G4 LUXE Simulations – Optimising for Photon Beam Generation via Bremsstrahlung

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- Kevin has been a Msci student for us at UCL for ~ 1 year

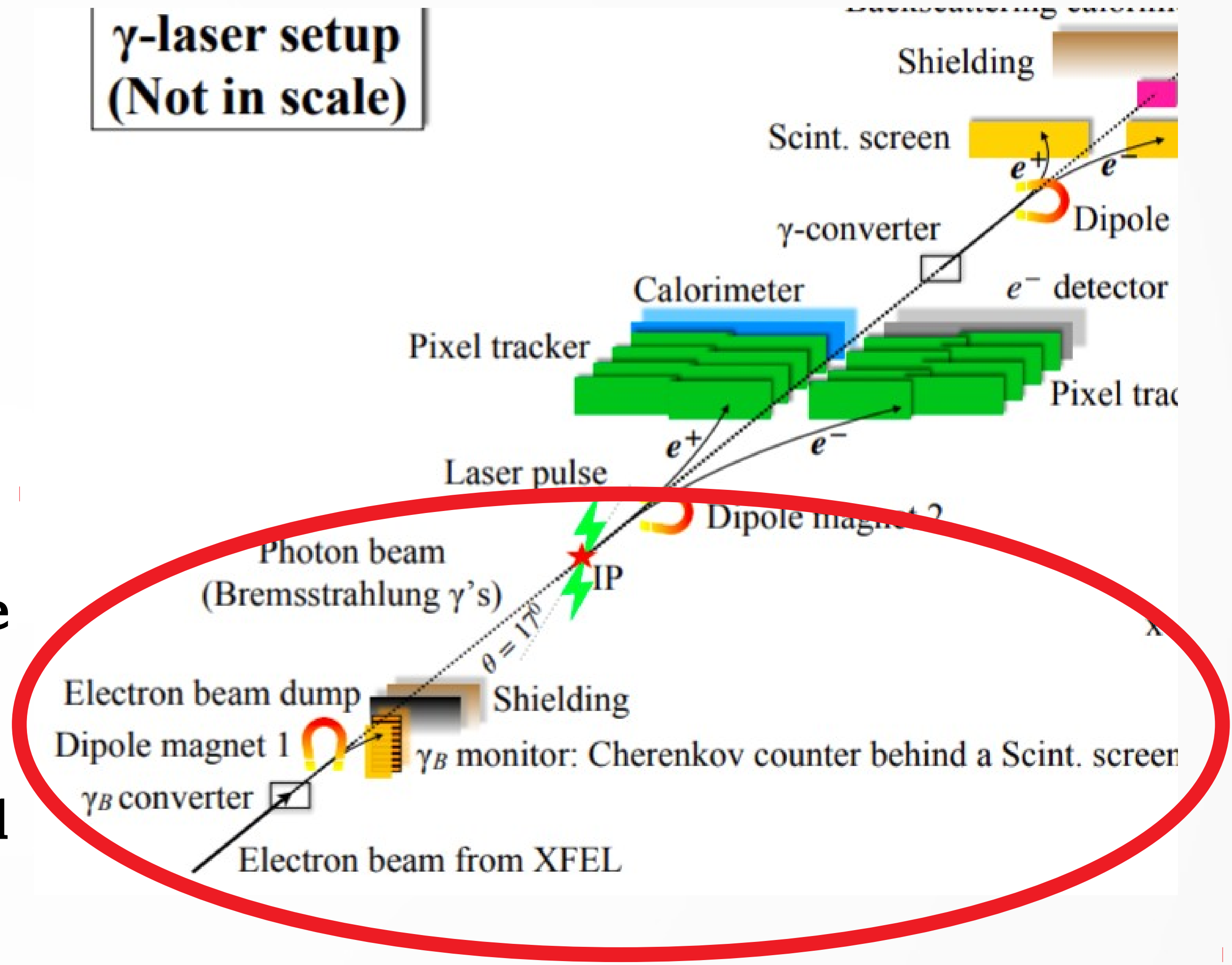
- His work-from-home project was to optimise a <u>vacuum chamber</u> for the electron detectors at the Gamma-generation region of the gamma-LASER mode, and the <u>Bremsstrahlung target</u> at the same region

- All using (versions of) the LUXE G4 lxsim simulation

- We then show these results & should discuss the implementations of each of these

- The objective of the vacuum chamber would be to minimise scattering from the electrons designed to be detected (minimising matter)

- The objective of the target design is to optimise high-energy photon flux in the IP



Brem. Region Vacuum Chamber

- Vacuum chamber was implemented in G4 for the post-target electron detectors in gamma-LASER mode

- Opposite we have relative numbers of electrons detected for various chamber solutions

- As we have seen before, an unaltered beampipe provides much scattering

- Any 'vacuum chamber' design is very helpful

- but the difference between beam windows of varying thickness is unclear with the statistics available

