ITOP Cherenkov identification of low momentum muons

D. J. Summers, L. M. Cremaldi, R. S. Kroeger, and D. A. Sanders
University of Mississippi - Oxford, University, MS 38677 USA

R. Godang
University of South Alabama, Mobile, AL 36688 USA

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ITOP Cherenkov identification of low momentum muons may aid in the reconstruction of decays such as $\bar{B} \to D^{(*)}\tau^-\nu_\tau$, $B^+ \to \tau^+\nu_\tau$, and $\bar{B}^0_d \to D^{*+}\mu^-\bar{\nu}_\mu$. At low momentum, the range difference in the KLM detector between muons and pions is shrinking while the Cherenkov angular difference is growing. The τ lepton branching ratio to $\mu^+\nu\bar{\nu}$ is large, 17.4%. The Belle II iTOP has about $5\,\sigma$ of separation between kaons and pions at 4.0 GeV/c using a Cherenkov angle difference of 0.39 degrees, as shown in Table 1. Pions and muons at 0.8 GeV/c have a Cherenkov angle difference of 0.37 degrees in quartz. Mississippi has previously built a Cherenkov counter for π/μ separation [1]. The KLM muon identification efficiency at 1.5, 0.8, and 0.5 GeV/c is 90%, 70%, and 0%, respectively. For a Belle II solenoidal field of 1.5 T and an ITOP radius of 1.2 meters, muons with a p_t greater than 270 MeV/c ($p = 0.3BR$) will reach the ITOP. As can be seen in Fig.1, low momentum muons are important.

Low momentum muon identification may aid $B^+ \to \tau^+\nu_\tau$ physics at Belle II. The B^+ is a $u\bar{b}$ state which can annihilate to produce a virtual W^+ which then decays to $\tau^+\nu_\tau$. The smallness of the V_{ub} matrix element, 0.00347, makes the decay rare in the Standard Model. Non Standard Model mediators, such as charged Higgs bosons, in addition to the W^+ might enhance or suppress the decay rate. BABAR searched for $B^+ \to \tau^+\nu_\tau$ decays with hadronic and semileptonic B tags. At BABAR a reconstructed B decay and the Υ(4S) 4-vector give the B^+ 4-vector. The τ lepton is identified in the following decay modes: $e^+\nu\bar{\nu}$, $\mu^+\nu\bar{\nu}$, $\pi^+\bar{\nu}$, and $\pi^+\pi^0\bar{\nu}$, which have branching ratios of 17.8%, 17.4%, 10.9%, and 25.5%, respectively. As noted in Table 2, BABAR and Belle see indications and evidence for $B^+ \to \tau^+\nu_\tau$ decay, respectively. The branching ratios in Table 2 are close to those predicted by the Standard Model. Note that helicity suppression is proportional to the square of mass, greatly favoring decay into $\tau^+\nu_\tau$ over decay into lower mass charged leptons. Belle II, with 80x the luminosity of BABAR, should be able to make a very accurate observation. More statistics should also improve signal and background shapes which contribute to the systematic errors.

The SLAC BABAR collaboration reports a $3.4\,\sigma$ excess versus the standard model[2] in $\bar{B} \to D^{(*)}\tau^-\nu_\tau$ decay. Belle also has $\bar{B} \to D^{(*)}\tau^-\nu_\tau$ data but it has not yet been completed for publication [3].

