Heavy Flavor at the Tevatron

Sabato Leo
UIUC
On behalf of the CDF ad D0 collaborations

Les Rencontres de Physique de la Vallee d'Aoste
03/04/2015

CKM: Mixing measurements

Testing QCD: HF production

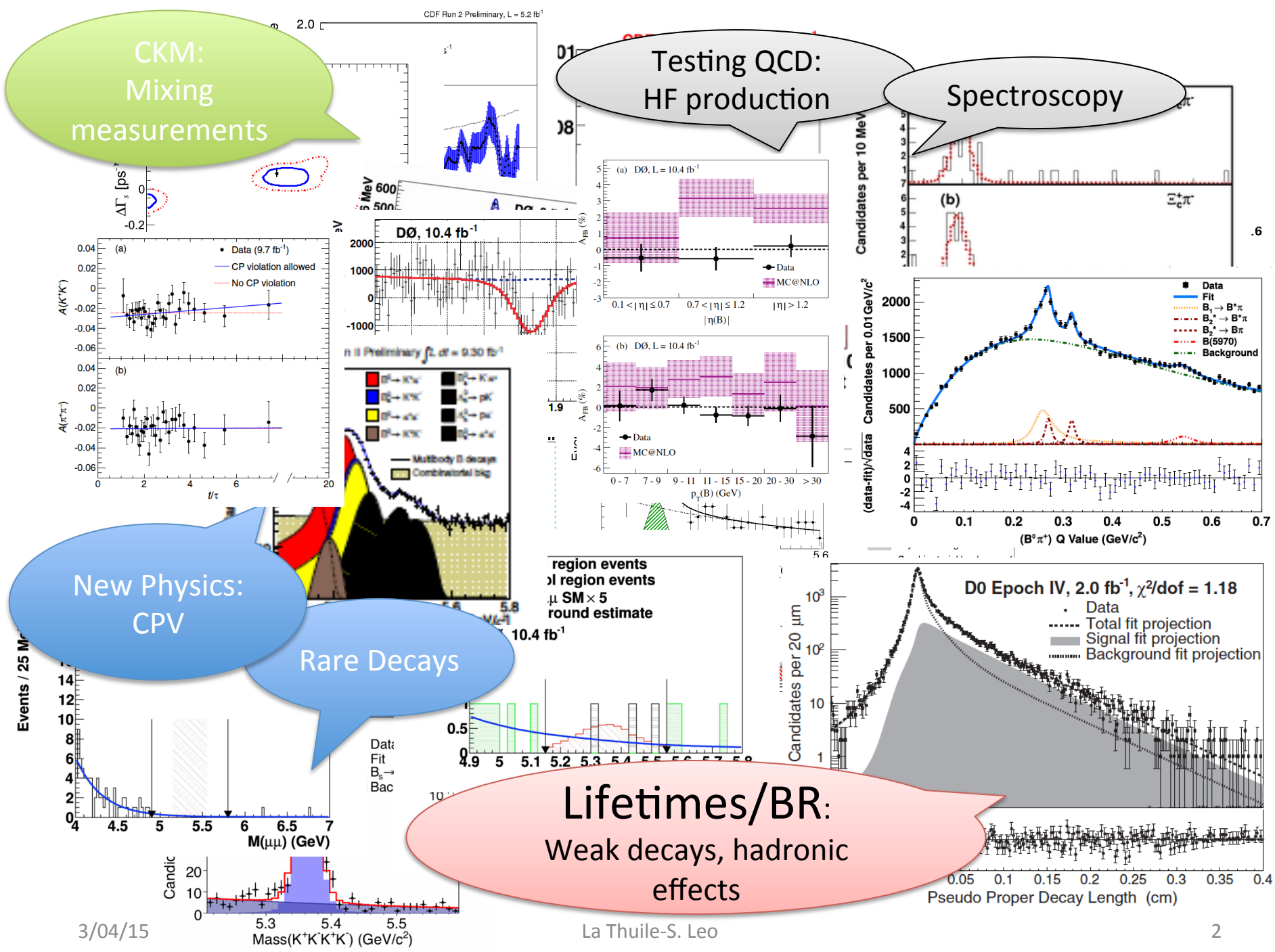
Spectroscopy

New Physics: CPV

Rare Decays

Lifetimes/BR:

Weak decays, hadronic effects



Flavor physics at the Tevatron

- 10 years of 1.96 TeV proton-antiproton collisions
- CDF and D0 have about 10 fb^{-1} of data on tape each
- Even if designed for high p_T physics...
  - High-rate of all species of heavy flavors actually higher than "B factories" (CDF + D0)
  - Excellent mass resolution (CDF)
  - Precision vertex reconstruction capabilities (CDF)
  - Powerful trigger on displaced vertices (CDF)
  - Charge-symmetric detector (D0)
- CDF and D0 have shown that first class flavor physics can be done in hadron collisions

Recent results

- Final results using the full 10 fb^{-1} sample
  - b-Baryon, excited B-mesons (CDF)
  - B mesons forward-backward production asymmetry (D0)
  - Flavor specific decay B_s lifetime (D0)
  - Direct (B meson charmless decays) and indirect (charm meson decays) CP violation (CDF)
  - Direct CP-violation measurement (D0)

