Rare decay searches at CDF II

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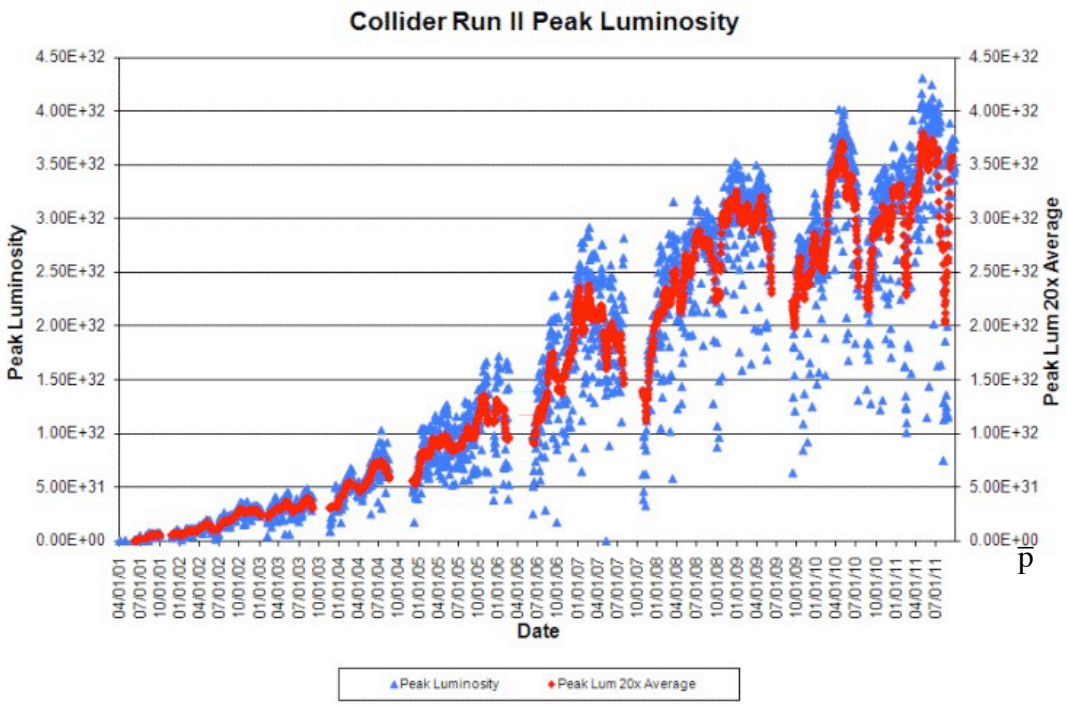
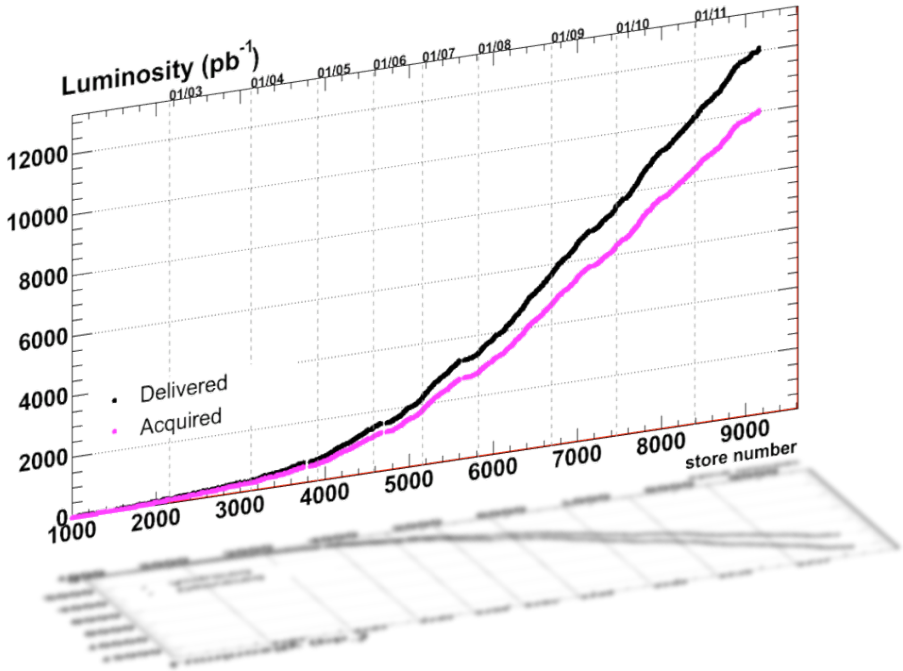
Tevatron

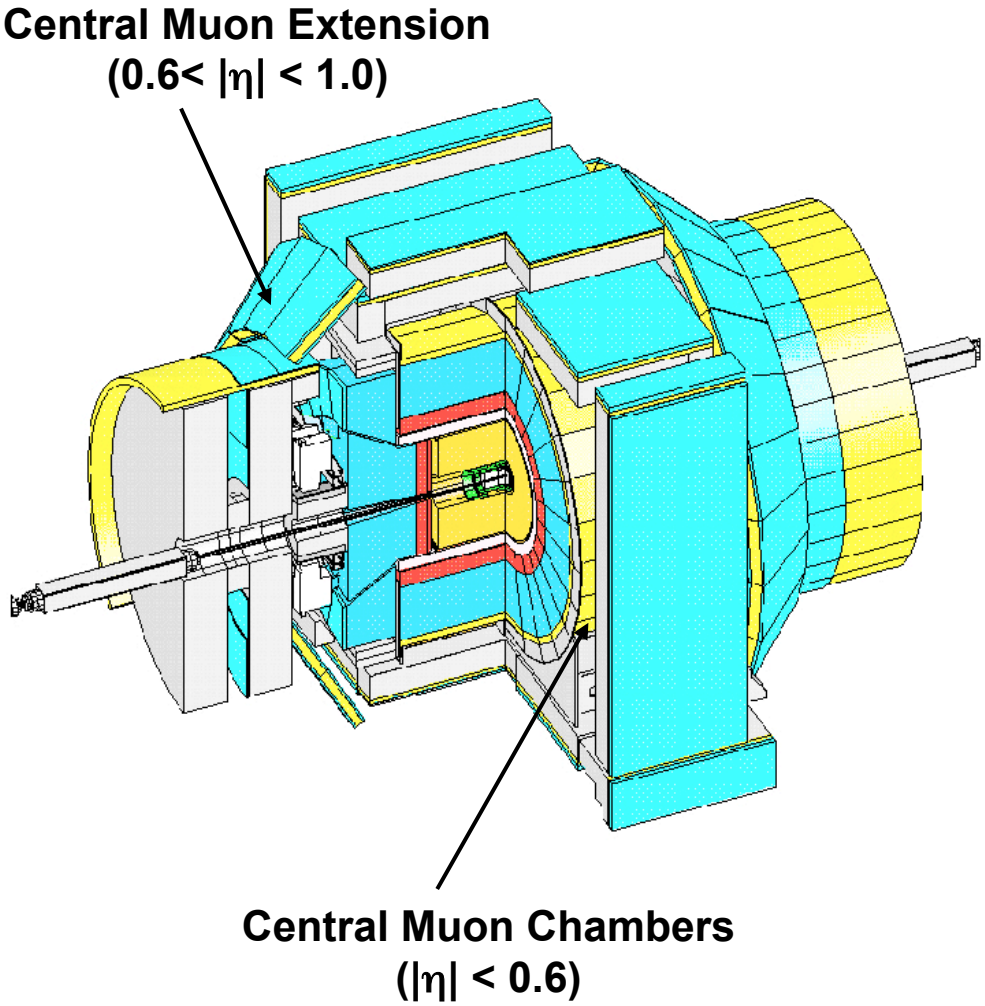


- Tevatron ended running on October 2011, after 30 years of operation.
- Peak luminosity increased almost until the very end, with typical values of **3.5×10^{32} cm^{-2} s^{-1}**



- **p anti-p collisions at $\sqrt{s}$=1.96 TeV**
- **>50 pb^{-1} collected per week**
- **Delivered 12 fb^{-1} and recorded ~10 fb^{-1}**

CDF II



- Multipurpose detector
  - ✓ Silicon vertex detector (SVT)
  - ✓ Central tracking
  - ✓ Calorimeters
  - ✓ Muon systems
- Silicon vertex trigger (two track trigger)
- Dimuon trigger
- Particle ID (TOF and dE/dx)
- Excellent p_T and mass resolution

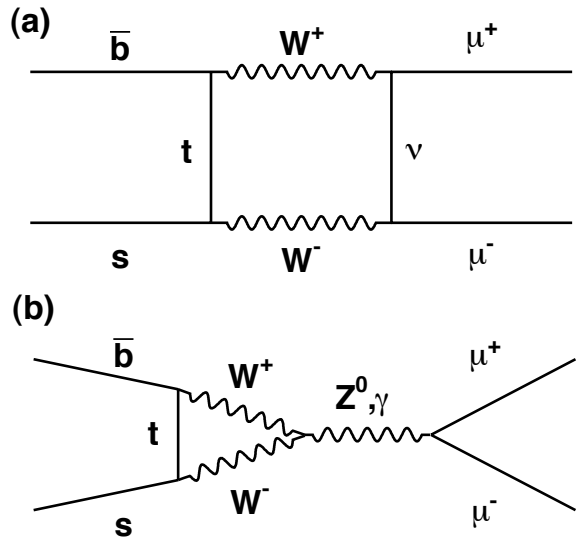
  $\sigma_{pT}/p_T = 0.07\%\ p_T \rightarrow \sigma_{M(B\rightarrow\mu\mu)} = 24\ \mathrm{MeV}/c^2$
- Decay length resolution σ_L=30 μm
- Muon chamber coverage $|\eta| < 1.1$

Search for $B_{s(d)} \rightarrow \mu^- \mu^+$

7 fb^{-1}	PRL 107, 191801 (2011)
9.7 fb^{-1}	new update

Motivation

- $B_{s(d)} \rightarrow \mu^-\mu^+$ decays are highly suppressed in SM. They can only occur through higher order FCNC diagrams.



- SM predicts very low rates

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

E.Gamiz et al., Phys. Rev. D 80, 014503 (2009)

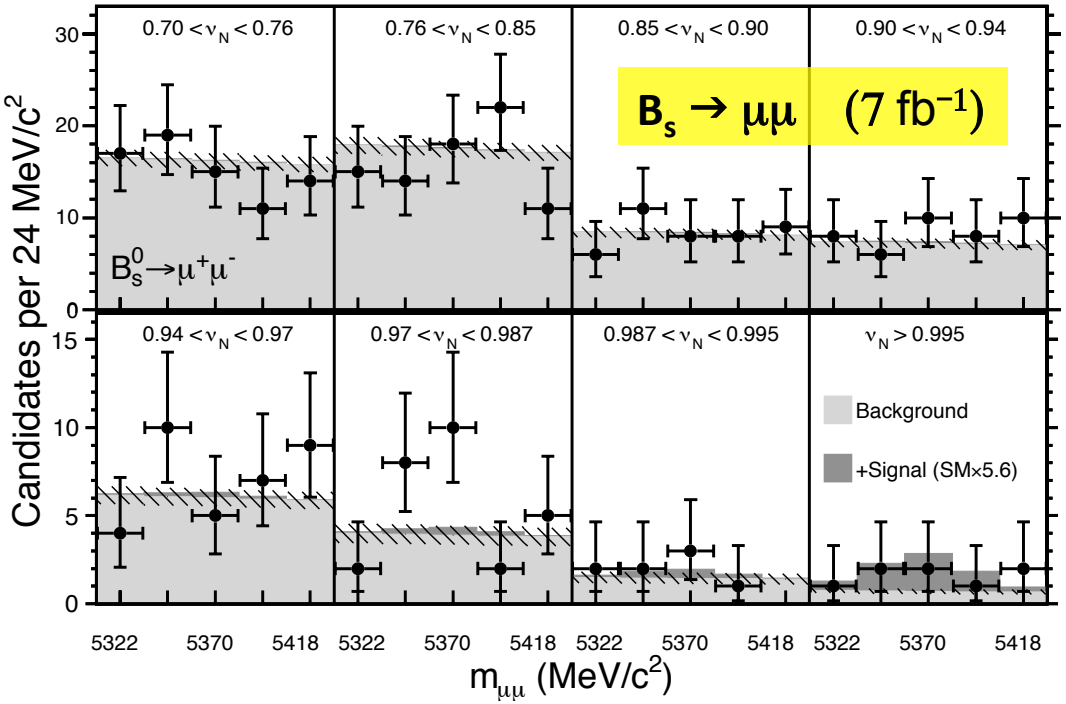
A.Buras et al., J. High Energy Phys. 10, 009 (2010)

- BR enhancement by several order of magnitude is possible in many NP theories. Importance to measure these BR's to discriminate among BSM models.

- Clean experimental signature. **Powerful probe to NP.**

- Challenge: reject >10^3 larger background, keeping signal efficiency high.

