Short Report: Study of the Background Produced in the Air Surrounding Liquid Hydrogen Target using FLUKA

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Abstract

This report presents the results from the study of the background in the detectors produced in the case of air surrounding the liquid hydrogen target. The contribution to the counting rates in this case is of the order of 10 % or more. The results are based on FLUKA simulation.

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The scope of this report is to compare electron rates between two cases: the liquid hydrogen target (LH2) being surrounded by air and being surrounded by vacuum. The results are obtained using FLUKA [FERRARI 2005, BATTISTONI 2007], a fully integrated particle physics Monte Carlo simulation package with many applications in high energy experimental physics and engineering, shielding, detectors and telescopes design, cosmic ray studies, dosimetry, medical physics and radiobiology. The physical mechanisms implemented in today's simulation software are very accurate and the differences between the simulated and measured results are in the most cases negligible.

The inputs for the simulation were obtained from Lorenzo Zana depository [ZANA 2022] but were slightly modified.

Figure 1. shows the side view of the Moller experiment set-up in Hall A as defined in the input file from Lorenzo Zana depository [ZANA 2022]. Figure 2. shows detailed geometry around the liquid hydrogen target. Lastly, Figure 3. shows the relative position of the detector plane next to the beam line 2650 cm downstream from the center of the target.

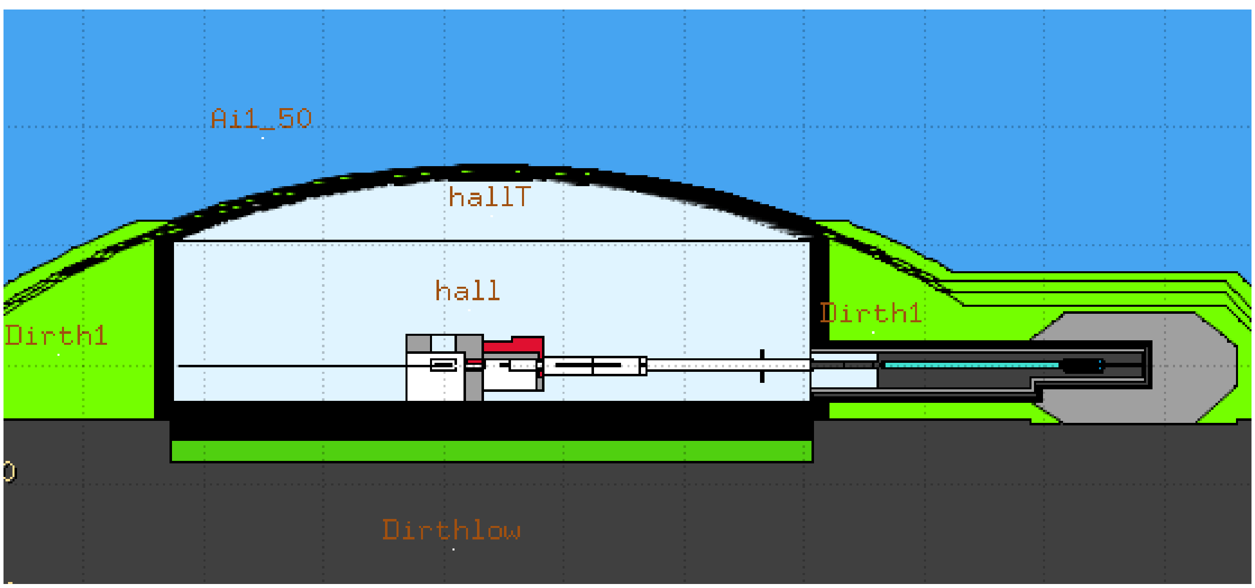

Figure 1. Side view of the Moller experiment set-up in Hall A as defined by the input file from Lorenzo Zana depository [ZANA 2022].

