sFLASH

PRESENT STATUS AND COMMISSIONING RESULTS

2nd International Particle Accelerator Conference

San Sebastian

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on behalf of the sFLASH group

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Hamburg University

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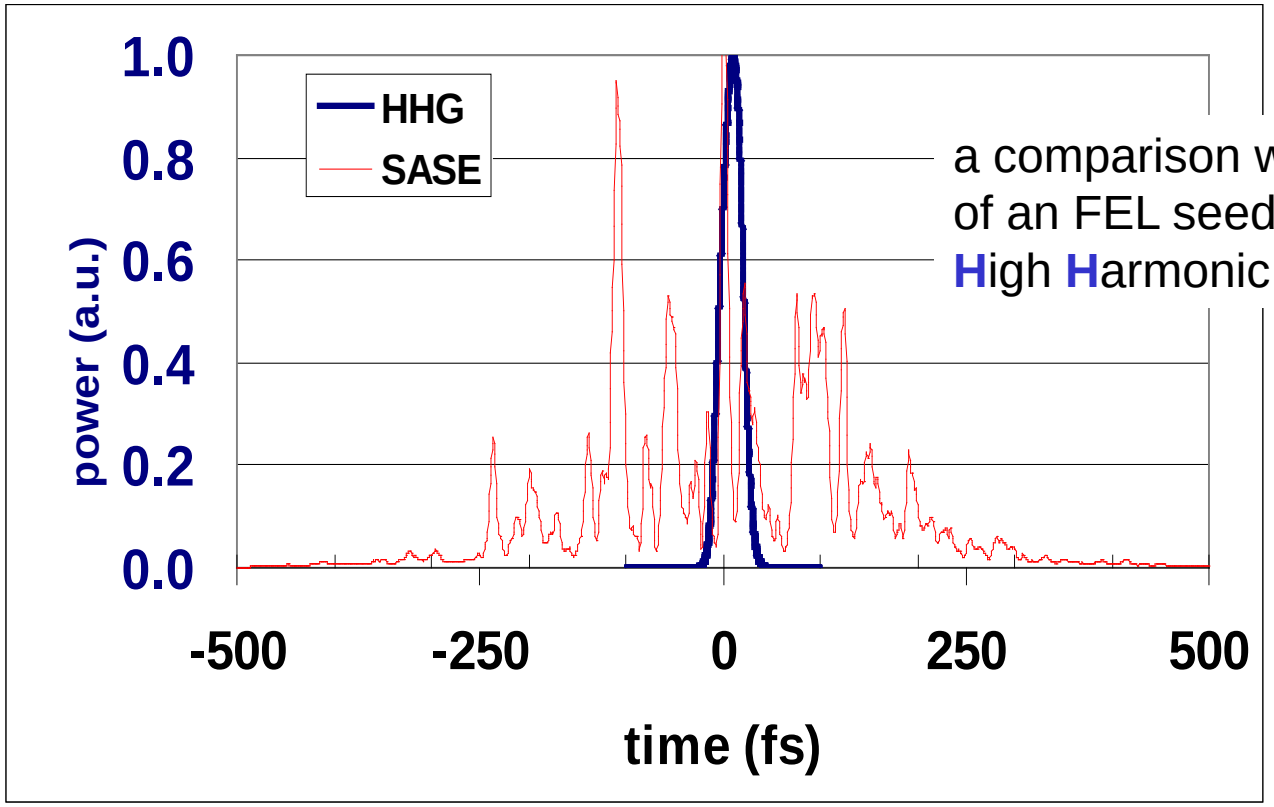
•DFG GrK 1355
•Joachim Herz Stiftung

Outline

1. Motivation and introduction to sFLASH-layout
2. Commissioning results
   - linac set up
   - transverse, longitudinal and frequency overlap
   - SASE performance
   - HHG-source performance
3. Summary and outlook

Motivation



a comparison with the output
of an FEL seeded using
High **H**armonic **G**eneration (**HHG**)

goals:

⇒ high shot-to-shot stability and high peak power (GW level)

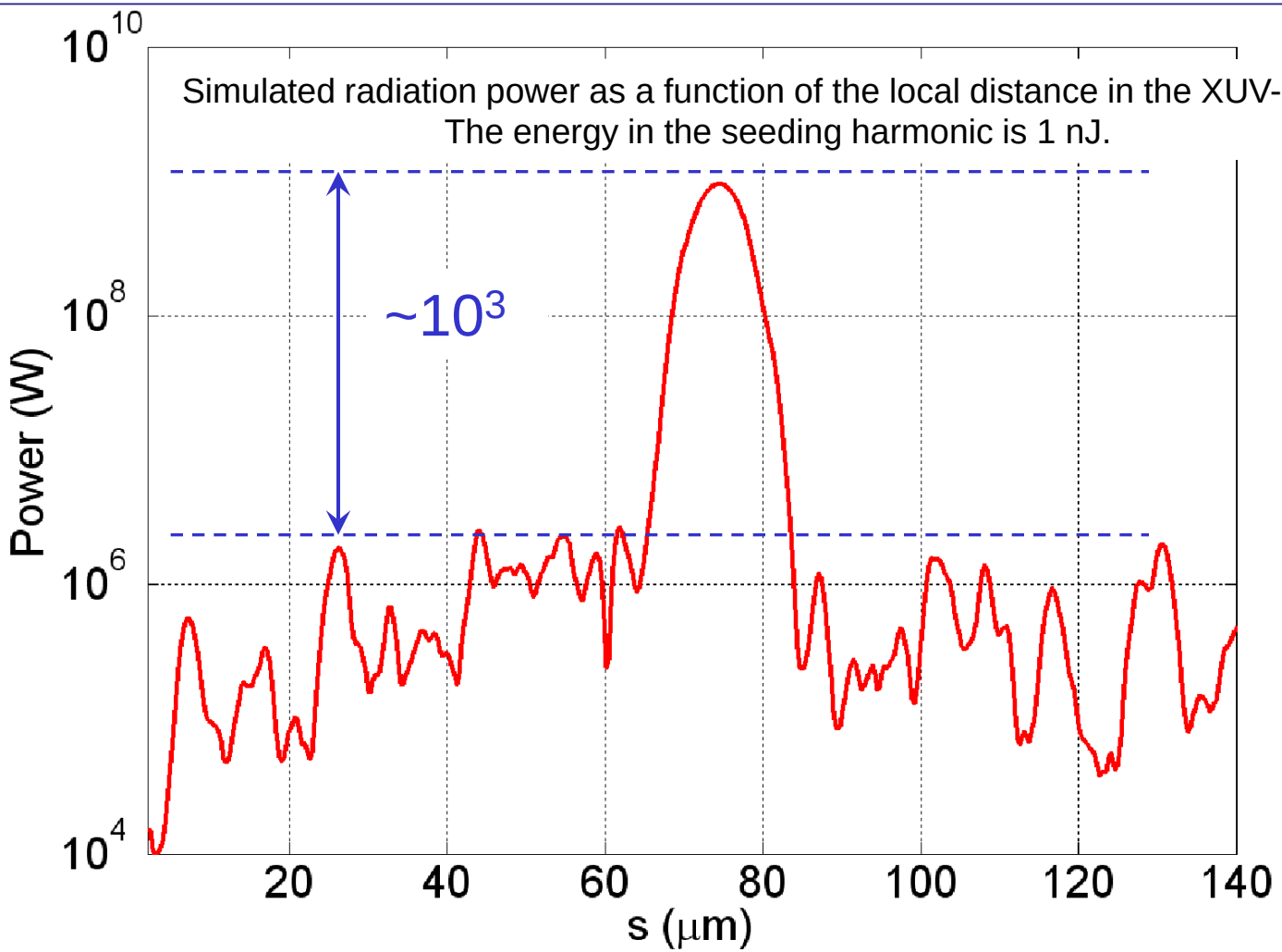
⇒ generation of fully coherent pulses

⇒ wavelength range < 40 nm

⇒ reduction of saturation length

⇒ Temporal stability for pump probe experiments on *fs* scale

Motivation



- The power contrast $P_{seeded}/P_{SASE} \sim 10^3$.
- The energy contrast $E_{seeded}/E_{SASE} \sim 10^2$

General requirements

- **spatial overlap** between electron bunch and HHG pulse

$\Rightarrow \Delta x, \Delta y < 100\ \mu m,\ \Delta x', \Delta y' < 100\ \mu rad$

- **stable HHG parameters** (pulse energy, chirp, frequency …)
- sub-100 fs **temporal overlap** between electron bunch and laser pulse
- **wavelength overlap** $\Delta\lambda/\lambda \leq$ 2e-3 @ 38 nm

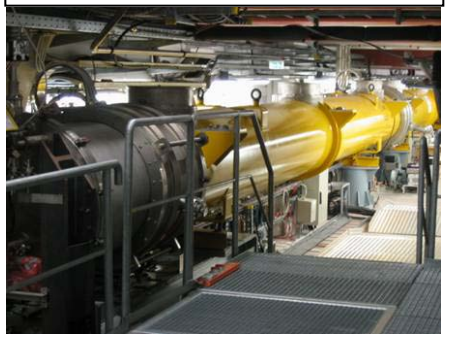
Requred electron bunch parameters

- Normalized transverse emittance < 3 μm,
- Peak current > 1kA
- Energy chirp < 0.1MeV/μm, slice energy spread σ_E/E< 2e-3
- Nominal conditions: I≈1.5 kA, E≈700 MeV

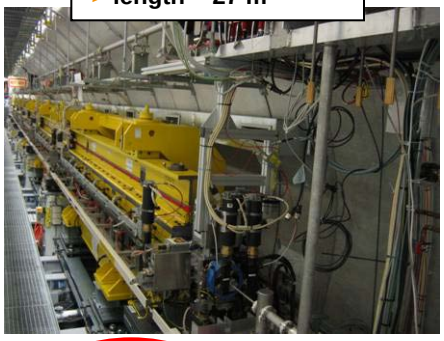
FLASH layout

> 3rd harmonic cavity 3.9 GHz

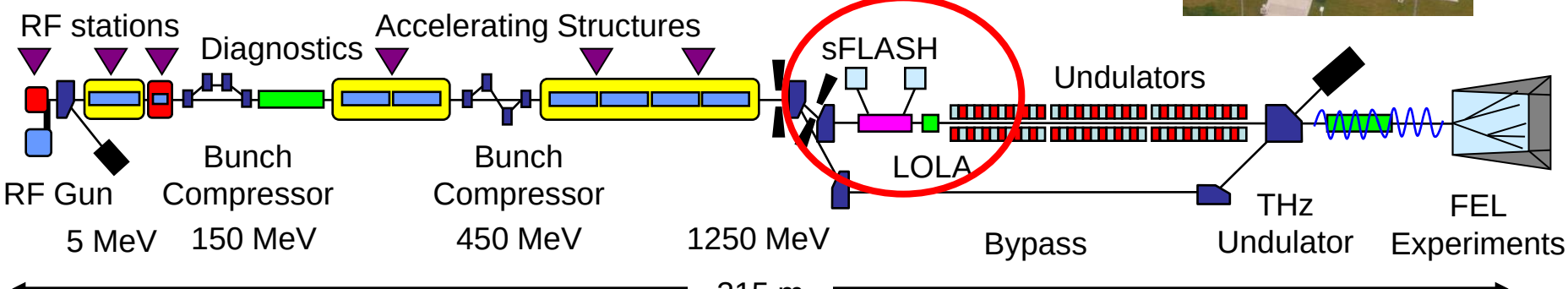
> TESLA type superconducting accelerating modules



> Fixed gap undulator
> length ~ 27 m



> FEL Experimental Hall



> Normal conducting 1.3 GHz RF gun
> Ce_2Te cathode
> Nd:YLF based ps photocathode laser

