MAX IV Design: Pushing the Envelope
Our outlook

• 3rd gen sources will be the SR workhorses for the foreseeable future
• Modern sources can be developed closer to the diffraction limit (New IDs, smaller emittance)
• Short-pulse (coherent as well as spontaneous) sources will complement rings and bring added value
Max IV strategy

3 and 1.5 GeV rings
+ 700 MeV MAX III

Coherent radiator, SPPS
3 GeV warm linac

• Linac for short pulses, rings for stability + mean brilliance
• 2 new rings + MAX III => broad spectral range, low cost
• Compact magnet technology => compact, exact lattice, small emittance and possibility to stack rings

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New Ring Characteristics

Many small "damping-ring" magnets (integrated dipole/quadrupole/sextupole) => small emittance, small apertures, good dynamic aperture

Apertures small, but so are $\beta$ and offmomentum functions functions => large admittance, energy acceptance

Apertures anyhow restricted by small gap IDs
Small apertures => special vac chambers

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# Ring main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy (GeV)</td>
<td>3</td>
<td>1.5</td>
<td>0.7 (MAX III)</td>
</tr>
<tr>
<td>Circumference (m)</td>
<td>287</td>
<td>287</td>
<td>36</td>
</tr>
<tr>
<td>No of straight sections</td>
<td>12</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Straight sect length (m)</td>
<td>4.6</td>
<td>4.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Circulating current (A)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Emittance (nmrad)</td>
<td>0.86*</td>
<td>0.34</td>
<td>13</td>
</tr>
<tr>
<td>RF (MHz)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Quadrupole bore radius (mm)</td>
<td>12</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>Dipole full gap (mm)</td>
<td>24</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Photon energy (und)</td>
<td>5eV-40 keV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Including 2 damping wigglers*
Linear Lattice

- Multiple Bend Achromat
- High gradient in the dipole magnet

\[ g \sim 10 \text{ T/m} \]
\[ \varepsilon \sim \gamma^2/N^3 \]
Magnet technology (MAX III)

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Matching Cell Dipole with Soft End

The synchrotron radiation power hitting the cold bores is restricted by the introduction of soft end magnet preceding the SC ID.

$\text{SR Power } \sim \frac{1}{\rho}$

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## Magnet parameters, New Rings

<table>
<thead>
<tr>
<th></th>
<th>Dipole</th>
<th>Quad</th>
<th>Sext</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>0.9</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Dipole field (T)</td>
<td>0.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gradient (T/m)</td>
<td>-9.3</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Sextupol (T/m^2)</td>
<td>0</td>
<td>744</td>
<td>2000</td>
</tr>
<tr>
<td>Octupole (T/m^3)</td>
<td>0</td>
<td>5004</td>
<td>0</td>
</tr>
</tbody>
</table>

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Work in progress:

Dipole ends with strong roll-off $\Rightarrow$

- No discrete sextupoles needed

- Lower dipol end fields, emittance reduction to 0.6 nm rad

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Impact of Octupole field

Sext: ON & Oct: OFF

Sext: ON & Oct: ON

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Effect of ID’s

<table>
<thead>
<tr>
<th></th>
<th>K-value</th>
<th>λ (mm)</th>
<th>No. of Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC Undulator</td>
<td>2.2</td>
<td>14</td>
<td>200</td>
</tr>
<tr>
<td>SC Wiggler</td>
<td>20</td>
<td>60</td>
<td>35</td>
</tr>
</tbody>
</table>

BetaX = 7 m
BetaY = 1.8 m

BARE LATTICE

6 UNDULATORS & 2 WIGGLERS

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Dynamic Aperture for off-momentum particles

BetaX = 7m
BetaY = 1.8m

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Injection aperture needed

- 2 mm Lambertson septum (effective thickness)
- $\sigma_{\text{inj}} < 0.1 \text{ mm}$
- $\sigma_{\text{stored}} < 0.1 \text{ mm}$

Injection aperture $\leq 3 \text{ mm}$
The minimum admittance needed is defined by elastic scattering and injection.

