Status of Radiation Damage on the XFEL.EU Undulator Systems

Frederik Wolff-Fabris

Undulator Systems – XFEL

IPAC'18, Vancouver, May 2nd, 2018

Outline

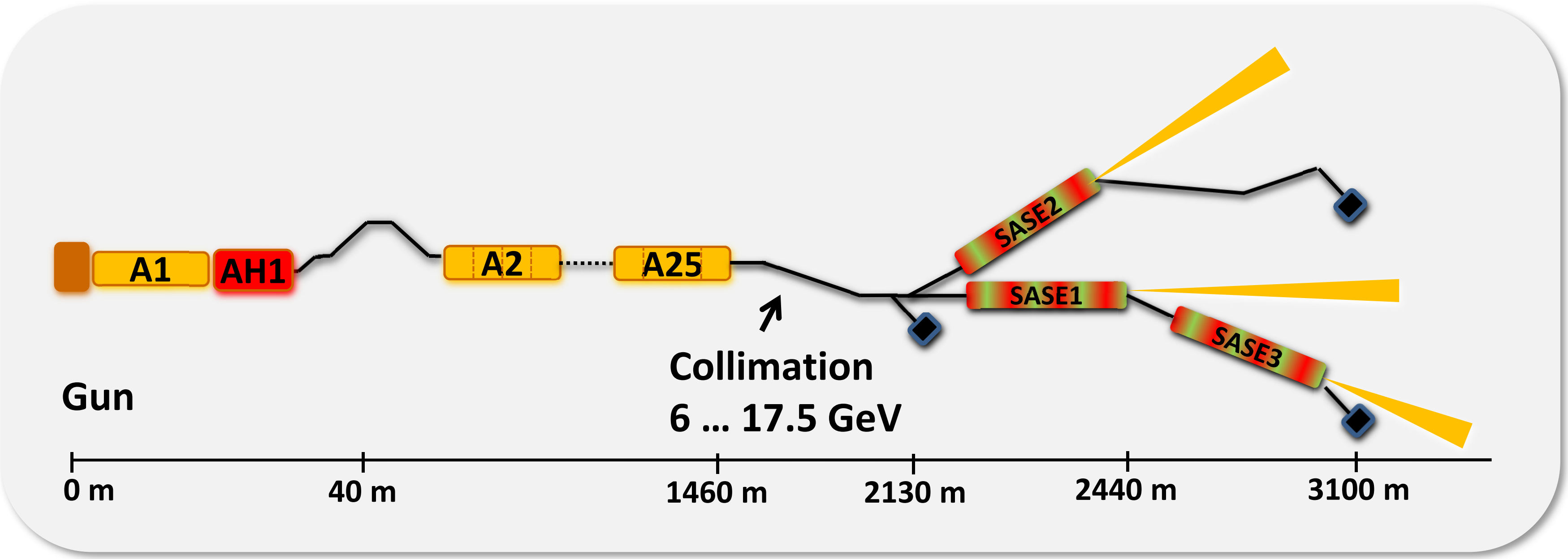
- 1. Introduction to XFEL.EU and Undulator dosimeter systems
- 2. Absorbed doses profile and characteristics on 1st year of operation
- 3. Measurements on de-magnetization effects
- 4. Summary: lessons, ongoing and future plans

Introduction to European XFEL GmbH

Schenefeld research campus on 14 August 2017

- The European XFEL is a leading new research facility that uses high-intensity X-ray light to study the structure of matter located in Hamburg and Schenefeld, Germany.
  - DESY and European XFEL are strong partners on construction, commissioning, and operation of X-ray free-electron laser
  - Supported by 12 countries

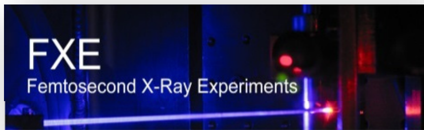
Commissioning Timeline (courtesy of M. Scholz and W. Decking)

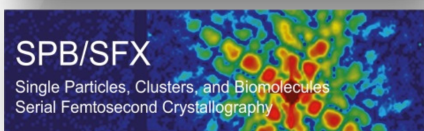


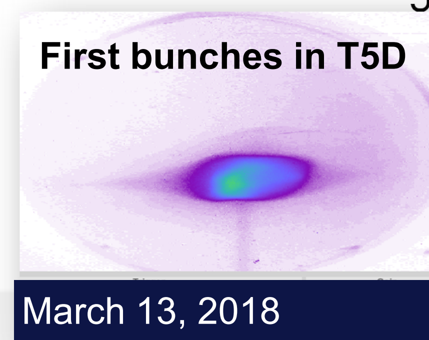
IPAC'17 talk by Winni Decking, IPAC'18 talk by Matthias Scholz

Commissioning Timeline (courtesy of M. Scholz and W. Decking)

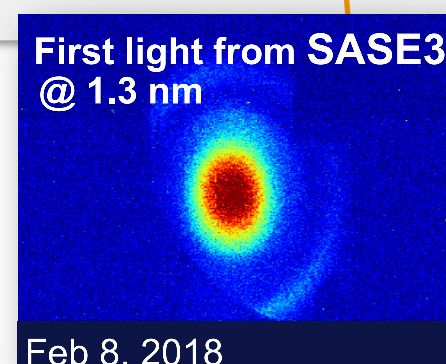
First user runs started in Sep. 2017







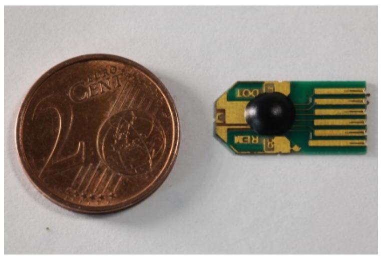
Quantity		Project Goal	Achieved
Electron energy	GeV	8,12.5,14,17.5	6-14.9
Bunch charge	pC	20 – 1000	100-500
Beam power	kW	500 kW	18 kW
Undulators in operation (lasing)		SASE1-3	SASE1,3
Photon energy (SASE1)	keV	0.25 - 25	1,6,9 -14
Photon pulses / s / undulator		27000	5000

