Pion tag of B meson flavour at HERA-B

C.H.Shepherd-Themistocleous[a]

[a] Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, D-22603 Hamburg, FRG

Abstract: The high rate of P–wave B mesons, recently measured at LEP, enables their use for tagging the flavour of neutral B mesons at HERA–B. A tagging power of 0.21 is found. This power is comparable to that of the conventional techniques.

1 Introduction

The study of $\mathcal{CP}$ violation at HERA-B requires the tagging of the initial flavour of a neutral B meson. It has been suggested that pions produced in b fragmentation may provide such a tag [1]. This type of tag has the advantage that no information from the $\overline{\mathrm{B}}$ hadron containing the associated b quark is required. The presence of narrow resonant states of b and light quarks decaying into $\mathrm{B}^0\pi$ would enhance the performance of such a tagging method. A further advantage is that good particle identification, as in the case of the kaon tag, is not a requirement for this tag.

Recent results from LEP [2] experiments have demonstrated the existence of, at least, the two predicted narrow P-wave B resonances[1]. It has also been established that pions both from B^{**} resonances and those that do not come from the decay of a B^{**} (refered to as non-resonant pions here) provide useful flavour tags. When a B^0 meson, which contains a d quark, is formed it implies that a $\overline{\mathrm{d}}$ will exist nearby in phase space. If this $\overline{\mathrm{d}}$ gives rise to a pion then it can only be a π^+ or a π^0. These are the pions that can provide a flavour tag when no B^{**} resonance exists in the event.

2 Modelling

A Monte Carlo simulation that does not include any detector simulation[2] was used. In a comparison of generator level simulation and OPAL data it was found that the purity and efficiency of the tags agreed very well. This implies that the physics and not detector effects are of paramount importance and therefore the use of a generator level simulation for this study at HERA-B is probably reasonable.

[1]a general P-wave B resonance is denoted B^{**} here
[2]Refered to as generator level simulation hereafter.

To retain any correlation there might be between pion charge and B flavour in the case where the B meson has not come from a B^{**} only the PYTHIA 5.7 generator was used.[3] The mean multiplicity for a $B\pi$ invariant mass is 2.0 for PYTHIA alone and 2.4 for PYTHIA+FRITIOF.

The parameters used for the P-wave B mesons are given in the table below. They are essentially taken from reference [3]

B^{**}	Mass (GeV)	Width (MeV)	Decay mode
B_2^+ $P_2(3/2)$	5.77	24	$B^{(*)}\pi^+$; $(B^{(*)}\pi^+\pi^0)^4$
B_1 $P_1(3/2)$	5.76	20	$B^*\pi^+$
B_1^* $P_1(1/2)$	5.67	100	$B^*\pi^+$
B_0^* $P_0(1/2)$	5.67	100	$B\pi^+$

[4]Branching fraction 30%.

There are no experimental measurements of the fractions of the different B^{**} that are produced. The extremes of equal fractions and fractions proportional to 2J+1 (where J is the spin of the B meson) are considered. The purities and efficiencies are not found to be strong functions of B^{**} species therefore the particular choice for this study is not very important.

3 Pion Tags

In all of the following only pions known to have come from the primary vertex are considered. Various kinematic variables were examined. Some of the more successful tagging variables are listed here. The tagging pion was chosen to be the one with the

- maximum cosine of the helicity angle ($\cos\alpha$). That is the angle between the $B\pi$ direction in the laboratory frame and the pion direction in the $B\pi$ centre of mass frame.
- maximum value of the π momentum projected along the B direction (P_ℓ).
- minimum value of the π momentum transverse to the B direction (P_t).
- minimum angle between the B and the π in the laboratory frame.
- value of the invariant mass closest to some particular value (X). The best choice of this value depends upon the masses of the B^{**}, their decay modes and their relative fractions.

Monte Carlo simulation samples with and without P-wave B mesons were studied separately. The purities obtained using these various tags on event samples where all the events contain one particular B^{**} are shown in table 2. The energy of the B in the event is always required to be greater than 40 GeV and pions are only considered if their energy is above 1 GeV.

As can be seen from the table when an invariant mass cut is applied there are no great differences between the tags shown (where the mass tag with the optimum value of X is considered) with the exception of the mass tag for B_1, which is somewhat better than the rest. When no invariant mass cut is applied the mass tag gives the best performance. It should

[3]The standard procedure for the HERA-B environment is to use PYTHIA to generate B hadrons; to keep these particles and then to generate the "rest" of the event with a beam momentum of the original minus that of the B hadrons using FRITIOF. Using this procedure however removes any correlation there might be between pion charge and B flavour in the case where the B meson has not come from a B^{**}.

be noted however that the performance of this tag depends on the value of X used. Since mass measurements do not yet exist for the various P-wave B mesons the estimates of the purities given here may prove to be inaccurate. The performances of the alternative tags do not depend significantly on the actual masses of the B^{**} and are therefore likely to be more reliable. If, for example, the differences between the masses of the B^{**} are found to be larger than expected the performance of the mass tag will be degraded. A further caution with regard to the mass tag is that if the mass difference between the charged and neutral B^{**} is large then simple use of $B^+\pi^-$ correlations to calibrate (or optimise) the performance of the tag for a particular value of X will be incorrect. Cuts in a variety of variables were investigated, but no improvement in the purity was found.

