CDF results on the search for rare $B_d, B_s \rightarrow \mu^+\mu^-$ and $X_s\mu^+\mu^-$ decays

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on behalf of CDF collaboration

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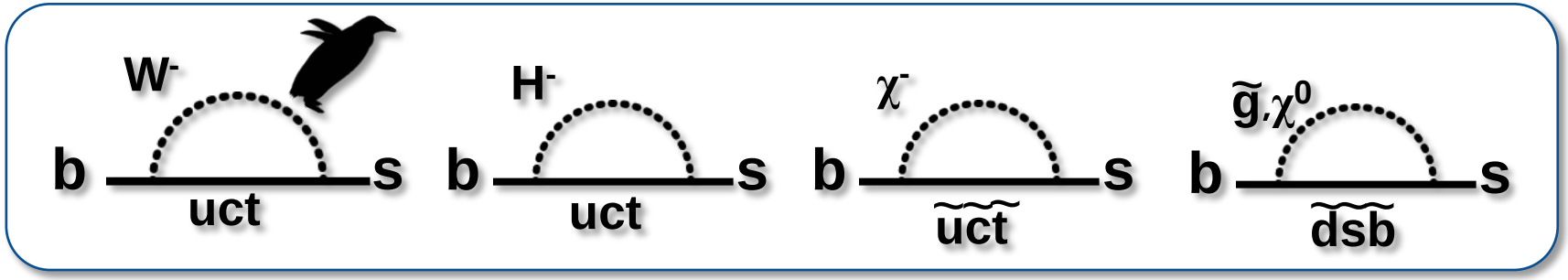
Looking for New Physics…

Key Tool: FCNC



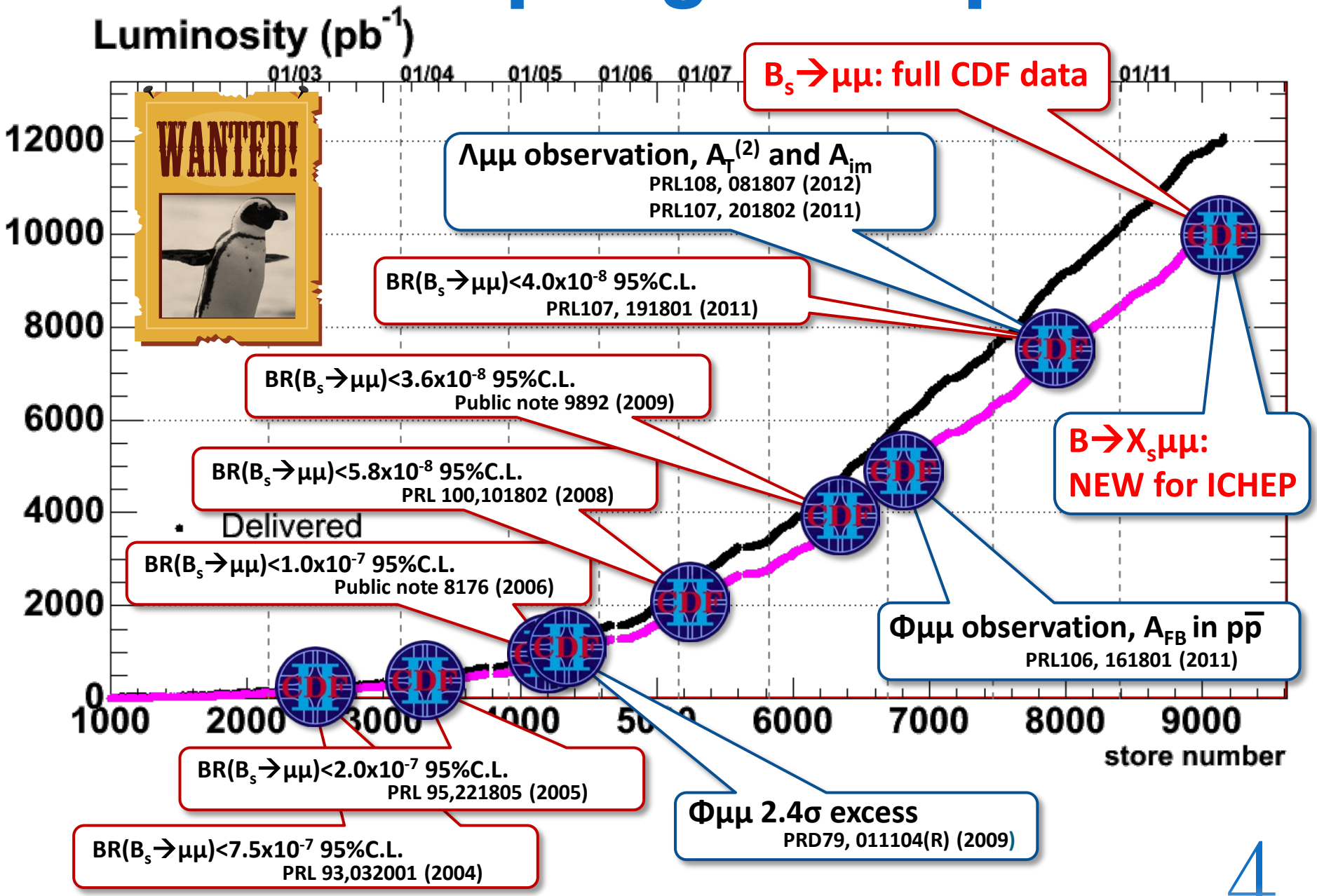
Flavor-Changing Neutral Current

SM
- Tree amplitudes forbidden
- Occur via higher order loop amplitudes

BSM
- Heavy BSM particle could contribute to the loop
  - ✓ Modifies the decay amplitude

Where are BSM penguins?

Tevatron: penguin explorer



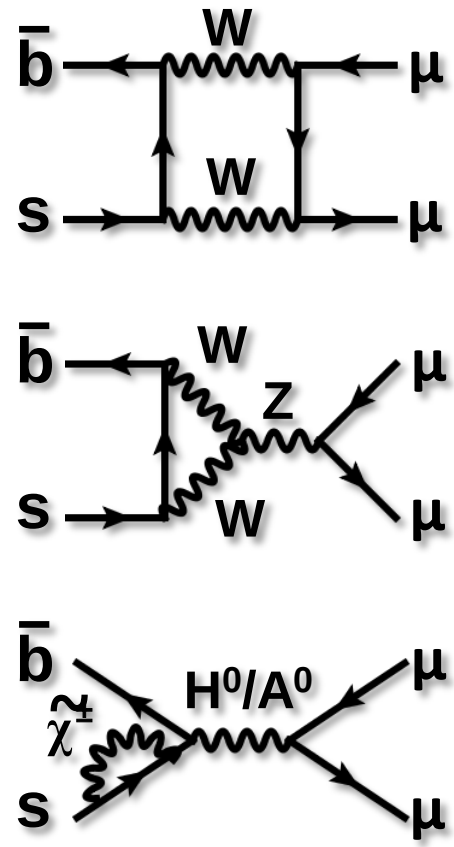
B→μμ

- **Highly suppressed in the SM**

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B_d^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