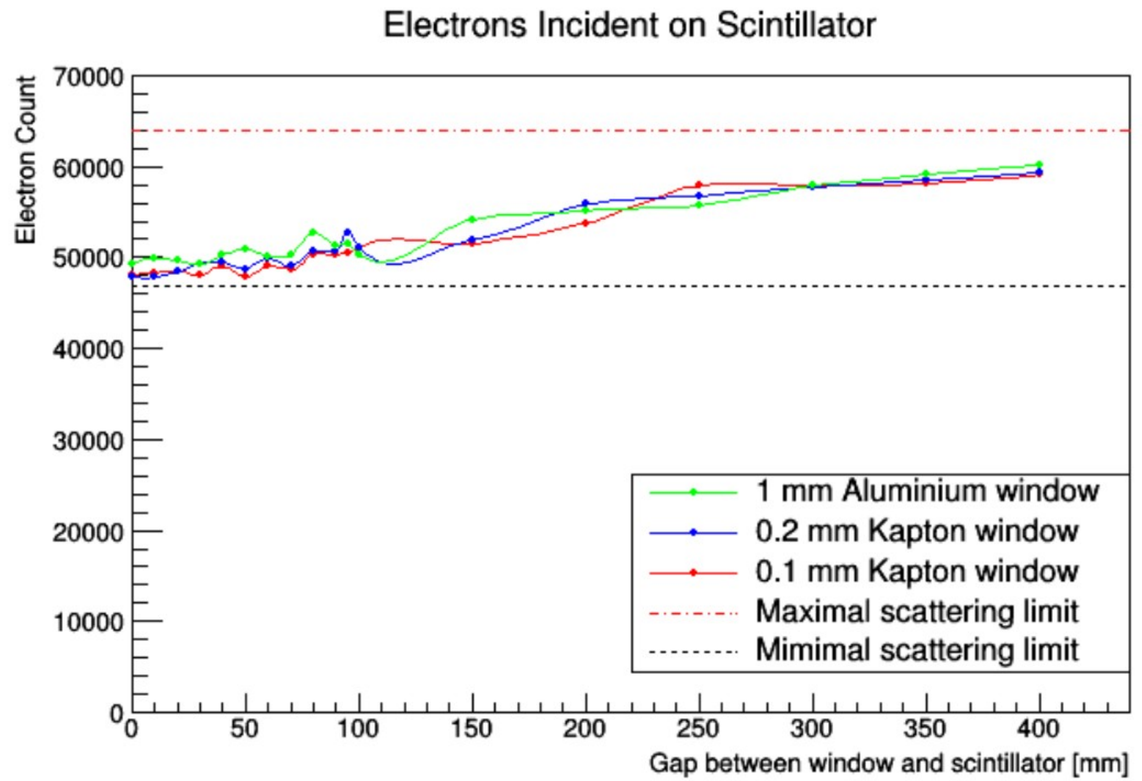
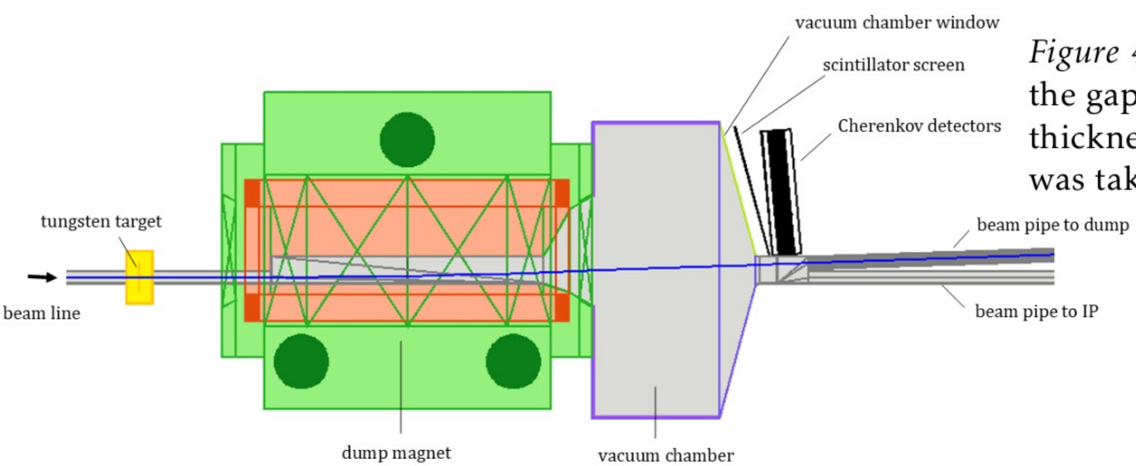


Figure 4.3: Results of simulations of electrons incident on the scintillator screen as a function of the gap between the vacuum chamber window and the screen, for various window materials and thicknesses. In each case, a random sample of 500,000 beam electrons with an energy of 17.5 GeV was taken.



- Opposite we have relative mean energy of electrons detected for various chamber solutions

- Any 'vacuum chamber' design is very helpful

- so the less-critical nature of these detectors may imply we can use a beam window solution with thicker foil i.e. better resistance to failure

- need more engineering input? Or can we move forward with information from e-laser IP chamber?

Brem. Region Vacuum Chamber

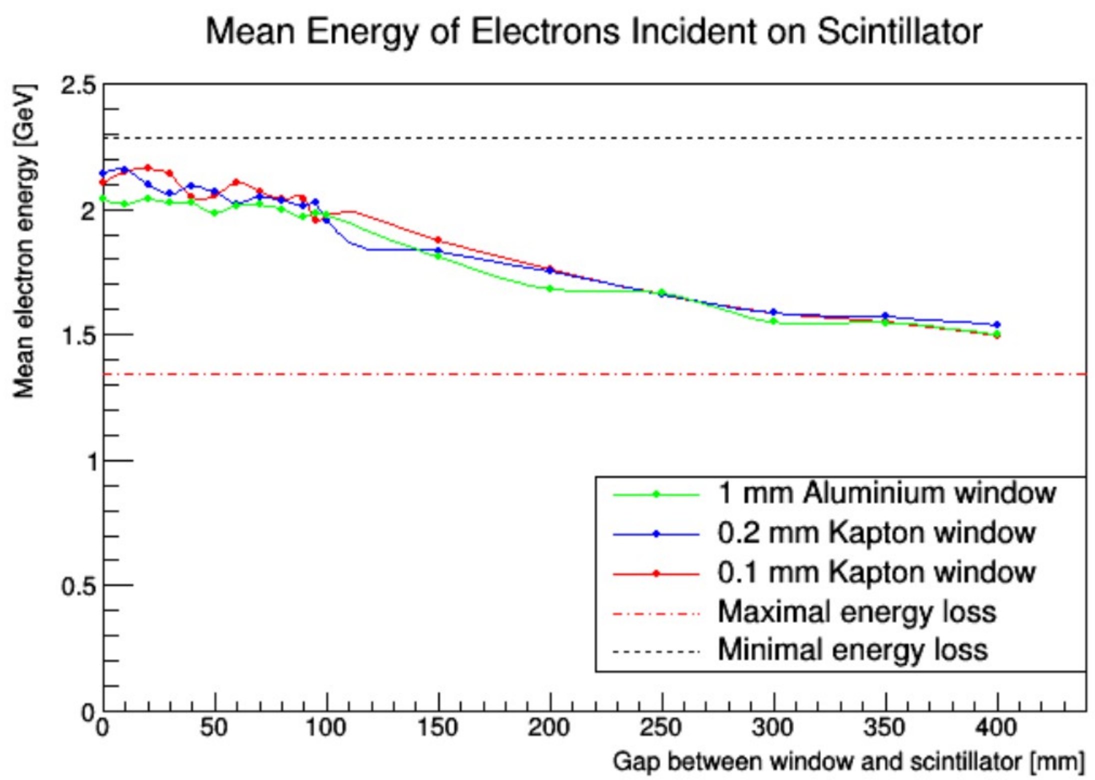
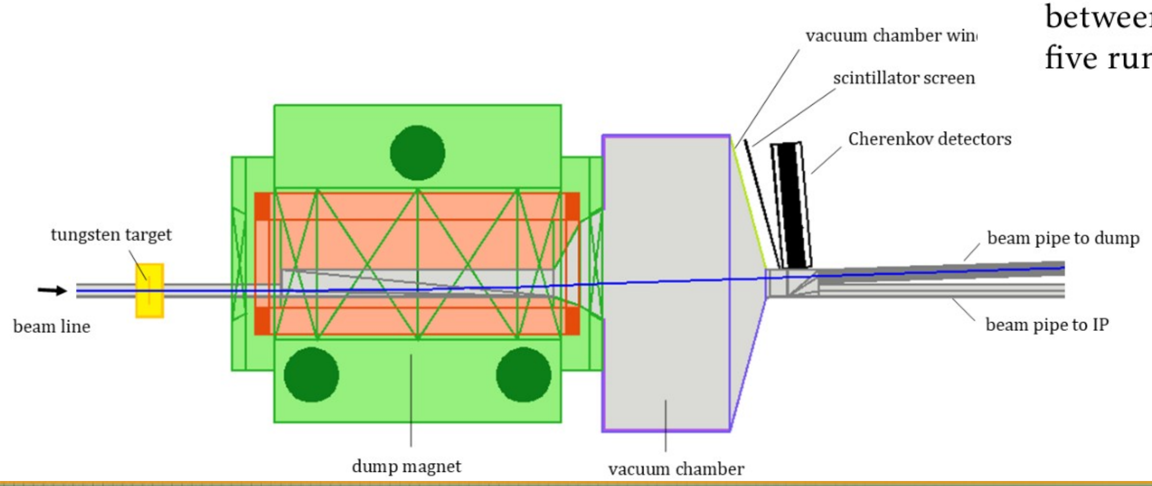


Figure 4.5: The mean energy of electrons incident on the scintillator screen as a function of the gap between the vacuum chamber window and the screen, for all window setups. The mean result of five runs of 100,000 beam electrons with energy 17.5 GeV was taken.



