

Rare Heavy Flavor Decays at DØ

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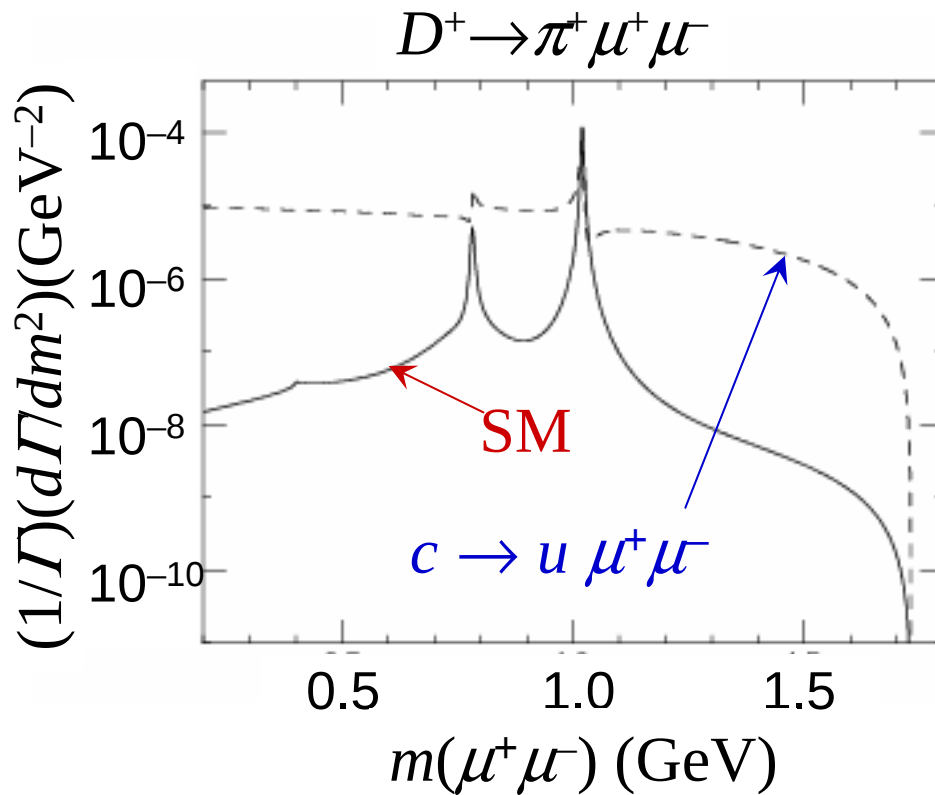
Outline

- Search for $D^+ \rightarrow \pi^+ \mu^+ \mu^-$
 - FCNC in Charm Sector
- Search for $B_s^0 \rightarrow \mu^+ \mu^-$ and $B_s^0 \rightarrow \phi \mu^+ \mu^-$
 - FCNC in Bottom Sector



FCNC in the Charm Sector

- Experimental limits exist for $b \rightarrow s$ and $s \rightarrow d$
- Some models predict violations from SM in up quark sector, but not down quark sector

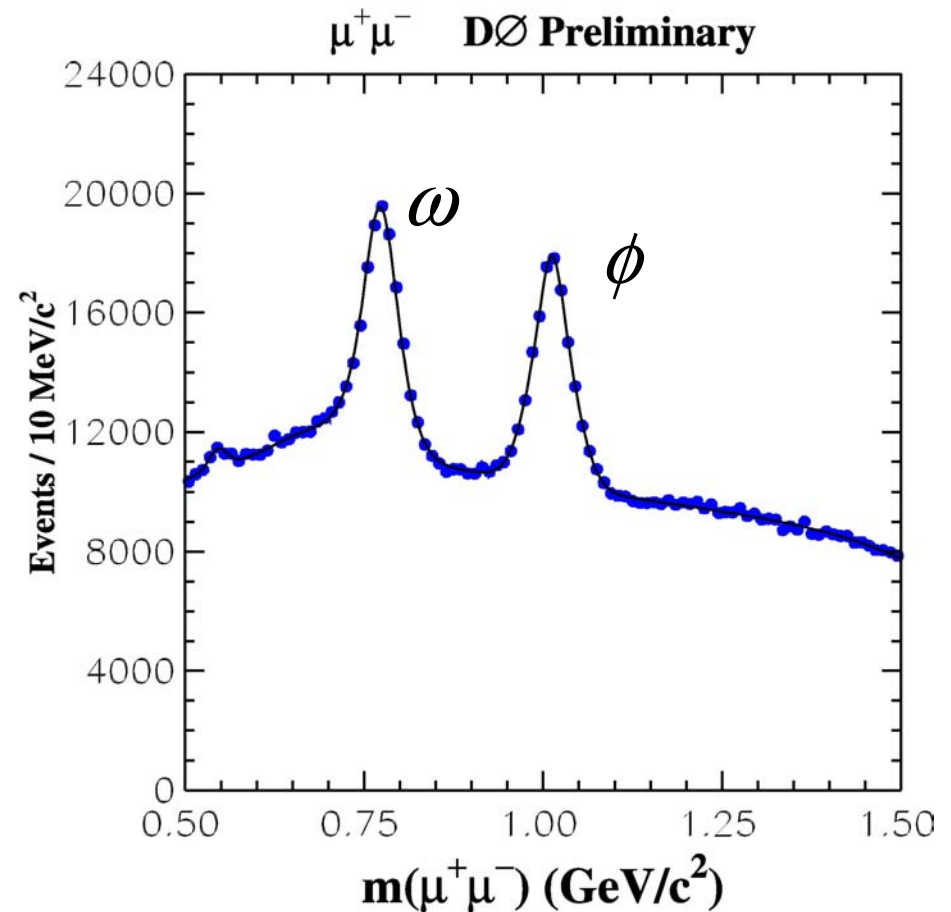


- RPV in the up sector
Burdman et.al.
hep-ph/0112234
- Little Higgs Models
Fajfer et.al.
hep-ph/0511048



