B-PHYSICS AT D0

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This report presents a study of the capabilities of the D0 detector to do B-related physics by utilizing the presence of a muon both as a trigger and as a tag. The almost complete muon coverage plus the fine calorimeter segmentation will allow D0 to expand upon the B-physics which have been done at UA1 with muons[1]. This report will briefly discuss the physics topics and then will present rate calculations from different muon sources along with studies on how to separate them based upon their topologies and kinematics.

I. Physics Issues

The D0 detector should be able to study a wide range of B-physics items both at high and low p_t. Among them will be:

A. B-production cross sections versus x and p_t including separating direct B-jet production from gluon splitting ($g \to BB$).
B. Searches for heavy states decaying into B's such as $Z^0 \to b\bar{b}$ and $H^0 \to b\bar{b}$.
C. $B^0 - \overline{B}^0$ oscillations through the like-to-unlike sign mu-pair ratio.
D. CP-violation through the dimuon like sign charge asymmetry and other charge asymmetries.
E. Searches for reconstructible rare decays such as ψK_S.

The first two items will depend upon being able to separate different sources of B-jets which will be discussed below. Though a complete study has not been done, by requiring both B's to decay leptonically, kinematic cuts may reduce the background from $g \to b\bar{b}$ and allow $Z^0 \to b\bar{b}$ to be observed. Items C-E are essentially exploring low-p_t events and here the crucial items will be trigger rates and backgrounds from π/K decay and charm. CP-violation at D0 has been discussed elsewhere[2] and only a few comments will be made here. Searches for rare B-decays at D0 have not been studied but the strategy would probably consist of triggering on one $B \to \mu X$ decay which then tags the presence of another B in the event. Decay channels with leptons and/or K_S's could then be reconstructed.

The most accessible CP-violating channel will be the like sign dimuon charge asymmetry $\alpha = (\mu^+\mu^+ - \mu^-\mu^-)/(\mu^+\mu^+ + \mu^-\mu^-)$. While this asymmetry is expected to be small, statistical limits should be close to current theoretical expectations. For example, an integrated luminosity of $10^{37} cm^{-2}$ (5 10^{38}) will give about 10^5 (5 10^6) like-sign dimuon events with a 1 sigma statistical error on α of .003 (.0005). Ignoring backgrounds from non-B decays (which should be correct to within 1.4), this should be compared to the α_{CP} from $B^\pm B_d^0$ decays estimated to be a "few" times 10^{-3}. As we cannot separate $B^\pm B_d^0$ from $B^0 B^0$ decays, a dilution factor of about 3 will reduce our sensitivity. The systematic error is hard to estimate at the current time though events such as $\Upsilon \to \mu^+\mu^-$ and $\psi \to \mu^+\mu^-$ will help in understanding both μ^+/μ^- and $p/\overline{p}$ differences.

It will probably also be possible to look for differences between $BB \to (\mu^+X) + (\psi X)$ and $BB \to (\mu^-X) + (\psi X)$ with the ψ's decaying either to electrons or muons (the

electron channels should have a higher acceptance and better mass resolution). An especially compelling channel is $B \rightarrow \psi K_S$ which is a CP-eigenstate expected to have large asymmetries. A rough calculation which starts from a 0.7 μbarn $B \rightarrow \mu$ trigger rate, assigns a single muon efficiency of 50%, a combined branching ratio for $B \rightarrow (l^+l^-) + (\pi^+\pi^-)$ of 5 10^{-5} and an acceptance/reconstruction efficiency on the ψK_S of .05 will give 100 events for an integrated luminosity of $10^{38} cm^{-2}$. Backgrounds to this channel have yet to be estimated.

II. Muon Rates and Sources

This study has used three sets of ISAJET events to estimate muon rates and the effects of kinematic cuts on separating different muon sources. A large sample of unbiased QCD events ($> 10^6$ total) were generated with p_t's in the ranges 5-10, 10-20, 20-40, 40-80 and 80-200 GeV/c. Only events with at least one lepton (electron or muon) were saved. These were used as a source for $B \rightarrow \mu X$ and $C \rightarrow \mu X$ events. A second sets of events were uncut minimum bias events plus uncut QCD jets from the p_t ranges above and were used to estimate the decay background. Each π or K was assigned a decay and punchthrough probability which then multiplied the cross section weight. Finally, a set of QCD events with $B \rightarrow \mu X$ decays forced were used to study dimuon correlations.

