Undulator for SLS and SLS-2 general

December 2017
SLS: 2.4 GeV

4 Undulator Beamlines soft x-ray:
8 eV – 2 keV all full polarized.

1 Undulator Beamline tender x-ray
up to 8 keV

5 Undulator Beamlines hard x-ray:
5 keV – 20 keV (35keV)

5 Dipole Beamlines
3 permanent magnet Superbends
SLS Brilliance

Brilliance [ph/sec/0.1%bw/mm²/mrad²]

Photon Energy [eV]

10 eV  100 eV  1 keV  10 keV

10¹⁵  10¹⁶  10¹⁷  10¹⁸  10¹⁹  10²⁰

UE44  UE56  UE212  U14  U19  W61

Super-Bend (3.1T)  Dipole (1.4T)
<table>
<thead>
<tr>
<th>ID</th>
<th>N</th>
<th>Gap [mm]</th>
<th>$B_z/B_x$ [T]</th>
<th>$K_z/K_x$</th>
<th>$N_{\text{per}}$</th>
<th>Harm</th>
<th>$E$ [keV]</th>
<th>Type</th>
<th>Magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>UE212/424</td>
<td>1</td>
<td>20</td>
<td>0.4/0.1</td>
<td>07.09.04</td>
<td>39</td>
<td>1-5</td>
<td>0.01-0.6</td>
<td>quasi-periodic ELM variable period</td>
<td>NdFeB</td>
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<tr>
<td>UE56</td>
<td>2</td>
<td>16</td>
<td>0.83/0.6</td>
<td>4.4/3.2</td>
<td>32</td>
<td>1-5</td>
<td>0.09-2</td>
<td>twin APPLE II</td>
<td>NdFeB</td>
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<tr>
<td>UE54</td>
<td>1</td>
<td>16</td>
<td>0.79/0.54</td>
<td>4.0/2.7</td>
<td>32</td>
<td>3-33</td>
<td>0.4-8</td>
<td>APPLE II</td>
<td>NdFeB</td>
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<tr>
<td>UE44</td>
<td>1</td>
<td>11.4</td>
<td>0.86/0.65</td>
<td>3.5/2.7</td>
<td>75</td>
<td>1-5</td>
<td>0.3-2</td>
<td>fixed gap APPLE II</td>
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<tr>
<td>U19</td>
<td>1</td>
<td>4.5</td>
<td>0.86</td>
<td>1.5</td>
<td>95</td>
<td>3-13</td>
<td>5-20</td>
<td>in-vac hybrid</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
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<tr>
<td>U19</td>
<td>2</td>
<td>4.5</td>
<td>0.89</td>
<td>1.6</td>
<td>95</td>
<td>3-13</td>
<td>5-20</td>
<td>In-vac hybrid</td>
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<tr>
<td>U19</td>
<td>1</td>
<td>5.5</td>
<td>0.85</td>
<td>1.5</td>
<td>95</td>
<td>3-13</td>
<td>5-18</td>
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<td>NdFeB</td>
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<tr>
<td>U14</td>
<td>1</td>
<td>4</td>
<td>1.15</td>
<td>1.5</td>
<td>120</td>
<td>3-13</td>
<td>5-30</td>
<td>cryogenic in-vac</td>
<td>NdFeB</td>
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<tr>
<td><strong>SwissFEL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U15</td>
<td>13</td>
<td>3</td>
<td>1.28</td>
<td>1.8</td>
<td>265</td>
<td>1</td>
<td>2-12*</td>
<td>In-vac Dy enhanced</td>
<td>NdFeB</td>
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<tr>
<td>UE40**</td>
<td>26</td>
<td>3</td>
<td>1.05/1.05</td>
<td>3.8/3.8</td>
<td>40</td>
<td>1</td>
<td>0.18-1.8*</td>
<td>APPLE III</td>
<td>SmCo$_5$</td>
</tr>
</tbody>
</table>