> Diagnostics and matching

> sFLASH undulators

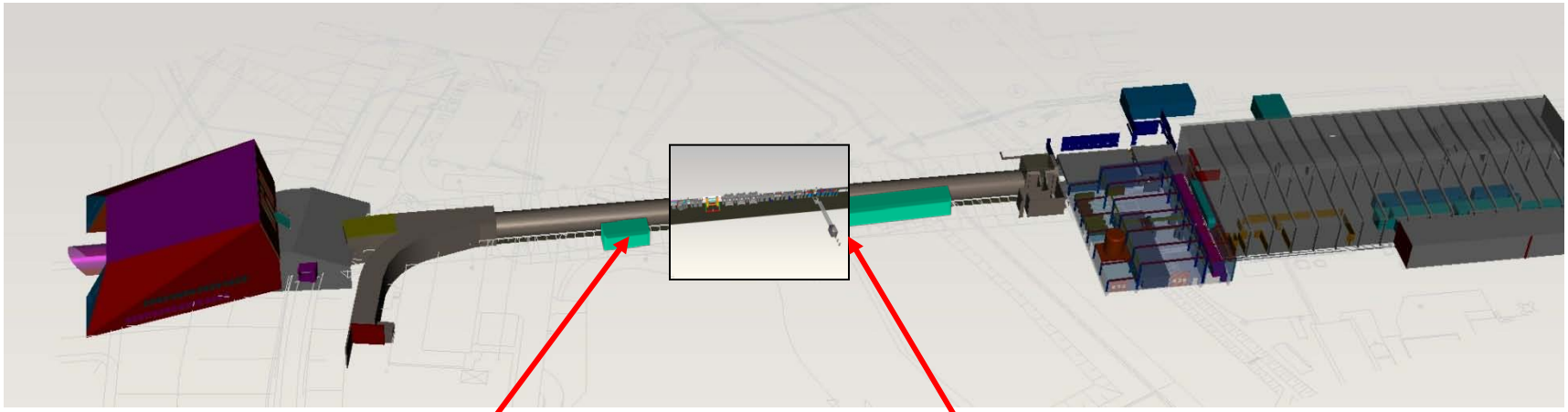
> FEL Experimental Hall

sFLASH building blocks

hutch for first experiments with sFLASH pulses

Ti:Sa laser system and HHG source

sFLASH building blocks



hutch for first experiments with sFLASH pulses

Ti:Sa laser system and HHG source

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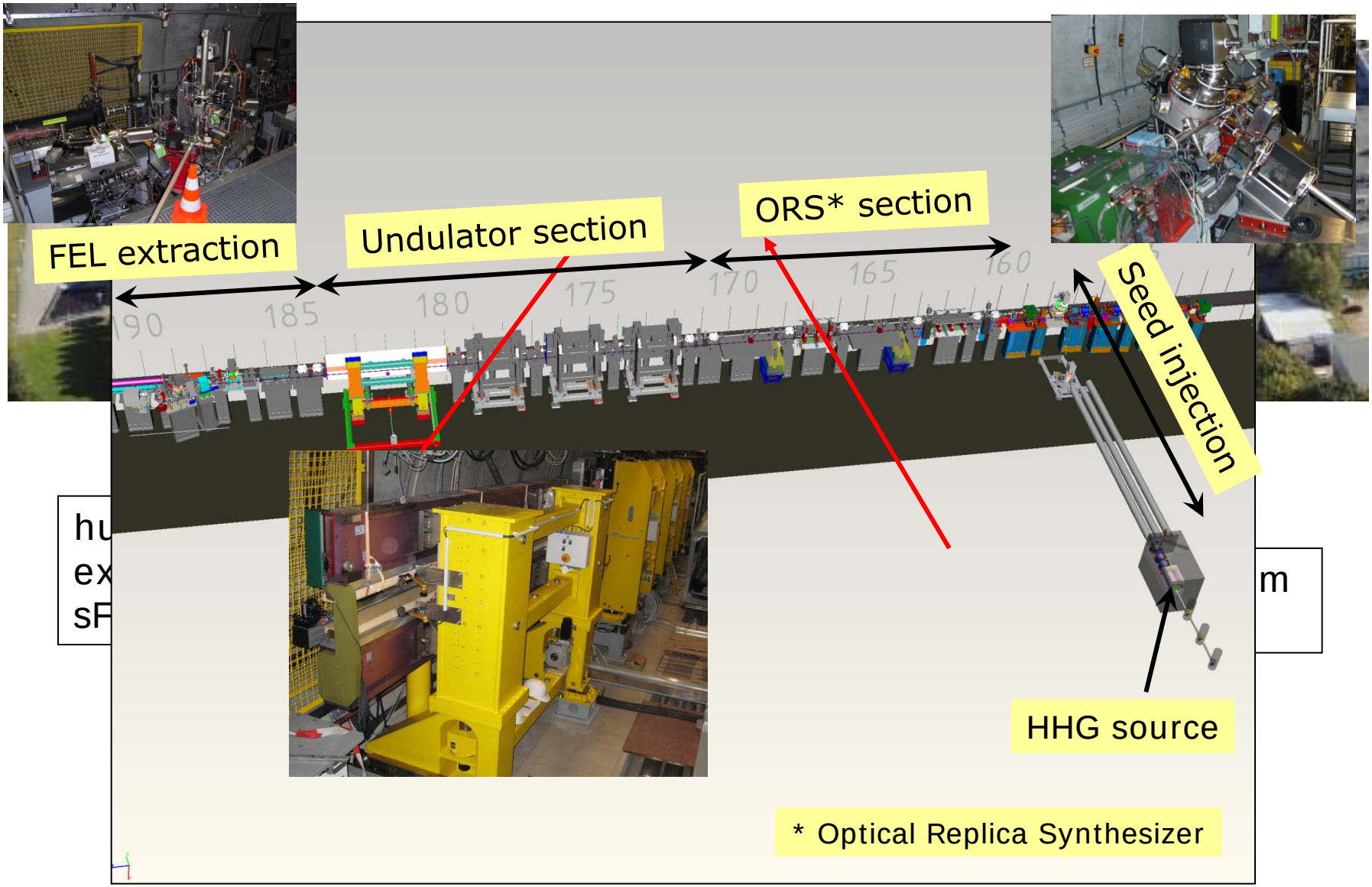
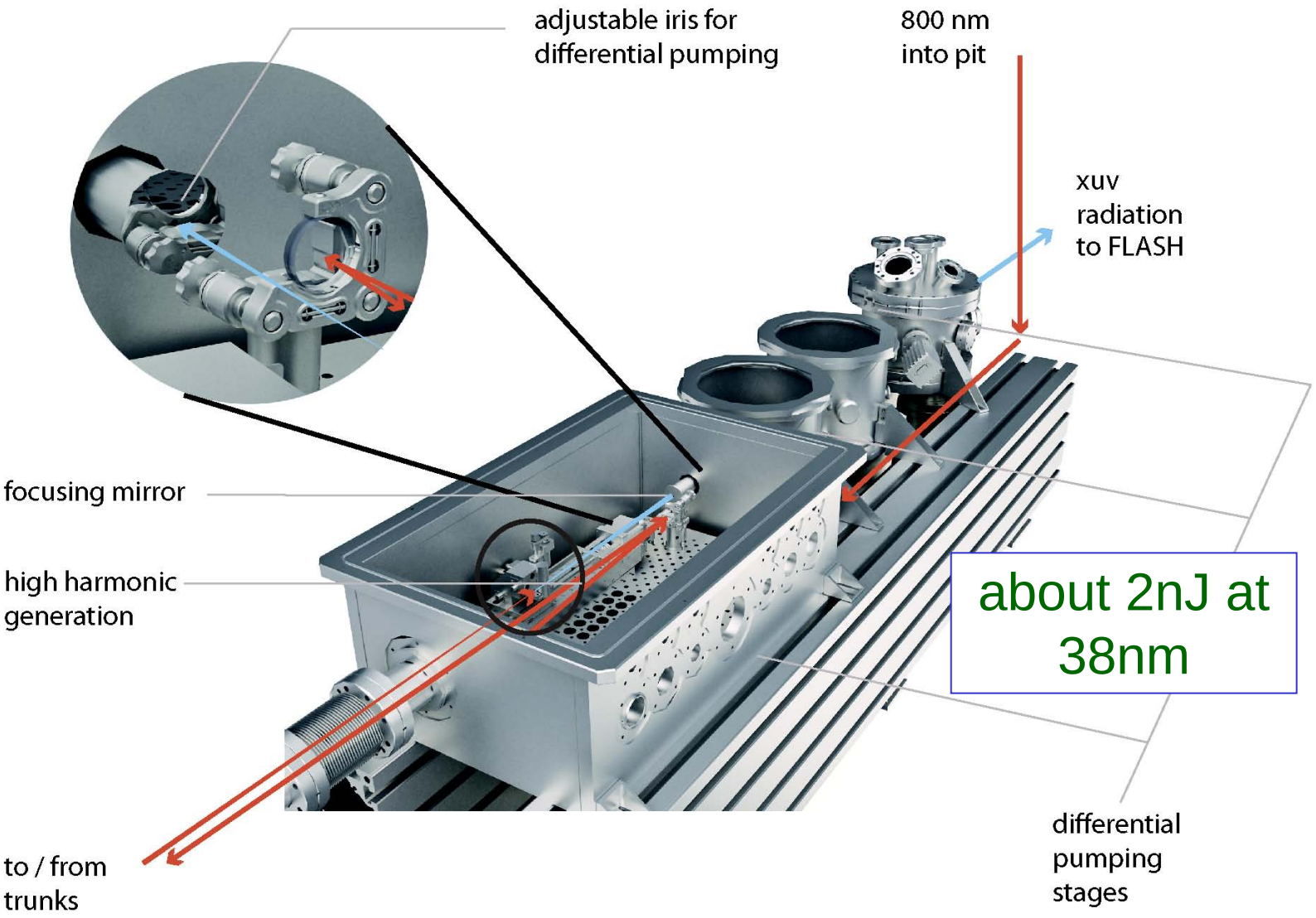
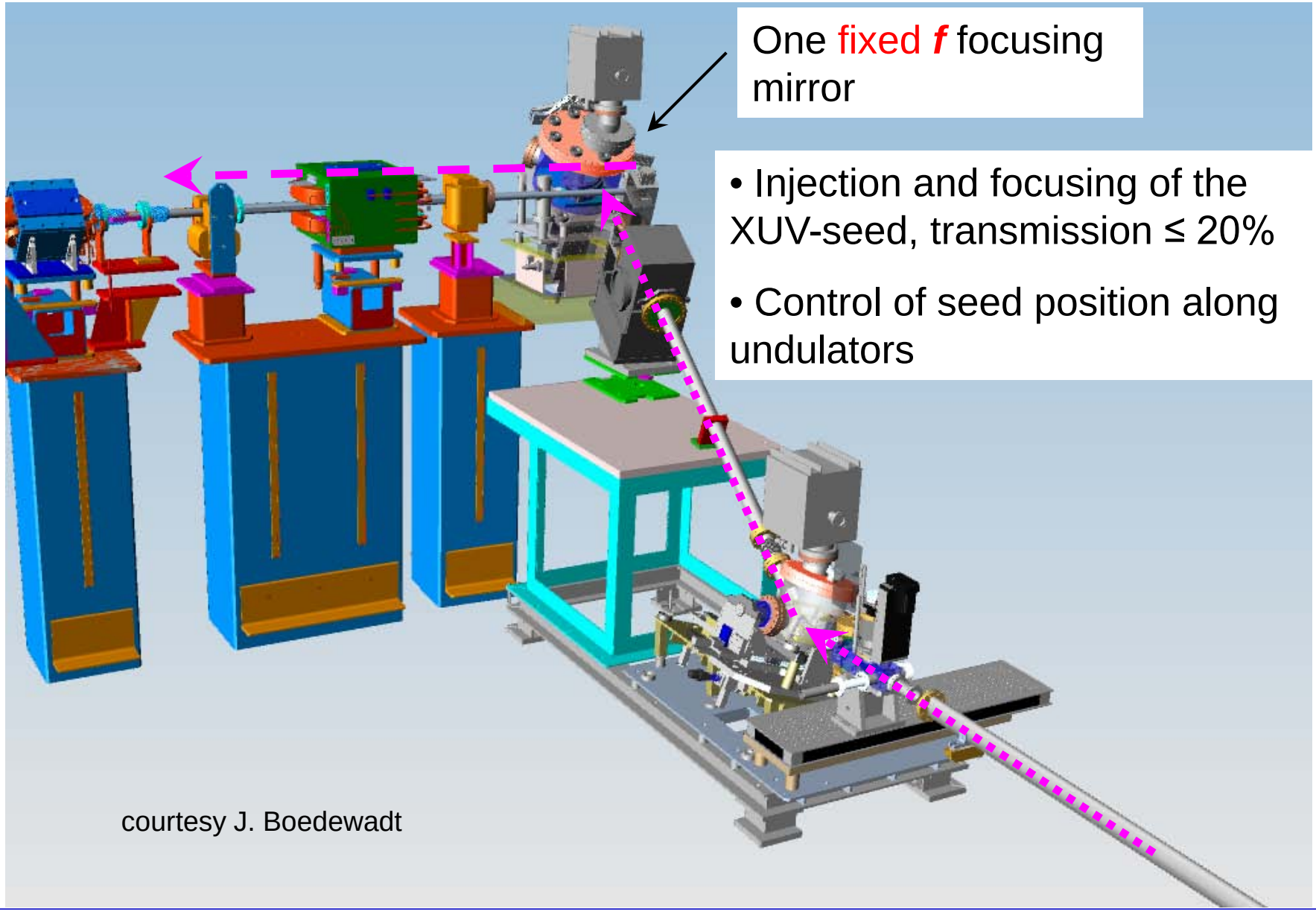


