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Can New Heavy Flavour Thresholds Be Seen in Two Particle Distributions?

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Abstract:

Using muons as triggers for heavy quark (c,b,t,...) events, we study $\mu\mu$ and μK pairs with respect to the relative angle θ. Immediately above a threshold, the new heavy meson decays result in a more spherical particle distribution and hence an essentially flat spectrum in $\cos\theta$. For energies much above such a threshold the events tend to become jetlike and give distributions peaked at $\cos\theta = \pm 1$. The method is illustrated for the case of a top quark with $m_t = 15$ GeV.

1. Introduction

Collective event measures such as sphericity and thrust enjoy great popularity in the search for new heavy flavour thresholds. An alternative to this approach would be to consider the properties of two particle correlations. In particular, the rise of sphericity at a new threshold corresponds to a flatter spectrum in $\cos\theta$, where θ is the relative angle between any two final state particles.

Characteristic of the new heavy mesons is that they are expected to decay weakly, giving muonic semileptonic branching ratios of the order of 10 - 15 % . These decays are, in quark language

$$c \to s\, \mu^+\, \nu_\mu$$

$$b \to c\, \mu^-\, \bar{\nu}_\mu$$

$$t \to b\, \mu^+\, \nu_\mu$$

We will suppose that the weak decays of heavy flavour quarks are of a cascade character: $t \to b \to c \to s$, so that (at least) one K meson will be found in the final state.

Because of the clean way in which a muon can be detected, and because of the characteristic K in the final state, we go on to study $\mu\mu$ and μK pairs.

We will illustrate our considerations with Monte Carlo studies made for the explicit case of a top quark with m_t = 15 GeV. We will consider the situation at E_{cm} = 32 GeV just above threshold. We have also considered T meson decay at 150 GeV/c and the results are very similar to charm and bottom meson decays at 32 GeV. The model used for the heavy meson decays is described in [1]. To generate the events we use a $q\bar{q}$ event generator [2] giving explicit energy, momentum and flavour conservation.

For two-particle correlations, three independent kinematical variables can be used, e.g. the momentum of each particle and the relative angle θ between the momenta. In our studies we have chosen to impose cuts on the momenta and then to study the resulting $\cos\theta$ spectra. Of some interest will also be the difference between like-sign and opposite-sign charged pairs.

2. Muon momentum spectra.

The muon spectra resulting from $c\bar{c}$, $b\bar{b}$ and $t\bar{t}$ events at 32 GeV are shown in Fig. 1. For b decays, we get a muon either in the first decay $b \rightarrow c$ or in the subsequent $c \rightarrow s$. Correspondingly, in t decays, there are three possibilities to obtain a muon (as well as a fourth possibility which we will neglect, i.e. if the t decay results in a heavy lepton τ^+ , the latter may decay into a μ^+). The amount of muons around is consequently expected to rise with each new threshold.

The further down the decay chain the muons are produced, the lower momentum will they have. Thus it is possible to impose momentum cuts so that we will strongly bias for muons produced in the first step of the decay chain.

3. $\mu\mu$ pair correlations

When studying muon pairs, we choose to demand that both muon momenta be larger than 1.5 GeV/c, to avoid low-energy muon pairs where the relative angle is due mostly to chance.

For charm events we will normally have two charmed mesons going out with large oppositely directed momenta, i.e. large $\beta = \frac{p}{E}$, and the decay products of these mesons will be distributed within two opposite narrow cones. We will then have a peak at $\theta \approx 180^{\circ}$. Mesons with low momenta could in principle produce pairs with $\theta \approx 90^{\circ}$, but such muons would have low momentum and are lost in the cut.

The situation will be similar for bottom events, but due to the higher rest mass, the cones will not be so narrow, giving a wider peak at $\theta \approx \approx 180^{\circ}$. Then, with two weak decays on each side, we will also have a peak at $\theta \approx 0^{\circ}$. This shape will be characteristic for any heavy quark high above its threshold.

Looking at top (or another heavy quark just above threshold), the situation will be different. The T and $\bar{T}$ mesons will be formed essentially at rest and then decay independently of each other. Thus, when one muon comes from the T and the other from the $\bar{T}$ decay sequence, the spectrum will be flat in $\cos\theta$. Muons coming from the same decay sequence will give an excess at $\theta > 90^{\circ}$ due to momentum conservation effects.