* incl. e-energy
** design phase
<table>
<thead>
<tr>
<th>SLS &amp; SwissFEL: concept</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLS</strong> 2.4 GeV</td>
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<tr>
<td><strong>soft x-ray</strong> variable polarization</td>
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<tr>
<td>APPLE II</td>
</tr>
<tr>
<td>twin UE56 (&lt;- BESSY II)</td>
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<tr>
<td>UE54 soft &amp; tender x-ray</td>
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<tr>
<td>fixed gap UE44</td>
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<tr>
<td>quasi-periodic elm</td>
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<tr>
<td><strong>hard x-ray</strong></td>
</tr>
<tr>
<td>in - vacuum (&lt;- SPring-8)</td>
</tr>
<tr>
<td>work horses: U19 -&gt; 20keV</td>
</tr>
<tr>
<td>CPMU U14 -&gt; 35keV</td>
</tr>
<tr>
<td>gap min = 4mm, 2m long</td>
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<tr>
<td><strong>SwissFEL</strong> 2 - 8 GeV</td>
</tr>
<tr>
<td><strong>soft x-ray</strong> variable polarization</td>
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<tr>
<td>APPLE-X (DELTA II)</td>
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<tr>
<td>UE38, Chic Modes</td>
</tr>
<tr>
<td><strong>in - vacuum</strong></td>
</tr>
<tr>
<td>U15 3mm, 4m long -&gt; 12keV</td>
</tr>
<tr>
<td>U10 sc ?! (2025 ff) -&gt; 36keV</td>
</tr>
</tbody>
</table>
SwissFEL in a nutshell

**construction phase I**
*2013-2016*

- **Linac 1**
  - 0.35 GeV
- **Linac 2**
  - 2.0 GeV
- **Linac 3**
  - 2.9-3.15 GeV

**2. Konstruktionsphase**
*2017-2020*

- **ATHOS 0.7-5nm**
- **ARAMIS 0.1-0.7 nm**

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**Aramis**

- Hard X-ray FEL, $\lambda = 0.1-0.7$ nm
- Linear polarization, variable gap, in-vacuum Undulators
- First users 2017

**Athos**

- Soft X-ray FEL, $\lambda = 0.65-5.0$ nm
- Variable polarization, Apple undulators
- First users 2020

**Main parameters**

- Wavelength from
  - 1 Å - 70 Å
- Photon energy
  - 0.2-12 keV
- Pulse duration
  - 1 fs - 20 fs
- $e^-$ Energy
  - 5.8 GeV
- $e^-$ Bunch charge
  - 10-200 pC
- Repetition rate
  - 100 Hz
SwissFEL ARAMIS U15
SwissFEL: Aramis U15
PSI measurement benches

Laser based SAFALI Measurement systems:\n
1\textsuperscript{st} without tank: trajectory and phase
2\textsuperscript{nd} inside tank: phase and calibration field vs gap

Senis Hall probe, linear motor laser based axes stabilization
Juri 2.0

Senis Hall probe, piezo stepper laser based axes stabilization

\textsuperscript{1)} SAFALI concept by T. Tanaka
U15 optimization step 1: center the axis

measure axial B
differential screws in columns
U15 opt. step 2: long range errors
U15 opt. step 2: long range errors

Pole height adj (μm)

position along the s axis (m)

UpStr  localK optimization  $\phi_{\text{error}} = 56.8^\circ$  DownStr
U15 opt. step 2: long range errors
U15 opt. step 3: local errors

- block keeper
- flexor design
- precise tuning with adjustable wedge
U15 opt. step 3: local errors

Yuri 2.0 automated optimization
after 1st Yuri run
after 3rd Yuri run

U15 opt. step 3: local errors

Pole height adj (μm)

position along the s axis (m)

HMB_2016-01-07_09_55.54
IDs for SwissFEL: Aramis U15

\[ \begin{align*}
  k_{\text{Hin}} & : -25.5 \quad k_{\text{Vin}} : 88.5 \ (\text{G} \cdot \text{cm}) \\
  k_{\text{Hout}} & : 56.7 \quad k_{\text{Vout}} : -115.7 \ (\text{G} \cdot \text{cm}) \\
  \text{long coil} & : 4.2 \ (\text{G} \cdot \text{cm})
\end{align*} \]
Aramis U15 Series Performance

SPEC <10°

optimization

VAC

Hitachi*

Hitachi

RMS phase error (°)

