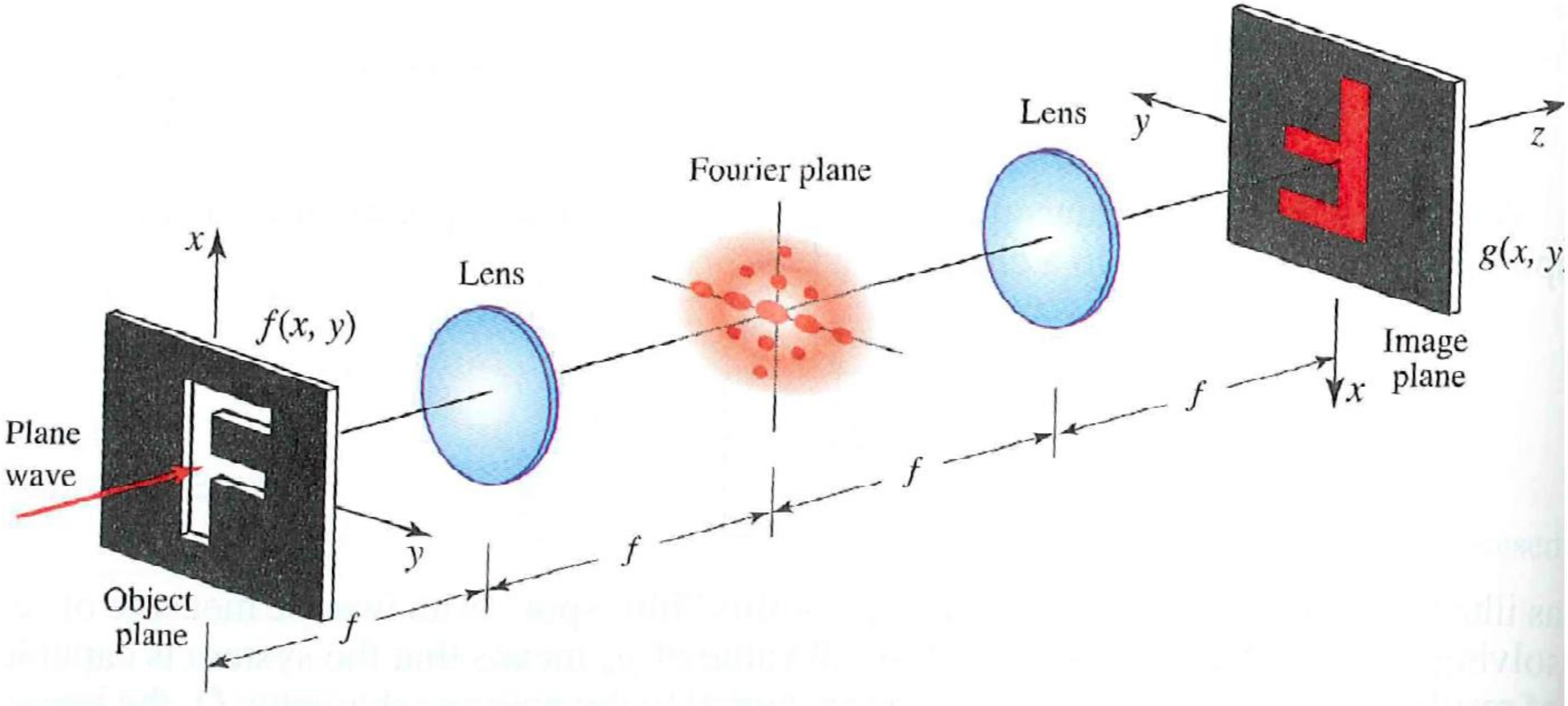
Conceptual layout of the accelerator

1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression



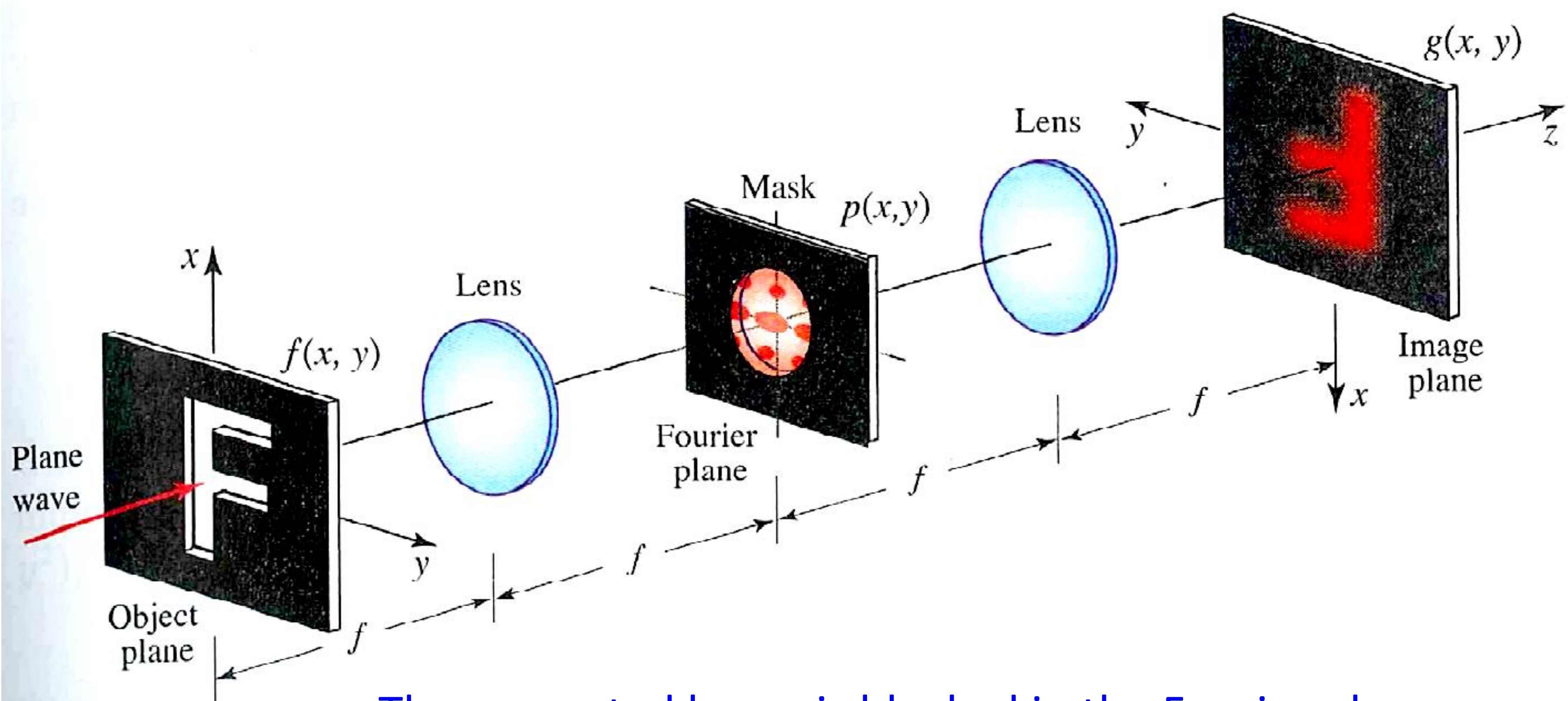
Conceptual layout of the accelerator

1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression



The unwanted beam is blocked in the Fourier plane.