Bremsstrahlung Target

- Bremsstrahlung is used to generate a photon beam, intercepting the e- beam with a thin, heavy metal target

- We saw no reason to change from Tungsten

- Below is a direct comparison to a CDR plot from Sasha

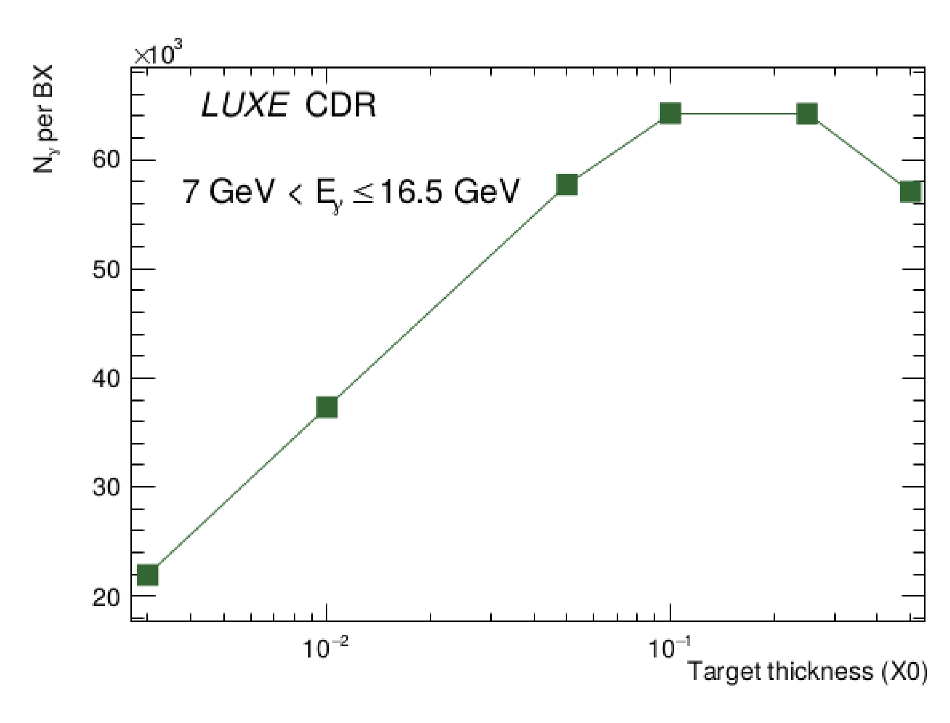
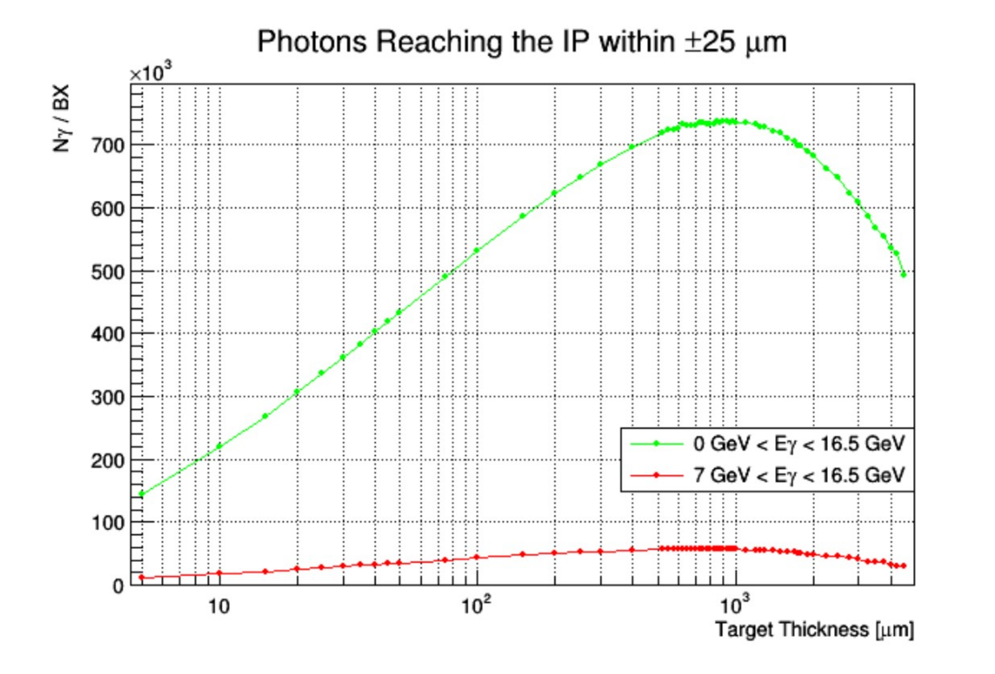


Figure 5.12. Average number of bremsstrahlung photons produced in the energy range 7 GeV $< E_\gamma \leqslant$ 16.5 GeV expected at the LUXE IP as a function of thickness of the tungsten target from GEANT4 simulation of 50 bunches of XFEL.EU electron beam of 16.5 GeV.



