Tevatron results on $B \rightarrow \mu\mu$, $B \rightarrow K^{*}\mu\mu$

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For the CDF and DØ Collaborations

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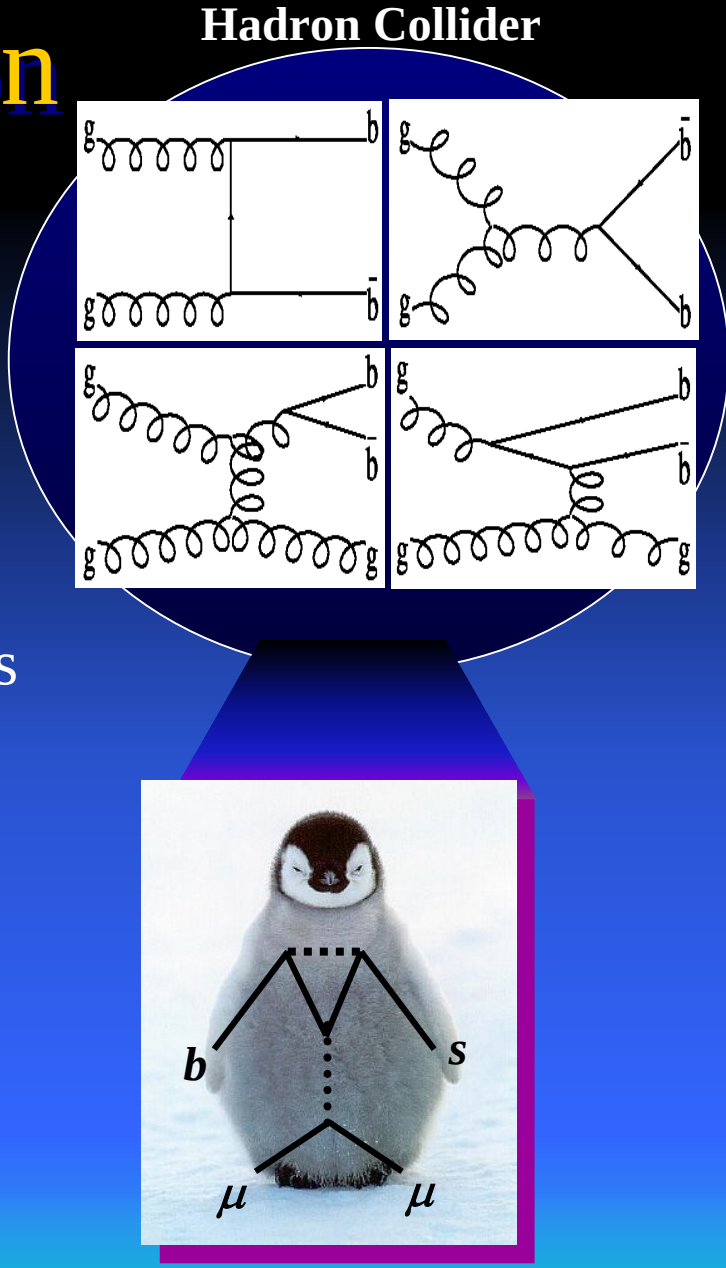
Outline

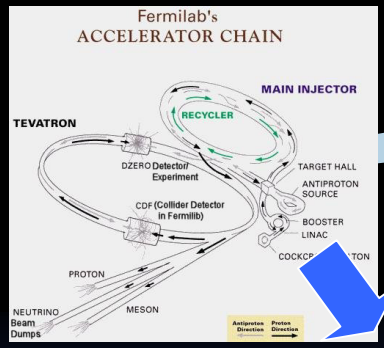
1. Introduction
2. Analysis procedures
3. $B \rightarrow K^{*} \mu^{+} \mu^{-}$
   1. Introduction
   2. Recent results from CDF
4. $B \rightarrow \mu^{+} \mu^{-}$
   1. Introduction
   2. CDF results
   3. DØ results
5. Summary

Introduction

- Both $B \rightarrow \mu^+\mu^-$ and $B \rightarrow K^*\mu^+\mu^-$ decay via Flavor Changing Neutral Current
  - –Forbidden at tree level in the SM
    - →Rare decays
  - –New physics in rare decays when new physics > SM
- Need a lot of B events to probe the decays
- Tevatron also works as a ***B***-factory : $\sigma_b \sim 30\mu b$ ($|y|<1$)
  - $-B^+, B^0, B_s, B_c, \Lambda_b, \Sigma_b, \Xi_b, \Omega_b, ??_b$
- Huge backgrounds (more than $\times 10^3$)
- High performance B triggers are required
  - –Muon trigger can be used for these searches



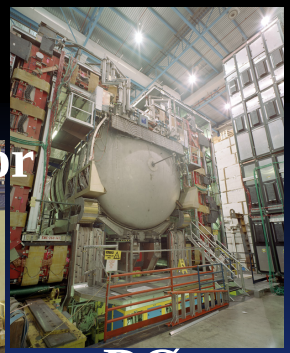
Analysis procedures



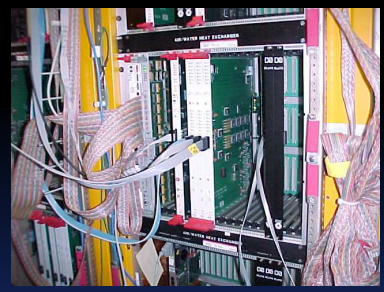
Tevatron
p-p̄ collisions

Detector

CDF



DØ



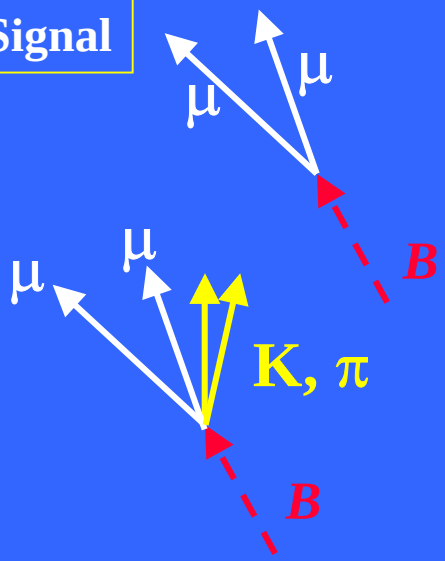
Triggers
(Muon triggers)

Tape

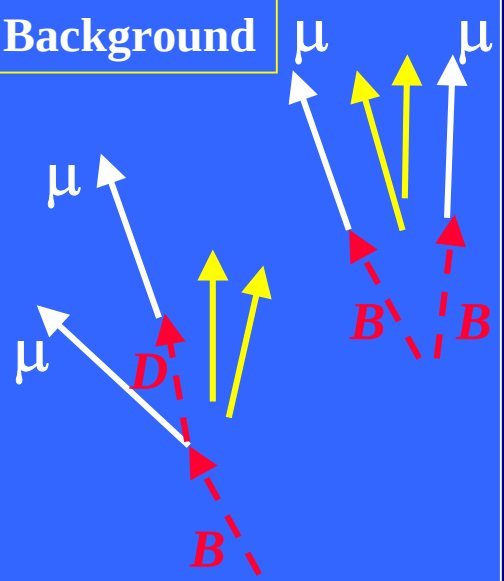
Offline Analysis

1. Preselection
   - Secondary vertex c/o dimuon (+α)
2. Multivariate classifier
   - Remove background
3. Measurements (Limits)

Signal



Background



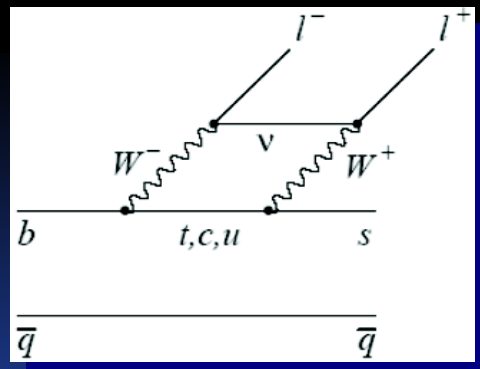
$B^0 \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-$

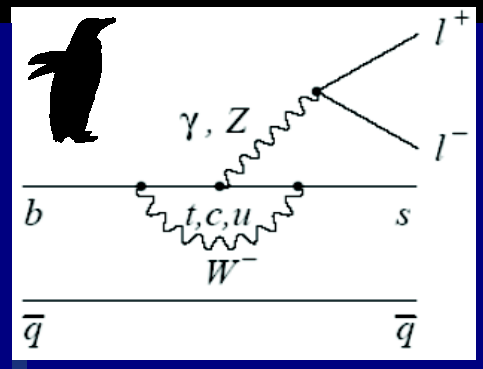
$B^+ \rightarrow K^+\mu^+\mu^-$

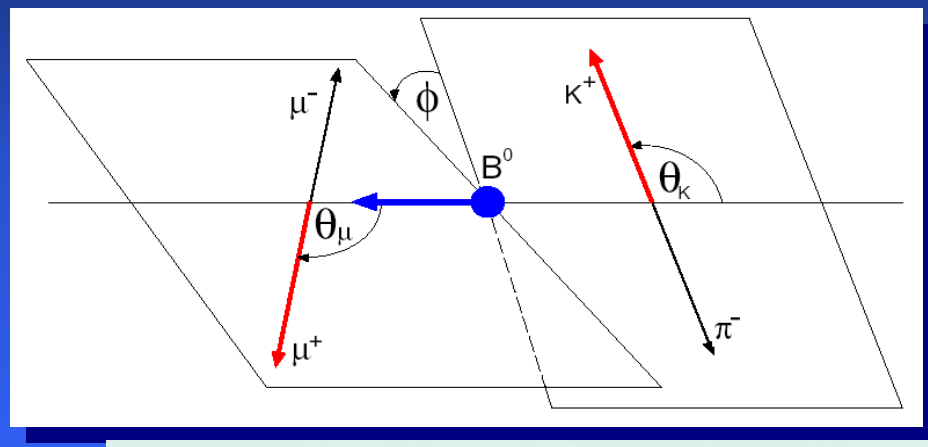
$B_s \rightarrow \phi\mu^+\mu^-$

$B^0 \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-$

- Non resonant μμ decays via box or penguin
- BR($B^0 \rightarrow K^{*0}\mu^+\mu^-$) ~$10^{-6}$
- New physics :
  - Larger BR
  - Modify kinematics
    - Dimuon mass spectrum
    - Angular distributions
- Our interests :
  - BR
  - A_{FB} : Forward-backward asymmetry
  - F_L : K^{*0} longitudinal polarization







Forward-Backward Asymmetry :

$$A_{FB}(q^2) \equiv \frac{\Gamma(q^2, \cos\theta_\mu > 0) - \Gamma(q^2, \cos\theta_\mu < 0)}{\Gamma(q^2, \cos\theta_\mu > 0) + \Gamma(q^2, \cos\theta_\mu < 0)}$$

$B \rightarrow X_s \mu^+\mu^-$ results in the past

: $1fb^{-1}$ (PRD 79:011104,2009)

- $BR(B^+ \rightarrow K^+\mu^+\mu^-) = (0.59 \pm 0.15 \pm 0.04) \times 10^{-6}$
- $BR(B^0 \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-) = (0.81 \pm 0.30 \pm 0.10) \times 10^{-6}$
- $BR(B_s \rightarrow \phi\mu^+\mu^-) / BR(B_s \rightarrow J/\psi\phi) < 2.6 \times 10^{-3}$ @95C.L.

: $0.45fb^{-1}$ (PRD 74:031107,2006)

- $BR(B_s \rightarrow \phi\mu^+\mu^-) / BR(B_s \rightarrow J/\psi\phi) < 4.4 \times 10^{-3}$ @95C.L.

*PDG $BR(B_s \rightarrow J/\psi\phi) = (0.9 \pm 0.3) \times 10^{-3}$

- All consistent with the SM predictions
- Didn't measure A_{FB} due to limited statistics

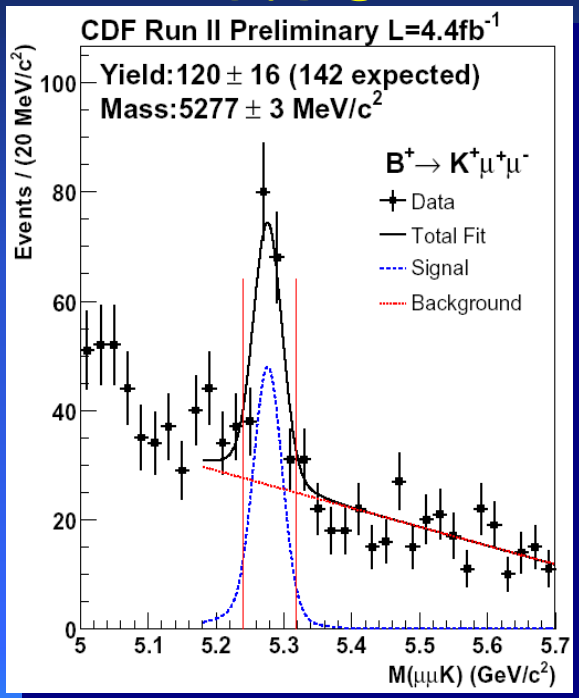
Update since last publication

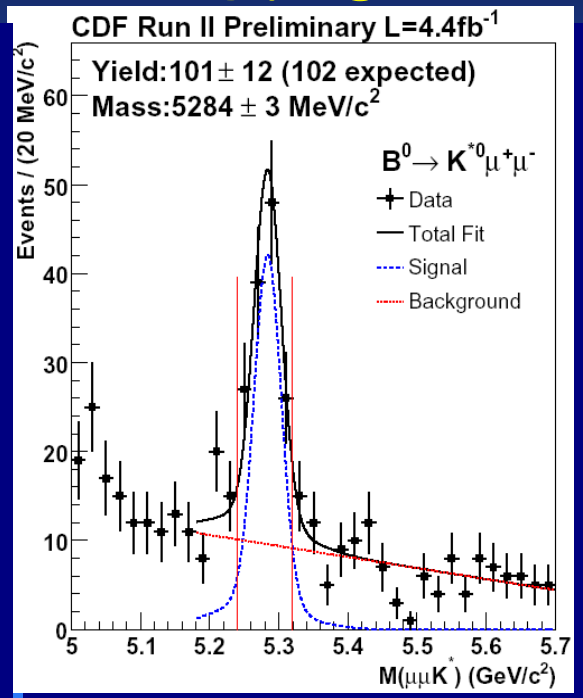
CDF Note 10047

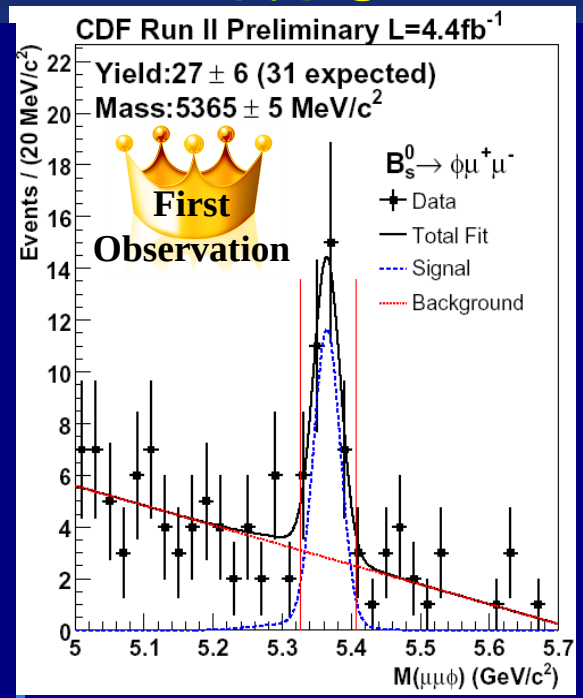
- Use 4.4fb^{-1} of data
- Various optimizations:
  - –Improved PID
    - Muon : Likelihood ID
      - – Cleaner dimuon candidates
    - Kaon, Pion : Combined log likelihood (TOF & dE/dx)
      - – Reduce combinatorial background
  - –Neural Networks for B signal selection
    - Cleaner B signal

Observations

Lumi	$B^+ \rightarrow K^+\mu^+\mu^-$	$B^o \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-$	$B_s \rightarrow \phi\mu^+\mu^-$
$1fb^{-1}$	4.5σ	2.9σ	2.4σ
$4.4fb^{-1}$	8.5σ	9.7σ	6.3σ







