A Search for $B_s^0 \to \mu^+\mu^-$ Decays at CDF

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May-24th 2011
LHC physics monthly meeting, KIAS

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

$3.7\,\mathrm{fb}^{-1}$
CDF public note 9892

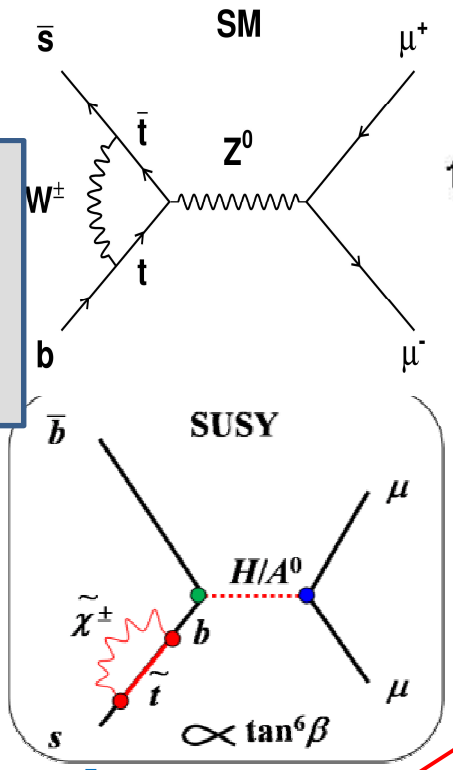
$7\ \mathrm{fb}^{-1}$
(final step, coming soon)

$B_s \to \mu\mu$ Physics Motivation

SM Expectation

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

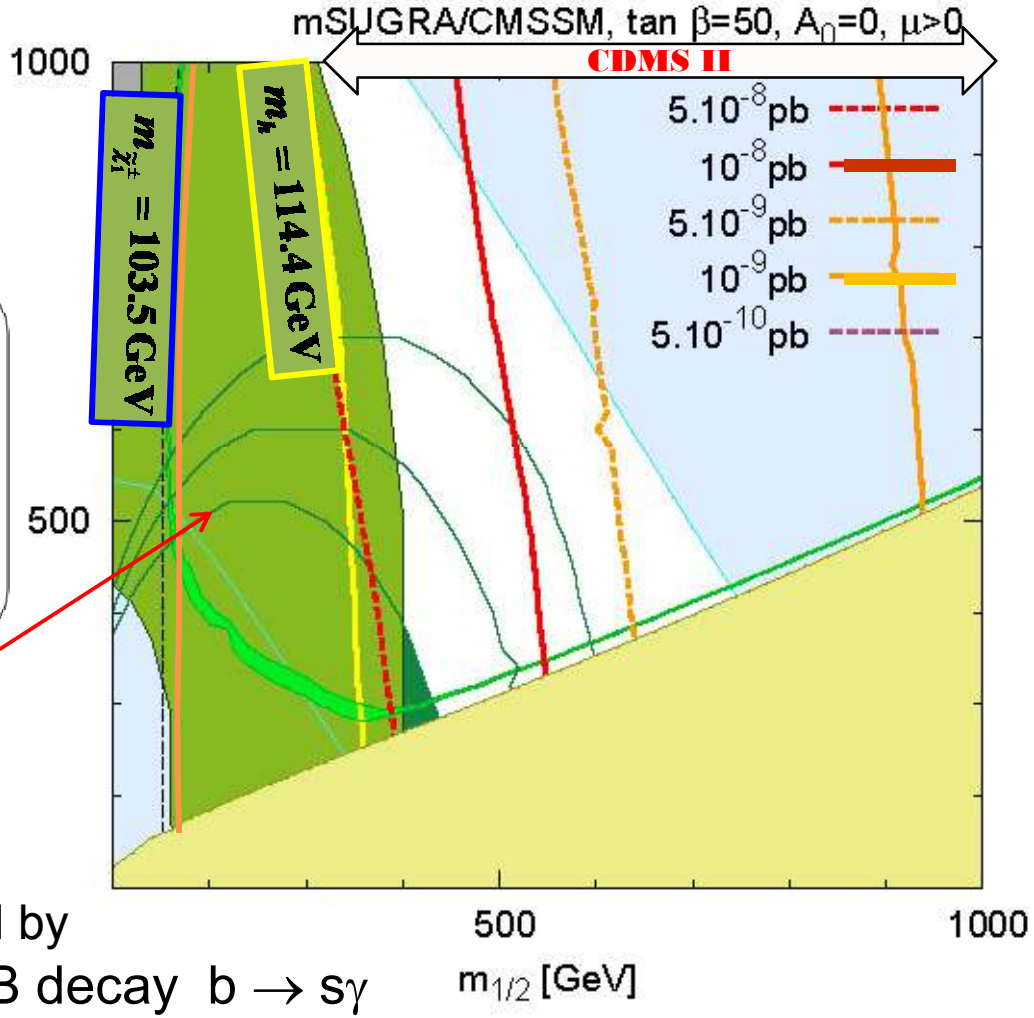
JHEP 1009 (2010) 106



Br enhancement By New Physics

$Br(B_s \to \mu\mu) = 2\times10^{-8}$
3×10^{-8}
4.7×10^{-8}

Rouzbeh Allahverdi, Bhaskar Dutta, Yudi Santoso
arXiv:0912.4329



Excluded by

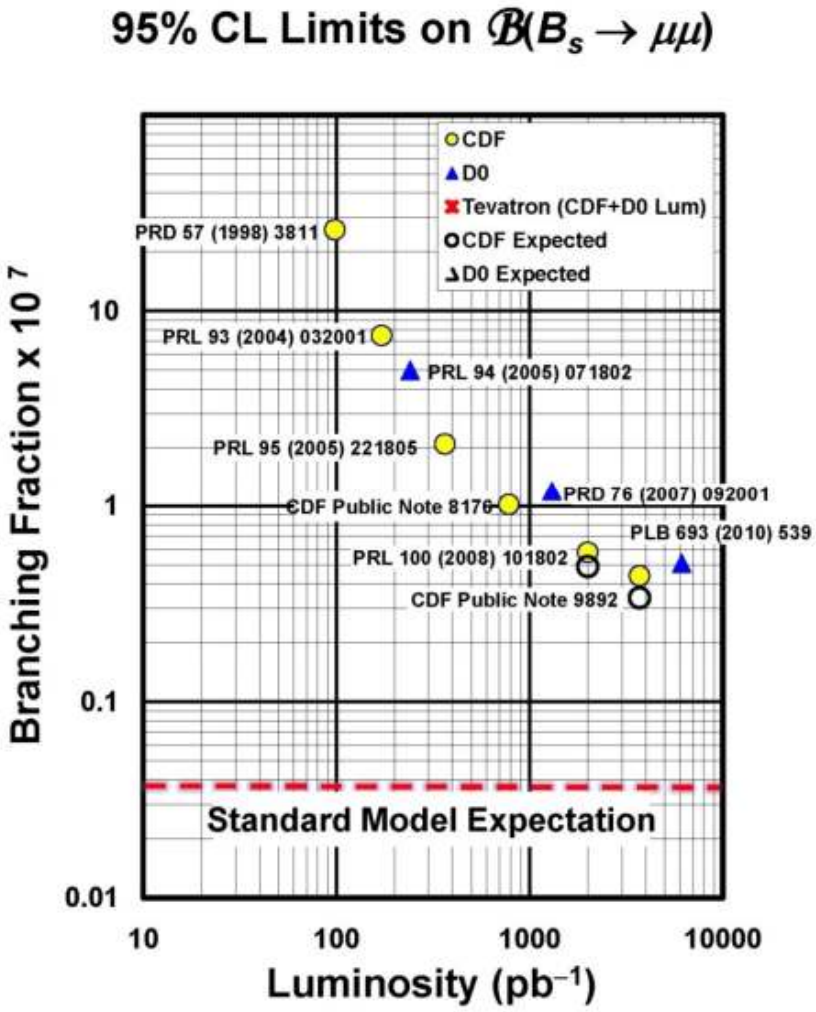
- a Rare B decay $b \to s\gamma$
- b No CDM candidate
- c Muon magnetic moment

