Heat and Radiation in the Water and Shielding in the18 MW Water Dump for ILC

Preliminary Results from FLUKA and FLUENT Computational Fluid Dynamics

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Reporting for SLAC-BARC Dump Group

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Starting Point for This Work

- SLAC 2.2 MW Water Dump, The Stanford Two-Mile Accelerator, R.B. Neal Ed, (1968).
- High Power Water Beam Dump for a LC, M. Schmitz, TESLA Collaboration Meeting, 16 Sept 2003.
- ILC Main Beam Dumps -- Concept of a Water Dump, D. Walz Snowmass, 18 Aug 2005.
- Dumps and Collimators, ILC Reference Design Report, 2007

The conclusion of this work is that the 18 MW Dump would be:

- High pressure (~10 atm) water rapidly circulated to remove heat by bulk mass flow.
- Instantaneous water temperature not to exceed 180 deg C (boiling point).
- Water cooled in two- or three-loop circulation to heat exchangers.
- Entrance window is thin Ti alloy with special cooling.
- Beam spot must be swept at radius large enough to reduce max heat density during one bunch train to prevent water boiling and window failure.

Many details to be worked out -- that's our goal.

Goals for This Work

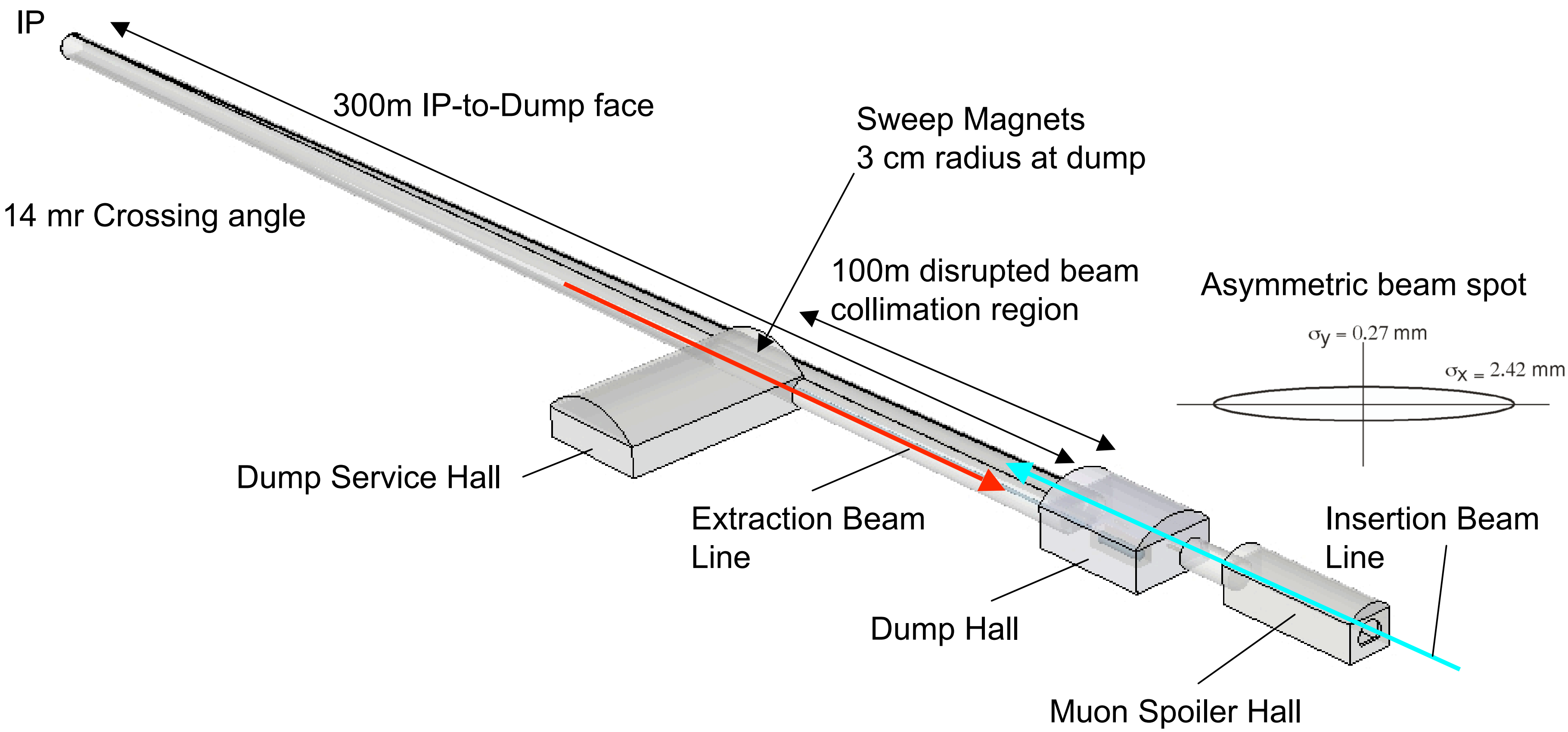
Studies of Heat and Radiation

- Study maximum heat density deposited for asymmetric beam spots and various sweep radii.
- Study thermal, mechanical, and hydrodynamic parameters for high-pressure, high-volume water flow to remove 18 MW while not boiling the water.
- Determine parameters for water tank, inlet and outlet headers, cooling loops that can lead to realistic design.
- Study prompt and residual radiation for realistic water tank, windows and shielding.
- Determine options for practical and adequate shielding.
- Explore ways to minimize costs.

Studies of Mechanical Design for Tank, Windows, and Window Changers, see John Amann's Talk

Beam Parameters and Layout - ILC RDR

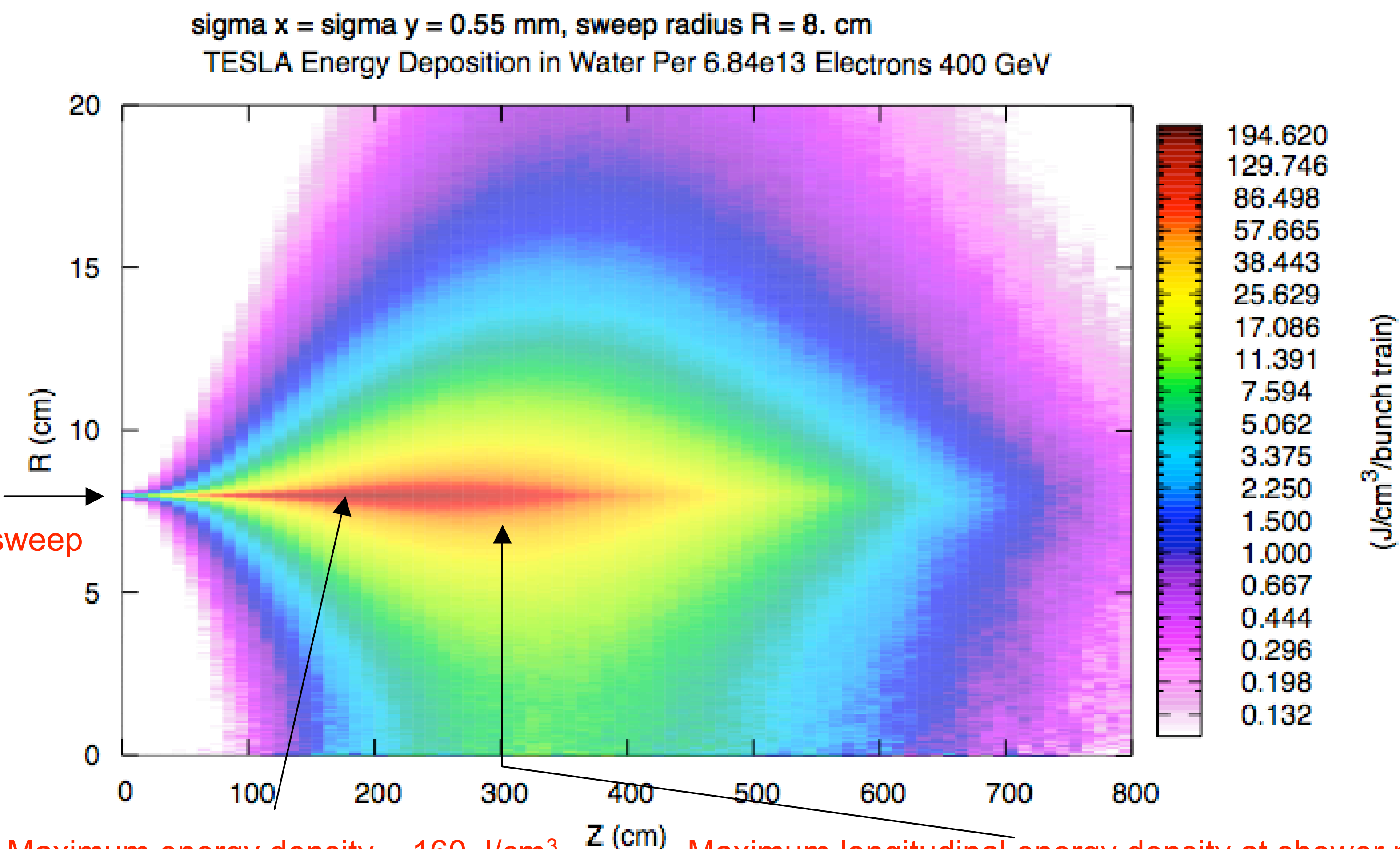
Beam: 500 GeV
4 Hz bunch train/sec, 2820 bunches/train, $2X10^{10}$ e^-/bunch
18 MW



Verification of Deposited Energy Density for TESLA Round Beam

High Power Water Beam Dump for a LC, M. Schmitz,
TESLA Collaboration Meeting, 16 Sept 2003.

