



T. Schmidt:: ID Group :: Paul Scherrer Institut

Experience with short-period, small gap undulators at the SwissFEL Aramis beamline

FEL19, Hamburg, August 28, 2019

Aramis undulator beamline
small gap operation
Instrumentation for
spontaneous synchrotron
radiation

The experience with the
Aramis undulators

- orbit
- alignment
- K calibration

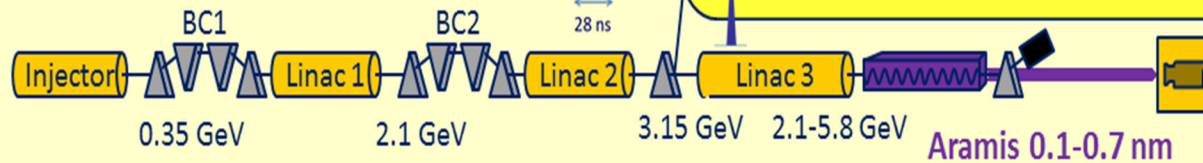
Link to other papers in the
conference or posters



SwissFEL ramp-up phase

1st Construction Phase

2013-16



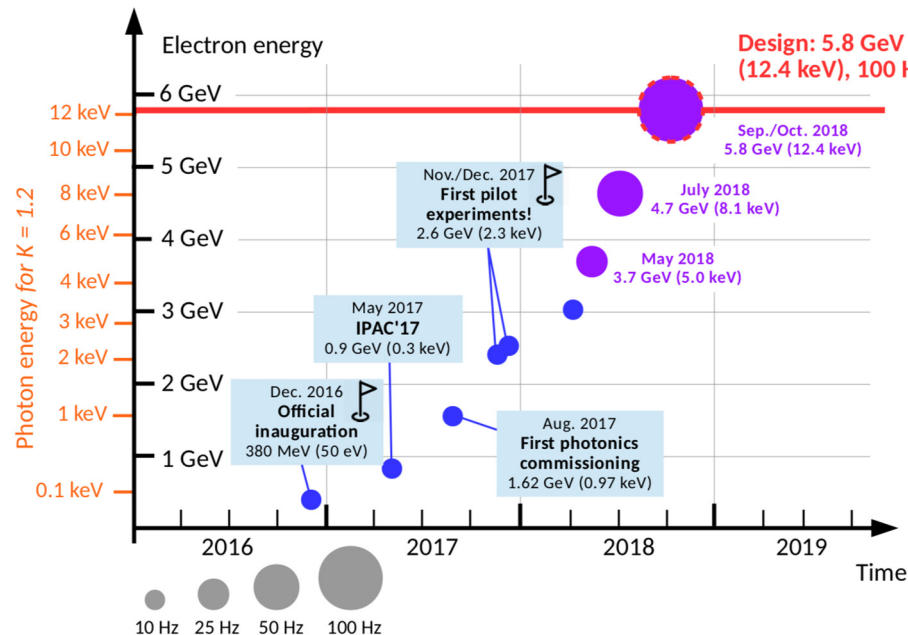
2nd Construction Phase 2017-20



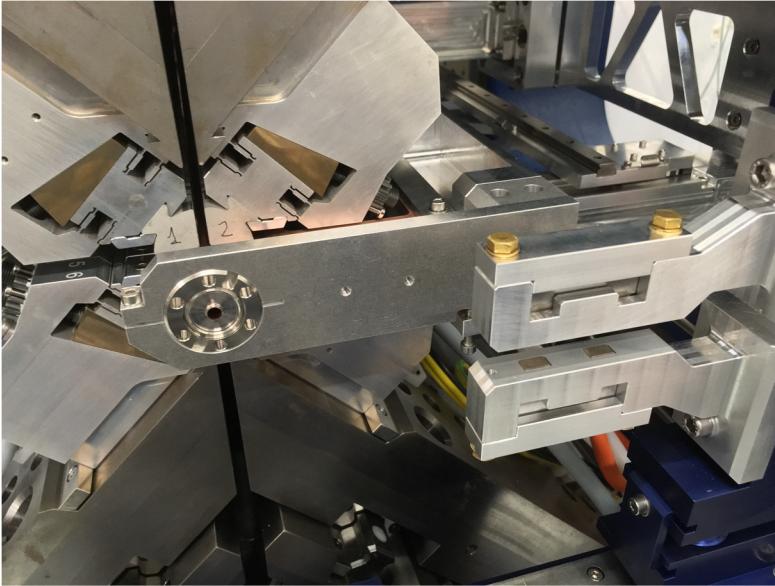
Athos 0.65-5nm

Aramis 0.1-0.7 nm

user
stations



Athos switchyard
two bunch acceleration
first light in undulators:
end 2019
pilot experiments:
summer 2020

Athos UE₃₈ APPLE X

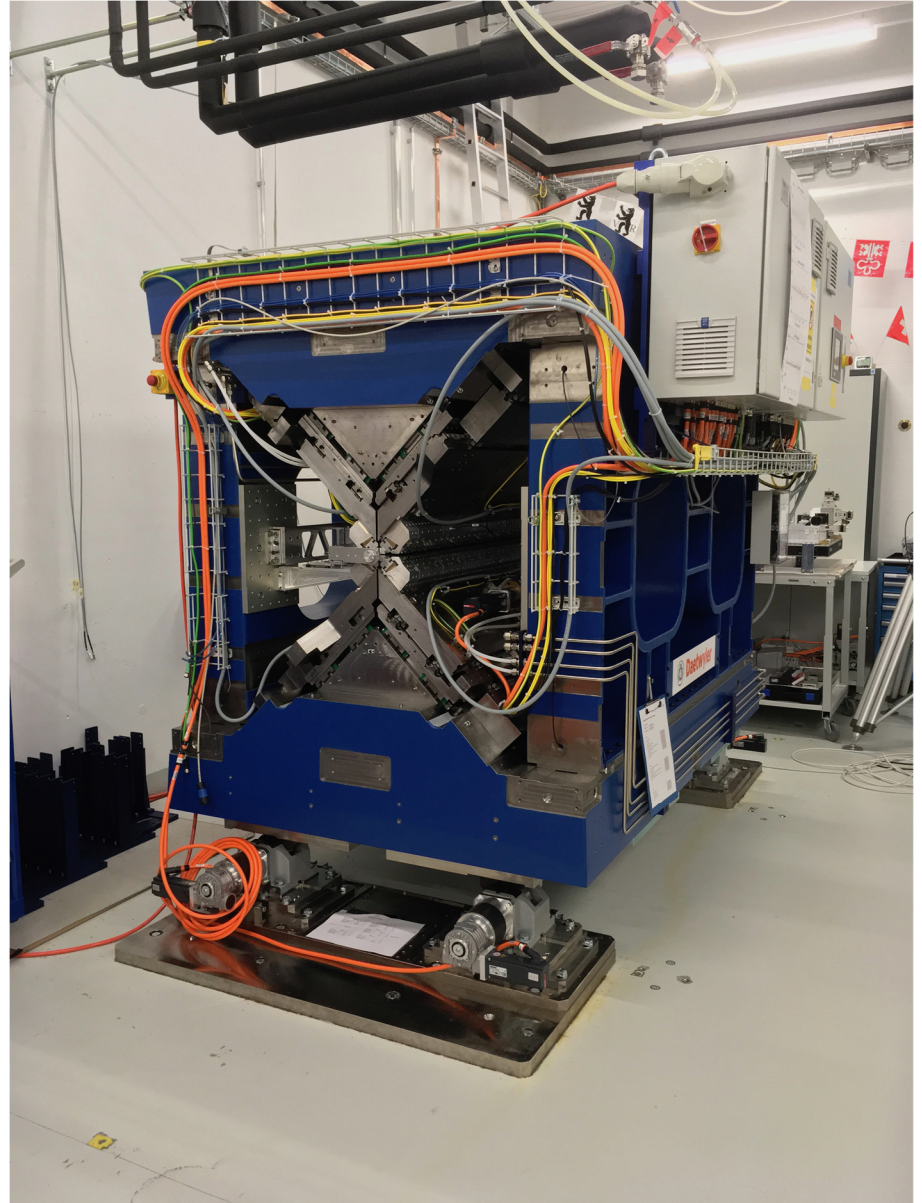
16 modules

2m 50 periods

$\lambda_U = 38\text{mm}$

$K = 3.8 - 1$

gap = 6.5mm diameter

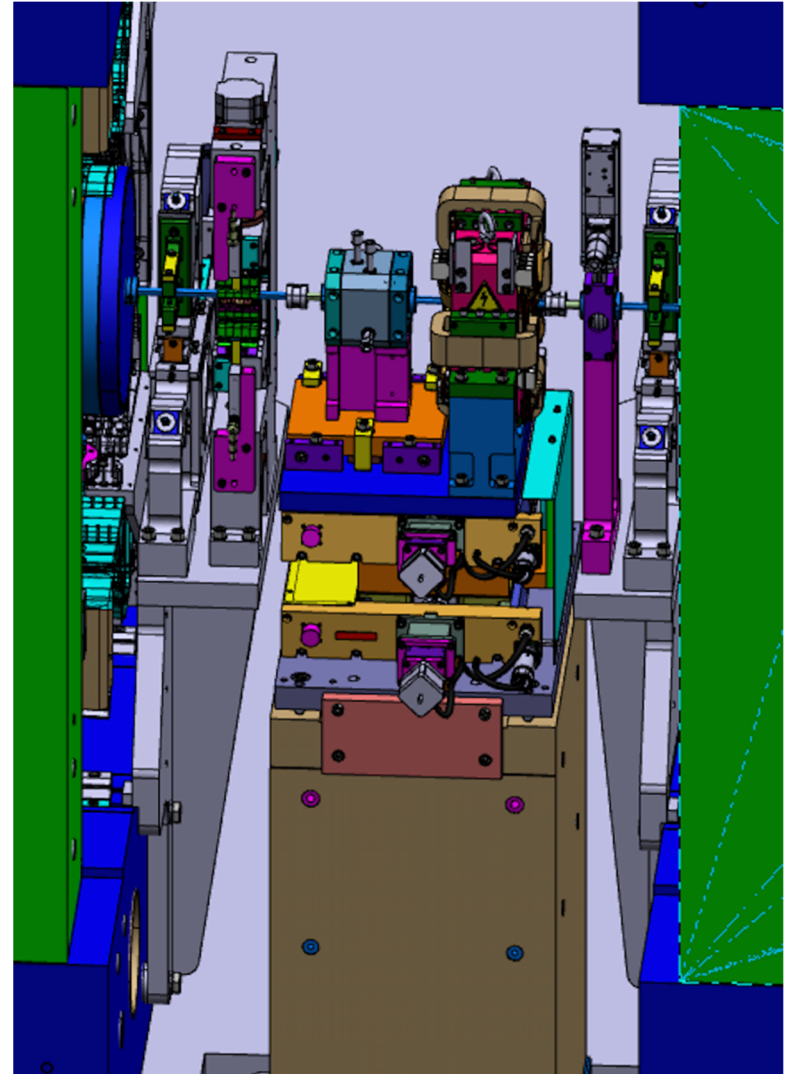
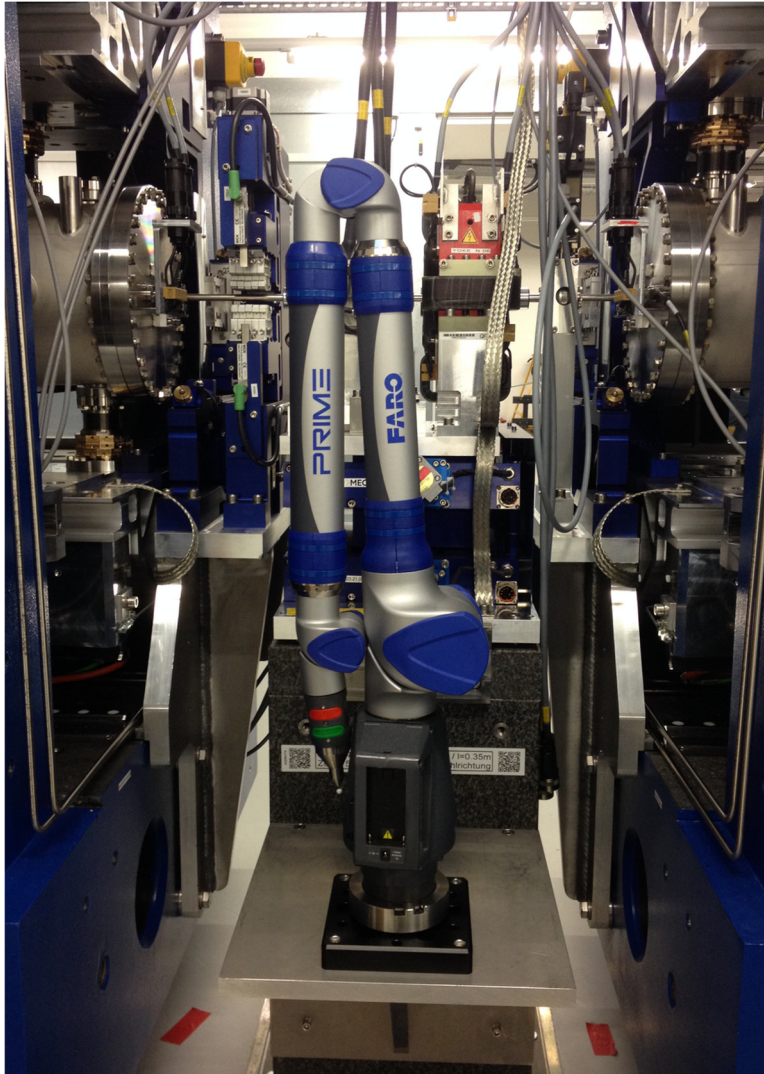


