Rare Heavy Flavor Decays at DØ

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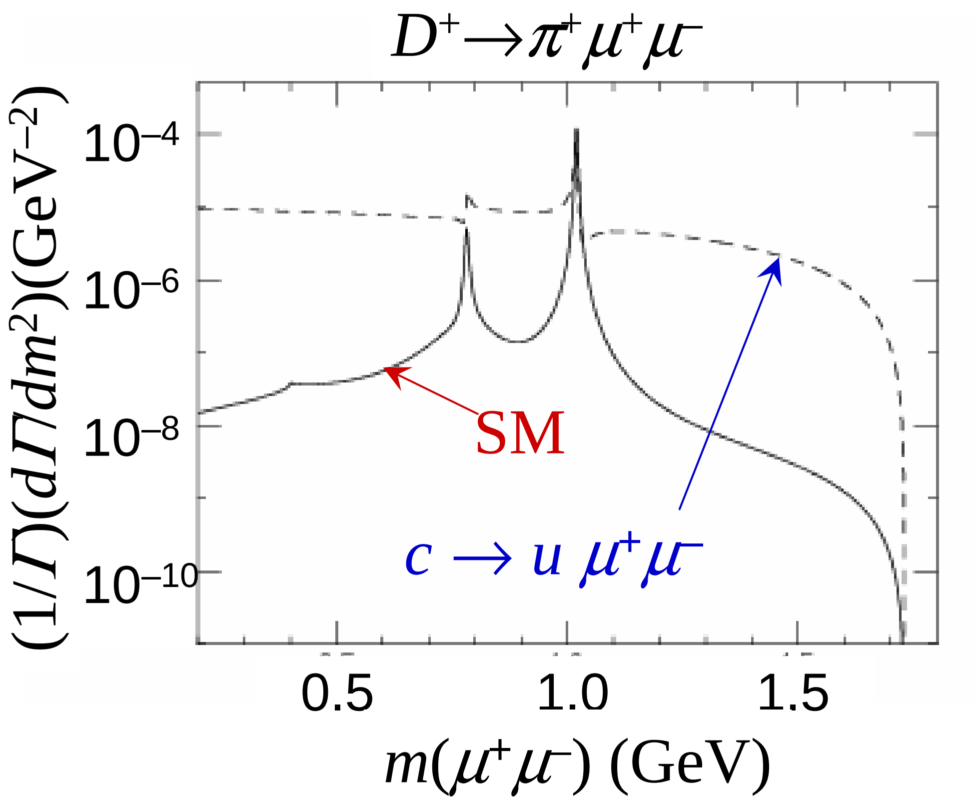
Outline

- 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

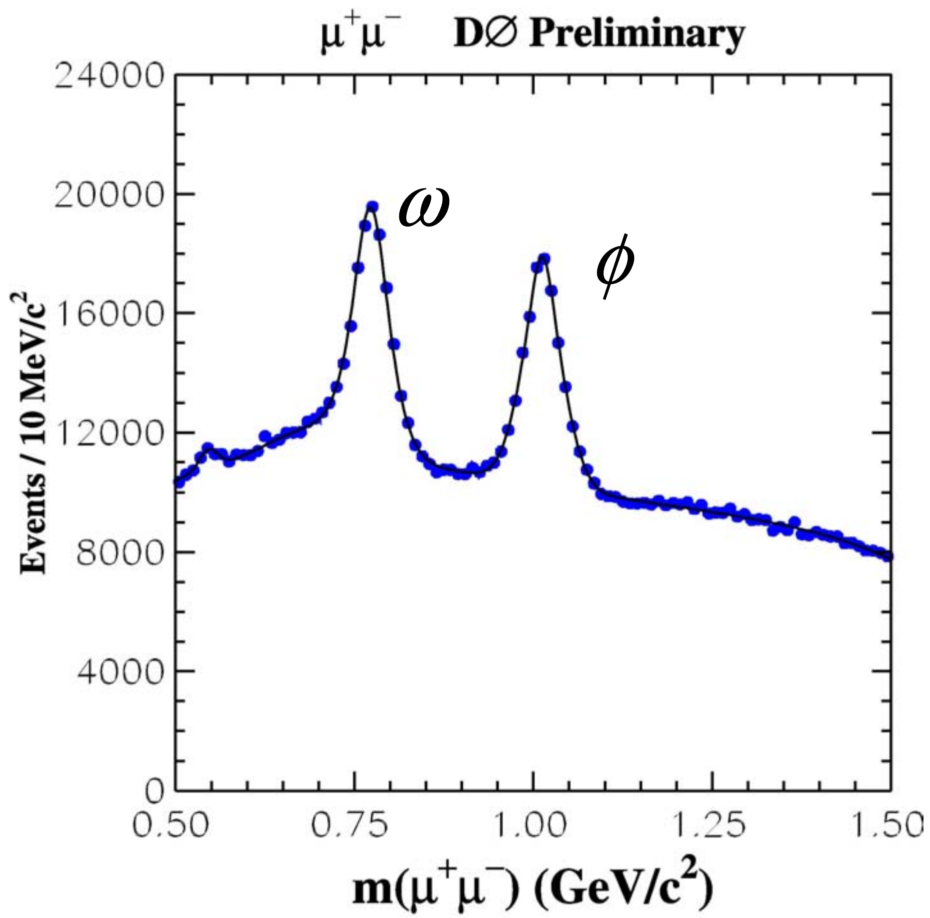
- Experimental limits exist for $b \rightarrow s$ and $s \rightarrow d$
- Some models predict violations from SM in up quark sector, but not down quark sector