A. J. Buras, JHEP09,106 (2010)

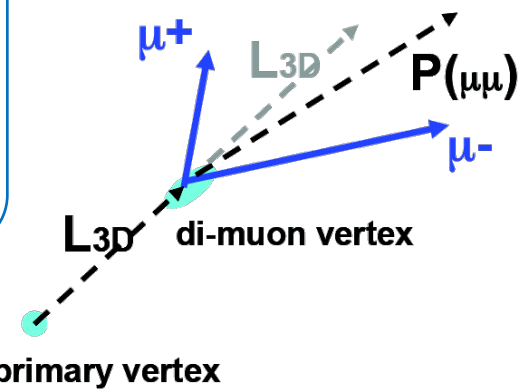
- **Enhanced in NP models (up to 100x)**
  - e.g. MSSM: BR(B→μμ) $(\tan\beta)^6$

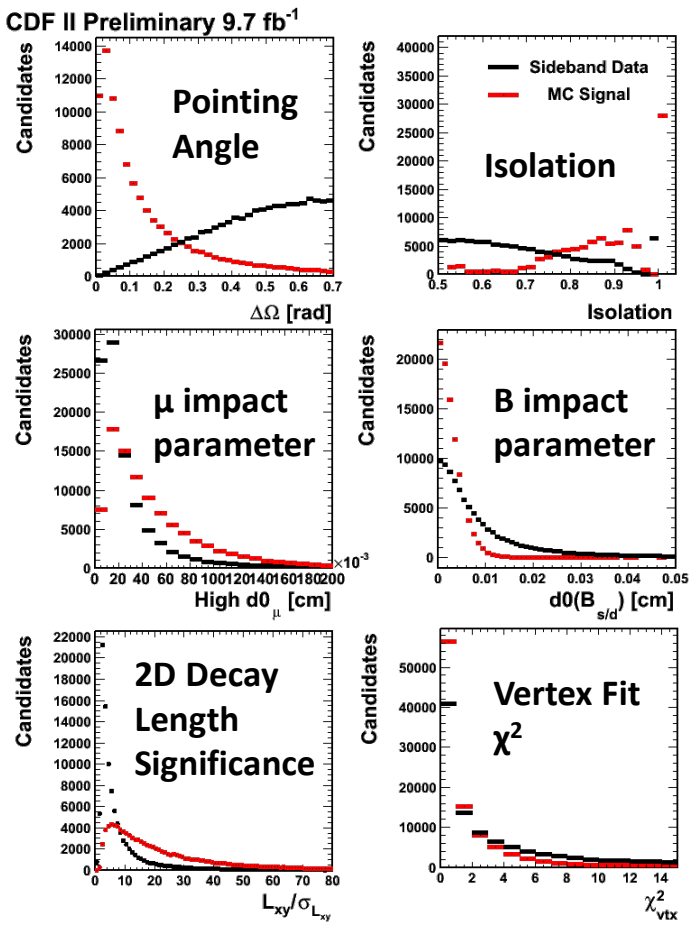


- **Experimental status**
  - **CDF** $Br(B_s \to \mu\mu) = 1.8^{+1.1}_{-0.9} \times 10^{-8}$ PRL107, 191801 (2011)
  - **DØ** $Br(B_s \to \mu\mu) < 5.1 \times 10^{-8}$ @95% C.L. PLB693, 539 (2010)
  - **LHCb** $Br(B_s \to \mu\mu) < 4.5 \times 10^{-9}$ @95% C.L. arXiv:1203.4493
  - **CMS** $Br(B_s \to \mu\mu) < 7.7 \times 10^{-9}$ @95% C.L. JHEP04 (2012) 033
  - **ATLAS** $Br(B_s \to \mu\mu) < 2.2 \times 10^{-8}$ @95% C.L. arXiv:1204.0735

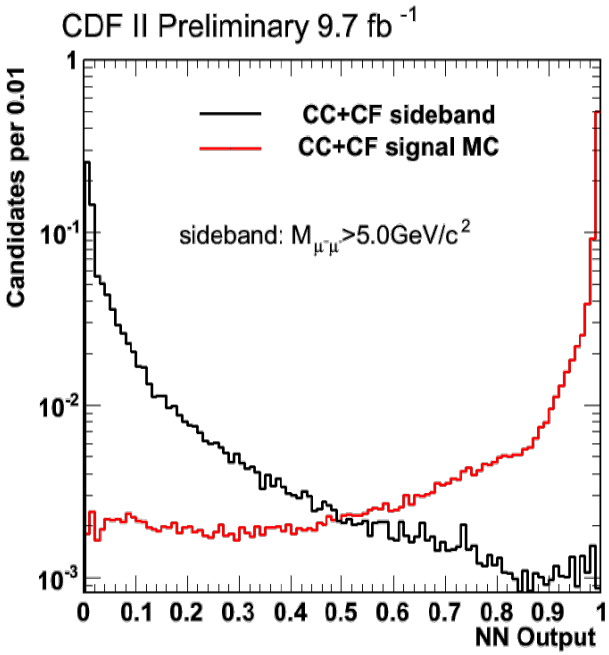
B→μμ: event selection

- Dimuon trigger
- Optimized event selection using NN
  - Identical NN weight used for 6.8 fb^{-1}
- Normalized by control sample ($B^+ \to J/\psi(\to \mu\mu)K^+$)

