Updated Search for Non-SM Physics in $B \rightarrow K^{(*)}\mu^+\mu^-$ Decays at CDF

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for the CDF collaboration

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Brown University, Providence, Rhode Island

Outline of Talk (6.8/fb Update):

- Introduction / Total BR's for $B \to K(*)\mu^+\mu^-$
- Differential BR's (distributions in $q^2 = M_{\mu\mu}^2$)
- Angular Analysis from dBR's (variables A_{FB} , F_L , $A_T^{(2)}$, A_{im})

  Pub. Submitted: arXiv: 1108.0695 2 Aug 2011

- First dBR Measurements of $B \to \phi\mu^+\mu^-$ and $\Lambda_b \to \Lambda\mu^+\mu^-$
- First Observation of $\Lambda_b \to \Lambda\mu^+\mu^-$ at CDF (!)

  (Hideki Miyake @ EPS-HEP 2011)

  Pub. submitted: arXiv: 1107.3753 19 Jul 2011

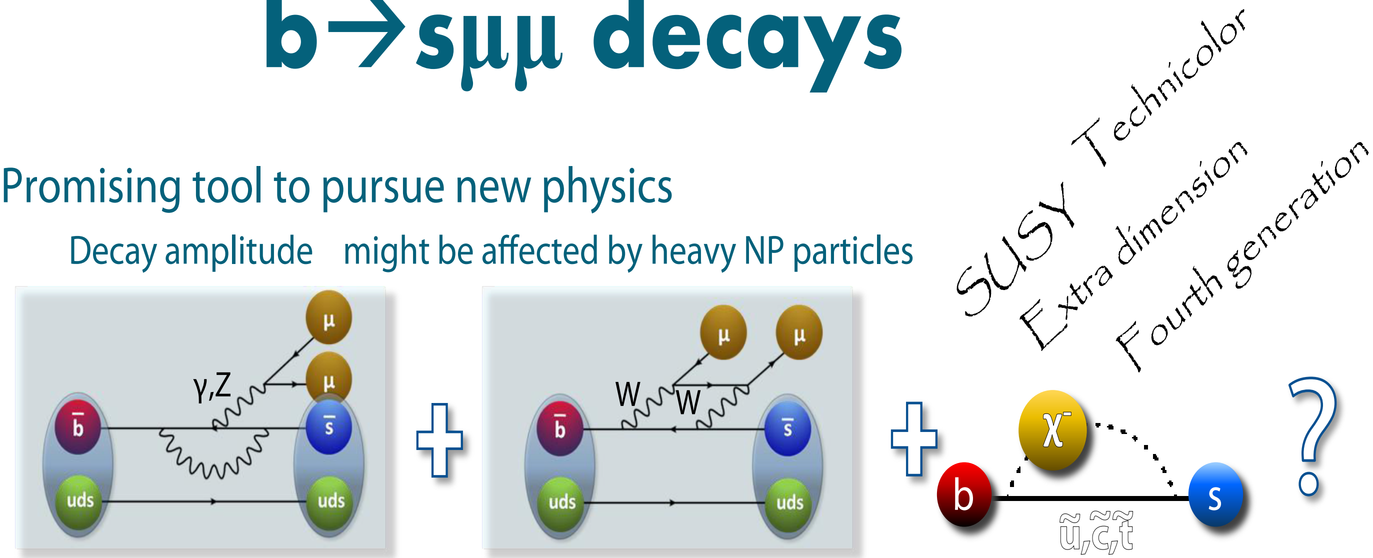
  Previous results:

  ($B \to \phi\mu\mu$ 4.4/fb) PRL 106, 161801 (2011)

$b \to s\mu\mu$ decays

Promising tool to pursue new physics

Decay amplitude might be affected by heavy NP particles



Use $\mu^+ \mu^-$ trigger, 1 or 2 hadrons @ displaced vertex

Signal Channels, BR ~$O(10^{-6})$

$B^0 \to K^{*0} \mu\mu$	$B^+ \to K^{*+} \mu\mu$
$B^+ \to K^+ \mu\mu$	$B^0 \to K_s \mu\mu$
$B_s \to \phi \mu\mu$	$\Lambda_b \to \Lambda \mu\mu$

Ref. Channels

$B^0 \to K^{*0} J/\psi$	$B^+ \to K^{*+} J/\psi$
$B^+ \to K^+ J/\psi$	$B^0 \to K_s J/\psi$
$B_s \to \phi J/\psi$	$\Lambda_b \to \Lambda J/\psi$

Total BR Analysis

Rare channel yield

$$\frac{\mathcal{B}(H_b \to h\mu^+\mu^-)}{\mathcal{B}(H_b \to J/\psi h)} = \frac{N_{h\mu^+\mu^-}}{N_{J/\psi h}} \times \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\varepsilon_{\mathrm{rel}}}$$

Control channel yield

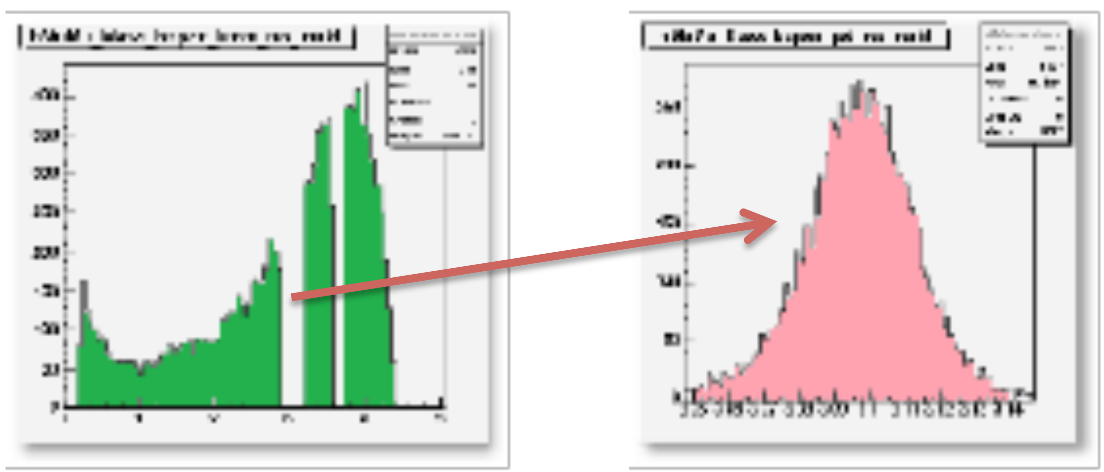
Relative efficiency (=ε(hμμ)/ε(J/ψh))

