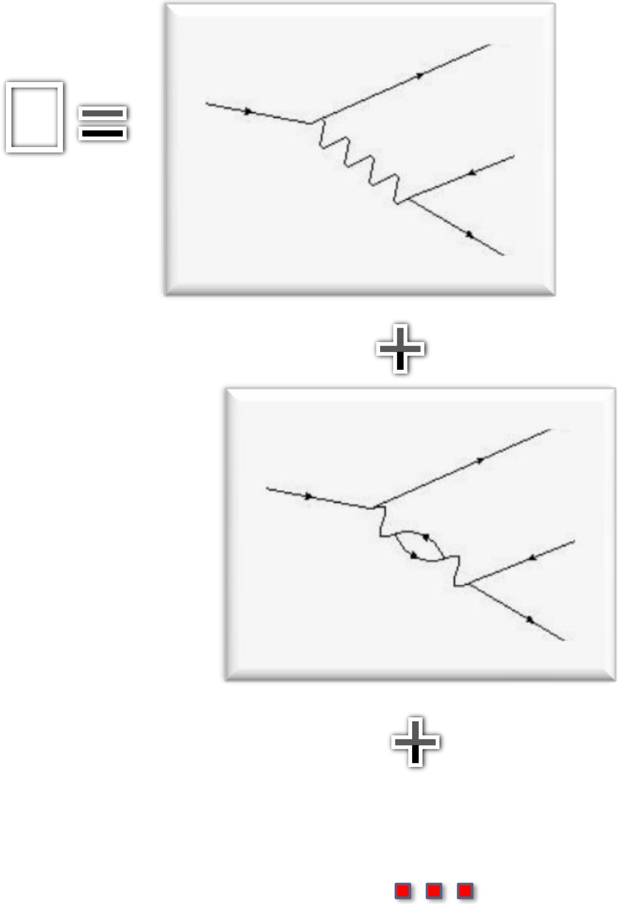
Search for Non-Standard Model Physics in Rare Decays at the Tevatron

BEACH 2010 Conference
G. Volpi on behalf of CDF and D∅ collaborations

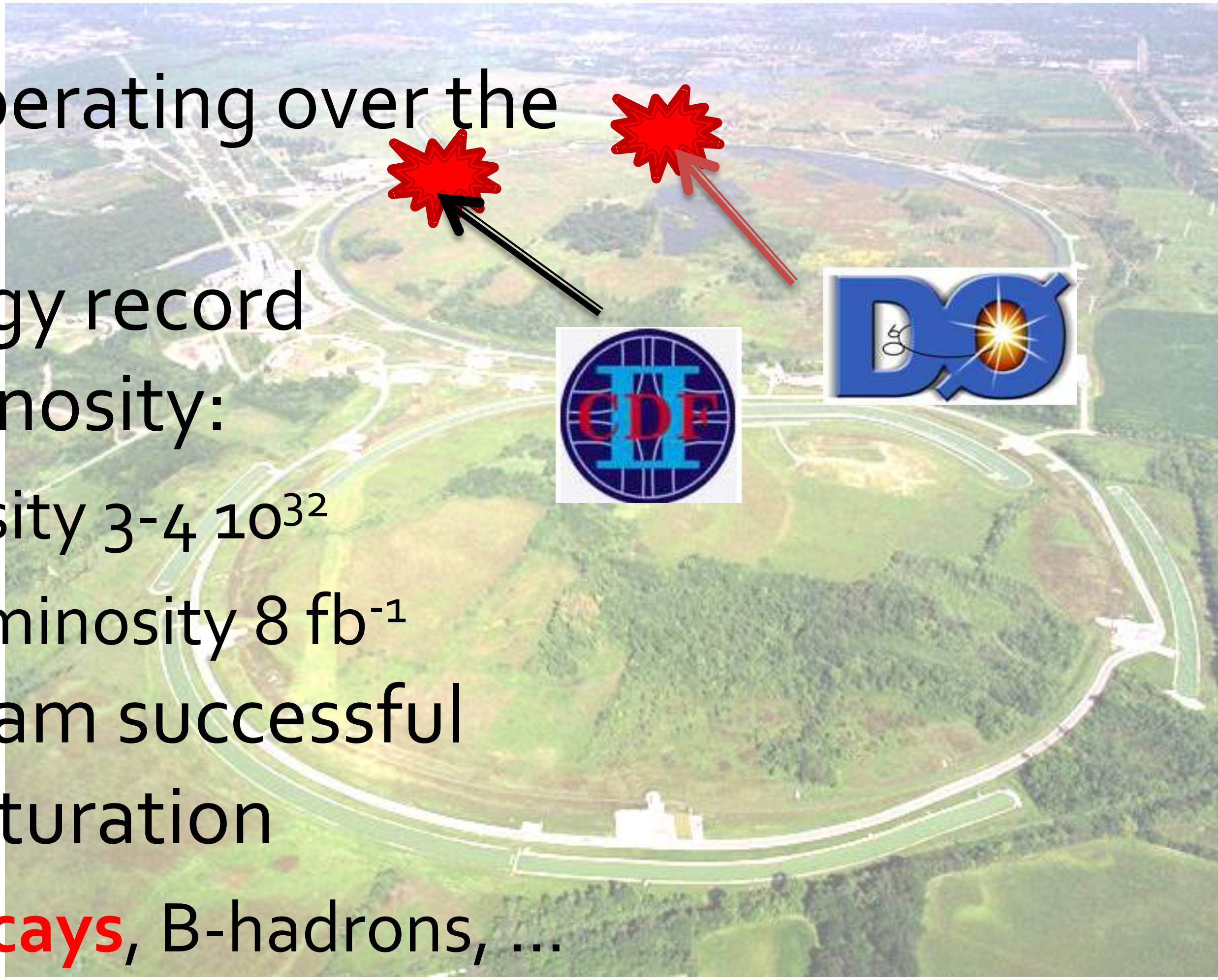
New Physics in rare decays

- Study of rare decays tests Standard Model at very high precision
- Decays suppressed at tree level
- Loops sensitive to BSM physics
- Unexpected contribution can be more evident

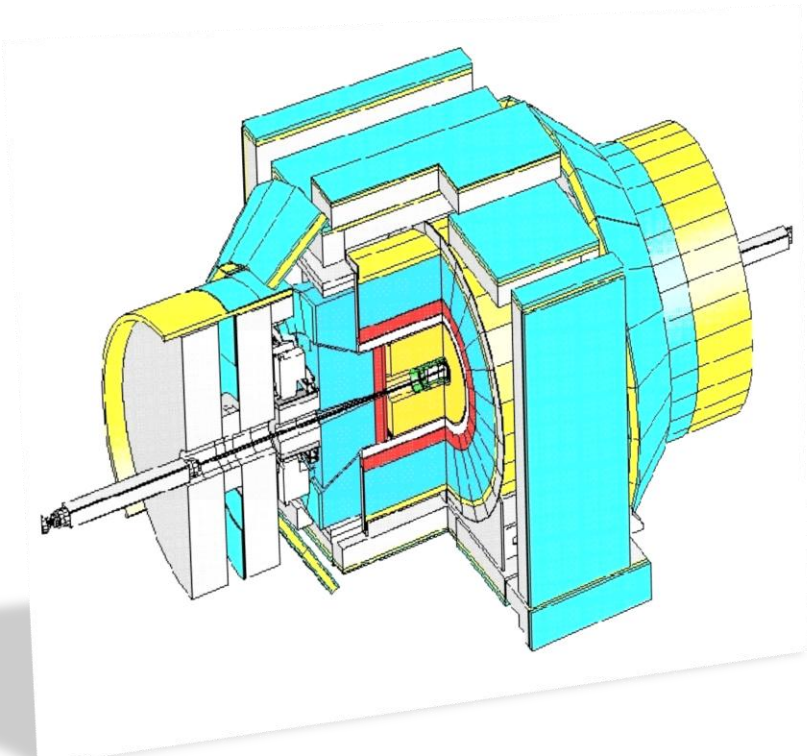


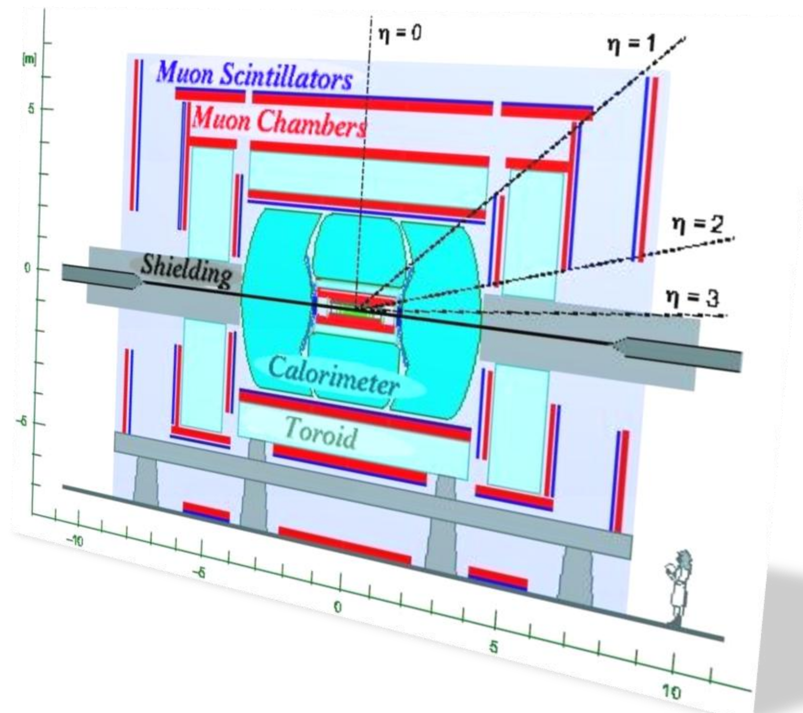
Tevatron accelerator

- Tevatron is operating over the design
- Lost the energy record
- Still best luminosity:
  - Initial luminosity 3-4 10^{32}
  - Integrated luminosity 8 fb^{-1}
- Physics program successful and at full maturation
  - CPV, **Rare decays**, B-hadrons, …



