Rate estimates in the time-of-flight scintillators using the OLYMPUS Monte Carlo simulation

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April 29, 2012

1 Overview

The OLYMPUS experiment has four running configurations: two toroid polarities (called positive and negative), and two beam species (electrons and positrons). Though the acceptance of the OLYMPUS detector for electrons in one polarity should match the acceptance for positrons in the other polarity, the requirement of a coincident detection of the recoiling proton creates the situation where the OLYMPUS detector has a different acceptance for each of the four configurations.

In this report, I have used the OLYMPUS Monte Carlo simulation to account for this changing acceptance. Using the results of this simulation, I have made an estimate of the rate of elastic scattering events that will be detected by the time-of-flight scintillators (ToFs).

2 Method

2.1 Event Generation

For the simulation, I generated a large number of elastic scattering events. Each event had both a lepton and a proton emerging from a single vertex in the target. The trajectories of the electron and proton obeyed elastic kinematics with a 2.01 GeV beam energy. The angular distribution of the events was proportional to the Rosenbluth cross section with dipole form-factors. Since the acceptance of the OLYMPUS detector is roughly from 20° to 80° in scattering angle, and ±15° in azimuthal angle (in one sector), I chose to generate events between 15° and 90° in scattering angle, and ±22° in azimuthal angle to make sure all of the detector acceptance was covered. The location of the scattering vertex was drawn from a triangular distribution along the beam direction. The perpendicular directions were sampled in Gaussian distributions centered at the origin with widths of 2.5 mm horizontally and 0.7 mm vertically to match our best estimate of the actual shape of the beam [1].

2.2 Simulation

The generated events were propagated through the OLYMPUS Monte Carlo. All of the detector elements were turned on and were active, even though for this estimation, only the ToF data were analyzed. The toroid magnetic field was scaled to 0.7428, matching the field used during OLYMPUS running ($\pm 5000A$ current). All of the relevant physics processes were turned on, including both lepton and proton bremsstrahlung, energy loss from ionization, and multiple scattering.

2.3 Rate Estimate

For this rate estimate, one million events were generated in each of the four running configurations. By calculating the total cross-section of the range of events produced the generator, I determined the equivalent integrated luminosity needed to produce a run of this size. Luminosity (L), rate (R), and total cross-section (σ) are related in the expression $R = L \times \sigma$. One can integrate both the rate and the luminosity over time and rearrange the expression to solve for the integrated luminosity (L_{int}) of a simulation in terms of the number of events generated (N).

$$L_{int} = \frac{N}{\sigma}$$

I calculated the cross-section by numerically integrating the Rosenbluth cross-section over the generator's angular range, arriving at 46.23 nb. My simulation of 1 million events thus corresponds to an integrated luminosity of 21.63 pb^{-1}. This number is the normalization factor for my rate estimates.

2.4 Criteria for a detection

In my analysis of the data produced by the simulation, I recorded an event as a detection if both the primary lepton (given by a track id of 1 in Geant4) and the primary proton (with a track id of 2) caused a hit in the ToFs. Secondary particles were ignored in my analysis. I did not take any data from any other subdetectors into account.

3 Results

3.1 Comparison to previous estimates

One of the previous rate estimates was reported in R. Milner's PANIC '11 proceedings [2]. This estimate was produced by integrating the Rosenbluth cross-section between a range of angles approximating the OLYMPUS detector acceptance (20° to 76° in scattering angle, and ±15° in azimuthal angle). This estimate did not attempt to account for the magnetic field, nor the change beam species, so it is the same for all four running configurations. The results were binned by lepton scattering angle in seven 8° bins. In table 1, I compare these numbers to the results of my simulation, making the adjustment to the units of expected counts per inverse femtobarn. The errors I report are statistical only, coming from the Poisson statistics of the simulation.

Bin	Range (°)	Integration (Counts / fb^{-1})	Monte Carlo Simulation (Counts / fb^{-1})			
			electrons, +	electrons, -	positrons, +	positrons, -
1	20 - 28	7.37 M	5.46 ± 0.02 M	6.90 ± 0.02 M	6.91 ± 0.02 M	5.41 ± 0.02 M
2	28 - 36	1.34 M	1.31 ± 0.008 M	1.35 ± 0.008 M	1.37 ± 0.008 M	1.29 ± 0.008 M
3	36 - 44	341 k	351 ± 4 k	357 ± 4 k	355 ± 4 k	347 ± 4 k
4	44 - 52	114 k	118 ± 2 k	119 ± 2 k	121 ± 2 k	120 ± 2 k
5	52 - 60	46.7 k	49.7 ± 2 k	47.3 ± 1 k	51.6 ± 2 k	50.1 ± 2 k
6	60 - 68	22.5 k	24.0 ± 1 k	22.3 ± 1 k	22.5 ± 1 k	21.7 ± 1 k
7	68 - 76	12.2 k	14.2 ± 0.8 k	11.8 ± 0.7 k	13.8 ± 0.8 k	11.8 ± 0.7 k

Table 1: Comparison of this simulation to simple cross-section integration estimate from [2].

