Flavor Changing Neutral Current at the Tevatron

The 12th International Conference on B-Physics at Hadron Machines
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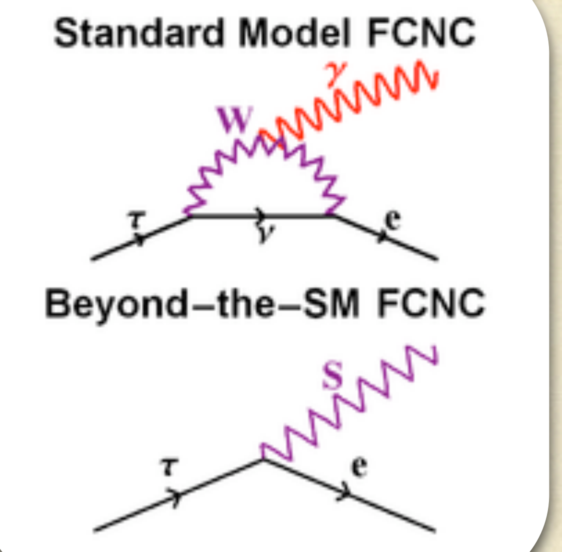
on behalf of the CDF and DØ Collaborations

Introduction

- Flavor Changing Neutral Currents (FCNCs) are processes that change the flavor of a fermion current without altering its electric charge.
- may occur in the Standard Model beyond the tree level, but they are highly suppressed (the GIM mechanism).
- NP could significantly enhance FCNC
- In this talk:
  $B^0_{(s)} \to \mu^+\mu^-$,
  $B^+ \to \mu^+\mu^- K^+$, $B^0 \to \mu^+\mu^- K^{*0}(892)$, $B^0_s \to \mu^+\mu^-\phi$,
  and $D^0 \to \mu^+\mu^-$
- And more: Charm Mixing,...

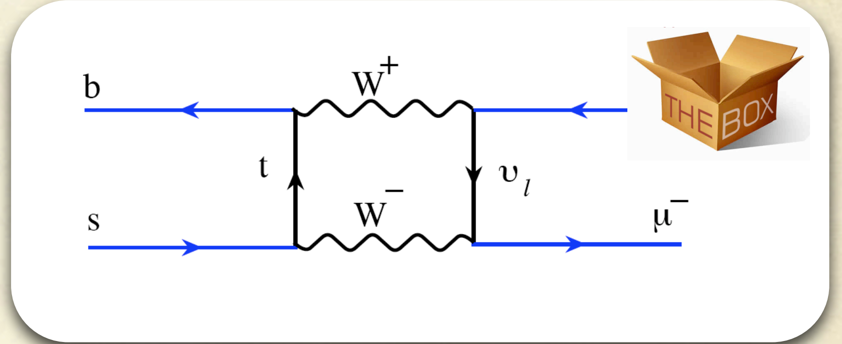


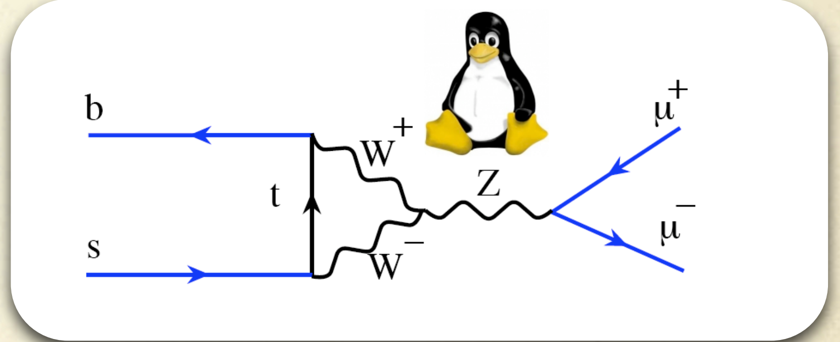
“A needle in a haystack”!

$B \to \mu^+\mu^-$

$B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ are the most studied FCNC processes. CKM, GIM and helicity suppression in SM lead to:

$BR(B^0_s \to \mu^+\mu^-) = (3.86 \pm 0.57) \times 10^{-9}$ $(|V_{ts}|^2)$
$BR(B^0 \to \mu^+\mu^-) = (1.00 \pm 0.14) \times 10^{-10}$ $(|V_{td}|^2)$





NP can enhance up to 100×
MSSM: $BR \propto \tan^6(\beta)$.
RPV SUSY enhances also at low $\tan(\beta)$.
Either observation or null result provides crucial information.

Current world's best upper limits from CDF on 2/fb:
$BR(B^0_s \to \mu^+\mu^-) < 4.7(5.8) \times 10^{-8}$ and $BR(B^0 \to \mu^+\mu^-) < 1.5(1.8) \times 10^{-8}$ @ 90(95)%CL, PRL 100, 101802 (2008).
Highlight: update on 3.7/fb from CDF and new expected limit from DØ on 5/fb.

$B \to \mu^+\mu^-$ – Strategy

$BR(B^0_s \to \mu^+\mu^-)$ is obtained by normalizing to the number of $B^+ \to J/\psi K^+ \to [\mu^+\mu^-]K^+$ where $\mu^+\mu^-$ vertex is reconstructed in the "same" manner (similar for B^0).

$B^0_s \to \mu^+\mu^-$ decays at 95%CL

TriggerAcceptance ratio from MC

Rec. efficiency ratio from MC/DATA

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{N_s}{N_+} \cdot \frac{\alpha_+}{\alpha_s} \cdot \frac{\epsilon_+}{\epsilon_s} \cdot \frac{1}{\epsilon_N} \cdot \frac{f_u}{f_s} \cdot \mathcal{B}(B^+),$$

From PDG08

$B^+ \to J/\psi K+$ decays from data

Efficiency of NN requirement from MC

$B \to \mu^+\mu^-$ – Strategy

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TriggerAcceptance ratio from MC

Rec. efficiency ratio from MC/DATA

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_s}{N_+} \cdot \frac{\alpha_+}{\alpha_s} \cdot \frac{\epsilon_+}{\epsilon_s} \cdot \frac{1}{\epsilon_N} \cdot \frac{f_u}{f_s} \cdot \mathcal{B}(B^+),$$

From PDG08

$B^+ \to J/\psi K+$ decays from data

Efficiency of NN requirement from MC

The challenge: Reject 10^6 bckg while keeping signal efficiency high.

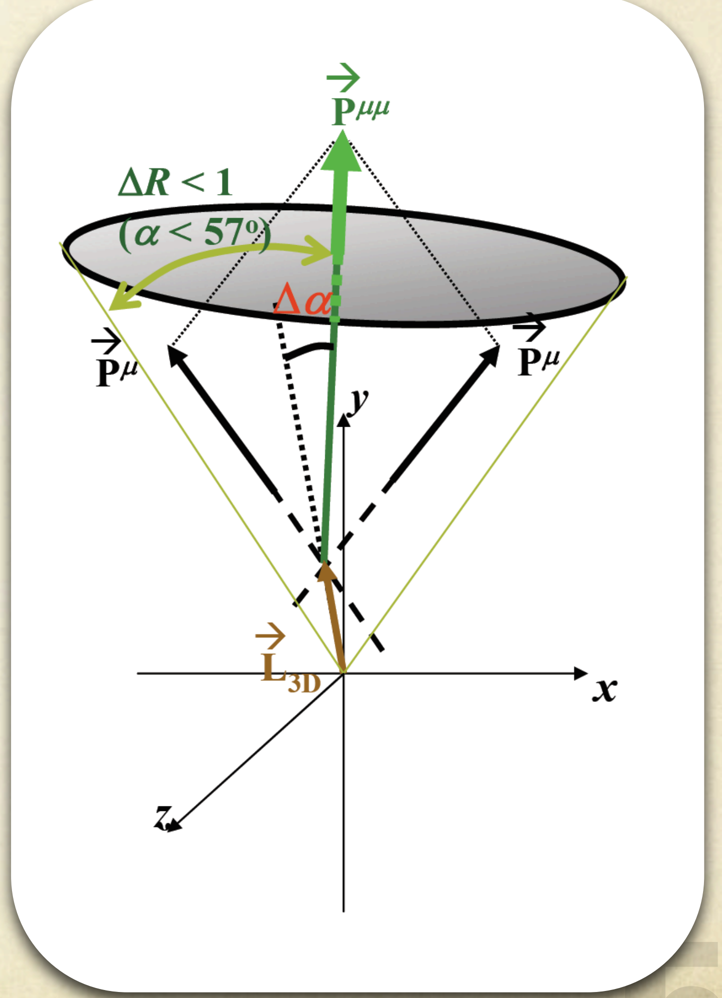
two tracks with p_T>2(2.2) GeV/c from di-muon triggers
pre-selection on kinematic discriminator variables
muon likelihood requirement (tracker, calorimeter and muon system information)
dE/dx from drift chamber to reject fake kaons
ANN discriminating to enhance signal and background separation

$B \to \mu^+\mu^-$ – Selection

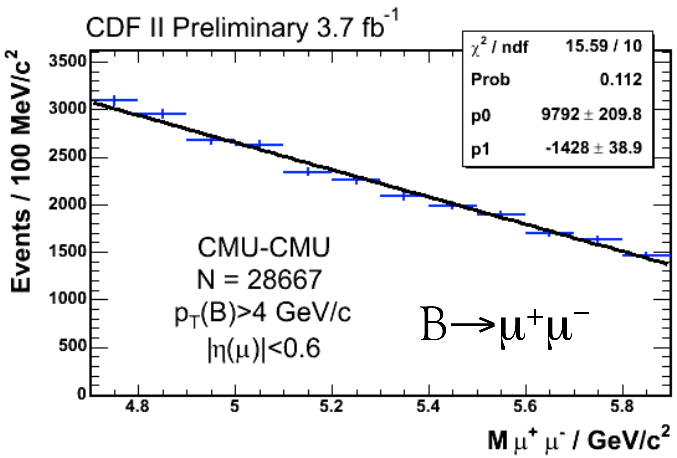
Selection based on following kinematics discriminating variables:

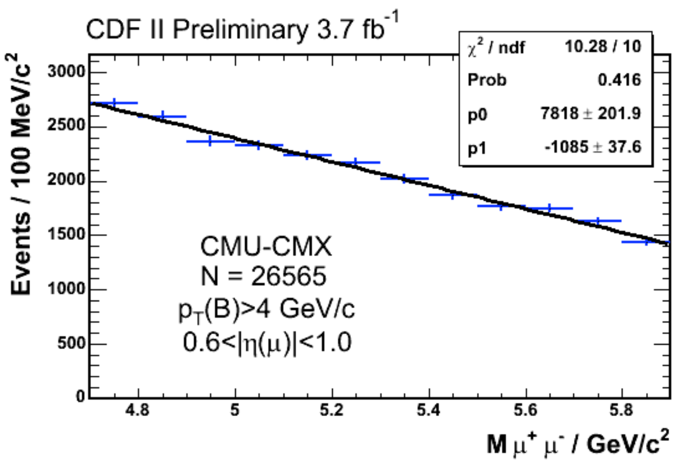
Transverse momentum of candidate $p_T^{\mu+\mu-}$ (>4GeV)
Transverse lower momentum of muon track p_T
Proper decay time $\lambda = L_{3D} \times M_{\mu\mu} / |p^{\mu+\mu-}|$
Significance of proper decay time λ/σ_λ (>2)
3D opening angle $\Delta\alpha$ (<0.7 rad)
Isolation of B candidate I (>0.5)

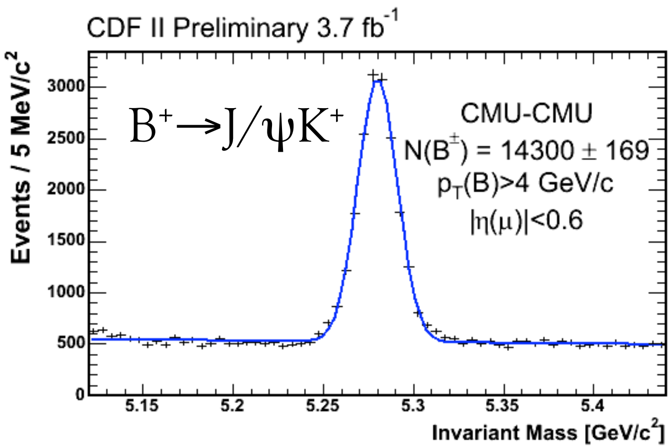
Since 2/fb results: +12% acceptance by recovering tracks that cross the COT spacers. Analysis methodology keeps being improved.

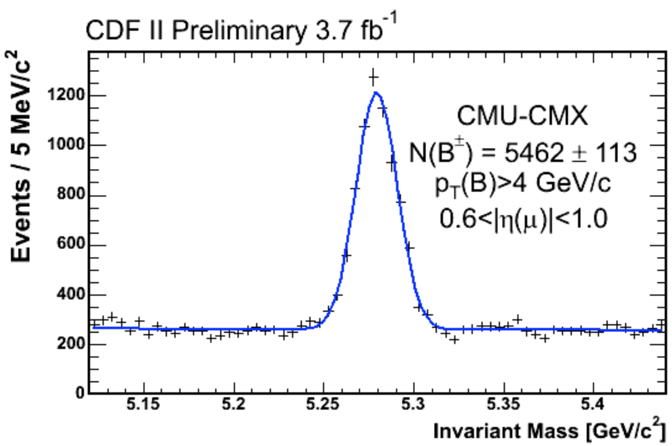


$B \to \mu^+\mu^-$ – Data samples (pre-selection)



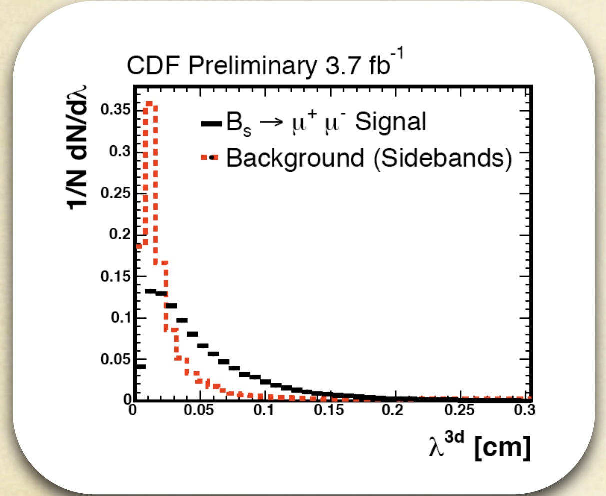






$B \rightarrow \mu^+\mu^-$ – ANN Selection

Discriminants: momenta, lifetime, B isolation and pointing to $p\bar{p}$ vertex.