The branching ratio of b quarks to B^{**} is only of the order of 30%. The performance of a pion tag in events that do not contain a B^{**} is therefore important to the ultimate performance of a pion tag of B flavour. The performance of the various tags on Monte Carlo simulation samples that do not contain any P-wave B mesons is given is table 2. Since only the PYTHIA generator was used and no effects due to the interactions of pions with nuclear material are considered it is probable that the numbers presented here are better than can be expected in the data. The purities found for the various tags can again be seen to be similar but are quite low. It is likely therefore that non-resonant pions will not provide a very useful tag at HERA-B. There may still however be a small effect due to the average number of pions with the correct sign being slightly larger than the average number with the wrong sign. This effect is a consequence of the fact that the light quark partner of the one that was used in forming the B meson will combine with another quark and if this forms a charged pion it will have the correct tagging sign. All other fragmentation pion production will be charge symmetric. All pions in an event are considered so that if a $B^0\ \overline{B^0}$ pair is produced the two tagging pions in the event are of opposite charge. If however the other B meson produced is a charged one then the two tagging pions will be of the same charge. This then is the origin of the average number of pions with the correct tagging sign being greater than the average number with the wrong sign.

4 Tagging Powers

The tag quality is characterised by two quantities: the dilution factor D, which determines the observed asymmetry, given the actual one: $A_{CP}^{obs} = D \times A_{CP}$, and the tagging power P, to which the error of the asymmetry measurement is inversely proportional: $\sigma_{A_{CP}} = 1/(P \times \sqrt{N_{B^0}})$. The tagging power is given by $D \times \sqrt{(\text{efficiency})}$. The results are quoted in terms of purity where $D = 2(\text{purity}) - 1 \equiv 1 - 2(\text{mistag fraction})$.

The average of the LEP experimental values gives a fraction of B^0 from B^{**} of $29 \pm 4\%$. A value of 30% is used for the results quoted here. Using a mass cut of $M_{B\pi} < 5.8$ gives a tagging power of 0.18 for the $\cos\alpha$ tag and 0.19 for the mass tag. Removing the mass cut improves the tagging power of the mass tag to 0.21. This is because the purity stays almost constant whilest the efficiency increases. The tagging power of the $\cos\alpha$ tag decreases to 0.12 when the mass cut is removed. A pion tag is likely therefore to be at least as good as the lepton tag reported on in the HERA-B proposal [4] and possibly better.

Assuming isospin invariance this tag can be studied in data using charged $B\pi$ correlations to determine the best tagging variable and to determine the the efficiency and purity. Given a

	Tagging Variable										
B^{**}	$\cos\alpha$		$\|M_{B\pi} - X\|$					P_ℓ		$\theta_{B\pi}$	
		$M_{B\pi}<5.8$		$M_{B\pi}<5.8$					$M_{B\pi}<5.8$		$M_{B\pi}<5.8$
			$X=5.72$	$X=5.72$	$X=5.70$	$X=5.68$	$X=5.66$				
B_2^*	0.56	0.68	0.68	0.70	0.66	0.64	0.63	0.54	0.69	0.57	0.67
B_1	0.55	0.65	0.76	0.78	0.75	0.71	0.66	0.53	0.68	0.55	0.63
B_1^*	0.57	0.68	0.66	0.68	0.68	0.69	0.71	0.54	0.68	0.58	0.67
B_0^*	0.56	0.68	0.69	0.71	0.70	0.71	0.72	0.54	0.70	0.57	0.67

Table 1: Values of purities for pion tags for B flavour where the B comes from a B^{**}. The efficiencies are 99% for no mass cut and 90% for an invariant mass cut of $M_{B\pi}< 5.8$. The B energy is required to be above 40 GeV and only pions with an energy above 1 GeV are considered.

Tagging Variable	Purity	
		$M_{B\pi}< 5.8$
$\cos\alpha$	0.55	0.55
P_ℓ	0.56	0.55
$\theta_{B\pi}$	0.56	0.56
$\|M_{B\pi} - X\|$		
$X = 5.65$	0.57	0.56
$X = 5.70$	0.57	0.56
$X = 5.75$	0.55	0.56

Table 2: Values of purities for pion tags of B flavour where the B does not come from a B^{**}. The efficiency is 97% for no mass cut and 74% for an invariant mass cut of $M_{B\pi}< 5.8$. The B energy is required to be above 40 GeV and only pions with an energy above 1 GeV are considered.

good determination of B^0 mixing, the decay $B^0 \to J/\psi K^*$, where the flavour of the decaying B^0 can be determined from the K^* decay, provides a good channel in which to study tagging because of its similarity to the $J/\psi K^0_S$ channel. The difficulties of simulating the behaviour of the non-resonant pion tag would be overcome in this way.

It may be possible to improve this type of tag by combining some of the tagging variables mentioned. The correlations of the various tagging variables mentioned were investigated [5] and all tags were found to be quite highly correlated. The least correlated tags appear to be the angular ($\theta_{B\pi}$) tag and the mass ($M_{B\pi}$) tag. A simple combination of these results does not however provide an improvement of the tag. The use of a neural net which could be trained on the data, by using charged $B\pi$ correlations may help.

5 Conclusion

The observation of P-wave mesons at LEP [2] has suggested that using pion charge to tag the flavour of neutral B mesons is possible.[5] Using a simple generator level Monte Carlo simulation of HERA-B conditions has suggested that this type of tag will work reasonably well and be at least as good a the lepton tag described in the HERA-B proposal. This tag also does not use information from the other B in the event and is therefore complimentary to the three tags discussed in the proposal.

[5] In a recent conference contribution [6] CDF reports on their observation of B-π flavour charge correlations.

References

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