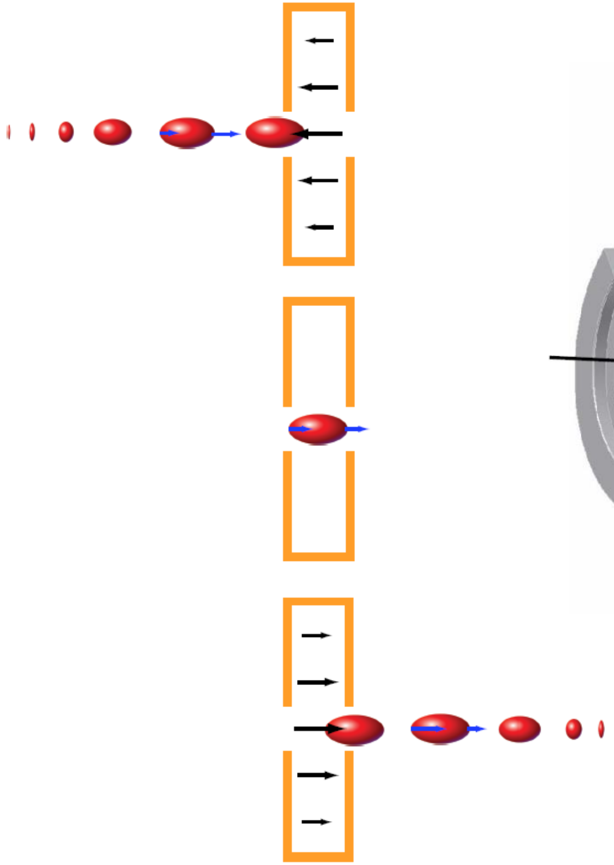
Conceptual layout of the accelerator

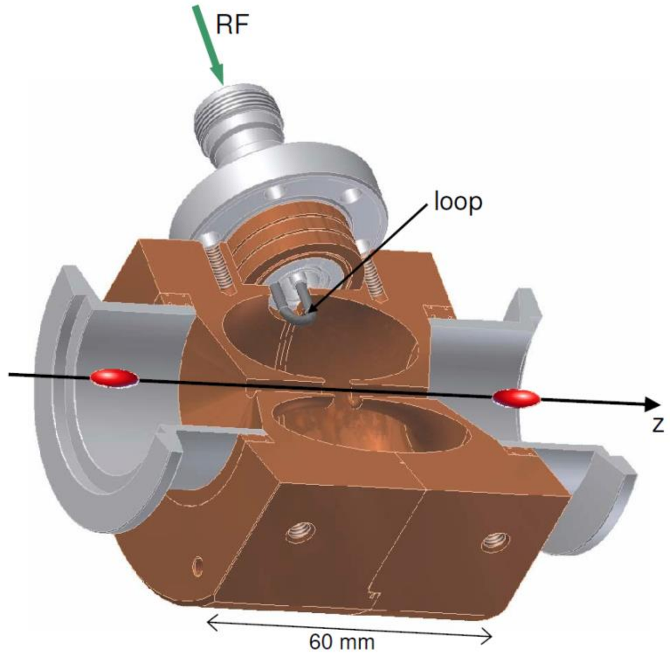
1. ellipsoidal bunches in blow-out regime

2. electron diffraction

3. beam structuring: 4-f imaging

4. bunch compression





Images from PhD thesis,
T. van Oudheusden

Updated layout and future work

1. ellipsoidal bunches in blow-out regime

2. bunch compression

3. acceleration to 3 MeV

4. electron diffraction

5. beam structuring: 4-f imaging

6. acceleration to 10 MeV

7. emittance exchange

8. laser undulator

9. FEL lasing

10. X-ray optics

11. end stations

Done

Partly done

Planned

Workflow for Coherent FREIA FEL

e-source	Beam structuring	Main accelerator	Emittance exchange	FEL lasing	X-ray science
gun cavity: Anatoliy – concept & RF design; Dragos: design & construction **e-dynamics:** Kevin & Zoltan **RF source:** Dragos **e-gun design & construction:** Kevin **beam characterization** Maja, Kevin	**e-diffraction:** Peter & Vitaliy – basic scaling; Jan Rusz – full simulations; Dragos – fabrication Kevin – heat load **plasmonic cathodes:** Dragos & Marek – concepts & EM simulations **optical modulation:** Georgii	**booster:** Anatoliy – RF design **e-dynamics:** Anatoliy, Kevin, Ye Zou **SC cavity:** Akira, Han & Roger **cryomodule** Rocio, Han, Roger **magnets:** Kevin, Roger	Zoltan Vitaliy Kevin	**optical cavity:** Vitaliy & Peter **coherent emission:** Vitaliy **X-ray shaping:** Peter	**science case:** Hermann

Summary

- Developed a simulation environment: CST + GPT + ASTRA + MATLAB
- Two beam dynamics codes are used for benchmark.
- Developed a low-energy design for potential experimental tests.
- Ongoing work on a higher-energy accelerator.