Fluka[1] results, binned in R-ϕ-Z, summed over ϕ



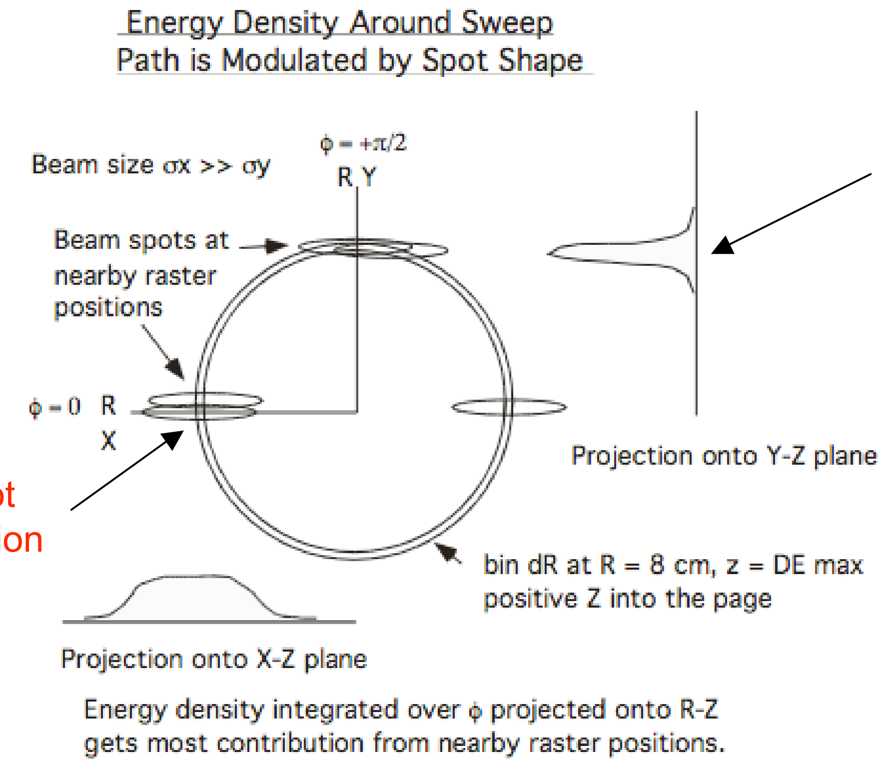
8 cm sweep radius

Maximum energy density ~ 160 J/cm^3

Maximum longitudinal energy density at shower max

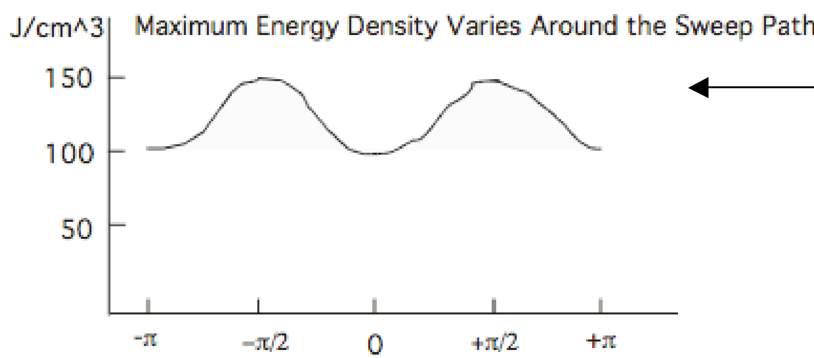
(1) - A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, "FLUKA: a multi-particle transport code", CERN 2005-10 (2005), INFN/TC_05/11, SLAC-R-773

Effect on Maximum Energy Density from Sweeping Asymmetric Beam Spot



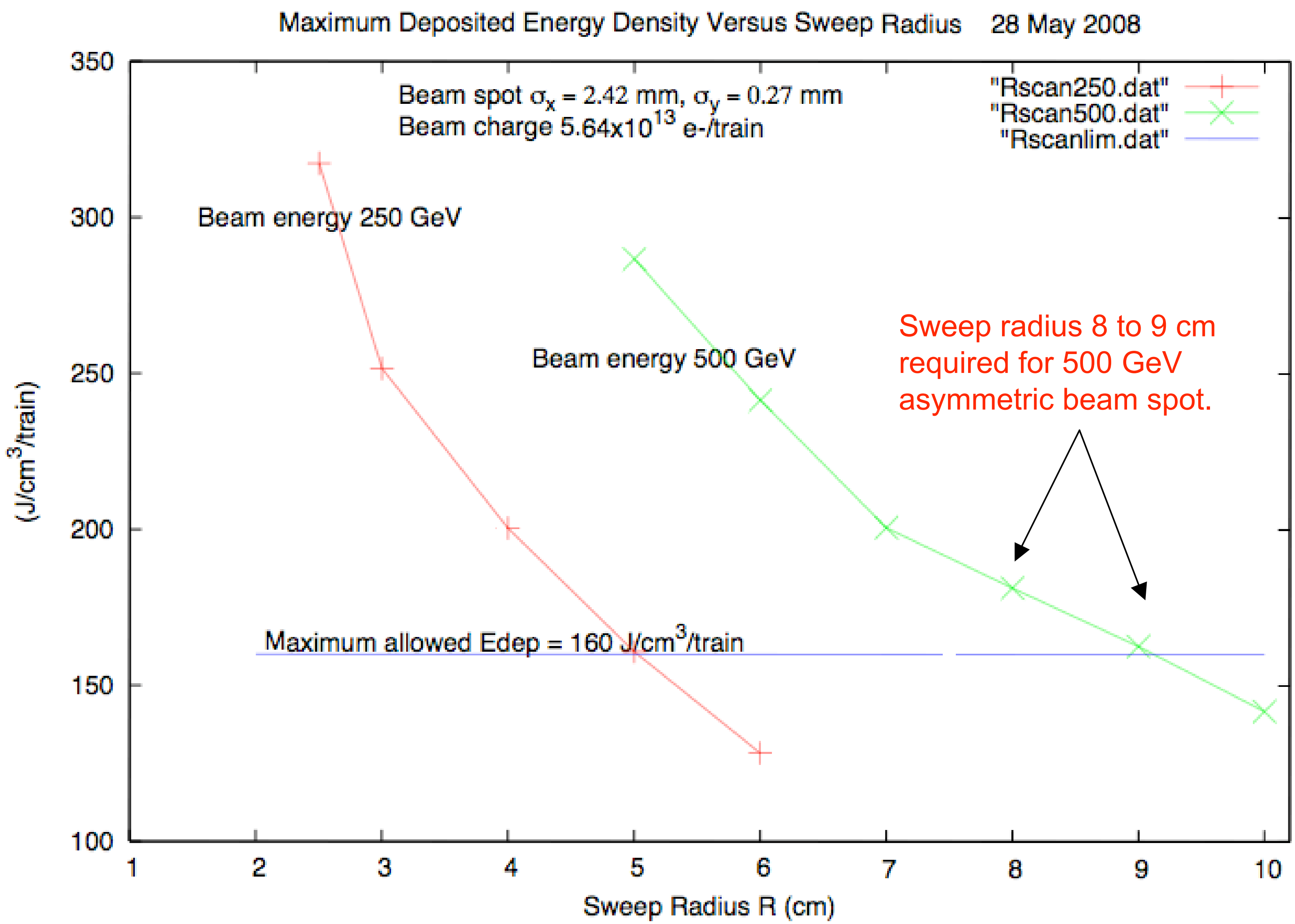
Energy density hot spot when sweep is in direction of long axis

Energy density cool spot when sweep is in direction of short axis



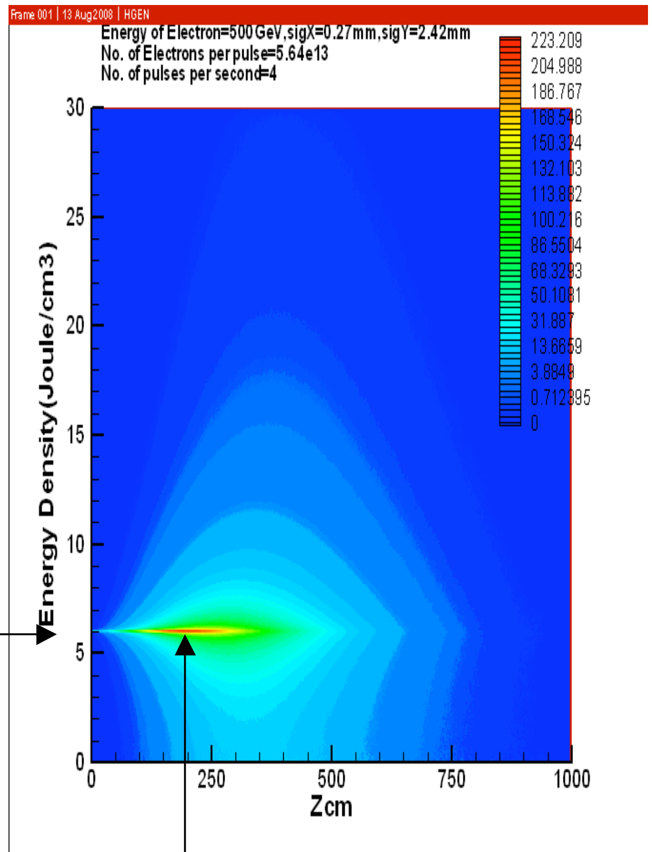
Design sweep radius and water cooling for the hot spots

Effect of Sweep Radius on Maximum Energy Density

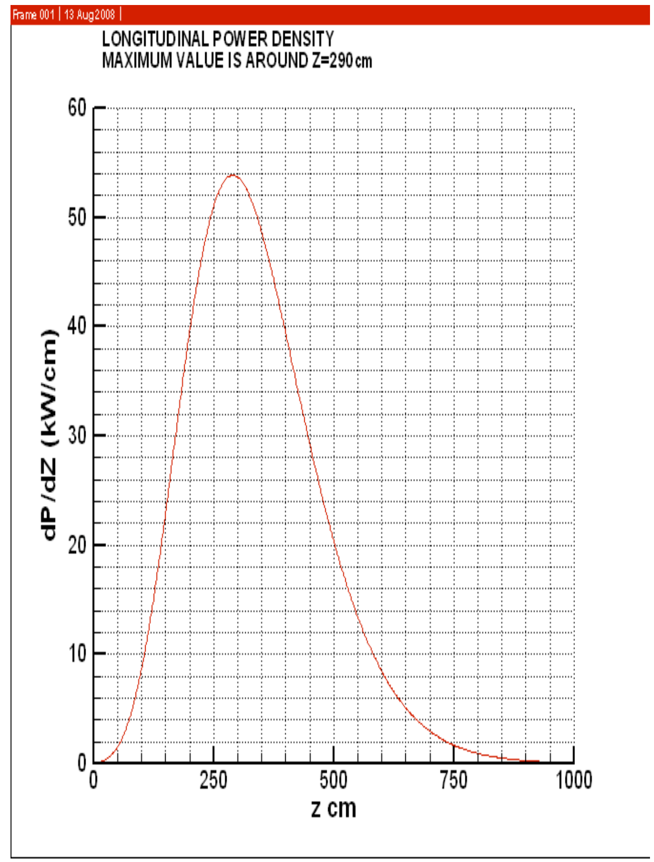


Study Water Temperature Variation in Space and Time

Fluka results for 500 GeV beam with asymmetric spot for input to
CFD analysis with FLUENT 6.3 by P. Satyamurthy and colleagues, BARC.



