Results and plans for analysis of b-hadron semileptonic decays at BTeV

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OUTLINE

I. Overview of BTeV

A. Goal
B. Spectrometer
C. Trigger/DAQ
D. Monte Carlo status

II. Overview of semileptonics

A. What are they
B. What can we measure
C. What can we compare to

III. One study: $B \to D^* \mu\nu$

A. How it was done
B. Results

IV. Current and Future work

BTeV

Goal: High-statistics study of decays of hadrons containing b and/or c quarks.

Basic idea

- Two-arm spectrometer in C0 region of Tevatron
- Forward coverage (10 mrad $<\theta<$ 300 mrad, 1.9 $<\eta<$ 5.3)

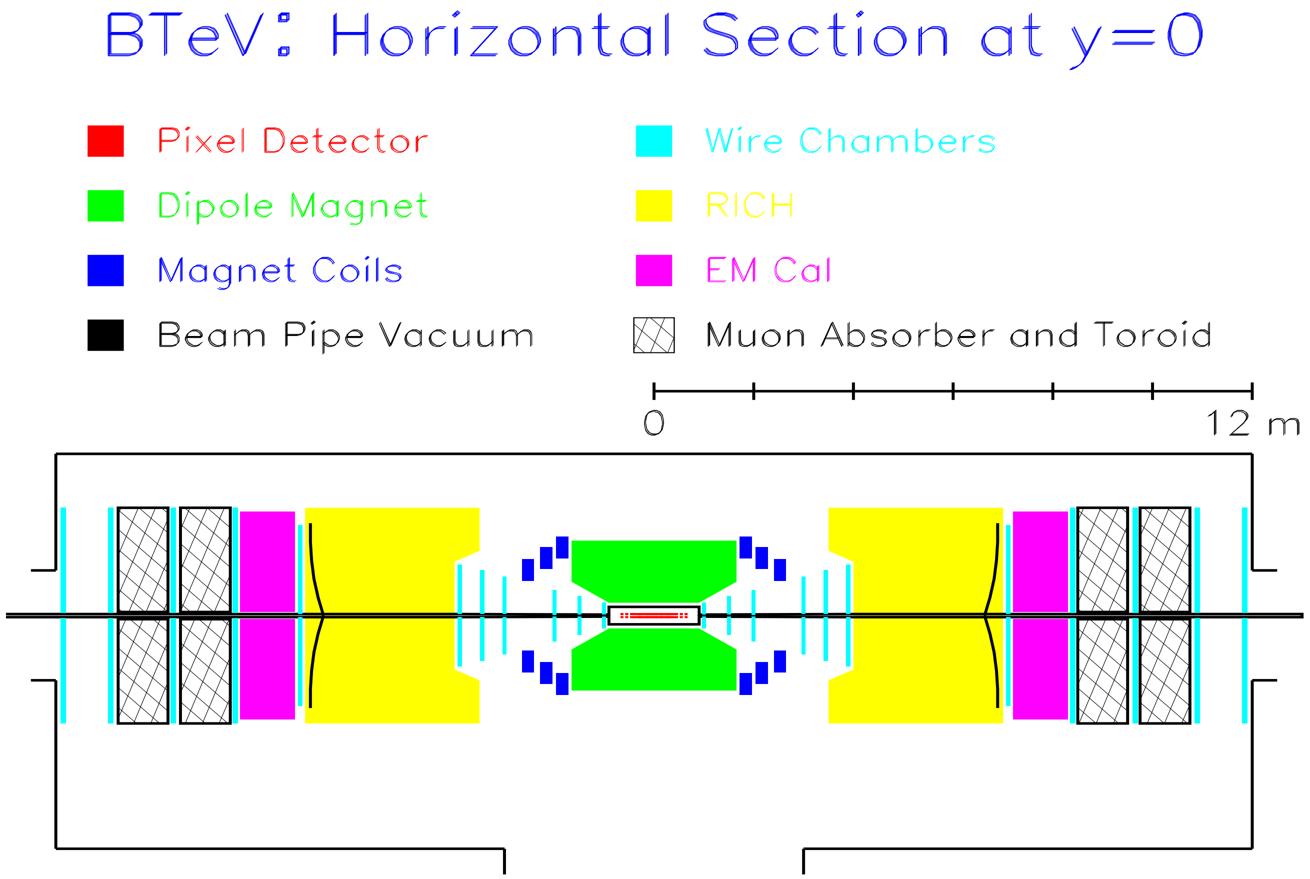
Advantages

- Forward produced $\rightarrow$ higher momentum
  - Large vertex separation
  - Good lifetime resolution
  - Good hadronic ($\pi/K/p$) particle ID (can use Čerenkov)
- Both b particles in same spectrometer
- Better than e^+e^- because $p\overline{p}$ gives higher cross section and B_s, B_c and b-baryons

Disadvantages

- High beam background in forward region
- Less coverage
- Not hermitic
- Worse than e^+e^- because $p\overline{p}$ is dirtier and no beam energy constraint

BTeV Spectrometer



- vertex region: 31 silicon pixel (50 μm$\times$400 μm) doublets along 90 cm – 28 million channels
- tracking: 7 straw tube stations/arm, 3 views/station, 3 planes/view + SSDs in center of first 3 stations – 120,000 + 60,000 channels