Bremsstrahlung Target

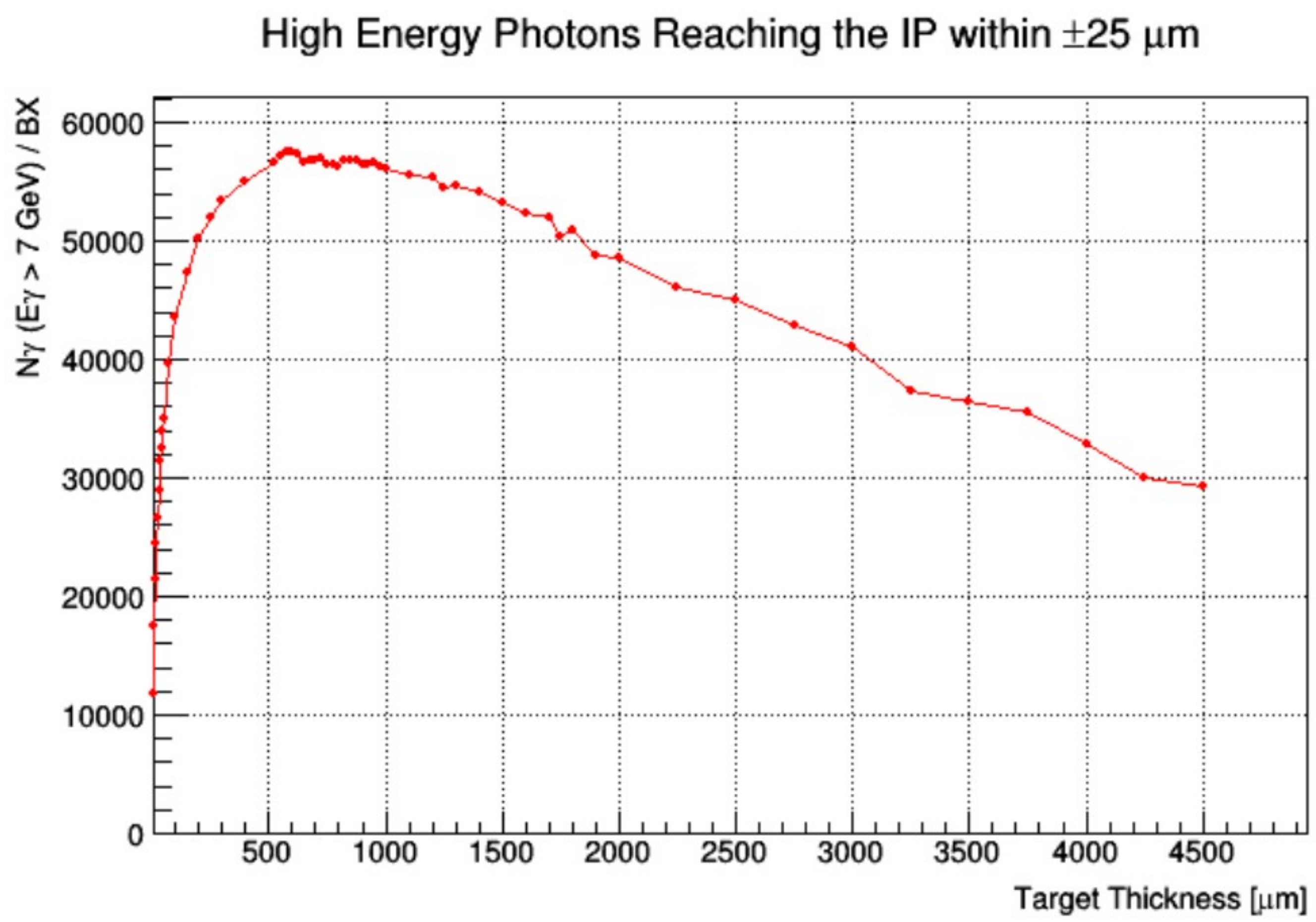


Figure 5.9: A linear plot of the number of high energy photons reaching the IP as a function of target thickness shows a small peak at a thickness 600 μm. The graph shows some statistical fluctuations due to relatively low statistics.

Bremsstrahlung Target

The bremsstrahlung target optimisation study has shown that:

- The maximum number of high energy photons per bunch crossing detected at the IP is about 57,440 per BX, peaking at a thickness $\approx 600\,\mu$m.
- This peak is relatively broad and flat, and thicknesses of between $500\,\mu$m and $1000\,\mu$m have a high energy photon count which falls within 2% of the maximum.
- If the maximum XFEL.EU beam energy can be used (17.5 GeV as opposed to 16.5 GeV), we can see an increase of in the high energy photon yield by a little over 20%.
- Moving the target closer to the IP has a large effect - a shift of a rather conservative 20 - 30 cm can increase the total count by a further 20%.

An optimal setup is thus proposed as an enhancement to the LUXE design. Doing so will have the potential to increase the total number of high energy photons detected within $\pm 25\,\mu$m of the interaction point by a factor of around 2.5, without the need for altering the current conceptual design in any major way. This optimisation is both realistic and achievable. It would be very interesting to see real data from a working prototype as the R&D project develops. The results of the two studies presented in this paper have demonstrated that there is still great potential to enhance the experiment's ability to study an exciting physics regime that is not yet understood or explored.

Bremsstrahlung Target

- So why not change to maximise high-E photon flux?

- Thicker target → more multiple-radiation Brem events → more difficult to measure photon spectrum using electron detectors

- This may be a secondary consideration compared to maximising flux

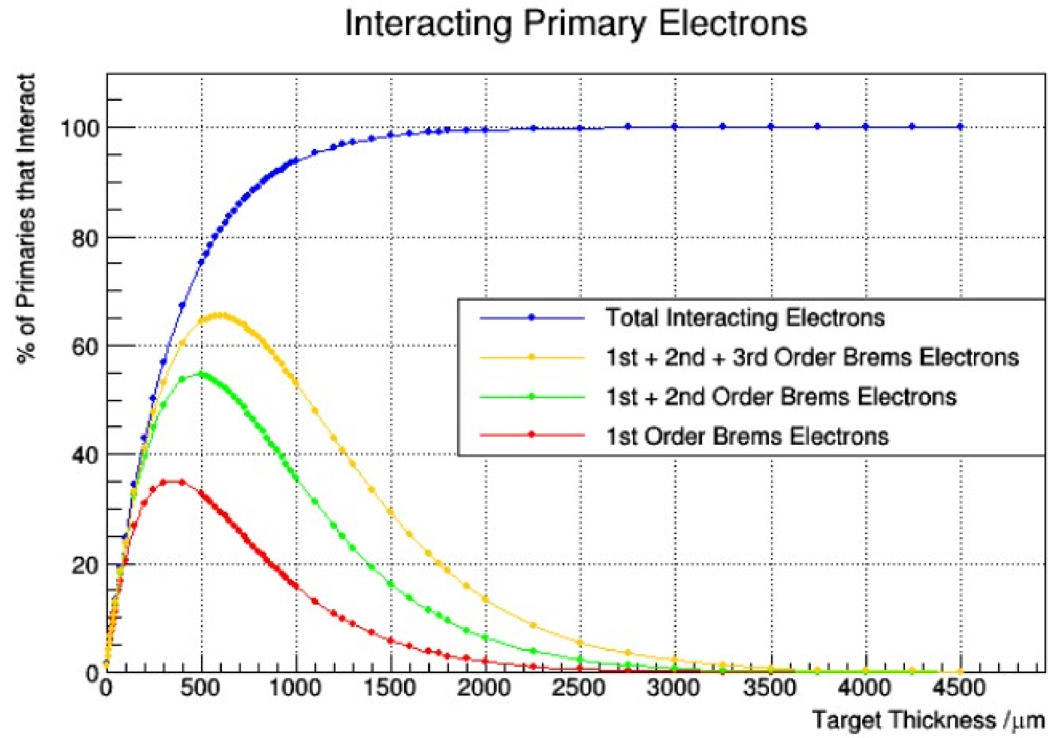


Figure 5.5: Percentage of primary electrons interacting via bremsstrahlung in the target, as a function of the target thickness.

backup

- Vacuum chamber was implemented in G4 for the post-target electron detectors in gamma-LASER mode

- Opposite we have relative numbers of electrons detected for detector coordinate 'x'

- As we have seen before, an unaltered beampipe provides much scattering

- Any 'vacuum chamber' design is very helpful

- but the difference between beam windows of varying thickness is unclear with the statistics available