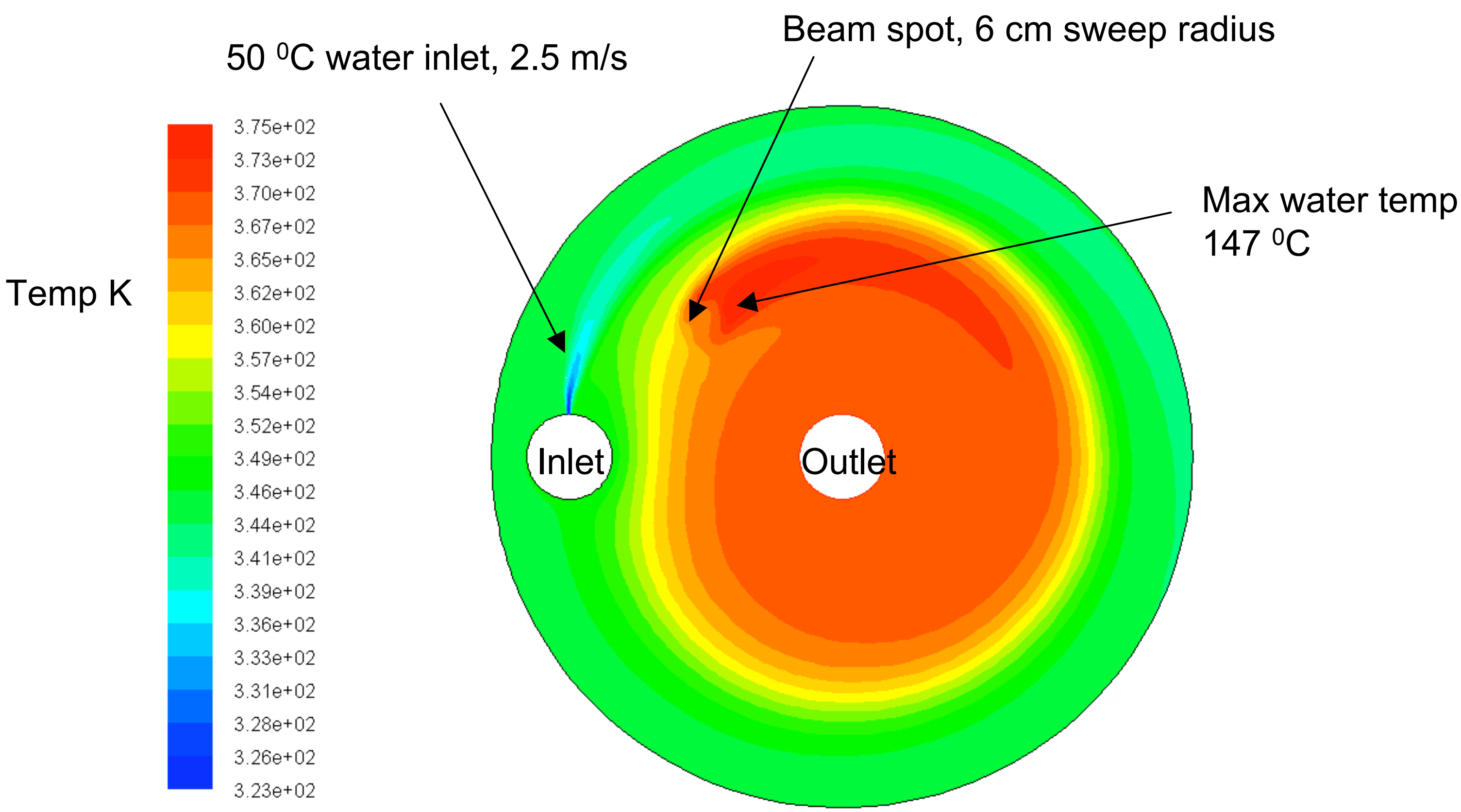
6 cm sweep



Next slide shows 2-D steady state solution for thin slice in z at energy density maximum z =1.82 m

Space Distribution of Steady State Water Temperature

Use 2-D FLUENT models to study water velocity, header size, beam spot location, sweep radius.

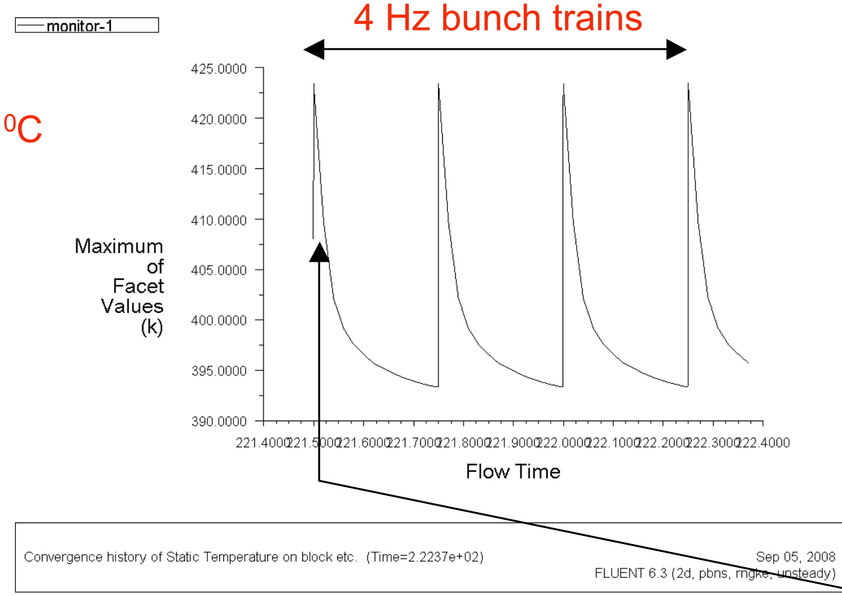


Temperature contours for CASE 5b (At location of Z=1.82 m for 2.50 m/s nozzle velocity without blocking outlet)

Time Dependence of Water Temperature

Water inlet T = 50 ^{0}C

4 Hz bunch trains

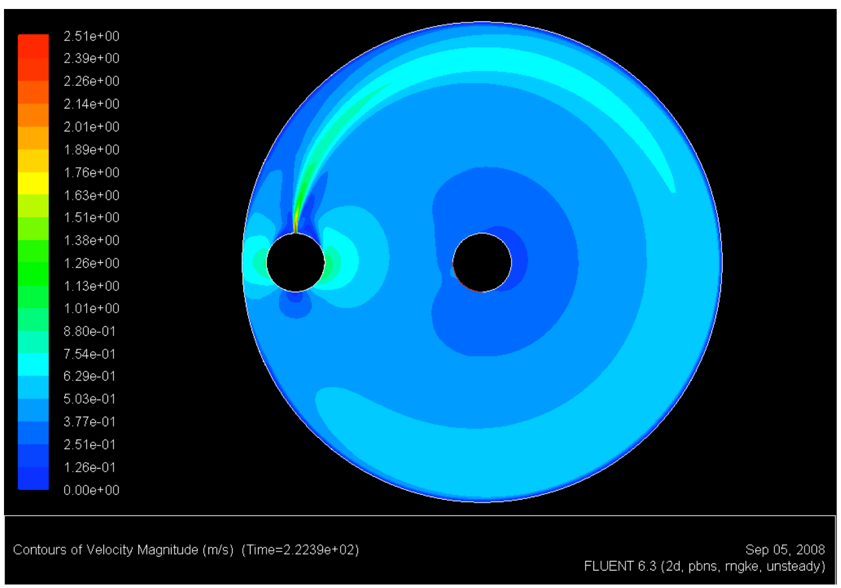


Transient max T ~152 ^{0}C
Water does not boil.

