Rare B and Charm Decays

Moriond QCD

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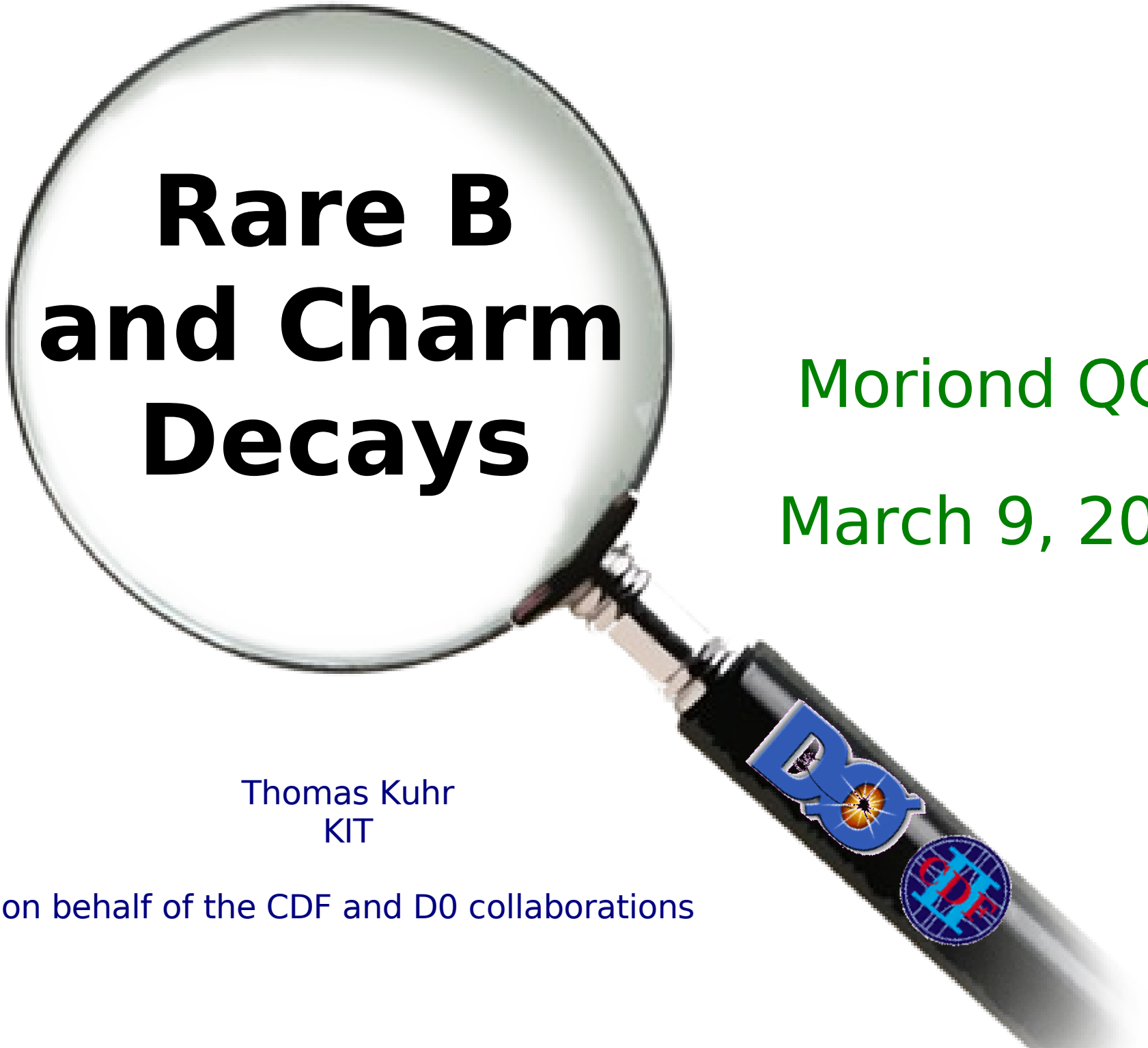
KIT

on behalf of the CDF and D0 collaborations



Rare Decays

Decays with (very) small BR predicted by the SM

➔ High sensitivity to new physics contributions!

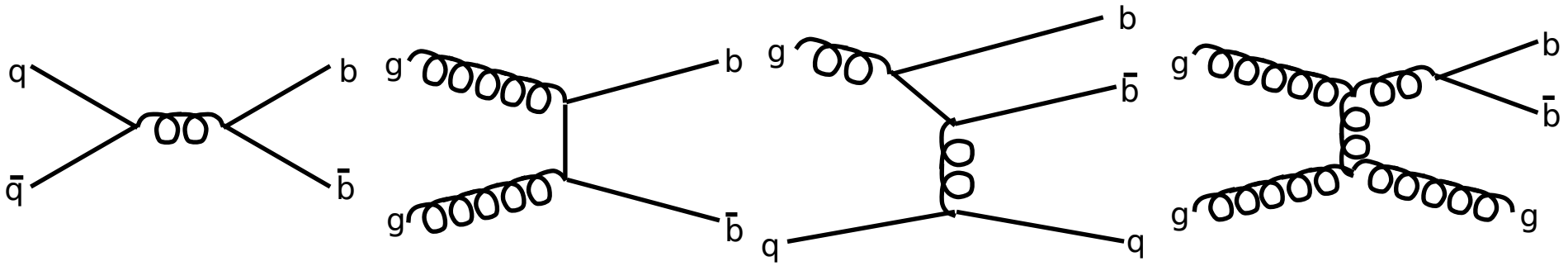
- Flavor changing neutral currents (FCNC)
  - $B^0_{(s)} \rightarrow \mu^+ \mu^-$
  - $D^0 \rightarrow \mu^+ \mu^-$
  - $D^+ \rightarrow \pi^+ \mu^+ \mu^-$