$B_s \rightarrow \mu\mu$ at CDF

- A powerful indirect search to probe cosmol ogically consistent SUSY at large tanβ. e.g.,
  - Arnowitt et al., PLB 538 (2002) 121 for mSUGRA;
  - S. Baek, Y.G. Kim, and P. Ko, JHEP 0502, 067 (2005) for non-universal Higgs sce nario.

- 3 PRLs (2004, 2005, 2008)
  → Producing the best limits on SUSY

- Goal: 2 x 10^{-8} with 6.9 fb^{-1} and two challenging updated methods :



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

Both in experiments And theories…

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

DØ

- 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

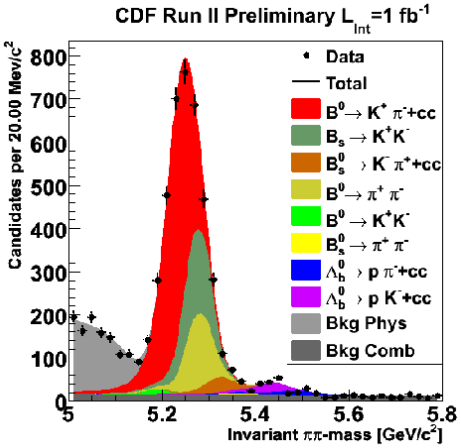
Theory

- 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 → c μ^-X → $\mu^+\mu^-$X
  - Double semileptonic decay: bb → $\mu^+\mu^-$X
  - Continuum $\mu^+\mu^-$, μ + fake, fake+fake
  - Peaking Background in signal region (B→hh)

3.7fb^{-1}



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

How to ?

3.7fb^{-1}

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

From Data, From MC, From PDG

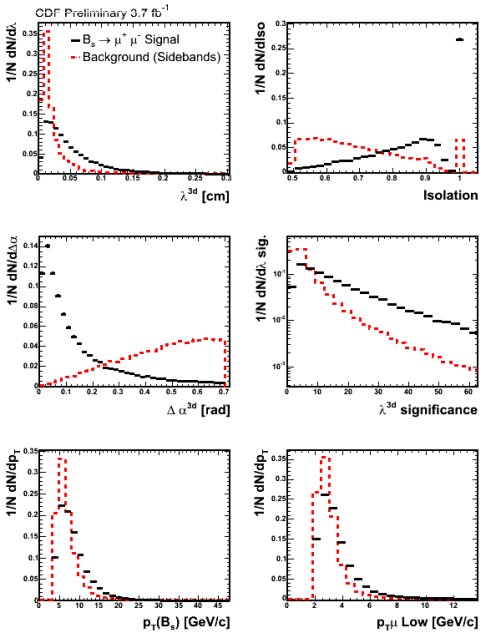
- Relative normalization search
  - Measure the rate of $B_s \to \mu^+\mu^-$ decays relative to $B \to J/\psi K^+$
  - Apply same sample pre-selection criteria
  - Uncertainties on Trigger and pre-selection efficiencies will cancel out in the ratios of the normalization
  - $B_s \to \mu^+\mu^-$ sample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

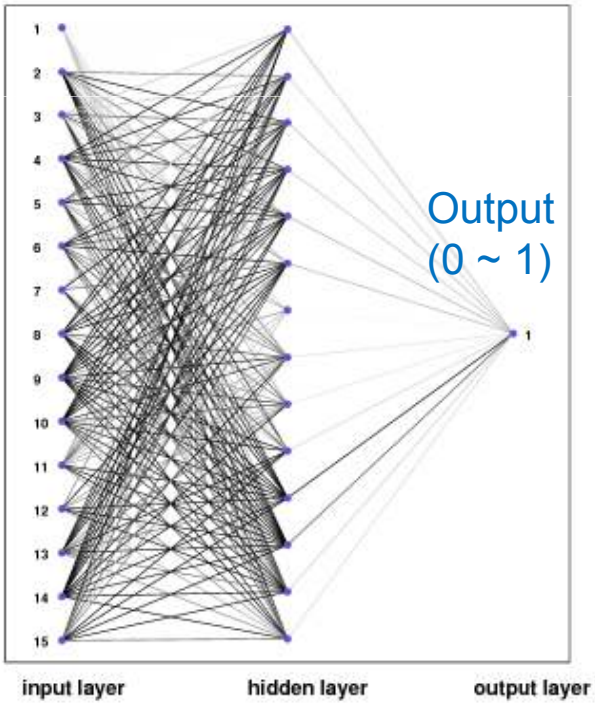
Signal Optimization

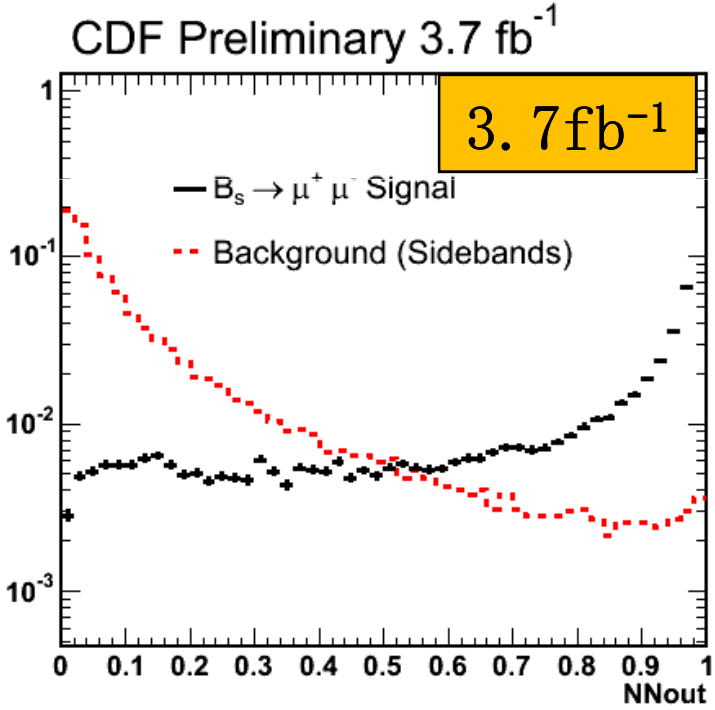
- NN input variables
- 3D pointing angle
- Isolation
- Proper decay length
- **Proper** decay length sig.
- $P_T(Bs)$
- $P_T(\mu)$