$B_s \to \mu\mu$: recap of 2011



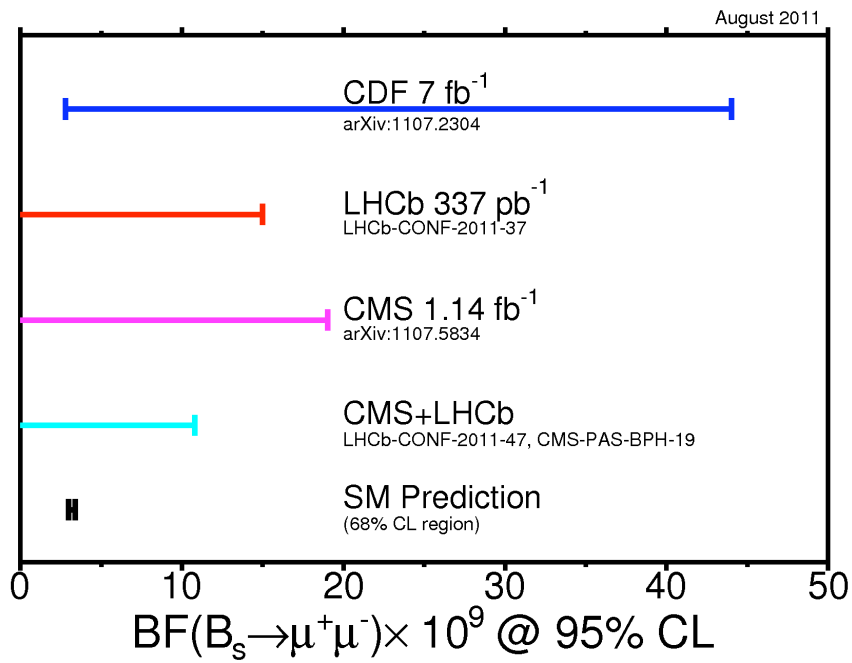
Interesting >2.5 σ excess of $B_s \to \mu\mu$ over BG observed by CDF in 7 fb^{-1}.

- CDF set a two-sided bound on the rate,

$$BR(B_s^0 \to \mu^-\mu^+) = \left(1.8^{+1.1}_{-0.9}\right) \times 10^{-8}$$

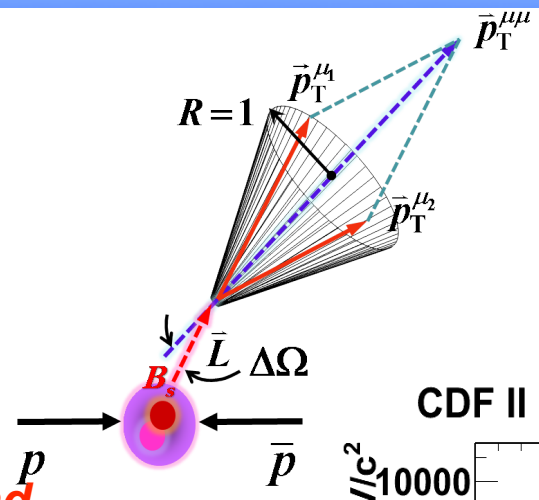
compatible with all other results, but could be first indication of a signal.

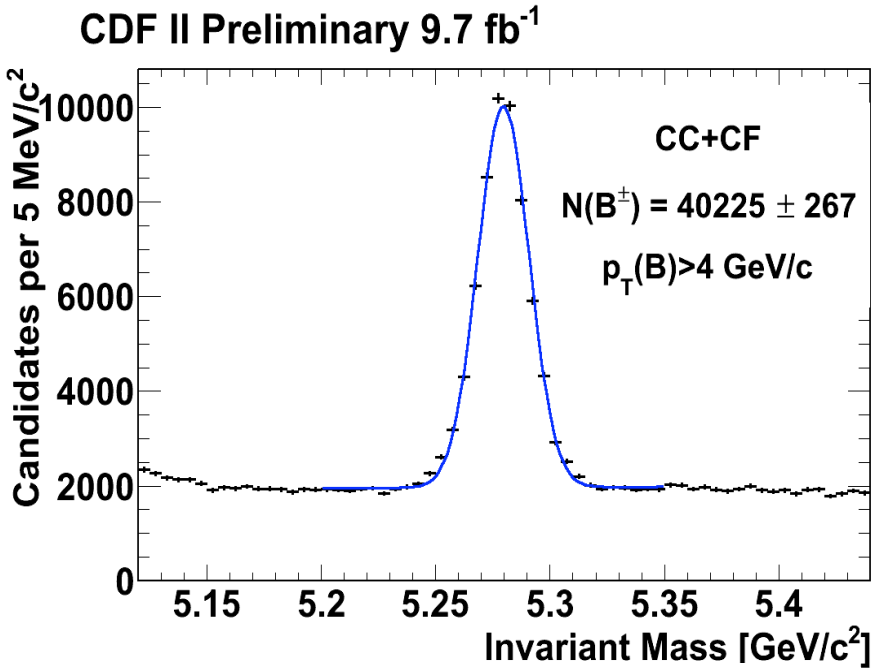
- CDF updates the analysis with whole Run II dataset (**+30% data**) while keeping the analysis unchanged.



Analysis Flow

- **Full CDF Run-II dataset 9.7 fb^{-1}**
- **Di-muon trigger $p_T > 2$ GeV/c**
- **Final state fully reconstructed**
- ***Neural Network (NN) classifier separates signal from background***
- Normalization mode $B^+ \to J/\psi(\mu^+\mu^-)\ K^+$
  - Apply same pre-selection as the signal
  - Used for background checks
  - Systematic uncertainties cancel in ratio, e.g. di-muon trigger efficiency

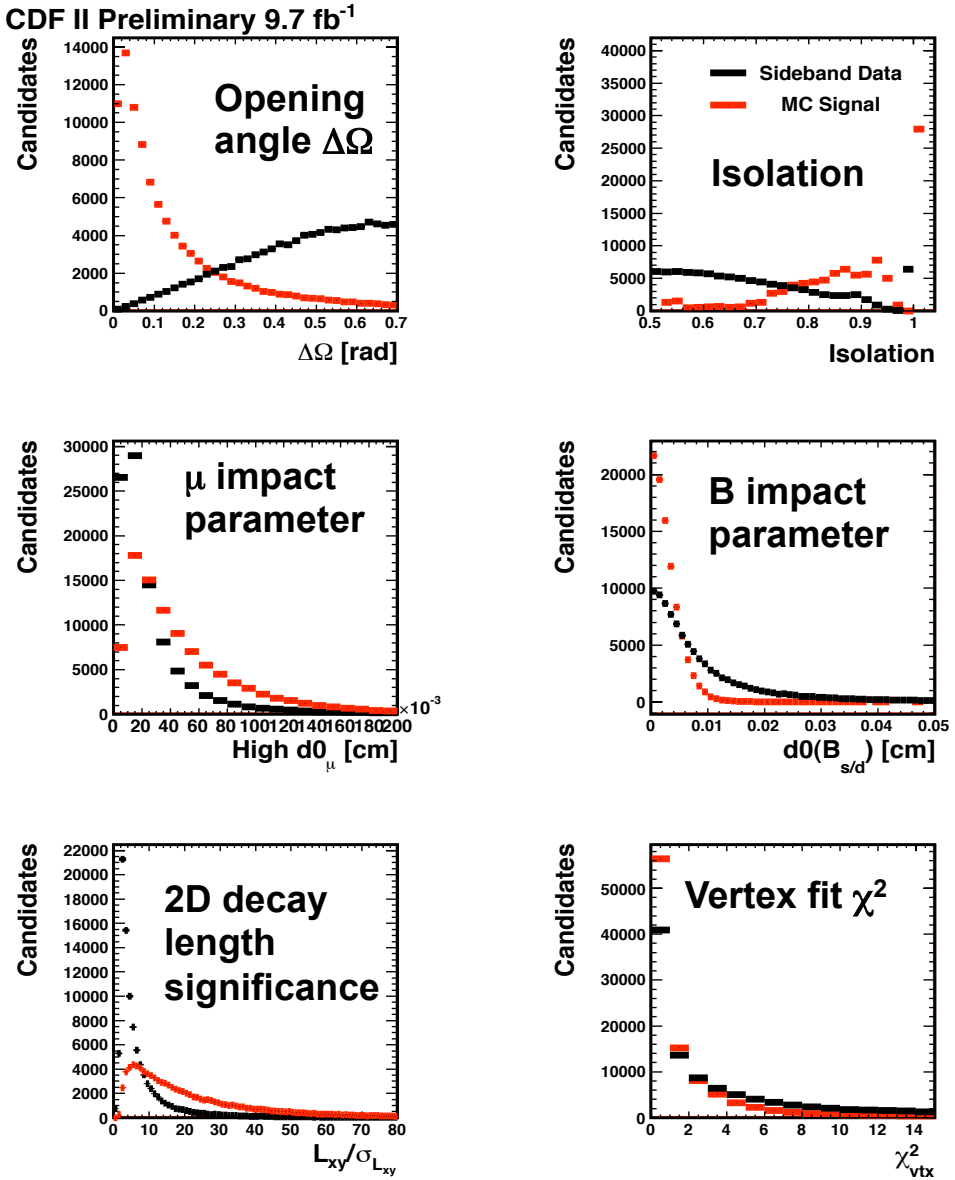




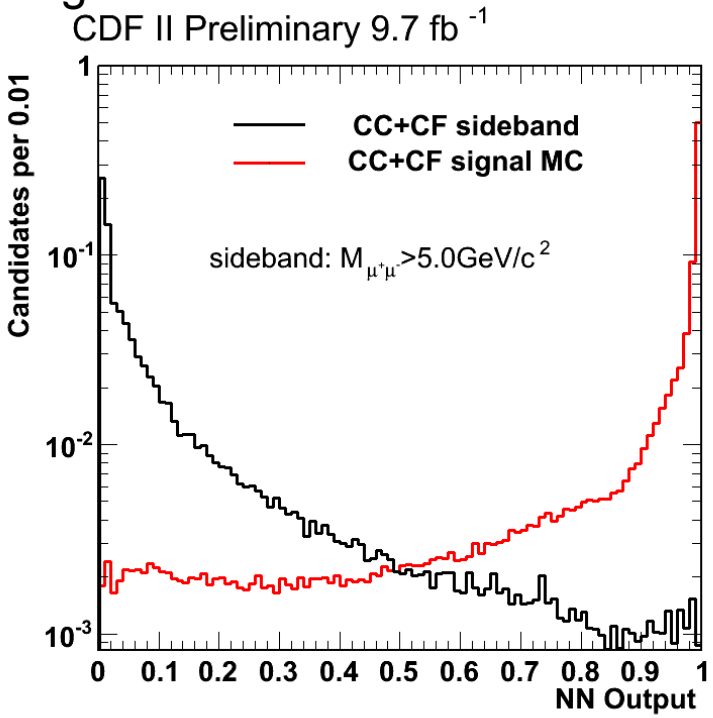
$$\mathcal{B}(B_s \to \mu^+\mu^-) = N_{B_s} \cdot \frac{1}{N_{B^+}} \frac{\epsilon^{trig}_{B^+}}{\epsilon^{trig}_{B_s}} \cdot \frac{\epsilon^{reco}_{B^+}}{\epsilon^{reco}_{B_s}} \frac{\alpha_{B^+}}{\alpha_{B_s}} \frac{1}{\epsilon^{NN}_{B_s}} \cdot \frac{f_u}{f_s} \cdot \mathcal{B}(B^+ \to J/\Psi K^+ \to \mu^+\mu^- K^+)$$

From Data, From MC, From PDG

Signal discrimination



- **14 discriminating variables** in NN
- NN optimized with signal MC and BG events sampled from mass-sidebands
- NN trained with 7 fb^{-1} applied to 9.7 fb^{-1} data
- Search region in $M(\mu\mu)$ with 2.5σ window, σ=24 MeV
- Validated NN with normalization mode and control region



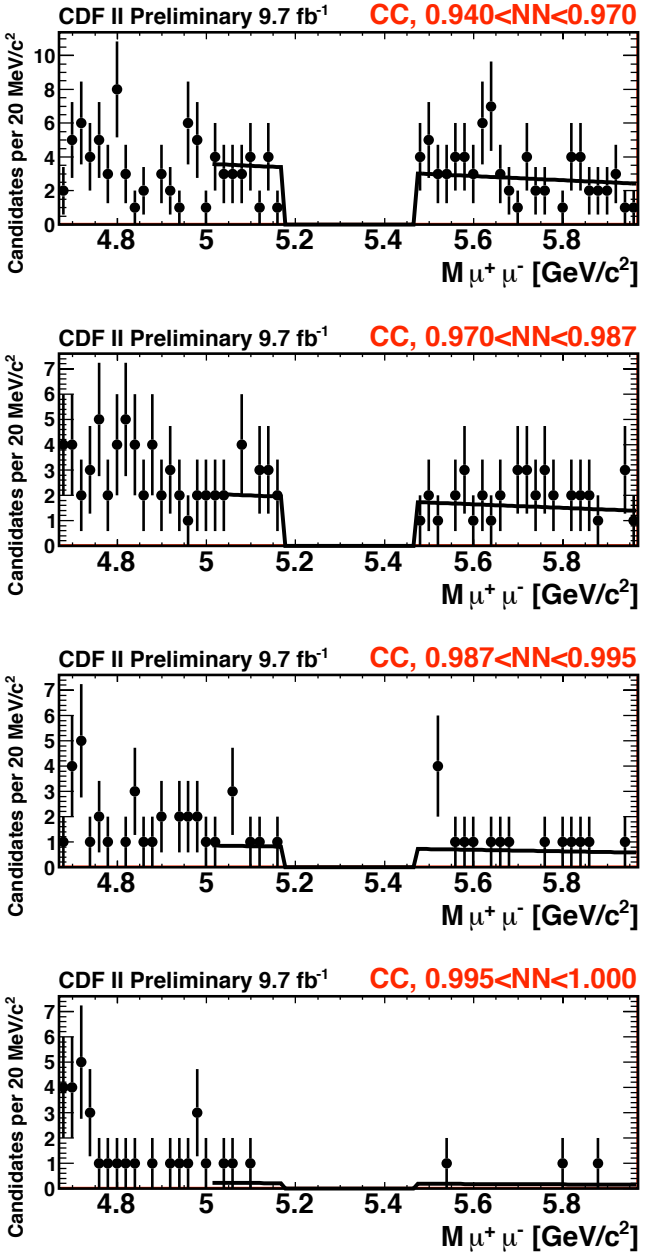
Background estimate

- **Background contributions:**
  - **Double semi-leptonic decay:** $b\bar{b} \to \mu^+\mu^-\bar{\nu}\nu XX'$
  - **Sequential semileptonic decay:** $B \to \mu^+\nu\bar{D}\left(\to \mu^-\bar{\nu}X\right)$
  - **Continuum $\mu^+\mu^-$, μ + fake, fake+fake**
  - **Peaking background in signal region B→hh**

- **Combinatorial background**
  - In each NN bin, continuum BG is estimated fitting the sidebands to linear function with common slope.
  - Estimate systematics due to shape uncertainty

- **Background from B→hh**
  - Estimated using MC and D*-tagged $D^0 \to \pi^+ K^-$ data
  - **~10% of combinatorial background in B_s**
  - **~50% of total BG in B_d**

- Check BG estimates with BG dominated control samples: no significant discrepancies.