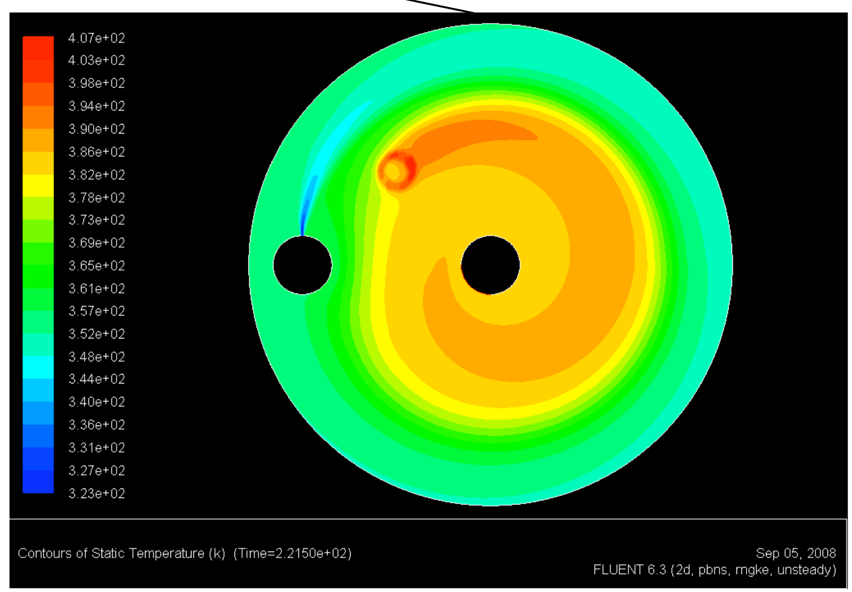
$\Delta T \sim 32\ ^0C$

Steady state T ~ 120 ^{0}C

Temperature at the hottest time just after one bunch train



Velocity distribution at 222.3 seconds

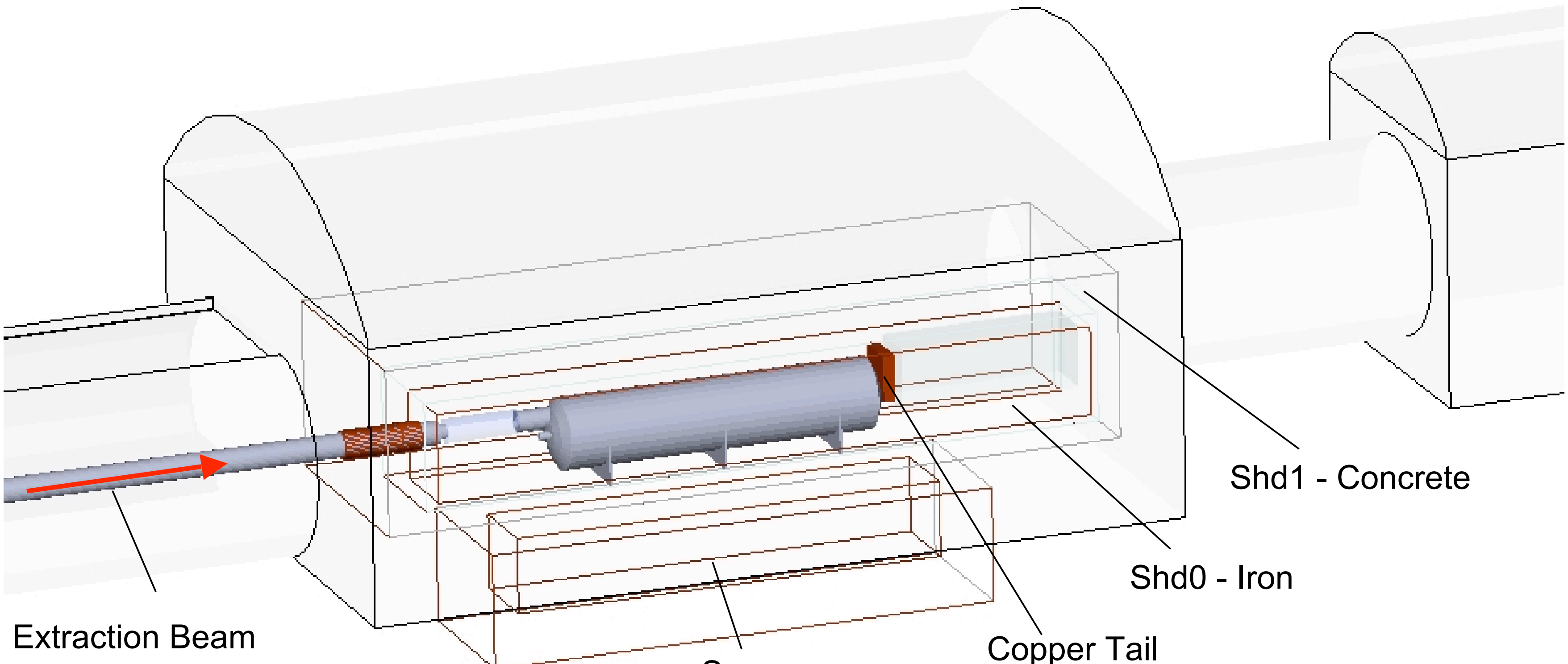


Temperature Distrubution at 221.5 seconds

Radiation and Shielding - Dump Hall-Tank Geometry Version 1

Modeled on 2.2 MW SLAC Beam Dump East.
Tank in open area covered with shielding.
External Tail Catcher and Back Stop.
Open sump for emergency water containment.
Shielding per ILC RDR - 50 cm Iron + 150 cm Concrete.
FLUKA[1] simulations of primary beam only, no disruption, no beam sweeping.

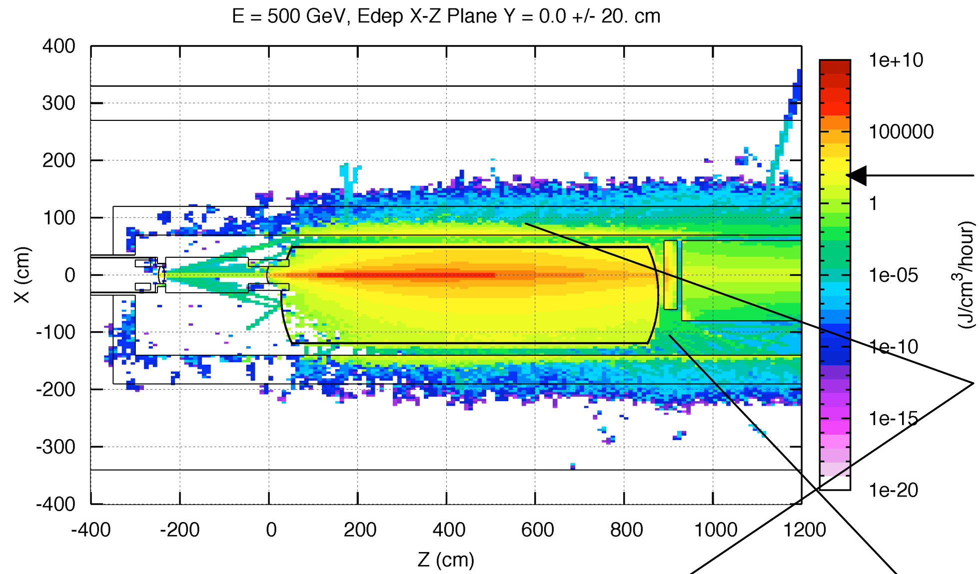
Not a good plan



(1) - A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, "FLUKA: a multi-particle transport code", CERN 2005-10 (2005), INFN/TC_05/11, SLAC-R-773

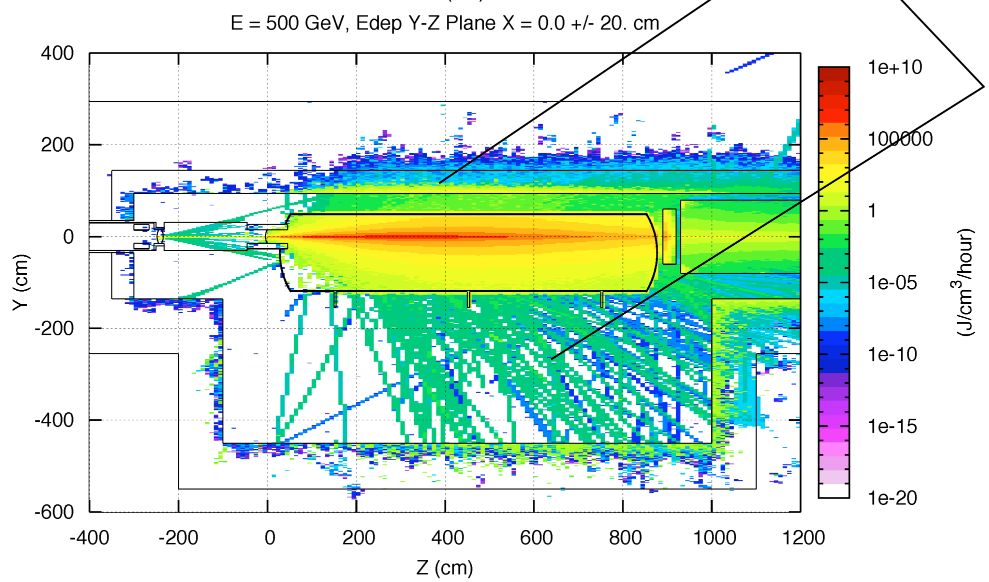
Prompt Energy Deposition - J/cm^3/hour - Geometry V1

Plan View



ΔT ~ 25 ^{0}C/hour

Elevation View



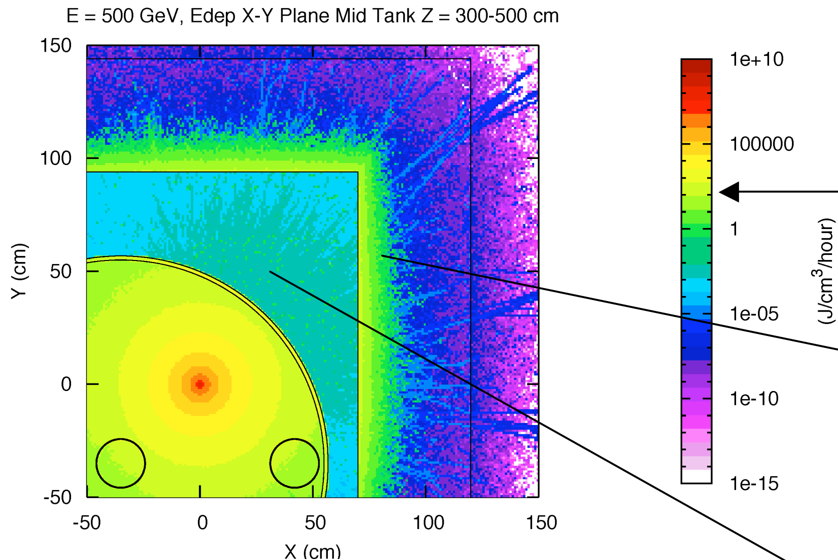
Problems

Large Edep in shield gives large temp increase, many ^{0}C/hour without active cooling

Large volume of activated air

Prompt Energy Deposition - J/cm^3/hour - Geometry V1

Section View
Mid Tank

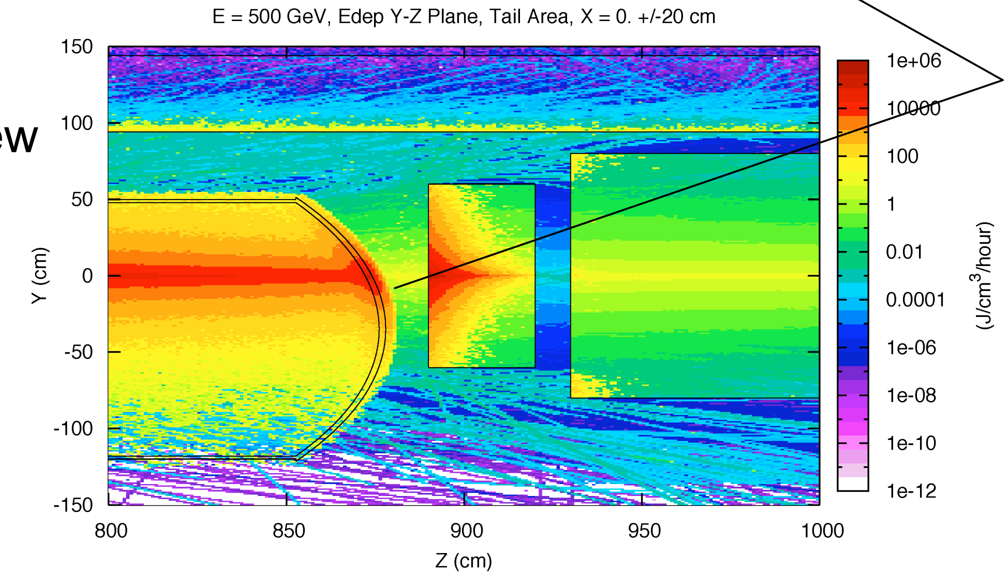


$\Delta T \sim 25\ ^0C$/hour

Problems

Large Edep in shield gives large temp increase, many ^0C/hour without active cooling

