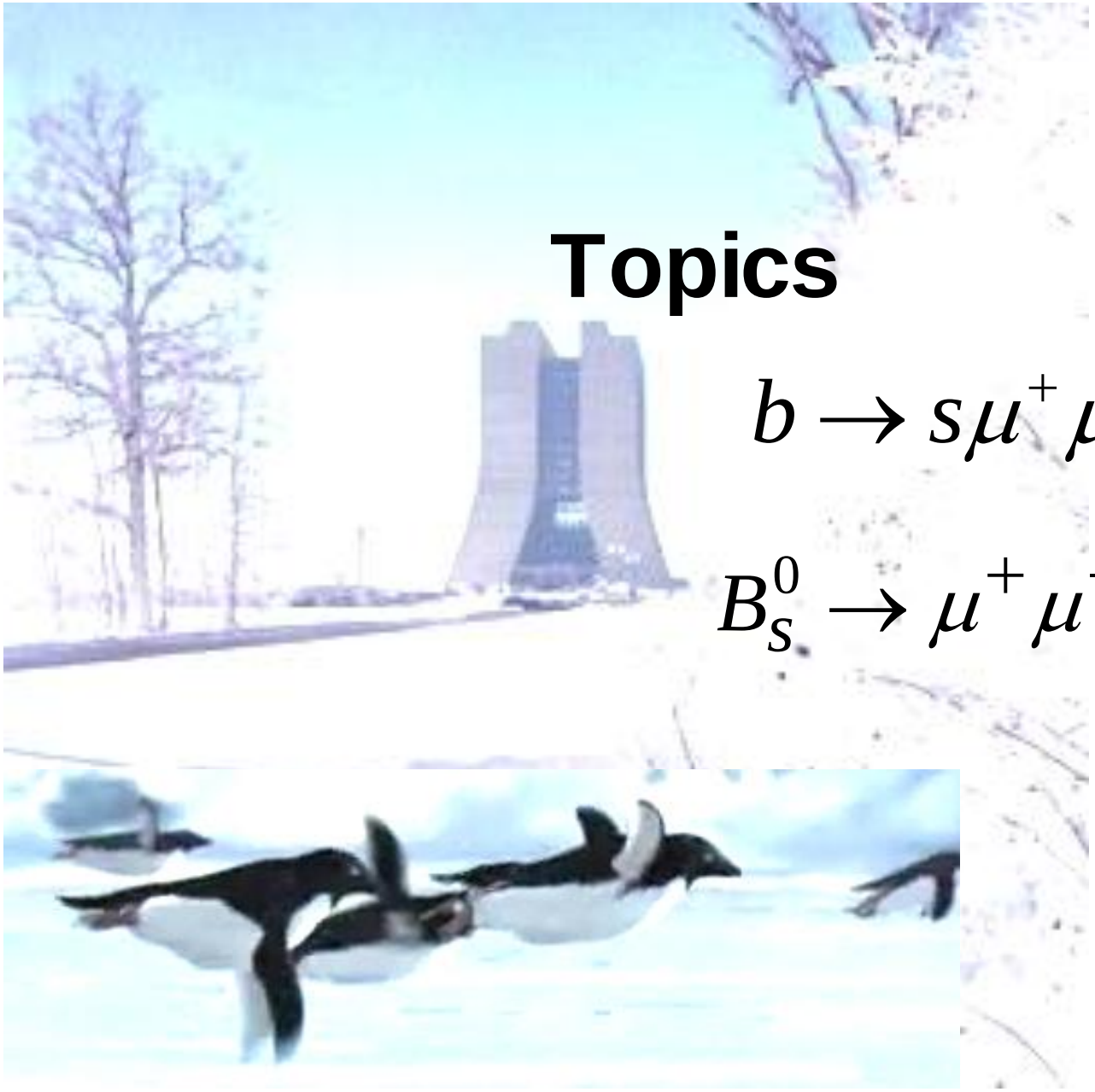
Rare Decays at Tevatron

Daejung Kong

KYUNGPOOK NATIONAL UNIVERSITY

On behalf of the CDF and DØ Collaborations

Beauty 2011, Amsterdam



Topics

$$b \to s\mu^+\mu^-$$

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

$$b \to s\mu^+\mu^-$$

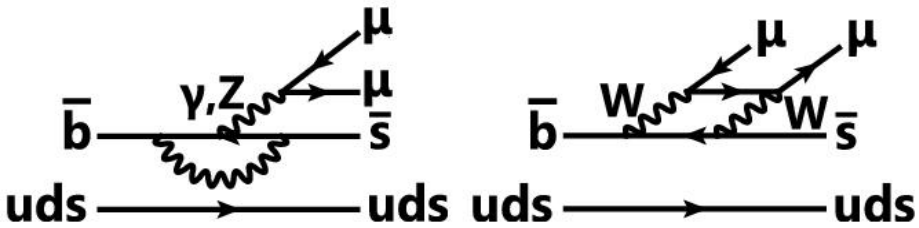
4.4fb^{-1}

http://arXiv.org/pdf/1101.1028
(accepted by PRL)

$b \to \mu\mu s$ & A_{FB}

Rare decay $b \to s\mu^+\mu^-$ **: FCNCs, forbidden at tree level**

SM Diagrams



Penguin Diagram Box Diagram

SM Expectation

$Br : 10^{-6} \sim 10^{-7}$

SM Test

→Branching Ratio

New Physics Test

→ A_{FB}

Interesting rare decay $b \to s\mu^+\mu^-$ **:**

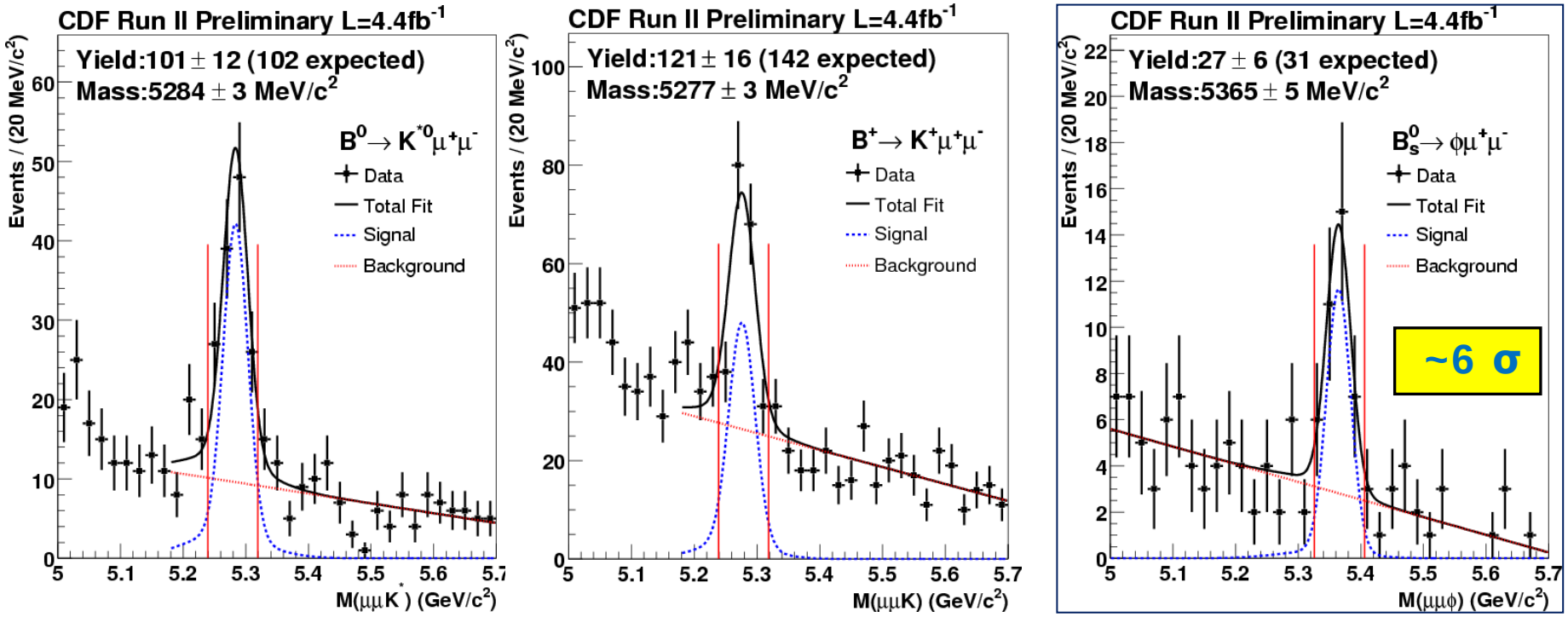
$B^+ \to \mu\mu K^+$: Babar, Belle, CDF
$B^0 \to \mu\mu K^*$: Babar, Belle, CDF
$B_s \to \mu\mu \phi$: CDF

