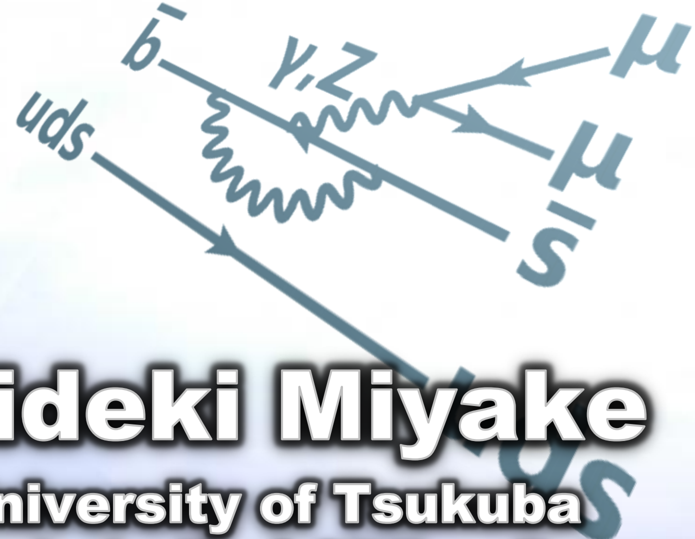
Updated search for non-SM physics in $B \to K^{(*)}\mu^+\mu^-$ Decays at CDF



Hideki Miyake

University of Tsukuba

on behalf of CDF collaboration

Supersymmetry 2011 (SUSY11)

Fermilab, Batavia, Illinois USA Aug 30th, 2011

Overview

- Multidimensional approach toward BSM with rich $b \rightarrow s\mu\mu$ samples

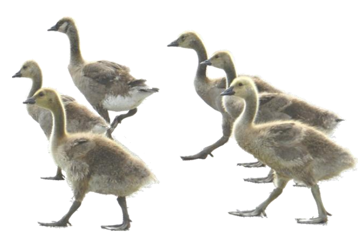
✓ **Various Observables**

✓ **Various Channels**

Total BR
- Requires little Data
- Limited sensitivity to NP

Differential BR
- Requires more Data
- Sensitive to NP

Angular analysis
- Requires lots of Data
- Most sensitive to NP



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

$B^+ \rightarrow K^+\mu\mu$

$B^+ \rightarrow K^{*+}\mu\mu$

$B^0 \rightarrow K_S\mu\mu$

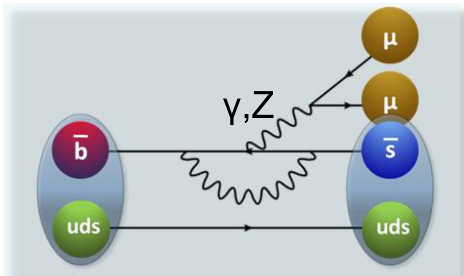
$B_s \rightarrow \phi\mu\mu$

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

b→sμμ decays

- **Promising tool to pursue new physics**
  - ✓ **Decay amplitude** might be affected by heavy NP particles

SUSY Technicolor
Extra dimension
Fourth generation



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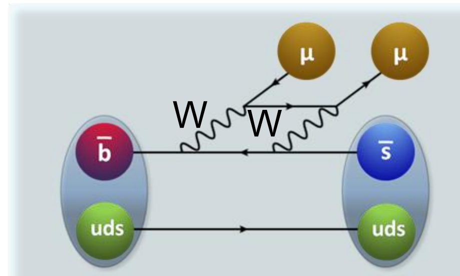

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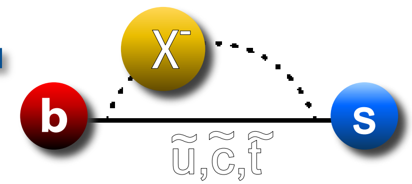
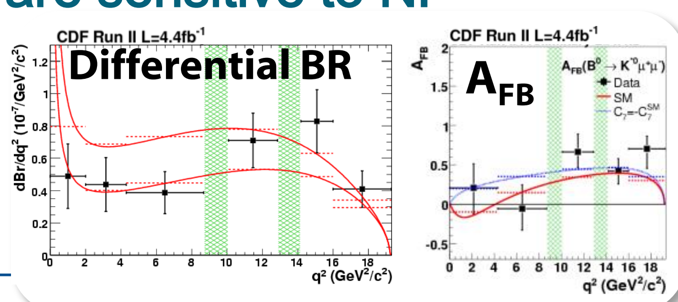
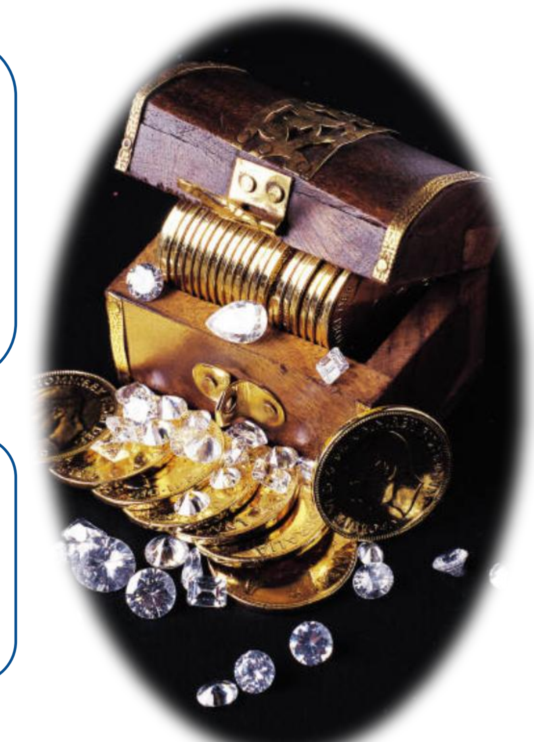


?

- **Various observables are sensitive to NP**
  - ✓ Total BR
  - ✓ Differential BR
  - ✓ Angular distribution (A_{FB}, F_L)



- **Hadron collider provides further probes**
  - ✓ $B_s \to \phi\mu\mu$ ←Observed by CDF ($4.4fb^{-1}$) PRL106,161801 (2011)
  - ✓ $\Lambda_b \to \Lambda\mu\mu$ ←No experimental constraint yet



b→sμμ decays (cont'd)

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i (C_i^{\text{SM}} + \Delta C_i) O_i + \sum_j C_j^{\text{NP}} O_j$$

O_i: Short distance operator

C_i: Wilson coefficient

ΔC_i: Modification to C_i^{SM}

C_j^{NP}: Coefficient of NP operator

C_7	photon-dipole
$C_{9,10}$	(axial-) vector

Dominant in SM

SUSY Technicolor

Extra dimension

Fourth generation

$C_{S,P}$	(pseudo-) scalar
$C_{7',9',10'}$	Helicity-flipped

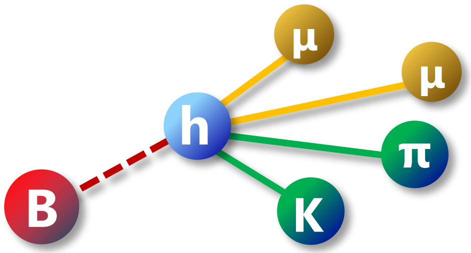
Suppressed in SM

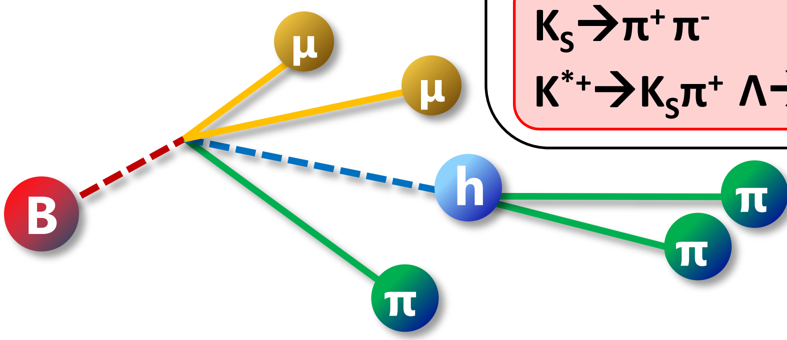
Observable:

$$A_{FB} = -C_{10}\xi(s)[\text{Re}(C_9)F_1 + \frac{1}{s}C_7F_2]$$

Various NP effect could be seen by the b→sμμ observables

Analysis flow





h hadrons

$\phi \to K^+ K^-$

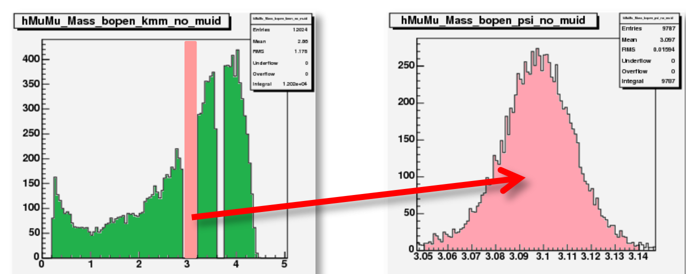
$K^{*0} \to K^+ \pi^-$

$K_S \to \pi^+ \pi^-$

$K^{*+} \to K_S \pi^+$ $\Lambda \to p \pi^-$

V^0 decay

Signal mode	Control sample
$B^0 \to K^{*0} \mu\mu$	$B^0 \to J/\psi K^{*0}$
$B^+ \to K^+ \mu\mu$	$B^+ \to J/\psi K^+$
$B_s \to \phi \mu\mu$	$B_s \to J/\psi \phi$
$B^+ \to K^{*+} \mu\mu$	$B^+ \to J/\psi K^{*+}$
$B^0 \to K_S \mu\mu$	$B^0 \to J/\psi K_S$
$\Lambda_b \to \Lambda \mu\mu$	$\Lambda_b \to J/\psi \Lambda$

