Increased radiation shielding in Gemini Target Area 3

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Introduction

The Gemini target area bunker was designed with a forward going electron beam dump consisting of 10cm lead backed by 10cm of high density polyethylene (HDPE) to provide a "hard stop" for the forward going electrons (North wall). The 10cm lead beam stop equates to the ~20 radiation lengths typically suggested for an electron beam dump.

During the initial period of operation, the electron energies in Gemini significantly increased and the shot repetition rate also rose towards its original design limits but operating in a "burst mode". As a result, a further 10cm lead was added to the rear of the existing beam dump in 2010 to reduce the leakage doses observed from the facility.

Over the last few years, the leakage dose has again increased (approaching the allowed leakage dose rate of 0.3mSv/year outside the facility). This is primarily due to user groups consistently achieving the high repetition rates at high electron energies (approaching 2GeV) for long periods and the facility commonly operating through the night.

Experiments scheduled this year are expected to further increase the maximum electron energy and so require larger magnetic fields to adequately resolve the energy spectrum. Because of this, it was decided to increase the shielding in the target area to cope with current demand and also to act pre-emptively for future requirements.

Enhancement of existing shielding wall

The existing shield wall is on the North side of the target area with access to the back of it from the services area. Ideally the whole beam dump would have been deconstructed and rebuilt with a thicker lead layer but in practice it was more straightforward simply to add shielding to the back of the wall. It was determined that a further increase of 10cm lead backed with 10cm high density polyethylene (HDPE) is sufficient to reduce the leakage dose to safe levels. A 10cm HDPE layer was also added at the front of the wall not as a safety requirement but rather to reduce backscatter into the room which interferes with diagnostics.

With this modification the shield wall now comprises (front to back):

10cm HDPE; 10cm Pb; 10cm HDPE; 20cm Pb; 10cm HDPE.

The additional HDPE front layer increases the risk of leakage through lateral emission since the material has a much longer radiation length. The position of the electron shower maximum is still maintained within the lead section of the beam dump, calculated through

$$T_{max} = 1.01\ [\ln (E_0 / E_c) - 1] \times X_0$$

where E_0, E_c and X_0 are the particle energy (MeV), critical energy (MeV) and radiation length (cm) respectively.

For the electrons generating a shower within the HDPE, any lateral components will be directed through the remaining HDPE or into the concrete shield depending on the location of the electrons relative to the edge of the dump. In the worst case scenario, the electron beam impacts close to the outer edge of the HDPE and sees minimal lateral shielding from the HDPE itself. In this case all lateral shielding is provided only through the concrete. In all other cases both the HDPE and concrete combine to provide the lateral shielding. The recommended values for lateral shielding is calculated through the Moliere radius:

$$R_m = (E_s / E_c) \times X_0$$

where E_s = 21.2MeV. The recommendation is for 3-5 Moliere radii. In the case of concrete this is calculated to 22cm for 5x Rm. The lateral shielding provided by the existing concrete is therefore more than adequate.

Construction of additional shielding within TA3

The current set of electron acceleration experiments are attempting to drive the electron energies higher, but to also better understand the mechanisms for energy stability. As a result, experiments are requesting to increase the electron energy dispersion of the diagnostic in order to achieve higher energy resolution at high electron energies. With a limited distance within the target area, a higher resolution requirement leads to the need for a higher dispersion magnet which means that the lower energy electron will be displaced off the existing beam dump (vertically). Outside of the existing beam dump is a 1m thick concrete wall which is insufficient to stop the electrons on its own. Based on calculations a minimum depth of concrete for sufficient shielding would be in the order of 2m.

Shielding design

The additional beam dump has been built within the target area in front of the existing concrete. The concrete thus provides back-shielding to attenuate the leakage dose from the new beam dump. The principal design is a replication of the existing design for Gemini – a 10cm thick lead wall. In addition, we added materials of an increasing atomic number at the front side to reduce backscatter into the room. These also increase the effectiveness of the beam dump but to a negligible effect since the thicknesses are relatively low.

Electrons deflected onto this shield wall will interact with 10cm high density polyethylene, followed by 2.5cm aluminium, 2.5cm steel and then the 10cm of lead acting as the primary beam dump. This is all backed by the 1m thick concrete wall. The electron beam dump sits vertically to accommodate our current electron spectrometer design with an overlap of the existing beam dump to ensure no leakage occurs. The beam dump will extend to the maximum height of the inside wall and will cover all trajectories for electrons above the critical electron energy (E_c) for the concrete of 50MeV.

Data collected from previous experiments show a maximum electron beam wander of ±20mRad. At a 4m distance (which is slightly greater than the distance to the shield wall) this is equivalent to a transverse distance of 8cm. To provide a large

