Annihilation and Radiative Decays of Heavy Mesons at D0

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D0 Collaboration

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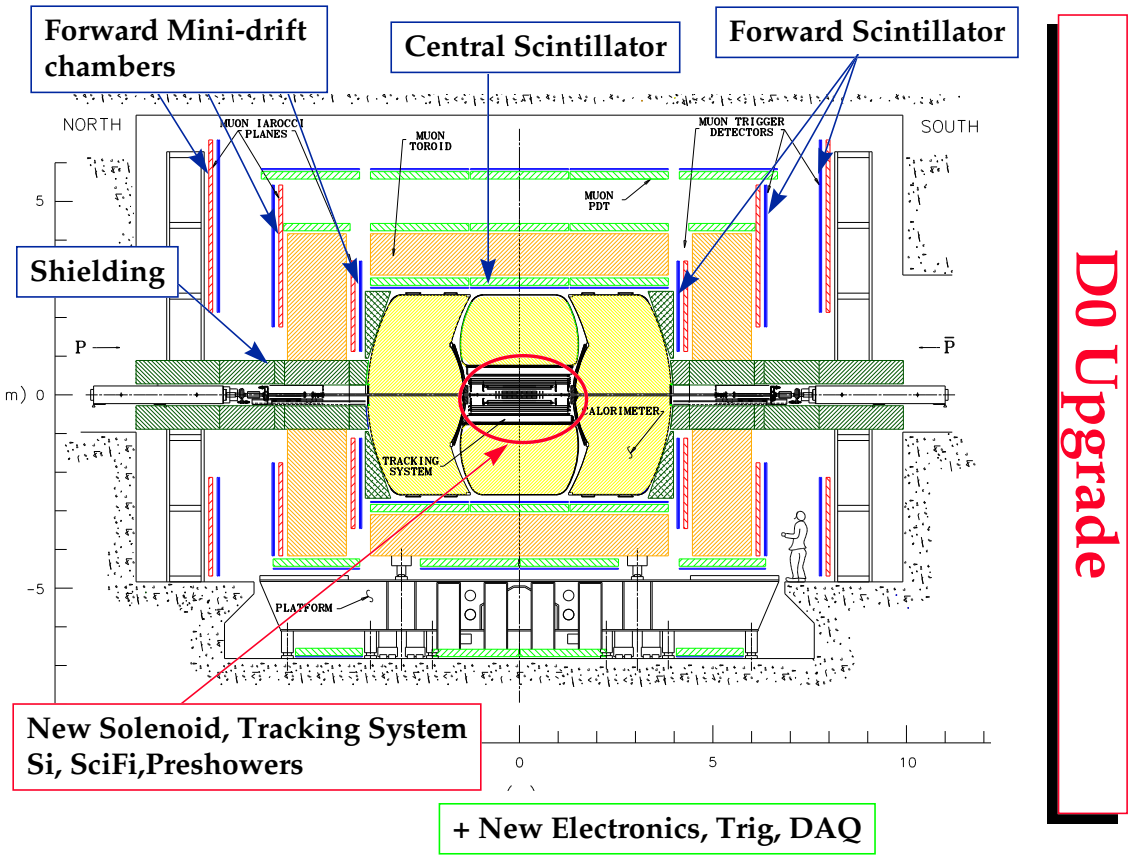
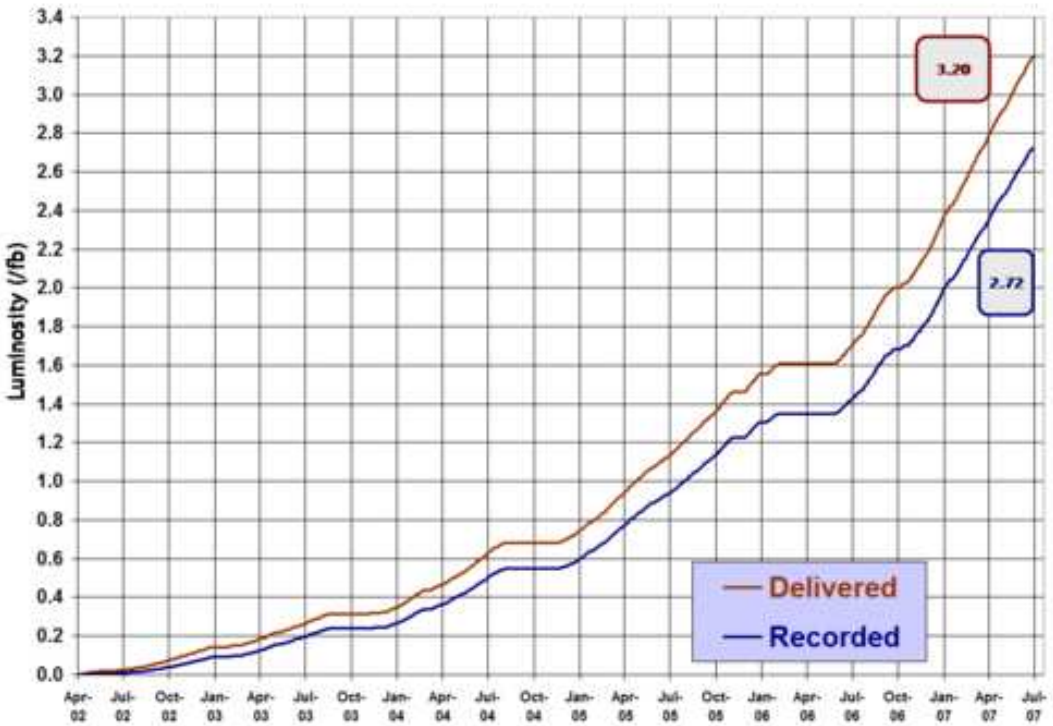
- The D0 Experiment
- FCNC and Physics Beyond the Standard Model.
  - $D^+ \to \pi^+\mu^+\mu^-$
  - $B_s \to \mu^+\mu^-$
- Summary

The D0 Detector



- Excellent muon and tracking coverage.
- Recent upgrades include additional silicon layer and improved track triggers.
- New L1 calorimeter triggers.