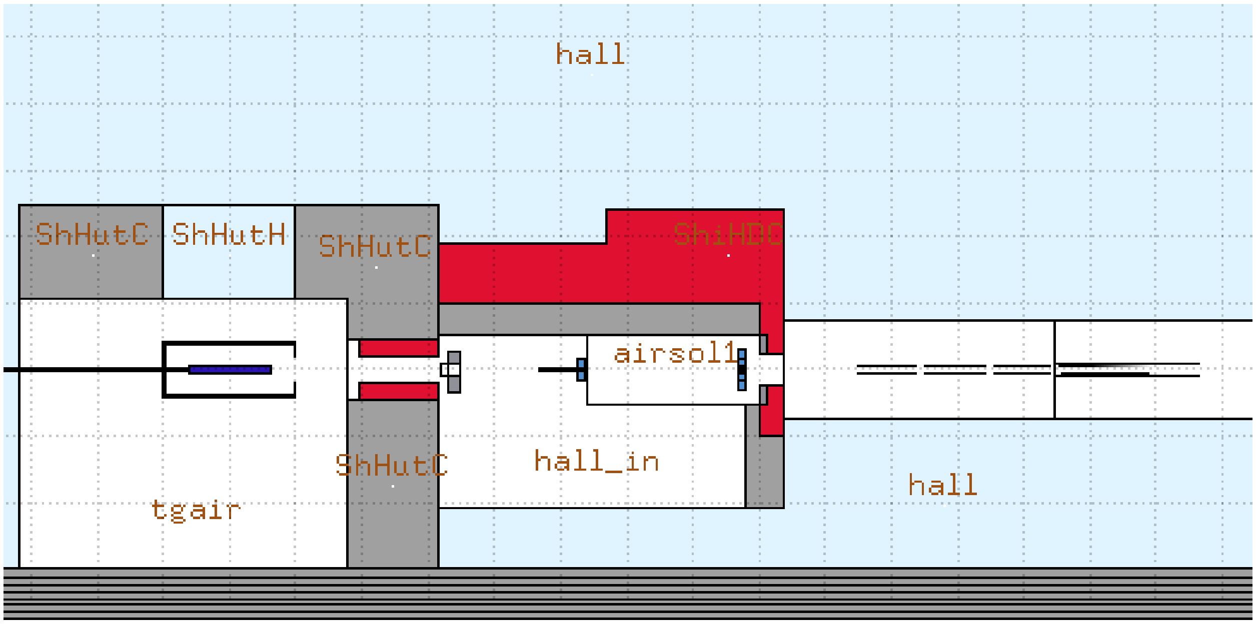

Figure 2. Side view of the Moller experiment set-up around in the liquid hydrogen target as defined by the input file from Lorenzo Zana depository [ZANA 2022].

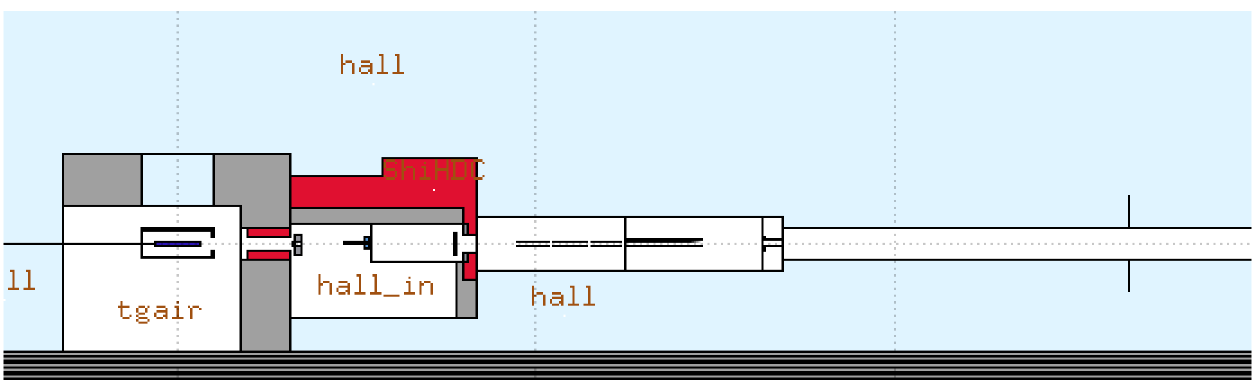

Figure 3. Side view of the Moller experiment as defined by the input file from Lorenzo Zana depository [ZANA 2022], with the detector plane next to the beam line at the position of 2650 cm from the center of the target.

