Electromagnetic Calorimeter in Hall A

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Abstract

A photon detector is needed for the real Compton scattering (RCS) experiment E97-108, approved for Hall A. An electromagnetic calorimeter is currently being designed for this purpose. Such a detector may be also applied for a broader range of experimental programs in Hall A, not only as a photon detector but also as a detector for scattered electrons at energies higher than 4 GeV - the limit of the existing HRS spectrometers in Hall A, in cases when a high energy resolution is not required.

Photon Detector for Real Compton Scattering

The initial motivation for building an electromagnetic calorimeter comes from the RCS[1] program which has been discussed at this workshop [2, 3]. The process $\gamma p \rightarrow \gamma p$ should be measured with a mixed e^-, γ beam produced on a copper radiator of 6% RL thickness in an energy range from 4 to 6 GeV, 10% below the end point. The radiator will be positioned in front of a LH_2 target. The scattered photons should be detected in an energy range of 1-4 GeV and at angles from 20 to 72 degrees in the lab frame, with the calorimeter. The recoil protons will be detected with the HRS spectrometer. In order to match the angular acceptance of the calorimeter to the acceptance of HRS, one should be able to put the calorimeter at distances from 6 to 17 m from the target, depending on the angle, and the calorimeter should cover an area of 1×1 m^2. There are several main sources of background.

1) **ep $\rightarrow$ ep** scattering. The electrons from the primary beam fall out of the kinematics acceptance (10% below the end point), however the electrons which have lost energy in the radiator may produce background kinematically indistinguishable from the $\gamma p \rightarrow \gamma p$ process. Several ways to reduce the background of charged particles are under consideration: a scintillator hodoscope, appropriately segmented and positioned in front of the calorimeter; a segmented gas Cherenkov counter in front of the calorimeter; a sweeping

magnet positioned between the calorimeter and the target. All or some of these options are going to be used.
2) $\gamma \mathbf{p} \rightarrow \pi^0 \mathbf{p}$ production with one photon detected in the calorimeter. This background should be reduced by kinematics criteria. In particular, a correlation of the scattered proton's direction and the lateral position of the shower in the calorimeter should provide a strong reduction.
In order to reduce the background one has to compare the energy and position of the photon candidate, reconstructed with the calorimeter, with the predictions obtained from detecting the recoil proton with the HRS. The expected energy resolution of such a prediction is about 1%, while the expected position resolution is about 1 cm. Therefore, the calorimeter should provide a position resolution of 0.5-1 cm, which is not too demanding. The optimal energy resolution of the calorimeter is about 1% for 2-4 GeV photons and this seems hard to achieve. And finally, radiation hardness should be considered while choosing the material for the calorimeter. Three different materials are compared in Table 1. If TF1 lead glass modules of 4×4 cm^2 lateral size

	LG TF1[4]	$PbWO_4$[5]	PbF_2
Rad.length (cm)	2.74	0.89	0.93
Molière R (cm)	4.7	2.2	2.22
Refraction index	1.647	2.16	1.82
Density (g/cm^3	3.86	8.28	7.77
Decay constant (ns)	Cherenkov	2.1, 7.5, 26	Cherenkov
Rad. hardness	low	high	high
σE/E (GeV)	$0.06/\sqrt{E}+0.02$	$0.034/\sqrt{E}+0.02$	$0.06/\sqrt{E}+0.02$
σX (cm)	$0.5/\sqrt{E}\oplus0.2$	$0.25/\sqrt{E}\oplus0.1$	$0.25/\sqrt{E}\oplus0.1$

Table 1: Parameters of different materials for the calorimeter. The constant term in the energy resolution formula is typical for detectors with at least several hundred modules. For the spatial resolution estimate the lateral cell sizes of 4×4 cm^2 for TF1 and 2×2 cm^2 for heavy crystals were assumed. It should be noted that $PbWO_4$ crystal technology is developing and some problems with production of radiation hard crystals still exist.

are used, the full number of modules needed is about 625. The resolution of such a calorimeter is sufficient for the RCS experiment, though its radiation hardness is marginal. If crystals are used, one may reduce the module size by a factor of two due to their lower Molière radius and keeping the same number of modules move the calorimeter closer to the target. The advantage of

$PbWO_4$ crystals is a high radiation hardness and a better energy resolution. The latter would help to reduce the background in RCS and also would be useful for other applications of the calorimeter.

