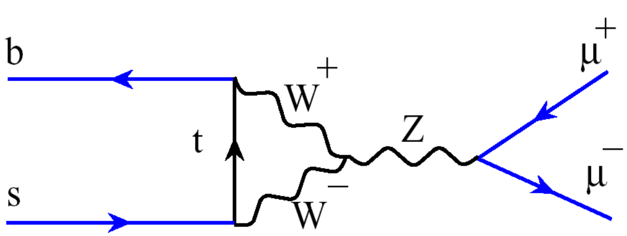
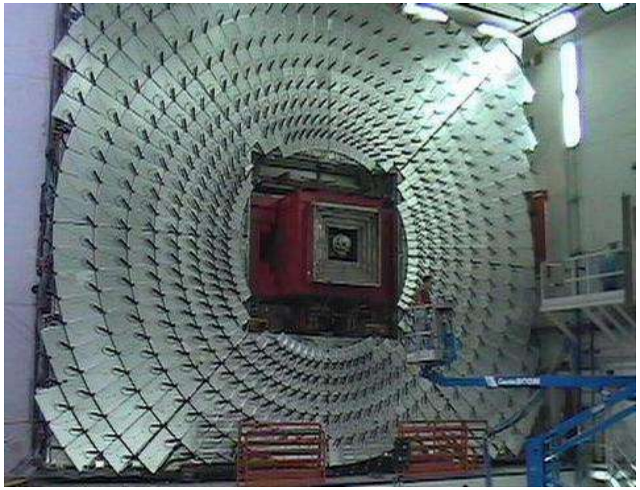
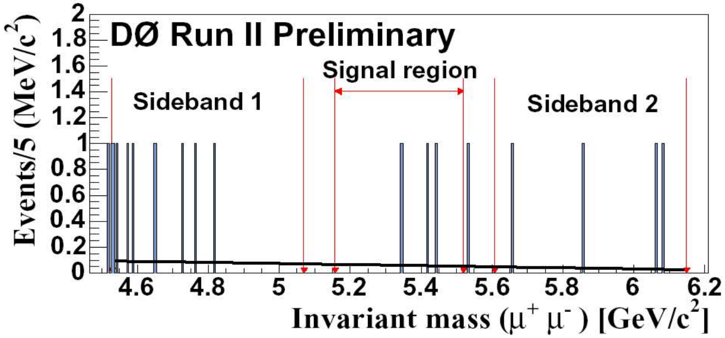
Search for Rare Flavor-Changing and Electroweak Penguin Decays of the B_s Meson at the DØ Experiment

Frank Fiedler, Munich University
on behalf of the DØ collaboration







DPF 2006, October 29 – November 3rd, 2006, Honolulu/HI/USA

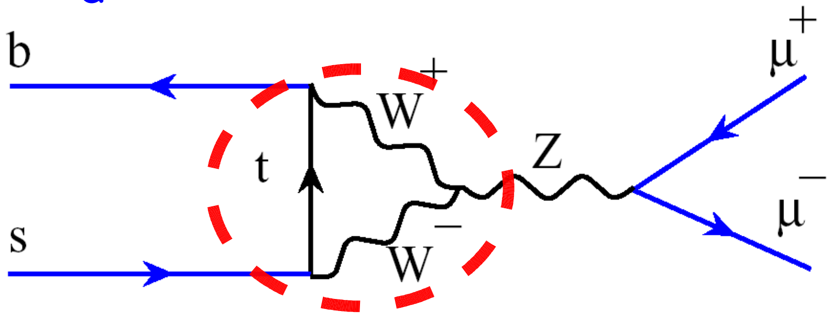
Motivation: $B_s \to \mu^+\mu^-$

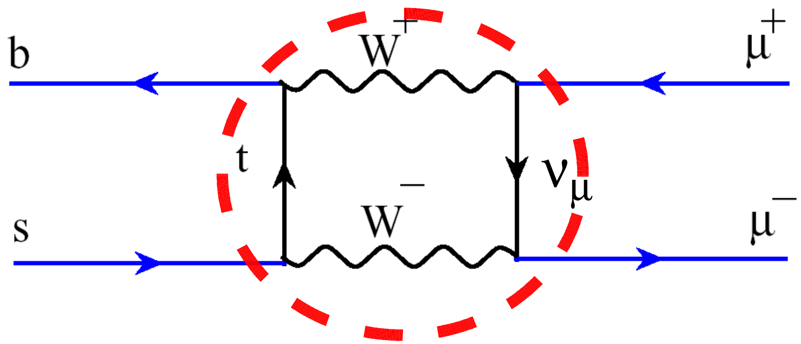
In the Standard Model:

- $B_s \to \mu^+\mu^-$: FCNC process, BF=0 at tree level
- Standard Model expectations:

  $BF(B_s^0 \to \mu^+\mu^-) = (3.42 \pm 0.54) \times 10^{-9}$

  $BF(B_d^0 \to \mu^+\mu^-) = (1.00 \pm 0.14) \times 10^{-10}$





Physics beyond the Standard Model:

- additional particles can contribute to loops
- MSSM: BF enhanced by up to 3 orders of magnitude
- enhancements in many models
- => hope to find something...!

