Estimates of Radiation Levels in the Main Linac Tunnel and Beam Dump Caverns for the CLIC Design Study

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Contents

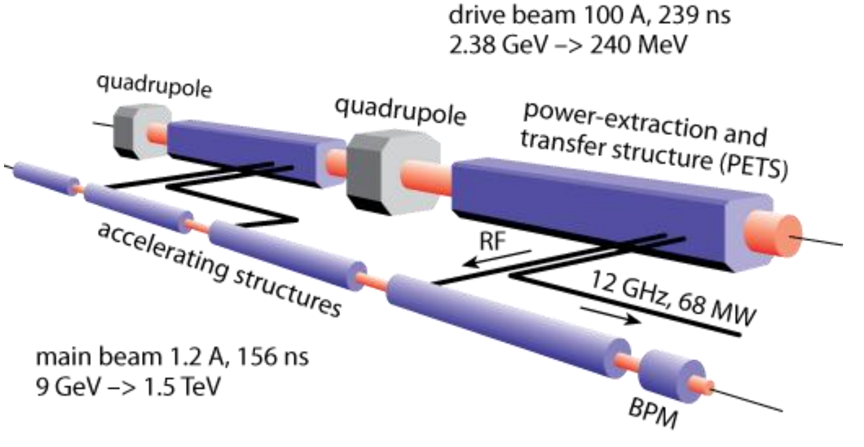
CLIC Study: Concept

- **CLIC** (**C**ompact **Li**near **C**ollider)
- Study for future e+ e- collider nominal c.o.m. energy 3 TeV
- Cost efficient – 48 km in length. Very high accelerating gradient **100 MV/m** and requires sufficient RF power at 12GHz..
- Novel **two-beam-acceleration concept:** high current electron **drive beam** decelerates in special power extraction transfer structures (PETs) and generated RF power transferred to the **main beam**

Beam Parameters:

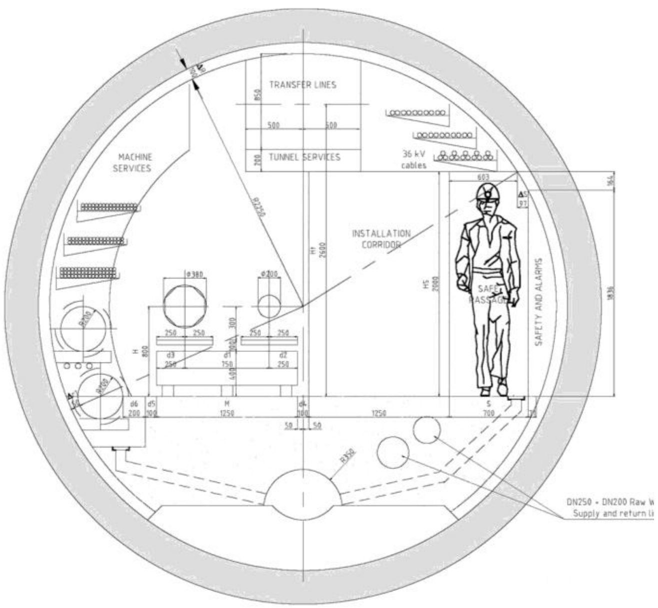
Drive Beam: 2.4 GeV → 0.24 GeV, 1.54e14 electrons per bunch train, 50 Hz

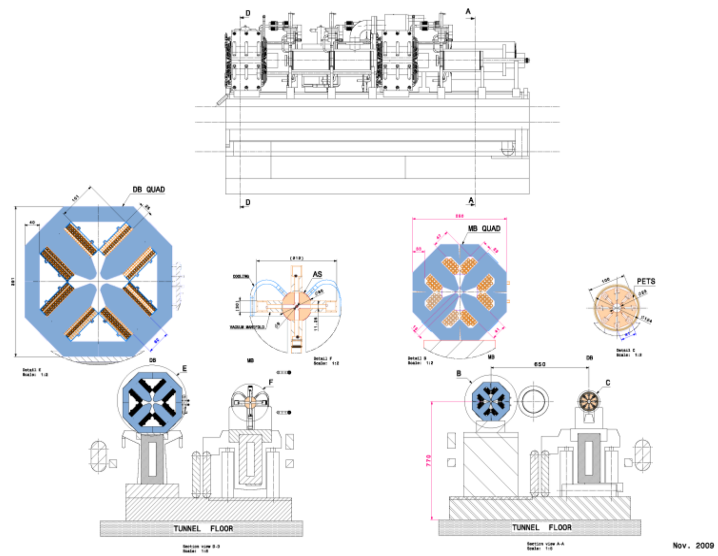
Main Beam: 9 GeV → 1.5 TeV 1.16e12 electrons per bunch train, 50 Hz



CLIC Study: Designs

- Designs subject to regular changes/updates
- Designs used for current study:





Radiation Levels in the CLIC Tunnel - Considerations

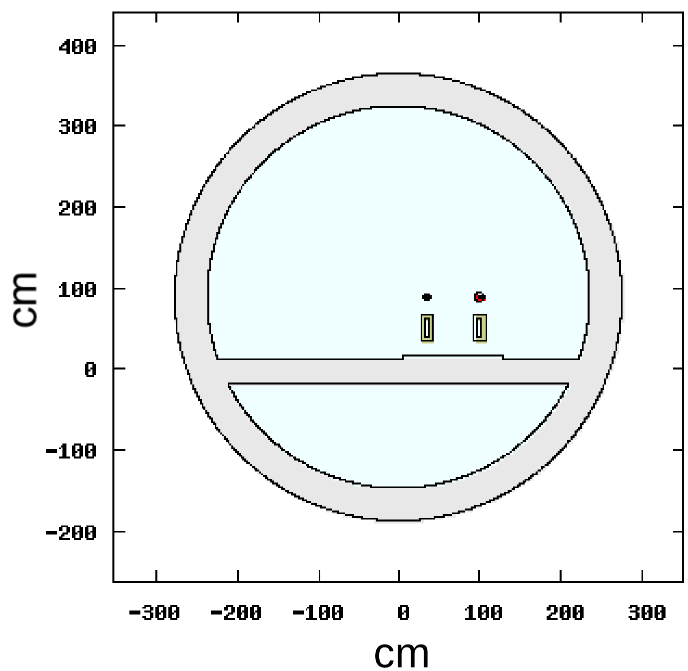
- **Losses**
- An estimation of the losses along the main linac apertures not yet known
- However, for an upper limit, from beam dynamics considerations, the losses should be controlled to less than 0.1% of total intensity over each linac in nominal operation.
- Main Beam linac 20,000 m: average losses 5e-8 m^{-1}
- Drive Beam 24 stations. each linac ~ 800 m: average losses 1.25e-6 m^{-1}
- The aperture restrictions in the MB linac are at the end of the accelerating structures, in the DB linac at the end of the PETs

- **Consequences**
- Radiation protection issues for personnel: Doses due to induced radioactivity - access in shutdown periods. (CERN limits - Ambient dose equivalent rates >100µSvh^{-1} necessitates detailed optmization of every intervention and strict control times)
- Damage to components: Radiation damage to QP magnets (Less than 1 MGy per year to epoxy will conservatively assure survival of magnet insulation over lifetime of accelerator.)
- Electronics Damage: Probabilistic - SEE's, Cumulative - Lattice displacement, total ionising dose

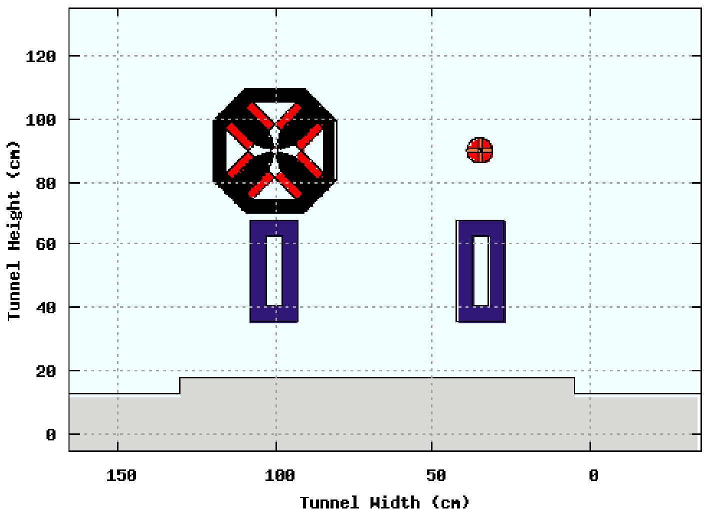
CLIC Tunnel FLUKA Simulations - Representation

- Tunnel / floor (concrete)
- PETs (solid cu)
- ASs (cu / cu half density)
- QPs (fe yoke, cu coils)
- Girders (SiC)