These events were passed through a muon trigger simulator. The p_t dependence of the muon trigger has been calculated previously using Monte Carlo[3] and a parameterization of those distributions were used for this study. The central region can be scaled using p_t with a threshold at about 4 GeV/c due to ranging out in the toroid. The forward trigger scales more with momentum with its threshold at about 10 GeV/c. This value assumes 4" drift cells which is true for angles above 11°. A design for the region from 3° – 11° utilizing 1" cells is being done by the Serpukhov group. This will allow the raising of the p_t threshold in the lower angle region. For now, the trigger acceptance for 4" cells will be used for the entire angular region. The p_t distribution before and after applying the trigger is shown in Figure 1 with the pseudorapidity given in Figure 2.

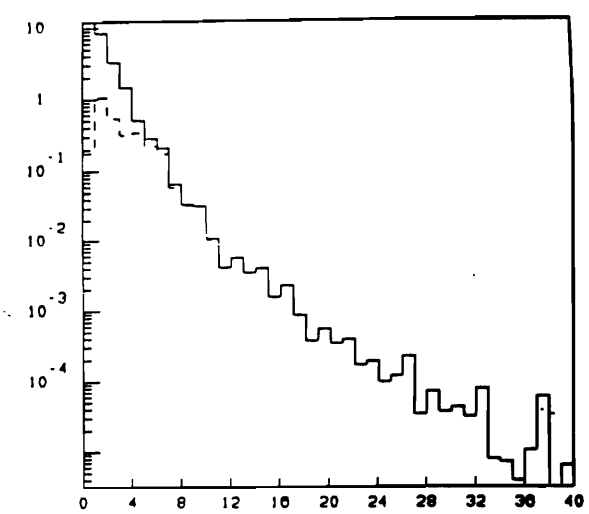

Figure 1. Single muon rate from QCD sources before (solid) and after (dashed) applying the muon trigger (in μb/GeV/c).

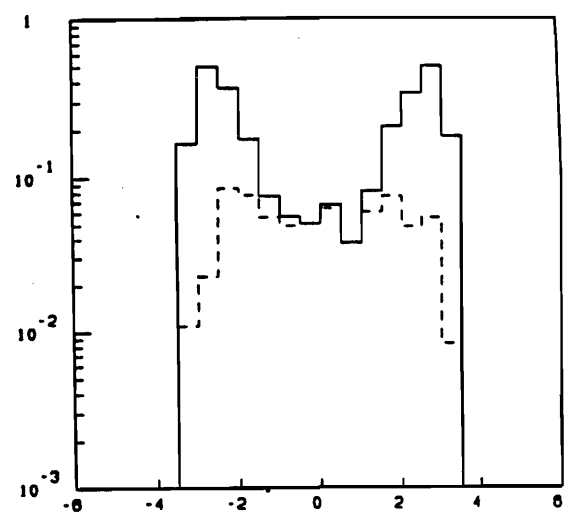

Figure 2 η distributions for all (solid) muons passing the trigger and those with p_t greater than 4 GeV/c (dashed).

The cross sections for muon production from QCD sources are given in Table 1 for both the total and with muon trigger cuts applied. The relative fraction of muons at a given muon p_t from B-decays is given in Figure 3a with the fraction of B's from gluon splitting versus all B-events shown in Figure 3b. It is seen that at $p_{t\mu}$ of 10 GeV/c, 80% of the QCD events come from B.

The muon rate at low p_t (and angles) will be dominated by π/K decays in flight. Due to both its smaller central region and more absorption material, the rates in D0 should be appreciably less than those in either UA1 or CDF. For now we will use ISAJET to determine the decay rates while recognizing that the low-p_t region is the place that is hardest to calculate. Again, a 5° minimum angle will be assumed, though the minimum angle at which D0 will be able to trigger can only be determined using the actual detector. Figure 4 gives the fraction of decays as a function of $p_{t\mu}$ assuming no cuts on the event. Table 2 summarizes the single muon rates (note that at $L = 10^{30}\ cm^{-2}sec^{-1}$ a 1 μb cross section corresponds to 1 Hz) and the dimuon rates assuming at least one of the muons passed the trigger with the other at least making it through the toroid.