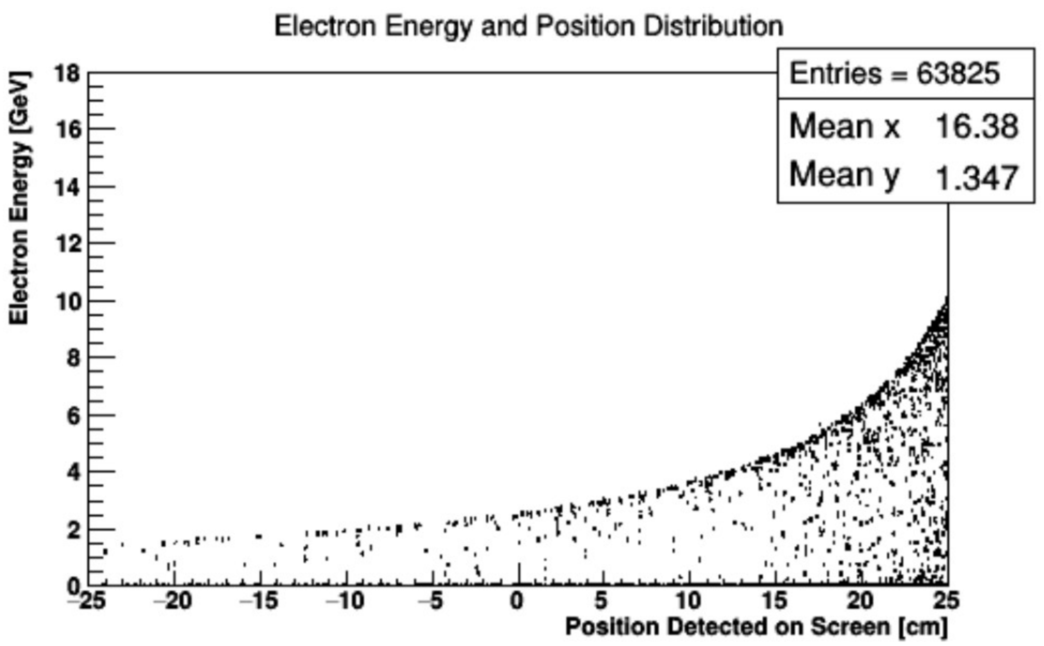
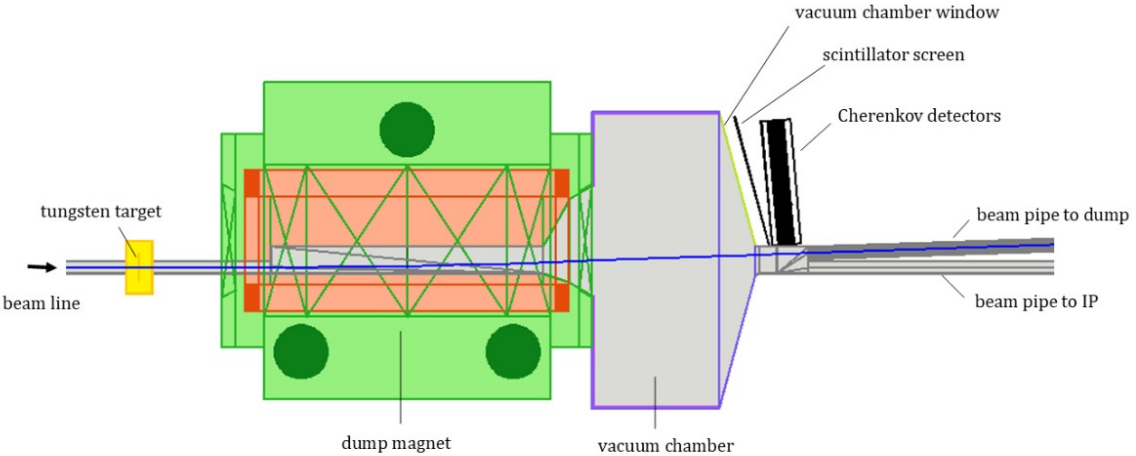


Figure 4.2: Electron energy and spatial distribution on the scintillator. The original setup was used, without a vacuum chamber, and a beam of 100,000 electrons with an energy of 17.5 GeV. Coordinates are local to the centre of the scintillation screen.



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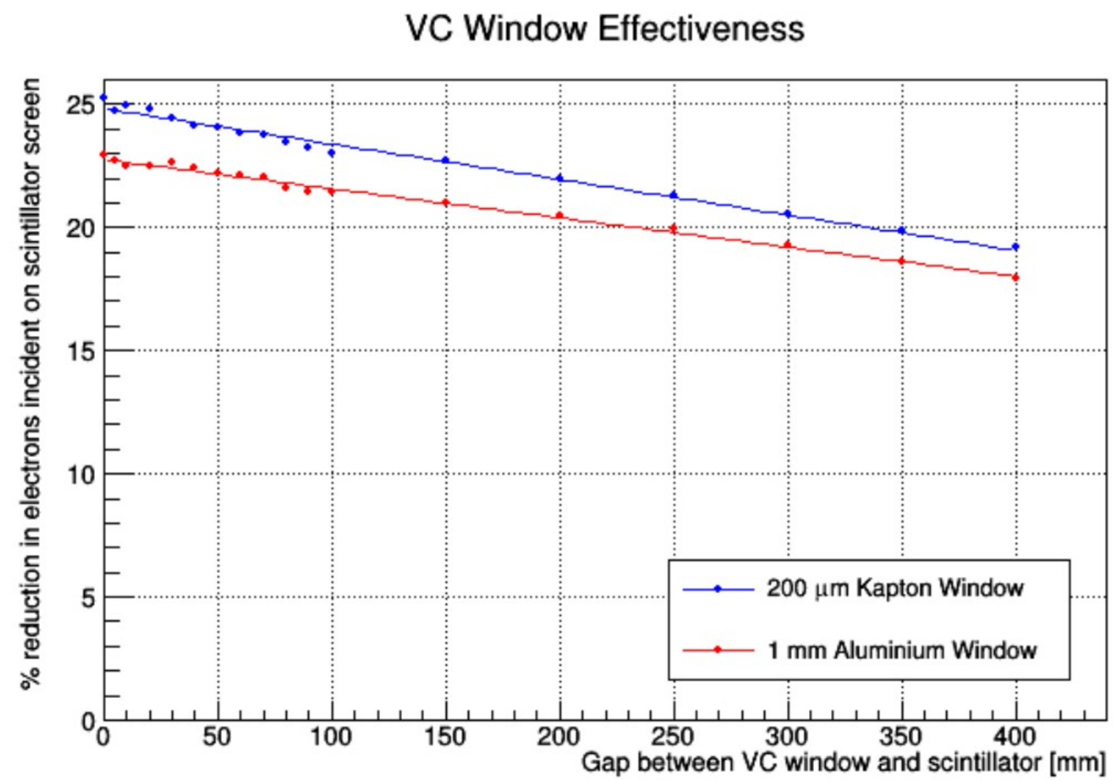
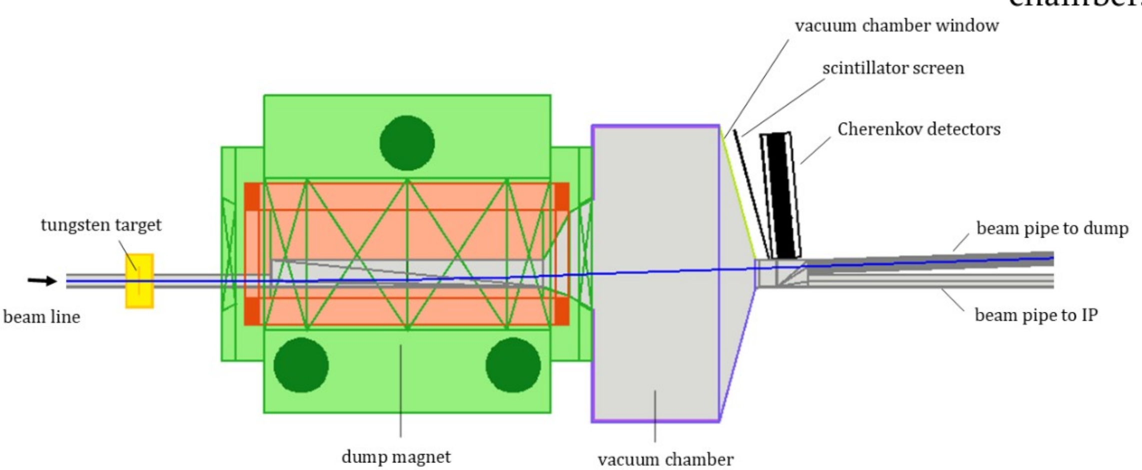