HHG source schematic

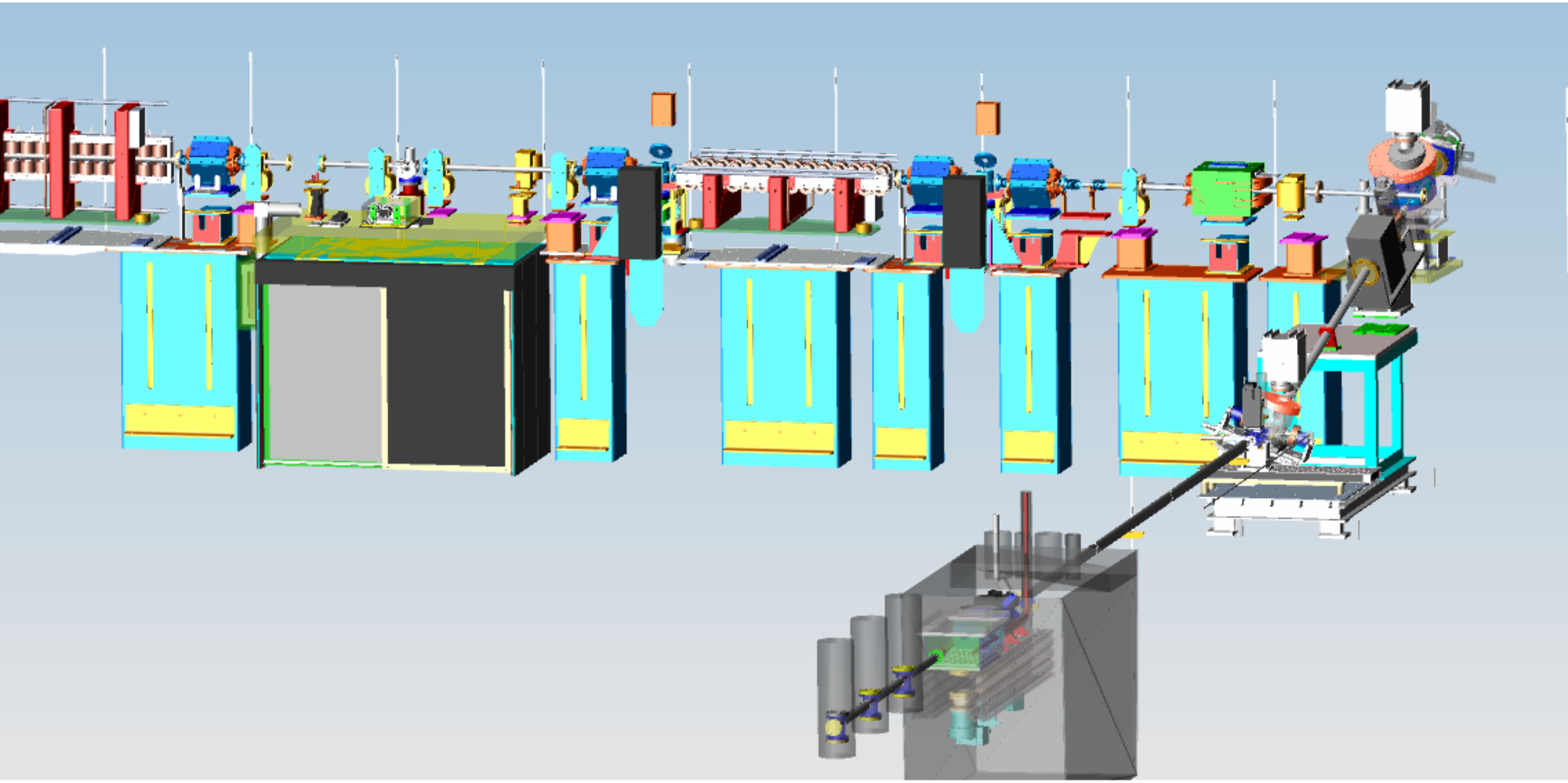
courtesy M. Mittenzwey



HHG injection beamline

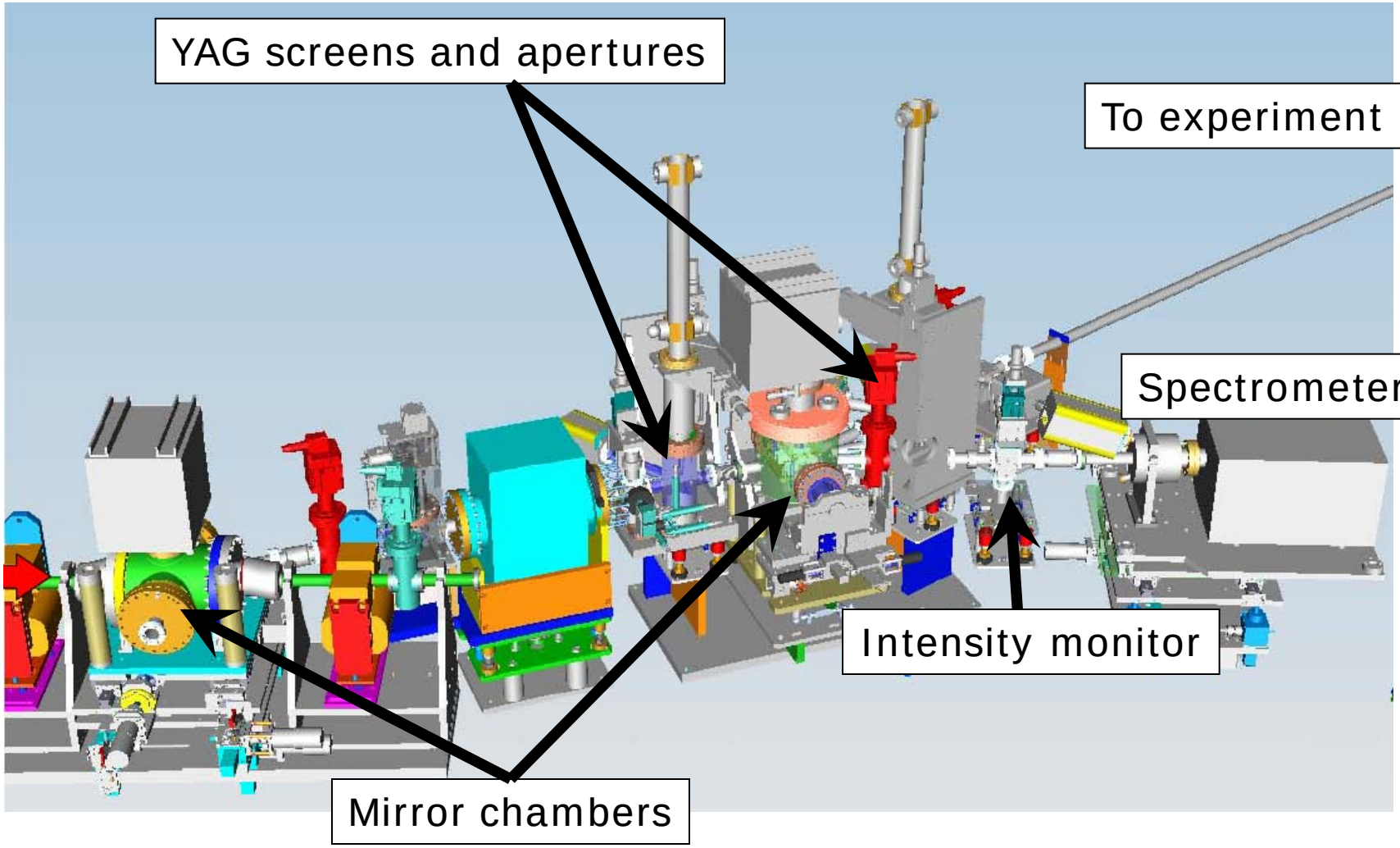


HHG injection beamline

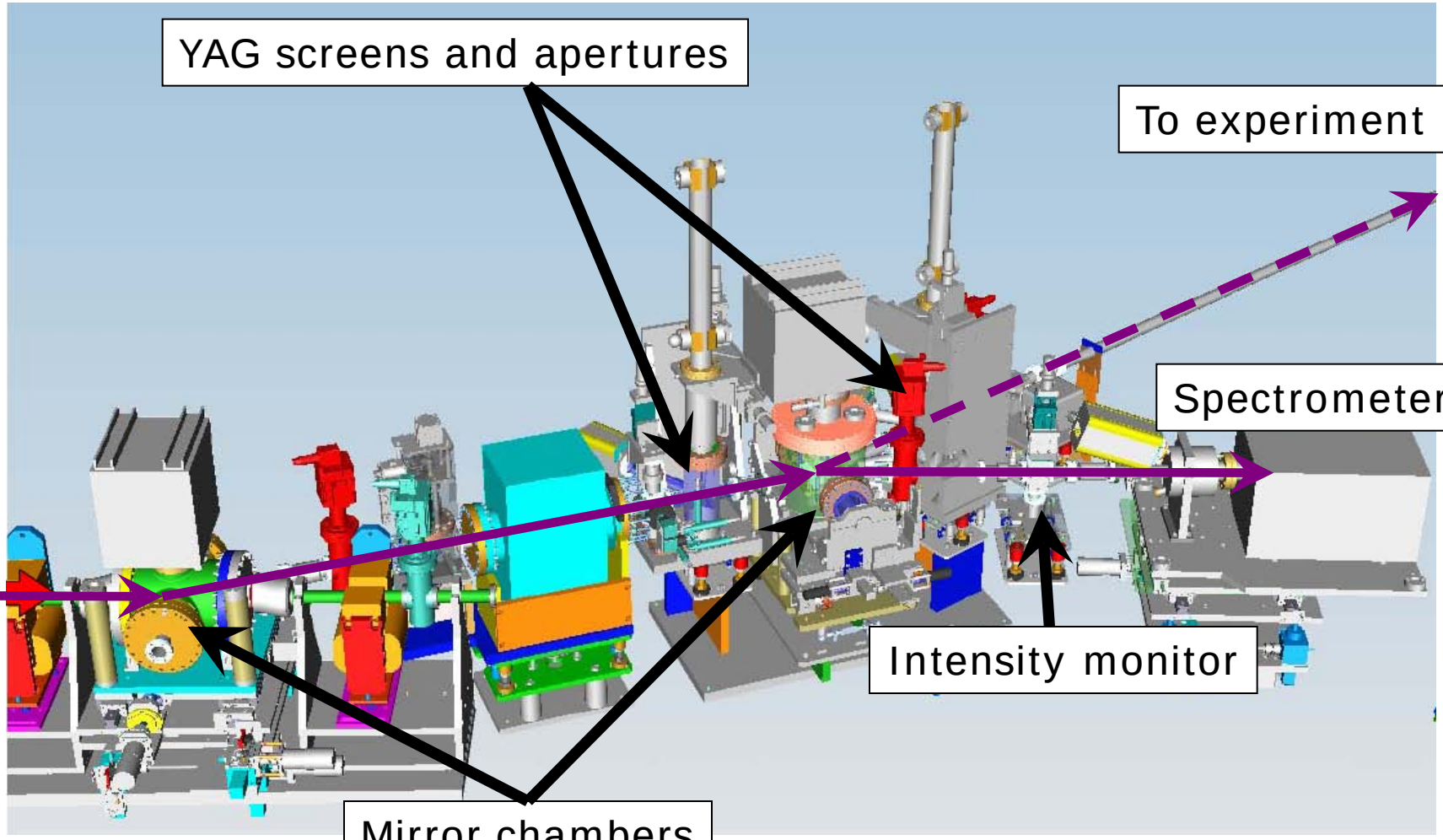


courtesy J. Boedewadt

Layout of the sFLASH photon beamline

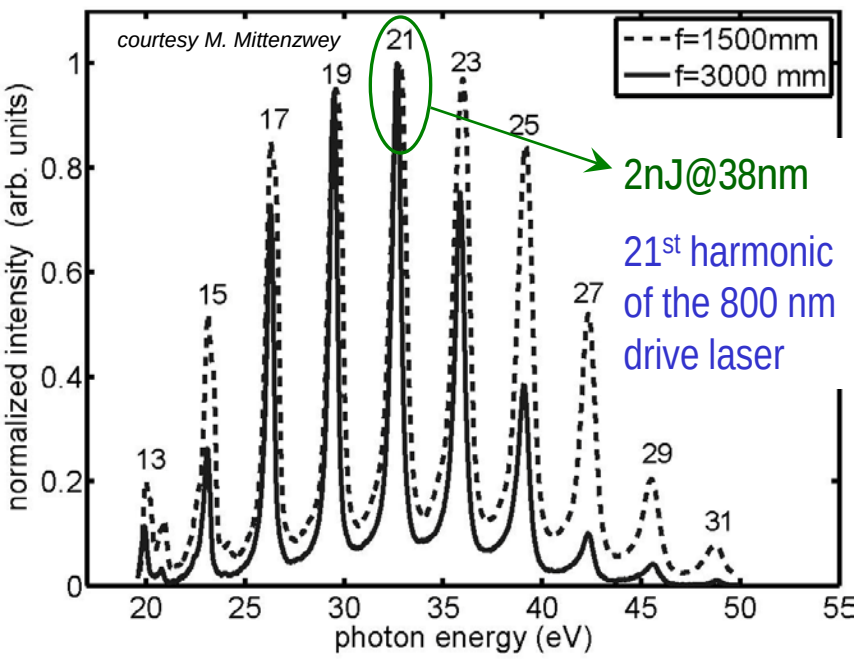


Layout of the sFLASH photon beamline

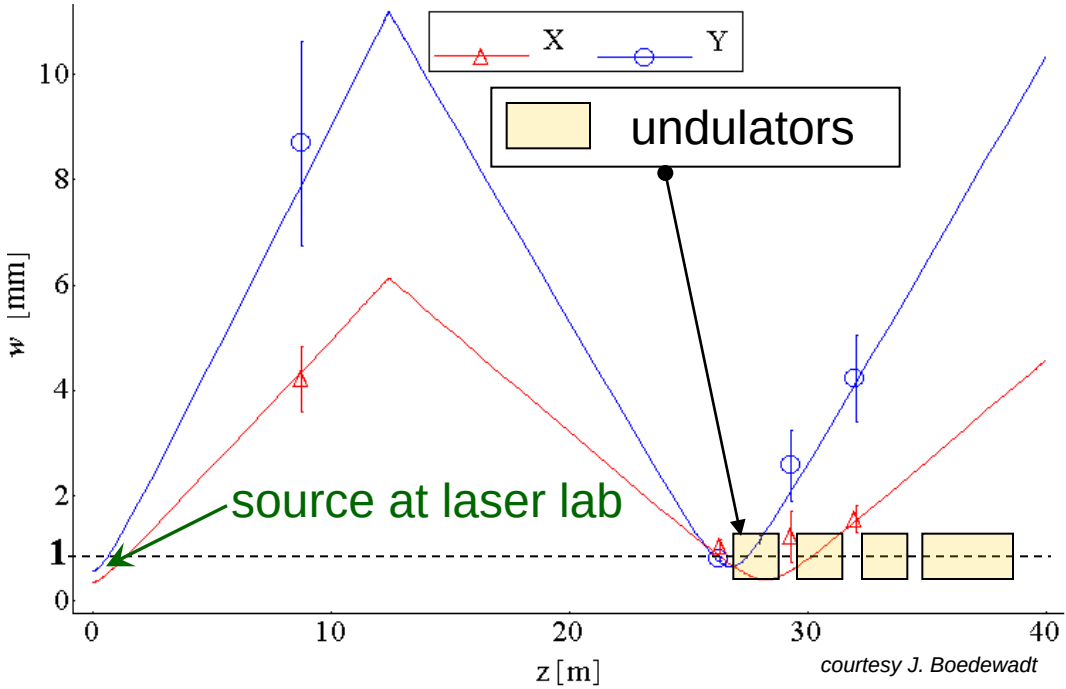


HHG seed characterization

HHG-spectrum measured in the laser lab



Seed size along the injection beamline and undulators

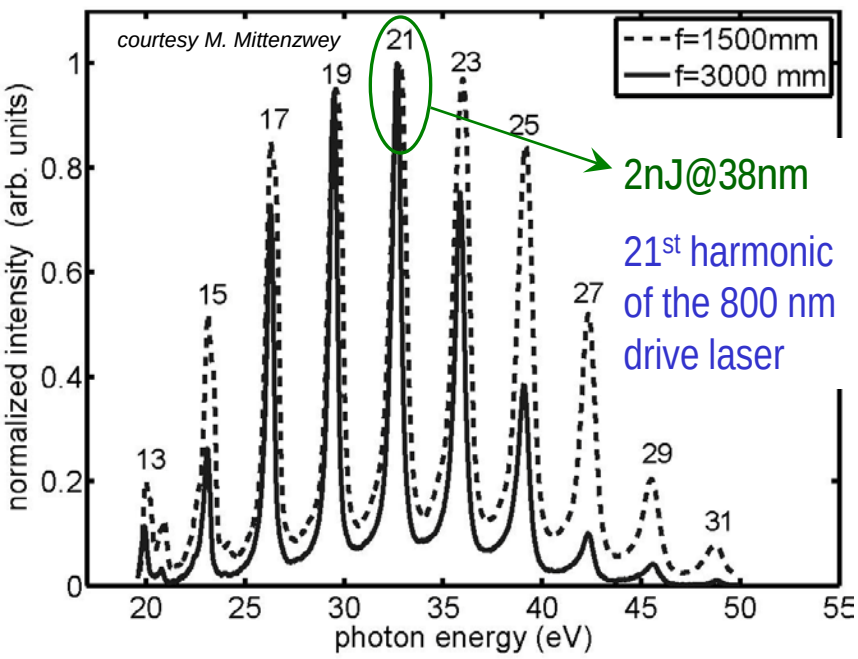


- HHG energy @ 38nm at the source ≈ **2 nJ**
- Full HHG energy at the undulator ≈ **0.4 nJ** (the best case with 20% transmission)