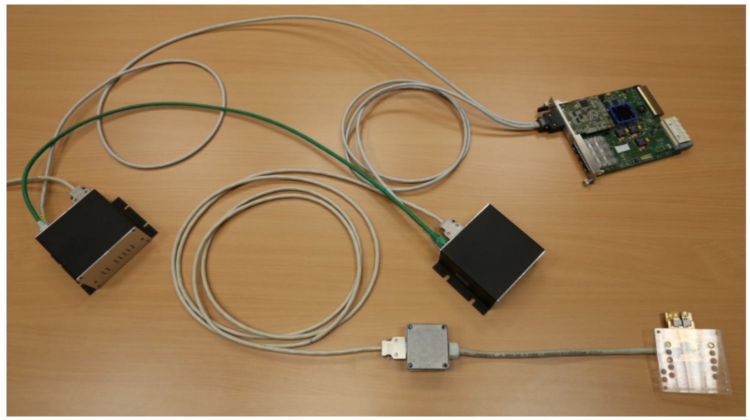


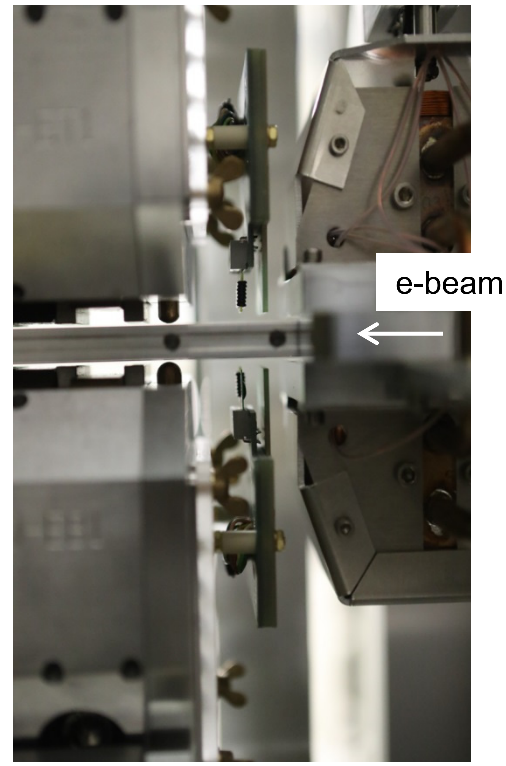
IPAC'17 talk by Winni Decking, IPAC'18 talk by Matthias Scholz

Tools to Evaluate Undulator Radiation Damage - DOSIMETERS

- **Radfet System:** implemented as an FMC module; Permits on-line dose readings; 2 Radfets installed at the entrance of each Undulator; Cross-calibrated with TLD-800.







- **Gafchromic films (EBT3 and HD-V2):** spatial distribution and dose ("more doses" = "darker")

- Additionally (not discussed here): BPMs, BLMs, machine protection system, Collimator, K-monochromator…

Tools to Evaluate Undulator Radiation Damage - DIAGNOSTIC UNDULATOR (DU)

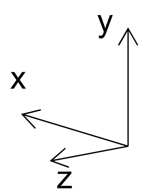
- U40 type undulator with 4 magnetic periods;
- Placed in front of each Undulator System;
- Easy to handle: frequent re-measurements;
- Allows a preview on expected radiation damage.

DU XFEL U40	
Period length	40 mm
Gap	12 mm, fixed
Peak Field	0.916 T
K	3.28
Number of Poles	8
Total length	≈ 350mm
Weight	≈ 47 Kg

e-beam

SASE2 DU

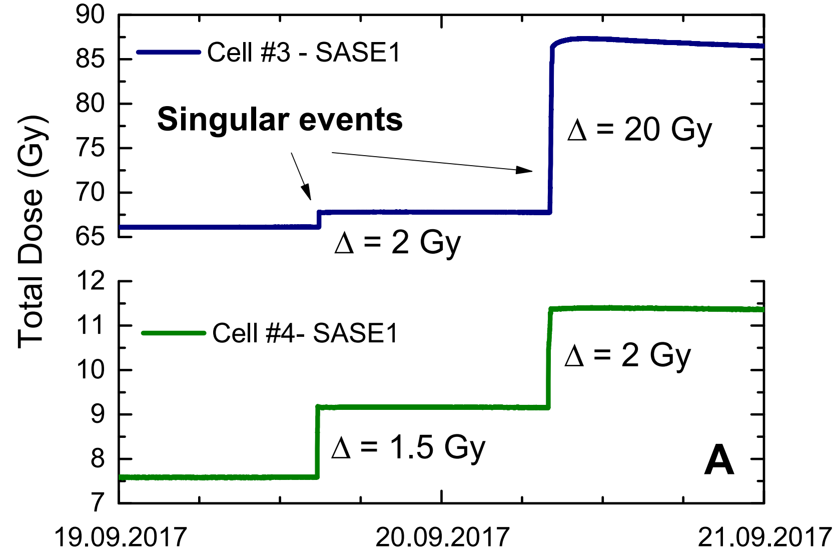
e-beam



Absorbed Doses Profile and Characteristics

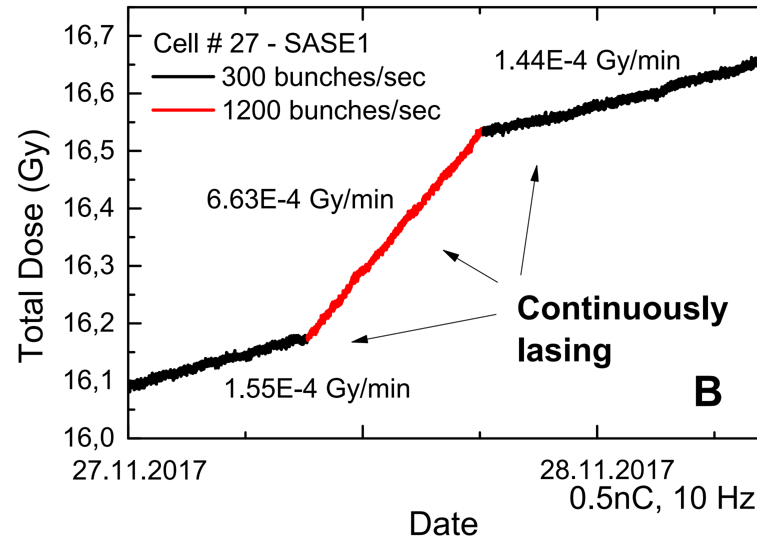
Singular Events

- Defined as step-like increase on absorbed doses in short time;
- Due to e-beam steering, changes on quads and air coils settings, e-beam energy change during BBA, opening/closing undulators;
- Seen in subsequent undulators and total dose reduces towards downstream direction.