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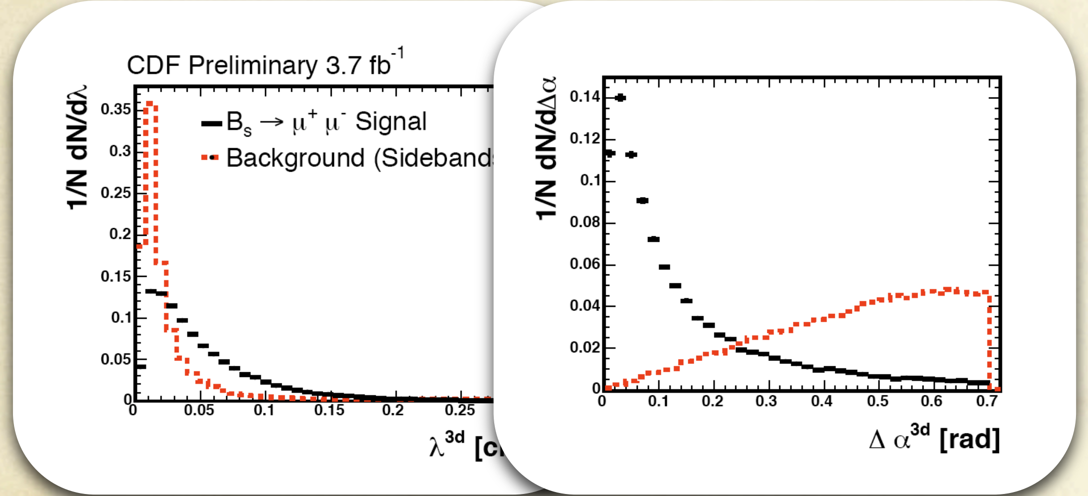

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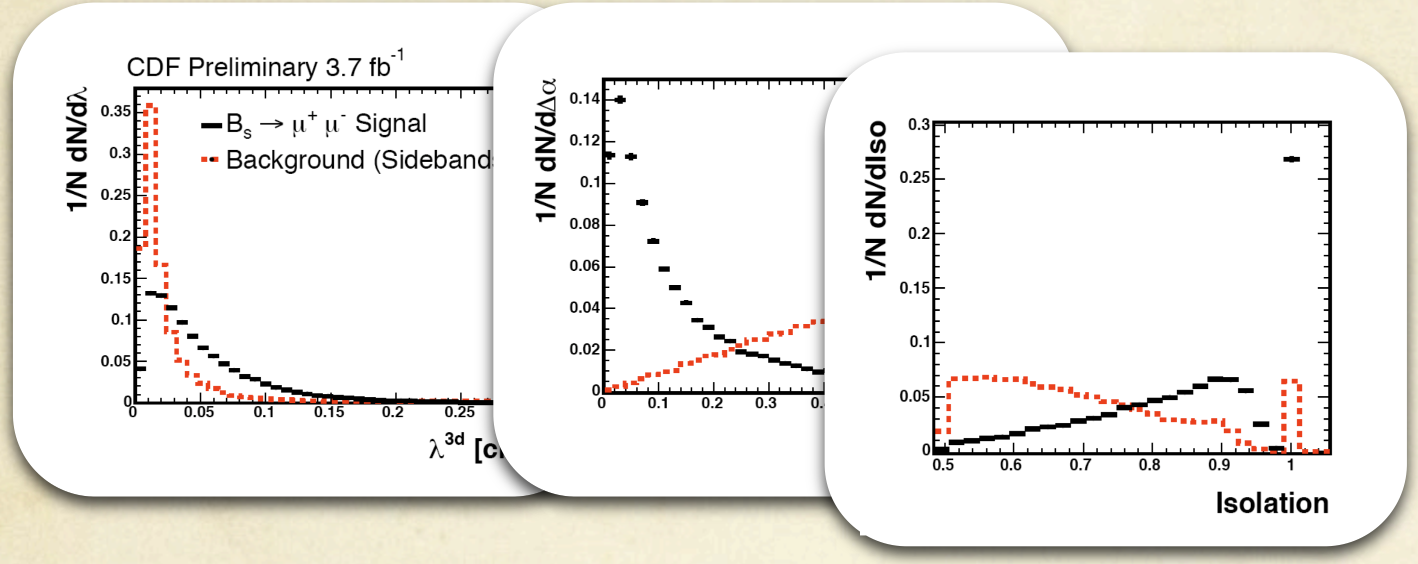

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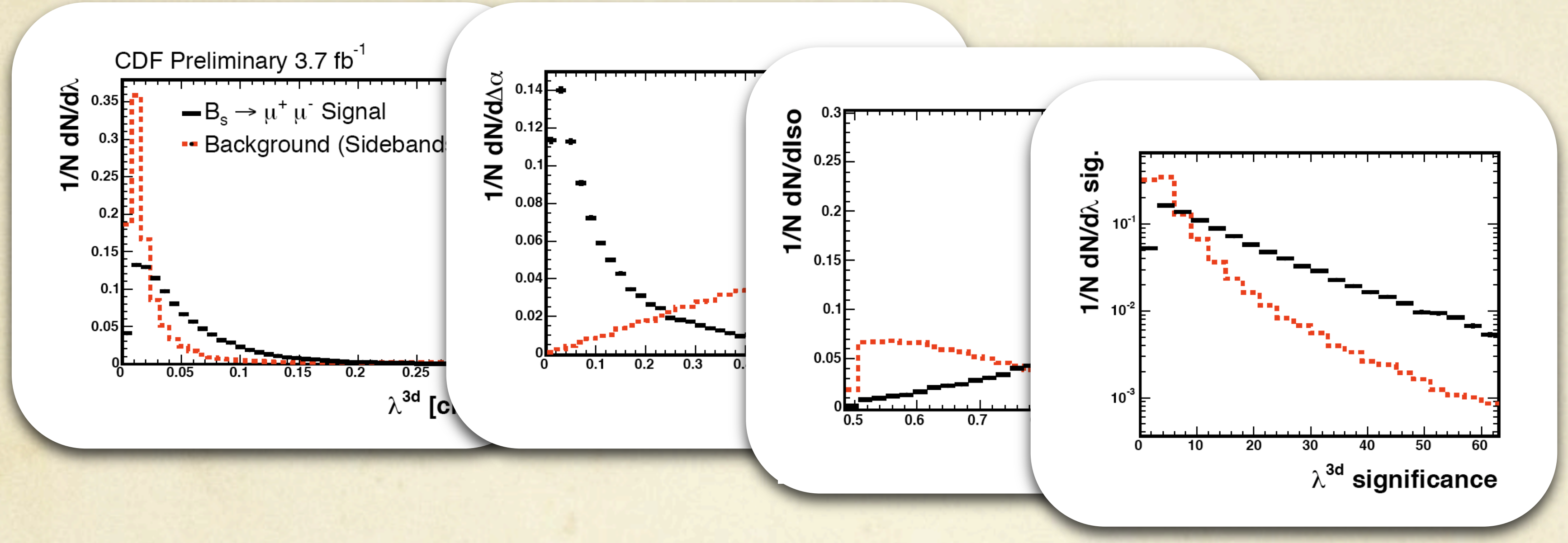

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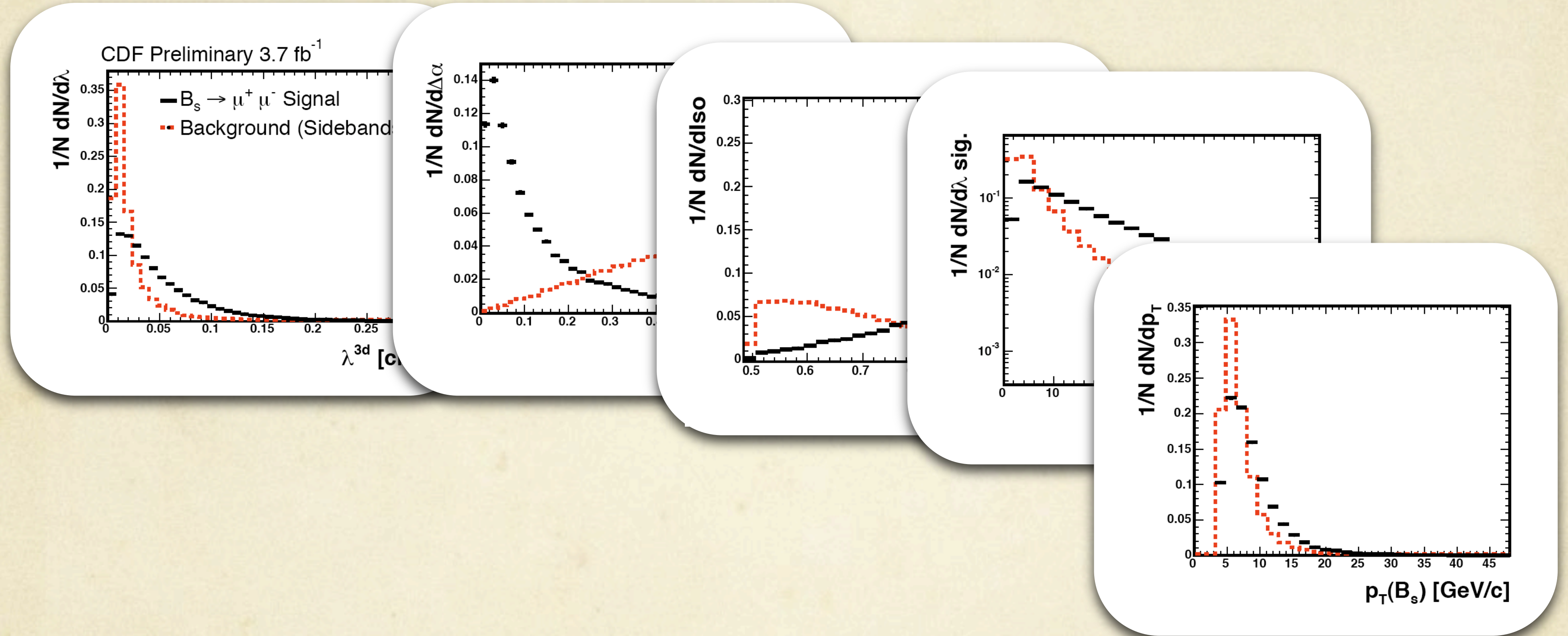

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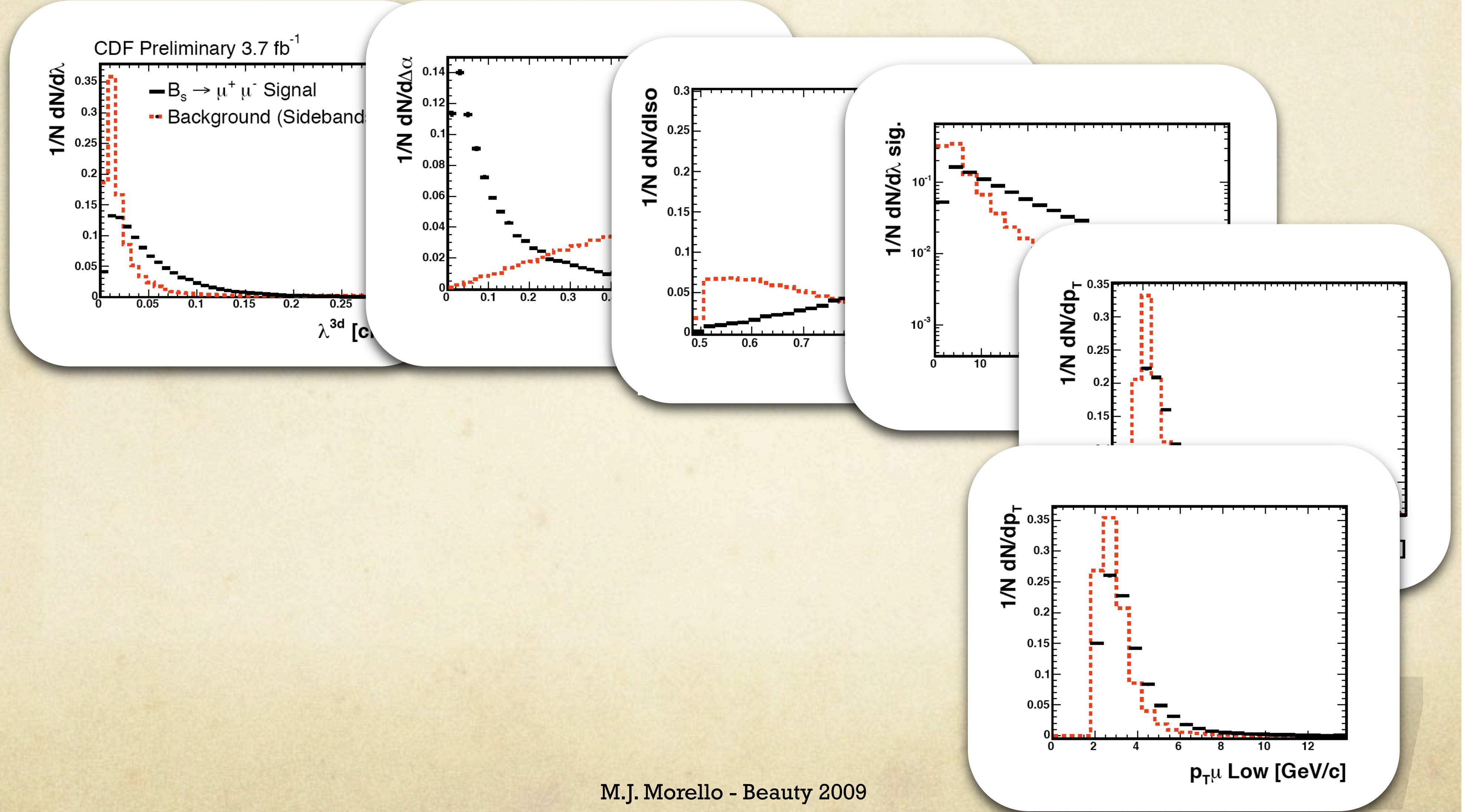

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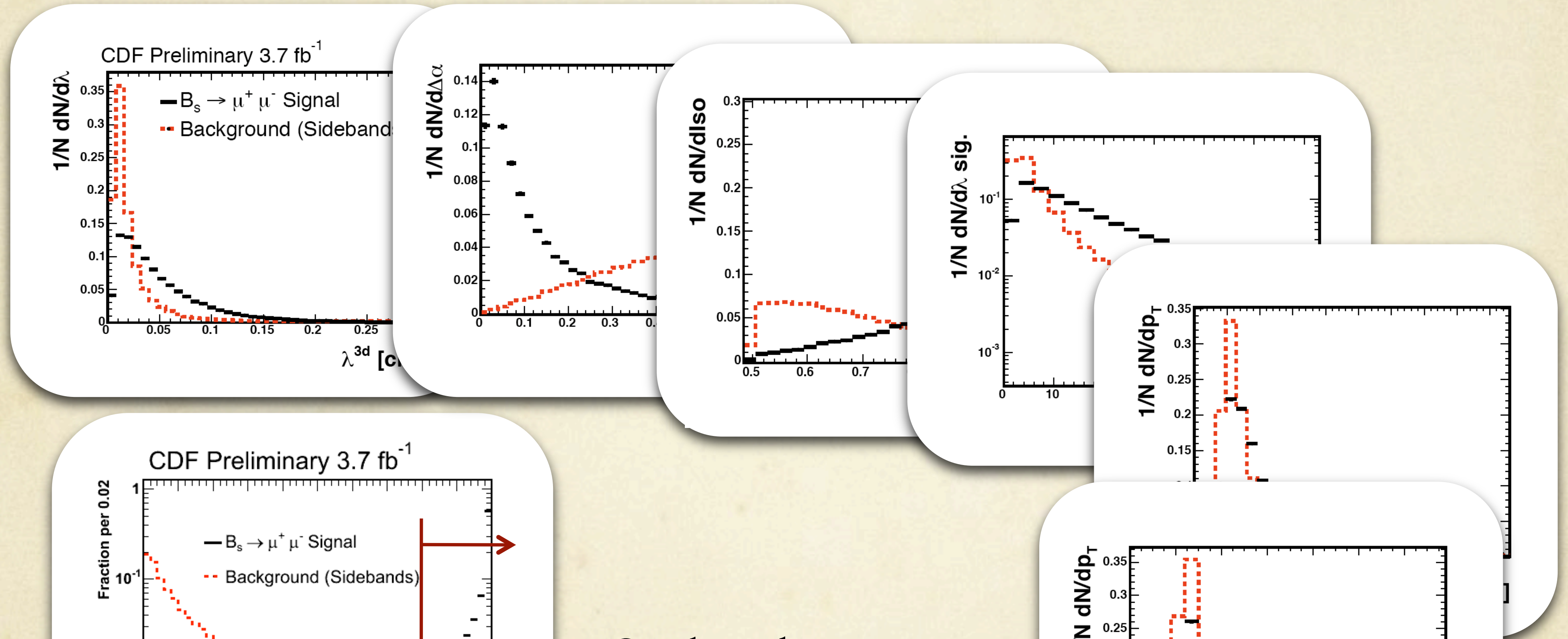
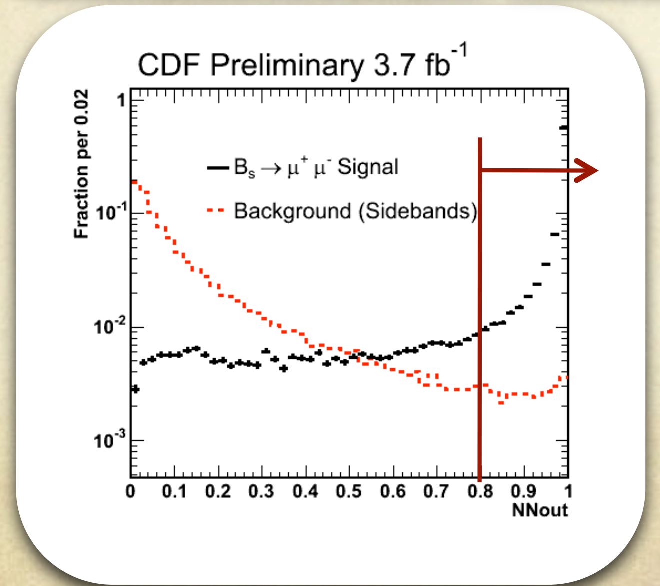
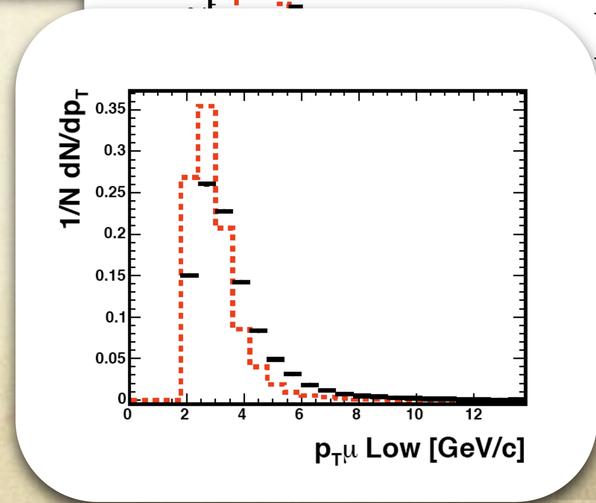