CDF and DØ experiments





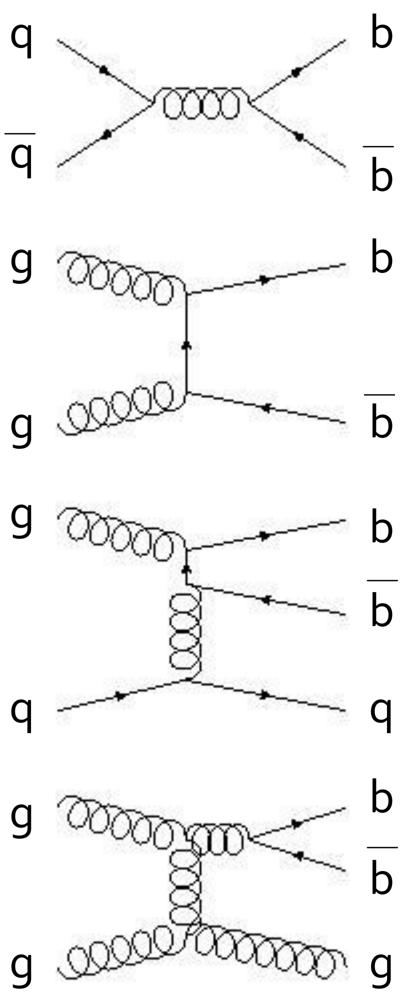
CDF

PID identification using dE/dx and ToF
Good tracking resolution, also at trigger level

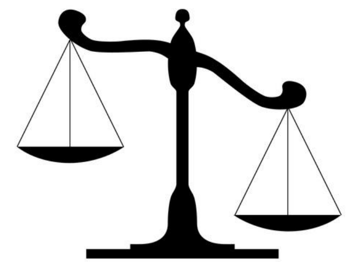
DØ

Extended muon coverage
Precise vertex reconstruction
Reversible magnet

B-Physics at Tevatron



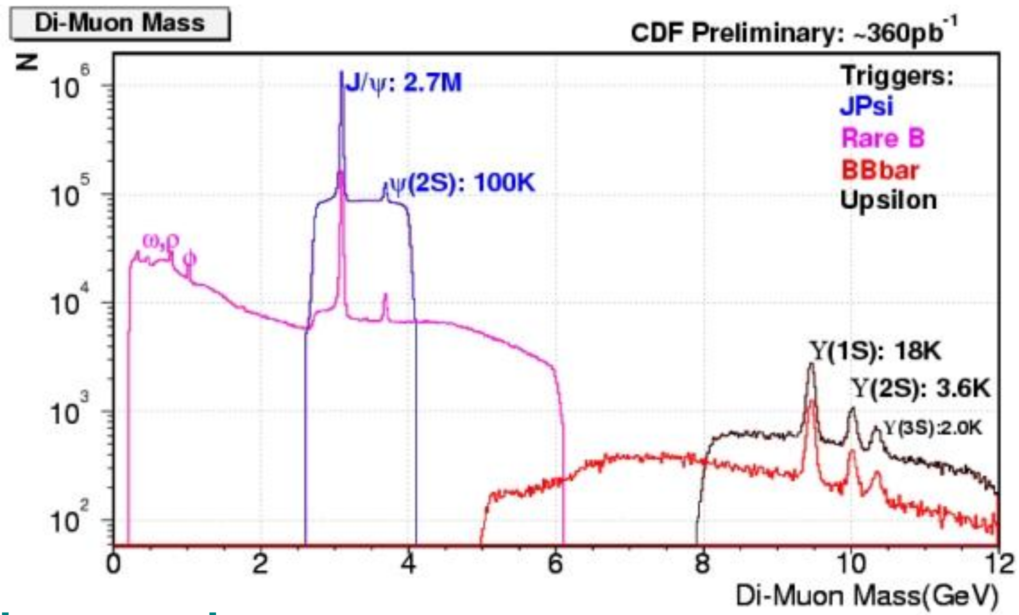
- Pros:
  - Production cross-section is HUGE
  - Ideal for exploring rarest channels
  - All species of b-hadrons:
    - B_u, B_d, B_s, Λ_b, Σ_b, …



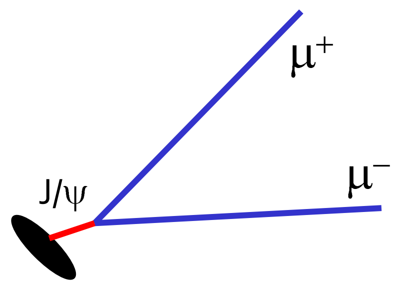
- Cons
  - QCD background $\sigma(b\bar{b})$x10^3
  - Sophisticated trigger selection required

Rate challenge

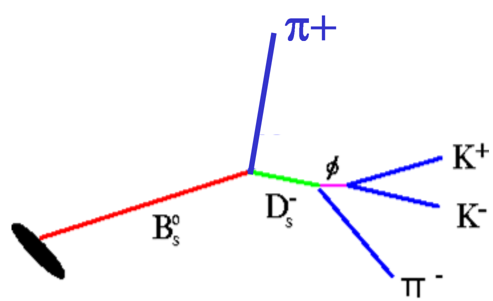
- Hard to store on tape all the produced collisions
  - 2 MHz → 100 Hz
- Developed strategy and hardware to collect high-purity samples
- On this talk:
  - Di-muon triggers, to look for 2 muons candidates
  - Track-trigger, to look for collisions with displaced vertex



di-muon trigger

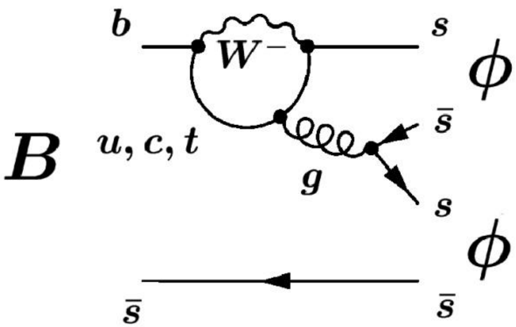


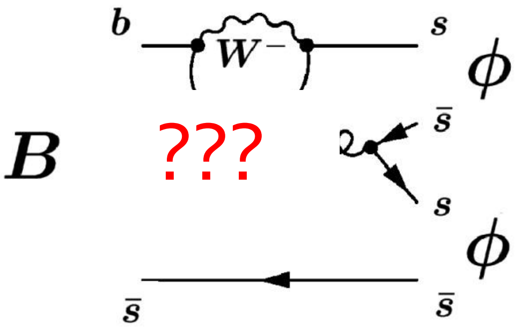
track trigger



$B^0_s \rightarrow \varphi\varphi$

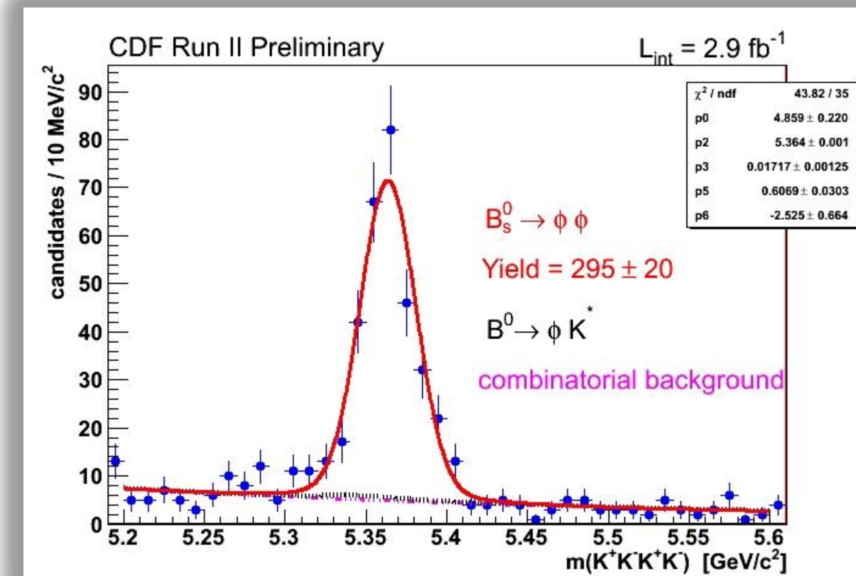
- B→VV decay penguin dominated
  - First observation at CDF with 180 pb^{-1}
    [PRL95,031801(2005)]
- Polarization Puzzle:
  - SM predict $A_0 \gg A_{\perp}, A_{\parallel}$
  - Confirmed in b→u trees and b→d penguins
  - Not confirmed in b→s penguins
    - NP? SM?

