Towards a Low Emittance X-ray FEL at PSI

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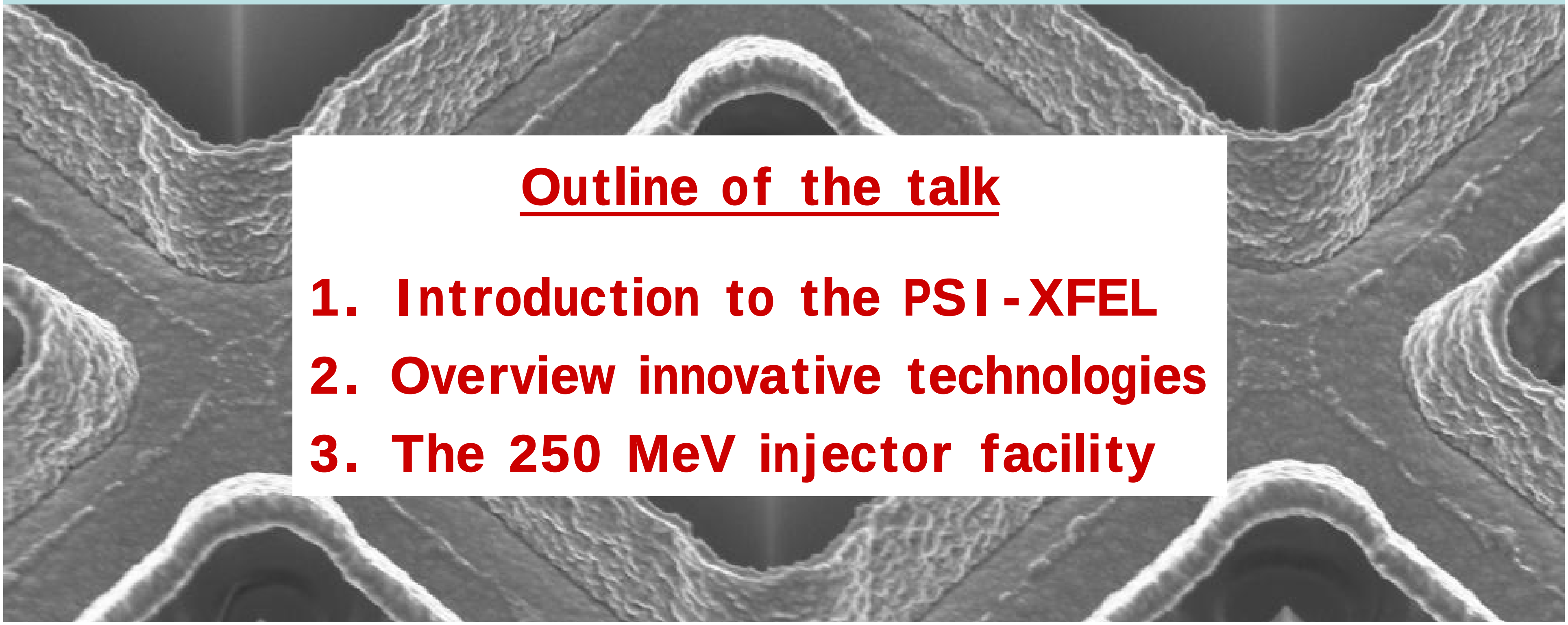


Outline of the talk

1. Introduction to the PSI-XFEL
2. Overview innovative technologies
3. The 250 MeV injector facility

Motivation

Switzerland contributes to the European XFEL
→ beamtime for Swiss users: 100-200 hours per year

But:
one would like to have 3000-5000 h/year for experiments
→ a national 1Å source would be needed

Drawback:
XFELs are presently too expensive to be financed as a national project within Europe
→ bring the cost down !

Solution:
shorter accelerator / lower beam energy
→ reduce beam emittance while keeping brightness

Realization

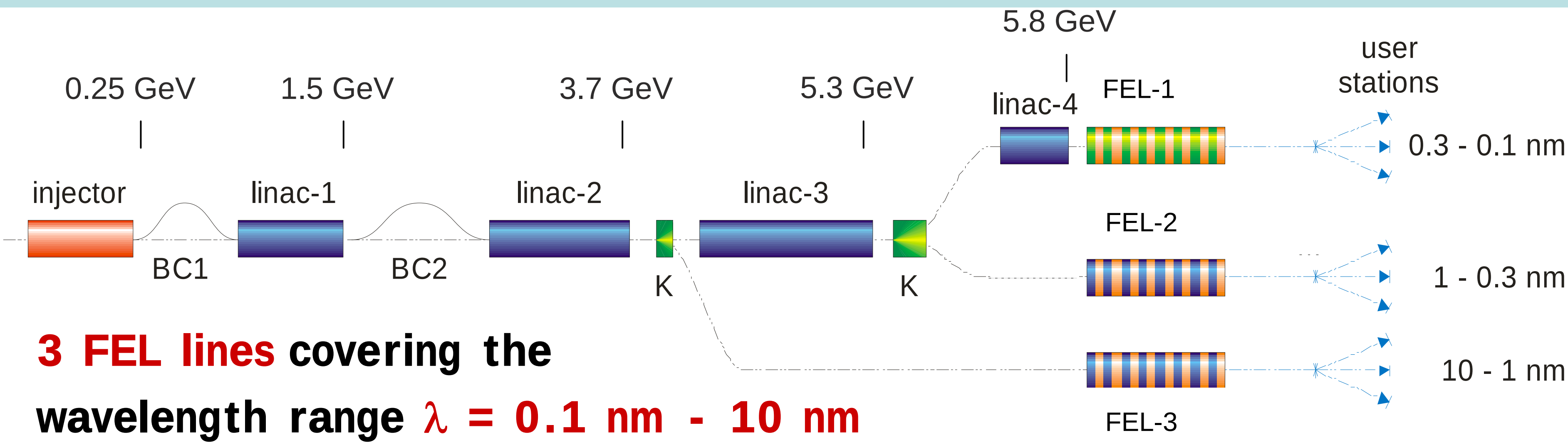
The PSI-XFEL is based on 3 innovative features :

1. Generate a low emittance electron beam
→ field emission from field emitter arrays (FEA) or single micro tips (needle cathodes)

2. Fast acceleration after the emission to avoid beam blow up due to space charge forces
→ diode configuration with high applied pulsed voltage

