New operation modes and online diagnostics at FLASH.

S. Düsterer for the FLASH team

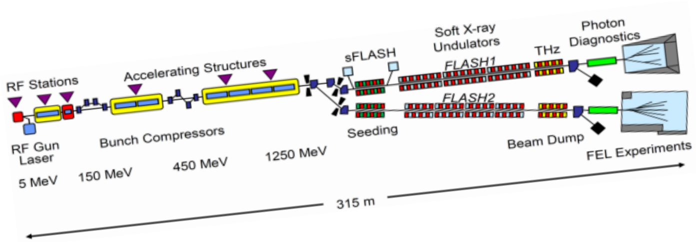
5 way meeting, 24th October 2016

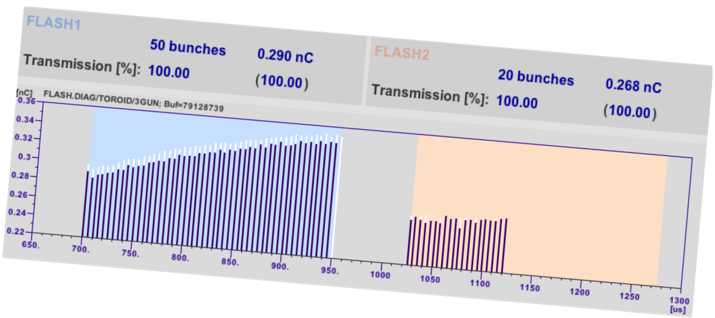
HELMHOLTZ GEMEINSCHAFT

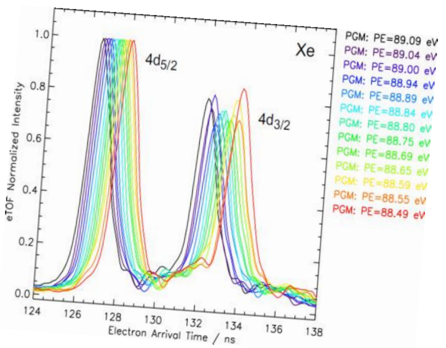
DESY

Outline

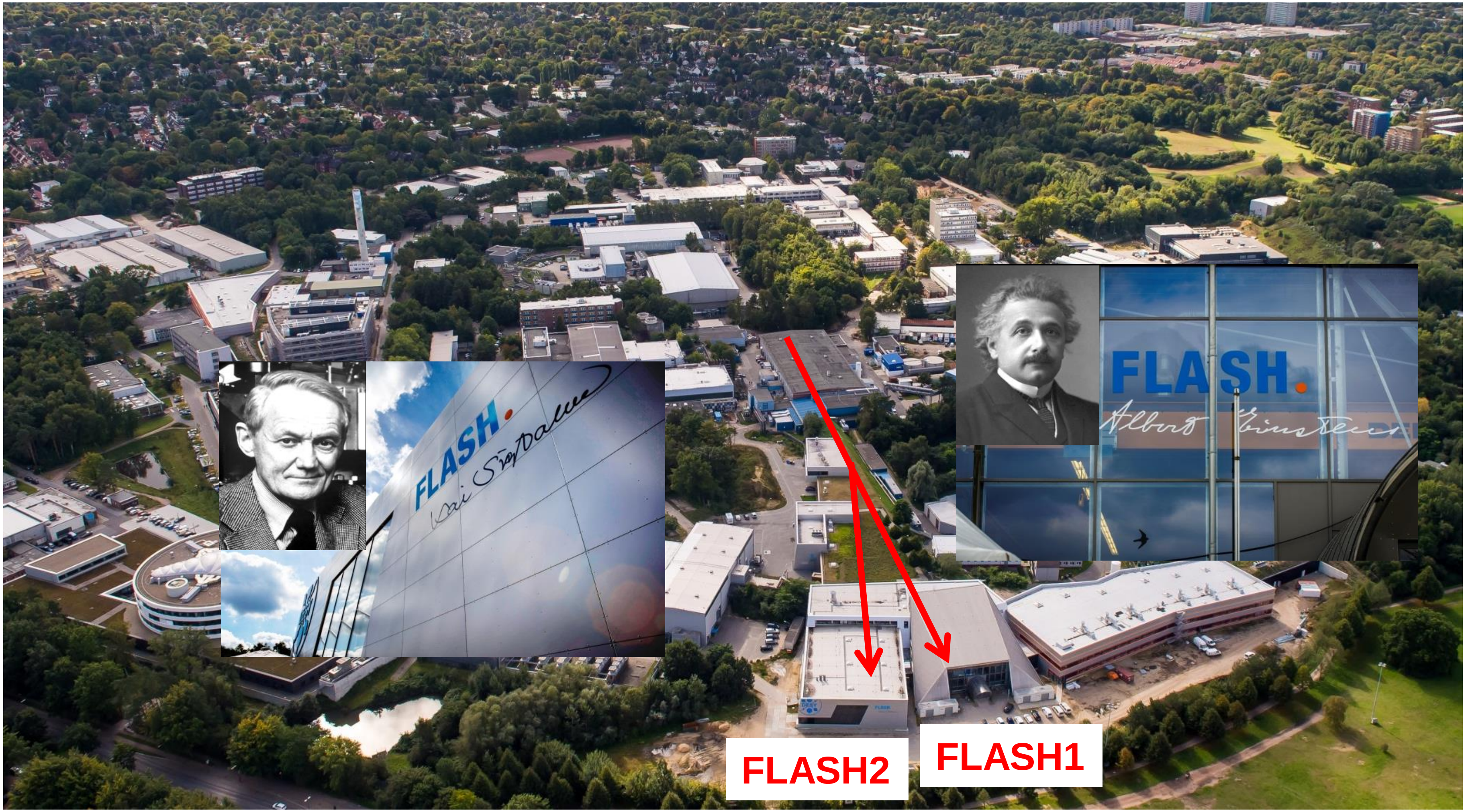
- FLASH = FLASH1 + FLASH2
- Novel options at FLASH2
- Online photon diagnostics at FLASH
- Future plans







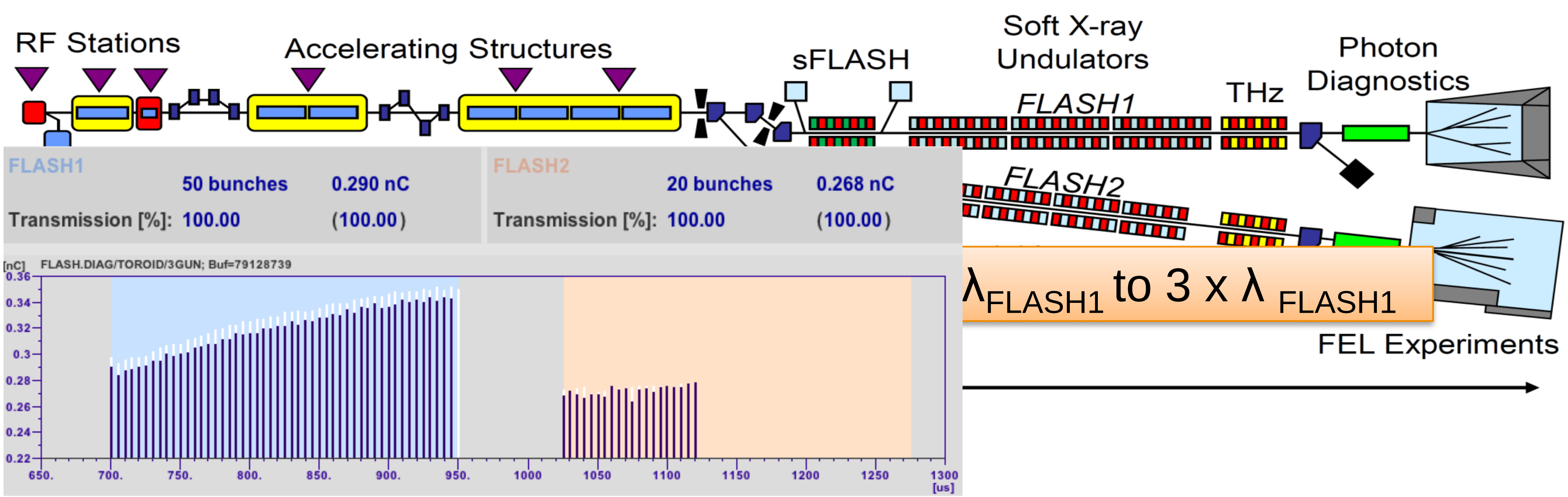
FLASH – Running two FELs in parallel



FLASH @ DESY

Photon beam (SASE)	FLASH 1	FLASH 2
Wavelength	4.2-52nm	3.1-90nm
Pulse Energy	1-500µJ	1-1000µJ
Pulse Duration (FWHM)	<30-200fs	<30-200fs
Pulses per second	10-8000	10-8000

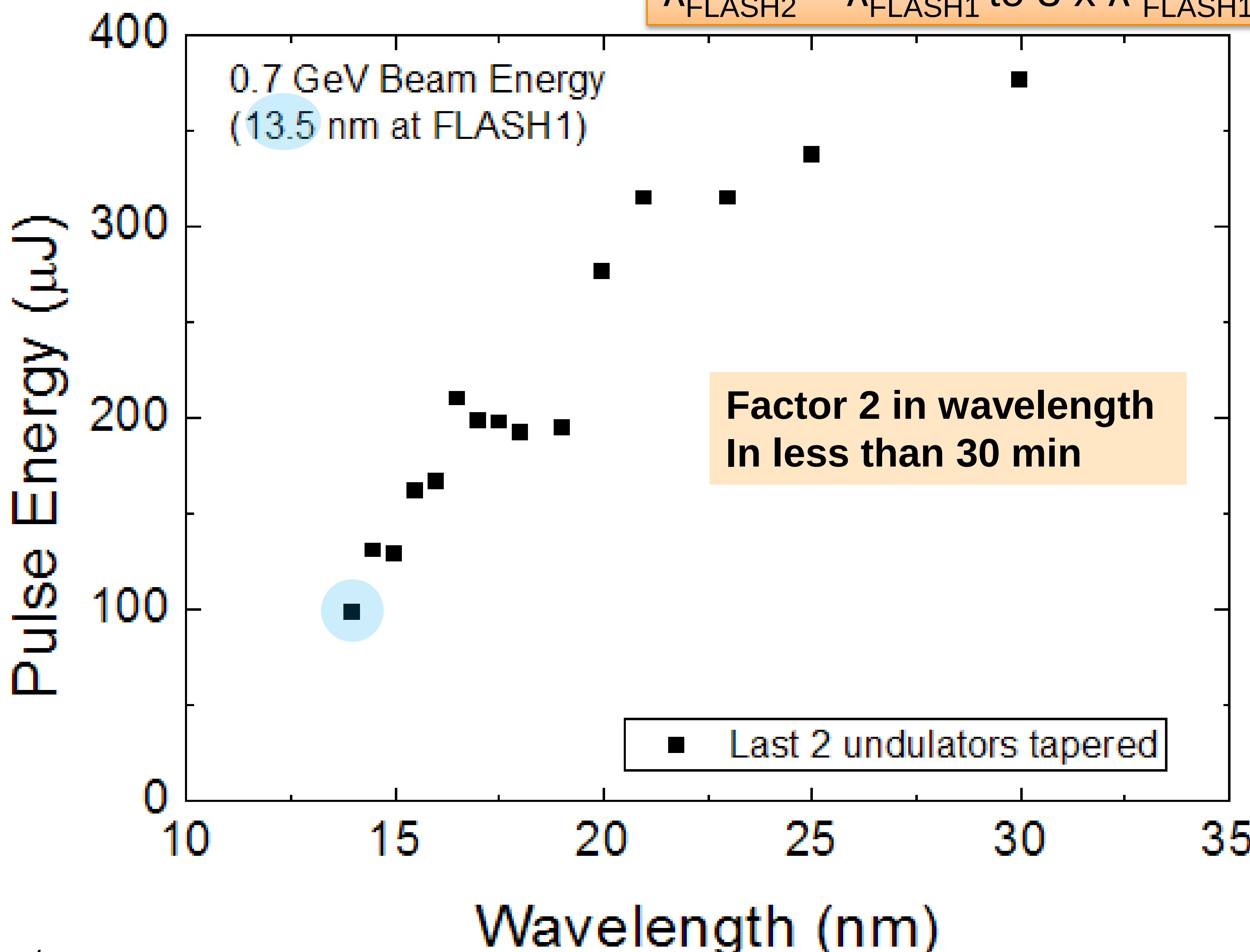
New record in average power (FLASH1)
4000 pulses with 200µJ @ 11nm → 0.8 W



λ_{FLASH1} to 3 x λ_{FLASH1}

FLASH2 – Fast Tunability

$\lambda_{FLASH2} \sim \lambda_{FLASH1}$ to $3 \times \lambda_{FLASH1}$



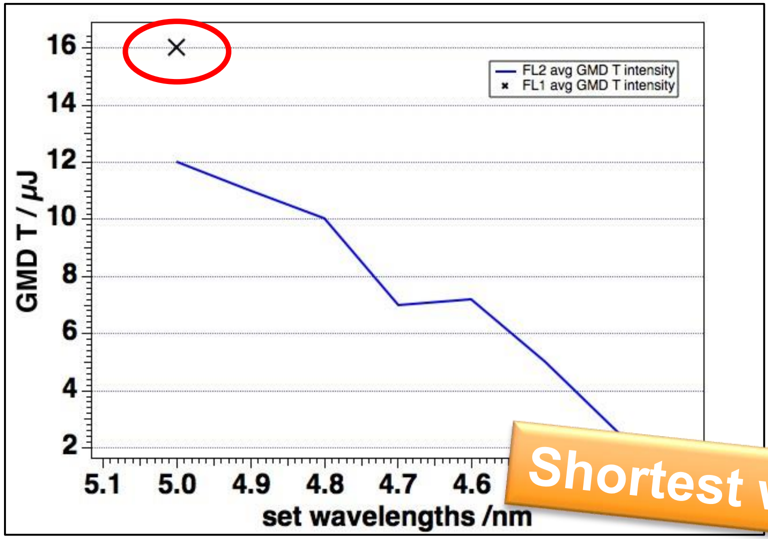
Factor 2 in wavelength
In less than 30 min

