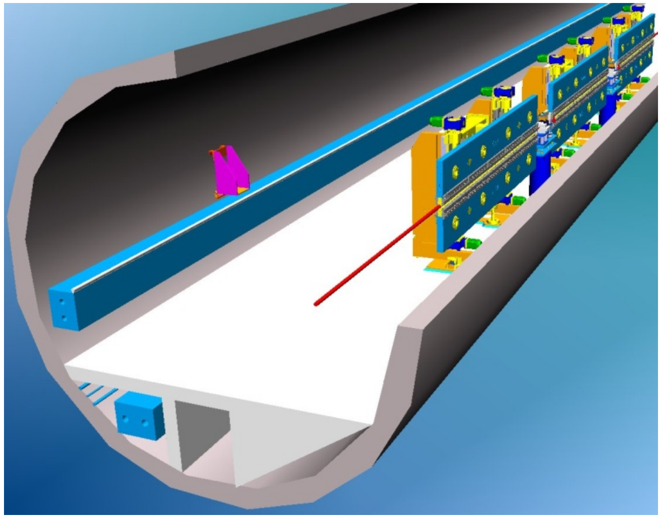
Status of the XFEL.EU Undulator Systems

J. Pflüger, European XFEL

Overview

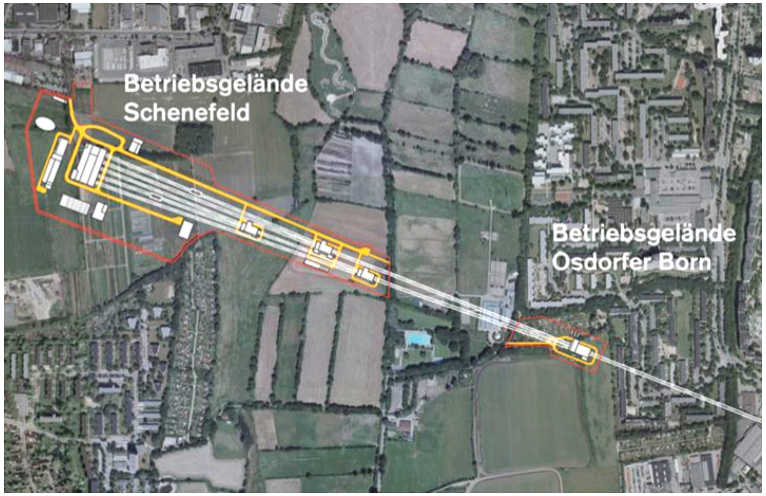
- XFEL.EU Undulator Systems & Controls
- Undulator Segments
  - Serial Production of Undulator Segments:
  - Representative Results
- Intersections
- Summary

