# Concept and Technology for the High Power Beam Dumps at TESLA

Snowmass-Workshop, July 2001
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## *A. Introduction*

***Parameters, Required Components***

## *B. Basics & Choice of Absorber Material*

***Heating, Size, Handling, Activation***

## *C. Components of Water based Beam Dump System*

***Water Dump***

***Entrance / Exit Window***

***Water Cooling and Preparation System***

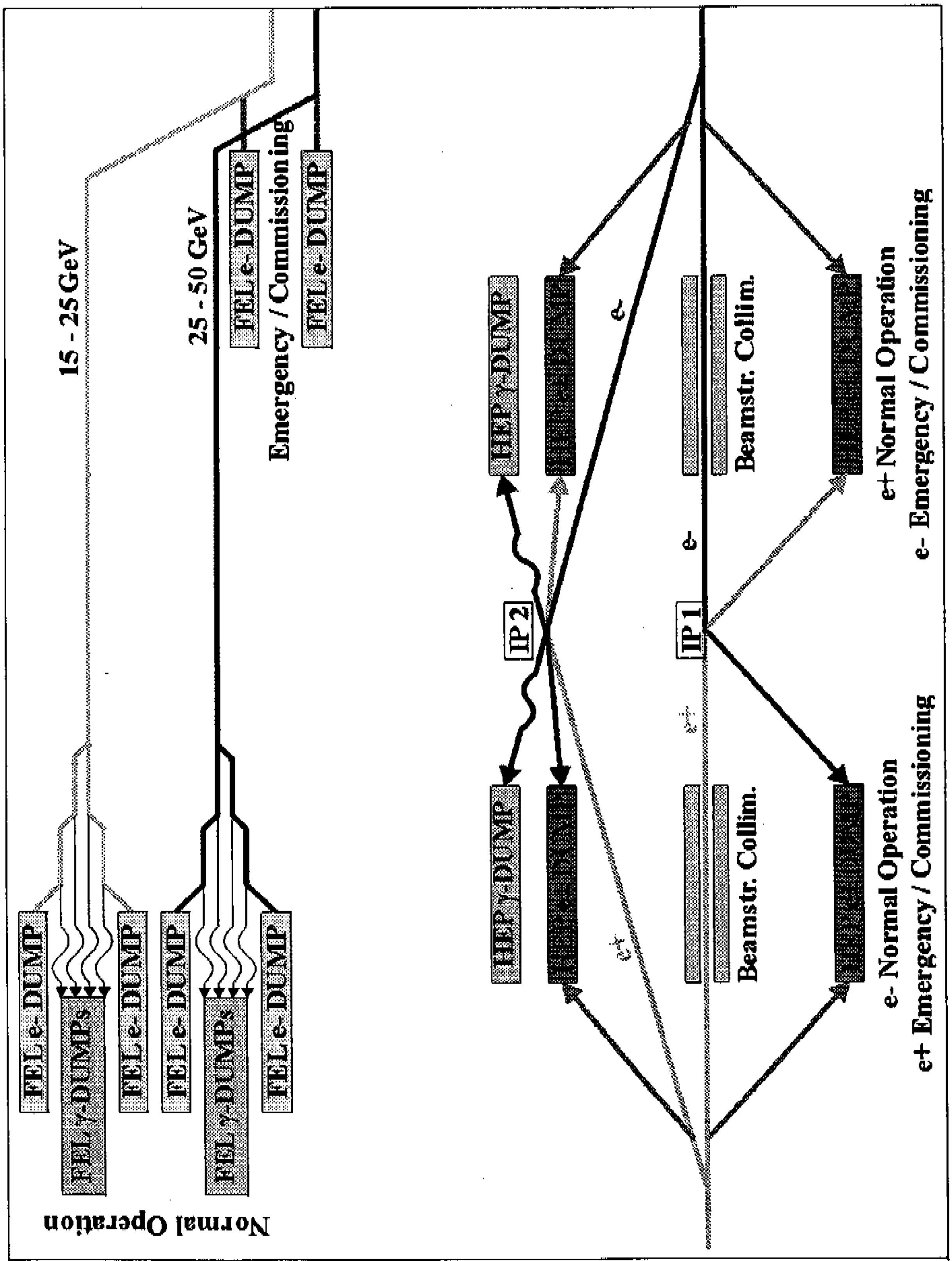
- ***Comparison with Existing Cooling System***

***Beam Deflection Systems***

- ***Fast Sweeping***
- ***Emergency Extraction***

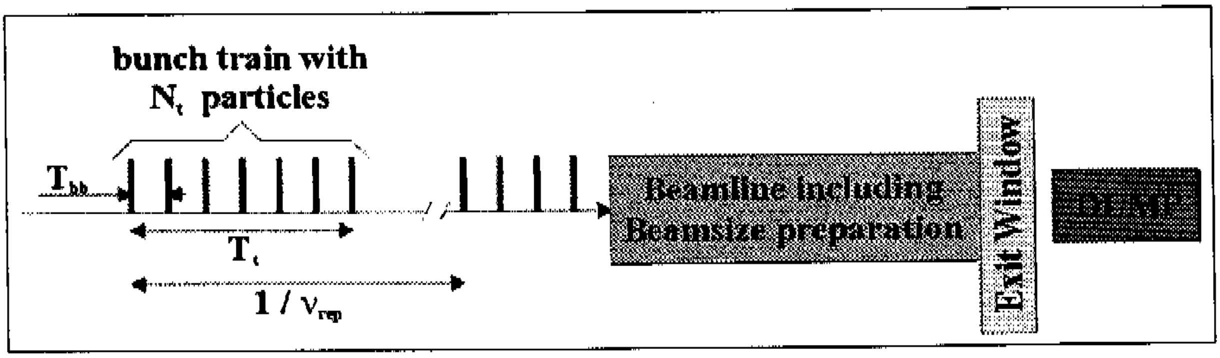
## *D. Summary, Work to be done*

# *A1: Variety of Beam Dumps*



Schematic Overview of required Beam Dumps

## *A2: Required Components, Beam Parameters*



| | HEP | | FEL | TTF II |
|---|---|---|---|---|
| particle energy, $E_0$ [GeV] | 400 | 250 | max. 50 | 2 |
| length of bunchtrain, $T_t$ | ≈ 1ms | | | |
| particles per train, $N_t$ [$10^{13}$] | 6.84 | 5.64 | 7.2 | 4 |
| repetition rate, $\nu_{rep}$ [Hz] | 4 | 5 | | 10 |
| bunches per train | 4886 | 2820 | 11500 | |
| bunch spacing, $T_{bb}$ [ns] | 176 | 337 | 93 | |
| avg. beam current, $I_{ave}$ [µA] | 44 | 45 | 57.7 | 64 |
| energy per train, $W_t$ | 4.4 MJ | 2.3 MJ | 575 kJ | 12.8 kJ |
| avg. beam power, $P_{ave}$ | 17.5 MW | 11.3 MW | max. 2 MW | 128 kW |
| | | | | |

**Dump related Beam Parameters**

⇒ **Need for:**

***e± Absorbers*** **for $E_0 \leq 400$GeV and $P_{ave} \leq 18$MW and $W_t \leq 4.4$ MJ**

***e± Exit / Entrance Windows*** **for $I_{ave} \leq 64$µA and $N_t \leq 7.2 \cdot 10^{13}$**

***e± Beamlines to the absorbers*** **including:**

- **fast extraction (kicker) systems for emergency beam lines**
- **fast sweeper systems to enlarge the eff. spot size within a bunch train**
- **slow sweeper systems to "dilute" average beam power (not for liquid absorbers)**

# B: Basic Considerations

$$\left.\begin{array}{l}\textbf{Questions of:}\\ \text{absorption}\\ \text{heating}\\ \text{mechanical stress}\\ \text{residual radioactivity}\\ \text{simplicity}\\ \text{accessibility}\\ \text{reliability}\end{array}\right\} \quad \begin{array}{l}\textbf{result in:}\\ \left\{\begin{array}{l}\text{choice of materials}\\ \text{absorber geometry}\\ \text{exit window design}\\ \text{req. spotsize at dump face resp. exit window}\\ \text{sweeping systems (slow, fast)}\end{array}\right.\end{array}$$

## B1: Simple electromagnetic shower description

- characterizing parameters: $X_0$ and $E_C$
- longitudinal position of shower maximum:

  $t_{max}(E_0) = 1.01 \cdot (\ln(E_0/E_C) - 1) \cdot X_0$ weak dependance on $E_0$

- e± multiplicity at shower maximum per primary particle:

  $M(E_0, t_{max}) = 0.31 \cdot E_0/E_C \cdot (\ln(E_0/E_C) - 0.37)^{-0.5}$ ≈ linear to $E_0$ for $E_0 >> E_C$

- radial shower characterized with: $R_{Moliere} = 21 \cdot X_0/E_C[\mathrm{MeV}]$
- 98% shower containment in:

  $$L_{99\%} = \left(1.52 \cdot \ln\left(\frac{E_0}{\mathrm{MeV}}\right) - 4.1 \cdot \ln\left(\frac{E_C}{\mathrm{MeV}}\right) + 17.6\right) \cdot X_0 \text{ and } R_{99\%} \approx 5 \cdot R_M$$