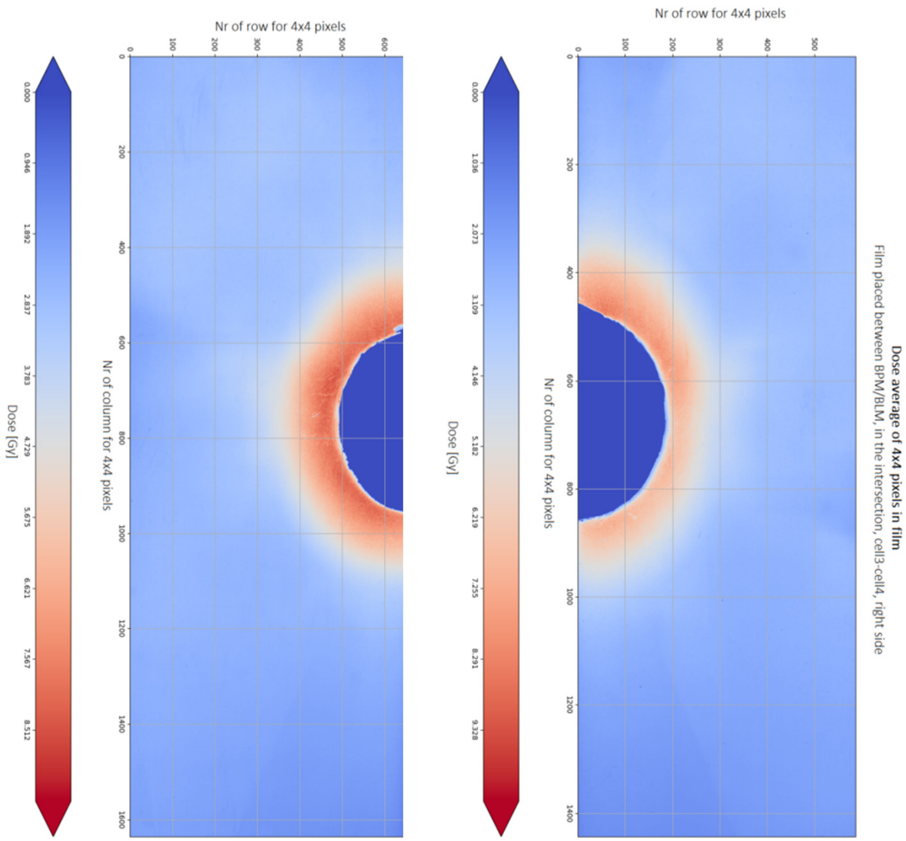


Continuously Lasing

- Defined as slow and steady rise of doses as function of time;
- Seen during stable beam conditions or while continuously lasing in the course of user operation.



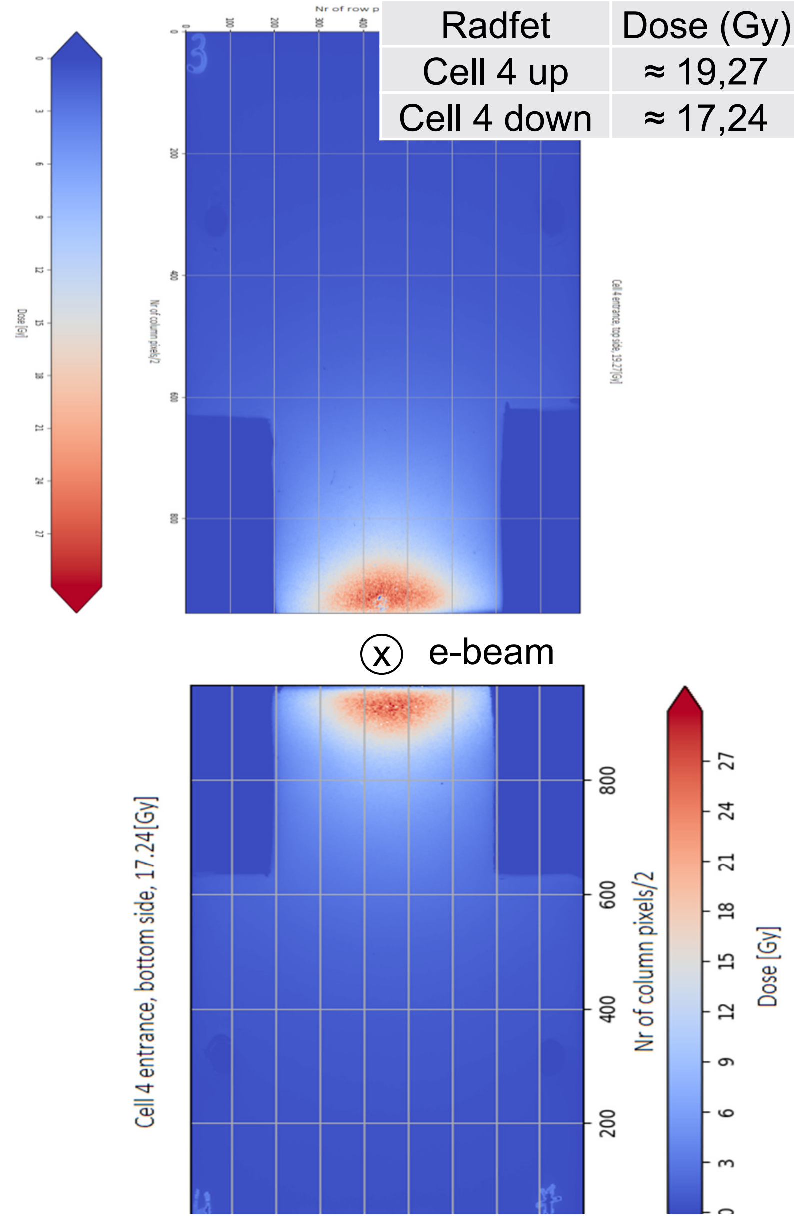
Gafchromic Films



<u>Film between BPM and BLM:</u>

Doses higher than 9 Gy around the vacuum chamber (dark blue, 50mm diameter), extending for more than a cm

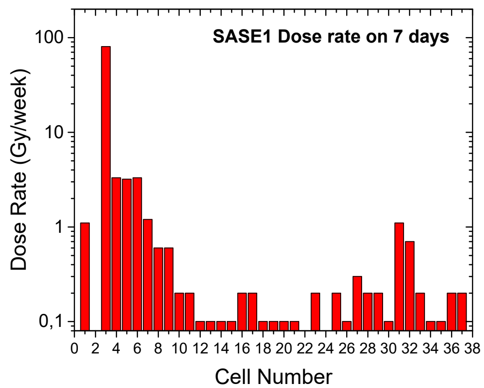
Radfet	Dose (Gy)
Cell 4 up	≈ 19,27
Cell 4 down	≈ 17,24



<u>Undulator's entrance</u>: Higher doses near the vacuum chamber; dispersion up to cm.

