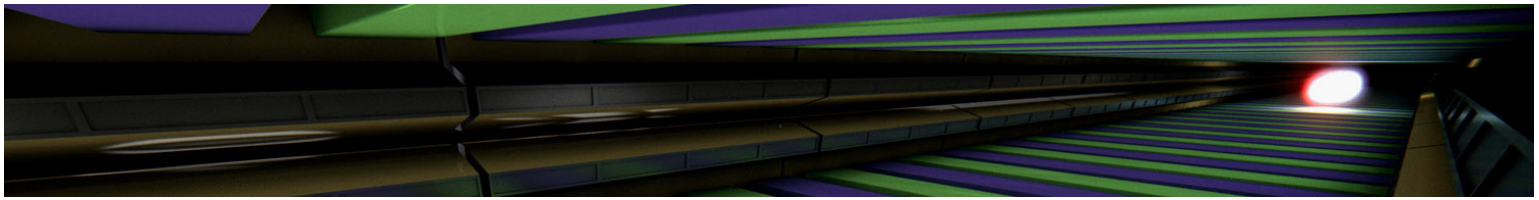


SQS Commissioning and first experiments (SASE-3)

M. Meyer, WP-85 (SQS)

1) SQS installation

- Status and Schedule

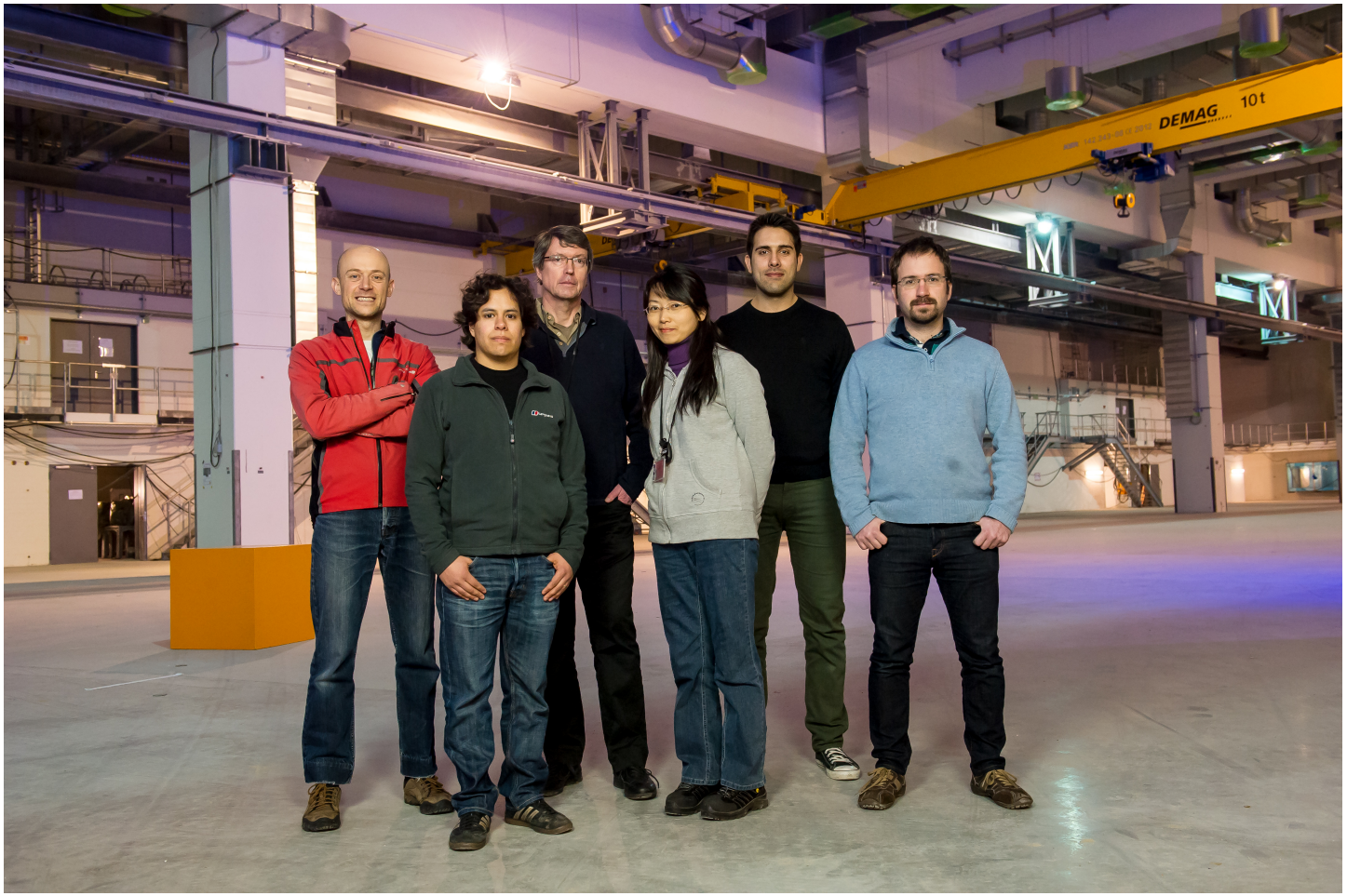
2) First experiments

- Commissioning experiments

- First “Science” application

  - **1) Non-linear Processes**
  - **2) Molecular Fragmentation**

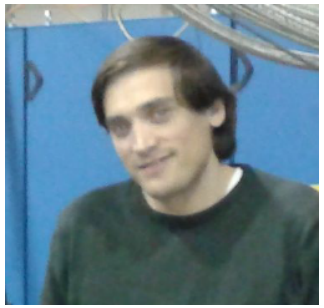
SQS – team (WP85)



A. de Fanis **M. Meyer** J. Rafipoor
A. Achner **H. Zhang** **T. Mazza**

Since mid 2015:

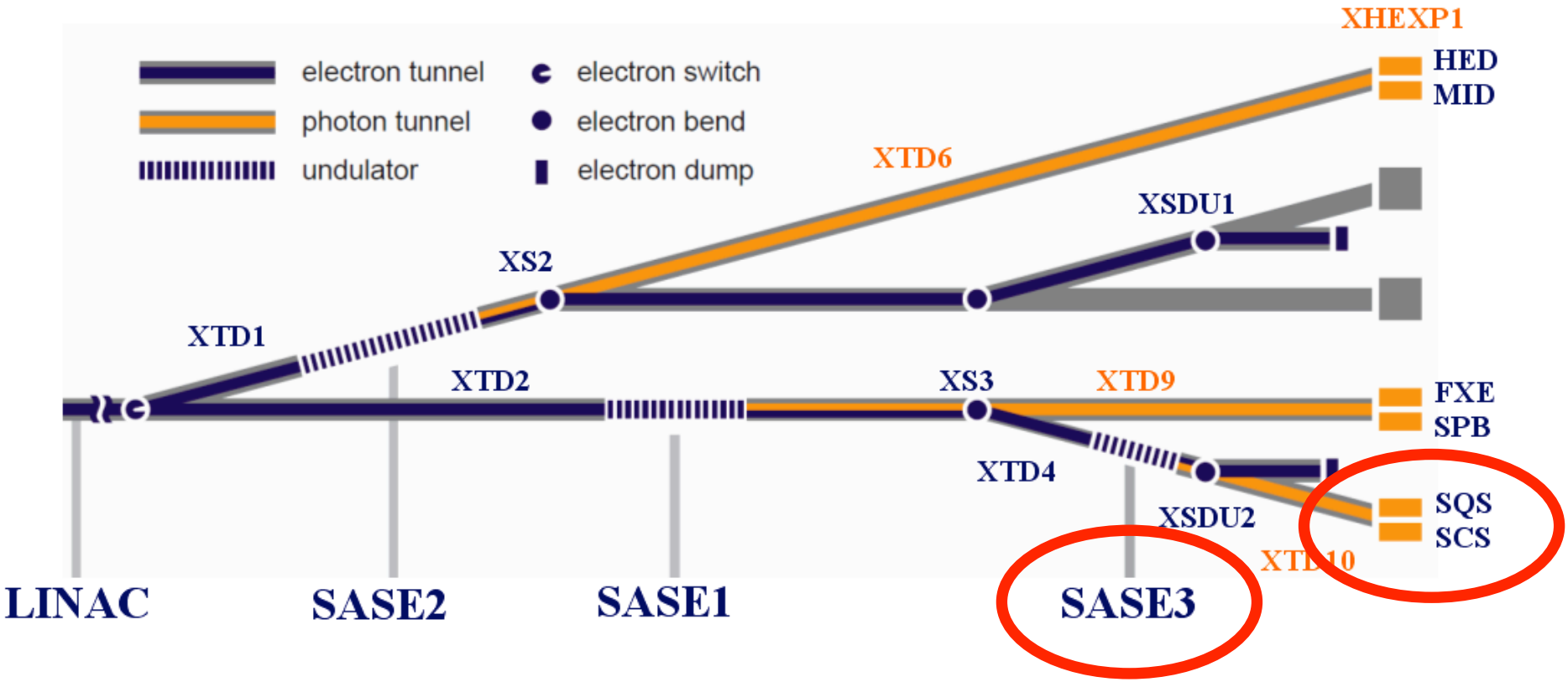
Th. Baumann



Y. Ovcharenko

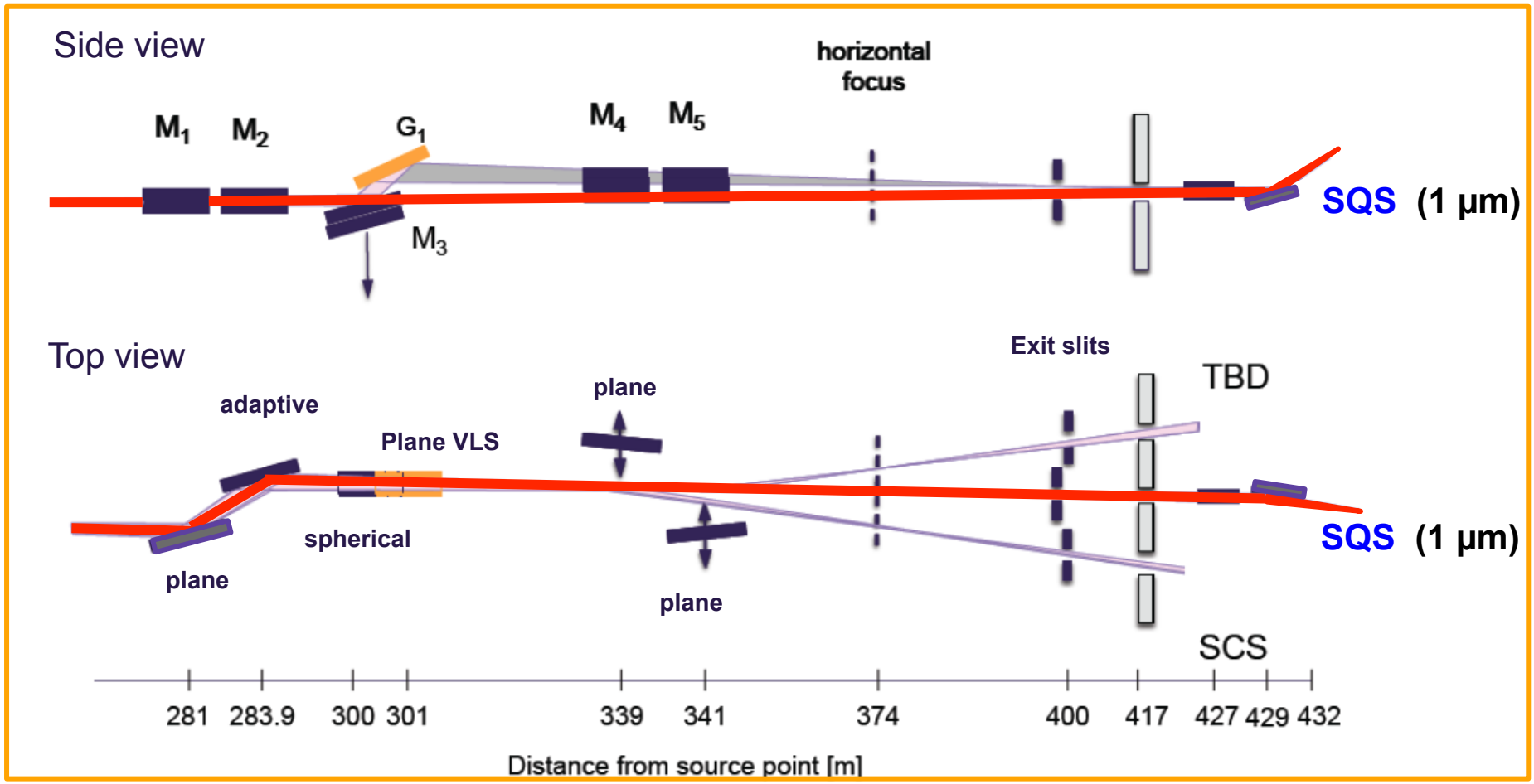
Photon beam transport systems

European XFEL



Photon beam transport systems

- **direct beam** → **Small Quantum System (SQS)**
- monochromatized → Spectroscopy @ Coherent Scattering **(SCS)**