- HHG energy coupled to electron beam ≈ **0.016 nJ** (due to $\sigma_{HHG} >> \sigma_{e^- beam}$)
- Effective seed power ≈ **800 W**. Shot noise power ~ 1**00 W**
- **Photon diagnostics integrates over radiation pulse→**

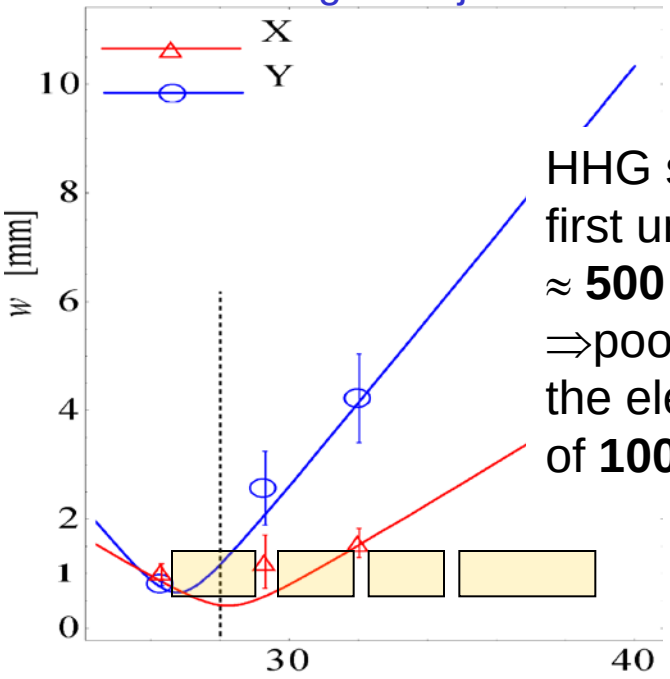
Energy contrast ~1 ⇒ difficult to demonstrate seeding

HHG seed characterization

HHG-spectrum measured in the laser lab



Seed size along the injection beamline and undulators



HHG size along the first undulator ≈ **500 μm** (rms), ⇒poor coupling to the electron beam of **100 μm** (rms).

courtesy J. Boedewadt

- HHG energy @ 38nm at the source ≈ **2 nJ**
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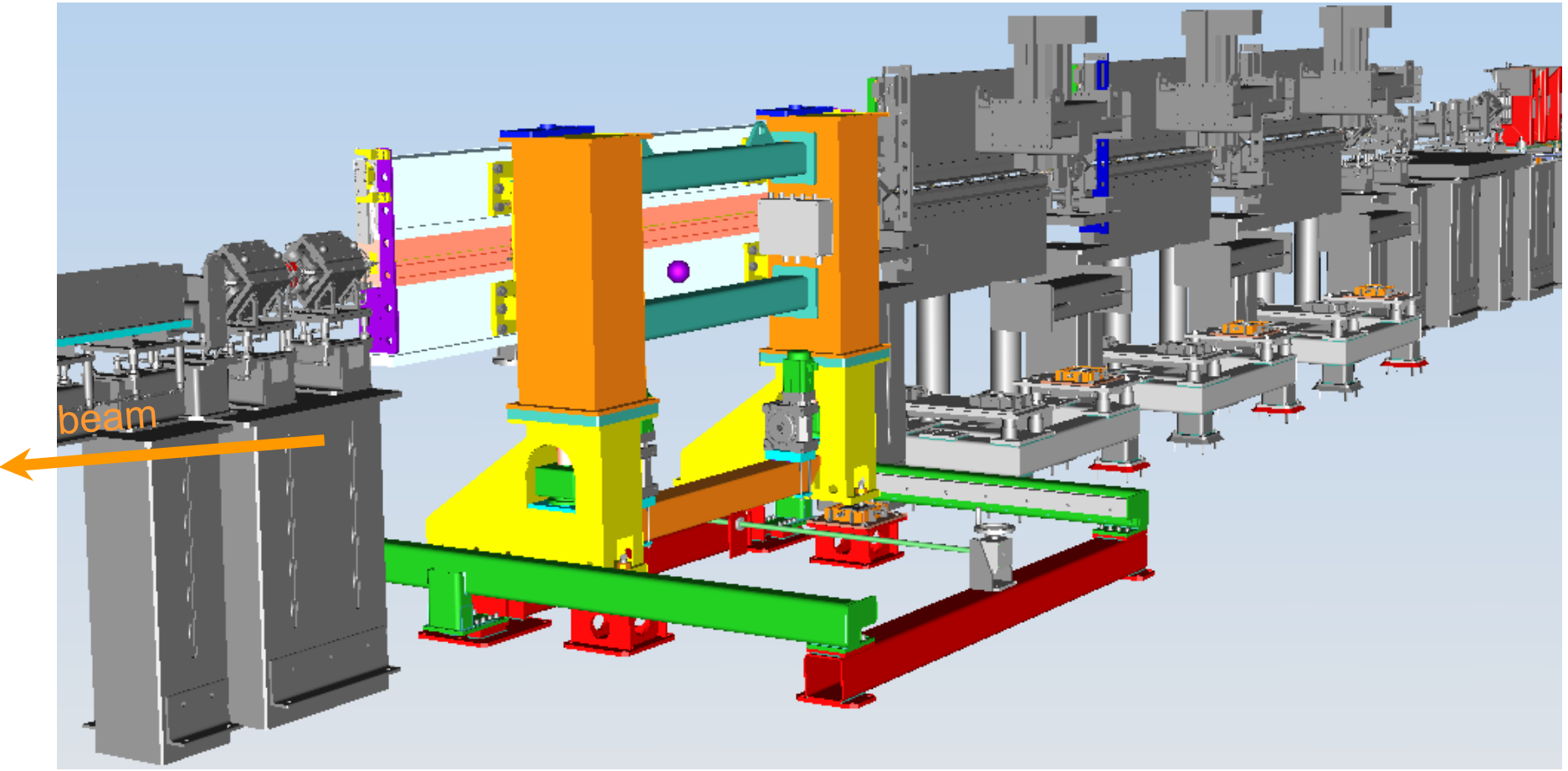
Energy contrast ~1 ⇒ difficult to demonstrate seeding

