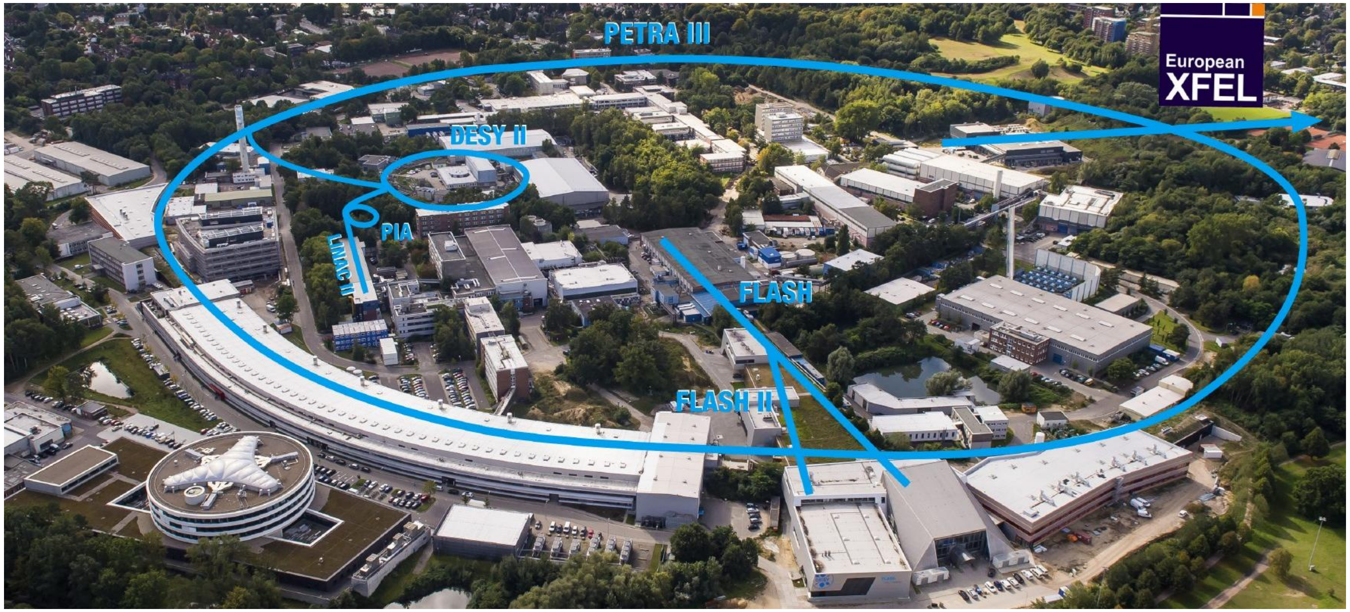
PETRA III, Status and Upgrade

(plus some slides on FLASH and XFEL)

M. Bieler,

for the PETRA III Team

ESLS XXV, Dortmund, 21.11.2017



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Content

- **PETRA III Overview**
- **PETRA User Operation 2017**
- **Plans for 2018**
- **PETRA IV**
- FLASH
- XFEL

PETRA III Overview

- 2.3 km circumference
- 6 GeV electrons
- 20 damping wigglers
- 19 (+ 5) undulator beamlines
- 1 nm rad x 10 pm rad
- 100 mA
- TopUp operation, 1% beam current variation

PETRA III Overview

- Max von Laue Hall:
- 1/8 of the circumference of PETRA III
- 8 double bend acromat cells
- 14 undulator beamlines:
  - 2 m Undulators: 11
  - 5 m Undulators: 3 (2+1)
  - 5 m Apple Undulator: 1

User Operation 2017

2017	Januar	Februar	März	April	Mai	Juni		Juli	Aug.	Sep.	Okt.	Nov.	Dez.
1		Shutdown	Shutdown	multi	. multi	. 40	1	. multi	Shutdown	. multi	Test Run 40	MDT	. 40
2	Shutdown	Shutdown	Shutdown	multi	. multi	. 40	2	. multi	Shutdown	. multi	. 40	. 40	. 40
3	Shutdown	Shutdown	Shutdown	multi	MDT	. 40	3	. multi	Shutdown	. multi	. 40	. 40	. 40
4	Shutdown	Shutdown	Shutdown	multi	. 40	. 40	4	. multi	Shutdown	. multi	MDT	. 40 TdoT	. 40
5	Shutdown			MDT	. 40	. 40	5	. multi	Shutdown	. multi	. 40	. 40	. 40
6	Shutdown	Shutdown		multi	. 40	. 40	6	Shutdown		MDT	. 40	Service	MDT
7	Shutdown	Shutdown		multi	. 40	MDT	7	Shutdown		. multi	. 40	Week	. 40
8		Shutdown		multi	. 40	. 40	8	Shutdown		. multi	. 40		. 40
9	Shutdown	Shutdown		. multi	. 40	. 40	9			. multi	. 40		. 40
10	Shutdown	Shutdown		. multi	MDT	. 40	10	Shutdown		. multi	. 40		. 40
11	Shutdown	Shutdown		. multi	. 40	. 40	11	Shutdown		. multi	MDT		. 40
12	Shutdown			MDT	. 40	. 40	12	Shutdown		. multi	. 40	Test Run multi	. 40
13	Shutdown	Shutdown		. multi	. 40	. 40	13	Shutdown	. multi	MDT	. 40	. multi	MDT
14	Shutdown	Shutdown		. multi	. 40	MDT	14	Shutdown	multi	. multi	. 40	. multi	. 40
15		Shutdown		. multi	Service	. 40	15	Shutdown	multi	. multi	. 40	MDT	. 40
16	Shutdown	Shutdown		. multi	Week	. 40	16		multi	. multi	. 40	. multi	. 40
17	Shutdown	Shutdown		. multi		. 40	17	Shutdown	. multi	. multi	. 40	. multi	. 40
18	Shutdown	Shutdown		. multi		. 40	18	Shutdown	. multi	. multi	MDT	. multi	. 40
19	Shutdown			. multi		. 40	19	Shutdown	. multi	. multi	. 40		. 40
20	Shutdown	Shutdown	multi	. multi		. 40	20	Shutdown	. multi	MDT	. 40	. multi	MDT
21	Shutdown	Shutdown	multi	. multi	. 40	MDT	21	Shutdown	. multi	. multi	. 40	. multi	. 40
22		Shutdown	multi	. multi	. 40	. multi	22	Shutdown	. multi	. multi	. 40	MDT	. 40
23	Shutdown	Shutdown	multi	. multi	. 40	. multi	23		MDT	. multi	. 40	. multi	Shutdown
24	Shutdown	Shutdown	multi	. multi	MDT	. multi	24	Shutdown	. multi	. multi	. 40	. multi	Shutdown
25	Shutdown	Shutdown	multi	. multi	. 40	. multi	25	Shutdown	. multi	Service	MDT	. multi	Shutdown
26	Shutdown		multi	MDT	. 40	. multi	26	Shutdown	. multi	Week	. 40		Shutdown
27	Shutdown	Shutdown	multi	. multi	. 40	. multi	27	Shutdown	. multi		. 40	. multi	Shutdown
28	Shutdown	Shutdown	multi	. multi	. 40	MDT	28	Shutdown	. multi		. 40	. multi	Shutdown
29			MDT	. multi	. 40	. multi	29	Shutdown	. multi		. 40	MDT	Shutdown
30	Shutdown		multi	. multi	. 40	. multi	30		MDT		. 40	. 40	Shutdown
31	Shutdown		multi		MDT		31	Shutdown	. multi		. 40		Shutdown

	Service Week
	Sunday (User Run)
	Userrun
MDT	Machine Development

External users from April 10 to July 5 and from Aug. 17 to Dec. 22

User Operation 2017

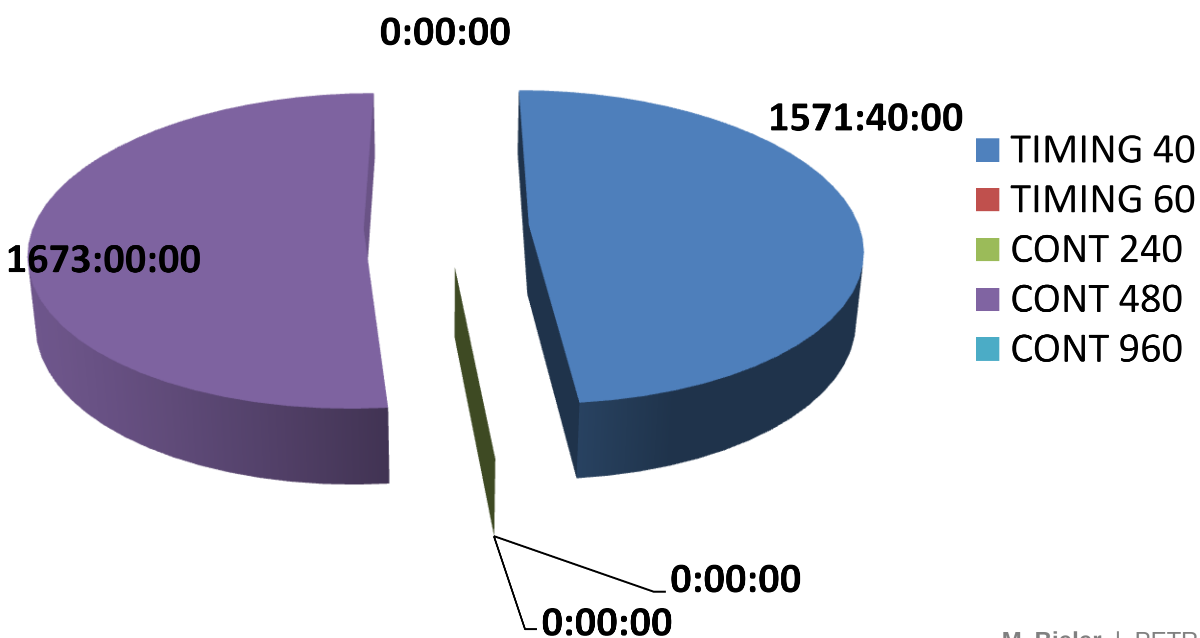
User Run 2017

Scheduled time: 3244 h

48 % Timing Mode (40 Bunches)

Availability 96.8 % (as of Nov. 16th)