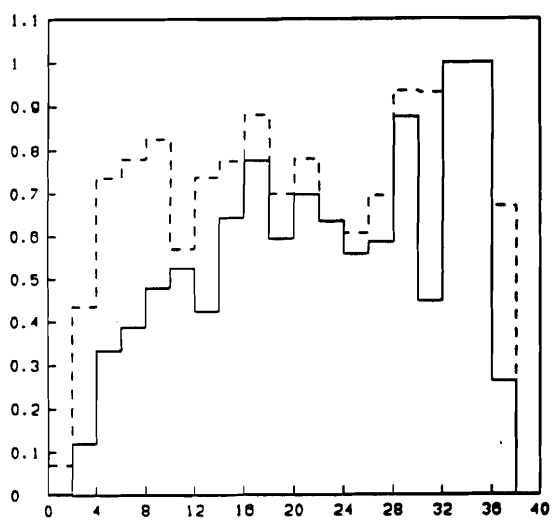

Figure 3a. The fraction of $B \to \mu$ events compared to all QCD sources (no π/K decays) after the trigger for all (solid) and with b-cuts (dashed) versus $p_{t\mu}$.

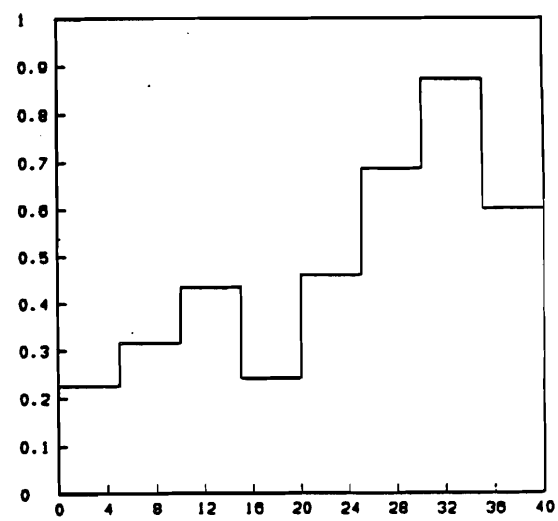

Figure 3b. The fraction of $g \to B \to \mu$ events compared to all $B \to \mu$ sources after the trigger versus $p_{t\mu}$.

Table 1. Muon Sources

Source	Total σ (μb)	Trigger (μb)
All QCD $\to \mu$	26.5	3.0
$C \to \mu$	20.8	1.9
C parton $\to \mu$	13.6	1.6
$B \to C \to \mu$	3.1	0.3
$B \to \mu$	5.3	1.1
B jet $\to \mu$	2.7	0.8
$g \to B \to \mu$	1.1	0.2

Table 2. Muon Trigger Rates

	Source	Raw	Trigger
1 μ	π/K Decays	500	30
	$B, C \to \mu$	15	3
2 μ	$B, C \to \mu\mu$		.17
	$B, C \to \mu + \pi$/K decay		.08

$\theta_\mu > 5°$; rates in μb; no additional cuts

III. Separating Muon Sources

As seen above, a $p_{t\mu}$ cut at about 6 GeV/c will give a sample which is more than half from B-decays. We have looked at enhancing this by decay and kinematic cuts applied to single muon events. No attempts to enhance the B-signal using dimuon correlations have been made.

The average angle between the π/K-direction and its decay muon is 6 mrad for those decay muons which pass the trigger. This obviously depends upon the momentum; for example it is 2 mrad for $p_{t\mu} > 5$ GeV/c. The resolutions of the three inner tracking chambers are 0.3 mrad, 0.7 mrad and 0.7 mrad for the microvertex, central and end chamber systems. These resolutions do not include any vertex or matching enhancements. We have not yet done a study of how well D0 will reject kink events and for now assign a kink cut of 2 mrad. This will tend to eliminate low-p_t decay events.

The second series of cuts relies upon the energy deposition in the calorimeter near the muon. B-decays should produce both fatter jets and more isolated muons compared to C-decays especially at lower-p_t. In both cases, some hadronic activity should be related with the muon as opposed to decays which often come from an isolated π or K. We have looked at this using a perfect detector (no segmentation, resolution or shower size) in order to get a first level feeling for the sensitivity we will have. The three requirements we have tried are ("b-cuts"):

A. $E_T(\Delta R < .3)/p_{t\mu} \quad < \quad 1 + .15 p_{t\mu}$: Isolation
B. $E_T(\Delta R < .3)/E_T(\Delta R < 1)/p_{t\mu} \quad < \quad .05$: Jet Width
C. $p_{t\mu}$ relative to hadron axis > 0.5 GeV/c

where the hadron axis in C. is just the sum of all calorimeter energy in a cone of ΔR less than 1 about the muon (i.e. no clustering)[4]. Distributions for item B are given in figure 5 for B, C and π/K sources. The relative number of $B \rightarrow \mu$ events to the sum of B and C with these cuts is shown in Figure 3a and the fraction of decay muons to all muon sources with both these cuts and the 2 mrad kink cut is given in Figure 4. Taking these results at face value, for $p_{t\mu} > 2$ GeV/c plus b-cuts and the kink cut gives a .5 μb $b \rightarrow \mu$ cross section with about 60% of the muon events coming from B-decays.

