Beam Halo Management
Lab FEL viewscreens

[Courtesy of S. Benson]
BERLinPro simulations (Astra)

at cathode after booster after dogleg

[Courtesy of A. Matveenko]
After linac

Particles lost at multiple apertures (0.02 m)

Starting positions at cathode

[Courtesy of A. Matveenko]

Christopher Mayes – October 20, 2011
- field emission from the cathode  
- field emission from the gun electrodes  
- discharges from the gun insulator  
- stray light reaching the cathode (big problem for high QE cathodes)  
  - sources: room lights, scattered laser light, x-rays/UV light from SRF cavities, x-rays/UV from gun electrode discharges  
- field emission from SRF cavities, that gets accelerated and exits the cavity  
- space charge?  
- non-uniform laser which makes long tails in time or space  
- ghost pulses from the laser,  
- cathode response time too long which produces tails in time (tails get defocused and become lost or turn into halo)  
- ions/ion scattering?

We have seen most of these in our injector and are working to reduce or get rid of them. We now think we have identified the main cause of our halo – poor laser mirrors before the cathode.
However . . .

Even with a perfect beam:

Gas scattering

Intra-beam scattering

Touschek scattering

Dark current from cavity field emission
Touschek Scattering (A. Piwinski 1998)

Scattering probability distribution

\[
\begin{align*}
  \frac{1}{\sigma_4^2} & = \frac{1}{\sigma_2^2} + \frac{D_2^2 + D_3^2}{\sigma_3^2} + \frac{D_4^2 + D_5^2}{\sigma_5^2} \\
  & = \frac{1}{\sigma_2^2 \sigma_4^2 \sigma_5^2} \left( \sigma_2^2 \sigma_4^2 \sigma_5^2 \right) \\
  B_1 & = \frac{\beta}{2 \beta^2 \gamma^2 \sigma_3^2} \left( 1 - \frac{\sigma_2^2 D_1^2}{\sigma_3^2} \right) + \frac{\beta^2}{2 \beta^2 \gamma^2 \sigma_3^2} \left( 1 - \frac{\sigma_2^2 D_2^2}{\sigma_3^2} \right) \\
  B_2 & = \frac{1}{4 \beta \gamma^2} \left( \frac{\beta^2}{\sigma_3^2} \left( 1 - \frac{\sigma_2^2 D_1^2}{\sigma_3^2} \right) - \frac{\beta^2}{\sigma_5^2} \left( 1 - \frac{\sigma_2^2 D_3^2}{\sigma_5^2} \right) \right)^2 + \frac{1}{\beta \gamma^2 \sigma_3^2 \sigma_5^2} \left( \sigma_3^2 \sigma_5^2 - \sigma_2^2 D_3^2 D_5^2 \right) \\
  \tau_m & = \beta \sigma_m^2 \\
  \int_{\tau_m}^{\infty} \left( 2 + \frac{1}{\tau} \right)^2 \left( \frac{\tau}{\tau_m} - 1 \right) + 1 - \frac{\sqrt{1+\tau}}{\sqrt{\tau/\tau_m}} \\
  & - \frac{1}{2\tau} \left( 4 + \frac{1}{\tau} \right) \ln \left( \frac{\tau/\tau_m}{1+\tau} \right) e^{-B_1 \tau} I_0(B_2 \tau) \frac{\sqrt{\tau} \, d\tau}{\sqrt{1+\tau}}
\end{align*}
\]

In order to simplify the representation we have introduced

\[
D_{ax} = \alpha_x D_{ax} + \beta_x D_{ax}
\]

and

\[
\beta_{ax}^2 = \alpha_x^2 D_{ax}^2 + \beta_x^2 D_{ax}^2 = \alpha_{ax}^2 + \beta_{ax}^2 (D_{ax}^2 + D_{ax}^2)
\]
Touschek particle

[Code developed by M. Ehrlichman using Bmad (D. Sagan)]
Touschek optimization 0

"Working Directory: test_sa_v1"

Current Density (pA/m)

Current (nA)

$B_x$, $B_y$ (m)

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Touschek optimization 1

Minimize heuristic function:

\[ G \propto \frac{H_x}{\sqrt{\sigma_x \sigma_y}} \]
Touschek optimization 2
Touschek optimization 3

"Working Directory: test_sa_v4"

Current Density (pA/m)

B, B (m)

Touschek Current (nA)
Halo Collimation

Protector

Collimator

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Halo Collimation

Typical Touschek distribution on a collimator face

<table>
<thead>
<tr>
<th>Protector</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
<th>P10</th>
<th>P11</th>
<th>P12</th>
<th>P13</th>
<th>P14</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (pA)</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.37</td>
<td>0.18</td>
<td>46</td>
<td>147</td>
<td>58</td>
<td>1360</td>
<td>0.01</td>
<td>0.04</td>
<td>0.09</td>
<td>0.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collimator</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (nA)</td>
<td>31.7</td>
<td>7.85</td>
<td>110</td>
<td>163</td>
<td>136</td>
<td>2.17</td>
</tr>
</tbody>
</table>
Photon Dose Rates (MCNPX)
Result:
- no significant hazard to personnel
- no significant demagnetization of undulator permanent magnets
Touschek halo tracking

- Chart showing a series of peaks and troughs along the s(m) axis.
- Another chart depicting a distribution of values along the x (µm) axis.

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Dark Current Tracking

\[ I_{FN}(E_{\perp}) = a_0 A_{FN} (\beta_{FN} E_{\perp})^2 \exp \left( -\frac{a_1}{\beta_{FN} E_{\perp}} \right) \]

\[ Q_n = N_A \cdot A_n \cdot \frac{\Delta \phi_n}{2\pi f_{rf}} \cdot I_{FN}(E_{\perp}(t_n)) \]
Gamma radiation in test cryomodule (MCNPX)
Field emission in two cryomodules
Field emission in one linac

Entrance

LA

Exit

\[ c \cdot p_{\text{exit}} (\text{MeV}) \]

\[ s_{\text{origin}} (\text{m}) \]
Two cryomodules: Left Exiting particles
Right exiting particles
Left moving particles through the center
Exit Halo

Energy Distributions

Entrance

Exit

Longitudinal Phase Space
Next steps: secondary emission, . . .

MCNPX calculations on a 3 mm slab of niobium

Electron yield

Electron energy (MeV)