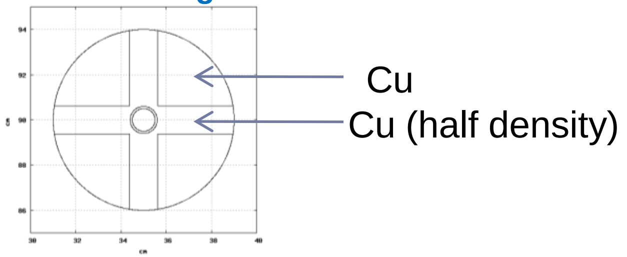
Tunnel Cross Section



Module Cross Sections through DB QP, MB accelerating structure



Accelerating Structure Cross Section

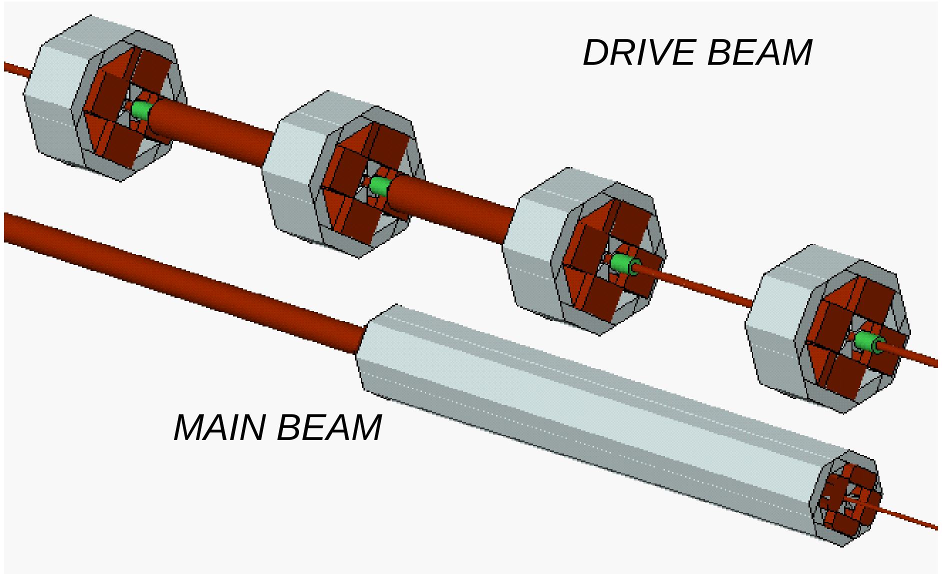


CLIC Tunnel FLUKA Simulations - Representation

The layout of the modules (incl. The length of the main beam quadrupole) was represented in accordance with their energy dependant position in the MB

Visualized using 'Simple Geo'

2 modules (type 1, type 4) at end of linac MB -1.5 TeV



CLIC Tunnel FLUKA Simulations – Parameters & Settings

- The losses, which are expected to have low impact angle are represented by electrons travelling in direction of the beam generated in a circular distribution just inside copper beam pipe
- Loss: " Standard Operational " Sample along several meters DB - at 4 points (end of PETs) per module, MB - continuously (approximation of 8 AS's per module)
- Loss: "Failure Mode" In 1 PET/AS just before QP
- For each beam, 2 loss energies simulated corresponding to max and min energies
  MB 9 GeV and 1.5 TeV, DB 0.24 GeV and 2.4 GeV
- MB: Transport thresholds were set at 10 MeV for electrons and positrons and 5 MeV for photons, resp. (prompt)
- DB: Transport thresholds were set at 1 MeV for electrons and positrons and 0.5 MeV for photons, resp. (prompt)
- Physics settings included photonuclear production, muon pair production, the request of the PEANUT model at all energies, the treatment of coalescence and the evaporation of heavy fragments (up to A = 24).
- Estimates: Absorbed Doses (prompt), 1 MeV neutron equiv. Fluence on silicon and >20 MeV Hadron Fluences
- Estimates: Residual Dose Rates – build up and decay of radiation simulated – inc an irradiation profile of180 days continuous running followed by 185 days shutdown for 11.5 yrs. Residual dose rates and residual nuclei scored at various cooling times in shutdown periods

CLIC Tunnel FLUKA Simulations – Results example 1

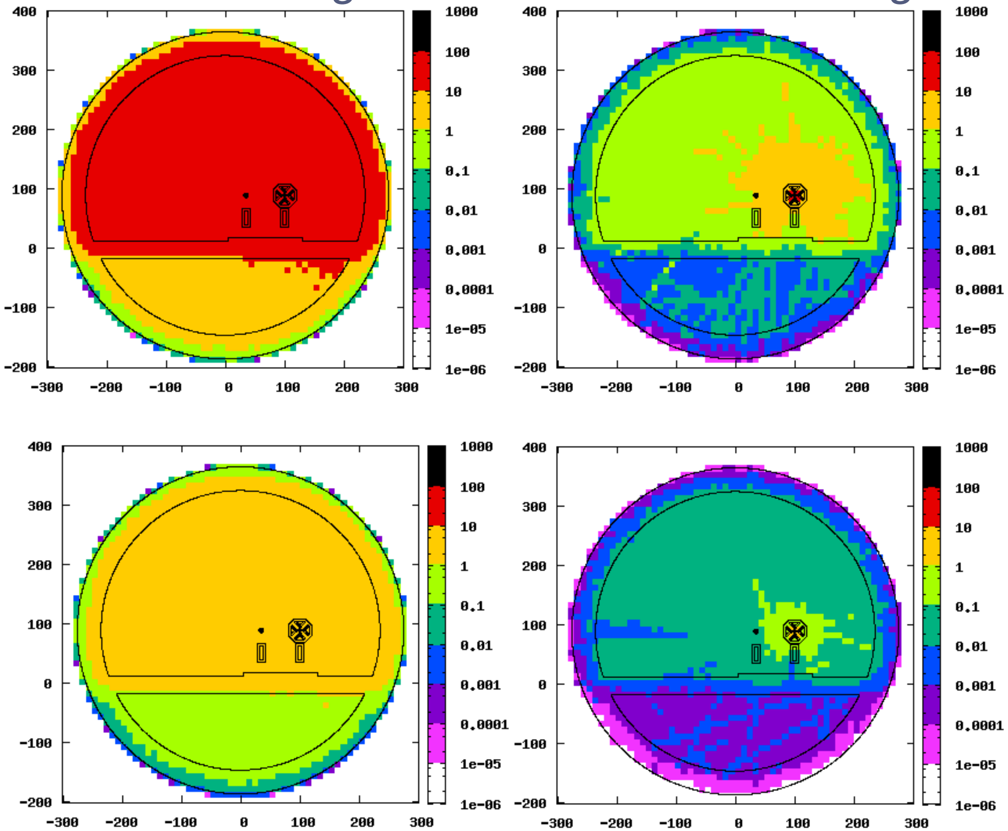
- DRIVE BEAM Ambient Dose Equivalent Rates H*(10)