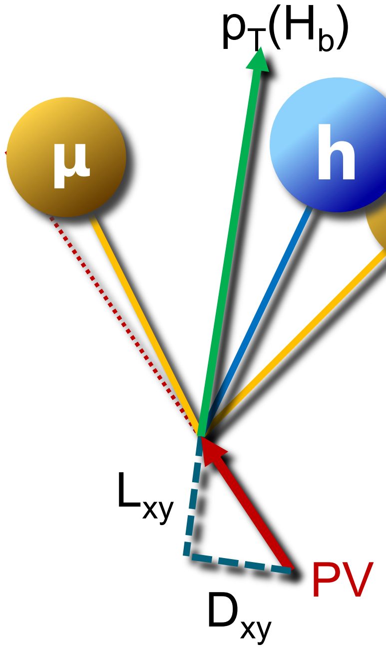


Dimuon mass

12 channel analysis!

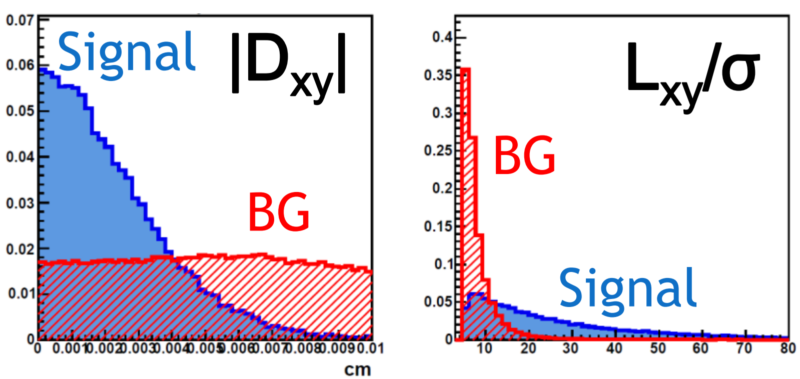
- **Start from dimuon trigger**
  - ✓ Reconstruct $H_b \to h\mu\mu$
  - ✓ Optimize event selection by NN
- **BR measurement**
- **Angular analysis**

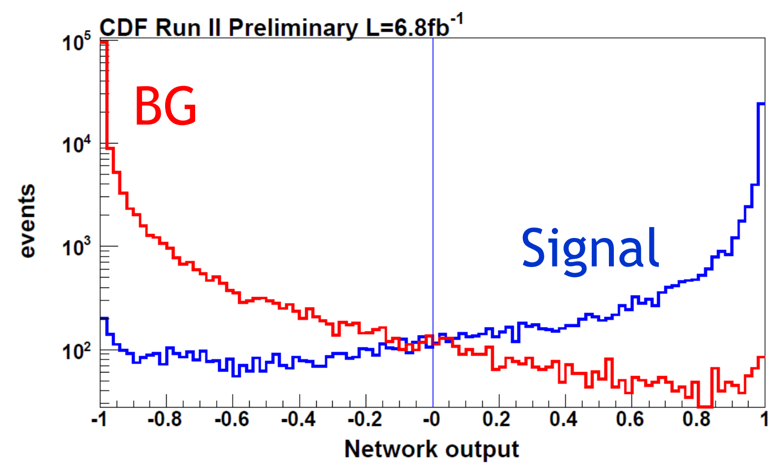
Event selection



- Preselection ($H_b \rightarrow h\mu\mu$)
  - ✓ $p_T(H_b)$, h mass…
- Charmonium(J/ψ, ψ') veto
- Charm (D, D_s, Λ_c) veto
- Employ NN to optimize event selection

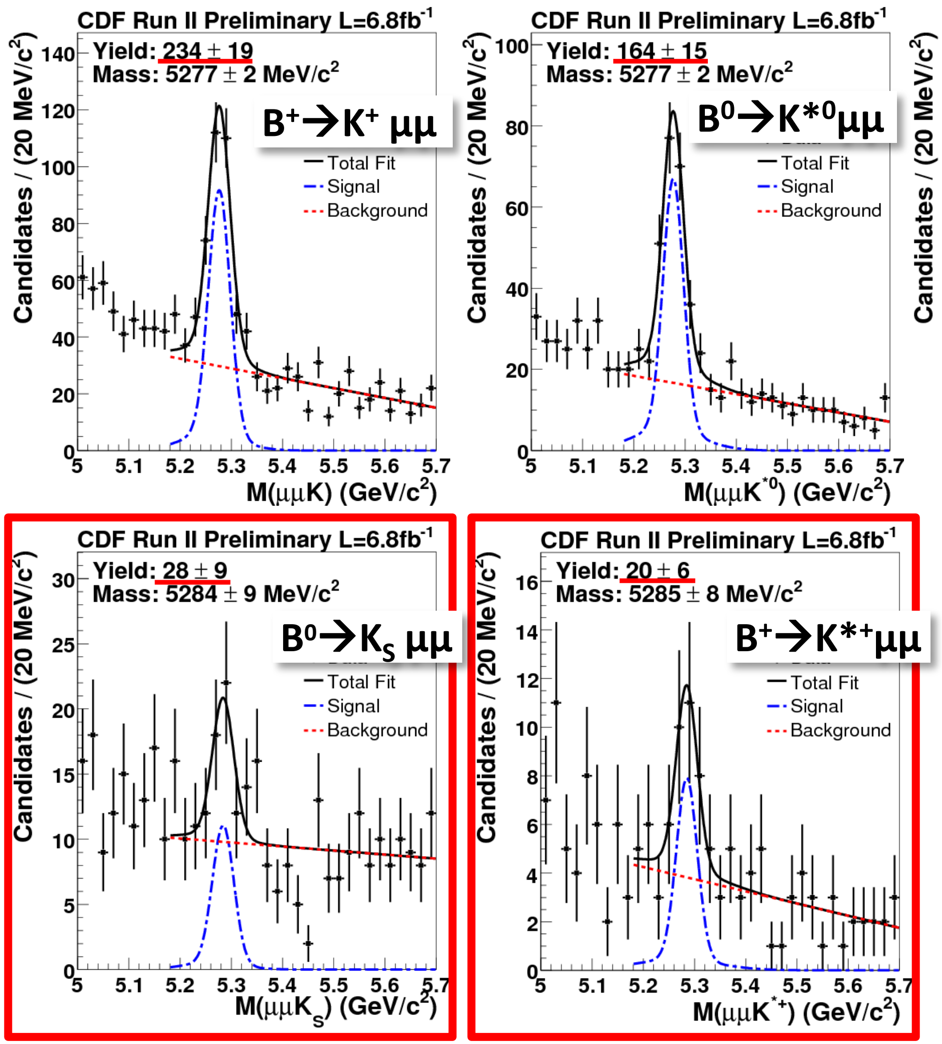
Kinematical variables





- $p_T(H_b)$, $p_T(h)$, $p_T(\mu)$, h mass, D_{xy}, L_{xy}/σ, muon likelihood…

Rare B yields @6.8fb^{-1}

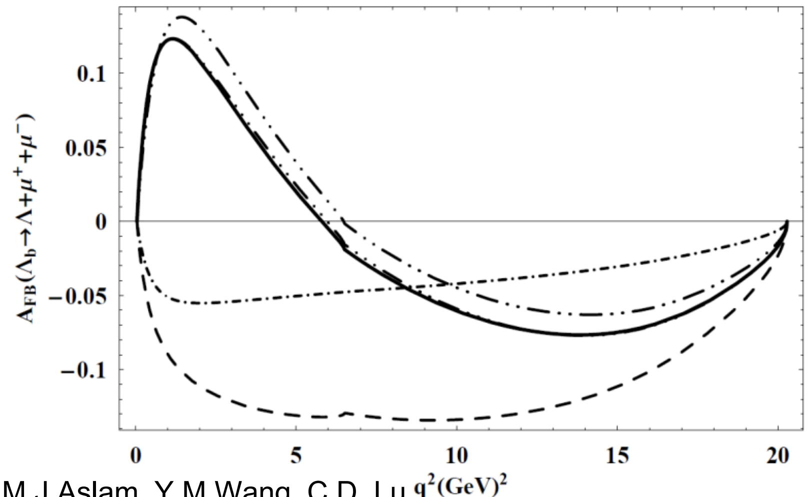


(*) First reconstruction in hadron collisions

Baryonic rare decay: $\Lambda_b \rightarrow \Lambda\mu\mu$

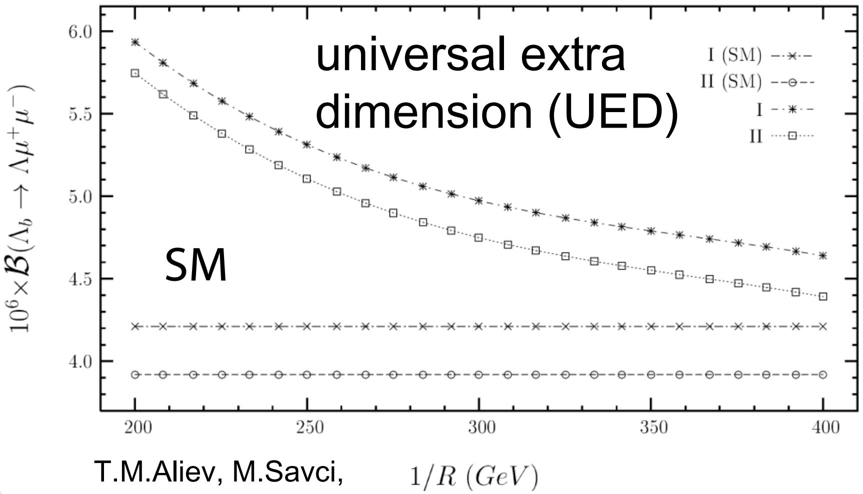
- Simple extension of $b \rightarrow s\mu\mu$ transition to b-baryon decays
  - ✓ Different sensitivity from $K^*\mu\mu$
- Small BR ~O(10^{-6})
- No experimental search result (although >25 theory papers)
- Can measure A_{FB} (difficult in $\phi\mu\mu$)