Bart Faatz

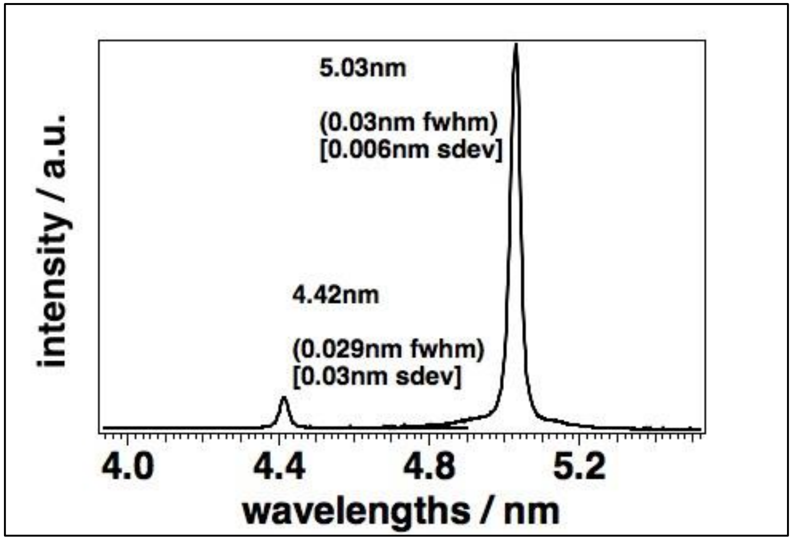
FLASH2 - Exploring Wavelengths lower than FLASH1

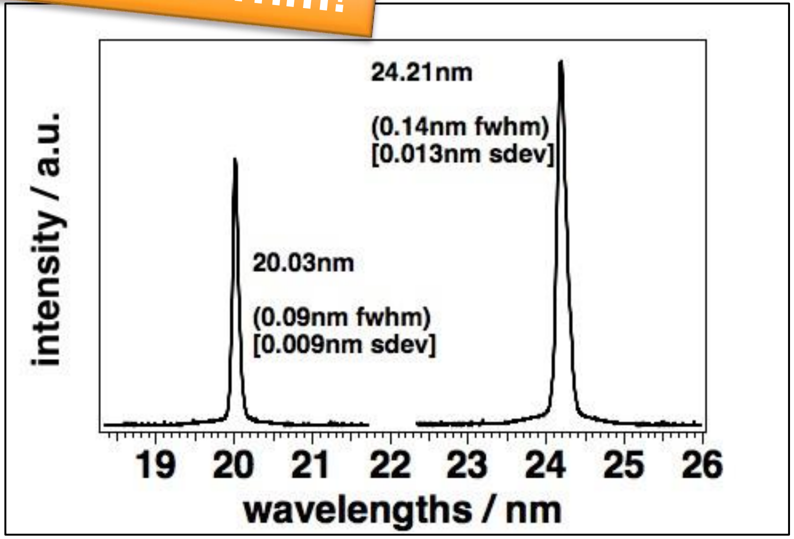
Marion Kuhlmann

$\lambda_{FLASH2} \sim \lambda_{FLASH1}$ to $3 \times \lambda_{FLASH1}$



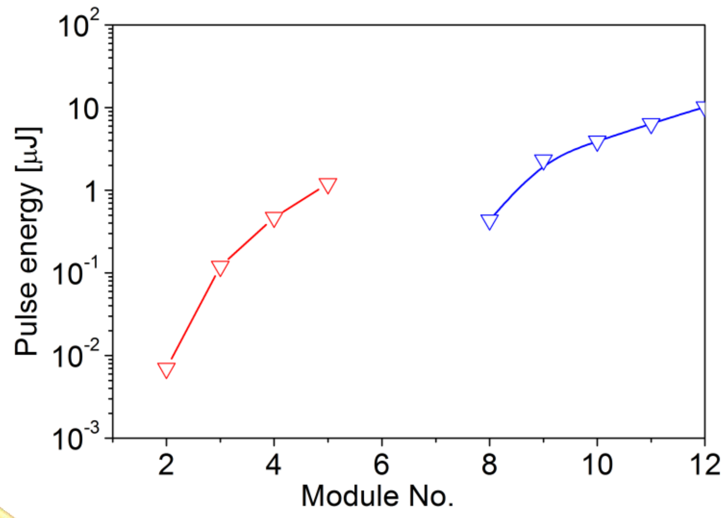
Shortest wavelength 3.1nm!

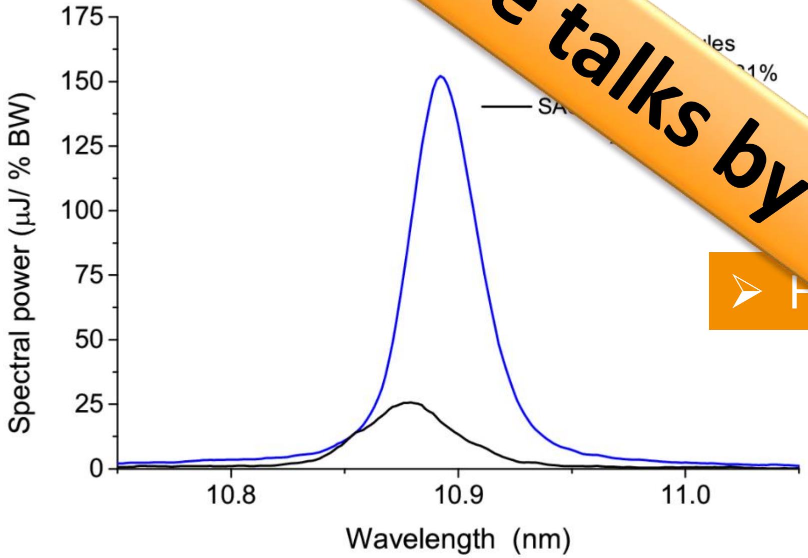




FLASH2 - New Operation Modes

- Frequency doubling

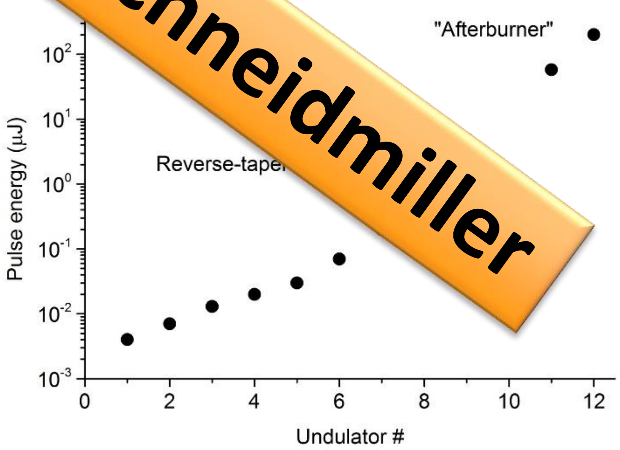




See talks by Evgeny Schneidmiller

- H… sing self seeding

- Reverse tapering - afterburner



FLASH2 now a regular user FEL

User schedule **FLASH1** (Oct / Nov 16)

Oct/Nov 2016, FLASH1 - Block3 last update: 06.10.2016 (changes Ulrich and 14.11.-19.11. FL1+2)

Date	Day	setup time in hours	day shift (7:00-19:00)						night shift (19:00 -7:00)					
24.10.16	Mo	4	Schnell	30.3 nm	BL1	L		11001711	Schnell	30.3 nm	BL1	L		11001711
25.10.16	Tu	5	Martins	14.9 nm	PG2		SD	11001717	Martins	14.9 nm	PG2		SD	11001717
26.10.16	We	4	Schnell	30.3 nm	BL1	L		11001711	Schnell	30.3 nm	BL1	L		11001711
27.10.16	Th		Schnell	30.3 nm	BL1	L		11001711	Schnell	30.3 nm	BL1	L		11001711
28.10.16	Fr	5	Martins	14.9 nm	PG2		SD	11001717	Martins	14.9 nm	PG2		SD	11001717
29.10.16	Sa		Martins	14.9 nm	PG2		SD	11001717	Martins	14.9 nm	PG2		SD	11001717
30.10.16	Su	4	Schnell	30.3 nm	BL1	L		11001711	Schnell	30.3 nm	BL1	L		11001711
31.10.16	Mo		Schnell	30.3 nm	BL1	L		11001711	Schnell	30.3 nm	BL1	L		11001711
1.11.16	Tu		Contingency (user @ FL2)						Contingency (user @ FL2)					
2.11.16	We	5	Martins	14.9 nm	PG2		SD	11001717	Martins	14.9 nm	PG2		SD	11001717
3.11.16	Th		Martins	14.9 nm	PG2		SD	11001717	Martins	14.9 nm	PG2		SD	11001717
4.11.16	Fr	4	von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
5.11.16	Sa		von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
6.11.16	Su	5	Ulrich	16.0 nm	PG1			11001736b	Ulrich	16.0 nm	PG1			11001736b
7.11.16	Mo	4	von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
8.11.16	Tu		von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
9.11.16	We	5	Ulrich	16.0 nm	PG1			11001736b	Ulrich	8.1 nm	PG1			11001736a
10.11.16	Th		Maintenance						Setup (Reference files)					
11.11.16	Fr	4	von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
12.11.16	Sa		von Korff Schmising	20.8 nm	BL2	L		11001719	von Korff Schmising	20.8 nm	BL2	L		11001719
13.11.16	Su	5	Ulrich	16.0 nm	PG1			11001736b	Ulrich	16.0 nm	PG1			11001736b
14.11.16	Mo	5	Ulrich	8.1 nm	PG1			11001736a	Ulrich	8.1 nm	PG1			11001736a
15.11.16	Tu		Ulrich	8.1 nm	PG1			11001736a	Ulrich	8.1 nm	PG1			11001736a
16.11.16	We	5	Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
17.11.16	Th		Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
18.11.16	Fr	5	Ulrich	8.1 nm	PG1			11001736a	Ulrich	8.1 nm	PG1			11001736a
19.11.16	Sa	5	Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
20.11.16	Su		Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
21.11.16	Mo		Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
22.11.16	Tu		Contingency (user @ FL2)						Contingency (user @ FL2)					
23.11.16	We	4	Boll	6.2 nm	BL1	L		11001729c	Boll	6.2 nm	BL1	L		11001729c
24.11.16	Th	5	Boll	4.2 nm	BL1	L		11001729b	Boll	4.2 nm	BL1	L		11001729b

User	wavelength	# bunches	rep rate	pulse dur.	pulse energy	Beamline	focus?	Laser /THz	Split + delay	application #
Schnell	30.3 nm +/- 1.00 nm	1		< 50 fs	50 µJ	BL1		L		11001711
Martins	14.9 nm +/- 0.10 nm	80	200kHz	< 50 fs	max. µJ	PG2			SD	11001717
von Korff Schmising	20.8 nm +/- 0.10 nm	1		< 50 fs	50 µJ	BL2		L		11001719
Boll	16.5 nm +/- 0.10 nm	1		< 50 fs	max. µJ	BL1		L		11001729a
Boll	4.2 nm +/- 0.10 nm	1		< 50 fs	max. µJ	BL1		L		11001729b
Boll	6.2 nm +/- 0.10 nm	1		< 50 fs	max. µJ	BL1		L		11001729c
Ulrich	8.1 nm +/- 0.10 nm	30	1MHz	>100 fs (uncritical)	max. µJ	PG1				11001736a
Ulrich	16.0 nm +/- 0.10 nm	250	1MHz	>100 fs (uncritical)	max. µJ	PG1				11001736b

User schedule **FLASH2** (Oct / Nov 16)

Oct/Nov 2016, FLASH 2 - Block3 last update: 5.9.2016 (2x Moshammer/Schnorr scheduled, shutdown entered)