4h Cooling | 1 Week Cooling

µSv h^{-1}

2.4 GeV

0.24 GeV



IRRADIATION: 180 days, 1.54E14 per bunch train, 50hz with losses 1.25E-6 m^{-1}

CLIC Tunnel FLUKA Simulations – Results example 2

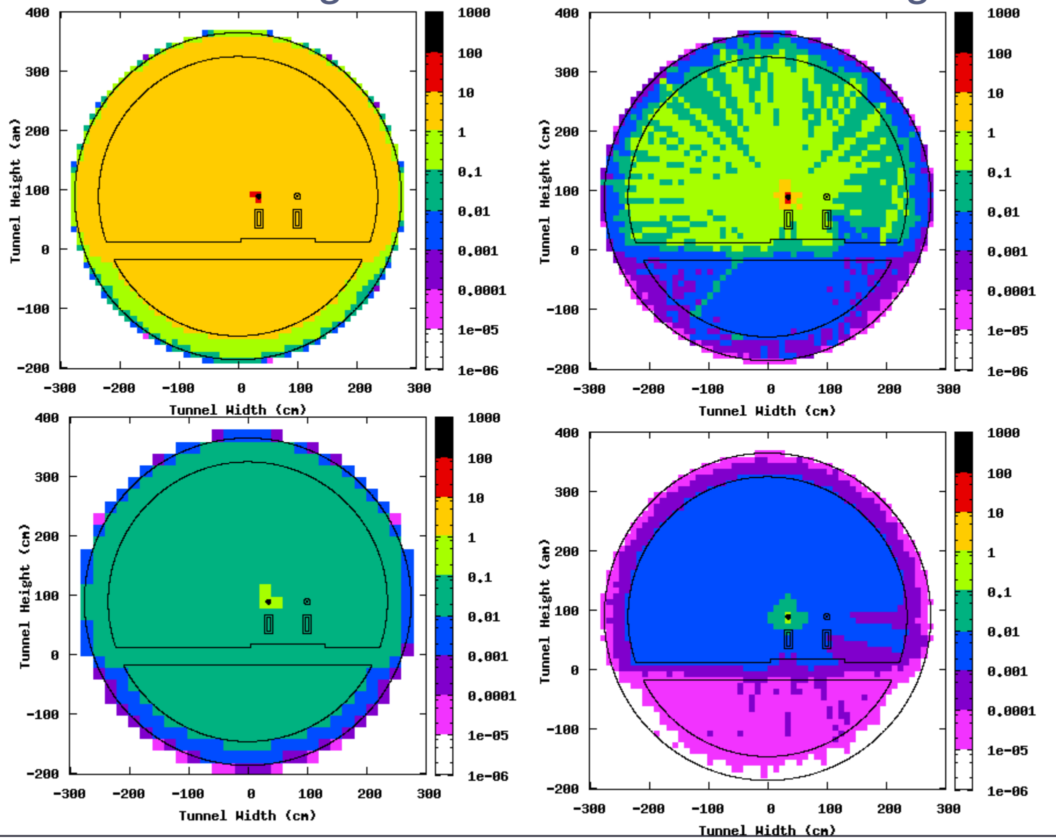
- MAIN BEAM, Ambient Dose Equivalent Rates H*(10)

4h Cooling *1 Week Cooling*

1.5 TeV

9GeV

μSv h^{-1}



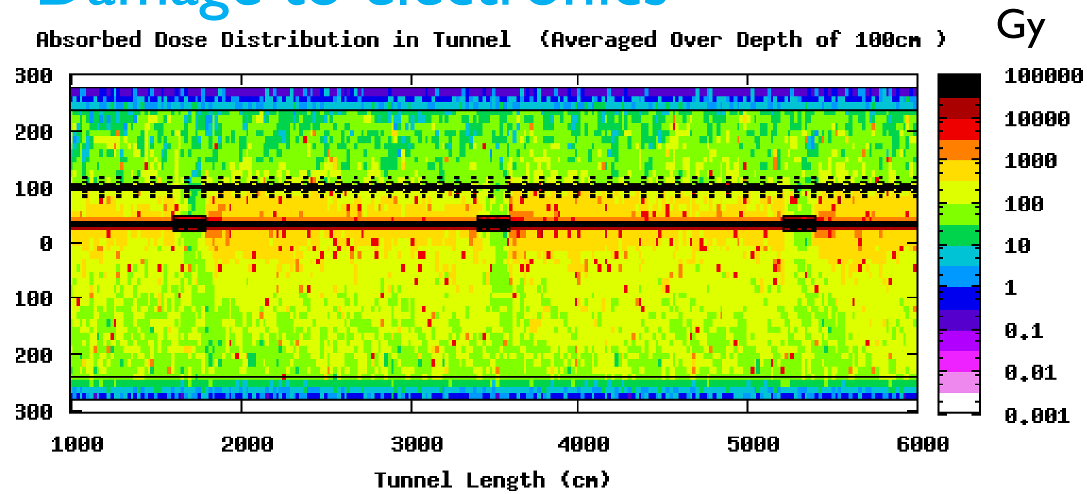
IRRADIATION: 180 days, 1.16E12 per bunch train, 50hz with losses 5E-8 m^{-1}