The situation illustrated in Fig. 2 suggests that one study the expression

$$R_{\mu\mu} = \frac{n(|\cos\theta| < 0.5)}{n_{tot}}$$

where n is the number of muon pairs with each muon having a momentum above some fixed minimum. $R_{\mu\mu}$ may be expected to make jumps upwards as each new threshold is passed, decreasing slowly with increasing energy in between. This is illustrated in Table I.

The main drawback with the method outlined above is that demanding two high-momentum muons in an event will decrease the counting rate appreciably. In the case we study, only some 8% of the $t\bar{t}$ events will survive. We also note that the effects of gluon jets as well as the electromagnetic decays $\rho^0, \omega, \phi \rightarrow \mu^+\mu^-$ may change the situation somewhat. The momentum-cut on the muons will, however, decrease these effects. We have also neglected exclusive channels like e.g. $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$.

4. μK pair correlations.

The kinematical considerations presented for $\mu\mu$ pairs are valid essentially without changes for μK pairs. High above a threshold, muons and kaons are concentrated within two narrow back-to-back cones, while immediately above a threshold the distribution will be essentially flat in $\cos\theta$, with a slight peak at $\theta \approx 180^\circ$ due to momentum conservation. This is shown in Fig. 3, where we have made momentum cuts at 3 GeV/c for the muons and 0.5 GeV/c for the kaons.

Unfortunately, many of these kaons are not end products in the decay chain $t \rightarrow b \rightarrow c \rightarrow s$ but the result of $s\bar{s}$ pairs formed during the jet fragmentation or in the subsequent decays. Hence a more careful study of the effects of e.g. gluon jets would be needed before using some measure $R_{\mu K}$ corresponding to $R_{\mu\mu}$.

A simple way to circumvent this influence is to include the relative charge of the muon and the kaon in the analysis and use the difference $N_{\mu^\pm K^\mp} - N_{\mu^\pm K^\pm}$ rather than the sum. Then the contributions from gluon jets will in principle cancel out.

With the muon momentum cut at 3 GeV/c, most of the muons will stem from the first step of the decay chain (Fig. 1).

For a charge + 2/3 quark high above its threshold, this will give a positive peak at $\theta \approx 0^{\circ}$ and a negative one at $\theta \approx 180^{\circ}$, since we will then have a μ^{+} and/or a K^{-} on one side and a μ^{-} and/or a K^{+} on the other. On the other hand, close to threshold, the μ^{+} and the K^{-} coming from the same dacay chain will, due to momentum conservation, give rise to a positive peak at $\theta \approx 180^{\circ}$. For a charge - 1/3 quark, the positions of the peaks will be reversed, since now a μ^{-} and a K^{-} would come from the same decay chain. Hence we will in principle have a method useful not only to detect a new quark threshold but also to find its charge. We feel, however, that the effects may be too small to be of real practical use, cf. Fig. 4.

We conclude that the study of μ-pair correlations in the relative angle provides a possible way to detect a heavy flavour threshold. The fact that we only use about 10% of the heavy flavour decay signal should be related to the need for a much less complicated detector-setup, or the use of an existing large angle detector together with a simple analysis program.

References

1) T. Sjöstrand,
A Monto Carlo Program for Heavy Quark Jet Generation
Lund Preprint, LU TP 79-8

2) T. Sjöstrand (in preparation)

Table I

Results of Monte Carlo runs at $E_{cm} = 32$ GeV and $E_{cm} = 150$ GeV, with 5000 events of each flavour at the two energies. We give n_{tot}, the total number of muon pairs where both muons have momenta larger than 1.5 GeV/c, $n_{0.5} = n(|\cos\theta| < 0.5)$, the number of events where $|\cos\theta| < 0.5$ as well, and $R_{\mu\mu} = n(|\cos\theta| < 0.5)/n_{tot}$

	n_{tot}	$n_{0.5}$	$R_{\mu\mu}$
$c\bar{c}$, $E_{cm} = 32$ GeV	19	0	0.
$b\bar{b}$, $E_{cm} = 32$ GeV	142	17	0.12
$t\bar{t}$, $E_{cm} = 32$ GeV	386	189	0.49
$c\bar{c}$, $E_{cm} = 150$ GeV	60	0	0.
$b\bar{b}$, $E_{cm} = 150$ GeV	455	6	0.013
$t\bar{t}$, $E_{cm} = 150$ GeV	797	101	0.13

Figure captions

The results of the Monte Carlo calculations at 32 GeV, with 5000 events each for $c\bar{c}$, $b\bar{b}$ and $t\bar{t}$. The distributions obtained, normalized to 1 event, are shown as dots; the hand-drawn curves are only intended as a guide to the eye.