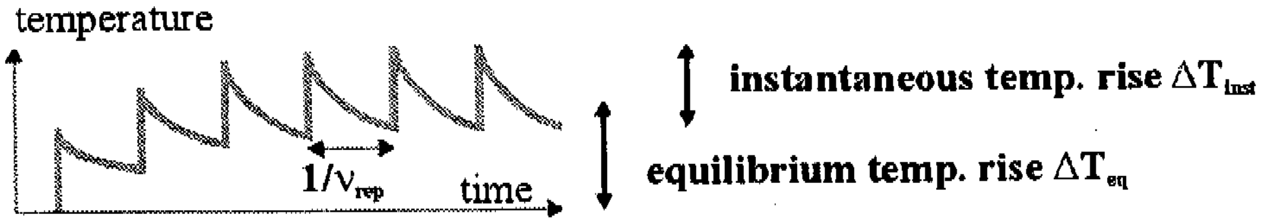
- power density per unit length

  $$\frac{dP}{dz} \approx \left.\frac{dE}{dz}\right|_{\text{min. ionizing part.}} \cdot \frac{I_{ave}}{e} \cdot \begin{cases} M(E_0, t_{max}) & \text{at shower maximum} \\ 1 & \text{at window resp. dump face} \end{cases}$$

| | | | Be | C | Al | Cu | $H_2O$ |
|---|---|---|---|---|---|---|---|
| $R_{99\%}$ | | cm | 33.4 | 34.7 | 23.4 | 8 | 47.2 |
| $L_{99\%}$ | 400GeV | cm | 632 | 488 | 197 | 36 | 694 |
| | 50GeV | cm | 520 | 409 | 168 | 32 | 580 |
| | 2GeV | cm | 348 | 286 | 125 | 25 | 403 |
| dP/dz at $z=t_{max}$ | 400GeV / 44μA | kW/cm | 45.9 | 76.0 | 201 | 1210 | 48.3 |
| | 50GeV / 57μA | kW/cm | 8.7 | 14.2 | 37.1 | 221 | 9.1 |
| | 2GeV / 64μA | kW/cm | 0.6 | 0.9 | 2.3 | 13.1 | 0.6 |

⇒ Carbon and Water good for high power absorbers

## *B2: Heating*



**instantaneous ⇔ thermal diffusion within $T_t$ negligible**

**e.g. thermal diff. length:** $\Lambda = \sqrt{\frac{\lambda \cdot T_t}{c \cdot \rho}} = \begin{cases} \textbf{0.01mm for water} \\ \textbf{0.37mm for carbon} \end{cases}$ ; $T_t = 1\text{ms}$

(λ=thermal conductivity; c=specific heat; ρ=mass density)

**Goal: $T_0 + (\Delta T_{eq})_{max} + (\Delta T_{inst})_{max} \leq T_{max}$ max. working temp. of material**

### *Heating of window (thickness << $X_0$ → "no" shower)*

- $\Delta T_{eq}$ **given by** $\frac{dP}{dz} = \left.\frac{dE}{dz}\right|_{min} \cdot \frac{I_{ave}}{e}$ $\neq f(E_0)$ **and heat conduction towards heat sink**
- $(\Delta T_{inst})_{max} = \frac{1}{c} \cdot \underbrace{\frac{1}{\rho} \cdot \left.\frac{dE}{dz}\right|_{min}}_{\neq f(\text{material})} \cdot \underbrace{\left(\frac{dN}{dA}\right)_{max}}_{= f(\text{spot size})}$ $\boxed{\rightarrow \text{lower limit of spotsize at window, } \sigma_{min}^{win}}$

### *Heating of absorber*

- $(\Delta T_{eq})_{max}$ **given by** $\left.\frac{dP}{dz}\right|_{z=t_{max}} = \left.\frac{dE}{dz}\right|_{min} \cdot M(E_0, t_{max}) \cdot \frac{I_{ave}}{e}$ **and:**

  **in solid absorbers by heat conduction towards heat sink**

  **need large area for heatflow** $\boxed{\rightarrow \text{slow sweep system}}$

  (slow sweeping: **beam distribution within thermal time constant of heat transport)**

  **may determine the transverse absorber size**

  **e.g. → 15m sweep length for 400GeV / 44μA in C-based absorber !**

  **(C-Cu sandwich needs 20cm sweeplength for $(dP/dz)_{max}$=1kW/cm to keep $(\Delta T_{eq})_{max} \leq$ 400K)**

  **in liquid absorbers by massflow of fluid**

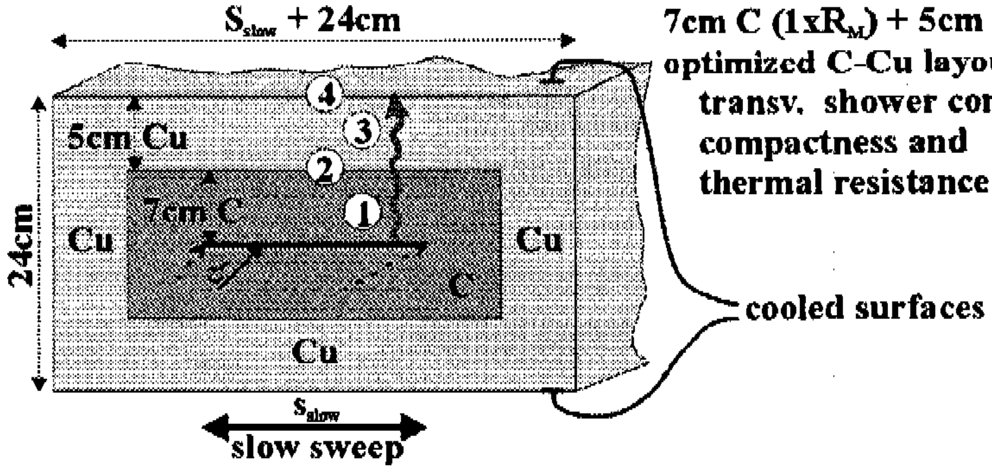
  **exchange shower core within subsequent bunchtrains** →ΔTeq≈0

  **by transverse fluid velocity at shower core** $v_{\perp} \approx R_M(H_2O) \cdot \nu_{rep} \approx 0.5\text{m/s}$

- $(\Delta T_{inst})_{max} = \frac{1}{c} \cdot N_t \cdot \underbrace{\left(\frac{1}{N} \cdot \frac{dE}{dm}\right)_{max}}$ $\boxed{\rightarrow \text{lower limit of spotsize at absorber face, } \sigma_{min}^{abs}}$

  **from shower simulation, f(spot size)**

# B3: Heat Conduction in Solid Absorbers → Length of Slow Sweep



**7cm C $(1\text{x}R_M)$ + 5cm Cu $(3.1\text{x}R_M)$**
**optimized C-Cu layout wrt.**
**transv. shower containment**
**compactness and**
**thermal resistance**

| | |
|---|---|
| 1.) heat conduction in 7cm C, $\lambda = 0.7\frac{\text{W}}{\text{cm}\cdot\text{K}}$ | $\rightarrow R_{\text{th}} = \frac{7\text{cm}}{0.7\frac{\text{W}}{\text{cm}\cdot\text{K}}} = 10\frac{\text{cm}^2\cdot\text{K}}{\text{W}}$ |
| 2.) heat transfer C→Cu, $\alpha = 0.5\frac{\text{W}}{\text{cm}^2\cdot\text{K}}$<br>! very sensitive on C-Cu contact, surface, pressure | $\rightarrow R_{\text{th}} = \frac{1}{\alpha} = 2\frac{\text{cm}^2\cdot\text{K}}{\text{W}}$ |
| 3.) heat conduction in 5cm Cu, $\lambda = 3\frac{\text{W}}{\text{cm}\cdot\text{K}}$ | $\rightarrow R_{\text{th}} = \frac{5\text{cm}}{3\frac{\text{W}}{\text{cm}\cdot\text{K}}} = 1.7\frac{\text{cm}^2\cdot\text{K}}{\text{W}}$ |
| 4.) heat transfer Cu→$H_2O$, $\alpha \cong 0.6\frac{\text{W}}{\text{cm}^2\cdot\text{K}}$ | $\rightarrow R_{\text{th}} = \frac{1}{\alpha} = 1.7\frac{\text{cm}^2\cdot\text{K}}{\text{W}}$ |
| sum of all contributions: | $R_{\text{th}} = 15\frac{\text{cm}^2\cdot\text{K}}{\text{W}}$ |

$$(\Delta T_{eq})_{max} \le 400\text{K} \Rightarrow \text{heatflux} \le \frac{(\Delta T_{eq})_{max}}{R_{th,ges}} = 27\frac{\text{W}}{\text{cm}^2}$$

**sweeplength $s_{slow}$ to stay below this heatflux-limit gives:**

$$\frac{1}{2}\cdot\left(\frac{dP}{dz}\right)_{max}\cdot\frac{1}{s_{slow}} \le 27\frac{\text{W}}{\text{cm}^2} \quad \boxed{\Rightarrow \quad s_{slow} \cong 20\,\text{cm}\Big/\tfrac{\text{kW}}{\text{cm}}\cdot\left(\frac{dP}{dz}\right)_{max}}$$

- **400GeV / 44μA / 18MW:** $\left(\frac{dP}{dz}\right)_{max} = 76\frac{\text{kW}}{\text{cm}} \Rightarrow s_{slow}=15\text{m}$ !
- **50GeV / 40μA / 2MW:** $\left(\frac{dP}{dz}\right)_{max} = 11\frac{\text{kW}}{\text{cm}} \Rightarrow s_{slow}=2.2\text{m}$ !