- 1.6 T, 3.2 m dipole centered on interaction region
- RICH for hadron separation
- EM Calorimeter – 10-20,000 $PbWO_4$ crystals
- Muon detector – 2 1 m toroidal iron filters 3 stations/arm, 3 views/station and 2 layers/view – 60,000 prop tubes
- DAQ buffers every beam crossing and Level 1 trigger uses vertex trigger, dimuon trigger, and maybe combination loose vertex plus single muon

Monte Carlo status

- PYTHIA generator
- MCfast and GEANT simulations are implemented
- No background from beam effects (scraping)
- Extra min-bias interactions added (<2.0> interactions/event)

The Semileptonic gold mine?

Semileptonic primer (experimentalist perspective)

- The matrix element for a semileptonic decay is composed of an understood virtual W decay to $\ell\nu$ and a not understood flavor change of a heavy quark
- Anything not understood $\Rightarrow$ hide in a form factor(s)
- $B\to$pseudoscalar $\ell\nu$ has 1-2 form factors
- $B\to$vector $\ell\nu$ has 3-4 form factors
- Correlations allow ratios of form factors to be used
- $b\to c$ transitions, HQET predicts all form factors are equal
- HQET predicts $Q\to q$ form factors are equal regardless of heavy quark flavor
- Measuring the form factor gives insight into QCD
- CKM matrix elements can also be extracted

