B-physics at the TeVatron

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Outline

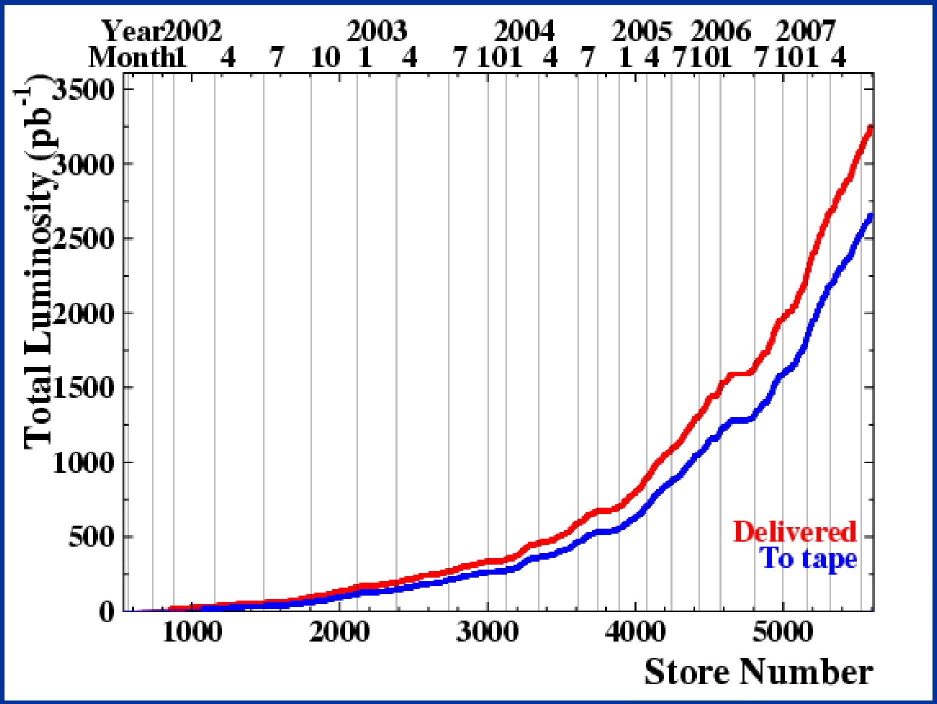
- Introduction
  - Tevatron, CDF and DØ detectors
  - B Physics at hadron colliders

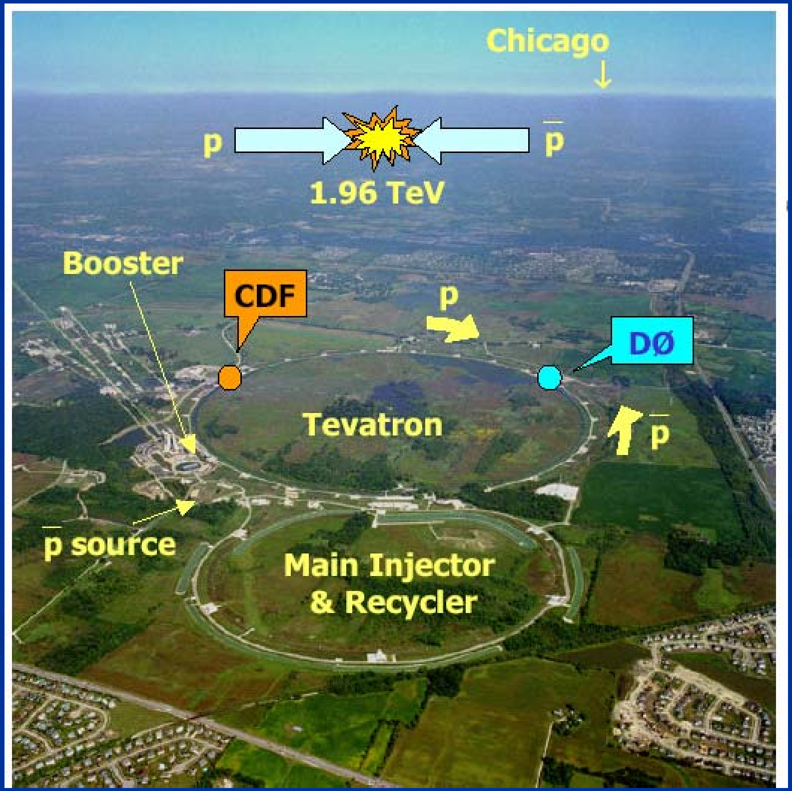
- In this talk
  - B^0_s mixing: measurement of Δm_s.
  - Lifetime, lifetime difference $\Delta\Gamma$ and CP violation in neutral B^0_s system
    - Untagged and tagged analysis of $B^0_s \to J/\Psi\phi$.
  - Λ^0_b Lifetime.
  - Charm mixing.
  - BR and A_{CP} of $B^0/B^0_s \to h^+h^-$ and $\Lambda^0_b \to p\pi(K)$ decays.
  - γ from $B^+ \to D^0_{CP}K^+$ and $B^0_s \to D_sK$.
  - Ξ_b Baryon (First Observation)
  - FCNC: $B^0_s \to \mu\mu$

- Conclusions.
- List of topics not covered.

Fermilab Tevatron

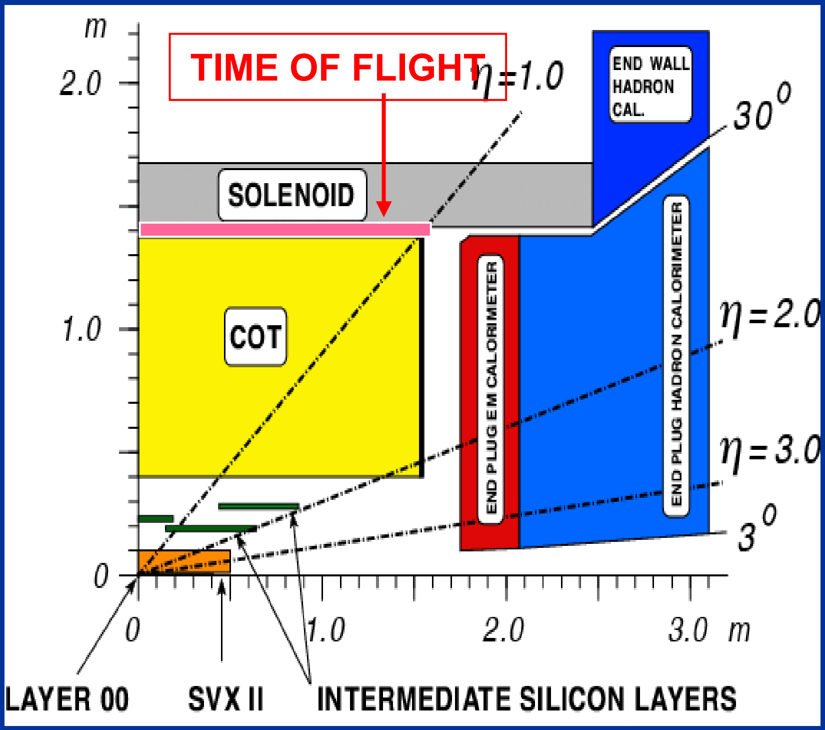
- $p\bar{p}$ collisions at 1.96 TeV
- 2.5 fb^{-1} “good” data on tape (results today 1-2fb^{-1})
- 1.7MHz collision rate (396 ns bunch spacing)
- Peak luminosity $2.92 \times 10^{32} cm^{-2}s^{-1}$
  - Average ~5-6 $p\bar{p}$ interactions per bunch crossing
- Anticipate luminosity as high as $3 \times 10^{32} cm^{-2}s^{-1}$
  - Challenging for the detector, trigger and event reconstruction

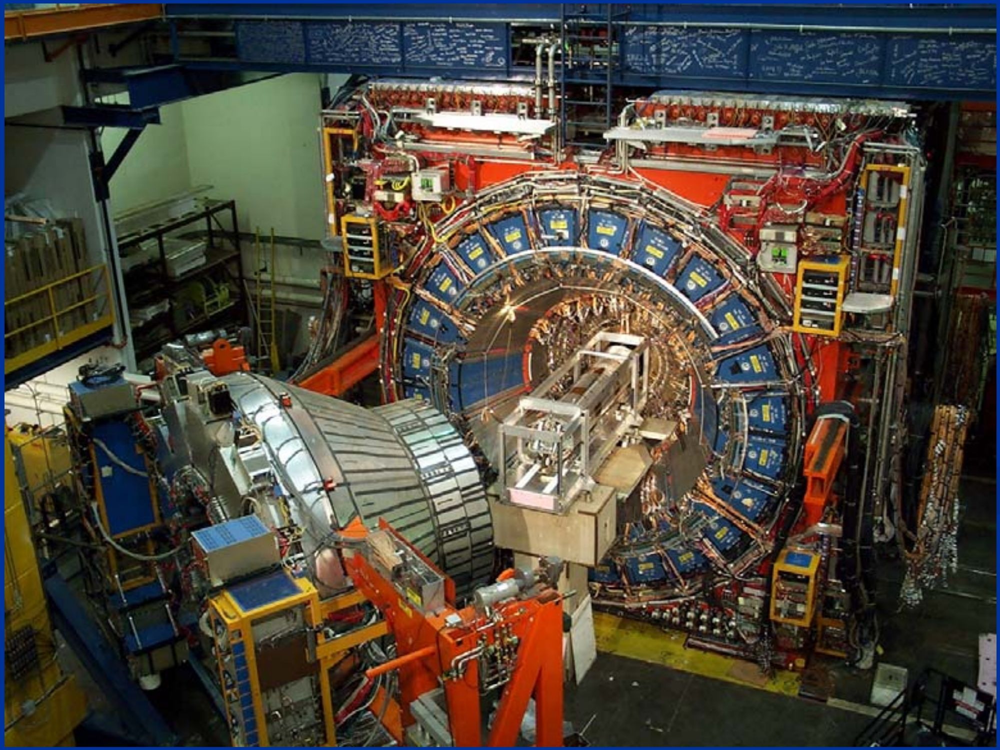




CDF detector

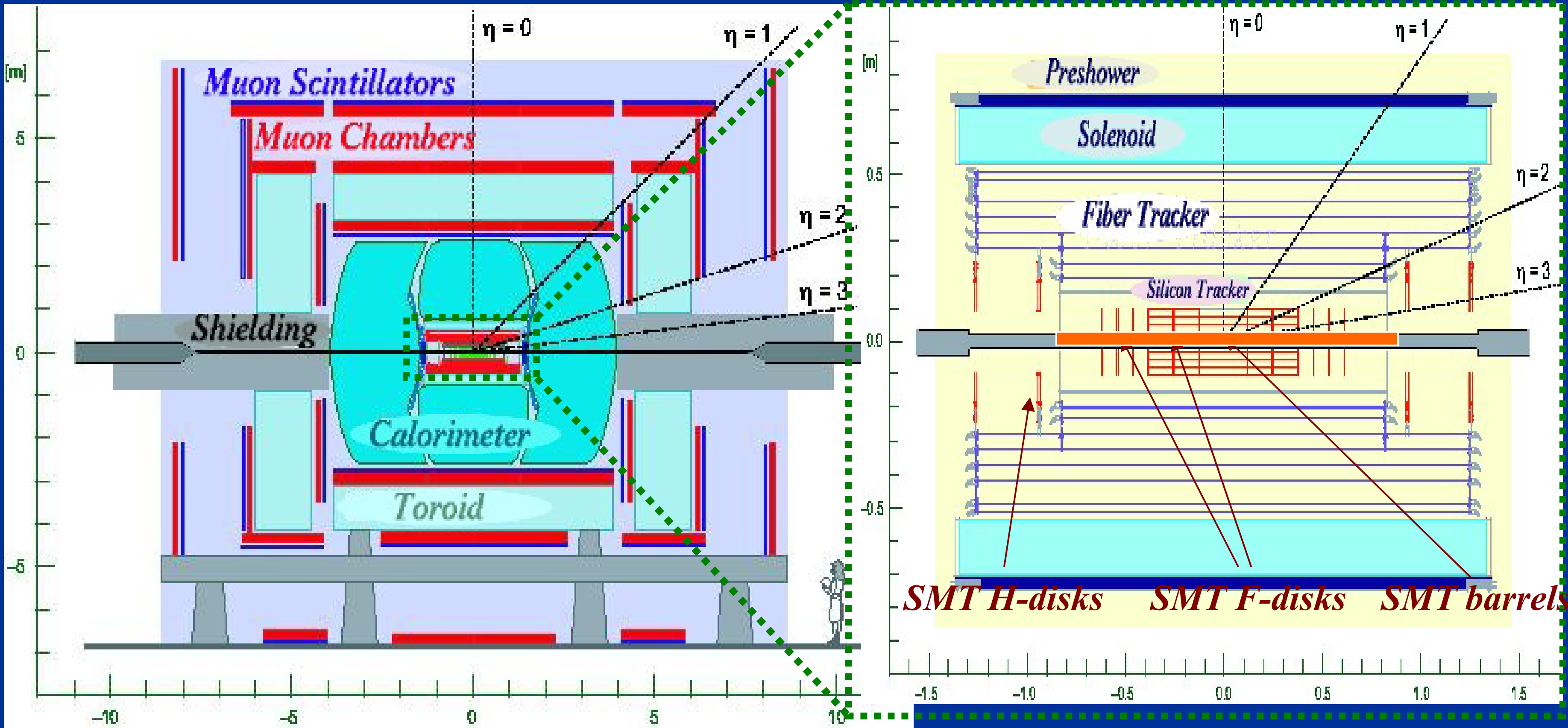
- Central tracking includes silicon vertex detector surrounded by drift chamber
  - p_T resolution $dp_T/p_T = 0.0015\ p_T\ GeV^{-1}$
  - excellent mass resolution ~14 MeV for $J/\psi \to \mu\mu$, ~22 MeV for $B \to hh$
  - good vertex resolution ~100 fs
- Particle identification: dE/dx (1.5σ K/π @ p>2GeV) and ToF
- Good electron and muon identification by calorimeters and muon chambers.





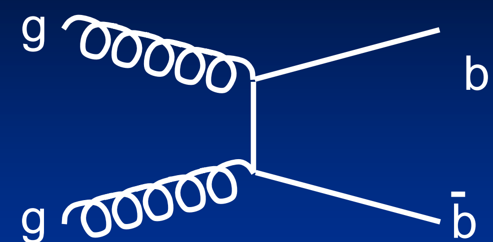
DØ Detector

- 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

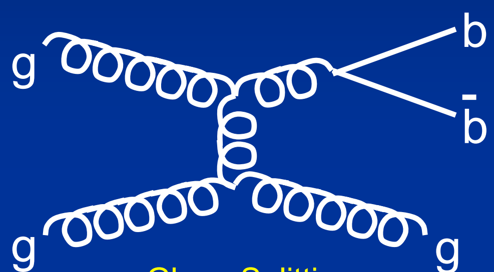


B Physics at the Tevatron

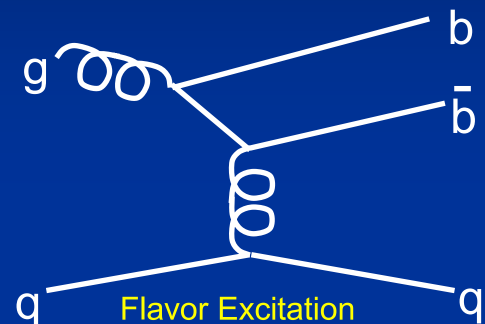
Mechanisms for b production in $p\bar{p}$ collisions at 1.96 TeV



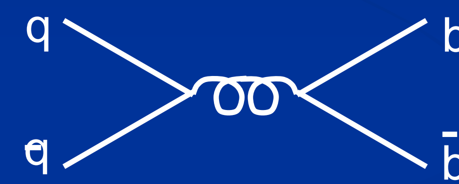
Flavor Creation (gluon fusion)



Gluon Splitting



Flavor Excitation



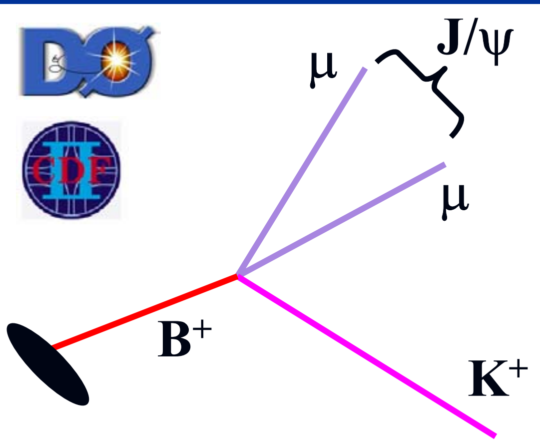
Flavor Creation (annihilation)

- At Tevatron, large b production cross section
  - Tevatron experiments CDF and DØ enjoy rich B Physics program
- Plethora of states accessible: B^0_s, B_c, Λ^0_b, Ξ_b, Σ_b…
  - complement the B factories physics program
- Total inelastic cross section at Tevatron is ~1000 larger that b cross section
  - large backgrounds suppressed by triggers that target specific decays.

B Triggers

J/ψ

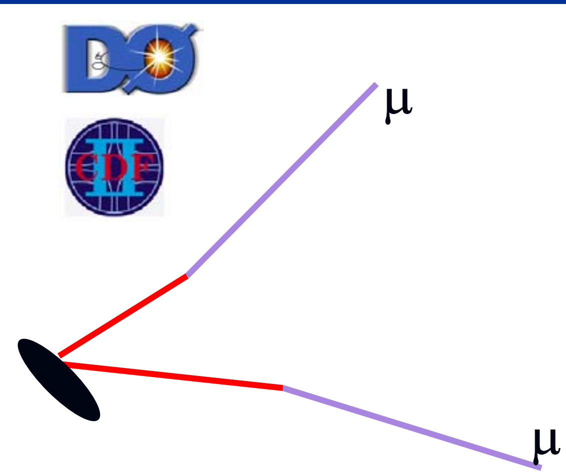
- $p_T(\mu)>1.5$GeV
- J/ψ mass requirement
- Opposite charge



$B^0 \rightarrow J/\psi\ K^{0*}$
$B^+ \rightarrow J/\psi\ K^+$
$\Lambda_b \rightarrow J/\psi\ \Lambda$
$B_c \rightarrow J/\psi\ \pi$
$B^0_s \rightarrow J/\psi\ \phi$
Ξ_b, B**

Dimuon

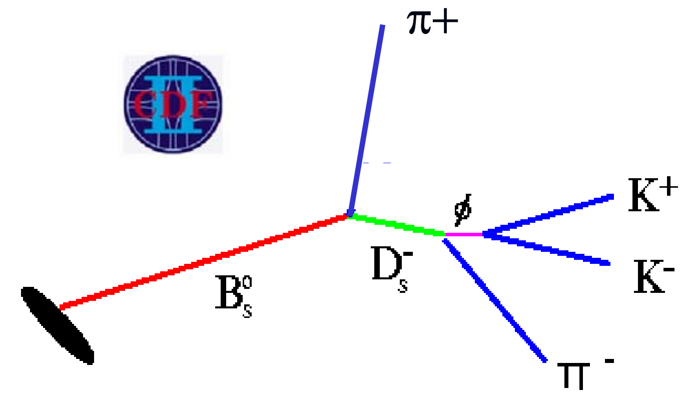
- $p_T(\mu)>1.5$ or 2 GeV
- Triggers with/without charge requirement



$B \rightarrow \mu\mu$+hadrons
$B \rightarrow \mu\mu$
$bb \rightarrow \mu\mu$
$cc \rightarrow \mu\mu$

Displaced Track

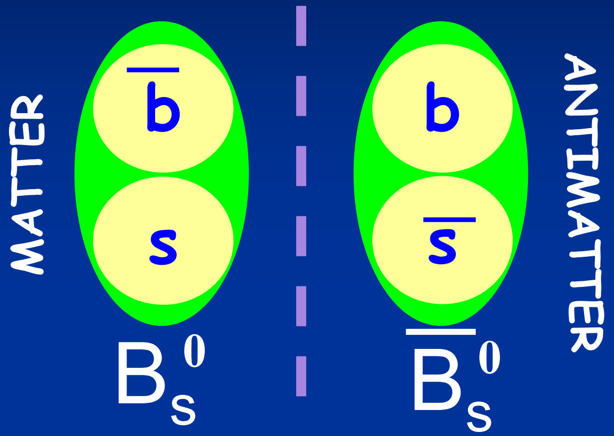
- p_T(track)>2 GeV
- IP(track)>80 or 120 μm
- Opposite charge



$B \rightarrow D_s\pi$
$B \rightarrow D_sK$
$B \rightarrow hh$
$\Lambda \rightarrow ph$
$D \rightarrow K\pi$

B^0_s Physics

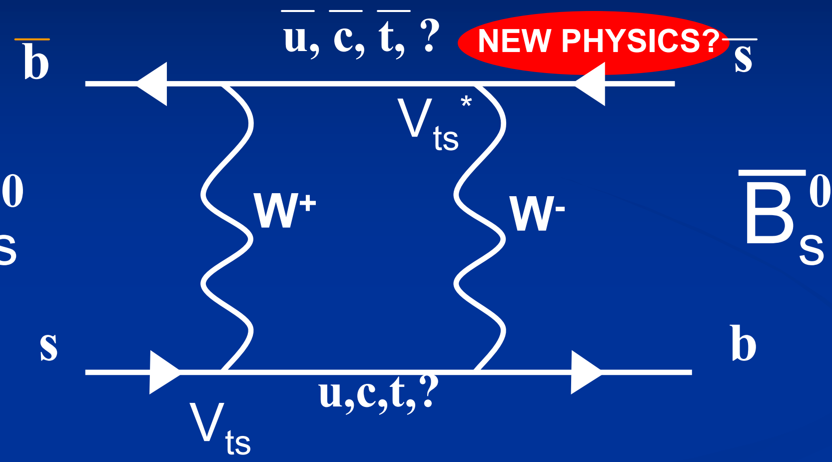
Bound states:



Matter ↔ antimatter:

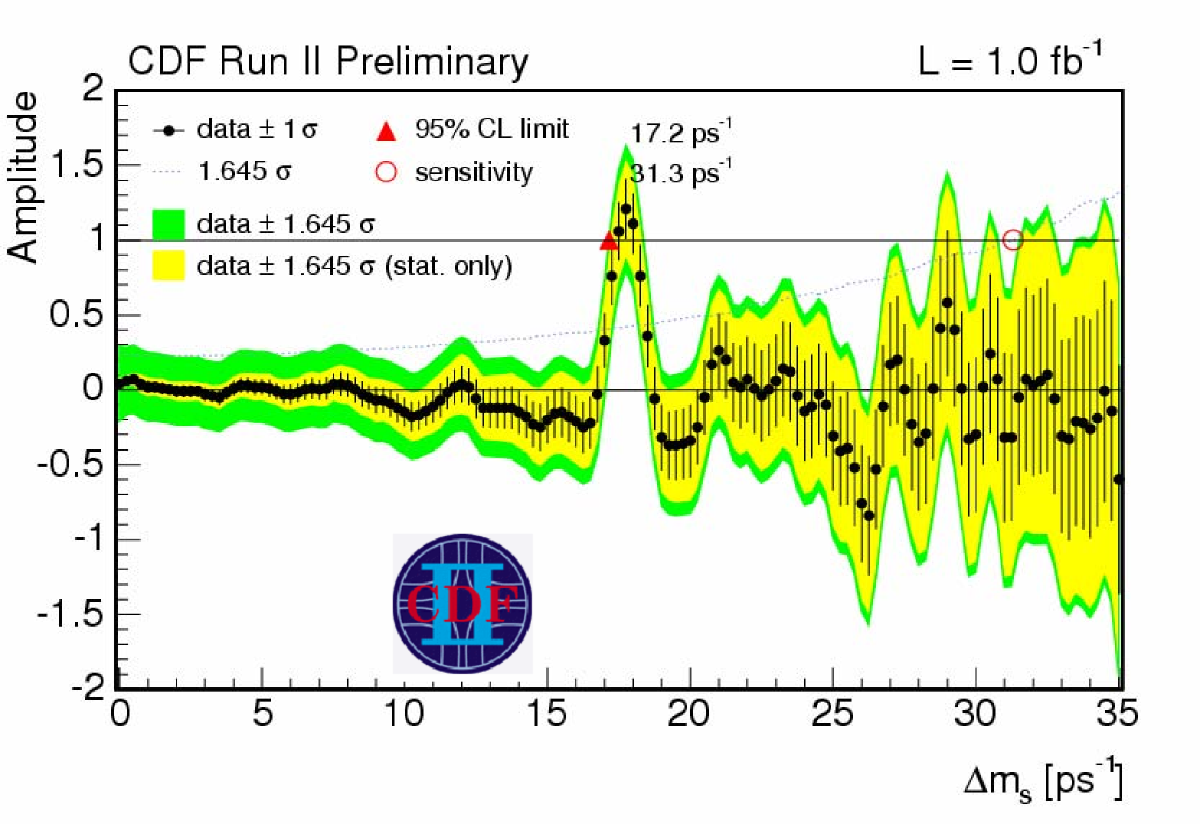
occurs

via B_s^0



- The mass eigenstates (H and L) are superpositions of $\bar{B}^0_s$ and B^0_s
- System characterized by 4 parameters (no CPV $\Leftrightarrow$ ϕ_s=0):
  - masses: m_H, m_L lifetimes: Γ_H, Γ_L (Γ=1/τ)
- CPV $\Leftrightarrow$ $\phi_s \neq 0$ then $\Delta\Gamma_s = |\Gamma_{12}|\cos(\phi_s)$, ϕ_s expected very small in SM.
- Δm_s has been measured very precisely.
- $\Delta\Gamma_s$ and ϕ_s so far measured imprecisely.

B^0_s mixing: Δm_s



Δm_s consistent with Standard Model expectation.

New Physics can alter the weak phase ϕ_s of the mixing amplitude. The same New Physics phase would also be visible through $\Delta\Gamma_s < \Delta\Gamma_s$(SM)

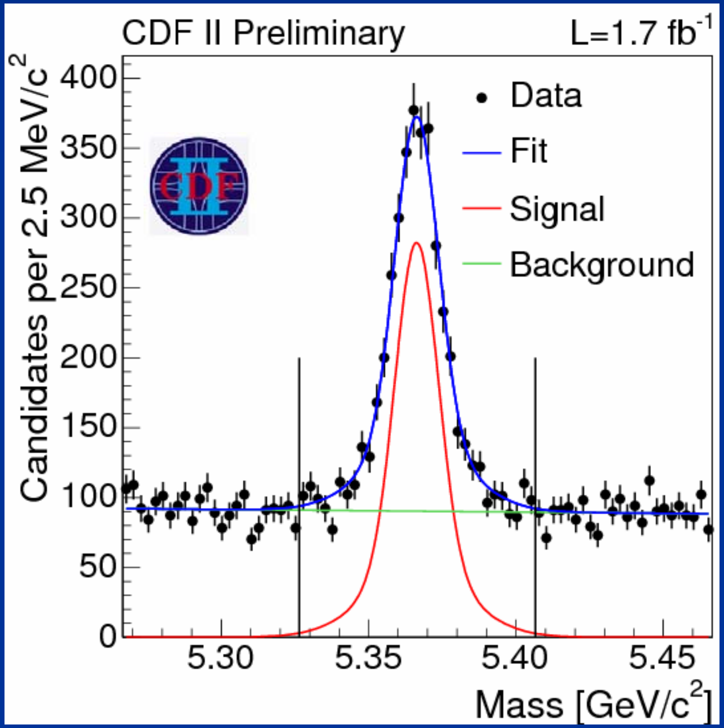
Δm_s = 17.77 ± 0.10 (stat) ± 0.07(syst) ps^{-1} (>5σ)

PRL 97, 242003 (2006) [hep-ex/0609040]

B_s Lifetime in $B^0_s \rightarrow J/\psi\phi$ Decays

Most precise B_s lifetime measurements from $B_s \rightarrow J/\Psi\Phi$ decays

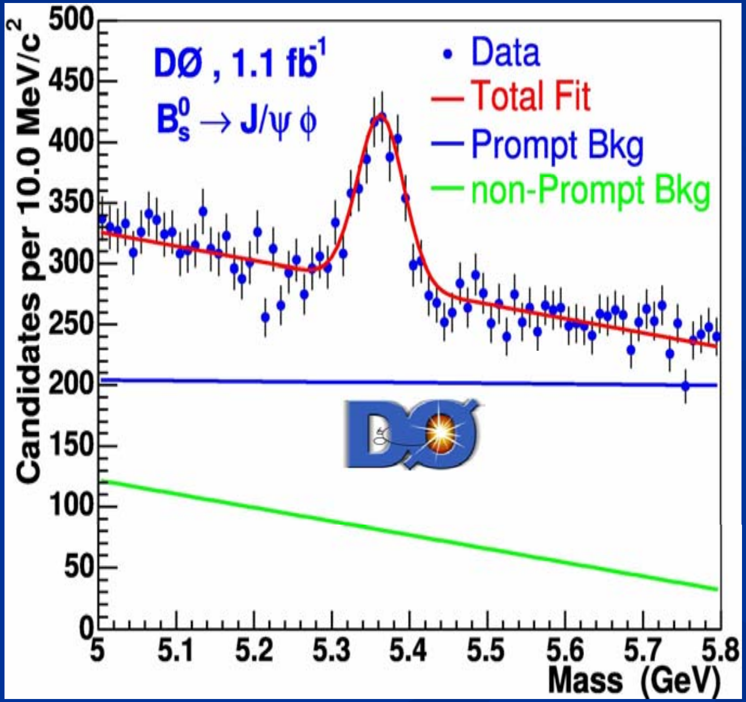
CDF ~2500 signal events in ~1.7 fb^{-1}



[arXiv:0712.2348 hep-ex]

$\tau_s = 1.52 \pm 0.04$ (stat) $\pm$ 0.02 (syst) ps
(world best measurement)

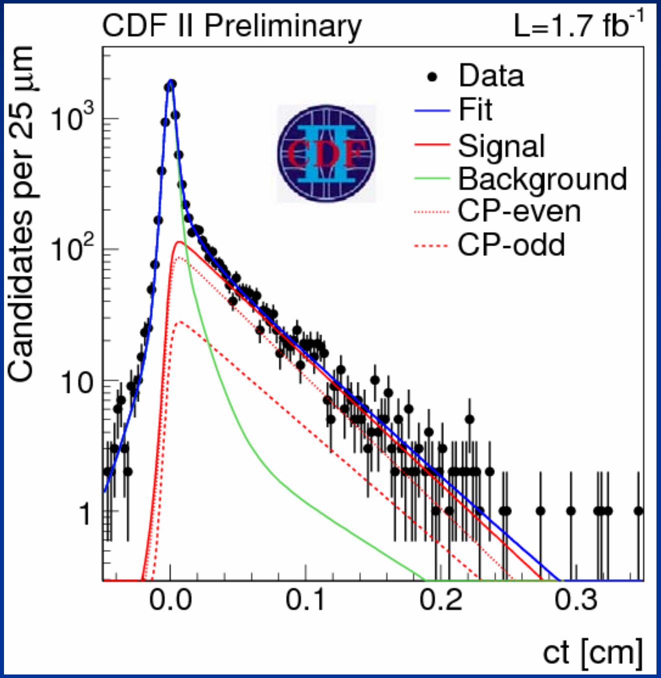
DØ ~900 signal events in ~1.1 fb^{-1}



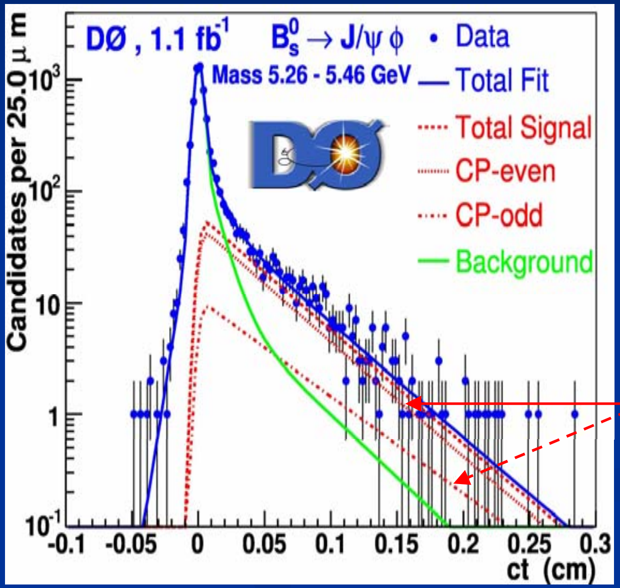
[Phys. Rev. Lett. 98, 121801 (2007)]

1.52 ± 0.08(stat) $^{+0.01}_{-0.03}$(syst) ps

Width Difference $\Delta\Gamma_s$



[arXiv:0712.2348 hep-ex]



[Phys. Rev. Lett. 98, 121801 (2007)]

CP-even (B_s^{light}) and CP-odd (B_s^{heavy}) components have different lifetimes → $\Delta\Gamma \neq 0$

$\Delta\Gamma_s = 0.08 \pm 0.06$ (stat) ± 0.01 (syst) ps^{-1}
(world best measurement)

$\Delta\Gamma_s = 0.12\ ^{+0.08}_{-0.10}$ (stat) ± 0.02 (syst) ps^{-1}

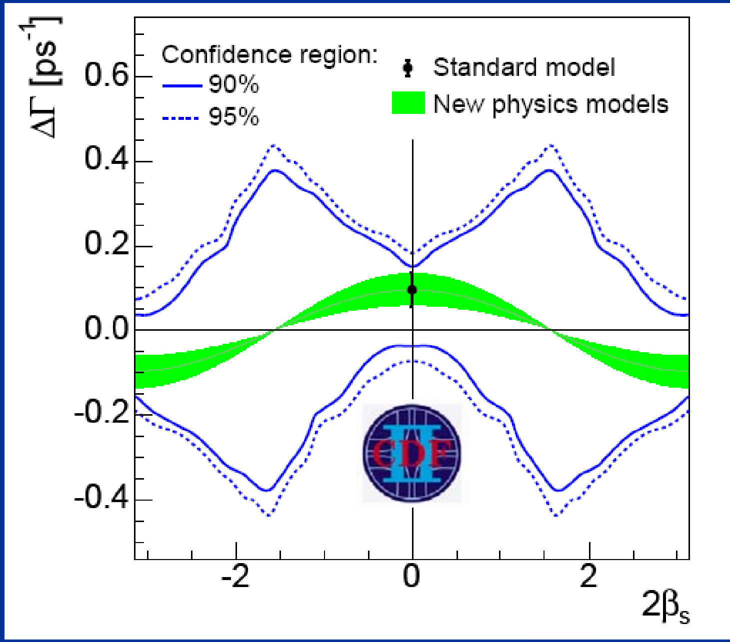
Cross check: CDF measures decay amplitudes and strong phases in high statistics $B^0 \to J/\Psi\, K^{*0}$ sample → agreement and competitive with B factories

β_s in Un-tagged $B^0_s \to J/\psi\phi$ Decays

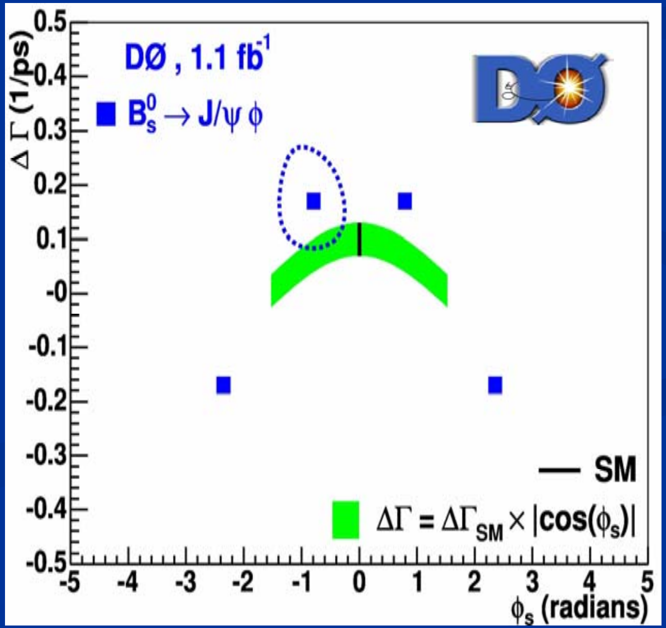
Without identification of the initial B_s flavor still have sensitivity to β_s.
Symmetries in the likelihood → 4 solutions are possible in $2\beta_s$-$\Delta\Gamma$ plane

Due to irregular likelihood and biases in fit, CDF only quotes confidence regions and *p*-value: **Standard Model probability 22%.**
DØ quotes point estimate (solution closest to the SM prediction and fit biases included in the systematics): **$\phi_s = -0.79 \pm 0.56$ (stat) $^{+0.14}_{-0.01}$ (syst).**

CDF: 90%, 95% C.L

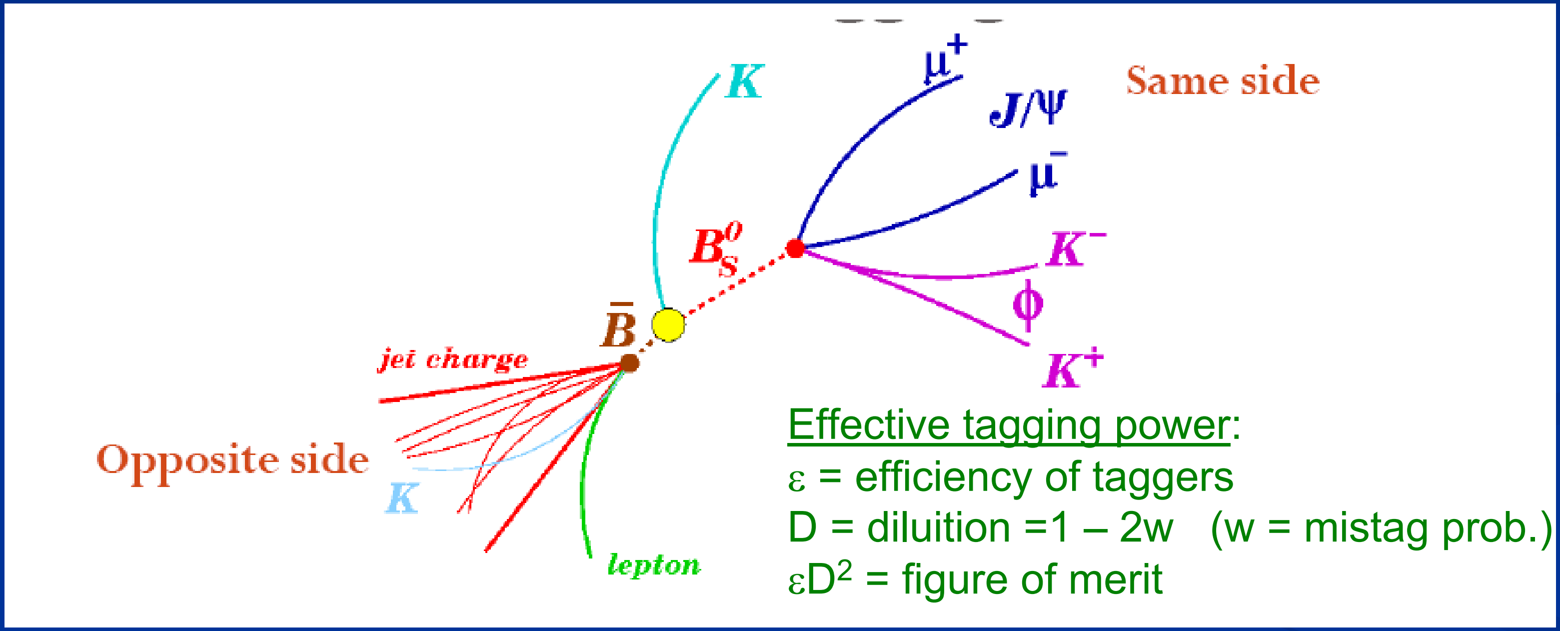


DØ: 39% C.L.



Flavor Tagging at CDF

Quarks produced in pairs at Tevatron. Tag either b quark which produces $B^0_s \rightarrow J/\psi\phi$ (SST), or other b quark Opposite Side (OST).



Jet Charge: the sum of **charges** of the **b-Jet** tracks correlated to the b-flavour

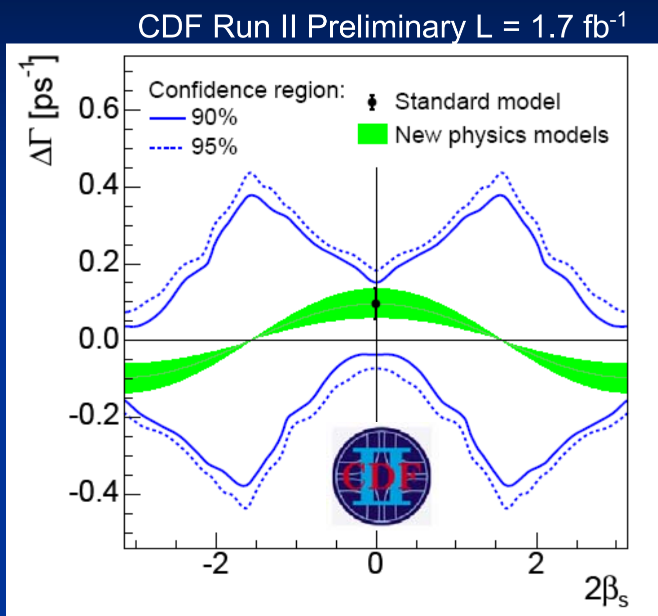
Soft Lepton (e,μ) due to $\mathbf{b \rightarrow \ell \nu X}$
ℓ charge correlated to b-flavour

$\varepsilon = 96 \pm 1$ %
$D = 11 \pm 2$ %
$\varepsilon D^2 \sim 1.2$ %

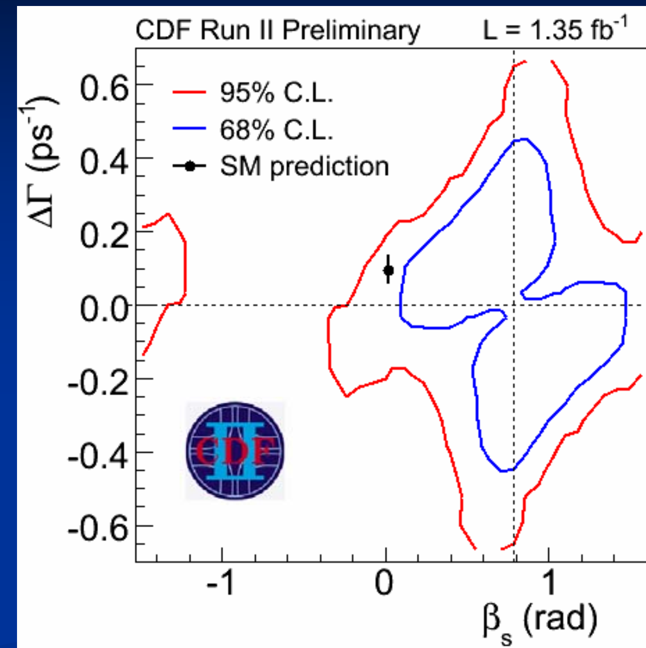
Same Side Kaon: for $\mathbf{B^0_s}$ is likely to have close in ΔR a $\mathbf{K^+}$ from fragmentation

$\varepsilon = 50 \pm 1$ %
$D = 27 \pm 4$ %
$\varepsilon D^2 \sim 3.6$ %

β_s in Tagged $B^0_s \to J/\psi\phi$ Decays (CDF)



flavor tagging →



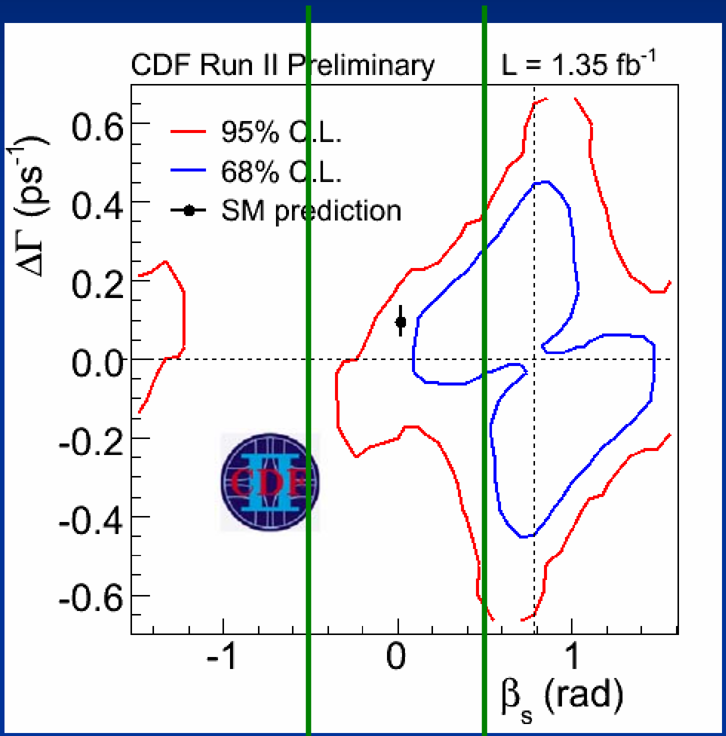
Assuming the SM predicted values for $2\beta_s$ =0.04 and $\Delta\Gamma_s$=0.096 ps^{-1} the p-value corresponding to our data is 15% (compatible at 1.5σ).

- Confidence regions procedure without external constraints:
  - 2βs in [0.32, 2.82] at the 68% C.L.

- Confidence regions with external constraints on strong phases, lifetime and $\Delta\Gamma_s$= 0.096+/- 0.039:
  - 2βs in [0.40, 1.20] at 68% C.L.

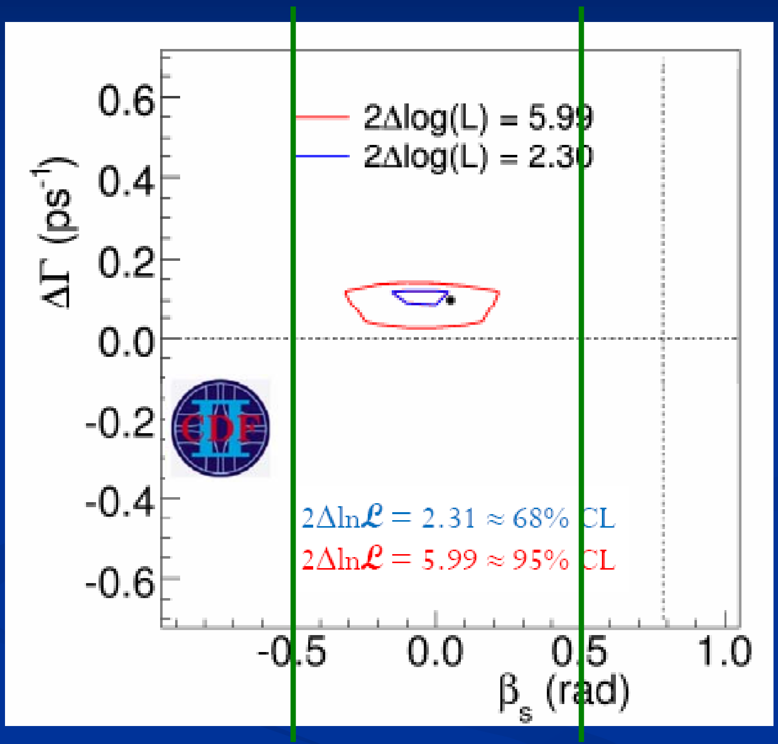
- **Available β_s parameter space is greatly reduced when using flavor tagging.**

Future sensitivity for β_s at CDF



Data Today 1.35 fb^{-1}

projection



Pseudo-experiments 6 fb^{-1} generated with β_s =0.02

Projected Confidence Regions in 6 fb^{-1} assuming same yield per fb^{-1} in future and same tagging efficiency and dilution.

Charge Asymmetry in Semileptonic $B^0_s \rightarrow \mu D_s X$ Decays

Study $B_s^0 \rightarrow \mu^+ D_s^- \nu X$ with $D_s^- \rightarrow \phi\pi^-$ $\phi \rightarrow K^+ K^-$

L = 1.3 fb^{-1} with total signal yield ≃27K events

Compare decay rates of B_s and B_s:

$$\boxed{A_{SL}^{s,unt} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^-) + N(\mu^- D_s^+)} = [1.23 \pm 0.97\,(\text{stat}) \pm 0.17\,(\text{syst})] \times 10^{-2}}$$

Suppressed systematic uncertainties do to regular change of magnet polarization at DØ .

Semileptonic charge asymmetry is related to $\phi_s = \arg(-M_{12}/\Gamma_{12})$

$$A_{SL}^{s,unt} = \frac{1}{2}\frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$$

Can combine this result with β_s measurement in $B_s \rightarrow J/\psi\phi$ to constrain NP

Combined DØ Constraints on B^0_s Width Difference and CP Violation Phase

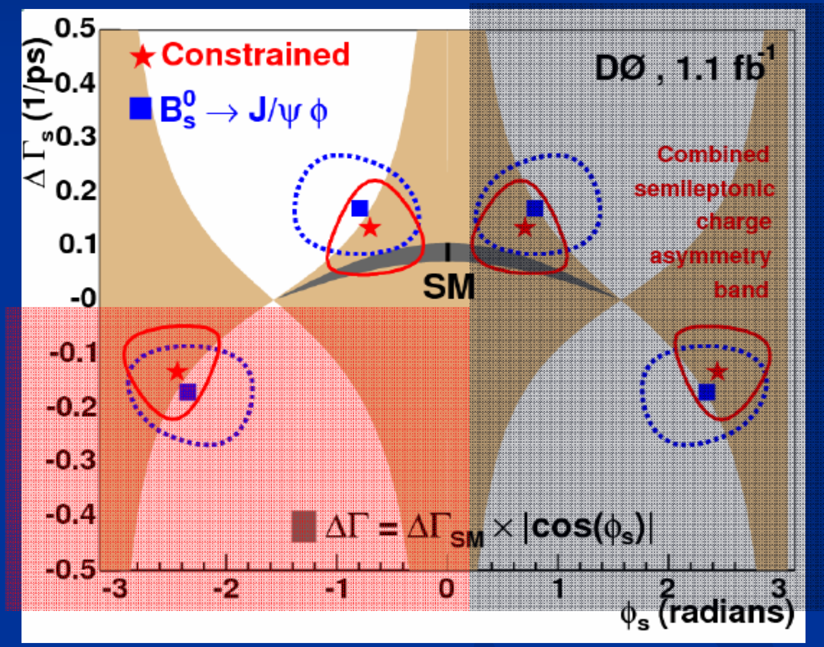
Combine width difference and CP violation phase from time dependent angular analysis $B^0_s \to J/\psi\phi$ with measurements from charge asymmetry in semileptonic decays

Contours indicate 39% C.L. regions:

Final combined DØ results with ~1 fb^{-1} :

$$\Delta\Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1}$$
$$\phi_s = -0.70^{+0.47}_{-0.39}.$$

From tagged $B_s \to J/\psi\phi$ analysis, CDF excludes ~half available space in ϕ_s-$\Delta\Gamma_s$ plane.



Based on flavor SU(3) symmetry, CDF constrains strong phases to B factories measurements → bottom – left solution is suppressed as well.

Expect tagged $B^0_s \to J/\psi\phi$ analysis from DØ soon
Expect updated analyses with 2x data from both experiments soon

Λ^0_b Lifetime

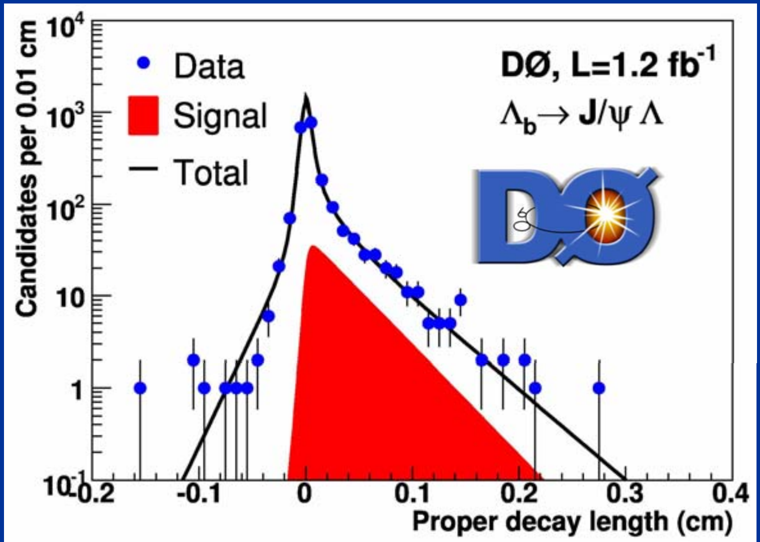
Important test of models that describe quark interactions between heavy and light quarks within bound states

HQET + Lattice QCD predicts: $\tau(\Lambda_b)/\tau(B^0) = 0.88 \pm 0.05$

DØ measures Λ_b lifetime two decay modes:

$\Lambda_b \rightarrow J/\psi\ \Lambda$

1.2 fb^{-1}, ~170 signal events

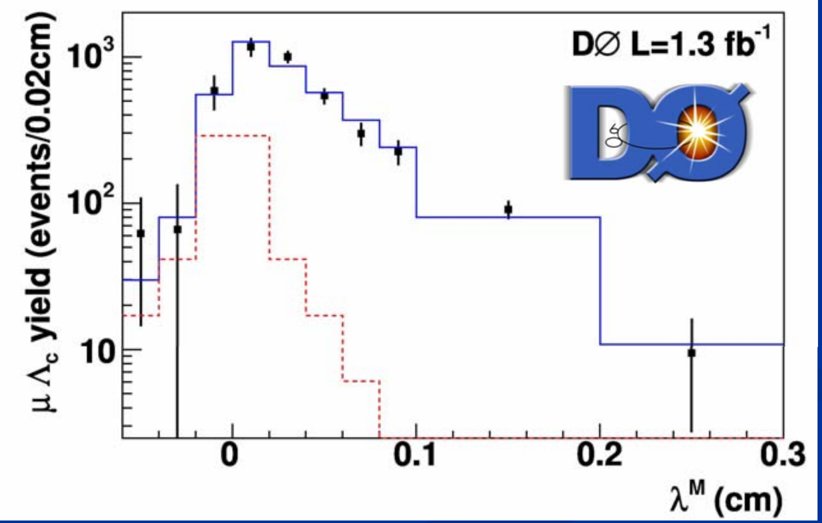


$$\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115}(\mathrm{stat}) \pm 0.042(\mathrm{syst})\ \mathrm{ps}$$

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.811^{+0.096}_{-0.087}\ (\mathrm{stat}) \pm 0.034\ (\mathrm{syst})$$

$\Lambda^0_b \rightarrow \mu\bar{\nu}\Lambda^+_c X$

1.3 fb^{-1}, ~4400 signal events



$$\tau(\Lambda^0_b) = 1.290\ ^{+0.119}_{-0.110}\ (\mathrm{stat})\ ^{+0.087}_{-0.091}\ (\mathrm{syst})$$

Λ^0_b Lifetime Current Status

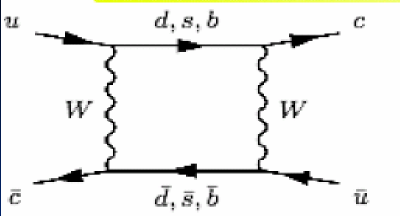
DØ measurements are in agreement with the theoretical predictions and with the world average $\tau(\Lambda_b^0) = 1.230 \pm 0.074$ ps

CDF measurement in $\Lambda_b \to J/\psi\ \Lambda$ ~3σ high w.r.t world average

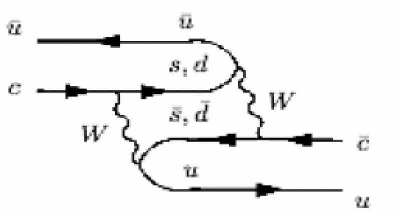
Expect CDF measurement in hadronic mode soon

decay mode	CDF lifetime (ps), 1 fb^{-1}	DØ lifetime (ps), 1.3 fb^{-1}
$\Lambda_b \to J/\psi\ \Lambda$	$1.593\ ^{+0.083}_{-0.078}$ (stat.) $\pm\ 0.033$ (syst.)	$1.218^{+0.130}_{-0.115}$(stat) $\pm\ 0.042$(syst) ps
$\Lambda_b^0 \to \mu\bar{\nu}\Lambda_c^+ X$	x	$1.290\ ^{+0.119}_{-0.110}$ (stat) $^{+0.087}_{-0.091}$ (syst)
$\Lambda_b^0 \to \Lambda_c^+\pi^-$	expected soon	x

Charm Mixing

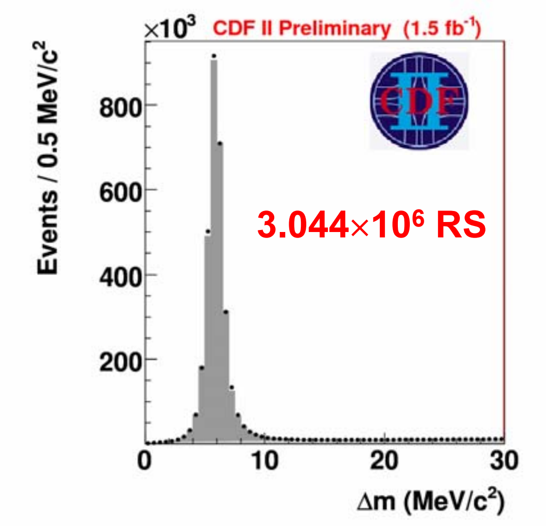


Mixing box diagram

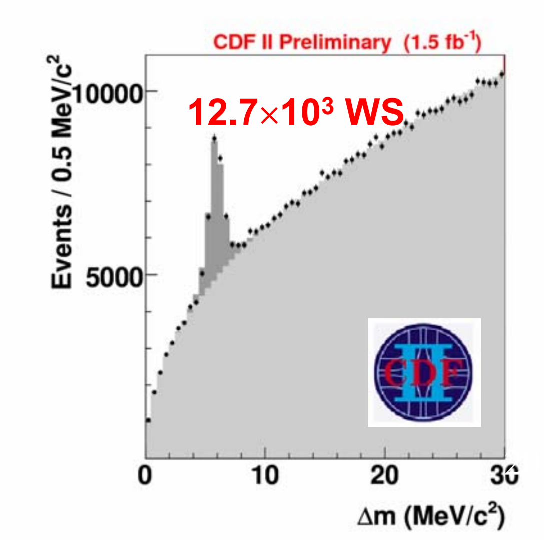


Mixing long distance diagram

- Charm mixing small in Standard model
  - Mixing in Bottom and Strange systems larger due to top participating in box diagram
- Sign of new physics if mixing oscillation different from expected
- B factories have presented evidence of charm mixing $D^0 \rightarrow K\pi/KK/\pi\pi$.



- Large charm samples in CDF data
  - $D^{*-} \rightarrow D^0\pi_{soft}$, $D^0 \rightarrow K\pi$
- π_{soft} charge tags D flavour at production
- RS: $D^{*-} \rightarrow D^0\pi_{soft}$
- WS: D^0 mixed or DCS decay



WS/RS ratio:

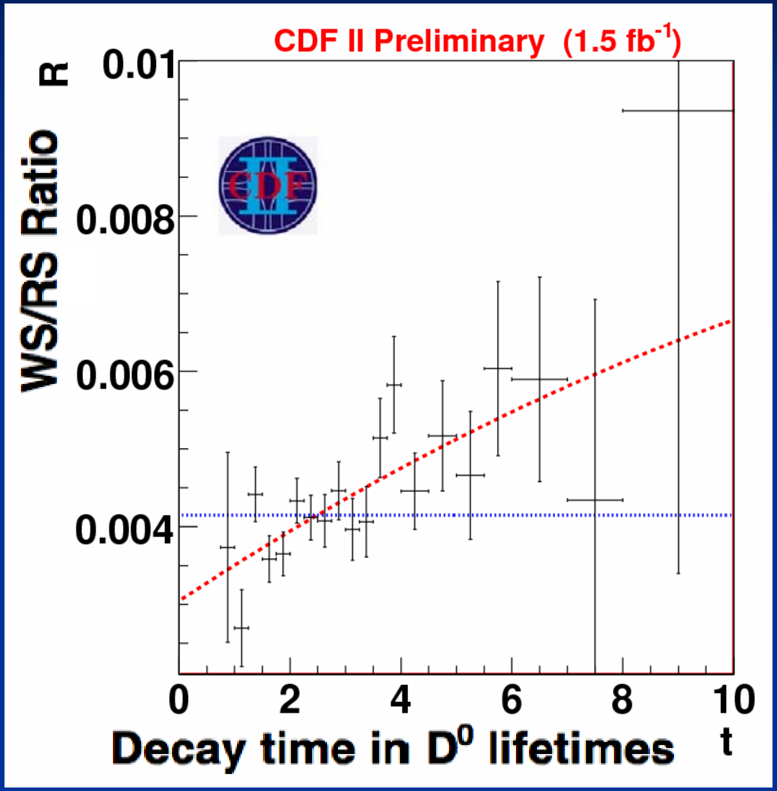
$$R(t) = R_D + y'\sqrt{R_D}\,t + \frac{x'^2 + y'^2}{4}\,t^2$$

$$x' = x\cos\delta + y\sin\delta \quad \text{and} \quad y' = -x\sin\delta + y\cos\delta$$

$$x = \Delta M/\Gamma \qquad y = \Delta\Gamma/2\Gamma$$

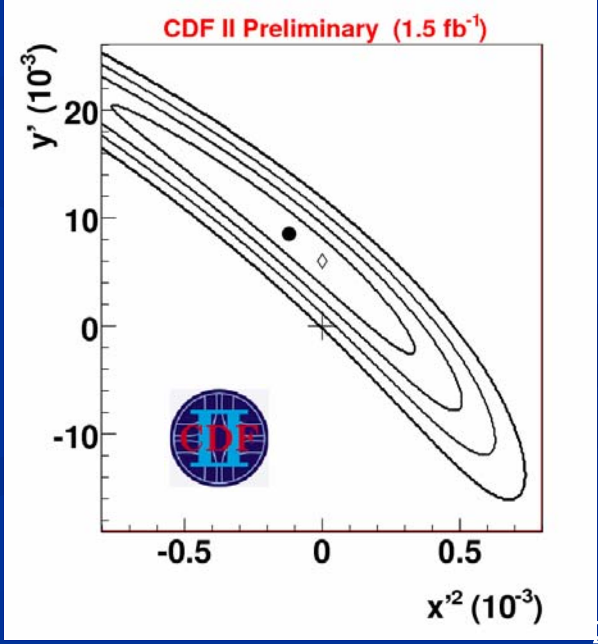
Charm Mixing at CDF

1.5 fb^{-1}



Perform binned fits to ratio of WS to RS as function of time of D^0 decay
Probability of no mixing is 0.13%
(Equivalent to 3.8σ significance)

Allowed regions of charm mixing parameter phase space:

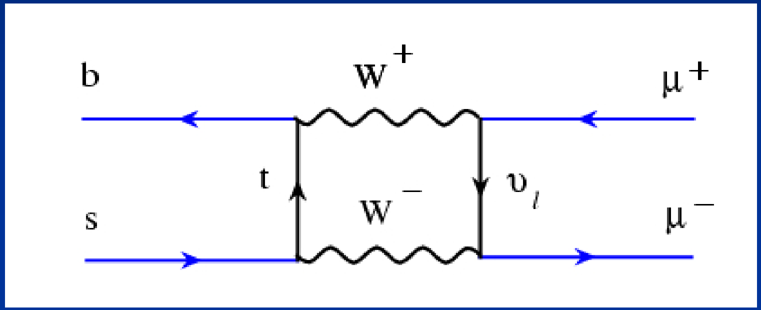


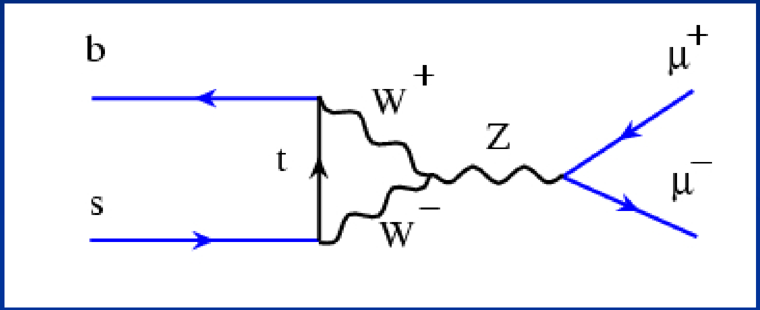
Experiment	$R_D\,(10^{-3})$	$y'\,(10^{-3})$	$x'^2\,(10^{-3})$	Mixing Signif.
CDF	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
BABAR [8]	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
Belle [9]	3.64 ± 0.17	$0.6\,^{+4.0}_{-3.9}$	$0.18\,^{+0.21}_{-0.23}$	2.0

[arXiv: 0712.1567 hep-ex]

$B \to \mu\mu$ in the Standard Model

- In Standard Model FCNC decay $B \to \mu\mu$ heavily suppressed





- Standard Model predicts:

$$\begin{cases} BR(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5)\times 10^{-9} \\ BR(B_d \to \mu^+\mu^-) = (1.00 \pm 0.14)\times 10^{-10} \end{cases}$$

[A. Buras Phys. Lett. B 566,115]

- $B_d \to \mu\mu$ further suppressed by CKM coupling $(V_{td}/V_{ts})2$
- Below sensitivity of Tevatron experiments
- SUSY scenarios (MSSM,RPV,mSUGRA) boost the BR by up to 100x

Observe no events $\Rightarrow$ set limits on new physics
Observe events $\Rightarrow$ clear evidence for new physics

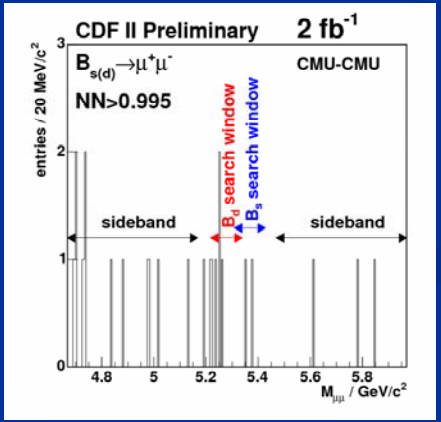
Methodology

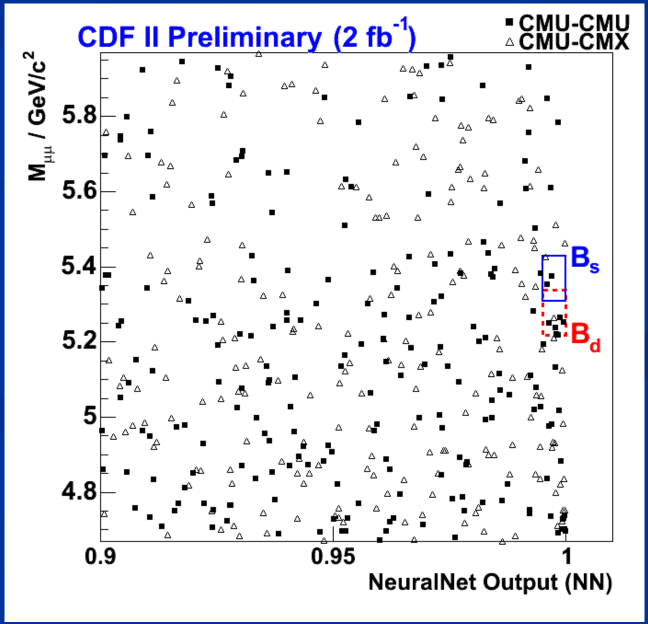
- Aim to measure BR or set limit:

$$BR(B_s \to \mu^+\mu^-) = \frac{N_{Bs}}{N_{B+}} \frac{\alpha_{B+} \cdot \varepsilon_{B+}^{total}}{\alpha_{Bs} \cdot \varepsilon_{Bs}^{total}} \frac{f_u}{f_s} BR(B^+ \to J/\psi K^+) BR(J/\psi \to \mu^+\mu^-)$$

- Use $B^+ \to J/\psi K^+$ as a control mode
- Neural network selection
- Use particle ID to suppress B→ hh, fake muon backgrounds
- Measure remaining background
- Measure acceptance and efficiency ratios

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





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

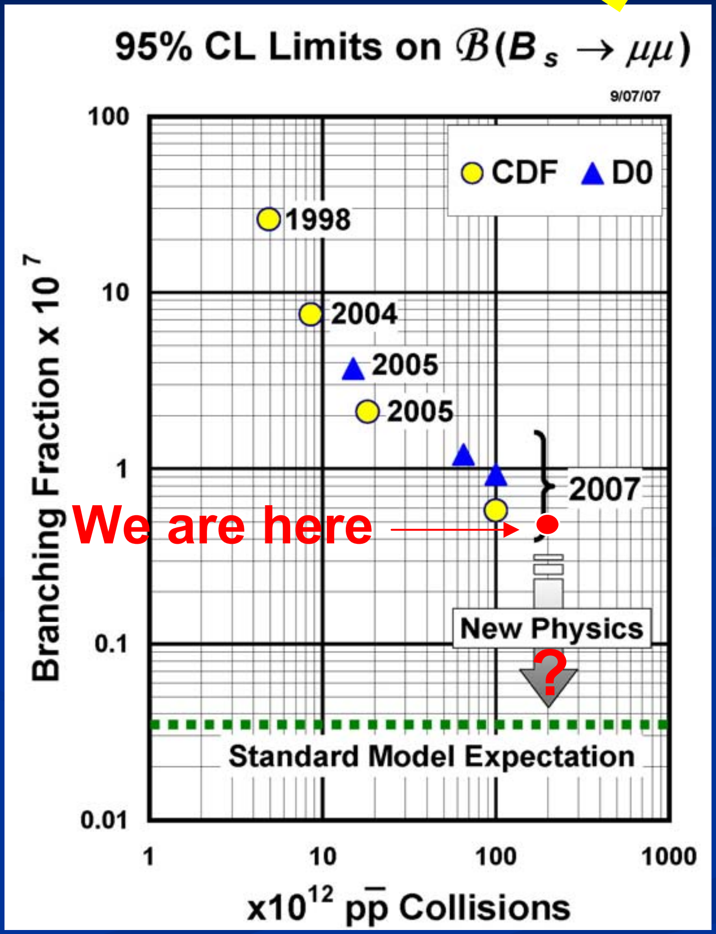
2 fb-1

No significant excess, set limits:

$BR(B^0_s \to \mu\mu) < 5.8 \cdot 10^{-8}$ @ 95%CL
$< 4.7 \cdot 10^{-8}$ @ 90%CL

$BR(B^0_s \to \mu\mu) < 9.3 \cdot 10^{-8}$ @ 95%CL
$< 7.5 \cdot 10^{-8}$ @ 90%CL

$BR(B^0_d \to \mu\mu) < 1.8 \cdot 10^{-8}$ @ 95%CL
$< 1.5 \cdot 10^{-8}$ @ 90%CL



Best existing limits

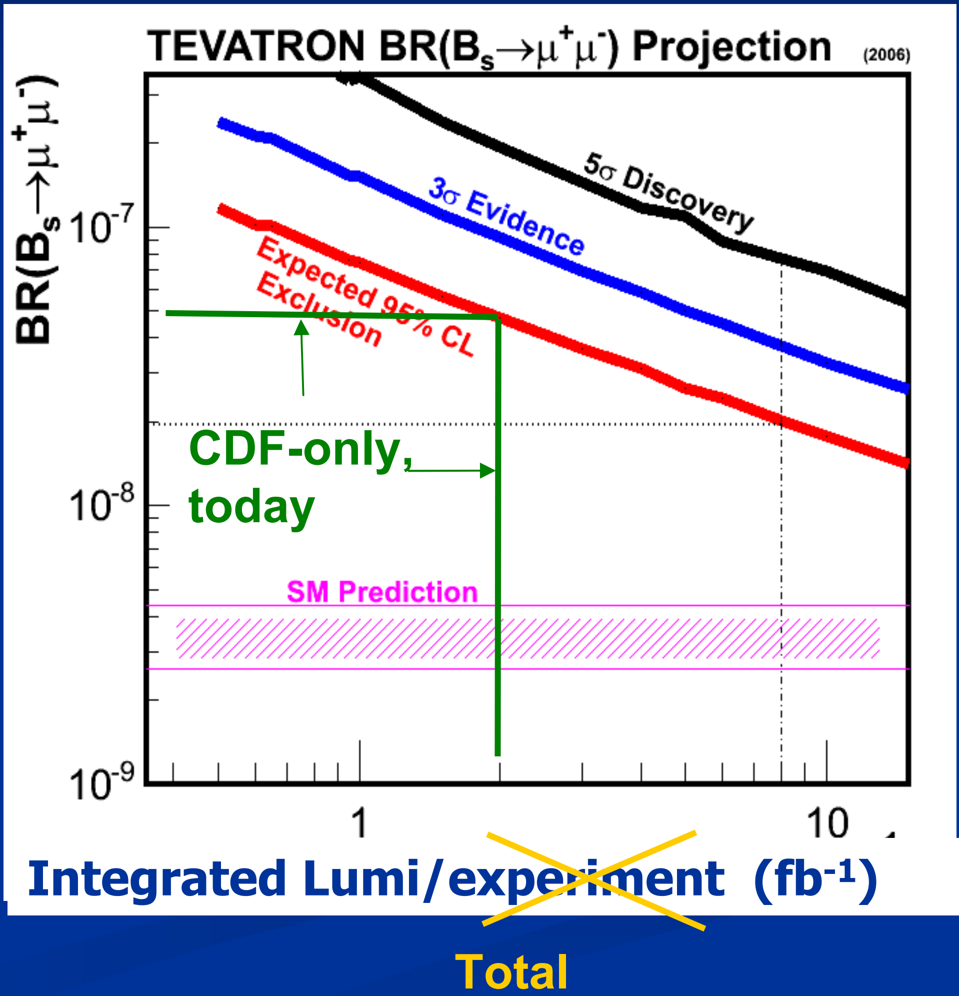
Combined Tevatron limit (unofficial)

$BR(B^0_s \to \mu\mu) < 4.5 \cdot 10^{-8}$ @ 95%CL **(13x SM)**

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

- Expectations from analysis performed on previous analysis (780 pb^{-1}), this is not a projection.
- $BR(B^0_s \to \mu\mu) < 2 \cdot 10^{-8}$ with 8 fb^{-1}. Corresponding to **6xSM**. Corresponding to 2 SM events reconstructed
- Conservative: in the past measurements were better than predictions.
- Today CDF sensitivity (with 2 fb^{-1}) is equal to the previous la sensitivity estimated for CDF+D0
- Possible further improvements of the analysis:
  - binned→unbinned analysis (*a la* B→hh)

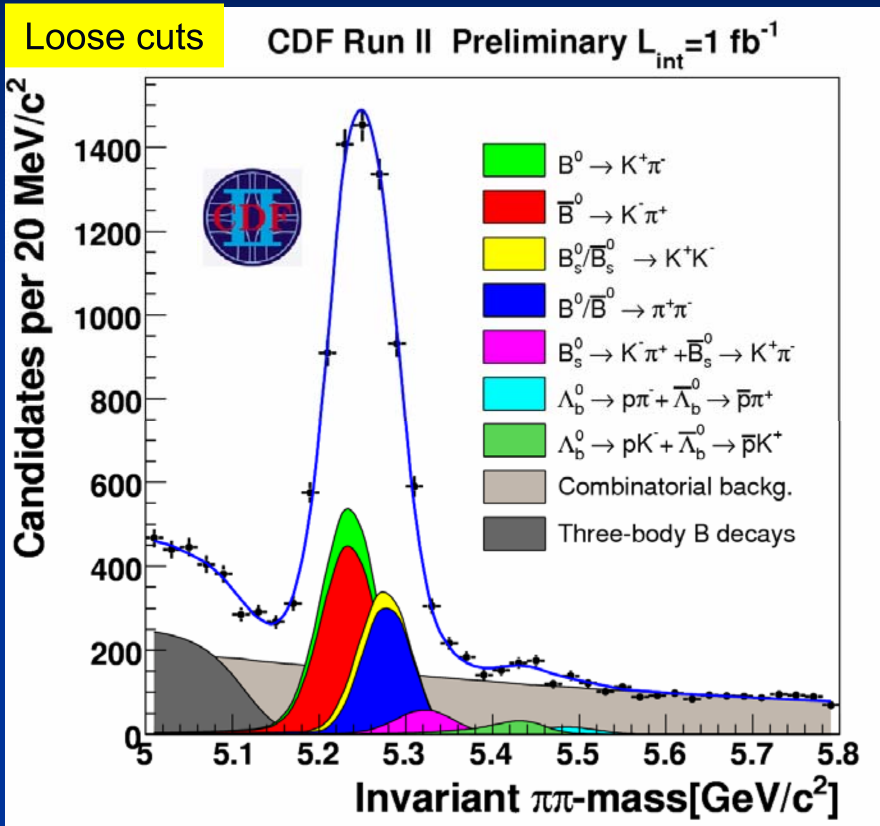
FNAL directorate plan is to run through 2010.



Direct $A_{CP}(B^0 \to K^+\pi^-)$

1 fb^{-1}

Loose cuts

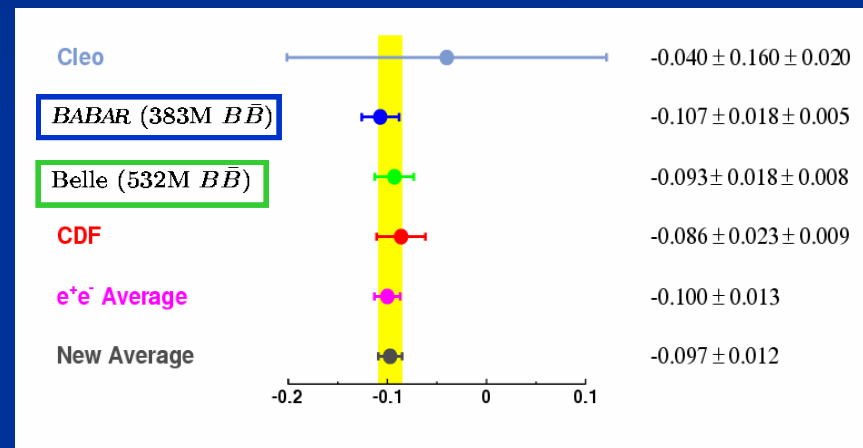


[hep-ex/0612018]

B^0 yields comparable to e^+e^-

4045 ± 84 $B^0 \to K^+\pi^-$

Large $B^0_s \to K^+K^-$ sample



Discrepancy with $A_{CP}(B^+ \to K^+\pi^0)$ up to **4.9 σ.**

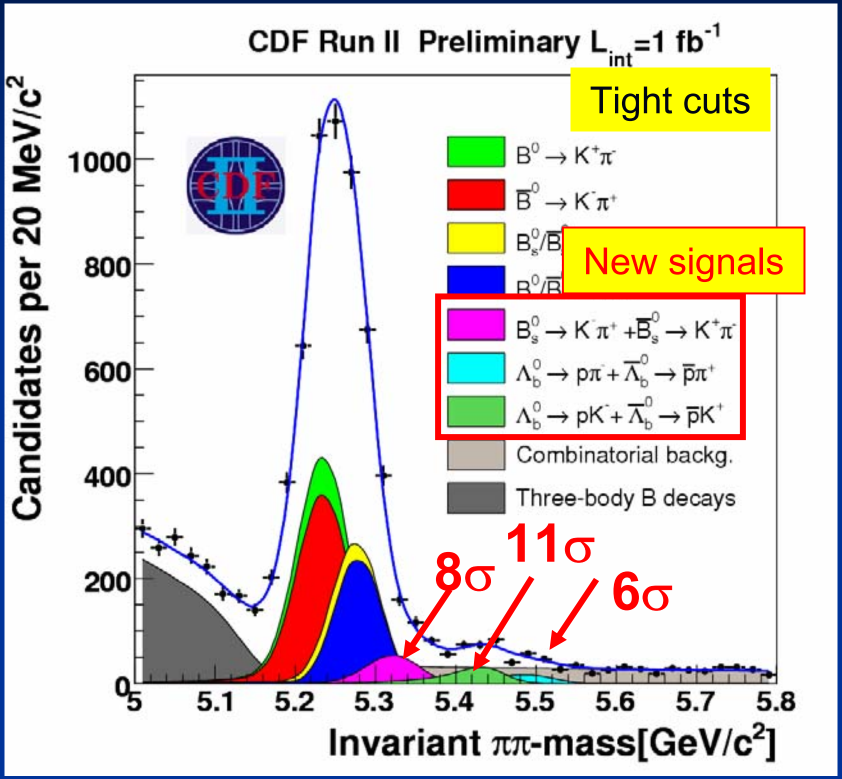
$$\frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023\ (stat.) \pm 0.009\ (syst.). \quad (13.14)$$

3.5 σ

Goal with Full Run II statistics 1%

$B^0_s \to K^-\pi^+$

1 fb-1

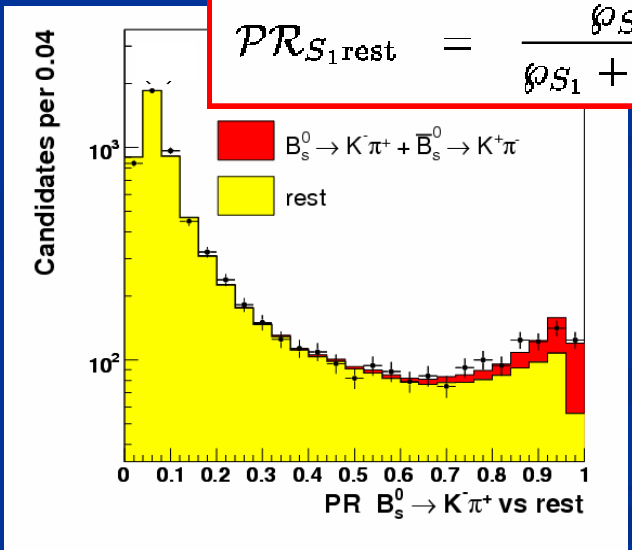


[hep-ex/0612018]

Selection optimized to observe and limit setting of $B^0_s \to K^-\pi^+$

First observation of three rare charmless decays: $B^0_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$ and $\Lambda^0_b \to pK^-$

$$\mathcal{PR}_{S_1 \mathrm{rest}} = \frac{\wp_{S_1}}{\wp_{S_1} + \wp_{\mathrm{rest}}}.$$



$B^0_s \to K\pi$ yield = 230 ± 34(stat.) ± 16(syst.)

$$BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.75\ (stat.) \pm 1.0\ (syst.)) \times 10^{-6}$$

Probability Ratio (PR) for data and projection shows the good separation achieved between $B^0_s \to K^-\pi^+$ and the rest (backgrounds and other signals) (mass, mometa and dE/dx of both tracks)

Direct $A_{CP}(B^0_s \to K^-\pi^+)$

1 fb^{-1}

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

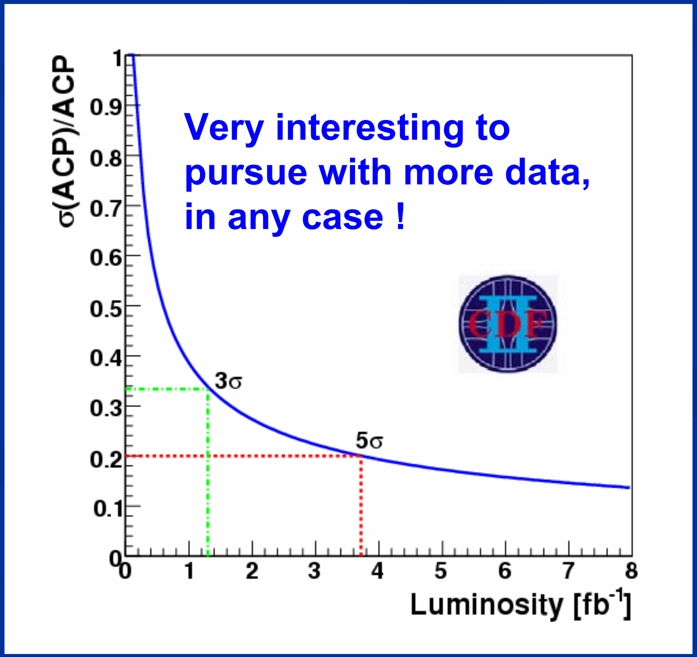
It is different from 0 by 2.3σ (stat. + syst.).

First measurement of DCPV in the $B^0_s \to K^-\pi^+$. Our measurement favors large CP violation as expected in the SM. On the other hand it is also compatible with 0 due to the large uncertainty.

Unique opportunity of checking for the SM origin of direct CP violation. Proposed by Gronau *[Phys.Rev. B482, 71(2000)]*, later shown to hold under much weaker assumptions by Lipkin *[Phys. Lett. B621,126, (2005)]*.

(SM =-1)

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}^0_s \to K^+\pi^-) - \Gamma(B^0_s \to K^-\pi^+)} = -0.78 \pm 0.39\ (stat.) \pm 0.12\ (syst.).$$

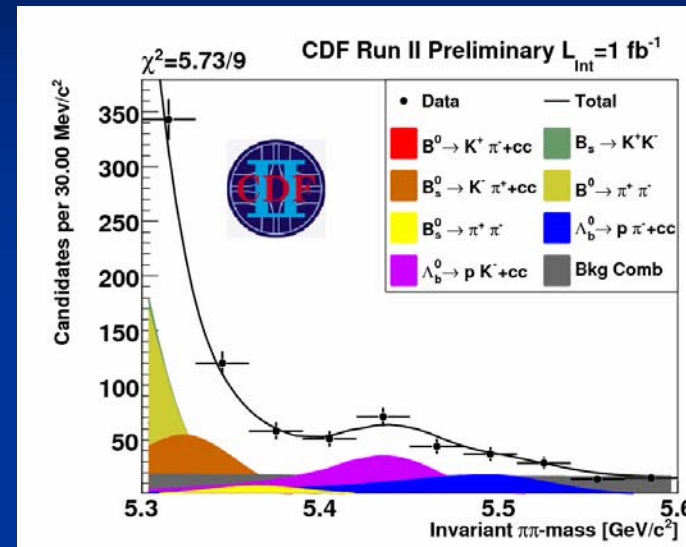


BR and A_{CP} in $\Lambda_b \to p\pi(K)$

1 fb^{-1}

First study of CP asymmetry in b baryon decays (SM prediction ~10%)
Use large sample collected by two displaced track trigger along with $B \to hh$.

Additionally, first branching fractions relative to $B^0 \to K\pi$ decays:

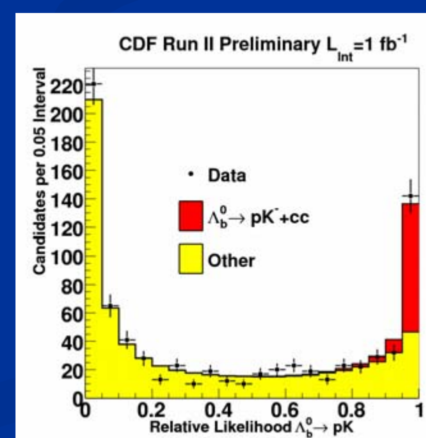


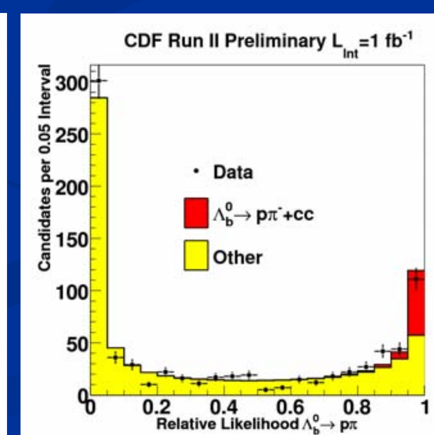
$$A_{CP}(\Lambda_b^0 \to p\pi^-) = \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)}{\mathcal{B}(\Lambda_b^0 \to p\pi^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)} = 0.03 \pm 0.17\ (stat.) \pm 0.05\ (syst.)$$

$$A_{CP}(\Lambda_b^0 \to pK^-) = \frac{\mathcal{B}(\Lambda_b^0 \to pK^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}K^+)}{\mathcal{B}(\Lambda_b^0 \to pK^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}K^+)} = 0.37 \pm 0.17\ (stat.) \pm 0.03\ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074\ (stat.) \pm 0.0058\ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089\ (stat.) \pm 0.0084\ (syst.)$$





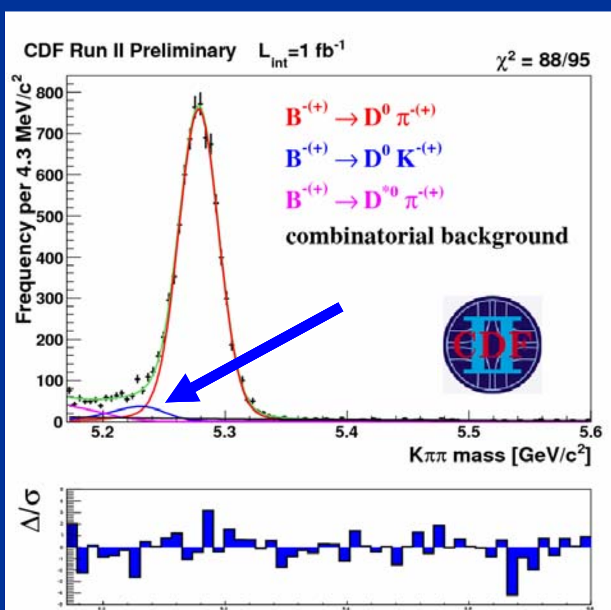
Minimal Supersymmetric Extensions of SM violating the R-parity could both suppress A_{CP} and enhance by factors ~100 BR with respect to SM predictions. *[PRD63,056006(2001)]*

BR and A_{CP} of $B^+ \to D^0_{CP} K^+$

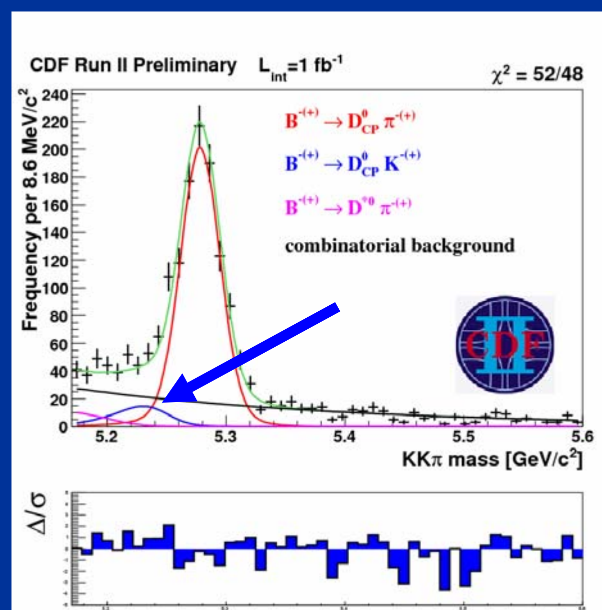
1 fb^{-1}

- Motivation: theorethically 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 $B^+ \to D^0 K^+$ with $D^0_{CP} \to K^+K^-/\pi^+\pi^-$, $D^0_{flav} \to \pi^+K^-$.

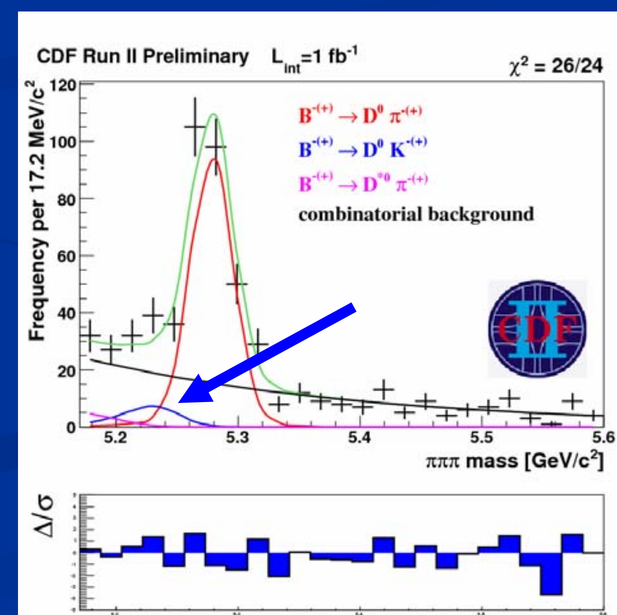
$B^+ \to D^0 K^+ \to [\pi^+K^-]K^+$ ~516



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



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



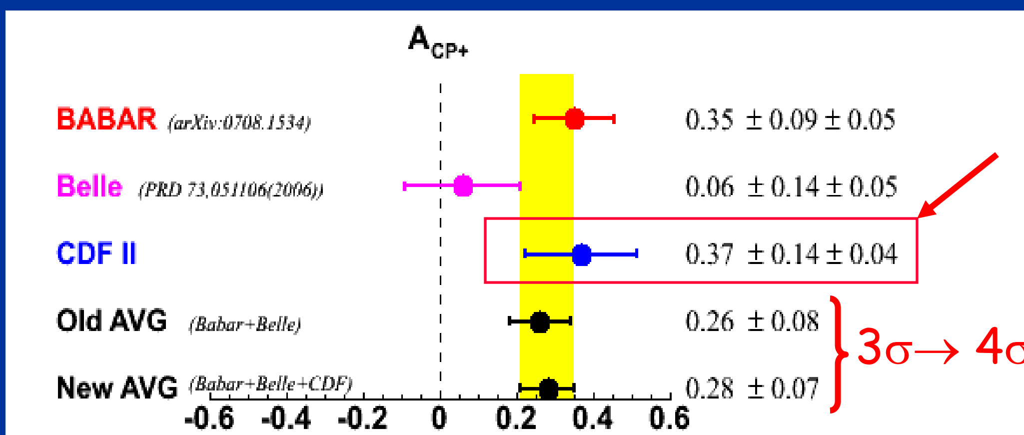
BR and A_{CP} of $B^+ \to D^0_{CP} K^+$

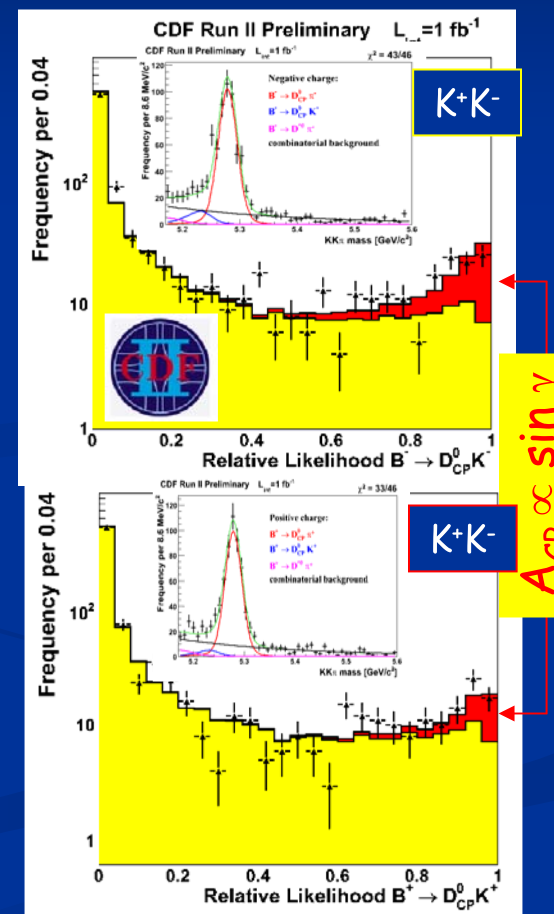
1 fb^{-1}

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

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

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





A first at a hadron collider. 1fb^{-1} ⟶ same precision of e^+e^-
Next step is to combine with Atwood-Dunietz-Soni (ADS) method to extract γ [PRD 63,036005 and PRL 78,3257].

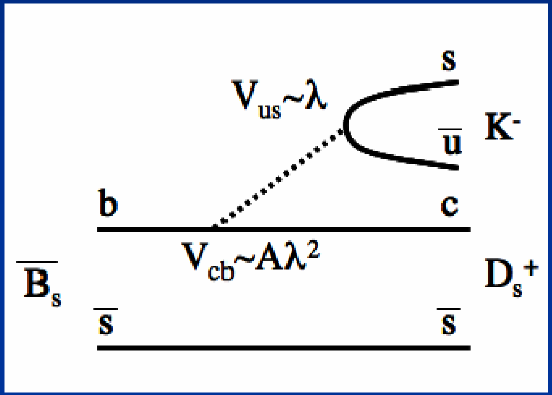
$B^0_s \to D_s K$ mode

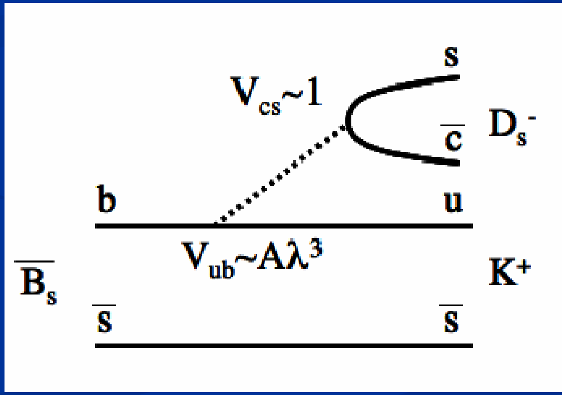
- Final states of both sign are accessible by both B^0_s and antiB^0_s mesons with similar size amplitude ($\sim\lambda^3$)

$$B^0_s \to D_s^{\pm} K^{\mp}$$
$$\overline{B}^0_s \to D_s^{\mp} K^{\pm}$$

- CP violation due to mixing can occur from the mixed and unmixed interference paths
- Need time-dependent CP asymmetries measurement
- Interesting comparison: $B^0_s \to D_s K$ can be suppressed or enhanced compared with $B^0 \to DK$
- First step: observation and BR measurement.

[Phys. C54,653 (1992) Nucl.Phys.B659:321-355,2003]





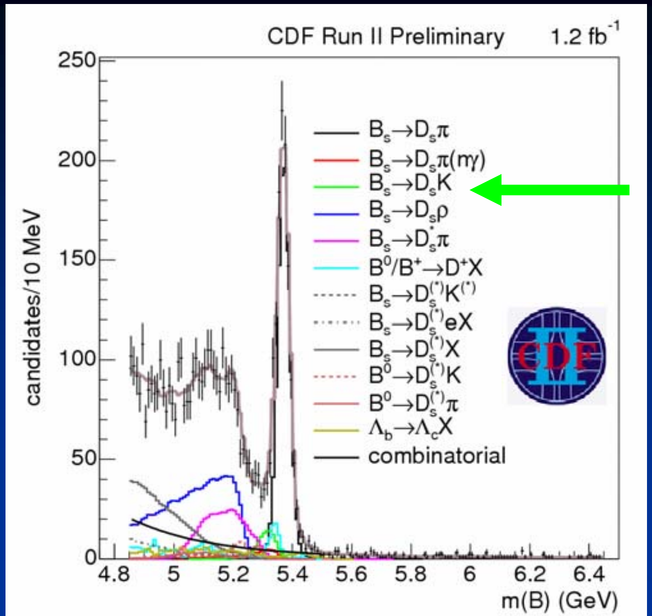
Untagged lifetime of $B^0_s \to D_s K$ may resolve the sign ambiguity in sen($2\beta_s$)

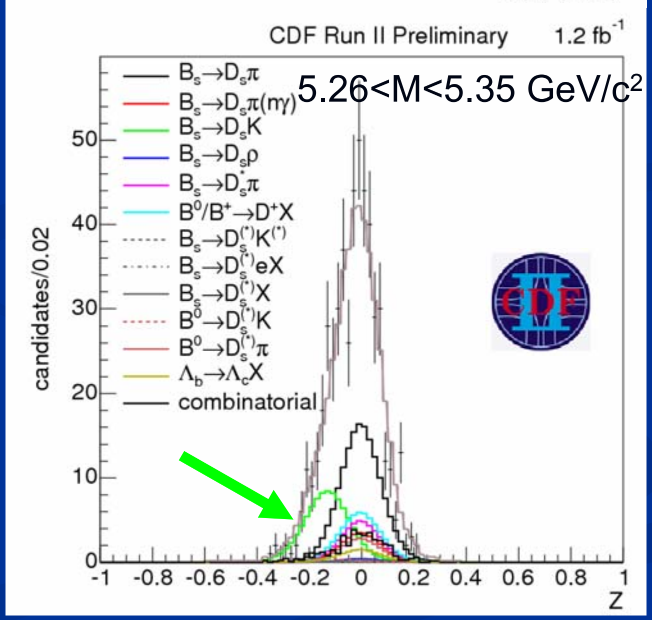
recent paper → [arXiv:0801.0143 hep-ph]

1.2 fb-1

BR($B^0_s \to D_s K$) First observation

- Combined mass and PID maximum likelihood fit on 1.2 fb^{-1}
  - $M_{D_s\pi}$ ($B^0_s \to D_s X \to [\phi\pi]X$)
  - dE/dx for the B-daughter track
- Important features:
  - Accurate study of physics background components from MC: $B^0_s \to D^{(*)}{}_s X, D_s\rho$ etc.
  - FSR tail from $B^0_s \to D_s\pi(n\gamma)$
- Main systematics from dEdx templates





7.9 σ

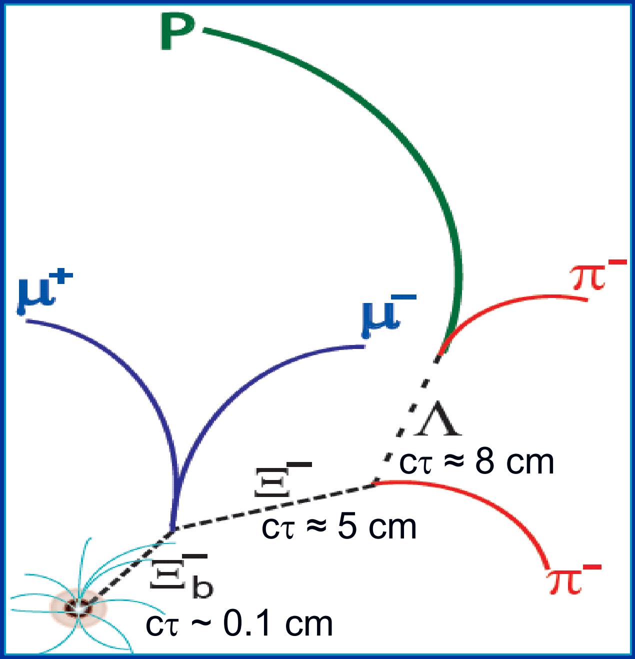
Yield ~109 ±19 $B^0_s \to D_s K$ events

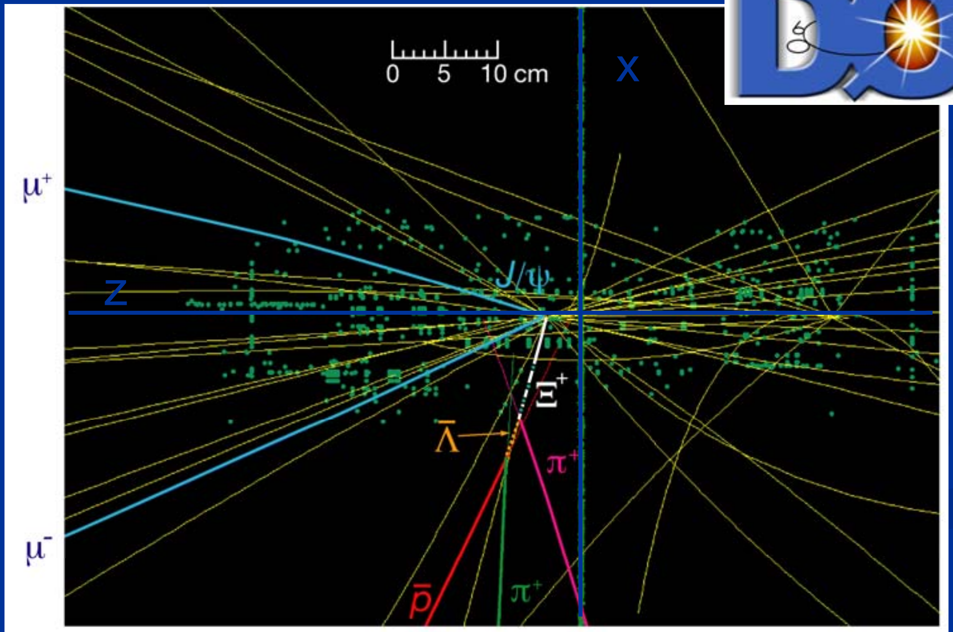
$$\mathcal{B}(\overline{B}^0_s \to D^\pm_s K^\mp)/\mathcal{B}(\overline{B}^0_s \to D^+_s \pi^-) = 0.107 \pm 0.019(\mathrm{stat}) \pm 0.008(\mathrm{sys})$$

Ξ_b Baryon (First Observation)

The third observed b baryon after Λ^0_b and CDF's recent discovery of Σ_b
Study b baryons → great way to test QCD which predicts $M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)$
Predicted mass: 5805.7 ± 8.1 MeV
Discovery decay mode at DØ:

$$\Xi_b^- \rightarrow J/\psi\, \Xi^-, \text{ with } J/\psi \rightarrow \mu^+\mu^-, \text{ and } \Xi^- \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^-$$





Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

Ξ_b Mass Measurement

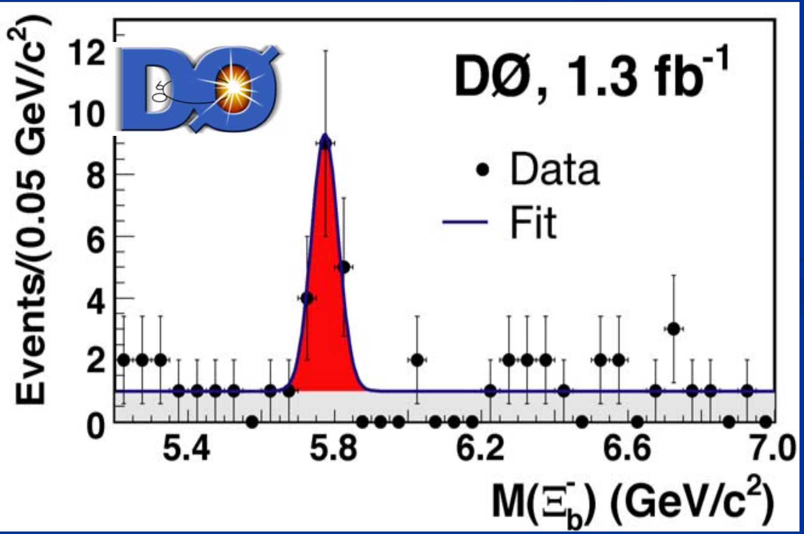
Clear excess in Ξ_b invariant mass distribution
Significance ~5.5σ

Number of signal events: $15.2 \pm 4.4(\text{stat})\ ^{+1.9}_{-0.4}\ (\text{syst})$
Mass: $5.774 \pm 0.011(\text{stat}) \pm 0.015(\text{syst})$ GeV (prediction 5805.7 ± 8.1 MeV)
Width: 0.037 ± 0.008 GeV in good agreement with MC expectation 0.035 GeV

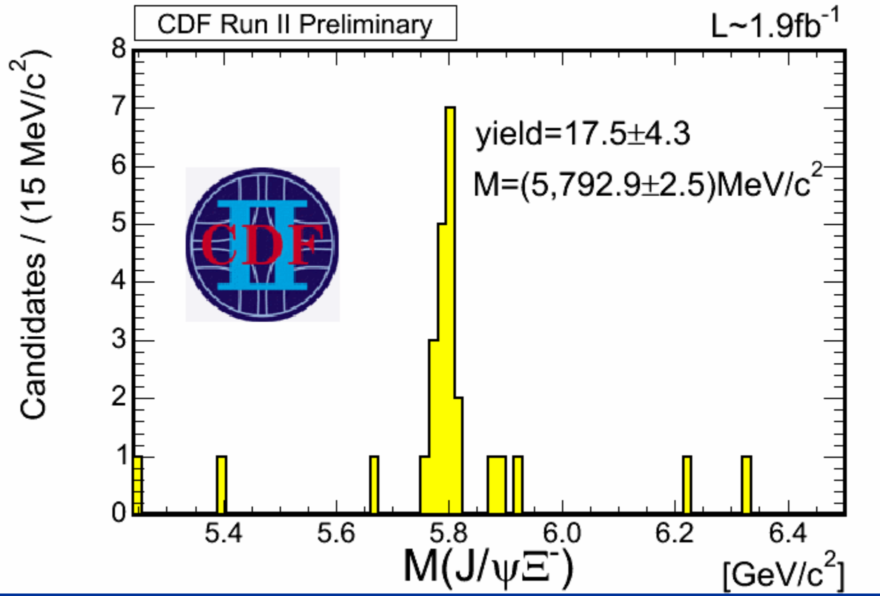
Production relative to $\Lambda_b \rightarrow J/\Psi\ \Lambda$

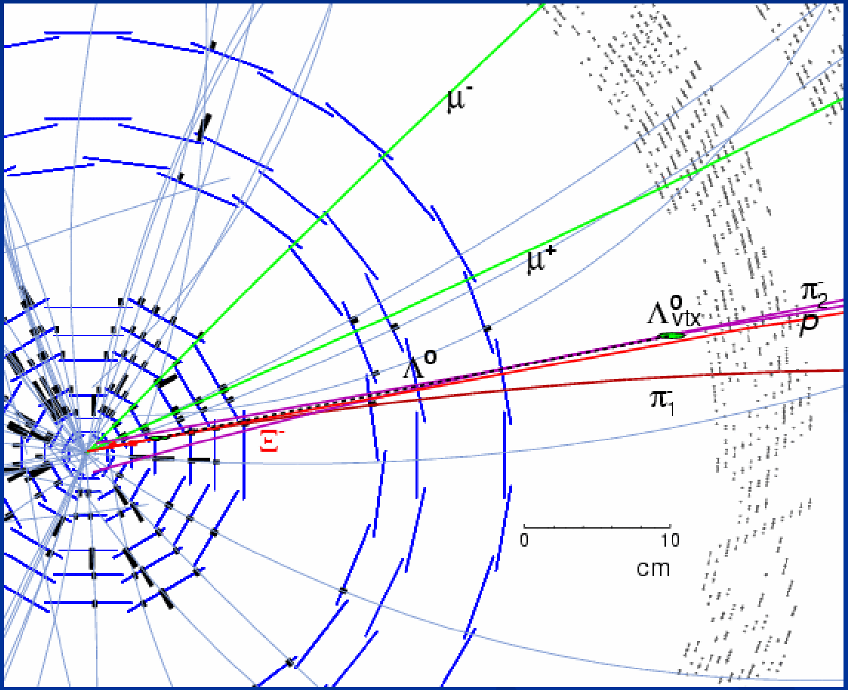
$$\boxed{\frac{f(b \rightarrow \Xi_b^-) \cdot Br(\Xi_b^- \rightarrow J/\psi\, \Xi^-)}{f(b \rightarrow \Lambda_b) \cdot Br(\Lambda_b \rightarrow J/\psi\, \Lambda)} = 0.28 \pm 0.09\,(\text{stat.})^{+0.09}_{-0.08}\,(\text{syst.})}$$

where f(b→X) : fraction of times
b quark hadronizes to X



Ξ_b Mass Measurement





$$M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV}/c^2$$

most precise measurement at 7.8σ significance

Conclusions

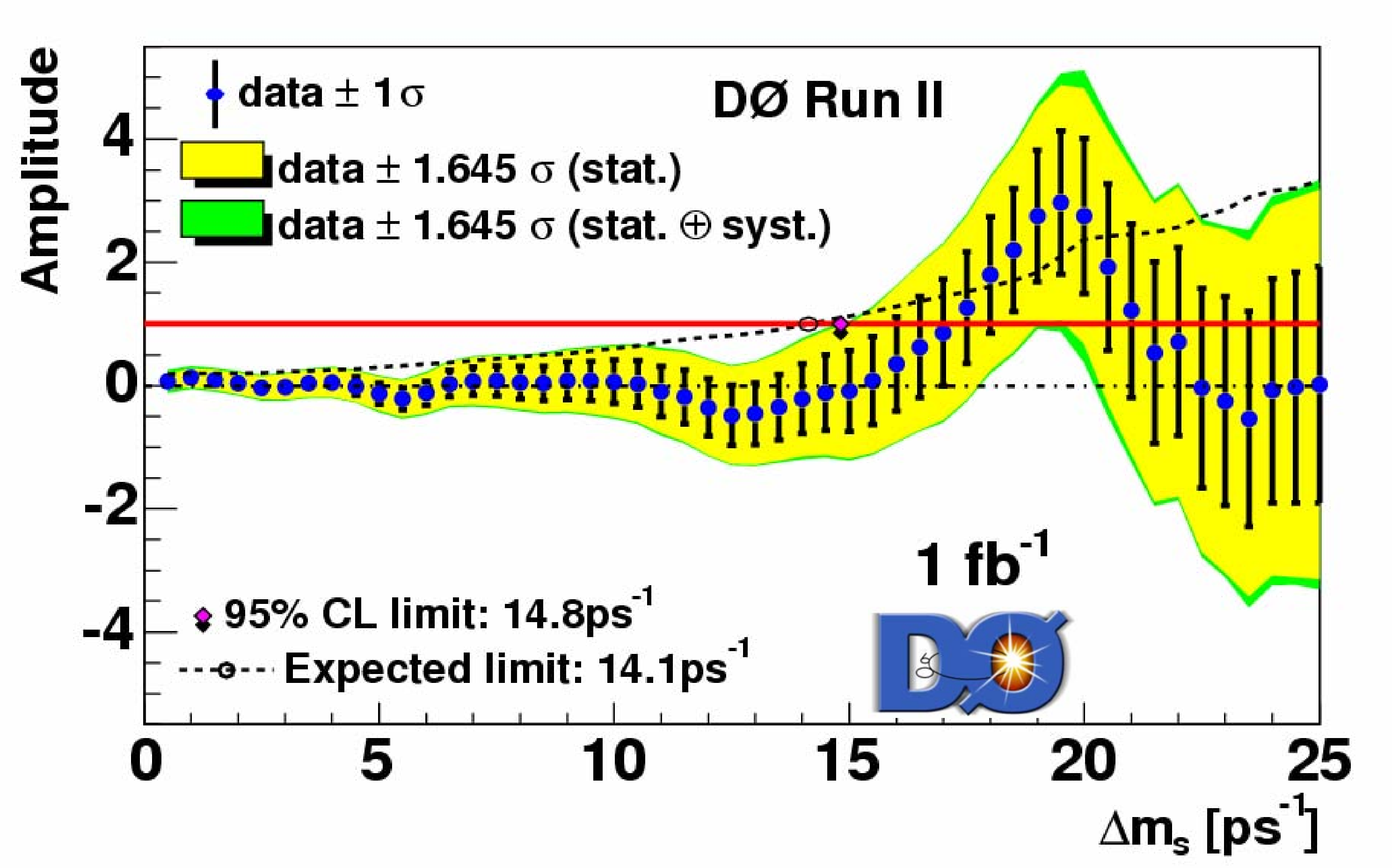
- Very rich B physics program at the Tevatron
- Great Tevatron performance → accumulate data fast and expect ~6 fb^{-1} by the end of the run.
- Expect updates of many analyses.
- Exciting time to study CP violation and search for new phenomena in B physics at Tevatron !

Topics not covered

- Charge asymmetry in semileptonic B^0_s decays,
- first observation of Σ_b,
- $B^0_s \rightarrow D_s(*)\ D_s(*)$,
- CP asymmetry in $B^+ \rightarrow J/\psi K^+$,
- Ψ(2S) production,
- Y(1S), Y(2S) polarization,
- $B_0 \rightarrow J/\psi\ K^{*0}$ angular analysis,
- orbitally excited B mesons,
- b-b correlations,
- B_c mass and lifetime
- ….. and many others….

Backup

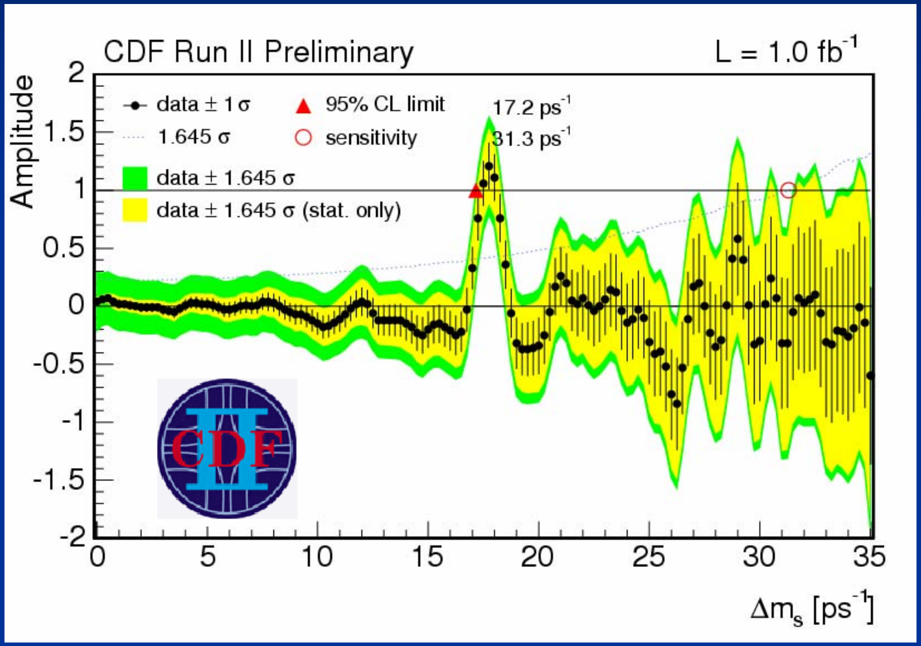
Δm_s

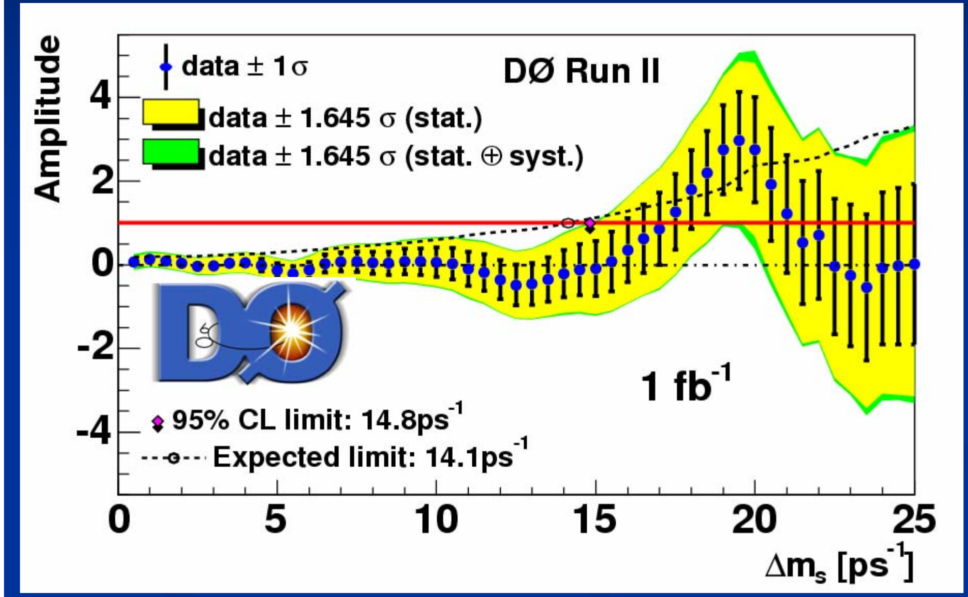


$17 < \Delta m_s < 21$ ps^{-1} at the 90% C.L

PRL 97 021802 (2006) [hep-ex/0603029]

B^0_s mixing: Δm_s





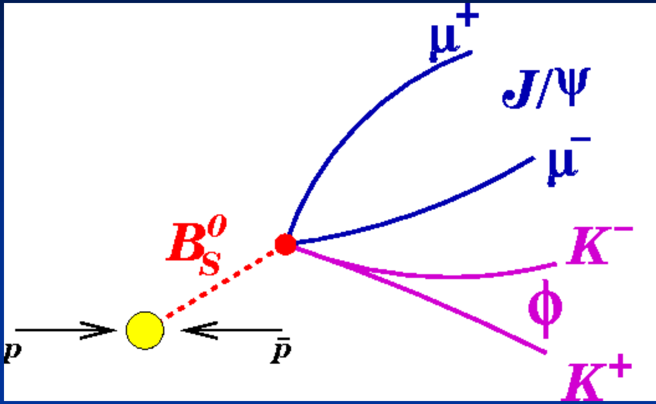
Δm_s = 17.77 ± 0.10 (stat) ± 0.07(syst) ps^{-1} (>5σ)

17 < Δm_s < 21 ps^{-1} at the 90% C.L

PRL 97, 242003 (2006) [hep-ex/0609040]

PRL 97 021802 (2006) [hep-ex/0603029]

Lifetime: $B^0_s \rightarrow J/\psi\phi$



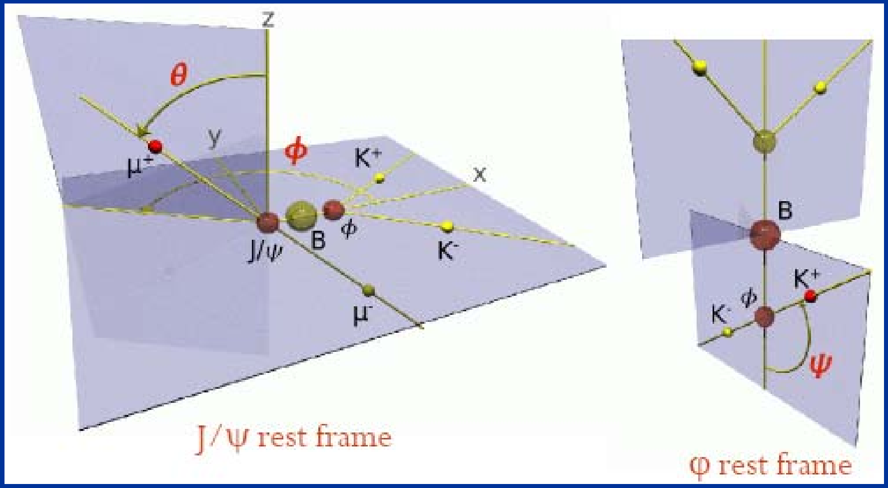
Extremely physics rich decay mode

Can measure lifetime, decay width, and, using known Δm_s, CP violating phase β_s

The decay of B_s (spin 0) to J/Ψ(spin 1) Φ(spin 1) leads to three different angular momentum final states:

L = 0 (s-wave), 2 (d-wave) → CP even ≈ $|B_s^L\rangle$

L = 1 (p-wave) → CP odd ≈ $|B_s^H\rangle$



three decay angles $\vec{\rho} = (\theta,\phi,\psi)$ describe directions of final decay products

$B^0_s \to J/\psi\phi$ Phenomenology

Three angular momentum states form a basis for the final state

Use alternative "transversity basis" in which the vector meson polarizations w.r.t. direction of motion are either:

- longitudinal (0) $\to$ CP even
- transverse ($\parallel$ parallel to each other) $\to$ CP even
- transverse ($\perp$ perpendicular to each other) $\to$ CP odd

Corresponding decay amplitudes: A_0, $A_\parallel$, $A_\perp$

At good approximation, mass eigenstates $|B_s^L\rangle$ and $|B_s^H\rangle$ are CP eigenstates

$\to$ use angular information to separate heavy and light states

$\to$ determine decay width difference

$$\Delta\Gamma = \Gamma_L - \Gamma_H$$

$\to$ some sensitivity to CP violation phase β_s

Determine B_s flavor at production (flavor tagging)

$\to$ improve sensitivity to CP violation phase β_s

$B^0_s \rightarrow J/\psi\phi$ Formulogy

B_s decay rate as function of time, decay angles and initial B_s flavor:

$$\frac{d^4P(t,\vec{\rho})}{dtd\vec{\rho}} \propto |A_0|^2\mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2\mathcal{T}_+ f_2(\vec{\rho})$$
$$+ |A_\perp|^2\mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp|\mathcal{U}_+ f_4(\vec{\rho})$$
$$+ |A_0||A_\parallel|\cos(\delta_\parallel)\mathcal{T}_+ f_5(\vec{\rho})$$
$$+ |A_0||A_\perp|\mathcal{V}_+ f_6(\vec{\rho}),$$

time dependence terms

angular dependence terms

terms with β_s dependence

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2)$$
$$\mp \eta\sin(2\beta_s)\sin(\Delta m_s t)],$$

terms with Δm_s dependence due to initial state flavor tagging

$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t)$$
$$- \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t)$$
$$\pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$
$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t)$$
$$- \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t)$$
$$\pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

'strong' phases:

$$\delta_\parallel \equiv \arg(A_\parallel^* A_0)$$
$$\delta_\perp \equiv \arg(A_\perp^* A_0)$$

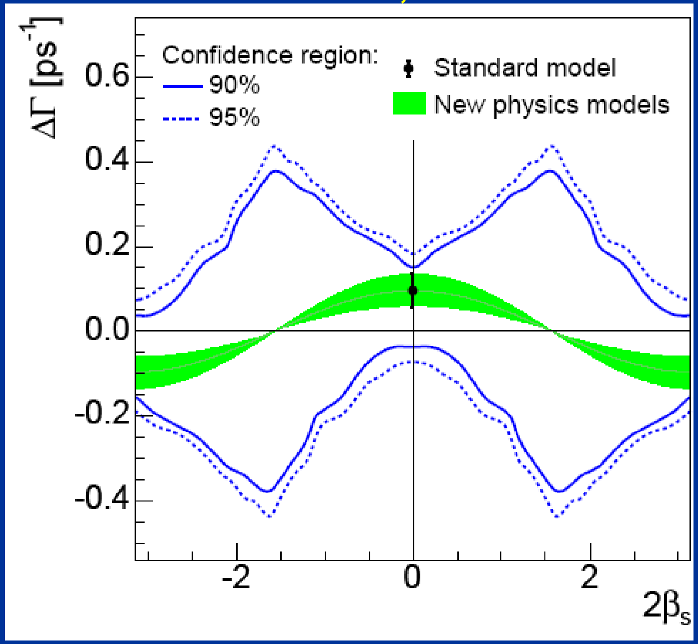
CP Violation Phase β_s in Un-tagged $B^0_s \to J/\psi\phi$ Decays

Without identification of the initial B_s flavor still have sensitivity to β_s

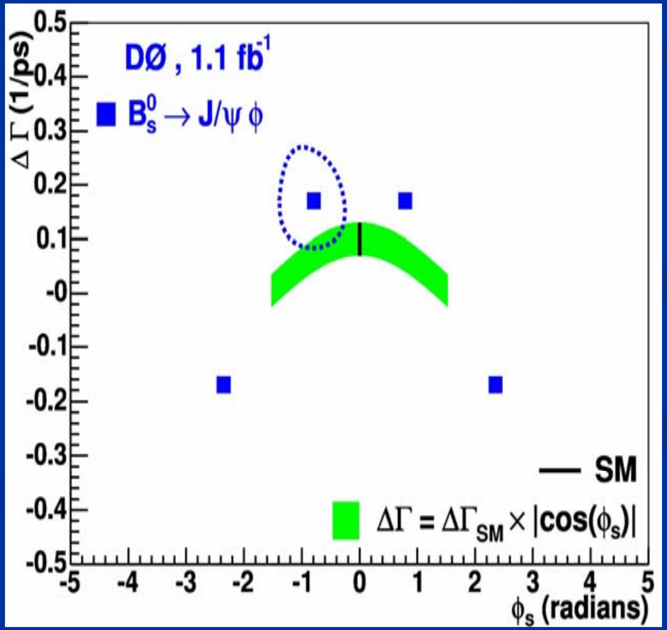
Due to irregular likelihood and biases in fit, CDF only quotes Feldman-Cousins confidence regions (Standard Model probability 22%)
DØ quotes point estimate: $\Phi_s = -0.79 \pm 0.56$ (stat) $^{+0.14}_{-0.01}$ (syst)

Symmetries in the likelihood → 4 solutions are possible in $2\beta_s$-$\Delta\Gamma$ plane

CDF: 90%, 95% C.L



DØ: 39% C.L.



CP Violation Phase β_s in Tagged $B^0_s \to J/\psi\phi$ Decays

Likelihood expression predicts better sensitivity to β_s but still double minima due to symmetry: $2\beta_s \to \pi - 2\beta_s$

$\Delta\Gamma \to -\Delta\Gamma$

$\delta_{||} \to 2\pi - \delta_{||}$

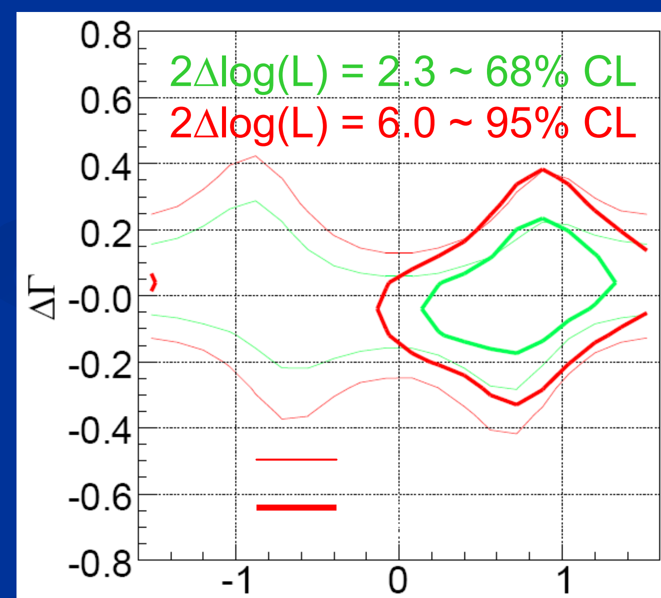
$\delta_{\perp} \to \pi - \delta_{\perp}$

Study expected effect of tagging using pseudo-experiments

Improvement of parameter resolution is small due to limited tagging power ($\varepsilon D^2 \sim 4.5\%$ compared to B factories ~30%)

However, $\beta_s \to -\beta_s$ no longer a symmetry
$\to$ 4-fold ambiguity reduced to 2-fold ambiguity
$\to$ allowed region for β_s is reduced to half

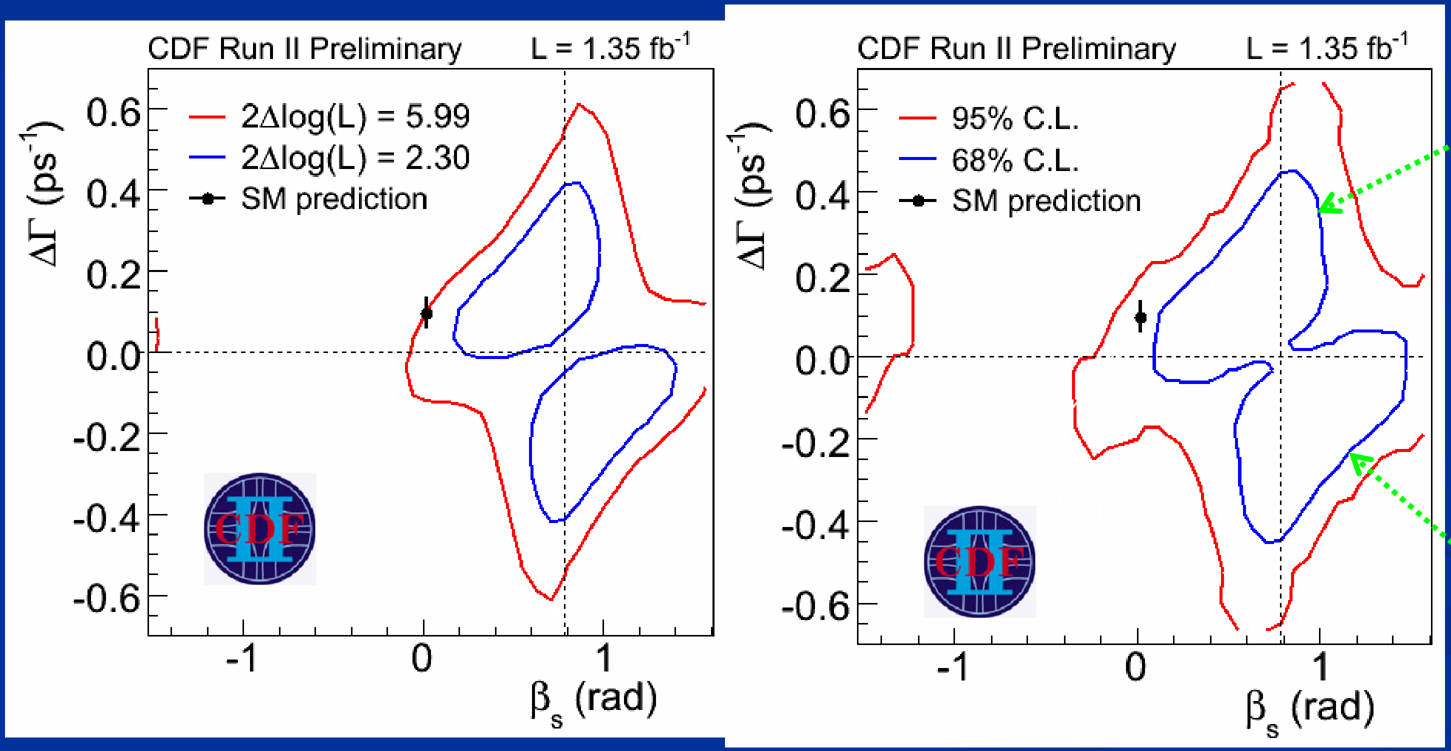
β_s-$\Delta\Gamma$ likelihood profile



β_s (rad)

CP Violation Phase β_s in Tagged $B^0_s \rightarrow J/\psi\phi$ Decays

First tagged analysis of $B^0_s \rightarrow J/\psi\phi$ (1.4 fb^{-1}).
Signal B_s yield ~2000 events with S/B ~ 1.
As in un-tagged analysis, irregular likelihood does not allow quoting point estimate.
Quote Feldman-Cousins confidence regions.



$\cos(\delta_\perp) < 0$
$\cos(\delta_\perp - \delta_\parallel) > 0$

strong phases can separate the two minima

$\cos(\delta_\perp) > 0$
$\cos(\delta_\perp - \delta_\parallel) < 0$

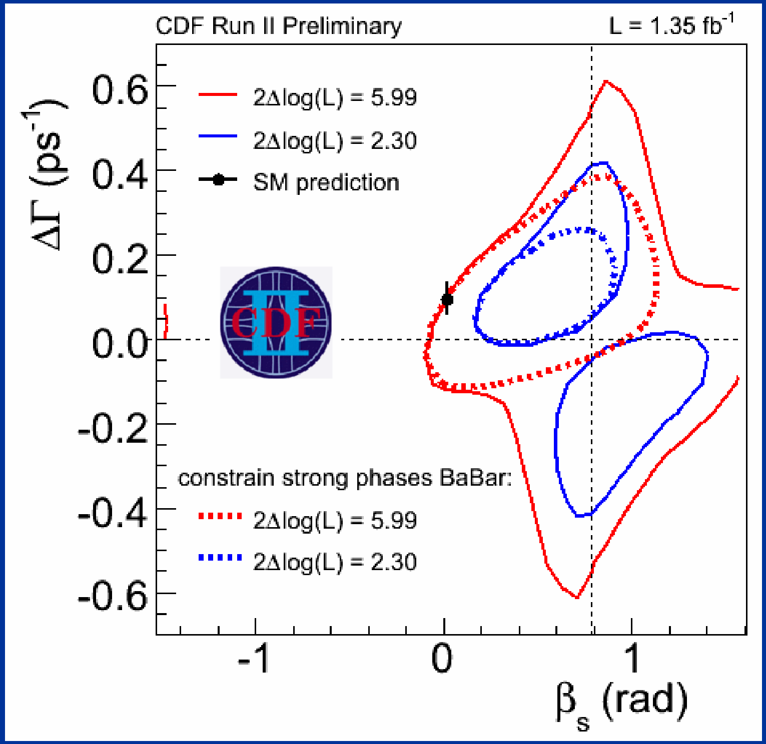
Confidence regions are underestimated when using 2ΔlogL = 2.3 (6.0) to approximate 68% (95%) C.L. regions

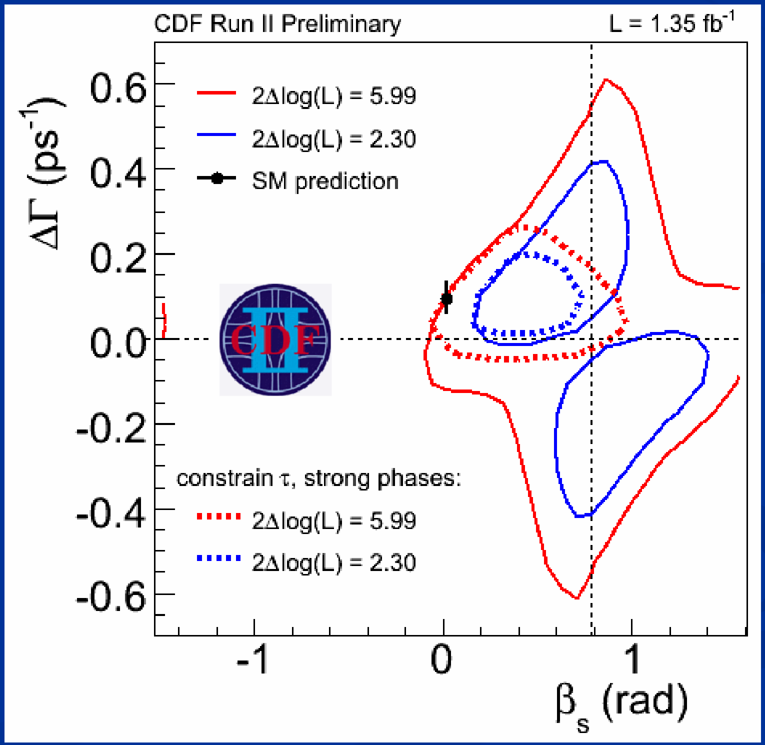
β_s in Tagged $B^0_s \rightarrow J/\psi\phi$ Decays with External Constraints (CDF)

Spectator model of B mesons suggests that B_s and B^0 have similar lifetimes and strong phases

Likelihood profiles with external constraints from B factories:

constrain strong phases: constrain lifetime and strong phases:





External constraints on strong phases remove residual 2-fold ambiguity

β_s in Tagged $B^0_s \rightarrow J/\psi\phi$ Decays Final Results (CDF)

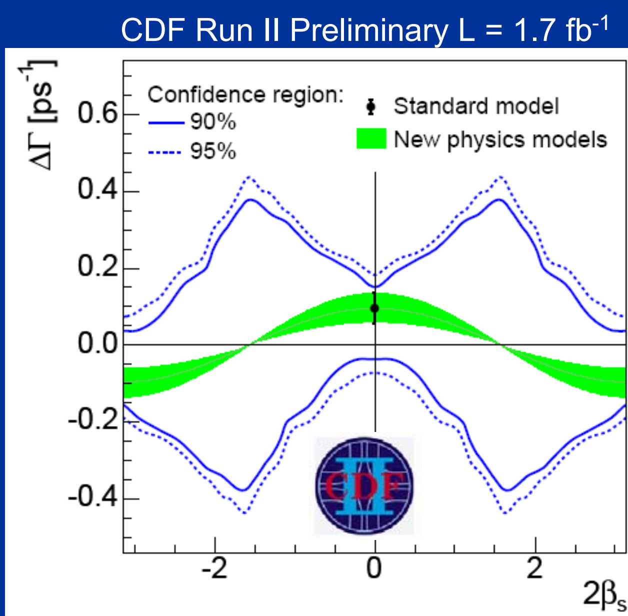
1D Feldman-Cousins procedure without external constraints:

$2\beta_s$ in [0.32, 2.82] at the 68% C.L.

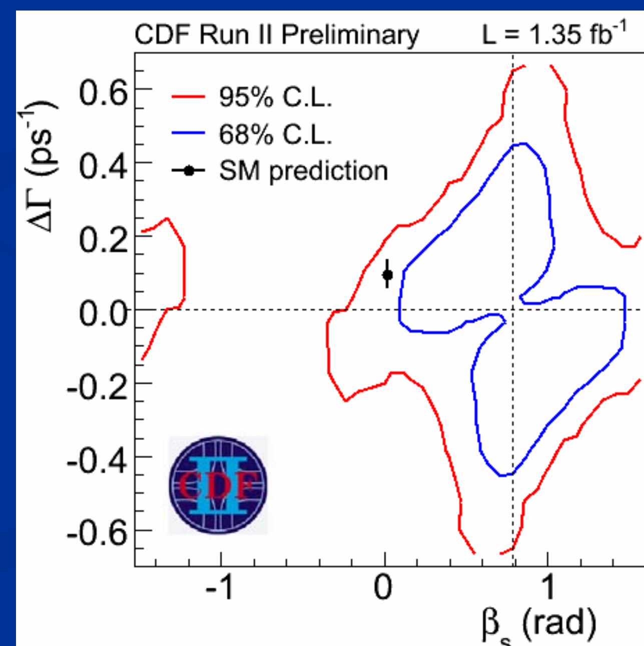
1D Feldman-Cousins with external constraints on strong phases, lifetime and $\Delta\Gamma$ = 0.096±0.039:

$2\beta_s$ in [0.40, 1.20] at 68% C.L.

Available β_s parameter space is greatly reduced when using flavor tagging:



flavor tagging



DØ results on β_s using flavor tagging expected soon.

Charge Asymmetry in Semileptonic $B^0_s \to \mu D_s X$ Decays (DØ, 1.3 fb^{-1})

Study $B^0_s \to \mu^+ D^-_s \nu X$ with $D^-_s \to \phi\pi^-$ $\phi \to K^+K^-$

L = 1.3 fb^{-1} with total signal yield ~27K events

Compare decay rates of B_s and B_s:

$$A^{s,unt}_{SL} = \frac{N(\mu^+D^-_s) - N(\mu^-D^+_s)}{N(\mu^+D^-_s) + N(\mu^-D^+_s)} = [1.23 \pm 0.97\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})] \times 10^{-2}$$

Suppressed systematic uncertainties do to regular change of magnet polarization at DØ .

Semileptonic charge asymmetry is related to $\phi_s = \arg(-M_{12}/\Gamma_{12})$

$$A^{s,unt}_{SL} = \frac{1}{2}\frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$$

In SM Φ_s is predicted to be very small $\phi^{\mathrm{SM}}_s = 4 \times 10^{-3}$

NP can significantly modify SM prediction $\phi_s = \phi^{\mathrm{SM}}_s + \phi^{\mathrm{NP}}_s$

If ϕ^{NP}_s dominates $2\beta_s = -\phi^{\mathrm{NP}}_s = -\phi_s$

Can combine this result with β_s measurement in $B_s \to J/\Psi\Phi$ to constrain NP

Charge Asymmetry in Inclusive B^0_s Decays (DØ, CDF)

Measure same sign muon charge asymmetry at DØ with 1 fb^{-1}:

$$A = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1}{4f}\left[A_{B^0} + \frac{f_s \chi_{s0}}{f_d \chi_{d0}} A_{B^0_s}\right]$$

$$f \cdot A \;=\; -0.0023 \pm 0.0011\ (\mathrm{stat}) \pm 0.0008\ (\mathrm{syst})$$

With knowledge of fragmentation fractions f_s and f_d, the integrated oscillation probabilities χ_d and χ_s and known B^0 semileptonic asymmetry from B factories:

$A_s = -0.0064 \pm 0.0101$ (stat+syst)

Similar measurement at CDF with 1.6 fb^{-1}:

$A_s = 0.020 \pm 0.021$ (stat) ± 0.016 (syst) ± 0.009 (inputs)

These measurements can be combined with asymmetries in $B_s \to \mu D_s X$ to further constraint CP violation phase.

Combined DØ Constraints on B^0_s Width Difference and CP Violation Phase

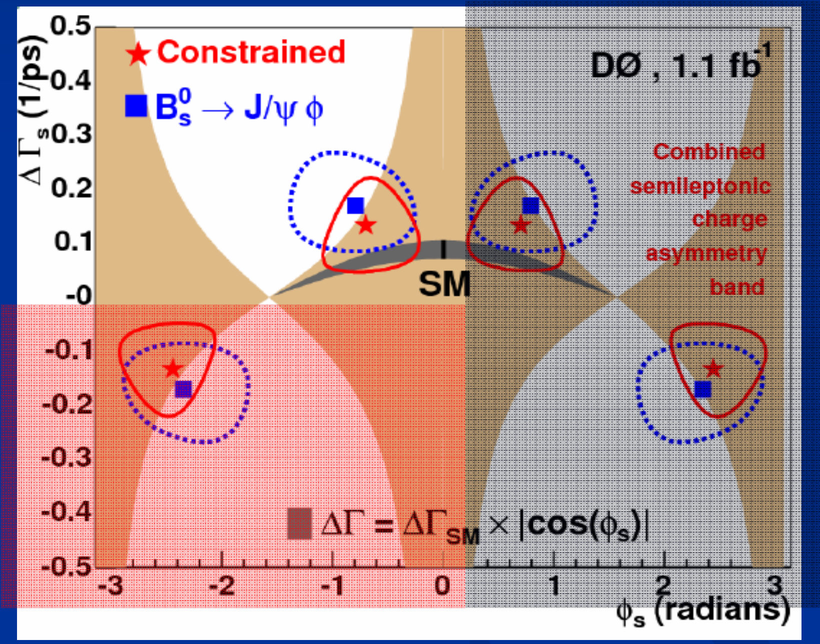
Combine width difference and CP violation phase from time dependent angular analysis $B^0_s \to J/\psi\phi$ with measurements from charge asymmetry in semileptonic decays

Contours indicate 39% C.L. regions:

Final combined DØ results with ~1 fb^{-1} :

$$\Delta\Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1}$$
$$\phi_s = -0.70^{+0.47}_{-0.39}.$$

From tagged $B_s \to J/\Psi\Phi$ analysis, CDF excludes ~half available space in Φ_s-$\Delta\Gamma$ plane (two RHS solutions)



Based on flavor SU(3) symmetry, CDF constrains strong phases to B factories measurements → bottom – left solution is suppressed as well.

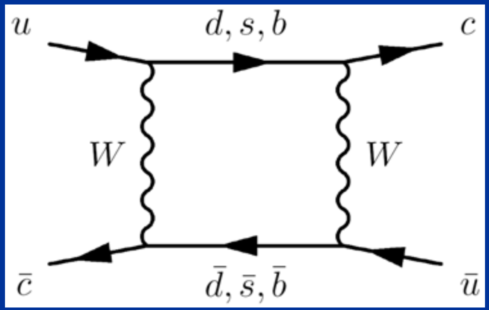
Expect tagged $B^0_s \to J/\psi\phi$ analysis from DØ soon
Expect updated analyses with 2x data from both experiments soon

D^0 Mixing

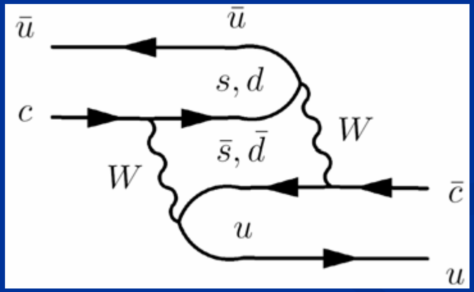
- After recent observation of fastest neutral meson oscillations in B_s system by CDF and DØ → time to look at the slowest oscillation of D^0 mesons ☺

- D^0 mixing in SM occurs through either:

'short range' processes (negligible in SM)



'long range' processes



	$\Delta M/\Gamma$	$\Delta\Gamma/\Gamma$
K^0	0.474	0.997
B^0	0.77	<0.01
B_s	27	0.15
D^0	< few%	< few%

- Recent D^0 mixing evidence ← different D^0 decay time distributions in

Belle
$D^0 \to \pi\pi$, KK (CP eigenstates) compared to $D^0 \to K\pi$

BaBar
doubly Cabibbo suppressed (DCS) $D^0 \to K^+\pi^-$ compared to Cabibbo favored (CF) $D^0 \to K^-\pi^+$
(*Belle* does not see evidence in this mode)

Evidence for D^0 Mixing at CDF (1.5 fb^{-1})

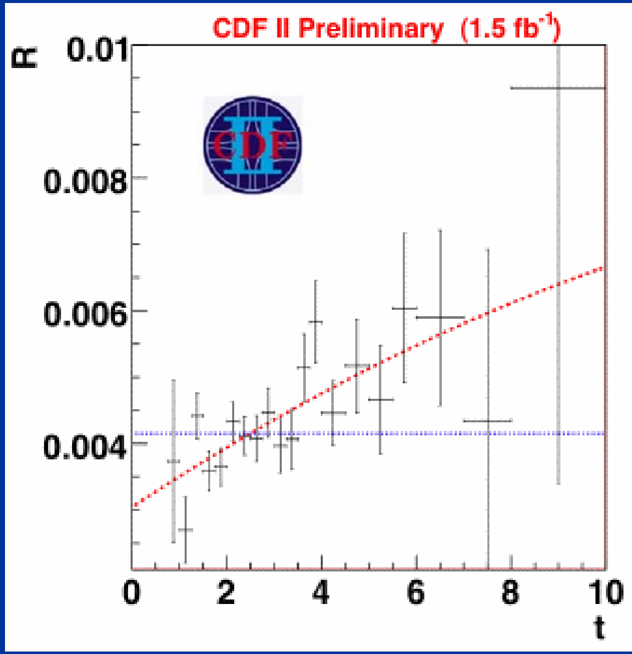
- CDF sees evidence for D^0 mixing at 3.8σ significance by comparing DCS $D^0 \to K^+\pi^-$ decay time distribution to CF $D^0 \to K^-\pi^+$ (confirms *BaBar*)
- Ratio of decay time distributions:

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

where $x' = x\cos\delta + y\sin\delta$ and $y' = -x\sin\delta + y\cos\delta$

δ is strong phase between DCS and CF amplitudes

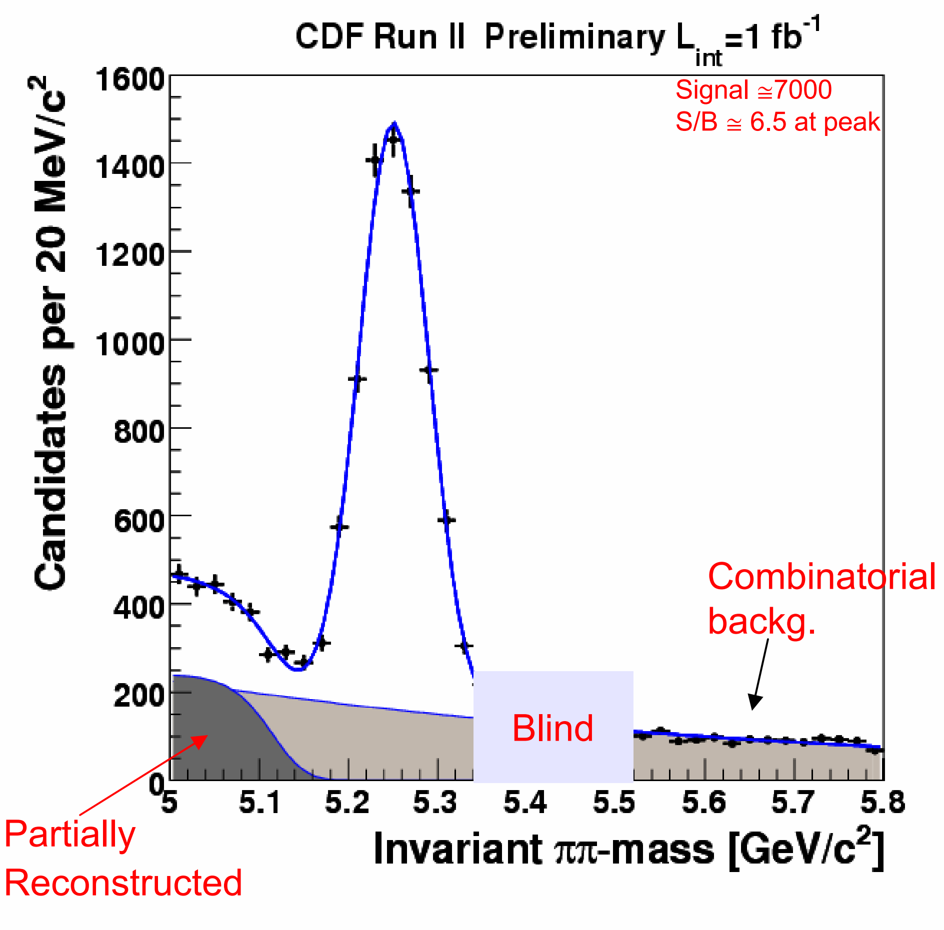
mixing parameters $x = \Delta M/\Gamma$ $y = \Delta\Gamma/2\Gamma$ are 0 in absence of mixing



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

$B \to h^+h^-$ signal (loose cuts)



Selection optimized to minimize statistical uncertainty on $A_{CP}(B^0 \to K\pi)$

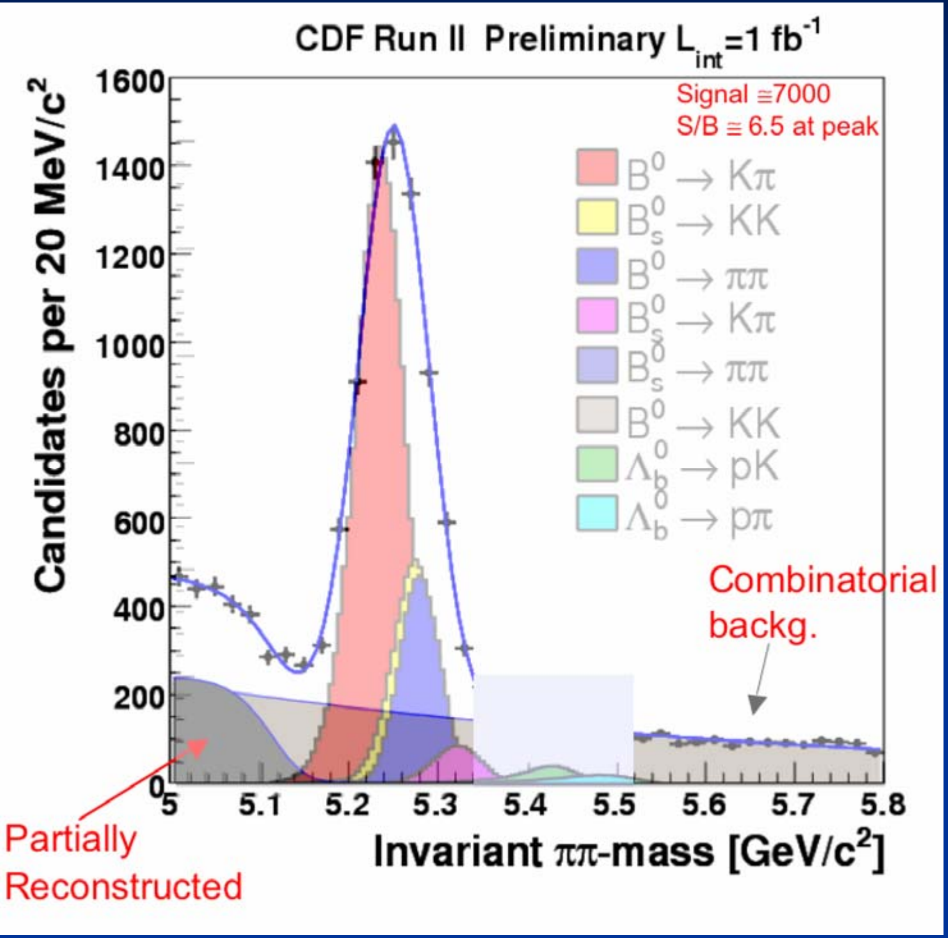
Despite good mass resolution (≅22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)

Note that the use of a single mass assignment ($\pi\pi$) causes overlap even with perfect resolution

Blinded region of unobserved modes: $B^0_s \to K\pi$, $B^0_s \to \pi\pi$, $\Lambda^0_b \to p\pi/pK$.

Need to determine signal composition with a **Likelihood fit**, combining information from **kinematics** (mass and momenta) and **particle ID** (dE/dx).

$B \to h^+h^-$ signal (loose cuts)



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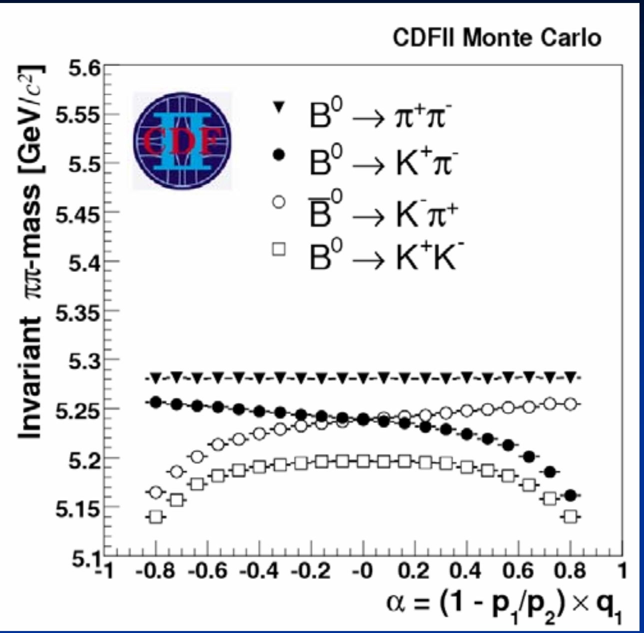
$B \to h^+h^-$

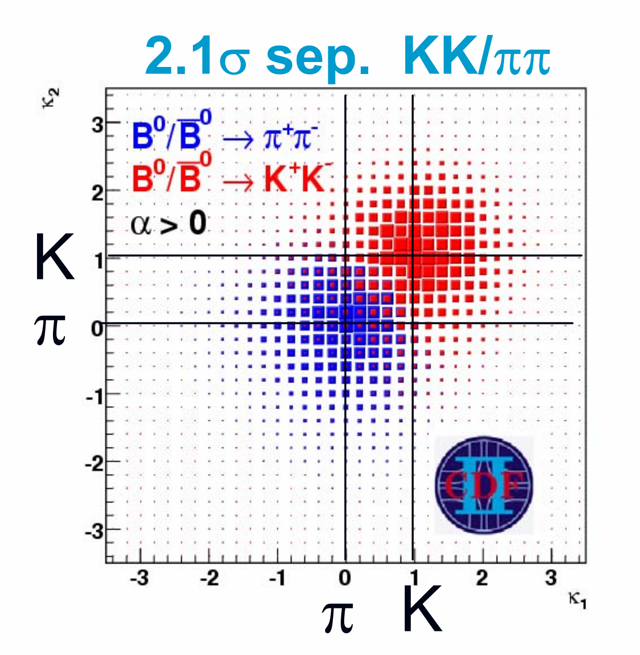
Very challenging analysis, it starts at trigger level. Then ML fit exploits information from invariant mass, momentum imbalance and dE/dx.

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass
2) $\alpha = (1-p_{min}/p_{max})q_{min}$
   signed p-imbalance
3) $p_{tot} = p_{min}+p_{max}$
   scalar sum of 3-momenta

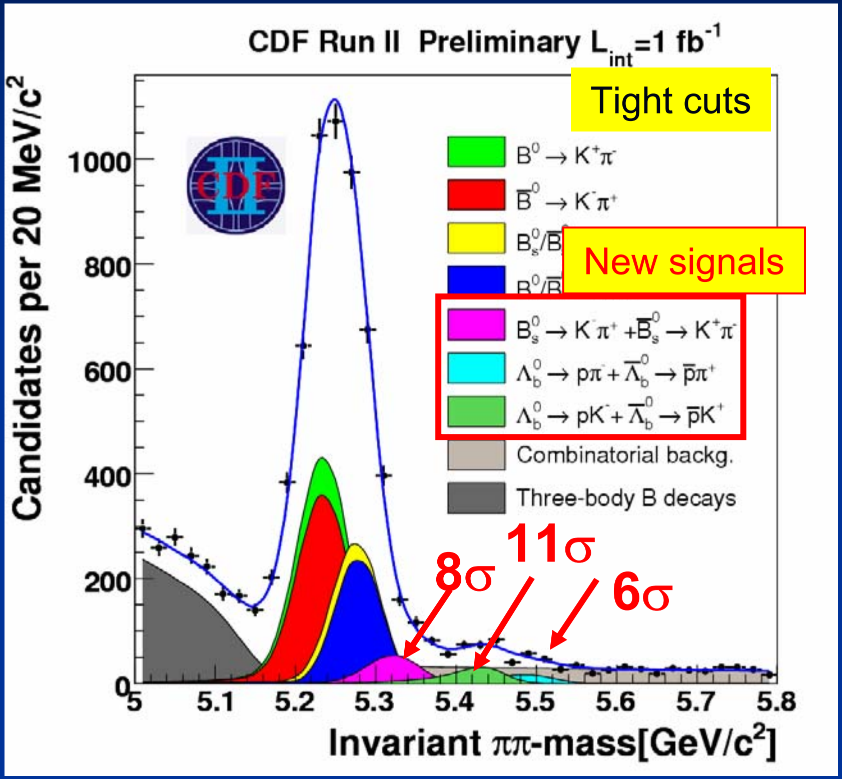
dE/dx carefully calibrated on pure K and π samples from 1.5M decays: $D^{*+} \to D^0\pi^+ \to [K^- \pi^+]\ \pi^+$
(sign of D^{*+} pion tags D^0 sign)

1.5σ K/π power separation for track p>2GeV/c achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID ($\equiv$75% for 2 particles)
[arXiv:physics/0611219]





$B^0_s \to K^-\pi^+$



Selection optimized to observe and limit setting of $B^0_s \to K^-\pi^+$

First observation of three rare charmless decays: $B^0_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$ and $\Lambda^0_b \to pK^-$

$BR(B^0_s \to K^-\pi^+)$ theoretical expectations are strongly related to α and γ:

QCDF, pQCD $[6 \div 10] \cdot 10^{-6}$

[Beneke&Neubert, NP B675, 333(2003)]
[Yu, Li, Lu, PRD71,074026 (2005)]

SCET: $(4.9 \pm 1.8) \cdot 10^{-6}$

[Williamson,Zupan,PRD74, 014003(2006)]

$B^0_s \to K\pi$ yield = 230 ± 34(stat.) ± 16(syst.)

$$BR(B_s^0 \to K^-\pi^+) = (5.0 \pm 0.75\ (stat.) \pm 1.0\ (syst.)) \times 10^{-6}$$

[hep-ex/0612018]

Direct $A_{CP}(B^0_s \to K^-\pi^+)$

Observation of this decay offers a unique opportunity of checking for the SM origin of direct CP violation. Proposed in *[Gronau Rosner Phys.Rev. B482, 71(2000)],* later shown to hold under much weaker assumptions in *[Lipkin, Phys. Lett. B621,126, (2005)]*.

$$\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-) = \Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-)$$

Currently unique to CDF. From our measured BR, we can predict DCPV using:

$$A_{CP}(B^0_s \to K^-\pi^+) = -A_{CP}(B^0 \to K^+\pi^-) \cdot \frac{\mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(B^0_s \to K^-\pi^+)} \cdot \frac{\tau(B^0)}{\tau(B^0_s)}$$

Low BR($B^0_s \to K^+\pi^-$) implies large asymmetry: DCPV$\cong$ +**37%**

Interesting case of large DCPV predicted under SM

Direct CPV in $B^0_s \to K^-\pi^+$

2.5 σ

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

[hep-ex/0612018]

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-)} = 0.84 \pm 0.42(\text{stat.}) \pm 0.15(\text{syst.})$$ (SM =1)

First measurement of DCPV in the B^0_s
Sign and magnitude agree with SM predictions within errors ⇒
no evidence for 'exotic' sources of CP violation (yet)

It can shed light on the Belle and BaBar discrepancy. Assuming perfect SU(3) symmetry and neglecting annihilation diagrams *[Buras et al., Nucl. Phys. B697, 133,2004]* : $A_{CP}(B^0 \to \pi^+\pi^-) \approx A_{CP}(B^0_s \to K^-\pi^+)$.
Exciting to pursue with more data, already on tape 2.5 fb^{-1}.

Gronau-Lipkin test

(SM =1)

$$R_3 = \frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)} = -0.78 \pm 0.39\ (stat.) \pm 0.12\ (syst.).$$

$\Delta = -0.00^{+0.07}_{-0.05},$

W.A. HAFG

This thesis

≈1

$$\boxed{\Delta} \equiv \frac{\mathcal{A}_{\rm CP}(B^0 \to K^+\pi^-)}{\mathcal{A}_{\rm CP}(B_s^0 \to K^-\pi^+)} + \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} \times \frac{\tau(B^0)}{\tau(B_s^0)}.$$

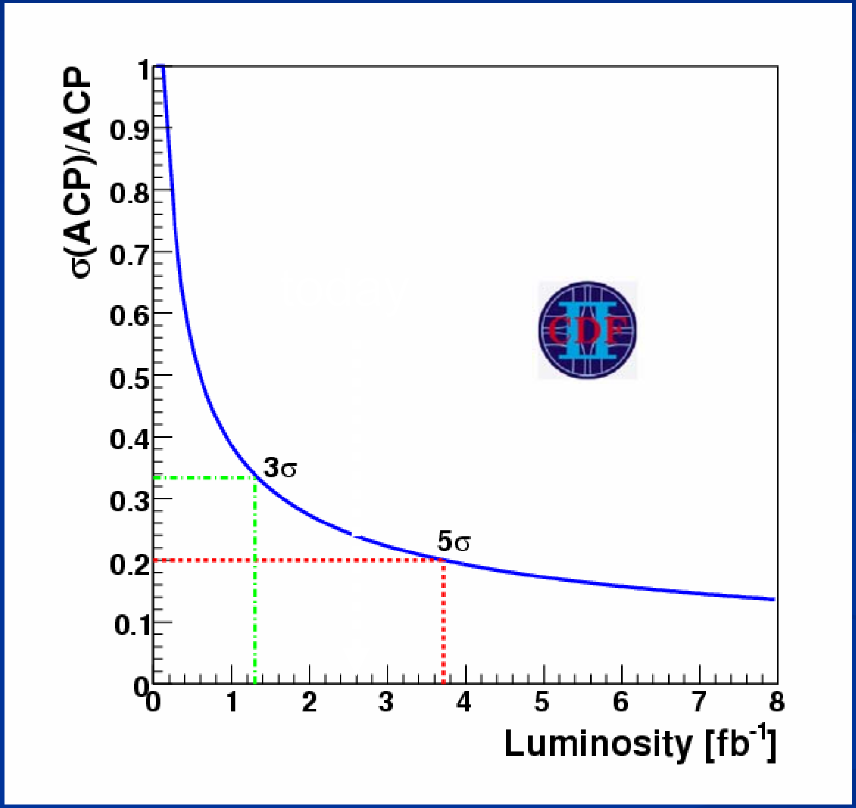
(SM =0)

$$\mathcal{A}_{\rm CP}(B_s^0 \to K^-\pi^+)|^{\rm SM} = 0.36^{+0.13}_{-0.11},$$

Test is still marginal but sign and magnitude agree with SM predictions
⇒ no evidence for exotic sources of CP violation (yet).

DCPV $B^0_s \to K^-\pi^+$: prospect

Assuming SM hypothesis ⇒ Gronau-Lipkin relation true



Very interesting to pursue with more data, in any case !

$B^0_s \to K^+K^-$ and Prospects for $A_{CP}(t)$

1 fb-1

$$BR(B_s^0 \to K^+K^-) = (24.4 \pm 1.4\ (stat.) \pm 4.6\ (syst.)) \times 10^{-6}$$

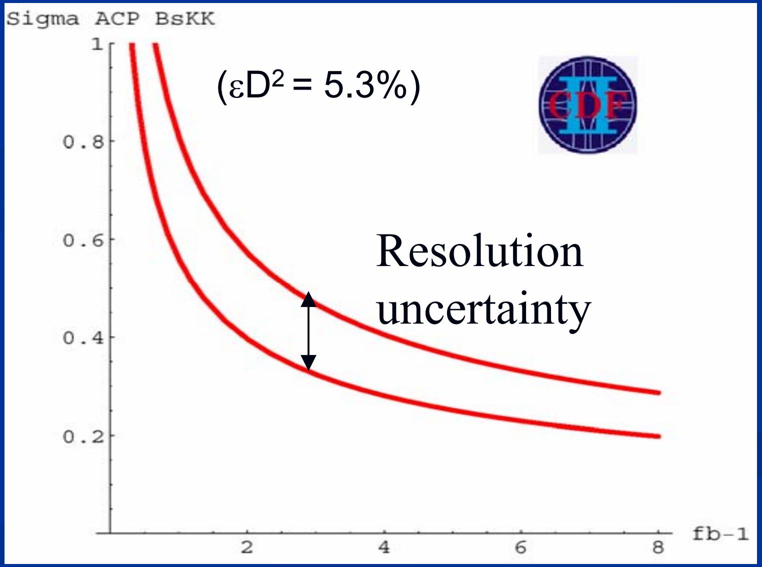
[hep-ex/0612018]

Interesting comparison to predictions to evaluate the SU(3)-breaking size.

Ingredients for a time-dependent $A_{CP}(t)$ ready:
large samples (1300 ev/fb^{-1})
tag dilutions calibrated, x_s measured

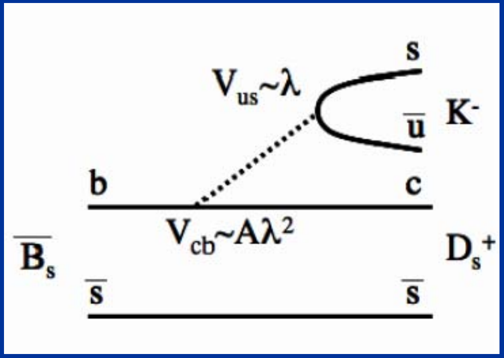
Can have $\sigma(A_{CP})$ ~0.2÷0.15 in runII
(translate to sensitivity on γ ~ 10 deg.)

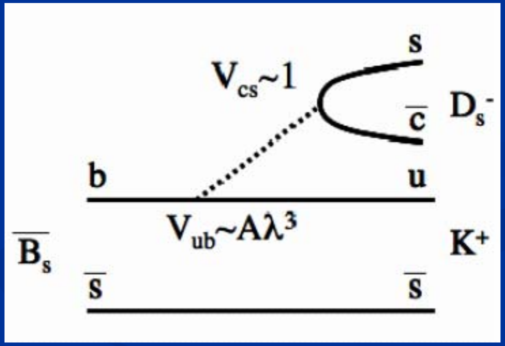
This resolution allows tests for NP.
[Baek et al, hep-ph/0610109]



$B^0_s \rightarrow D_s K$

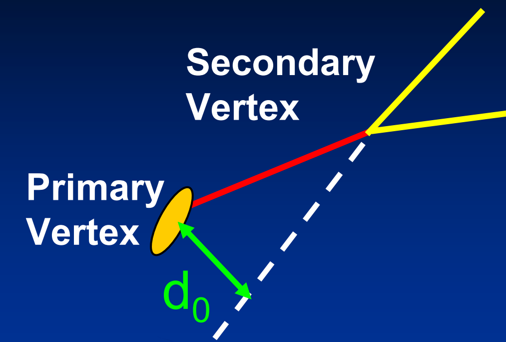
- CP violation interesting place to probe new physics
- First need to understand CP processes in SM framework
- B meson system can help constrain hadronic uncertainties
- CDF provides results in B^0_s system
- In $B^0_s \rightarrow D^-_s K^+$ decays, both B^0_s and antiB^0_s decays similar amplitude





- CP violation due to mixing can occur from the mixed and unmixed
- interference paths
- Need time dependent CP asymmetry measurement (later compare with $B^0 \rightarrow DK$)
- However! First step is observation and BR measurement.

$B^0_s \to D_s K$

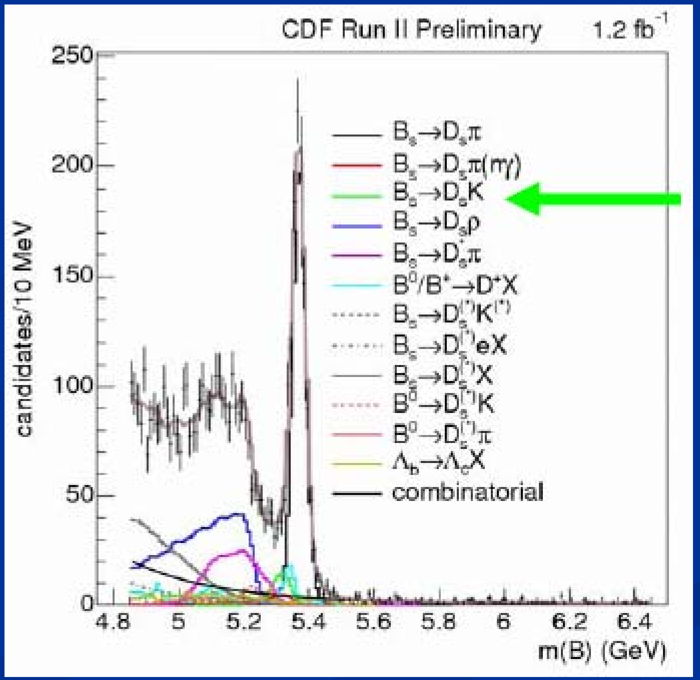


- Use displaced track trigger to gather these decays
- Use $B^0 \to D\pi$ as control mode

- Combined mass and particle identification
- likelihood fit
  - Mass($D_s\pi$/K)
  - dE/dx of B daughter track (π/K)

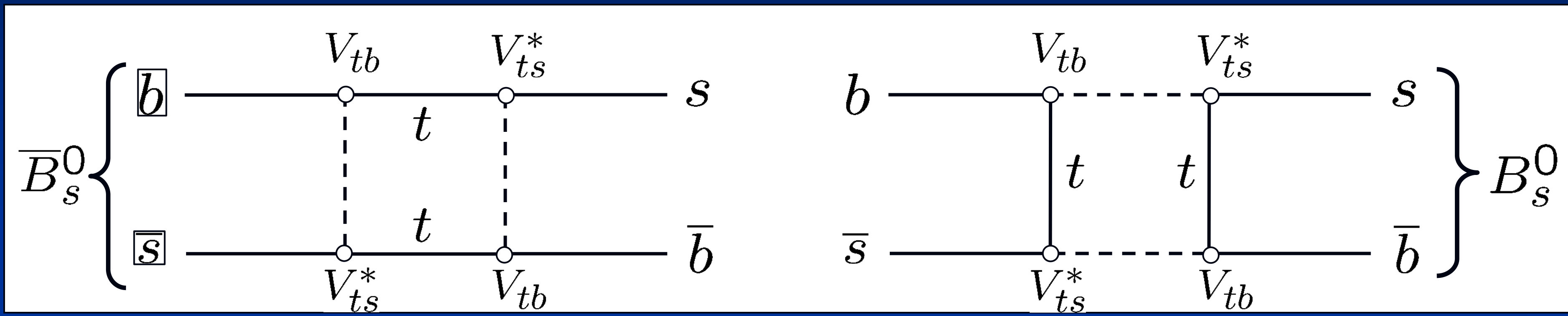
- Detailed study of background
- components in MC
- FSR tail from $B^0_s \to D_s\pi$ (+nγ)

- Yield 109±19, 7.9σ observation



$$\mathcal{B}(\overline{B}^0_s \to D_s^{\pm}K^{\mp})/\mathcal{B}(\overline{B}^0_s \to D_s^{+}\pi^{-}) = 0.107 \pm 0.019(\text{stat}) \pm 0.008(\text{sys})$$

B^0_s mixing



$$\Delta m_s \sim m_{B_s} f_{B_s}^2 B_{B_s} \left|V_{tb} V_{ts}^*\right|^2$$

$$\Delta m_d \sim m_{B_d} f_{B_d}^2 B_{B_d} \left|V_{tb} V_{td}^*\right|^2$$

$$\frac{\Delta m_s}{\Delta m_d} = \xi^2 \frac{m_{B_s}}{m_{B_d}} \frac{\left|V_{ts}\right|^2}{\left|V_{td}\right|^2}$$

Δm_d and masses are well measured →

$m_{Bs}/m_{Bd} = 0.9830$ PDG 2006
$\Delta m_d = 0.507 \pm 0.005$ PDG 2006

$$\xi = \frac{f_{B_s}}{f_{B_d}} \sqrt{\frac{B_{B_s}}{B_{B_d}}} = 1.210^{+0.047}_{-0.035}$$

From lattice QCD
[hep-lat/051013]

Search for B^0_s Oscillations

- Reconstruct B_s decays
- Measure proper decay time precisely
- Identify initial flavor state (B_s or $\overline{B}_s$)

$$\frac{1}{\sigma} = \sqrt{\frac{S}{S+B}}\sqrt{\frac{S\varepsilon D^2}{2}}e^{-\sigma_{ct}^2 \Delta m_s^2 / 2}$$

Effective tagging power:

ε = efficiency of taggers

D = 1 – 2w w = mistag prob.

εD^2 figure of merit

$$ct = \frac{L_{xy}}{\beta_T \gamma} = \frac{L_{xy}\, m(B)}{p_T(B)}$$

vertexing and momentum resolution

$$\sigma_{ct} = \left(\frac{\sigma_{L_{xy}} \cdot m(B)}{p_T(B)}\right) \oplus \left(\frac{\sigma_{p_T}}{p_T(B)}\right) \cdot ct$$

$\varepsilon D^2 \sim 1.5$ % OST

$\varepsilon D^2 \sim 4$ % SST

$\sigma_{ct} \sim 87$ fs for hadronic decays

σ_{ct} for semileptonic decays is worse

$B_s \rightarrow J/\Psi\Phi$ Phenomenology

Three angular momentum states form a basis for the final state

Use alternative “transversity basis” in which the vector meson polarizations w.r.t. direction of motion are either:

- longitudinal (0) $\rightarrow$ CP even
- transverse ($\parallel$ parallel to each other) $\rightarrow$ CP even
- transverse ($\perp$ perpendicular to each other) $\rightarrow$ CP odd

Corresponding decay amplitudes: A_0, $A_\parallel$, $A_\perp$

At good approximation, mass eigenstates $|B_s^L\rangle$ and $|B_s^H\rangle$ are CP eigenstates

$\rightarrow$ use angular information to separate heavy and light states

$\rightarrow$ determine decay width difference

$$\Delta\Gamma = \Gamma_L - \Gamma_H$$

$\rightarrow$ some sensitivity to CP violation phase β_s

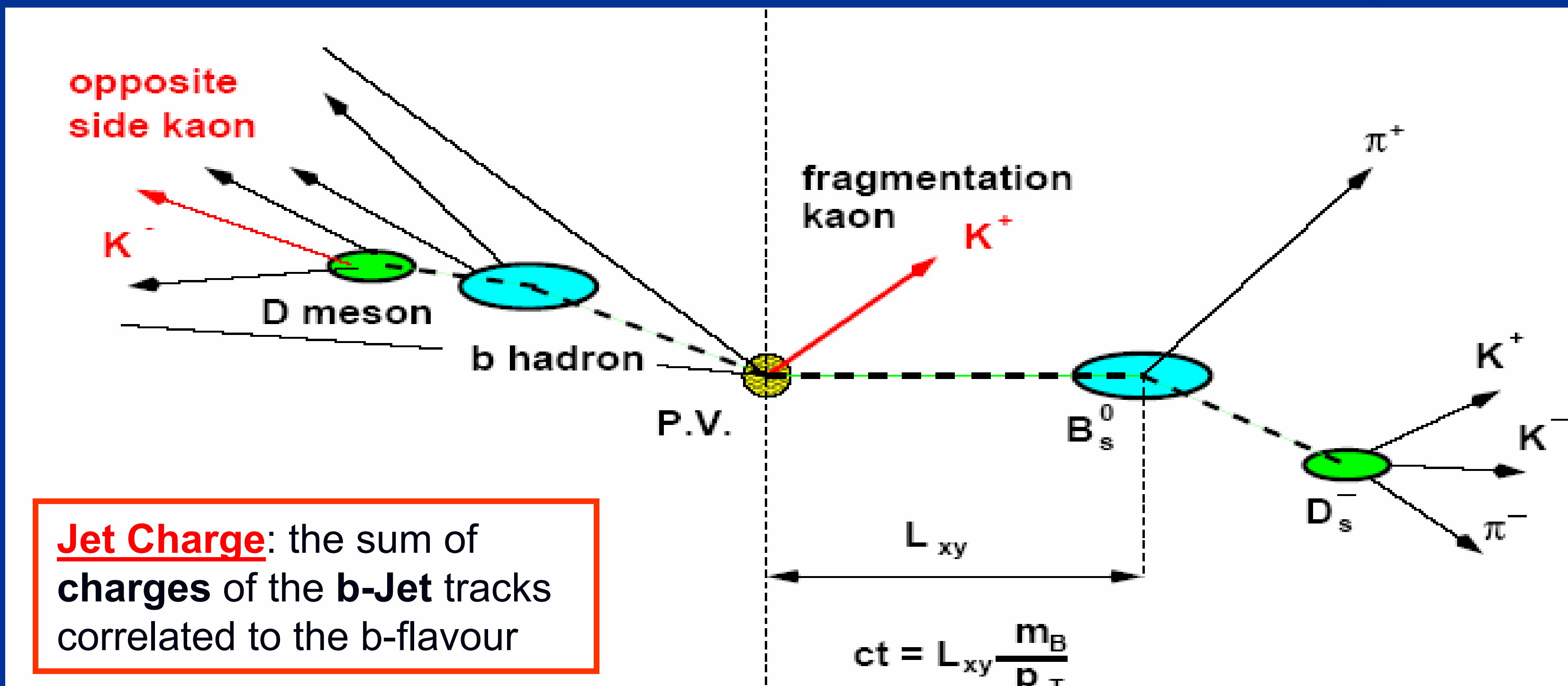
Determine B_s flavor at production (flavor tagging)

$\rightarrow$ improve sensitivity to CP violation phase β_s

Flavor Tagging

The dominant b quark production mechanism produce $b\bar{b}$ pairs.
We can define two zones:

Opposite Side | **Same Side**



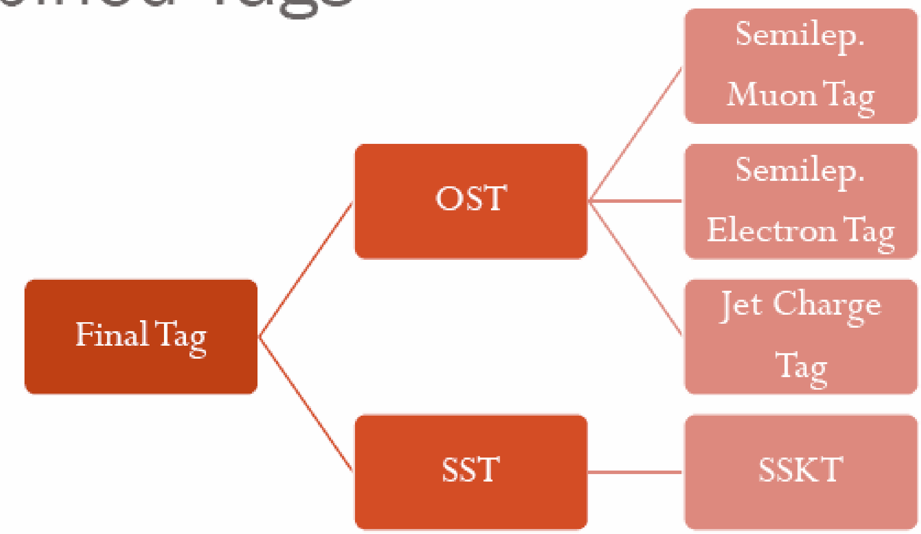
Jet Charge: the sum of **charges** of the **b-Jet** tracks correlated to the b-flavour

Soft Lepton (e,m) due to **b→ℓnX**
ℓ charge correlated to b-flavour

Same Side Kaon: for **B^0_s** is likely to have close in DR a **K+** from fragmentation

Combined Tags

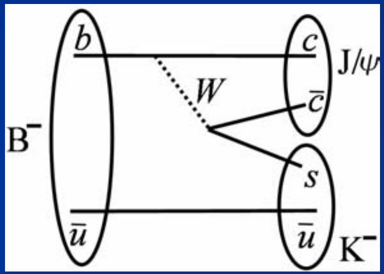
Combined Tags

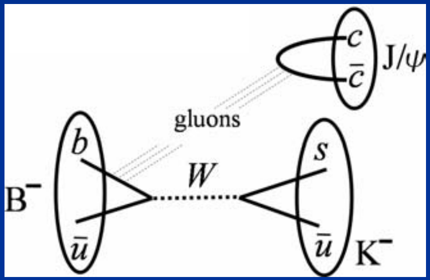


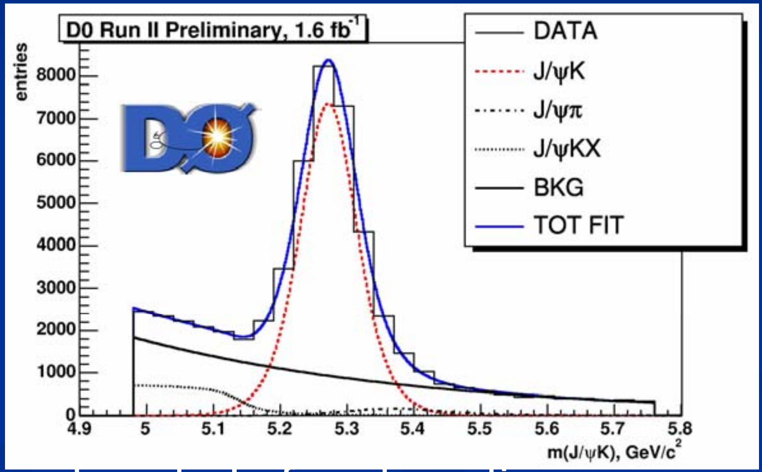
- OST
  - $\varepsilon = (96 \pm 1)\%$, average $\mathcal{D} = (11 \pm 2)\%$
- SSKT
  - $\varepsilon = (50 \pm 1)\%$, average $\mathcal{D} = (27 \pm 4)\%$
  - Calibrated only for first 1.35 fb^{-1} of data

Direct CP Violation in $B^+ \rightarrow J/\Psi K^+$ Decays (DØ, 1.6 fb^{-1})

SM predicts small (~1%) direct CP violation in $B^+ \rightarrow J/\Psi\, K^+$
Due to interference between direct and annihilation amplitudes







Signal yield ~28K $B^+ \rightarrow J/\Psi K^+$ decays
DØ reverses magnet polarities frequently → good control of systematic uncertainties in charge asymmetry measurements
Correct for K^+/K^- asymmetry

$$A = \frac{N(B^- \to J/\psi K^-) - N(B^+ \to J/\psi K^+)}{N(B^- \to J/\psi K^-) + N(B^+ \to J/\psi K^+)} = +0.0067 \pm 0.0074(stat) \pm 0.0026(syst)$$

Consistent with world average: $A_{CP}(B^+ \to J/\psi K^+) = +0.015 \pm 0.017$
but factor of two better precision → best measurement

Λ^0_b Lifetime (DØ, 1.3 fb^{-1})

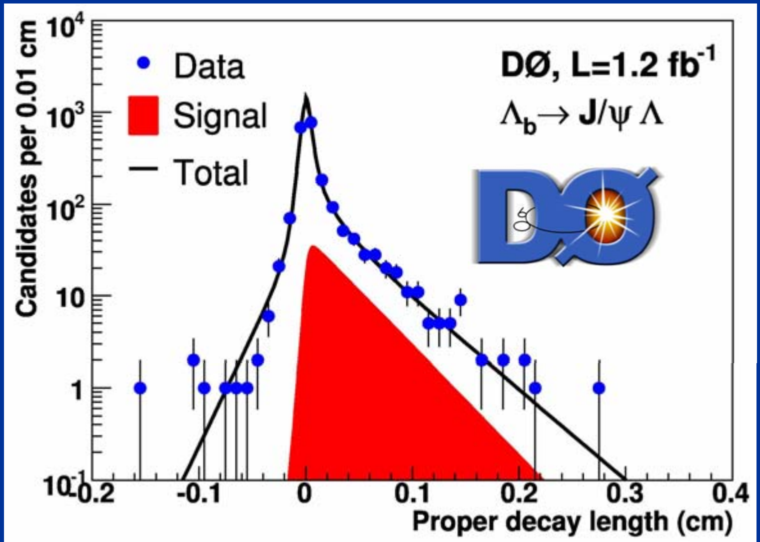
Important test of models that describe quark interactions between heavy and light quarks within bound states

HQET + Lattice QCD predicts: $\tau(\Lambda_b)/\tau(B^0) = 0.88 \pm 0.05$

DØ measures Λ_b lifetime two decay modes:

$\Lambda_b \to J/\psi\ \Lambda$

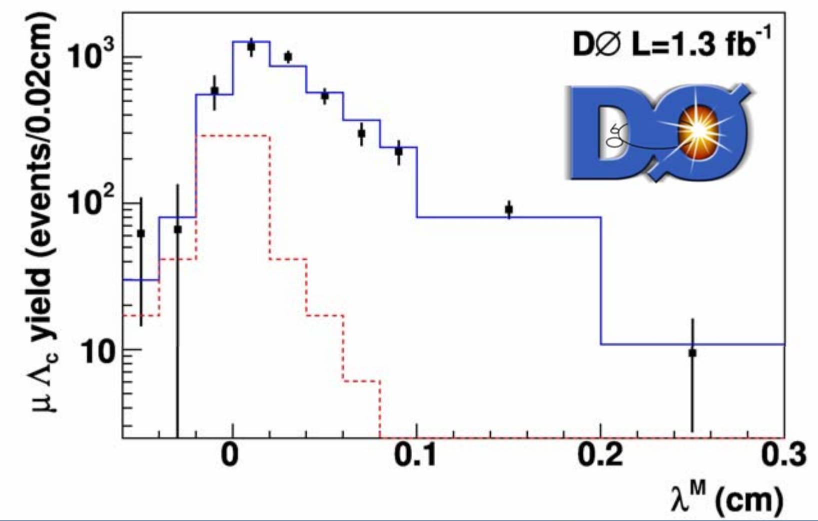
1.2 fb^{-1}, ~170 signal events



$\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115}(\text{stat}) \pm 0.042(\text{syst})$ ps

$\Lambda^0_b \to \mu\bar{\nu}\Lambda^+_c X$

1.3 fb^{-1}, ~4400 signal events



$\tau(\Lambda^0_b) = 1.290\ ^{+0.119}_{-0.110}\ (\text{stat})\ ^{+0.087}_{-0.091}\ (\text{syst})$

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.811^{+0.096}_{-0.087}\ (\text{stat}) \pm 0.034\ (\text{syst})$$

Λ^0_b Lifetime Current Status

DØ measurements are in agreement with the theoretical predictions and with the world average $\tau(\Lambda_b^0) = 1.230 \pm 0.074\ \mathrm{ps}$

CDF measurement in $\Lambda_b \to J/\psi\ \Lambda$ ~3σ high w.r.t world average

Expect CDF measurement in hadronic mode soon

decay mode	CDF lifetime (ps), 1 fb^{-1}	DØ lifetime (ps), 1.3 fb^{-1}
$\Lambda_b \to J/\psi\ \Lambda$	$1.593\ ^{+0.083}_{-0.078}\ (\mathrm{stat.}) \pm 0.033\ (\mathrm{syst.})$	$1.218^{+0.130}_{-0.115}(\mathrm{stat}) \pm 0.042(\mathrm{syst})\ \mathrm{ps}$
$\Lambda_b^0 \to \mu\bar{\nu}\Lambda_c^+ X$	x	$1.290\ ^{+0.119}_{-0.110}\ (\mathrm{stat})\ ^{+0.087}_{-0.091}\ (\mathrm{syst})$
$\Lambda_b^0 \to \Lambda_c^+\pi^-$	expected soon	x

Ξ_b Baryons (DØ, 1.3 fb^{-1})

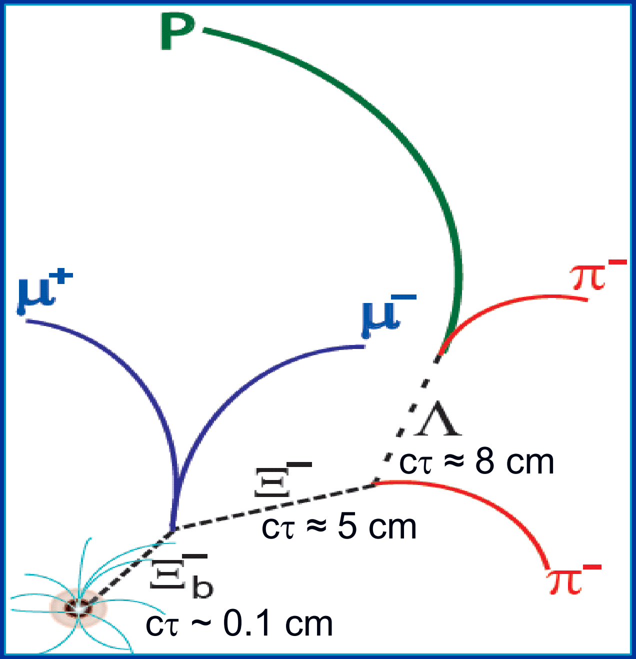
The third observed b baryon after Λ^0_b and CDF's recent discovery of Σ_b

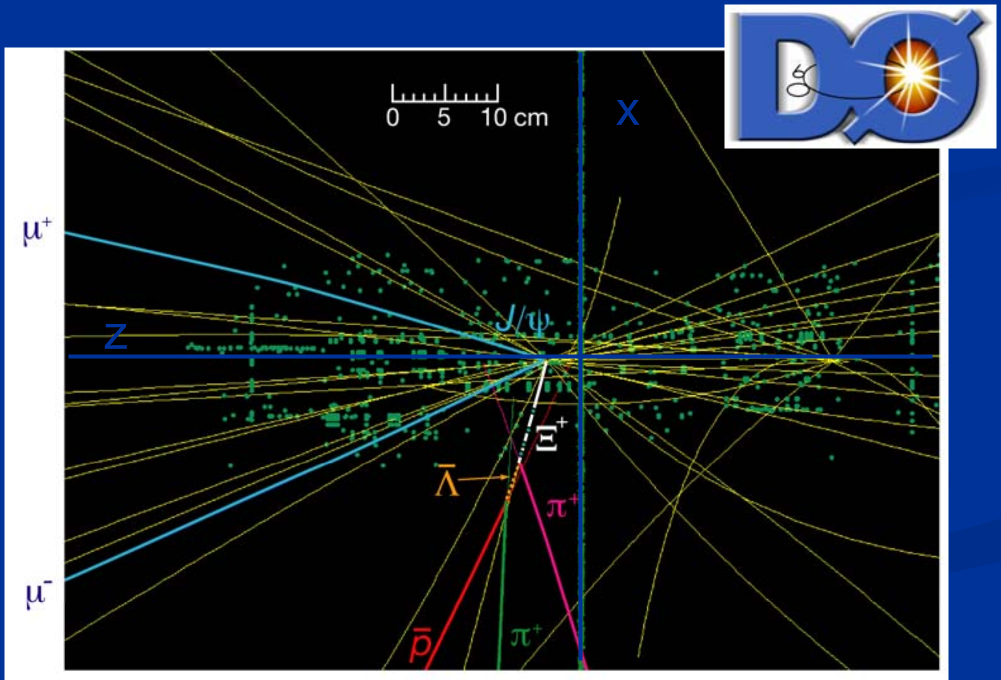
Study b baryons → great way to test QCD which predicts $M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)$

Predicted mass: 5805.7 ± 8.1 MeV

Discovery decay mode at DØ:

$$\Xi_b^- \rightarrow J/\psi\, \Xi^-, \text{ with } J/\psi \rightarrow \mu^+\mu^-, \text{ and } \Xi^- \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^-$$





Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

Ξ_b Mass Measurement (DØ, 1.3 fb-1)

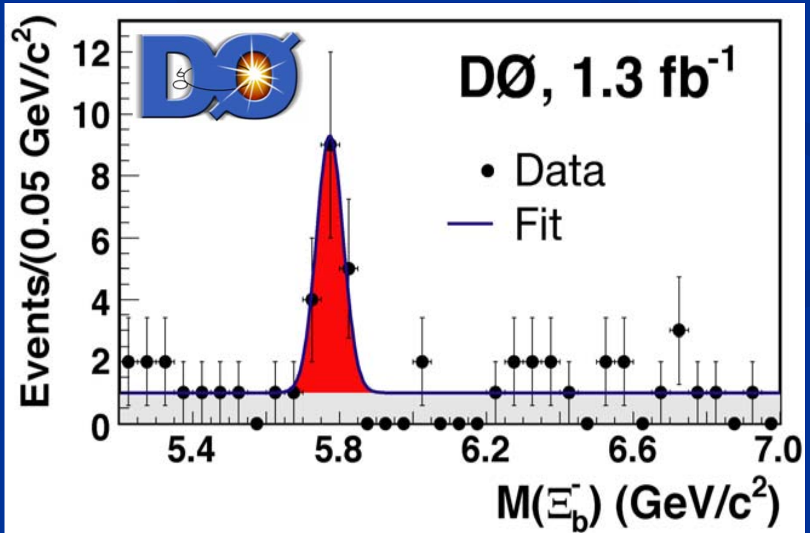
Clear excess in Ξ_b invariant mass distribution
Significance ~5.5σ

Number of signal events: $15.2 \pm 4.4(\text{stat})\ ^{+1.9}_{-0.4}$ (syst)
Mass: 5.774 ± 0.011(stat) ± 0.015(syst) GeV (prediction 5805.7 ± 8.1 MeV)

Width: 0.037 ± 0.008 GeV in good agreement with MC expectation 0.035 GeV
Production relative to $\Lambda_b \to J/\Psi\ \Lambda$

$$\boxed{\frac{f(b \to \Xi_b^-) \cdot Br(\Xi_b^- \to J/\psi\, \Xi^-)}{f(b \to \Lambda_b) \cdot Br(\Lambda_b \to J/\psi\, \Lambda)} = 0.28 \pm 0.09\ (\text{stat.})^{+0.09}_{-0.08}\ (\text{syst.})}$$

where f(b→X) : fraction of times b quark hadronizes to X

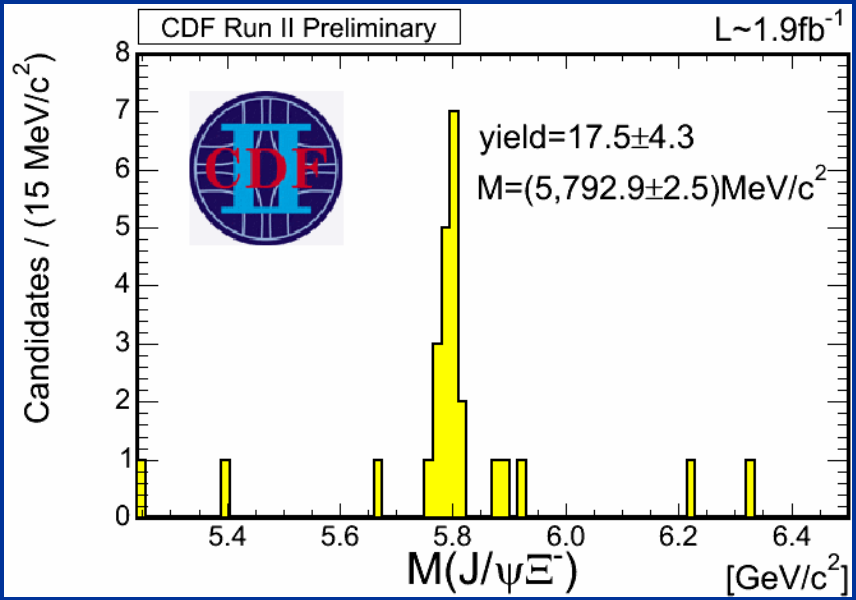


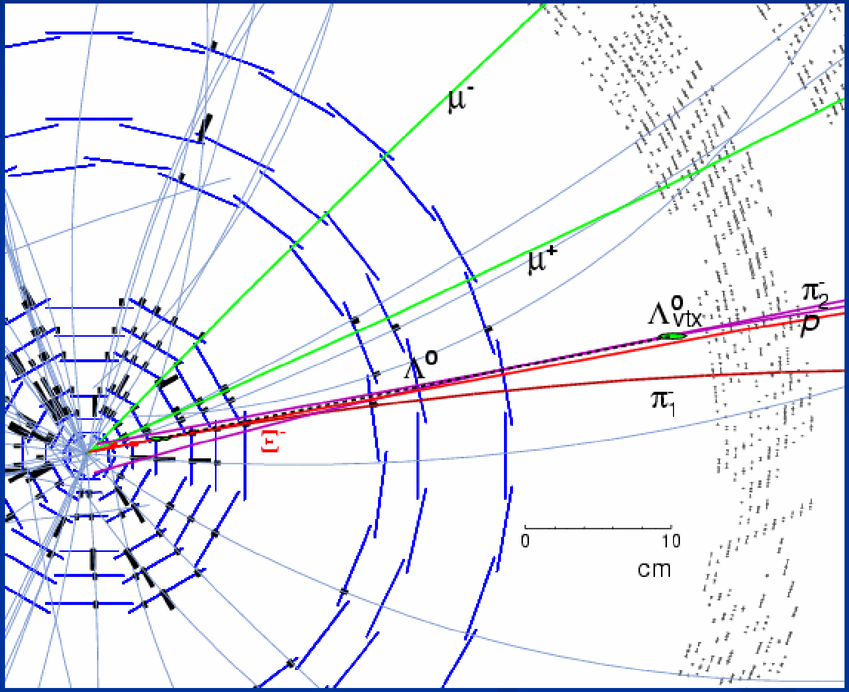
Ξ_b Mass Measurement (CDF, 1.9 fb-1)

Ξ tracked in SVX for the first time at hadron collider

→ reduce background

→ improve secondary vertex precision

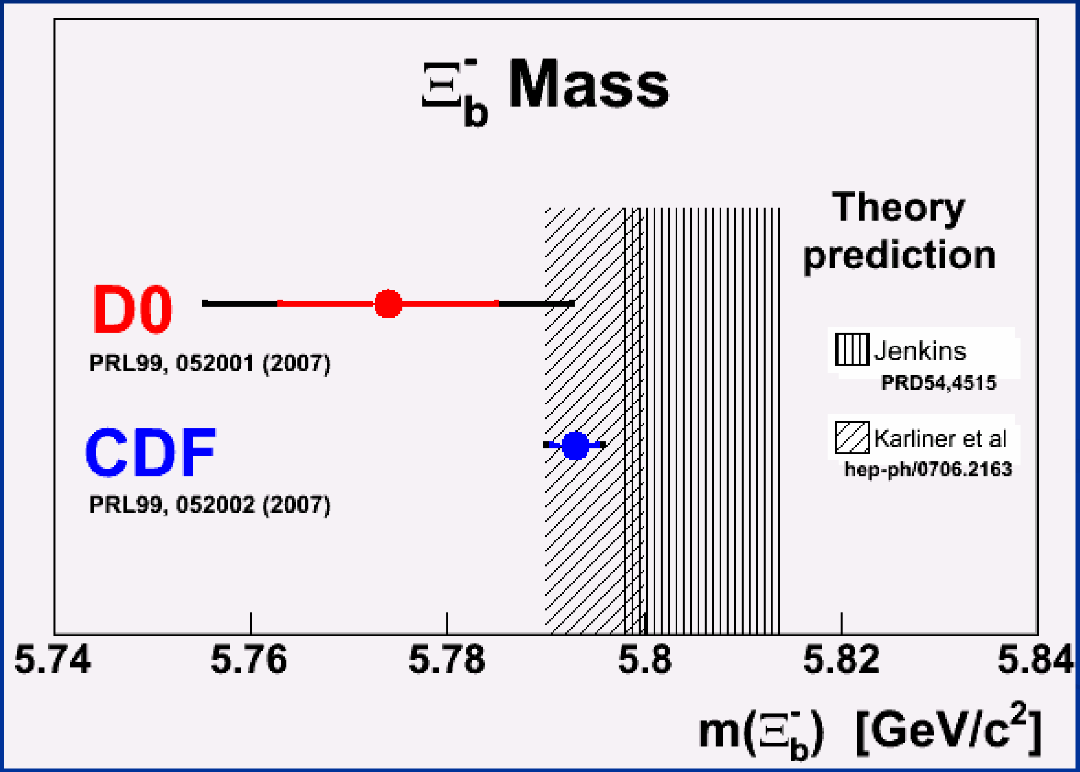




$$M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV}/c^2$$

most precise measurement at 7.8σ significance

Ξ_b Current Status

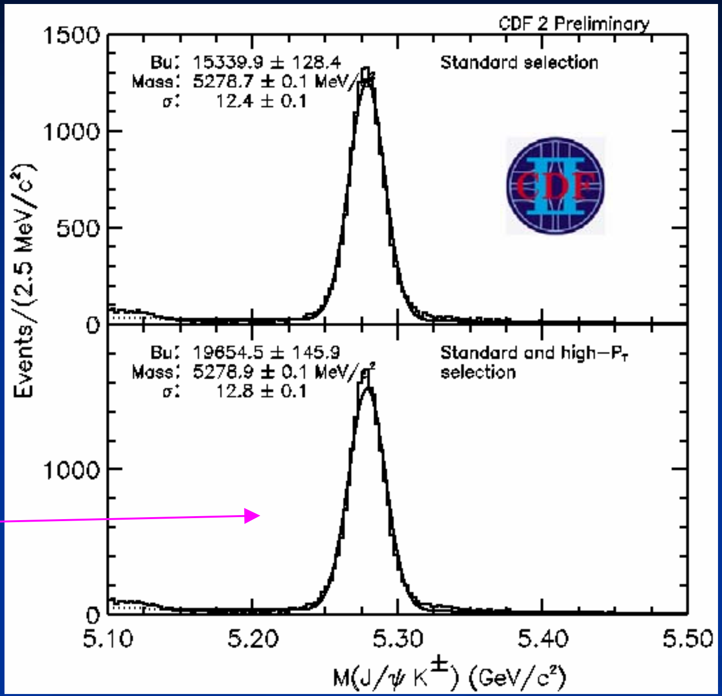


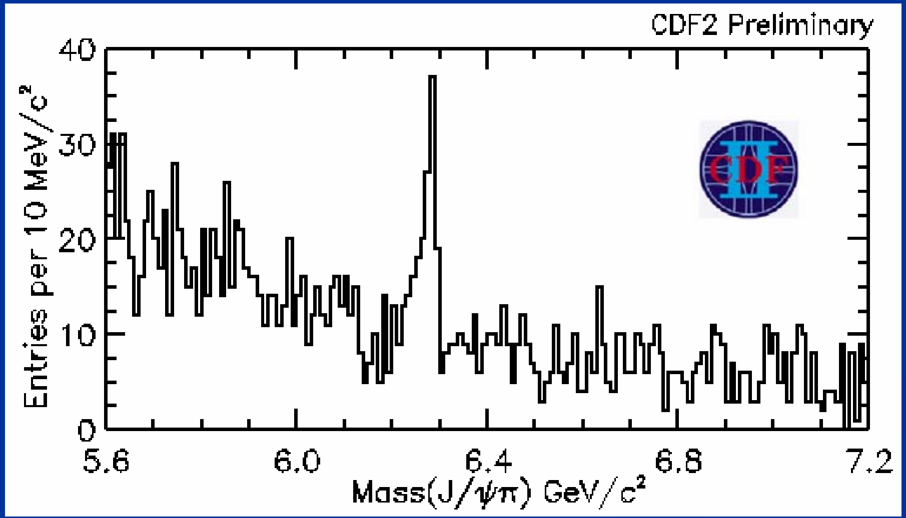
Ξ_b also observed in hadronic decays at CDF

With more data will study other properties of Ξ_b

$B_c \rightarrow J/\psi\pi$ (2.2 fb^{-1})

- B_c is not produced at B factories
- Precision test of lattice QCD
- Full reconstruction and CDF tracking give precise mass measurement
- New analysis
  - Tune selection on the data: $B^+ \rightarrow J/\psi K$ control mode
  - Measure mass of the B_c





Poisson probability of background fluctuation to the observed excess is 1.1×10^{-19} (Corresponds to 9σ)

$$\boxed{M(B_c) = 6274.1 \pm 3.2 \pm 2.6\ \mathrm{MeV}/c^2}$$

$$M(B_c)_{Lattice} = 6304 \pm 12\,^{+18}_{-0}\ \mathrm{MeV}/c^2$$

B_c Mass in $B_c \to J/\Psi\pi$ (CDF, 2.2 fb^{-1})

B_c contains both heavy quarks b, c → each quark can decay

Mass predictions:

NR potential models 6247 - 6286 MeV

lattice QCD 6304 +/- 12 $^{+18}_{-0}$ MeV

Three decay possibilities:

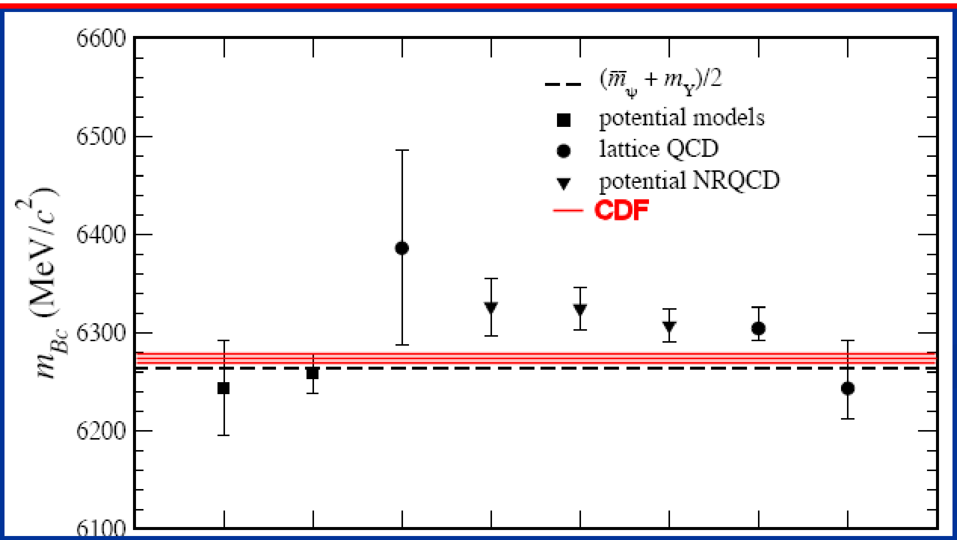
c quark decays: $B_c^+ \to B_s^0 \pi^+$, and $B_c^+ \to B_s^0 \ell^+ \nu$

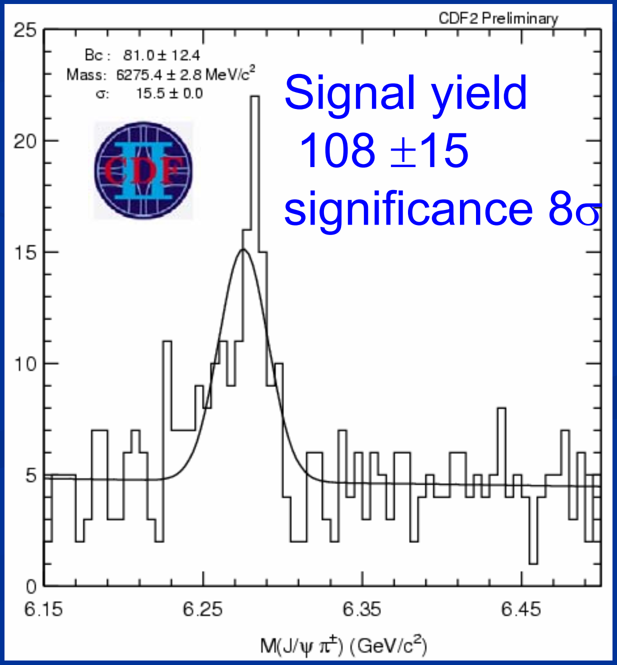
b quark decays: $B_c^+ \to J/\psi \pi^+$; $B_c^+ \to J/\psi D_s^+$; $B_c^+ \to J/\psi \ell^+ \nu$

annihilation: $B_c^+ \to J/\psi \ell^+ \nu$

Best mass measurement:

$$6275.6 \pm 2.9\ (\text{stat.}) \pm 2.5\ (\text{syst.})\ \text{MeV}/c^2$$

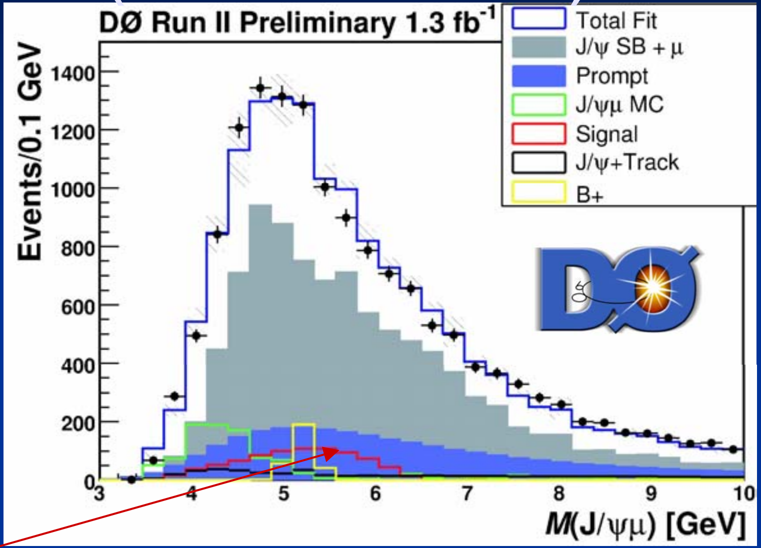




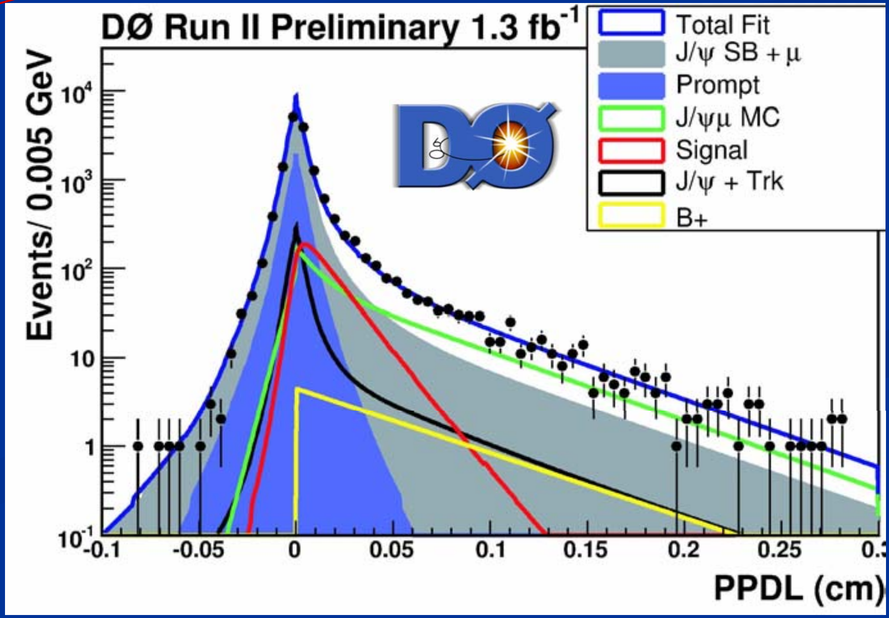
B_c Lifetime in $B_c \to J/\Psi\mu X$ (DØ, 1.4 fb^{-1})

Lifetime expected ~1/3 of other B mesons
Main challenge in partially reconstructed mode
$B_c^+ \to J/\psi \ell^+ \nu$ is understanding multiple backgrounds:

- real J/Ψ + fake muon
- fake J/Ψ + real muon
- real J/Ψ + real muon → from bb events
  - $B^+ \to J/\psi K^+$ where K → μνν
- prompt J/Ψ + μ



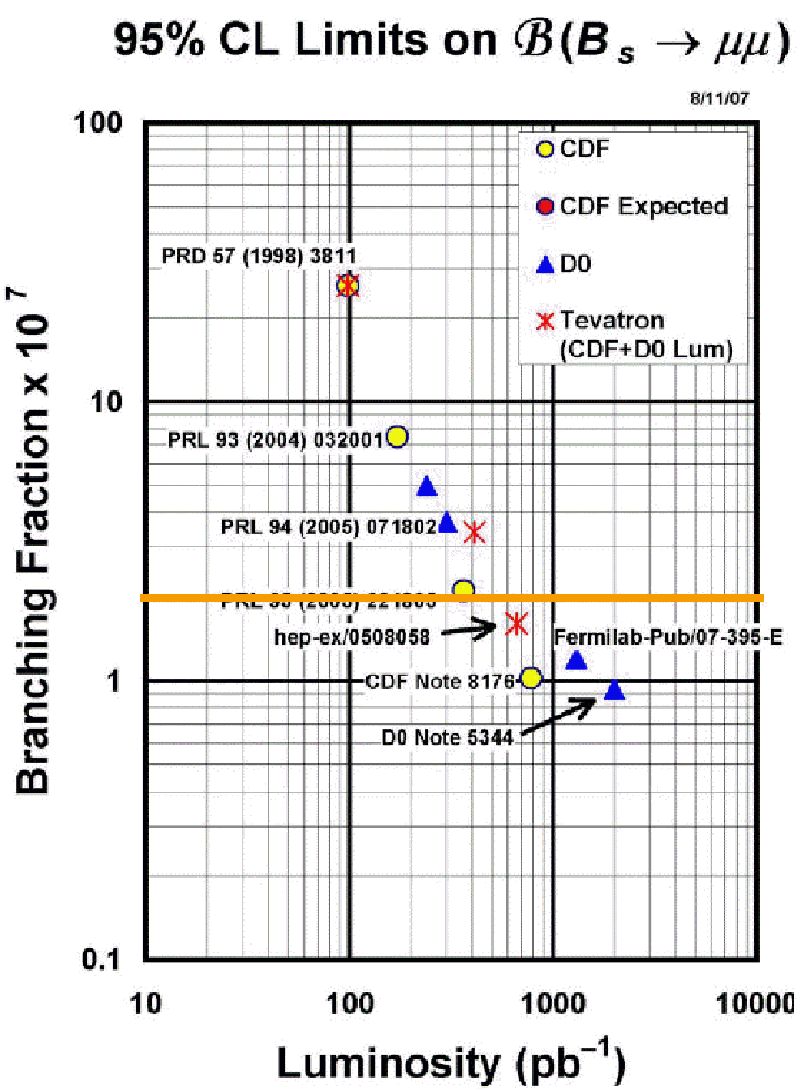
Mass – lifetime simultaneous fit used to disentangle small signal fraction among large fraction of backgrounds

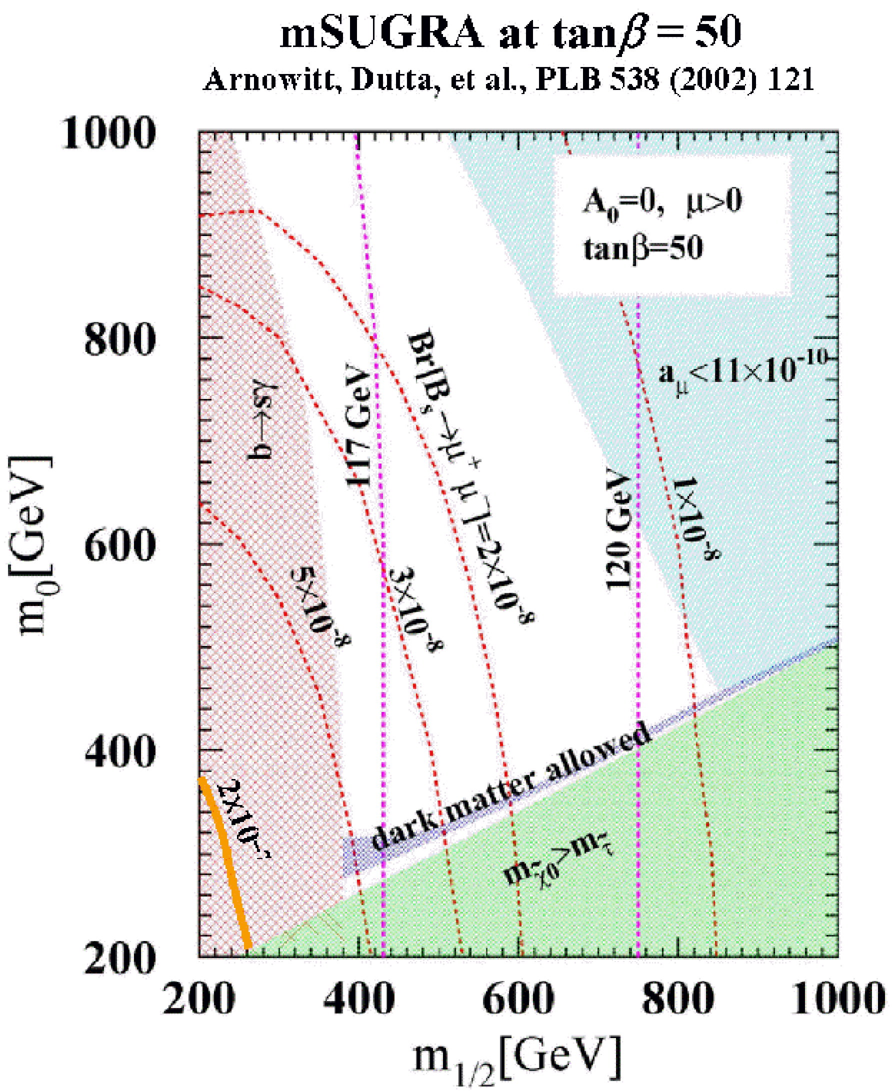


- Most precise B_c lifetime measurement:

$$\tau(B_c^\pm) = 0.444^{+0.039}_{-0.036}\,(\mathrm{stat})^{+0.039}_{-0.034}\,(\mathrm{sys})\ \mathrm{ps}$$

Implications



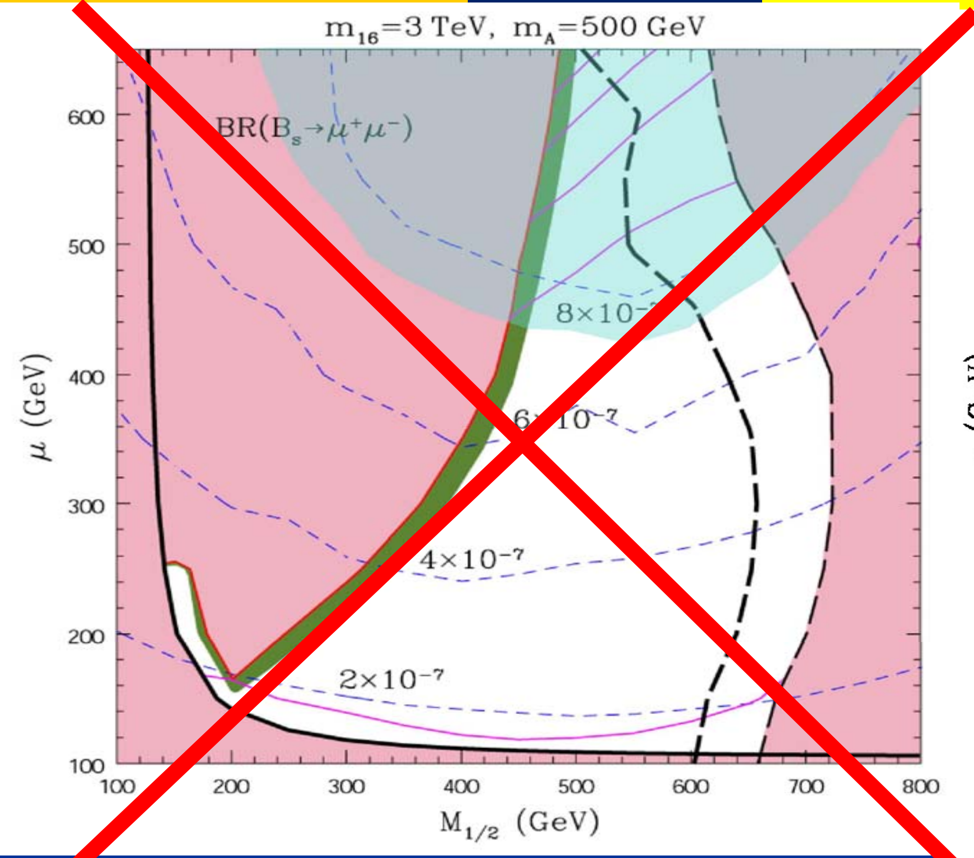


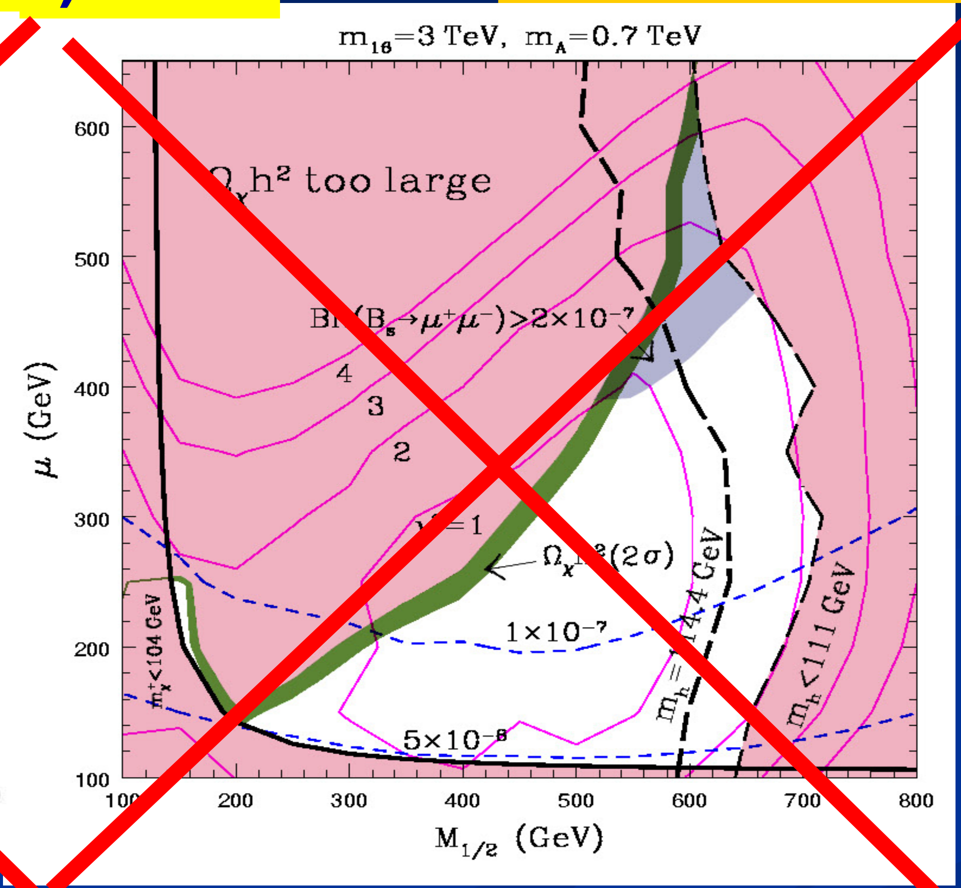
Gli spazi per New Physics si riducono…

R. Dermisek *et al.*, JHEP 0304 (2003) 037

SO(10) GUT

R. Dermisek *et al.*, hep-ph/0507233 (2005)





tan(b)~50 constrained by unification of Yukawa couplings

Pink regions are excluded by either theory or other experiments

Green region is the WMAP preferred region

Blue dashed line is the Br(Bs→mm) contour. Light blue region excluded by old Bs→mm analysis