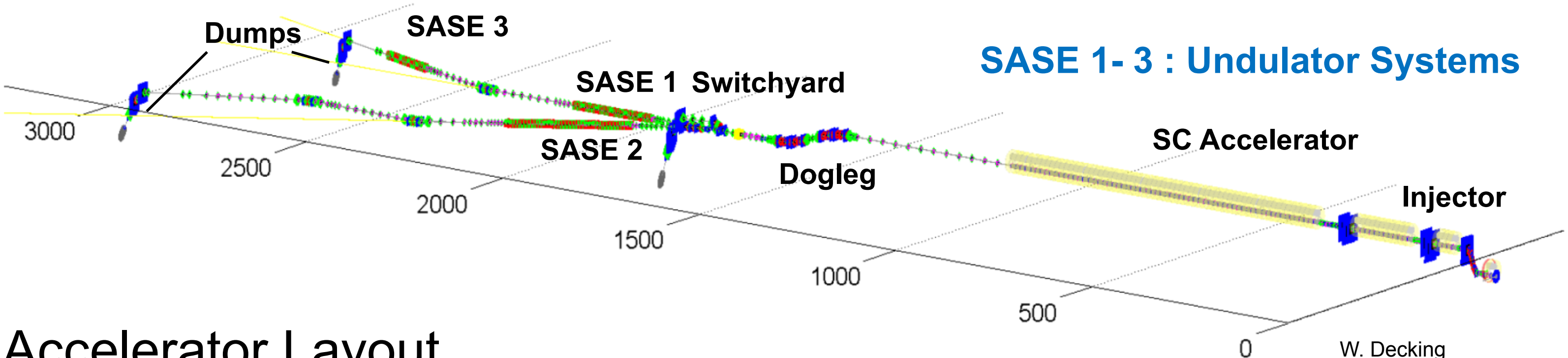
Undulator Systems



European XFEL Overview

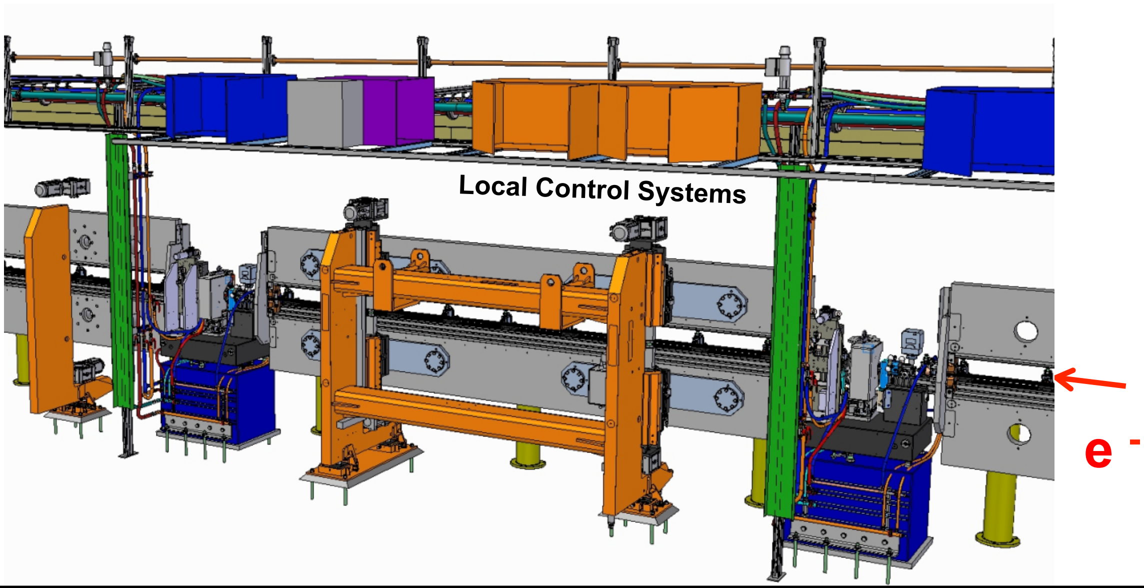
Aerial View

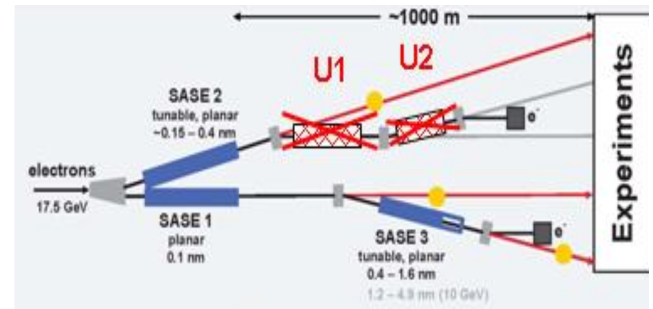


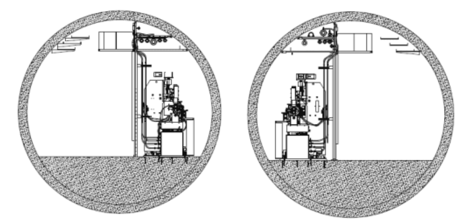


Accelerator Layout

Tunnel Installation of SASE2 Undulator System – Final WP71 Deliverables

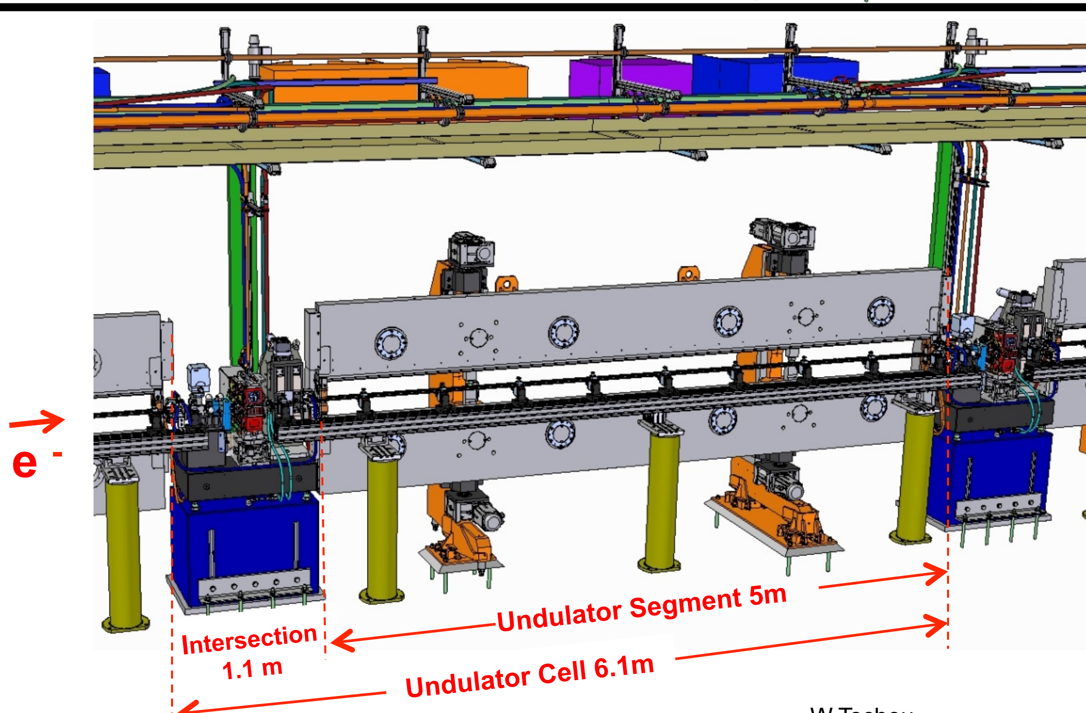






SASE2 SASE1/3

Downstream View



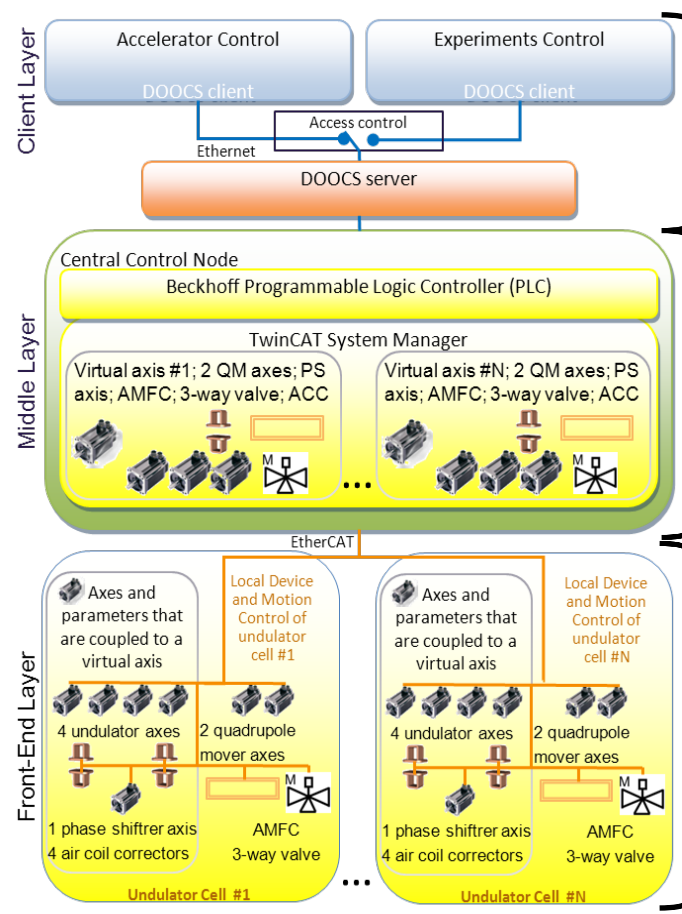
	SASE1/2	SASE3
λ_0 [mm]	40	68
Operational Gap Range [mm]	10-20	10-25
K-Range	3.9–1.65	9.0-4
Radiation Wavelength Range [nm]		
@ 17.5 GeV	0.147-0.040	1.22-0.27
@ 14.0 GeV	0.230-0.063	1.90-0.42
@ 8.5 GeV	0.625-0.171	5.17-1.15
# of Segments	35	21
System Length [m]	213.5	128.1

W.Tscheu

European XFEL

Undulator Control System

- Developed at XFEL.EU
- XFEL.EU guidelines & standards
- Based exclusively on industrial Automation Technology
- Using the fast EtherCAT protocol
- Hardware from Beckhoff GmbH
- Running the TwinCAT software
- The Topology reflects Hardware