Elevation View
Tail Catcher



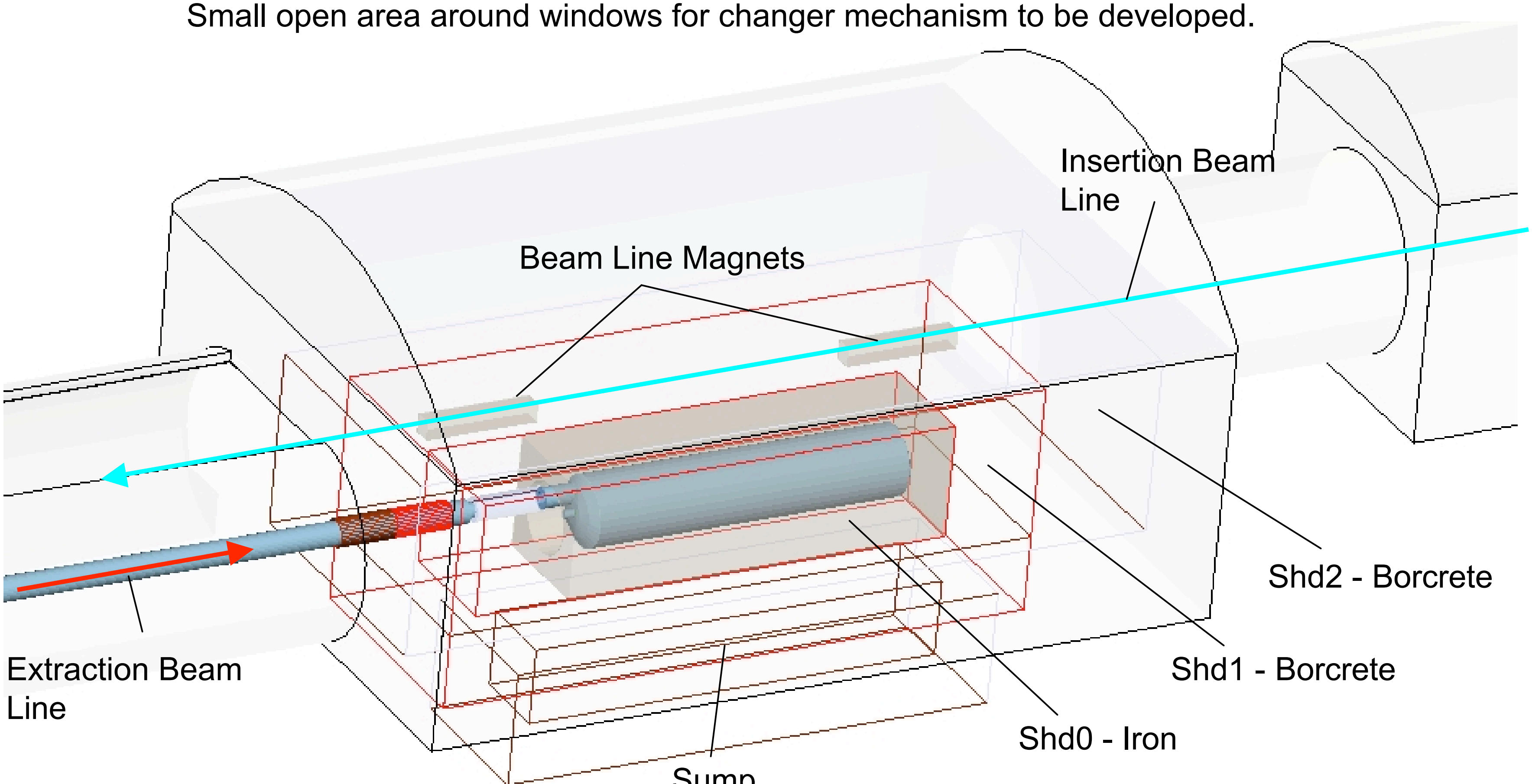
Large volume of activated air

Independent tail catcher:
-> large Edep in tank end wall
-> requires separate water
-> leaves gaps for air activation

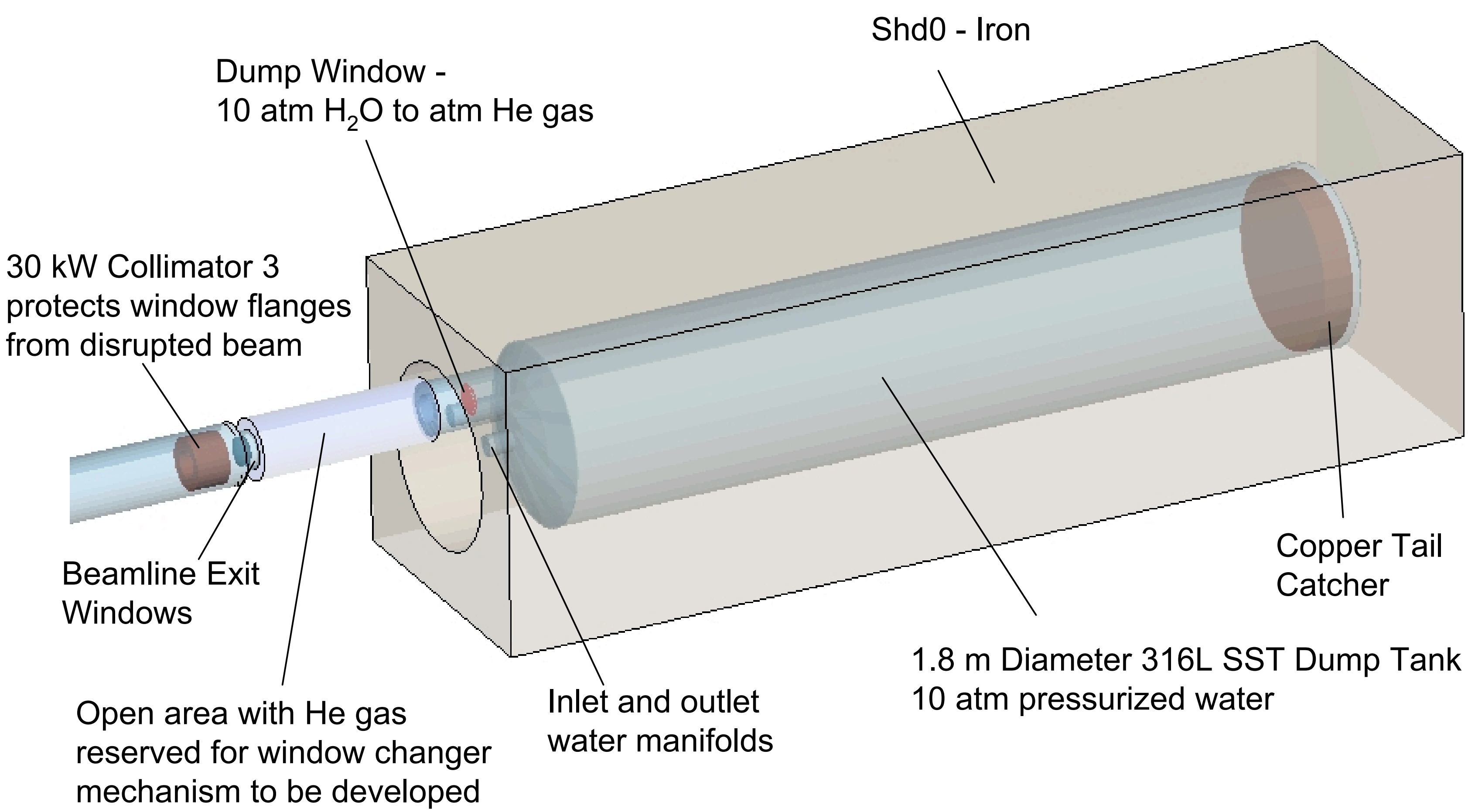
Dump Hall - Tank - Geometry Version 2

Surround Dump Tank with 50 cm Iron + ~200 cm Borcrete (Concrete + 5% Boron).
Minimize volume of activated air.
Tail Catcher inside Dump Tank.
Small open area around windows for changer mechanism to be developed.

This plan can work.



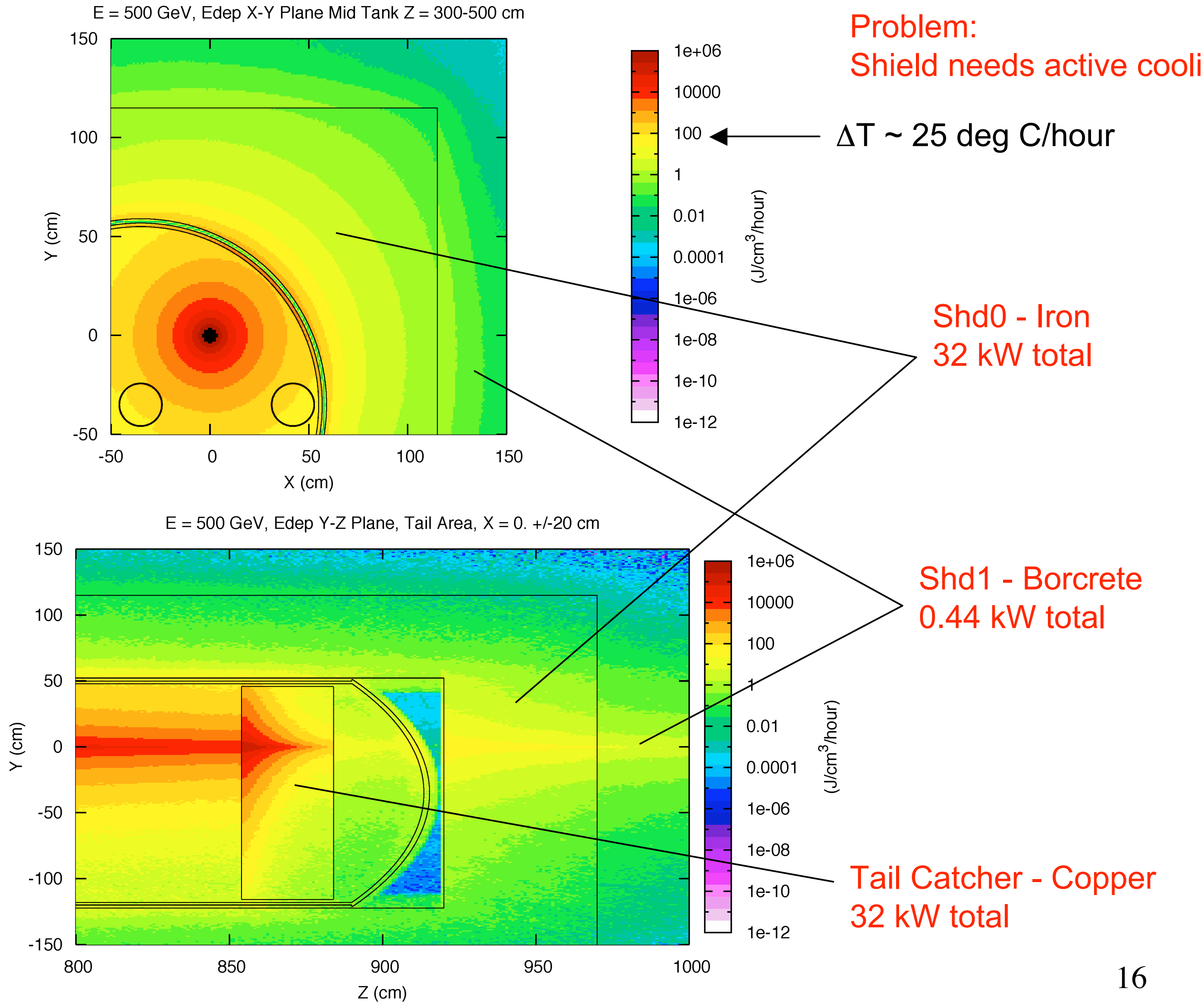
Dump Tank - Shd0 - Windows - Geometry Version 2



