Optics development and plans for a Robinson Wiggler at the Metrology Light Source

J. Feikes, T. Goetsch, M. Ries, G. Wüstefeld

Helmholtz-Zentrum Berlin (HZB)

tobias.goetsch@helmholtz-berlin.de

European Synchrotron Light Source XXI Workshop 2013 / Karlsruhe, Germany

21st Nov 2013
Outline

Overview Metrology Light Source

Optics development
- Standard user optics
- Optics scans and low-ε optics

First steps towards a Robinson Wiggler
- Theory
- Challenges
Outline

Overview Metrology Light Source

Optics development
- Standard user optics
- Optics scans and low-ε optics

First steps towards a Robinson Wiggler
- Theory
- Challenges
MLS key parameters
MLS key parameters

Lattice
Energy
Circumference
Design-emittance $\varepsilon_x$
Cavity Voltage
Tunes $Q_x/Q_y$

DBA
50 MeV to 629 MeV
48 m
100 nm rad
500 kV
3.18 / 2.23
Established user optics at the MLS

- Standard user optics with $\varepsilon \approx 100$ nm rad
- Low-$\alpha$ user optics with $\sigma_{z0} = 1$ ps
- 10 ps optics
- Low-$\varepsilon$ optics (4 times smaller emittance)
- And more ... (neg. $\alpha$ optics, 50 MeV optics)

⇒ change of optics easy → time span of minutes
Established user optics at the MLS

- standard user optics with $\varepsilon \approx 100 \text{ nm rad}$
- low-$\alpha$ user optics with $\sigma_{z0} = 1 \text{ ps}$
- 10 ps optics
- low-$\varepsilon$ optics (4 times smaller emittance)
- and more ... (neg. $\alpha$ optics, 50 MeV optics)

$\Rightarrow$ change of optics easy $\rightarrow$ time span of minutes
Established user optics at the MLS

- standard user optics with $\varepsilon \approx 100 \text{ nm rad}$
- low-$\alpha$ user optics with $\sigma_{z0} = 1 \text{ ps}$
- 10 ps optics
  - low-$\varepsilon$ optics (4 times smaller emittance)
  - and more ... (neg. $\alpha$ optics, 50 MeV optics)

$\Rightarrow$ change of optics easy $\Rightarrow$ time span of minutes
Established user optics at the MLS

- standard user optics with $\varepsilon \approx 100$ nm rad
- low-$\alpha$ user optics with $\sigma_{z0} = 1$ ps
- 10 ps optics
- low-$\varepsilon$ optics (4 times smaller emittance)
- and more ... (neg. $\alpha$ optics, 50 MeV optics)

$\Rightarrow$ change of optics easy $\rightarrow$ time span of minutes
Established user optics at the MLS

- standard user optics with $\varepsilon \approx 100$ nm rad
- low-$\alpha$ user optics with $\sigma_{z0} = 1$ ps
- 10 ps optics
- low-$\varepsilon$ optics (4 times smaller emittance)
- and more ... (neg. $\alpha$ optics, 50 MeV optics)

⇒ change of optics easy → time span of minutes
Established user optics at the MLS

- standard user optics with $\varepsilon \approx 100 \text{ nm rad}$
- low-$\alpha$ user optics with $\sigma_{z0} = 1 \text{ ps}$
- 10 ps optics
- low-$\varepsilon$ optics (4 times smaller emittance)
- and more ... (neg. $\alpha$ optics, 50 MeV optics)

$\Rightarrow$ change of optics easy $\rightarrow$ time span of minutes
Outline

Overview Metrology Light Source

Optics development
  Standard user optics
  Optics scans and low-$\varepsilon$ optics

First steps towards a Robinson Wiggler
  Theory
  Challenges
- short lifetime: $\tau(150\ mA) = 3.5\ h$
- losses dominated by Touschek effect
  - Touschek mainly depends on:
    - bunch volume / current, energy, acceptance
- septum with smallest aperture crucial for geometrical acceptance
短寿命: \( \tau(150 \text{ mA}) = 3.5 \text{ h} \)