3. Low initial current to reduce beam blow up by space charge effects
→ 3-fold bunch compression scheme for high electron pulse compression

Proposed layout of the PSI-XFEL



3 FEL lines covering the wavelength range λ = 0.1 nm - 10 nm

XFEL Parameters:

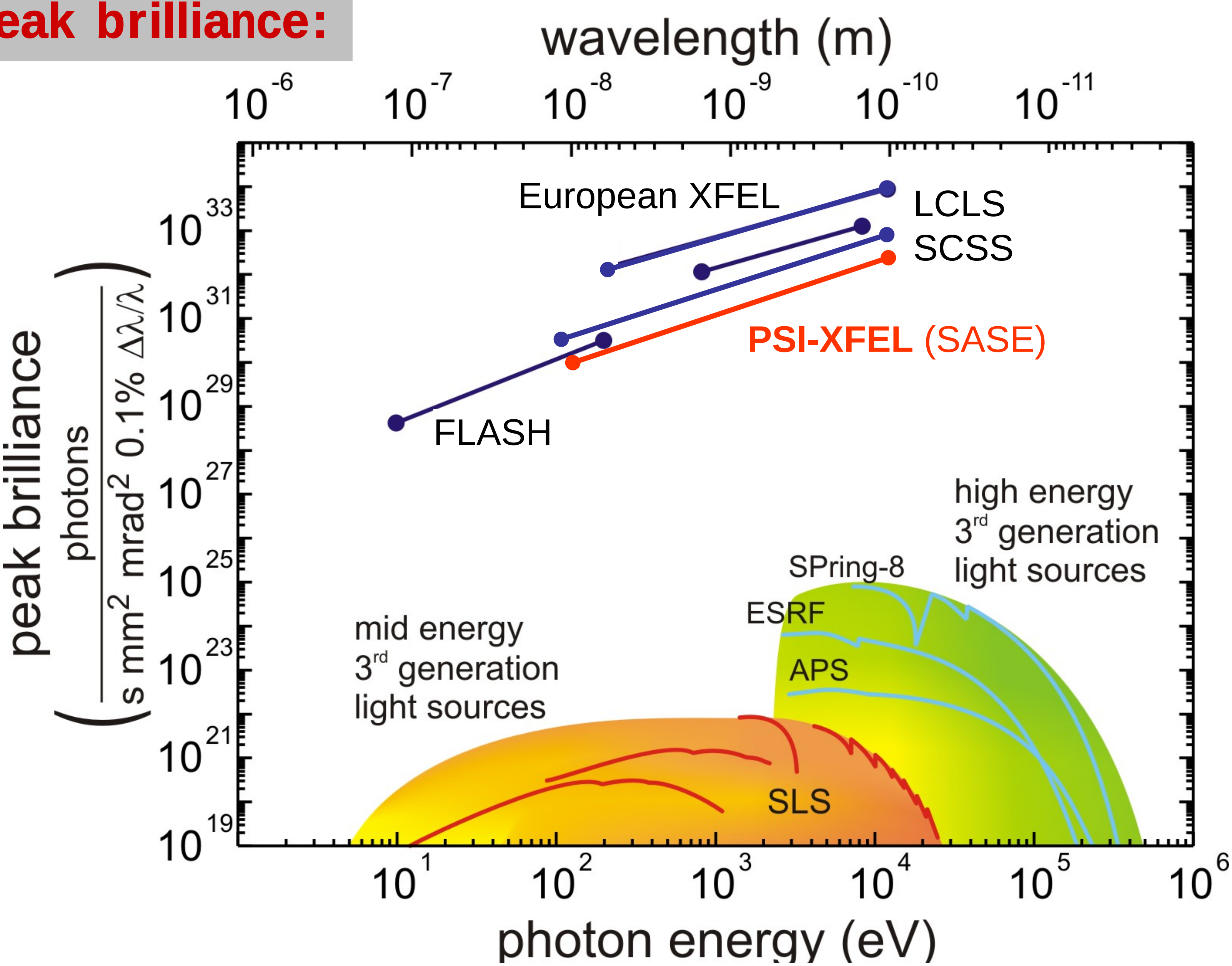
Target values @ undulator entrance (5.8 GeV, Q= 200 pC)

peak current	**1.5 kA**
slice emittance	**0.2 mm mrad (rms)***
energy spread	**10^{-4}**
undulator length	**30 m**
undulator period	**15 mm**