External Access for DOOCS and Experiments

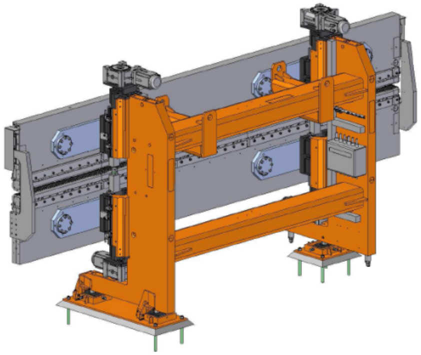
Global Control in Computer Service Room

Up to 35 Local Control Systems in Tunnel

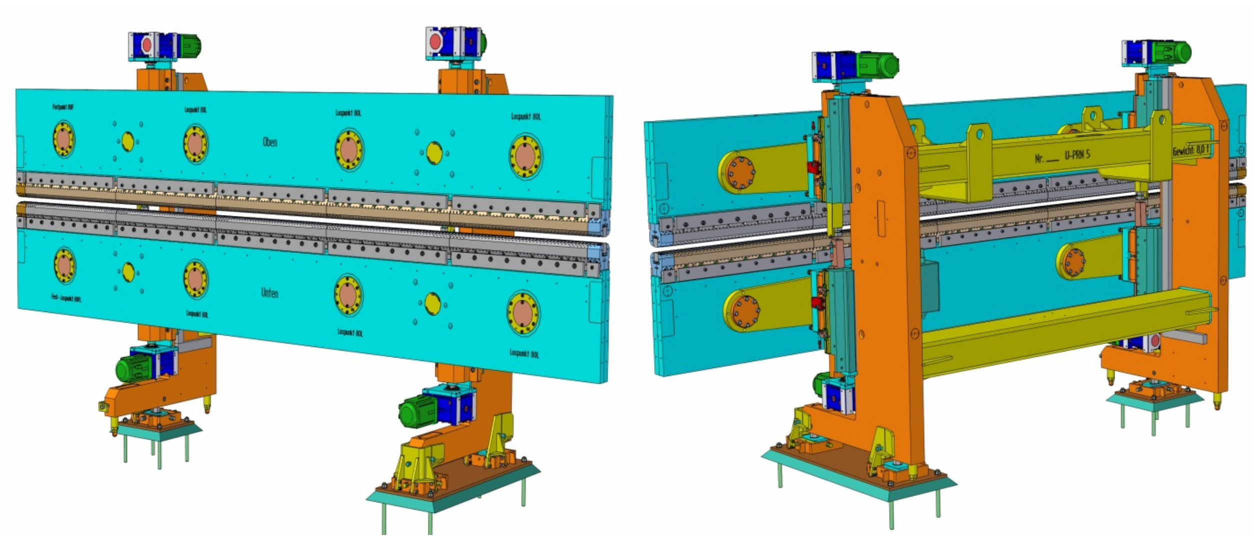
1…. up to 35

S. Karabekyan, A Beckmann, M. Yakopov

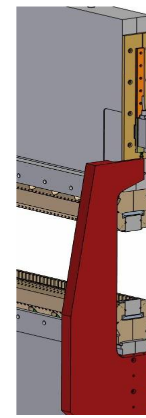
Undulator Segments



Standard Undulator Segment Support Structure



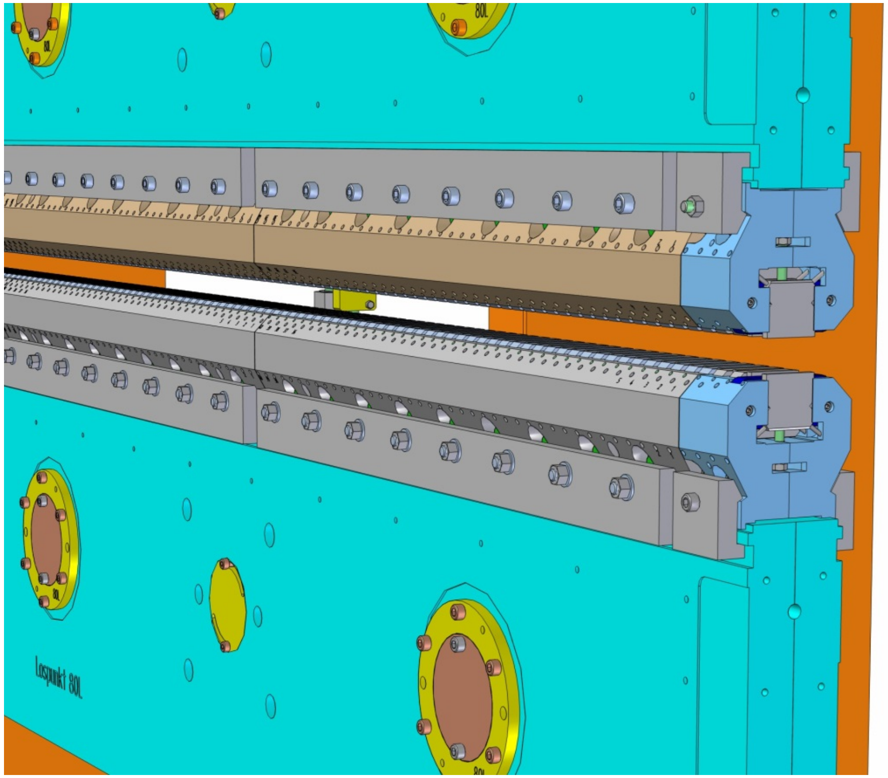
■ **Gap Measurement Accuracy** ±1µm



■ **Special Attention:**

1. Shear deformation and compressive deformation
2. Material pairing / Bimetallic bending
3. Four point support of girders
4. Four Motors, electronic gears
5. Forced girder guiding
6. Precision measurement of gap / Motor feedback to ±1µm, avoiding Abbé errors

Magnetics I: Design



- Standard Support System with Standard Interface
- Different Magnet Structures may be adopted
- Same Material for girder and Magnet support structure: AlMg
- Structure is segmented into~ 0.9m long modules + End sections
- Structure is clamped onto the interface

Production of Undulator Segments

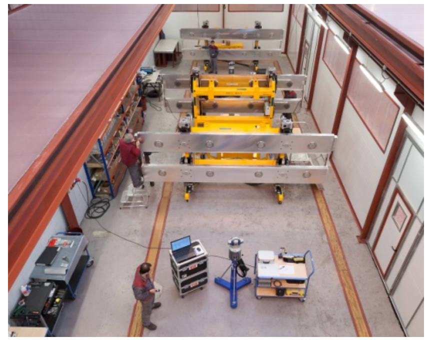
- The Focus is on Serial Production. R&D is long ago!!
- Industrial Part
  - Mechanical Support System including Local Motion Control System: 2 Suppliers
  - Magnetic Structure
  - Documentation in EDMS
- XFEL.EU Part
  - Integration: Mechanics & Magnetics @ XFEL.EU
  - Commissioning @XFEL.EU
  - Magnetic Measurement & Tuning
  - Preparation for Installation
  - Documentation in EDMS

Production Cycle: Industrial Production

KINKELE

Mechanical Support Systems

NORTEMECANICA, S.A.



Magnetic Structuress

VAC VACUUMSCHMELZE

Local Control Systems

BECKHOFF New Automation Technology

Production @ XFEL.EU in Building 36

New Undulator Segments

3 climatized Magnetic Labs

Assembly Area for Magnetic Structures

Segments waiting for Magnetic Measurements

Measured and tuned Segments

Incoming Magnetic Structures from VAC

2nd Hall with 700m² for storage

Steps @ XFEL.EU:

- Mounting of magnetic structures
- 1st Commissioning
- Magnetic Measurements & Tuning
- Preparation for Installation

Schedule:

- Total Time ≈ 2 Years (starting Oct/12)
- 3 Weeks/Segment !
- → 3 Magnetic Labs needed running in parallel
- Scheduled End: Oct / End 2014

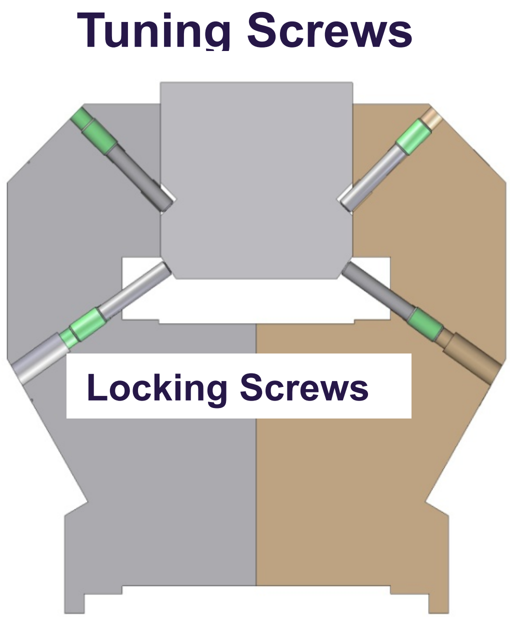
December 2012

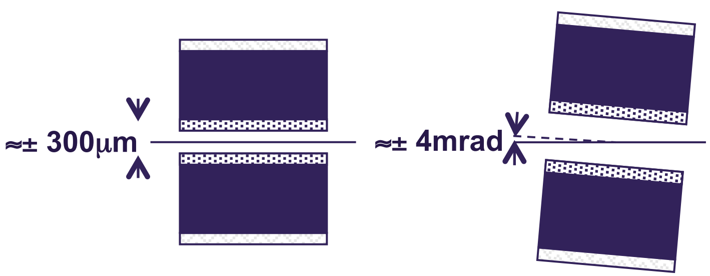
Results

Magnetic Measurements

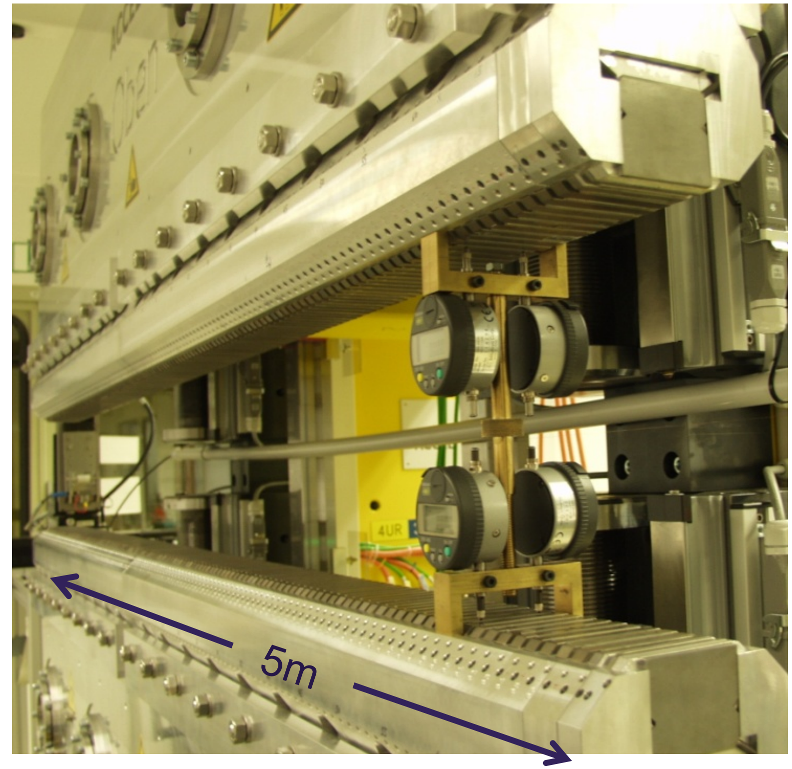
U. Englisch, Y. Li, S.Utermann, F. Wolff-Fabris