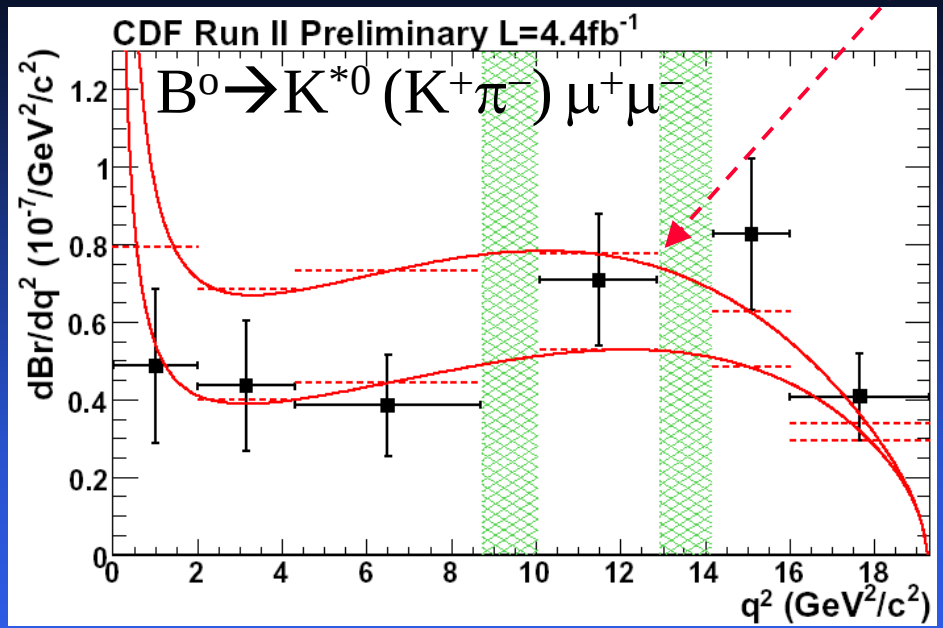
Enough signals to measure A_{FB}

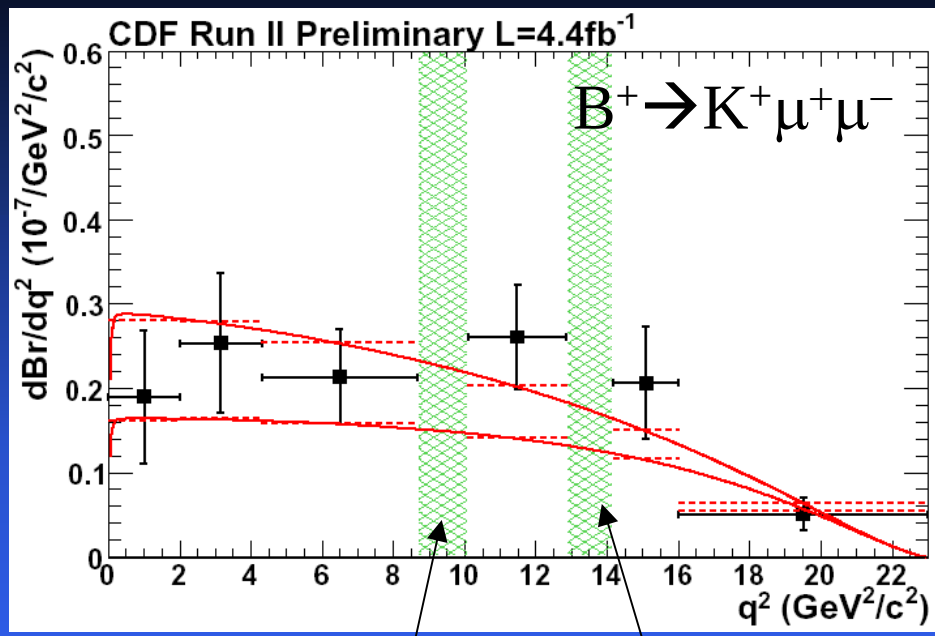
Branching fraction measurements

- **BR($B^+ \rightarrow K^+\mu^+\mu^-$)**
  $=(0.38\pm0.05(\text{stat.})\pm0.03(\text{syst.}))\times10^{-6}$
- **BR($B^0 \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-$)**
  $= (1.06\pm0.14(\text{stat.})\pm0.09(\text{syst.}))\times10^{-6}$
- **BR($B_s \rightarrow \phi\mu^+\mu^-$)**
  $= (1.44\pm0.33(\text{stat.})\pm0.46(\text{syst.}))\times10^{-6}$
  - ✧ First measurement in the world
  - ✧ The rarest B_s decay we have observed so far
- Most precise measurements for single final state!!
- All consistent with the SM predictions and *B*-factories

Differential branching fraction

Allowed region by SM

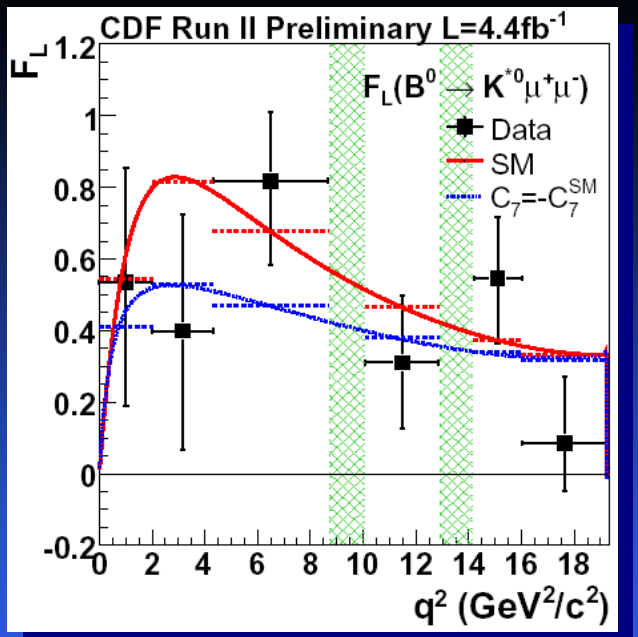


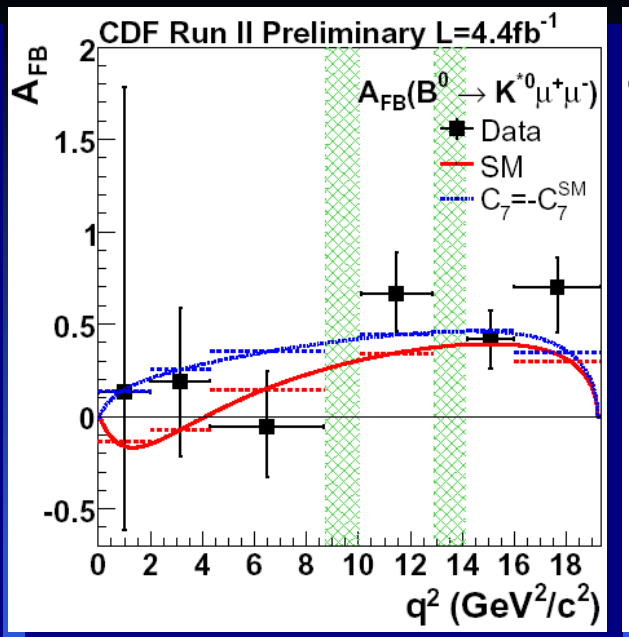


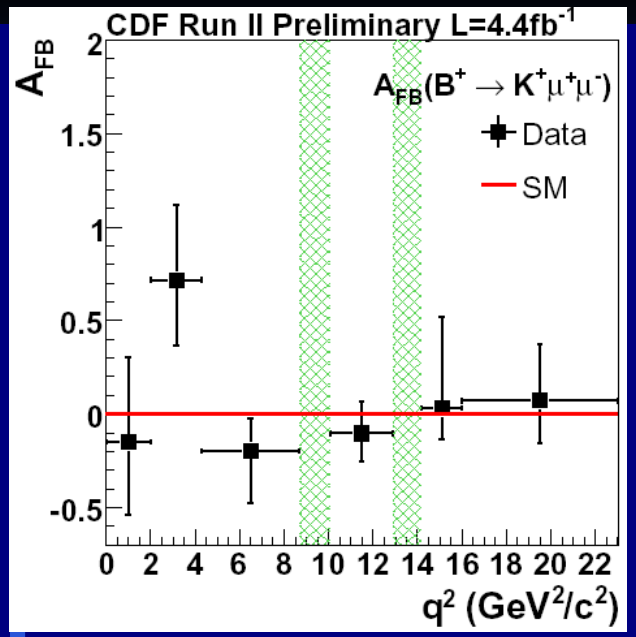
- $q^2 = m_{\mu\mu}{}^2 c^2$
- q^2 distributions could show a hint of new physics

F_L and A_{FB} measurements

- First measurement in hadron collisions



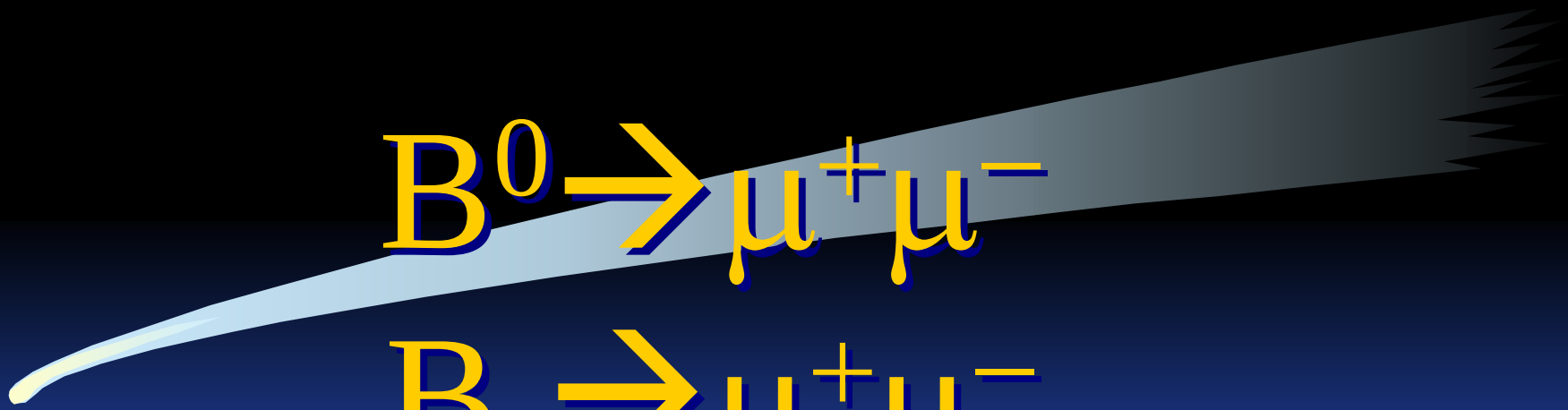




$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$

- Competitive results with *B*-factories


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

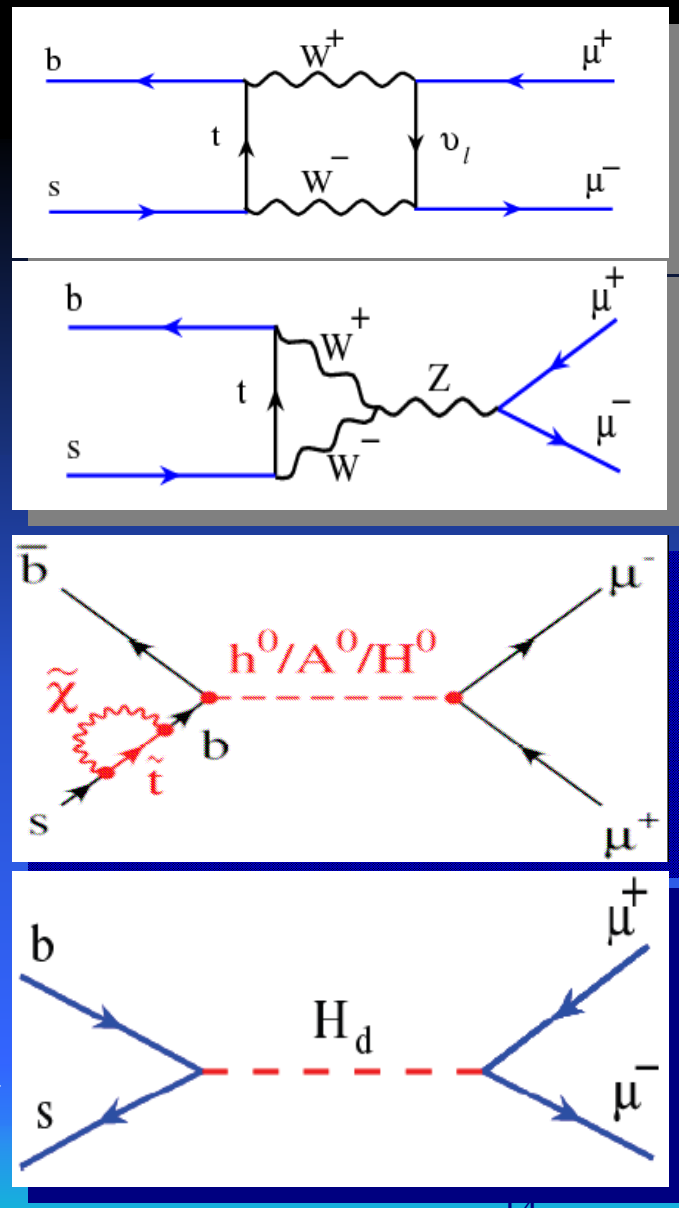
$B \rightarrow \mu^+\mu^-$

- SM prediction :

  A.J.Buras, hep-ph/0904.4917:

  - $BR(B_s \rightarrow \mu^+\mu^-) = (3.6 \pm 0.3) \times 10^{-9}$
  - $BR(B^0 \rightarrow \mu^+\mu^-) = (1.1 \pm 0.1) \times 10^{-10}$

    suppressed by $|V_{td}/V_{ts}|^2$
- Can be enhanced by
  - **MSSM** ($BR(B \rightarrow \mu^+\mu^-) \propto \tan^6 \beta$)
  - **GUT SO(10)**
  - **SUSY R-parity violating models**
  - **Non-minimal flavor violating model**
- SM signal is beyond the detectors' sensitivity at Tevatron
  - Current observation of $B \rightarrow \mu^+\mu^-$ would imply new physics

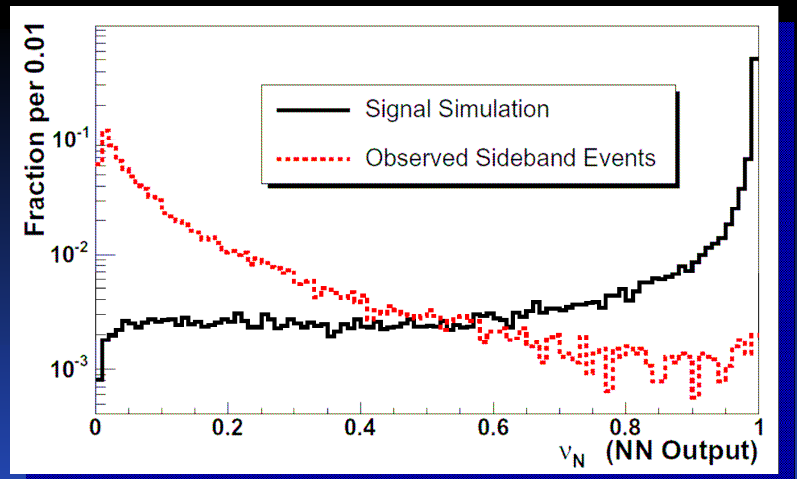


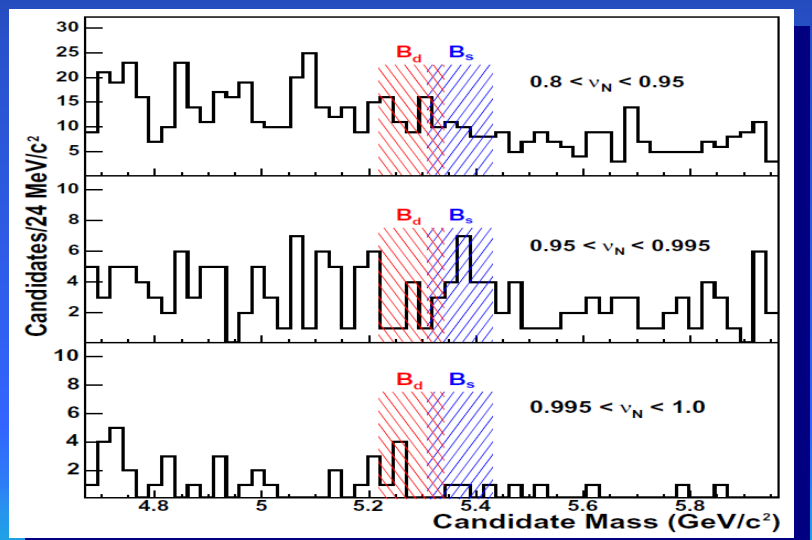
The best published results (2008)

PRL 100,101802(2008)

- Use 2fb^{-1} of data
- Use Neural Networks (NN)
- Subdivide the signal region into several NN and mass bins

  → 15% improvement





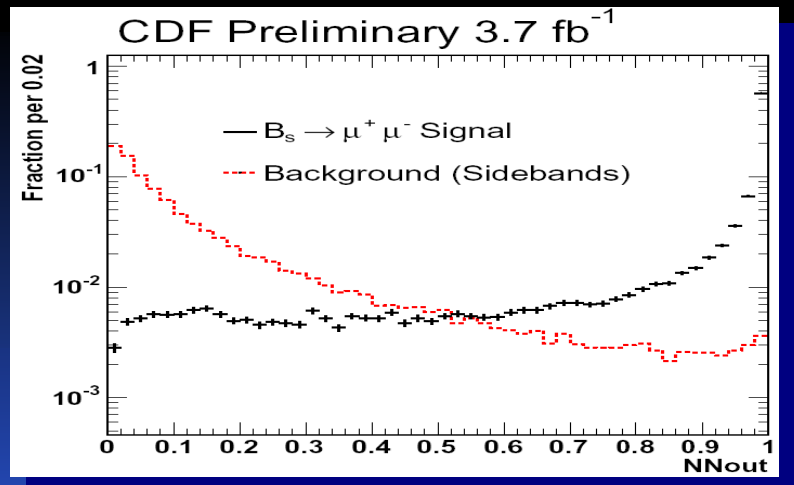
Observed limits@95% C.L.