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

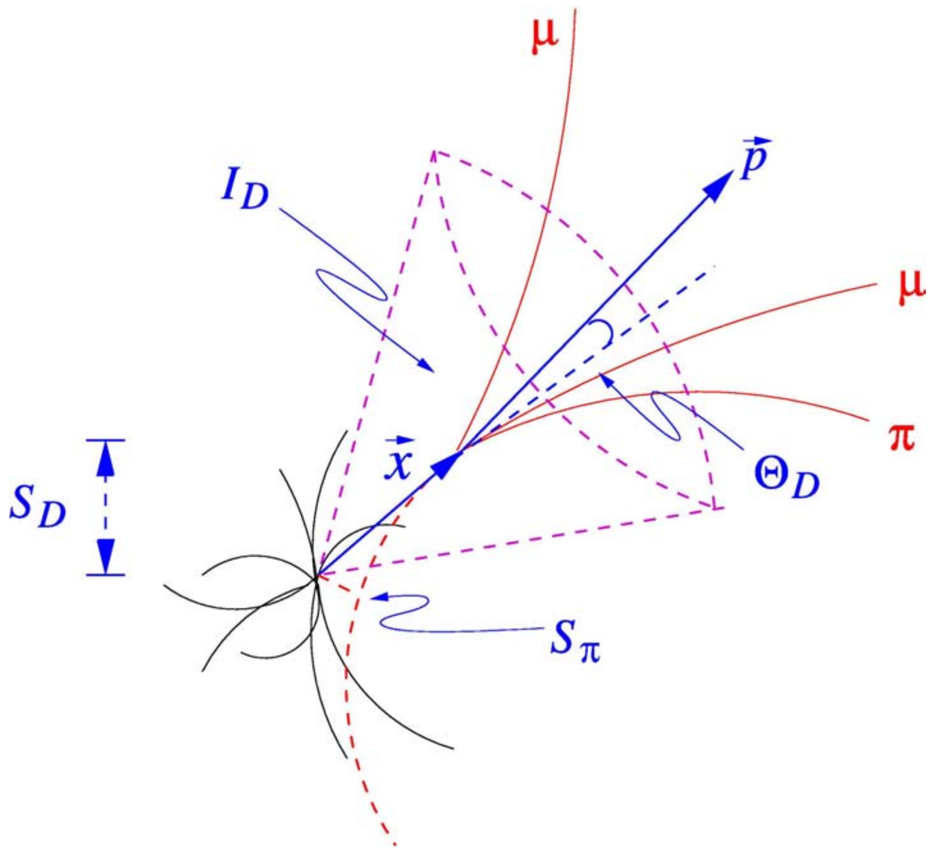
$c \to u\mu^+\mu^-$ Analysis

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



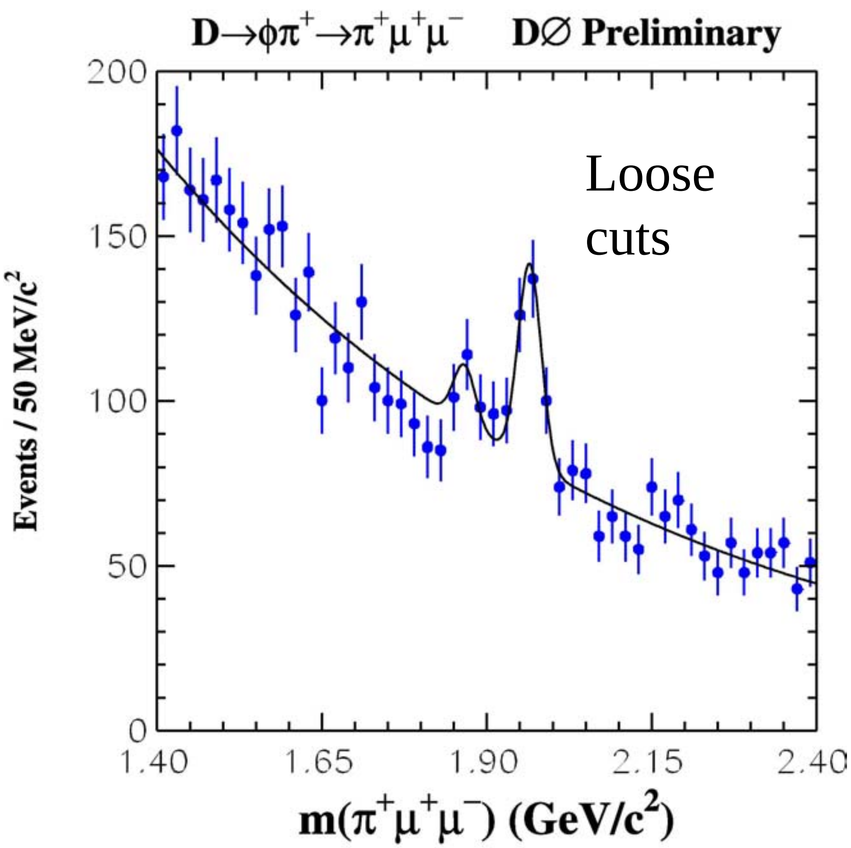
Selection and Optimization Criteria

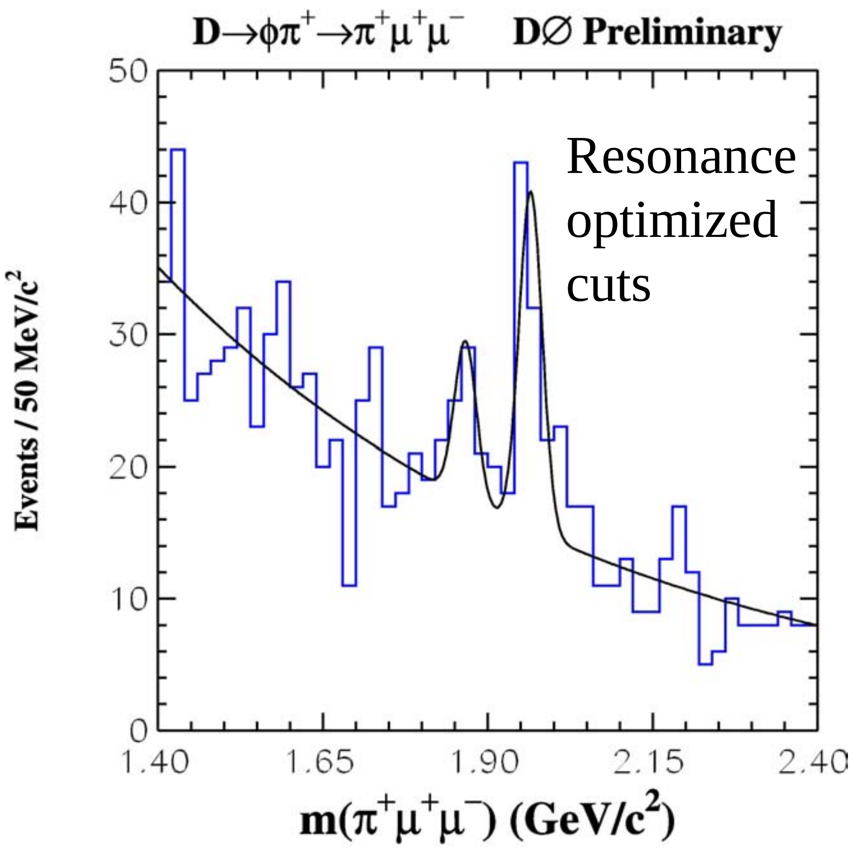
- Isolation: $I_D = p(D)/\sum p_{\text{cone}}$
  - $R = (\Delta\eta^2 + \Delta\phi^2)^{½} < 1.0$
- Transverse flight length significance: S_D
- Collinearity angle: Θ_D
- Pion impact parameter significance: S_π
- $M = \chi^2_{\text{vtx}} + \kappa_\pi^2 + \Delta R_\pi^2$
  - $\kappa_\pi = 1/p_T(\pi)$



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

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