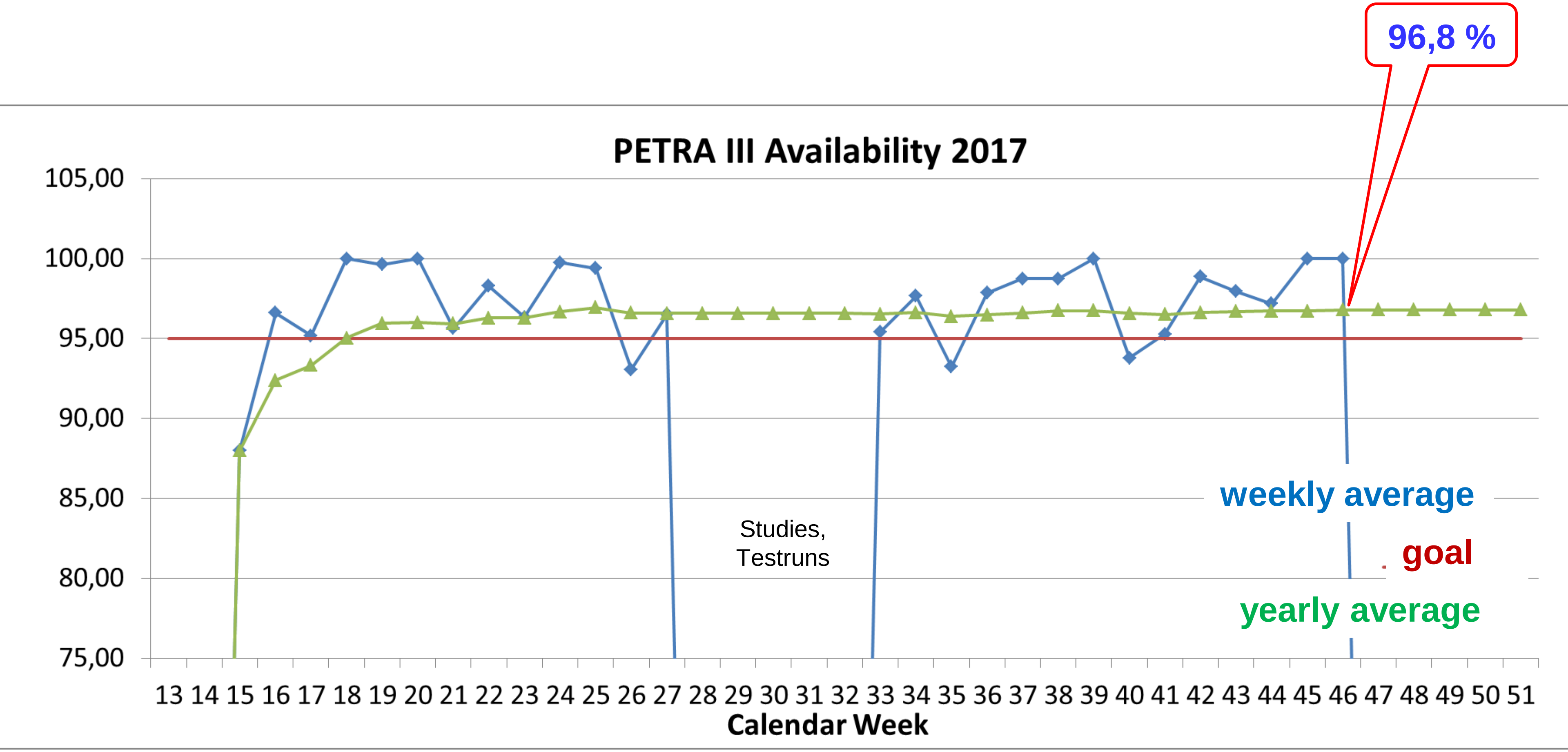
DISTRIBUTION OF OPERATION MODES



5 bunch patterns:

- **Timing Mode**
  - **40 bunches, 192 ns**
  - **60 bunches, 128 ns**
- **Continuous Mode**
  - **240 bunches, 32 ns**
  - **480 bunches, 16 ns**
  - **960 bunches, 8 ns**

Availability 2017



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY

Availability 2017

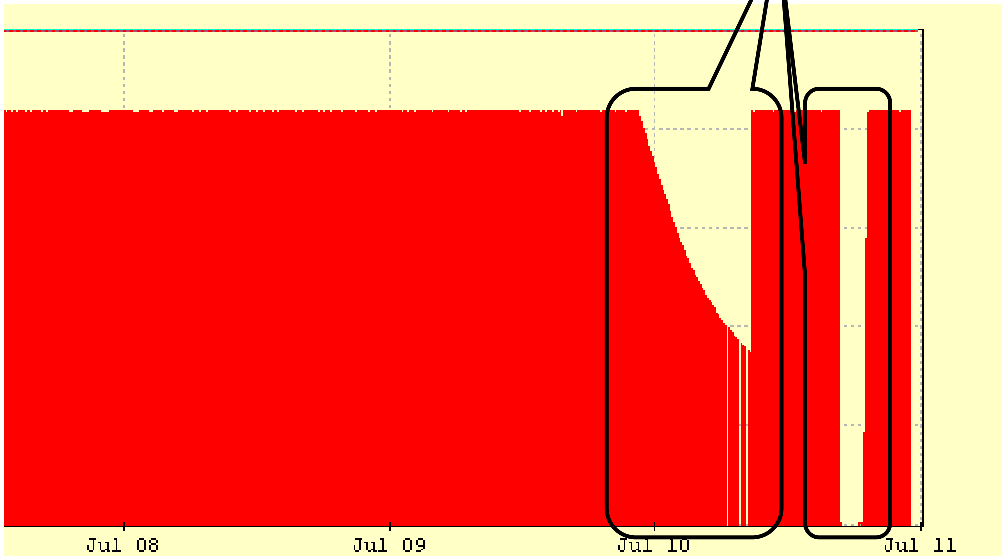
Definition:

$$\text{Availability} = \frac{\text{delivered beam time}}{\text{scheduled beam time}}$$

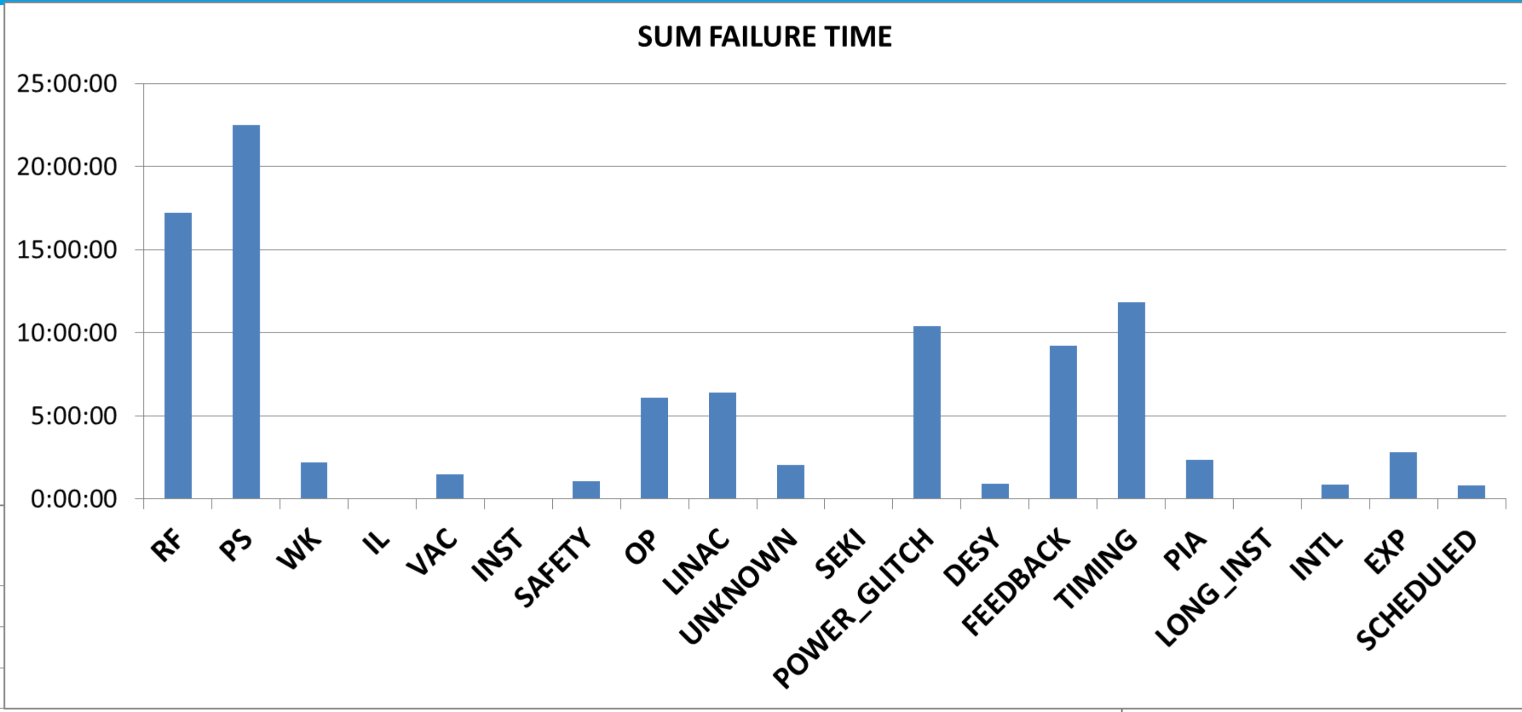
This rather unique 'warmup time' (recommended by MAC in Nov. 2011) reduced the availability in 2017 from 97,8% to 96.8%

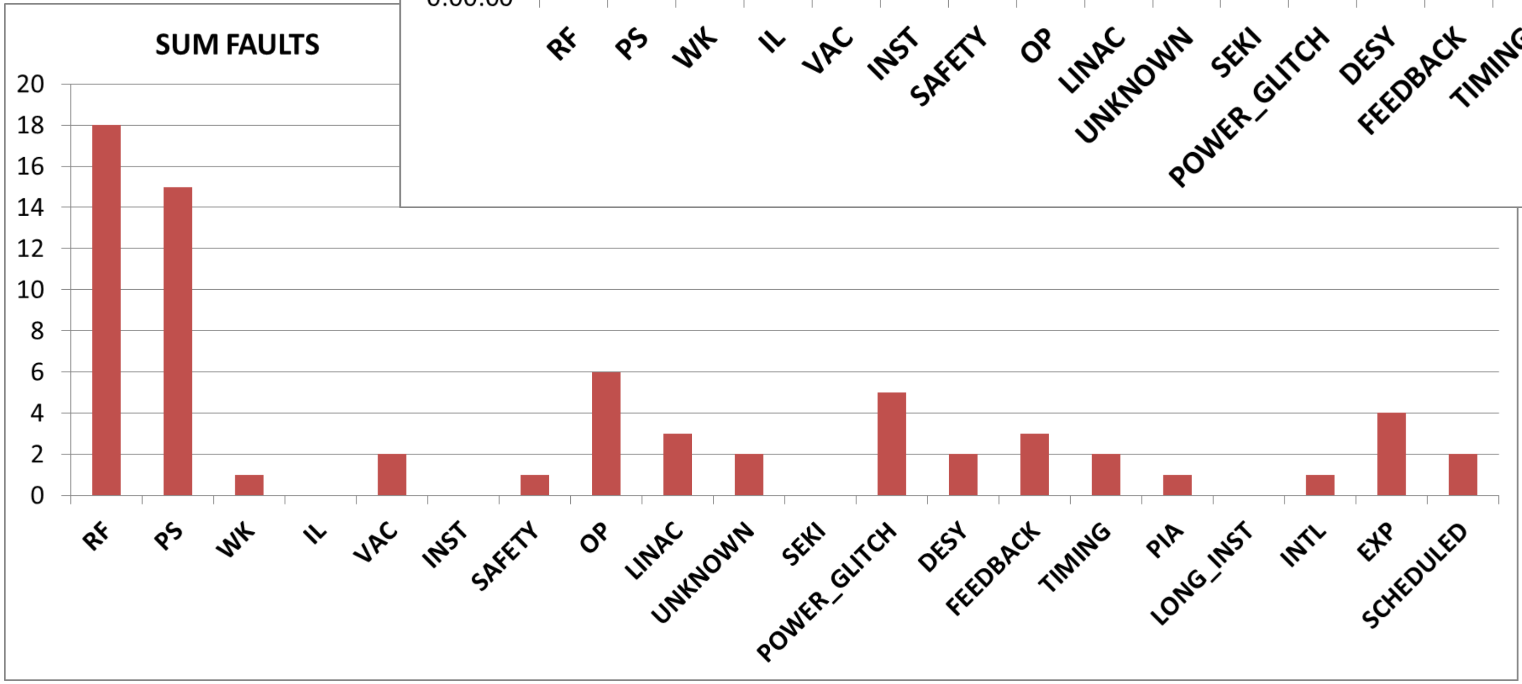
Definition:

Fault: Every beam loss of more than 25%, plus 1 hour (or 1 downtime)



Availability 2017

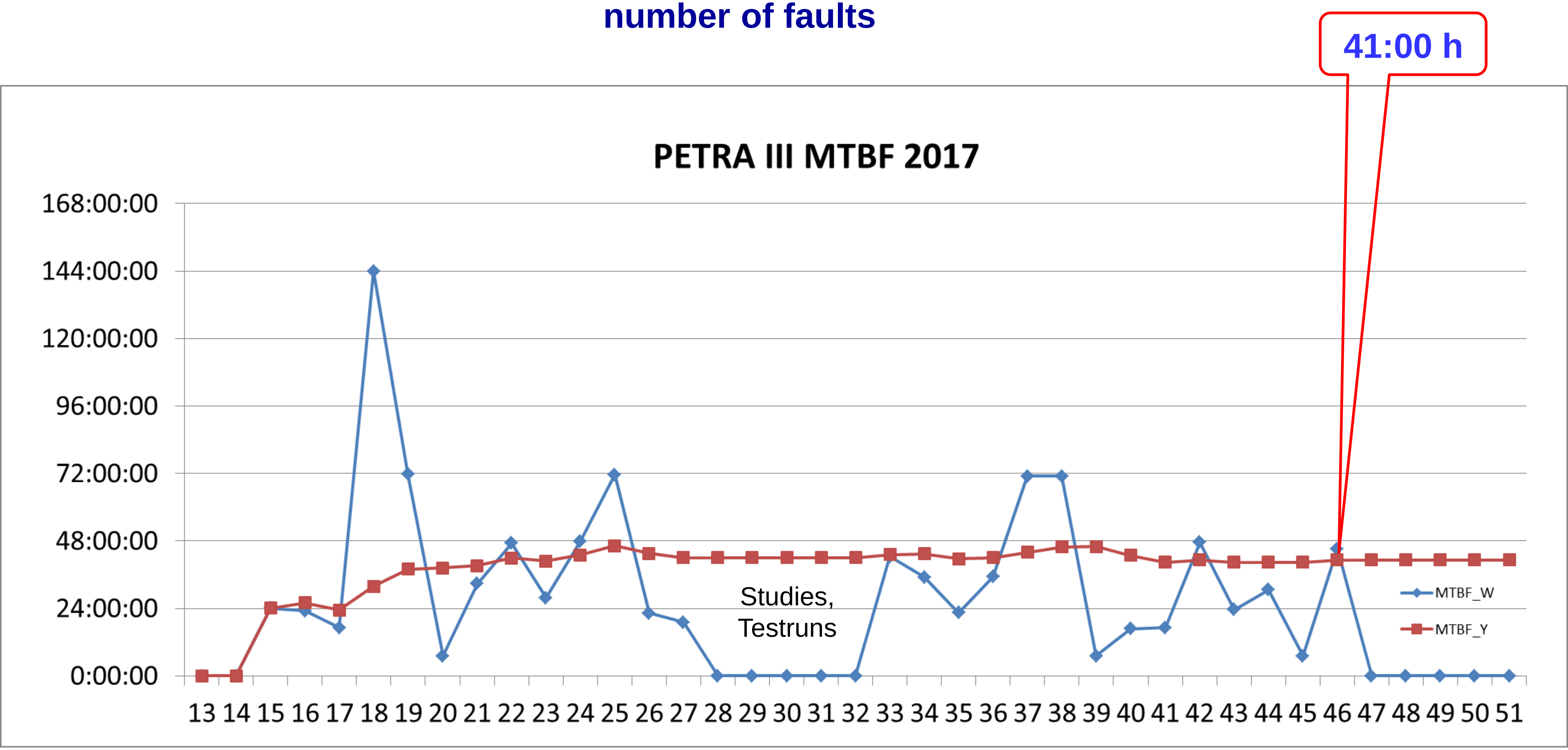




MTBF 2017

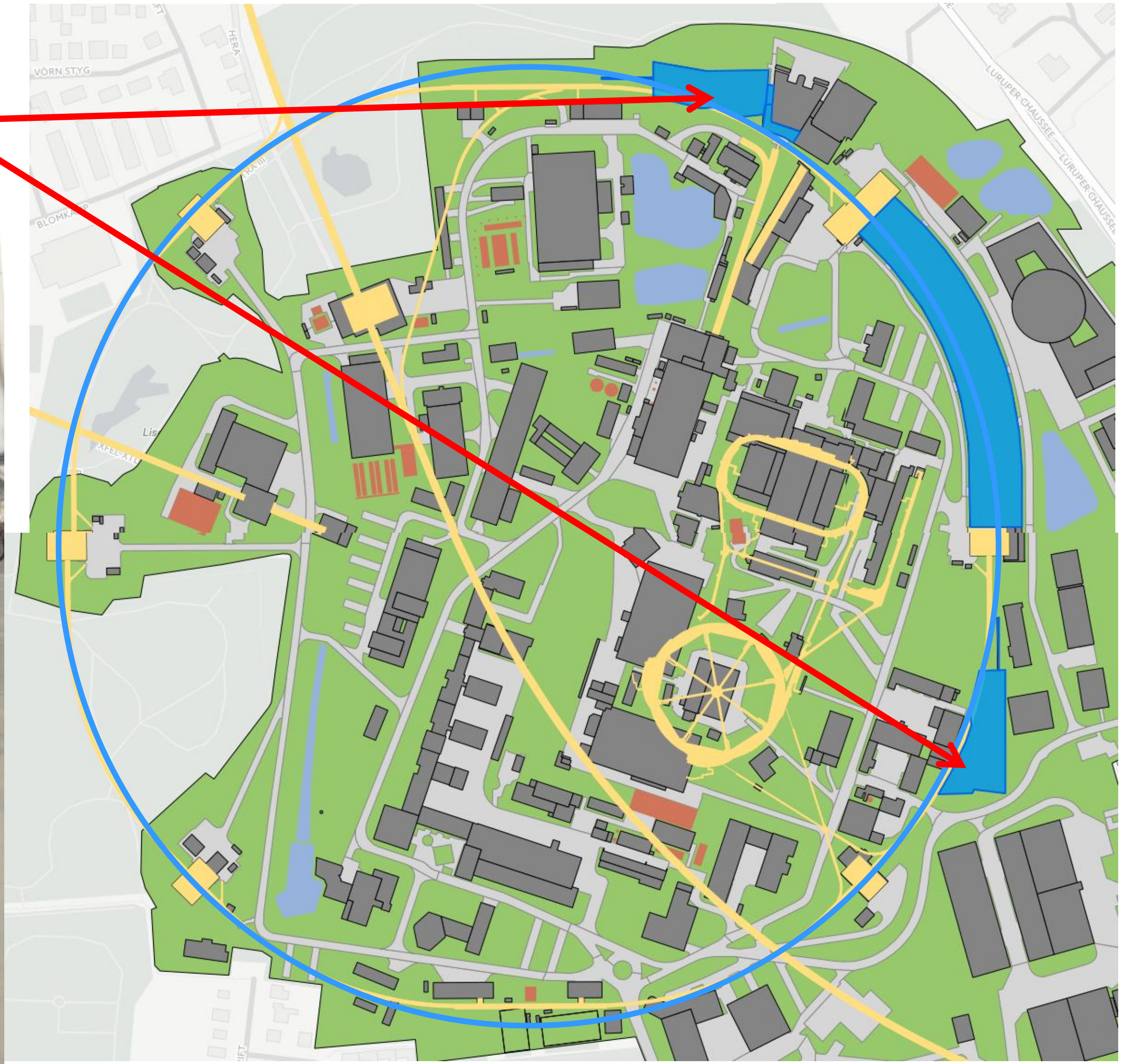
Definition:

$$\text{Mean Time between Failures} = \frac{\text{delivered beam time}}{\text{number of faults}}$$



Status of Extension Beamlines

3 extension beamlines are operational: PU24, PU64, PU65. PU22, PU23 are due next week.