Notice that in the forward bin, the Monte Carlo rates are lower than the integration, while in many of the middle bins, the rates are higher. I think this reflects differences between the ToF acceptance and the acceptance that was assumed in the integration.

3.2 Rates in individual tof bars

It is interesting to consider the rates that individual ToF bars should encounter from both electrons and protons. These numbers are shown in table 2, given in our familiar units of expected counts per inverse femtobarn. To generate this numbers, my analysis was slightly different. In instead of counting events, I counted the number of primary particle hits in the ToFs, with the condition of lepton and proton coincidence. This matters only when a single particle hits two adjacent ToF bars. I counted this as a hit in each ToF bar; two hits in that sector. These numbers correspond to the rates experienced from particles from elastic events in each ToF bar. The total rates (the sum of all of the ToF bar rates) is shown in the last row. Again, errors are statistical only.

4 Conclusions

There are several interesting features in the Monte Carlo results. First and foremost, there is a surge in the rate when the lepton is bent outwards (positive polarity for positrons, negative polarity for electrons). This increase is large: more than a factor of two in the total rate through the ToF acceptance (See table 2). When the lepton is bent outwards, higher cross-section events at more forward angles are bent into the acceptance of the forward ToFs. In a final analysis, we will likely make a bin the events by lepton scattering angle like is done in table 1. Setting a defined range of scattering angles for our event sample is like making a fiducial cut. This helps keep the acceptance

	ToF Bar	Monte Carlo Simulation (Counts / fb^{-1})			
		electrons, +	electrons, -	positrons, +	positrons, -
Left	0	1.55 ± .008 M	1.88 ± 0.009 M	1.88 ± 0.009 M	1.54 ± .008 M
	1	851 ± 6 k	2.20 ± 0.01 M	2.19 ± 0.01 M	842 ± 6 k
	2	485 ± 5 k	1.37 ± 0.008 M	1.36 ± 0.008 M	485 ± 5 k
	3	272 ± 4 k	703 ± 6 k	706 ± 6 k	276 ± 4 k
	4	233 ± 3 k	673 ± 6 k	667 ± 6 k	240 ± 3 k
	5	151 ± 3 k	432 ± 4 k	401 ± 4 k	175 ± 3 k
	6	121 ± 2 k	323 ± 4 k	288 ± 4 k	148 ± 3 k
	7	119 ± 2 k	307 ± 4 k	244 ± 3 k	189 ± 3 k
	8	162 ± 3 k	409 ± 4 k	250 ± 3 k	292 ± 4 k
	9	175 ± 3 k	434 ± 4 k	251 ± 3 k	341 ± 4 k
	10	350 ± 4 k	879 ± 6 k	437 ± 4 k	725 ± 6 k
	11	675 ± 6 k	1.64 ± 0.009 M	789 ± 6 k	1.18 ± 0.007 M
	12	1.15 ± 0.007 M	2.78 ± 0.01 M	1.48 ± 0.008 M	889 ± 6 k
	13	1.02 ± 0.007 M	2.23 ± 0.01 M	2.48 ± 0.01 M	160 ± 3 k
	14	243 ± 3 k	254 ± 3 k	2.54 ± 0.01 M	6.98 ± 0.6 k
	15	9.48 ± 0.7 k	25.9 ± 1 k	531 ± 5 k	2.91 ± 0.4 k
	16	1.90 ± 0.3 k	19.3 ± 0.9 k	20.5 ± 1 k	1.01 ± 0.2 k
	17	1.39 ± 0.2 k	14.5 ± 0.8 k	14.9 ± 0.8 k	370 ± 100
Right	18	1.59 ± 0.008 M	2.02 ± 0.01 M	1.98 ± 0.01 M	1.57 ± 0.009 M
	19	876 ± 6 k	2.21 ± 0.01 M	2.22 ± 0.01 M	879 ± 6 k
	20	500 ± 5 k	1.41 ± 0.008 M	1.41 ± 0.008 M	499 ± 5 k
	21	275 ± 4 k	694 ± 6 k	693 ± 6 k	266 ± 4 k
	22	250 ± 3 k	704 ± 6 k	692 ± 6 k	258 ± 3 k
	23	154 ± 3 k	441 ± 5 k	425 ± 4 k	172 ± 3 k
	24	123 ± 2 k	329 ± 4 k	297 ± 4 k	154 ± 3 k
	25	125 ± 2 k	313 ± 4 k	238 ± 3 k	183 ± 3 k
	26	150 ± 3 k	391 ± 4 k	252 ± 3 k	286 ± 4 k
	27	181 ± 3 k	442 ± 5 k	260 ± 3 k	345 ± 4 k
	28	339 ± 4 k	868 ± 6 k	429 ± 4 k	716 ± 6 k
	29	664 ± 6 k	1.63 ± 0.009 M	768 ± 6 k	1.17 ± 0.007 M
	30	1.14 ± 0.007 M	2.72 ± 0.01 M	1.47 ± 0.008 M	847 ± 6 k
	31	979 ± 7 k	2.09 ± 0.01 M	2.42 ± 0.01 M	146 ± 3 k
	32	227 ± 3 k	258 ± 3 k	2.41 ± 0.01 M	6.52 ± 0.5 k
	33	9.75 ± 0.7 k	26.7 ± 1 k	520 ± 5 k	2.87 ± 0.4 k
	34	2.03 ± 0.3 k	19.3 ± 0.9 k	20.1 ± 1 k	1.53 ± 0.3 k
	35	647 ± 0.2 k	13.5 ± 0.8 k	12.9 ± 0.7 k	92.5 ± 70
Total		15.2 ± 0.03 M	33.1 ± 0.04 M	33.0 ± 0.04 M	15.0 ± 0.03 M

