$B \rightarrow X_s \mu \mu$ Results from CDF

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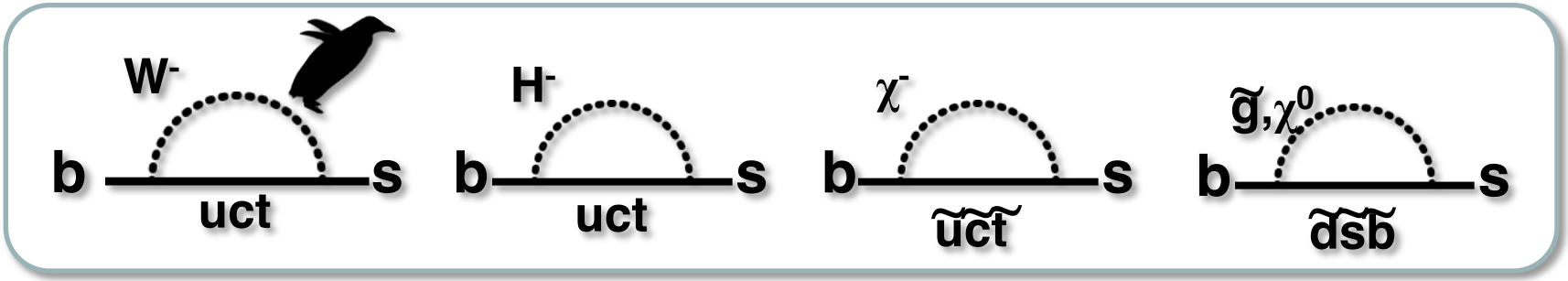
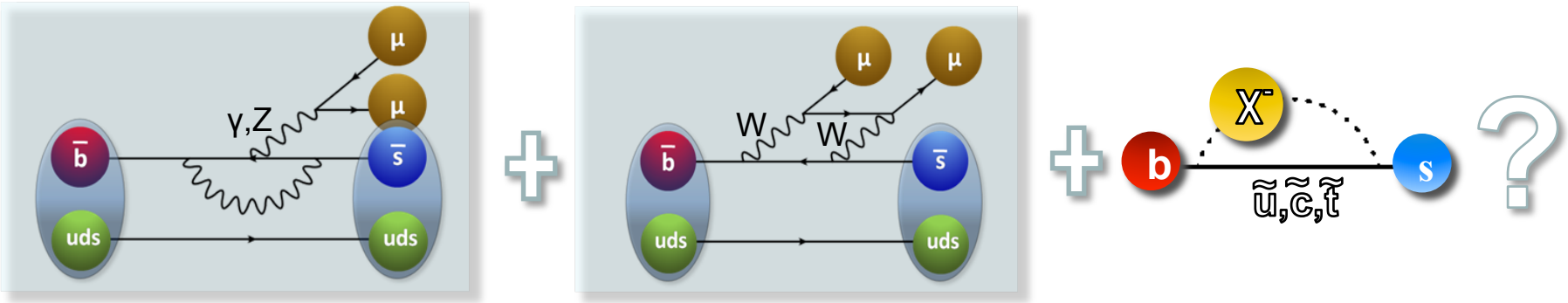
Search for NP in FCNC processes



- In SM Flavor Changing Neutral Current processes are forbidden via tree amplitudes. They occur via higher order loop (Penguin) diagrams.
- In BSM heavy exotic particle can participate in the loops and modify the amplitudes.
  - Very interesting in search for BSM physics.