- All measurements published in 2014 or early 2015

Spectroscopy

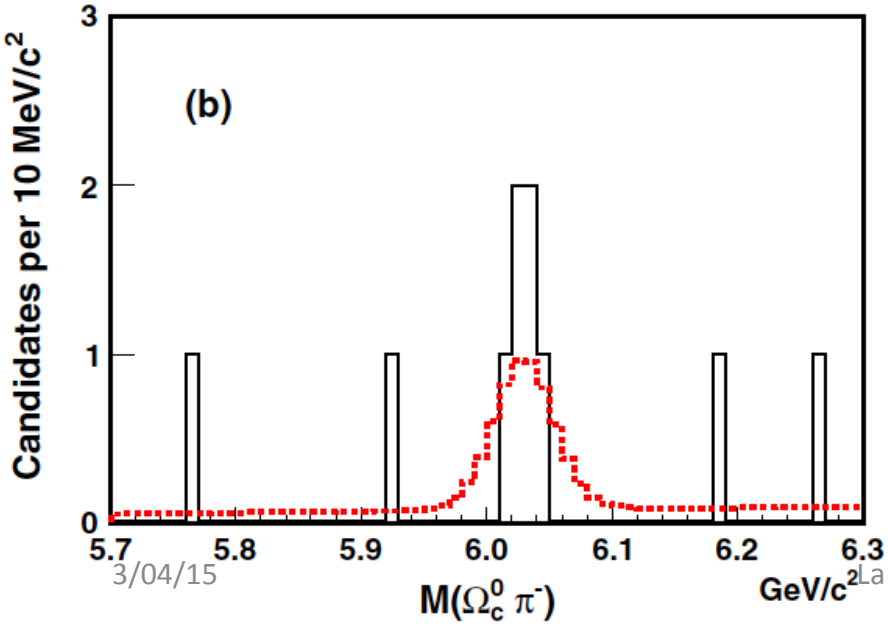
PHYSICAL REVIEW D **89,** 072014 (2014)

Mass and lifetime measurements of bottom and charm baryons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

T. Aaltonen,[21] S. Amerio,[39b,39a] D. Amidei,[31] A. Anastassov,[15,v] A. Annovi,[17] J. Antos,[12] G. Apollinari,[15] J. A. Appel,[15]

- Spectroscopy of b and c baryons allow for HQET test
  - Precise measurements of their mass, production, lifetime, and decay

Baryon	Mass (MeV/c^2)
Ξ_c^0	$2470.85 \pm 0.24 \pm 0.55$
Ξ_c^+	$2468.00 \pm 0.18 \pm 0.51$
Λ_b	$5620.15 \pm 0.31 \pm 0.47$
Ξ_b^-	$5793.4 \pm 1.8 \pm 0.7$
Ξ_b^0	$5788.7 \pm 4.3 \pm 1.4$
Ω_b^-	$6047.5 \pm 3.8 \pm 0.6$
$M(\Xi_c^0) - M(\Xi_c^+)$	$2.85 \pm 0.30 \pm 0.04$
$M(\Xi_b^-) - M(\Xi_b^0)$	$4.7 \pm 4.7 \pm 0.7$



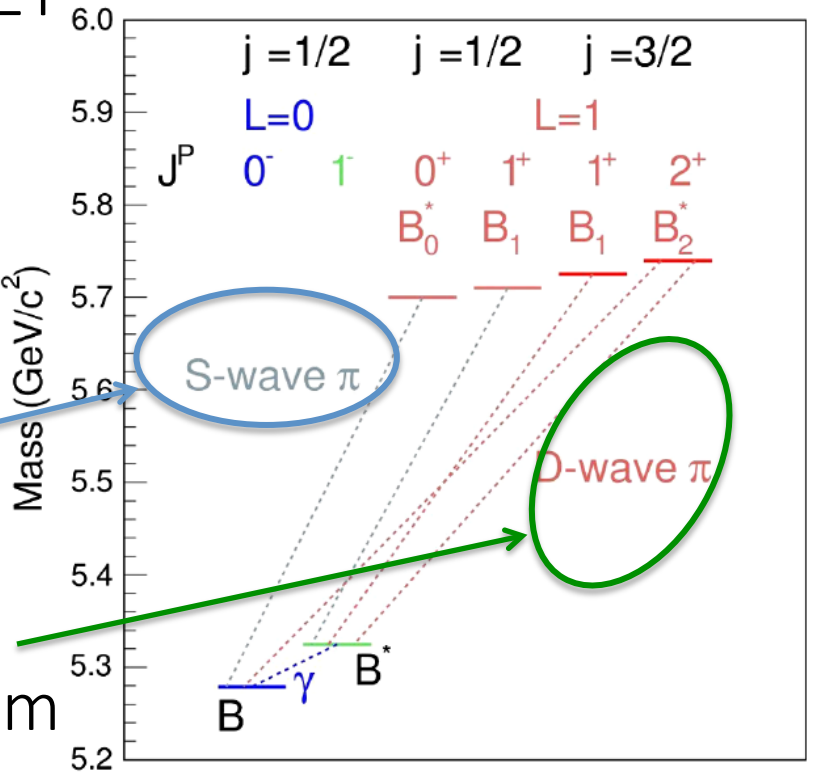
- Trigger on displaced tracks and J/ψ->μμ
- Reconstructed decays: Λ_b->J/ψΛ, Ξ^-_b->J/ψΞ^-, Ω^-_b->J/ψΩ^-…
- First observations of $\Omega_b \rightarrow \Omega^0_c \pi^-$ 3.3σ significance

PHYSICAL REVIEW D **90,** 012013 (2014)