Prompt Energy Deposition - J/cm^3/hour - Geometry V2

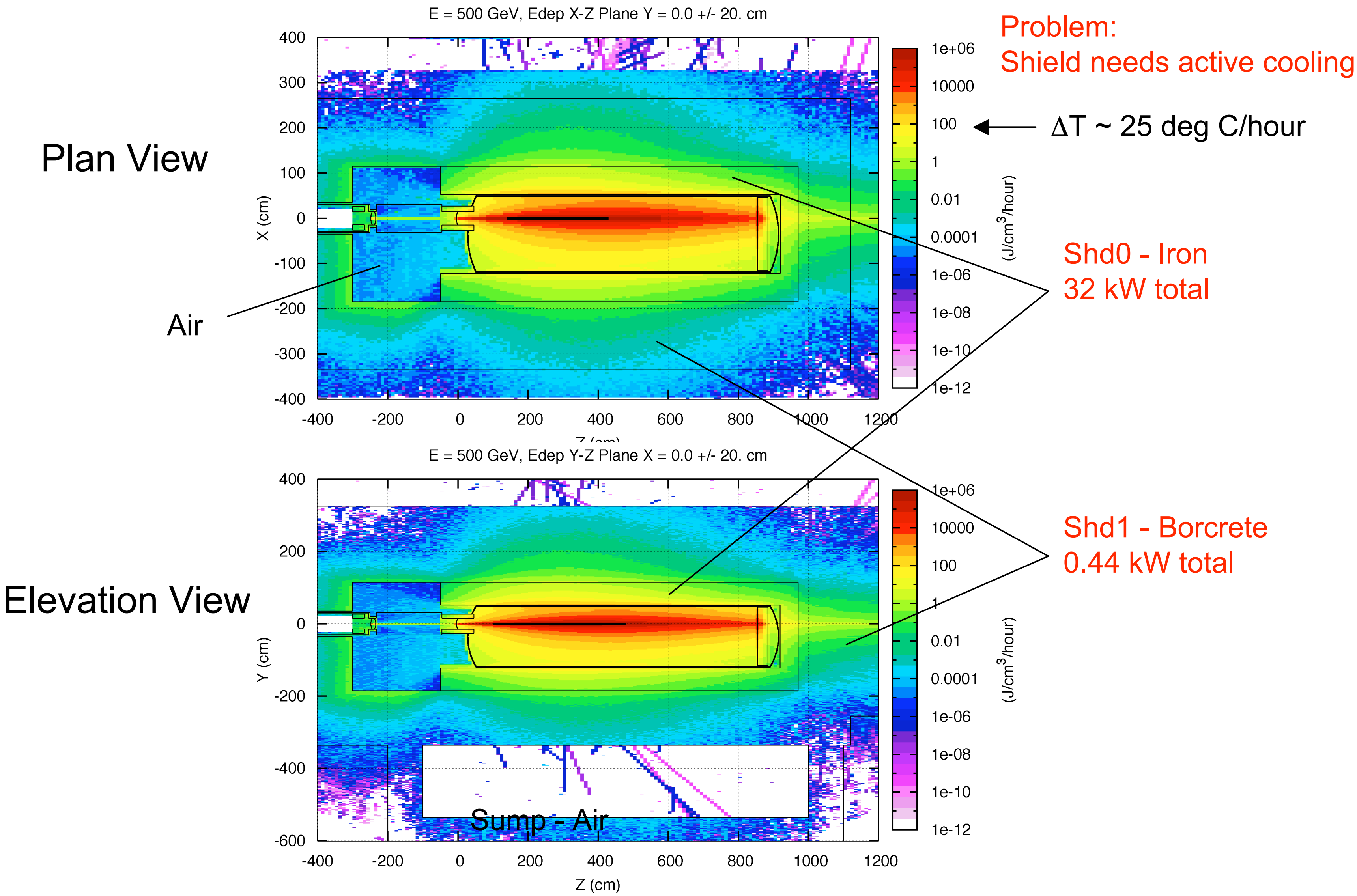
Section View
Mid Tank

Elevation View
Tail Catcher



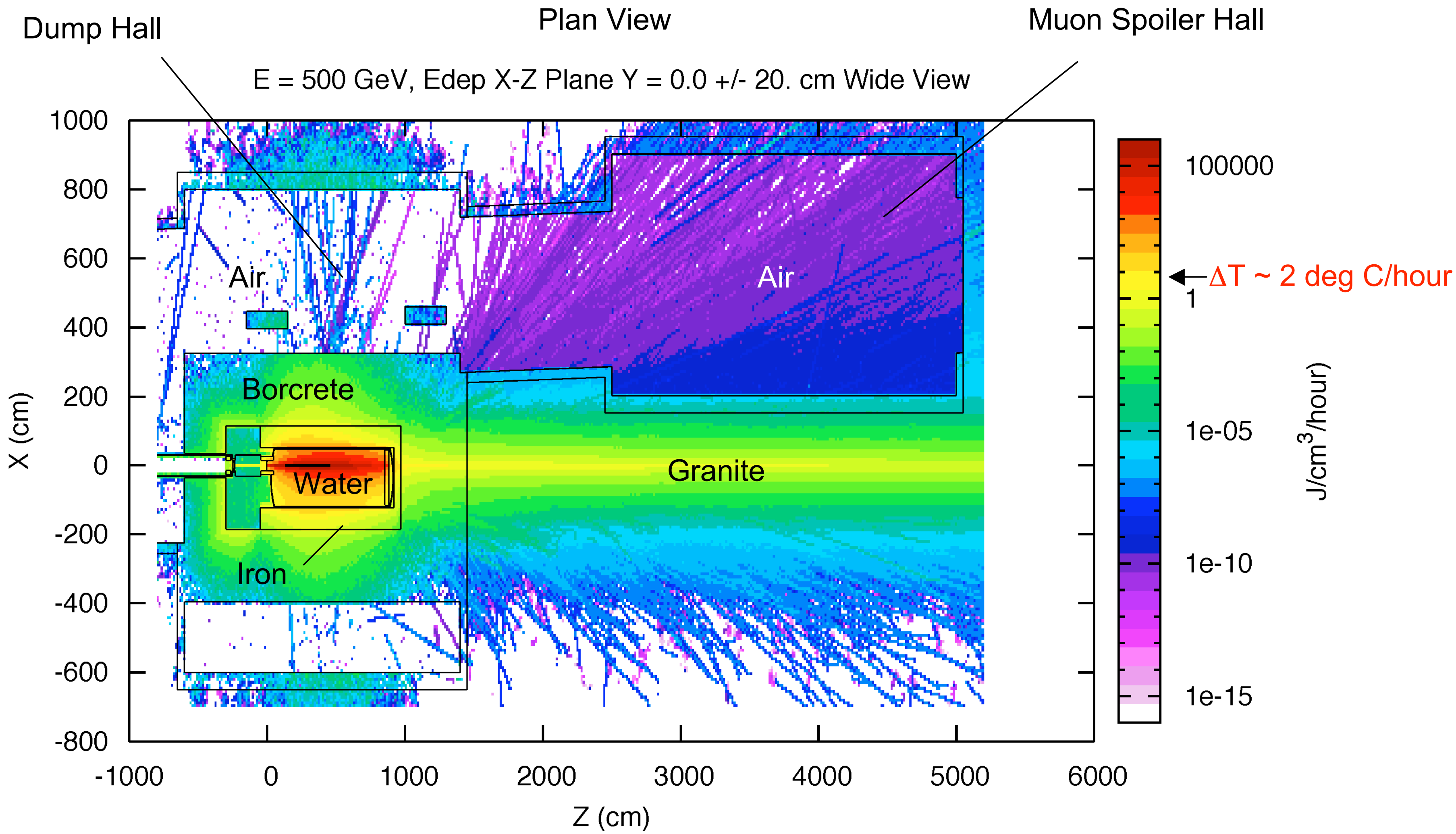
Problem:
Shield needs active cooling

Prompt Energy Deposition - J/cm^3/hour - Geometry V2



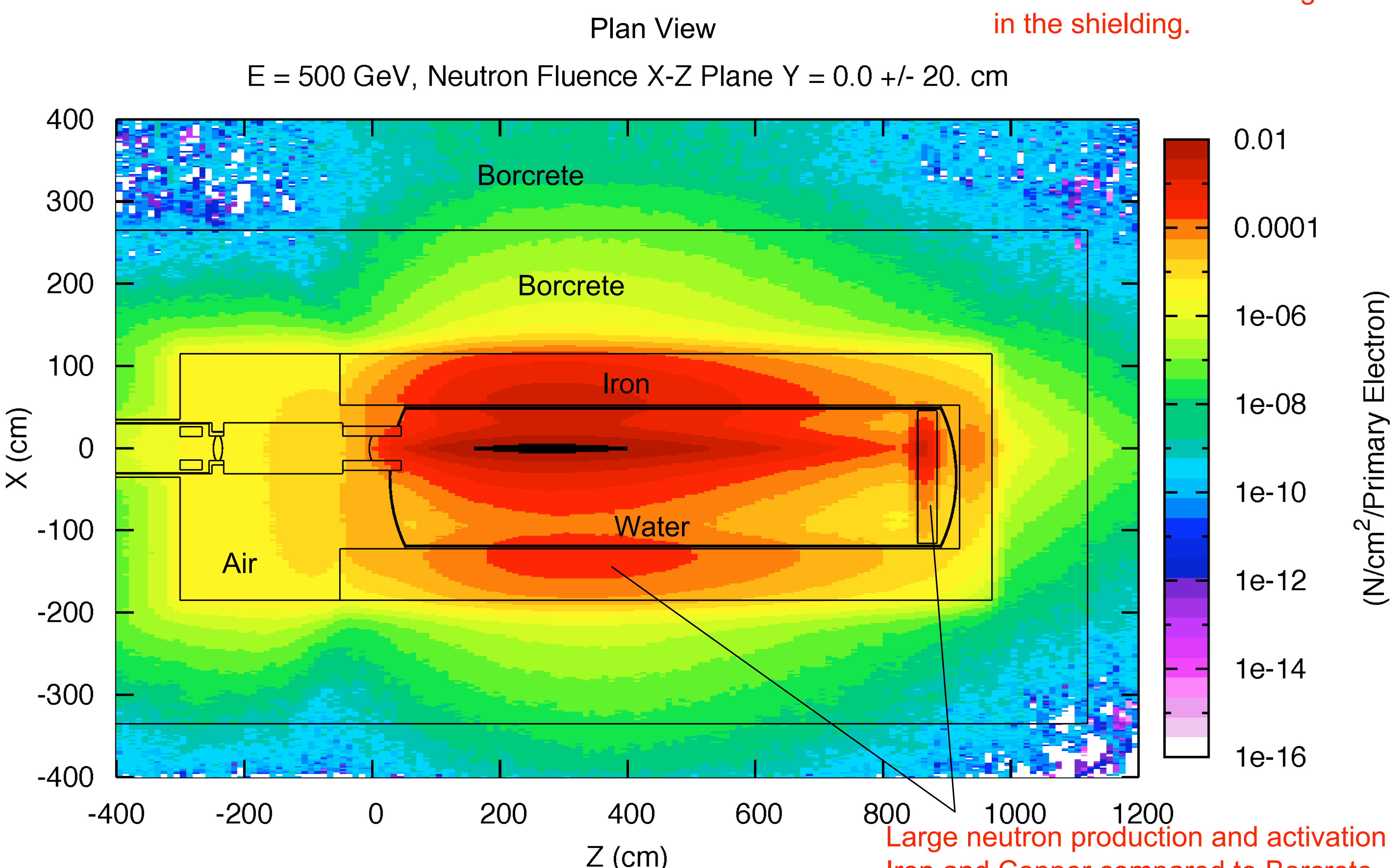
Prompt Energy Deposition - J/cm^3/hour - Geometry V2