Background estimate (cont.)

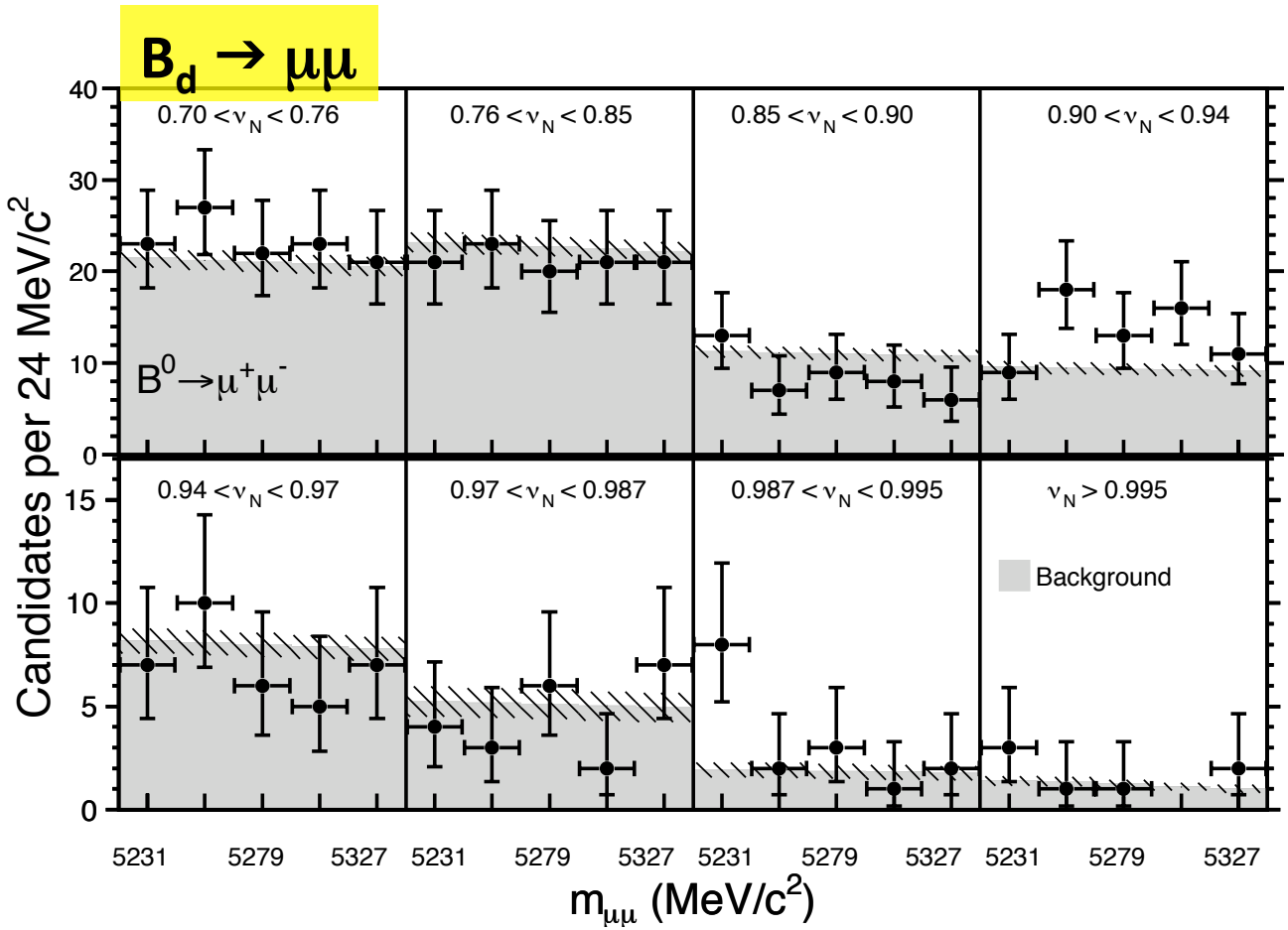
B→hh BG estimates for B_s signal window

NN Bin \ Mass Bin (GeV/c^2)	5.310−5.334	5.334−5.358	5.358−5.382	5.382−5.406	5.406−5.430
CC					
0.700<NN<0.760	0.003± < 0.001	0.001± < 0.001	-	-	-
0.760<NN<0.850	0.006±0.001	0.002± < 0.001	0.001± < 0.001	-	-
0.850<NN<0.900	0.005±0.001	0.002± < 0.001	0.001± < 0.001	-	-
0.900<NN<0.940	0.007±0.001	0.003± < 0.001	0.001± < 0.001	-	-
0.940<NN<0.970	0.011±0.001	0.003± < 0.001	0.001± < 0.001	-	-
0.970<NN<0.987	0.013±0.002	0.005±0.001	0.002± < 0.001	0.001± < 0.001	-
0.987<NN<0.995	0.019±0.002	0.007±0.001	0.002± < 0.001	0.001± < 0.001	-
0.995<NN<1.000	0.074±0.010	0.026±0.003	0.009±0.001	0.003± < 0.001	0.001± < 0.001
CF					
0.700<NN<0.760	0.001± < 0.001	-	-	-	-
0.760<NN<0.850	0.002± < 0.001	0.001± < 0.001	-	-	-
0.850<NN<0.900	0.002± < 0.001	0.001± < 0.001	-	-	-
0.900<NN<0.940	0.002± < 0.001	0.001± < 0.001	-	-	-
0.940<NN<0.970	0.003± < 0.001	0.001± < 0.001	-	-	-
0.970<NN<0.987	0.004±0.001	0.002± < 0.001	0.001± < 0.001	-	-
0.987<NN<0.995	0.004±0.001	0.002± < 0.001	0.001± < 0.001	-	-
0.995<NN<1.000	0.021±0.003	0.009±0.001	0.003± < 0.001	0.002± < 0.001	-

Predicted vs. observed no. events for all control samples.

Control Sample	Prediction	Nobs	Prob(N>=Nobs)
OS-	2665.2±61.4	2552	90%
SS+	26.4±4.0	36	9%
SS-	61.8±6.1	69	25%
FM+	727.9±28.9	760	21%
Sum	3481.3±68.3	3417	76%

Di-muon mass for B_d signal regions



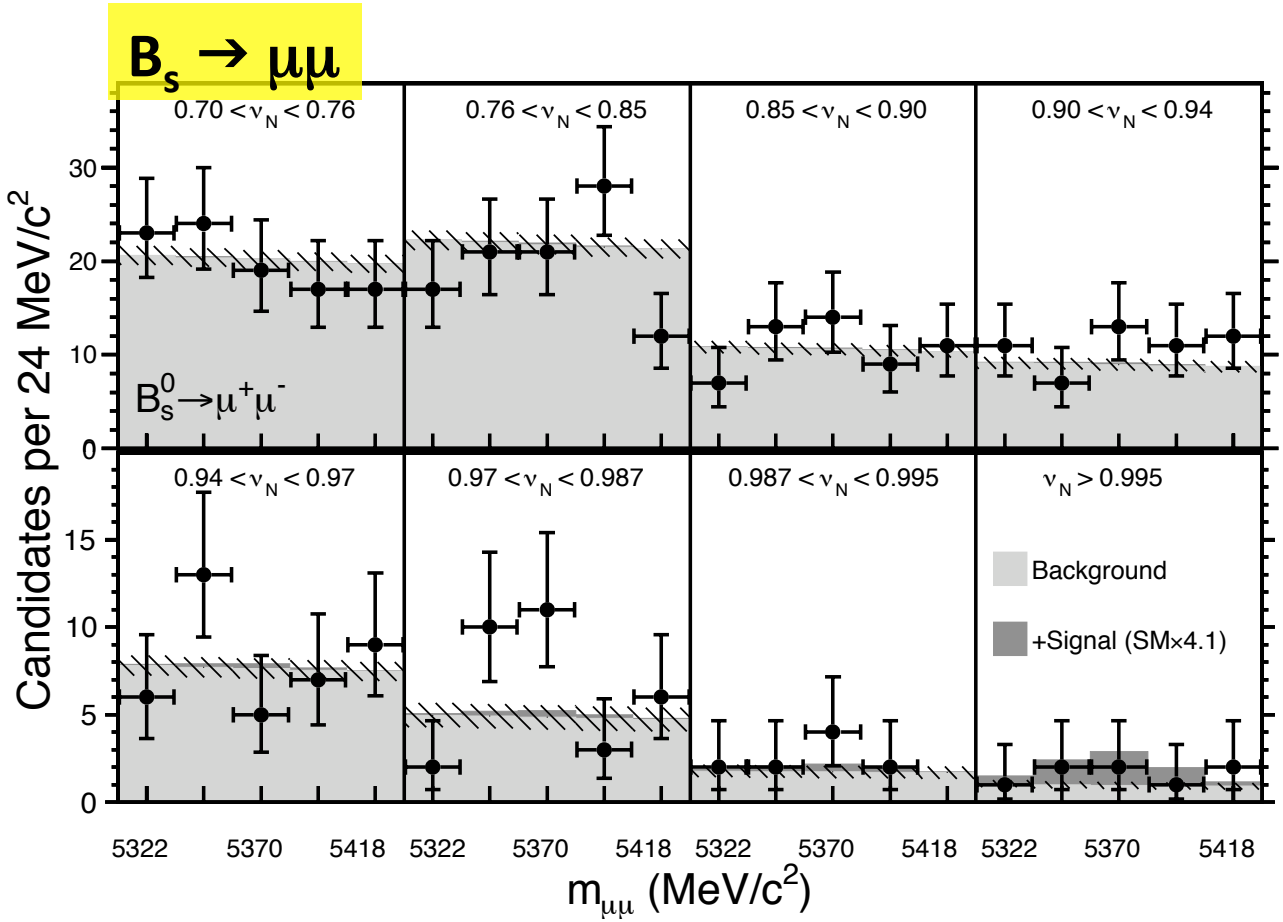
Consistent with SM BG prediction (p-value 41%).