$A_{FB}(\Lambda_b \rightarrow \Lambda\mu\mu)$



M.J.Aslam, Y.M.Wang, C.D. Lu
PRD78:114032 (2008)

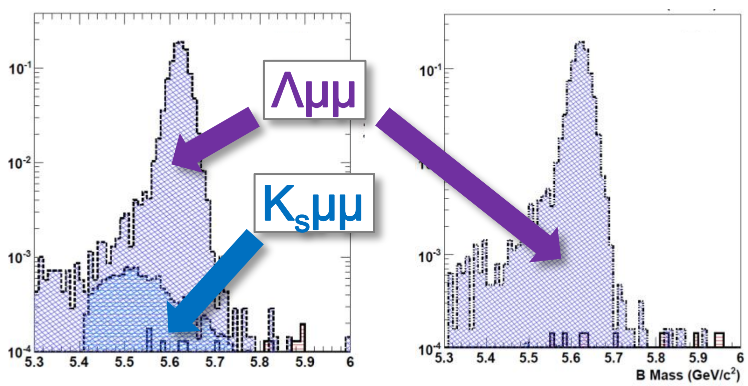
BR($\Lambda_b \rightarrow \Lambda\mu\mu$) vs UED parameter



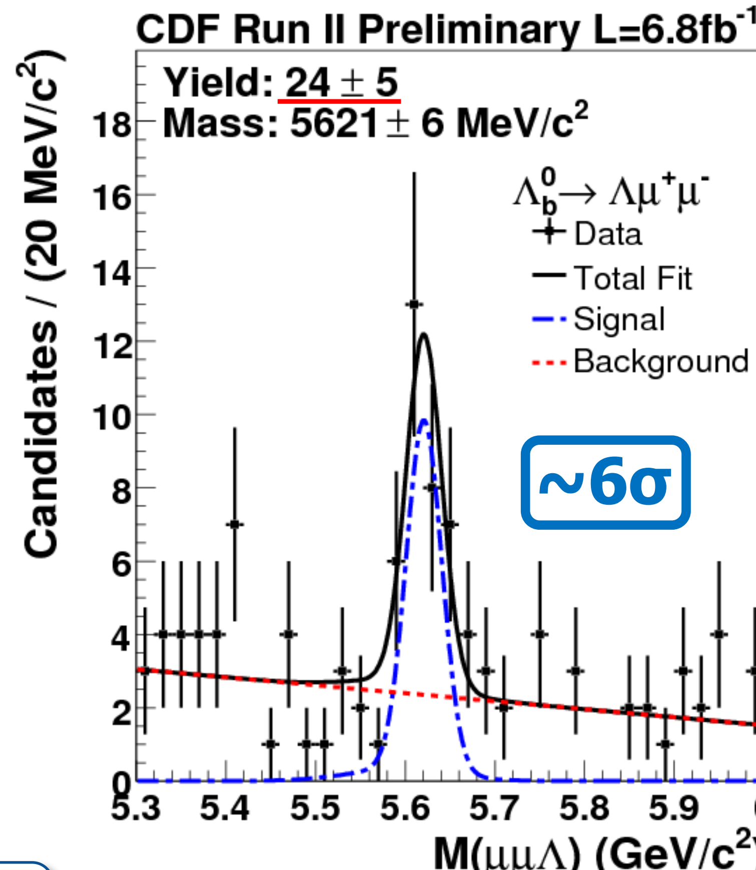
T.M.Aliev, M.Savci,
EPJC50:91-99 (2007)

$\Lambda_b \to \Lambda\mu\mu$ observation

- First experimental search for baryonic $b \to s\mu\mu$ decay



- Reduce possible $K_s\mu\mu$ contamination
  - ✓ Momentum imbalance of V^0 daughters



First observation!

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

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)

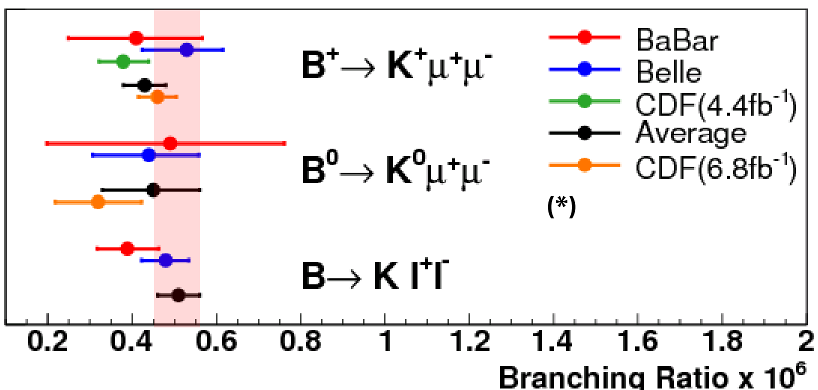
Total BR

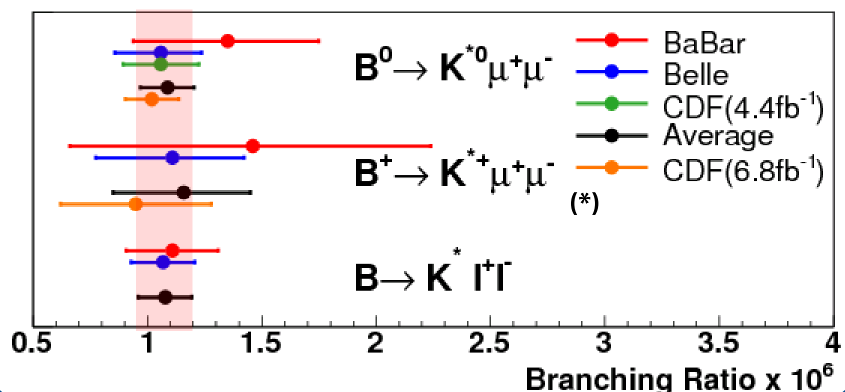
Rare channel yield

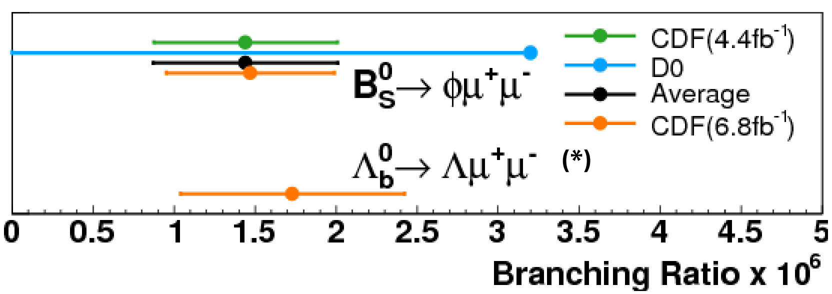
$$\frac{\mathcal{B}(H_b \to h\mu^+\mu^-)}{\mathcal{B}(H_b \to J/\psi h)} = \frac{N_{h\mu^+\mu^-}}{N_{J/\psi h}} \times \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\varepsilon_{\rm rel}}$$

