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A MONTE CARLO MODEL TO PRODUCE BARYONS IN e^+e^- ANNIHILATION

by

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A Monte Carlo Model to Produce Baryons in e^+e^- Annihilation

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The fragmentation models of Field and Feynman¹⁾ and Anderson et al.²⁾ have had remarkable success in describing a number of processes, including the annihilation of electrons and positrons into hadrons via a virtual photon. Some modifications to their original models were necessary when higher energies became available with PETRA. Five quark flavors (charm and bottom in addition to up, down, and strange quarks)^{3,2)} had to be produced and corrections due to quantum chromodynamics⁴⁻⁶⁾ had to be applied. With these modifications the models were found to reproduce the data very well. However, the models have the shortcoming in that they do not include baryons, although experiments⁷⁾ show that baryons are copiously produced in e^+e^- annihilations.

This paper describes a simple and naive model for producing baryons in e^+e^- annihilations⁸⁾. Its basic idea leans heavily on the Field-Feynman approach which assumes quark fragmentation to proceed via the production of a quark-antiquark pair as the vacuum is polarized by the passage of the quark. This quark and the antiquark form the pair combine to form a meson. The quark left from the pair proceeds to polarize the vacuum again to form a second meson. This process continues until not enough energy is left to form another meson (Fig. 1a). The kinematics of the process are described by a fragmentation function

$$f^m(z) = (1 - a_m) + 3a_m(1 - z)^2$$

where $z = (E / p_{Tm}) / (E + p_{Tq})$ is the fractional energy transferred to the meson m from the quark q , and by a transverse momentum dependence which is assumed to be $\exp(-k_T^2 / 2\sigma_q^2)$. The constants a_m and σ_q are free parameters of the model. A further free parameter determines the flavor of the quark-antiquark pair produced in the sea (only u, d, s quarks) and another one gives the relative ratio of pseudoscalar to vector mesons P/V produced in the fragmentation process.

To add baryon production we shall assume that from time to time two quark-antiquark pairs are produced in the sea rather than one. The two quarks may then align with the fragmenting quark and combine to form a baryon. The two antiquarks will polarize the vacuum and form an antibaryon with an antiquark (Fig. 1b). At each step in the fragmentation process the probability

Abstract:

A simple model is described extending the Field-Feynman model to baryon production in quark fragmentation. The model predicts baryon baryon correlations within jets and in opposite jets produced in electron-positron annihilation. Existing data is well described by the model.

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for this to occur is given by a new free parameter P_{B1} and must be fixed by comparing the model with data. This model has the immediate consequence that baryon and antibaryon are produced next to each other in the fragmentation chain. The resulting correlation in a longitudinal variable like rapidity should be experimentally verifiable.

In order to allow also for the possibility that baryons are the leading particles in the opposite jets a second mechanism is considered. A quark-antiquark pair is produced in the sea. It aligns itself with the original quark-antiquark pair in such a way that the two quarks together and the two antiquarks, respectively, initiate the fragmentation process in each jet (Fig. 1c). Although it may be possible to compute the probability for this process from the process shown in Fig. 1b, it is treated in this model as an additional free parameter (P_{B2}). Evidently this mechanism will lead to baryon baryon correlations between opposite jets.

Just as in the meson case, the kinematics of the fragmentation into a baryon must be described by a fragmentation function and a transverse momentum dependence. Since a large amount of data, which is not available yet, would be required to fix these parameters the model calculations shown below assume the shape of the baryon fragmentation function and transverse momentum dependence to be the same as for mesons. Similarly, the ratio between the production of baryons in the octet or decuplet O/D is set equal to P/V . The flavor of the two quarks produced in the sea is determined independently of each other by the same ratio of $u, d,$ and s quarks as for single quarks in meson production. Since $s/(u + d) = 0.25$ one would expect a sizeable production of cascade particles (e.g. the Ξ), in fact the calculation described below predict $\Xi + \bar{\Xi} / \Lambda + \bar{\Lambda}$ to be about 20%.

A difficulty remains: while all baryons in the octet and decuplet are well known and their decays and branching ratios have been measured, very little is known about charmed and bottom baryons. For the charmed baryon model calculations exist, of which one⁹⁾ was used in this Monte Carlo event generator to determine branching ratios. Baryons containing bottom quarks have been excluded; this however should have little effect on the use of the model, since bottomed baryons are expected to occur in only about 1% of the events.