Tevatron

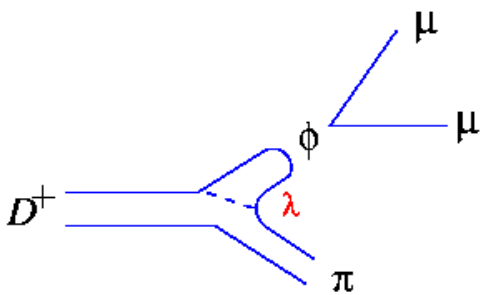


- Recorded Integrated luminosity approaching 3 fb^{-1}.
  - Peak luminosity of $2.8 \times 10^{32}/\text{cm}^2/\text{s}$.
  - Weekly integrated luminosity 45-50 pb^{-1}.
- D0 Analyses:
  - $D^+ \to \pi^+\mu^+\mu^-$: 1 fb^{-1}
  - $B_s \to \mu^+\mu^-$: 2 fb^{-1}

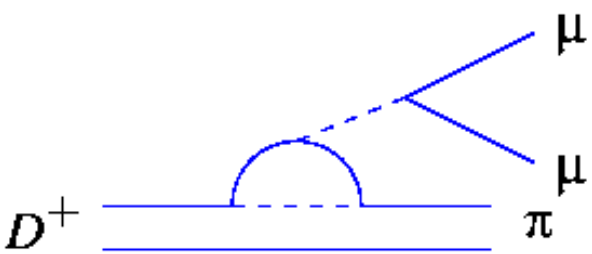
FCNC in the Charm Sector

- Rare decays provide a means to search for physics beyond the Standard Model.
  - New physics often enhances decay rates.
- Stringent limits from down-type charge decays.
  - $b \to s\gamma$
  - $b \to s l^+ l^-$
  - $K \to \pi\nu\bar{\nu}$
- Some models provide for enhancements only in up-type sector.
  - R parity violating SUSY. [Burdman, 2002]
  - Little Higgs models. [Fajfer, 2001]

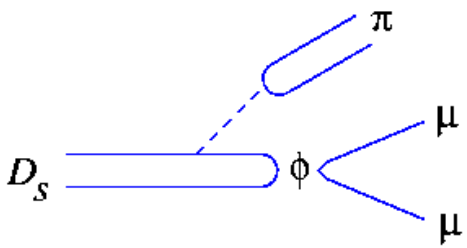
$D^+ \to \pi^+\mu^+\mu^-$ Introduction



- Resonant production
  - $D^+ \to \phi\pi^+ \to \pi^+\mu^+\mu^-$
  - BR $\sim 10^{-6}$



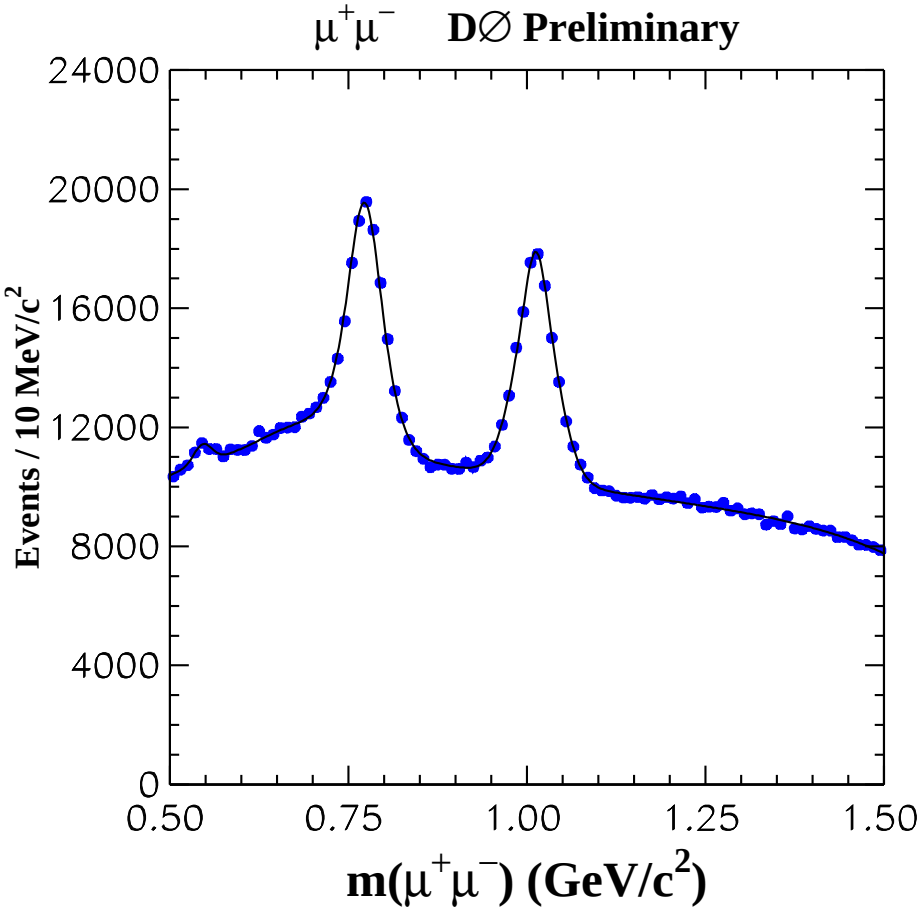
- Non-resonant production
  - GIM suppressed.
  - BR $\sim 10^{-8}$