1.0  1.2  1.4  1.6  1.8

K

SPEC <10°
Undulator Performance: magnet strength

\begin{figure}
\centering
\includegraphics[width=\textwidth]{undulator_performance.png}
\caption{Graphs showing the relationship between gap (mm) and K for different magnet strengths.}
\end{figure}
• Monochromator Energy Scan over the third harmonic, from 6345eV to 6465eV, in steps of 15eV, using Si111 crystals.
• SR from SARUN15 observed on MCP at $K = 1.2$
• Undulator being measured set to $K = 1.2$, with the rest at $K = 0.072$ (full open)
• The monochromator was set to 6375eV, third harmonic, using Si111 crystals.

Need to fine adjust $K$ and electron trajectory in the individual undulators
First time resolved Pilot Experiment by SwissFEL: Semiconductor to metal transition in Ti3O5 nanocrystals

Collaboration:
SwissFEL and M. Cammarata et al., Univ. Rennes

-3rd Harm: 6.6 KeV
(fund. 2.2 KeV 220 μJ)
-Laser: 800nm, 42 mJ/cm²

November 30, 2017
SwissFEL in a nutshell

**construction phase I**
2013-2016

- **Injector**
  - 0.35 GeV

- **Linac 1**
  - 2.0 GeV

- **Linac 2**
  - 2.9-3.15 GeV

- **Linac 3**
  - 2-5.8 GeV

**2. Konstruktionsphase**
2017-2020

- **ATHOS 0.7-5 nm**
- **ARAMIS 0.1-0.7 nm**

**user stations**

---

**Aramis**

- Hard X-ray FEL, $\lambda=0.1-0.7$ nm
- Linear polarization, variable gap, in-vacuum Undulators
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**Athos**

- Soft X-ray FEL, $\lambda=0.65-5.0$ nm
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- First users 2020

**Main parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
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<tr>
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</tr>
<tr>
<td>Photon energy</td>
<td>0.2-12 keV</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>1 fs - 20 fs</td>
</tr>
<tr>
<td>$e^-$ Energy</td>
<td>5.8 GeV</td>
</tr>
<tr>
<td>$e^-$ Bunch charge</td>
<td>10-200 pC</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>100 Hz</td>
</tr>
</tbody>
</table>
Overview of Athos Operation Modes

**Basic Modes + Enhancement**
- SASE
- Optical klystron
- Harmonic lasing

**Special Modes**
- High-power and short pulses*
- Two color*

**Spectral Control**
- High-brightness SASE
- Large bandwidth mode*
- Self-seeding

**External Synchronization**
(requires external laser, not available yet)
- Mode-locked lasing
- Slicing
- HHG seeding

Legend:
- APPLE-X Configuration
- Chicanes
- Self-seeding chicane
- Tilt*
- Baseline
- Not Baseline
Optimization of undulator module length

Summary of FEL performance as a function of the undulator module length

- In most of FEL facilities, the module length is not optimized based on FEL performance.
- Typical undulator module length is about 3-5 m for robust operation.
- Most of the modes benefit from shorter modules.

Baseline on physics and costs

**Final module length is 2 m**
(in original design was 4 m)
APPLE history

APPLE II

APPLE X

Fixed gap
Fig. 5. Horizontal component of the $K$ gradient versus $K$ for different gaps. The analytical model (solid line) is presented together with the computer simulation results with RADIA (red square markers).

transverse gradient undulator
tapered undulator (with yaw by cam-shaft movers)

45° linear polarization in standard APPLE (II or X) operation has longitudinal forces (green) the mode above gives 45° without any longitudinal forces proposed by EUXFEL
APPLE X operation
Full control on fields & gradients

Full symmetry
\[
\begin{align*}
\hat{B}_{x1} &= \hat{B}_{y1} \\
\partial_x \hat{B}_{x1} &= \partial_y \hat{B}_{y1}
\end{align*}
\]

circular
\[
\begin{align*}
K &= 4\kappa \hat{B}_{x1} \cos \frac{1}{2} \phi_e \\
\partial_x K &= G_0 \left(1 - \xi^2\right)^{1/2}
\end{align*}
\]
\[
\kappa = \frac{e\lambda_U}{2\pi mc} \\
G_0 = 2\kappa \left(\partial_x \hat{B}_{1x} - \partial_x \hat{B}_{1y}\right) \\
\xi = K/K_0
\]