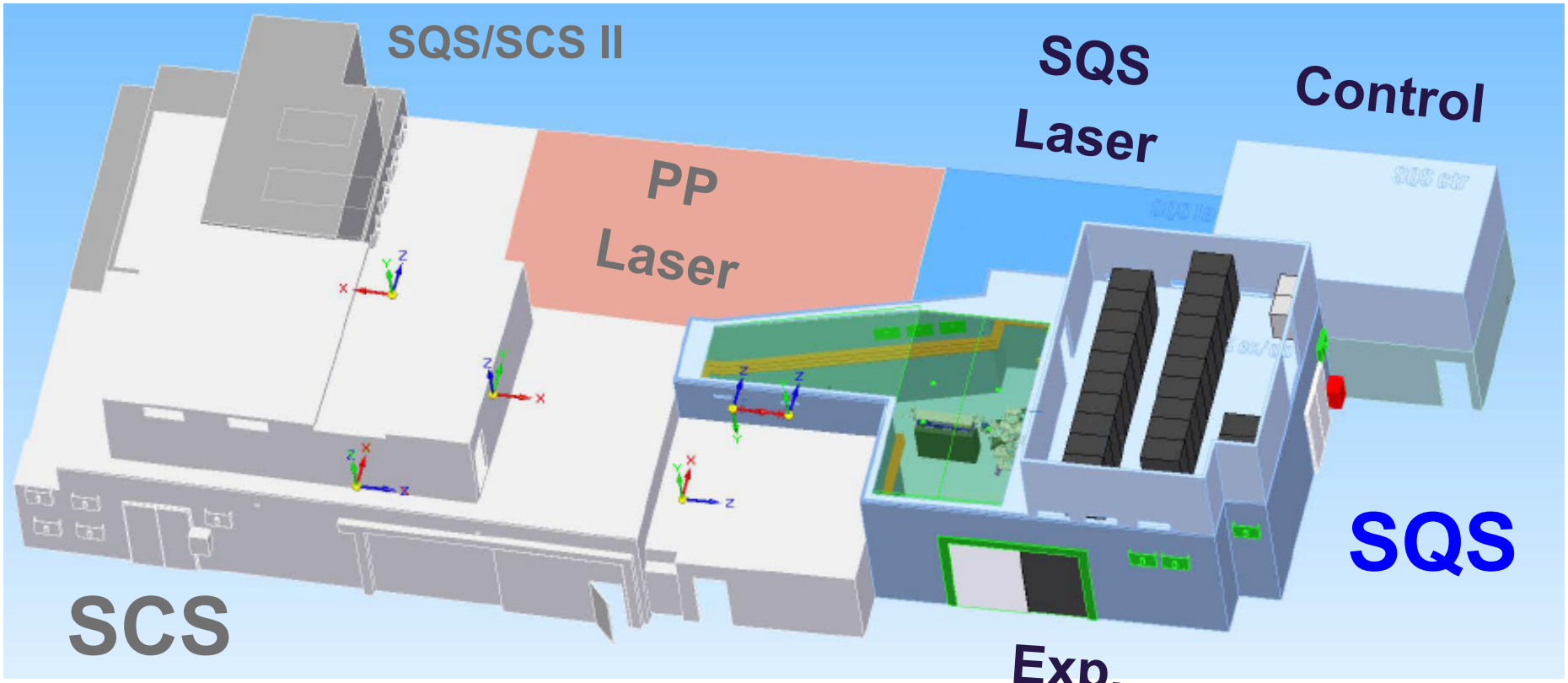


European XFEL

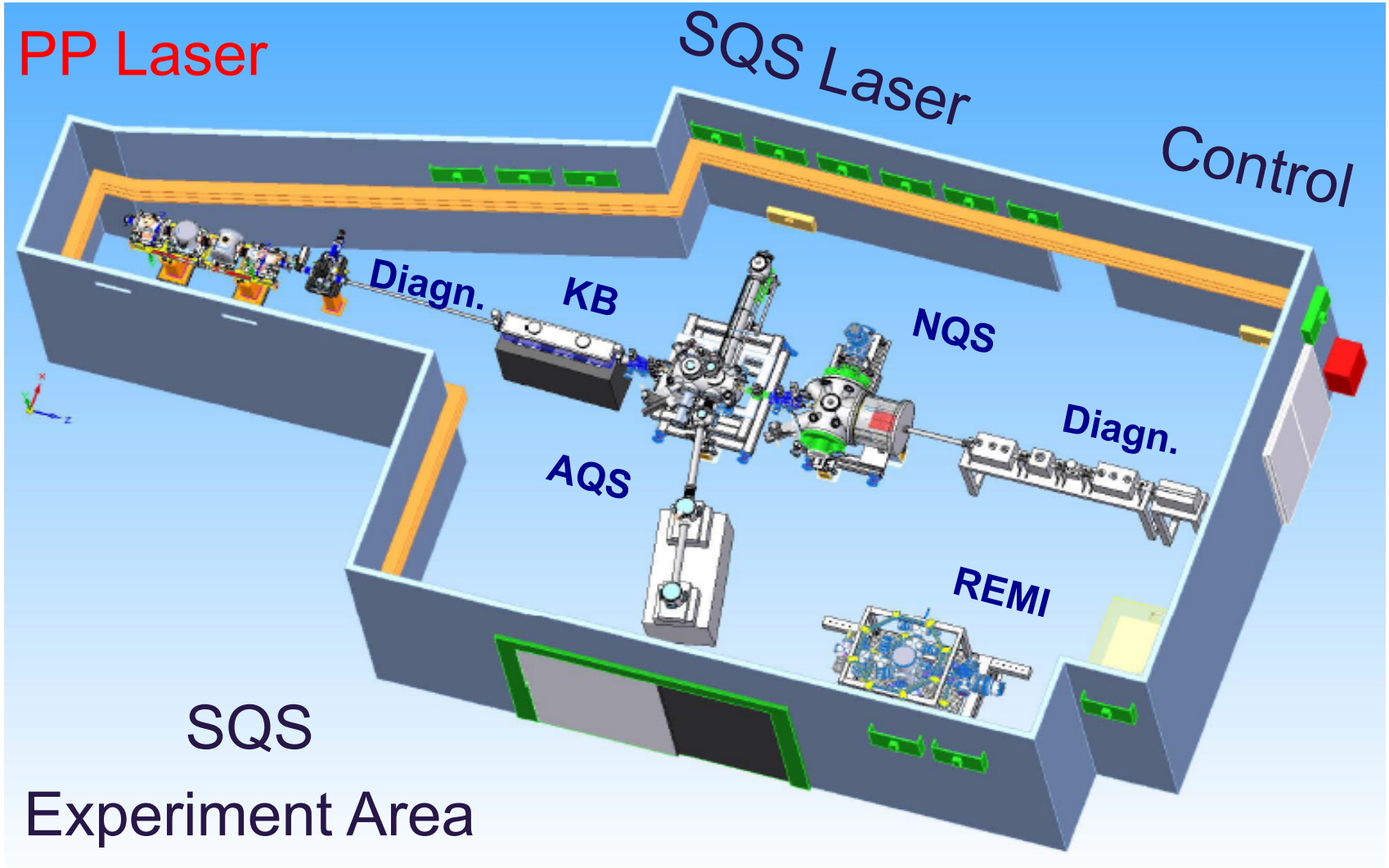
SASE3 – October 2015

General Layout of SASE3 Area

SASE3

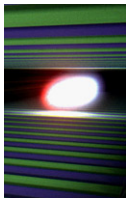


General Layout of SQS Scientific Instrument



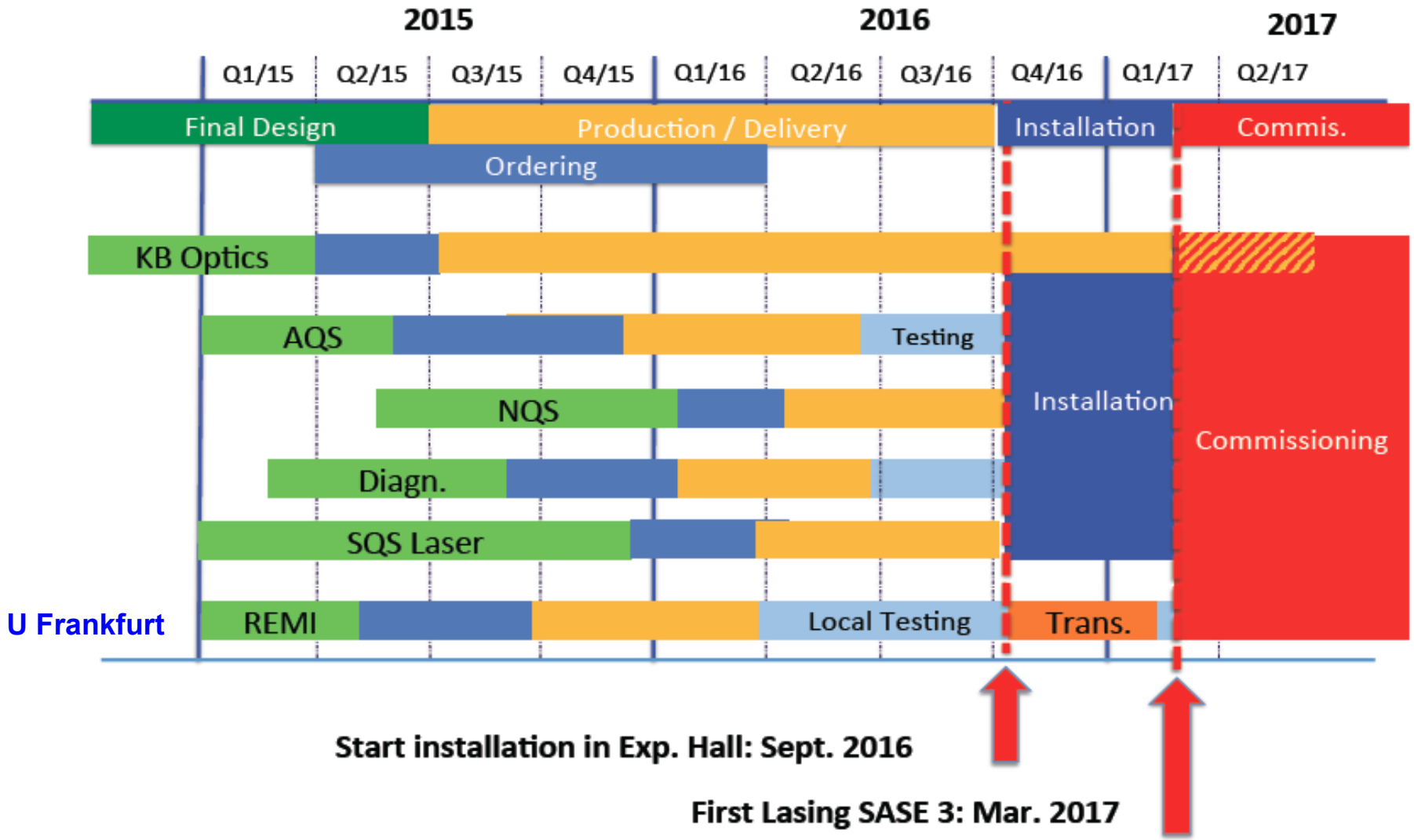
European XFEL

Milestone update (PSPO)



Milestone Name	Date
SASE1	
HUTCH PRR	18.03.2014
SASE1 Hutch construction start	14.04.2015
FXE BIG ITEMS	03.08.2015
SPB/SFX BIG ITEMS	13.07.2015
HUTCH CONSTRUCTION COMPLETE (INSTRUMENT INSTALLATION POSSIBLE)	09.10.2015
INFRASTRUCTURE PRR	25.02.2015
ALL HUTCHES & BASIC INFRASTRUCTURE DONE (INSTALLATION OF SENSITIVE COMPONENTS POSSIBLE)	26.04.2016
COMPLETE HUTCHES AND INFRASTRUCTURE DONE	19.07.2016
SASE3	
HUTCH PRR	17.03.2015
SASE3 Hutch construction start	05.08.2015
HUTCH CONSTRUCTION COMPLETE (INSTRUMENT INSTALLATION POSSIBLE)	11.03.2016
INFRASTRUCTURE PRR	24.09.2015
ALL HUTCHES & BASIC INFRASTRUCTURE DONE (INSTALLATION OF SENSITIVE COMPONENTS POSSIBLE)	28.09.2016
COMPLETE HUTCHES AND INFRASTRUCTURE DONE	23.11.2016
SASE2	
HUTCH PRR	15.10.2015
SASE2 Hutch construction start	23.02.2016
HUTCH CONSTRUCTION COMPLETE (INSTRUMENT INSTALLATION POSSIBLE)	06.07.2016
INFRASTRUCTURE PRR	16.11.2015
ALL HUTCHES & BASIC INFRASTRUCTURE DONE (INSTALLATION OF SENSITIVE COMPONENTS POSSIBLE)	22.11.2016
COMPLETE HUTCHES AND INFRASTRUCTURE DONE	17.01.2017

Schedule for SQS Scientific Instrument



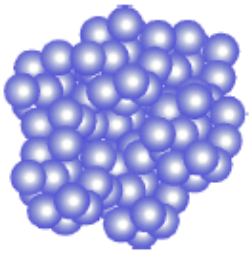
European XFEL

SASE3 & SQS Performances

SASE3	**hν = 260 – 3000 eV**	**P = 0.2 – 11.0 mJ**	**Lin./Circ. Pol.**
	ΔT = 2 – 100 fs	**Coherence: 0.96**	**Split & Delay**

Atoms 

Molecules 

Clusters 

Non-linear phenomena

10^{17} – 10^{18} W / cm^2

Time-resolved studies

low jitter (<10 fs)

Imaging experiments

Spatial coherence

European XFEL

High repetition rate:

< 27000 pulses/ sec

→ **High data collection rate**

Multi-particle coincidences

!!!!!

