Overview of the accelerator development for light source in NSRRC

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On behalf of Accelerator Div.

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Contents

• Overview of 3\textsuperscript{rd} Generation Light Source
• Taiwan Light Source
  – Layout and milestone
  – Operation statistics
  – Application of low energy Linac
• Taiwan Photon Source
  – The design and layout
  – Commissioning of accelerators
  – Future Plan
3rd Generation Light Sources around the World

[Map showing locations of 3rd generation light sources around the world.}

- Operational: 26
- Commissioning: 2
- Construction: 2
- Planned: 4
## 3rd Generation Light Sources in Operation (1)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm.rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ALS</td>
<td>1.9</td>
<td>196.8</td>
<td>6.3</td>
<td>500</td>
<td>12x6.7m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>2. ESRF</td>
<td>6.0</td>
<td>844.4</td>
<td>3.7</td>
<td>200</td>
<td>32x6.3m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>3. TLS</td>
<td>1.5</td>
<td>120</td>
<td>25</td>
<td>360</td>
<td>6x6m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>4. ELETTRA</td>
<td>2.0/2.4</td>
<td>259</td>
<td>7</td>
<td>300</td>
<td>12x6.1m</td>
<td>Operation (1994)</td>
</tr>
<tr>
<td>5. PLS/PLS-II</td>
<td>3.0</td>
<td>280.56</td>
<td>5.8</td>
<td>400</td>
<td>12x6.8m</td>
<td>Operation (1995)</td>
</tr>
<tr>
<td>6. APS</td>
<td>7.0</td>
<td>1104</td>
<td>3.0</td>
<td>100</td>
<td>40x6.7m</td>
<td>Operation (1996)</td>
</tr>
<tr>
<td>7. SPring-8</td>
<td>8.0</td>
<td>1436</td>
<td>2.8</td>
<td>100</td>
<td>44x6.6m, 4x30m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>8. LNLS</td>
<td>1.37</td>
<td>93.2</td>
<td>70</td>
<td>250</td>
<td>6x3m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>9. MAX-II</td>
<td>1.5</td>
<td>90</td>
<td>9.0</td>
<td>200</td>
<td>10x3.2m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>10. BESSY-II</td>
<td>1.7</td>
<td>240</td>
<td>6.1</td>
<td>200</td>
<td>8x5.7m, 8x4.9m</td>
<td>Operation (1999)</td>
</tr>
<tr>
<td>11. Siberia-II</td>
<td>2.5</td>
<td>124</td>
<td>65</td>
<td>200</td>
<td>12x3m</td>
<td>Operation (1999)</td>
</tr>
<tr>
<td>12. NewSUBARU</td>
<td>1.5</td>
<td>118.7</td>
<td>38</td>
<td>500</td>
<td>2x14m, 4x4m</td>
<td>Operation (2000)</td>
</tr>
<tr>
<td>13. SLS</td>
<td>2.4-2.7</td>
<td>288</td>
<td>5</td>
<td>400</td>
<td>3x11.7m, 3x7m, 6x4m</td>
<td>Operation (2001)</td>
</tr>
</tbody>
</table>
## 3rd Generation Light Sources in Operation (2)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm.rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. ANKA</td>
<td>2.5</td>
<td>110.4</td>
<td>50</td>
<td>200</td>
<td>4×5.6m, 4×2.2m</td>
<td>Operation (2002)</td>
</tr>
<tr>
<td>15. CLS</td>
<td>2.9</td>
<td>170.88</td>
<td>18.1</td>
<td>500</td>
<td>12×5.2m</td>
<td>Operation (2003)</td>
</tr>
<tr>
<td>16. SPEAR-3</td>
<td>3.0</td>
<td>234</td>
<td>12</td>
<td>500</td>
<td>2×7.6m, 4×4.8m, 12×3.1m</td>
<td>Operation (2004)</td>
</tr>
<tr>
<td>17. SAGA-LS</td>
<td>1.4</td>
<td>75.6</td>
<td>7.5</td>
<td>300</td>
<td>8×2.93m</td>
<td>Operation (2005)</td>
</tr>
<tr>
<td>18. ASP</td>
<td>3.0</td>
<td>216</td>
<td>7-16</td>
<td>200</td>
<td>14×5.4m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>19. DIAMOND</td>
<td>3.0</td>
<td>561.6</td>
<td>2.7</td>
<td>300</td>
<td>6×8m, 18×5m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>20. SOLEIL</td>
<td>2.75</td>
<td>354.1</td>
<td>3.74</td>
<td>500</td>
<td>4×12m, 12×7m, 8×3.8m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>21. SSRF</td>
<td>3.5</td>
<td>432</td>
<td>3.9</td>
<td>300</td>
<td>4×12m, 16×6.5 m</td>
<td>Operation (2009)</td>
</tr>
<tr>
<td>22. PETRA-III</td>
<td>6.0</td>
<td>2304</td>
<td>1.0</td>
<td>100</td>
<td>1×20m, 8×5m</td>
<td>Operation (2009)</td>
</tr>
<tr>
<td>23. ALBA</td>
<td>3.0</td>
<td>268.8</td>
<td>4.5</td>
<td>400</td>
<td>4×8m, 12×4.2m, 8×2.6m</td>
<td>Operation (2010)</td>
</tr>
<tr>
<td>24. NSLS-II</td>
<td>3.0</td>
<td>792</td>
<td>2.1</td>
<td>500</td>
<td>15×9.3m, 15×6.6m</td>
<td>Operation (2016)</td>
</tr>
</tbody>
</table>

