B lifetimes, CP violation and rare decays at Tevatron

for the CDF and DØ Collaborations
16 Okt 2006, HQL06

- Introduction
- Tevatron Experiments
- Results
- Summary

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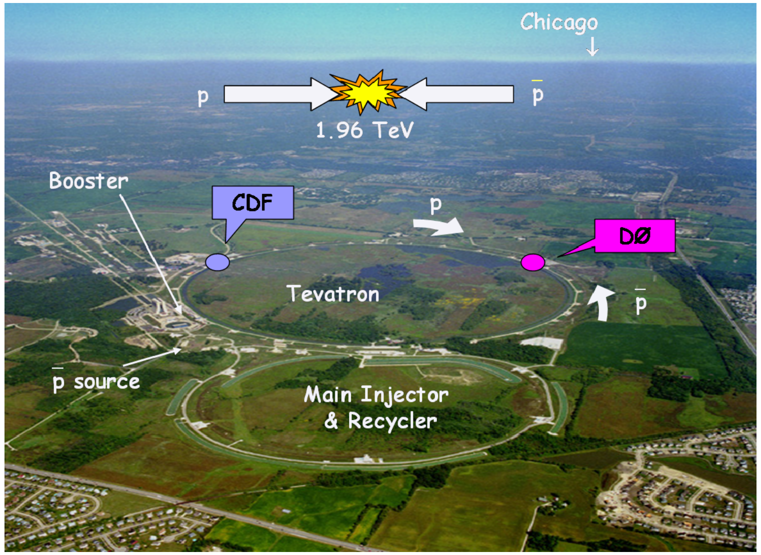
The Tevatron



- The Tevatron is a $p\bar{p}$ collider at $\sqrt{s}$ = 1.96 TeV.
- Large cross section:

  $\sigma(p\bar{p} \to bX) \approx 100\,\mu b$

- $O(10^5)$ larger than e^+e^- at $\Upsilon(4S)/Z^0$
- Production of all kind of B hadrons e.g. $B^{\pm}$, B^0 , B_s, B_c, Λ_b, ...
- Total inelastic x-section is $\sim 10^3 \times \sigma(b\bar{b})$
  $\rightarrow$ Messy enviroment with large combinatorics
  $\rightarrow$ need for highly selective trigger.

Tevatron experiments

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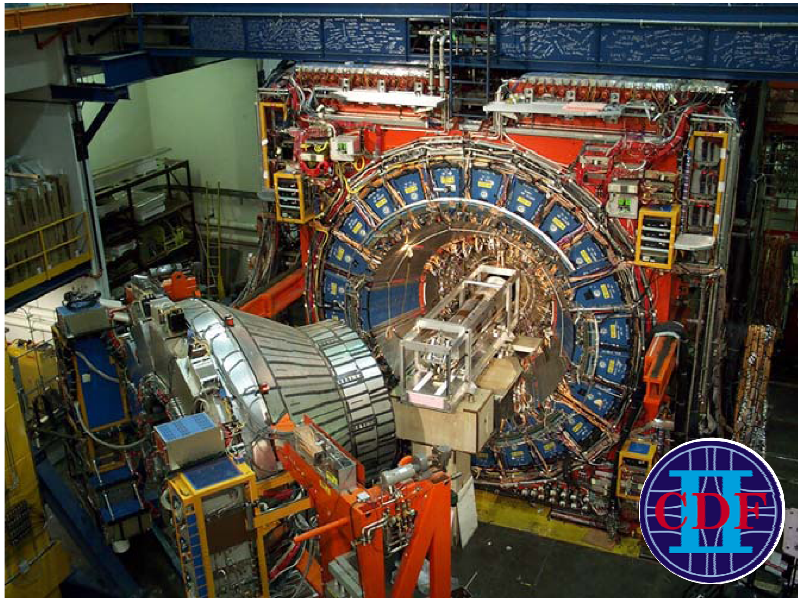
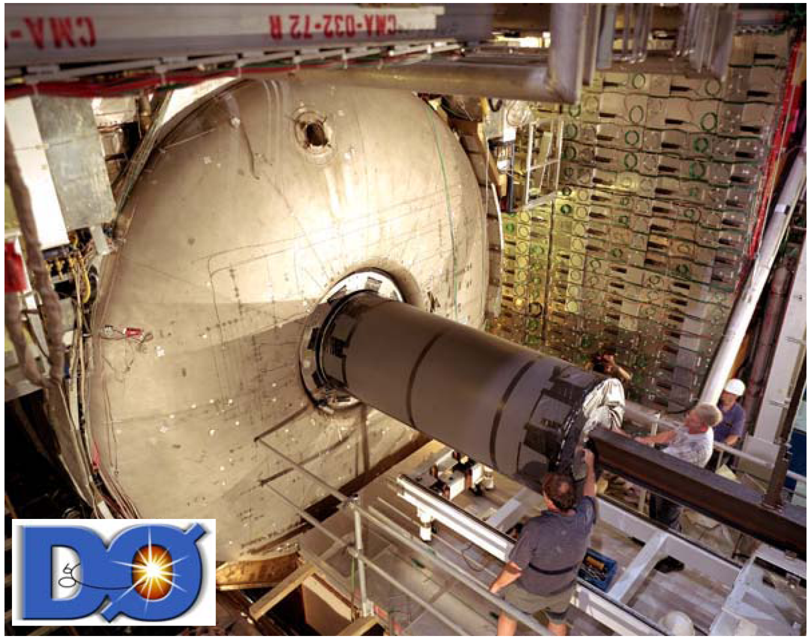
¬ Both detectors:

- silicon microvertex detectors
- central tracking in solenoid
- EM and Had calorimeters
- muon system
- high rate trigger/DAQ system





¬ DØ:

- excellent muon ID and trigger at L1
- excellent tracking acceptance

¬ CDF:

- particle ID (ToF and dE/dx)
- displaced track trigger at L2
- excellent mass resolution

Outline

¬ Many interesting B Physics results has been produced and already published by CDF and DØ Collaborations

¬ Concentrate on selected latest results for:

- B Lifetime measurements
- CP violation measurements
- Search for rare B decays

¬ B_s Lifetime Difference and Mixing (Tuesday, 17th of october : Stephanie Menzemer)

¬ Spectroscopy and decays of B hadrons (Thursday, 19th of october : Manfred Paulini)

B Lifetime measurements

Interests in B hadron lifetimes

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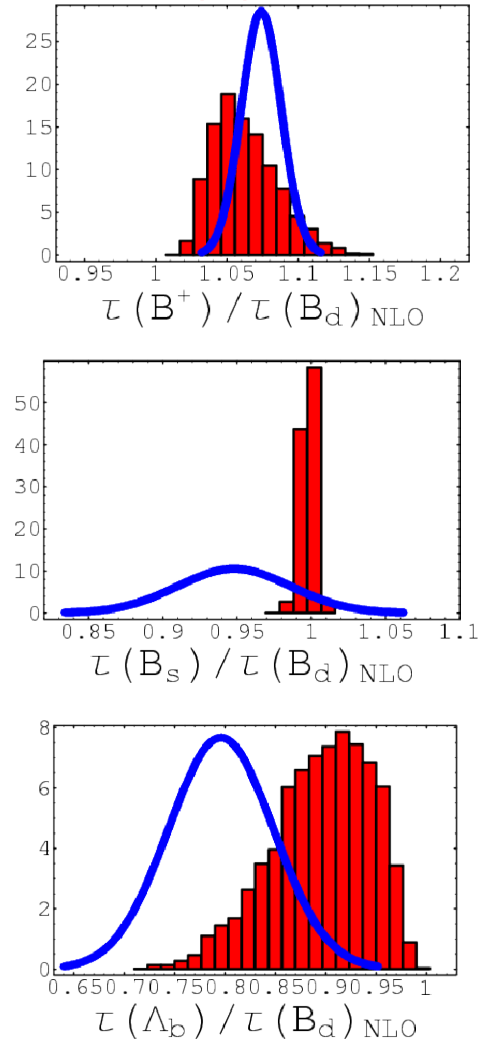
- Test of non-spectator effects in decays of heavy hadrons which give rise to lifetime hierarchy:

  $t(B^+) \geq t(B^0) \approx t(B_s^0) > t(\Lambda_b) \gg t(B_c)$

- Heavy Quark Expansion includes these effects (expansion in $1/m_b$) and predicts lifetime ratios:
  - $t(B^+)/t(B^0) = 1.00 \pm 0.05 \times (f_B/200\ \mathrm{MeV})^2$
  - $t(B_s^0)/t(B^0) = 1.00 \pm 0.01$
  - $t(\Lambda_b)/t(B^0) \sim 0.9$
- The B^+,B^0 lifetimes are precisely measured at B-factories. Λ_b and B^0_s ratios can be measured at Tevatron.