- 损失主要由托斯切克效应造成
- 托斯切克主要取决于:
  - 堆积体积/电流，能量，接受度
- 最小间隙的隔板对于几何接受度至关重要
Standard user optics 2012

- short lifetime: $\tau(150\, \text{mA}) = 3.5\, \text{h}$
- losses dominated by Touschek effect
  - Touschek mainly depends on:
    - bunch volume / current, energy, acceptance
  - septum with smallest aperture crucial for geometrical acceptance
▶ short lifetime: $\tau(150\, \text{mA}) = 3.5\, \text{h}$
▶ losses dominated by Touschek effect
  ▶ Touschek mainly depends on:
    bunch volume / current, energy, acceptance
▶ septum with smallest aperture crucial for geometrical acceptance
short lifetime: $\tau(150 \text{ mA}) = 3.5 \text{ h}$

losses dominated by Touschek effect

- Touschek mainly depends on:
  - bunch volume / current, energy, acceptance

- septum with smallest aperture crucial for geometrical acceptance
Improving the lifetime

- increase geometrical acceptance to decrease losses through Touschek effect
  - geometrical acceptance dominated by aperture at septum
  - geometrical acceptance can be manipulated by
    - decreasing dispersion function $\eta_x$
      (possible as all 24 quadrupoles are powered independently)
    - increasing minimum aperture $a_x$ through orbit bump
Improving the lifetime

▶ increase geometrical acceptance to decrease losses through Touschek effect
▶ geometrical acceptance dominated by aperture at septum
▶ geometrical acceptance can be manipulated by
  ▶ decreasing dispersion function $\eta_x$
    (possible as all 24 quadrupoles are powered independently)
  ▶ increasing minimum aperture $a_x$ through orbit bump
Improving the lifetime

- Increase geometrical acceptance to decrease losses through Touschek effect
- Geometrical acceptance dominated by aperture at septum
- Geometrical acceptance can be manipulated by
  - Decreasing dispersion function $\eta_x$
    (possible as all 24 quadrupoles are powered independently)
  - Increasing minimum aperture $a_x$ through orbit bump

![Graph showing $\eta_x$ vs. s/m for 2012 and 2013, with septum and aperture limits indicated.]
Improving the lifetime

- increase geometrical acceptance to decrease losses through Touschek effect
- geometrical acceptance dominated by aperture at septum
- geometrical acceptance can be manipulated by
  - decreasing dispersion function \( \eta_x \)
    (possible as all 24 quadrupoles are powered independently)
  - increasing minimum aperture \( a_x \) through orbit bump

![Graph showing aperture limits at septum and rest of ring](image_url)
Standard user optics with improved lifetime

- lifetime improved by 80%:
  \[ \tau_{\text{old}}(150 \text{ mA}) = 3.5 \text{ h} \quad \rightarrow \quad \tau_{\text{new}}(150 \text{ mA}) = 6 \text{ h} \]
  @ same source size

- in operation since February 2013

- small drawback: emittance increase of \( \Delta \varepsilon / \varepsilon \approx 10\% \)
Standard user optics with improved lifetime

- lifetime improved by 80%:
  \[ \tau_{\text{old}}(150 \text{ mA}) = 3.5 \text{ h} \quad \rightarrow \quad \tau_{\text{new}}(150 \text{ mA}) = 6 \text{ h} \]
  @ same source size

- in operation since February 2013

- small drawback: emittance increase of \( \Delta \varepsilon / \varepsilon \approx 10\% \)

\[ \begin{align*}
\beta_{x,y} & / \text{m} \\
\eta_{x} & / \text{m} \\
\end{align*} \]

\begin{align*}
s / \text{m} \\
0 & 12 & 24 & 36 & 48 \\
\end{align*}

\begin{align*}
\tau & / \text{h} \\
2012; V = 310 \text{ kV} & \quad 2013; V = 500 \text{ kV} \\
80 & 100 & 120 & 140 \\
I / \text{mA} \\
0 & 2 & 4 & 6 & 8 & 10 & 12 \\
\end{align*}
Standard user optics with improved lifetime