Aramis Undulator Line

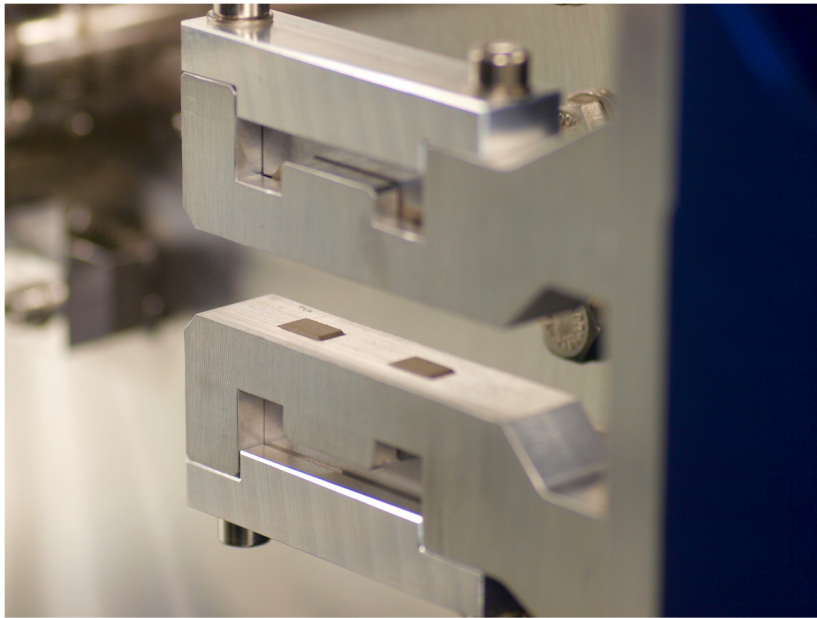


Undulator Intersection

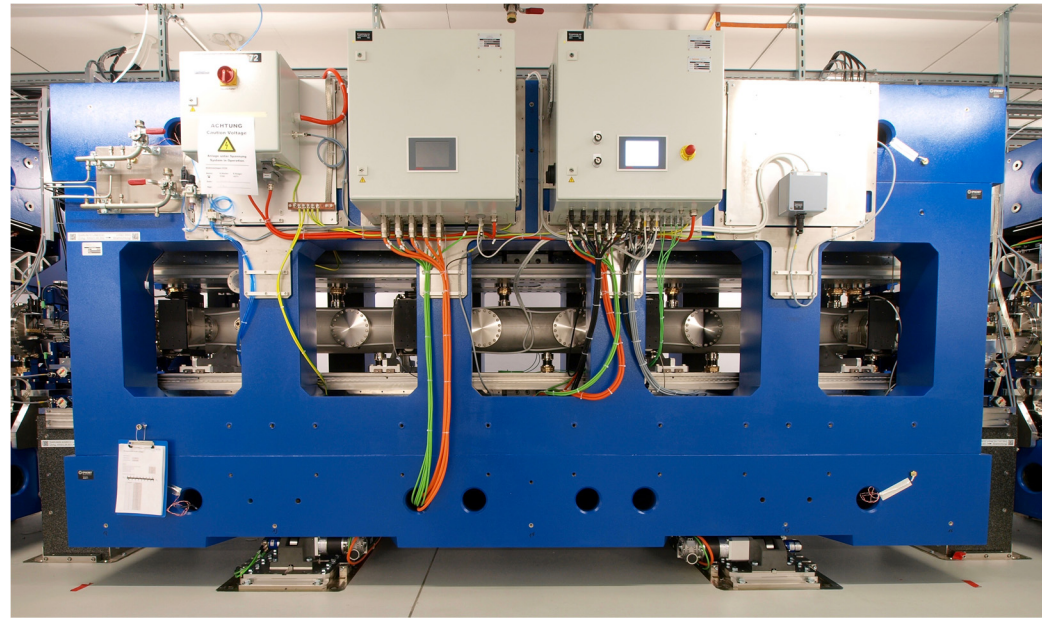
Alignment Quads, Phase Matcher, BPM and Quadrupole, Valve



Alignment Quads for Undulator beam based alignment

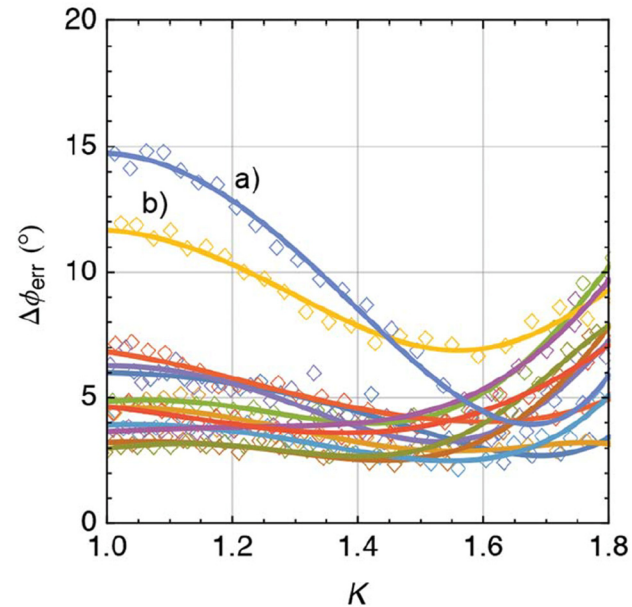
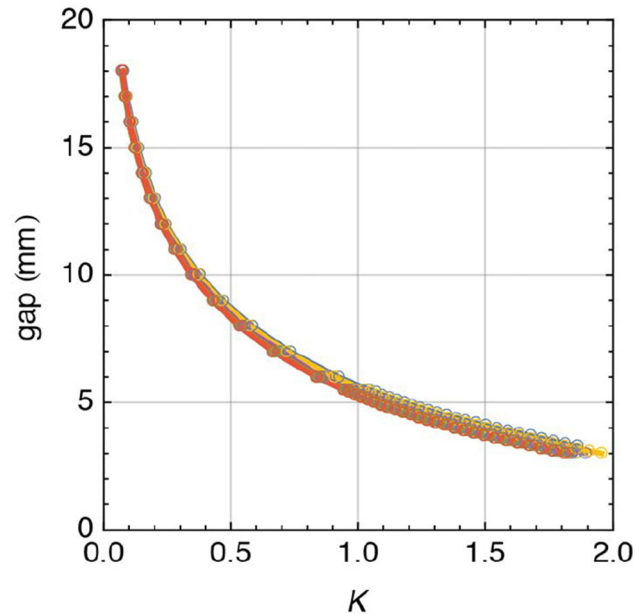


aligned to beam axis in lab
pneumatic in and out
1st setup in beam

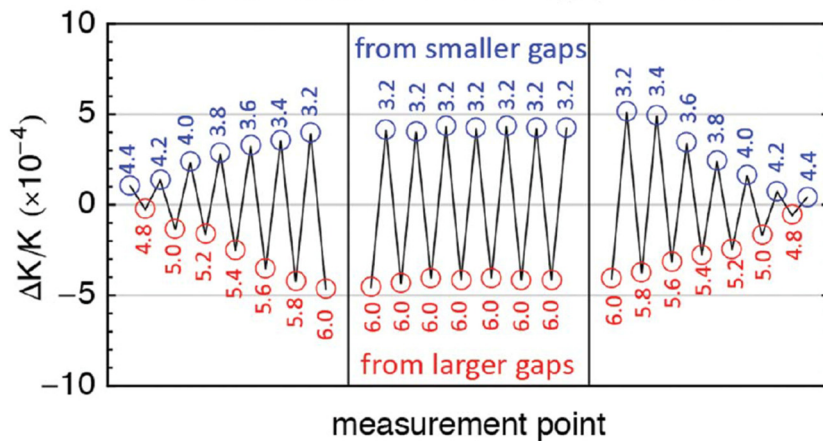


5 axis cam-shaft mover:
remotely controlled, μm precision
(hor., **vert.**, **pitch**, yaw, roll)

Aramis U15 magnetic performance



all measurements done @ gap = 4.6mm



Magnetic assessment and modelling of the Aramis undulator beamline

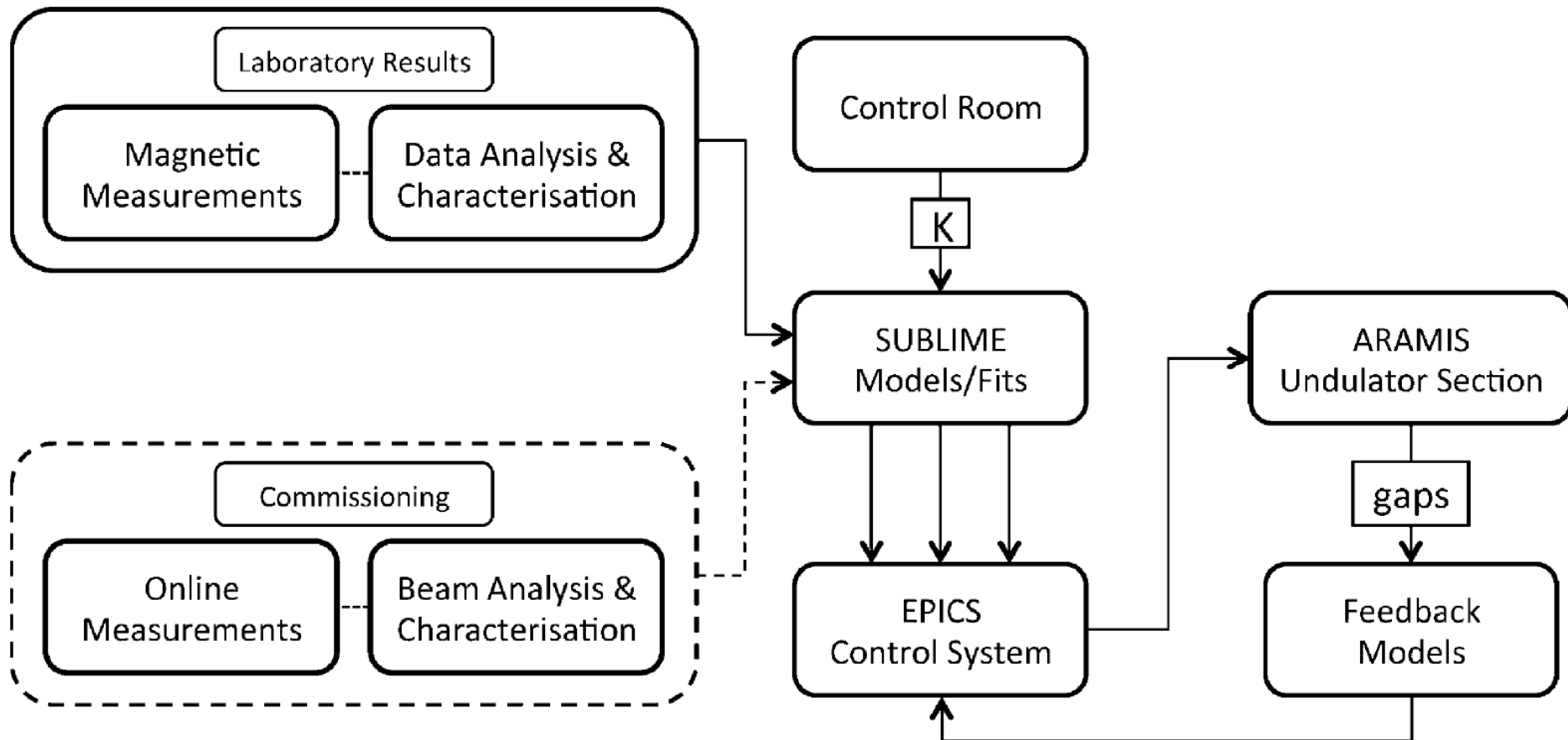
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^aPaul Scherrer Institute, CH-5232 Villigen PSI, Switzerland, and ^bDepartment of Microelectronics and Nanoelectronics, University of Malta, Msida, Malta. *Correspondence e-mail: marco.calvi@psi.ch

