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Canada’s national laboratory for particle and nuclear physics

Shielding Design for the ARIEL e-Linac 100 kW tunning BD & the EHDT beamline Using FLUKA

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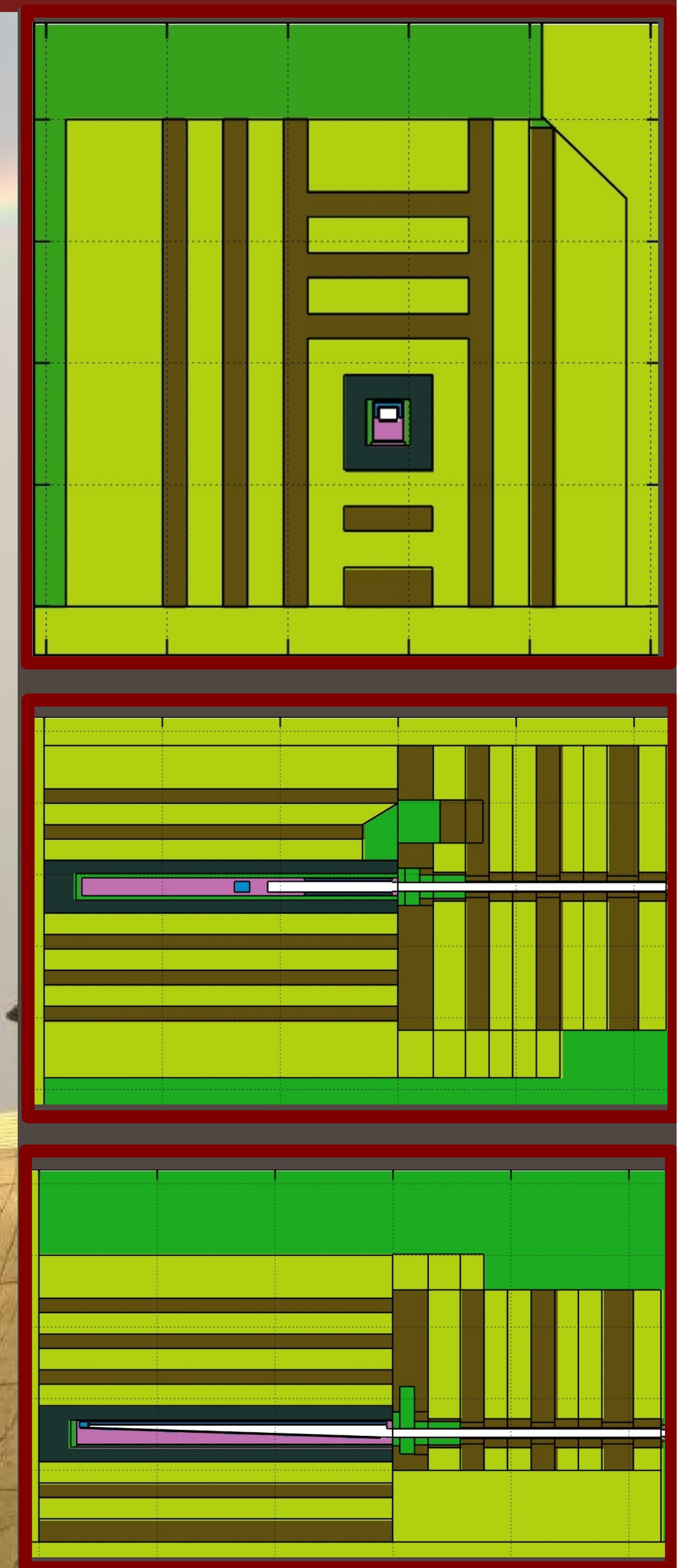


ARIEL overview

ARIEL, TRIUMF's Advanced Rare IsotopE Laboratory, will expand the Rare Isotope Beam (RIB) science program at the existing Isotope Separator and ACcelerator (ISAC) facility, providing two additional beams, resulting in three simultaneous driver beams, and increasing RIB delivery to experimental halls.

Major components of ARIEL

1. Extensive renovation of the existing p-hall into e-hall
2. A new proton beam line (BL4N), delivering 100 μA at 500 MeV (50 kW) from the existing (500 MeV) H^- cyclotron
3. An SRF electron accelerator (eLinac), producing continuous electron beam of 10 mA at 50 MeV (500 kW)
4. A new helium compressor building, housing the cryogenics
5. A 100 kW tunning beam dump for commissioning and beam dev.
6. A tunnel connecting the new beams to the targets
7. A new target hall, housing two target stations
8. A new RIB front-end for selection, acceleration, and transport of the generated RIBs

ARIEL - Electron driver

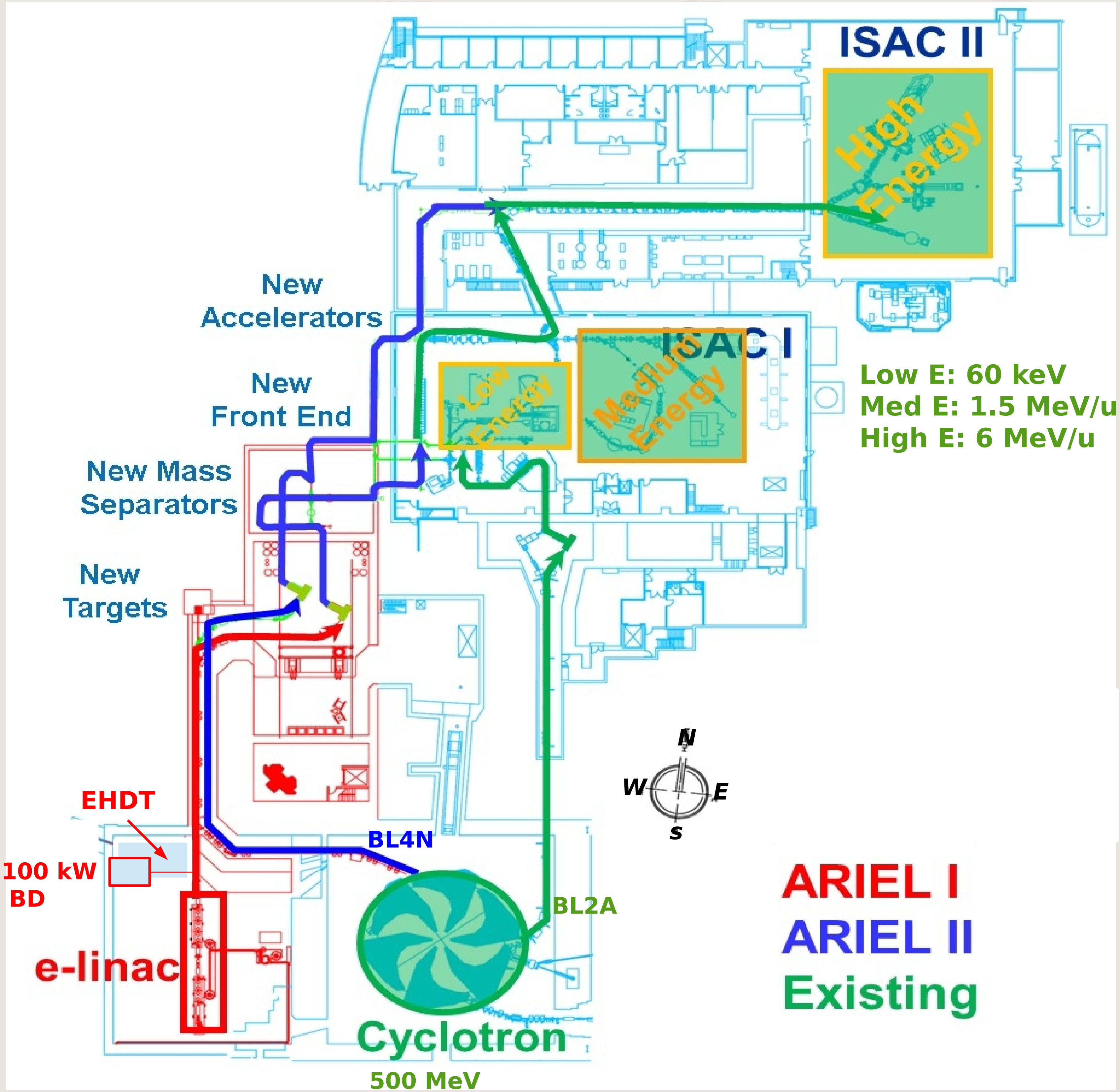
The electron driver advantages:

- Photo-production of Neutron-rich species off of actinide targets
- Lower isobaric contamination
  ---> less background, simpler nuclide separation
- Lower activation of the target components and target area
  ---> easier remote handling, lower radioactive waste (storage & disposal)

Stage 1: ^{8}Li production from BeO target, ^{9}Be(γ,p)^{8}Li, for materials science, with 25 MeV, 100 kW e beam

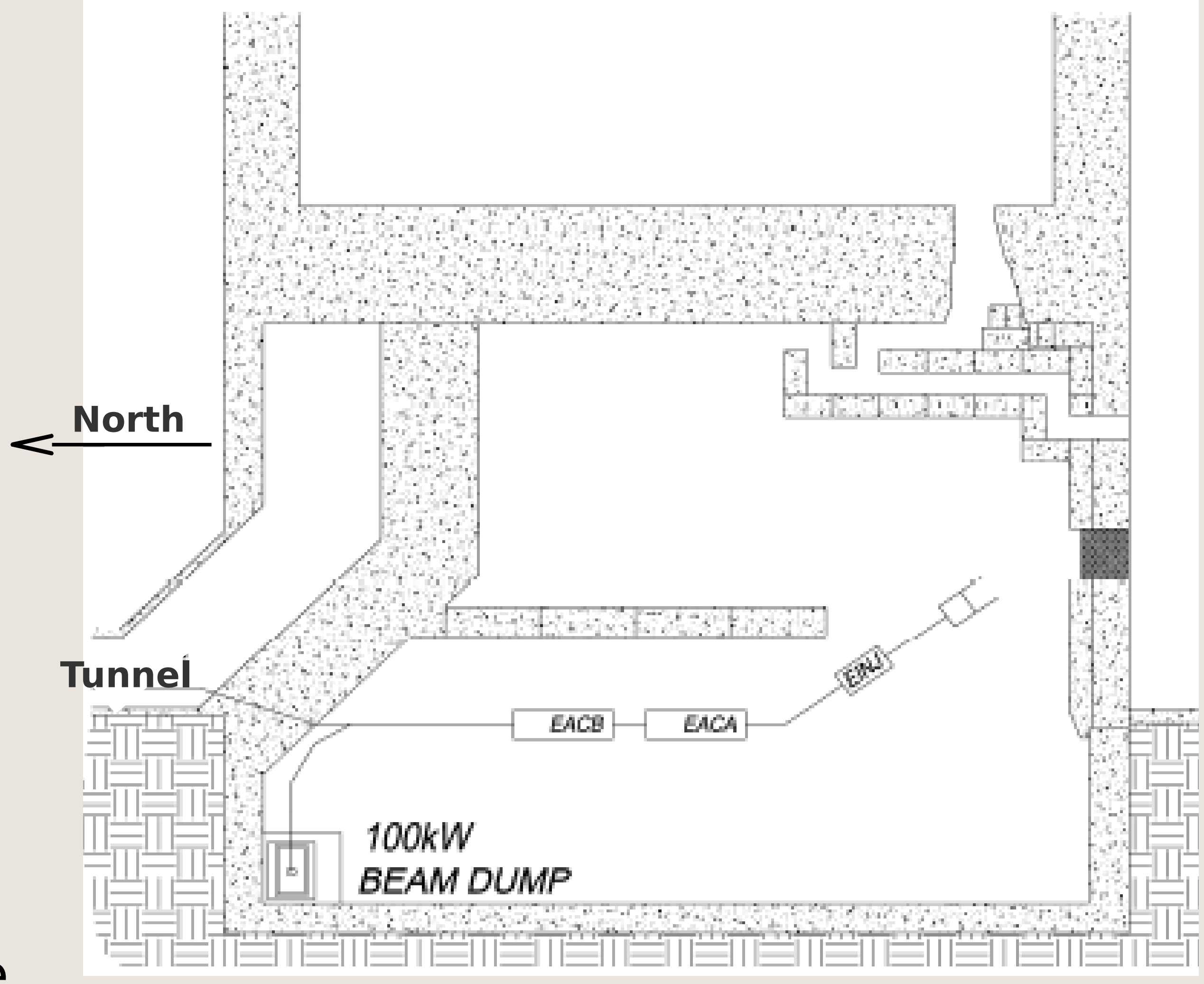
Stage 2: Neutron-rich isotope production from UCx target for nuclear structure, nuclear astrophysics, and fundamental interactions

TRIUMF Beam Lines and Experimental Facilities

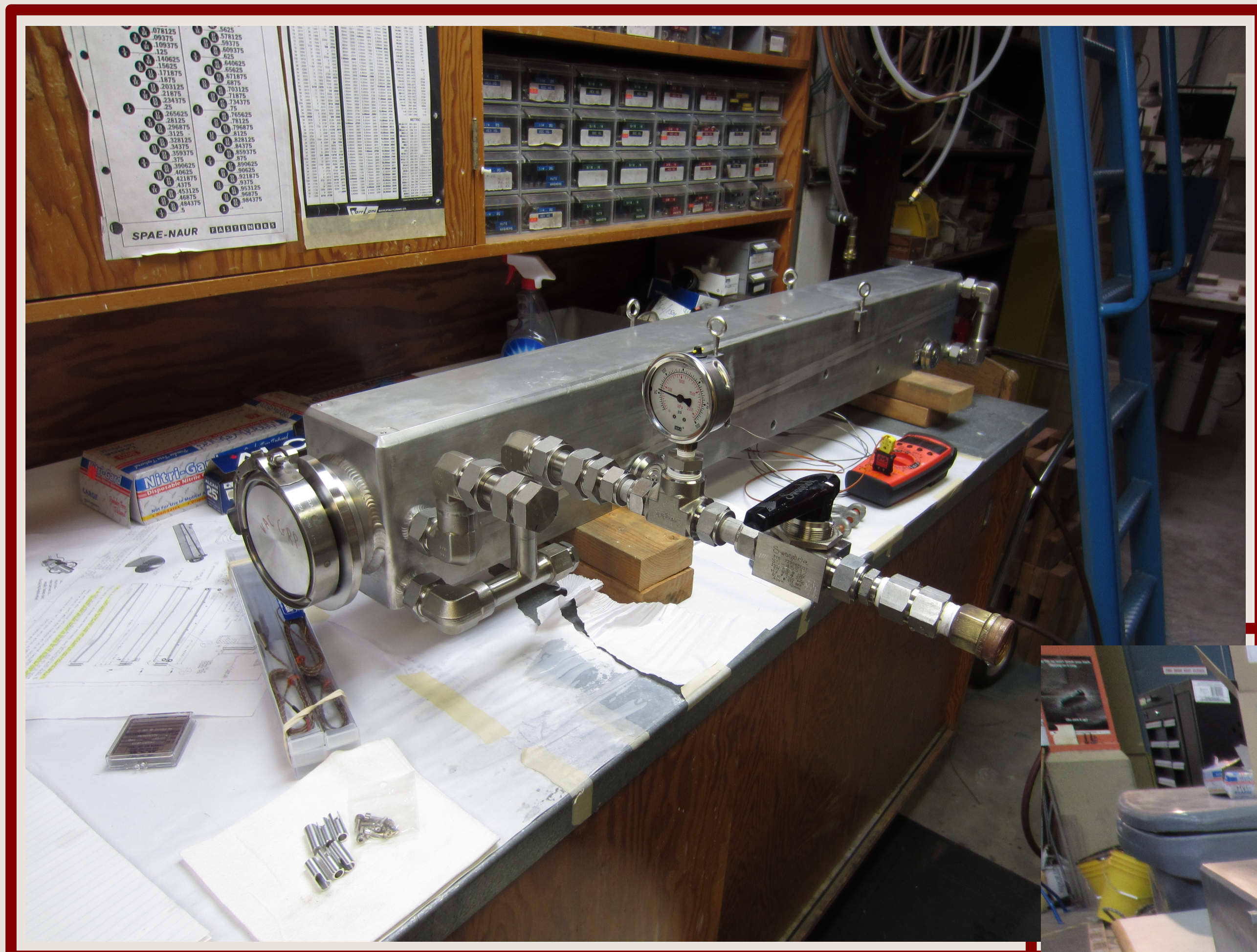


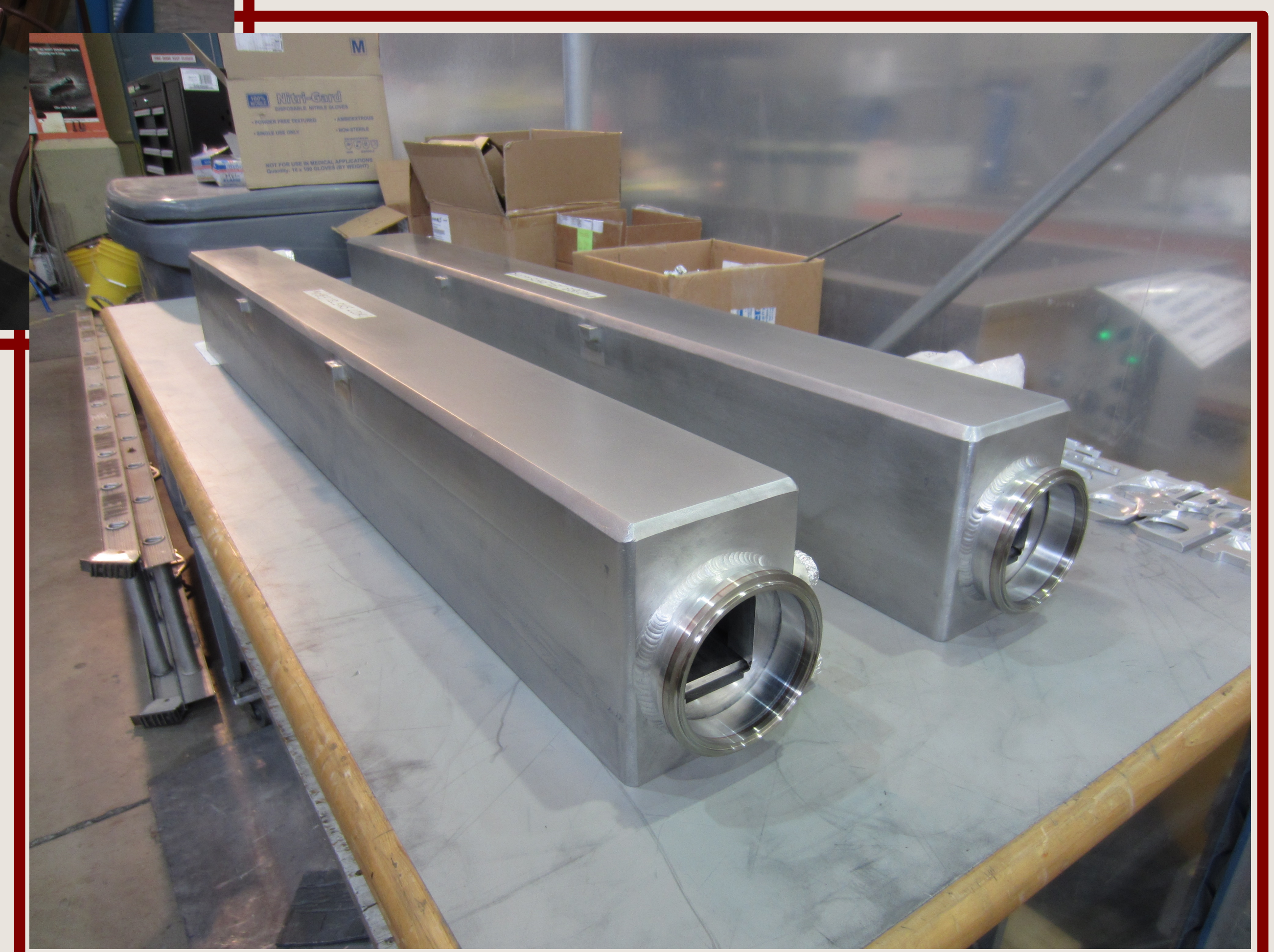
100 kW e-Linac Beam Dump (BD)

- Sits in the North West corner of the e-Hall (at B2 level)
- Is made up of Al-6061-T6
- Has a rectangular shape (134 cm L x 12.6 cm W x 16.9 cm H)
- Incident plate is at 3.06^{O} WRT the horizontal plane to distribute the heat deposition
- Beam energy range: (25-75 MeV)
- Beam is spread in transverse planes via a H and a V raster magnet, to 4x4 cm at the entrance to the BD
-
- Deionized water is used for cooling the BD and shielding immediately surrounding the BD



Beam Dump





100 kW e-Linac Beam Dump – The Project

- Specify Shielding configuration, dimensions and materials for the

  a) BD (local & bulk)

  b) EHDT beam line (bulk and other)

- Find estimates for
  - Power deposition in the BD and the local 'lead' shielding
  - Residual dose rates from the BD and BD+shielding
  - Activation of various BD & shielding components
  - Thickness of a flask/casket for transporting the BD at the end of operation

BD, BD local & bulk shielding, designed by Isaac Earle
EHDT bulk & extra shielding, designed by Vance Strickland

100 kW e-Linac Beam Dump – Operating Conditions

Maximum power on the BD will be 100 kW but the beam energy/intensity will be variable

Initial studies showed:

1) 25 MeV, 4 mA
   Worse-case for power deposition in the BD & BD cooling water regions close to the beam due to the shorter range of electrons

2) 75 MeV, 1.3 mA
   Worse case for
   - power deposition in the lead shielding down stream of the BD
   - prompt and residual dose rates & activation

===> Simulations for
- both 25 and 75 MeV beams for detailed Power Deposition studies
- 75 MeV beam for detailed Shielding Design studies

Shielding Design for the BD

- eHall is an Exclusion Area
  - No occupancy during beam operation
  - Dose rate limits are only for equipment protection & to reduce activation of components in the area

- Dose Rate requirements

Direction	**Above (90°)**	**Below (90°)**	**North (90°)**	**South (90°)**	**West (ds)**	**East (us)**
DR limits (mSv/h)	10 at 3m from BL	10 at wall & soil	10 at wall & soil	3 at 3m from BL	10 at wall & soil	3 AQAP

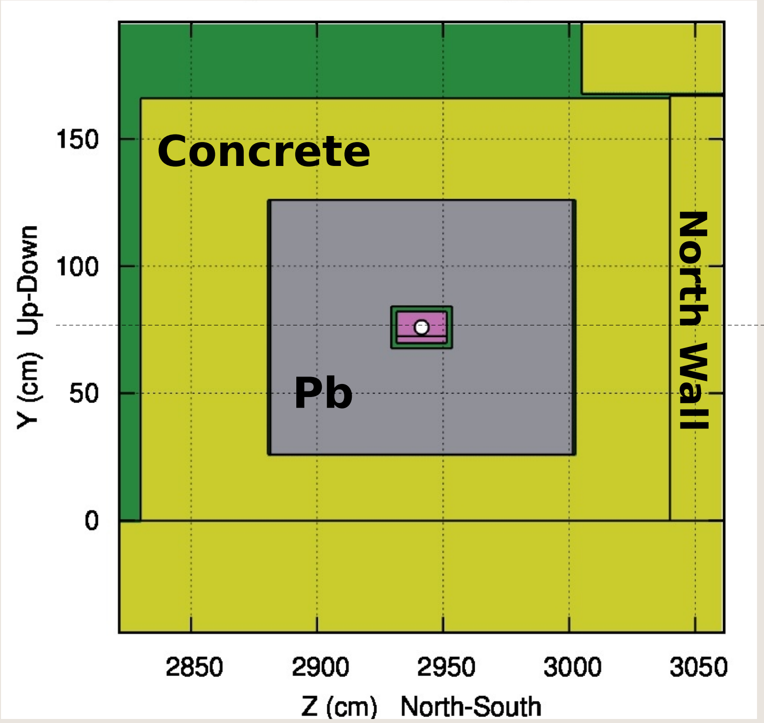
BL: beamline
AQAP: As Quickly As Possible

- Spacial constraints dictating the extent of the shielding
  - Walls on the north and west
  - Floor below
  - EHDT beam line components on the East side

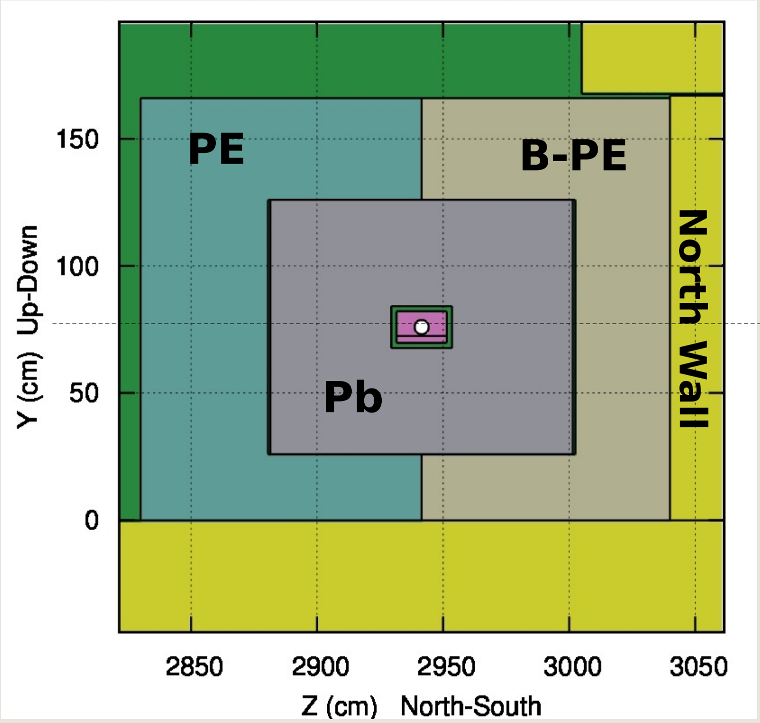
- Engineering design & remote-handling requirements
  - modularity
  - voids for services

BD Local Shielding – 1st attempt

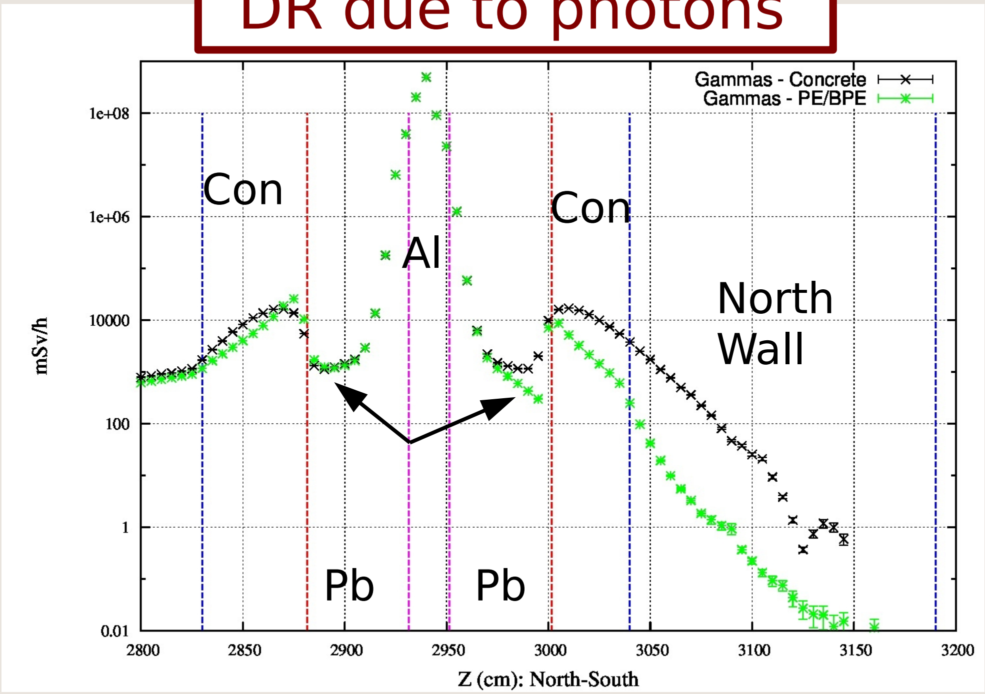
1) Local: Inner layer of Pb
Bulk: Outer layer of concrete



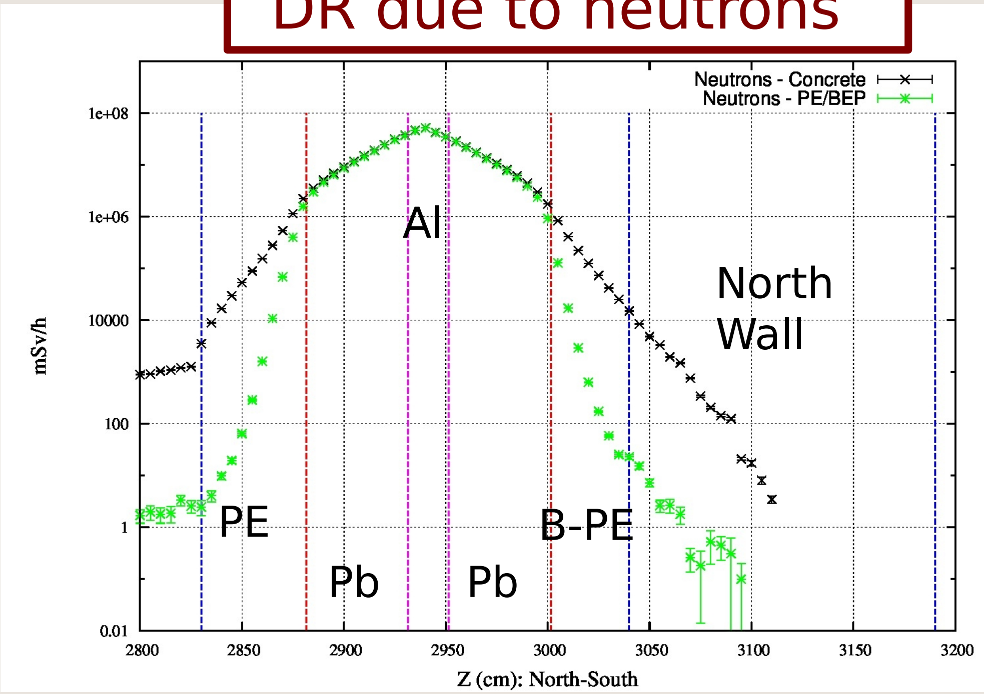
2) Local: Inner layer of Pb
Bulk: Outer layer of PE/BPE (5% Boron)



DR due to photons



DR due to neutrons



BD Local Shielding – Configurations Studied

- From transmission curves, Ignoring γ build-up inside the lead, extracted TVLs for photons in lead, and for neutrons in concrete, PE, and BPE

Particle in Medium		TVL (cm)	
		0°	90°
Photons	Lead	5.3	4.3
Neutrons	Concrete	21	19
	Polyethylene (PE)	N/A	7
	Borated PE	N/A	7

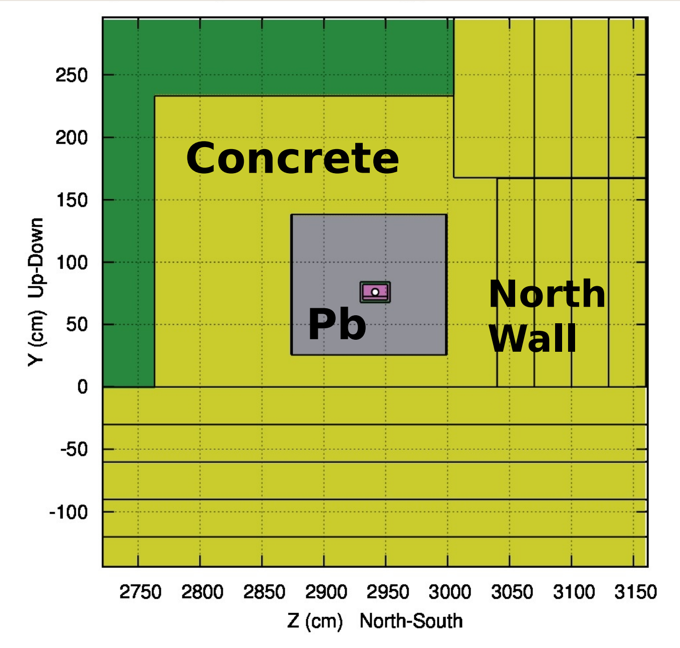
- Using these TVLs, assuming all photon attenuation in lead and neutron
- attenuation in concrete or PE/BPE, and DR limits from requirements, obtained extra shielding required.