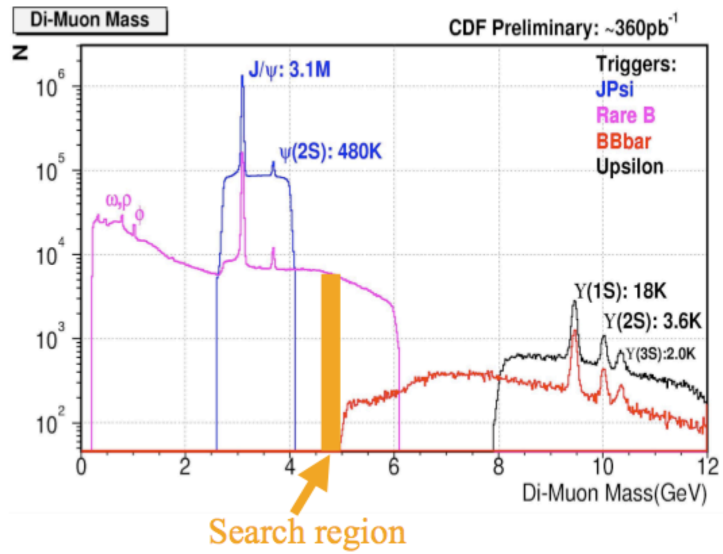
Combine discriminants into a Neural Network



$B \to \mu^+\mu^-$ – Background

Possible offenders:

Continuum μμ from Drell-Yan
Sequential b→ c→ s semileptonics
Double semileptonic bb → μμ+X
b/c → μ + fake
Fake + fake (dominated by resonant B → hh)



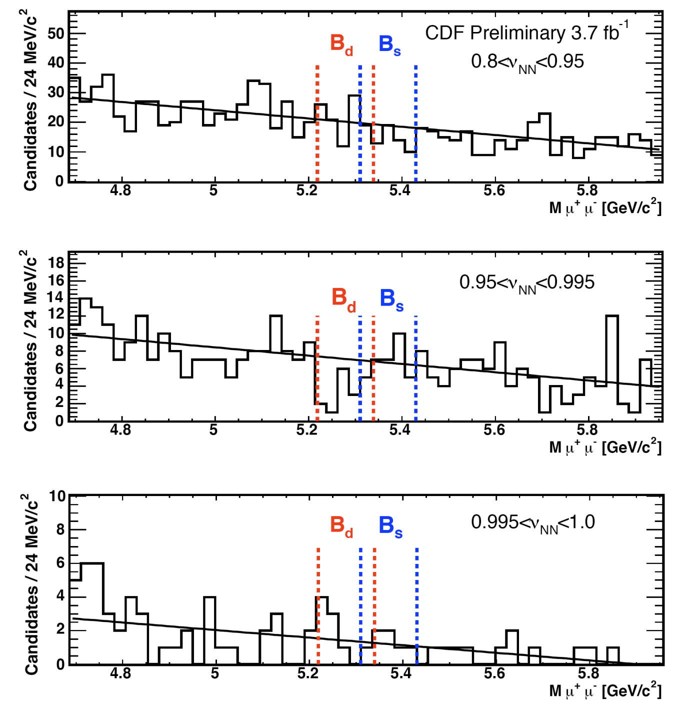
Suppress fakes: calorimeter, dE/dx, muon-track matching. All calibrated on $J/\psi \to \mu\mu$, $D^0 \to K\pi$, $\Lambda \to ph$ decays in data.
Combinatorial: extrapolate from sidebands into signal region
Extensive checks with background-enriched control samples: same-sign di-muons, di-muons with <0 decay-length, at least one muon failing fake veto

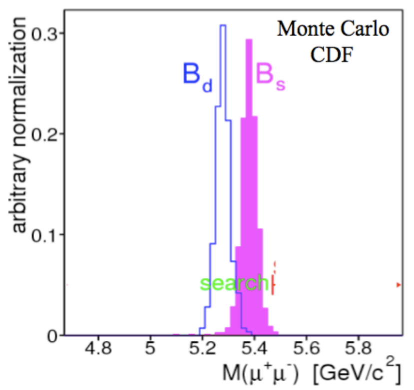
$B^0_s \to \mu^+\mu^-$ – CDF results (Update)

NEW

Preliminary CDF results on 3.7/fb
Public CDF note 9892
$BR(B^0_s \to \mu^+\mu^-) < 3.6(4.3)\times10^{-8}$ @ 90(95)%CL
$BR(B^0 \to \mu^+\mu^-) < 6.0(7.6)\times10^{-9}$ @ 90(95)%CL

Improves world's best published CDF results on 2/fb (PRL 100, 101802 (2008)) by a factor of 1.4
SES=3.2×10^{-9} → expected 1.2 SM events, 0.7 in ν_{NN}>0.995
9*SM with 3.7/fb at 90%CL.
Plenty of NP models already excluded.



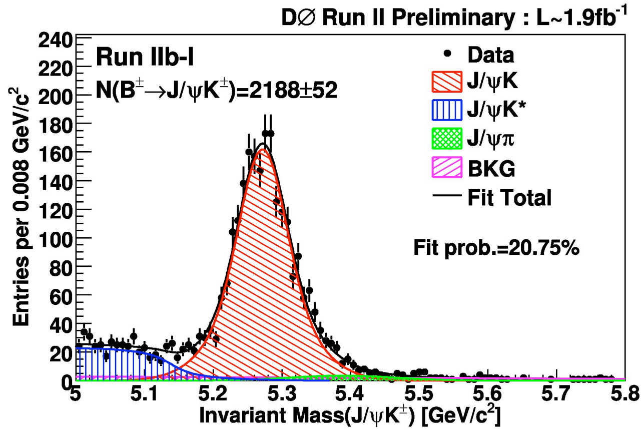


Mass resolution: $\sigma_m \approx 23$ MeV/c^2 ≈1/4 of B^0 - B^0_s mass difference. Allows independent search for B^0 mode. Probes non-MFV models where $BR(B^0_s)/BR(B^0) \neq (V_{td}/V_{ts})^2$

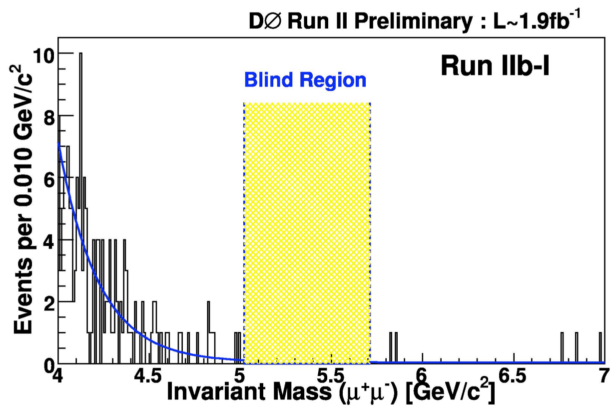
$B^0_s \to \mu^+\mu^-$ – DØ results

D0 analysis similar to CDF one:
BDT (boosted decision tree) in place of ANN
Divide data into 3 periods →3 independent analyses:
Run-IIa(1.3/fb), Run-IIb-I(1.9/fb), Run-IIb-II(1.6/fb).

Signal box is still blinded. Expected upper limit assuming no signal.



Expected upper limit on 5/fb
DØ conf-note 5906
BR($B^0_s \to \mu^+\mu^-$) < $4.3(5.3)\times10^{-8}$ @ 90(95)%CL



Preliminary DØ result on 2/fb
DØ conf-note 5344
BR($B^0_s \to \mu^+\mu^-$) < $7.5(9.3)\times10^{-8}$ @ 90(95)% CL

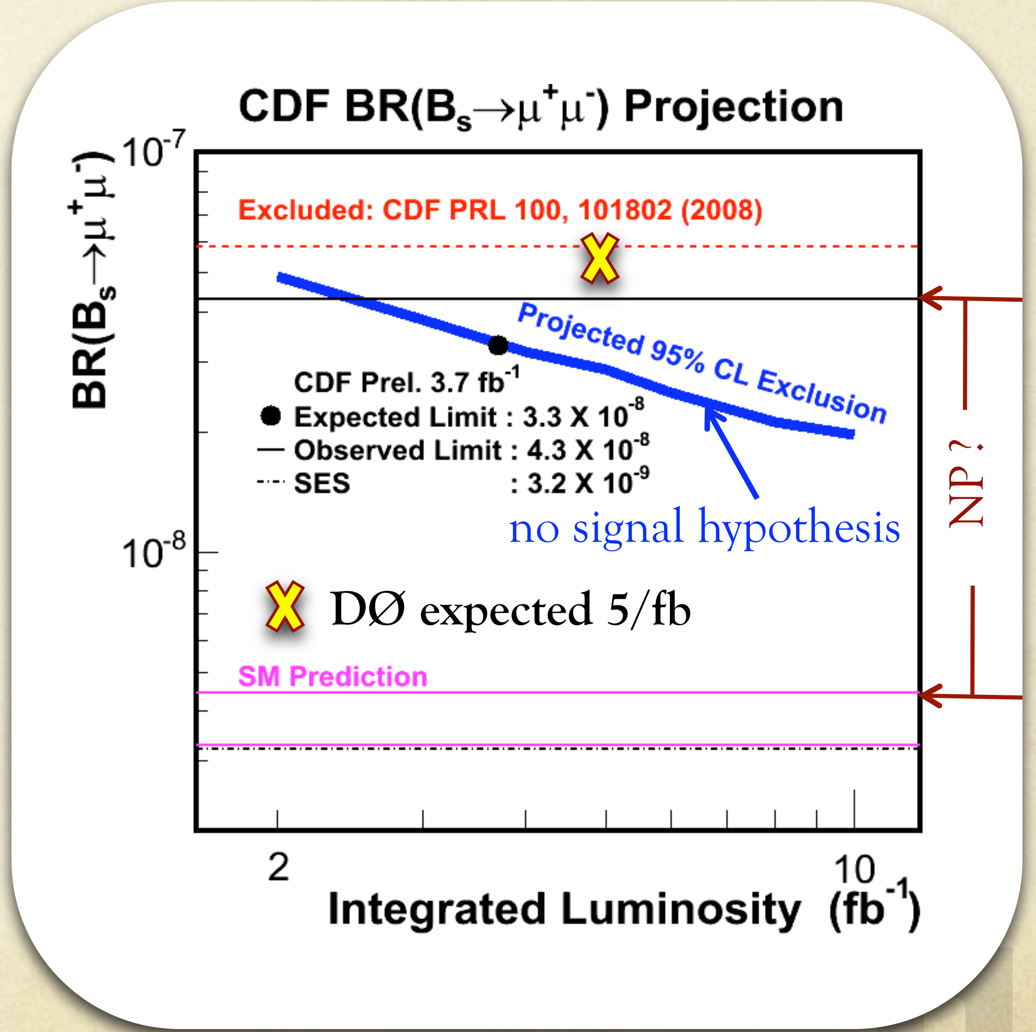
No sufficient mass resolution to search for B^0.

$B^0_s \to \mu^+\mu^-$ – Outlook

Single Event Sensitivity < SM expectation
Expected limit < observed limit.
Hint of small excess?

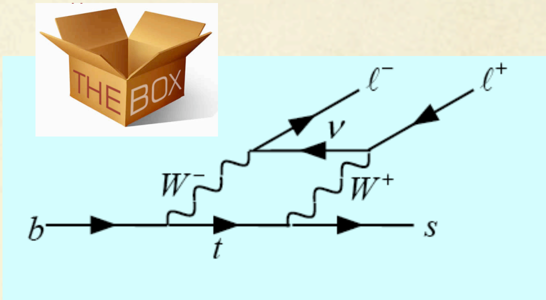
No analysis improvements assumed:
expected limit is 2×10^{-8} (6×SM) at 8/fb in 2010 from CDF
Combined with DØ may reach 4×SM
Keep in mind: proposal for running through 2011 and analysis improvements from CDF and DØ

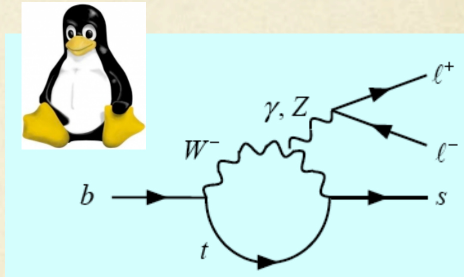
Expect combined limit $O(10^{-8})$ by end of Run II.



$B^+ \to \mu^+\mu^-K^+$, $B^0 \to \mu^+\mu^-K^{*0}(892)$, and $B^0_s \to \mu^+\mu^-\phi$

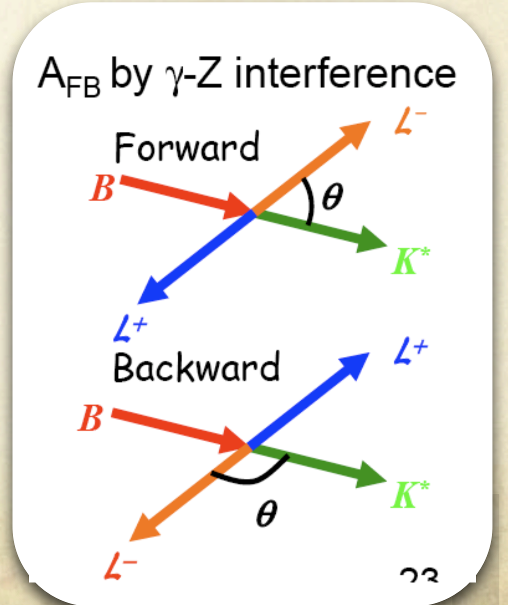
Non-resonant FCNC $b \to \mu\mu s$ processes can occur via box or penguin diagram, as $B \to \mu\mu$. Sensitive to NP via internal loops.
BR and Angular distribution of decay products may be sensitive to NP.