Table 2: The rates from Monte Carlo of both electrons and protons is shown for each ToF bar. There is a factor of two increase in the total rate when the leptons are bent outwards.

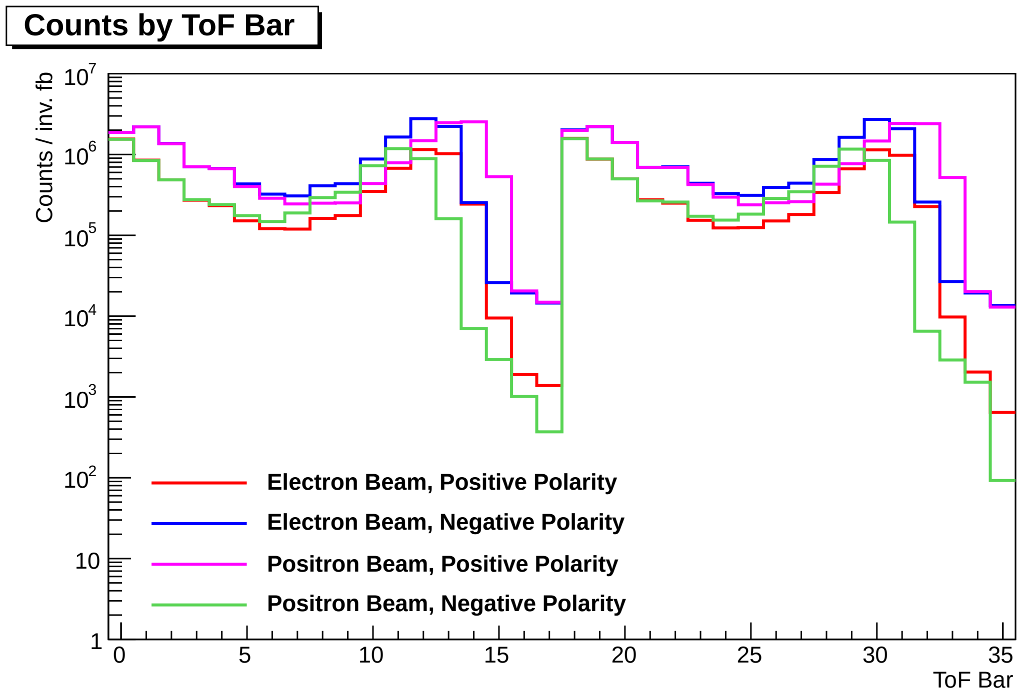

Figure 1: The distribution of ToF bar rates changes significantly with the change in magnet polarity and lepton sign.

more constant across different polarities and lepton signs because we will reduce edge effects at the limits of our acceptance. One can see that the rates in table 1 do not vary as significantly, and the largest deviation is in the first bin, at the forward edge of our acceptance.

Another interesting thing to see is how the shapes of the ToF bar rate distributions change with the polarity and beam sign. To see this more easily, I've plotted the results from table 2 in a histogram, shown in figure 1. The forward peak, which comes from the scattered leptons, is shifted due to the appropriate bending of the leptons in the toroid field. The backward peak, which comes from the recoiling protons, also moves. But since the proton sign doesn't change, negative polarity bends the peak forward, while positive polarity bends it backwards.

This simulation could easily be improved by greater statistics. The data set corresponds to only 21.63 inverse pb; whereas, the OLYMPUS dataset is projected to be several inverse femtobarns. The simulation was run in a day using 12 cores, so it would not be much of inconvenience to collect a lot more simulated data. At some point an estimate would become limited by systematic errors, but it is hard to estimate those for the Monte Carlo.

References

[1] F. Brinker, "Doris," in *OLYMPUS Collaboration Meeting Slides*, April 2009.

[2] R. Milner, "The olympus experiment," in *Proceedings of Panic11: The 19th Particles and Nuclei Internation Conference*, 2011.