E907 Cherenkov Digitization Algorithm

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Abstract

This note documents the algorithm used to simulate the response of the E907 Cherenkov counter in the experiments detector simulation. It is current as of April 8th, 2009.

1 GEANT Hits

2 Hits to photo-electrons

Each GEANT hit represents a segment of a track and is projected forward until it hits a single mirror. The number of photoelectrons produced in the PMT assigned to that mirror is calculated as

$$N_{\mathrm{PE}} = r_{\mathrm{T}} r_{\mathrm{C}} \int_{\lambda_1}^{\lambda_2} \int_{\lambda_1'}^{\lambda_2'} \epsilon_{\mathrm{PMT}}(\lambda') w(\lambda, \lambda') T(\lambda) N(\lambda) d\lambda' d\lambda, \tag{1}$$

where λ is the wavelength of Cherenkov photons produced by the particle, N is the number of Cherenkov photons produced, T is the transparency of the radiator gas [**?**], w is a function which represents the efficiency of the pTP waveshifter to absorb a photon at wavelength λ and reemit it as wavelength λ' and ϵ is the efficiency of the PMT to yield a photoelectron from an incident photon of wavelength λ'. The constant r_{C} varies from mirror-to-mirror and represents the relative efficiency of the mirror in question to the central mirror number 17. The value of this constant is taken to be the calibration constant "xxx" from the calibration database table "XXX". The final constant r_{T} is tuned to match the overall light levels in the Monte Carlo to the data. Additional documentation on each of these factors is provided below.

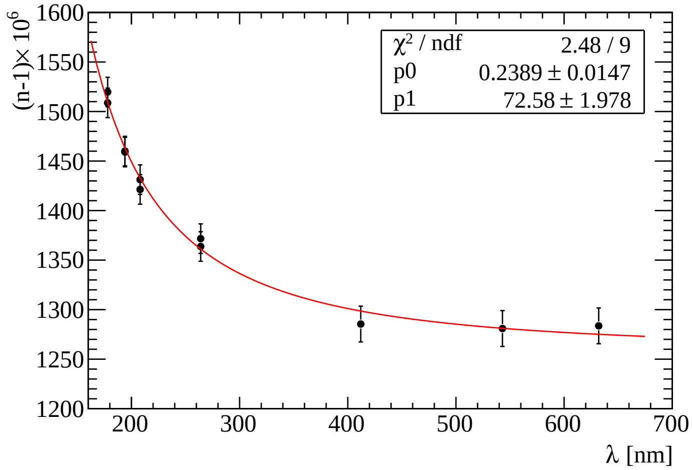

Figure 1: The index of refraction in C_4F_{10} points were read of a plots from [2, 3] scaled to 29 C and atmospheric pressure. The red curve is the parameterization from Eq. 4.

2.1 N_λ

The number of Cherenkov photons per unit wavelength is computed from the standard formula for Cherenkov radiation

$$N(\lambda) = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) ds d\lambda, \tag{2}$$

where α is the fine structure constant and the particle considered makes a step of size ds[cm], has charge z [in units of e], and has speed βc. The index of refraction for the CKOV gas (C_4F_{10}) is assumed to follow a Sellmeier parameterization

$$n(\lambda) = 1.0 + \frac{A}{1/\lambda_0^2 - 1/\lambda^2} \times 10^{-6}. \tag{3}$$

The parameters A and λ_0 were determined to be

$$\begin{aligned} A &= 0.2389 \pm 0.0147 \\ \lambda_0 &= 72.58 \pm 1.98 \text{ nm} \end{aligned} \tag{4}$$

from a fit to data from [2, 3] adjusted to the typical conditions of the MIPP Cherenkov counter, $T = 29$ C (as read by temperature probe near DC3) and atmospheric pressure. The data and fit results are shown in Fig. 1. As shown

