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

Preliminary Results from FLUKA,
FLUENT Computational Fluid Dynamics,
and Mechanical Design

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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, Radiation, and Mechanical Design

- 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.

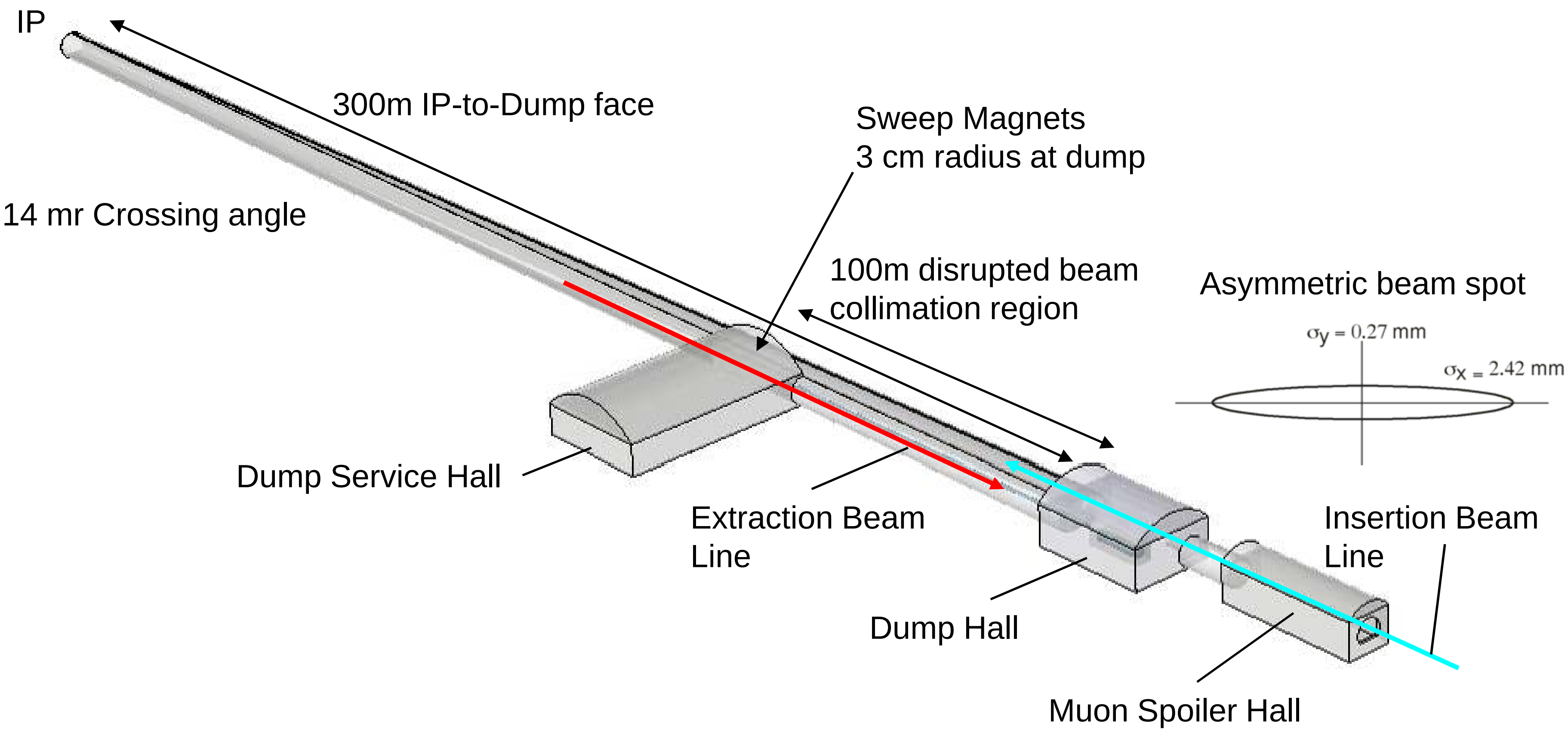
- Determine options for practical and adequate shielding.

- Preliminary design for tank, windows, window changers.

- Explore ways to minimize costs.

Beam Parameters and Layout - ILC RDR

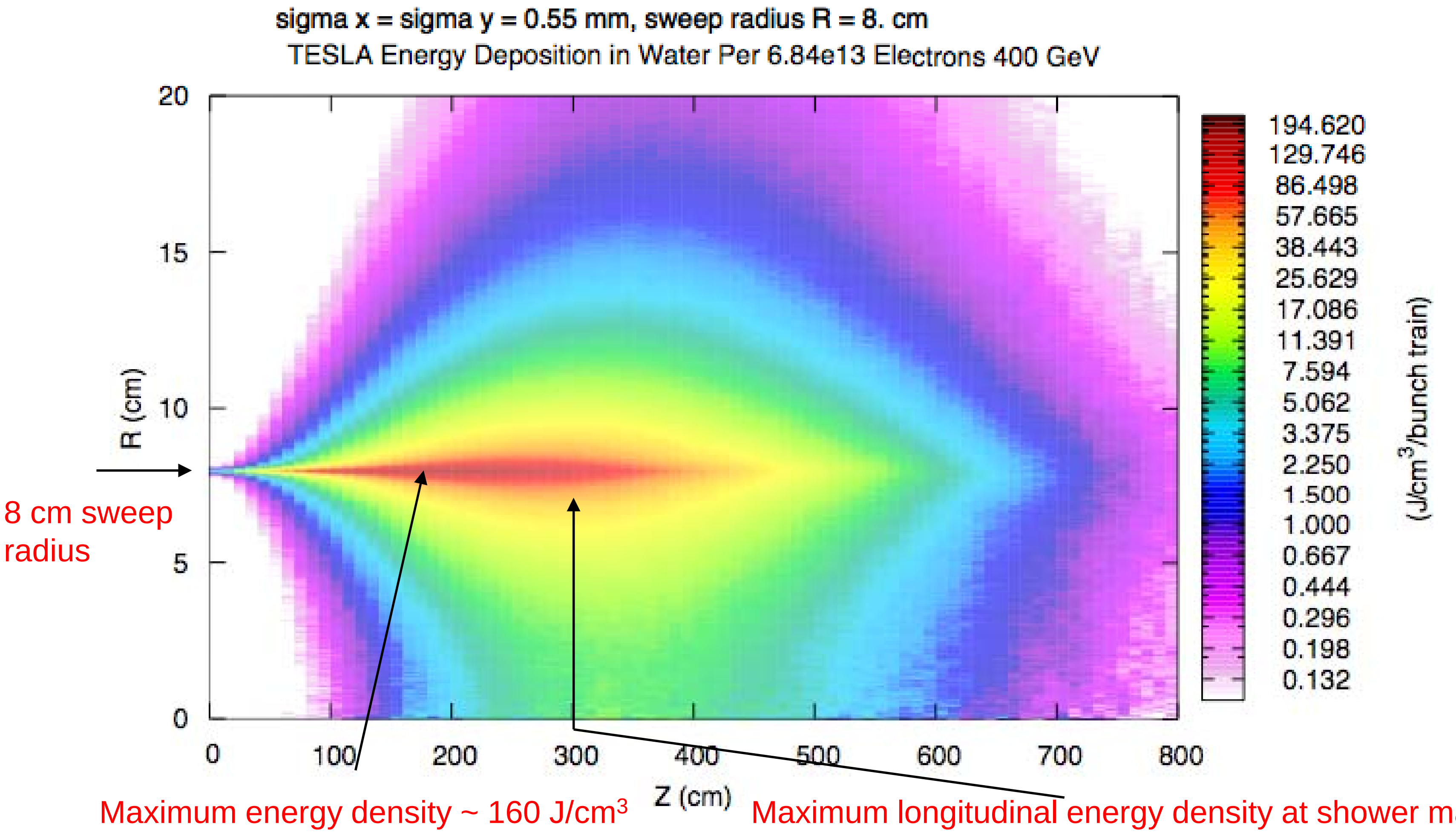
Beam: 500 GeV
4 Hz bunch train/sec, 2820 bunches/train, $2X10^{10}$ e^-/bunch
18 MW



Verification of Deposited Energy Density for TESLA Round Beam

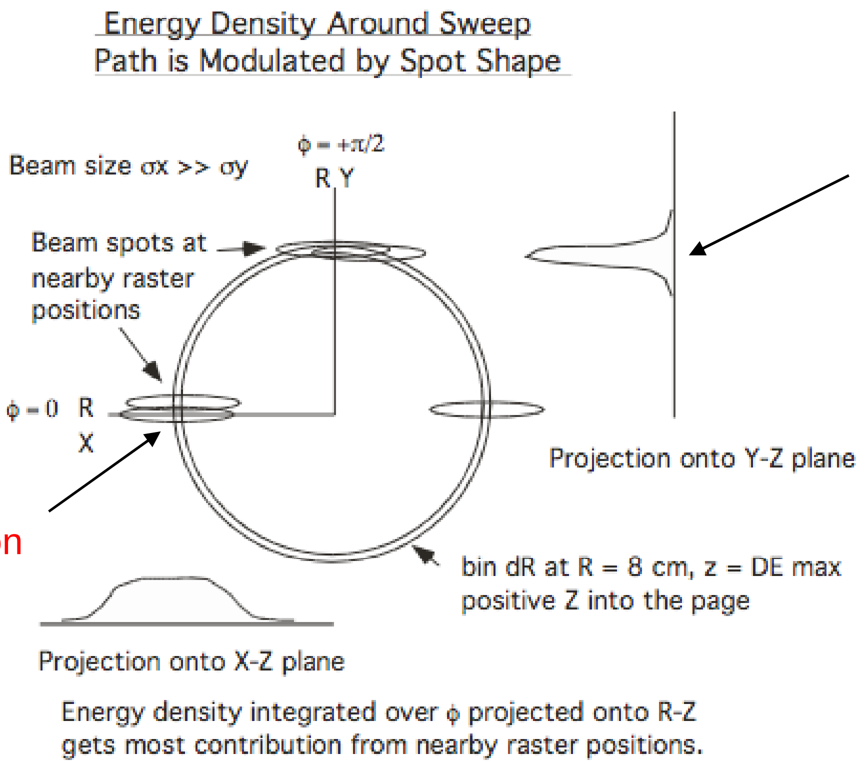
High Power Water Beam Dump for a LC, M. Schmitz,
TESLA Collaboration Meeting, 16 Sept 2003.

