XFEL - INJ 1/2 Dumps

Remarks / Requirements

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XFEL Injector Beam Dynamics Review Meeting, DESY, 23rd Oct. 2006

A. Dump Layout

B. Beam Size Requirements

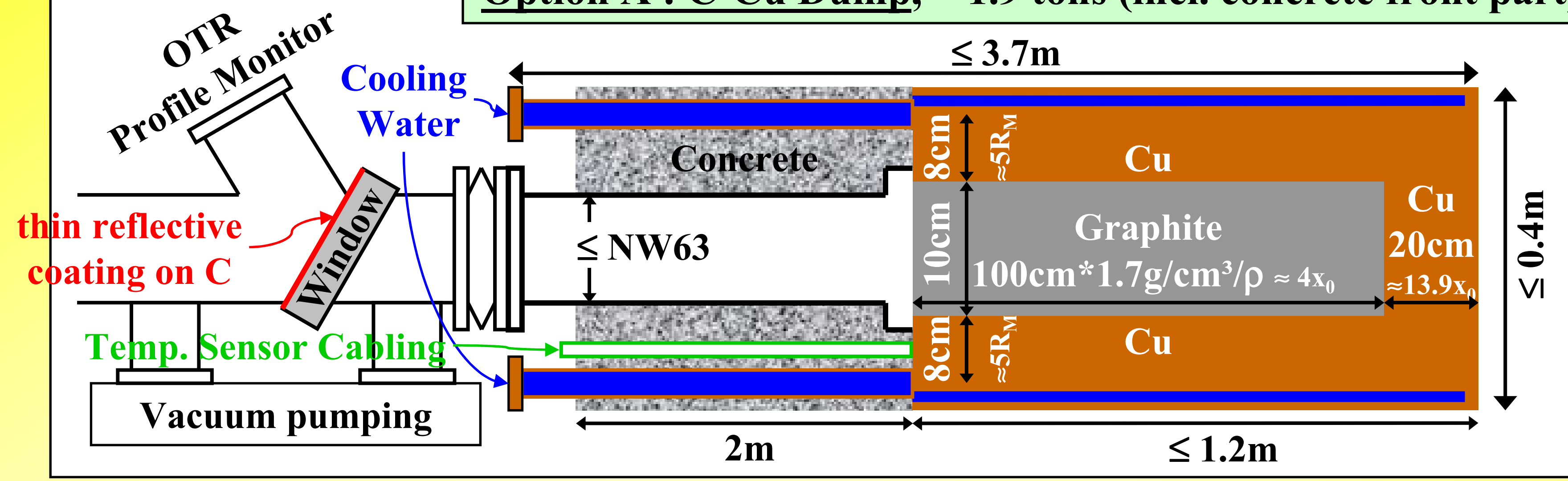
C. Fast Sweeper Space Requirements

D. Summary / Questions

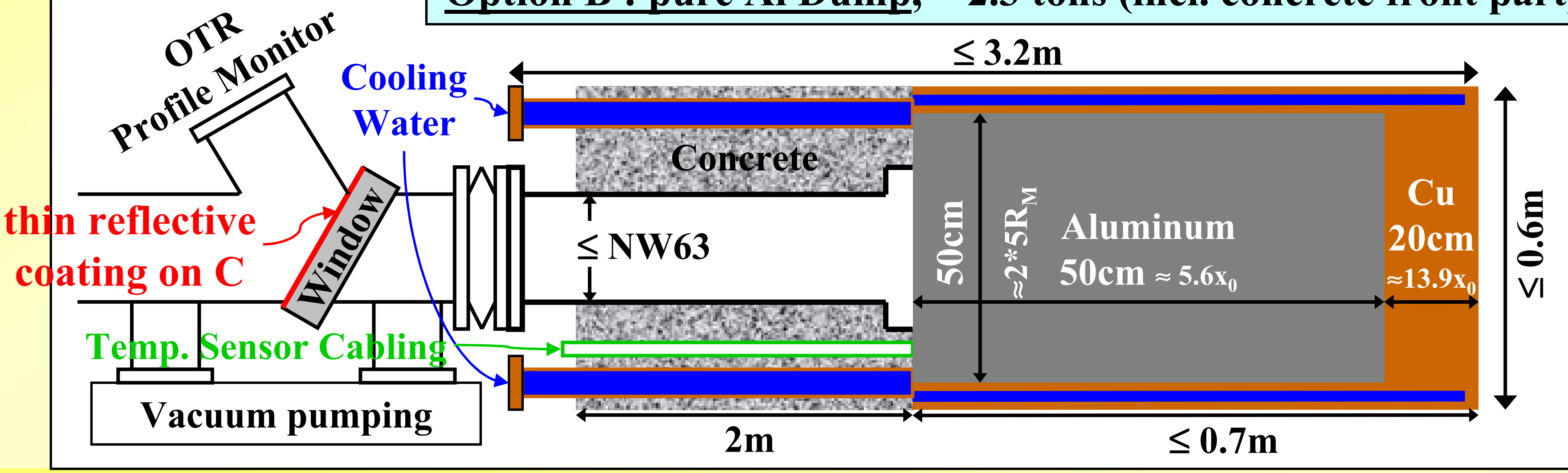
Dump Layout: 2 possible options

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, ≈ 1.9 tons (incl. concrete front part)

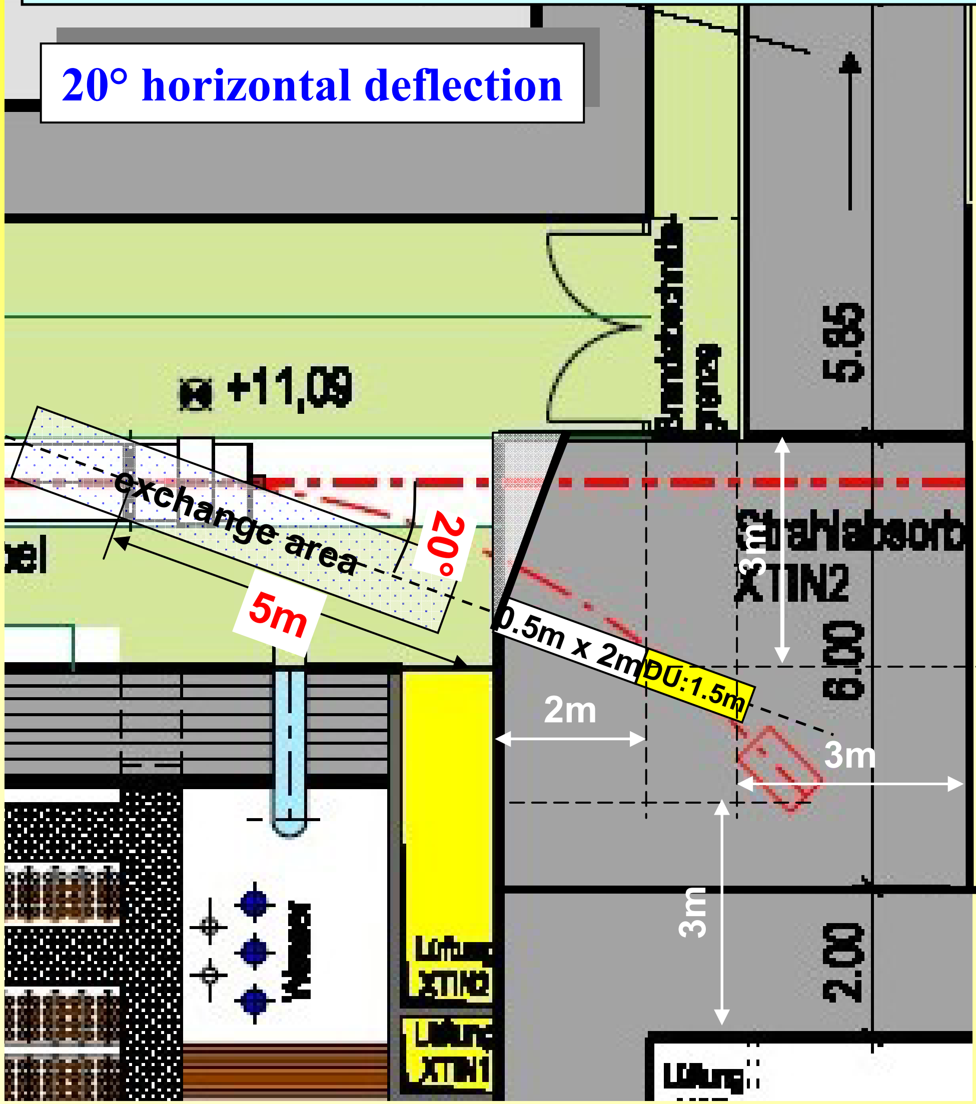


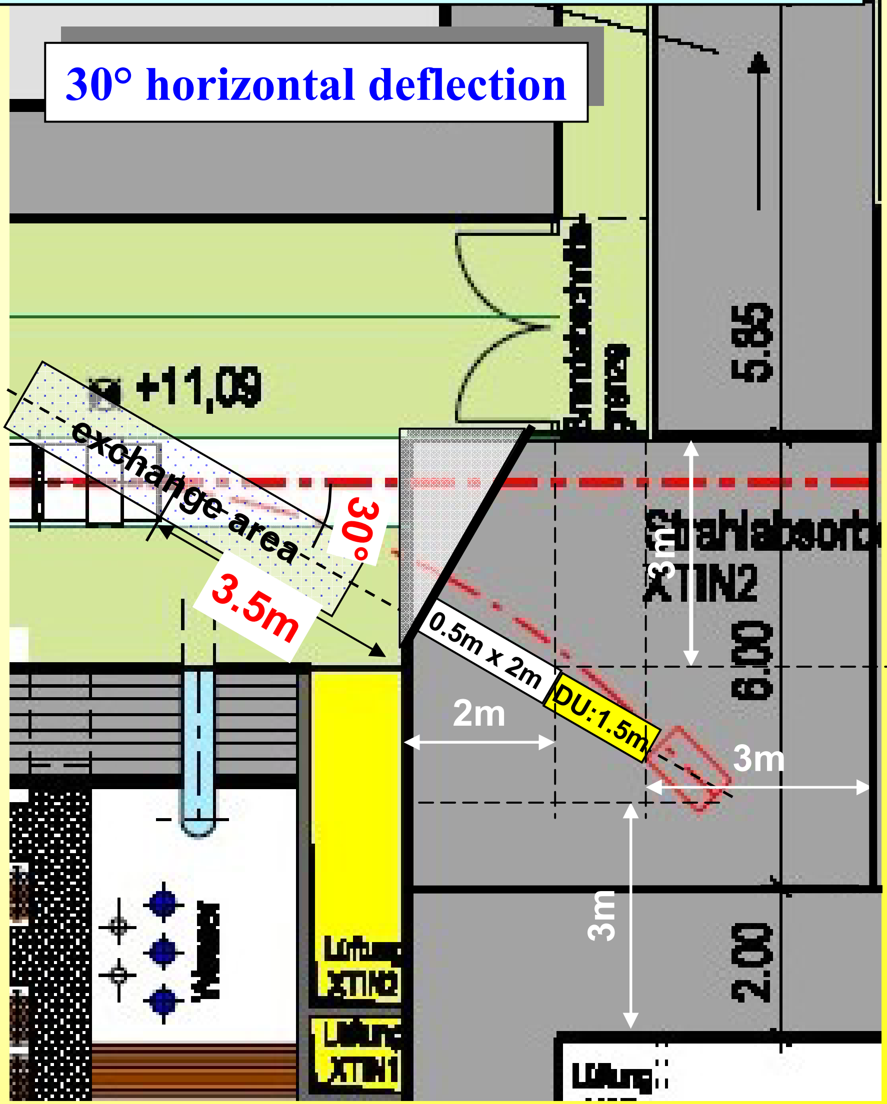
Option B : pure Al Dump, ≈ 2.3 tons (incl. concrete front part)



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



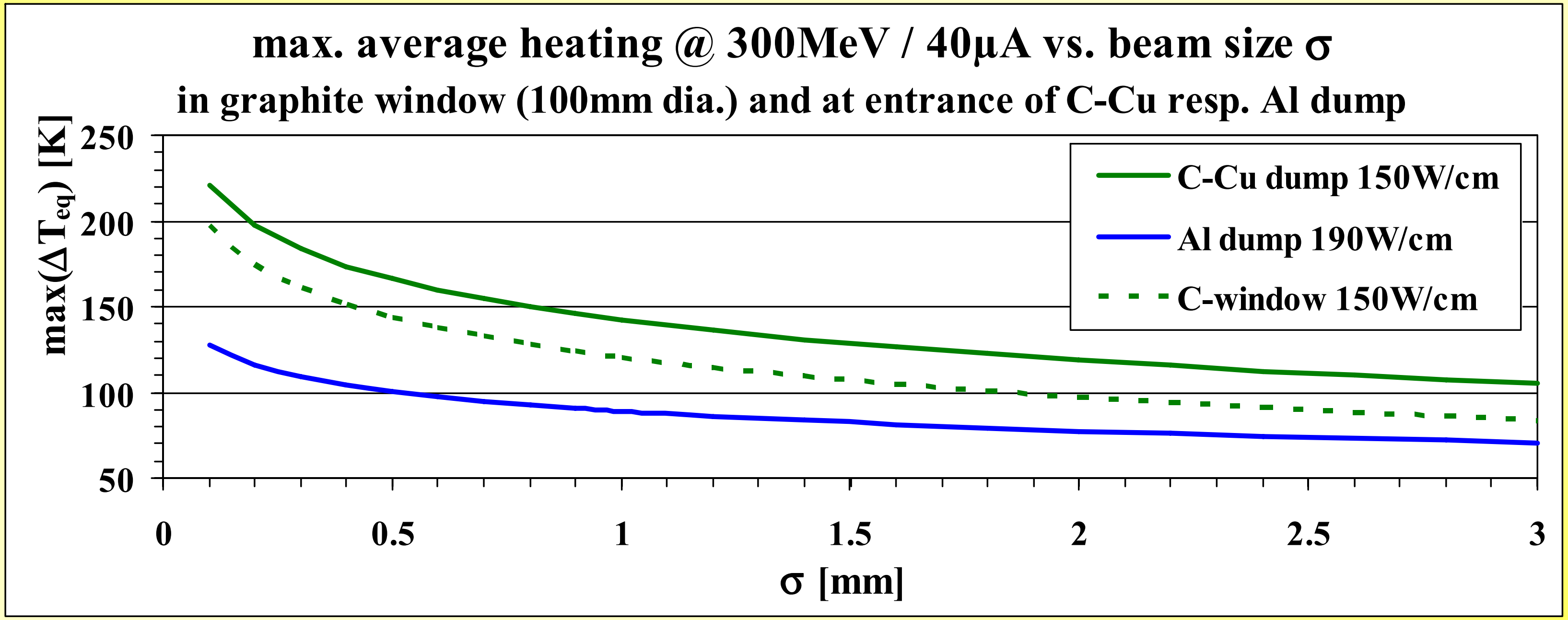


Beam Size Requirements: properties of materials

Material Properties	normal C	Al
density, ρ [g/cm³]	1.7 – 1.9	2.7
specific heat capacity, c [J/g/K]	~ 1 @ 150°C	0.9
thermal conductivity, λ [W/cm/K]	0.7	2.0
Temperature Limits		
T_{melt}	≥ 3000°C	660°C
cyclic heating, max(ΔT_{inst})	~ 150-200 K derived from tensile strength	~ 50 K plasticity limit
max($T_{operation}$)	~ 500-600°C, oxidation limit	~ 250°C
average heating $T_{heat\ sink}$ ~ 60°C ⇒ max(ΔT_{eq})	~ 350 K	~ 150 K

Beam Size Requirements: average heating

	C-Cu dump		Al dump	
max(dP/dz) [W/cm] @ 300MeV / 40µA	@ entrance	@ shower max.	@ entrance	@ shower max.
	150	190	210	380



- 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 ($\sigma \leq 2$mm, $E_0 \leq 500$MeV on C and Al) allow analytical estimation:

$$\max(\Delta T_{inst}) = \frac{1}{c} \cdot \max\left(\frac{dE}{dm}\right) = \frac{1}{c} \cdot \frac{1}{\rho} \frac{dE}{dz} \cdot \frac{N_t}{2\pi \cdot \sigma^2} = 1.9 \frac{\mathrm{MeV} \cdot \mathrm{cm}^2}{\mathrm{g}} \cdot \frac{1}{c} \cdot \frac{N_t}{2\pi \cdot \sigma^2}$$

$$\Rightarrow \max(\Delta T_{inst}) = 48\mathrm{K} \cdot 1 / c\ [\mathrm{J/g/K}] \cdot N_t\ [10^{13}] \cdot 1 / \sigma^2\ [\mathrm{mm}^2]$$

- reduction factor by fast circular sweep with radius R_f: $\approx 2.5 \cdot R_f / \sigma$, for $R_f >> \sigma$

*) $\Lambda = \sqrt{\frac{\lambda \cdot T_t}{\rho \cdot c}} \overset{T_t = 1\mathrm{ms}}{=} \begin{cases} 200\mu\mathrm{m} \text{ in C} \\ 280\mu\mathrm{m} \text{ in Al} \end{cases}$

	300MeV on C $\max(\Delta T_{inst}) \leq 150$K $\Leftrightarrow \leq 150$J/g			300MeV on Al $\max(\Delta T_{inst}) \leq 50$K $\Leftrightarrow \leq 45$J/g		
	σ	R_f	N_t	σ	R_f	N_t
	0.89mm	0	$2.5 \cdot 10^{13}$	1.6mm	0	$2.5 \cdot 10^{13}$
thermal diffusion is not included *)	0.1mm	0	$3.1 \cdot 10^{11}$	0.1mm	0	$9.8 \cdot 10^{10}$
		3.5mm	$2.5 \cdot 10^{13}$		10mm	$2.5 \cdot 10^{13}$
single bunch limit (since fast sweep is not intra bunch sweep)	≈20µm	---	2nC ⇔ $1.25 \cdot 10^{10}$	≈ 35µm	---	2nC ⇔ $1.25 \cdot 10^{10}$

- w/o intra train sweep ⇒ $\sigma \approx 1$ 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

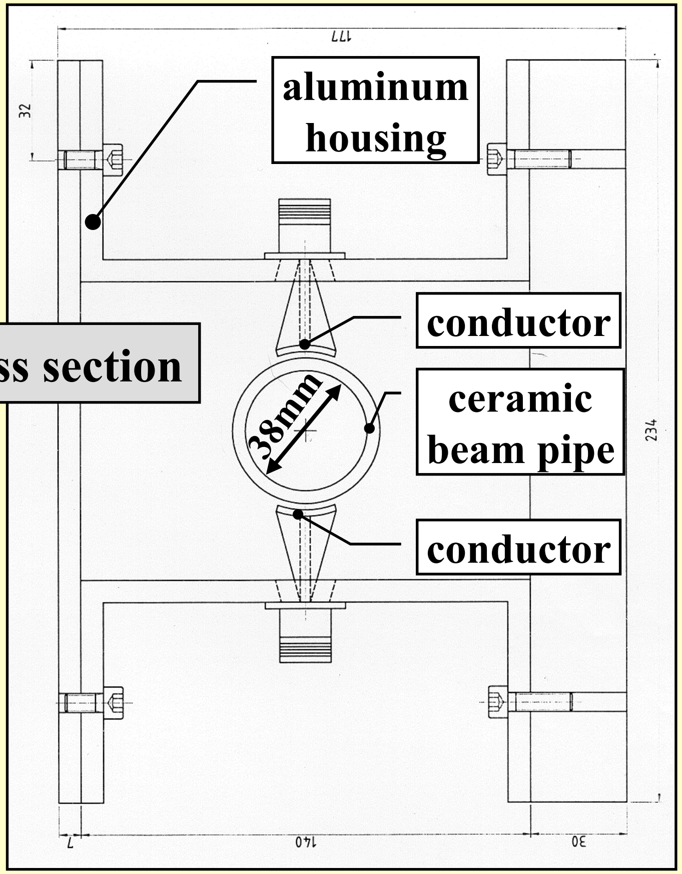
Fast Sweeper Space Requirements

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 ≈ 2.15mT / 100A
- reasonable length ≈ 1m
- 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 ∫B·dl ≈ 2mT·m

kicker cross section



	max. Kick	R_f	⇒ drift
300 MeV	2 mrad	5 mm – 10mm	2.5 m – 5 m

⇒ dump arm should provide 1m installation space + ≥ 2.5m drift towards window

Summary / Questions

Summary

- Average heating no issue, slow sweep not required
- Cyclic effects determine the beam size
  single bunch limit ≥ 20µm to 35 µm, can not be decreased by fast sweeping
  bunch train limit ≥ 0.9mm to 1.6mm 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 ?