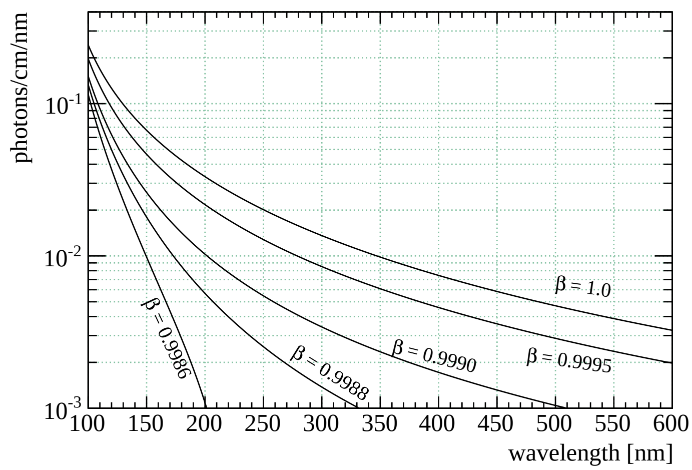

Figure 2: The number of Cherenkov photons produced per cm per nm for particles with β's between 0.9980 and 1.0. Threshold is roughly 0.9985 when the number of photons produced near 200 nm goes above zero.

in the figure, particles with $\beta = 0.9986$ just begin to produce light above 200 nm and go over threshold. This β corresponds to $p = 2.7$ GeV for pions, 9.7 GeV/c for kaons, and 18.4 GeV/c for protons.

2.2 $w(\lambda', \lambda)$

The PMT's used in the CKOV are coated with the waveshifter p-terphenyl (pTP) [1]. The absorption and emission spectra for pTP were taken from [**?**,]nd [**?**,] The absorption data is well described by two guassians centered on $\lambda = 190$ mn and $\lambda = 275$ nm.

3 Tuning to data

For the most part the CKOV digitization relies on first principles, measured, and calibrated quantities. There are, however, two parameters left to tune. The first, and most important is the overall scale factor r_T which adjusts the over all light level of the Monte Carlo. The second scale factor is a parameter which controls how much Gaussian noise to add to a signal. The code contains a third parameter (a constant noise level) which was not needed and is effectively redundant with the calibrated pedestal RMS's.

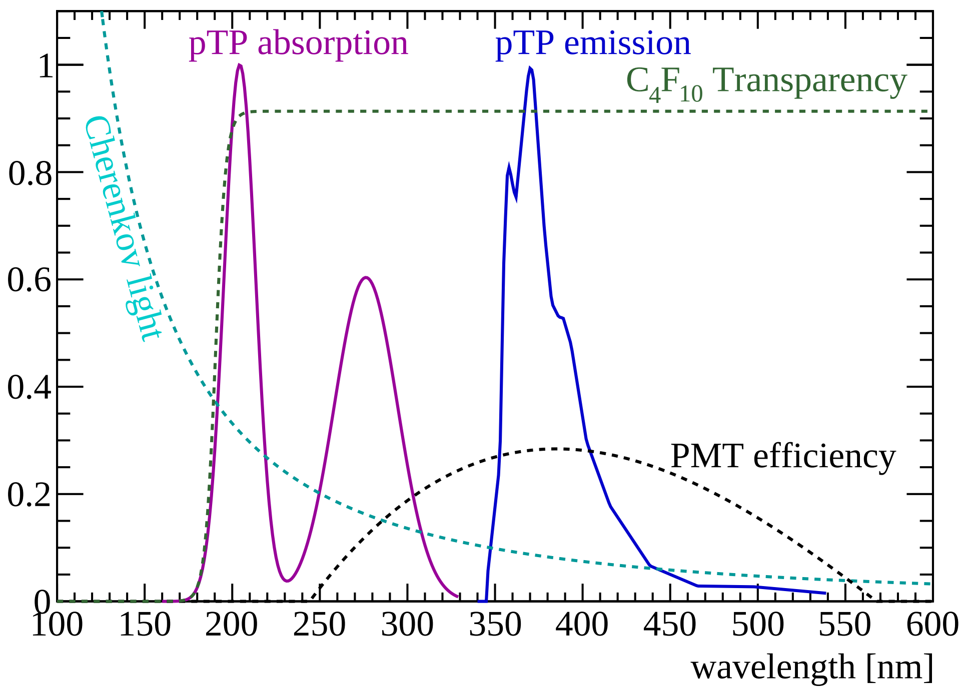

Figure 3: Summary of photoelectron production in the CKOV. The number of Cherenkov photons generated per cm per nm by a $\beta = 1$ charged particle is shown by the cyan dashed curve. This is absorbed by the pTP wave shifter according to the purple curve. This light is reemitted according to the blue curve. The efficiency of the PMT is shown in the dashed black curve.