⇒ application regime of C-Cu type absorber limited by
reasonable slow-sweeplength ≈ 0.5m
i.e. $\left(dP/dz\right)_{max} \le 2.5\frac{\text{kW}}{\text{cm}} \Leftrightarrow P_{ave} \le 500\text{kW}$

C-Cu absorber design for $P_{ave} \ge 500\text{kW}$ become quite complicated

# B4: Minimum Spot Size due to Instantaneous Heating of Absorber

- $$\frac{\Delta Q}{\Delta m} = \int_{T_0}^{T_0+\Delta T_{inst}} c \cdot dT \geq N_t \cdot \underbrace{\left(\frac{1}{N} \cdot \frac{dE}{dm}\right)_{max}}_{\text{f(spot size)}} \Rightarrow \sigma_{min,Abs}$$
- **simulation results for gaussian input beam with $\sigma = \sigma_x = \sigma_y$**

  **can be fitted over a wide range by:** $\left(\frac{1}{N} \cdot \frac{dE}{dm}\right)_{max} = a \cdot (\sigma/\text{mm})^b$

| **electrons with $E_0$ hitting a carbon resp. water absorber**<br>**(carbon and water behave similar because of same $X_0 \cdot \rho$)** | | |
|---|---|---|
| **$E_0$** | **a [$10^{-12}$ J/g/e-]** | **b** |
| **400 GeV** | **232** | **-1.35** |
| **250 GeV** | **184** | **-1.42** |
| **50 GeV** | **42.4** | **-1.42** |
| **25 GeV** | **21.8** | **-1.42** |
| **2 GeV** | **7.70** | **-1.77** |

- **$\sigma_{min,Abs}$ lower limit of spot size at absorber face**

| | | **$\sigma_{min,Abs}$** | |
|---|---|---|---|
| | | **water** | **carbon** |
| **$E_0$ [GeV]** | **$N_t$ [$10^{13}$]** | **$\Delta T_{inst}$=40K**<br>**$\Leftrightarrow$ 160 J/g** | **$\Delta T_{inst}$=400K**<br>**$\Leftrightarrow$ 660J/g** |
| **400** | **6.84** | **30mm** | **11mm** |
| **250** | **5.64** | **19mm** | **7.0mm** |
| **50** | **7.2** | **8.0mm** | **2.9mm** |
| **25** | **7.2** | **5.0mm** | **1.8mm** |
| **2** | **4** | **1.5mm** | **0.65mm** |

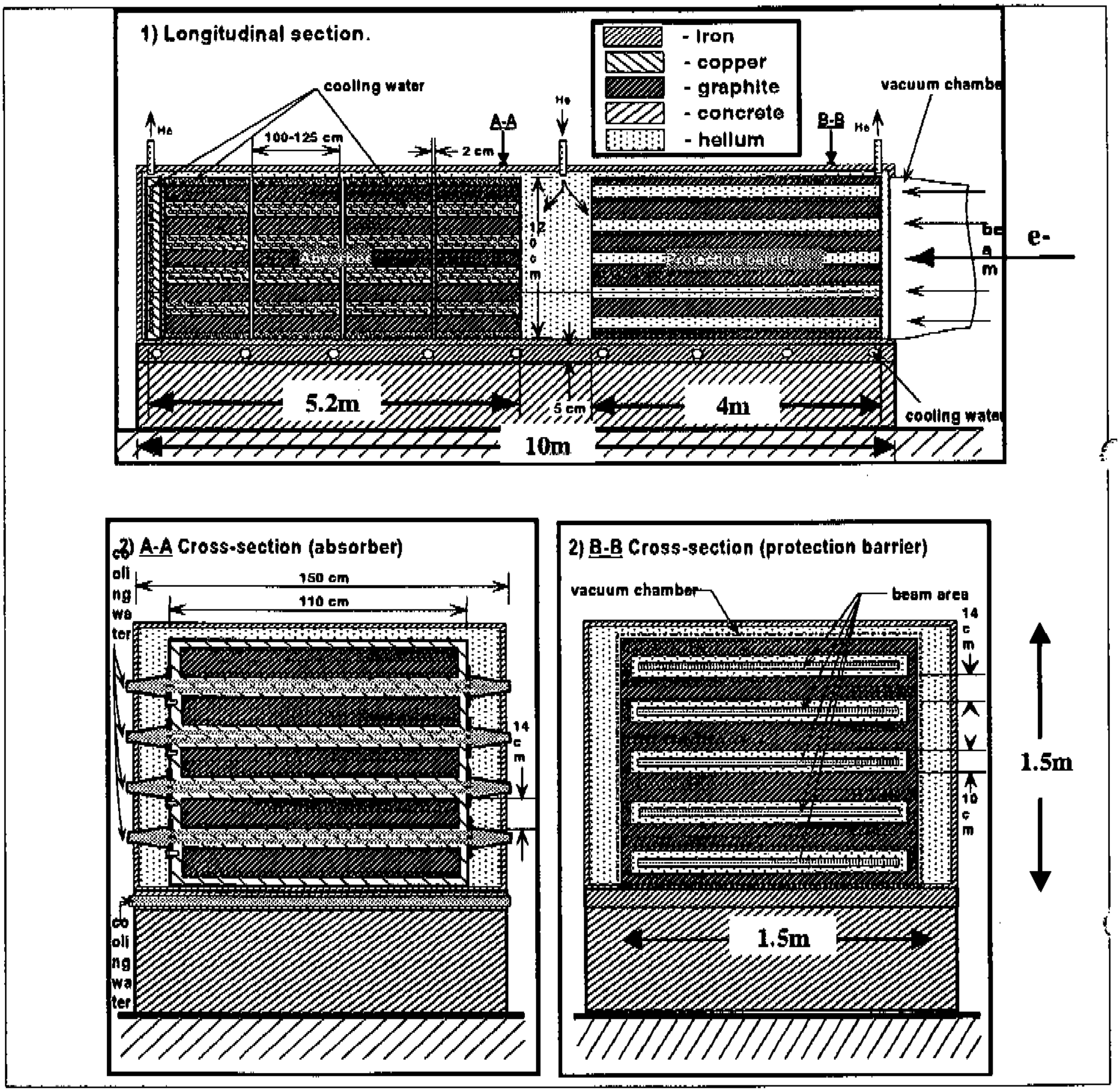
**(evapouration heat of water at normal conditions ≈2200J/g)**

**carbon absorber requires less spot size, but still large compared to natural beam size**

**⇒ need fast sweeping system for beam dilution within bunch train passage**

# *B5: C-Cu Absorber Layout for 250GeV / 8MW / 4·$10^{13}$$e^-$*

## *Absorber*

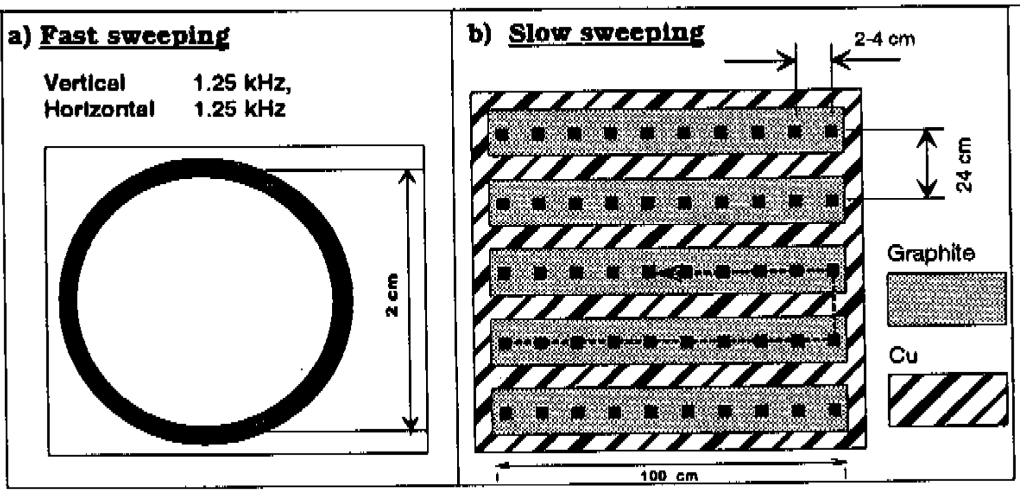


- slow sweeping with $s_{slow} \approx 6$m, failure → protector section
- fast sweeping to achieve effective spot size $\sigma_{min,Abs} \approx 5.5$mm ⇔ ≈ 100mm$^2$
- 40 tons
- noble gas containment to keep $^3$H and to prevent C from oxidation

⇒ Very Complicated Design in terms of handling, weight, acces, window, .....