$b \to \mu\mu s$ Mass Distribution

- Dimuon Trigger
- Employed Neural Network to optimize event selection

4.4fb^{-1}

First Observation



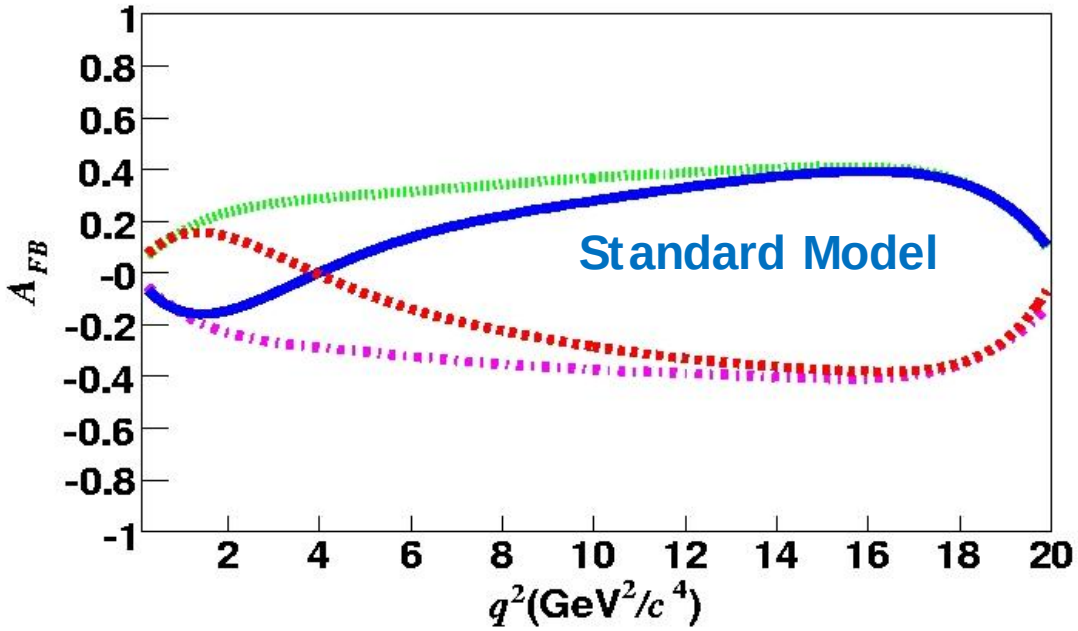
- **BR(Bs→φμμ)=[1.44±0.33(stat)±0.46(syst)]×10^{-6}**

  Consistent with theory ~1.61×10^{-6}

Forward-Backward Asymmetry

- Sensitive to non-SM physics:
- Forward backward asymmetry in $B^0 \rightarrow \mu\mu K^*$ decay

Predictions exist for several new physics scenarios

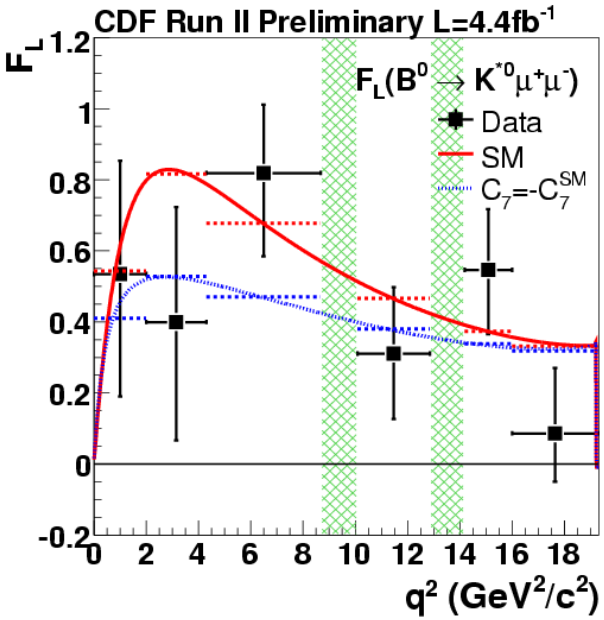


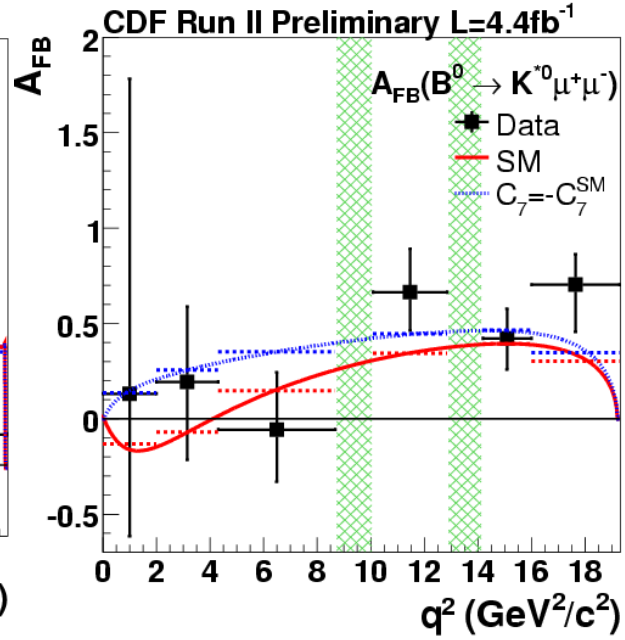
A_{FB} Results

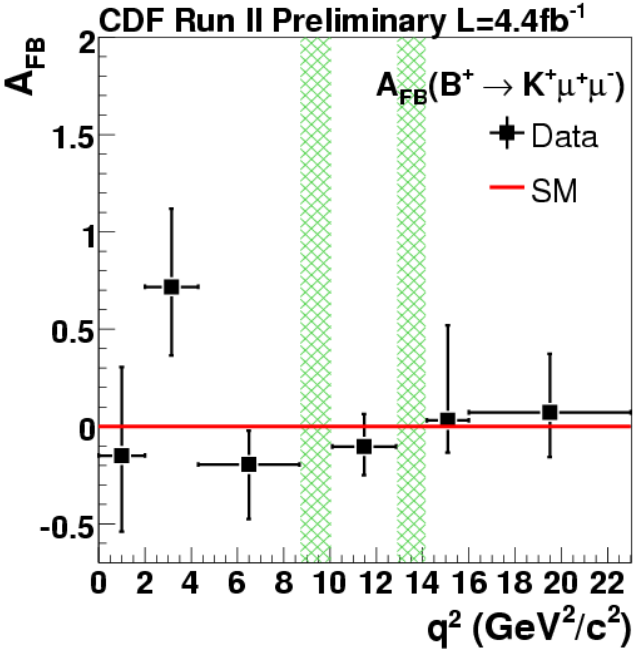
4.4fb^{-1}

K* Polarization

A_{FB} : Forward-Backward Asymmetry







Compatible and competitive with the B factories

- **BaBar384M BB, PRD79,031102(R) (2009) and**
- **Belle 657M BB, PRL103,171801(2009)**

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

3.7 fb^{-1}

CDF public note 9892

6.1 fb^{-1}

PLB 693 539 (2010)

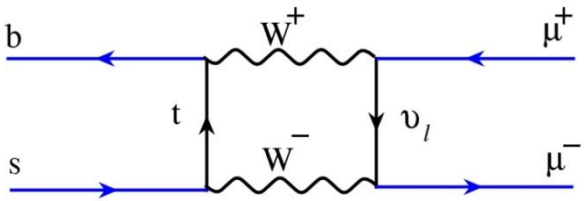
7 fb^{-1}

(new, update)