Pole Tuning at XFEL Undulator Segments





- No Shims are used
- All errors are tuned by moving Poles
- Bipolar Field Corrections



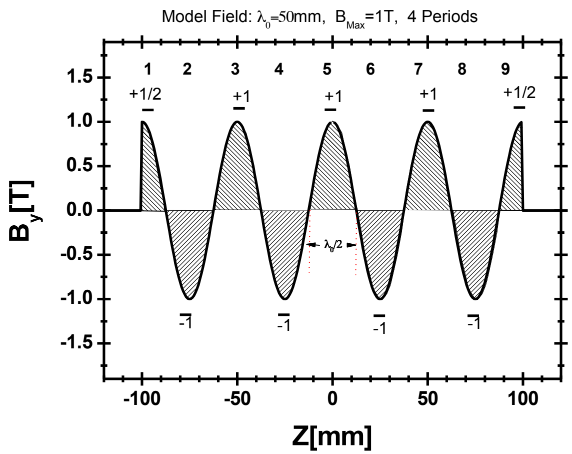
U40: 246 pairs of poles

U68: 144 pairs of poles

B_Y and B_Z tuning is combined

B_Y Field: Pole Height Tuning I

Local K-Tuning



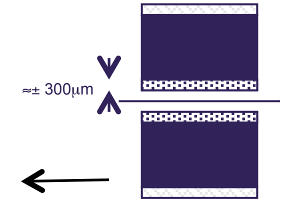
$$K_j = \frac{e}{mc}\int_{z_j-\lambda_0/4}^{z_j+\lambda_0/4} B_y(z)\,dz$$

$$\Delta K_j = K_j - K = \frac{e}{mc}\frac{\lambda_0}{2} S_j$$

$$S_j = \frac{mc}{e}\frac{2}{\lambda_0}\Delta K_j$$

Limit to 3 next neighbors

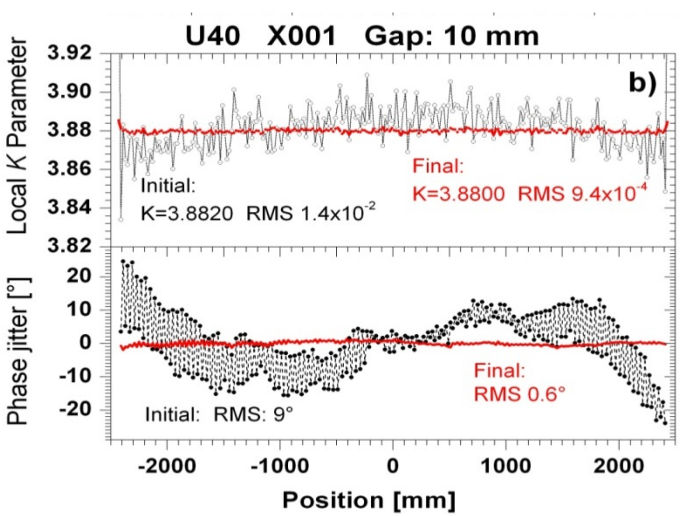
$$S_j = \sum_{i=-3}^{3} a_i\, p_{j+i}$$

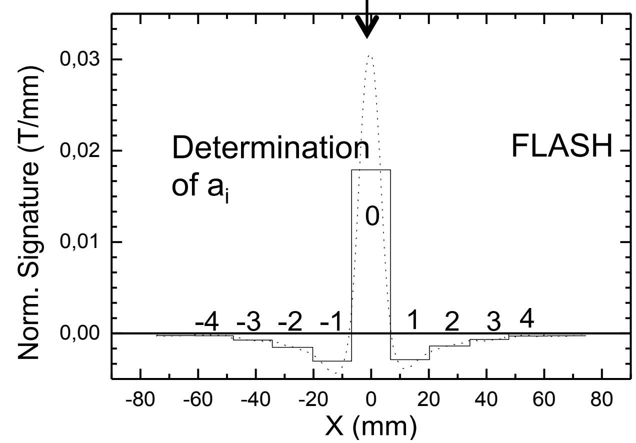


Local gap change

Local Field Change

Influence of neighbors





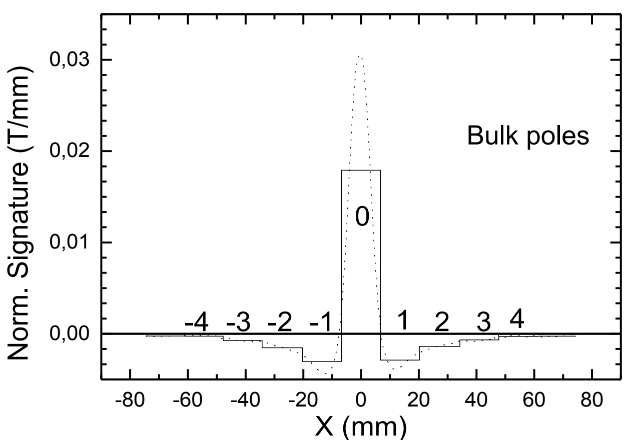
B_Y Field: Pole Height Tuning II

$$
\begin{array}{lcccccccccccc}
S_1 & = & a_0 \cdot p_1 & + & a_1 \cdot p_2 & + & a_2 \cdot p_3 & + \dots + & a_{i-1} \cdot p_i & + \dots + & a_{N-1} \cdot p_N \\
S_2 & = & a_{-1} \cdot p_1 & + & a_0 \cdot p_2 & + & a_1 \cdot p_3 & + \dots + & a_{i-2} \cdot p_i & + \dots + & a_{N-2} \cdot p_N \\
S_3 & = & a_{-2} \cdot p_1 & + & a_{-1} \cdot p_2 & + & a_0 \cdot p_3 & + \dots + & a_{i-3} \cdot p_i & + \dots + & a_{N-3} \cdot p_N \\
\cdot & = & & & & & \cdot & & & & \cdot \\
\cdot & = & & & & & \cdot & & & & \cdot \\
S_j & = & a_{1-j} \cdot p_1 & + & a_{2-j} \cdot p_2 & + & a_{3-j} \cdot p_3 & + \dots + & a_{i-j} \cdot p_i & + \dots + & a_{N-j} \cdot p_N \\
\cdot & = & & & & & \cdot & & & & \cdot \\
\cdot & = & & & & & \cdot & & & & \cdot \\
S_N & = & a_{1-N} \cdot p_1 & + & a_{2-N} \cdot p_2 & + & a_{3-N} \cdot p_3 & + \dots + & a_{i-N} \cdot p_i & + \dots + & a_0 \cdot p_N
\end{array}
$$

Tuned Poles:

U40: N =246

U68: N= 144



The Characteristic Coefficients a_i were measured for U40/U68:

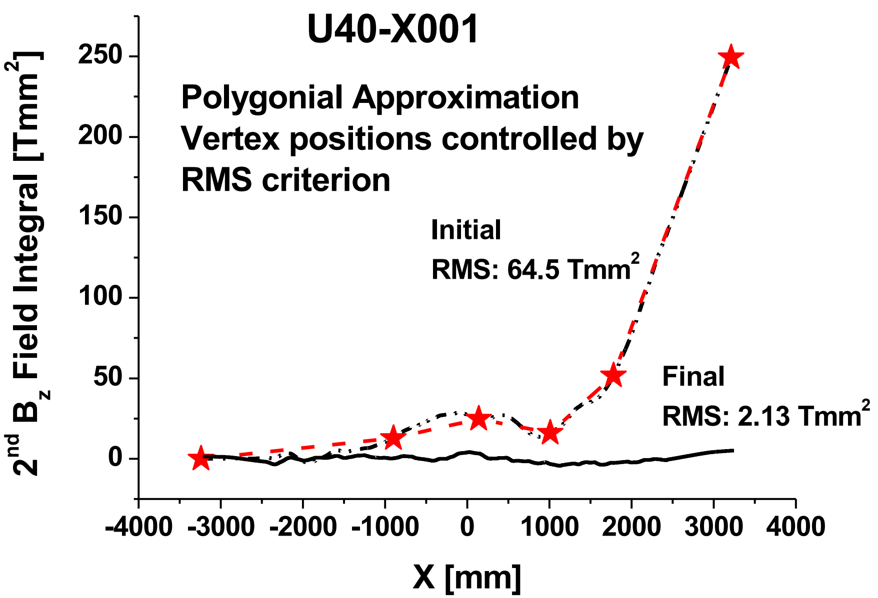
- For the 3 poles next to the end 'End Poles'
- For all other poles 'Bulk Poles'
- Tuning done at the 'Tuning Gap':
  U40: 14mm
  U68: 16 mm