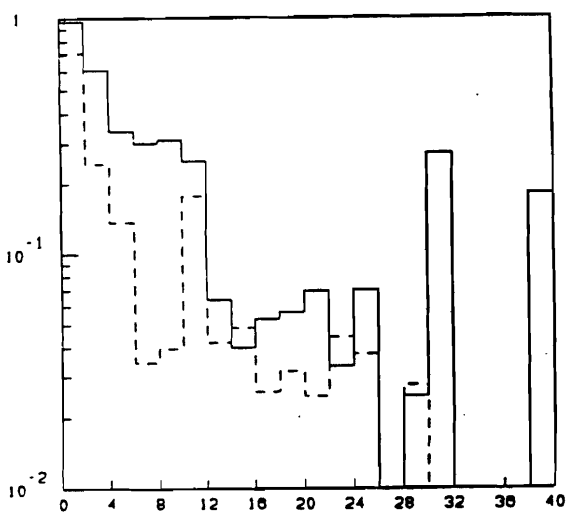

Figure 4. The fraction of muon events passing the trigger from π/K decays versus $p_{t\mu}$ for all (solid) events and those with kink and b-cuts (dashed).

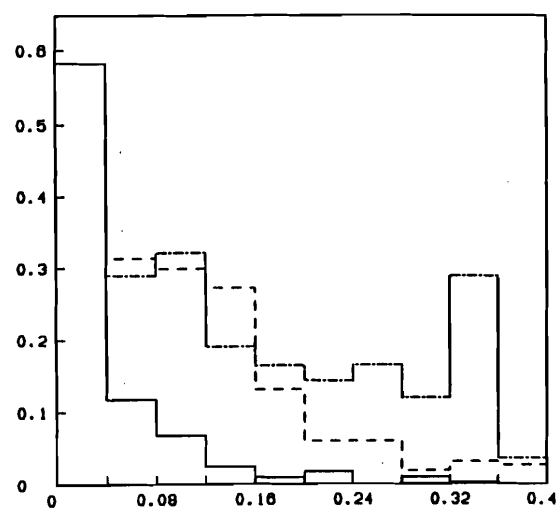

Figure 5. The $E_T(\Delta R < .3)/E_T(\Delta R < 1)/p_{t\mu}$ distributions for muons from B (solid), C (dashed) and π/K (dash-dot) decays.

We also tried to differentiate between direct B production and B's produced by gluon splitting. Following earlier studies[5], we looked at distributions such as the $z = p_{t\mu}/p_{tjet}$, the invariant mass of the jet and the E_T in a small ΔR cone compared to a large one. None of these gave dramatic differences. By far the greatest separation came from looking at the $\Delta\phi_{\mu\mu}$ and $\Delta R_{\mu\mu}$ in dimuon events. Figures 6 and 7 show these distributions for jets with p_t between 20 and 40 GeV/c and for p_t's between 80 and 200 GeV/c. The direct B's are more back-to-back with those from gluon splitting tending to go in the same direction.

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1. C. Albajar et al., Phys. Lett. **186B**, (1987), p. 237 and p. 247. Also, A. Kernan, these proceedings.
2. D. Hedin, D0 Note 574 (1987).
3. D. Green, D0 Note 283 (1985); D. Hedin, D0 Note 362 (1986).
4. $\Delta R = \sqrt{\Delta\phi + \delta\eta}$ is the usual UA1 defined parameter.
5. As an example, see T. Gottschalk, Snowmass-86, 67 (1986).