Control channel yield

h=K, K*, φ, Λ



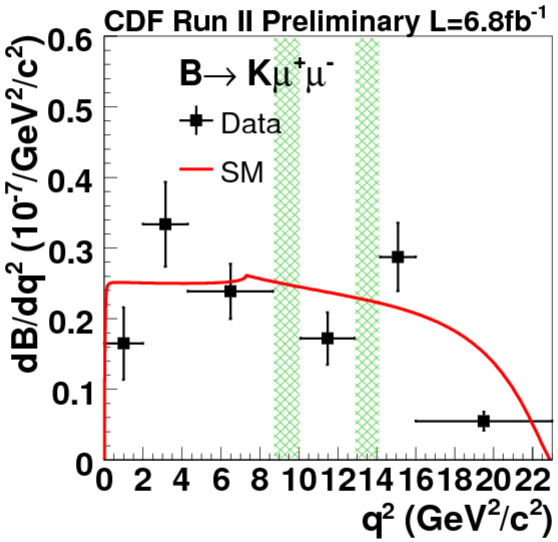




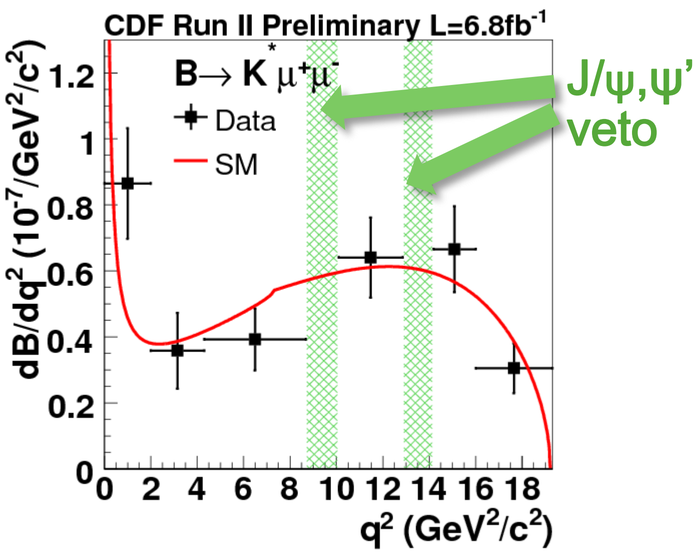
(*) All BRs except CDF@6.8fb^{-1} are taken from HFAG 2010 August

World's most precise b→sμμ BR measurements!

Differential BR (1)



- Access more precise decay amplitude structure
  - ✓ Divided by six q^2 bin ($q^2=M_{\mu\mu}{}^2$)
- Large theoretical and experimental uncertainties
  - ✓ Experimental uncertainty is dominated by stat. error

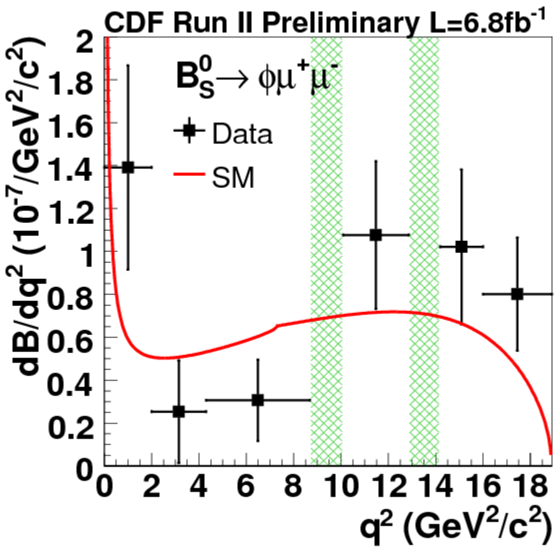


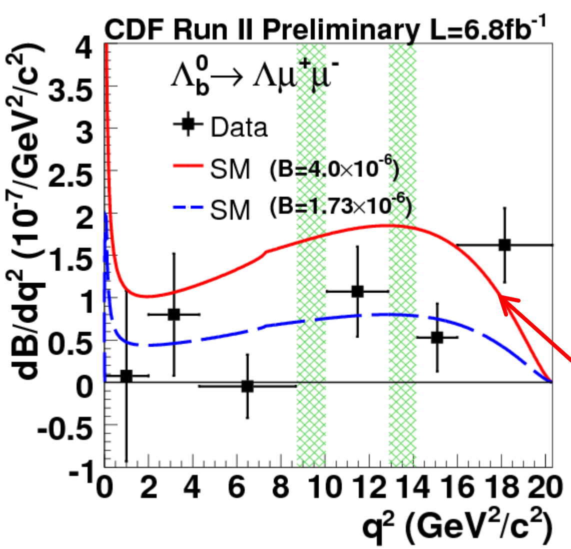
$B\to K\mu\mu$	$B\to K^*\mu\mu$
$B^+\to K^+\mu\mu$	$B^0\to K^{*0}\mu\mu$
$B^0\to K^0\mu\mu$	$B^+\to K^{*+}\mu\mu$

(*) First measurements in hadron collisions

- Combined BR is calculated assuming isospin symmetry

Differential BR (2)

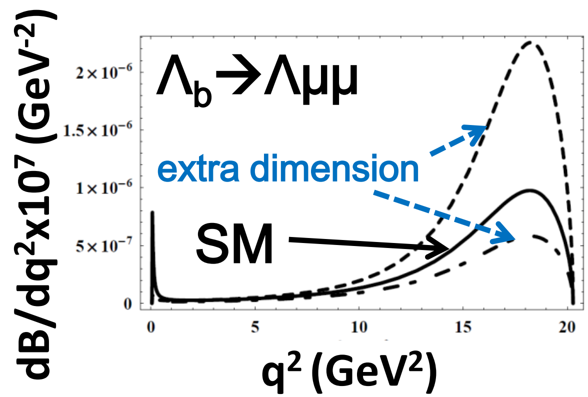




- Most theory calculation are on B→K(*)μμ
  - ✓ Precise dB measurements other than B→K(*)μμ could improve the theoretical prediction
  - ✓ Could give unique constraint on BSM in future
- First results from an experiment

SM prediction

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

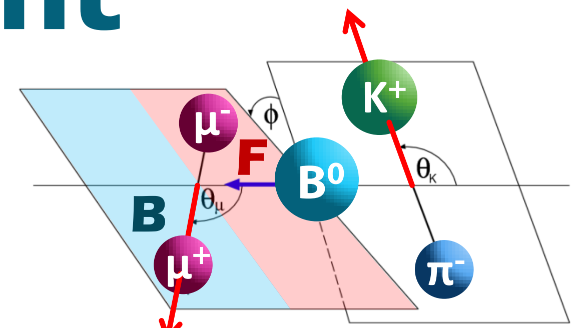


Y.-M. Wang, M.J. Aslam, C.-D. Lu, arXiv:0810.0609 (2008)

A_{FB} measurement

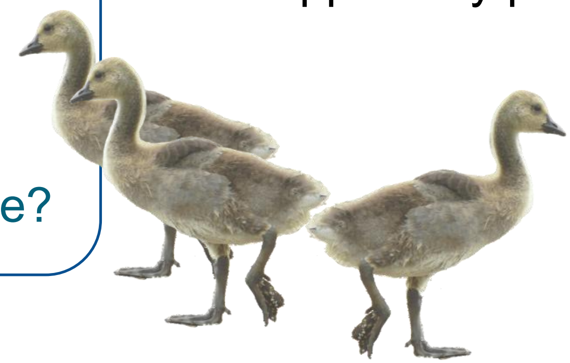
- **Forward-Backward asymmetry:**

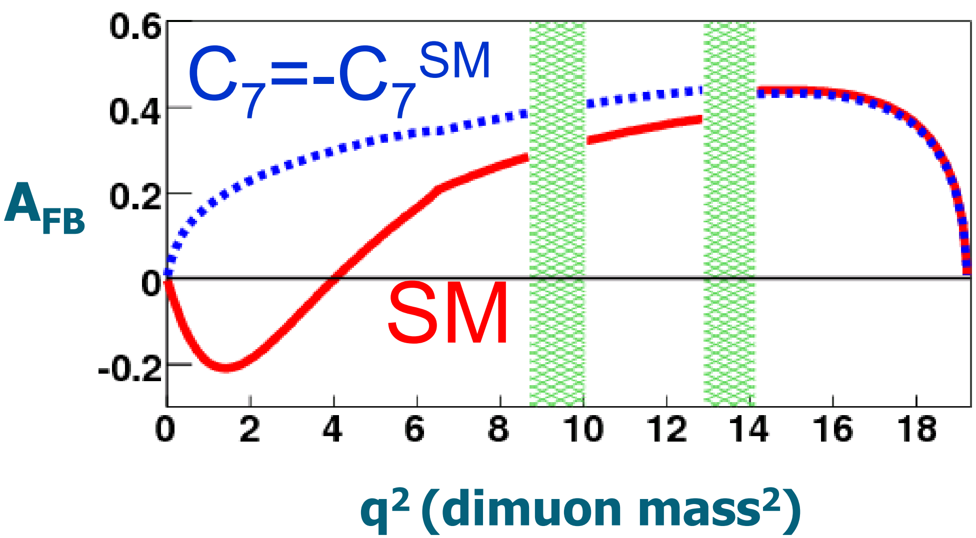
$$A_{FB}(q^2) \equiv \frac{\Gamma(q^2, \cos\theta_\mu > 0) - \Gamma(q^2, \cos\theta_\mu < 0)}{\Gamma(q^2, \cos\theta_\mu > 0) + \Gamma(q^2, \cos\theta_\mu < 0)}$$