The table above lists various light sources along with their energy, circumference, emittance, current, straight section sizes, and status of operation.
## New 3\textsuperscript{rd} Generation Light Sources in Commissioning, Construction and Plan

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm.rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>25. TPS</td>
<td>3.0</td>
<td>518.4</td>
<td>1.6</td>
<td>500</td>
<td>6×12m, 18×7m</td>
<td>Operation (2016)</td>
</tr>
<tr>
<td>26. MAX IV</td>
<td>3.0</td>
<td>528</td>
<td>0.32</td>
<td>500</td>
<td>19×4.6m, 40×1.3m</td>
<td>Operation (2016)</td>
</tr>
<tr>
<td>27. Solaris (Poland)</td>
<td>1.5</td>
<td>96</td>
<td>6</td>
<td>500</td>
<td>12×3.5m</td>
<td>Commi.&amp;Oper.</td>
</tr>
<tr>
<td>28. Indus-2 (?)</td>
<td>2.5</td>
<td>172.5</td>
<td>58</td>
<td>300</td>
<td>8×4.5m</td>
<td>Commi.&amp;Oper.</td>
</tr>
<tr>
<td>29. SESAME</td>
<td>2.5</td>
<td>133.12</td>
<td>26</td>
<td>400</td>
<td>8×4.44m, 8×2.38m</td>
<td>Construction</td>
</tr>
<tr>
<td>30. Sirius</td>
<td>3.0</td>
<td>518</td>
<td>0.28</td>
<td>500</td>
<td>10×7m, 10×6m</td>
<td>Construction</td>
</tr>
<tr>
<td>31. CANDLE</td>
<td>3.0</td>
<td>216</td>
<td>8.4</td>
<td>350</td>
<td>16×4.8m</td>
<td>Planned</td>
</tr>
<tr>
<td>32. ILSF (IPAC14)</td>
<td>3.0</td>
<td>528</td>
<td>0.417</td>
<td>400</td>
<td>20×5.11m</td>
<td>Planned</td>
</tr>
<tr>
<td>33. SLiT-J (SRI 2012)</td>
<td>3.0</td>
<td>~300</td>
<td>1.8</td>
<td>300</td>
<td>12×4m</td>
<td>Planned</td>
</tr>
<tr>
<td>34. BAPS</td>
<td>6.0</td>
<td>~1295</td>
<td>~0.06</td>
<td>200</td>
<td>48×6m</td>
<td>Planned</td>
</tr>
</tbody>
</table>
SR circumference and beam emittance

TPS is designed to produce electron beams with emphasis on small emittance and great brilliance, stability and reliability.

Emittance vs. Circumference

Z.T. Zhao, SSRF
Taiwan Light Source
TLS accelerator layout and key milestones

- The 1st 3rd G light source in Asia (1993)
- The 2nd LS using SRF cavity (2005)
- The 3rd LS full time top-up injection (2005)
- The most densely-packed SR ring with the highest number of superconducting IDs!