$H_b = B^0, B^+, B_s, \Lambda_b$

$h = K^{*0}, K^{*+}, K^+, Ks, \Phi, \Lambda$

Trigger on $\mu^+ \mu^-$: Rare (Signal) Channels Reference Channels (e.g. $J/\psi \to \mu^+ \mu^-$)

Charmonium Veto Bands ➔



Fitted Events in Signal and Reference Modes

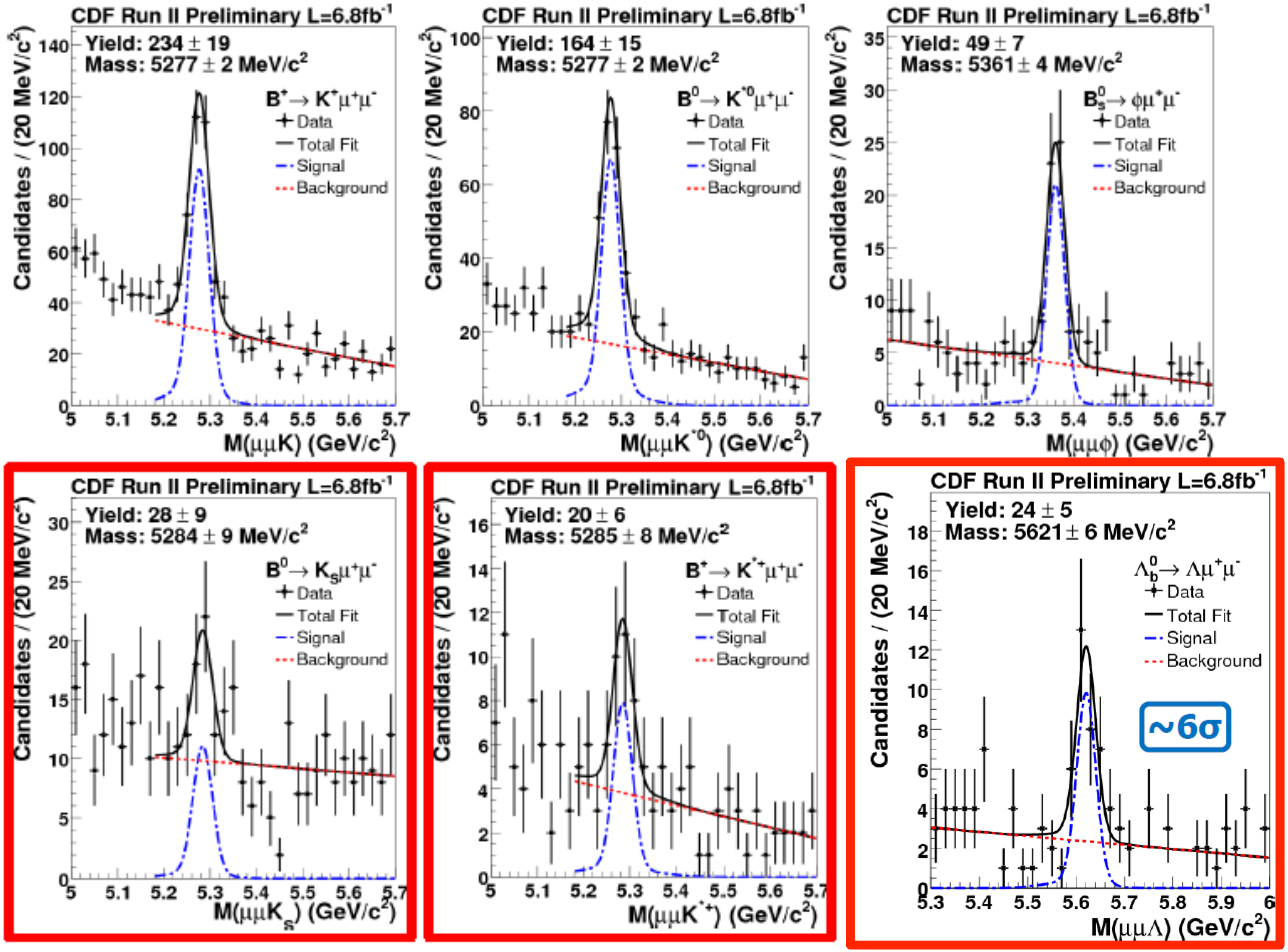
Analysis dates back to CDF Run I. New CDF results have:

- higher luminosity, additional triggers, better particle ID,
- loosened selection, better Neural Network optimization,
- more physics channels.

Details in ArXiv:1107.3753 , ArXiv:1108.0695 . NEW RESULTS:

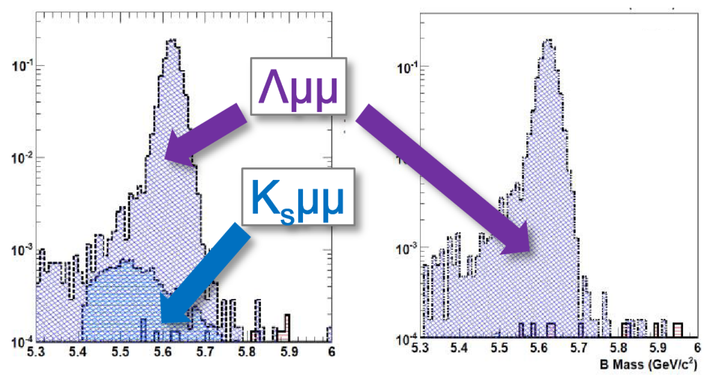
Mode		$N_{h\mu^+\mu^-}$	s (σ)	$N_{J/\psi h}$
B^+	$K^+\mu^+\mu^-$	234 ± 19 (345)	13.7	72156 ± 272 (83773)
B^0	$K^{*0}\mu^+\mu^-$	164 ± 15 (234)	13.7	28299 ± 233 (40320)
B_s^0	$\varphi\mu^+\mu^-$	49 ± 7 (66)	9.0	4555 ± 79 (5656)
B^0	$K_S^0\mu^+\mu^-$	28 ± 9 (63)	3.5	9470 ± 90 (10699)
B^+	$K^{*+}\mu^+\mu^-$	20 ± 6 (36)	3.5	4557 ± 79 (5709)
Λ_b^0	$\Lambda\mu^+\mu^-$	24 ± 5 (34)	5.8	1736 ± 53 (2523)