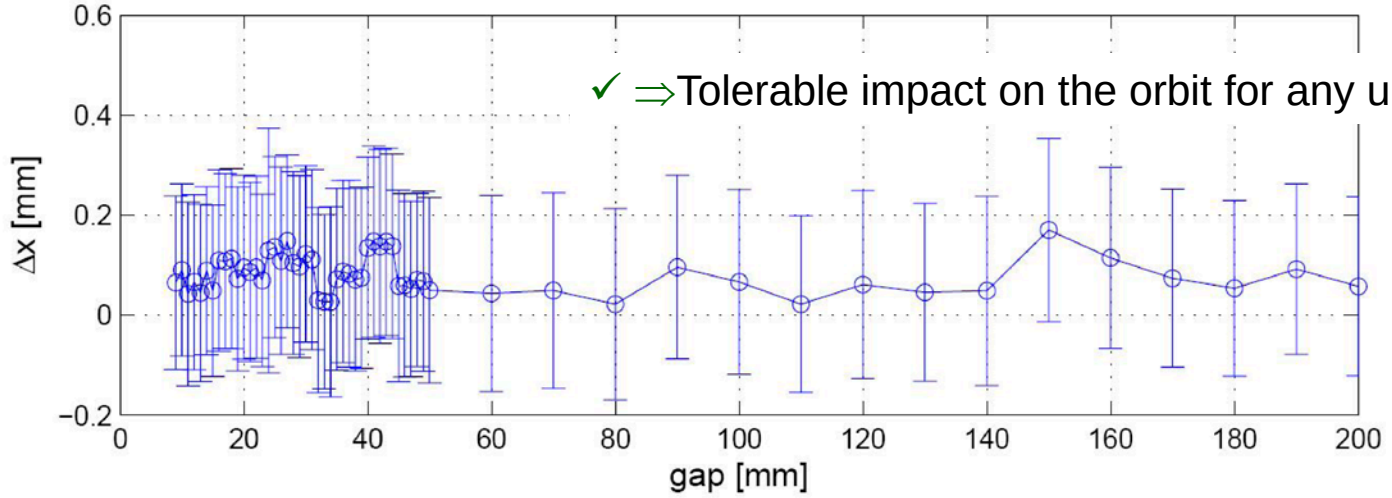
Undulator commissioning



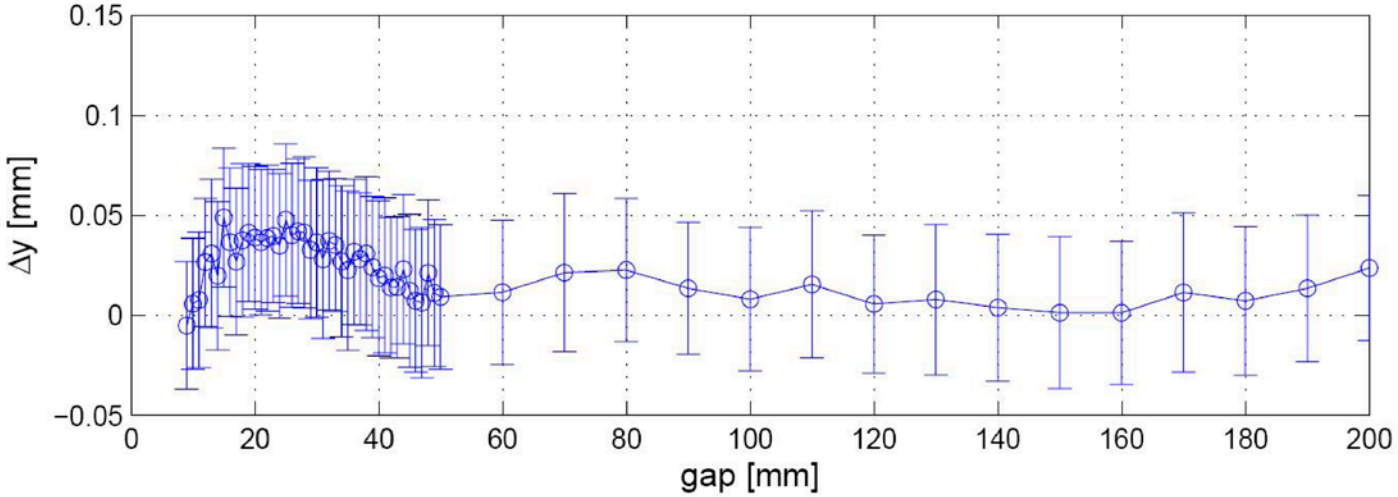
- Four planar variable-gap undulators of 10m total length with period of 31.4mm and 33mm
- Wire scanners, OTR stations, YAG screens, BPMs in undulator intersections
- Two air coils per undulator to compensate the residual field integrals
- Magnetic measurements and tuning performed at a measurement bench

Undulator commissioning

Beam position as a function of the gap of the first sFLASH-undulator



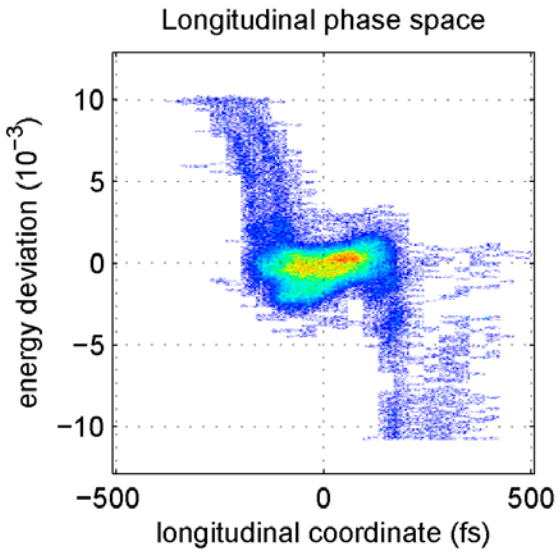
✓ ⇒Tolerable impact on the orbit for any undulator gap