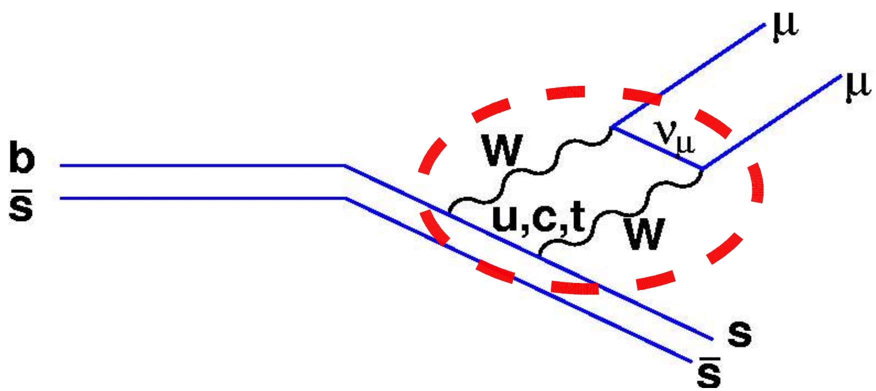
Motivation: $B_s \to \phi\mu^+\mu^-$

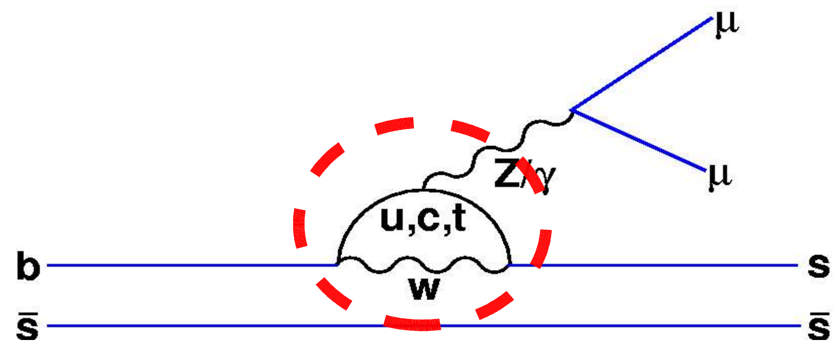
In the Standard Model:

- $B_s \to \phi\mu^+\mu^-$: larger expected BF

  $BF(B_s^0 \to \phi\mu^+\mu^-) = 1.6 \times 10^{-6}$ (~30% theory uncertainty)

  $BF(B_d^0 \to X_s\mu^+\mu^-)$ measured at BaBar/Belle





- sensitivity close to prediction => test the Standard Model!

Physics beyond the Standard Model:

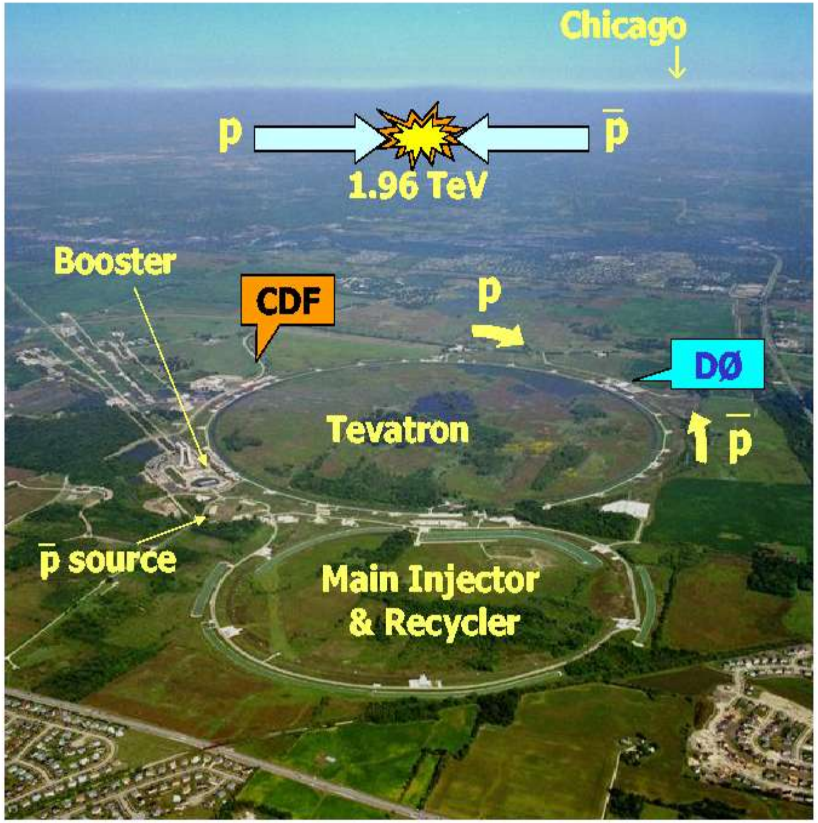
- additional particles can contribute to loops
- => hope to find something...!

Production of B_s Mesons

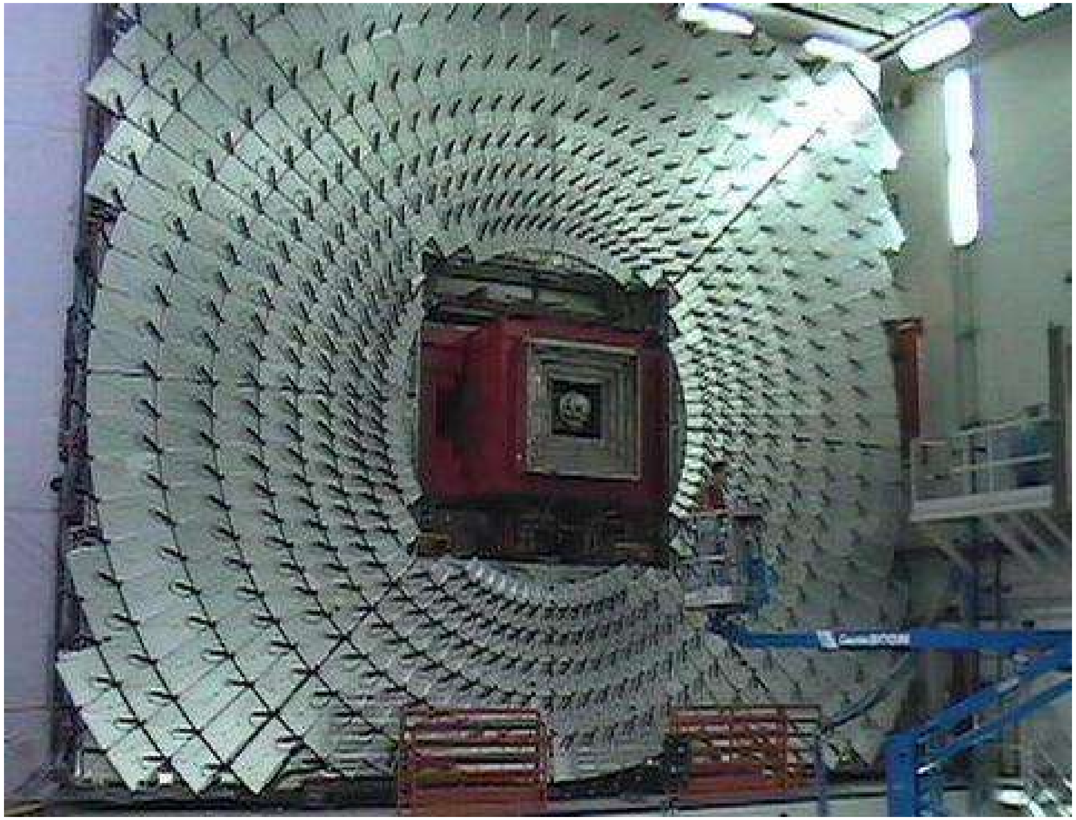
- No production of B_s mesons in Υ(4s) decays
- Tevatron: abundant source of bbbar events

  hadronization: $f(b\to B_s) \sim 10\%$

The Tevatron:



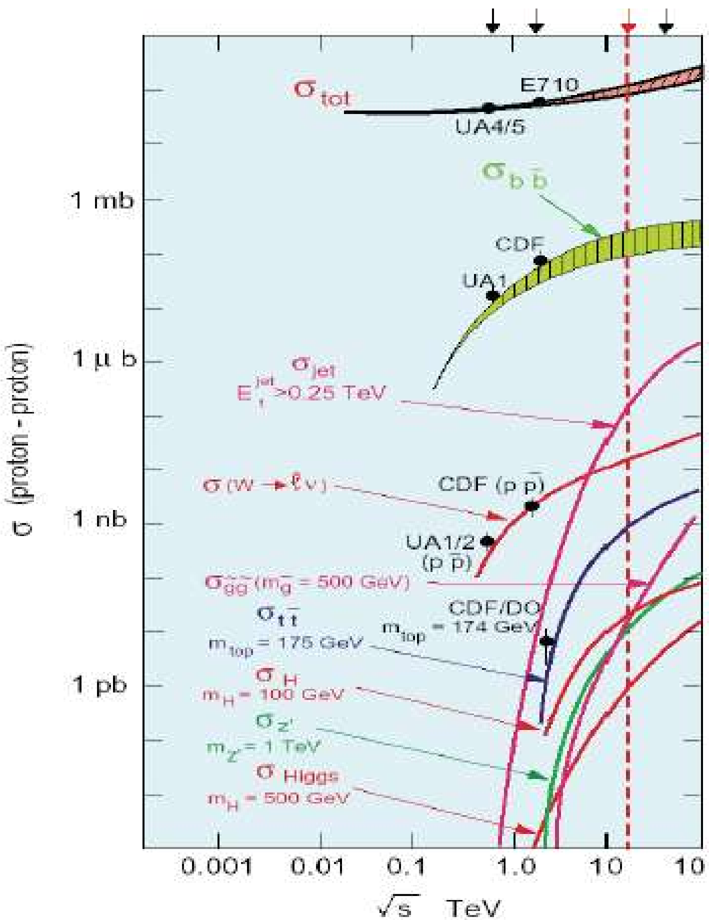
DØ muon detector:

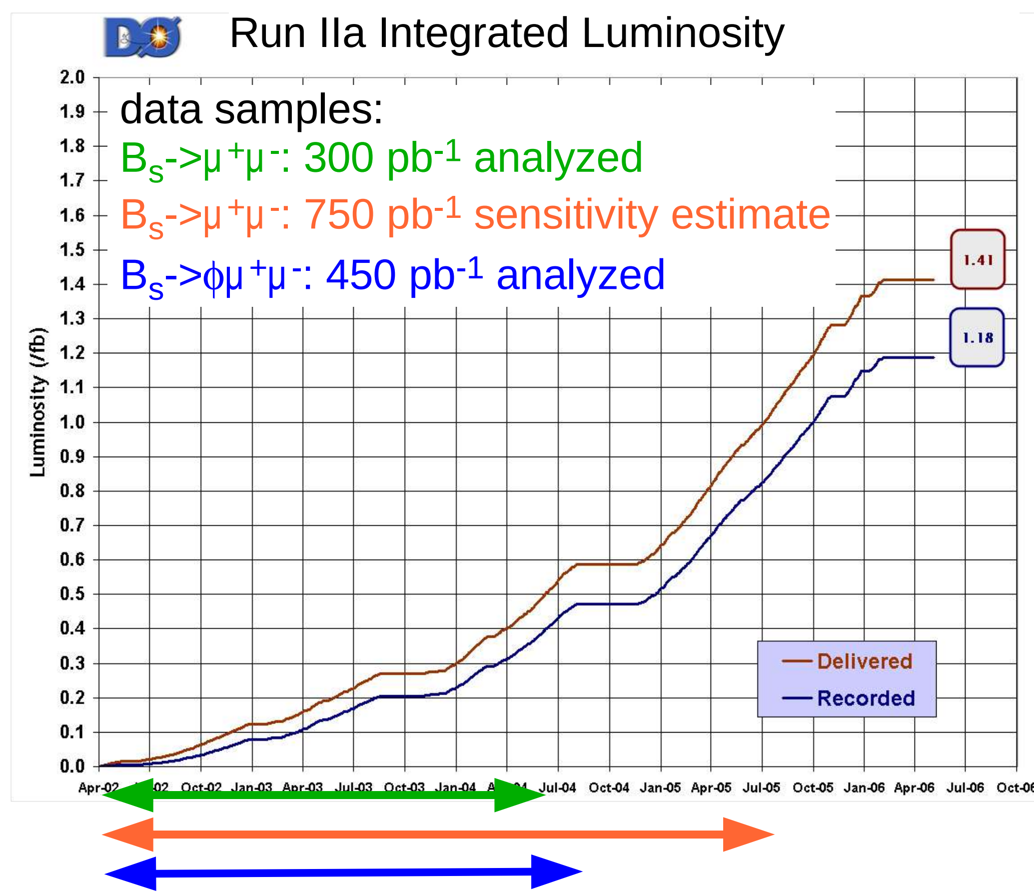


Production of B_s Mesons

- No production of B_s mesons in Υ(4s) decays
- Tevatron: abundant source of bbbar events

  hadronization: f(b->B_s) ~ 10%





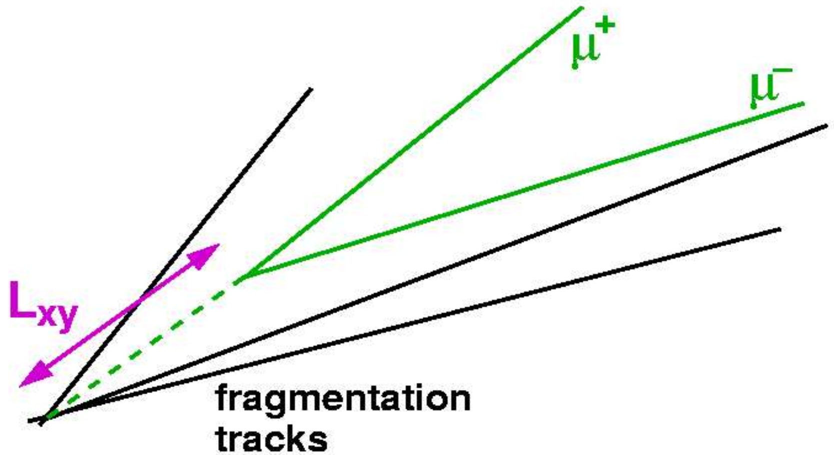
Search for $B_s \to \mu^+\mu^-$

Concepts:

- preselection of dimuon events
  optimized selection of $B_s \to \mu^+\mu^-$ decay candidates
- reconstruct resonant decay $B^+ \to J/\Psi\ K^+$
  => efficiency normalization
- side band technique
  => background subtraction
- blind analysis
  => avoid bias

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

Event preselection:



- dimuon trigger
- two muons: $p_T(\mu) > 2.5$ GeV
  $|\eta(\mu)| < 2.0$
  opposite charges
- muons form common secondary vertex (reconstructed in 3d):
  $\chi^2/dof < 10$
  $4.5 \text{ GeV} < m(\mu^+\mu^-) < 7.0 \text{ GeV}$
  minimum number of hits in vertex (3) and tracking detectors (4)
  $\delta L_{xy} < 0.15$ mm (L_{xy}: secondary vertex decay length in xy)
  $p_T(\mu^+\mu^-) > 5$ GeV

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

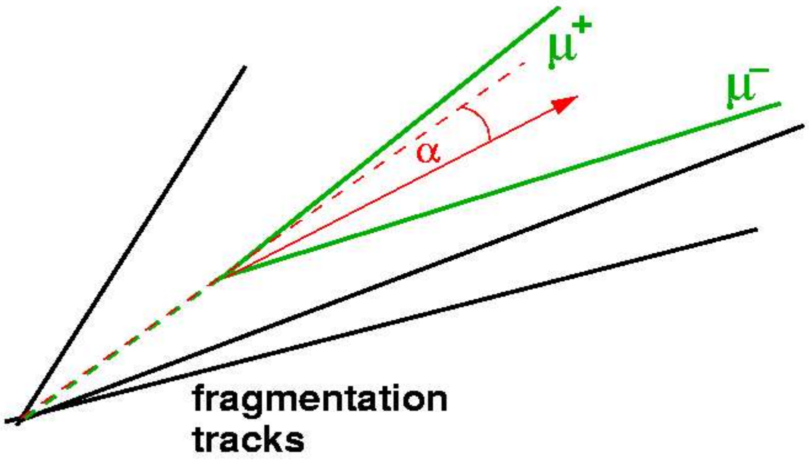
Final event selection:

-> pointing angle

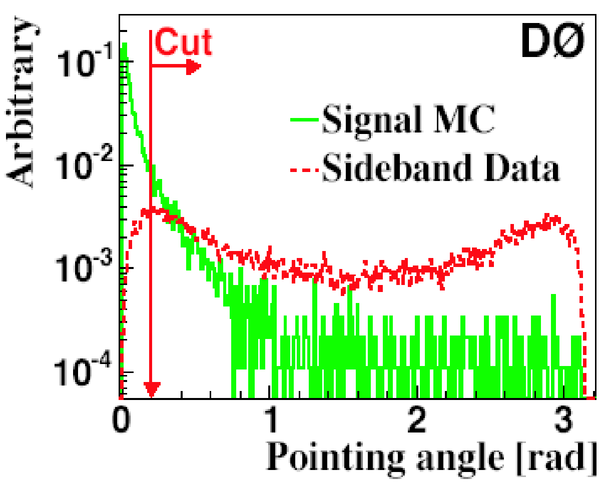
-> isolation

-> decay length significance

- cut optimization based on
  MC signal
  background from data sidebands



PRL 94, 071802 (2005)



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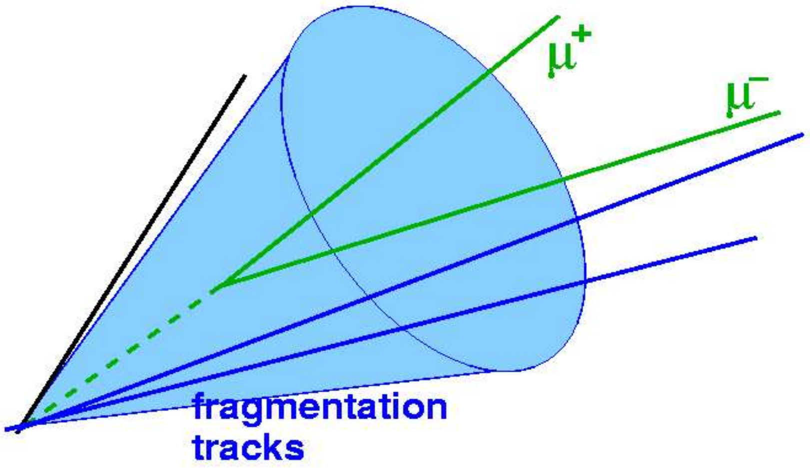
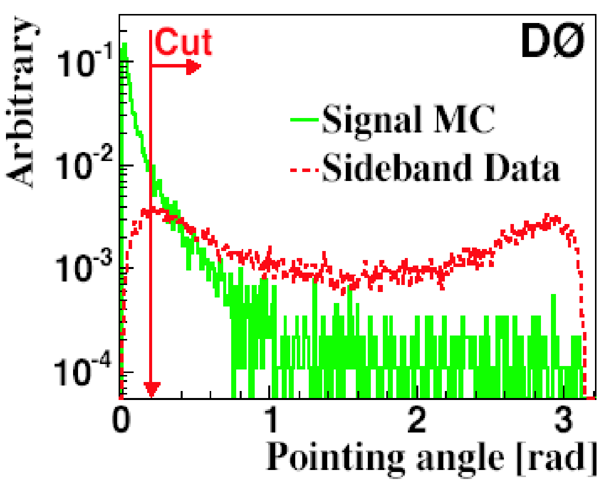
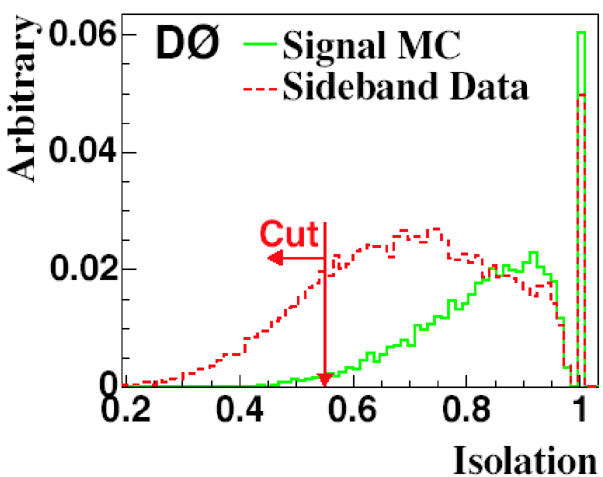