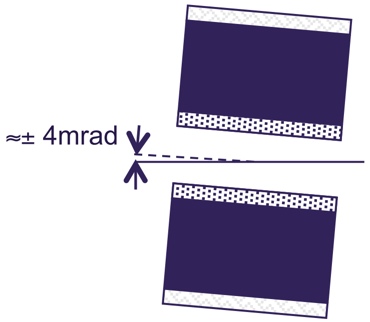
♦**Most Poles need to be tuned**

♦ **One Tuning Step is (usually) sufficient**

B_Z Field: Pole Tilt

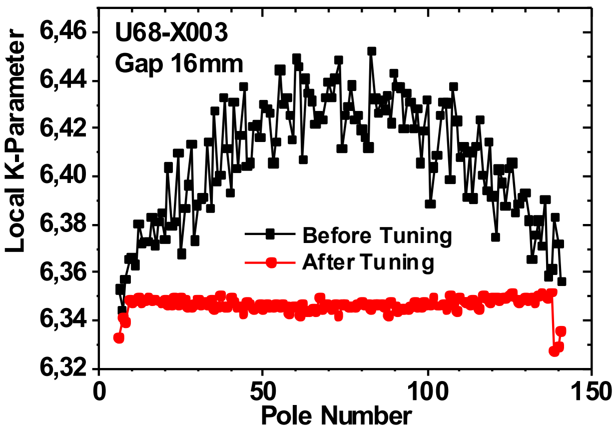
- B_Z is due to errors only.
- Ideal B_Z trajectory 2nd Field Integral is a Null line
- Correction by Tilting Poles

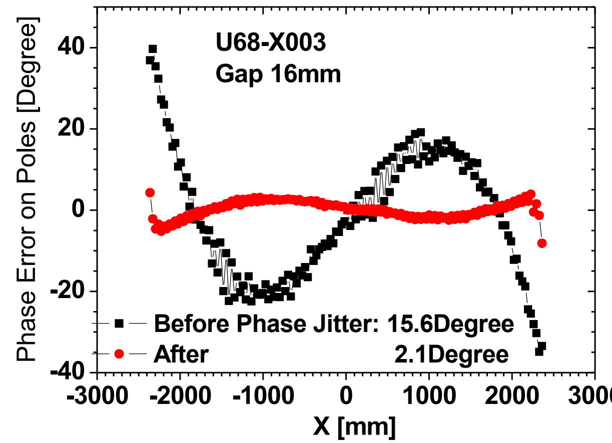


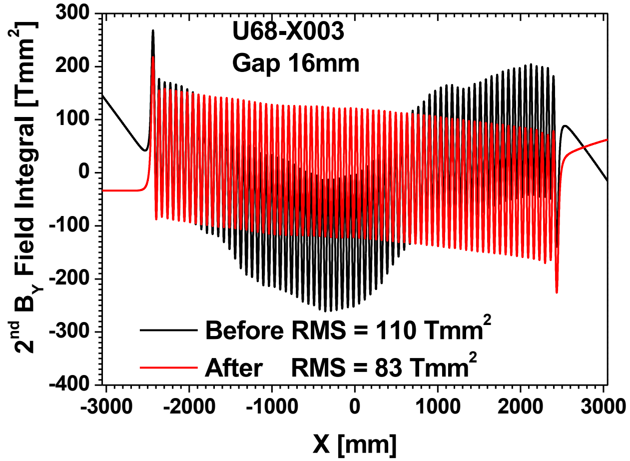


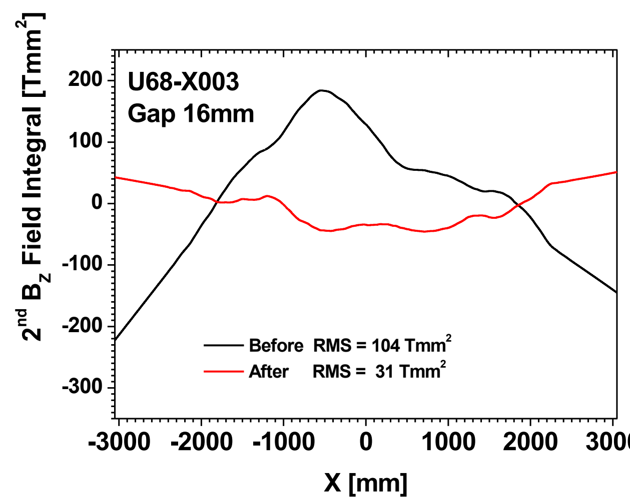
	λ_0 [mm]	Tuning Gap [mm]	Tilt Kick Signature [Tmm/mrad]
U40	40	14	0.0127
U68	68	16	0.0325