- lifetime improved by 80%:
  \[ \tau_{\text{old}}(150 \text{ mA}) = 3.5 \text{ h} \quad \rightarrow \quad \tau_{\text{new}}(150 \text{ mA}) = 6 \text{ h} \]
  @ same source size
- in operation since February 2013
- small drawback: emittance increase of \( \Delta \varepsilon/\varepsilon \approx 10 \% \)
Optics scans to find new operation modes

- grouped in five quadrupole families
  - quadrupole family strength varied at constant step size
  - $1 \times 10^{12}$ settings checked
  - $2 \times 10^6$ stable solutions
  - run time on 2.66 GHz single core: 200 h
Optics scans to find new operation modes

- grouped in five quadrupole families
- quadrupole family strength varied at constant step size
  - $1 \times 10^{12}$ settings checked
  - $2 \times 10^6$ stable solutions
  - run time on 2.66 GHz single core: 200 h
Optics scans to find new operation modes

- grouped in five quadrupole families
- quadrupole family strength varied at constant step size
- $1 \times 10^{12}$ settings checked
- $2 \times 10^6$ stable solutions
- run time on 2.66 GHz single core: 200 h
Optics scans to find new operation modes

- grouped in five quadrupole families
- quadrupole family strength varied at constant step size
- $1 \times 10^{12}$ settings checked
- $2 \times 10^6$ stable solutions
- run time on 2.66 GHz single core: 200 h
Optics scans to find new operation modes

- grouped in five quadrupole families
- quadrupole family strength varied at constant step size
- $1 \times 10^{12}$ settings checked
- $2 \times 10^6$ stable solutions
- run time on 2.66 GHz single core: 200 h
Filtering for low-$\varepsilon$

- apply filter for low-$\varepsilon$
- search for nice solution in an “easy” reachable region
- picked solution promised 4 times smaller emittance
- after injection and energy ramp: 190 mA beam current left
  $\rightarrow$ optics transition with full current
  $\rightarrow$ 186 mA left after optics change
Filtering for low-$\varepsilon$

▶ apply filter for low-$\varepsilon$
▶ search for nice solution in an “easy” reachable region
▶ picked solution promised 4 times smaller emittance
▶ after injection and energy ramp: 190 mA beam current left
   → optics transition with full current
   → 186 mA left after optics change
Filtering for low-\(\varepsilon\)

- apply filter for low-\(\varepsilon\)
- search for nice solution in an “easy” reachable region
- picked solution promised 4 times smaller emittance
  - after injection and energy ramp: 190 mA beam current left
    → optics transition with full current
    → 186 mA left after optics change
Filtering for low-$\varepsilon$

- apply filter for low-$\varepsilon$
- search for nice solution in an “easy” reachable region
- picked solution promised 4 times smaller emittance
- after injection and energy ramp: 190 mA beam current left
  $\rightarrow$ optics transition with full current
  $\rightarrow$ 186 mA left after optics change
Low-$\varepsilon$ optics

- measured emittance reduction of factor 4 (source point imaging)
  - emittance reduction double checked by lifetime measurement
  - now operational up to 185 mA
  - increasing demand from users
  - drawback: short lifetime $\tau_{low-\varepsilon} \approx 1.2$ h
Low-ε optics

- measured emittance reduction of factor 4 (source point imaging)
- emittance reduction double checked by lifetime measurement
- now operational up to 185 mA
- increasing demand from users
- drawback: short lifetime $\tau_{\text{low-ε}} \approx 1.2 \text{ h}$
Low-$\varepsilon$ optics

- Measured emittance reduction of factor 4 (source point imaging)
- Emittance reduction double checked by lifetime measurement
- Now operational up to 185 mA
- Increasing demand from users
- Drawback: short lifetime $\tau_{\text{low-}\varepsilon} \approx 1.2$ h
Low-$\varepsilon$ optics