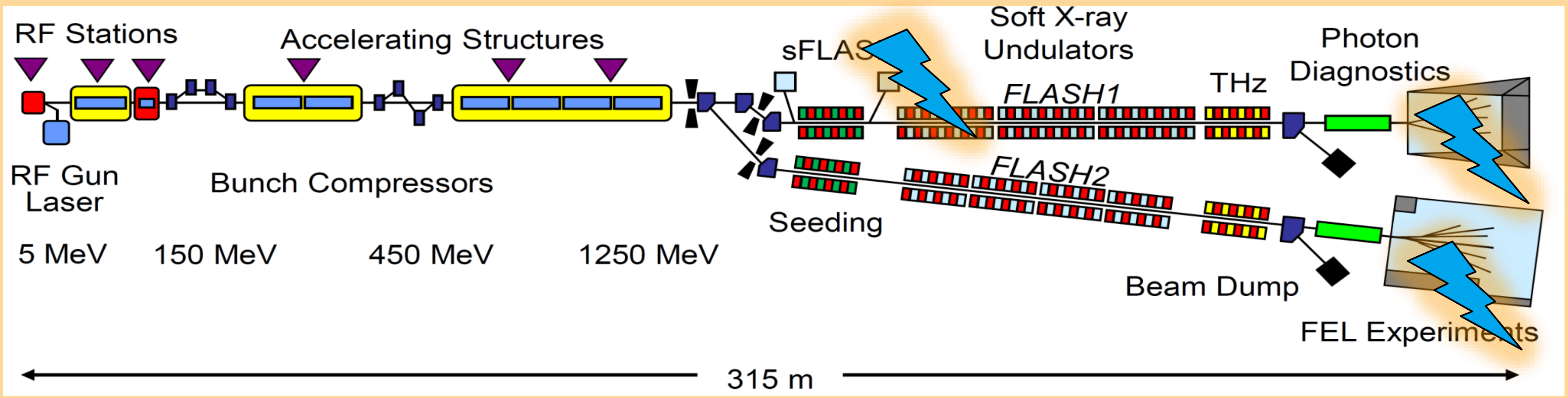
Date	Day	setup	day shift (7:00-19:00)				night shift (19:00 -7:00)			
24.10.16	Mo	6	Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
25.10.16	Tu		FL2 Operation	14.9 nm -	44.7 nm		FL2 Operation	14.9 nm -	44.7 nm	
26.10.16	We	5	Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
27.10.16	Th		Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
28.10.16	Fr		FL2 Operation	14.9 nm -	44.7 nm		FL2 Operation	14.9 nm -	44.7 nm	
29.10.16	Sa		FL2 Operation	14.9 nm -	44.7 nm		FL2 Operation	14.9 nm -	44.7 nm	
30.10.16	Su	5	Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
31.10.16	Mo		Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
1.11.16	Tu		Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
2.11.16	We		FL2 Operation	14.9 nm -	44.7 nm		FL2 Operation	14.9 nm -	44.7 nm	
3.11.16	Th		FL2 Operation	14.9 nm -	44.7 nm		FL2 Operation	14.9 nm -	44.7 nm	
4.11.16	Fr	6	Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
5.11.16	Sa		Moshammer/Schnorr	51.8 nm	FL26	11000976	Moshammer/Schnorr	51.8 nm	FL26	11000976
6.11.16	Su		FL2 Operation	16 nm -	48 nm		FL2 Operation	16 nm -	48 nm	
7.11.16	Mo		FL2 Operation	20.8 nm -	62.4 nm		FL2 Operation	20.8 nm -	62.4 nm	
8.11.16	Tu		FL2 Operation	20.8 nm -	62.4 nm		FL2 Operation	20.8 nm -	62.4 nm	
9.11.16	We		FL2 Operation	16 nm -	48 nm		FL2 Operation	16 nm -	48 nm	
10.11.16	Th		Maintenance				Setup (Reference files)			
11.11.16	Fr	6	Moshammer/Schnorr	20.7 nm	FL26	11002462a	Moshammer/Schnorr	20.7 nm	FL26	11002462a
12.11.16	Sa		Moshammer/Schnorr	20.7 nm	FL26	11002462a	Moshammer/Schnorr	20.7 nm	FL26	11002462a
13.11.16	Su		FL2 Operation	16 nm -	48 nm		FL2 Operation	16 nm -	48 nm	
14.11.16	Mo	6	Moshammer/Schnorr	20.7 nm	FL26	11002462a	Moshammer/Schnorr	20.7 nm	FL26	11002462a
15.11.16	Tu		Moshammer/Schnorr	20.7 nm	FL26	11002462a	Moshammer/Schnorr	20.7 nm	FL26	11002462a
16.11.16	We		FL2 Operation	6.2 nm -	18.6 nm		FL2 Operation	6.2 nm -	18.6 nm	
17.11.16	Th		FL2 Operation	6.2 nm -	18.6 nm		FL2 Operation	6.2 nm -	18.6 nm	
18.11.16	Fr		FL2 Operation	8.1 nm -	24.3 nm		FL2 Operation	8.1 nm -	24.3 nm	
19.11.16	Sa		FL2 Operation	6.2 nm -	18.6 nm		FL2 Operation	6.2 nm -	18.6 nm	
20.11.16	Su	5	Moshammer/Schnorr	13.8 nm	FL26	11002462b	Moshammer/Schnorr	13.8 nm	FL26	11002462b
21.11.16	Mo		Moshammer/Schnorr	13.8 nm	FL26	11002462b	Moshammer/Schnorr	13.8 nm	FL26	11002462b
22.11.16	Tu		Moshammer/Schnorr	13.8 nm	FL26	11002462b	Moshammer/Schnorr	13.8 nm	FL26	11002462b
23.11.16	We		Shutdown				Shutdown			
24.11.16	Th		Shutdown				Shutdown			

User	wavelength	# bunches	rep rate	pulse dur.	pulse energy	Beamline	focus?	Laser /THz	Split + delay	application #
Moshammer/Schnorr	51.8 nm +/- 1 nm	80	200kHz	50 fs	10 µJ	FL26				11000976
Moshammer/Schnorr	20.7 nm	40	100kHz	50-100 fs	50 µJ	FL26				11002462a
Moshammer/Schnorr	13.8 nm	40	100kHz	50-100 fs	50 µJ	FL26				11002462b

FLASH multiple beamlines

New FLASH 2 publication:

B Faatz, E Plönjes, et al :
Simultaneous operation of two soft x-ray free-electron lasers driven by one linear accelerator
New J. Phys. **18** 062002 (2016)



3 FELs in parallel:

T Plath et al
Free-electron laser multiplex driven by a superconducting linear accelerator.
J Synchrotron Radiat. **23** 1070 (2016)

Online diagnostic tools .

The *Atomic Photoionization Process* is a perfect candidate for non-destructive, pulse-resolved photon metrology tools.

➢ intensity	Gas-Monitor Detectors (GMD)
➢ beam position	GMD Split Electrodes
➢ spectral distribution	Photoionization spectra / VLS grating
➢ polarisation	Photoemission distribution
➢ XUV pulse duration	THz streaking
➢ coherence	split & delay lines, diffraction
➢ focus size	wave-front sensor

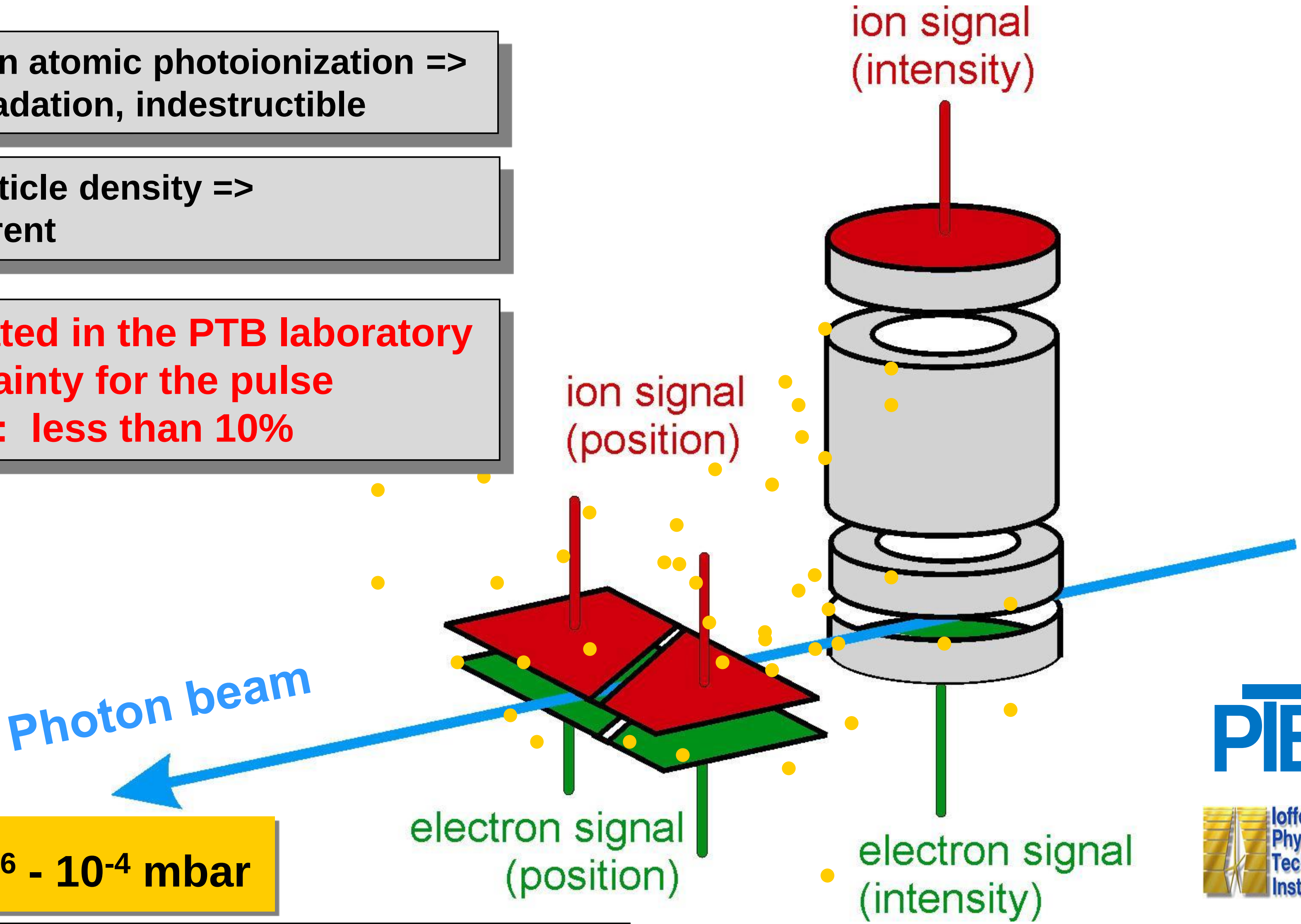
The effort for developing such detector systems is extremely high, in particular due to the tight requirements on robustness and reliability.

Online intensity and beam position monitoring.

Based on atomic photoionization => no degradation, indestructible

Low particle density => transparent

Calibrated in the PTB laboratory Uncertainty for the pulse energy: less than 10%

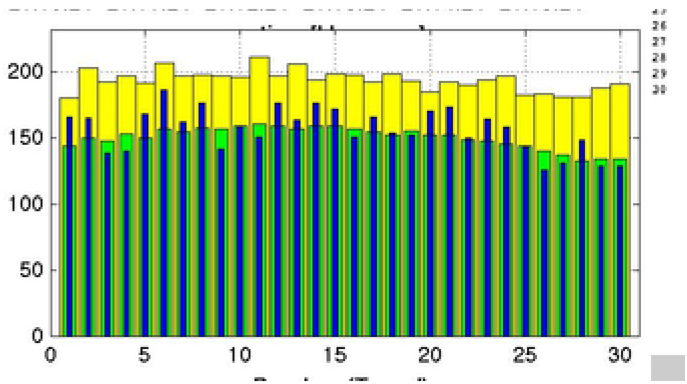


10^{-6} - 10^{-4} mbar

Reference number at the German Patent Office: 102 44 303

GMD pulse resolved

- Pulse resolved energy and **beam position** (FLASH2)



- Online quality checks
  - traffic light indicators
  - resolution checks for measured parameters

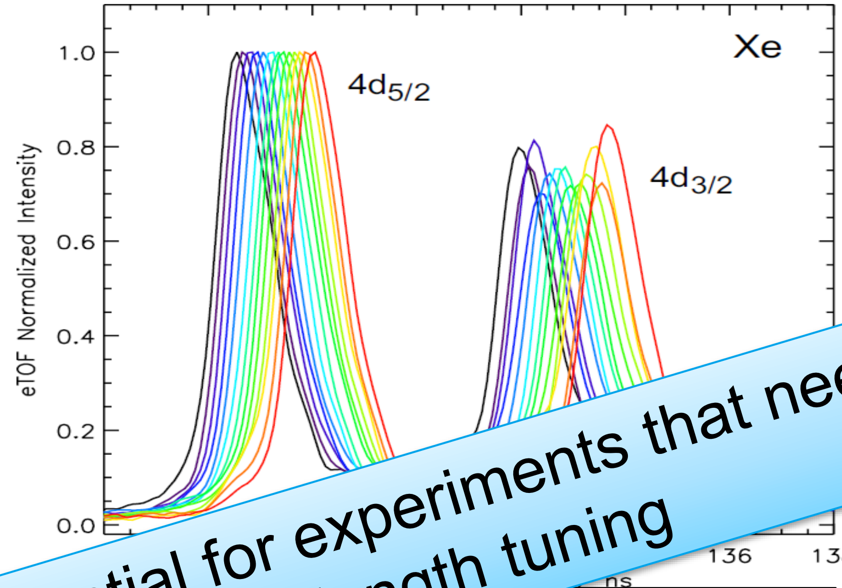
Online measuring wavelength using photoionization.

> Electrons

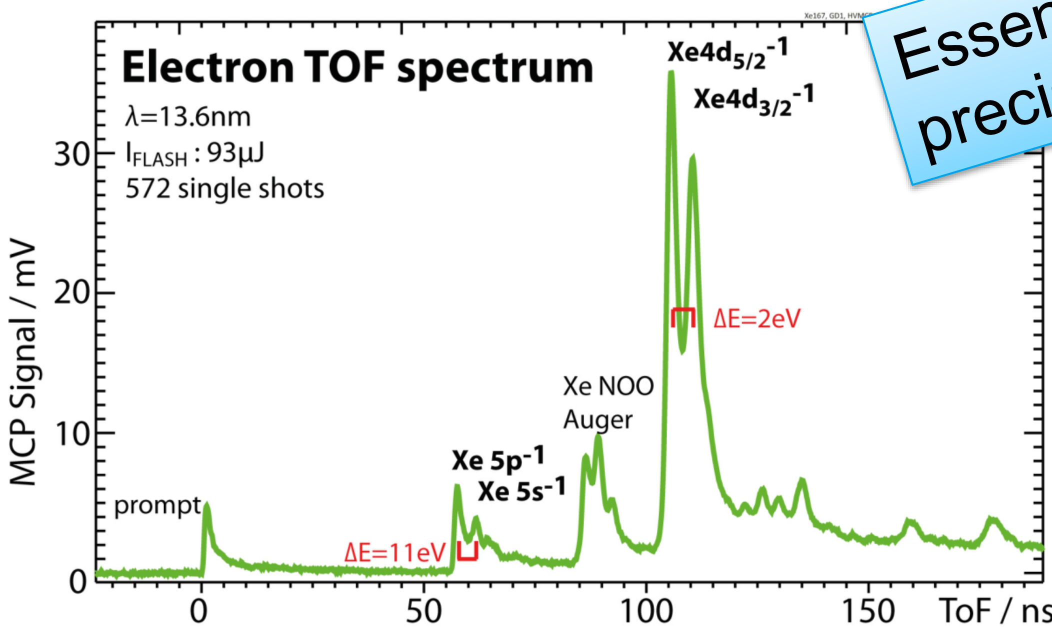
Determination of the kinetic energy of photoelectrons directly from the flight time

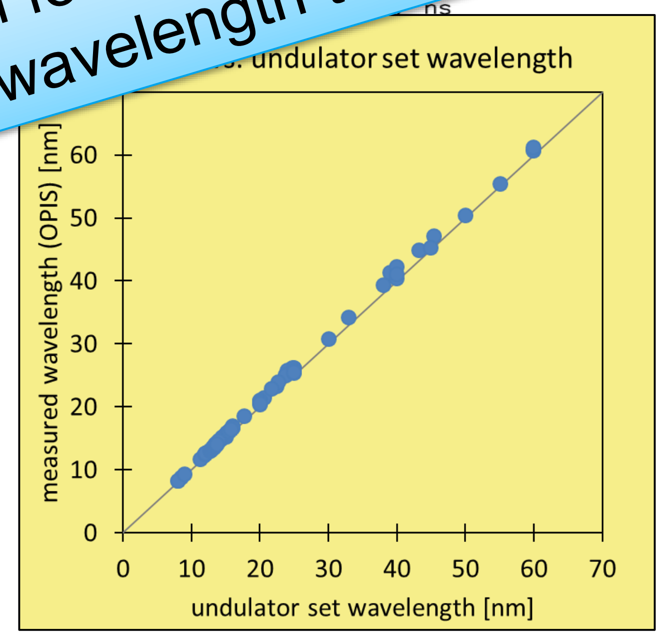
$$E_{FEL} = E_{kin} + E_{bind}, \quad \lambda_{FEL} = hc/E_{FEL}$$