Fig. 1a Muon momentum distribution in $c\bar{c}$ events

1b Muon momentum distributions in $b\bar{b}$ events

—×—×—×—×— in primary decay $b \to \mu \nu_\mu c$

———————— in secondary decay $c \to \mu \nu_\mu s$

1c Muon momentum distribution in $t\bar{t}$ events

—+—+—+—+—+— in primary decay $t \to \mu \nu_\mu b$

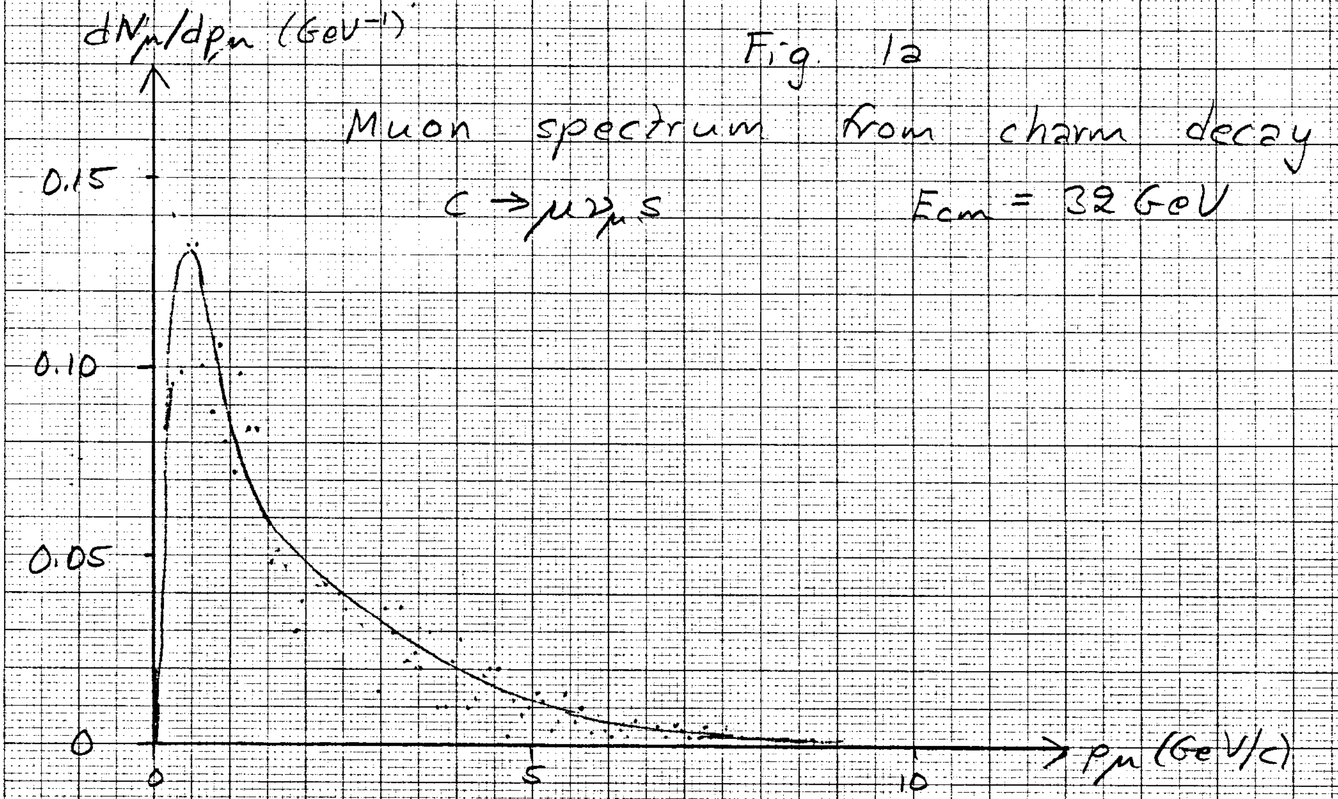
—×—×—×—×— in secondary decay $b \to \mu \nu_\mu c$

