RECENT RESULTS FROM TRISTAN

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Representing the TRISTAN Collaborations

ABSTRACT

I report here on recent results from the three major TRISTAN experiments: VENUS, TOPAZ, and AMY. These include a neural network analysis of $b\overline{b}$ forward-backward asymmetry, a measurement of the running of α_s, evidence for color coherence, measurement of the photon structure function F_2 up to $Q^2 = 390$ (GeV/c)^2, and a measurement of charm production in two-photon events.

1 Introduction

1.1 TRISTAN the Machine

The TRISTAN facility at KEK, the National Laboratory for High Energy Physics in Japan, is an electron-positron collider which has operated at center-of-mass energies between 52 GeV and 64 GeV. An overview of the facility is shown in Fig. 1. The first collisions at TRISTAN were attained in November 1986, exactly the date that had been announced four years earlier at the inaugural ceremony. In addition to its "on-time" schedule, TRISTAN was remarkable in other ways. It achieved a peak luminosity of 4.5×10^{31} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ which exceeded the design luminosity by about a factor of four. It was also the first accelerator to make extensive use of superconducting RF cavities which supplied 40% of the RF power at TRISTAN. This program was a notable success.

The experimental program at TRISTAN was conducted by the three large-scale, multipurpose detectors VENUS, TOPAZ, and AMY, shown in Fig. 2. A fourth detector, SHIP, operated during the first few years of TRISTAN running and searched for highly ionizing tracks by surrounding one of the interaction regions with sheets of CR-39 plastic. As of the end of 1994, TRISTAN had delivered more than 300 pb^{-1} of integrated luminosity to each of the three large-scale detectors. The AMY detector finished data-taking in June 1994 while TOPAZ and VENUS will run until June 1995 to accumulate a total of more than 400 pb^{-1} of integrated luminosity. In 1995, TRISTAN will be shut down for installation of the KEK B-factory.

1.2 TRISTAN the Physics

Unlike LEP and the SLC, TRISTAN does not operate at the highest collision energy and does not enjoy the large cross section at the Z resonance. However, because of its unique energy range around 60 GeV, its physics program is unique.

Figure 1: The KEK laboratory with the various components of the TRISTAN facility indicated.

Figure 2: The three multipurpose detectors.

At TRISTAN energies, the electron-positron annihilation cross section is near a minimum. Although this leads to a low event rate, it can provide a sensitivity to new physics since the Standard Model background is small. Also, at TRISTAN, the forward-backward asymmetries are nearly maximal and provide an important check of the Standard Model away from the Z peak. In the area of QCD studies, which are generally limited by systematic uncertainties, TRISTAN has made important contributions despite the greater statistical precision of LEP. Finally, TRISTAN provides the best conditions for studying two-photon physics. The two-photon cross section increases with increasing center-of-mass energy. TRISTAN is the highest center-of-mass electron-positron collider except for LEP and SLC, both of which have lower integrated cross sections and which suffer from annihilation background. As a result, TRISTAN experiments have accumulated the most two-photon events and have attained the largest reach in Q^2 for studying the photon structure function.

In this report, I will review the recent results on:

- $b\bar{b}$ forward-backward asymmetry,
- running of α_s,
- measurement of color coherence in jet fragmentation,
- measurement of the F_2 photon structure function, and
- charm production in two-photon events.

2 Electroweak Physics

2.1 $b\bar{b}$ Forward-Backward Asymmetry

The AMY group has undertaken a study of $b\bar{b}$ forward-backward asymmetry using a neural network analysis. Previous analyses by LEP, PEP, PETRA, and TRIS-

TAN groups have relied on strong cuts on the transverse momentum of leptons in order to enhance the sample of $b\overline{b}$ events. Backgrounds from $c\overline{c}$, $b \to c \to l$, and events with a pion misidentified as a lepton are then subtracted through reliance on a Monte Carlo simulation.

As an alternative method, the AMY group has used a neural network to classify each event as $b\overline{b}$ or background on an event-by-event basis. Events used in the neural network analysis were those containing a muon with transverse momentum > 0.4 GeV. The relationship between the number of observed events, N, and the true number of events, n, is given by the following:

$$\begin{aligned} N_{b\bar{b}} &= \epsilon_{b\bar{b}} n_{b\bar{b}} + (1-\epsilon_{bkg}) n_{bkg} \\ N_{bkg} &= \epsilon_{bkg} n_{b\bar{b}} + (1-\epsilon_{b\bar{b}}) n_{b\bar{b}}, \end{aligned}$$