$b \rightarrow s\mu\mu$ signals (CDF 6.8 fb^{-1})



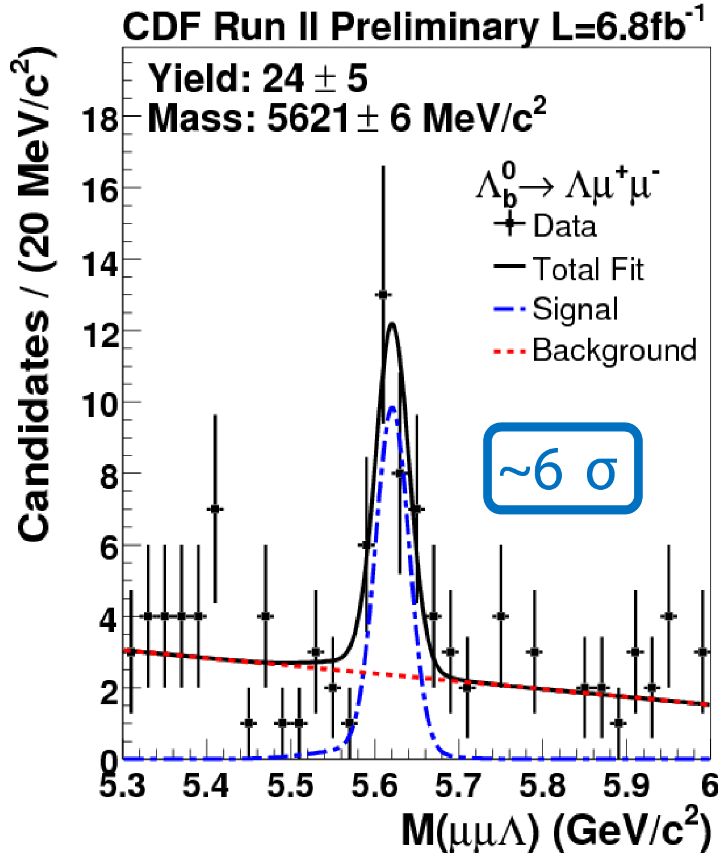
$\Lambda_b \rightarrow \Lambda\mu\mu$ observation

First experimental search for baryonic $b \rightarrow s\mu\mu$ decay



Reduce possible $K_s\mu\mu$ contamination

Momentum imbalance of V^0 daughters



First observation!

$$\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda\mu^+\mu^-) = [1.73 \pm 0.42(\mathrm{stat}) \pm 0.55(\mathrm{syst})] \times 10^{-6}$$

The rarest Λ_b decay to date

Expectations

- ✓ $(4.0\pm1.2)*10^{-6}$ Phys.Rev.D81,056006 (2010)
- ✓ $4.4*10^{-6}$ Phys.Rev.D78,114032 (2008)
- ✓ $2.08*10^{-6}$ Phys.Rev.D64,074001 (2001)

FCNC in $b \to s\mu\mu$ decays (CDF 6.8 fb^{-1})

- Rare decays with BR ~O(10^{-6}) in SM are good probes of NP

Mode	Relative $\mathcal{B}(10^{-3})$	Absolute $\mathcal{B}(10^{-6})$
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$	$2.45 \pm 0.59 \pm 0.29$	$1.73 \pm 0.42 \pm 0.55$
$B_s^0 \to \phi\mu^+\mu^-$	$1.13 \pm 0.19 \pm 0.07$	$1.47 \pm 0.24 \pm 0.46$
$B^+ \to K^+\mu^+\mu^-$	$0.46 \pm 0.04 \pm 0.02$	$0.46 \pm 0.04 \pm 0.02$
$B^0 \to K^{*0}\mu^+\mu^-$	$0.77 \pm 0.08 \pm 0.03$	$1.02 \pm 0.10 \pm 0.06$
$B^0 \to K^0\mu^+\mu^-$	$0.37 \pm 0.12 \pm 0.02$	$0.32 \pm 0.10 \pm 0.02$
$B^+ \to K^{*+}\mu^+\mu^-$	$0.67 \pm 0.22 \pm 0.04$	$0.95 \pm 0.32 \pm 0.08$

first observed by *CDF:*

$B_s \to \Phi\mu\mu$ (PRL106,161801 (2011))

$\Lambda_b \to \Lambda\mu\mu$ (arXiv:1107.3753)