Many observables sensitive to NP:

- −branching ratio, q^2 distribution
- −K* longitudinal polarization (F_L)
- −forward-backward asymmetry (A_{FB})
- −isospin analysis (A_I)



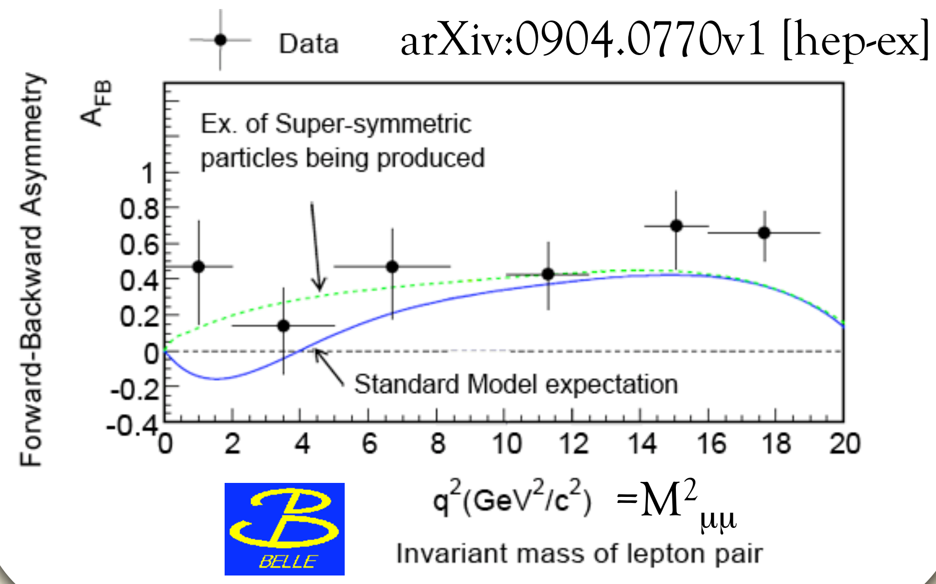
$B \to \mu^+\mu^- h$ – Current status

B^+/B^0 decays observed at the first time by B-factories. BRs $O(10^{-6})$ in agreement with SM predictions.

Current results show an hint of excess asymmetry $A_{FB}(q^2)$. SUSY and 4^{th} generation models "predict" an excess of A_{FB}.

Needs more statistics. TeVatron can help.

~250 $B \to l^+l^-K^*$ in 657M $B\bar{B}$



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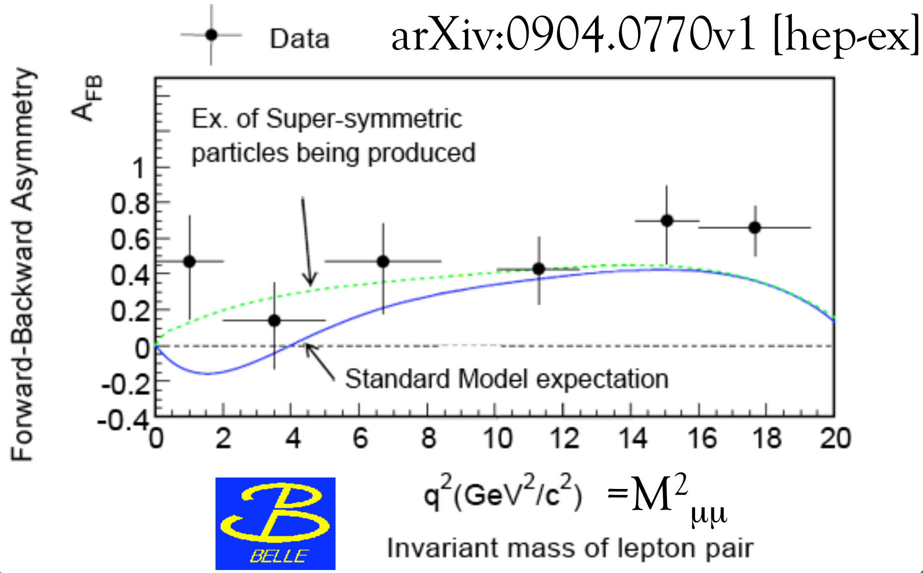
Needs more statistics. TeVatron can help.

CDF and DØ already search for these decays modes. $B^0_s \to \mu\mu\phi$ is still missing, unique at the TeVatron:

~250 $B \to l^+l^-K^*$ in 657M $B\bar{B}$



$BR(B^+ \to \mu\mu K^+) = [0.59 \pm 0.15(stat.) \pm 0.04(syst.)] \times 10^{-6}$ (4.5σ)
$BR(B^0 \to \mu\mu K^{*0}) = [0.81 \pm 0.30(stat.) \pm 0.10(syst.)] \times 10^{-6}$ (2.9σ)
$BR(B^0_s \to \mu\mu\phi)/BR(B^0_s \to J/\psi\phi) < 2.3(2.6) \times 10^{-3}$ @ 90(95)%CL. (2.4σ)

Phys. Rev. D 79, 011104 (2009)
CDF $L_{int}=1/fb$

$BR(B^0_s \to \mu\mu\phi) / BR(B^0_s \to J/\psi\phi) < 4.4 \times 10^{-3}$ @ 95%CL.

DØ Phys. Rev. D 74, 031107 (2006)
$L_{int}=0.45/fb$

NEW

$B \to \mu^+\mu^- h$ – Results on 4.4\fb

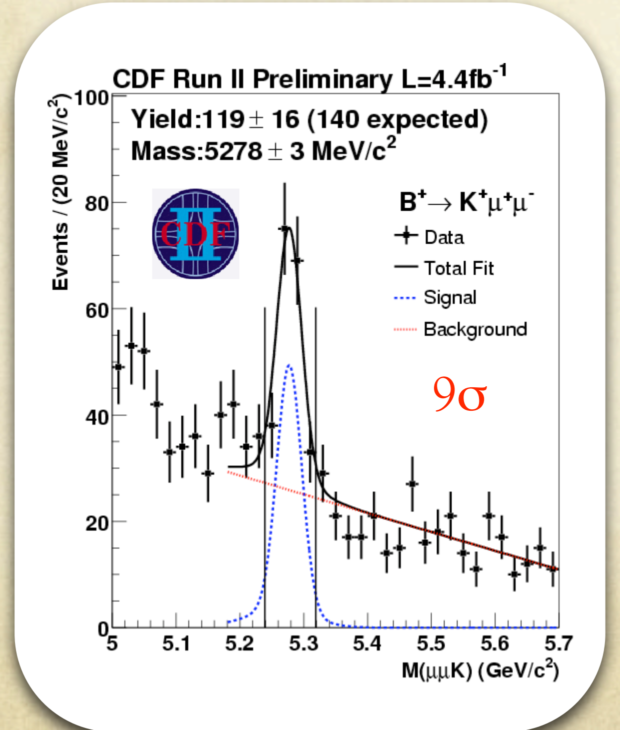
Analysis in progress. Today just a little taste!

Observed B^0 and B^+ decay modes at CDF. B^0_s mode is still blinded (never observed before), expected about 30 B^0_s decays with significance larger than 5σ.

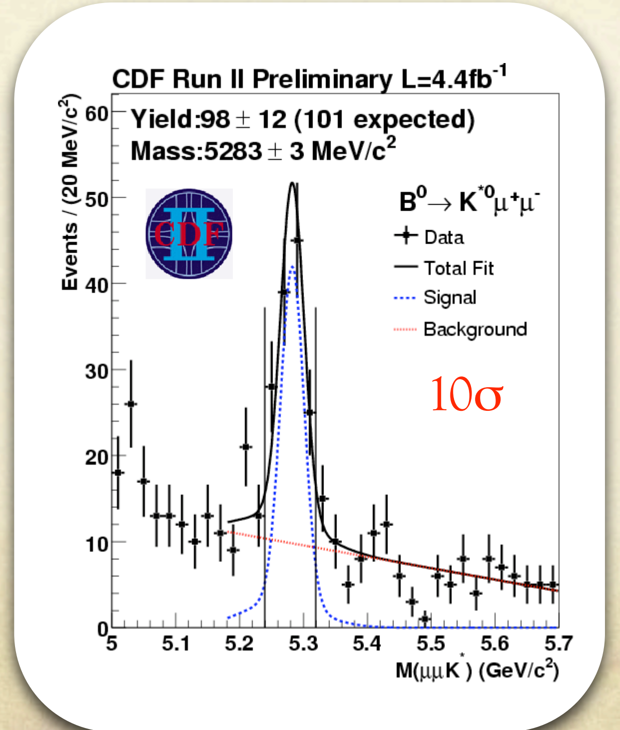
Soon measurement of A_{FB} comparable in precision with current ones.

Hope to turn the hint into an evidence of deviation from SM. B-Factories-TeVatron average?

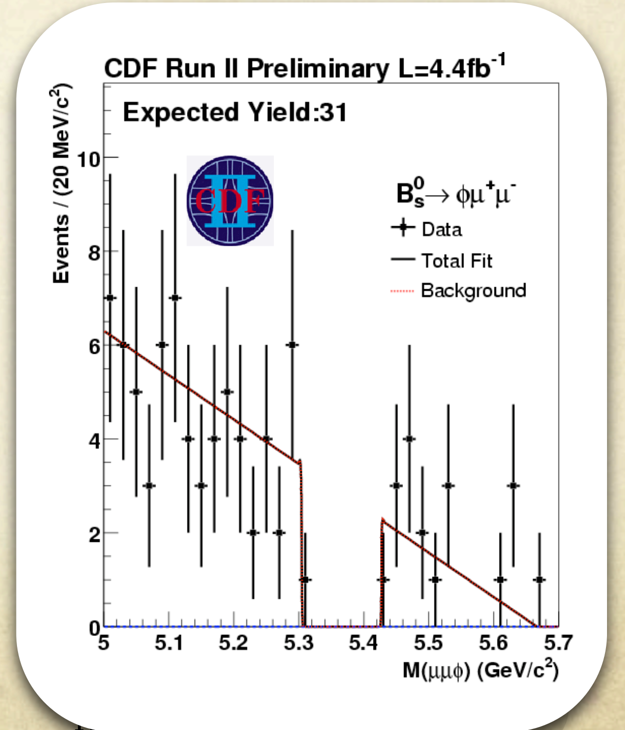
$B^+ \to \mu^+\mu^- K^+$



$B^0 \to \mu^+\mu^- K^{*0}(892)$

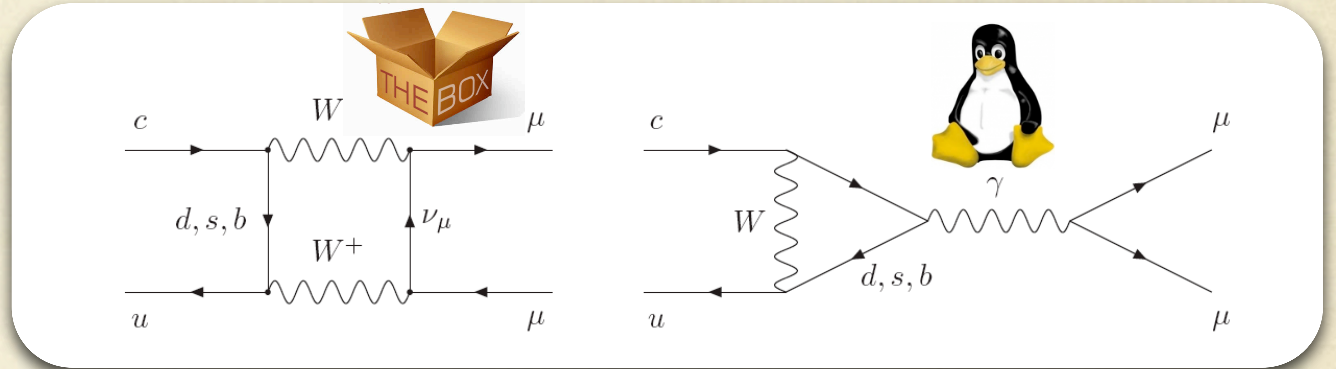


$B^0_s \to \mu^+\mu^- \phi$

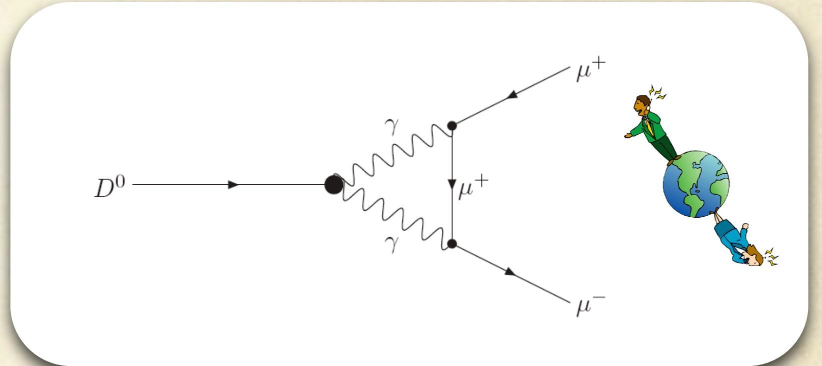


$D^0 \rightarrow \mu^+\mu^-$

Very suppressed in the SM by the GIM mechanism. $BR(D^0 \rightarrow \mu^+\mu^-) \approx 10^{-18}$ for short-distance.



Prediction of BR increases in the SM by including long-distance processes up to $BR(D^0 \rightarrow \mu^+\mu^-) \approx 4 \times 10^{-13}$.

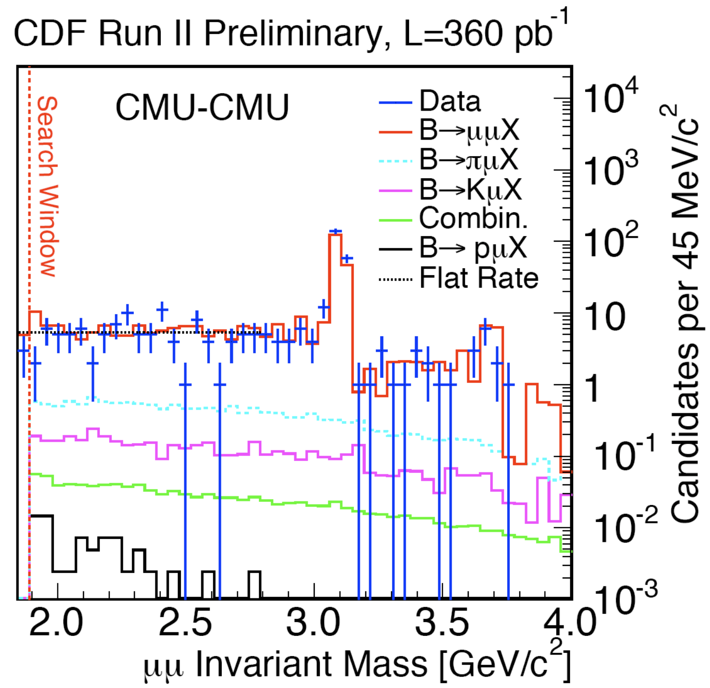


NP contributions can significantly enhance the BR, Phys. Rev. D66, 014009 (2002).
Several extensions of SM can affects this: R-parity violating SUSY, multiple Higgs doublets, extra fermions, extra dimensions and extended technicolor models. Some of these scenarios reach the range $BR(D^0 \rightarrow \mu^+\mu^-) \approx [10^{-8} \text{-} 10^{-10}]$.

$D^0 \to \mu^+\mu^-$ – Results

Count events in 3 different categories: CMU-CMU, CMU-CMX,CMX-CMX. Then combine results to produce a single upper limit (frequentist):

Preliminary CDF results on 0.36/fb
Public CDF note 9226
$BR(D^0 \to \mu^+\mu^-) < 2.1(3.0) \times 10^{-7}$ @ 90(95)%CL

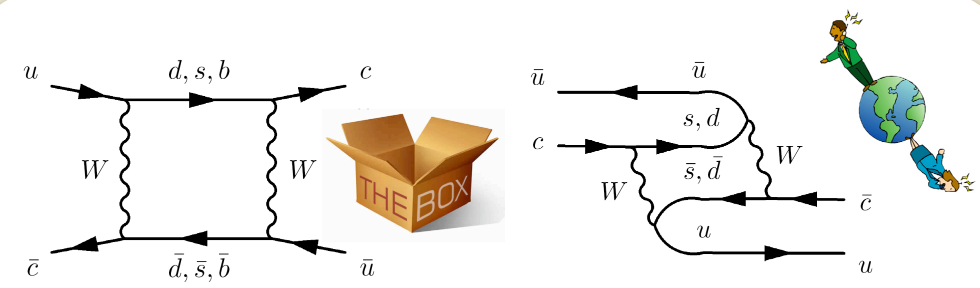


Babar: $BR(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-6}$ @ 90 %CL
PRL 93, 191801(2004)
Belle: $BR(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7}$ @ 90 %CL
Preliminary result shown at EPS09.