- Resonant production only.
  - $D_s \to \phi\pi^+ \to \pi^+\mu^+\mu^-$.
- No box or penguin diagrams.
- BR $\sim 10^{-5}$

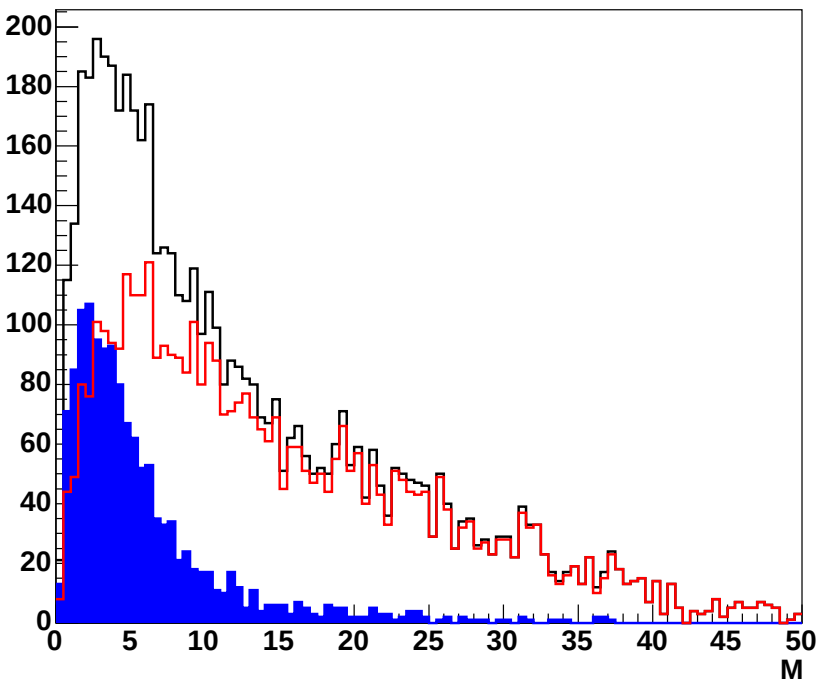
Analysis Strategy

- Search for resonant, long-distance decays.
  - $D^+, D_s \to \phi\pi^+ \to \pi^+\mu^+\mu^-$
  - Copious number of $\phi \to \mu^+\mu^-$ decays.
- Optimize cuts for D_s and D^+.
- Search for non-resonant contribution.
  - Outside of $\phi \to \mu^+\mu^-$ window.



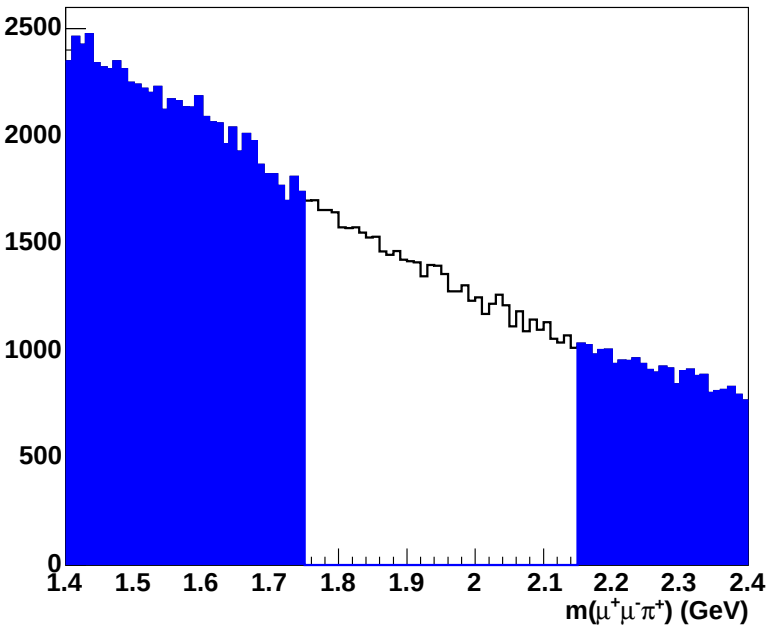
Event Selection

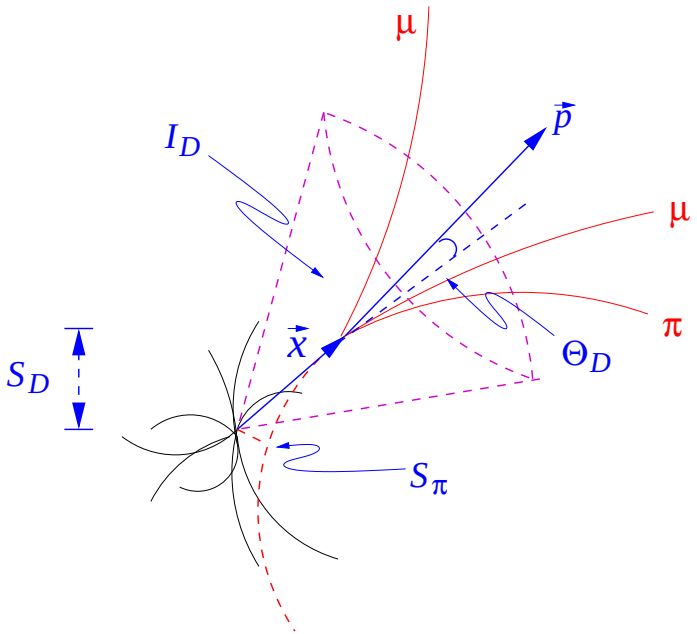
- Require dimuon trigger.
- Require track in same jet and with same vertex as dimuon pair.
- $1.3 < m_{\pi\mu^+\mu^-} < 2.5$ GeV/c^2.