Fluka(1) results, binned in R-ϕ-Z, summed over ϕ



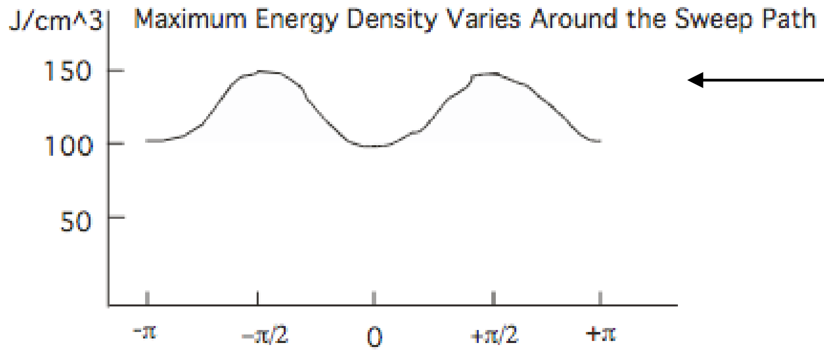
(1) - A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, "FLUKA: a multi-particle transport code", CERN 2005-10 (2005), INFN/TC_05/11, SLAC-R-773

Effect on Maximum Energy Density from Sweeping Asymmetric Beam Spot



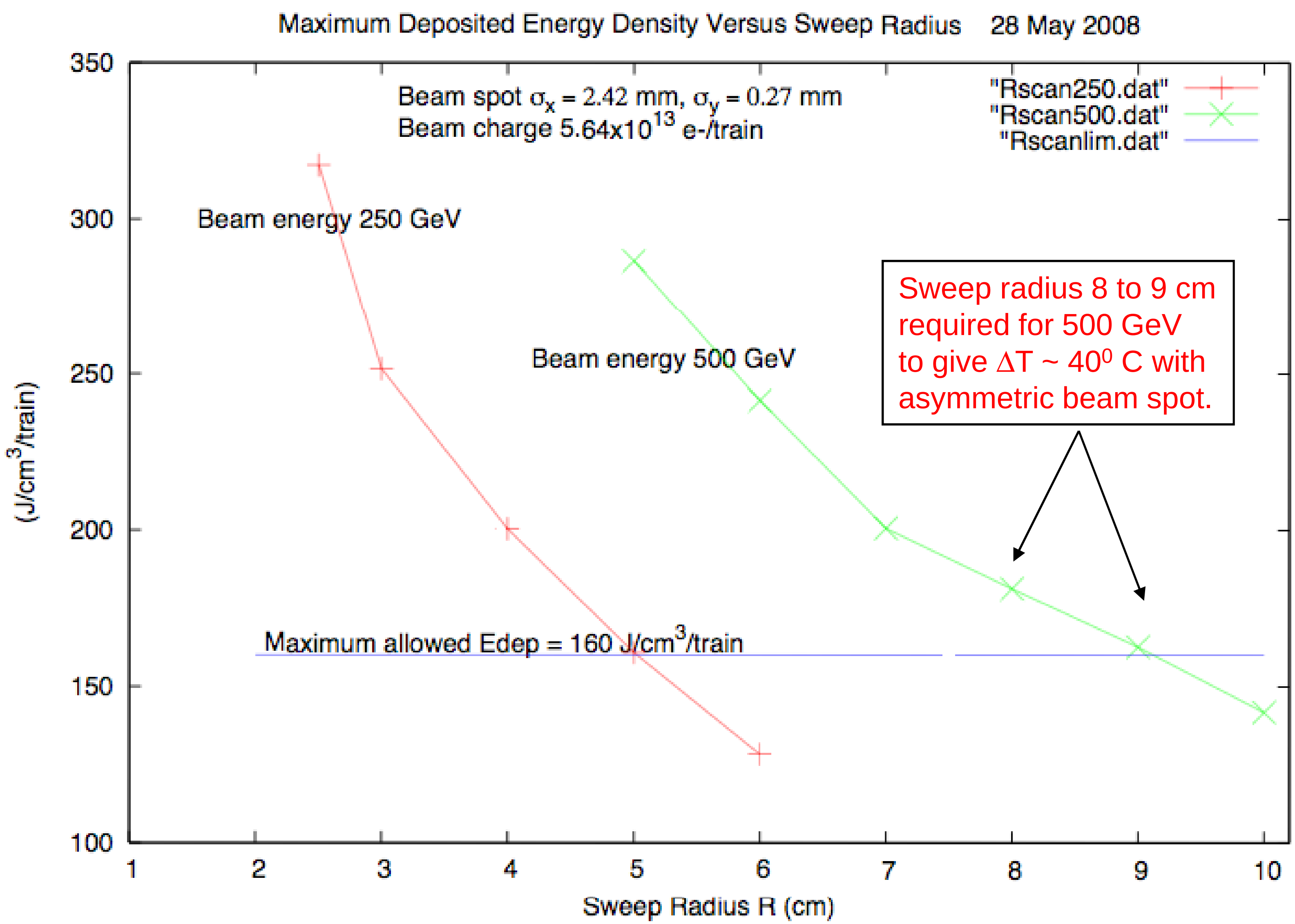
Energy density hot spot when sweep is in direction of long axis

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



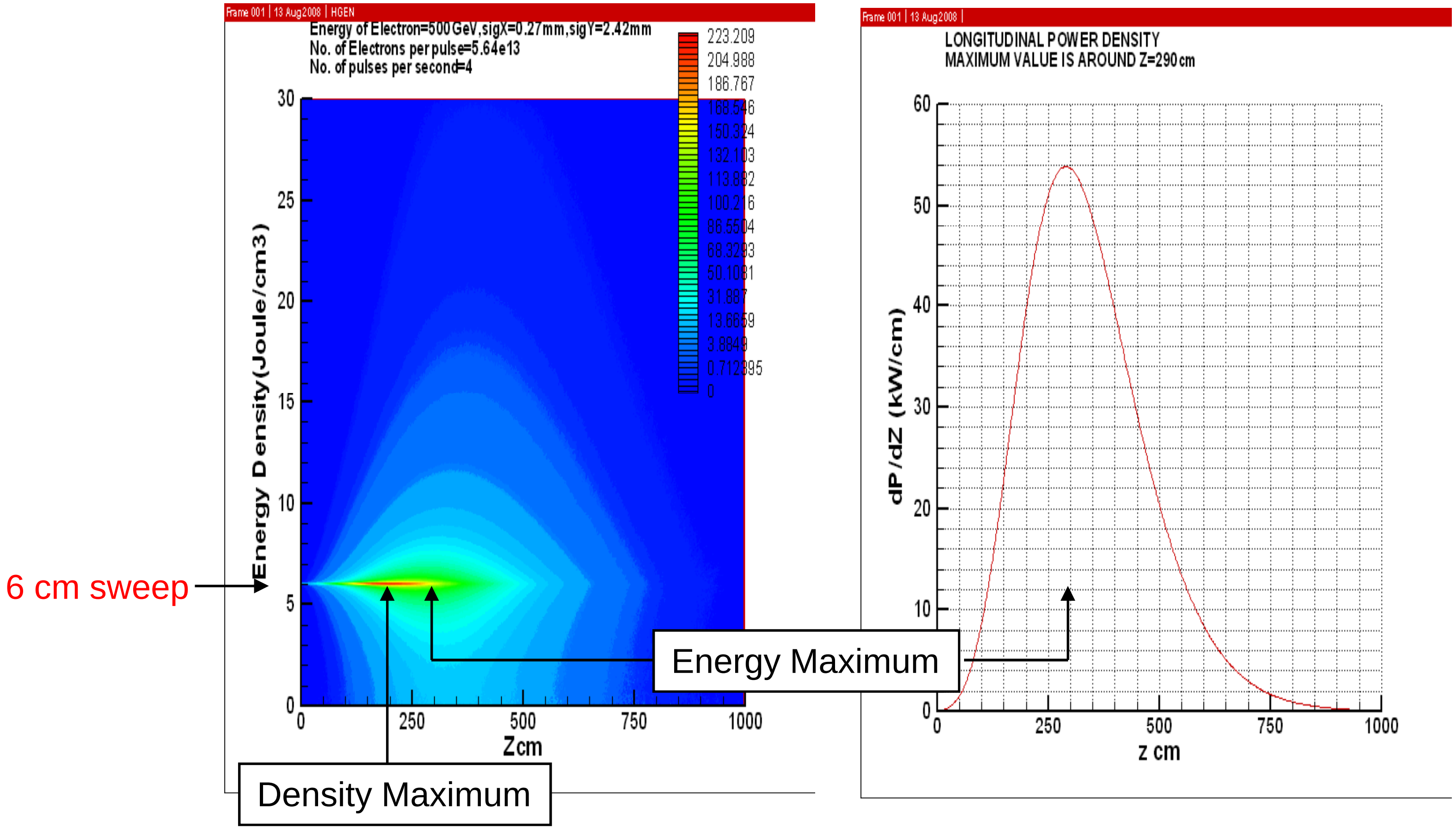
Design sweep radius and water cooling for the hot spots

Effect of Sweep Radius on Maximum Energy Density



Study Water Temperature Variation in Space and Time

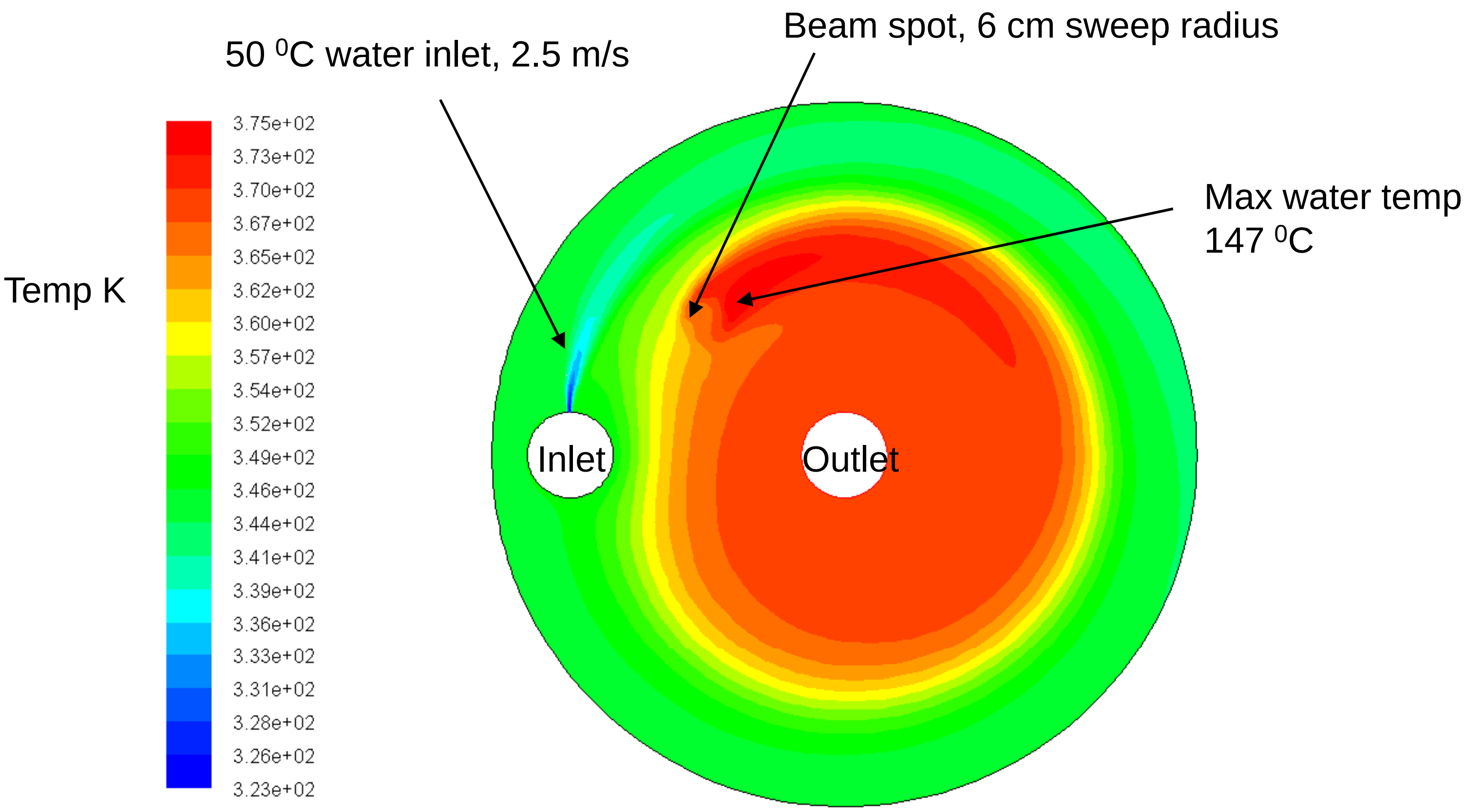
Fluka results for 500 GeV beam with asymmetric spot for input to
CFD analysis with FLUENT 6.3 by P. Satyamurthy and colleagues, BARC.