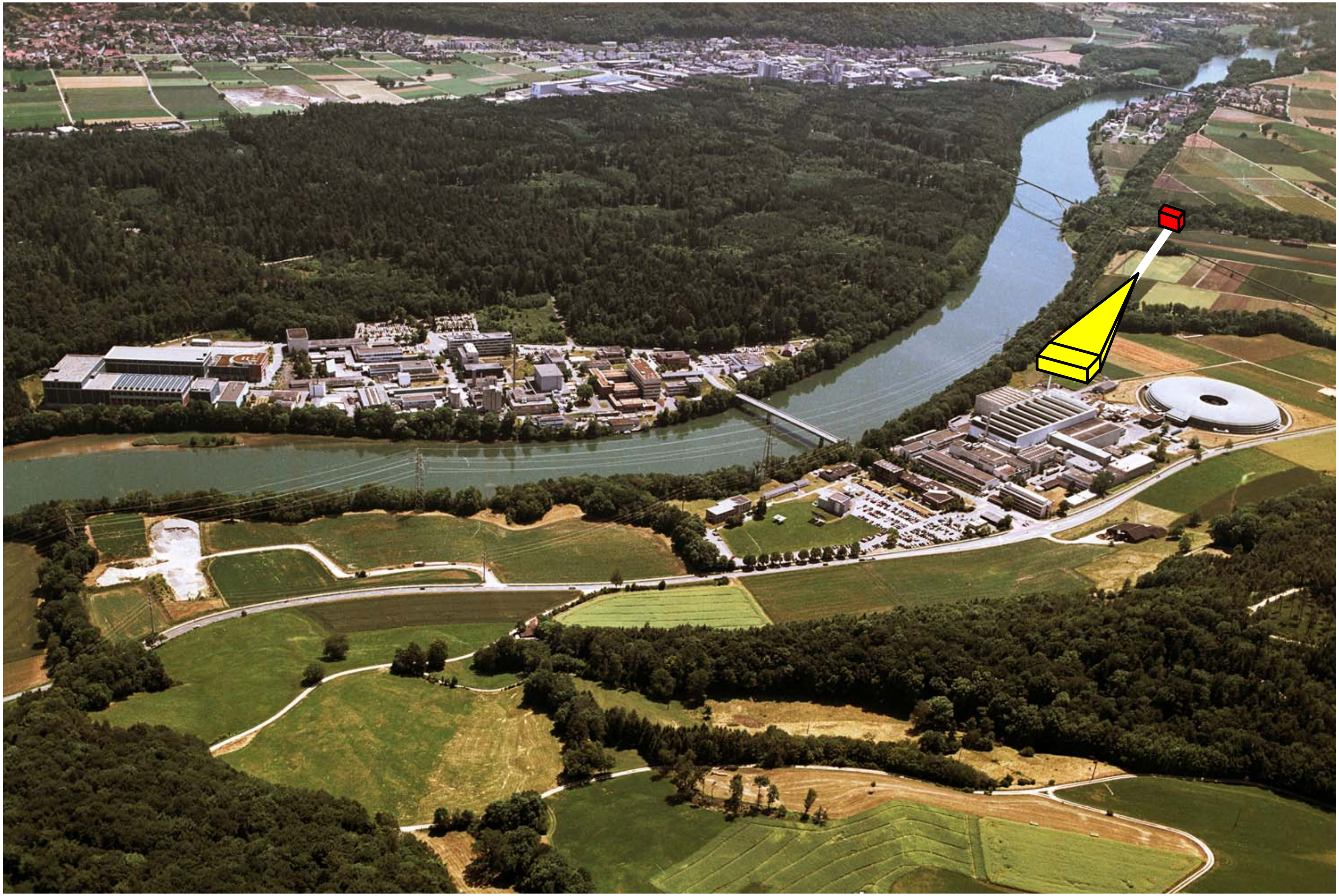
* 1pC slice

International context

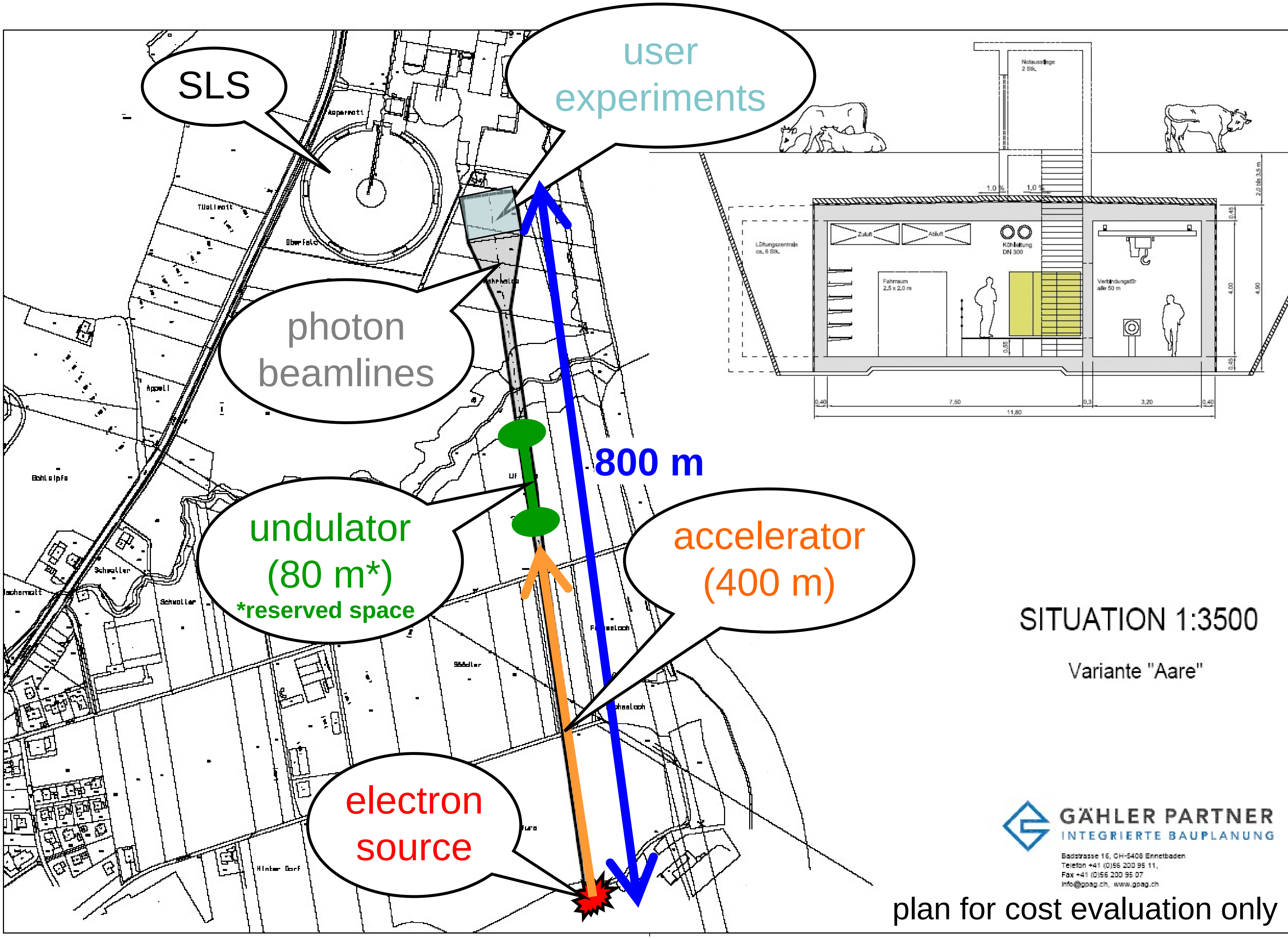
Peak brilliance:



The PSI-XFEL Site



PSI-XFEL Construction



Project Realization Strategy

Development of the critical technology

- low emittance electron source
- high voltage generation and high gradient acceleration
- two-frequency cavity for bunch compression

→ ongoing

Experimental verification of this technology

- Construction of a high voltage and high gradient facility
- Construction of a 250 MeV injector facility