Complete SASE1 system – Weekly absorbed doses

- Overall improvement on time
- Systematic higher doses at SASE1 middle/end
- Operate with open undulators from cell#31



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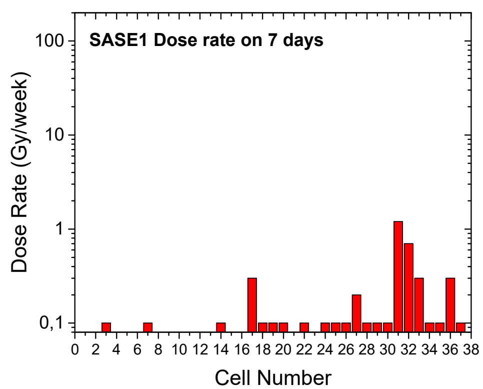
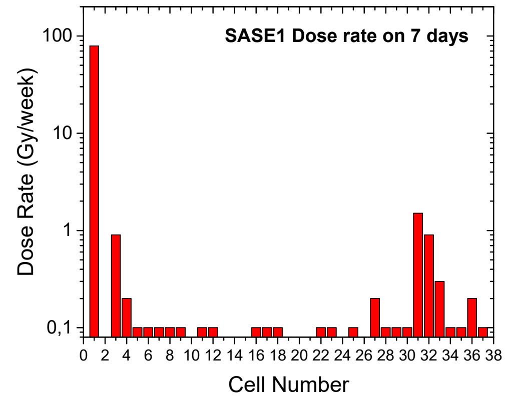
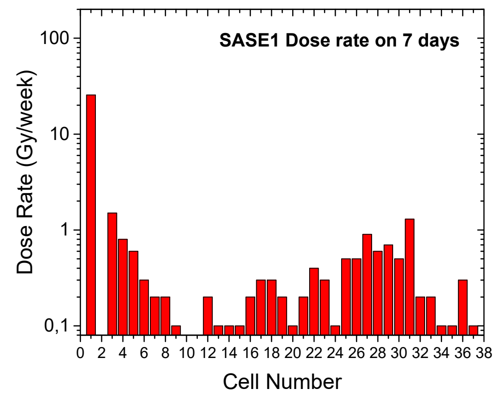


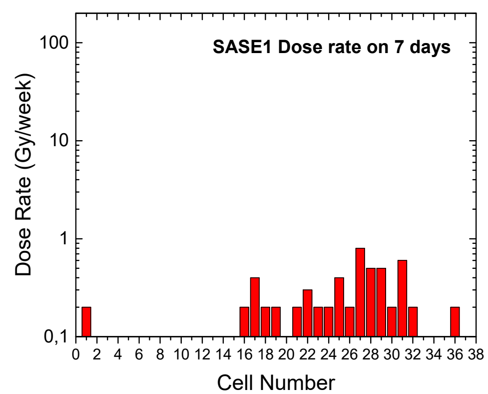
Oct 9, 2017



Nov 8, 2017



Nov 27, 2017



Apr 09, 2018

Complete SASE1 system – Weekly absorbed doses

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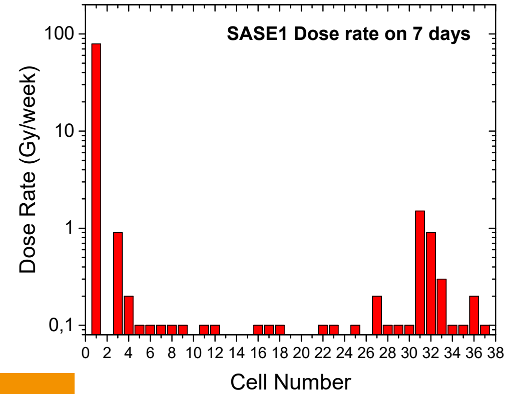

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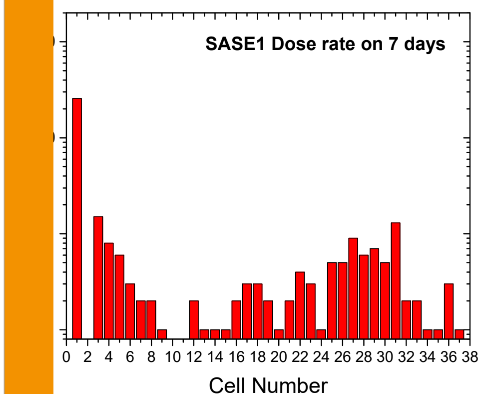

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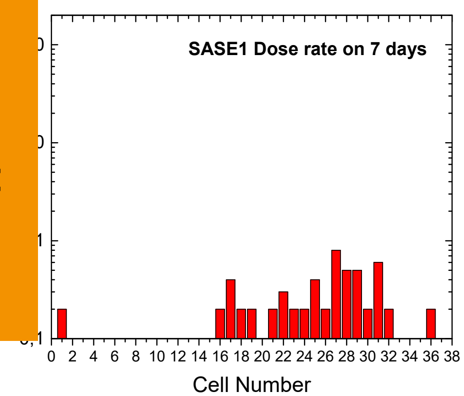

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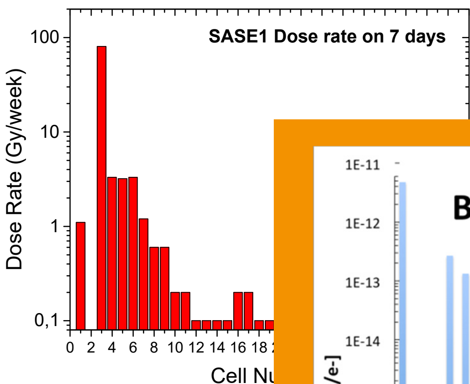
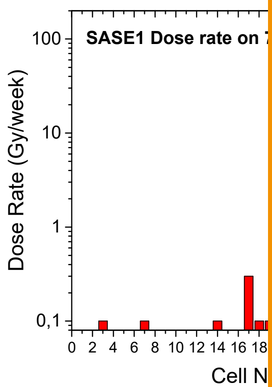
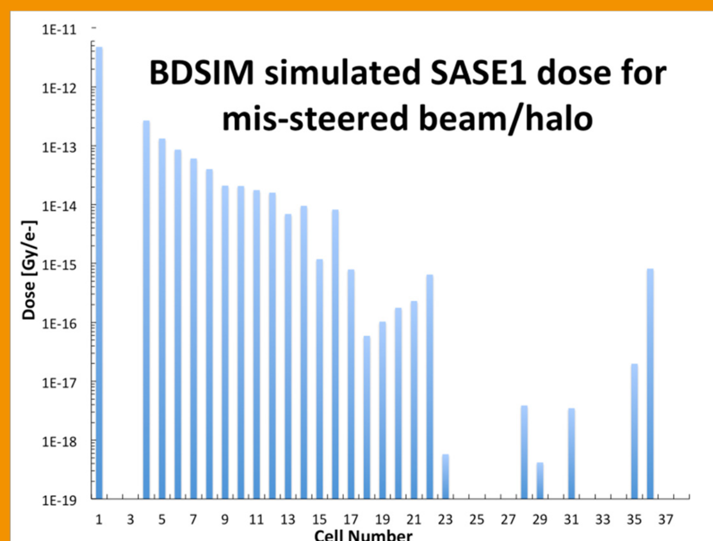






Poster THPMF022 by Shan Liu et al: Study of possible beam losses after post-linac collimation at XFEL.EU