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.

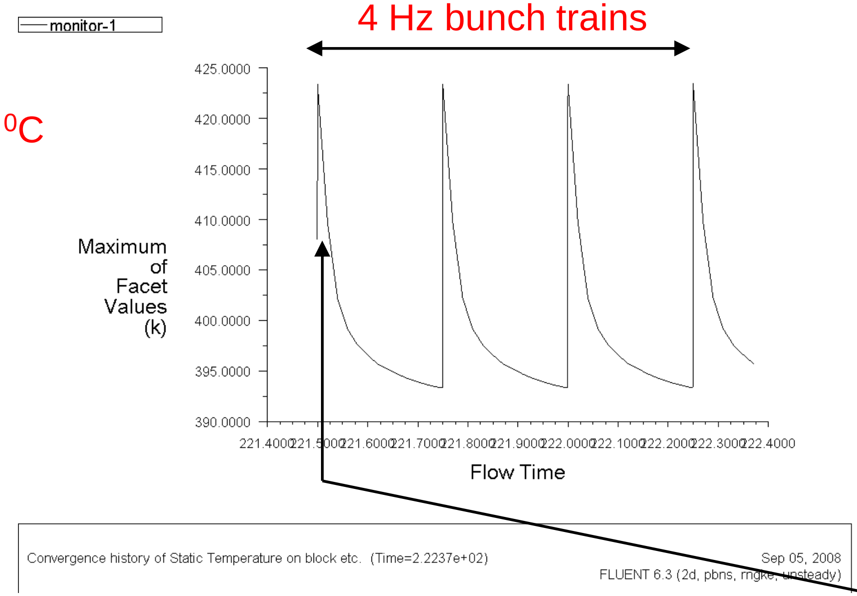


Temperature contours for CASE 5b (At location of Z=1.82 m fo r 2.50 m/s nozzle velocity without blocking outlet)

Time Dependence of Water Temperature

Water inlet T = 50 ^{0}C

4 Hz bunch trains

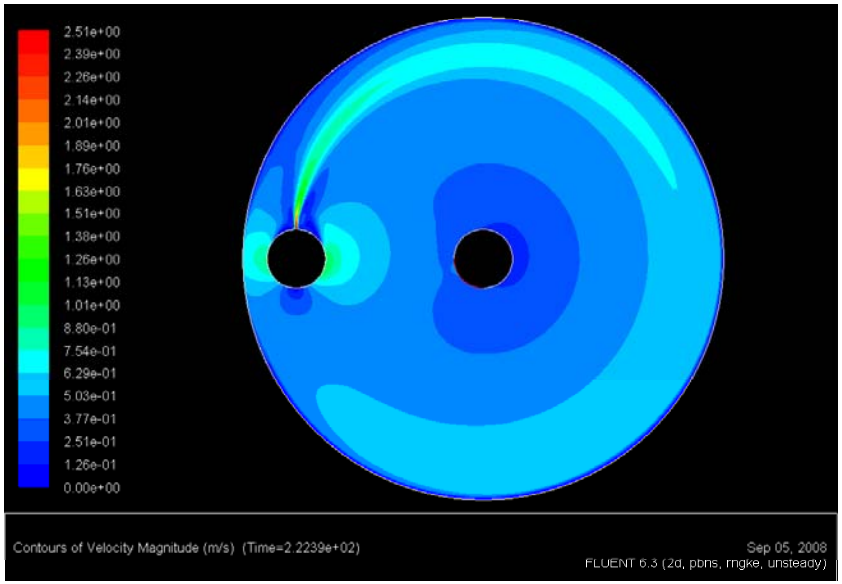


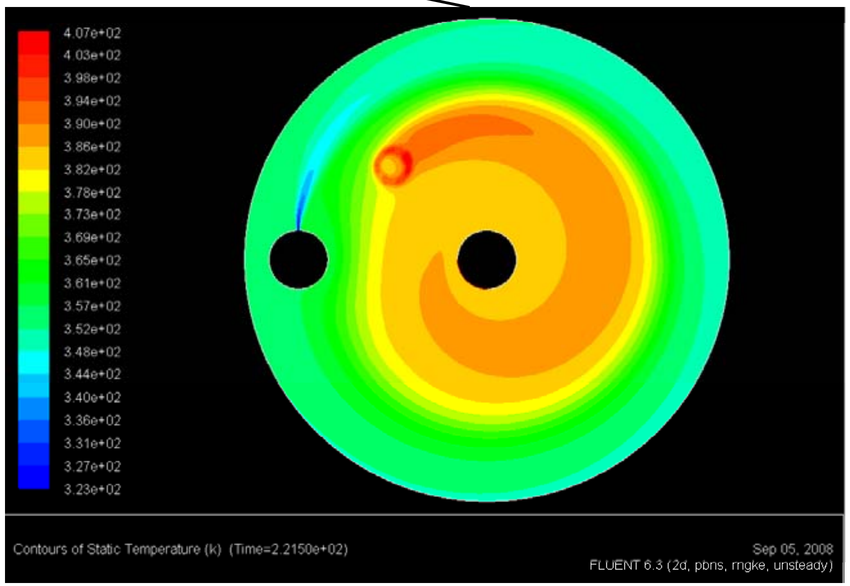
Transient max T ~152 ^{0}C
Water does not boil.

ΔT ~ 32 ^{0}C

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

Studying Double Inlet Header To Reduced Inlet Velocity

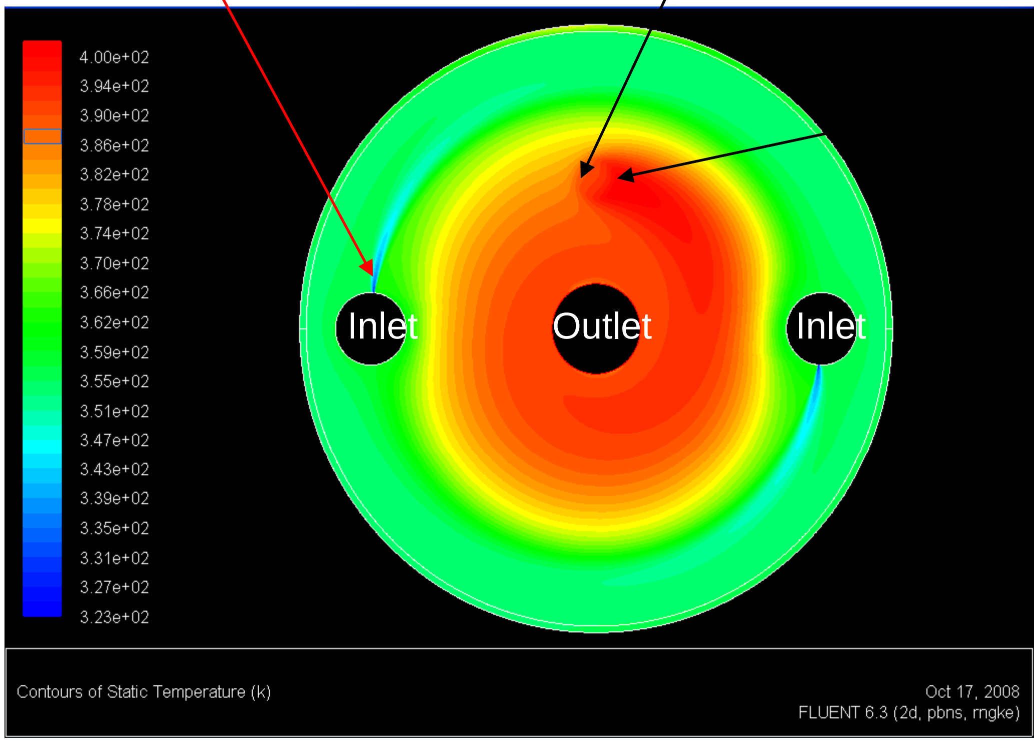
Use 2-D FLUENT models to study water temp, with various beam spot locations.

Beam spot, 6 cm sweep radius

50 ^{0}C water inlet, 2.17 m/s (was 2.5 m/s with single inlet)

Max water temp
154 ^{0}C (peak)