The overall simulation is straightforward. It consists of propagating 11 GeV electron beam through 125 cm long liquid hydrogen target with the inclusion of all possible reactions as defined in FLUKA and counting scattered electrons at the position of the detector plane. Two cases were studied under the same condition. In one case the material assigned to the volumes *tgair*, *hall_in*, and *airsol1* shown in Figure 2. was *vacuum*, and in the other case *air*. Radial distributions of the electrons were recorded at the detector plane. All the dimensions were taken from MOLLER Technical Design Report [TDR 2024]. The magnetic field was taken from Lorenzo Zana depository [ZANA 2022]. While the description of the magnetic field will be improved in future, for the purpose of this study small uncertainty in the description of the magnetic field is not very important if the same field is applied in both cases. The expected radial distribution of the electrons at the detector plane is shown in Figure 4.

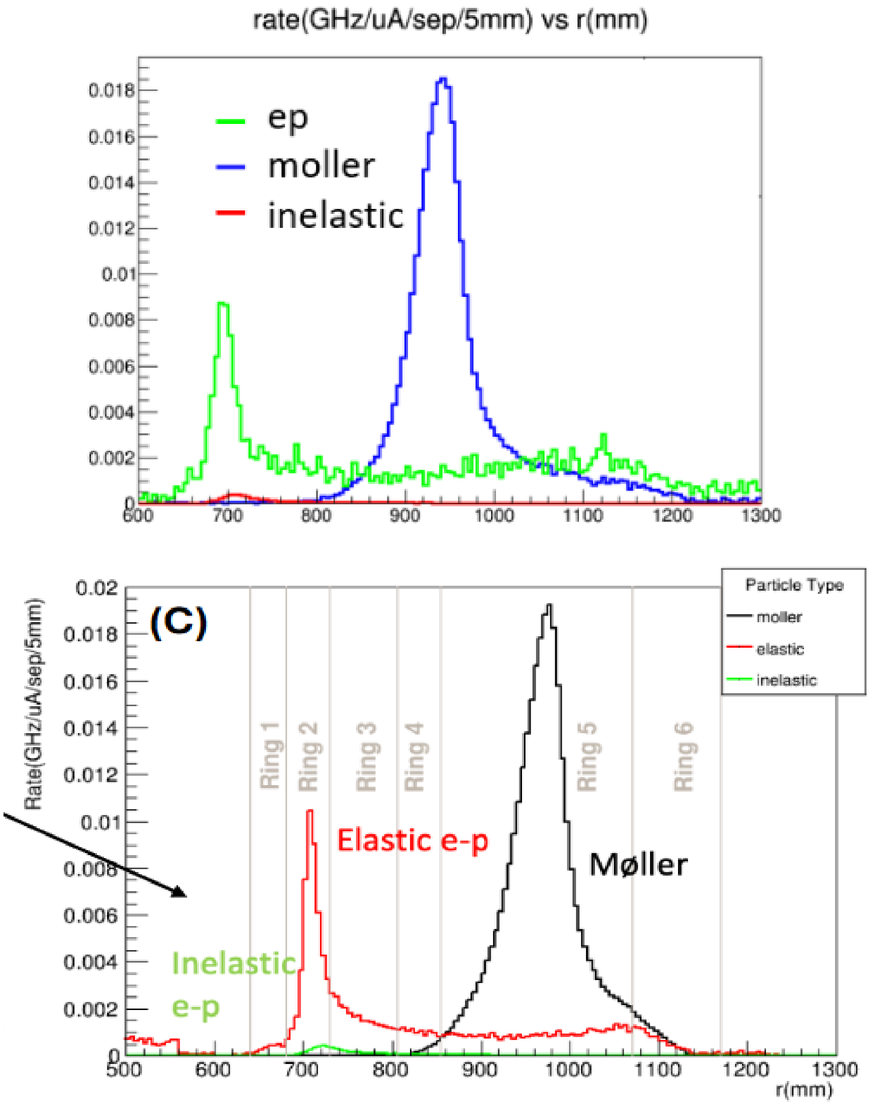

Figure 4. Radial distribution of the electrons at the detector plane **taken from the Technical Design Report (top)** ***[TDR 2024], and from the preliminary poster by Sayak Chatterjee (bottom) [Sayak 2024]. "Rings" represent the names of the detectors occupying particular radial position.***

Figure 5 shows the radial distribution of the electrons at the detector plane obtained by FLUKA in the case when the material assigned to the volumes tgair, hall_in, and airsol1 was vacuum. The goal of this report is to compare the electron rates between the case when the liquid hydrogen target is surrounded by vacuum and the case when it is surrounded by air. Figure 6 overlays the rates for the two cases. Figure 7 shows the difference in total rates for the beam current of 65 μA on a scale appropriate to compare integrated rates.