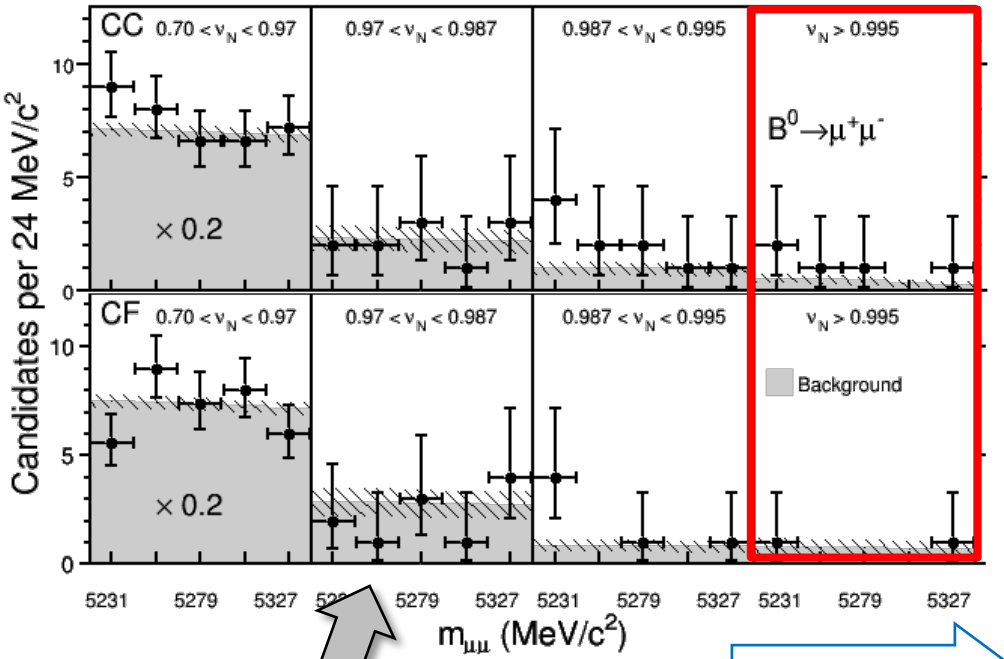


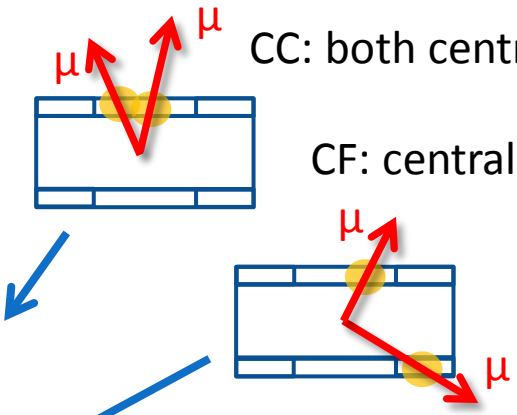


14 Discriminating variables



$B_d \rightarrow \mu\mu$: results with 10 fb^{-1}



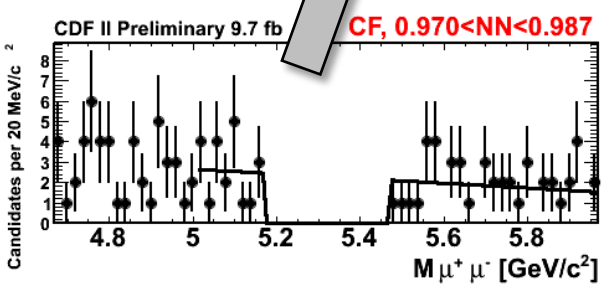


CC: both central muon

CF: central+forward muon

signal like

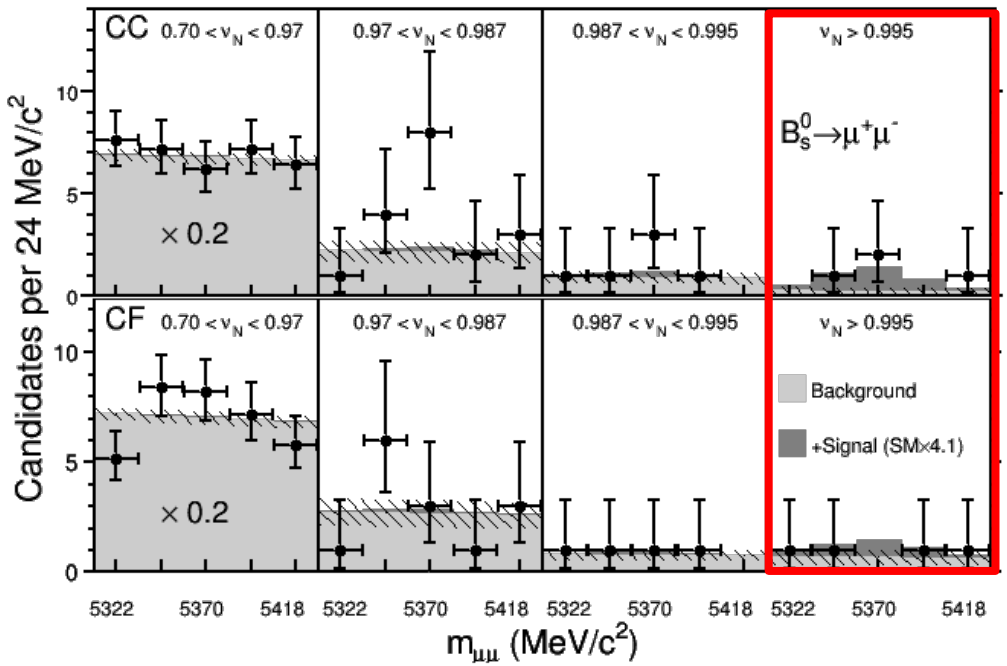
- **Divide signal region by NN discriminant and muon topology**
- **Estimate BG from each mass sideband**

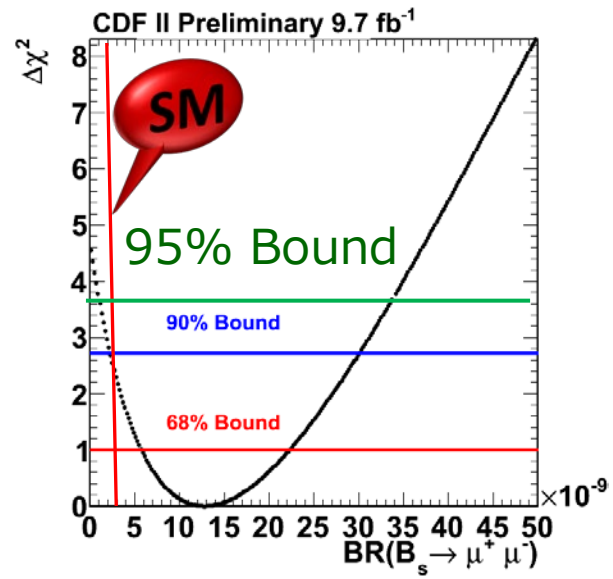


- **Good consistency with expected limit:**
  $BR(B_d \rightarrow \mu^+\mu^-)_{exp} < 4.2\times10^{-9}$ at 95% C.L.

  $BR(B_d \rightarrow \mu^+\mu^-) < 4.6\times10^{-9}$ at 95% C.L.
- **Consistent with SM**

$B_s \rightarrow \mu\mu$: results with 10 fb^{-1}





- **Last summer excess not reinforced by new data, but still there**
  - **Keep observing a >2σ fluctuation over BG only, which allows us to quote a BR**