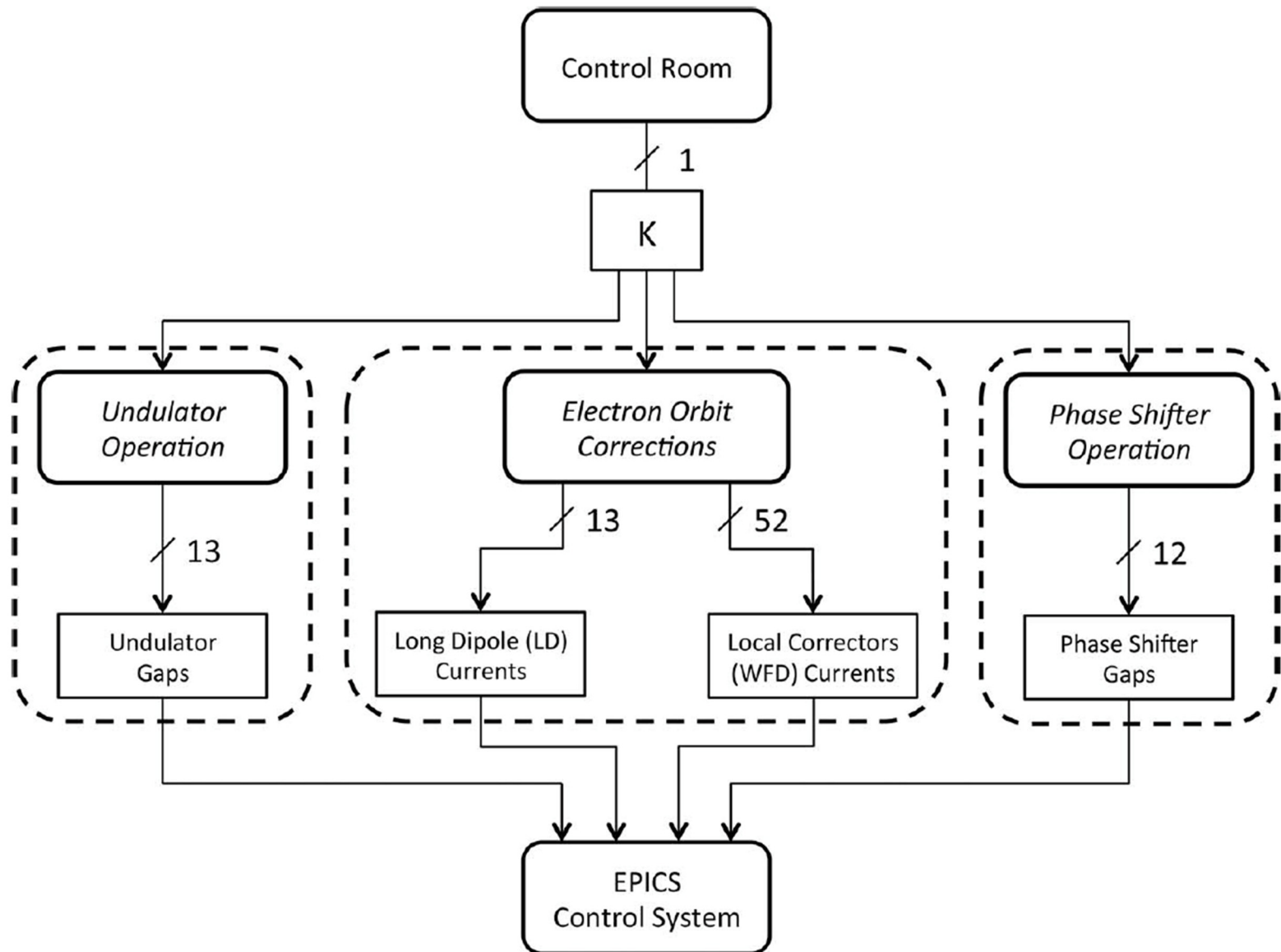
Within the SwissFEL project at the Paul Scherrer Institute (PSI), the hard X-ray line (Aramis) has been equipped with short-period in-vacuum undulators, known as the U15 series. The undulator design has been developed within the institute itself, while the prototyping and the series production have been implemented through a close collaboration with a Swiss industrial partner, Max Daetwyler AG, and several subcontractors. The magnetic measurement system has been built at PSI, together with all the data analysis tools. The Hall probe has been designed for PSI by the Swiss company SENIS. In this paper the general concepts of both the mechanical and the magnetic properties of the U15 series of undulators are presented. A description of the magnetic measurement equipment is given and the results of the magnetic measurement campaign are reported. Lastly, the data reduction methods and the associated models are presented and their actual implementation in the control system is detailed.

Aramis U15 operational concept

SUBLIME: aramiS Undulator BeamLine Model



Aramis U15 operational concept



Aramis U15 operational concept

ID control panel

Aramis Undulator Line Overview Panel

All gap motor ON U15 Gap Panel Expert (SARUN03 - SARUN15) U15 Mover Panel Expert (SARUN03 - SARUN15) U15 Positions Overview Phase Shifter Overview

SARUN03	SARUN04	SARUN05	SARUN06	SARUN07	SARUN08	SARUN09	SARUN10	SARUN11	SARUN12	SARUN13	SARUN15
U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils	U15 corrector coils
Apply	Apply	Apply	Apply	Apply	Apply	Apply	Apply	Apply	Apply	Apply	Apply
UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS	UPHS
0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg	0 deg
QFU	QFU	QFU	QFU	QFU	QFU	QFU	QFU	QFU	QFU	QFU	QFU
GAP rbc (mm): 17.9729	GAP rbc (mm): 18.3505	GAP rbc (mm): 18.0074	GAP rbc (mm): 17.9212	GAP rbc (mm): 17.9682	GAP rbc (mm): 17.9693	GAP rbc (mm): 17.9569	GAP rbc (mm): 17.9876	GAP rbc (mm): 17.8171	GAP rbc (mm): 18.0293	GAP rbc (mm): 18.0000	GAP rbc (mm): 18.1067
Go !	Go !	Go !	Go !	Go !	Go !	Go !	Go !	Go !	Go !	Go !	Go !
K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720	K: +0.0720
Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open	Full Open

Apply same K to all undulators = +0.0720 All Full Open Apply all correctors Set all phase matcher to 0 degrees ! Tapering Panel QFF Quadrupole BPM8 X-Y table

Beam Energy @ Beam Dump Beam Energy at Beam Dump (MeV): 6292.167 FEL photon energy from SARUN15 and BD beam energy (keV): 25.001 FEL photon energy from SARUN03 and ECOL beam energy (keV): 23.539 FEL Wavelength (nm) from ECOL: 0.053

Undulator alignment procedure with QFU (choose SARUN03 - SARUN15) FEL pulse energy meas. script Script not started Energy @ beam dump when no FEL (MeV) 0.000 FEL Pulse energy estimate from energy drop (uJ): 0.0

Aramis U15 operational concept

Aramis Undulator Line Overview Panel

All gap motor ON

U15 Gap P

SARUN03	SARUN04	SARUN05	SARUN06	SARUN07	SARUN08
☐ SARUN03 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): 17.9729 Go ! K: +0.0720 Full Open	☐ SARUN04 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): 18.3505 Go ! K: +0.0720 Full Open	☐ SARUN05 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): 18.0074 Go ! K: +0.0720 Full Open	☐ SARUN06 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): 17.9212 Go ! K: +0.0720 Full Open	☐ SARUN07 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): 17.9682 Go ! K: +0.0720 Full Open	☐ SARUN08 U15 corrector coils ☒ Apply UPHS 0 deg QFU QFU GAP rbck (mm): Go ! K: +0.0720 Full Open

Apply same K to all undulators = +0.0720 All Full Open ☒ Apply all correctors Set all phase

Beam Energy @ Beam Dump

Beam Energy at Beam Dump (MeV):

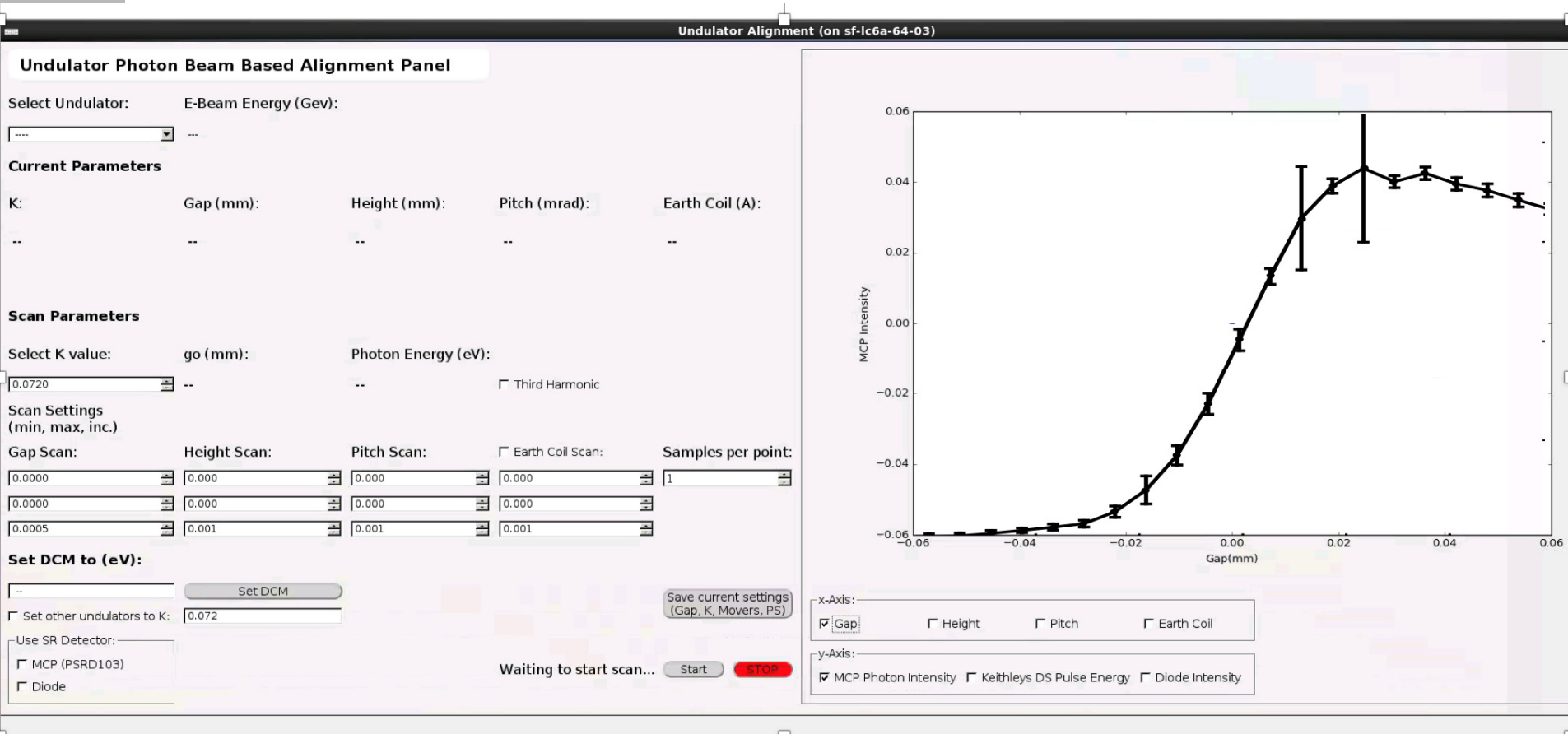
6292.167

FEL photon energy from SARUN15

Undulator alignment procedure with QFU (choose SARUN03 - SARUN15)

 FEL pulse energy meas. script ☒

Undulator optimisation panel



Finding a straight electron orbit

1 – 2 / year

- 1) Straight orbit first – beam based BBA
- 2) Align Undulator modules to it – also BBA with Q_A
- 3) Improve Undulator alignment with photons (spont. rad.)

