Review of Heavy Flavor Physics at the Tevatron

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for the CDF and DØ collaborations

DPF-APS Meeting, August 12, 2011
Brown University, Providence, Rhode Island

Introduction

- Flavor Physics probes New Phenomena by either:
  - searching for small deviations from SM in high statistics, precision measurements (mostly B factories and Kaon experiments) or
  - hunting for quantities highly suppressed in SM with the hope that small NP effects would enhance the observed quantities:
    - BR of rare decays, small CPV phases and asymmetries

- Recent Heavy Flavor Physics results from CDF and D0 with up to 8 fb^{-1}

  - Rare decays:
    - *$B_s \to \mu\mu$ (CDF, D0)*
    - *$b \to s\mu\mu$ (CDF)*

  - CPV in:
    - in $B_s \to J/\Psi\Phi$, BR and lifetime in $B_s \to J/\Psi f_0$ (CDF, D0)
    - BR, polarization and CPV in $B_s \to \Phi\Phi$ (CDF)
    - di-lepton asymmetry (D0)
    - hadronic B decays (CDF)

  - New particles and decay modes
    - Ξ^0_b (CDF)

$B_s \to \mu\mu$ (CDF 7 fb^{-1}, D0 6.1 fb^{-1})

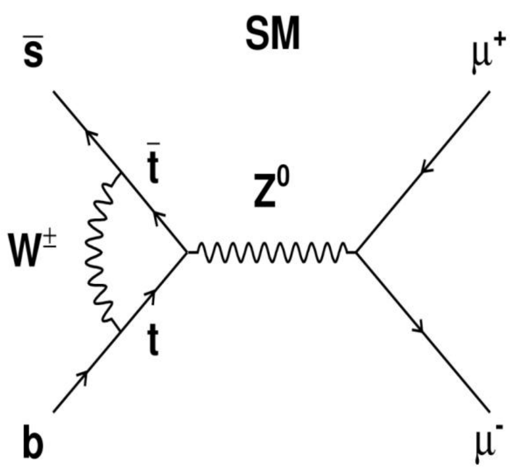
Kevin Pitts (CDF), Friday, Aug 12, HF session

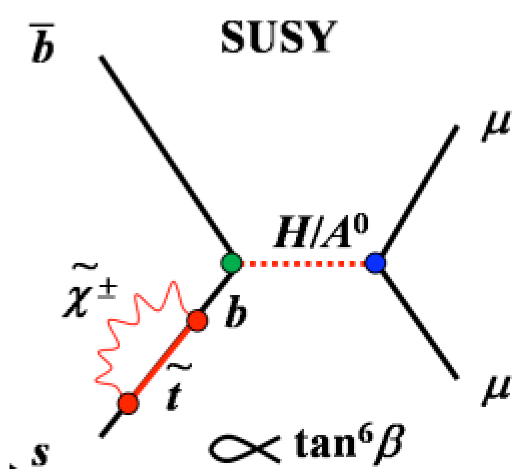
- In SM both Cabibbo and helicity suppressed; rate predicted with ~10% accuracy:

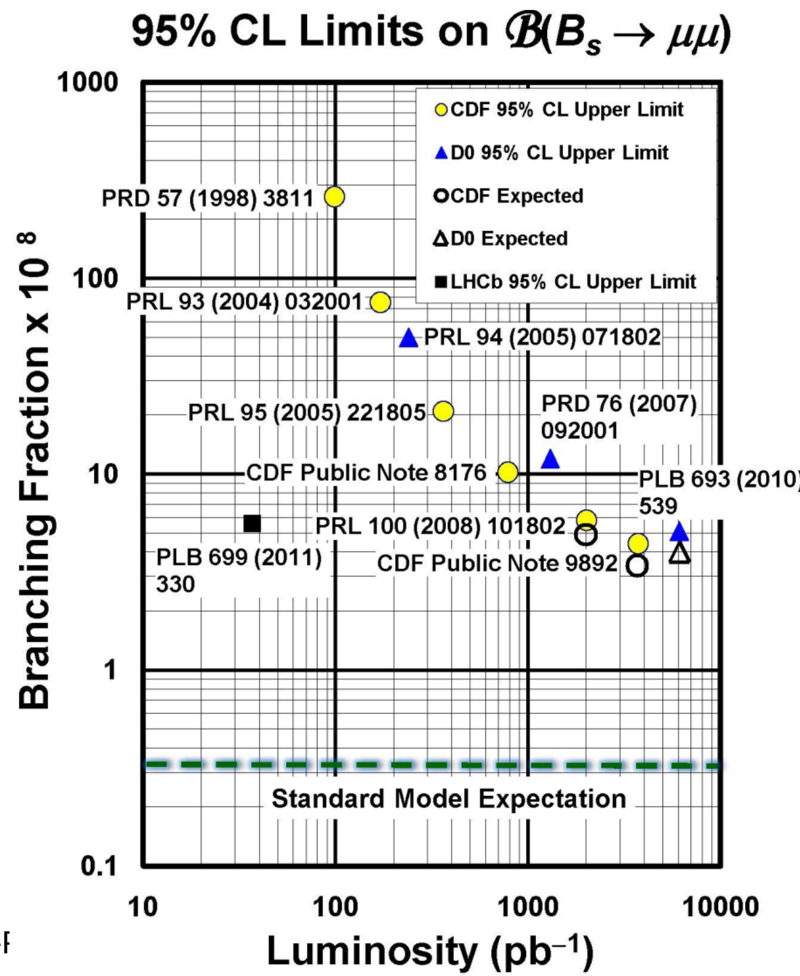
  - $BR (B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$ *Buras et al., JHEP 1010:009,2010*
  - $BR (B^0 \to \mu^+\mu^-) = (0.1 \pm 0.01) \times 10^{-9}$

- Various New Physics models predict enhanced BR:
  MSSM, mSUGRA, RPV-SUSY, FV, RS, SM4

e.g. Choudhury, Gaur, PRB 451, 86 (1999); Babu, Kolda, PRL 84, 228 (2000), Dedes, Dreiner, Nierste, PRL87:251804 (2001)







$B_s \rightarrow \mu\mu$ (CDF 7 fb^{-1}, D0 6.1 fb^{-1})

Kevin Pitts (CDF), Friday, Aug 12, HF session

- D0 results with 6.1 fb^{-1}

$BR(B_s \rightarrow \mu\mu) < 51 \times 10^{-9}$ @95%CL

PLB 693 539 (2010)

- New CDF limits (7 fb^{-1}):

arXiv:1107.2304v1

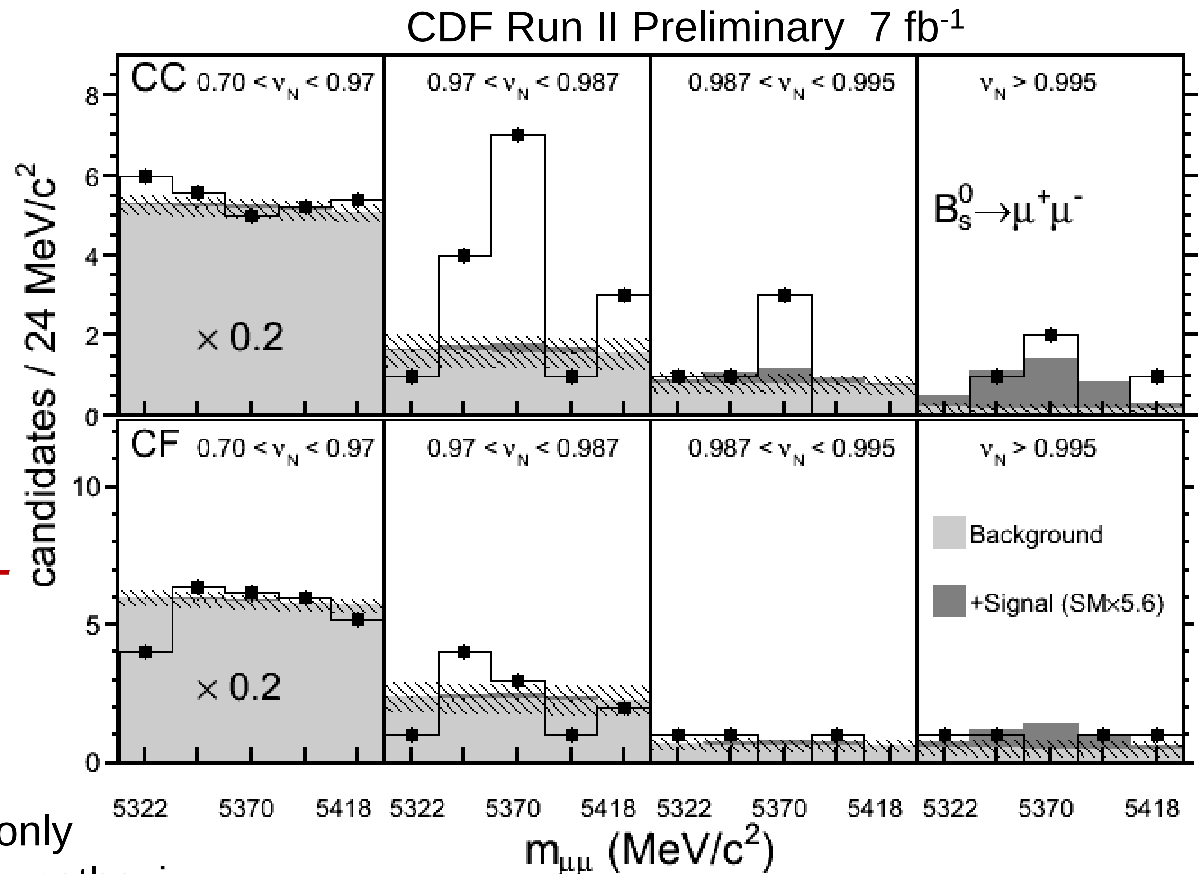
$BR(B^0 \rightarrow \mu\mu) < 6 \times 10^{-9}$ @95%CL

- expected *4.6×10^{-9}*
- theory *$(0.1 \pm 0.01) \times 10^{-9}$*

$BR(B_s \rightarrow \mu\mu) < 46 \times 10^{-9}$ @95%CL

- **expected *15×10^{-9}***
- **theory = *$(3.2 \pm 0.2) \times 10^{-9}$***

Buras et al., JHEP 1010:009,2010



- B_s limit 2.8 sigma discrepant,
p-value = 0.27%, with background only hypothesis, p-value = 2.1% in SM hypothesis

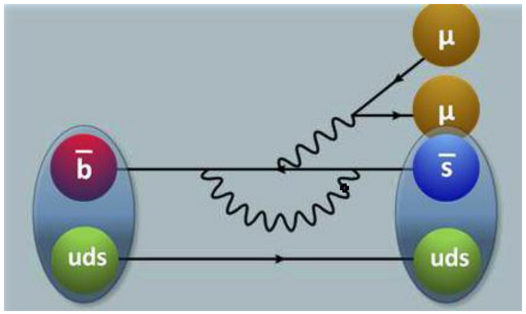
- First two sided limit: ***$4.6 \times 10^{-9} < BR(B_s \rightarrow \mu\mu) < 39 \times 10^{-9}$* at 90% CL** *($BR = 18^{+11}_{-8} \times 10^{-9}$)*
- Consistent with LHCb: *$BR(B_s \rightarrow \mu\mu) < 12$ (15) $\times 10^{-9}$ @ 90 (95)% CL* Justine Serrano, EPS 2011

CMS: *$BR(B_s \rightarrow \mu\mu) < 16$ (19) $\times 10^{-9}$ @ 90 (95)% CL* arXiv:1107.5834v1

FCNC in $b \to s\mu\mu$ decays (CDF 6.8 fb^{-1}) arXiv:1107.3753, arXiv:1108.0695v1

Austin Napier, Wed, Aug 10, HF session

- Rare decays with BR ~O(10^{-6}) in SM; good probes of NP



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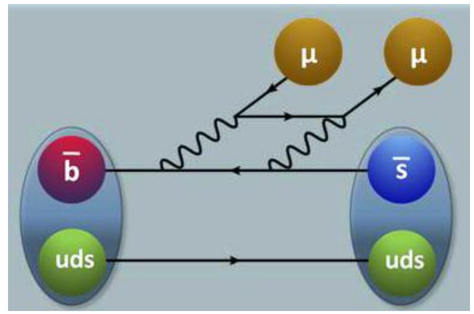


+NP?

- Various channels:
  - $B^0 \to K^{*0}\mu\mu$
  - $B^+ \to K^+\mu\mu$
  - $B^+ \to K^{*+}\mu\mu$
  - $B^0 \to K^0_s\mu\mu$,

  first observed by *CDF:*
  - $B_s \to \Phi\mu\mu$ (PRL106,161801 (2011))
  - $\Lambda_b \to \Lambda\mu\mu$ (arXiv:1107.3753)

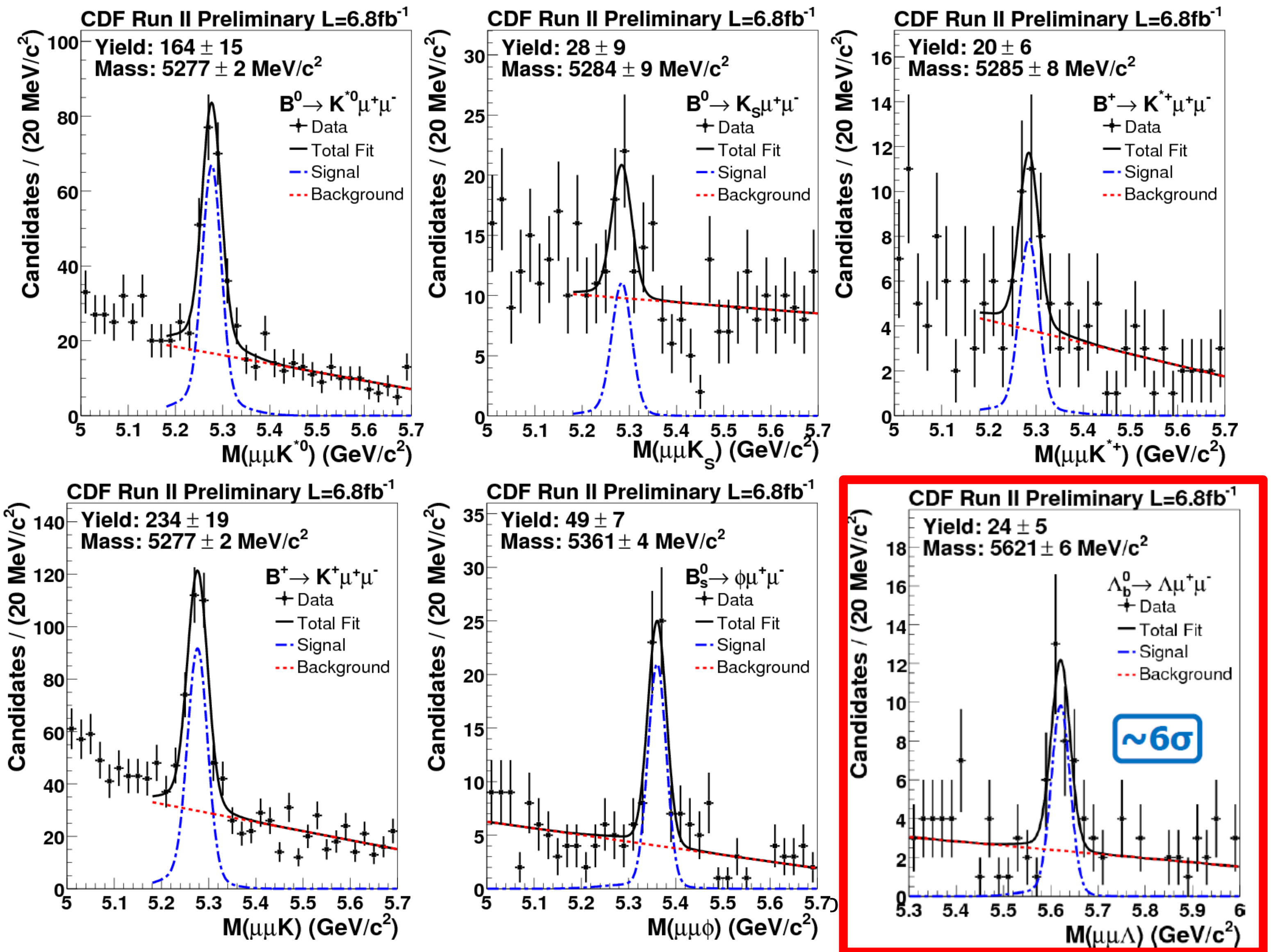
Mode	Relative $\mathcal{B}(10^{-3})$	Absolute $\mathcal{B}(10^{-6})$
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$	$2.45 \pm 0.59 \pm 0.29$	$1.73 \pm 0.42 \pm 0.55$
$B_s^0 \to \phi\mu^+\mu^-$	$1.13 \pm 0.19 \pm 0.07$	$1.47 \pm 0.24 \pm 0.46$
$B^+ \to K^+\mu^+\mu^-$	$0.46 \pm 0.04 \pm 0.02$	$0.46 \pm 0.04 \pm 0.02$
$B^0 \to K^{*0}\mu^+\mu^-$	$0.77 \pm 0.08 \pm 0.03$	$1.02 \pm 0.10 \pm 0.06$
$B^0 \to K^0\mu^+\mu^-$	$0.37 \pm 0.12 \pm 0.02$	$0.32 \pm 0.10 \pm 0.02$
$B^+ \to K^{*+}\mu^+\mu^-$	$0.67 \pm 0.22 \pm 0.04$	$0.95 \pm 0.32 \pm 0.08$

- Most precise BR measurements
- BR theoretical calculations of $\Lambda_b \to \Lambda\mu\mu$

$(4.0\pm1.2)*10^{-6}$	Phys.Rev.D81,056006 (2010)
$4.4*10^{-6}$	Phys.Rev.D78,114032 (2008)
$2.08*10^{-6}$	Phys.Rev.D64,074001 (2001)

b → sμμ signals (CDF 6.8 fb^{-1})

Austin Napier, Wed, Aug 10, HF session



Angular analysis of $B^{0/+} \to K^{*0/+}\mu\mu$ (CDF 6.8 fb^{-1}) arXiv:1108.0695v1

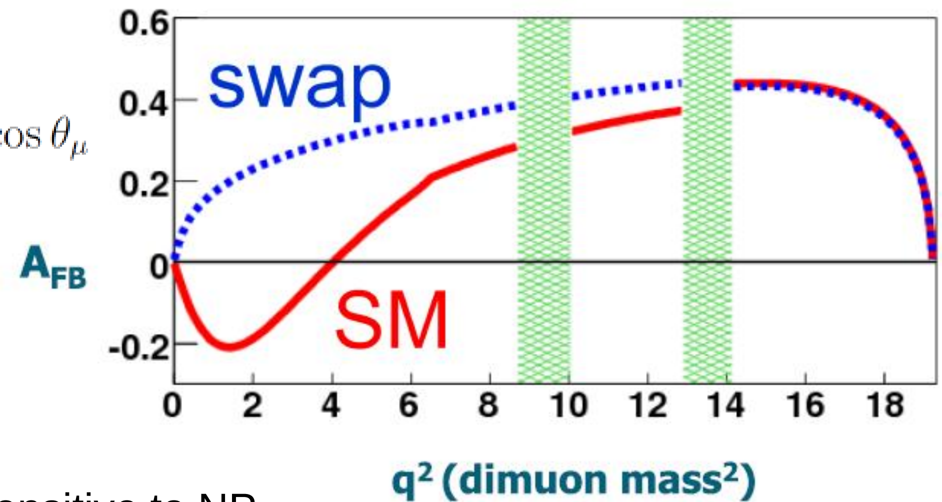
Austin Napier, Wed, Aug 10, HF session

- Differential decay rates

$$\frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$

$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$\frac{1}{2\pi}\left[1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi\right]$$

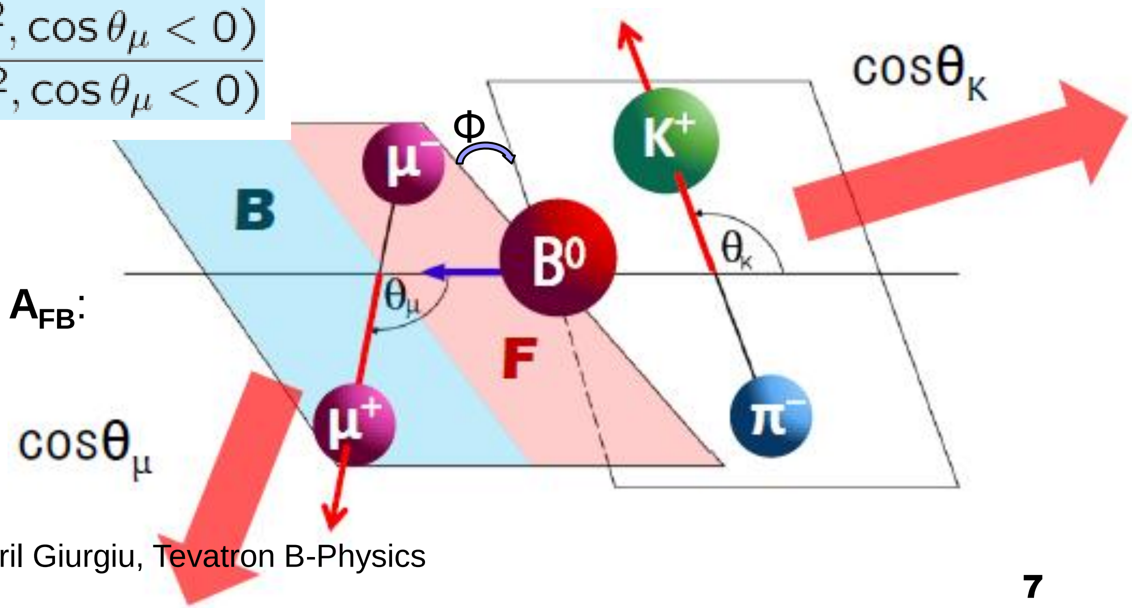


- Forward backward asymmetry AFB is most sensitive to NP

$$A_{FB}(q^2) \equiv \frac{\Gamma(q^2, \cos\theta_\mu > 0) - \Gamma(q^2, \cos\theta_\mu < 0)}{\Gamma(q^2, \cos\theta_\mu > 0) + \Gamma(q^2, \cos\theta_\mu < 0)}$$

- 2.7σ deviation from SM at Belle

- Other angular parameters besides $\mathbf{A_{FB}}$:
  $\mathbf{F_L}$, $\mathbf{A_T^{(2)}}$, $\mathbf{A_{im}}$



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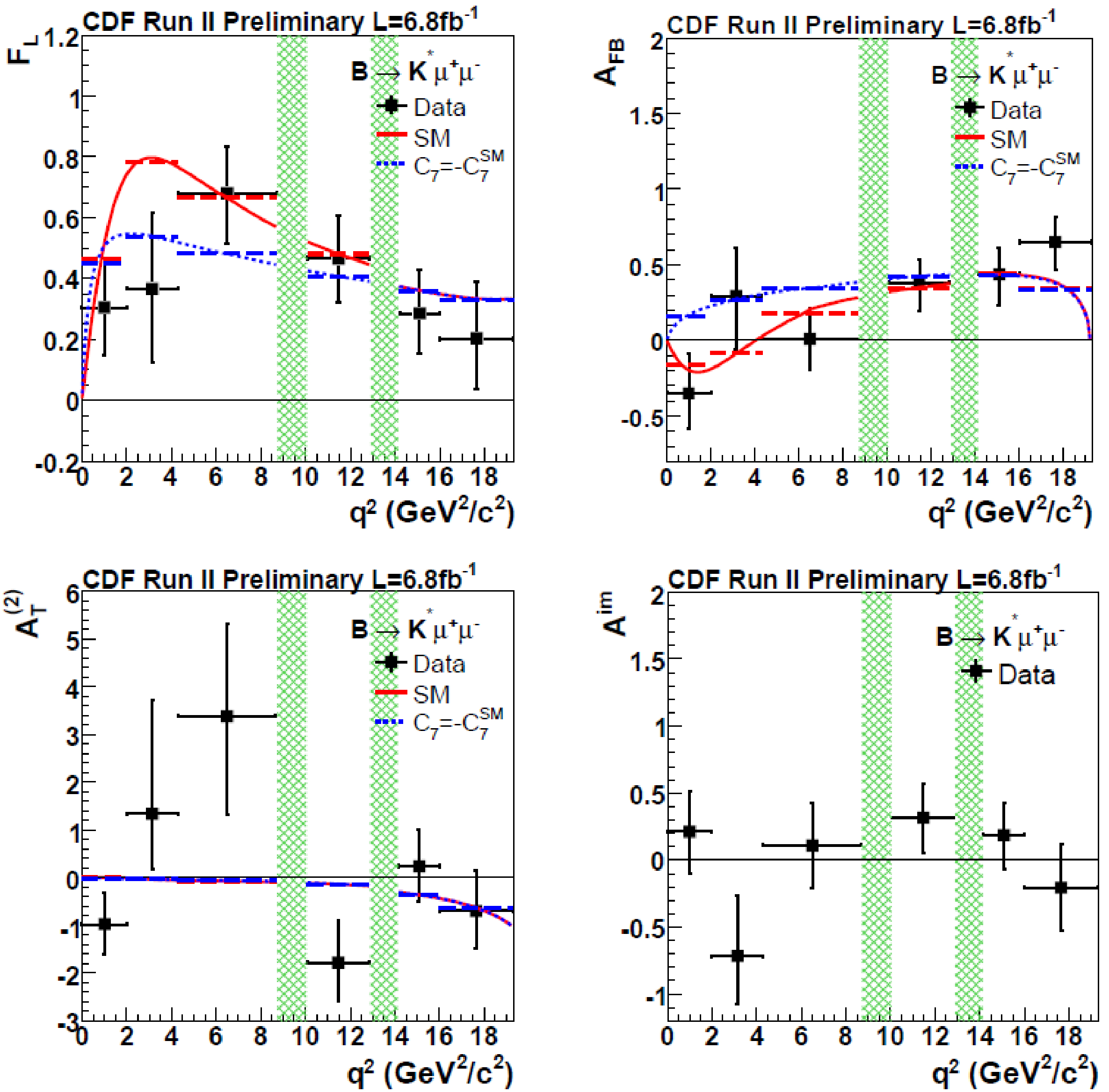


- First measurement of $A_T^{(2)}$, A_{im}
- A_{FB} and F_L competitive with Belle
- No significant deviation from SM

Same Sign Di-Muon Asymmetry (D0)

Bruce Hoeneisen, Tuesday, Aug 9, HF session

- Same sign di-lepton asymmetry very small in SM ~$O(10^{-4})$ → sensitive NP probe

$$A^b_{\rm sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = C_d a^d_{\rm sl} + C_s a^s_{\rm sl}$$

$$a^q_{\rm sl} = \frac{\Gamma(\bar{B}^0_q(t) \to \mu^+ X) - \Gamma(B^0_q(t) \to \mu^- X)}{\Gamma(\bar{B}^0_q(t) \to \mu^+ X) + \Gamma(B^0_q(t) \to \mu^- X)} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q \quad \phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

$$a^d_{\rm sl}({\rm SM}) = (-4.8^{+1.0}_{-1.2}) \times 10^{-4}$$
$$a^s_{\rm sl}({\rm SM}) = (2.1 \pm 0.6) \times 10^{-5}$$

$$C_d = 0.594 \pm 0.022,$$
$$C_s = 0.406 \pm 0.022.$$

HFAG, arXiv 1010.1589 [hep-ex] (2010)

- SM prediction $A^b_{\rm sl} = (-0.028^{+0.005}_{-0.006})\%$

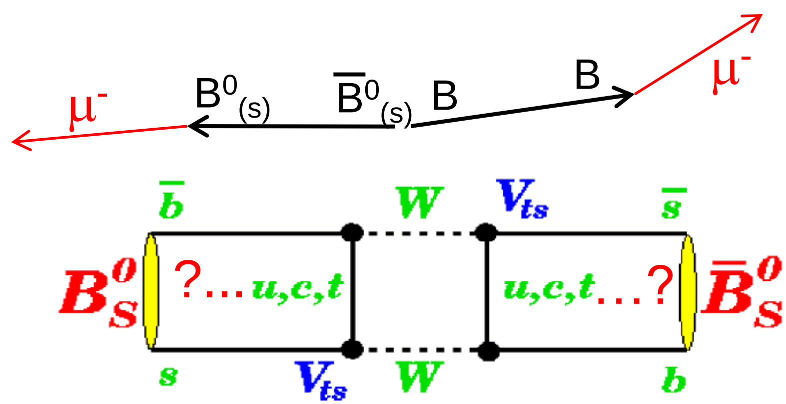
Lentz, Nierste, JHEP 0760, 072 (2007)

- Initial D0 measurement with 6 fb^{-1}

Abazov,PRD 82, 032001(2010), Abazov, PRL 105, 081801 (2010

$$A^b_{\rm sl} = -0.00957 \pm 0.00251\ ({\rm stat}) \pm 0.00146\ ({\rm sys})$$

was 3.2σ away from SM expectation



- Updated measurement released by D0 at EPS 2011

Updated Like-Sign Di-Lepton Asymmetry (D0 9 fb^{-1})

Bruce Hoeneisen, Tuesday, Aug 9, HF session

- Analysis updated with 9 fb^{-1} from previous 6 fb^{-1}

- Improved muon selection:
  - 13% increase in statistics due to looser muon longitudinal momentum selection
  - 20% reduction in K and π decay in flight backgrounds

- Muon impact parameter studies support hypothesis that muons are indeed from B decays

- New result is 3.9σ away from the SM expectation:

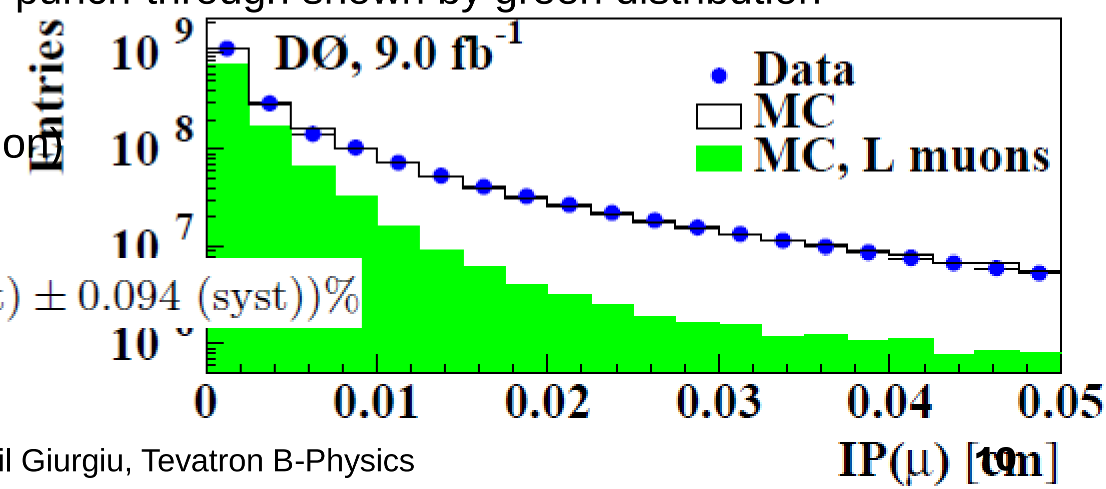
$$A^b_{sl} = (-0.787 \pm 0.172 \text{ (stat)} \pm 0.093 \text{ (syst)})\%$$

- Good agreement between muon impact parameter distributions in data and MC

- Muons from hadron decays and from punch-through shown by green distribution

- With an impact parameter cut at 120μm (enhanced mixed B_d contribution) obtain consistent asymmetry:

$$A^b_{sl}(IP_{>120}) = (-0.579 \pm 0.210 \text{ (stat)} \pm 0.094 \text{ (syst)})\%$$

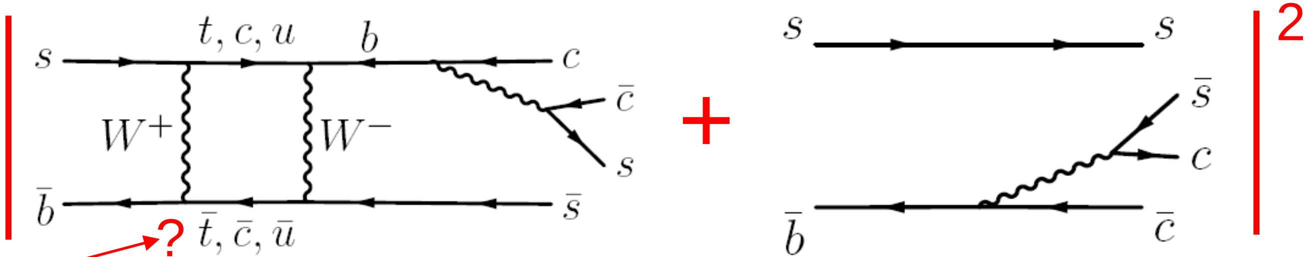


CP Violation in $B_s \rightarrow J/\Psi\Phi$

Avdhesh Chandra (D0), Wed, Aug 10 CPV session

- *CP* violation in B_s system accessible through interference of decays with and without mixing:

Decay rate ~



New Physics particles ?

$$\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- *CP* violation phase β_s in SM is predicted to be very small in SM (0.02 rad)
- New physics particles running in the mixing diagram may enhance β_s

- Note: certain SUSY models with large tan(β) predict enhanced $BR(B_s \rightarrow \mu\mu)$ for large CP violating mixing phase in $B_s \rightarrow J/\Psi\Phi$ Altmannshofer, Buras, Gori, Paradisi, Straub,Nucl.Phys.B830:17-94,2010

- Multidimensional likelihood function involves B_s decay time and mass, decay angles of daughter muons/kaons and flavor tagging

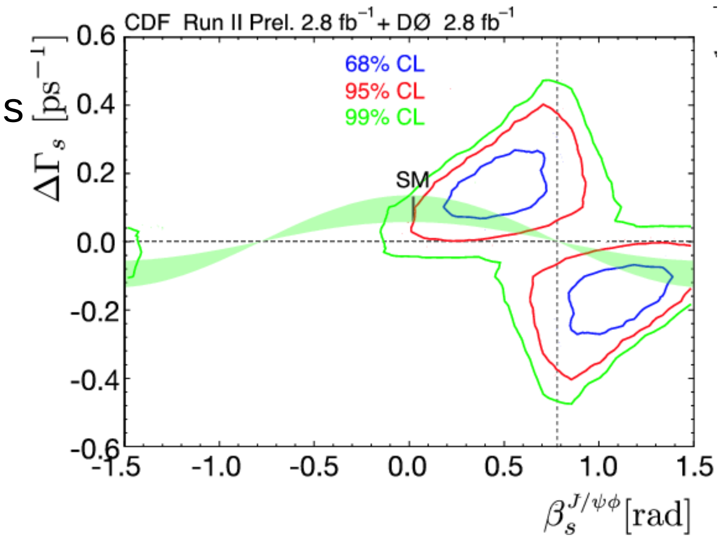
CP Violation in $B_s \rightarrow J/\Psi\Phi$ (D0 8 fb^{-1}, CDF 5.2 fb^{-1})

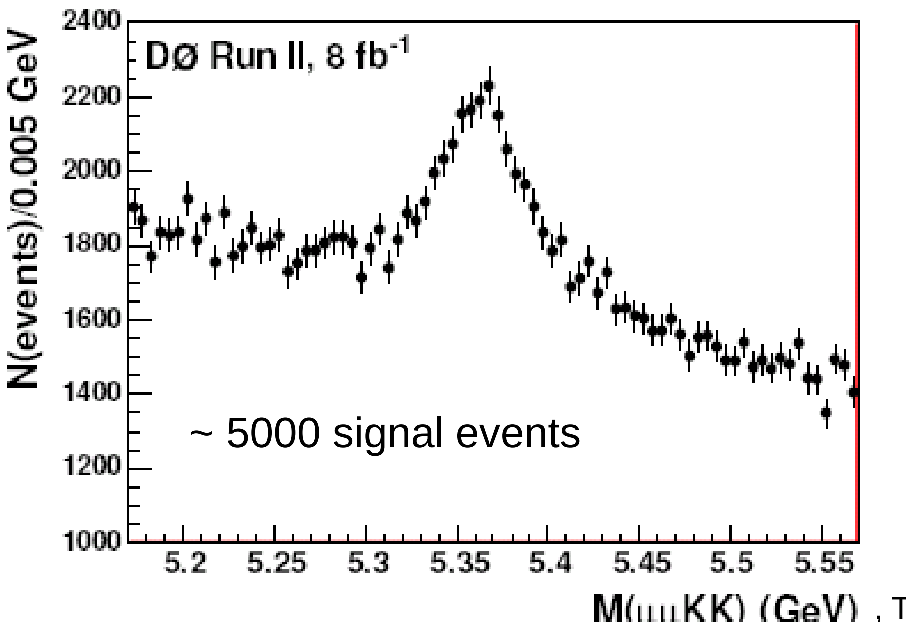
Avdhesh Chandra (D0), Wed, Aug 10, CPV session

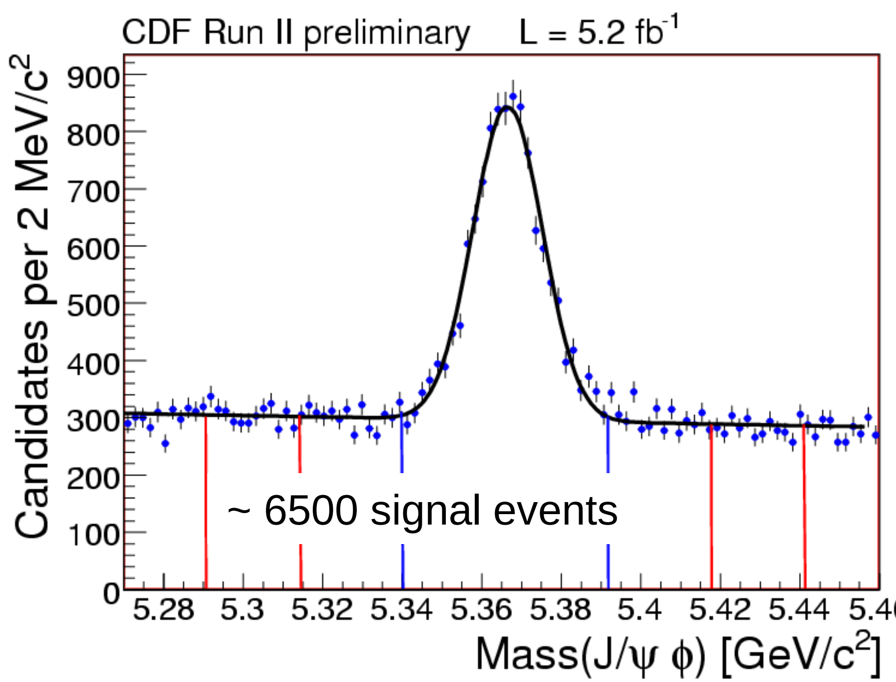
- Both CDF and D0 early results showed slight deviations from SM (~2σ combined CDF+D0)

- Updated results from CDF with 5.2 fb^{-1} (2010) and most recent update from D0 with 8 fb^{-1} (EPS 2011)

- Both experiments include S-wave contribution
  - different s-wave fractions to be understood







CP Violation in $B_s \rightarrow J/\Psi\Phi$ (D0 8 fb^{-1}, CDF 5.2 fb^{-1})

Avdhesh Chandra (D0), Wed, Aug 10 CPV session

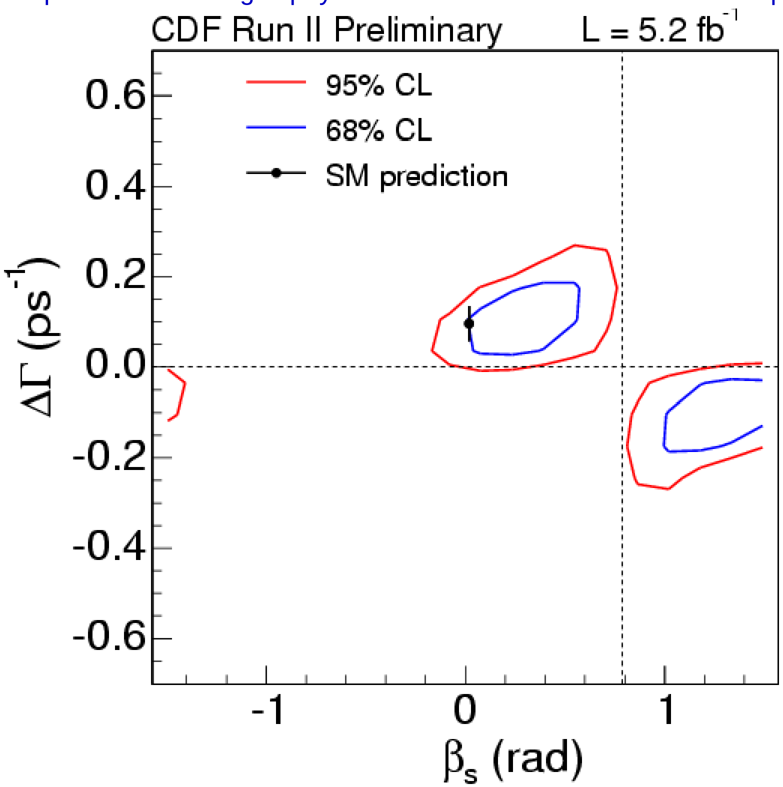
- Updated results show better agreement with SM (1σ level each)

- New Physics may still be present but require better sensitivity than Tevatron experiments

-Tevatron analyses will be updated with full dataset

β_s in [-0.02,0.52] U [1.08,1.55] at 68% CL CDF Note 10206

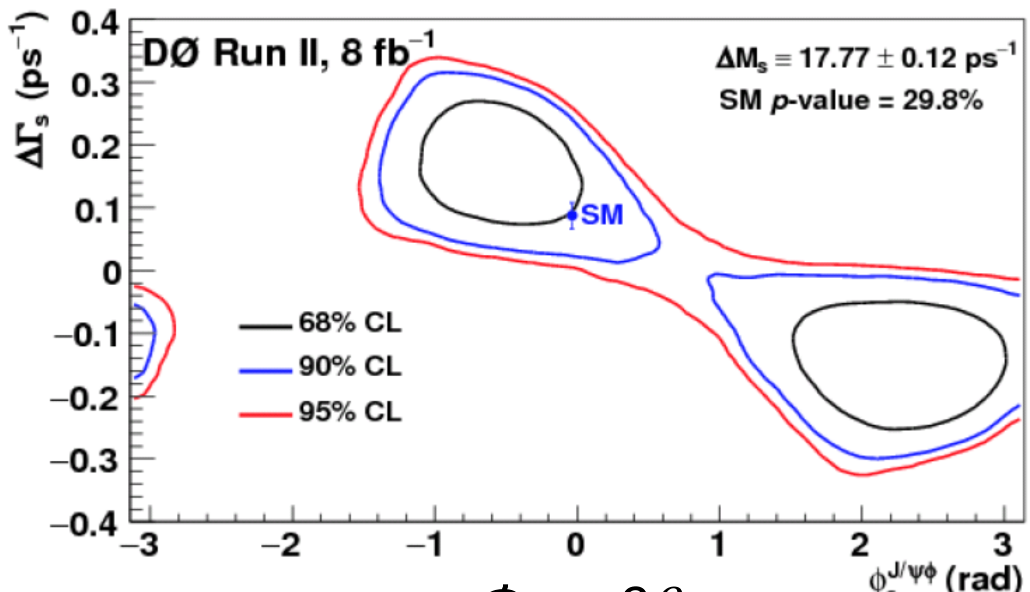
http://www-cdf.fnal.gov/physics/new/bottom/100513.blessed-BsJpsiPhi_5.2fb/



$\Phi_s = -0.55^{+0.38}_{-0.36}$ (rad)

$\beta_s = 0.28^{+0.19}_{-0.18}$ (rad)

Avdhesh Chandra (D0), Wed, Aug 10 CPV session



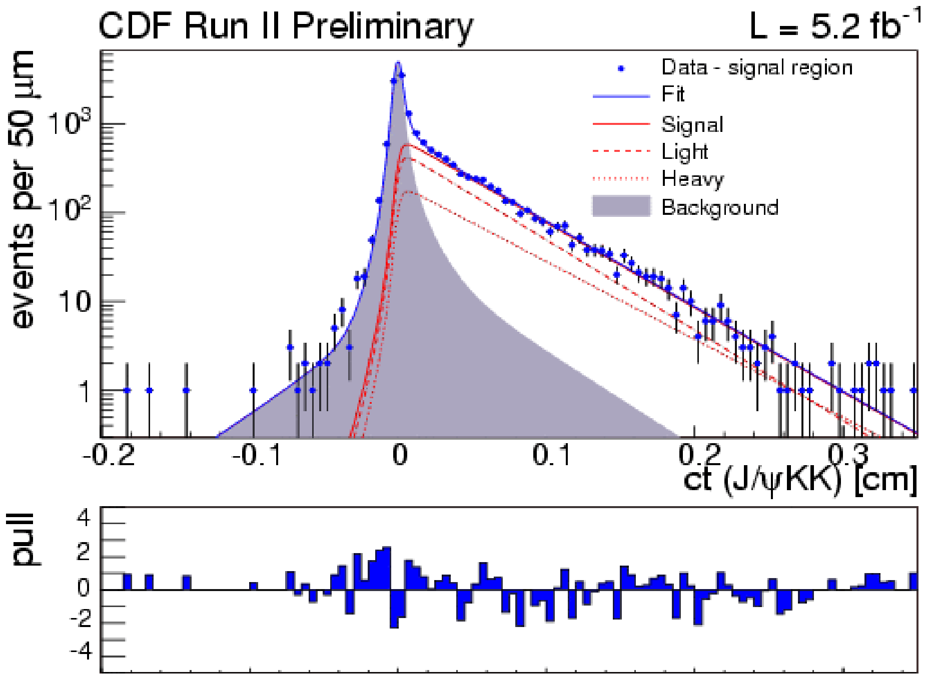
$\Phi_s = -2\beta_s$

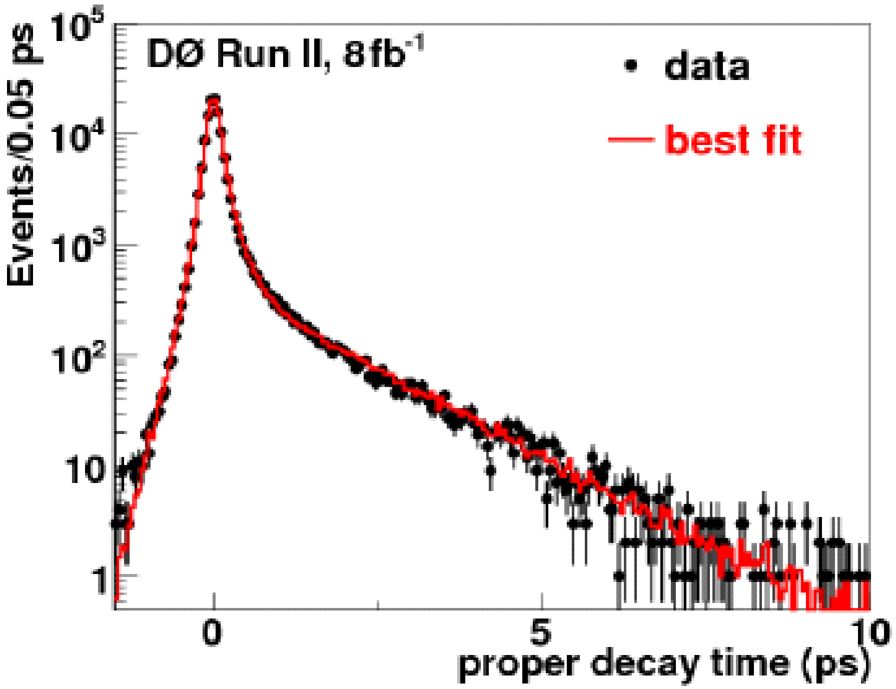
B_s Lifetime, Decay Width Difference and Polarizations

Avdhesh Chandra (D0), Wed, Aug 10 CPV session

- $B_s \rightarrow J/\Psi\Phi$ decays provide most precise measurements of B_s lifetime τ_s and decay width difference $\Delta\Gamma_s$

CDF	*D0*
$\tau_s = 1.52 \pm 0.03\ (stat) \pm 0.01\ (syst)\ ps$	$\tau_s = 1.443^{+0.038}_{-0.035}\ (stat + syst)\ ps$
$\Delta\Gamma_s = 0.075 \pm 0.035\ (stat) \pm 0.01\ (syst)\ ps^{-1}$	$\Delta\Gamma_s = 0.163^{+0.065}_{-0.064}\ (stat + syst)\ ps^{-1}$
$\lvert A_{\parallel}(0)\rvert^2 = 0.231 \pm 0.014\ (stat) \pm 0.015\ (syst)$	$\lvert A_{\parallel}(0)\rvert^2 = 0.231^{+0.024}_{-0.030}\ (stat + syst)$
$\lvert A_0(0)\rvert^2 = 0.524 \pm 0.013\ (stat) \pm 0.015\ (syst)$	$\lvert A_0(0)\rvert^2 = 0.558^{+0.017}_{-0.019}\ (stat + syst)$





$B_s \to J/\Psi f_0(980)$, $f_0 \to \pi\pi$

- Final state in $B_s \to J/\Psi f_0$ is CP odd $\to$ a sufficiently large sample would allow determination of CPV parameter β_s without angular analysis

- Related mode $B_s \to J/\Psi f_0(980)$, $f_0 \to KK$ may be useful to solve the β_s ambiguity

- Measure ratio: $R_{f_0/\phi} = \frac{\mathcal{B}(B_s^0 \to J/\psi f_0)}{\mathcal{B}(B_s^0 \to J/\psi \phi)} \frac{\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)}$

- First experimental limit on $B_s \to J/\Psi f_0$ from Belle:

$$\mathcal{B}(B_s^0 \to J/\psi f_0)\mathcal{B}(f_0 \to \pi^+\pi^-) < 1.63 \times 10^{-4} \text{ at } 90\% \text{ C.L.}$$

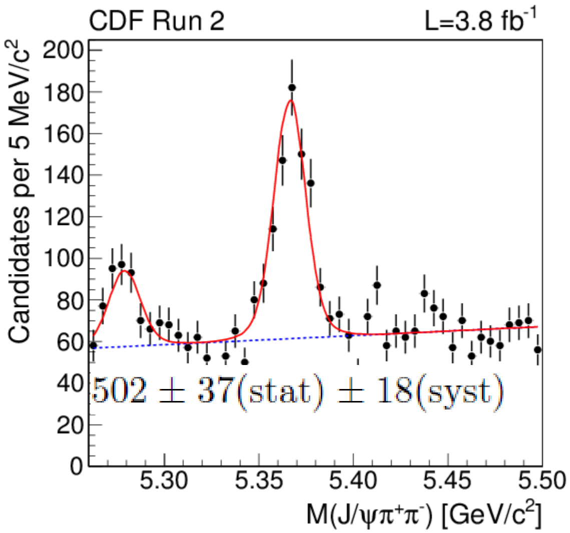
- First observation from LHCb: $R_{f_0/\phi} = 0.252^{+0.046}_{-0.032}(\text{stat})\,^{+0.027}_{-0.033}(\text{syst})$

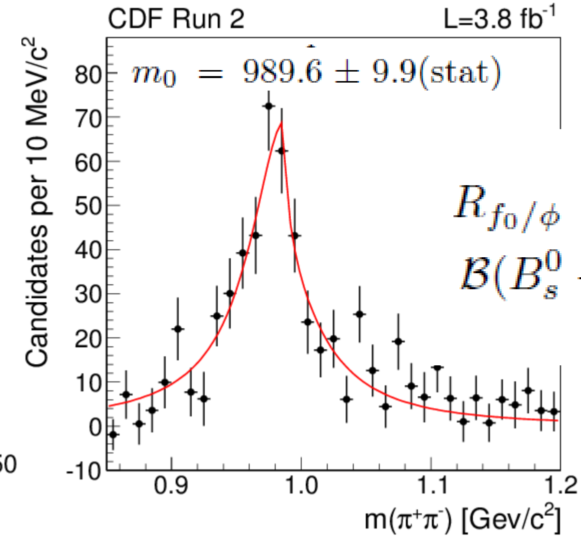
- Followed by Belle: $\mathcal{B}(B_s^0 \to J/\psi f_0)\mathcal{B}(f_0 \to \pi^+\pi^-) = (1.16^{+0.31}_{-0.19}\,^{+0.15}_{-0.17}\,^{+0.26}_{-0.18}) \times 10^{-4}$

$$R_{f_0/\phi} = 0.206^{+0.055}_{-0.034}(\text{stat}) \pm 0.052(\text{syst})$$

$B_s \rightarrow J/\Psi f_0(980)$, $f_0 \rightarrow \pi\pi$, BR Results (CDF 3.8 fb^{-1}, D0 8 fb^{-1})

Brad Abbott (D0), William Wester (CDF) Thu, Aug 11, HF session



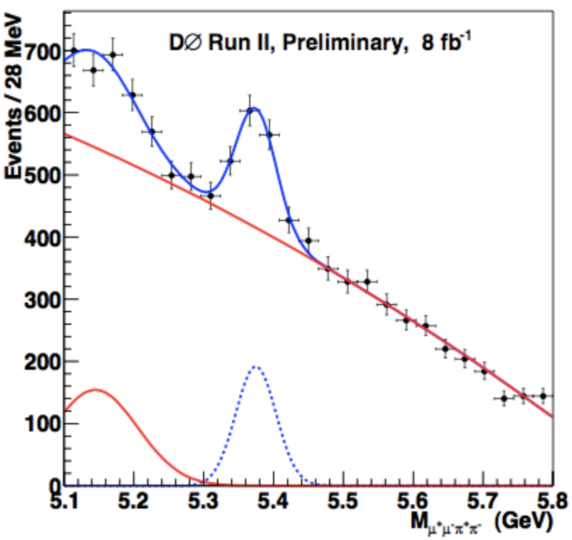


CDF arXiv:1106.3682

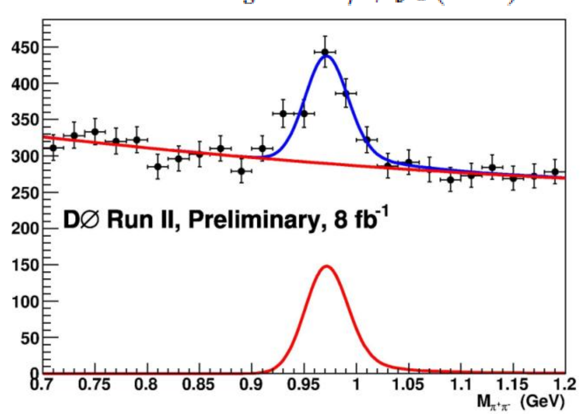
$$R_{f_0/\phi} = 0.257 \pm 0.020(\text{stat}) \pm 0.014(\text{syst})$$

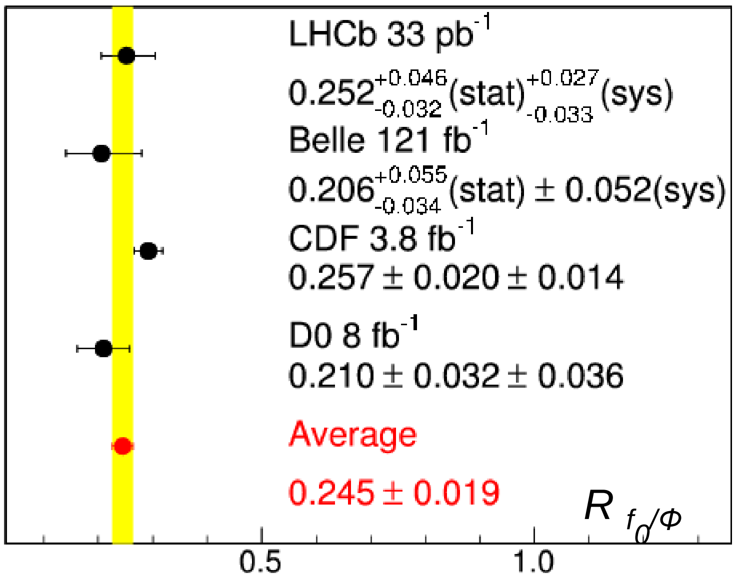
$$\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))\mathcal{B}(f_0(980) \rightarrow \pi^+\pi^-) = (1.63 \pm 0.12 \pm 0.09 \pm 0.50) \times 10^{-4}$$

D0 **Note 6152-CONF** $R_{f_0/\phi} = 0.210 \pm 0.032(\text{stat}) \pm 0.036(\text{syst})$



$498 \pm 74\ B_s^0 \rightarrow J/\psi f_0(980)$





B_s Lifetime in $B_s \to J/\Psi f_0(980)$, $f_0 \to \pi\pi$ Decays (CDF 3.8 fb^{-1})

William Wester, Thu, Aug 11, HF session

- Using: - theoretical prediction $\Delta\Gamma_s^{SM} = (0.087 \pm 0.021)$

A. Lenz and U. Nierste, J. High Energy Phys. 06, 072 (2007).
U. Nierste and A. Lenz, arXiv:hep-ph/1102.4274.

- world average B^0 lifetime (PDG 2010) $\tau_d = (1.525 \pm 0.009)$ ps and $\tau_d \approx \tau_s$

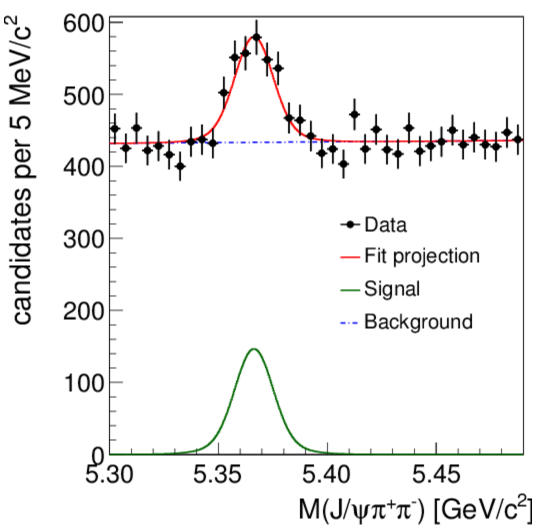
- Calculate $\tau_s^H = (1.630 \pm 0.030)$ ps and $\tau_s^L = (1.427 \pm 0.023)$ ps.

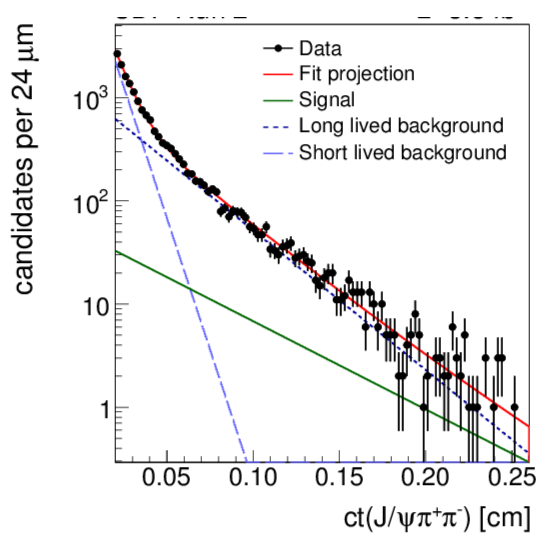
- CP odd final state + CPV≈0 in SM → first lifetime measurement of B_s heavy mass eigenstate :

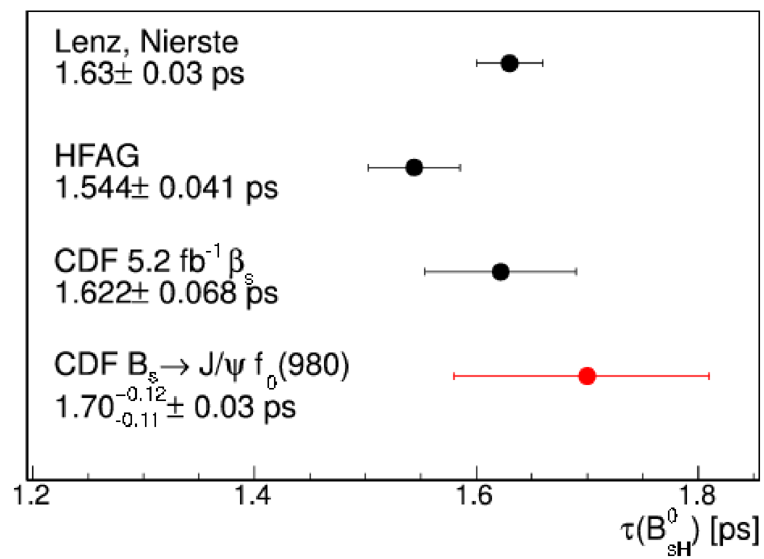
$$\tau(B_s^0 \to J/\psi f_0) = 1.70^{+0.12}_{-0.11}(\text{stat}) \pm 0.03(\text{syst})\ \text{ps}$$

arXiv:1106.3682

- Good agreement with theoretical expectations and similar measurements in $B_s \to J/\Psi\Phi$ decays

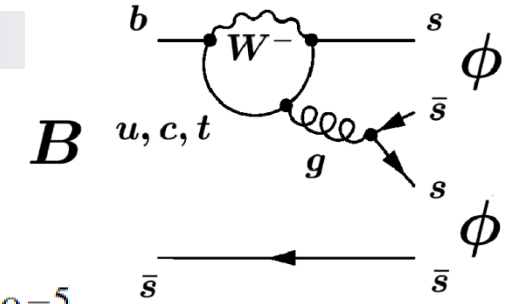






$B_s \to \Phi\Phi$, BR, Polarization (CDF 2.9 fb^{-1})

William Wester, Thu, Aug 11, HF session



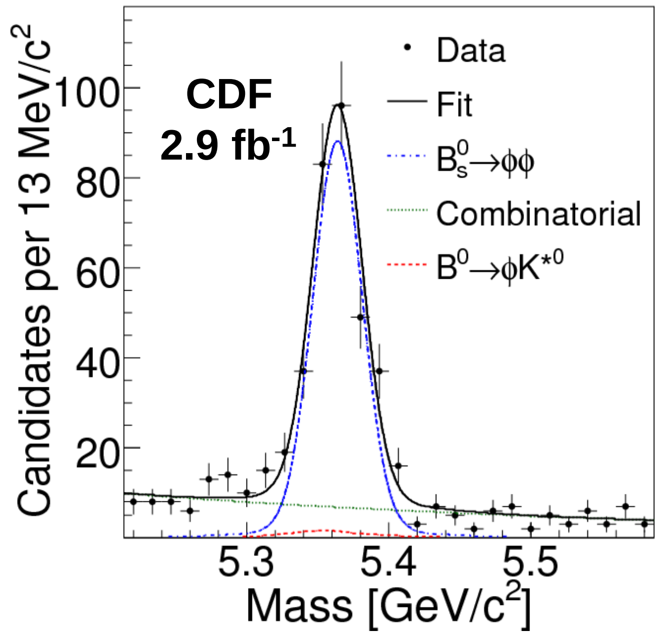
- Branching fraction:

$$\mathscr{B}(B_s \to \phi\phi) = [2.40 \pm 0.21(stat.) \pm 0.27(syst.) \pm 0.82(BR)] \times 10^{-5}$$

- Polarization fractions:
  - transverse (lin. comb of ±1 helicity):

    $f_T = 0.652 \pm 0.041$ (stat) ± 0.021 (syst)
  - longitudinal (zero helicity):

    $f_L = 0.348 \pm 0.041$ (stat) ± 0.021 (syst)



- Inconsistent with SM expectation ***$f_T / f_L \sim M_V / M_B << 1$***

- Consistent with "polarization puzzle" in other $b \to s$ penguin transitions from Belle and Babar, like

  $B \to \Phi K^*$, ρK^*… where $f_L \approx f_T$

- NP and SM explanations could be distinguished using Triple Products $TP = q \cdot (\varepsilon_1 \times \varepsilon_2)$

A.Datta and D.London, International Journal of Modern Physics A, 19:2505, 2004, A.Datta, M.Duraisamy, D.London , arXiv:1103.2442, 2011

($q = p(\Phi_1) - p(\Phi_2)$ is momentum difference and ε_i is Φ_i polarization)

- In $B \to \Phi K^*$ TP measurements favor SM explanations. What about $B_s \to \Phi\Phi$?

$B_s \to \Phi\Phi$, Search for CPV (CDF 2.9 fb^{-1})

William Wester, Thu, Aug 11, HF session

- TP asymmetry, A_{TP} : - sensitive to CPV in decays
  - expected to be very small in SM

- In $B_s \to \Phi\Phi$: TP asymmetries are related to asymmetries on angular quantities like:

$A_{TPu} \sim A_u = A(\cos\Phi \sin\Phi)$

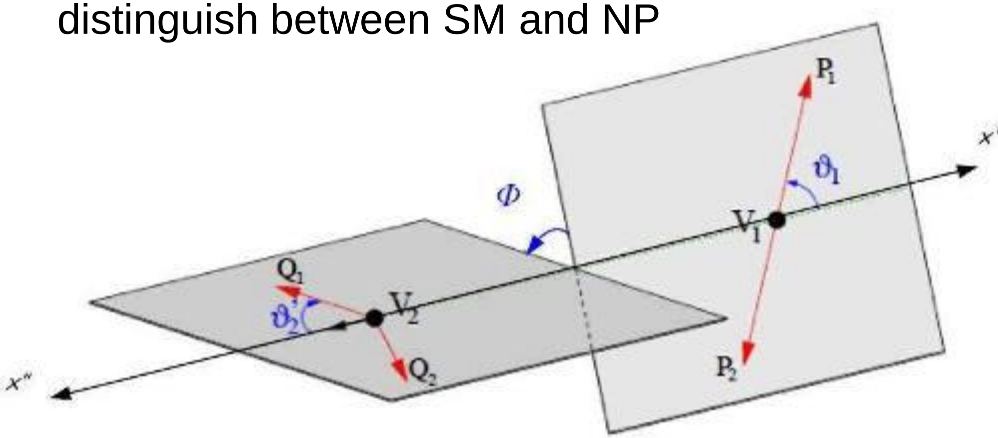
$A_{TPv} \sim A_v = A(\sin(\pm\Phi))$, where +/- correspond to $\cos\theta_1\cos\theta_2$>/<0

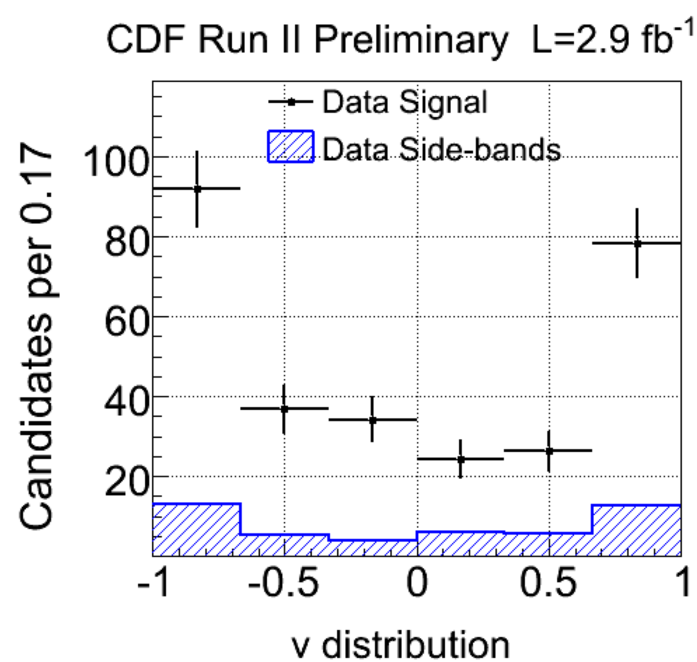
$\mathbf{A_{TPu} = -0.007 \pm 0.064\ (stat) \pm 0.018\ (syst)}$

$\mathbf{A_{TPv} = -0.120 \pm 0.064\ (stat) \pm 0.016\ (syst)}$

arXiv:1107.4999

- First TP constraints in $B_s \to \Phi\Phi$ decays
- $A_{TPv} \sim 1.8\sigma$ from zero; more data would help distinguish between SM and NP



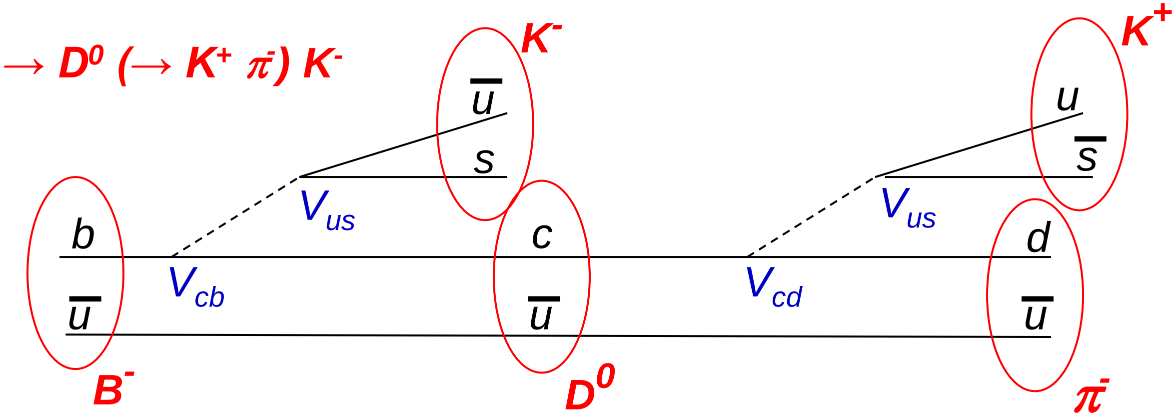


CP Violation in B → DK Decays, Paola Garosi, Tue, Aug 11, CPV session

- Measurements of BR and CP asymmetries in $B^- \rightarrow D^0 K^-$ can be used to determine CMK angle γ using "ADS" method D. Atwood, I. Dunietz, A. Soni, Phys. Rev. Lett. 78, 3257, (1997), D. Atwood, I. Dunietz, A. Soni, Phys. Rev. D 63, 036005, (2001) Note: CDF provided results for GLW method in 1/fb, *PRD81, 031105(2010)*

- Interference of two decay amplitudes of comparable sizes is sensitive to angle γ

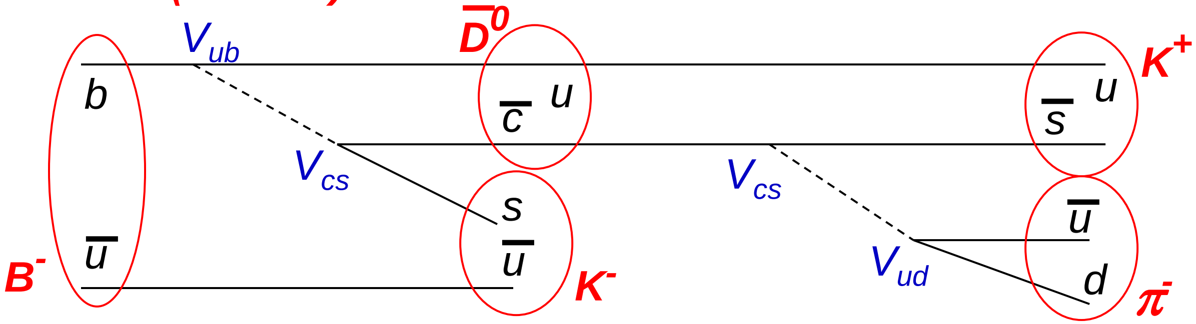
$B^- \rightarrow D^0 (\rightarrow K^+ \pi^-) K^-$



$B^- \rightarrow D^0 K^-$
color allowed
$V_{cb}V^*_{us} \sim \lambda^3$

$D^0 \rightarrow K^+ \pi^-$
doubly Cabibbo suppressed
$V_{cd}V^*_{us} \sim \lambda^2$

$B^- \rightarrow \overline{D}^0 (\rightarrow K^+ \pi^-) K^-$



$B^- \rightarrow \overline{D}^0 K^-$
color suppressed
$V_{cb}V^*_{us} \sim \lambda^3 e^{i\gamma}$

$\overline{D}^0 \rightarrow K^+ \pi^-$
Cabibbo favored
$V_{cd}V^*_{us} \sim 1$

CP Violation in B → DK Decays (CDF 7 fb^{-1})

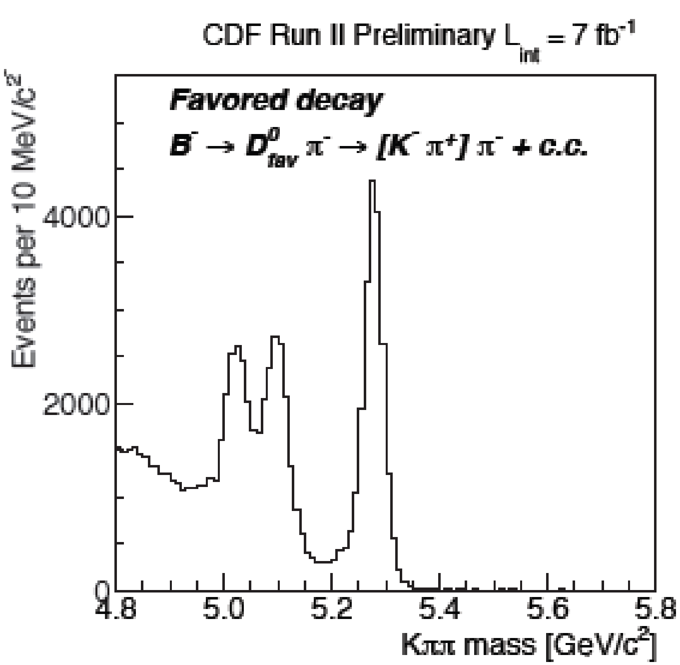
Paola Garosi, Tue, Aug 11, CPV session

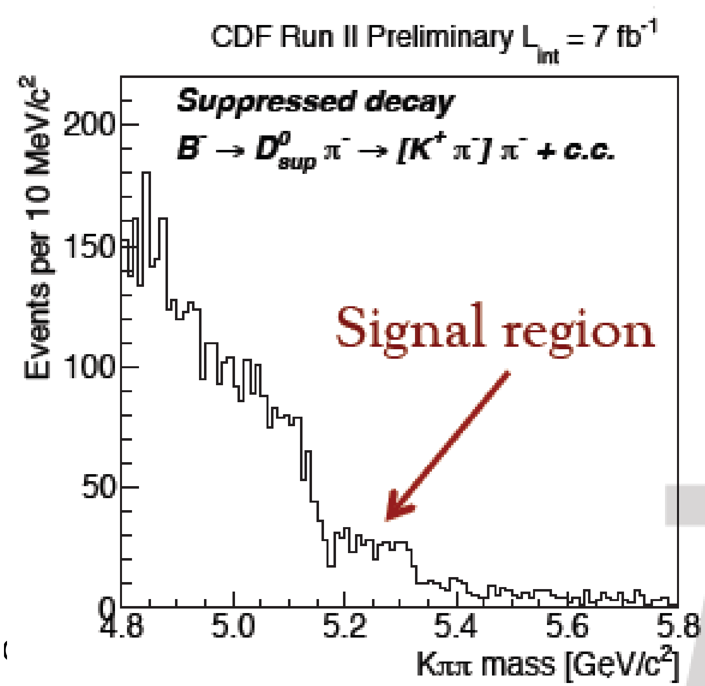
- Observables:

$$R_{ADS} = \frac{\mathcal{BR}(B^- \to [K^+\pi^-]_{D^0}K^-) + \mathcal{BR}(B^+ \to [K^-\pi^+]_{D^0}K^+)}{\mathcal{BR}(B^- \to [K^-\pi^+]_{D^0}K^-) + \mathcal{BR}(B^+ \to [K^+\pi^-]_{D^0}K^+)}$$

$$A_{ADS} = \frac{\mathcal{BR}(B^- \to [K^+\pi^-]_{D^0}K^-) - \mathcal{BR}(B^+ \to [K^-\pi^+]_{D^0}K^+)}{\mathcal{BR}(B^- \to [K^+\pi^-]_{D^0}K^-) + \mathcal{BR}(B^+ \to [K^-\pi^+]_{D^0}K^+)}$$

are related to angle γ:





use kinematics and PID to determine sample composition

CP Violation in B → DK Decays (CDF 7 fb^{-1})

Paola Garosi, Tue, Aug 11, CPV session

- First evidence of $B^- \to D^0_{suppressed} (\to K^+\pi^-) K^-$ at 3.2σ level

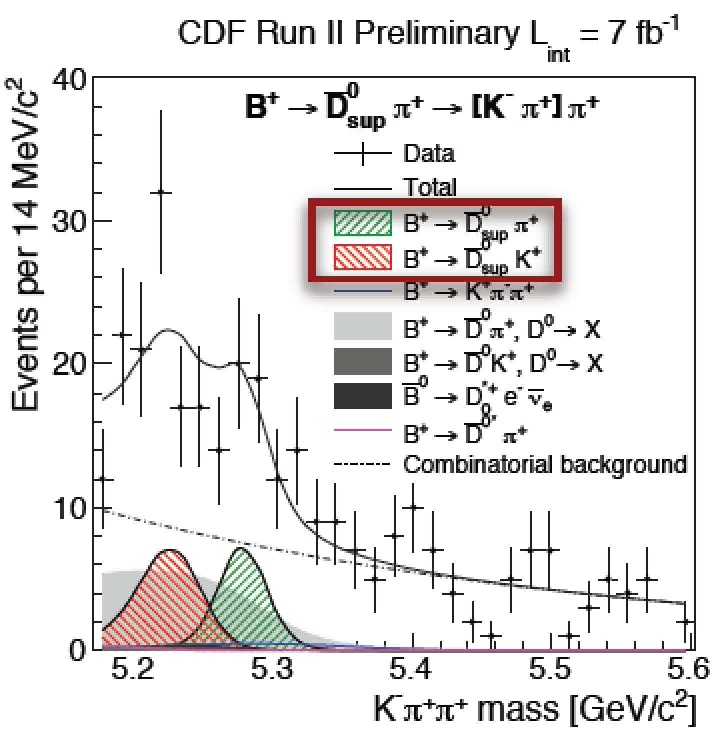
$$R_{ADS}(\pi) = [2.8 \pm 0.7(stat) \pm 0.4(syst)] \cdot 10^{-3}$$

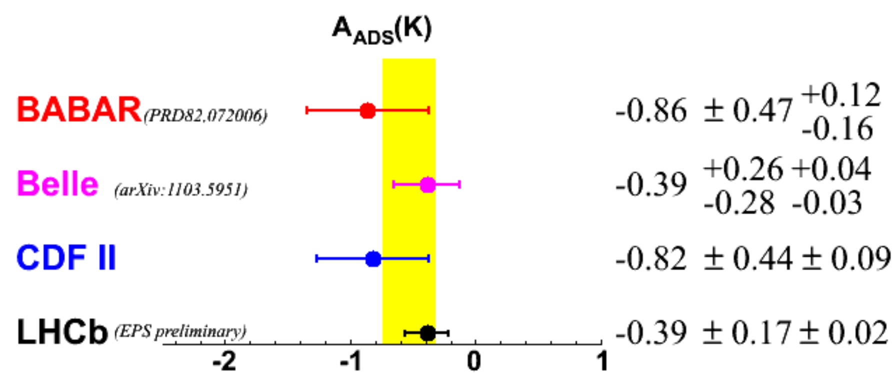
$$A_{ADS}(\pi) = 0.13 \pm 0.25(stat) \pm 0.02(syst)$$

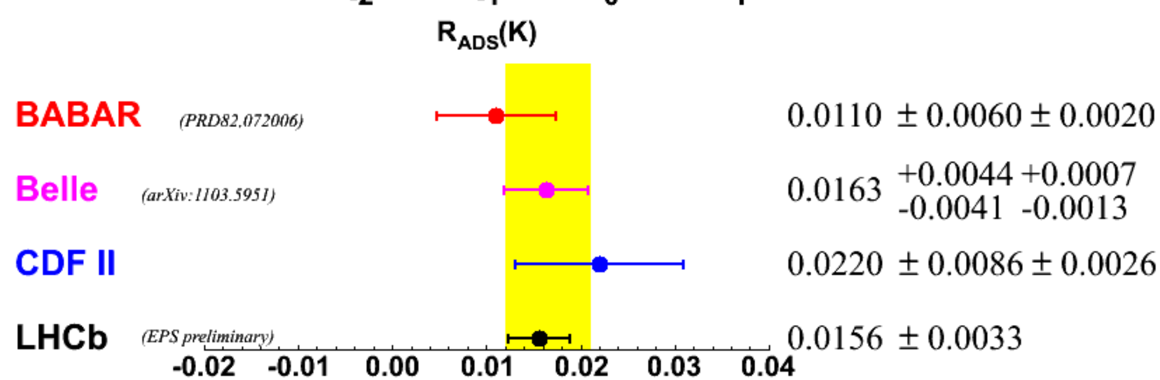
$$R_{ADS}(K) = [22.0 \pm 8.6(stat) \pm 2.6(syst)] \cdot 10^{-3}$$

$$A_{ADS}(K) = -0.82 \pm 0.44(stat) \pm 0.09(syst)$$

- CDF measurements compatible and competitive with B factories







Two Body Charmless B Decays (B → hh)

Ben Carls, Thu, Aug 11, HF session

- Important to improve knowledge of strong interactions dynamics

- Significant contribution from higher-order (penguin) transitions provides sensitivity to NP

- Sensitive to CKM angle γ

- Channels previously investigated at CDF:

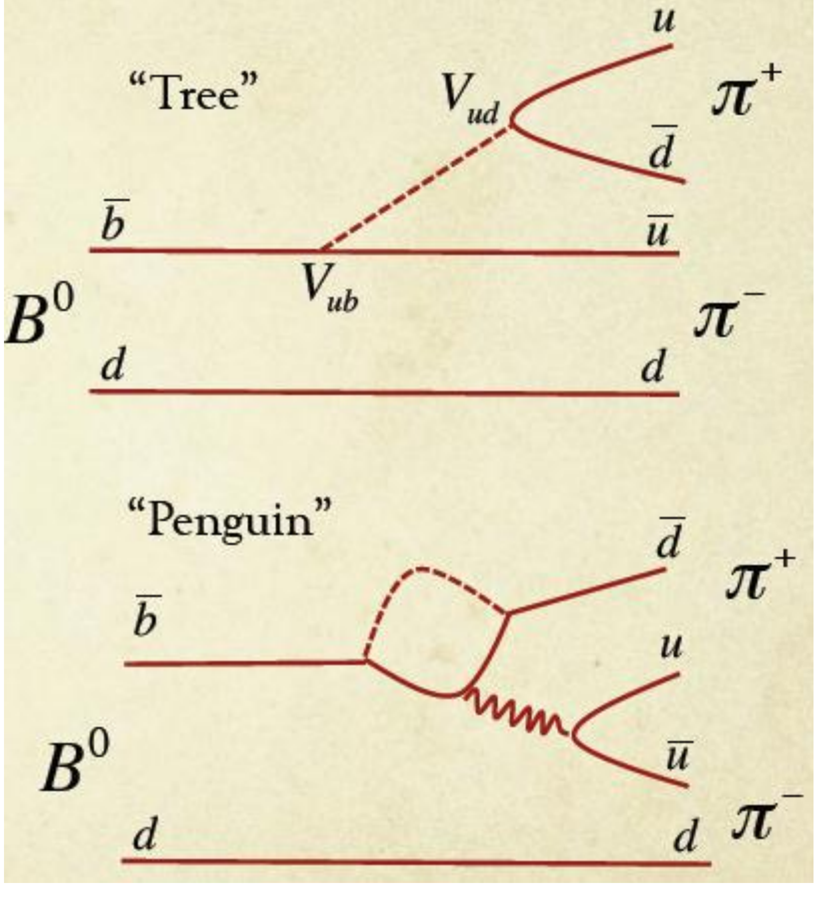
$B^0_s \to K^+K^-$, PRL 97, 211802 (2006)

$B^0_s \to K^-\pi^+$, $\Lambda^0_b \to p\pi^-$, $\Lambda^0_b \to pK^+$, PRL 103, 031801 (2009)

$A_{CP}(B^0_s \to K^-\pi^+)$, $A_{CP}(\Lambda^0_b \to p\pi^-)$, $A_{CP}(\Lambda^0_b \to pK^+)$
PRL 106, 181802 (2011)

- Most recent results from CDF:

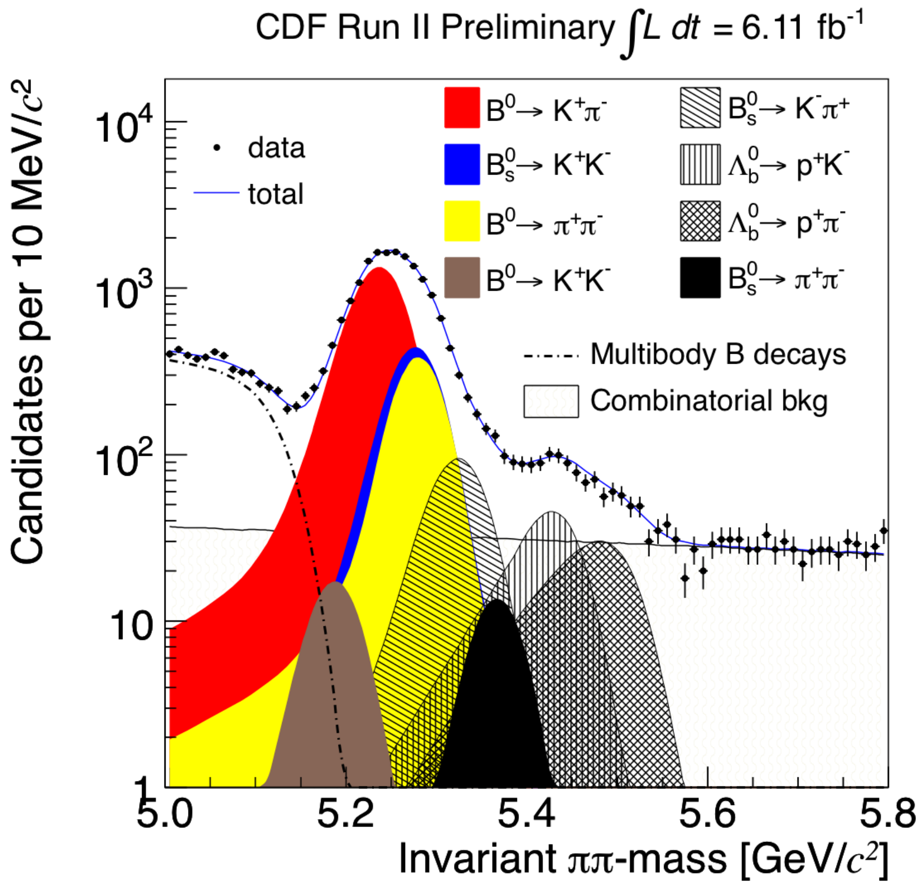
First evidence for $B^0_s \to \pi^+\pi^-$ and
bounds on $B^0 \to K^+K^-$



First Evidence of $B^0_s \to \pi^+\pi^-$ Decays (CDF 6.1 fb^{-1})

Ben Carls, Thu, Aug 11, HF session

- Events selected by trigger requiring two oppositely charged tracks displaced w.r.t. PV
- Both tracks are assigned pion mass
- Both kinematic and PID info used to separate decay modes
- $\pi^+\pi^-$ invariant mass distribution dominated by $B^0 \to K\pi$, $B^0 \to \pi\pi$
- Observe $B_s \to \pi\pi$ mode with 3.7σ significance
- Set two-sided 90% CL bounds on BR($B^0 \to K^+K^-$)



Mode	N_s	Significance
$B^0 \to K^+K^-$	$120 \pm 49 \pm 42$	2.0σ
$B^0_s \to \pi^+\pi^-$	$94 \pm 28 \pm 11$	3.7σ

CDF Note 10498

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}$ (10^{-6})	Limit (10^{-6})
$B^0 \to K^+K^-$	$\frac{\mathcal{B}(B^0 \to K^-K^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.012 \pm 0.005 \pm 0.005$	$0.23 \pm 0.10 \pm 0.10$	$[0.05, 0.46]$ at 90% C.L.
$B^0_s \to \pi^+\pi^-$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B^0_s \to \pi^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.008 \pm 0.002 \pm 0.001$	$0.57 \pm 0.15 \pm 0.10$	–

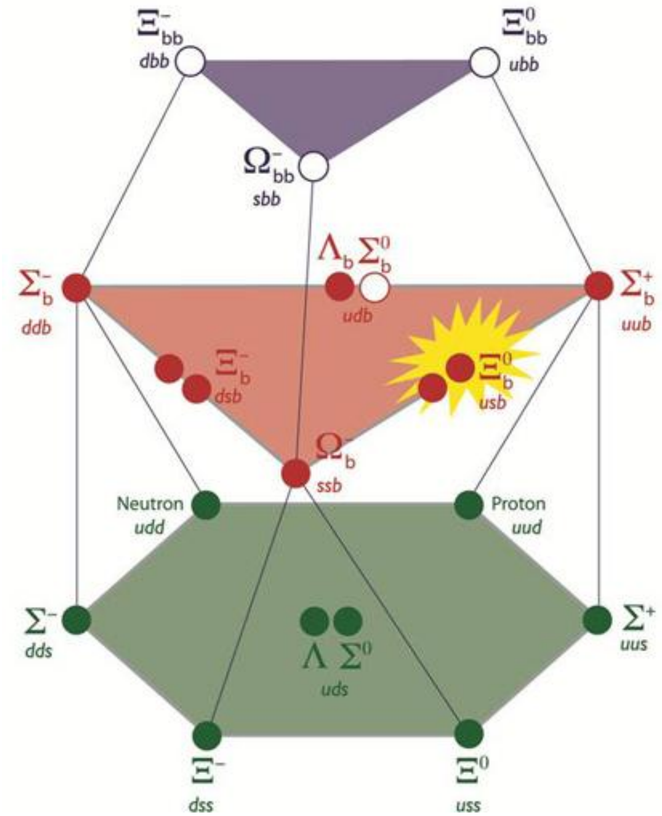
Ξ^0_b (CDF 4.2 fb^{-1})

- b-baryons states previously observed at Tevatron:
  Ξ^-_b(dsb), Σ_b (uud, ddb), Ω_b(ssb)

- Ξ^0_b (usb), recently observed by CDF

- Important to keep checking quark model and measure masses of states to compare to theory
  (E. Jenkins, P.R. D77 (2008) 034012, R. Lewis and R.M. Woloshyn, P.R. D79 (2009) 014502, D. Ebert et al., P.R. D72 (2005) 034026, M. Karliner et al., Ann. Phys. (NY) 324 (2009) 2, A. Valcarce et al., Eur. Phys. J. A37 (2008) 217)

- Decay modes observed for the first time



$$\Xi^0_b \rightarrow \Xi^+_c \, \pi^-$$

$$\Xi^+_c \rightarrow \Xi^- \pi^+ \pi^+, \; \Xi^- \rightarrow \Lambda \, \pi^-, \text{ and } \Lambda \rightarrow p \, \pi^-$$

$$\Xi^-_b \rightarrow \Xi^0_c \, \pi^-$$ (Ξ^-_b observed before, but not in this decay mode; use as cross check)

$$\Xi^0_c \rightarrow \Xi^- \pi^+, \; \Xi^- \rightarrow \Lambda \, \pi^-, \text{ and } \Lambda \rightarrow p \, \pi^-$$

Observation of Ξ_b (CDF 4.2 fb^{-1})

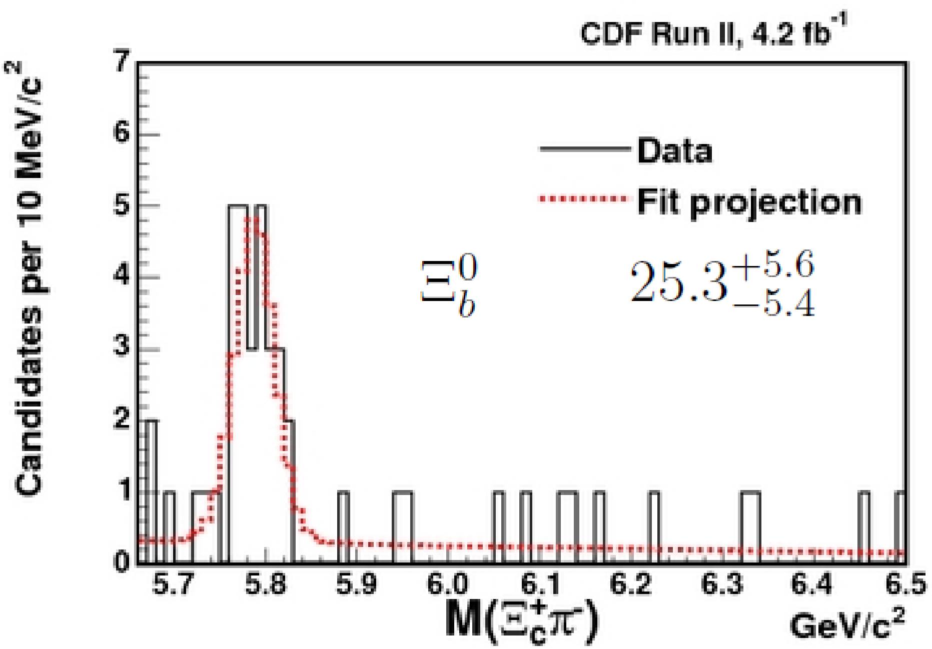
- Measured Ξ^-_b mass: $5796.7 \pm 5.1(\mathrm{stat}) \pm 1.4(\mathrm{syst})\ \mathrm{MeV}/c^2$ in good agreement with earlier best measurement in $J/\psi\,\Xi^-$ final state: $5790.9 \pm 2.6(\mathrm{stat}) \pm 0.8(\mathrm{syst})\ \mathrm{MeV}/c^2$

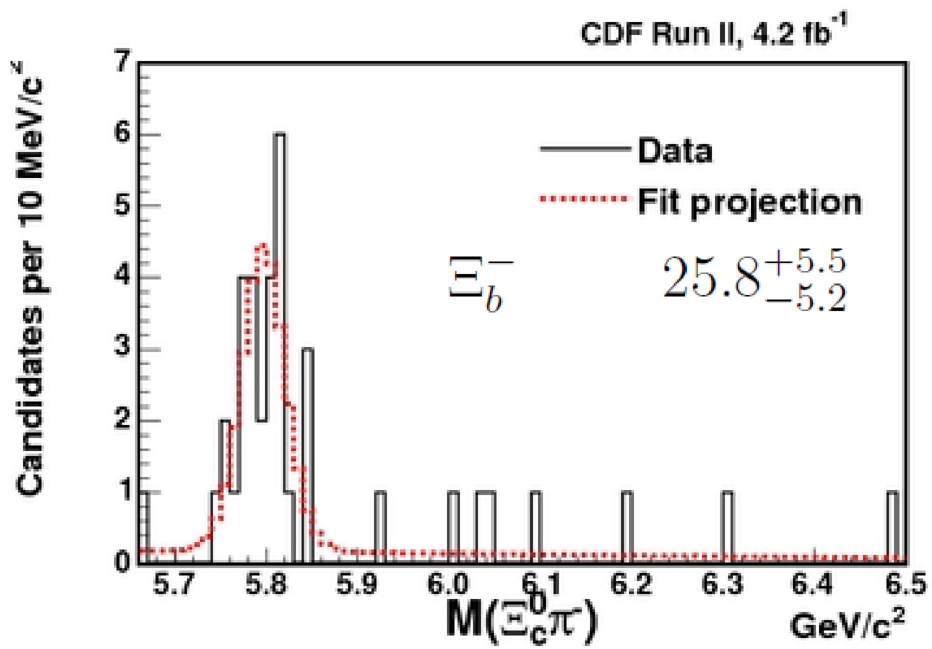
- First measurement of Ξ^0_b mass : $5787.8 \pm 5.0(\mathrm{stat}) \pm 1.3(\mathrm{syst})\ \mathrm{MeV}/c^2$

- Largest systematics from mass resolution (1 MeV) and momentum scale (0.5 MeV)

- Significance of each peaks > 6.8σ

- Mass difference $M(\Xi_b^-) - M(\Xi_b^0) = 3.1 \pm 5.6(\mathrm{stat}) \pm 1.3(\mathrm{syst})\ \mathrm{MeV}/c^2$





Conclusions

- D0 and CDF continuing to produce a rich and exciting program in heavy flavor physics
  - interesting effects in same-sign di-muon asymmetry and $B_s \rightarrow \mu\mu$
  - best measurements of mixing B_s phase β_s / Φ_s

- Exciting competition with LHCb and complementary to e^+e^- machines

- Many interesting results will benefit from more data.
  - anticipate ~10 fb^{-1} for analysis by the end of this year.

- Results will continue beyond the end of the Run

- Topics not covered: http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
  http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm
  - First measurement of B_c lifetime in fully-reconstructed $J/\Psi\pi$ decays, CDF, **New for DPF,**
    see talk by William Wester, Thu, Aug 11, HF session
  - Production fraction times branching fraction $f(b \rightarrow \Lambda_b)*BR(\Lambda_b \rightarrow J/\Psi\Lambda)$, D0, arXiv:1105.0690,
    see talk by Ivan Heredia Fri, Aug 12, HF session
  - Measurement of the time-integrated mixing probability of B mesons (CDF note 10335)
  - Measurement of time-integrated CP violation in $D^0 \rightarrow h^+h^-$ decays (CDF note 10296)
  - Observation of Y(4140) in the $J/\Psi\Phi$ Mass Spectrum in $B^+ \rightarrow J/\psi\, \Phi\, K^+$ (CDF note 10244)
  - Measurement of the resonance properties of $\Sigma_b^{(*)}$ baryons (CDF note 10286)
  - Measurement of the resonance properties of charm baryons
  - Observation of the $B_s \rightarrow J/\psi K_s$ and $B_s \rightarrow J/\psi K^*$ decays (CDF, Phys. Rev. D83, 052012 (2011))
  - Upsilon Polarization, CDF, see talk by Niharika Ranjan, Tue, Aug 9, HF session

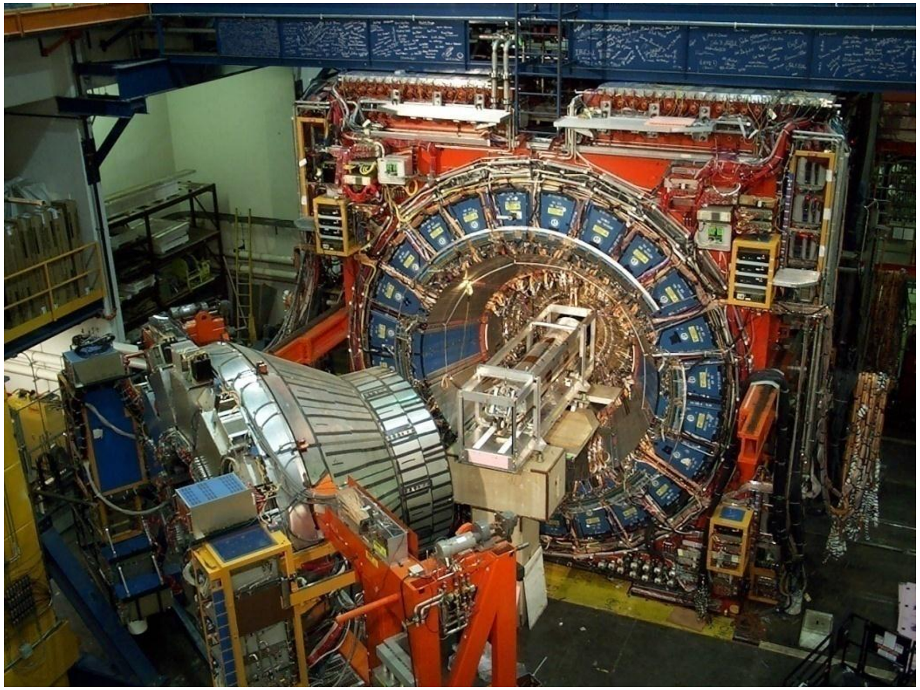
CDF II Detector

- Central tracking: - silicon vertex detector
  - drift chamber

$\delta p_T/p_T = 0.0015\, p_T$

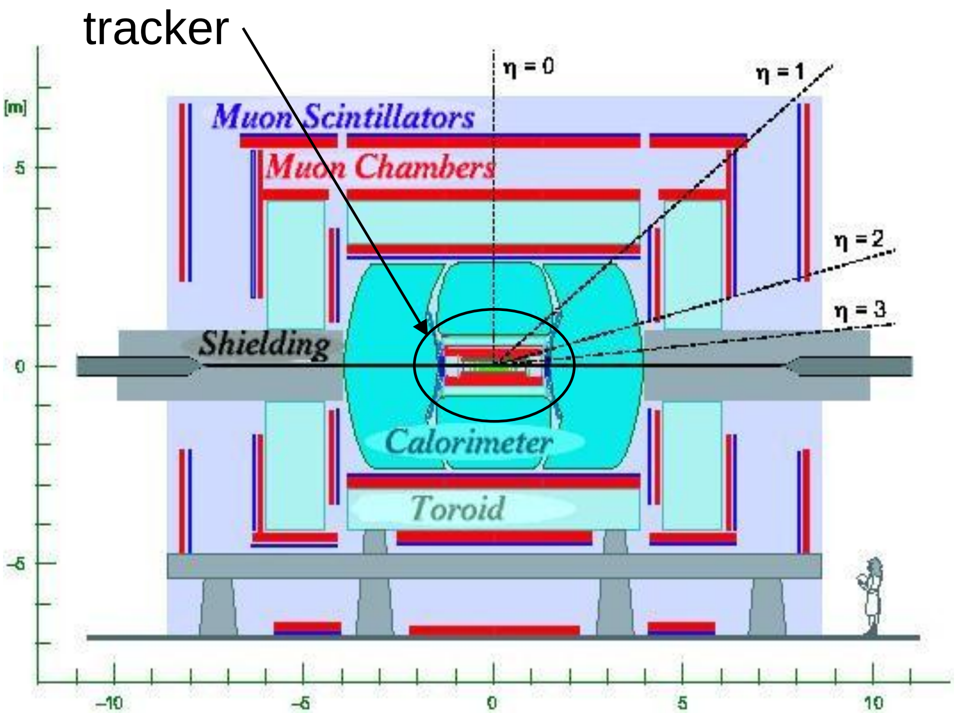
$\rightarrow$ excellent mass resolution

- Particle identification: dE/dX and TOF
- Good electron and muon ID by calorimeters and muon chambers



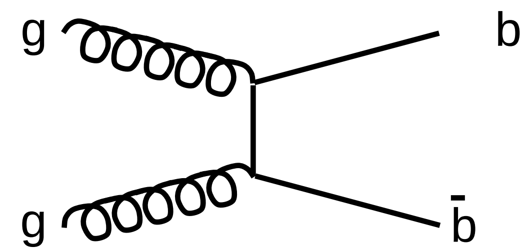
DØ Detector

- Excellent tracking and muon coverage
- Excellent calorimetry and electron ID
- 2 Tesla solenoid, polarity reversed weekly
  $\rightarrow$ good control of charge asymmetry systematic effects
- Silicon layer 0 installed in 2006 improves track parameter resolution

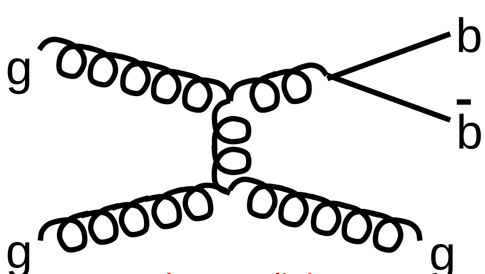


B Physics at the Tevatron

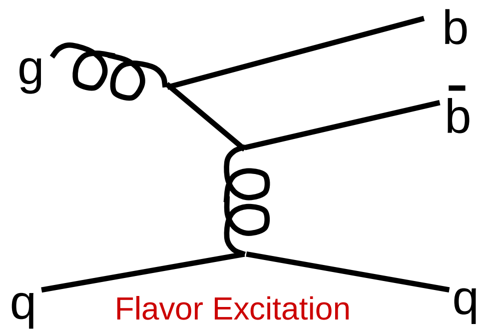
- Mechanisms for b production in $p\bar{p}$ collisions at 1.96 TeV



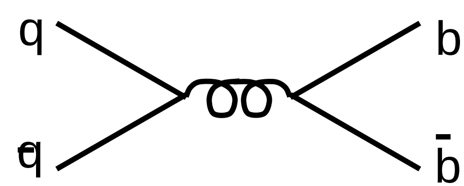
Flavor Creation (gluon fusion)



Gluon Splitting



Flavor Excitation



Flavor Creation (annihilation)

- At Tevatron, b production cross section is much larger compared to B-factories
  → Tevatron experiments CDF and DØ enjoy rich B Physics program

- Plethora of states accessible only at Tevatron: B_s, B_c, 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

B_s $(B^0) \rightarrow \mu\mu$ Analysis Improvements (CDF 7 fb^{-1})

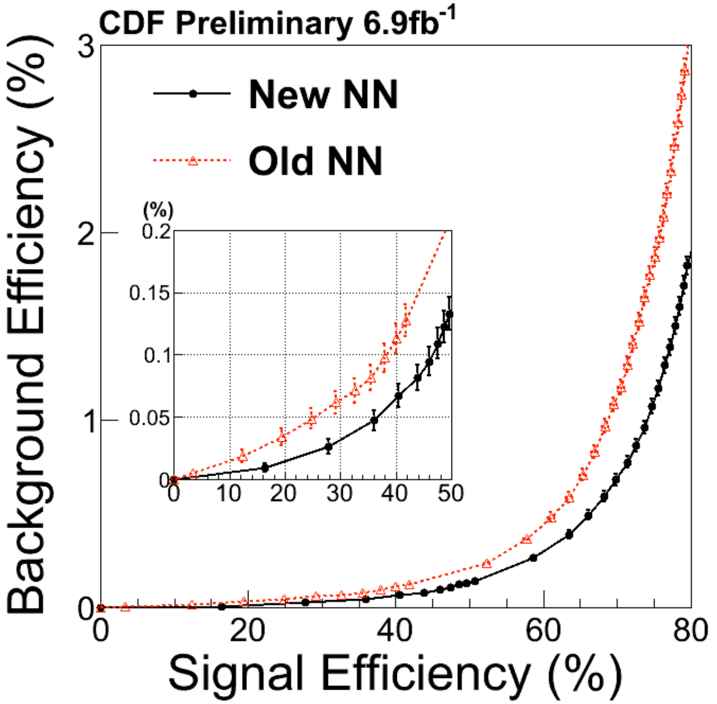
Kevin Pitts (CDF), Friday Aug 12, HF session

-With respect to previous analysis

- 50% more data (7/fb)

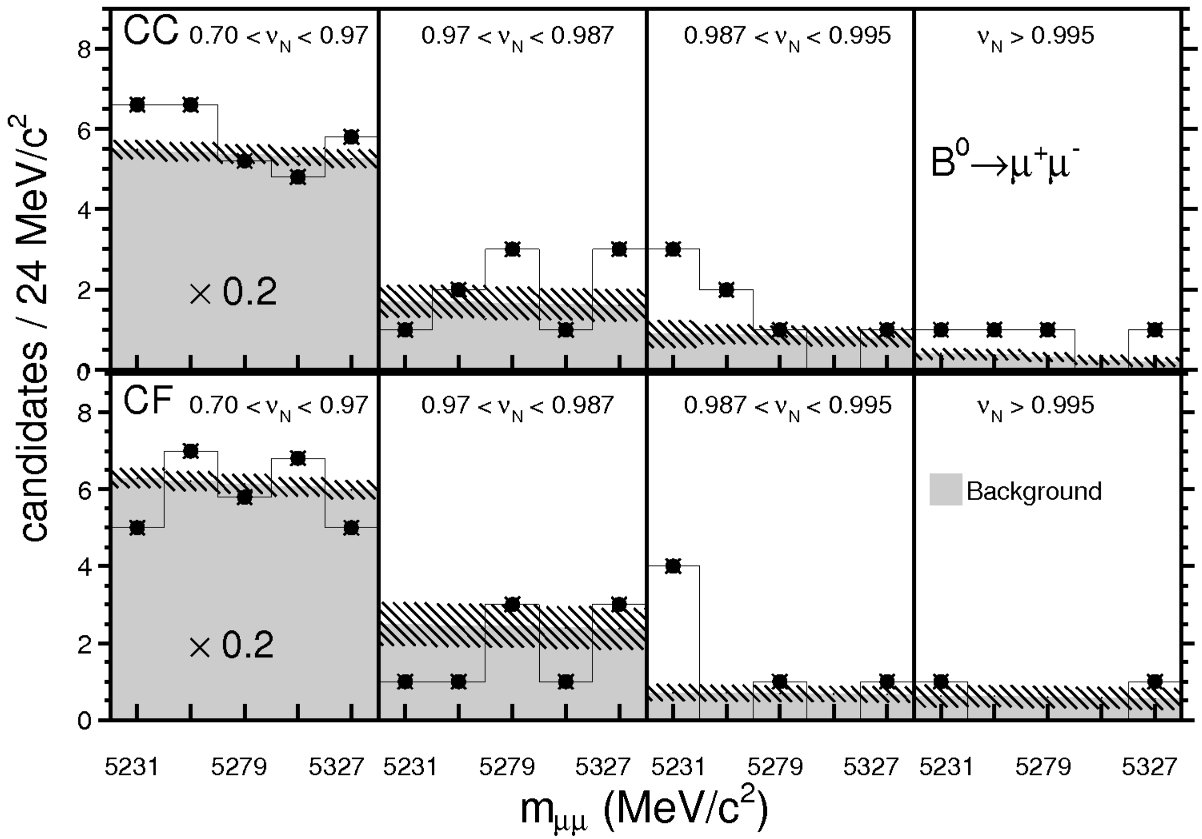
- 20% increase in muon acceptance from
    - including forward muons
    - improved tracking acceptance

- Improved NN signal selection
    - twice background rejection for same signal efficiency



$B^0 \rightarrow \mu\, \mu$ (CDF 7 fb^{-1})

Kevin Pitts (CDF), Friday, Aug 12, HF session



- In background only hypothesis, data p-value is 23%

$BR(B^0 \rightarrow \mu\mu) < 6 \times 10^{-9}$ @95%CL

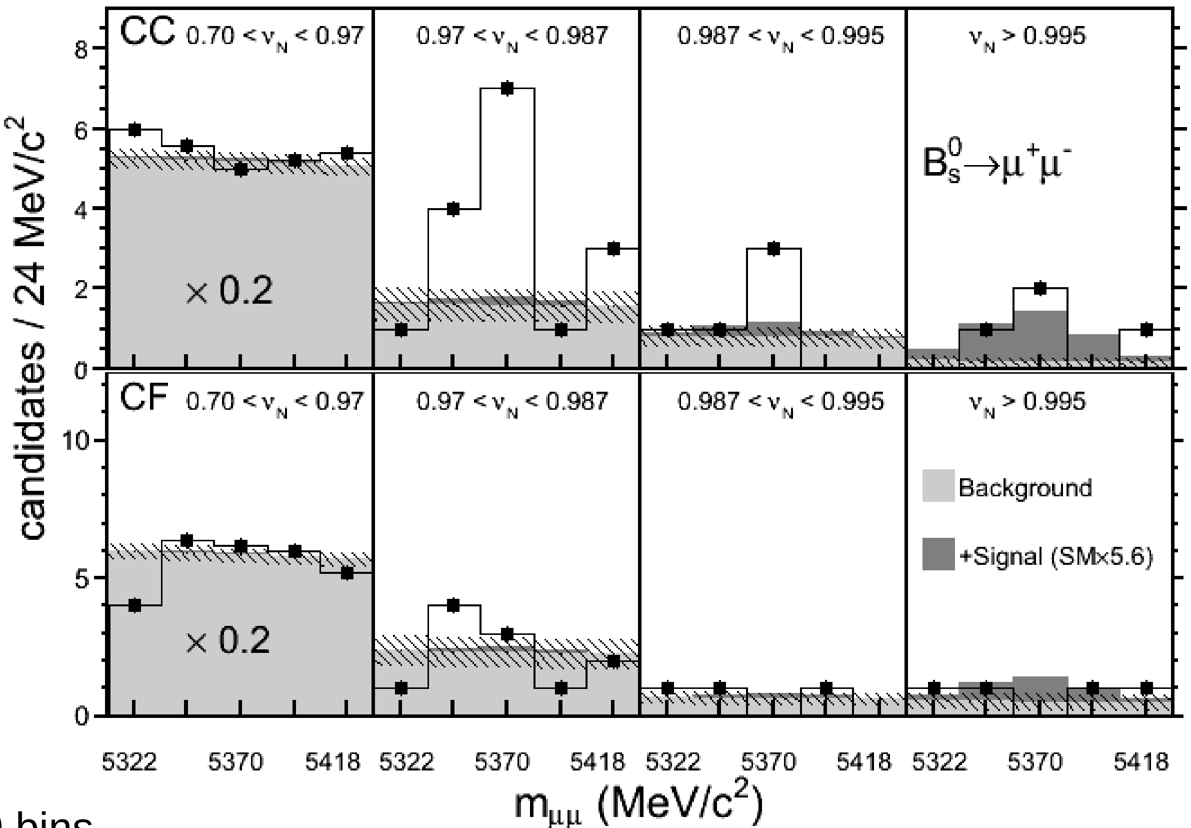
- expected *4.6×10^{-9}*
- theory *$(0.1 \pm 0.01) \times 10^{-9}$*

$B_s \rightarrow \mu\,\mu$ Cross checks (CDF 7 fb^{-1})

Kevin Pitts (CDF), Friday, Aug 12, HF session

- p-values for highest two NN bins:
  - background-only: 0.66%
  - background + SM: 4.1%

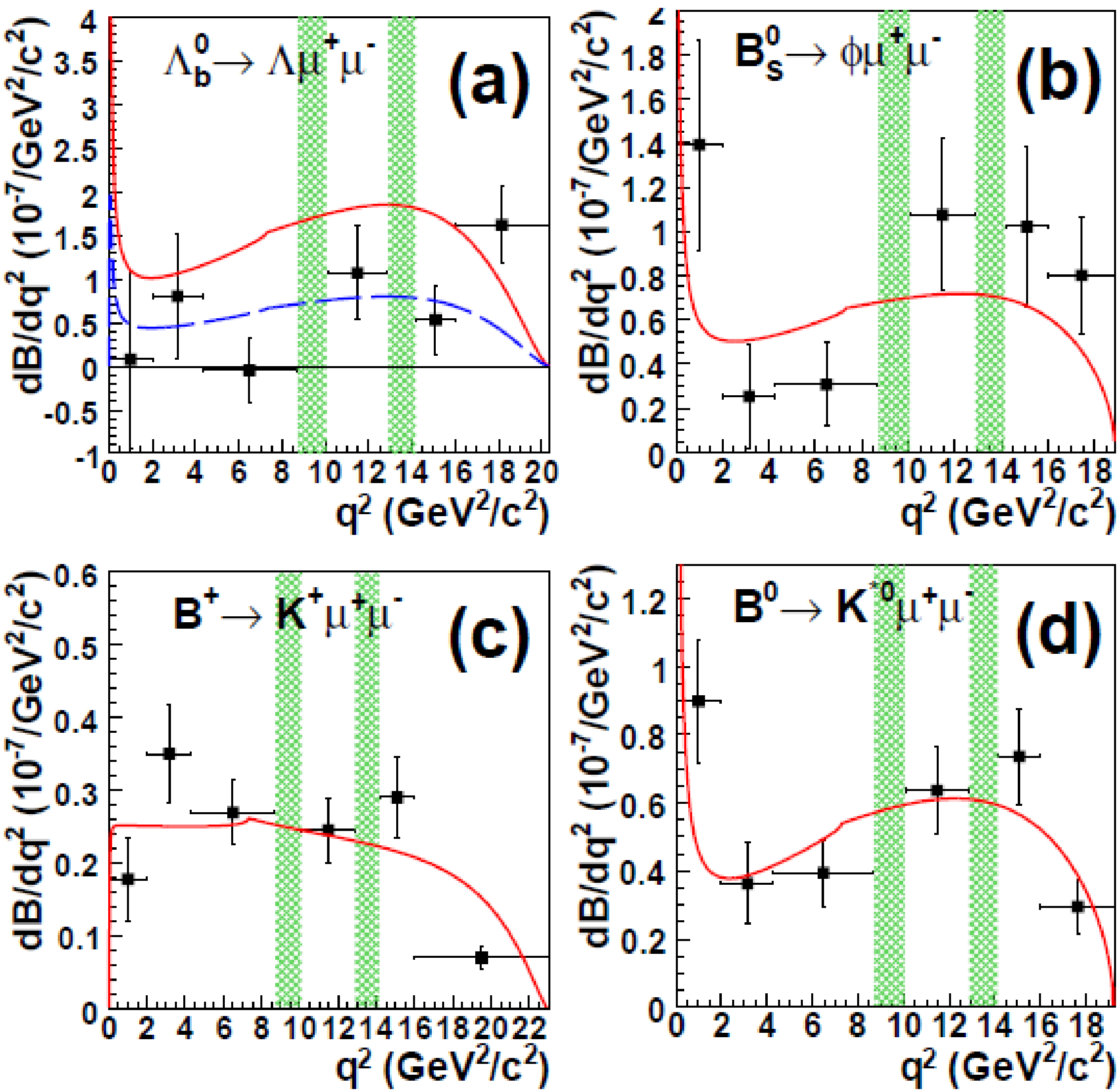
- Reason for excess in 3rd highest NN bin of CC sample?
  - Peaking background, B→hh ?
    Not seen in B^0
  - Combinatorial background ?
    No NN bias observed, nothing seen in B^0
  - Statistical fluctuation ?
    Possible in one out of 80 bins



$b \to s\mu\mu$ differential BR (CDF 6.8 fb^{-1})

Austin Napier, Wed, Aug 10, HF session

- BR as function of $\mu\mu$ squared invariant mass (q^2) in good agreement with theory (red curves):

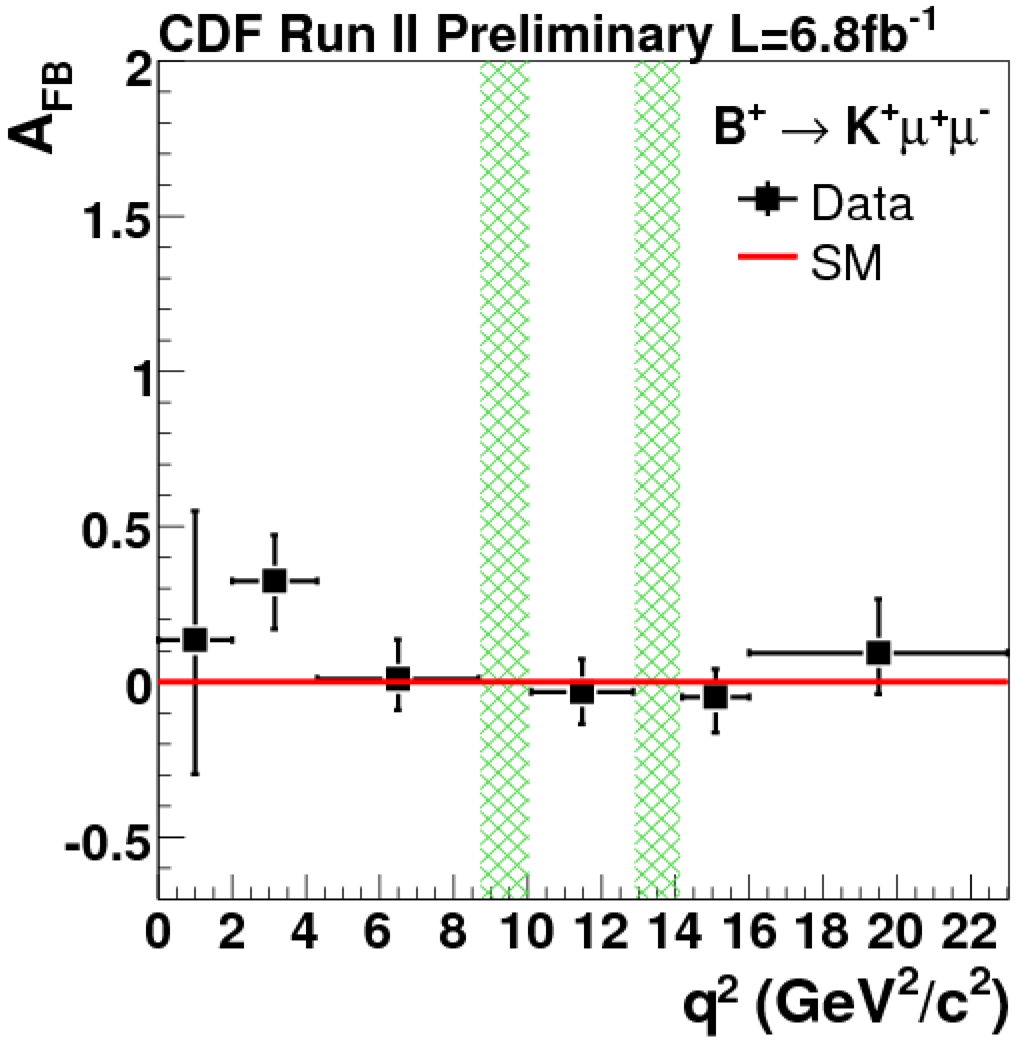


Phys. Rev. D **81**,056006 (2010).
Phys. Rev. D **61**, 074024 (2000).
Phys. Rev. D **71**, 014015 (2005);
Phys. Rev. D **71**, 014029 (2005).

- For Λ_b :

  - Red curve = SM prediction based on BR = 4 x 10^{-6} T. M. Aliev, K. Azizi, and M. Savci, PRD81, 056006 (2010)

  - Blue curve = SM rescaled to CDF measurement (1.73 x 10^{-6})

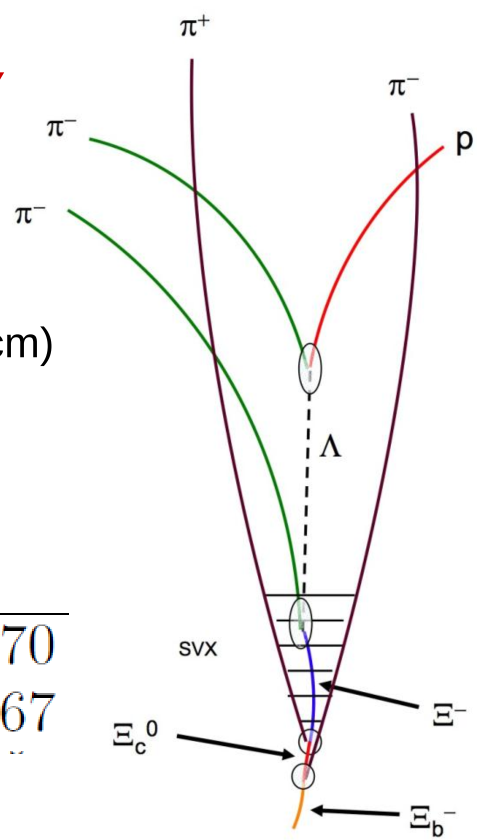


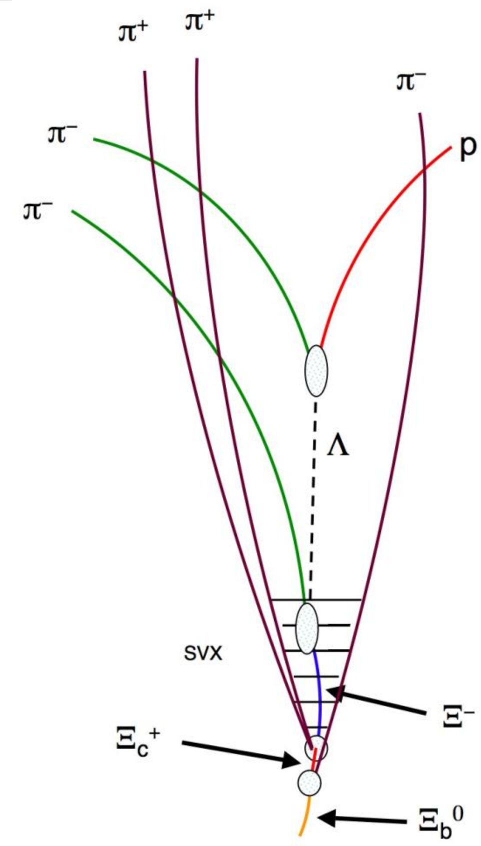
CDF Run II Preliminary L=6.8fb^{-1}
A_{FB}
$B^+ \rightarrow K^+\mu^+\mu^-$
Data
SM
2
1.5
1
0.5
0
-0.5
0 2 4 6 8 10 12 14 16 18 20 22
q^2 (GeV^2/c^2)

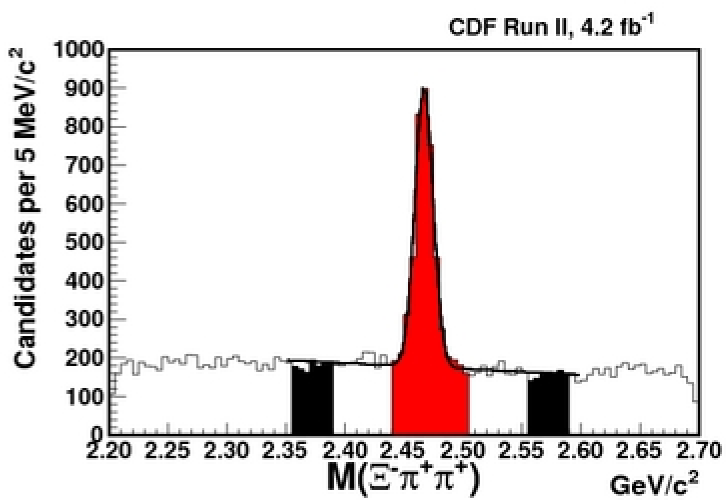
Event Topology

- Long lived Ξ^- ($c\tau$ = 4.9 cm) tracked through the silicon detector

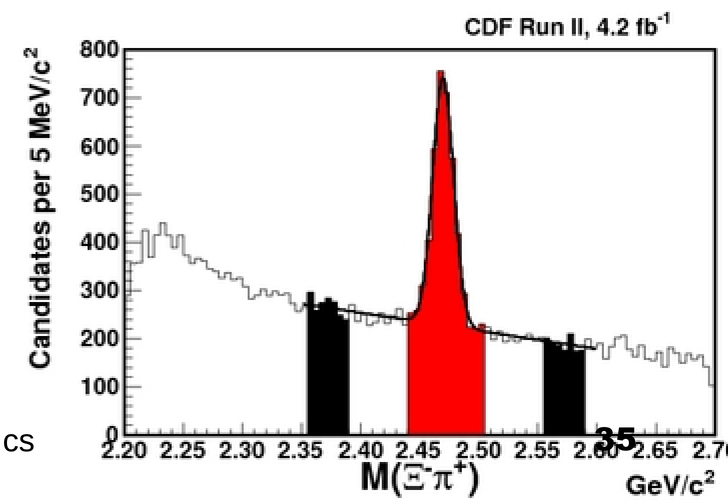
Resonance	Yield
Ξ_c^0	2110 ± 70
Ξ_c^+	3048 ± 67







cs



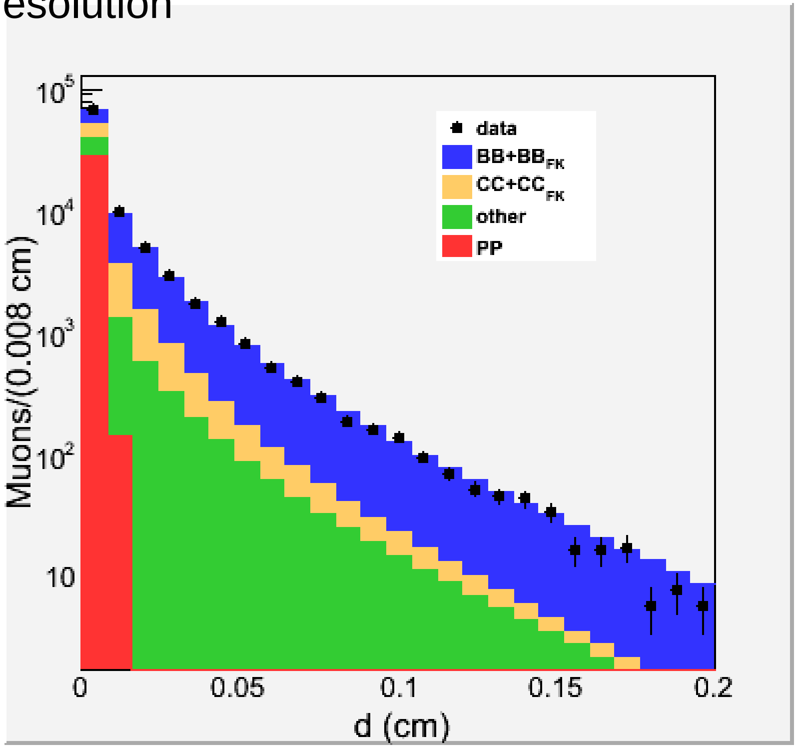
Integrated Mixing Probability of B Mesons (CDF 1.5 fb^{-1})

CDF Note 10335

- Use di-m*uon* sample which contains double semi-leptonic decays of *b* and anti-*b* hadrons

- Determine sample composition (bottom, charm, prompt…) by fitting impact parameter of di-muons with pre-determined templates (b, c from simulation, prompt from data)

- Muons reconstructed in silicon tracker for good IP resolution



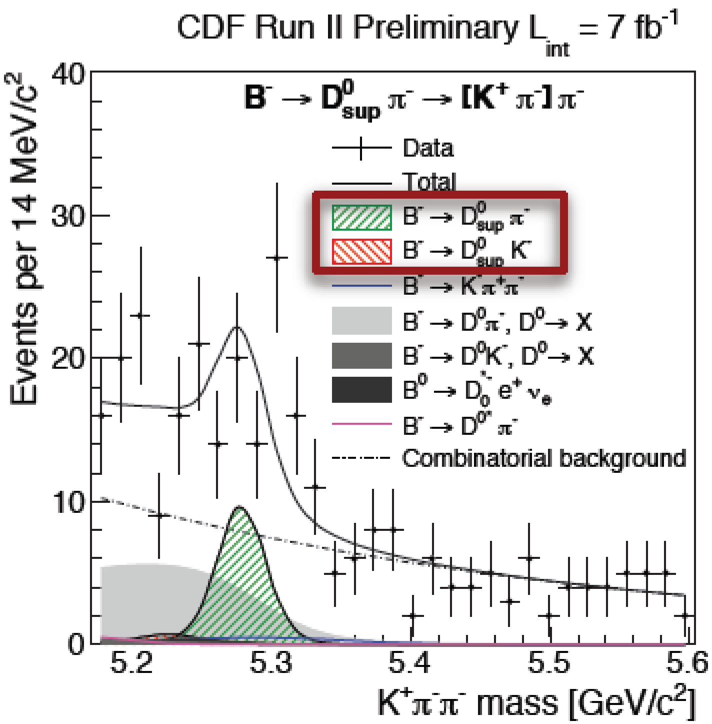
- Observed ratio of *same-sign* to *opposite-sign* di-muons leads to measurement of average time-integrated mixing probability of the mixture of *b*-flavored hadrons which decay semi-leptonically,

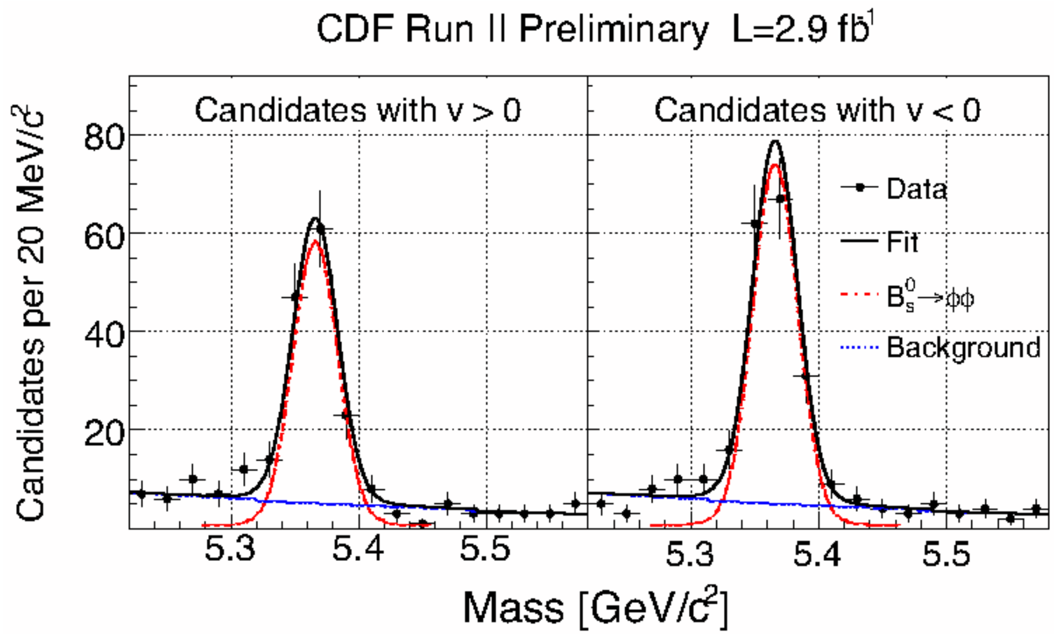
$\bar{\chi} = 0.126 \pm 0.008$, CDF Note 10335

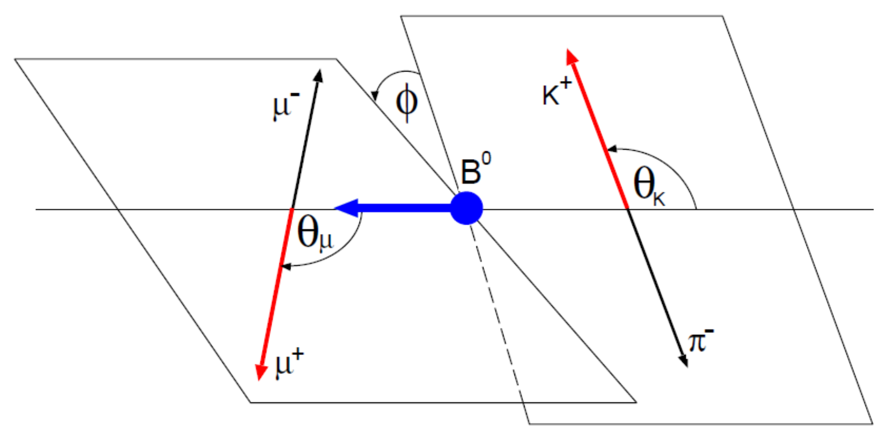
that is consistent with the average LEP value

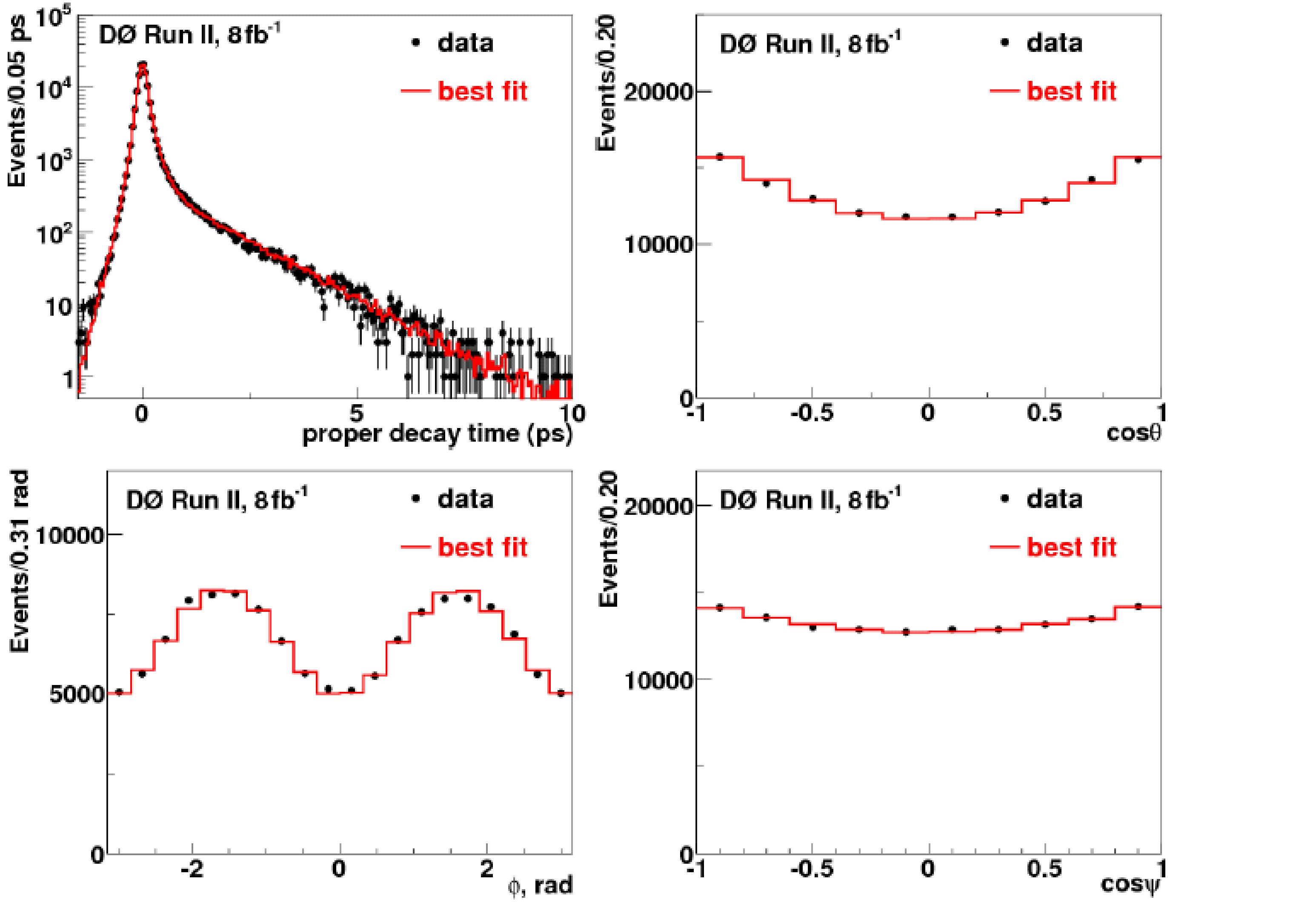
$\bar{\chi} = 0.1259 \pm 0.0042$

- Next step: measure A_{sl}


CDF Run II Preliminary L_int = 7 fb^-1
B^- → D^0_sup π^- → [K^+ π^-] π^-
Data
Total
B^- → D^0_sup π^-
B^- → D^0_sup K^-
B^- → K^-π^+π^-
B^- → D^0π^-, D^0→ X
B^- → D^0K^-, D^0→ X
B^0 → D_0^*- e^+ ν_e
B^- → D^0* π^-
Combinatorial background
Events per 14 MeV/c^2
K^+π^-π^- mass [GeV/c^2]
0
10
20
30
40
5.2
5.3
5.4
5.5
5.6


CDF Run II Preliminary L=2.9 fb^-1
Candidates with v > 0
Candidates with v < 0
Data
Fit
B^0_s→φφ
Background
Candidates per 20 MeV/c^2
Mass [GeV/c^2]
20
40
60
80
5.3
5.4
5.5


μ^-
μ^+
φ
B^0
K^+
π^-
θ_μ
θ_K


DØ Run II, 8 fb⁻¹
data
best fit
Events/0.05 ps
proper decay time (ps)
Events/0.20
cosθ
Events/0.31 rad
φ, rad
cosψ