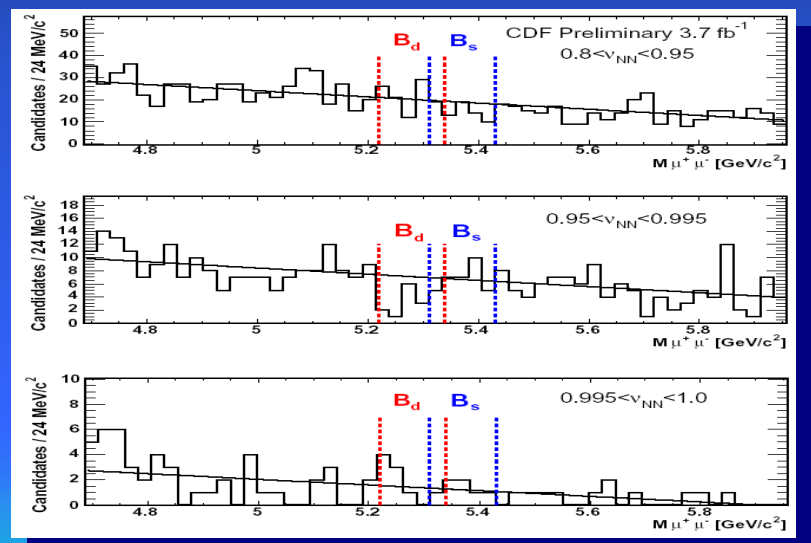
- **BR($B^0 \rightarrow \mu\mu$) < 1.8×10^{-8}**
- **BR($B_s \rightarrow \mu\mu$) < 5.8×10^{-8}**
  (4.9×10^{-8} expected)

Updated results using 3.7fb^{-1}

CDF Note 9892

- Same baseline as the published analysis
- More data
  - Added 1.7fb^{-1}
  - Additional acceptance gain (tracking region) by 12%





Best!

Observed limits@95% C.L.

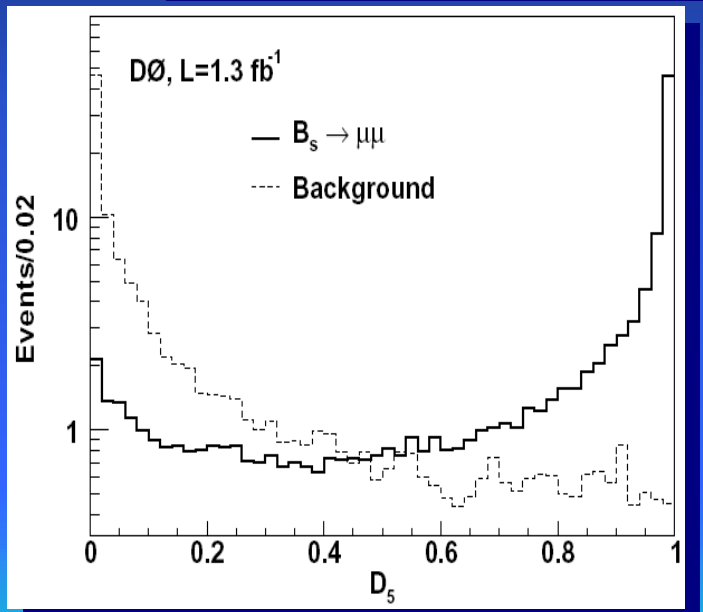
- **BR($B^0 \to \mu\mu$) < 7.6×10^{-9} (9.1×10^{-9} expected)**
- **BR($B_s \to \mu\mu$) < 4.3×10^{-8} (3.3×10^{-8} expected)**

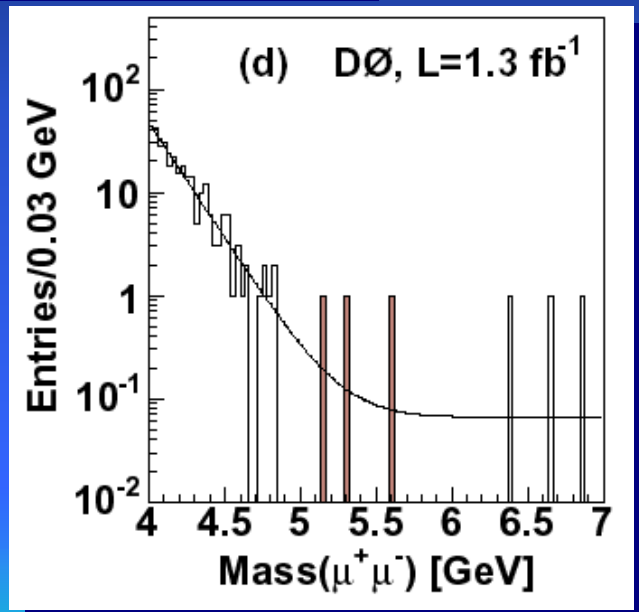
DØ results

- Last published result : 2007, using 1.3fb^{-1}
  - Likelihood ratio to reduce background

Observed limit @95%C.L
•BR($B_s \rightarrow \mu\mu$) < 12×10^{-8}

PRD 76, 092001(2007)



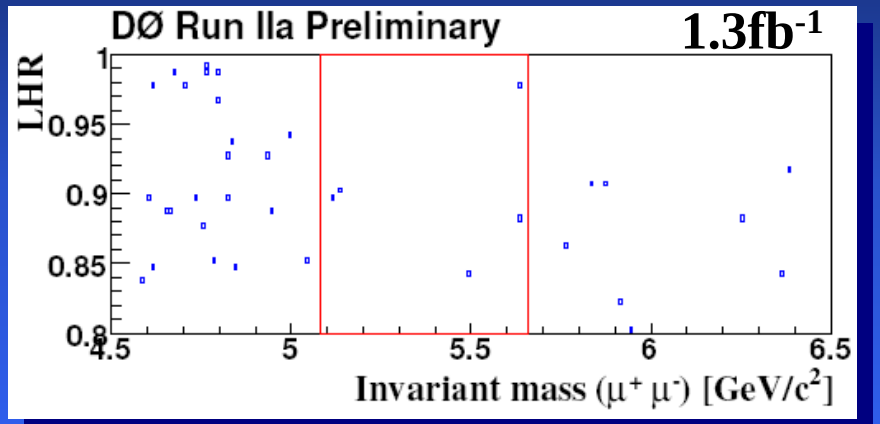


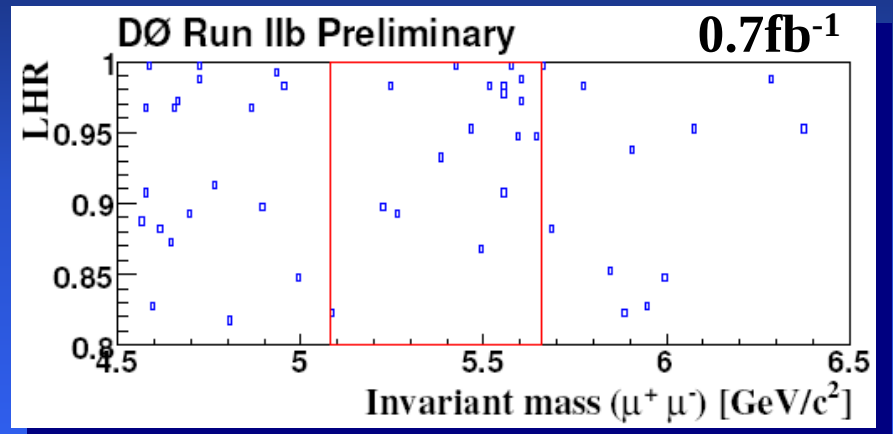
Complicated bkg parameterization

Preliminary result using 2fb^{-1}

- Start adding RunIIb data
  - Several upgrades (e.g. Layer 0 silicon)
  - High instantaneous luminosity
  - First 1.3fb^{-1} = Run IIa, later=Run IIb
  - Challenge : High luminosity modeling

DØ Note 5344



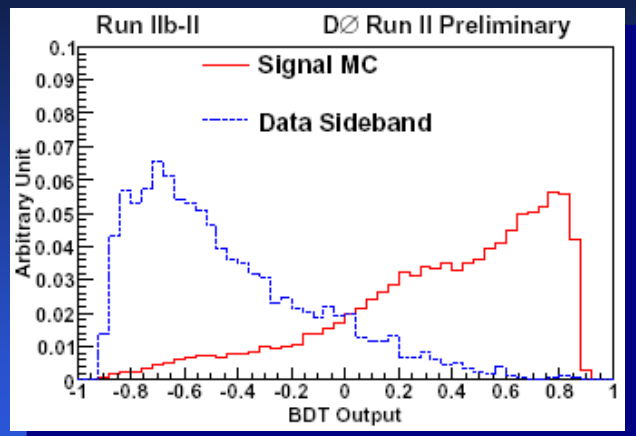


Observed limit @95%C.L
•BR($B_s \rightarrow \mu\mu$) < 9.5×10^{-8}

Higher background level in Run IIb

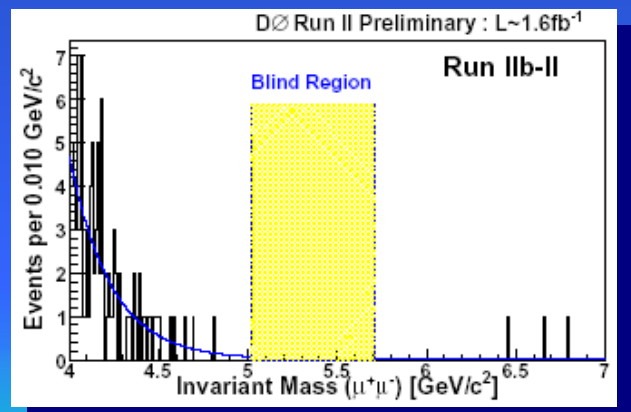
Preliminary result using 4.8fb^{-1}

- Use Boosted Decision Tree — DØ Note 5906
  - 5 inputs : B_s Isolation, p_T, vertex χ^2, IP/σ, L_{xy}/σ
- Subdivide the data into three samples based on trigger/luminosity configuration
- **Box still remained blinded**



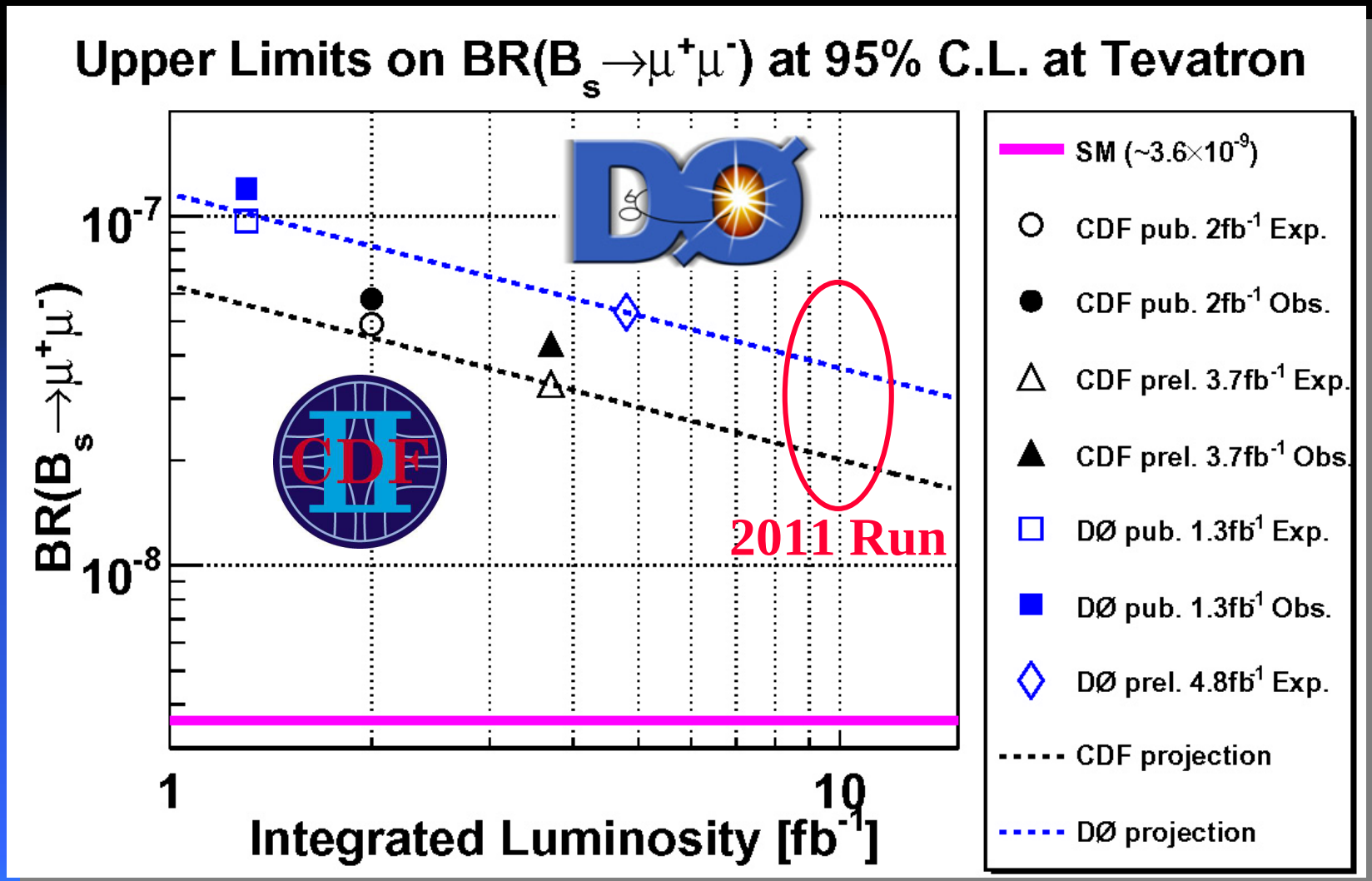
"Expected" limit @95%C.L

•BR($B_s \rightarrow \mu\mu$) < 5.3×10^{-8}



- Further studies on going
  - Understanding background
  - Increasing acceptance
  - Finding new and better discriminants
  - Then, we will open the box

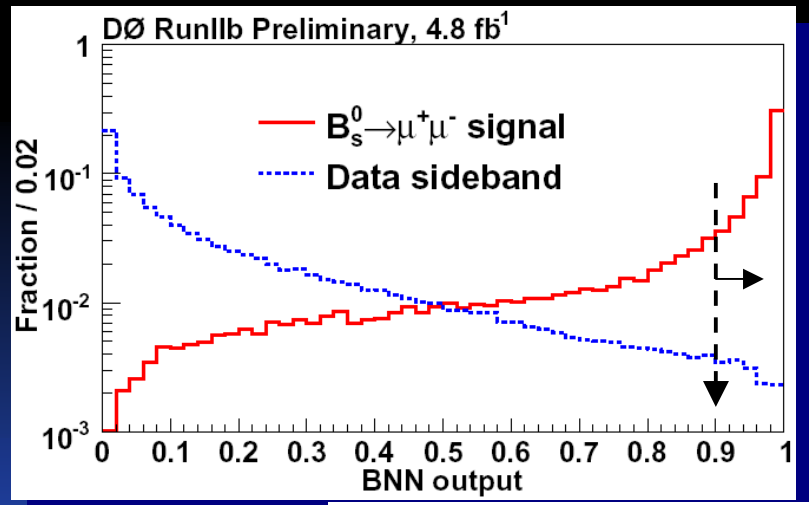
$B_s \rightarrow \mu\mu$ projections

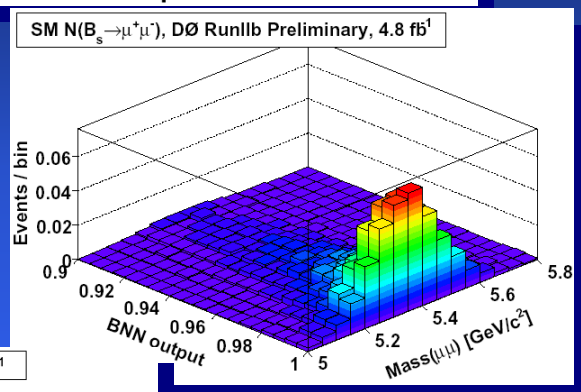


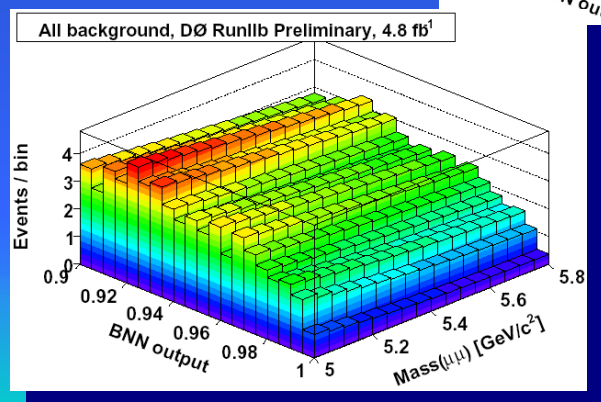
Projection : a simple luminosity projection from the recent expected limit assuming no signal