Pole Tuning: U68-X003-N001 @ Gap=16mm

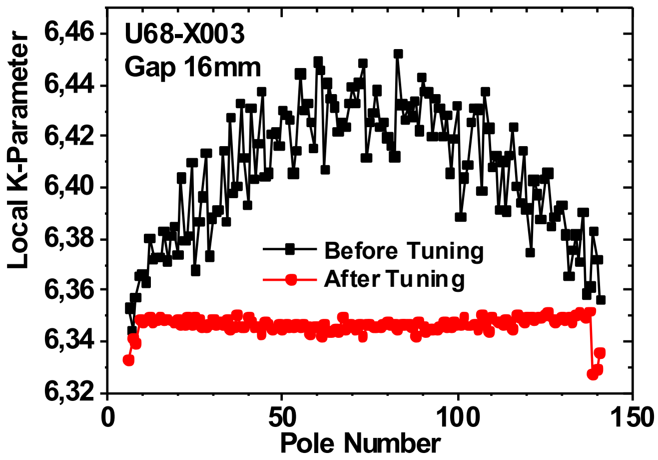


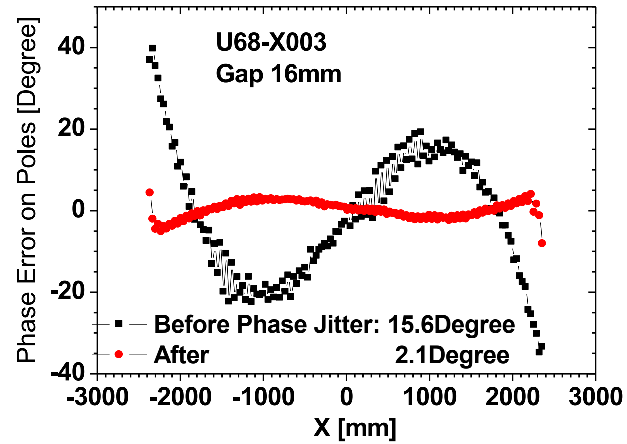


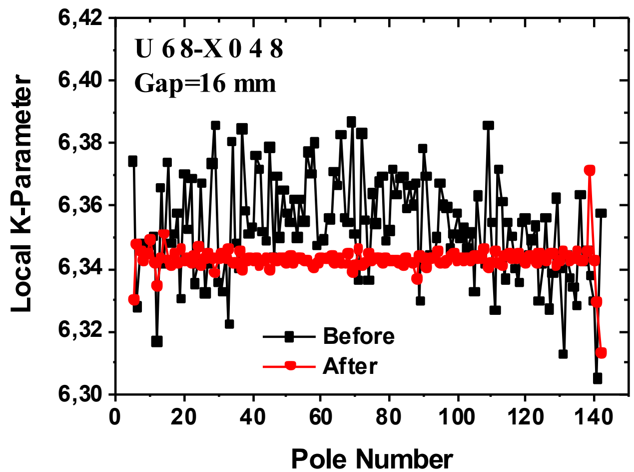


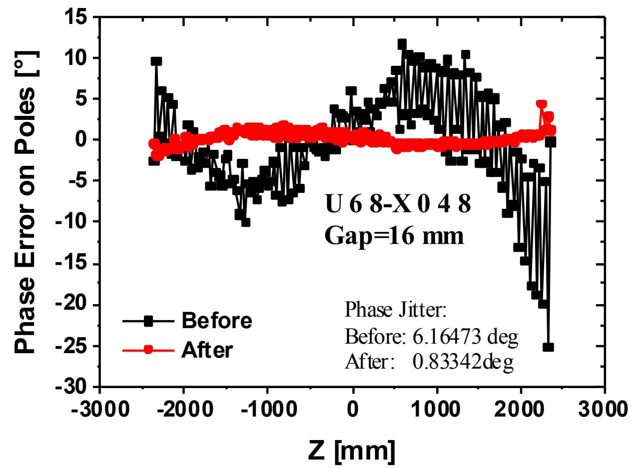


Another U68: U68-X048



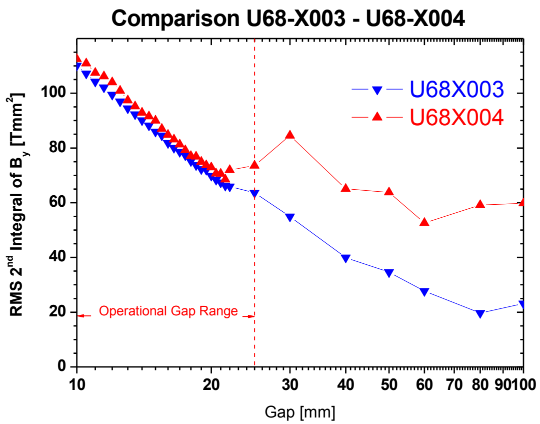


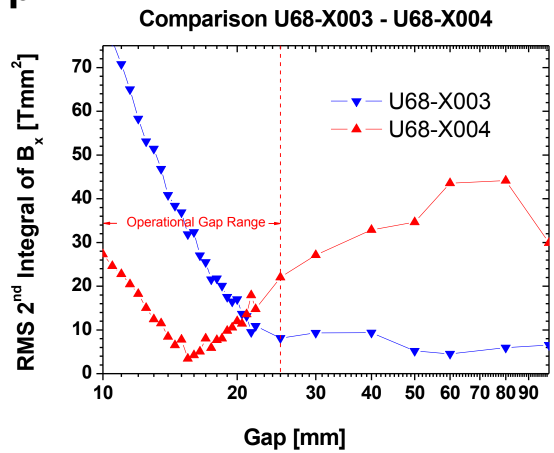




U68-X003 / X004: Comparison of Gap dependent Results

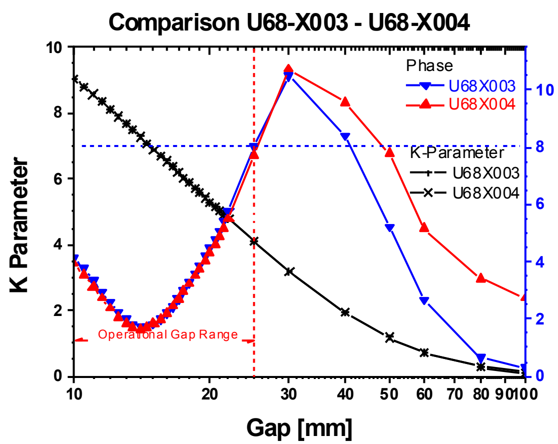
Transverse Overlap





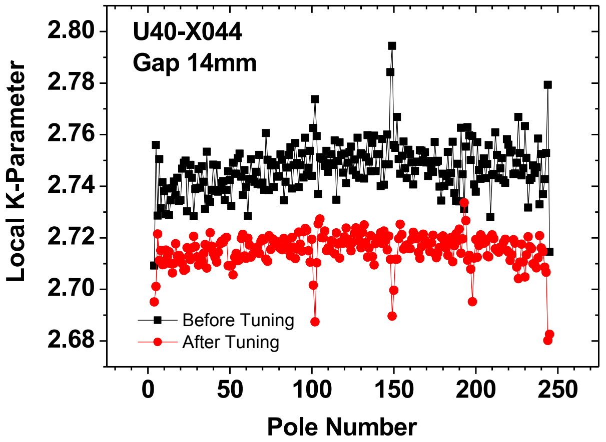
K-Parameter

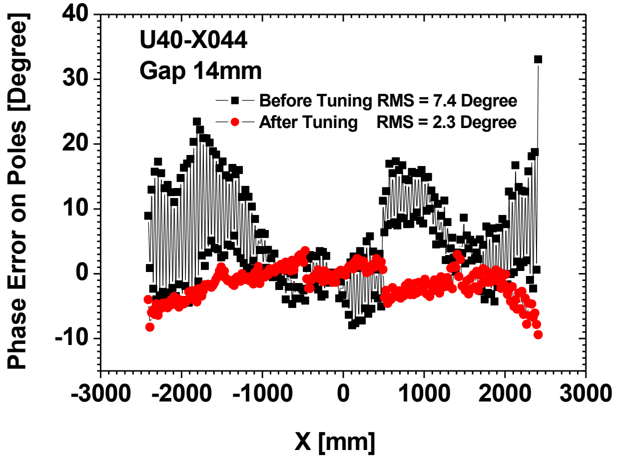
Longitudinal Overlap / Phase Jitter

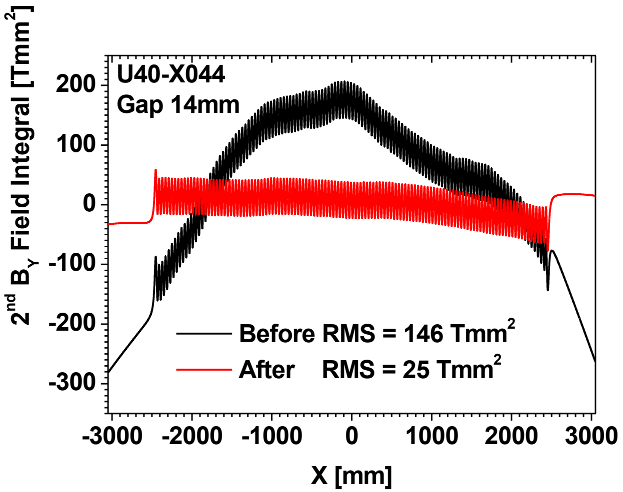


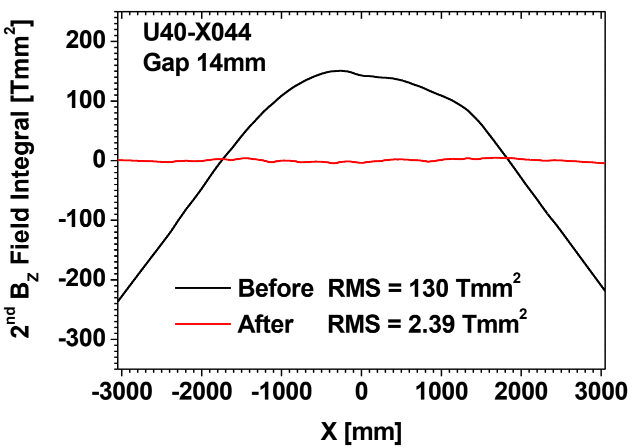
	Specs	Result
Operational Gap Range [mm]	10-25	---
B_0 @ 10mm Gap [T]	1.69	1.66
K @ 10mm Gap	10.5	9.3
RMS $I2_Y$ [Tmm^2]	< 210	< 90
RMS $I2_Z$ [Tmm^2]	< 100	< 70
Phase Jitter [°]	< 8	< 8