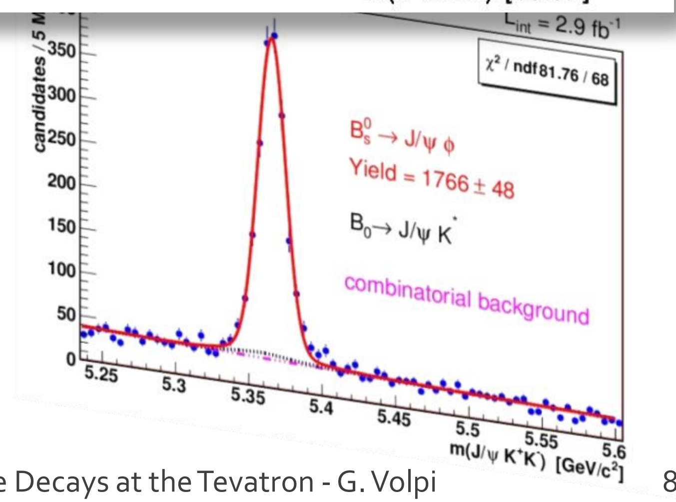




$B^0_s \rightarrow \phi\phi$ BR measurement

- Data collected using hadronic trigger
  - Displaced tracks required
  - Based on 2.9 fb^{-1}
- Branching ratio normalized to $B^0_s \rightarrow J/\psi\phi$
  - Independent sample from sin(2□$_s$) analysis



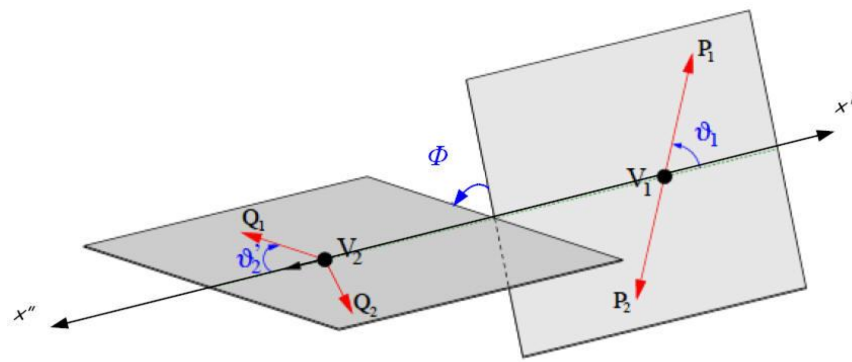


$$BR(B^0_s \rightarrow \phi\phi) = (2.40 \pm 0.21 \pm 0.27 \pm 0.82) \times 10^{-5}$$

http://www-cdf.fnal.gov/physics/new/bottom/090618.blessed-Bsphiphi2.9/

$B^o_s \rightarrow \varphi\varphi$ polarization

- P→VV decay
- Decay rate is function of angles in ϕ rest frame
- ML fit used to disentangle polarization contributions
  - Untagged and time integrated
  - Trigger selection effects on the angular templates considered

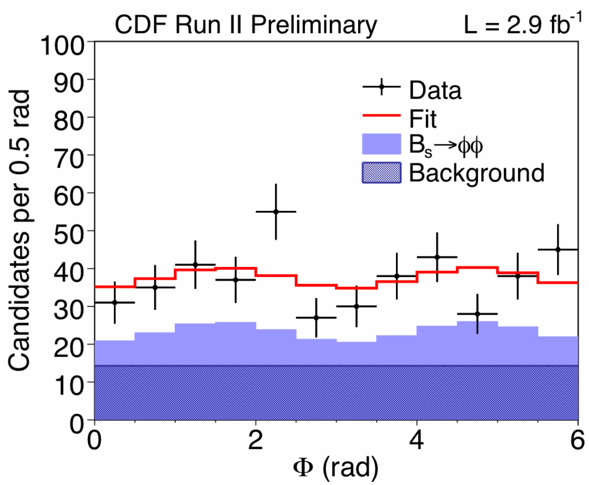


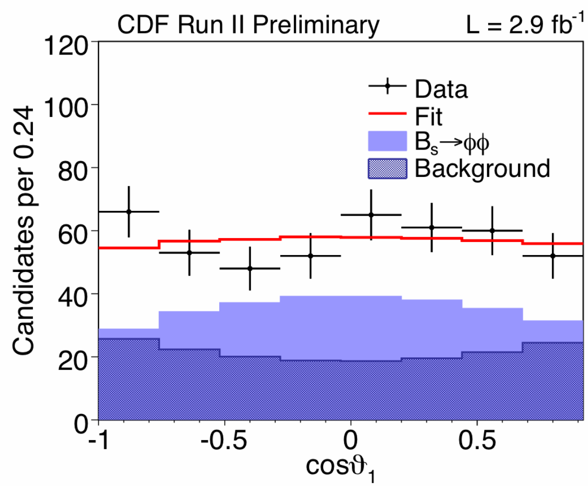
$$\vec{\omega} \equiv (\cos\vartheta_1, \cos\vartheta_2, \Phi)$$

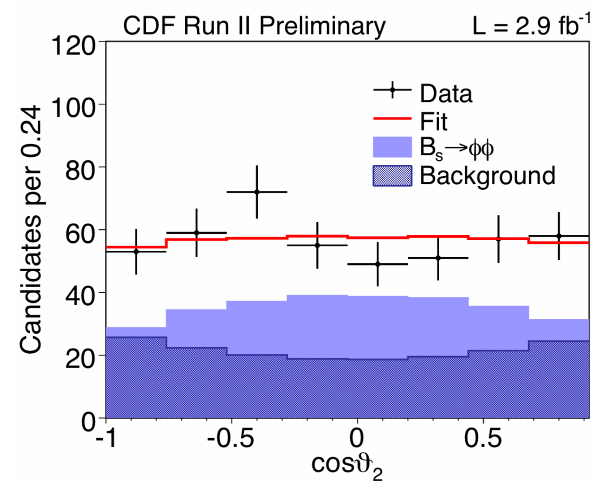
$$\frac{d^3\Lambda(\vec{\omega})}{d^3\vec{\omega}} = \frac{9}{32\pi}\frac{1}{\widetilde{W}}\left[\widetilde{F}_e(\vec{\omega}) + \widetilde{F}_o(\vec{\omega})\right]$$

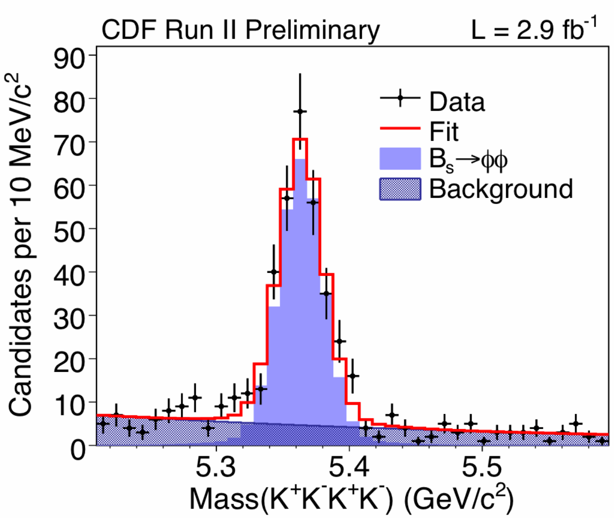
$$\widetilde{F}_i = \widetilde{F}_i(A_0, A_\perp, A_\parallel)$$