# *B5: C-Cu Absorber Layout for 250GeV / 8MW / $4\cdot10^{13}e^-$*

## *Sweeping Systems*

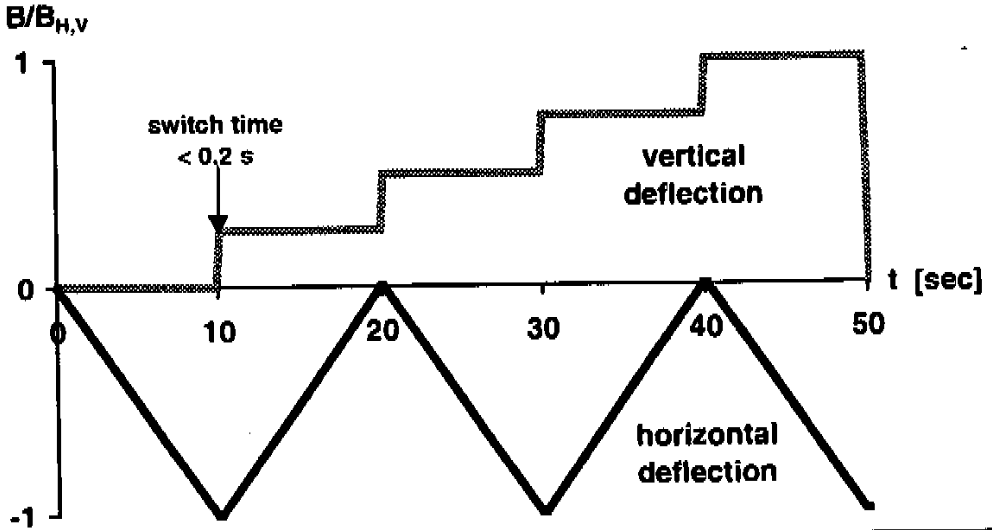


a) **Fast sweeping**

b) **Slow sweeping**

**Beam distribution at the dump face according to fast and slow sweeping**

**(assumption for fast sweeping: $N_t=4\cdot10^{13}$, $\sigma_x=3mm$, $\sigma_y=0.5mm$, $(\Delta Tinst)_{max}=400K \Rightarrow R_{fast}=1cm$)**



**Scheme of full deflection cycle of the slow sweeping system**

# ***B6: Residual Radioactivity, Produced Isotopes***

$$A(t)=\frac{p}{\delta}\cdot\left(1-e^{-\delta\cdot t}\right)$$

$\delta \equiv \ln 2 / t_{1/2}$
$p \equiv$ production rate
$p/\delta \equiv$ saturation activity

$3.7\cdot 10^{10}\,\mathrm{Bq} = 1\,\mathrm{Ci}$
$1\,\mathrm{Sv} = 100\,\mathrm{rem}$

**Water**

$^{15}$O(2min), $^{13}$N(10min), $^{11}$C(20min), all negligible since short lived

$^{7}$Be(54d), 478keV $\gamma$ : $p = 71\frac{\mathrm{GBq}}{\mathrm{MW\cdot d}}$, $p/\delta = 5.5\frac{\mathrm{TBq}}{\mathrm{MW}}$

$^{3}$H(12a), 20keV $\beta^{-}$ : $p = 0.69\frac{\mathrm{TBq}}{\mathrm{MW\cdot a}}$, $p/\delta = 12\frac{\mathrm{TBq}}{\mathrm{MW}} = 122\frac{\mathrm{cm}^3}{\mathrm{MW}} = 0.033\frac{\mathrm{g}}{\mathrm{MW}}$

→ ≥150d operation, ≥2h wait, 1m distance (pure water dump) $\boxed{12\,\mathrm{mSv}/\mathrm{h\cdot MW}}$

$H_2$ production by radiolysis: $\approx 0.3\frac{\mathrm{liter}}{\mathrm{s\cdot MW}}$

**Carbon**

$^{11}$C(20min)

$^{7}$Be(54d): $p = 0.56\frac{\mathrm{TBq}}{\mathrm{MW\cdot d}}$, $p/\delta = 43\frac{\mathrm{TBq}}{\mathrm{MW}}$

$^{3}$H(12a): $p = 2.2\frac{\mathrm{TBq}}{\mathrm{MW\cdot a}}$, $p/\delta = 39\frac{\mathrm{TBq}}{\mathrm{MW}} = 390\frac{\mathrm{cm}^3}{\mathrm{MW}} = 0.1\frac{\mathrm{g}}{\mathrm{MW}}$

→ ≥150d operation, ≥2h wait, 1m distance (pure C dump) $\boxed{8.8\,\mathrm{mSv}/\mathrm{h\cdot MW}}$

$H_2$ production photonuclear: $\approx 1\frac{\mathrm{liter}}{\mathrm{a\cdot MW}}$

$H_2$ absorption capability of C at room temperature: $\approx 0.3\frac{\mathrm{cm}^3}{\mathrm{g}}$

**Aluminium**

$^{7}$Be(54d), $^{18}$F(110min), $^{22}$Na(2.6a), $^{24}$Na(15h),

→ ≥1a operation, ≥2d wait, 1m distance (pure Al dump, <u>no selfshielding</u>) $\boxed{340\,\mathrm{mSv}/\mathrm{h\cdot MW}}$

**Copper**

$^{64}$Cu(12.7h), $^{60}$Co(5.3a), $^{58}$Co(79.8d), $^{57}$Co(270d), $^{56}$Co(77.3d), $^{54}$Mn(312d)

→ ≥100d operation, ≥1d wait, 1m distance (Cu layer of $H_2O$ dump calculation) $\boxed{770\,\mathrm{mSv}/\mathrm{h\cdot MW}}$

⇒ Water and Carbon favourable candidates

# *B7: Comparison of Water ⟵⟶ Carbon based Absorber Schemes*

| | **Water** | **Carbon** |
|---|---|---|
| **hydrogen production** | – | + |
| **residual radioactivity** | ++<br>**extraction of activity into ion exchanger** | + |
| **accessibility / exchange / handling** | +<br>**water can be pumped in storage tank** | – –<br>**heavy** |
| **slow sweep system** | **no** | **yes** |
| **transverse size determined by** | **shower containment** $\neq f(E_0, P_{ave})$ | **sweeplength scales with** $P_{ave}$ |
| **flexibility wrt. different** $P_{ave}$ | **change heat exchanger / water preparation**<br>**beamline and absorber remain unchanged** | **change sweeplength**<br>**→ changes of:**<br>**absorber**<br>**vacuum system**<br>**exit window** |

- **At $P_{ave} \geq 0.5$MW a water based dump has important advantages compared to carbon systems.**
- **C-Cu based schemes can be used for low power applications (emergency dump, ...)**

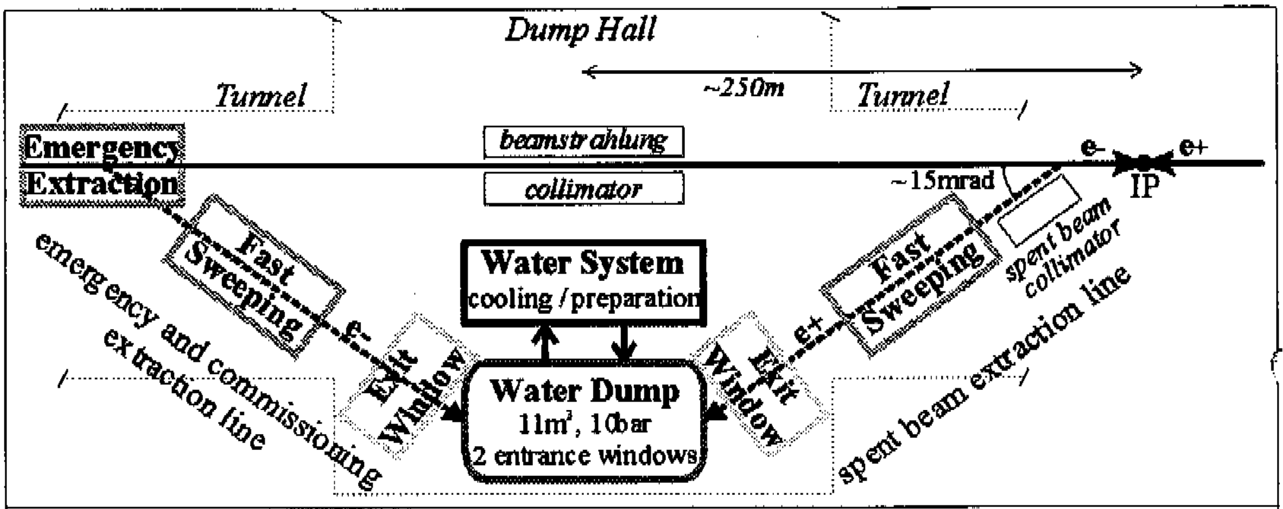
- **LC (HEP + FEL) needs ≥ 6 high power beam absorbers.**
  **Water dump systems can fulfil the different requirements by using identical (similar) hardware for the crucial components (absorber, exit window, sweep system)**

⇒ Water Dump System is the most reasonable choice
for high power absorbers with $P_{ave} \geq 0.5$MW

# C: Components of Water based Beam Dump System

**Look at 250 GeV / 12 MW / $5.64 \cdot 10^{13}$e- Main Linac Dump**

**Representing the Concept for all High Power Beam Dumps at TESLA**



**Main Linac Beam Dump System with its Subsystems (schematic side view)**

**Subsystems:**

- **Water Dump**
- **Entrance / Exit Window**
- **Water Cooling and Preparation System**
- **Beam Deflection Systems**
  - **Fast Sweeping**
  - **Fast Extraction**

# *C1: Water Dump*

- **cylindrical water vessel, dia.=1.2m, L=10m, Vol=11.3m$^3$**
  **→ $E_{leak}$ / $E_{in}$ < 1% (still 120kW) at $E_{in}$ = 250GeV or 400GeV**

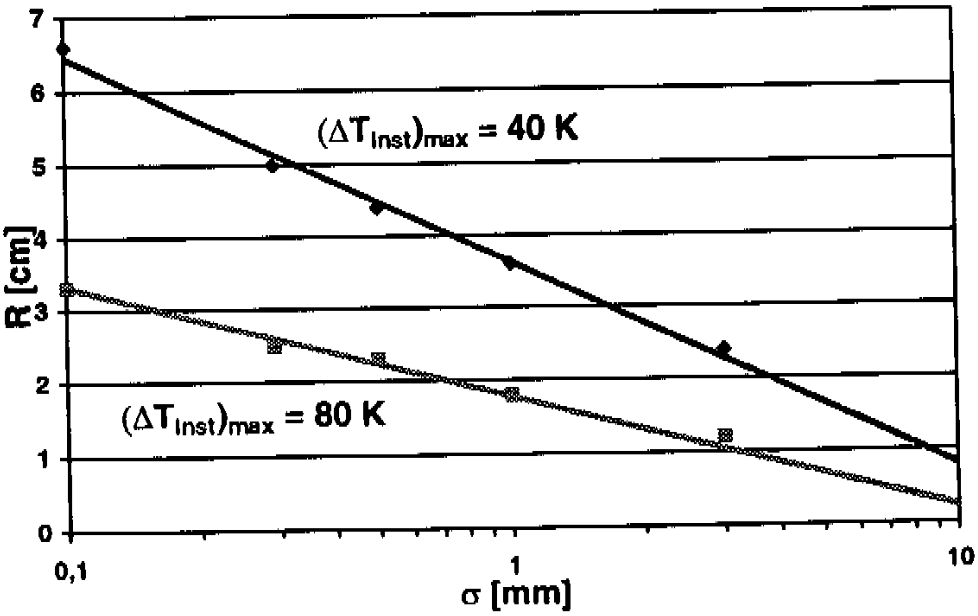
- **beam can enter from both sides, vert. angle 15mrad**
  **→ same dump for emergency/commissioning or normal operation ($P_{max}$ !)**

- **transverse water flow at shower core, $v_\perp \approx R_M \cdot \nu_{rep}$ = 10cm · 5Hz ≈ 0.5m/s**

- **10 bar static pressure**
  **→ higher boiling temperature (≈160°C) and improved $H_2$ recombination**

- **$T_{forward}$ = 50°C, $T_{return}$ = 80°C and $(\Delta T_{inst})_{max} \leq$ 40K to stay below T ≤ 100°C**
  **→ mass flow to external heat exchanger dm/dt = 100kg/s**
  **→ $\sigma_{min,Abs} \geq$ 19mm (250 GeV / 5.64·10$^{13}$e-) resp. 30mm (400 GeV / 6.84·10$^{13}$e-)**
  **has to be fulfilled by fast sweeping system**

**TESLA undisrupted beam at dump: 1x0.3mm$^2$ ⇔ <σ> ≈ 0.5mm**
**→ fast sweeping with R=4.5cm**



**Required Sweep radius R vs beam size σ for a given $(\Delta T_{inst})_{max}$ caused by one bunch train with 5.64 x 10$^{13}$ e$^-$ at 250GeV hitting a water absorber**

## *C1: Water Dump cont'd*

- saturation activity concentration at 12MW (total water mass $M \approx 10^4$ kg)
  $^3$H: 146TBq/$10^4$ kg = 14.6 GBq/kg
  no outside dose rate (20keV $\beta^-$), but prevent from leakage ! → gastight system
  $^7$Be: 60TBq/$10^4$ kg = 6.0 GBq/kg → estimated equivalent dose rates
  1m far from dump vessel: ≈ 150mSv/h
  at surface of a 300mm pipe: ≈ 500mSv/h
  $^7$Be dominant contributor for dose level ! → ion exchanger / filter system

- hydrogen production with 0.3 liter/s/MW (at normal conditions)
  → hydrogen recombiner

- shielding: 3m normal concrete + 7m sand
  → soil + ground water activation + surface dose rates << natural levels
  "no" air gaps between vessel and shielding to minimize air activation

Questions wrt. design of vessel (picture):

- system of water in / outlets that fulfills overall mass flow <u>and</u> $v_\perp$ criterion
- pressure load on vessel walls due to pulsed beam
- material selection and wall thickness is determined by:
  static and cyclic load
  ageing due to neutron flux, up to $10^9$ neutrons/s/cm$^2$ at vessel wall
  corrosion effects

⇒ more detailed design work on water vessel necessary
including pressure (transient) and water flow calculation

# *C2: Entrance / Exit Windows*

- **heat load only detemined by $(dN/dA)_{max}$ and $I_{ave}$, not $E_0$**

- **requirements on window:**

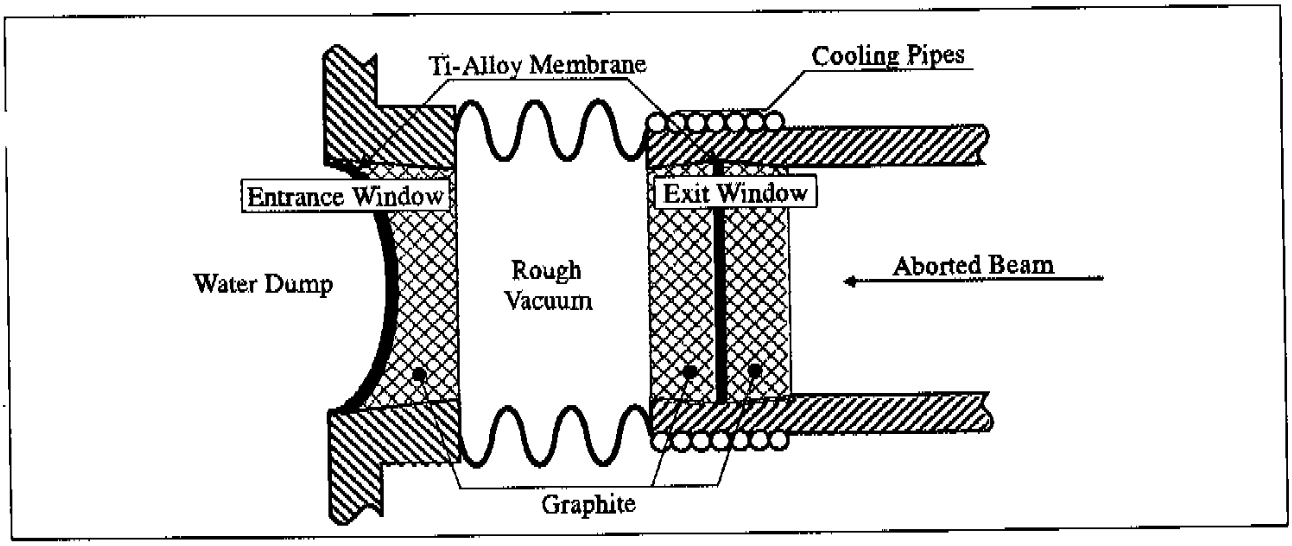
  **high mechanical strength wrt. cyclic stress ($10a \cdot 5Hz \approx 10^9$ cycles)**

  **high specific heat and good vacuum properties**

  **→ Ti-C sandwich concept**

  **Ti-membrane (0.5mm) as seal**

  **graphite for reinforcement and heat conduction**



- **two window concept with intermediate vacuum volume**

  **→ safety against dump water leaking into vacuum system or environment**

  **→ avoids air activation and enables leakage control of both windows**

- **$(\Delta T_{eq})_{max} \leq 150K$ at $I_{ave}=64\mu A$, $\sigma=1mm$, window dia.=100mm**

- **$(dN/dA)_{max} \leq 4 \cdot 10^{12}$ e-/mm² limit due to cyclic stress limits**

  **round gaussian beam: $(dN/dA)_{max,gauss} = N_t / 2\pi\sigma^2$**

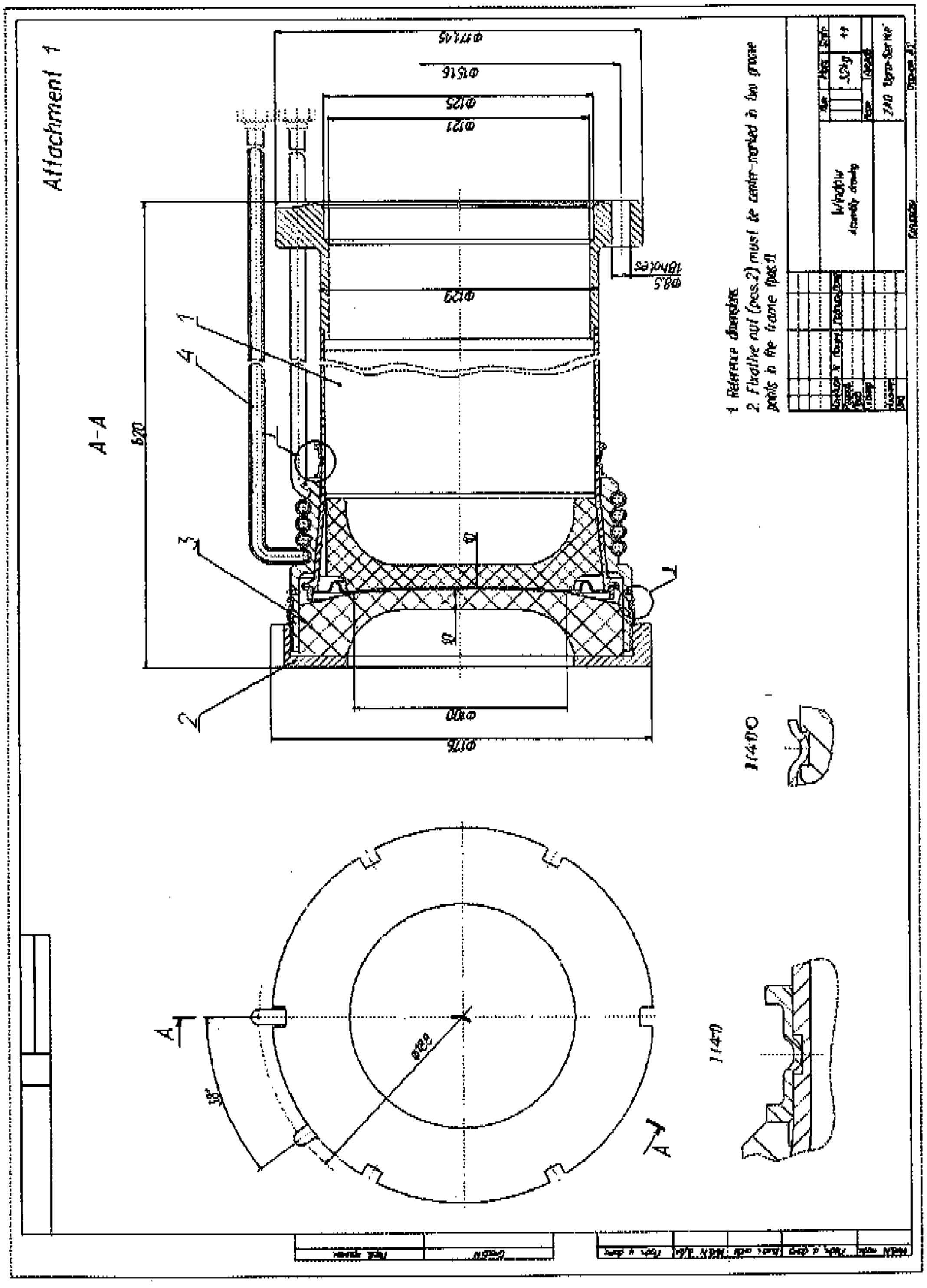
  $N_t=5.64 \cdot 10^{13}e- \Rightarrow \sigma_{min,Win} \geq 1.5mm$, i.e. $\sigma_{min,Win} << \sigma_{min,Abs}$

  **add circular sweep with $R > \sigma$ : $(dN/dA)_{max,sweep} = N_t / 5\pi R\sigma$**

  $N_t=5.64 \cdot 10^{13}e-$, $\sigma=0.5mm$, $R = 4.5cm \Rightarrow (dN/dA)_{max,sweep} = 1/25\ (dN/dA)_{max}$

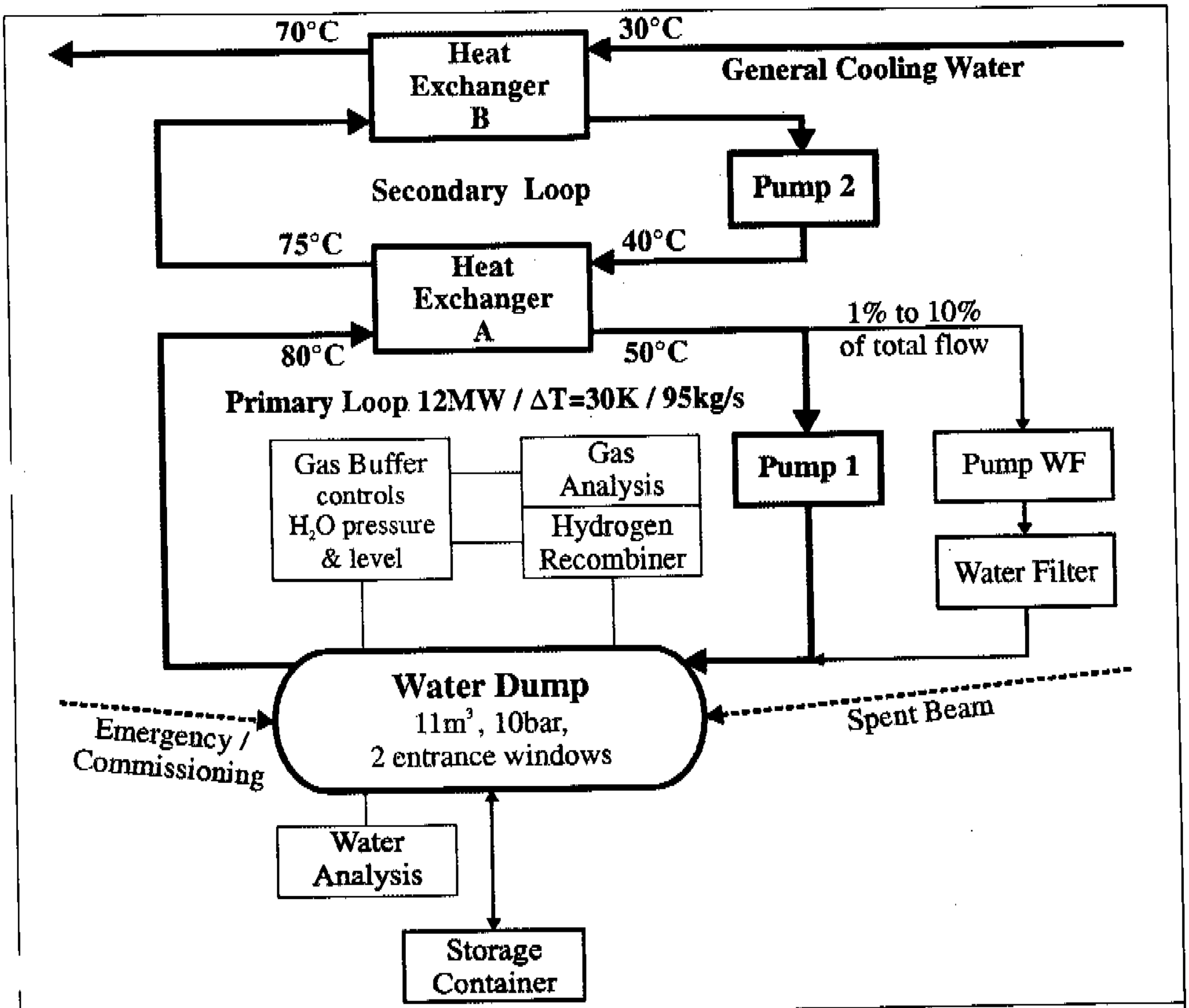
⇒ window not endangered as long as spot size fulfills absorber requirements concerning instantaneous heating

## C2: Entrance / Exit Windows, cont'd



C-Cu sandwich type exit window design for TTF2 (IHEP Protvino)

# *C3: Water Cooling and Preparation System*



Scheme of water system for the water based beam dump

- **two loop system separates radioactive water from general cooling system, pressure of secondary loop beyond that of primary**
  **→ safety against contamination of general cooling water**
- **primary loop must be leak tight**
  **gasket connections**
  **→ only gastight components (pumps, ...)**
- **12MW / ΔT=30K → 100kg/s=340m³/h → main piping = 300mm dia.**

## *Gas Buffer*

- maintain static pressure of 10bar in water via noble gas volume
- compensates for slow thermal expansion of water
- collects all gaseous constituents not dissolved in water, esp. hydrogen
- level of gas – water boundary as leakage indicator

## *Hydrogen Recombiner, Gas Analysis*

- catalytic recombination $2H_2 + O_2 \rightarrow 2H_2O$ at palladium or platinum surface
  (catalyser is supported in porous material or silica gel spheres)
- $H_2$ production with 0.3liter/s/MW, but also recombination process (10bar, 60°C)
  → equilibrium $H_2$ concentration level, how high?
- $H_2$ concentration monitored by gas analysis
  → detects dangerous concentrations, indicates malfunctioning of recombiner

## *Storage Tank*

- temporary storage of system water in case of maintainance or leakage
- whole water system embedded in special painted basin
  → leakage water can be collected and flushed into storage tank
- located at deepest position to allow passive flow, independent of pumps

## *Water Analysis*

- chemical analysis (acidity, ion concentration, …)
- physical analysis (conductivity, …)
- radiological analysis (activity, radionuclei concentration, …)