- Select best candidate based upon M
- $M = \chi^2_{vtx} + \kappa^2_\pi + \Delta R^2_\pi$
  - χ^2_{vtx}: From 3 track vertex.
  - κ^2_π: inverse transverse pion p.
  - ΔR^2_π: Angular sep. of π and dimuon system.

$\pi\mu^+\mu^-$ Mass Distribution

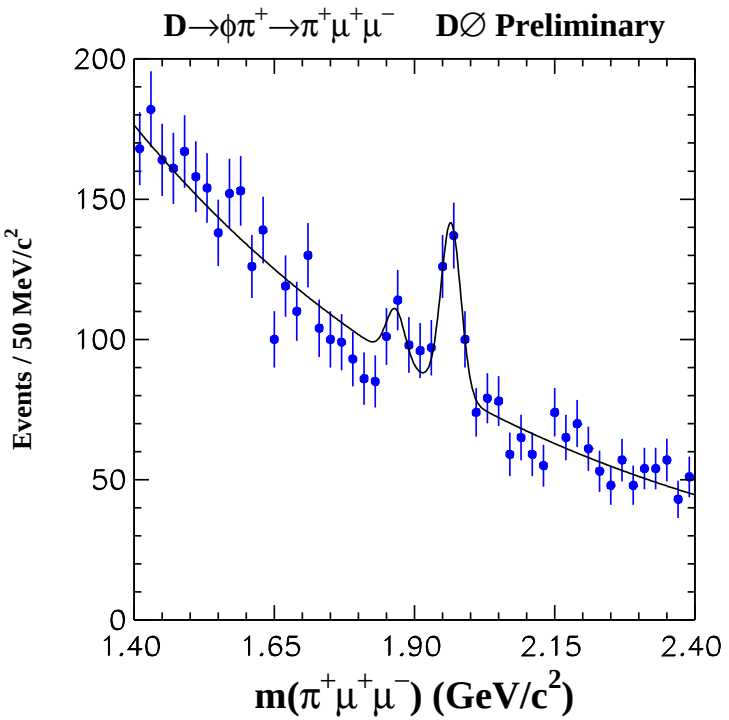




- Define four additional variables to suppress backgrounds.
  - Isolation: $I_D = p(D)/\sum p_{cone}$.
  - Transverse length significance: S_D (normalized to vertex measurement errors).
  - Collinearity: Θ_D between momentum and decay position vectors.
  - Pion impact parameter: S_π.

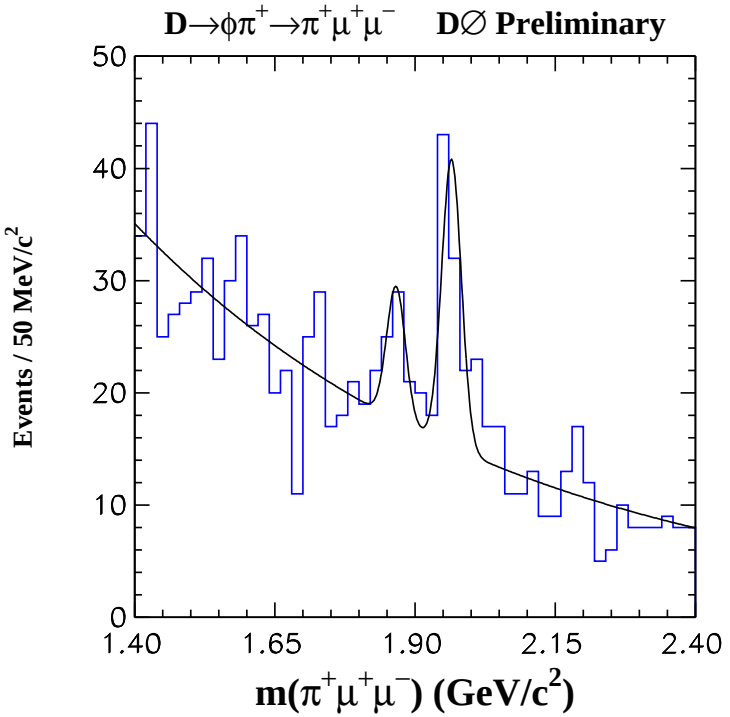
$D \to \pi\mu^+\mu^-$ Results

Loose Cuts



- D_s: 133 ± 25 candidates.
- D^+: 37 ± 19 candidates.

D_s optimized cuts



- D_s: 65 ± 11 candidates.
- D^+: 26 ± 9 candidates.

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

Standard Model prediction: 1.77×10^{-6}.