where $\epsilon_{b\bar{b}}$ and ϵ_{bkg} are the fraction of $b\overline{b}$ and background events that are identified by the neural network as $b\overline{b}$ events. The values of $\epsilon_{b\bar{b}}$ and ϵ_{bkg} are determined by running the neural network on Monte Carlo events. After the values of $N_{b\bar{b}}$ and N_{bkg} are determined, the above equations are inverted on a bin-by-bin basis in $\cos\theta$ to obtain $n_{b\bar{b}}$ as a function of $\cos\theta$ from which the observed asymmetry can be obtained, as shown in Fig. 3. The Born level asymmetry is obtained from the observed asymmetry by a Monte Carlo unfolding. The result is in agreement with the Standard Model prediction in which $B\overline{B}$ meson mixing is included, as shown in Fig. 4.

3 QCD Physics

3.1 Running of α_s

The TOPAZ group has made a study of the running of α_s by comparing measurements from three experiments run at different center-of-mass energies. These are:

Figure 3: The differential cross section for $b\overline{b}$ production. The solid line is a fit.

Figure 4: The measured Born forward-backward $b\overline{b}$ asymmetry. The solid curve is the Standard Model including $B\overline{B}$ meson mixing. The dashed curve is without mixing.

- the TPC/2γ detector at PEP; $\sqrt{s} = 29$ GeV,
- the TOPAZ detector at TRISTAN; $\sqrt{s} = 58$ GeV, and
- the ALEPH detector at LEP; $\sqrt{s} = 91.2$ GeV.

Previously, results from different experiments have been compared. However, this was the first attempt to compare results using the same analysis procedures, the same theoretical calculations, and the same Monte Carlo simulation. The Durham jet clustering algorithm,

$$y_{ij} \;=\; \frac{2min(E_i^2, E_j^2)}{E_{vis}^2}(1 - \cos\theta_{ij})$$

was used. The quantity $L = -\ln y_3$, with y_3 the value of y in the algorithm for which a given event changes from a two-jet to a three-jet event, was measured and compared with a calculation based on an all-order resummation matched to the exact $O(\alpha_s^2)$ calculation. Parton showering and hadronization were simulated by the JETSET 7.3 Monte Carlo. The average values of L obtained from R matching and $\ln R$ matching were used. The comparison was made over the range $1.2 < L < 4.4$ in which corrections due to hadronization effects were less than 20%. Figure 5 shows the dependence of the determined values of α_s as a function of the renormalization point μ. Since in the range of $-1 < \ln(\mu^2/ECM^2) < 1$ the obtained value does not depend strongly on μ, values were averaged over this range. Figure 6 shows the values for the three experiments at the different center-of-mass energies. Allowing α_s to run gives a fit value for $\Lambda_{\overline{MS}}$ of 350 MeV with a $\chi^2 = 0.68$ for two degrees of freedom. Requiring α_s to be constant gives a fit value of α_s of 0.130 with a fit $\chi^2 = 15.0$ for two degrees of freedom.

3.2 Color Coherence

In a simple model, the ratio of the particle multiplicity of gluon jets to the particle multiplicity of quark jets is determined by the ratio of the gluon to quark color

Figure 5: The measured values of α_s obtained at three center-of-mass energies as functions of $\ln{(\mu^2/s)}$. The two curves for each energy indicate the values obtained with R and $\ln r$ matching.

Figure 6: The measured values of α_s obtained at three center-of-mass energies. The curve indicates the QCD prediction with the best fit result of $\Lambda_{\overline{MS}} = 350$ MeV.

factors and is 2.25. However, this ratio has been measured by several groups to be about 1.3. One explanation for this suppression may arise from color coherence. This results from interference of the amplitudes for soft gluon emission during the parton showering process.[1] A manifestation of this color coherence occurs in the ratio of subjet multiplicity in three-jet to two-jet events. The AMY group has found evidence for this.

The concept of subjet multiplicity is illustrated in Fig. 7. The Durham algorithm is used with a cutoff value $y_1 = 0.007$ to determine the jet multiplicity of an event. A second cutoff parameter $y_0 << y_1$ is then used to determine the cluster (subjet) multiplicity within the jets. The ratio of the average value of $M_3 - 3$ to the average value of $M_2 - 2$ is then measured as a function of y_0 where M_3 is the subjet multiplicity in three-jet events and M_2 is the subjet multiplicity in two-jet events. Figure 8 shows the data and comparisons with several Monte Carlo models: LUND7.3 (JETSET)[2] with coherent and with incoherent parton showering, HERWIG5.7 (Ref. 3), and ARIADNE4.04 (Ref. 4) along with a next-to-leading log calculation.[1] The coherent Monte Carlo models generally agree with the data whereas the incoherent model is in significant disagreement.