- Commission in Apr. & open to users in Oct. 1993
- 1.3 to 1.5 GeV ramping in operation in 1996
- 240 mA operation beam current in 1996
- Booster full energy injection in 2000
- Sc. wavelength shifter in operation in 2002
- Cryogenic system & SW6 available in 2004
- SRF cavity in operation in Feb. 2005
- Top-up injection implemented in Oct. 2005
- 1st IASW installed in 2006 & 2nd IASW in 2009
- 360 mA top-up & 3rd IASW in 2010
The Largest Cryo-plants (2x460W) in Taiwan

Cryo. Sys. Operation Cost
Maintenance (cryogenic system): 1,357 kNT
Safety/Inspection: 395 kNT
Maintenance (utility): 195 kNT
Electricity (335 kW/350days): 7,035 kNT.

Total: 8,982 kNT
**Superconducting RF (SRF) project**

**Goals:**
- Increase the stored beam current and photon flux
- Eliminate beam instabilities by higher-order-modes (HOMs) free cavities
- Reduce the number of RF transmitters and cavities
- Extra space for ID in straight
- LHe cryogenic system to TLS
Superconducting Insertion Devices

Superconducting Wavelength Shifter (6 T, SWLS) at injection section

Superconducting Wiggler (3.2T, SW6) at downstream of SRF straight section
Statistics of TLS operation

More than 5,000 hrs. users time annually with availability in 96~99%.

Delivered: 5,256 hrs.; Availability: 98.67%; MTBF*: 84.56 hrs.

* MTBF: Mean Time Between Failures
TLS Operation Statistics

Number of experiments and user-runs

Beamlines in TLS and SPring-8

Brilliance of TLS IDs
Distribution of International Users (199 institutes)

- **USA**: 29
- **Japan**: 31
- **China (Include Hong Kong)**: 14
- **Korea**: 18
- **Germany**: 14
- **Poland**: 2
- **Switzerland**: 1
- **Croatia**: 1
- **India**: 7
- **Thailand**: 7
- **Malaysia**: 1
- **Singapore**: 6
- **Australia**: 25
- **New Zealand**: 2
- **Canada**: 6
- **Mexico**: 1
- **Costa Rica**: 1
- **Saudi Arabia**: 1
- **Netherlands**: 4
- **UK**: 5
- **France**: 11
- **Spain**: 1
- **Italy**: 6
- **Sweden**: 1
- **Russia**: 2
- **China**: 1
- **Japan**: 31
- **Korea**: 18
- **USA**: 29
- **Canada**: 6
- **Mexico**: 1
- **Costa Rica**: 1
- **Saudi Arabia**: 1
- **Netherlands**: 4
- **UK**: 5
- **France**: 11
- **Spain**: 1
- **Italy**: 6
- **Sweden**: 1
- **Russia**: 2
- **China**: 1
Taiwan Photon Source
Major parameters of Taiwan Photon Source

<table>
<thead>
<tr>
<th>Energy</th>
<th>3 GeV (maximum 3.3 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>500 mA at 3 GeV (Top-up injection)</td>
</tr>
<tr>
<td>SR circumference</td>
<td>518.4 m (h = 864 = 2^5·3^3, dia.= 165.0 m)</td>
</tr>
<tr>
<td>BR circumference</td>
<td>496.8 m (h = 828 = 2^2·3^2·23, dia.= 158.1 m)</td>
</tr>
<tr>
<td>Lattice</td>
<td>24-cell DBA</td>
</tr>
</tbody>
</table>
| Straight sections | 12 m x 6 (σ_v = 12 μm, σ_h = 160 μm)  
7 m x 18 (σ_v = 5 μm, σ_h = 120 μm) |

| Storage Ring Circumference (m) | 518.4 |
| Energy (GeV) | 3.0 |
| Beam current (mA) | 500 |
| Natural emittance (nm-rad) | 1.6 |
| Straight sections (m) | 12 (x6) + 7 (x18) |
| Radiofrequency (MHz) | 499.654 |
| Harmonic number | 864 |
| RF voltage (MV) | 3.5 |
| Energy loss per turn (dipole) (keV) | 852.7 |
| Betatron tune | 26.18 / 13.28 |
| Momentum compaction (α_1, α_2) | 2.4x10^{-4}, 2.1x10^{-3} |
| Natural energy spread | 8.86x10^{-4} |
| Damping time (ms) | 12.20 / 12.17 / 6.08 |
| Natural chromaticity | -75 / -26 |
| Synchrotron tune | 0.00609 |
| Bunch length (mm) | 2.86 |
Comparison of brightness between TLS and TPS