Study of orbitally excited *B* mesons and evidence for a new *Bπ* resonance

T. Aaltonen,[21] S. Amerio,[39b,39a] D. Amidei,[31] A. Anastassov,[15,v] A. Annovi,[17] J. Antos,[12] G. Apollinari,[15] J. A. Appel,[15]

- Important testing ground for HQET
  - Light-heavy quark system similar to hydrogen atom
  - Fine and hyperfine splitting
- j=1/2 states too broad to be distinguishable from bkg
- j=3/2 states yield two structures in the Bπ invariant mass spectrum
  - Use Q value (=m(Bh)-m(B)-m_h) to account for the undetected low energy photon in the B^{**}->Bh decays
- Trigger on displaced tracks and J/ψ->μμ



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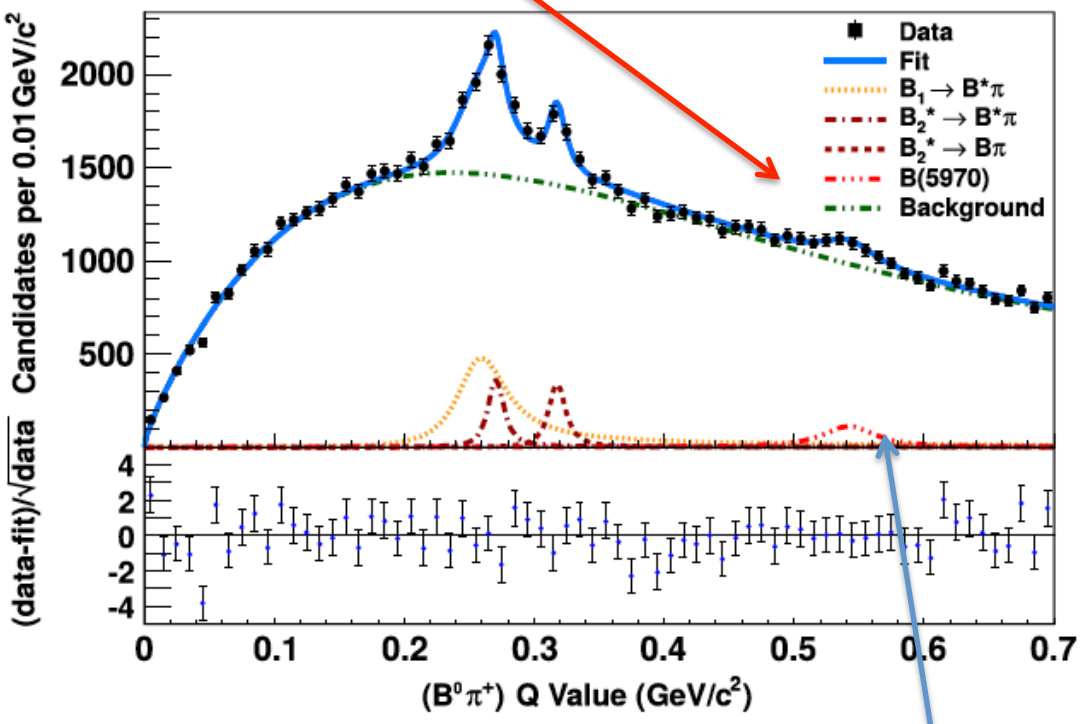
- First evidence of resonances (4.4σ) consistent with two states of orbitally excited (L=1) B-mesons
  - In both $B^+\pi^-$ (2600 sig. ev.) and $B^0\pi^+$ (1400 sig. ev.) samples



$B(5970)^+ = 5961 \pm 5 \pm 12$ MeV/c²

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- First evidence of resonances (4.4σ) consistent with two states of orbitally excited (L=1) B-mesons
  - In both $B^+\pi^-$ (2600 sig. ev.) and $B^0\pi^+$ (1400 sig. ev.) samples
- Masses and widths of fully reconstructed B^{**0}, B^{**+} and B_s^{**0} mesons also measured along with their relative production rates

	Q (MeV/c^2)	Γ (MeV/c^2)
B_1^0	$262.7 \pm 0.9^{+1.1}_{-1.2}$	$23 \pm 3 \pm 4$
B_2^{*0}	$317.9 \pm 1.2^{+0.8}_{-0.9}$	$22^{+3\ +4}_{-2\ -5}$
B_1^+	$262 \pm 3^{+1}_{-3}$	$49^{+12\ +2}_{-10\ -13}$
B_2^{*+}	$317.7 \pm 1.2^{+0.3}_{-0.9}$	$11^{+4\ +3}_{-3\ -4}$
B_{s1}^0	$10.35 \pm 0.12 \pm 0.15$	$0.5 \pm 0.3 \pm 0.3$
B_{s2}^{*0}	$66.73 \pm 0.13 \pm 0.14$	$1.4 \pm 0.4 \pm 0.2$

width measured for the first time

first time observation

Production

Measurement of the Forward-Backward Asymmetry in the Production of $B^{\pm}$ Mesons in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

V. M. Abazov,[31] B. Abbott,[67] B. S. Acharya,[25] M. Adams,[46] T. Adams,[44] J. P. Agnew,[41] G. D. Alexeev,[31] G. Alkhazov,[35]

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- using $B^{\pm} \rightarrow J/\psi K^{\pm}$ decays
- U
-
-
-
  - 3.6σ deviation from MC@NLO determination

