Summary of the Rare B and C Decay Session
HQL10

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University of Virginia

Rare B Decays is very active topic

10^{6} bb → 10^{9} bb → $10^{11\text{-}12}$ bb
Past Present Future

Will upper limits change to measurements by HQL12?

One Theory Overview Talk
Gino Isidori

Seven Experimental Talks

Present:	Babar	C. Jessop	$B \to K\nu\nu$, $B \to K^+\tau\tau$, $B \to \gamma\gamma$, $B \to X_d\gamma$ (V_{td}/V_{ts})
	CDF1	M. Resigni	$B_s \to J/\Psi K_s$, $B_s \to J/\Psi K^*(890)$, $B_s \to \phi\phi$ (pol.)
	CDF2	S. Farrington	$B_{s,d} \to \mu\mu$, $B_{s,d} \to K^*\mu\mu$, $B_s \to \phi\mu\mu$, $B^+ \to K^+\mu\mu$, $D \to \mu\mu$
	DO	I. Rigg-Baudot	$B_s \to \mu\mu$
	Atlas	V. Sipica	$B_s \to \mu\mu$ plus $b \to s\mu\mu$ transition prospects
Future:	CMS	L. Martini	$B_s \to \mu\mu$ prospects
	LHCb	N. Tuning	$B_s \to \mu\mu$, $B^0 \to K^*\mu\mu$, $B^0 \to K^*\gamma$, B_s $B^0 \to \phi\gamma$ prospects

Searches for NP beyond the SM

Isidori Conclusions

- No large new sources of flavor symmetry breaking at the TeV scale.
- Several anomalies in the CKM picture are starting to show up.

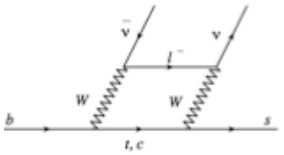
		SM pred.	data	pull
The $A_{\psi K}$ - sin(2β) tension	$A_{\psi K}$	$.771 \pm .036$	$.654 \pm .026$	2.7σ
CPV in Bs mixing	$\phi_s = -2\lvert\beta_s\rvert$	$.038 \pm .003$	$\sim 0.7 \pm 0.3$	$\sim 2\sigma$
$B \to \tau \nu$	$10^4\, B(B \to \tau\nu)$	0.81 ± 0.07	1.72 ± 0.28	3.2σ

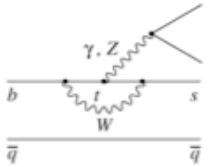
- May well be the *first signals of new physics at the TeV scale*.
- Rare decays are the key tool to make progress in this field.
- Clean leptonic and semileptonic *B* decays are those with the largest discovery potential in most realistic NP models

Search for $B \to K\nu\bar{\nu}$

BaBar
$B^{+,0} \to K\nu\nu$

Standard Model

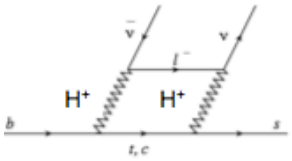


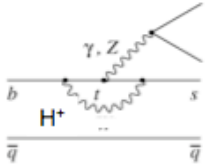


$B(B^0 \to K\nu\bar{\nu}) \sim 3.2\text{-}5.2 \times 10^{-6}$

Altmannshofer,Buras,Straub,Wick JHEP 0904, 02 (2009)
Buchalla,Hiller,Isidori 63 014015 (2000)

Physics Beyond Standard Model

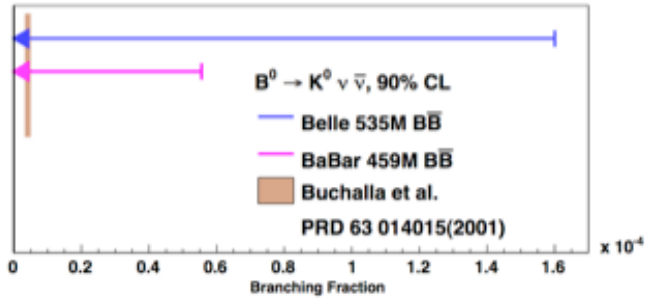




$B(B^0 \to K\nu\bar{\nu}) \sim O(10^{-5})$

(MSSM,unparticles,extra dimensions)
Yamada PRD 77 014025,Aliev etal JHEP 07(.072
Colangeo etal PRD 73 115006

Mode	$\mathcal{B} \times 10^{-5}$	90% CL	95% CL
K^+	$0.2^{+0.8}_{-0.7}$	< 1.3	< 1.6
K^0_s	$1.7^{+3.1}_{-2.1}$	< 5.6	< 6.7
Comb. K^+, K^0_s	$0.5^{+0.7}_{-0.7}$	< 1.4	< 1.7
low-q^2	$0.2^{+0.6}_{-0.5}$	< 0.9	< 1.1
high-q^2	$-1.8^{+3.8}_{-3.8}$	< 3.1	< 4.6

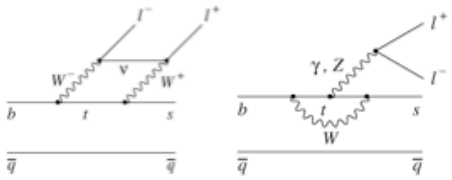


Previous Measurements

Experiment	BF (90% CL)	Dataset	Reference
Belle	$< 1.4 \times 10^{-5}$	492 fb^{-1}	*Chen etal PRL 99 221802, 2007*
BaBar	$< 5.2 \times 10^{-5}$	82 fb^{-1}	*Aubert et al. 94 1018011*