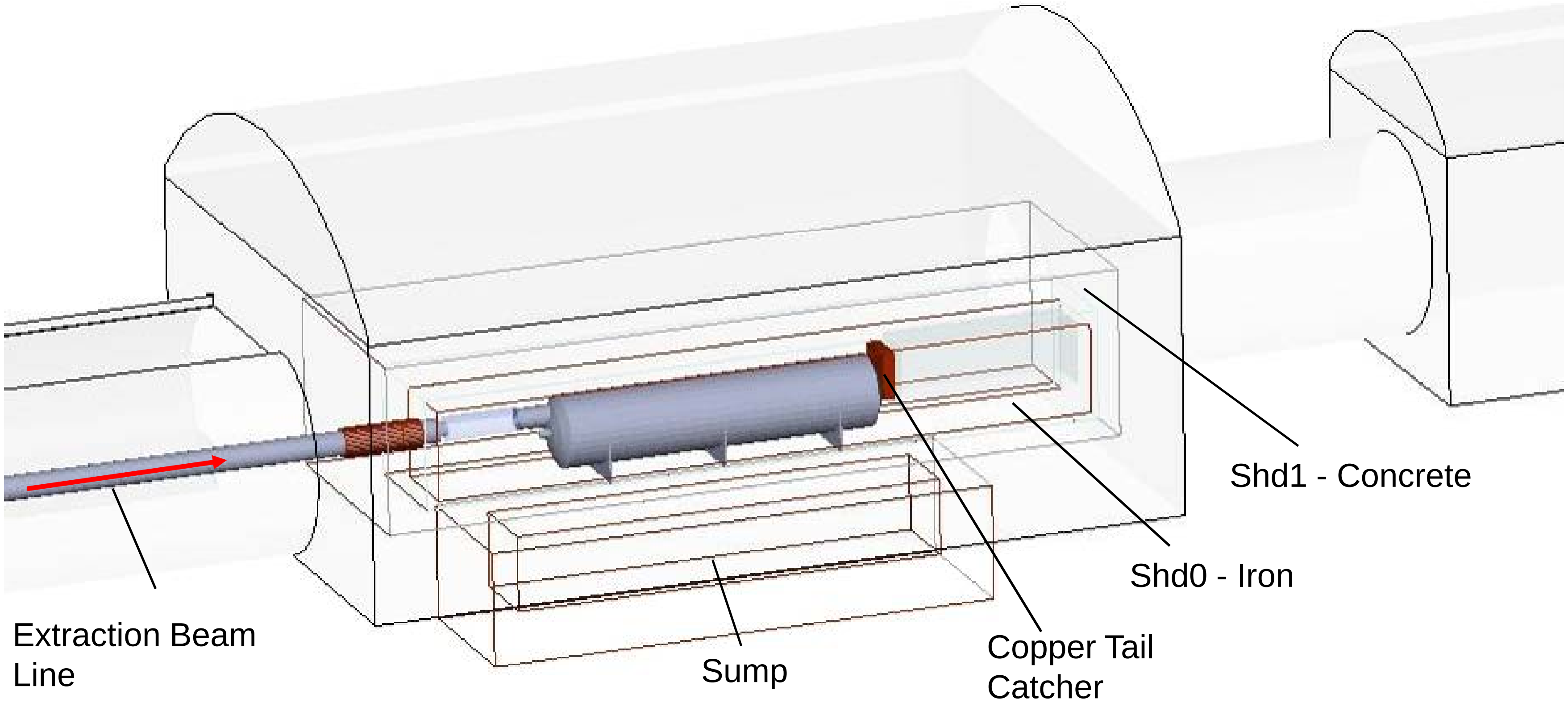
Temp K



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

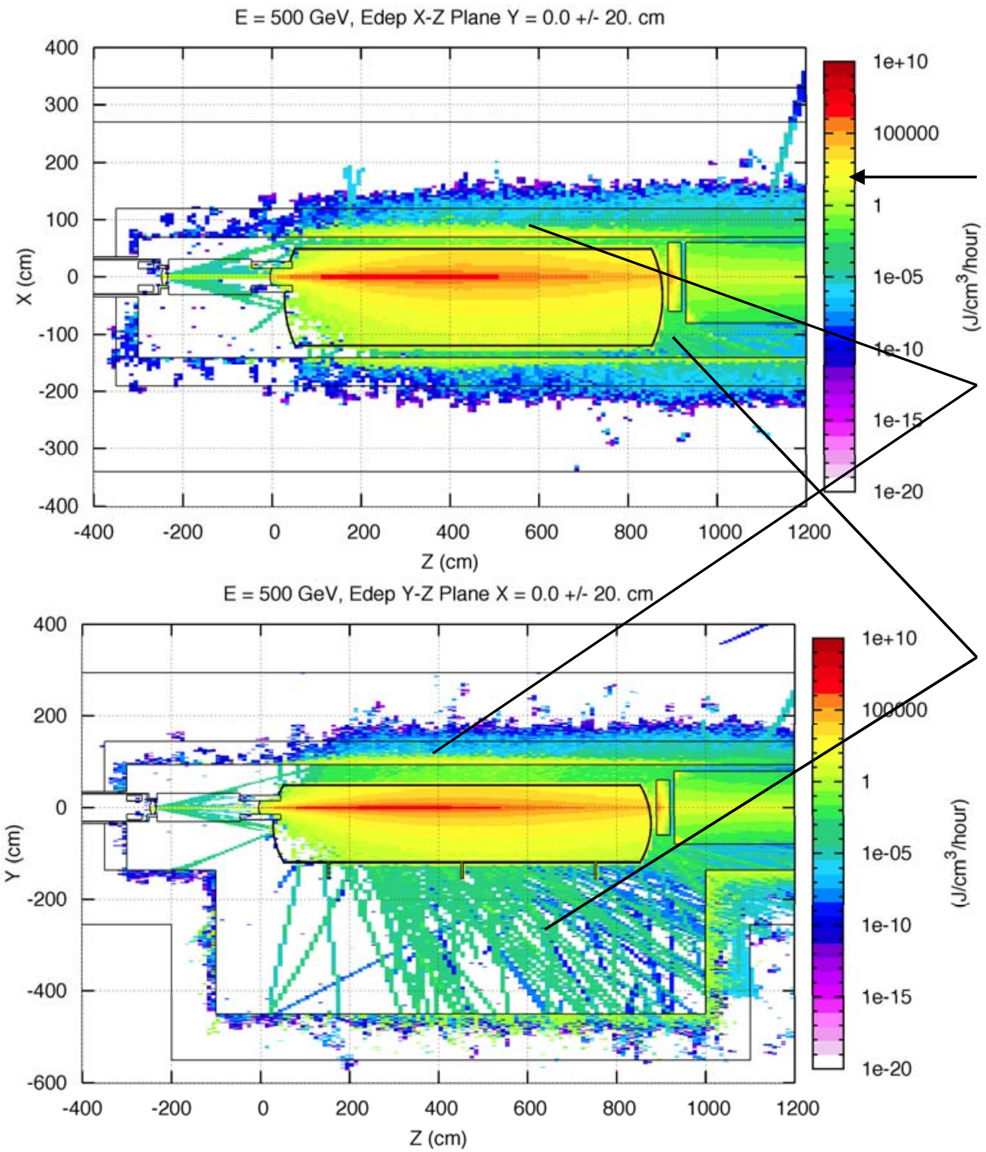


(1) - A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, "FLUKA: a multi-particle transport code", CERN 2005-10 (2005), INFN/TC_05/11, SLAC-R-773

