Tevatron heavy flavor results on B lifetimes and decays and D asymmetries

Rencontres de Moriond EW 2014

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Introduction

- Heavy flavor production and Triggers at the Tevatron
- CDF and D0 detectors
- Overview of most recent CDF and D0 results related to B lifetimes, decays and D asymmetries

See also

Bruce Hoeneisen: "Anomalous DiMuon charge asymmetry"

Julie Hogan "Forward-backward Asymmetry of b quarks in $B^+ \rightarrow J/\psi K^+$ decays at the D0 Experiment"

CDF results:
http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
D0 results:
www-d0.fnal.gov/d0_publications/d0_pubs_list_runII_bytopic_byyear.html

Heavy Flavor Production at Tevatron

For the last 20 years Tevatron has enjoyed a very rich heavy flavor Physics program with more than 150 published papers

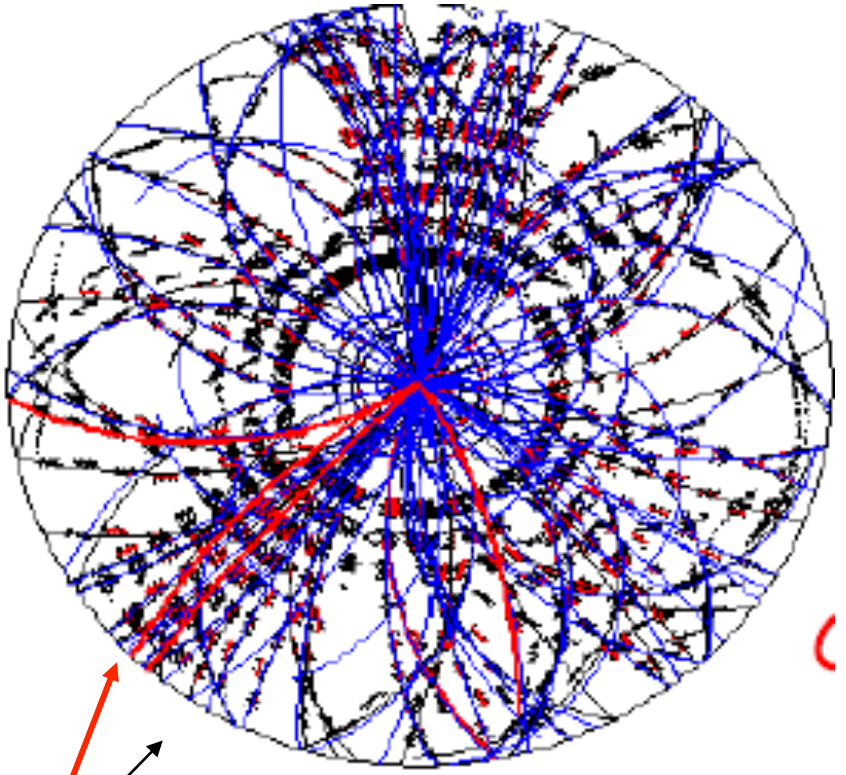
Pros

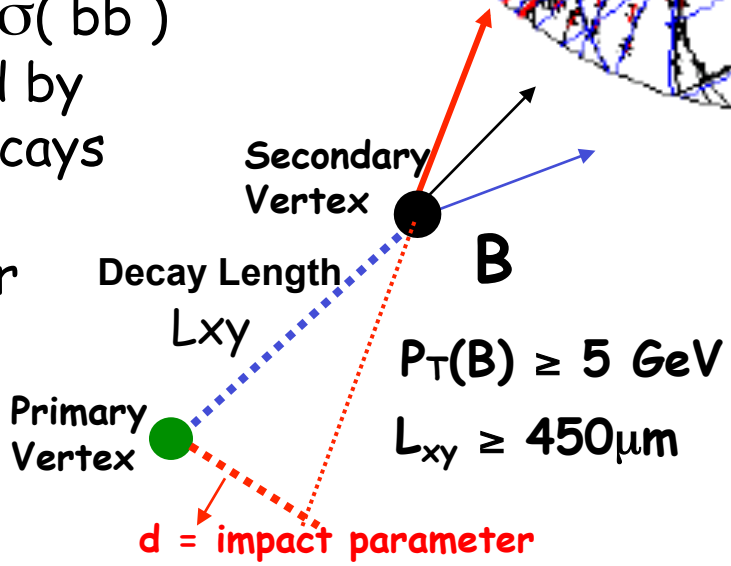
- Large b production cross section
- All B species produced
  B_d, B_u, B_s, Λ_b, Ξ_b, Σ_b, Ω_b
  with production fractions
  fd : fu : fs : $f\Lambda$ ~ 4: 4 : 1 : 1

