Observation of $\Lambda_b \to \Lambda \mu^+ \mu^-$ Decay and 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

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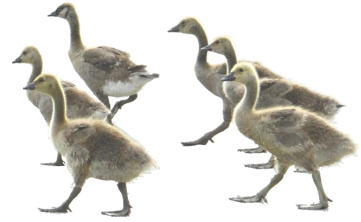
Overview

- Multidimensional approach toward BSM with rich b→sμμ samples

✓ Various Observables

- Total BR
  - Little Data
  - Early access
- Differential BR
- Angular analysis
  - Lots of Data
  - Precise



✓ Various Channels

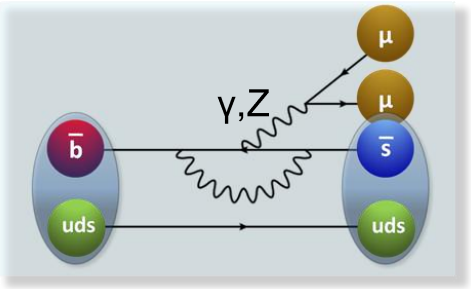
- $B^0 \to K^{*0}\mu\mu$
- $B^+ \to K^+\mu\mu$
- $B^+ \to K^{*+}\mu\mu$
- $B^0 \to K_S\mu\mu$
- $B_s \to \phi\mu\mu$

Not yet observed

- $\Lambda_b \to \Lambda\mu\mu$

b→sμμ decays

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



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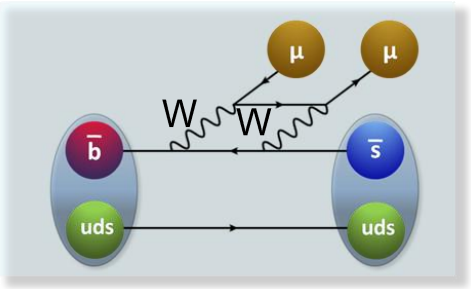

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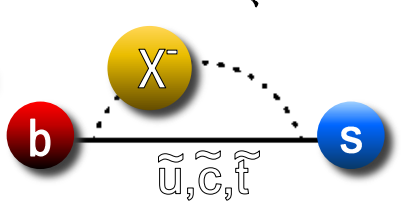
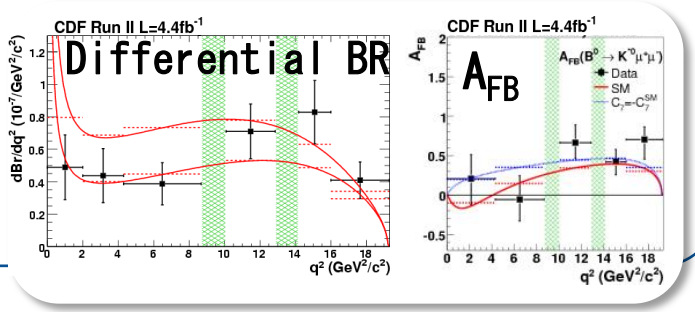


SUSY Technicolor Extra dimension Fourth generation

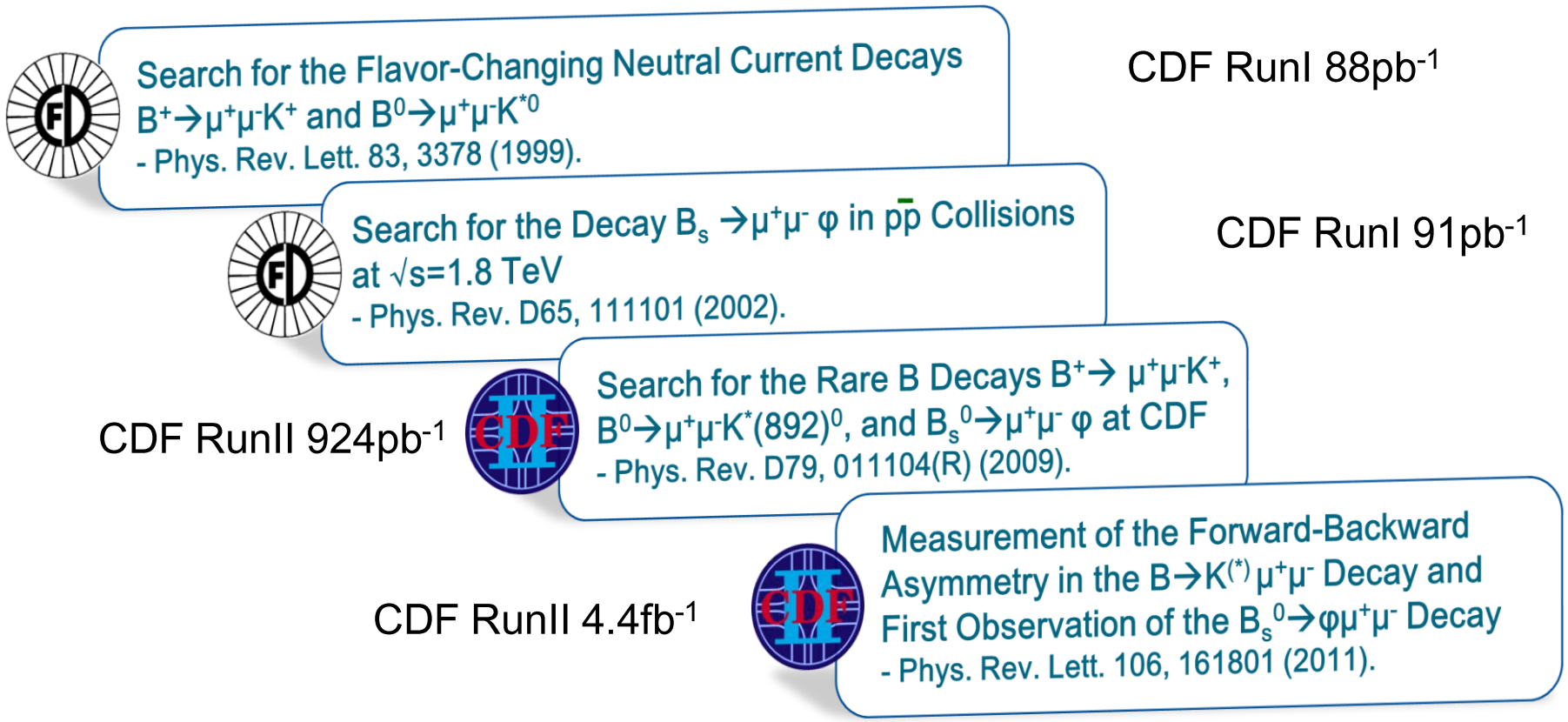
?

