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Understanding Lepton Identification at BTeV

Abstract

We show that muon and electron identification is possible using the RICH detector at momenta up to 15 GeV/c and 23 GeV/c, respectively. Lepton identification in the RICH complements nicely both muon identification in the toroid system and electron identification in the lead-tungstate crystals. This is mainly due to the limited solid angle of these devices and the correlation of lepton momenta with angle. It is possible to obtain large gains in acceptance of $J/\psi \to \ell^+\ell^-$ by using the RICH in conjunction with the other devices.

1 Introduction

The BTeV spectrometer covers the forward region with a nominal acceptance of approximately ±300 mr in both the vertical and horizontal directions with respect to the beam line. Tracking coverage indeed fills the aperture. The muon detection system (MUON) and electromagnetic calorimeter (ECAL), however, cover smaller regions. Furthermore, the minimum muon momentum required to penetrate the toroids is 5 GeV/c. The RICH detector, however, covers the full solid angle. It should be capable of identifying muons and electrons over a useful momentum range. We will show that adding RICH identification can significantly improve the reconstruction efficiency in many interesting modes and thus change our projected physics reach significantly.

In this note, we concentrate on detection of $J/\psi \to \ell^+\ell^-$ decays, though these considerations will apply for all final states containing leptons.

2 Lepton Identification with Different Detectors

The BTeV tracking system covers forward region up to ±300 mr. The three detectors that can be used as particle ID have different coverage. Let us be quantitative.

The MUON detector has three stations on each arm, at z positions of 950.0, 1085.0, and 1195.0 cm from the center of the SM3 magnet. The radial coverage of each station is approximately, 36 cm to 240 cm, taking the octagonal acceptance as circular. For proper muon identification, the track is required to hit all three stations, which implies an angular coverage of 38 mr to 200 mr in the non-bend plane.

The ECAL can be used to identify electrons, but it also has coverage smaller than 300 mr. The approximate Z location is 740 cm, with an outer radius of 160 cm that corresponds to 210 mr coverage in the non-bend plane. In the center the calorimeter has a ±9.88 cm square hole for the beam pipe. Effectively the angular coverage starts 14-19 mr, but the detector is very inefficient at small radii; this will be accounted for later.

The RICH detector has the largest angular coverage among these three detectors. The window of RICH detector is a ±135 cm square at z ≈386 cm. Tracks right at the edge will lose half their Cherenkov photons. To ensure that all tracks will be well identified, we require that the impact point of the track be at least 10 cm from the edge, in a ±125 cm square, which covers slightly more than ±300 mr. The inner pipe is 2.3 cm radius, corresponding to a lower angular limit of 6 mr.

These three detectors have different identification efficiencies and purities. To determine a precise efficiency curve, we need a much more detailed simulation for a given required purity. Here we just make a conservative estimate of the momentum range, and for tracks within the range we assume 100% efficiency.

The MUON detector has two 1 m thick toroid magnets in each arm. This limits the detection of muon only to tracks with momentum greater than 5 GeV/c. The ECAL has no limitation on momentum as long as the electron hits the crystals.

Next we estimate the momentum reach of the RICH detector. The BTeV RICH detector uses freon (C_4F_{10}) as gas radiator. The Cherenkov angle θ can be expressed as:

$$\cos^2\theta = \frac{1}{n^2\beta^2} = \frac{1}{n^2} + \frac{m^2}{n^2p^2}, \tag{1}$$

where m and p are particle mass and momentum, and n is the index of refraction. For our freon radiator, $n = 1.00138$. Figure 1(left) shows the Cherenkov angles as function of track momentum for proton, kaon, pion, muon and electron.

There is a lower momentum limit for a particle to produce Cherenkov radiation, due to the requirement that $\cos\theta < 1$. For $\mathrm{C_4F_{10}}$, the lower limits are 2.66 GeV/c, 2.01 GeV/c, and 0.0097 GeV/c for π, μ and electron, respectively.

At the high momentum end we must consider the difference in Cherenkov angles for the various mass hypotheses and divide by the angular resolution. The BTeV RICH detector should provide Cherenkov angle resolution of 0.09 mr. To make a conservative estimate we require 4σ separation, i.e. the ratio of the difference in Cherenkov angles to the resolution be 4 or greater. Now we know that we can get some usful separation at somewhat higher momentum, but we hope that ignoring this more than compensates for our assumption that we have 100% efficiency when the separation is more than 4σ. For a 4σ separation requirement, the RICH detector can distinguish between muons and pions with momenta up to 15 GeV/c, and between electrons and pions up to 23 GeV/c as shown in Figure 1 (right). The separations of electrons and muons from kaons and protons are better. Thus the RICH detector can provide quite good lepton identification in the “lower” momentum range.