Search for $B^+ \to K^+\tau^+\tau^-$

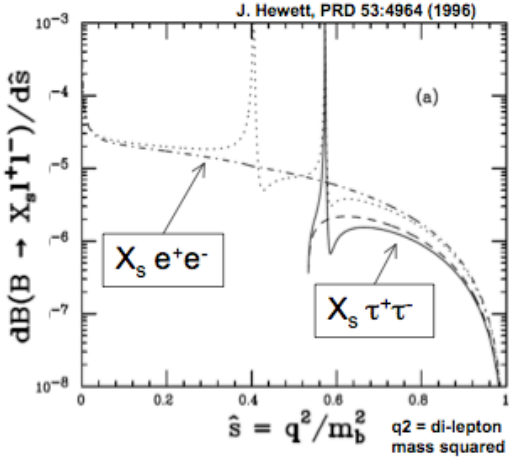
Standard Model



$B(B \to X_s l^+ l^-)$

Lepton	$0.6 \leqslant \hat{s} \leqslant 1$
Electron	8.5×10^{-7}
Muon	8.5×10^{-7}
Tau	4.3×10^{-7}

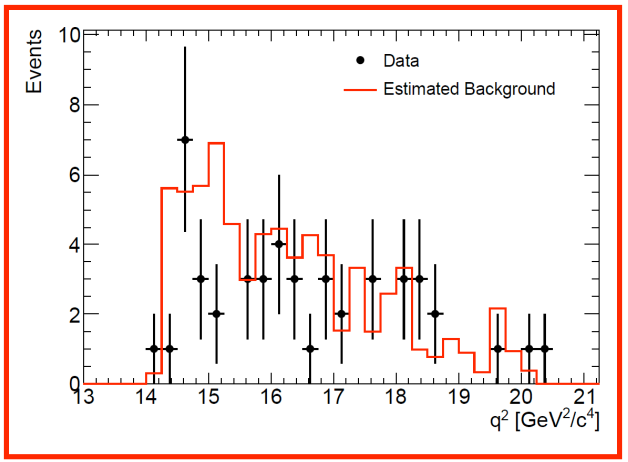
$B^+ \to K^+\tau^+\tau^-$ ~50% of total inclusive rate



Standard Model rate comparable to $\mu^+\mu^-$ or e^+e^- channels but new physics with a mass dependent coupling such as a Higgs in the Next-to-MSSM could enhance by $(m_\tau/m_\mu)^2$ ~280 (G.Hiller PRD 70 034018 (2004))

BaBar

$B^+ \to K^+\tau\tau$

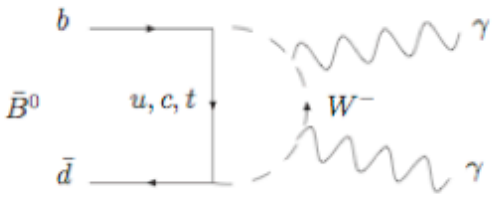


$B(B^+ \to K^+\tau^+\tau^-) < 0.0033$ (90% CL)

(First limit to date)

Search for $B^0 \to \gamma\gamma$

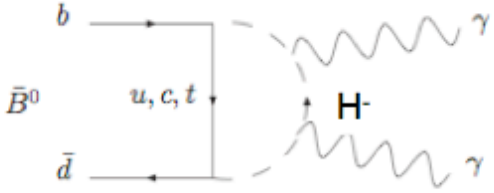
Standard Model



$B(B^0 \to \gamma\gamma) \sim 3 \times 10^{-8}$

(Bosch and Buchalla,,JHEP 0208:054 (2002))

Physics Beyond Standard Model



$B(B^0 \to \gamma\gamma) \sim O(10^{-7})$

Aliev and Turin, PRD 58 095014

(2HDM models or R-parity violating SUSY)

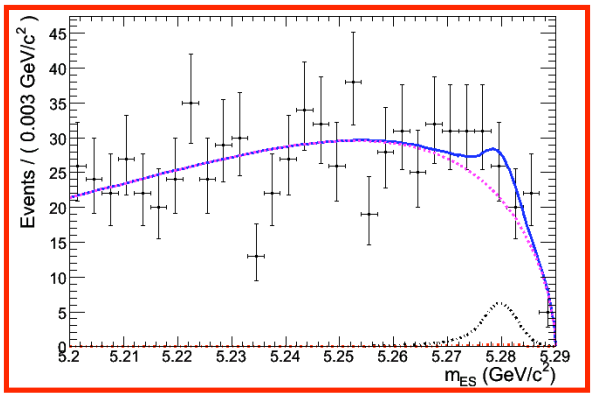
Experimental constraints from $b \to d\gamma$ experiment

Previous Measurements

Experiment	BF (90% CL)	Dataset	Reference
L3	$< 1.9 \times 10^{-5}$	2.95×10^6 ($Z \to$ had)	Acciarri et al. Phys. Lett. B, 363, 1995
BaBar	$< 1.7 \times 10^{-6}$	19 fb^{-1}	Aubert et al. PRL 87, 24, 2001
Belle	$< 6.1 \times 10^{-7}$	104 fb^{-1}	Villa et al. PRD 73, 2006

BaBar

$B^0 \to \gamma\gamma$



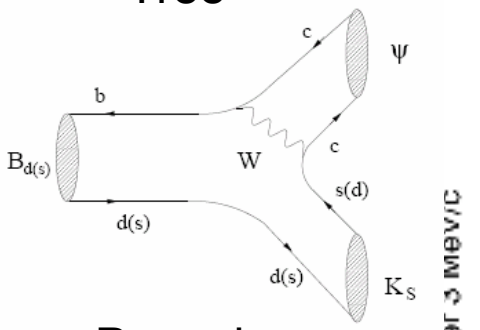
$BR(B^0 \to \gamma\gamma) < 3.3 \times 10^{-7}$