Discriminating variables

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

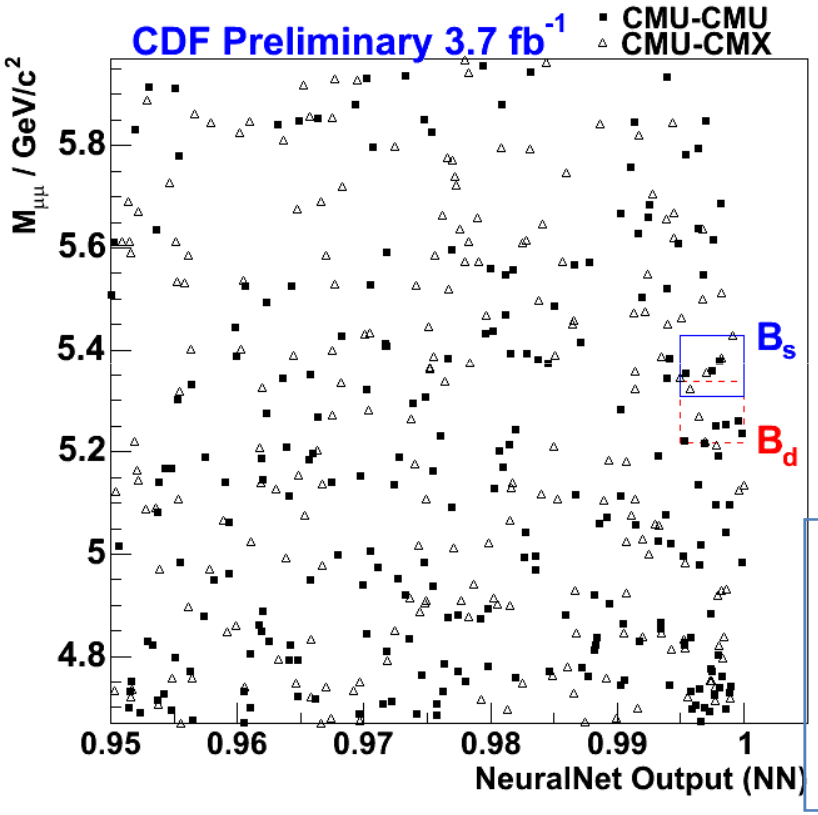






Results

$3.7 fb^{-1}$



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

$BR(B_s \rightarrow \mu\mu) < 4.3 \times 10^{-8}$ @ 95% CL

$BR(B_d \rightarrow \mu\mu) < 7.6 \times 10^{-9}$ @ 95% CL

CDF public note 9892

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

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

World Best

< 4.3×10^{-8} ($3.7\,fb^{-1}$) CDF

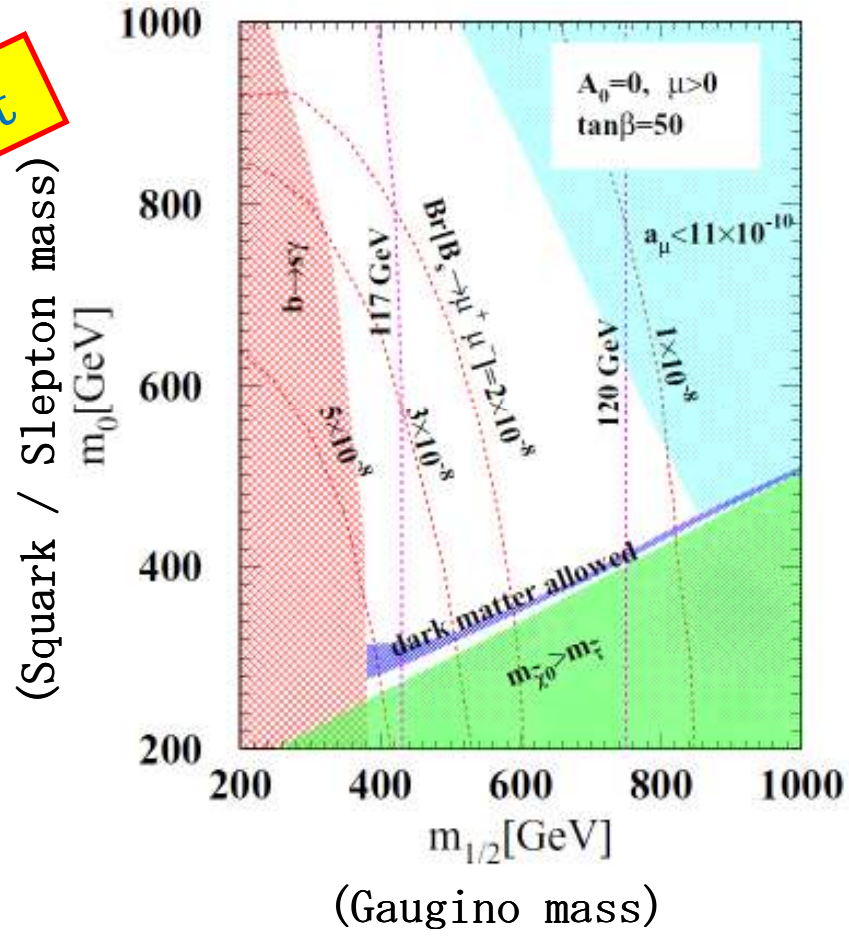
CDF public note 9892

< 5.1×10^{-8} ($6.1\,fb^{-1}$) DØ

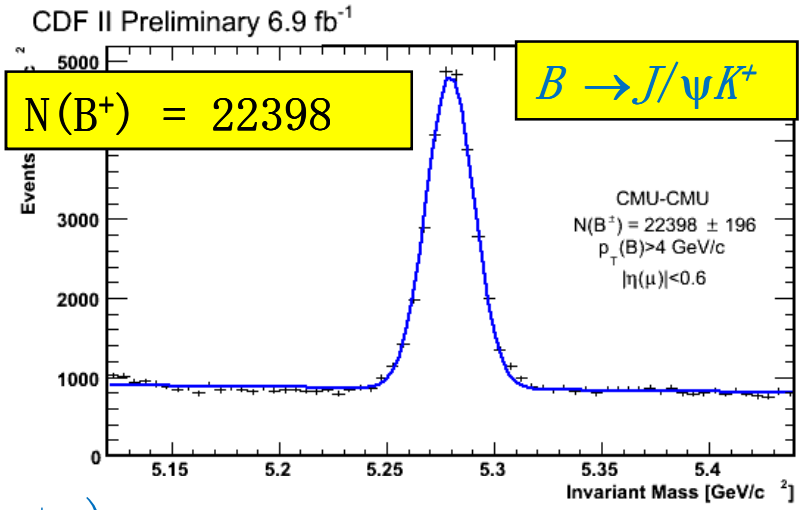
PLB 693 539 (2010)