Plans for 2018

2018	Januar	Februar	März	April	Mai	Juni	2018	Juli	Aug.	Sep.	Okt.	Nov.	Dez.	2018
2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018
1		a c # BO61	IB	. multi	. 40	. multi	1	. 40	f61 cc # VN N		. multi	. 40	. multi	1
2	#	a c # BO61	IB	. multi	. 40	. multi	2	. 40	f61 cc # VN N		. multi	. 40	. multi	2
3	#			. multi	. 40	. multi	3	. 40	f61 cc # VN N	. 40	. multi	. 40	. multi	3
4	#			MDT #	. 40	#	4	MDT #		. 40	. multi	. 40	. multi	4
5	#	c #	IB	. multi	. 40	#	5	. multi		. 40	. multi	. 40	MDT	5
6		c #	IB	. multi	. 40		6	. multi	f61 cc #	. 40	. multi	. 40	. multi	6
7		c #	IB	. multi	. 40	. 40	7	. multi	f61 cc #	. 40	. multi	MDT #	. multi	7
8	a b #	c #	IB	. multi	. 40	. 40	8	. multi	f61 cc #	. 40		. 40	. multi	8
9	a b #	c #	IB	. multi	MDT #	. 40	9	. multi	f61 cc #	. 40	#	. 40	. multi	9
10	a b #			. multi	. multi	. 40	10	. multi	f61 cc #	. 40	#	. 40	. multi	10
11	a b #			MDT	. multi	. 40	11	MDT		. 40	#	. 40	. multi	11
12	a b #	IMv	d IB	. 40	. multi	. 40	12	. multi		MDT #		bb #	MDT #	12
13		IEv	d IB	. 40	. multi	MDT SRI18	13	. multi	f61 cc IP61 #	. 40		bb #	. multi	13
14		IEv	d IB	. 40	. multi	. 40	14	. multi	f61 cc IP61 #	. 40		bb #	. multi	14
15	a c #	NG IEv	e so seM	. 40	. multi	. 40	15	. multi	IB	. 40	. multi	bb #	. multi	15
16	a c #	NG IEv	e so seM	. 40	MDT	. 40	16	. multi	IB	. 40	. multi	bb	. multi	16
17	a c #			. 40	. multi	. 40	17	. multi	IB	. 40	MDT		. multi	17
18	a c #			MDT # IP21v	. multi	. 40	18	V61 K61 f61 cc #		. 40	. multi		. multi	18
19	a c #	NG IEv	e so seM	. 40	. multi	. 40	19	V61 K61 f61 cc #		MDT	. multi	. 40	. multi	19
20		NG IM	e so seM	. 40	. multi	MDT #	20	V61 K61 f61 cc #	IB	. 40	. multi	. 40	. multi	20
21		NG IM	MDT #	. 40	. multi	. 40	21		IB	. 40	. multi	MDT	Shutdown	21
22	a c # VV61	NG IE	e so seM	. 40	. multi	. 40	22		IB	. 40	. multi	. 40	Shutdown	22
23	a c # VV61	NG IE	e so seM	IP21 #	MDT #	. 40	23	V61 K61 f61 cc #	IB	. 40	. multi	. 40	Shutdown	23
24	a c # VV61			IP21 #	. multi	. 40	24	V61 K61 f61 cc #	IB	. 40	MDT #	. 40	Shutdown	24
25	a c # VV61			IP21 #	. multi	. 40	25	f61 cc # VN N		. 40	. 40	. 40	Shutdown	25
26	a c # VV61	NG IE	. multi	IP21 Prüfung	. multi	. 40	26	f61 cc # VN N		MDT #	. 40	. 40	Shutdown	26
27		NG IE	. multi		. multi	MDT	27	f61 cc # VN N	IB	. multi	. 40	. 40	Shutdown	27
28		NG	MDT		. multi	. 40	28		IB	. multi	. 40	MDT #	Shutdown	28
29	a c # BO61		. multi		. multi	. 40	29		dd e	. multi	. 40	. multi	Shutdown	29
30	a c # BO61		. multi	. 40	MDT	. 40	30	f61 cc # VN N	dd e	. multi	. 40	. multi	Shutdown	30
31	a c # BO61		. multi		. multi		31	f61 cc # VN N	dd e		MDT		Shutdown	31

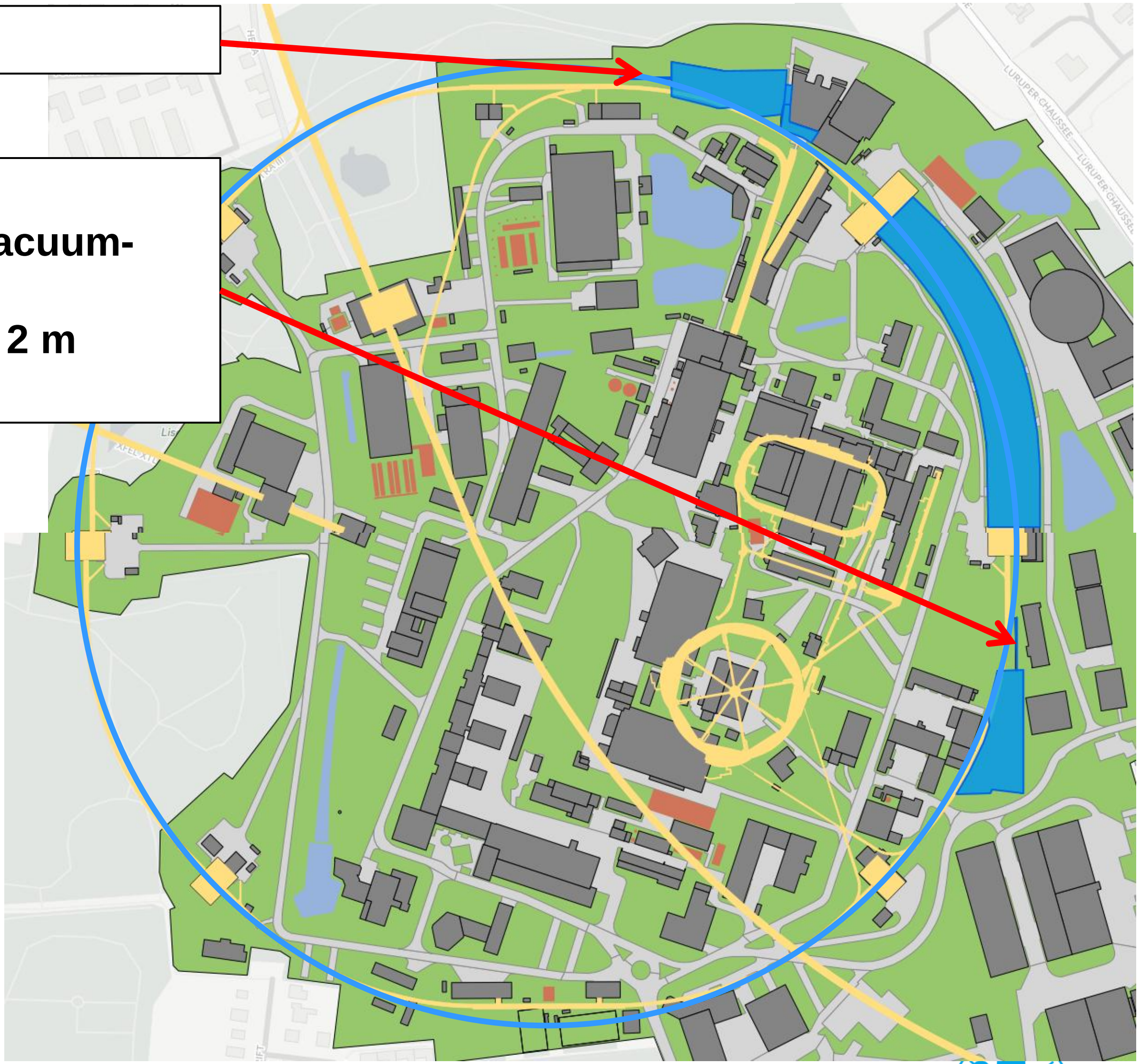
set-up
service week
user time
MDT machine time
Sunday/holiday

Shutdowns in Jan/Febr and July/Aug

Plans for Winter 2017/2018

Hole in the wall for P61

Straight section east:
- **Installation of the 4 m In-Vacuum-Undulator P21a**
- **Installation of a temporary 2 m device at P21b**



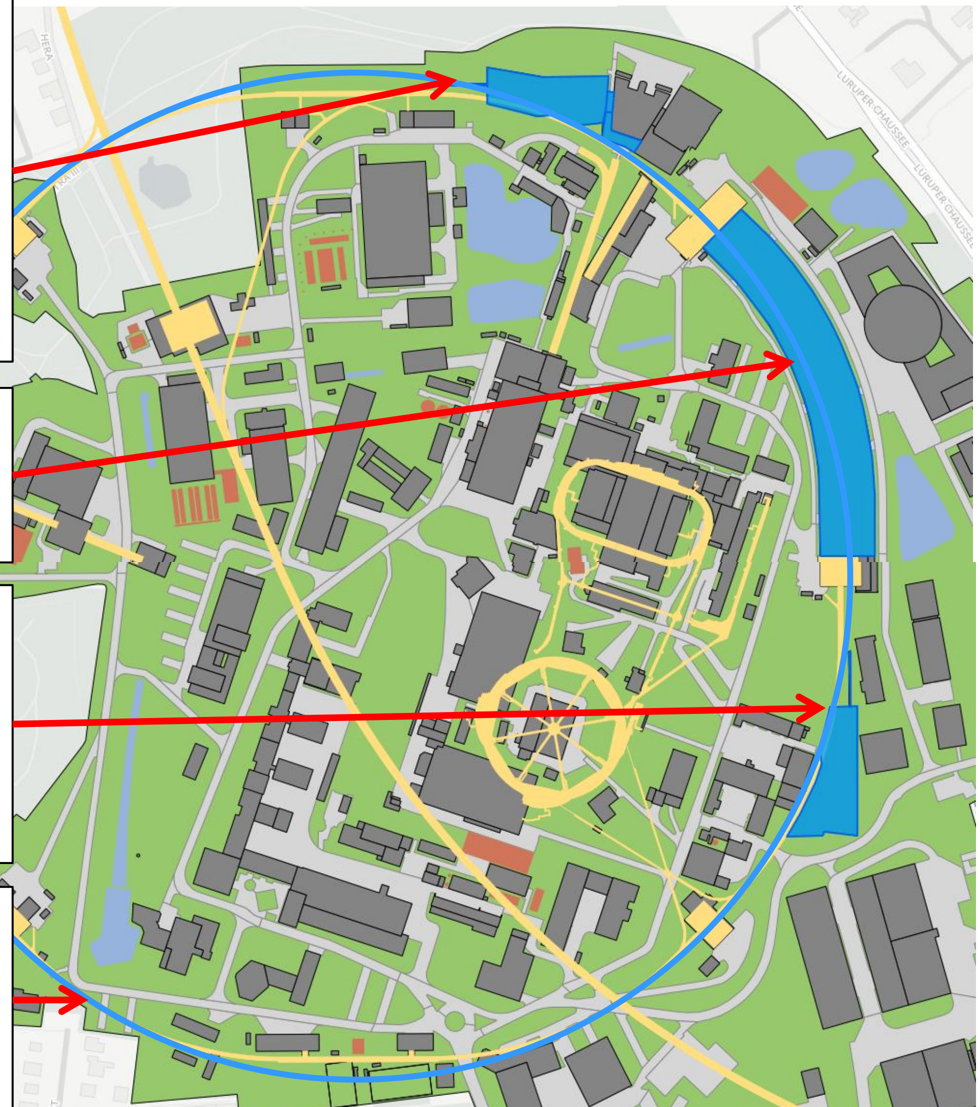
Plans for Summer 2018

Straight section north, damping wigglers:
- **Exchange of last absorber in damping wiggler section**
- **Installation of front end for P61 in the tunnel, including a power absorber**