Extension to Higher Energies

There is an interest in extending the RCS studies to higher energies. Furthermore, the calorimeter can be used for other programs in Hall A at higher energies, since the momentum acceptance of the HRS is limited to 4 GeV while the calorimeter performance is only improved with energy. The calorimeter can be used for detection of scattered electrons at energies E>4 GeV. The acceptance of the calorimeter would be 10-20 mster which is larger than the acceptance of the HRS. The angular resolution of such a detector is even better than the resolution of the HRS, though the energy resolution is much worse. Nevertheless, for a number of tasks the energy resolution is not very important, for example for studying the process $^3\vec{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e}')$. Another application would be to study semi-exclusive processes, like $\mathrm{e},\mathrm{e}'\pi^0$ or the GDH sum rule in $^3\vec{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{M})$, where M is a meson, like ω. The calorimeter should detect the neutral decay of the mesons. A program to detect meson decays would require about twice larger acceptance of the calorimeter than the RCS program does.

Prototyping and Tests

Feasibility of the project depends on the occupancy of the detector in the real environment, the energy and spatial resolution one can achieve in this environment and the efficiency of the veto detectors. In order to study that a prototype calorimeter was built. This prototype consists of a array of 5×5 modules built of lead glass TF1, 4×4 cm^2 size. In front of the lead glass array an array of plastic scintillation counters of 8×4 × 4 cm^3 size was set, for a prototype of the veto counters. Between the veto counters and the lead glass array a MPWC with 1 mm pitch was positioned in order to study the spatial resolution of the calorimeter. A threshold gas Cherenkov detector was put in front of the veto array. The setup was tested in Hall A, using the elastic scattering ep $\rightarrow$ ep of 4.23 GeV, 50μA beam on the 15 cm LH_2 target, with the calorimeter installed at an angle of 34^o to the beam, at the electron arm side and at a distance of about 11 m from the target, while the proton arm was set to 33^o and P=2.35 GeV/c. The mean electron energy was about 2.6 GeV. Clean elastic events were selected using the signals from the hadron arm in coincidence with a signal from the calorimeter. A coarse calibration of all the lead glass modules was performed. The energy resolution obtained using this calibration is σ=6.5%, to be compared with 5.7% expected (see Table 1). The position of the hit was evaluated as the logarithmically weighted baricenter of the shower. Comparing this with the coordinate measured in the MWPC an average resolution of σ=0.67 cm was obtained. The contribution of the MWPC resolution is negligible. The angular difference in the out of the plane projection between the scattered proton, reconstructed in the HRS, and the line connecting the shower center and the target center has a width of σ=2.9 mrad and is dominated by the HRS resolution. In order to test the efficiency of the veto counters the events were selected with certain position of the shower when electron should pass in one of the two adjacent veto counters. The efficiency of at least one signal in these two counters was measured to be about 99%. The counting rate in one counter was about 250 kHz. Assuming the resolution time of 10 ns, one obtains a rate of accidental coincidences of about 0.5%. Both the efficiency and the accidental rates are acceptable for the RCS experiment.

Conclusion

An electromagnetic calorimeter for Hall A is being designed. Its primary goal is to detect photons in the RCS experiment at 4-6 GeV, and also it is considered to be used at higher beam energies both as photon and electron detector. The first tests demonstrated the feasibility of the project as far as the particle rates, energy and angular resolutions and selecting of charged/neutral particles are concerned. The work on selecting the material for the calorimeter and optimizing its parameters is in progress.

References

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