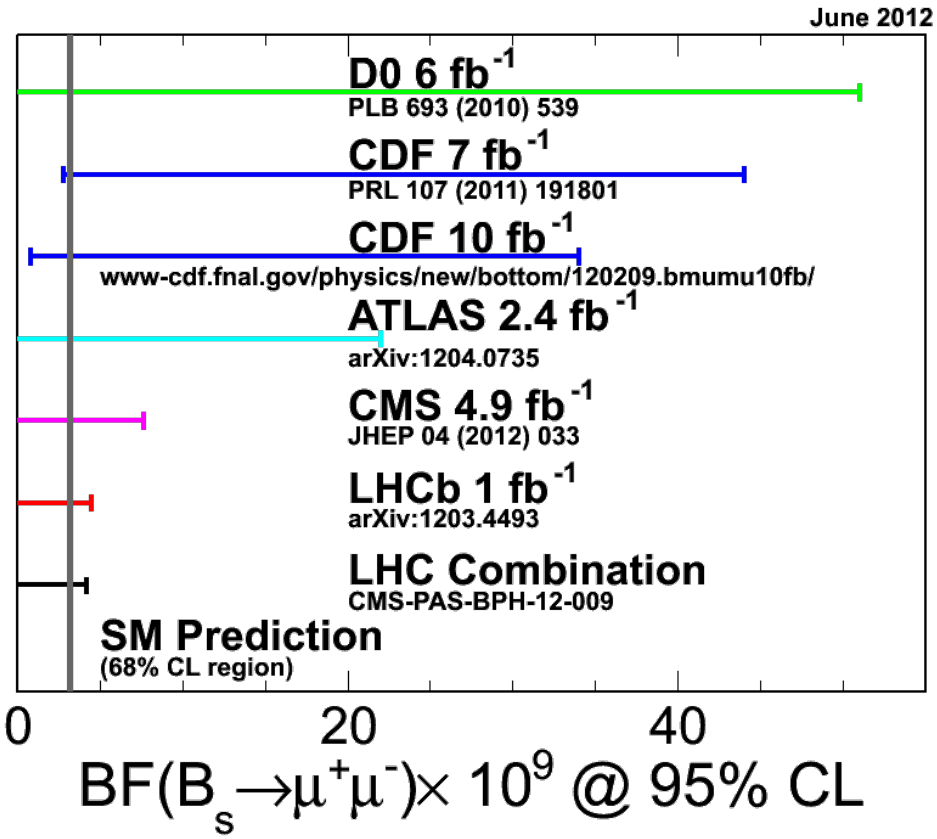
$BR(B_s \rightarrow \mu^+\mu^-) = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$

$0.8 \times 10^{-9} < BR(B_s \rightarrow \mu^+\mu^-) < 3.4 \times 10^{-8}$ 95% C.L.

Summer'11

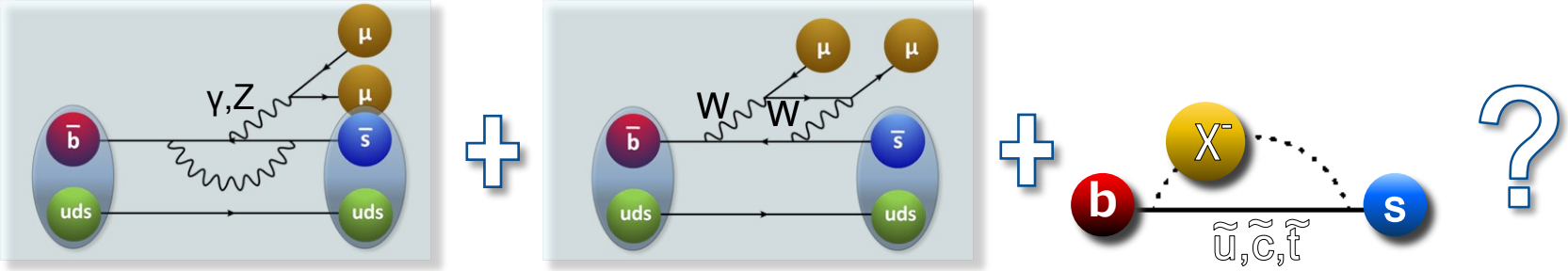
$BR(B_s \rightarrow \mu\mu) = 1.8^{+1.1}_{-0.9} \times 10^{-8}$