- Mean WL resolution < 0.1 eV
- Absolute reference: Auger lines

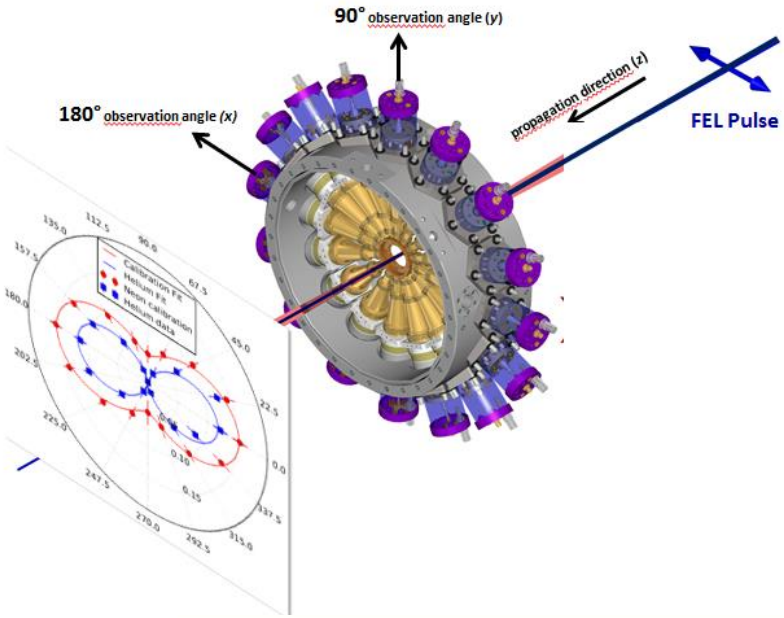


Essential for experiments that need precise wavelength tuning





Gas based detectors – Polarization measurement.



Polarisation: Measurement of angular distribution of the emitted photoelectrons by 16 TOFs.

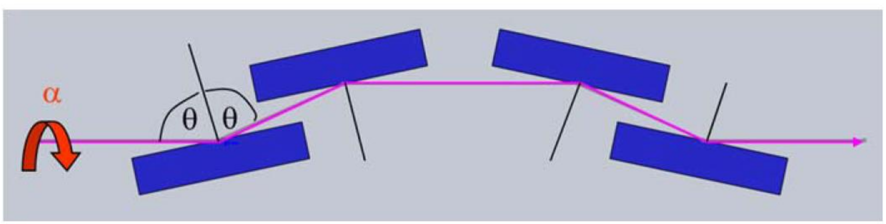
Not yet integrated in the Beamlines

Collaboration with J. Viefhaus (PETRA III)

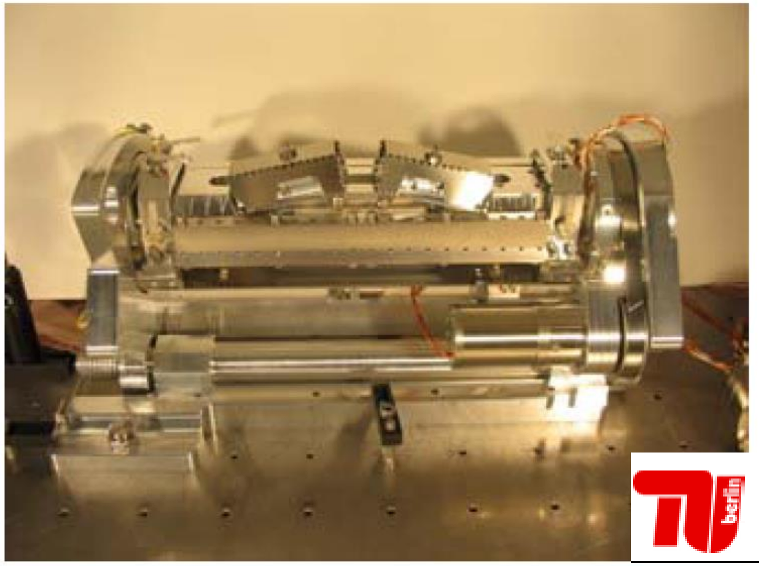
Allaria E et al Phys. Rev. X **4** 041040 (2014)

Düsterer etJ. Phys. B: At. Mol. Opt. Phys. **49** 165003 (2016)

basic geometry



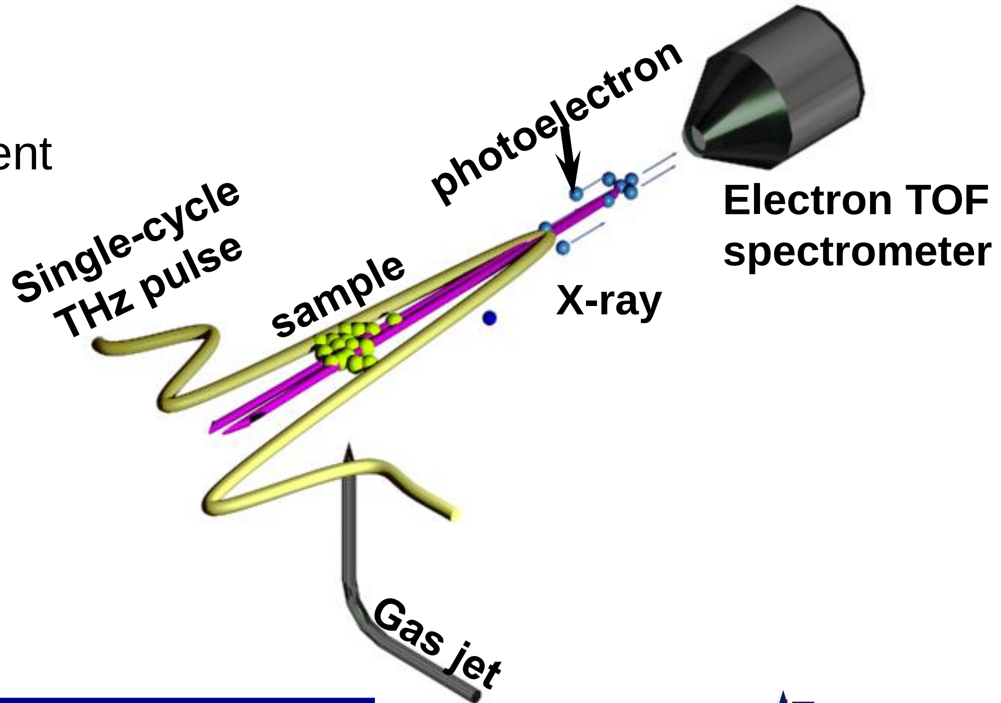
- photon energies between 30 eV and 70 eV (3d metal M edges)
- **Available for BL1, 2 and 3**
- ~ 10% transmission
- maximal degree of circular polarization around 80%



The most difficult one - pulse duration

Extensive study on different techniques: Düsterer et al, PRSTAB **17**, 120702 (2014)

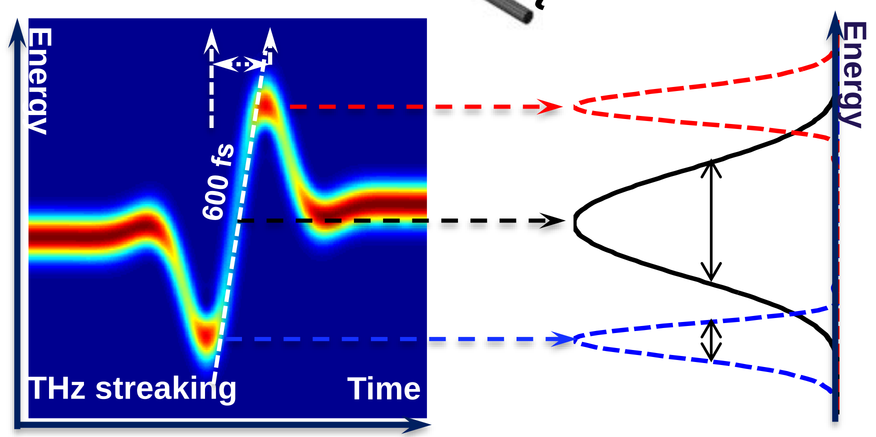
- non-invasive
- online monitoring
- single bunch resolved measurement



THz Streaking

(permanent installation at FLASHII planned for 2017/8)

Measuring the pulse duration and arrival time by means of a single cycle THz streaking field.

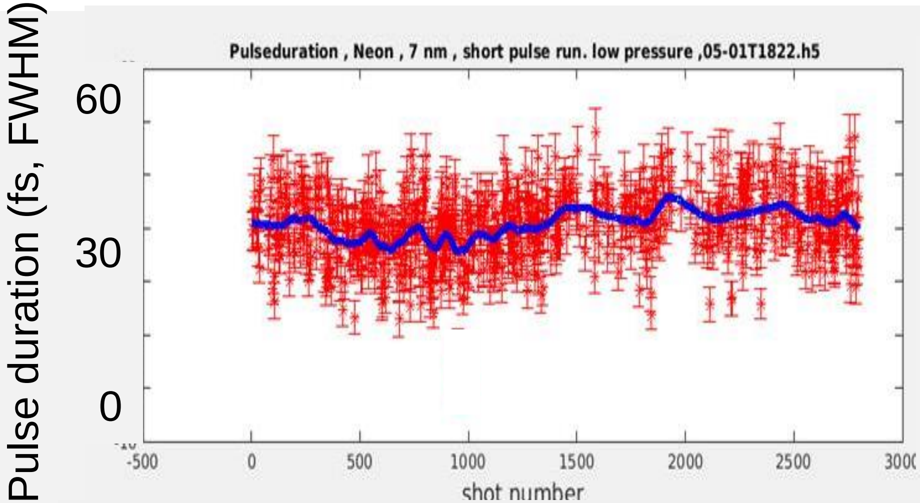


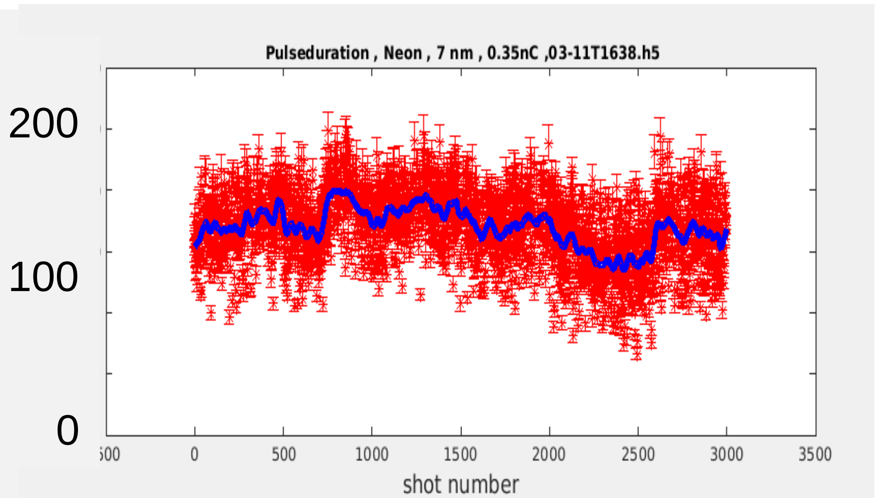
Nat. Photonics **3**, 523 (2009), Nat. Photonics **6**, 852 (2012)

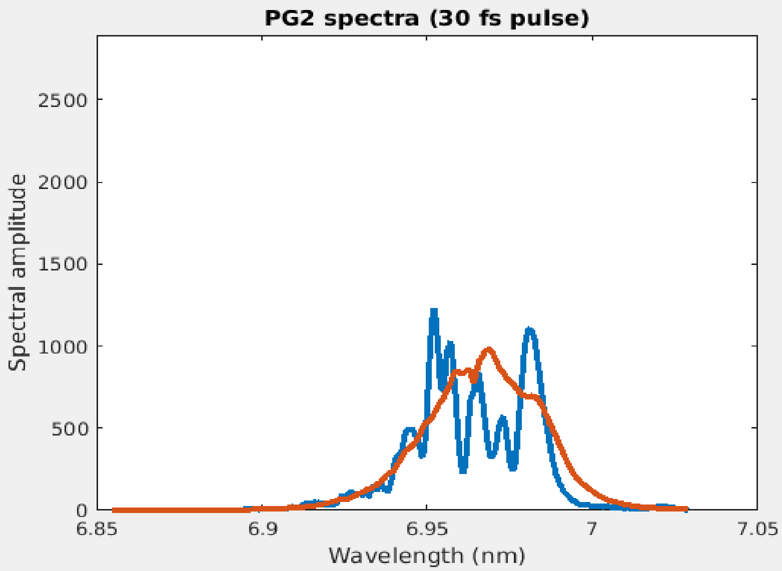
Pulse duration for different FEL settings