Commissioning of SQS

- **SQS & SCS (SASE3)**
  - First Lasing March 2017
  - Early user operation from October 2017

“Day – one” parameter: SASE3

Rep. rate : 100 kHz

Photon energy: 1.0 – 1.5 keV

Pulse energy: up to 3 mJ

Pulse duration: 50 fs

Electron beam energy: 17.5 GeV

Shifts 2017 for SASE3 (SQS)

(no parallel operation)

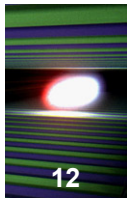
Commissioning (total): 150 shifts (12 hours)

SQS Instrument : ≈ 25 shifts
(including beam transport)

“friendly” user operation : ≈ 10 shifts

European XFEL

Commissioning of SQS



1) Non-linear processes

Multi-photon processes

Nonlinear: Signal ~ I^N

Intensity

$$I \sim \frac{\text{pulse energy [J]}}{\text{pulse duration [sec] x focus area [cm}^2\text{]}}$$

Example: 10 μJ, 10 fs, 10 μm

~ 10^{15} W/cm^2

“Day – one” parameter: SASE3

Rep. rate : 100 kHz

Photon energy: 1.0 – 1.5 keV

Pulse energy (P): up to 3 mJ

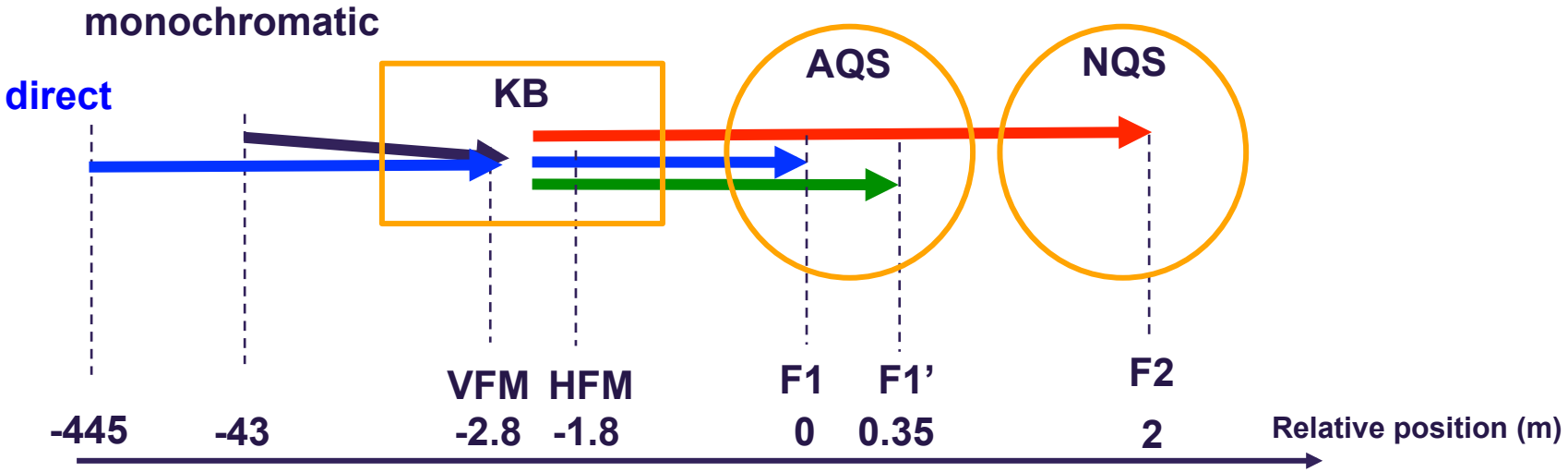
Pulse duration (T): 50 fs

SQS KB system:

Focus diameter: 1 micron

6 x 10^{18} W/cm^2

KB focusing optics (in coll. with WP-73)



Requirements

- 3 interaction points
- ≤ 1 micron focus
- variable focus size
- high transmission
- large wavelength range

Challenges

- **Bendable mirrors**
- Length 800 mm
- Large bending range
- Slope error 50 nrad
- Cooling system

Simulations for KB optics (Mechanical benders)

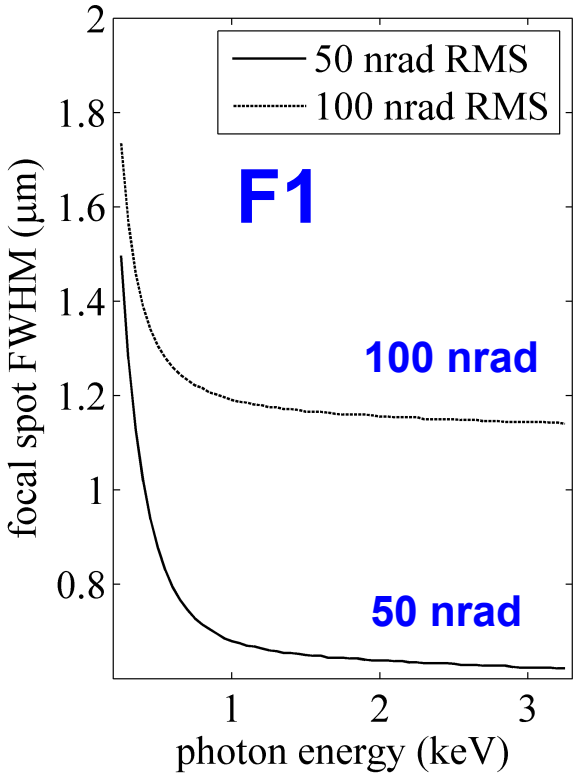
Bending range: VFM 600 – 1100 m
HFM 400 – 850 m