Figure 4.4: The effectiveness of the vacuum chamber, defined as the percentage decrease in the number of electrons detected in the scintillator, as compared to the original setup with no vacuum chamber.



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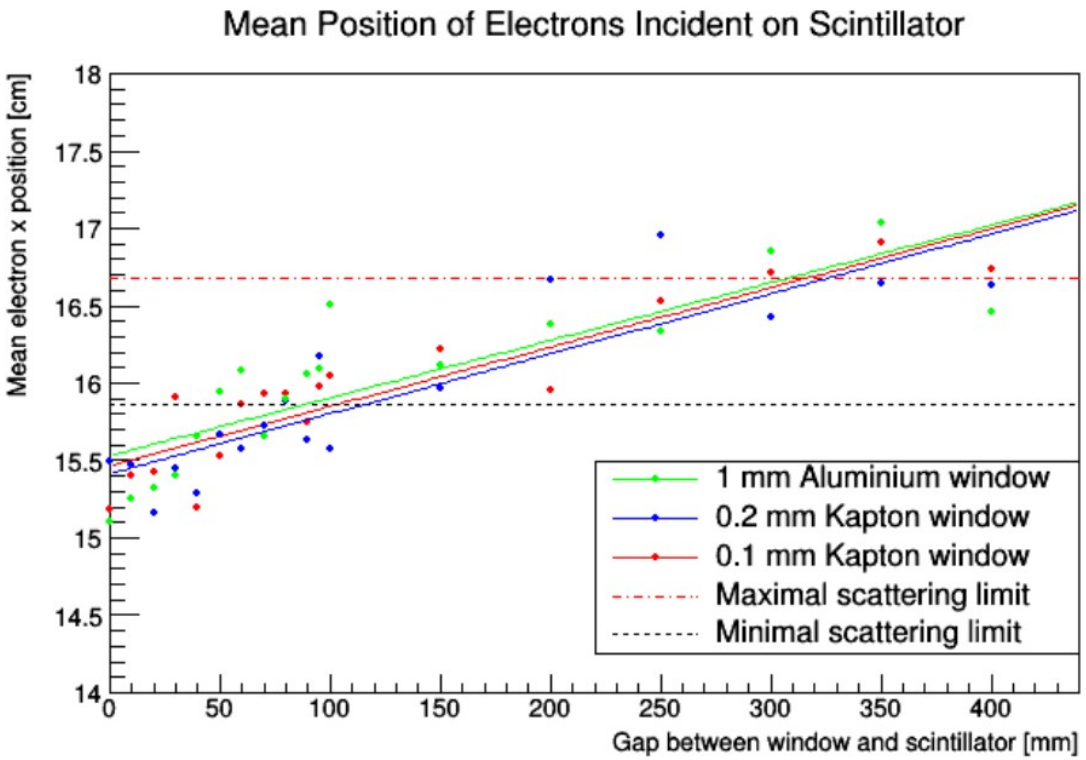
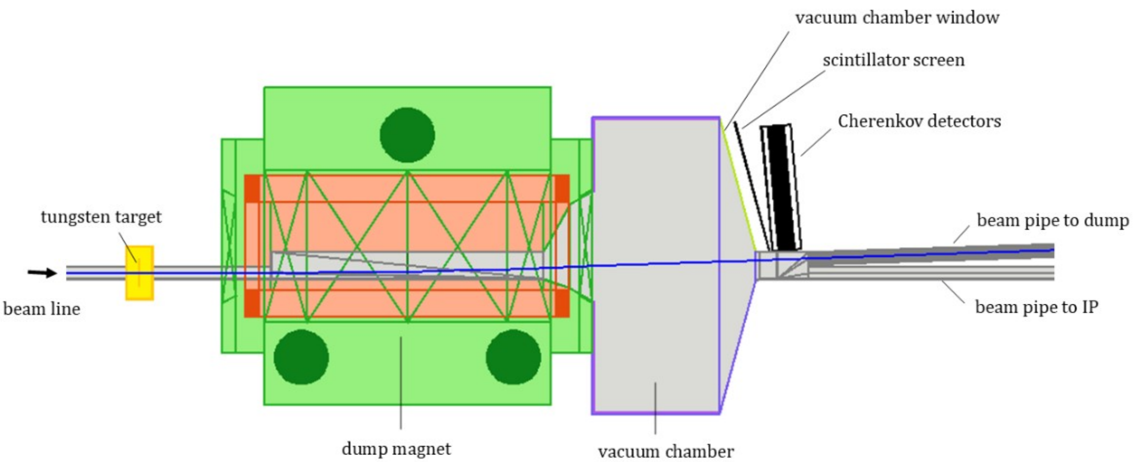


Figure 4.6: The mean position of the electrons incident on the scintillator screen. Coordinates are given local to the centre of the screen.