$c \rightarrow u\mu^+\mu^-$ Analysis

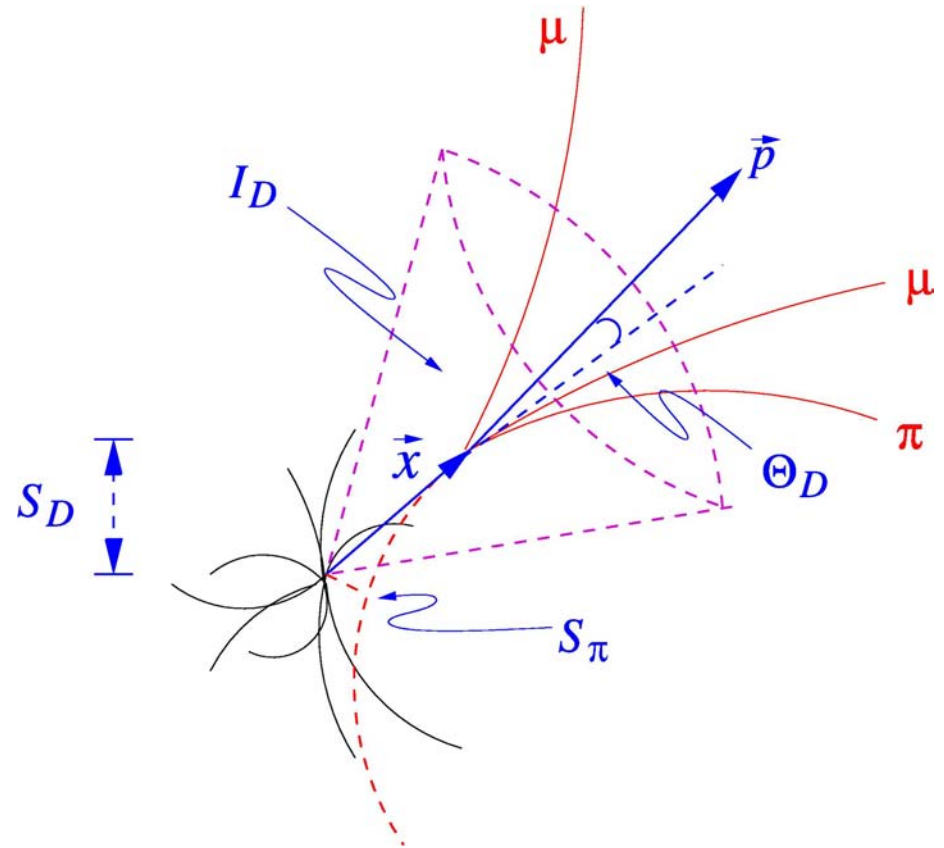
- $\sim 1 \text{ fb}^{-1}$ of data
- Find $D_s^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ \mu^+ \mu^-$
 - (100% of $D_s^+ \rightarrow \pi^+ \phi$)
 - $\text{BF}(D_s^+ \rightarrow \pi^+ \phi) = 0.036 \pm 0.009$
 - $\text{BF}(\phi \rightarrow \mu^+ \mu^-) = (2.850 \pm 0.19) \times 10^{-4}$
- Search for $D^+ \rightarrow \pi^+ \mu^+ \mu^-$
for $m(\mu^+ \mu^-) \neq m(\phi)$
- Add track to low mass dimuon candidate





Selection and Optimization Criteria

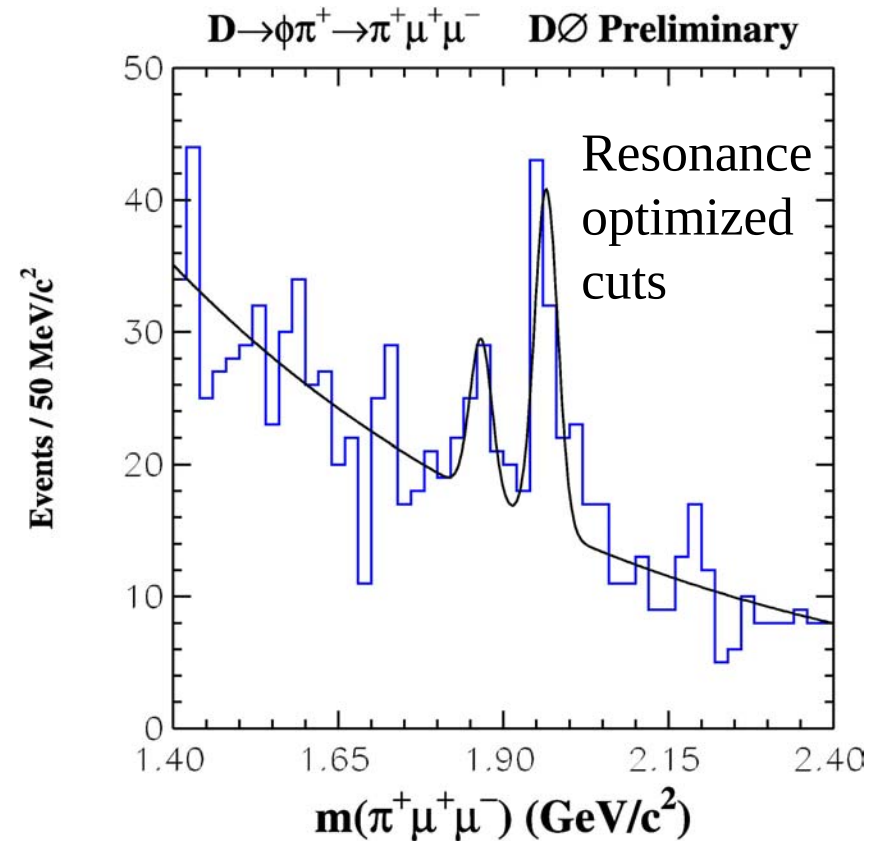
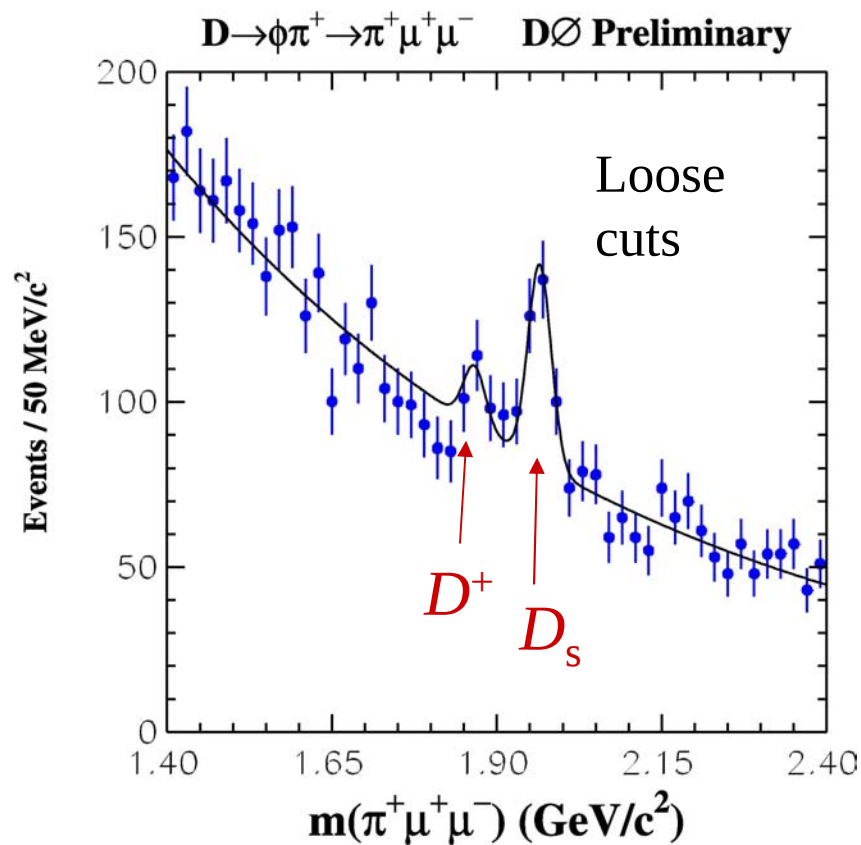
- Isolation: $I_D = p(D)/\Sigma p_{\text{cone}}$
 - $R = (\Delta\eta^2 + \Delta\phi^2)^{1/2} < 1.0$
- Transverse flight length significance: S_D
- Collinearity angle: Θ_D
- Pion impact parameter significance: S_π
- $M = \chi^2_{\text{vtx}} + \kappa_\pi^2 + \Delta R_\pi^2$
 - $\kappa_\pi = 1/p_T(\pi)$