C. Tarantino, hep-ph/0310241



Λ_b Lifetime in Λ_b à J/ψ Λ

- 538 ± 38 Λ_b events

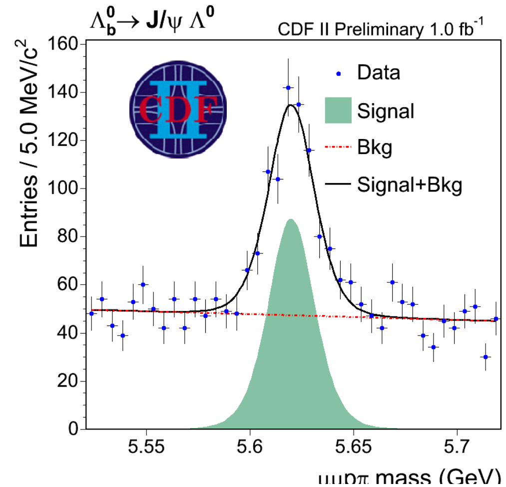
$$\tau(\Lambda_b) = 1.593^{+0.083}_{-0.078}\ (\text{stat}) \pm 0.033\ (\text{syst})\ \text{ps}$$

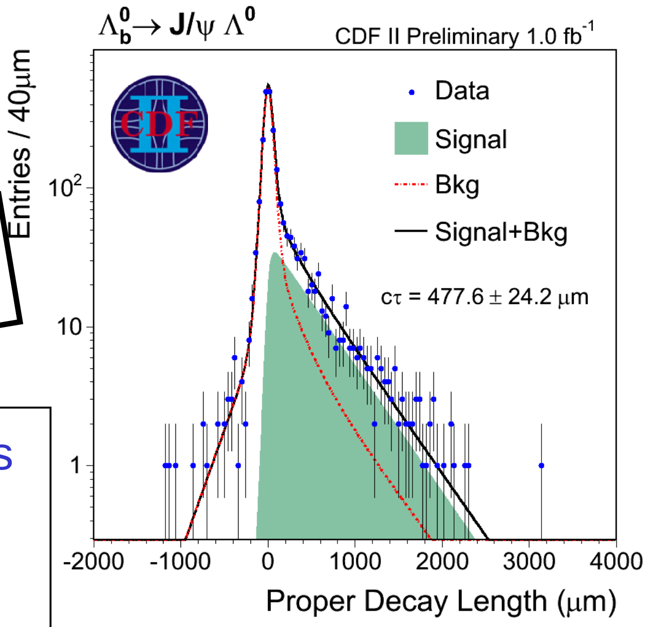
- Using world average B^0 à J/ψ K^0_s lifetime:

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 1.041 \pm 0.057\ (\text{stat} + \text{syst})$$

$$\tau(\Lambda_b) = 1.298 \pm 0.137\ (\text{stat}) \pm 0.050\ (\text{syst})\ \text{ps}$$

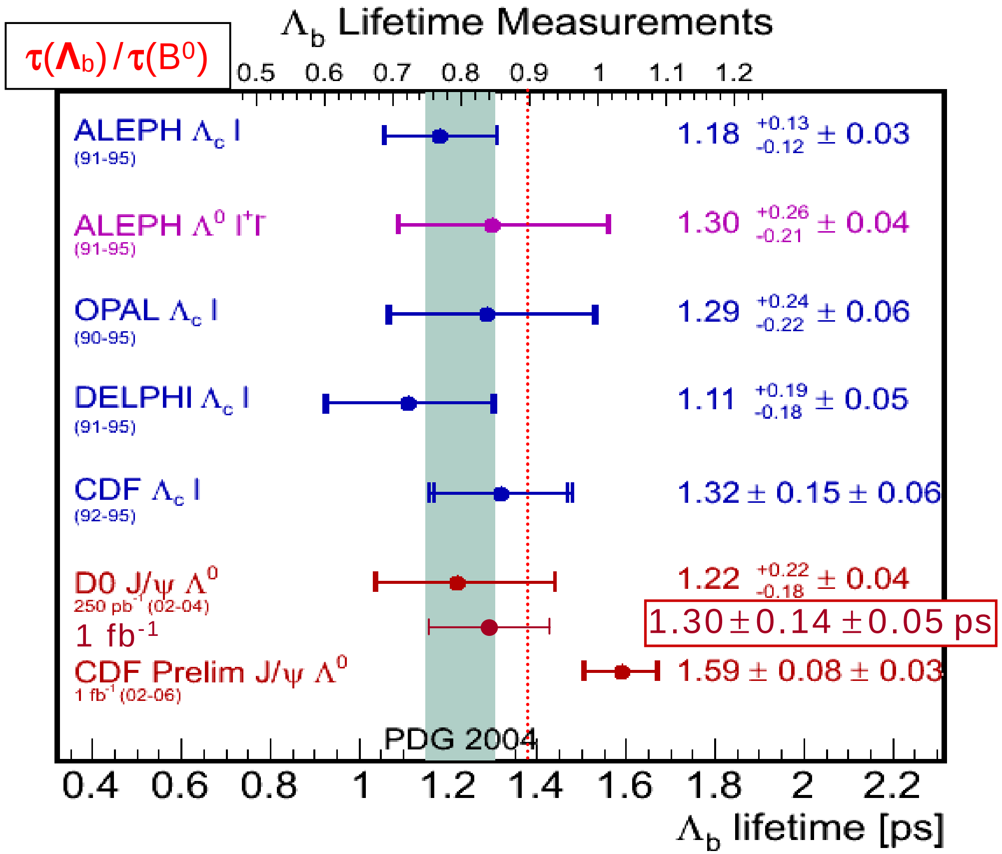
$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.870 \pm 0.102\ (\text{stat}) \pm 0.041\ (\text{syst})$$





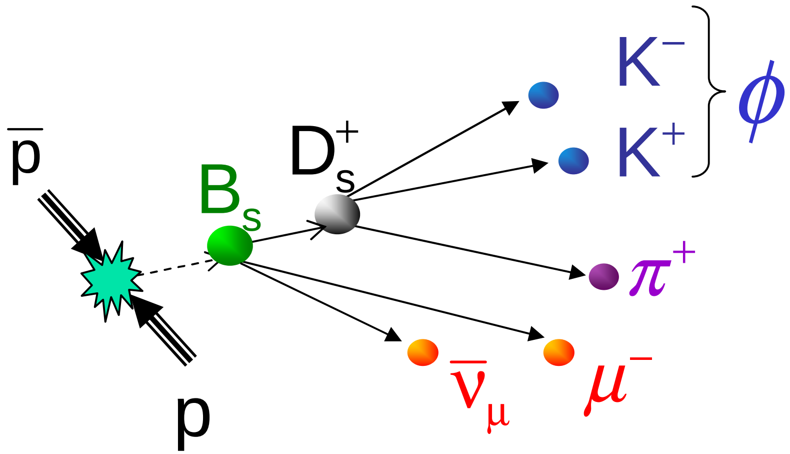
Λ_b Lifetime in Λ_b à $J/\psi\ \Lambda$ (2)

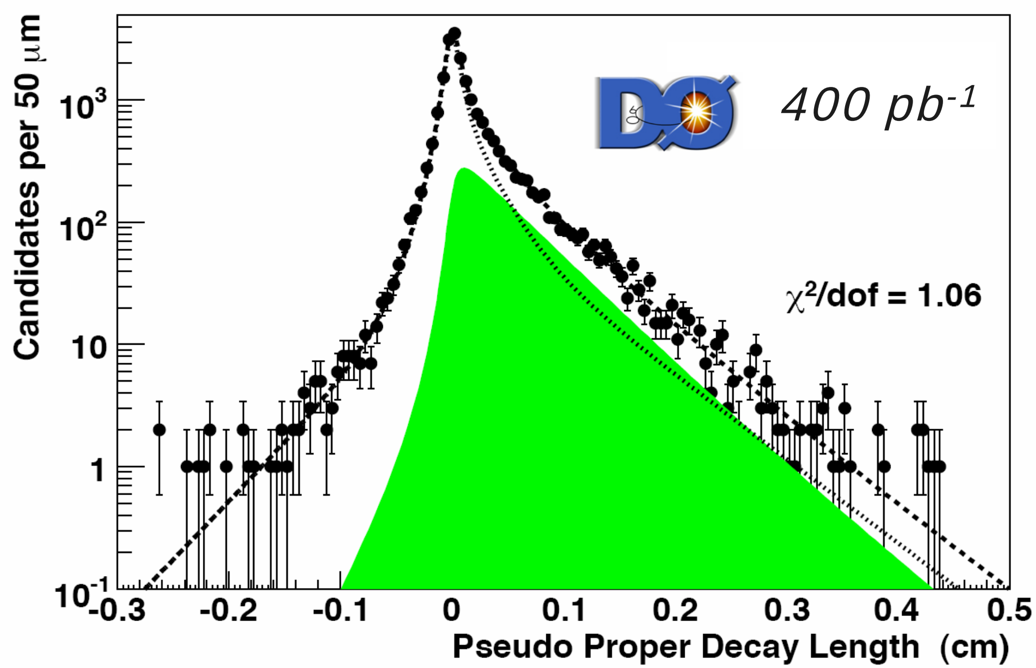
- The world average on $t(\Lambda_b)/t(B^0)$ measurements used to show ~2σ lower value than the NLO prediction so far.
- DØ result consistent with prediction
- CDF result sits above the prediction!
- Need more experimental inputs to conclude the issue.



B_s Lifetime in B_s à $D_s \mu \nu$ X

- Semileptonic decay from muon trigger





400 pb^{-1}

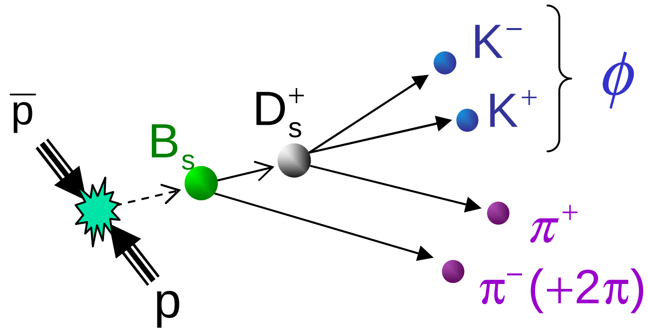
$$\tau_{B_s^0} = 1.420 \pm 0.043\,(\text{stat}) \pm 0.057\,(\text{syst})\,\text{ps}$$

360 pb^{-1}

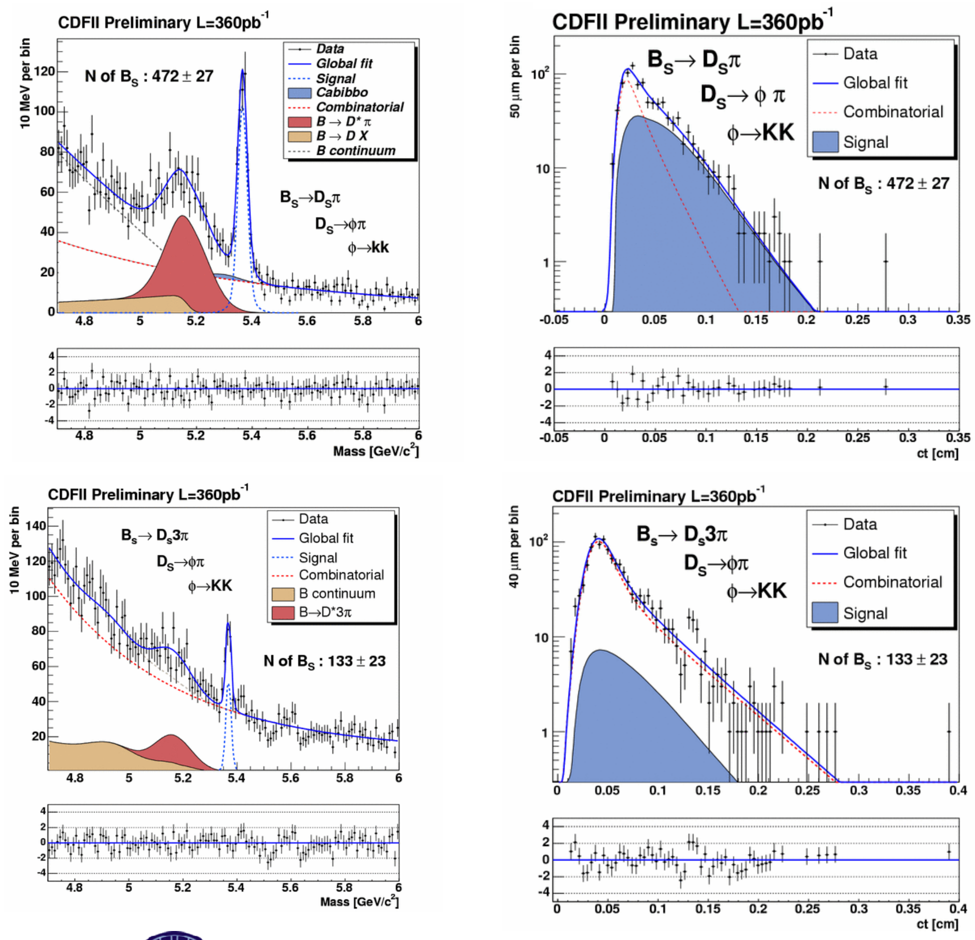
$$\tau_{B_s^0} = 1.381 \pm 0.055\,(\text{stat})^{+0.052}_{-0.046}\,(\text{syst})\,\text{ps}$$

$$\tau_{B_s^0}^{WE} = 1.466 \pm 0.059\,\text{ps}$$

B_s Lifetime in B_s à $D_s\ \pi$, 3π



360 pb⁻¹



- Fully reconstructed hadronic decays from displaced track trigger
- Trigger bias is removed by a Monte Carlo approach.
- Mass and decay length fitted simultaneously to extract lifetime.

$$\tau(B_s^0) = 1.60 \pm 0.10\,(\text{stat}) \pm 0.02\,(\text{syst})\ \text{ps}$$

B^+/B^0 Lifetime ratio

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360 pb^{-1} CDF II

$B \rightarrow D\pi, 3\pi$:

$$\frac{\tau(B^+)}{\tau(B_d^0)} = 1.10 \pm 0.02\ (stat) \pm 0.01 (syst)$$

World's single best result!

260 pb^{-1} CDF II

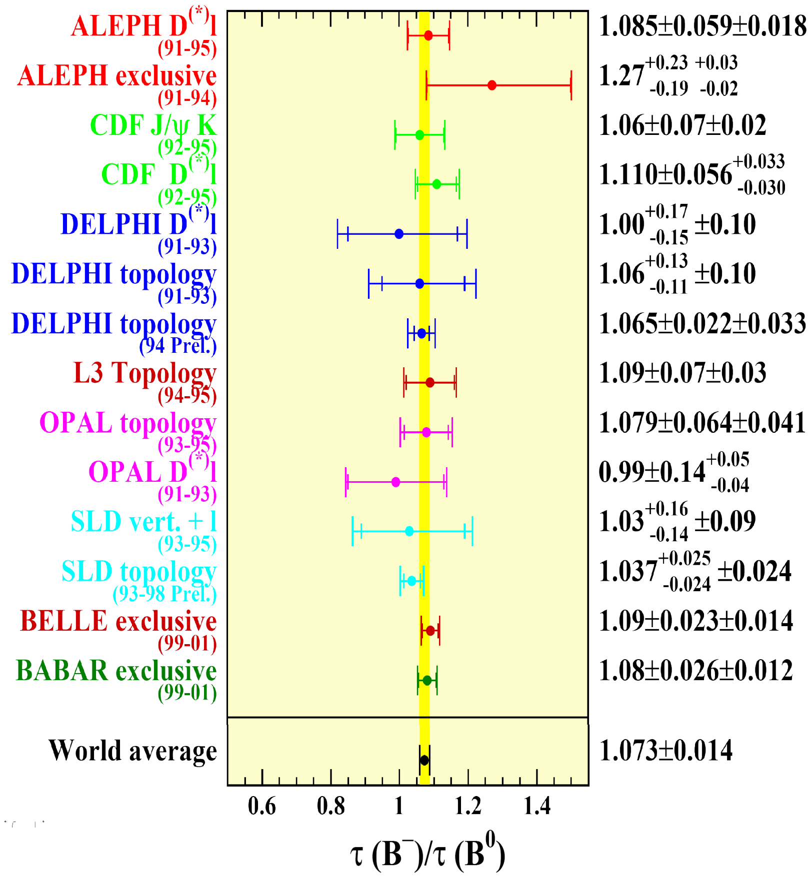
$B \rightarrow l^- \bar{\nu} DX$:

$$\frac{\tau(B^+)}{\tau(B_d^0)} = 1.123 \pm 0.040\ (stat)\ ^{+0.041}_{-0.039} (syst)$$

440 pb^{-1} DØ

$B \rightarrow l^- \bar{\nu} DX$:

$$\frac{\tau(B^+)}{\tau(B_d^0)} = 1.080 \pm 0.016\ (stat) \pm 0.014 (syst)$$



CP violation measurements

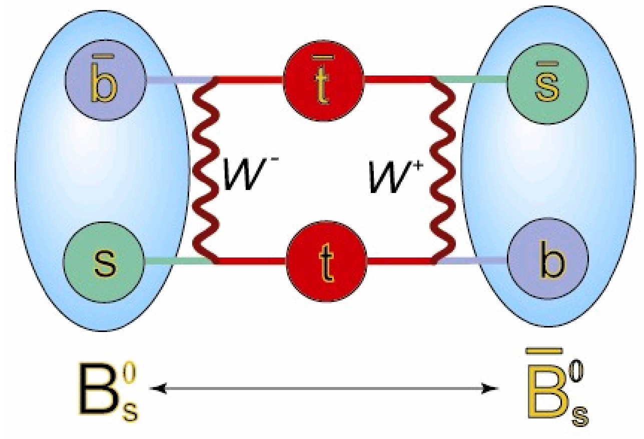
charge asymmetry in B decays

- Three possible contributions for CP violation
  - mixing, decay and interference

- in case of mixing the flavour specific B Decays CP violation is given by charge asymmetry

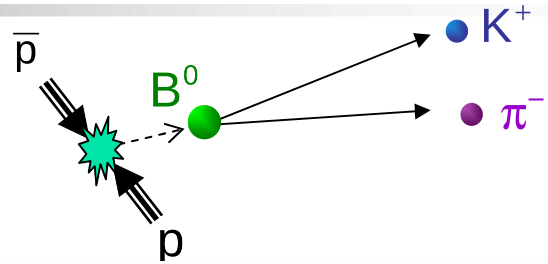
$$A_f = \frac{N(B \to fX) - N(\overline{B} \to \overline{f}X)}{N(B \to fX) + N(\overline{B} \to \overline{f}X)} = \frac{\Delta\Gamma}{\Delta m}\tan\phi$$

- Describtion of oscillation by three physical quantities
  - $|M_{12}|, |\Gamma_{12}|$: elements of complex mass matrix
  - CP violating phase $\quad \phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$



- Details for Δm_s and $\Delta\Gamma_s/\Gamma_s$ measurement
  $\rightarrow$ see talk of Stephanie Menzemer

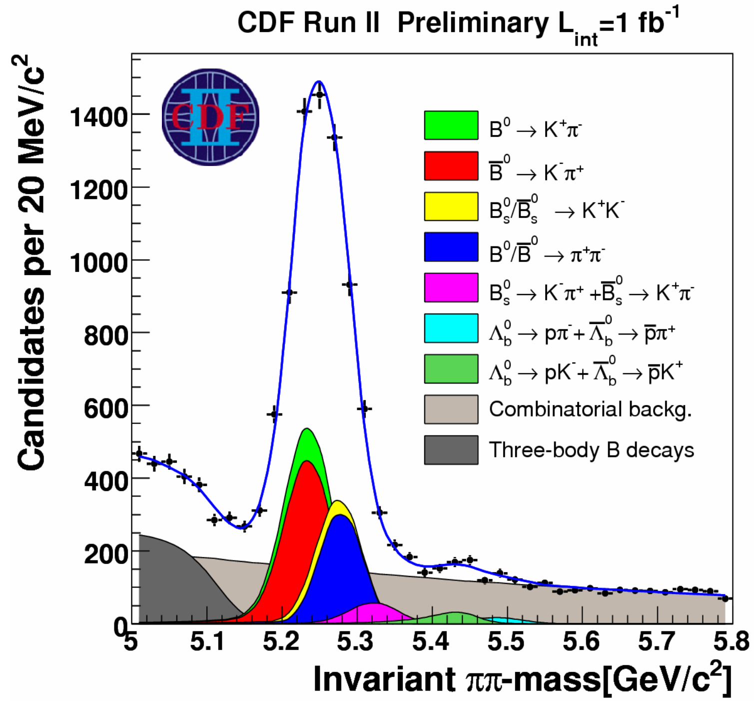
Asymmetry in $B^0 \to K^+\pi^-$



- decay rate asymmetry in the hadronic mode $B^0 \to K^+\pi^-$ from interference between decay and mixing

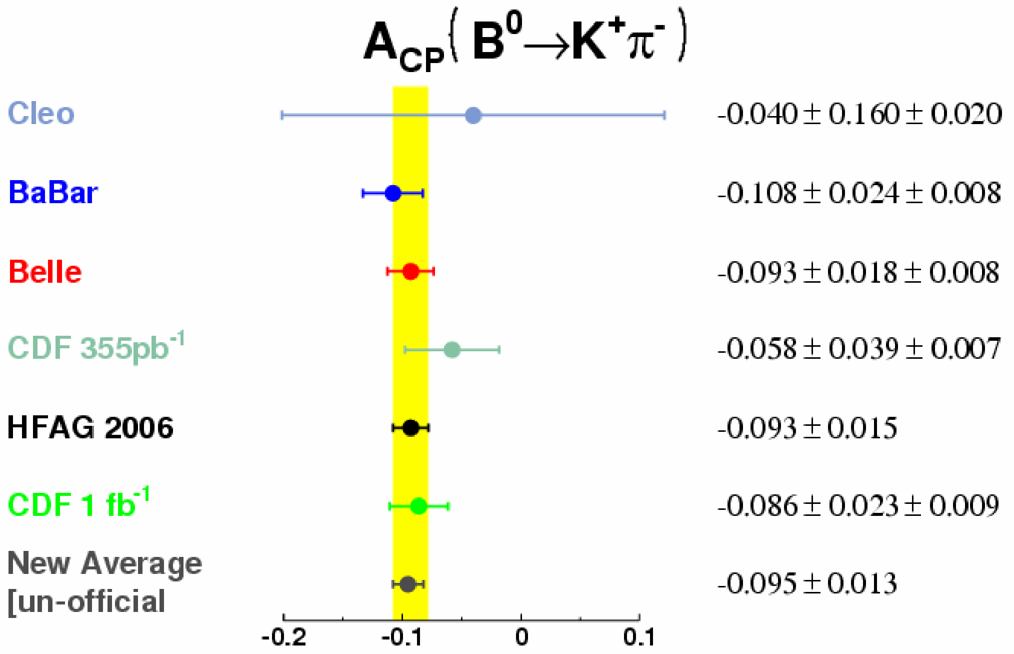
- $B^0 \to h^+h^-$ like B factories, but unique large sample of $B^0_s \to h^+h^-$

parameter	fraction	yield
$B^0 \to \pi^+\pi^- +$ c.c.	(0.160 ± 0.009)	1121 ± 63
$B^0 \to K^+\pi^- +$ c.c.	(0.577 ± 0.010)	4045 ± 84
$B^0_s \to K^+K^- +$ c.c.	(0.186 ± 0.009)	1307 ± 64



$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023\ (stat.) \pm 0.009\ (syst.)$$

Asymmetry in $B^0 \rightarrow K^+\pi^-$ (2)



- CDF is becoming a major player in the CPV game. The CDF results is the second world's best measurement.

- In agreement with the current HFAG world average (calculated with the previous CDF result on 355 pb^{-1}).

Asymmetry in $B^0s \to K^+\pi^-$

¬ Large SM expectation for this asymmetry (A_{CP}~0.37)

$$A_{CP} = \frac{N(\overline{B}_s^0 \to K^+\pi^-) - N(B_s^0 \to K^-\pi^+)}{N(\overline{B}_s^0 \to K^+\pi^-) + N(B_s^0 \to K^-\pi^+)} = 0.39 \pm 0.15\ (stat.) \pm 0.08\ (syst.)$$

¬ Compare rates and asymmetries of $B^0 \to K^+\pi^-$ and $B^0_s \to K^-\pi^+$ unique to CDF – to probe NP with minimal assumption.

using HFAG the amplitude ratio can be calculated:

$$\frac{|A(\bar{B}_d \to \pi^+K^-)|^2 - |A(B_d \to \pi^-K^+)|^2}{|A(B_s \to \pi^+K^-)|^2 - |A(\bar{B}_s \to \pi^-K^+)|^2} = 0.84 \pm 0.42(\text{stat.}) \pm 0.15(\text{syst.})$$

¬ consistent with SM ([Lipkin, Phys. Lett. B621:126,.2005] ,[Gronau Rosner Phys.Rev. D71 (2005) 074019]) prediction of 1

Semileptonic rate Asymmetry in B decays

- decay rate asymmetry in semileptonic modes from mixing only

- special interest for rate asymmetry for B_s mesons (not measured from B factories)

$$A_{SL}^{s} = \frac{N(\overline{B}_s \to l^+ X) - N(B_s \to l^- X)}{N(\overline{B}_s \to l^+ X) + N(B_s \to l^- X)} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

- SM expectation:

$$\phi_s \approx 0.3^\circ$$

$$A_{SL}^{s} = (0.21 \pm 0.04) \times 10^{-4}$$

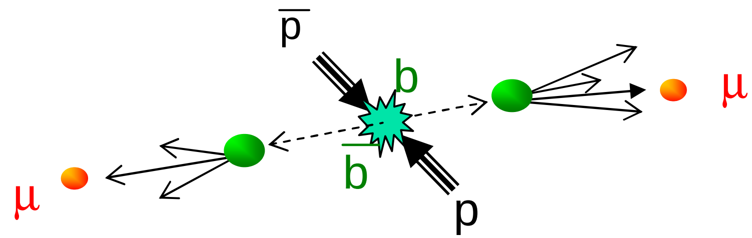
- New physics could anhance the asymmetry:

$$A_{SL}^{s}(NP) \approx 0.5 \times 10^{-2}$$

Dimuon charge asymmetry

¬ all B mesons give contribution to dimuon charge asymmetry

$$A_{SL} = \frac{N(b\bar{b} \to \mu^+\mu^+X) - N(b\bar{b} \to \mu^-\mu^-X)}{N(b\bar{b} \to \mu^+\mu^+X) + N(b\bar{b} \to \mu^-\mu^-X)}$$



→ clean channel

- relatively few processes contribute to sam-sign samples
- To first order no charge asymmetry in background processes

→ Need to take into account detector effects, polarity and sign of pseudorapidity

Dimuon charge asymmetry (2)

- Most precise measurement of A_{SL}

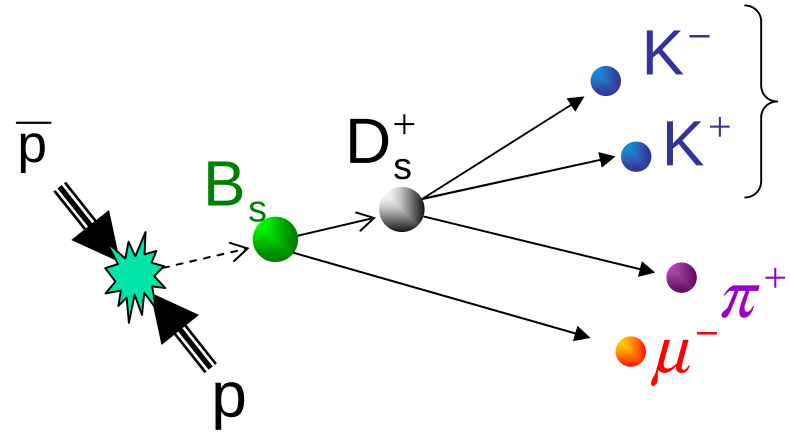
$$A_{SL} = -0.0044 \pm 0.0040 \pm 0.0028$$

- A_{SL} contains contribution from B_d and B_s
  $\rightarrow$ Use B factory results to extract A^s_{SL}

$$A^s_{SL} = -0.0076 \pm 0.0102 \quad \text{(dimuon)}$$

Asymmetry in B_s à $D_s\mu\nu$

¬ decay rate asymmetry in the semileptonic mode $B_s \rightarrow D^-_s\mu^+$



¬ calculate over total untagged rate asymmetry

$$A_{SL}^{untagged} = \frac{1}{2} A_{SL}^{s} = \frac{N(B_s \rightarrow D_s^- \mu^+) - N(\overline{B}_s \rightarrow D_s^+ \mu^-)}{N(B_s \rightarrow D_s^- \mu^+) + N(\overline{B}_s \rightarrow D_s^+ \mu^-)}$$

¬ first direct measurement

$$A_{SL}^{s} = 0.0245 \pm 0.0193 \pm 0.0035$$

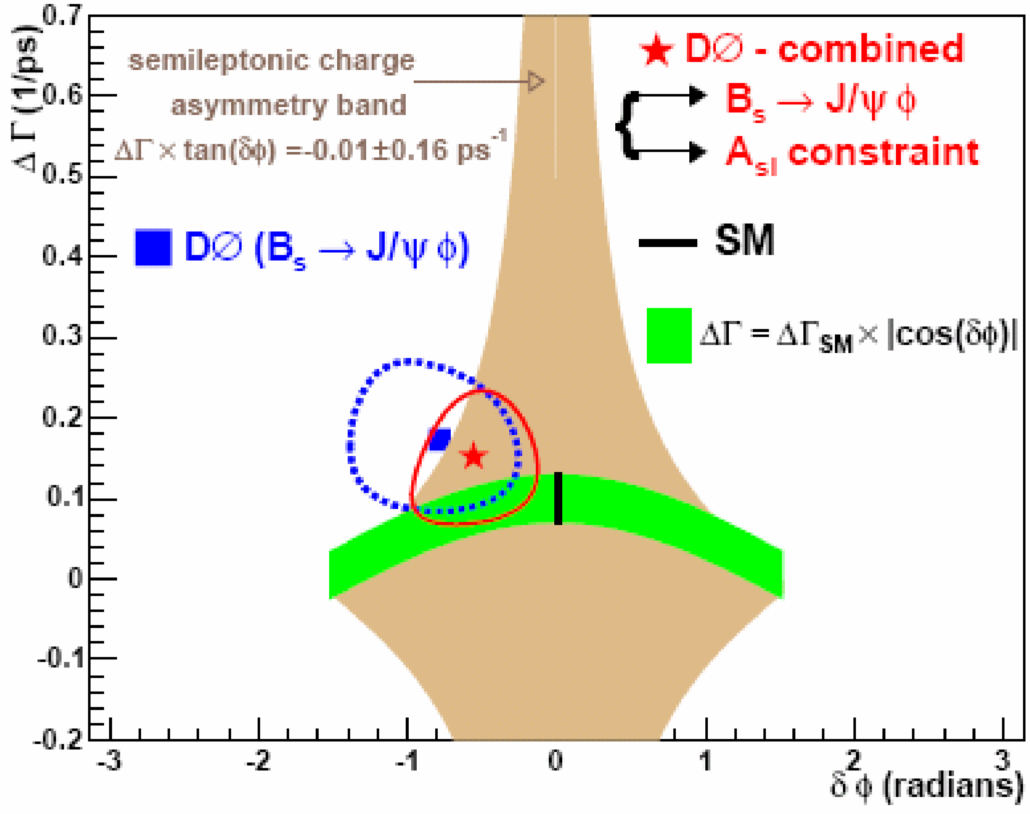
¬ combination with dimuon measurement

$$A_{SL,c}^{s} = -0.0007 \pm 0.0090$$

Combined DØ Results

- DØ result on $B_s \to J/\psi\phi$
  - $\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03\ ps^{-1}$
  - $\phi_s = -0.79 \pm 0.56 \pm 0.01$
- Combined DØ Result

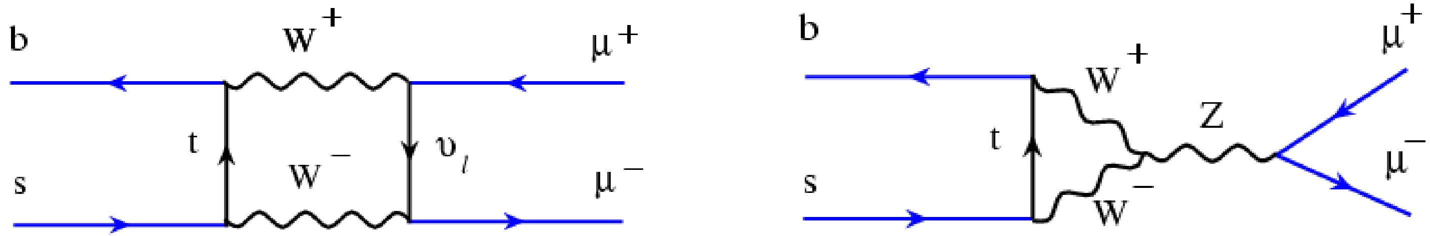
$$\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}\ ps^{-1}$$
$$\phi_s = -0.56^{+0.44}_{-0.41}$$



Search for rare B decays

Motivation for rare decays

¬ In the Standard Model, the FCNC decay of B à $\mu^+\mu^-$ is heavily suppressed



SM prediction à $BR(B_s \rightarrow \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$

(Buchalla & Buras, Misiak & Urban)

¬ B_d à $\mu\mu$ is further suppressed by CKM factor $(v_{td}/v_{ts})^2$

¬ SM prediction is below the sensitivity of current experiments (CDF+D0): SM à Expect to see 0 events at the Tevatron

Any signal at the Tevatron would indicate new physics!!

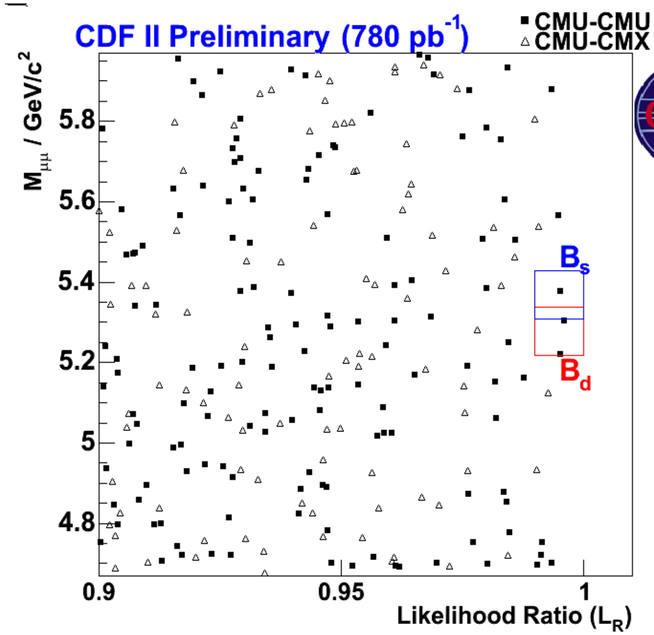
Search for rare decay $B_s \to \mu\mu$

- CDF constructs a likelihood ratio using three discriminating variables

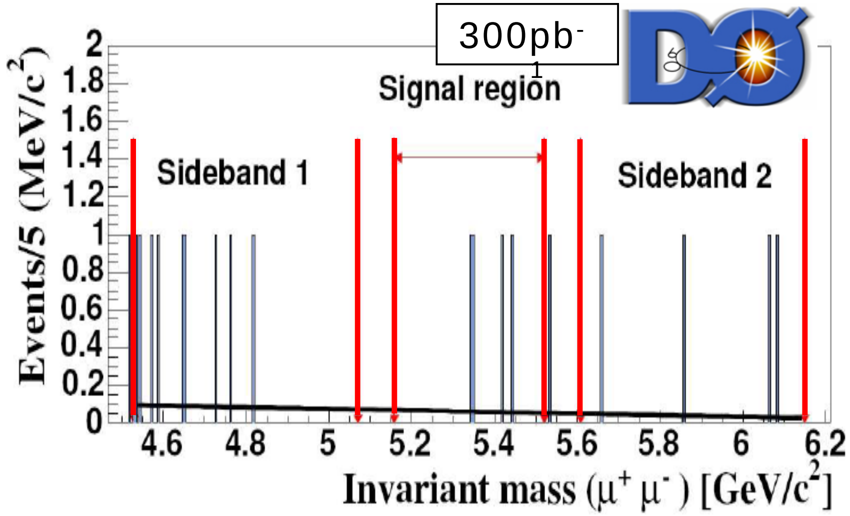
$$L_R = \frac{\prod_i P_s(x_i)}{\prod_i P_s(x_i) + \prod_i P_b(x_i)}$$

$P_{s/b}$ is the probability for a given sig/bkg to have a value of *x*, where *i* runs over all variables.

- observe 1 $B_s \to \mu\mu$, expect 0.88 ± 0.30 (cc)
- observe 0 $B_s \to \mu\mu$, expect 0.39 ± 0.21 (cf)



- DØ optimizes cuts on three discriminating variables and Maximize S/(1+sqrt(B))
- 300pb^{-1}: observe 4, expect 4.3 ± 1.2
- +400pb^{-1}(blind): expect 2.2 ± 0.7



Limits for rare decay $B_s \rightarrow \mu\mu$

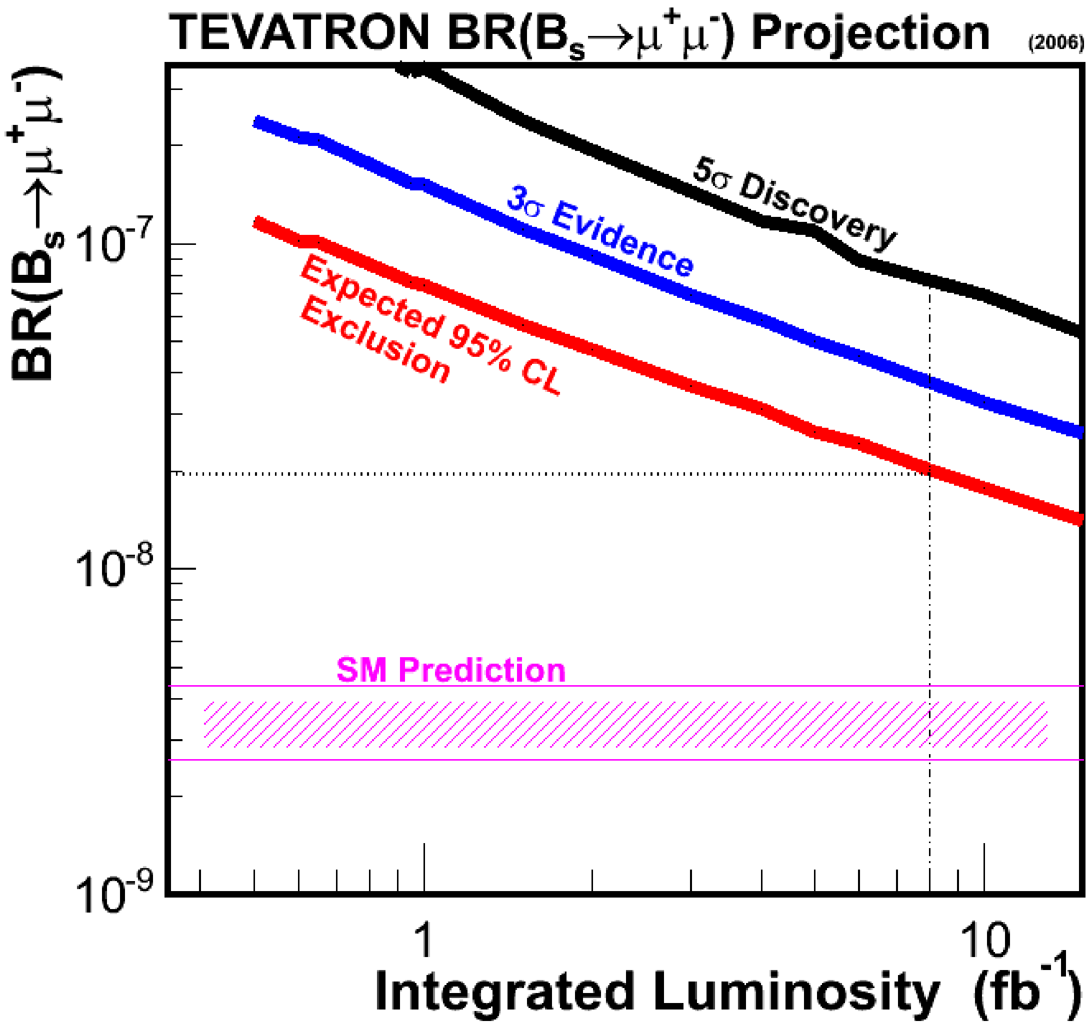
- Evolution of limits (in 95%CL):

CDF $B_s \to \mu\mu$	176 pb^{-1}	7.5×10^{-7}	Published
DØ $B_s \to \mu\mu$	240 pb^{-1}	5.1×10^{-7}	Published
DØ $B_s \to \mu\mu$	300 pb^{-1}	4.0×10^{-7}	Prelim.
DØ $B_s \to \mu\mu$	700 pb^{-1}	$<2.3\times10^{-7}>$	Prelim. Sensitivity
CDF $B_s \to \mu\mu$	364 pb^{-1}	2.0×10^{-7}	Published
CDF $B_s \to \mu\mu$	780 pb^{-1}	1.0×10^{-7}	Prelim.

90% CL

Babar $B_d \to \mu\mu$	111 fb^{-1}	8.3×10^{-8}	Published
CDF $B_d \to \mu\mu$	364 pb^{-1}	4.9×10^{-8}	Published
CDF $B_d \to \mu\mu$	780 pb^{-1}	3.0×10^{-8}	Prelim.

Tevatron reach for $B_s \to \mu\mu$



- Conservative projection based on sensitivity of current analyses
- Ongoing efforts to significantly improve sensitivity of the analyses
- Tevatron can push down to at least low 10^{-8} region

Summary

- measured Λ_b, Bs and B+/B0 lifetimes with high precision
  - competitive or leading results

- precise or first measurements of CP violation in the B sector with
  - hadronic decays $B^0 \rightarrow K\pi$
  - semileptonic decays $bb \rightarrow \mu\mu$ and $B_s \rightarrow D_s \mu\nu$

- CDF and DØ already constrain new physics models, which contribute to the decay $B_s \rightarrow \mu\mu$
  - No event seen in ~800pb^{-1}
  - CDF and DØ will push sensitivity to 10^{-8} level

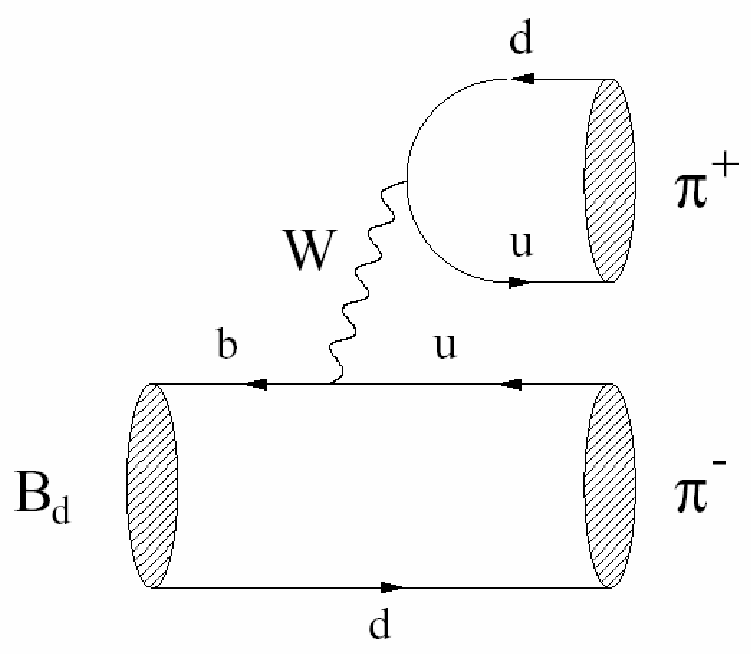
- CDF and DØ are complementory to the B factories and for some measurements the precision become more and more competitive

- more results from Stephanie and Manfred

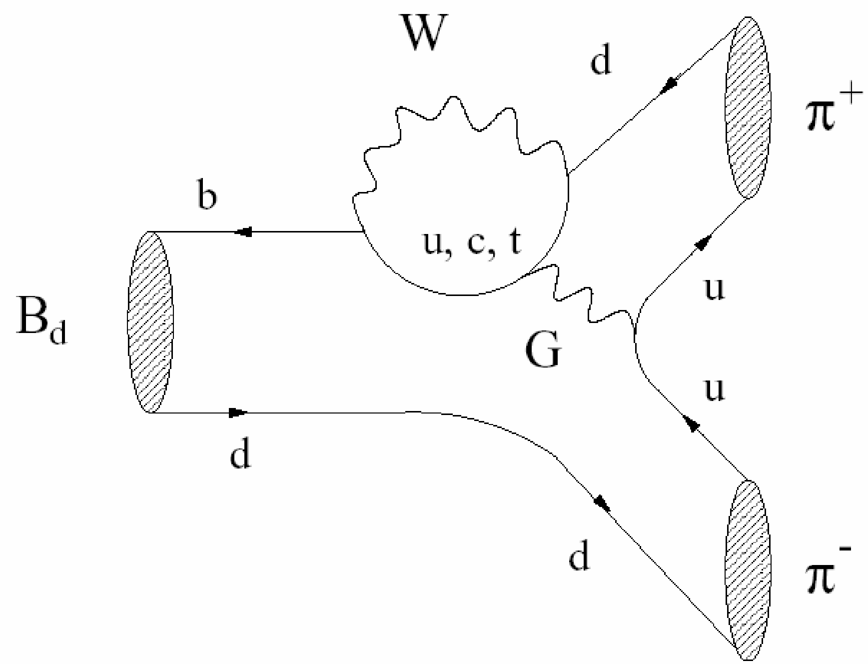
Backup

Feynman diagrams for rate asymmetry

Tree level diagram



Pinguin diagram

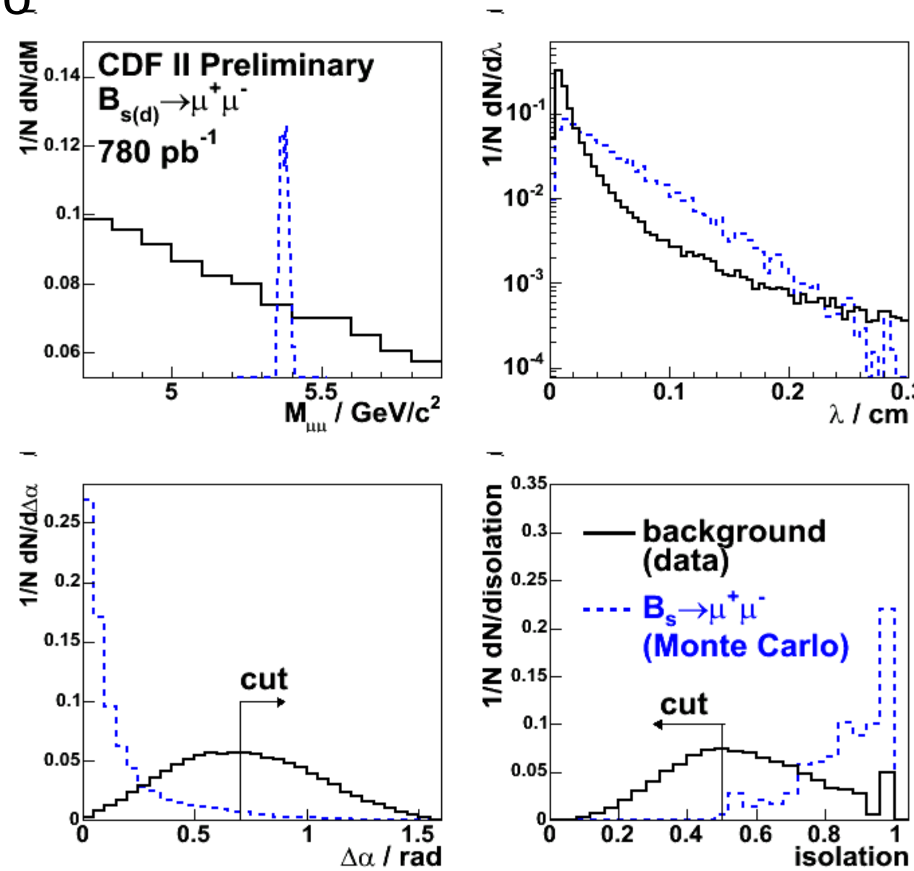


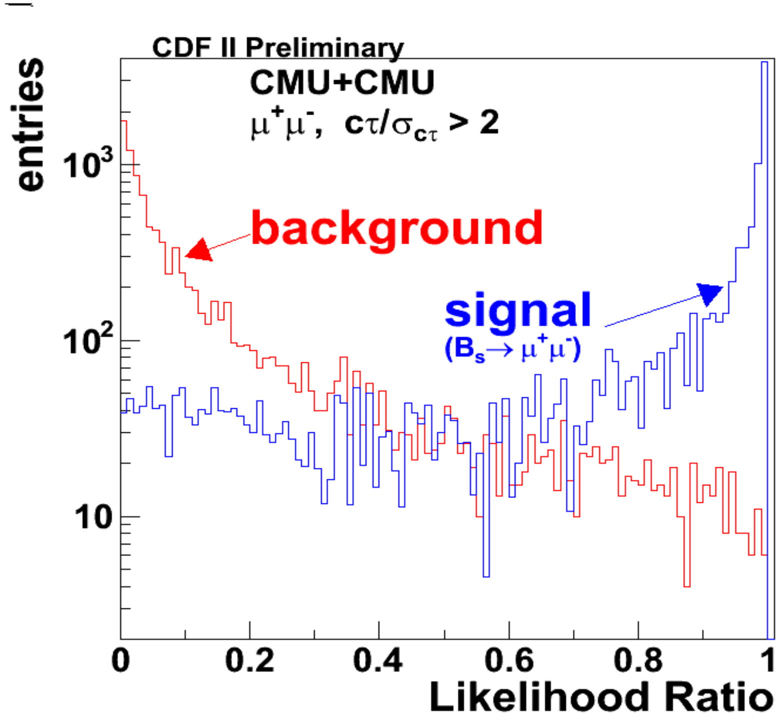
CDF Optimisation for $B_s \to \mu\mu$

- CDF constructs a likelihood ratio using discriminating variables λ, Δα, Iso

$$L_R = \frac{\prod_i P_s(x_i)}{\prod_i P_s(x_i) + \prod_i P_b(x_i)}$$

$P_{s/b}$ is the probability for a given sig/bkg to have a value of *x*, where *i* runs over all variables.





- Optimize on expected upper limit
- L_R(optimized)>0.99

DØ Optimisation for $B_s \to \mu\mu$

- Optimize cuts on three discriminating variables
  - Pointing angle
  - 2D decay length significance
  - Isolation
- Random Grid Search
- Maximize S/(1+sqrt(B))