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

Plan View

Elevation View



ΔT ~ 25 ^{0}C/hour

Problems

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

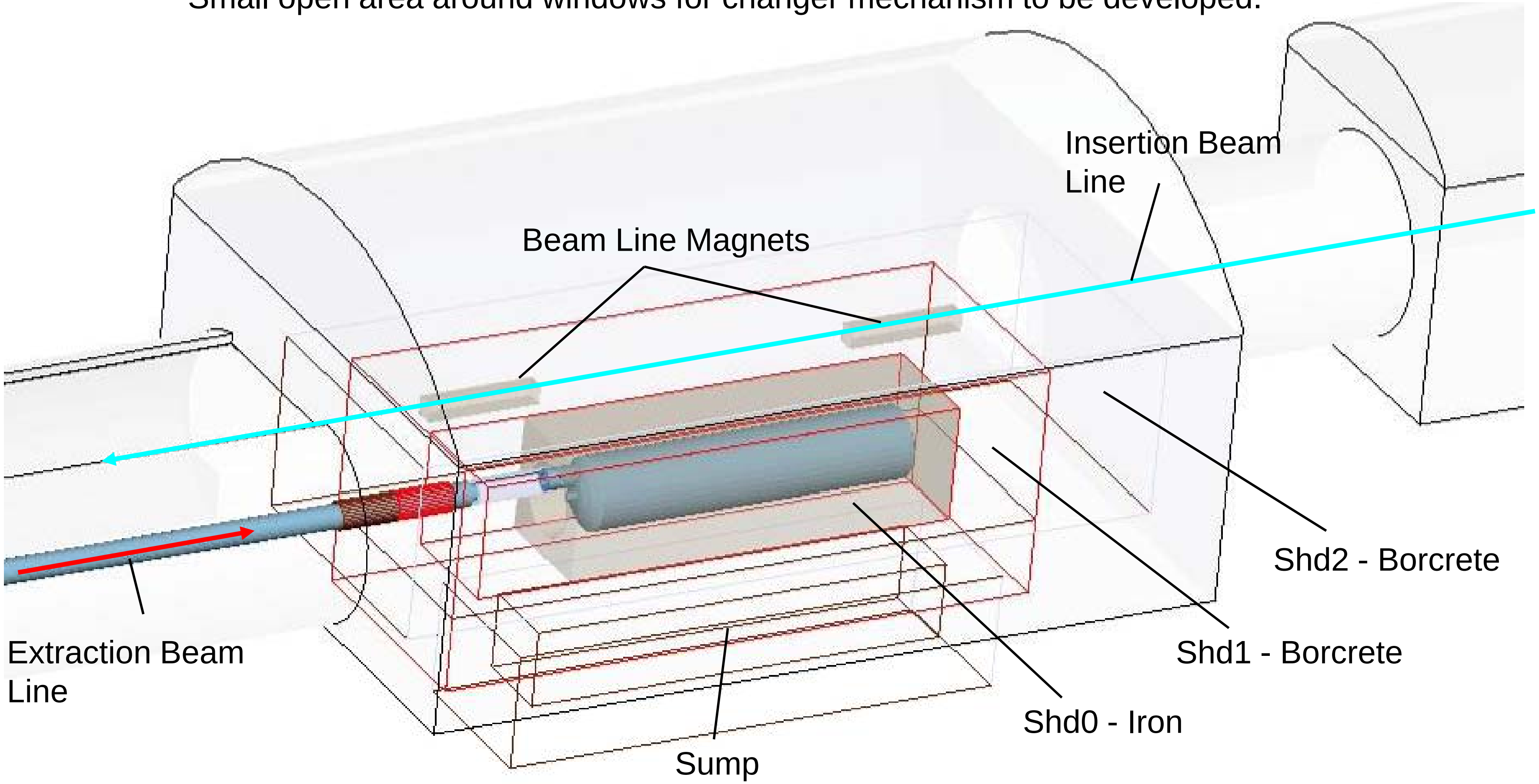
Large volume of activated air

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

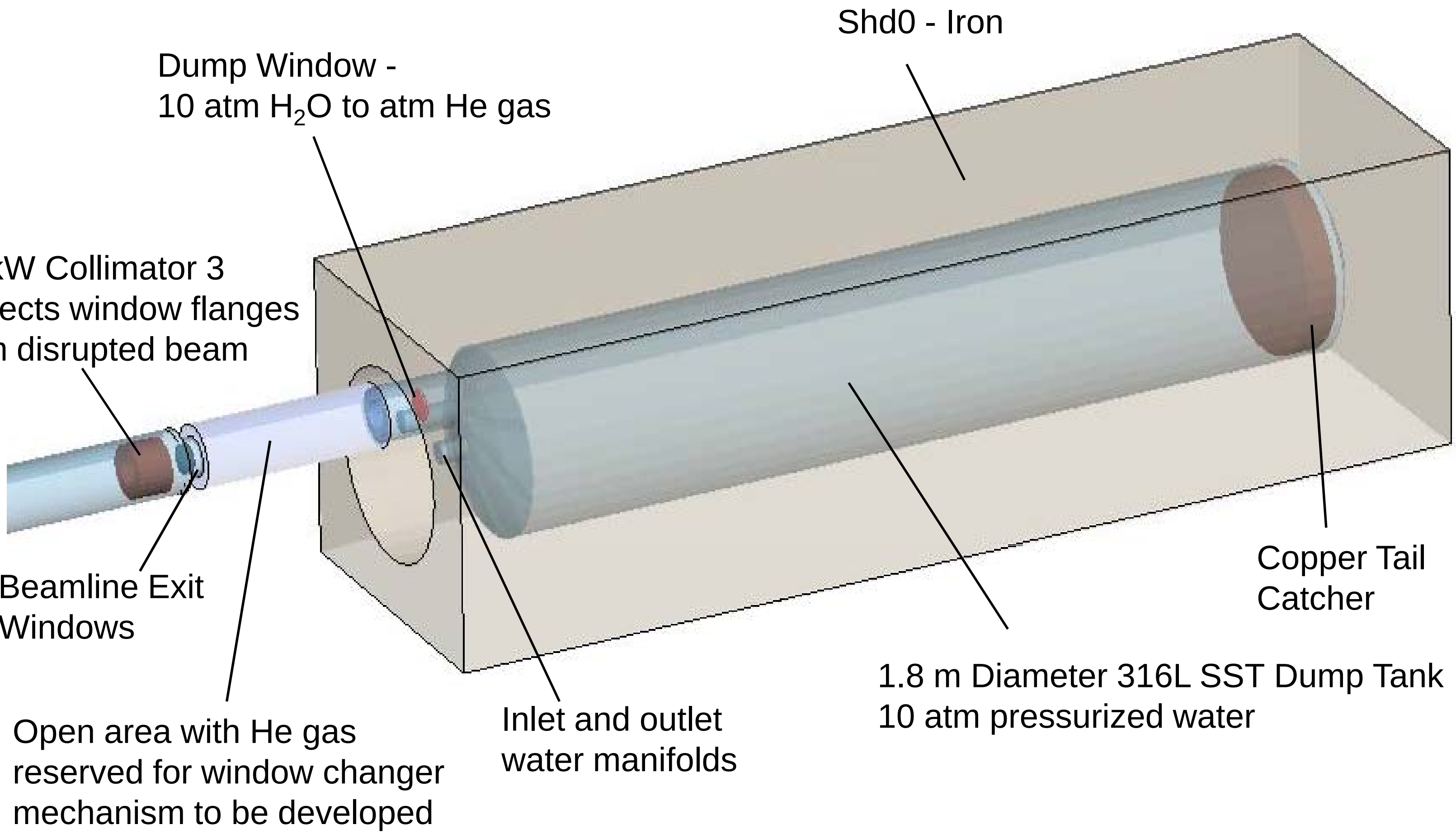
Dump Hall - Tank - Geometry Version 2

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.