Even the rocks get hot!



Neutron Fluence

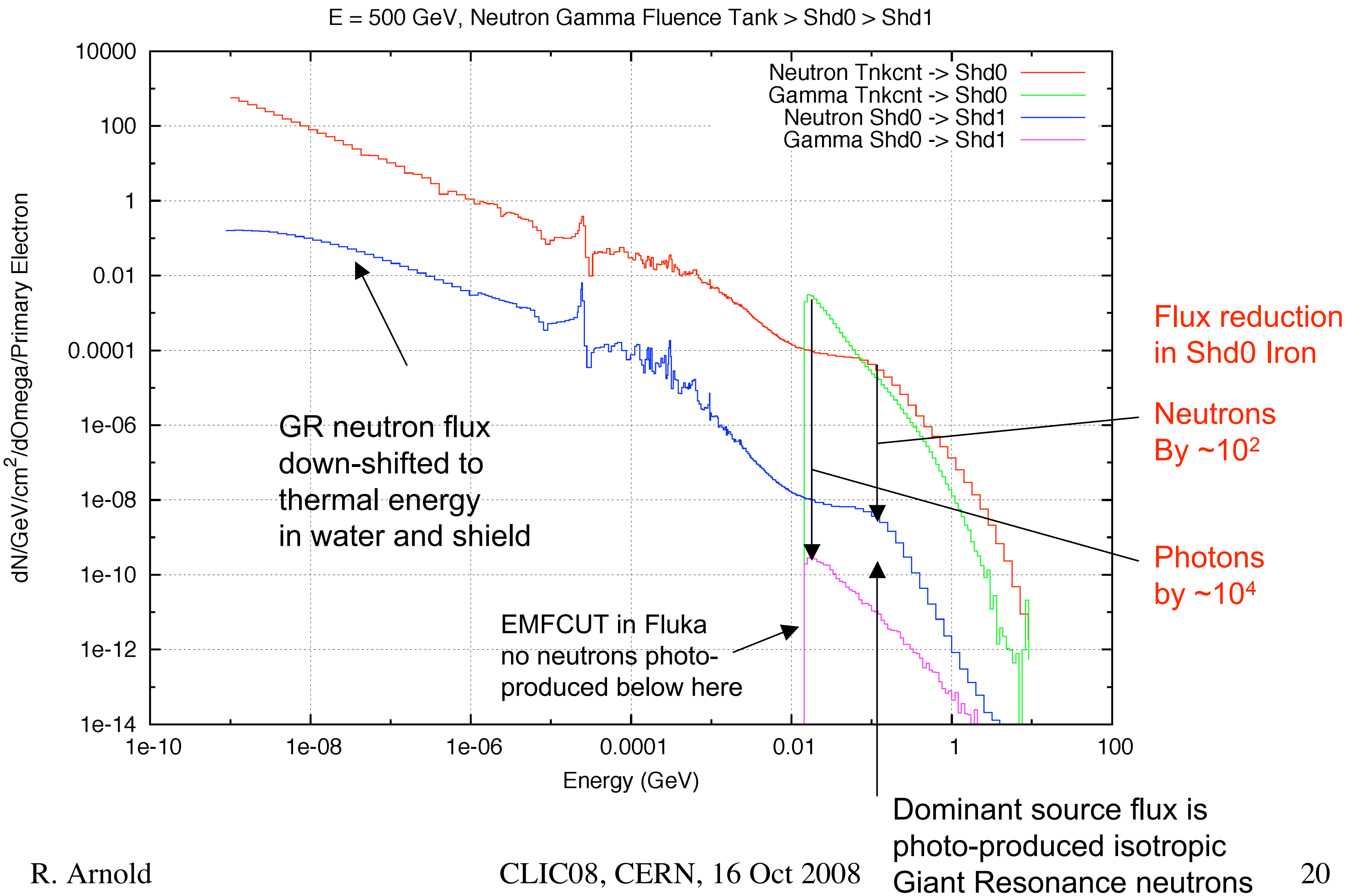
Neutrons carry the energy and activation to wide regions in the shielding.



Large neutron production and activation in Iron and Copper compared to Borcrete

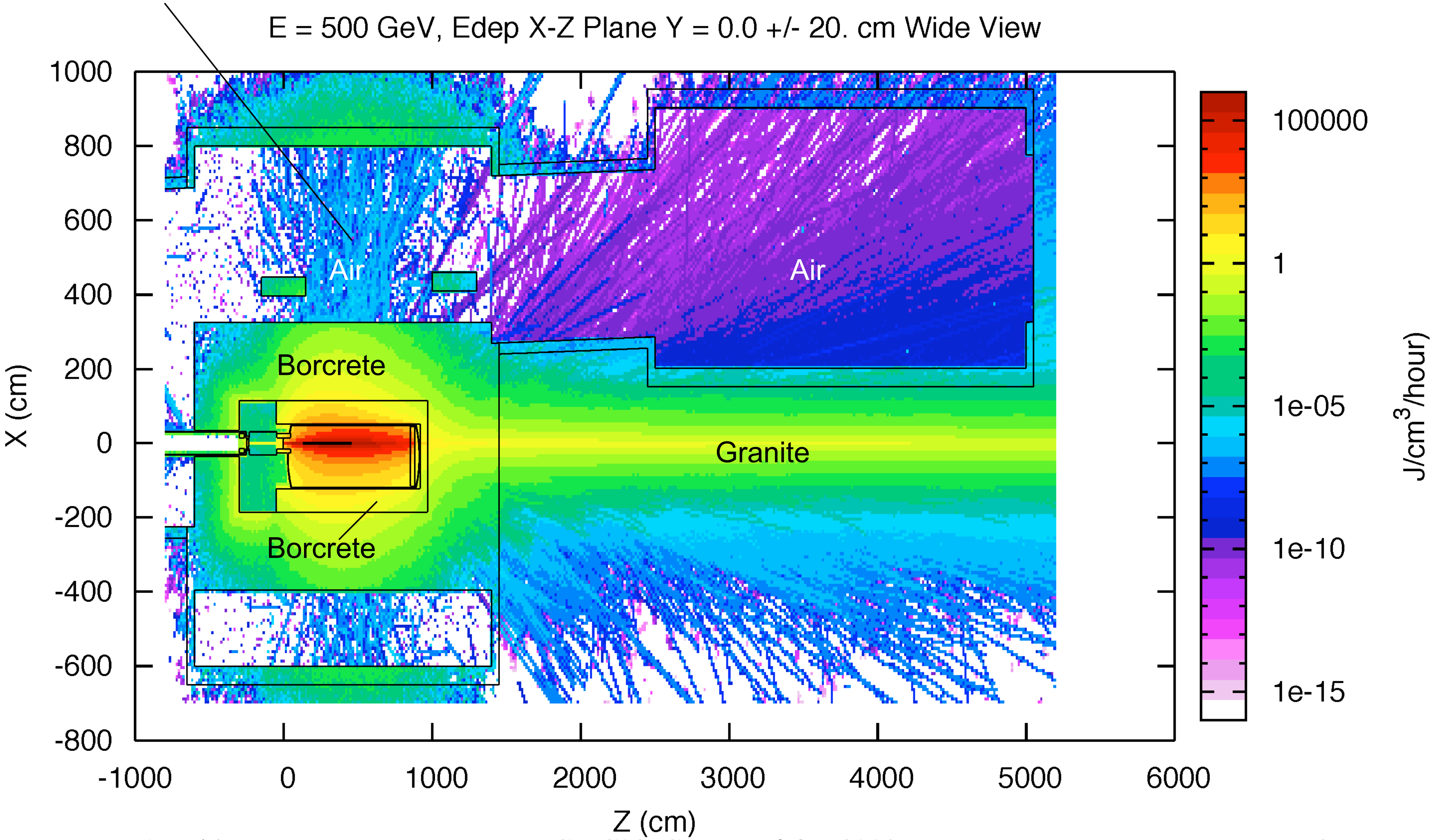
Neutron-Gamma One-Way Fluence
Tank --> Shd0 --> Shd1

Photons are effectively absorbed but neutrons get through.