Pole Tuning : U40-X044-K004 @ Gap=14mm



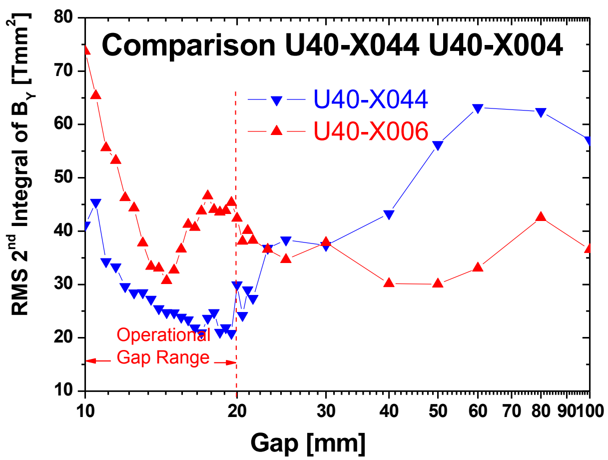


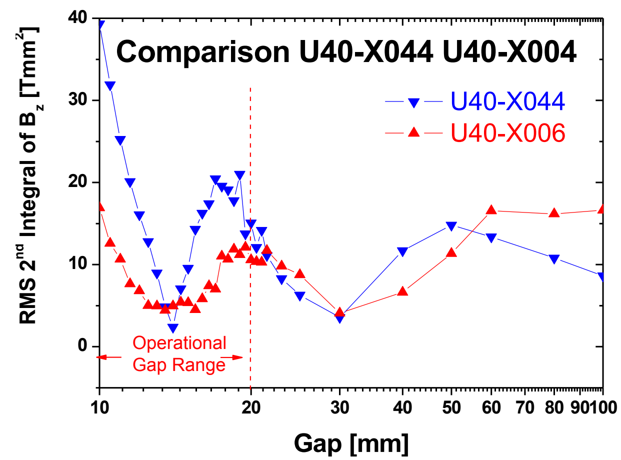




U40-X044 / X004: Comparison of Gap dependent Results

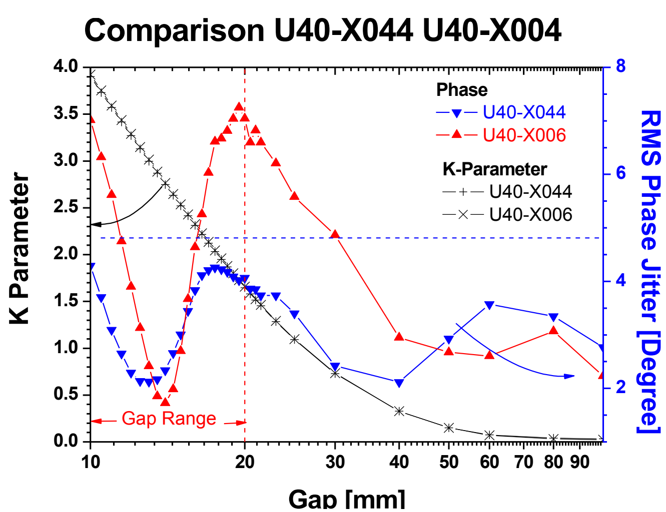
Transverse Overlap





K-Parameter

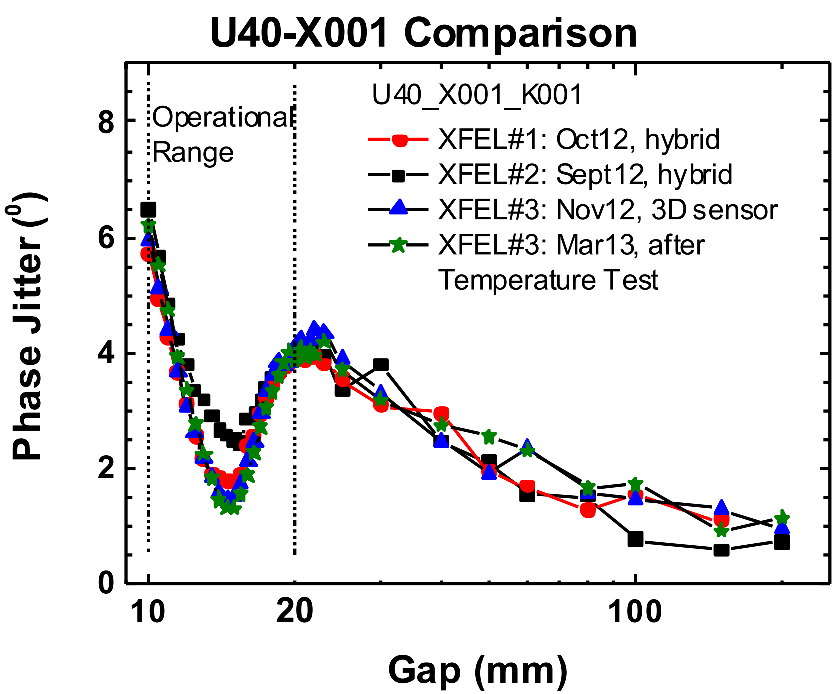
Longitudinal Overlap / Phase Jitter

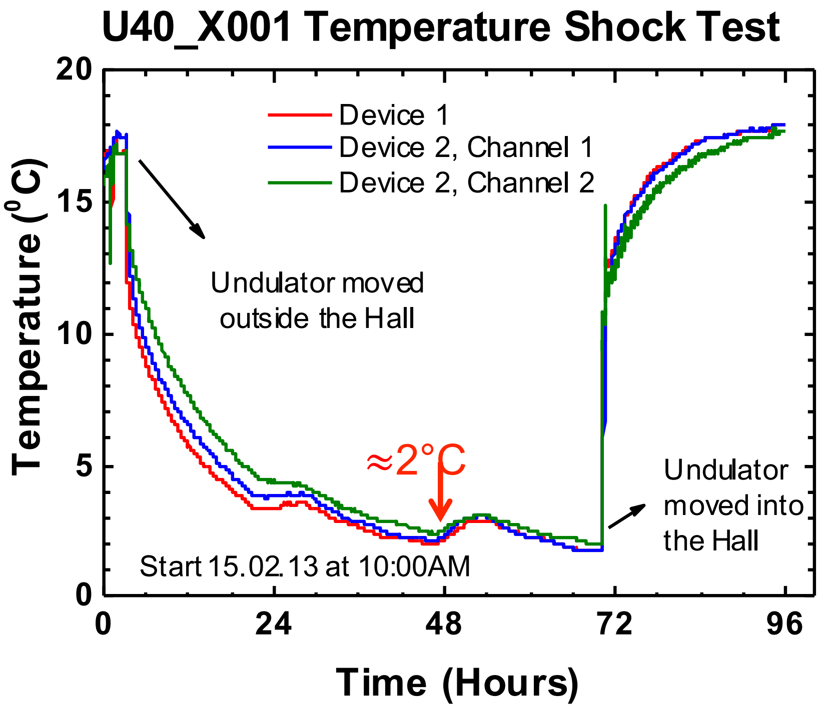


	Specs	Result
Operational Gap Range [mm]	10-20	---
B_0 @ 10mm Gap [T]	1.14	1.13
K @ 10mm Gap	4	3.9
RMS $I2_Y$ [Tmm^2]	< 100	< 50
RMS $I2_Z$ [Tmm^2]	< 100	< 40
Phase Jitter [°]	< 8	< 7

Comparison of Magnetic Results

- Measurement Results be independent of the Bench→ Comparison of Measurements done at all labs
- Influence of low temperature exposition





Further Plans: Influence of Transport Conditions to Osdorfer Born

Present Status of Production

Status of Undulator Production August 22, 2013

- **Delivery Status:**
  - **64 Support Systems**
  - **54 Magnet structures**
- **Prepared for Measurements: 48**
- **Waiting for magnetic measurements: 10 Segments**
- **Measured, tuned, ready for Installation: 38**
  → Magnetic Length: 190m
- **Scheduled End of Production: 12 / 2014**