New result using 6.1fb^{-1}

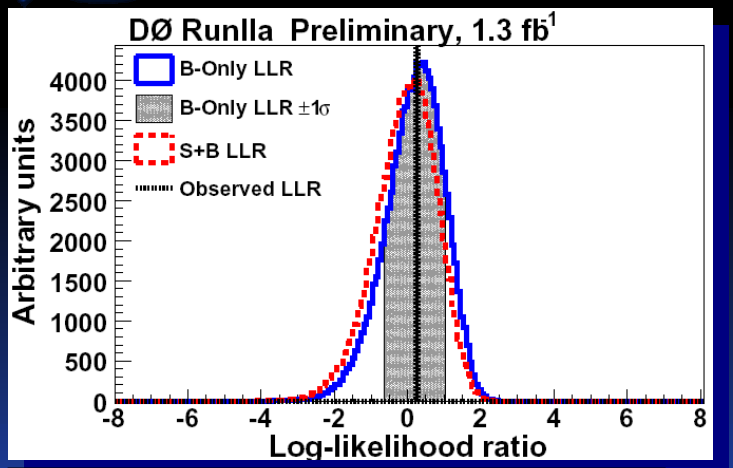
- Just approved!
- Run IIa 1.3fb^{-1} + Run IIb 4.8fb^{-1}
- **A lot of improvements**:
  - –Acceptance gain :
    - Muon ID : ~10%
    - Trigger : ~16%
  - –Bayesian Neural Networks
  - –Better understanding of BNN input variables
  - –Background modeling from MC and data sidebands
  - –Subdivide the signal region into several BNN and mass bins
- **The blinded signal box has been opened**



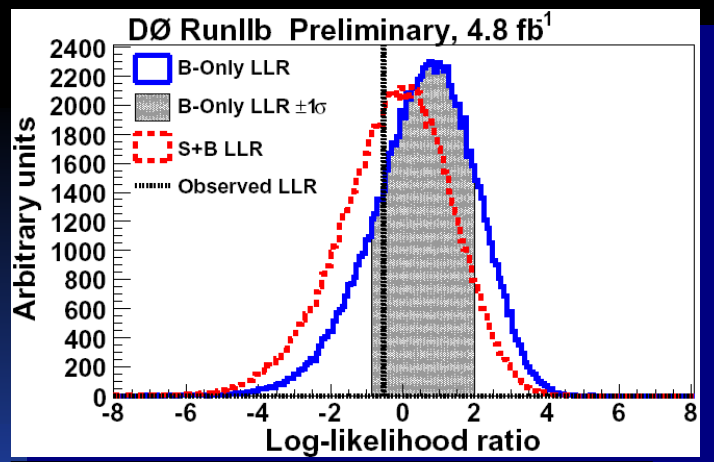




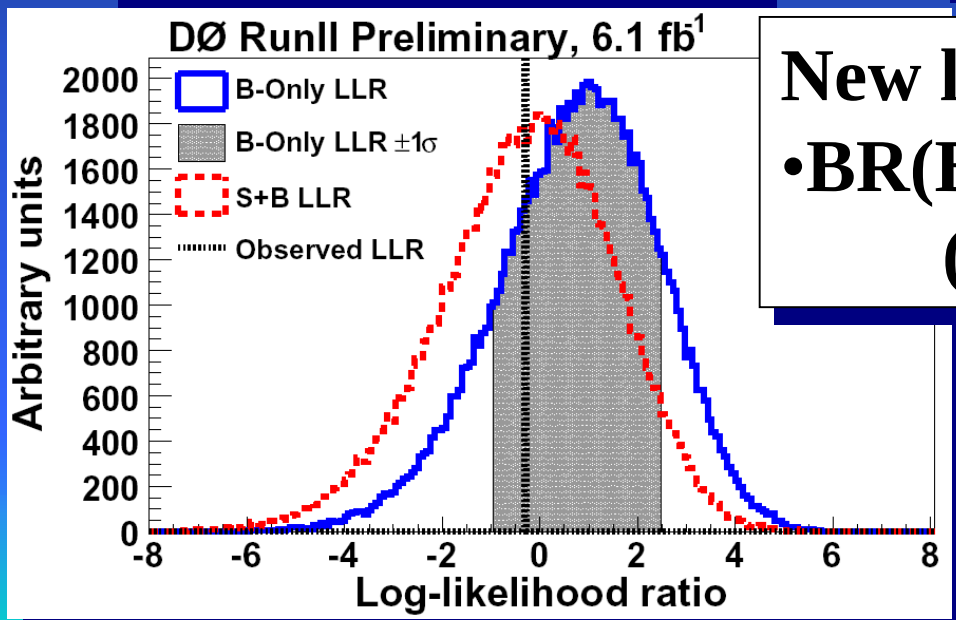
Preliminary result using 6.1fb^{-1}



BR($B_s \rightarrow \mu\mu$) < 7.9×10^{-8} @95%C.L
(8.1×10^{-8} expected)



BR($B_s \rightarrow \mu\mu$) < 6.7×10^{-8} @95%C.L
(4.4×10^{-8} expected)



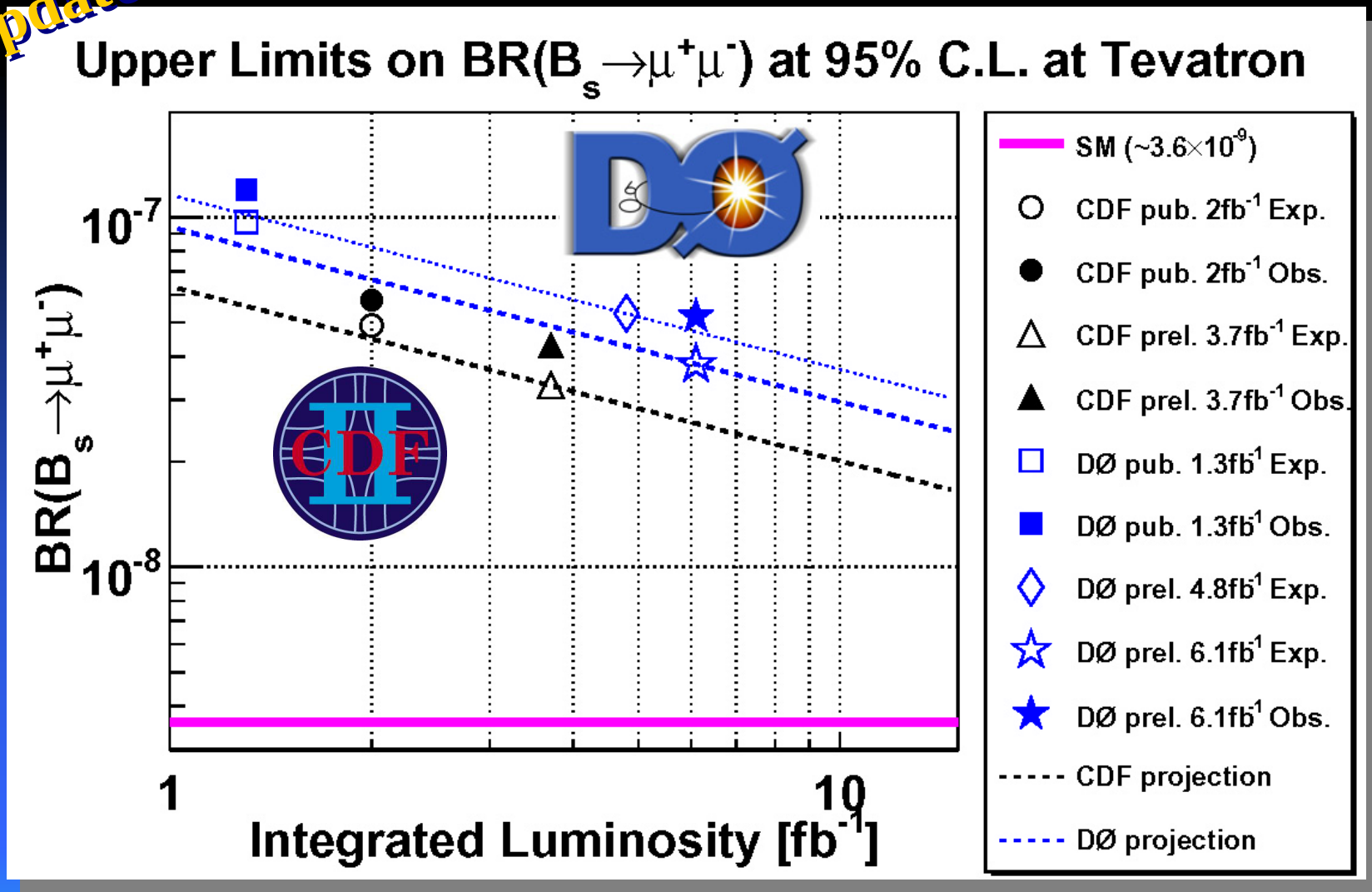
New limit @95%C.L

•BR($B_s \rightarrow \mu\mu$) < 5.2×10^{-8}
(3.8×10^{-8} expected)

Largest systematics : fragmentation ratio between B_s and B^+ (15%)

$B_s \rightarrow \mu\mu$ projections

Updated

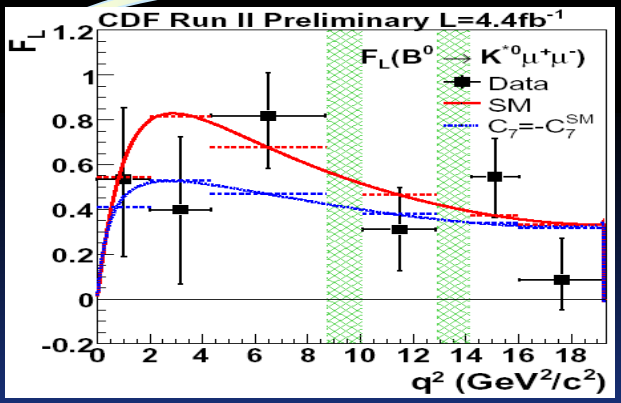


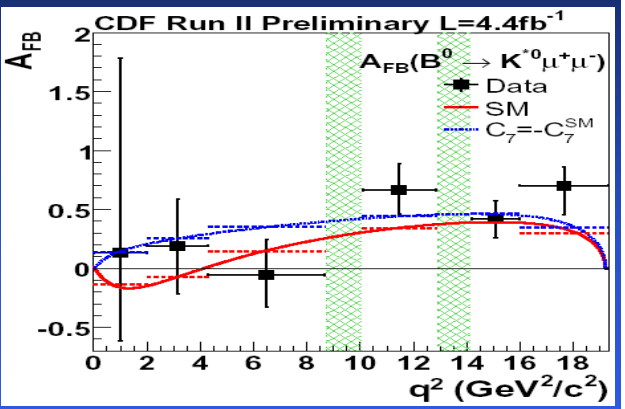
Summary

- New results on FCNC decays at Tevatron
  - $B \rightarrow K^{*} \mu\mu$
    - CDF results using 4.4 fb^{-1}
      - First measurement of A_{FB} at Tevatron
      - First observation $B_s \rightarrow \phi\mu\mu$
  - $B \rightarrow \mu\mu$:
    - CDF results using 3.7 fb^{-1}
      - $BR(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$, $BR(B^0 \rightarrow \mu\mu) < 7.6 \times 10^{-9}$
      - World best results
    - DØ result using 6.1 fb^{-1}
      - $BR(B_s \rightarrow \mu\mu) < 5.2 \times 10^{-8}$
    - Still no evidence for new physics
- Wait! We have more data in hand now
  - More than 7 fb^{-1} recorded on tape as of today
  - More exciting results coming soon! Stay tuned!

Backup

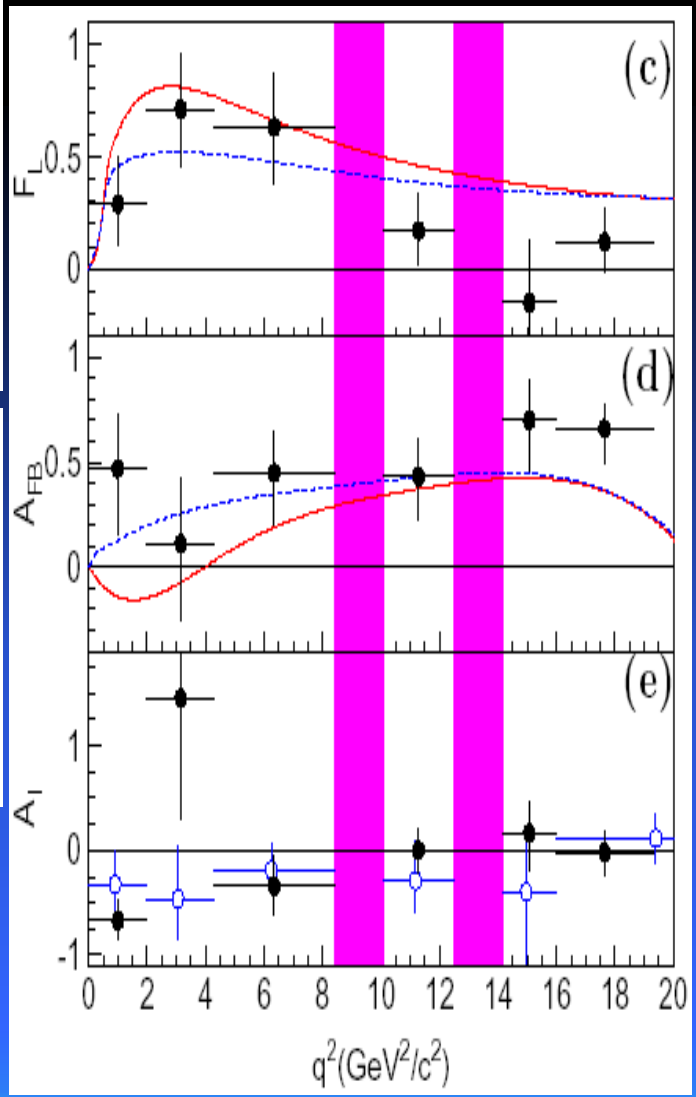
CDF





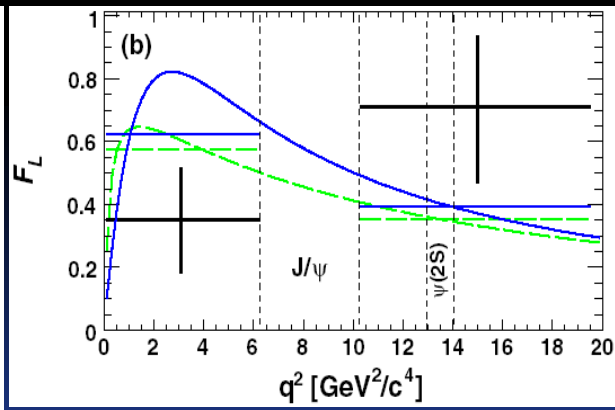
CDF Note 10047

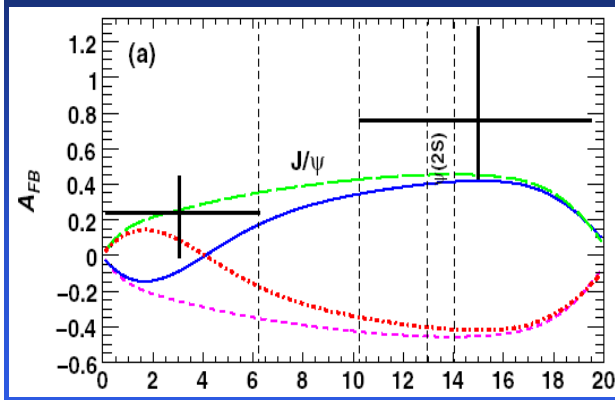
Belle



PRL103,171801(2009)