Loop and penguin processes in SM

- Charmless hadronic B decays
  - $\Lambda_b \rightarrow p\pi$ / pK

CKM suppressed in SM

Heavy hadron production at the Tevatron



➔ Huge $b\bar{b}$ and $c\bar{c}$ cross section

➔ Production of all heavy hadron species in fragmentation

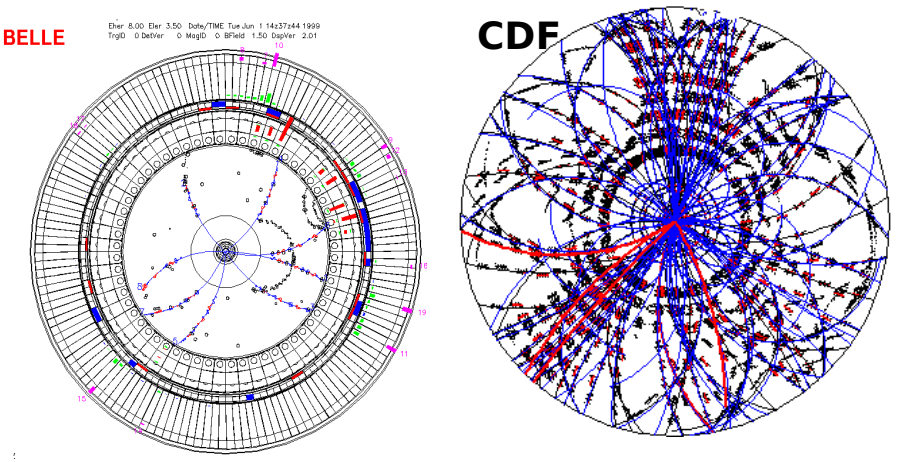
but

✗ inelastic cross section ~10^3 times larger than $\sigma(b\bar{b})$

→ Trigger: muon pairs, displaced tracks

✗ Background tracks from fragmentation

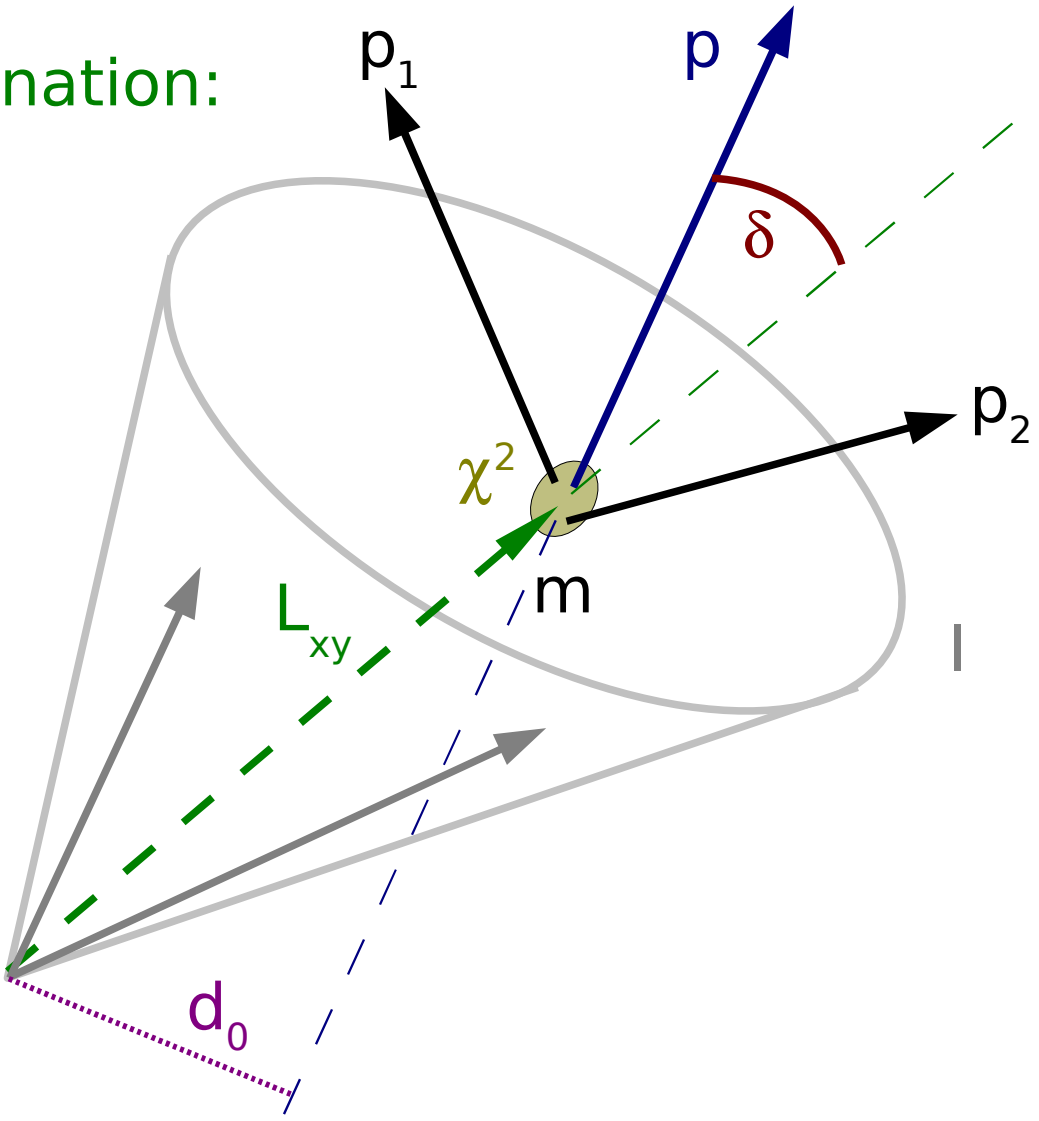
→ High combinatorial background



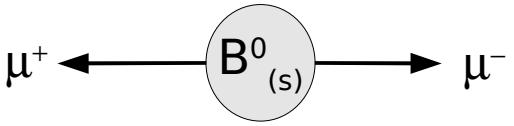
Signal extraction

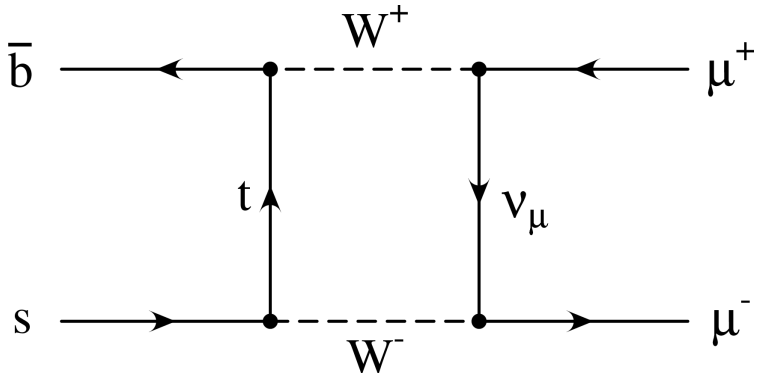
Signal background discrimination:

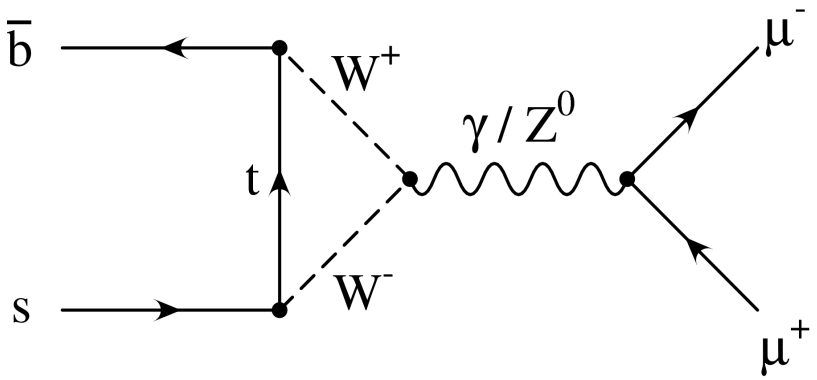
- Invariant mass (m)
- Lifetime (L_{xy})
- Momentum (p)
- Pointing angle (δ)
- Decay topology (p_1,p_2)
- Vertex fit quality (χ^2)
- Isolation (I)



$B^0_{(s)} \to \mu^+ \mu^-$

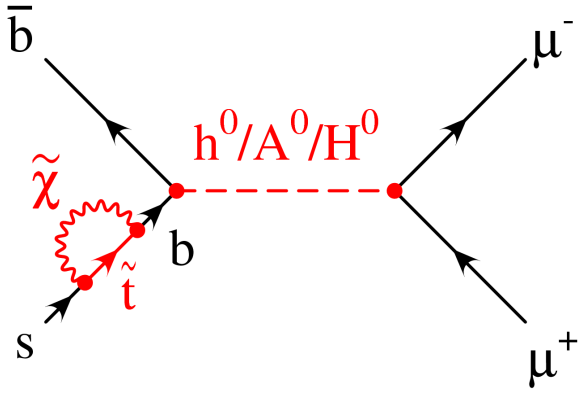


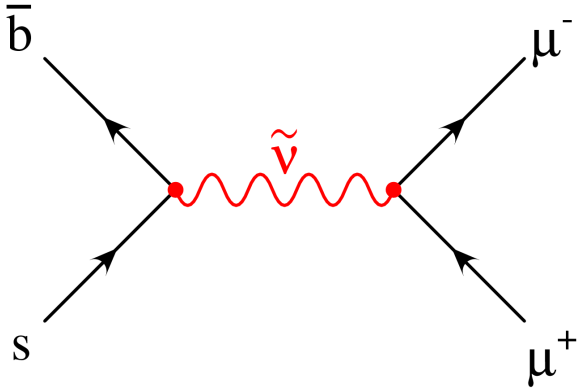




SM: $BR(B_s \to \mu^+ \mu^-) = (3.42 \pm 0.54) \times 10^{-9}$ Buras, Phys. Lett. B566, 115 (2003)

$BR(B^0 \to \mu^+ \mu^-) = (1.00 \pm 0.14) \times 10^{-10}$ suppressed by $(V_{td}/V_{ts})^2$



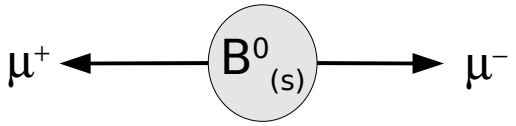


At current sensitivity any signal would indicate new physics

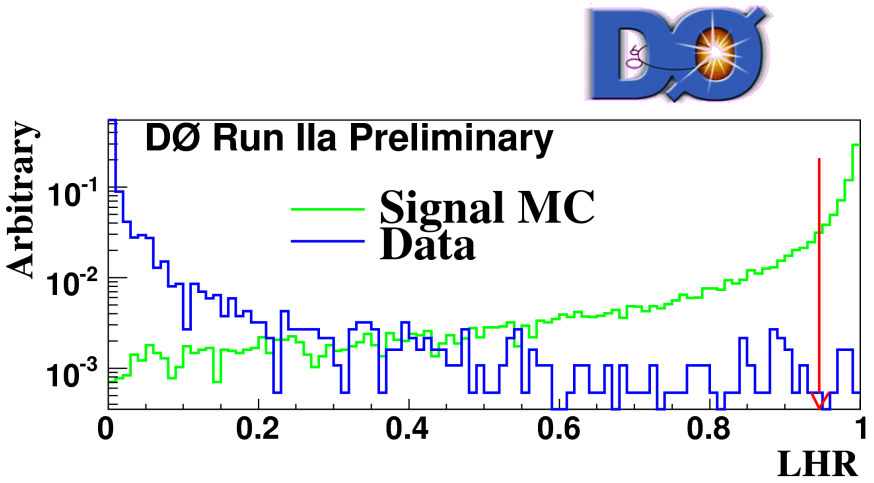
NP: MSSM: BR ~ $\tan^6(\beta)$

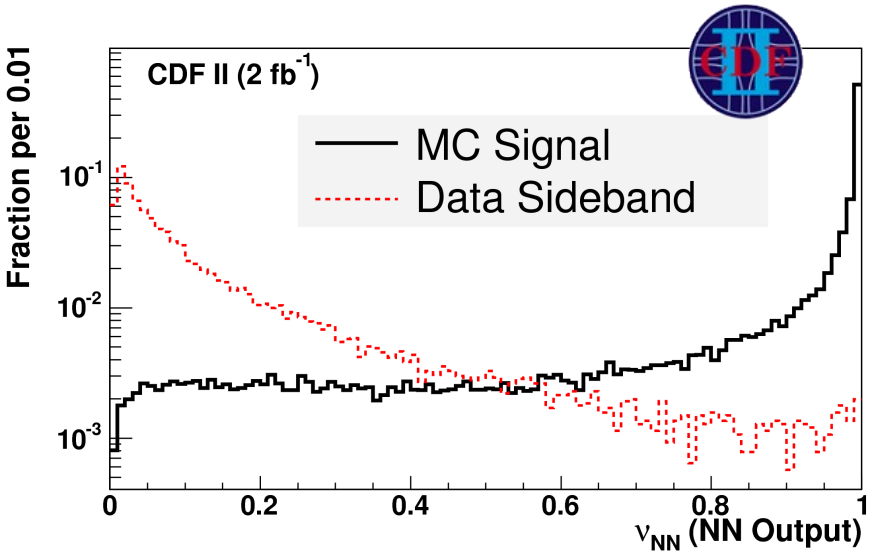
R-parity violating SUSY: enhancement also at low $\tan(\beta)$

Selection optimization

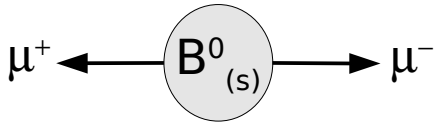


- Signal: MC
  Bkg: data mass sidebands
- Discriminating variables combined in
  - ➔ Likelihood ratio (D0)
  - ➔ Neural network (CDF)
- Check for bias of NN
  - ✔ $\mu^+\mu^+$, $\mu^-\mu^-$, negative lifetime and fake muon sample
  - ✔ background vs. background NN training