$B^o_s \rightarrow \phi\phi$ polarization









$|Ao|^2=0.348\pm0.041\pm0.021$

$|A□ |^2=0.287\pm0.043\pm0.011$

$|A□|^2=0.365\pm0.044\pm0.027$

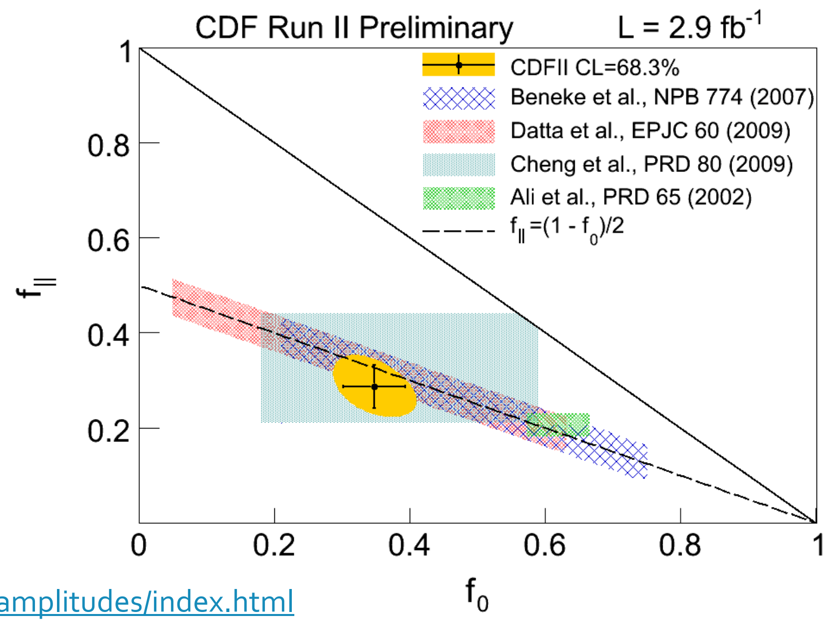
$\cos\delta□=-0.91^{+0.15}_{-013}\pm0.09$

$B^0_s \to \phi\phi$ polarization

	f_L [%]	f_T [%]
CDF Run II	$34.8 \pm 4.1(\text{stat}) \pm 2.1(\text{syst})$	$65.2 \pm 4.1(\text{stat}) \pm 2.1(\text{syst})$
QCD factorization 1	48^{+0+26}_{-0-27}	52^{+0+26}_{-0-27}
QCD factorization 2	34 ± 28	66 ± 28
QCD factorization 3	86.6	13.4
Naive factorization	88.3	11.7
NLO EWP 1	86.3	13.7
NLO EWP 2	86.3	13.7
perturbative QCD	$61.9^{+3.6+2.5+0.0}_{-3.2-3.3-0.0}$	$38.1^{+3.6+2.5+0.0}_{-3.2-3.3-0.0}$

$f_L = f_0 = |A_0|^2 = 0.348 \pm 0.041 \pm 0.021$

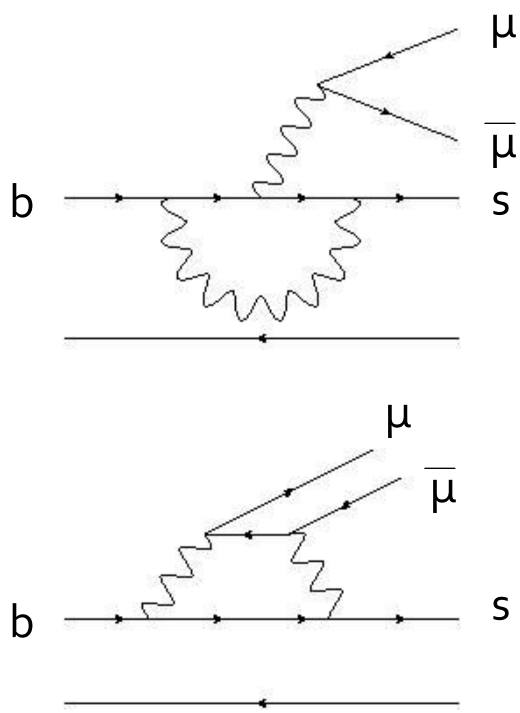
$f_T = 0.652 \pm 0.041 \pm 0.021$



http://www-cdf.fnal.gov/physics/new/bottom/100304.blessed-Bsphiphi_amplitudes/index.html

$B \rightarrow h\mu\mu$

- Decay are FCNC mediated via EW penguin and box
- $B^{0/+} \rightarrow K^{(*)}\mu\mu$ observed at B-factories
- $B^0_s \rightarrow \phi\mu\mu$ not yet observed
- BSM affects:
  - Branching Ratios
  - Differential BR
  - FB Asymmetry



B→hμμ

- Data collected using di-muon trigger
- Based on 4.4 fb^{-1} after quality cuts
- Signal normalized using the B→J/ψh mode
  - Cut selection for the normalization mode
  - Veto on muons from J/ψ and ψ′
  - Final selection based on ANN

$$\frac{B(B \to h\mu^+\mu^-)}{B(B \to J/\psi h)} = \frac{N^{NN}_{h\mu^+\mu^-}}{N^{loose}_{J/\psi h}} \cdot \frac{\epsilon^{loose}_{J/\psi h}}{\epsilon^{loose}_{h\mu^+\mu^-}} \cdot \frac{1}{\epsilon^{NN}_{h\mu^+\mu^-}} \times B(J/\psi \to \mu^+\mu^-)$$

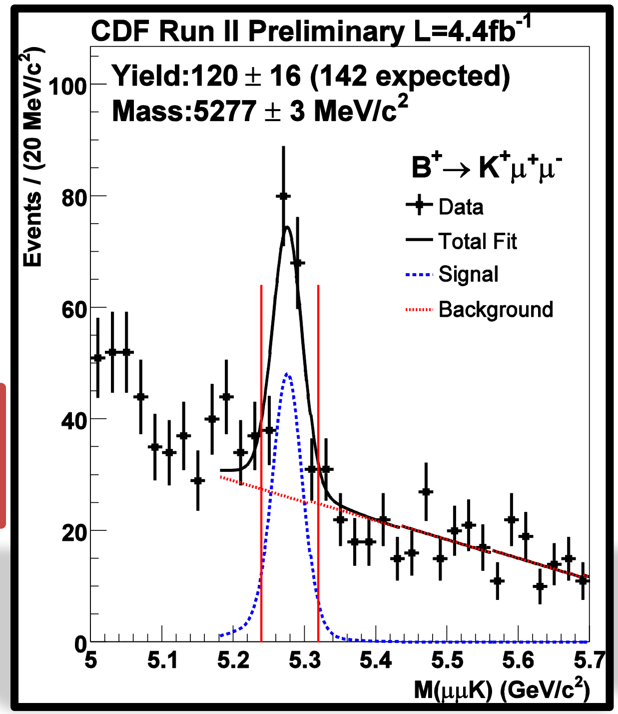
B→K(*)μμ Branching Ratios

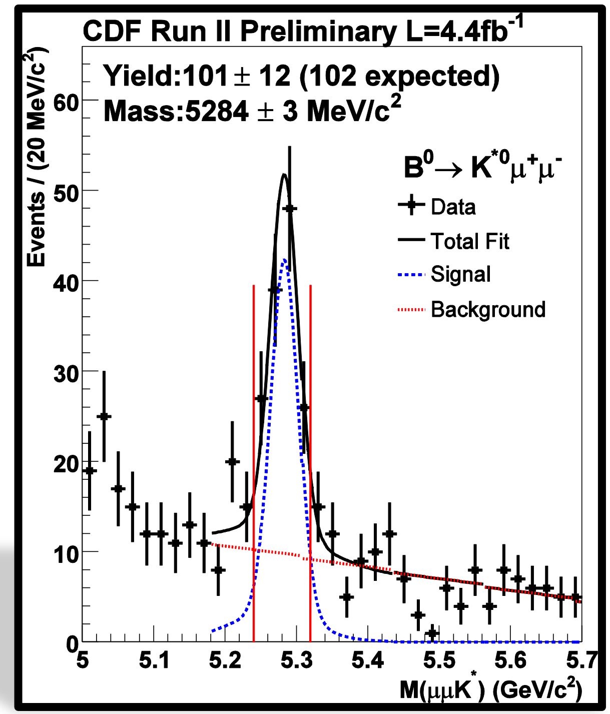
HFAG Sep 2009 averages:

$$B(B^+ \to K^+\mu^+\mu^-) = (0.52^{+0.08}_{-0.07}) \times 10^{-6}$$

$$B(B^0 \to K^*\mu^+\mu^-) = (1.05^{+0.15}_{-0.13}) \times 10^{-6}$$

Measurements competitive with B-factories

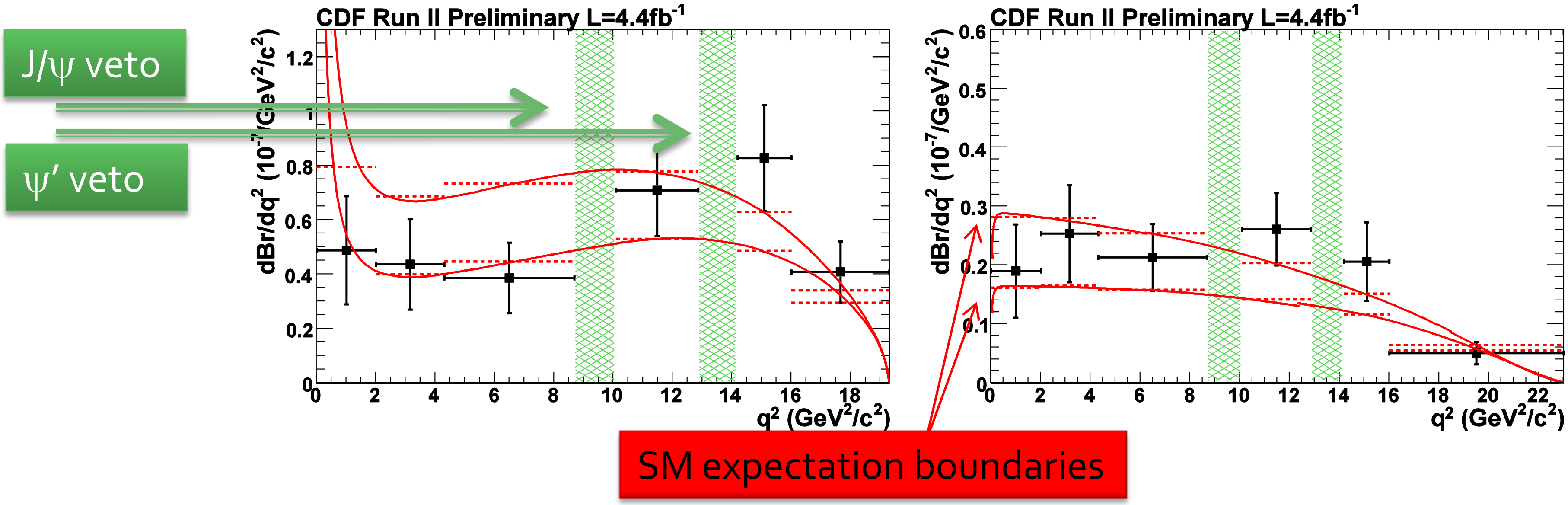




$$B(B^+ \to K^+\mu^+\mu^-) = (0.38 \pm 0.05 \pm 0.03) \times 10^{-6}$$

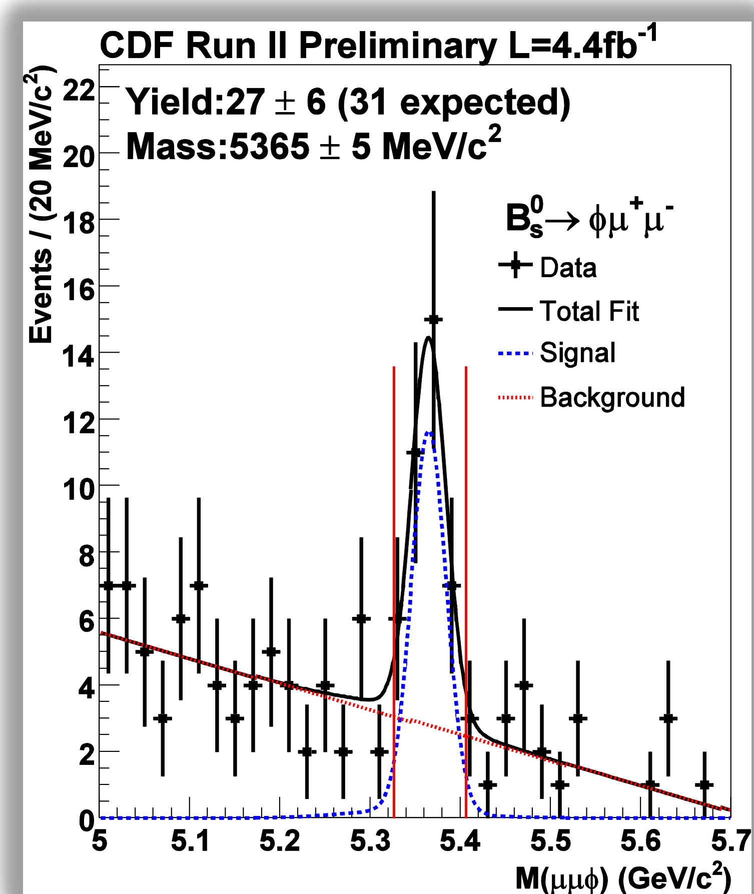
$$B(B^0 \to K^*\mu^+\mu^-) = [1.06 \pm 0.14 \pm 0.09] \times 10^{-6}$$

B⁰->K$^{(*)}$μμ differential BR



- BSM physics could change the shape
- Results are compatible with the SM and other measurements

$B^o_s \to \phi\mu\mu$ Branching Ratios



- First observation
- Peak significativity ~6σ

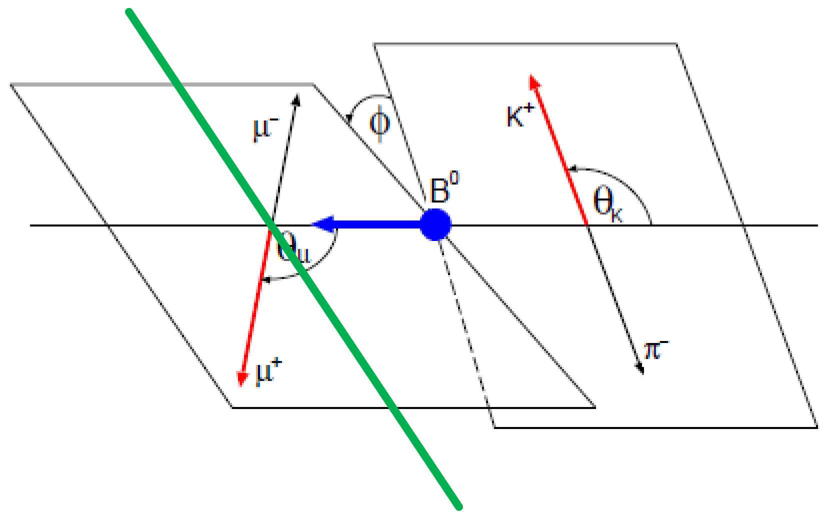
$$B\left(B_s^0 \to \phi\mu^+\mu^-\right) = \left(1.44 \pm 0.33 \pm 0.46\right) \times 10^{-6}$$

- Rarest decay so far
- New B→Vll mode
  - Measurement of polarization can give addition NP constraints

B->K$^{(*)}$μμ FB asymmetry (a)

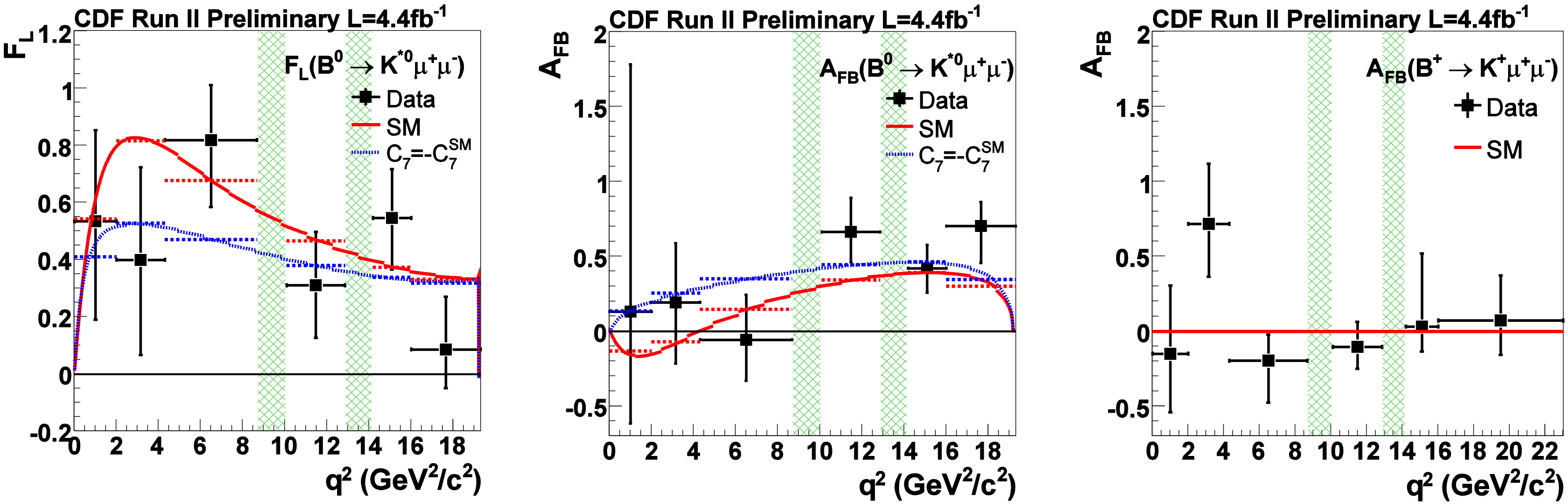
- Emission in di-muon rest-frame function decay direction
- Emission angle for K also affected the BR