———————— in tertiary decay $c \to \mu \nu_\mu s$

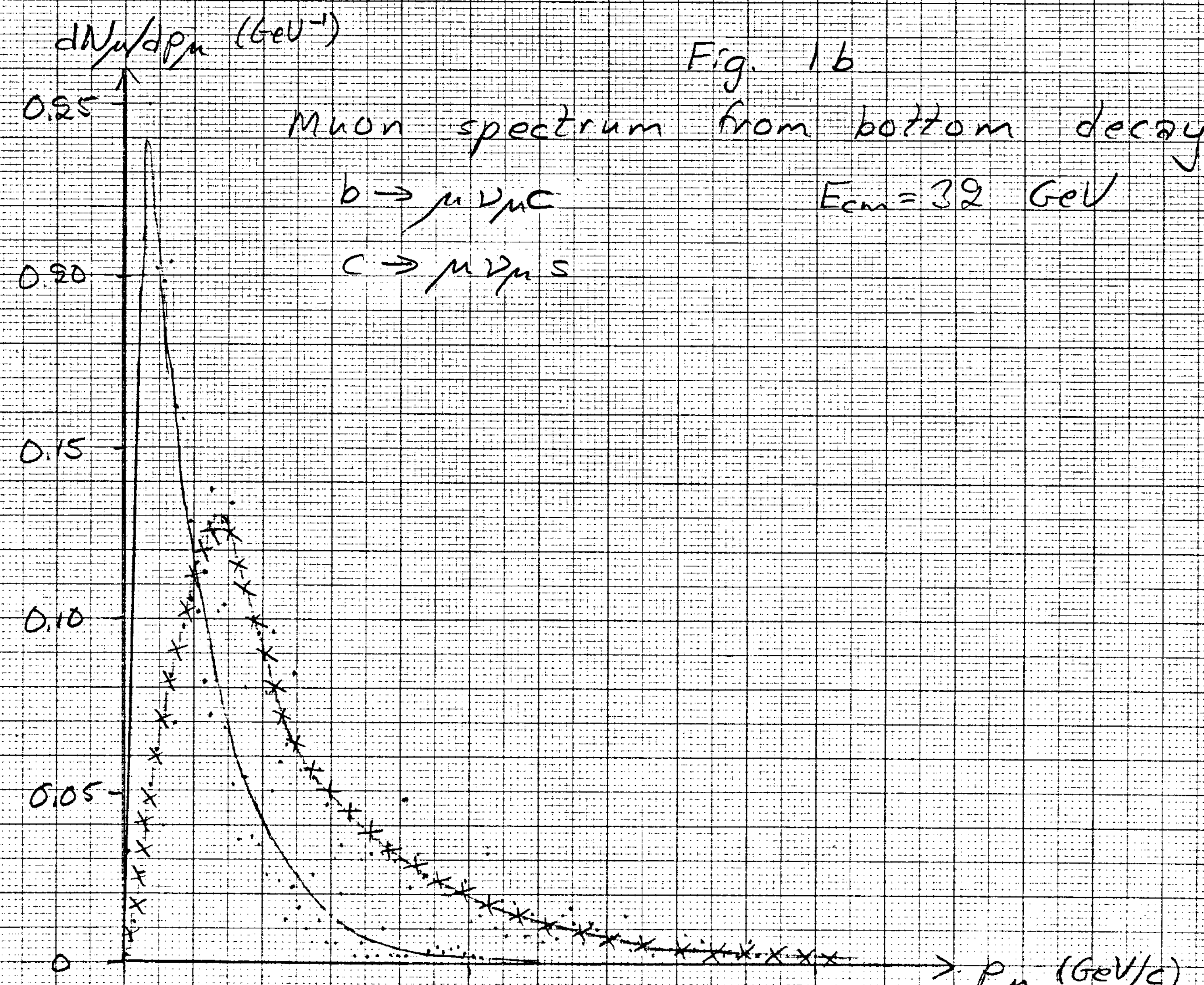
Fig. 2 Relative angle distributions for muon pairs, when both muon momenta are larger than 1.5 GeV/c.

Fig. 3 Relative angle distributions for muon-charged kaon pairs when muon momentum is larger than 3 GeV/c and kaon momentum larger than 0.5 GeV/c.