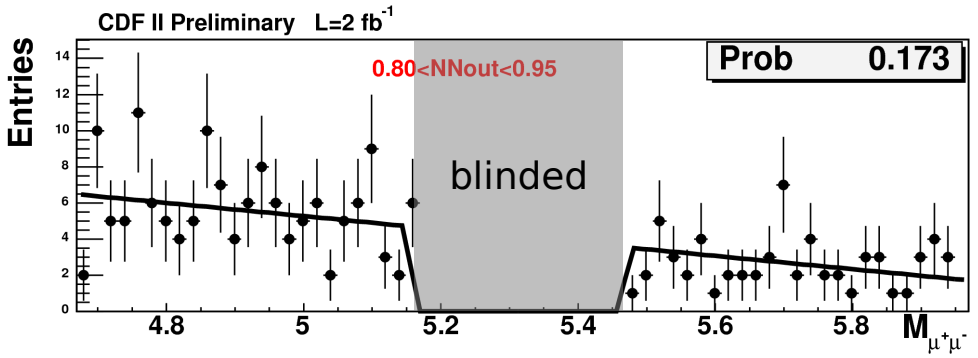


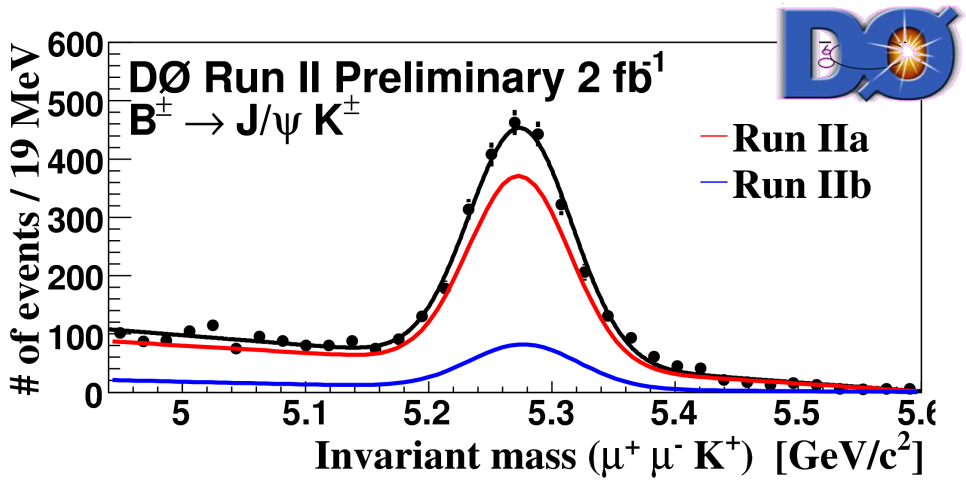


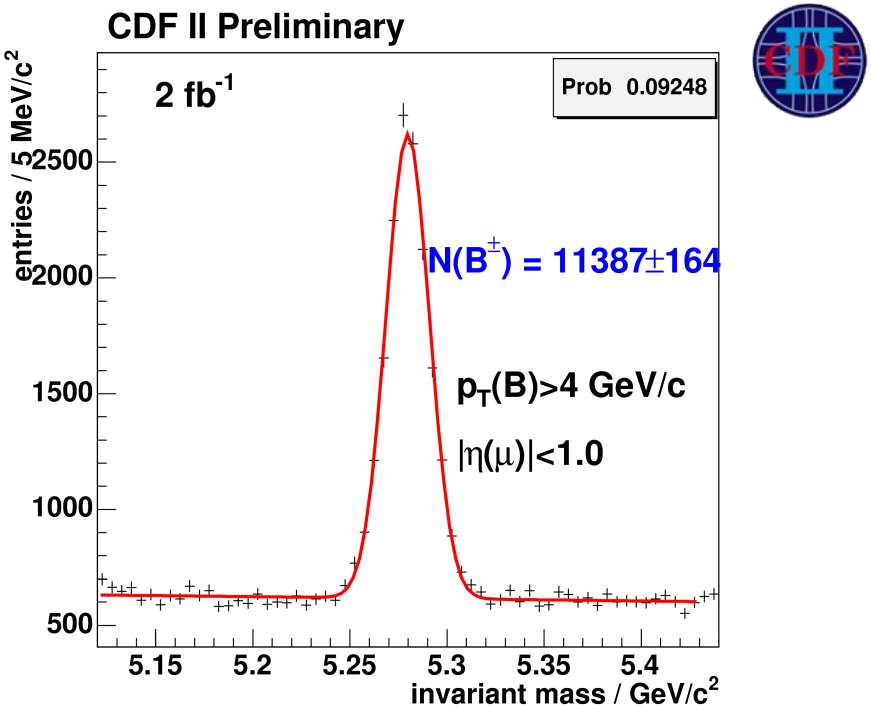
Backgrounds and normalization



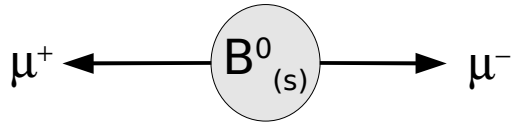
- Combinatorial background estimated from fit to mass sidebands
- $B \to h^+h'^-$ background about ten times smaller
- Normalization: $B^+ \to J/\psi\, K^+$

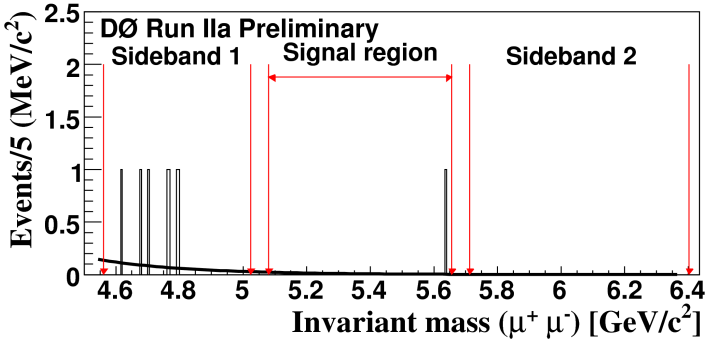


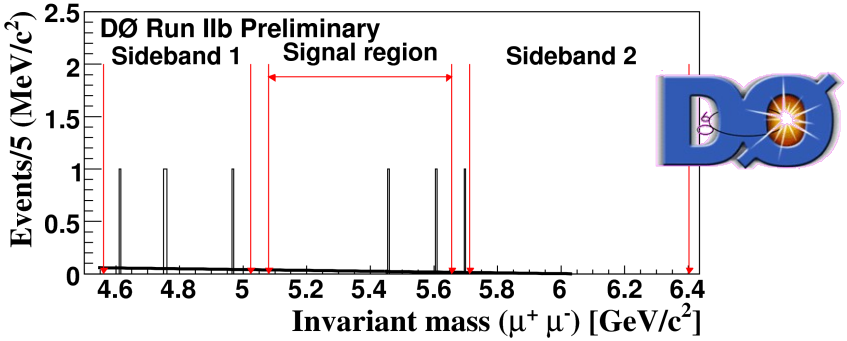




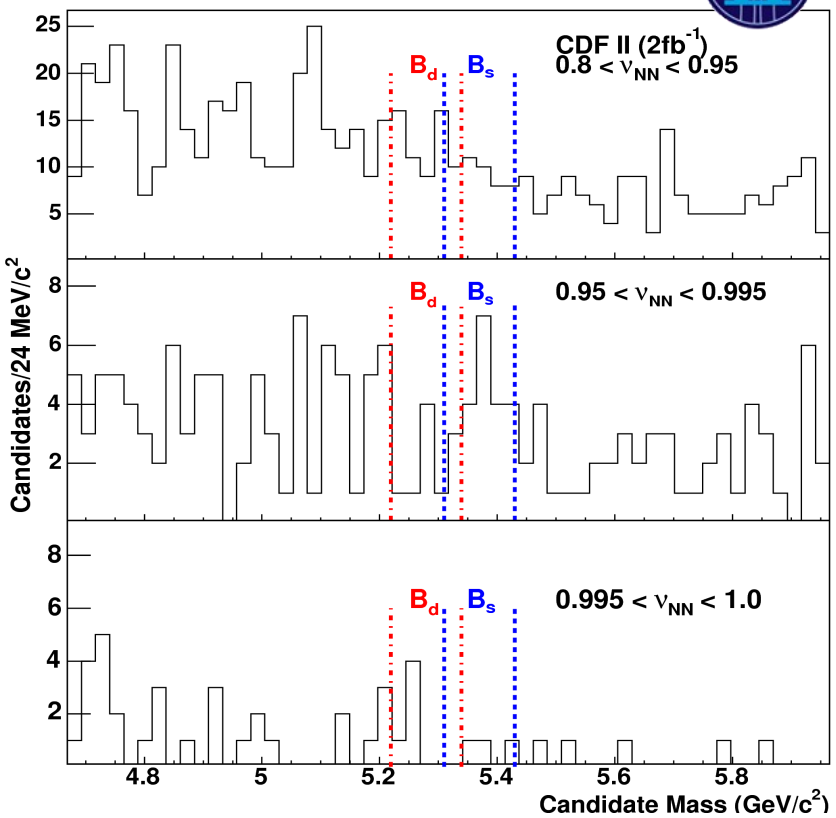
Limit calculation



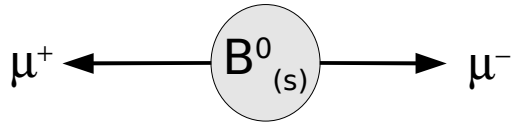




- No significant excess
  ⇒ calculate limit
- CDF: Split sample in 5 mass bins and 3 NN output bins
  → 15% improved sensitivity
- Bayesian limit calculation including systematic uncertainties