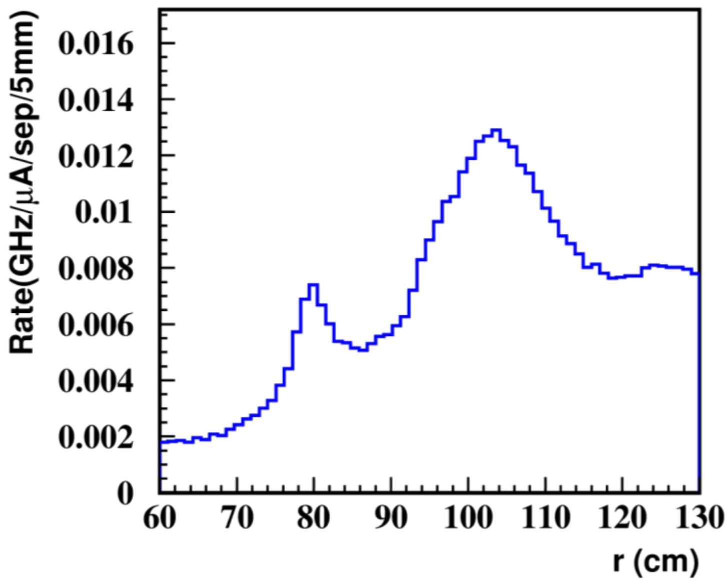

Figure 5. Radial distribution of the electrons at the detector plane generated by FLUKA in the same scale as Figure 4. The material assigned to the volumes tgair, hall_in, and airsol1 was vacuum.

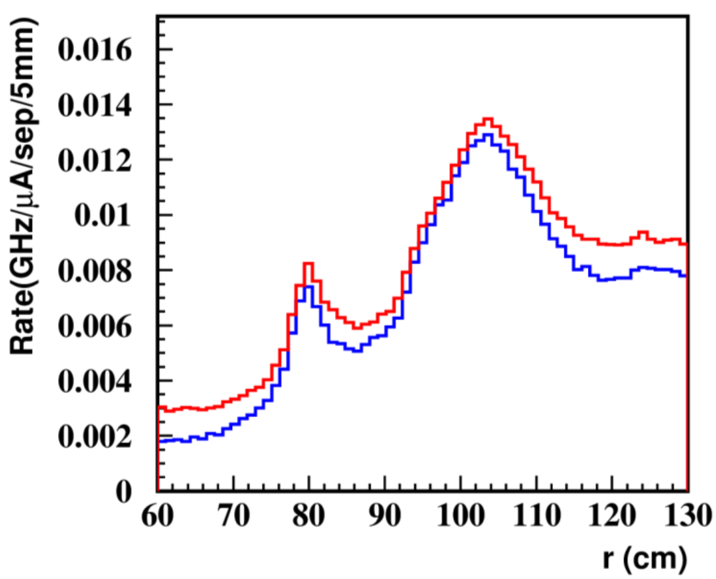

Figure 6. Overlay of the radial distributions of electrons at the detector plane generated by FLUKA in the same scale as Figures 4 and 5. The top (red) curve is for the air assigned to the volumes tgair, hall_in and airsol1, and the lower (blue) curve for the vacuum.