$$D^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ \mu^+ \mu^-$$

$$0.96 < m(\mu^+ \mu^-) < 1.06 \text{ GeV}/c^2$$



$$n(D^+) = 26 \pm 9 \quad n(D_s) = 65 \pm 11$$



Extracting the Resonant Branching Fraction

$$\frac{n(D^+)}{n(D_s)} = \frac{f_{c \rightarrow D}^+}{f_{c \rightarrow D}^s} \times \frac{f_p^s}{f_p^+} \times \frac{\epsilon^+}{\epsilon^s} \times \frac{\text{BF}(D^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ \mu^+ \mu^-)}{\text{BF}(D_s^+ \rightarrow \phi \pi^+) \times \text{BF}(\phi \rightarrow \mu^+ \mu^-)}$$

$f_{c \rightarrow D}$: Fraction produced in fragmentation

f_p : Prompt fraction

ϵ : Reconstruction efficiency

$$\frac{\text{BF}(D^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ \mu^+ \mu^-)}{\text{BF}(D_s^+ \rightarrow \phi \pi^+) \times \text{BF}(\phi \rightarrow \mu^+ \mu^-)} = 0.17 \pm 0.07 \pm 0.05$$

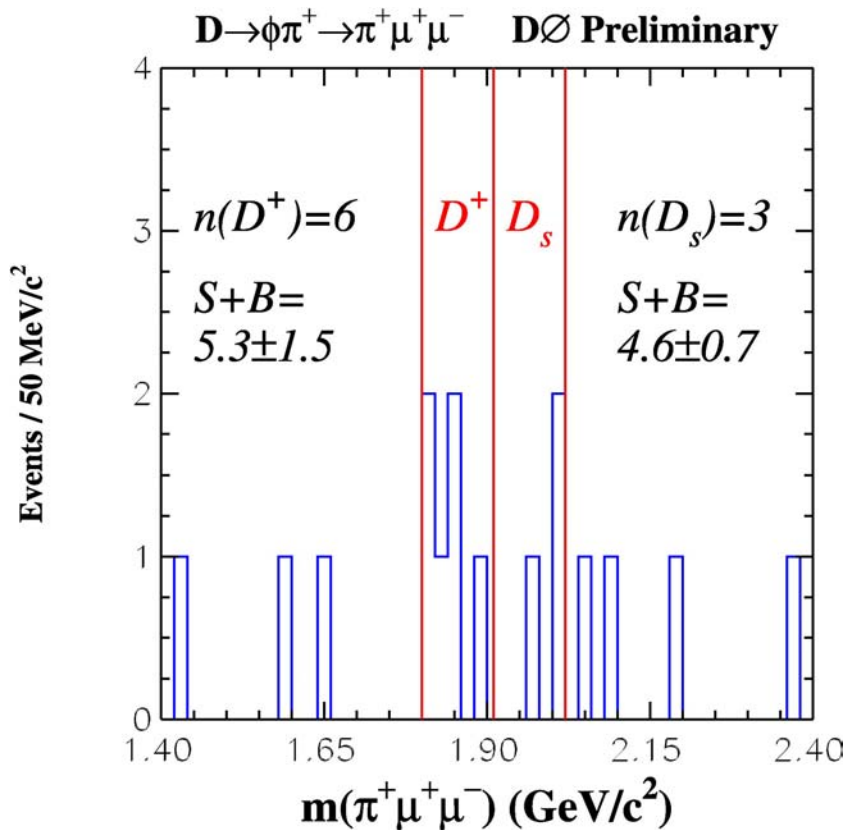
$$\text{BF}(D^+ \rightarrow \pi^+ \phi \rightarrow \pi^+ \mu^+ \mu^-) = (1.75 \pm 0.7 \pm 0.5) \times 10^{-6}$$

$$\text{SM: } 1.77 \times 10^{-6} \quad \text{CLEO-c } (\phi \rightarrow ee): (2.7^{+3.6}_{-1.8} \pm 0.2) \times 10^{-6}$$

