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Issues for High-Luminoisity Fixed-Target Rare-*B*-Decay Experiments*

D. Kaplan
Northern Illinois University
DeKalb, Illinois 60115

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Daniel M. Kaplan
Northern Illinois University

1 Introduction

Fermilab E789[1,2] is the prototype of a new approach to the study of heavy-quark decays using fixed target. The apparatus acceptance is restricted to charged particles of relatively large momentum ($\gtrsim$10 GeV) emerging at relatively large angles ($\geq$20 mrad), allowing operation at high interaction rates. At rates up to 10 interactions per RF-bucket, the experiment may have sensitivity at the level of 10^{-6} per running period for such rare decay modes as $B \to \pi^+\pi^-$.[1]

Could such an approach be extended to give sensitivity to standard-model CP violation in the beauty sector? Since the predicted[3] CP asymmetry in $B \to \pi^+\pi^-$ is of order 10^{-1}, this is a particularly attractive mode to consider. The simplest CP asymmetry would be a difference in absolute rates for $B^0 \to \pi^+\pi^-$ and $\overline{B^0} \to \pi^+\pi^-$, requiring tagging of the b-quark charge for its observation. Assuming a plausible branching ratio of 10^{-5} for $B \to \pi^+\pi^-$,[3] E789 should reconstruct some 30 events per run. In a restricted-acceptance experiment such as E789, the most plausible tagging technique is detection of single muons from semileptonic decay of the B. Since the B semileptonic branching ratios are $\approx$ 10% and the E789 acceptance for muons from B decay is $\approx$ 10%, fewer than 1 tagged event per run would be expected. We are thus looking for at least two orders of magnitude improvement in the product luminosity $\times$ acceptance $\times$ tagging efficiency.

2 Accidentals Background

In a previous note[2] I considered some problems associated with increasing the luminosity by an order of magnitude, to 100 interactions per bucket. Here I consider an additional facet of the problem: rejecting accidental hadron pairs (i.e. pairs of particles from independent proton-nucleon interactions). Since at this rate a typical bucket yields 10^3 charged particles, it is not at all obvious that a hadron-pair trigger can provide a useful level of rejection, or that off-line analysis can distinguish accidental pairs from real ones.

To address this issue, I used the Lund Monte Carlo[4] to simulate single-hadron production in 800-GeV proton-nucleon collisions. To save computer time, I first generated 10^5 Pythia events, histogrammed the distributions vs. p_t and $p_{||}$, and evaluated the range in those variables over which the E789 apparatus has non-zero acceptance: $1 < p_t < 3.5$ GeV, $20 < p_{||} < 120$ GeV. I then found approximate parametrizations[5] to those distributions in the relevant ranges and generated the equivalent of 10^7 Pythia events using those parametrizations. In each event, all generated charged hadrons were traced through a simulation of the E789 apparatus. The 4-momenta of accepted particles were saved to disk. A parametrization of ISR data on charged-particle multiplicity,[6] combined with the distribution of beam-spill duty factor experimentally observed by the E772 collaboration during the 1987 Fermilab fixed-target run, served to normalize the expected rate of accidental hadron-pairs. The resulting pair rate, 36 pairs accepted for 10^5 buckets at 100 interactions/bucket average luminosity, is arguably not reliable within a factor of three, but it does serve to indicate the order of magnitude of the problem. It predicts a hadron-pair rate of 4×10^5 per 20-second beam spill at 100 interactions/bucket.

To evaluate the rejection, I formed pairs from the accepted single hadrons. Each pair was required to have zero electric charge; to be accepted by the apparatus, this meant that one particle needed to have positive p_y, and the other to have negative p_y. If necessary one momentum vector was reflected across the midplane to achieve this. The pair invariant mass was required to satisfy $5 < m < 6$ GeV. To simulate origin in independent interactions, the interaction vertex for each particle was thrown independently within a volume of space typical of the E789 interaction region: $-0.01 < y < 0.01$ cm, $-0.1 < z < 0.1$ cm, and x gaussian with $\sigma = 0.5$ cm. The point of closest approach of the two tracks was then found, and cuts were made on Δx, Δy, and Δz at closest approach: $|\Delta x| < 100\mu$m, $|\Delta y| < 100\mu$m, and$|\Delta z| < 4$ mm. Of 3.4×10^6 pairs, none survived these vertex cuts. This implies a vertex rejection $< 7 \times 10^{-7}$ at 90% confidence level, thus of the 4×10^5 accidental pairs produced per pulse, fewer than 0.3 survive. Of the 1-GeV mass bin considered, only 1% is in the B region within the E789 mass resolution, so the combined rejection leaves fewer than 3×10^{-3} events per pulse, compared with 0.01 $B \to \pi^+\pi^-$ accepted per pulse. Further cuts could have been made on the pair momentum vector (to require that it point to the target) but were not needed to achieve adequate rejection.

3 Conclusion

Accidental hadron-pair background need not limit operation of an E789-type detector at 100 interactions/RF-bucket. This background can be rejected at the necessary level ($< 10^{-8}$) through precise vertex cuts in the off-line analysis. Some on-line vertex rejection is also desirable, to cope with the $>10^5$ accidental pairs produced per pulse. For E789 in particular, rejecting this background will require additional silicon planes to provide resolution in x comparable to the current sub-100-μm resolution in y, and the vertex trigger processor (currently operating only in the $y-z$ view, with rejection at the 10^{-1} level) will need to be upgraded to make use of this x information.

References

1. Fermilab Proposal 789 (revised), D. M. Kaplan and J.-C. Peng, spokesmen, September 1988.

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3. I. I. Bigi and B. Stech, "Non Multa, Sed Multum - Future Lessons from Two-Prong, Two-Body Decays of Beauty," in **Proceedings of the Workshop on High Sensitivity Beauty Physics at Fermilab**, A. J. Slaughter, N. Lockyer, and M. Schmidt, eds., Fermilab, November 1987, p. 239.

4. T. Sjostrand, Computer Phys. Comm. **27** (1982) 243. I used Pythia version 4.8.

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6. W. Thomé et al., Nucl. Phys. B129, 365 (1977).