A New Photoemission Branch Line at SSRL
Beam Line 5

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**Present Status of ARPES System at SSRL**

- **ARPES End Station on NIM Branchline**
  - **Smiley Advantages:**
    - high resolution; low energy; high order suppression; good beam stability
  - **SADF Disadvantages:**
    - limited photon energy range; no polarization control; large beam size

- **Dedicated for High Resolution ARPES**
  - High temperature superconductors
  - Complex oxides
  - Novel low dimensional systems
  - Materials in delicate balance
  - Topological insulators
  - ....

- **Planned Upgrade**
  - New refocusing mirror
  - New undulator PGM branchline
New Undulator Branchline

• **Significantly Improved Performance**
  - Wider photon energy
  - Variable polarizations
  - Smaller beam size

• **Complementary to NIM Branchline**
  - NIM – ultrahigh resolution in low energy
  - PGM – higher energy, higher flux, flexibility
    - spin-resolved ARPES
    - PLD-MBE thin film growth

• **Project Milestones**
  - First proposal submitted in Feb 2005
  - Resubmitted in 2006 & 2009
  - Funding received in Sept 2009
  - EPU procured in Sept 2010
  - CDR for optical design completed in Dec 2010
  - Monochromator and gratings procured in Sept 2011
  - Installation of new EPU during 2012 shutdown
  - Installation of PGM branchline after 2012 shutdown
  - Commission starts early 2013
Design Goal

- Energy range between 20 and 200 eV
- RP> 25,000 in the high resolution mode
- RP> 10,000 in the high flux mode
- At RP 10,000 flux > 10^{12} photons/s
- Spot size < 100 × 50 μm^2 (hor. × ver.)
- Higher orders should be minimized
- Linear horizontal, vertical, and circular polarization
- Available space is 31 m from the ID center
Critical Decision I: Undulator

• Existing Undulator
  - Planar, 10-pd x 183mm, 18.5mm gap $\Rightarrow$ 7 eV

• Single vs. Twin Device

• New Undulator
  - APPLE II, 15-pd x 140mm, 13mm gap $\Rightarrow$ 7 eV
  - High K $\Rightarrow$ strong high orders, high heat load
Critical Decision I: Undulator

- **Existing Undulator**
  - Planar, 10-pd x 183mm, 18.5mm gap ⇒ 7 eV
- **Single vs. Twin Device**
- **New Undulator**
  - APPLE II, 15-pd x 140mm, 13mm gap ⇒ 7 eV
  - High K ⇒ strong high orders, high heat load
Critical Decision II: Monochromator

CPGM

FVLSPGM

SLS - SIS

CLS - REIXS

BESSY – UE112

PETRA III – P04
Resolution Terms

Grating Equation:
\[ n k \lambda = \sin \alpha + \sin \beta \]

Resolution Entrance:
\[ n k \delta \lambda_{en} = \cos \alpha \delta \alpha = \cos \alpha s_{en}/r_1 \]

Resolution Exit:
\[ n k \delta \lambda_{ex} = \cos \beta \delta \beta = \cos \beta s_{ex}/r_2 \]

Slope error \( \epsilon \)
\[ \sin \alpha + \sin \beta = 2 \cos \theta \sin \Delta \]
\[ \theta = \frac{\alpha + \beta}{2}; \quad \Delta = \frac{\alpha - \beta}{2} \]

\[ n k \delta \lambda_{err} = \delta(2 \cos \theta \sin(\Delta + \epsilon)) \approx 2\epsilon \cos \theta \cos \Delta \]
\[ n k \delta \lambda_{err} \approx \epsilon(\cos \alpha + \cos \beta) \]

Aberrations: Coma, spherical, astigmatic coma...
\[ k(w) = k_0 (1 + 2b_2 w + 3b_3 w^2 + \ldots) \]

\[ f_{20} = \frac{\cos^2 \alpha}{d \text{SoGr}} + \frac{\cos^2 \beta}{d \text{Gr Ex}} - 2b_2 n k_0 \lambda \]

\[ f_{30} = \sin \alpha \frac{\cos^2 \alpha}{d \text{SoGr}^2} + \sin \beta \frac{\cos^2 \beta}{d \text{Gr Ex}^2} - 2b_3 n k_0 \lambda. \]

PM: \[ \gamma = 0.5(\alpha - \beta) \]

\[ n k \lambda = \sin \alpha + \sin \beta \quad \& \quad f_{20} = 0 \]

\[ c = \frac{\cos \beta}{\cos \alpha} \]


## Critical Decision II: Monochromator

<table>
<thead>
<tr>
<th></th>
<th>FVLSPGM</th>
<th>CPGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanics</td>
<td>SX-700 type</td>
<td>SX-700 type</td>
</tr>
<tr>
<td>Fixed exit slit</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>c value</td>
<td>Fixed, Some order suppression</td>
<td>Variable, Slightly better order suppression, Resolution vs Flux</td>
</tr>
<tr>
<td>Optical components</td>
<td>Can use only planes in between source and slit</td>
<td>+toroid and cylinder, More reflections, Cannot achieve $10^5$ at 1 keV</td>
</tr>
<tr>
<td>Large horizontal</td>
<td>With single mirror</td>
<td>Two demagnifying mirrors.</td>
</tr>
<tr>
<td>Demagnification.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct Heat Induced</td>
<td>Yes, variable focal length.</td>
<td>No</td>
</tr>
<tr>
<td>deformations M2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Critical Decision III: Entrance Slit