$BR(B^0 \to \gamma\gamma) = (1.7 \pm 1.1(stat) \pm 0.2(sys)) \times 10^{-7}$

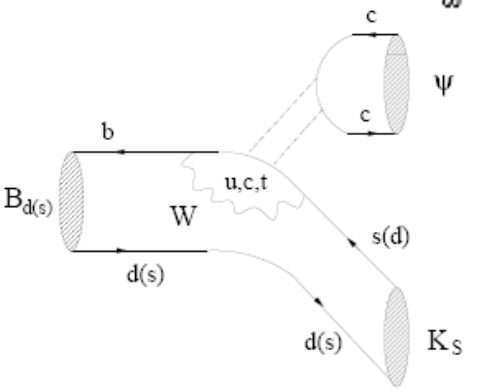
1.9 sigma significance

CDF

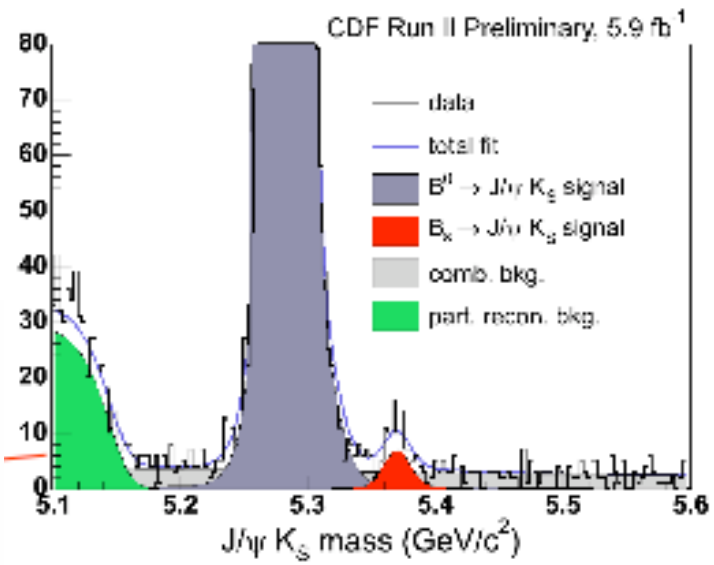
Tree



Penguin

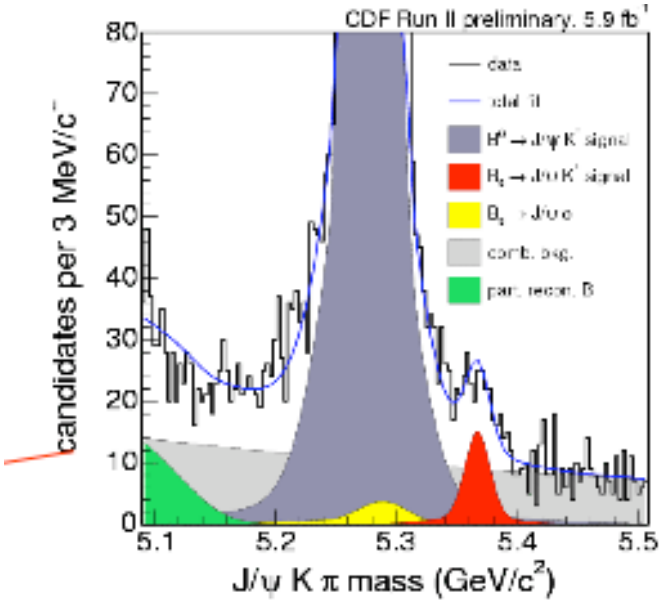


$B_s \rightarrow J/\Psi K_s$



$N(B_d \rightarrow J/\Psi K_s) = 5954 \pm 79$
$N(B_s \rightarrow J/\Psi K_s) = 64 \pm 14$
$BR(B_s \rightarrow J/\Psi K_s) = (3.5 \pm 0.6(stat) \pm 0.4(sys) \pm 0.4(frag) \pm 0.1(PDG)) \times 10^{-5}$

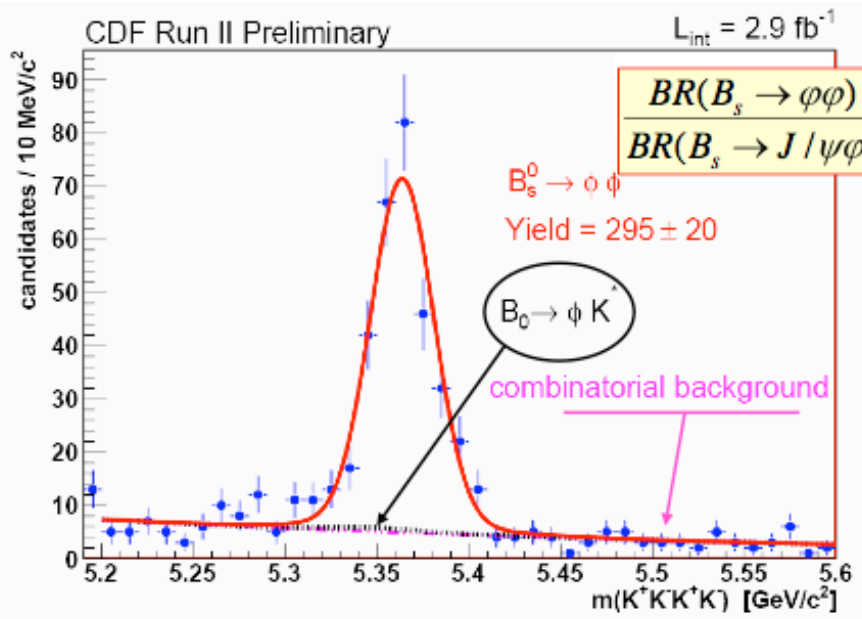
$B_s \rightarrow J/\Psi K^*$



$N(B_d \rightarrow J/\Psi K^*) = 9540 \pm 110$
$N(B_s \rightarrow J/\Psi K^*) = 158 \pm 25$
$BR(B_s \rightarrow J/\Psi K^*) = (8.3 \pm 1.2(stat) \pm 3.3(sys) \pm 1.0(frag) \pm 0.4(PDG)) \times 10^{-5}$

CDF

$B_{s,} \rightarrow \phi\phi$ BR



- **CDF main result:**

$$\frac{BR(B_s \rightarrow \varphi\varphi)}{BR(B_s \rightarrow J/\psi\varphi)} = (1.78 \pm 0.14(stat.) \pm 0.20(sys.)) \cdot 10^{-2}$$