The physics prospects for semileptonics

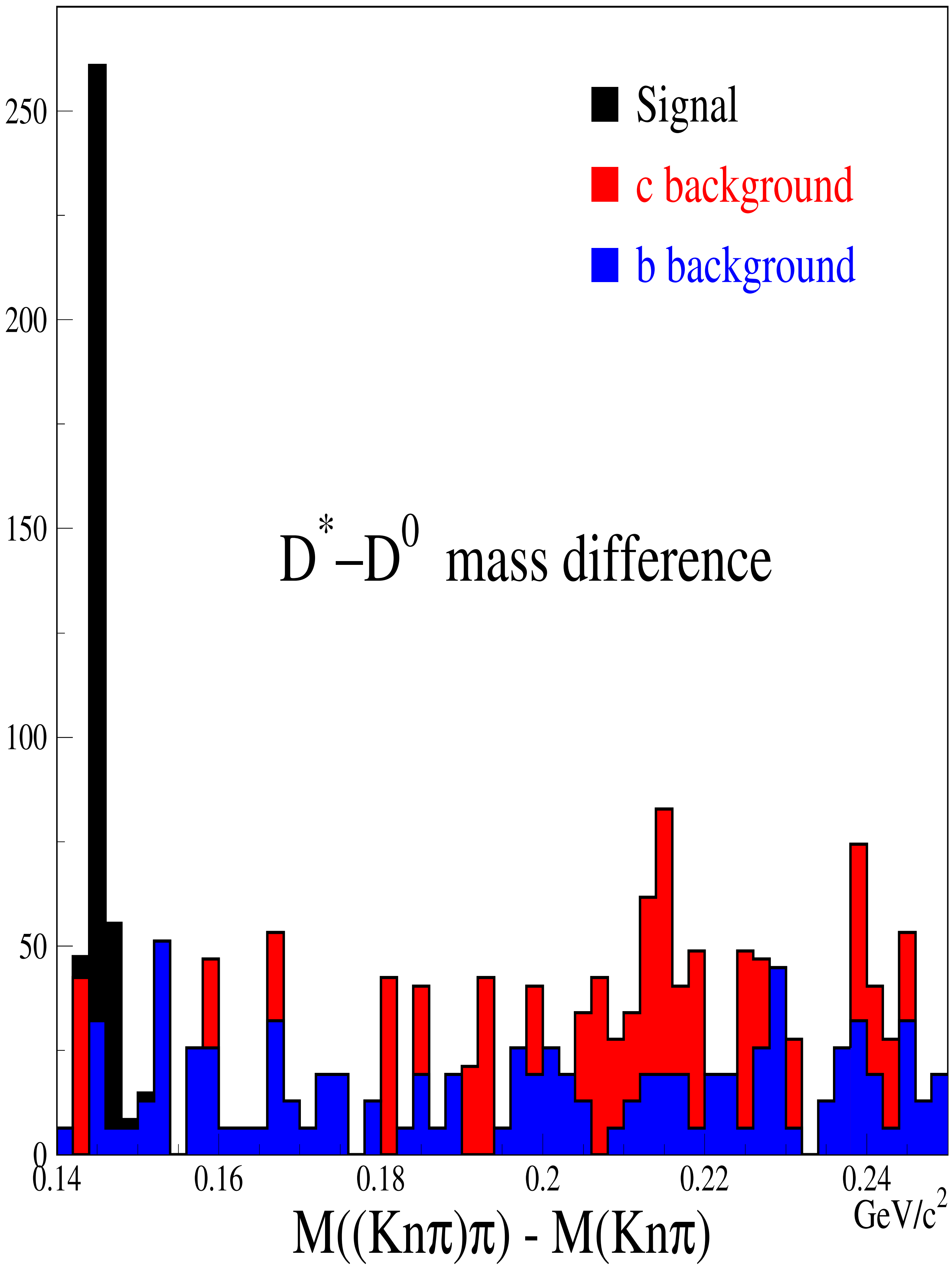
- **Measure form factors, compare to theory and charm**
  - Measure $B \to D\ell\nu$ and $B \to D^*\ell\nu$ form factors. Compare to HQET and lattice predictions.
  - Measure $B \to \rho\ell\nu$ and $B \to \pi\ell\nu$ form factors. Compare to charm (test HQET). Compare to lattice predictions.
- **Measure $|V_{cb}|$**
  - $\frac{d\Gamma(B \to D^*\ell\nu)}{dw} \propto K(w)|V_{cb}|^2\mathcal{F}^2(w)$ where $w = v \cdot v' = (M^2 + m^2 - q^2)/(2Mm)$, M = B mass, m = D^* mass, q = virtual W invariant mass, $K(w)$ = known function of w and $\mathcal{F}(w)$ = hadronic form factor.
  - Measure $|V_{cb}|\mathcal{F}(w)$ vs w and extrapolate to $w = 1$ where theorists can calculate $\mathcal{F}(1)$.
- **Measure $|V_{ub}|$**
  - Use $D \to \pi\ell\nu$ and $D \to \rho\ell\nu$ decays to normalize lattice theory (HQET).
  - Use $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$ decays to extract $|V_{ub}|$.
  - Hadron colliders can also use $B_s \to K\ell\nu$ and $B_s \to K^*\ell\nu$ to measure $|V_{ub}|$.
- **Physics with $B_s, B_c, \Lambda_b \to X\ell\nu$?**
  - Check SU(3) with B_s decays?
  - Gain information about spectator quark in B_c decays? Maybe calculate form factors without lattice?
  - More form factors in Λ_b decays?
  - Only possible at Tevatron (until LHC)