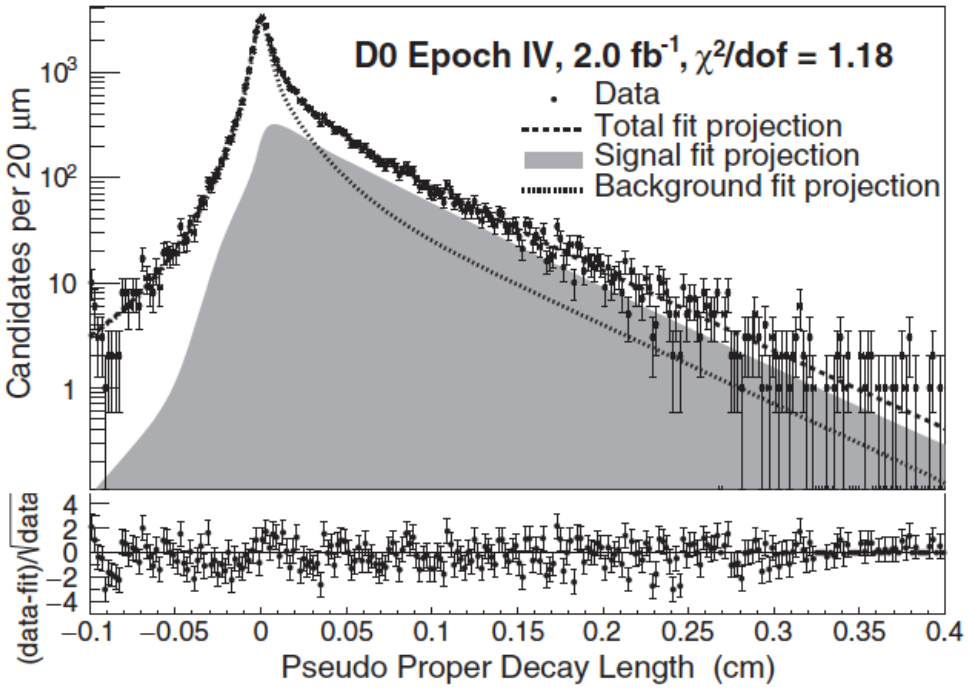
Attend Julia Hogan' talk later today

Lifetimes

Measurement of the B_s^0 Lifetime in the Flavor-Specific Decay Channel $B_s^0 \to D_s^- \mu^+ \nu X$

V. M. Abazov,[31] B. Abbott,[67] B. S. Acharya,[25] M. Adams,[46] T. Adams,[44] J. P. Agnew,[41] G. D. Alexeev,[31] G. Alkhazov,[35]

- with $D^-_s \to \phi\pi^-$ and $\phi \to K^+K^-$
  - Decay products charge tag production flavor
  - Using $(D^-_s\mu^+)$,~72028 tot. ev.
- Unbinned LL fit
  - Data partitioned to account for time- luminosity-dependent effects
  - $\tau(B^0)$ Simultaneously to validate the method



$$c\tau_{fs}(B^0_s) = 443.3 \pm 2.9(\text{stat.}) \pm 6.3(\text{syst.})\ \mu\text{m}$$

$$\tau_{fs}(B^0_s)/\tau(B^0) = 0.964 \pm 0.013(\text{stat.}) \pm 0.007(\text{syst.})$$

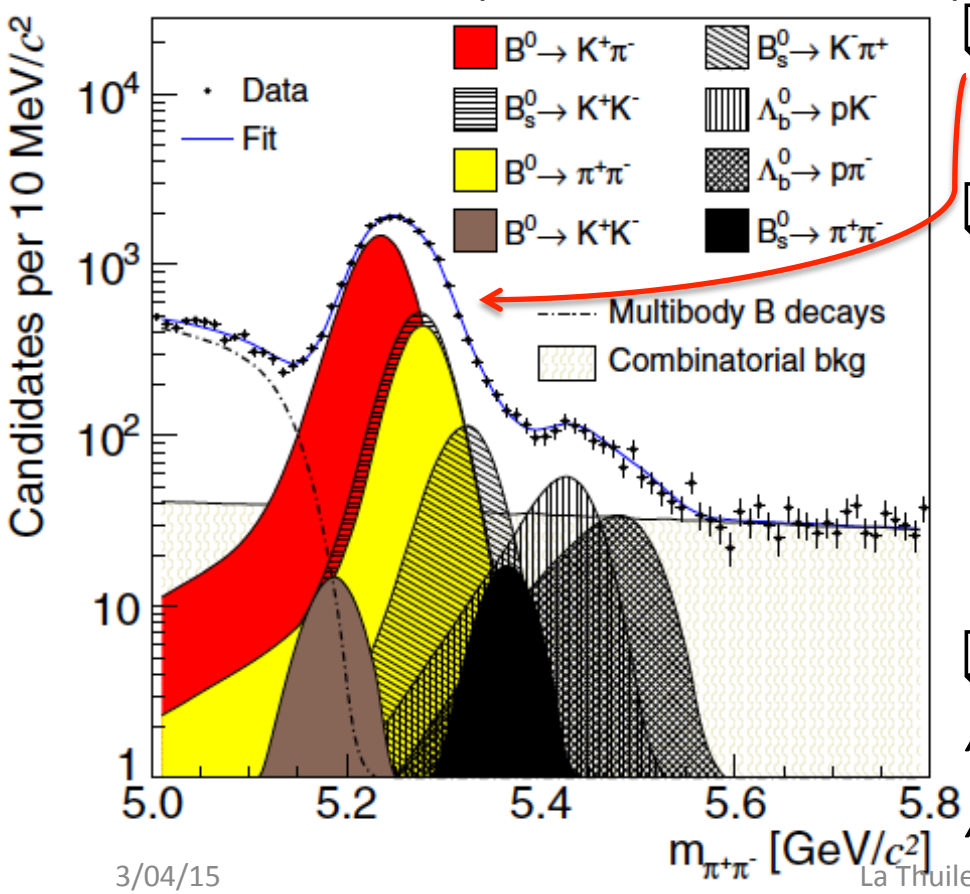
Consistent with world average, agreement with lattice QCD predictions