→ 2008-2011

Construction of an X-FEL

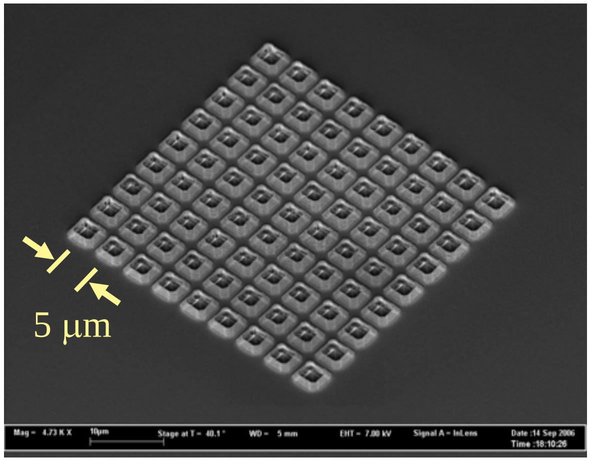
- FEL-3 / 10 nm – 1 nm
- FEL-2 / 1 nm – 0.3 nm
- FEL-1 / 0.3 – 0.1 nm

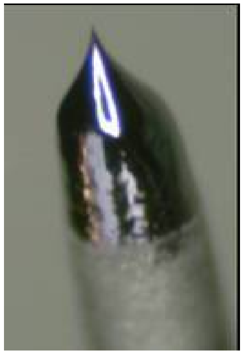
→ development after successful demonstration of the low emittance accelerator concept

(2011-2016)

Experimental Verification of the Critical Technology (1)

Low emittance electron source





Challenge: sufficient current, low emittance
(5.5 A, < 0.05 mm mrad)

Possible electron sources:

1. Field Emitter Arrays (FEA)

extracted current: I/tip ~ 10 µA (DC)

2. single tip field emitter (needle cathode)

→ pure field emission: 470 mA (2ns)
→ emission triggered by laser: I ~ 2.9 A (16ps)

3. scaled photo cathode

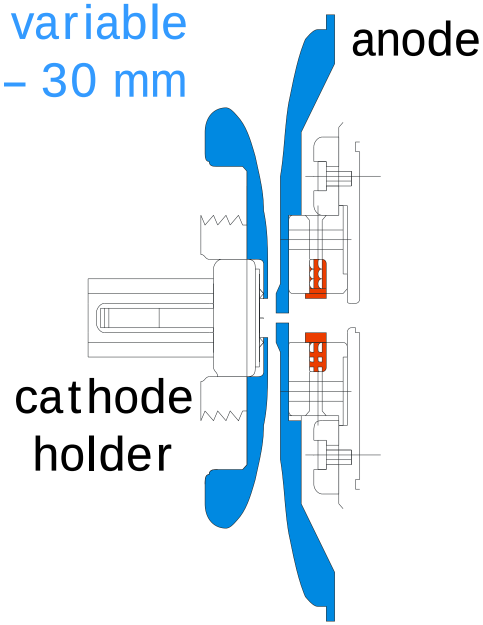
start-up solution to give more time for the FEA development

Note: Parameters for photo emission and field emission are chosen such that the accelerator design is the same for both !

Experimental Verification of the Critical Technology (2)

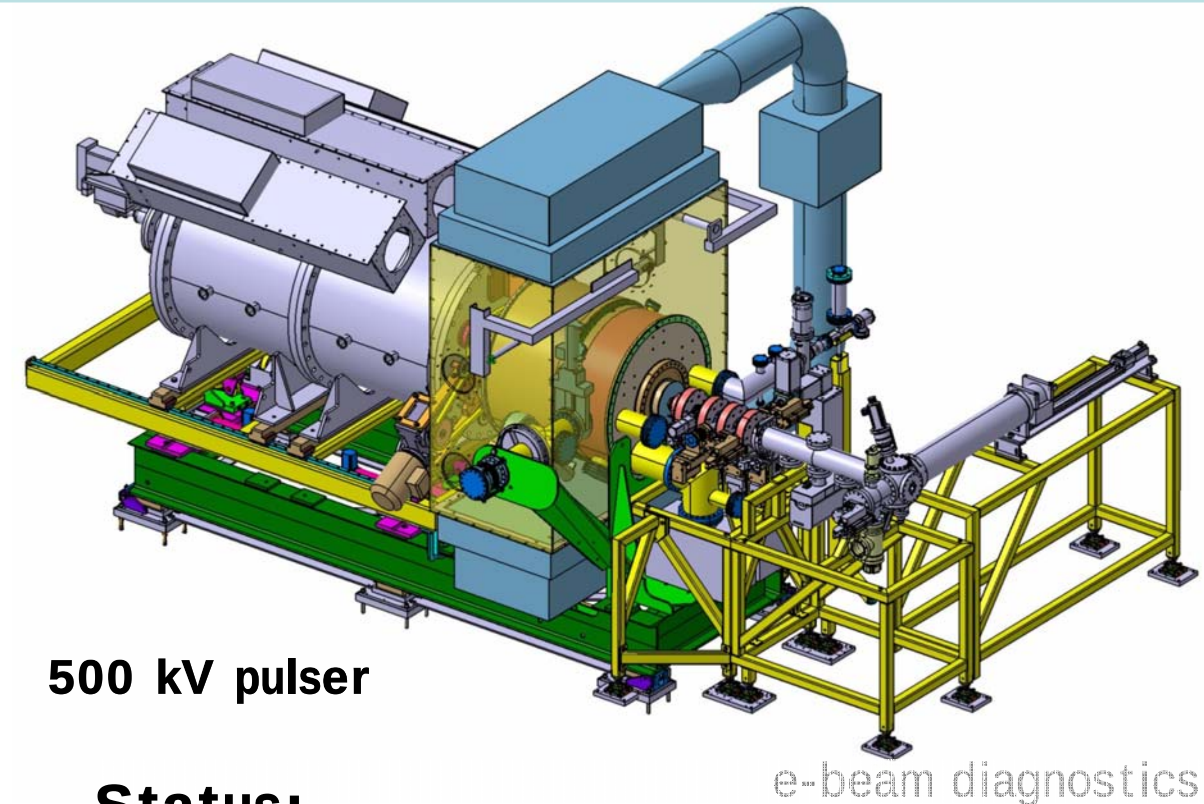
High gradient acceleration

gap variable
0 (4) – 30 mm



max. gradient:
125 – 250 MV/m

500 kV   1 MV



Status:

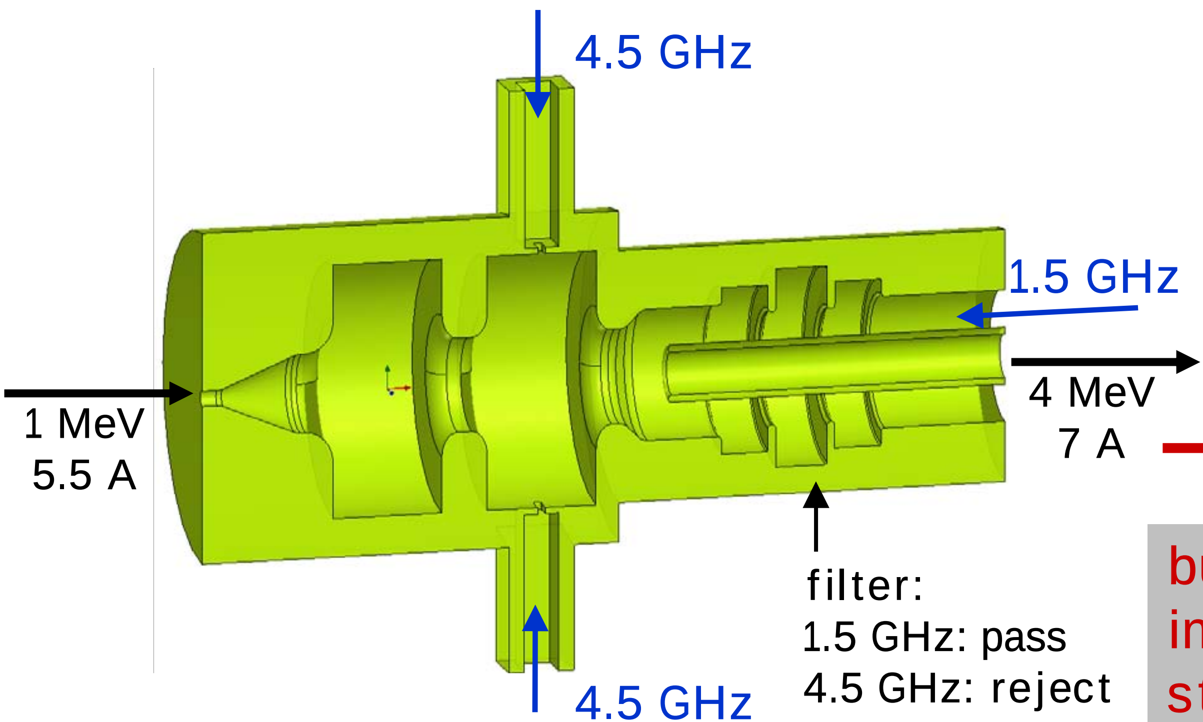
- **500 kV pulser installed in test bunker**
- **HV tests done successfully**
- **start of operation end 2007**
- **later upgrade to 1 MV foreseen**

Experimental Verification of the Critical Technology (3)

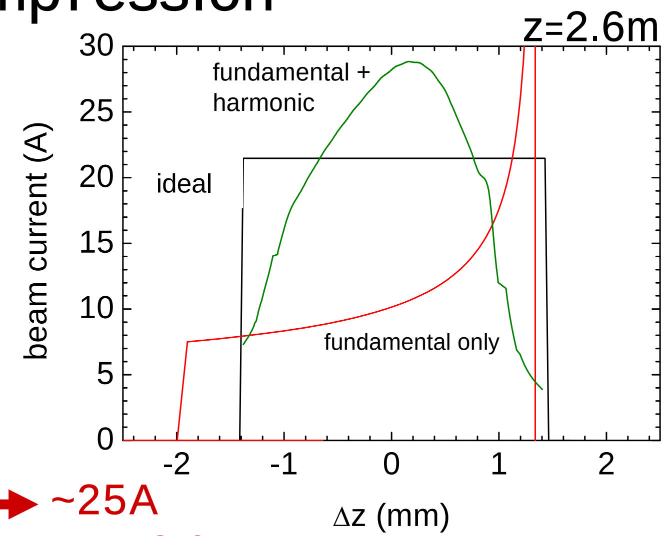
Bunch compression scheme

2-frequency cavity for large compression:

- off-crest acceleration with fundamental frequency leads to energy chirp for ballistic bunching
- harmonic frequency flattens accelerating field and allows pulse shape control during rf-compression



~25A at z=2.6 m



bunch compression finalized in following accelerating structures and magnetic BC

Experimental Verification of the Critical Technology (3)

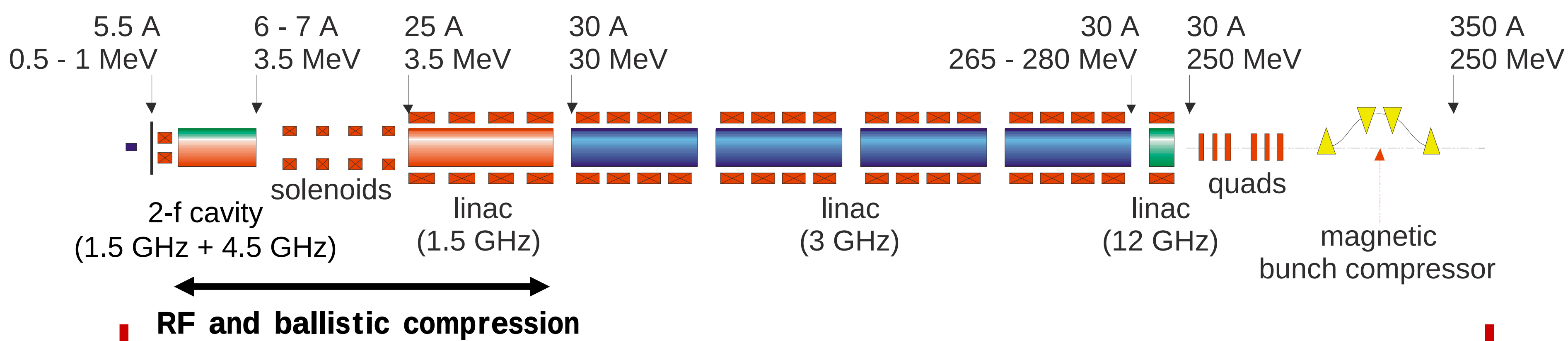
Emittance preservation

high compression ratio and transport of the emittance in the relativistic regime to be verified

→ **build 250 MeV Injector Facility**

Construction + Operation: 2008 – 2011

Conceptual Layout (CDR):