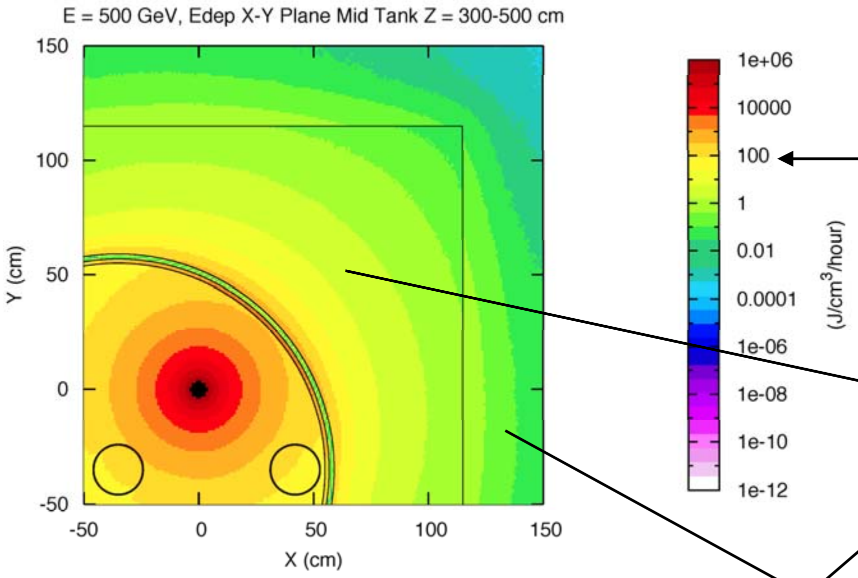


Dump Tank - Shd0 - Windows - Geometry Version 2



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

Section View
Mid Tank

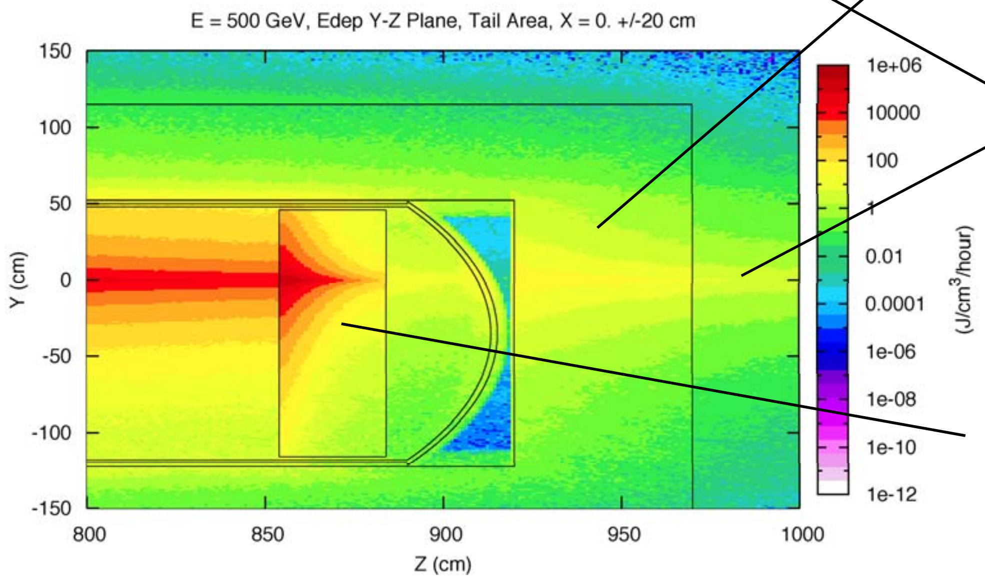


Problem:
Shield needs active cooling

ΔT ~ 25 deg C/hour

Shd0 - Iron
32 kW total

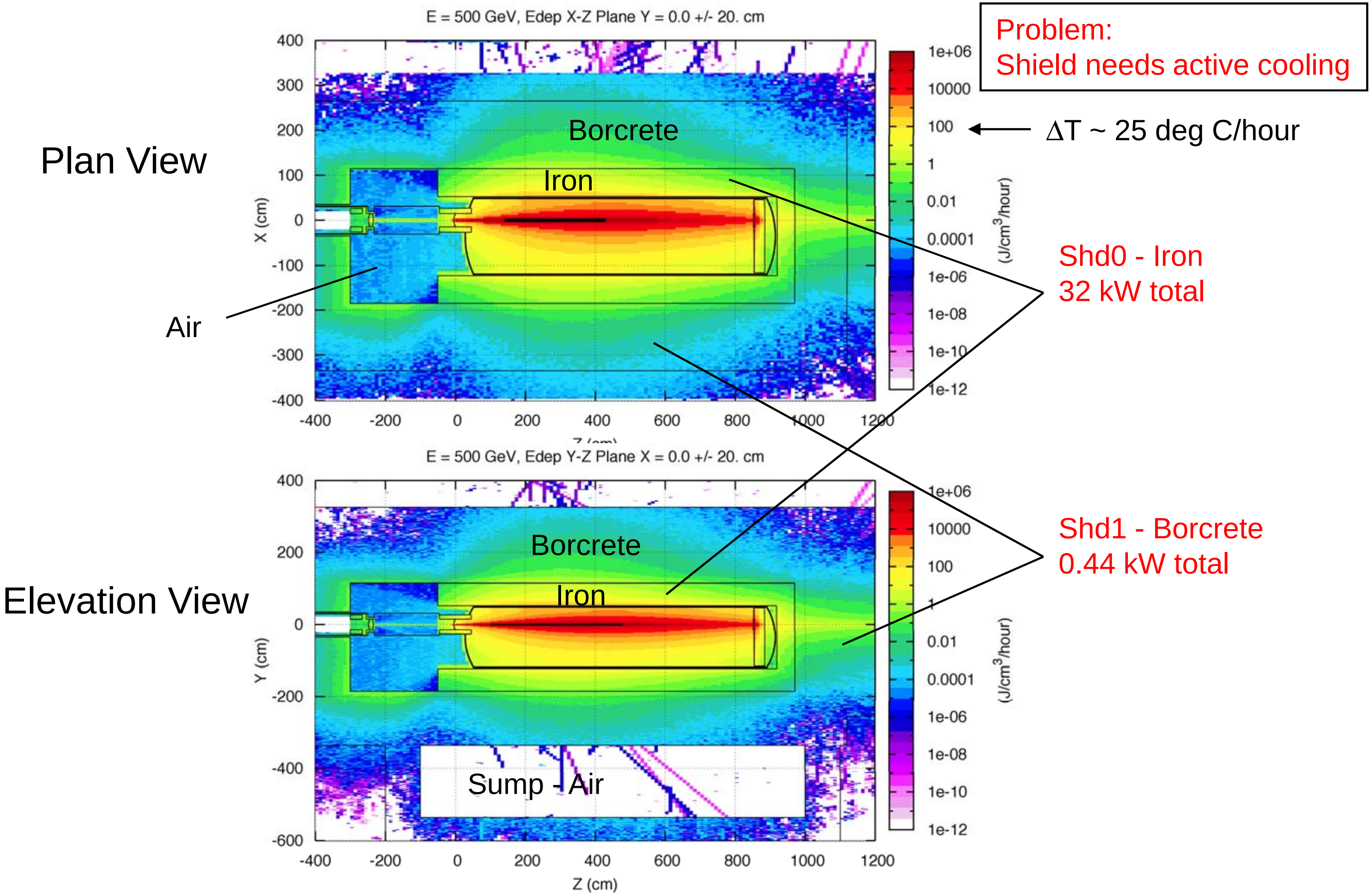
Elevation View
Tail Catcher



Shd1 - Borcrete
0.44 kW total

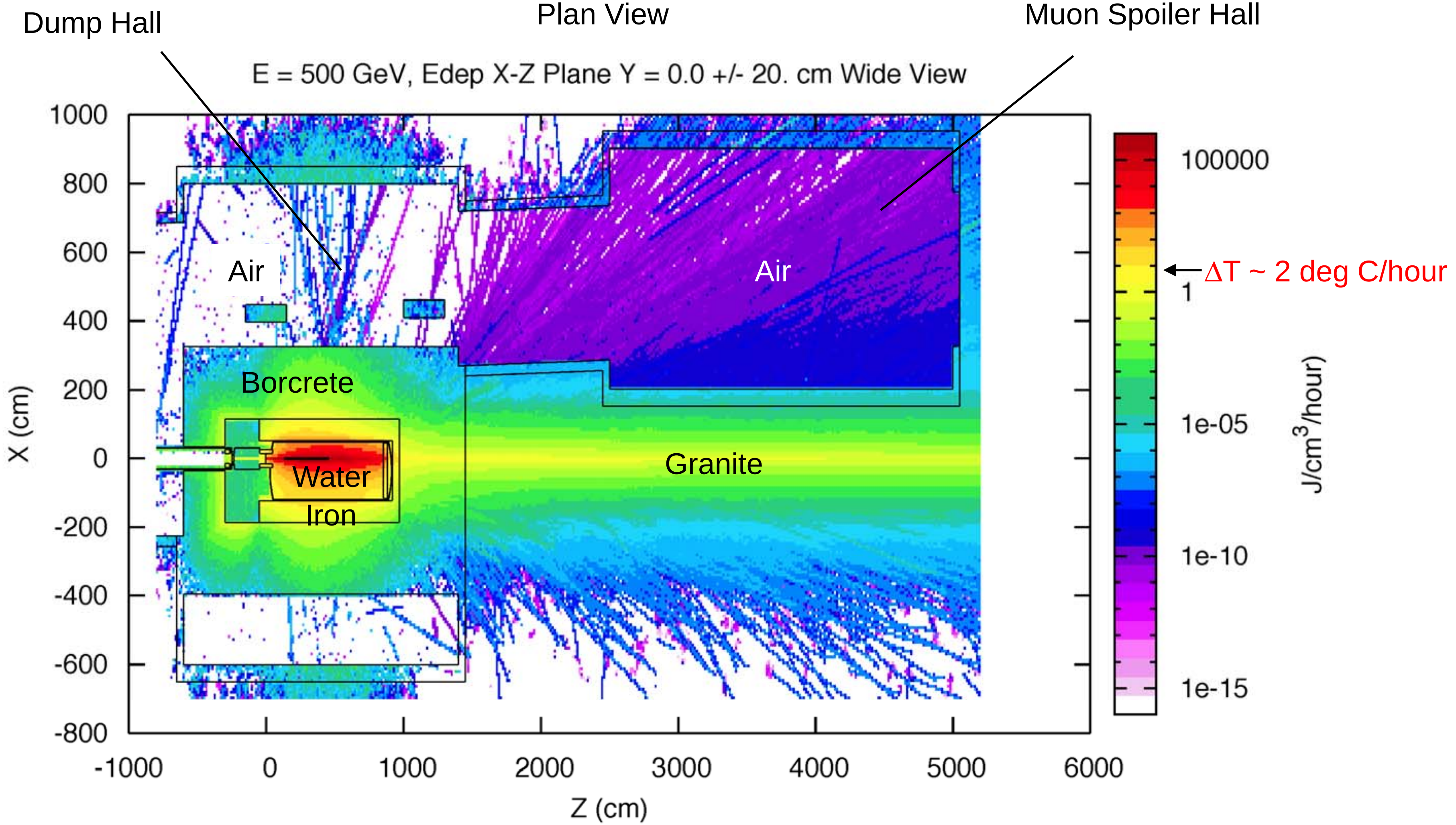
Tail Catcher - Copper
32 kW total

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



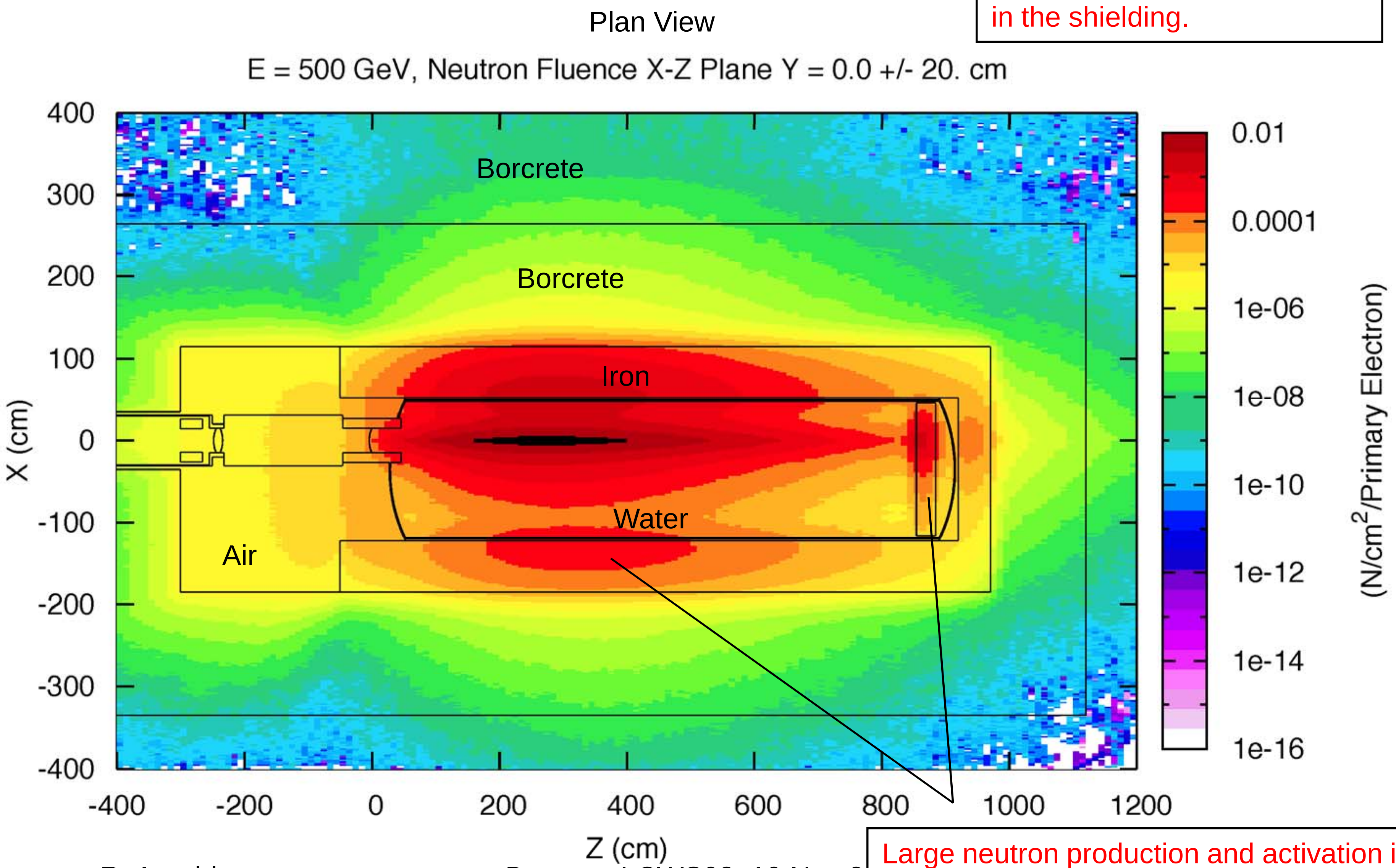
Prompt Energy Deposition - J/cm^3/hour - Geometry V2

Even the rocks get hot!



Neutron Fluence

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



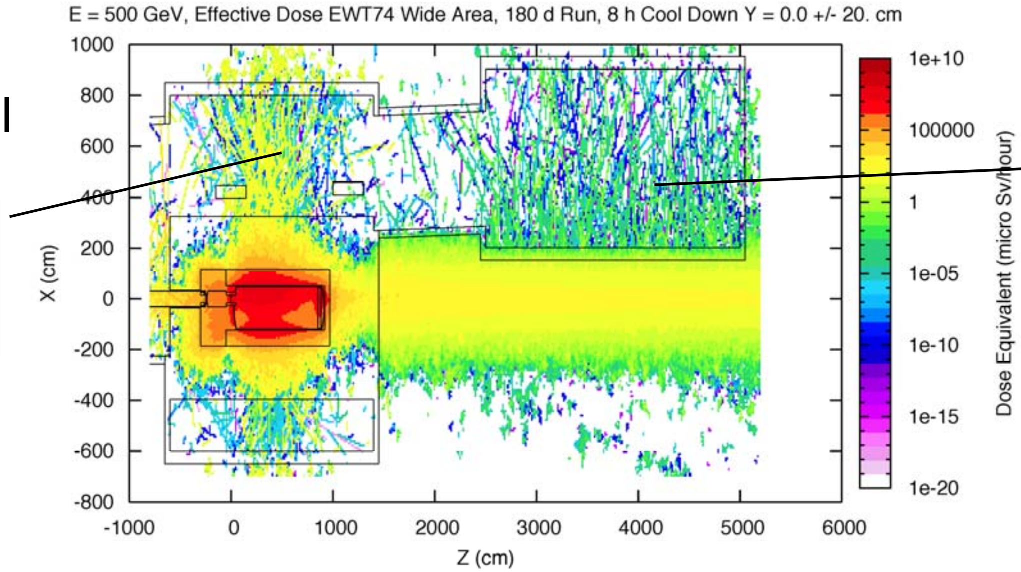
Large neutron production and activation in Iron and Copper compared to Borcrete