  [F. Kruger and J. Matias, Phys. Rev. D71]
- NP is expected to show a clear discrepancy from SM



$$A_{FB} = \frac{\Gamma\left(B\left(q^2, \cos(\vartheta_{\mu^+}) > 0\right)\right) - \Gamma\left(B\left(q^2, \cos(\vartheta_{\mu^+}) < 0\right)\right)}{\Gamma\left(B\left(q^2, \cos(\vartheta_{\mu^+}) > 0\right)\right) + \Gamma\left(B\left(q^2, \cos(\vartheta_{\mu^+}) < 0\right)\right)}$$

B^o->$K^{(*)}\mu\mu$ FB asymmetry (b)

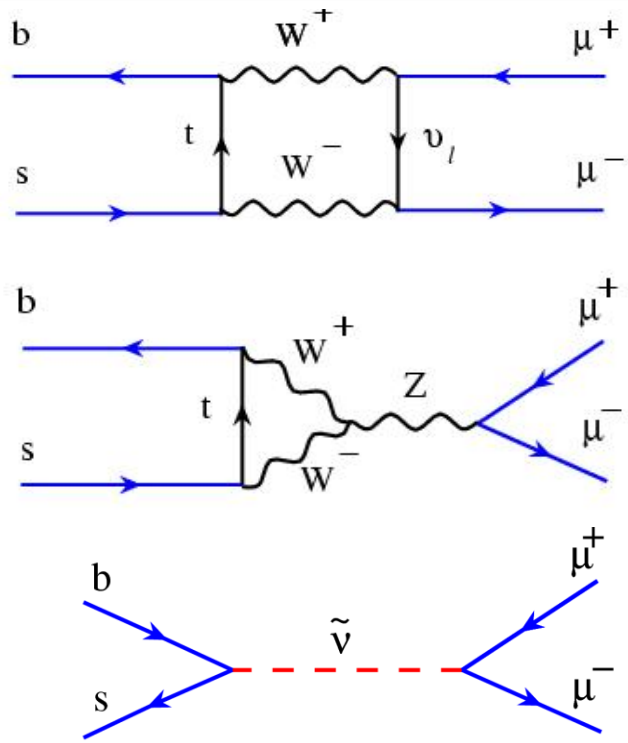


- Consistent with SM
- Consistent and competitive with B-factory measurements
  - Almost reaching Belle statistic
- BSM models constrained

http://www-cdf.fnal.gov/physics/new/bottom/091112.blessed-b2smumu_afb/index.html

$B^0_{(s)} \to \mu\mu$

- Most popular SM benchmark in flavor
- Theoretical prediction with small uncertainties
- Clean experimental signature
- Powerful probe to reject or discover BSM effects



$$Br(B_s \to \mu^+\mu^-) = (3.6 \pm 0.3) \cdot 10^{-9}$$

$$Br(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \cdot 10^{-10}$$

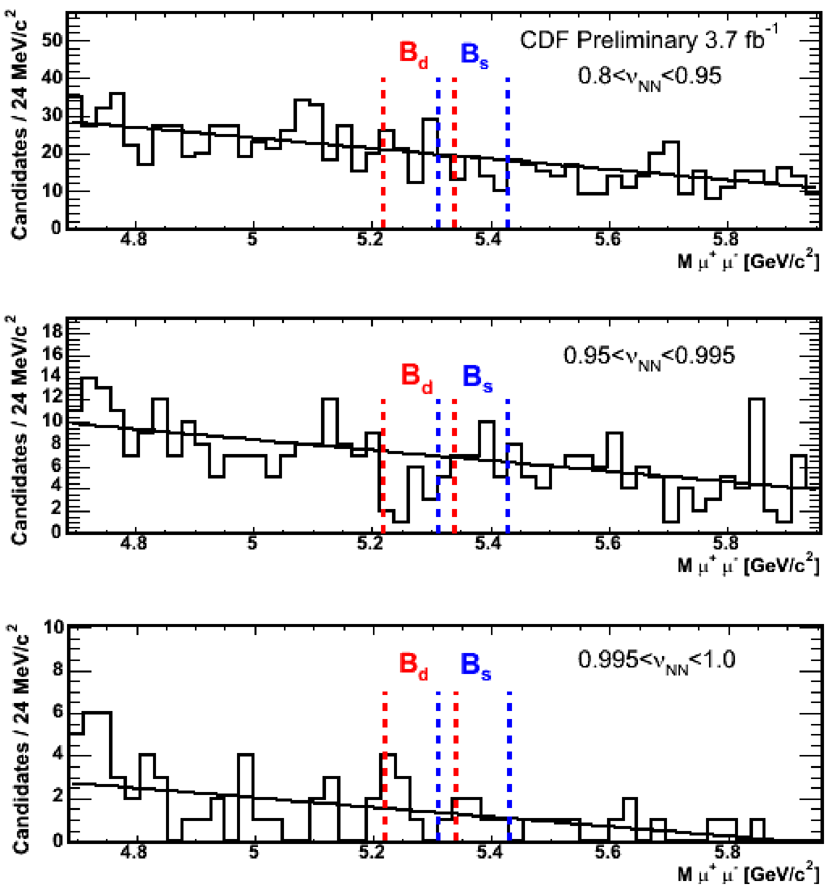
A. J. Buras, Prog. Theor. Phys. 122, 145 (2009)

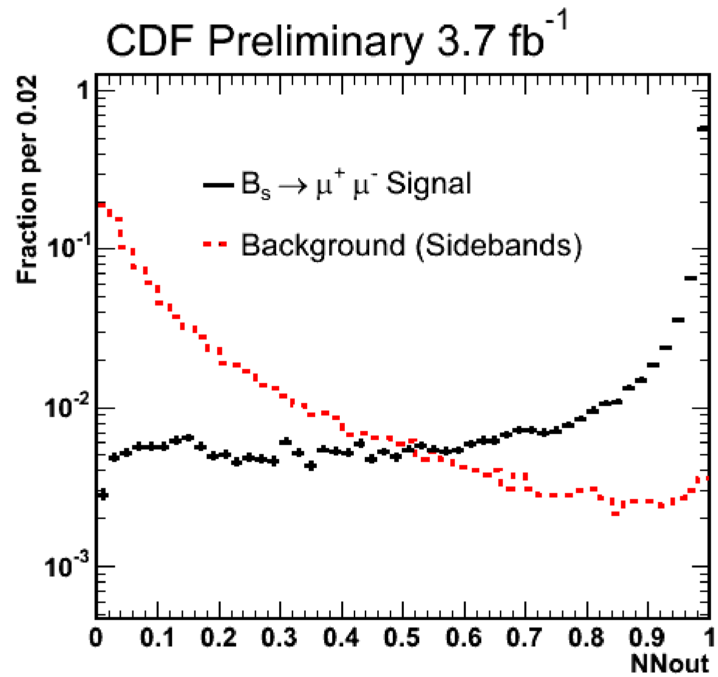
$B^0_{(s)} \rightarrow \mu\mu$ analysis

- Data collected using di-muon triggers
- Final selection based using MVA analysis
  - Decay length, Isolation, pointing angle, ...
  - NN with final observation in 2D plot
    - CDF measurement using 3 NN bins: 0. 80, 0.95, 0.995
    - D∅ measurement using M(μμ) in 5.0-5.8 GeV/c², NN in 0.9-1.0
- $B^+ \rightarrow J/\psi K^+$ used as normalization in s.e.s.

$$\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-)^{95\%\mathrm{C.L.}} = \frac{N^{95\%}_{B^0_s}}{N_{B+}} \cdot \frac{\alpha_{B+}}{\alpha_{B^0_s}} \cdot \frac{\epsilon^{\mathrm{base}}_{B+}}{\epsilon^{\mathrm{base}}_{B^0_s}} \cdot \frac{1}{\epsilon^{\mathrm{NN}}_{B^0_s}} \cdot \frac{f_u}{f_s} \cdot \mathcal{B}(B^+ \rightarrow J/\psi K^+)$$