Perfect shape only for ONE position

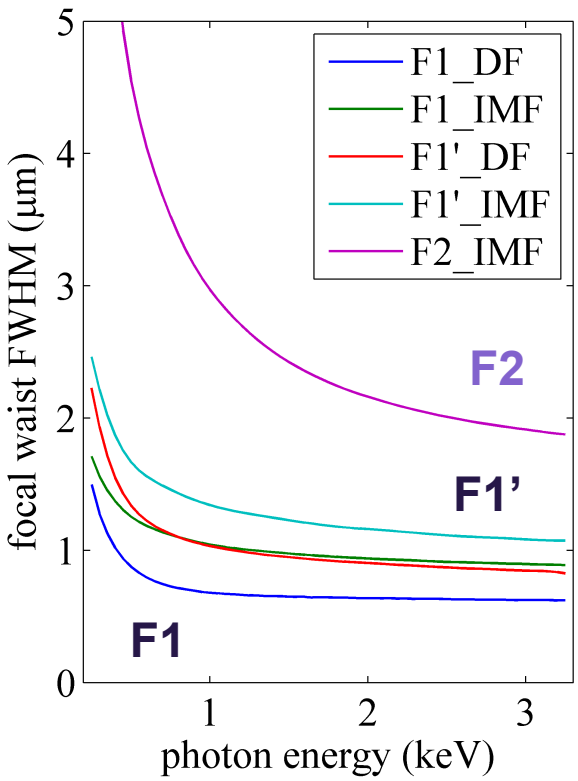
T. Mazza
WP85

Direct / Intermediate

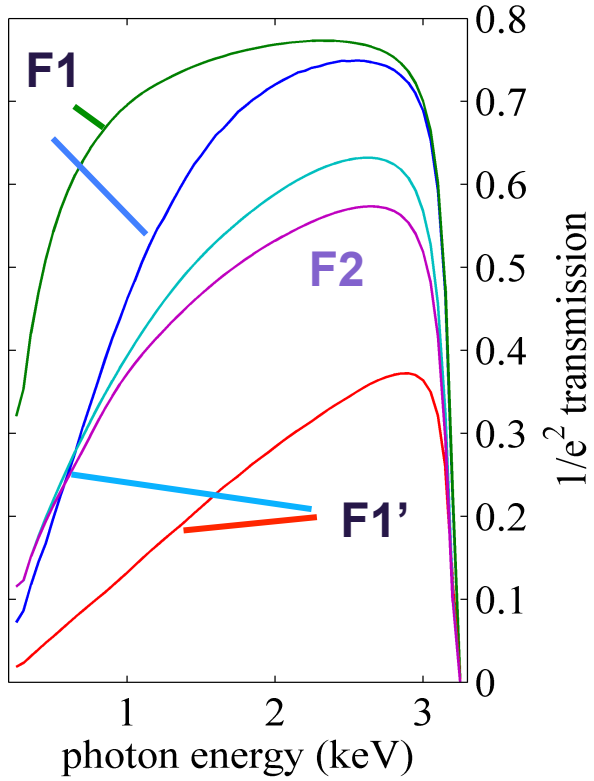
Focus size



Focus size



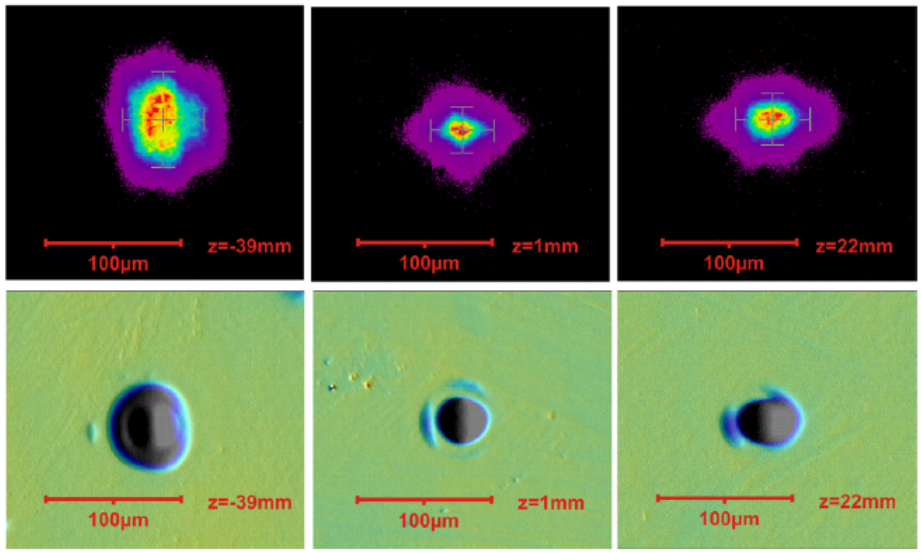
Transmission



Commissioning of SQS

Characterization of KB performances

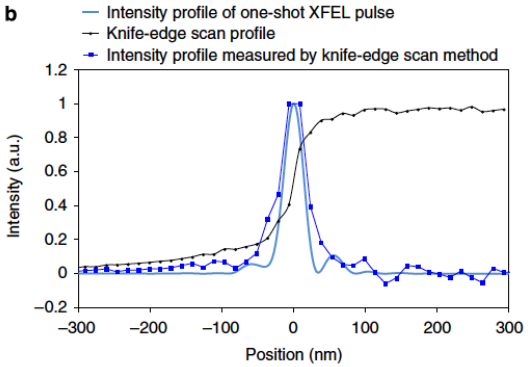
- **Hartmann-type wavefront sensor**



FLASH:
B. Flöter et al., NJP 12, 83015, 2010

- **PMMA Imprints**

- **Knife edge scan**



SACLA
H. Mimura et al., Nat.Comm. 5, 3539, 2014

Commissioning of SQS

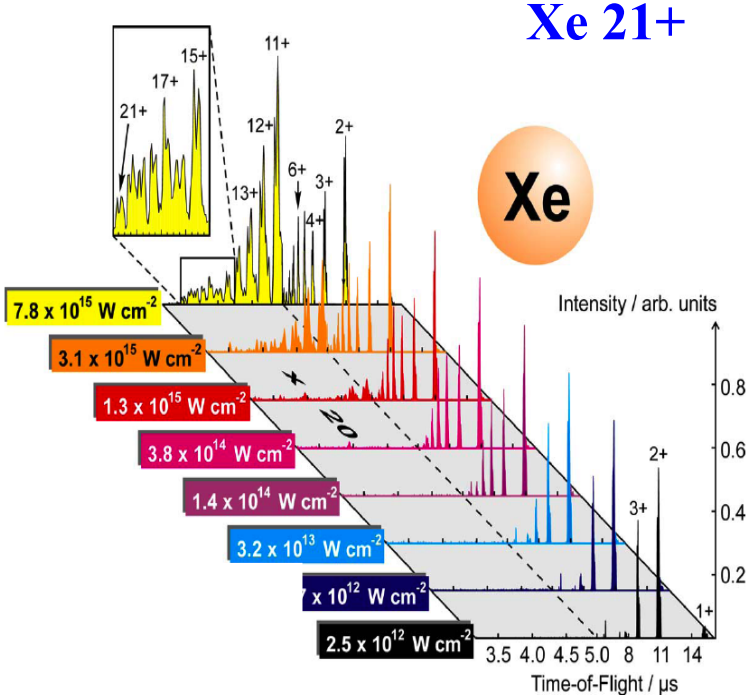
- **Reference for SQS performance cf. LCLS, FLASH**

λ (FLASH) = 13.3 nm

Sorokin et al., PRL 99, 213002 (2007)

hν = 93 eV

Xe 21+

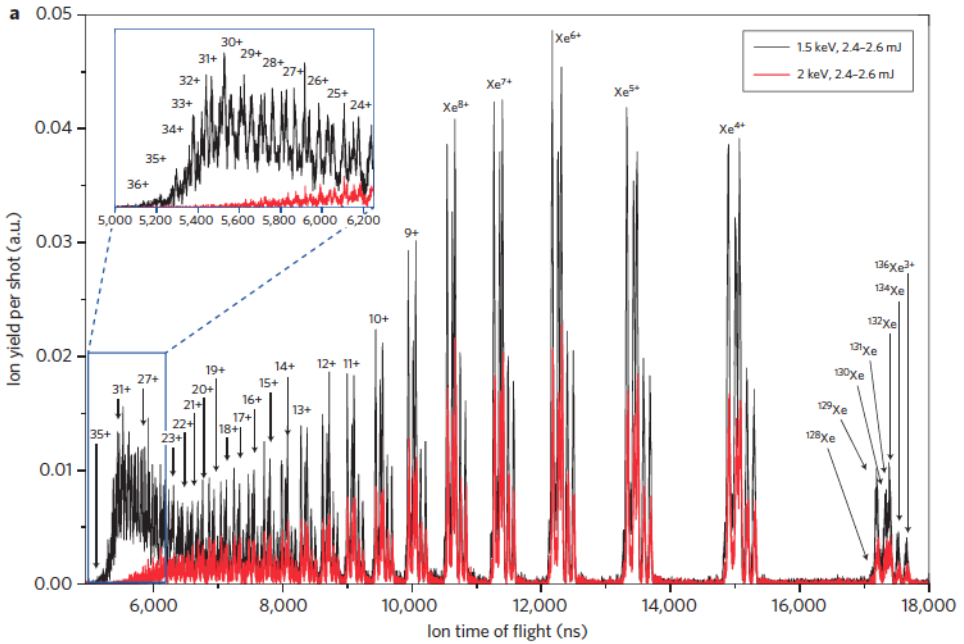


λ (LCLS) = 0.8 nm

Rudek et al., Nat.Phot. 6, 858 (2012)