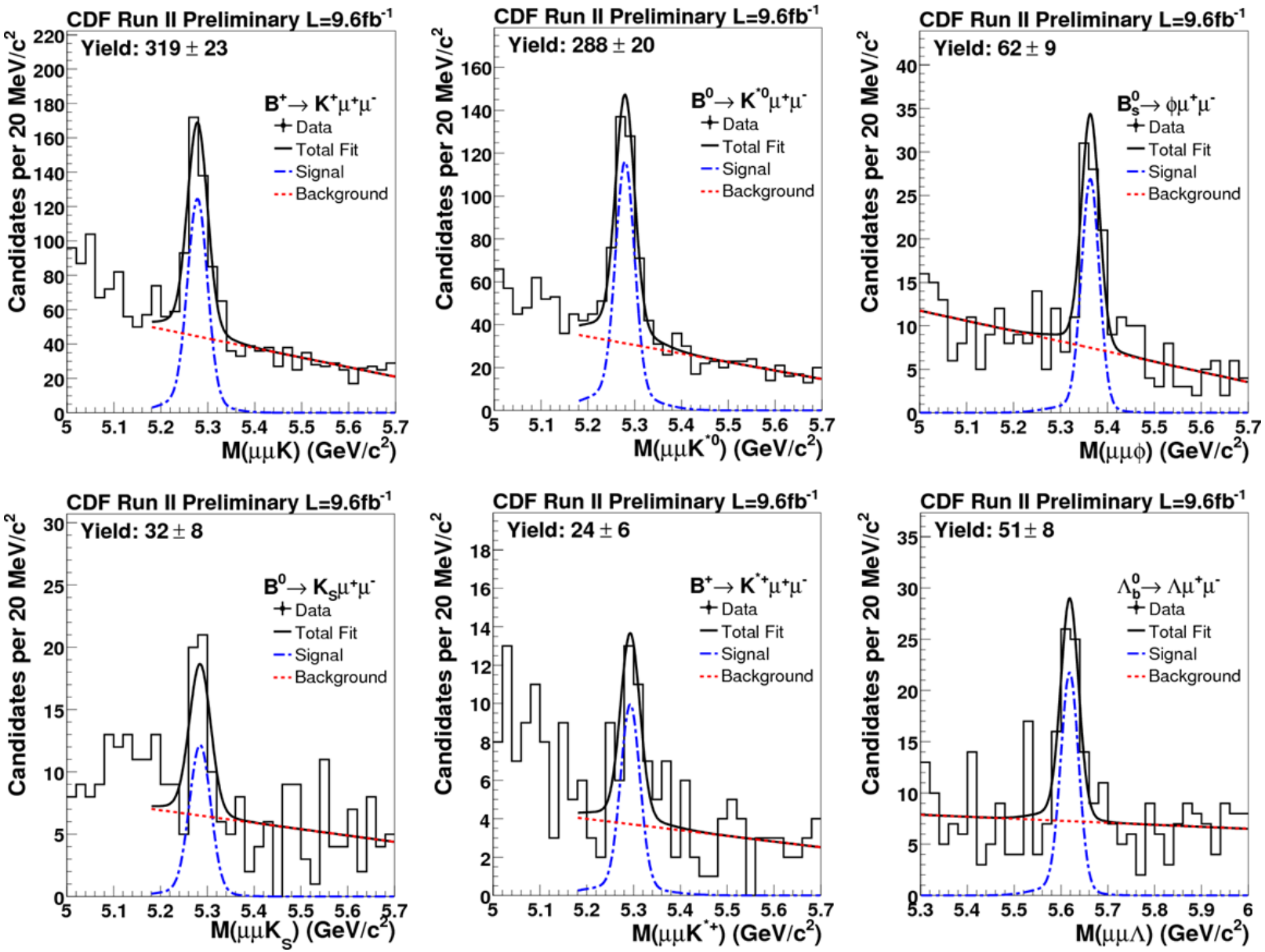
$B \rightarrow X_s \mu \mu$: A Golden Probe



- Three body decay provides observables sensitive to NP
  - Total and differential BR, isospin asymmetry, forward-backward asymmetry…
  - CDF first measurements: Transverse polarization and T-odd CP asymmetries **[PRL108, 081807 (2012)]**
- Many modes:
  - CDF first observations: $B_s \rightarrow \phi\, \mu\mu$ **[PRL106, 161801 (2011)]**

    $\Lambda_b \rightarrow \Lambda\, \mu\mu$ **[PRL107, 201802 (2011)]**
  - $B^0 \rightarrow K^{*0}, K_s\, \mu\mu$ $\quad B^+ \rightarrow K^{*+}, K^+\, \mu\mu$