Result



Limits on BR($B_s \to \mu^+ \mu^-$) at 90% CL

- D0 (2 fb^{-1}): 7.5×10^{-8}
- CDF (2 fb^{-1}): 4.7×10^{-8}
- SM: 3.4×10^{-9}

Limits on BR($B^0 \to \mu^+ \mu^-$) at 90% CL

- CDF (2 fb^{-1}): 1.5×10^{-8}
- BaBar (2007): 5.2×10^{-8}
- Belle (2003): 1.6×10^{-7}
- SM: 1.0×10^{-10}

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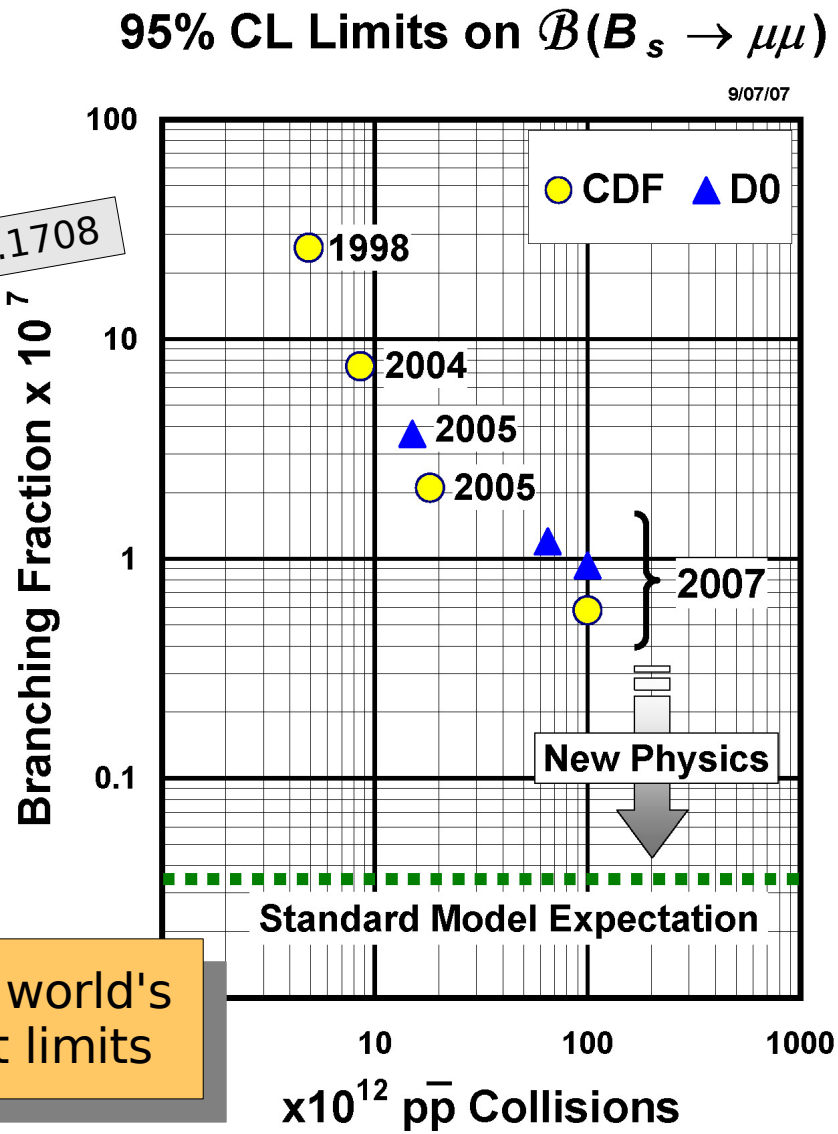
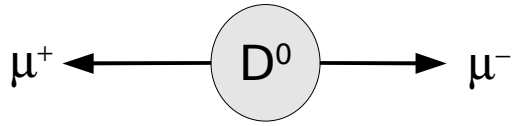
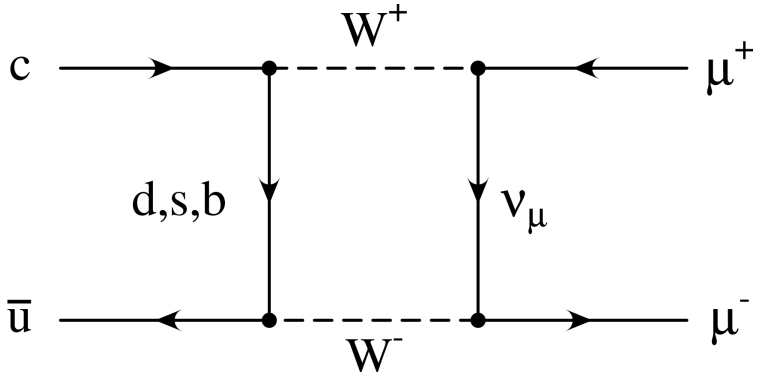


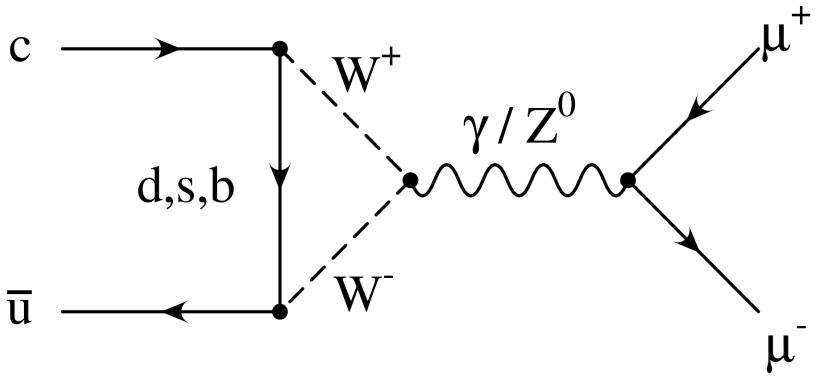
New world's best limits

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



- $B^0_{(s)}$: *down type quarks* $\leftrightarrow$ D^0: *up type quarks*





SM:

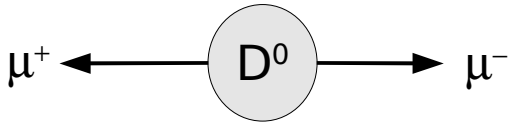
- Short range contr. GIM suppressed: BR ~ 10^{-18}
- Long range contr. (e.g. $D^0 \to \rho/\omega/\phi\ \gamma \to \gamma\gamma \to \mu^+ \mu^-$): BR $\geq 4 \times 10^{-13}$

At current sensitivity any signal would indicate new physics

NP:

- No significant enhancement in R-parity conserving SUSY
- BR up to $O(10^{-6})$ possible in R-parity violating SUSY

Analysis overview



- Displaced track trigger

  ➔ Normalization to $D^0 \to \pi^+\pi^-$

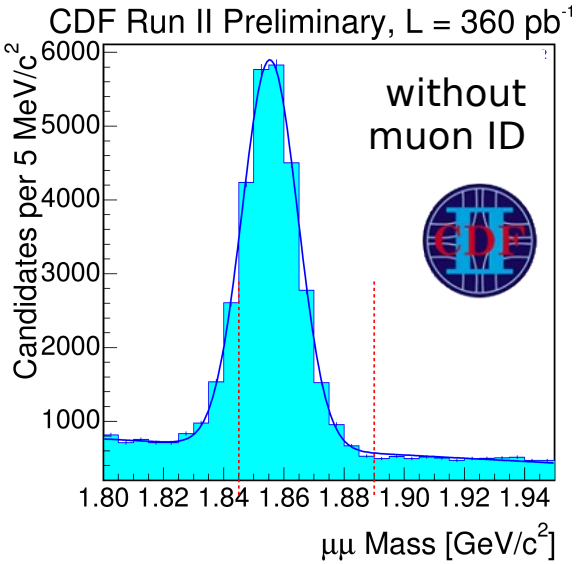
- Background reduction by D^* tag

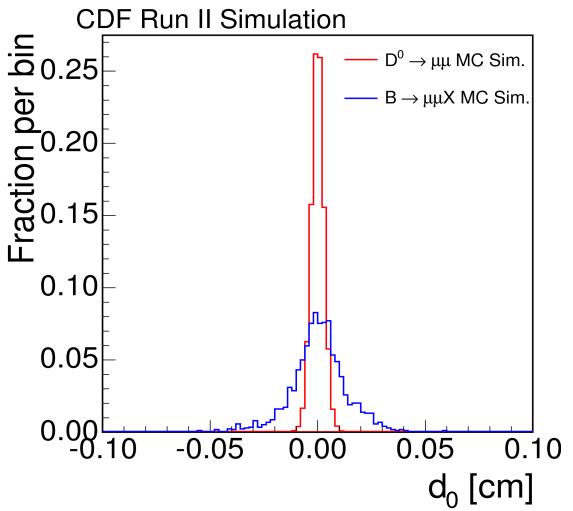
- Muon ID efficiency from $J/\psi \to \mu^+\mu^-$ data

- Muon mistag rate from $D^0 \to K^+\pi^-$ data

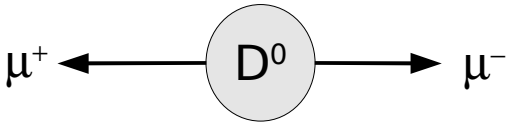
- Backgrounds estimated from MC

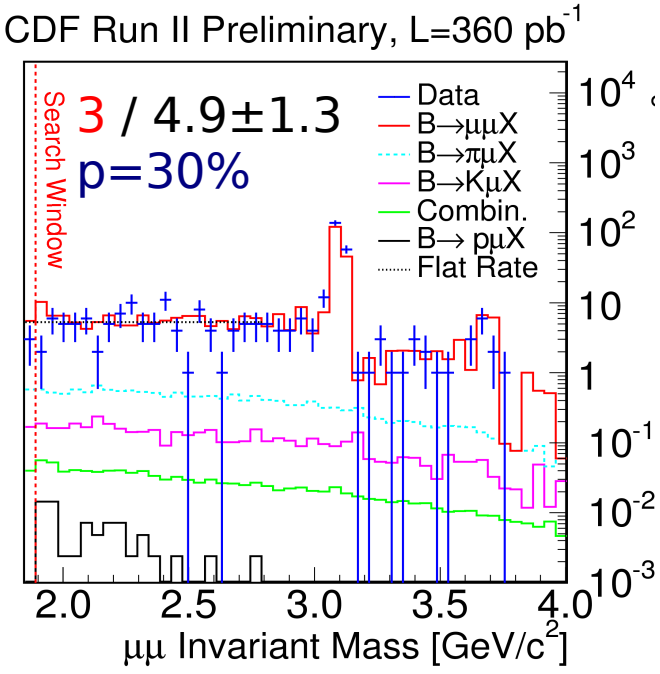
- Dominant $B \to \mu\mu X$ background reduced by cut on probability ratio using impact parameter (d_0) and decay length significance

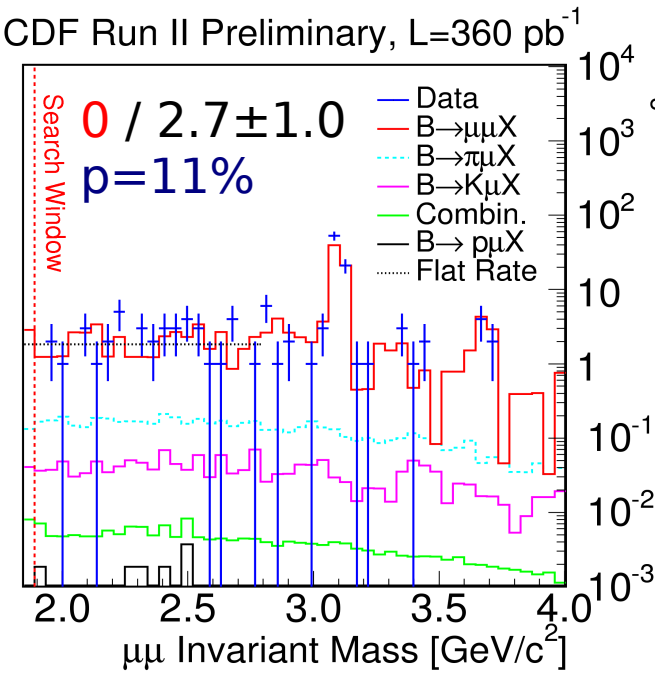


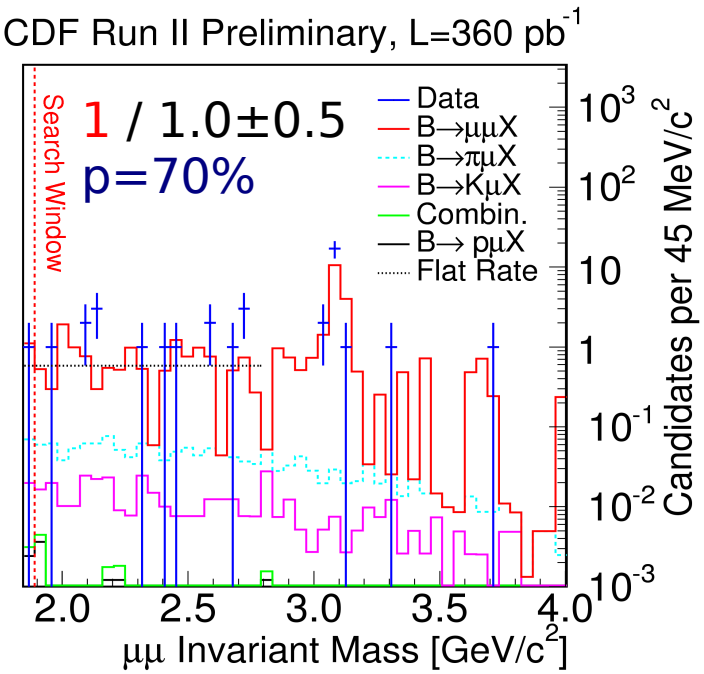


Result







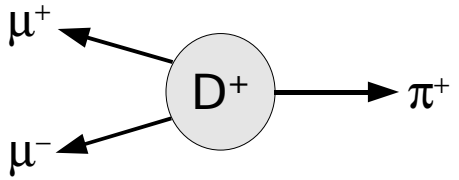


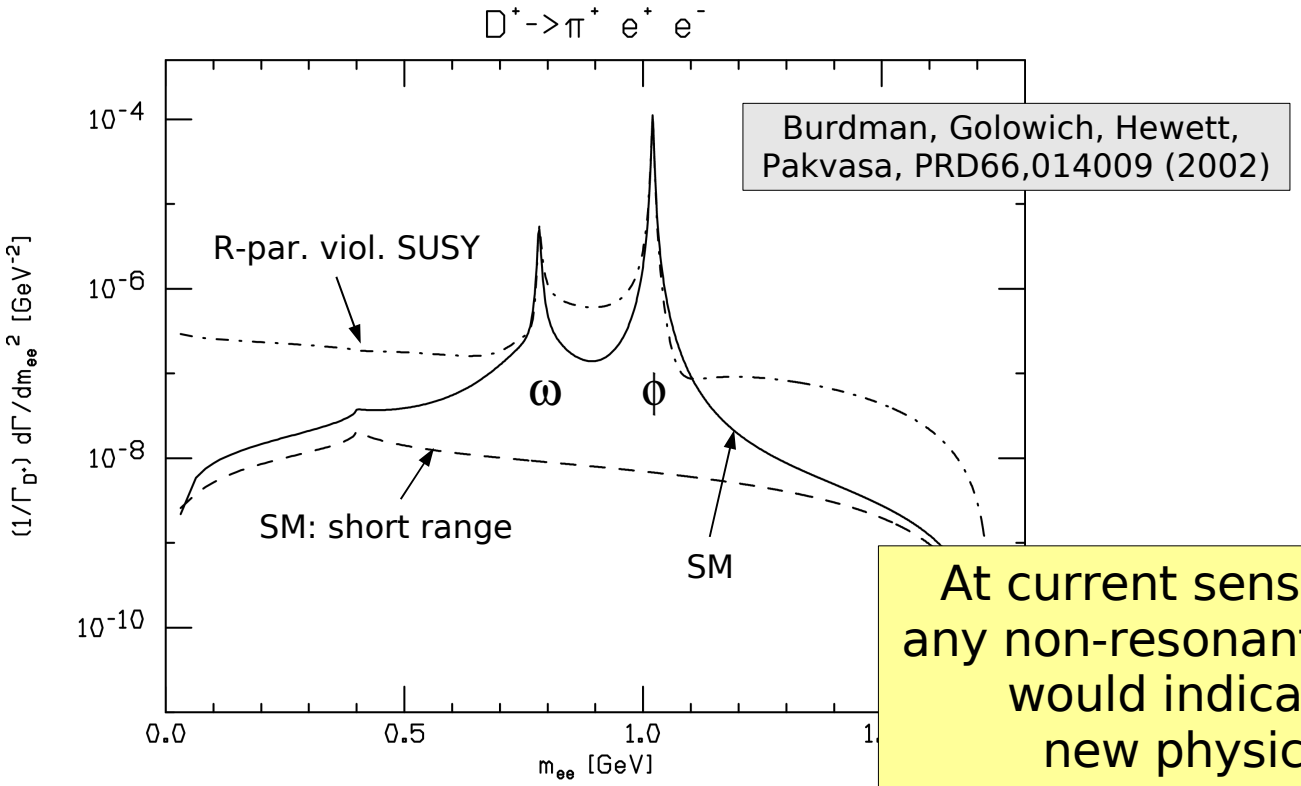
Bayesian limit on BR($D^0 \to \mu^+ \mu^-$) at 90% CL

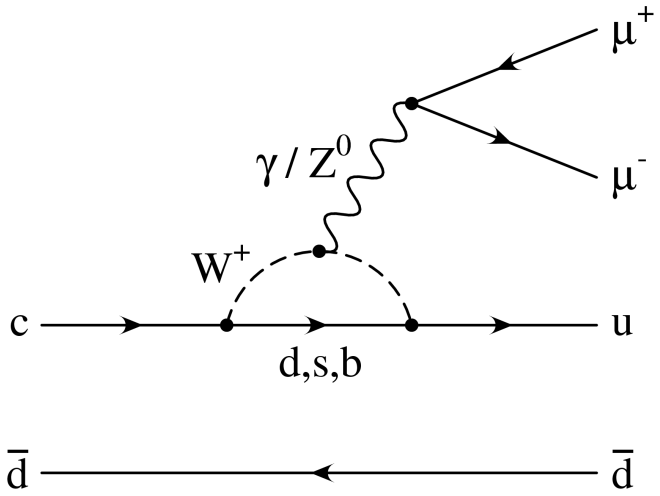
- CDF (360 pb^{-1}): 4.3×10^{-7}
- CDF (69 pb^{-1}): 25×10^{-7}
- HERA-B (2004): 20×10^{-7}
- BaBar (2004): 13×10^{-7}

New world's best limit

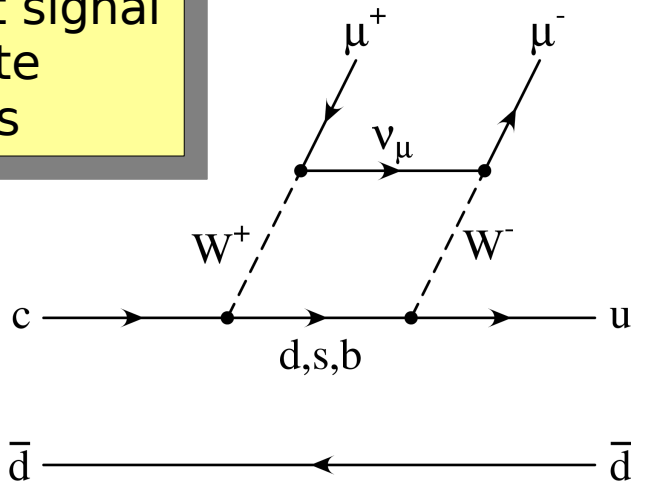
$D^+ \to \pi^+ \mu^+ \mu^-$







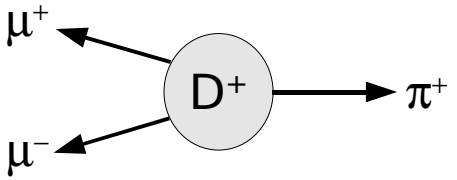
At current sensitivity any non-resonant signal would indicate new physics



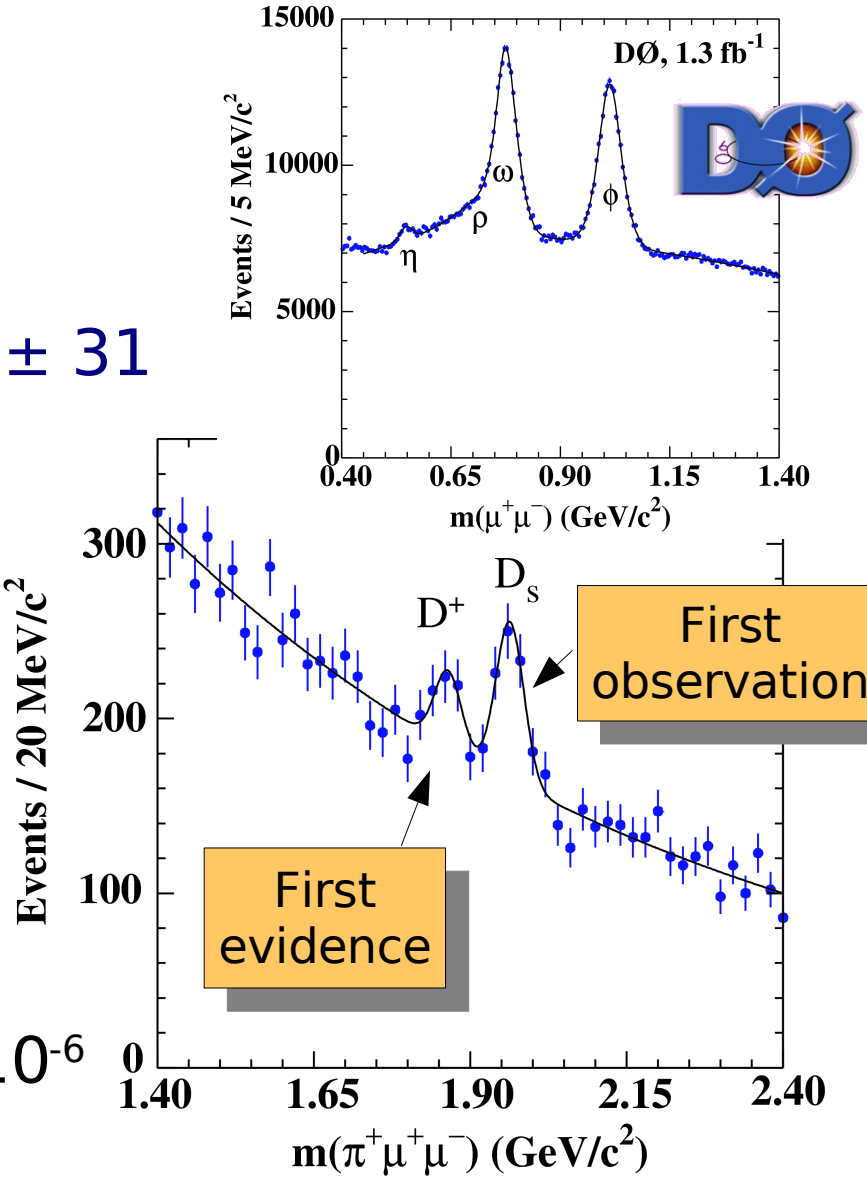
SM: Long range contr.: BR = 1.9 x 10^{-6}
Contributions depend on $m_{\mu\mu}$

NP: BR up to 1.5 x 10^{-5} possible in R-parity violating SUSY

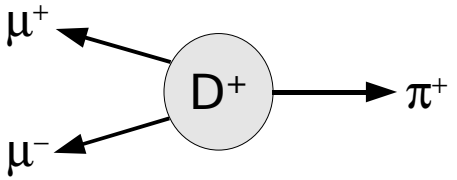
Resonant $D^+_{(s)}$ decay



- Selection of events with $m(\mu^+\mu^-)$ in ϕ signal region
- Fit $m(\pi^+\mu^+\mu^-)$ spectrum:
  $N(D_s^+) = 254 \pm 36$, $N(D^+) = 115 \pm 31$
- Statistical significance:
  8σ for D_s^+ and D^+, 4.1σ for D^+
- Use D_s^+ as normalization mode:
  $BR(D^+ \to \phi\,\pi^+ \to \mu^+\mu^-\pi^+) =$
  $(1.8 \pm 0.5 \pm 0.6) \times 10^{-6}$
- Consistent with $BR(D^+ \to \phi\,\pi^+) \times BR(\phi \to \mu^+\mu^-) = (1.86 \pm 0.26) \times 10^{-6}$



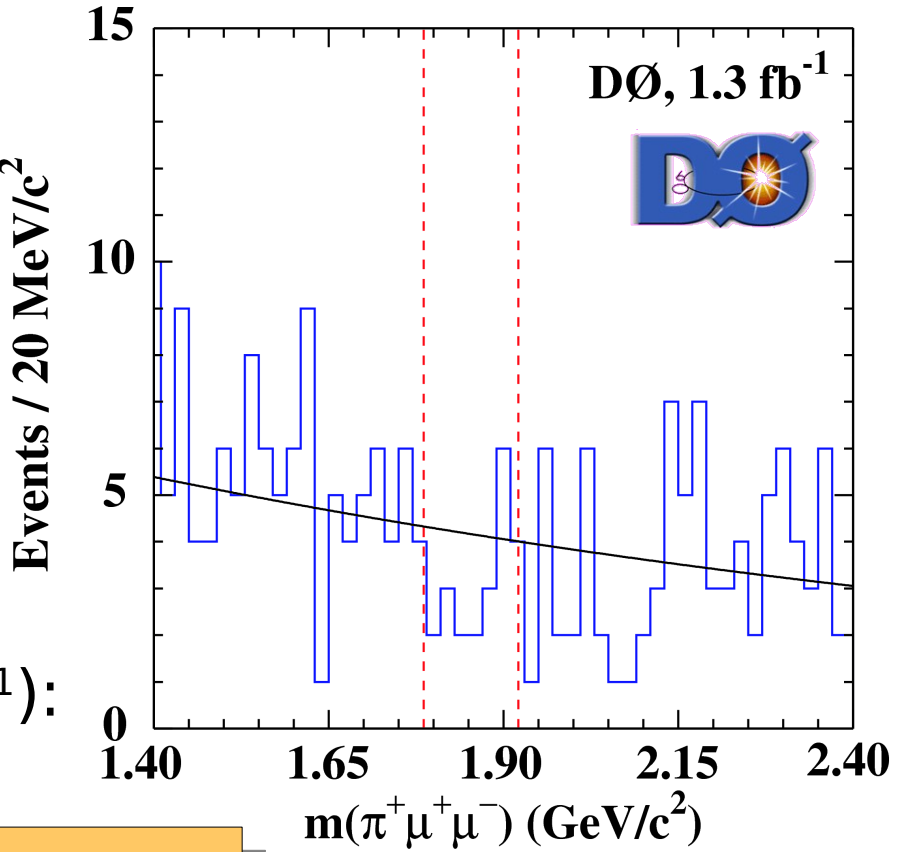
Continuum decay



- Exclude ϕ mass region
- 19 candidates in D^+ window
- Background expectation:
  $25.8 \pm 4.6 \rightarrow$ p-value = 14%
- Normalization to
  $D^+ \rightarrow \phi\,\pi^+$, $\phi \rightarrow \mu^+\,\mu^-$

➔ 90% C.L. Bayesian limit (1.3 fb^{-1}):
$BR(D^+ \rightarrow \pi^+\,\mu^+\,\mu^-) < 3.9 \times 10^{-6}$

- BaBar (2006): 2.4×10^{-5}
- Focus (2003): 7.4×10^{-6}



New world's best limit

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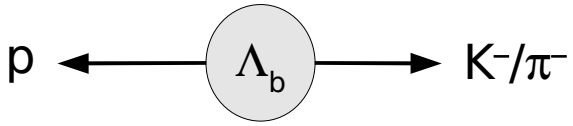
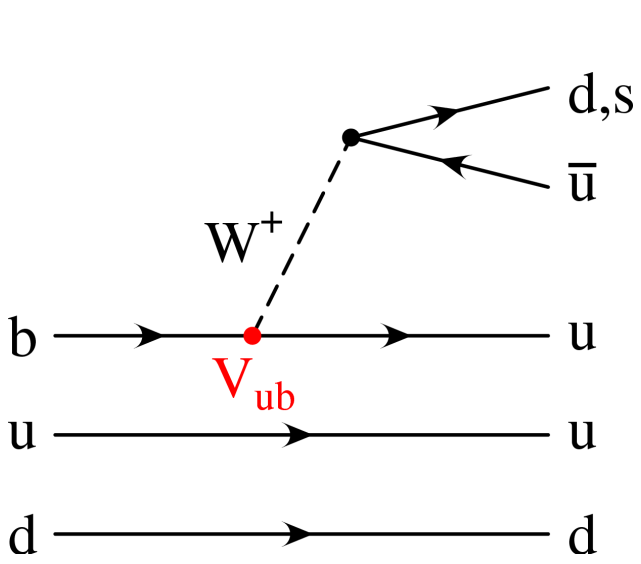
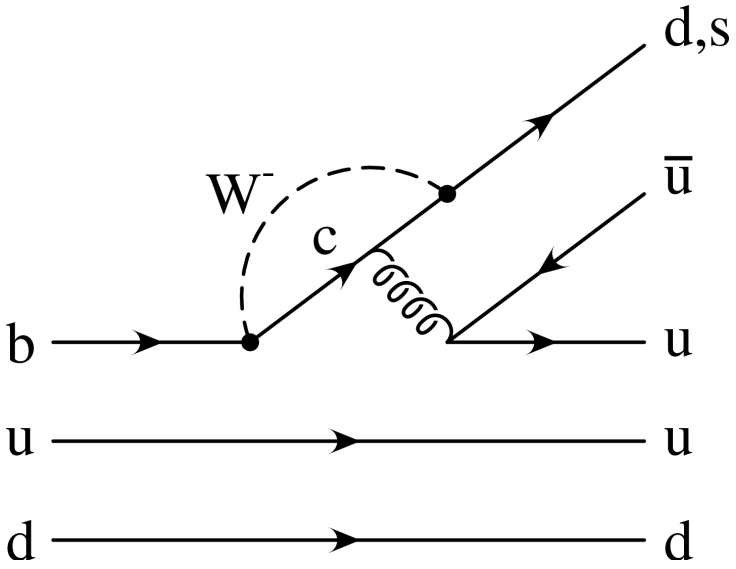
$\Lambda_b \rightarrow p\ K^-/\pi^-$







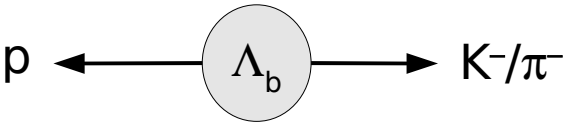
SM:

- Tree level process suppressed by V_{ub}
- Penguin contributions of comparable size
  $\rightarrow$ direct CP violation
- BR = $O(10^{-6})$, A_{CP} = O(10%)

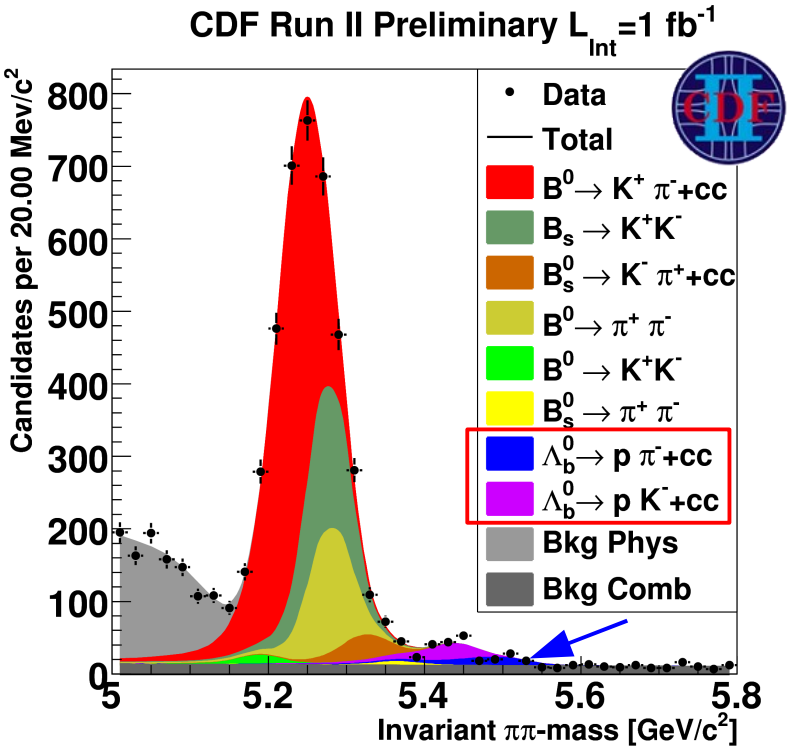
Measurement constrains (new) physics parameters

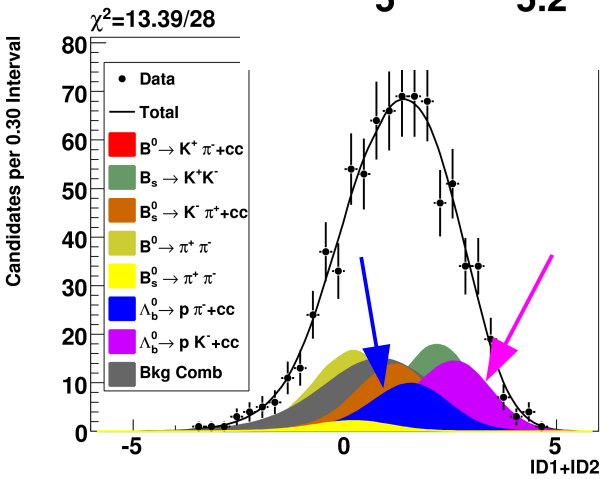
NP: R-parity violating SUSY can increase BR by up to a factor of $O(10^2)$ and reduce A_{CP} by O(10)

Signal extraction

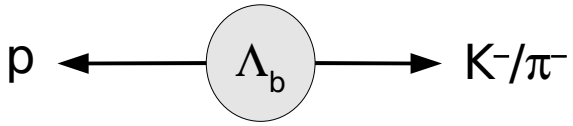


- "Spin-off" of $B \to h^+h'^-$ analysis (first observation of both rare Λ_b decays)
- Unbinned fit of
  - m($\pi\pi$)
  - decay particle momenta
  - PID(dE/dx)
- D^* data used to
  - check mass model
  - calibrate dE/dx





BR measurement



Normalize to $B^0 \to K^+ \pi^-$ CDF: 1 fb^{-1}

- $f_{\Lambda b} \cdot BR(\Lambda_b \to p\pi^-) / f_{B0} \cdot BR(B^0 \to K^+\pi^-) = 0.0415 \pm 0.0074 \pm 0.0058$
- $f_{\Lambda b} \cdot BR(\Lambda_b \to pK^-) / f_{B0} \cdot BR(B^0 \to K^+\pi^-) = 0.0663 \pm 0.0089 \pm 0.0084$

First BR measurement of hadronic charmless b baryon decay

Derived results:

hep/ex 0801.4375

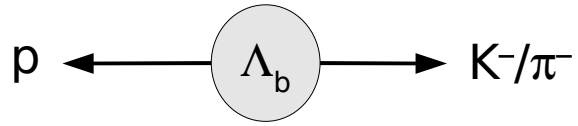
	$f_{\Lambda b}/f_{B0}$ from CDF	$f_{\Lambda b}/f_{B0}$ from PDG	*prediction*
$BR(\Lambda_b \to p\pi^-)$ $[10^{-6}]$	$1.4 \pm 0.3\ ^{+0.9}_{-0.5}$	$3.1 \pm 0.6 \pm 0.7$	*1*
$BR(\Lambda_b \to pK^-)$ $[10^{-6}]$	$2.2 \pm 0.3\ ^{+1.4}_{-0.8}$	$5.0 \pm 0.7 \pm 1.0$	*2*

Mohanta, Giri, Khanna, PRD63:074001 (2001)

Normalize to $\Lambda_b \to \Lambda_c^+ \pi^-$:

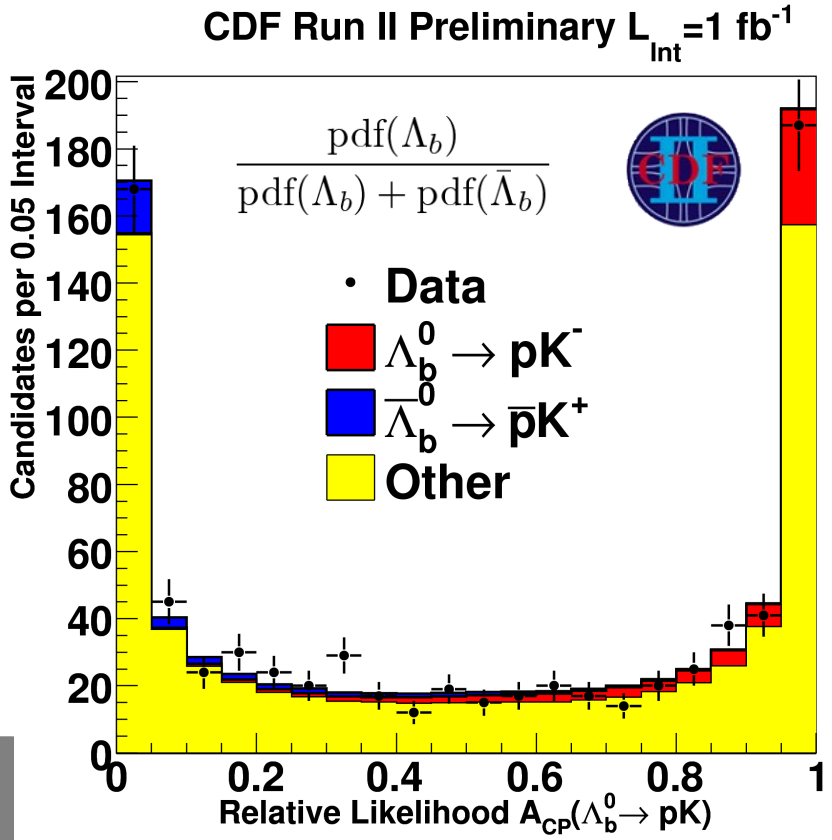
$BR(\Lambda_b \to p\pi^-) / BR(\Lambda_b \to \Lambda_c^+ \pi^-)$ $[10^{-3}]$	$0.355 \pm 0.063 \pm 0.080 \pm 0.096$ $(BR(\Lambda_c^+))$
$BR(\Lambda_b \to pK^-) / BR(\Lambda_b \to \Lambda_c^+ \pi^-)$ $[10^{-3}]$	$0.567 \pm 0.076 \pm 0.120 \pm 0.150$ $(BR(\Lambda_c^+))$