To tune the two free parameters, I plotted the response of the CKOV counter in several momentum slices in the momentum range where pions, kaons, and protons turned on. In each case clear peaks are seen in the response and the light level of the MC was adjusted until the locations of these peaks agreed between data and Monte Carlo. The noise factor was increased until the long tails of the response agreed.

Figure 4 shows three of the five plots used to tune the response corresponding to the momentum range where pions turn on. The plots made near the kaon and proton threshold are shown in Fig. 5. In general, the plots suffer from poor Monte Carlo statistics, but show overall reasonable agreement.

There are two remaining momentum regions to plot, and although I did not use them in tuning, I have plotted them. These are the regions below pion threshold, where there should be essentially no light except for that due to electrons, and the region near the beam momentum which should contain essentially only beam tracks. I did not use the low momentum region for tuning as the number of electron tracks is highly uncertain and the region where there is expected to be no light is not useful for tuning the signal sizes. I did not use the beam tracks for tuning as the response is dominated by a single mirror (17) and do not represent the CKOV counter as a whole. Nevertheless, I have compared the response of data and MC in these regions in Fig. 6.

References

[1] D. Christian (11 Feb. 2009), E. Hahn (20 Feb. 2009), private communications.
O. Ullaland, Nucl. Instr. and Meth. A 553 (2005) 107.

[2] T.A. Filippas et al., Nucl. Instr. and Meth. B 196 (2002) 340.

[3] T. Skwarnicki, Nucl. Instr. and Meth. A 553 (2005) 339.