No excess is observed.

$$\mathrm{BR}(B_d^0 \rightarrow \mu^-\mu^+) < 3.8 \times 10^{-9} \quad @\ 90\%\ \mathrm{C.L.}$$

$$\mathrm{BR}(B_d^0 \rightarrow \mu^-\mu^+) < 4.6 \times 10^{-9} \quad @\ 95\%\ \mathrm{C.L.}$$

Di-muon mass for B_s signal regions



Slight excess in high NN bins (>0.97).

p-values assuming:

- **BG only: 0.94%**
- **$B_s \rightarrow \mu^+\mu^-$ SM + BG: 7.1%**

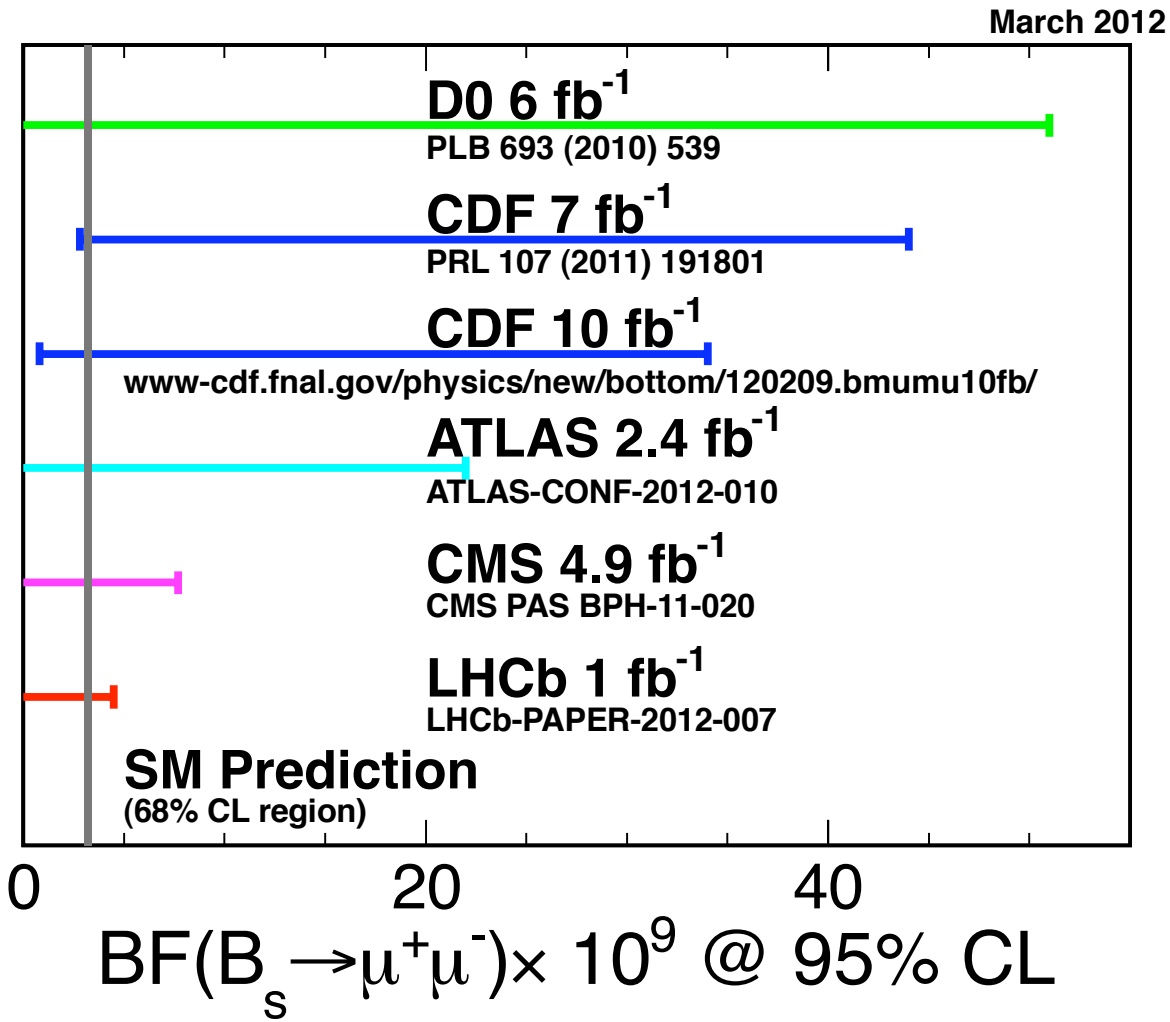
Summer 2011 hint of signal not reinforced by new data, but remains >2σ significant over BG only.

$$\mathrm{BR}(B_s^0 \rightarrow \mu^-\mu^+) = \left(1.3^{+0.9}_{-0.7}\right) \times 10^{-8}$$

$$2.2 \times 10^{-9} < \mathrm{BR}(B_s^0 \rightarrow \mu^-\mu^+) < 3.0 \times 10^{-8} \ @\ 90\%\ \mathrm{C.L.}$$

$$0.8 \times 10^{-9} < \mathrm{BR}(B_s^0 \rightarrow \mu^-\mu^+) < 3.4 \times 10^{-8} \ @\ 95\%\ \mathrm{C.L.}$$

$B_s \to \mu\mu$ current experimental status



$b \to s\mu^+\mu^-$ decays

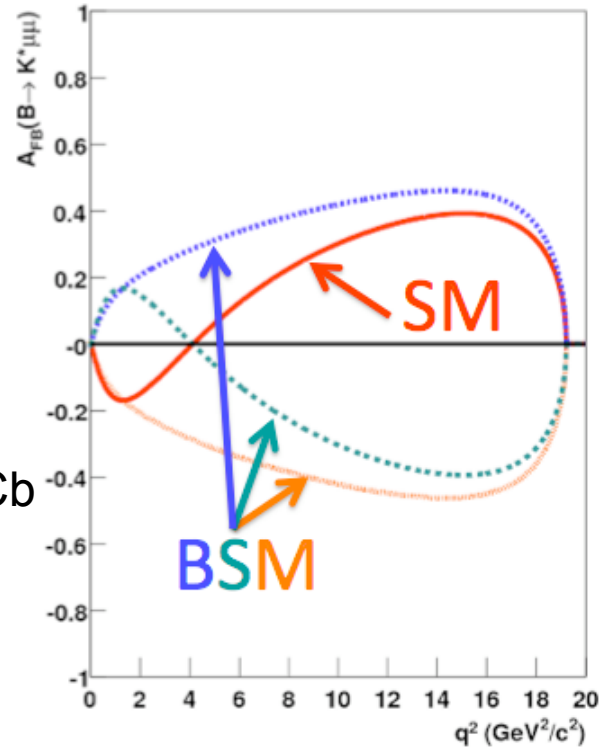
6.8 fb^{-1} BR PRL 107, 201802 (2011)

A_{FB} PRL 108, 081807 (2012)

Motivation

- $b \to s\,\mu^-\mu^+$ are rare FCNC decays, forbidden at tree level in SM. SM predicts very low rates BR~10^{-6}.
- Measure branching fractions is a good test for SM.
- **Forward-backward asymmetry** sensitive to BSM physics. A_{FB} in $B \to \mu\mu K^*$ decay: predictions exist for several new physics scenarios.
- <u>Experimental status</u>

  $B^+ \to K^+ \mu^+\mu^-$ BaBar, Belle, CDF
  $B^0 \to K^{*0} \mu^+\mu^-$ BaBar, Belle (2.7σ deviation for A_{FB}), CDF, LHCb
  $B_s^0 \to \phi\, \mu^+\mu^-$ CDF, DØ, LHCb
  $B^0 \to K_S\, \mu^+\mu^-$ Belle, CDF, LHCb
  $B^+ \to K^{*+} \mu^+\mu^-$ BaBar, Belle, CDF, LHCb
  $\Lambda_b^0 \to \Lambda\, \mu^+\mu^-$ CDF



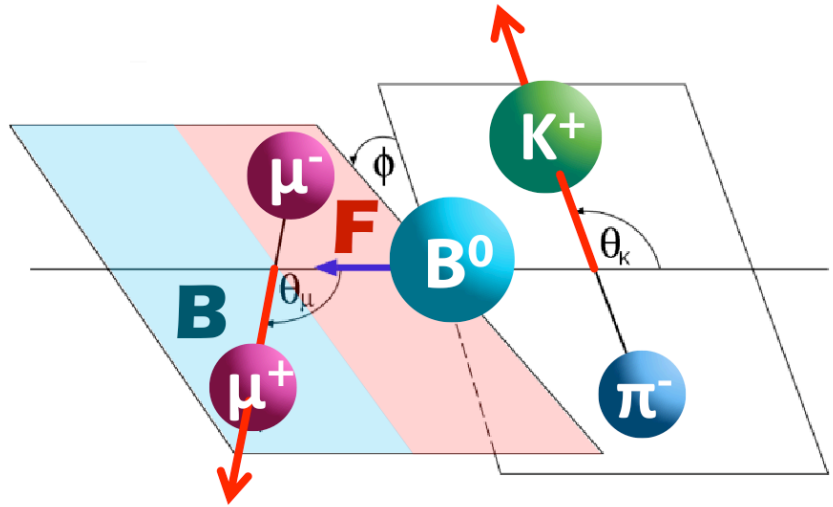
Analysis Flow

- Di-muon trigger $p_t > 1.5$ GeV/c
- Loose pre-selection based on kinematical cuts + *NN* (optimized for best sensitivity)
- Remove resonant region (J/ψ, ψ(2S))
- Remove BG (B→charm) by kinematics and muon likelihood cuts
- Measure the **Branching Fractions** of $H_b \to \mu^+\mu^- h$

Signal Mode	Hadron Decay
$B^+ \to \mu^+\mu^- K^+$	-
$B^0 \to \mu^+\mu^- K^{*0}$	$K^{*0} \to K^+\pi^-$
$B_s \to \mu^+\mu^- \phi$	$\phi \to K^+K^-$
$B^+ \to \mu^+\mu^- K^{*+}$	$K^{*+} \to K_s\pi^+$
$B^0 \to \mu^+\mu^- K_s$	$K_s \to \pi^+\pi^-$
$\Lambda_b \to \mu^+\mu^- \Lambda$	$\Lambda \to p\pi^-$

by normalizing to resonant modes
$H_b \to J/\psi(\mu^+\mu^-)\, h$

- **Measurements of the distributions of θ_K θ_μ and ϕ.**

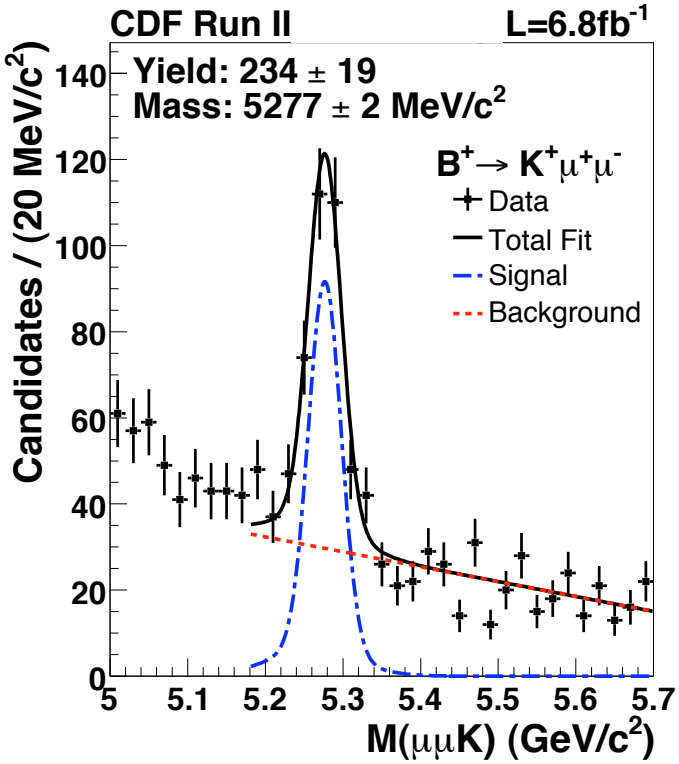


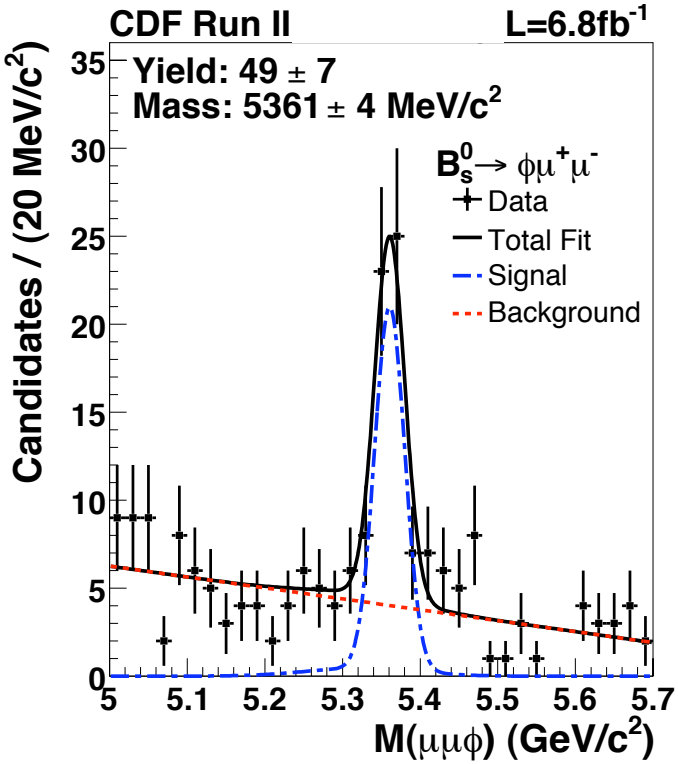
Four angular observables are extracted from angular distributions:

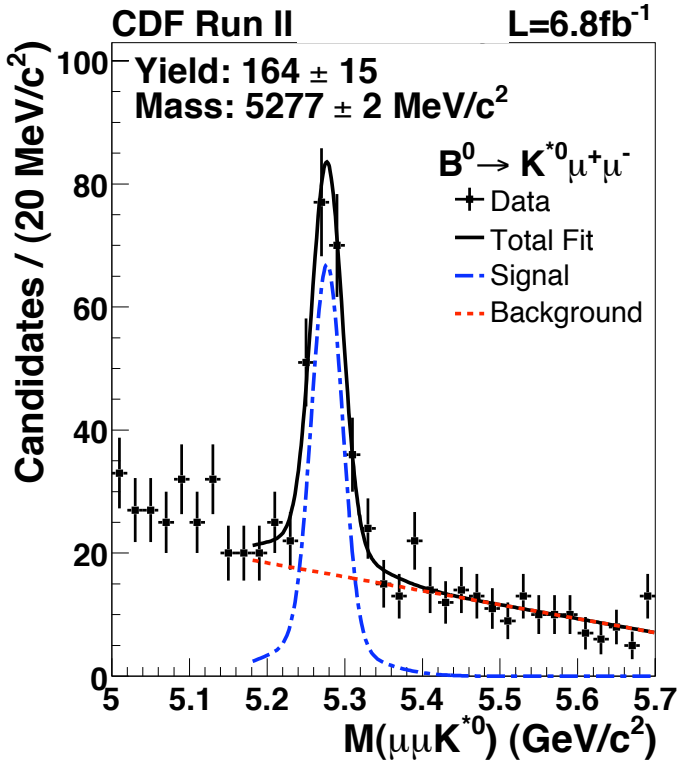
- F_L K* longitudinal polarization fraction
- A_{FB} forward-backward asymmetry
- $A_T^{(2)}$ tranverse polarization asymmetry
- A_{im} T-odd CP asymmetry

as a function of $q^2 = M_{\mu\mu}^2 c^2$ (GeV^2/c^2).