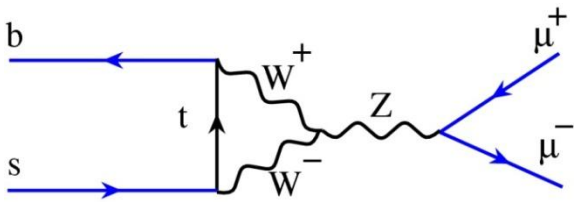
$B_s^0 \to \mu^+\mu^-$

Rare decay $B_s^0 \to \mu^+\mu^-$: FCNCs, forbidden at tree level

SM Diagrams



Box Diagram



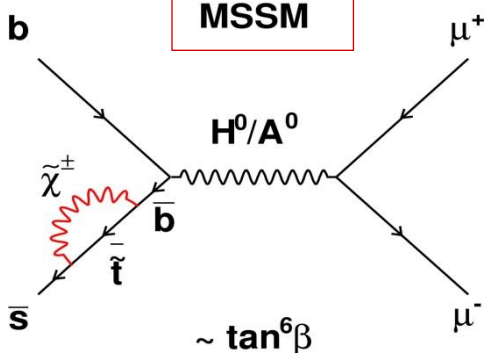
Penguin Diagram

SM Expectation

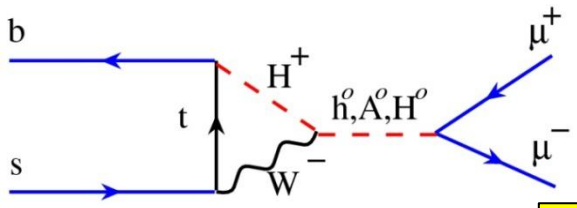
$Br : (3.2 \pm 0.2) \times 10^{-9}$

JHEP 1009 (2010)106

MSSM



2HDM



Penguin Diagram

NP Expectation

Br enhancement

Powerful Probe to New Physics

$B_s^0 \to \mu^+\mu^-$ for new Physics

How hot ?

CDF

- CDF Public Note 9892 (2009)
- PRL 100 (2008) 101802
  → Cited 168 times
- CDF Public Note 8176 (2006)
- PRL 95 (2005) 221805
  → Cited 50 times
- PRL 93 (2004) 032001
  → Cited 77 times
- PRD 57 (1998) 3811

D0

- PLB 693(2010) 539
  → Cited 10 times
- PRD 76 (2007) 092001
  → Cited 29 times
- PRL 94 (2005) 071802
  → Cited 81 times

LHCb

- arXiv:1103.2465v1

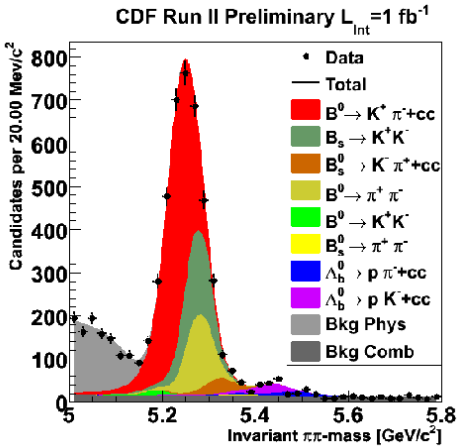
Theory

- JHEP 1009 (2010)106
- ....
- JHEP 0502 (2005) 067
- .....
- PLB 538 (2002) 121
- ....
- ....

How difficult ?

- Need to discriminate signal from background
- Need to retain decent signal
  - Reduce background by a factor of > 1000
- Signal
  - Final state fully reconstructed
  - B_s is long lived , B fragmentation is hard
- Background
  - Sequential semi-leptonic decay: $b \to c\mu^- X \to \mu^+\mu^- X$
  - Double semileptonic decay: $bb \to \mu^+\mu^- X$
  - Continuum $\mu^+\mu^-$, μ + fake, fake+fake
  - Peaking Background in signal region ($B \to hh$)

3.7 fb^{-1}



$B_s^0 \to \mu^+\mu^-$ for new Physics

How to ?

3.7 fb^{-1}

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B^+}} \frac{\epsilon^{trig}_{B^+}}{\epsilon^{trig}_{B_s}} \frac{\epsilon^{reco}_{B^+}}{\epsilon^{reco}_{B_s}} \frac{\alpha_{B^+}}{\alpha_{B_s}} \frac{1}{\epsilon^{NN}_{B_s}} \frac{f_u}{f_s} \cdot \mathcal{BR}(B^+ \to J/\Psi K^+ \to \mu^+\mu^- K^+)$$

From Data, From MC, From PDG

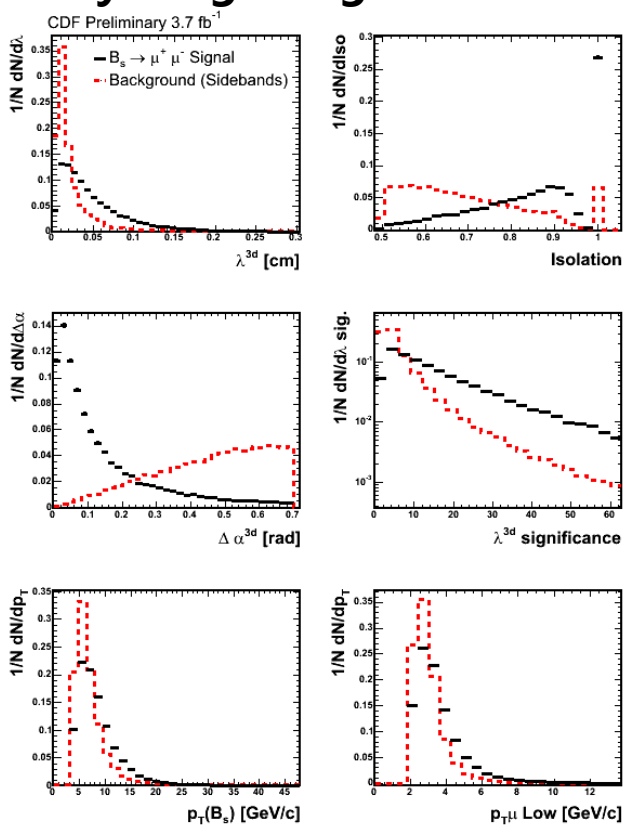
- **Relative normalization search**
  - Measure the rate of $B_s \to \mu^+\mu^-$ decays relative to $B \to J/\psi K^+$
  - Apply same sample pre-selection criteria
  - Uncertainties on Trigger and pre-selection efficiencies will cancel out in the ratios of the normalization
  - **$B_s \to \mu^+\mu^-$ sample is highly purified with ANN event selection**

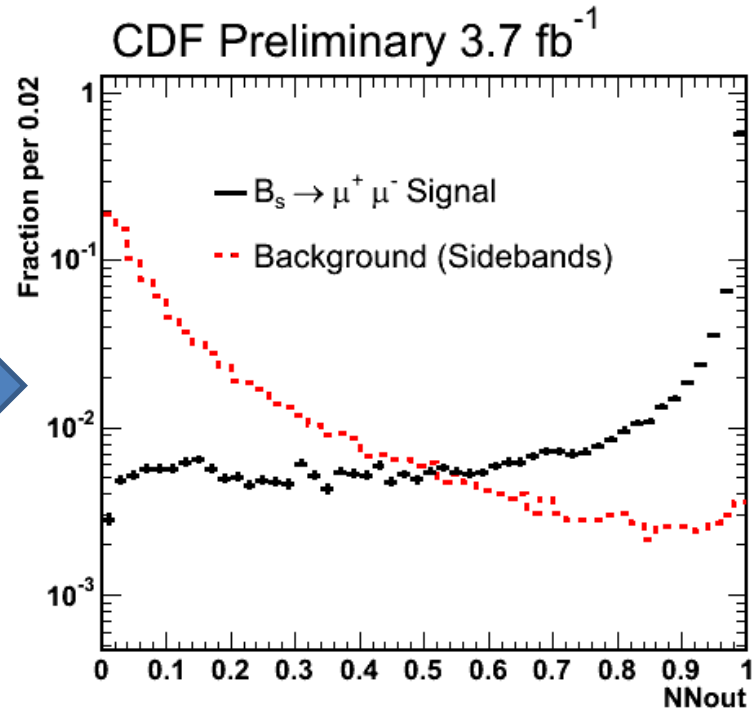
Signal Optimization

- **NN input variables**
- **3D pointing angle**
- **Isolation**
- **Proper decay length**
- **Proper decay length sig.**
- **$P_T(Bs)$**
- **$P_T(\mu)$**