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

Extracting the Resonant Branching Fraction

$$\frac{n(D^+)}{n(D_s)} = \frac{f^{+}_{c\to D}}{f^{s}_{c\to D}} \times \frac{f^{s}_{p}}{f^{+}_{p}} \times \frac{\varepsilon^{+}}{\varepsilon^{s}} \times \frac{\mathrm{BF}(D^+ \to \pi^+\phi \to \pi^+\mu^+\mu^-)}{\mathrm{BF}(D_s^+ \to \phi\pi^+) \times \mathrm{BF}(\phi \to \mu^+\mu^-)}$$

$f_{c\to D}$: Fraction produced in fragmentation
f_p: Prompt fraction
ε: Reconstruction efficiency

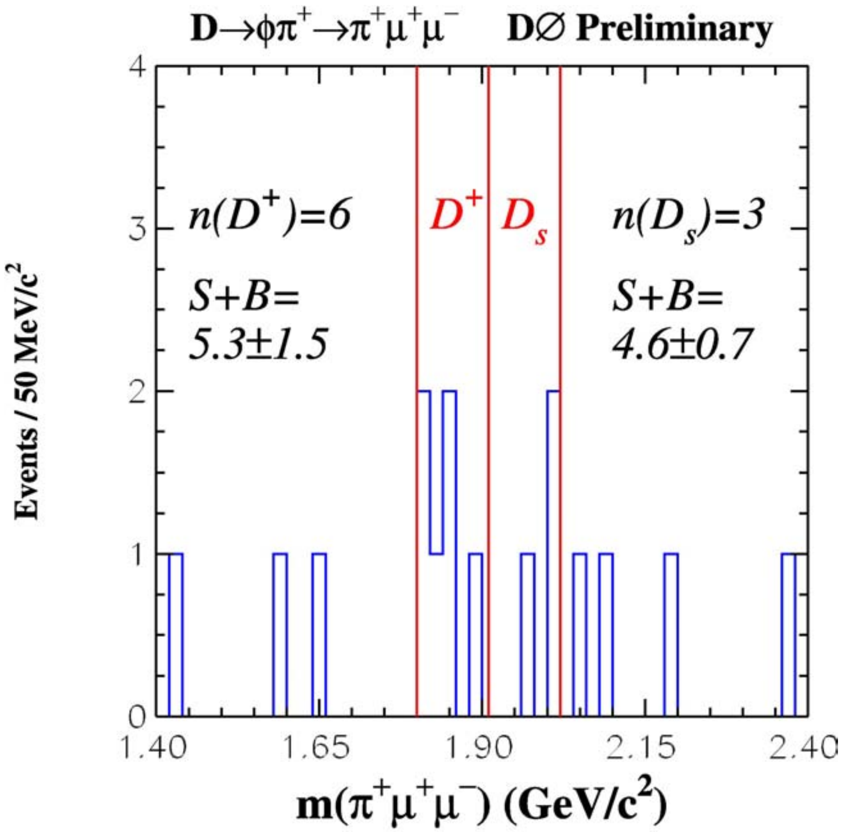
$$\frac{\mathrm{BF}(D^+ \to \pi^+\phi \to \pi^+\mu^+\mu^-)}{\mathrm{BF}(D_s^+ \to \phi\pi^+) \times \mathrm{BF}(\phi \to \mu^+\mu^-)} = 0.17 \pm 0.07 \pm 0.05$$

