Energy recovery from Beam Dump, etc

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Plan of this talk

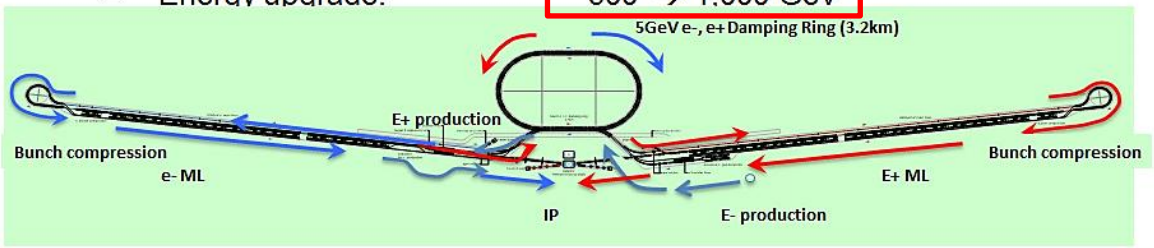
1. Introduction
2. Water beam dump designed in TDR
3. Alternative discussed design : noble gas dump
4. Collective deceleration for compact beam dump
5. Summary and outlook

1. Introduction

Beam dump from a view point of Green-ILC

Requirements from Physics Exp.

- Basic requirements :
  - Luminosity : $\int Ldt$ = 500 fb^{-1} in 4 years
  - E_{cm} : 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- Extension capability :
  - Energy upgrade: 500 → 1,000 GeV



1. Less radiation is more Green for the environment.
2. Bunch of energy is wasted here. (10MW)
   If energy can be recovered, it is further Green.

Obligation to Us

Infrastructure : 50 MW
RF System : 70 MW
Cryogenics : 70 MW
Beam Dump : 10 MW

200 MW

loss rate

50 % : 25 MW
50 % : 35 MW
90 % : 60 MW
100 % : 10 MW ← This talk

~ 130 MW ← Increase recovery

← Improve efficiencyçy

2. Water beam dump designed in TDR

8.8 Beam dumps and Collimators

8.8.1 Main Dumps

four dumps

10 bar water vessels

30cm diameter, 1mm thick Ti window

The beam-delivery system contains two tune-up dumps and two main beam dumps. These four dumps are all designed for a peak beam power at nominal parameters of 18 MW at 500 GeV per beam, which is also adequate for the 14 MW beam power of the 1 TeV upgrade. The dumps consist of 1.8 m-diameter cylindrical stainless-steel high-pressure (10 bar) water vessels with a 30 cm diameter, 1 mm-thick Ti window and also include their shielding and associated water systems (Fig. 8.15). The design [188] is based on the SLAC 2.2 MW water dump [189, 190].

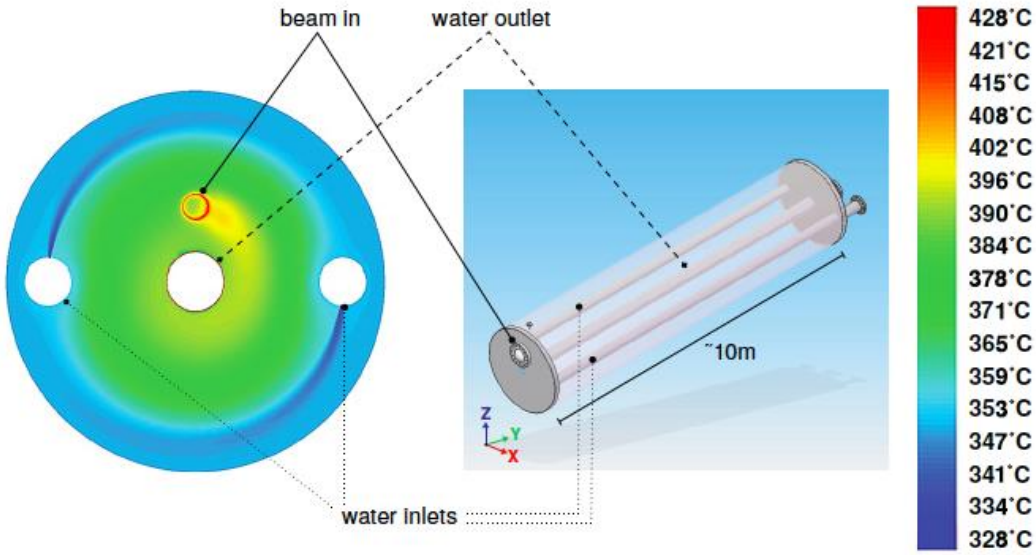


Figure 8.15 Temperature distribution at the shower maximum of the beam in the main 18 MW dump just after passage of the beam train (left). (The geometry of the dump is also shown on the right.) The colour bar shows temperature in kelvin; the maximum temperature is 155 °C [191].