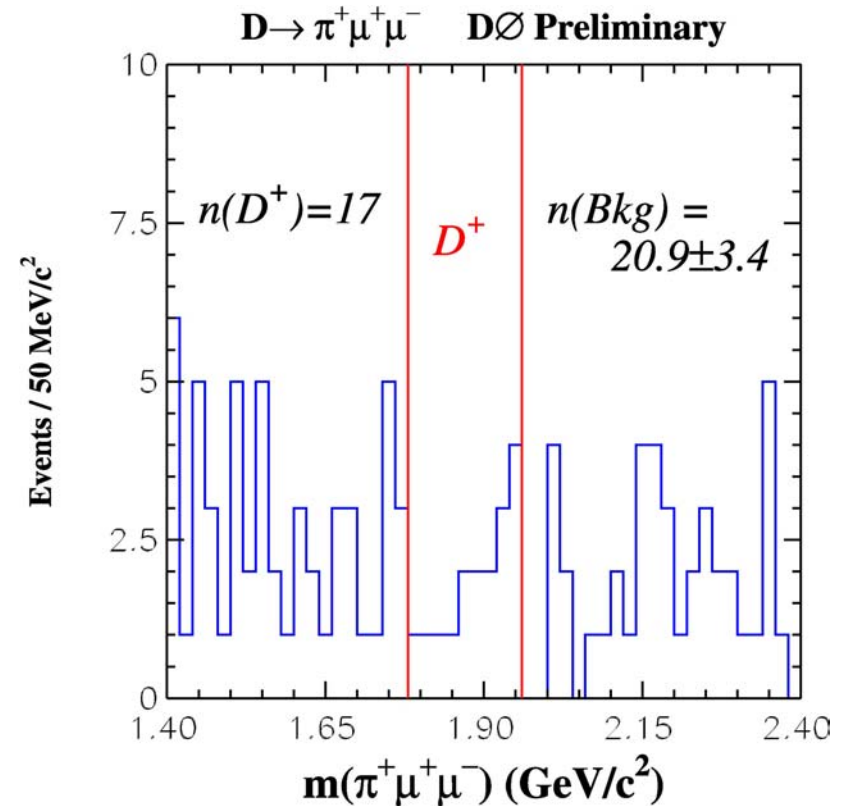


Nonresonant $D^+ \rightarrow \pi^+ \mu^+ \mu^-$

$$0.96 < m(\mu\mu) < 1.06 \text{ GeV}/c^2$$



$$0.2 < m(\mu\mu) < 0.96 \text{ GeV}/c^2$$
$$1.06 < m(\mu\mu) < 1.76 \text{ GeV}/c^2$$

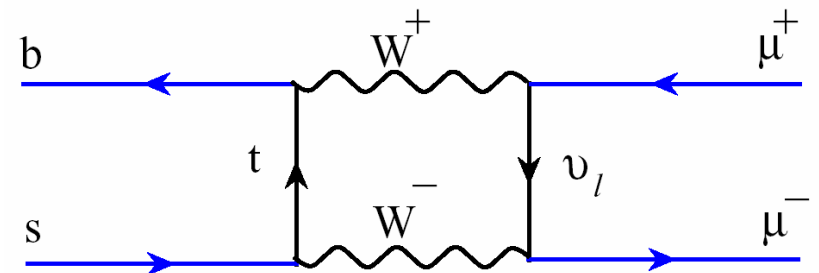
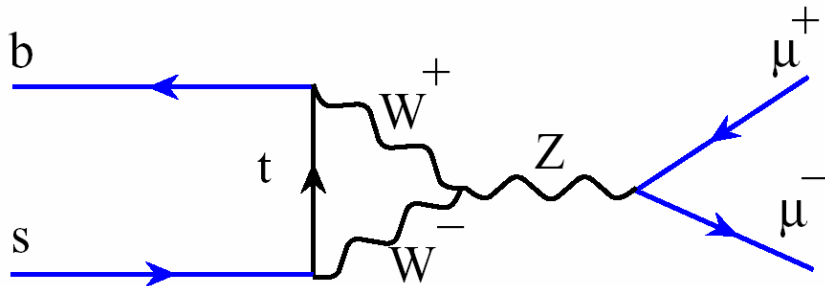


$$\text{BF}(D^+ \rightarrow \pi^+ \mu^+ \mu^-) < 4.7 \times 10^{-6} @ 90\% \text{ C.L.}$$



$$B_s^0 \rightarrow \mu^+ \mu^-$$

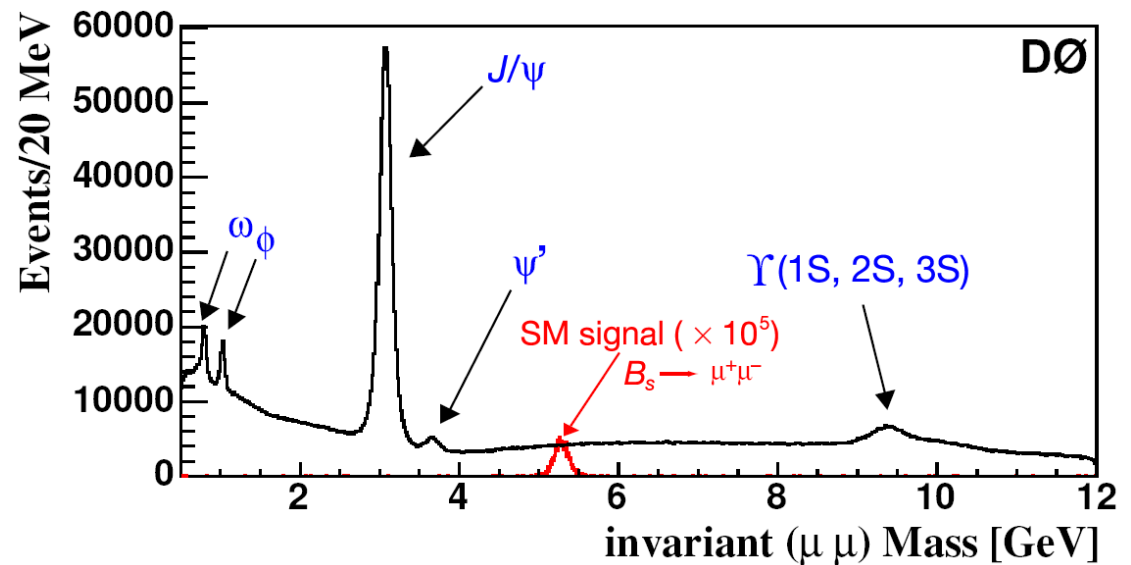
- FCNC with zero cross section at tree level
- SM Branching Fraction:
 - $\text{BF}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.42 \pm 0.54) \times 10^{-9}$
 - $\text{BF}(B_d^0 \rightarrow \mu^+ \mu^-) = (1.00 \pm 0.14) \times 10^{-10}$
- Non-SM processes can enhance $\text{BF}(B_s^0 \rightarrow \mu^+ \mu^-)$
 - MSSM enhances BF up to 3 orders of magnitude
 - 2HDM, minimal supergravity, minimal SO(10) GUT, all have BF enhancements