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

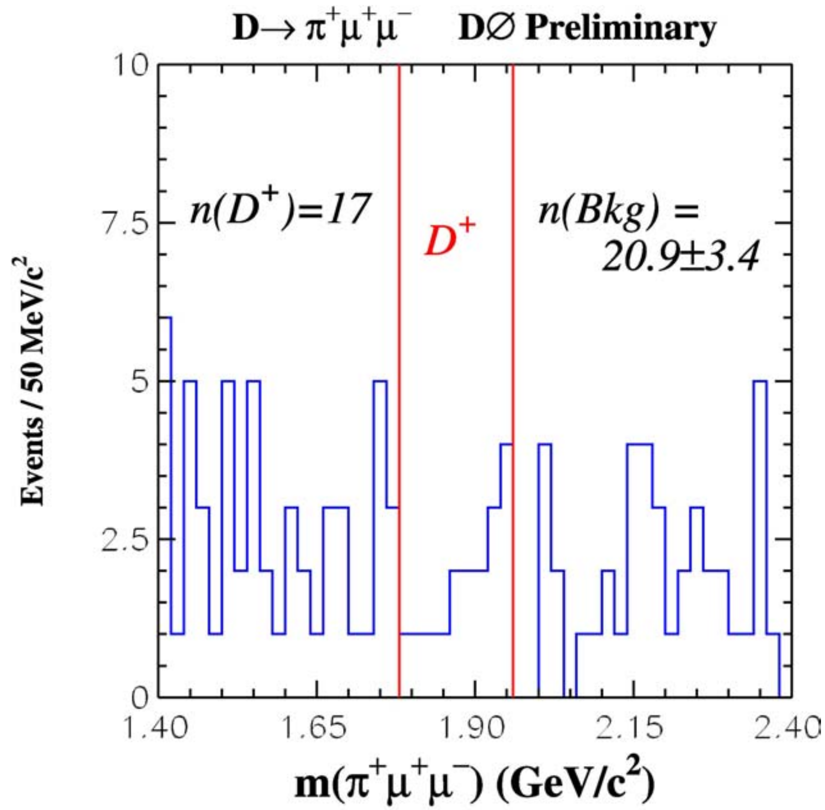
SM: 1.77×10^{-6} CLEO-c ($\phi\to ee$): $(2.7^{+3.6}_{-1.8} \pm 0.2)\times10^{-6}$

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

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



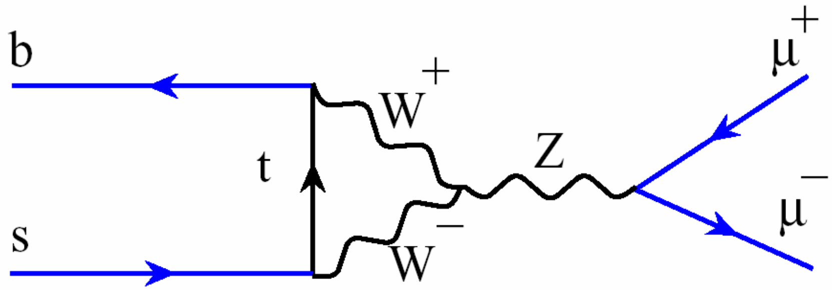
$0.2 < m(\mu\mu) < 0.96$ GeV/c^2
$1.06 < m(\mu\mu) < 1.76$ GeV/c^2

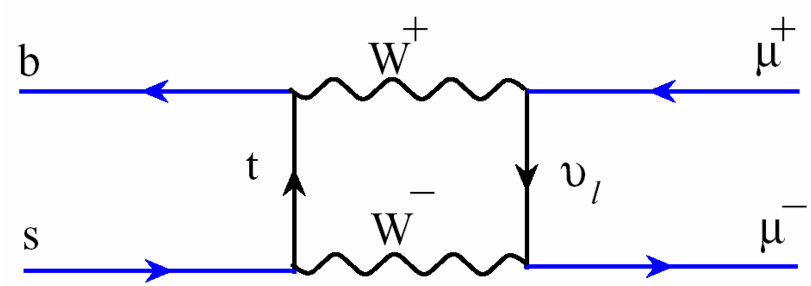


BF($D^+ \to \pi^+ \mu^+ \mu^-$) $< 4.7\times10^{-6}$ @ 90% C.L

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

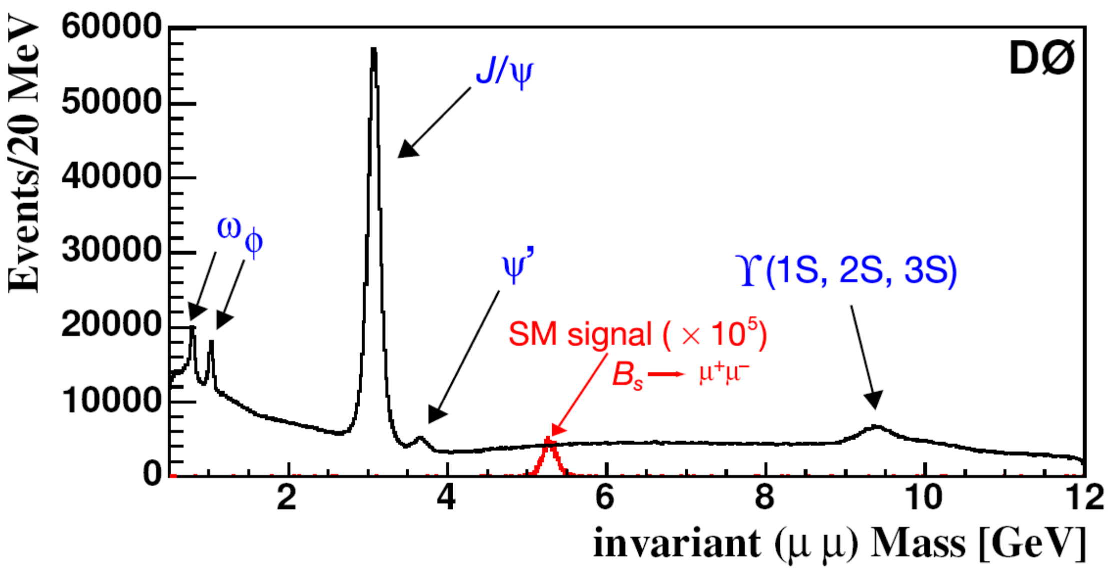
- FCNC with zero cross section at tree level
- SM Branching Fraction:
  - $BF(B_s^0 \to \mu^+ \mu^-) = (3.42 \pm 0.54) \times 10^{-9}$
  - $BF(B_d^0 \to \mu^+ \mu^-) = (1.00 \pm 0.14) \times 10^{-10}$
- Non-SM processes can enhance $BF(B_s^0 \to \mu^+ \mu^-)$
  - MSSM enhances BF up to 3 orders of magnitude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