< 5.6×10^{-8} ($0.036\,fb^{-1}$) LHCb

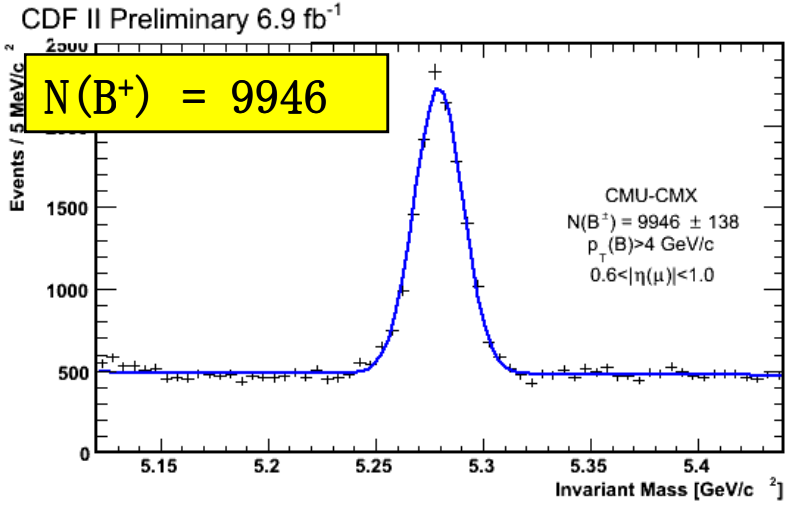
arXiv:1103.2465v1



After 3.7fb^{-1} @ CDF Since 2009 ..



- ~ 2X DATA added, now ~ 7 fb^{-1}
- Increased muon acceptance (add +30% data)
- New NN event selection for better signal efficiency
- Improved B->hh background estimation



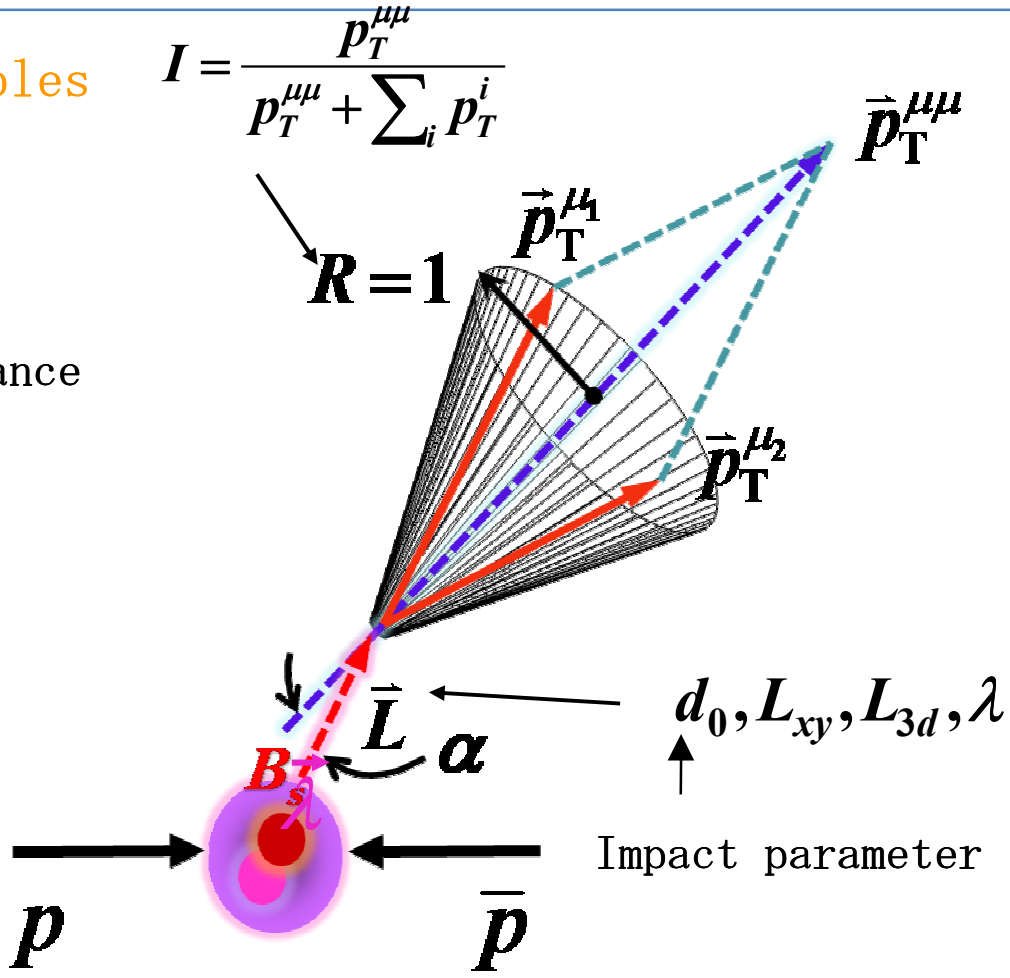
New Neural Network

✓ New 14 variable NN to increase S/B

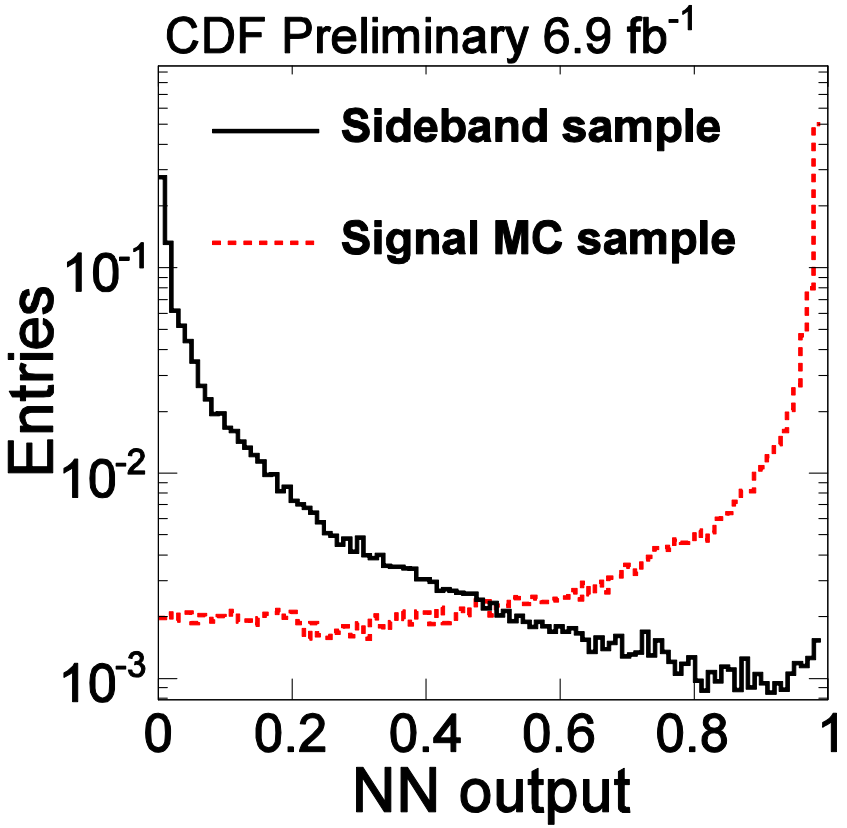
✓ Carefully chose input variables to avoid bias for di-muon mass shape