$B^0 \rightarrow K^{*0}\mu\mu$ decay plane

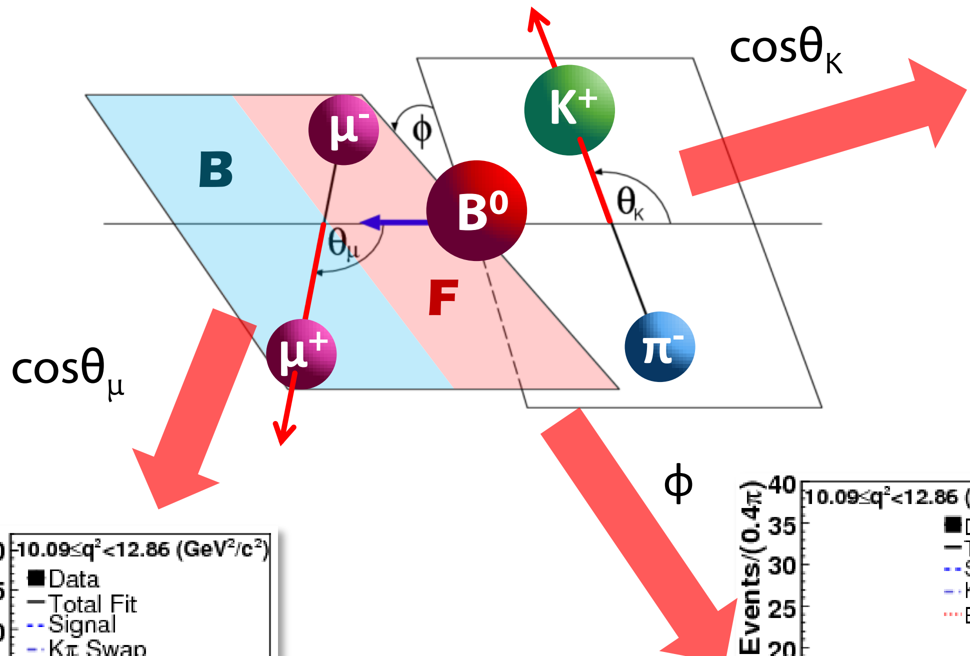
- **Most interesting observable of b→sll**
  - ✓ NP could swap the sign of A_{FB} at low q^2
  - ✓ Belle claims 2.7σ deviation from SM
  - ✓ BR($B \rightarrow X_s ll$) disfavors the swap solution…puzzle?

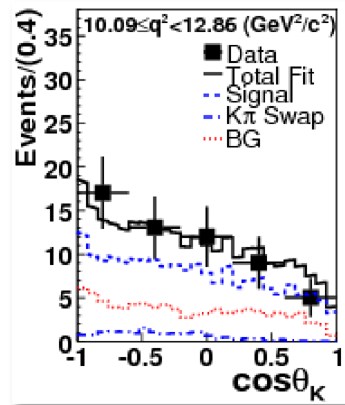




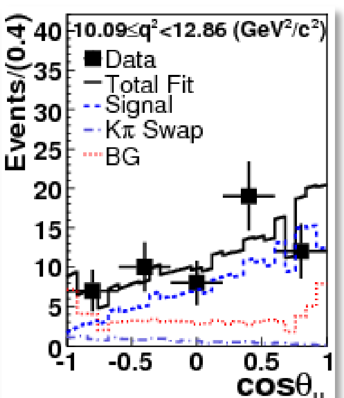
Angular analysis

- One can extract various information from the decay angular distribution

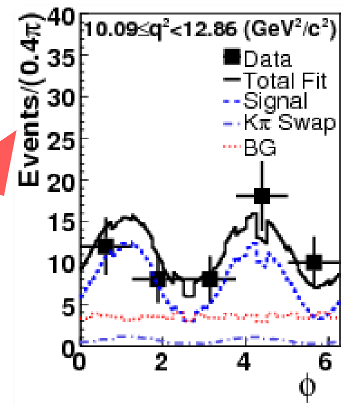




K* polarization
F_L



FB Asymmetry
A_{FB}



sensitive to RH currents

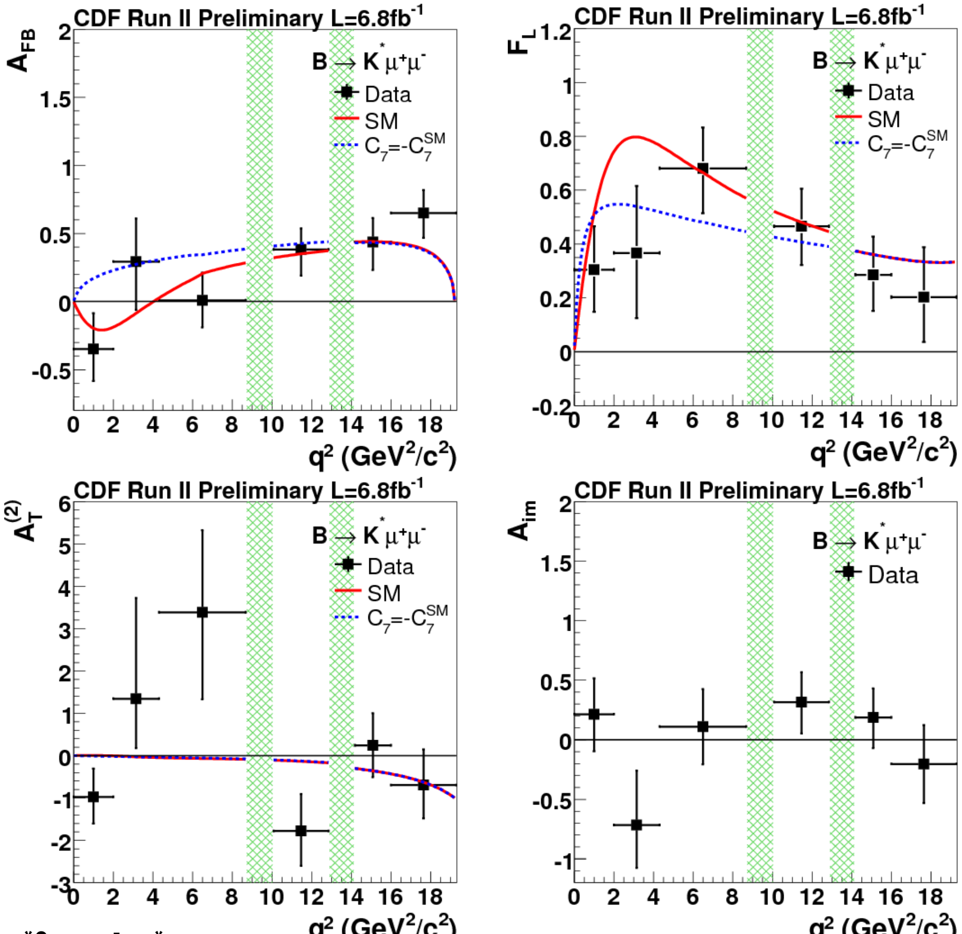
$A_T^{(2)}$ Transverse polarization asymmetry

A_{im} T-odd CP asymmetry

Angular fit results

A_{FB}

F_L



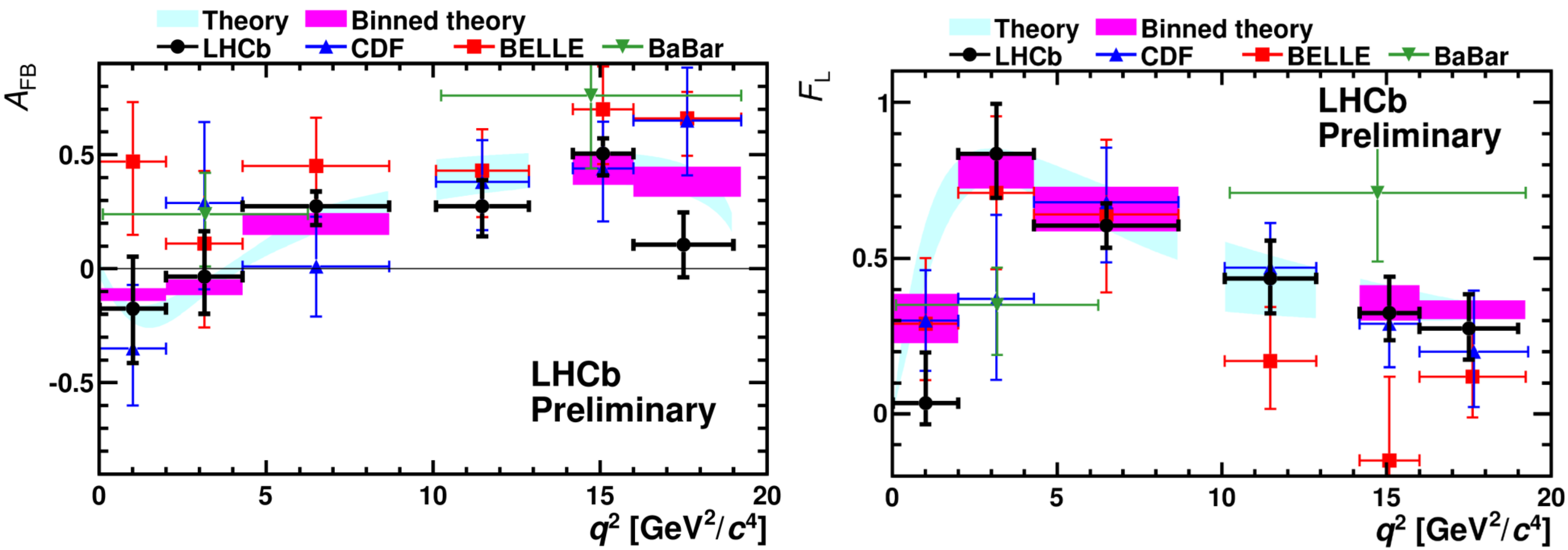
$A_T^{(2)}$

A_{im}

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

- First measurement of right-handed currents sensitive $A_T^{(2)}$ and A_{im}
- No significant deviation from SM with current accuracy