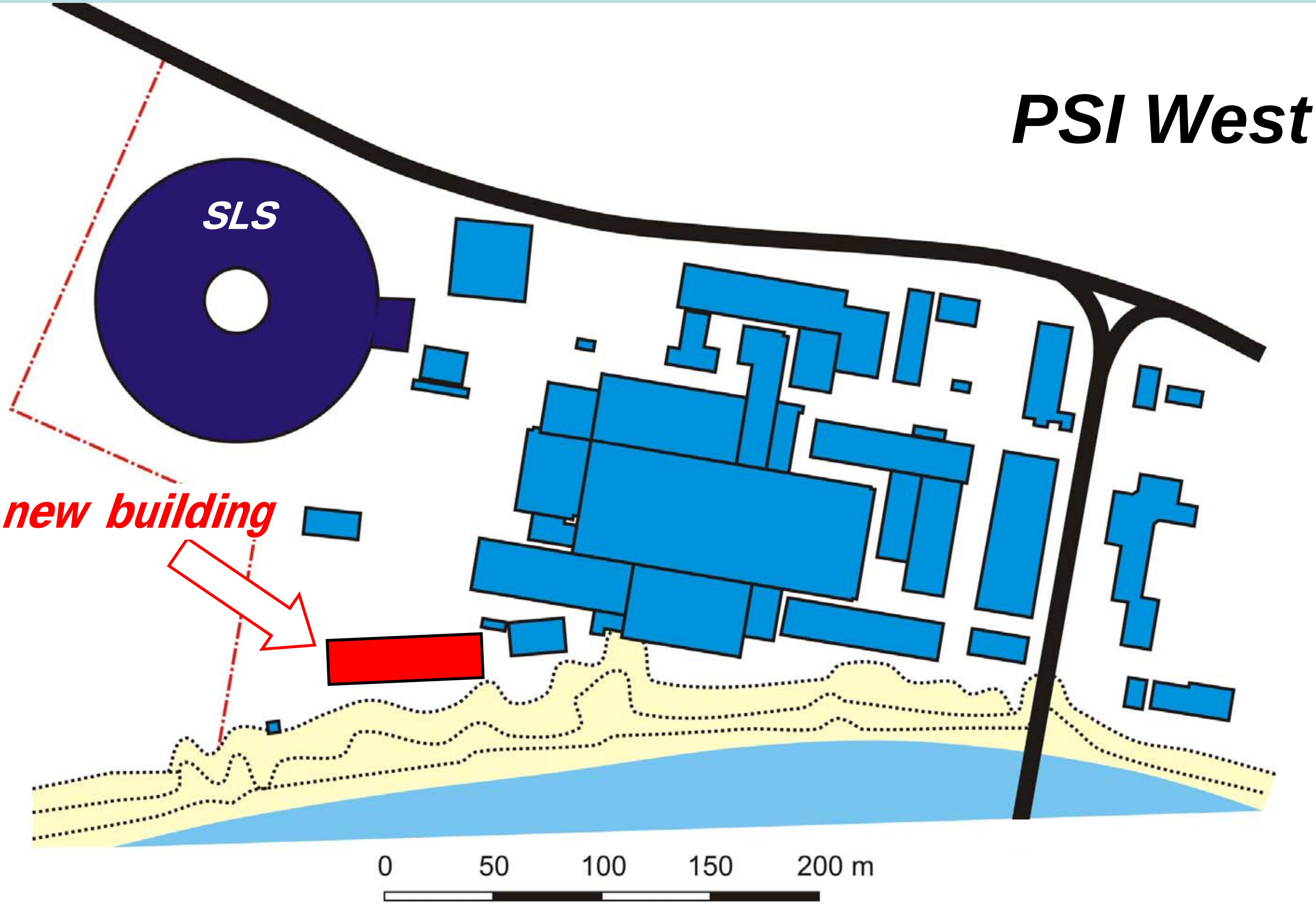
$\varepsilon_n \leq$ 0.05 mm mrad

slice emittance

(1pC slice)