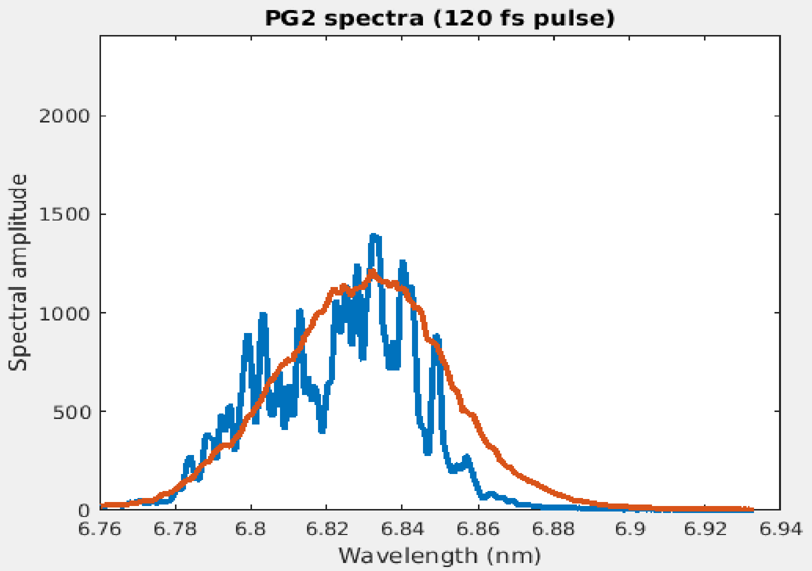
7 nm, 15 µJ, 0.20 nC -> ~30 fs FWHM

7 nm, 50 µJ, 0.35 nC -> ~ 120 fs FWHM

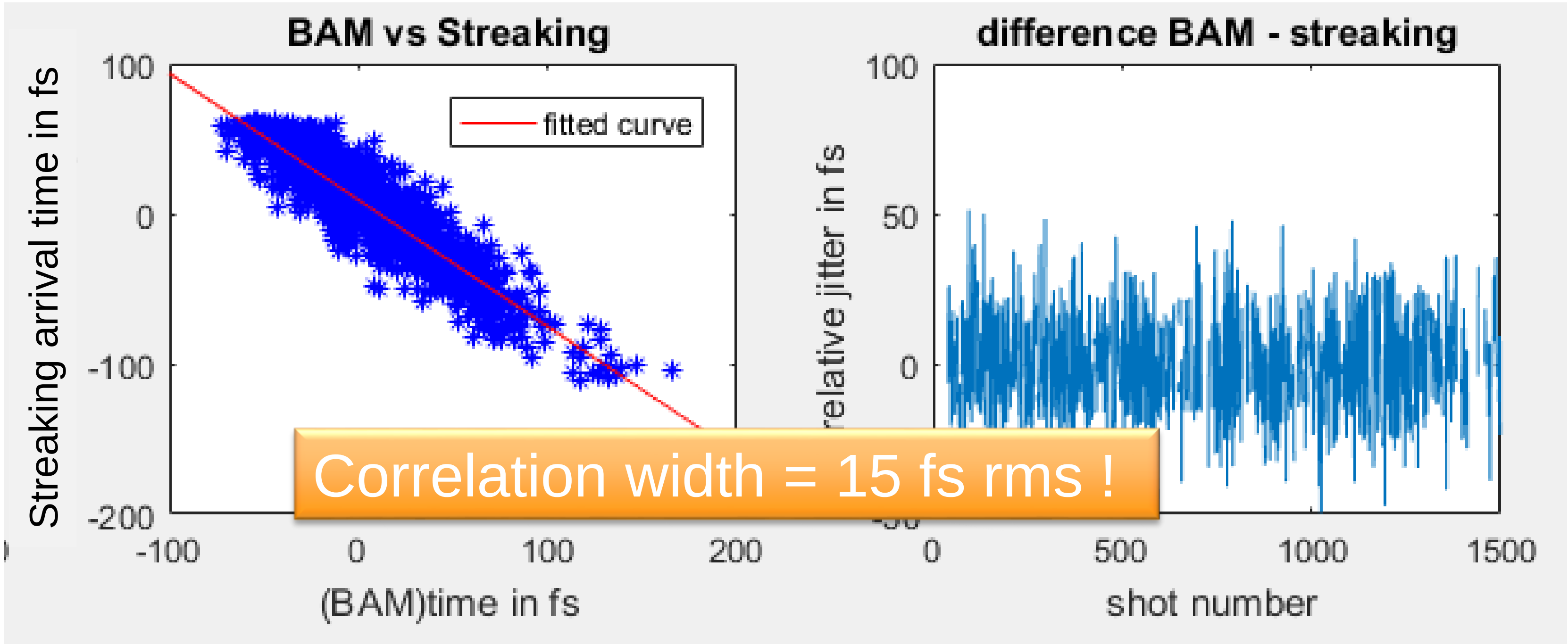




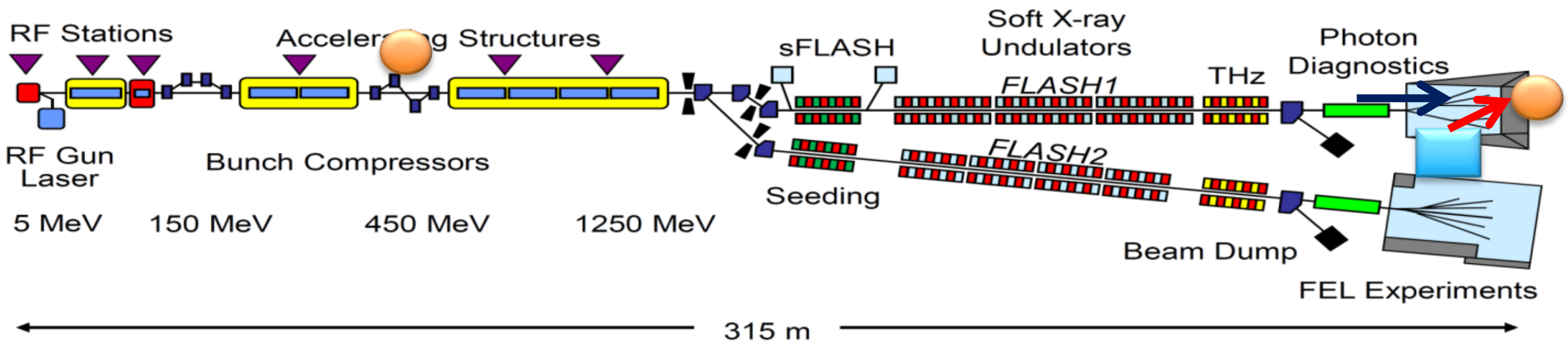




Arrival time measurements –> precission for pump-probe



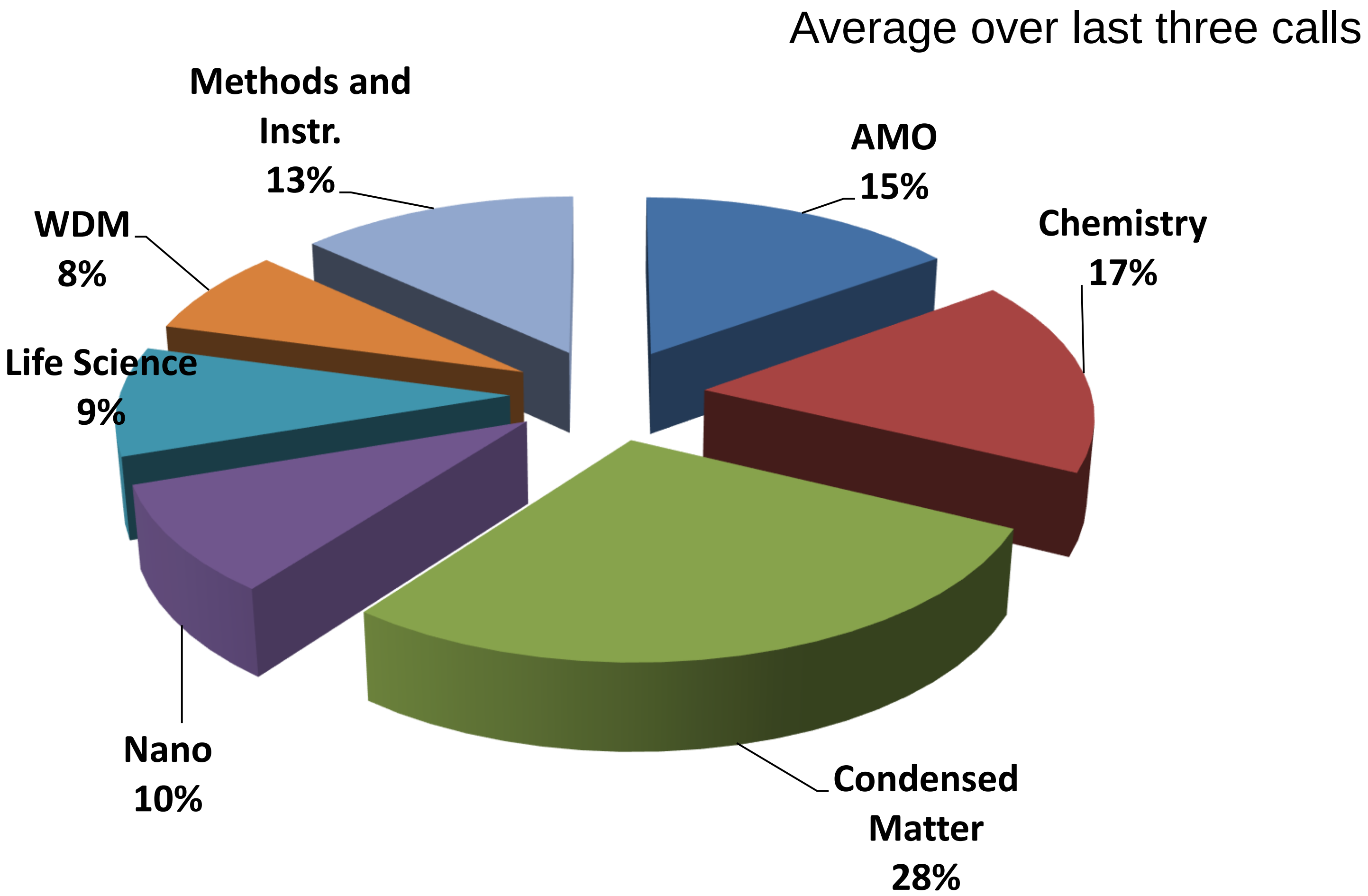
- Measuring electron bunch arrival time 200 m away from the experiment
- Comparing to Pump-probe laser vs XUV pulse



FLASH facility

Present and future

Science@FLASH

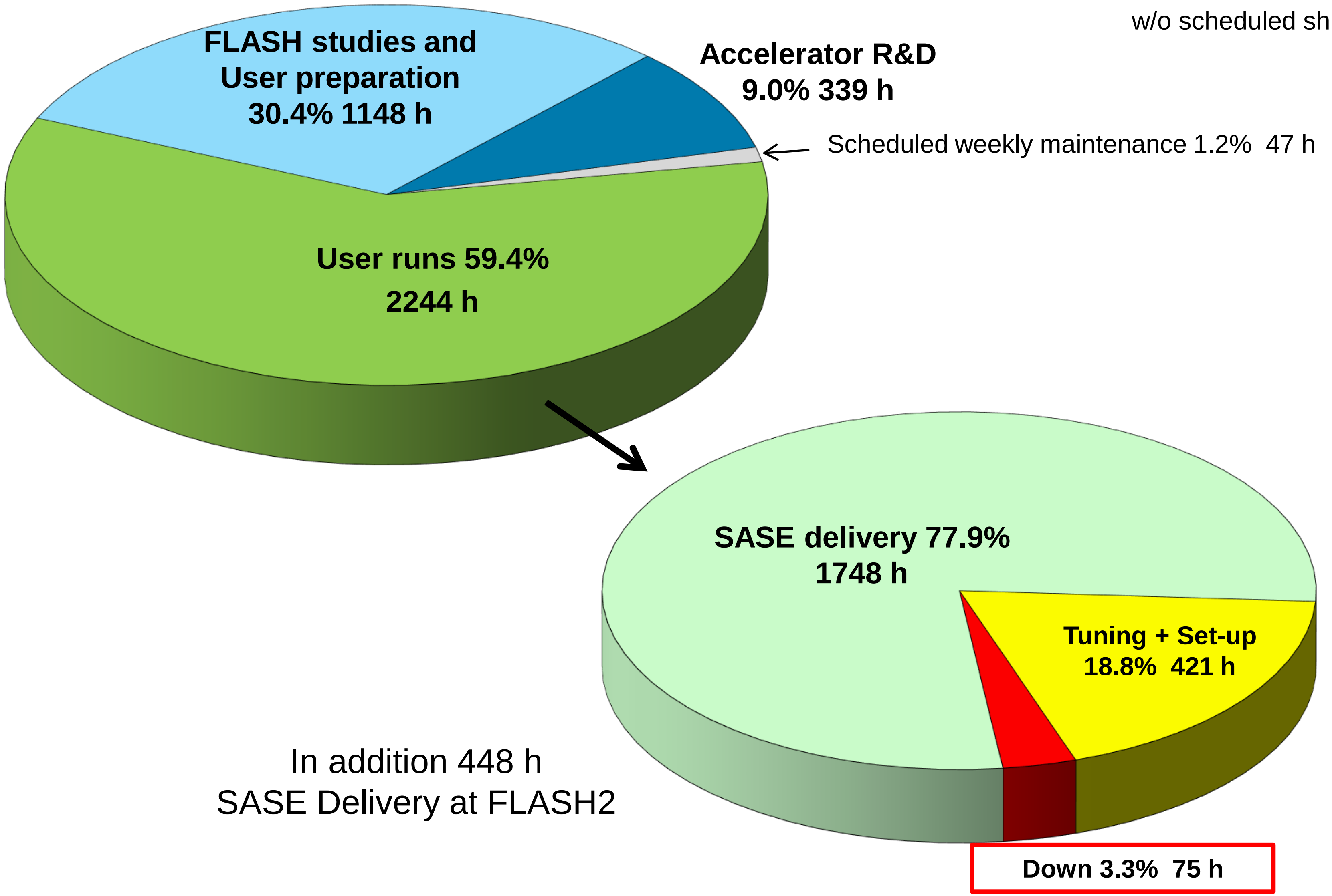


~80 % time-resolved (pump-probe) experiments

- **~ 50% Optical/XUV**
- **XUV/XUV**
- **THz/XUV**

FLASH1 User Period 7 (January – June 2016)

1.1. – 26.6.2016
w/o scheduled shutdowns (501 h)