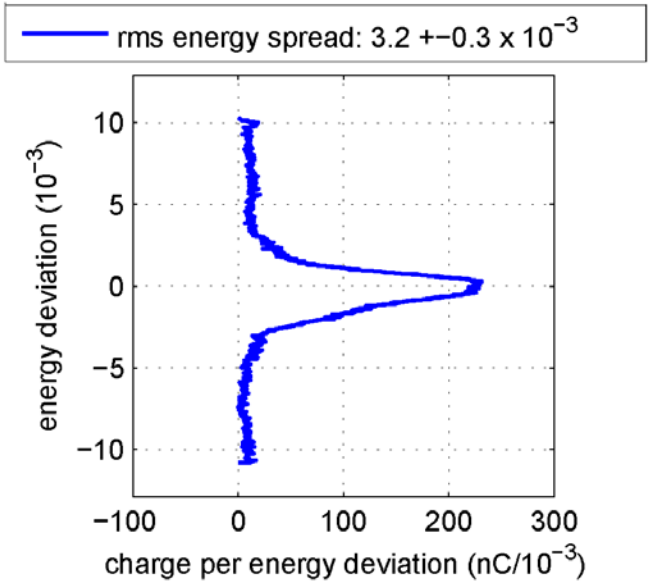


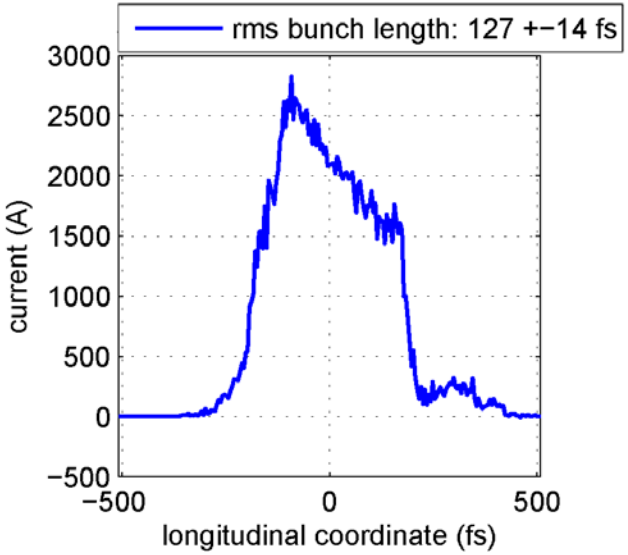
Linac set up

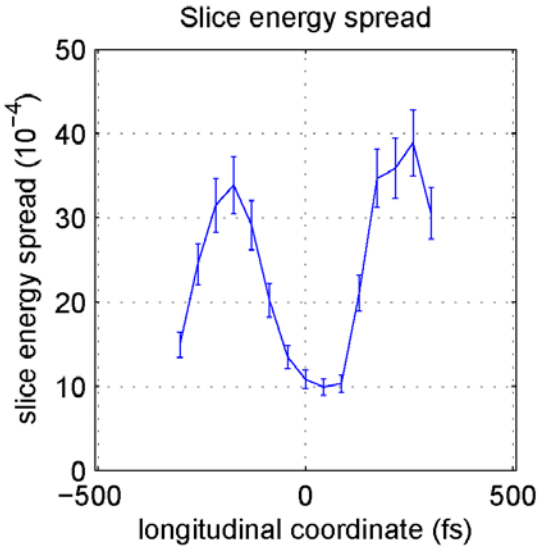
E≈700 MeV

Q≈1 nC

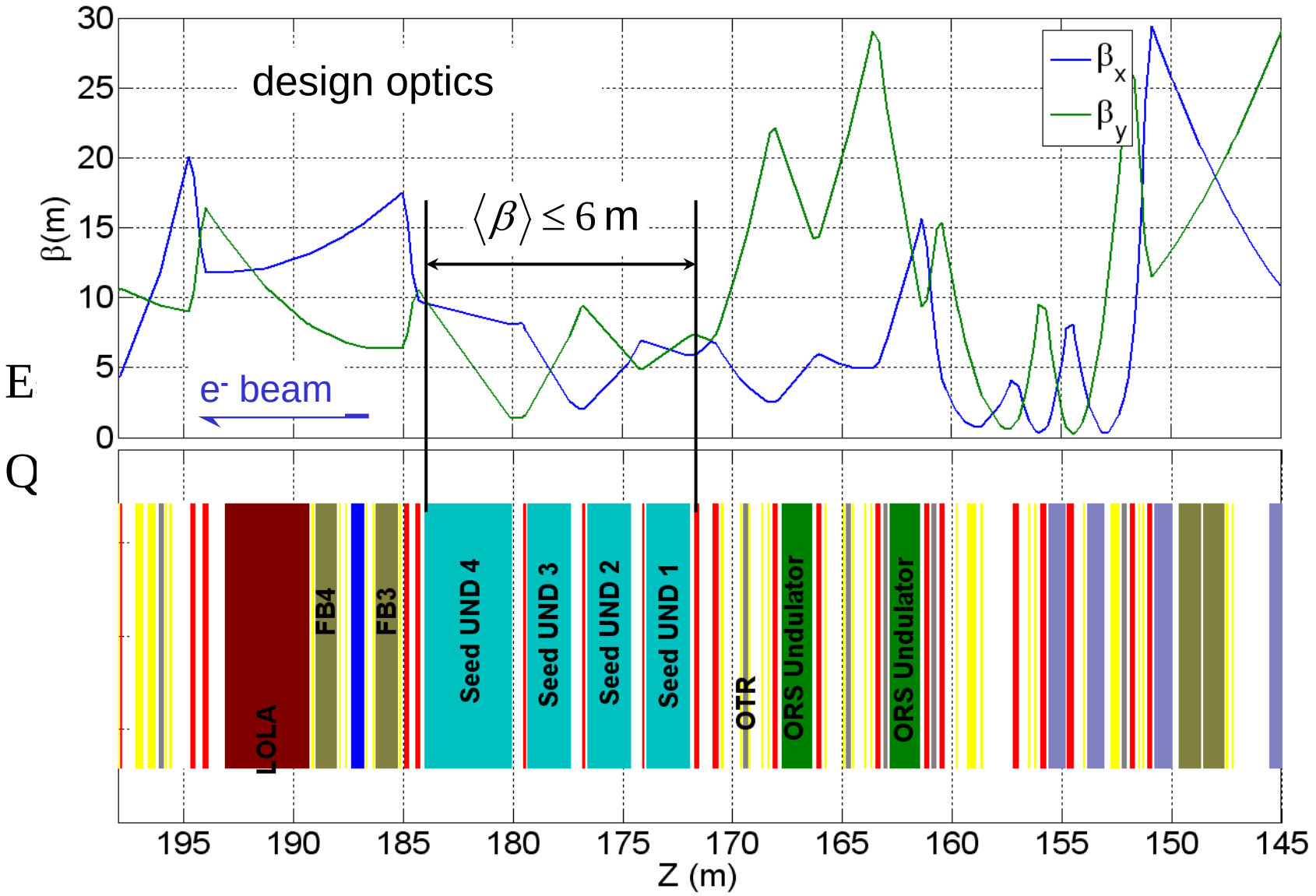




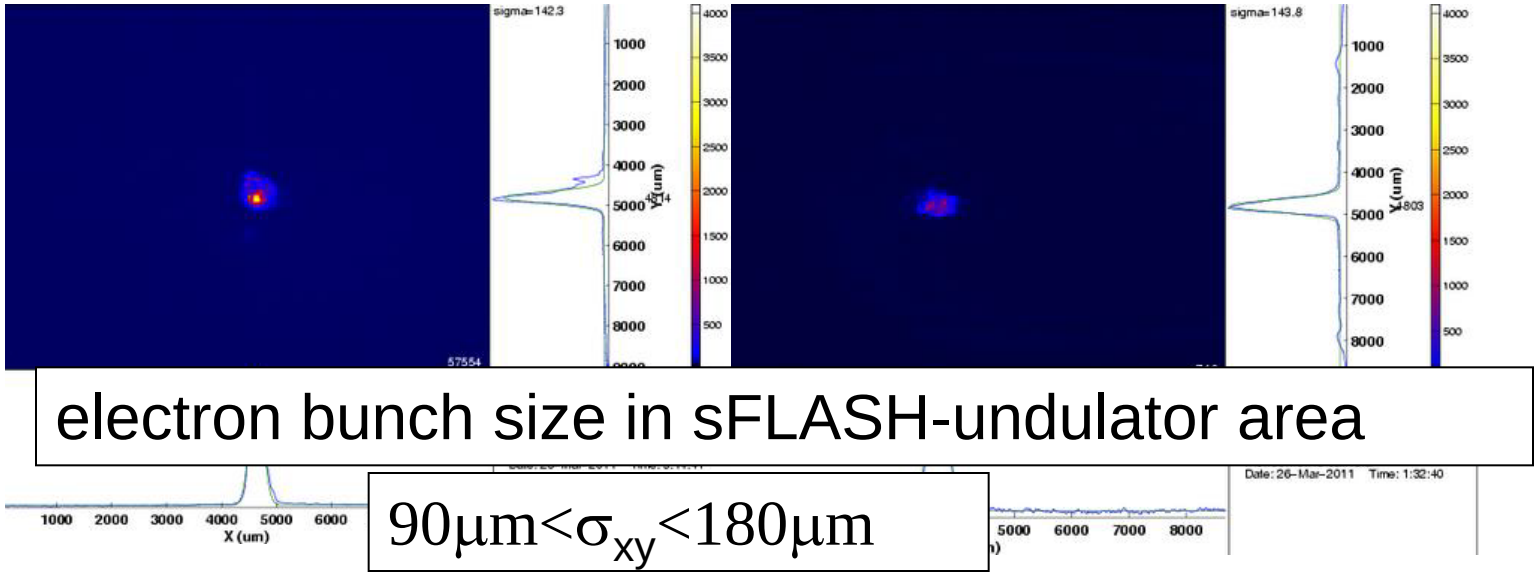




Linac set up

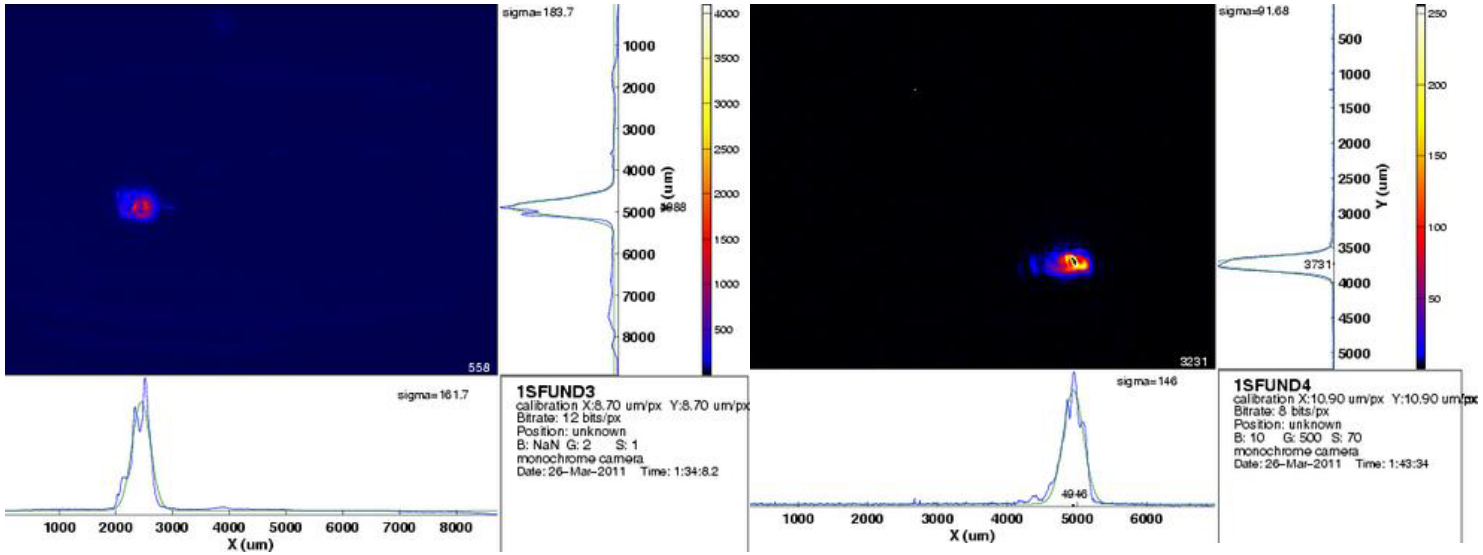

design optics
β_x
β_y
$\langle\beta\rangle \leq 6$ m
β(m)
e- beam
E
Q
LOLA
FB4
FB3
Seed UND 4
Seed UND 3
Seed UND 2
Seed UND 1
OTR
ORS Undulator
ORS Undulator
Z (m)