Full control of
- Energy
- Polarization
- Gradients

inclined
\[
K = 2\kappa \hat{B}_{1x} \left[2 + \cos \phi_e + \cos(\phi_e \pm 2\phi_p)\right]^{1/2}
\]
\[
\partial_x K = 0
\]

M. Calvi et al., Transverse gradient in Apple-type undulators, *J. Synchrotron Rad.*, 2017, 24, 600-608
Spectral control: bandwidth increase

In a TGU there is a dependence of the undulator field on the transverse position

\[ \frac{K(x) - K_0}{K_0} = \alpha x \]

\( K_0 \): on-axis field
\( \alpha \): gradient

A tilted beam traveling through a TGU will produce broadband XFEL radiation. Easy to tune!

\[
\begin{array}{ccc}
\text{Tilted electron beam} & \text{Transverse-gradient undulator} & \text{Large-bandwidth XFEL pulse}
\end{array}
\]

\[ [E. \ Prat, \ M. \ Calvi, \ and \ S. \ Reiche, \ JSR \ 23, \ 874 \ (2016)] \]

- Additional possibilities of the scheme:
  - Multiple colors with slotted foil at the undulator entrance
  - FEL pulse compression (sign of the chirp can be controlled)

- Alternative method: energy-chirped electron beam + optimize laser distribution at the source. Results: \( \sim 3\% \) bandwidth for 0.1 nm and 5.8 GeV @ Aramis

\[ \text{Simulations (10\% bandwidth)} \]

\[ \text{Spectrum} \]

\[ \text{Power profile} \]

\[ \text{XFEL pulses of 20\% bandwidth and few GW power can be obtained} \]
Two-color FEL pulses

In a first section the “tail” is centered and lases at $\lambda_1$. The electron beam is delayed and the “head” is realigned. In a second stage the “head” lases at $\lambda_2$.

Tunability for Athos

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Pulse Length</td>
<td>2 – 10 fs</td>
</tr>
<tr>
<td>Individual Pulse Energy</td>
<td>50 – 250 $\mu$J</td>
</tr>
<tr>
<td>Relative Delay</td>
<td>-10 to 1000 fs</td>
</tr>
<tr>
<td>Photon energy</td>
<td>Factor 5 (e.g. 240 – 1200 eV)</td>
</tr>
</tbody>
</table>

[S. Reiche and E. Prat, JSR 23, 869 (2016)]
[A. Lutman et al, Nat. Photonics 10, 745 (2016)]
SwissFEL UE38 (APPLE X)
Athos undulator frame (cast iron)
Athos undulator frame (cast iron)
UE38 keeper block

Serial block
4 periods each
UE38 keeper block

- Flexor +- 50μm
- Differential screw
- Preload
Hall probe bench with Yuri 3.0
Hall probe bench with Yuri 3.0
Magnets for Athos UE38

shaped field magnets: inhomogeneous magnetization performance study\(^1\) with Arnold Magnetics, Lupfig AG, Switzerland under way

use of SmCo magnets
- temperature stability
- nonlinearities
**UE38 magnet material options**

<table>
<thead>
<tr>
<th>Magnet A</th>
<th>Magnet B</th>
<th>shaped field</th>
<th>K</th>
<th>Photon Energie [eV] @ 2.65 GeV</th>
<th>Photon Energie [eV] @ 2.9 GeV</th>
<th>in Specs @ 2.65 / 2.9 GeV</th>
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<tbody>
<tr>
<td>SmCo$_5$</td>
<td>SmCo$_5$</td>
<td>nein</td>
<td>3.42</td>
<td>256</td>
<td>306</td>
<td>ja / nein</td>
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<td>SmCo$_5$</td>
<td>SmCo$_5$</td>
<td>ja</td>
<td>3.57</td>
<td>238</td>
<td>285</td>
<td>ja / nein</td>
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<tr>
<td>SmCo$_5$</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>nein</td>
<td>3.74</td>
<td>220</td>
<td>263</td>
<td>ja / nein</td>
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<tr>
<td>SmCo$_5$</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>ja</td>
<td>3.9</td>
<td>203</td>
<td>243</td>
<td>ja / ja</td>
</tr>
<tr>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>nein</td>
<td>3.95</td>
<td>199</td>
<td>238</td>
<td>ja / ja</td>
</tr>
<tr>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>ja</td>
<td>4.11</td>
<td>185</td>
<td>222</td>
<td>ja / ja</td>
</tr>
</tbody>
</table>