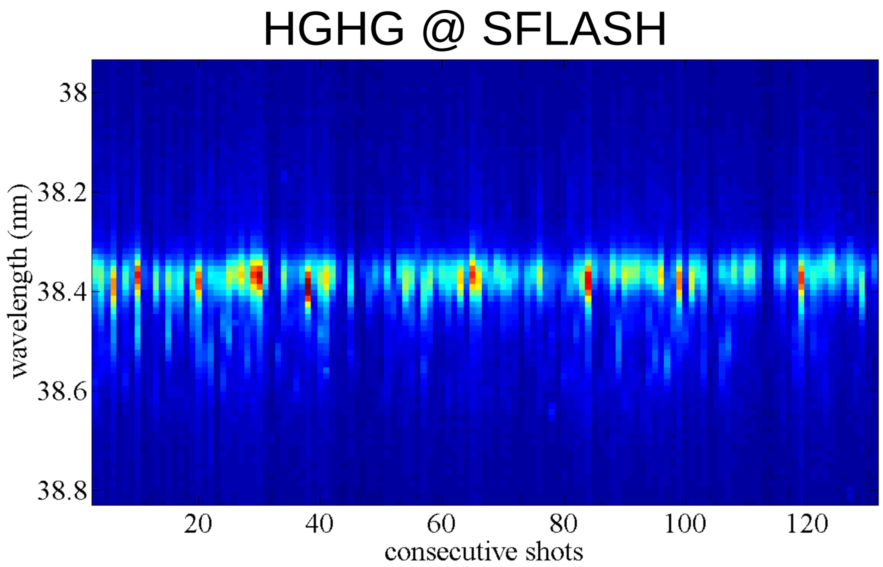


In addition 448 h
SASE Delivery at FLASH2

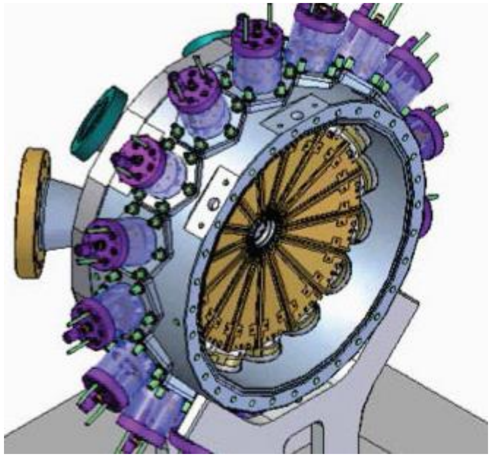
FLASH – plans for 2017 to 2020

- Variable gap undulators for FLASH1

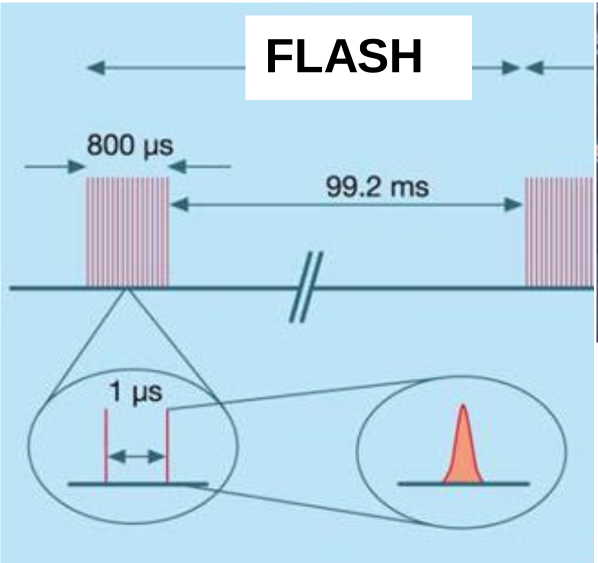
- external seeding FLASH2

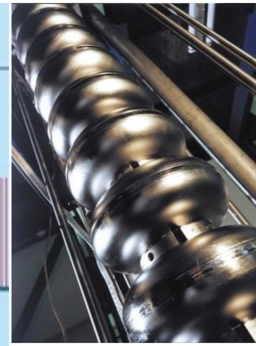


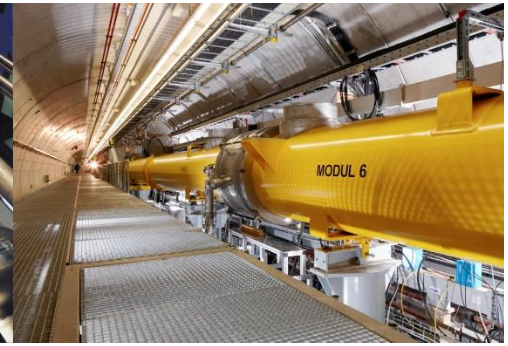
- Variable polarization (Delta undulator)



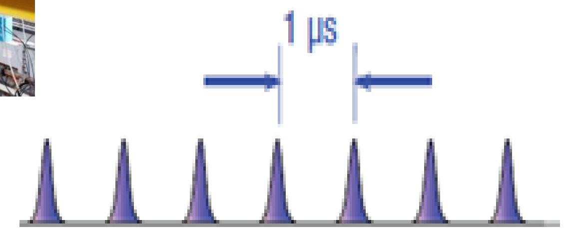
FLASH2020 – A High-Repetition Rate Soft X-Ray Camera







FLASH2020



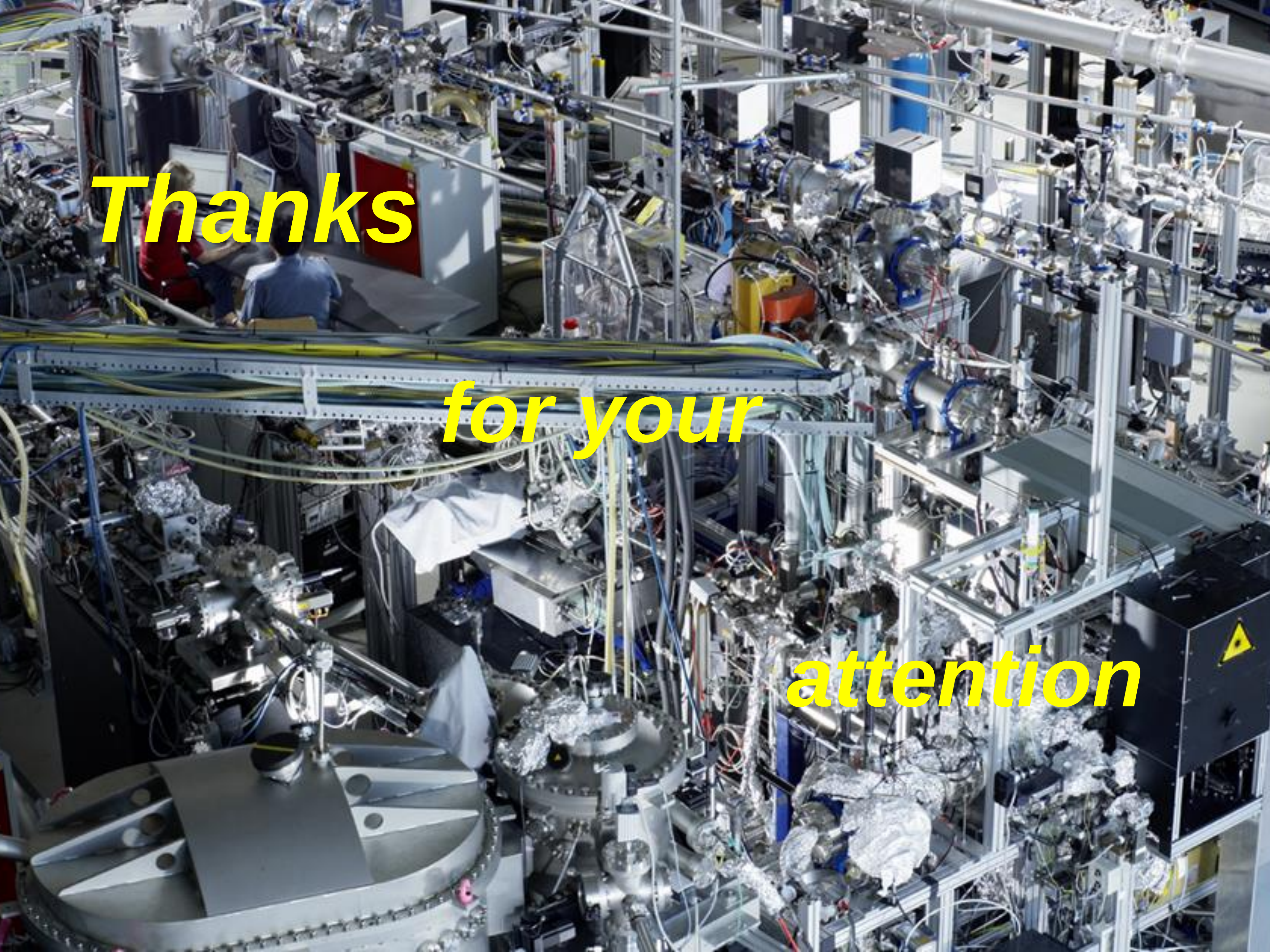
Gain x 125

FLASH2020

- cw operation up to 1MHz
- fundamental 30-550eV
- multiple FEL lines with up to 100kHz
- external seeding up to 100kHz
- complementary to XFEL/LCLS-II

SCIENCE

- Time-resolved coincidences
- Electronic structure movies
- Single-shot nanoscale imaging
- Light-induced dynamics and control
- Nonlinear spectroscopy


Thanks
for your
attention

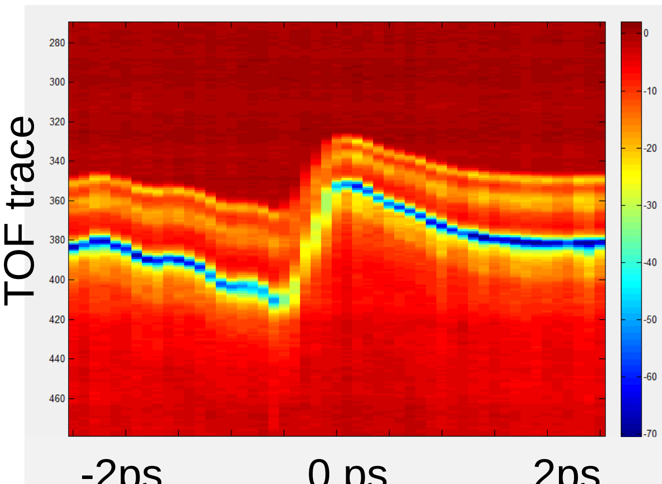
FLASH facility

Present and future

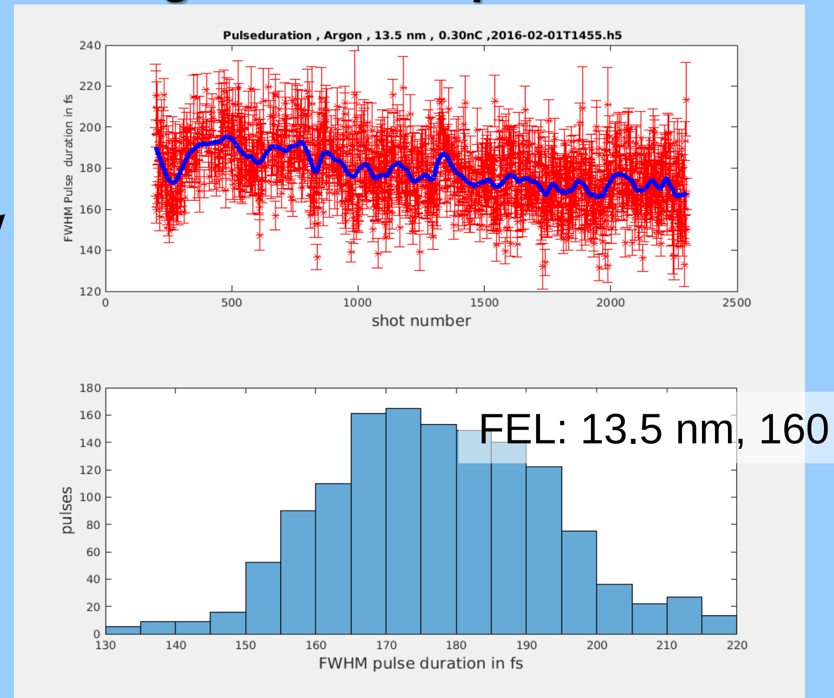
THz Streaking

Streaking raw data

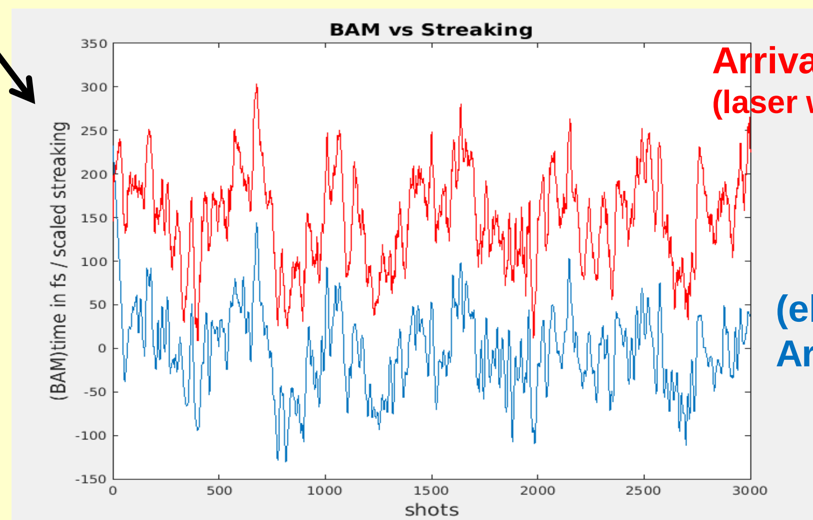
(delay scan)