4 Two-Photon Physics

4.1 Measurement of F_2

Both the AMY and TOPAZ groups have made measurements of the photon structure function F_2 (Ref. 5). Figure 9 illustrates the definition of the kinematical quantities. The differential cross section is given by

$$\frac{d\sigma}{dE_{tag}d\cos\theta_{tag}} = \frac{4\pi\alpha^2 E_{tag}}{Q^4 y} \times [1 + (1-y)^2]F_2(x,Q^2) - y^2 F_L(x,Q^2)$$

Figure 7: Illustration of the concept of subjet multiplicity.

Figure 8: The measured values of $< M_3 - 3 > / < M_2 - 2 >$ are plotted as a function of y_0 for $y_1 = 0.007$ in comparison with the predictions of the LUND coherent, LUND incoherent, HERWIG, and ARIADNE models, and also with a next-to-leading log calculation.

where: $$\begin{aligned} Q^2 &= -q^2 = 4E_{tag}E_{beam}\sin{(\theta_{tag}/2)}^2 \\ x &= -q^2/2k\cdot q = Q^2/(Q^2+W^2) \\ y &= q\cdot k/p\cdot k = (1-E_{tag}/E_{beam})\cos{(\theta_{tag}/2)}^2 \quad , \end{aligned}$$

and W is the invariant mass of the hadronic system.

Figure 9: Definition of kinematical quantities in two-photon scattering.

Since F_L/F_2 is expected to be about 20% and $y^2/(1-y)^2$ is about 20% for $E_{tag} \approx E_{beam}/2$, the term involving F_L can be ignored. The measurement thus provides a rather direct determination of F_2. For comparing the experimental measurements with theoretical predictions, several different models were used for various contributions to the differential cross section. A perturbative QCD model by Field, Kapusta, and Poggioli (FKP)[6] was used to simulate contributions of the light quark (u, d, s) to F_2. The quark parton model (QPM)[7] was used for the heavy quark (c, b) point-like contribution. Finally, the vector meson dominance model (VMD) was used for the hadronic part. A transverse momentum parameter p_t^0 defines the boundary between the perturbative and hadronic regimes.

Taking an average over the range $0.3 < x < 0.8$, the following values are obtained:

$< F_2/\alpha >$	$< Q^2 >$ (GeV/c)^2	Experiment
0.38 ± 0.08	16	TOPAZ
0.63 ± 0.07	73	AMY
0.49 ± 0.15	80	TOPAZ
0.72 ± 0.37	338	TOPAZ
0.85 ± 0.18	390	AMY

These results are plotted in Fig. 10 along with values from other experiments. Included in the figure are the FKP predictions for various p_t^0 values. The data are consistent with a $\ln Q^2$ dependence. A fit to the FKP prediction gives a value of $p_t^0 = 0.45 \pm 0.07$ GeV.

4.2 Charm Production in Two-Photon Events

A measurement of the amount of charm produced in two-photon events is of particular interest. The charm production cross section is more sensitive to the gluon content of the photon structure than are the lighter quark cross sections. In addition, the theoretical calculation of the charm production cross section is simpler than for the lighter quarks and therefore has been completed to higher orders in α_s. Also, the charm production is less sensitive to cut-off parameters such as p_T^{min} and the background from the hadronic (VDM) part is very small.

The TOPAZ group has used two methods for identifying charm. One is by full reconstruction of the process $D^{*+} \rightarrow D^0\pi^+$ followed by $D^0 \rightarrow K^-\pi^+x$ along with the charge-conjugated process.[8] Here, the D^0 is first reconstructed and then the mass difference $M(\pi^+) - M(D^0)$ is determined. The second method looks for soft pions resulting from $D^* \rightarrow D^0\pi^+$ (Ref. 9).

Figure 10: The Q^2 evolution of the structure function F_2 for the x-region between 0.3 and 0.8. The c- and b-quark contributions are subtracted. Included in the figure are the FKP(uds) + VMD predictions for $p_T^0 = 0.1$ (dotted), 0.5 (solid), and 1.0 (dashed). The VMD contribution (dot-dashed) is indicated separately.

In the D^* reconstruction method, D^*'s were measured in range of transverse momentum with respect to the beam axis of 1.6 GeV/c $< p_T^{D^*} <$ 6.6 GeV/c. Since the lower $p_T^{D^*}$ region is sensitive to the charm quark mass and to the renormalization scheme, only data with $P_T^{D^*} >$ 2.6 GeV/c were used. Integrating over 2.6 GeV/c $< p_T^{D^*} <$ 6.6 GeV/c and $|\cos\theta_{D^*}| < 0.77$ where θ_{D^*} is the angle of the D^* with respect to the beam axis, the cross section is 11.35 ± 3.64 pb. The corresponding calculated cross section using a direct (QPM) plus LAC1[10] model with an average gluon $p_t = 0.44$ GeV is 5.59 pb. The measured value is in excess by 1.6 σ.