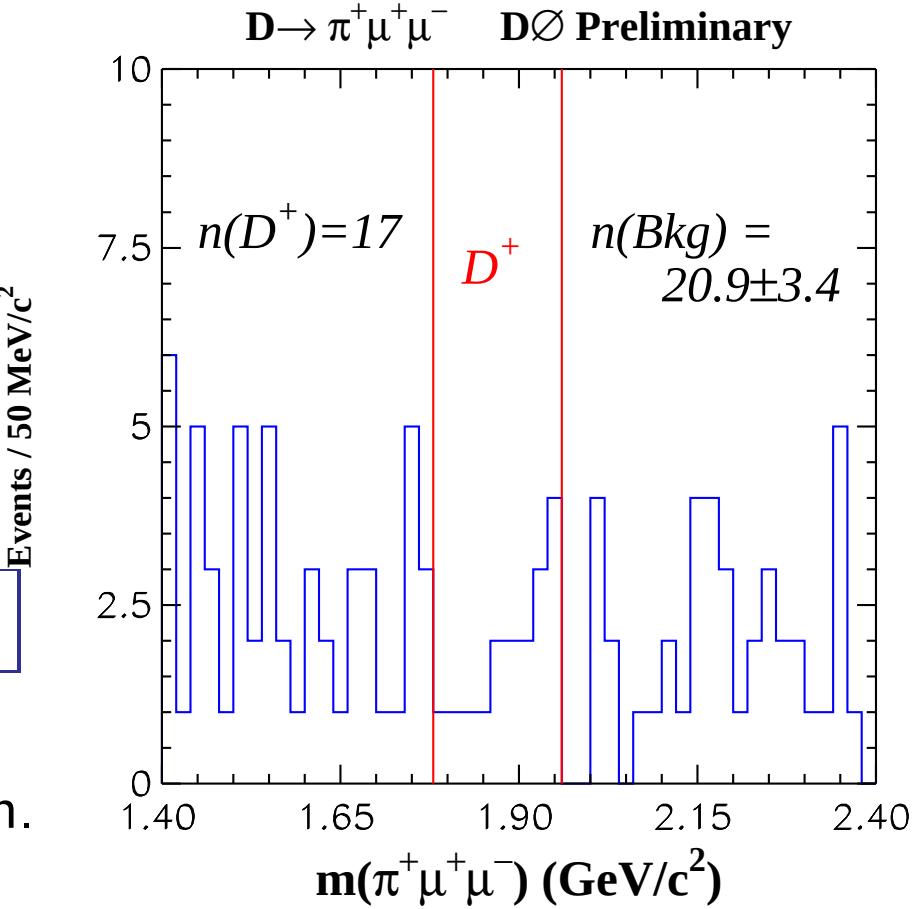
Non-Resonant $D \to \pi\mu^+\mu^-$ Search

- Search in window outside $\phi \to \mu^+\mu^-$ region.
- Find 17 events.
  - Expected background from sidebands: 20.9 ± 3.4

D0 preliminary

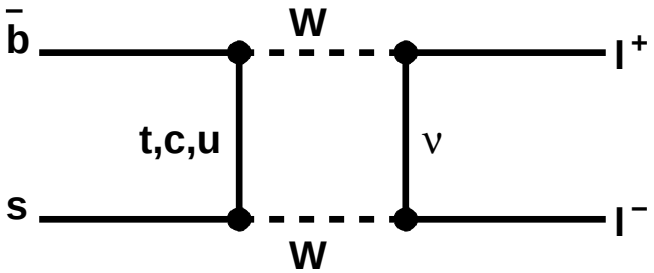
$BR < 4.7 \times 10^{-6}$ (90% CL)

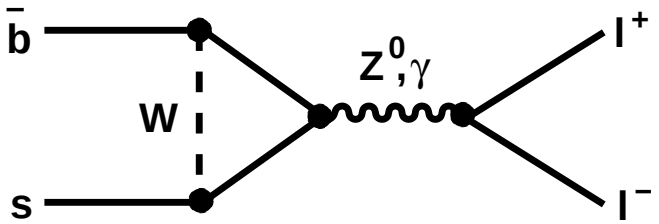
- Below allowed parameter space for R parity violation.



- CLEO: $< 7.4 \times 10^{-6}$ 90% CL ($D^+ \to \pi^+ e^+ e^-$).
- FOCUS:$< 8.8 \times 10^{-6}$ 90% CL.
- BaBar:$< 24.4 \times 10^{-6}$ 90% CL.