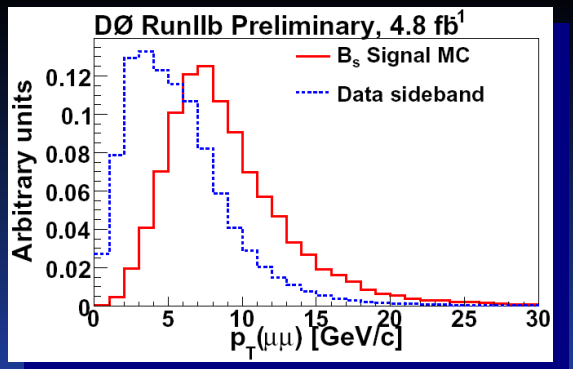
BaBar

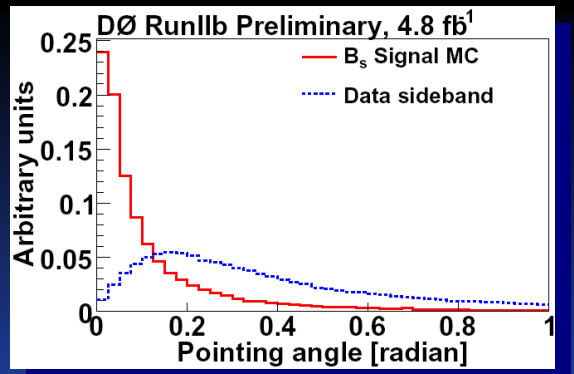


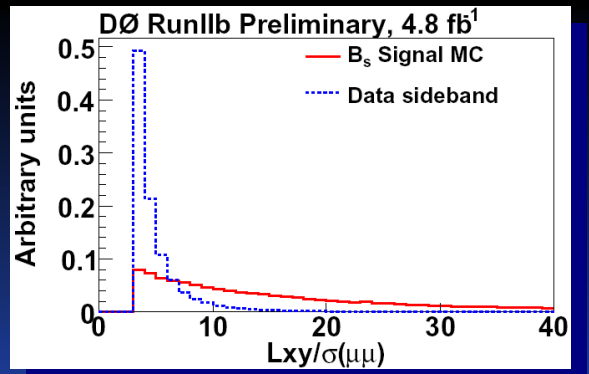


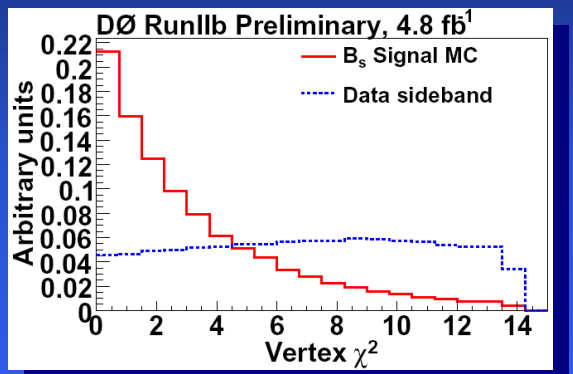
PRD79,031102(R) (2009)

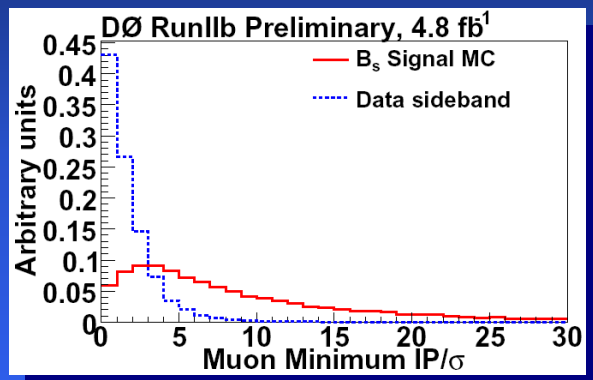
6 inputs to BNN

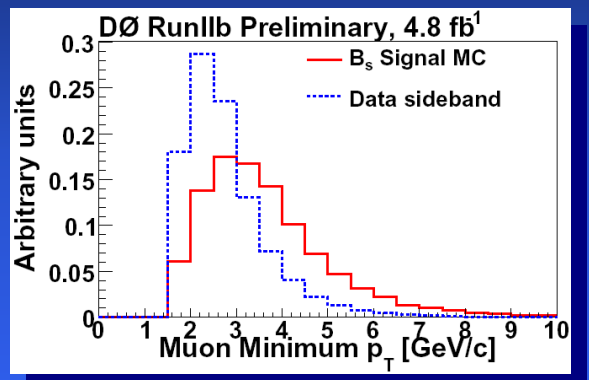












- Plots only for RunIIb are shown here
- RunIIa distributions are similar to RunIIb

Run IIa dimuon mass distributions in the highest four BNN bins

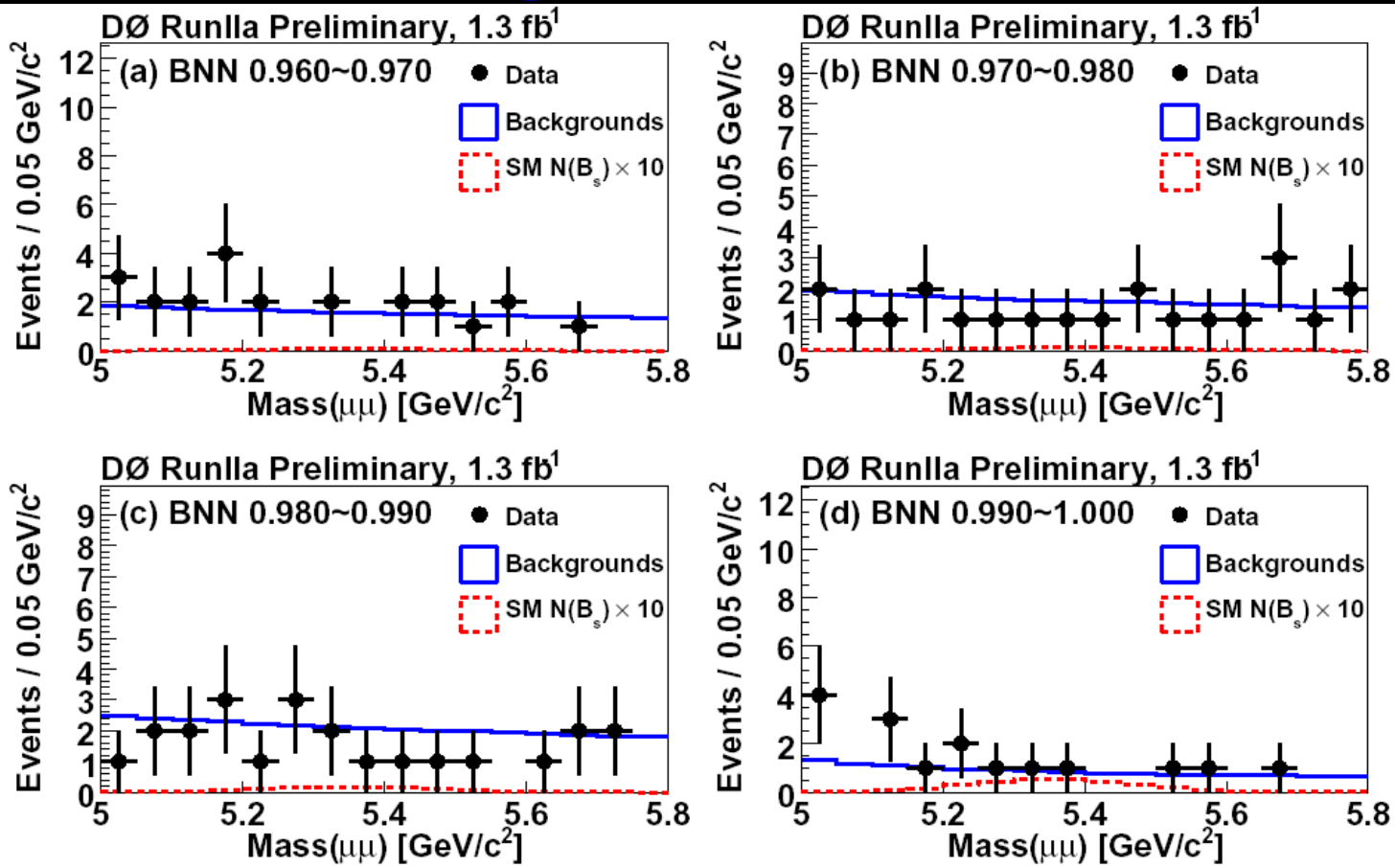


FIG. 12: Distributions of dimuon mass for data (dots with error bars), expected background distribution (solid line) and the SM signal distribution multiplied by a factor of 10 (dashed line) in the highest four BNN bins in Run IIa: (a) $0.96 \leq \text{BNN} \leq 0.97$, (b) $0.97 \leq \text{BNN} \leq 0.98$, (c) $0.98 \leq \text{BNN} \leq 0.99$, (d) $0.99 \leq \text{BNN} \leq 1.00$.

Run IIb dimuon mass distributions in the highest four BNN bins

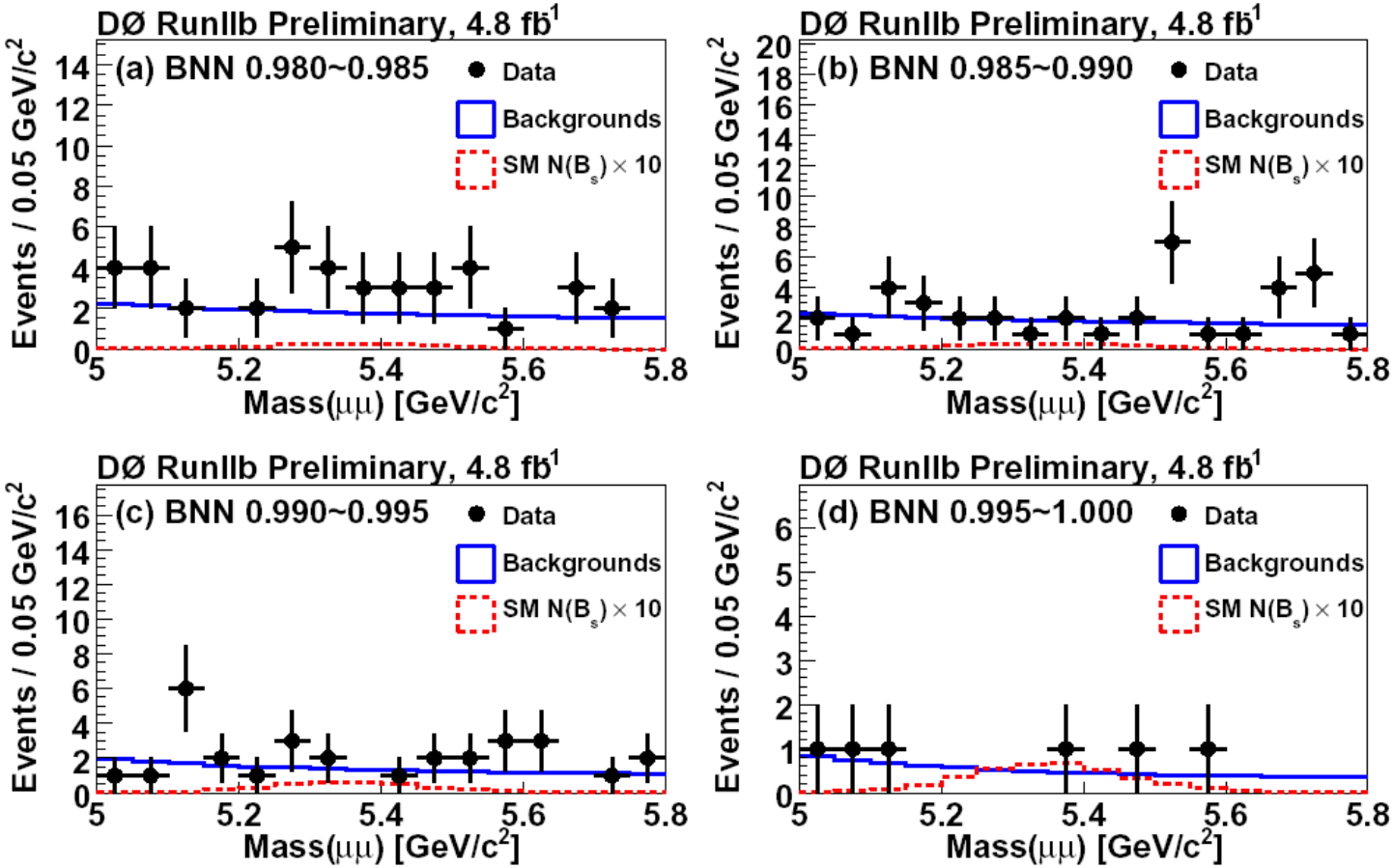
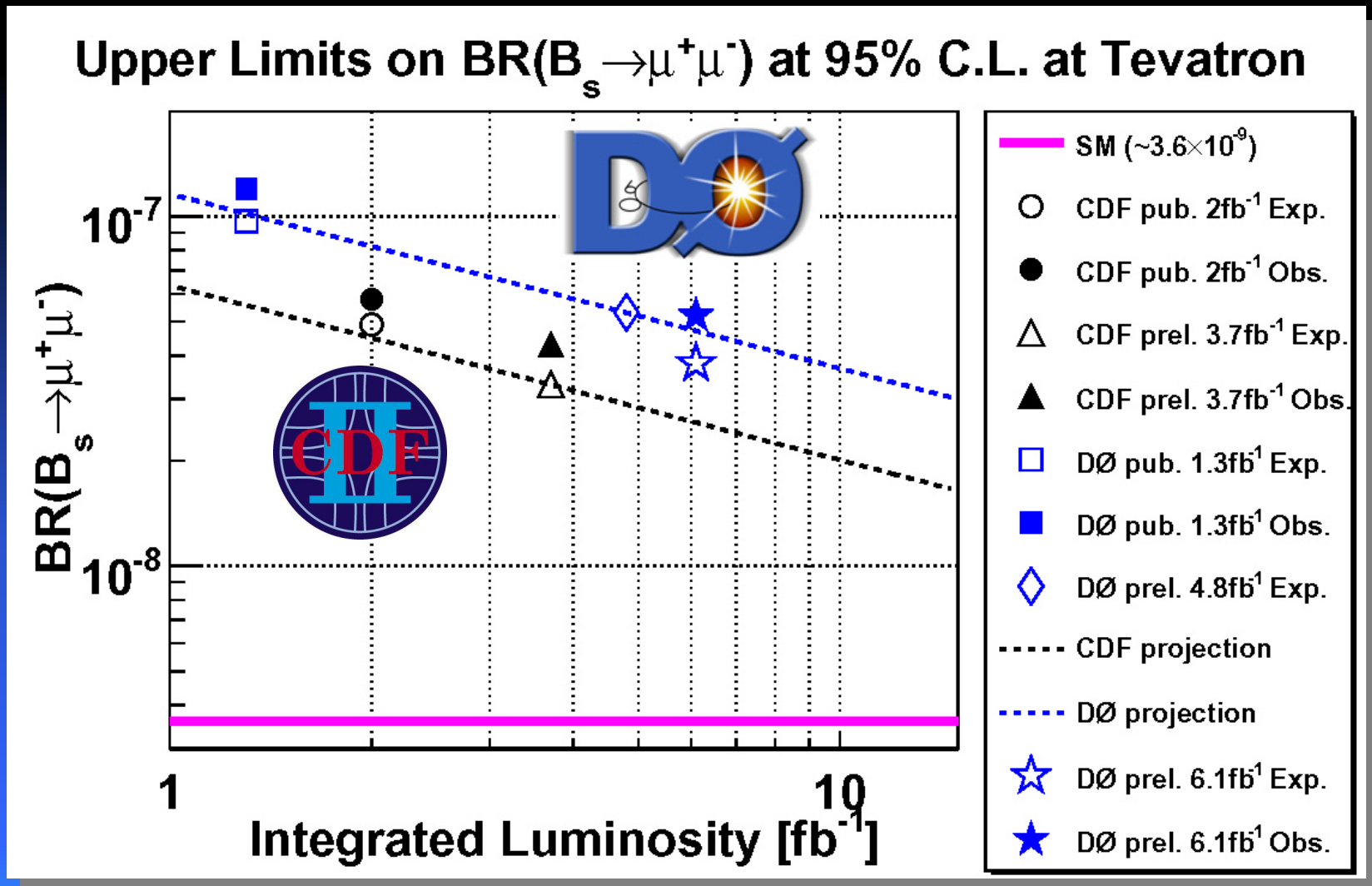


FIG. 13: Distributions of dimuon mass for data (dots with error bars), expected background distribution (solid line) and the SM signal distribution multiplied by a factor of ten (dashed line) in the highest four BNN bins in Run IIb: (a) $0.980 \leq \text{BNN} \leq 0.985$, (b) $0.985 \leq \text{BNN} \leq 0.990$, (c) $0.990 \leq \text{BNN} \leq 0.995$, (d) $0.995 \leq \text{BNN} \leq 1.000$.

$B_s \rightarrow \mu\mu$ projections



Systematics on the single event sentsitivity

TABLE I: Sources of uncertainty and their contributions to the relative uncertainty (%) in the single event sensitivity.