A computer program has been written to incorporate the features of this

model. The parameters P_{B1} and P_{B2} which determine the overall rate of baryon production were fixed by comparing the predictions of the model with data obtained by the TASSO¹⁰⁾ and JADE¹³⁾ collaborations at PETRA on the production of protons and antiprotons in the momentum range of 0.5 GeV/c to 2.0 GeV/c at center of mass energies $\sqrt{s} = 30$ GeV and 34 GeV respectively. A value of $P_{B1} = 0.075$ describes the number of protons and antiprotons in this momentum range well, while the data is not sensitive to the value of P_{B2} .

All other parameters affecting the baryons were set equal to those similar parameters affecting mesons. The latter ones had been determined by the TASSO group in an analysis to measure the strong coupling constant α_s ¹¹⁾ (using a Monte Carlo event generator not including baryons). The values of the parameters used in the calculations are

$$\begin{aligned} \text{mesons } a_m &= 0.56 & \sigma_q &= 0.32 \text{ GeV}/c & P/V &= 1.27 & u = d &= 2s \\ \text{baryons } a_B &= 0.56 & \sigma_q &= 0.32 \text{ GeV}/c & O/D &= 1.27 & u = d &= 2s \\ P_{B1} &= 0.075 & P_{B2} &= 0.075 & \text{ or } & 0.0. \end{aligned}$$

Very little other data exists to compare the model with. However, recently the inclusive lambda cross section up to values of Feynman x of 0.6 has been measured by the TASSO collaboration¹²⁾ and the JADE collaboration¹³⁾. Fig. 2 shows the data compared to predictions of this model and good agreement is obtained up to the highest x points. The curves in Fig. 2 show also that the effect due to the parameter P_{B2} is relatively small. Clearly correlations between baryons in opposite jets need to be measured to show the existence of the process shown in Fig. 1c.

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Figure Captions:

- Fig. 1a Diagram for $e^+e^- \rightarrow$ mesons.
- Fig. 1b Diagram for $e^+e^- \rightarrow$ mesons and baryons.
- Fig. 1c Diagram for $e^+e^- \rightarrow$ mesons and baryons with leading baryons in each jet.
- Fig. 2 Inclusive spectra of protons, antiprotons, lambdas, and anti-lambdas. Data by the TASSO¹⁰⁻¹² and the JADE¹³ Collaborations. (All data points have been scaled with W^{-2} to the energy of 33 GeV).
Solid curves: $P_{B1} = P_{B2} = 0.075$.
Dashed curves: $P_{B1} = 0.075, P_{B2} = 0$.

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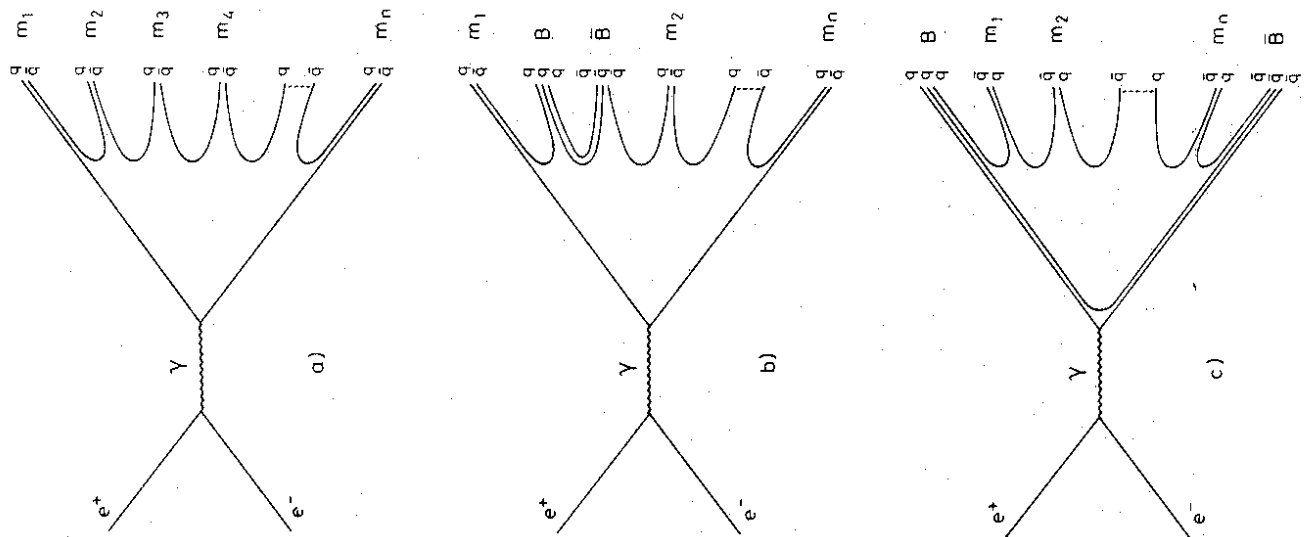