$B_s \rightarrow \mu\mu$: comparison

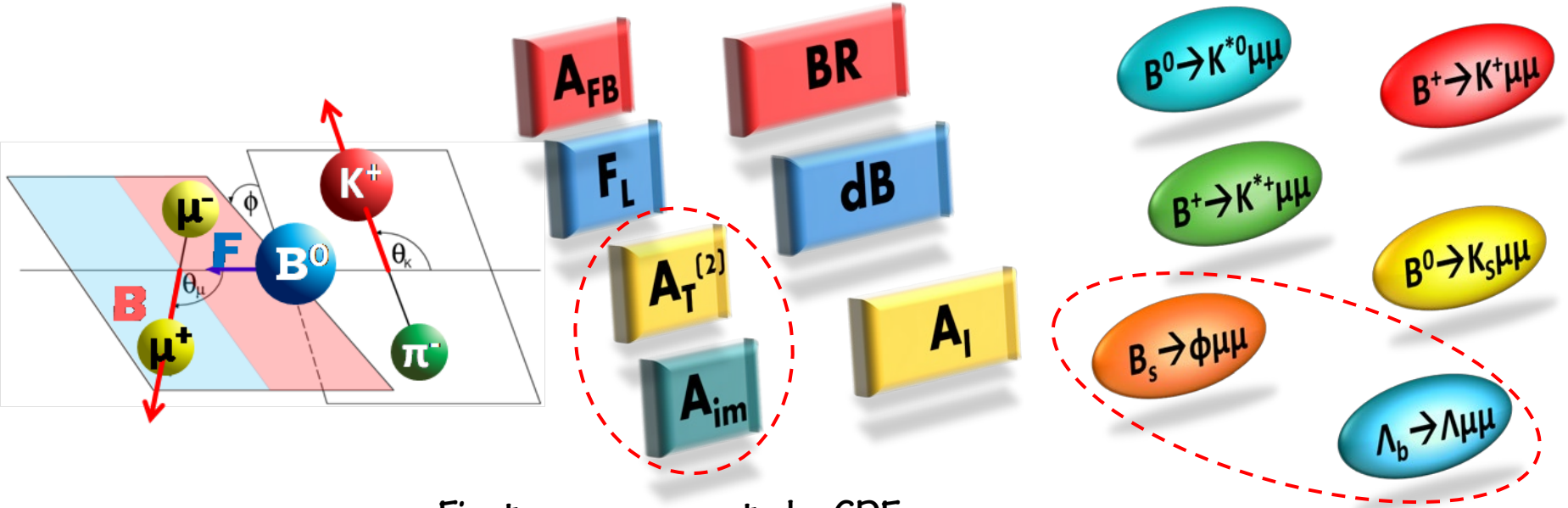


- **Compatible with SM and other experiments**

$B \to X_s \mu\mu$



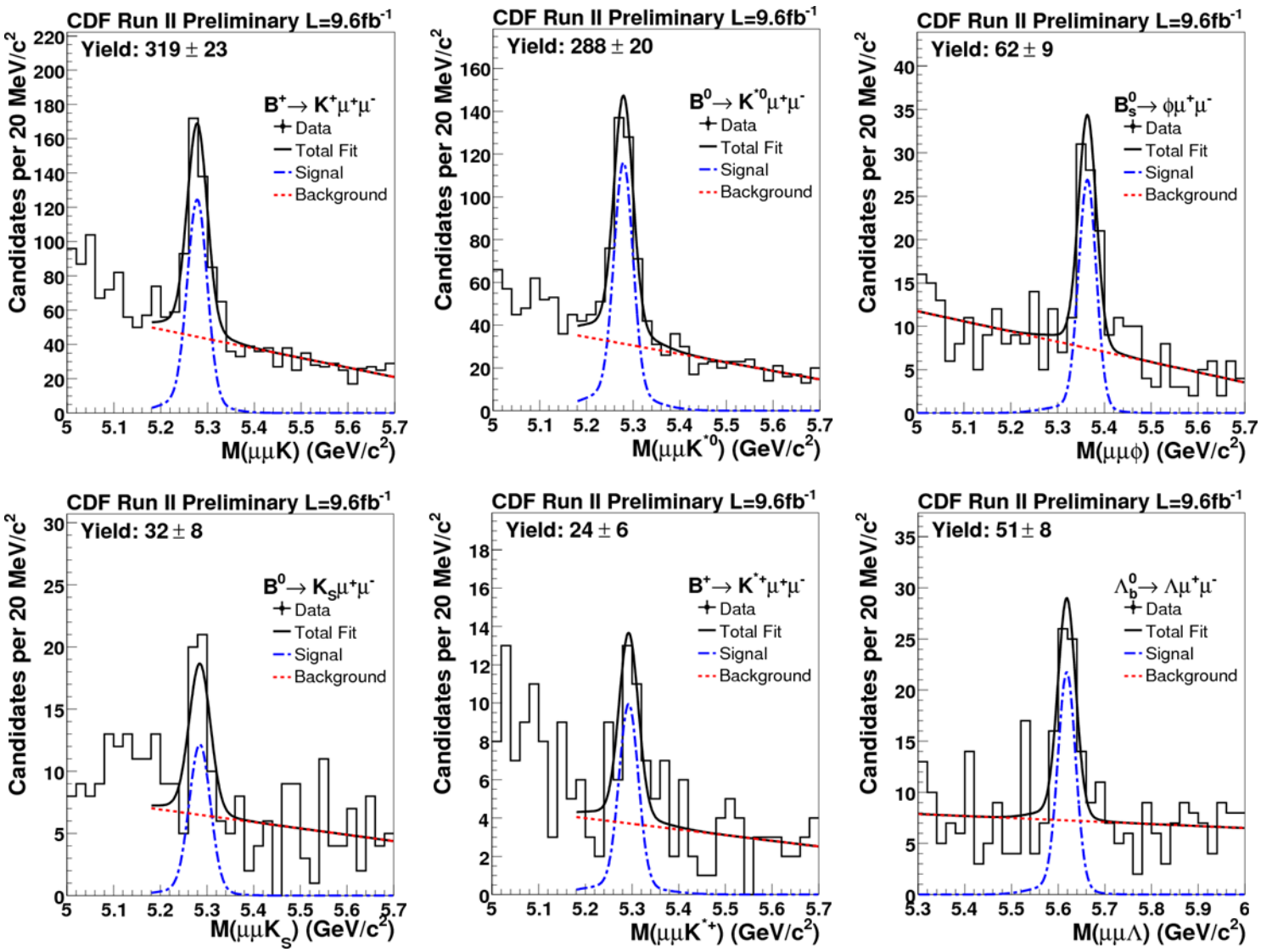
- $b \to s\mu\mu$: yet another golden probe
- Three body decay provides many observables sensitive to NP
  - Total/differential BR, isospin asymmetry, forward-backward asymmetry…



First measurements by CDF
PRL108, 081807 (2012)

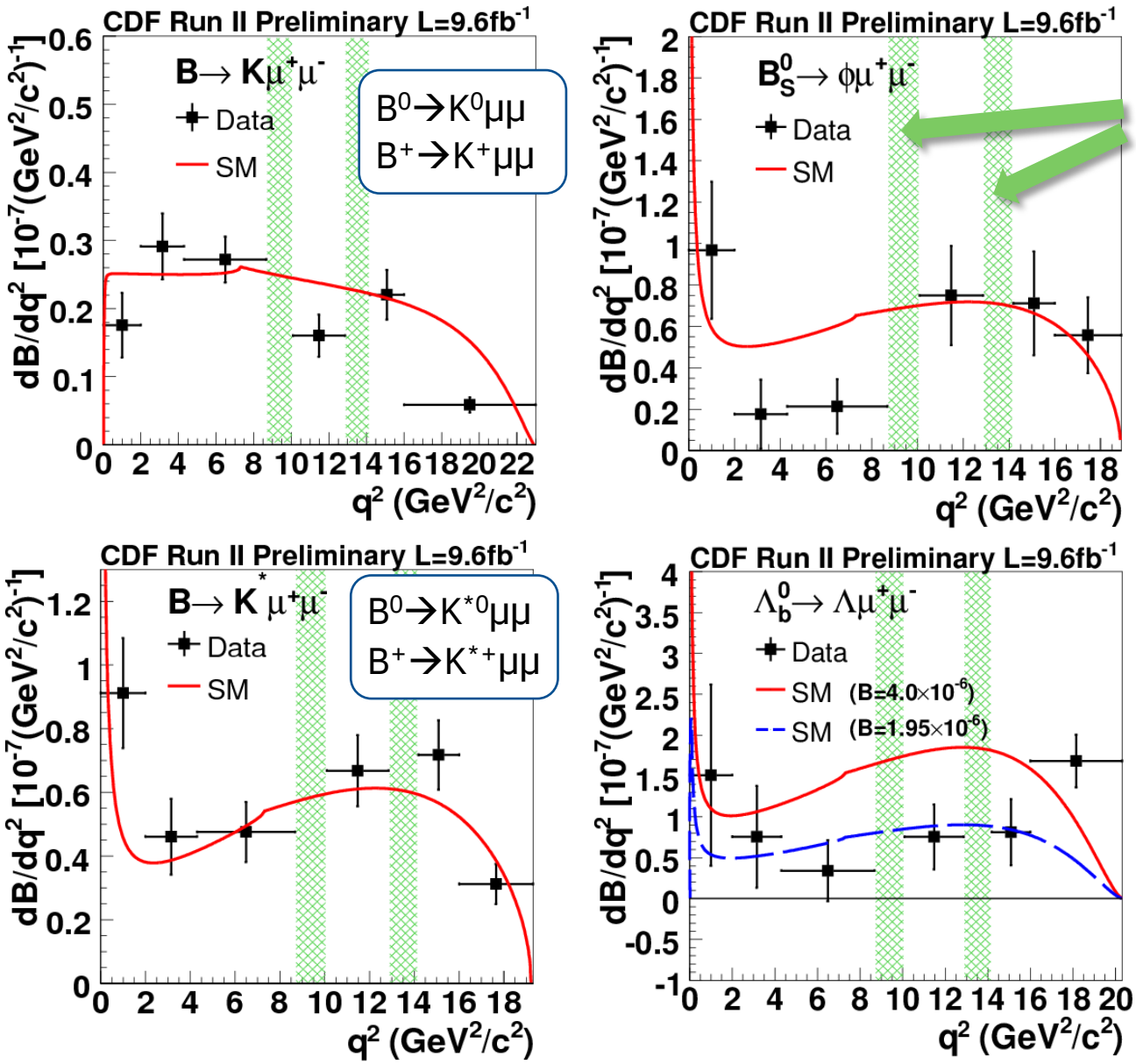
First observations by CDF
PRL106, 161801 (2011) PRL107, 201802 (2011)