Source	Run IIa	Run IIb
$N(B^+)$ stat.	4.6	2.7
$N(B^+)$ syst.	1.5	0.7
Kaon reconstruction	1.7	8.5
Trigger	0.5	0.9
B_s^0 p_T spectrum	6.4	6.6
B^+ MC stat.	0.9	1.1
B_s^0 MC stat.	0.6	0.6
$\mathcal{B}\left(B^+ \to J/\psi\left(\mu^+\mu^-\right)K^+\right)$	3.4	3.4
f_u/f_s	15.2	15.2
Total	17.6	19.2

Control plots : BNN distributions for $B^+ \rightarrow J/\psi K^+$

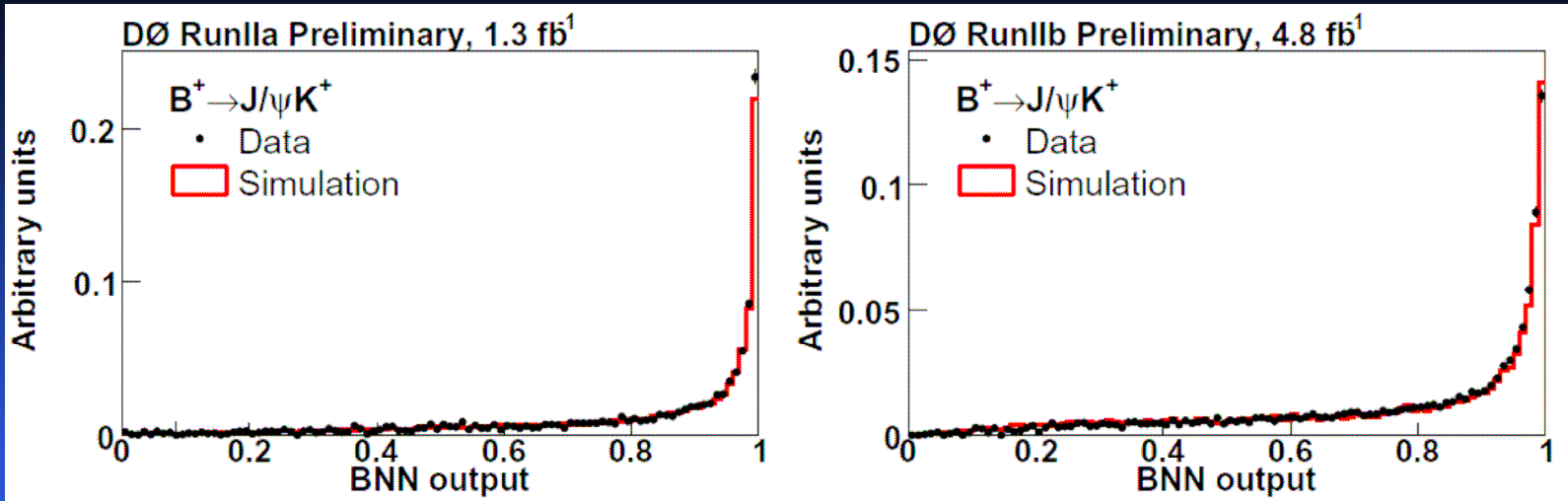
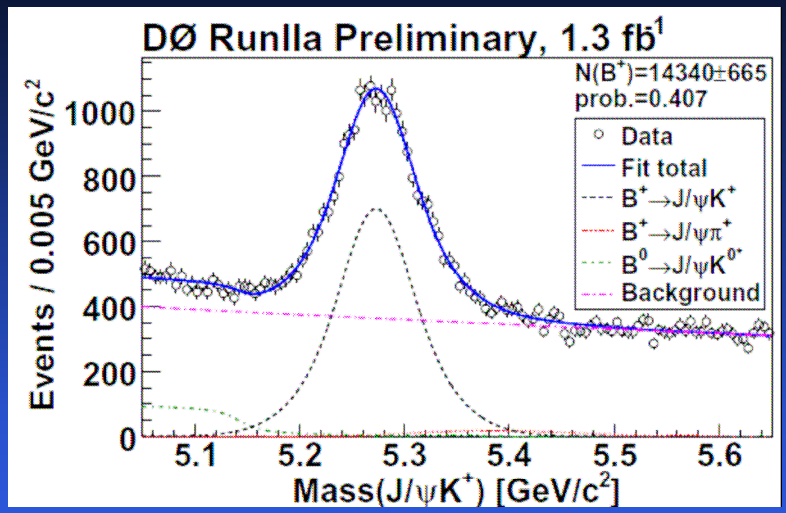
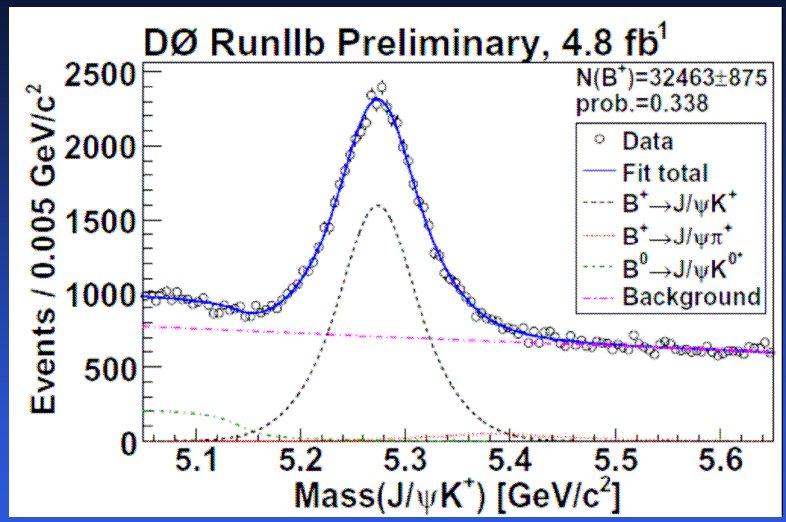


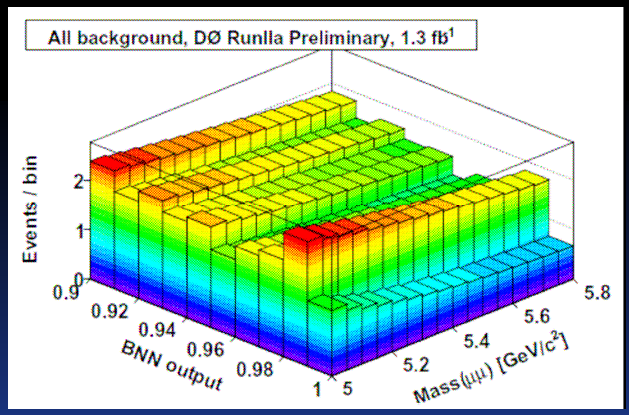
FIG. 15: Distributions of the BNN output for $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$.

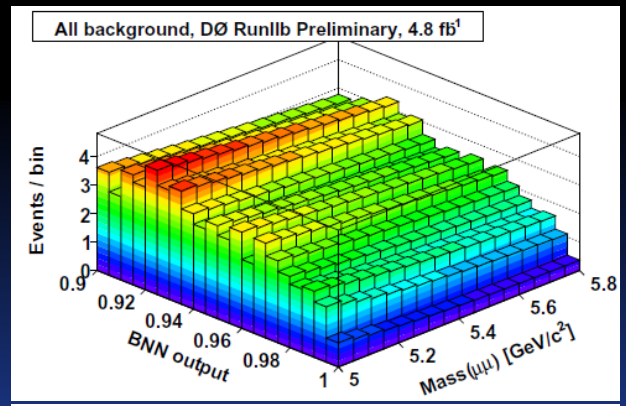
Normalization channel : $B^+ \rightarrow J/\psi K^+$

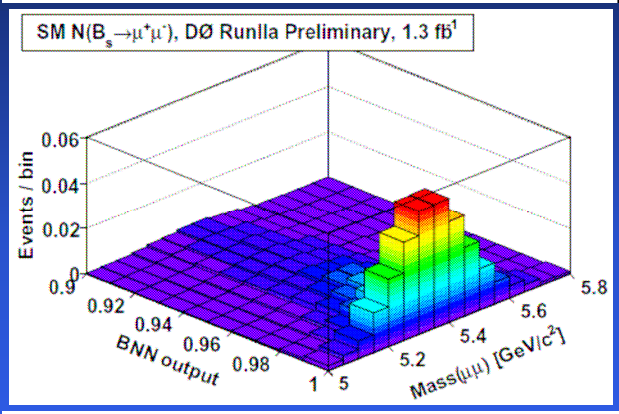


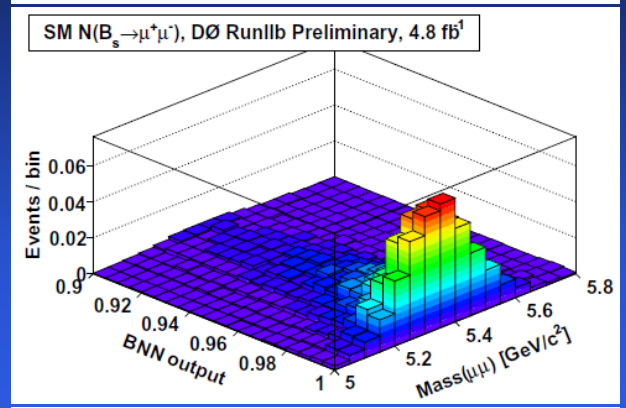


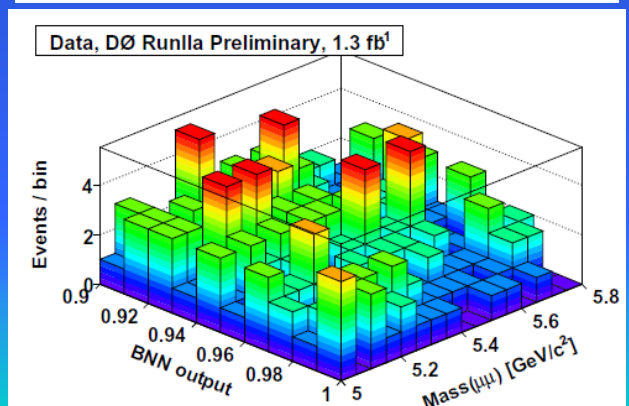
Data in the signal region

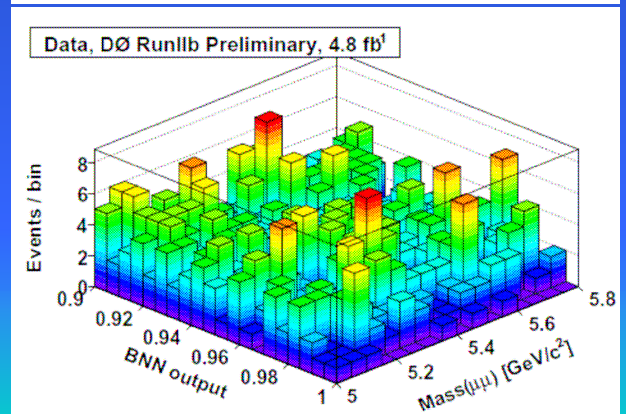










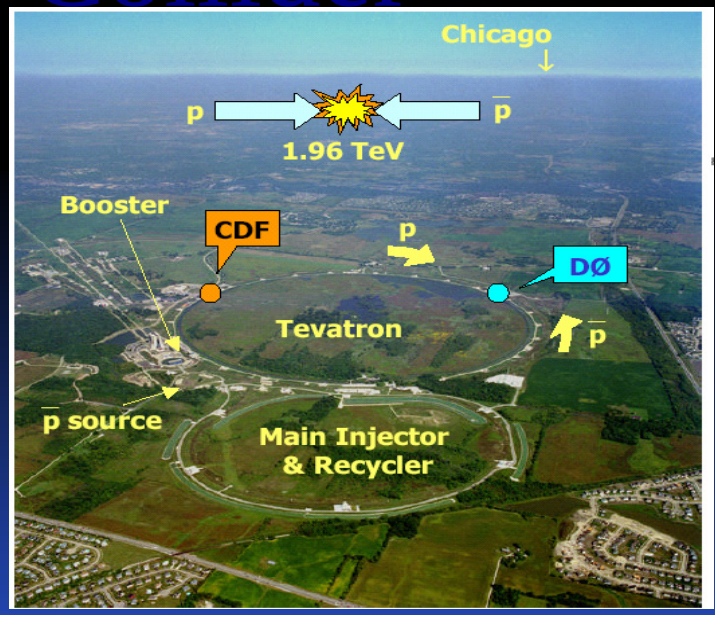


Summary

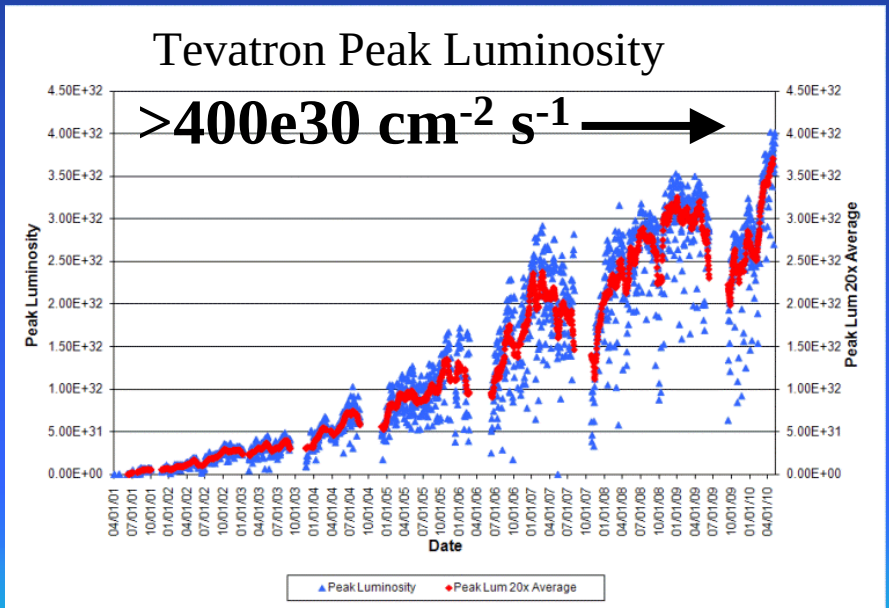
- New results on FCNC decays at Tevatron
  - $B \rightarrow K^{*}\mu\mu$
    - CDF results using 4.4 fb^{-1}
      - First measurement of A_{FB} at Tevatron
      - First observation $B_s \rightarrow \phi\mu\mu$
  - $B \rightarrow \mu\mu$
    - CDF results using 3.7 fb^{-1}
      - $BR(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$, $BR(B^0 \rightarrow \mu\mu) < 7.6 \times 10^{-9}$
      - World best results
    - DØ result using 4.8 fb^{-1}
      - $BR(B_s \rightarrow \mu\mu) < 5.3 \times 10^{-8}$ (*expected limit)
- Wait! We have more data in hand now
  - More than 7 fb^{-1} recorded on tape as of today
  - More exciting results coming soon! Stay tuned!

The Tevatron Collider

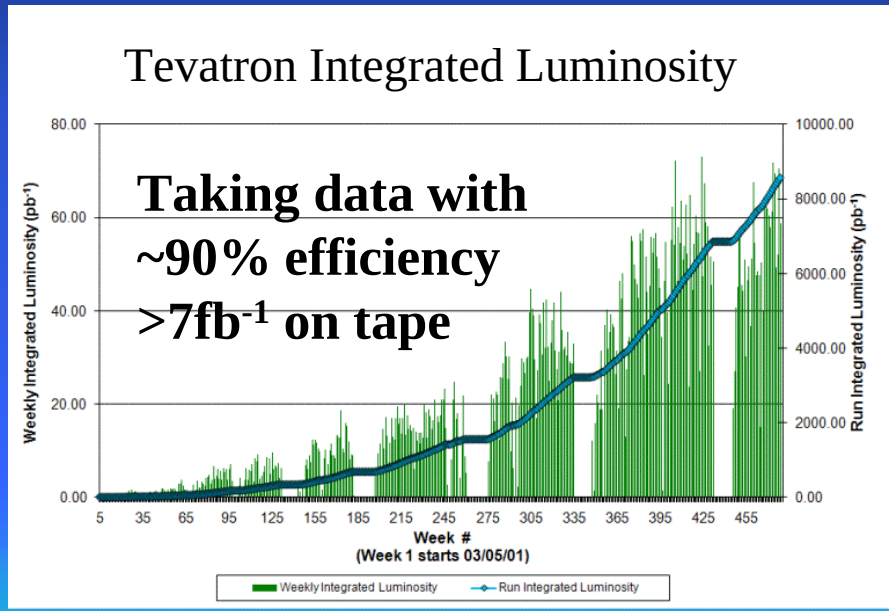
- Proton-antiproton collider
- Run II with $\sqrt{s}$=1.96 TeV
- Collisions every 396 ns



Tevatron Peak Luminosity



Tevatron Integrated Luminosity

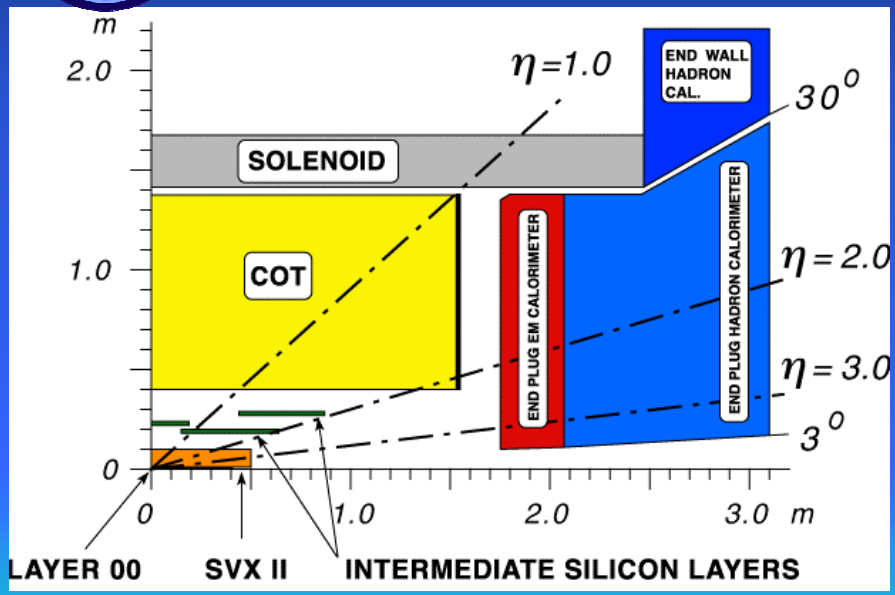


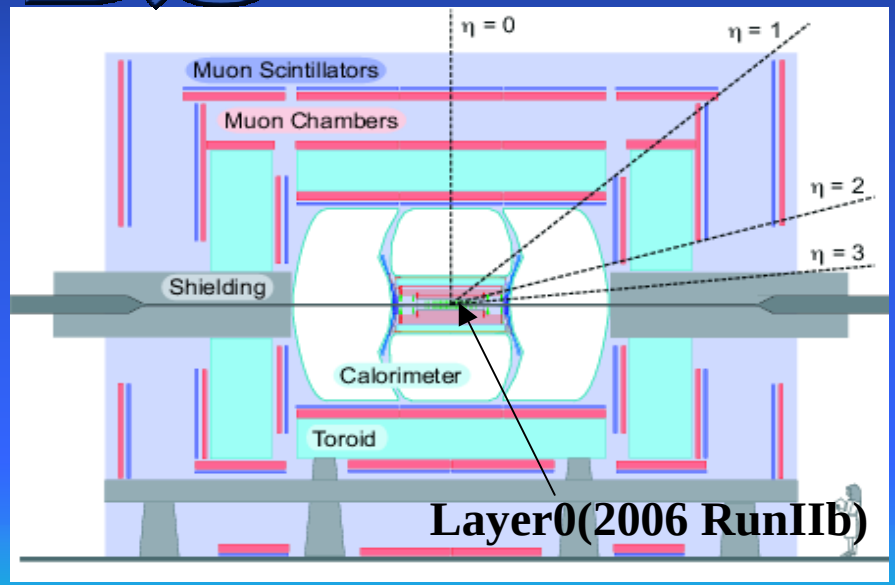
The CDF & DØ detector

- CDF and DØ : General purpose detector

Tracking : Silicon + Drift Chamber
|η|<2, 1.3 cm < R < 132 cm
Muon : |η| < 1.0, p_T > 1.5 GeV
Excellent momentum resolution!