Direction		North (90°)	South	Above	Below	West (0°)	East
Thickness (cm)	Pb	47	57	52	42	38	37
	Concrete or PE	N/A N/A	111 53	95 48	N/A N/A	N/A N/A	113 73
Total (cm)	Pb + con. Pb + PE		168 * 110	147 100			150 110

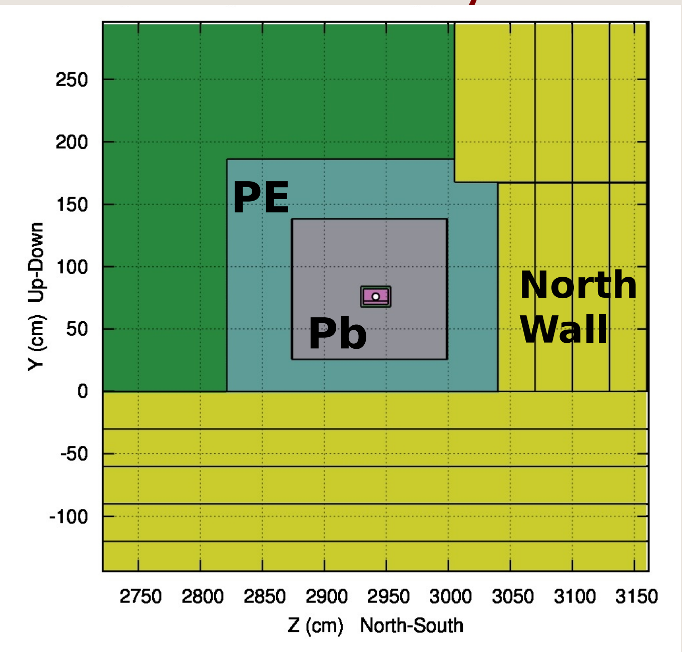
* Total available space for shielding to the south: 99.5 – 103 cm (depending on the width of the BD)

BD Local Shielding – 2nd attempt

1) Local: Inner layer of Pb
Bulk: Outer layer of concrete

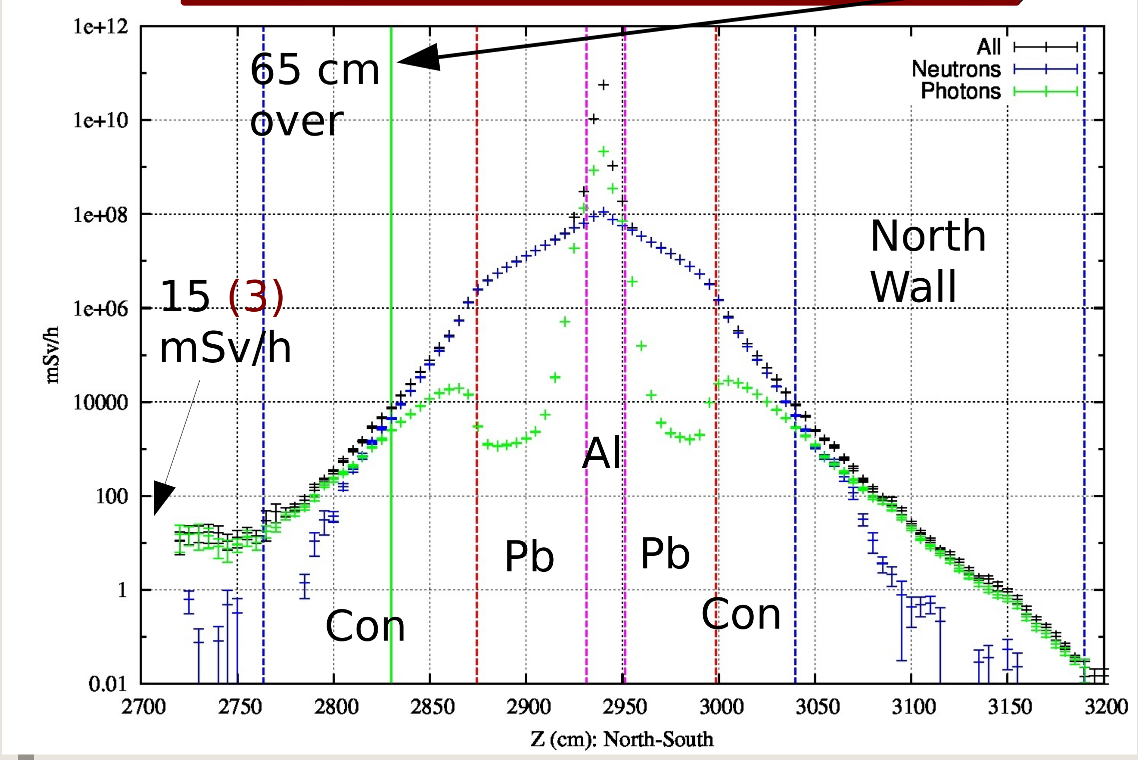


2) Local: Inner layer of Pb
Bulk: Outer layer of PE

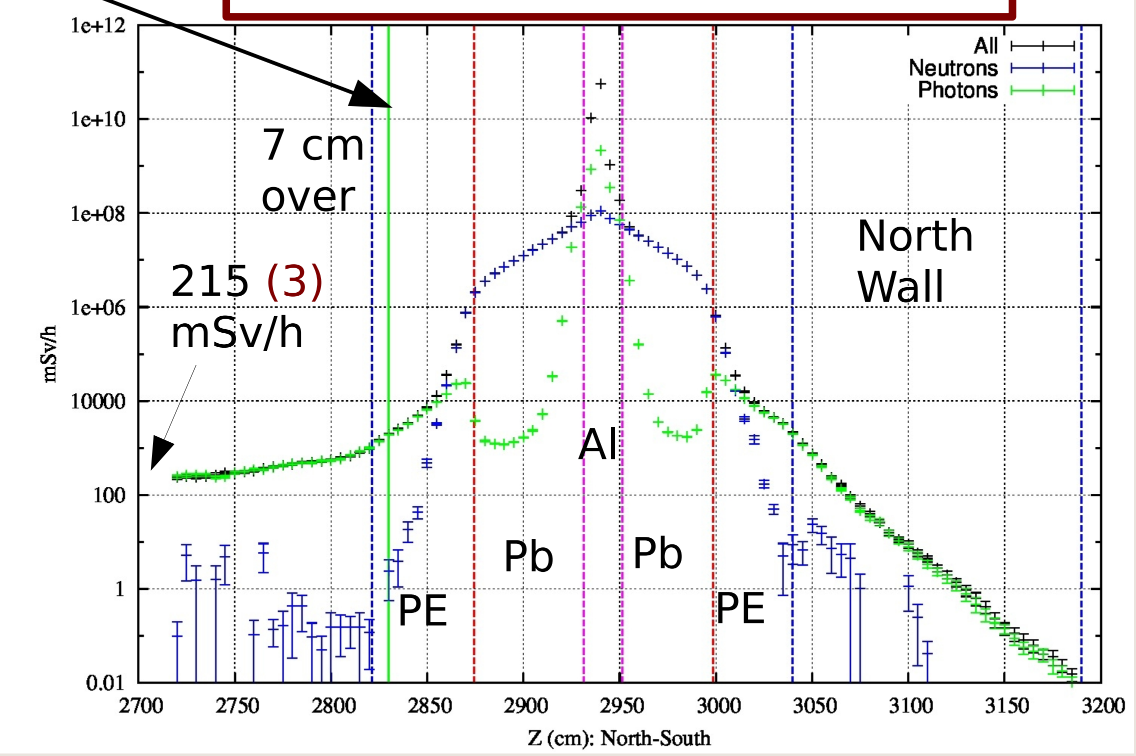


Limit for shielding extension indicated by green lines

DR for Pb + concrete



DR for Pb + PE



Material properties & Neutron Yield

Element	Z	Density (g/cm^3)	Rad. Length, X_0 (cm)	Photon attenuation length, μ, for E = 10 MeV (cm^{-1})	Electron Threshold Energy for neutron production (MeV)
Al	13	2.699	8.90	0.0626	13.03
Fe	26	7.87	1.76	0.235	~ 10
Cu	29	8.96	1.44	0.278	9.91
Pb	82	11.35	0.56	0.564	6.73

- Higher Z materials attenuate photons better than lower Z materials, with larger attenuation lengths
- At 75 MeV, electron beam energy is above neutron production threshold for all of the above materials
- The thicker the material, the higher the neutron yield

Neutron yields from infinitely thick targets

Neutron yields from infinitely thick targets, per kW of beam power, as a function of beam energy, $E_{0,}$ disregarding target self-shielding.

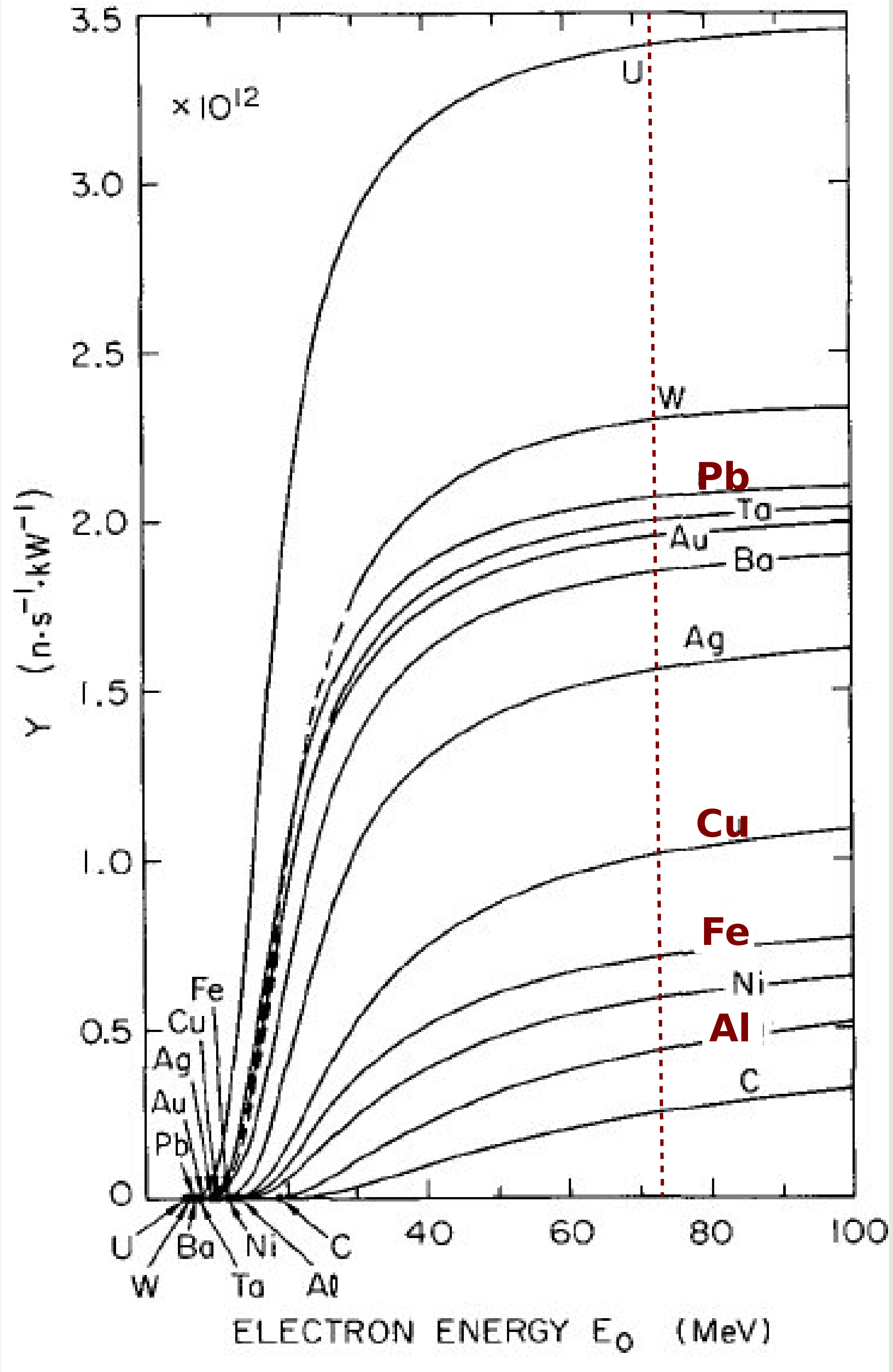
IAEA TRS 188

Lead has a fairly large photo-neutron cross-section:

At 75 MeV, electrons generate about
- 2x as much neutrons in Pb than in Cu
- 3x as much neutrons in Pb than in Fe
- 4.5x as much neutrons in Pb than in Al

These neutrons in turn generate more gammas through (n,γ) reactions
This secondary photon production leads to the observed build-up effect in Pb

Similar photon build-up behaviour was observed when Pb was replaced with carbon steel, albeit at a smaller magnitude

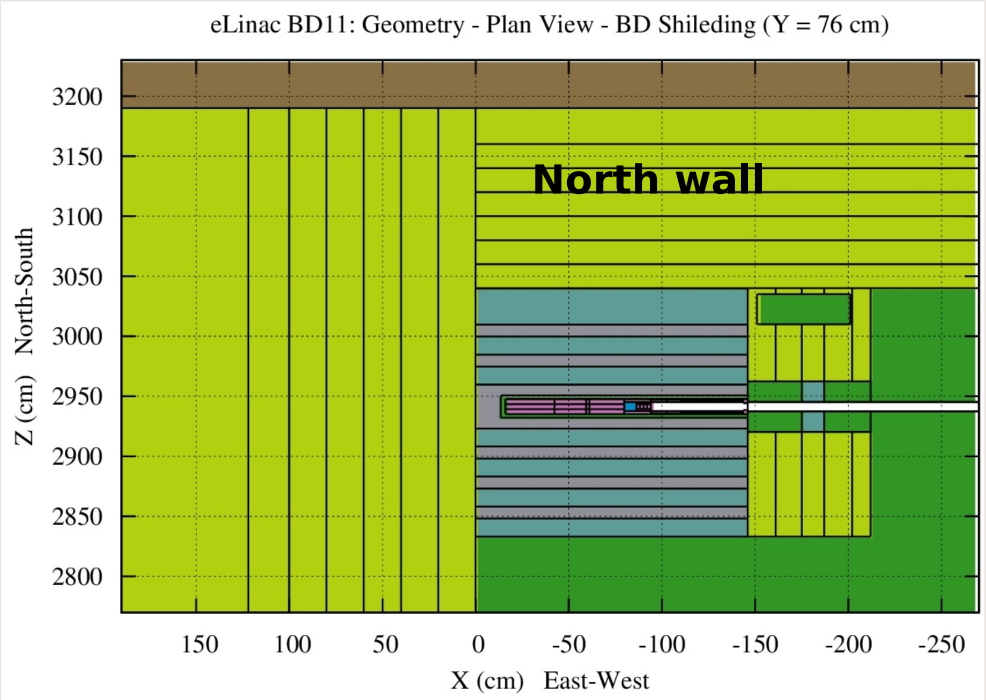


Solution:

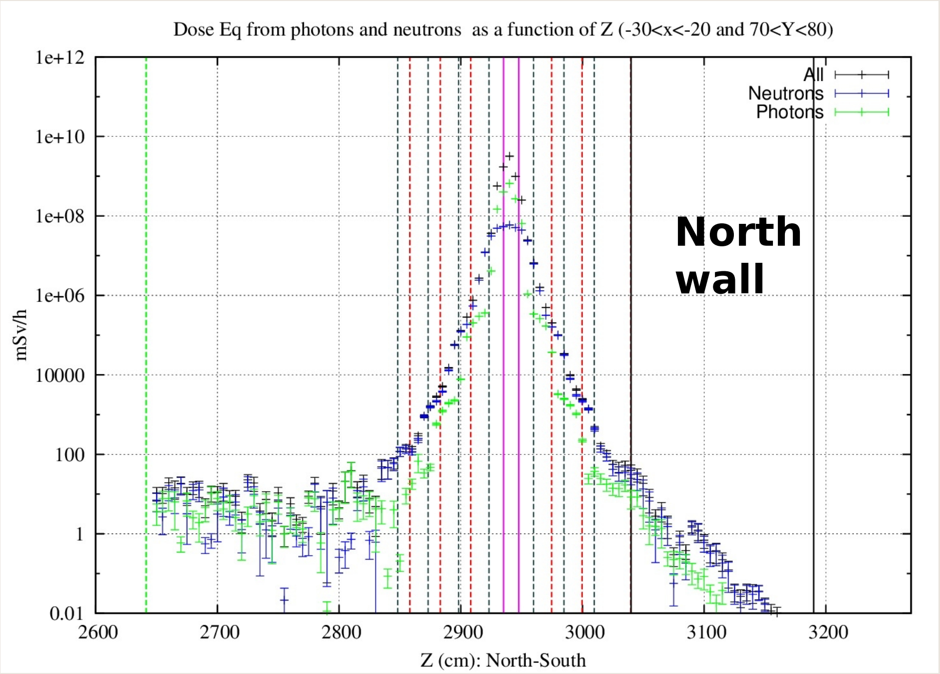
- Determine optimum Pb thickness by the lowest photon DR
- Add a layer of low Z material, immediately after Pb, to attenuate/absorb the generated neutrons.
- Implement a layering design (high Z, low Z material) for gradual attenuation of both neutrons and photons
- Use a Russian Dull configuration in the geometry for simplicity

BD Local & Bulk Shielding
Configurations tested

- Pb, PE layering design



Direction	North (90°)	South	Above	Below	West (0°)	East
Thickness (cm)	10 Pb 15 PE 10 Pb 15 PE 10 Pb 30 PE	10 Pb 15 PE 10 Pb 15 PE 10 Pb 15 PE 10 Pb 15 PE	10 Pb 15 PE 10 Pb 15 PE 10 Pb 15 PE 10 Pb 15 PE	10 Pb 15 PE 10 Pb 15 PE 16 Pb	13.5 Pb	66 Con 12 PE
Total (cm)	90	100	100	66	13.5	66



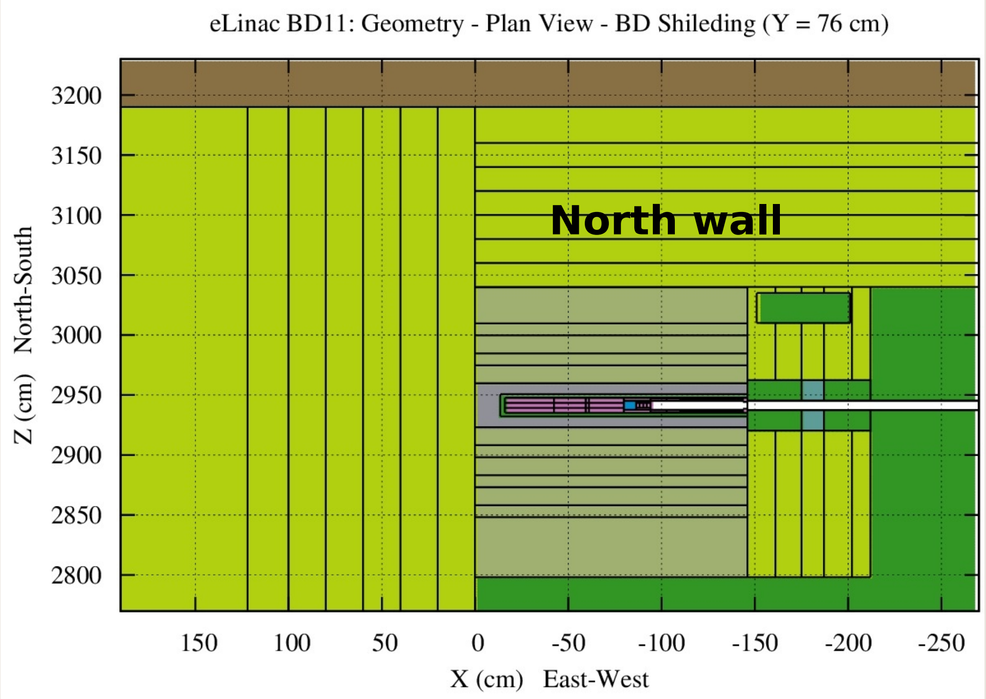
- Would need extra layers on the south to meet the DR limit

-

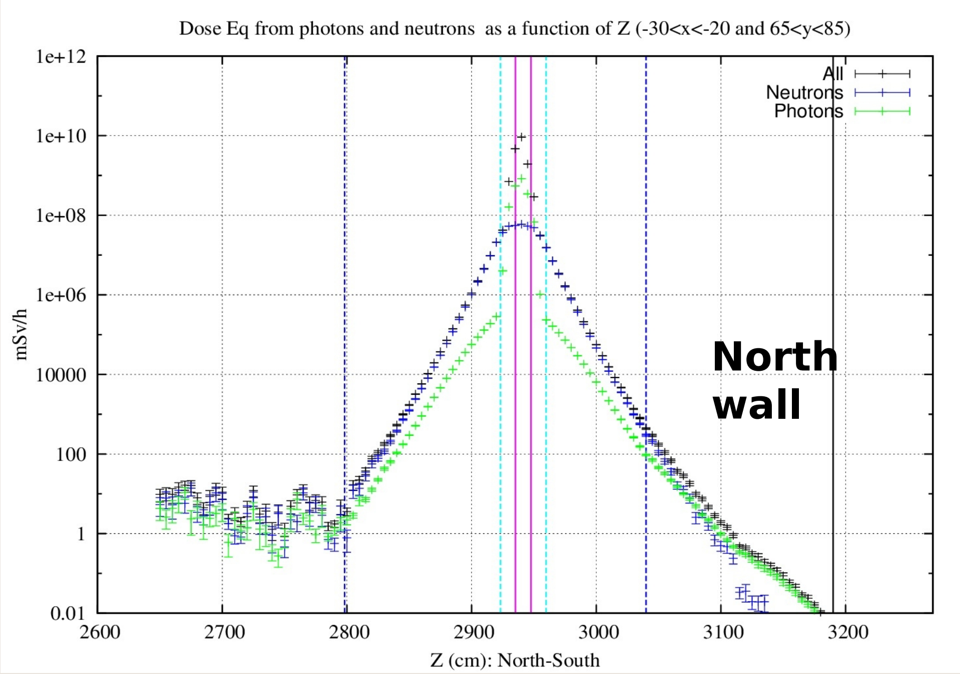
- Rejected
  - Exceeding extension limit on the south
  - 1E5 Gy radiation damage threshold for PE
    Inner layers of PE are sitting in high radiation fields (1E4 Sv/h)
    With BD anticipated operation time of 1 month per year for 20 years (14400 h), only the last two outer layers of PE will survive the radiation environment

BD Local & Bulk Shielding
Configurations tested

- Pb + High Density Concrete (HDC)



Direction	North (90°)	South	Above	Below	West (0°)	East
Thickness (cm)	10 Pb 80 HDC	10 Pb 120 HDC	10 Pb 105 HDC	10 Pb 56 HDC	13.5 Pb	66 con 12 PE
Total (cm)	90	130	115	66	13.5	78



- Met DR limits

- Rejected
  - Exceeding extension limit on the south
  - Higher cost – special mix with hematite or magnetite aggregates
  - Unknown composition unless tested through ICP-MS, ICP-AES, ...
  - Higher possibility for non-uniform composition
  - Not as effective in attenuating neutrons because of combined attenuation of high energy neutrons (inelastic interactions) and low energy neutrons (elastic scattering)

- Steel, PE layers
  Rejected for the same reason as for Pb, PE Layers

- Steel, concrete layers (i.e. no Inner Pb layer)
  Rejected for higher dose rates due to photons on the West wall (d.s. of the BD)

  Further study showed a 10 cm steel inserted into the West wall behind the BD could have achieved the same dose rates as that for the configuration with an inner layer of Pb but cutting through the wall and installing the steel piece, and resealing would have taken too much time and effort.

- Inner layer of Steel and outer bulk of Concrete
  Not as efficient as the layering design for attenuating photons and neutrons. Rejected for not meeting the extension limit

BD Local & Bulk Shielding
Final Design

- BD shielding

  Local: Inner layer of Lead surrounding the Beam Dump

  Bulk: Layers of ASTM A36 carbon steel and concrete

  - Russian dull configuration of layers changed to the to match the planned engineering design
  - Cut-outs/voids for services and water package modelled into the geometry

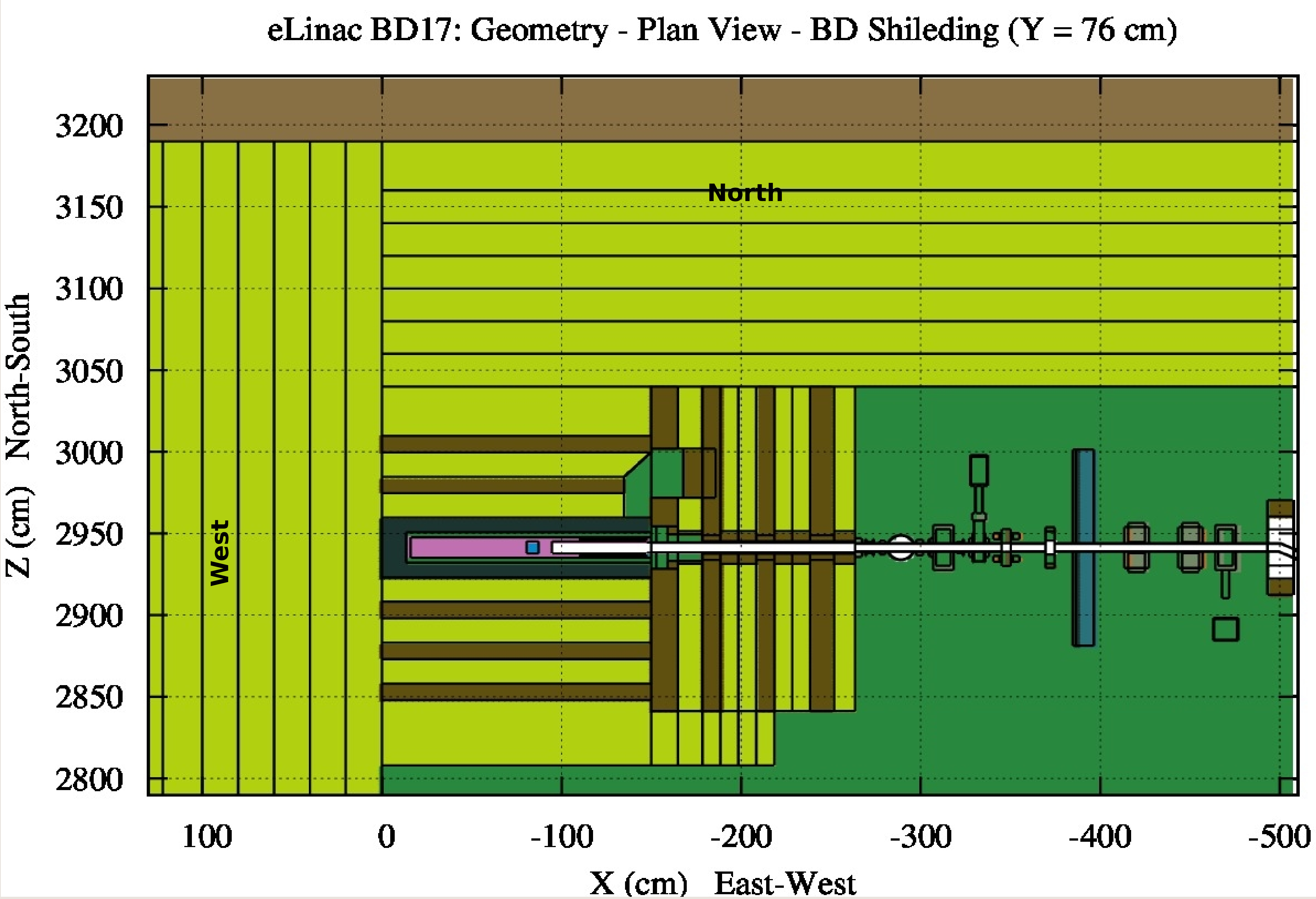
- EHDT Bulk & other shielding

  Bulk: - Layers of A36 steel and concrete, with an inner ASTM A36 carbon steel insert around the beam pipe

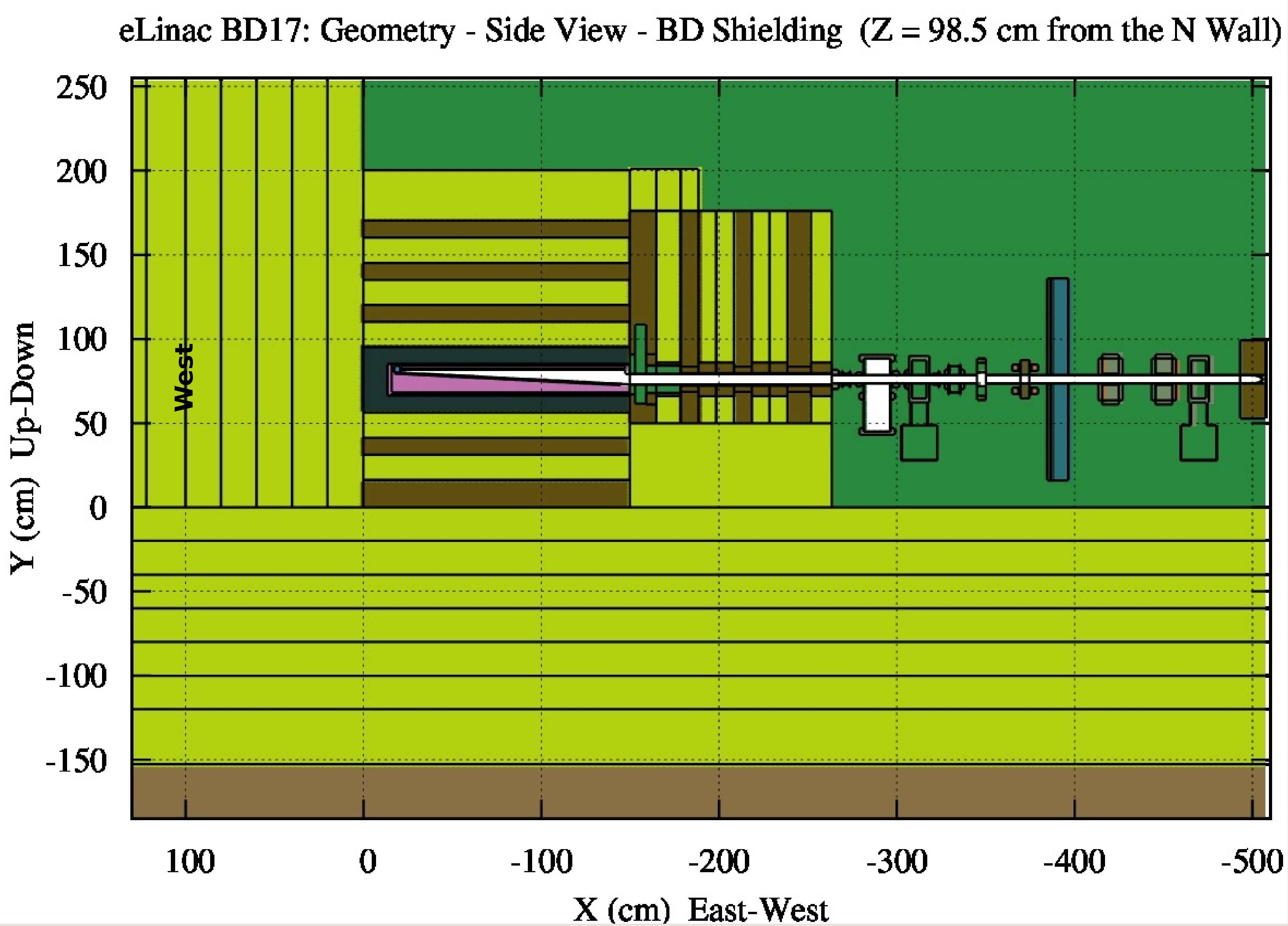
  - Supported on a 50 cm concrete block
  - Two extra concrete blocks on the top and to the south of the bulk shielding at the interface with the BD shielding

- Other: A 1” Pb & 4” PE collimator immediately down stream of the raster magnets with a 1” Pb ring inside the PE slab