- Unbiased optimization based on MC signal and data sidebands
- Extensively tested for mass bias

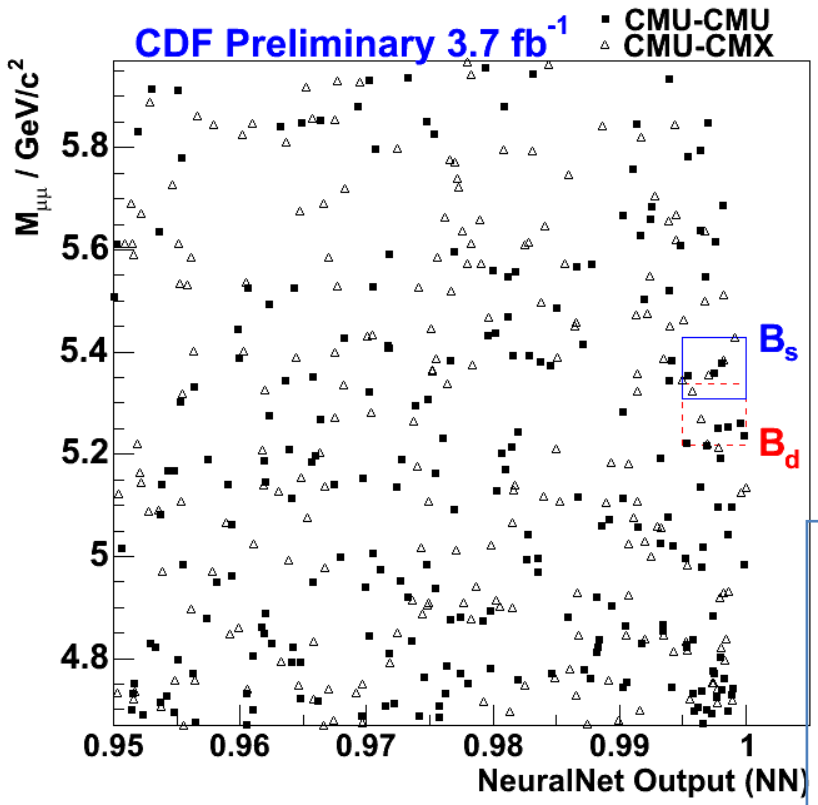
3.7 fb^{-1}





Results

3.7 fb^{-1}



Channel	Expected	Observed
B_s central	4 ±1	3
B_s forward	2.08 ± 0.78	4
B_d central	5.3± 1	5
B_d forwad	2.78 ± 0.78	3

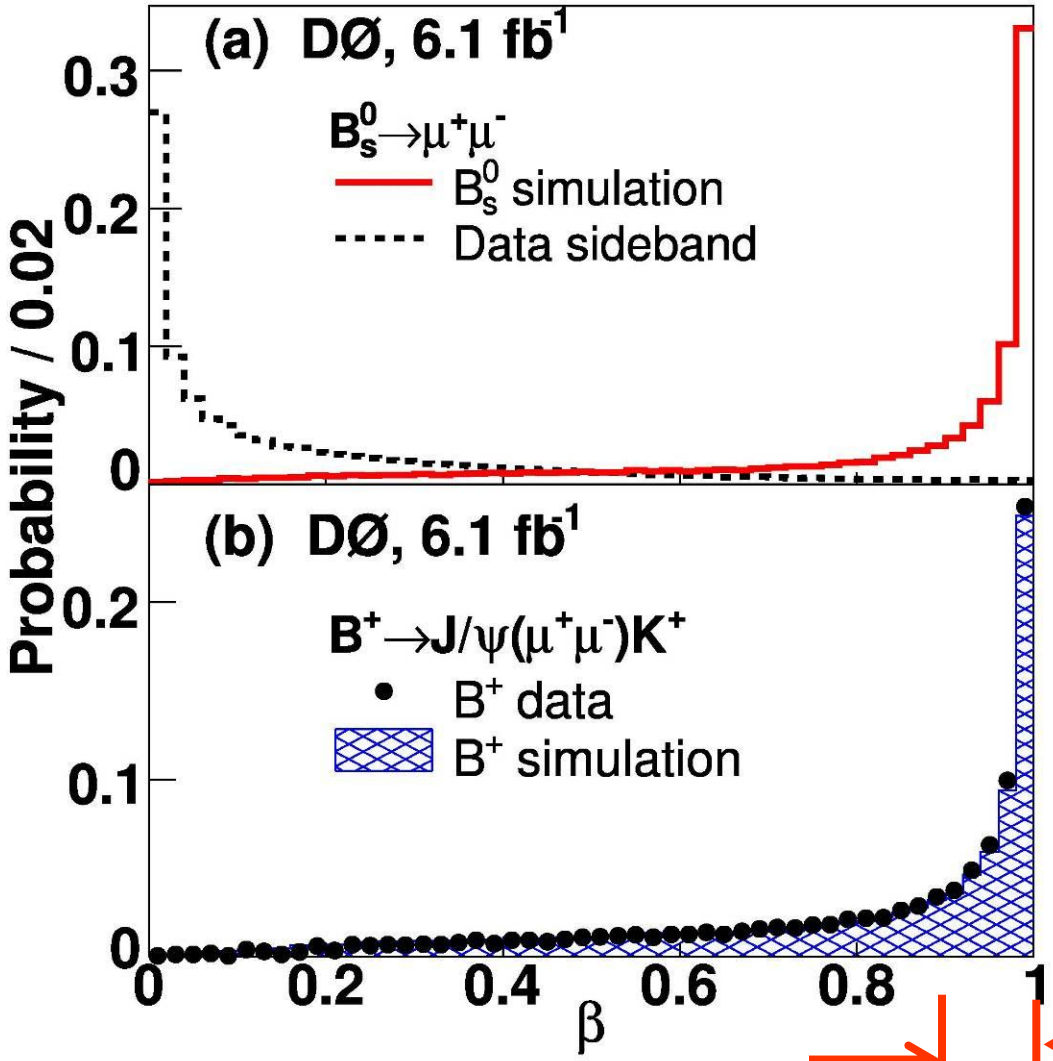
World Best

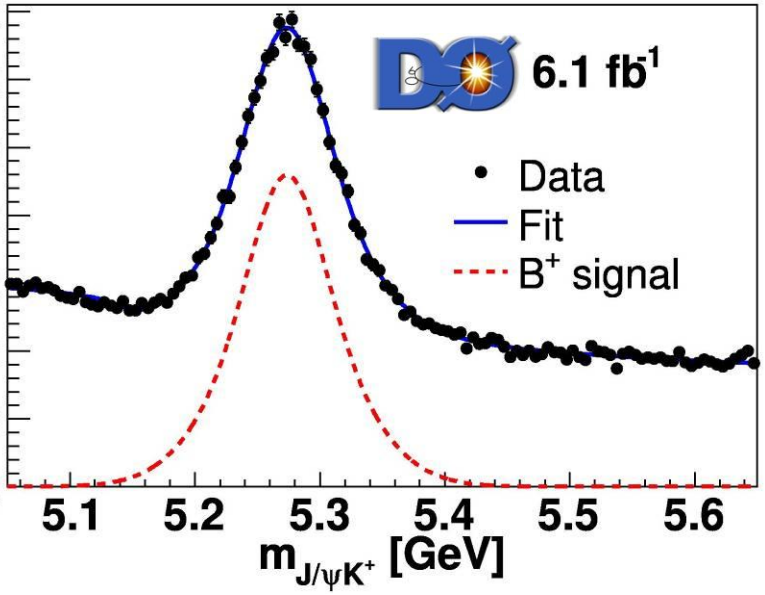
$BR(B_s \rightarrow \mu\mu) < \begin{cases} 4.3\times10^{-8} \\ 3.6 \end{cases}$ @ $\begin{cases} 95\% \text{ CL} \\ 90 \end{cases}$