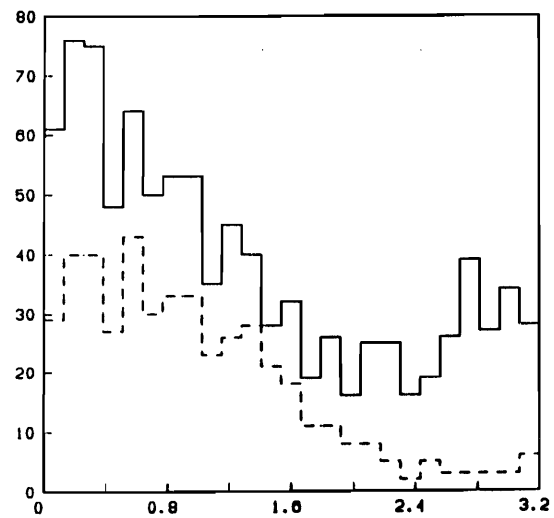

Figure 6a. The $\Delta\phi_{\mu\mu}$ distibutions for $BB \rightarrow \mu\mu$ events from all sources (solid) and gluon splitting for jets with p_t between 20 and 40 GeV/c.

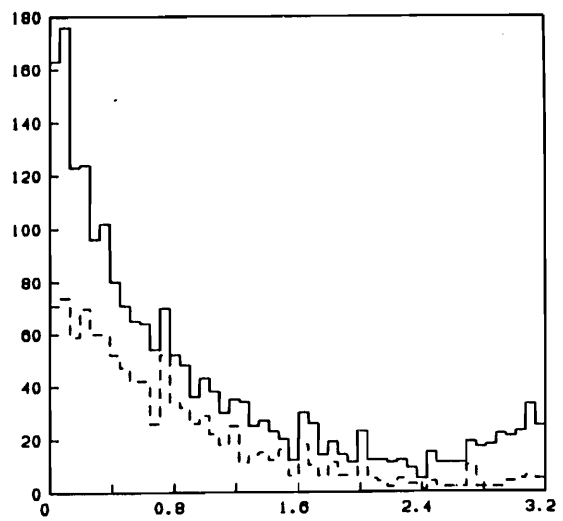

Figure 6b. The $\Delta\phi_{\mu\mu}$ distibutions for $BB \rightarrow \mu\mu$ events from all sources (solid) and gluon splitting for jets with p_t between 80 and 200 GeV/c.

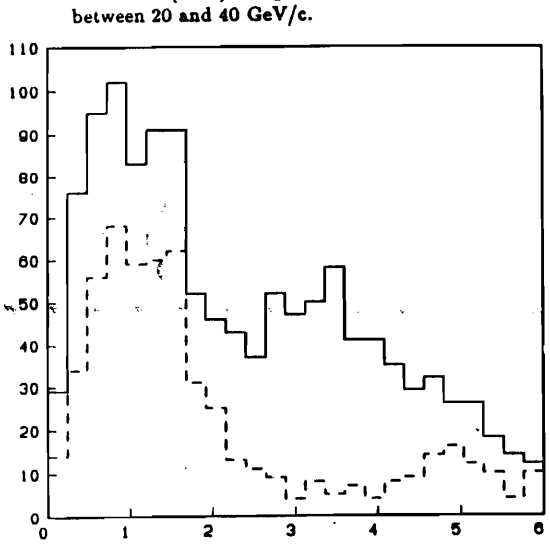

Figure 7a. The $\Delta R_{\mu\mu}$ distibutions for $BB \rightarrow \mu\mu$ events from all sources (solid) and gluon splitting for jets with p_t between 20 and 40 GeV/c.

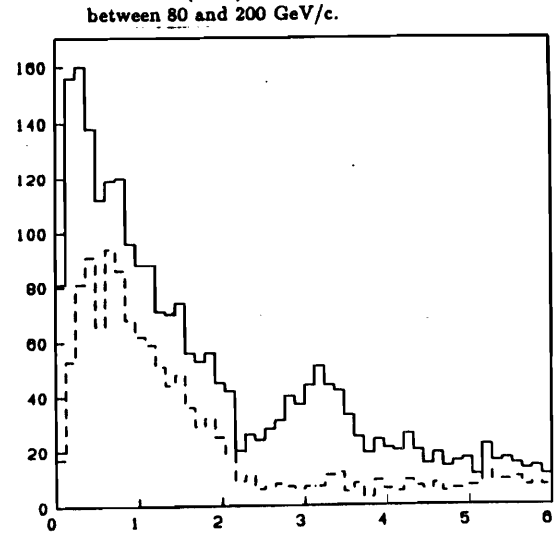

Figure 7b. The $\Delta R_{\mu\mu}$ distibutions for $BB \rightarrow \mu\mu$ events from all sources (solid) and gluon splitting for jets with p_t between 20 and 40 GeV/c.