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

Plan View

10 µSv = 1 mrem

Dump Hall and Muon Spoiler Hall

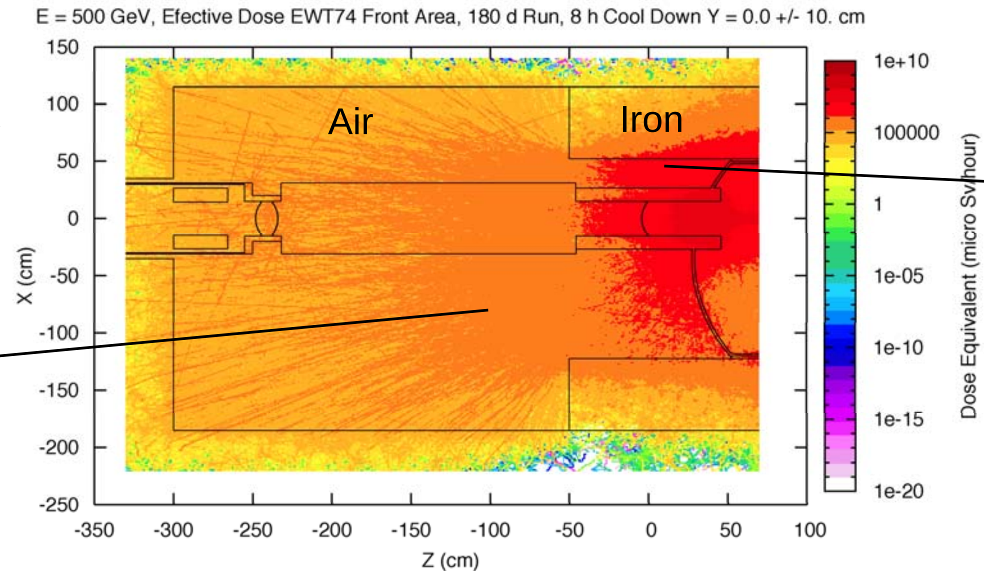


1 to 10 mrem/h
Radiation Area
Access Controlled

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

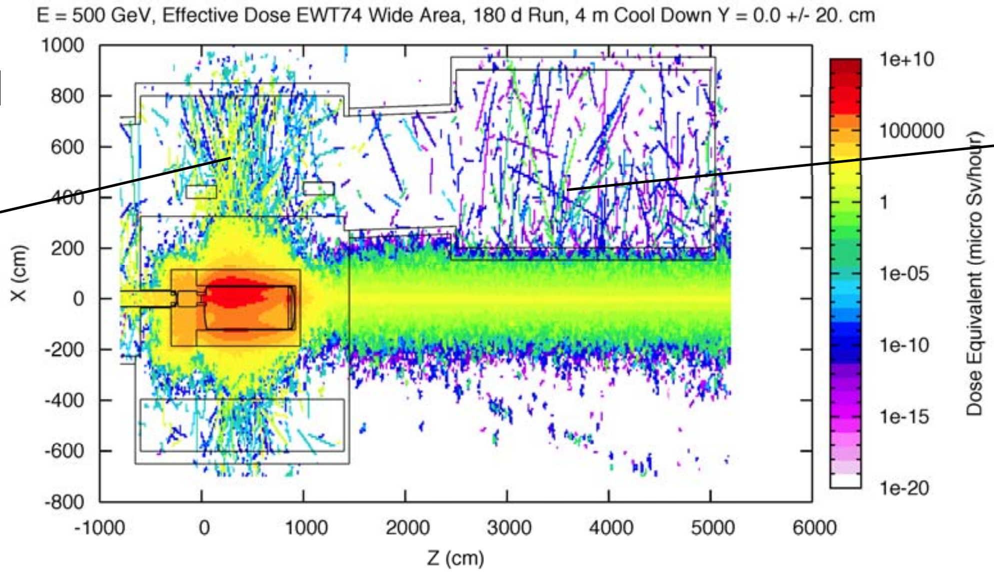
< 10 Rad/h
High Radiation Area

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

Plan View

10 μSv = 1 mrem

Dump Hall and
Muon Spoiler Hall

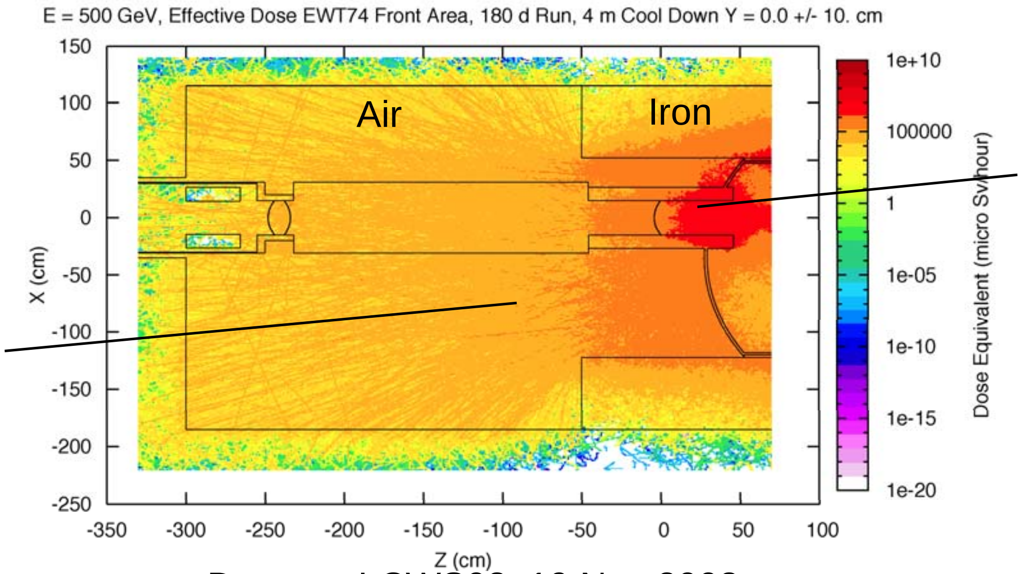


1 to 10 mrem/h
Radiation Area
Access Controlled

Less than 1 mrem/h
Accessible

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

Beamline and
Tank front window



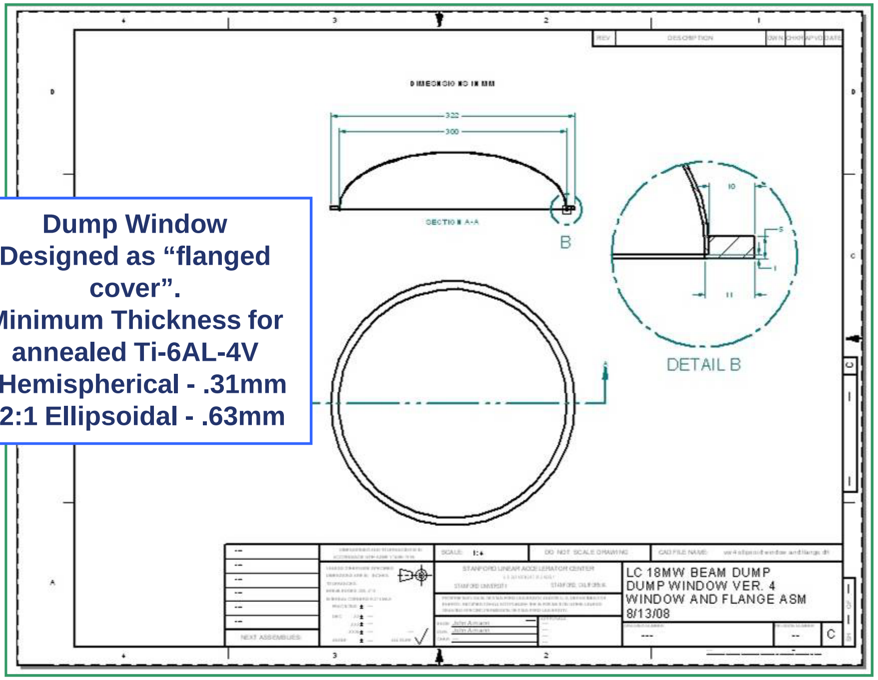
< 100 Rad/h
High Radiation Area
Humans don't go here

< 10 Rad/h
High Radiation Area

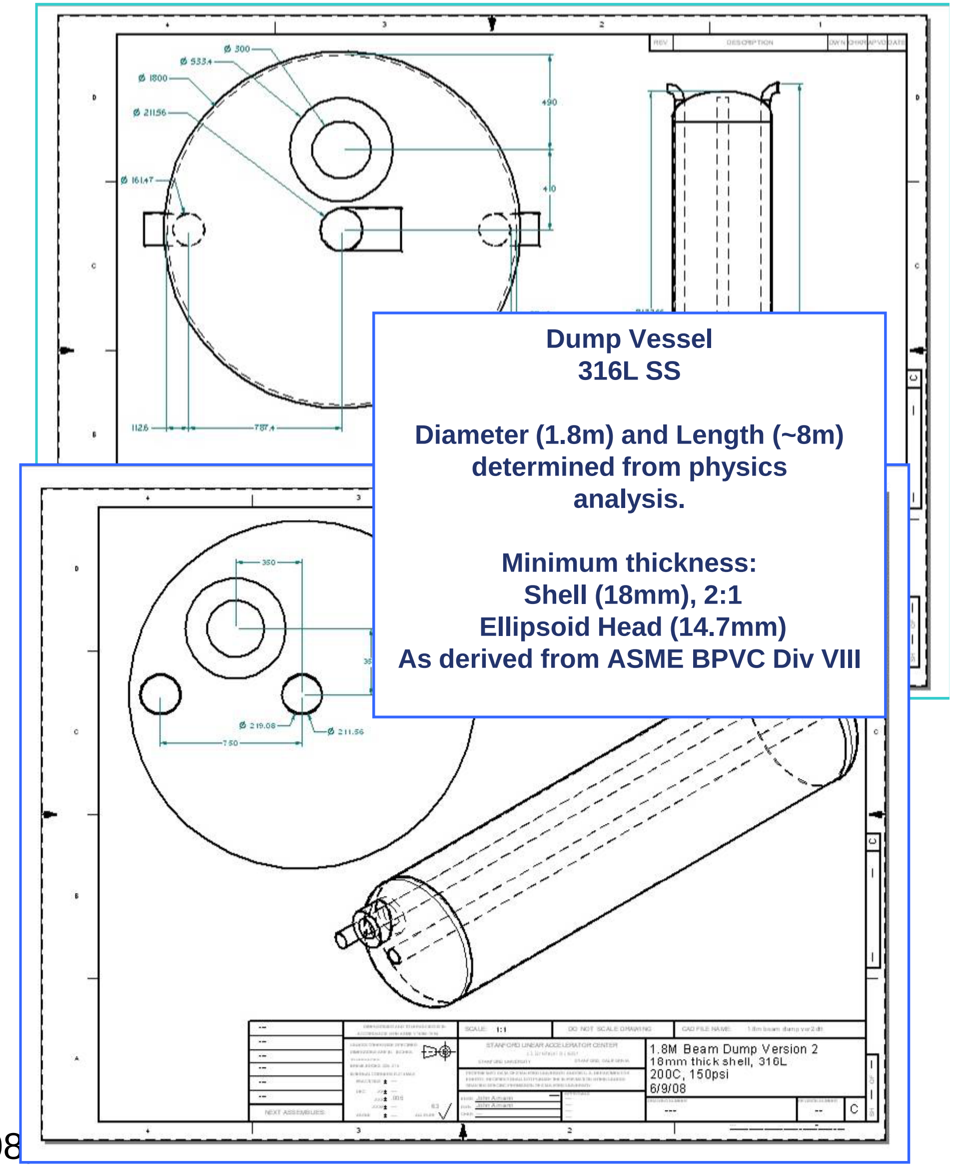
Some Mechanical Design Constraints

- Dump + Shield must fit in beam dump between incoming and outgoing beam lines, few meters in RDR.
- Minimize material at downstream end of dump vessel.
- Remote/robotic window interchange due to activation.
- Separate machine vacuum from dump water.
- Remote/robotic service of other items possibly needed, radioactive filters for one.
- All metal construction, no lubricants, polymers.
- Manufacturability.
- Very High Reliability.
- Beam Spot Rastering – Required for Window Survival!
- If operated in USA, must conform to ASME BPVC.