Rare B yields 9.6 fb^{-1}



Measured BRs

- Relative BRs

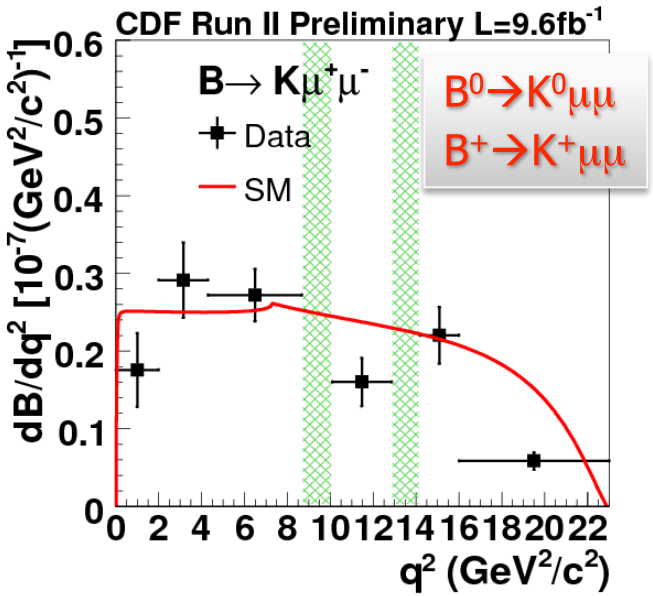
$$
\begin{aligned}
\mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to J/\psi K^+) &= [0.44 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)/\mathcal{B}(B^0 \to J/\psi K^{*0}) &= [0.85 \pm 0.07(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)/\mathcal{B}(B_s^0 \to J/\psi\phi) &= [0.90 \pm 0.14(\text{stat}) \pm 0.07(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^0 \to K^0\mu^+\mu^-)/\mathcal{B}(B^0 \to J/\psi K^0) &= [0.44 \pm 0.10(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-)/\mathcal{B}(B^+ \to J/\psi K^{*+}) &= [0.62 \pm 0.18(\text{stat}) \pm 0.06(\text{syst})] \times 10^{-3}, \\
\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-)/\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda) &= [2.75 \pm 0.48(\text{stat}) \pm 0.27(\text{syst})] \times 10^{-3}.
\end{aligned}
$$

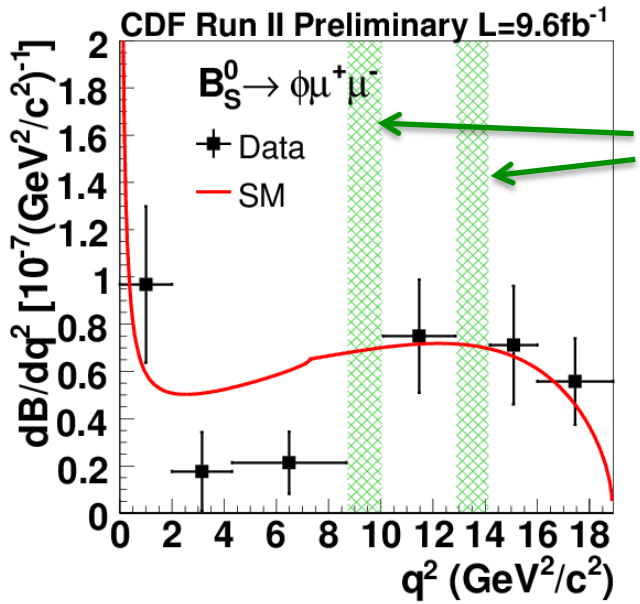
➔ Consistent with SM. Check angular variables.