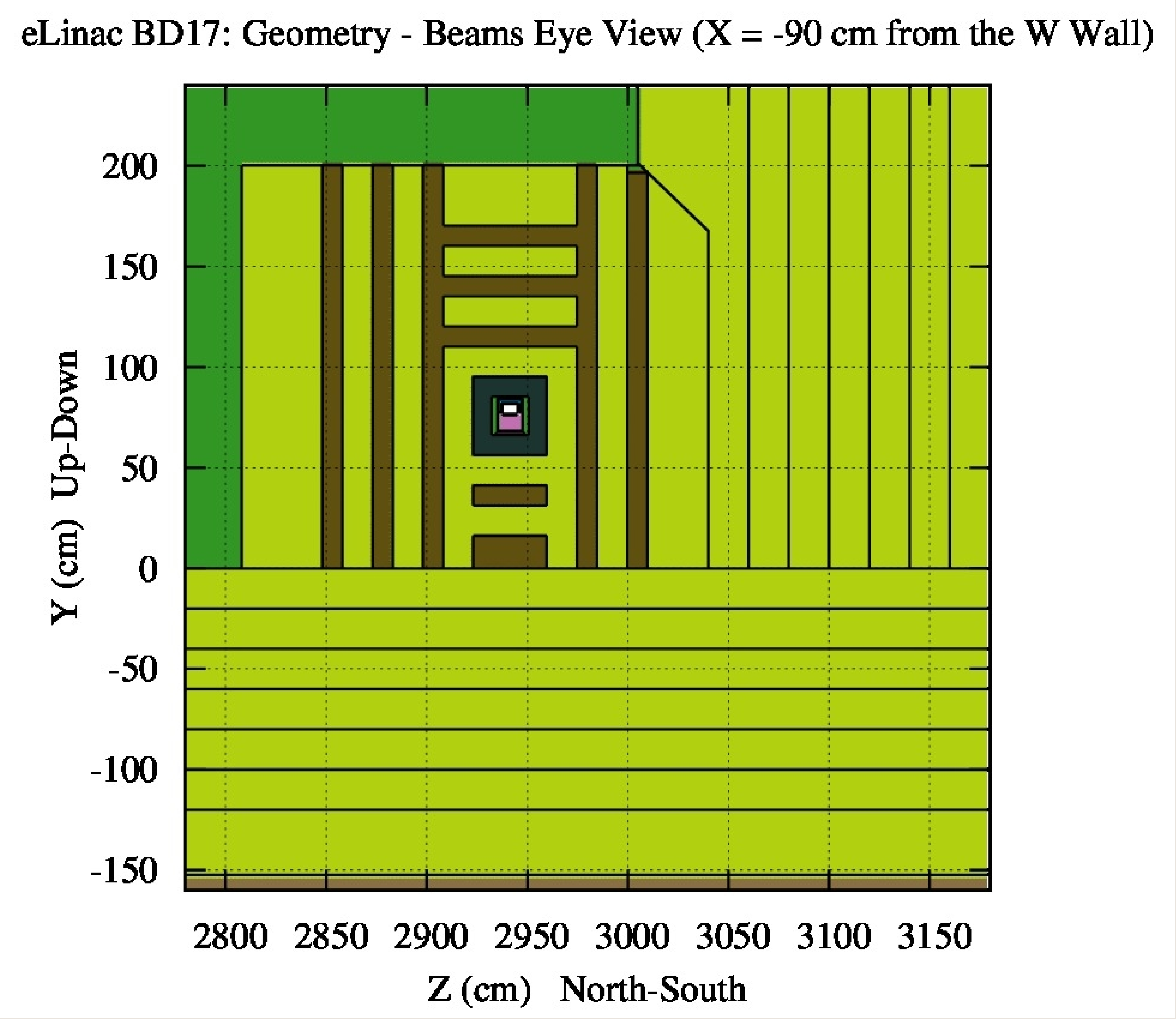
Geometry – Top View



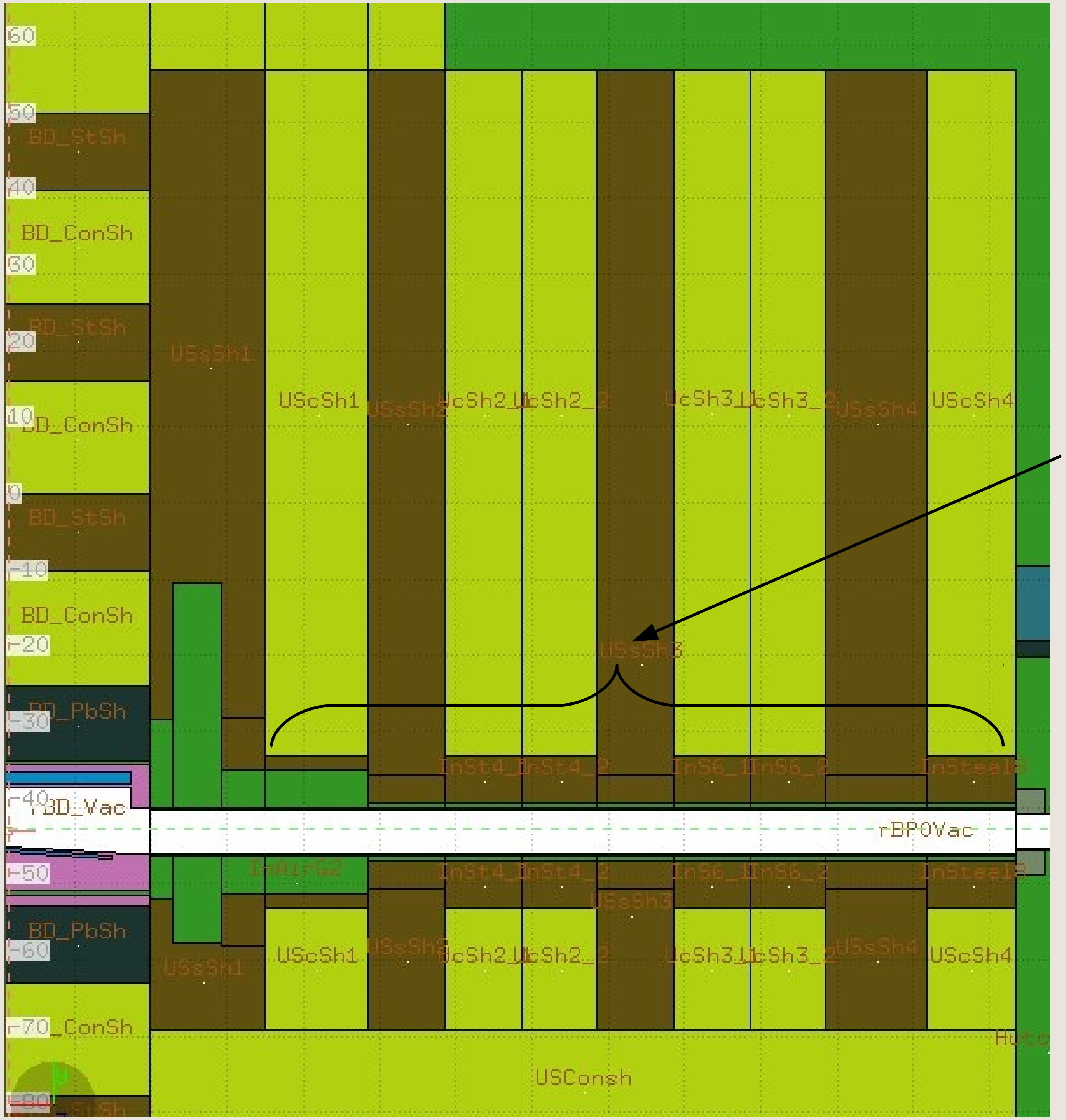
Geometry – Side View



Geometry – Beam's Eye View



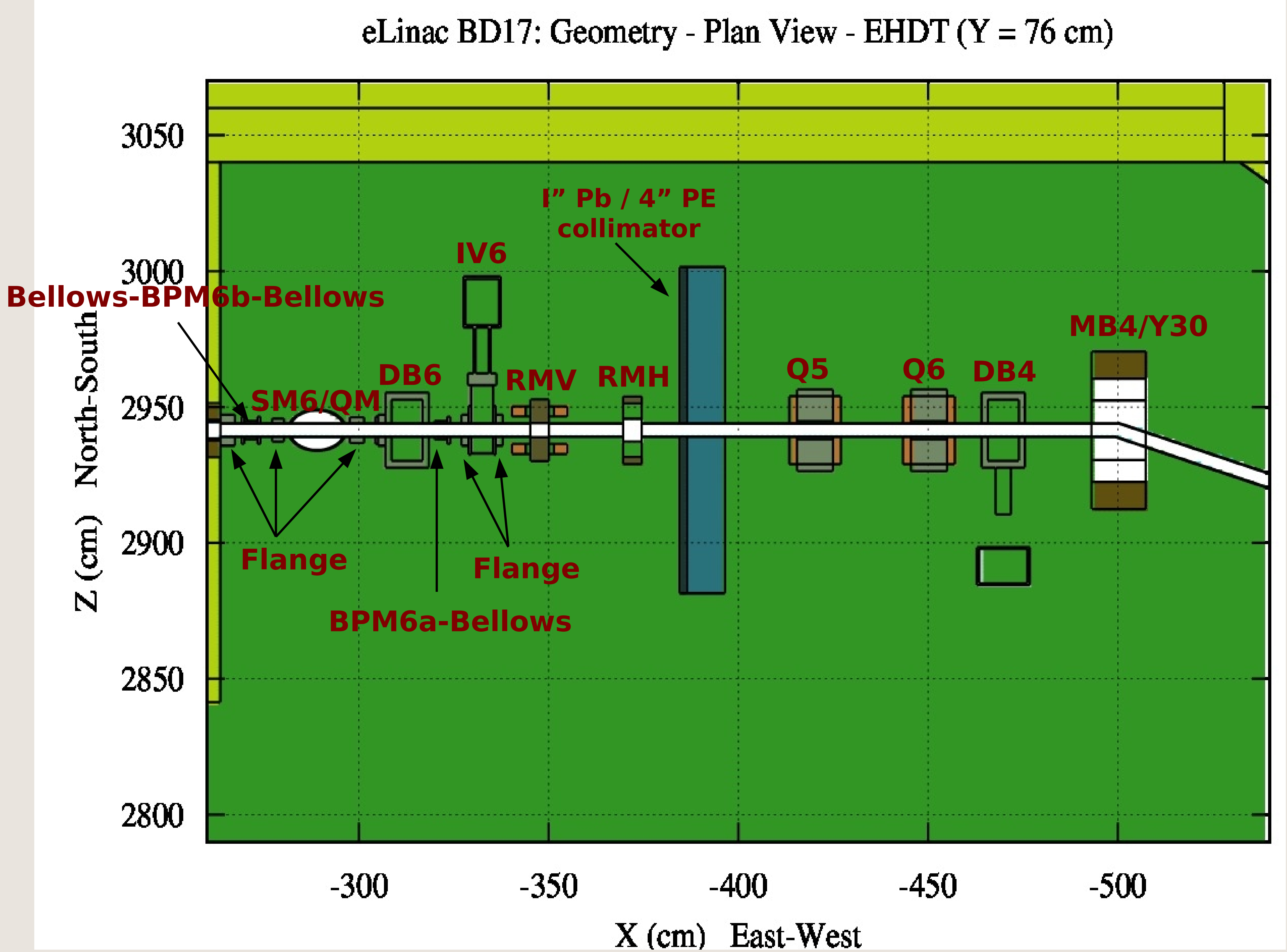
Geometry – Side View
Steel insert around the BP inside the EHDT bulk shielding



A36 Carbon Steel insert

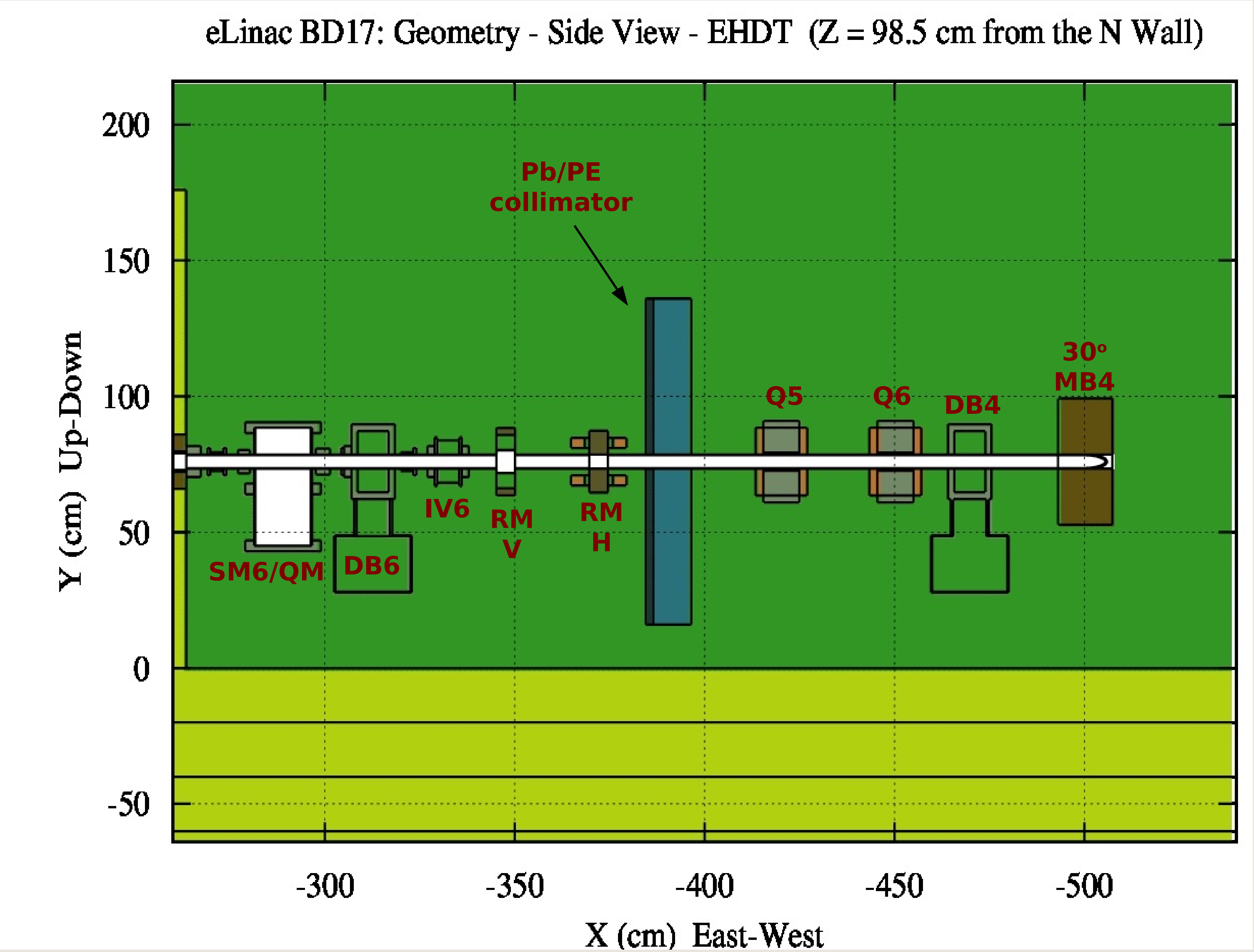
Geometry – Top View

EHDT – Beam line components modelled & Pb/PE shielding



Geometry – Side View

EHDT – Beam line components modelled & Pb/PE shielding



BD Local & Bulk Shielding
Final Design

Direction	Middle section		Sides			
	Above (90 °)	Below	North (90°)	South	West (0°)	East
Thickness (cm)	10 lead	10 lead	10 lead	10 lead	13.5 lead	0 lead
	15 conc 10 steel 15 conc 10 steel 15 conc 10 steel 30 conc	15 conc 10 steel 15 conc 16.2 steel	15 conc 10 steel 15 conc 10 steel 30.25 conc	15 conc 10 steel 15 conc 10 steel 15 conc 10 steel 40 conc		15 steel 13.6 conc 10 steel 20 conc 10 steel 20 conc 13 steel 11.7 conc
Total (cm)	10 lead 75 conc 30 steel 115	10 lead 30 conc 26 steel 66	10 lead 60 conc 20 steel 90	10 lead 85 conc 30 steel 125 *	13.5 lead 13.5	0 lead 65 conc 48 steel 113

* 22 cm over the 103 cm limit for extension of shielding to the south.
This is OK since the limit allowed for a 40 cm clearance.

Shielding Simulations - Challenges

- Low statistics upstream of the EHDT bulk shielding, despite using biasing and long runs (3-4 days)
- Beamline components under design (changing location of components, few components under design, ...)
- Specific questions to answer in regards to the upstream

Shielding Simulations – Implementation

Employed the 2-step method

1st step

* Used for assessing/estimating
  - Prompt dose rates outside the BD, at the walls, on the soil and outside of the EHDT bulk shielding
  - Residual Dose rates from BD and BD + shielding
  - Activation in various BD and BD (Al-6061, water) and BD shielding components (lead, concrete, steel)
  - Shielding flask design for transportation of BD at the end of its life

* Repeated after major modifications to the setup:
  - BD dimensions
  - Voids and cut-outs
  - BD and EHDT bulk shielding design modifications

1st step (cont)

* Based on 1.5B primaries
* Used importance biasing in the walls, floor, and EHDT bulk shielding
  Divided up regions into subregions (10 – 20 cm)
  Set importances in BIASING card

* Wrote out particles crossing the EHDT shielding boundaries
  Used USRDUMP card to activate the call to mgdraw.f
  'Uspart.dat' defined as the name of the output file

  Runs eLin_BD-A - eLin_BD-Z, 30 cycles each, 2M primaries/cycle
  30 data files per run, 750 files total
  eLin_BD-A001_USpart.dat ... eLin_BD-Z030_Uspart.dat

* Checked distribution of the particles written out to make sure all relevant boundaries were included

Shielding Simulations - Implementation

2nd step

* Used for assessing/estimating

- Additional shielding configuration for EHDT: Pb/PE hutch, collimator, or collimator + wall

- Effect of filling 30° bending magnet (MB4) vacuum box with stainless steel for shielding backscattered photons through the beam pipe

- Effect of the raster magnets (RMH and RMV) on the backscattered electrons

- Effect of drilling a hole in the angled east wall in containing the radiation field from doubly back-scarred particles

- Dose rates at the CCD camera housed in DB4 (2 m u.s. of the EHDT bulk sh.)

- Dose rate at the turbo pump housed in SM6-QM (20 cm u.s. of the EHDT bulk sh.)

2nd step (cont)

* Used particles from the 1st step as source

- Concatenated eLin_BD-A*_Uspart.dat into eLin_BD-A_Uspart.dat
  26 data files for 2nd step
- Added in the SOURCE card
- Created source-A.f ... source-Z.f
  Source-A.f: OPEN(UNIT=47, file='../eLin_BD-A_USpart.dat', status='old')
- Set up 26 runs, eLin_BD-A – eLin_BD-Z each with its own executable,
  eLikn_BD_A ... eLin_BD_Z
  Each run 20 cycles, 2M primaries

* Normalization for the 2nd step

- Summed up the weights of all particles written out from the first step:
  W_sum = 1.27731e+05
- Number of primaries generated in the first step:
  N_prim = 1.5E9
- Normalization = W_sum/N_prim = 8.5154E-5
- Applied this normalization to all distributions in 2nd step

Shielding Simulations - Implementation

2nd step (cont)

* Biasing

Used importance biasing only for the walls

* Magnetic field

- Used MGNFIELD card to activate call to magfld.f
- Modified user routine magfld.f to define magnetic fields for the three dipoles (RMH, RMV, MB4)

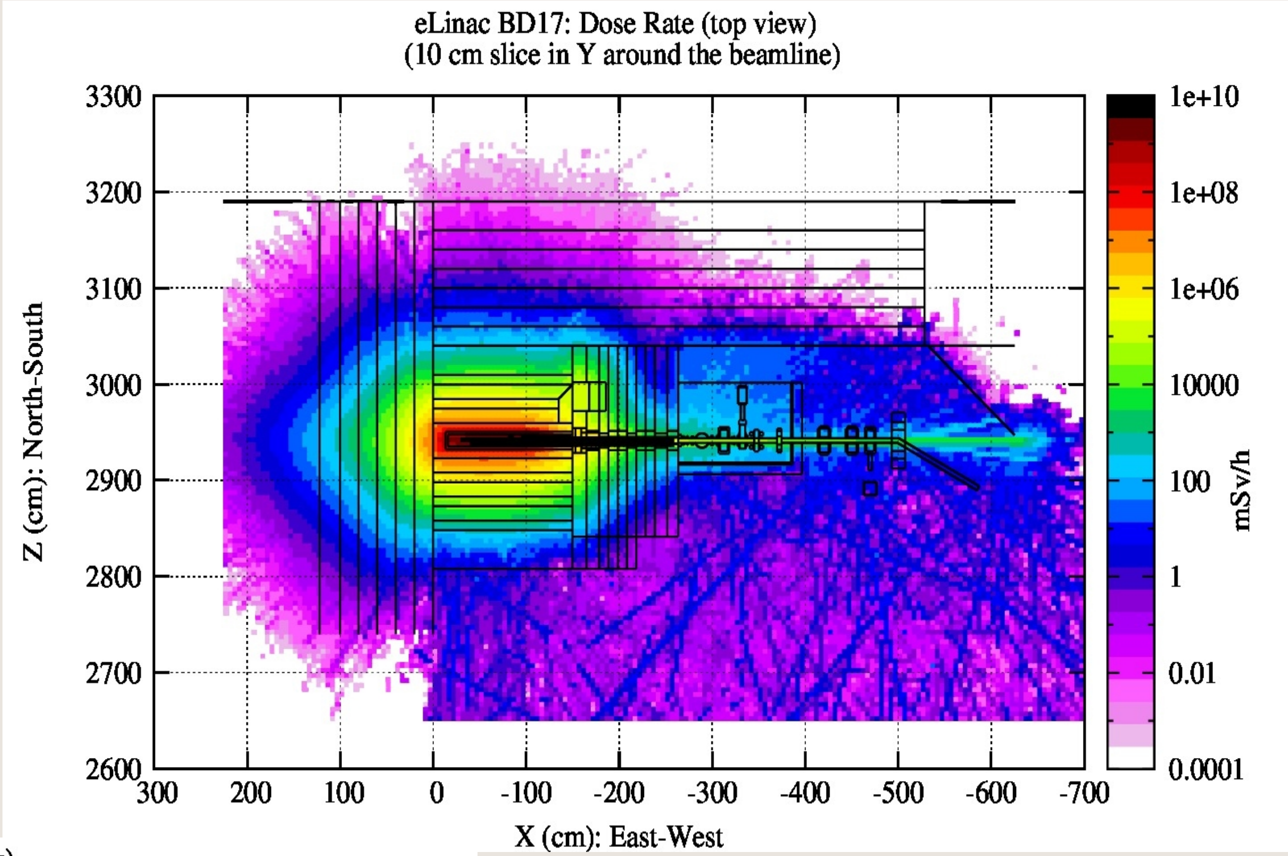
  RM B field = 0.027 T (RMV: $-B_y$, RMH: $+B_z$)

  MB4 B field = 0.74 T (+By)
- Set Field to 'Magnetic' in ASSIGNMA card for the three magnetic regions

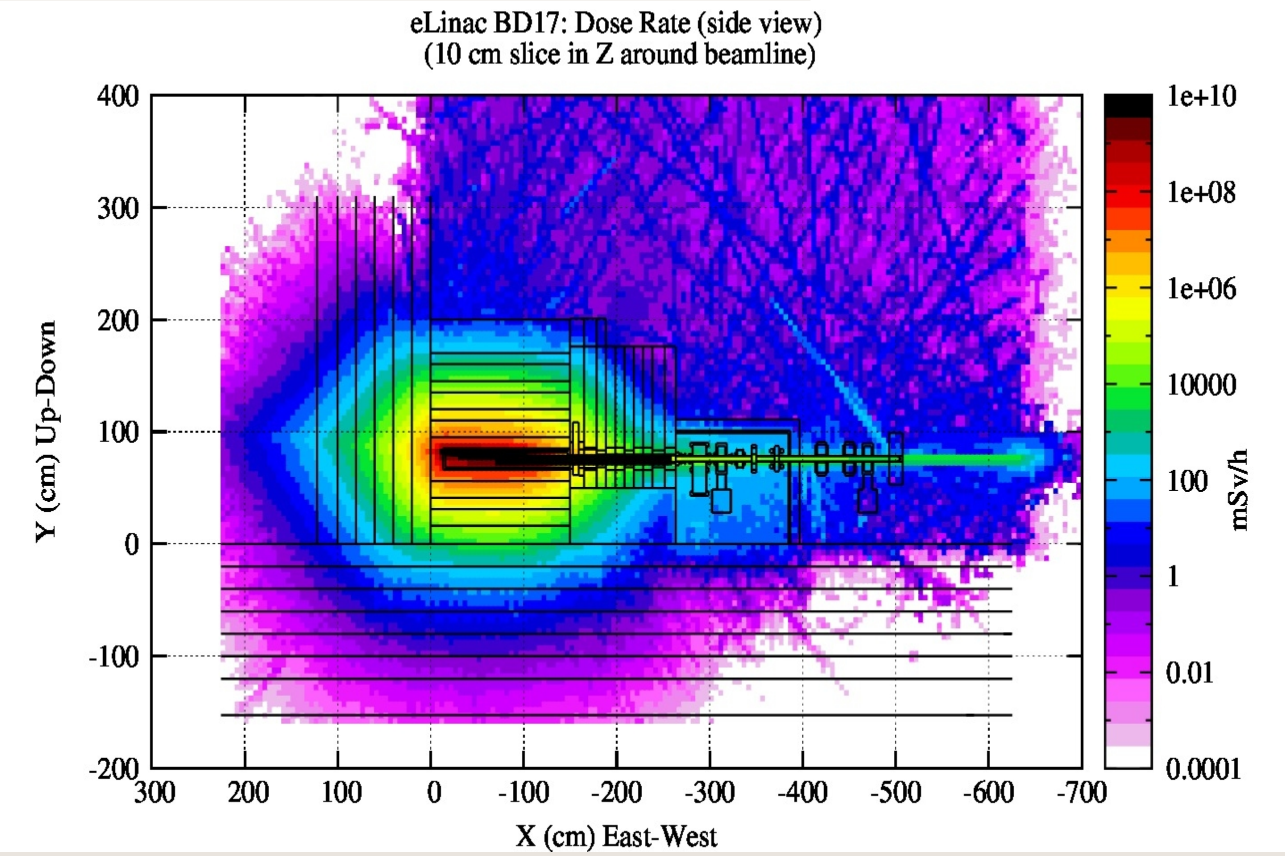
Total Dose Rate Distributions outside the BD

1st step results

Top View



Side View



Dose Rates Around the BD Shielding
1st step results

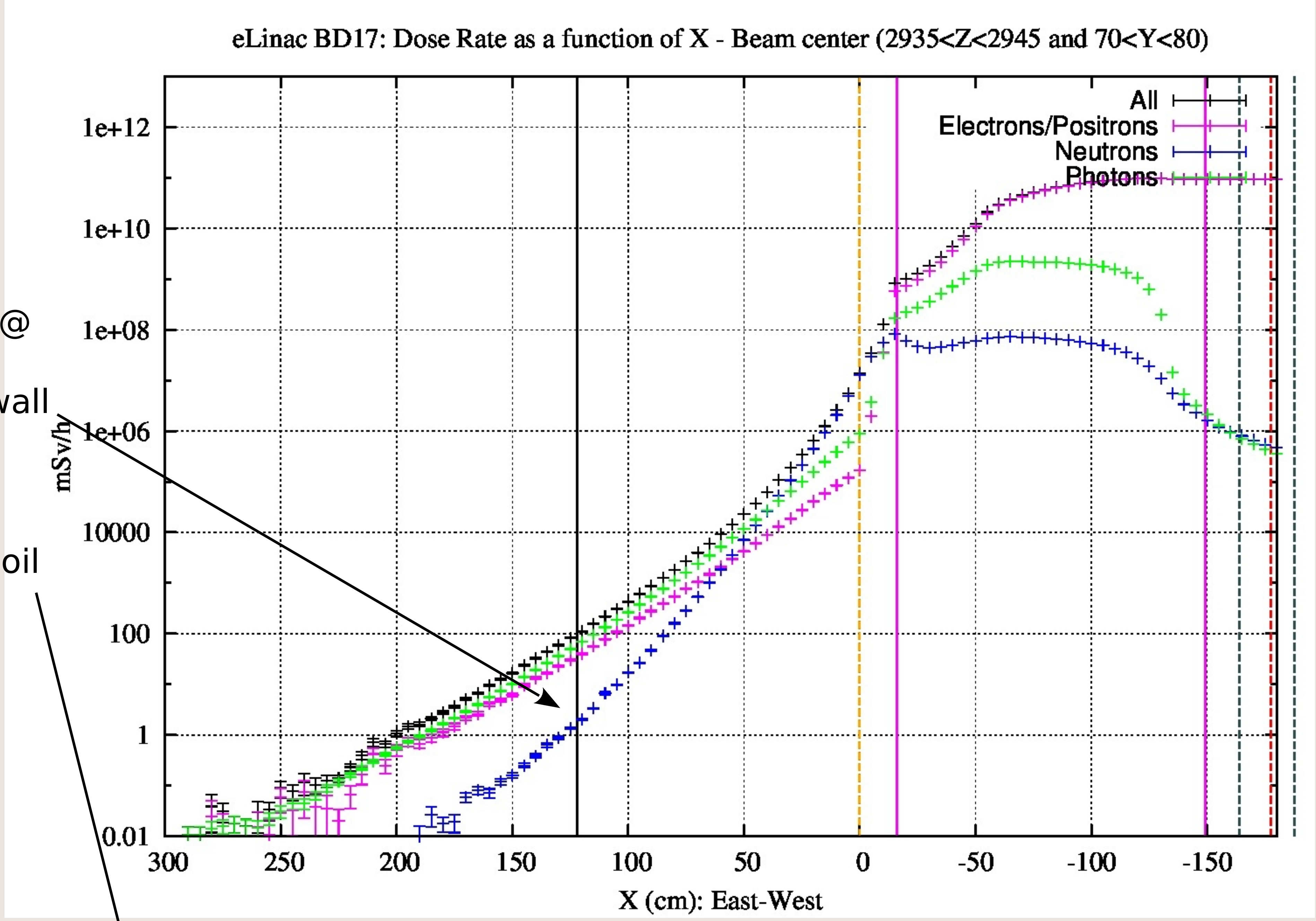
Transmission Curves – East/West

West side

DR from neutrons @

- entrance to the wall
  2 mSv/h
  Limit: 10 mSv/h

- entrance to the soil
  << 0.01 mSv/h
  Limit: 10 mSv/h



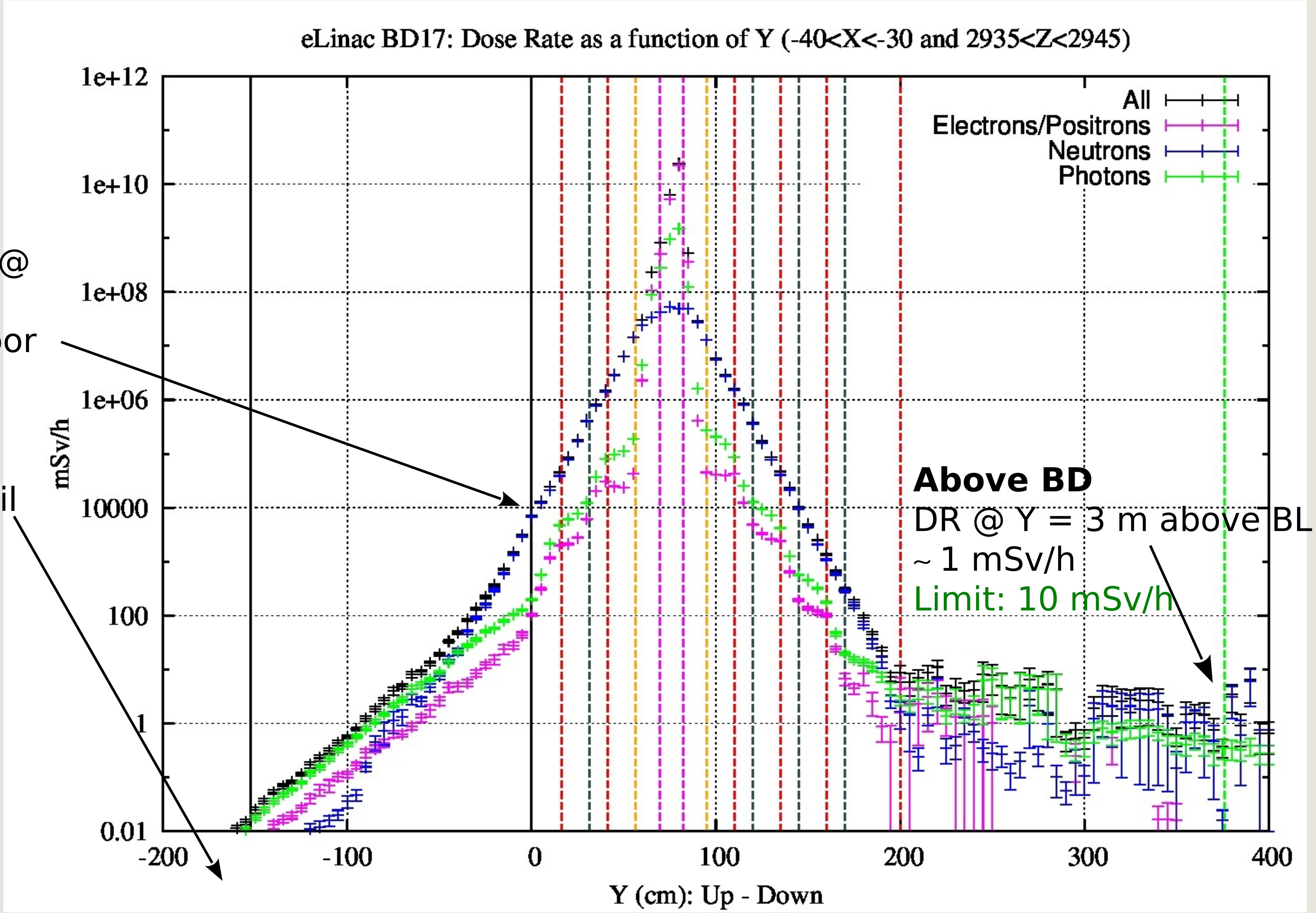
Dose Rates Around the BD Shielding
1st step results