One study ($B^0 \to D^{*-}\mu^+\overline{\nu_\mu}$)

$$B^0_d \to D^{*-}\,\mu^+\,\overline{\nu_\mu}$$
$$\hookrightarrow \overline{D^0}\pi^-$$
$$\hookrightarrow K^+ n\pi \quad (n = 1, 3)$$

$$\text{PDG99 BR} = 0.046 \times 0.683 \times (0.0383 + 0.076) = 0.36\%$$

- Cuts applied
  - Good vertices ($\chi^2/dof < 4$)
  - K: $p > 3$ GeV, RICH ID
  - μ: $p > 5$ GeV, μ ID
  - π from $\overline{D^0}$ decay: $p > 1$ GeV, not ID'd as K, μ, or e
  - primary–B separation $> 2\ \sigma$
  - B–D separation $> 5\ \sigma$
  - primary–D separation $> 5\ \sigma$
  - B momentum vector passes within 1 mm of primary
- Assumptions
  - Particle ID is 100% efficient for particles in acceptance
  - Kaon ID has 2% misid rate
  - Lepton ID has 0.5% misid rate
  - Background dominated by generic b and c events
  - Assume 70% trigger efficiency = 60% efficiency for DK decays plus 10% for the muon



Signal
c background
b background
D*–D0 mass difference
0
50
100
150
200
250
0.14
0.16
0.18
0.2
0.22
0.24
GeV/c2
M((Knπ)π) - M(Knπ)

$B^0 \rightarrow D^{*-}\mu^+\overline{\nu_\mu}$ results

- Acceptance + Reconstruction efficiency = 1.5%
- Neither b nor c background peaks under $D^* - D^0$ mass difference plot

Luminosity	2×10^{32} cm^{-2}s^{-1}
Running time	10^7 s
$\sigma_{b\bar{b}}$	100μb
$\sigma_{c\bar{c}}$	500μb
Number of $B\overline{B}$ events	2×10^{11}
Number of $B_d^0/\overline{B_d^0}$'s	1.5×10^{11}
$\mathcal{B}(B_d^0 \rightarrow D^{*-}\mu^+\overline{\nu_\mu})$	0.046
$\mathcal{B}(D^{*-} \rightarrow \overline{D^0}\pi^-)$	0.683
$\mathcal{B}(\overline{D^0} \rightarrow K^+\pi^-) + \mathcal{B}(\overline{D^0} \rightarrow K^+\pi^-\pi^+\pi^-)$	0.1143
Reconstruction efficiency	0.015
Trigger efficiency	0.70
Reconstructed $B_d^0 \rightarrow D^{*-}\mu^+\overline{\nu_\mu}$	6 million

- CLEO obtains a 5% measurement of $|V_{cb}|$ and a 20% measurement of $|V_{ub}|$ with 800 $B \rightarrow D^*\mu\nu$ and 120 $B \rightarrow \rho\ell\nu$ events. The theoretical uncertainties are currently of the same order as the experimental uncertainties.
- Theory will likely limit the CKM element measurement from semileptonic decays at BTeV.

The Present and Future

- Current work – vetting the muon system
  - Writing muon identification code
  - Trigger studies (dimuon and single muon with loose vertex requirement)
  - Background investigation in muon system
- Near future (1-2 months)
  - Parameterize efficiency and misid using muon ID code and GEANT
  - “Real” analysis of semimuonic modes (including reconstructing the ν momentum, investigating our q^2 resolution, and obtaining form factors)
  - Run MCfast for “real” analysis of at least one semimuonic mode