Bremsstrahlung Region Vacuum Chamber

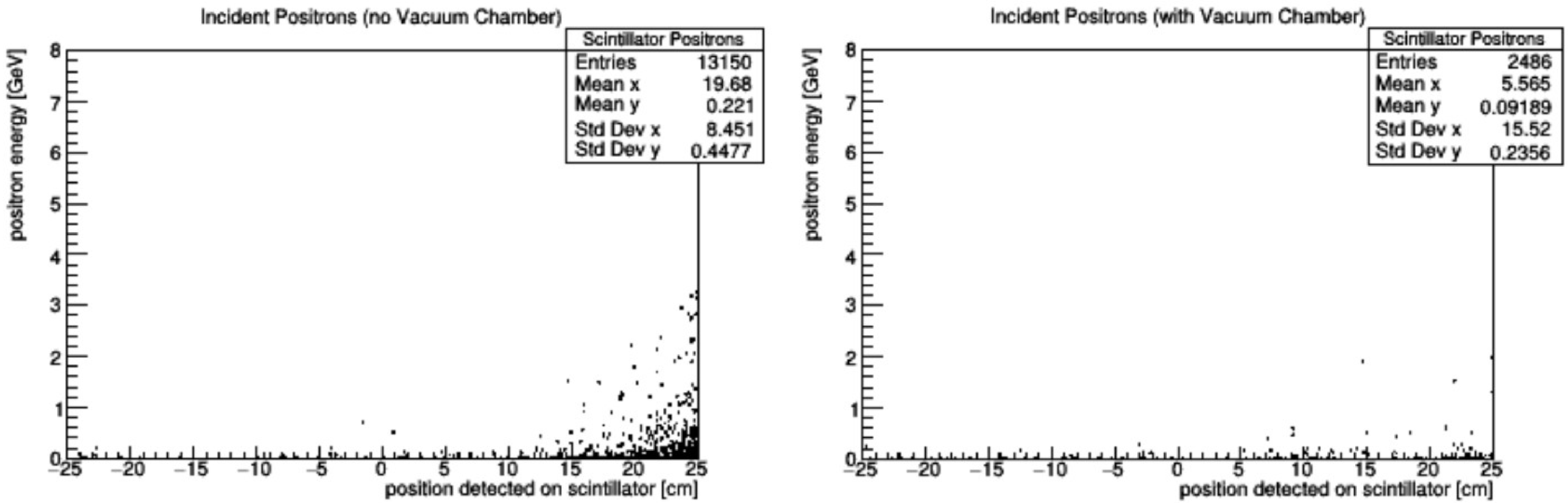


Figure 4.7: Positrons detected in the scintillator in simulations of a bunch of half a million 17.5 GeV electrons, for the original setup with no vacuum chamber (left) and with a 200 μm Kapton window vacuum chamber (right) with no gap between the window and the scintillator.

Bremsstrahlung Target

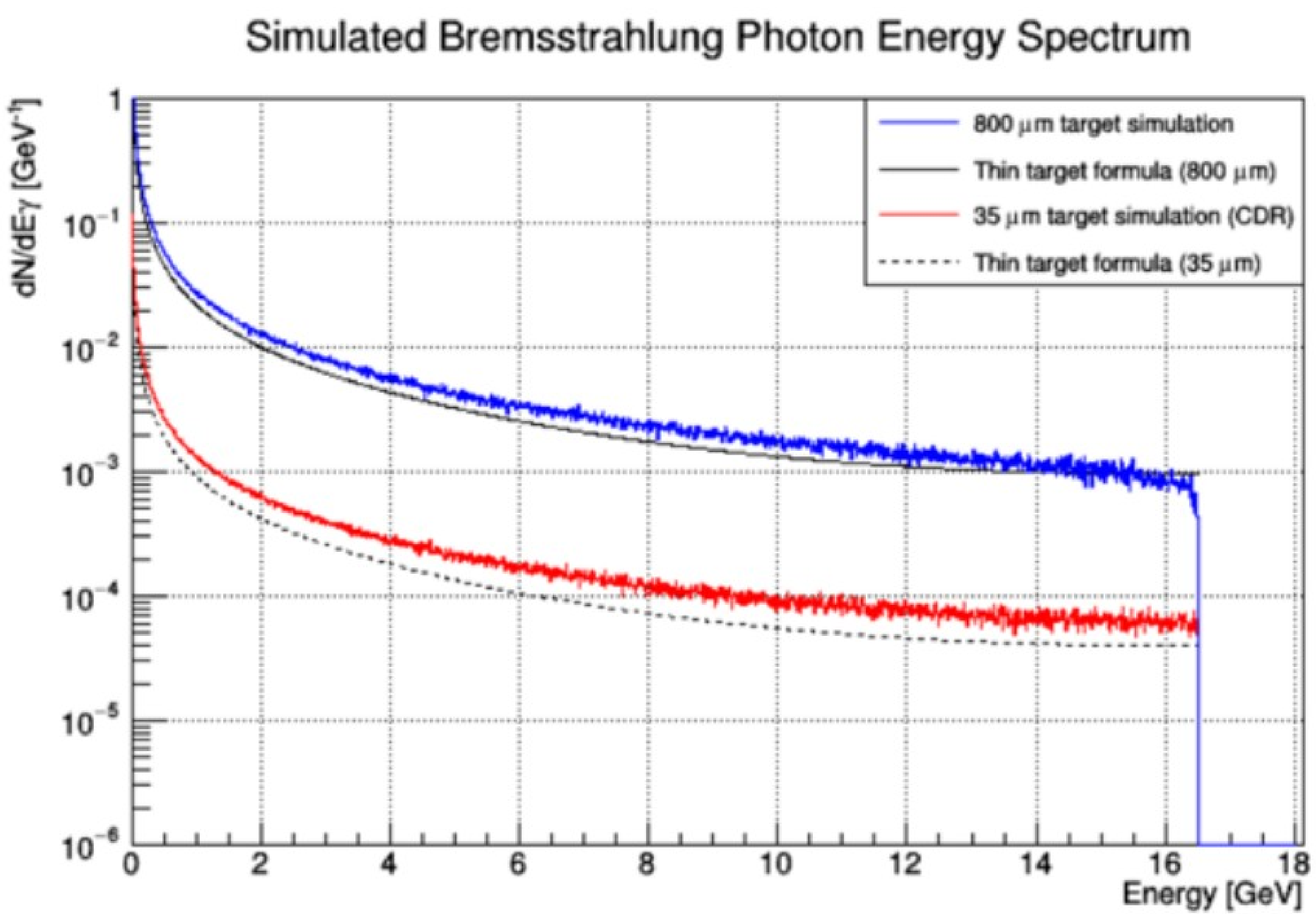


Figure 5.3: The photon energy spectrum for a target width of 800 μm shows that there is a slight falling off in the production of the very highest energy photons.