A_{FB}/F_L comparison



Ulrik Egede, PANIC 2011

http://web.mit.edu/panic11/talks/monday/PARALLEL-2I/3-1640/egede/151-0-Egede.pdf

- General agreement across experiments and with the SM
- CDF competitive with Belle/LHCb

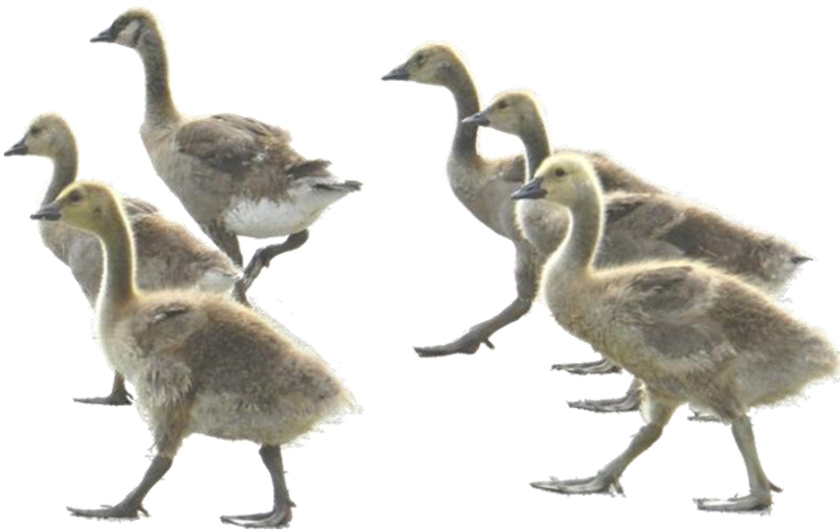
Summary

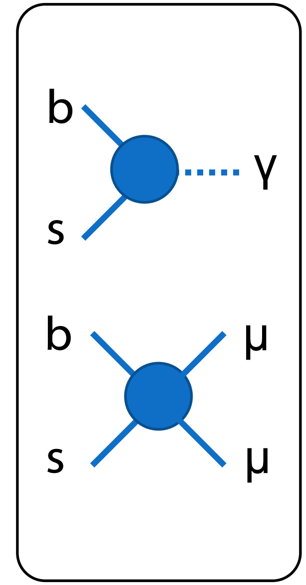
- CDF updated the $b \rightarrow s\mu\mu$ analysis with $6.8 fb^{-1}$
  - ✓ Not only more data, analysis greatly improved

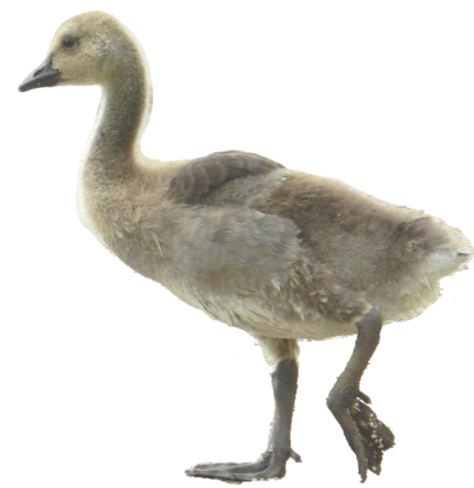
- Results:
  - ✓ First observation of $\Lambda_b \rightarrow \Lambda\mu\mu$
  - ✓ First measurement of dB in $B_s \rightarrow \phi\mu\mu$ and $\Lambda_b \rightarrow \Lambda\mu\mu$
  - ✓ First measurement of $A_T^{(2)}$ and A_{im}
  - ✓ World's best or comparable precision
    - ✓ Total and differential BR in exclusive $b \rightarrow s\mu\mu$ decays
    - ✓ A_{FB} and F_L measurement
  - ✓ No discrepancy with SM found yet

- CDF leads exploration of $b \rightarrow s\mu\mu$ physics
- Submitted two PRL arXiv:1107.3753 arXiv:1108.0695

Backup





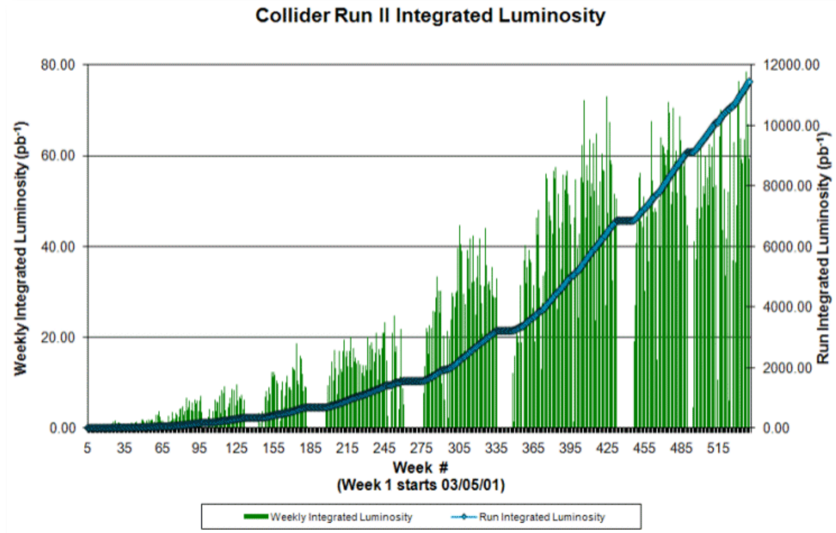


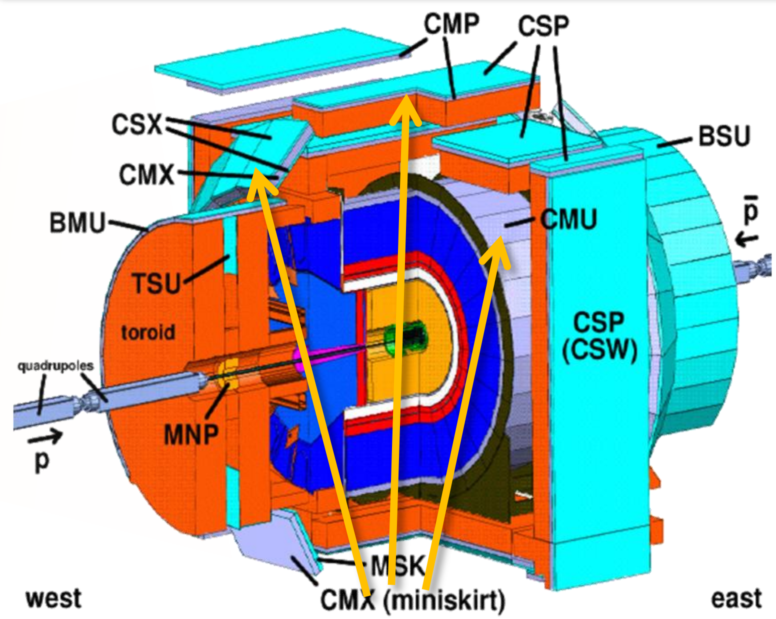
References

- 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.

Tevatron and CDF detector

- Tevatron
  - ✓ $p\bar{p}$ collisions at $\sqrt{s}$=1.96TeV
- CDF II detector
  - ✓ A general purpose detector
- >9.7fb^{-1} data on tape
  (6.8 fb^{-1} used for the analysis)





Muon chambers
used in this analysis

CDF analysis history

Search for the Flavor-Changing Neutral Current Decays $B^+ \rightarrow \mu^+\mu^- K^+$ and $B^0 \rightarrow \mu^+\mu^- K^{*0}$
- Phys. Rev. Lett. 83, 3378 (1999).

CDF RunI 88 pb^{-1}

Search for the Decay $B_s \rightarrow \mu^+\mu^- \varphi$ in $p\bar{p}$ Collisions at $\sqrt{s}$=1.8 TeV
- Phys. Rev. D65, 111101 (2002).

CDF RunI 91 pb^{-1}

Search for the Rare B Decays $B^+ \rightarrow \mu^+\mu^- K^+$, $B^0 \rightarrow \mu^+\mu^- K^*(892)^0$, and $B_s^0 \rightarrow \mu^+\mu^- \varphi$ at CDF
- Phys. Rev. D79, 011104(R) (2009).