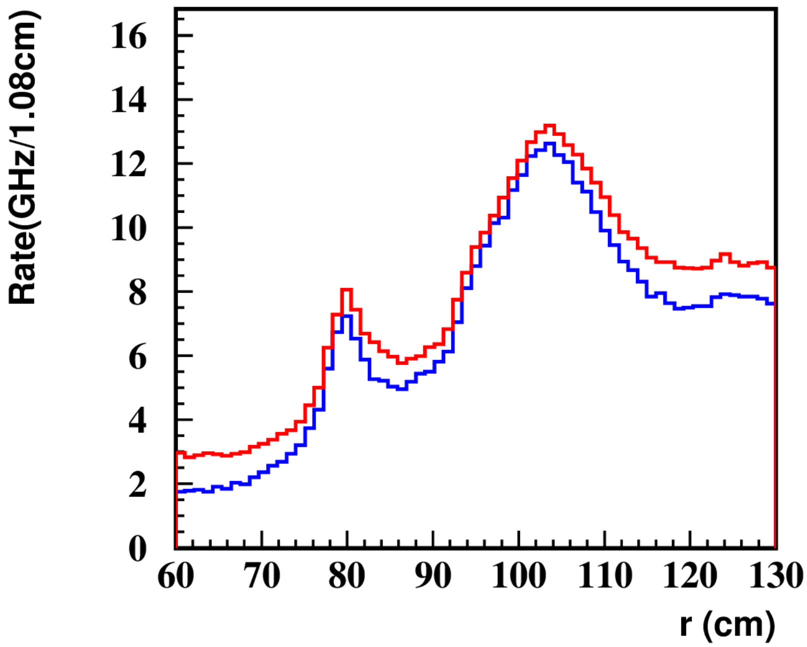

Figure 7. Overlay of the radial distributions of electrons at the detector plane generated by FLUKA in the absolute rate scale. The top (red) curve is for the air assigned to the volumes tgair, hall_in, and airsol1 and the lower (blue) curve for the vacuum. The beam current was 65 μA.

The rates obtained integrating the differential rates shown in Figure 7 are shown in Table 1.

First, from the results shown in Table 1 one concludes that the contribution of the air to the counting rate is significant, of the order of 10 % and more. This information is not part of the estimation of rates shown in Figure 4 and is helpful if one needs to justify surrounding the liquid hydrogen target by vacuum. So, this increase in background rate is a solvable problem.

Second, a more significant problem is the difference in the total counting rates easily observed if one compares the rates shown in Figure 4 with the rates shown in Figure 5. Figure 5 shows a significant background absent in Figure 4. Since in this case the target is surrounded by vacuum the background shown can only be produced in the target itself.

Total rate for the Moller scattering is estimated to be 134 GHz [TDR 2024]. (Our estimate is 150 GHz. Actually, if one takes the luminosity from the TDR report of $2.4 \cdot 10^{39}$ cm^{-2} sec^{-1} and the cross section of ~60 μbarn the total rate in Table 1 in TDR should be 144 GHz.) The total rate for the Moller scattering, detected by the Ring 5 detector, shown in Table 1, is 224 GHz for the case of vacuum. This is an increase between 50 and 67 % depending on what estimated Moller rate we take as a correct one. This increase in the rate can only be attributed to the secondary scattering inside the liquid hydrogen and will be studied in the next report.

Rates							
	Total (all Rings: 72-124 cm)	eP (Ring 2: 75-82 cm)	eP at maximum	ee (Ring 5: 93-114 cm)	ee at maximum	Backgrnd (60 -70 cm)	Backgrnd (120 -130 cm)
Air	455 GHz	52.9 GHz	8.6 GHz	238 GHz	14.2 GHz	29 GHz	95 GHz
Vacuum	412 GHz	46.6 GHz	7.2 GHz	224 GHz	12.6 GHz	18 GHz	83 GHz
Difference	43 GHz	6.3 GHz	1.4 GHz	14 GHz	1.6 GHz	11 GHz	12 GHz
Air Contribution	10.5 %	13.5 %	19 %	6.3 %	13 %	61 %	14.5 %

Table 1. Integrated electron rates when the liquid hydrogen target is surrounded by vacuum and when it is surrounded by air for different radial positions. The dimensions of the Ring detectors did not change, but positions were shifted according to the shift of electron peaks due to the difference in the magnetic fields.

Conclusion

We have presented the results from the study of the background in the detectors produced by the air surrounding the target. While the details can be found in Table 1, in the summary the contribution of air to the counting rate is of the order of 10 % or more. We also mentioned the contribution of the secondary scatterings in the liquid hydrogen target to the counting rate of the order of 50 to 70 %. While this result is here only mentioned, this contribution will be studied in more details in the next report.

The results are based on FLUKA simulation. We suggest that those results are independently verified.

References

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