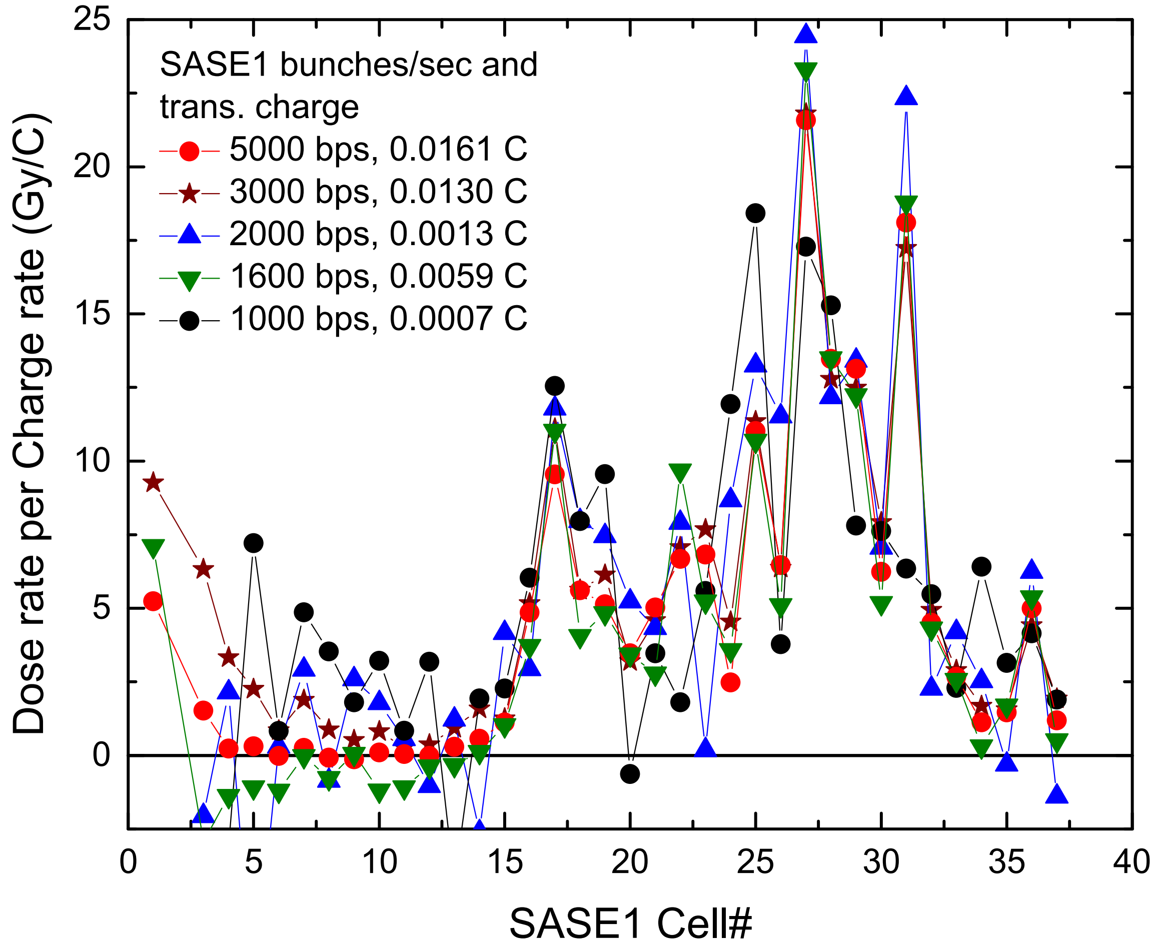
User operation mode – dose rate per transmitted charge rate

Dose rate at each segment is proportional to the transmitted charge rate, independent to the operational mode.

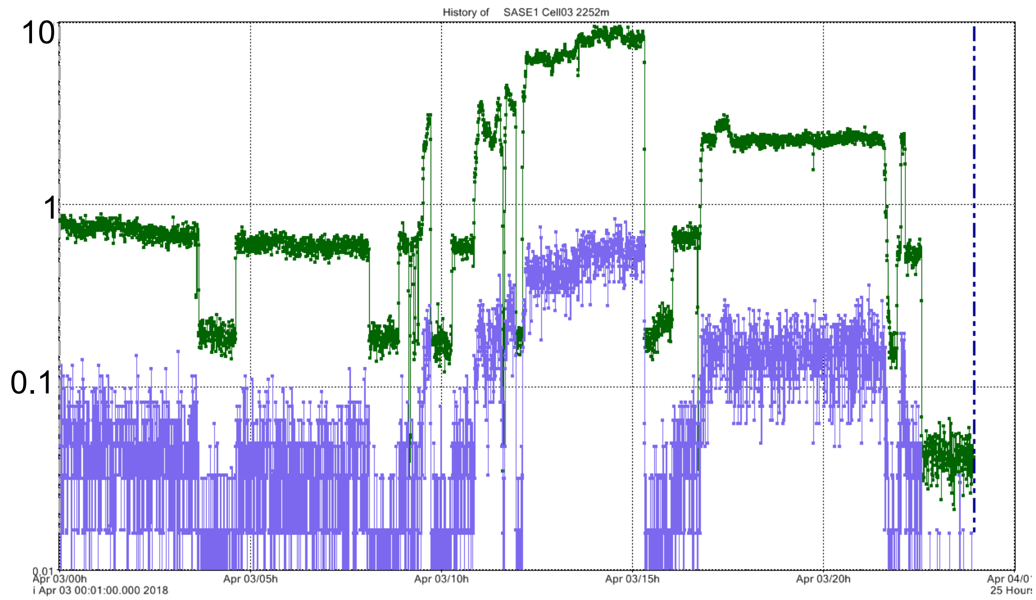
End of SASE1 with higher dose rate per charge rate ratio;

This may pose limitations at higher repetition modes;