- Absolute BRs

$$
\begin{aligned}
\mathcal{B}(B^+ \to K^+\mu^+\mu^-) &= [0.45 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-) &= [1.14 \pm 0.09(\text{stat}) \pm 0.06(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) &= [1.17 \pm 0.18(\text{stat}) \pm 0.37(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^0 \to K^0\mu^+\mu^-) &= [0.33 \pm 0.08(\text{stat}) \pm 0.03(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-) &= [0.89 \pm 0.25(\text{stat}) \pm 0.09(\text{syst})] \times 10^{-6}, \\
\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-) &= [1.95 \pm 0.34(\text{stat}) \pm 0.61(\text{syst})] \times 10^{-6}.
\end{aligned}
$$

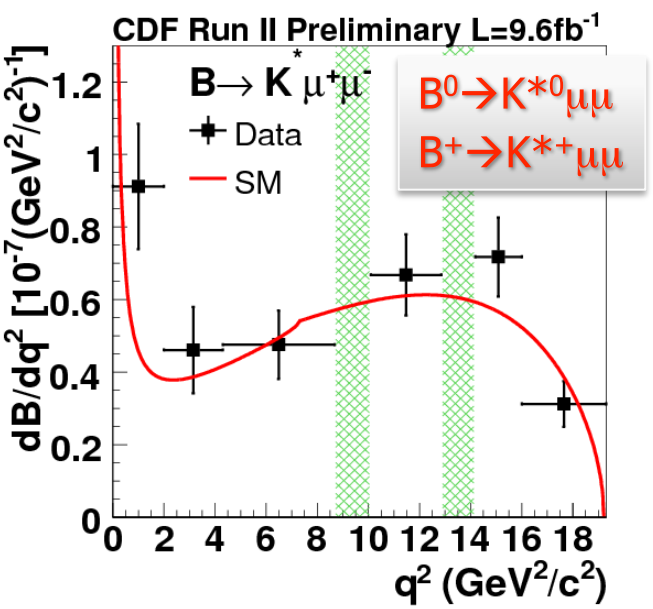
Differential BRs

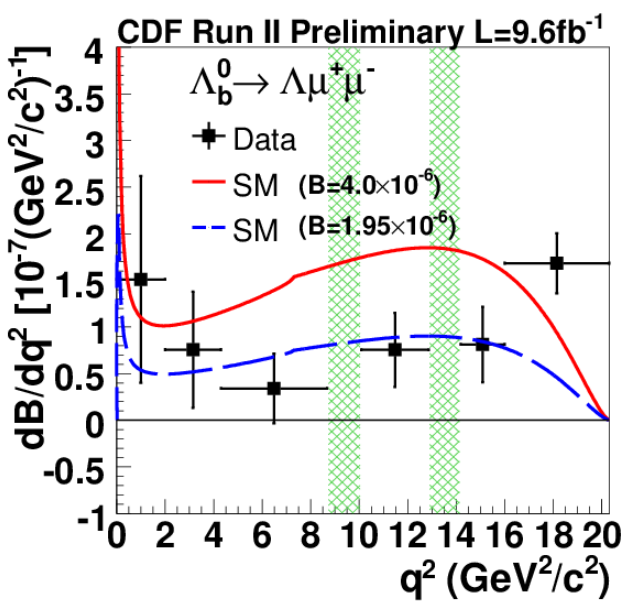




J/ψ,ψ' veto

$q^2 = M^2_{\mu\mu}c^2$





- SM based on BR 4.0×10^{-6}

T. M. Aliev, K. Azizi, M. Savci, PRD81, 056006 (2010)

- SM scaled to our value 1.95×10^{-6}

Isospin asymmetry

- Isospin asymmetry:

$$A_I = \frac{dB(B^0) - r\, dB(B^+)}{dB(B^0) + r\, dB(B^+)}$$

$$1/r = \tau(B^+)/\tau(B^0) = 1.071 \pm 0.009$$

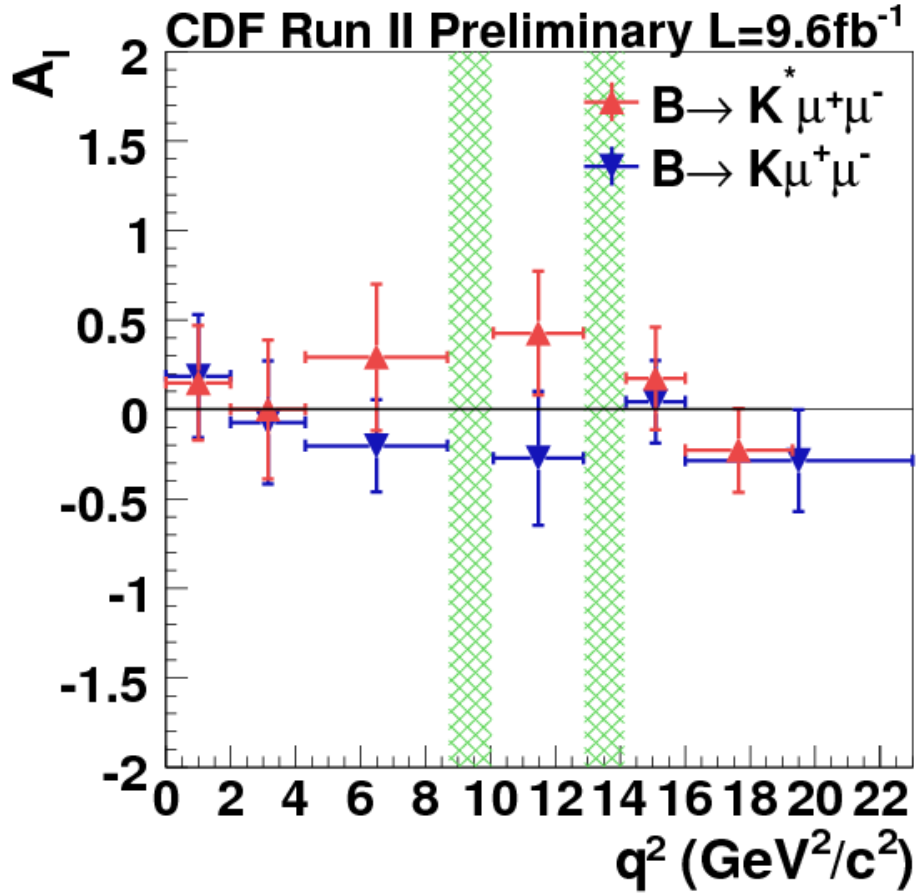
- Integrated asymmetries:

$$A_I(B \to K\mu\mu) = -0.11 \pm 0.13(stat) \pm 0.05(syst)$$

$$A_I(B \to K^*\mu\mu) = 0.16 \pm 0.14(stat) \pm 0.06(syst)$$

Belle: $0.33^{+0.38}_{-0.44}$

BaBar: $-0.20^{+0.30}_{-0.23}$



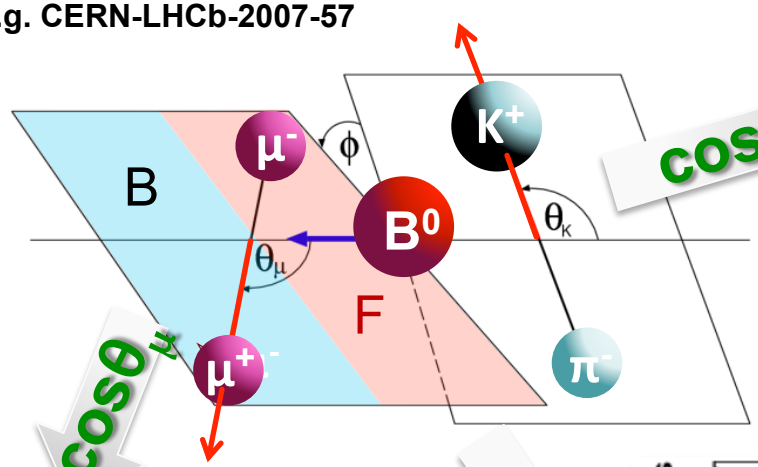
LHCb: -0.15±0.16

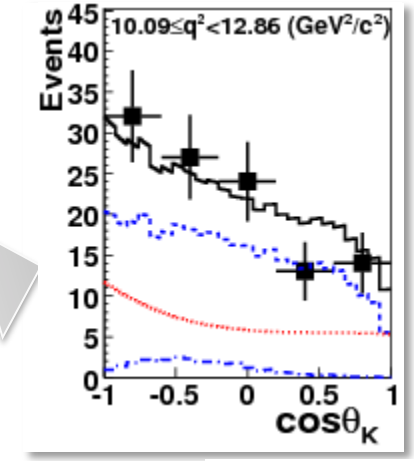
➔ Consistent with zero. Same trend as other experiments.