Rare B yields @ 9.6 fb^{-1}



- **Steady increasing in significance since 6.8 fb^{-1}**

Differential BR

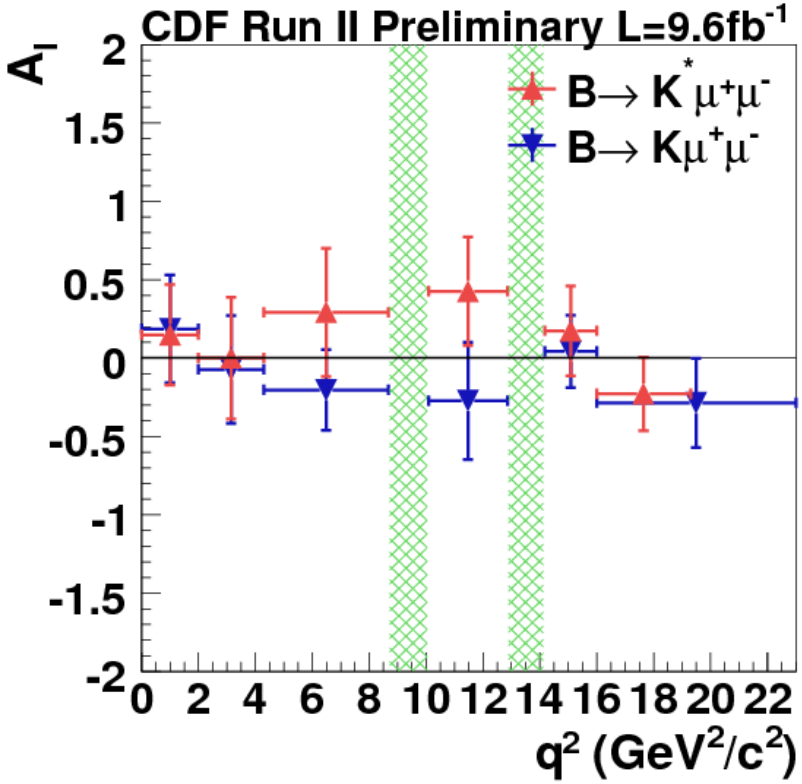


- Red Curve:
  SM prediction based on 4.0×10^{-6}

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

- Blue Curve:
  SM prediction rescaled to our total BR (1.95/4.0)

Isospin asymmetry



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

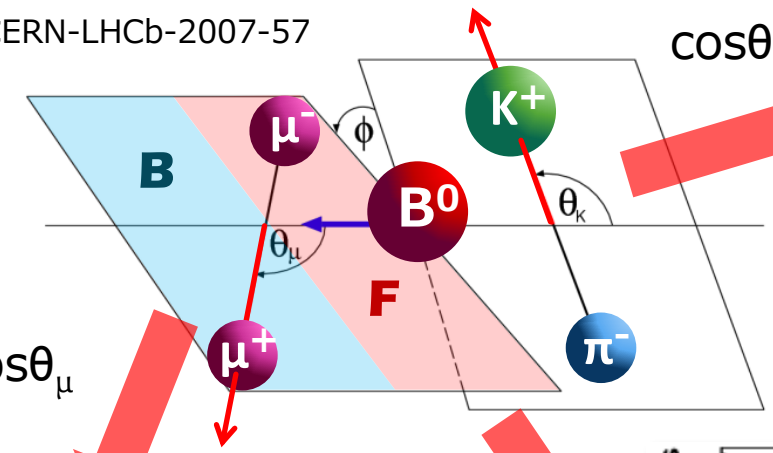
$$r = \tau(B^0)/\tau(B^+) = 1/1.071$$

- **Similar tendency as other experiments, though also consistent with zero**

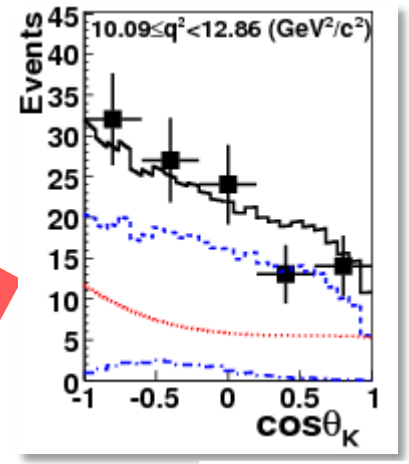
Angular analysis

- **One can extract various information from the decay angular distribution**

e.g. CERN-LHCb-2007-57



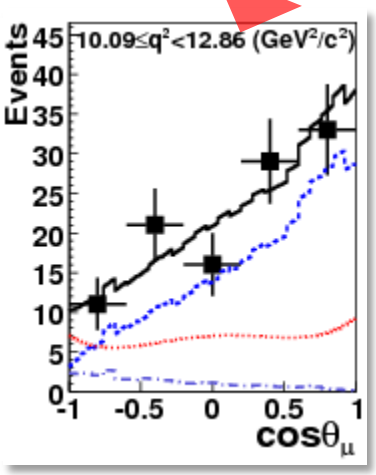
$\cos\theta_K$



K* polarization
F_L

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

$\cos\theta_\mu$

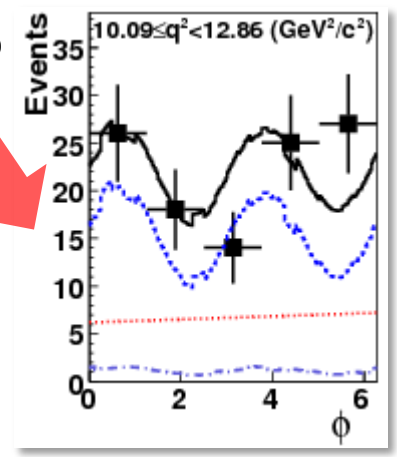


Data
Total Fit
Signal
Kπ Swap
BG

FB Asymmetry
A_{FB}

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

ϕ



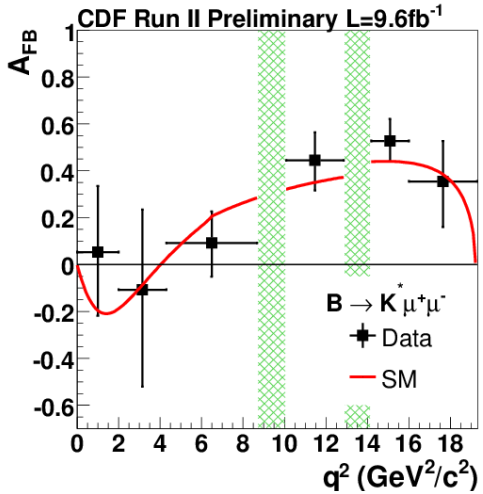
$A_T^{(2)}$ Transverse polarization asymmetry