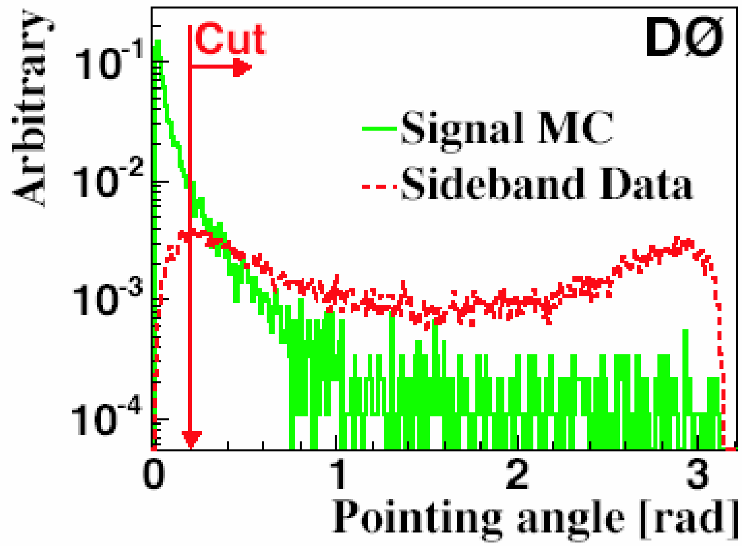
Search for $B_s^0 \rightarrow \mu^+ \mu^-$

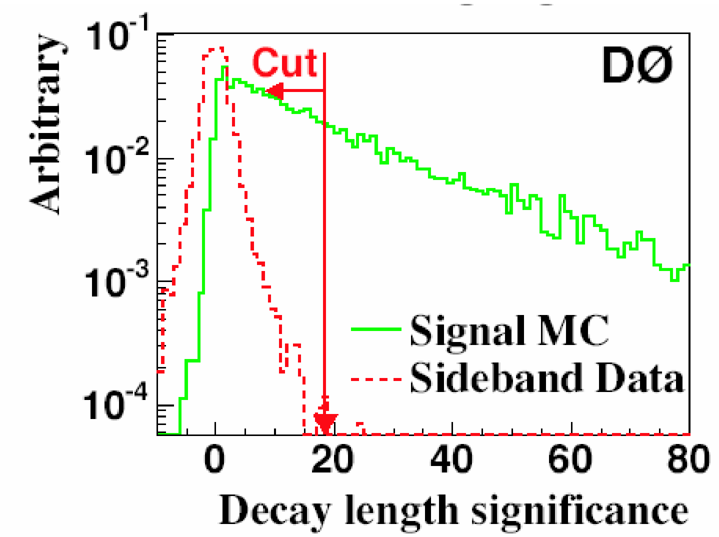
- 300 pb^{-1} data analyzed (*PRL 94, 071802 (2005)*)
- Sensitivity for 0.7 fb^{-1} determined
- Blind analysis to avoid bias
- Side bands used for background determination
- Normalize to resonant decay $B^+ \rightarrow J/\psi K^+$
  - $p_T(\mu) > 2.5$ GeV/c
  - $|\eta(\mu)| < 2$
  - $\chi^2_{vertex}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