Transmission Curves –Up/Down

Below BD
DR from neutrons @

- entrance to the floor
  ~7 Sv/h
  Limit: 10 mSv/h

- entrance to the soil
  < 0.001 mSv/h
  Limit: 10 mSv/h

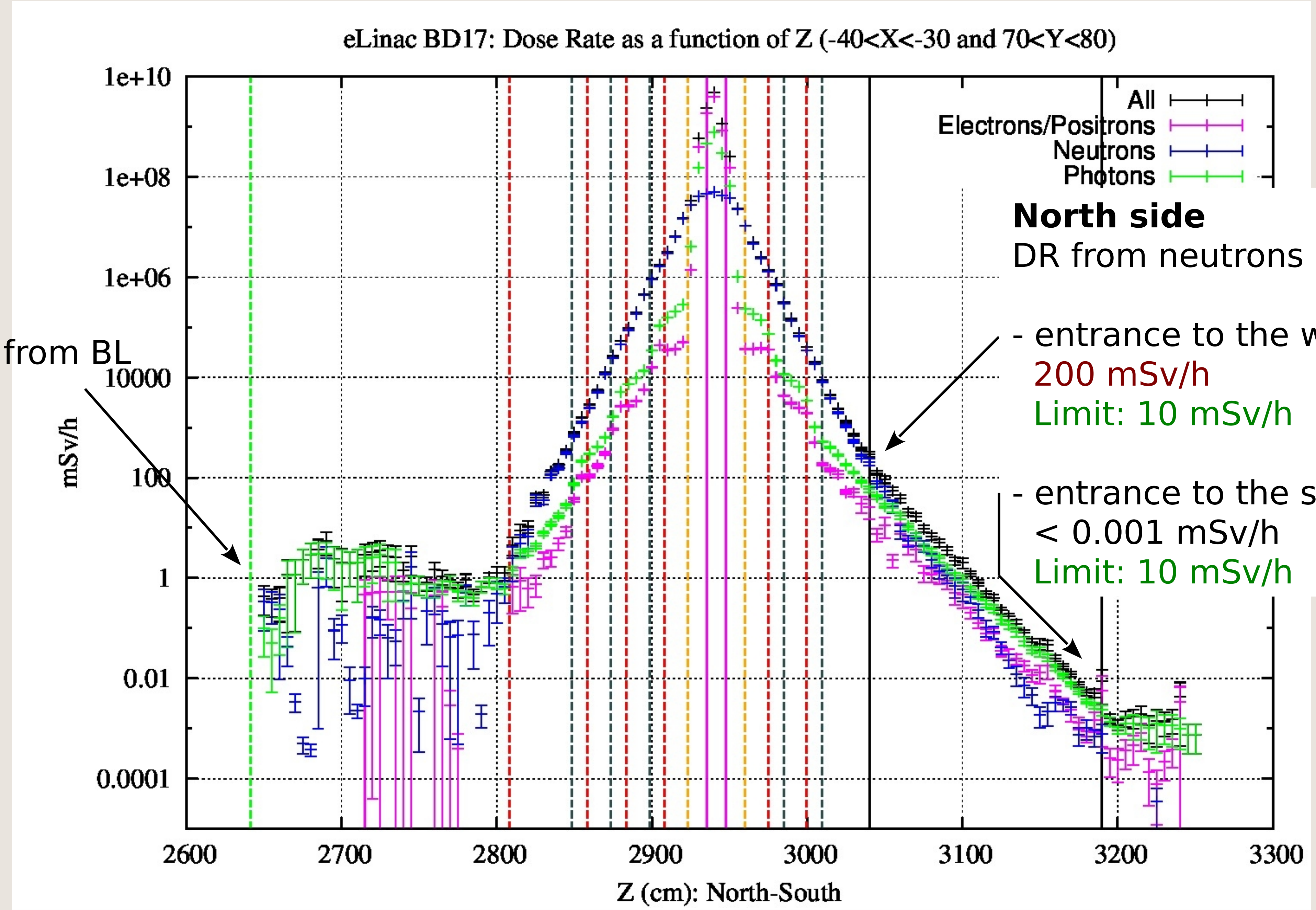


Above BD
DR @ Y = 3 m above BL
~ 1 mSv/h
Limit: 10 mSv/h

Dose Rates Around the BD Shielding
1st step results

Transmission Curves –North/South

South side
DR @ Z = 3 m from BL
~1 mSv/h
Limit: 3 mSv/h



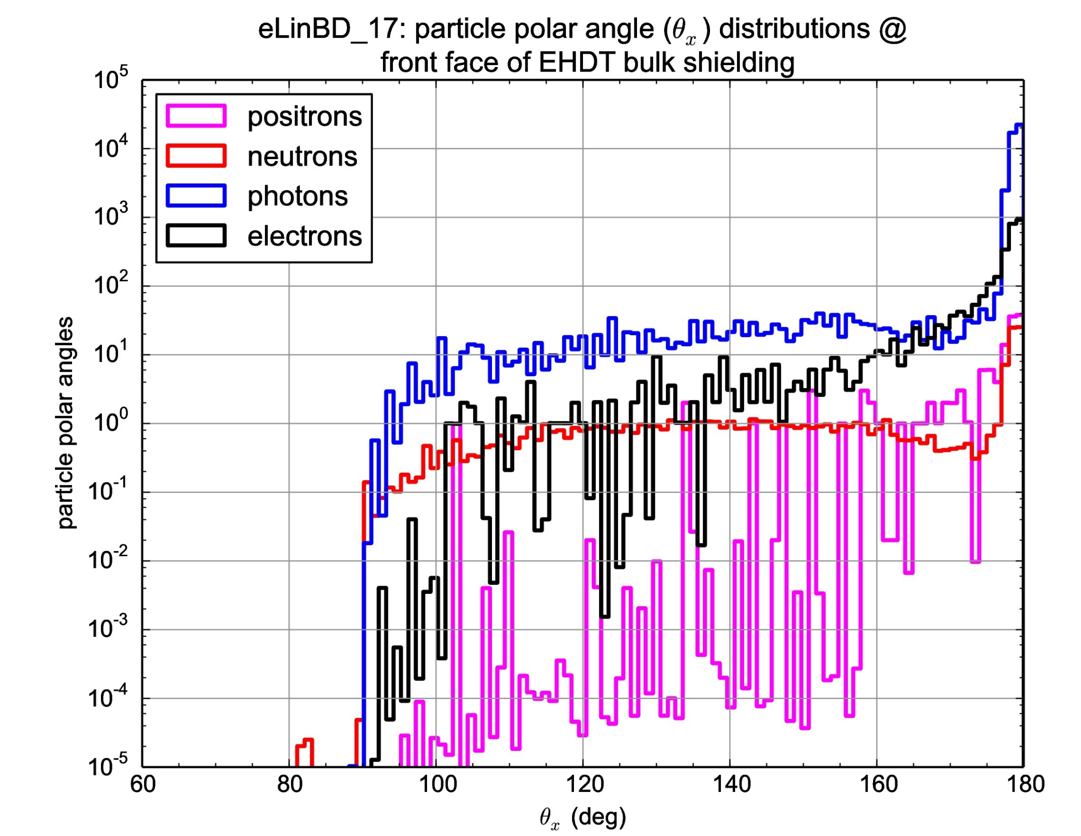
North side
DR from neutrons @

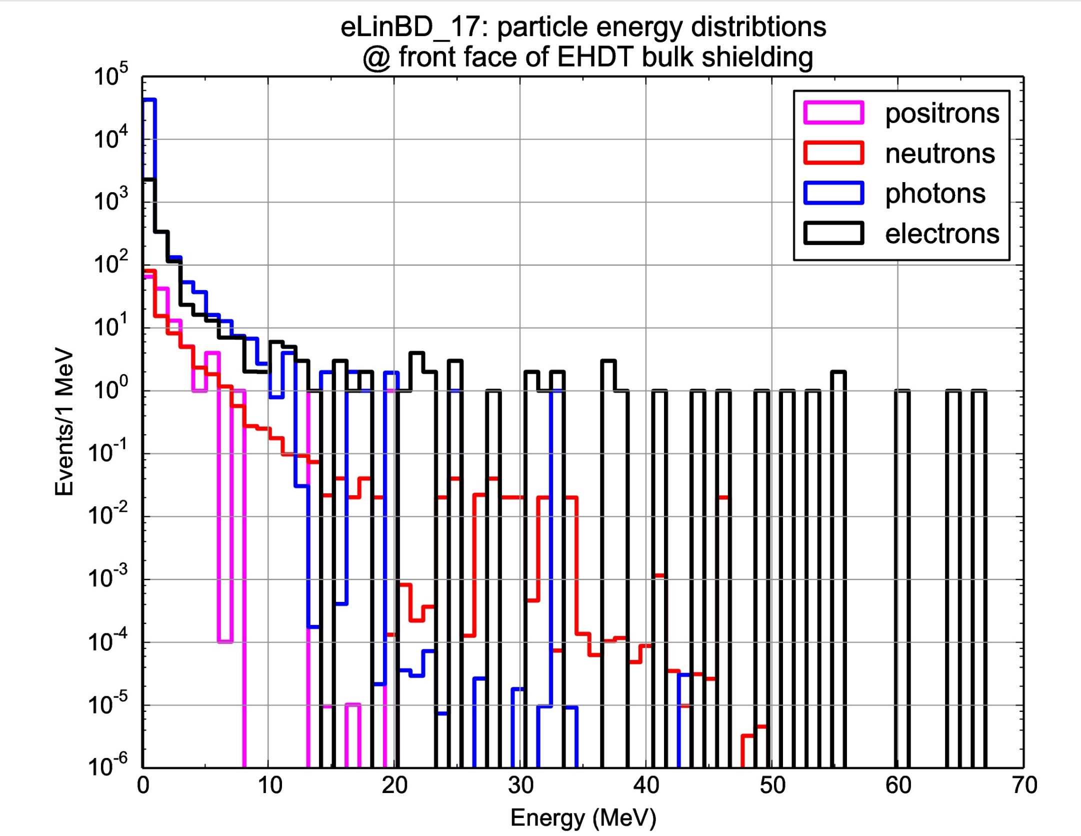
- entrance to the wall
  200 mSv/h
  Limit: 10 mSv/h

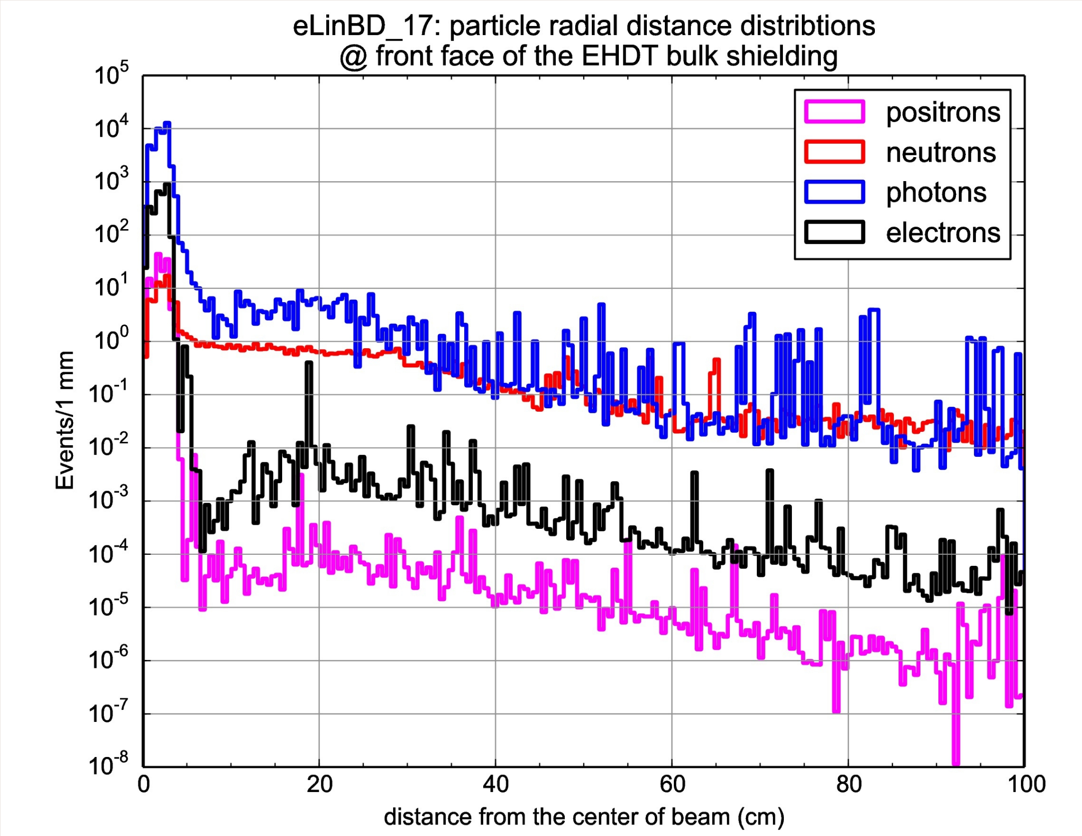
- entrance to the soil
  < 0.001 mSv/h
  Limit: 10 mSv/h

Particle Distributions from the 1st step run

7.7M out of 22M events shown







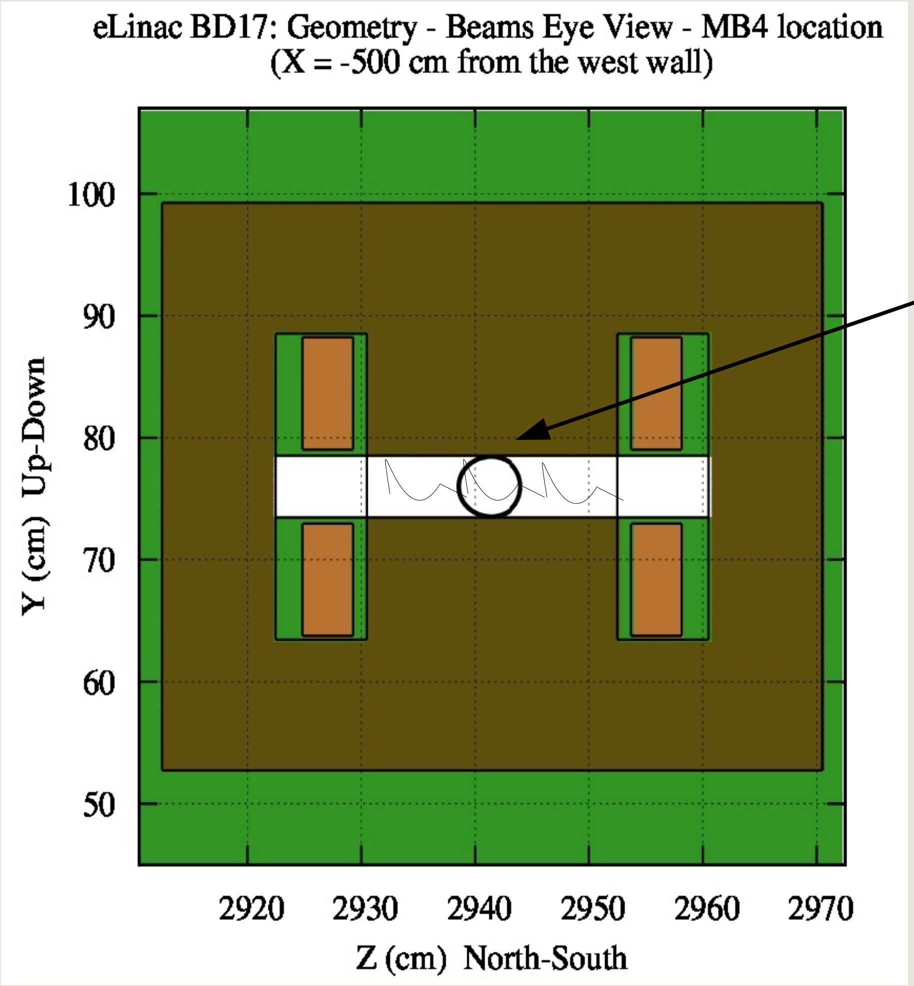
Questions to answer regarding the upstream region

Is it beneficial to set the vacuum box of MB4 to S.S.?

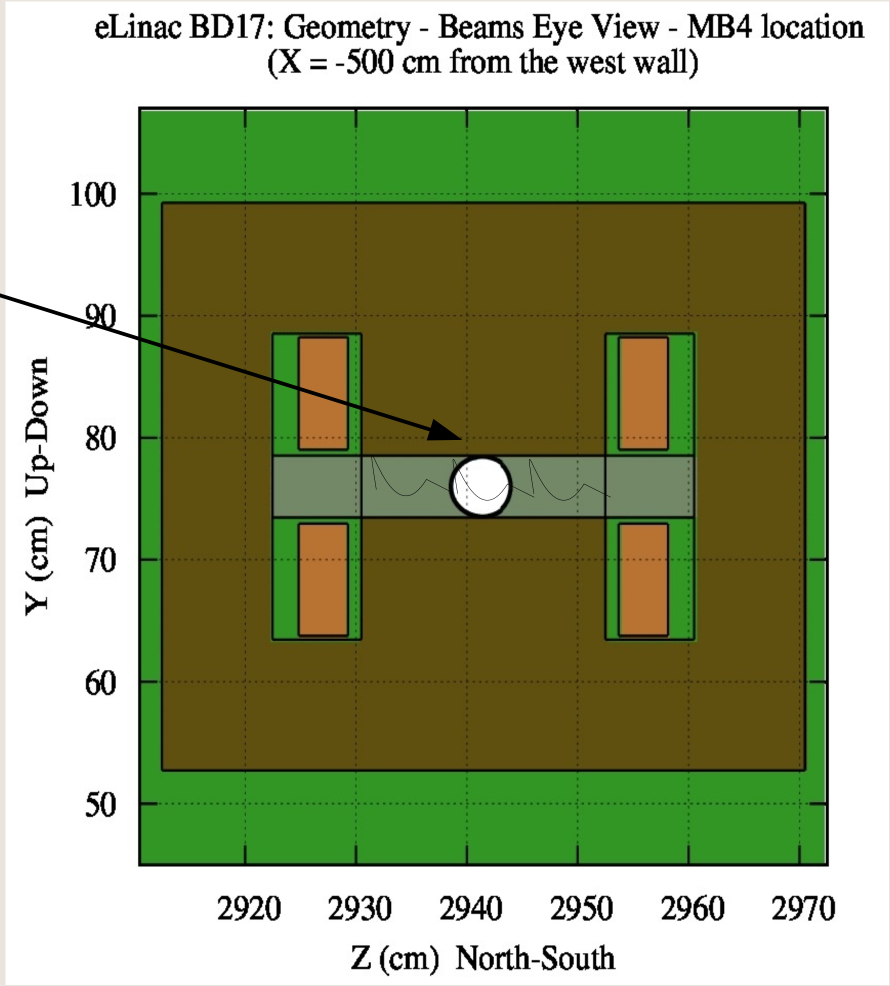
To get the e+/e- coming down the beam pipe to shower in the S.S. and to shield the photons in the S.S.

2nd step 1:
vac. Box filled with vacuum

2nd step 2:
vac. Box filled stainless steel



MB4
field region
(B/N poles only)

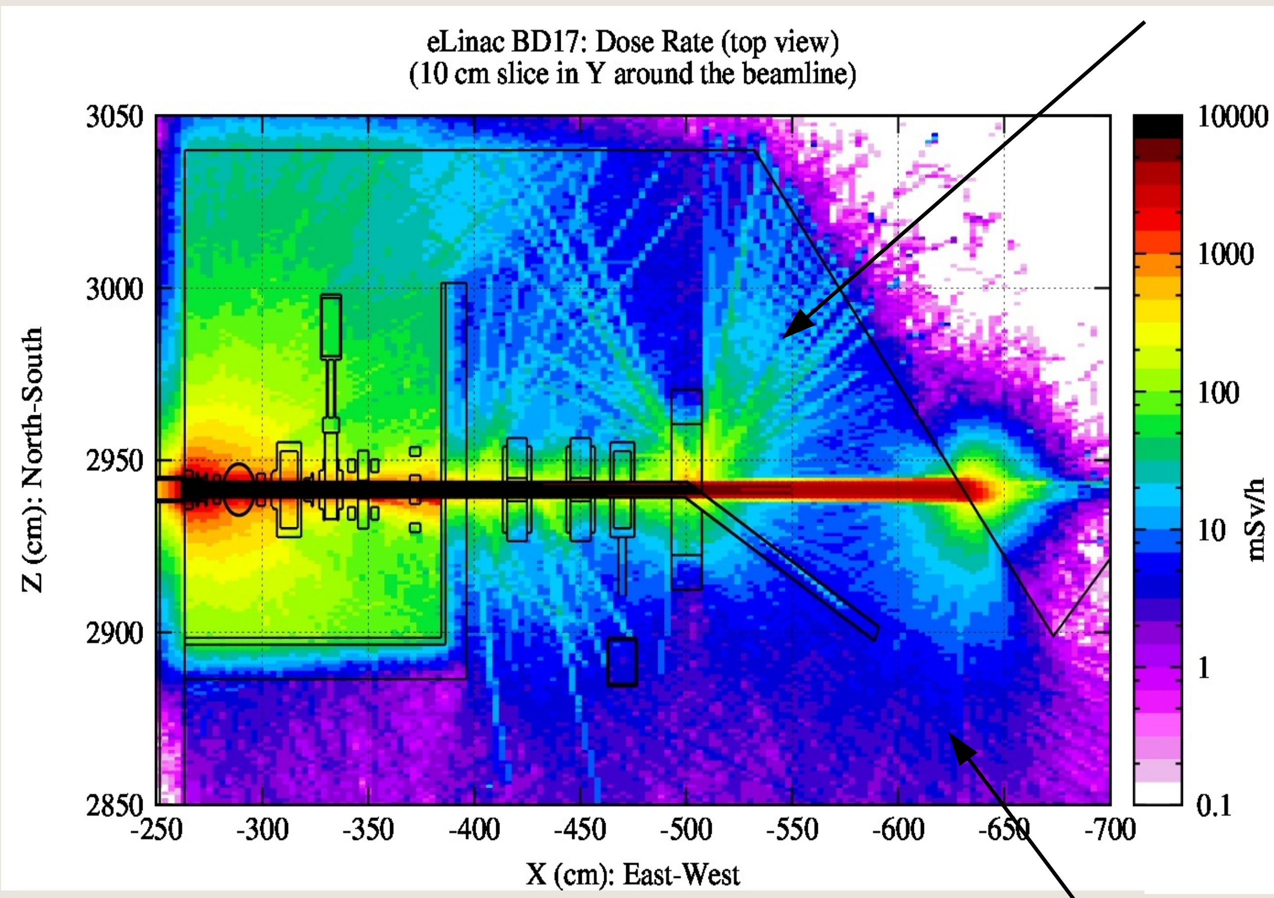


Yoke & poles: carbon steel
Coils: Copper
Field: 0.74 Tesla along +y direction

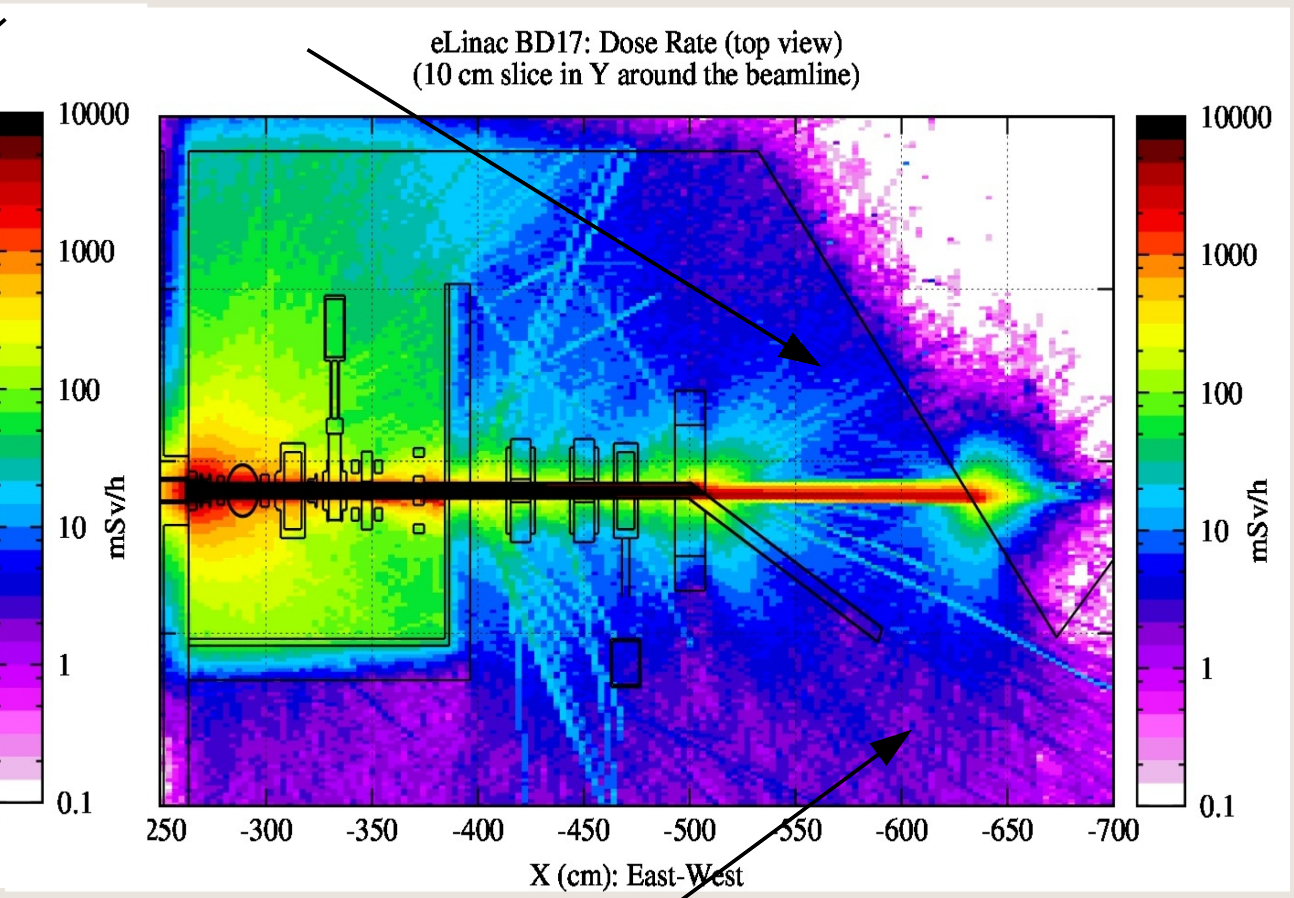
Total Dose Rate Distributions upstream of the BD

2nd step results

2nd step 1:
vac. Box filled with vacuum



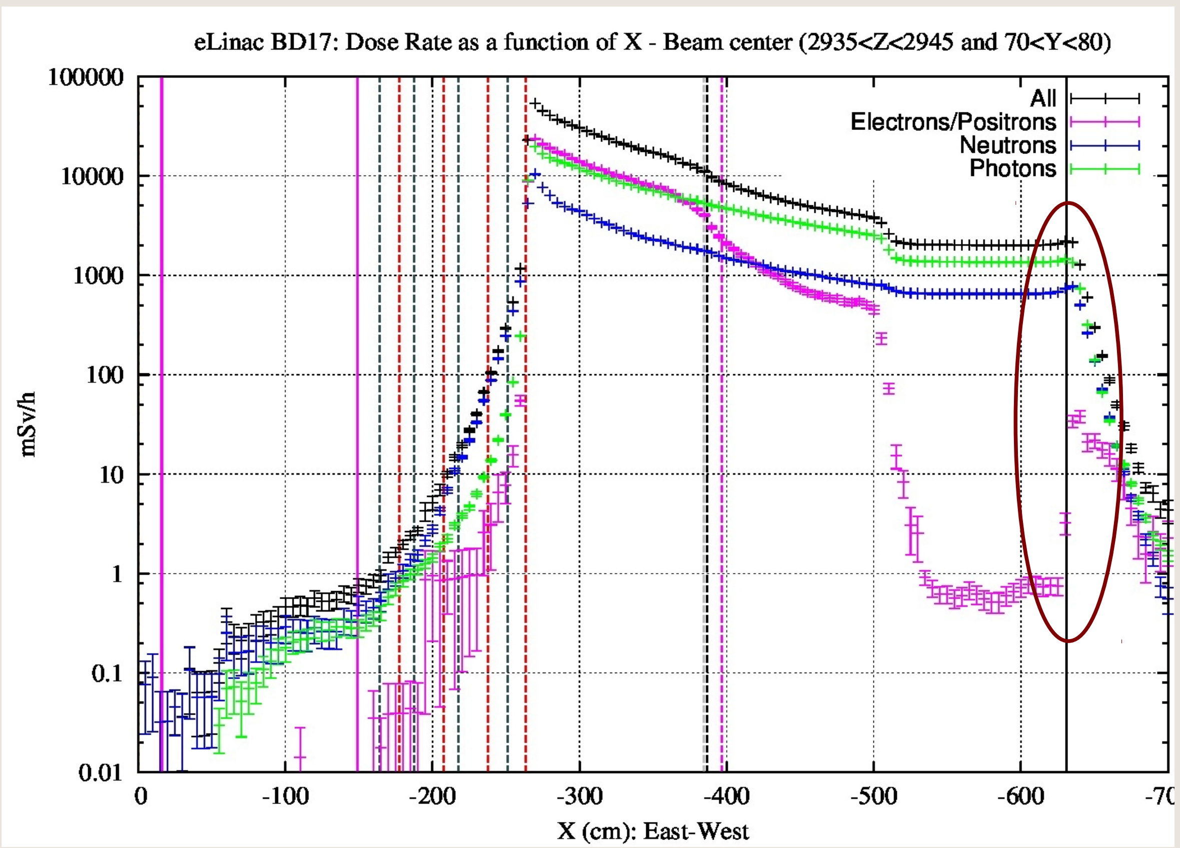
2nd step 2:
vac. Box filled stainless steel