5/fb of data already on tape for analysis. More than 8(10)/fb of physics-quality data on tape by end of 2010 (2011, if Run II further extended). Through improvements of the analysis (kinematics, dEdx, ANN), goal is to approach 10^{-8} region.

D^0 mixing

Charm mixing very small in the SM.
Top quark do not participate in the box diagram. “Long distance” contribution hard to calculate but lesser than $O(10^{-3})$.

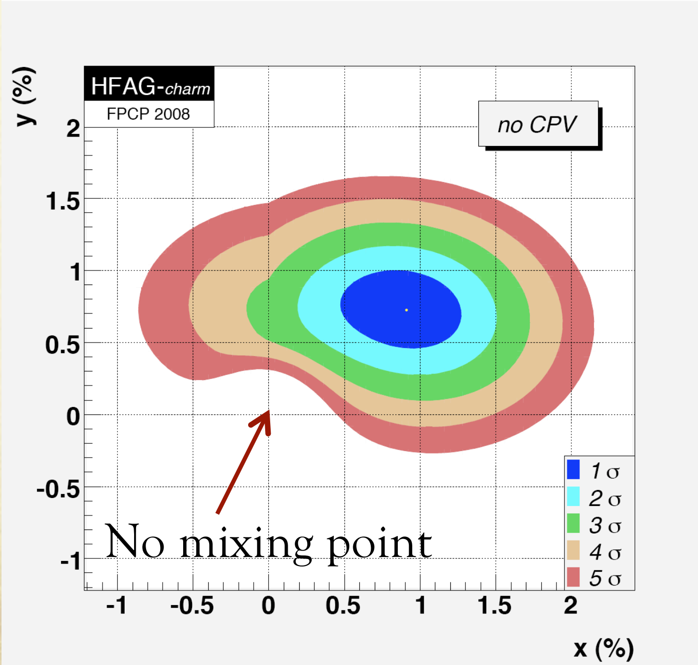


$x \approx O(10^{-5})$, $y \approx O(10^{-7})$ $x,y < O(10^{-3})$

Mixing parameters (x,y) larger than the expected or CP violation effects in the mixing would be “unequivocal” sign of NP.

First evidence of charm-mixing from
Babar PRL98,211802(2007) 3.9σ
and Belle PRL98,211803(2007) 3.2σ
confirmed by CDF 3.8σ. See next slides.

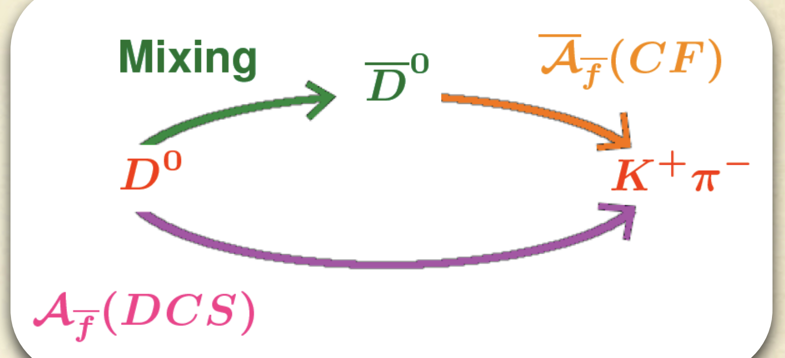
Average indicates no-mixing hypothesis ruled out with significance larger than 5σ, but “world” is still waiting for single experiment “observation”.



D^0-mixing – $D^0 \to K^- \pi^+$

Use $D^0 \to K^- \pi^+$ decays tagged by charge of soft pion in the decay $D^{*+} \to D^0 \pi^+$.

Measure time-dependent of R(t)=WS/RS(t) where:
- wrong sign (WS) $D^{*+} \to D^0 \pi^+ \to [K^+ \pi^-] \pi^+$
- right sign (RS) $D^{*+} \to D^0 \pi^+ \to [K^- \pi^+] \pi^+$.



WS from two processes: Mixing then CF decays or DCS decays.

$$\frac{\mathcal{A}_{\overline{f}}(DCS)}{\overline{\mathcal{A}}_{\overline{f}}(CF)} = \sqrt{R_D}\, e^{-i\delta_{K\pi}}$$

$$x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}$$
$$y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$$

$$x = \frac{\Delta M}{\Gamma} = \frac{M_H - M_L}{(\Gamma_H + \Gamma_L)/2}$$
$$y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{(\Gamma_H + \Gamma_L)}$$

(Assuming |x|,|y|<<1 and no CPV)

$$R(t) = R_D + \sqrt{R_D}\, y' \,(\Gamma_D t) + \frac{x'^2 + y'^2}{4} (\Gamma_D t)^2$$

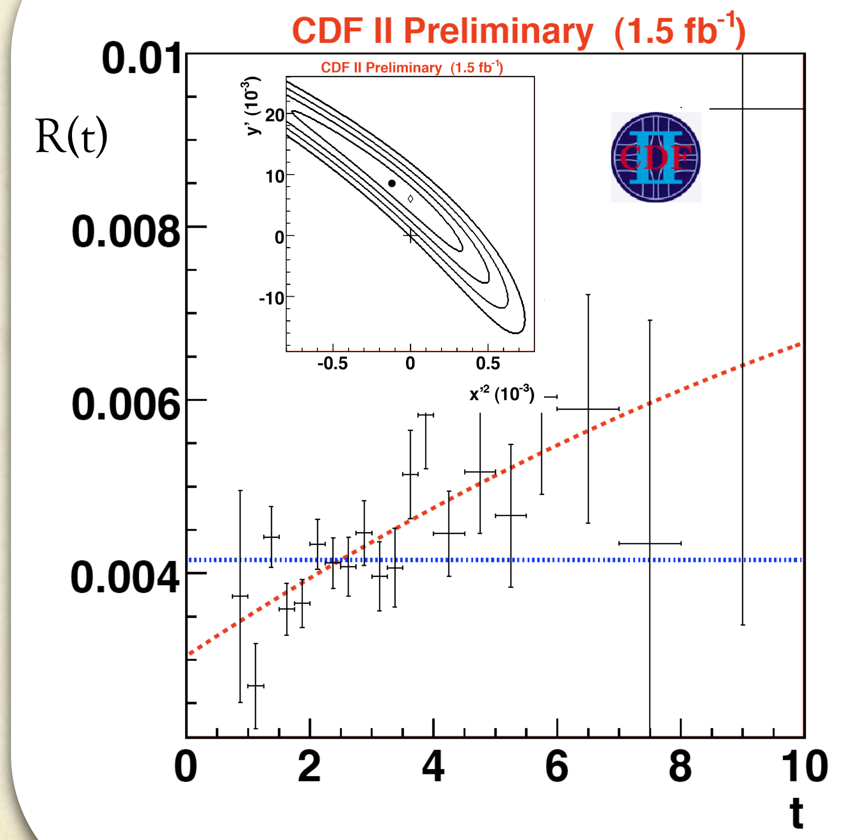
Charm samples at CDF are the largest in the world
CDF's time resolution capability allows time dependent measurement.

D^0-mixing – Results

L_{int}= 1.5\fb PRL 100,121802(2008)

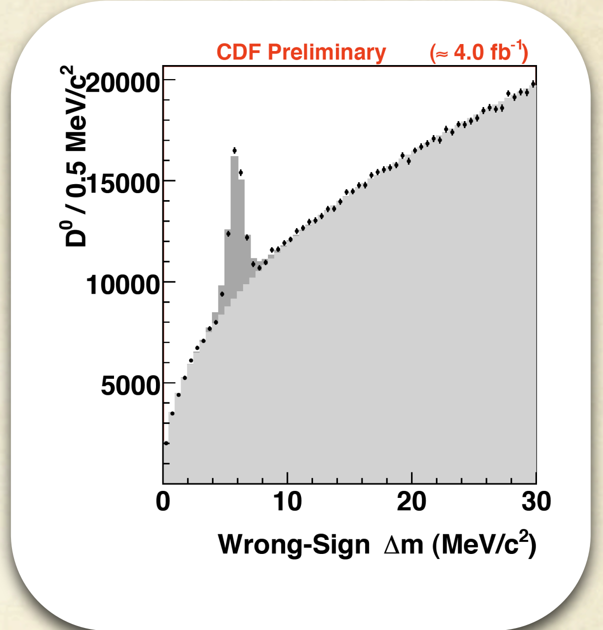
Fit type	$R_D(10^{-3})$	$y'(10^{-3})$	$x'^2(10^{-3})$	χ^2 / d.o.f.
Unconstrained	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	19.2 / 17
Physically allowed	3.22 ± 0.23	6.0 ± 1.4	0	19.3 / 18
No mixing	4.15 ± 0.10	0	0	36.8 / 19

Experiment	$R_D(10^{-3})$	$y'(10^{-3})$	$x'^2(10^{-3})$	Mixing Signif.
CDF	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
BABAR [8]	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
Belle [9]	3.64 ± 0.17	$0.6\ ^{+4.0}_{-3.9}$	$0.18\ ^{+0.21}_{-0.23}$	2.0



Using just a "first part of data" available, CDF confirms evidence of mixing hypothesis at 3.9σ. Next step: observation.

D^0-mixing – Future and more



D0 – mixing with $D^0 \to K^+\pi^-$

In 4.2/fb of data about 24k WS $D^{*+} \to D^0\pi^+ \to [K^+\pi^-]\pi^+$ events time-integrated, a factor ×2 in statistics

Scaling for $1/\sqrt{S}$ and assuming published central values→ 5σ at the next iteration (assuming no analysis improvements).

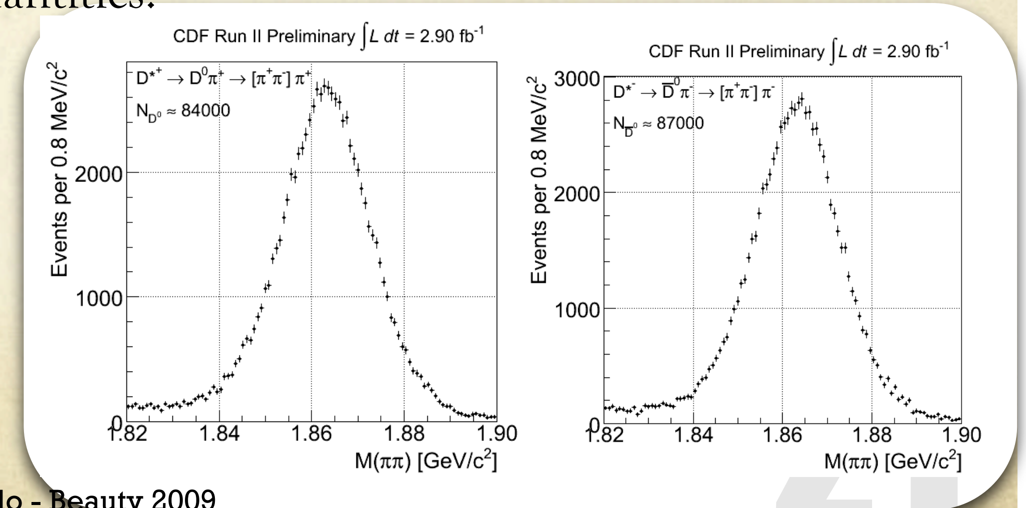
D0 – mixing with $D^0 \to \pi^+\pi^-/ K^+K^-$

Analysis underway to measure of $y_{CP}=\tau(h^+h^-)/\tau(K^+\pi^-)-1$ to confirm/improve BaBelle results. Very promising at CDF, but hard due to trigger cuts on pt/lifetime quantities.

Direct CP asymmetries in $D^0 \to \pi^+\pi^-/ K^+K^-$

In 2.9/fb we expect 0.24% statistical error, about ×2 better than current best published measurements.

Very soon measurement on 5/fb.



Conclusions

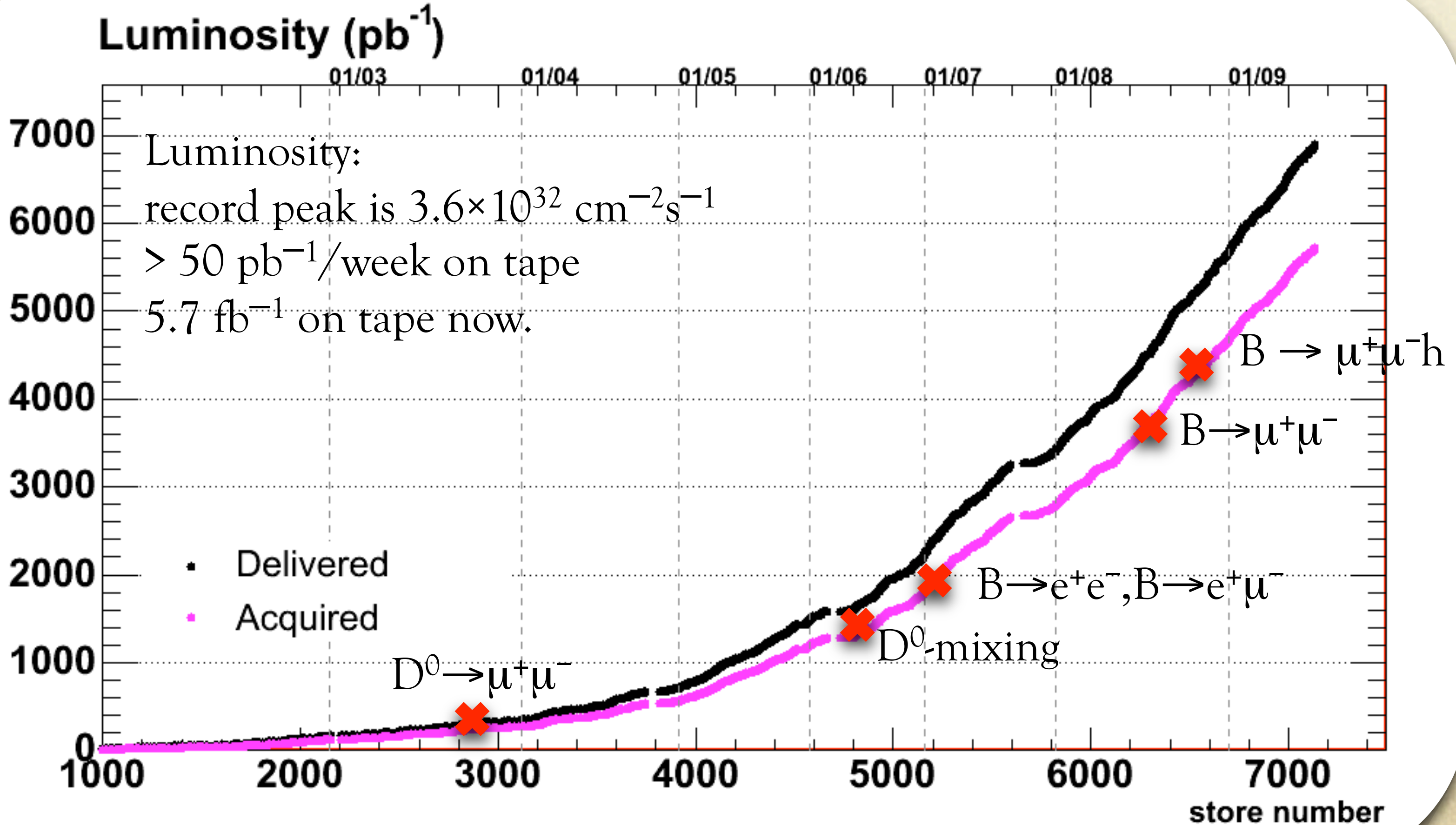
- New world's best upper-limits on $B \rightarrow \mu^+\mu^-$ from CDF. $BR(B^0_s \rightarrow \mu^+\mu^-)$=9*SM with 3.7/fb at 90%CL. An expected upper limit from D0 on 5/fb, result is coming. Expect combined limit $O(10^{-8})$ by end of Run II.
- Result on 1/fb of $B \rightarrow \mu^+\mu^- h$, analysis on 4.4/fb in progress to measure of A_{FB} in B^0/B^+. Expect first observation of $B^0_s \rightarrow \mu^+\mu^-\phi$, unique at the TeVatron.
- Very competitive upper limit on $D^0 \rightarrow \mu^+\mu^-$ on 0.36/fb. Expect world's best $O(10^{-8})$ with full statistics to constrain SUSY models.
- D0-mixing analysis on $D^0 \rightarrow K^-\pi^+$ is in progress (4.2/fb). Expect 5σ single experiment observation and best measurements of y' and x'

Tevatron continues regularly to update measurements and taking data. We have a mountain of data to analyze, more and more are coming....