$\varepsilon_n \leq$ 0.1 mm mrad

Location of the 250 MeV injector facility

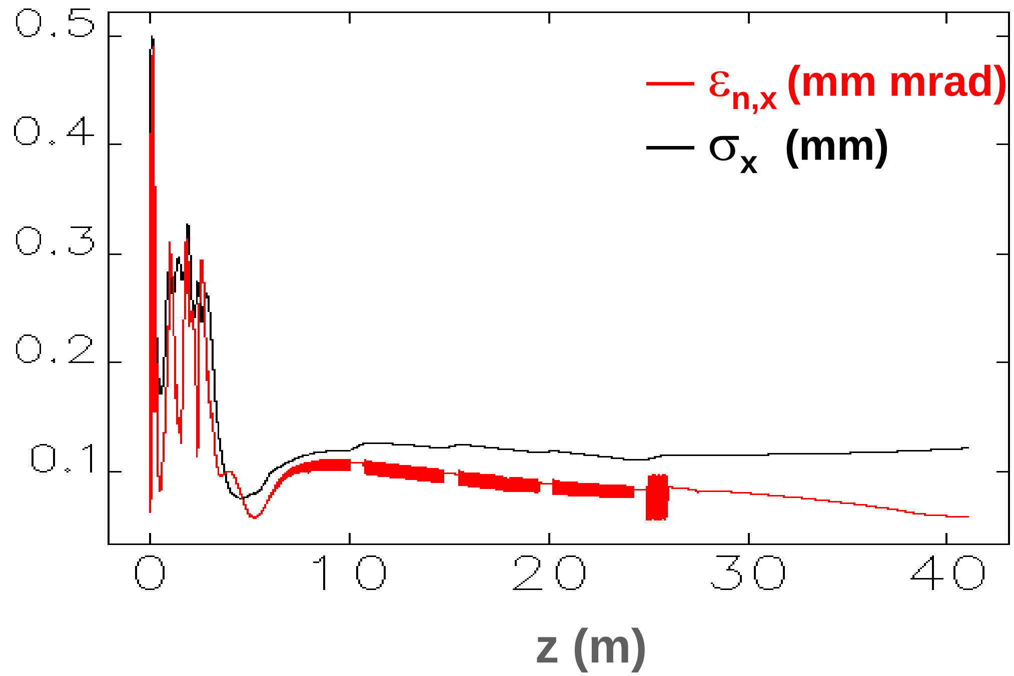


Simulations of the 250 MeV injector

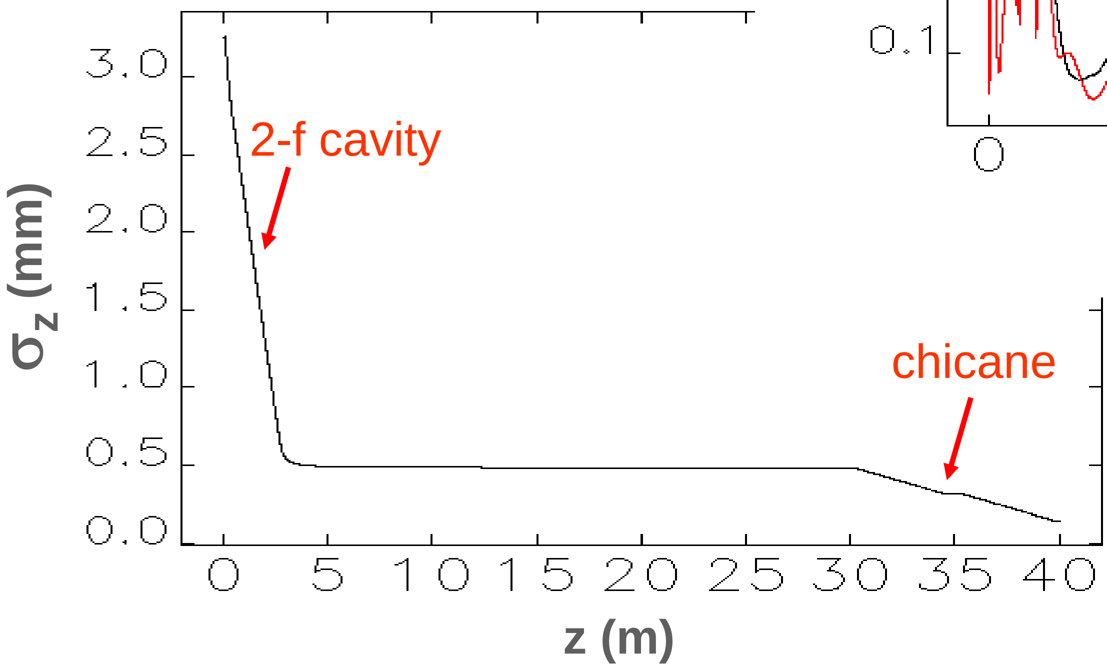
Example: Beam Envelope Tracking

(HOMDYN results)

growth of projected emittance and beam size:



bunch length:



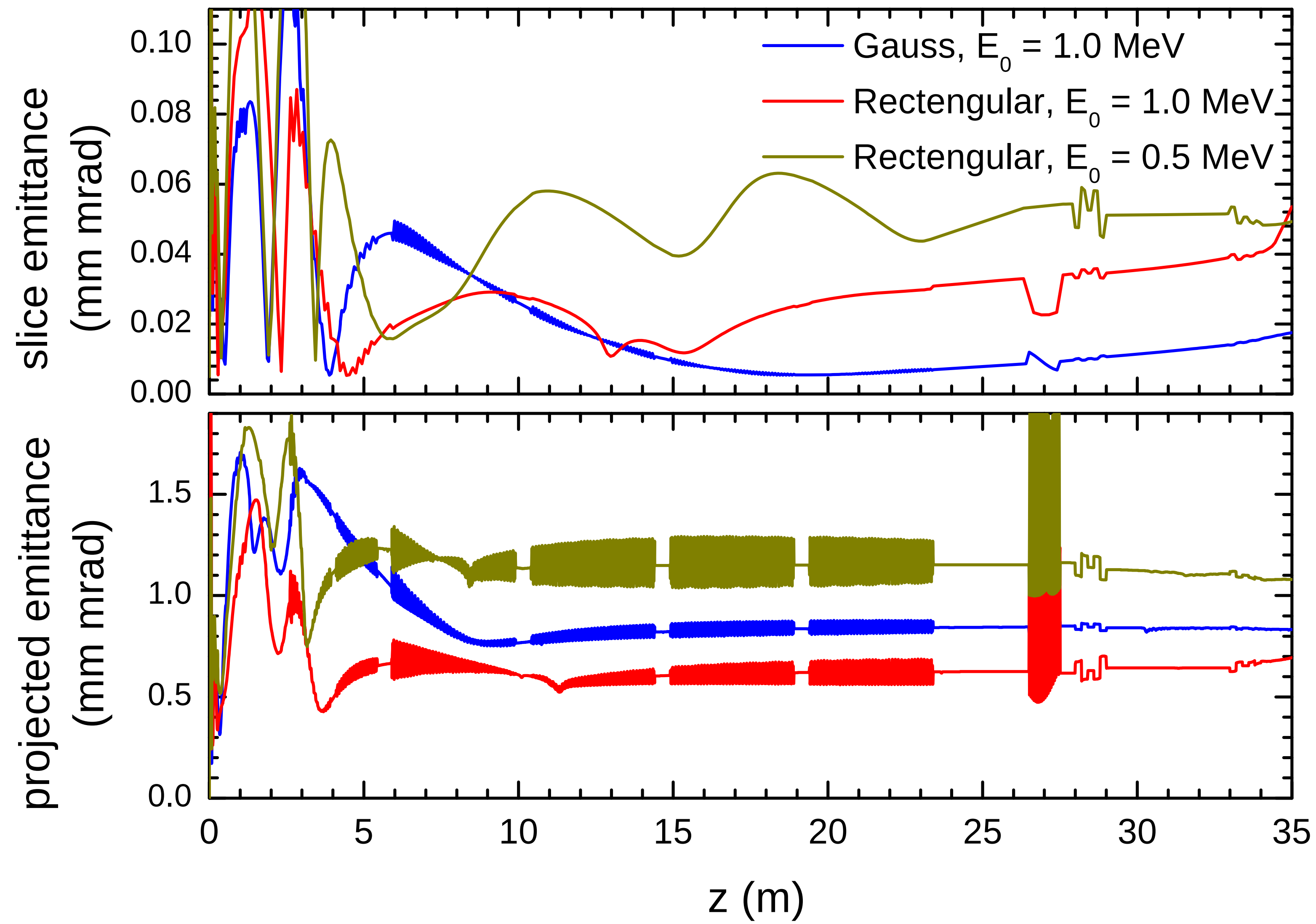
Simulations of the 250 MeV injector

Example: Beam Envelope Tracking

(BET results)