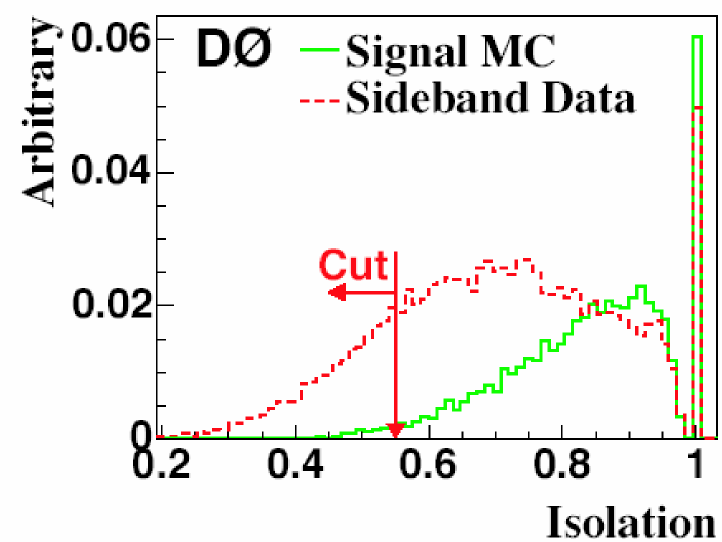


Analysis and Optimization

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



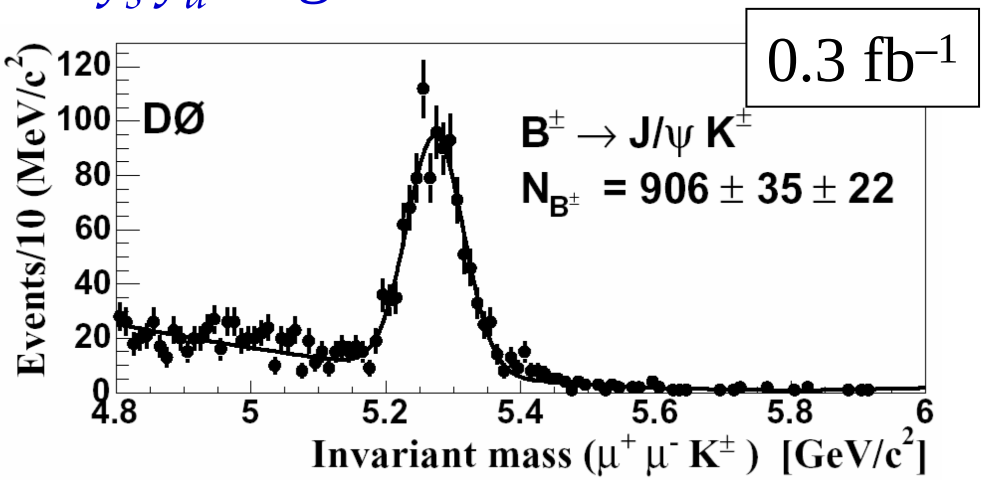


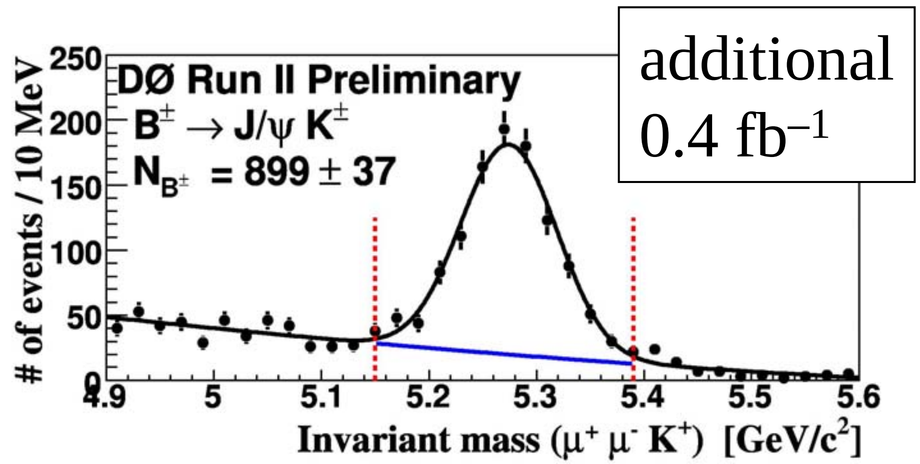


Analysis and Normalization

$$\mathrm{BF}\left(B_s^0 \to \mu^+\mu^-\right) \le \frac{N_{\mathrm{ul}}}{N_{B^\pm}} \cdot \frac{\varepsilon_{\mu\mu K}^{B^\pm}}{\varepsilon_{\mu\mu}^{B_s^0}} \cdot \frac{\mathrm{BF}\left(B^\pm \to J/\psi\left(\mu^+\mu^-\right)K^\pm\right)}{\dfrac{f_{b\to B_s}}{f_{b\to B_{u,d}}} + R\cdot \dfrac{\varepsilon_{\mu\mu}^{B_d^0}}{\varepsilon_{\mu\mu}^{B_s^0}}}$$

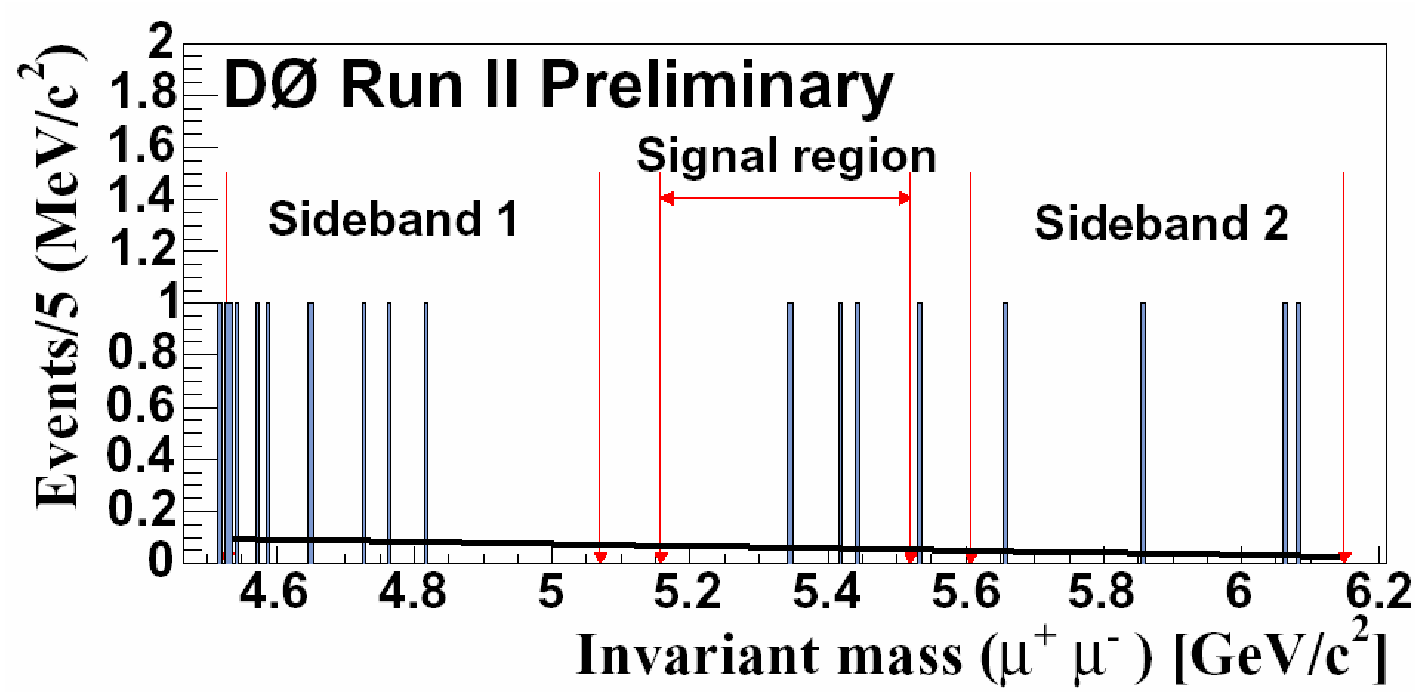
- R = BF(B_d)/BF(B_s) is small due to $|V_{td}/V_{ts}|^2$
- $\varepsilon_{B^+}/\varepsilon_{Bs}$ efficiency
- $\varepsilon_{Bd}/\varepsilon_{Bs}$ relative efficiency for $B_d \to \mu^+\mu^-$ versus $B_s \to \mu^+\mu^-$
- f_s/f_u fragmentation ratio