Search for $B_s^0 \rightarrow \mu^+ \mu^-$

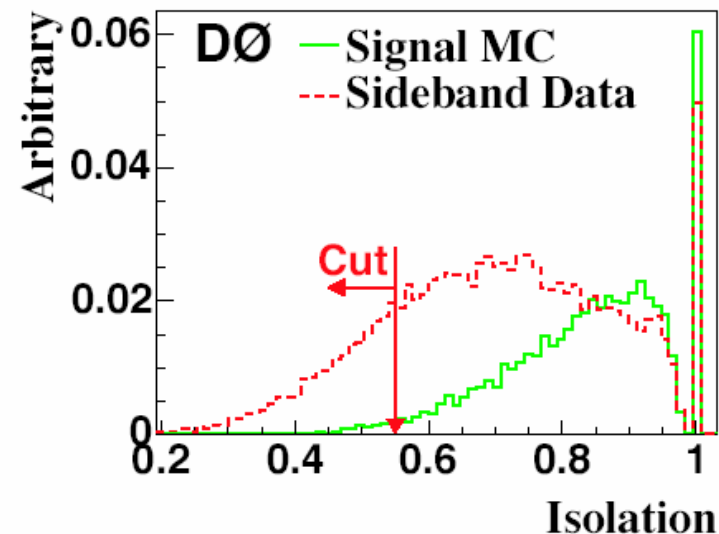
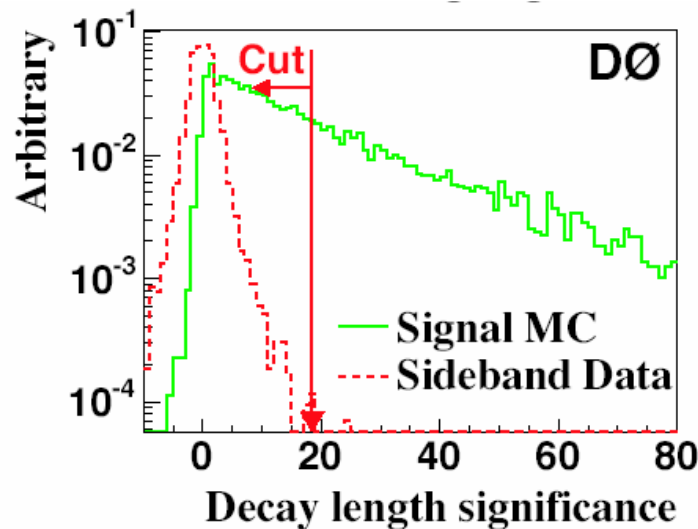
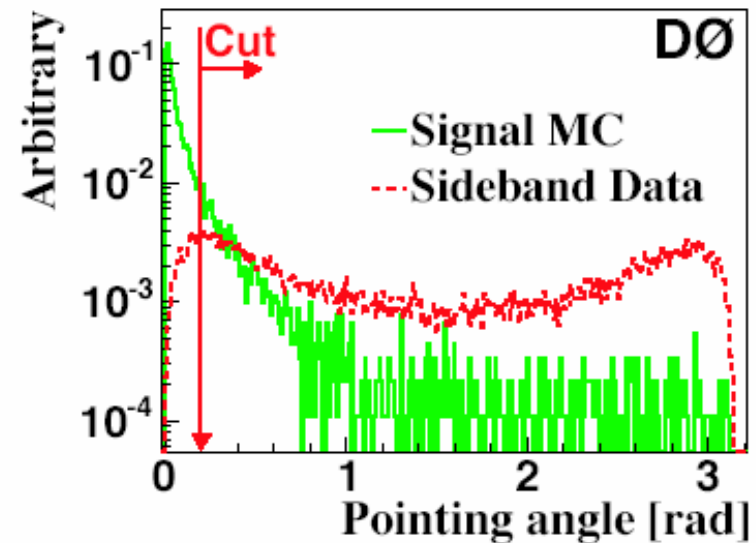
- 300 pb⁻¹ data analyzed (*PRL* 94, 071802 (2005))
- Sensitivity for 0.7 fb⁻¹ determined
- Blind analysis to avoid bias
- Side bands used for background determination
- Normalize to resonant decay $B^+ \rightarrow J/\psi K^+$
- $p_T(\mu) > 2.5$ GeV/c
- $|\eta(\mu)| < 2$
- $\chi^2_{\text{vertex}} < 10$
- CFT hits > 4
- SMT hits > 3
- $p_T(B_s) > 5$ GeV/c
- $\delta L_{xy} < 0.15$ mm





Analysis and Optimization

- Optimization using MC signal and background from data sidebands using:
 - Collinearity (Pointing) Angle
 - Decay length significance
 - Isolation

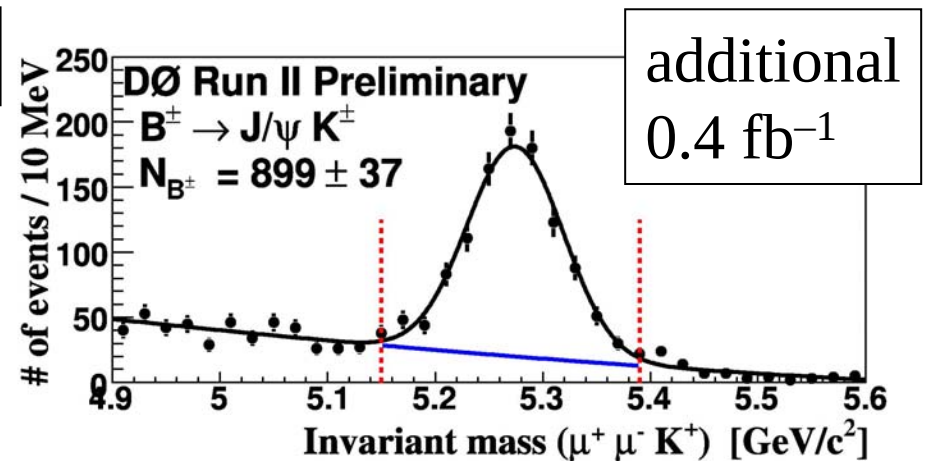
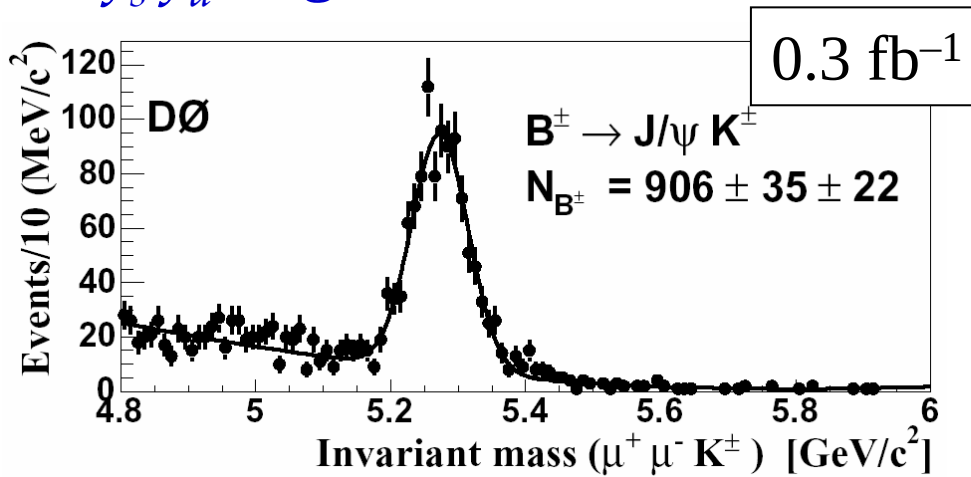