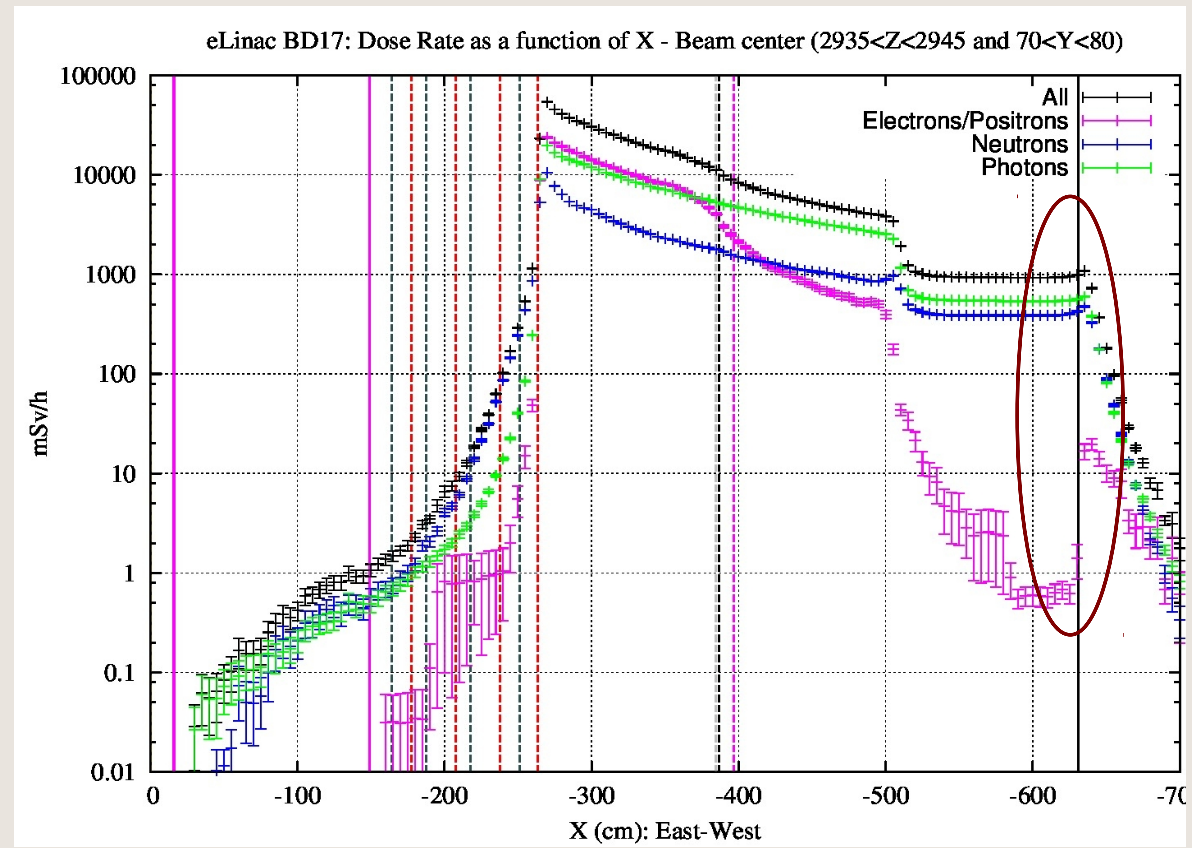
Dose Rates upstream of the BD

2nd step results

2nd step 1: vac. Box filled with vacuum



2nd step 2: vac. Box filled stainless steel



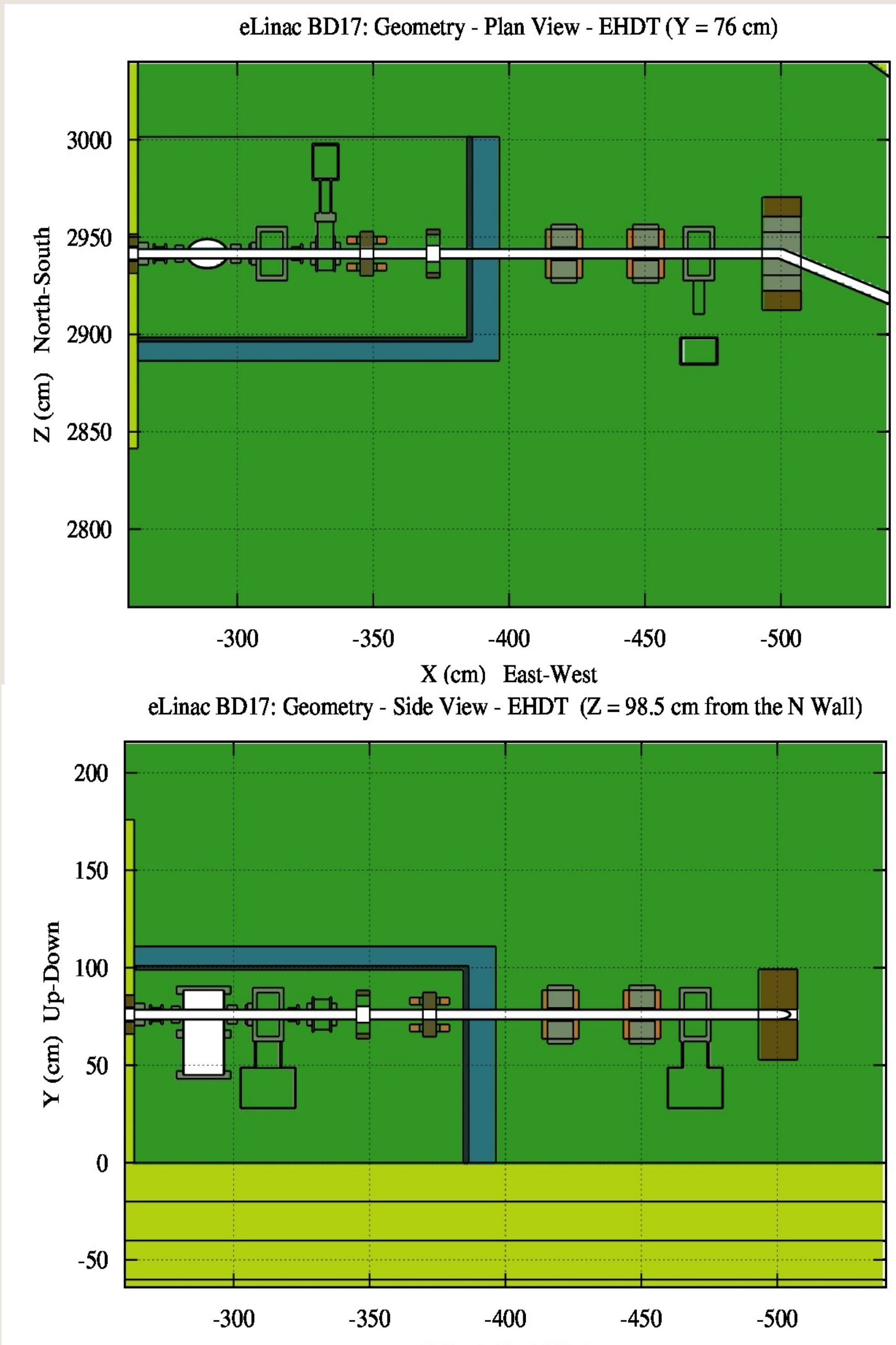
Dose Rates @ the surface of the east wall (mSv/h)

	Vac in MB4 vac box	SS in MB4 vac box
photons	1315	540
neutrons	720	420
e+/e-	3	1
Total	~ 2160	~ 970

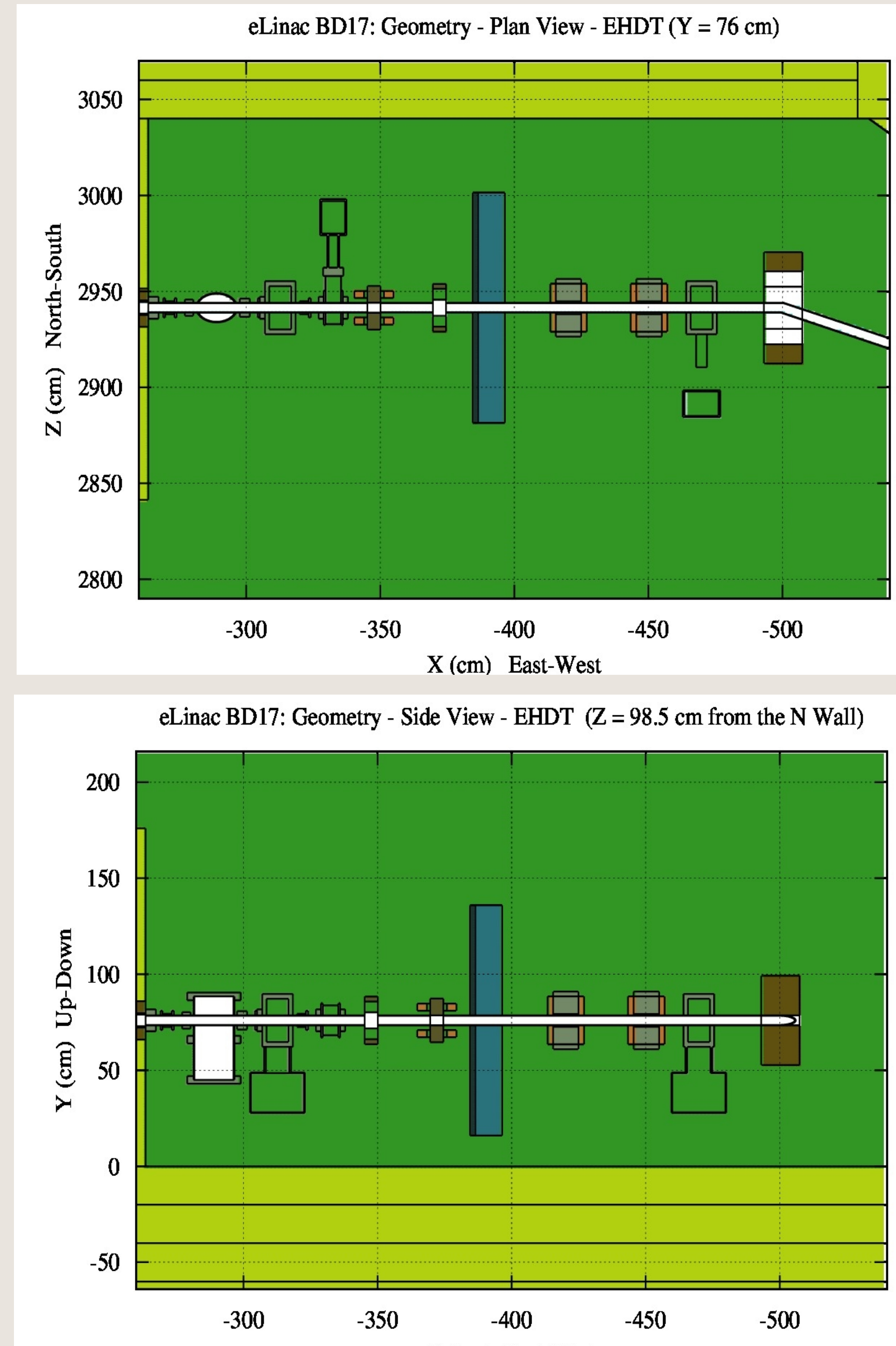
Questions to answer regarding the upstream region

Hutch or Collimator (1” Pb + 4” PE)?

2nd step 1: Pb/PE hutch



2nd step 1: Pb/PE collimator

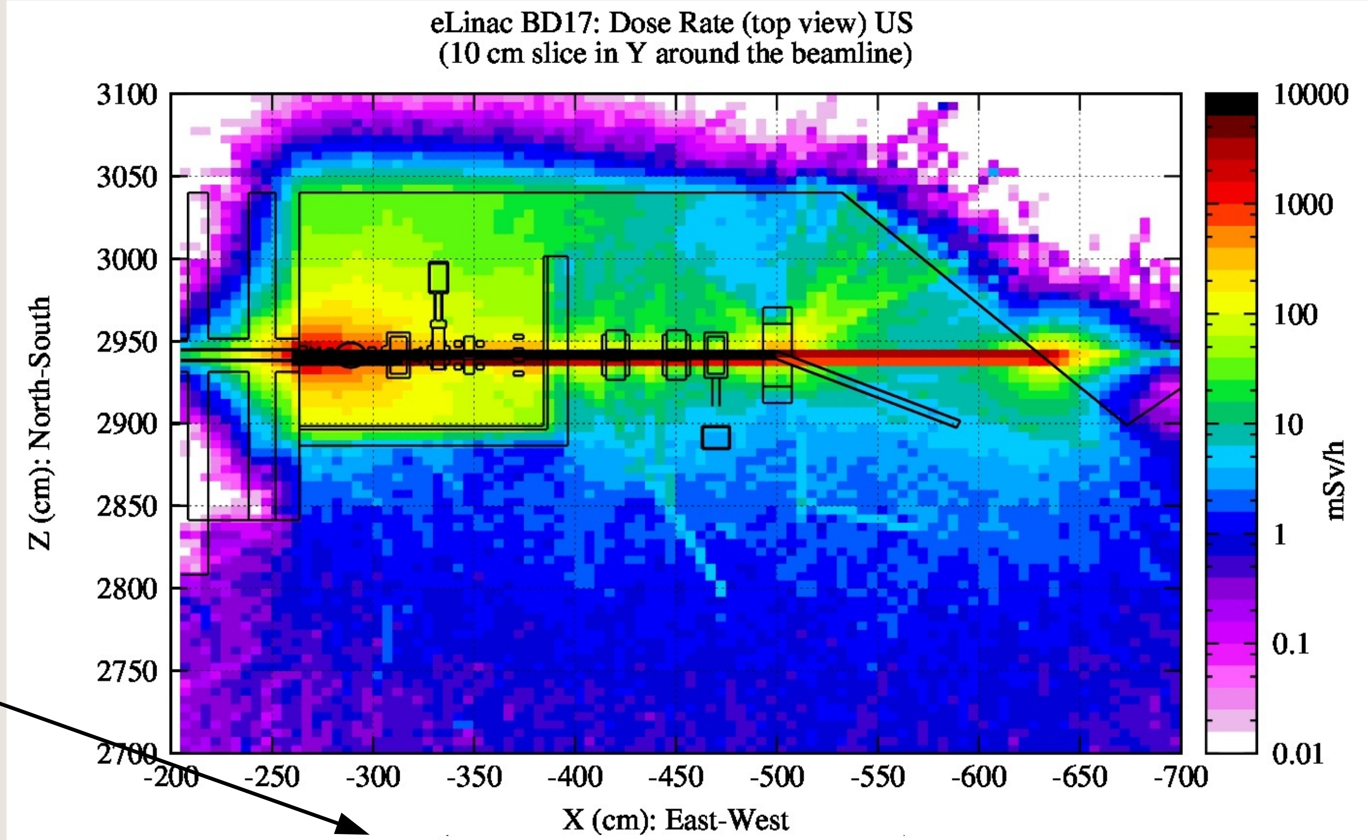


Total Dose Rate Distributions upstream of the BD
2nd step results

Plan view

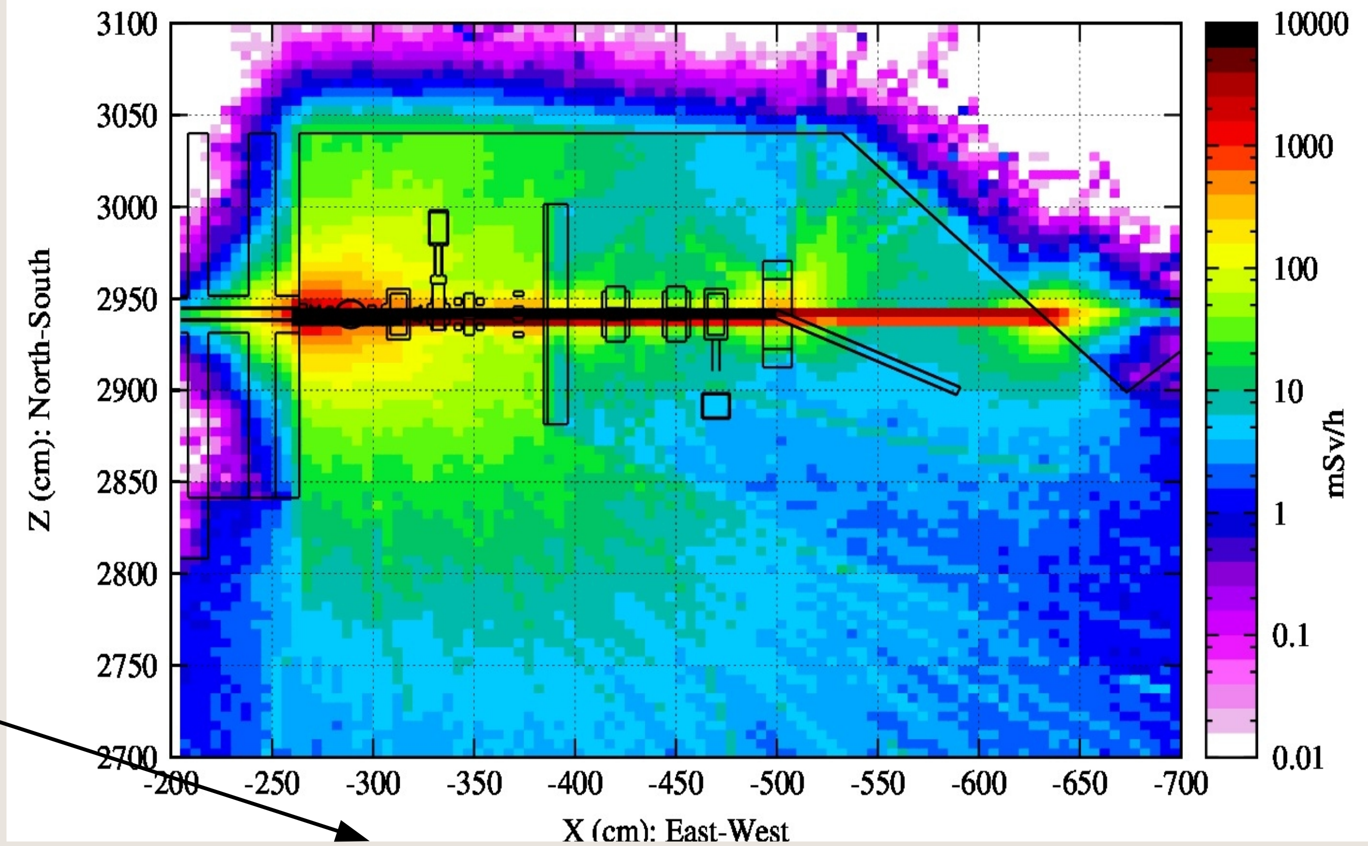
2nd step 1: Pb/PE hutch

DR @ Z = 2650, ~0.7 mSv/h



2nd step 1_PbPE_coll: Pb/PE collimator

DR @ Z = 2650, ~3 mSv/h

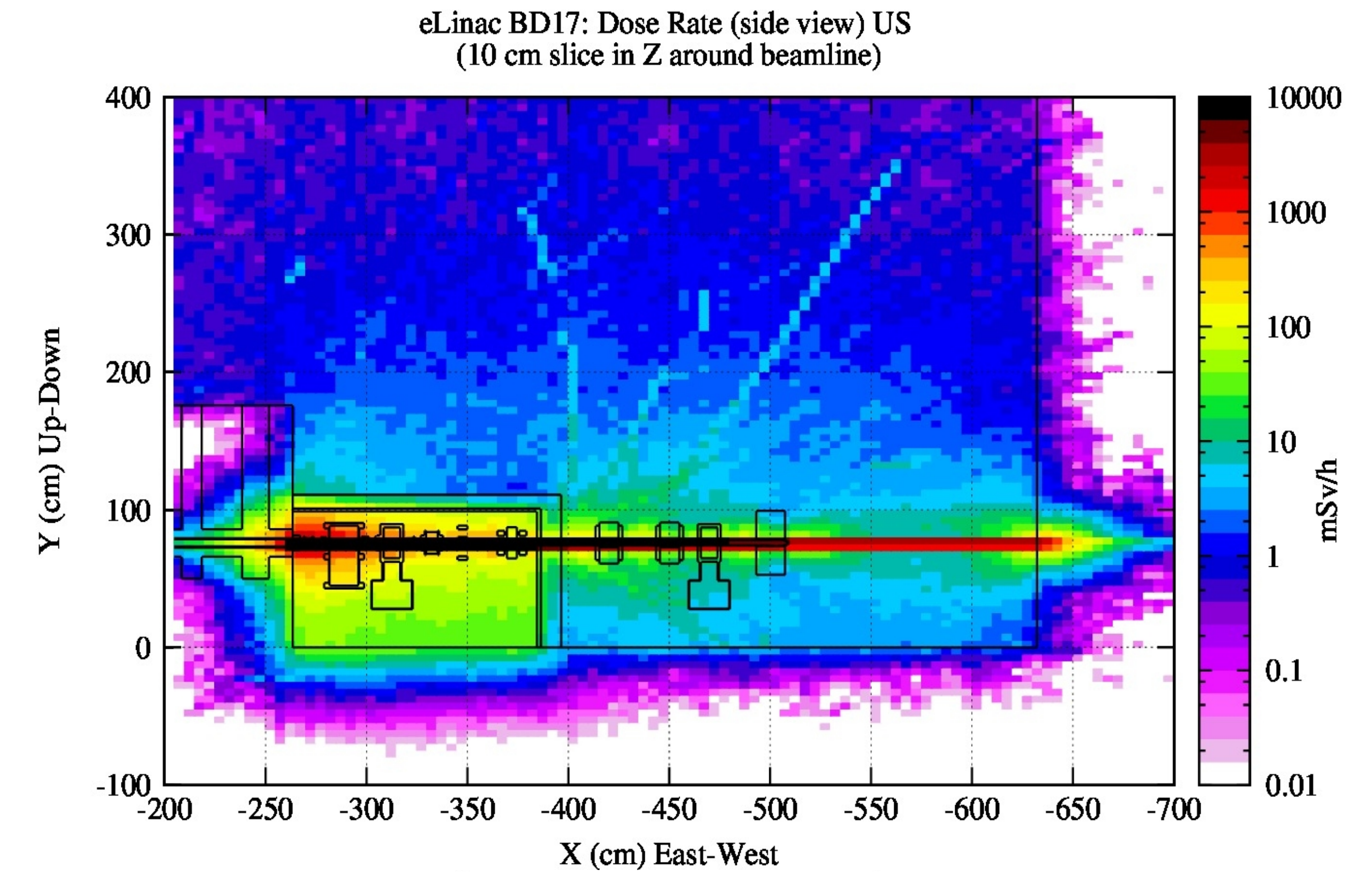


Total Dose Rate Distributions upstream of the BD

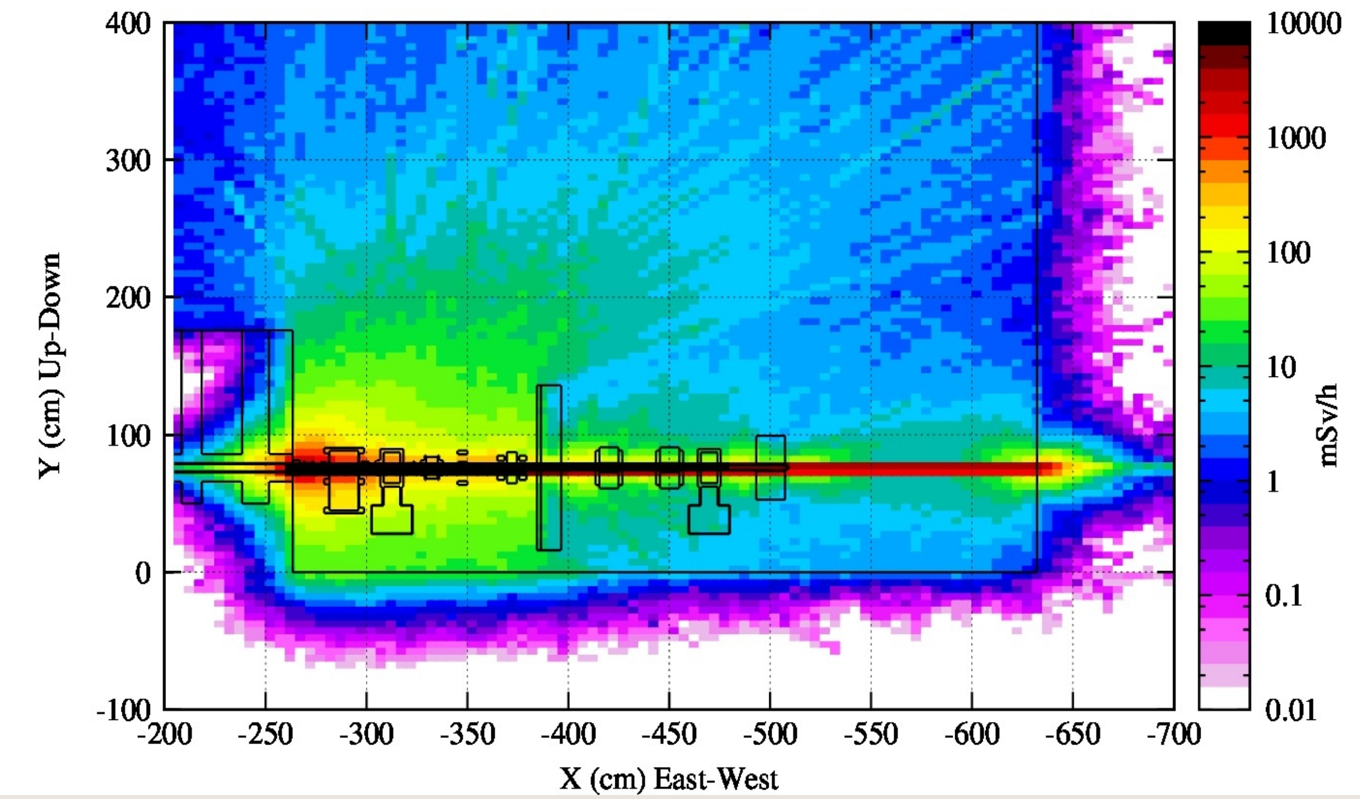
2nd step results

Side view

2nd step 1: Pb/PE hutch



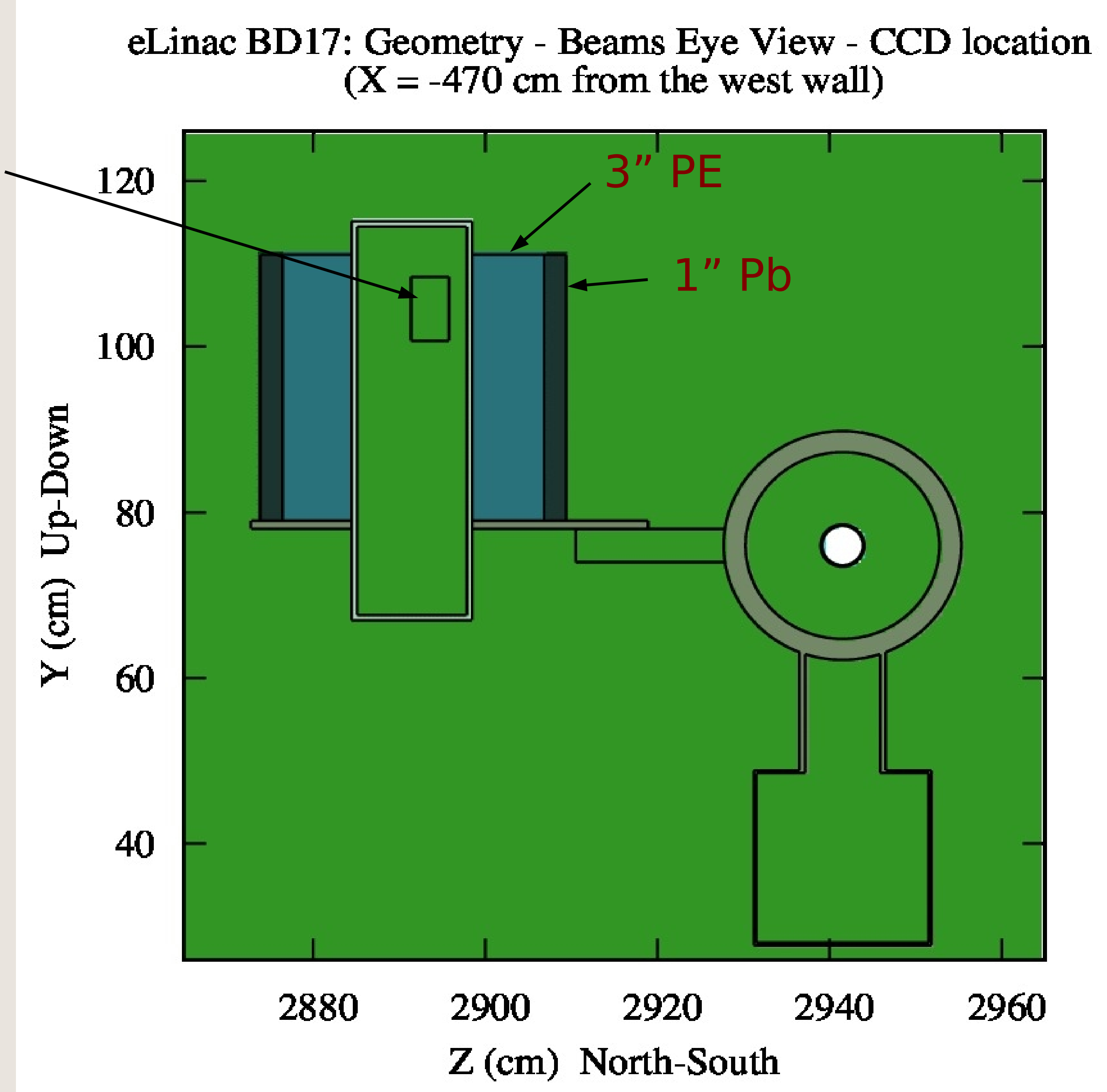
2nd step 1_PbPE_coll: Pb/PE collimator



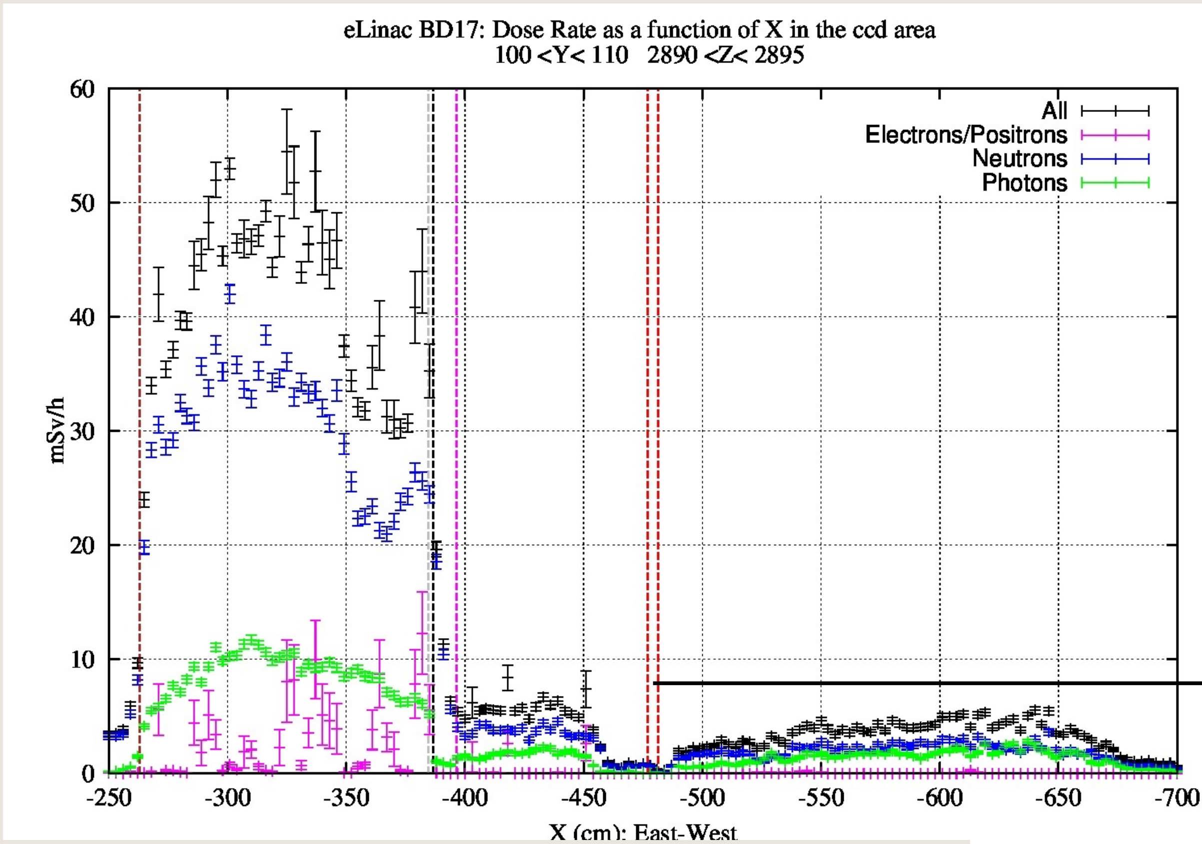
Questions to answer regarding the upstream region

Dose rates at the CCD camera location housed in DB4?