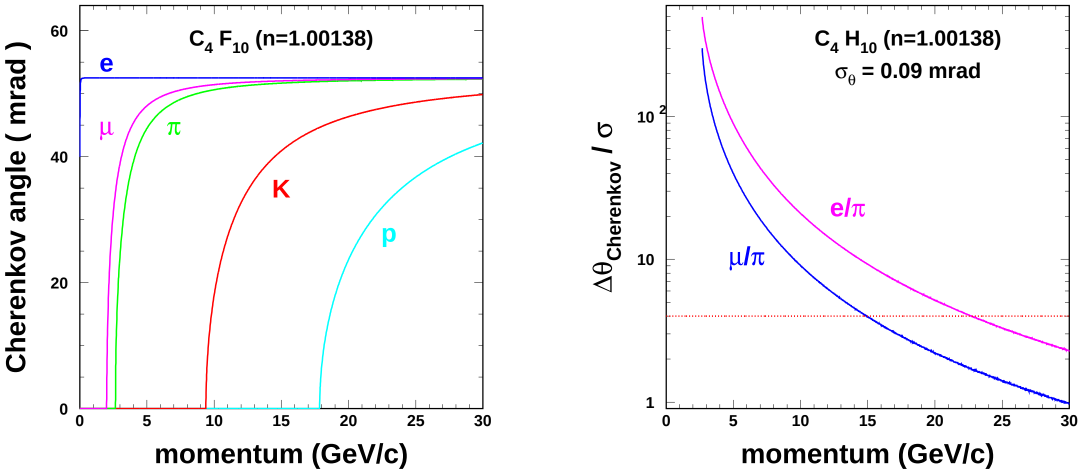

Figure 1: (left) The Cherenkov angle for the various particle species as a function of momentum. (right) The number of standard deviation separation for μ/π and e/π as a function of momentum

3 Lepton Identification for Tracks from J/ψ

To quantify our estimates we use the $B^o \to J/\psi K_s$, $J/\psi \to \ell^+\ell^-$ mode, because this is a bench mark mode and because it involves two leptons and thus serves as a good base to further enunciate the issues. The J/ψ can be reconstructed both in the $\mu^+\mu^-$, and the e^+e^- modes. To illustrate the coverage of BTeV for lepton identification, we simulated only $\mu^+\mu^-$ mode; the e^+e^- mode is similar except for bremstrallung, which we have ignored for now.

Figure 2 shows the polar angle distribution of the muons at the J/ψ decay vertex versus their momentum. Also shown are rough estimations of the angular coverage of the three detectors. Tracks at large angles, that are beyond detection in some systems, are at mostly lower energies. A significant number of high momentum tracks are not detected in the muon system because they have small angles. In this plot, each track passes a quality selection defined by requiring more than 20 hits, at least 4 of which must be in the pixel detector.

Since lower momentum tracks deflect significantly inside magnetic field, the polar angle vs the momentum plot does not precisely reflect the geometry coverage. Shown in Figure 3 are (a) the momentum distribution, and (b) the polar angle distribution at the J/ψ decay vertex with acceptance of different detectors accurately taken into account by tracking all the particles through the magnetic field.

For good tracks, the RICH detector has an acceptance of 95% for ±300 mr; the 5% loss results from magnetic field bending, the spread of the primary interaction position in z, and our requirement that the track be at least 10 cm within the aperture. The ECAL detector has smaller angular coverage and the resulting acceptance is only about 66%.

The MUON detector also covers a smaller than ideal solid angle and has a relatively big hole around beam pipeline. It also cannot detect tracks below 5 GeV/c The total acceptance is 48%.

The missing tracks in MUON and ECAL are dominated by lower energy tracks at large

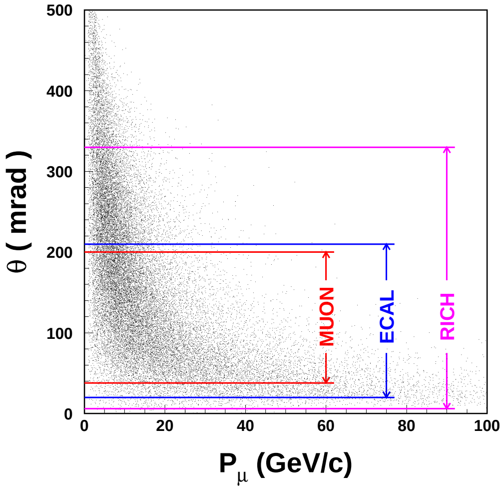

Figure 2: The momentum of muons from J/ψ decay versus their laboratory production angle. The lines indicate the geometric acceptance in the absence of a magnetic field taking the origin as the center of the magnet (z=0).

polar angles. It is just these tracks that the RICH is capable of identifying.

4 J/ψ Reconstruction Efficiency

We use $J/\psi \to \mu^+\mu^-$ samples from $B^o \to J/\psi K^o_s$ decays to study the reconstruction efficiency with different lepton identification methods. The selection criteria are:

- Two good tracks each with enough hits ($N_{total} > 20$, $N_{pixel} \geq 4$),
- A good quality vertex ($\chi^2 > 6.635$ or $prob > 0.01$),
- Invariant mass consistent with J/ψ ($|M - M_{J/\psi}| < 3\sigma$),
- Pass mass constrained fit ($\chi^2 > 6.635$ or $prob > 0.01$),
- A significant detached vertex (B decay length $> 4\sigma$).