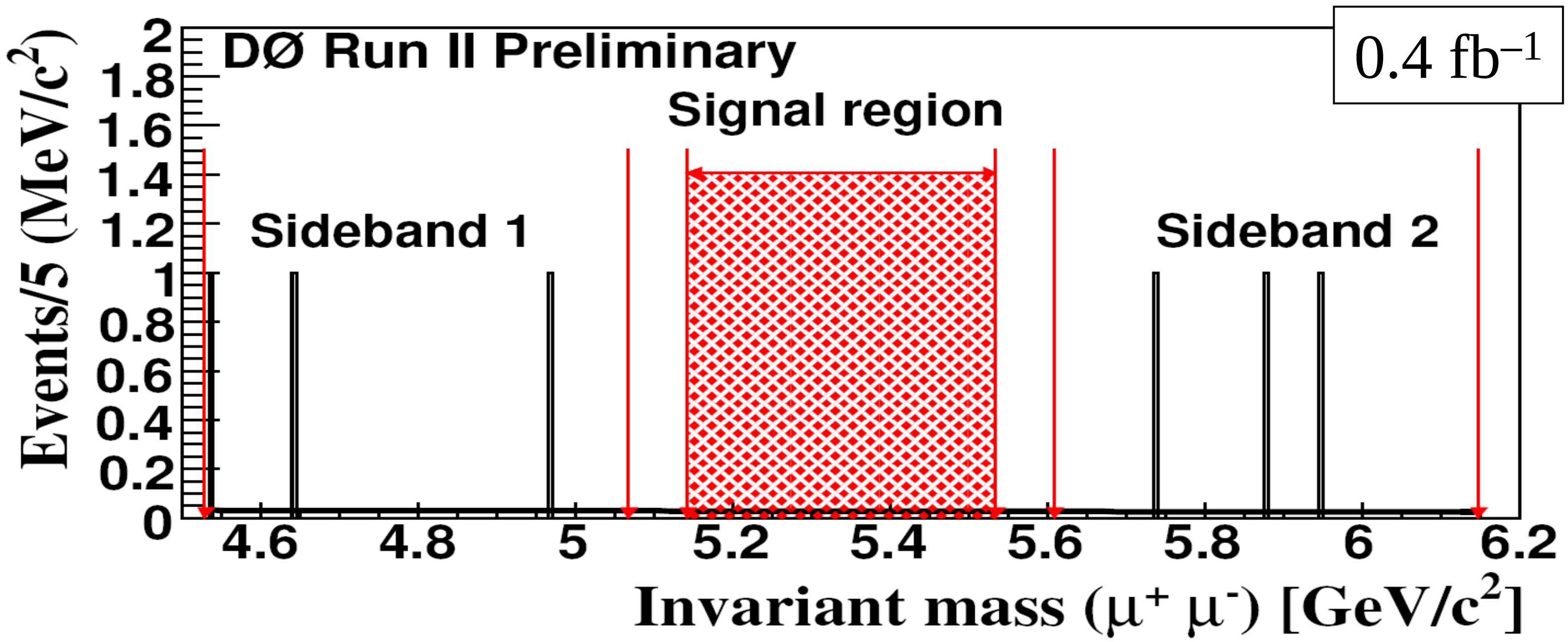
300 pb^{-1} Limit (published 2005)

Observed 4, expect 4.3 ± 1.2



$$BF(B_s \rightarrow \mu^+\mu^-) < 5.0\times10^{-7} \text{ @ } 95\% \text{ C.L.}$$