axial magnet A responsible for shift dependent kicks
better performance of SmCo$_5$
Sm$_2$Co$_{17}$ better suited for use in shaped field because of less anisotropy
Ultra-thin Vacuum chamber for UE38

Cu chamber
galvanic on silicon hose
round or elliptical up to 2:1

diameter 5.0mm
wall thickness 0.2mm
magnet aperture 6.5mm
minimum gap 3.0mm
4 motors for various modes:
- Chicane
- Offset
- Phase Matching
**Chicane mode:**

200\(\mu\)m offset and 1.5\(\mu\)m phase advance

**Phase matcher mode:**

at 80mm gap
SwissFEL & SLS-2: concept

**SLS 2.0** 2.4 GeV

- **Soft x-ray** variable polarization
  - APPLE II / APPLE X
  - gap min = 4mm, 2m long

- **Hard x-ray**
  - in - vacuum
  - U19 -> CPMU14 / 12
  - U10 sc ?!
  - gap min = 4mm, 2m long

**SwissFEL** 2 - 8 GeV

- **Soft x-ray** variable polarization
  - APPLE-X (DELTA II)
  - UE38, Chic Modes

- **in - vacuum**
  - U15 3mm, 4m long -> 12keV
  - U10 sc?! (2025 ff) -> 36keV

2.9 - 3.4 GeV
SLS-2 beamline options - I

courtesy Andreas Streun
<table>
<thead>
<tr>
<th></th>
<th>Injection</th>
<th></th>
<th>free exp area</th>
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<tr>
<td>2</td>
<td>RF</td>
<td>EEHG</td>
<td>free exp area</td>
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<td>U60</td>
<td>U14</td>
<td>XIL</td>
<td>μXAS</td>
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<td>UE50</td>
<td>Phoenix</td>
<td>X-Treme</td>
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<td>entrance</td>
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<td>U14</td>
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<tr>
<td>10</td>
<td>U14</td>
<td></td>
<td>PX II</td>
<td></td>
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<tr>
<td>11</td>
<td>UE56</td>
<td>UE56</td>
<td>SIM</td>
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<tr>
<td>12</td>
<td>UE90</td>
<td>UE90</td>
<td>SIS</td>
<td></td>
</tr>
</tbody>
</table>

4 free slots
SLS-2 Undulator Control

SLS: VME / OMS motor control
    + Siemens S5 PLC
    Design < 2000 (2 cabinets per ID)

SwissFEL: Beckhoff Motion Control
    combines
    motor control
    safety
    compact, low price
    fast Ethercat connection
    cabinets on board

SLS-2: will adapt SwissFEL design
    external cabinets: 1 per ID
    one design for all types
    APPLE X ist most complex
SIS Undulator UE212/424
UE212 quasi-periodic electromagnetic

Polarization:
LH$, LV, circular
2 x 21 periods

Field:
145 x 28 A turns
(120 x 20 A turns)
$B_{\text{max}} = 0.4T$ (0.1T)
$E_{\text{min}} = 10\text{eV}$ (100eV$^*$)
*20eV Update
Quasi-periodic harmonic suppression

Field
Trajectory
Spectrum

1st
3rd
5th

Periodic Quasi-periodic
Harmonic suppression in Photoemission Spectra

Optimization by
- Amplitude variation (ID)
- PGM (20 – 800 eV) or NIM (8 – 30 eV) monochromator
SIS: replacement of the elm qp undulator UE212