PRL 94, 071802 (2005)





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

Final event selection:

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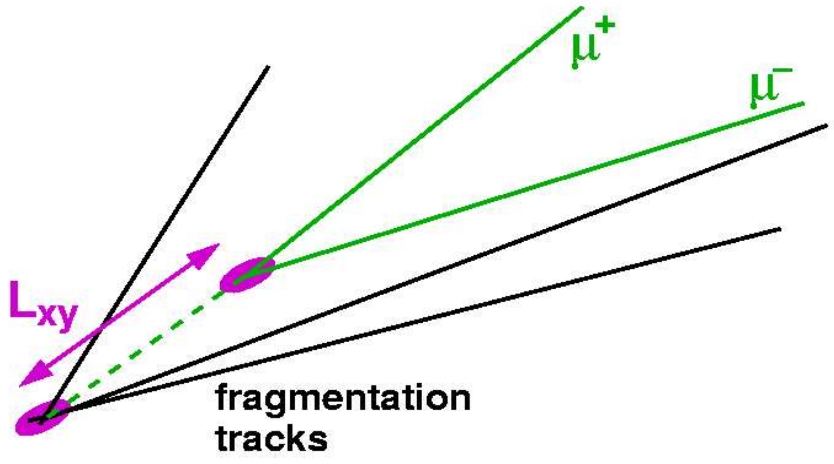
- cut optimization based on MC signal background from data sidebands



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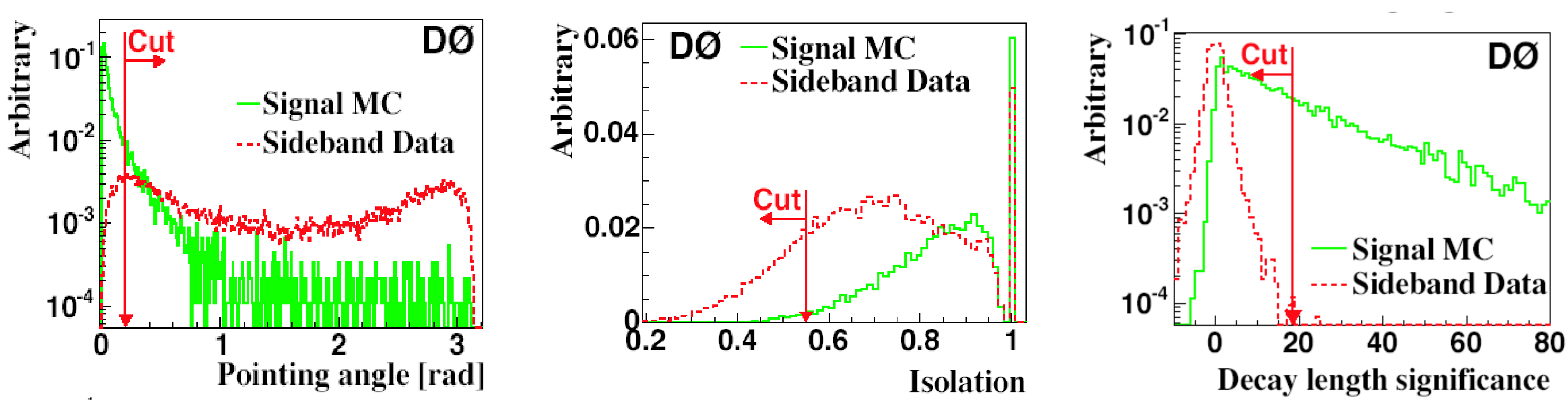

Normalization

- Analysis based on the ratio
  $B_s \to \mu^+\mu^-$ / $B^+ \to J/\Psi(\to\mu^+\mu^-)\, K^+$:

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

- Branching fraction we want to calculate
  and number of observed events (for example: upper limit)
- Branching fraction for reference process
  and number of observed events

Normalization

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- Branching fraction we want to calculate
  and number of observed events (for example: upper limit)
- Branching fraction for reference process
  and number of observed events
- Efficiency ratio: signal / reference process
- Production ratio: B_s (signal) / B^+ (reference)

Normalization

- Analysis based on the ratio
  $B_s \rightarrow \mu^+\mu^-$ / $B^+ \rightarrow J/\Psi(\rightarrow\mu^+\mu^-)\,K^+$:

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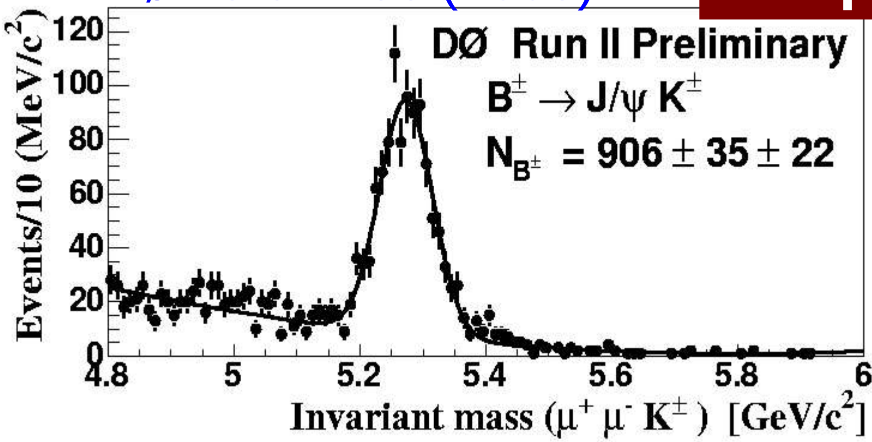
- Branching fraction we want to calculate
  and number of observed events (for example: upper limit)
- Branching fraction for reference process
  and number of observed events
- Efficiency ratio: signal / reference process
- Production ratio: B_s (signal) / B^+ (reference)
- Account for $B_d \rightarrow \mu^+\mu^-$ contributions (but R expected to be small)

