TWO PHOTON PHYSICS AT A HIGH ENERGY LINEAR COLLIDER : FORWARD CALORIMETRY ISSUES

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A high energy e^+e^- linear collider is an ideal place to study physics related to the structure of real and virtual photons and to the dynamics of QCD. By detecting the scattered e^+ and/or e^- at small forward angles, one or two virtual photons can be tagged. If only one virtual photon is tagged, the total hadronic mass measurement depends on hadronic detection at very small angles. Monte Carlo studies on the use of forward calorimetry at an e^+e^- linear collider are reported here.

1 Forward Calorimetry at a High Energy Linear Collider

Measuring cross sections of the type, $e^+e^- \rightarrow e^+e^- + hadrons$, at a linear collider relies on the ability to detect the scattered e^+ and/or e^- at very small angles, tagging the virtual photon(s) involved in the interaction. A fine-grained electromagnetic calorimeter located close to the beam pipe is needed to measure the Q^2 of the tagged γ^*. In current linear collider interaction region (IR) designs, the minimum detection angle is limited to $20-30\ mr$ due to mechanical constraints (beam pipes and focussing magnets). Beam-related backgrounds may force an increase in the minimum angle for some IR designs.

For interactions of one γ^* and one real photon (untagged), the total mass, $W_{\gamma^*\gamma}$, must be determined by measuring the energy and position of the produced hadrons. Even with hadronic calorimetry down to angles of 30 mr, as much as half of the total $W_{\gamma^*\gamma}$ escapes undetected into the beam pipe.

2 Beam-Related Background Masking Scenarios

A major feature of the IR is thick shielding in the form of a conical mask around the beam pipe. This shielding is necessary to protect the central detector from beam-related backgrounds. At LEP and SLC, electromagnetic calorimetry placed inside the IR masks has been used to detect scattered e^+ and e^- at small angles, primarily to determine the total luminosity. This technique can also be used to tag virtual photons.[1]

Current NLC IR designs consider two scenarios - aggressive masking, where the shielding is located from $30-55\ mr$, and conservative masking, where the shield is positioned from $80-110\ mr$. The PYTHIA monte carlo program, modified to generate γ^* scattering, was used to study kinematic reconstruc-

tion in the forward regions.[2] The following table shows the location, type of calorimetry, and resolutions used to smear generated particles in this study.

Scenario/Position	EMC	HAC
Aggressive Masking		
Outer Detector ($> 55\ mr$)	$15\%/\sqrt{E} \oplus 1\%$	$50\%/\sqrt{E} \oplus 3\%$
Mask ($30 - 55\ mr$)	$25\%/\sqrt{E} \oplus 2\%$	$100\%/\sqrt{E} \oplus 5\%$
Conservative Masking		
Outer Detector ($> 110\ mr$)	$15\%/\sqrt{E} \oplus 1\%$	$50\%/\sqrt{E} \oplus 3\%$
Mask ($80 - 110\ mr$)	$25\%/\sqrt{E} \oplus 2\%$	$100\%/\sqrt{E} \oplus 5\%$
Inner Detector ($30 - 80\ mr$)	$15\%/\sqrt{E} \oplus 1\%$	$75\%/\sqrt{E} \oplus 5\%$

3 γ^* Tagging - Energy Measurement and Angular Segmentation

Virtual photon tagging requires electromagnetic calorimetry inside or at the position of the conical mask. Q^2 reconstruction depends on the energy resolution and more importantly on the radial angular segmentation since, at small angles, $Q^2 \approx E_{beam} E_{tag} \theta_{tag}^2$.

Figure 1 illustrates reconstruction abilities of the two scenarios for the energy of the scattered e^+ or e^-. The top left plot compares measured energies in the aggressive (blue) and conservative (red) scenarios with the true value (solid line). The top right and bottom left plots contain gaussian fits to the differences between reconstructed and true energy. A double gaussian was used for the aggressive scenario since tagging spanned two different calorimetric regions. In the bottom right plot, resolutions (σ/E) are plotted versus energy along with expected curves (dashed-dotted lines) for the two masking scenarios.