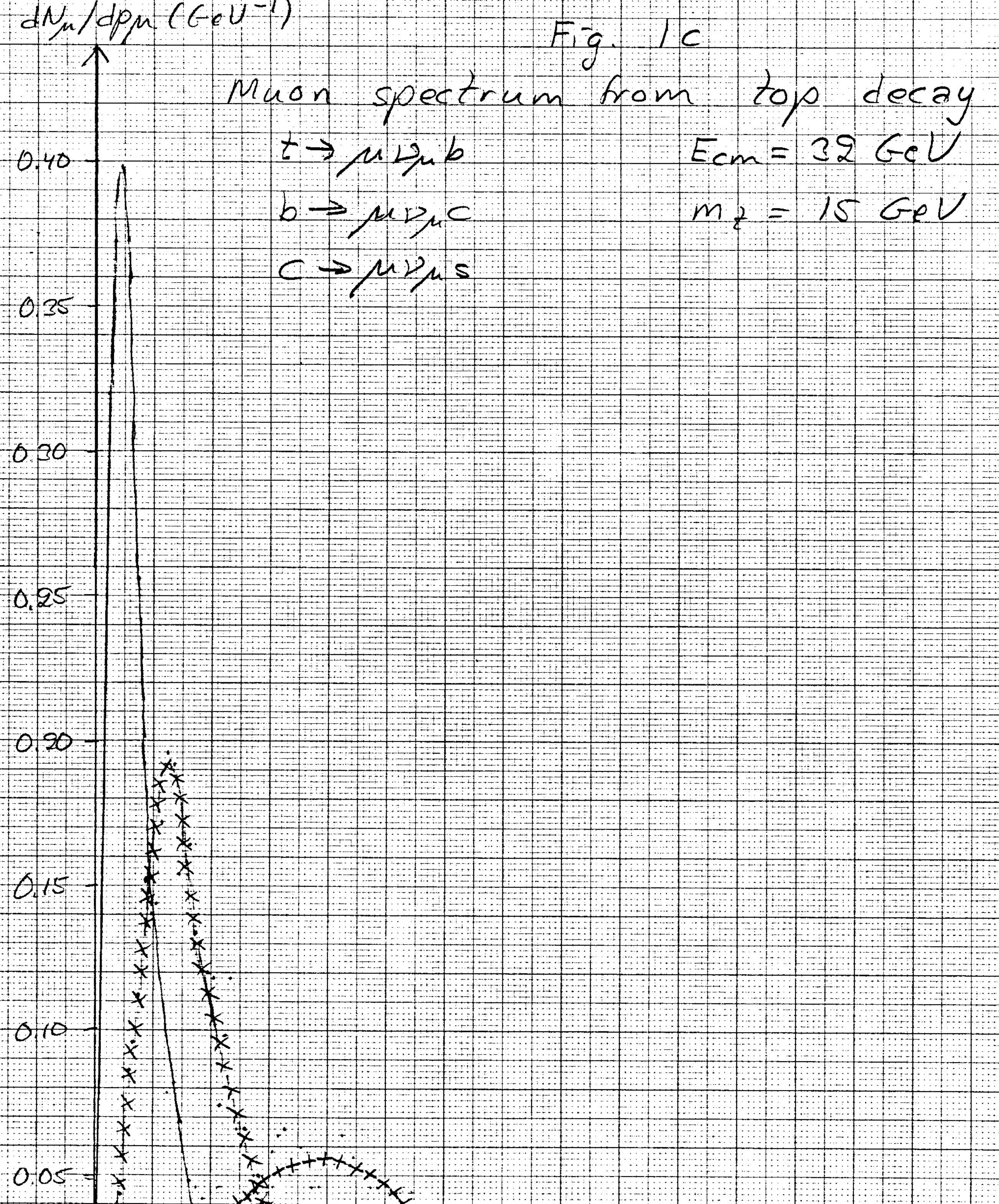
Fig. 4 Difference between opposite charge and like charge relative angle distributions for muon-charged kaon pairs, with the same momentum cuts as in Fig. 3.



dNμ/dpμ (GeV⁻¹)
Fig. 1a
Muon spectrum from charm decay
c → μ νμ s
Ecm = 32 GeV
0.15
0.10
0.05
0
5
10
pμ (GeV/c)



dNμ/dpμ (GeV⁻¹)
Fig. 1b
Muon spectrum from bottom decay
b → μ νμ c
c → μ νμ s
Ecm = 32 GeV
0.25
0.20
0.15
0.10
0.05
0
5
10
pμ (GeV/c)