CP Violation

Measurements of Direct *CP*-Violating Asymmetries in Charmless Decays of Bottom Baryons

T. Aaltonen,[21] S. Amerio,[39a,39b] D. Amidei,[31] A. Anastassov,[15,v] A. Annovi,[17] J. Antos,[12] G. Apollinari,[15] J. A. Appel,[15]

- Direct CP violation in charmless decays of B mesons have shown discrepancies from expectations



- Several decays reconstructed in single narrow peak
- ML fit to kinematics and particle identification, corrected for detector induced charged asymmetries
- Unique baryon results

$$A(\Lambda_b^0 \to p\pi^-) = +0.06 \pm 0.07(\text{stat.}) \pm 0.03(\text{syst.})$$

$$A(\Lambda_b^0 \to pK^-) = -0.10 \pm 0.08(\text{stat.}) \pm 0.04\ (\text{syst.})$$

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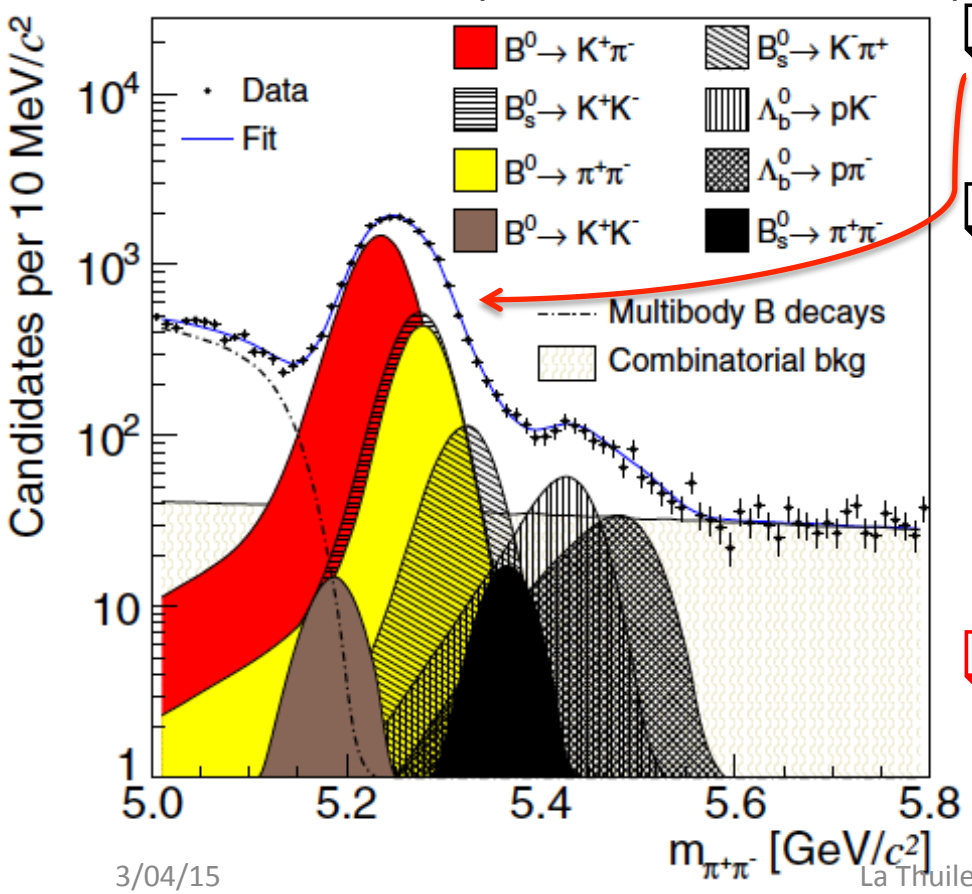


- Several decays reconstructed in single narrow peak
- ML fit to kinematics and particle identification, corrected for detector induced charged asymmetries
- Results are compatible with current results from B-factories and LHCb

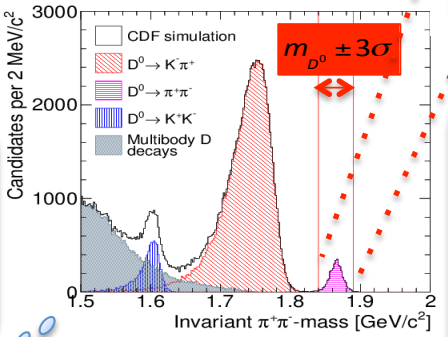
PHYSICAL REVIEW D 90, 111103(R) (2014)

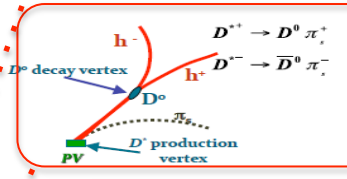
Measurement of indirect *CP*-violating asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays at CDF

T. Aaltonen,[21] S. Amerio,[39a,39b] D. Amidei,[31] A. Anastassov,[15,v] A. Annovi,[17] J. Antos,[12] G. Apollinari,[15] J. A. Appel,[15]