QUASI-PERIODIC KNOT-APPLE UNDULATOR

LH, LV, circular without on axis power quasi-pedicic field distribution

drawback: only fundamental

with $K = 0.5$

- $U_{80} = 613\text{eV}$
- $U_{90} = 545\text{eV}$
- $U_{100} = 490\text{eV}$

pretty complicated

S. Sasaki et al, POSSIBILITY FOR QUASI-PERIODIC KNOT-APPLE UNDULATOR, 2014

first device under construction for SSRF

Workshop on IDs for 4GLS (Berkeley 2017):

Quasiperidic APPLE devices are too much compromise
twin APPLE undulators

LH, LV out of circular light
no harmonics, no power on axis
standard operation for higher energies
use of harmonics possible
range 10 (15) eV – 600 (1000) eV

polarization control with single shot polarimeter

courtesy Jens Viefhaus (DESY)
SwissFEL UE38 prototype
SLS-2 UE90 design study

Field enhancement: 8%

Note: PSI builds 4 UE90 of APPLE X type for EUXFEL
UE90 2x1.9m  2x19 periods
Flux in 1x1mm at 25m

40 x 40 μrad
UE90
LH in crossed mode

UE90
Circ
Stokes Parameter for different phases between crossed undulators

$x,y$ in 25m distance from source point
<table>
<thead>
<tr>
<th>Energy [eV]</th>
<th>$B_{ext} / B_{int}$ [T]</th>
<th>$K_{ext} / K_{int}$</th>
<th>Aperture @25m [mm x mm]</th>
<th>$\text{Flux}_{\text{crossed}}$ P &gt; 80% [x $10^{14}$]</th>
<th>Aperture @25m [mm x mm]</th>
<th>$\text{Flux}_{\text{crossed}}$ P &gt; 70% [x $10^{14}$]</th>
<th>Aperture @25m [mm x mm]</th>
<th>Flux$_{int}$ P 100% [x $10^{14}$]</th>
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<tbody>
<tr>
<td>12</td>
<td>0.84 / 1.19</td>
<td>7.05 / 9.98</td>
<td>4 x 4</td>
<td>3.2</td>
<td>5.6 x 5.6</td>
<td>6</td>
<td>10 x 10</td>
<td>15</td>
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<td>5.45 / 7.70</td>
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<td>4 x 4</td>
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<td>3.79 / 5.35</td>
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<td>2.4</td>
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<td>4.9</td>
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<tr>
<td>60</td>
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<td>3.04 / 4.29</td>
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<td>2.3</td>
<td>2.24 x 2.24</td>
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<td>90</td>
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<td>1.3</td>
<td>1.76 x 1.76</td>
<td>3.9</td>
<td>4 x 4</td>
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</tbody>
</table>

**Pros**

- No on-axis harmonics
- Better than quasi-periodic
- Scheme with 2 undulators allows to use both modes
- No on-axis heat load
- Depending on photon energy, flux and polarization demand by the users

**Cons**

- 5 x less flux at 12eV
- 10 x less at 90eV
- Degree of polarization 80%
UE90 blue edge

<table>
<thead>
<tr>
<th>Harmonic Content</th>
<th>Series1</th>
<th>Series2</th>
<th>Series3</th>
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<td>4</td>
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<td>47%</td>
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<td>4%</td>
<td>38%</td>
<td>7%</td>
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<td>3</td>
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<tr>
<td>5%</td>
<td>11%</td>
<td>8%</td>
<td>14%</td>
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</tbody>
</table>
Vacuum chambers for single pass machines:
round, simple
Injection requires larger horizontal apertures
vacuum chambers with antechambers
complicated to impossible

from undulator point of view

On-axis injection schemes highly desireable

Various on-axis injector schemes under development at ALS, BAPS, SOLEIL, SLS

Only when these schemes are in baseline a project can profit!
fixed gap APPLE II

Upgrades required:
Add cam-shaft mover
to allow (in situ) alignment
UE44 SLS to SLS-2

**Flux**

- **SLS + SLS-2**
  - Flux graph showing energy vs. flux with data points.

**Brilliance**

- **SLS-2**
  - Brilliance graph showing energy vs. brilliance with data points.