CLIC Tunnel FLUKA Simulations – Results example 3

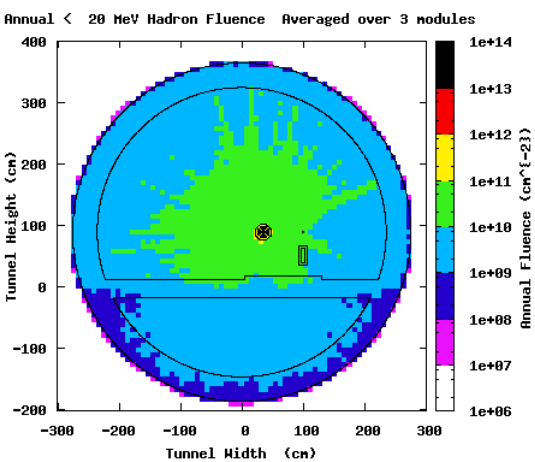
MAIN BEAM, 1.5 TeV - Damage to electronics

NORMALISATION:
180 days,1.16E12 per bunch train, 50hz, Losses 5E-8 m^{-1}

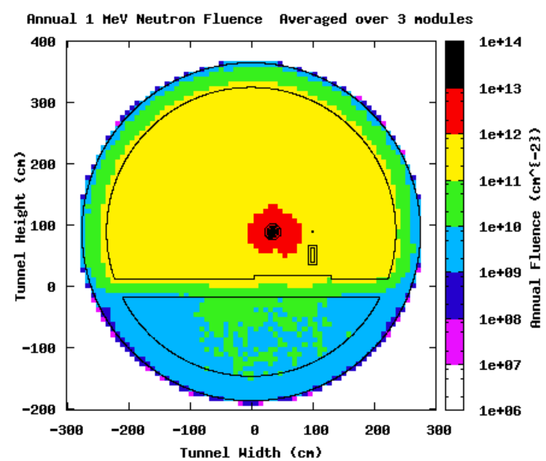
Annual Absorbed Dose



Annual >20MeV Hadron Fluence



Annual 1 MeV neutron equivalent fluence on Silicon

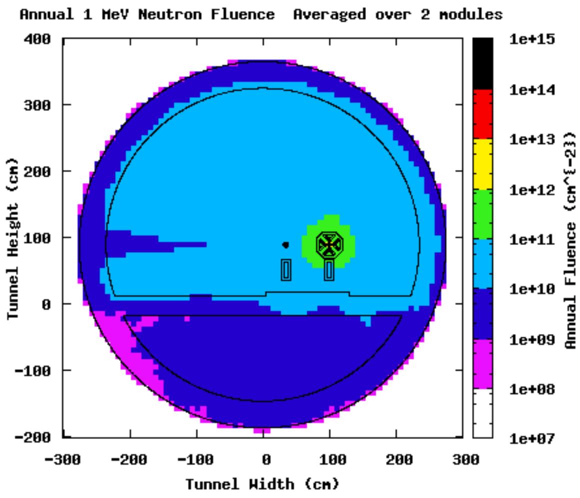


CLIC Tunnel FLUKA Simulations – Results example 4

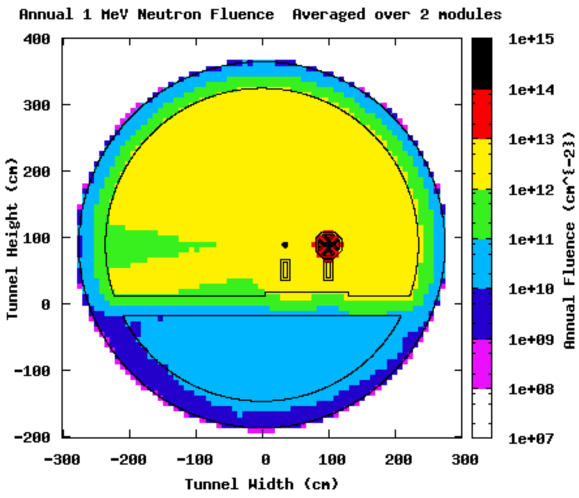
- DRIVE BEAM, 2.4 GeV -Damage to electronics