- Syst. dominated by polarization uncertainties (will be reduced)
- Use BR($B_s \rightarrow J/\psi\phi$) = $[13.5 \pm 4.6] \cdot 10^{-2}$
  - updated from PDG using more recent f_s/f_d

for absolute branching ratio:

$$BR(B_s \rightarrow \varphi\varphi) = (24.0 \pm 2.1(stat.) \pm 2.7(sys.) \pm 8.2(BR)) \cdot 10^{-6}$$

CDF

$B_s \rightarrow \phi\phi$ polarization

- In B→VV decays 3 decay product relative angular momentum states possible:
  - 3 independent decay amplitudes
  - Best decomposed in a longitudinal and two transverse polarization amplitudes A_0,$A_{//}$(CP even), $A_\perp$(CP odd)

- Naïve expectation: $|A_0|>>|A_{//}|\sim|A_\perp|$
  - V-A nature of weak interaction and conservation helicity in qcd

$$
\begin{aligned}
|A_0|^2 &= 0.348 \pm 0.041(\text{stat}) \pm 0.021(\text{syst}) \\
|A_\parallel|^2 &= 0.287 \pm 0.043(\text{stat}) \pm 0.011(\text{syst}) \\
|A_\perp|^2 &= 0.365 \pm 0.044(\text{stat}) \pm 0.027(\text{syst})
\end{aligned}
$$

Obviously violated: Penguin effects favored over FSI
new physics?

CDF

$B_{s,d} \to K^* \mu\mu$, $B_s \to \phi\mu\mu$, $B^+ \to K^+\mu\mu$ new physics

- B Rare Decays $B \to \mu^+\mu^- h$:
  - $B^+ \to \mu\mu\, K^+$
  - $B^0 \to \mu\mu\, K^*$

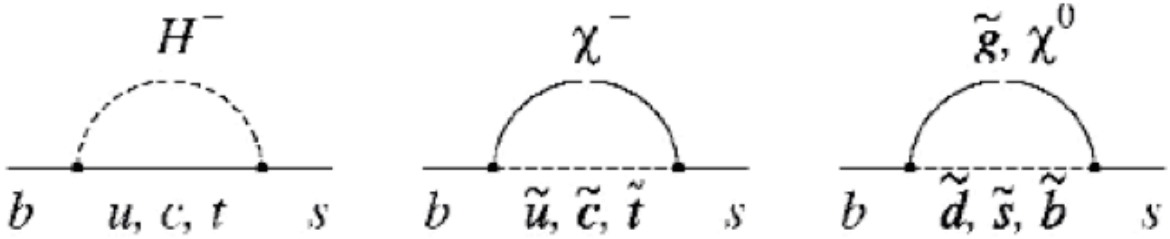
  } observed at Babar,Belle,CDF

  - $B_s \to \mu\mu\, \phi$

  } not seen until now

PRL103:171801,2009
PRD 79:031102,2009
PRD 79:011104,2009

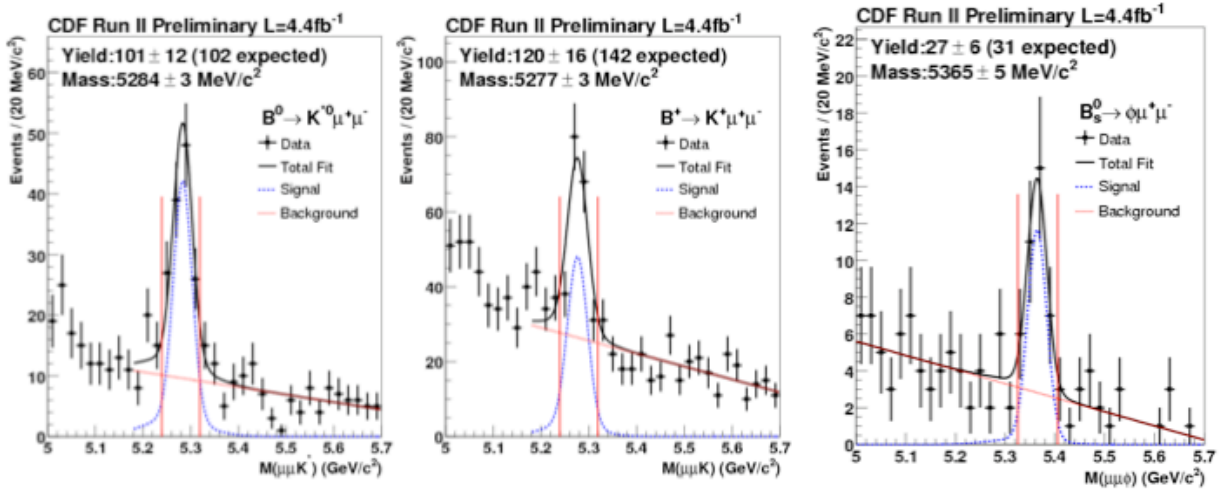
- FCNC $b \to s\gamma^*$
- Penguin or box processes in the Standard Model:



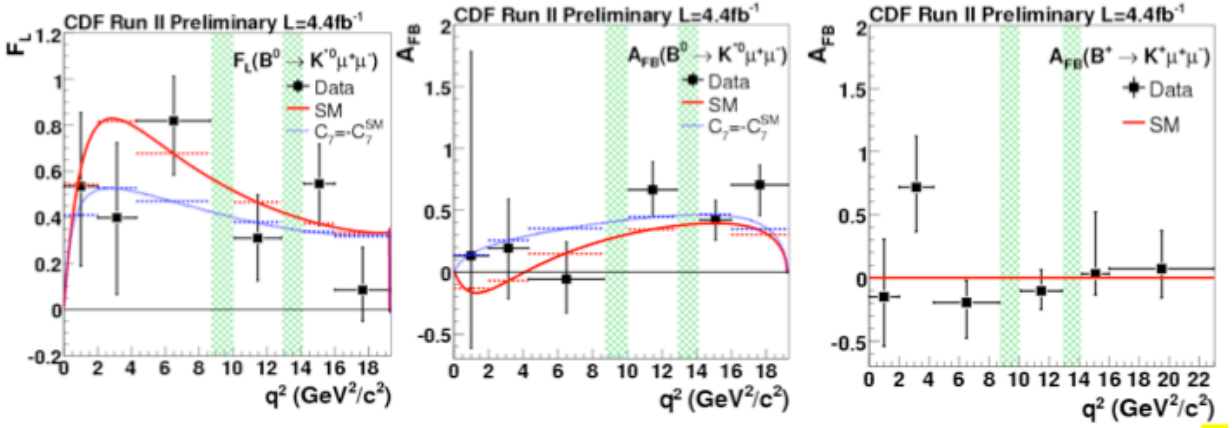
- Predicted BR($B_s \to \mu\mu\, \phi$)=1.61x10^{-6}

hep-ph/0303246

- Candidate invariant mass distributions



- Forward backward asymmetry



CDF

$B_{s,d} \rightarrow K^* \mu\mu$,
$B_{s,} \rightarrow \phi \mu\mu$,
$B^+ \rightarrow K^+ \mu\mu$

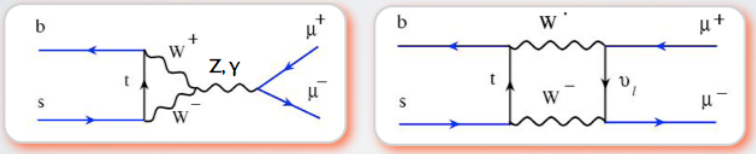
B →hμμ
First Observation
In the B_s Mode

First Measurement
Of Asymmetries
At Hadron Collider

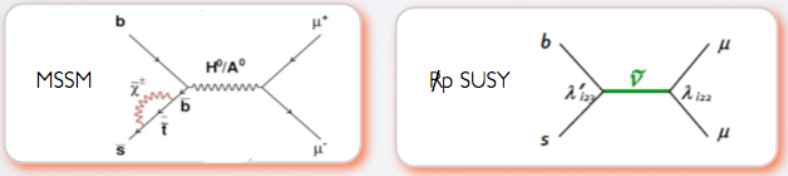
$B_s \rightarrow \mu^+\mu^-$

- FCNC processes have very low rate in SM and are well understood:

$\mathcal{B}(B_s \rightarrow \mu^- \mu^+)_{SM} = (3.6 \pm 0.3)\times10^{-9}$ A.J. Buras, Prog.Theor.Phys.122

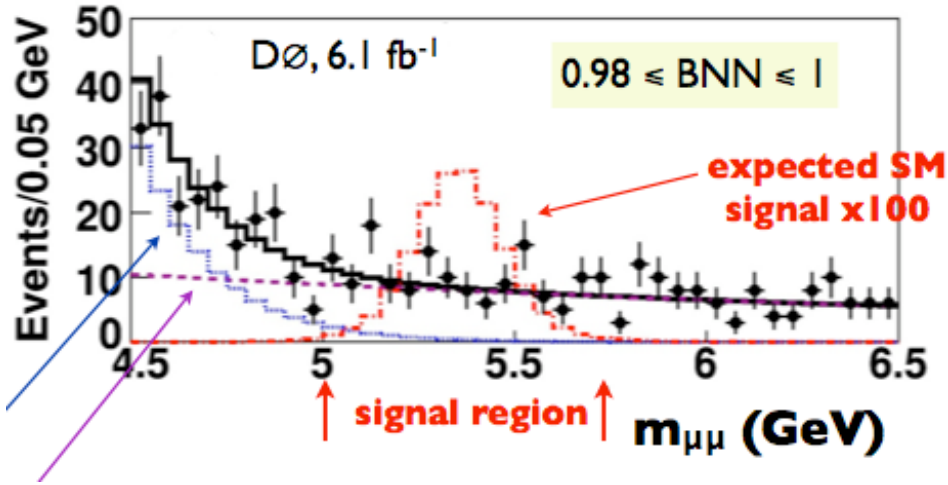


- whereas many Beyond SM theories predict enhancements.



→ sensitivity to new physics

D0
$B_s \rightarrow \mu\mu$

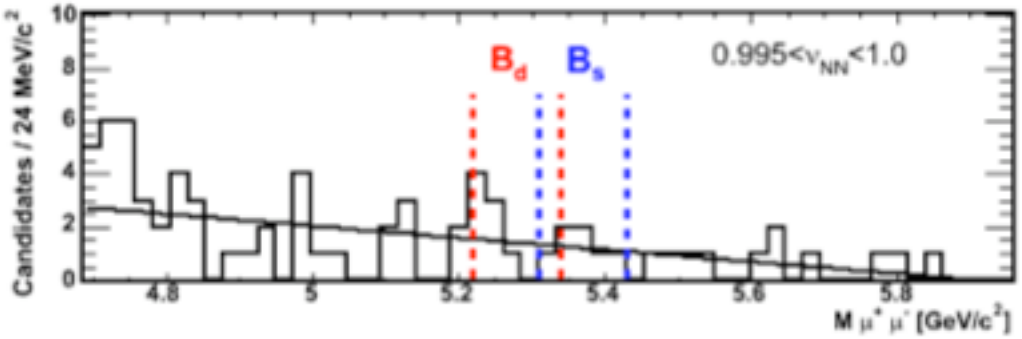


D0 Result

$\mathcal{B}(B_s \rightarrow \mu^- \mu^+) < 5.1\times10^{-8}$

(CDF: BR < 4.3×10^{-8})