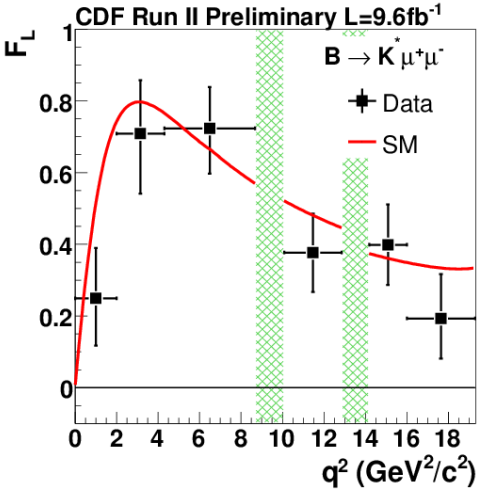
A_{im} T-odd CP asymmetry

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

Angular fit results

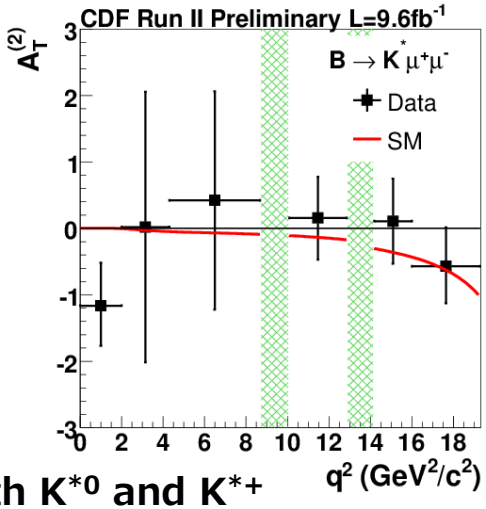
A_{FB}

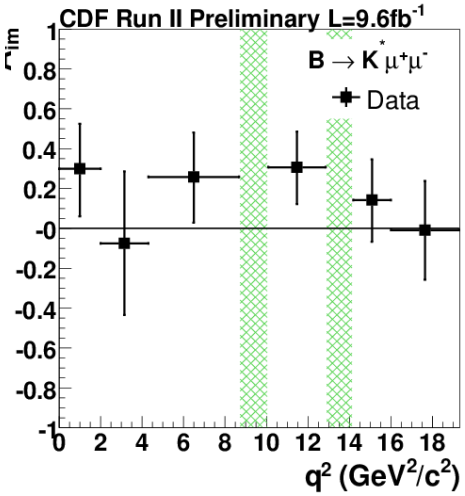




F_L

$A_T^{(2)}$





A_{im}

Simultaneous fit with K^{*0} and K^{*+}

- Consistent with previous measurements
- No significant deviation from SM with current precision

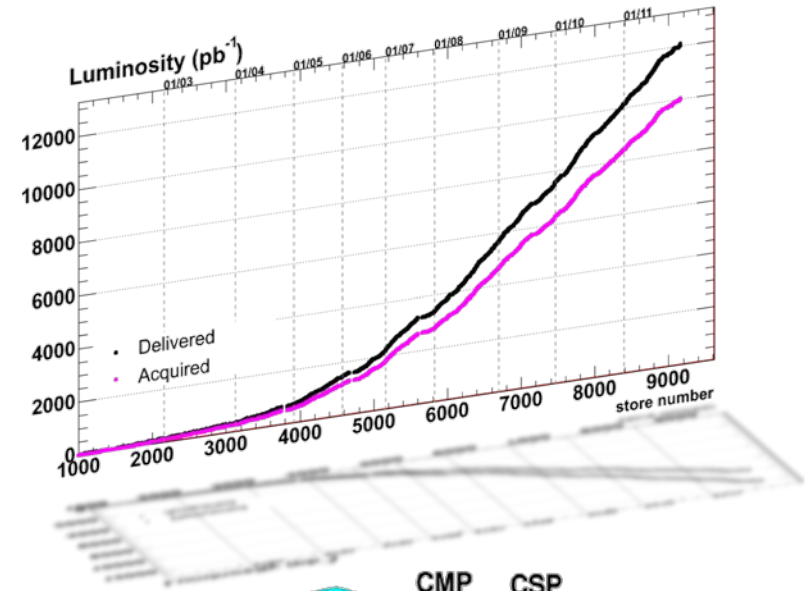
Summary

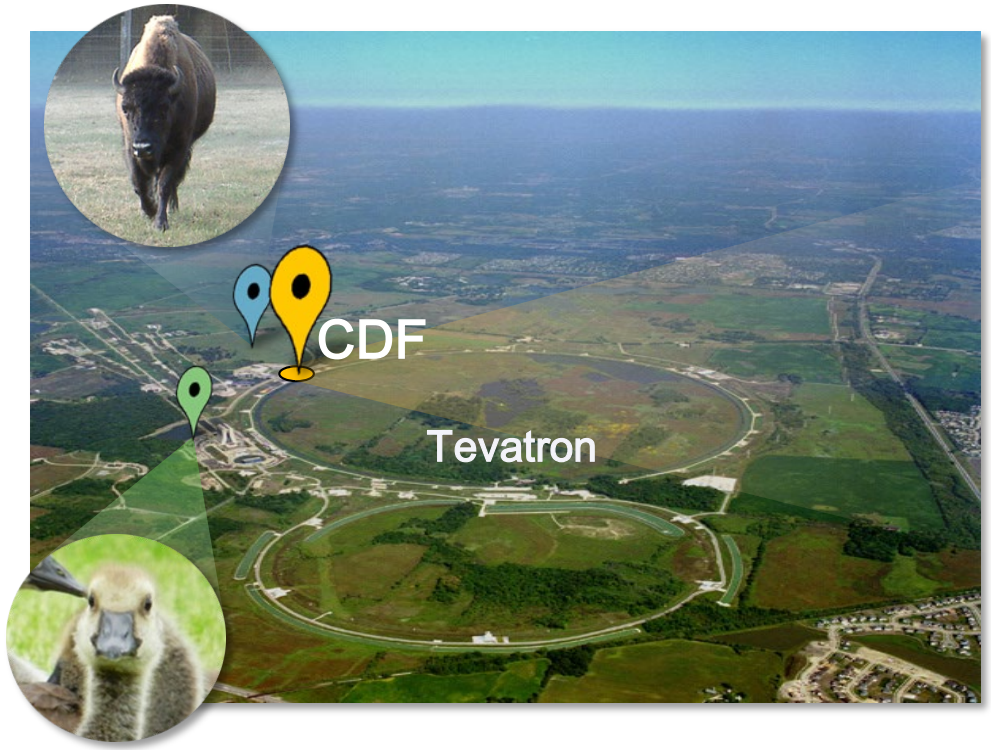
- CDF has led rare B decay analyses through Run II
  - Many analyses still ongoing
- Updated the flagship analyses using the full data sample
  - $B_s \rightarrow \mu\mu$
  - $B \rightarrow X_s \mu\mu$
- All results are consistent with SM and other experiments