$B^0_{(s)} \rightarrow \mu\mu$ results at

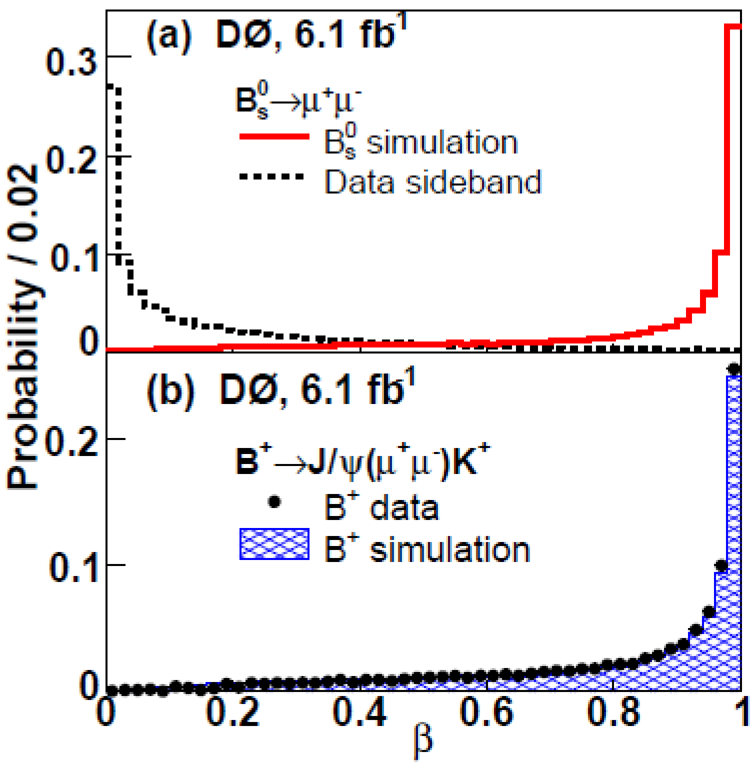


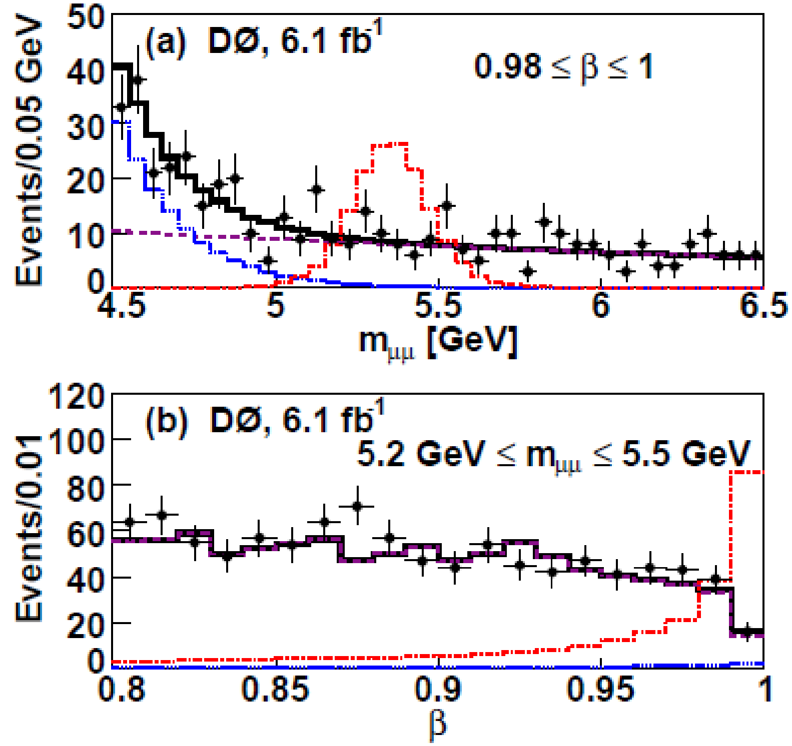


$BR(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$ @ 95% CL
$< 3.6 \times 10^{-8}$ @ 90% CL
$BR(B_d \rightarrow \mu\mu) < 7.6 \times 10^{-9}$ @ 95% CL
$< 6.0 \times 10^{-9}$ @ 90% CL

http://www-cdf.fnal.gov/physics/new/bottom/090813.blessed-Bsd2mumu//welcome.html

$B^0_{(s)} \rightarrow \mu\mu$ results at DØ

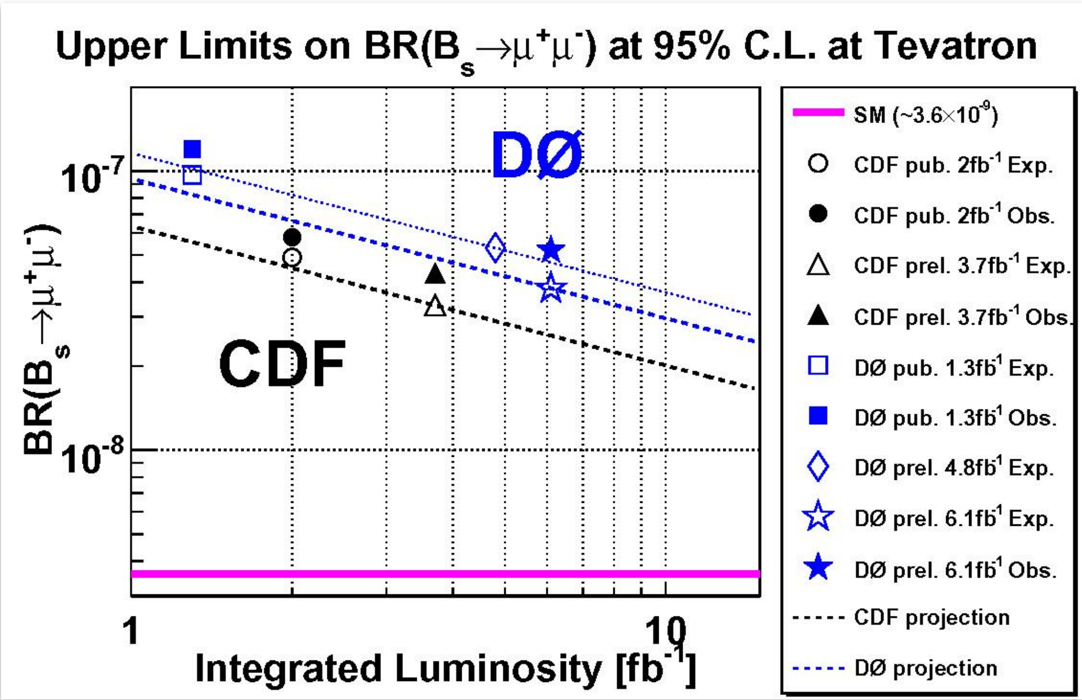


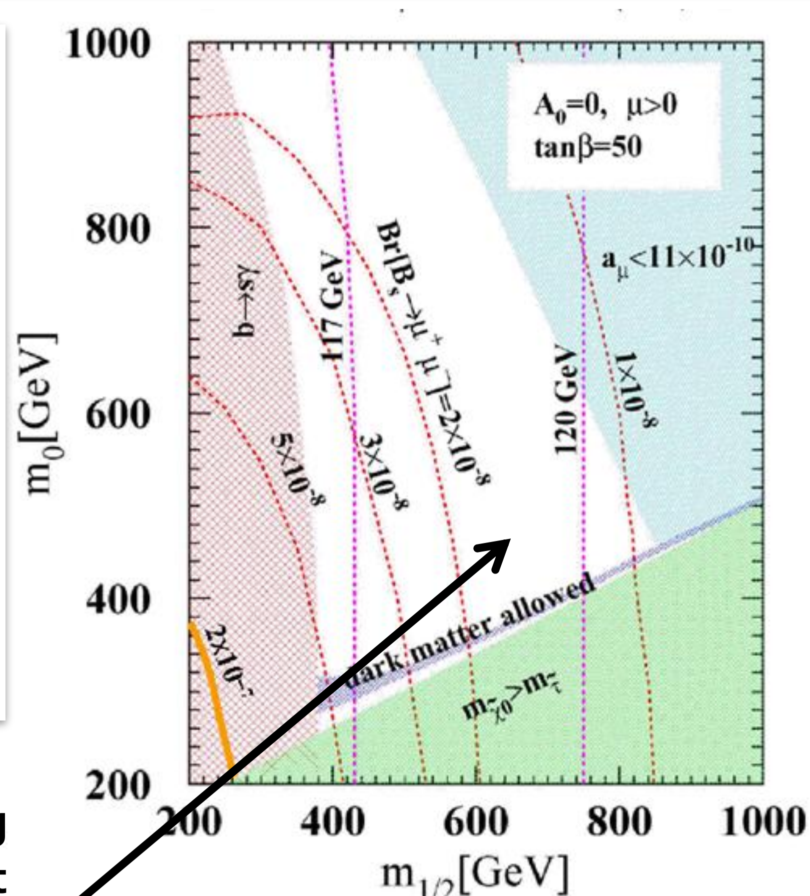


$BR(B_s \rightarrow \mu\mu) < 5.1\times10^{-8}$ @ 95% CL
$< 4.9\times10^{-8}$ @ 90% CL