CDF
$B_{s,d} \rightarrow \mu\mu$



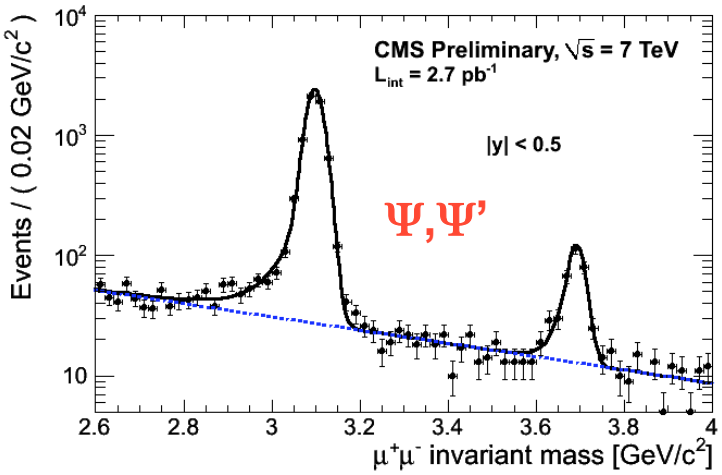
μμ Mass Spectrum
(neural net parameter >0.995)

$BR(B_s \rightarrow \mu\mu) < \begin{cases} 4.3\times10^{-8} \\ 3.6 \end{cases} @ \begin{cases} 95\%\ CL \\ 90 \end{cases}$

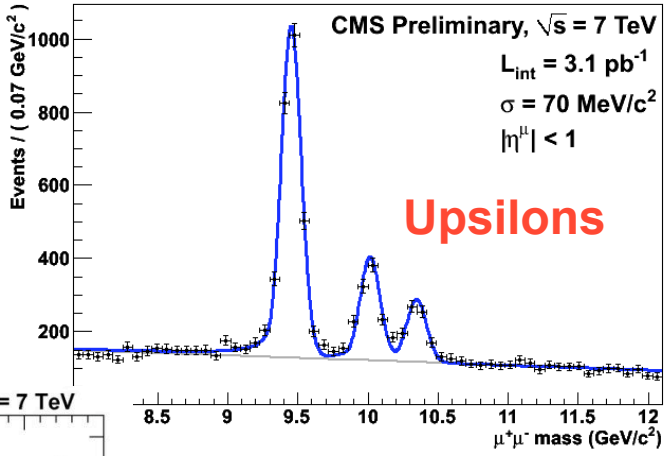
$BR(B_d \rightarrow \mu\mu) < \begin{cases} 7.6\times10^{-9} \\ 6.0 \end{cases} @ \begin{cases} 95\%\ CL \\ 90 \end{cases}$

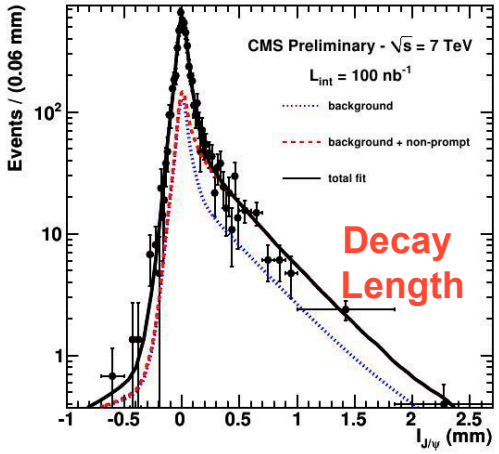
CMS

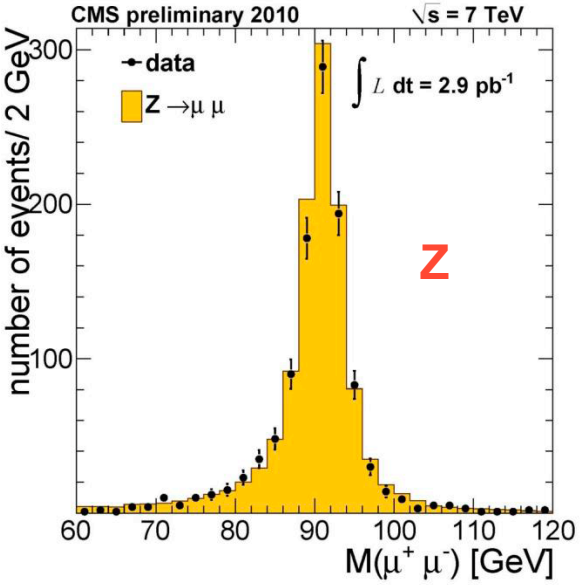
Expectations For $B_s \to \mu\mu$



CMS μμ Signals







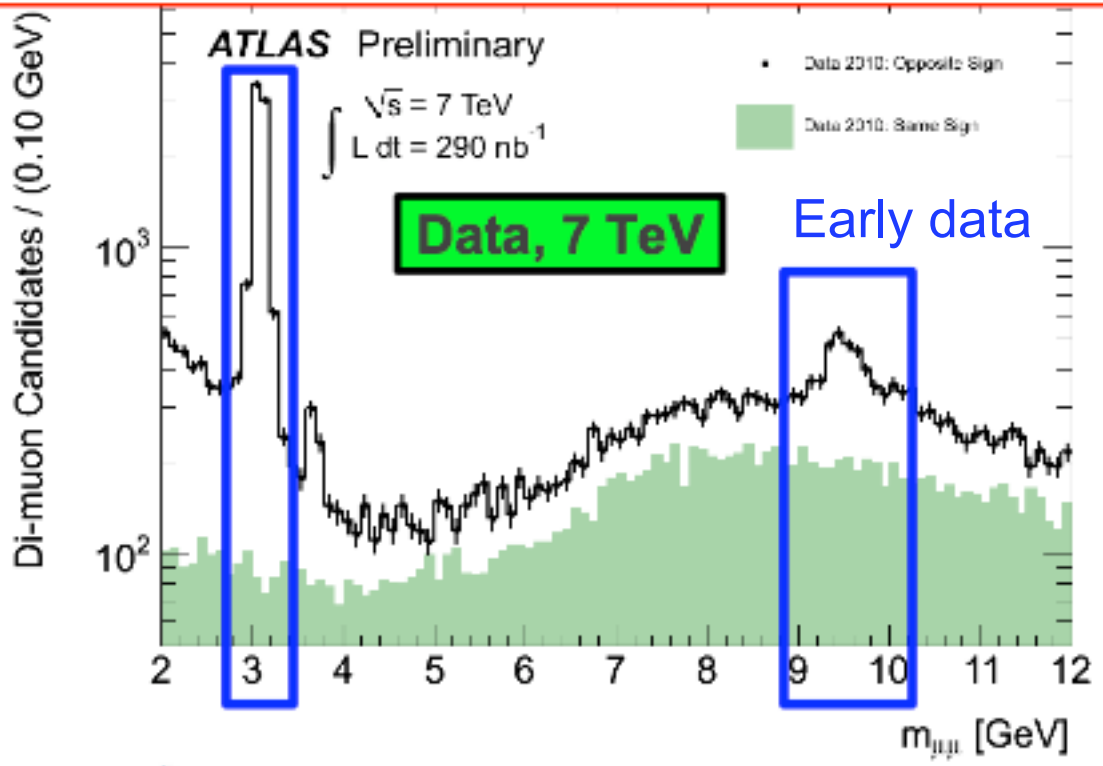
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \leq 1.6 \times 10^{-8}$$