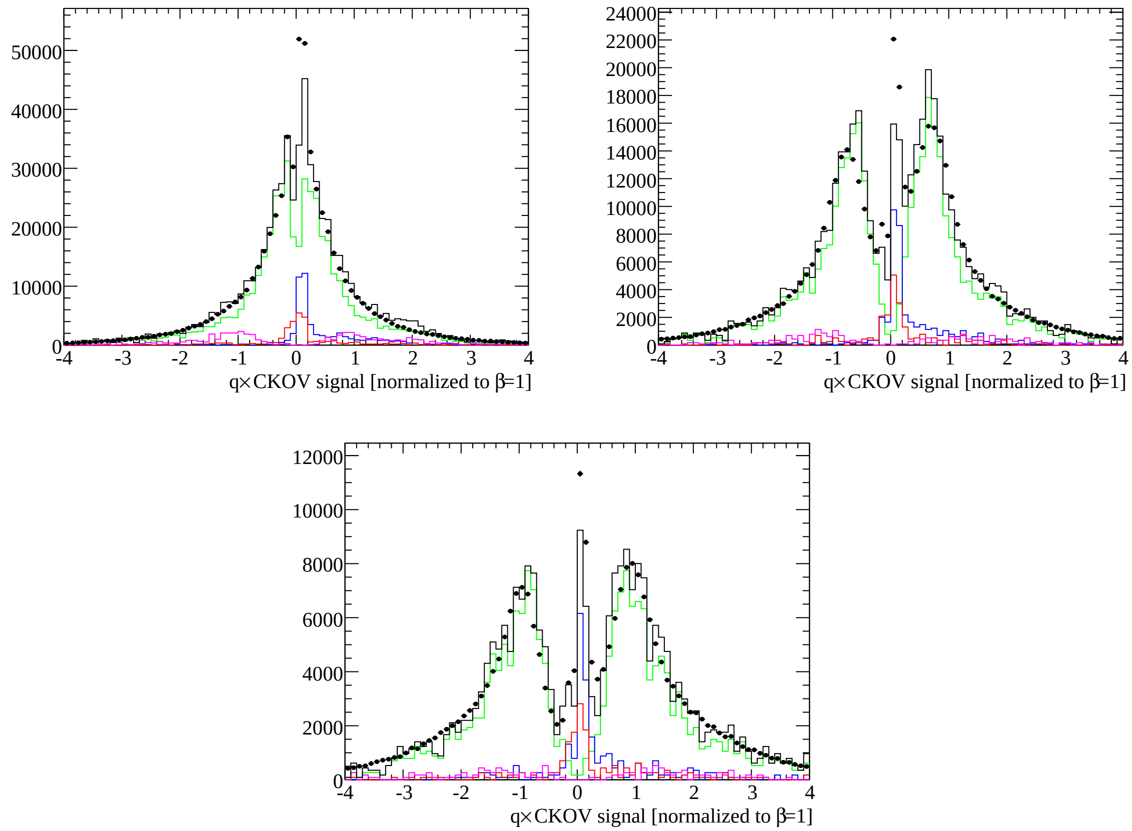

Figure 4: Three of the 5 histograms used for tuning the light response of the CKOV. The three histograms show the light response of the counter in data (points) and Monte Carlo (histograms). The full NuMI data set is used while a smaller set of 15k events in used for the MC. The three plots show the response of the CKOV for tracks in the region where pions turn on but before kaons turn on ($2.5 < p < 3.8$ GeV/c, $3.8 < p < 5.8$ GeV/c, $5.8 < p < 9.0$ GeV/c in order. The CKOV response is multiplied by the track charge so that negative tracks appear on the left and positive tracks appear on the right. The MC in shown broken down by pions (green), kaons (red), protons (blue) and electrons (magenta). The MC is normalized to equal area with respect to the data.

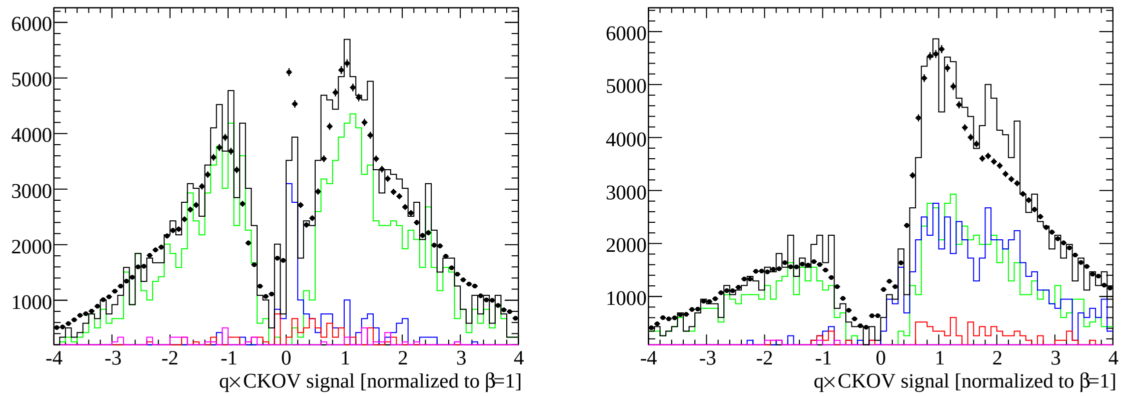

Figure 5: CKOV response in region $9 < p < 17$ GeV/c where kaons turn on (left) and $17 < p < 62$ GeV/c protons turn on (right).

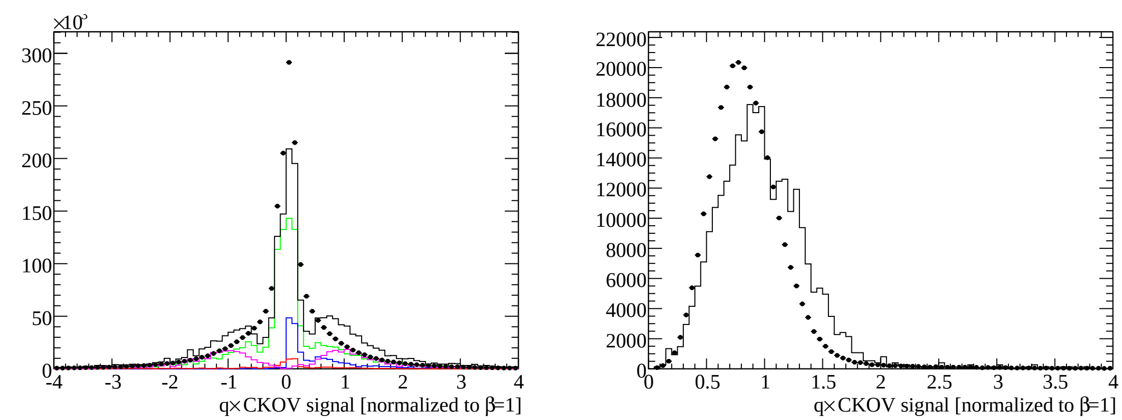

Figure 6: Comparison of CKOV response in region below pion threshold (left) and for beam particles hitting mirror 17 (right).