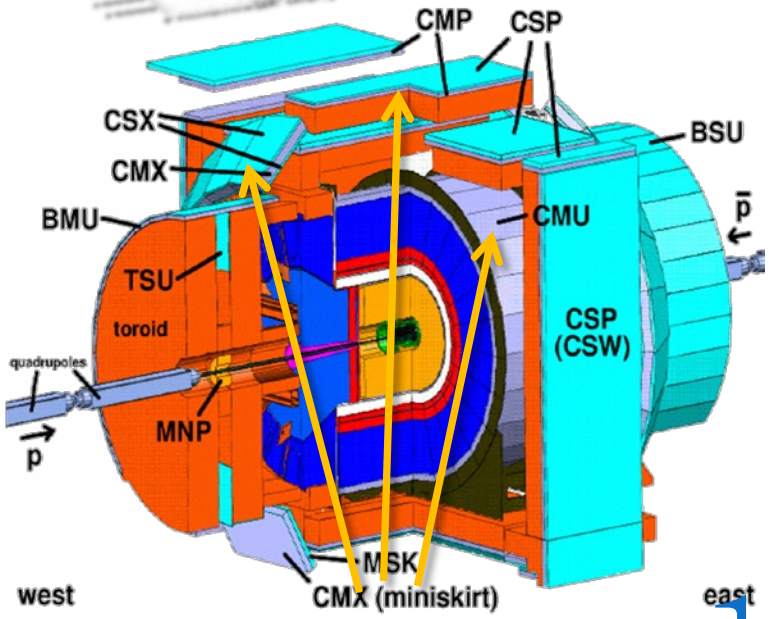
Backup

Tevatron and CDF detector

- Tevatron
  - $p\bar{p}$ collisions at $\sqrt{s}$=1.96TeV
- CDF II detector
  - A general purpose detector
- Final data sample ~ 10 fb^{-1}







Muon chambers used in this analysis

BR

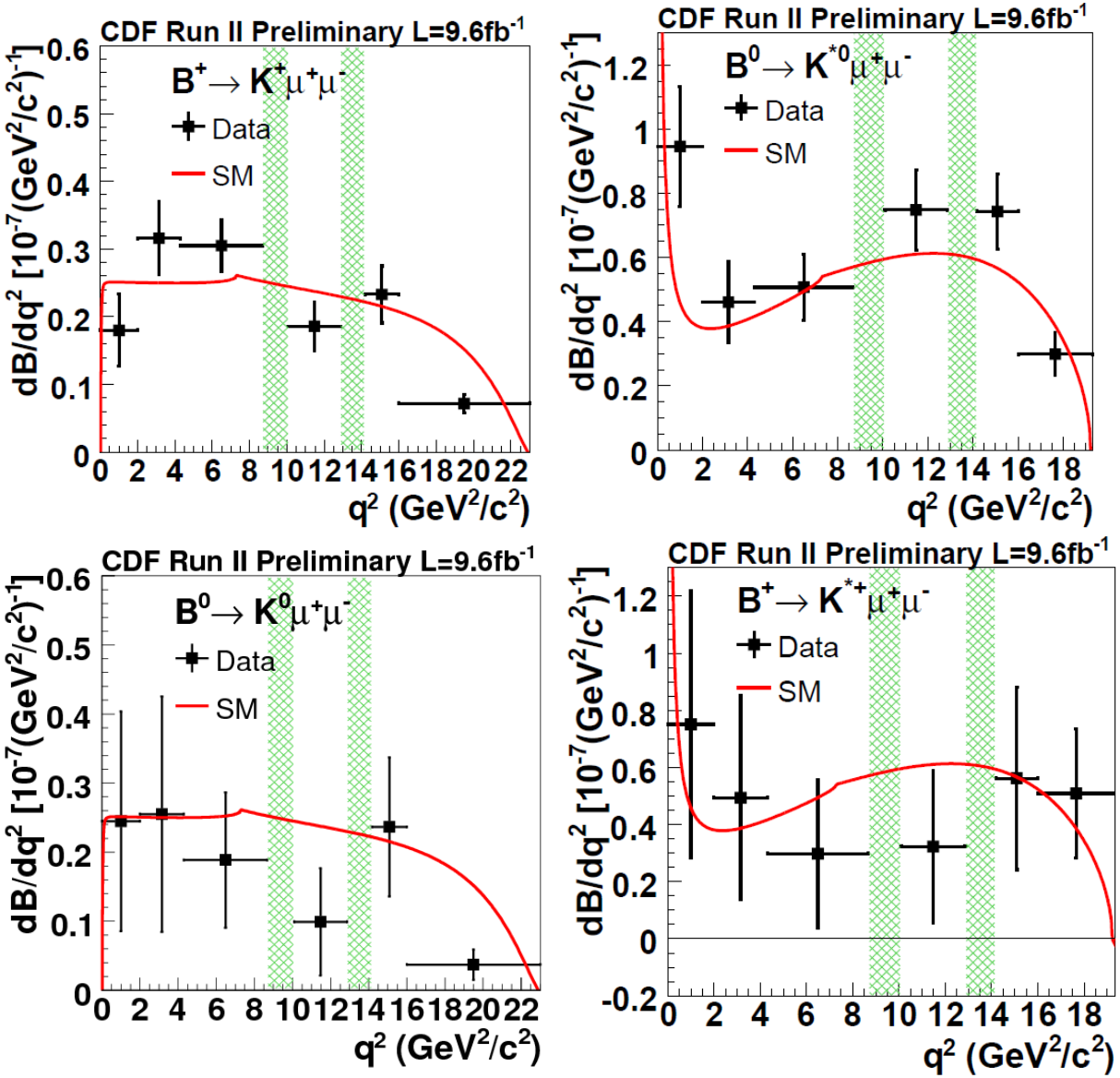
Relative BR

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

Absolute BR

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

Differential BR



Angular fit results

$B^0 \to K^{*0}\mu\mu$

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

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

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

References

- p16: photos by HeatherW, available under a Creative Commons Attribution-NonCommercial 2.0 Generic
- p17: photos by Peter Gaylard, available under a Creative Commons Attribution 2.0 Generic

- We draw theoretical curves of the angular observables by EOS. However we stress that these curves are plotted at the other kinematical region than the original authors expected to use.