## *Water Filter / Ion Exchanger*

- extraction of dangerous or harmful particles / ions
  → maintain purity of water, i.e. keep its parameters constant
  → minimize concentration of $^7$Be in primary loop
  to avoid contamination of components due to adsorption on surfaces
  (esp. in heat exchanger due to thermal gradient)
  → accumulate and localize activity in filter

- reduction of saturation activity of nuclei with $\tau = t_{1/2} \cdot \ln 2$ by factor F

$$F = 1 + \varepsilon \cdot \beta \cdot \tau \cdot \frac{dm/dt}{M}$$

  $\varepsilon \equiv$ extraction efficiency of filter for ion of interest
  $\beta \equiv$ fraction of total mass flow dm/dt through filter
  M ≡ total water mass inventory of primary loop

  for $^7$Be: $F=10^3$ if $\varepsilon \cdot \beta = 1.5\%$ with $dm/dt=100$ kg/s, $M=10^4$ kg

- 1.5% of total flow through filter → saturation activity of $^7$Be reduced by $10^3$
  expected dose level at primary loop without filter ≈ 500mSv/h
  will drop to ≈0.5mSv/h (except for ion filter)
  → add shielding

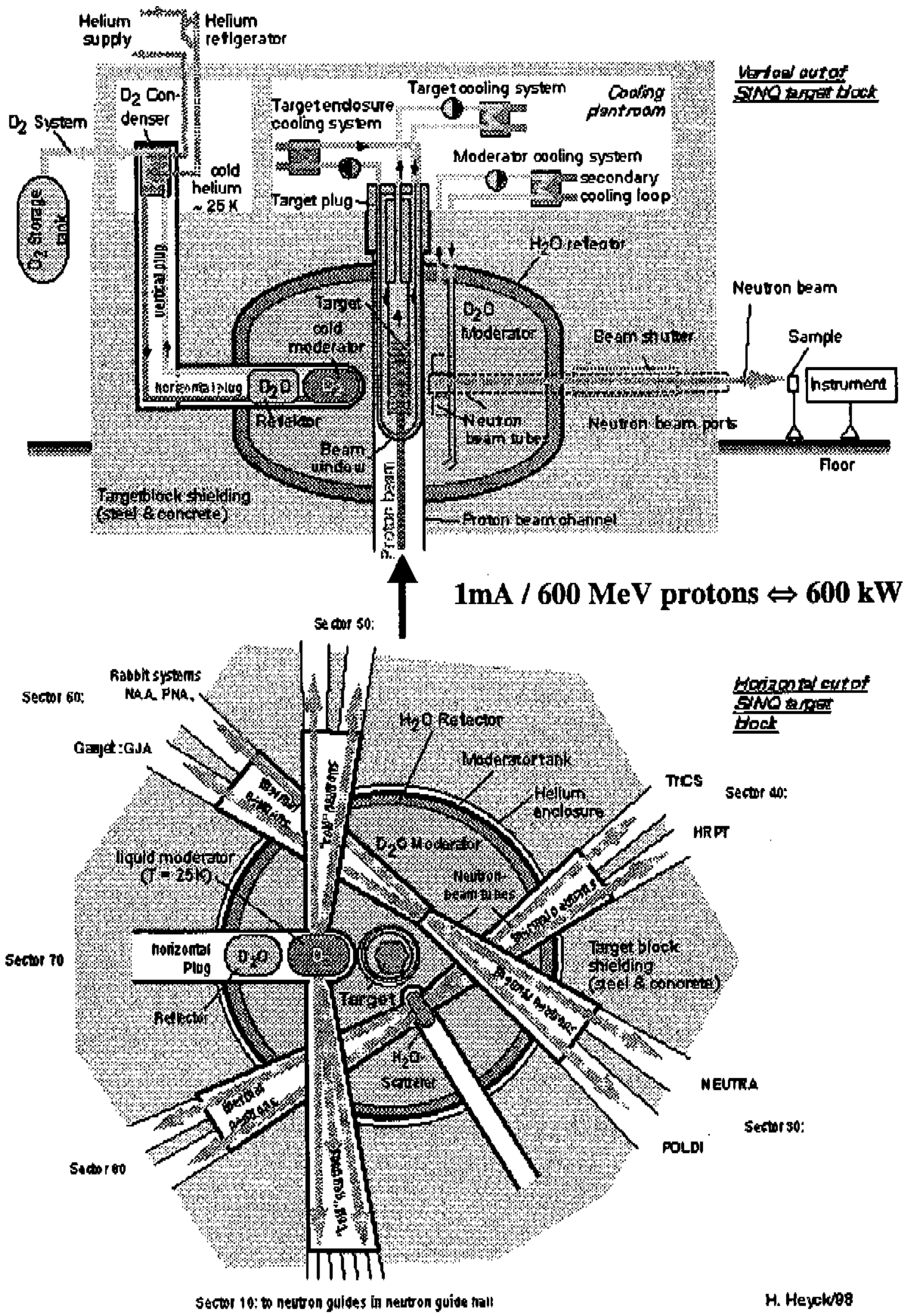
- filter shielded with ≈10cm Pb ⇔ $10^3$ reduction for ≤ 1MeV $\gamma$'s
  → directly at shielded filter: ≤ mSv/h
  whole water system shielded with ≈1m concrete ⇔ $10^3$ reduction for ≤ 1MeV $\gamma$'s
  → outside water system shielding: ≤ μSv/h

## *Delay Line*

- allow decay of short lived radionuclei
  → protects filter from radiation destruction, which affect its
  mechanical filter properties and / or ion exchange capability

# *C3.1: Comparison with Cooling System for SINQ at PSI*

***Principle of the Spallation Neutron Source SINQ***



1mA / 600 MeV protons ⇔ 600 kW

Spallation Neutron Source SINQ at PSI, schematic side and top view

## C3.1: Comparison with Cooling System for SINQ at PSI, cont'd

- central cooling plant with 4 individual cooling systems

| circuit | total power | total mass flow | medium | 7Be concentration reduction due to filter |
|---|---|---|---|---|
| target: | 650 kW | 15 kg/s | $D_2O$ | 760 |
| target window | 35 kW | 2 kg/s | $D_2O$ | 1000 |
| moderator | 111 kW | 2.9 kg/s | $D_2O$ | 610 |
| reflector | 211 kW | 8.4 kg/s | $H_2O$ | 750 |

- whole system gastight, made from stainless steel
- no hydrogen recombiner required
- max. measured 3H concentration: 12GBq/kg (moderator)
  → similar to what we expect at saturation: ≈ 15GBq/kg
- max. measured 7Be concentration with filter: 2MBq/kg (target)
  recalculated without filter: ≈1GBq/kg
  → factor 6 higher to what we expect at saturation : ≈ 6GBq/kg
- residual activity dominated by 7Be, adsorption on inner surfaces
  ≈100μSv/h in cooling plant, ≤1mSv/h at shielded ion filter or heat exchanger
  → with / without water does not make a difference to dose rate at components
  → strong recommendation to put emphasis on sufficient filtering
- neutron flux $\approx 10^{14}$ neutrons/s/cm$^2$ ,
  → $10^5$ times larger to what we expect

Compared to the 250GeV main linac dump cooling system is this one:

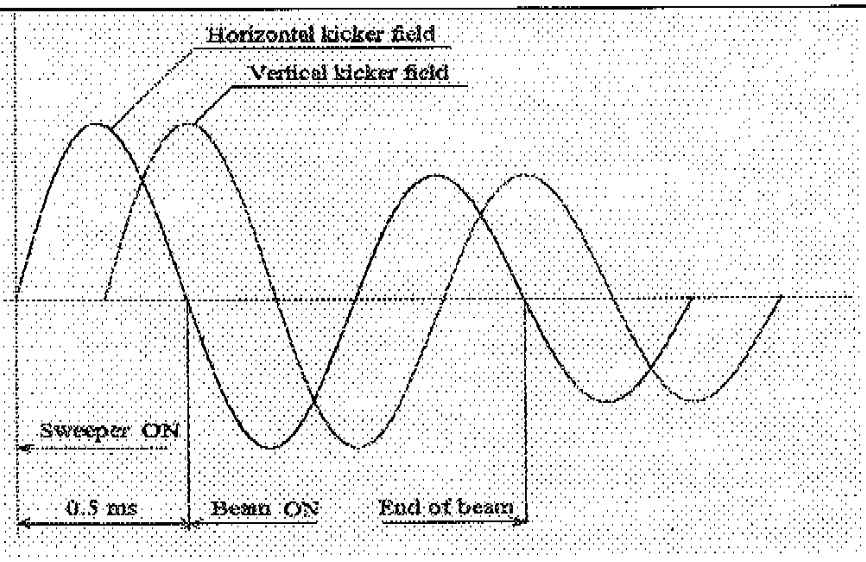
a factor of 20 smaller in terms of thermal power
a factor of 6 smaller in terms of mass flow
a factor $10^5$ more critical in terms of material ageing due to neutron flux
but quite comparable concerning radiological aspects

⇒ technology and experience in handling radioactive water systems exist
(also from research reactors, nuclear power stations, ...