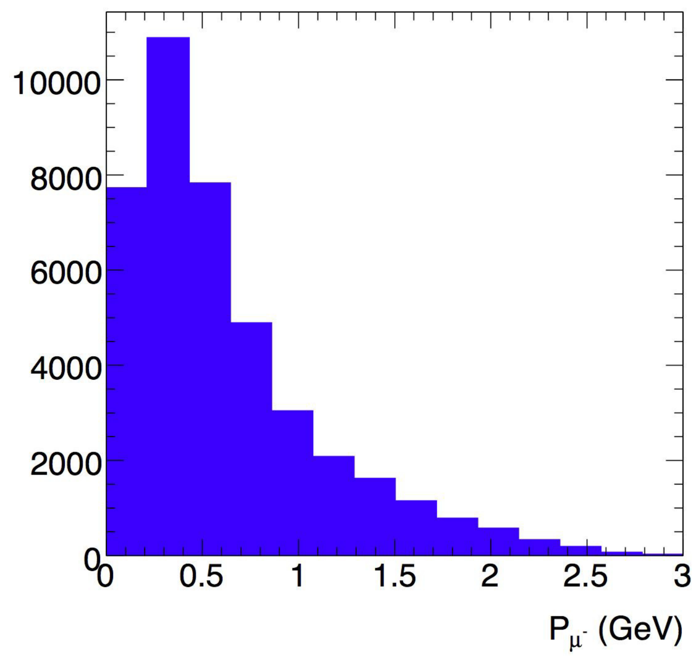

Figure 1: Belle II simulated muon momentum from $\bar{B}_d^0 \to D^{*+}\mu^-\bar{\nu}_\mu$ decays. Note that many of the muons are too low in momentum to be identified by the KLM range detector. However, the ITOP Cherenkov may be able to identify low momentum muons.

Table 1: Chrenekov (ITOP) angle in quartz (n = 1.458) in degrees for e, μ, π, K, and p. The half thickness, x, of an ITOP quartz bar is 1 cm and the radiation length (X_0) of quartz is 12.29 cm. The multiple scattering angle is $\theta_0 = 57.3\,(0.0136/\beta p)\sqrt{x/X_0}$ degrees. Below 1.0 GeV/c the muon-pion Cherenkov angular difference is larger than the multiple scattering of the muon. And it is the opening angle of the Cherenkov cone that is being measured rather than the track direction. At 0.8 GeV/c, where the KLM efficiency for identifying muons is falling rapidly, the π/μ angular difference is equal to the K/π angular difference at 4.0 GeV/c.

GeV/c	e	μ	π	K	p	β(muon)	θ_0(muon)	$\theta(\mu - \pi)$
0.2	46.70	39.13	33.24	0.00	0.00	0.8841	1.26	5.89
0.4	46.70	44.81	43.41	0.00	0.00	0.9668	0.58	1.40
0.6	46.70	45.86	45.24	27.35	0.00	0.9848	0.38	0.62
0.8	46.70	**46.23**	**45.87**	36.30	0.00	0.9914	0.28	0.36
1.0	46.70	46.39	46.17	40.10	19.86	0.9945	0.22	0.22
1.2	46.70	46.49	46.33	42.13	29.47	0.9961	0.19	0.16
1.4	46.70	46.54	46.43	43.34	34.34	0.9972	0.16	0.11
1.6	46.70	46.58	46.49	44.13	37.33	0.9978	0.14	0.09
1.8	46.70	46.60	46.53	44.67	39.33	0.9983	0.12	0.07
2.0	46.70	46.62	46.56	45.05	40.75	0.9986	0.11	0.06
3.0	46.70	46.66	46.64	45.97	44.06	0.9994	0.07	0.02
4.0	46.70	46.68	**46.66**	**46.28**	45.21	0.9997	0.06	0.02
5.0	46.70	46.68	46.67	46.43	45.75	0.9997	0.05	0.01

Table 2: Current $B^+ \to \tau^+\nu_\tau$ Decay Status

Exp.	BR($B^+ \to \tau^+\nu_\tau$)	Statistical	Systematic	σ	$B\bar{B}$	B Tag	Ref.
BaBar	1.8×10^{-4}	+0.9 -0.8	±0.4 ±0.2	$2.2\,\sigma$	383×10^6	$D^{(*)0}X^-$	[4]
BaBar	1.7×10^{-4}	±0.8	±0.2	$2.3\,\sigma$	459×10^6	$D^0\ell^-\bar{\nu}_\ell X$	[5]
Belle	1.79×10^{-4}	+0.56 -0.49	+0.46 -0.51	$3.5\,\sigma$	449×10^6	$D^{(*)0}X^-$	[6]
Belle	1.54×10^{-4}	+0.38 -0.37	+0.29 -0.31	$3.6\,\sigma$	657×10^6	$D^{(*)0}\ell^-\nu_\ell$	[7]

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