$dN_\mu/dp_\mu\ (GeV^{-1})$
Fig. 1c
Muon spectrum from top decay
$t \to \mu \nu_\mu b$
$b \to \mu \nu_\mu c$
$c \to \mu \nu_\mu s$
$E_{cm} = 32$ GeV
$m_t = 15$ GeV
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
5
10
p_μ (GeV/c)

Fig. 2 Relative angle between muons

both muon momenta > 1.5 GeV/c

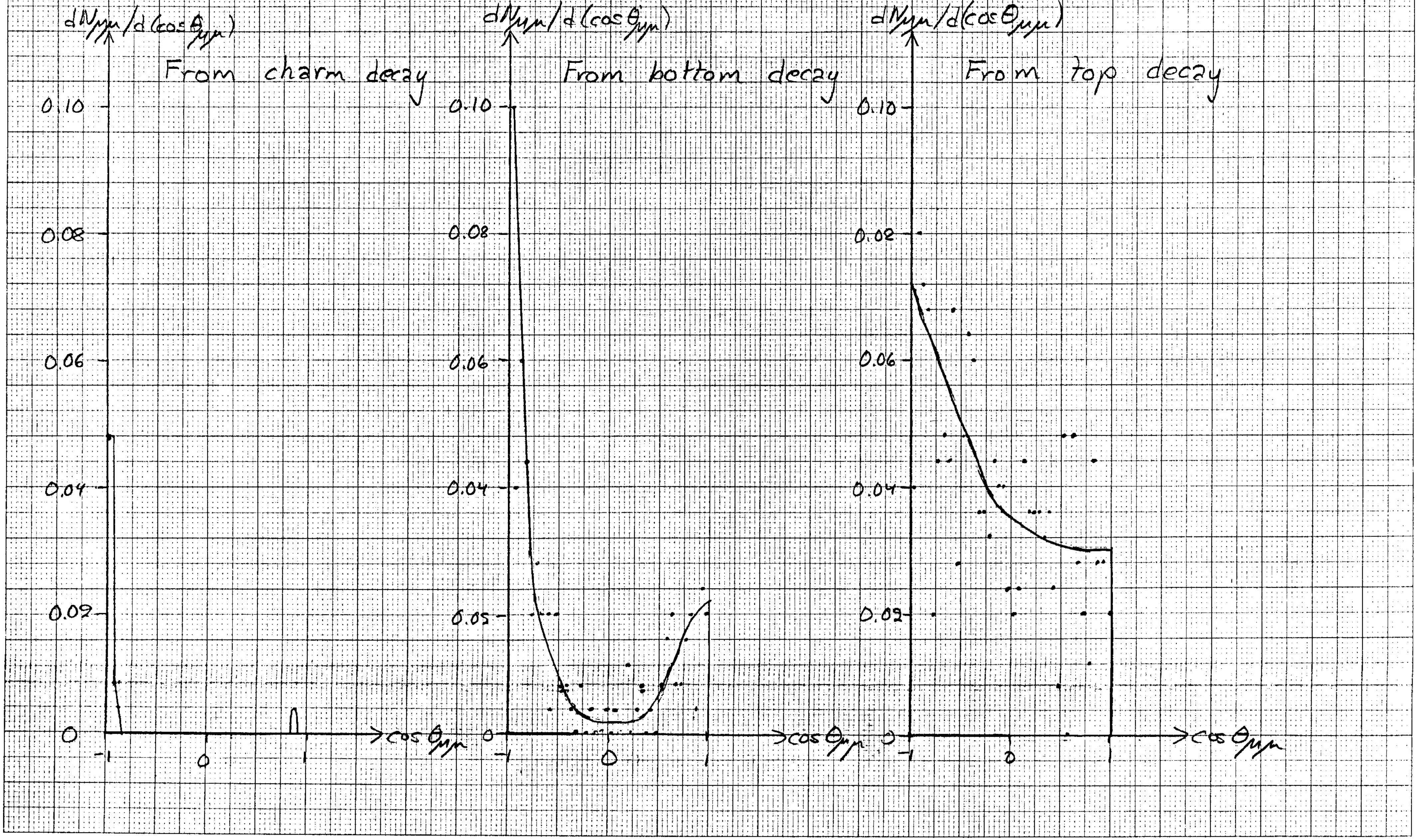


Fig 3 Relative angle between muon and charged kaon

$p_\mu > 3$ GeV/c, $p_K > 0.5$ GeV/c

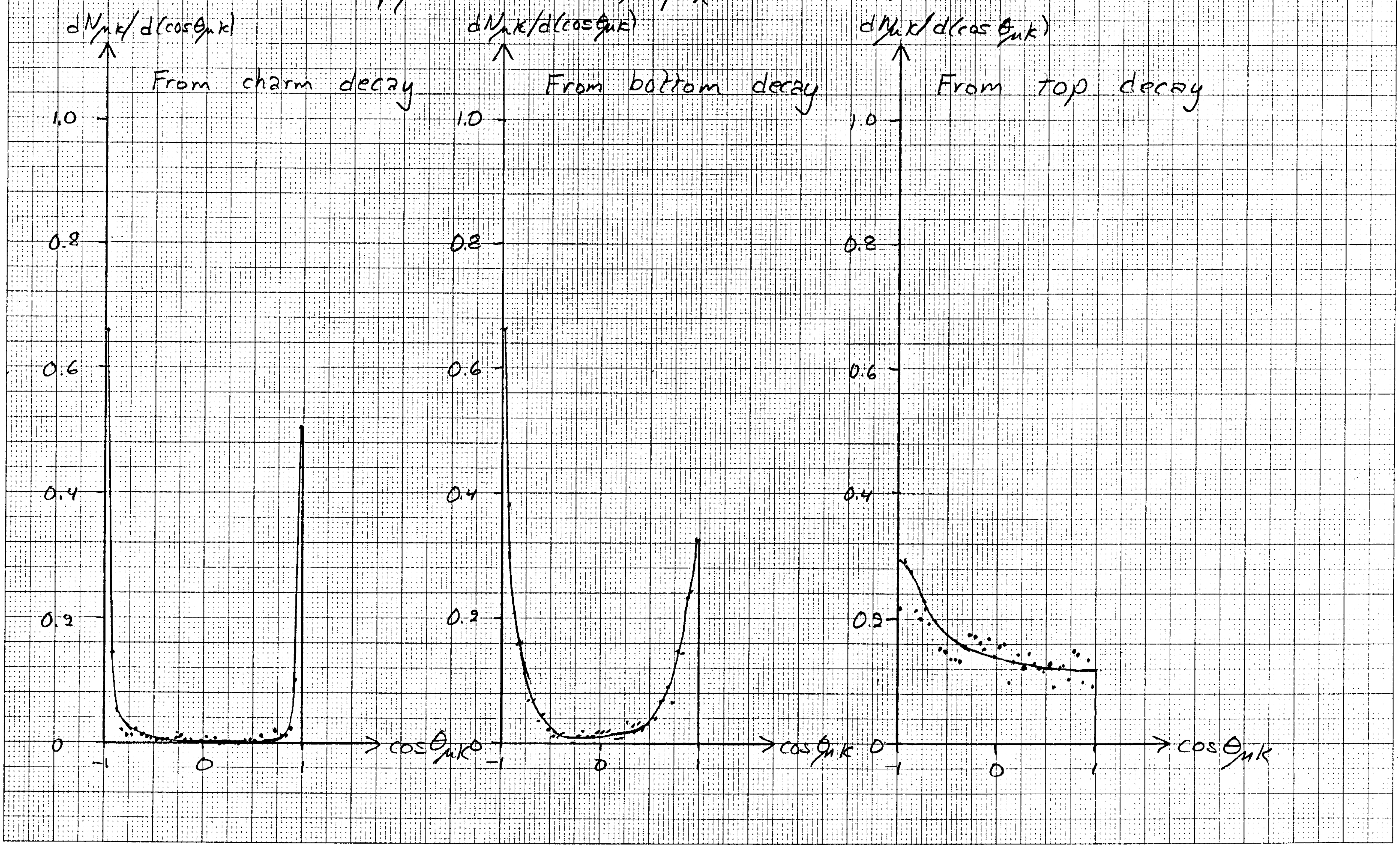


Fig. 4 Relative angle between muon and charged kaon

$p_\mu > 3$ GeV/c $p_K > 0.5$ GeV/c