Analysis and Normalization

$$\text{BF}(B_s^0 \rightarrow \mu^+ \mu^-) \leq \frac{N_{\text{ul}}}{N_{B^\pm}} \cdot \frac{\epsilon_{\mu\mu K}^{B^\pm}}{\epsilon_{\mu\mu}^{B_s^0}} \cdot \frac{\text{BF}(B^\pm \rightarrow J/\psi(\mu^+ \mu^-) K^\pm)}{\frac{f_{b \rightarrow B_s}}{f_{b \rightarrow B_{u,d}}} + R \cdot \frac{\epsilon_{\mu\mu}^{B_d^0}}{\epsilon_{\mu\mu}^{B_s^0}}}$$

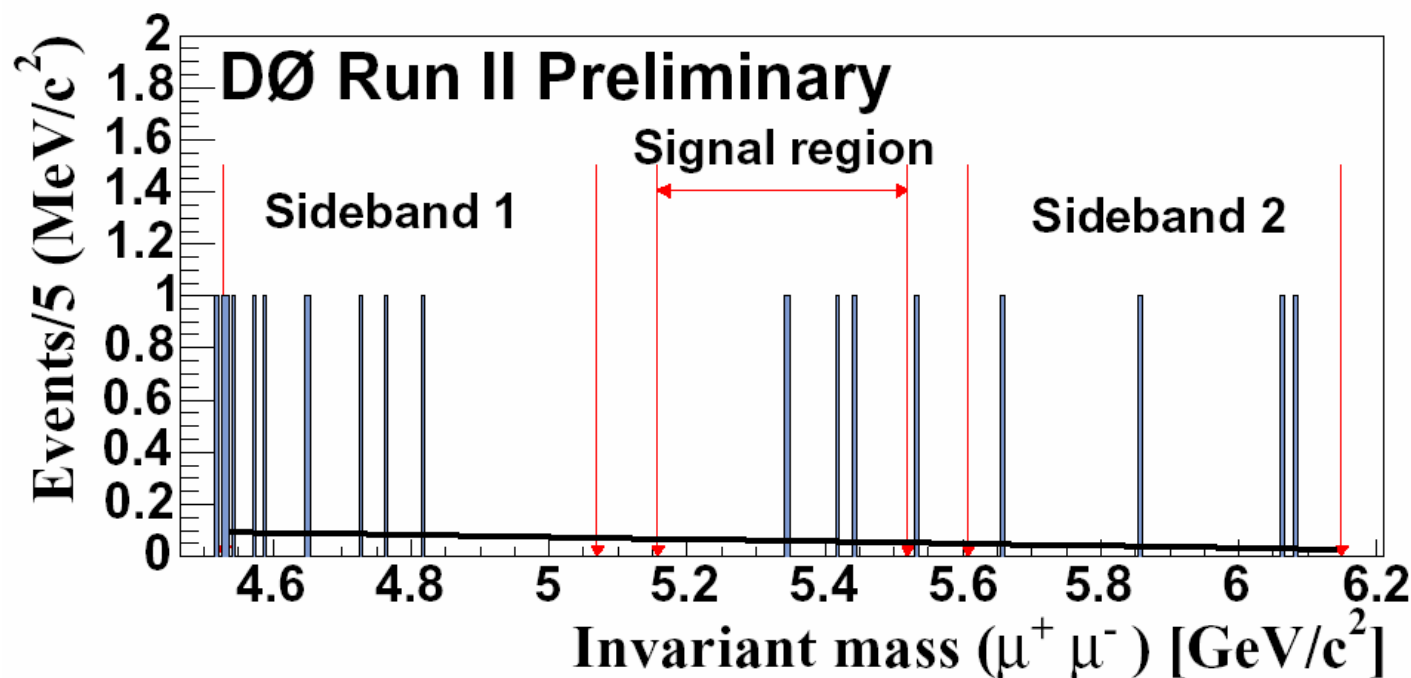
- $R = \text{BF}(B_d)/\text{BF}(B_s)$ is small due to $|V_{td}/V_{ts}|^2$
- $\epsilon_{B^\pm}/\epsilon_{B_s}$ efficiency
- $\epsilon_{B_d}/\epsilon_{B_s}$ relative efficiency for $B_d \rightarrow \mu^+ \mu^-$ versus $B_s \rightarrow \mu^+ \mu^-$
- f_s/f_u fragmentation ratio





300 pb⁻¹ Limit (published 2005)