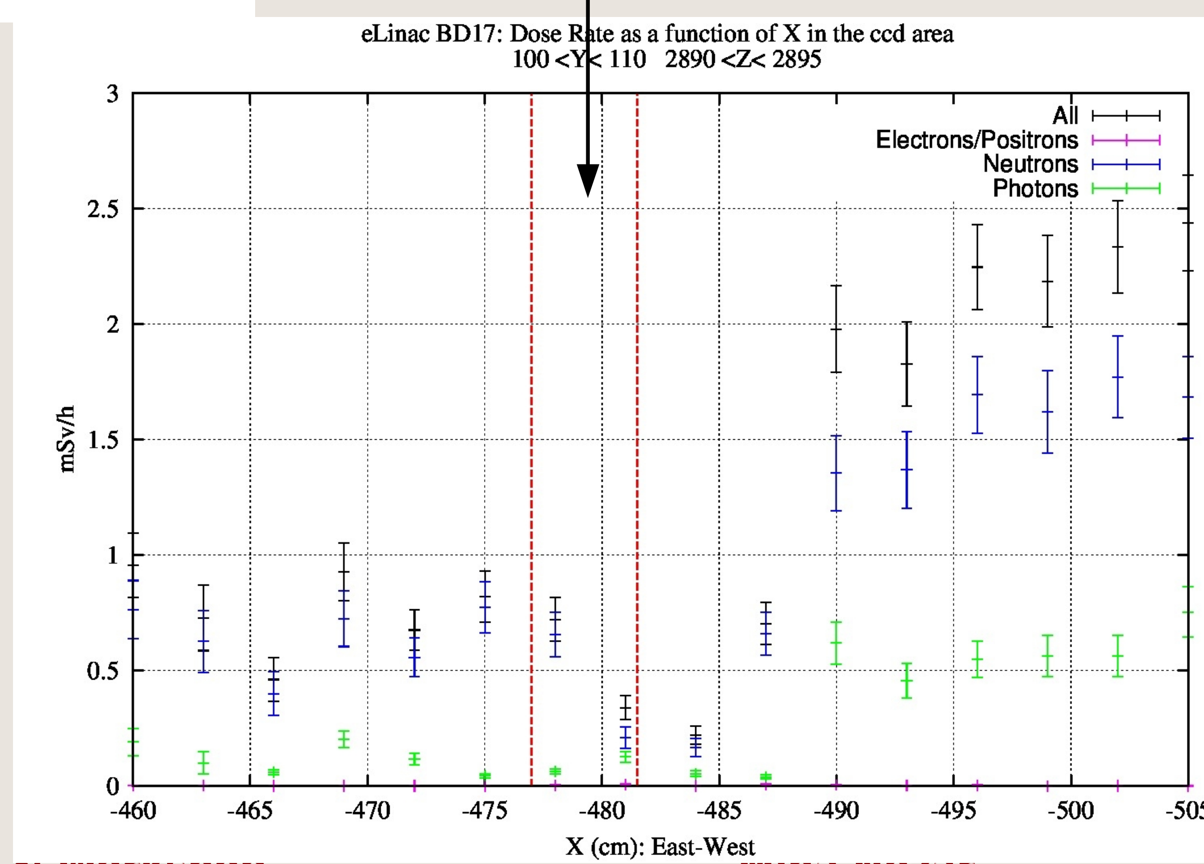
CCD camera
~ 29 cm above beamline
~ 80 cm south of the beamline



Total Dose Rate as a function of X (East/West)
at (Y,Z) of the CCD camera



DR at the CCD camera
< 1 mSv/h

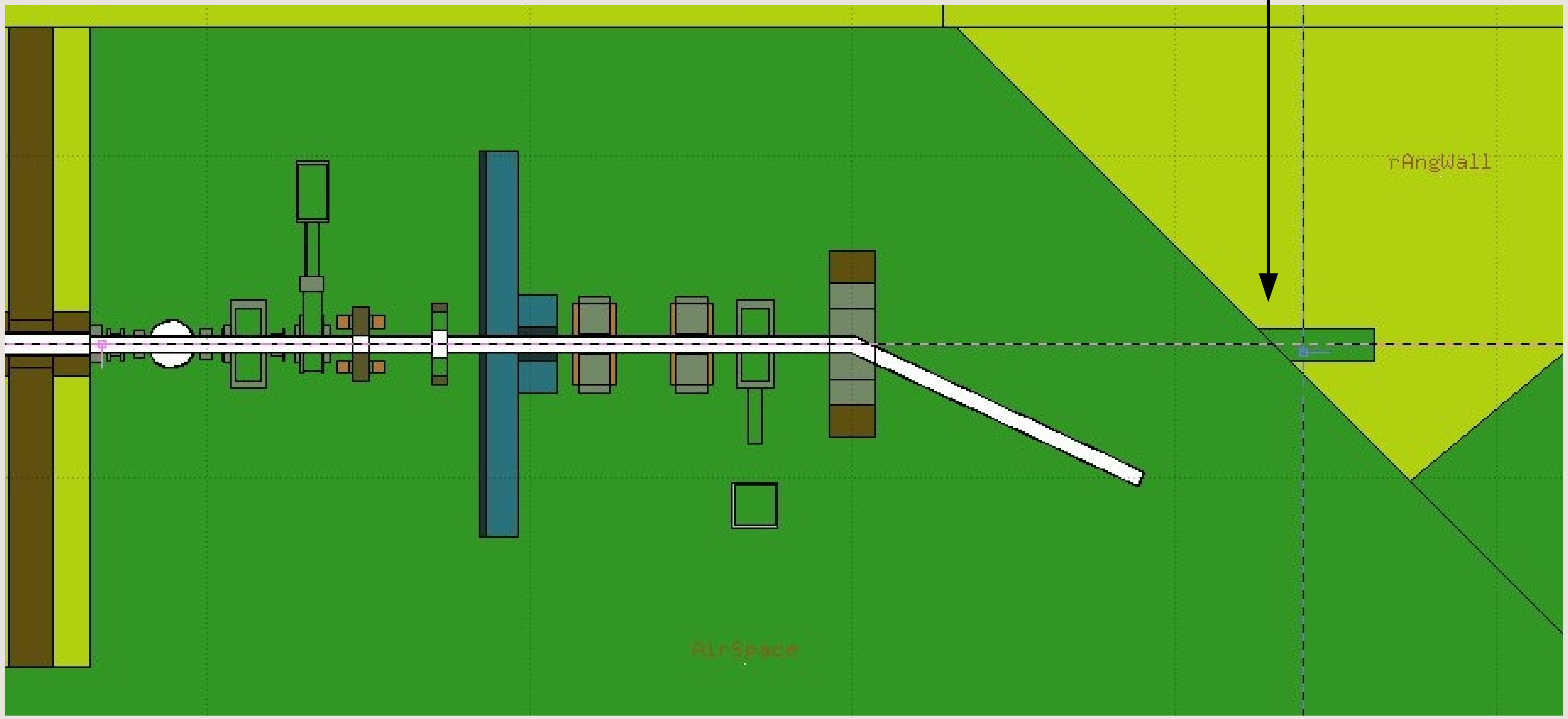


Questions to answer in regards to the upstream

Effect of drilling a hole in the East wall in-line with the beamline

Tried few dimensions for the cylindrical hole in the East (angled) wall.

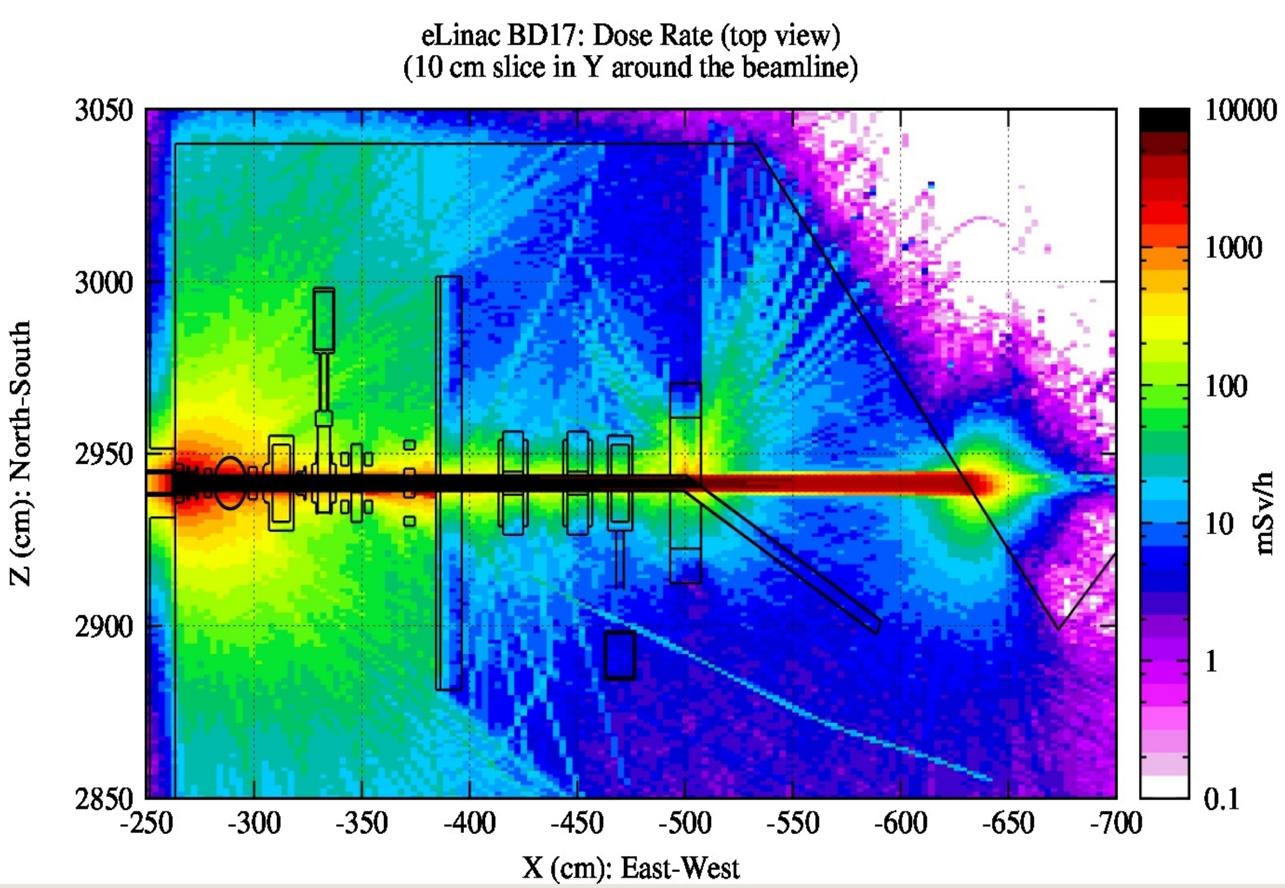
a) r = 9 cm, L = 50 cm
b) r = 9 cm, L = 30 cm
c) r = 5 cm, L = 40 cm



Effect of drilling a hole in the East wall in-line with the beamline

Dose Rate distribution (Top View)

No hole in the west wall

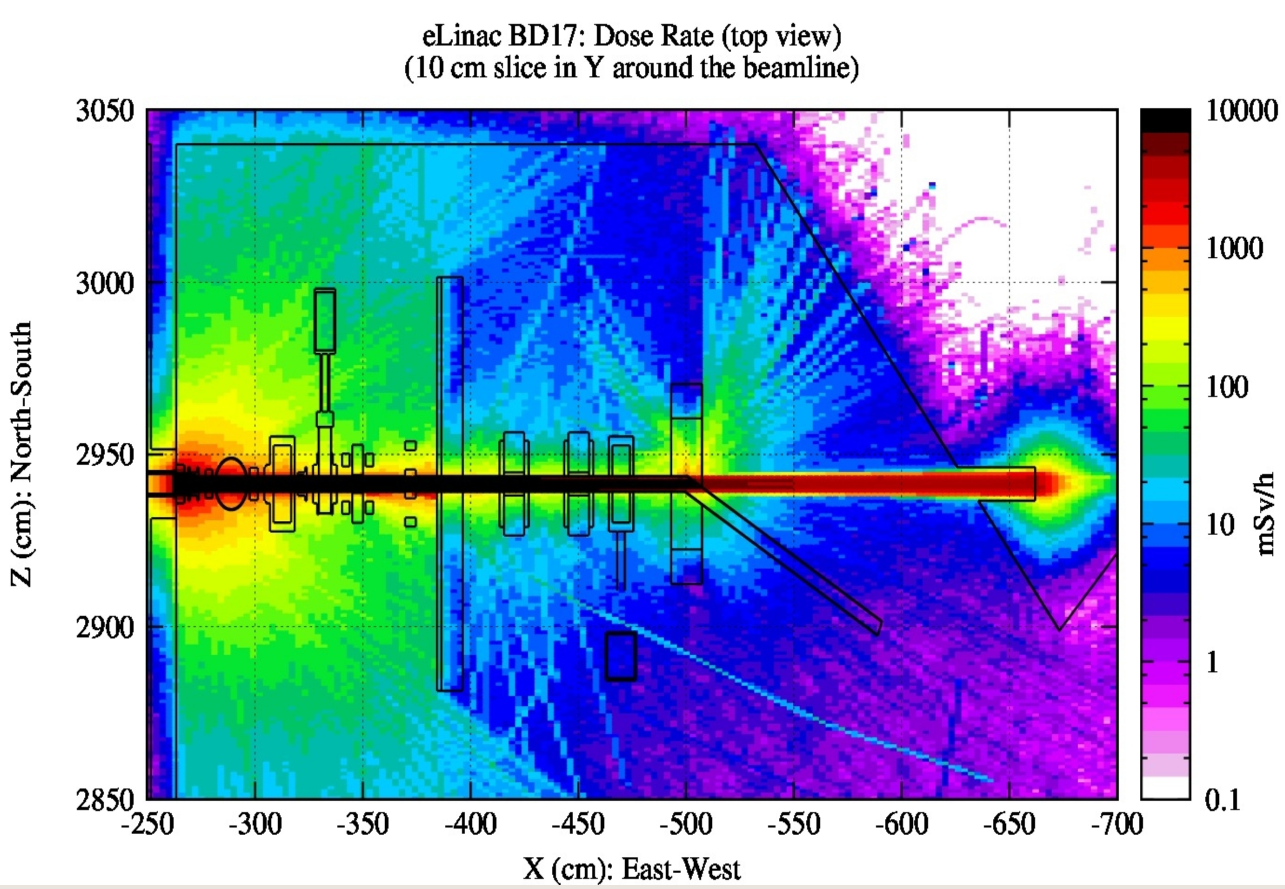


Drilling a bore hole in the east wall (R = 5 cm, L = 40 cm) will reduce the shower from the backscattered particles into the e-Hall.

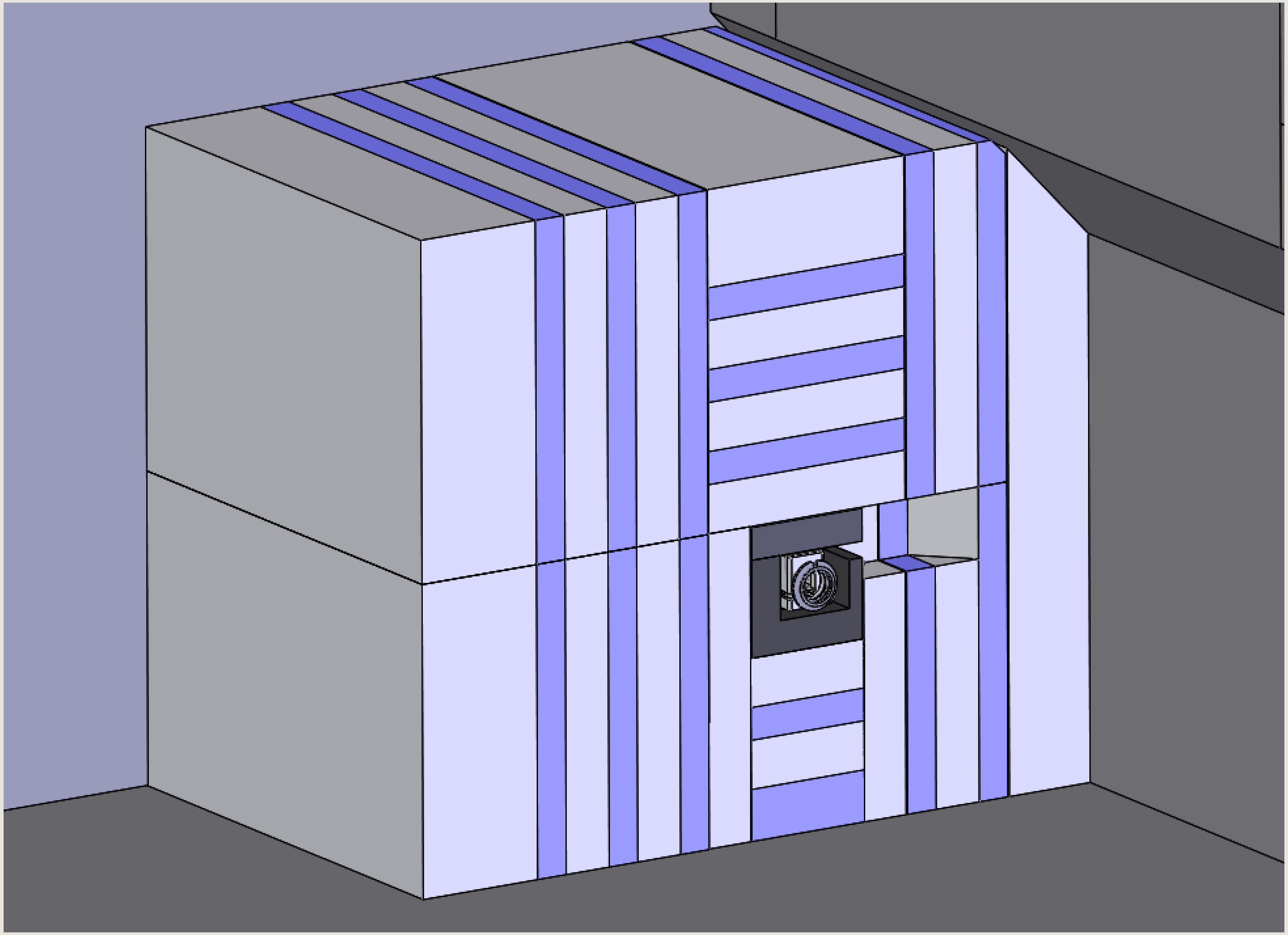
Effect of drilling a hole in the East wall in-line with the beamline

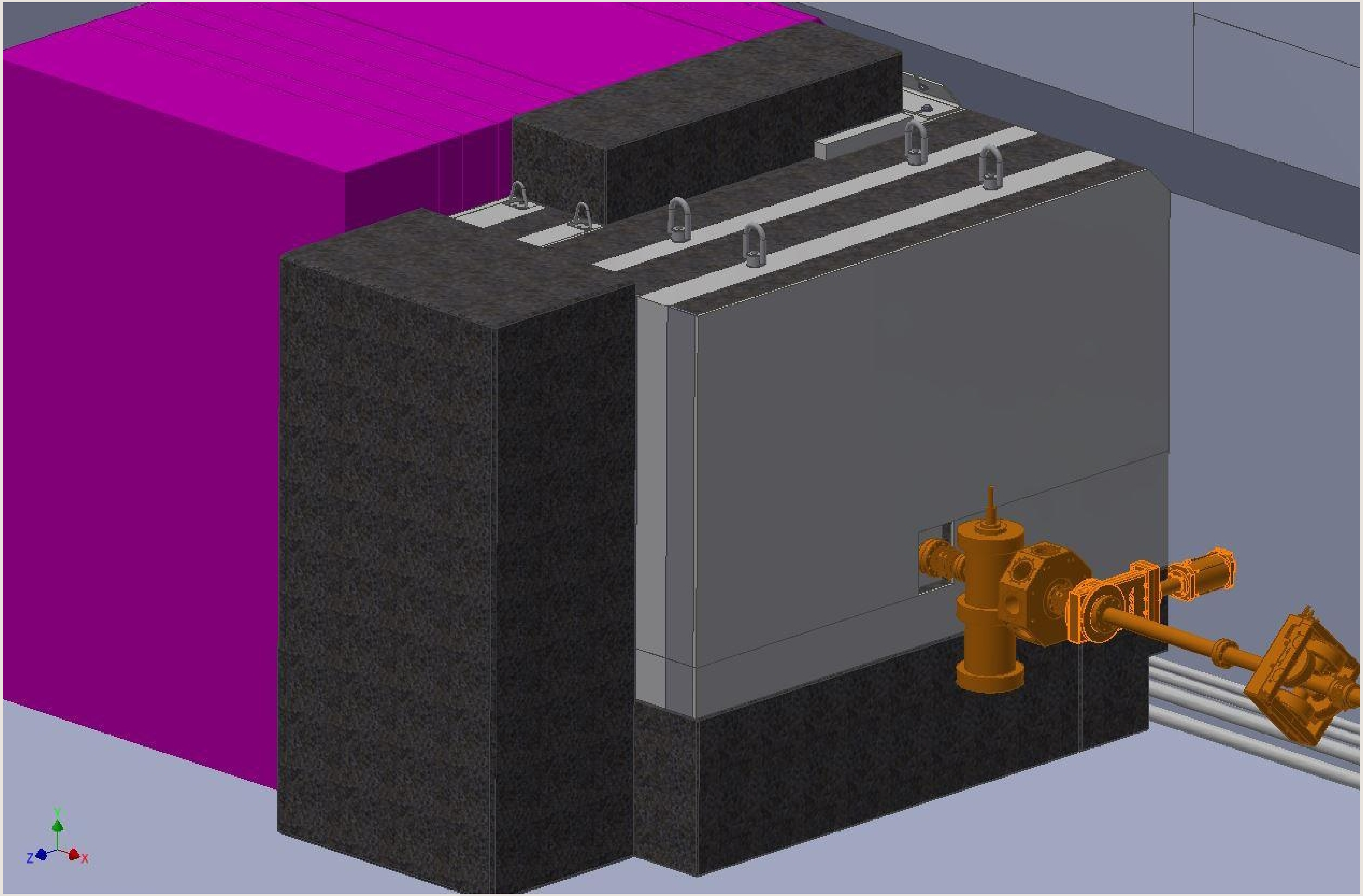
Dose Rate distribution (Top View)

R = 5 cm , L_{long} = 40 cm



Drilling a bore hole in the east wall (R = 5 cm, L = 40 cm) will reduce the shower from the backscattered particles into the e-Hall.




Y
Z
X

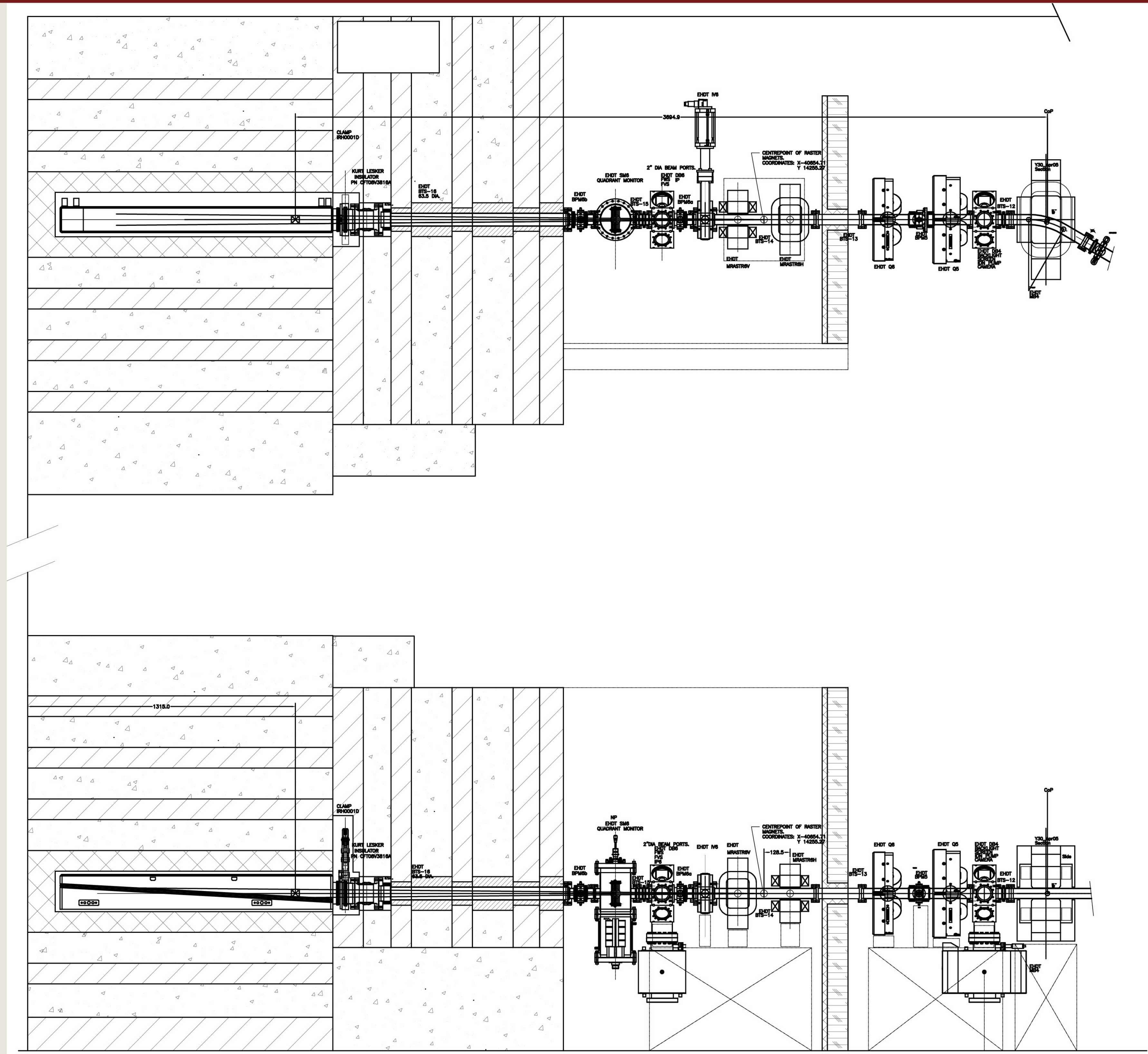
TRIUMF

ARIEL BD and EHDT Shielding

Design drawing

PLAN VIEW

SIDE VIEW



Shielding flask for BD Transport (4)

- Used the existing Lead shielding to determine the thickness of the shielding flask for BD transport at the end of its life (or sooner)

- fluka_dev-2014 was used to set the decay medium for Pb region to something other than VACUUM or BLACKHOLE

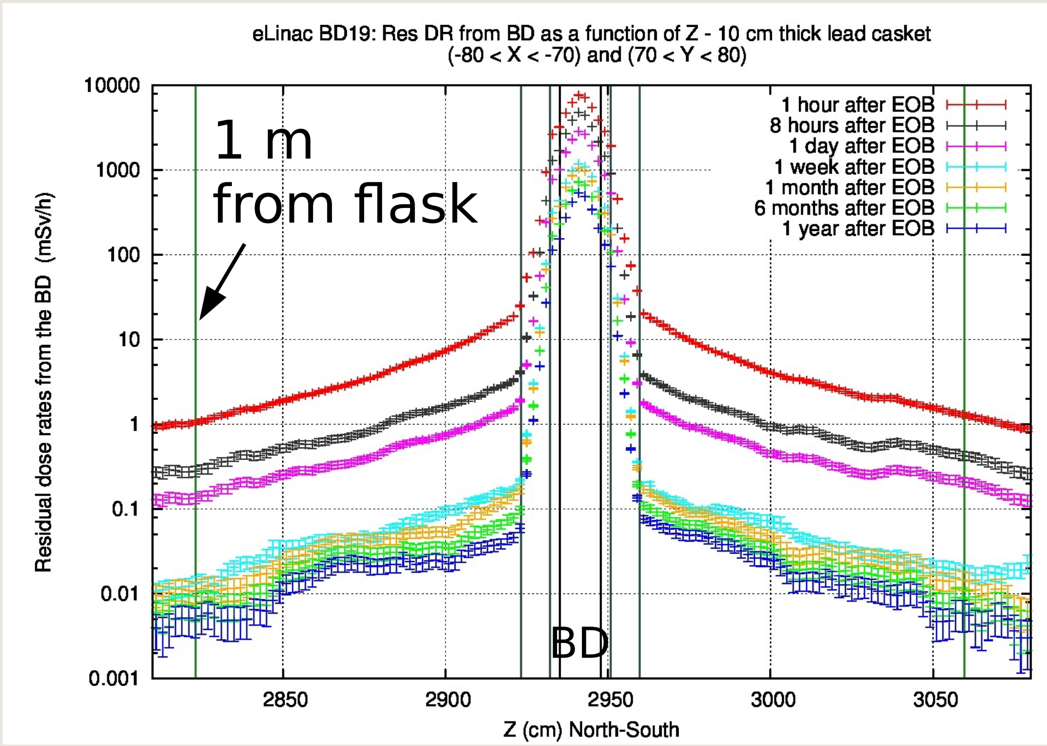
- Two materials were considered:
  1- Lead
  2- Carbon Steel

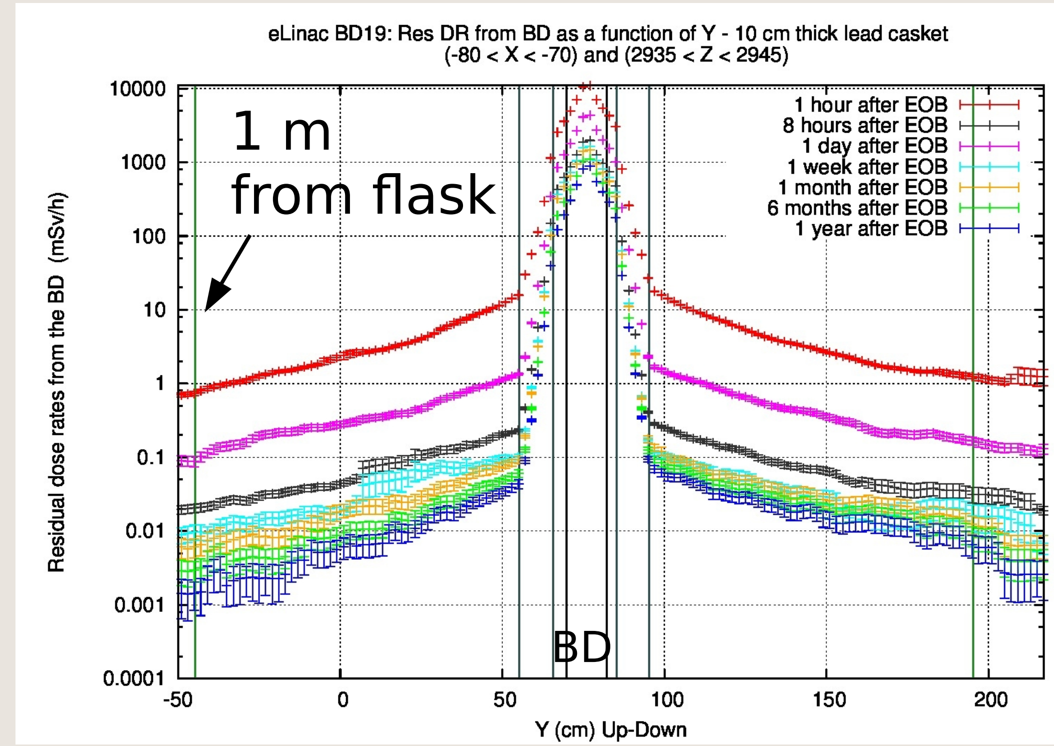
- Residual dose rates for each of the above two cases were examined at different cooling times