Back-up

Prospects

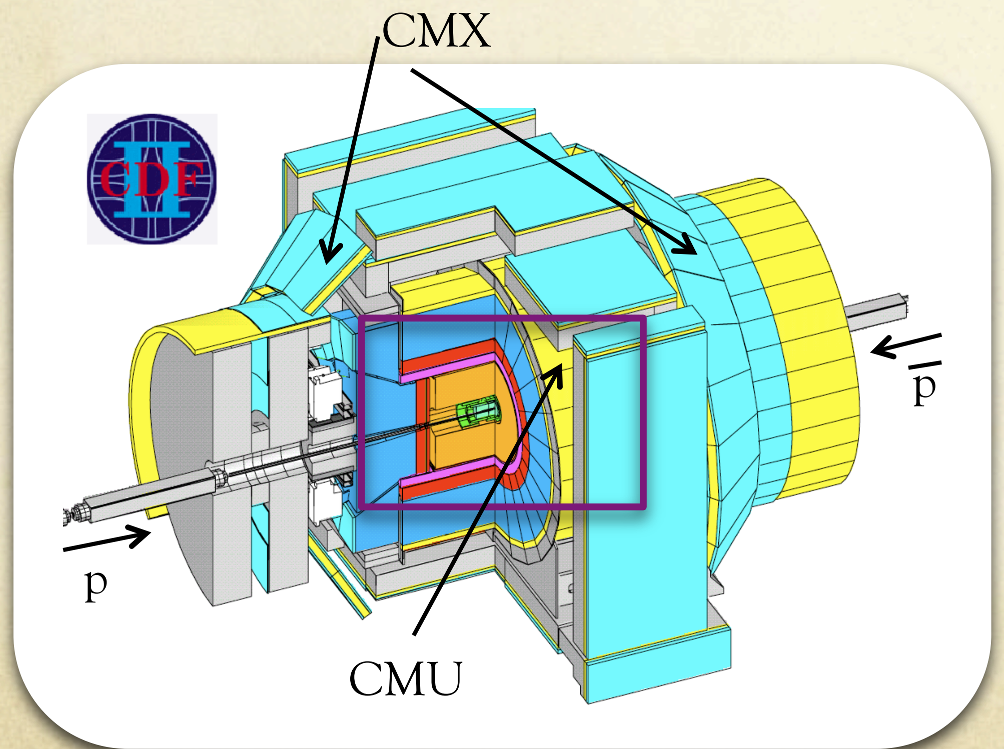
More than 5/fb of data already on tape good for analysis.
More than 8(10)/fb by end of 2010 (2011, if Run II further extended)

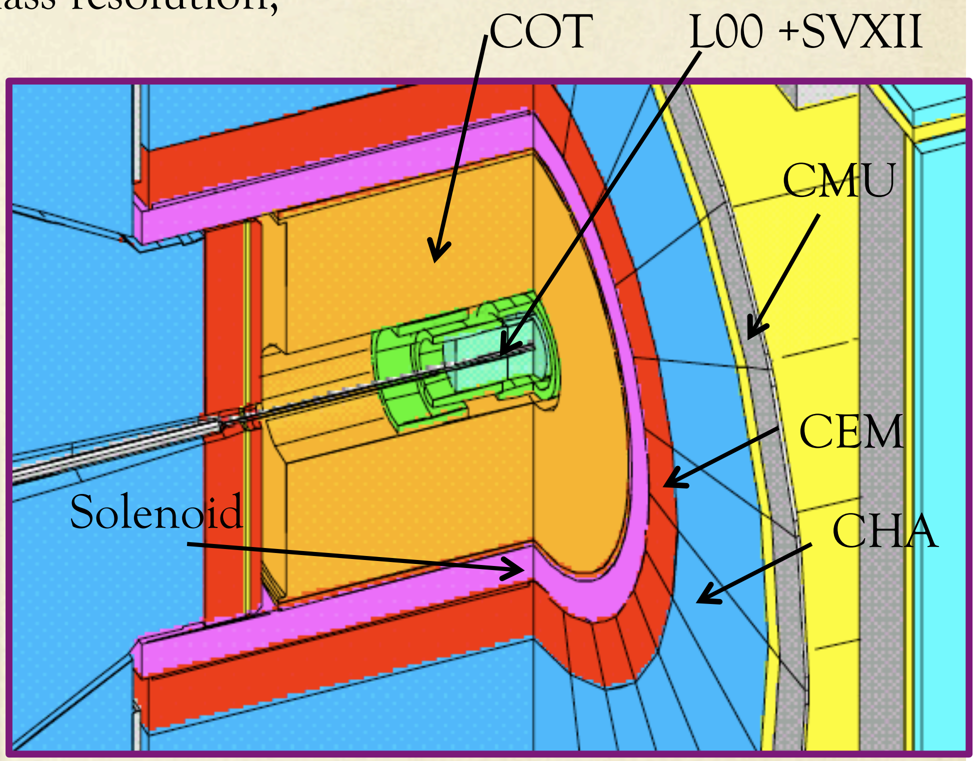


CDF detector

See M.Kreps talk for more details.

Central tracking includes silicon vertex detector surrounded by drift chamber;
p_T resolution $dp_T/p_T = 0.0015\ p_T$ → excellent mass resolution,
Particle identification: dE/dX and TOF;
Good electron and muon identification by calorimeters and muon chambers.

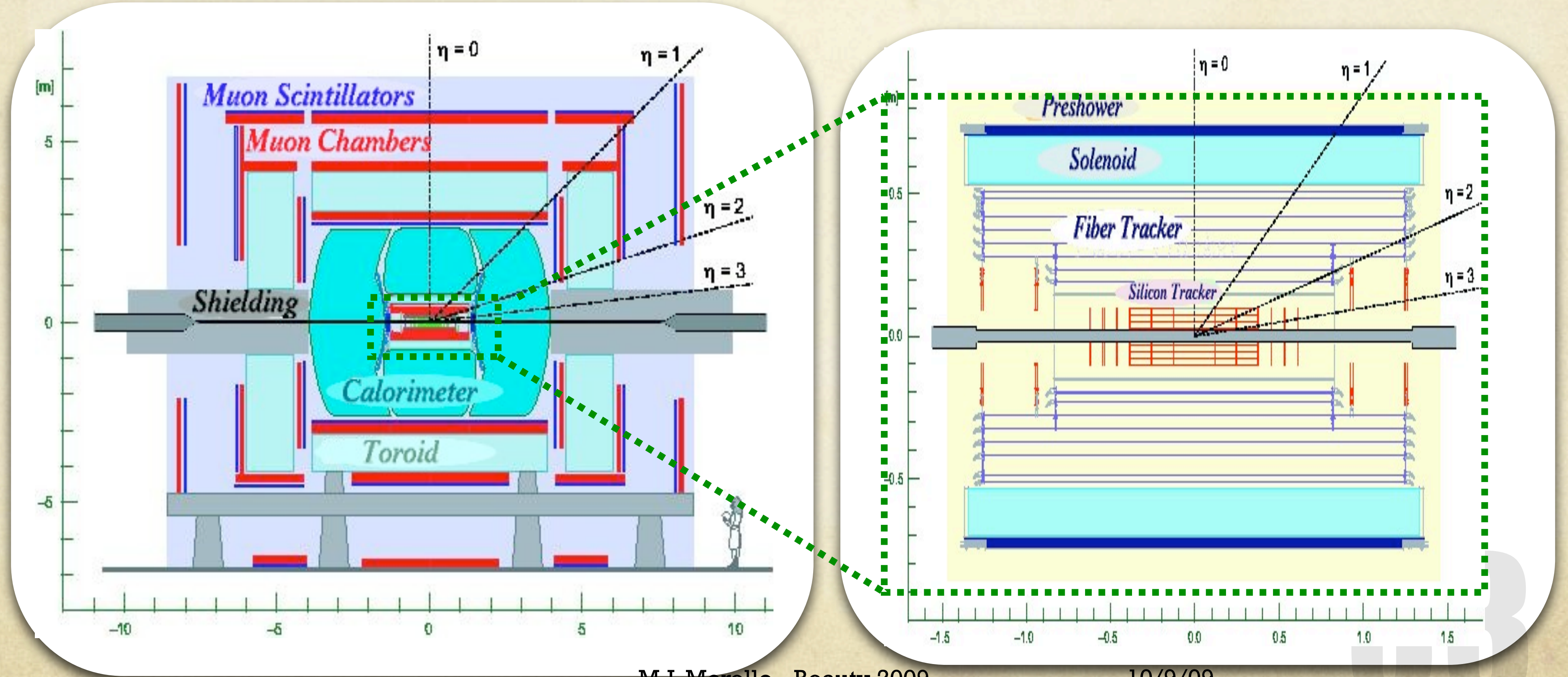




CMU (|η|<0.6, pt>1.4GeV/c) 4 layers of planar drift chambers
CMX(0.6<|η|<1, pt>2GeV/c) conical sections of drift tubes

DØ detector

Excellent coverage of Tracking and Muon Systems
Excellent calorimetry and electron ID
2T Solenoid, polarity reversed weekly
High efficiency muon trigger with muon p_T measurement at Level1 by toroids

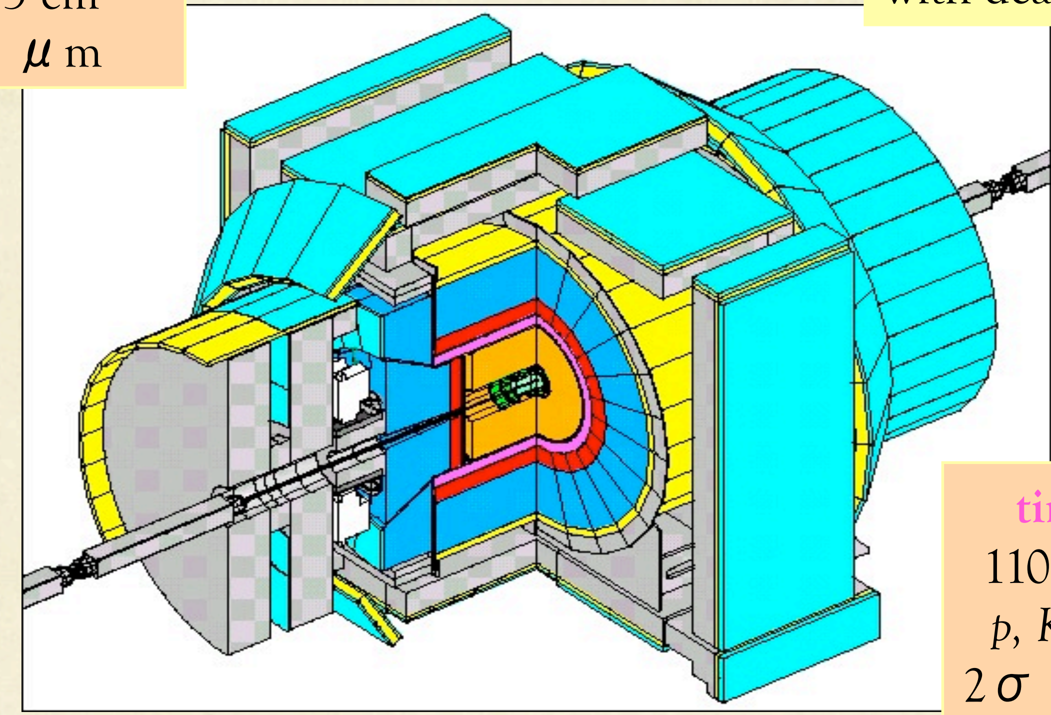


The CDF II detecto

132 ns front end
chamber tracks at L1
silicon tracks at L2
25000 / 300 / 100 Hz
with dead time < 5%

1.4 T magnetic field
Lever arm 132 cm

7 to 8 silicon layers
$1.6 < r < 28$ cm, $|z| < 45$ cm
$|\eta| \leq 2.0$ σ(hit) ~ 15 μm



Some resolutions:
p_T ~0.15% p_T (c/GeV)
J/Ψ mass ~14 MeV
EM E ~ 16%/√E
Had E ~ 80%/√E
d_0 ~ 40 μm
(includes beam spot)

time-of-flight
110 ps at 150 cm
p, K, π identific.
2 σ at p_T<1.6 GeV

96 layer drift chamber $|\eta| \leq 1.0$ $44 < r < 132$ cm, $|z| < 155$ cm 30k channels, σ(hit) ~ 140 μm
dE/dx for p, K, π identification

scintillator and tile/fiber sampling calorimetry
$|\eta| < 3.64$

μ coverage
$|\eta| \leq 1.5$
84% in

$B^0_s \to \mu^+\mu^-$ – Strategy

$BR(B^0_s \to \mu^+\mu^-)$ is obtained by normalizing to the number of $B^+ \to J/\psi K^+ \to [\mu^+\mu^-]K^+$ where $\mu^+\mu^-$ vertex is done in the "same" manner.