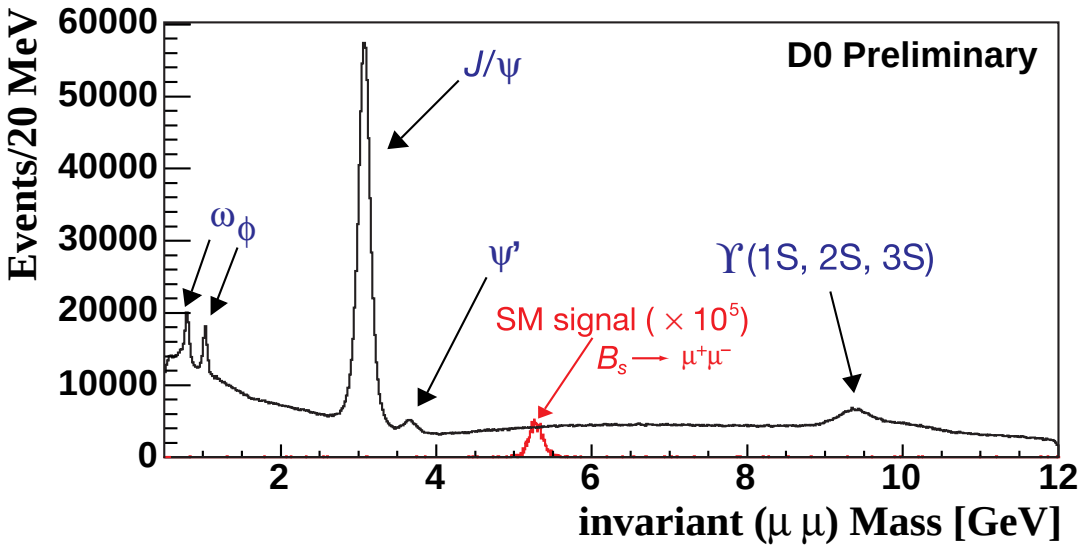
$B_s \to \mu^+\mu^-$ Introduction





- FCNC in B_s decays.
  - BR $= 0$ at tree level.
- Standard Model prediction:
  - BR$(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$ [Buras, 2003]
- To date best published limit:
  - BR$(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$ 90% CL [CDF]
- BR $\propto \tan^6\beta$ in MSSM and $\tan^4\beta$ in 2HDM.
  - The BR can be enhanced up to 3 orders of magnitude.
  - For values of $\tan\beta \sim$ (30-50) $\to$ BR $\sim 10^{-6}$
  - 3rd generation Yukawa unification in SUSY GUTs $\to$ large $\tan\beta$.

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



- Look at all dimuon candidates.
  - Dimuon triggers.
  - Two opposite sign tracks.
  - Good vertex and $p_T(B) > 5.0$ GeV/c.
- Large backgrounds.
  - Two components: same-b and separate-b.
- Two data sets: Run IIa and Run IIb
  - Extra silicon layer added for RunIIb.

$B_s \to \mu^+\mu^-$ Likelihood ratio

- To reduce backgrounds, we form a likelihood ratio based upon the following variables.

$$LHR = \frac{\prod_{i=1}^{6} S_i(x)}{\prod_{i=1}^{6} S_i(x) + \prod_{i=1}^{6} B_i(x)}$$

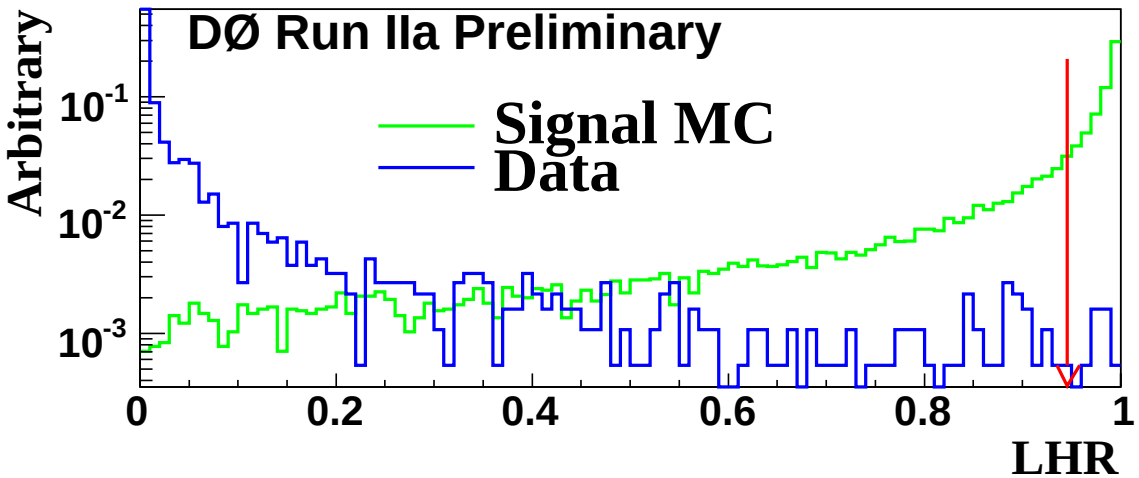
  - Isolation.

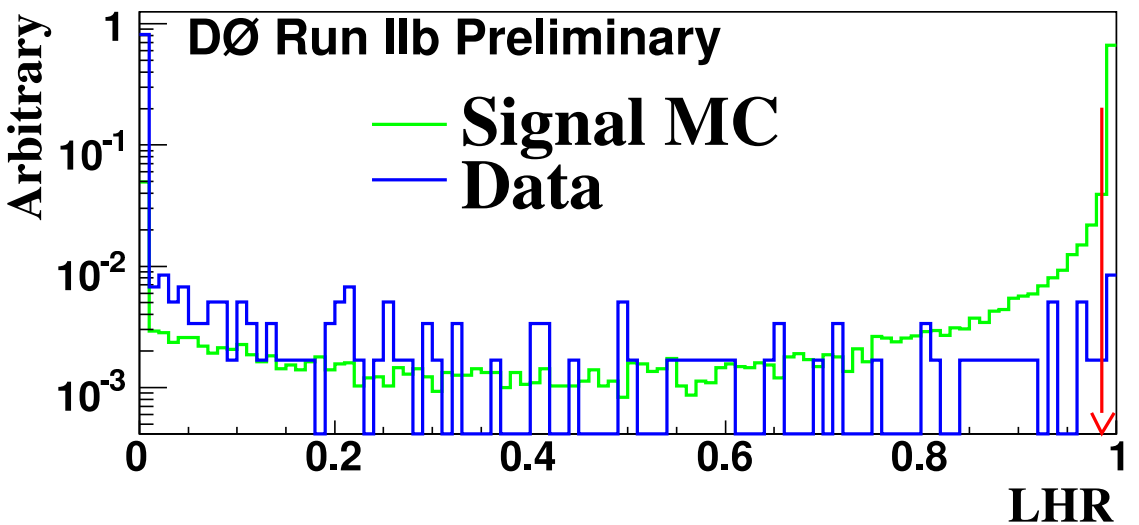
$$I = \frac{|\vec{p}(\mu\mu)|}{|\vec{p}(\mu\mu)| + \sum_{tracki \neq B} p_i(\Delta R < 1)}$$

  - Decay length significance.
  - Angle between decay direction and momentum vectors.
  - B impact parameter significance.
  - Minimum muon impact parameter.
  - χ^2 vertex probability.