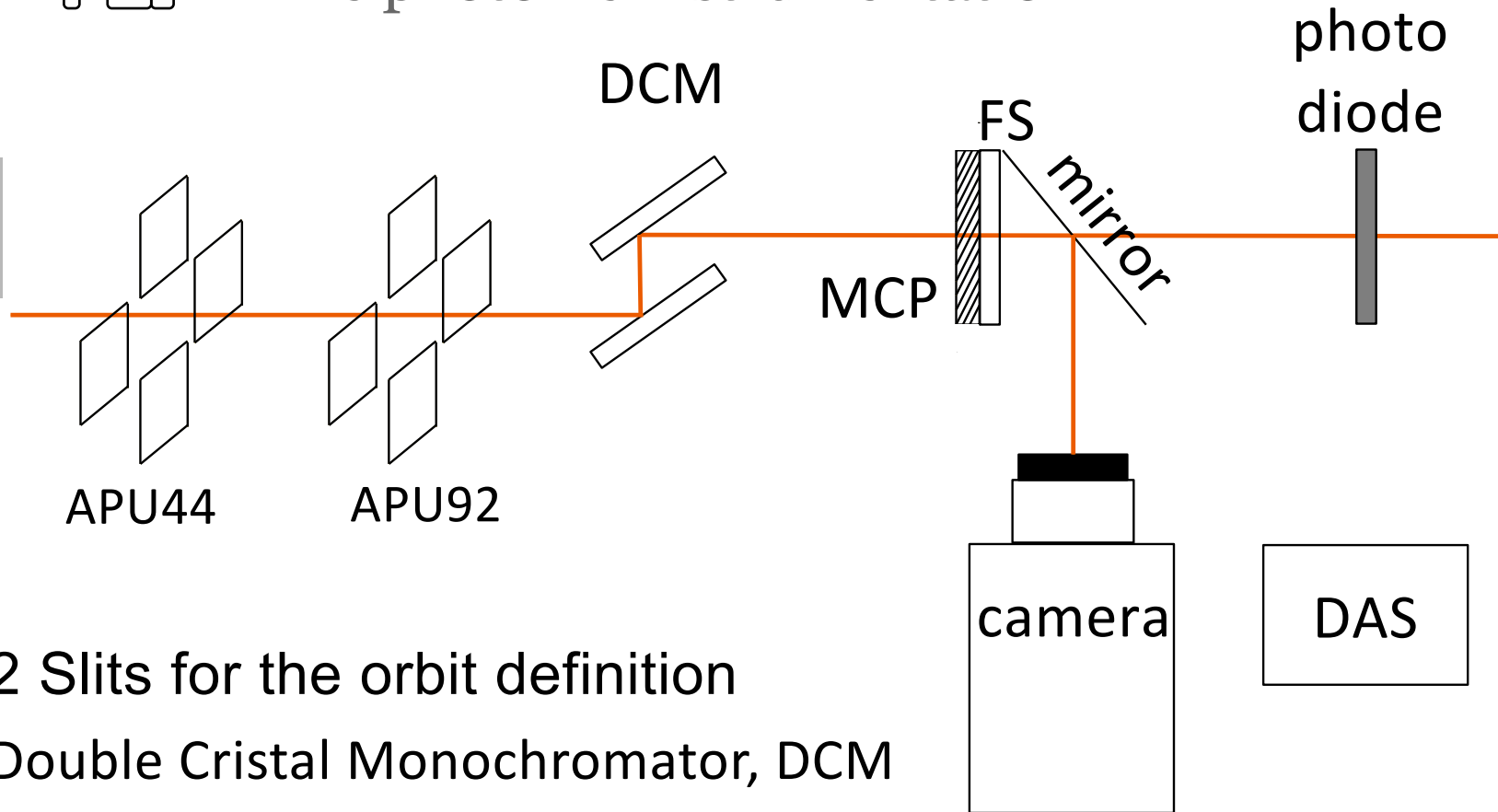
special bunch compression setup:

minimise projected energy spread

- 4) Optimise with FEL signal (PSICO)

daily

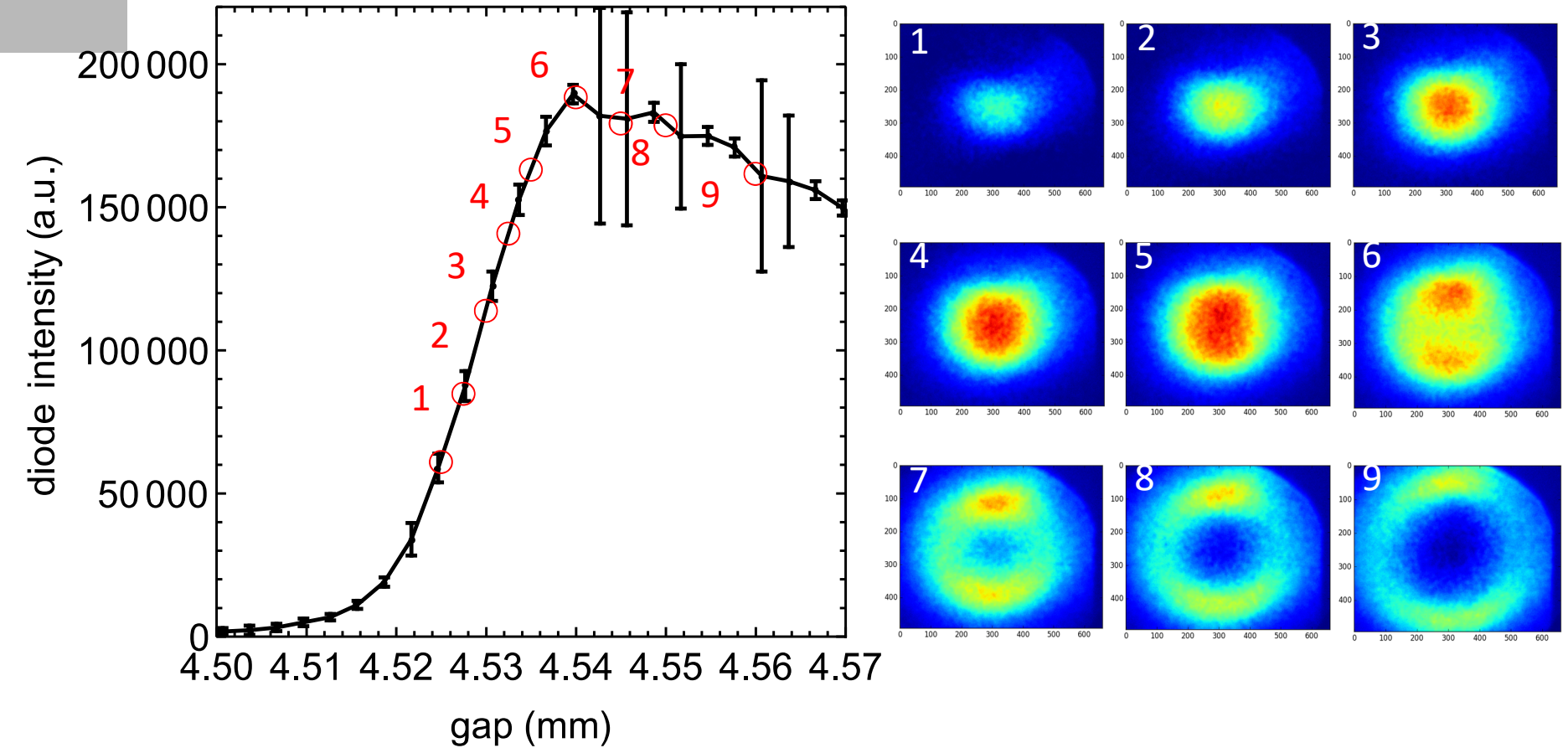
The photonic instrumentation



- 2 Slits for the orbit definition
- Double Cristal Monochromator, DCM
- Silicon Photo Diode
- Multi Channel Plate, Double stage
MCP operated @ 1.5kV

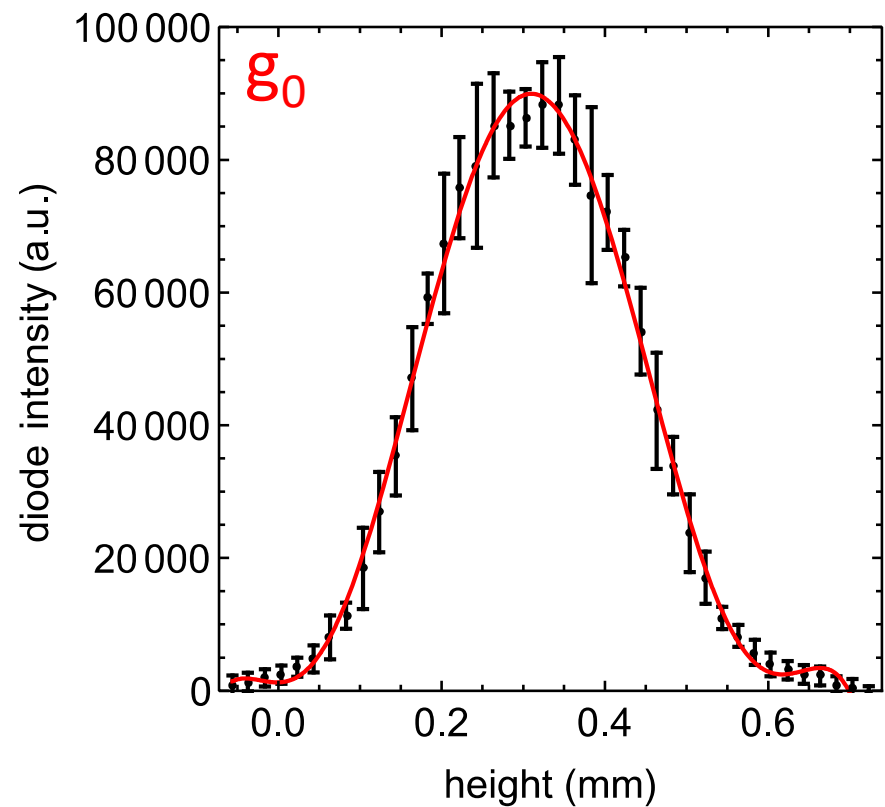
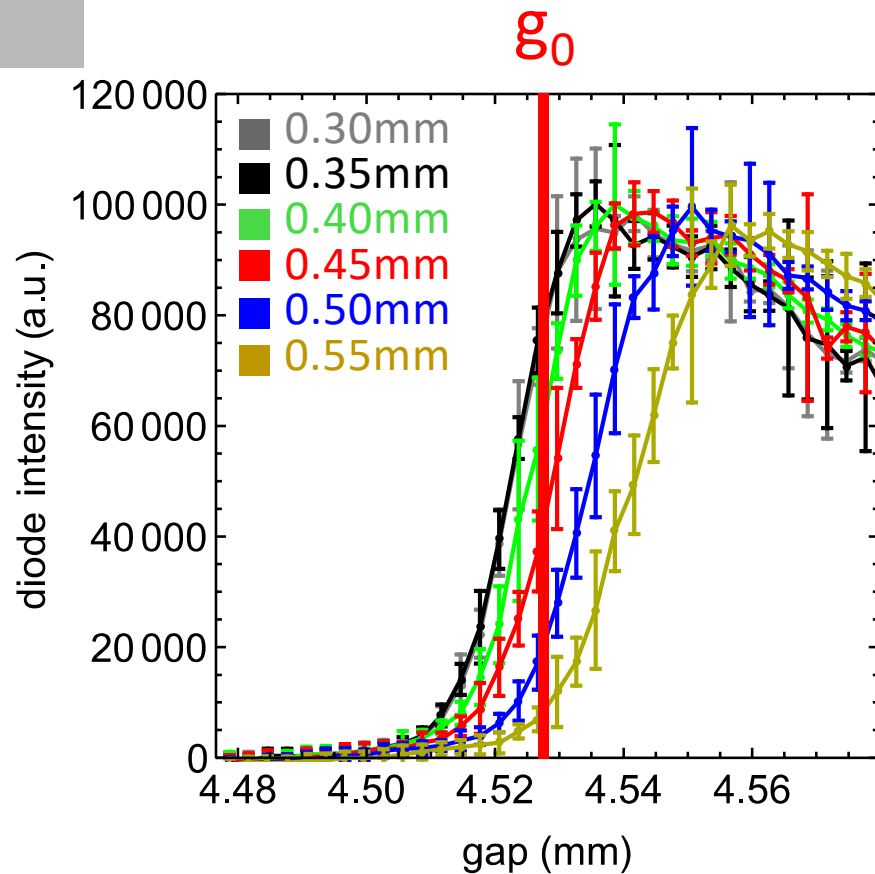
Blue edge - gap scan : example