Linac set up

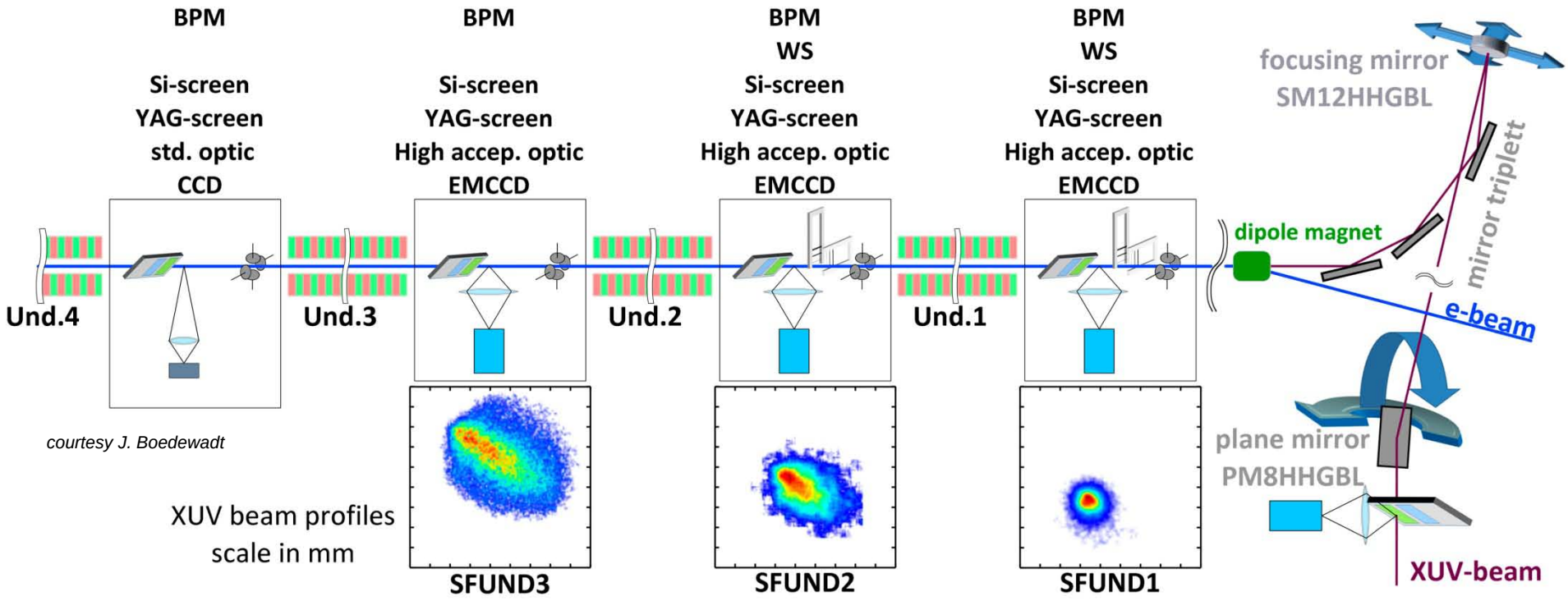


electron bunch size in sFLASH-undulator area

$90\mu m < \sigma_{xy} < 180\mu m$



Concept for finding the transverse overlap

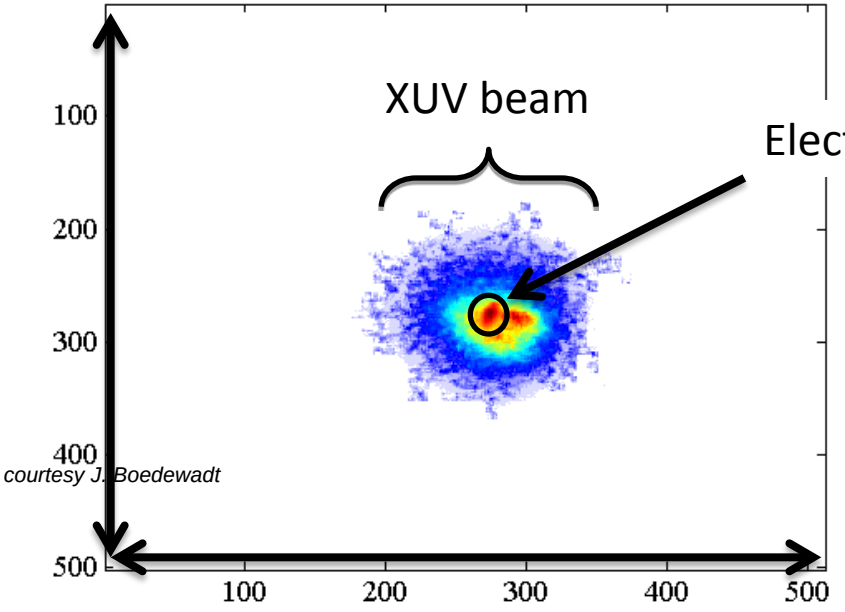


XUV beam profiles

Concept for finding the transverse overlap

Superimposed beam profiles measured on Ce:YAG screen

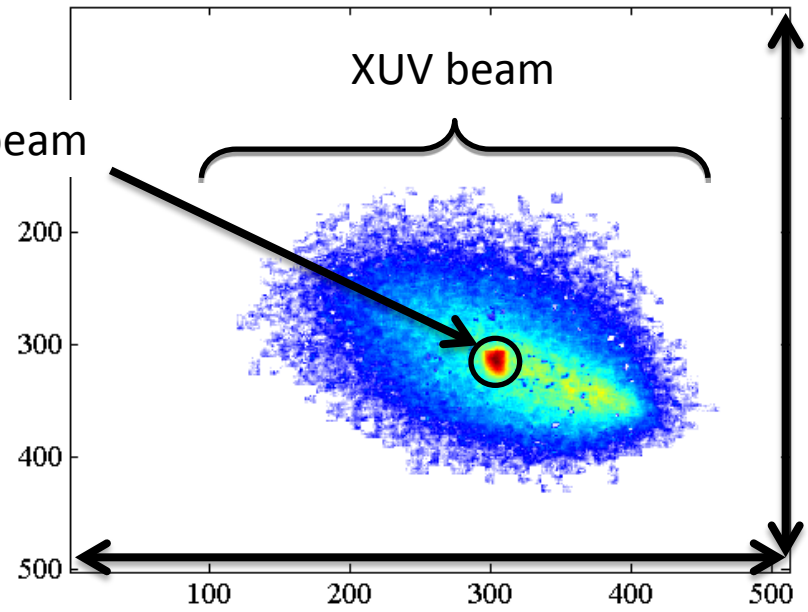
upstream Undulator 1



courtesy J. Boedewadt

Scale 9x9 mm²

downstream Undulator 1



Scale 9x9 mm²

$\Delta X, \Delta Y < 50\ \mu m$

$\theta < 50\ \mu rad,$

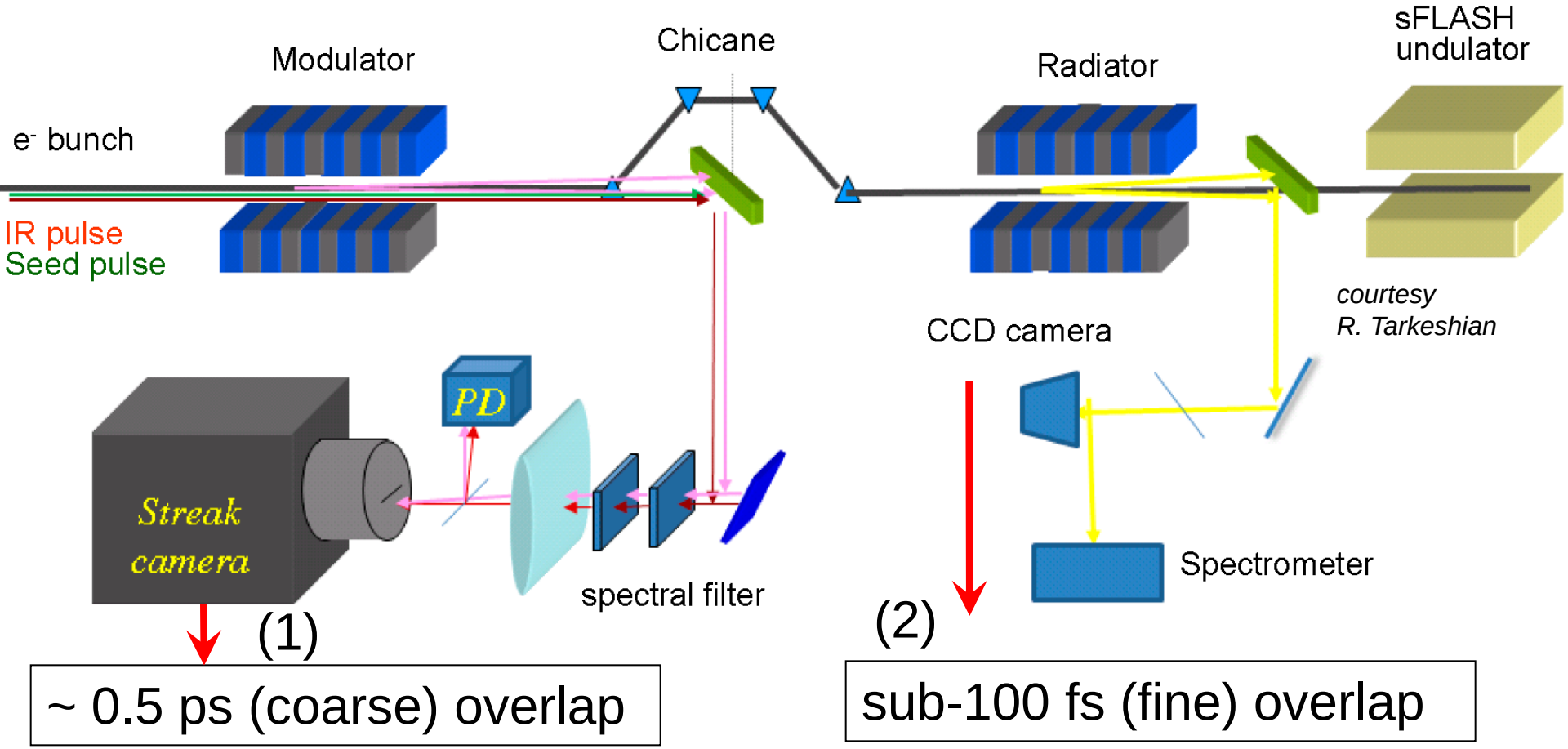
$\Rightarrow$

$$\Delta\lambda/\lambda = \gamma^2\theta^2 \Big/ \left(1+k^2\right)$$

Concept for finding the temporal overlap

1) Streak camera measurement using spontaneous undulator radiation and HHG-drive laser → 0.5 ps resolution

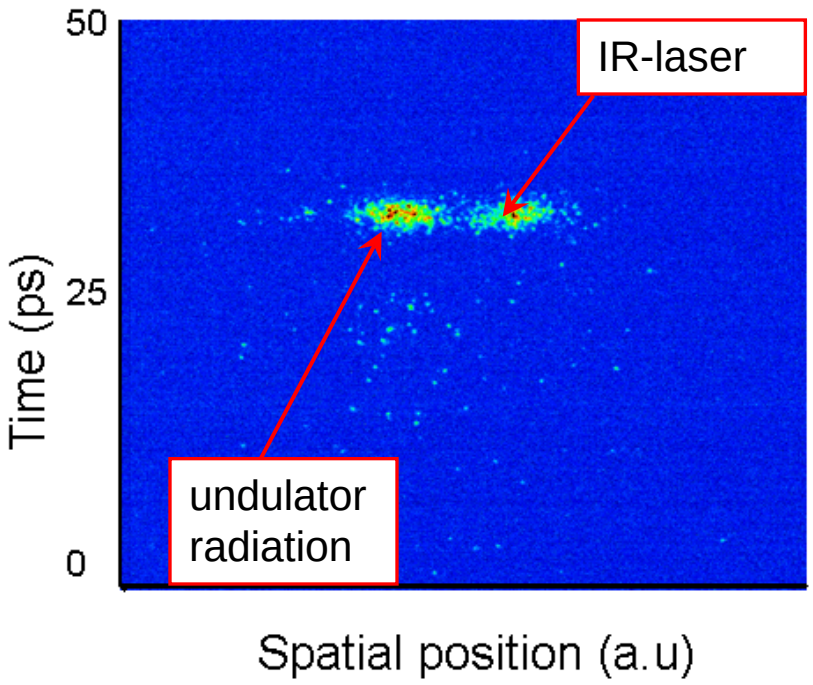
2) Modulator-radiator based system using coherent light from the radiator→<100 fs