Bremsstrahlung Target

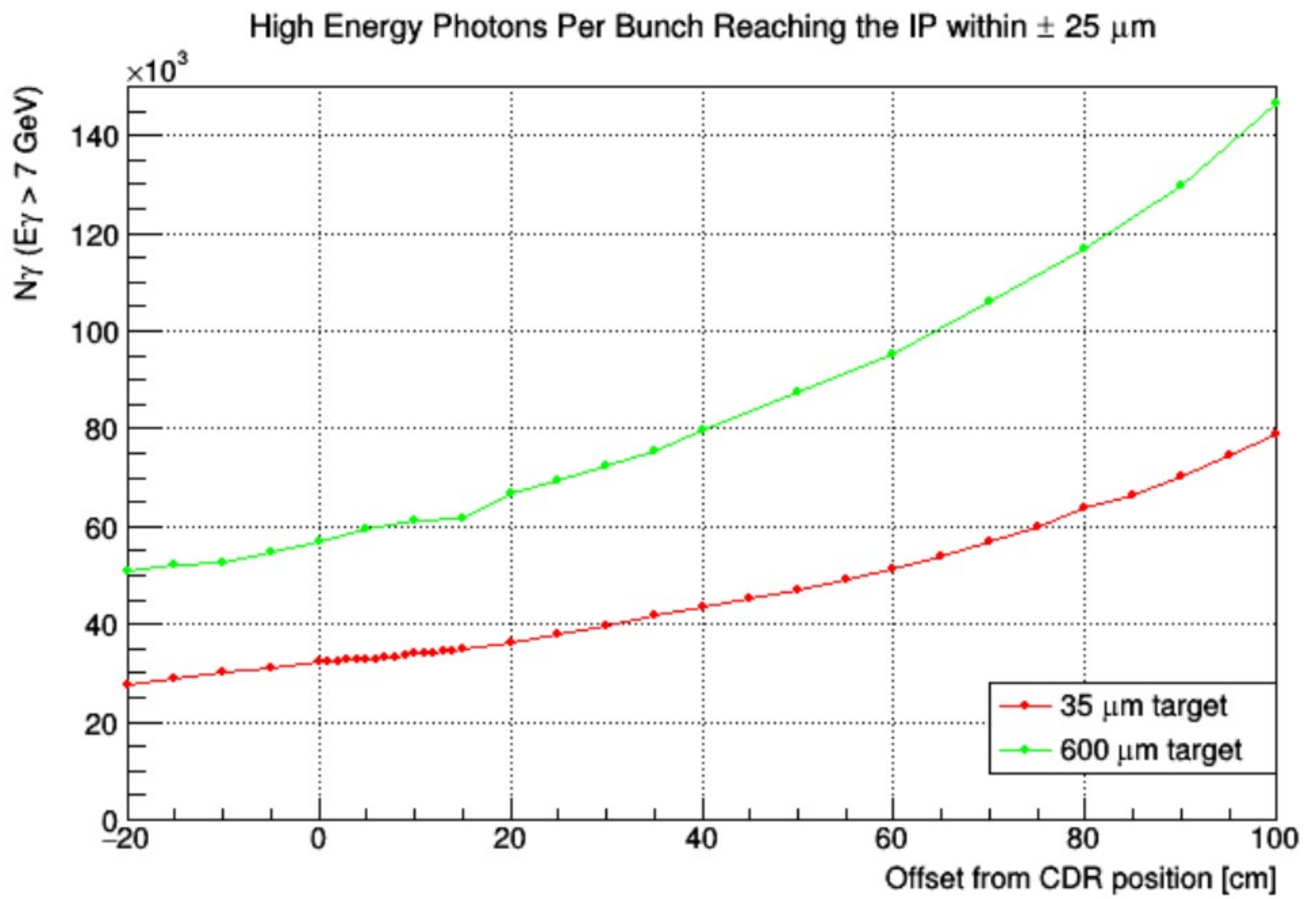
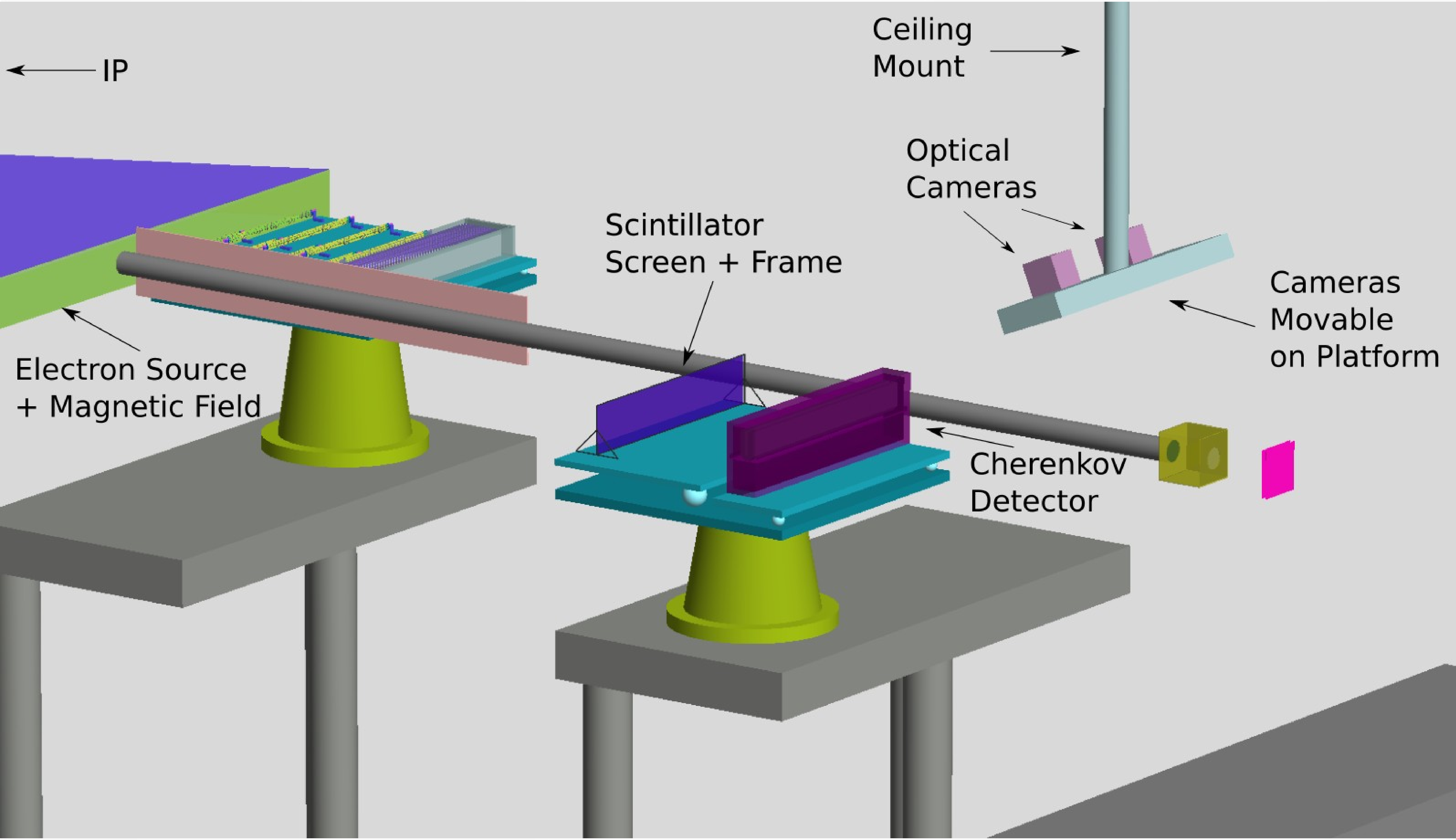


Figure 5.13: The effect of moving the bremsstrahlung target from its position 7.5 m from the IP, as given in the *CDR*. Figures along the x–-axis are given as an offset from the original position (0 cm).


IP
Ceiling Mount
Optical Cameras
Scintillator Screen + Frame
Cameras Movable on Platform
Electron Source + Magnetic Field
Cherenkov Detector