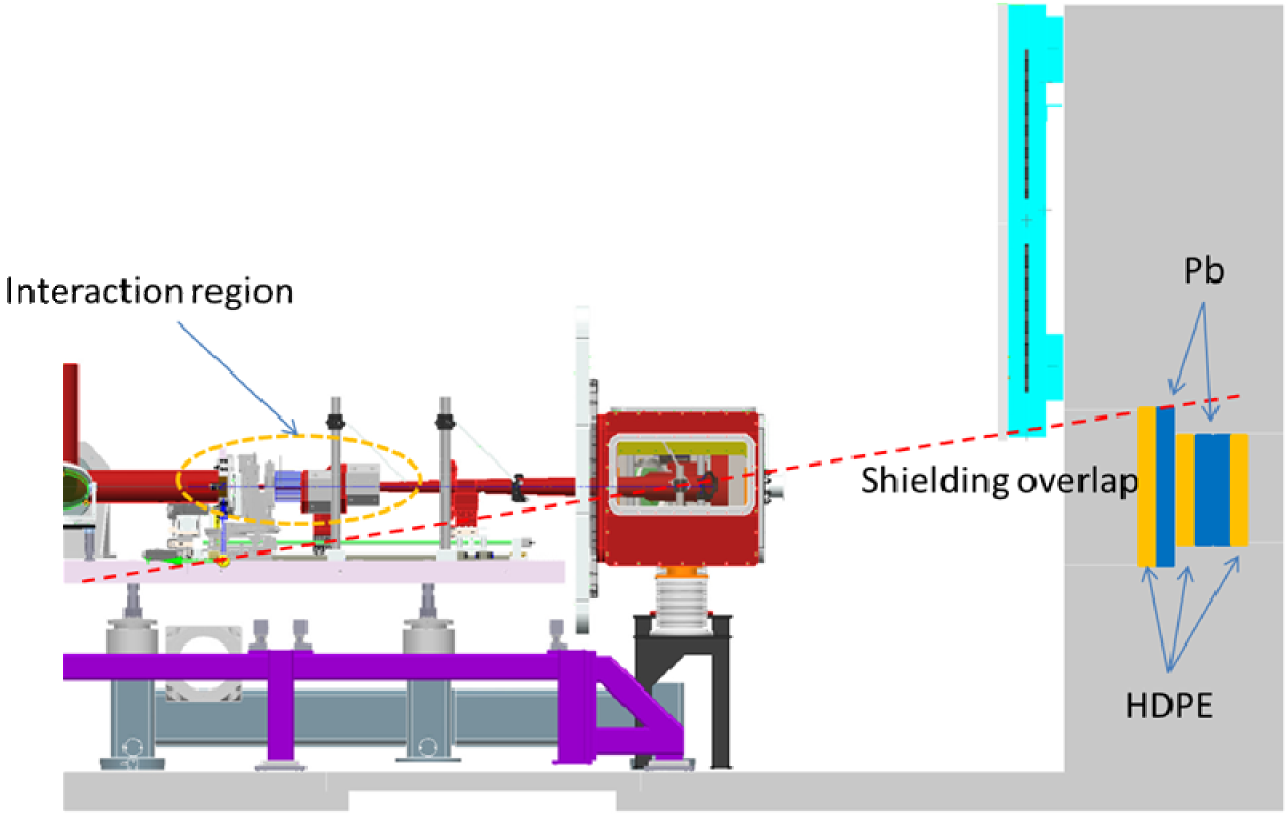

Figure 1. Cross section of the Gemini facility (North end). The modified central shield and new vertical shield can be seen.

safety factor and allow for future experiments to align on a slightly different axis the shield wall has been made 50cm wide. The shield wall is rigidly fixed to the inside wall as a permanent structure.

Shielding calculations

The distance over which 99% of the electron cascade has been used for shower generation is calculated below. For a 1GeV electron, this is equivalent to 10cm of lead. For 4GeV electrons this increases to 11cm of lead.

$$L_{99} = [1.52 \ln (E_0) - 4.1 \ln (E_c) + 17.6] \times X_0$$

where E_0, E_c and X_0 are the particle energy (MeV), critical energy (MeV) and radiation length (cm) respectively.

The typical recommendation for electron beam dumps is 20 radiation lengths, which in the case of lead is 0.56cm. This recommended value is calculated at 11cm. The 10cm beam dump, backed by the concrete to attenuate low energy x-rays and produced neutrons should be adequate as a radiation shield.

To prove the analytical data GEANT4 simulations were run using 16pC 1.2 GeV electrons onto 10cm lead and backed by 1m of Portland concrete. All particles passing through to the rear of the shield wall were summed. The data was scaled to represent a realistic electron beam charge of 80pC and a conservative data fit created. These data were used in conjunction with the ICRP 74 air kerma data to produce a summed (1MeV data bins) dose at the rear of the shield. This dose is dominated by the photon yield and is calculated at 4.97nGy cm^2.

The peak of the electron cascade is calculated at ~2cm into the lead shield. Using this as the source point and a conservative scatter of only 5 degrees, the emitted dose will expand over an area of 70cm^2 at the rear of the concrete wall (the nearest occupied location). Using a radiation weighting factor of 1, the expanded area and factoring for up to 100,000 shots a resultant leakage dose of 7μSv would be generated.

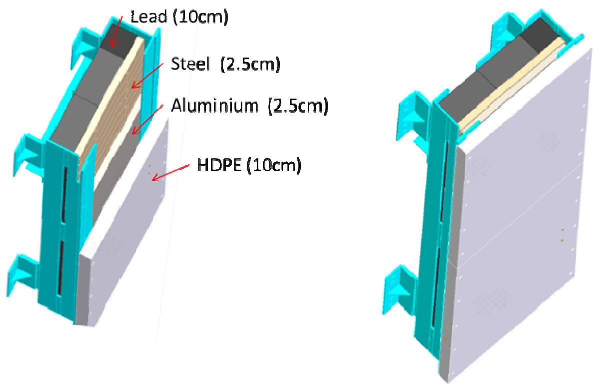

Figure 2. 3D drawings of the new vertical shield. Left – showing the construction drawing leading from the rear most sections forward and Right - the completed frame.

Conclusions

The increase in electron energies and shot rate since the construction of the Gemini facility have necessitated enhancements to the radiation shielding originally installed in the target area. In response to experimental demands we have added extra shielding in the beamline direction and also constructed a beam dump inside the area to safely dump electrons swept vertically by the electron spectrometer.