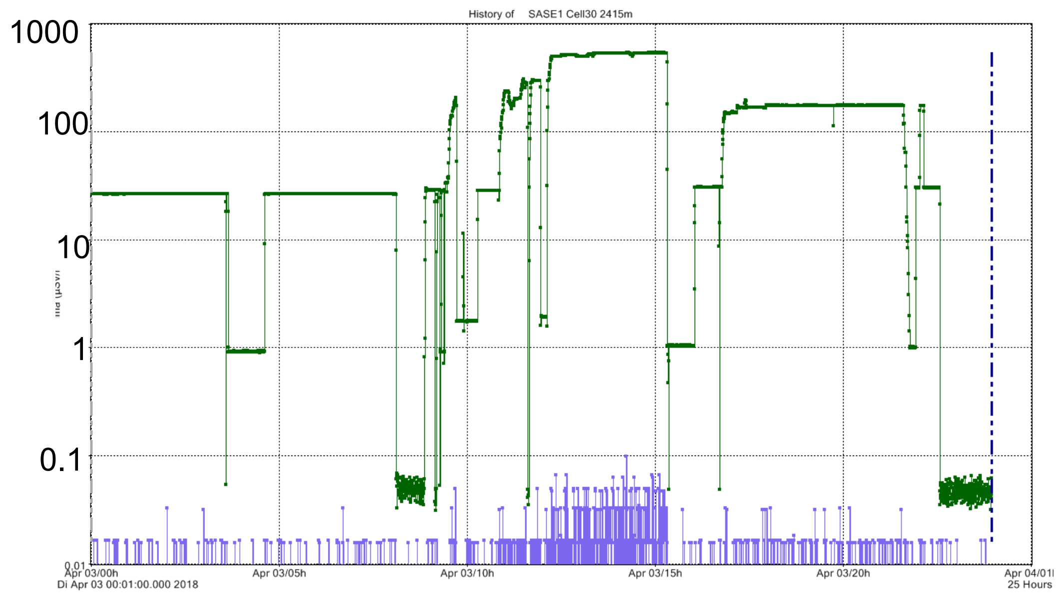
Must understand the profile to allow safe operation at 27000bps.



- **Pandora detector for Neutrons and Gamma** (Courtesy of Dirk Noelle and Albrecht Leuchner)



<u>Cell#3 – SASE1</u>: moderate photon signal (green), neutron signal (purple) significantly higher than noise.

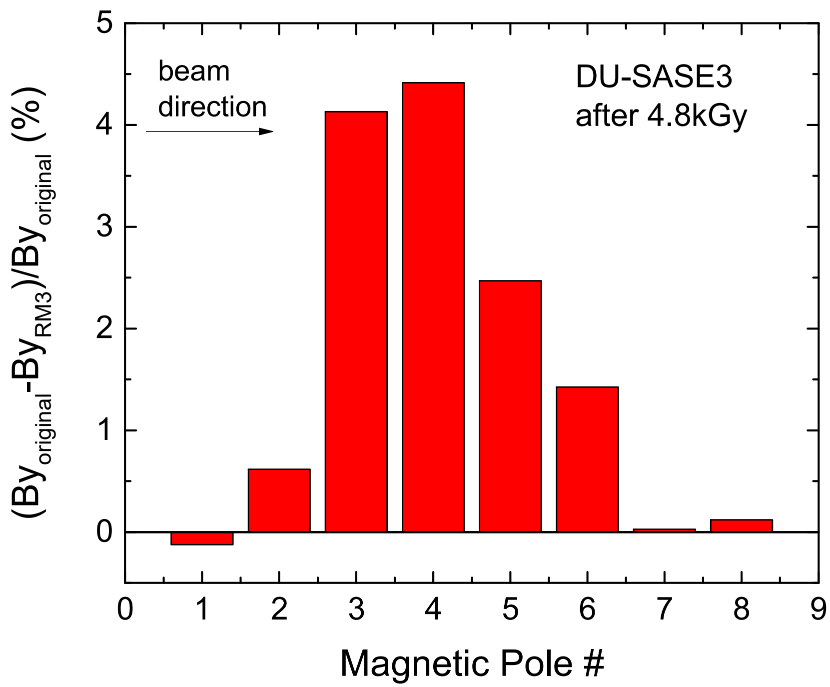


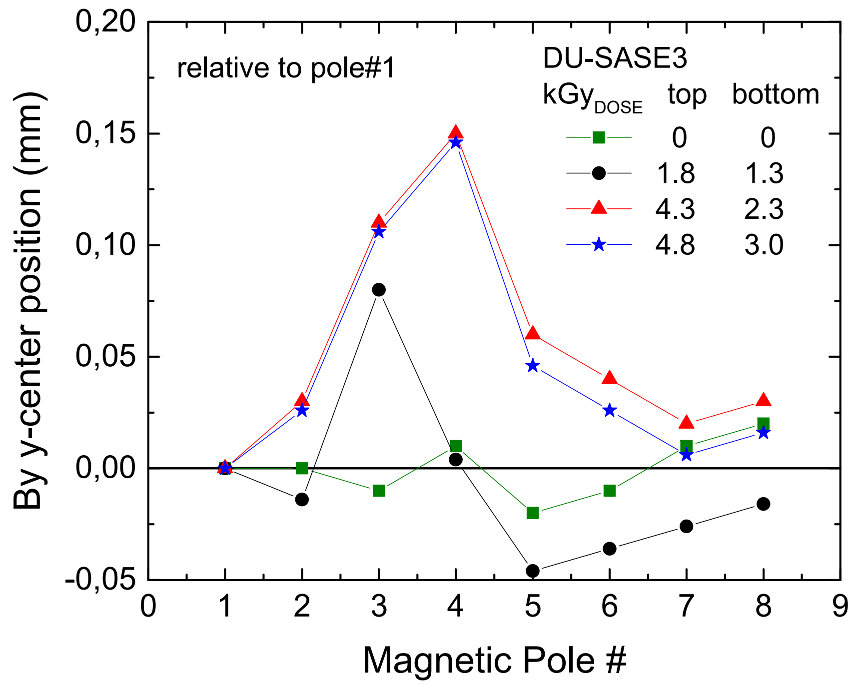
<u>Cell#30 – SASE1</u>: photon signal is 3 orders higher than cell#3; neutron signal comparable to background; Vacuum pressure was higher at 5000bps and may indicate beam-gas scattering.

De-magnetization Measurements

Diagnostic Undulators (DU)

Magnetic field degradation is seen in both SASE1 and SASE3 DUs with change on profile.