Because of the small mass difference between D^* and D^0, the p_T of the pion with respect to the D^* direction in the process $D^* \rightarrow D^0\pi^+$ is about 40 MeV/c. In the soft pion method, the distribution of p_T^2 of pions with respect to the axis of the jet with which it is associated is measured and the charm production is indicated by an excess at low p_T^2.

The background in the p_T^2 distribution due to noncharm production was estimated by Monte Carlo incorporating LAC1[10] and VMD models normalized to the data for $p_T^2 > 0.02$ (GeV/c)^2. The following function

$$MC \times (a + bp_T^2) \ + \ Ae^{-p_T/\beta}$$

was fitted to the data as shown in Fig. 11 where MC is the Monte Carlo distribution and a, b, A, β are parameters determined by the fit. The Monte Carlo distribution was multiplied by $(a + bp_T^2)$ to account for higher order effects. The second term in the function above represents the signal due to charm. A Monte Carlo was used to determine a conversion matrix and to unfold the $d\sigma_{D^*}/dp_T$ distribution from the measured $d\sigma_\pi/dp_T$ distribution. The $d\sigma_{D^*}/dp_T$ distribution is shown in Fig. 12. The open circles are from the full reconstruction analysis, the open squares are from the soft pion analysis, and the closed squares are from the combined analysis. Integrating over 2.6 GeV/c $< p_T^{D^*} <$ 6.6 GeV/c and $|\cos\theta_{D^*}| < 0.77$, the cross section from the soft pion analysis is 10.60 ± 2.20 pb.

The measured value is in excess by 2.3 σ. An average of the two methods gives 10.70 ± 1.83 corresponding to a 2.8 σ excess.

Figure 11: Distributions of p_T^2: (a) for soft π^+, (b) for soft π^-, (c) in the forward direction, (d) in the backward direction, (e) for positive charge asymmetry, and (f) for negative charge asymmetry. The data points are background subtracted. The solid lines are the best fit to the function given in the text.

5 Summary

The recent results from TRISTAN reported on here are:

- The Standard Model with $B\overline{B}$ meson mixing agrees with the measured forward-backward $b\bar{b}$ asymmetry.

- The QCD coupling strength α_s has been shown to run as expected by comparison of results obtained from three experiments at different center-of-mass energies using the same analysis techniques.

- Evidence for the color coherence effect has been seen in the ratio of subjet multiplicities in three-jet to two-jet events.

- The photon structure function F_2 has been measured at the highest Q^2 value and is in agreement with QCD predictions.

- An excess of charm in two-photon events is seen at about the 3 σ level.

TRISTAN has been a highly productive facility with many unique measurements made as a result of its unique energy range. The conversion of the TRISTAN infrastructure at KEK to a B-factory is now eagerly awaited.

Figure 12: The differential cross section for D^* vs. p_T. The open circles are for the full reconstruction method, the open squares are for the soft pion method, and the closed squares are for the combined results. The histograms are the theoretical predictions. The cross-hatched area is the direct process. The singly-hatched area is the resolved process (LAC1).

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References

[1] S. Catani, B. R. Webber, Y. L. Dokshitzer, and F. Fiorani, Nucl. Phys. B **383**, 419 (1982).

[2] T. Sjostrand, Comp. Phys. Comm. **43**, 367 (1987).

[3] G. Marchesini and B. R. Webber, Nucl. Phys. B **310**, 461 (1988).

[4] L. Lonnblad, Comp. Phys. Comm. **71**, 15 (1992).

[5] AMY Collab., S. K. Sahu et al., Phys. Lett. B **346**, 208 (1995); TOPAZ Collab., K. Muramatsu et al., Phys. Lett. B **332**, 478 (1994).

[6] J. H. Field, F. Kapusta, and L. Poggioli, Phys. Lett. B **181**, 362 (1986).

[7] V. M. Budnev et al., Phys. Rep. **15**, 181 (1975).

[8] TOPAZ Collab., R. Enomoto et al., Phys. Rev. D **50**, 1879 (1994).

[9] TOPAZ Collab., R. Enomoto et al., Phys. Lett. B **328**, 535 (1994).

[10] H. Abramowicz, K. Charchula, and A. Levy, Phys. Lett. B **269**, 458 (1991).