- Most precise BR measurements

- BR theoretical calculations of $\Lambda_b \to \Lambda\mu\mu$

$(4.0\pm1.2)*10^{-6}$	Phys.Rev.D81,056006 (2010)
$4.4*10^{-6}$	Phys.Rev.D78,114032 (2008)
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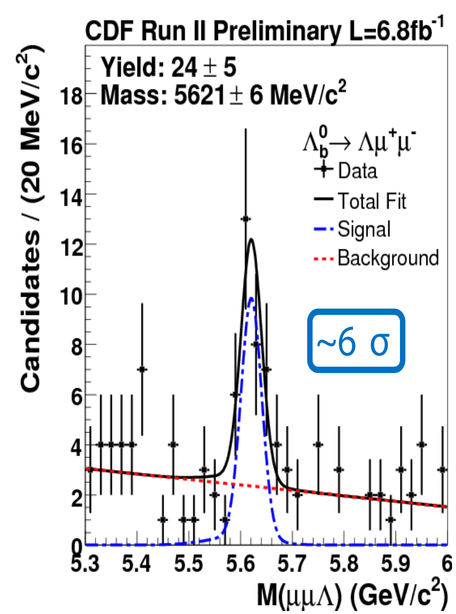
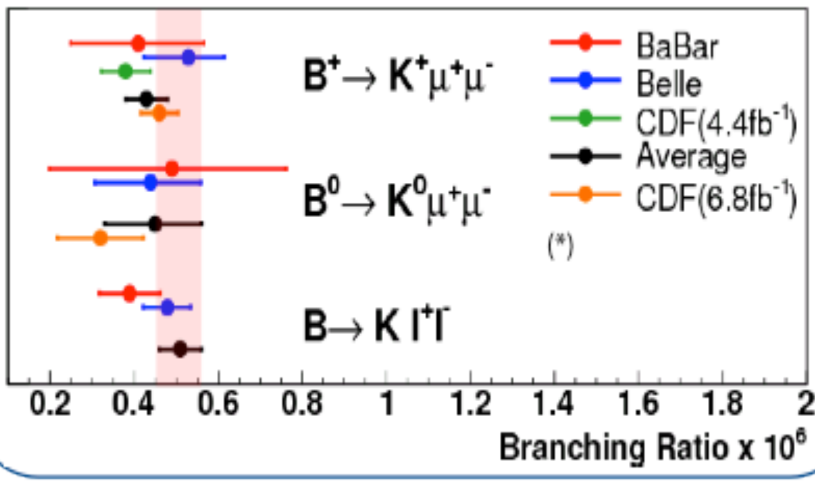
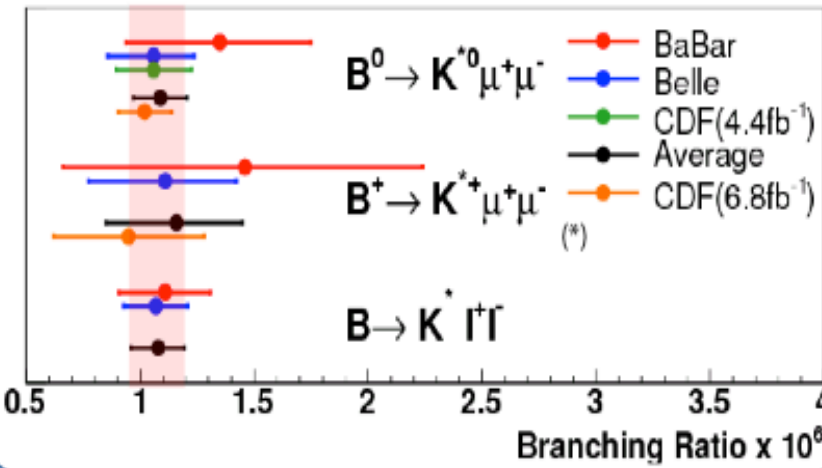
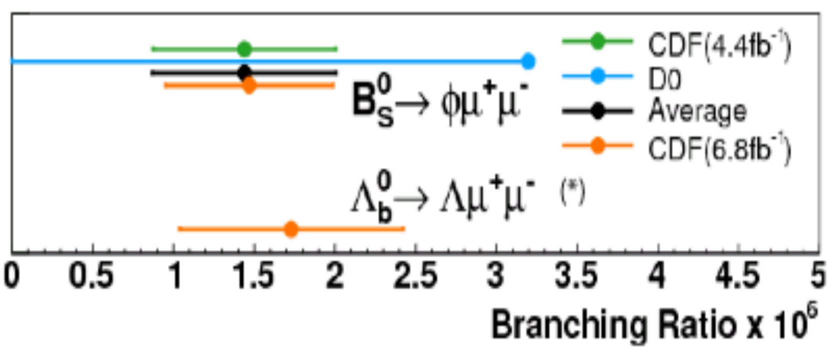