$BR(B_d \rightarrow \mu\mu) < \begin{cases} 7.6\times10^{-9} \\ 6.0 \end{cases}$ @ $\begin{cases} 95\% \text{ CL} \\ 90 \end{cases}$

CDF public note 9892

Signal Optimization

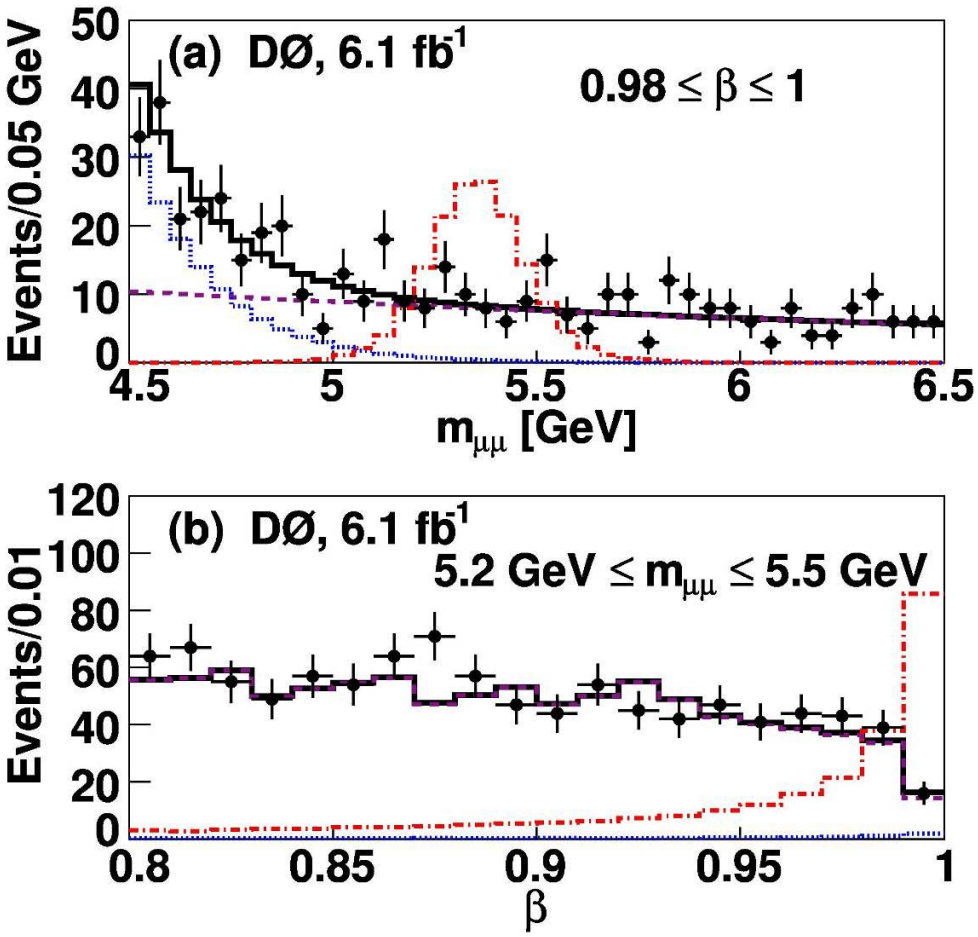




Expect ~3 signal events in the data with these cuts

Signal region

Results



$$BR(B_s \to \mu\mu) < \begin{cases} 5.1\times10^{-8} \\ 4.9 \end{cases} @ \begin{cases} 95\%\ CL \\ 90 \end{cases}$$

PLB 693 539 (2010)

Current limits on $B_s^0 \to \mu^+\mu^-$

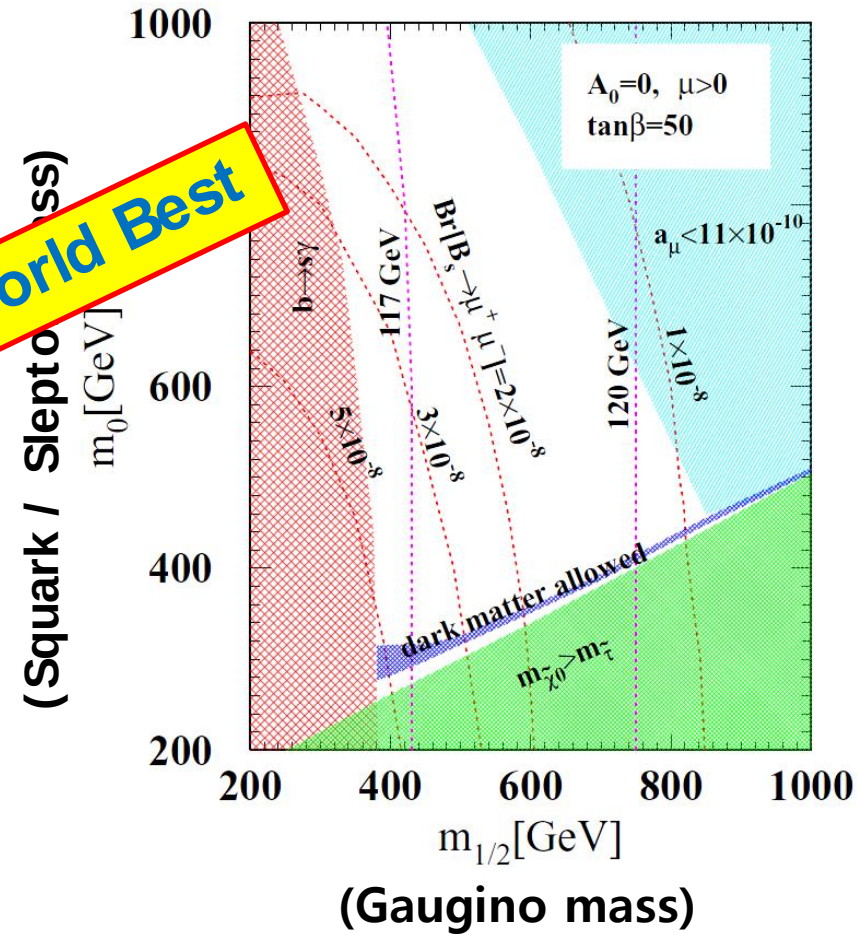
BR($B_s \to \mu\mu$) @ 95% CL

< 4.3×10^{-8} ($3.7\,fb^{-1}$)
CDF public note 9892

< 5.1×10^{-8} ($6.1\,fb^{-1}$)
PLB 693 539 (2010)