The X-ray spectrum (photon energy $8 \text{ keV} \sim 70 \text{ keV}$): 
the brightness of bending magnet $>10^2$. 
the brightness of IDs: $4\sim6$ orders of mag.
Milestone for Major Acc. Components

- Linac passed the acceptance and under operation since July 2011.
- Two sets of 300 kW transmitters completed acceptance tests in Feb. 2011.
- The 700 W LHe system completed acceptance in Nov. 2012.
- BPM electronics passed acceptance in July 2012.
- The module #1 and #2 of SRF cavity passed 300 kW high-power test in 2013.
- Completed installation of accelerators inside the shielding wall in August, 2014.
- Test of booster hardware integration was completed on Dec. 11, 2014.
- Full energy inject to storage ring with stored beam up to 5 mA, on Dec. 31, 2014.
- Optimization the performance of booster and storage ring during the Q1 of 2015. (stored current > 100 mA, booster to storage ring efficiency > 75%, measured all beam optics parameters with installed Petra cavities.)
- Installation of 10 insertion devices and 2 superconducting SRF cavities in Q2 and Q3 of 2015.
- Re-start the TPS accelerators and commissioning of 6 beamlines, 10 IDs and 2 SRF cavities in September of 2015. (stored current > 520 mA with DMB lattice)
Process welding of BC in Chu-Tung

Upper and lower leaf of BC

Welding pumping port

Alignment for the bending chamber

Bending chamber in auto-welding stage
Assembly of vacuum system and storage in Chu-Tung
Field qualification of SR and BR magnets

**SR dipole magnet**

**Field dispersion**

- **SR-DM:**
  - The mean value of $b_0L$ is -1.3201 Tm.
  - The standard deviation of $b_0L$ is 0.0009 Tm (0.07%).
  - The $b_0L$ dispersion is better than 0.16%. (85.4% of magnets are better than ±0.1%).

**BR-dipole magnet**

**Field dispersion**

- **BR-BH:**
  - The mean value of BH and BD is -0.6586 Tm and -1.3173 Tm with 987A charged respectively.
  - The standard deviation of BH and BD is 0.0007 Tm (0.11%) and 0.0019 Tm (0.14%) with 987A charged, respectively.

**SR quadrupole/sextupole magnet**

**Field dispersion**

- **SR-QM:**
  - The $b_1L$ of Short-QM and Long-QM are better than ±0.4%.
  - The $b_1L$ dispersion of 95.4% of SM are better than ±0.5%.
  - The integral field strength of QM/SM magnet will be fine-tuned with an independent power supply.

**BR-quadrupole magnet**

**Field dispersion**

- **BR-QP:**
  - The $b_1L$ dispersion of BR-QP is better than ±0.4%.
  - The $b_1L$ dispersion of BR-QF is better than ±0.5%.
Integration of magnets, vacuum chambers and girders

Installation of a 14 m vacuum cell on the girders.

Anchor the 14 m vacuum cell on the girders.

Assembling of a 14 m vacuum cell with magnets in the tunnel.

Installation of the vacuum system for the 1/12 section of booster.
Commissioning of Accelerators
Booster commissioning


Beam Current (peak): 0.16 mA at 3 GeV

Beam profile measured by synchrotron light monitor
Storage Ring Commissioning at 1.5 GeV

- Dec. 24, extracted 3 GeV beam but DC septum leakage field affected booster
- Dec. 26, 1.5 GeV beam injected, multi-turn with one H corrector
- Dec. 27, stored beam with sextupoles and RF on. RF, sextupole, and quad scan
- Dec. 29, accumulated beam with kicker scan
The first synchrotron light from TPS storage ring at 3GeV, 1mA

*December 31, 2014*
BR and SR commissioning and optimization

On 15 Jan. 2015

TPS Storage Ring Beam Intensity Monitor

Beam Current 100.674 mA
Beam Lifetime 100.3 min

Beam Current History

BR inj. with single bunch

注射中電流增加光源亮度增強
Before Optics Correction
( Beta function )

Before Optics Correction
( Dispersion function )

After Optics Correction
( Beta function iteration 3 )

After Optics Correction
( Dispersion function iteration 3 )

Blue line is LOCO fitting result

TPS commissioning  C.C. Kuo, IPAC’15
**Coupling Ratio and Emittance**

**MOPTY074**

- **Visible Optics**
- **CdWO₄ 0.2mm Converter**
- **Pinhole**
- **H: 50 µm**
- **V: 50 µm**

