XFEL - INJ 1/2 Dumps
Remarks / Requirements

A. Dump Layout
B. Beam Size Requirements
C. Fast Sweeper Space Requirements
D. Summary / Questions
Required capability: $E_0 \leq 300$ MeV, $N_t \leq 2.5 \cdot 10^{13}$ e$^{-}$ = 4 µC, $I_{ave} \leq 40$ µA, $P_{ave} \leq 12$ kW

Option A: C-Cu Dump, $\approx 1.9$ tons (incl. concrete front part)

Option B: pure Al Dump, $\approx 2.3$ tons (incl. concrete front part)
Dump Layout: integration in XSE

Top view sketch of horizontal bend into dump arm, showing available beam line length vs bend angle and required space in case of exchange.

20° horizontal deflection

30° horizontal deflection
# Beam Size Requirements: properties of materials

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>normal C</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>density, $\rho$ [g/cm³]</td>
<td>1.7 – 1.9</td>
<td>2.7</td>
</tr>
<tr>
<td>specific heat capacity, $c$ [J/g/K]</td>
<td>$\sim 1 @ 150^\circ$C</td>
<td>0.9</td>
</tr>
<tr>
<td>thermal conductivity, $\lambda$ [W/cm/K]</td>
<td>0.7</td>
<td>2.0</td>
</tr>
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<table>
<thead>
<tr>
<th>Temperature Limits</th>
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<tbody>
<tr>
<td>$T_{\text{melt}}$</td>
<td>$\geq 3000^\circ$C</td>
<td>660°C</td>
</tr>
</tbody>
</table>
| cyclic heating, $\max(\Delta T_{\text{inst}})$ | $\sim 150$-$200$ K  
derived from tensile strength | $\sim 50$ K  
plasticity limit |
| $\max(T_{\text{operation}})$ | $\sim 500$-$600^\circ$C, oxidation limit | $\sim 250^\circ$C |
| average heating  
$T_{\text{heat sink}} \sim 60^\circ$C $\Rightarrow \max(\Delta T_{\text{eq}})$ | $\sim 350$ K | $\sim 150$ K |
Beam Size Requirements: average heating

Beam Size Requirements:

- average heating

max. average heating @ 300MeV / 40µA

<table>
<thead>
<tr>
<th></th>
<th>C-Cu dump</th>
<th>Al dump</th>
</tr>
</thead>
<tbody>
<tr>
<td>max(dP/dz) [W/cm]</td>
<td>@ entrance</td>
<td>@ entrance</td>
</tr>
<tr>
<td>@ 300MeV / 40µA</td>
<td>150</td>
<td>190</td>
</tr>
</tbody>
</table>

max. average heating @ 300MeV / 40µA vs. beam size $\sigma$
in graphite window (100mm dia.) and at entrance of C-Cu resp. Al dump

- considering the beam as a dc heat source, i.e. if no pulsed stress is involved
  $\Rightarrow \sigma \approx 0.1$mm to tolerate average heating by 300MeV / 40µA beam
- also o.k. for average heating @ shower max. (dP/dz higher, but r-profile wider)
Beam Size Requirements: instantaneous heating

- our cases here ($\sigma \leq 2\text{mm}$, $E_0 \leq 500\text{MeV}$ on C and Al) allow analytical estimation:

$$\max(\Delta T_{\text{inst}}) = \frac{1}{c} \cdot \max \left( \frac{dE}{dm} \right) = \frac{1}{c} \cdot \frac{1}{\rho} \cdot \frac{dE}{dz} \cdot \frac{N_t}{2\pi \cdot \sigma^2} = 1.9 \cdot \frac{\text{MeV} \cdot \text{cm}^2}{g} \cdot \frac{1}{c} \cdot \frac{N_t}{2\pi \cdot \sigma^2} \approx \frac{20}{\mu\text{m}} \cdot \frac{1}{c} \cdot \frac{\text{J}}{\text{g} \cdot \text{K}} \cdot \frac{N_t}{10^{13}} \cdot \frac{1}{\sigma^2} \left[ \text{mm}^2 \right]$$

- reduction factor by fast circular sweep with radius $R_f$: $\approx 2.5 \cdot \frac{R_f}{\sigma}$, for $R_f \gg \sigma$

<table>
<thead>
<tr>
<th>300MeV on C</th>
<th>300MeV on Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\max(\Delta T_{\text{inst}}) \leq 150\text{K} \iff \leq 150\text{J/g}$</td>
<td>$\max(\Delta T_{\text{inst}}) \leq 50\text{K} \iff \leq 45\text{J/g}$</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>$R_f$</td>
</tr>
<tr>
<td>0.89mm</td>
<td>0</td>
</tr>
<tr>
<td>0.1mm</td>
<td>3.1$\cdot 10^{11}$</td>
</tr>
<tr>
<td>3.5mm</td>
<td>2.5$\cdot 10^{13}$</td>
</tr>
</tbody>
</table>

- w/o intra train sweep $\Rightarrow \sigma = 1$ to 2 mm to tolerate inst. heating by full bunch trains
- smaller spot sizes require less charge or fast sweep radii of 4 to 10mm
Kicker Scheme (F. Obier et al.)

- 1 winding current loop
  outside of ceramic vacuum chamber NW35
- inner surface of chamber sputtered
  with 1μm Ti stabilized stainless steel
- \( B \approx 2.15 \text{mT} / 100 \text{A} \)
- reasonable length \( \approx 1 \text{m} \)
- both deflection planes can be put on same chamber
- operation as resonant L-C circuit in cw-mode
  pro: easy control, no sync. with beam necessary
  cons: C’s close to beam line may degrade with time

→ 100A @50kHz possible

⇒ 1m Kicker gives \( \int B \cdot dl \approx 2 \text{mT} \cdot \text{m} \)

<table>
<thead>
<tr>
<th>max. Kick</th>
<th>( R_f )</th>
<th>( \Rightarrow \text{drift} )</th>
</tr>
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<tbody>
<tr>
<td>300 MeV</td>
<td>2 mrad</td>
<td>2.5 m – 5 m</td>
</tr>
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⇒ dump arm should provide 1m installation space + ≥ 2.5m drift towards window
Summary

- Average heating no issue, slow sweep not required
- Cyclic effects determine the beam size
  - single bunch limit $\geq 20 \mu m$ to $35 \mu m$, cannot be decreased by fast sweeping
  - bunch train limit $\geq 0.9 mm$ to $1.6 mm$ w/o fast sweep
- Fast sweeper requires 1m installation length and 2.5m resp. 5m drift space
- C-Cu dump can deal with smaller spot size than Al dump

Questions

1. Should we install beam profile measurement integrated in the window?
2. How to guarantee, that relation of beam size and charge stays within safe limits?
3. What is maximum single bunch charge?
4. Is there enough space available for fast sweeper + drift?
5. Beam position variation at dump entrance? (defines C-core & beam pipe aperture)
6. What is going to be installed in the dump arm?