Angular analysis $B \to K^* \mu\mu$

- **Extract various information from the decay angular distribution**

  e.g. CERN-LHCb-2007-57

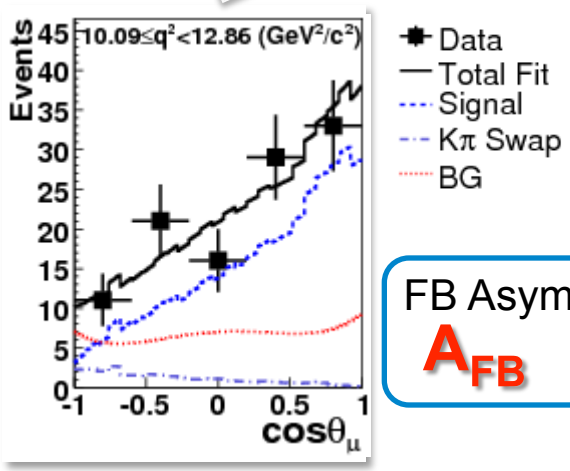




K* polarization

F_L

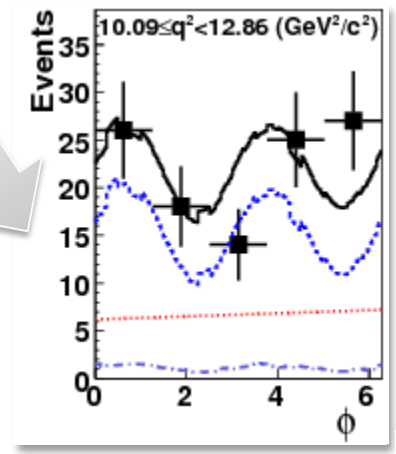
$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$