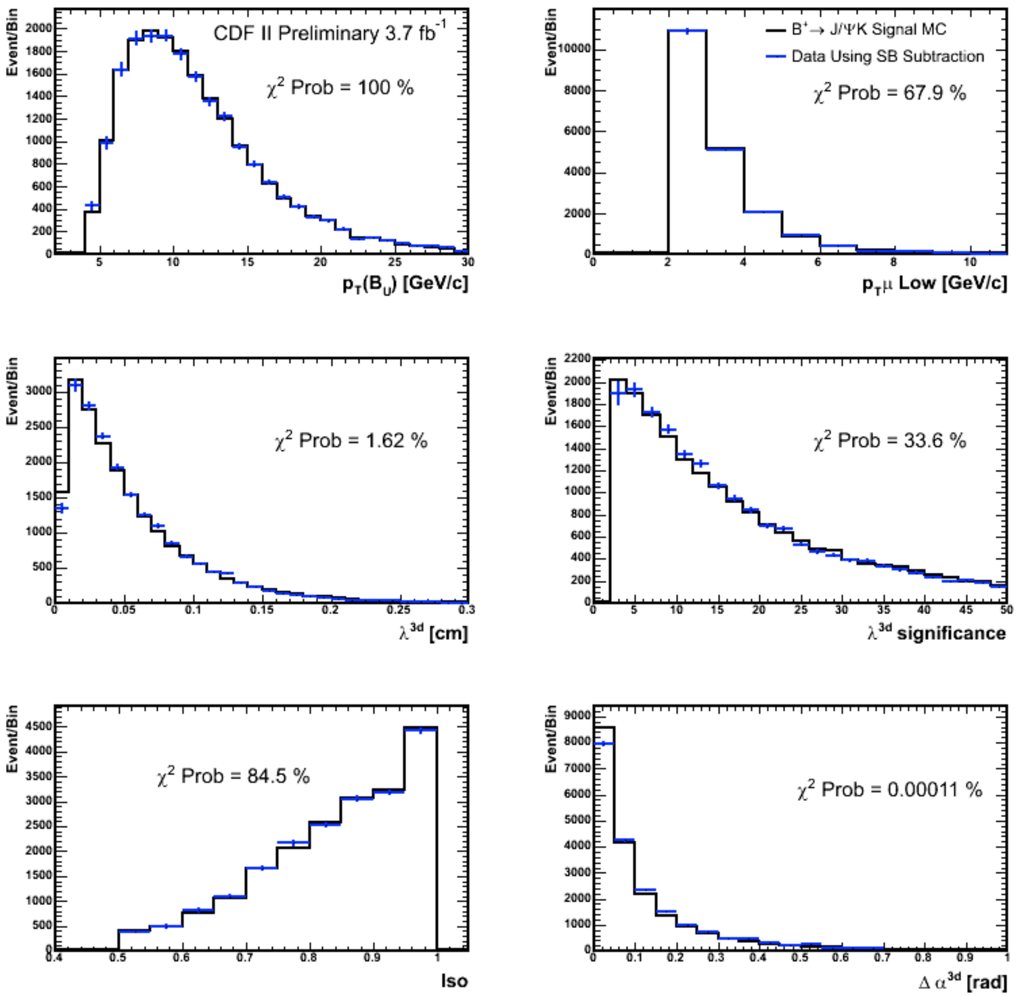
$$\mathcal{B}(B^0_s \to \mu^+\mu^-)^{95\%\mathrm{C.L.}} = \frac{N^{95\%}_{B^0_s}}{N_{B^+}} \cdot \frac{\alpha_{B^+}}{\alpha_{B^0_s}} \cdot \frac{\epsilon^{\mathrm{base}}_{B^+}}{\epsilon^{\mathrm{base}}_{B^0_s}} \cdot \frac{1}{\epsilon^{\mathrm{NN}}_{B^0_s}} \cdot \frac{f_u}{f_s} \cdot \mathcal{B}(B^+ \to J/\psi K^+)$$

- N_{B^+}: 20K
- $\alpha_{B^+}/\alpha_{B^0_s}$: 0.2-0.3
- $\epsilon^{\mathrm{base}}_{B^+}/\epsilon^{\mathrm{base}}_{B^0_s}$: 0.8
- $\epsilon^{\mathrm{NN}}_{B^0_s}$: 0.8
- $\frac{f_u}{f_s} \cdot \mathcal{B}(B^+ \to J/\psi K^+)$: From PDG08

The challenge: Reject 10^6 bckg while keeping signal efficiency high.

two tracks with p_T>2(2.2) GeV/c from di-muon triggers CMU-CMU(CMU-CMX)
pre-selection on kinematic discriminating variables
muon likelihood requirement (tracker, calorimeter and muon system information)
dE/dx from drift chamber to reject fake kaons
ANN discriminating to enhance signal and background separation

MC comparison $B^+ \rightarrow J/\psi K^+$



$B^0_s \to \mu^+\mu^-$

	CMU-CMU		CMU-CMX	
$(\alpha_{B+}/\alpha_{B^0_s})$	0.300 ± 0.018	$(\pm 6\%)$	0.196 ± 0.014	$(\pm 7\%)$
$(\epsilon^{trig}_{B+}/\epsilon^{trig}_{B^0_s})$	0.99935 ± 0.00012	(-)	0.97974 ± 0.00016	(-)
$(\epsilon^{reco}_{B+}/\epsilon^{reco}_{B^0_s})$	0.82 ± 0.03	$(\pm 4\%)$	0.83 ± 0.03	$(\pm 4\%)$
$\epsilon^{NN}_{B^0_s}(NN > 0.80)$	0.776 ± 0.047	$(\pm 6\%)$	0.789 ± 0.047	$(\pm 6\%)$
N_{B+}	14300 ± 170	$(\pm 1\%)$	5460 ± 110	$(\pm 2\%)$
f_u/f_s	3.86 ± 0.59	$(\pm 15\%)$	3.86 ± 0.59	$(\pm 15\%)$
$BR(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+)$	$(5.94 \pm 0.21) \times 10^{-5}$	$(\pm 4\%)$	$(5.94 \pm 0.21) \times 10^{-5}$	$(\pm 4\%)$
SES (All bins)	5.1×10^{-9}	$(\pm 18\%)$	8.5×10^{-9}	$(\pm 19\%)$
SES (Combined)	3.2×10^{-9} $(\pm 18\%)$			

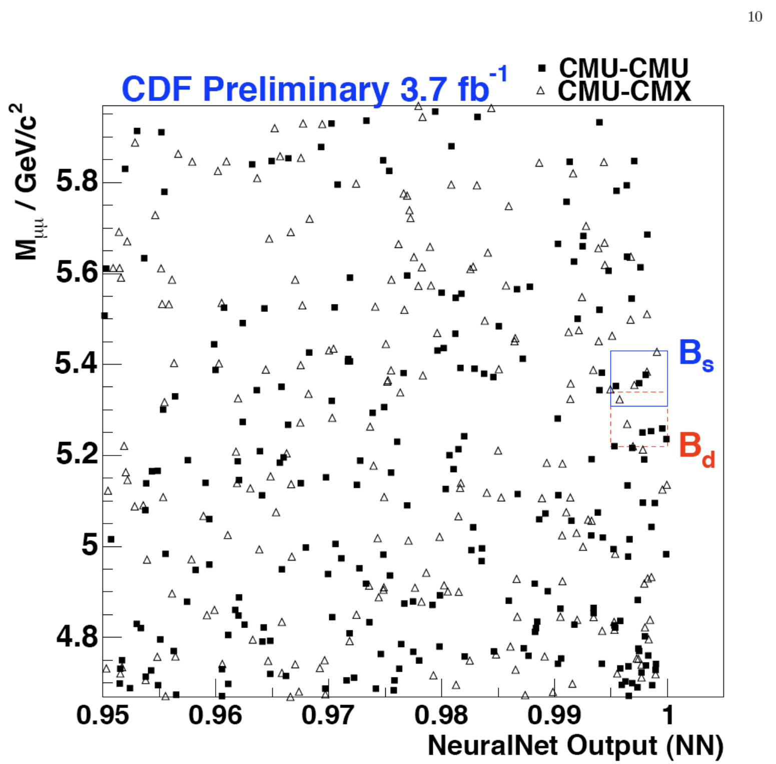
TABLE I: A summary of the inputs used in equation 1 to estimate the $\mathcal{B}(B^0_s \to \mu^+\mu^-)$. The relative uncertainties are given parenthetically. The single-event-sensitivities, SESs, for the sum of all NN bins, corresponding to $N_{B^0_s} = 1$, is shown in the two last rows.

B^0_s signal window

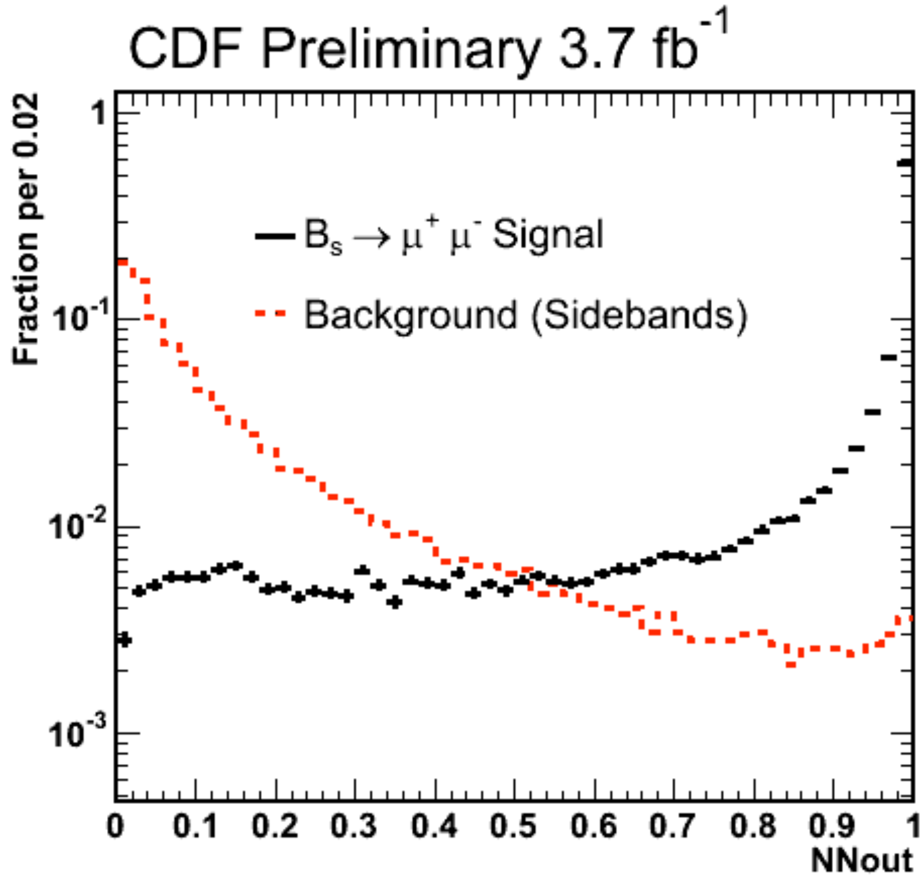
	Mass Bin (GeV)	5.310-5.334	5.334-5.358	5.358-5.382	5.382-5.406	5.406-5.430	Total
UU NN bin 0.80-0.95	Exp Bkg	9.66 ± 0.47	9.46 ± 0.46	9.27 ± 0.46	9.08 ± 0.46	8.88 ± 0.45	46.3 ± 2.4
	Obs	7	5	10	5	5	32
UU NN bin 0.95-0.995	Exp Bkg	3.42 ± 0.27	3.33 ± 0.27	3.25 ± 0.27	3.17 ± 0.26	3.09 ± 0.26	16.2 ± 1.4
	Obs	2	3	4	3	5	17
UU NN bin 0.995-1.0	Exp Bkg	0.869 ± 0.17	0.821 ± 0.18	0.783 ± 0.19	0.75 ± 0.19	0.717 ± 0.21	4.0 ± 1.0
	Obs	0	1	2	0	0	3
UX NN bin 0.80-0.95	Exp Bkg	9.94 ± 0.48	9.8 ± 0.48	9.66 ± 0.48	9.51 ± 0.47	9.37 ± 0.47	48.3 ± 2.4
	Obs	12	8	9	9	5	43
UX NN bin 0.95-0.995	Exp Bkg	3.5 ± 0.29	3.47 ± 0.29	3.43 ± 0.29	3.39 ± 0.29	3.36 ± 0.29	17.2 ± 1.4
	Obs	3	4	3	7	0	17
UX NN bin 0.995-1.0	Exp Bkg	0.467 ± 0.14	0.438 ± 0.15	0.412 ± 0.15	0.387 ± 0.16	0.362 ± 0.16	2.08 ± 0.78
	Obs	1	1	0	1	1	4

TABLE II: B^0_s signal window for CMU-CMU(top) and CMU-CMX(bottom): Expected backgrounds, including $B \to hh$, and number of observed events

	$\mathcal{B}(B^0_s \to \mu^+\mu^-)$ 90%	95%	$\mathcal{B}(B^0_d \to \mu^+\mu^-)$ 90%	95%
Expected $\mathcal{B}$	2.7×10^{-8}	3.3×10^{-8}	7.2×10^{-9}	9.1×10^{-9}
Observed $\mathcal{B}$	3.6×10^{-8}	4.3×10^{-8}	6.0×10^{-9}	7.6×10^{-9}



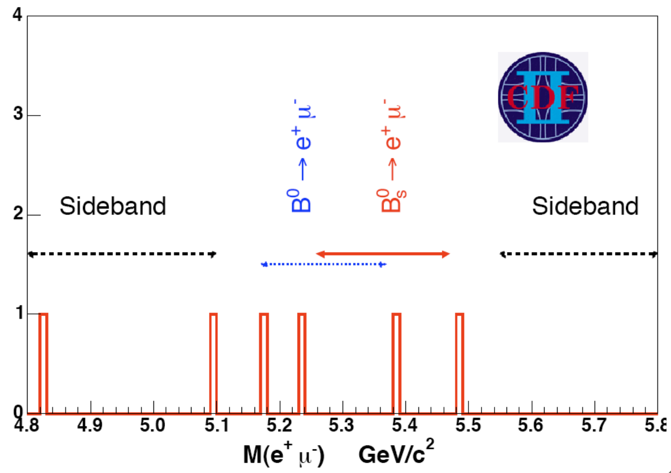
10
CDF Preliminary 3.7 fb-1
CMU-CMU
CMU-CMX
M_μμ / GeV/c^2
5.8
5.6
5.4
5.2
5
4.8
0.95
0.96
0.97
0.98
0.99
1
NeuralNet Output (NN)
B_s
B_d


CDF Preliminary 3.7 fb-1
Fraction per 0.02
1
10-1
10-2
10-3
Bs → μ+ μ- Signal
Background (Sidebands)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
NNout

B→e⁺e⁻ and LFV

Similar to $B \to \mu^+\mu^-$ analysis. Search of "very rare" FCNC $B \to e^+e^-$ and stronger LFV $B \to e^+\mu^-$ processes. $B^0 \to K^+\pi^-$ used as reference.

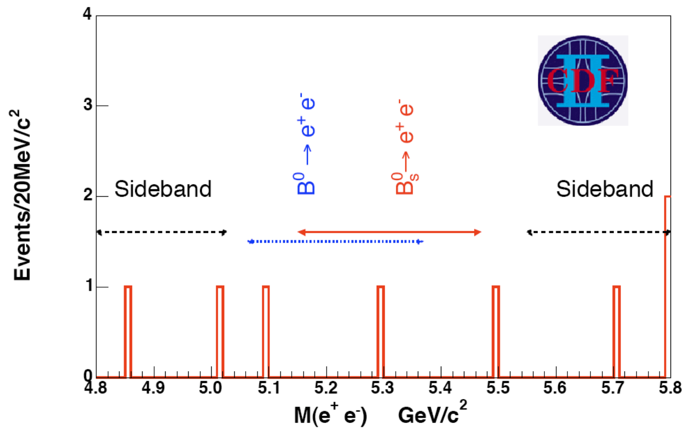
$BR(B \to e^+e^-) \approx 10^{-15}$ in SM, while LVF processes are allowed in some SM extensions or in models beyond SM (Pati-Salam PRD10, 275 (1974); SUSY, ...)



PRL 102, 201801(2009) – L_{int}=2/fb

TABLE II: Branching ratio limits at 90(95) % C.L.

$\mathcal{B}(B^0_s \to e^+\mu^-) < 2.0\ (2.6) \times 10^{-7}$
$\mathcal{B}(B^0 \to e^+\mu^-) < 6.4\ (7.9) \times 10^{-8}$
$\mathcal{B}(B^0_s \to e^+e^-) < 2.8 \times 10^{-7}$
$\mathcal{B}(B^0 \to e^+e^-) < 8.3 \times 10^{-8}$

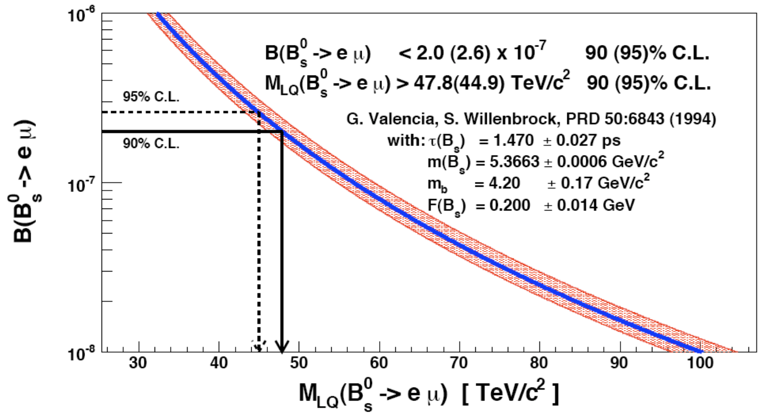


Most stringent limits to date. World's best limit on Pati-Salam leptoquarks masses: M_{LQ}>47.8 TeV/c² @ 90%CL.

Lepton Flavor Violation

TABLE I: Values used to calculate the limits on $\mathcal{B}(B^0_{(s)} \to e^+\mu^-)$ and $\mathcal{B}(B^0_{(s)} \to e^+e^-)$ and their uncertainties.