hν = 1.5 keV
hν = 2.0 keV

Xe 35+



7.8 x10^15 W/cm^2

6 x 10^18 W/cm^2

1x10^17 W/cm^2

Commsioning experiments at SQS

Multiple ionization of atoms

“Day – one” parameter: SASE3

Rep. rate : 100 kHz

Photon energy: 1.0 – 1.5 keV

Pulse energy (P): up to 3 mJ

Pulse duration (T): 50 fs

Focus diameter: 1 micron

I(SQS) ≤ 6 x 10^{18} W/cm^2

Interest

Rep. rate : **< 100 kHz**

1.0 – 1.5 keV

P > 3 mJ

T : 50 fs

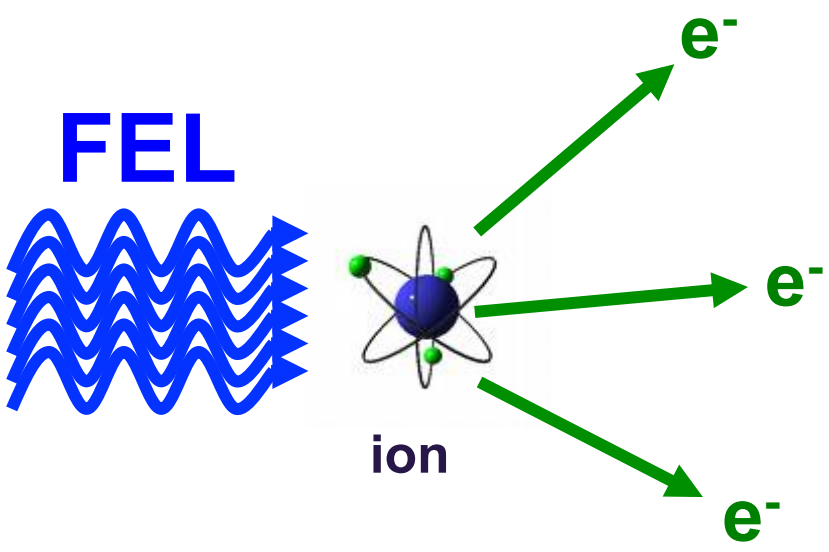
Focus diameter: 1 micron

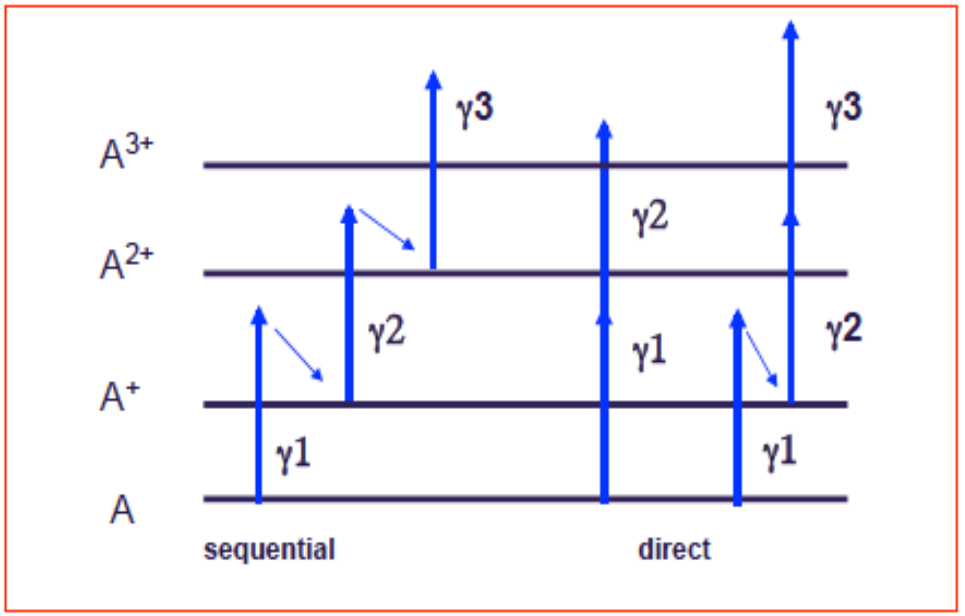
I(SQS) > 6 x 10^{18} W/cm^2

European XFEL

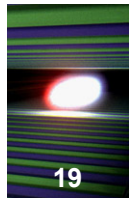
First „science“ experiments at SQS

- **Electron – Ion Coincidences (atoms)**
  - **Dynamical information -**
  - **Determination of ionization pathways -**





First „science“ experiments at SQS



- **Electron – Ion Coincidences (atoms)**
  - **Dynamical information -**
  - **Determination of ionization pathways -**

Requirements:

Unambiguous correlation between electron and ion

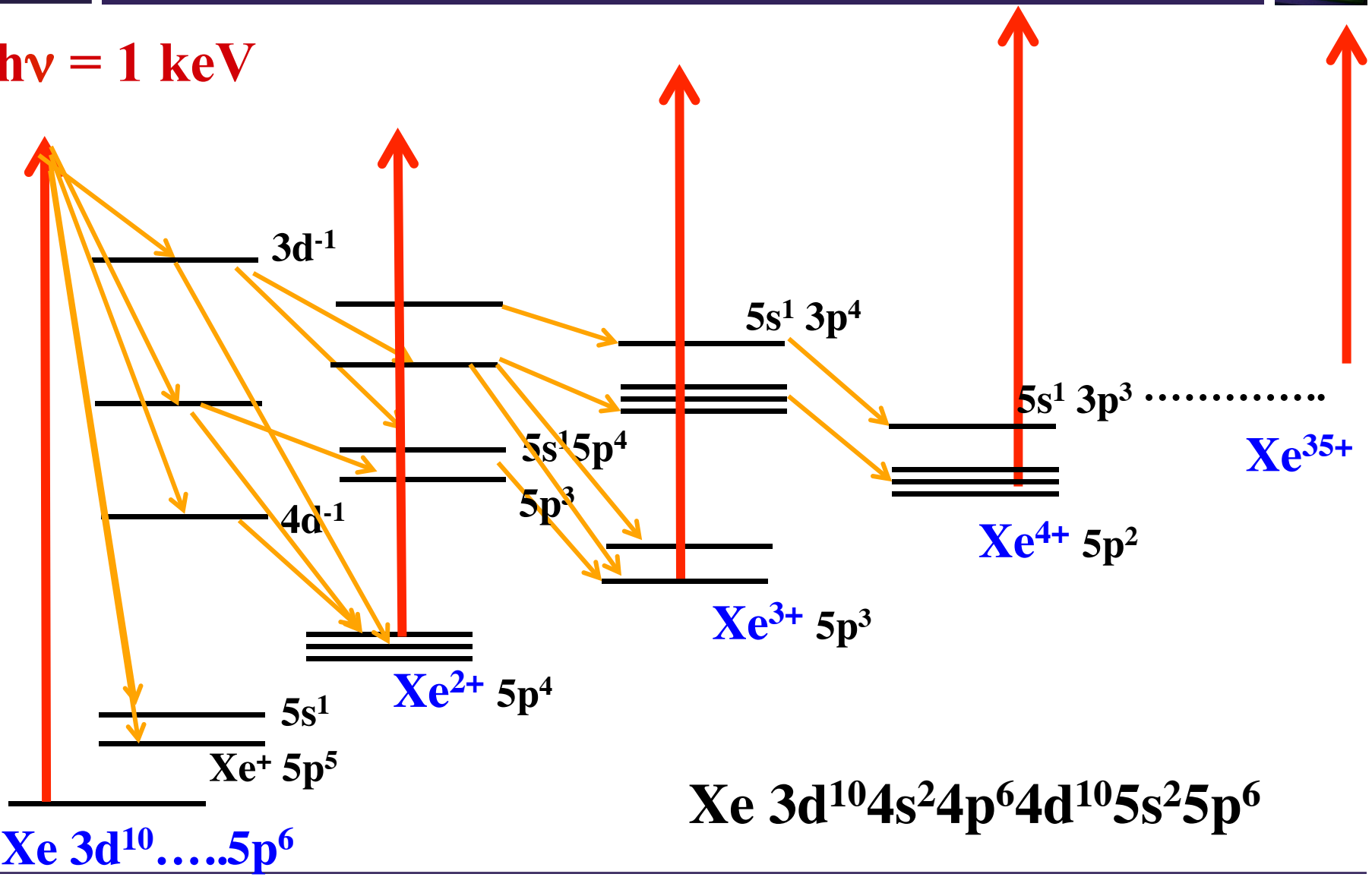
→ 1 photon-atom interaction per pulse

Electron spectra: Time-of-flight E(kin) > 13 eV → < 220 ns

Ion spectra: Time-of-flight Xe (m/q) < 136 → < 10 μs

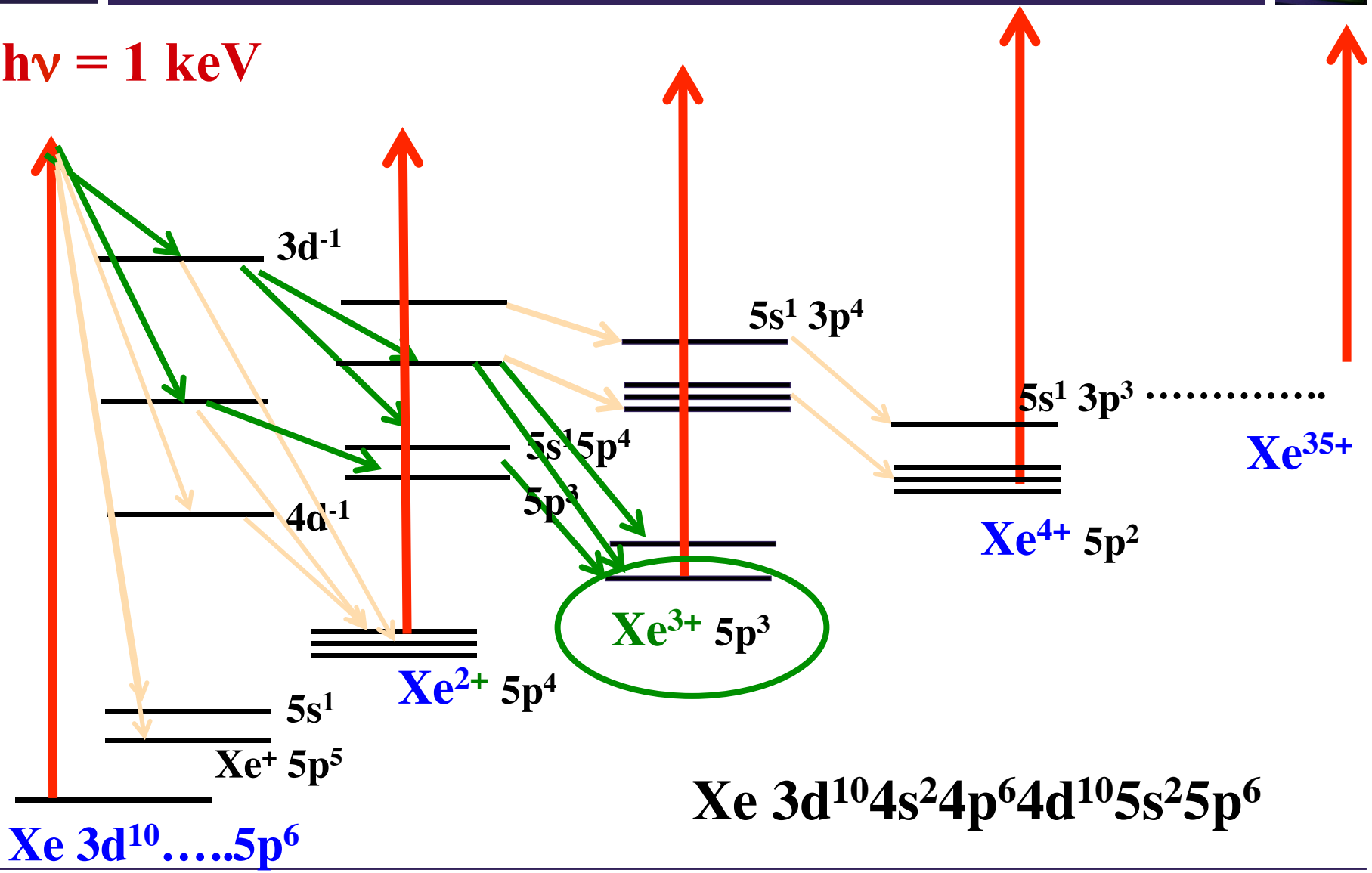
European XFEL

SQS: Coincidence method



European XFEL

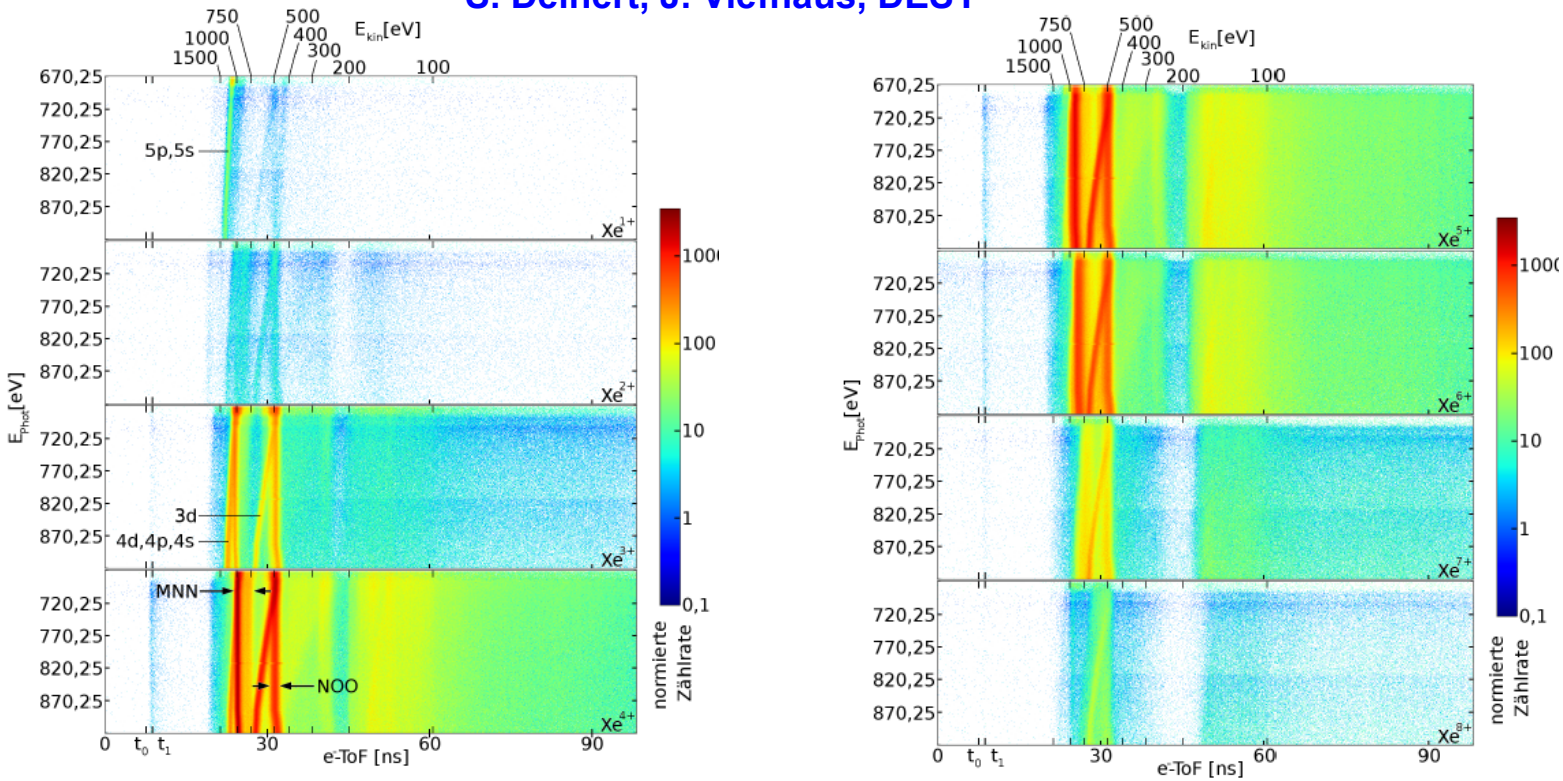
SQS: Coincidence method



Coincidences : Xe (PETRA III)

Synchrotron (MHz) – linear one-photon processes (< Xe8+)

S. Deinert, J. Viefhaus, DESY

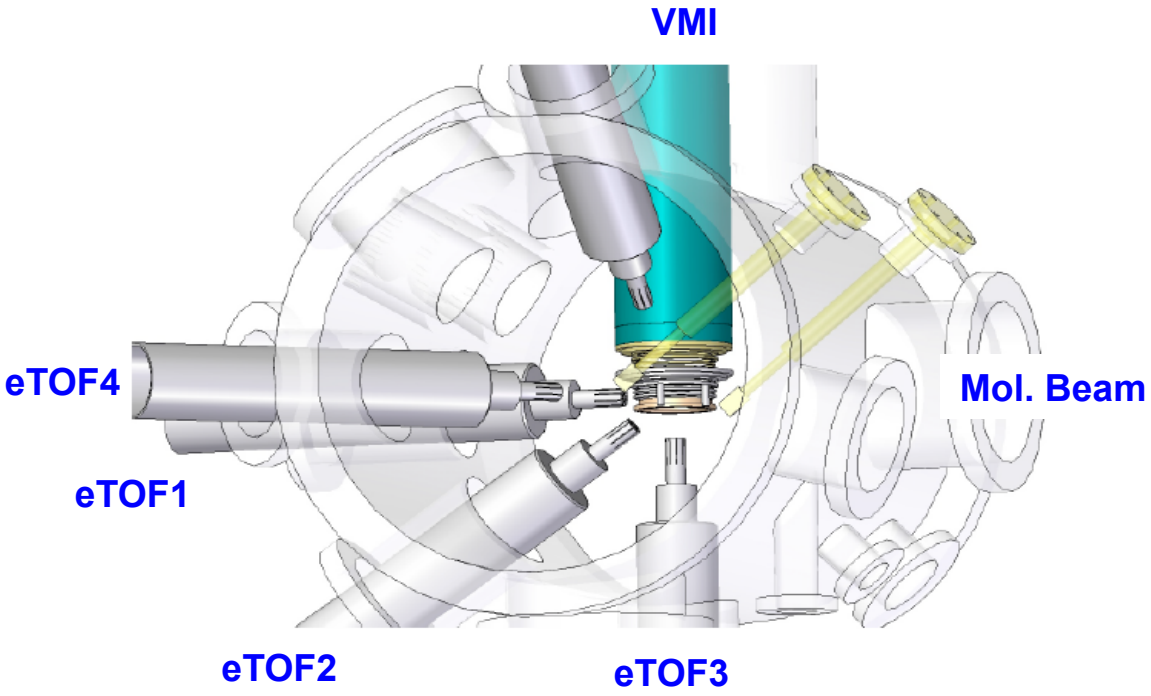


→ **European XFEL – new regime / new dynamics**

“non-linear multi-phon ionization”

AQS experimental chamber

“ions”



Dipole plane
eTOF1 = 0°
eTOF2 = 54.7 °
eTOF3 = 90°

“electrons”

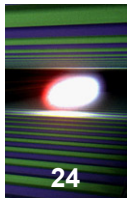
AQS: Atomic-like Quantum Systems

Targets: atoms & small molecules
Molecular beam
Vacuum: 10^{-11} mbar
Focus: ≤ 1 mu → 50 mu

electrons, ions, photons

- HR electron spectroscopy
- Angle-resolved spectroscopy
- Non-dipole studies
- HR fluorescence spectroscopy
- e / e – coincidences
- e / ion - coincidences