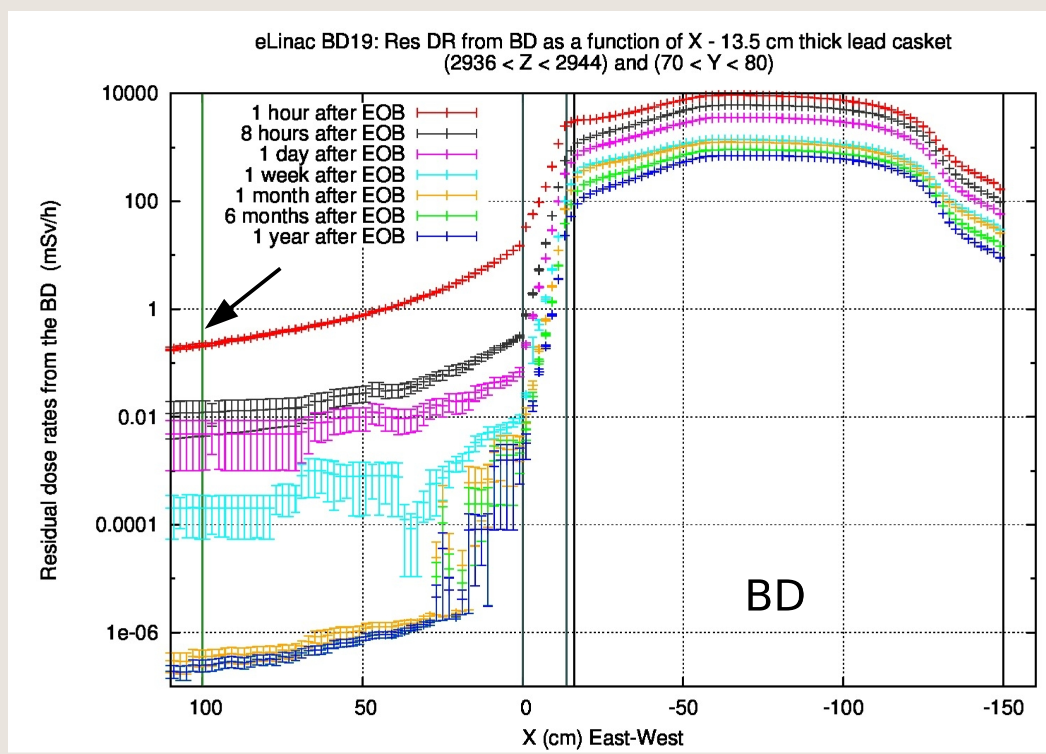
- TVLs were determined from transmission curves

- Thicknesses of sides, top/bot, and front/back were determined to meet the DR limit of 0.5 mSv/h at 1 m from the surface of the flask

Shielding flask for BD Transport
Transmission curves for Pb

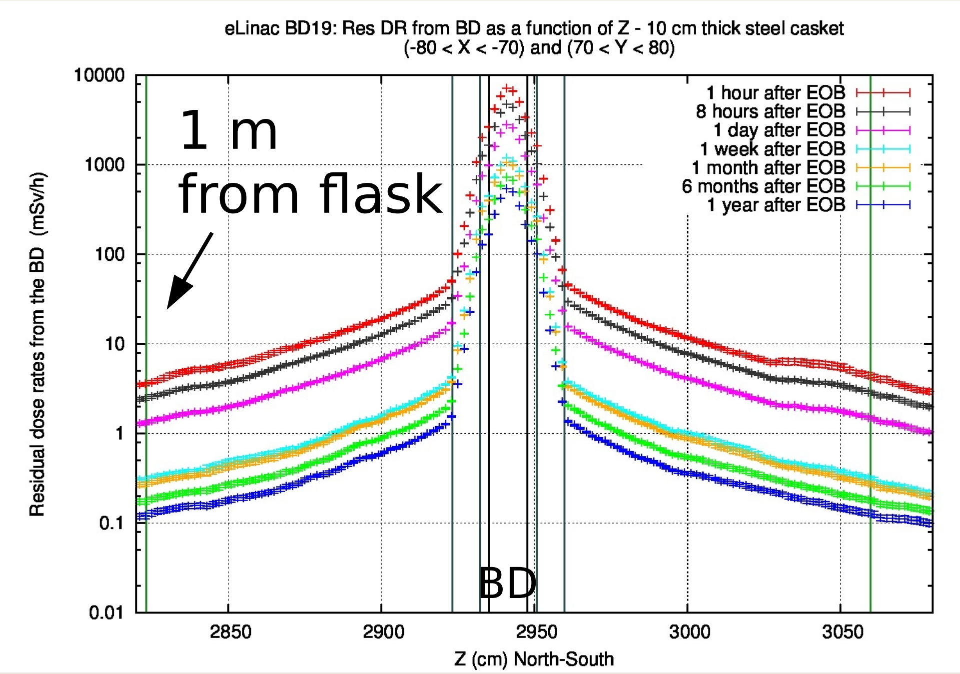


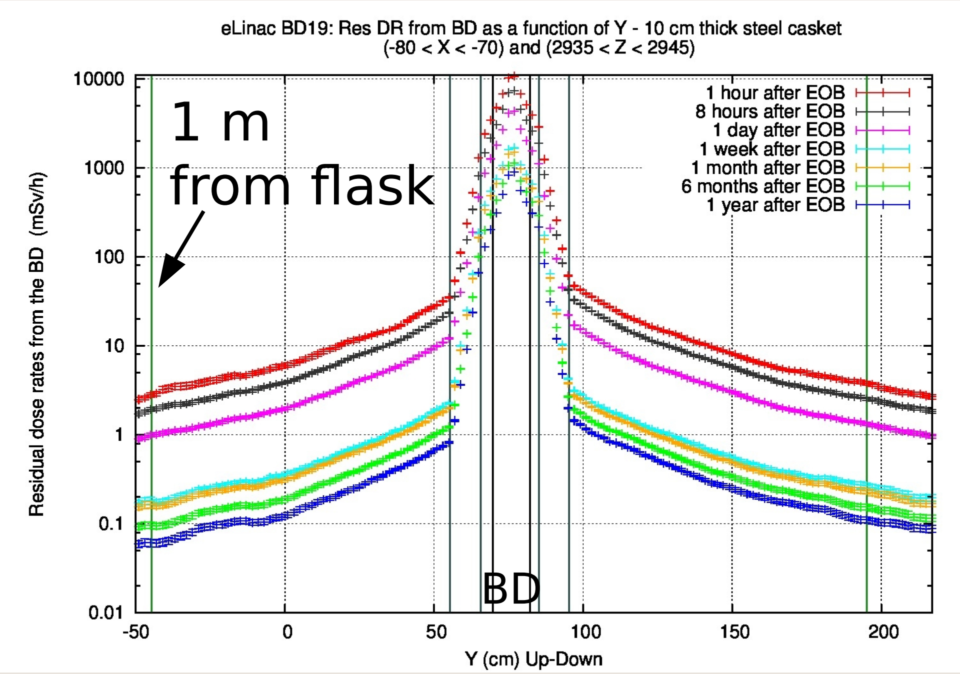


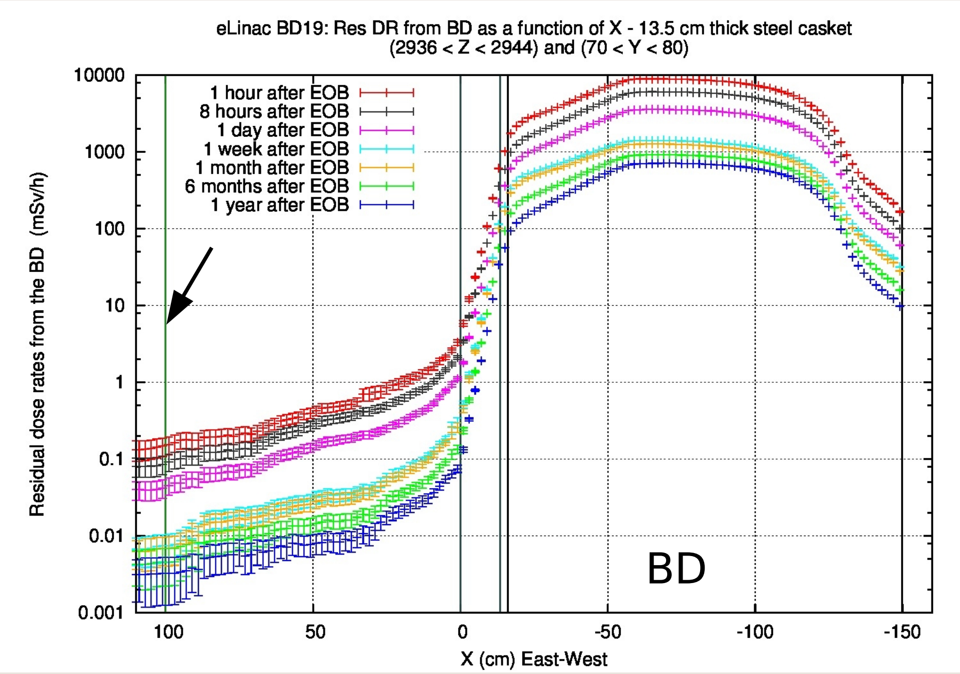


Later, looked at 2 and 3 day cooling times as well

Shielding flask for BD Transport
Transmission curves for Carbon Steel







Shielding flask for BD Transport

Thicknesses of lead and steel required for three different cooling times

- Thickness calculations take into account the observed factor of 10 reduction in DR through 1 m of air
- Steel TVL/thicknesses ~ 1.5x that of Lead
- Results agreed with calculations using
  - activities in the BD and Γ lines to calculate res. DR at the entrance to the flask,
  - attenuation coefficient for Pb/steel, and build-up factors to find the thickness required to achieve the DR limit

	TVL (cm) Thickness (cm)					
Cooling Time	**1 day after EOB**		**2 days after EOB**		**1 week after EOB**	
Material	**Lead**	**Steel**	**Lead**	**Steel**	**Lead**	**Steel**
Front & Behind (X)	3.77 7.6	5.81 11.4	3.80 6.3	- 9.5 *	3.41 5.4	5.17 8.1
Top & Bottom (Y)	3.96 10.1	5.99 15.2	3.72 8.7	- 13.1 *	3.22 7	4.97 10.5
Sides Left & Right (Z)	3.58 9	5.7 13.5	3.37 7.7	- 11.6 *	2.94 6.3	4.86 9.5

* Derived from scaling Lead/Steel TVLs for 1 day after EOB

Power Deposition in the BD, cooling Water, and Lead Shielding (9)

Purpose

Use in ANSYS simulations for thermal and stress analysis to determine

- the design of the water channels under the incident plate (size & extent)
- whether water cooling is needed in the lead shielding immediately surrounding the BD (yes)
- the #, size, and ideal spacing of the cooling tube network in the lead shielding
- the water flow rate to meet the limiting constraints of water boiling

Challenge

Power deposition distribution via USRBIN scoring not good enough since we needed to know average power distribution in different material, and sub-regions within a given material.

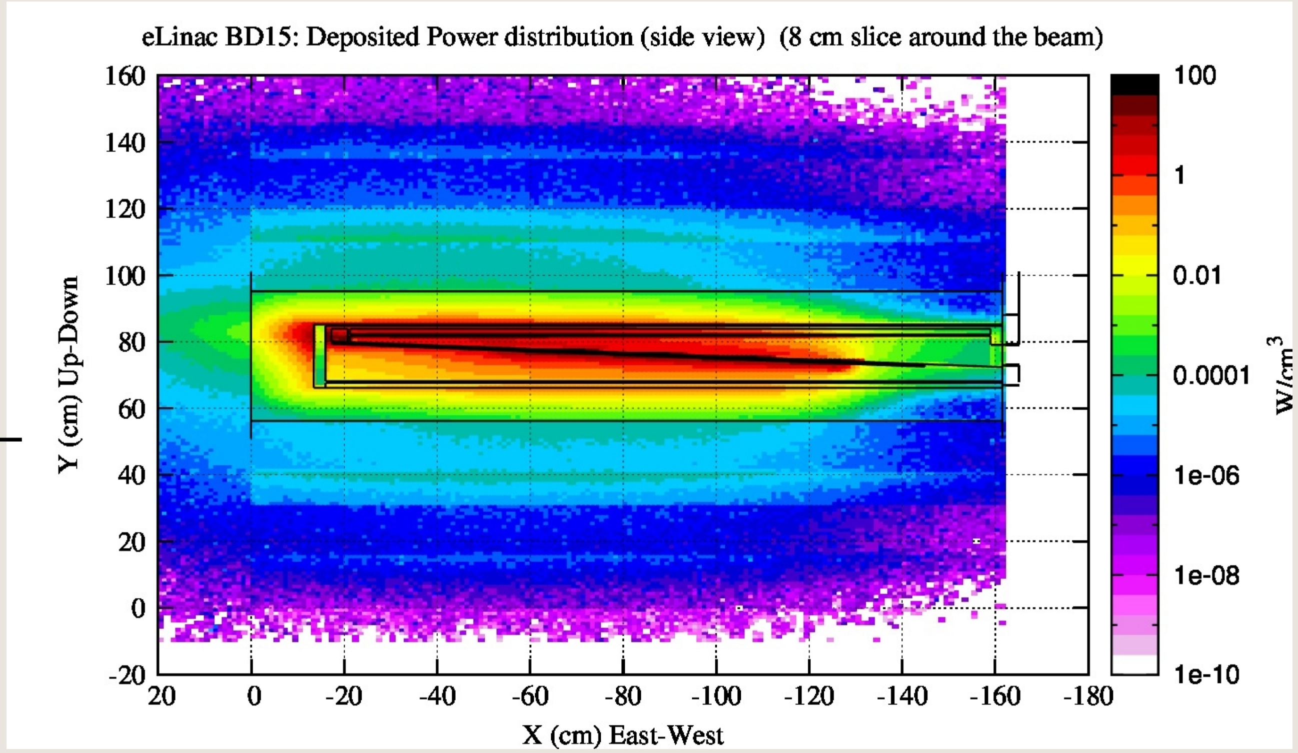
Implementation

- Used spacial distributions of energy deposition via USRBIN scoring to determine the size and number of sub-regions (more regions in the sensitive areas)
- Beam Dump components were divided into 59 sub-regions
- Lead shielding was divided into 31 sub-regions
- Energy deposition in each volume was recorded using the SCORE card
- Average power dep. was determined using beam intensity for each of the two beam energy settings.

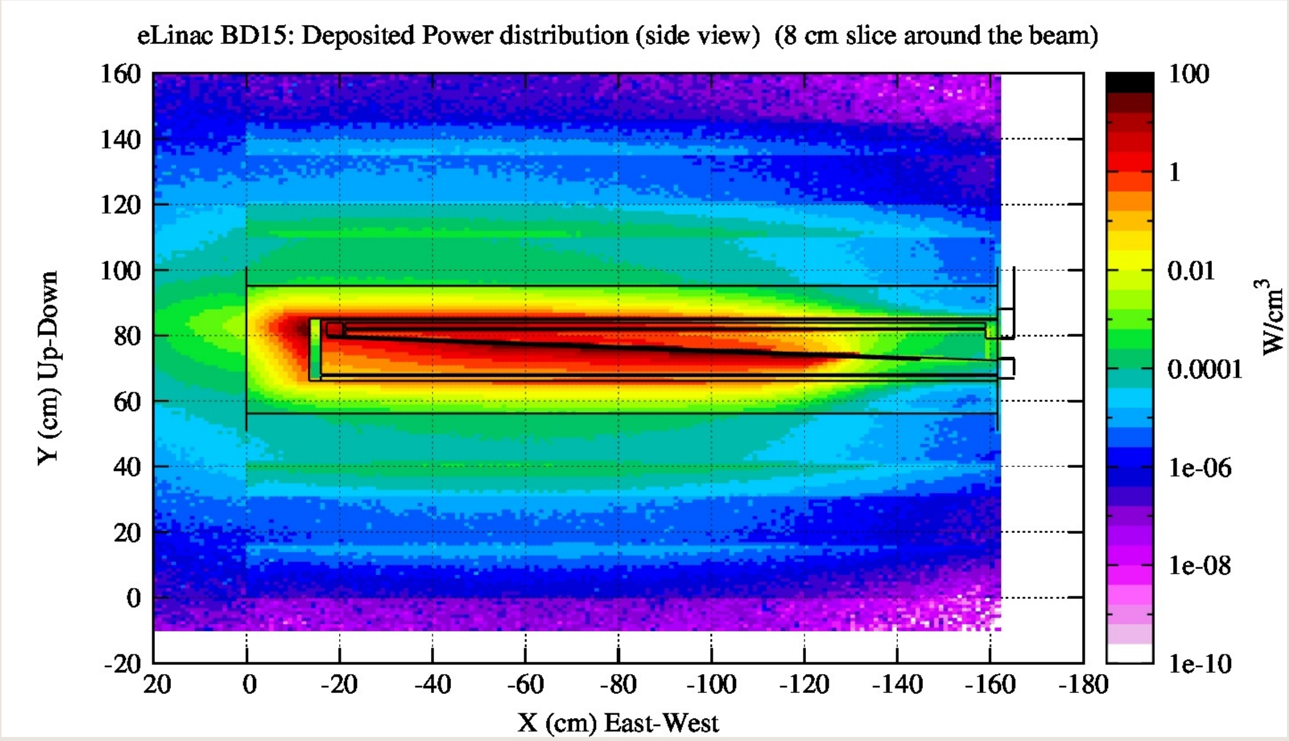
Power Deposition in the BD, cooling Water, and Lead Shielding

Region	Dep. Energy (GeV/prim)	Dep. Power (kW)
Al	1.93E-2 5.42E-2	77.25 72.31
Wat	3.42E-3 8.14E-3	13.67 10.86
Pb Sh	2.26E-3 1.25E-2	9.04 16.65
Con Sh	3.35E-6 2.81E-5	0.01 0.04
St Sh	2.11E-6 2.02E-5	0.01 0.03
Total	0.025 0.075	99.97 99.89

25 MeV, 4 mA

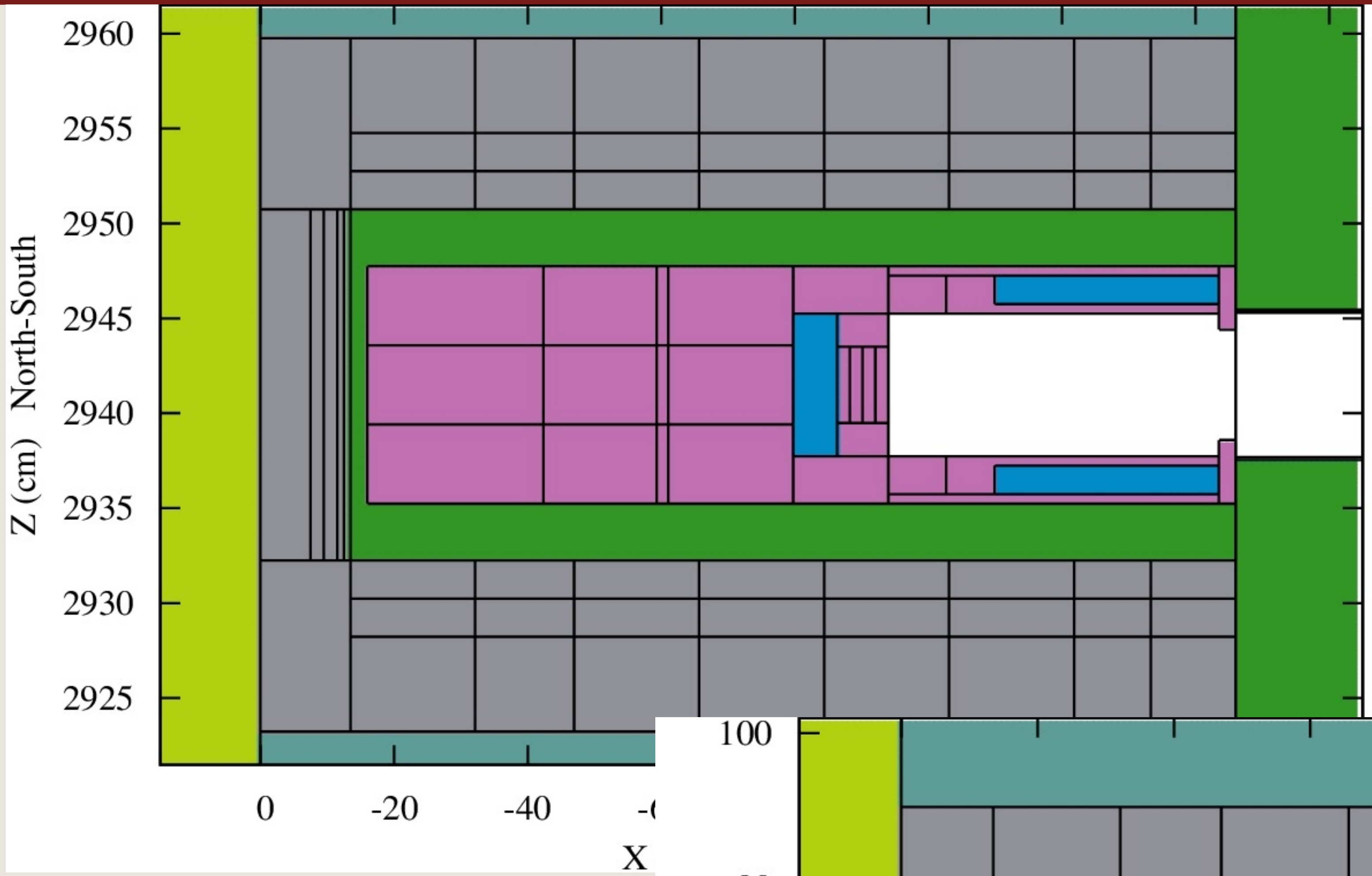


75 MeV, 1.3 mA

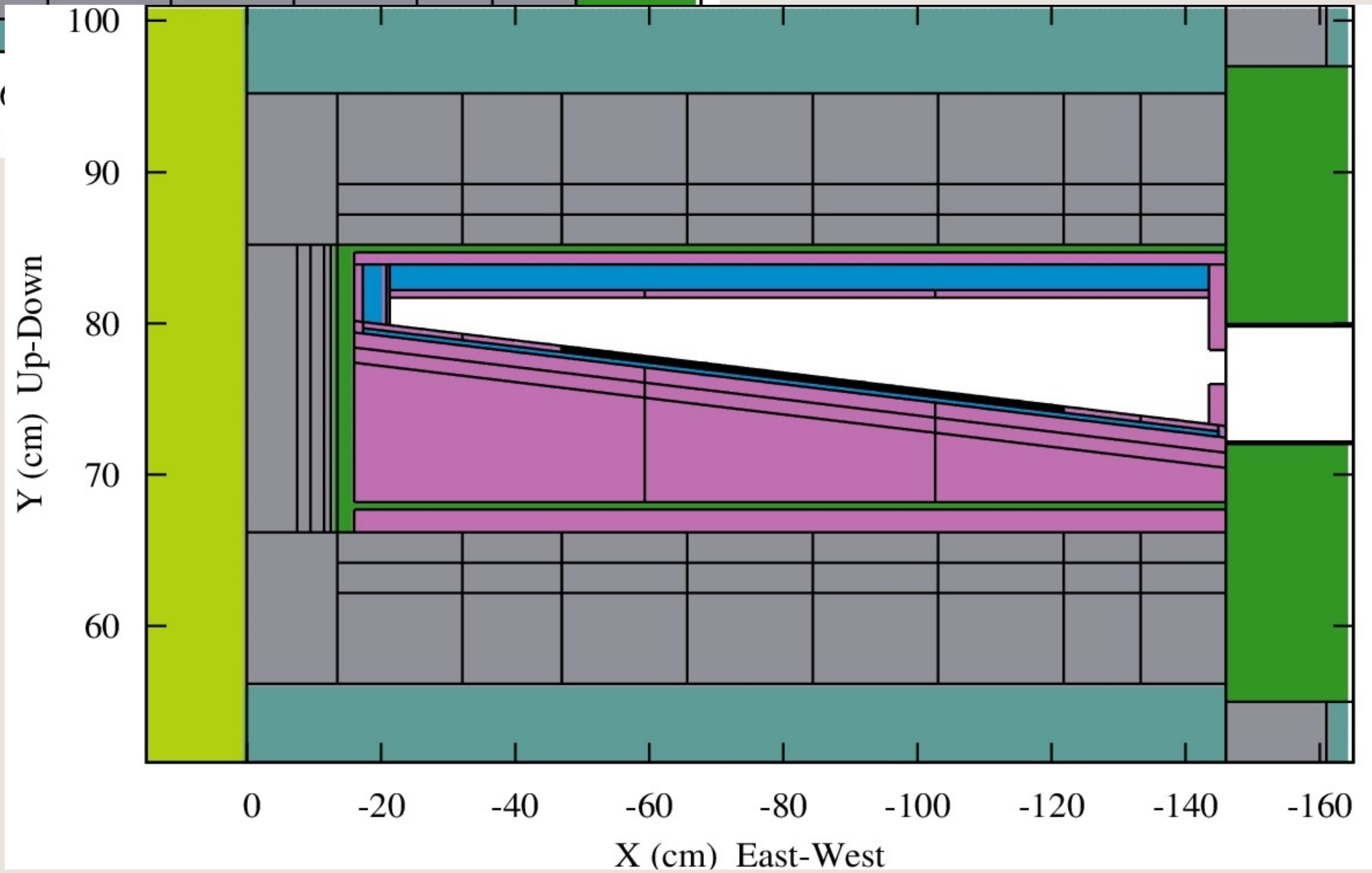


Beam Dump geometry as modelled in flair

Top View

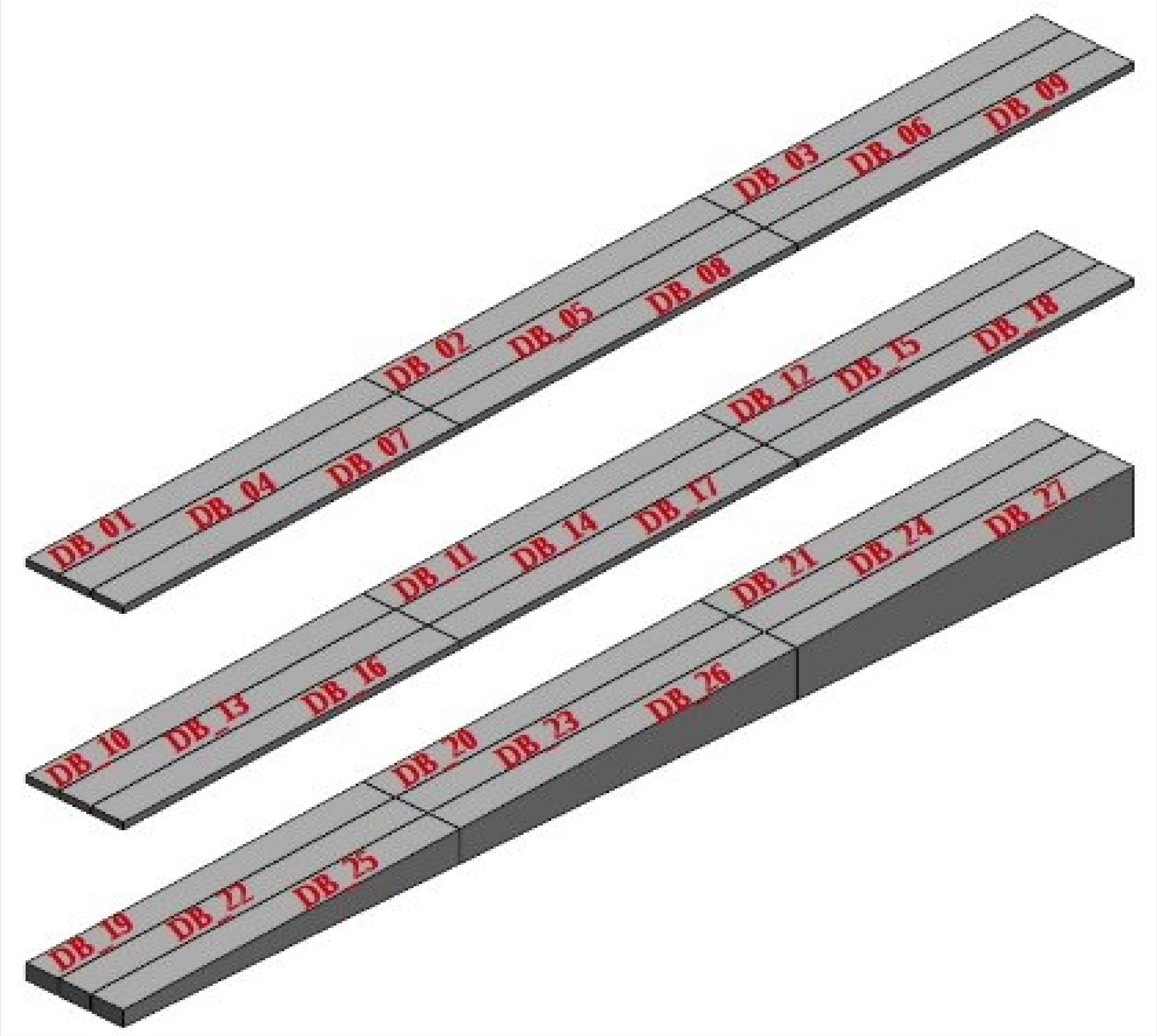


Side View



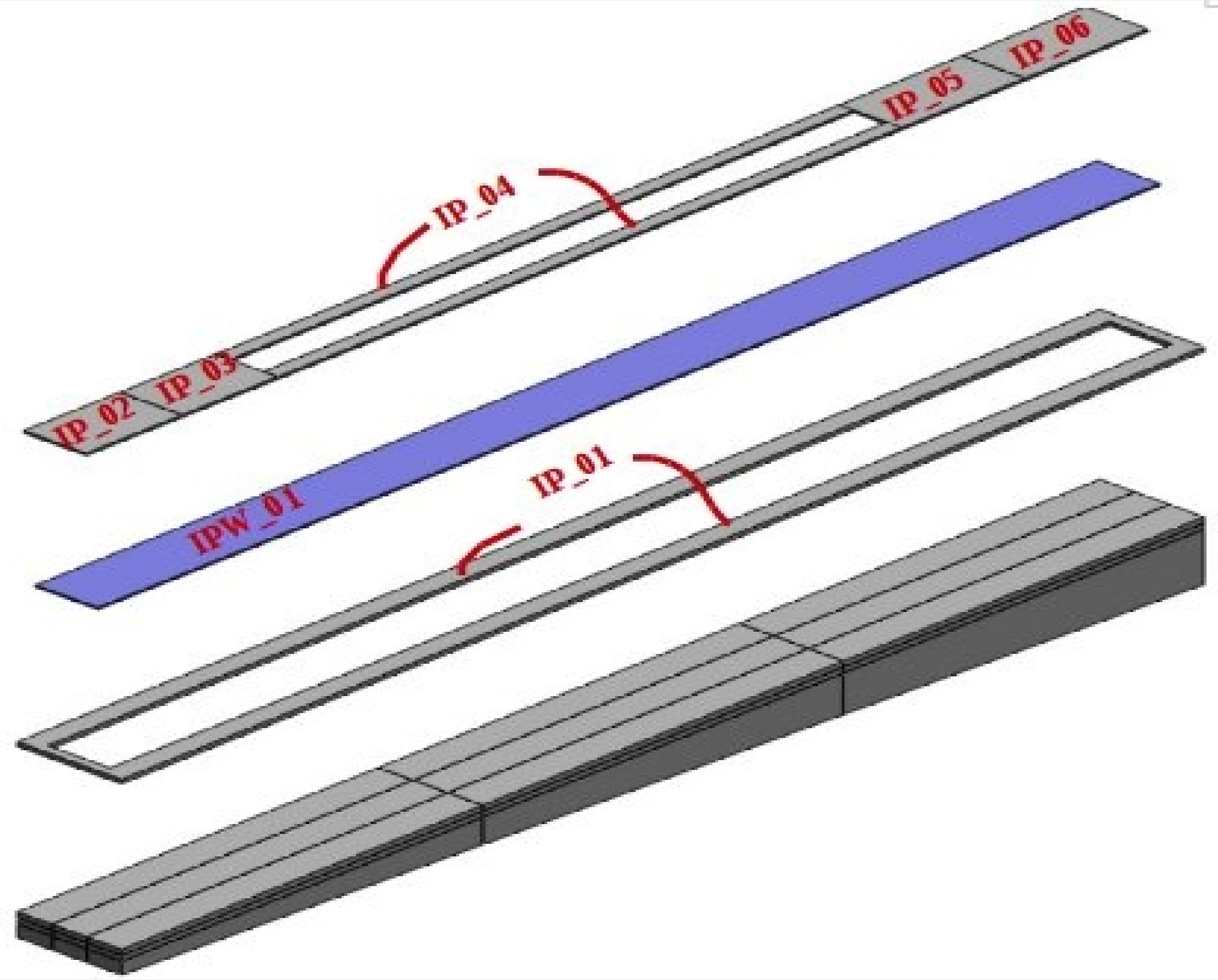
Power Deposition in the BD & Cooling Water