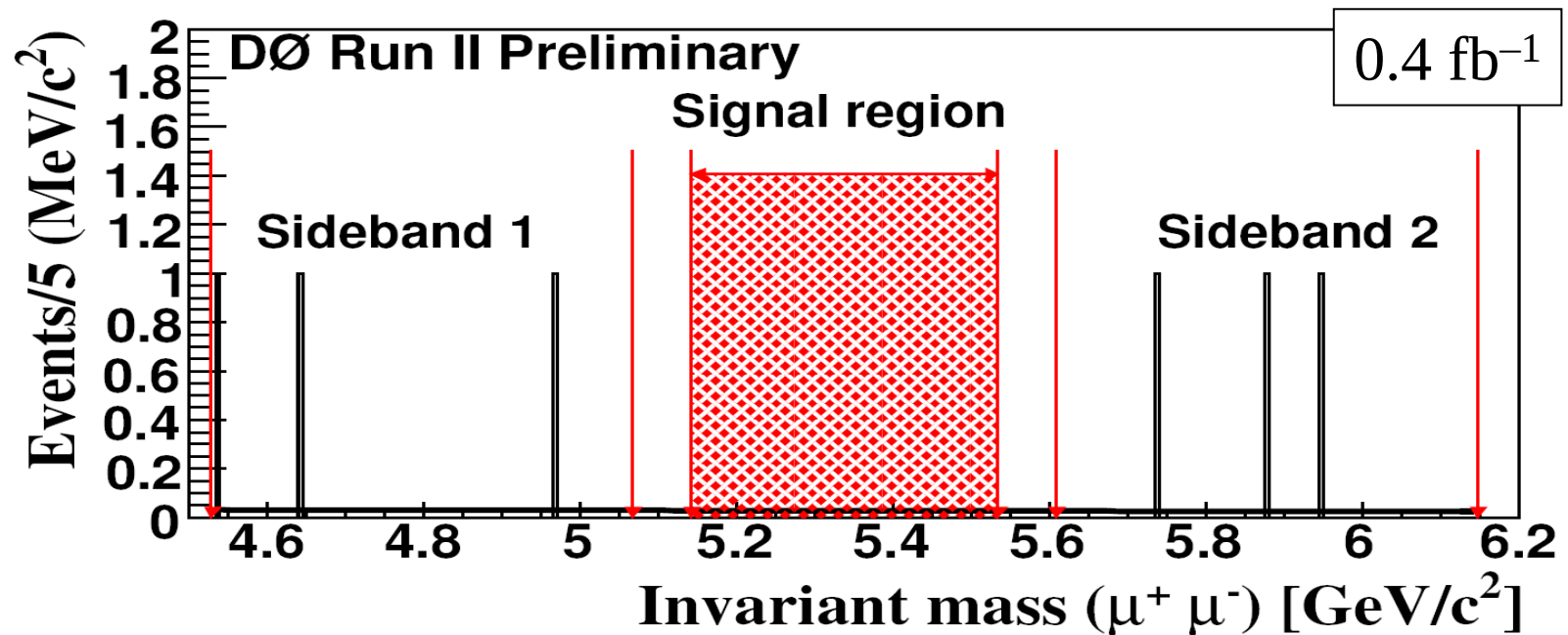
Observed 4, expect 4.3 ± 1.2



$$\text{BF}(B_s \rightarrow \mu^+ \mu^-) < 5.0 \times 10^{-7} @ 95\% \text{ C.L.}$$



DØ Sensitivity 0.7 fb^{-1}

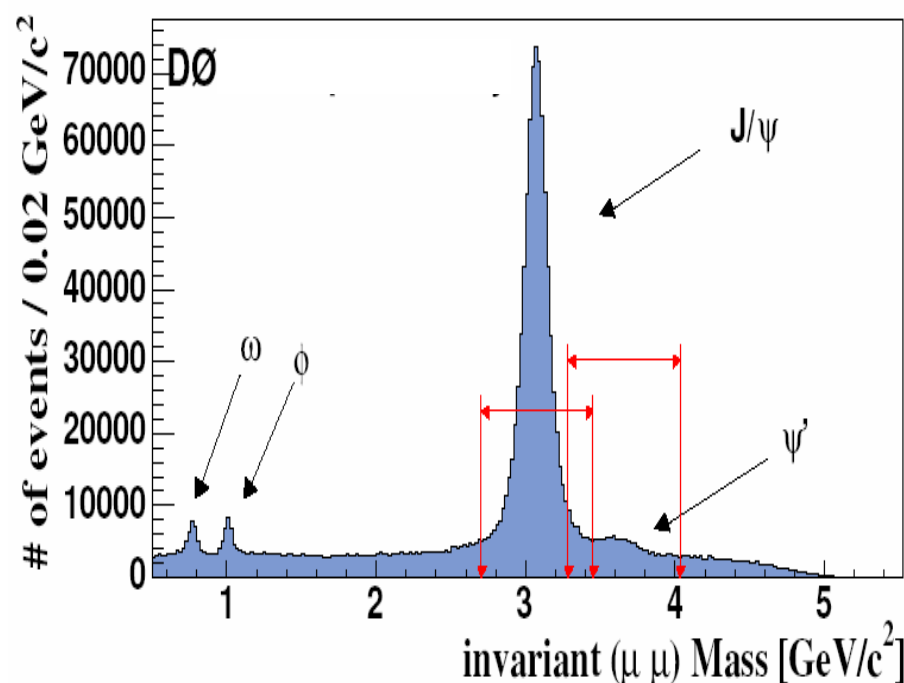


- For new dataset of 0.4 fb^{-1}
 - Expect 2.2 ± 0.7 background events
 - Expect a sensitivity of about 3.0×10^{-7} @ 95% C.L.
- Combined 0.7 fb^{-1} sensitivity of 1.9×10^{-7} @ 95% C.L