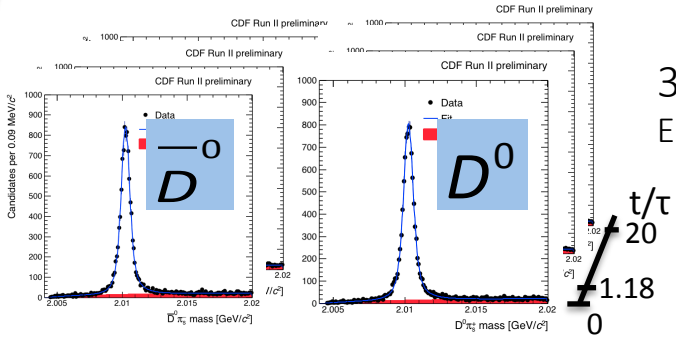
Trigger on displaced tracks

Offline: M(h^+h^-)used to separate $D^0 \to KK$ and $D^0 \to \pi\pi$





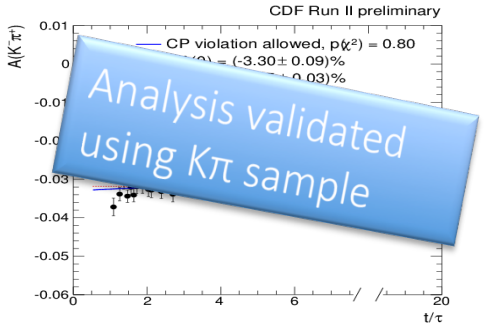
$D^* \to D^0 \pi$ decays to identify flavour at production time



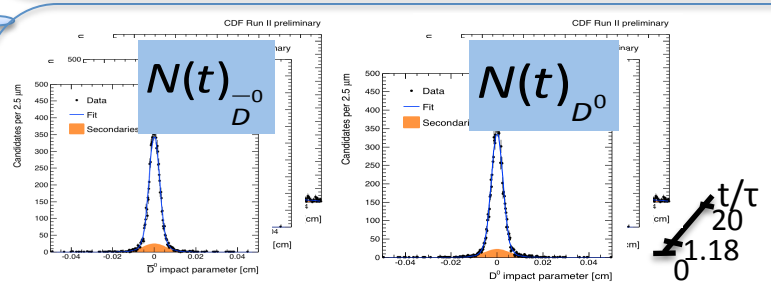
30 t/τ Bins: Equally populated

$D^0\pi_s$ mass used to separate signal from backgrounds

Fit asymmetry of prompt signal vs decay time with linear function



Analysis validated using Kπ sample



D^0 IP used to separate promptly produced D^* from those originated in B decays

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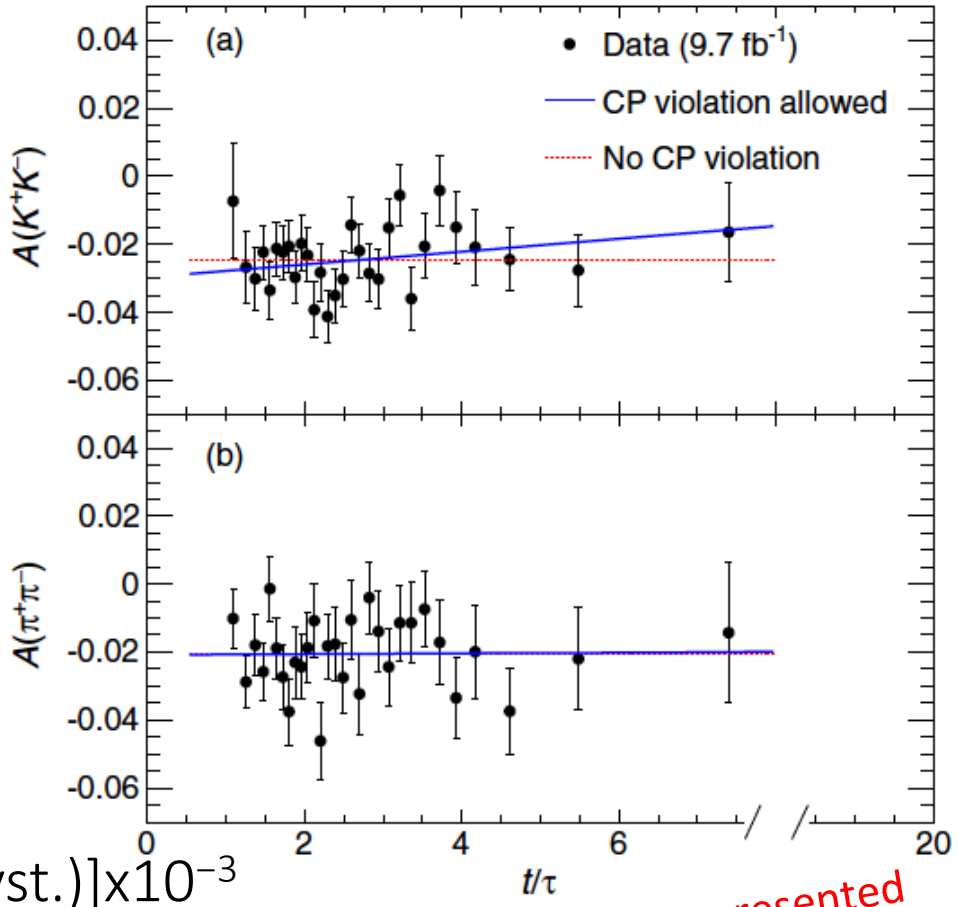
- Fit asymmetry of prompt signal vs decay time allows to measure effective-lifetime asymmetry(A_Γ)
- Results consistent with SM and other experimental determinations