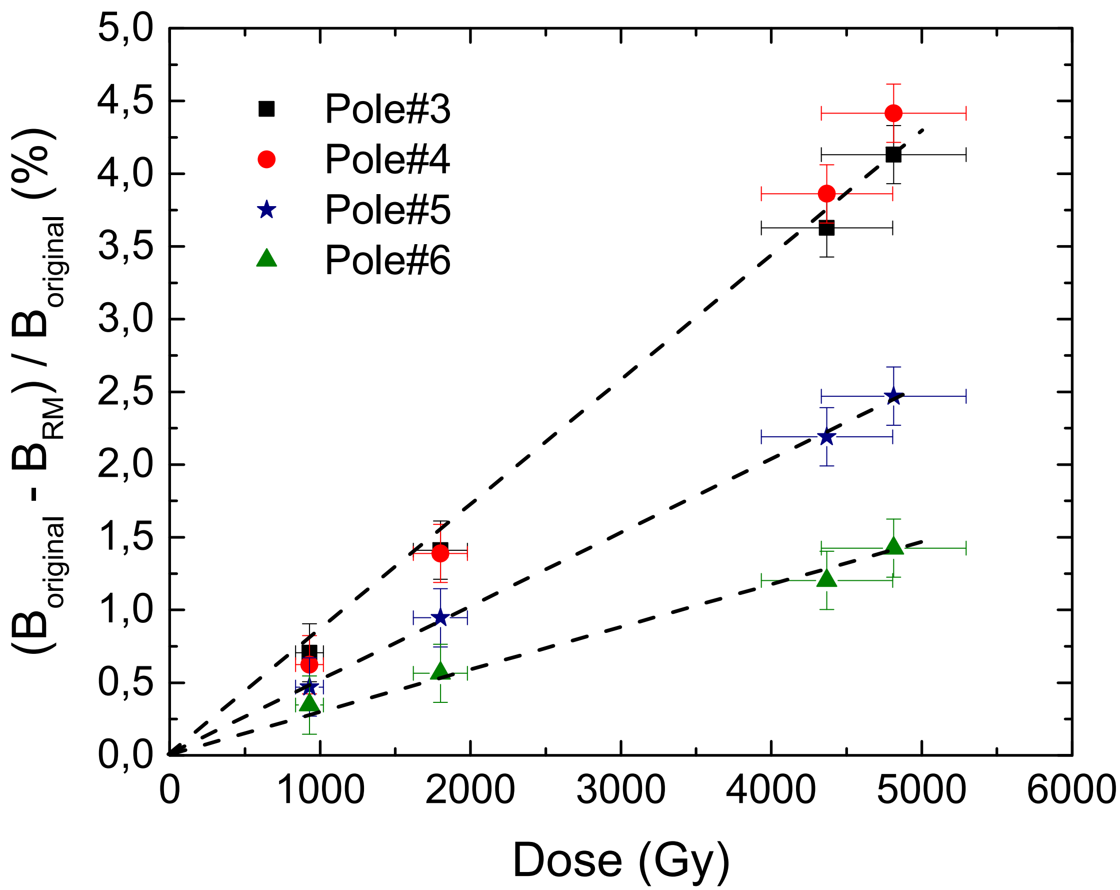


Degradation Profile:

- Pole 1 seems to gain (SASE1 DU as well)
- Low degmagnetizing field @ End Poles 1,2,7,8
- Full Demagnetizing fields @ Poles 3,4,5,6
- Shielding effects of poles 5,6?

Diagnostic Undulators (DU)

Including data from DU-SASE1 after 0.9 kGy: magnetic field degradation on the DUs appears to be in linear behaviour with absorbed doses.



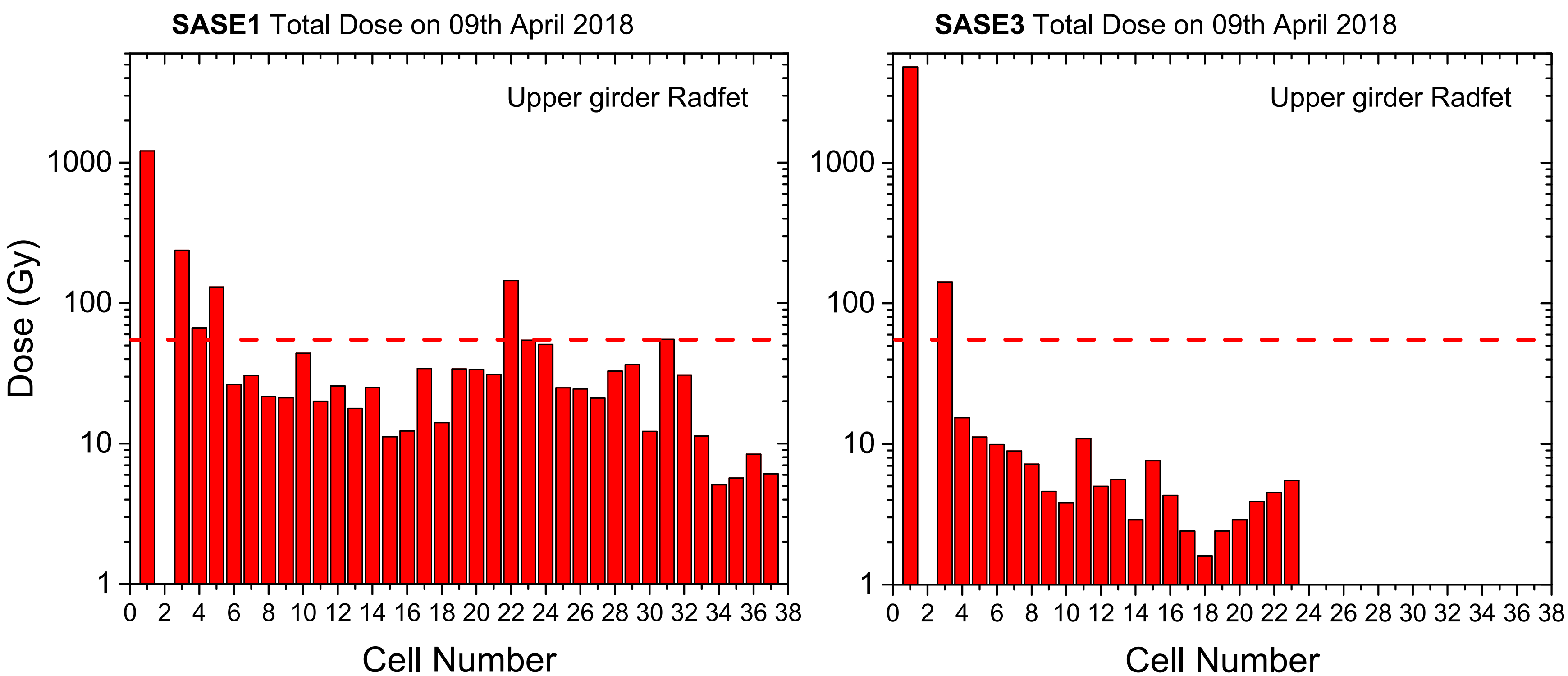
A wideband dose limit of **55 Gy** for the 5-m undulators can be estimated based on a change of $\frac{\Delta B}{B} = 4.10^{-4}$

With $6.63.10^{-4}$ Gy/min rate at 1200bps (cell#27-SASE1)

About 2.5 days to absorb 55 Gy at 1nC, 27000 bps

Total Doses on 5-m Undulators (as of April 2018)