b→sμμ mass distributions







$BR(B^+ \to K^+\mu^+\mu^-) =$
$[0.46 \pm 0.04 \pm 0.02]\times10^{-6}$

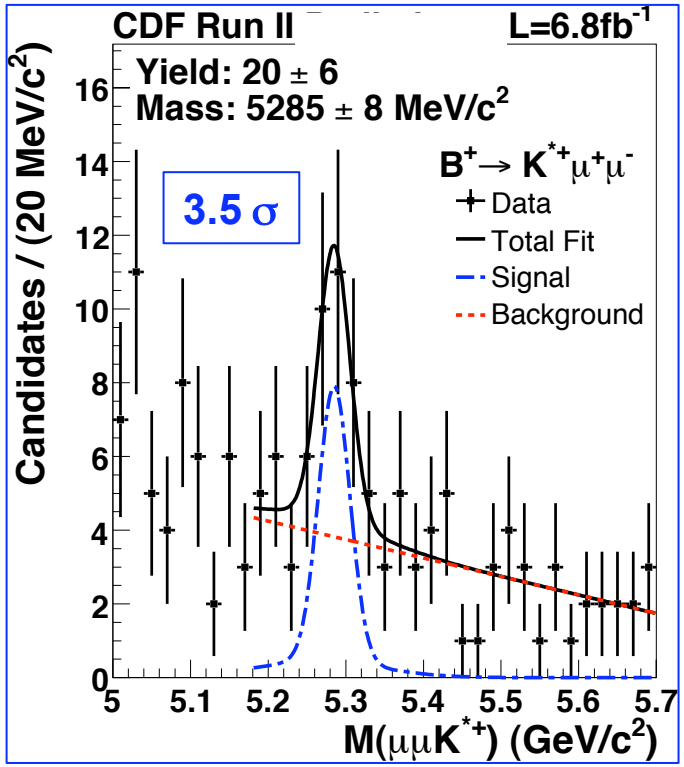
$BR(B_s^0 \to \phi\mu^+\mu^-) =$
$[1.47 \pm 0.24 \pm 0.46]\times10^{-6}$

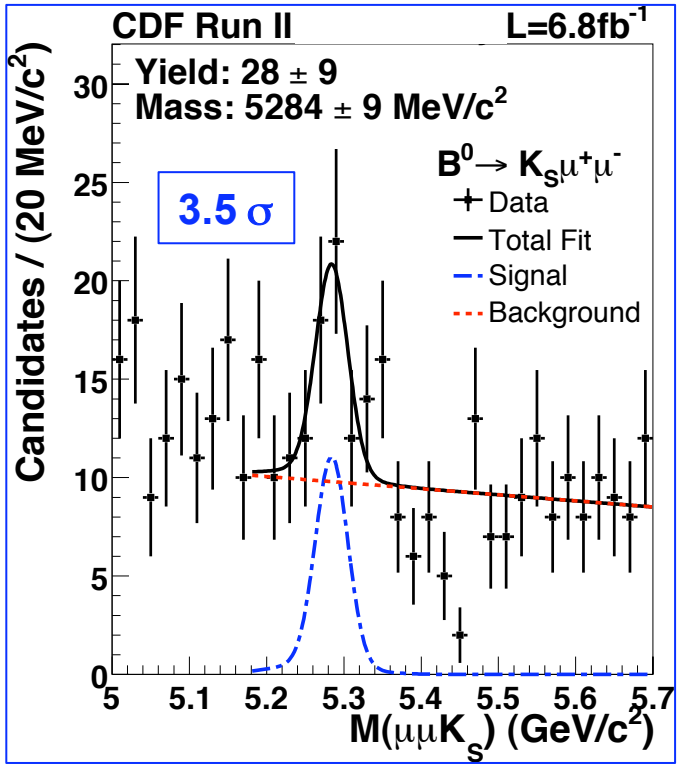
$BR(B^0 \to K^{*0}\mu^+\mu^-) =$
$[1.02 \pm 0.10 \pm 0.06]\times10^{-6}$

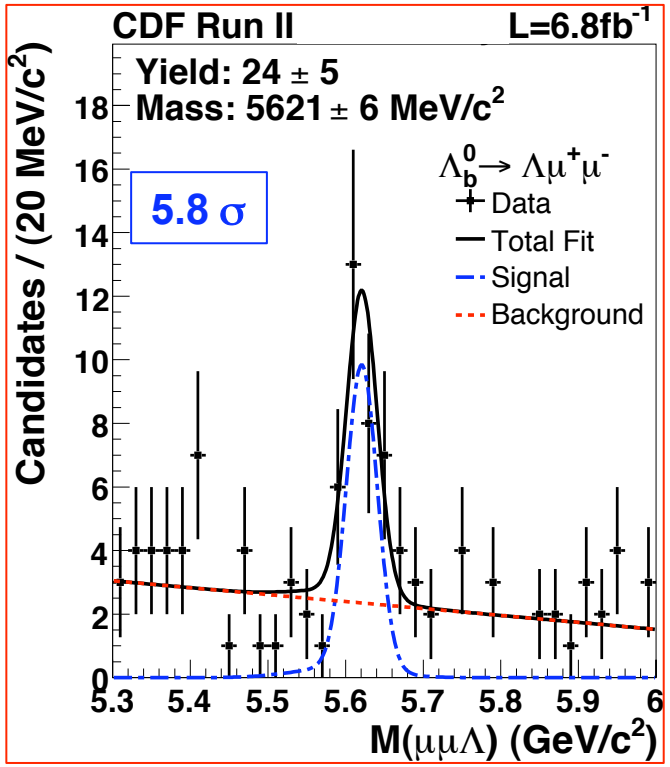
b→sμμ mass distributions (cont.)

First measurement in hadron collisions

World's first observation !!







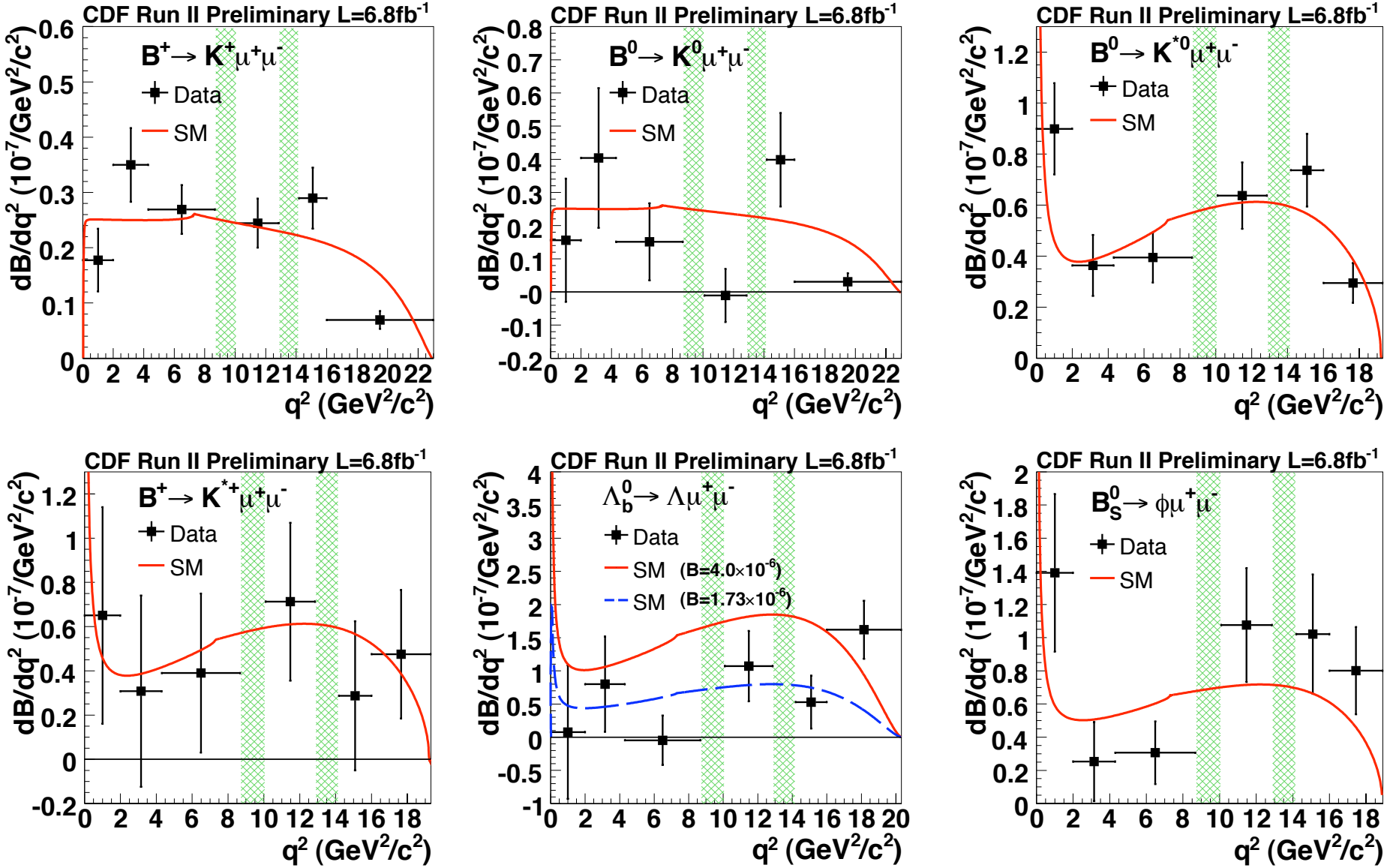
$BR(B^+ \to K^{*+}\mu^+\mu^-) =$
$[0.95 \pm 0.32 \pm 0.08]\times10^{-6}$

$BR(B^0 \to K^0\mu^+\mu^-) =$
$[0.32 \pm 0.10 \pm 0.02]\times10^{-6}$

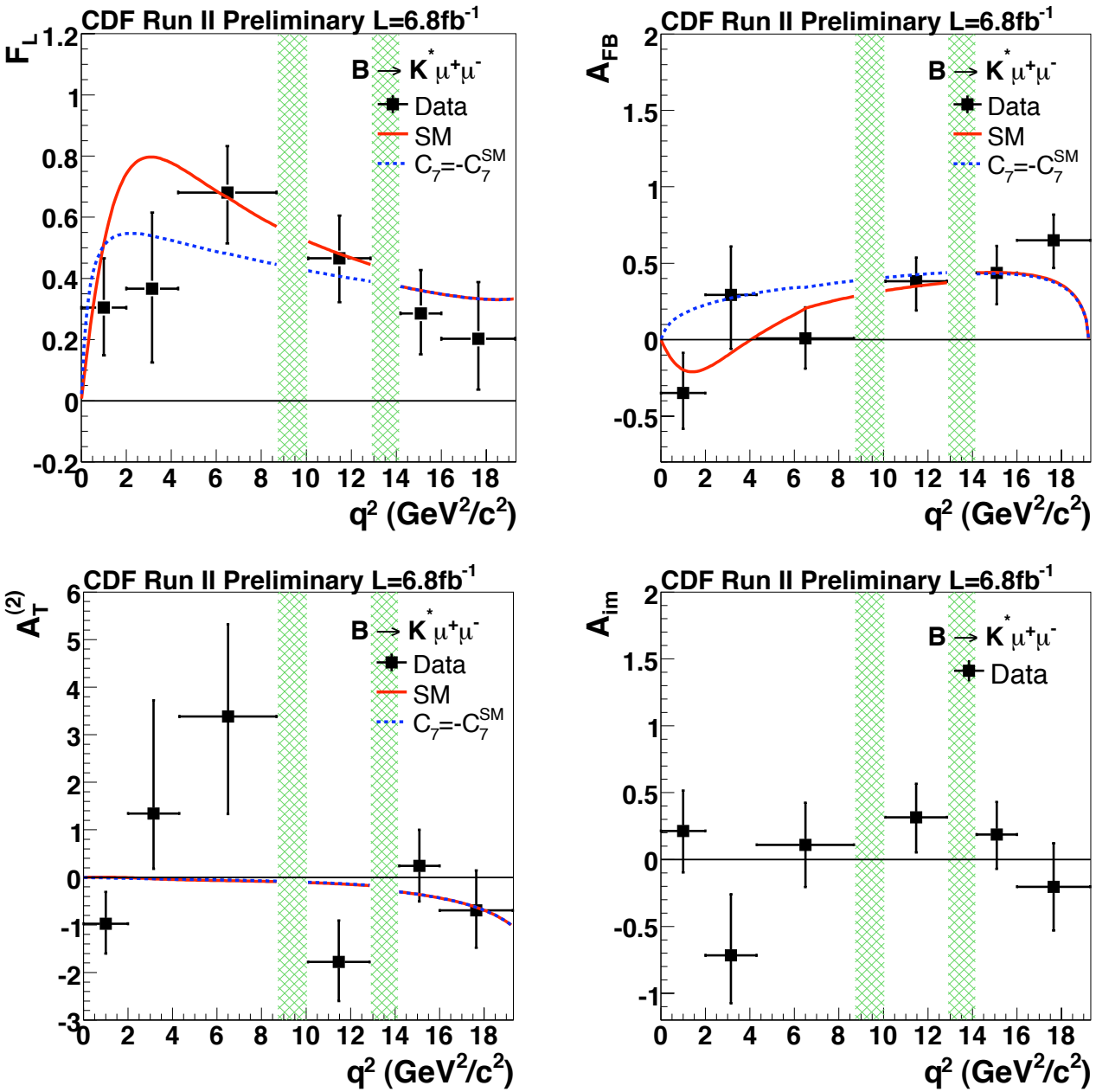
$BR(\Lambda_b^0 \to \Lambda\mu^+\mu^-) =$
$[1.73 \pm 0.42 \pm 0.55]\times10^{-6}$