< 5.6×10^{-8} ($0.036\,fb^{-1}$)
arXiv:1103.2465v1

World Best



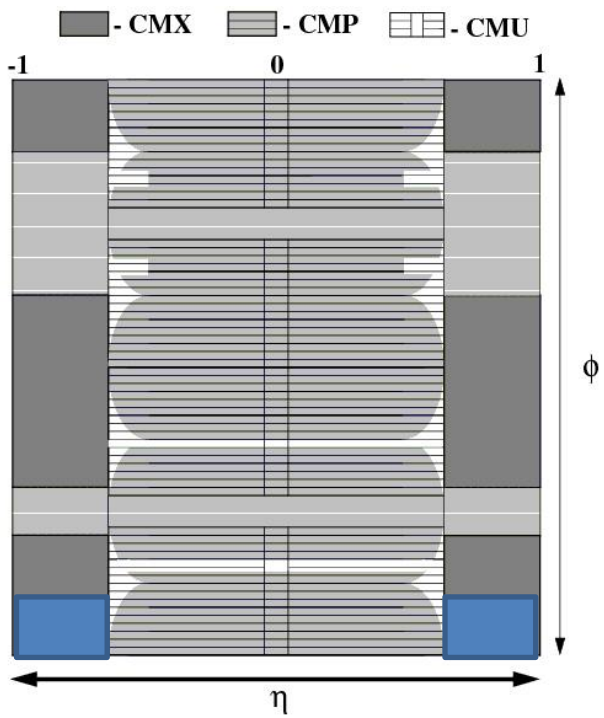
After 3.7 fb^{-1} @ CDF

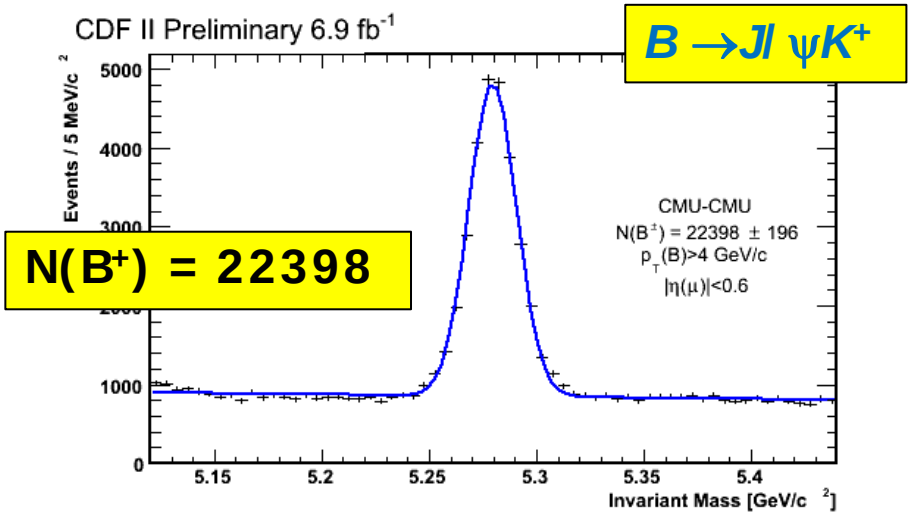
Since 2009 …

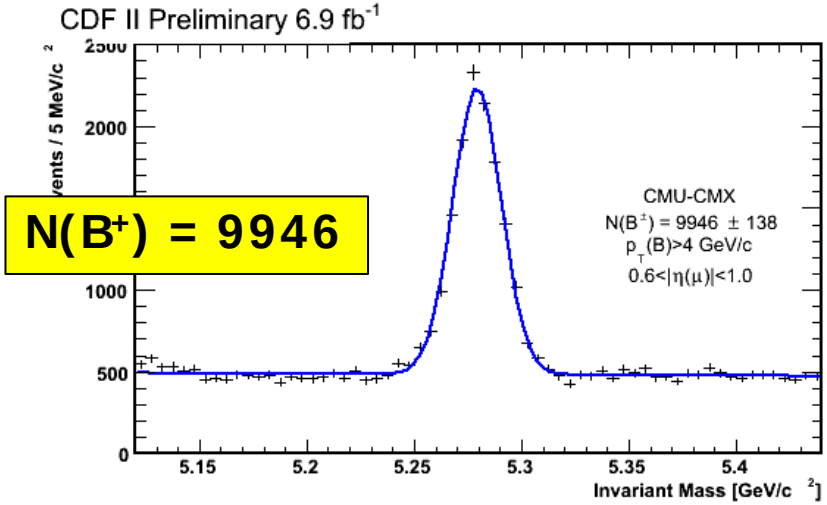
Improvements

- ~ 2X DATA added, ~ 7 fb^{-1}
- Increased muon acceptance
- New ANN with better signal efficiency
- Improved background prediction

Normalization Sample







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

- CMU-CMU : increased ~ 50%
- CMU-CMX : increased ~(50 + 30)%

increased muon acceptance

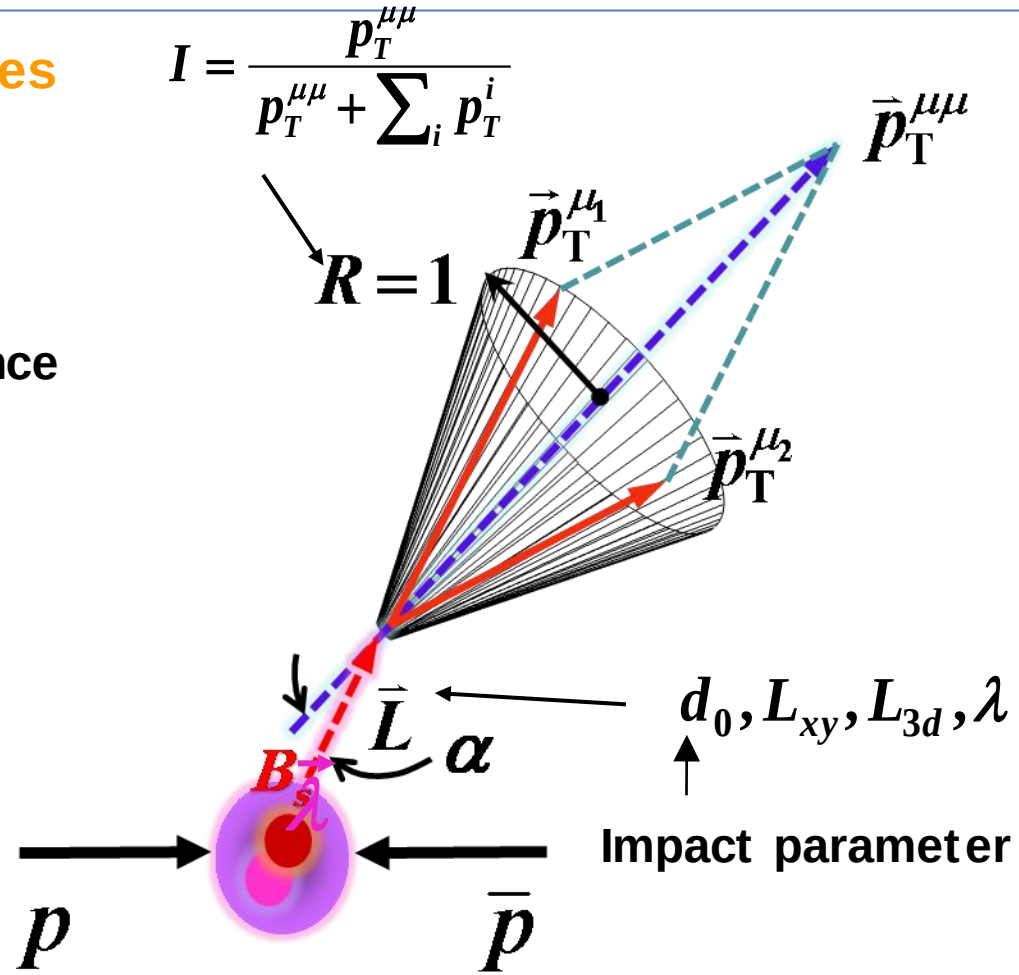
New Neural Network

- ✓ New 14 variable NN to increase S/ B
- ✓ Carefully chose input variables to avoid bias in Bs Mass distribution