<table>
<thead>
<tr>
<th>At the middle of SS.</th>
<th>Stable</th>
<th>Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 GeV</td>
<td>Horizontal</td>
<td>57.14×10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>55.55×10⁻⁶</td>
</tr>
<tr>
<td>1.5 GeV</td>
<td>Horizontal</td>
<td>57.14×10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>55.55×10⁻⁶</td>
</tr>
</tbody>
</table>
NEG-coated test dipole vac chamber (in MAX II)
Brilliance for EPUs on MAX IV

- 1.98 m long 69.1 mm period EPU with 57 poles on the 0.7 GeV ring
- 4 m long EPU with 41 mm period and 193 poles on the 1.5 GeV ring
- 4 m long EPU with 35 mm period and 226 poles on the 3 GeV ring.

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Beam 1/e lifetime (h) @ 0.5 A
& 100 MHz +5th harmonic Landau Cavity

<table>
<thead>
<tr>
<th>Process</th>
<th>3 GeV</th>
<th>1.5 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touschek</td>
<td>10.5</td>
<td>89</td>
</tr>
<tr>
<td>El scattering</td>
<td>71.5</td>
<td>132</td>
</tr>
<tr>
<td>Bremsstrahlung</td>
<td>64.6</td>
<td>60.8</td>
</tr>
<tr>
<td>Total</td>
<td>8.4</td>
<td>24.5</td>
</tr>
</tbody>
</table>

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Linac Injector

• 17 stations, 200 MeV each (Redundancy)
• Duty-factor=0.001 + Variable pulse length=> 220 Hz ≤ Rep rate ≤ 1 kHz
• Solid state modulators: Variable pulse length, high stability, low EM noise
• Electron source: according to SCSS
• SPPS in phase 1
• FEL driver in phase 2

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Linac Module (17 of them)

1 35 MW klystron
1 Pair of SLED cavities
2 pcs 5 m linac structures

20 MV/m max gradient
Max dutyfactor 0.001
Solid state modulators
=>variable pulse length

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<table>
<thead>
<tr>
<th>RF pulse length (μs)</th>
<th>Rape rate (Hz)</th>
<th>Max energy (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 (SLED)</td>
<td>220</td>
<td>3.4</td>
</tr>
<tr>
<td>3.0 (SLED)</td>
<td>330</td>
<td>3.0</td>
</tr>
<tr>
<td>1.0 (no SLED)</td>
<td>1000</td>
<td>1.9 (FEL)</td>
</tr>
</tbody>
</table>

3.4 MW from the wall

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**MAX IV Linac**

3 GeV  
1 nC Charge  
100 fs bunch length  
0.1 % $\Delta E/E$

**Wiggler**  
Length 10 m  
$PL = 5$ cm  
Field = 2 T

Flux density / pulse for 10 keV photons 30 m from source

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MAX IV Linac

3 GeV
1 nC Charge
100 fs bunch length
0.1 % \( \Delta E/E \)
3\times10^{-10} \text{ Emittance}

**Undulator**
Length 10 m
PL = 1.9 cm
K = 0.5 - 2.2

Peak Brill. = 1.1\times10^{26}

Total flux of photons / pulse through slits 1\times1 mm^2 30 m from source

![Graph showing peak brilliance vs. photon energy](image-url)

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Thanks for your attention!
Injection rates

- 5 h life-time, 1% beam current variation => 3 minutes between injections
- Stored charge = 0.5 μC => 5 nC at each injection
- Fill 5 consecutive bunches with 1 nC in each
Legend

• 2002: Starting looking at “damping ring” lattices.
• 2004: CDR application awarded (Wallenberg Foundation).
• Nov 2005: Machine evaluated by the Swedish Research Council (VR).
• Dec 2006: Scientific Case evaluated by VR. (Phase 1).
• 2007: VR funds Detailed Design Study.
• June 2007: Letter from VR to Dep of Education: VR recommends the MAX IV project warmly and recommends the Department to find ways to finance MAX IV. (Phase 1).

For ev questions

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Damping RW Instability

- Small gap IDs introduce high deflecting RW impedance($1/b^3$).

- Slightly positive chromaticity shifts the beam spectrum toward positive frequencies which acts damping.

*Vertical damping time = 4.515 msec*

**100 MHz vs 100 MHz+5th harmonic cav.**

**500 MHz vs 500 MHz+3rd harmonic cav.**

Chromatic Freq. $\omega_z = 8.8\text{GHz}$

with

$\xi_v = +1$

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100 MHz RF system

- Five RF generator stations
- Each station consists of two cavities and two 60 kW tetrode amplifiers
- The RF power from the two amplifiers are combined in a switch-less hybrid combiner
- A 3db hybrid divides the power to the cavities
100 MHz cavity

E-field lines of the high order mode at 456 MHz

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