A_Γ ($\pi^+\pi^-$) = [-0.1 ± 1.8 (stat.) ± 0.3 (syst.)]x10^{-3}

$A_\Gamma(K^+K^-)$ = [-1.9 ± 1.5 (stat.) ± 0.4 (syst.)]x10^{-3}

Second best result when first presented
Still better than B-factories

PHYSICAL REVIEW D **90,** 111102(R) (2014)

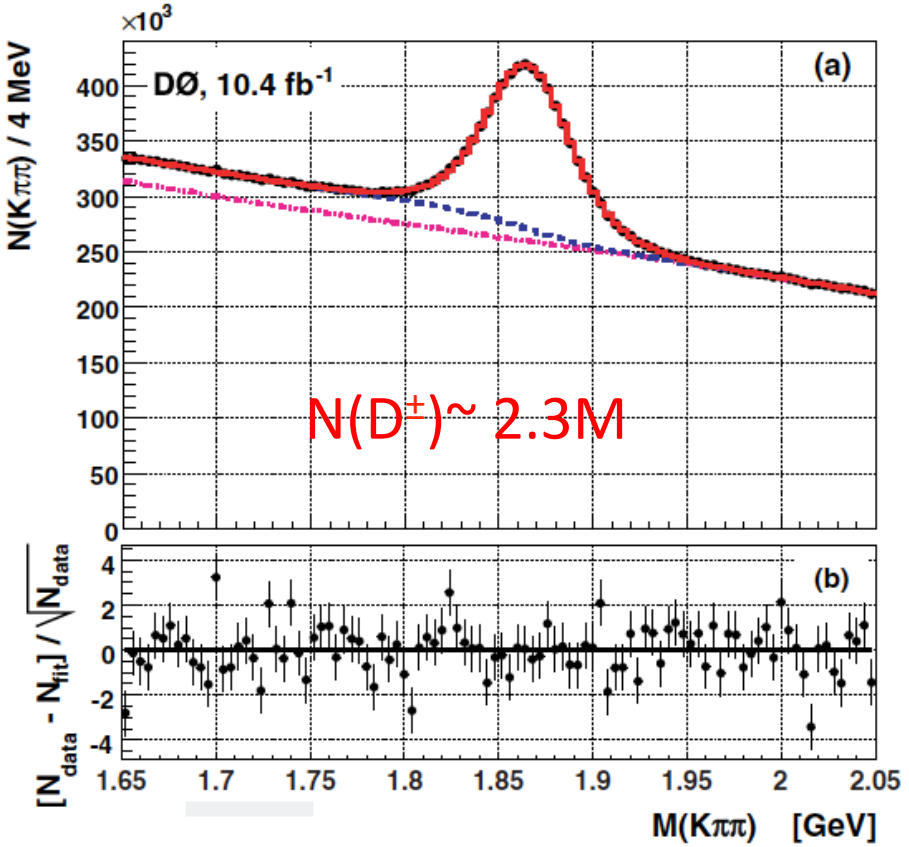
Measurement of the direct *CP*-violating parameter A_{CP} in the decay $D^+ \to K^-\pi^+\pi^+$

V. M. Abazov,[31] B. Abbott,[67] B. S. Acharya,[25] M. Adams,[46] T. Adams,[44] J. P. Agnew,[41] G. D. Alexeev,[31] G. Alkhazov,[35]

- Sensitive to direct CP-violating parameter A_{CP}

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

- Simultaneous fit of the invariant mass distributions for the sum and difference of charge-specific sample



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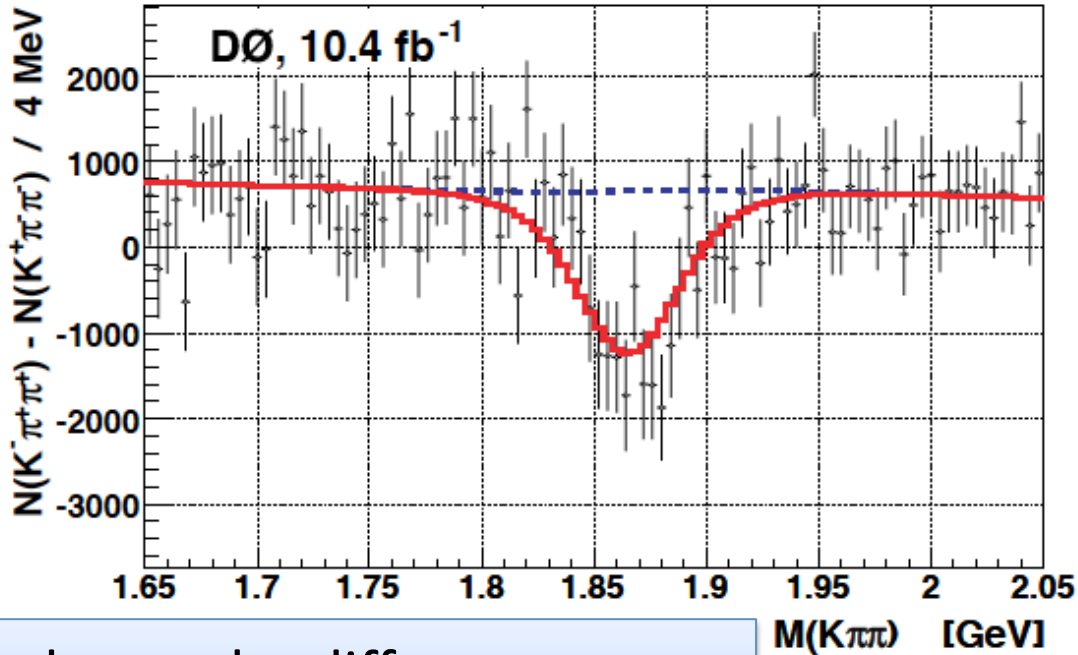
- Simultaneous fit of the invariant mass distributions for the sum and difference of charge-specific sample
  - corrected for detector-related asymmetries using MC and data-driven methods