- Sunny
- Cloudy
Before Insulation

From 1-May-20-0000 to 13-Jun-1052 - right before insulation test

After Insulation

From 14-Jun-2010 17:53:50 to 30-Jun-2010 23:59:59 - right after insulation test

BL7: 7x reduction

BL13: x3.5x reduction

Critical Decision III: Entrance Slit

BL13: x3.5x reduction

BL7: 7x reduction
Ray Tracing: HRG1

20 eV, 20.0005 eV
$\sigma_x$: 3.4, $\sigma_y$: 0.01

50 eV, 50 eV + 1.3 meV
$\sigma_x$: 2.3, $\sigma_y$: 0.006

HRG1: 600 l/mm, c=4

Resolution (eV)

Photon Energy (eV)
Ray Tracing: Refocusing

Astigmatic coma corrected
Elliptical Toroid

Sample, 20 eV HFG, 10 µm slit
αx: 0.015, αy: 0.006

Sample, 50 eV HRG1, 10 µm slit
αx: 0.015, αy: 0.0033

\[ rm_2 = rs_2 = \frac{rm_1 \times rs_1}{2rm_1 - rs_1} \]

28.5:1.3 meridional horizontal
2.5:1.3 sagittal vertical
Mirror Coating and Reflectivity

- Best choice: C coated Si
  - High reflectivity
  - Suppress higher orders
- Other options: SiC or Si
- Use APPLE II to correct phase and s/p ratio
Grating Efficiency and Order Suppression

<table>
<thead>
<tr>
<th>Grating</th>
<th>c</th>
<th>Line Density $k_0$</th>
<th>Trapezoidal angle</th>
<th>Groove Depth</th>
<th>Groove Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFG</td>
<td>2.0</td>
<td>300 l/mm</td>
<td>28°</td>
<td>40 nm</td>
<td>2.4 μm</td>
</tr>
<tr>
<td>HRG1</td>
<td>4.0</td>
<td>600 l/mm</td>
<td>28°</td>
<td>75 nm</td>
<td>1.5 μm</td>
</tr>
<tr>
<td>HRG2</td>
<td>4.0</td>
<td>600 l/mm</td>
<td>28°</td>
<td>30 nm</td>
<td>1.5 μm</td>
</tr>
</tbody>
</table>

$E_1 \times R_1$

$E_1 \times R_1 + E_2 \times R_2 + E_3 \times R_3 + E_4 \times R_4$
Flux at Sample

- ID
- Band pass correction
- Grating efficiencies
- Reflectivity M0, M1, M2, M3
Large Angle Mono

- $\delta<12^\circ$, $\epsilon<17^\circ$
- $\delta<27^\circ$, $\epsilon<33.5^\circ$
- can use higher line density, small $c$
- higher order suppression
- beam walking behavior
Large Angle Mono - Grating Efficiency

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<th>Groove Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOSG</td>
<td>1.5</td>
<td>1200 l/mm</td>
<td>28°</td>
<td>23 nm</td>
<td>0.45 μm</td>
</tr>
<tr>
<td>HRG</td>
<td>3.0</td>
<td>1200 l/mm</td>
<td>28°</td>
<td>30 nm</td>
<td>0.65 μm</td>
</tr>
<tr>
<td>HRG2</td>
<td>4.0</td>
<td>600 l/mm</td>
<td>28°</td>
<td>30 nm</td>
<td>1.5 μm</td>
</tr>
</tbody>
</table>

$E_1 \times R_1$  
$E_1 \times R_1 + E_2 \times R_2 + E_3 \times R_3 + E_4 \times R_4$
Large Angle Mono – Resolution

$\delta < 12^\circ, \varepsilon < 17^\circ$

- HFG: 300 l/mm, c=2
  - Total
  - Source
  - 10 µm slit
  - Gr: 0.2 µrad
  - M2: 0.2 µrad

$\delta < 27^\circ, \varepsilon < 33.5^\circ$

- HOSG: 1200 l/mm, c=1.5
  - Total
  - Source
  - 10 µm slit
  - Gr: 0.2 µrad
  - M2: 0.2 µrad

- HRG1: 600 l/mm, c=4
  - Total
  - Source
  - 10 µm slit
  - Gr: 0.2 µrad
  - M2: 0.2 µrad

- HRG: 1200 l/mm, c=3
  - Total
  - Source
  - 10 µm slit
  - Gr: 0.2 µrad
  - M2: 0.2 µrad
Large Angle Mono – Grating Efficiency

\[ \delta < 12^\circ, \varepsilon < 17^\circ \]

\[ \delta < 27^\circ, \varepsilon < 33.5^\circ \]
High Order Suppression
Flux Comparison

Flux (photons/s)

Photon Energy (eV)

RP: 10000

s p

HFG
HOSG
HRG
HRG2
HRG1
Flux Comparison

RP: 30000

s, p

HRG1
HRG2
HRG
Flux Comparison

![Graph showing flux comparison of different energy levels. The x-axis represents photon energy in eV, and the y-axis represents flux (photons/s). The graph includes lines for different energy levels and labels for specific regions.](image-url)
Heat Load Compensation

Ideal +Heat +Heat+change c

c value 2.183 to 2.201 93% beam