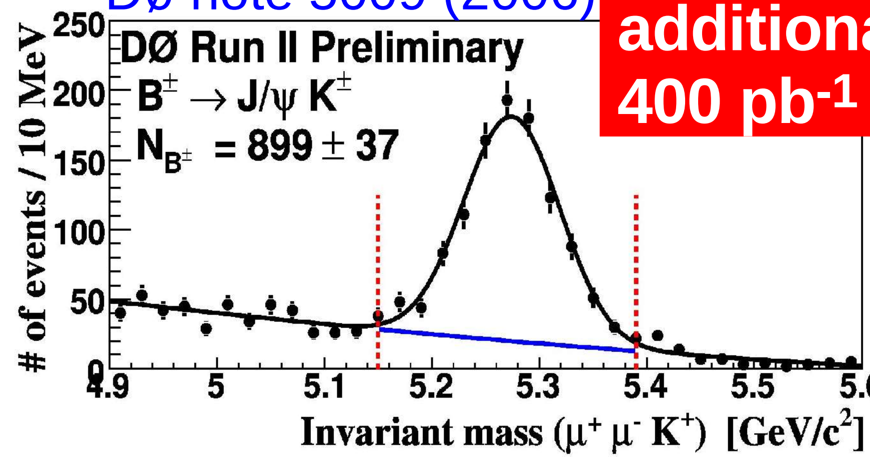
Results

- Observed $B^+ \to J/\Psi(\to\mu^+\mu^-)\, K^+$ signal:

DØ note 4733 (2005) **300 pb^{-1}**

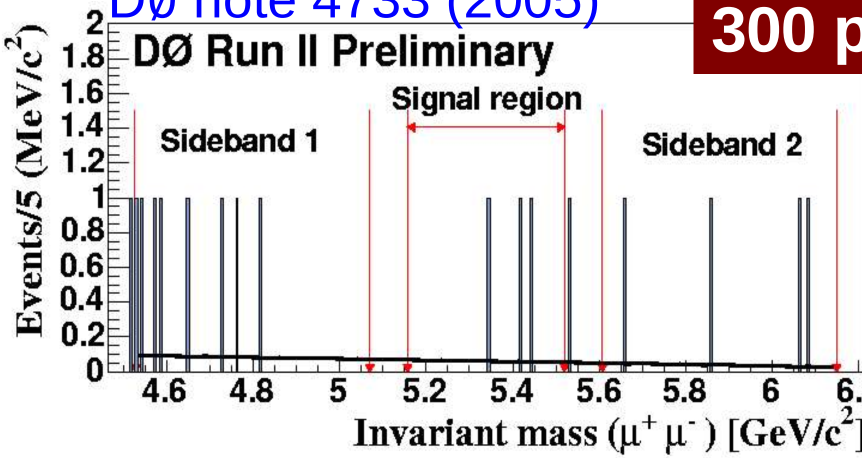


DØ note 5009 (2006) **additional 400 pb^{-1}**

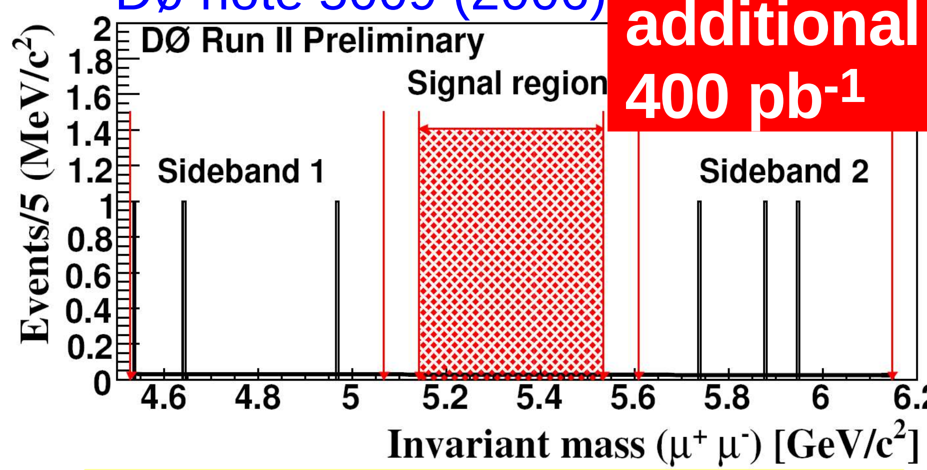


- Selected $B_s \to \mu^+\mu^-$ candidates:

DØ note 4733 (2005) **300 pb^{-1}**



DØ note 5009 (2006) **additional 400 pb^{-1}**

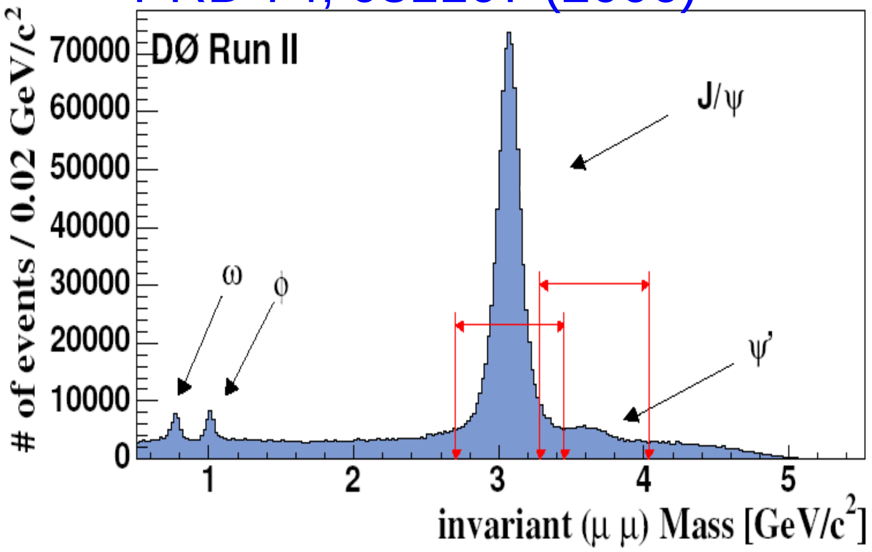


$BF(B_s \to \mu^+\mu^-) < 3.7\times10^{-7}$ (95% CL)

comb. sensitivity: 2.3×10^{-7}

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

PRD 74, 031107 (2006)