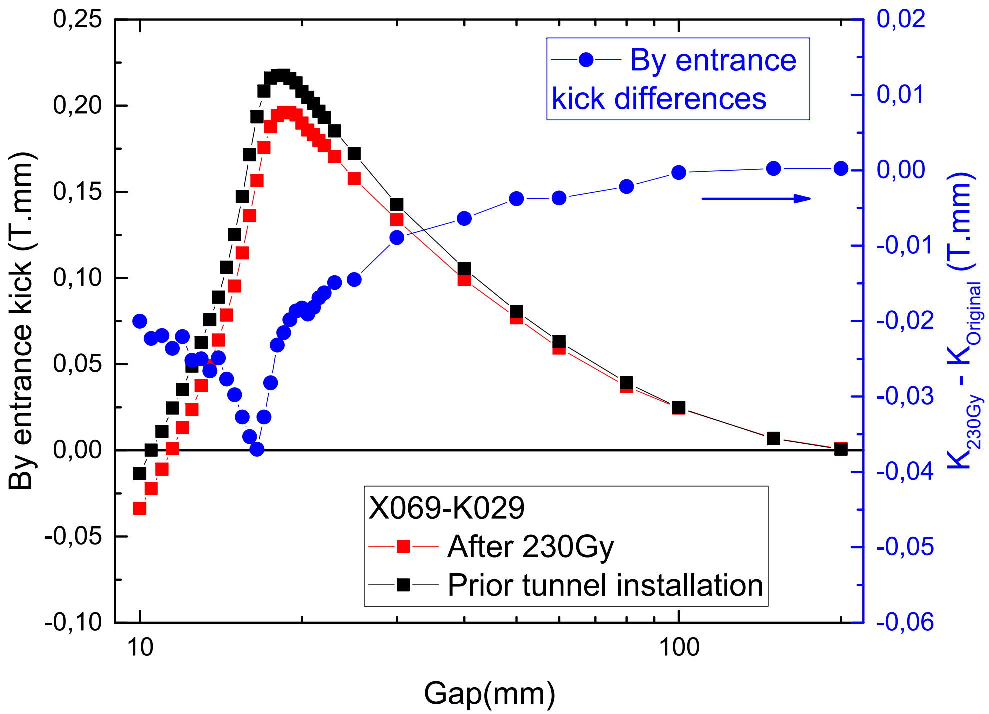
Several segments in SASE1 and SASE3 are above the wideband limit of 55 Gy.

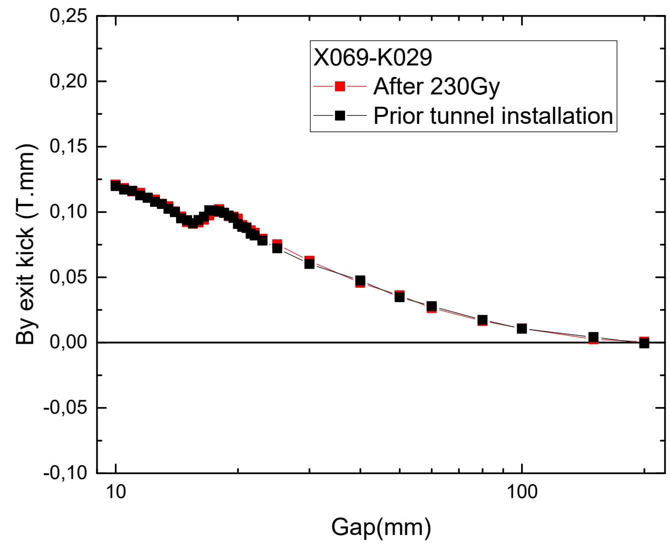


5-m SASE1 - Cell#3 Undulator after 230 Gy (Moving wire measurements):

- Changes up to 30-40 G.cm in the entrance vertical kick $K_{1(y)}$:

$$\begin{cases} K_{1(y,x)} = \dfrac{I_{1(y,x)}}{2} - \dfrac{F_{2(y,x)}}{L} \\ K_{2(y,x)} = \dfrac{I_{1(y,x)}}{2} + \dfrac{F_{2(y,x)}}{L} \end{cases}$$





Mag. Field change on entrance magnets (Hall probe): $\dfrac{\Delta B}{B} = -5 \times 10^{-4}$

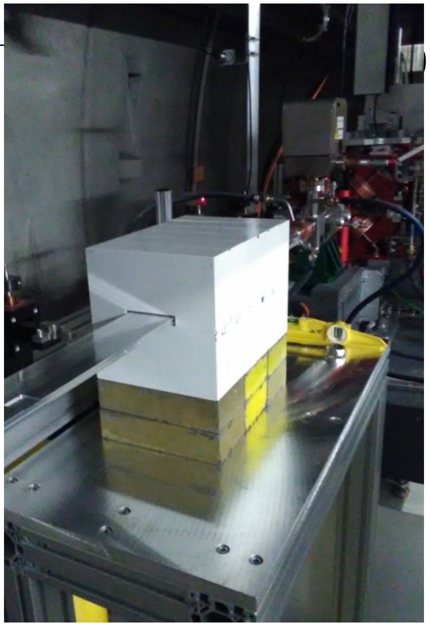
May indicate different degradation rate

SUMMARY: Lessons

- We demonstrate the importance of radiation monitoring to the Undulators.
- Absorbed Doses
  - Systematic persistent profile of doses, quite reproducible;
  - Dose rate scales with transmitted charge rate;
  - End of SASE1 presents higher doses when stable beam conditions has to be addressed, understood and minimized;
- De-magnetization
  - DU sees high de-magnetization with consequences to the magnetic field profile;
  - Initial wideband 55 Gy limit for the 5-m undulators is currently set;
  - 5-m segment at SASE1-Cell#3 has shown magnetic field changes at its entrance end.

SUMMARY: ongoing and future plans

1. Hits due to miss-steering
    1. Machine protection system
    2. First passage steering: low charge beams
    3. Operator awareness and training
    4. Shielding + low power beam stop



2. Optimize the e$^-$ beam operation:
    1. BBA orbit alignment
    2. Identify radiation field
    3. Study and improve collimation
    4. Beam dynamic simulations: halo, beam-gas scattering, 40/8 chamber
3. Re-measurements and prepare exchange of undulators
    1. Building 10% spare 5-m undulators for replacement of damaged segments
    2. Evaluate alternative technologies.
4. Continue discussions with colleagues from other facilities.

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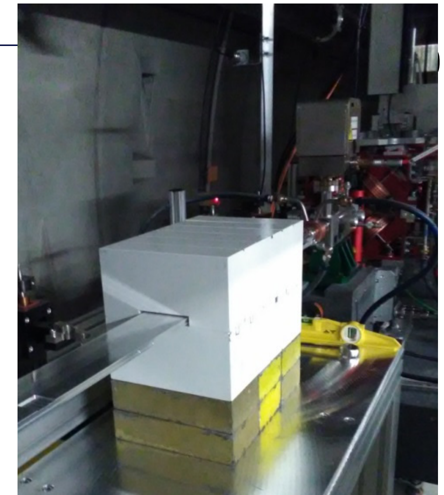

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MARWIN

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ACKNOWLEDGMENTS

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- **Frank Schmidt-Föhre**, **Winfried Decking, Dirk Noelle, Shan Liu and DESY machine coordinators and operators**;
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European XFEL

DESY.

Stockholms universitet

Thank you!