Single shot XUV pulse duration



Arrival time

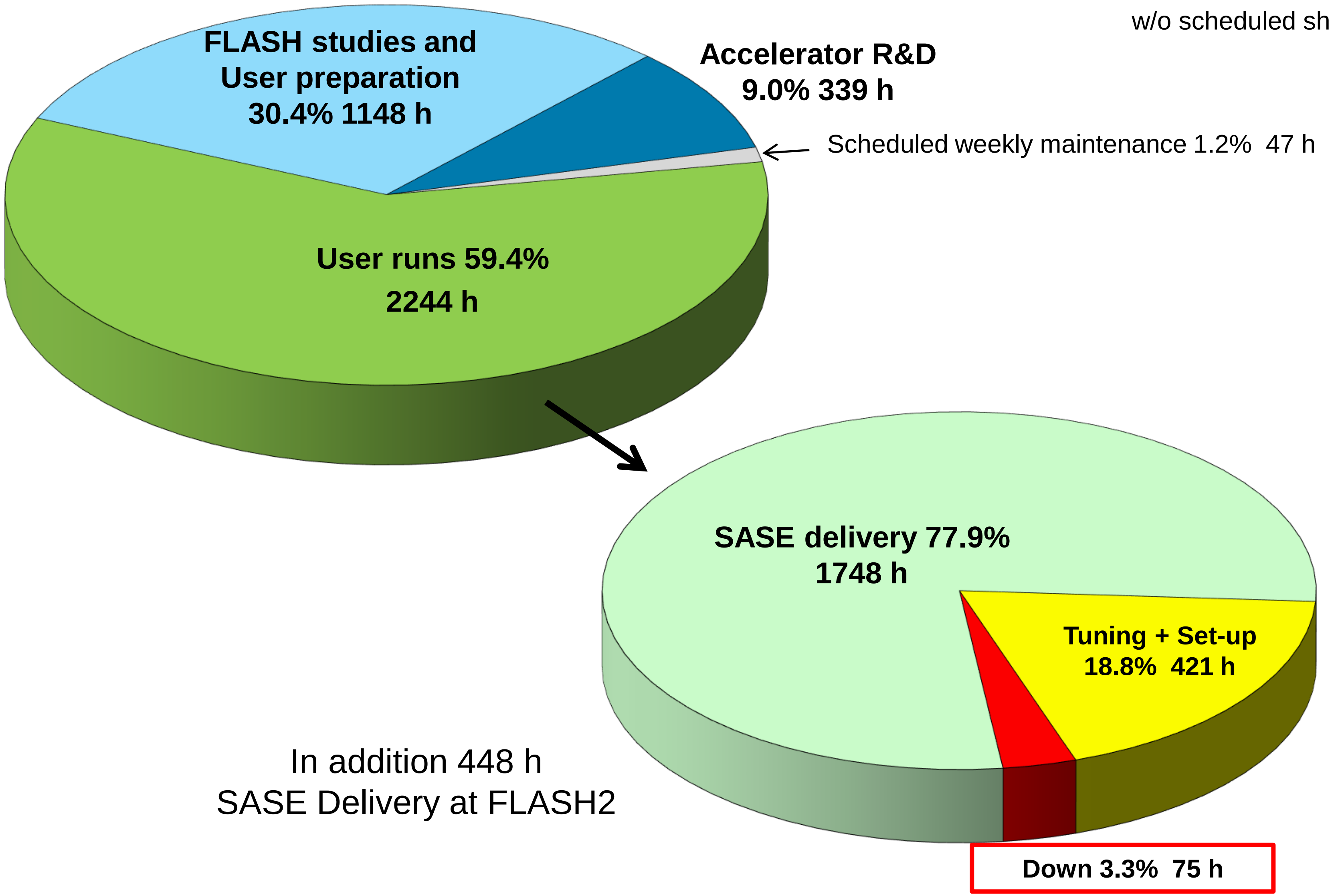


Arrival time by streaking
(laser with <10 fs rms synch !)

(electron) Beam Arrival time Monitor

FLASH1 User Period 7 (January – June 2016)

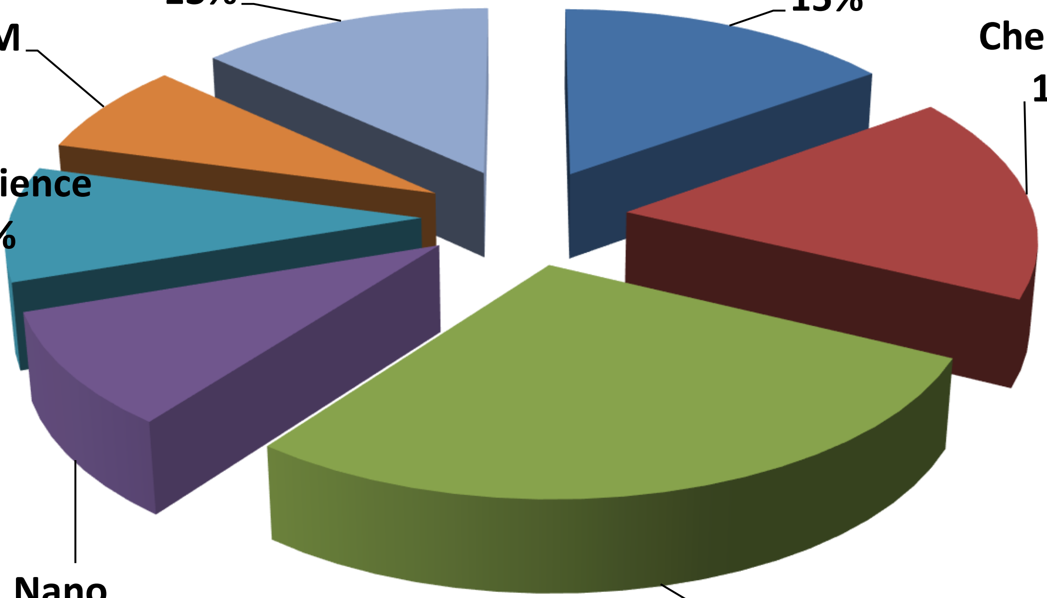
1.1. – 26.6.2016
w/o scheduled shutdowns (501 h)



In addition 448 h
SASE Delivery at FLASH2

Science@FLASH

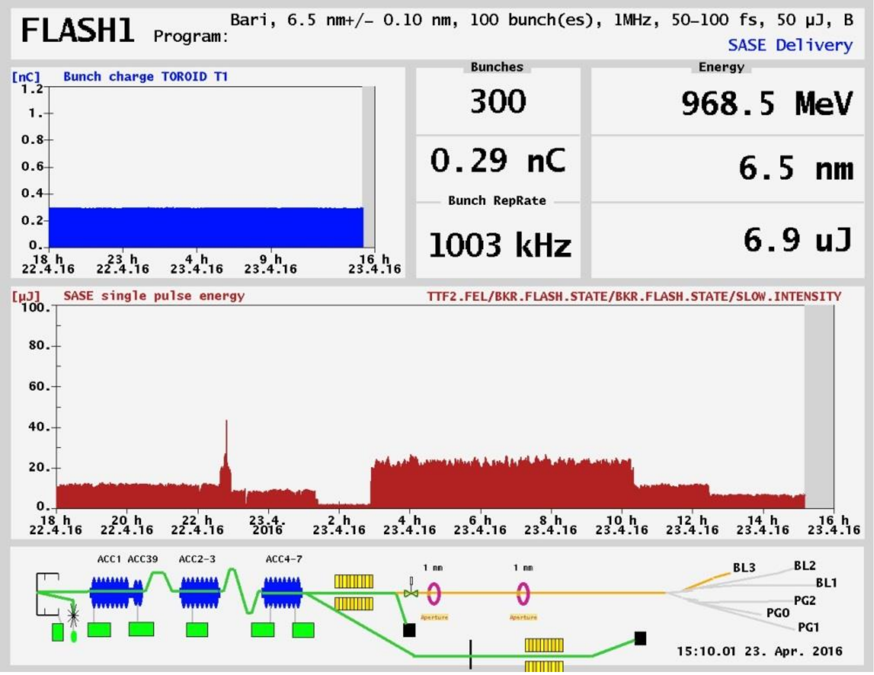
Average over last three calls

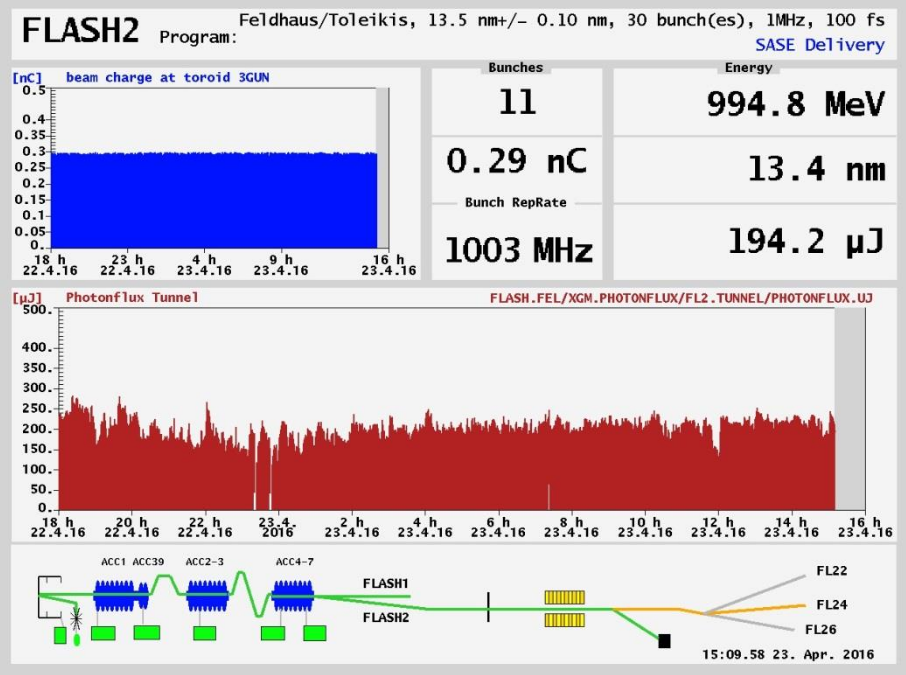


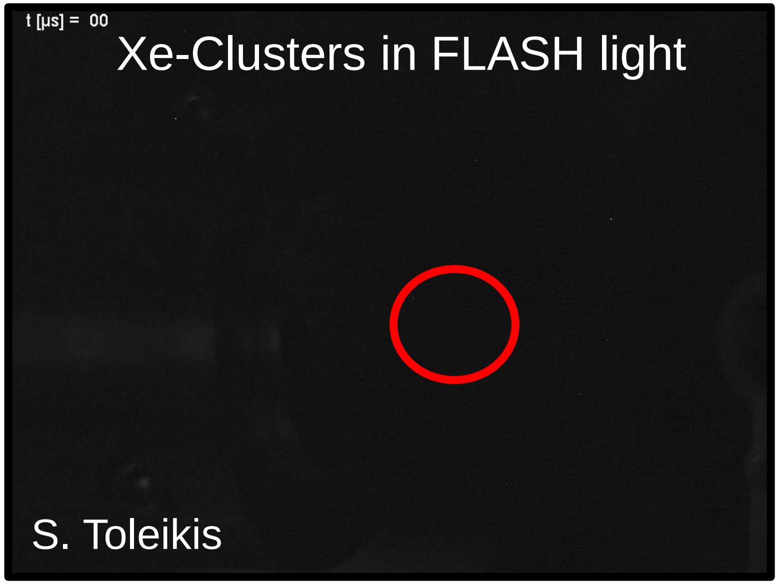
~80 % time-resolved (pump-probe) experiments