CDF RunII 924 pb^{-1}

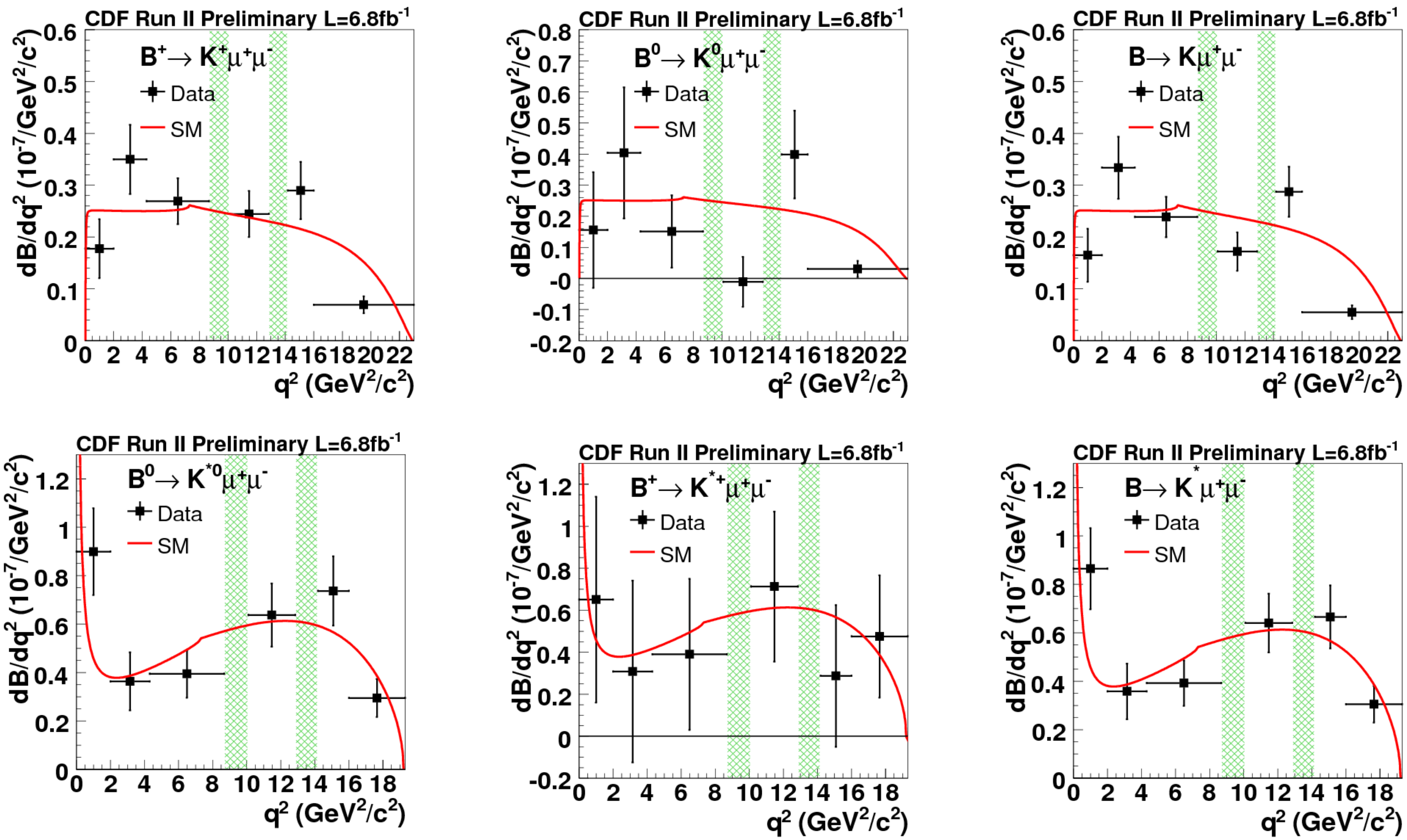
Measurement of the Forward-Backward Asymmetry in the $B \rightarrow K^{(*)} \mu^+\mu^-$ Decay and First Observation of the $B_s^0 \rightarrow \varphi\mu^+\mu^-$ Decay
- Phys. Rev. Lett. 106, 161801 (2011).

CDF RunII 4.4 fb^{-1}

This talk:
Update using 6.8fb^{-1}

Differential BR

- Combined BR is calculated by isospin symmetry assumption



Angular analysis summary

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

q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A^{im}
$[0.00, 2.00)$	$0.31^{+0.17}_{-0.16} \pm 0.02$	$-0.37^{+0.27}_{-0.32} \pm 0.11$	$-0.77^{+0.69}_{-0.66} \pm 0.27$	$0.37^{+0.31}_{-0.33} \pm 0.08$
$[2.00, 4.30)$	$0.35^{+0.26}_{-0.24} \pm 0.03$	$0.30^{+0.32}_{-0.36} \pm 0.17$	$1.42^{+2.01}_{-1.13} \pm 1.15$	$-0.80^{+0.48}_{-0.29} \pm 0.13$
$[4.30, 8.68)$	$0.60^{+0.17}_{-0.18} \pm 0.05$	$-0.08^{+0.22}_{-0.21} \pm 0.03$	$1.80^{+1.64}_{-1.68} \pm 1.53$	$0.03^{+0.34}_{-0.34} \pm 0.06$
$[10.09, 12.86)$	$0.40^{+0.16}_{-0.16} \pm 0.02$	$0.42^{+0.17}_{-0.21} \pm 0.10$	$-1.04^{+0.87}_{-0.83} \pm 0.46$	$0.47^{+0.26}_{-0.28} \pm 0.09$
$[14.18, 16.00)$	$0.32^{+0.14}_{-0.14} \pm 0.03$	$0.40^{+0.18}_{-0.21} \pm 0.07$	$0.40^{+0.80}_{-0.81} \pm 0.19$	$0.15^{+0.25}_{-0.26} \pm 0.01$
$[16.00, 19.30)$	$0.16^{+0.22}_{-0.18} \pm 0.06$	$0.66^{+0.18}_{-0.26} \pm 0.19$	$-0.91^{+0.84}_{-0.76} \pm 0.40$	$-0.30^{+0.36}_{-0.35} \pm 0.14$
$[0.00, 4.30)$	$0.33^{+0.14}_{-0.14} \pm 0.02$	$-0.08^{+0.21}_{-0.20} \pm 0.05$	$-0.20^{+0.63}_{-0.63} \pm 0.07$	$-0.02^{+0.28}_{-0.28} \pm 0.01$
$[1.00, 6.00)$	$0.60^{+0.21}_{-0.23} \pm 0.09$	$0.36^{+0.46}_{-0.28} \pm 0.11$	$1.64^{+1.81}_{-1.85} \pm 2.21$	$-0.02^{+0.40}_{-0.40} \pm 0.03$