Mono: 2395eV



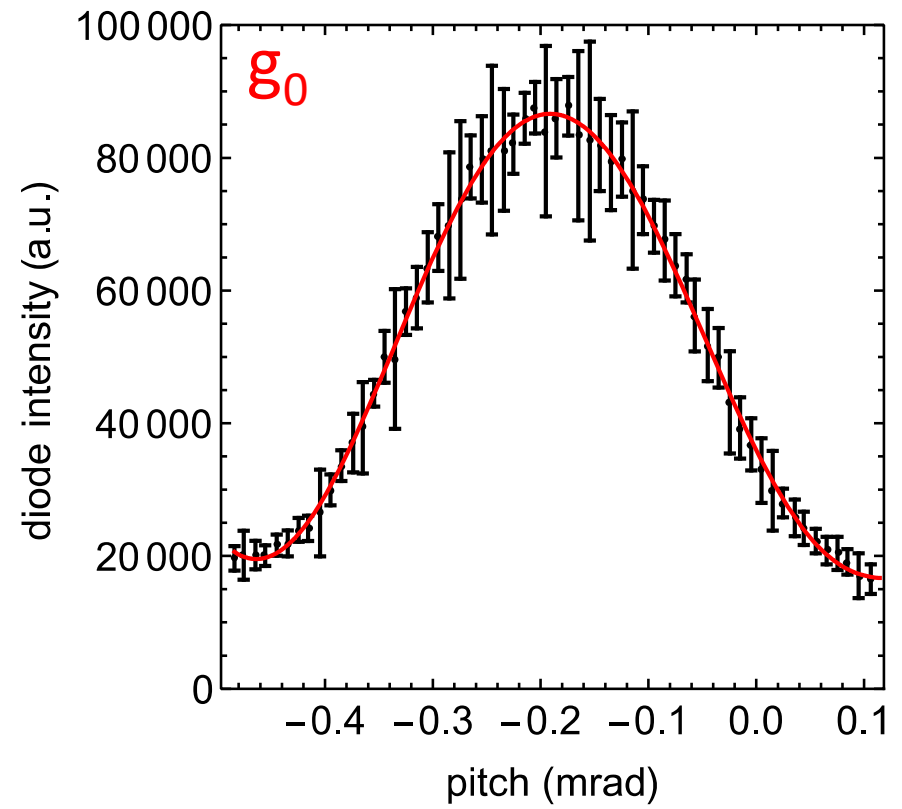
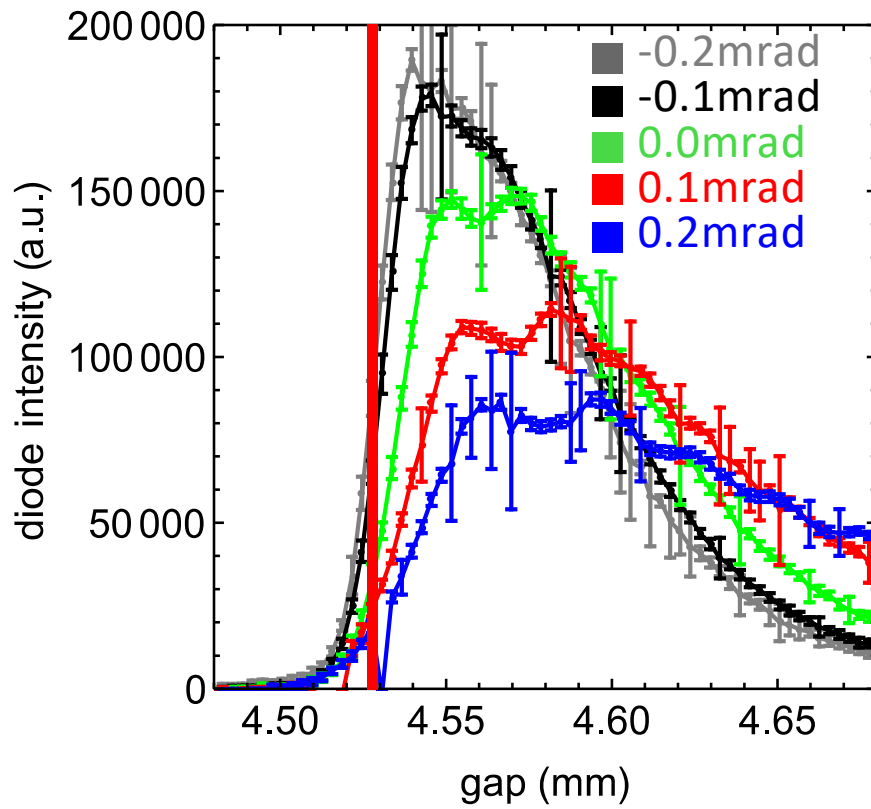
Alignment : height