- measured emittance reduction of factor 4 (source point imaging)
- emittance reduction double checked by lifetime measurement
- now operational up to 185 mA
- increasing demand from users
- drawback: short lifetime $\tau_{\text{low-}\varepsilon} \approx 1.2$ h

standard user, $\sigma_x = 442 \mu$m

low-$\varepsilon$, $\sigma_x = 220 \mu$m
Low-ε optics

- measured emittance reduction of factor 4 (source point imaging)
- emittance reduction double checked by lifetime measurement
- now operational up to 185 mA
- increasing demand from users
- drawback: short lifetime $\tau_{\text{low-ε}} \approx 1.2$ h
Outline

Overview Metrology Light Source

Optics development
   Standard user optics
   Optics scans and low-\(\varepsilon\) optics

First steps towards a Robinson Wiggler
   Theory
   Challenges
A Robinson Wiggler for the MLS

Robinson Wiggler from PS (CERN)

L. Nadolski, ESLS XIX, Horizontal Emittance Reduction using a Robinson Wiggler

Touschek lifetime depends linearly on bunch size and length:

\[
\tau_T \propto \sigma_x \sigma_z, \quad \sigma_x = \sqrt{\varepsilon_x \beta_x + \sigma^2_\delta \eta_x^2}, \quad \sigma_z \propto \sigma_\delta
\]

With Robinson Wiggler one can transfer damping between horizontal and longitudinal plane:

- reduce horizontal emittance
- increase energy spread

\[ \rightarrow \text{keep } \sigma_x \approx \text{const. but increase } \sigma_z \Rightarrow \text{lifetime improvement} \]
A Robinson Wiggler for the MLS

Robinson Wiggler from PS (CERN)

L. Nadolski, ESLS XIX, Horizontal Emittance Reduction using a Robinson Wiggler

Touschek lifetime depends linearly on bunch size and length:

\[ \tau_T \propto \sigma_x \sigma_z, \quad \sigma_x = \sqrt{\varepsilon_x \beta_x \sigma_z^2 + \sigma_{\delta x}^2 \eta_x^2}, \quad \sigma_z \propto \sigma_{\delta} \]

With Robinson Wiggler one can transfer damping between horizontal and longitudinal plane:

- reduce horizontal emittance
- increase energy spread
  - keep \( \sigma_x \approx \text{const.} \) but increase \( \sigma_z \) \( \Rightarrow \) lifetime improvement
A Robinson Wiggler for the MLS

Robinson Wiggler from PS (CERN)

L. Nadolski, ESLS XIX, Horizontal Emittance Reduction using a Robinson Wiggler

Touschek lifetime depends linearly on bunch size and length:

\[ \tau_T \propto \sigma_x \sigma_z, \quad \sigma_x = \sqrt{\varepsilon_x \beta_x + \sigma_{\delta x}^2 \eta_x}, \quad \sigma_z \propto \sigma_{\delta x} \]

With Robinson Wiggler one can transfer damping between horizontal and longitudinal plane:

- reduce horizontal emittance
- increase energy spread
  \[ \rightarrow \text{keep } \sigma_x \approx \text{const. but increase } \sigma_z \Rightarrow \text{lifetime improvement} \]

L. Nadolski - IPAC 2012 - MOPPP062
Theoretical background

Effect on the emittance:

\[ \varepsilon_x \propto \frac{1}{1 - D} \]

Effect on the energy spread and bunch length:

\[ \sigma_z \propto \sigma_\delta \propto \frac{1}{\sqrt{2 + D}} \]

with

\[ D = \frac{l_4}{l_2} \]

\[ l_4 = \int \eta_x \left( \frac{1}{\rho^3} + 2\frac{k}{\rho} \right) ds, \quad \text{with} \quad k = \frac{1}{B\rho} \frac{\partial B_y}{\partial x} \]

\[ l_2 = \int \frac{1}{\rho^2} ds \]
Theoretical background

Effect on the emittance:

\[ \varepsilon_x \propto \frac{1}{1 - D} \]