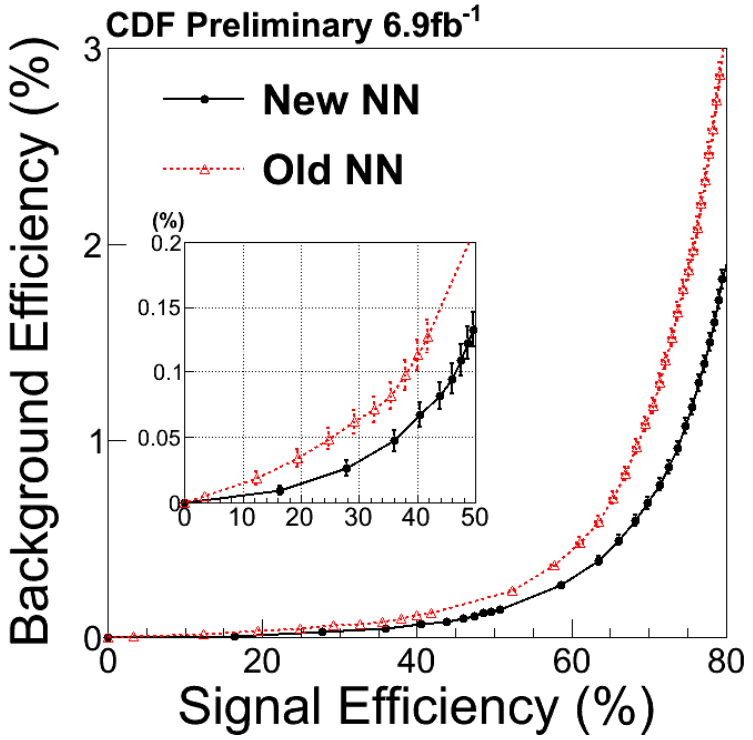
- Neural Network Input Variables
  - 3D proper decay length
  - Isolation
  - Pointing angle ($\Delta\alpha_{3d}$)
  - Lower $|p_T(\mu)|$
  - 3D proper decay length significance