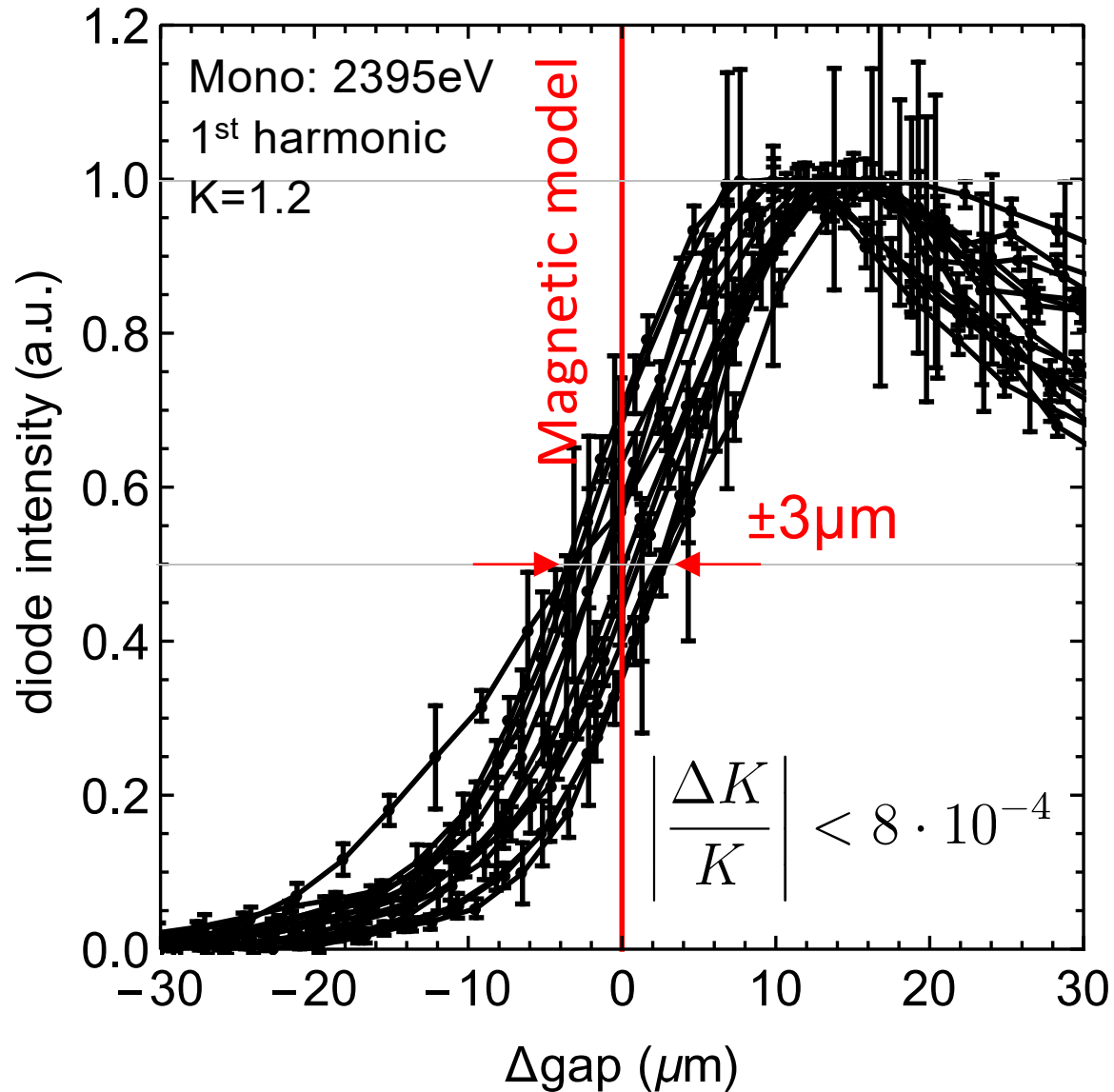
Mono: 2395eV

1st harmonic

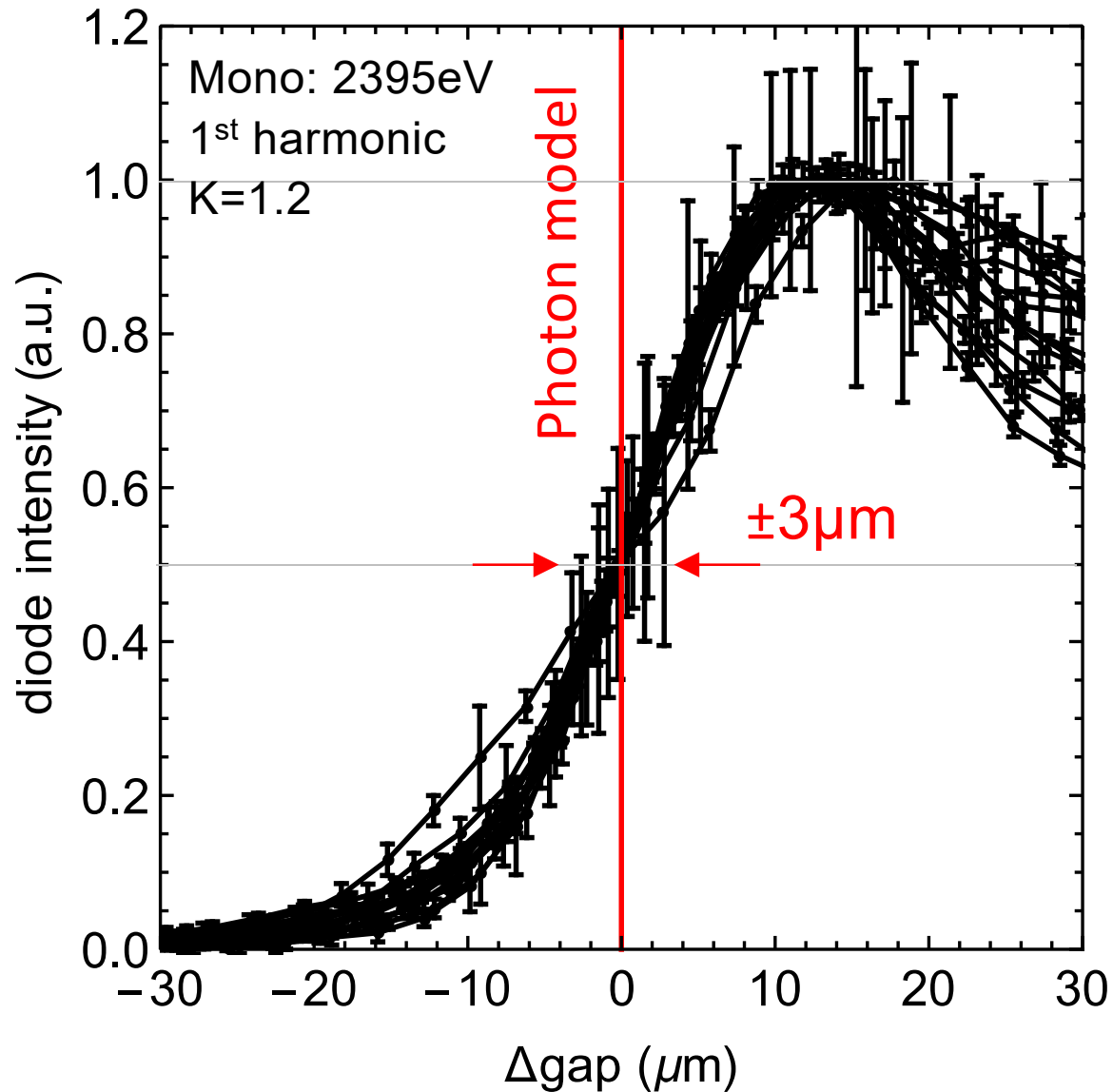
Alignment : pitch

Mono: 2395eV

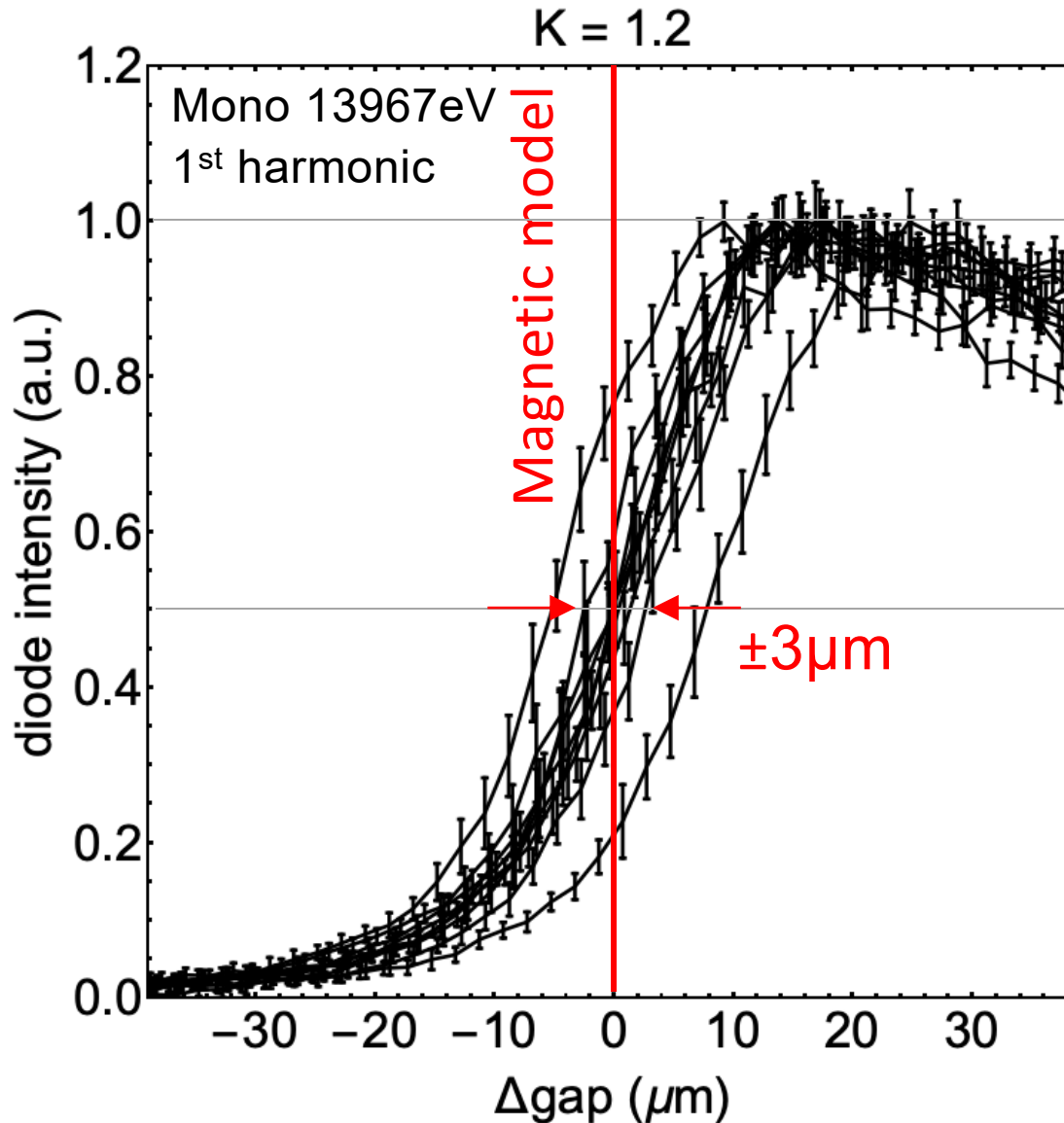
1st harmonic g_0 

K-calibration : March 2018

SARNU03
 SARUN04
 SARUN05
 SARUN06
 SARUN07
 SARUN08
 SARUN09
 SARUN10
 SARUN11
 SARUN12
 SARUN13
 SARUN14
 SARUN15

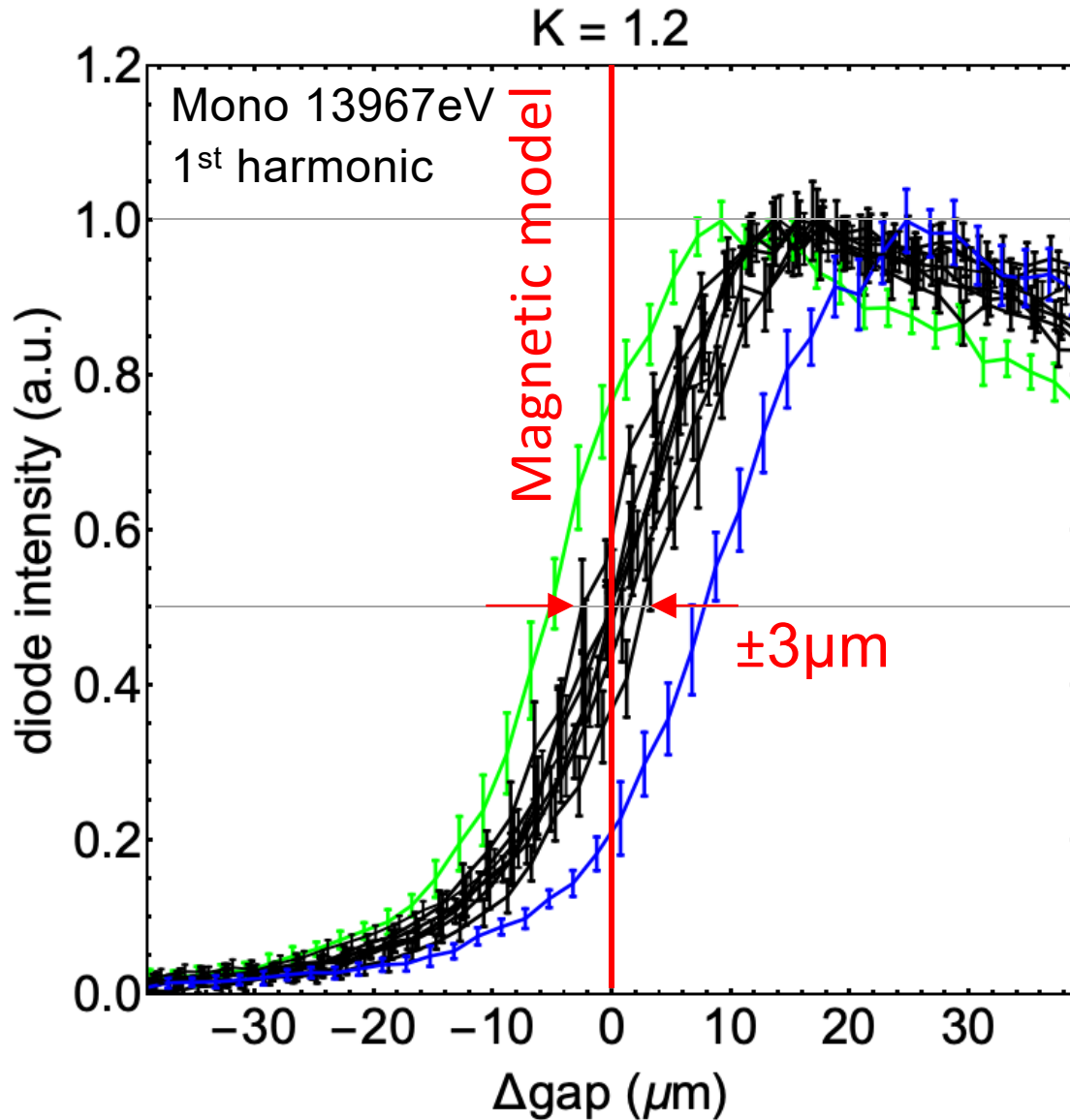
K-calibration : March 2018

SARUN03
SARUN04
SARUN05
SARUN06
SARUN07
SARUN08
SARUN09
SARUN10
SARUN11
SARUN12
SARUN13
SARUN14
SARUN15

Blue edges of measured modules – $K=1.2$ 

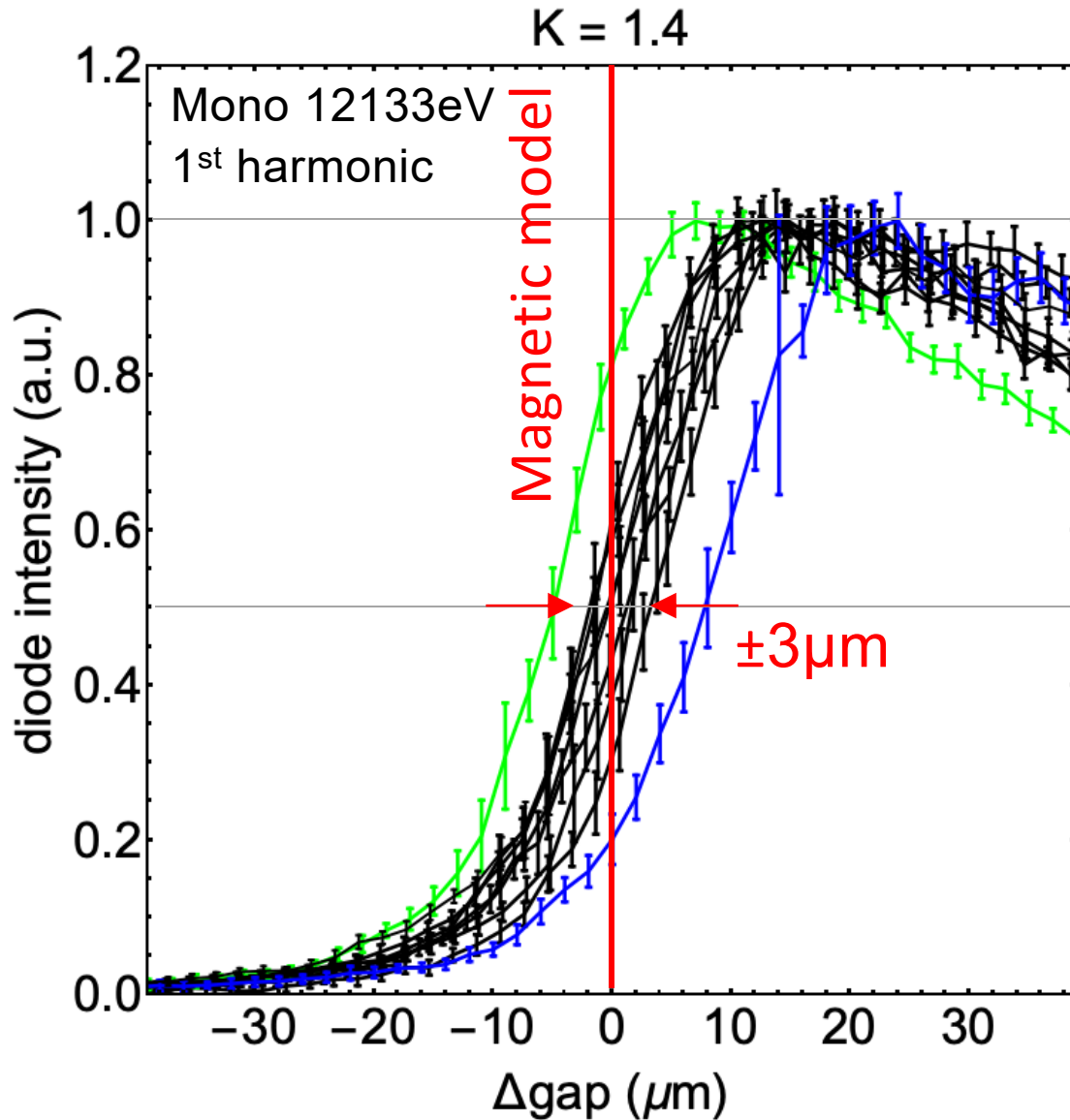
SARNU07
SARUN08
SARUN09
SARUN10
SARUN11
SARUN12
SARUN13
SARUN14
SARUN15