Effect on the energy spread and bunch length:

\[ \sigma_z \propto \sigma_\delta \propto \frac{1}{\sqrt{2 + D}} \]

with

\[ D = \frac{l_4}{l_2} \]

\[ l_4 = \oint \eta_x \left( \frac{1}{\rho^3} + 2 \frac{k}{\rho} \right) ds, \quad \text{with} \quad k = \frac{1}{B\rho} \frac{\partial B_y}{\partial x} \]

\[ l_2 = \oint \frac{1}{\rho^2} ds \]
Theoretical background

Effect on the emittance:

\[
\varepsilon_x \propto \frac{1}{1 - D}
\]

Effect on the energy spread and bunch length:

\[
\sigma_z \propto \sigma_\delta \propto \frac{1}{\sqrt{2 + D}}
\]

with

\[
D = \frac{l_4}{l_2}
\]

\[
l_4 = \int \eta_x \left( \frac{1}{\rho^3} + 2\frac{k}{\rho} \right) ds,
\text{ with } k = \frac{1}{B\rho} \frac{\partial B_y}{\partial x}
\]

\[
l_2 = \int \frac{1}{\rho^2} ds
\]
Theoretical background

Effect on the emittance:

\[ \varepsilon_x \propto \frac{1}{1 - D} \]

Effect on the energy spread and bunch length:

\[ \sigma_z \propto \sigma_\delta \propto \frac{1}{\sqrt{2 + D}} \]

with

\[ D = \frac{l_4}{l_2} \]

\[ l_4 = \int \eta_x \left( \frac{1}{\rho^3} + 2 \frac{k}{\rho} \right) ds, \quad \text{with} \quad k = \frac{1}{B\rho} \frac{\partial B_y}{\partial x} \]

\[ l_2 = \int \frac{1}{\rho^2} ds \]
Theoretical background

Effect on the emittance:

\[ \varepsilon_x \propto \frac{1}{1 - D} \]

Effect on the energy spread and bunch length:

\[ \sigma_z \propto \sigma_\delta \propto \frac{1}{\sqrt{2 + D}} \]

with

\[ D = \frac{l_4}{l_2} \]

\[ l_4 = \int \eta_x \left( \frac{1}{\rho^3} + 2 \frac{k}{\rho} \right) ds, \quad \text{with} \quad k = \frac{1}{B\rho} \frac{\partial B_y}{\partial x} \]

\[ l_2 = \int \frac{1}{\rho^2} ds \]
Required field strength

\[ D \text{ as a function of } \eta_x \text{ and } B \partial B / \partial x \]

- required fields to achieve \( D = -2 \) at \( \eta_x = 1.2 \text{ m} \) for device of length \( l = 0.8 \text{ m} \):
  \[ k = 15 \text{ T m}^{-1} \text{ and } B = 1.4 \text{ T} \]

- feasible: MLS quads today: 13 T m\(^{-1}\)
  MLS bends today: 1.4 T
Required field strength

$D$ as a function of $\eta_x$ and $B \partial B / \partial x$

$D$ as a function of $B$ and $\partial B / \partial x$ for $\eta_x = 1.2$ m

- required fields to achieve $D = -2$ at $\eta_x = 1.2$ m for device of length $l = 0.8$ m:
  
  $k = 15$ T m$^{-1}$ and $B = 1.4$ T

- feasible: MLS quads today: 13 T m$^{-1}$
  MLS bends today: 1.4 T
Robinson Wiggler

→ sequence of dipoles with field and gradient of opposite sign

Different design options:

▶ 4-pole wavelength shifter
  • use as radiation source with higher photon energy
  • strong effect on optics

▶ $n$-pole wiggler
  • use as an undulator
  • weaker effect on the optics

Some constraints for the optics:

▶ dispersion should be 1.2 m at the wiggler and 0 m at the septum

▶ $\beta$-functions should have reasonable values
Robinson Wiggler

→ sequence of dipoles with field and gradient of opposite sign

Different design options:

- 4-pole wavelength shifter
  - use as radiation source with higher photon energy
  - strong effect on optics

- $n$-pole wiggler
  - use as an undulator
  - weaker effect on the optics

Some constraints for the optics:

- dispersion should be 1.2 m at the wiggler and 0 m at the septum
- $\beta$-functions should have reasonable values
Robinson Wiggler

→ sequence of dipoles with field and gradient of opposite sign

Different design options:

▶ 4-pole wave length shifter
  - use as radiation source with higher photon energy
  - strong effect on optics

▶ \( n \)-pole wiggler
  - use as an undulator
  - weaker effect on the optics

Some constraints for the optics:

▶ dispersion should be 1.2 m at the wiggler and 0 m at the septum

▶ \( \beta \)-functions should have reasonable values
Robinson Wiggler

→ sequence of dipoles with field and gradient of opposite sign

Different design options:

- 4-pole wave length shifter
  - use as radiation source with higher photon energy
  - strong effect on optics

- \( n \)-pole wiggler
  - use as an undulator
  - weaker effect on the optics

Some constraints for the optics:

- dispersion should be 1.2 m at the wiggler and 0 m at the septum

\( \beta \)-functions should have reasonable values
Robinson Wiggler

→ sequence of dipoles with field and gradient of opposite sign

Different design options:

▶ 4-pole wavelength shifter
  • use as radiation source with higher photon energy
  • strong effect on optics

▶ n-pole wiggler
  • use as an undulator
  • weaker effect on the optics

Some constraints for the optics:

▶ dispersion should be 1.2 m at the wiggler and 0 m at the septum

▶ $\beta$-functions should have reasonable values
First tracking results

10 pole wiggler of total length \( l = 1 \text{ m} \), described by sequence of horizontally displaced quadrupoles in MADX-PTC.

\( \eta_x = 1 \text{ m} \)

\( k = 21 \text{ T m}^{-1} \)

\( B \) was varied by varying the displacement of the sequence

20 Mio. turns tracked

dependencies as expected:

- increase of energy spread
- reduction of horizontal emittance
- source size at EUV-beamline has a minimum for \( B \frac{\partial B}{\partial x} = 10 \text{ T}^2 \text{ m}^{-1} \) (→ \( D = -1 \))
First tracking results

10 pole wiggler of total length \( l = 1 \) m, described by sequence of horizontally displaced quadrupoles in MADX-PTC.

\( \eta_x = 1 \) m

\( k = 21 \) T m\(^{-1}\)

\( B \) was varied by varying the displacement of the sequence

20 Mio. turns tracked

dependencies as expected:

- increase of energy spread
- reduction of horizontal emittance
- source size at EUV-beamline has a minimum for

\[
B \frac{\partial B}{\partial x} = 10 \, \text{T}^2 \, \text{m}^{-1} \quad (\rightarrow D = -1)
\]
First tracking results

10 pole wiggler of total length $l = 1 \text{ m}$, described by sequence of horizontally displaced quadrupoles in MADX-PTC.

$\eta_x = 1 \text{ m}$

$k = 21 \text{ T m}^{-1}$

$B$ was varied by varying the displacement of the sequence

20 Mio. turns tracked

dependencies as expected:

- increase of energy spread
- reduction of horizontal emittance
- source size at EUV-beamline has an minimum for $B \frac{\partial B}{\partial x} = 10 \text{ T}^2 \text{ m}^{-1}$ (→ $D = -1$)
First tracking results

10 pole wiggler of total length $l = 1 \text{ m}$, described by sequence of horizontally displaced quadrupoles in MADX–PTC.

$\eta_x = 1 \text{ m}$

$k = 21 \text{ T m}^{-1}$

$B$ was varied by varying the displacement of the sequence

20 Mio. turns tracked

dependencies as expected:

- increase of energy spread
- reduction of horizontal emittance
- source size at EUV-beamline has an minimum for $B \frac{\partial B}{\partial x} = 10 \text{ T}^2 \text{ m}^{-1}$ ($\rightarrow D = -1$)
Challenges and realisation

- find optics with
  - $\eta_x = 0 \text{ m at the septum and } \eta_x = 1.2 \text{ m at the Robinson Wiggler}$
  - $\beta$-functions below 20 m

- optics need to fulfil demands from user side
→ many constraints!