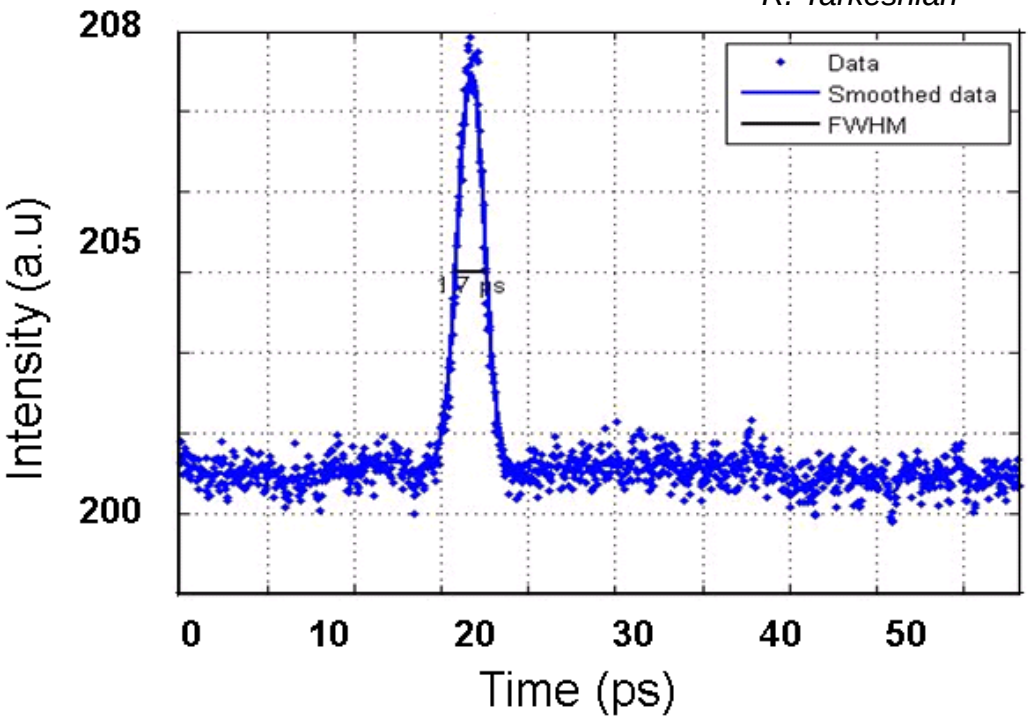
~ 0.5 ps (coarse) overlap

sub-100 fs (fine) overlap

Coarse temporal overlap

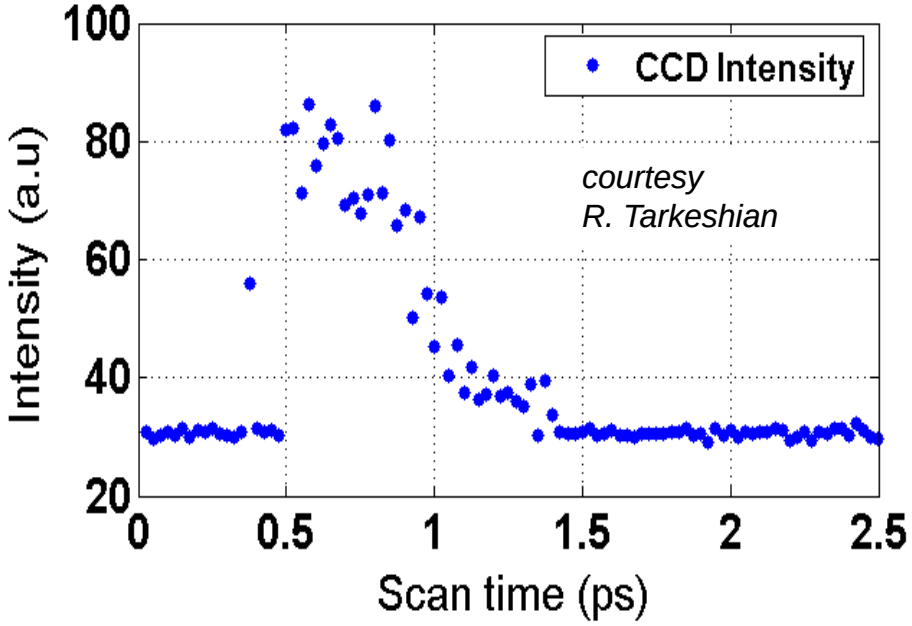


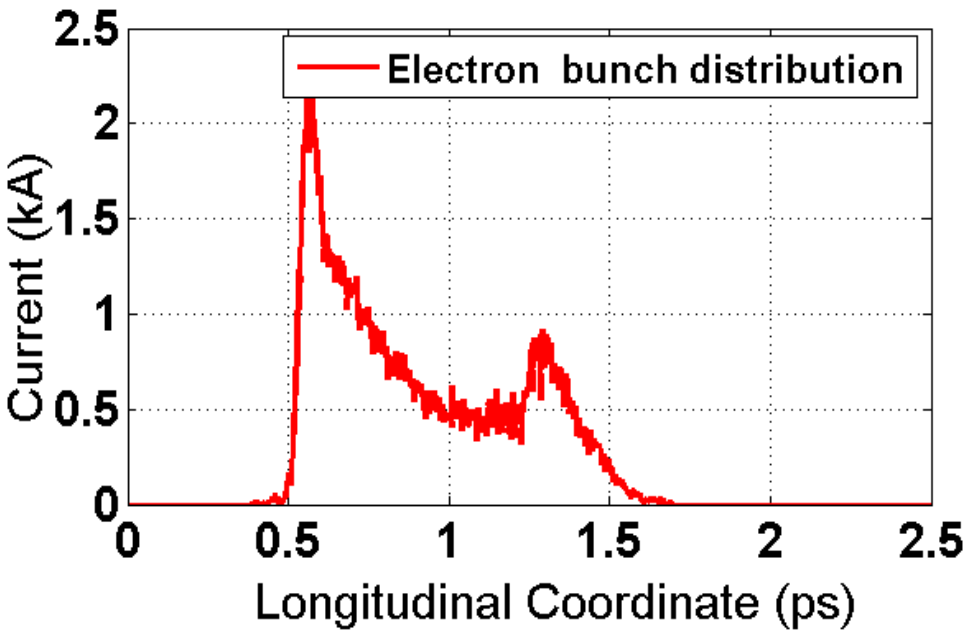
courtesy
R. Tarkeshian



Temporal overlap (~ 0. 5 ps) between the HHG drive laser pulse and spontaneous undulator radiation measured with the streak camera

Demonstration of sub-100 fs temporal overlap

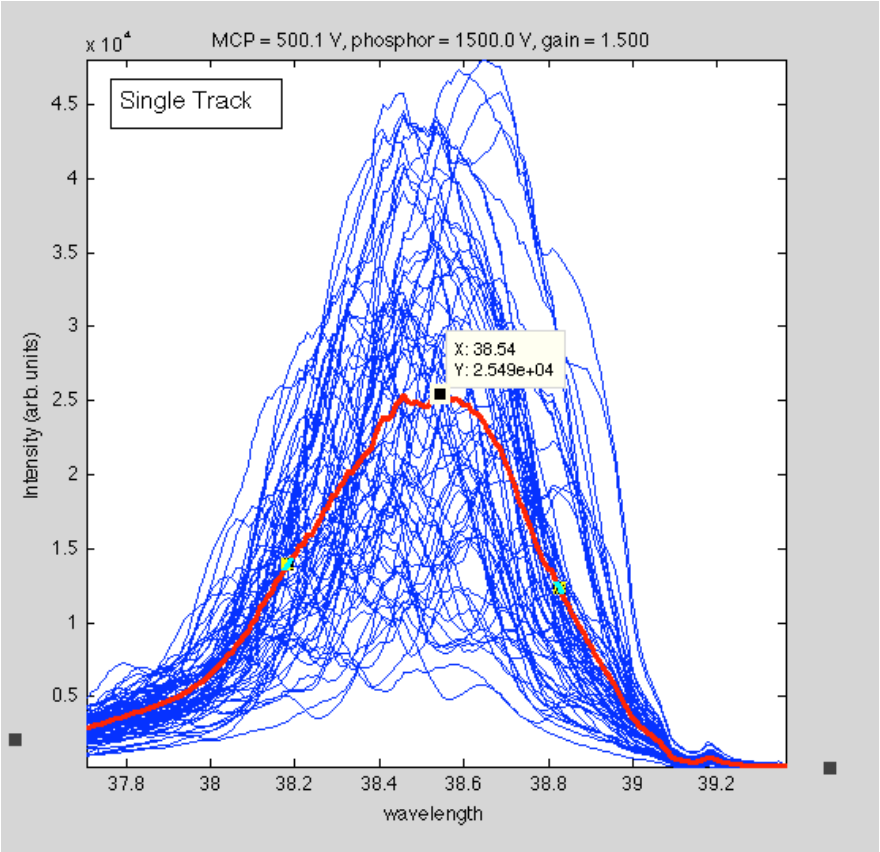


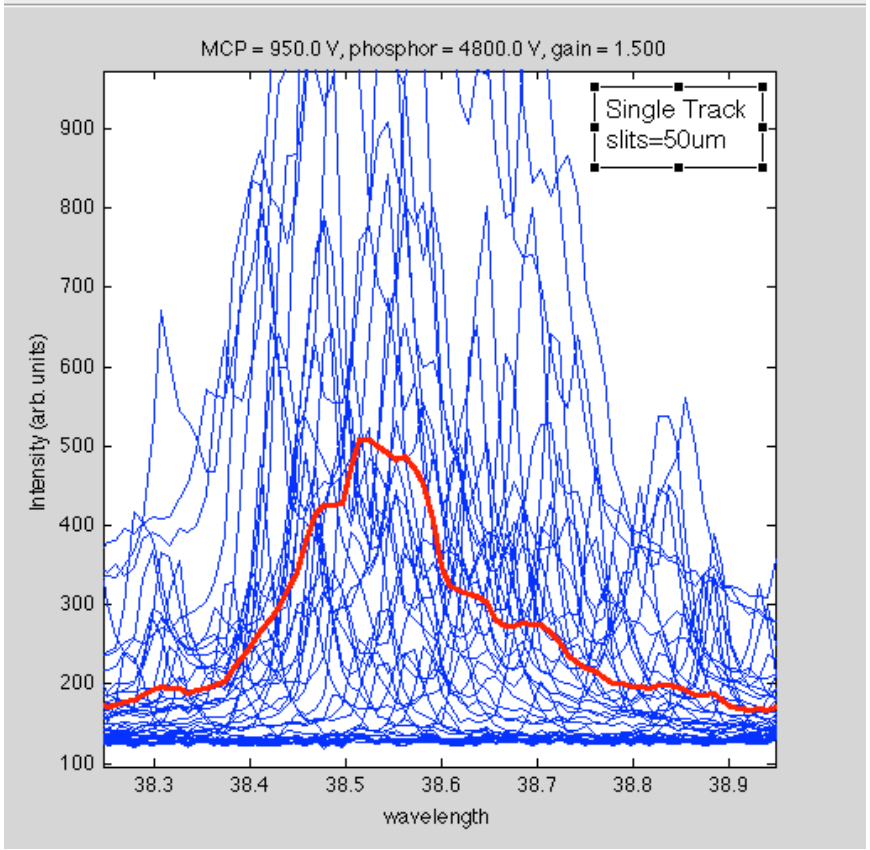


(left)-Measurement of the intensity of the emitted coherent radiation as a function of the relative delay (25 fs step) of the IR-pulse. The temporal overlap between the IR-light and the electron bunch enhances the radiation intensity.

(right)-Longitudinal charge distribution measured with transverse deflecting cavity. To be compared with the measurement in the left.

Demonstrating the frequency overlap





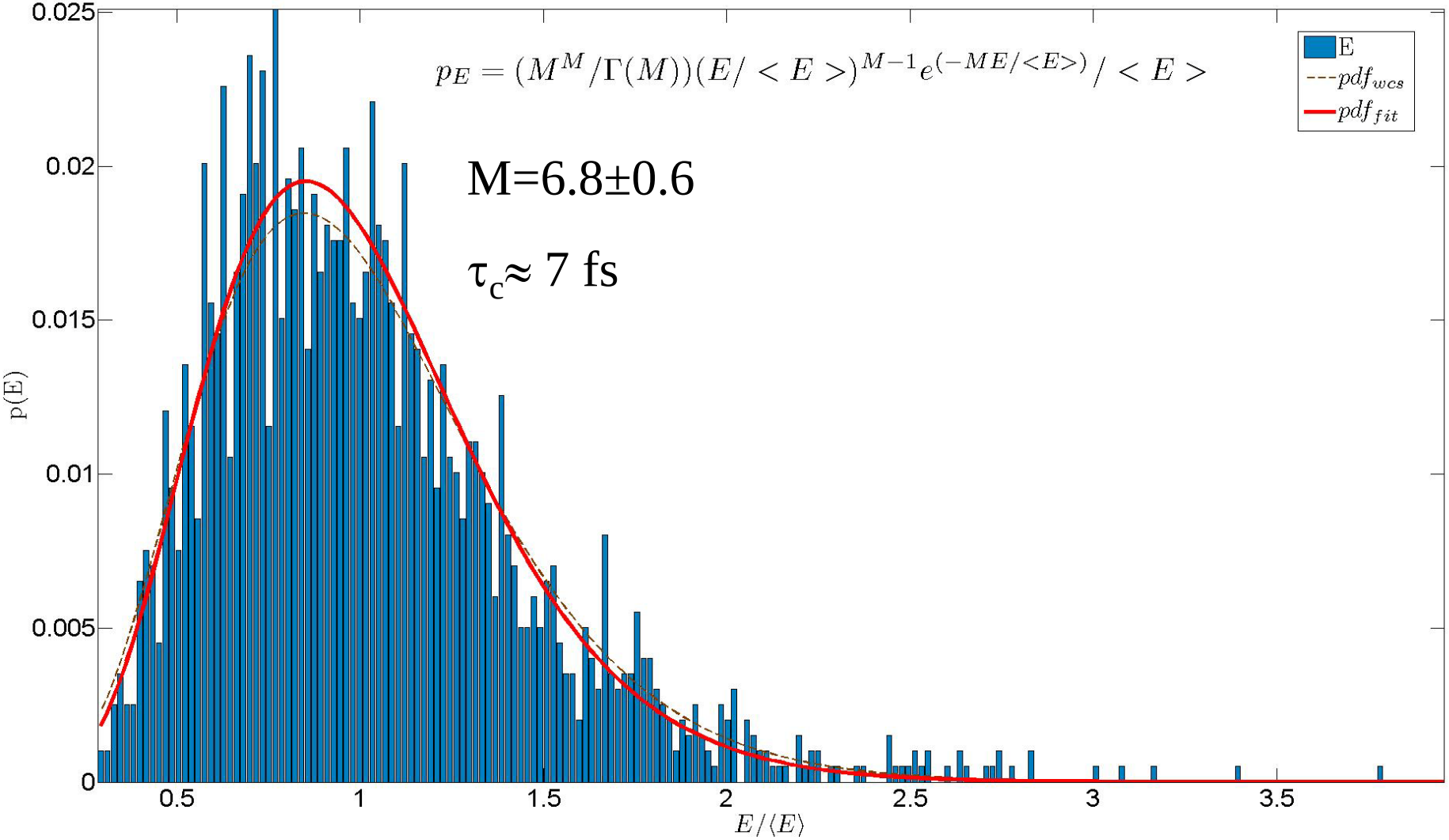
(left) Single-shot spectra of the SASE-radiation.

(right) Single-shot spectra of the HHG seed.

The red curve is the average over all single shots.

sFLASH-SASE

➢ Mandatory! Proofs, that the FEL-amplifier works at the right wavelength with sufficient gain in linear regime(1e5-1e6)



Summary and outlook

- sFLASH fully commissioned (300 hours FLASH beamtime)
- {X,Y,X',Y',t,λ} overlap demonstrated
  - ✓ $\Delta X, \Delta Y < 50\ \mu m$, $\Delta X', \Delta Y' < 50\ \mu rad$
  - ✓ $\Delta t < 100$ fs
  - ✓ $\Delta\lambda/\lambda < 0.001$
- sFLASH-SASE achieved on regular basis
- HHG-source generates up to 2nJ@38 nm

sFLASH upgrade (starting September 2011)

- 1-stage 800 nm compressor → **~3 times more energy in IR**
- Adaptive optics in injection beamline → **improved coupling**
- Additional XUV-diagnostics → **online HHG characterization after injection**
- Resume operation beginning 2012