Blue edges of measured modules – $K=1.2$



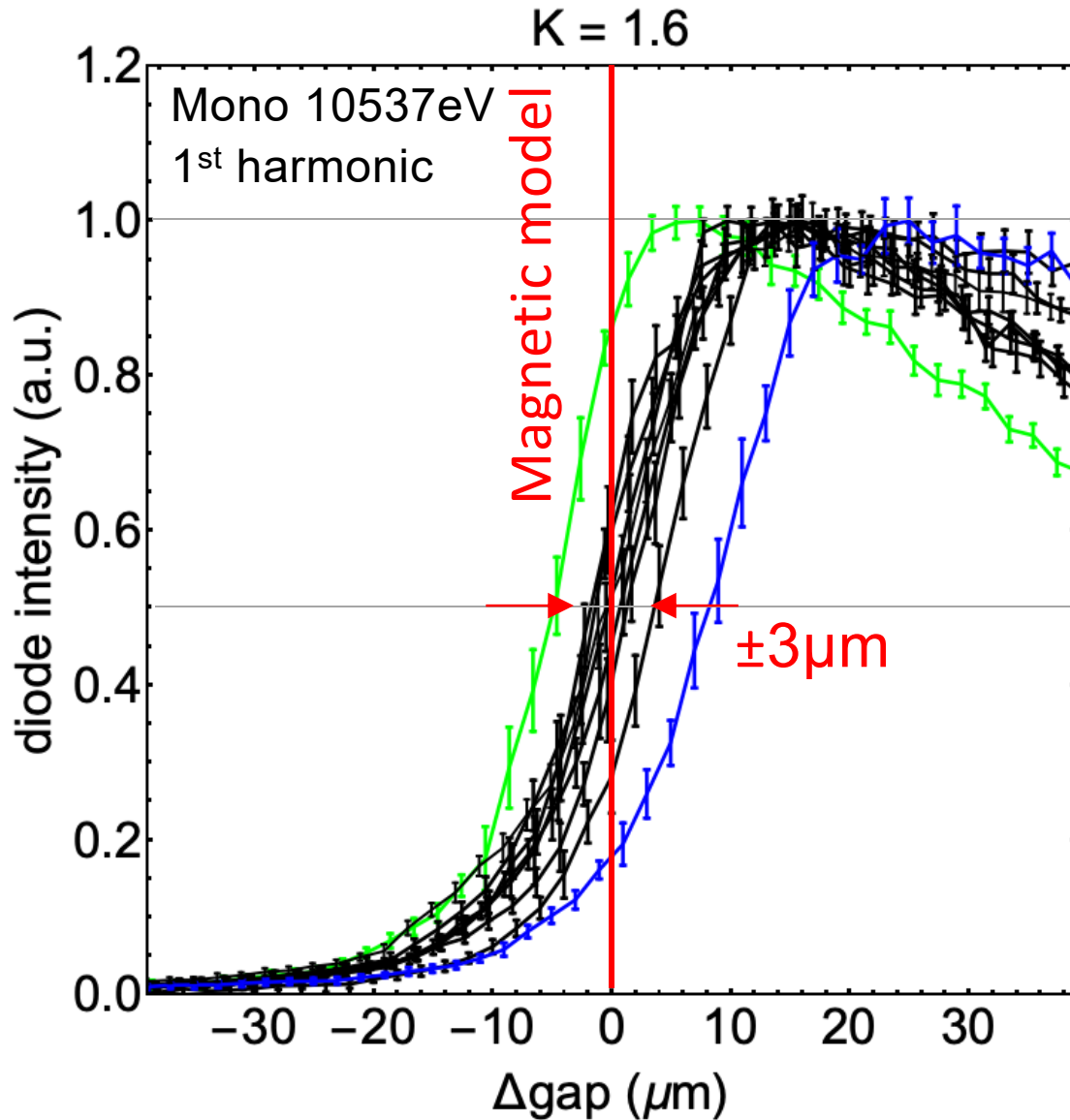
SARUN07
SARUN08
SARUN09
SARUN10
SARUN11
SARUN12
SARUN13
SARUN14
SARUN15

Blue edges of measured modules – $K=1.4$



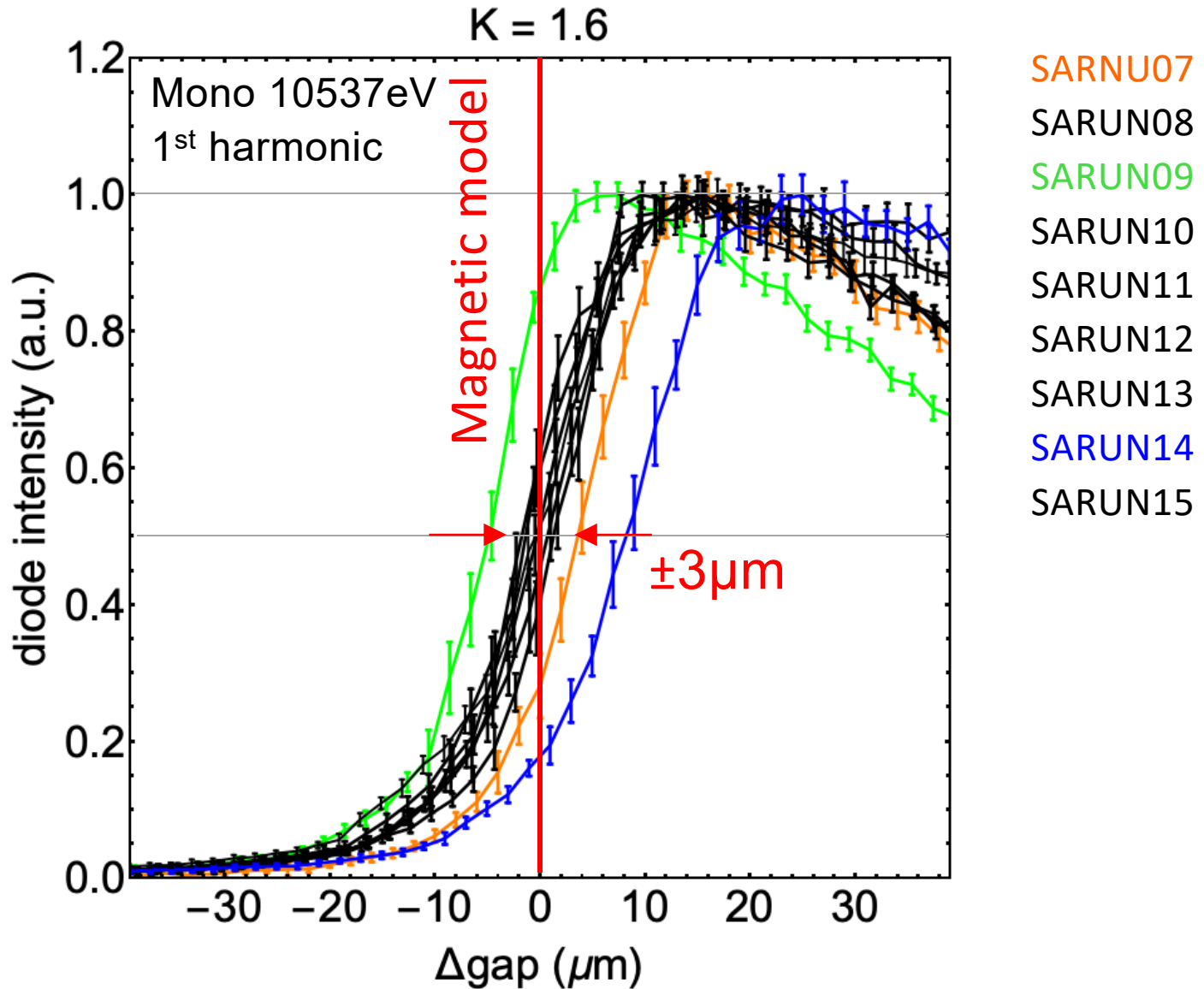
SARNU07
SARUN08
SARUN09
SARUN10
SARUN11
SARUN12
SARUN13
SARUN14
SARUN15

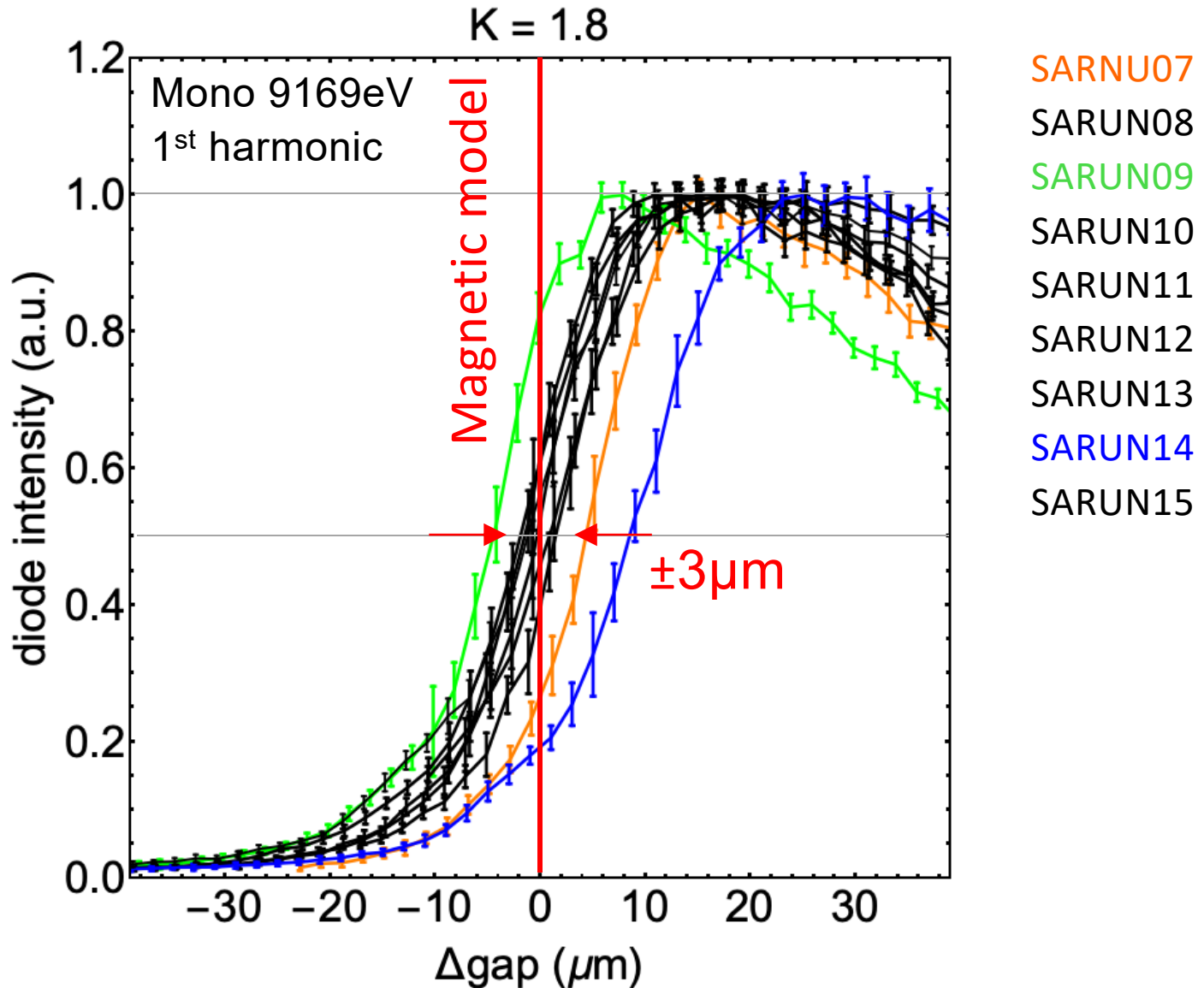
Blue edges of measured modules – $K=1.6$