**Source point in Dipole #2**

<table>
<thead>
<tr>
<th>Pinhole camera</th>
<th>without skew quad</th>
<th>with skew quad</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. Emittance (nm.rad)</td>
<td>1.55</td>
<td>1.64</td>
</tr>
<tr>
<td>V. Emittance (pm.rad)</td>
<td>25.6 ±3</td>
<td>15.7 ±3</td>
</tr>
<tr>
<td>Emittance ratio (%)</td>
<td>1.65</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated Emittance ratio (%)</th>
<th>without skew quad</th>
<th>with skew quad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betatron Coupling</td>
<td>0.170</td>
<td>0.001</td>
</tr>
<tr>
<td>Vertical Dispersion</td>
<td>0.156</td>
<td>0.038</td>
</tr>
</tbody>
</table>

**Design Natural Emittance** $\varepsilon_{x0} = 1.6$ nm.rad

**Discrepancy:** Orbit noise, instabilities, resolution in instrument
Vacuum Conditioning

- At the end of phase-I commissioning, dynamic pressure reached $1.17 \times 10^{-7}$ Pa at 100 mA after 35 A.h beam dose
- Lifetime at 100 mA reached more than 6 hours
Beam Current

- Beam current reached 100 mA in multi-bunch mode
- Single-bunch recorded 12 mA
- ~ 0.4 mA/s accumulation rate in multi-bunch mode

Single bunch impurity (TCSPC) near $10^{-5}$ with rf knock-out in storage ring

MOPTY074
Installation of IDs, SRF cavities and Other Hardware
Double minimum-\(\beta_y\) lattice

**Momentum acceptance & Touschek lifetime**

**Bruck’s formula:**

\[ T_{\text{p}} = \frac{1.627102 \times 10^{-9}}{400 \text{ mA} / 800 \text{ bunches}} \]

Ex: \(1.621212 \times 10^{-9}\)
Ey: \(1.627102 \times 10^{-11}\)

\[ T = 16.94 \quad \text{Tp:10.87 / Tn:38.38 (hrs)} \]

Bunch current: 400 mA / 800 bunches
Bunch length: 2.86 mm
IDs at Straight Section of Double Mini-βy Lattice

Fast corrector
Corrector in vertical dir
Corrector in hor. dir.
Quadrupole triplets to create double minimum

Two collinear EPU48

Phase correctors

Two collinear IU22
Elliptical Polarized Undulators at long straight

EPU48
3.2m & 3.2m

\[ \text{RMS Phase Error (Degree)} \]

\[ \text{Gap 13 mm} \]

\[ \text{Related flux density (%)} \]

\[ \text{Phase mode (\( \pi \))} \]
In-vacuum undulators at 12 m straight
Capacity: 890W @4.5K or 239 liter/hour
Stability: +/-2 mbar at compressor inlet & +/-3 mbar at Dewar
Major RF sub-system

Performance of SRF modules 2.4 MV: $Q_0 > 5 \times 10^8$

- Installed 5-cells Petra cavities for phase-I

- SRF cavity installed in tunnel
Instabilities in transverse and longitudinal directions

- Transverse instability suppressed by adequate chromaticity setting and by bunch-by-bunch feedbacks (BBF) in vertical planes.
- Stabilized beam up to 500 mA without problem.
- No longitudinal instability observed.

Vertical BBF “OFF”

Vertical feedback “ON”

Beam profile image @ 100 mA

Longitudinal Stable Beam @ 480 mA

480 mA Longitudinal Stable Beam (June 22, 2016)
IU22-23 Measured on 2015/11/18

- **W/O feedback**
- **Feedforward**
- **Slow orbit FB only**
- **Feedforward + slow orbit FB**

**ID Gap**

**Hor. Pos (µm)**

**Ver. Pos (µm)**

**Time (sec)**
Performance of fast orbit feedback system

The measured bandwidth of FOFB. Horizontal around 250Hz and vertical around 300 Hz.