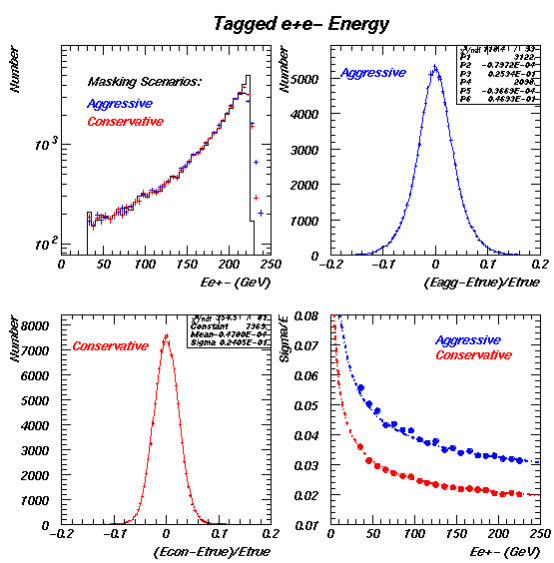

Figure 1: Scattered e^+ and e^- energy reconstruction.

Figure 2 shows the importance of angular segmentation in Q^2 reconstruction. The top plots show reconstruction abilities of the two scenarios assuming exact angular determination. The bottom left plot shows differences between reconstructed and true Q^2 in the aggressive scenario for 0, 0.5 cm, and 1 cm pad sizes. Clear deformation of the gaussian shape is seen for 1 cm pads. The bottom right plot shows the differences as a function of Q^2. At low Q^2, finite radial segmentation shifts the result towards higher Q^2, while at high Q^2, the constant term in the energy resolution shifts the result to lower Q^2.

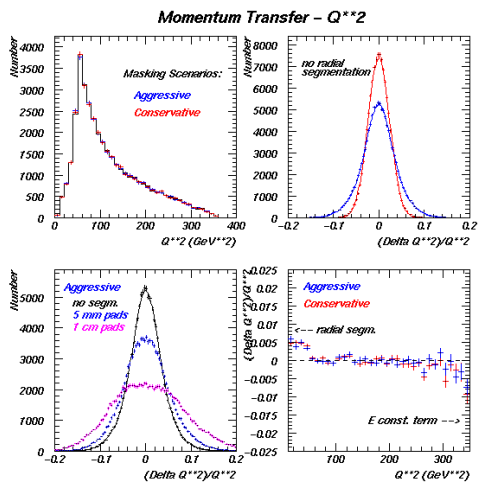

Figure 2: Angular segmentation and Q^2 reconstruction.

4 Doubly Tagged Measurements - $W_{\gamma^*\gamma^*}$ and Y

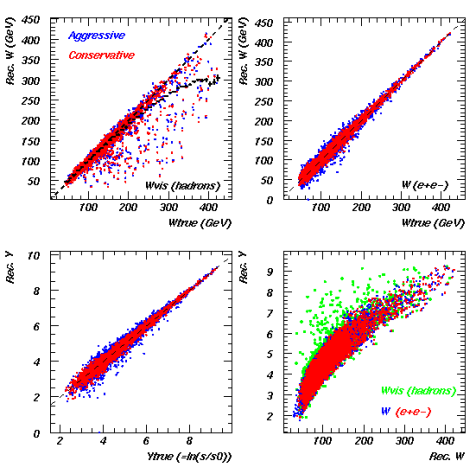

Figure 3: $W_{\gamma^*\gamma^*}$ and Y reconstruction.

For doubly tagged interactions, all kinematics can be reconstructed from the scattered e^+ and e^- measurements; including the total mass, $W_{\gamma^*\gamma^*}$, and the rapidity separation of the two virtual photons, $Y = \ln(s/s_0)$, where $s_0 = \sqrt{Q_1^2 Q_2^2}/y_1 y_2$. The top left plot of Figure 3 shows W_{vis} (from observed hadrons) versus $W_{\gamma^*\gamma^*}$ with the improvement obtained by taking advantage of double tagging shown in the top right. The bottom left plot compares reconstructed to true Y. The bottom right plot shows Y versus $W_{\gamma^*\gamma^*}$. If W_{vis} is used, false high Y interactions are observed at low $W_{\gamma^*\gamma^*}$.