  - 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
  - $|d_0(Bs)|$



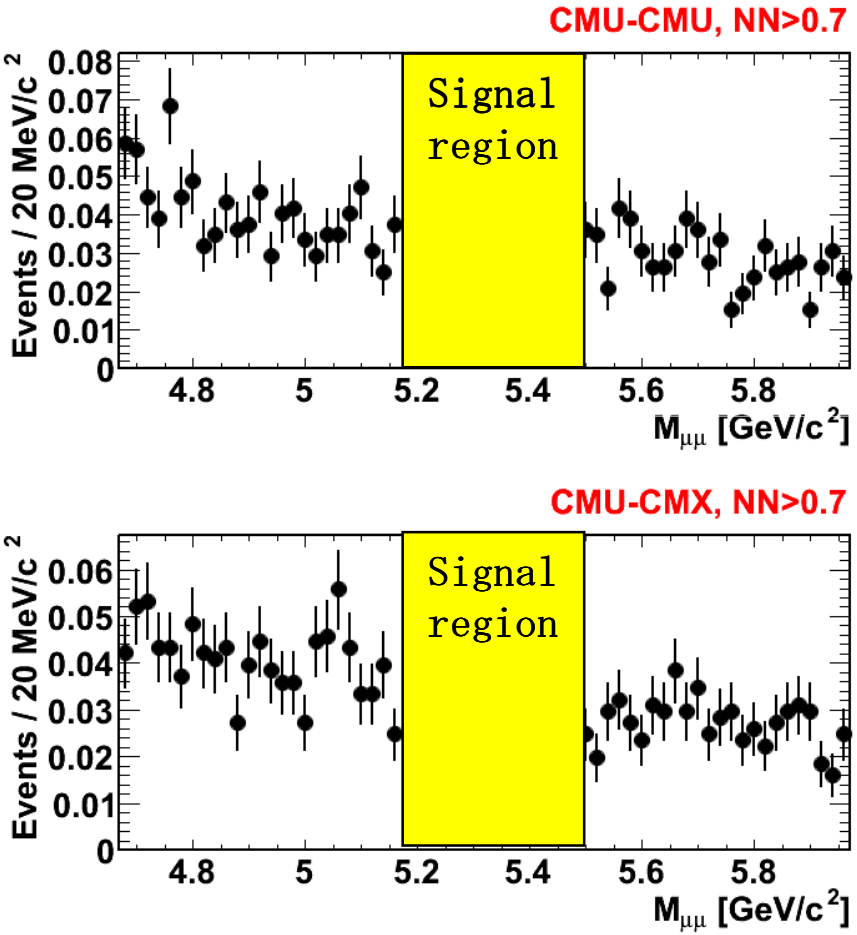
New Neural Network result





Twice background rejection at same signal efficiency

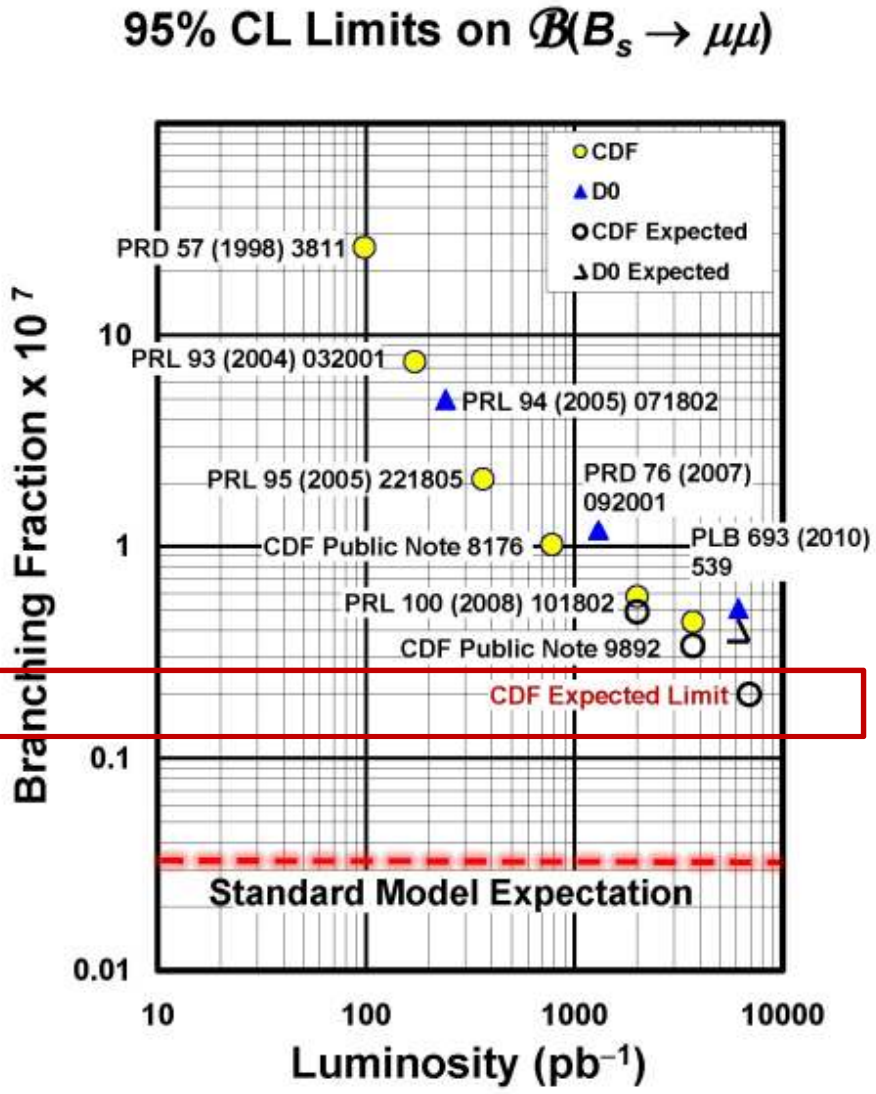
BKG region & Bias Check



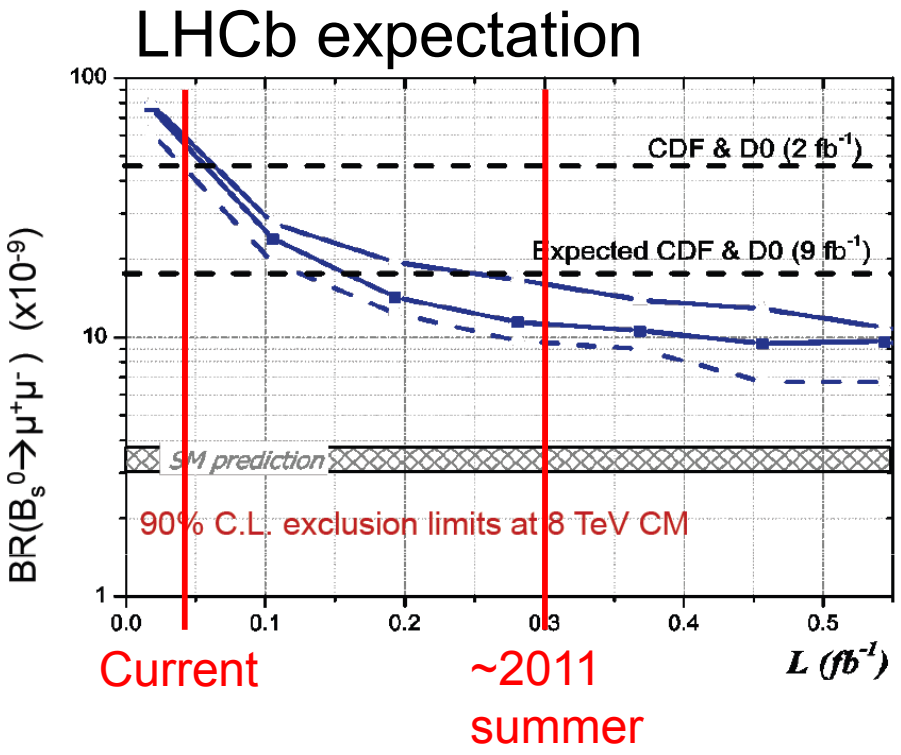
… Now we are at a final step to unblind to get Br. Fraction!

New Expected Limit at CDF

	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} :	$\sim 2\times10^{-8}$	



Then LHCb…



- It's just a matter of time (and lumiosity) that LHCb reaches the Bsmumu horizon.
- We are in a hard competition, but no doubt that now is the most exciting time!

Summary

- ✓ FCNCs decays provide powerful probe to New Physics
- ✓ CDF and DØ experiment lead rare decay searches in B sector
- ✓ CDF on its final step to provide most sensitive information on B→μμ rate with 2x data and improved analysis

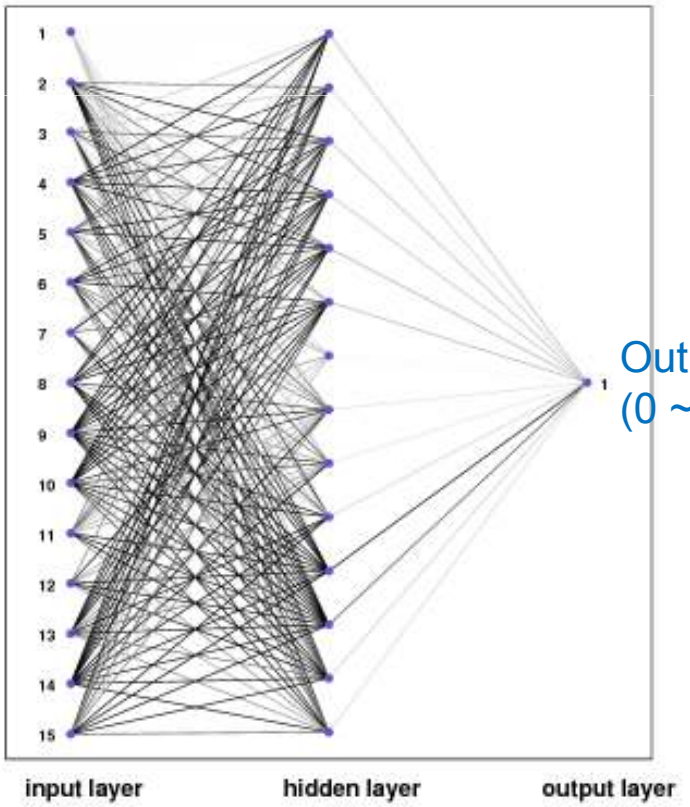
The Neural Network (NN) event selection

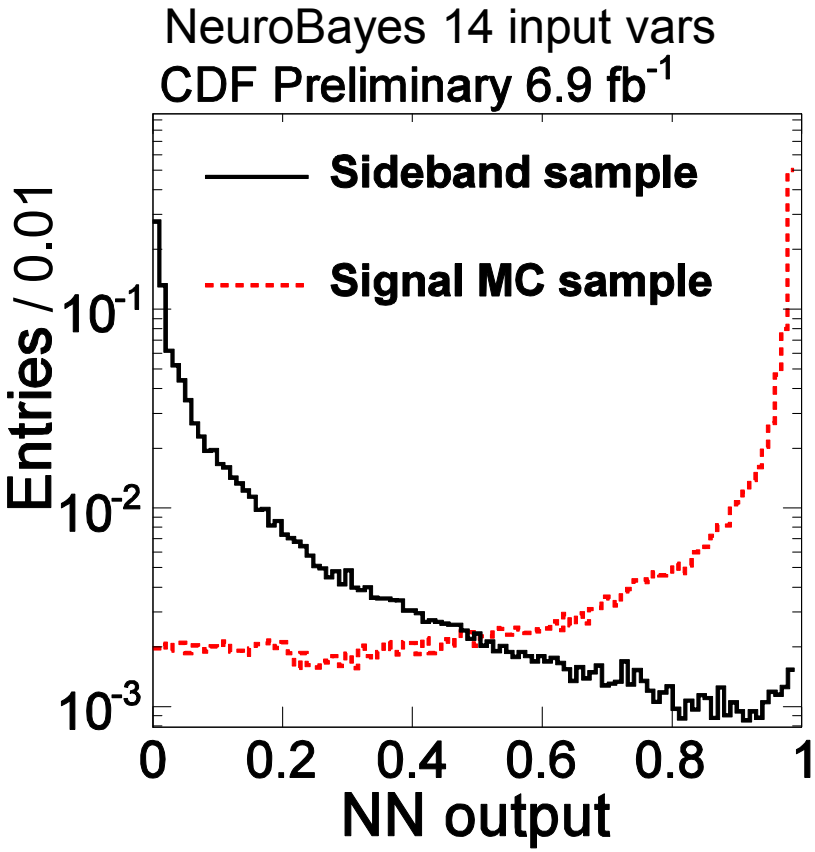
- A powerful multi-particle S/N discrimination method.
- At first NN is trained the NN using signal (by well-validated MC) and background (by di-muon mass sideband) reference samples.
- The trained NN is applied for signal-region events.