$B_s \to \mu^+\mu^-$ Likelihood Ratio

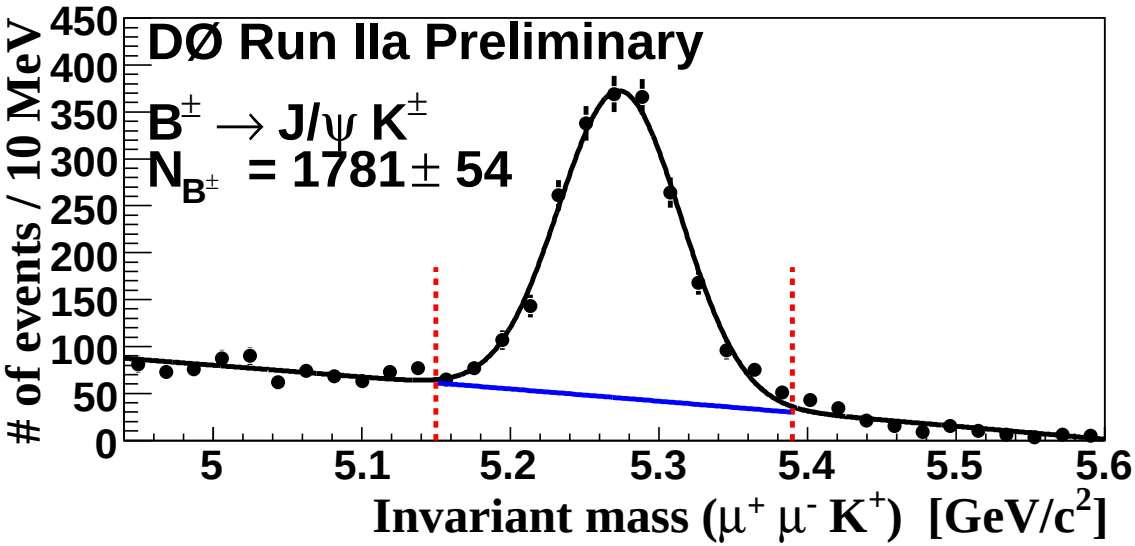
- Signal peaks near one.
  - Run IIb data peaks more sharply due to better detector resolution.
- Run IIa: LHR > 0.946
- Run IIb: LHR > 0.986