First „science“ experiments at SQS



- **Electron – Ion Coincidences (atoms)**
  - **Dynamical information -**
  - **Ionization pathways -**

“Day – one” parameter: SASE3

Rep. rate : 100 kHz

Photon energy: 1.0 – 1.5 keV

Pulse energy (P): up to 3 mJ

Pulse duration (T): 50 fs

Focus diameter: 1 micron

Interest

Rep. rate : **> 100 kHz**

1.0 – 1.5 keV

P > 3 mJ

T : 50 fs

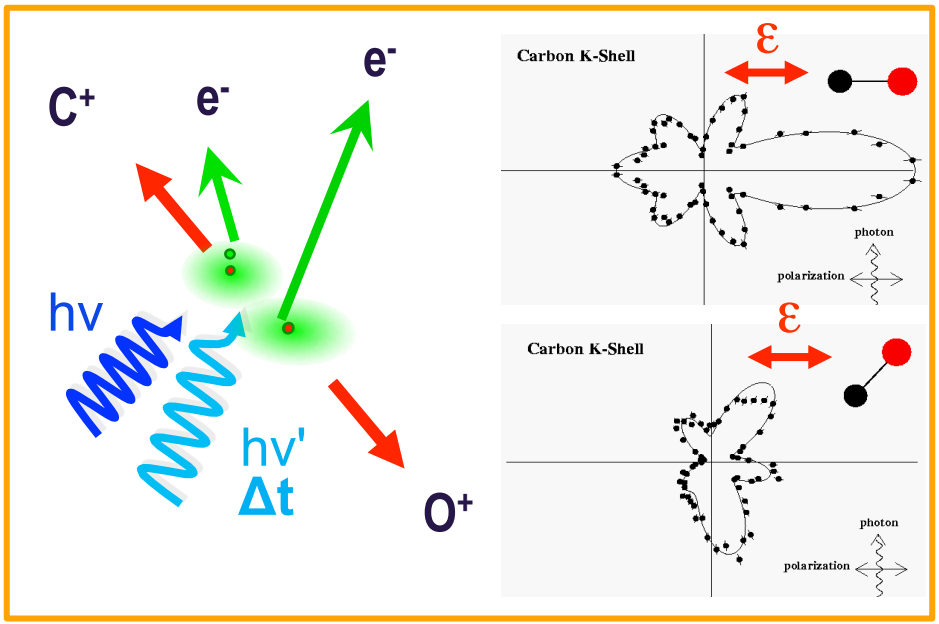
Focus diameter: 1 micron

$I(SQS) \leq 6 \times 10^{18}$ W/cm^2

European XFEL

Second „science“ experiments at SQS

- **Electron – Ion Coincidences (molecules)**
  - **Dissociation Channel -**
  - **Temporal evolution of bond breaking -**



Landers & Dörner PRL **87** (2001), 013002

electron – ion – ion **coincidences**

1 pulse = 1 event !!

Dissociation dynamics (ALS)

“linear”

European FEL

→ **“non-linear”**

→ **Pump-Probe**

fs – dynamics

Temporal evolution

Molecular alignment

Intense fields

Second „science“ experiments at SQS

- **Electron – Ion Coincidences (molecules)**

  - **Dissociation Channel -**
  - **Temporal evolution of bond breaking -**

“Small“ molecules: N_2, O_2, CO, CO_2, N_2O, CH_4, C_{60}, ...

Electron spectra: Time-of-flight E(kin) > 13 eV → < 220 ns

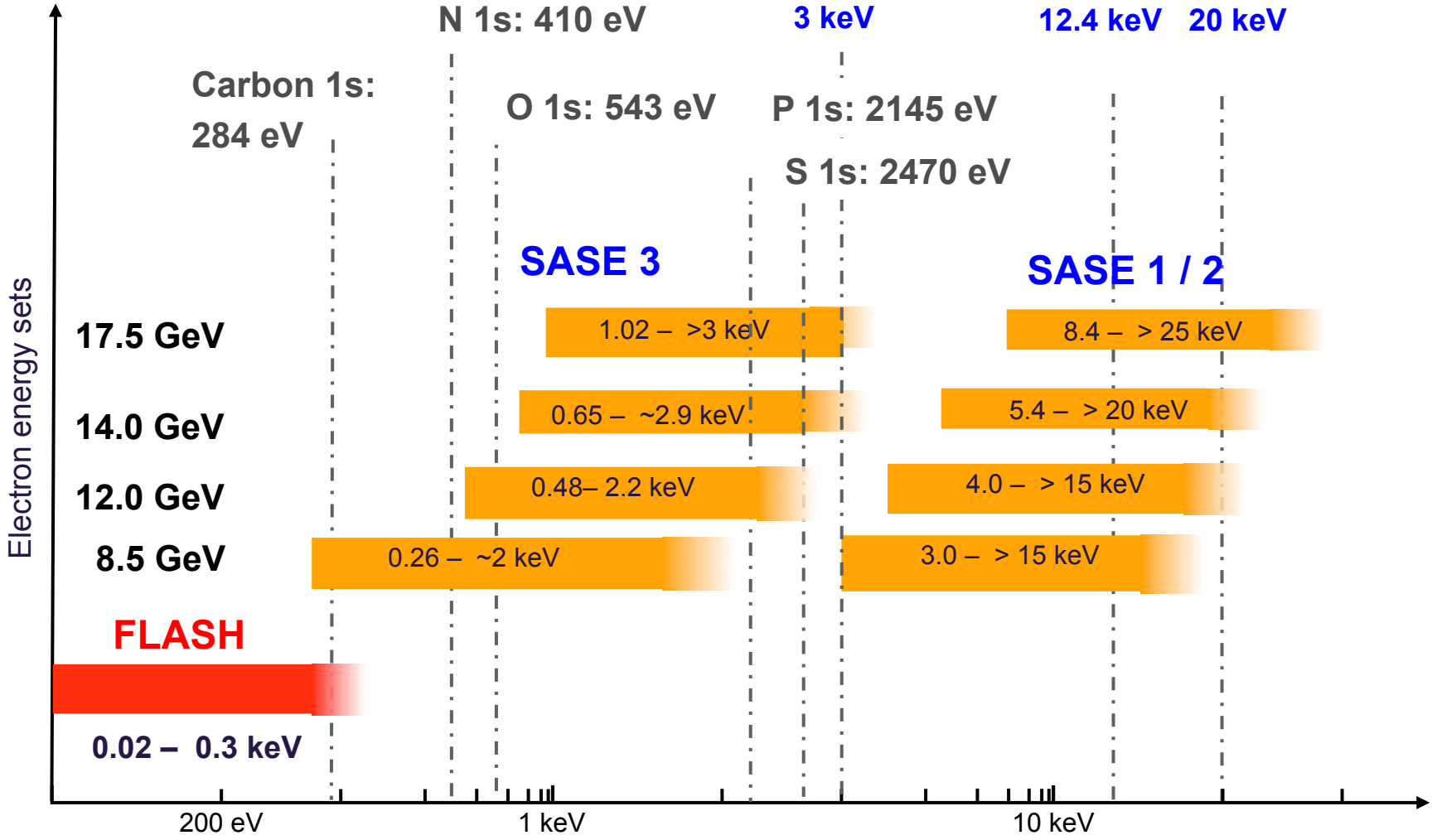
Ion spectra: Time-of-flight m/q (CO_2) < 44 → < 10 μs

Site specific excitation of localized core (1s) electrons

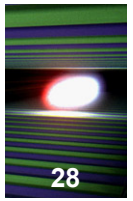
C-1s: 290 eV, N-1s: 410 eV, O-1s: 560 eV

European XFEL

Photon energy ranges



Second „science“ experiments at SQS



- **Electron – Ion Coincidences (molecules)**
  - **Dynamical information -**
  - **Fragmentation pathways -**

“Day – one” parameter: SASE3

Rep. rate : 100 kHz

Photon energy: 1.0 – 1.5 keV

Pulse energy (P): up to 3 mJ

Pulse duration (T): 50 fs

Focus diameter: 1 micron

Electron beam energy: 8.5 GeV

Interest

Rep. rate : **> 100 kHz**

0.25 – 1.5 keV

P < 3 mJ

T < 50 fs

Focus diameter: 1 micron

Early stage of operation:

surface contamination !!

Conclusion

- Commissioning experiments

→ SQS Reference for non-linear processes

e.g. Xe multiple ionization **“intensity”**

- **First “Science” application**

1) Non-linear Processes

→ SQS coincidence performances **“repetition rate”**

e.g. first state-resolved ion spectra of Xe multiple ionization

2) Molecular Fragmentation

→ SQS XUV & coincidence performances **“soft X-rays”**

e.g. first “site-selective” molecular dynamics


European XFEL
Thank you
for your attention!