NORMALISATION: 180 days,1.54E14 per bunch train, 50hz, Losses 1.25E-6 m^{-1}

Annual >20MeV Hadron Fluence

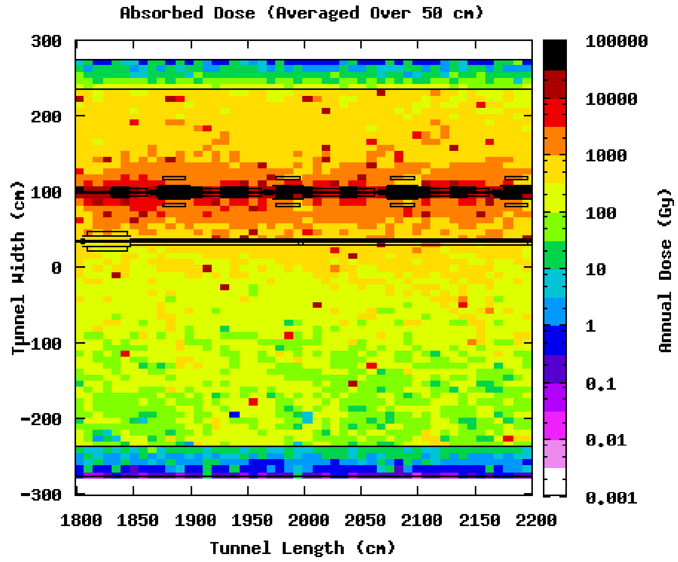


Annual 1 MeV neutron equivalent fluence on Silicon



Annual Absorbed Dose

Gy

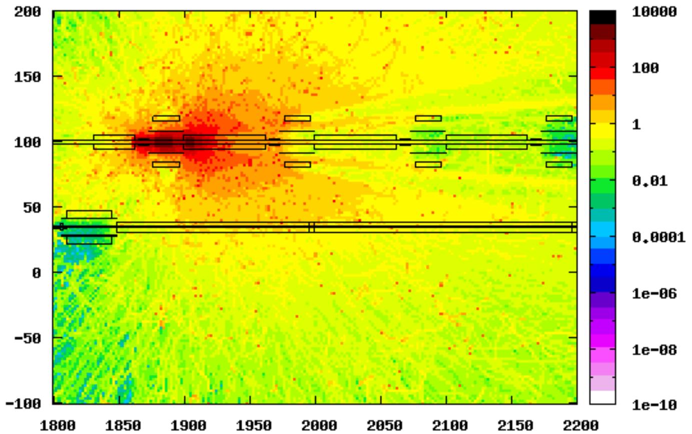


CLIC Tunnel FLUKA Simulations – Results example 5

- ## Failure Mode Losses – Prompt Doses

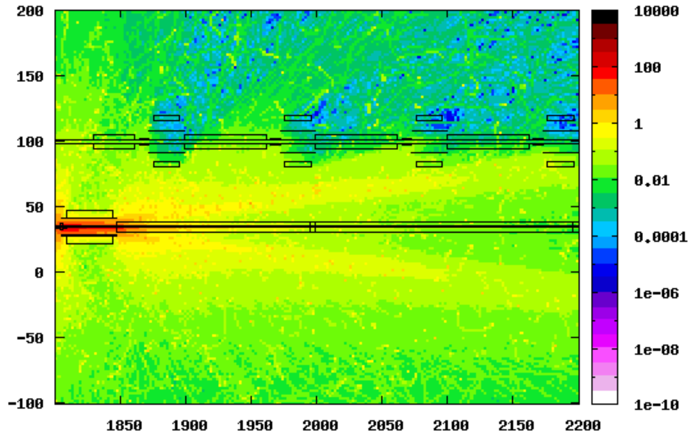
Gy

DB 2.4 GeV



1 bunch train

MB 9 GeV



1 bunch train

"Cross talk" worst for MB side at start of linac

Radiation Levels in the DB Dump Cavern: Considerations

- Dump cavern in early design stage – likely to change
- Dump – no existing design (Alumin. balls in bath? – Jeff lab idea but no study made. Composite Fe/graphite dump – as at CTF3 ?)
- Power to dump ~ 0.3 MW
- Estimate of transverse dilution (to be reworked) B. Jeanerret :

  Central density at dump entrance : $f(0,0)=10^{13}\ e^-/cm^2$

  With round gaussian beam, to start : $f(x,y) = (N_0/2\pi\sigma) \times \exp(-(x^2+y^2)/2/\sigma^2)$

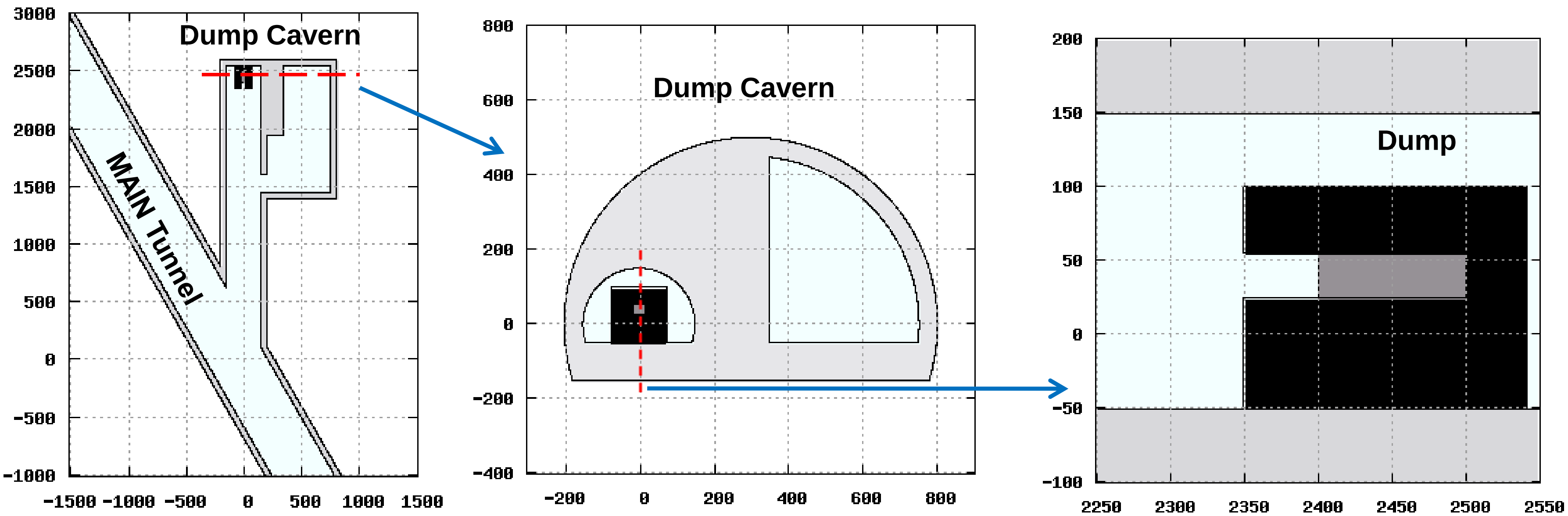
  → $\sigma = N_0/(2\pi\ f(0,0)) = 2.4$ cm