Expected Upper Limit for 1 fb^{-1}

Atlas

Expectations for $B_s \rightarrow \mu\mu$

Selection not optimised for $B_s^0 \rightarrow \mu^+\mu^-$ searches



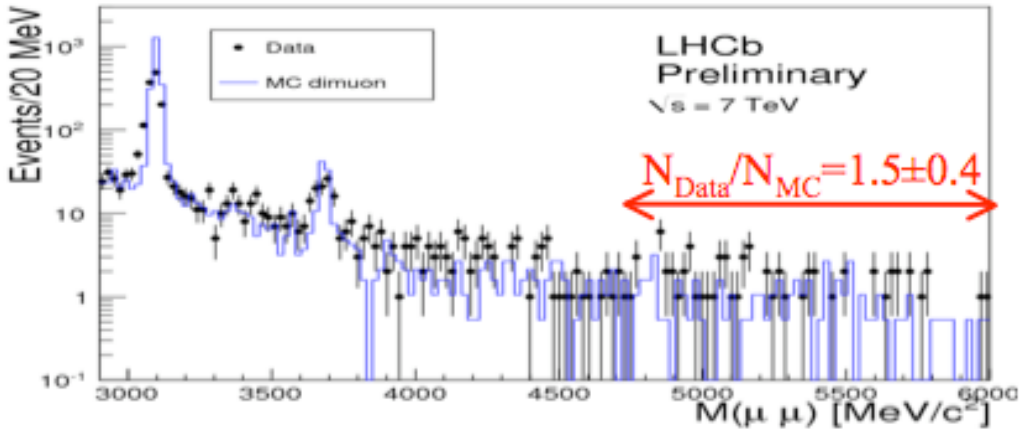
Expected events for 10 fb^{-1}:

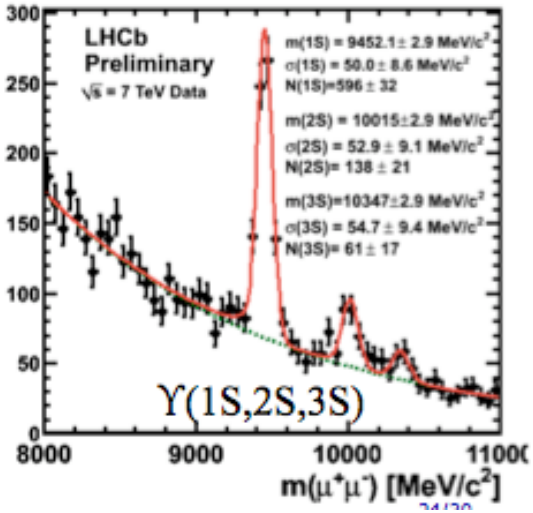
- 5.7 signal
- 14 background

LHCb

Expectations for $B_s \to \mu\mu$

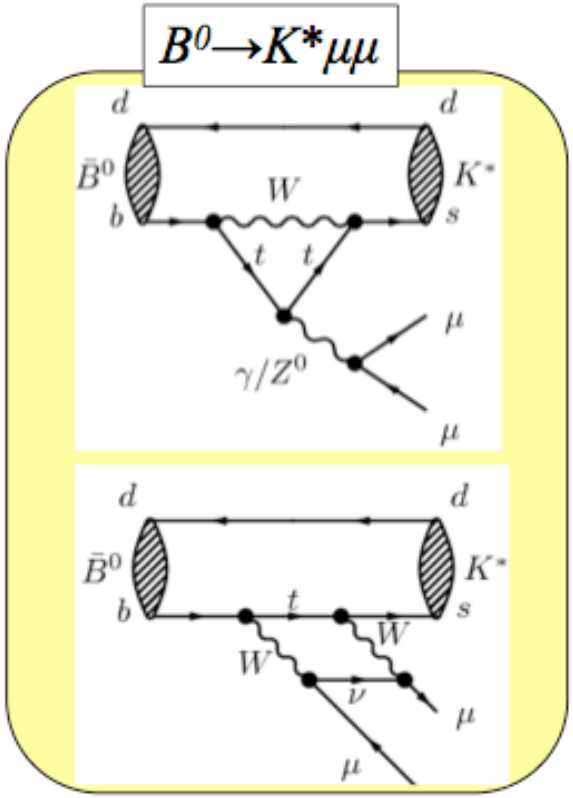
Early Data





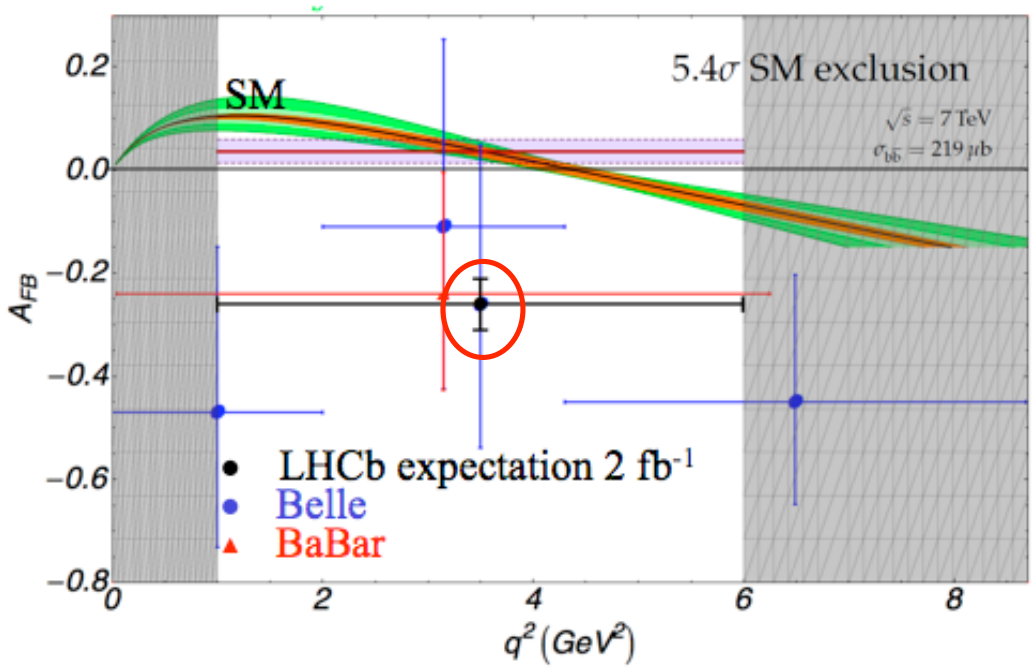
➢ *With 50 pb^{-1} possibly already approach new limit*
BR($B^0_s \to \mu\mu$)>3.4×10^{-8} @ 90%CL

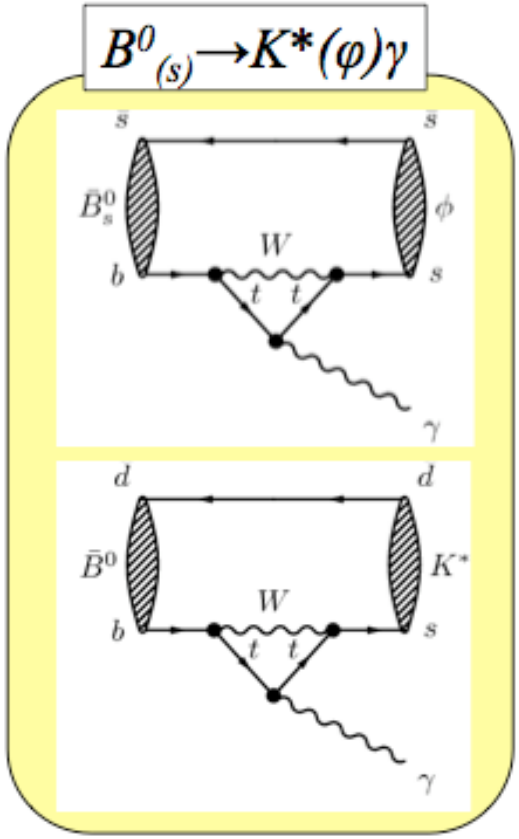
➢ *With 1 fb^{-1} possible to claim NP at 5σ if BR ~ 5 × BR$_{SM}$:*
BR($B^0_s \to \mu\mu$)>1.7× 10^{-8}



LHCb

$B_s \to K^* \mu\mu$ Prospects For F/B Asymmetry Measurement





LHCb
Expectations for $B_s \to K^*\gamma$, $B_s \to \phi\gamma$

- Branching Ratio constrains NP models
  - $BR_{theory}(B^0 \to X_s\gamma) = 3.15 \pm 0.23 \times 10^{-4}$ *Belle, PRL, 103: 241801,2009*
  - $BR_{exp}(B^0 \to X_s\gamma) = 3.56 \pm 0.26 \times 10^{-4}$ *M. Misiak, PRL, 98:022002,2007*
- ➢ Polarization of photon can still reveal large NP effects

b→s

In Conclusion

- A rich set of rare B decay data available at present.
- Present rare B decay data nibbles around the edges of New Physics, within a factor of ~10-15 of the SM expectation for $B_s \rightarrow \mu\mu$. (More to come from Babar, Belle, CDF, and Dzero. Factor of 2 for CDF.D0)
- The new data is beginning to come out from the LHC experiments
- At integrated L=10 pb^{-1} beautiful plots of SM signals, Ψ,Ψ', Upsilonium, etc.
- Atlas, CMS and LHCb will get within a factor of 3-4 of SM expectations for $B_s \rightarrow \mu\mu$ in the first run (1 fb^{-1}) but probably will not challenge them until the second run depending on the LHC luminosity and energy.
- Much better feeling than from HQ08. There is something more than SM. What will we have by HQL12? Measurements rather than upper limits?

Babar	$B \to K \nu\nu$
	$B \to K^+ \tau\tau$
	$B \to \gamma\gamma$
CDF	$B_s \to J/\Psi K_s$
	$B_s \to J/\Psi K^*(890)$
	$B_s \to \phi\phi$
	$B_{s,d} \to \mu\mu$
DO	$B_s \to \mu\mu$
Atlas	$B_s \to \mu\mu$
CMS	$B_s \to \mu\mu$
LHCb	$B_s \to \mu\mu$,
	$B^0 \to K^* \mu\mu$
	$B^0 \to K^* \gamma$