Fig. 1

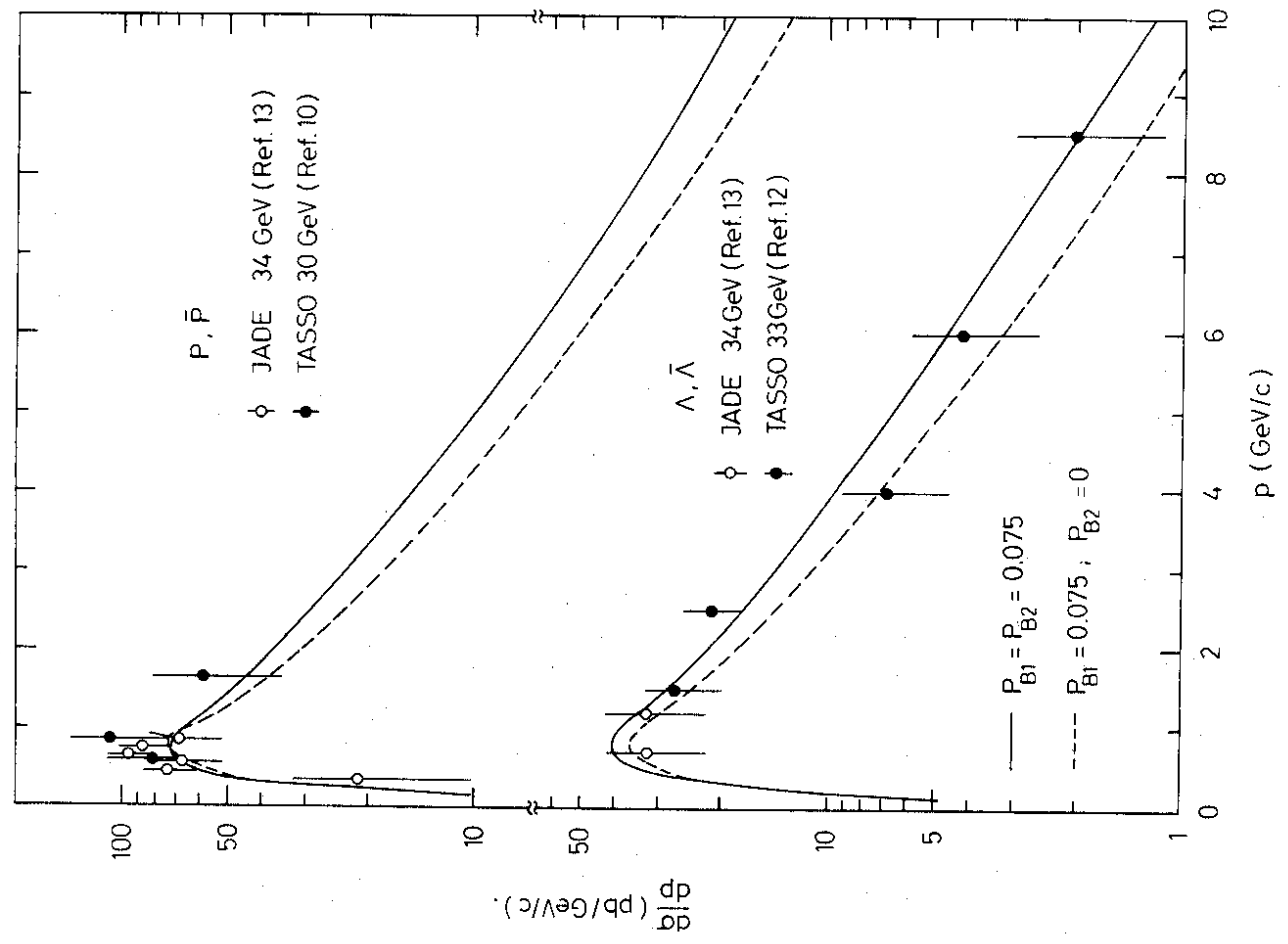


Fig. 2