A_{CP} measurement



$$A_{CP}(\Lambda_b \to p\,h^-) = \frac{\mathcal{B}(\Lambda_b \to p\,h^-) - \mathcal{B}(\bar{\Lambda}_b \to \bar{p}\,h^+)}{\mathcal{B}(\Lambda_b \to p\,h^-) + \mathcal{B}(\bar{\Lambda}_b \to \bar{p}\,h^+)}$$

- Efficiency ratio from inclusive $\Lambda^0 \to p\pi^-$, $\bar{\Lambda}^0 \to \bar{p}\pi^+$ (and $D^0 \to K^-\pi^+$, $\bar{D}^0 \to K^+\pi^-$)
  - $A_{CP}(\Lambda_b \to p\pi^-) =$ $0.03 \pm 0.17 \pm 0.05$
  - $A_{CP}(\Lambda_b \to pK^-) =$ $0.37 \pm 0.17 \pm 0.03$

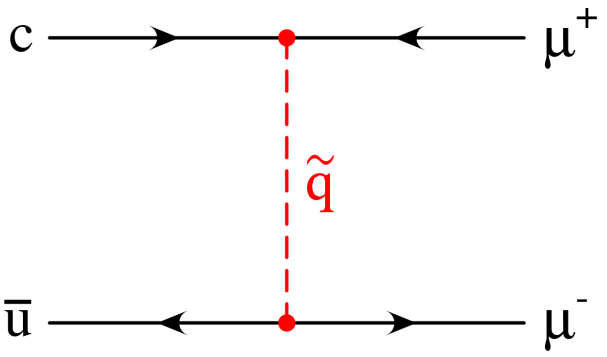


First direct CP violation measurement of hadronic charmless b baryon decay

Summary of Tevatron results

- New world's best limits on FCNC decays
  - $B_s \to \mu^+ \mu^-$
  - $B^0 \to \mu^+ \mu^-$
  - $D^0 \to \mu^+ \mu^-$
  - $D^+ \to \pi^+ \mu^+ \mu^-$

$\lambda_{21k}\lambda_{22k} < 9.8 \times 10^{-4}$ @ 90% C.L.



- First measurement of hadronic charmless b baryon decay
  - BR
  - A_{CP}

➔ Significant reduction of new physics parameter space

Backup

General analysis procedure

- Optimization of selection
  (cuts, likelihood ratio, neural network)
- Background estimation $\rightarrow N_{sig} = N_{cand} - N_{bkg}$
- Normalization to mode with well known BR
  and similar final state

$$\mathcal{B}(sig \rightarrow X) = \frac{N_{sig}}{N_{norm}} \cdot \frac{\epsilon_{norm}}{\epsilon_{sig}} \cdot \frac{f_{norm}}{f_{sig}} \cdot \mathcal{B}(norm \rightarrow X')$$

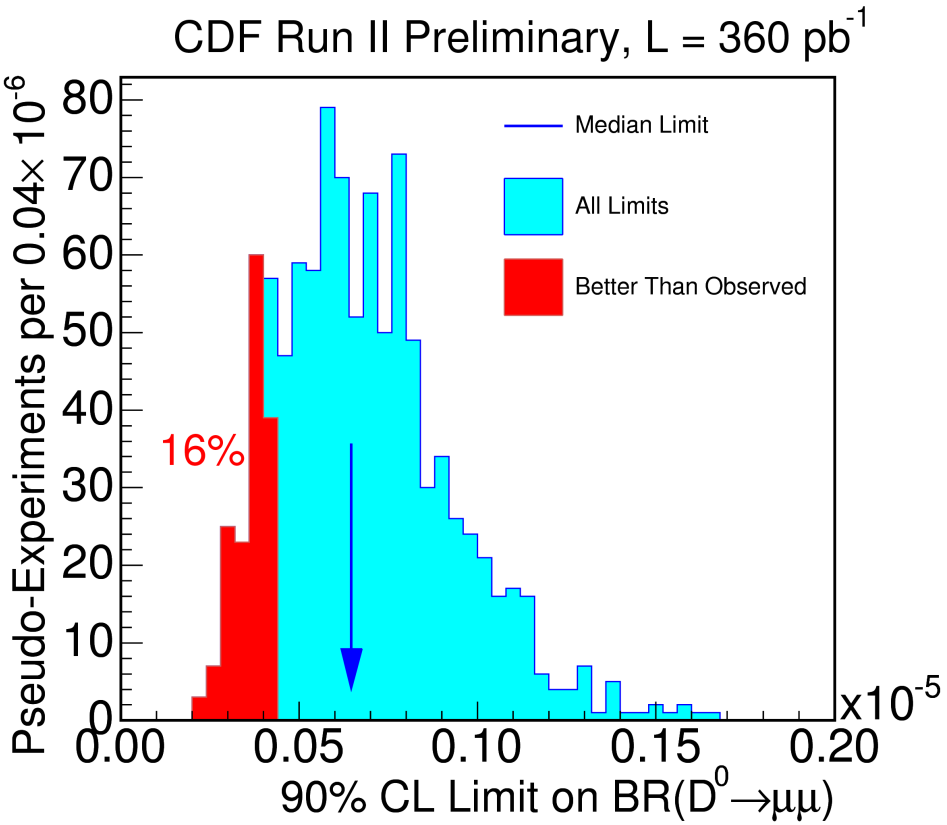
- If significant signal $\rightarrow$ measure BR
  else $\rightarrow$ calculate limit

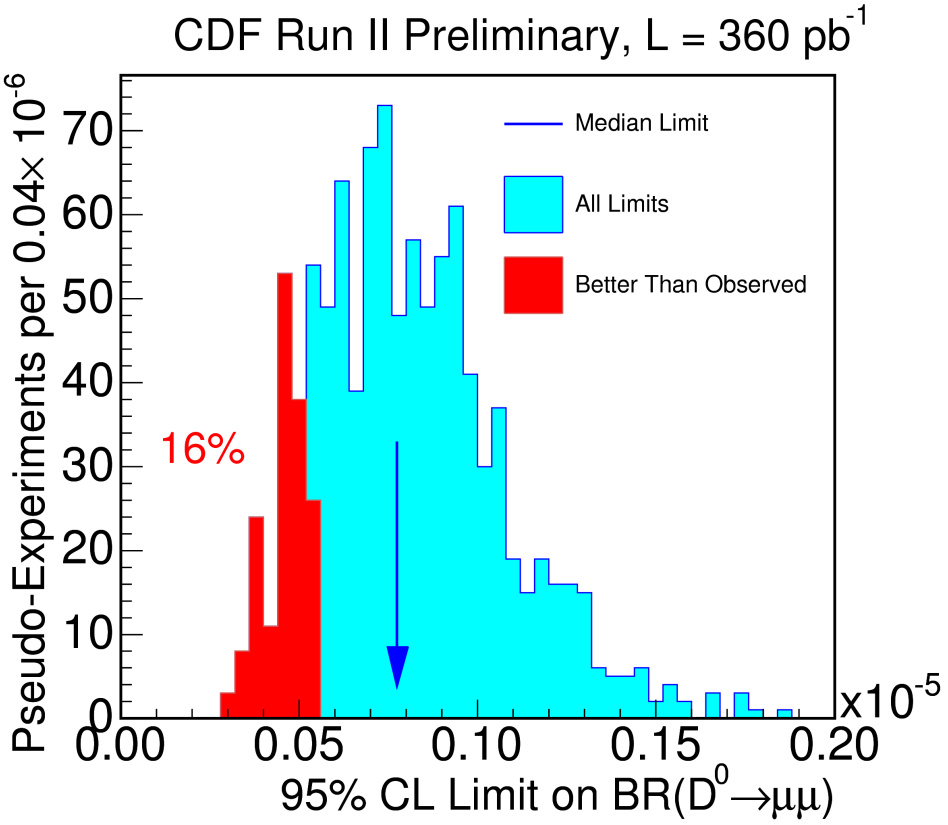
$D^0 \to \mu^+ \mu^-$

Backgrounds

Detector	CMU-CMU	CMU-CMX	CMX-CMX
Combinatorial Background	0.040 ± 0.007	0.008 ± 0.001	0.0007 ± 0.0001
D0 → $\pi\pi$ Double Tags	0.530 ± 0.005	0.057 ± 0.001	0.012 ± 0.002
D0 → Kπ Double Tags	< 0.01	< 0.01	< 0.01
Semileptonic D0 Decays	< 0.36	< 0.20	< 0.10
B Decays Involving One Real Muon	0.54 ± 0.06	0.13 ± 0.03	0.07 ± 0.02
B Decays Involving Two Real Muons	3.8 ± 1.3	2.5 ± 1.0	1.0 ± 0.5
Total Expected Background	4.9 ± 1.3	2.7 ± 1.0	1.0 ± 0.5
Observed Events	**3**	**0**	**1**

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


CDF Run II Preliminary, L = 360 pb-1
Median Limit
All Limits
Better Than Observed
16%
Pseudo-Experiments per 0.04× 10-6
x10-5
90% CL Limit on BR(D0→μμ)


CDF Run II Preliminary, L = 360 pb-1
Median Limit
All Limits
Better Than Observed
16%
Pseudo-Experiments per 0.04× 10-6
x10-5
95% CL Limit on BR(D0→μμ)