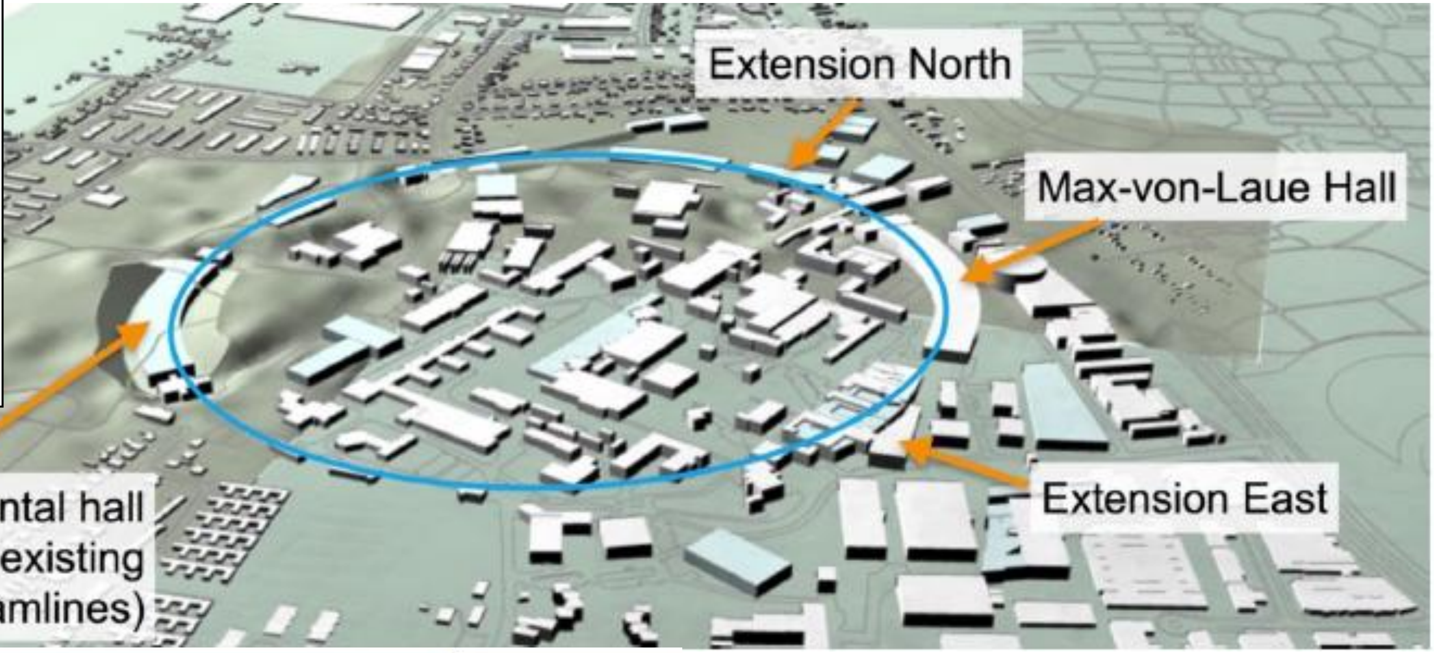
Von Laue Hall:
- **Installation of the 4 m In-Vacuum-Undulator P07**

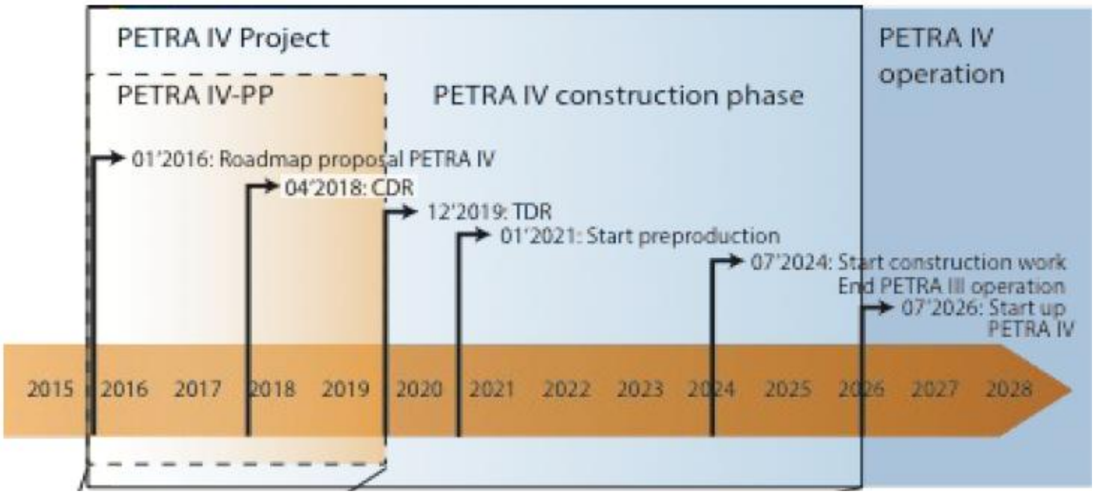
November 2018:
- **Removal of temporary 2 m device at P21b**
- **Installation of refurbished 2 m Undulator from P07 at P21b**

Somewhere in the arc:
- **Installation of NEG coated dipole chambers, NO bake out (Test for PETRA IV)**



PETRA IV



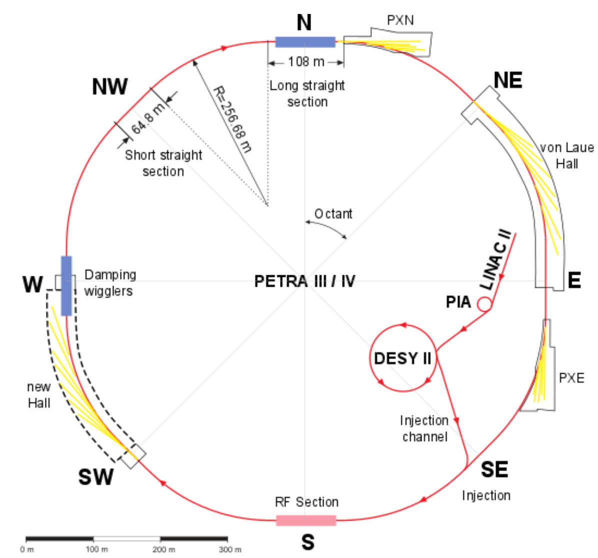


PETRA IV:

- **4.5 – 6 GeV**
- **100 – 200 mA**
- **10 -30 pm rad**
- **~ 30 Beamlines**

PETRA IV, Lattice design status

Parameter	PETRA III (DW)	H7BA 25.2 m (DW)
Nat. emittance ε_0 (with DW)	5100 pm (1280 pm)	15 pm (9.3 pm)
Energy spread σ_p (with DW)	$0.82 \cdot 10^{-3}$ ($1.23 \cdot 10^{-3}$)	$0.73 \cdot 10^{-3}$ ($1.44 \cdot 10^{-3}$)
Energy loss/turn U_0 (with DW)	1.3 MeV (5.1 MeV)	1.37 MeV (4.6 MeV)
Momentum compaction factor α_c (with DW)	$1.13 \cdot 10^{-3}$ ($1.13 \cdot 10^{-3}$)	$1.46 \cdot 10^{-5}$ ($1.46 \cdot 10^{-5}$)
Max. gradient g	17 T/m	100 T/m
Dispersion D_x at SF	750 cm	4.2 cm



"Reference Lattice"

Hybrid Seven Bend Achromat scaled and adopted from ESRF-EBS
8 cells / arc (cell length: 25.2 m / new version ~ 26 m)**,**
injection in one long straight section,
damping wigglers in another straight section

Work in Progress

FLASH Facility

FLASH.
Free-Electron Laser in Hamburg

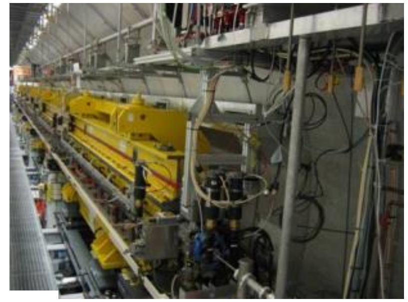
FLASH Layout 2017

FLASH.
Free-Electron Laser in Hamburg

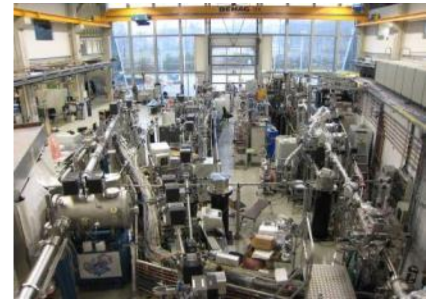
> 3rd harmonic sc module 3.9 GHz

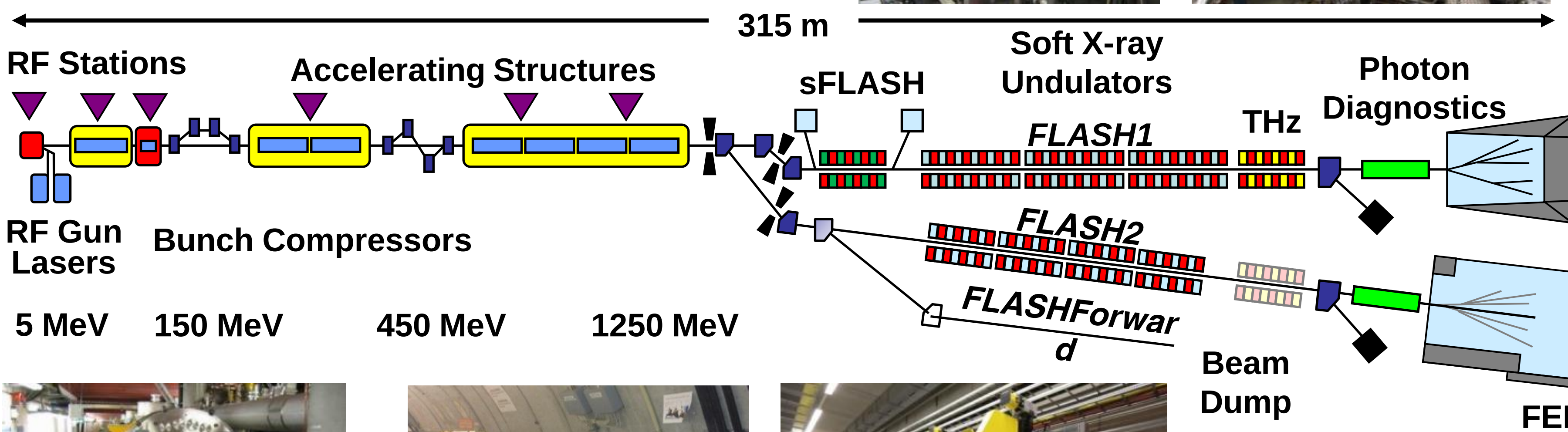
> TESLA type superconducting accelerating modules 1.3 GHz