The reconstruction efficiency before any lepton identification is 22%. (The K_s is not explicitly reconstructed in this study.)

We assume MUON detector has 100% identification efficiency within the acceptance. For ECAL, we use the efficiency curve as function of radius from $B^o \to K^*\gamma$ simulation (Figure 7.6 in the BTeV proposal). For RICH detector, we assume it has 100% efficiency in identifying muons between 2 GeV/c and 15 GeV/c, and electrons below 22.7 GeV/c. Although the RICH can still provide identification at somewhat higher momenta, for simplicity we just assume the efficiency is zero.

Different methods have been used to reconstruct $J/\psi \to \mu^+\mu^-$ in the proposal. One method is to simply identify both muons. This has an advantage of reducing backgrounds

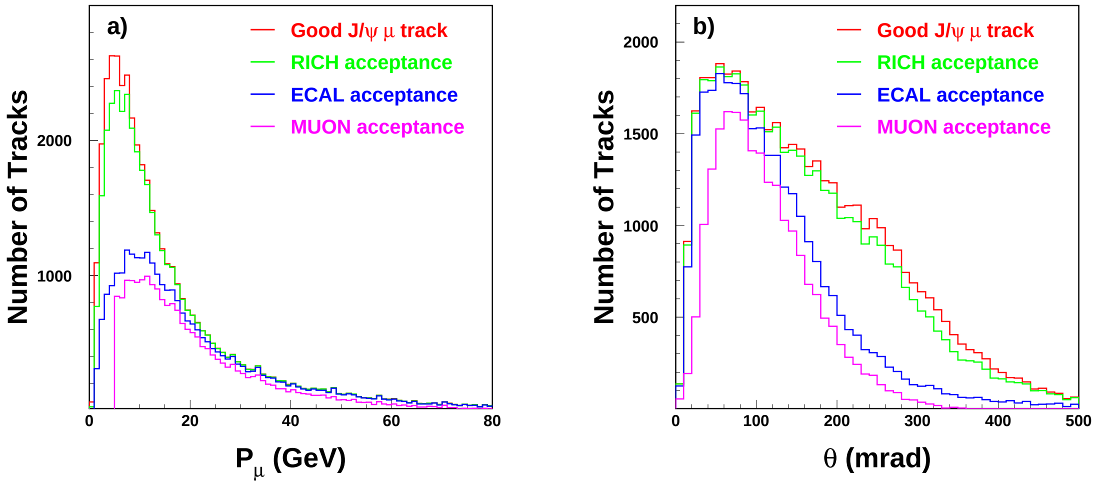

Figure 3: (left) The momentum distributions of muons from J/ψ decay that exit the magnet "good track," and that are in the geometric acceptance of the indicated apparatus. (right) The production angle distribution.

but can have low efficiency. (This method was used for the $J/\psi K_s$ final state.) Another method is to require good muon identification for only one of the two muon tracks from a two-track detached vertex. (This method was used for the $J/\psi\eta^{(\prime)}$ studies.) Listed in Table 1 are J/ψ reconstruction efficiencies for different muon identification methods for the two J/ψ detection methods. Adding the RICH increases the efficiency by 19% when only one of two tracks is required to be a muon and a whopping 96% when both tracks are required to be identified. Using the RICH and MUON systems the difference between identifying one or two leptons is not as large, between 71% and 96%.

Table 1: Lepton identification efficiency for $J/\psi \to \mu^+\mu^-$.

	muon identification	
	single track	both tracks
MUON only	80.6 %	36.4%
MUON + RICH	96.0%	71.3%
Ratio	1.19	1.96

Although electron identification efficiency in ECAL is about 80% at large radii, the efficiency is much less at small radii where the density of tracks is high. The identification efficiency of $J/\psi \to e^+e^-$ is quite small using only ECAL identification as shown in Table 2. The RICH detector boosts the efficiency by 37% in the case where only one identified track is required. When both tracks are required to be identified, it boosts the efficiency by a factor of 3.

If radiation does not turn out to be a severe problem, we can usefully add our electron and muon samples together to obtain a rather large increase in these important final states.

Table 2: Lepton identification efficiency for $J/\psi \to e^+e^-$.

	electron identification	
	single track	both tracks
ECAL only	69.3 %	21.6%
ECAL + RICH	94.9%	67.5%
Ratio	1.37	3.12

5 Conclusions

For lack of space in the hall the MUON detector is smaller than we like. For lack of money the ECAL is also smaller. However, the identification of muons and electrons is brought back to essentially full acceptance by use of the RICH.

We simulated decay $B^o \to J/\psi K^o$ with $J/\psi \to \mu^+\mu^-$ to estimate the reconstruction efficiency for different identification methods. The RICH detector increases the efficiency significantly.

It is important that the RICH detector resolution not be compromised. Its use is more important than only $\pi/K/p$ separation.