Consequences

- Radiation Protection issues for personnel: Access in shutdown period, doses due to induced Radioactivity. CERN limits - Ambient dose equivalent rates $>100\mu Svh^{-1}$ necessitates detailed optmization of every intervention and strict control times
- Prompt Dose interference with beam monitoring equipment in main tunnel
- Electronics Damage: Probabilistic - SEE's, Cumulative - Lattice displacement, total ionising dose

CLIC DB Dump Cavern Simulations - Representation

- FLUKA 'geometry'



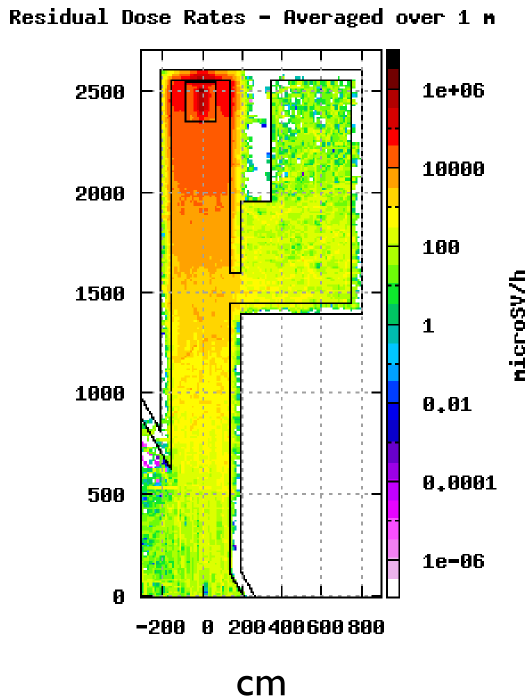
Composite Dump: graphite block surrounded by iron
Graphite Block 30 by 30 by 100 cm. 100cm graphite ~ 5 irradiation lengths

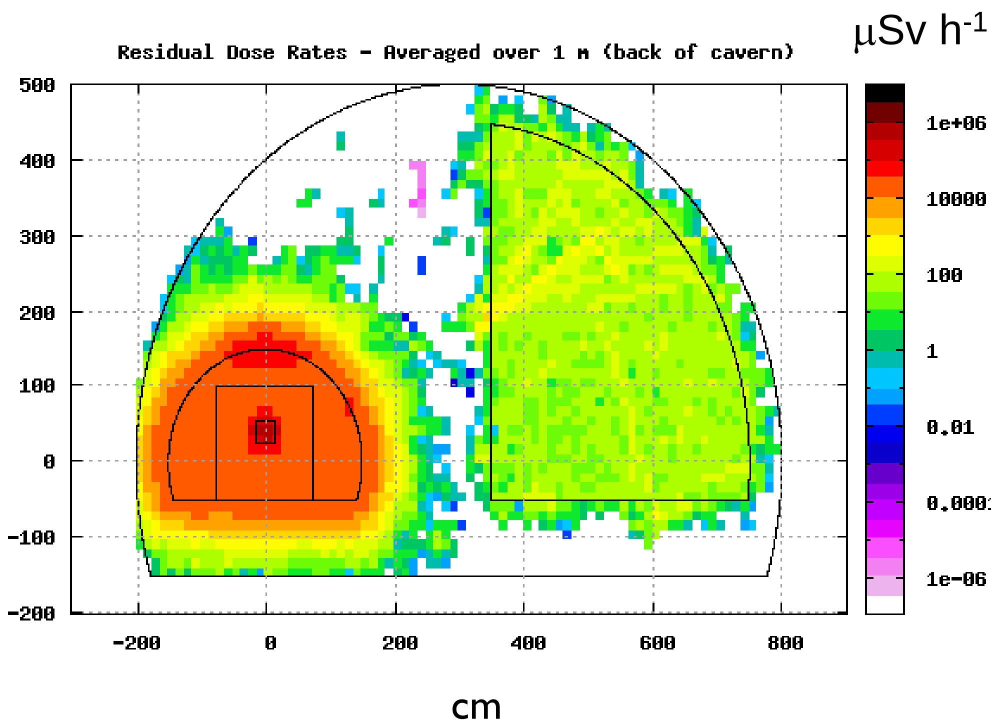
CLIC DB Dump FLUKA Simulations - Settings