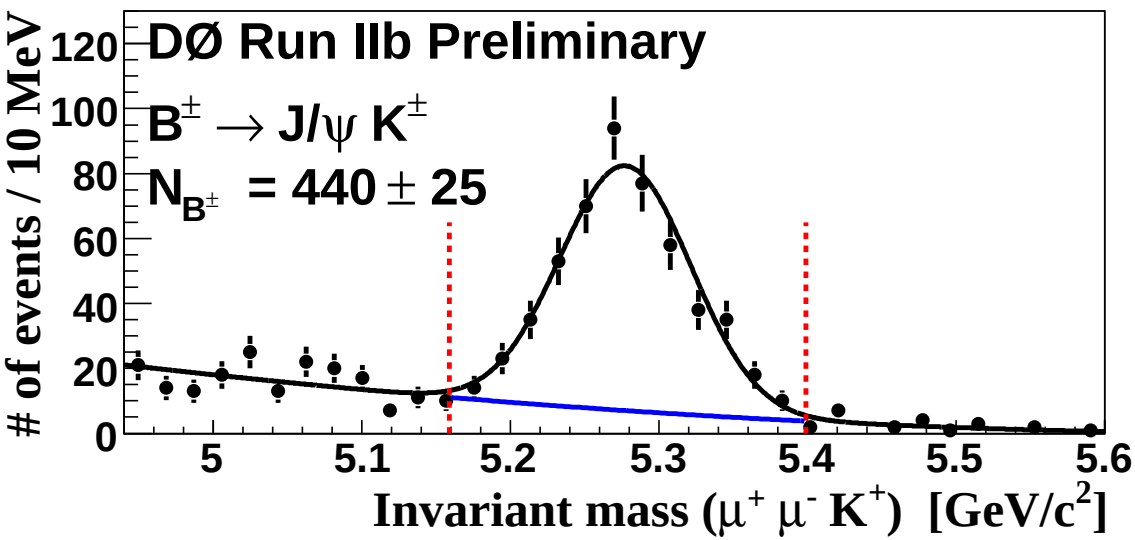




$B^+ \to J/\psi K^+$ Decays

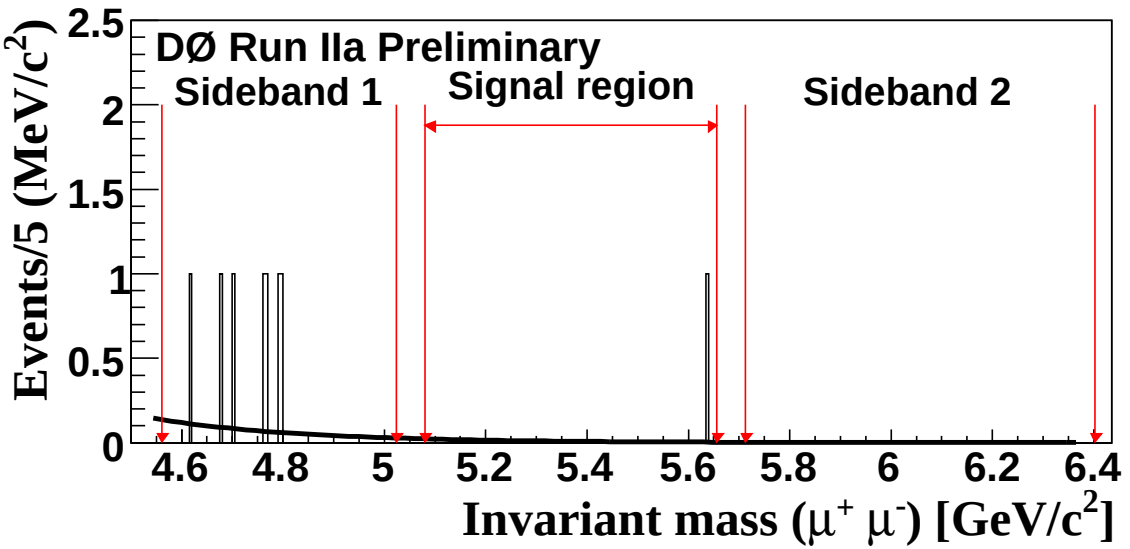
- Use $B^+ \to J/\psi K^+$ decays for normalization.
- Similar selection cuts as $B_S \to \mu^+\mu^-$ events.
  - Add track consistent with a kaon.
  - Require $\mu^+\mu^-$ mass consistent with J/ψ.
- Clean signal with low background.
  - Run IIa data: 1781 ± 54 events.
  - Run IIb data: 440 ± 25 events.

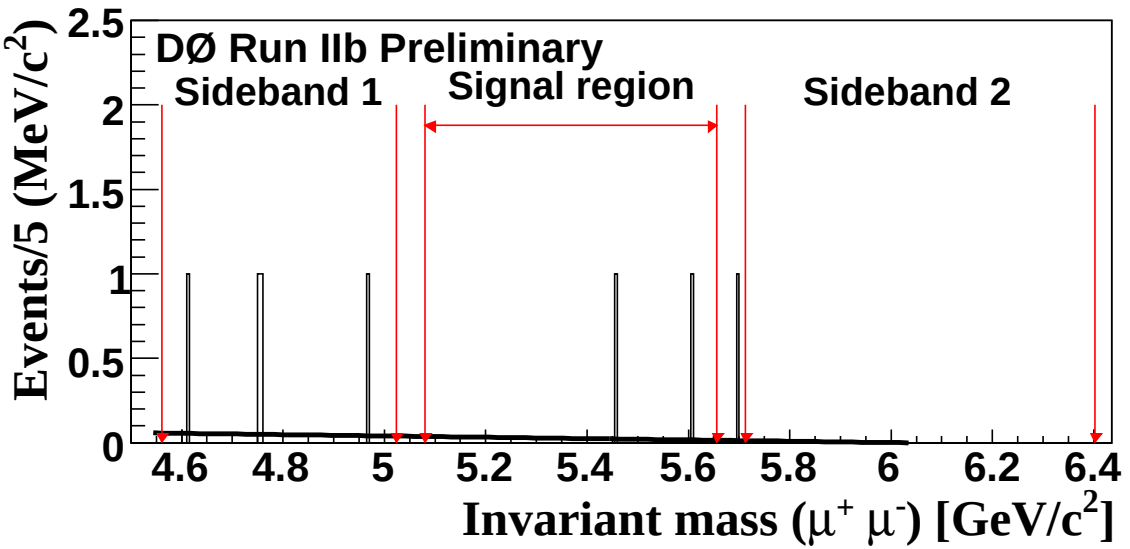




$B_s \to \mu^+\mu^-$ Background

- Use sidebands to estimate backgrounds.
  - Run IIa
    - Exponential extrapolation $\to 0.8 \pm 0.2$ events.
    - One candidate event.
  - Run IIb
    - Linear extrapolation $\to 1.5 \pm 0.3$ events.
    - Two candidate events.





Upper Limit Calculation

$$BR(B_s \to \mu\mu) < \frac{n_{\rm UL}}{n_{B^\pm}} \frac{\epsilon_{B^\pm}}{\epsilon_{B_s}} \frac{BR(\bar{b} \to B^\pm)}{BR(\bar{b} \to B_s)} BR(B^\pm \to J/\psi K) BR(J/\psi \to \mu\mu).$$

- $n_{\rm UL}$ is the 95% CL upper bound on the number of signal events.
- $n_{B^\pm}$ is the number of $B^\pm$ events in the data.
- ϵ_X is the reconstruction efficiency for $X = B^+$, B_s.
  - Many uncertainties cancel in the ratio.
- Fragmentation fractions: $\frac{BR(\bar{b}\to B^\pm)}{BR(\bar{b}\to B_s)} = 0.258 \pm 0.039$ from latest world average.

$$\boxed{\text{BR} < 9.3 \times 10^{-8} \text{ (95\% CL) (D0 preliminary)}}$$

- Combined CDF & D0 limit: 5.8×10^{-8} 95% CL.

Summary

- D0 has made significant contributions to FCNC decays.
- Charm Decays.
  - Clear observation of $D_s^+ \to \phi\pi^+$
  - Evidence for $D^+ \to \phi\pi^+$
  - Most stringent limit for $D^+ \to \pi^+\mu^+\mu^-$.
- Bottom Decays.
  - New analysis with 2 fb^{-1}.
  - BR($B_s \to \mu^+\mu^-$) $< 9.3 \times 10^{-8}$ (95% CL).
- No hints of new physics yet.
  - Large data sets will continue to appear from Tevatron.