FB Asymmetry

A_{FB}

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



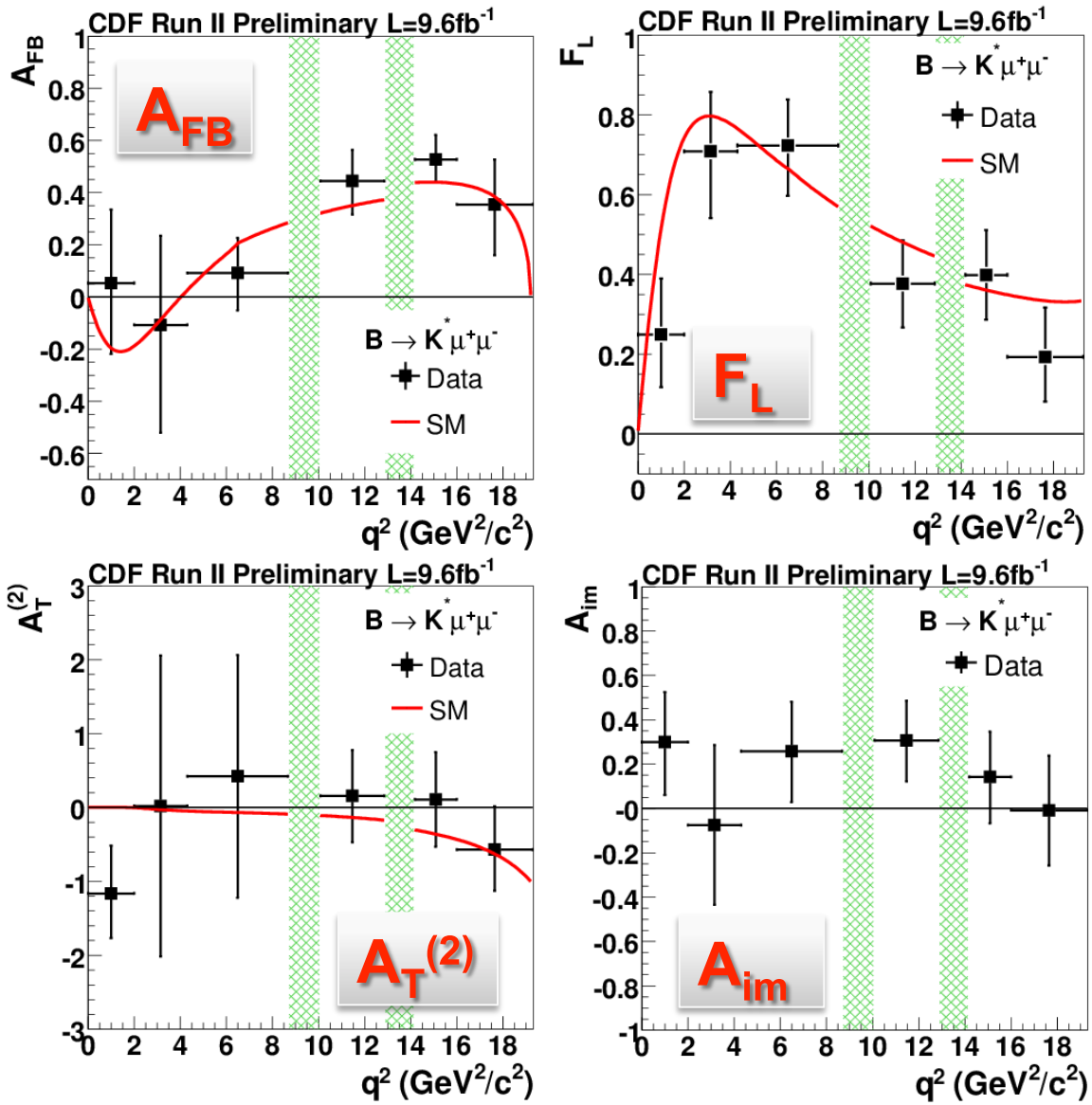
$A_T^{(2)}$ Transverse polarization asymmetry

A_{im} T-odd CP asymmetry

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

Angular fit results

- Simultaneous fit with K^{*0} and K^{*+}
- Consistent with previous measurements
- No significant deviation from SM within current precision



Conclusions

- CDF continues to explore rare B decays with its full 10 fb^{-1} data sample.
- Total and differential BRs in various $B \rightarrow X_s \mu\mu$ FCNC rare decays have been measured with full data sample.
- Results from $B \rightarrow K^* \mu\mu$ angular analysis are consistent with SM and other experiments.
- For more results visit our results pages:
  - CDF: http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

BACKUP SLIDES

Angular fit results

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

q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A_{im}
$[0.00, 2.00)$	$0.26^{+0.14}_{-0.13} \pm 0.04$	$0.07^{+0.29}_{-0.28} \pm 0.11$	$-0.97^{+0.66}_{-0.63} \pm 0.29$	$0.39^{+0.23}_{-0.24} \pm 0.08$
$[2.00, 4.30)$	$0.72^{+0.15}_{-0.17} \pm 0.09$	$-0.11^{+0.34}_{-0.45} \pm 0.16$	$0.40^{+2.16}_{-2.17} \pm 0.55$	$-0.01^{+0.38}_{-0.38} \pm 0.04$
$[4.30, 8.68)$	$0.72^{+0.12}_{-0.13} \pm 0.06$	$0.12^{+0.14}_{-0.15} \pm 0.04$	$-0.08^{+1.68}_{-1.66} \pm 0.33$	$0.25^{+0.24}_{-0.24} \pm 0.09$
$[10.09, 12.86)$	$0.35^{+0.11}_{-0.11} \pm 0.04$	$0.43^{+0.13}_{-0.13} \pm 0.07$	$0.22^{+0.60}_{-0.61} \pm 0.08$	$0.35^{+0.18}_{-0.19} \pm 0.06$
$[14.18, 16.00)$	$0.45^{+0.12}_{-0.12} \pm 0.04$	$0.49^{+0.10}_{-0.09} \pm 0.07$	$0.15^{+0.72}_{-0.72} \pm 0.14$	$0.16^{+0.21}_{-0.22} \pm 0.03$
$[16.00, 19.30)$	$0.09^{+0.14}_{-0.12} \pm 0.08$	$0.42^{+0.22}_{-0.23} \pm 0.09$	$-0.62^{+0.56}_{-0.53} \pm 0.13$	$0.02^{+0.26}_{-0.27} \pm 0.04$
$[0.00, 4.30)$	$0.44^{+0.11}_{-0.11} \pm 0.03$	$-0.04^{+0.23}_{-0.23} \pm 0.07$	$-0.59^{+0.68}_{-0.67} \pm 0.19$	$0.25^{+0.21}_{-0.21} \pm 0.05$
$[1.00, 6.00)$	$0.78^{+0.13}_{-0.15} \pm 0.08$	$0.29^{+0.25}_{-0.21} \pm 0.06$	$-0.45^{+2.24}_{-2.22} \pm 0.76$	$0.51^{+0.28}_{-0.29} \pm 0.15$