- 0.24 GeV electron beam on dump, circular gaussian dist. -sigma 2.4 cm
- Transport thresholds for electrons and positrons & photons, were set at 0.5 MeV prompt and 0.05 MeV decay)
- Physics settings included photonuclear production, muon pair production, the treatment of coalescence and the evaporation of heavy fragments (up to A = 24).
- Estimates: Absorbed Doses (prompt), 1 MeV neutron equiv. , fluence on silicon and >20 MeV Hadron Fluences , enrgy distribution in dump
- Estimates: Residual Dose Rates – included simulation of build up and decay of radiation simulated an irradiation profile of 180 days continuous running followed by 185 days shutdown for 11.5 yrs. Residual dose rates and residual nuclei scored at various cooling times in shutdown periods

CLIC DB Dump FLUKA Simulations – Results e.g. 1

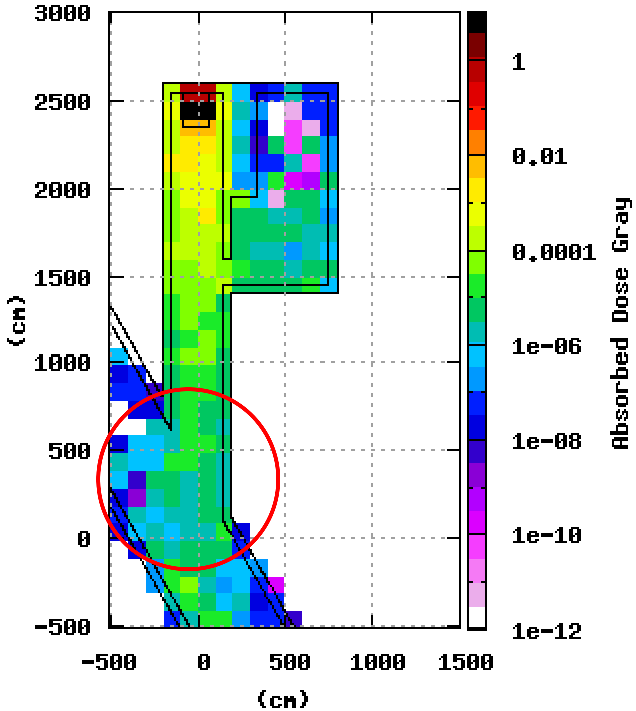
- Residual Ambient Dose Equivalent Rates 180days operation, 1 hour cooling

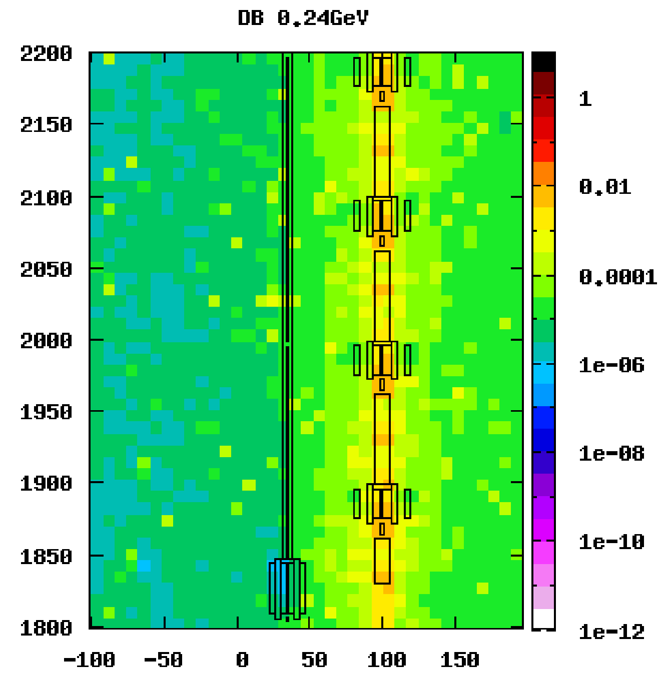




CLIC DB Dump FLUKA Simulations – Results e.g. 2

- Prompt Doses ~ factor 100 difference between DB contributions (assuming max. satndard operational losses along DB 1.25e-6/m)





NORMALISATION: 1 second,1.54E14 per bunch train, 50hz

NORMALISATION: 1 second,1.54E14 per bunch train, 50hz, Losses 1.25 E-6 m^{-1}

Summary

- Access to the main tunnel in shutdown periods would require standard intervention practices and little or no remote handling of gear
- Placement, type (rad hardness) and shielding of electronics will require careful consideration or damage could be limiting factor for permitted beam losses
- A calculation of the maximum absorbed dose in a very fine mesh over the QP coil regions indicates that fractional beam loss per QP required to be below the1 MGy per year limit in the coils is greater than the fractional loss where the machine cannot operate (beam dynamics 0.1%). (i.e. Damage to QP coils unlikely to be a limiting factor for operational losses).
- Distinguishing losses between the two different beam lines will be especially difficult at the beginning of the Main Beam Linac
- Residual Ambient Dose equivalent rates after 1 hr cooling reasonable in 'shielded area' of cavern but not close to dump. The dump cavern should be redesigned for easier / safer (rad protection) access.
- Shielding should be along the dump tunnel to reduce res. dose rates in tunnel and prompt doses interfering with beam monitoring equipment