asymmetry due to the different interaction cross sections of K^+ and K^-

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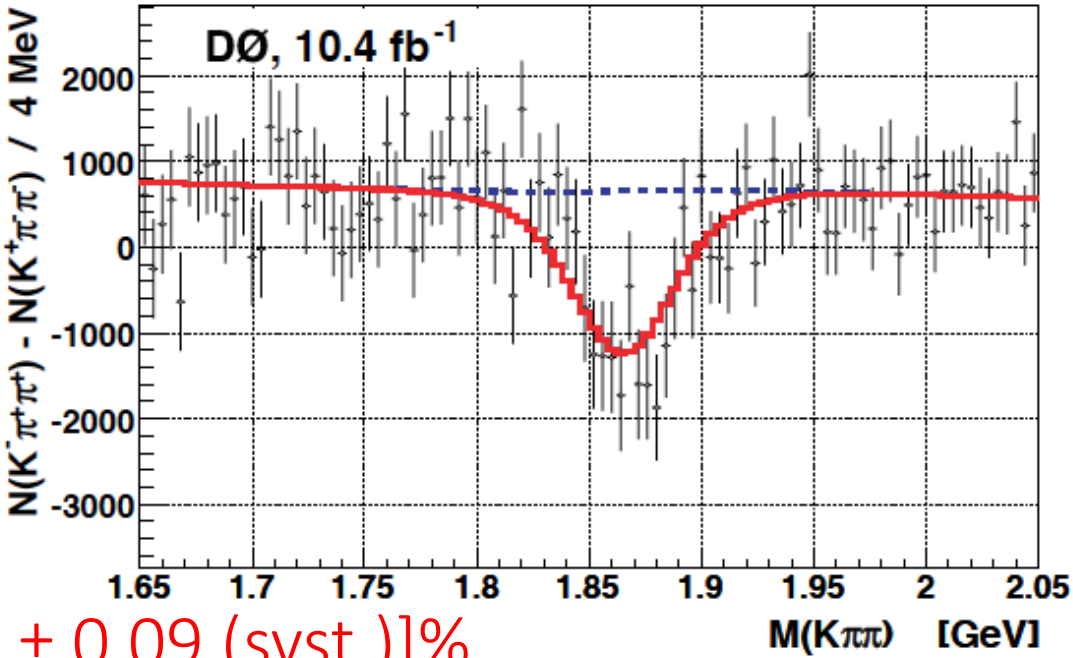

- A_{CP} = [−0.16 ± 0.15 (stat.) ± 0.09 (syst.)]%
  - consistent with zero (SM)
  - most precise measurement to date

Tevatron results overview

- Tevatron experiments pioneered flavor physics in hadron collisions showing that a world-class program is achievable
  - thanks to lots of luminosity, well designed and understood detectors, and analysis creativity and ingenuity.

- Produced more than 100 (CDF) +50 (D0) flavor papers in 10 years, some of which are the most cited of the whole Run II
  - still many in the 2014/15 period

- Today shown a number of recent interesting measurement in each of the HF sectors
  - Production, spectroscopy, Lifetime, CPV…

~~Tevatron~~

Shoot the papers out!

More still on the way..

Supporting slides

BACKUP

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Λ_b->J/ψΛ,
Ξ^-_b->J/ψΞ^-,
Ω^-_b->J/ψΩ^-,
Ξ^0_c->$\Xi^-\pi^+$,
Ξ^+_c->$\Xi^-\pi^+\pi^+$,
Ξ^-_c->$\Xi^0_c\pi^-$,
Ξ^0_b->$\Xi^+_c\pi^-$

TABLE I. Mass ranges around the known mass values [1] used for the b-hadron decay products.

Resonance (final state)	Mass range (MeV/c^2)
$J/\psi(\mu^+\mu^-)$	±80
$K^*(892)^0(K^+\pi^-)$	±30
$K^0_S(\pi^+\pi^-)$	±20
$\Lambda(p\pi^-)$	±9
$\Xi^-(\Lambda\pi^-)$	±9
$\Omega^-(\Lambda K^-)$	±8
$\Xi^0_c(\Xi^-\pi^+)$	±30
$\Xi^+_c(\Xi^-\pi^+\pi^+)$	±25
$\Omega^0_c(\Omega^-\pi^+)$	±30

TABLE II. Signal yields and purity for charmed hyperon samples. Only statistical uncertainties are listed.

	Full sample		Tracked in SVX II	
State	Yield	Purity	Yield	Purity
Ξ^0_c	5614 ± 247	0.15 ± 0.01	3412 ± 84	0.63 ± 0.01
Ξ^+_c	7984 ± 354	0.11 ± 0.01	5065 ± 104	0.61 ± 0.01
Ω^0_c	416 ± 135	0.03 ± 0.01	124 ± 31	0.22 ± 0.05

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$B^0 \to D^- \mu^+ X$