Search for $B_s^0 \rightarrow \phi \mu^+ \mu^-$

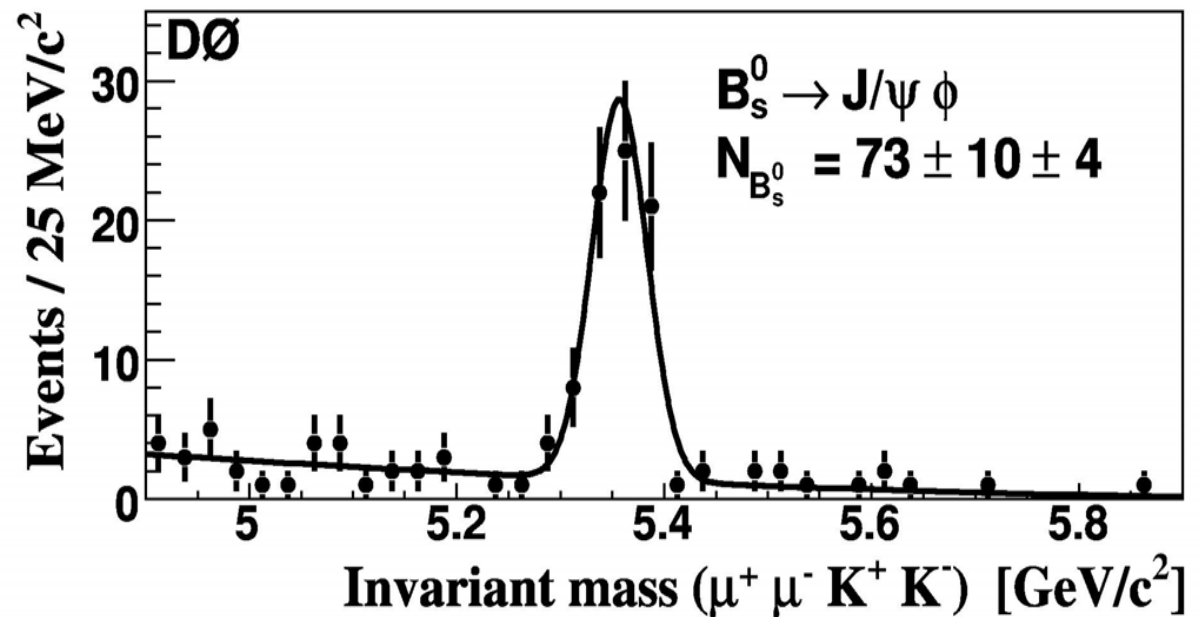
- $\sim 0.45 \text{ fb}^{-1}$ of data
- Similar selection criteria to $B_s^0 \rightarrow \mu^+ \mu^-$
- $0.5 < m(\mu\mu) < 4.4 \text{ GeV}/c^2$ – excluding $\pm 5\sigma$ around J/ψ & $\psi(2S)$
- $\phi \rightarrow K^+ K^-$
- $p_T(K) > 0.7 \text{ GeV}/c$
- $1.008 < m(\phi) < 1.032 \text{ GeV}/c^2$





Analysis Method

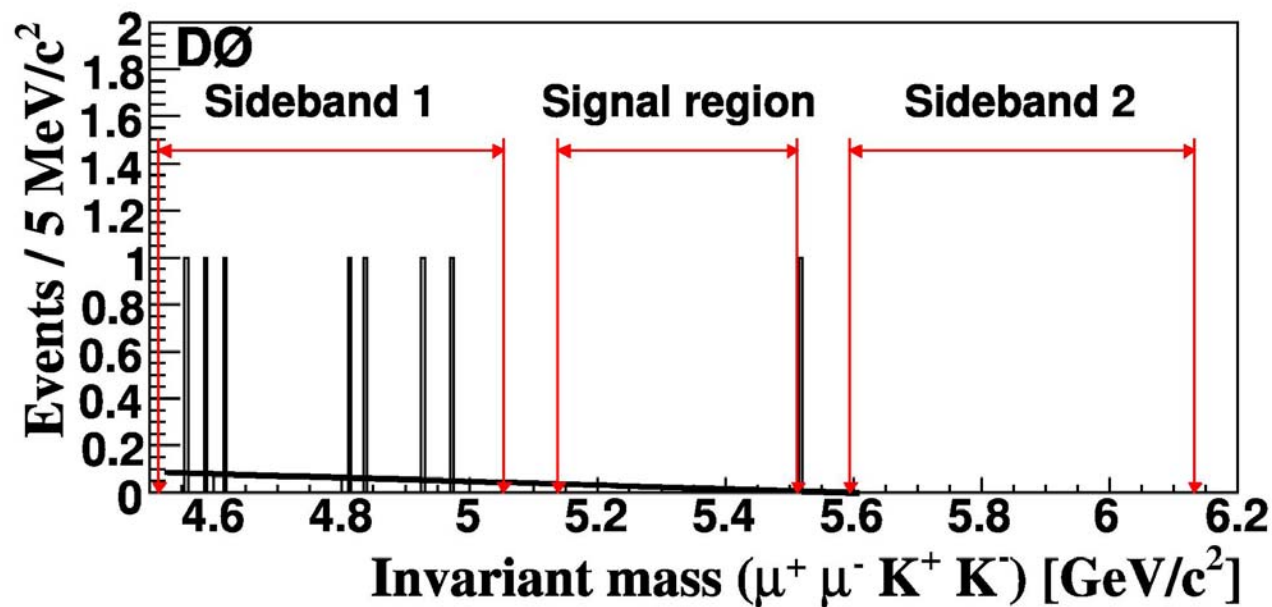
- Blind analysis – Optimization using MC signal and background from data sidebands using:
 - Pointing Angle < 0.1 rad
 - Decay length significance > 10.3
 - Isolation > 0.72
- Normalize to resonant decay
 $B_s \rightarrow J/\psi \phi$





$B_s^0 \rightarrow \phi \mu^+ \mu^-$ Results

- Expected background from sidebands: 1.6 ± 0.4 events
- Observe zero events in signal region





$B_s^0 \rightarrow \phi \mu^+ \mu^-$ Results

$$\frac{\text{BF}(B_s^0 \rightarrow \phi \mu^+ \mu^-)}{\text{BF}(B_s^0 \rightarrow J/\psi \phi)} = \frac{N_{\text{ul}}}{N_{B_s^0}} \cdot \frac{\mathcal{E}_{J/\psi \phi}}{\mathcal{E}_{\phi \mu^+ \mu^-}} \cdot B(J/\psi \rightarrow \mu^+ \mu^-)$$

$$\frac{\text{BF}(B_s^0 \rightarrow \phi \mu^+ \mu^-)}{\text{BF}(B_s^0 \rightarrow J/\psi \phi)} < 4.4 \times 10^{-3}$$

@ 95% C.L

$$\text{BF}(B_s^0 \rightarrow \phi \mu^+ \mu^-) < 4.1 \times 10^{-6}$$

(10 times better than best limit)

Accepted for PRD Rapid Communication

- SM $\text{BF}(B_s^0 \rightarrow \phi \mu^+ \mu^-) \sim 1.6 \times 10^{-6}$ (30% uncertainty)
(Geng and Liu, *J. Phys G* 29, 1103 (2003))
- Accessible with about 4 fb^{-1} of data



Conclusions

- Searches for FCNC can give insight into physics beyond the Standard Model
- New DØ limits on $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $B_s^0 \rightarrow \phi \mu^+ \mu^-$ are world's best
- New limit on $B_s^0 \rightarrow \mu^+ \mu^-$ should be coming soon