Beam Spectrum (no booster power supply ramping)
• Replace the B-Chamber of Cell#2, curing abnormal vacuum burst as I >230 mA. Top-up injection with stored current 300 mA on 12/6/2015.
• Stored beam current exceed design goal 500 mA, I > 520 mA, on Dec. 12, 2015.
• Thanks to members of Machine Advisory Committee, consultants and technical supports from various laboratories. With these strong supports around the world, we made the Taiwan Photon Source possible. This shining photon source will serve scientific communities worldwide for the next 30 years.
Longitudinal beam profile of TPS booster ring during ramping

- 13.7ms: 0.15GeV
- 20ms: 0.19GeV
- 30ms: 0.31GeV
- 40ms: 0.48GeV
- 50ms: 0.68GeV
- 60ms: 0.91GeV
- 70ms: 1.16GeV
- 80ms: 1.43GeV
- 90ms: 1.71GeV
- 100ms: 1.97GeV
- 110ms: 2.22GeV
- 120ms: 2.45GeV
- 130ms: 2.65GeV
- 140ms: 2.80GeV
- 150ms: 2.91GeV
- 160ms: 2.97GeV
Robinson Damping Wiggler (RDW) on TPS

- Robinson wiggler is made of four combined function magnets in one period so that the Product of dipole and quadruple field strength is negative.

IU22 Spectrum with/without RDW

<table>
<thead>
<tr>
<th>Harmonic number</th>
<th>Brilliance without MRW photon s⁻¹ (0.1% BW mm² mrad⁻¹)</th>
<th>Brilliance with MRW photon s⁻¹ (0.1% BW mm² mrad⁻¹)</th>
<th>Increasing gain ratio of IU22</th>
</tr>
</thead>
<tbody>
<tr>
<td>IU22 with 0.74 T</td>
<td>3.38 x 10¹⁰</td>
<td>4.22 x 10¹⁰</td>
<td>0.25</td>
</tr>
<tr>
<td>IU22 with 0.92 T</td>
<td>3.11 x 10¹⁰</td>
<td>2.62 x 10¹⁰</td>
<td>0.177</td>
</tr>
</tbody>
</table>

Radiation Spectrum from RDW

- MRW radiation power 9.1 KW @ 500mA.
- Instead of the general wiggler.

<table>
<thead>
<tr>
<th>IDs</th>
<th>Dipole field (T)</th>
<th>Quadrupole field (T m⁻¹)</th>
<th>Period number N</th>
<th>Total length (m)</th>
<th>Operating mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robinson wiggler</td>
<td>0.82</td>
<td>40</td>
<td>16</td>
<td>4.8</td>
<td>Low-dispersion &amp; Low-emittance</td>
</tr>
<tr>
<td>Damping wiggler</td>
<td>2</td>
<td>0</td>
<td>50</td>
<td>5.0</td>
<td>Achromat</td>
</tr>
</tbody>
</table>

Impact of RDW on emittance and energy spread

Schematic diagram of Robinson wiggler

Changing damping partition in horizontal/energy.
Short bunch by low-alpha lattice

- Emittance = 32.5 nm-rad
  \[ \alpha = \alpha_1 + \alpha_2 \delta + \alpha_3 \delta^2 \]
  \[ (\alpha_1, \alpha_2, \alpha_3) = (1E-6, -6.74E-5, -2.47E-2) \]
- Bunch length \( \sim 0.6 \) ps
  (3.5 MV rf)
- Integrated sextupole < 6.0 m\(^{-2}\)

TPS low alpha, low emittance

- Emittance = 3.2 nm-rad,
  \[ (\alpha_1, \alpha_2, \alpha_3) = (2.62E-5, 1.19E-4, -1.19E-2) \]
- Bunch length \( \sim 3.1 \) ps
  (3.5 MV rf)
- SF \( \sim 9.0 \) m\(^{-2}\)

Short bunch by laser slicing

modulator:
- W250
- 0.9T
- 4.5 m
Laser:
- 800 nm
- 1-10 kHz
- 3.5 mJ
- Pulse < 35 fs

Beam Separation

Summary of Estimation on Pulse Length

<table>
<thead>
<tr>
<th>Modulator position</th>
<th>Radiator position</th>
<th>Laser (fsec)</th>
<th>Laser slippage (fsec)</th>
<th>Betatron dependence (fsec)</th>
<th>Dispersion dependence (fsec)</th>
<th>Slice bunch at radiator (fsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>R1</td>
<td>50</td>
<td>48</td>
<td>1.36</td>
<td>30.0</td>
<td>75.54</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>50</td>
<td>48</td>
<td>1.88</td>
<td>44.1</td>
<td>82.17</td>
</tr>
<tr>
<td>A</td>
<td>R1</td>
<td>50</td>
<td>48</td>
<td>1.35</td>
<td>27.9</td>
<td>74.73</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>50</td>
<td>48</td>
<td>1.88</td>
<td>44.1</td>
<td>82.17</td>
</tr>
<tr>
<td>B</td>
<td>R1</td>
<td>50</td>
<td>48</td>
<td>1.35</td>
<td>30.9</td>
<td>70.99</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>50</td>
<td>48</td>
<td>1.90</td>
<td>46.9</td>
<td>83.71</td>
</tr>
</tbody>
</table>
TPS Beamline construction plan

- Based on the allocated budget, there will be three phases of the construction plan to install 25 beamlines.