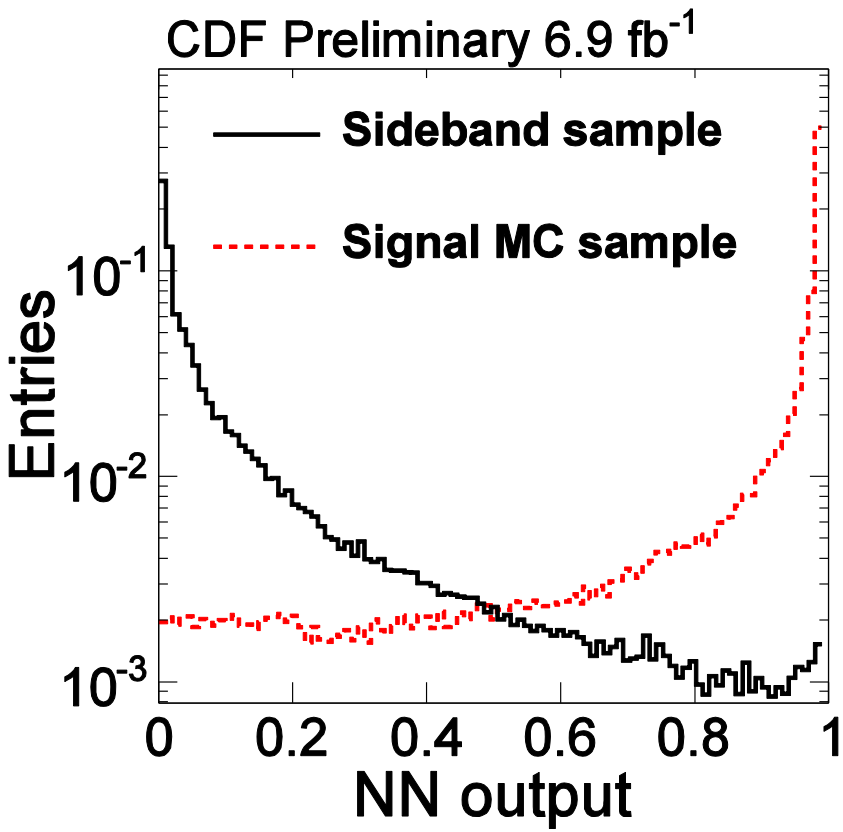
Neural Network Input Variables

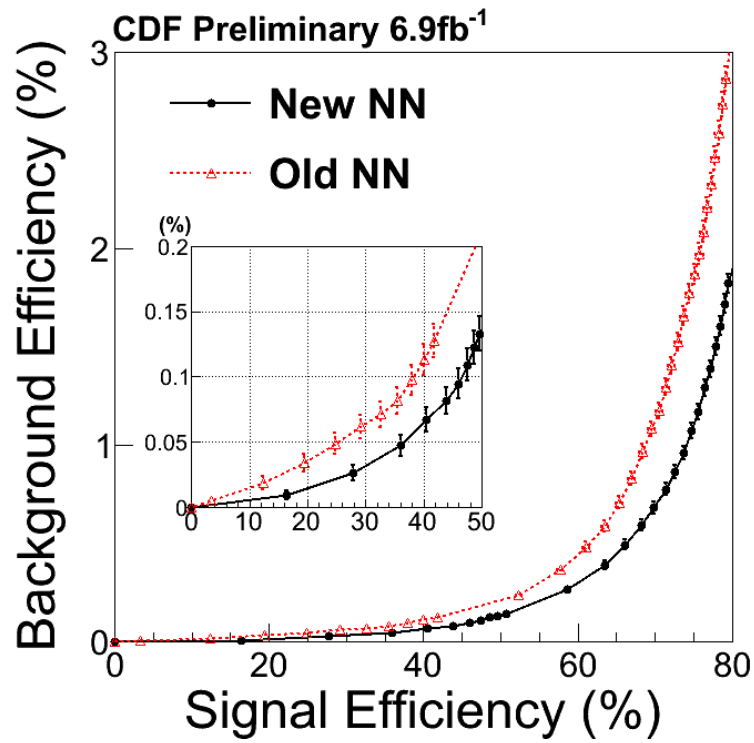
- 3D proper decay length
- Isolation
- Pointing angle ($\Delta\alpha_{3d}$)
- Lower $|p_T(\mu)|$
- 3D proper decay length significance

- Larger $|d_0(\mu)|$
- Smaller $|d_0(\mu)|$
- Smaller $|d_0(\mu)|$ significance
- Larger $|d_0(\mu)|$ significance
- Vertex Fitting χ^2
- Decay length (L_{3d})
- 2D pointing angle ($\Delta\alpha_{2d}$)
- L_{xy} significance
- $|d_0(Bs)|$



New Neural Network result



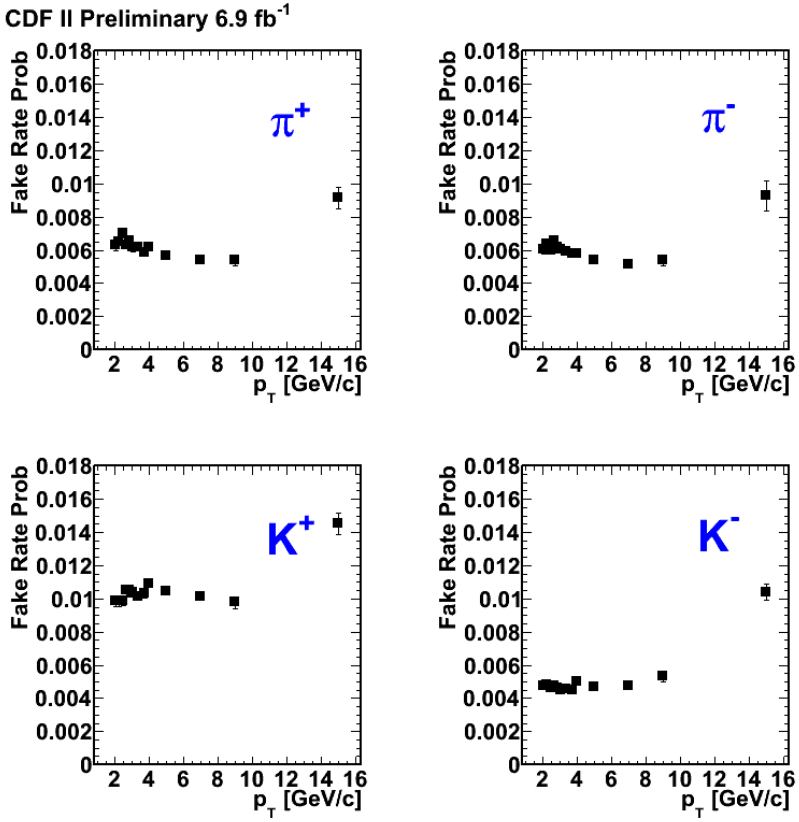


Twice background rejection at same signal efficiency

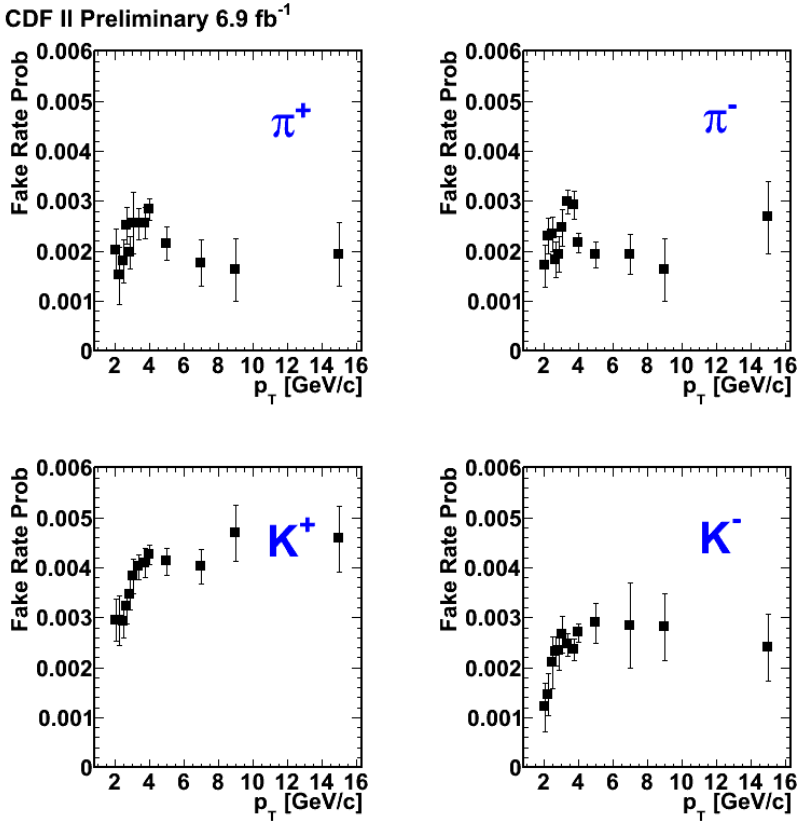
Fully data driven analysis

- **Muon Fake rate for B→hh background prediction**
  - → Used pions and kaons from D*-tagged $D^0 \rightarrow K^- \pi^+$ events
  - → Expected difference in kaons→ difference in s and $\bar{s}$ cross sections