Beam Dump – Basic Parameters (preliminary)



Dump Window
Designed as "flanged cover".
Minimum Thickness for annealed Ti-6AL-4V
Hemispherical - .31mm
2:1 Ellipsoidal - .63mm



Dump Vessel
316L SS

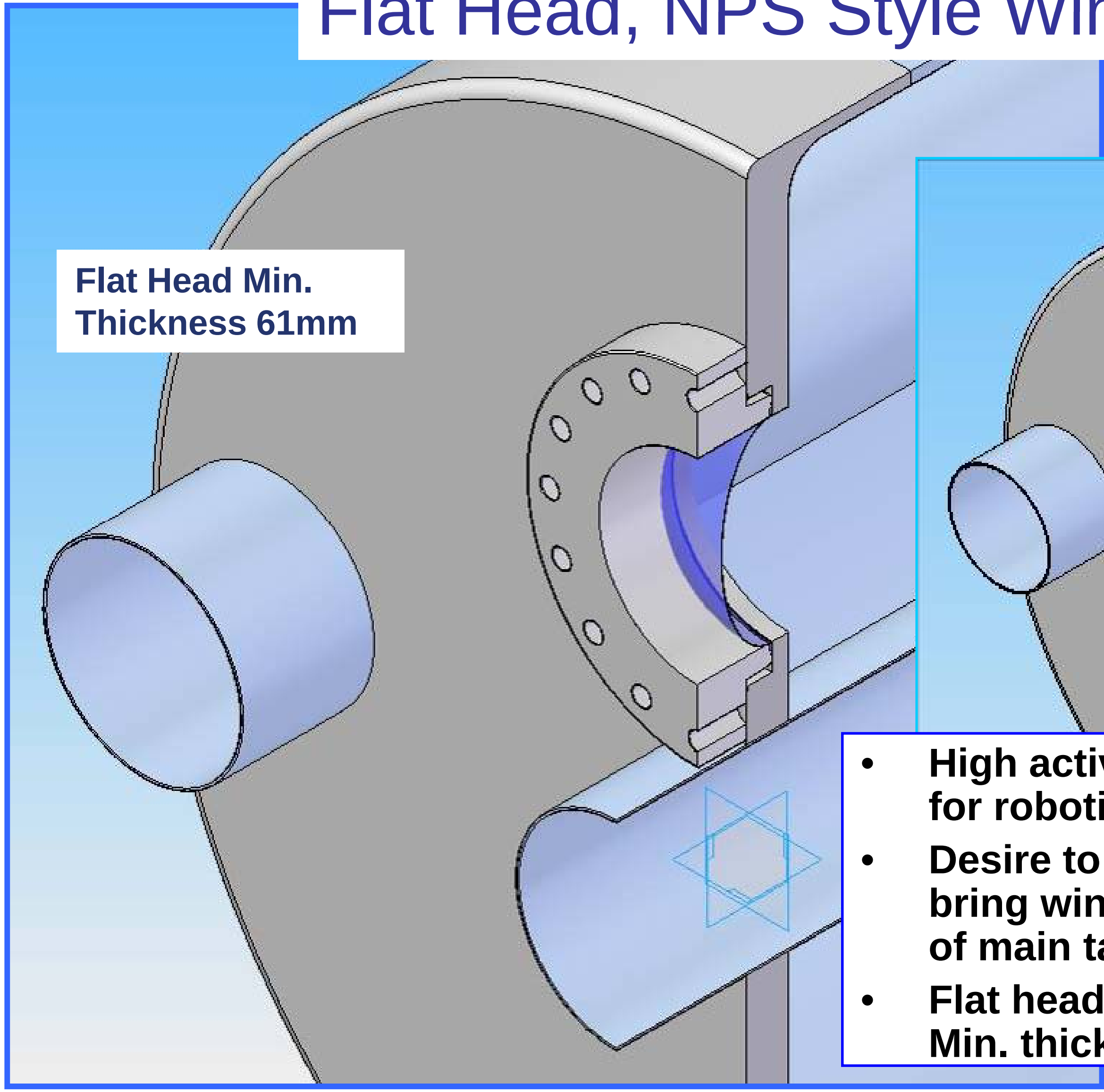
Diameter (1.8m) and Length (~8m) determined from physics analysis.

Minimum thickness:
Shell (18mm), 2:1
Ellipsoid Head (14.7mm)
As derived from ASME BPVC Div VIII

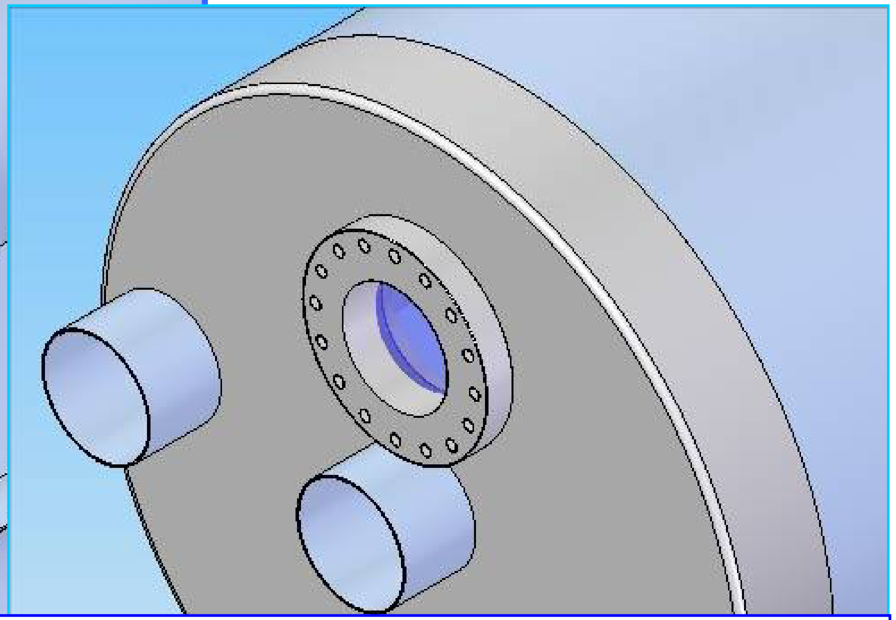
Ideal shape – Hemispherical
Easier to manufacture – Ellipsoidal
Other options –
Toro-spherical (limits max allowable stress = much thicker)
Hemi-cylindrical (more difficult gasket design, interchange)

Materials – D. Walz suggests Ti alloy
Ti-6Al-4V or Ti-13V-11Cr-3Al

Variation of Baseline Design
Flat Head, NPS Style Window Flange



12” Headers



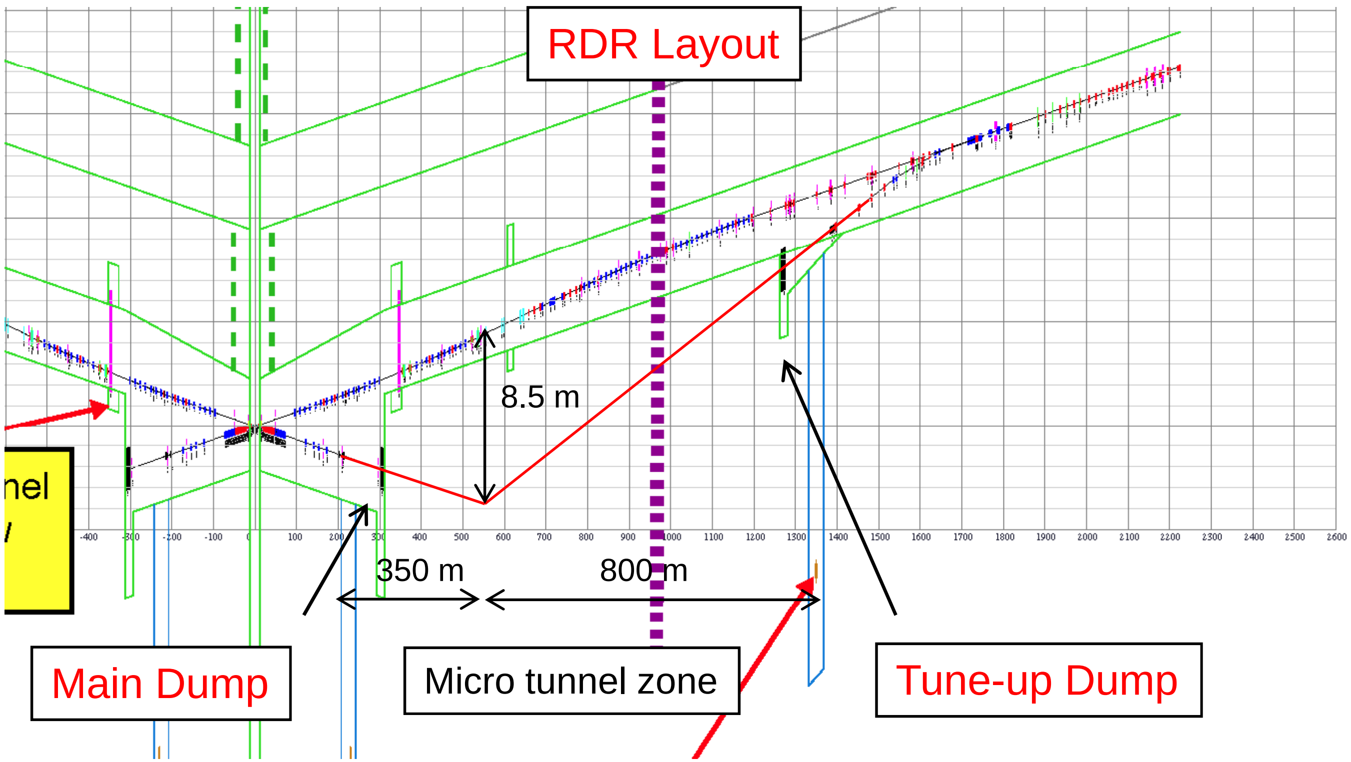
- High activity, need simple, robust, design for robotic maintenance.
- Desire to eliminate cooling sleeve and bring window surface near to vortex flow of main tank.
- Flat head design under investigation. Min. thickness ~61mm vs.

Micro Tunneling and Dumps Location

Would micro tunneling help to optimize the Minimum Machine design?

Small-bored lined beamline tunnels with a few lateral access points could possibly solve several problems:

- increase extraction line length with cheap tunnels to increase sweep radius
- merge Main and Tune-up Dumps, eliminate underground facilities and halls, reduce costs
- move dumps farther away from insertion beamline to reduce vibrations and radiation hazard



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 40^0 to 50^0 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 ~ 50^0 C, maximum temp <~150^0
  - Two-loop cooling systems can be used to reduce costs and complexity

- Dump shielding must surround the tank to contain heat and radiation.
  - 50 cm Iron + ~200 cm Borcrete is about right.
  - 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 of Ti alloy is feasible.
  - Window area is highly activated. Robust design required.
  - Inspection and change requires remote handling.

Work To Do - Some In Progress

- Dump Tank, Windows, Water Loops - Converge on Conceptual Design
  - Header size and location, tank size, beam location, water mass and velocity.
  - Windows and changer mechanism
  - Water cooling loops
  - Tail catcher.
- Refine and Optimize Shielding
  - Material, layout and thickness.
  - Design modular water-cooled shielding with adequate performance, flexibility, access to dump and windows.
  - Study - air activation, dose to adjacent beamline, residual radiation for access.
- Beamline (with Minimum Machine Layout)
  - Provide extraction line long enough for adequate sweep radius.
  - Study power loss and radiation issues from upbeam collimators, optimize design.
  - Design vacuum system exit windows - double, thin, gas-cooled.
- Dump Systems (working from SLAC Beam Dump East example)
  - Plan water cooling systems, rad water containment and handling, specifications for pumps, pipes, scrubbers, ventilation, cooling, instrumentation.
- Testing
  - Beam damage testing of windows with small beam spots
  - Build models of tank and headers for water flow tests.

More Topics That Need Investigation

- Environmental activation and heat from muon and neutron flux in surrounding rock + soil. Study radiation for shallow site.
- Potential vibration sources from high velocity water in headers and tank that could disturb adjacent beamline.
- Possibility to merge main dumps with tuneup dumps using micro tunneling.
  - Implications for design of tanks, headers, windows, tail catchers, etc for double ended dump
  - Muon flux in tunnels to IP.
  - Potential cost savings or not?
- Study dump requirements and potential arrangements for Minimum Machine.