- ~ 50% Optical/XUV
- XUV/XUV
- THz/XUV

First users at FLASH2 – April 2016

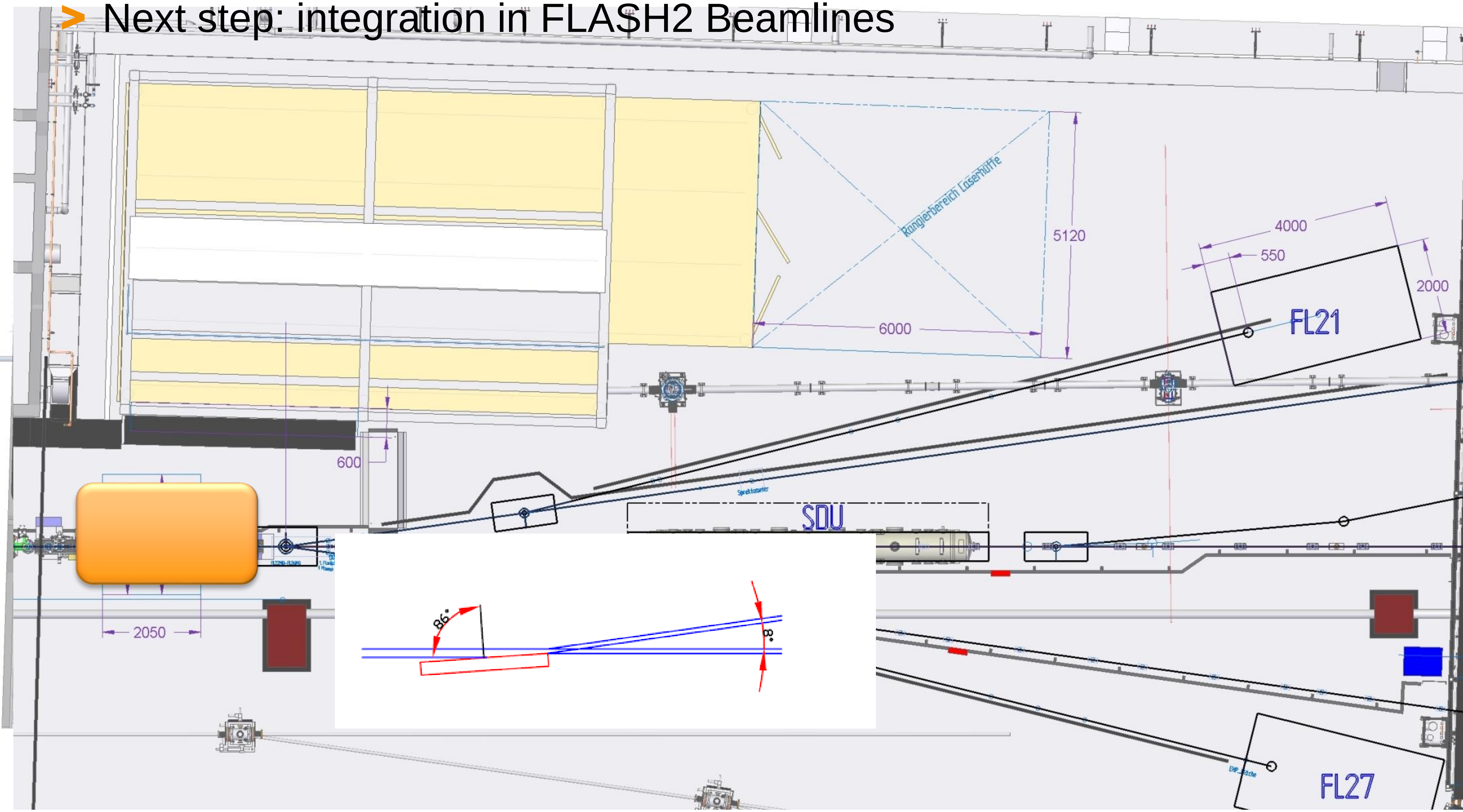




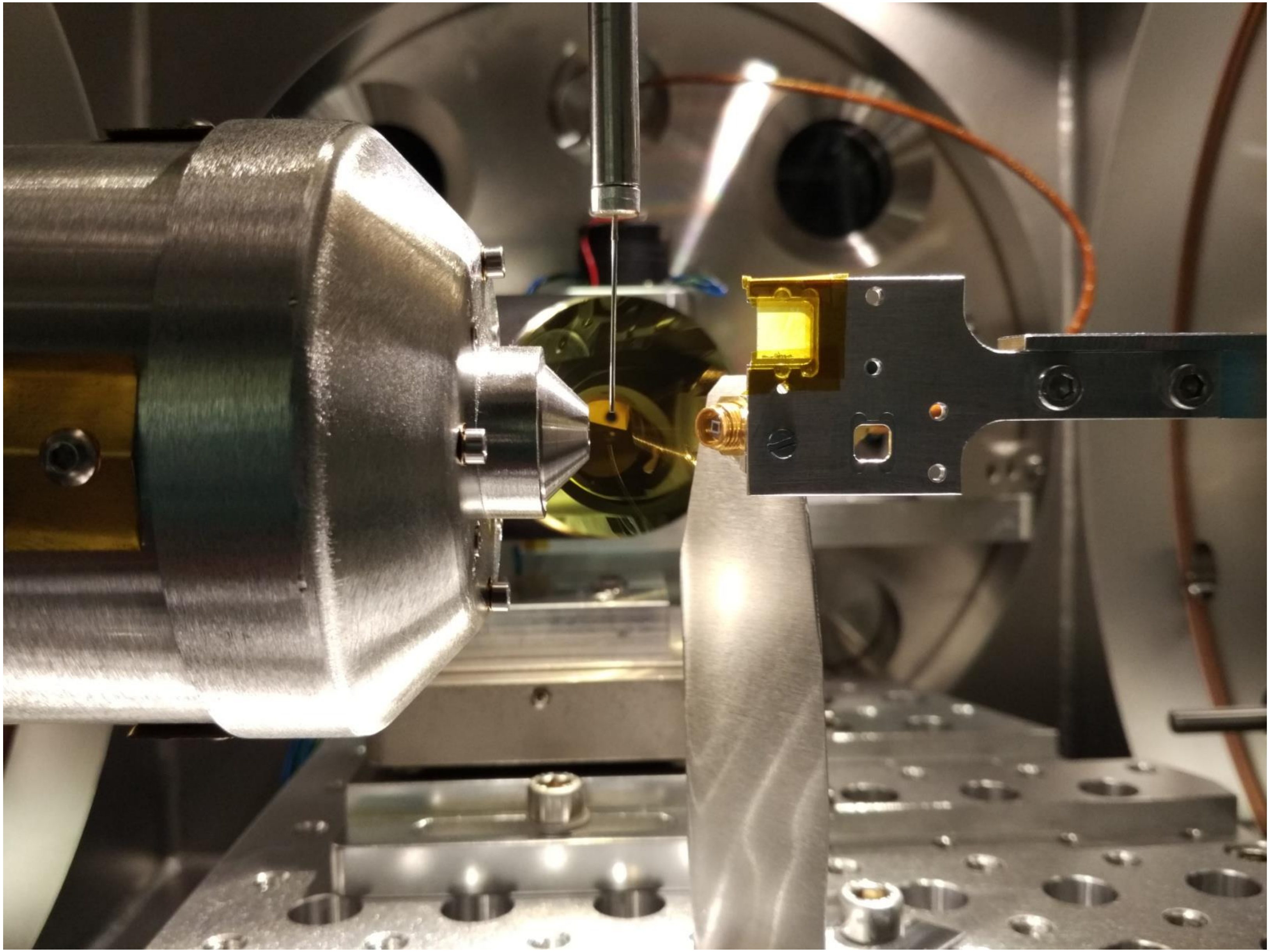


THz Streaking at FLASH 2

- So far „commissioning“ beamtimes (at FLASH1)
- Next step: integration in FLASH2 Beamlines



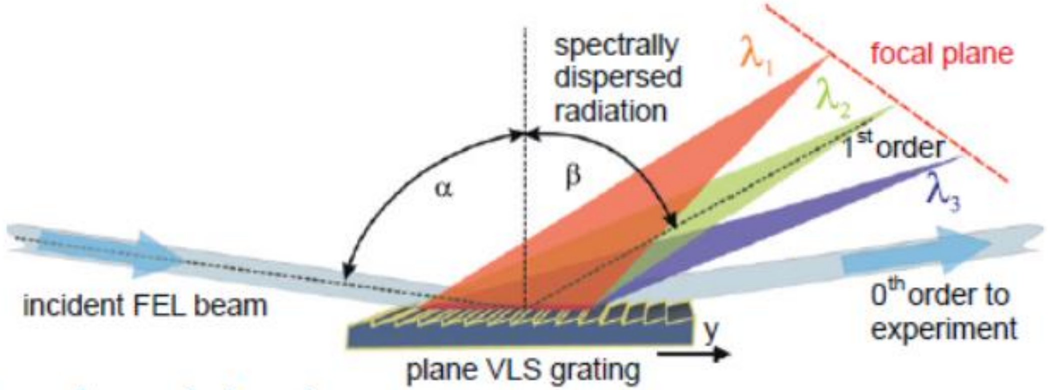
THz streaking setup



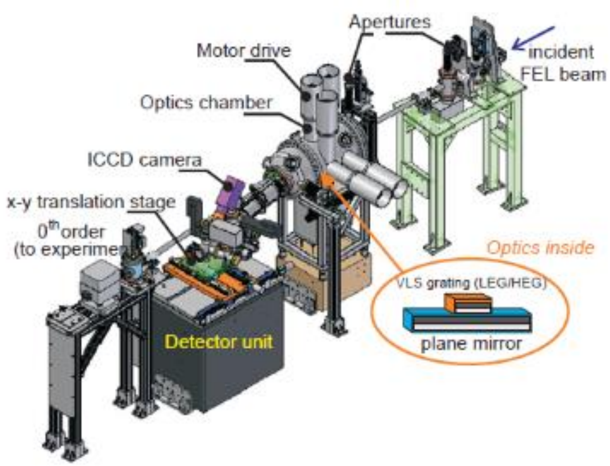
Online VLS grating spectrometer

- Higher resolving power as OPIS

Working principle



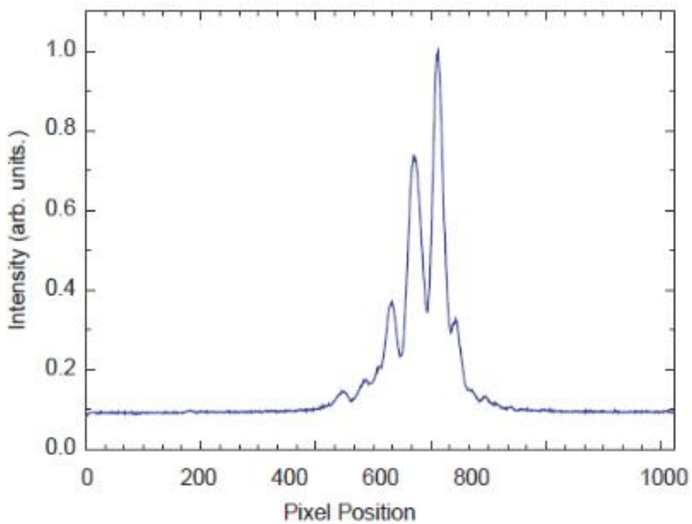
Experimental setup



Brenner, C. et al.. NIM A, 635 (2011) S99-S103

Results:

Resolving power ~2000-3000

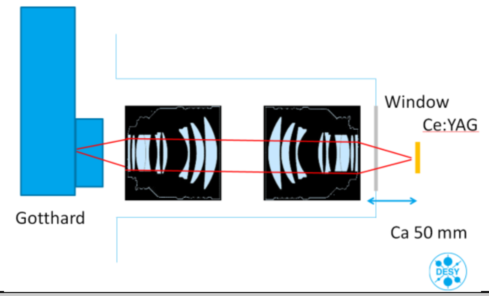


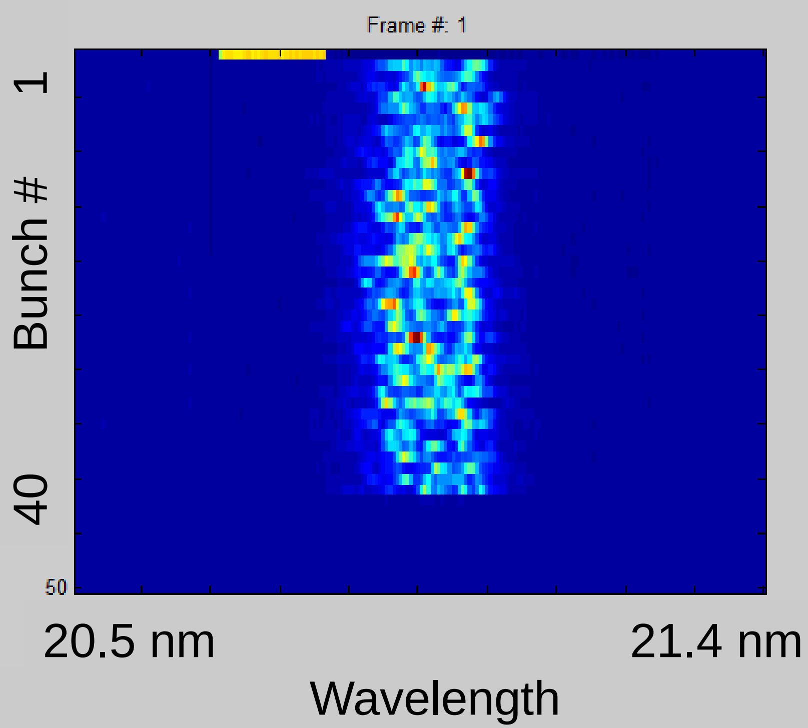
Online VLS spectrometer with fast 1D detector

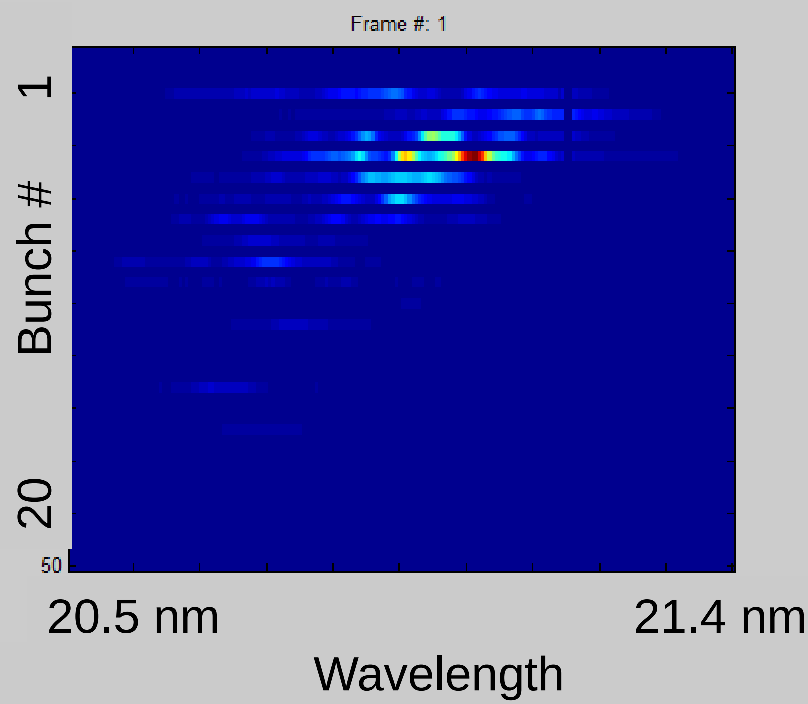
https://www.psi.ch/detectors/gotthard

Recent upgrade: use 1 MHz (burst) line detector (Gotthard, PSI)

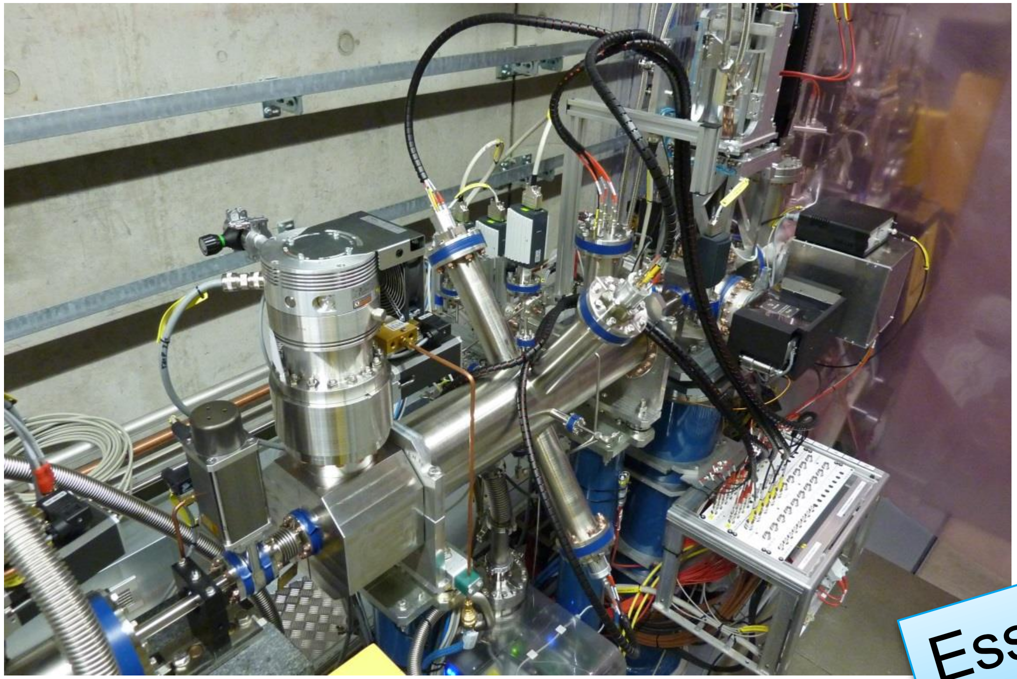
Acquire FEL ***each*** FEL spectrum in the bunchtrain







Online Wavelength Spectrometer OPIS @ FLASH2.



FLASH2 tunnel photon diagnostics section

Commissioning of OPIS in the tunnel diagnostics section:

- Vacuum interlock tests: gas inlet system
- Self-calibration: Auger lines, resonances
- Optimize operatio
- Wavel

Essential for experiments needing precise wavelength tuning