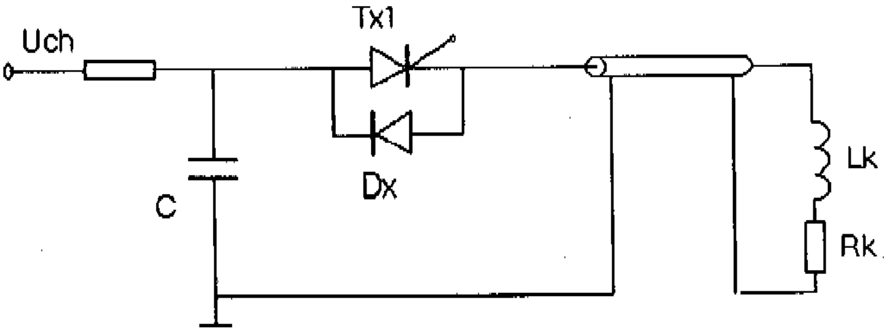
# C4: Beam Deflection Systems

## C4.1: Fast Sweeping

- fast means: beam sweeping within bunch train passage time
  → increases effective spot size by distributing bunches of a train
  along a circular line with radius R on the face of the dump
- hor. and vert. deflectors, excited at same frequency (≥1kHz), 90° phase shifted
- number of modules large enough to allow 1 to fail
- pulsed due to power reasons and triggered early enough to allow failure detection before next bunchtrain is started from injector



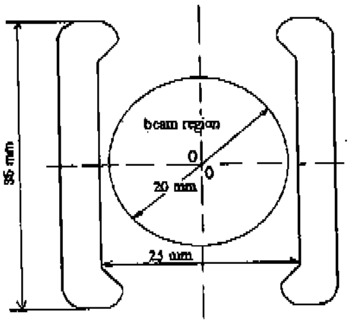
**Timing scheme to allow functioning check in order to inhibit beam operation**

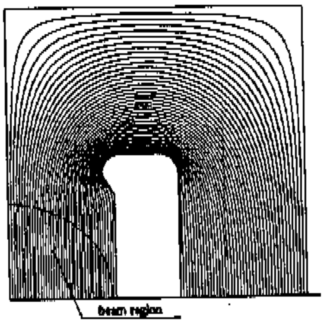


**Scheme of the pulsed power supply for the sweeper module**

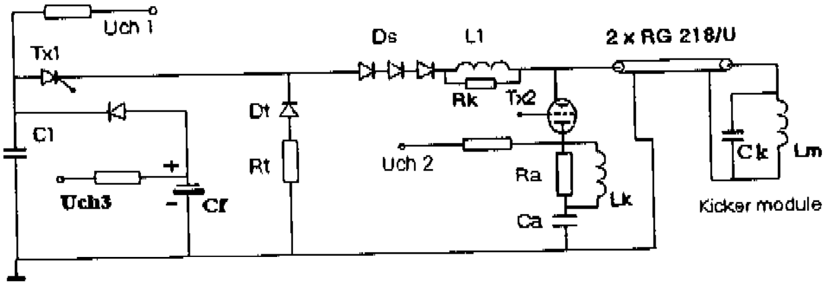
## C4.1: Emergency Extraction

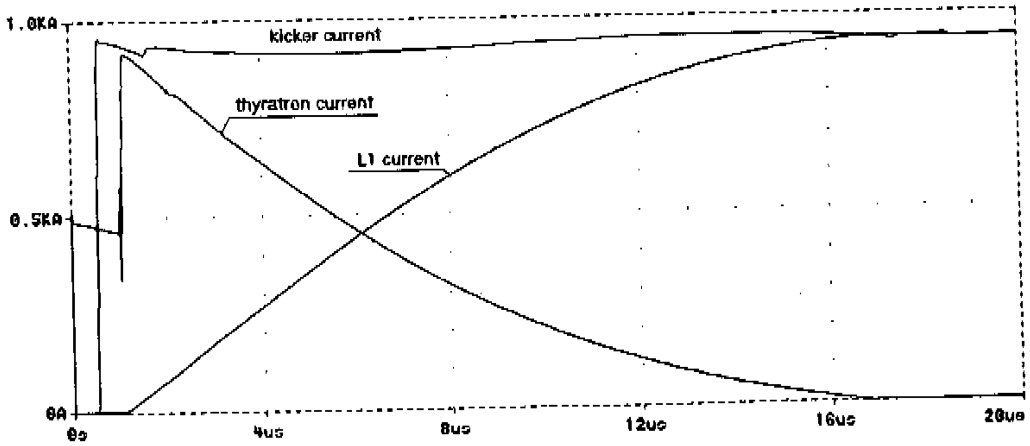
- **extract beam far upstream of IP in case of failure**
- **0.2mrad total kick, risetime 100ns, flat top ≥80μs, stability ±2.5%**
  **→ fast risetime combined with long flat top is challenging task**
- **missing kick of 3.5% allowed → 30 independent modules**
- **kicker inside vacuum chamber assumed**





- **fast thyratron circuit ($U_{ch2}$=20kV), slow C1-L1 circuit ($U_{ch1}$=$U_{ch2}$/10) and big Cf at ≈20V to compensate for current droop**





**⟹ needs more R&D**

# *D: Summary, Work to be done*

- water based system is the only reasonable and most flexible scheme,
  that can be applied for all high power beam dump systems at TESLA
  → variety of components and spare parts is limited
  (e.g. use same water vessel and window type for FEL and HEP dumps
- water vessel needs more detailed design work in terms of
  waterflow distribution in vessel and
  transient pressure development within one bunch train passage
- window construction on the way,
  but experimental tests are required to guarantee a reliable design
- technology on water systems exists,
  but careful design necessary in terms of failure handling:
  i.e. fast exchange of components, leakage scenarios, remote handling, robotics
- fast sweeper system is existing technology
- emergency extraction system is quite a challenge and
  needs definitely more R&D work

## *Material Properties*

| | | Be | C dense | C normal | Al | Ti | Fe | Cu | Pb | W | Concrete | Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | 9.01 | 12.01 | 12.01 | 26.98 | 47.88 | 55.85 | 63.54 | 207.2 | 183.9 | 20.5 | |
| Z | | 4 | 6 | 6 | 13 | 22 | 26 | 29 | 82 | 74 | 10.5 | 7.23 |
| Density | g/cm³ | 1.85 | 2.24 | 1.7 | 2.7 | 4.54 | 7.87 | 8.96 | 11.35 | 19.3 | 2.5 | 1 |
| rad. length Xo | cm | 35.3 | 19.1 | 25.1 | 8.9 | 3.56 | 1.76 | 1.44 | 0.56 | 0.35 | 10.7 | 36.1 |
| Ec | MeV | 111 | 76 | 76 | 40 | 24.4 | 20.7 | 18.8 | 7.4 | 8.2 | 57 | 80.3 |
| Rmoliere | cm | 6.68 | 5.28 | 6.94 | 4.67 | 3.06 | 1.79 | 1.61 | 1.59 | 0.896 | 3.94 | 9.44 |
| dE/dx min | MeV/cm | 2.61 | 3.99 | 3.03 | 4.37 | 6.85 | 11.6 | 12.9 | 11.7 | 21.1 | 3.68 | 2.03 |
| nucl.coll.length | cm | 30.2 | 29.9 | | 26.1 | | 10.5 | 9.6 | 10.2 | 5.72 | 27 | 60.1 |
| nucl. interaction length | cm | 40.6 | 38.5 | | 39.4 | 27.5 | 16.8 | 15.1 | 17.1 | 9.59 | 40 | 84.9 |
| melting temp | °C | 1280 | 3800 | 3800 | 659 | 1670 | 1536 | 1083 | 327 | 3380 | | 0 |
| boiling temp. | °C | 3000 | | | 2270 | 3280 | 3070 | 2585 | 1751 | 5500 | | 100 |
| spec. heat cap. | J/g/K | 1.02 | 0.71 | 0.71 | 0.94 | 0.52 | 0.47 | 0.39 | 0.13 | 0.134 | 0.88 | 4.19 |
| thermal conductivity | W/m/K | 165 | 168 | 168 | 204 | 15.5 | 81 | 384 | 34.7 | 130 | ~1 | 0.6 |
| therm. 1dim-expansion coeff. | E-6/K | 12.3 | 7.8 | 7.8 | 23.8 | 8.2 | 12 | 17 | 29 | 4.5 | 10 | |
| therm. 3dim-expansion coeff. | E-3/K | | | | | | | | | | | 0.18 |
| E-modul | GPa | 290 | 8.4 | 8.4 | 73 | 108 | 175 | 120 | 17 | 355 | | |
| plasticity limit | MPa | | 650 | 650 | 40-160 | 300-740 | 500 | 200-400 | 10-20 | 400-1500 | | |
| | | | | | | | | | | | | |
| average plasticity limit | MPa | | 650 | 650 | 100 | 500 | 500 | 300 | 15 | 900 | | |
| dTmax=plst.limit/(E*alpha) | °K | | 9921 | 9921 | 58 | 565 | 238 | 147 | 30 | 563 | | |
| dTmax=0.2*(Tmelt-20°C) | °K | 252 | 756 | 756 | 128 | 330 | 303 | 213 | 61 | 672 | | |
| | | | | | | | | | | | | |
| dTmax 1.) | °K | 252 | 756 | 756 | 58 | 330 | 238 | 147 | 30 | 563 | | 50 |
| | | | | | | | | | | | | |

1.) Min(plast.limit or 20%Tmelt) and 50°C for water