Tracking : Silicon + Fiber Tracker
|η|<3, 1.6 cm < R < 52 cm
Muon : |η| < 2.0, p_T > 1.5 GeV
Excellent muon coverage!





CP violation in B_s mixing from heavy Higgs exchange

Bogdan A. Dobrescu, Patrick J. Fox and Adam Martin
Theoretical Physics Department, Fermi National Accelerator Laboratory, Batavia, Illinois, USA
(Dated: May 22, 2010)

The anomalous dimuon charge asymmetry reported by the D0 Collaboration may be due to the tree-level exchange of some spin-0 particles which mediate CP violation in $B_s - \bar{B}_s$ meson mixing. We show that for a range of couplings and masses, the heavy neutral states in a two Higgs doublet model can generate a large charge asymmetry. This range is natural in "uplifted supersymmetry", and may enhance the $B^- \to \tau\nu$ and $B_s \to \mu^+\mu^-$ decay rates. However, we point out that on general grounds the reported central value of the charge asymmetry requires new physics not only in $B_s - \bar{B}_s$ mixing but also in $\Delta B = 1$ transitions or in $B_d - \bar{B}_d$ mixing.

arXiv:1005.4238 [hep-ph]

MSSM and $B_s \rightarrow \mu\mu$

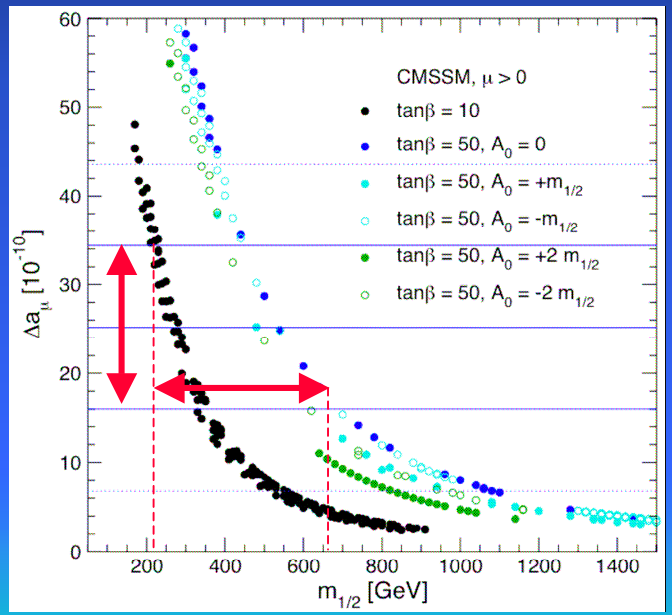
- E821 at BNL : anomalous magnetic moment of the muon (Phys.Rev.D73:072003,2006)
  - $\alpha_\mu^{exp} - \alpha_\mu^{SM} \cong (3\pm1) \times 10^{-9}$

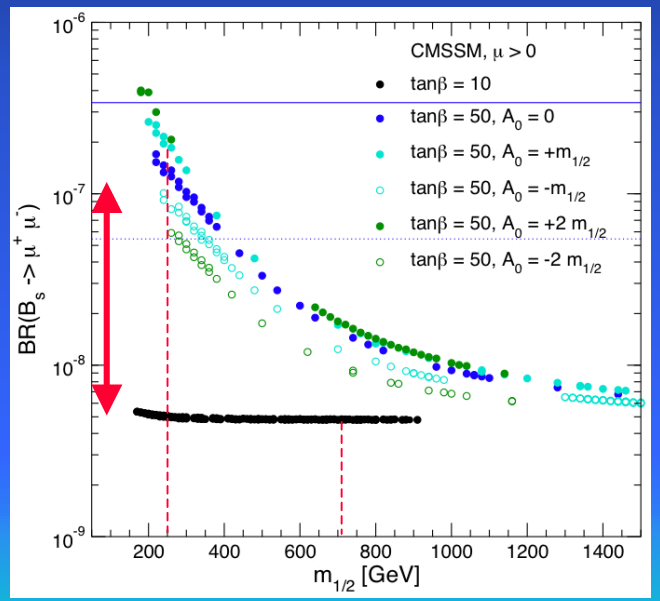
→ **CMSSM** model (JHEP 0502 (2005) 013) suggests

250 GeV < gaugino mass($m_{1/2}$) < 650 GeV

→BR($B_s \rightarrow \mu\mu$) : $5\times10^{-9} \sim 1\times10^{-7}$

→Reachable at Tevatron



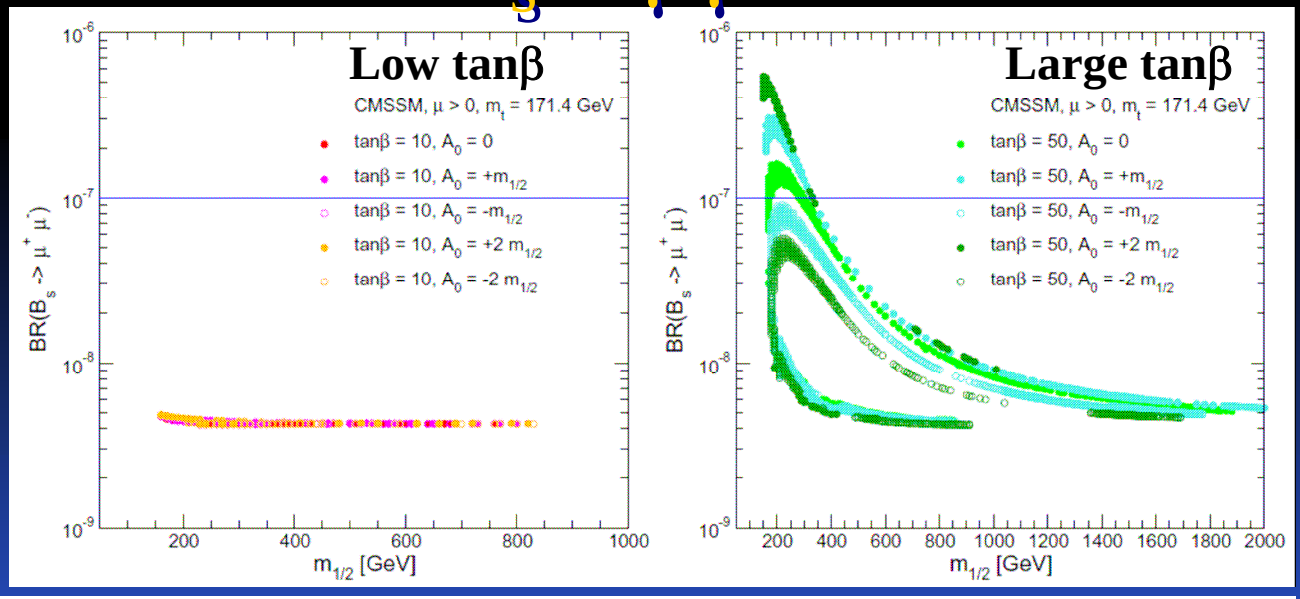


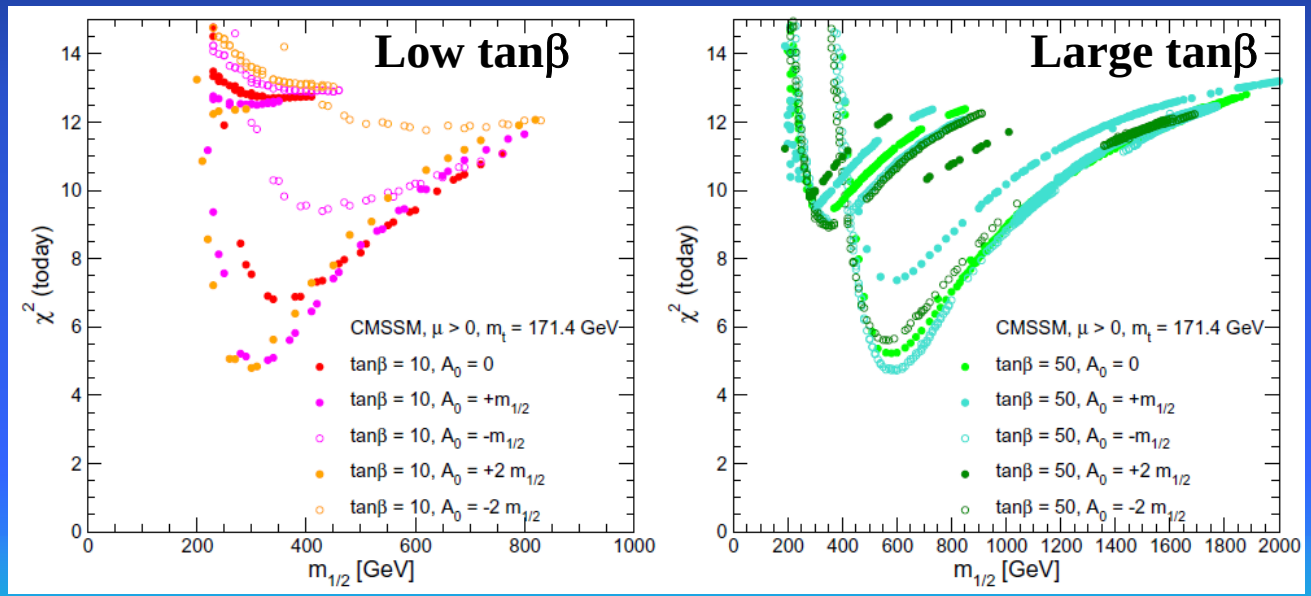
MSSM and $B_s \rightarrow \mu\mu$

JHEP 0708(2007)083

Constraint on $m_{1/2}$ from $B_s \rightarrow \mu\mu$ →

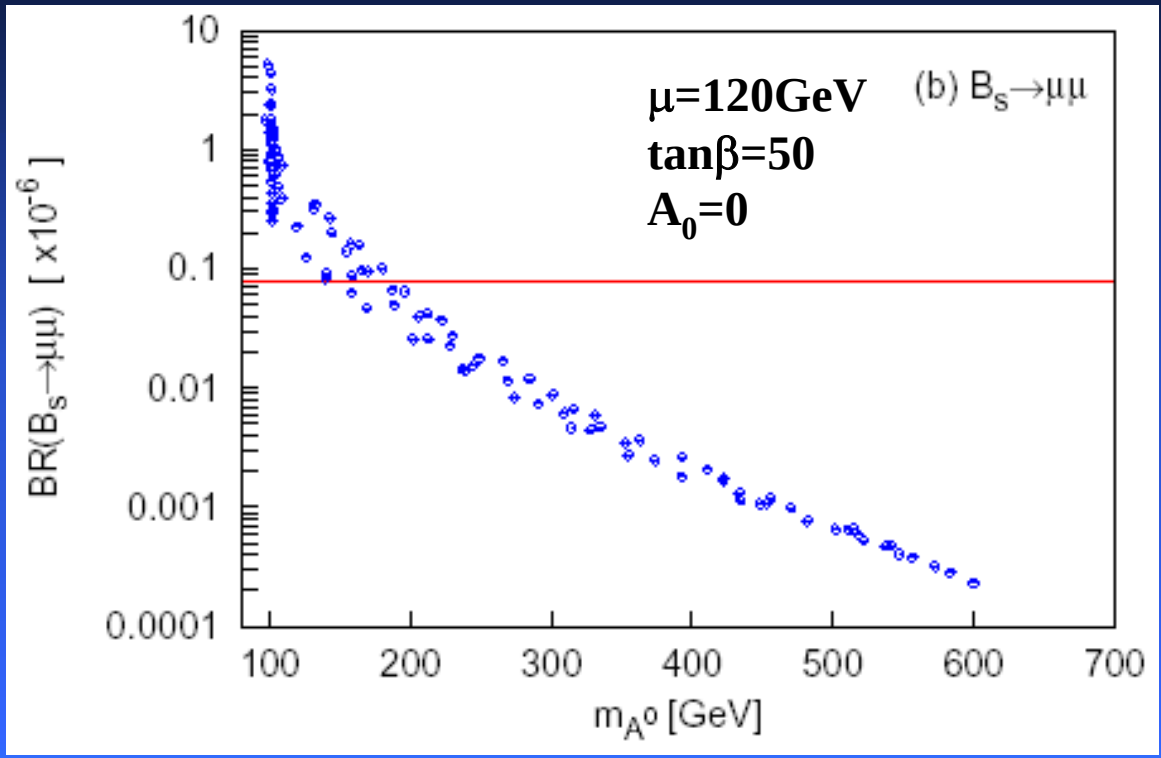
χ^2 combining results of LEP2, $(g-2)_\mu$, $b \rightarrow s\gamma$, $B_s \rightarrow \mu\mu$, $B \rightarrow \tau\nu$ →





MSSM and $B_s \rightarrow \mu\mu$

- Nucl. Phys. B760 (2006) 38-63
- **MSSM+ν_R with large tanβ**

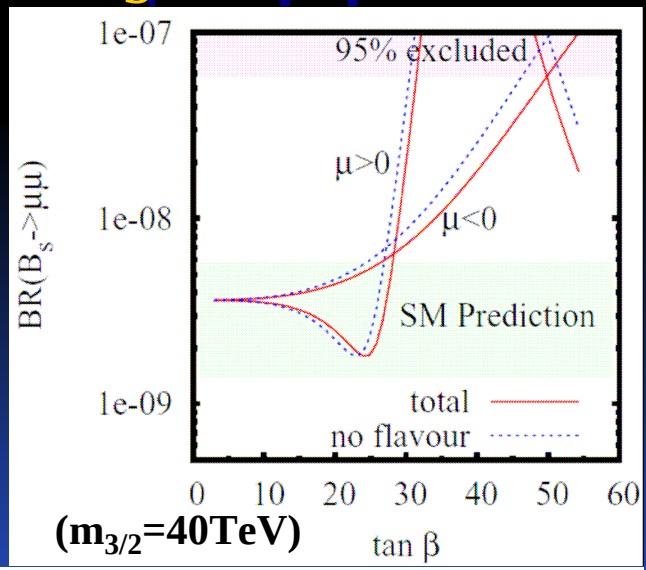


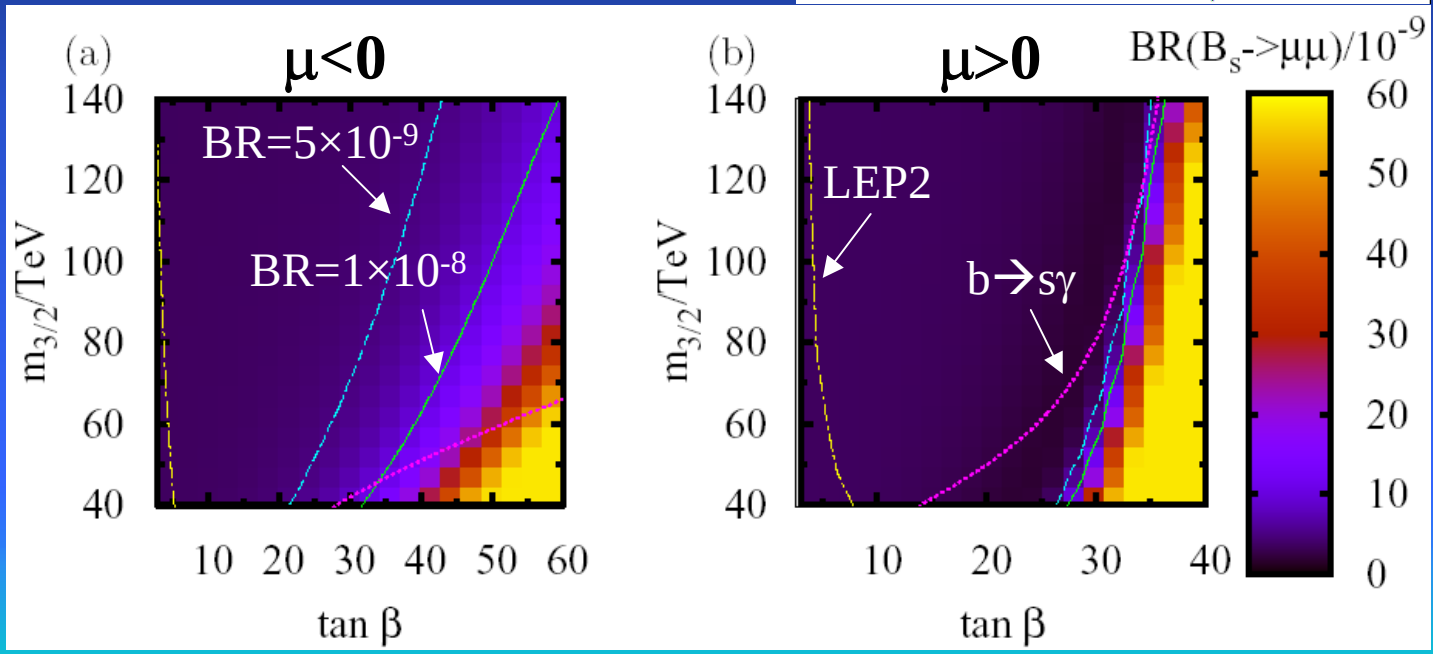
- Important information for lepton flavour violating Higgs decays