Lower Plate: 27 Regions



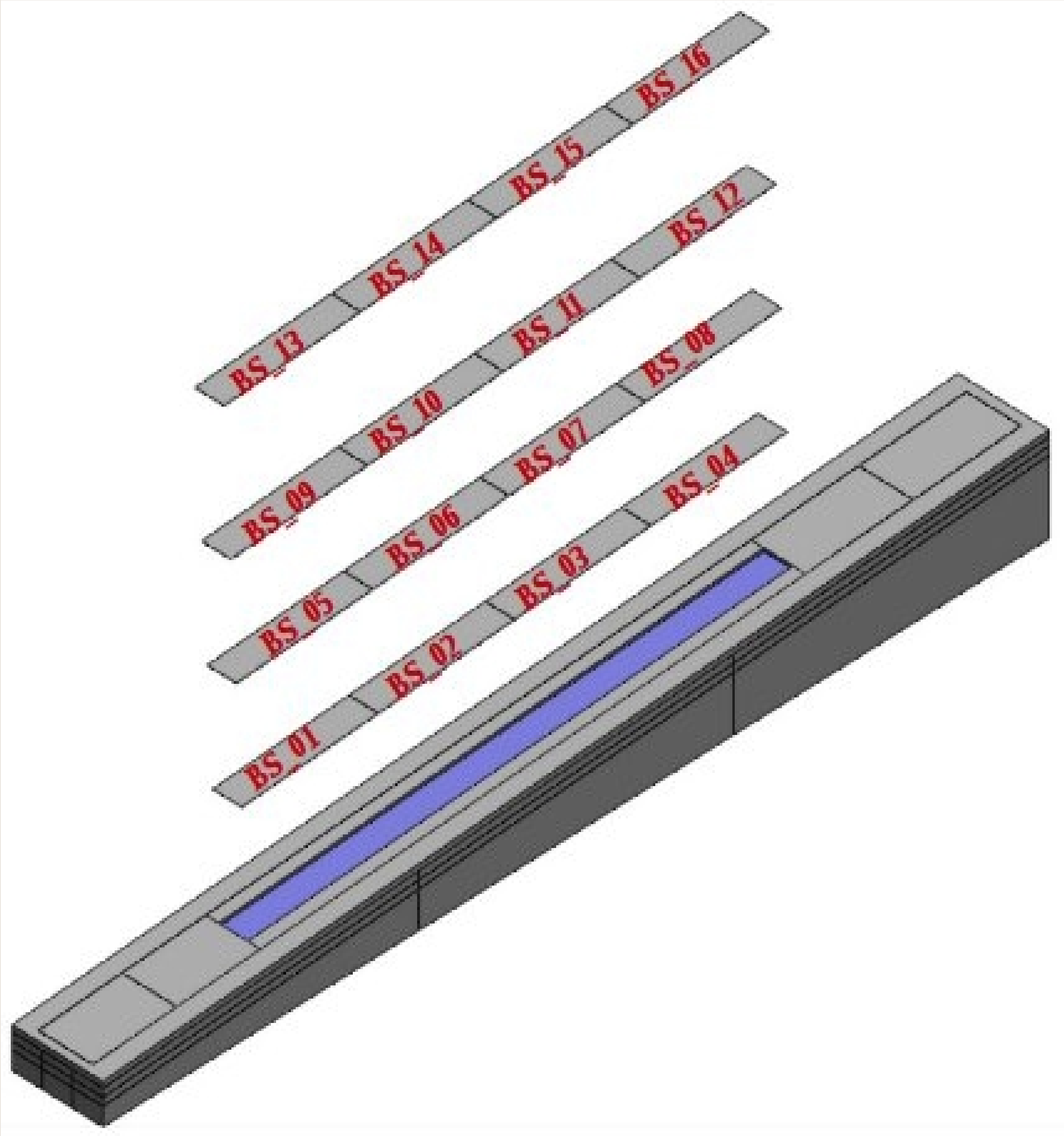
Power Deposition in the BD & Cooling Water

Incident Plate & Water: 7 Regions



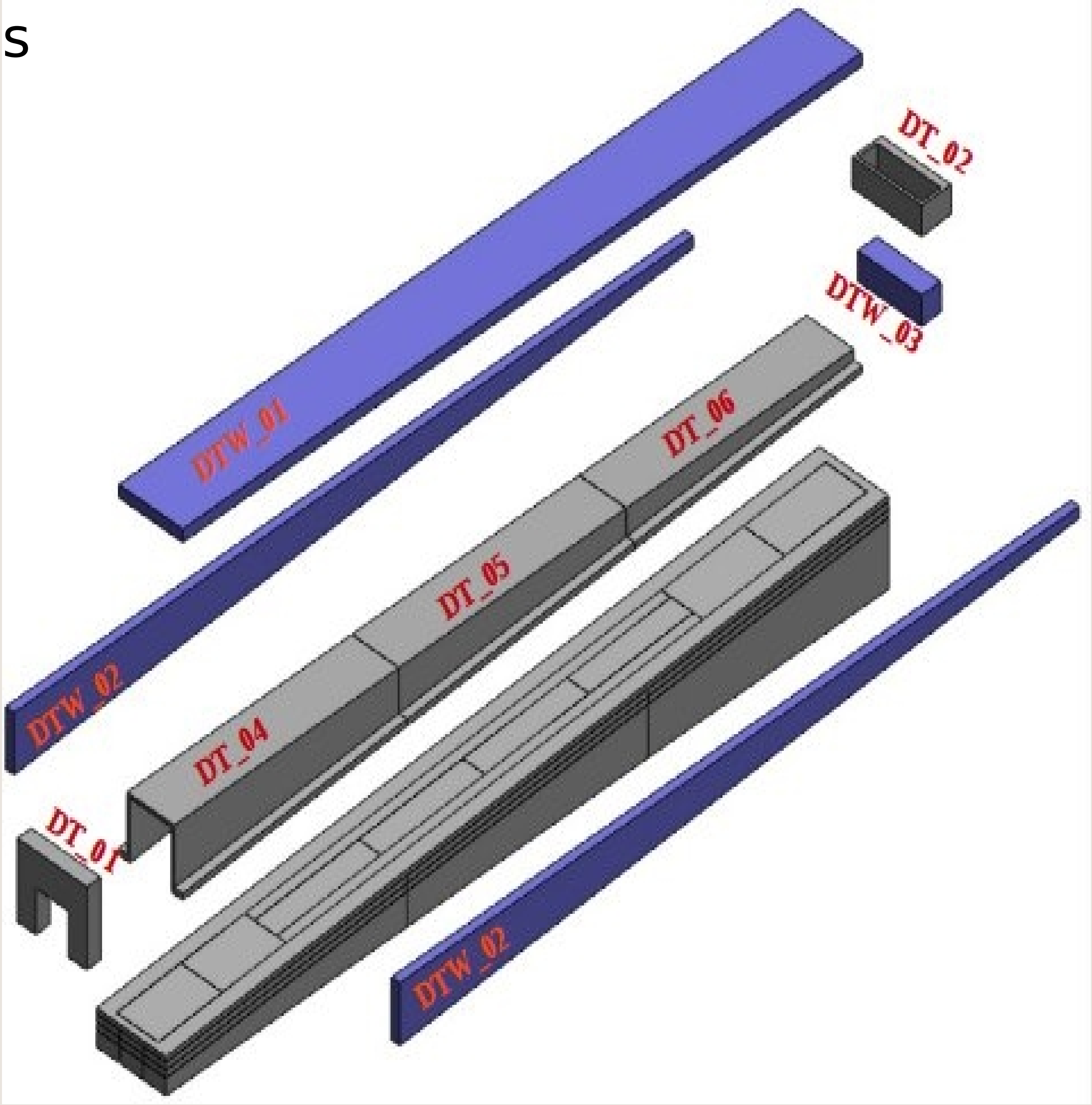
Power Deposition in the BD & Cooling Water

Beam Spot: 16 Regions



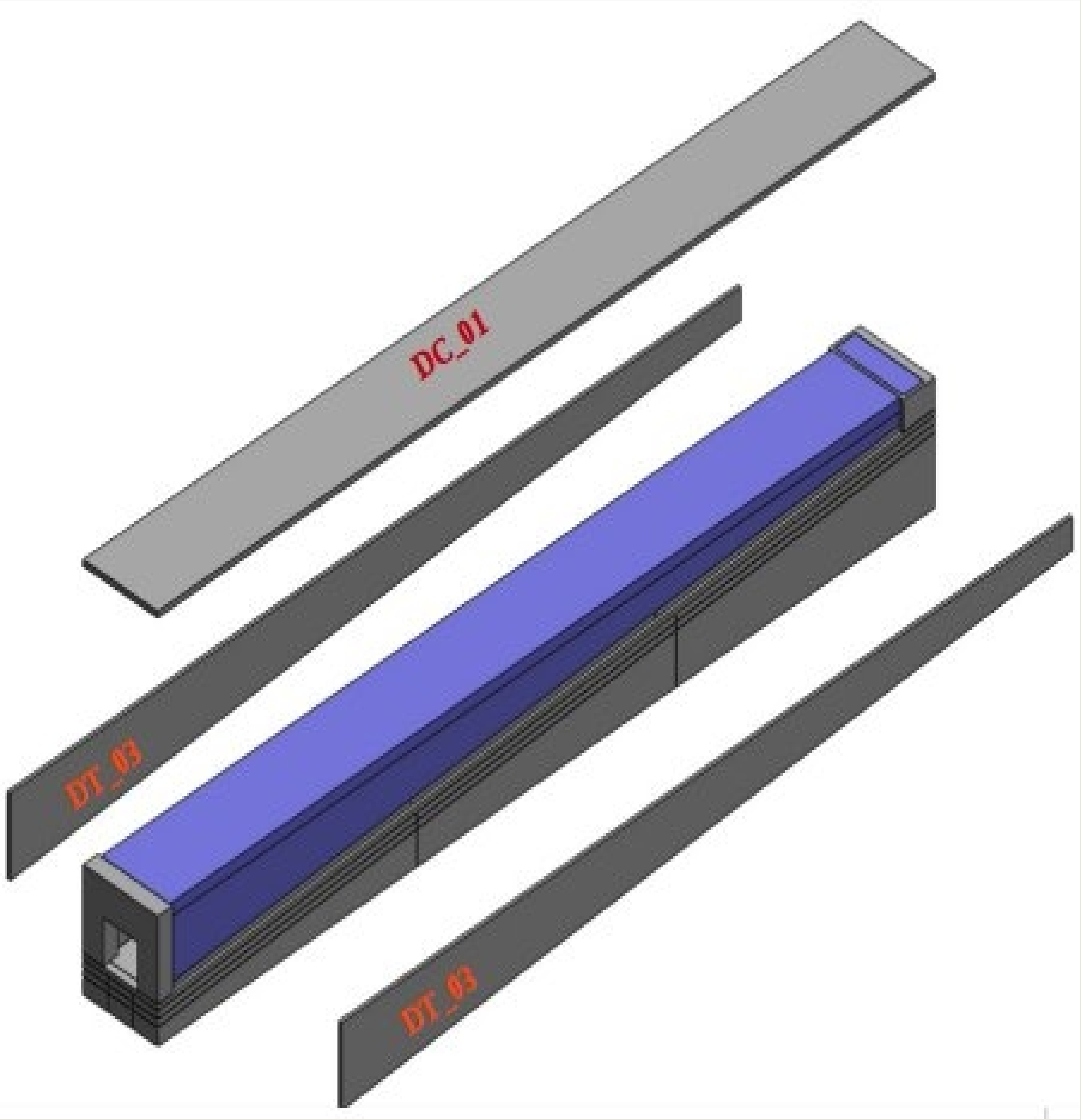
Power Deposition in the BD & Cooling Water

Top Plate & Water: 8 Regions

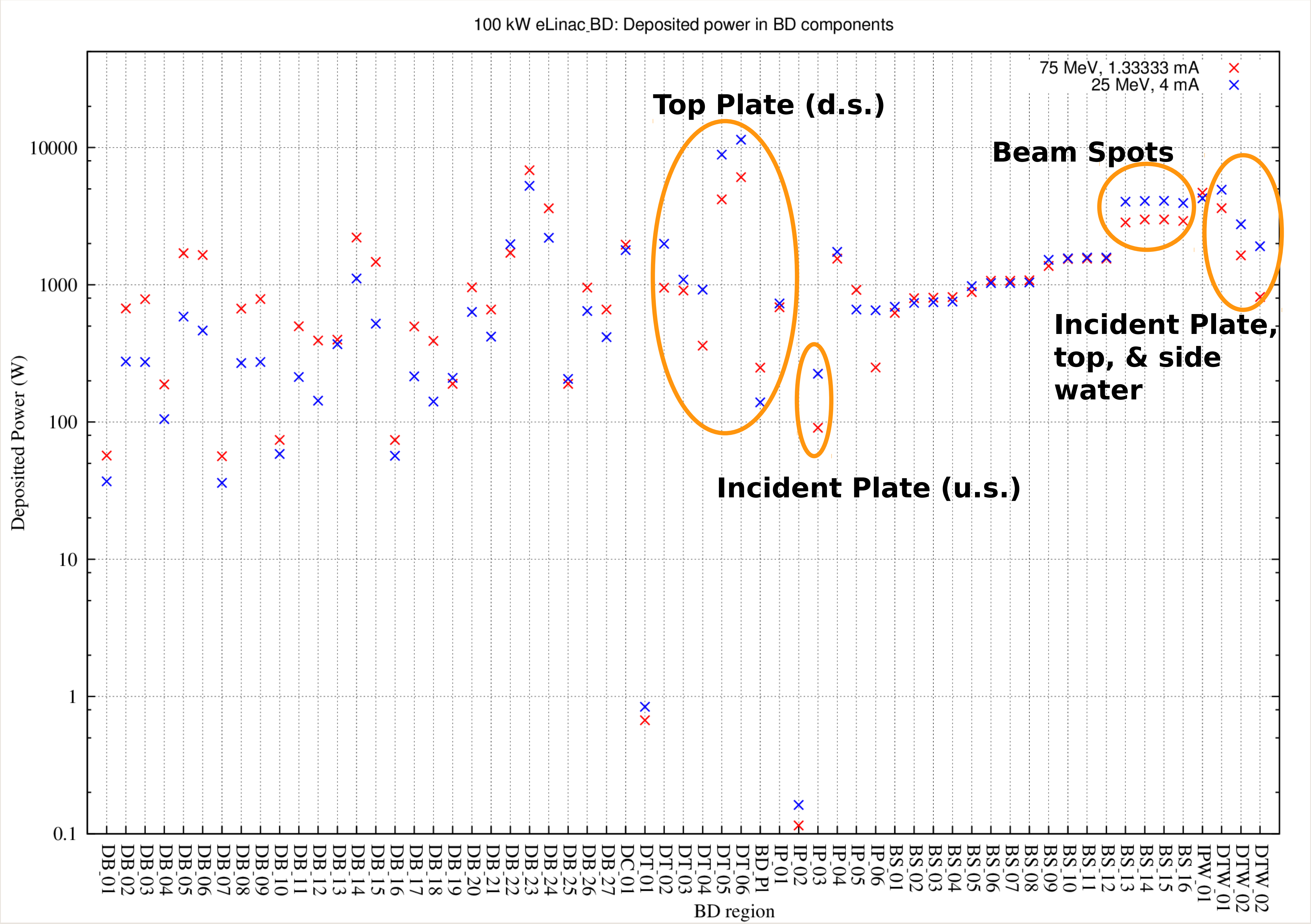


Power Deposition in the BD & Cooling Water

Top Plate Cover: 2 Regions

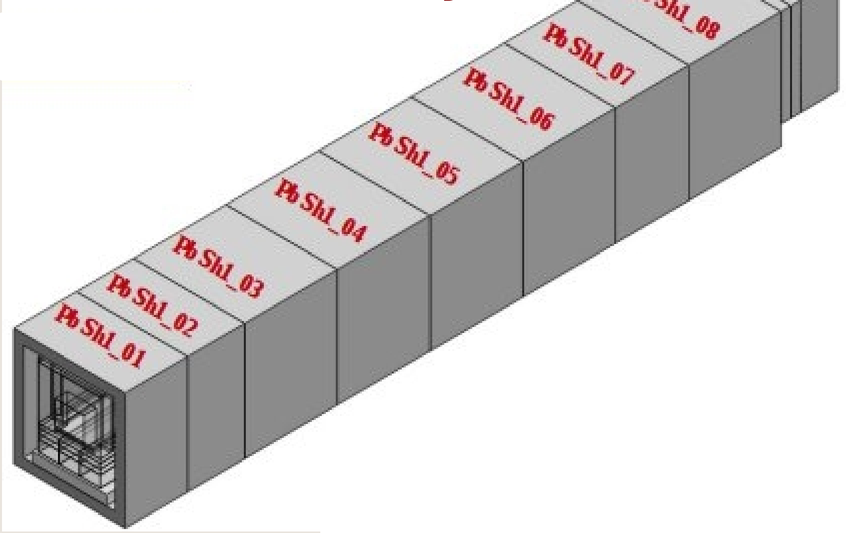


Power Deposition in the BD & Cooling Water

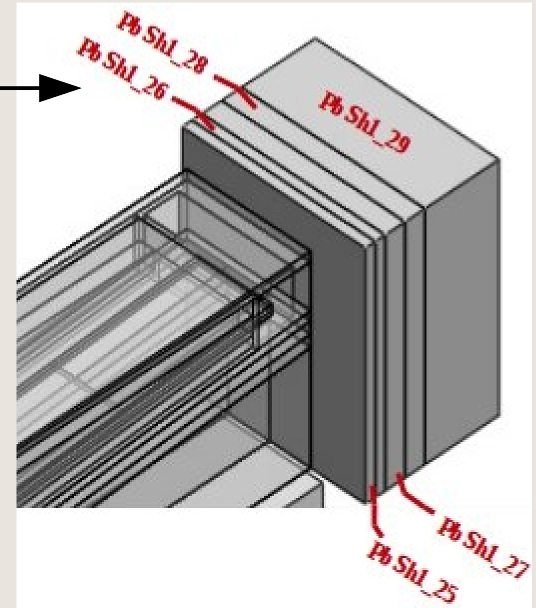


Power Deposition in the Pb Shielding

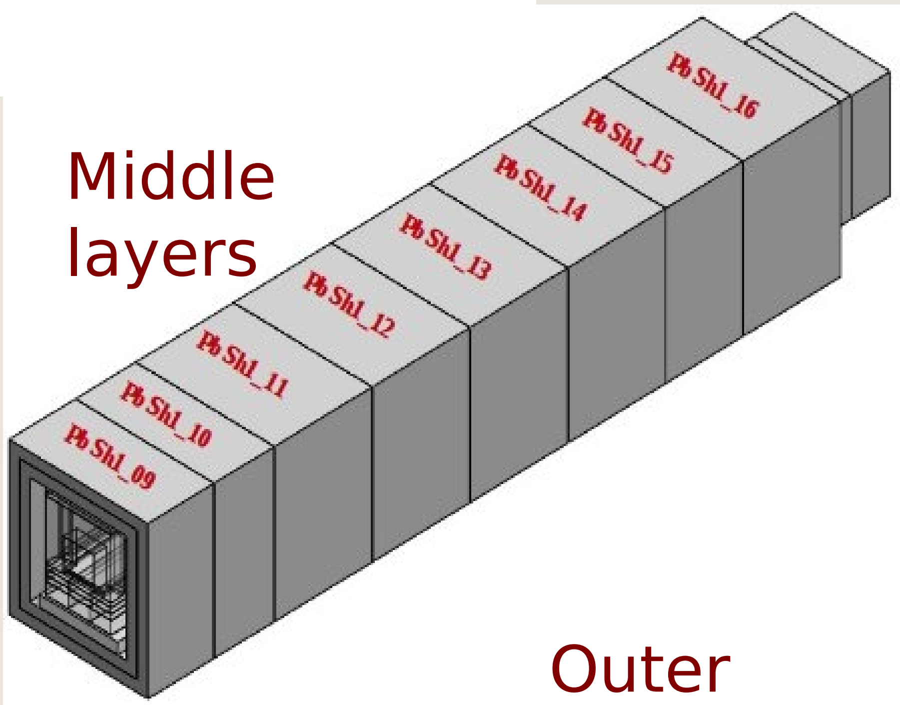
Innermost layers



Downstream layers



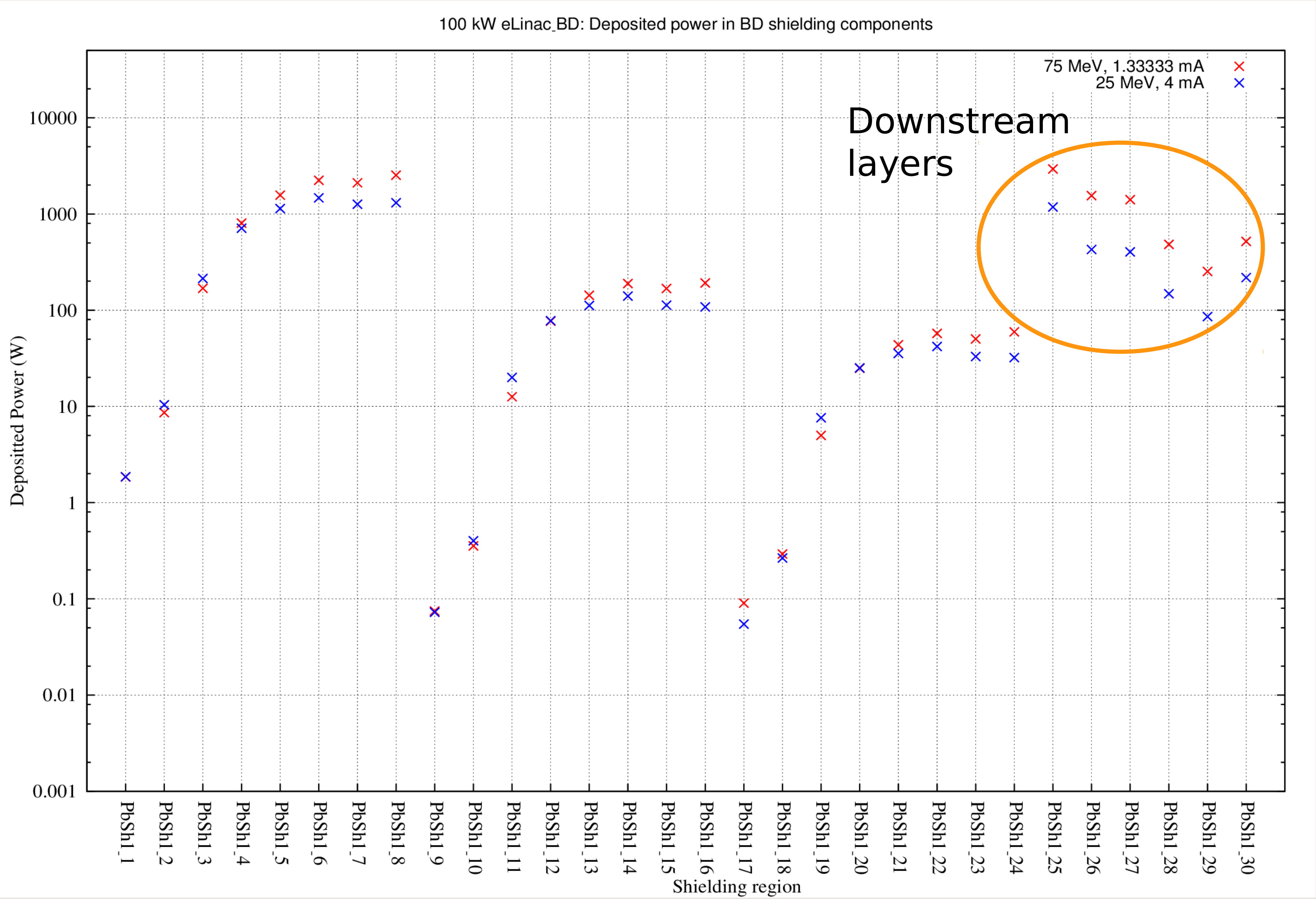
Middle layers



Downstream outer layer

Outer layers

Power Deposition in the Pb Shielding



Water cooling Network inside the Pb Shielding

Pb Shielding

Residual DR from BD and BD Local shielding (2)

Radiation Profile set in IRPROFi card:

Beam intensity: 1.3 mA = 8.322E15 e/s
Operation scenario: Beam on for 1 month of the year, for 20 years

- There are 8760 hours per year, and 720 hours per month
- Divide into 15 + 5 years

  First 15 years: beam on all the time with beam intensity scaled by fraction of the time beam on

  (720/8670) = (720/8760) * 1.33333 mA = 0.082 * 8.322E15 = 6.824e14 e/s

  The remaining 5 years, beam on for 720 hours at full intensity of 1.3 mA, off for 8040 h

Decay times set in DCYTIMES card: 1h, 12h, 1d, 1w, 30d, 90d, 180d, 365d

Decay material set to vacuum in ASSIGNMA cards for the relevant regions

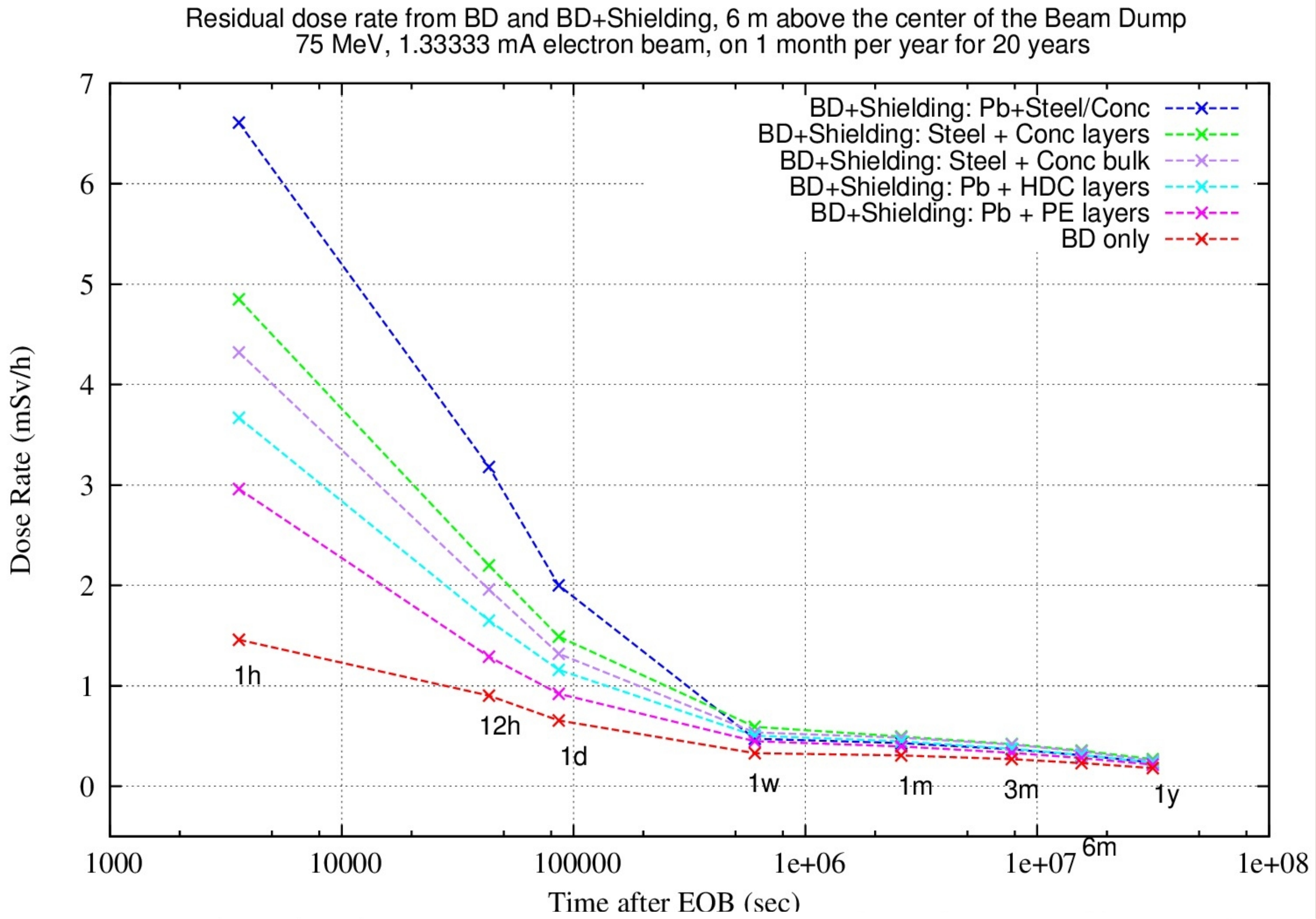
Scoring: Via USRBIN (DOSE-EQ) and DCYSCORE cards

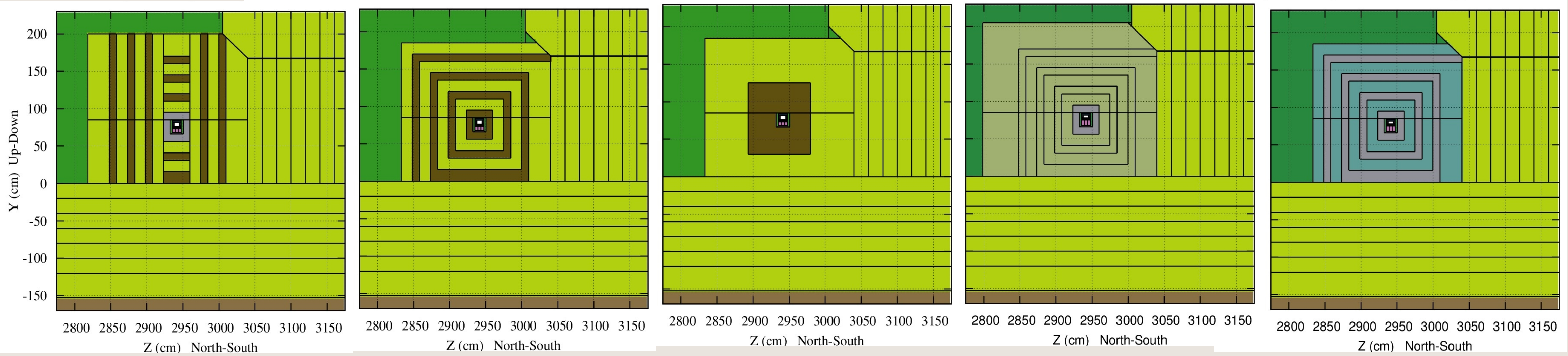
5x5x5 cm bins around the BD

Generated 2-D plots for each decay time (50 cm bin in X)

Grabbed res. DR values for point (Y, Z) = (676, 2940)

Residual DR from BD and BD Local shielding





Concluding Remarks

FLUKA simulations were successfully used to

- design the Water Cooling Network and the shielding configuration for the TRIUMF ARIEL eLinac 100 kW Beam Dump

  - A compact shielding configuration, employing a layering scheme, proved to provide the best solution for the BD at the two operating limits of 4 mA @ 25 MeV and 1.3 mA @ 75 MeV

  - An inner layer of lead surrounding the Al BD, was used to attenuate photons. Layered slabs of concrete and steel were used to attenuate/absorb generated neutrons and to further attenuate photons, respectively

- design the EHDT shielding, estimating dose rates on few beam line components, and finding solutions to further reduce the dose rates, creating cooler radiation fields in the area

- estimate residual dose rates from the BD and BD & shielding
- estimate activities in the BD components (Al and water), and shielding
- design a shielding flask for transport of the BD at the end of operation

TRIUMF

Thanks are due to

Isaac Earle, Vance Strickland, Tim Emmens, Roland Kokke, George Clark, Anne Trudel, Shane Koscielinak, Eric Guetre, Maxim Kinakin, Ewart Blackmore, Thomas Planche, Kelvin Raywood, Greg Hackman, Jane Richards, Kyla Shauer, Doug Preddy (for the beautiful rainbow pic), ...
from TRIUMF

Curtis Baffes, Igo Ranko
from FNAL

Keith Welch
from Jlab

and the FLUKA community:
Alberto Fasso, Vasilis Vlachoudis, Francesco Cerutti, Mario Santana, Alessio Mergghetti, ...

EXTRA SLIDES