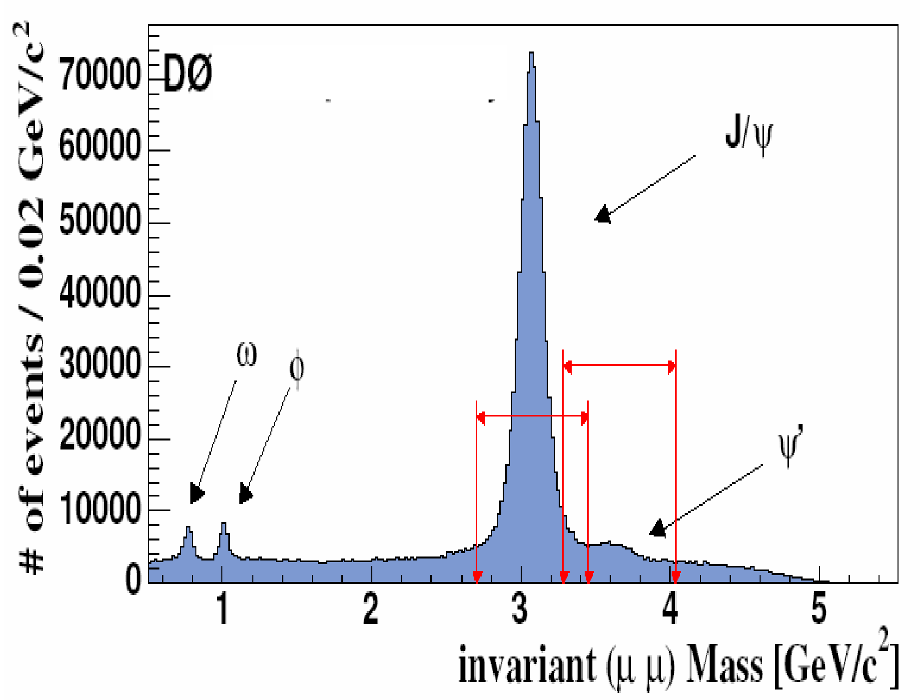
DØ Sensitivity 0.7 fb^{-1}



- 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

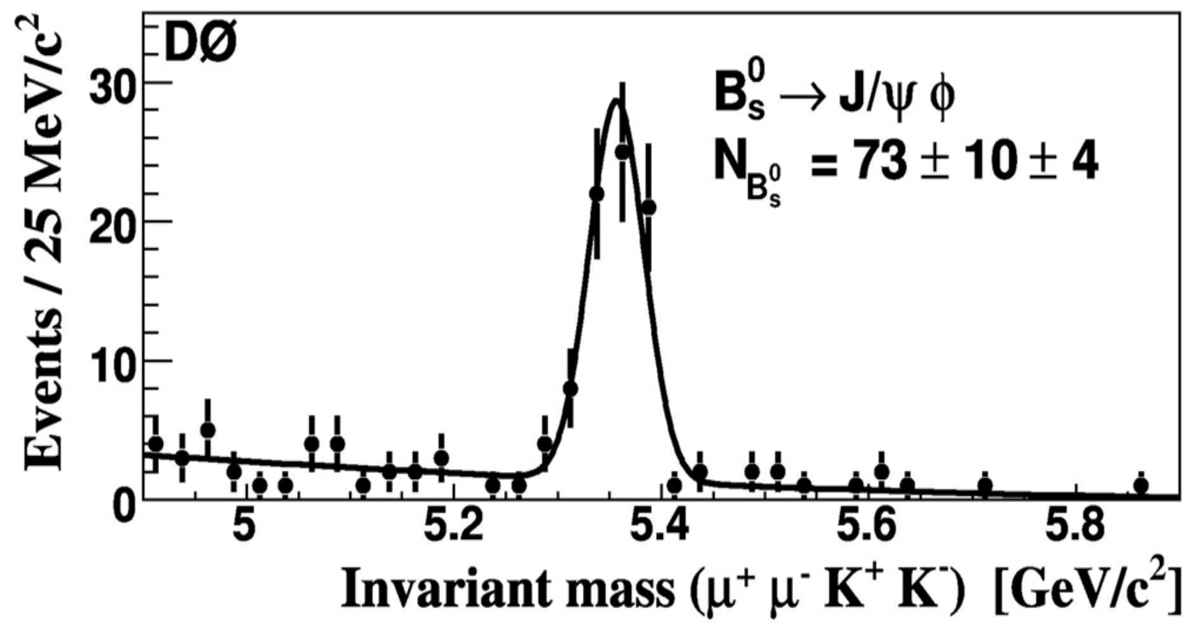
Search for $B_s^0 \to \phi \mu^+ \mu^-$

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



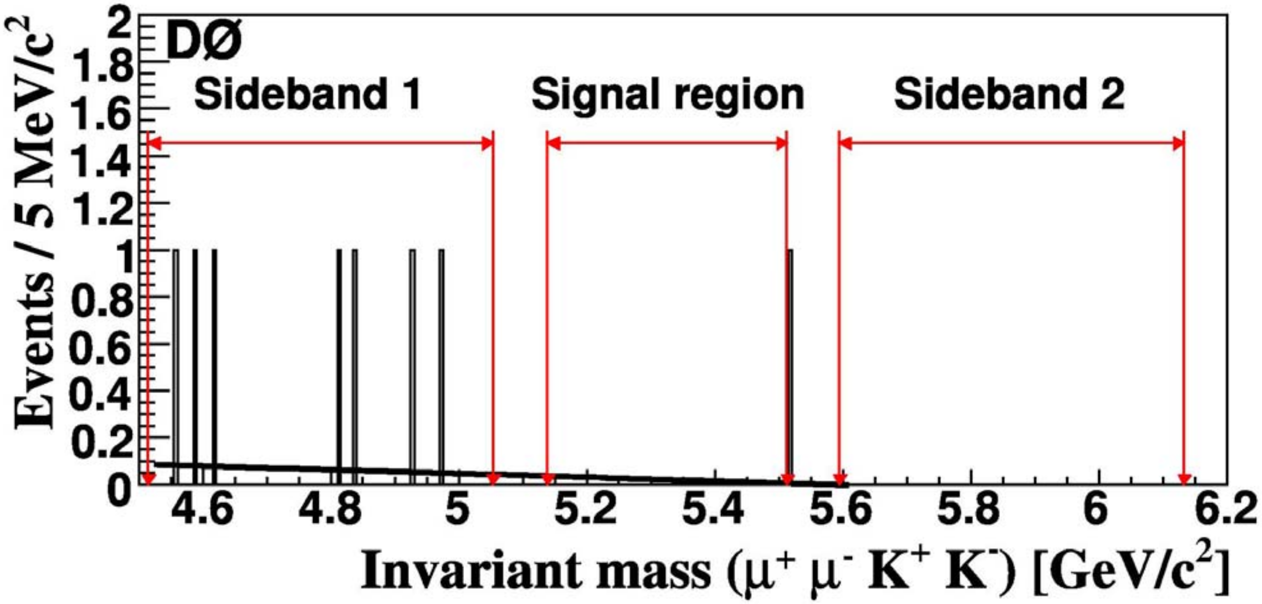
Analysis Method

- 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 $B_s \to J/\psi\, \phi$



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

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



$B_s^0 \to \phi\,\mu^+\,\mu^-$ Results

$$\frac{\mathrm{BF}\left(B_s^0 \to \phi\mu^+\mu^-\right)}{\mathrm{BF}\left(B_s^0 \to J/\psi\,\phi\right)} = \frac{N_{\mathrm{ul}}}{N_{B_s^0}} \cdot \frac{\varepsilon_{J/\psi\phi}}{\varepsilon_{\phi\mu^+\mu^-}} \cdot B\left(J/\psi \to \mu^+\mu^-\right)$$

$$\frac{\mathrm{BF}\left(B_s^0 \to \phi\mu^+\mu^-\right)}{\mathrm{BF}\left(B_s^0 \to J/\psi\,\phi\right)} < 4.4\times10^{-3}$$

@ 95% C.L

$$\mathrm{BF}\left(B_s^0 \to \phi\mu^+\mu^-\right) < 4.1\times10^{-6}$$

(10 times better than best limit)

Accepted for PRD Rapid Communication

- SM BF($B_s^0 \to \phi\,\mu^+\,\mu^-$) ~ 1.6×10^{-6} (30% uncertainty)
- 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