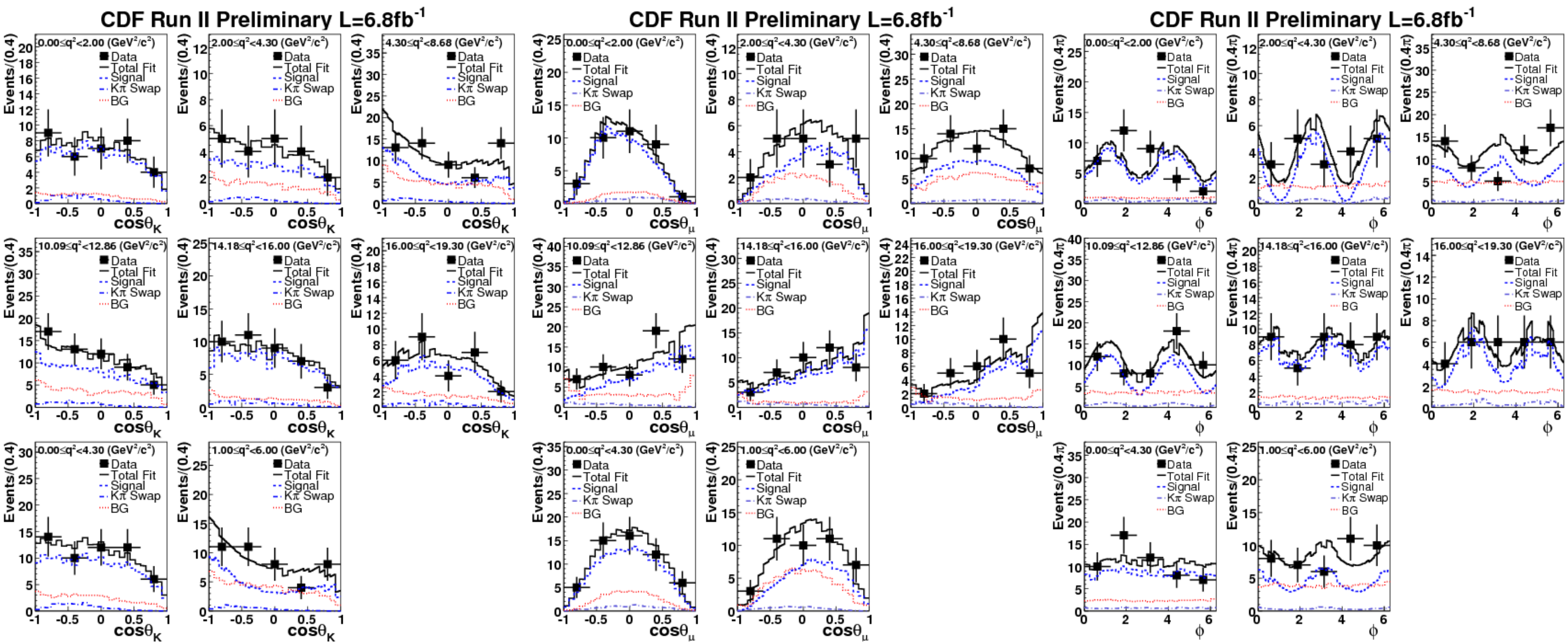
$B \to K^* \mu\mu$

q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A^{im}
$[0.00, 2.00)$	$0.30^{+0.16}_{-0.16} \pm 0.02$	$-0.35^{+0.26}_{-0.23} \pm 0.10$	$-0.97^{+0.67}_{-0.63} \pm 0.35$	$0.21^{+0.30}_{-0.31} \pm 0.10$
$[2.00, 4.30)$	$0.37^{+0.25}_{-0.24} \pm 0.10$	$0.29^{+0.32}_{-0.35} \pm 0.15$	$1.34^{+2.38}_{-1.17} \pm 0.92$	$-0.72^{+0.46}_{-0.36} \pm 0.21$
$[4.30, 8.68)$	$0.68^{+0.15}_{-0.17} \pm 0.09$	$0.01^{+0.20}_{-0.20} \pm 0.09$	$3.38^{+1.94}_{-2.05} \pm 3.61$	$0.11^{+0.31}_{-0.32} \pm 0.09$
$[10.09, 12.86)$	$0.47^{+0.14}_{-0.14} \pm 0.03$	$0.38^{+0.16}_{-0.19} \pm 0.09$	$-1.78^{+0.88}_{-0.82} \pm 0.78$	$0.32^{+0.25}_{-0.26} \pm 0.06$
$[14.18, 16.00)$	$0.29^{+0.14}_{-0.13} \pm 0.05$	$0.44^{+0.18}_{-0.21} \pm 0.10$	$0.24^{+0.76}_{-0.75} \pm 0.20$	$0.19^{+0.24}_{-0.26} \pm 0.04$
$[16.00, 19.30)$	$0.20^{+0.19}_{-0.17} \pm 0.05$	$0.65^{+0.17}_{-0.18} \pm 0.16$	$-0.69^{+0.84}_{-0.78} \pm 0.28$	$-0.20^{+0.33}_{-0.33} \pm 0.09$
$[0.00, 4.30)$	$0.33^{+0.14}_{-0.13} \pm 0.03$	$-0.08^{+0.21}_{-0.20} \pm 0.05$	$-0.30^{+0.62}_{-0.61} \pm 0.12$	$-0.10^{+0.27}_{-0.26} \pm 0.06$
$[1.00, 6.00)$	$0.69^{+0.19}_{-0.21} \pm 0.08$	$0.29^{+0.20}_{-0.23} \pm 0.09$	$1.65^{+2.17}_{-2.21} \pm 2.55$	$0.09^{+0.34}_{-0.35} \pm 0.06$

$B^+ \to K^+ \mu\mu$

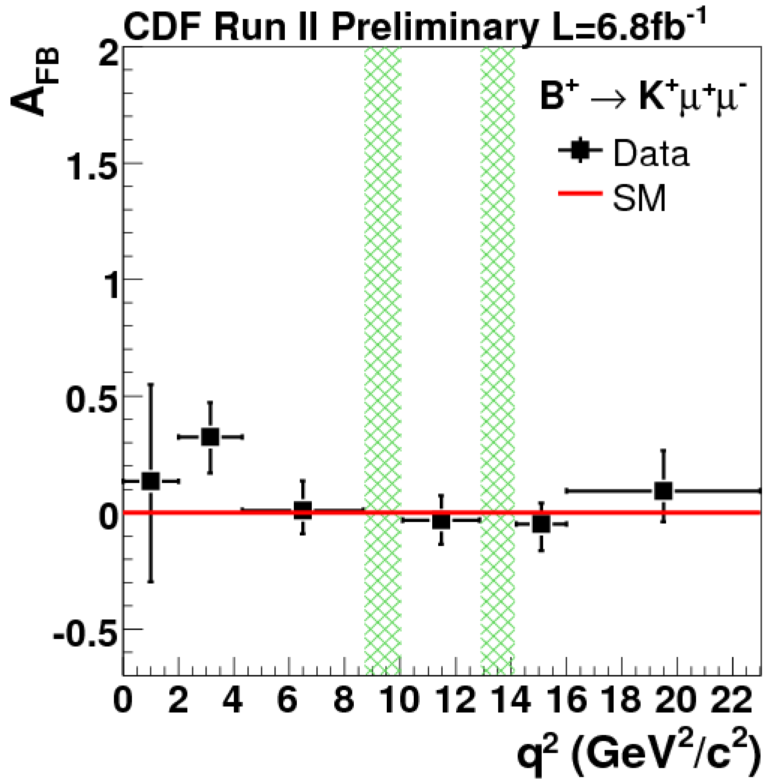
q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A^{im}
$[0.00, 2.00)$	-	$0.13^{+0.42}_{-0.43} \pm 0.07$	-	-
$[2.00, 4.30)$	-	$0.32^{+0.15}_{-0.16} \pm 0.05$	-	-
$[4.30, 8.68)$	-	$0.01^{+0.13}_{-0.10} \pm 0.01$	-	-
$[10.09, 12.86)$	-	$-0.03^{+0.11}_{-0.10} \pm 0.04$	-	-
$[14.18, 16.00)$	-	$-0.05^{+0.09}_{-0.11} \pm 0.03$	-	-
$[16.00, 23.00)$	-	$0.09^{+0.17}_{-0.13} \pm 0.03$	-	-
$[0.00, 4.30)$	-	$0.31^{+0.16}_{-0.16} \pm 0.04$	-	-
$[1.00, 6.00)$	-	$0.13^{+0.09}_{-0.09} \pm 0.02$	-	-

Angular distributions



A_{FB} in $B^+ \rightarrow K^+\mu\mu$

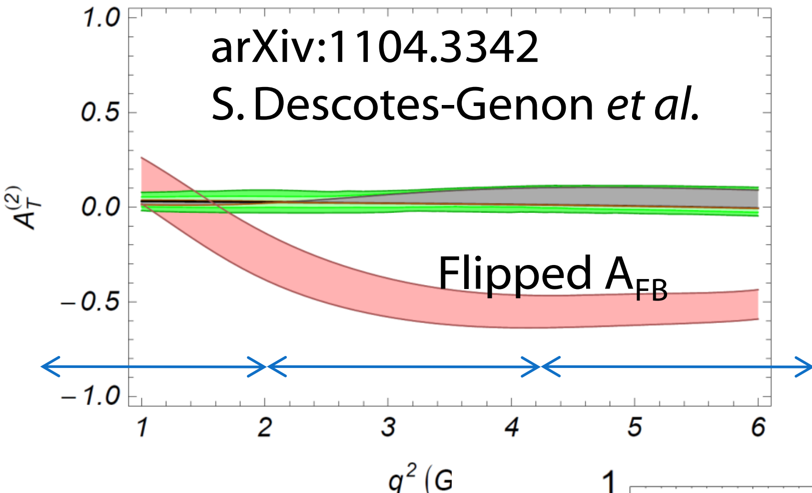
A_{FB}



- Consistent with zero as expected

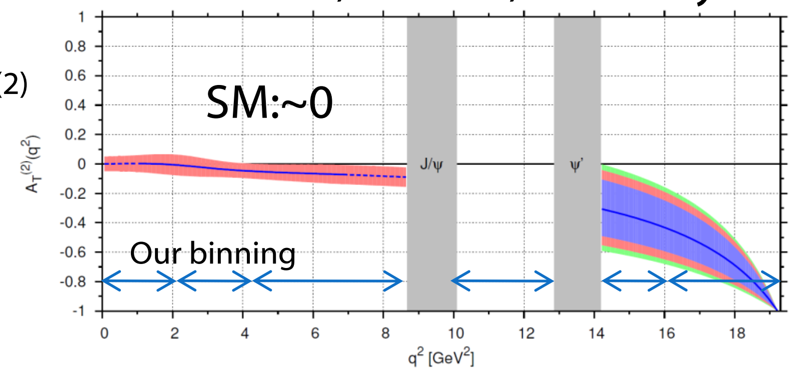
$A_T^{(2)}$ and A^{im} (cont'd)

- **Several NP models expect large discrepancy from the SM…**



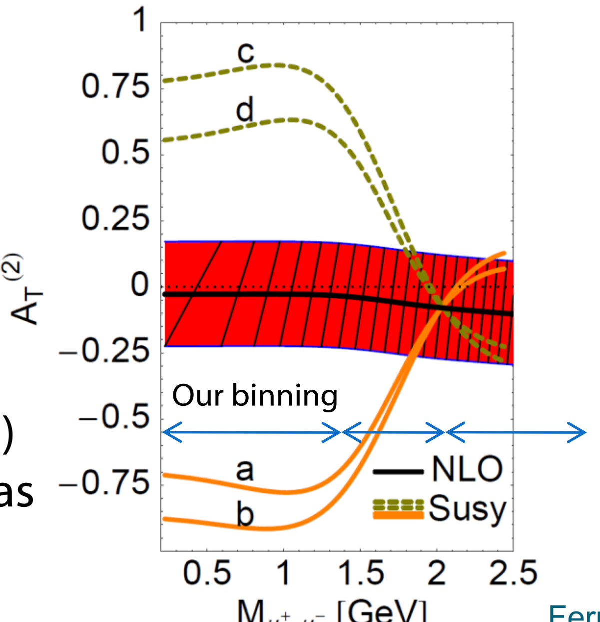
arXiv:1006.5013
C. Bobeth, G. Hiller, D. van Dyk

$A_T^{(2)}$



SM:~$-0.48^{+0.19}_{-0.16}$ (last 2bins)

JHEP 0704:058 (2007)
E. LungHi and J. Matias



JHEP 0901:019 (2009)
W. Altmannshofer *et al.*

$A^{im}=A_9$