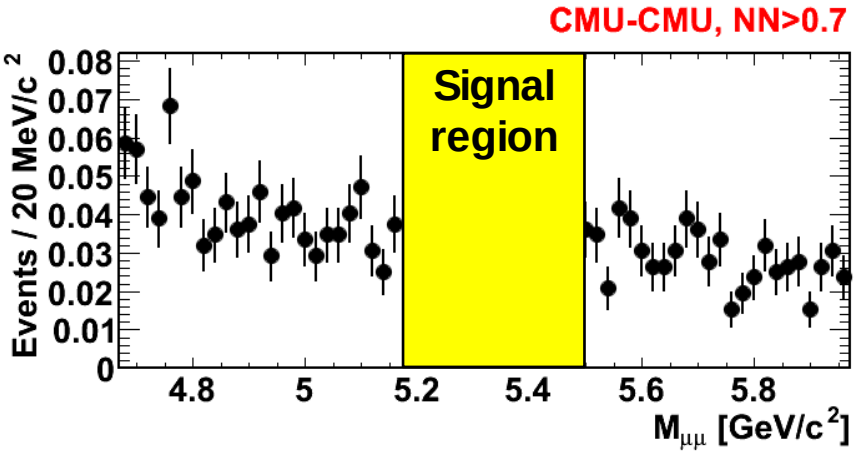
CMU-CMU

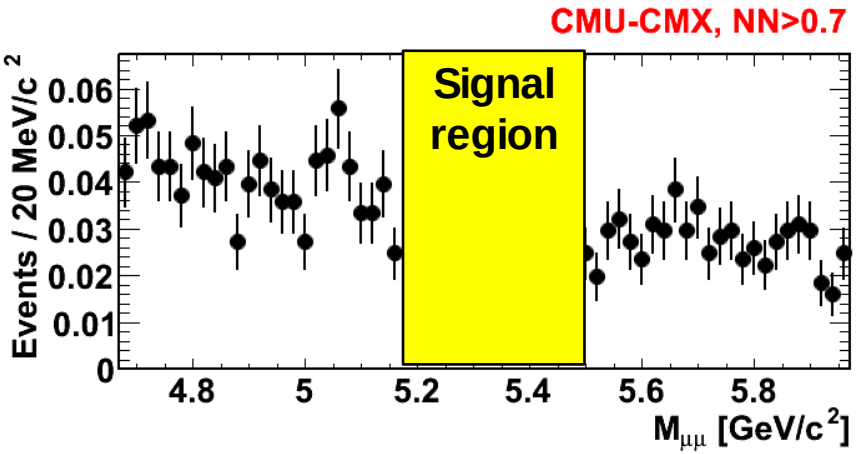


CMU-CMX

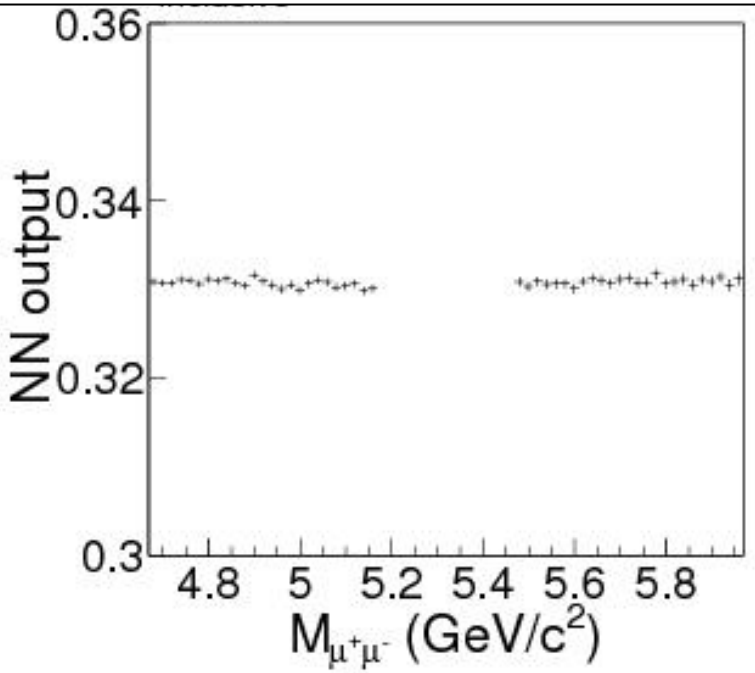


BKG region & Bias Check





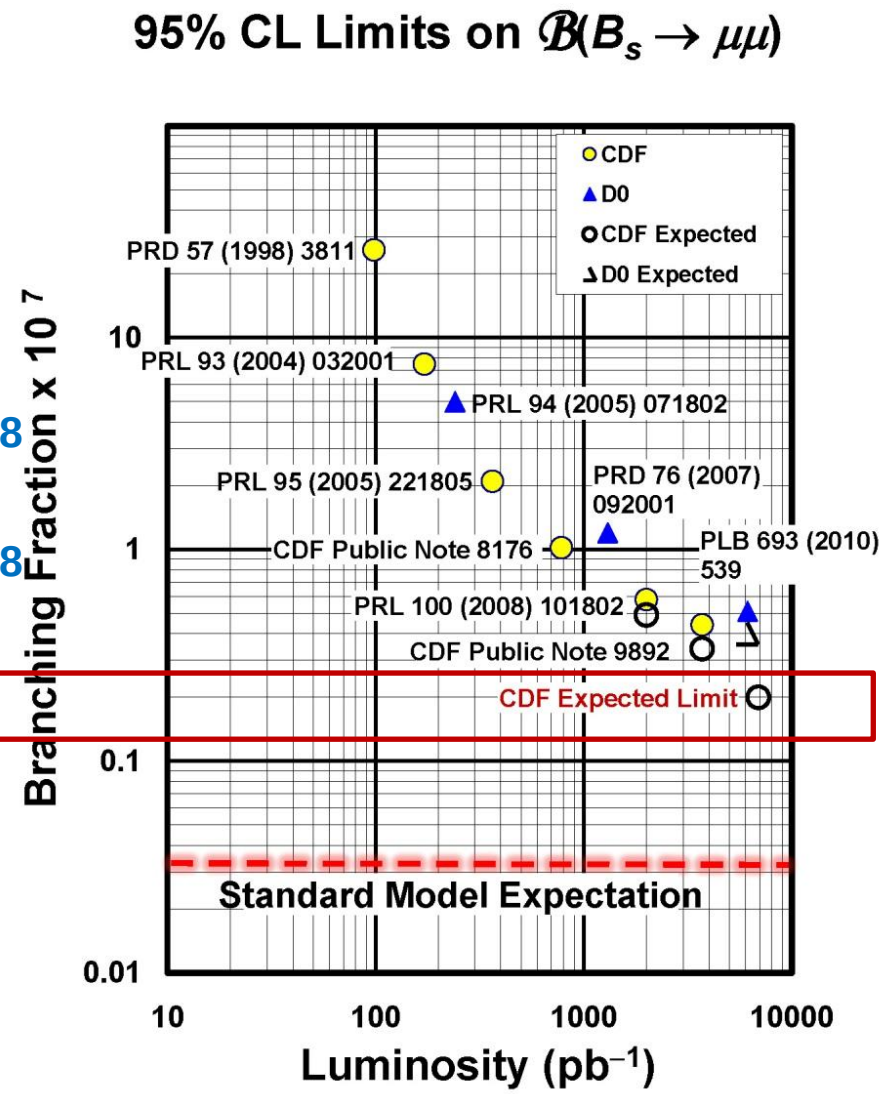
Mass Bias Check with Sideband region



NO correlation b/w NN and Mass

New Expected Limit

	Expected	Observed
2.0 fb^{-1}	4.9×10^{-8}	5.8×10^{-8}
3.7 fb^{-1}	3.4×10^{-8}	4.4×10^{-8}
6.9 fb^{-1}	$\sim2\times10^{-8}$	



Summary

- ✓ FCNCs decays provide powerful probe to New Physics
- ✓ CDF and DØ experiment lead rare decay searches in B sector
- ✓ CDF on its way to provide most sensitive information on $B \rightarrow \mu\mu$ rate with 2x data and improved analysis