- $B \rightarrow K^{*}\mu\mu$ [B^0,B^+ combined]

q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A_{im}
$[0.00, 2.00)$	$0.25^{+0.14}_{-0.13} \pm 0.04$	$0.05^{+0.28}_{-0.27} \pm 0.10$	$-1.16^{+0.65}_{-0.60} \pm 0.34$	$0.30^{+0.23}_{-0.24} \pm 0.07$
$[2.00, 4.30)$	$0.71^{+0.15}_{-0.17} \pm 0.07$	$-0.11^{+0.34}_{-0.41} \pm 0.16$	$0.02^{+2.04}_{-2.04} \pm 0.30$	$-0.08^{+0.36}_{-0.36} \pm 0.07$
$[4.30, 8.68)$	$0.72^{+0.12}_{-0.13} \pm 0.05$	$0.09^{+0.14}_{-0.14} \pm 0.04$	$0.42^{+1.64}_{-1.64} \pm 0.64$	$0.26^{+0.22}_{-0.23} \pm 0.08$
$[10.09, 12.86)$	$0.38^{+0.11}_{-0.11} \pm 0.04$	$0.44^{+0.12}_{-0.13} \pm 0.08$	$0.16^{+0.62}_{-0.62} \pm 0.08$	$0.31^{+0.18}_{-0.18} \pm 0.06$
$[14.18, 16.00)$	$0.40^{+0.11}_{-0.11} \pm 0.04$	$0.53^{+0.09}_{-0.09} \pm 0.07$	$0.11^{+0.64}_{-0.64} \pm 0.11$	$0.14^{+0.20}_{-0.21} \pm 0.02$
$[16.00, 19.30)$	$0.19^{+0.12}_{-0.11} \pm 0.07$	$0.35^{+0.17}_{-0.19} \pm 0.06$	$-0.57^{+0.59}_{-0.56} \pm 0.12$	$-0.01^{+0.25}_{-0.25} \pm 0.04$
$[0.00, 4.30)$	$0.43^{+0.11}_{-0.11} \pm 0.03$	$-0.04^{+0.23}_{-0.22} \pm 0.07$	$-0.76^{+0.66}_{-0.65} \pm 0.22$	$0.15^{+0.20}_{-0.20} \pm 0.06$
$[1.00, 6.00)$	$0.76^{+0.12}_{-0.14} \pm 0.07$	$0.19^{+0.17}_{-0.21} \pm 0.05$	$-0.07^{+1.90}_{-1.90} \pm 0.19$	$0.42^{+0.24}_{-0.26} \pm 0.13$

Sources of systematics q^2[1.00-6.00]

	A_{FB}	F_L	$A_T^{(2)}$	A_{im}
Signal fraction and B mass shape		✔	✔	✔
Angular acceptance				
Angular background	✔	✔	✔	✔
K-π swap				
Peaking background				
Fit bias	✔			✔
Trigger bias				
F_L fit			✔	
TOTAL	0.064	0.078	0.758	0.152