SARNU07
SARUN08
SARUN09
SARUN10
SARUN11
SARUN12
SARUN13
SARUN14
SARUN15

Blue edges of measured modules – K=1.6



Blue edges of measured modules – $K=1.8$ 

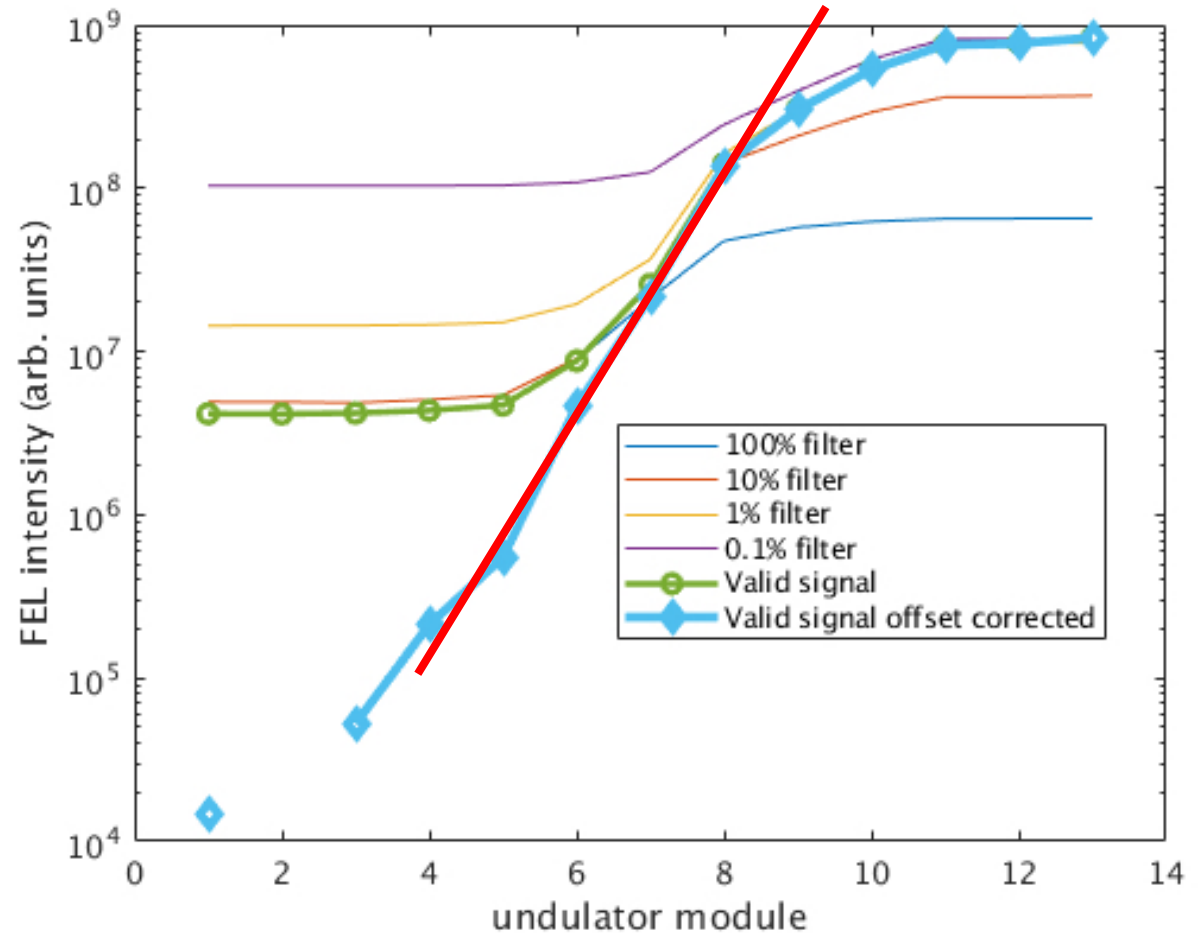
Summary table of calibration errors in Gap

	SARUN07	SARUN08	SARUN09	SARUN10	SARUN11	SARUN12	SARUN13	SARUN14	SARUN15
K	gap setting error (μm)								
1.0	2.4	-2.4	-5.6	-2.1	-1.1	-0.7	1.1	8.4	-0.1
1.1	2.6	-2.2	-5.3	-2.7	-0.8	-1.1	1.4	8.0	0.1
1.2	2.2	0.0	-5.8	-2.4	-0.8	-1.3	1.0	7.2	-0.2
1.3	2.7	0.9	-5.7	-2.5	-1.3	-1.7	1.1	7.2	-0.7
1.4	2.7	1.4	-5.6	-2.0	-1.1	-1.8	0.8	6.7	-1.1
1.5	3.3	0.7	-5.9	-2.1	-0.7	-1.9	0.4	7.4	-1.2
1.6	3.0	0.9	-5.7	-1.8	-1.0	-1.8	0.2	7.5	-1.2
1.7	3.3	0.8	-5.5	-1.7	-1.2	-2.6	0.6	7.6	-1.4
1.8	3.7	1.1	-5.4	-2.0	-1.2	-2.5	0.3	8.1	-2.0
Average:	2.9	0.1	-5.6	-2.2	-1.0	-1.7	0.7	7.6	-0.9

Summary table of calibration errors in K

K	SARUN07	SARUN08	SARUN09	SARUN10	SARUN11	SARUN12	SARUN13	SARUN14	SARUN15
				$\Delta K/K$ $\times 10^{-4}$					
1.0	-5.9	5.7	13.6	5.2	2.6	1.6	-2.6	-20.3	0.1
1.1	-6.4	5.4	13.2	6.6	2.1	2.7	-3.4	-19.9	-0.3
1.2	-5.7	-0.1	14.7	6.2	2.0	3.2	-2.5	-18.4	0.4
1.3	-7.1	-2.5	15.0	6.6	3.4	4.4	-2.8	-18.8	1.7
1.4	-7.3	-3.7	15.2	5.4	2.9	4.7	-2.2	-18.0	3.0
1.5	-9.0	-1.9	16.2	5.7	1.8	5.2	-1.1	-20.2	3.2
1.6	-8.1	-2.4	15.4	4.9	2.8	5.0	-0.6	-20.3	3.3
1.7	-8.7	-2.1	14.3	4.6	3.0	6.8	-1.5	-19.9	3.6
1.8	-9.5	-2.9	13.9	5.3	3.2	6.3	-0.7	-20.9	5.2
Average:	-7.5	-0.5	14.6	5.6	2.6	4.4	-1.9	-19.6	2.3

Gain Curves

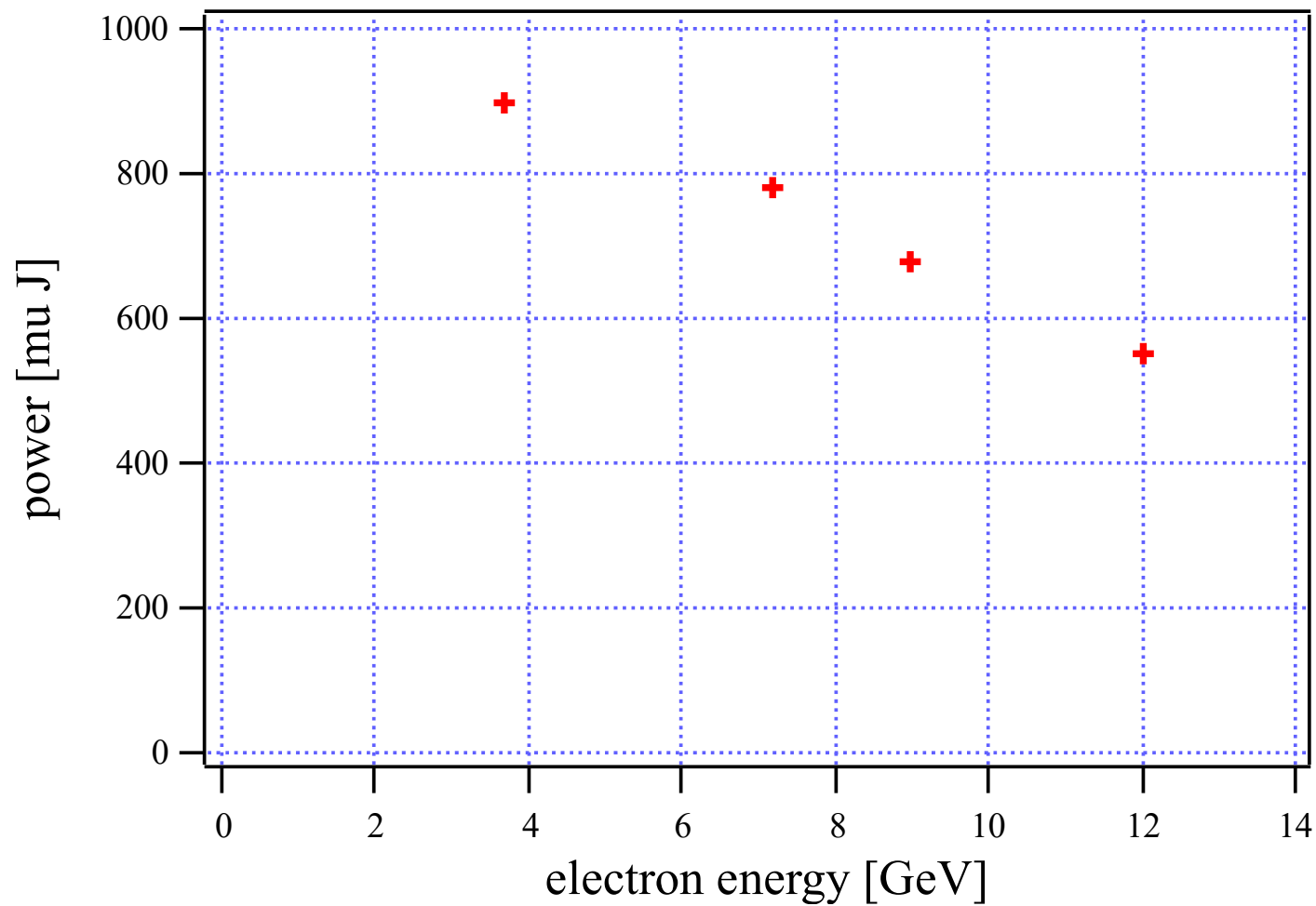


Gain curve measured march 10th 2019

5.8 GeV, 200 pC, K = 1.2

$L_g = 2.2$ m

Power achievements



- Basis is a straight orbit
- The undulator alignment procedure is straightforward
 - 1 shift required for all modules
- K calibration:
 - time consuming
 - the optic acceptance does not allow to collect the total flux
 - stability of the calibration
 - to be repeated 1 – 2 / year
- room for improvements

Acknowledgments

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M.Locher, M.Schmidt, S.Danner

Machine:

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F. Löhl, T. Schietinger,

Controls: A. Alarcon

Operation: C.Kittel, N.Hiller, D.Voulot

Photon Diagnostic: C.Arrel, P.Juranic, L.Patthey

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