19 beam ports available for industrial and international collaboration.
Design of first-phase beamlines

(μ-focus macromolecular crystallography)

(High resolution Inelastic soft-x-ray scattering)

(Sub-μ soft x-ray photoelectron & fluorescence emission)

(Soft matter small angle scattering)

(Sub-μ x-ray diffraction)

(Nano-probe x-ray diffraction)

(Multi-purpose coherence x-ray scattering)
Development of Taiwan Synchrotron Facilities

A new 3 GeV ring to link the energy gap and for the future x-ray sciences in Taiwan.

Reduce TLS energy for IR and VUV sciences

THz and UV FEL

SPring-8 Compact XFEL SASE Source (SCSS)
High-brightness photocathode gun and THz FEL project

~30MeV; ~50 pC
Application-II: FEL Driver Linac

![Diagram of FEL Driver Linac system](image)

- **Photo-cathode rf gun system**
  - \( \sim 75 \text{ MeV} \)
- **3 m linac section**
- **5.2 m linac section**
  - **Bunch compressor**
  - **SLED**
  - **35 MW TH2100 klystron**
  - **Scandinova solid-state HV modulator**

**Table 2**: Linac simulation result for the VUV Baseline case.

<table>
<thead>
<tr>
<th></th>
<th>( L_0 ) entrance</th>
<th>( L_0 ) exit</th>
<th>( L_1 ) exit</th>
<th>( L_2 ) exit</th>
<th>( L_3 ) exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS bunch time duration ( \sigma_t ) [fs]</td>
<td>2247</td>
<td>2294</td>
<td>2290</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Slice peak current ( I_p ) [A]</td>
<td>12.0</td>
<td>11.7</td>
<td>14</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Beam energy ( E_{avg} ) [MeV]</td>
<td>3.54</td>
<td>93.08</td>
<td>138</td>
<td>231</td>
<td>325</td>
</tr>
<tr>
<td>Slice beam energy rms spread ( \sigma_{\gamma}/\gamma_{avg} ) [%]</td>
<td>0.016</td>
<td>0.002</td>
<td>0.001</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Slice rms ( x )-emittance ( \epsilon_{nx} ) [( \mu )m]</td>
<td>0.59</td>
<td>0.56</td>
<td>0.56</td>
<td>0.74</td>
<td>0.74</td>
</tr>
<tr>
<td>Slice rms ( y )-emittance ( \epsilon_{ny} ) [( \mu )m]</td>
<td>0.59</td>
<td>0.56</td>
<td>0.56</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>
Summary

- **Taiwan Light Source**
  - 1.5 GeV beam energy provides 5000~5500 hrs with 360 mA top-up to users. Photon energy can be up to ~30 keV by SC wigglers.
  - Beamlines in SPring-8 provide hard x-ray to users.
  - From MOST’s point of view, the long term-strategy about TLS fate needs to be planned with the operation of TPS.
  - Coherent Transition Radiation, THz and UV FEL will be tested with photocathode gun.

- **Taiwan Photon Source**
  - Ten insertion devices and two SRF cavities installed in Q2 and Q3, 2015.
  - Double mini-βγ lattice and phase-I BLs commissioning since Q4, 2015.
  - 3 GeV storage ring top-up injection with 480 mA.
  - Start normal operation in September 2016.
  - Single bunch and hybrid operation modes were tested with beamline.
  - Robinson damping wiggler under investigation, potentially can reduce emittance by ~50% with increase of energy spread.
Acknowledgement

- Thanks to the TPS team for their hardworking and devotion to the project, and efforts made to accomplish the system integration and commissioning successfully in very short period.

- We also very appreciate to the helps from all experts worldwide for the achievement in this community.
Taiwan Photon Source (TPS)

Thank you for your attention!