The dumps absorb the energy of the electromagnetic shower cascade in 11 m ($30\,X_0$) of water. Each dump incorporates a beam-sweeping magnet system to move the charged beam spot in a circular arc of 6 cm radius during the passage of the 1 ms-long bunch train. Each dump operates at 10 bar pressure and also incorporates a vortex-flow system to keep the water moving across the beam. In normal operation with 500 GeV beam energy, the combination of the water velocity and the beam sweepers limits the water temperature rise during a bunch train to 155 °C [191]. The pressurisation raises the boiling temperature of the dump water; in the event of a failure of the sweeper, the dump can absorb up to 250 bunches without boiling the dump water.

8.8.1.2 Mitigation of water-activation products

Activation products are primarily the result of photo-spallation on ^{16}O, primarily ^{15}O, ^{13}N, ^{11}C, ^{7}Be and ^{3}H (tritium). The first three radionuclides have short half lives and decay after $\sim$ 3 hours. The ^{7}Be is removed from the system by filtering it out in a mixed-bed ion-exchange column located in the dump-support cavern. Tritium, a $\sim$ 20 keV β emitter with a half life of 12.3 years, builds up in the water to some equilibrium level; the tritium is contained by the integrity of the dump system and the backup measures described in the preceding section.

8.8.1.4 Shielding and protection of site ground water

Assuming a dry rock site, as in the baseline configuration, 50 cm of iron and 150 cm of concrete shielding are needed between the dump and other areas of the tunnel enclosure to protect equipment from radiation damage. If the chosen site is not dry, the area surrounding the dump must be enveloped by an additional 2 m-thick envelope of concrete to prevent tritium production in the ground water.

Scheme of the water system for the water beam dump

TESLA

DESY, February 2001, TESLA Report 2001-04

Concept of the High Power $e^{\pm}$ Beam Dumps for TESLA

W. Bialowons, M. Maslov, M. Schmitz, V. Sytchev

- 70°C hot water can be obtained.