Event preselection:

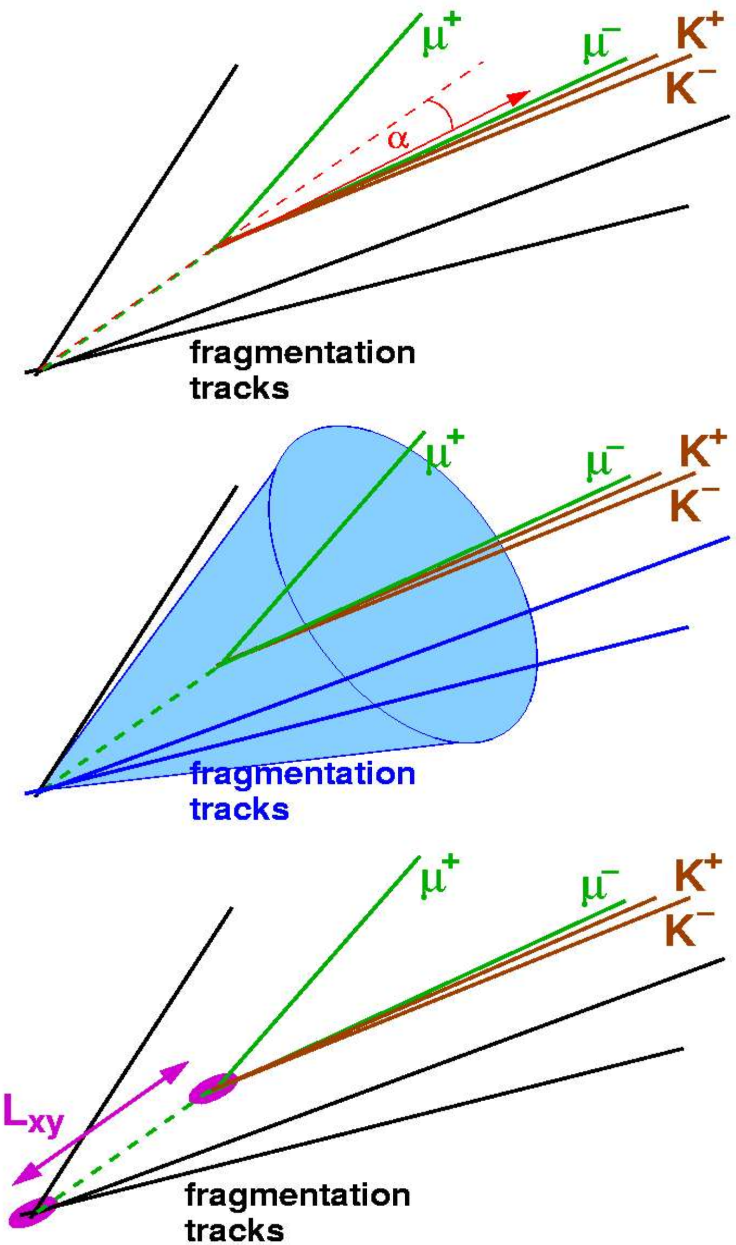
- similar to $B_s \rightarrow \mu^+\mu^-$ preselection
- dimuon trigger
- two muons (as before)
- dimuon system: as before, but
  - 0.5 GeV < $m(\mu^+\mu^-)$ < 4.4 GeV
  - exclude 2.72 GeV < $m(\mu^+\mu^-)$ < 4.06 GeV (5σ around J/Ψ, Ψ')
- two additional tracks: $\phi \rightarrow KK$ decay
  - $p_T > 0.7$ GeV
  - 1.008 GeV < m_{KK} < 1.032 GeV
- tracks form common secondary vertex:
  - $\chi^2/dof < 36$
  - 4.4 GeV < $m(\mu^+\mu^- KK)$ < 6.2 GeV
  - $p_T(\mu^+\mu^- KK) > 5$ GeV

efficiency and thus result depends on decay model

A. Ali et al., PRD 66, 034002 (2002)
A. Ali et al., PRD 61, 074024 (2000)
P. Ball, R. Zwicky, PRD 71, 014029 (2005)

Final event selection:

- similar to $B_s \to \mu^+\mu^-$ selection
  - -> pointing angle
  - -> isolation
  - -> decay length significance
- cut optimization based on
  MC signal
  background from data sidebands



Normalization

- Analysis based on the ratio
  B_s -> $\mu^+\mu^-$ ϕ(->K^+K^-) / B_s -> J/Ψ(->$\mu^+\mu^-$) ϕ(->K^+K^-):

$$\frac{\mathcal{B}(B_s^0 \to \phi\,\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = \frac{N_{\rm ul}}{N_{B_s^0}} \cdot \frac{\epsilon_{J/\psi\phi}}{\epsilon_{\phi\mu^+\mu^-}} \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

- Branching fraction we want to calculate
  and number of observed events (for example: upper limit)
- Branching fraction for reference process
  and number of observed events

Normalization

- Analysis based on the ratio
  $B_s \to \mu^+\mu^- \phi(\to K^+K^-)$ / $B_s \to J/\Psi(\to \mu^+\mu^-)\, \phi(\to K^+K^-)$:

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

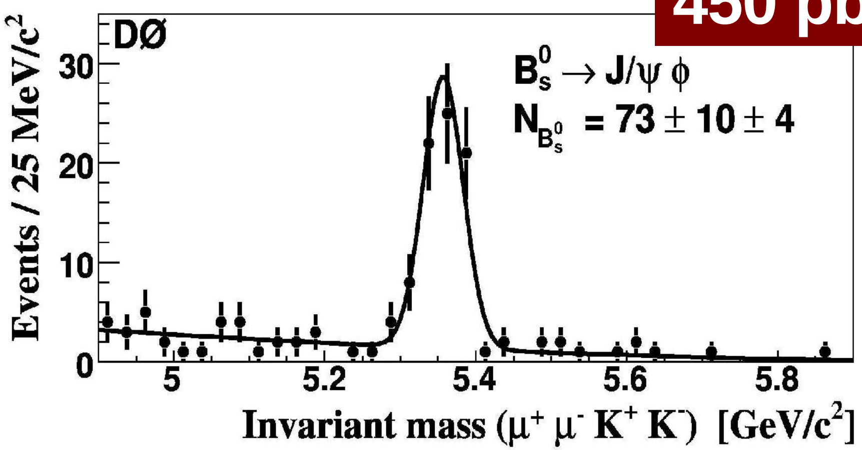
- Branching fraction we want to calculate
  and number of observed events (for example: upper limit)
- Branching fraction for reference process
  and number of observed events
- Efficiency ratio: signal / reference process
- Branching fraction $J/\Psi \to \mu^+\mu^-$ in reference process

Result

- Observed $B_s \to J/\Psi(\to\mu^+\mu^-)\ \phi(\to K^+K^-)$ signal:

PRD 74, 031107 (2006)

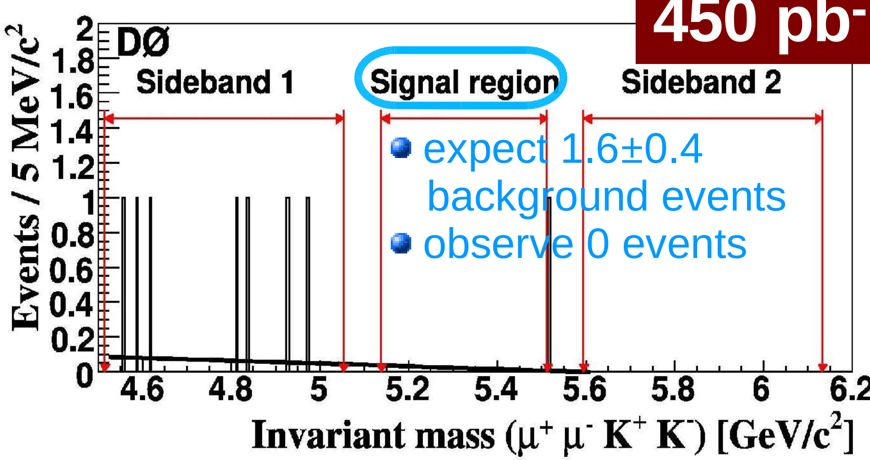
450 pb^{-1}



- branching fraction (PDG):
  $BF(B_s \to J/\Psi(\to\mu^+\mu^-)\ \phi(\to K^+K^-))$
  $= (9.3 \pm 3.3) \times 10^{-4}$

- Selected $B_s \to \mu^+\mu^-\ \phi(\to K^+K^-)$ candidates:

450 pb^{-1}



- expect 1.6±0.4 background events
- observe 0 events

- results: limits @ 95% CL

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

$$BF(B_s^0 \to \varphi\mu^+\mu^-) < 4.1\times10^{-6}$$

10 times better than previous limit (CDF I, PRD 65, 111101 (2002))

Conclusions

- Searches for FCNC processes may yield information on physics beyond the Standard Model
- Hadron colliders (->Tevatron): "natural B_s laboratory"

BF($B_s \to \mu^+\mu^-$):

- SM expectation: = $(3.42 \pm 0.54) \times 10^{-9}$

limit: < 3.7×10^{-7} (95% CL) (300 pb^{-1}) DØ note 4733 (2005)

sensitivity: < 2.3×10^{-7} (95% CL) (700 pb^{-1}) DØ note 5009 (2006)

- Probing new physics models
- Further improvements soon (likelihood selection, full Run IIa dataset)

BF($B_s \to \mu^+\mu^- \phi(\to K^+K^-)$):

- SM expectation: = 1.6×10^{-6} (±30%)

limit: < 4.1×10^{-6} (95% CL) (450 pb^{-1}) world's best limit! PRD 74, 031107 (2006)

SM expectation accessible at Tevatron Run II!

Backup Slides

Optimization of the Selection

- Optimization based on
  - signal MC events
  - background data events from mass sidebands ($>3\sigma$ away from Bs mass)
- Procedure to find the optimum cut values:
  - random grid search (N. Amos et al., proceedings of CHEP95, p. 215)
  - optimization (G. Punzi, proceedings of Phystat03, p. 79): maximize the variable

$$P = \frac{\varepsilon(B_s \rightarrow \mu^+\mu^-)}{a/2 + \sqrt{N_{bkg}}}$$

ε: selection efficiency (MC)

N_{bkg}: expected number of background events

a: number of standard deviations at which the signal hypothesis is tested ($a=2 \rightarrow \sim 95\%$ CL)

Limit Calculation

- Limits take into account
  - statistical uncertainty on the background expectation
  - systematic uncertainties, e.g. for $B_s \to \mu^+\mu^-$:

    ratio of $B_s/B_{u/d}$ hadronization fractions

    $B^+ \to \mu^+\mu^- K^+$ / $B_s \to \mu^+\mu^-$ efficiency ratio

    number of reconstructed $B^+ \to \mu^+\mu^- K^+$ decays

    $B^+ \to J/\Psi K^+$ branching fraction

    $J/\Psi \to \mu^+\mu^-$ branching fraction
- Integrate over probability functions (parametrize uncertainties), prescription: J. Conrad et al, PRD 67, 012002 (2003)
  G.J. Feldman, R.D. Cousins, PRD 57, 3873 (1998)
- Alternative:
  Bayesian approach (flat prior, Gaussian uncertainties)
  I. Bertram et al., Fermilab-TM-2104 (2000)

$B_s \to \mu^+\mu^-$: Compare with CDF

references:	DØ note 5009	CDF note 8176
integrated luminosity:	700 pb^{-1}	780 pb^{-1}
muon $p_T >$:	2.5 GeV	2.0 GeV (CMU), 2.2 GeV (CMX)
muon $\|\eta\| <$:	2.0	1.0
$p_T(B_s) >$:	5.0 GeV	4.0 GeV
$\mu\mu$ mass resolution:	90 MeV	24 MeV
selection:	cut-based	likelihood-based
resulting limit (95%CL):	2.3×10^{-7} (sensitivity)	1.0×10^{-7}