Discriminating variables

Outputs from NN range 0 (BG like) ~ 1 (signal like)

$d_0(B_s)$
$p_T(\mu)$
.
.
.

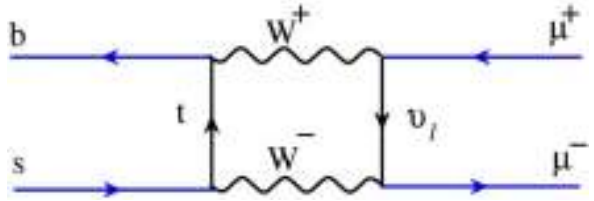




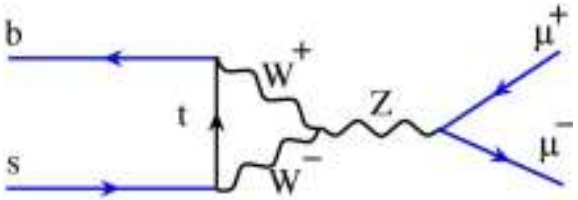
$B_s^0 \to \mu^+\mu^-$

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

SM Diagrams



Box Diagram



Penguin Diagram

SM Expectation

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

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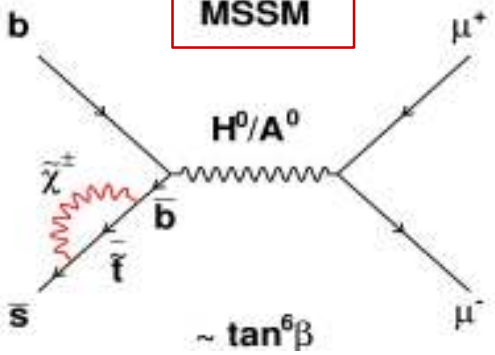
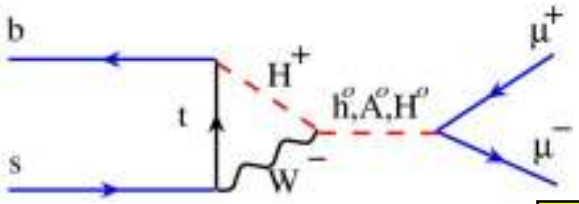
MSSM