- Energy recovery

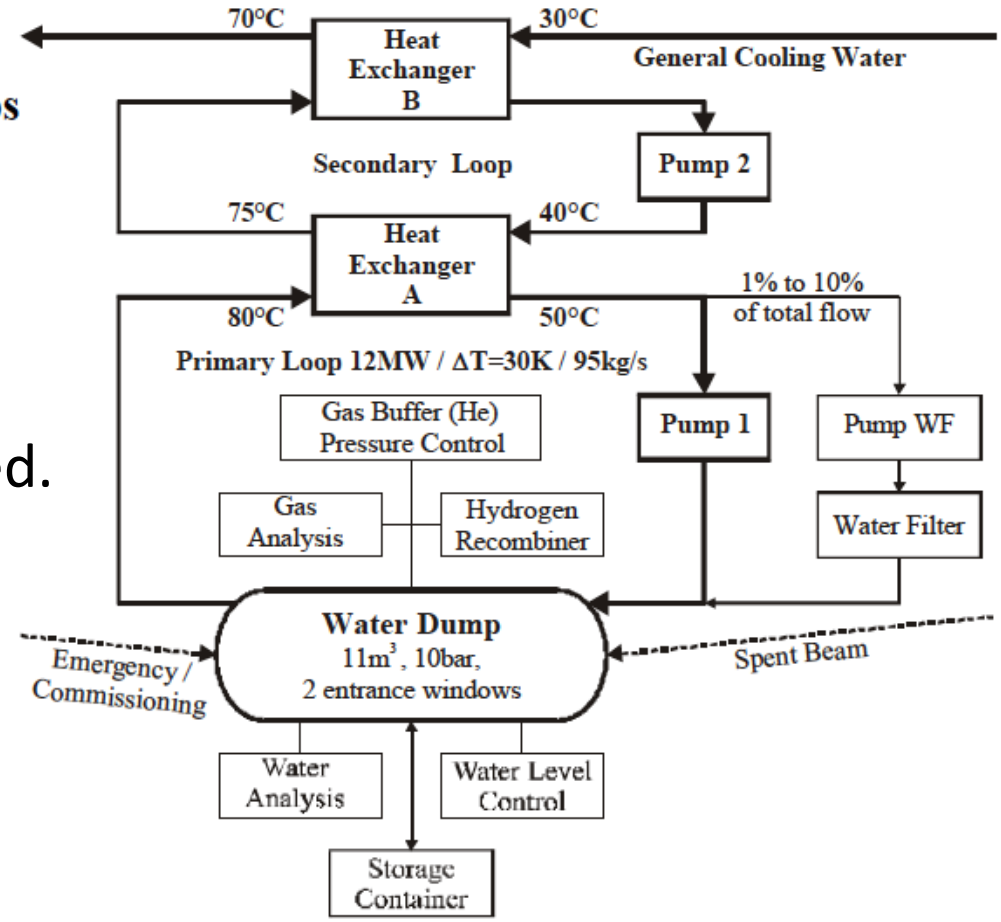
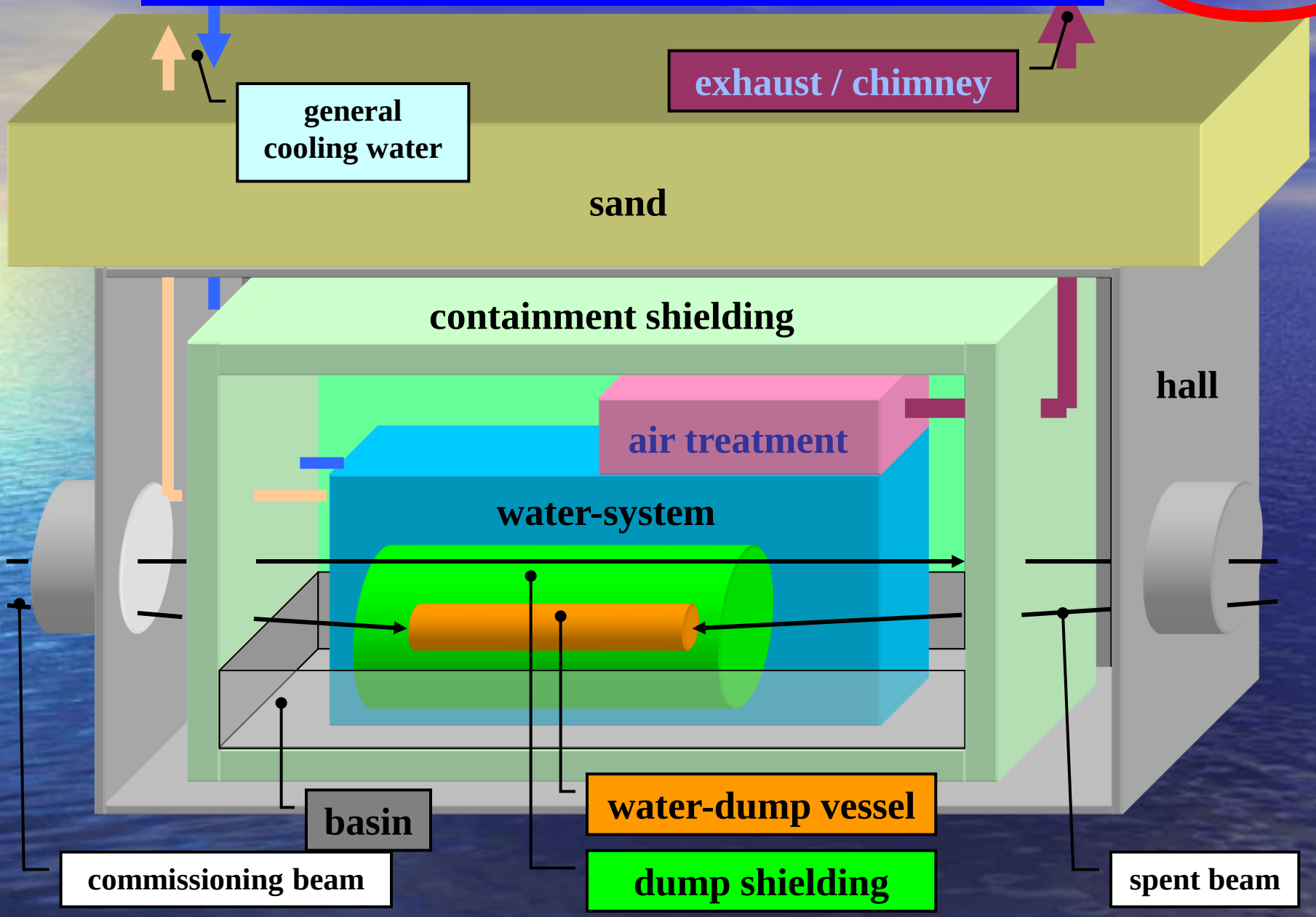