- funding already available
- if feasibility study successful
  → device will be built!
Challenges and realisation

- find optics with
  - $\eta_x = 0\,\text{m}$ at the septum and $\eta_x = 1.2\,\text{m}$ at the Robinson Wiggler
  - $\beta$-functions below 20 m
- optics need to fulfil demands from user side
  ⇒ many constraints!
- funding already available
- if feasibility study successful
  → device will be built!
Challenges and realisation

- find optics with
  - $\eta_x = 0$ m at the septum and $\eta_x = 1.2$ m at the Robinson Wiggler
  - $\beta$-functions below 20 m
- optics need to fulfil demands from user side
  $\Rightarrow$ many constraints!

- funding already available
- if feasibility study successful
  $\rightarrow$ device will be built!
Challenges and realisation

- find optics with
  - $\eta_x = 0 \text{ m at the septum and } \eta_x = 1.2 \text{ m at the Robinson Wiggler}$
  - $\beta$-functions below 20 m
- optics need to fulfil demands from user side
  $\Rightarrow$ many constraints!

- funding already available
  - if feasibility study successful
    $\rightarrow$ device will be built!
Challenges and realisation

- find optics with
  - $\eta_x = 0 \text{ m at the septum and } \eta_x = 1.2 \text{ m at the Robinson Wiggler}$
  - $\beta$-functions below 20 m

- optics need to fulfil demands from user side
  ⇒ many constraints!

- funding already available
  - if feasibility study successful
    → device will be built!
Summary / Outlook

- achieved performance improvement for the MLS
  - improved lifetime by 80% for the standard user optics
  - low-$\varepsilon$ optics with 4 times smaller emittance
- increasing demand for low emittance from user side
- Robinson Wiggler could further enhance the MLS performance by
  - improving the lifetime by bunch lengthening
  - reducing the horizontal emittance
- first tracking results positive regarding bunch lengthening and emittance reduction
- further studies needed including probable usability as a radiation source
Summary / Outlook

- achieved performance improvement for the MLS
  - improved lifetime by 80% for the standard user optics
  - low-$\varepsilon$ optics with 4 times smaller emittance
- increasing demand for low emittance from user side
- Robinson Wiggler could further enhance the MLS performance by
  - improving the lifetime by bunch lengthening
  - reducing the horizontal emittance
- first tracking results positive regarding bunch lengthening and emittance reduction
- further studies needed including probable usability as a radiation source
Summary / Outlook

- achieved performance improvement for the MLS
  - improved lifetime by 80% for the standard user optics
  - low-\(\varepsilon\) optics with 4 times smaller emittance
- increasing demand for low emittance from user side
- Robinson Wiggler could further enhance the MLS performance by
  - improving the lifetime by bunch lengthening
  - reducing the horizontal emittance
- first tracking results positive regarding bunch lengthening and emittance reduction
- further studies needed including probable usability as a radiation source
Summary / Outlook

- achieved performance improvement for the MLS
  - improved lifetime by 80% for the standard user optics
  - low-\(\varepsilon\) optics with 4 times smaller emittance
- increasing demand for low emittance from user side
- Robinson Wiggler could further enhance the MLS performance by
  - improving the lifetime by bunch lengthening
  - reducing the horizontal emittance
- first tracking results positive regarding bunch lengthening and emittance reduction
- further studies needed including probable usability as a radiation source
Summary / Outlook

- achieved performance improvement for the MLS
  - improved lifetime by 80% for the standard user optics
  - low-$\varepsilon$ optics with 4 times smaller emittance
- increasing demand for low emittance from user side
- Robinson Wiggler could further enhance the MLS performance by
  - improving the lifetime by bunch lengthening
  - reducing the horizontal emittance
- first tracking results positive regarding bunch lengthening and emittance reduction
- further studies needed including probable usability as a radiation source
Thank you for your attention

We acknowledge for support & discussion:
A.-S. Müller (KIT), A. Jankowiak (HZB), G. Ulm (PTB)
B. Holzer, W. Herr (CERN)
L. Nadolski (SOLEIL)