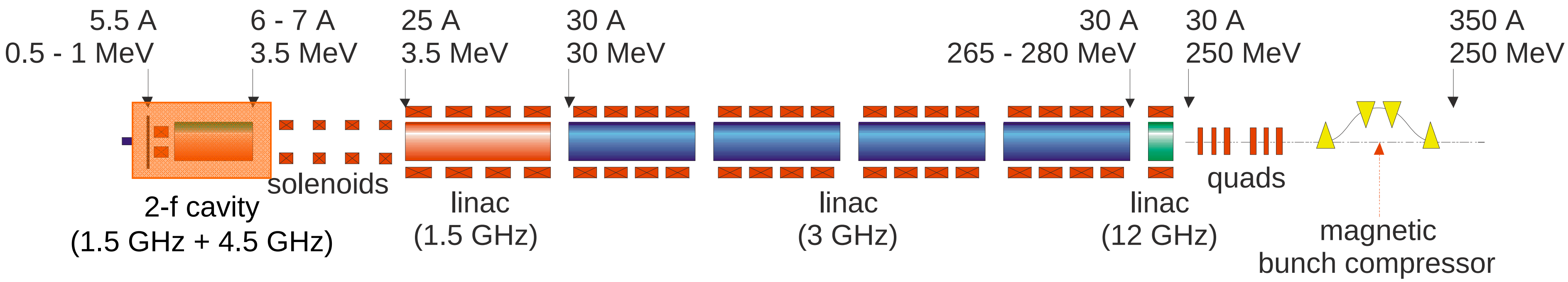
emittance growth:

slice = 10 % of total charge



Simulations of the 250 MeV injector

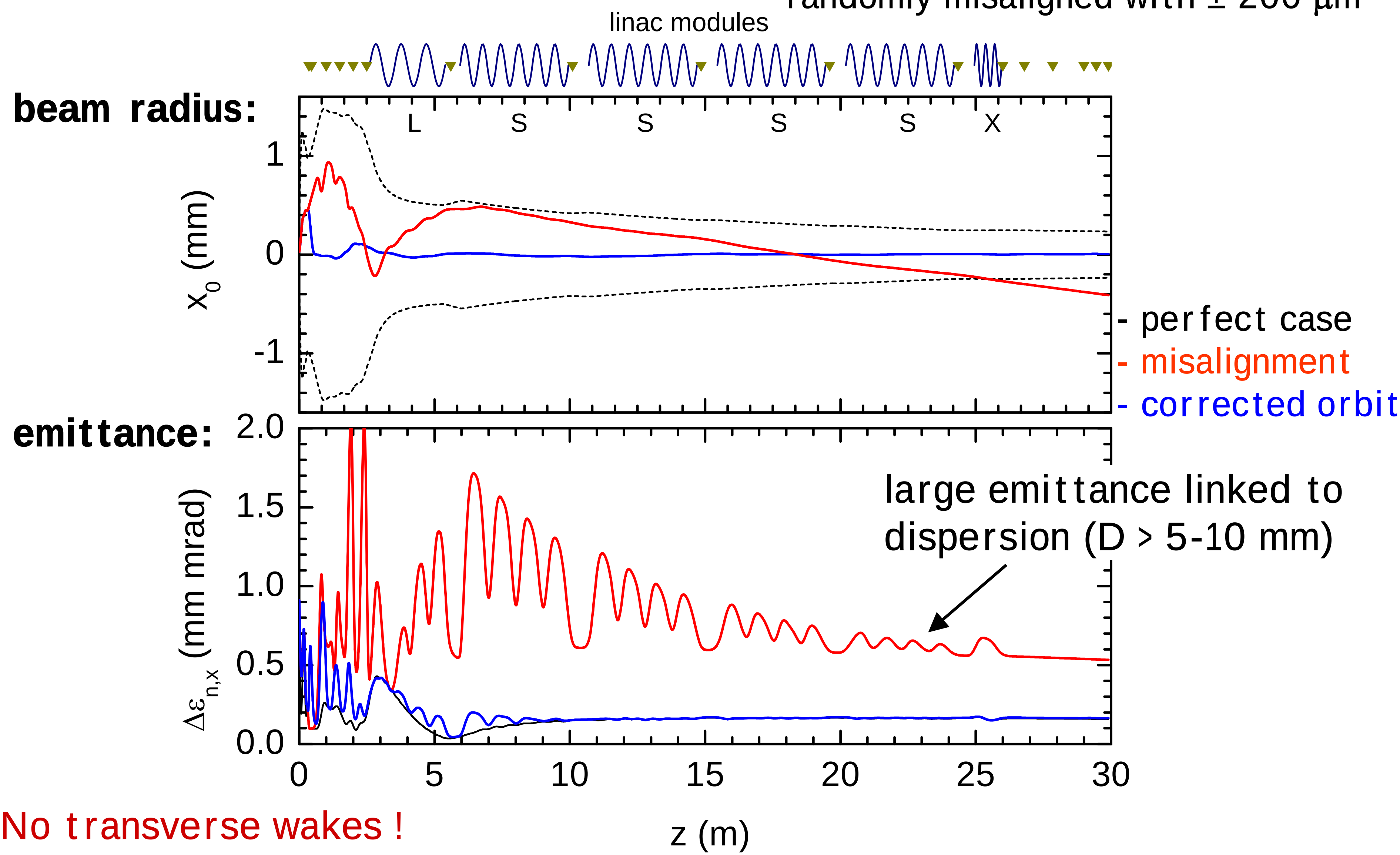
Example: Field tolerance studies



- **basic tolerance studies are done, but need to be verified**
- **pulser, first solenoid, and fundamental of 2-f cavity are most critical components (tolerances below $5 \cdot 10^{-3}$)**
- **other tolerances more relaxed**

Simulations of the 250 MeV injector

Example: Misalignment studies all solenoids and accelerator structures randomly misaligned with ± 200 μm



No transverse wakes !

Summary and outlook

Proof of critical technology for PSI-XFEL

- development and experimental verification ongoing

250 MeV injector to be built

- beam dynamics simulations of the injector are well advanced
- different codes are used: envelope tracker (HOMDYN, BET), particle codes (IMPACT-T, MAFIA, GPT, CAPONE)
- S2E simulation results show feasibility of the concept (bunch compression, emittance preservation)
- basic tolerance studies are done
- alignment requirements seem not to be too tight

→ build the thing and test the concept experimentally