CDF B(b→sμμ) measurements are among the world's most precise

Differential Branching Ratios



b→sμμ angular results



- Simultaneous fit of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$
- First measurements of $A_T^{(2)}$ and A_{im}
- CDF b → sμμ A_{FB} measurement is among the most accurate to date. Consistent with B factories.
- **No signicant deviation from SM with current statistics.**

Summary

Search for $B_{s(d)} \to \mu^-\mu^+$

- Latest and final update reaches a sensitivity very close to SM prediction after a decade of Tevatron leadership in the B_s sector.
- CDF observed an excess of $B_s \to \mu^-\mu^+$ events at >2σ level relative to BG only hypothesis. Set a two-sided bound on the rate, compatible with SM and other experiments:

$$2.2 \times 10^{-9} < \mathrm{BR}(B_s^0 \to \mu^-\mu^+) < 3.0 \times 10^{-8} \ @\ 90\%\ \mathrm{C.L.}$$

$b \to s\mu^+\mu^-$ decays

- First observation of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$.
- First measurements of $B^+ \to K^{*+}\mu^+\mu^-$ and $B^0 \to K^0_S\,\mu^+\mu^-$ at hadron collider.
- Amongst world's best results on BR and A_{FB}. Extend the reach to new observables.
- Final update soon with full CDF dataset (15-30% more data).

BACKUP SLIDES

Probing New Physics

Plenary talk
A.Buras, Beauty 2011:

Maximal Enhancements of $S_{\psi\varphi}$, $Br(B_s \to \mu^+\mu^-)$ and $K^+ \to \pi^+\nu\bar{\nu}$

(without taking correlation between them)

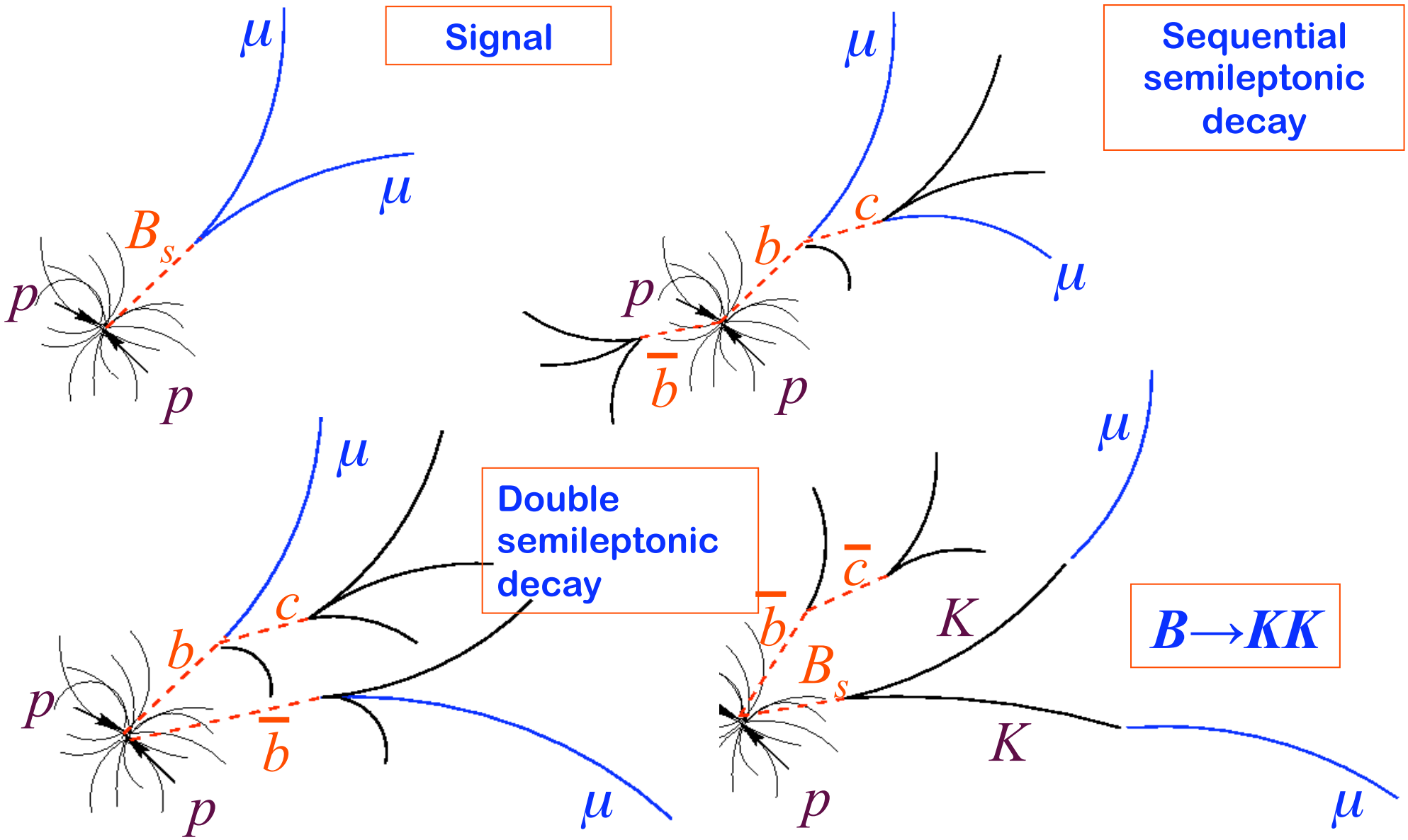
Model	Upper Bound on ($S_{\psi\varphi}$)	Enhancement of $Br(B_s \to \mu^+\mu^-)$	Enhancement of $Br(K^+ \to \pi^+\nu\bar{\nu})$
CMFV	0.04	20%	20%
MFV	0.04	1000%	30%
LHT	0.30	30%	150%
RS	0.75	10%	60%
4G	0.80	400%	300%
AC	0.75	1000%	2%
RVV	0.50	1000%	10%

Large RH Currents

RS = RS with custodial protections
AC = Agashe, Carone
RVV = Ross, Velaso-Sevilla, Vives (04)

$U(1)_F$
$SU(3)_F$

$B_s(B^0)$ Signal vs. Background



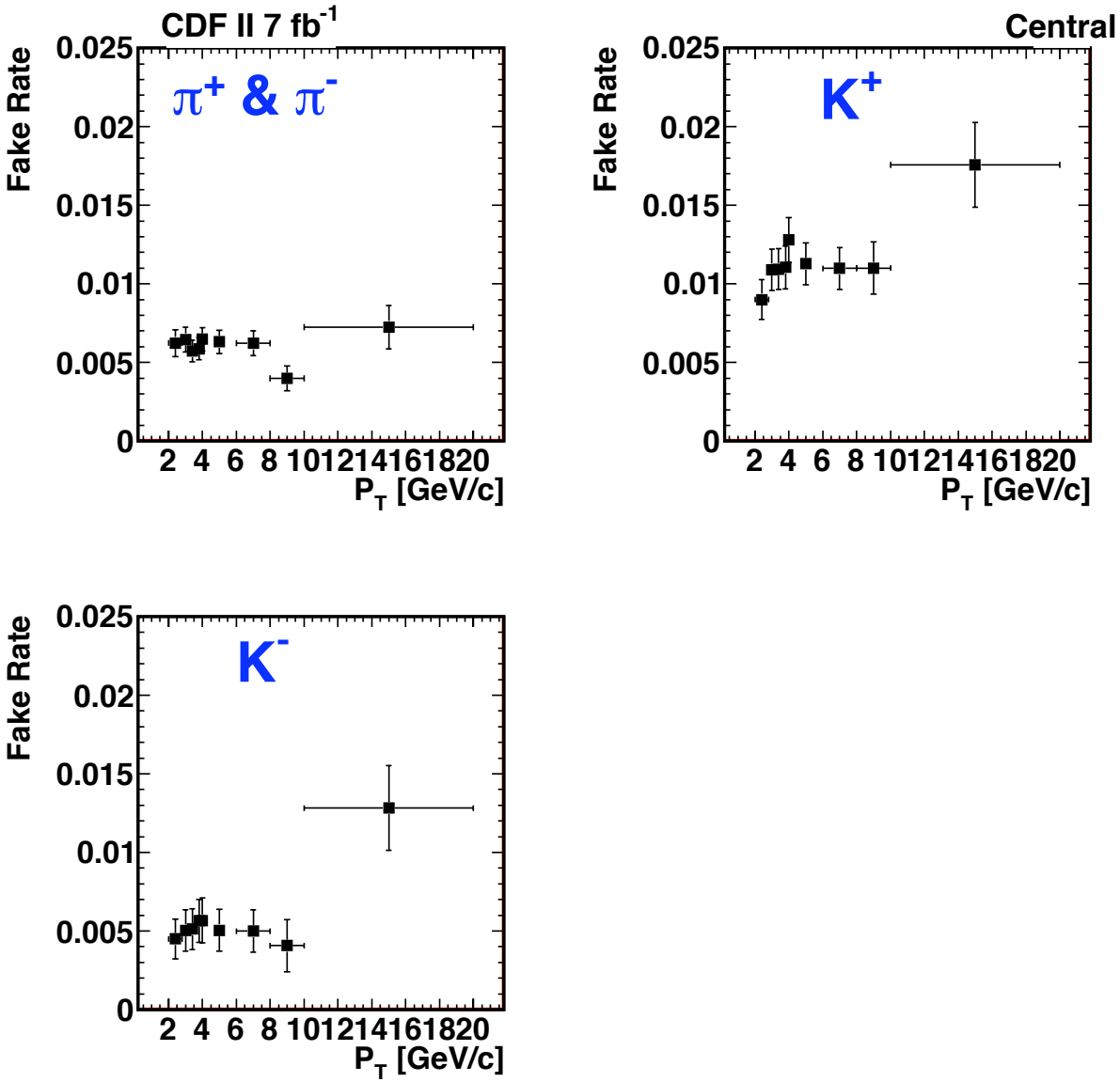
From B. Casey, ICHEP2010

B_s acceptances and efficiencies

	CC		CF	
$(\alpha_{B^+}/\alpha_{B_s})$	0.307 ± 0.018	$(\pm 6\%)$	0.197 ± 0.014	$(\pm 7\%)$
$(\epsilon^{trig}_{B^+}/\epsilon^{trig}_{B_s})$	0.99935 ± 0.00012	(-)	0.97974 ± 0.00016	(-)
$(\epsilon^{reco}_{B^+}/\epsilon^{reco}_{B_s})$	0.86 ± 0.06	$(\pm 8\%)$	0.84 ± 0.06	$(\pm 9\%)$
$\epsilon^{NN}_{B_s}(NN > 0.70)$	0.915 ± 0.042	$(\pm 4\%)$	0.864 ± 0.040	$(\pm 4\%)$
$\epsilon^{NN}_{B_s}(NN > 0.995)$	0.461 ± 0.021	$(\pm 4.7\%)$	0.468 ± 0.022	$(\pm 4.6\%)$
N_{B^+}	28081 ± 219	$(\pm 1\%)$	12144 ± 153	$(\pm 1\%)$
f_u/f_s	3.55 ± 0.47	$(\pm 13\%)$	3.55 ± 0.47	$(\pm 13\%)$
$BR(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+)$	$(6.01 \pm 0.21) \times 10^{-5}$	$(\pm 4\%)$	$(6.01 \pm 0.21) \times 10^{-5}$	$(\pm 4\%)$
SES (All bins)	2.3×10^{-9}	$(\pm 18\%)$	3.3×10^{-9}	$(\pm 18\%)$

Table: A summary of the inputs used to estimate the $\mathcal{B}(B_s \to \mu^+\mu^-)$. The relative uncertainties are given parenthetically. The single-event-sensitivities, SESs, for the sum of all NN bins, corresponding to $N_{B_s} = 1$, is shown in the two last rows.