5 Singly Tagged Measurements - W_{vis} and x Reconstruction

For singly tagged interactions, $W_{\gamma^*\gamma}$ can not be determined solely from tagging parameters and must be measured from the produced hadrons (W_{vis}) and corrected with Monte Carlo (MC) models in order to reconstruct x. The top plot in Figure 4 shows the W_{vis} measurement for the aggressive (blue) and conservative (red) scenarios compared to the true $W_{\gamma^*\gamma}$. The bottom plot compares the reconstructed $W_{\gamma^*\gamma}$ to the true value. Depending on the choice of MC model, W_{vis} can be different from $W_{\gamma^*\gamma}$ by as much as 50 %. Even worse than the size of the correction itself is that various MC models yield different size corrections, leading to large systematic uncertainties in x.

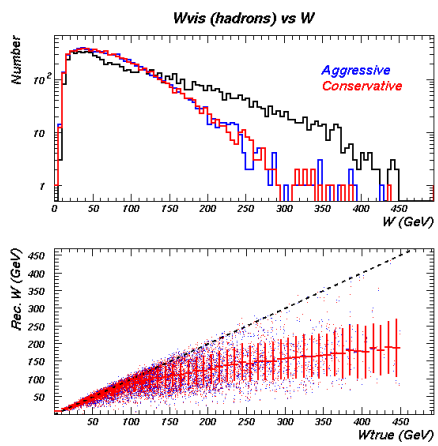

Figure 4: W_{vis} measurements from observed hadrons.

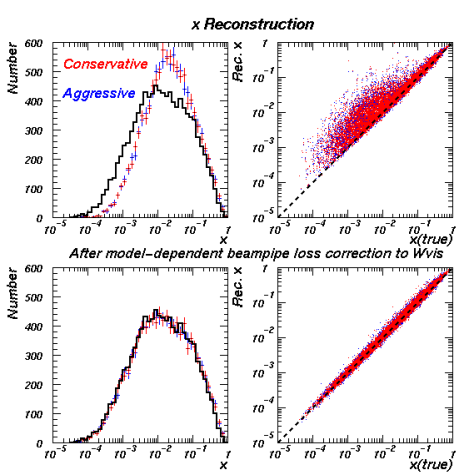

Figure 5: x reconstruction before and after correction to W_{vis}.

Figure 5 shows x reconstructed from W_{vis} (assuming hadron energy and angle are measured at 30 mr), comparing results from the two masking scenarios to true x. The top left plot shows the shift from low to high x which results from using uncorrected W_{vis} (crosses) compared to true x (line). The top right plot further illustrates this point. The bottom plots have been made after using PYTHIA to correct W_{vis}. The differences, both between W_{vis} and $W_{\gamma^*\gamma}$ and between different MC models, lead to big corrections and systematic uncertainties, especially in the large $W_{\gamma^*\gamma}$ (low x) region.

6 Conclusions and Future Plans

Standard electromagnetic calorimetry at small angles is capable of measuring the energy input to Q^2 reconstruction of tagged virtual photons. Comparisons of the measurement performance of two masking scenarios indicate no real preference, however, ease of construction would seem to favor the conservative masking approach. Studies of radial angular segmentation indicate that pad sizes of 0.5 *cm* or less are adequate for good Q^2 reconstruction. For doubly tagged interactions, complete kinematic reconstruction is obtained with only electromagnetic calorimetry in the forward regions.

For singly tagged interactions, complete kinematic reconstruction is not possible since the real photon is not tagged. Hadronic calorimetry is necessary for reconstruction of the total hadronic mass, $W_{\gamma^*\gamma}$, used in the determination of x, at very small angles. The corrected x depends heavily on Monte Carlo models leading to large systematic errors and eventually limiting the extent of the measurement of x. Further investigation is needed to push hadron detection closer to the beam pipe and to improve MC models.

No beam-related background contributions were considered in these studies. These may have a significant effect on kinematic reconstruction in the forward regions and future studies will include background effects.

References

1. M. Acciarri *et al.*, *Phys. Lett.* B **453**, 333 (1999).
2. T. Sjöstrand, *Comp. Phys. Comm.* **82**, 74 (1994).