http://www-do.fnal.gov/Run2Physics/WWW/results/final/B/B10B/

$B^0_{(s)} \rightarrow \mu\mu$ projections

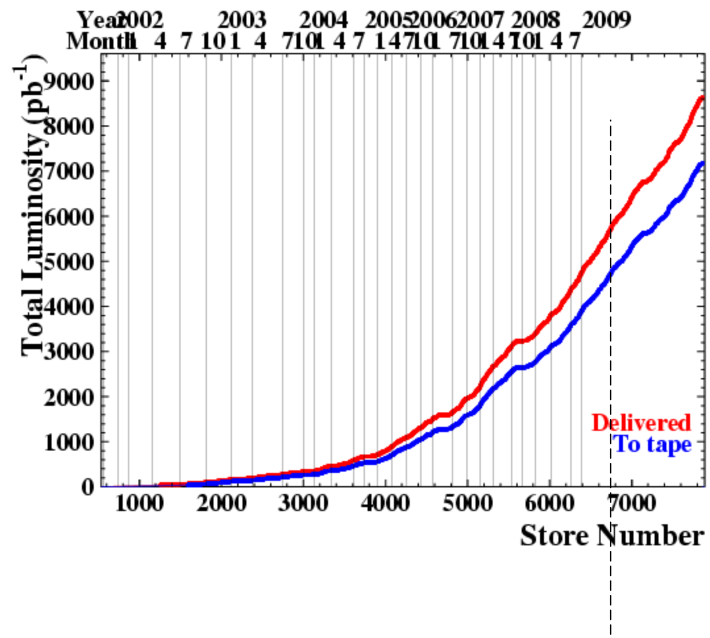




CDF+D∅ are expected to reach ~2 10^{-8} using the whole sample. SM observation difficult but BSM constrained

Conclusions

- Tevatron experiments are leading search for NP in rare B decays
  - First observation of $B^0_s \rightarrow \varphi\mu\mu$
  - Best measurement on: $B^0_s \rightarrow \varphi\varphi$, and $B^0_{(s)} \rightarrow \mu\mu$
  - Competitive results on $B \rightarrow K\mu\mu$
- Not all the current data is used
- New data are coming
  - 2011 confirmed, discussion to extend ongoing



Luminosity range used in this talk

Backup slides

$B^o_s \rightarrow \varphi\varphi$

$B_s \longrightarrow \phi\phi$

Variable	cut
L_{xy}	$> 330\mu m$
$P_T^{K\ min}$	> 0.7 GeV/c
χ^2_{xy}	< 17
d0(B)	$< 65\mu m$
$d0^{\phi}_{max}$	$> 85\mu m$

$B_s \longrightarrow J/\psi\phi$

Variable	cut
L_{xy}	$> 290\mu m$
P_T^{ϕ}	> 1.36 GeV/c
χ^2_{xy}	< 18
d0(B)	$< 65\mu m$
$P_T^{J/\psi}$	> 2.0 GeV/c

$$\frac{BR(B_s \rightarrow \phi\phi)}{BR(B_s \rightarrow J/\psi\phi)} = [1.78 \pm 0.14^{stat} \pm 0.20^{syst}] \cdot 10^{-2}$$

$B^0_s \rightarrow \varphi\varphi$

Parameter	Fit value
M [GeV/c^2]	5.3636 ± 0.0012
σ [GeV/c^2]	0.0165 ± 0.0011
f_{b}	0.381 ± 0.030
b [c^2/GeV]	2.68 ± 0.67
$\lvert A_0\rvert^2$	0.348 ± 0.041
$\lvert A_{\parallel}\rvert^2$	0.287 ± 0.043
$\cos\delta_{\parallel}$	$-0.91^{+0.15}_{-0.13}$
B	$0.49^{+0.31}_{-0.26}$

$$\frac{d^3\Lambda(\vec{\omega})}{d\vec{\omega}}\mathcal{A}(\vec{\omega})$$

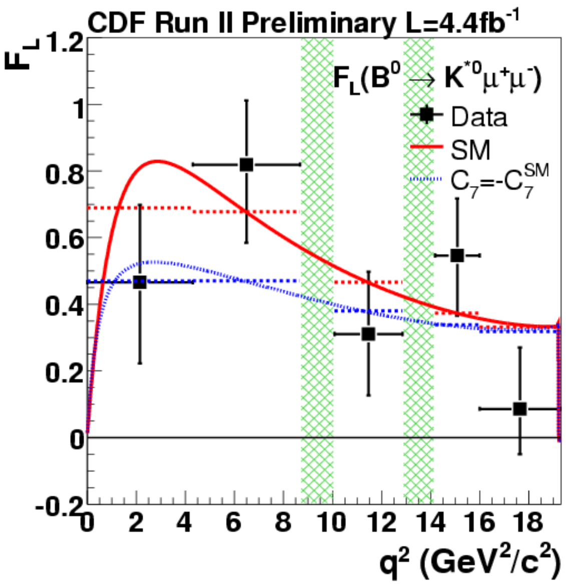
$$\frac{d^3\Lambda(\vec{\omega})}{d\vec{\omega}} = \frac{9}{32\pi}\frac{1}{\tilde{\mathrm{W}}}\left[\tilde{\mathcal{F}}_{\mathrm{e}}(\vec{\omega}) + \tilde{\mathcal{F}}_{\mathrm{o}}(\vec{\omega})\right]$$

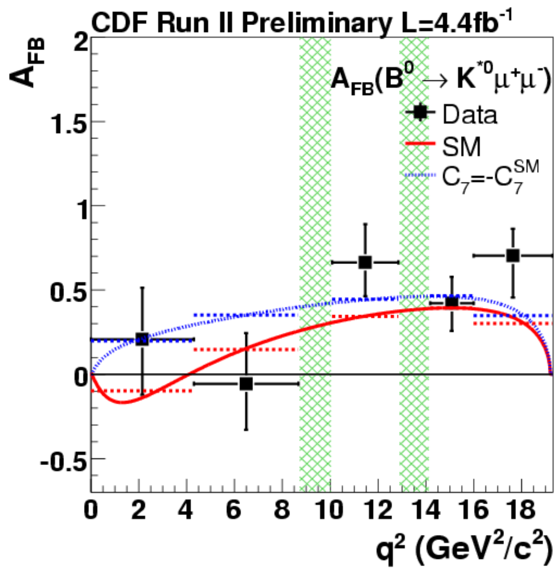
$$\tilde{\mathcal{F}}_{\mathrm{e}} = \frac{2}{\Gamma_{\mathrm{L}}}\left[|A_0|^2 f_1(\vec{\omega}) + |A_{\parallel}|^2 f_2(\vec{\omega}) + |A_0||A_{\parallel}|\cos\delta f_5(\vec{\omega})\right]$$

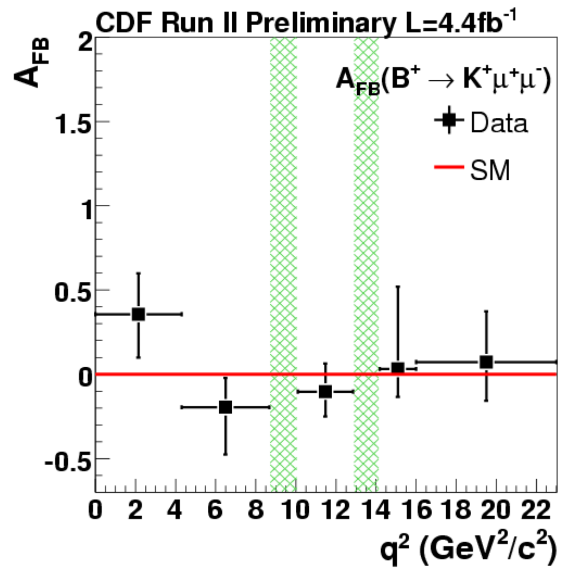
$$\tilde{\mathcal{F}}_{\mathrm{o}} = \frac{2}{\Gamma_{\mathrm{H}}}|A_{\perp}|^2 f_3(\vec{\omega})$$

$$\tilde{\mathrm{W}} = \frac{|A_0|^2 + |A_{\parallel}|^2}{\Gamma_{\mathrm{L}}} + \frac{|A_{\perp}|^2}{\Gamma_{\mathrm{H}}}$$

B→hμμ


CDF Run II Preliminary L=4.4fb^{-1}
F_L
$F_L(B^0 \to K^{*0}\mu^+\mu^-)$
Data
SM
$C_7=-C_7^{SM}$
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 2 4 6 8 10 12 14 16 18
q^2 (GeV^2/c^2)


CDF Run II Preliminary L=4.4fb^{-1}
A_{FB}
$A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$
Data
SM
$C_7=-C_7^{SM}$
2
1.5
1
0.5
0
-0.5
0 2 4 6 8 10 12 14 16 18
q^2 (GeV^2/c^2)


CDF Run II Preliminary L=4.4fb^{-1}
A_{FB}
$A_{FB}(B^+ \to K^+\mu^+\mu^-)$
Data
SM
2
1.5
1
0.5
0
-0.5
0 2 4 6 8 10 12 14 16 18 20 22
q^2 (GeV^2/c^2)

$B^0_{(s)} \rightarrow \mu\mu$ projections