Fake Rates for pions and kaons as a function of p_T



Combinatorial Background for B_s

NN Bin \ Mass Bin (GeV/c^2)	5.310−5.334	5.334−5.358	5.358−5.382	5.382−5.406	5.406−5.430
CC					
0.700<NN<0.760	10.42±0.72	10.33±0.71	10.23±0.70	10.14±0.70	10.04±0.69
0.760<NN<0.850	11.02±0.74	10.92±0.74	10.82±0.73	10.72±0.72	10.62±0.71
0.850<NN<0.900	4.69±0.46	4.65±0.45	4.61±0.45	4.56±0.44	4.52±0.44
0.900<NN<0.940	4.49±0.45	4.45±0.44	4.41±0.44	4.37±0.43	4.33±0.43
0.940<NN<0.970	3.85±0.41	3.81±0.41	3.78±0.40	3.74±0.40	3.71±0.39
0.970<NN<0.987	2.21±0.30	2.19±0.30	2.17±0.30	2.14±0.30	2.12±0.29
0.987<NN<0.995	0.92±0.19	0.91±0.19	0.91±0.19	0.90±0.19	0.89±0.19
0.995<NN<1.000	0.24±0.10	0.24±0.10	0.24±0.10	0.23±0.10	0.23±0.10
CF					
0.700<NN<0.760	10.18±0.72	10.05±0.71	9.93±0.70	9.80±0.69	9.68±0.68
0.760<NN<0.850	11.21±0.76	11.08±0.75	10.94±0.74	10.80±0.73	10.66±0.72
0.850<NN<0.900	6.11±0.54	6.03±0.53	5.96±0.52	5.88±0.52	5.81±0.51
0.900<NN<0.940	4.65±0.46	4.59±0.46	4.54±0.45	4.48±0.44	4.42±0.44
0.940<NN<0.970	3.94±0.42	3.90±0.42	3.85±0.41	3.80±0.41	3.75±0.40
0.970<NN<0.987	2.74±0.35	2.71±0.34	2.67±0.34	2.64±0.34	2.61±0.33
0.987<NN<0.995	0.83±0.19	0.82±0.18	0.81±0.18	0.80±0.18	0.79±0.18
0.995<NN<1.000	0.71±0.17	0.70±0.17	0.69±0.17	0.68±0.17	0.67±0.16

Table: Combinatorial background estimates with statistical error for B_s signal window.

Combinatorial Background for B_d

NN Bin \ Mass Bin (GeV/c^2)	5.219−5.243	5.243−5.267	5.267−5.291	5.291−5.315	5.315−5.339
CC					
0.700<NN<0.760	10.78±0.74	10.69±0.74	10.59±0.73	10.50±0.72	10.40±0.72
0.760<NN<0.850	11.41±0.77	11.30±0.76	11.21±0.76	11.10±0.75	11.00±0.74
0.850<NN<0.900	4.85±0.47	4.81±0.47	4.77±0.46	4.72±0.46	4.68±0.46
0.900<NN<0.940	4.64±0.46	4.60±0.46	4.56±0.45	4.52±0.45	4.48±0.44
0.940<NN<0.970	3.98±0.42	3.95±0.42	3.91±0.42	3.88±0.41	3.84±0.41
0.970<NN<0.987	2.28±0.32	2.26±0.31	2.24±0.31	2.22±0.31	2.20±0.30
0.987<NN<0.995	0.95±0.20	0.95±0.20	0.94±0.20	0.93±0.20	0.92±0.19
0.995<NN<1.000	0.25±0.10	0.25±0.10	0.24±0.10	0.24±0.10	0.24±0.10
CF					
0.700<NN<0.760	10.65±0.75	10.52±0.74	10.40±0.73	10.27±0.72	10.15±0.72
0.760<NN<0.850	11.73±0.80	11.60±0.79	11.46±0.78	11.32±0.77	11.18±0.76
0.850<NN<0.900	6.39±0.56	6.31±0.55	6.24±0.55	6.16±0.54	6.09±0.53
0.900<NN<0.940	4.87±0.48	4.81±0.48	4.75±0.47	4.70±0.47	4.64±0.46
0.940<NN<0.970	4.13±0.44	4.08±0.44	4.03±0.43	3.98±0.43	3.94±0.42
0.970<NN<0.987	2.87±0.36	2.83±0.36	2.80±0.35	2.77±0.35	2.73±0.35
0.987<NN<0.995	0.87±0.20	0.86±0.19	0.85±0.19	0.84±0.19	0.83±0.19
0.995<NN<1.000	0.74±0.18	0.73±0.18	0.72±0.18	0.71±0.17	0.70±0.17

Table: Combinatorial background estimates with statistical error for B_d signal window.

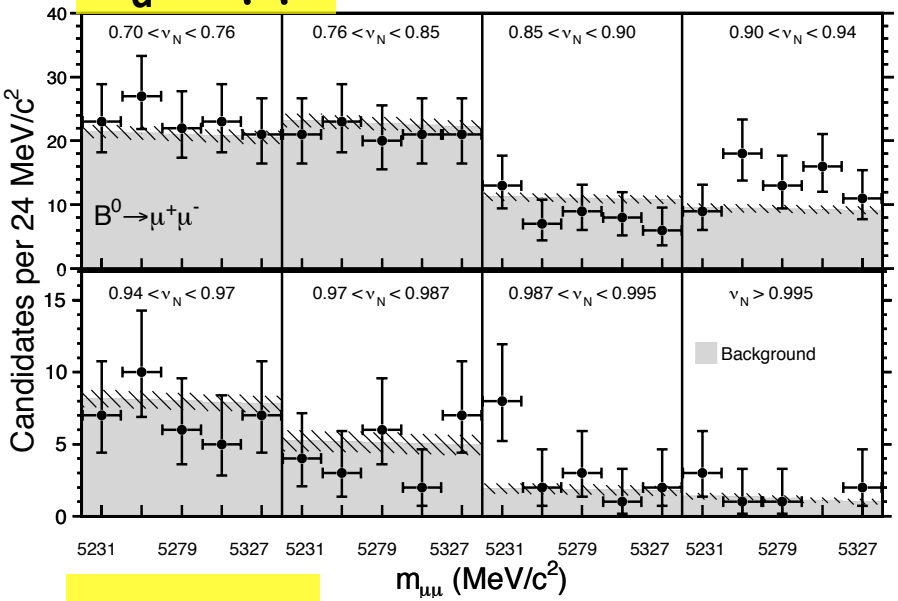
B→hh Background for B_d

NN Bin \ Mass Bin (GeV/c^2)	5.219−5.243	5.243−5.267	5.267−5.291	5.291−5.315	5.315−5.339
CC					
0.700<NN<0.760	0.015±0.002	0.013±0.001	0.011±0.001	0.006±0.001	0.002± < 0.001
0.760<NN<0.850	0.027±0.003	0.027±0.003	0.019±0.002	0.011±0.002	0.004±0.001
0.850<NN<0.900	0.022±0.002	0.019±0.002	0.014±0.002	0.008±0.001	0.003± < 0.001
0.900<NN<0.940	0.030±0.003	0.029±0.003	0.022±0.003	0.013±0.002	0.004±0.001
0.940<NN<0.970	0.047±0.005	0.039±0.004	0.031±0.004	0.016±0.002	0.005±0.001
0.970<NN<0.987	0.060±0.006	0.052±0.006	0.040±0.005	0.023±0.003	0.009±0.001
0.987<NN<0.995	0.084±0.008	0.083±0.009	0.061±0.008	0.033±0.004	0.011±0.001
0.995<NN<1.000	0.325±0.032	0.298±0.031	0.221±0.028	0.126±0.017	0.050±0.006
CF					
0.700<NN<0.760	0.004± < 0.001	0.004± < 0.001	0.003± < 0.001	0.002± < 0.001	0.001± < 0.001
0.760<NN<0.850	0.007±0.001	0.008±0.001	0.006±0.001	0.004±0.001	0.001± < 0.001
0.850<NN<0.900	0.006±0.001	0.006±0.001	0.005±0.001	0.003± < 0.001	0.001± < 0.001
0.900<NN<0.940	0.008±0.001	0.008±0.001	0.007±0.001	0.004±0.001	0.001± < 0.001
0.940<NN<0.970	0.011±0.001	0.011±0.001	0.009±0.001	0.005±0.001	0.002± < 0.001
0.970<NN<0.987	0.017±0.002	0.018±0.002	0.015±0.002	0.008±0.001	0.003± < 0.001
0.987<NN<0.995	0.014±0.001	0.015±0.002	0.012±0.002	0.007±0.001	0.002± < 0.001
0.995<NN<1.000	0.078±0.008	0.084±0.009	0.065±0.008	0.038±0.005	0.014±0.002

Table: $B \to hh$ background estimates for B_d signal window.

Di-muon mass for $B_{s(d)}$ signal regions

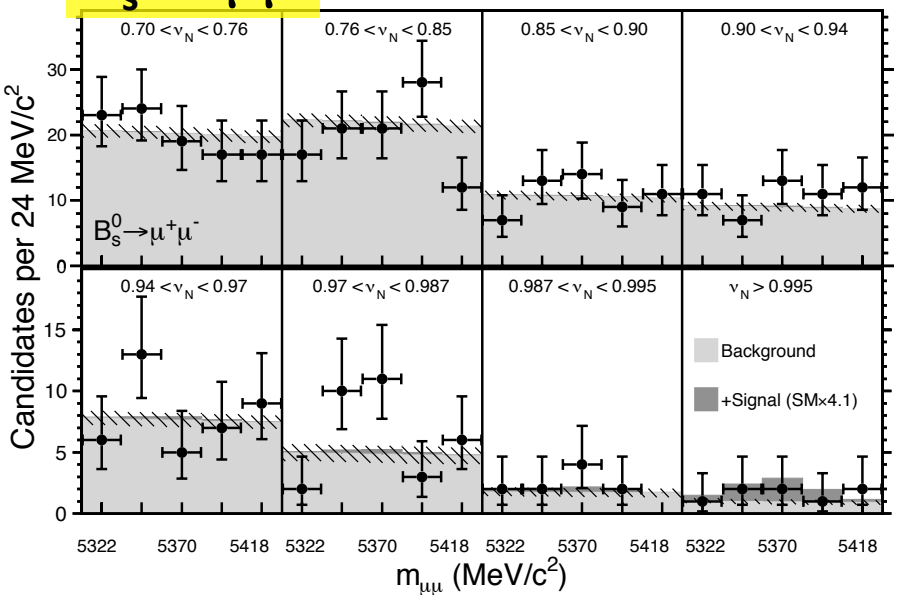
$B_d \rightarrow \mu\mu$



$B_d \rightarrow \mu\mu$ channel: consistent with SM BG prediction. No excess.

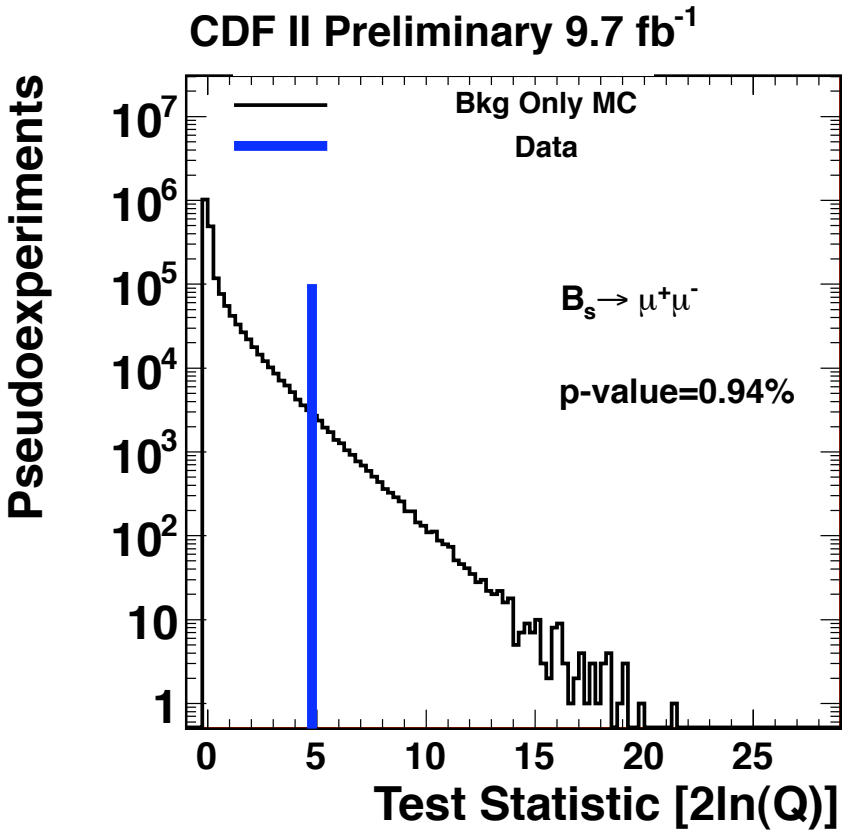
$$\mathrm{BR}(B_d^0 \rightarrow \mu^-\mu^+) < 3.8\times10^{-9} \quad @\ 90\%\ \mathrm{C.L.}$$
$$\mathrm{BR}(B_d^0 \rightarrow \mu^-\mu^+) < 4.6\times10^{-9} \quad @\ 95\%\ \mathrm{C.L.}$$

$B_s \rightarrow \mu\mu$



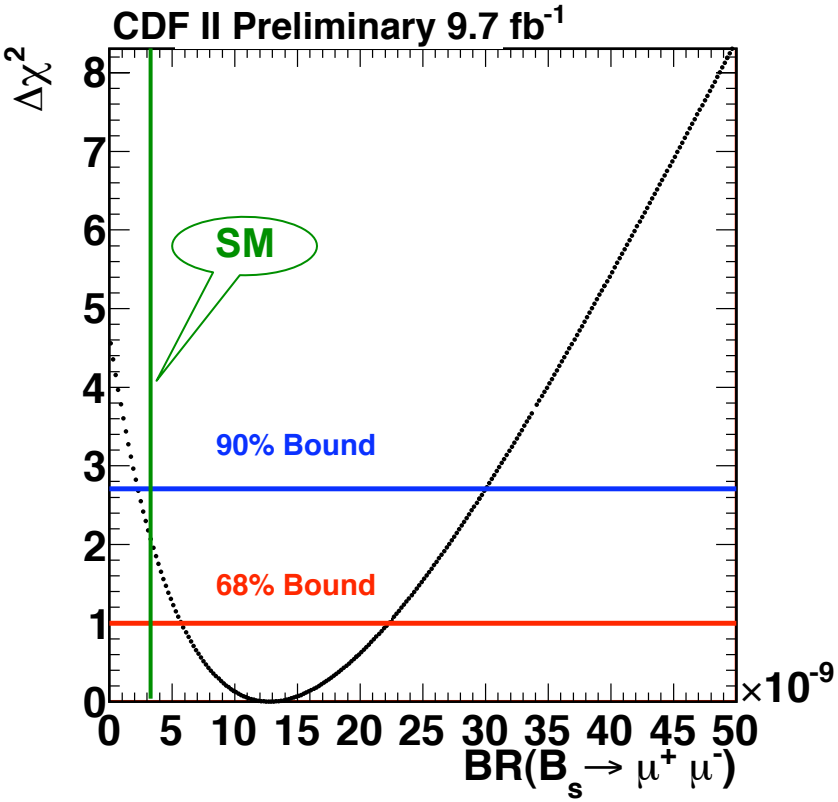
In $B_s \rightarrow \mu\mu$ channel, slight excess in high NN bins (>0.97).