Prompt Energy Deposition - J/cm^3/hour - Shd0 Borcrete

Borcrete shielding would be easier than iron to construct in modular sections with embedded water cooling. Larger prompt and activation dose in Dump Hall compared to Iron, but may be acceptable. Needs more study.



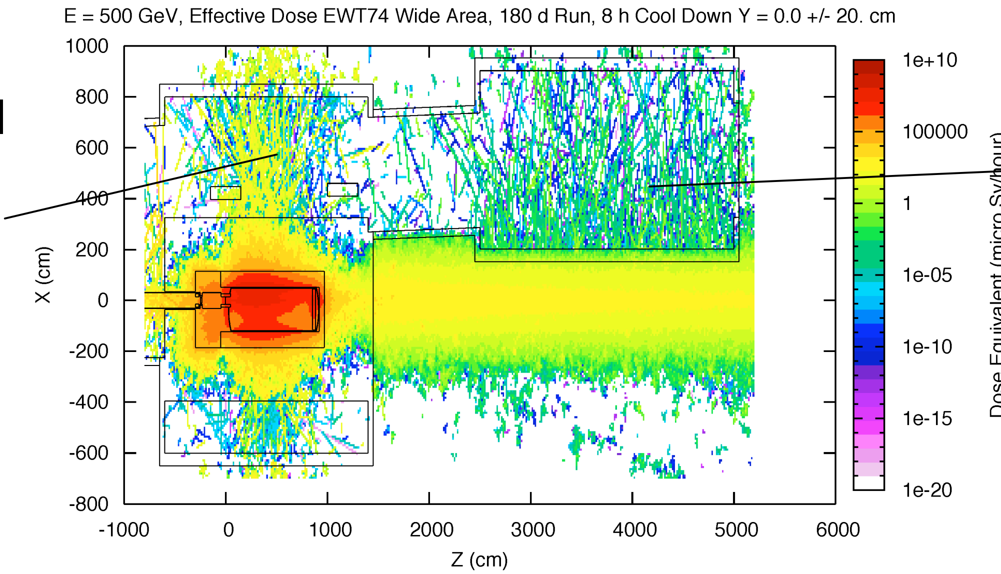
Activation Decay Radiation - 8 h Cool Down - μSv/h

Plan View

10 μSv = 1 mrem

Dump Hall and Muon Spoiler Hall

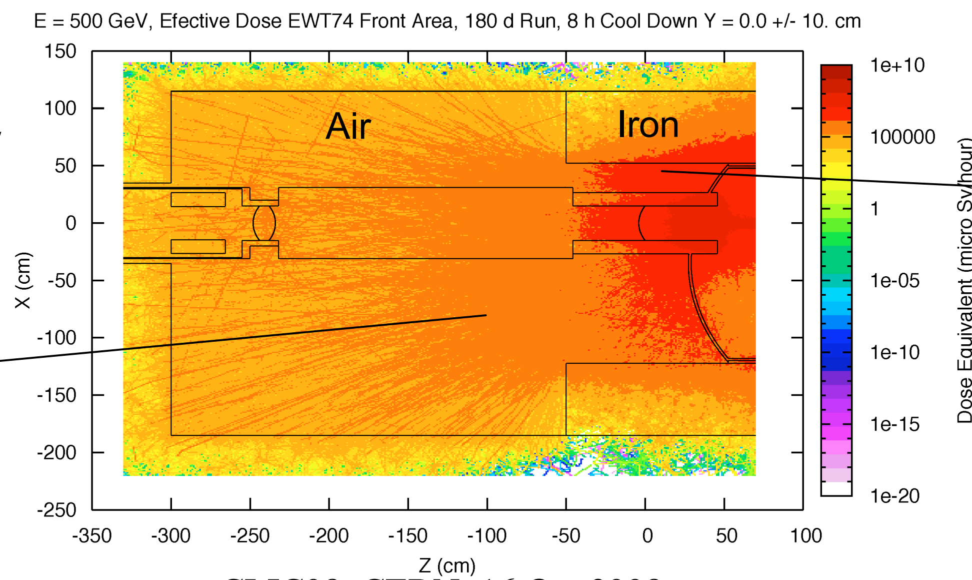
1 to 10 mrem/h
Radiation Area
Access Controlled



Less than 1 mrem/h
Accessible

Iron Shd0 and
316L SST Tank
are highly activated

Beamline and Tank front window



< 100 Rad/h
High Radiation Area
Humans don't go here

< 10 Rad/h
High Radiation Area

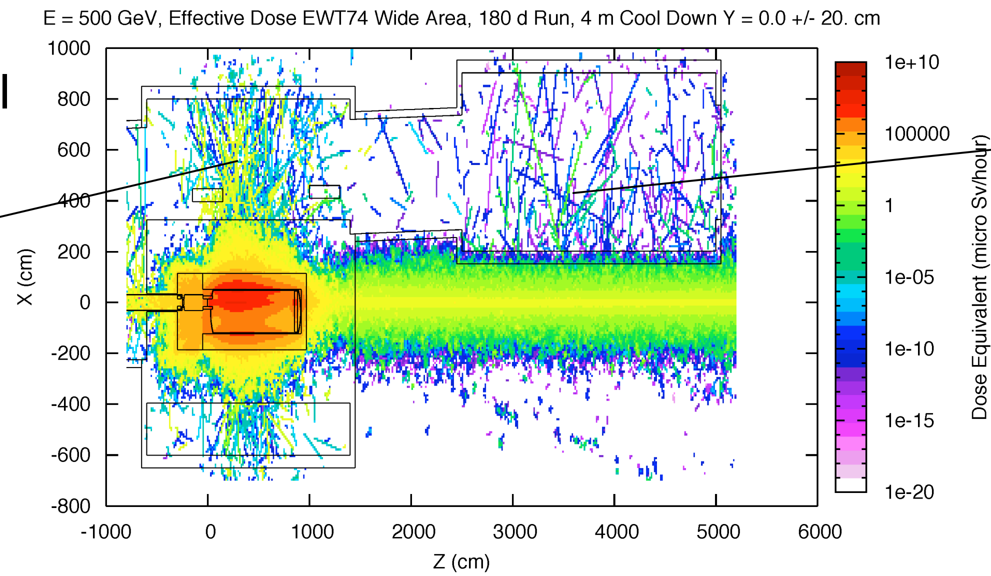
Activation Decay Radiation - 4m Cool Down - μSv/h

Plan View

10 μSv = 1 mrem

Dump Hall and Muon Spoiler Hall

1 to 10 mrem/h
Radiation Area
Access Controlled

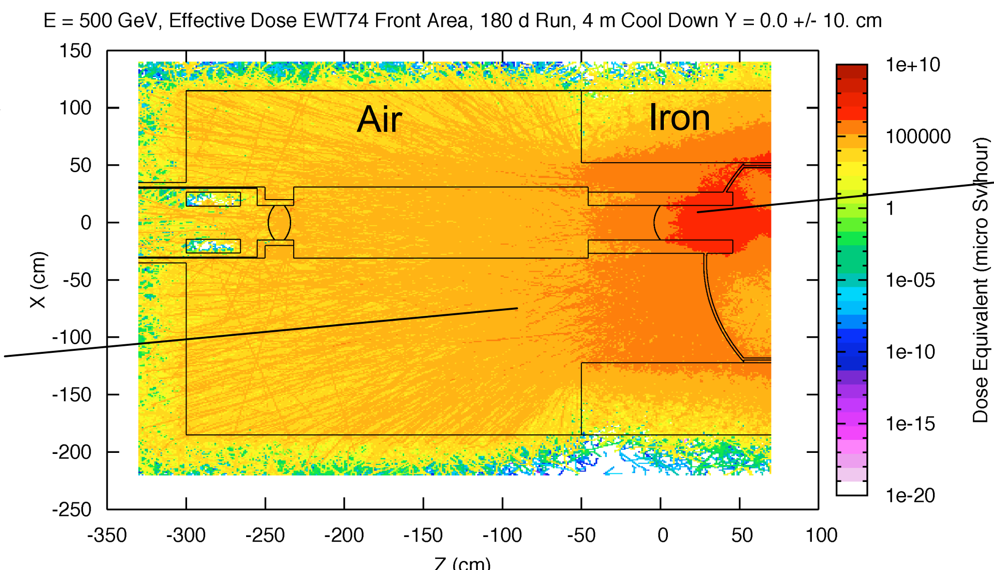


Less than 1 mrem/h
Accessible

Iron Shd0 and 316L SST Tank are highly activated with long decay life.

Beamline and Tank front window

< 10 Rad/h
High Radiation Area



< 100 Rad/h
High Radiation Area
Humans don't go here

Preliminary Conclusions from SLAC-BARC ILC Dump Work In Progress

- Sweep radius and maximum heat density in water
  - Sweep radius of 6 to 9 cm is required to keep maximum ΔT at 40 to 45 deg C.
  - RDR plan for 100 m path, 3 cm radius not adequate, needs stronger magnets or longer extraction line to the dump -- more costly.

- Water flow volume and velocity required to remove 18 MW while keeping maximum temperature below 180 deg C can be achieved.
  - Water speed ~1.5 to 2 m/s; mass rate ~ 150 kg/s.
  - Inlet temperature ~ 50 deg C,
  - Maximum temperature <~150 deg C.
  - Two-loop cooling systems can be used to reduce costs and complexity.
  - Details of headers, tank design, optimum beam location need more work.

- Dump shielding must surround the tank to contain heat and radiation.
  - 50 cm Iron + ~200 cm Borcrete is about right, needs optimization.
  - Presents problems for access, maintenance and inspection.
  - Shielding absorbs 35 to 40 kW and must be actively cooled.
  - Optimum size, material, configuration (access tunnels?) needs more work.
  - Window area is highly activated. Inspection and change requires remote handling.

Implications Of This Work For CLIC Dumps

Large disruption causing very wide momentum spread for electrons and positrons and the large photon flux at CLIC will make it difficult to contain extracted extracted beams into well shielded dumps.

The large beam power and large disrupted beam flux would lead to high values for heat and radiation load in the extraction beam line, and could cause unwanted background at the IP.

Extraction line and beam dumps at CLIC will be a challenge, and investigations of realistic arrangements are needed to determine the best options.