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



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

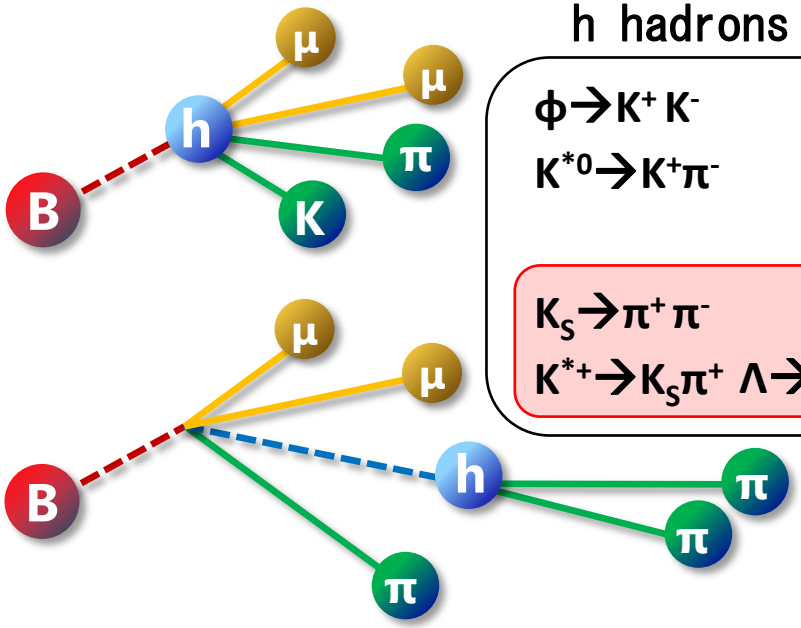
CDF analysis history



NEW for EPS

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

Analysis flow



h hadrons

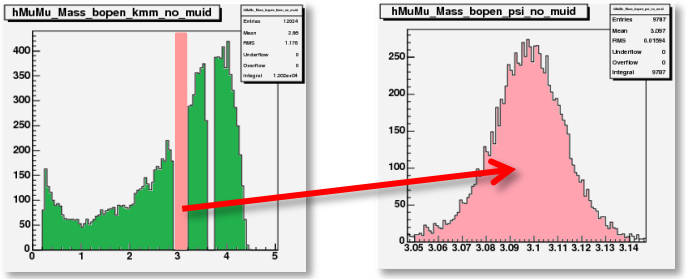
$\phi \rightarrow K^+ K^-$

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

$K_S \rightarrow \pi^+ \pi^-$

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

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

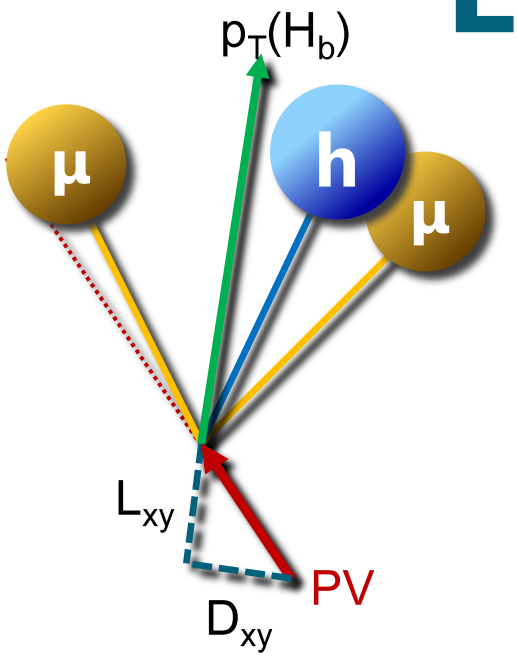


Dimuon mass

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

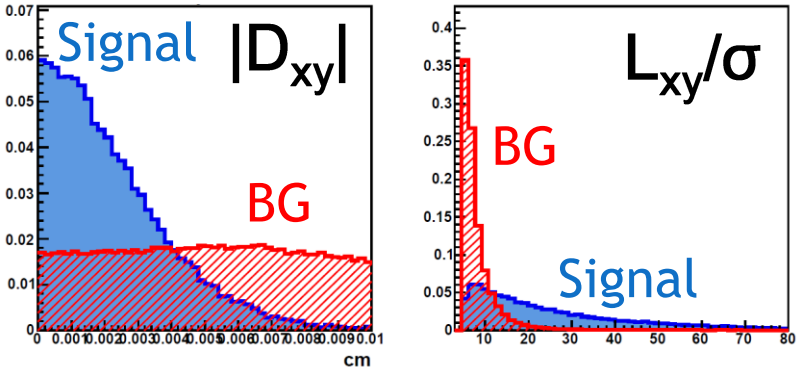
12 channel analysis!

Event selection

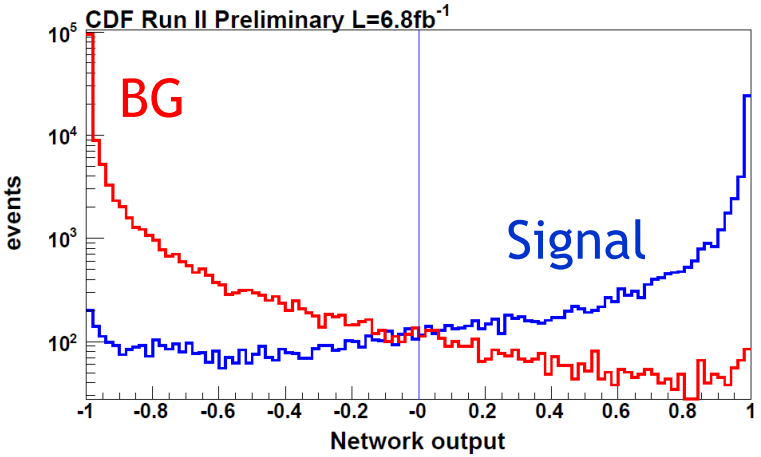


- Preselection ($H_b \rightarrow h\mu\mu$)
  - $p_T(H_b)$, h mass…
- Charmonium(J/ψ, ψ') veto
- Charm (D, D_s, Λ_c) veto
- Employ NN to optimize event selection

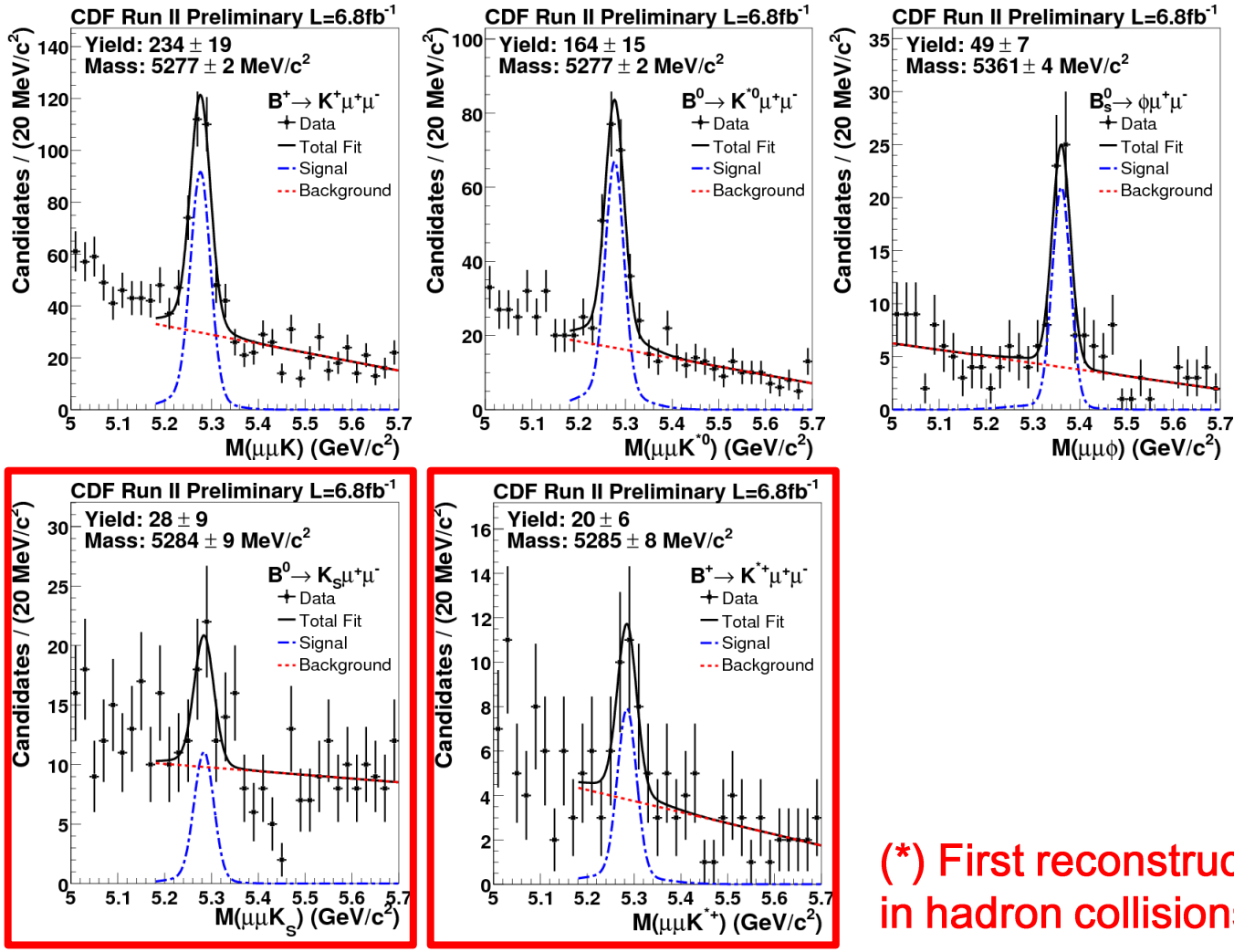
Kinematical variables



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



Rare B yields @6.8fb^{-1}

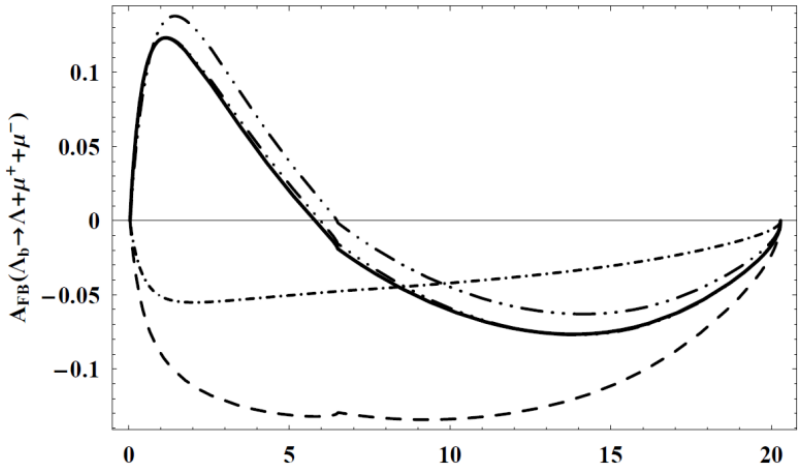


(*) First reconstruction in hadron collisions

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

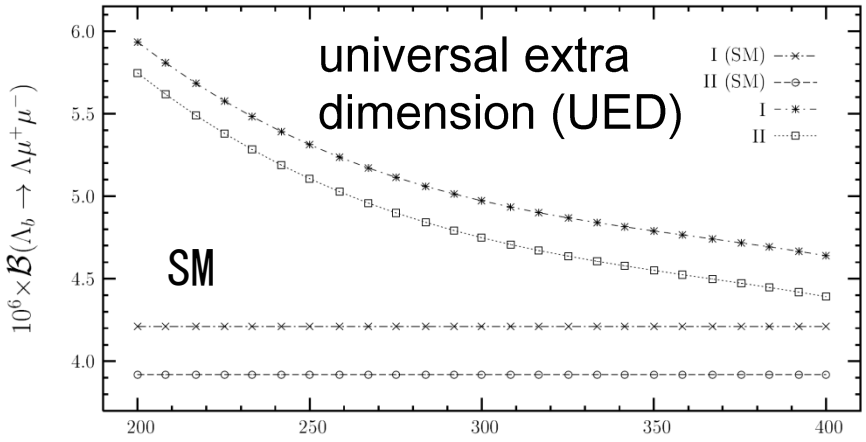
- Simple extension of b→sμμ transition to b-baryon decays
  - Different sensitivity from K*μμ
- Small BR ~O(10^{-6})
- No experimental search result (although >25 theory papers)
- Can measure A_{FB} (difficult in φμμ)

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



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

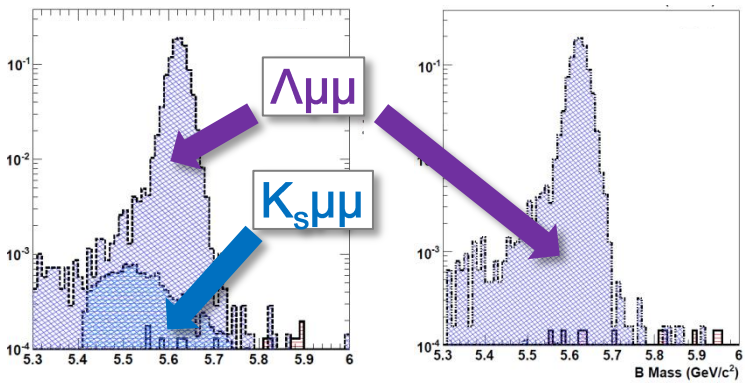
$BR(\Lambda_b \rightarrow \Lambda\mu\mu)$ vs UED parameter



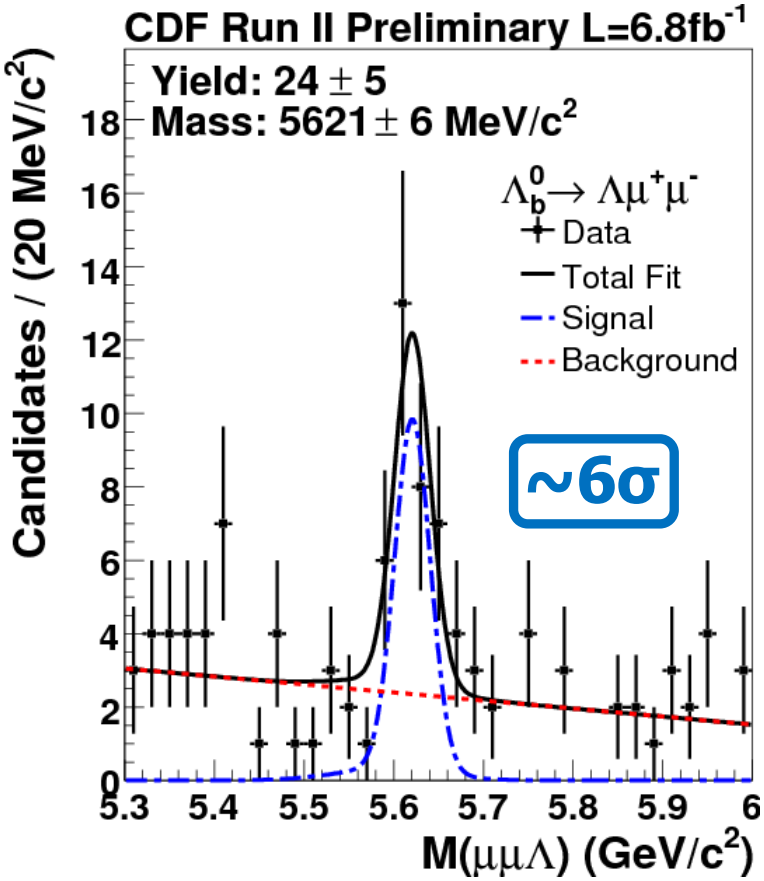
T.M.Aliev, M.Savci,
EPJC50:91-99 (2007)

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

- First experimental search for baryonic b→sμμ 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)

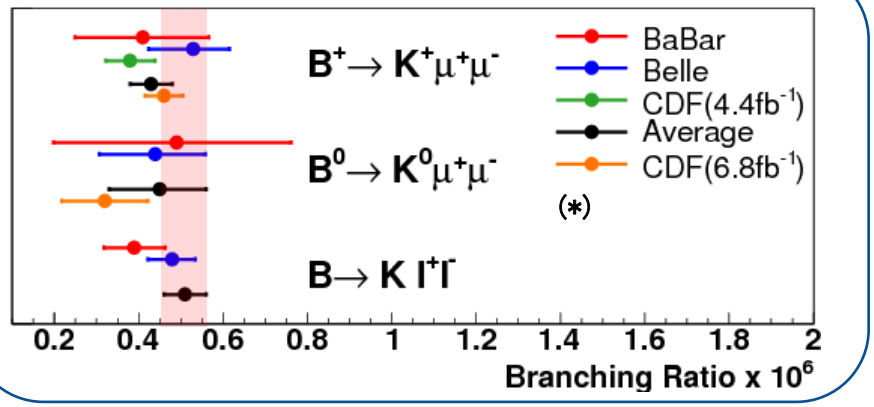
Total BR

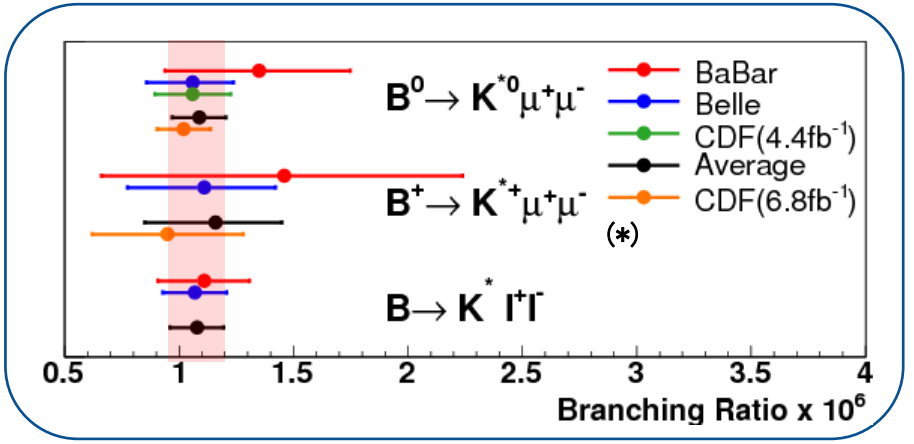
Rare channel yield

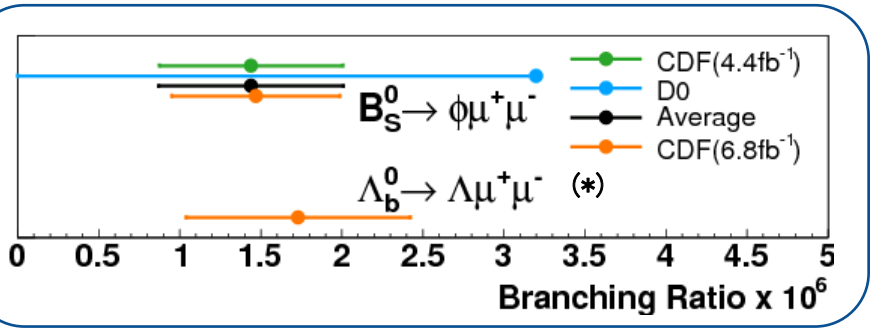
$$\frac{\mathcal{B}(H_b \to h\mu^+\mu^-)}{\mathcal{B}(H_b \to J/\psi h)} = \frac{N_{h\mu^+\mu^-}}{N_{J/\psi h}} \times \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\varepsilon_{\rm rel}}$$

Control channel yield

h=K, K*, φ, Λ



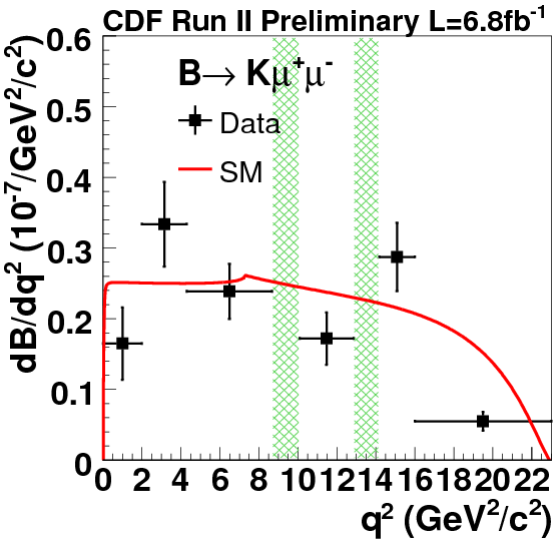




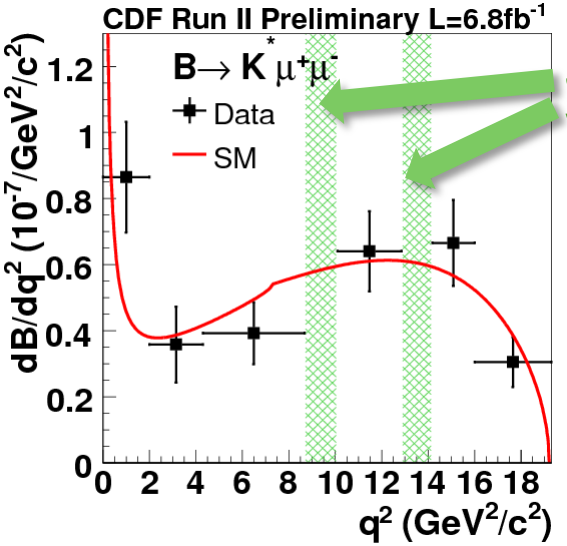
(*) All BRs except CDF@6.8fb^{-1} are taken from HFAG 2010 August

World's most precise b→sμμ BR measurements!

Differential BR (1)



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

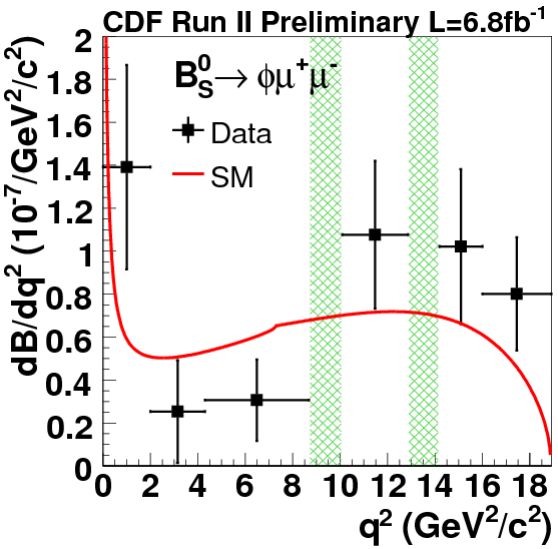


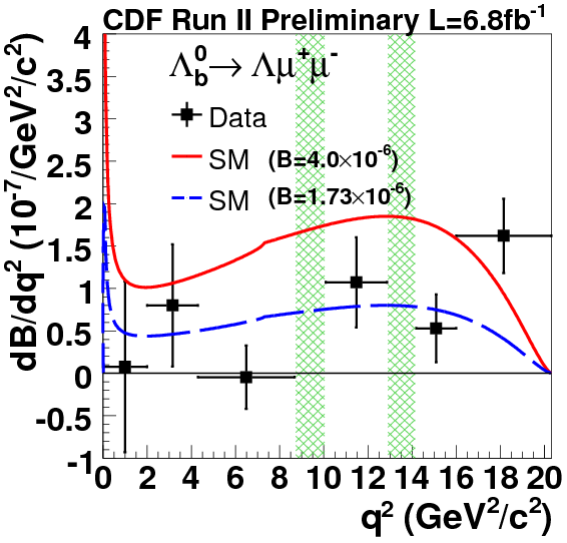
$B^+ \to K\mu\mu$	$B^0 \to K^{*0}\mu\mu$
$B^0 \to K^0\mu\mu$	$B^+ \to K^{*+}\mu\mu$
$B \to K\ \mu\mu$	$B \to K^*\ \mu\mu$

(*) First measurements at hadron collider

- Combined BR is calculated assuming isospin symmetry

Differential BR (2)





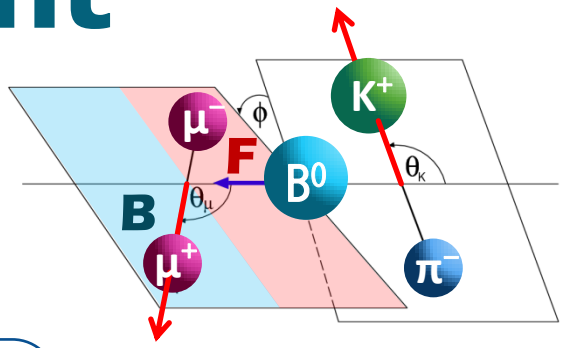
- First dBR measurements other than $B \rightarrow K^{(*)}\mu\mu$
  - $B_s \rightarrow \phi\mu\mu$
  - $\Lambda_b \rightarrow \Lambda\mu\mu$
- Different sensitivity to BSM
  - e.g. extra dimension, 4th generation…

- 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 (1.73/4.0)

A_{FB} measurement

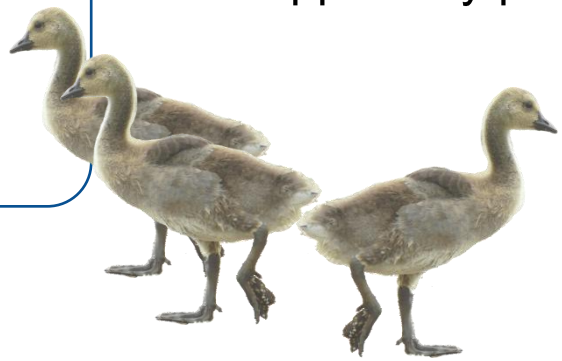
- Forward-Backward asymmetry:

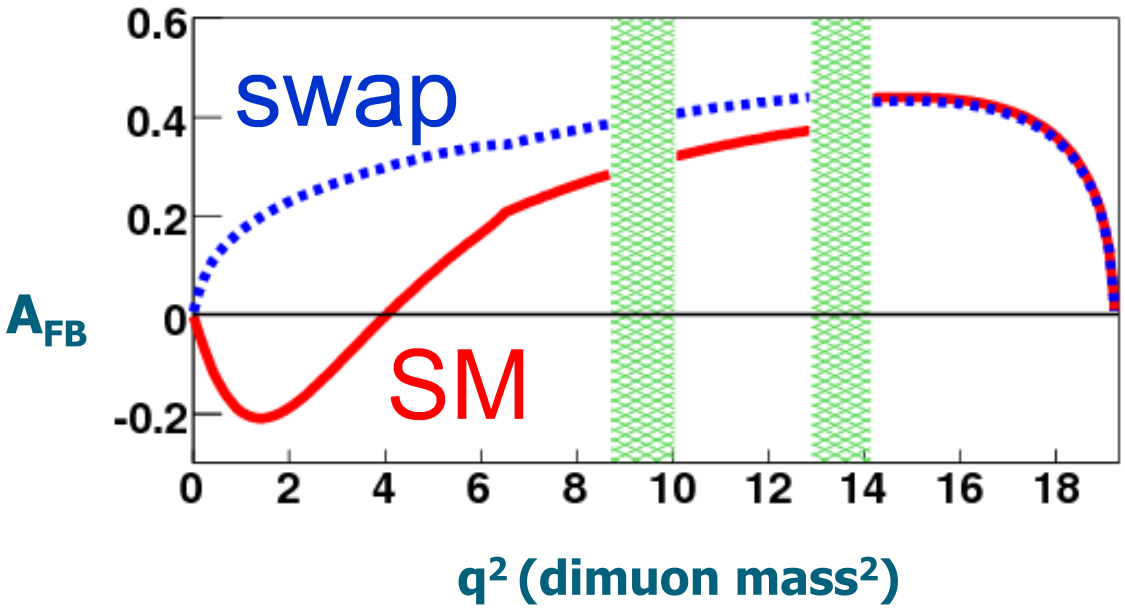
$$A_{FB}(q^2) \equiv \frac{\Gamma(q^2, \cos\theta_\mu > 0) - \Gamma(q^2, \cos\theta_\mu < 0)}{\Gamma(q^2, \cos\theta_\mu > 0) + \Gamma(q^2, \cos\theta_\mu < 0)}$$



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

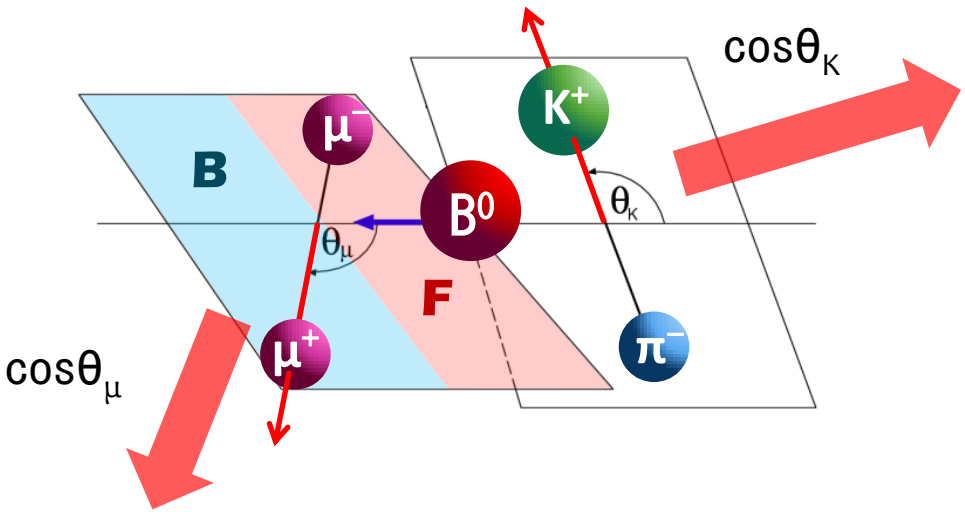
- Most interesting observable of b→sll
  - NP could swap the sign of A_{FB} at low q^2
  - Belle claims 2.7σ deviation from SM
  - BR(B→$X_s$ll) disfavors the swap solution…puzzle?

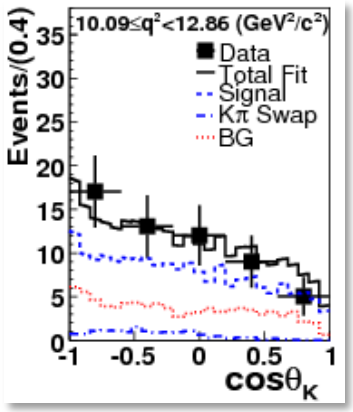




Angular analysis

- One can extract various information from the decay angular distribution

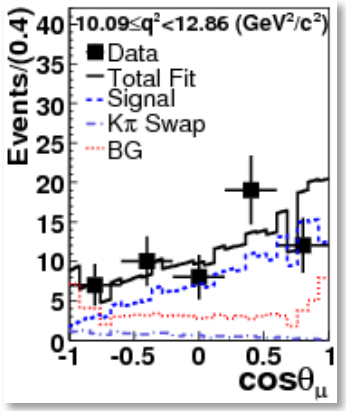




K* polarization

F_L

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



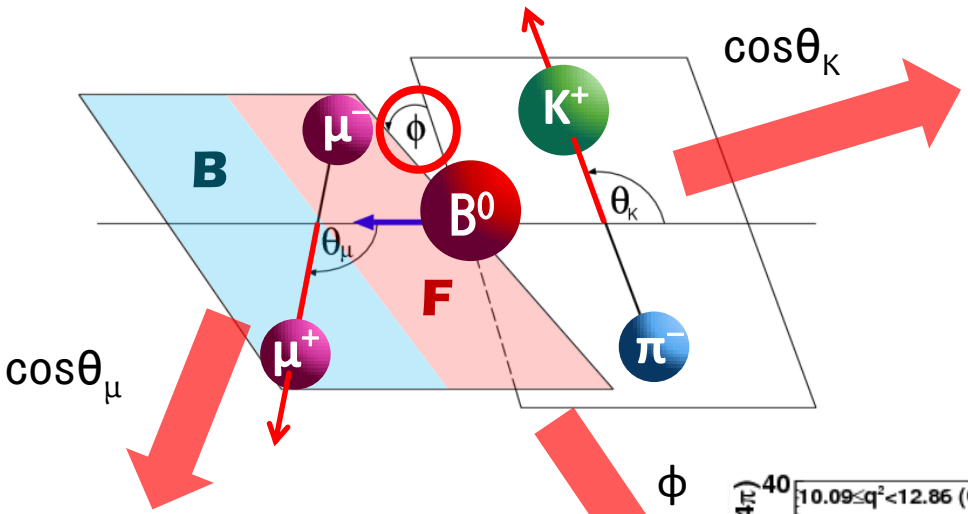
FB Asymmetry

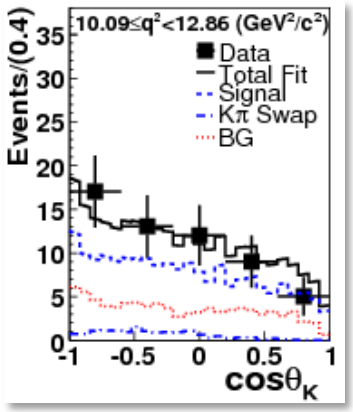
A_{FB}

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

Angular analysis

- One can extract various information from the decay angular distribution

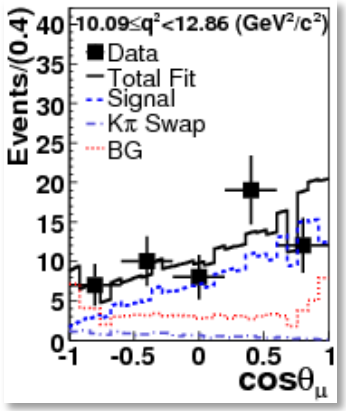




K* polarization

F_L

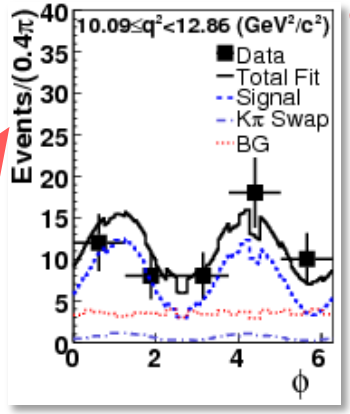
$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$



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

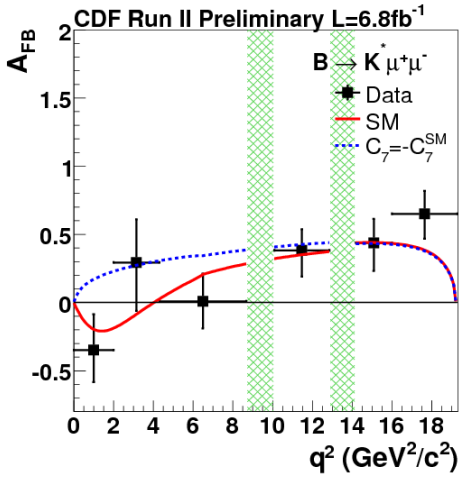
$A_T^{(2)}$ Transverse polarization asymmetry

A_{im} T-odd CP asymmetry

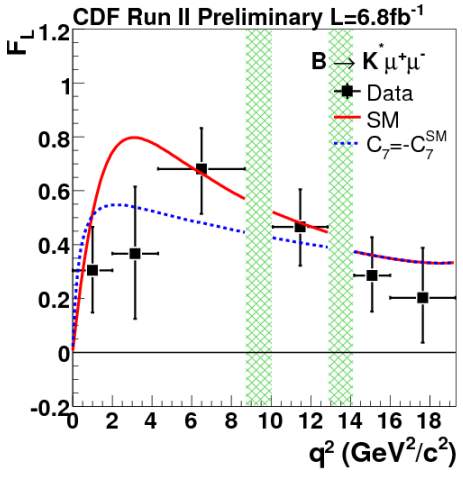
$$\frac{1}{2\pi}\left[1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi\right]$$

Angular fit results

A_{FB}

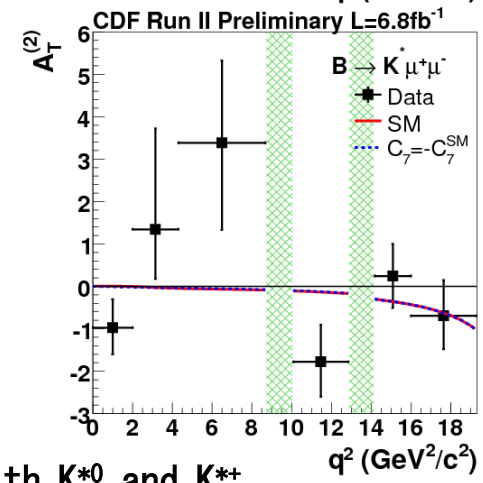


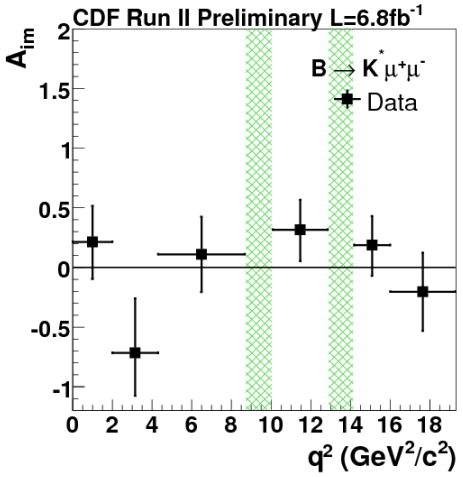
F_L



NEW

$A_T^{(2)}$





NEW

A_{im}

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

- First measurement of right-handed currents sensitive $A_T^{(2)}$ and A_{im}
- Among the most precise A_{FB}/F_L measurements
  - comparable resolution with Belle
- No significant deviation from SM with current accuracy

Summary

- CDF updated the $b \to s\mu\mu$ analysis with $6.8fb^{-1}$
  - Not only more data, analysis greatly improved
  - Statistics almost doubled with x1.5 data
  - New channels ($B^0 \to K_S\mu\mu$, $B^+ \to K^{*+}\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$)

- Results:
  - First observation of $\Lambda_b \to \Lambda\mu\mu$
  - Among the most precise BR in exclusive $b \to s\mu\mu$ decays
  - First measurement of dBR in $B_s \to \phi\mu\mu$ and $\Lambda_b \to \Lambda\mu\mu$
  - Among the most precise A_{FB} measurement
  - First measurement of $A_T^{(2)}$ and A_{im}

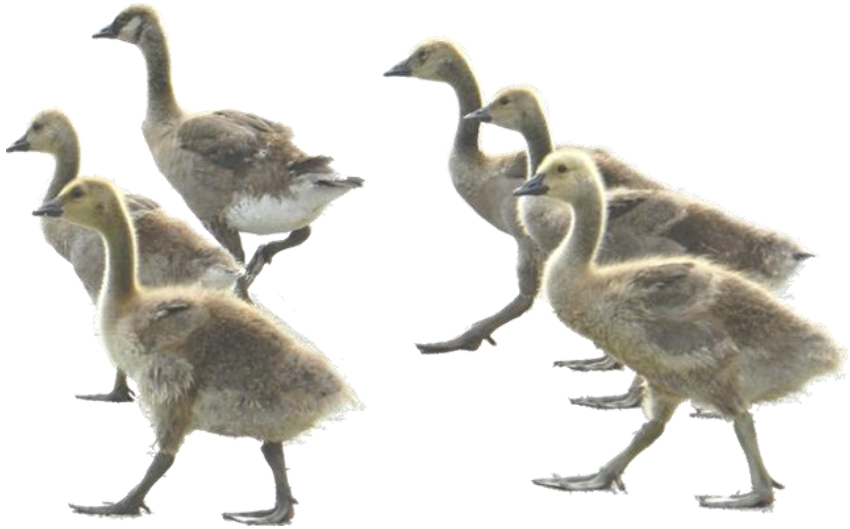
- CDF leads exploration of $b \to s\mu\mu$ physics
- Submitted the result to PRL (arXiv:1107.3353)

Special Thanks

We are deeply grateful to Wolfgang Altmannshofer, Christoph Bobeth, Danny van Dyk, and Joaquim Matias, who helped us by close communication and many valuable suggestions about the analysis.

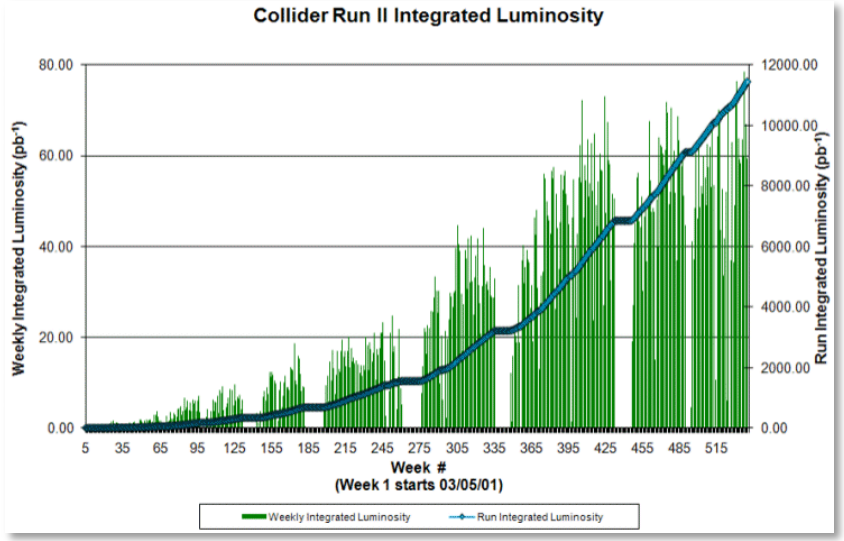
Thank you so much!

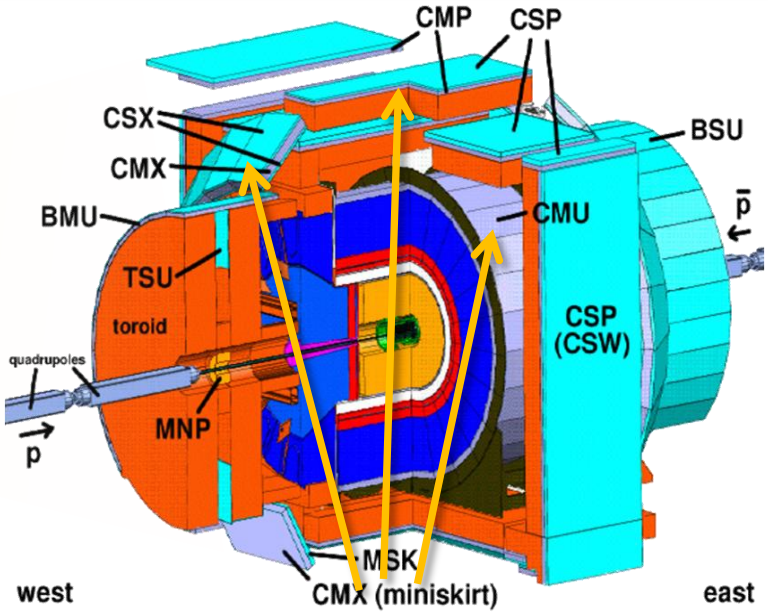
Backup



Tevatron and CDF detector

- Tevatron
  - $p\bar{p}$ collisions at $\sqrt{s}$=1.96TeV
- CDF II detector
  - A general purpose detector
- >9.5fb^{-1} data on tape
  (6.8 fb^{-1} used for the analysis)





Muon chambers
used in this analysis

BR systematics

Source	$K^+\mu^+\mu^-$	$K^{*0}\mu^+\mu^-$	$\phi\mu^+\mu^-$	$K^0_S\mu^+\mu^-$	$K^{*+}\mu^+\mu^-$	$\Lambda\mu^+\mu^-$
Theory model	0.9	0.7	1.7	0.5	0.7	3.4
MC reweight	2.8	1.5	1.8	3.5	0.5	4.0
Trigger turn-on	0.8	2.3	4.4	2.9	4.5	7.2
Particle ID	-	0.4	2.0	-	-	-
Low p_T hadrons	0.2	0.2	0.2	0.2	0.2	0.2
B_s lifetime	-	-	0.2	-	-	-
Polarization	-	0.5	0.1	-	0.5	6.6
Control mode stat.	0.5	0.9	1.7	1.2	2.0	3.3
MC stat.	0.2	0.4	0.3	0.1	0.5	0.3
NN cut	0.1	0.2	0.3	0.4	0.4	1.8
Efficiency total	3.4	3.2	5.7	4.9	5.1	11.7

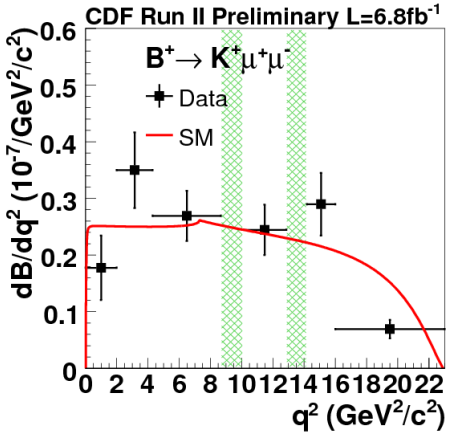
TABLE II: Efficiency systematic errors as percentage contributions.

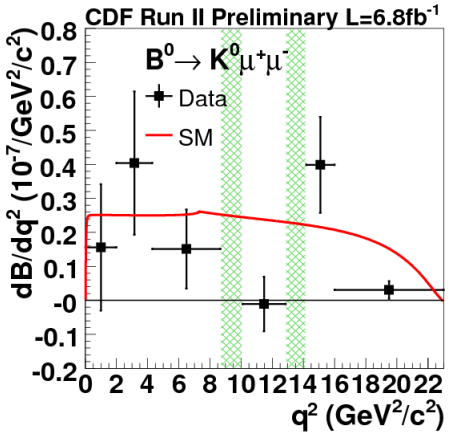
Source	$K^+\mu^+\mu^-$	$K^{*0}\mu^+\mu^-$	$\phi\mu^+\mu^-$	$K^0_S\mu^+\mu^-$	$K^{*+}\mu^+\mu^-$	$\Lambda\mu^+\mu^-$
Efficiency	3.1	3.1	5.8	4.7	5.1	11.7
BR($J/\psi \to \mu^+\mu^-$)	1.0	1.0	1.0	1.0	1.0	1.0
Signal PDF	0.2	0.3	0.2	0.4	0.3	0.4
Background PDF	2.3	0.9	2.6	1.3	2.2	1.0
Peaking BG	0.9	1.6	1.1	0.6	0.9	0.1
BR($H_b \to J/\psi h$)	3.4	4.5	30.8	3.7	5.6	29.7
Total	5.3	5.8	31.5	6.2	8.0	32.0

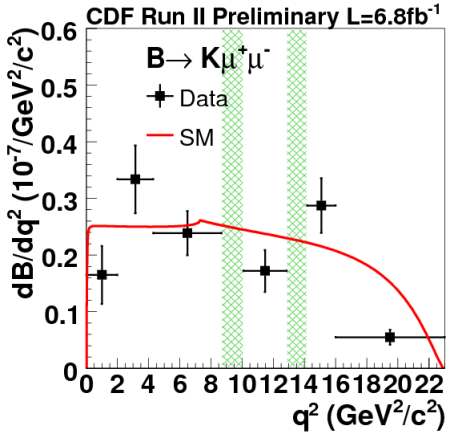
TABLE III: Total systematic errors as percentage contributions.

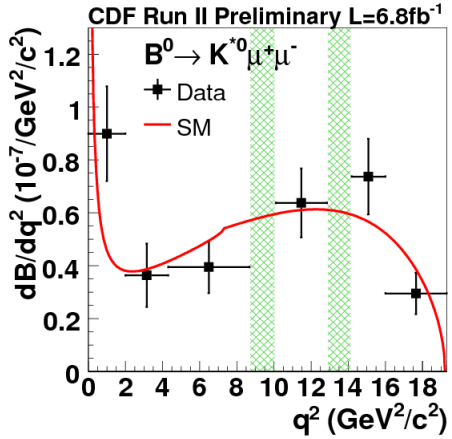
Differential BR

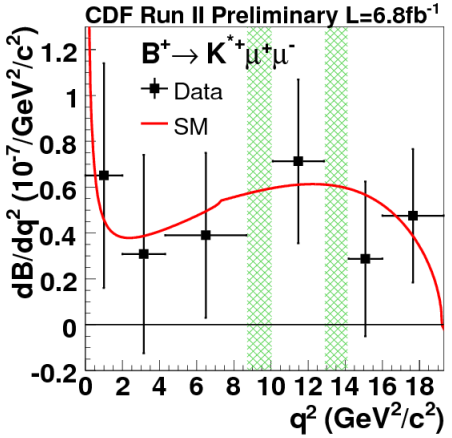
- Combined BR is calculated by isospin symmetry assumption

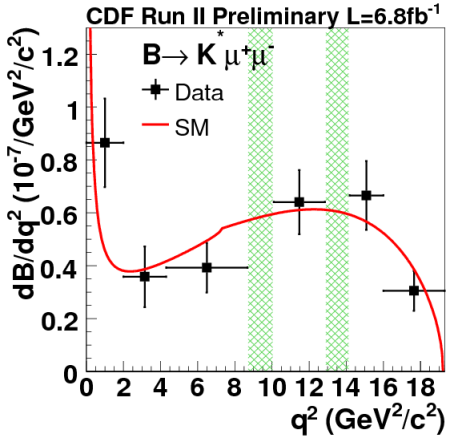








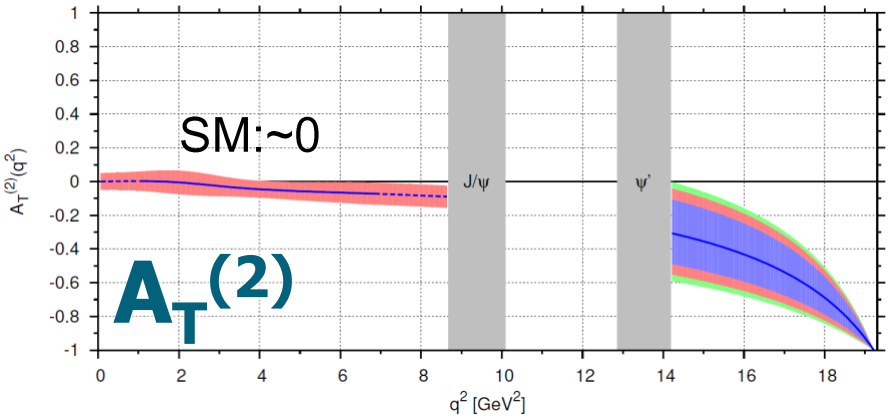




New probes: $A_T^{(2)}$ and A_{im}

- 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 $O(\pm 1)$
- Provide unique discrimination of NP models
- No experimental result so far
  - We can measure them with the world largest sample

BSM:~±1



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

Angular analysis summary

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

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

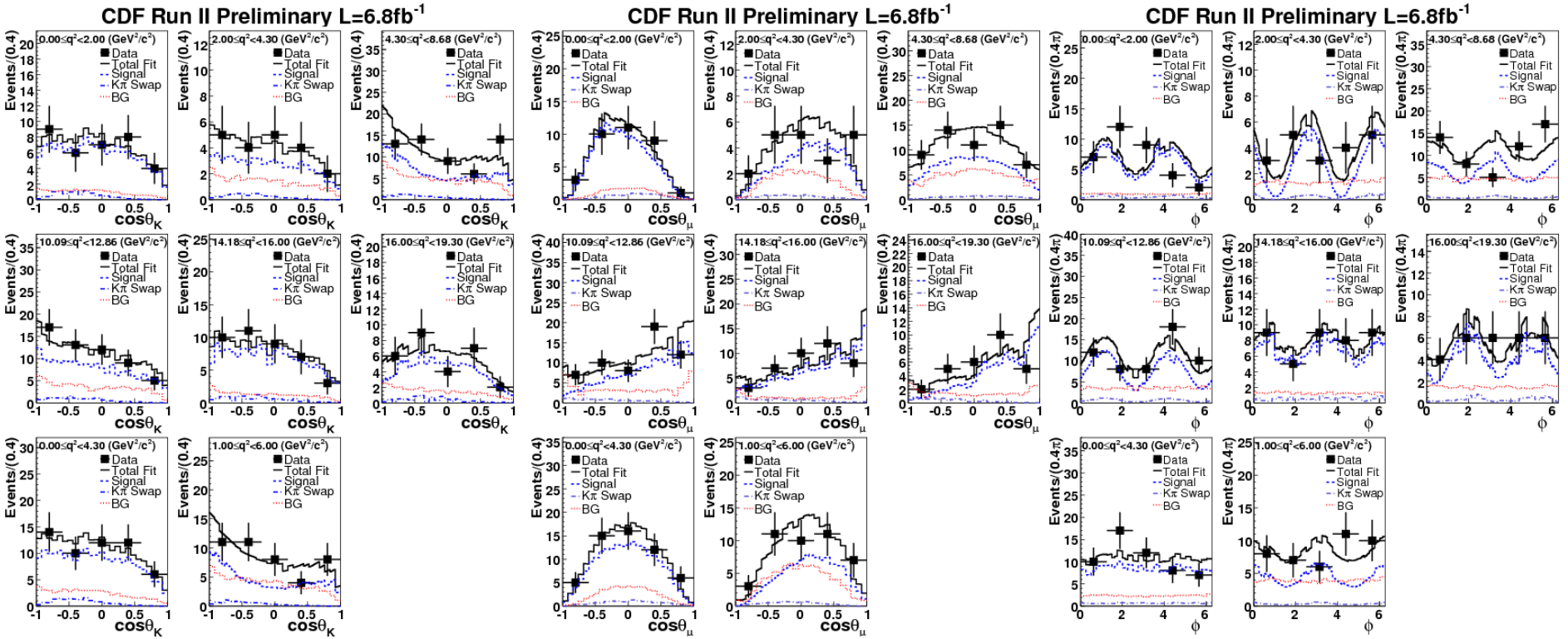
$B \to K^* \mu\mu$

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

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

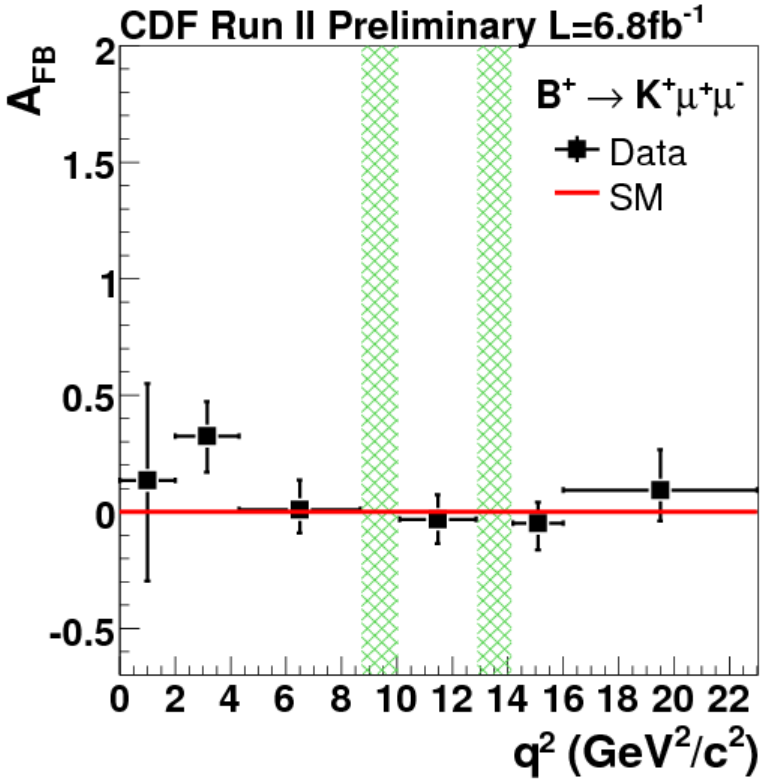
q^2 range	F_L	A_{FB}	$A_T^{(2)}$	A^{im}
$[0.00, 2.00)$	-	$0.13^{+0.42}_{-0.43} \pm 0.07$	-	-
$[2.00, 4.30)$	-	$0.32^{+0.15}_{-0.16} \pm 0.05$	-	-
$[4.30, 8.68)$	-	$0.01^{+0.13}_{-0.10} \pm 0.01$	-	-
$[10.09, 12.86)$	-	$-0.03^{+0.11}_{-0.10} \pm 0.04$	-	-
$[14.18, 16.00)$	-	$-0.05^{+0.09}_{-0.11} \pm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

Angular distributions



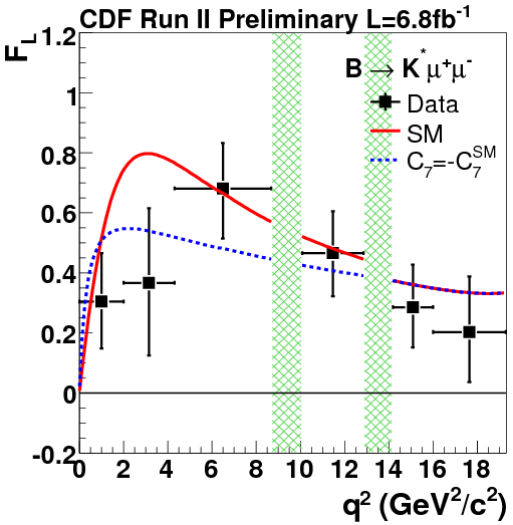
A_{FB} in $B^+ \to K^+\mu\mu$

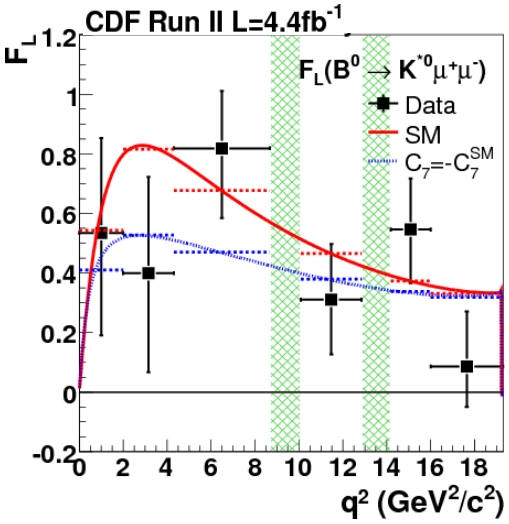
A_{FB}

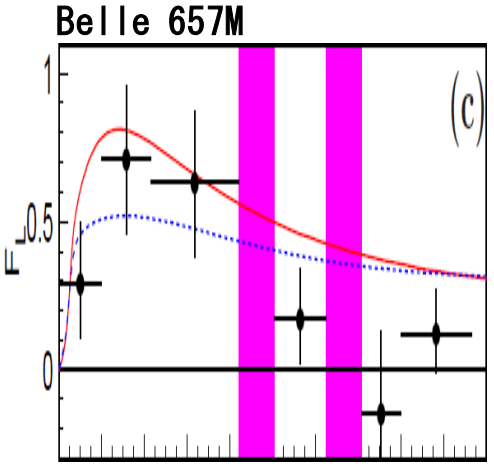


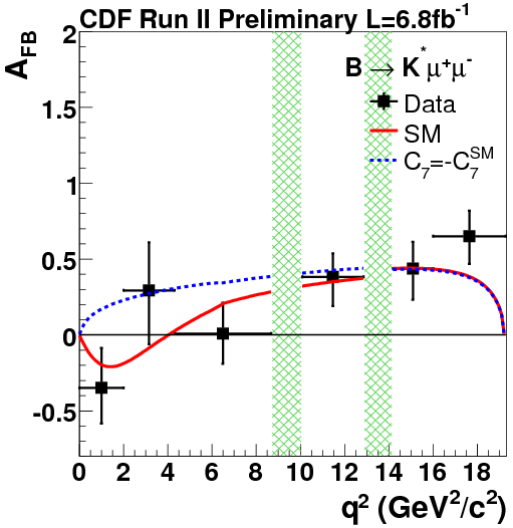
Consistent with zero as expected

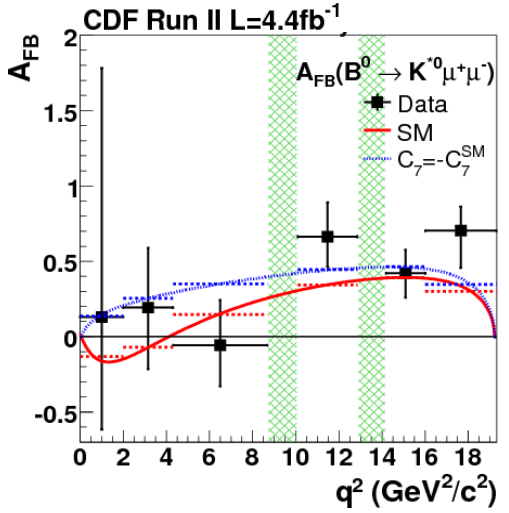
A_{FB} comparison



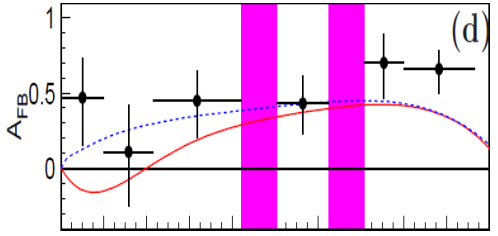








Belle 657M : PRL 103, 171801 (2009)
CDF 4.4fb^{-1}: PRL 106, 161801 (2011)



References

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- 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.