$B_s \to \mu\mu$ limits



p-values assuming:

- **BG only: 0.94%**
- **$B_s \to \mu^+\mu^-$ SM + BG: 7.1%**



$$\mathrm{BR}(B_s^0 \to \mu^-\mu^+) = \left(1.3^{+0.9}_{-0.7}\right) \times 10^{-8}$$

$$2.2 \times 10^{-9} < \mathrm{BR}(B_s^0 \to \mu^-\mu^+) < 3.0 \times 10^{-8} \ @\ 90\%\ \mathrm{C.L.}$$

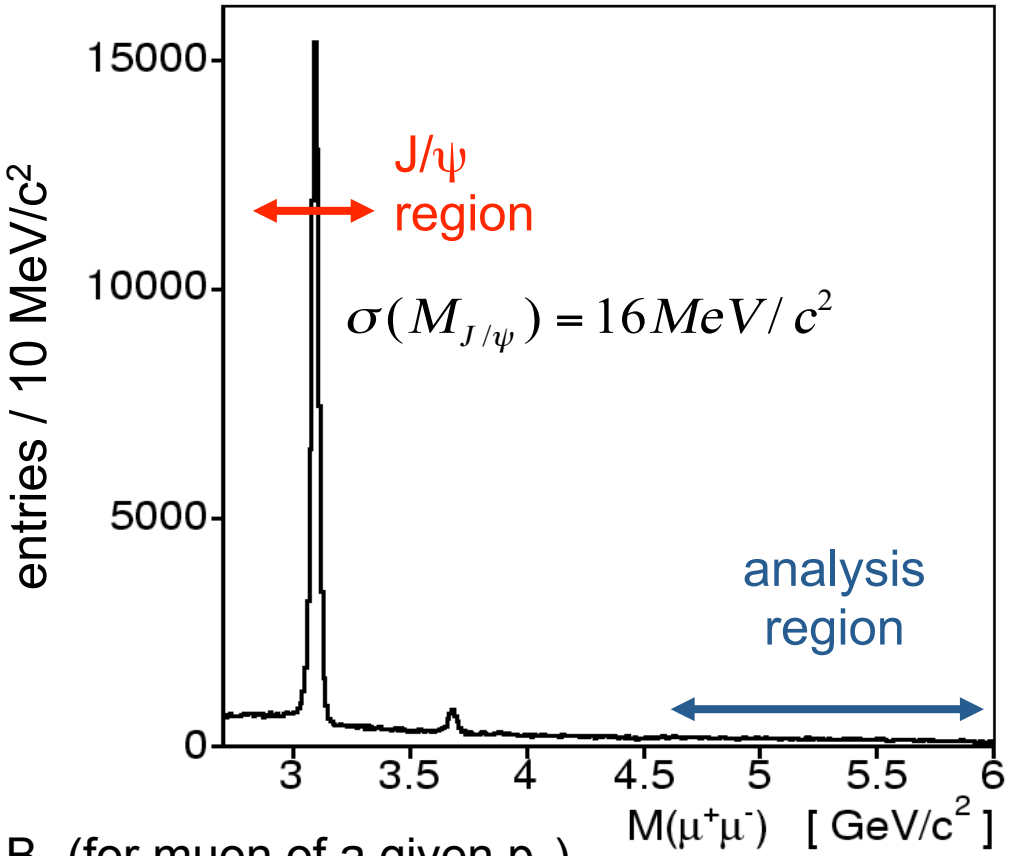
$$0.8 \times 10^{-9} < \mathrm{BR}(B_s^0 \to \mu^-\mu^+) < 3.4 \times 10^{-8} \ @\ 95\%\ \mathrm{C.L.}$$

Trigger

Data collected using dimuon trigger

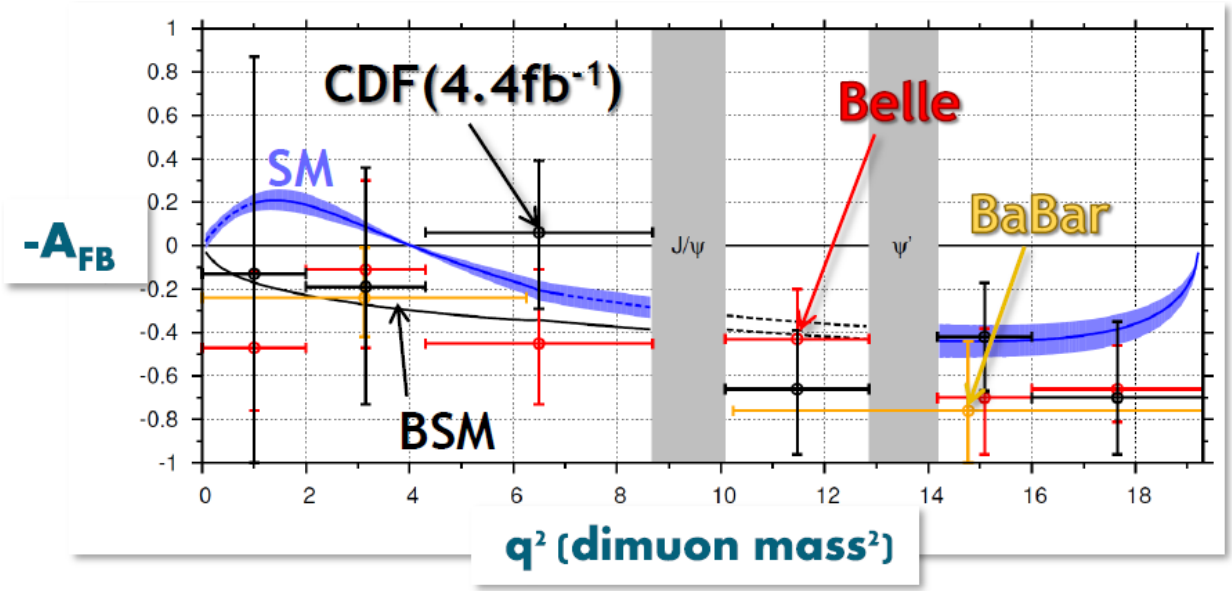
- "CC":
  - 2 central muons "CMU", $|\eta|<0.6$,
  - $p_T>1.5$ GeV
  - $2.7<M_{\mu\mu}<6.0$ GeV
  - $p_{T(\mu)}+p_{T(\mu)}>4$ GeV

- "CF":
  - one central, one forward muon "CMX", $0.6<|\eta|<1.0$
  - $p_T>2$ GeV
  - other cuts same as above



Trigger efficiency same for muons from J/ψ or B_s (for muon of a given p_T)

A_{FB}: BaBar, Belle and CDF (4.4 fb^{-1})



A_{FB}>0 even at low q^2

CDF: comparable resolution as Belle

N(K*ll) ~250 (Belle)
N(K*μμ)~100 (CDF)

C.Bobeth *et al.*
arXiv:1006.5013v2

Angular observables

allel. The distributions of θ_μ, θ_K, and ϕ are projected from the full differential decay distribution and can be parametrized with four angular observables, A_{FB}, F_L, $A_T^{(2)}$, and A_{im} [1–5]:

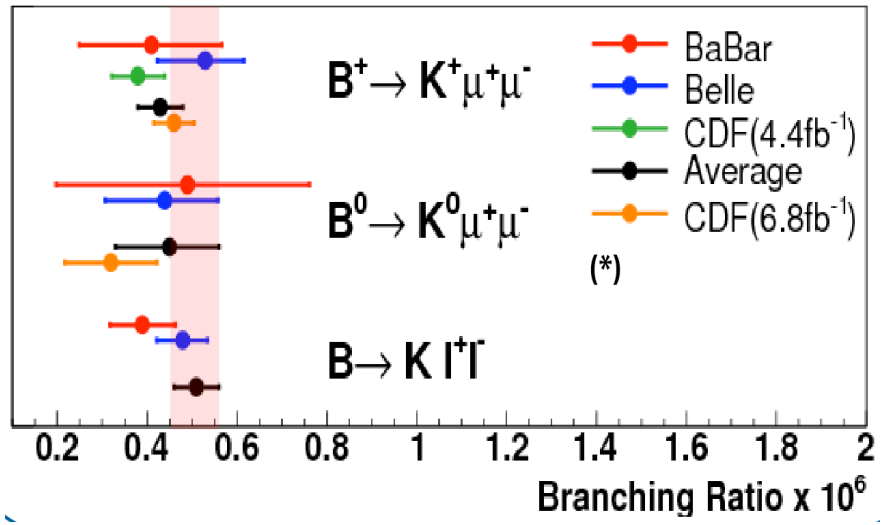
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K),$$

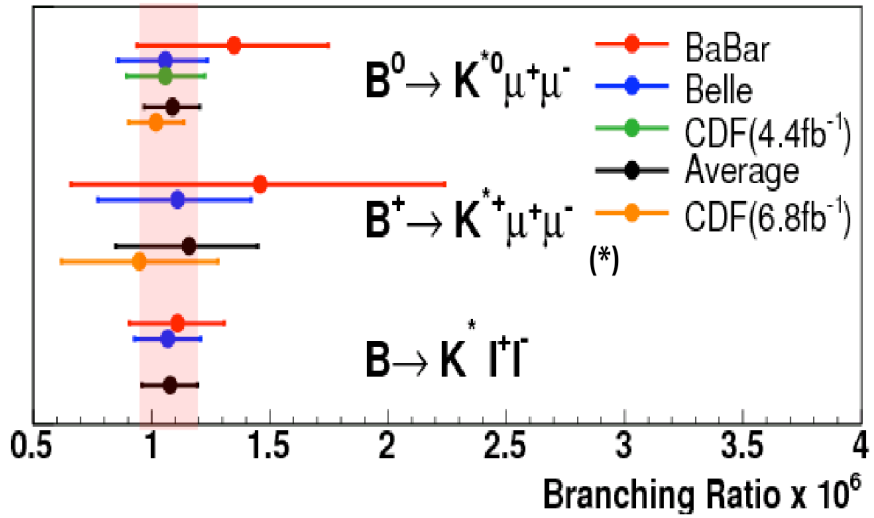
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu,$$

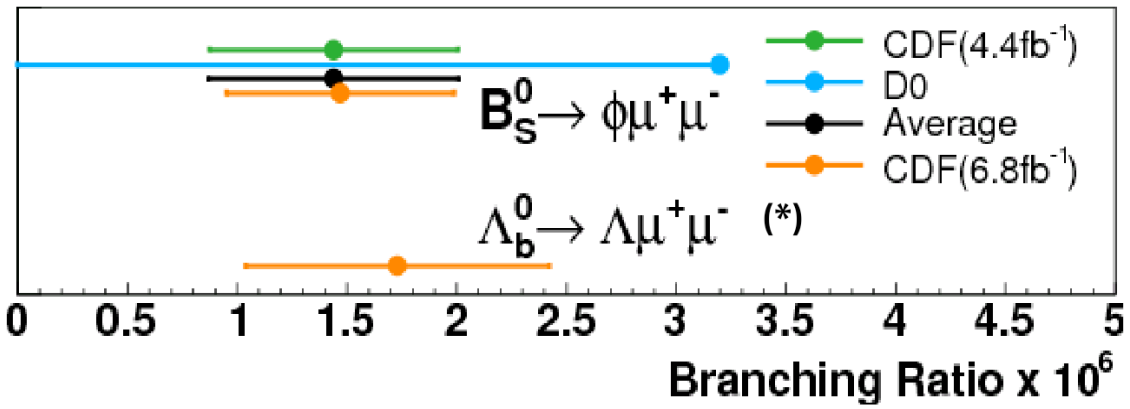
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\phi} = \frac{1}{2\pi}\left[1+\frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi\right],($$

where $\Gamma \equiv \Gamma(B \to K^*\mu^+\mu^-)$, A_{FB} is the muon forward-backward asymmetry, F_L is the K^* longitudinal polarization fraction, $A_T^{(2)}$ is the transverse polarization asymmetry [1], and A_{im} is the time-reversal-odd charge-and-parity asymmetry (T-odd CP asymmetry) [2, 6]. In

b→sμμ BR summary (nov. 2011)







CDF B(b→sμμ) measurements are the world's most precise