Source	Values	$\mathcal{B}(B^0_s \to e^+\mu^-)$	$\mathcal{B}(B^0 \to e^+\mu^-)$	$\mathcal{B}(B^0_s \to e^+e^-)$	$\mathcal{B}(B^0 \to e^+e^-)$
$N(B^0 \to K^+\pi^-)$	6387 ± 214	3.4%	3.4%	3.4%	3.4%
$\mathcal{B}(B^0 \to K^+\pi^-)$	$(19.4 \pm 0.6) \times 10^{-6}$	3.1%	3.1%	3.1%	3.1%
$f_{B^0}/f_{B^0_s}$	3.86 ± 0.59	15.3%	-	15.3%	-
$\epsilon^{rel}_{B^0_s \to e^+\mu^-}$	0.207 ± 0.016	7.6%	-	-	-
$\epsilon^{rel}_{B^0 \to e^+\mu^-}$	0.210 ± 0.012	-	5.9%	-	-
$\epsilon^{rel}_{B^0_s \to e^+e^-}$	0.129 ± 0.011	-	-	8.9%	-
$\epsilon^{rel}_{B^0 \to e^+e^-}$	0.128 ± 0.011	-	-	-	8.9%
Total		17.7%	7.5%	18.3%	10.0%



$B \rightarrow \mu^+\mu^- h$ – Results L_{int}=1/fb

Missing: $B^0_s \rightarrow \mu\mu\phi$, Prediction: $BR(B \rightarrow \mu\mu\phi) = 1.6\times10^{-6}$ J. Phys. G 29, 1103 (2003)

Phys. Rev. D 79, 011104 (2009)

$BR(B^+ \rightarrow \mu\mu K^+) = [0.59 \pm 0.15(stat.) \pm 0.04(syst.)]\times10^{-6}$ (4.5σ)

$BR(B^0 \rightarrow \mu\mu K^{*0}) = [0.81 \pm 0.30(stat.) \pm 0.10(syst.)]\times10^{-6}$ (2.9σ)

$BR(B^0_s \rightarrow \mu\mu\phi)/BR(B^0_s \rightarrow J/\psi\phi) < 2.3(2.6)\times10^{-3}$ @ 90(95)%CL. (2.4σ)

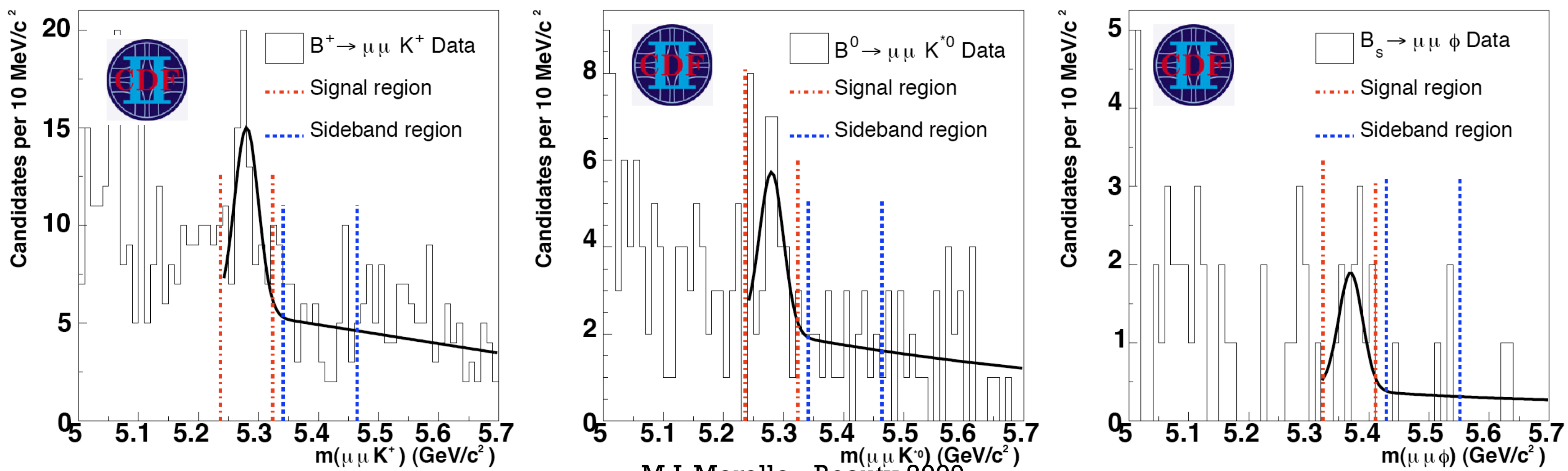
L_{int}=1/fb

Phys. Rev. D 74, 031107 (2006)

$BR(B^0_s \rightarrow \mu\mu\phi) / BR(B^0_s \rightarrow J/\psi\phi) < 4.4\times10^{-3}$ @ 95%CL.

L_{int}=0.45/fb

Phys. Rev. D 79, 011104 (2009)



$B^+ \to \mu^+\mu^- K^+$, $B^0 \to \mu^+\mu^- K^{*0}(892)$, and $B^0_s \to \mu^+\mu^-\phi$

CDF analysis summary

TABLE I: Systematic uncertainties on the relative efficiency quoted in percent.

Channel	B^+	B^0	B_s
Theory model	1.5	3.1	1.6
$p_T(B)$ spectrum	0.6	1.3	1.4
Trigger turn-on	1.3	1.3	1.2
Low momentum hadrons	0.2	0.2	0.2
B_s^0 decay width difference	–	–	8.7
Polarization	–	0.6	0.1
Norm. channel statistics	1.3	2.1	5.1
$B^+ \to J/\psi\pi^+$ contribution	0.1	–	–
MC statistics	1.6	2.6	2.2
Total	2.9	5.0	10.6

TABLE II: Summary of systematic uncertainties quoted in percent.

Channel	B^+	B^0	B_s
Total rel. eff. uncertainty	2.9	5.0	10.6
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0	1.0	1.0
Background prediction	5.2	3.1	10.2
$\mathcal{B}(B \to J/\psi h)$	3.5	4.5	35.5

Decay mode	$B^+ \to \mu^+\mu^- K^+$	$B^0 \to \mu^+\mu^- K^{*0}$	$B_s^0 \to \mu^+\mu^-\phi$
N_{obs}	90	35	11
N_{bkg}	45.3 ± 5.8	16.5 ± 3.6	3.5 ± 1.5
N_{sig}	44.7 ± 5.8	18.5 ± 3.6	7.5 ± 1.5
Gaussian significance	$4.5\,\sigma$	$2.9\,\sigma$	$2.4\,\sigma$
$N_{J/\psi h}$	6361 ± 82	2423 ± 52	431 ± 22
$\epsilon_{\mu^+\mu^- h}/\epsilon_{J/\psi h}$	0.71 ± 0.01	0.74 ± 0.02	0.84 ± 0.02
Rel $\mathcal{B} \times 10^3$	$0.59 \pm 0.15 \pm 0.03$	$0.61 \pm 0.23 \pm 0.07$	$1.23 \pm 0.60 \pm 0.14$
Abs $\mathcal{B} \times 10^6$	$0.59 \pm 0.15 \pm 0.04$	$0.81 \pm 0.30 \pm 0.10$	$1.70 \pm 0.82 \pm 0.64$
Rel $\mathcal{B}$ 95(90)%C.L. limit $\times 10^3$	—	—	2.6(2.3)
Abs $\mathcal{B}$ 95(90)%C.L. limit $\times 10^6$	—	—	6.0(5.0)

$D^0 \to \mu^+\mu^-$ – Analysis

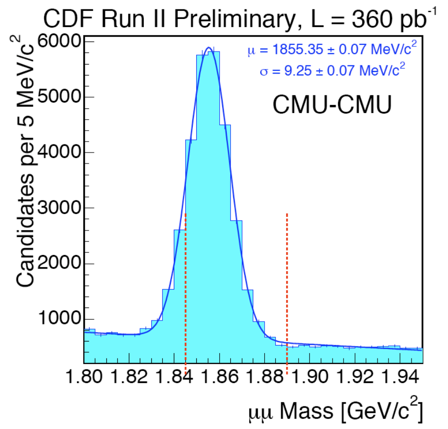
Normalization mode $D^0 \to \pi^+\pi^-$ from Two Track Trigger:

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{\mu\mu}}{N_{\pi\pi}} \frac{A_{\pi\pi}}{A_{\mu\mu}} \frac{\mathcal{B}(D^0 \to \pi^+\pi^-)}{\epsilon_{\mu\mu}}$$

Number of $D^0 \to \pi^+\pi^-$ observed

Ratio from acceptance from MC

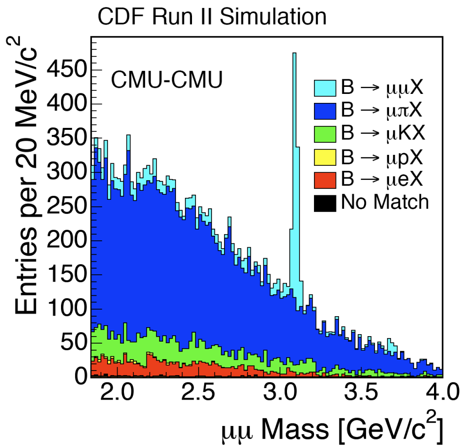
Efficiency of di-muon identification from $J/\psi \to \mu^+\mu^-$



D^{*+} tag used to remove non-D^0 backgrounds

Muon likelihood requirement (tracker, calorimeter and muon system information) as $B \to \mu^+\mu^-$ analysis.

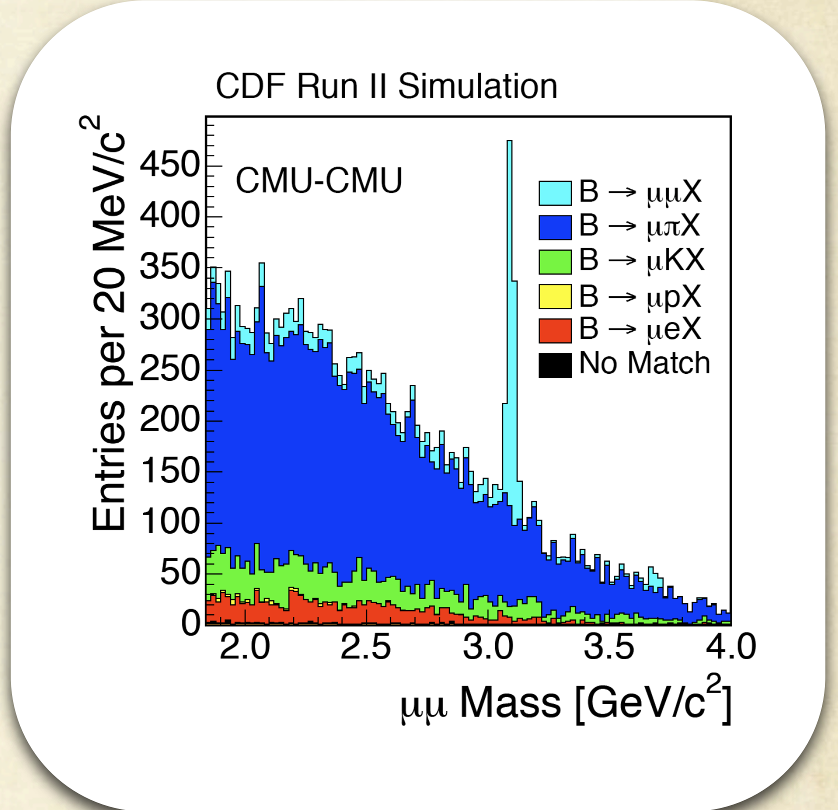
Backgrounds estimated using $D^0 \to K^-\pi^+$ and $D^0 \to \pi^+\pi^-$, high mass side-band data and Monte Carlo samples. Dominant background $B \to \mu^+\mu^- X$.



$D^0 \to \mu^+\mu^-$ – Backgrounds

It is crucial to understand and control backgrounds:

- fake from $D^0 \to \pi\pi$ and $D^0 \to K\pi$
- $D^0 \to \mu\nu X$ where X gives a fake μ
- $B \to \mu\nu X$ where X gives a fake μ
- $B \to \mu\nu D \to \mu\mu X$
- **$B \to \mu\mu X$ is found to be the largest source**



MC reproduces high mass sidebands in data (before muon id).
Use to estimate background contributions.
Likelihood Ratio (impact parameter and decay length) cut to remove dominant $B \to \mu^+\mu^- X$ background.

× 100%
× ≈ 0.5%
× ≈ 1.0%
× ≈ 0.0%

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

Table 1: Background contributions for the optimized analysis selection. Contributions from different sources are summed in quadrature to yield the total estimate. The final row is the number of observed decays in the search window for each channel.

Source	CMU-CMU	CMU-CMX	CMX-CMX
Combinatorial Background	0.040 ± 0.007	0.008 ± 0.001	0.0007 ± 0.0001
$D^0 \to \pi\pi$ double fakes	0.53 ± 0.005	0.057 ± 0.001	0.012 ± 0.002
$D^0 \to K\pi$ double fakes	< 0.01	< 0.01	< 0.01
Semimuonic D^0 decays	< 0.36	< 0.20	< 0.10
Semimuonic B Decays	0.54 ± 0.06	0.13 ± 0.03	0.07 ± 0.02
Cascade semimuonic B decays	3.8 ± 1.3	2.5 ± 1.0	1.0 ± 0.5
Total	4.9 ± 1.3	2.7 ± 1.0	1.0 ± 0.5
N_{obs}	3	0	1

D^0-mixing – Analysis

1.5/fb of data collected with impact parameter trigger

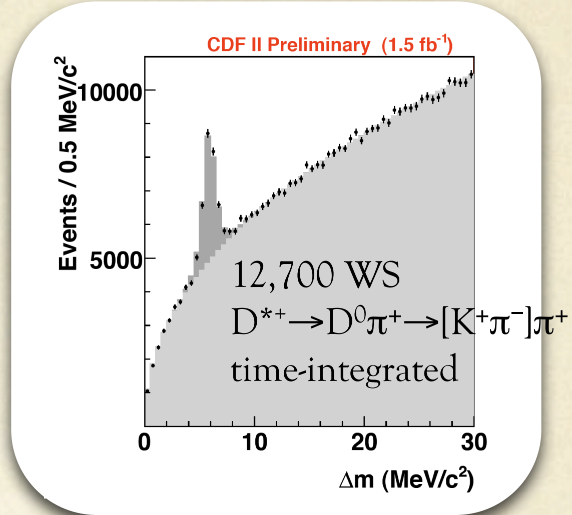
Clean up WS from RS → Apply opposite mass assignment + PID cuts exclude > 96.4% RS decays from WS signal. Keeps 78% of signal.

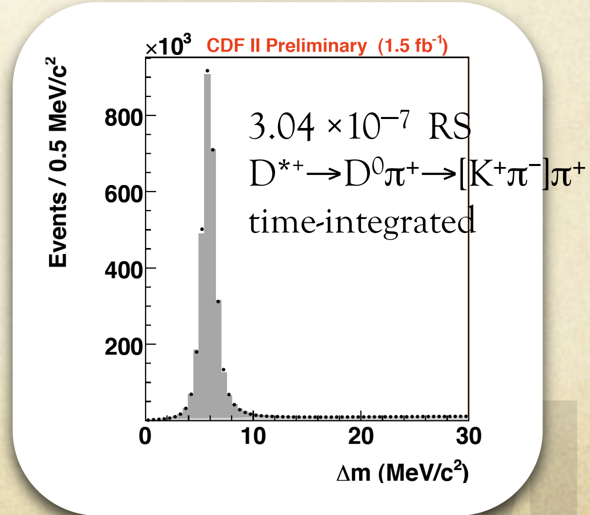
Shapes from RS events distributions. Data driven analysis.

Fit of WS and RS invariant Kπ-mass in 60 $\Delta m = m_{D^*} - m_{D0} - m_{\pi}$ bins, and in 20 cτ proper time bins.

Non-prompt B→D*X subtracted using impact parameter distribution of D*.

Most of systematic uncertainty enters at second order in the ratio WS/RS.





$B^0_s \rightarrow \mu^+\mu^-$ – D0 analysis

D0 analysis is very similar to CDF one, here just results: