Recent Heavy Flavor Physics Results from the Tevatron

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on behalf of CDF & D0 Collaboration

Moriond QCD and High Energy Interactions
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Introduction and Outline

- CDF and D0 experiments: about 10 fb^{-1} on tape each

- Recent results on full statistics:
  - ✔ Spectroscopy: new b- and c-hadrons, excited B mesons

    Mass and lifetime measurements of bottom and charm baryons in $p\bar{p}$ collisions at sqrt(s) 1.96 TeV PRD 89, 072014 (2014)

    Study of orbitally excited B mesons and evidence for a new Bp resonance PRD 90, 012013 (2014)
  - ✔ Bs lifetime in flavor specific decay

    Measurements of Bs lifetime in the Flavor specific decay channel accepted PRL
  - ✔ CP Violation: B meson and Charm system
  - ✔ Forward-Backward asymmetries (B, Λ_b, $b\bar{b}$)

In this talk

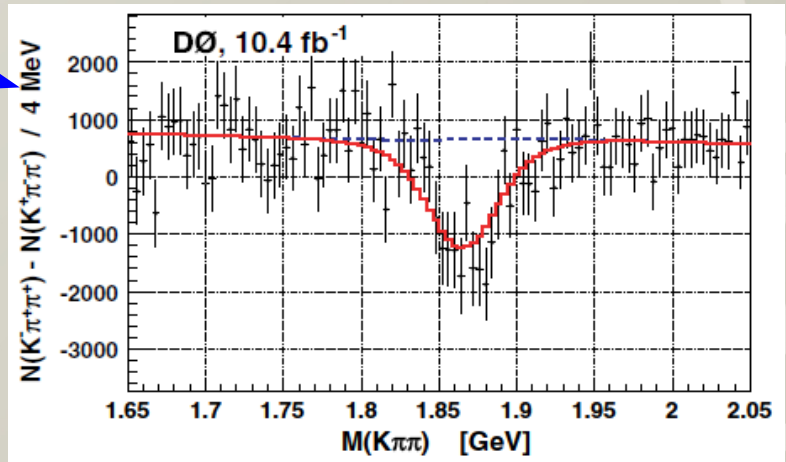
CP Violation in Charm decay

- Direct CPV
  - Different decay amplitude for $D \to f$ and $\overline{D} \to \overline{f}$
- Indirect CPV
  - Difference in mixing probabilities for charm and anti-charm
  - Interference between direct decay and decay proceeding via mixing

Sensitive probes to New Physics

- Direct CP violation using $D^+ \to k^-\pi^+\pi^+$ and $D^- \to k^+\pi^-\pi^-$

$$A_{CP} = \frac{\Gamma(D^+ \to K^-\pi^+\pi^+) - \Gamma(D^- \to K^+\pi^-\pi^-)}{\Gamma(D^+ \to K^-\pi^+\pi^+) + \Gamma(D^- \to K^+\pi^-\pi^-)}$$



- SM: $A_{CP} \sim 0 \to$ any deviation means NP

$$A_{CP} = -0.16 \pm 0.15(\text{stat}) \pm 0.09(\text{syst})$$

CP Violation in Charm decay

$D^0 \to \pi^+\pi^-$ $D^0 \to k^+k^-$ D^0 from $D^{*+/-}$ to tag D^0 flavor

sample mean decay time

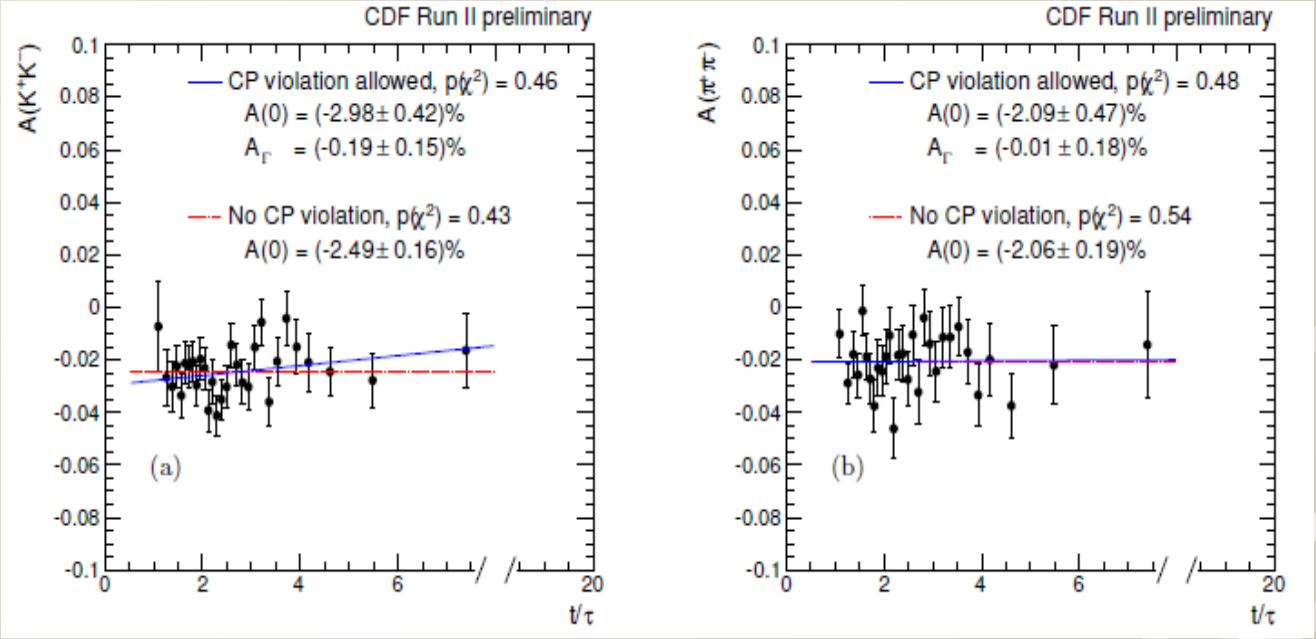
$$\mathcal{A}_{CP}(t) = \frac{d\Gamma(D^0 \to h^+h^-)/dt - d\Gamma(\overline{D}^0 \to h^+h^-)/dt}{d\Gamma(D^0 \to h^+h^-)/dt + d\Gamma(\overline{D}^0 \to h^+h^-)/dt} \xRightarrow{\text{slow mixing}} \mathcal{A}_{CP}(t) \approx \mathcal{A}_{CP}^{\rm dir}(h^+h^-) - \frac{\langle t \rangle}{\tau} A_\Gamma(h^+h^-)$$

- ✔ D^0 IP used to separate $B \to D^*x$ from prompt D^*
- ✔ Evaluated A_{CP} in bins of $\langle t \rangle/\tau$ of prompt signals.

$A(0)$ = intercept

$A_{CP}^{dir} + A^{det}$

A_Γ = slope



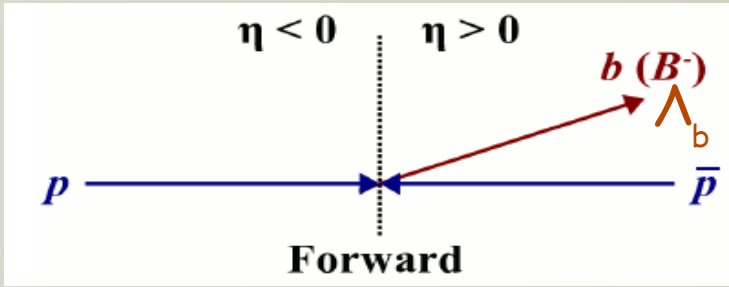
$$A_\Gamma(\pi^+\pi^-) = (-0.1 \pm 1.8\ (\text{stat}) \pm 0.3\ (\text{syst})) \times 10^{-3}$$
$$A_\Gamma(K^+K^-) = (-1.9 \pm 1.5\ (\text{stat}) \pm 0.4\ (\text{syst})) \times 10^{-3}$$

Combined $A_\Gamma = (-1.2 \pm 1.2) \times 10^{-3}$

b-hadron Forward-Backward Asymmetries: Introduction

- Production mechanism dominated by gluon-gluon fusion → no A_{FB}
- A_{FB} receives contribution in $q\bar{q}$ and qg interactions from interference:
  - initial and final-state radiative gluon diagrams
  - box diagram with Born one
  - different amplitudes in flavor excitation
  - electro-weak process ($q\bar{q} \rightarrow Z/\gamma \rightarrow b\bar{b}$)
- A_{FB} depends on $m(b\bar{b})$

In $p\bar{p}$ collisions $F=b,B^-,\Lambda_b$ ($\bar{b},B^+,\bar{\Lambda}_b$) following p ($\bar{p}$) direction



D0:

A_{FB} using fully reconstructed B meson and Λ_b

CDF:

A_{FB} with $b\bar{b}$ jets in low and high mass

A_{FB} with fully reconstructed B meson

Reconstruct $B^{\pm} \to J/\Psi K^{\pm}$ $J/\Psi \to \mu^+\mu^-$ K= track, no PID

$$A_{FB}(B^{\pm}) = \frac{N(-q_B\eta_B > 0) - N(-q_B\eta_B < 0)}{N(-q_B\eta_B > 0) + N(-q_B\eta_B < 0)}$$

q_B = B charge

η_B = B pseudo rapidity

reject event with $|\eta_B|<0.1$

Correct for reconstruction asymmetries by weighting events

Maximum Likelihood fit:

4 components each with event fraction, f_i, and asymmetry, A_i

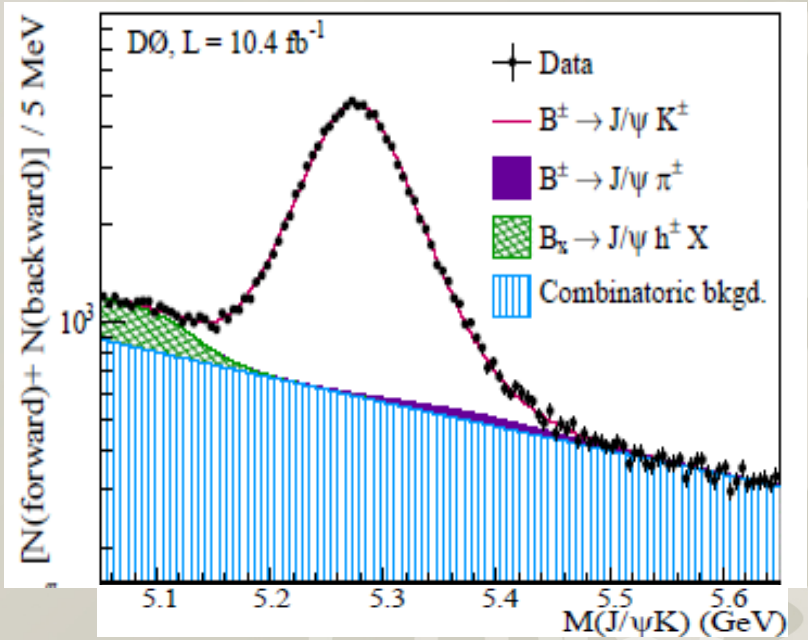
$$\mathcal{L}_n = \alpha(E_K)[f_S(1+q_{FB}A_S)S + f_P(1+q_{FB}A_P)P + f_T(1+q_{FB}A_T)T] + f_E(1+q_{FB}A_E)E,$$

Signal: $B^{\pm} \to J/\Psi K^{\pm}$ double Gaussian

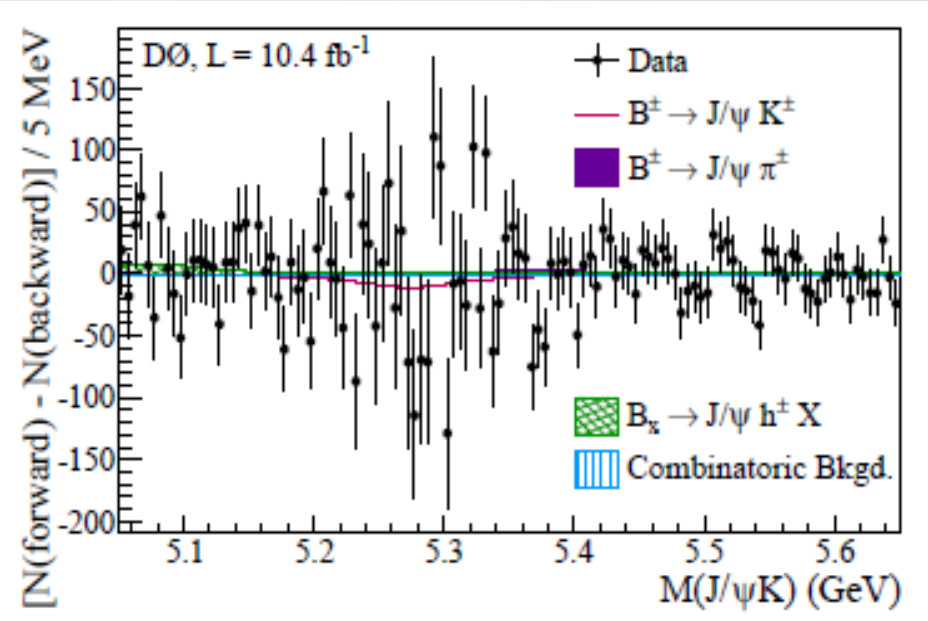
Pion: $B^{\pm} \to J/\Psi \pi^{\pm}$ shifted double Gaussian

Threshold: partial B reconstruction

Exponential: combinatorial background



A_{FB} with fully reconstructed B meson: Result

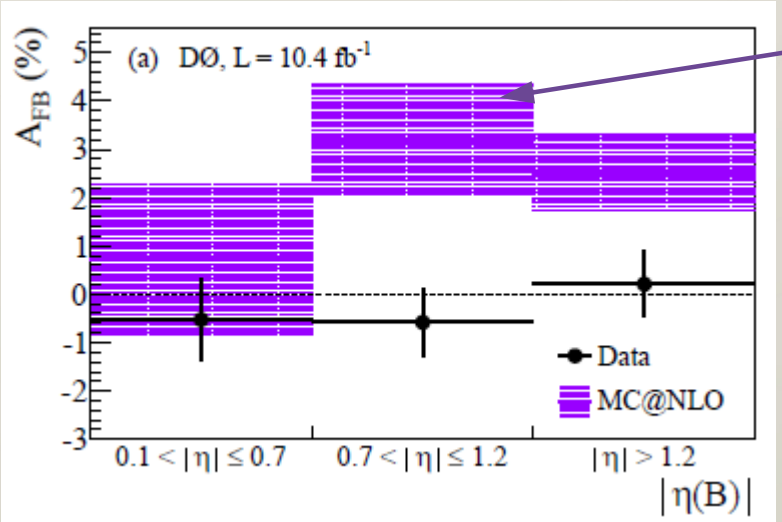


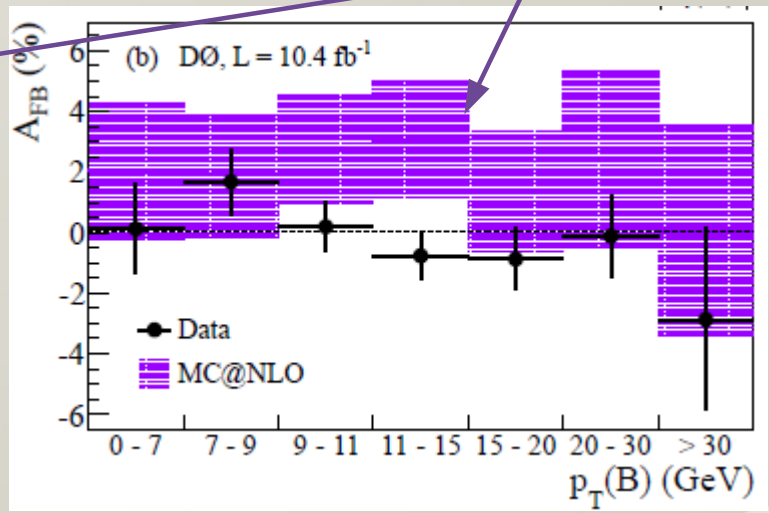
89328 signal ev./160360 cand.

χ^2 / d.o.f = 249 / 214

$A_{FB}(B^{\pm}) = [-0.24 \pm 0.41(stat) \pm 0.19(syst)]\%$

Renomarlization and factorization scale



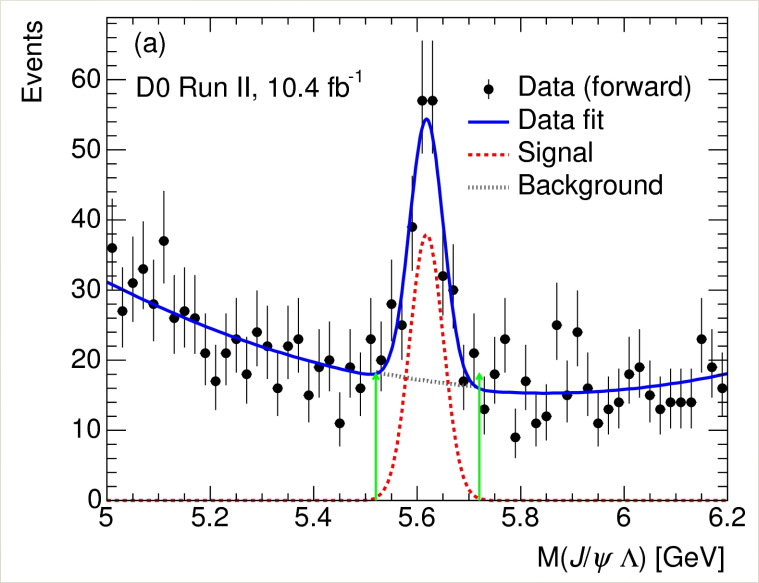


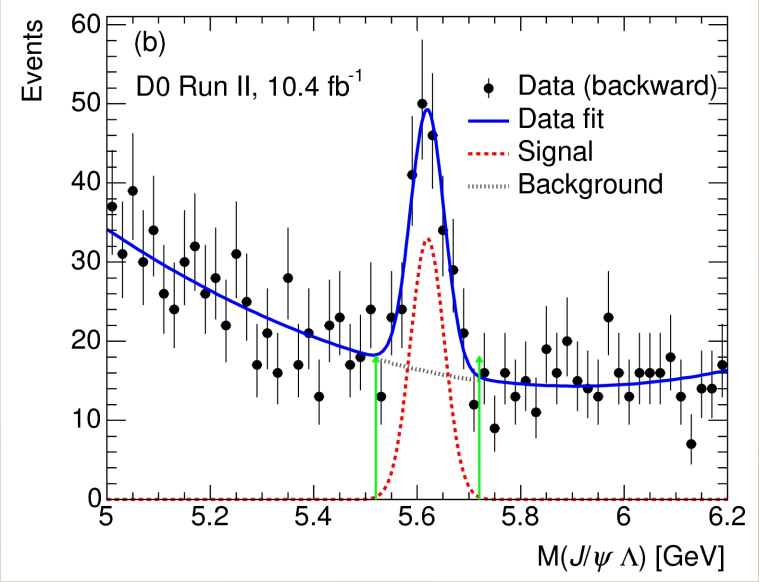
Comparison with MC@NLO show a ~3σ difference Rigorous MC determination needed.

A_{FB} with Λ_b baryons

- ✔ Hadronization process can change direction of particle with b
- ✔ Mechanism to describe baryon-beam particle correlation (by Rosner)
- ✔ Reconstruct $\Lambda_b \to J/\Psi\,\Lambda$ with $J/\Psi \to \mu^+\mu^-$ $\Lambda \to p\pi^-$

Measure: $A_{FB} = \dfrac{\sigma(F) - \sigma(B)}{\sigma(F) + \sigma(B)}$ $\quad R = \dfrac{\sigma(B)}{\sigma(F)}$





Binned Maximum Likelihood fit:

Gaussian for signal + Chebyshev polynomial for background

Background = $J/\Psi\,\Lambda$ in Λ_b side bands

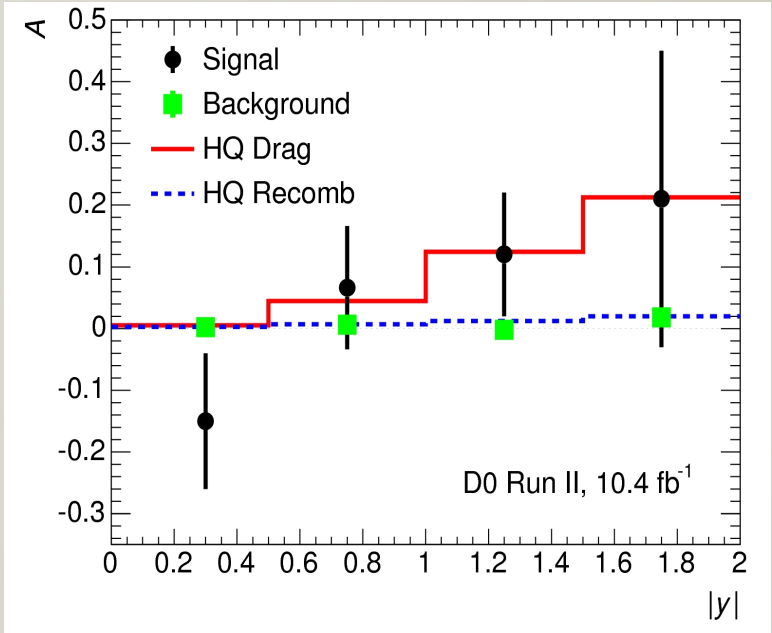
A_{FB} with Λ_b baryons: Results

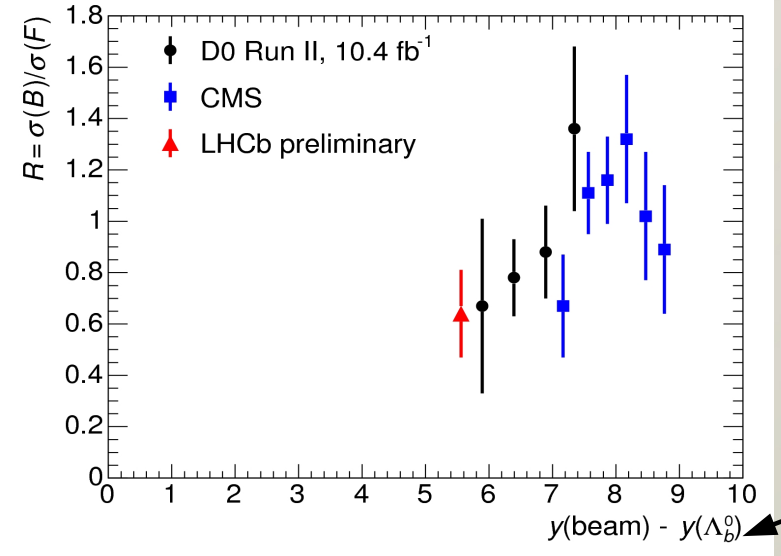
Fit invariant mass distribution of F/B in rapidity bins, exclude $|\eta_B|<0.1$

$$A_{FB} = 0.04 \pm 0.07\,(\text{stat}) \pm 0.02\,(\text{syst})$$

Result:

- ✔ agreement with no A_{FB}, HQ Recomb and HQ Drag (Rosner)
- ✔ disagreement with MC@NLO + Herwig (large A_{FB} expected ~1 at y=2)





Rapidity loss

R fall with decreasing rapidity loss

Integrated over y

$$R = 0.92 \pm 0.12\,(\text{stat}) \pm 0.04\,(\text{syst})$$

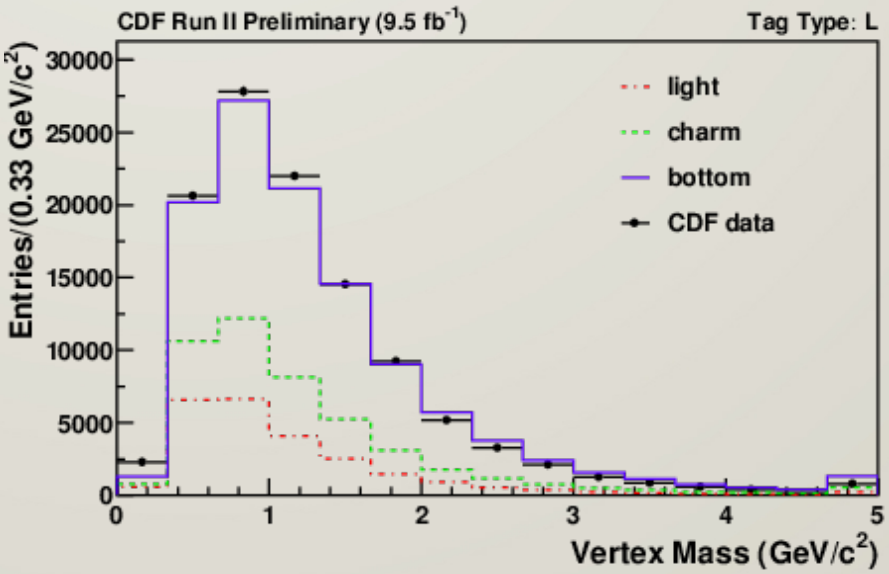
A_{FB} in $b\bar{b}$ pairs at high mass

Measure $A_{FB} = \frac{N(F)-N(B)}{N(F)-N(B)}$ compare to

$m_{b\bar{b}}$ [GeV c^{-2}]	$A_{FB}(b\bar{b})$ [%]
[150, 225]	$2.2 \pm 0.7 \pm 0.2$ %
[225, 325]	$4.2 \pm 1.3^{+0.6}_{-0.5}$ %
[325, 1960]	$7.8 \pm 2.3^{+1.7}_{-1.4}$ %

PRL111,062003

- ✔ Sample with at least two jets with two b-quarks
- ✔ b-quark identified requiring displaced secondary vertex



- ✔ vertex mass used to determine sample composition
- ✔ b-quark charge via jet charge:

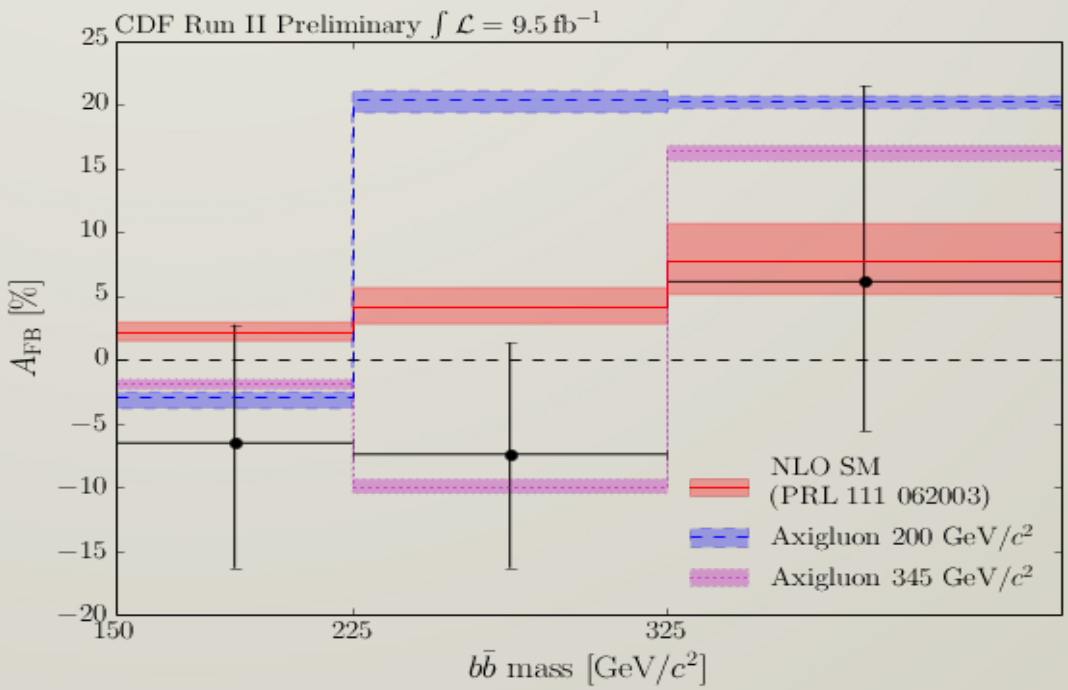
$$Q_{jet} = \frac{\sum_t q_t (\vec{p}_t \cdot \vec{p}_{jet})^{0.5}}{\sum_t (\vec{p}_t \cdot \vec{p}_{jet})^{0.5}}$$

- ✔ $M(b\bar{b})$ resolution determined by using MC simulation in the three mass bin → allow b-hadron jet energy

A_{FB} in $b\bar{b}$ pairs at high mass: Results

- Poisson Likelihood includes: background asymmetry, charge confusion rate, sample purity, mass smearing and signal asymmetry
- Use Bayesian technique to extract the hadron-jet level A_{FB}
- A_{FB} Posterior probability distribution obtained for each mass bin

Maximum of posterior probabilities:



Error bar: 68% credible intervals

Results consistent with:

- zero,
- SM (PRL111)
- axigluon m=345 GeV

Model with 200 GeV axigluon excluded

A_{FB} in $b\bar{b}$ pairs at low mass

- Measure $A_{FB} = \frac{N(\Delta y_b > 0) - N(\Delta y_b < 0)}{N(\Delta y_b > 0) + N(\Delta y_b < 0)}$ and compare to SM

$$\Delta y_b = Q(\mu)(y_{AJ} - y_{\mu J})$$

$M_{b\bar{b}}$ [GeV/c^2]	A_{FB}^{bb} [%]
[35, 75]	$0.18 \pm 0.05\ ^{+0.01}_{-0.01}$
[75, 95]	$2.84 \pm 0.20\ ^{+0.69}_{-0.58}$
[95, 130]	$1.79 \pm 0.37\ ^{+0.24}_{-0.20}$
> 130	$3.52 \pm 1.01\ ^{+0.28}_{-0.24}$
Inclusive	$0.30 \pm 0.07\ ^{+0.04}_{-0.03}$

PRL111,062003

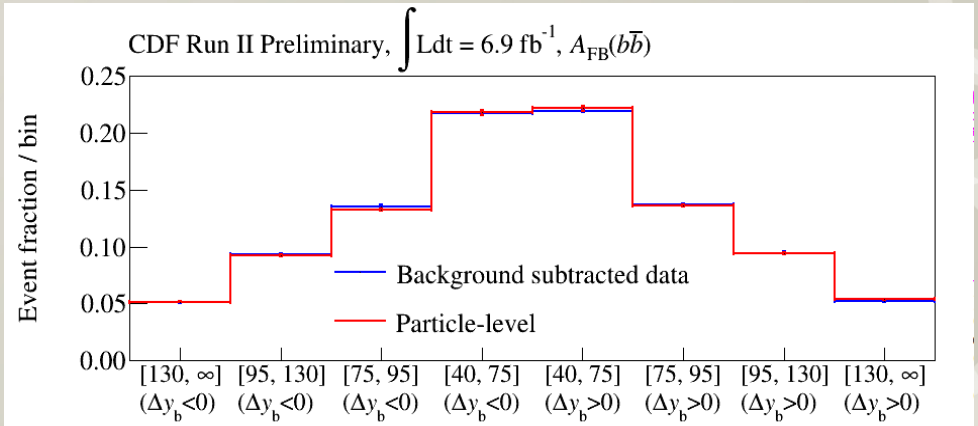
- Two b-quark jets using displaced secondary vertices
- b-quark flavour: charge muon in the jet (muon Jet)

A_{FB} at particle level → unfold M_{bb} and Δy_b distributions

To have 1D ditribution events divided in:

two Δy_b bins: >0 and <0

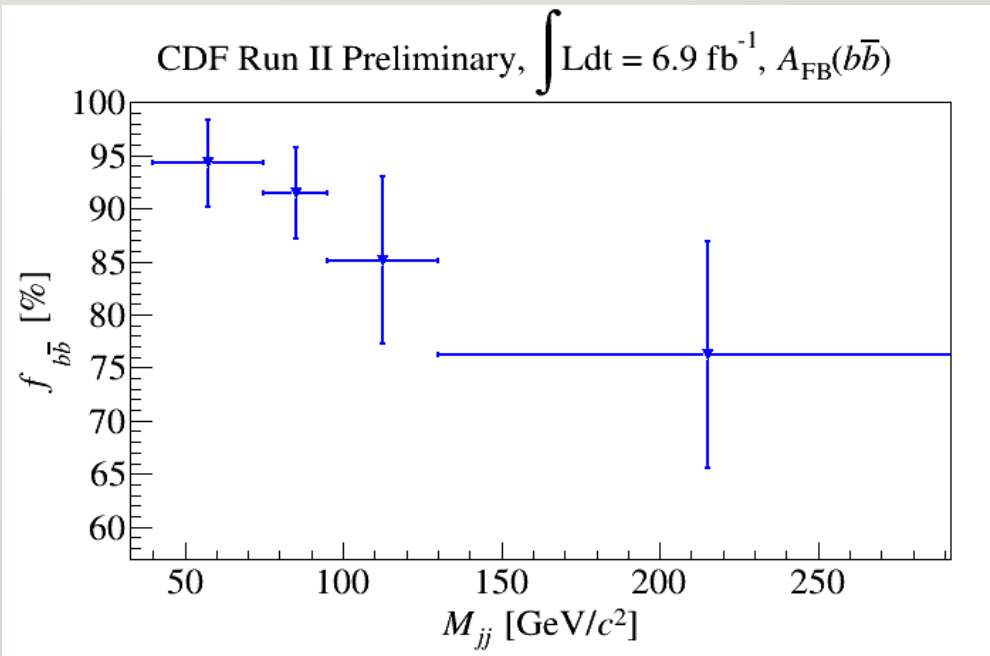
four M_{bb} bins: [40, 75], [75, 95], [95, 130], [130,∞]



input distributions

A_{FB} in $b\bar{b}$ pairs at low mass

- Unfolding matrix takes into account all experimental effects: detector resolution, acceptance, background, correct jet charge for b → c → μ and B^0-B^0 mixing
- $b\bar{b}$-fraction in Mjj bin
  - b-fraction in muon-jets → Ptrel distribution in Mjj bins
  - b-fraction in away jets → Mvtx distribution in Mjj bins



$b\bar{b}$ fraction in each Mjj bin by by computing the average b fraction between its lowest and highest value

A_{FB} in $b\bar{b}$ pairs at low mass: Results

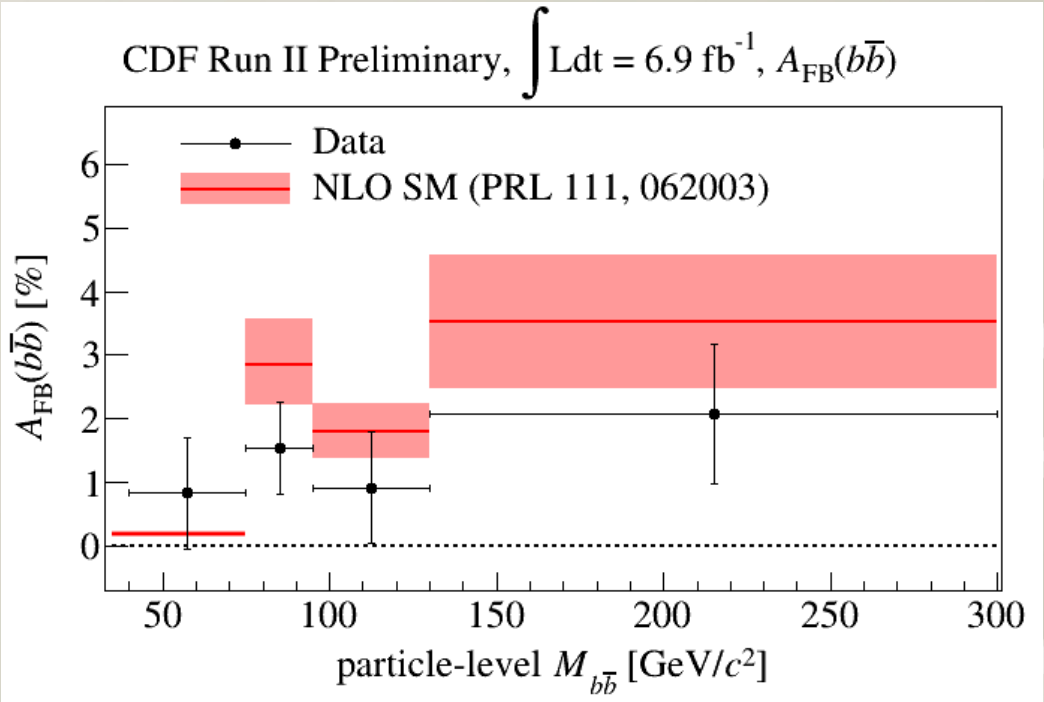
Systematic errors:

CDF Run II Preliminary, $\int Ldt = 6.9\,fb^{-1}$, $A_{FB}(b\bar{b})$					
Absolute uncertainty of A_{FB} [%]					
	$M_{b\bar{b}}$ [GeV/c^2]				Integrated
	[40; 75]	[75; 95]	[95; 130]	[130; ∞]	
$f_{b\bar{b}}$ uncert.	0.06	0.06	0.04	0.01	0.04
Background A_{FB}	0.11	0.17	0.27	0.34	0.17
JES	0.24	0.15	0.02	0.10	0.10
ISR/FSR	0.09	0.07	0.06	0.12	0.05
total	0.29	0.24	0.28	0.37	0.22

Integrated asymmetry: (1.2 ± 0.7)%

A_{FB} :

- increase with $Mb\bar{b}$
- spike around Z pole mass
- agreement with theoretical prediction.



Conclusions

- LHC almost took over the Tevatron for Heavy Flavor Physics
- There are measurements like CP Violation for which Tevatron still competes with LHC
- For the Forward-Backward Asymmetries determination Tevatron data are unique. Other measurements are in the pipeline!