Figure 6: Scheme of the water system for the water based beam dump

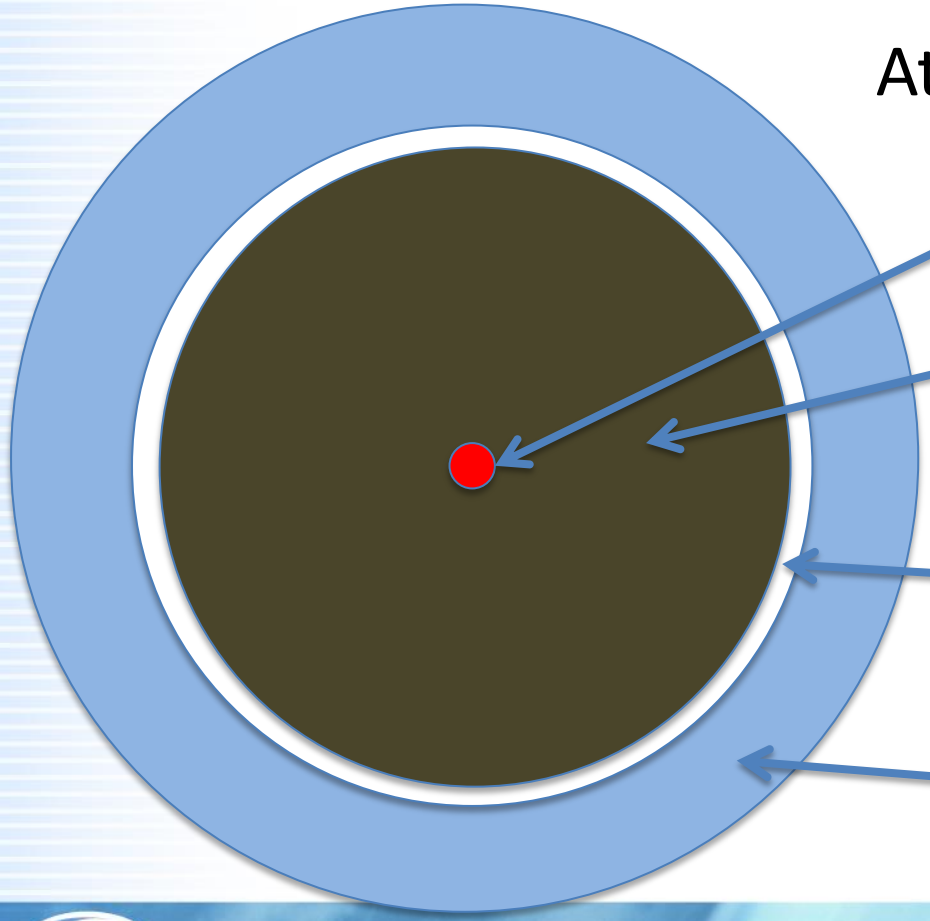
A.3 Schematic Layout of Water Beam Dump



3. Alternative discussed design: noble gas dump

Based on “Another idea of a LC dump”
by Albrecht Leuschner 16/09/2003

Cross section of a tunnel



At a Length of 1000m

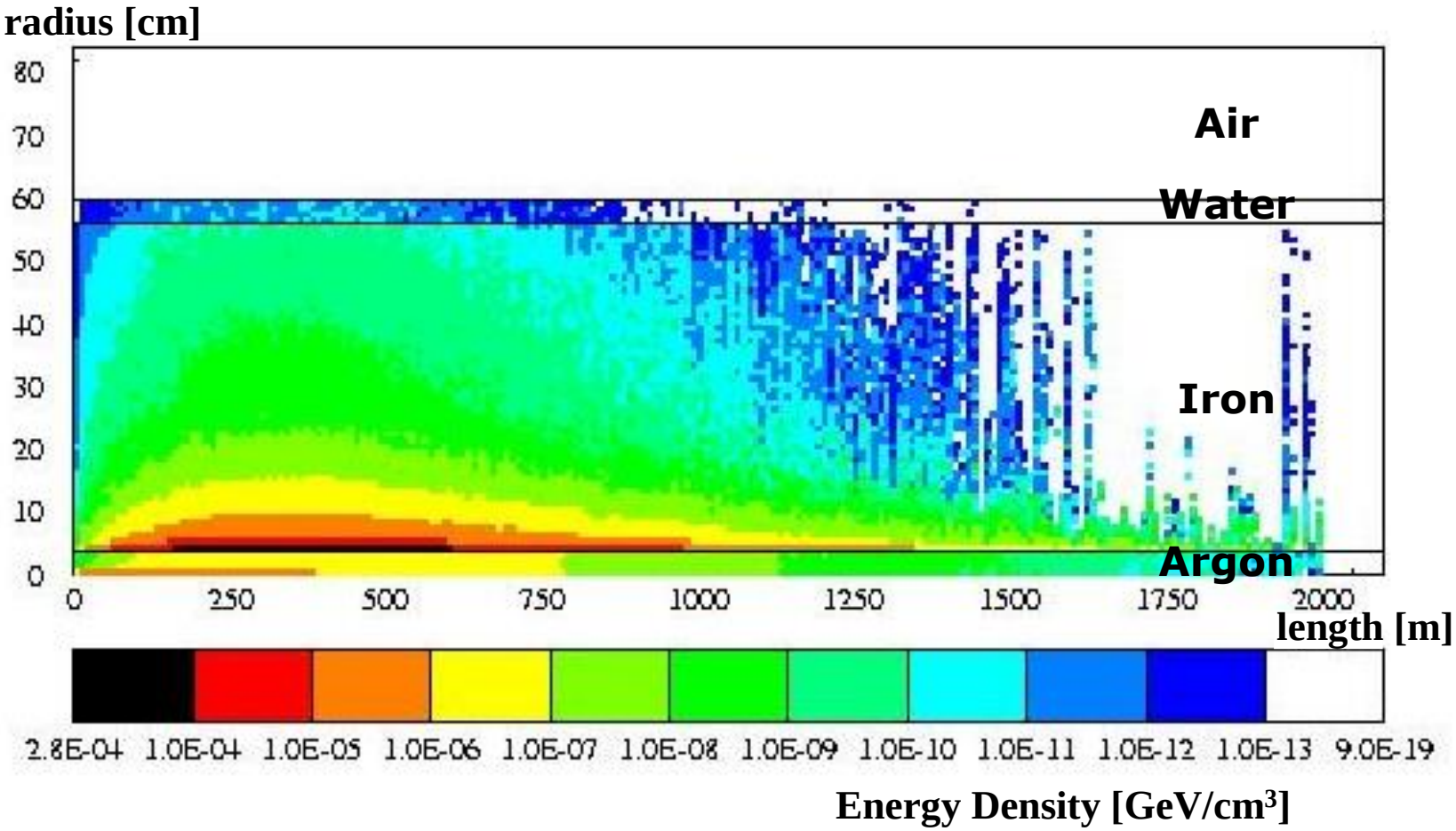
Ar filled beam pipe

Iron Cylinder

Water cooling

Air

Energy deposition with 400 GeV electron



Pros/cons

	Water dump	Gas dump
length	10 m	1000 m
Window pressure	10 bar static, 0.5 bar dyn.	1 bar static, 0.01 bar dyn
Window diameter	30 cm	8 cm
Hydrogen gas producing	Several liter/sec @ 20 MW	no
Tritium production	300 TBq	30 TBq (in Iron)
Component Activity	1.2 mSv/h	~ 1 … 10 mSv/h

4. Collective deceleration for compact beam dump

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Collective deceleration: Toward a compact beam dump

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(Received 10 December 2009; published 5 October 2010)

Bethe-Bloch formula for stopping power in material

$$-(dE/dx)_I = (F/\beta^2)[\ln(2m_e\gamma^2 v^2/I) - \beta^2], \quad (1)$$

where E is the electron kinetic energy, $F = 4\pi e^4 n_{e,m}/m_e c^2 = e^2 k_{pe,m}^2$, $n_{e,m}$ is the electron density in the stopping material, $k_{pe,m} = \omega_{pe,m}/c$ is the plasma wave number, and $\beta = v/c$ is the normalized electron velocity.

The collective stopping power for wakefield deceleration of the electron bunch is large;

$$-(dE/dx)_{\text{coll-wave break}} = m_e c \omega_{pe} (n_b/n_e). \qquad (5)$$

Equation (5) is exact for the resonant excitation of a wake-field with bunch length $\sigma_L/\lambda_{pe} \approx 0.5$, transverse size $\sigma_T/\lambda_{pe} \geq 0.3$, and modest density ratio $n_b/n_e < 10$

where λ_{pe} is the plasma wavelength of the background plasma with density n_e, n_b is the bunch density.

For a long beam $\sigma_L/\lambda_{pe} \gg 1$, the stopping power decreases exponentially with the factor $k_{pe}\sigma_L \times \exp(-k_{pe}^2\sigma_L^2/2)$. For a narrow beam $\sigma_T/\lambda_{pe} \ll 1$, the stopping power decreases with the factor $k_{pe}^2\sigma_T^2$.

From $\sigma_L/\lambda_{pe} = ½$, then $\sigma_L = \pi\ c/\omega_{pe}$ and $n_b = N_b/(\sigma_L \sigma_T^2)$
where N_b is number of particles in a bunch.

$-(dE/dx)_{coll\text{-}wave\ break}$ [GeV/cm] = 5.74 × N_b/σ_T^2[cm]

means

L_{dump}[m] = 1.7 × 10^{13} σ_T^2/N_b E_0[GeV], w/ $\sigma_T > 0.6\ \sigma_L$

In the case of ILC, N_b=2 × 10^{10}, E_0=500 GeV,

L_{dump}[m] = 4.3 × 10^5 σ_T^2[cm]
= 130 m w/ σ_L = 300 μ m, σ_T = 0.6 × σ_L = 180 μ m
= 10 m w/ σ_T = 50 μ m, σ_L = σ_T/0.6 = 83 μ m

< 1000 m

Energy recovery from plasma wakefield

- The paper claimed that "in principle, the energies from the decelerated beams deposited in the form of organized plasma wakefield may be recovered into electricity."
- Any electric circuit such as a metallic loop in the plasma picks up coherent electric currents caused by the plasma collective oscillations. Then, external circuit extract electric energies rather than heat.
- "Because the energy of the plasma electrons is much less than that of the beam electrons, the collisions do not give rise to excessive radioactivation."

6. Summary and outlook

- The water dup system in TDR is well studied and a lot of simulation have been carried out.
- It, however, has issues to further study points;
  (1) Dump window with 10 bar,
  (2) Treatment of Hydrogen gas production,
  (3) Mitigation of water-activation products,
  (4) 70^{o}C hot-water can be obtained

- Gas dump design
  - (1) No dump window problem because of 1 bar
  - (2) No hydrogen gas production problem
  - (3) Less iron-activation
  - (4) too long facility (1000 m and 4 dumps)
- Collective deceleration dump
  - (1) maybe no dump window problem
  - (2) maybe no hydrogen gas production problem
  - (3) Less activation
  - (4) More or less short length facility
  - (5) Electricity can be extracted as electric energies

- From the view point of Green-ILC, it is worth to study the possibilities to apply collective deceleration dump system.
- It should be checked that it works for the ILC long beam condition.
- It may be better to introduce the bunch compression after the collision point for the better condition to shorten the length of the beam dump facility.
- Efficiency of recovering energy is most important from the view point of Green-ILC