Comparison with Other Experiments





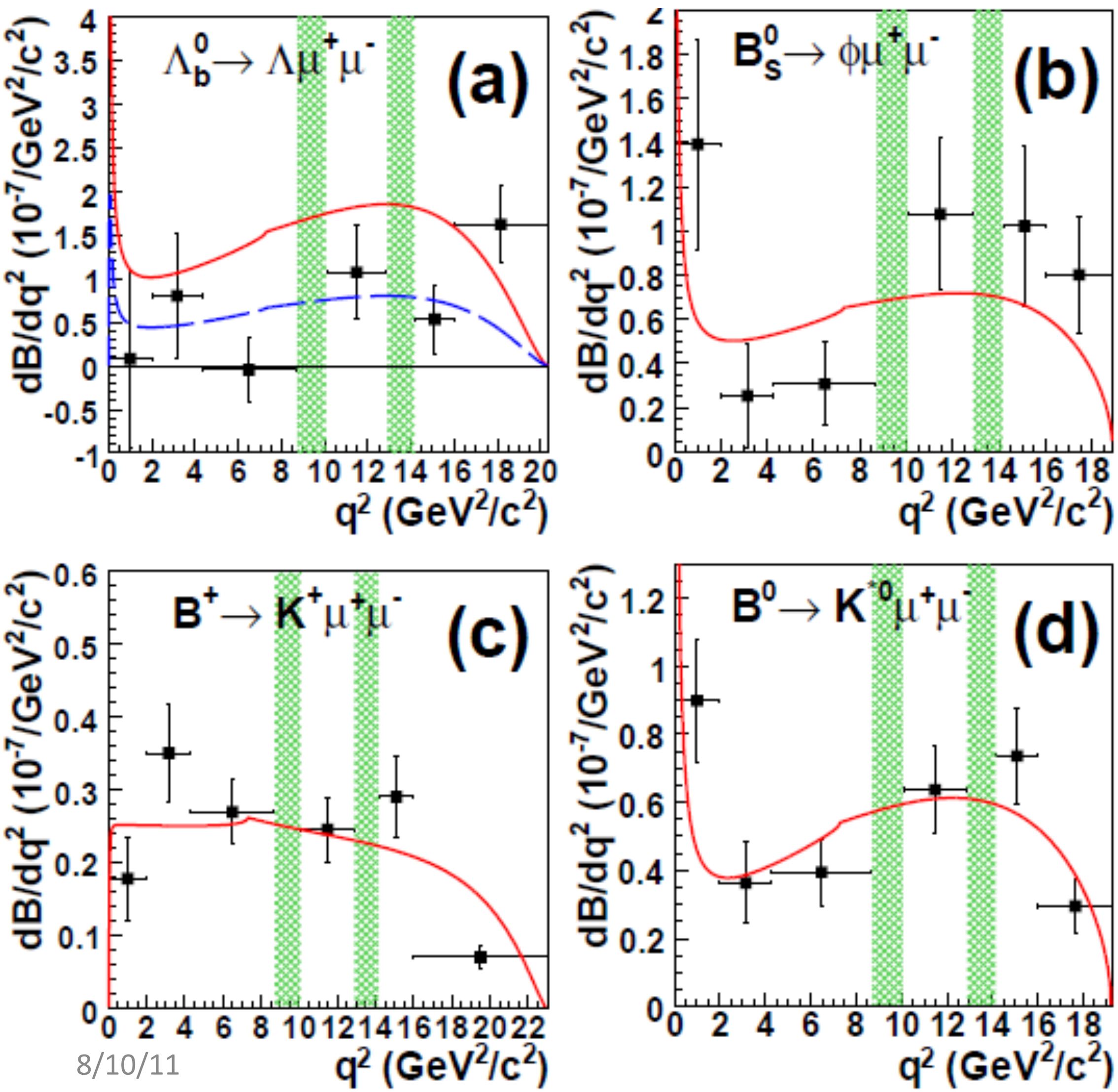


(*) All BRs except CDF@6.8fb^{-1} are taken from HFAG 2010 August

World's most precise $b \to s\mu\mu$ BR measurements!

b → sμμ differential BR (CDF 6.8 fb^{-1})

- Enhanced sensitivity to NP from differential BR (dBR) dependence on q^2.
- dBR as function of μμ squared invariant mass (q^2) in good agreement with theory:



Phys. Rev. D **61**, 074024 (2000).
Phys. Rev. D **81**,056006 (2010).
Phys. Rev. D **71**, 014015 (2005);
Phys. Rev. D **71**, 014029 (2005).

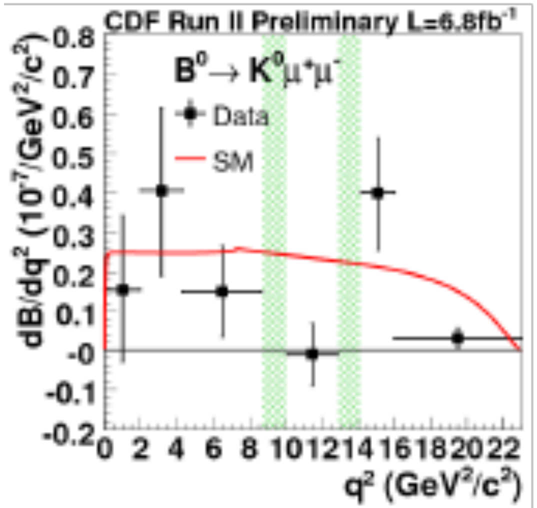
Red curves: SM predictions; (a) based on 4.0x10^{-6}

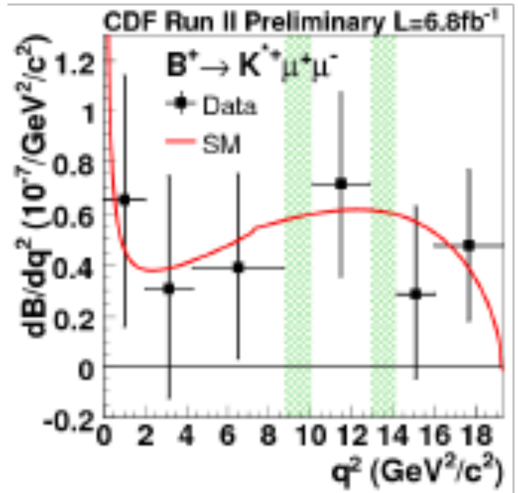
Blue curve(a): rescaled SM prediction to our total BR (1.73/4.0)

Green bands: charmonium veto

(a) and (b) are first measurements!

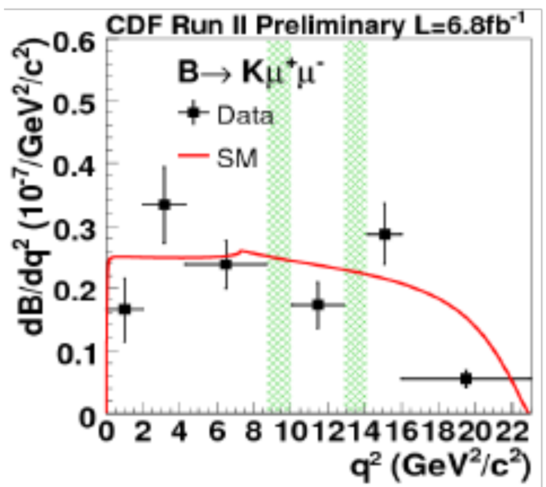
Differential BR’s (2)

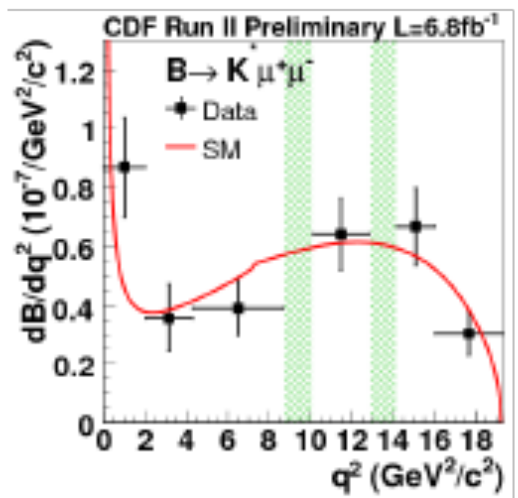




Results for K_s (left) and $K^{*+} \rightarrow K_s\, \pi^+$ (right).