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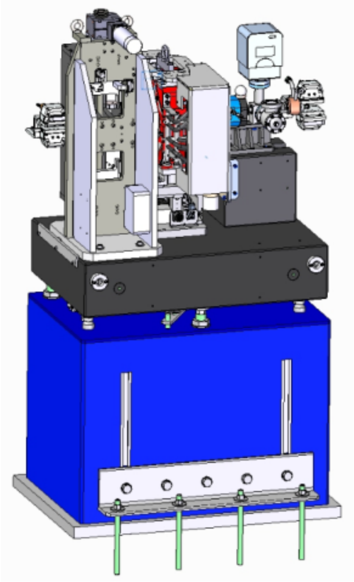
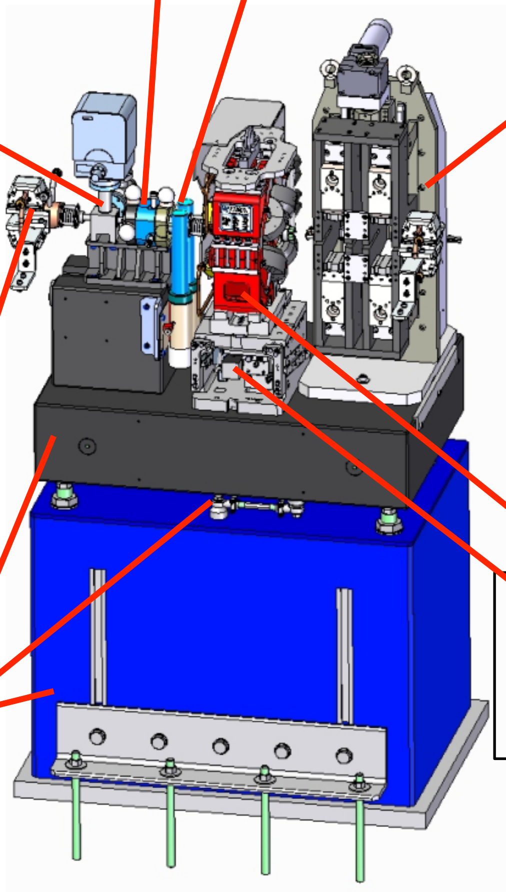
Intersections



SASE2 Type Intersection



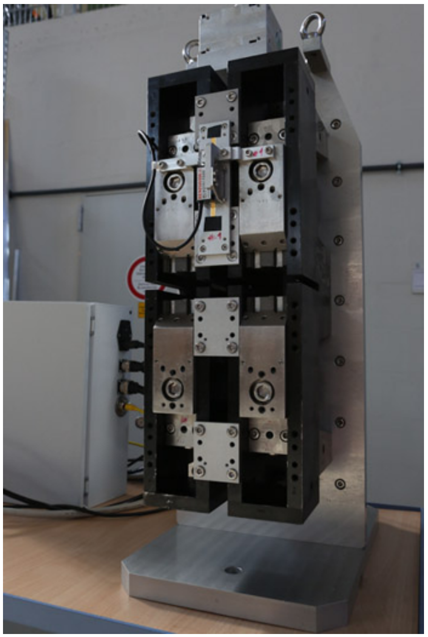
Status 1/2013:

- **Delivered: Quadrupoles, WP12**
- **In Production 91 Intersections:**
  - **Phase Shifters (Nov 12), WP71**
  - **BPMS, WP17**
  - **BLMs, WP17**
  - **Vacuum systems, WP19**
  - **Air Coil Correctors, WP71**
  - **Base Plates, WP71**
  - **Adjustors, WP71**
  - **Concrete Pillars , WP71**
  - **Quadrupole Movers, Ciemat**
- **Released for production:**
  - **Control Cabinets Ciemat (Oct 13)**
- **Start of Assembly @ XFEL: June 2014**

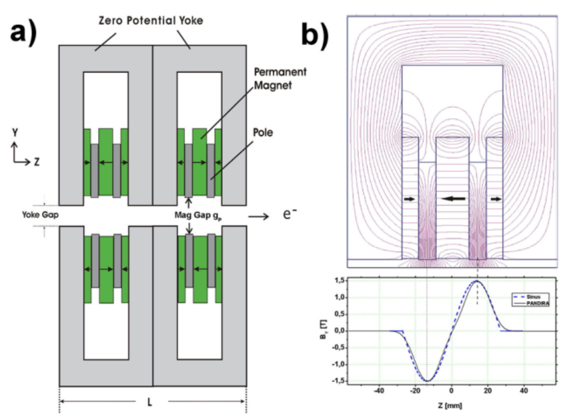
European XFEL

Phase Shifter Prototypes by IHEP Beijing

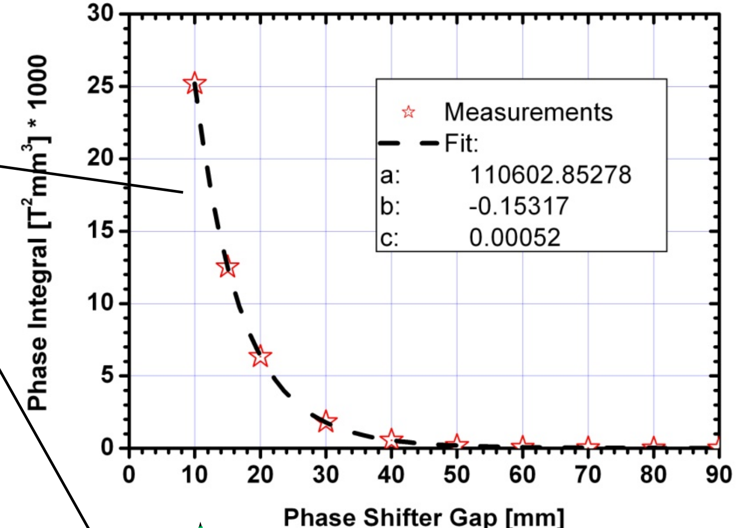
中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

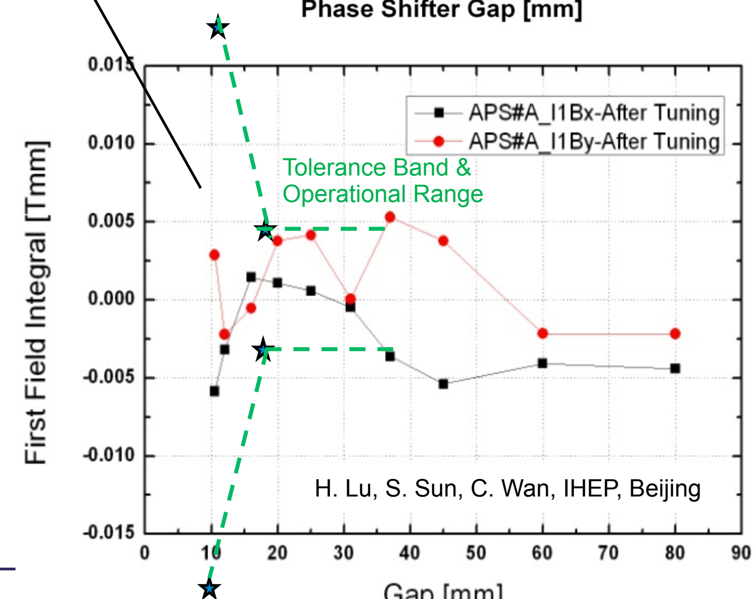


- Period length: 55mm
- Gap range: 10.5 to ≈>100mm
- Max. Phase Integral @ gap 10.5mm : ≥23400 T^2mm^3
- **1st Hor/Ver Field Integral Tolerance: ±0.004 Tmm**
- **Dynamic Operation without retuning!**
- 2nd Hor/Ver Field Integral Tolerance: ±67 Tmm^2
- Phase adjustment accuracy: ± 10° (5°)
- Min. Gap precision for 5/10° at SASE1/2 ±15/30 µm



1st Phase Shifter Prototype





H. Lu, Y. Li, J. Pflueger, NIM A605 (2009),399

Summary

- Production of Undulator Segments in full Swing
  - Industrial Production is well in Schedule
  - Magnetic measurements & Tuning @XFEL.EU being ramped up
  - Magnetic Measurements & Tuning:
    - → Methods and techniques work fine
    - → 38 Segments tuned to Specs → “Ready for Installation”
- Intersections:
  - Phase Shifter Prototypes in Specs
  - All Components are in production
- Production of Undulator Systems in schedule!

XFEL.EU Undulator Systems Group, WP71

WP71 Status March 3, 2013, left to right:
Yufang Yang, Suren Karabekyan, Xiaoyu Li, Georg Deron, Yuhui Li, Bora Ketenoglu, Uwe Englisch, Joachim Pflüger, Andreas Beckmann, Sonia Utermann, Martin Knoll, Majid Bagha-Shanjani, Fredrik Wolff-Fabris, Hongxian Lin, Karl-Heinz Berndgen, not shown: Mikhail Yakopov

The End