**Coherent fraction SLS**

- **SLS-2**
  - Coherent fraction graph showing energy vs. coherent fraction with data points.
EEHC for ADRESS

Echo Enabled Harmonic Generation

R. Molo et al., ECHO-ENABLED HARMONIC GENERATION AT DELTA, Proceedings of IPAC2011, San Sebastián, Spain
EEHC in SLS-2 in 2 straights

**Straight 1**
Rf cavities + modulator 1

**Arc** which is the dispersive element $R_{56}$

**Straight 2**
modulator 2 + phase matcher + APPLE X

**A unique opportunity for SLS-2!**
negligible increase of energy spread

about 1% density modulation
Increase in coherent flux: 100-10000

Note: EEHC developed for FEL
Studies for
Hefei storage ring, DELTA, SLS-2, ...
SIM UE56 / Phoenix, X-treme UE54

APPLE II

UE56 twin undulators

UE54 serves two beamlines

X-treme soft x-ray

Phoenix tender x-ray

37th harmonic !!!

SLS-2 lattice allows a second undulator
Hydraulik Drive for shift gap axis

Hydraulik driven Cylinder as alternative to motor/spindel drive system

System: Bosch Rexroth 4WRPDH
valve with integrated regulation and interfaces or μ-controller with valve

resolution valve: 0.001%
cycle time: <1ms

regulations:
- position
- force
- pressure
- position/pressure, position/force

connections:
EtherCAT, EtherNet, PROFINET, …

Hydraulik Test Stand
PX, c-SAXS, μ-XAS U19 / MS U14
SLS-2 Brilliance

![Graph] (X:\dcs_sls2\docs\sls2\SLS-2\Brilliance.pdf)
smaller $\varepsilon$ -> clearer spectra
smaller (better) optics
operation without monochromator
U19 in Vacuum Undulatoren -> Cryo Undulatoren CPMU14 based on PrFeB

Upgrade of the existing in-vacuum undulators
Higher fields, but smaller horizontal pole width <- small emittance

needs to be realized in the year 2023 machine dark time

CPMU14 based on NdFeB at 135K: no change

All in-vacuum undulators can be installed in any place
In-situ Measurement / Optimization Bench

- Screw robot
- Hall probe
### SLS – SLS-2 Reference Table

<table>
<thead>
<tr>
<th>Facility</th>
<th>Instrument</th>
<th>@ Energy</th>
<th>Brilliance</th>
<th>Flux</th>
<th>Flux dens</th>
<th>coh. Flux</th>
<th>tot Power [kW]</th>
<th>Brilliance increase</th>
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<td>0.07</td>
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</tbody>
</table>

-Calculated with Spectra 10.0

-Note: for SIS the SLS-2 calculations are based on a UE90 instead of a UE212
Super longitudinal gradient bending

for $\pm 0.5$ mrad fan angle
full vertical acceptance

- 2.9 T at SLS
- 5.4 T at SLS-2
- ESRF-EBS
  (6 GeV)
  0.86 T 2-pole wiggler

Superconducting dipoles
SwissFEL Outlook

phase 1 (2013-2016)

- Linac 1
  - 0.35 GeV
- Linac 2
  - 2.0 GeV
- Linac 3
  - 3.15 GeV
- BC1
- BC2

phase 2 (2017-2020)

- ATHOS 0.7-5 nm
  - 2.9-3.4 GeV
- ARAMIS 0.1-0.7 nm
  - 2-5.8 GeV
- PORHOS 0.03-0.7 nm
  - 2-7 GeV

phase 3 (2025-2029)

- Supraleitende Undulatoren U10
  - (4K – flüssig He)
- Einsatz auch in SLS-2 für Micro-Tomcat
GdBCO @ 4-10K
Nb₃Sn @ 1.8K
PrFeB @ 77K
magnetic gap = 4.0mm

E.R. Moog, R.J. Dejus, and S. Sasaki, Light Source Note: ANL/APS/LS-348
James Clarke, FLS 2012, March 2012
Staggered array with HTS bulks

Staggered array with HTS bulks

Thanks for your interest

and special thanks to
J. Chavanne, O. Chubar, P. Elleaume for RADIA, SRW ...
T. Tanaka for SPECTRA