- New!

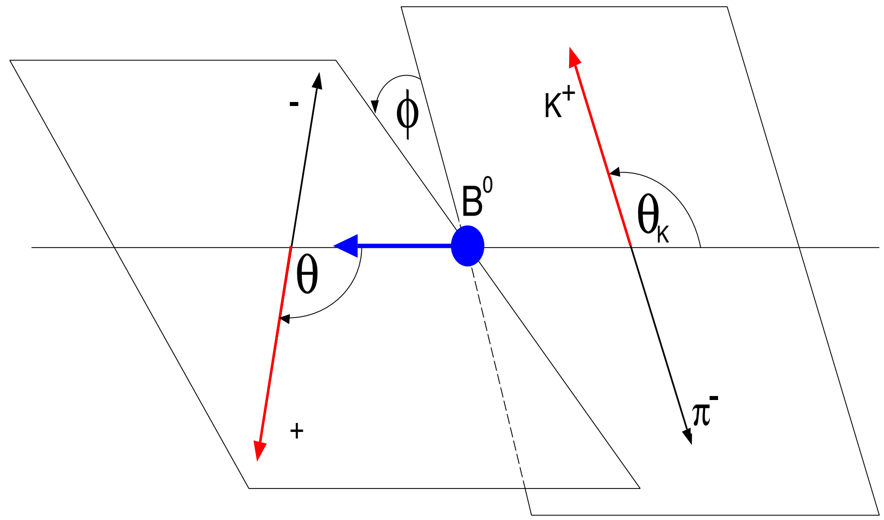




Combined results for K (left) and K^* (right).

- Assume isospin symmetry.

$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ Decay Variables

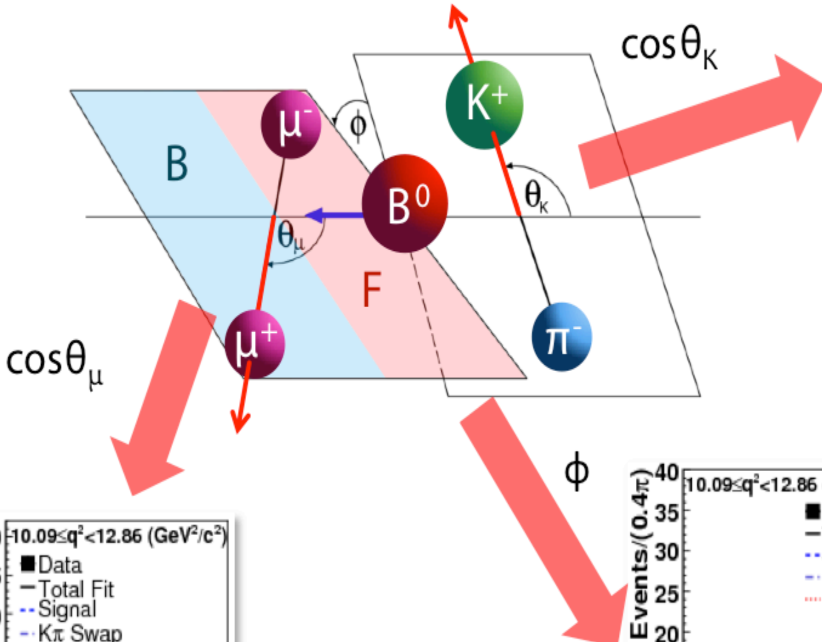


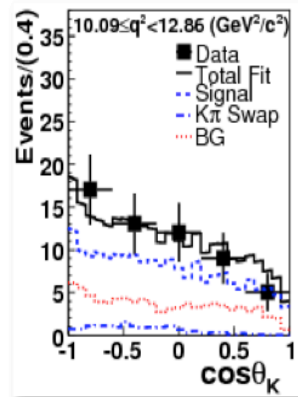
Asymmetries provide most powerful probe for New Physics.

- Four angular observables: F_L, A_{FB}, $A_T^{(2)}$, A_{im} which depend on K^* Polarization Amplitudes.
- Small theoretical uncertainties. Asymmetries can be accessed with current data (Belle, BaBar, CDF, early LHCb.)

Angular analysis

One can extract various information from the decay angular distribution

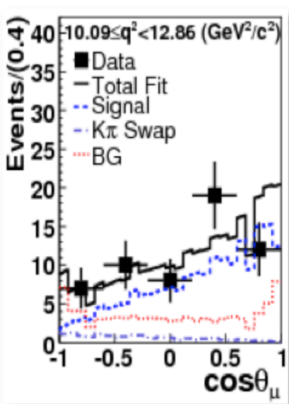




K* polarization

F_L

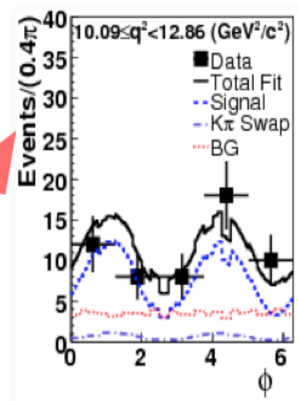
$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$



FB Asymmetry

A_{FB}

$$\frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$



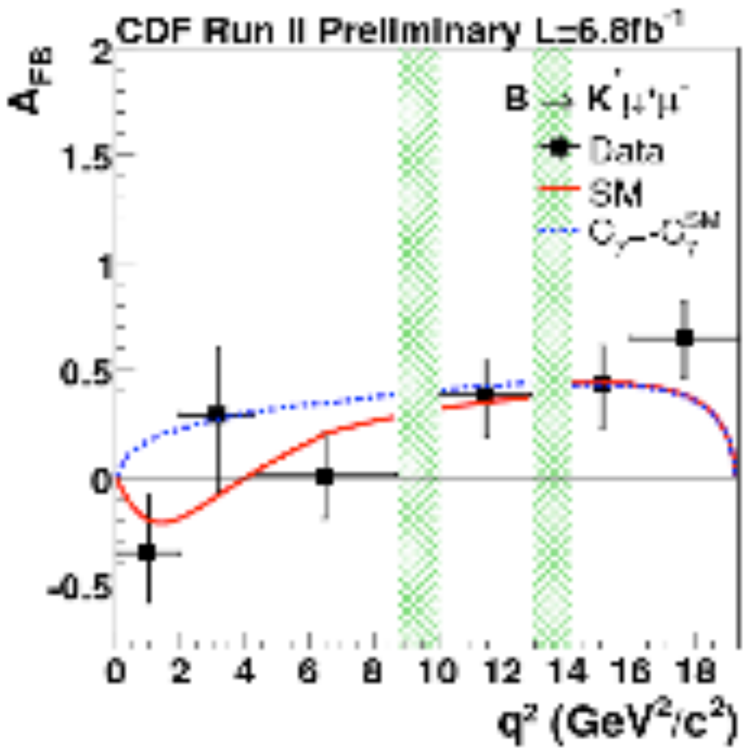
NEW

$A_T^{(2)}$ Transverse polarization asymmetry

A_{im} Triple product asymmetry

$$\frac{1}{2\pi}\left[1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi\right]$$

Muon Forward-Backward Asymmetry (A_{FB})

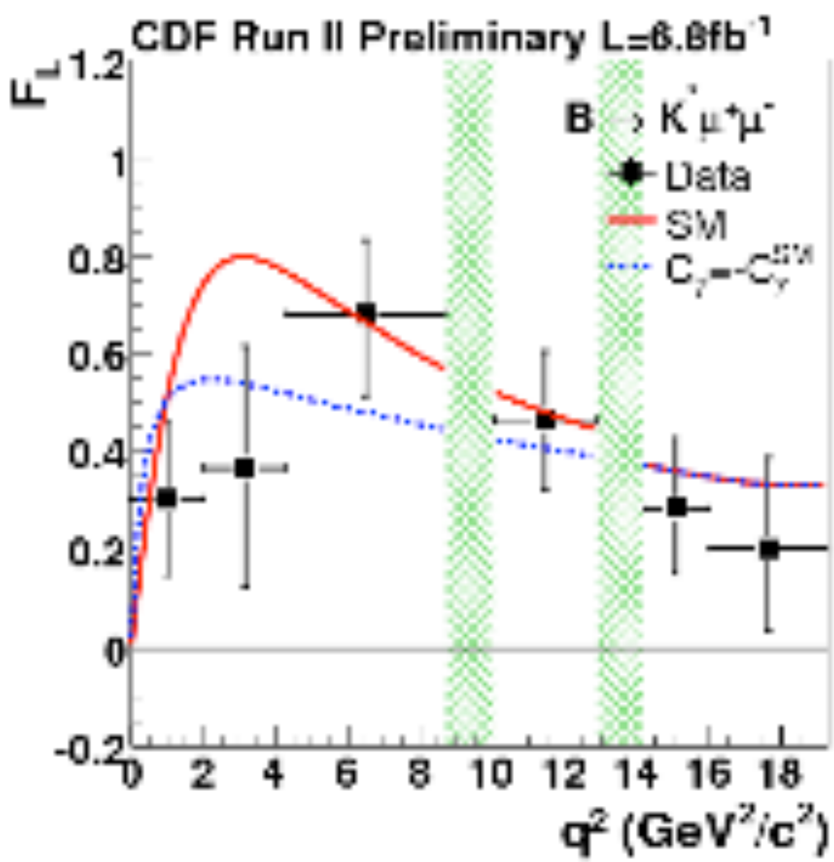


Belle claimed 2.7σ discrepancy with SM.

CDF data are among world's most accurate and do not yet suggest non-SM effects.

Red Curve: SM prediction (note zero crossing point prediction).
Blue curve: NP could swap the sign of A_{FB} at low q^2 (and give no crossing point).

K^* Longitudinal Polarization Fraction

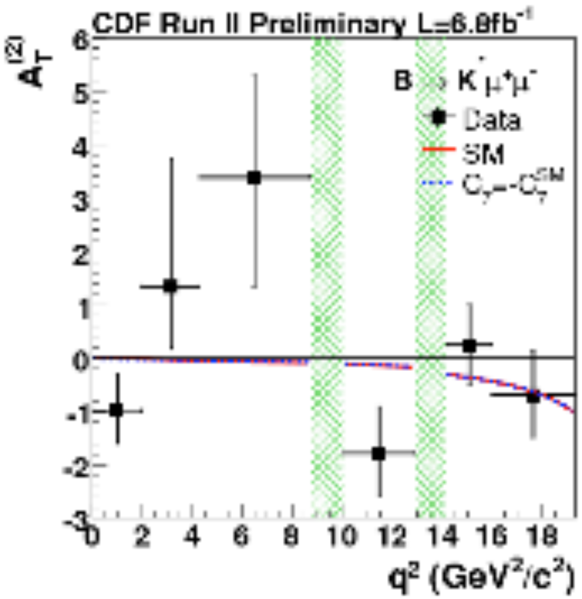


F_L determined from angular distribution of K^* decay products (e.g. $K^+ \pi^-$ or $K_s\pi^+$).

Simultaneous fit to all K^* modes.

Green bands: charmonium veto

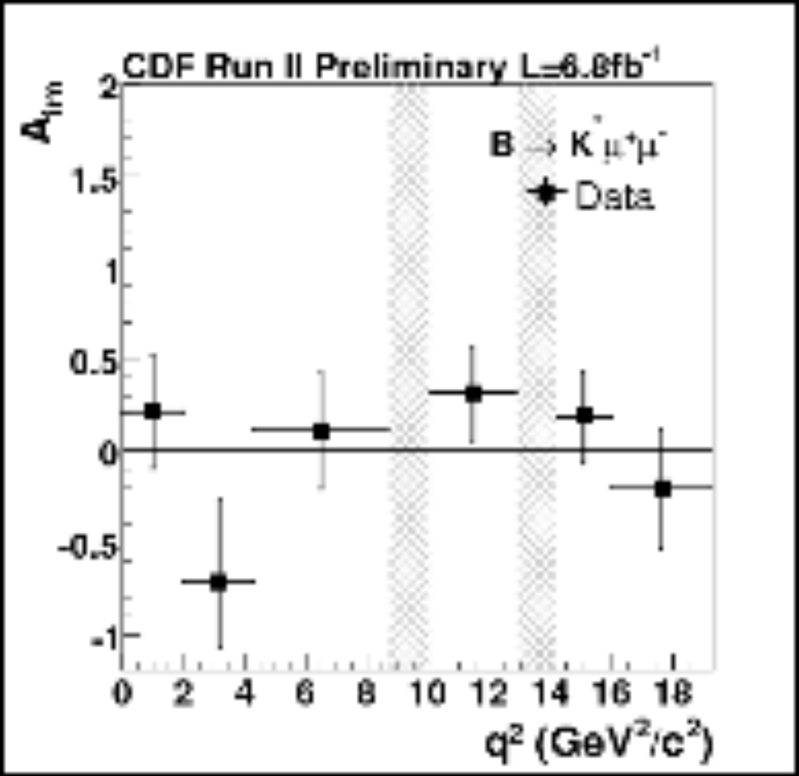
Transverse Polarization Asymmetry ($A_T^{(2)}$)



- First time anyone looks at this variable.
- Magnitude grows as q^2 increases (SM).
- Obtained from fits to ϕ angular distribution.
- Sensitive to CP-conserving RH currents (not just swapped sign of C_7).

- Data in reasonably good agreement with SM predictions.
- Swapped sign has little effect, but different predictions from other BSM models.

T-odd CP asymmetry (A_{im})



Obtained from fits to ϕ angular distribution.

A_{im} is sensitive to CP-violating Right-Handed currents.

Measuring $A_T^{(2)}$ and A_{im}
More statistics needed!

SM predicts the T-odd CP asymmetry A_{im} to be ~ zero.

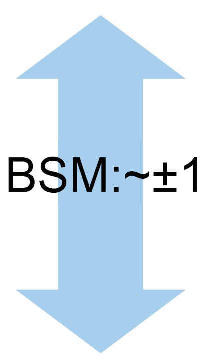
New probes: $A_T^{(2)}$ and A_{im}

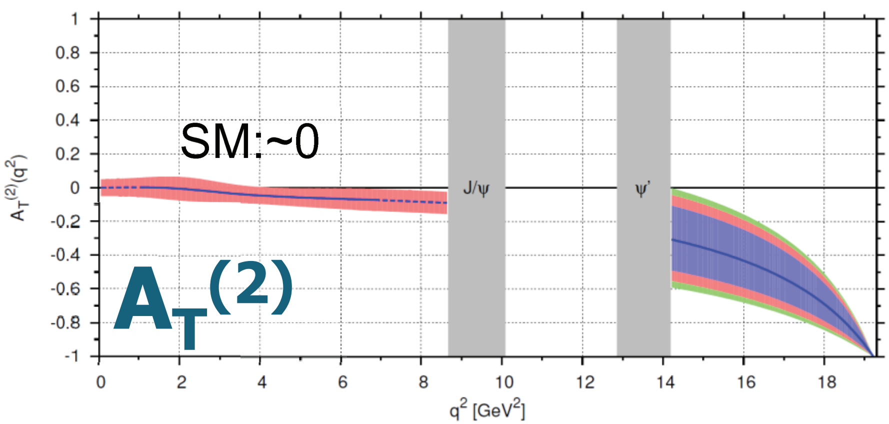
Right-handed current sensitive observables

- Small in SM ($A_T^{(2)}$ is negatively large in high q^2)
- Strongly affected by RH current up to $\mathcal{O}(\pm 1)$

Provide unique discrimination of NP models

No experimental result so far





arXiv:1006.5013
C. Bobeth, G. Hiller, D. van Dyk

Conclusions

- Updated $B \to K(*)\mu^+\mu^-$ analysis with 6.8/fb of data.
  Nearly 2x statistics. New channels (K_s ,K^{*+}).
- More precise Total BR's for exclusive $b \to s\mu\mu$ decays.
- First measurement of dBR in $B_s \to \phi\mu\mu$.
  First observation of $\Lambda_b \to \Lambda\mu\mu$.
  Pub. submitted: arXiv: 1107.3753 19 Jul 2011
- First measurements of $A_T^{(2)}$ and A_{im} (add. probes for NP).
- Precision of A_{FB} and F_L competitive with other experiments, and among world's most accurate.
  Pub. Submitted: arXiv: 1108.0695 2 Aug 2011

BACKUP

Angular Dependence of Decay Rates

$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

F_L

$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$

F_L , A_{FB}

$$\frac{1}{\Gamma}\frac{d\Gamma(B \to K^{*}\mu^+\mu^-)}{d\varphi} = \frac{1}{2\pi}[1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\varphi + A^{im}\sin 2\varphi].$$

$A_T^{(2)}$, A_{im}

Observables

$$A_{FB} = \frac{3}{2}\frac{\mathrm{Re}(A_{\perp L}A^{*}_{\parallel L}) - \mathrm{Re}(A_{\perp R}A^{*}_{\parallel R})}{|A_0|^2 + |A_{\parallel}|^2 + |A_{\perp}|^2},$$

$$F_L = \frac{|A_0|^2}{|A_0|^2 + |A_{\parallel}|^2 + |A_{\perp}|^2},$$

$$A_T^{(2)} = \frac{|A_{\perp}|^2 - |A_{\parallel}|^2}{|A_{\perp}|^2 + |A_{\parallel}|^2},$$

$$A^{im} = \frac{\mathrm{Im}(A_{\perp L}A^{*}_{\parallel L}) + \mathrm{Im}(A_{\perp R}A^{*}_{\parallel R})}{|A_0|^2 + |A_{\parallel}|^2 + |A_{\perp}|^2}.$$