CDF Hot Topics

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6th Flavor Physics and CP Violation Conference
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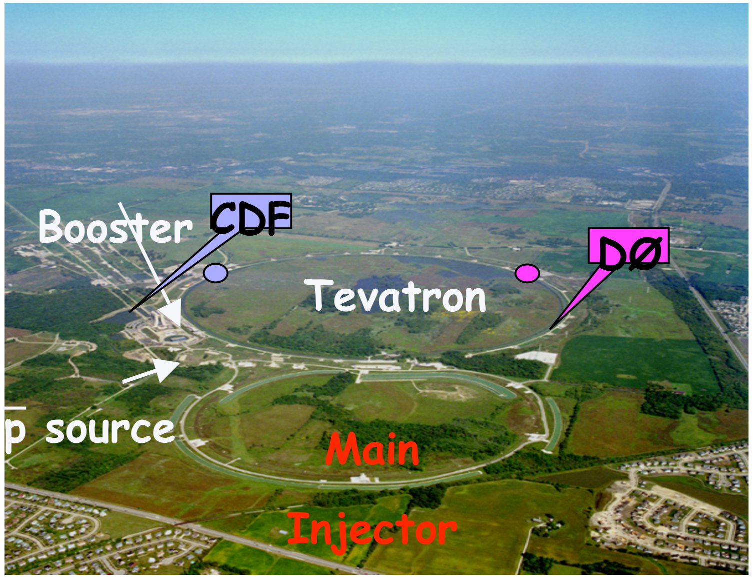
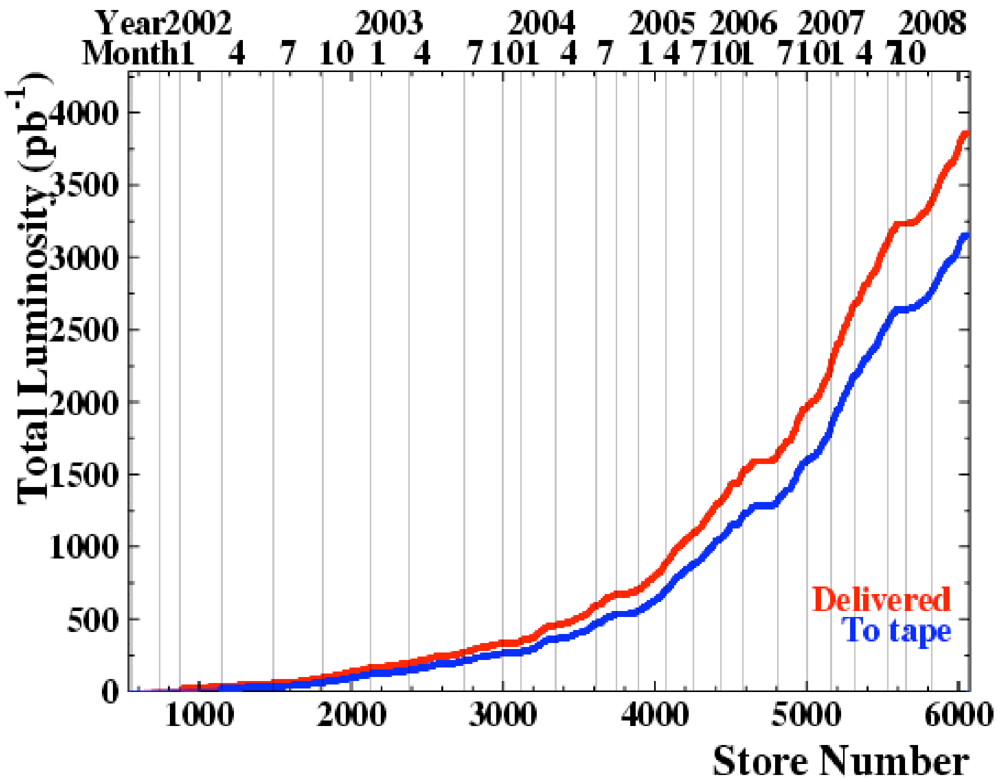
Outline

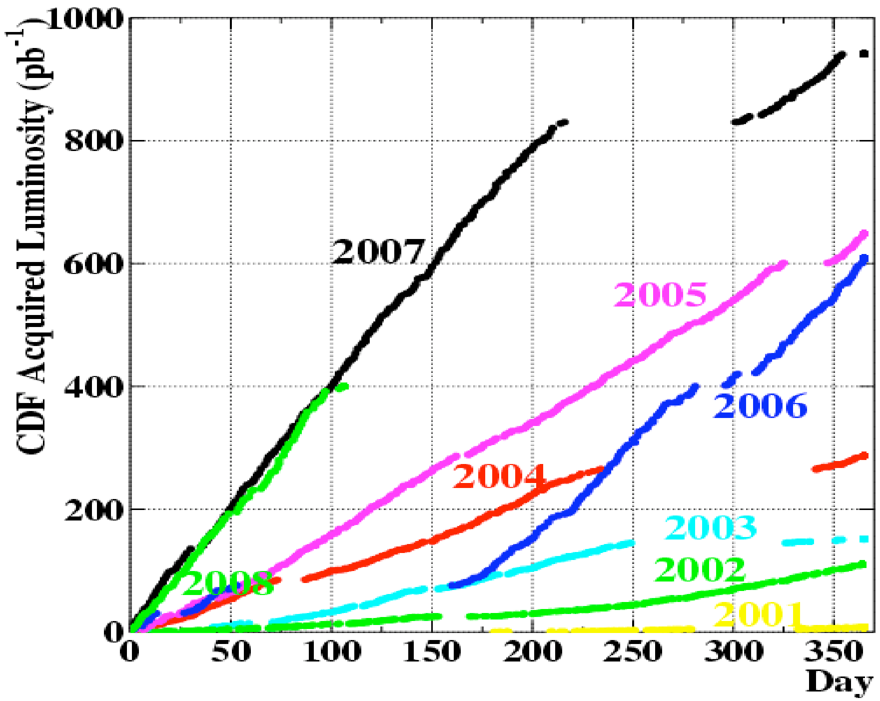
- **Overview of the Tevatron and CDF detector**
  - CDF Heavy Flavor Triggers
- **CDF recent results**
  - β_s measurement (flavor tagged)
  - B_c lifetime measurement (semileptonic decay mode)
  - Search for $B^0_{(s)} \rightarrow \mu\mu$ rare decay
  - $B^0_{(s)}$ lifetime measurement (fully hadronic decay mode)
  - BRs and CP violation in $B \rightarrow DK$ and $\Lambda^0_b \rightarrow pK/\pi$
  - Charm Mixing
  - Search for $D^0 \rightarrow \mu\mu$ rare decay
- **Conclusions**

The Tevatron Collider

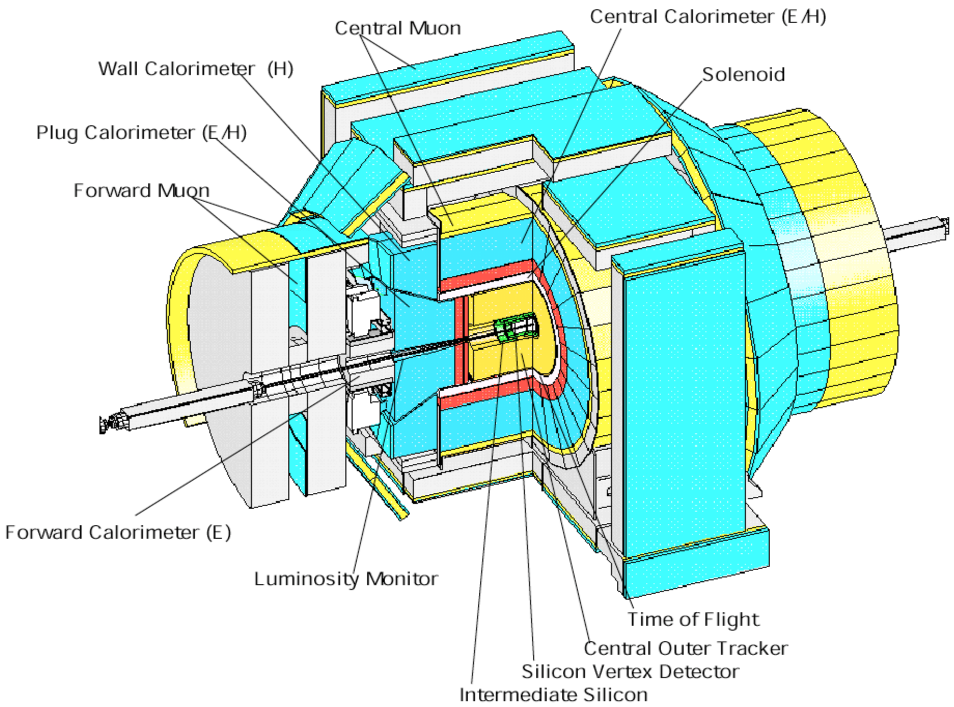
- pp collisions @1.96 TeV, performing very well
- Total deliv. Lumi. ~3.9 fb^{-1} (~3.2 fb^{-1} acquired)
- Initial inst. Lumi. 3.15 x 10^{32} cm^{-2} s^{-1}
- Approved running in 2009, possible 2010 ?

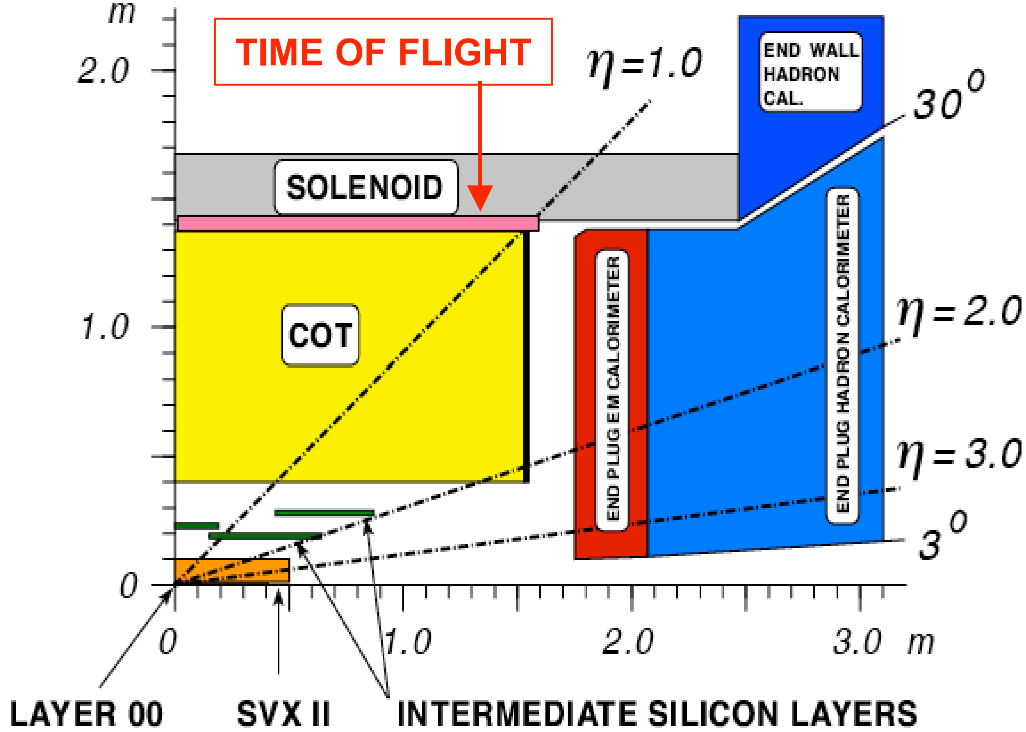






The CDF Detector

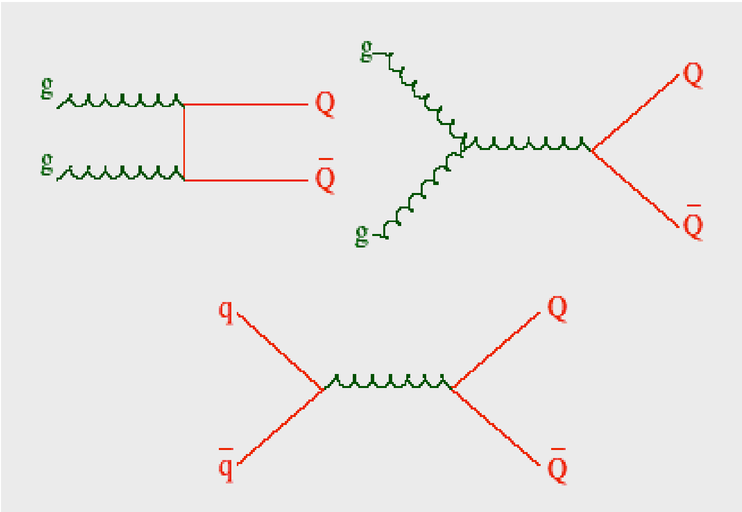




- Central Drift chamber in 1.4 T magnetic field
  - Excellent vertex & mass resolution ($\sigma(p_T)/p_T{}^2 \sim 0.1\%\ \mathrm{GeV}/c^{-1}$)
  - dE/dx measurement used for PID (1.4σ K/π separation)
- Silicon VerteX detector
  - I.P. resolution: 35 μm @2GeV/c
- Time-of-Flight detector for PID at low momentum
- Muon coverage $|\eta| < 1$

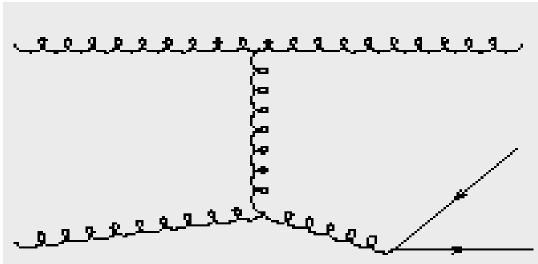
Heavy Flavor Production at Tevatron

Leading Order Diagrams

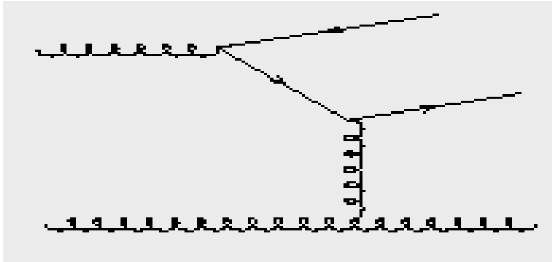


O (α_s^2): flavor creation

NLO Diagrams

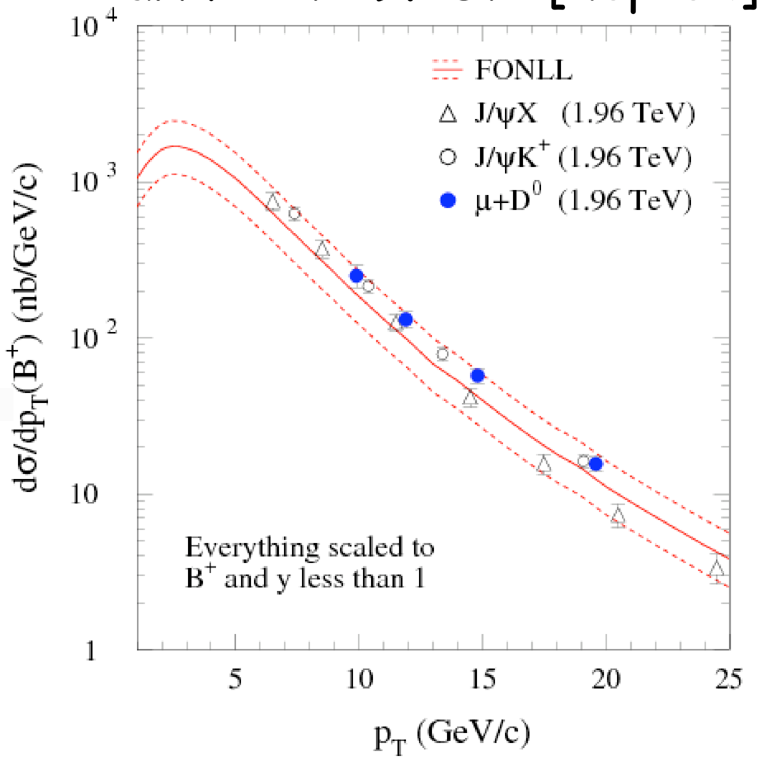


O (α_s^3): gluon splitting



O (α_s^3): flavor excitation

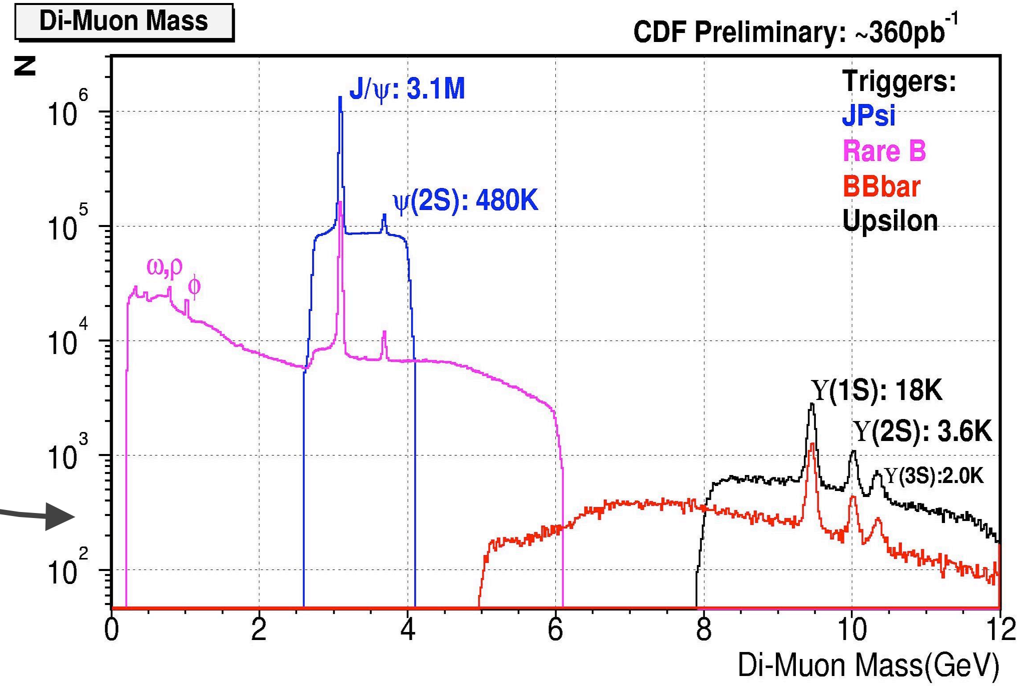
arXiv:0709.4572[hep-ex]



- At Tevatron, b production cross section is much larger compared to B factories
  - → CDF is enjoying a very rich B Physics program
- Plethora of states accessible at Tevatron (B_d, B_u, B_s, Λ_b, Ξ_b, Σ_b)
  - → Complement the B factories physics program
- Total inelastic cross section at Tevatron is ~1000 larger than b cross section
  - → Large backgrounds suppressed by triggers that target specific decays

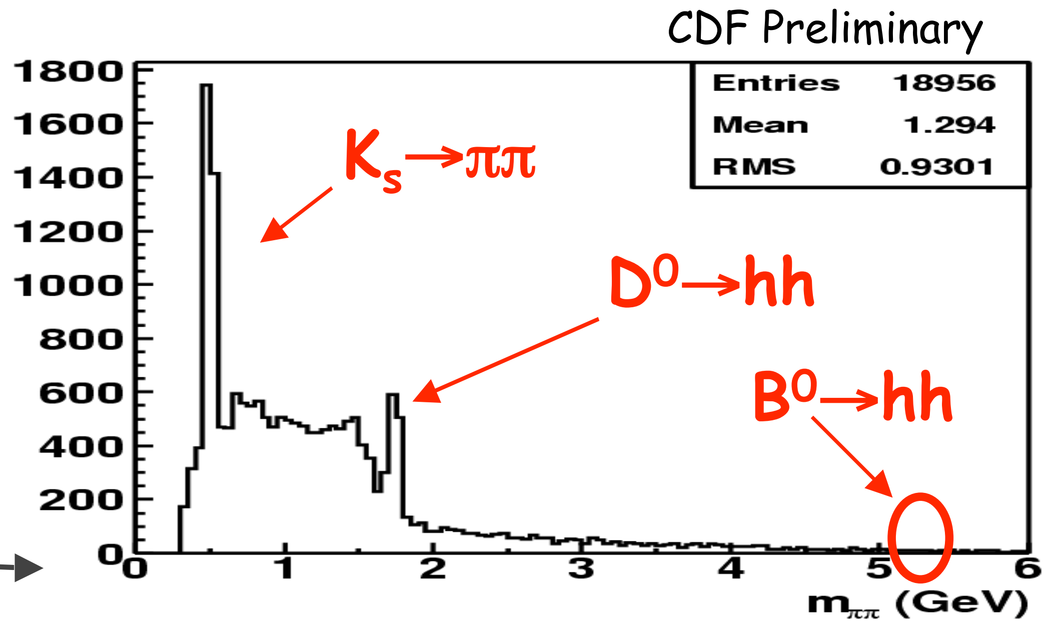
CDF Trigger Strategy

- **Di-Muon Trigger**
  $J/\psi \rightarrow \mu\mu$, $B^0_{(s)} \rightarrow \mu\mu$
  $Pt(\mu) > 1.5$ GeV/c



- **Lepton + 1 displaced track**
  $B \rightarrow l\nu X$
  $Pt(l) > 4$ GeV/c, $pt(trk) > 2$ GeV/c
  $120 < |d_0| < 1000$ μm

- **2 displaced tracks**
  $\Lambda^0_b/B^0_{(s)} \rightarrow hh$, Σ_b, B_s and D^0 mixing
  $Pt > 2$ GeV/c, $\Sigma pt > 5.5$ GeV/c
  $120 < |d_0| < 1000$ μm



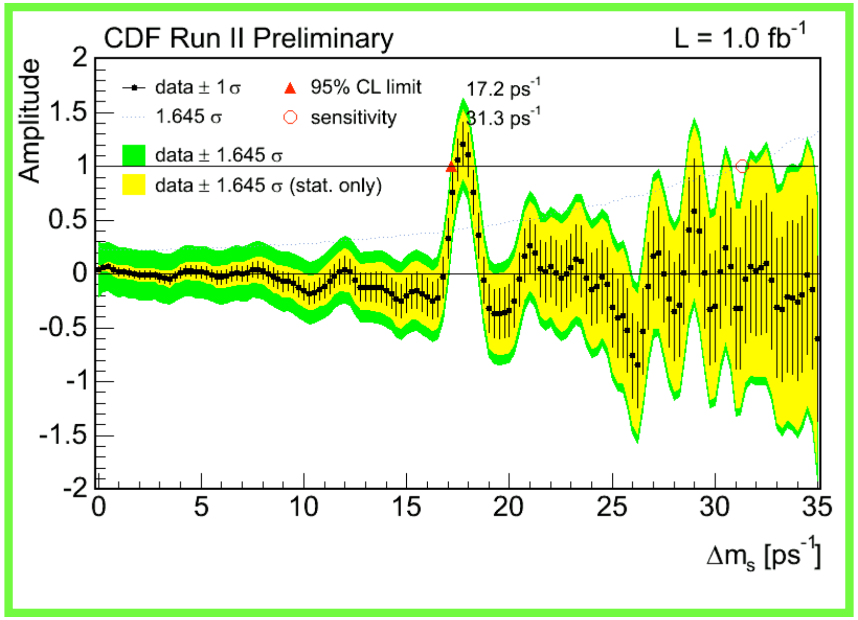
New Physics in B^0_s mixing

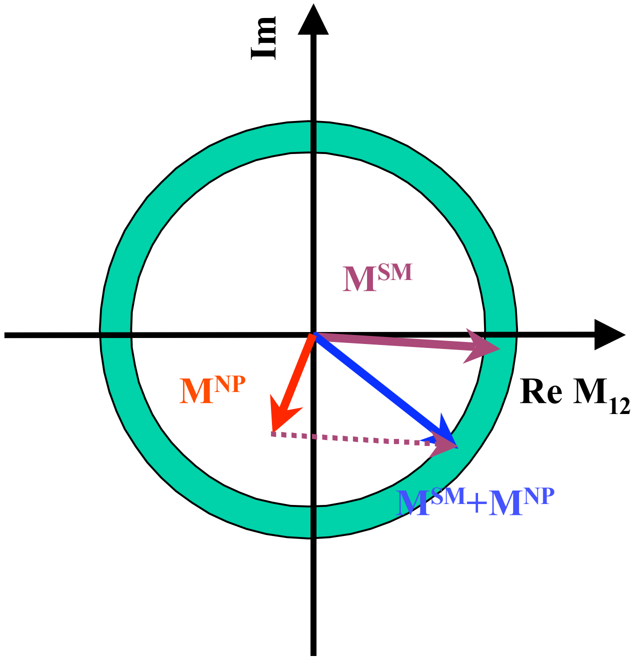
- B_s mixing oscillation well established

CDF: $\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$

(PRL 97:242003, 2006)

$\Delta m_s = M_H - M_L \sim 2 \times |M_{12}|$ determines $|M_{12}|$ in good agreement with the Standard Model





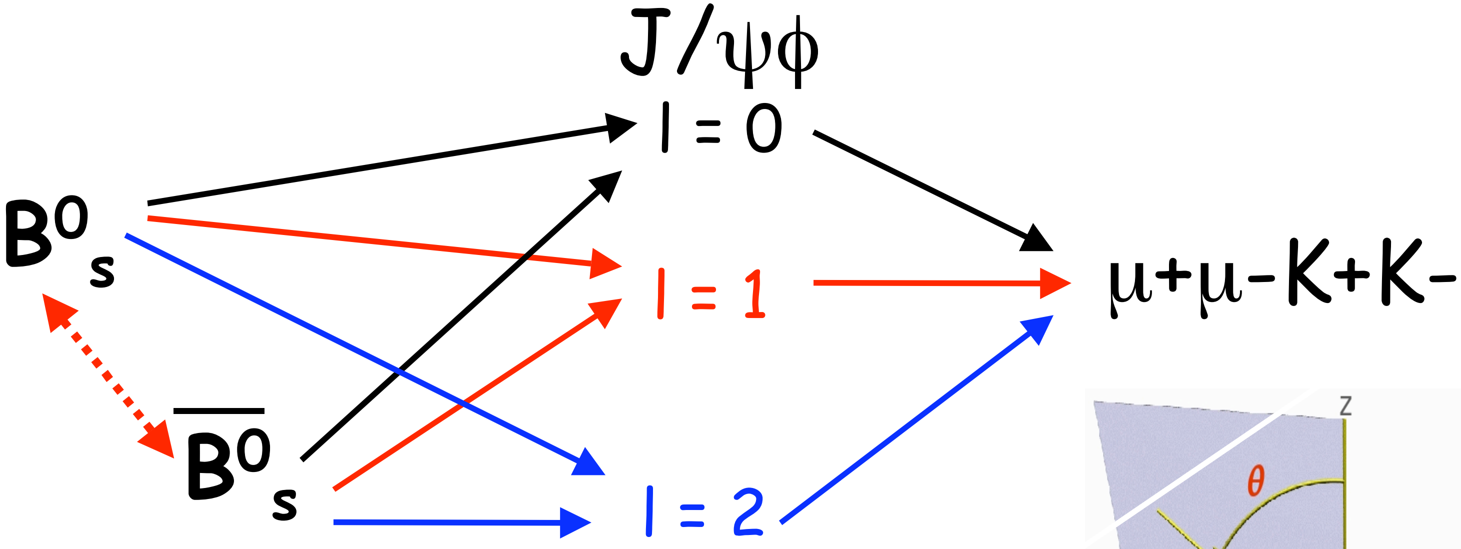
- Phase of mixing amplitude $M_{12} = |M_{12}| \exp(i\phi_M)$ poorly determined, but needed to constrain SM

- Large CP violation phase $\phi_M \rightarrow$ New Physics

- If NP occurs in mixing $\rightarrow 2\beta_s = -\phi_M$ can be measured in $B^0_s \rightarrow J/\psi\phi$ decays

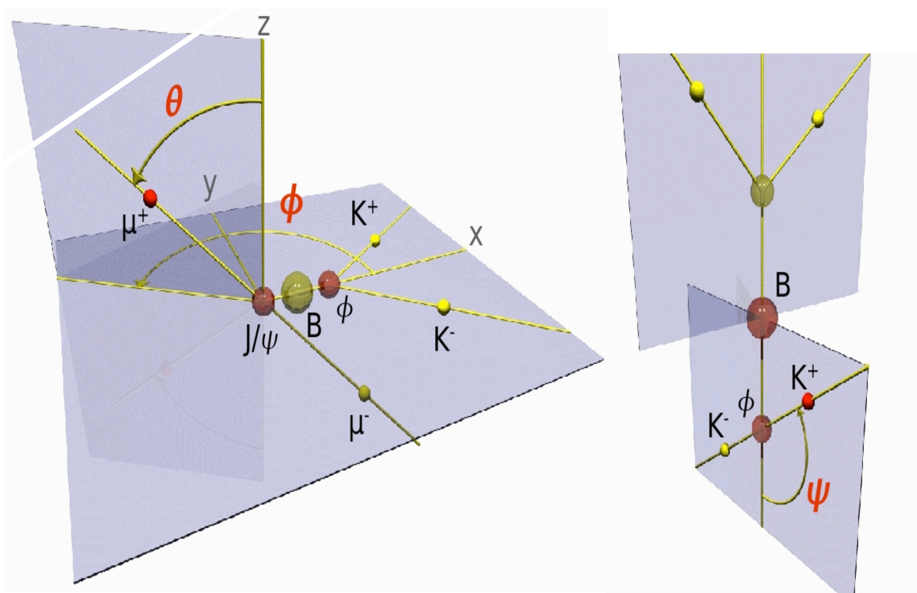
β_s measurement in $B^0_s \rightarrow J/\psi\phi$

B^0_s (pseudoscalar) $\rightarrow J/\psi$ (vector) ϕ (vector): Final states CP-even (S or D-wave, short-lived and light) and CP-odd (P-wave, long-lived, heavy).



- Exploit β_s depencence of decay rate to CP-even and CP-odd final states

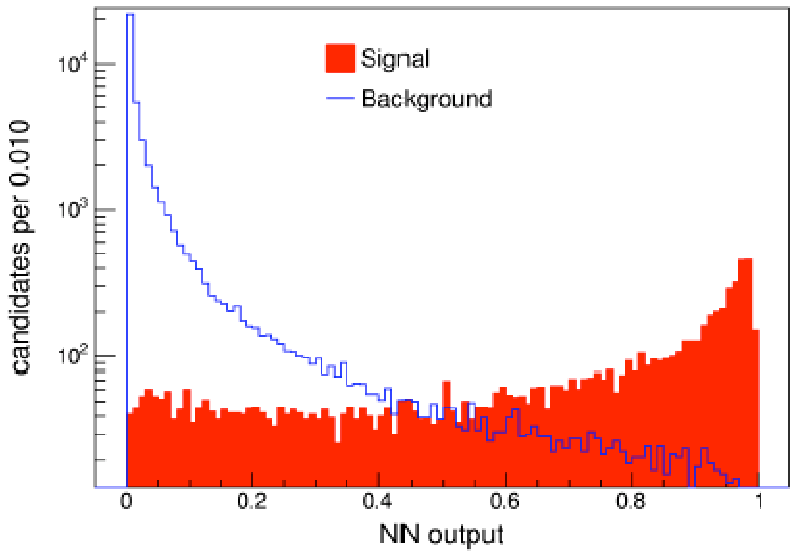
- Angular correlations (transversity basis) → separation of CP-components.



Transversity basis: (θ, Φ, Ψ)

$B^0_s \to J/\psi\phi$ Signal reconstruction

Reconstruct $B^0_s \to J/\psi(\to\mu\mu)\phi(\to K+K-)$ in 1.35 fb-1. NN maximizes $S/\sqrt{(S+B)}$. Trained on MC for signal and mass sidebands for background

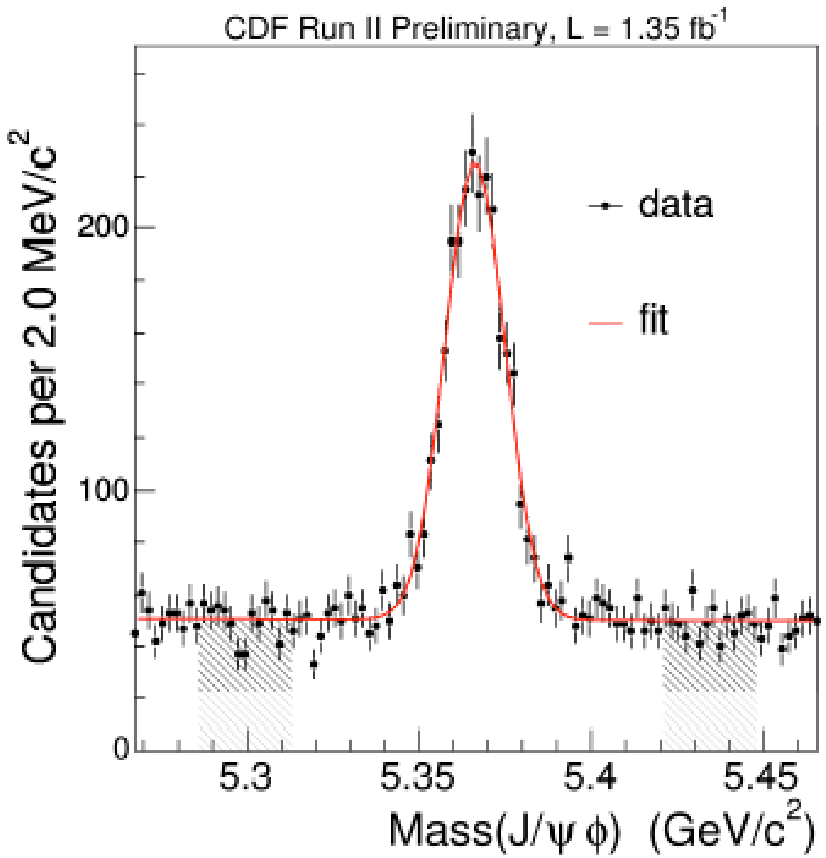


B^0_s use p_T and vertex quality

J/ψ use p_T and vertex prob.

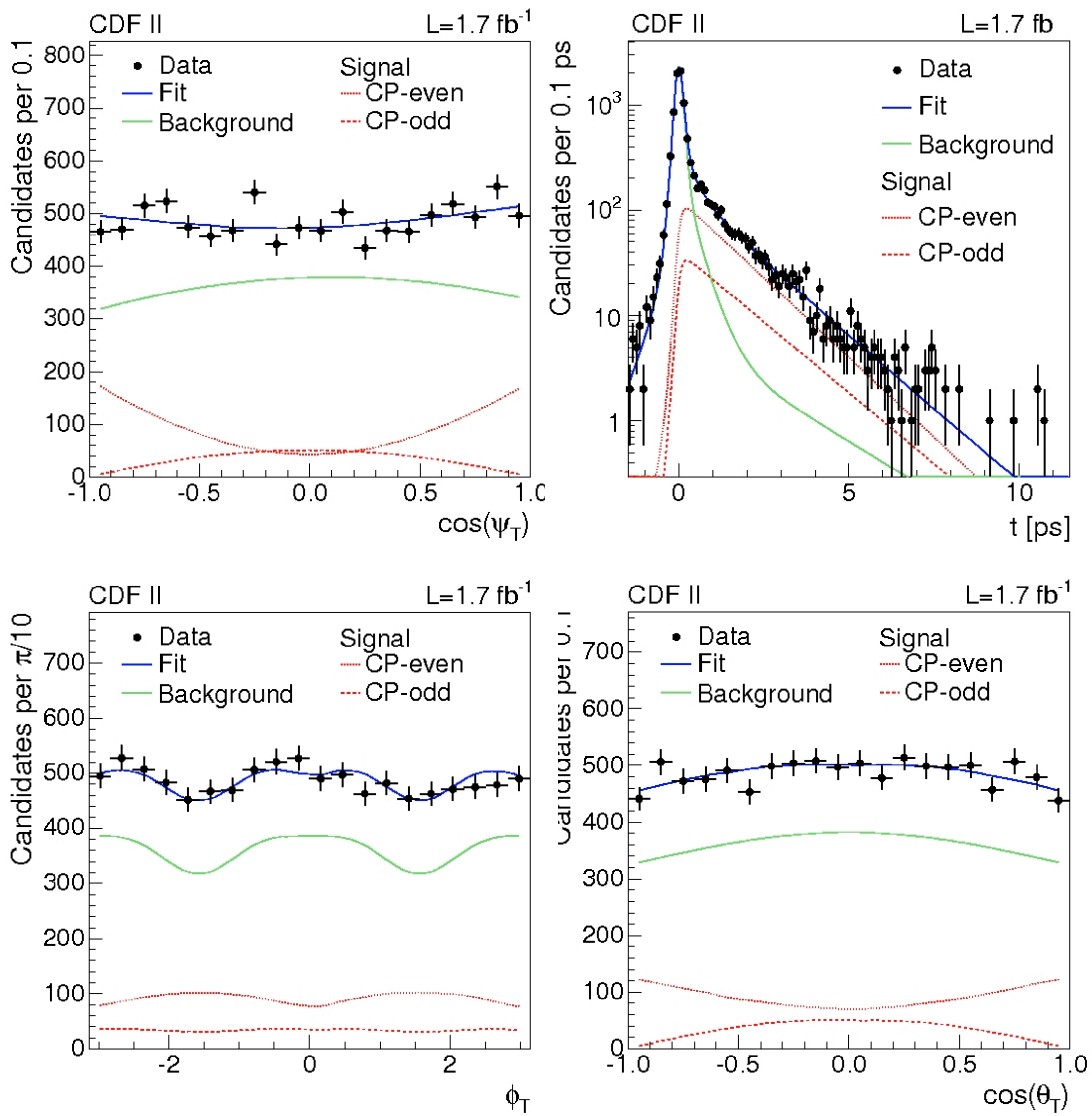
ϕ use mass and vertex qual.

PID (dE/dx + TOF) K from ϕ



~2000 decays, S/B~2

Angular/Lifetime variables



First step: untagged measurement
(β_s fixed to Standard Model value)

$\tau(B^0_s)$=1.52±0.04 (stat.)±0.02 (syst.) ps

$\Delta\Gamma$=0.076 +0.059-0.063 ± 0.006 ps^{-1}

Best $\Delta\Gamma$ and $\tau(B^0_s)$ world measurement

(PRL 100:121803, 2008)

More details in
Chunlei Liu, "Lifetimes and Mixing"

B flavor tagging

OST: exploits the decay products of the other b-hadron in the event

SST: exploits the charge/species correlations with associated particles produced in fragmentation that results in the reconstructed meson

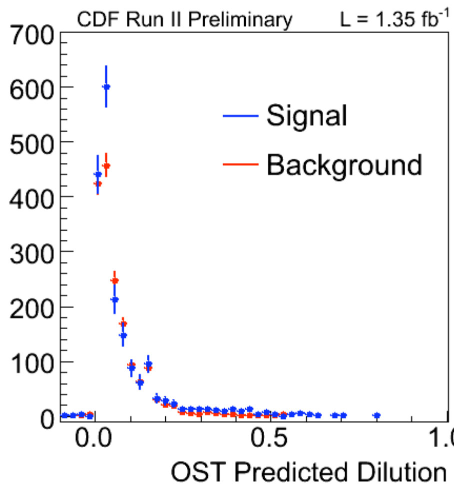
OST: calibrated on fully rec. B^+ sample

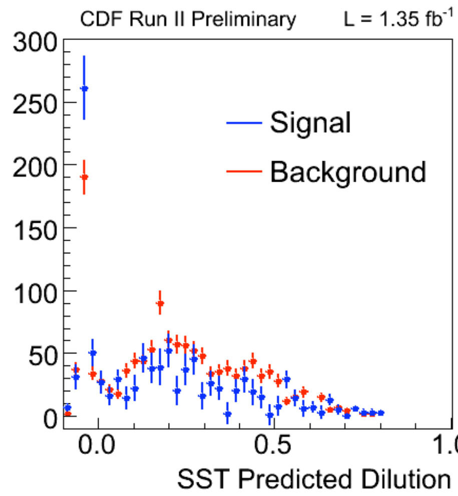
SST: calibrated on MC, (but checked on B^0_s mixing measurement)

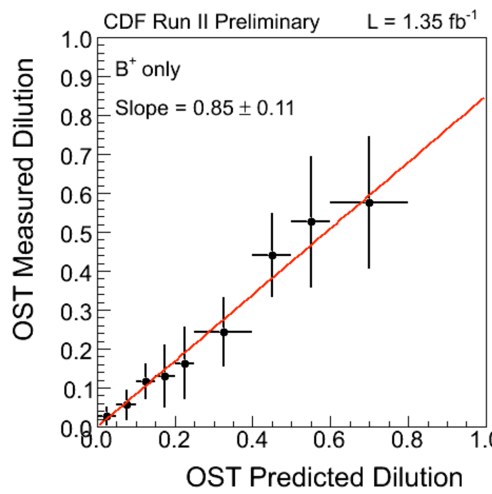
OST efficiency: 96 ± 1%
OST dilution: 11 ± 2%

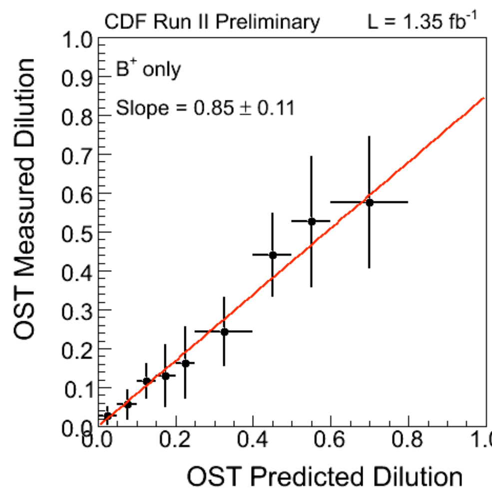
SST efficiency: 50 ± 1%
SST dilution: 27 ± 4%

Total: $\varepsilon D^2 \sim 4\%$









$\Delta\Gamma-\beta_s$ results

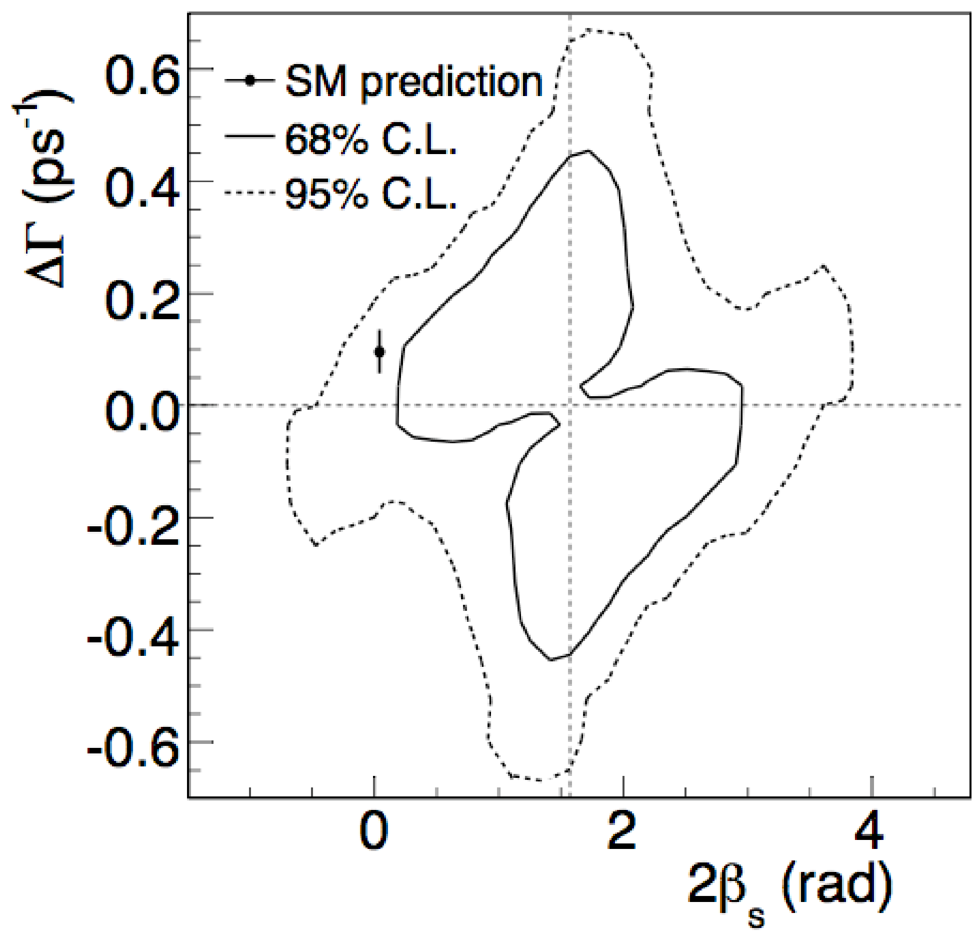
• Confidence region with profile-Lilkelihood Ratio ordering and rigorous frequentist inclusion of systematic uncertainties

• 2D region is projection of a multidimensional region in the space of all (27) fit parameters

• Assuming the SM, the probability of observing a fluctuation as large or larger than what observed in data is 15% (P-value), corresponding to a 1.5σ effect

• D0 finds similar deviation in 2.8 fb^{-1}

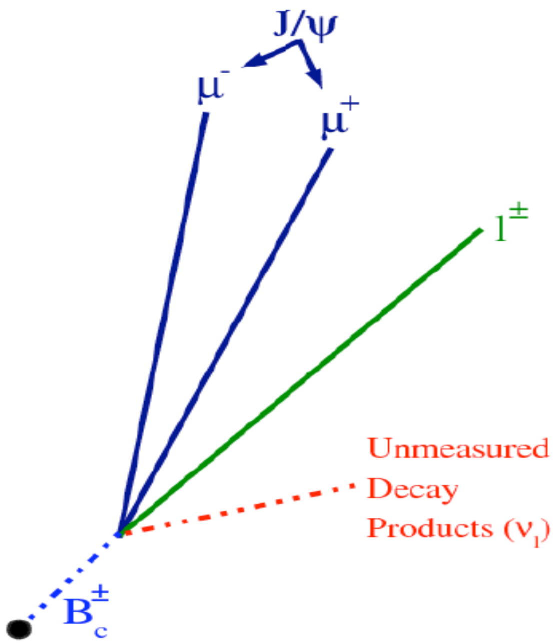
• UTfit Collaboration claims evidence of New Physics: arXiv:0803.0659v1[hep-ph]

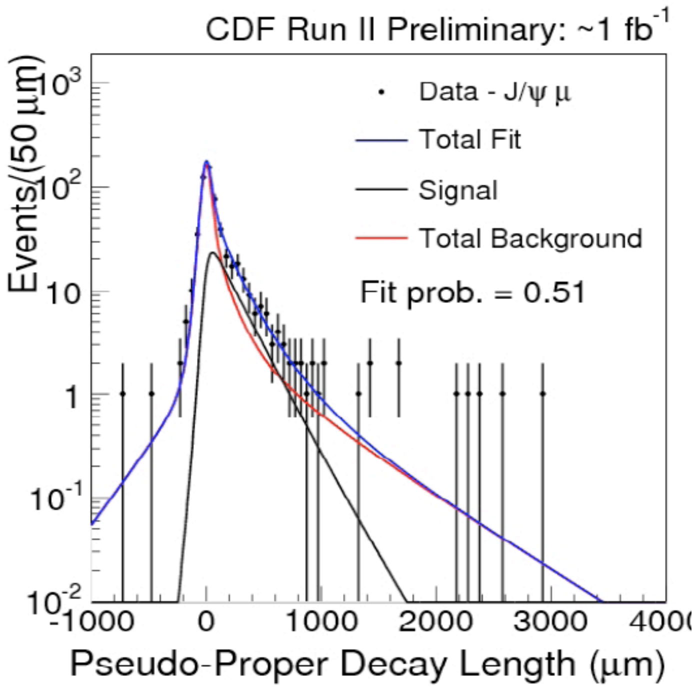


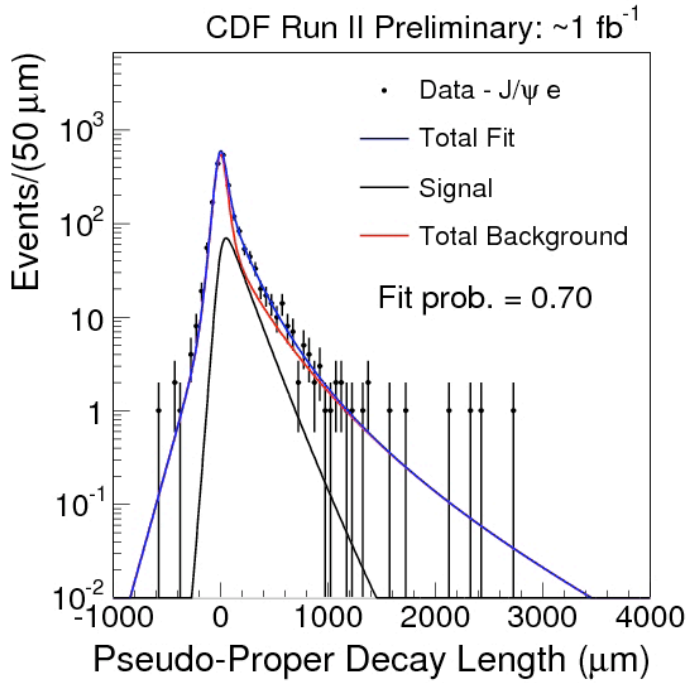
PRL 100, 161802, 2008

B_c Lifetime in $B_c \rightarrow J/\psi l X$

- Both b and c quark decay/annihilate → B_c lifetime shorter than lighter B species
- Prediction: $\tau(B_c) = 0.47 - 0.59$ ps [arXiv:hep-ph/0308214v1]







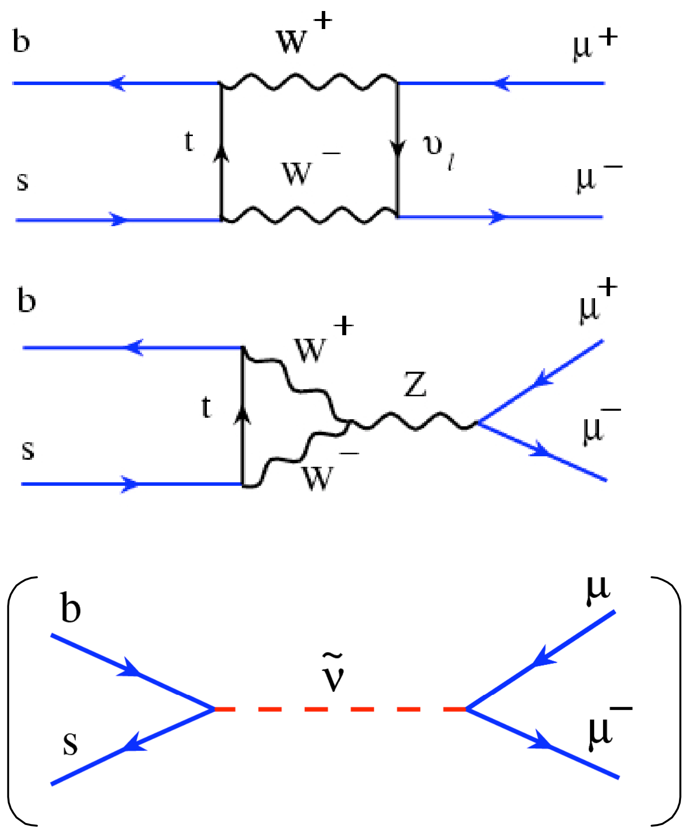
- Use $B_c \rightarrow J/\psi l X$ (correct for missing momentum $ct = \frac{L_{xy} \cdot m_B^{rec}}{p_T} \cdot \boxed{K}$)

$$\tau(B_c) = 0.475\ {}^{+0.053}_{-0.049}(stat) \pm 0.018(syst)\ \text{ps}$$

More details in Chunlei Liu, "Lifetimes and Mixing"

Search for $B^0_{(s)} \rightarrow \mu\mu$: motivations

- Strongly suppressed in the SM:
  - FCNC mediated only by loop or penguin processes
  - Internal loops involve transitions suppressed by CKM
- Many NP models can increase the BR
- CDF is not expected to see any signal in SM hypothesis
  - Any excess will be a NP hint
- Analysis uses 2 fb^{-1} of data coming from di-muon trigger

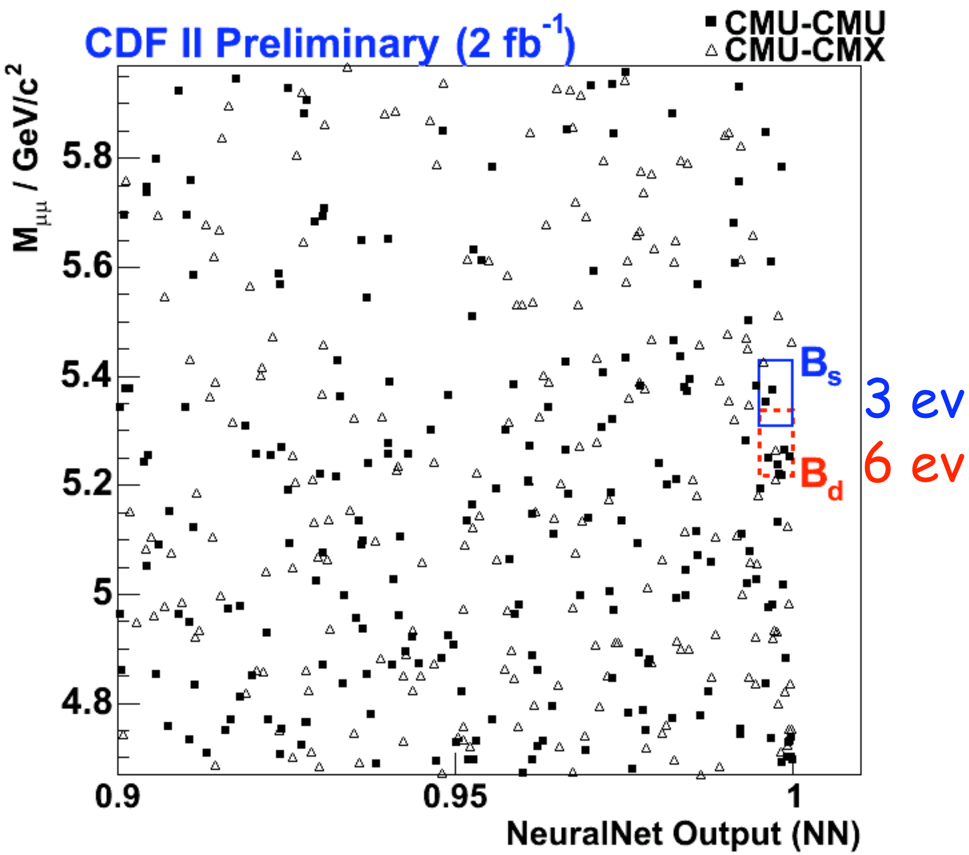


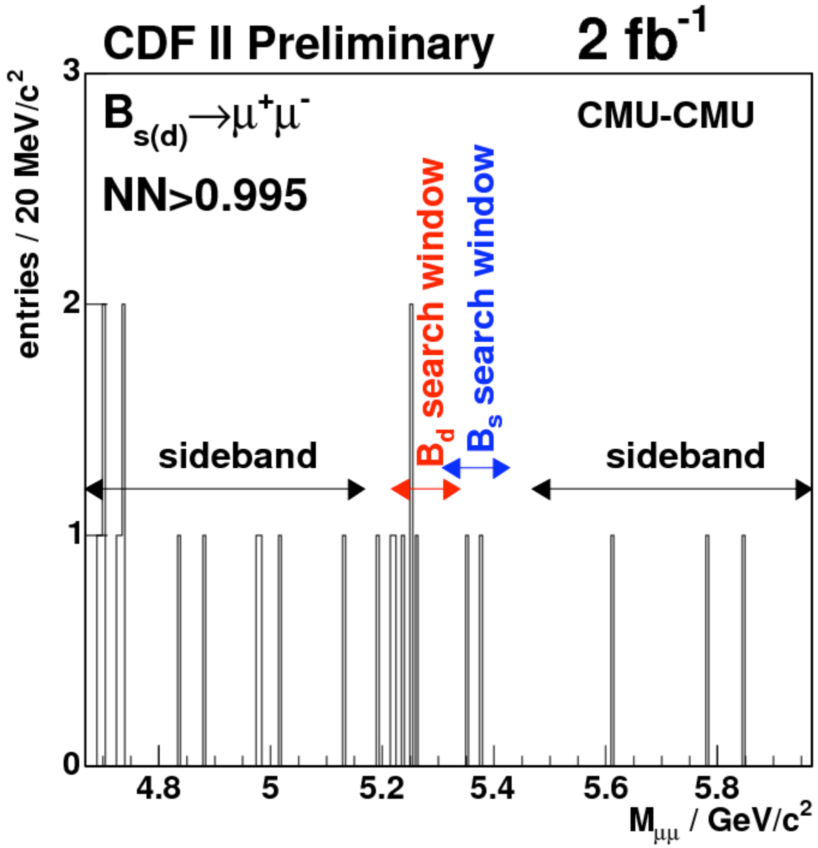
$BR(B^0_{(s)} \rightarrow \mu\mu) = (3.4 \pm 0.5) \times 10^{-9}$

A. Buras Phys. Lett. B 566,115

$BR(B^0 \rightarrow \mu\mu) = (1.00 \pm 0.14) \times 10^{-10}$

Search for $B^0_{(s)} \rightarrow \mu\mu$: results





$Br(B_s \rightarrow \mu\mu) < 5.8 \times 10^{-8}$ @ 95% CL

$< 4.7 \times 10^{-8}$ @ 90% CL

$Br(B_d \rightarrow \mu\mu) < 1.8 \times 10^{-8}$ @ 95% CL

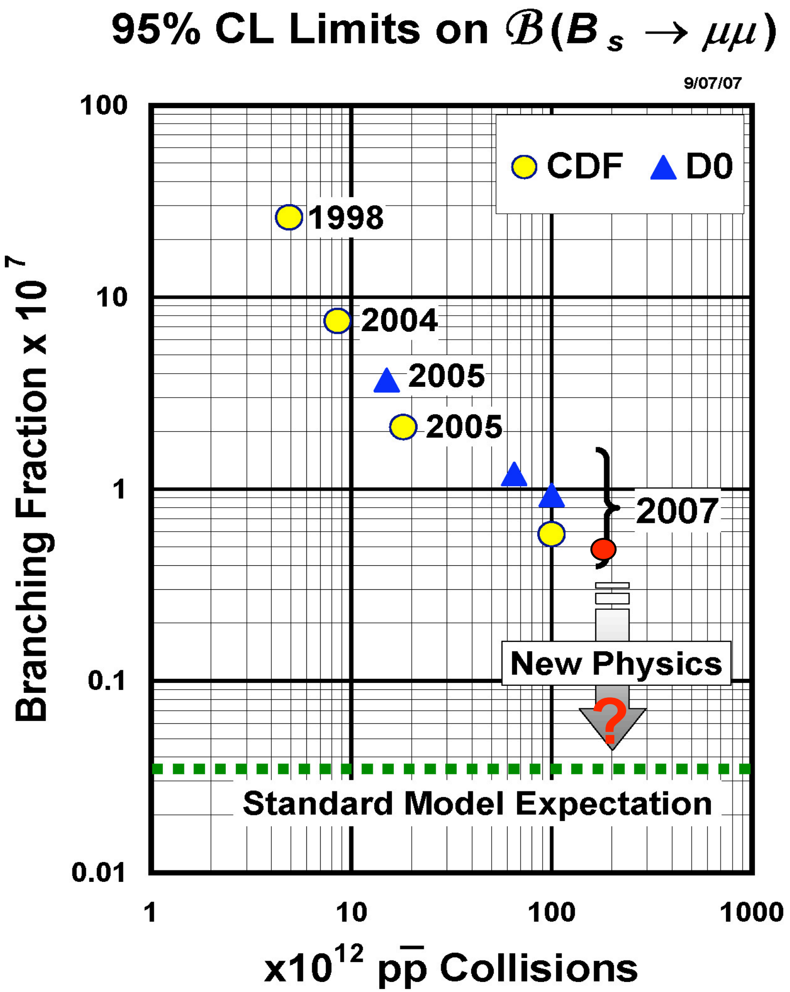
$< 1.5 \times 10^{-8}$ @ 90% CL

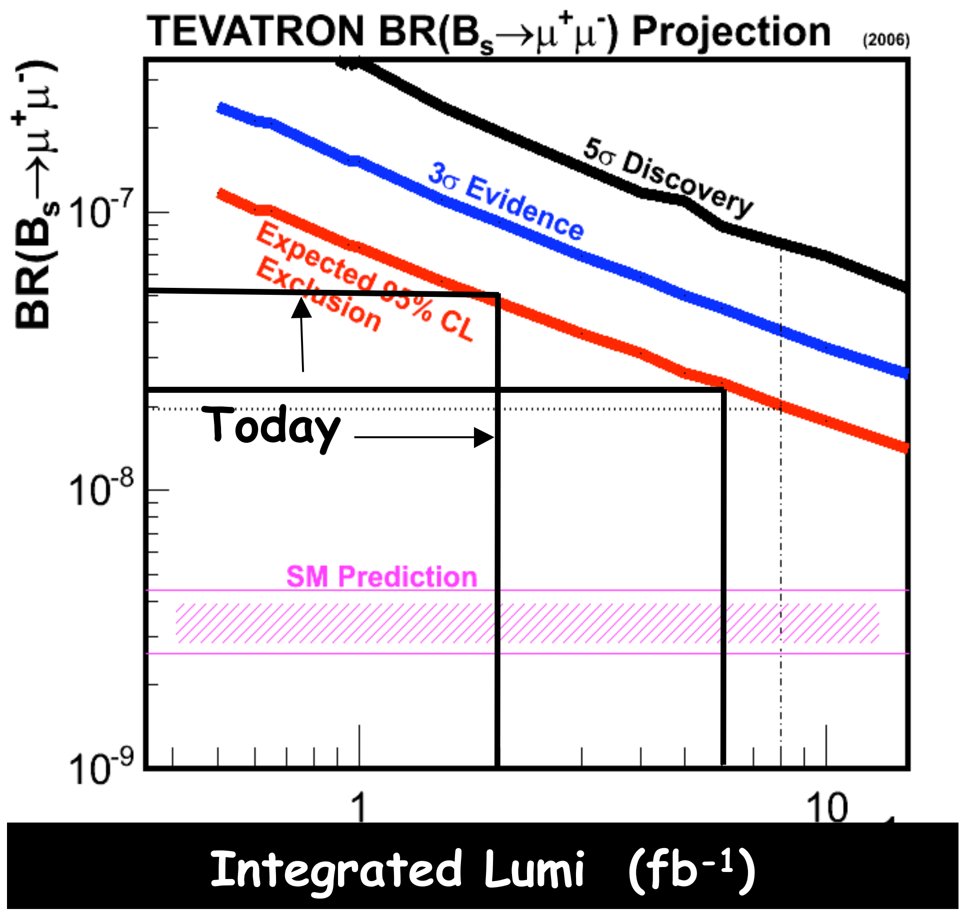
World Best Limits

In case of observation CDF mass resolution allows to separate B^0 from B^0_s

PRL 100:101802,2008

Tevatron sensitivity for $B^0_s \to \mu\mu$





- BR < 2.5×10^{-8} with 6 fb-1. corresponds to **7xSM**.

(Conservative estrapolation based on the actual analysis, not generic simulations)

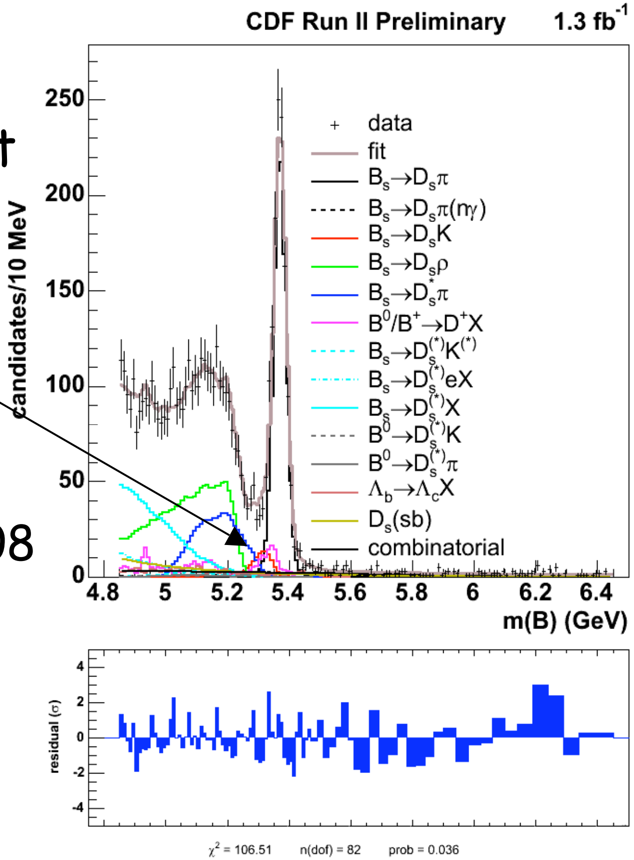
$B^0_s \to D_s\pi$ Lifetime

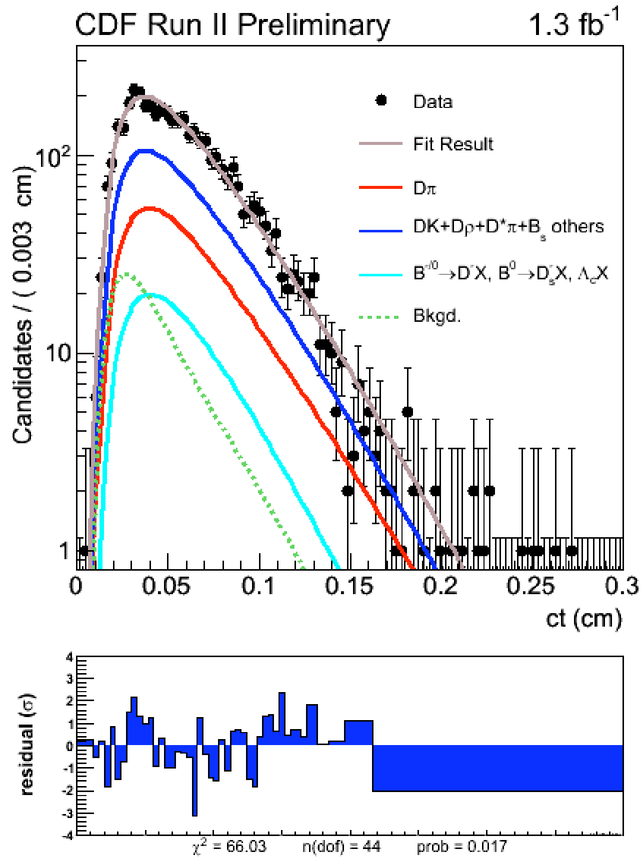
First B^0_s lifetime measurement in hadronic sample

(Evidence of $B^0_s \to D_sK$ from previous analysis)

$$\frac{BR(B^0_s \to D_sK)}{BR(B^0_s \to D_s\pi)} = 0.107 \pm 0.019 \pm 0.008$$

See Chunlei Liu's talk "Lifetime and Mixing"



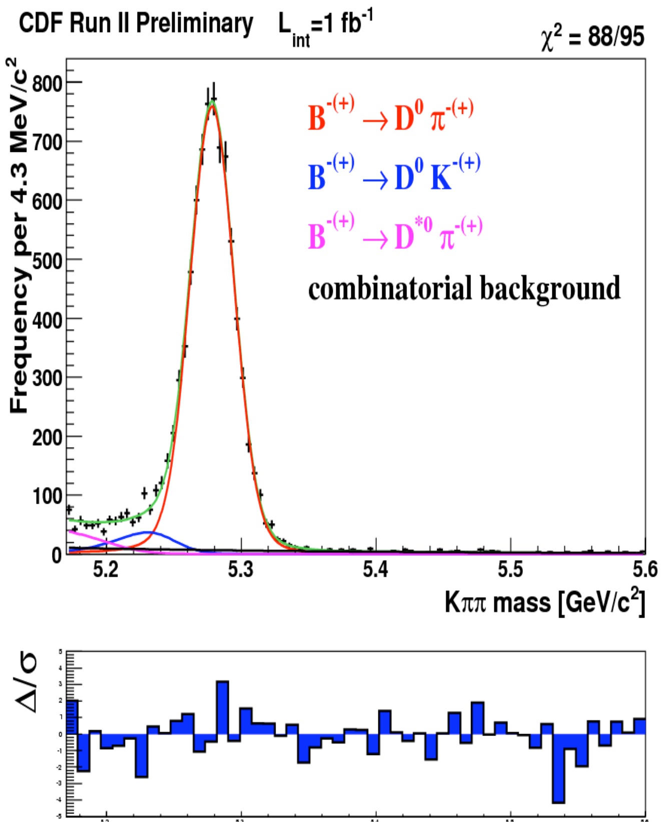


- First measurement in hadronic sample (crosscheck with $B^0 \to D^-\pi^+$, $B^+ \to D^0\pi^+$)
  - ~ 1100 fully reconstructed $B^0_s \to D_s\pi$ decays
  - **~ 2000 partially reconstructed $B^0_s \to D_s\pi/\rho$ decays**
  - $c\tau(B^0_s) = 455.0 \pm 12.2$ (stat.) ± 7.4 (syst.) μm (most precise meas. to date)

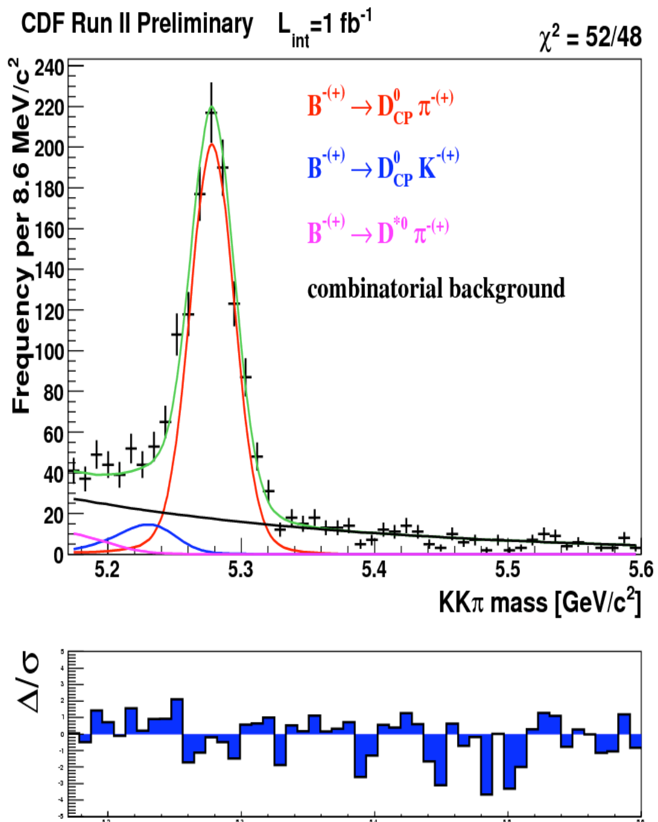
BR and A_{CP} in $B^+ \rightarrow D^0_{CP} K^+$

- Motivation: theoretically clean Measurement of CKM angle γ via GLW (Gronau-London-Wyler) method *[PLB253,483 and PLB265,172]*
- Method: Unbinned kinematics+dE/dx fit, simultaneous of modes $B^+ \rightarrow D^0 K^+$ with $D^0_{CP} \rightarrow K^+K^- / \pi^+\pi^-$ and $D^0_{flav} \rightarrow \pi^+ K^-$

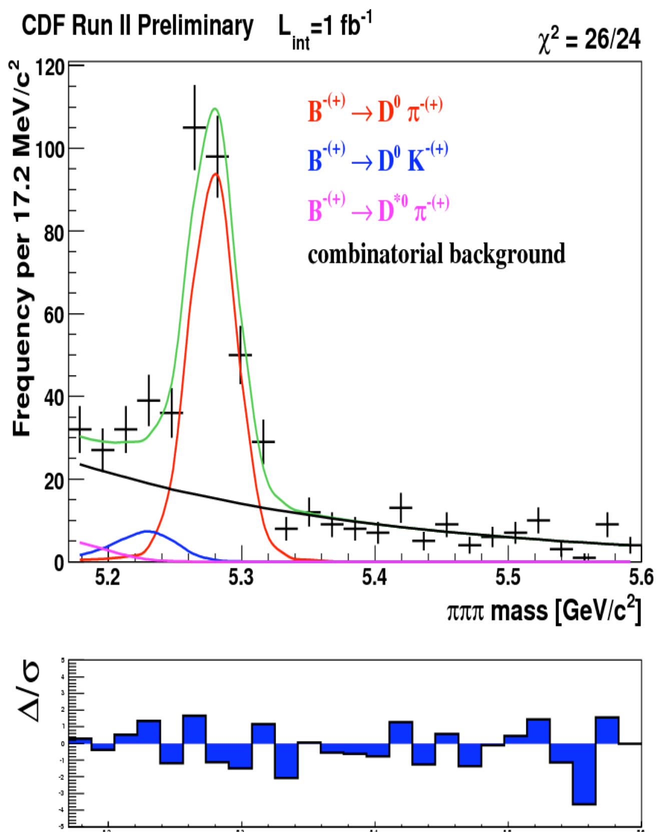
$B^+ \rightarrow D^0 K^+ \rightarrow [\pi^+ K^-] K^+$
~516 events



$B^+ \rightarrow D^0 K^+ \rightarrow [K^+ K^-] K^+$
~103 events



$B^+ \rightarrow D^0 K^+ \rightarrow [\pi^+ \pi^-] K^+$
~26 events

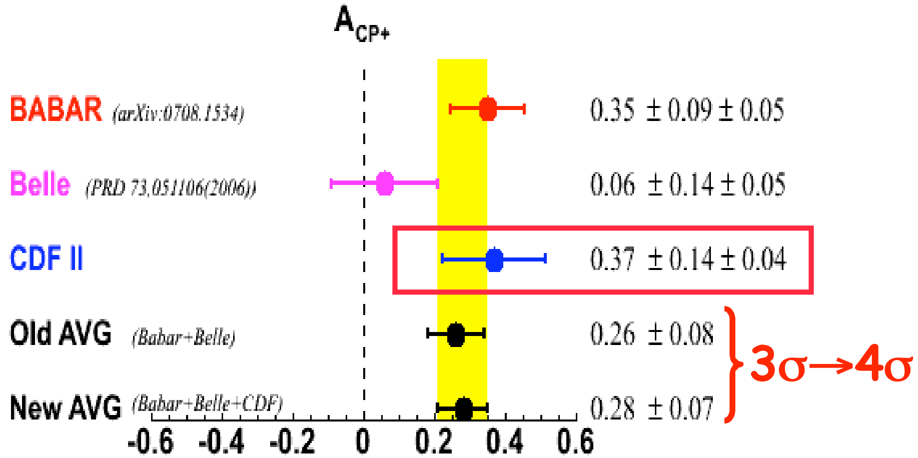


BR and Acp in B → D^0K

$$R = \frac{BR(B^- \to D^0K^-) + BR(B^+ \to \overline{D}^0K^+)}{BR(B^- \to D^0\pi^-) + BR(B^+ \to \overline{D}^0\pi^+)} = 0.0745 \pm 0.0043(stat.) \pm 0.0045(syst.)$$

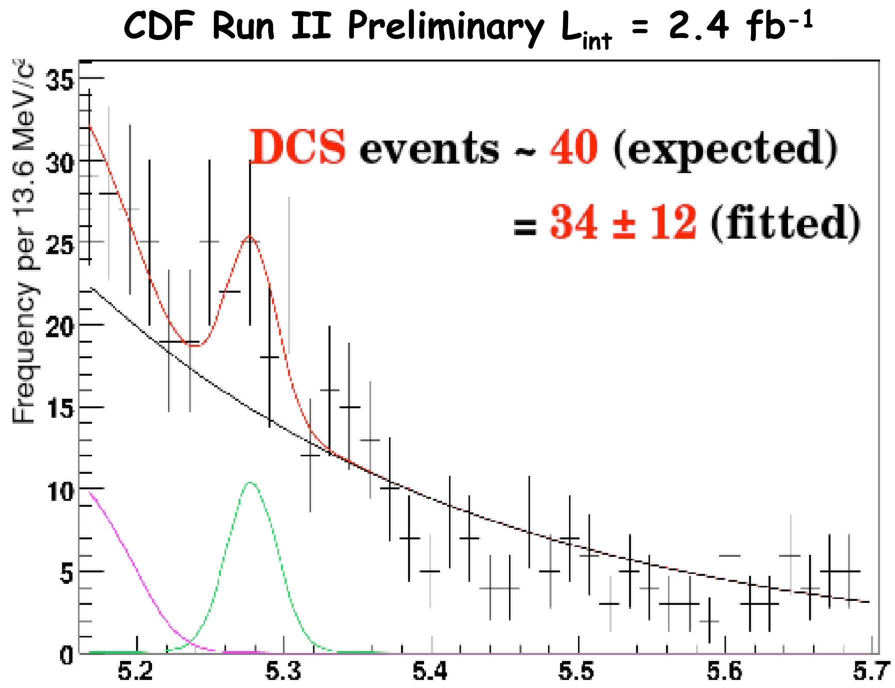
$$R_{CP+} = \frac{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)}{[BR(B^- \to D^0K^-) + BR(B^+ \to \overline{D}^0K^+)]/2} = 1.57 \pm 0.24(stat.) \pm 0.12(syst.)$$

$$A_{CP+} = \frac{BR(B^- \to D^0_{CP+}K^-) - BR(B^+ \to D^0_{CP+}K^+)}{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)} = 0.37 \pm 0.14(stat.) \pm 0.04(syst.)$$



- A first at a hadron collider, with 1 fb^{-1} achieved same precision of e^+e^- experiments
- Next step: combine with ADS method to extract γ *[PRD63,036005 , PRL78,3257]*

- First evidence of $B^+ \to D_{DCS}\,\pi^+$ in 2.4 fb^{-1} (Preliminary result, no kinematics/dE/dx but only mass info used in the fit)



BRs of $\Lambda^0_b \to pK/\pi$ decays

$$\frac{\sigma(\bar{p}p \to \Lambda_b^0 X) \times BR(\Lambda_b^0 \to p\pi^-)}{\sigma(\bar{p}p \to B^0 X) \times BR(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074(\text{stat.}) \pm 0.0058(\text{syst.})$$

$$\frac{\sigma(\bar{p}p \to \Lambda_b^0 X) \times BR(\Lambda_b^0 \to pK^-)}{\sigma(\bar{p}p \to B^0 X) \times BR(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089(\text{stat.}) \pm 0.0084(\text{syst.})$$

Using the PDG value $f_{baryon}/f_d = 0.25 \pm 0.04$

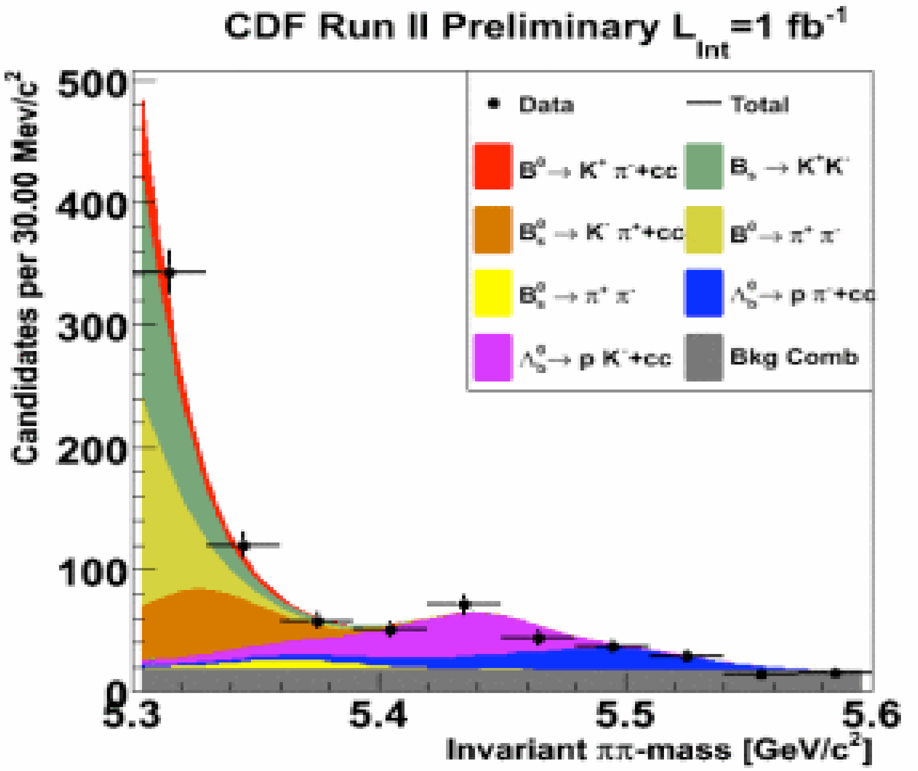
$BR(\Lambda_b^0 \to pK) = (5.0 \pm 0.7 \pm 1.0) \times 10^{-6}$

$BR(\Lambda_b^0 \to p\pi) = (3.1 \pm 0.6 \pm 0.7) \times 10^{-6}$

Predictions:

$BR(\Lambda_b^0 \to pK) = 2 \times 10^{-6}$

$BR(\Lambda_b^0 \to p\pi) = 1 \times 10^{-6}$

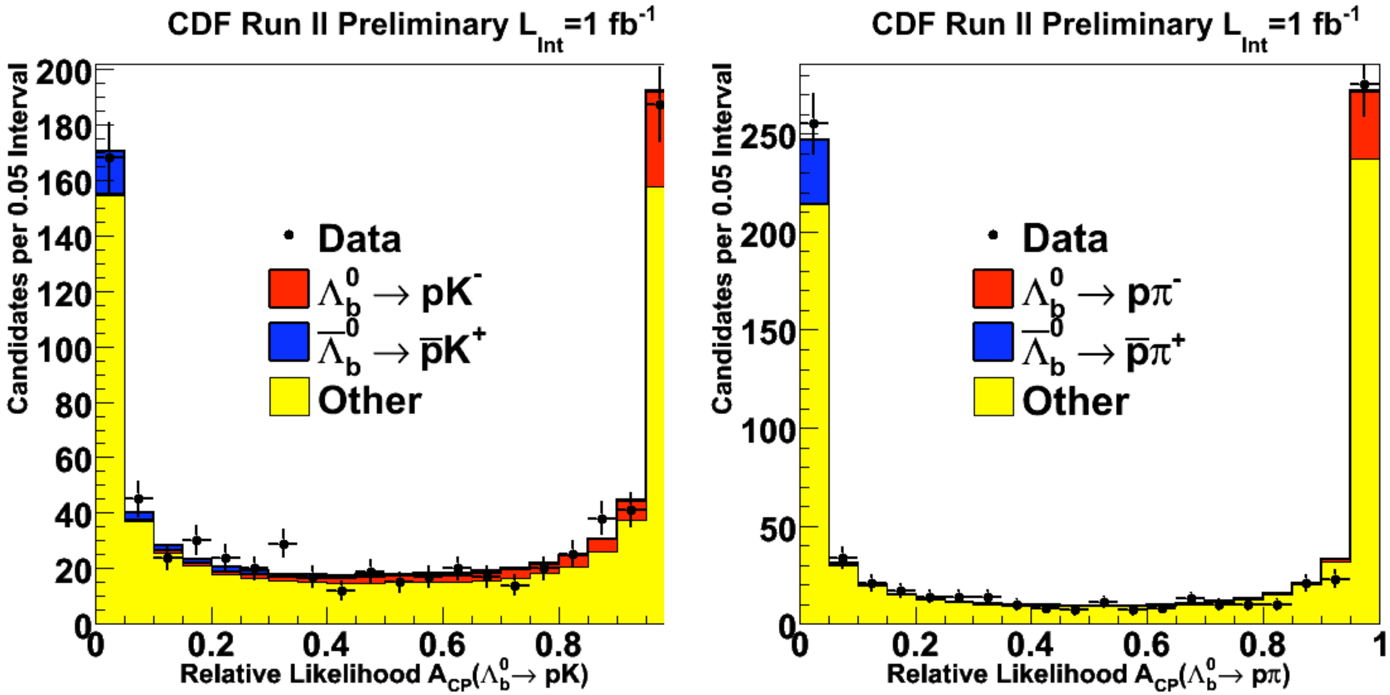


First BR measurement of Charmless Λ^0_b decays

See also Andreas Warburton, "Bs/b-baryon decays"

A_{cp} in $\Lambda^0_b \rightarrow pK/\pi$ decays

$$RL = \frac{\text{pdf}\ (\Lambda_b{}^0)}{\text{pdf}\ (\Lambda_b{}^0) + \text{pdf}\ (\overline{\Lambda}_b{}^0)}$$



$$ACP(\Lambda_b{}^0 \rightarrow p\pi) = \frac{BR(\Lambda_b{}^0 \rightarrow p\pi) - BR(\Lambda_b{}^0 \rightarrow p\pi)}{BR(\Lambda_b{}^0 \rightarrow p\pi) + BR(\Lambda_b{}^0 \rightarrow p\pi)} = 0.03 \pm 0.17(\text{stat.}) \pm 0.05(\text{syst.})$$

2.1σ

$$ACP(\Lambda_b{}^0 \rightarrow pK) = \frac{BR(\Lambda_b{}^0 \rightarrow pK) - BR(\Lambda_b{}^0 \rightarrow pK)}{BR(\Lambda_b{}^0 \rightarrow pK) + BR(\Lambda_b{}^0 \rightarrow pK)} = 0.37 \pm 0.17(\text{stat.}) \pm 0.03(\text{syst.})$$

First CPV measurement in Λ^0_b decays

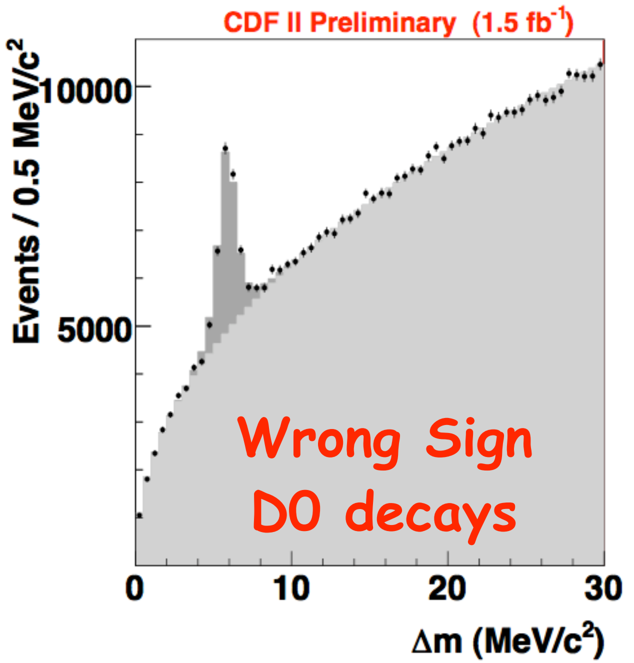
See also Michael Kreps, "Direct CP violation in B decays"

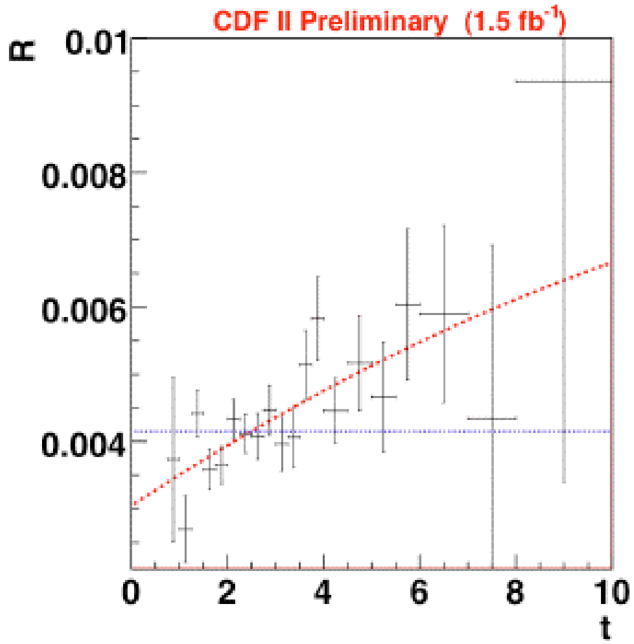
Charm Mixing

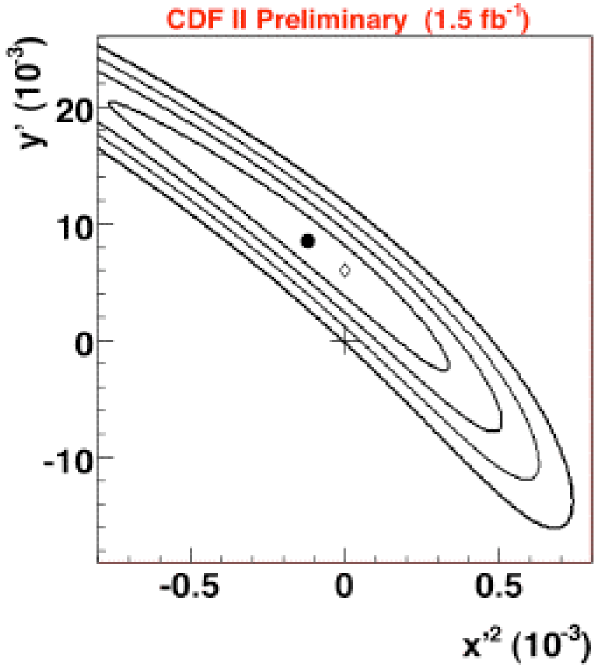
- Charm mixing small in Standard Model, sign of new physics if mixing oscillation different from expected: first evidence from B Factories

- Use large $D^* \to \pi_{soft} D^0$ ($D^0 \to K\pi$) samples from hadronic trigger

- Binned fit to WS/RS versus D^0 decay time: $R(t) = R_D + y'\sqrt{R_D}\,t + \frac{x'^2 + y'^2}{4} t^2$



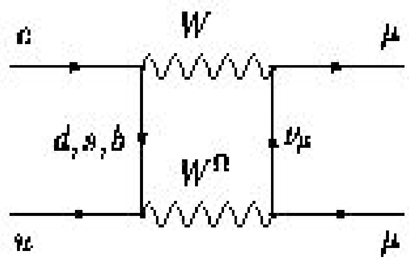


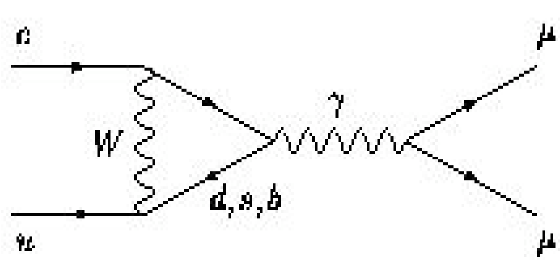


CDF observes a 3.8σ effect, see also Chunlei Liu's talk, "Lifetime and Mixing"

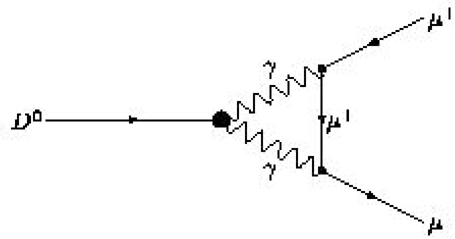
PRL 100:121802, 2008

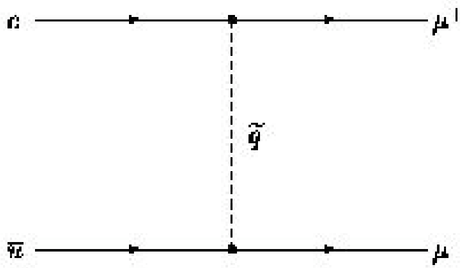
Search for $D^0 \rightarrow \mu\mu$



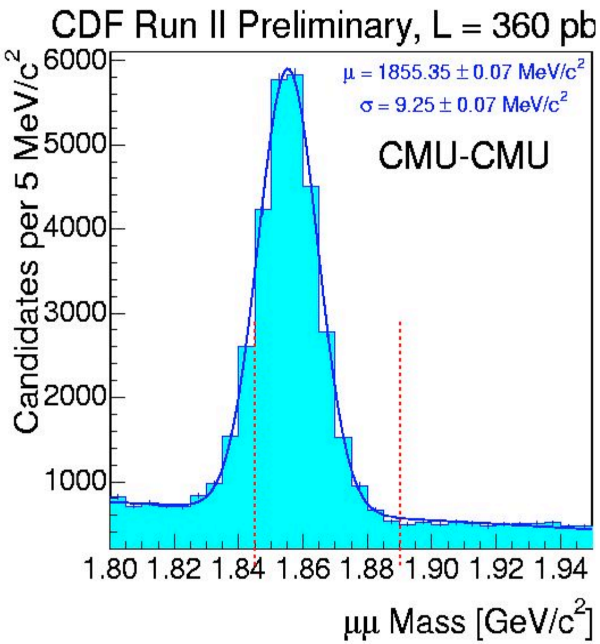


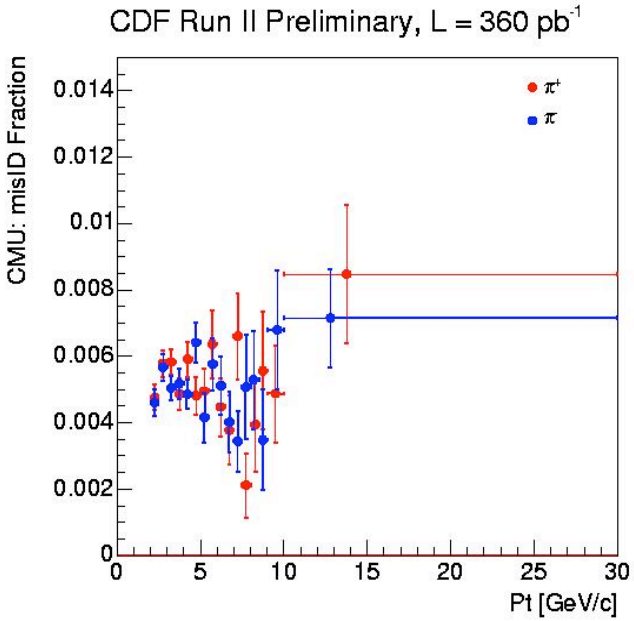
- FCNC in D mesons area
- Greatly suppressed in SM
  - Short-distance interaction suppressed by GIM mechanism: BR ~ 10^{-18}
  - Long-distance interaction up to ~10^{-13}
  - R-parity violating SUSY up to 10^{-6}
- Analysis based on 360 pb^{-1} of data from displaced track trigger



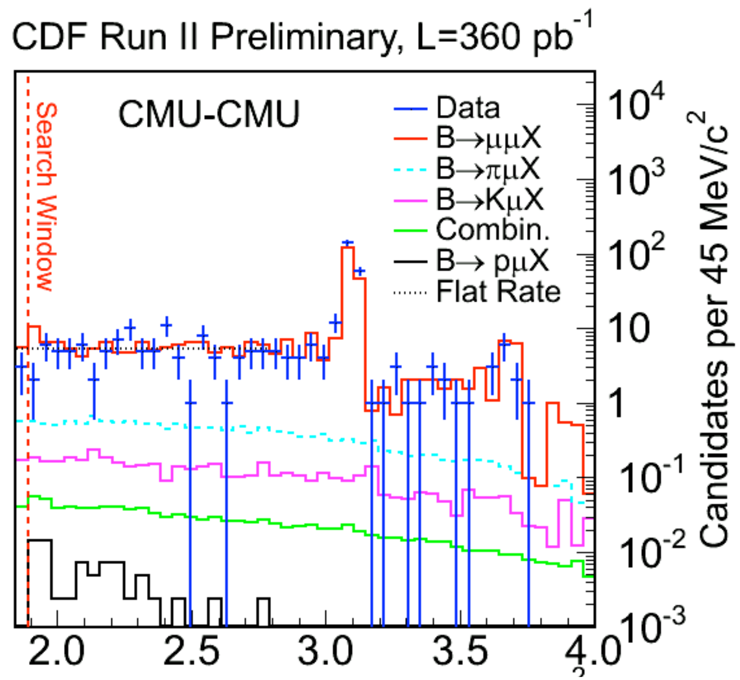


Search for $D^0 \to \mu\mu$: results





- Normalise to $D^0 \to \pi\pi$
- Bck suppression from D*
- μ miss-tag from $D^0 \to K\pi$
- Main bck due to $B \to \mu\mu X$



- No significant excess found
- Set world best (bayesian) limits:
  - BR($D^0 \to \mu\mu$) < 5.3×10^{-7} @95 % CL
  - BR($D^0 \to \mu\mu$) < 4.3×10^{-7} @90% CL

Conclusions

- **CDF is performing highly specialised/third generation analyses**
  - β_s measurement already got some relevance in the community
  - B_c lifetime in semileptonic decays
  - World best limit on $BR(B^0_{(s)} \to \mu\mu)$, world best $B^0_{(s)}$ lifetime measurement
  - BRs and CP in $B \to DK$ and $\Lambda^0_b \to pK/\pi$
  - Charm Mixing (3.8σ effect), world best limit ot $BR(D^0 \to \mu\mu)$ rare decay
- **More results/details in the following talks**
  1) Chunlei Liu, "Lifetimes and Mixing"
  2) Andreas Warburton, "Bs/b-baryon decays"
  3) Michael Kreps, "Direct CP violation in B decays"
- **And a lot more results expected in the next few years (3 fb^{-1} already on tape, expect 2x more data in 2009-2010)**