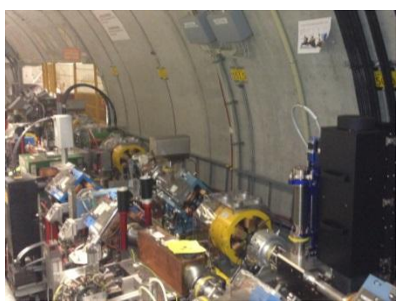
> FLASH1 fixed gap undulators



> FLASH1 Hall Albert Einstein







> Normal conducting 1.3 GHz RF gun
> Ce_2Te cathode
> Three photocathode lasers

> Extraction to FLASH2

> FLASH2 variable gap undulators

> FLASH2 Hall Kai Siegbahn

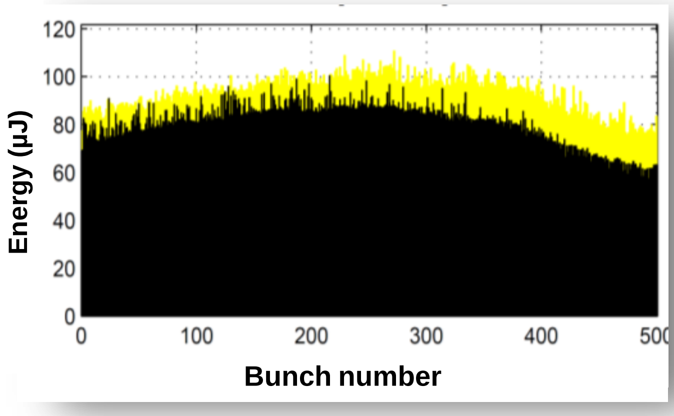
FLASH Parameters

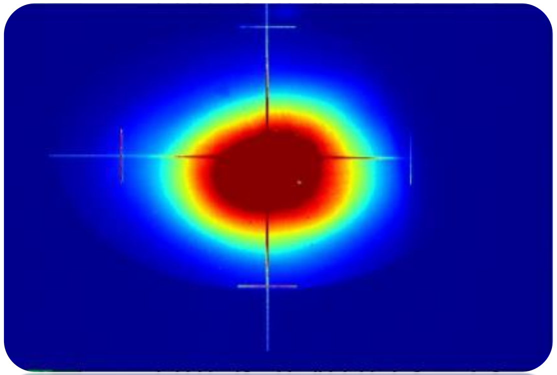
FLASH. Free-Electron Laser in Hamburg

FEL Radiation Parameter FL1 / FL2

Wavelength (fundamental)	4.2 – 51 nm / 4 – 90 nm
Single pulse energy	1 – 500 µJ / 1 – 1000 µJ
Pulse duration (FWHM)	< 30 – 200 fs
Peak power	1 – 5 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 – 2 % / 0.5 – 2 %
Photons per pulse	$10^{11} – 10^{14}$
Peak Brilliance	$10^{28} – 10^{31}$ B*

* photons/s/mrad²/mm²/0.1%bw





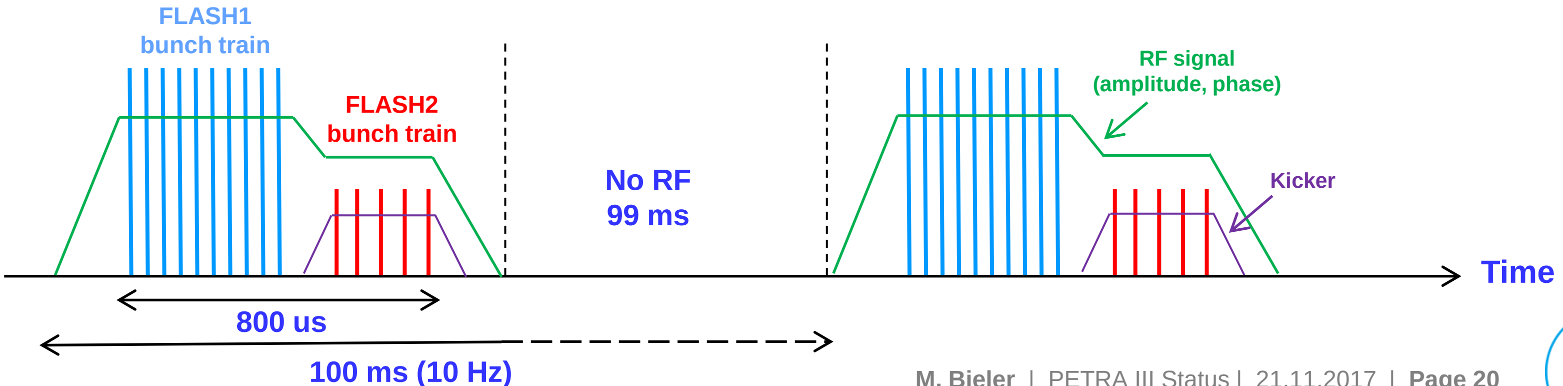
> more than 270 publications on photon science at FLASH, many in high impact journals
http://photon-science.desy.de/facilities/flash/publications/scientific_publications

DESY

Simultaneous Operation

FLASH.
Free-Electron Laser in Hamburg

- Two photon experiments - one at FLASH1 and one at FLASH2 – are served simultaneously, both with a 10 Hz pulse train repetition rate
- Take advantage of superconducting accelerator: long RF pulse (1 ms) → long electron bunch train shared between FLASH1 and FLASH2
  - fast kicker and Lambertson septum to extract a part of bunch train to FL2
- Flexibility for photon experiments
  - two undulator beamlines → different wavelengths
  - three photocathode lasers → different bunch pattern and bunch charge
  - flexible RF-system → different amplitude and phase
  - different bunch charge and compression → different pulse durations

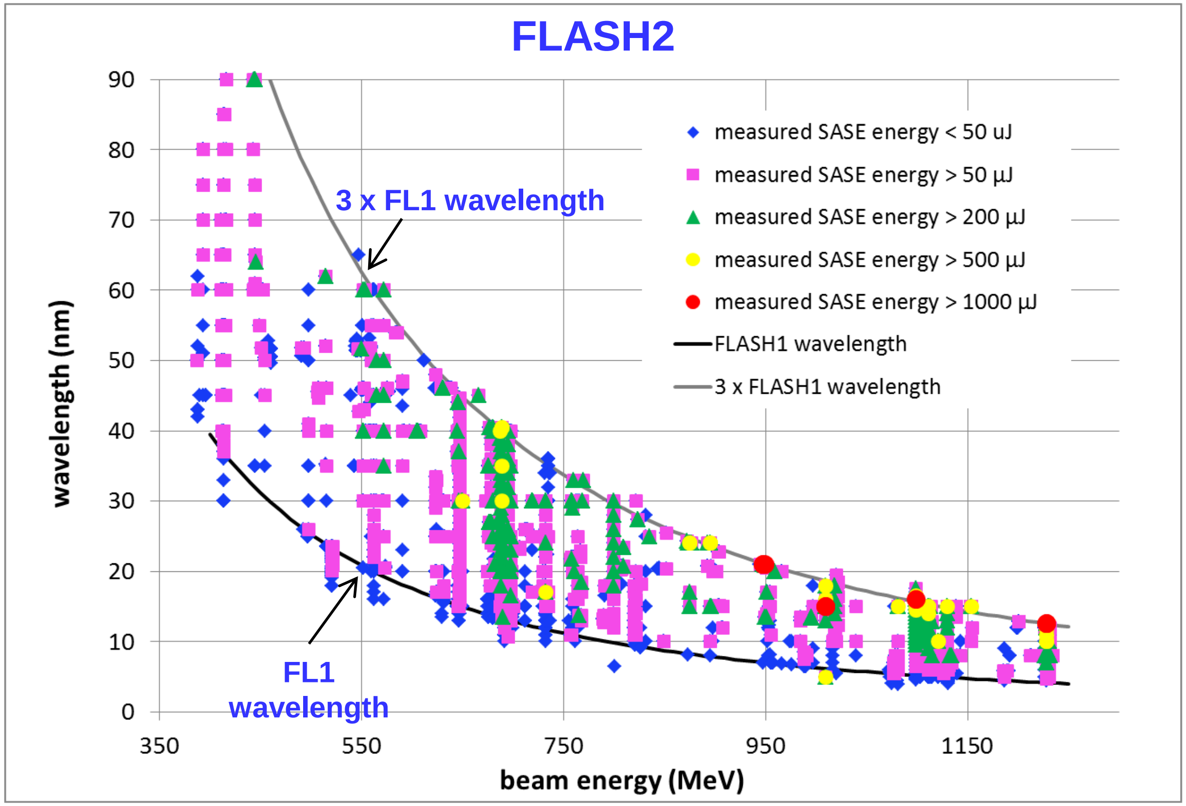


DESY

Wavelength Tunability

FLASH. Free-Electron Laser in Hamburg

- FLASH1 (fixed gap undulators): wavelength defined by the electron beam energy
- FLASH2 (variable gap undulators): wavelength tunable (1 – 3 x FL1 wavelength)
  - with a fixed electron beam energy: small undulator gap = long wavelength
    large undulator gap = short wavelength



DESY

Summary and Outlook

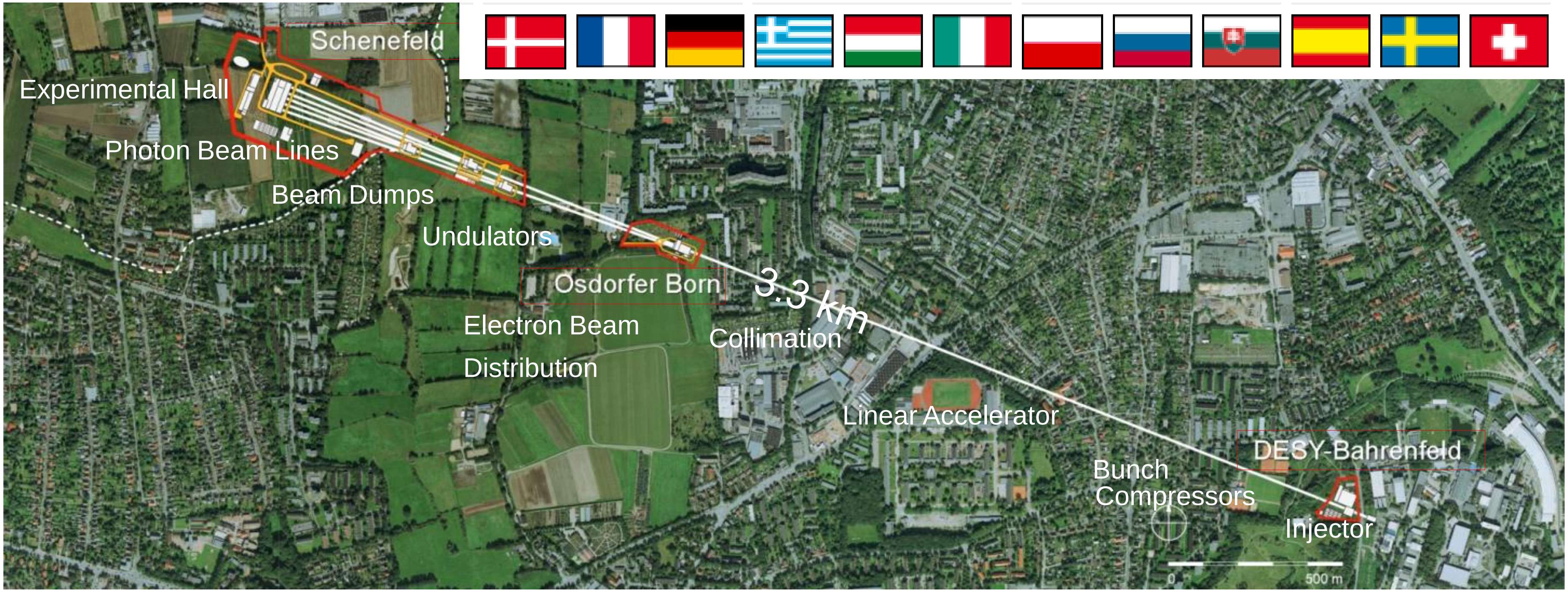
FLASH. Free-Electron Laser in Hamburg

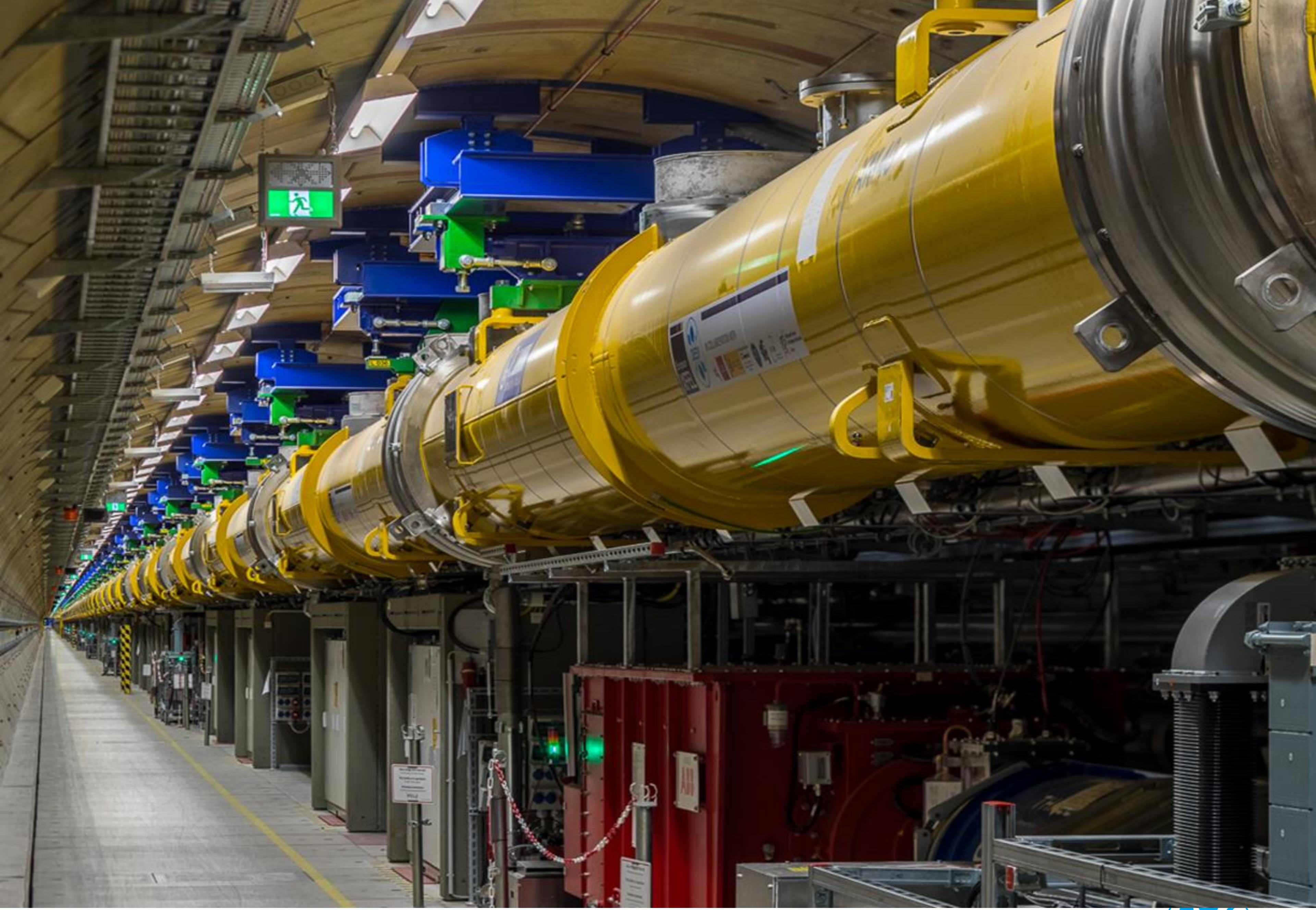
- FLASH1 and FLASH2 in simultaneous user operation
- ~ 7500 h operation hours / year
  - 60% user experiments
  - 30% FLASH studies
    machine studies and improvements,
    photon beamlines, user preparation
  - 10% accelerator R&D

DESY

European XFEL at a Glance

- International project realised in Hamburg, Germany
- 17.5 GeV superconducting linac, almost 1 MW beam power
- 27000 pulses per second in 10 Hz burst mode
- Three variable gap undulators for hard and soft X-rays
- Initially 6 equipped experiments





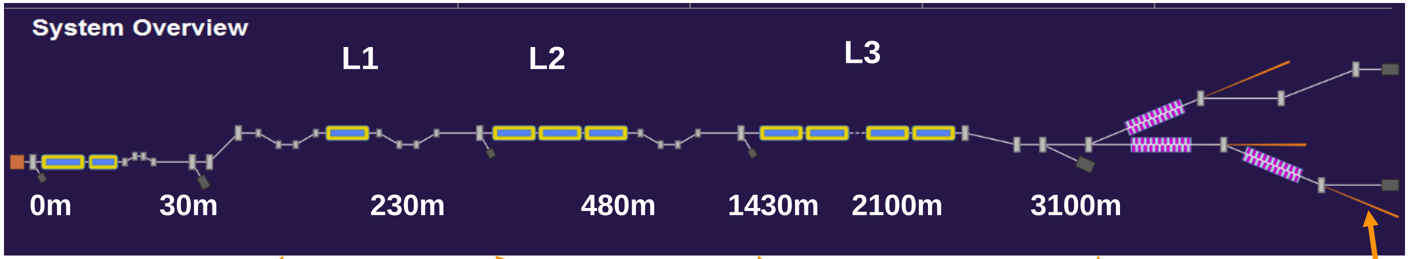
DESY

Injector in Operation – First Beam in 12/2015

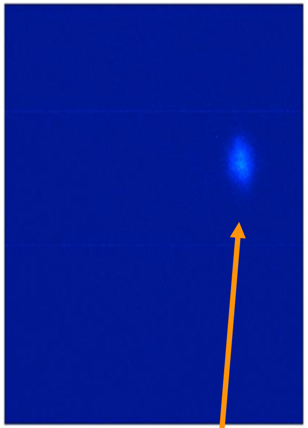
- Injector cool-down started beginning of 12/2015
- First Beam on December 18th , 2015 - commissioning till Q2/2016
- Full bunch train length (2700 bunches) reached and beam stopped in injector beam dump
- Projected emittance as expected (1...1.5 mm mrad)
- Slice emittance measurements give 0.5 mm mrad for 500pC;   also over bunch train

Operation History Since May 2017

Beamline Commissioning Progress



Photon beam @ OTRC.2615.T9



13/01 → **15/01 @ 130 MeV**
19/01 @ 600 MeV

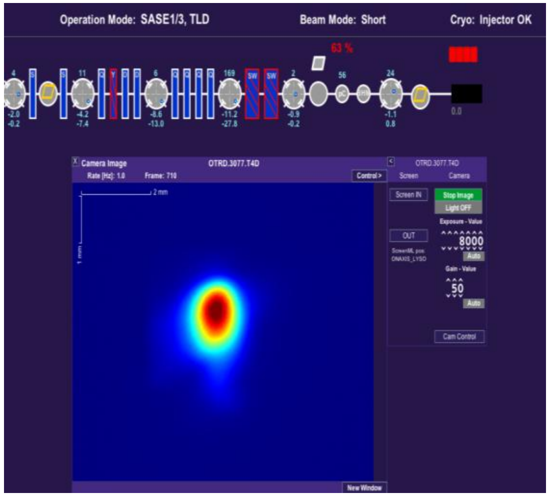
→ **02/02 @ 600 MeV**
22/02 @ 2.5 GeV

→ **25/02 @ 2.5 GeV**
19/03 @ 6 GeV
08/04 @ 12 GeV

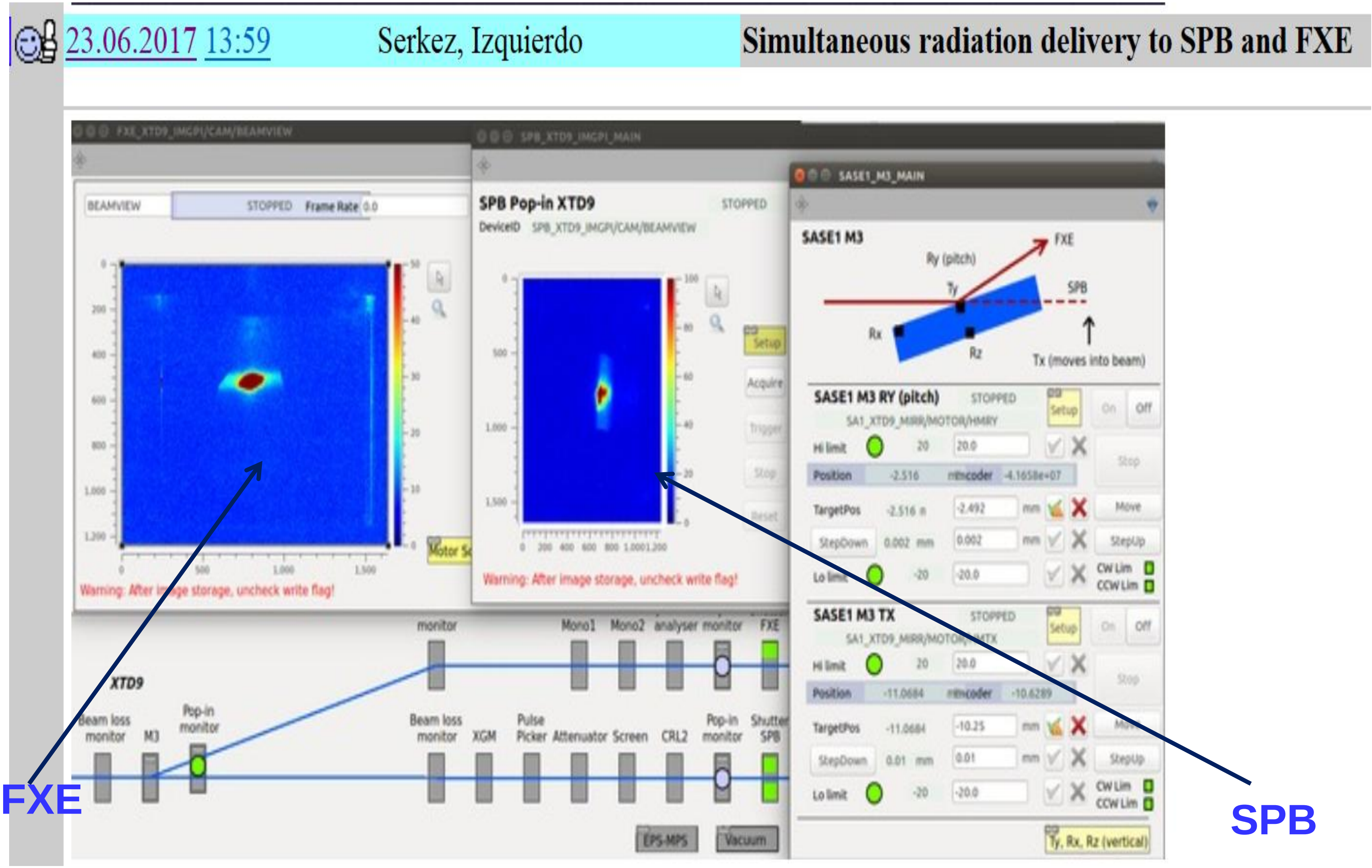
→ **27/04 First e-Beam**

→ **2/05 First Lasing @ 1.6 keV, 6.4 GeV, 500 pC, without BBA**

27/04 Beam spot before dump



23.06. First Photons in the Experimental Hutches

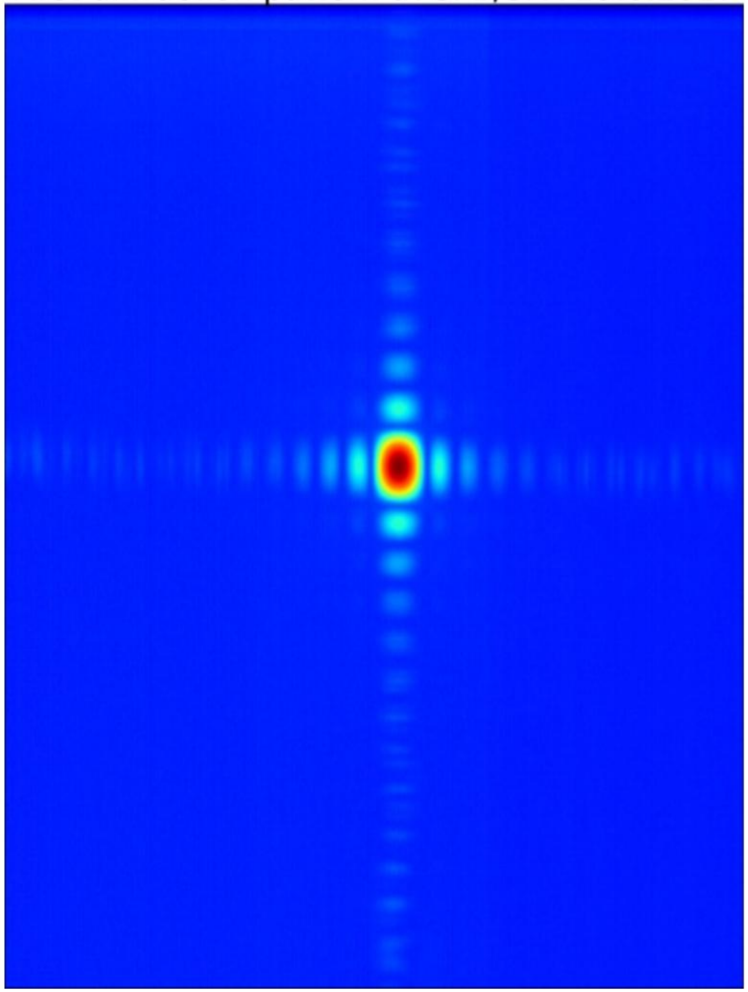


29.06.2017 XFEL's first coherent, far-field diffraction pattern measured at SPB/SFX

29.06.2017 16:20 Adrian Mancuso for SPB/SFX team **XFEL's first coherent, far-field diffraction pattern measured at SPB/SFX**

Measured ~ 4am today (29.06.17), from a 10 um x 10 um square aperture over a ~20 m propagation distance.
Note the very high visibility of the fringes and even the presence of higher order maxima
in the pattern.

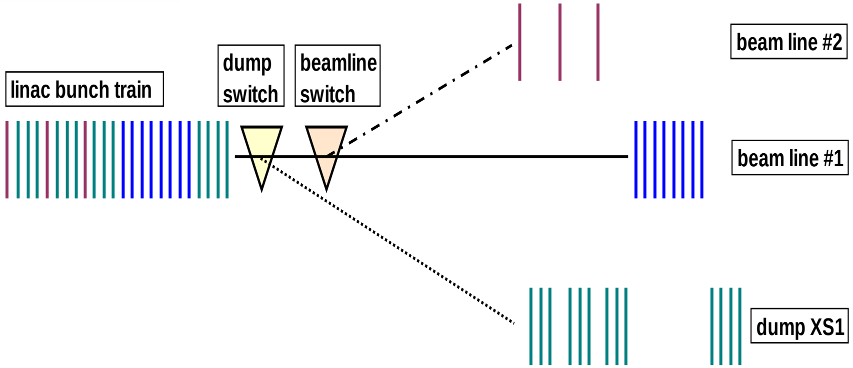
First diffraction pattern at SPB/SFX 29.6.2017

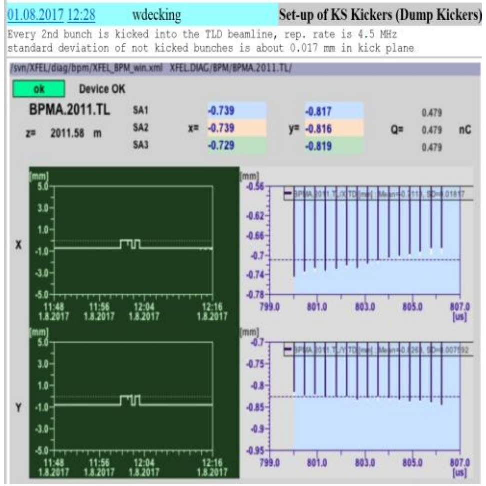


1.08. First Test of "Complex" Bunch Pattern (1.125 MHz -> 563 kHz)

01.08.2017 14:07 **XFEL** xfeloper **XFEL_xgmd_sase_viewer.xml**

```
the GMD takes for averaing the number of bunches from the laser. Therefore sending half of the bunches
 to the XTD gives the wrong average SASE intensity. Same SASE would result in 0.5 x the
 GMD reading for 30 bunches.
```

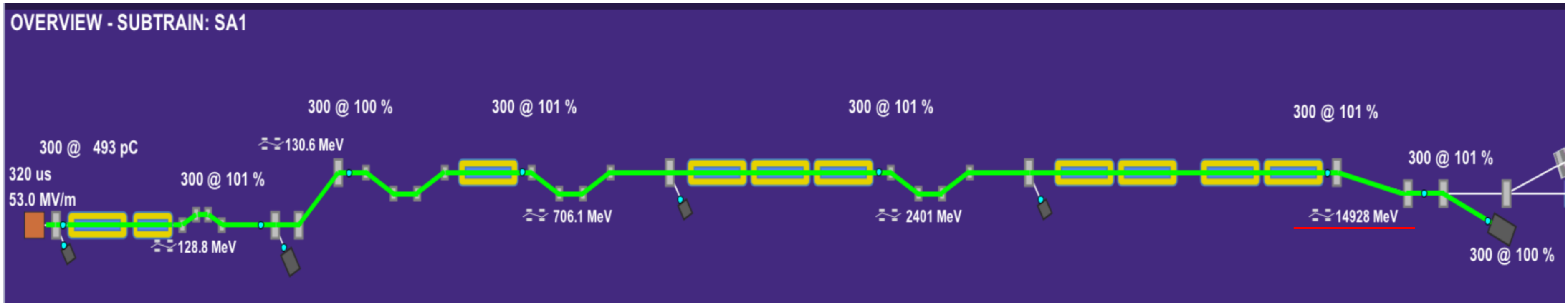


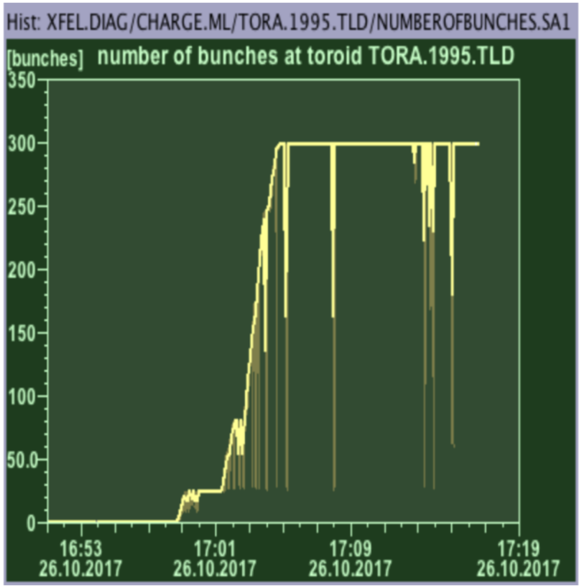


XGM reading: average is over 30 bunches, "real" intensity is 800 µJ

Switching @ 4.5 MHz Rep Rate

300 Bunch Operation; Maximum Energy 14.9 GeV

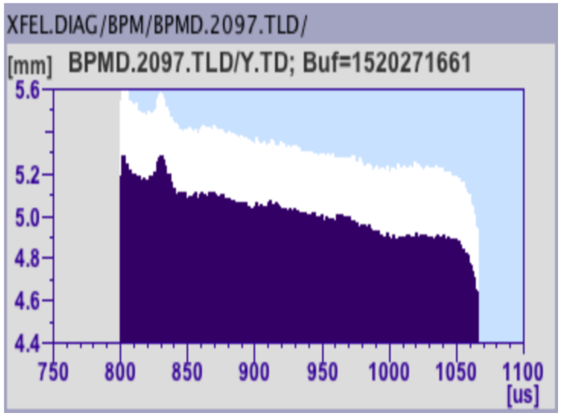




Measured bunch numbers in the dump line
Only few cuts by BLM alarms

- Machine was set up with low losses to TLD
  - Beam loading compensation and learning feed forward on
- Number of bunches simply stepped up
- Limit given by current Gun RF pulse
- Only few pulse cuts by MPS

Work in Progress



Vertical (dispersive) beam position vs. bunch number

Many thanks for slides about

- PETRA: R. Wanzenberg, …
- FLASH: S. Schreiber, K. Honkavara, …
- XFEL: W. Decking, D. Nölle, H. Weise, …

Thank you for your attention!