2HDM



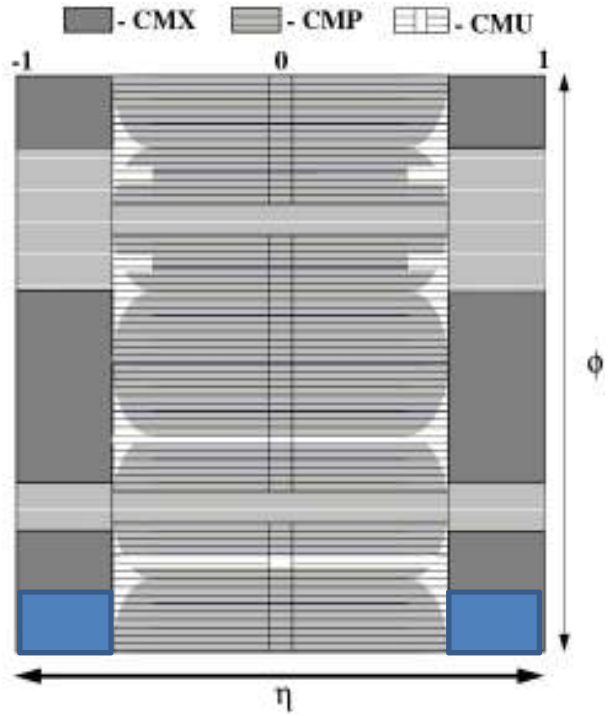
Penguin Diagram

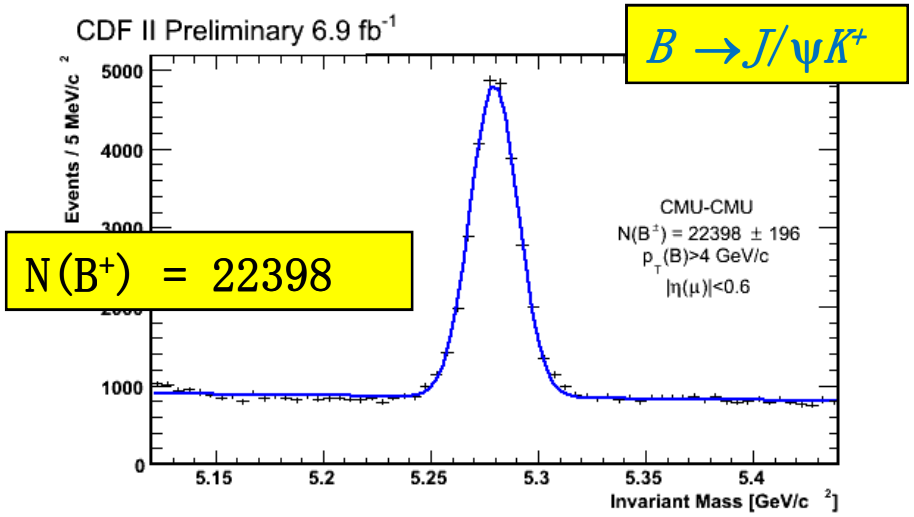
NP Expectation

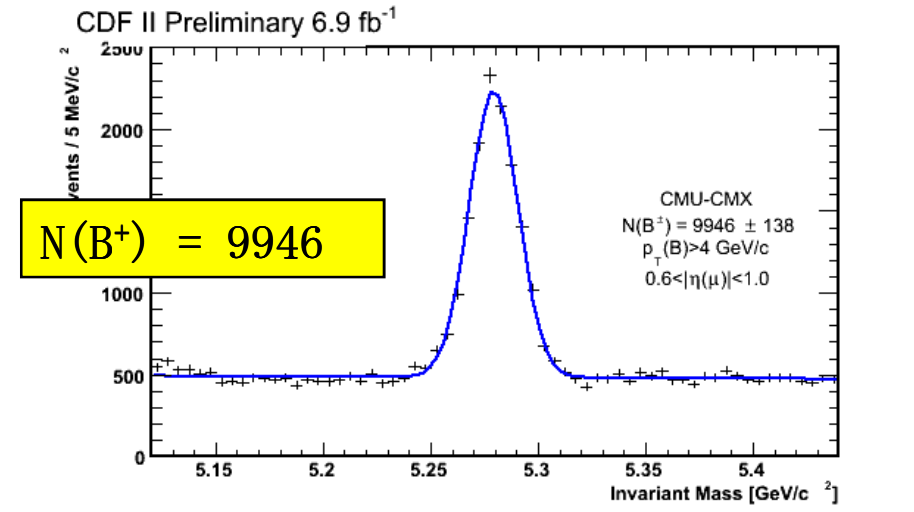
Br enhancement

Powerful Probe to New Physics

Normalization Sample







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

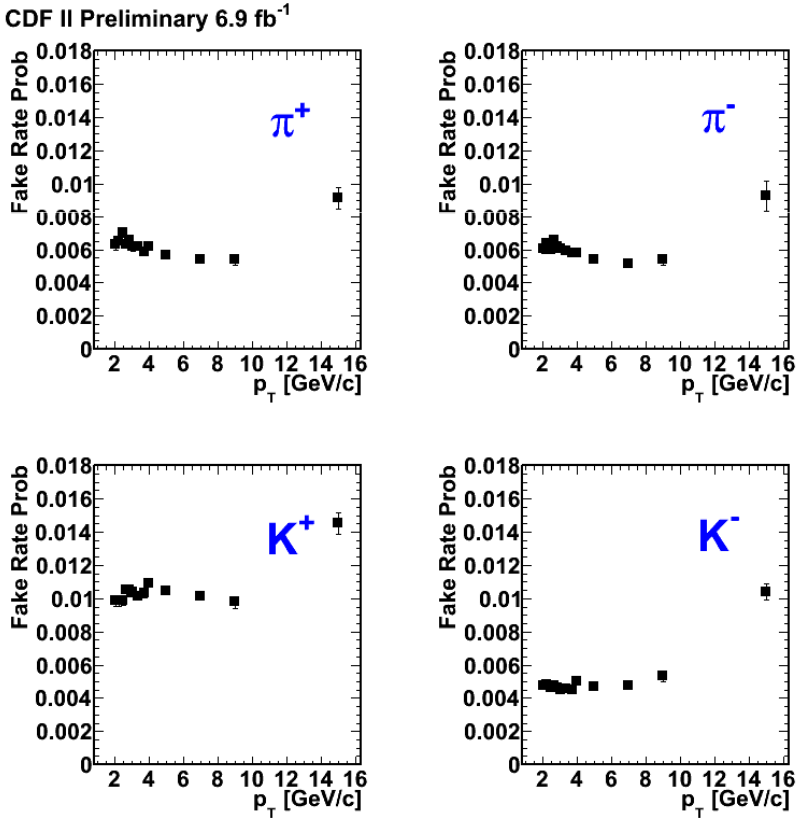
- CMU-CMU : increased ~ 50%
- CMU-CMX : increased ~(50 + 30)%

increased muon acceptance

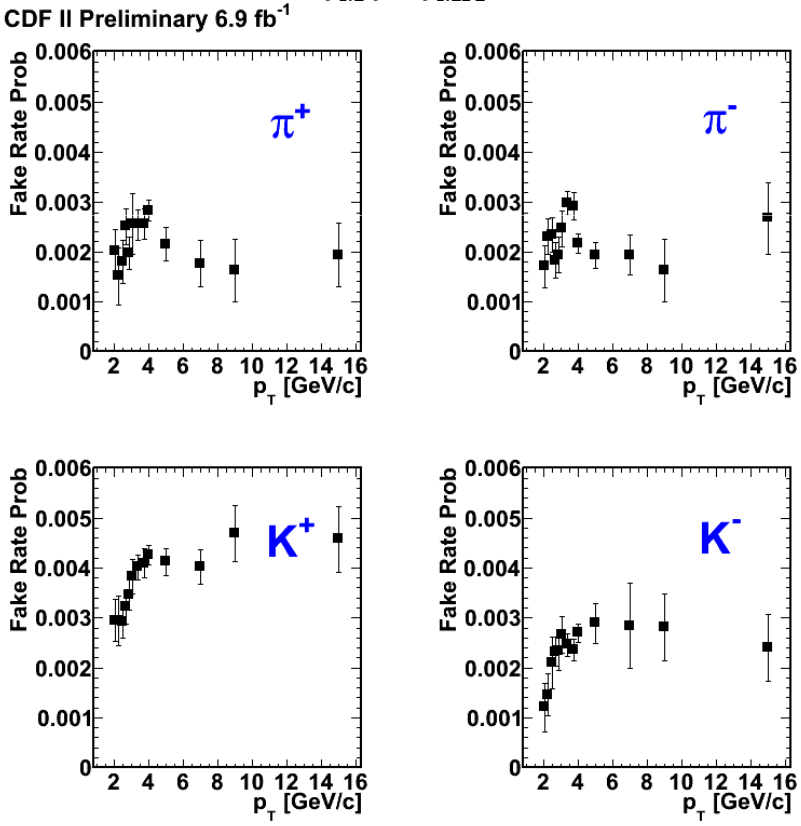
Fully data driven analysis

- 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

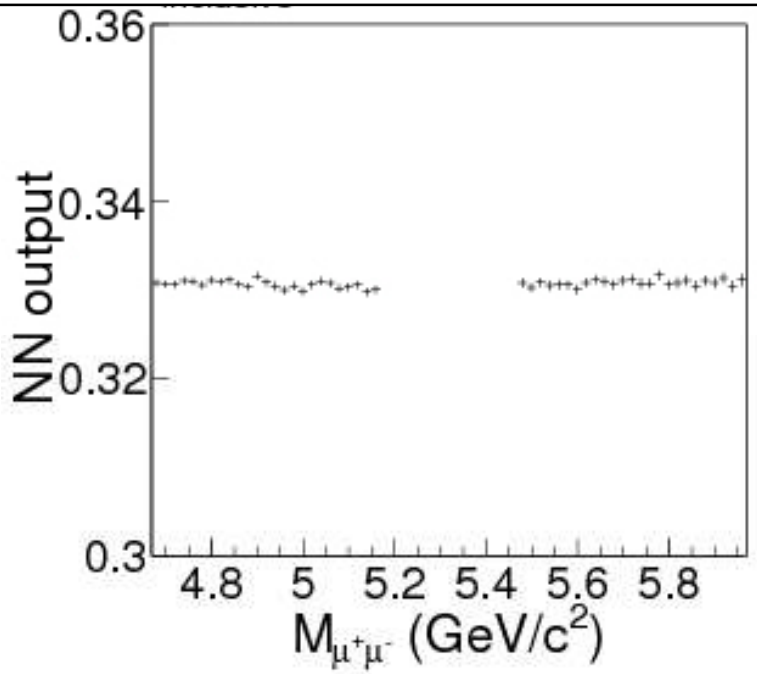


CMU-CMX



Bias Check from NN event selection

Mass Bias Check with Sideband region



NO correlation b/w NN and Mass