MSSM and $B_s \rightarrow \mu\mu$

- JHEP 0904:088,2009

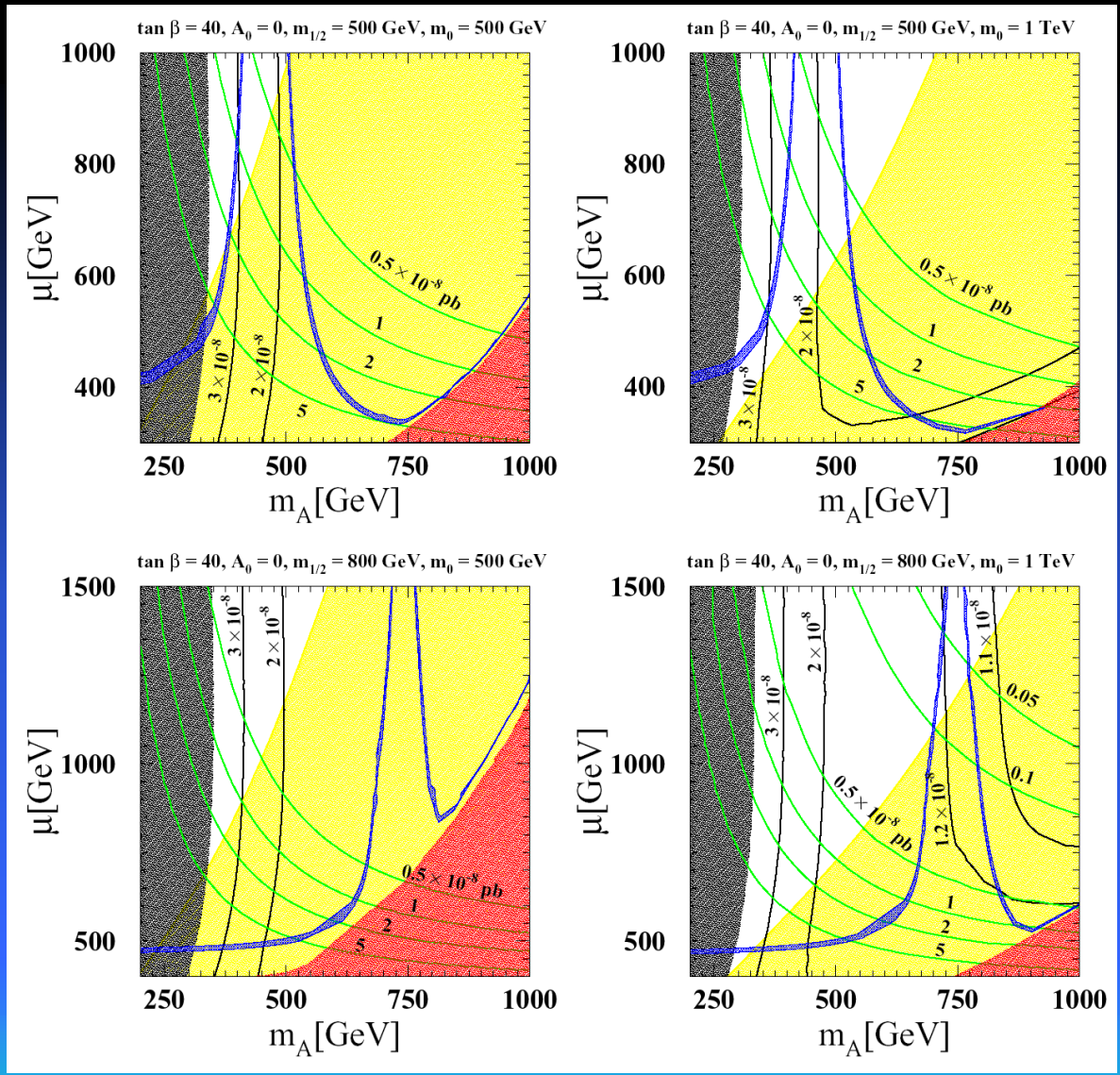
  AMSB MSSM model





MSSM and $B_s \rightarrow \mu\mu$

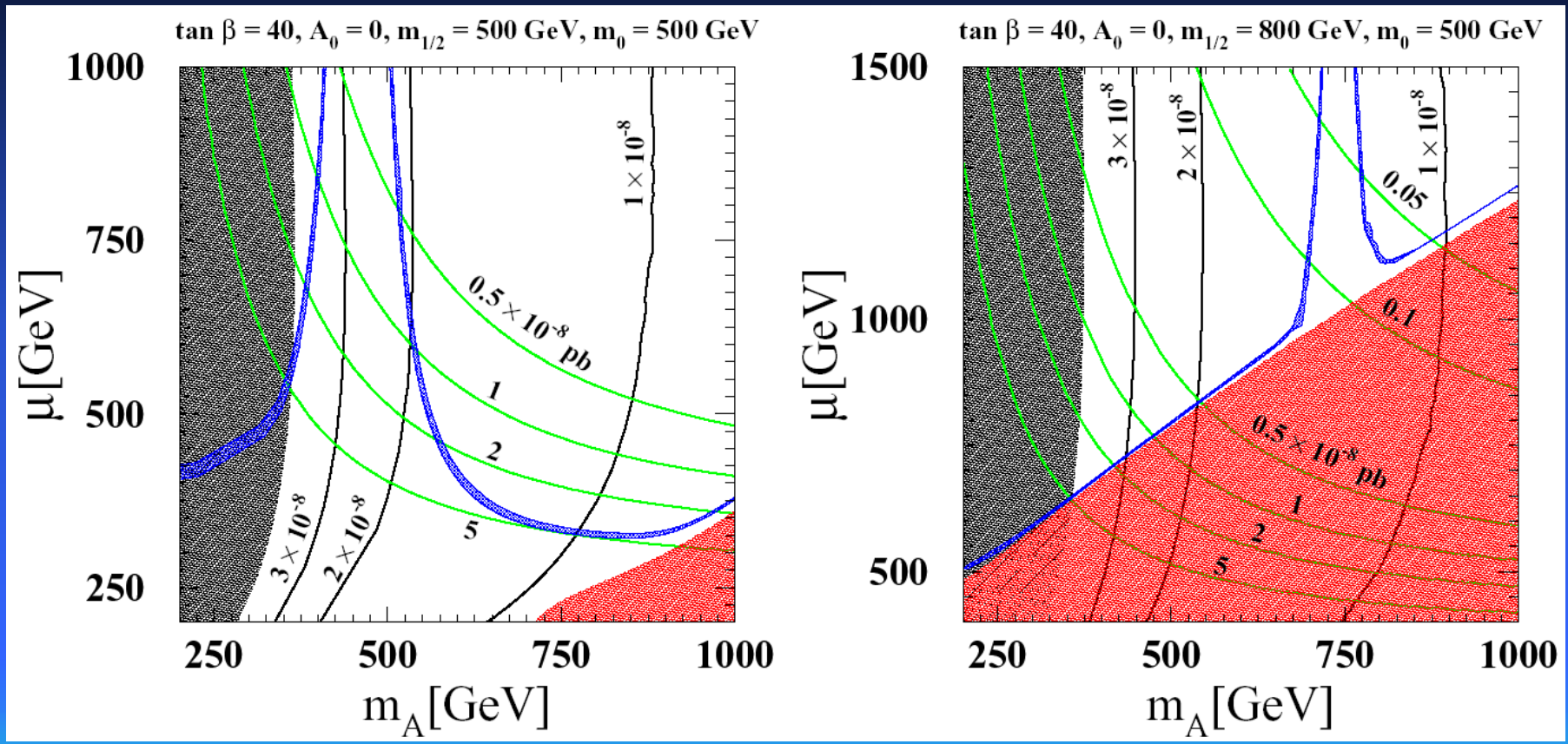
- PRD 80:095005,2009 SU(5)



MSSM and $B_s \rightarrow \mu\mu$

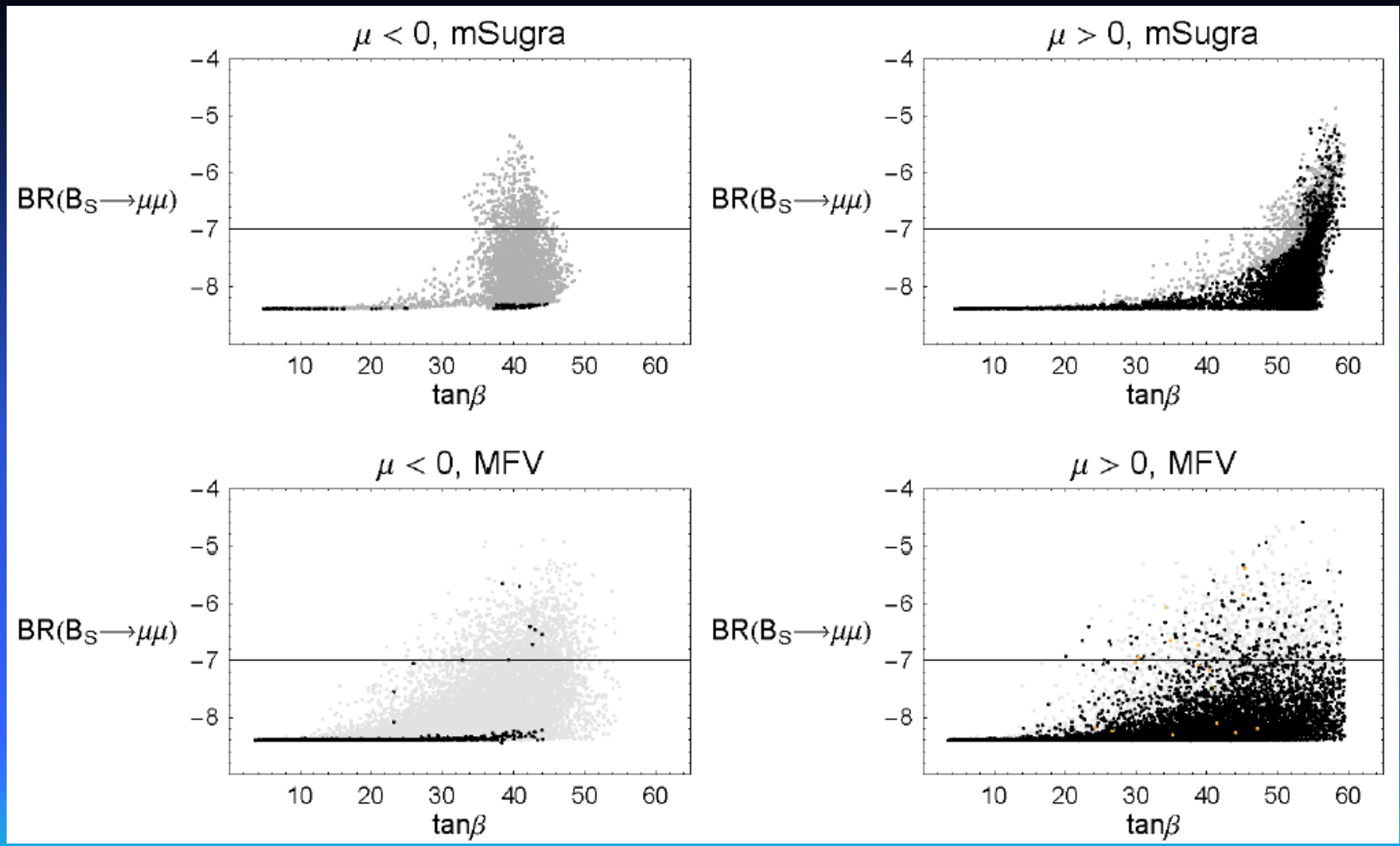
- PRD 80:095005,2009

  SO(10)



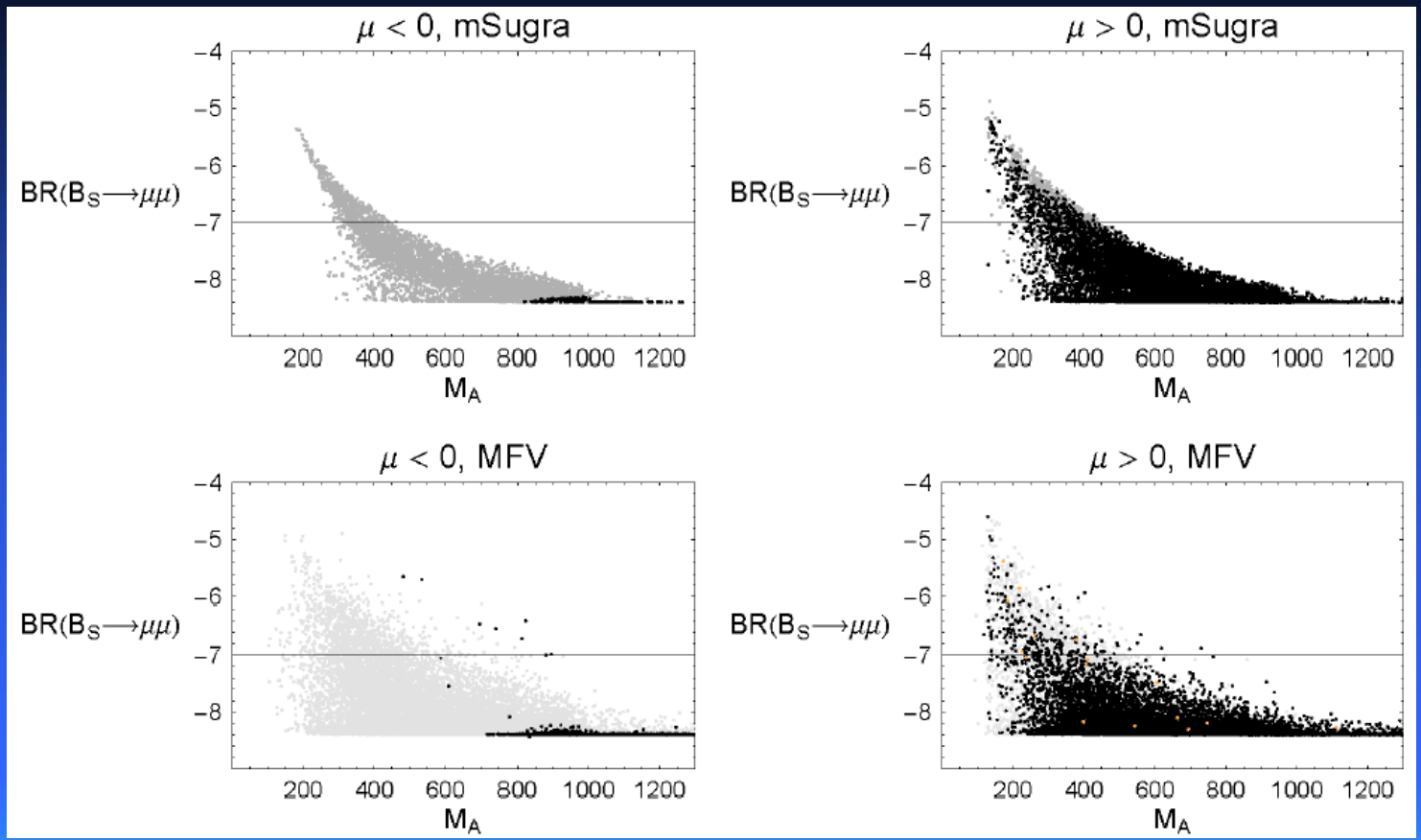
MSSM and $B_s \rightarrow \mu\mu$

- Phys.Rev.D74:075003,2006



MSSM and $B_s \rightarrow \mu\mu$

- Phys.Rev.D74:075003,2006




CDF
II


DØ


CDF
II


DØ