Cons

- $\sigma(p\bar{p})$ ~100 mb = ~10^3 - 10^4 x $\sigma(b\bar{b})$
- Large backgrounds suppressed by triggers targeting specific decays

The CDF Secondary Vertex Trigger (>10 years of work) granted access to the hadronic modes





CDF B Triggers

Di-Muon (J/ψ)

Pt(μ) > 1.5 GeV

J/ψ modes down to low Pt(J/ψ) (~ 0 GeV)

Displaced trk + lepton (e, μ)

IP(trk) > 120μm

Pt(lepton) > 4 GeV

Semileptonic modes

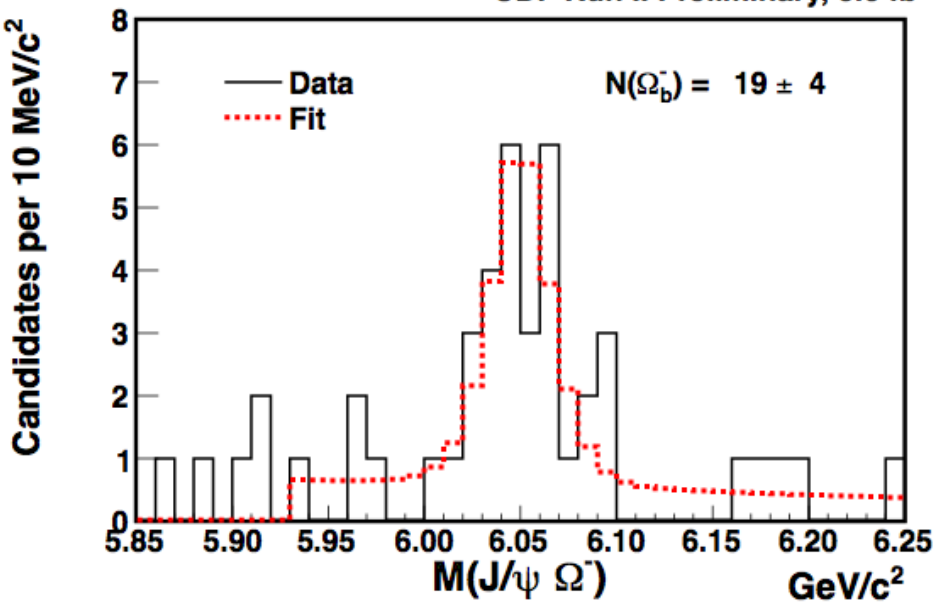
2-Track Trig.

Pt(trk) > 2 GeV

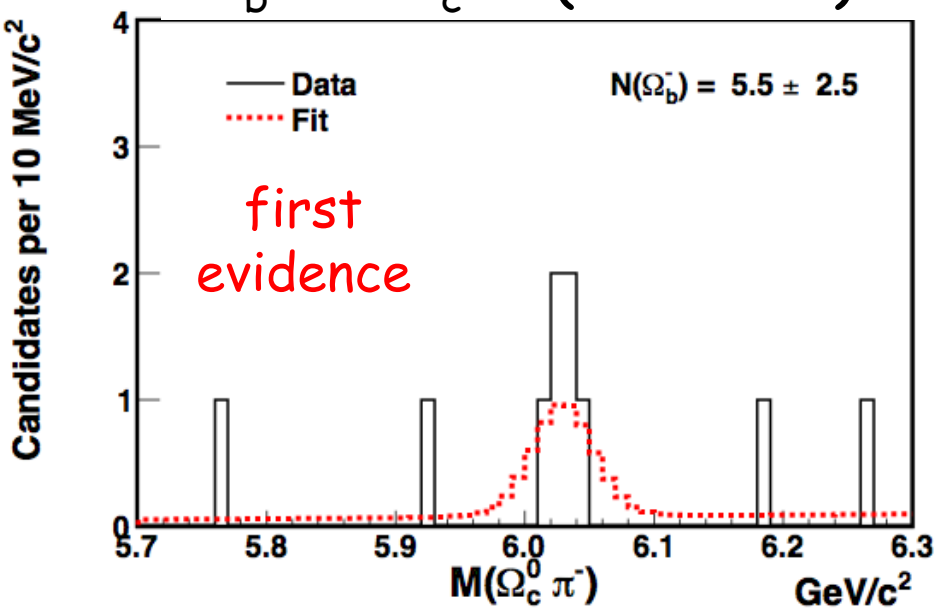
IP(trk) > 100 μm

Fully hadronic modes

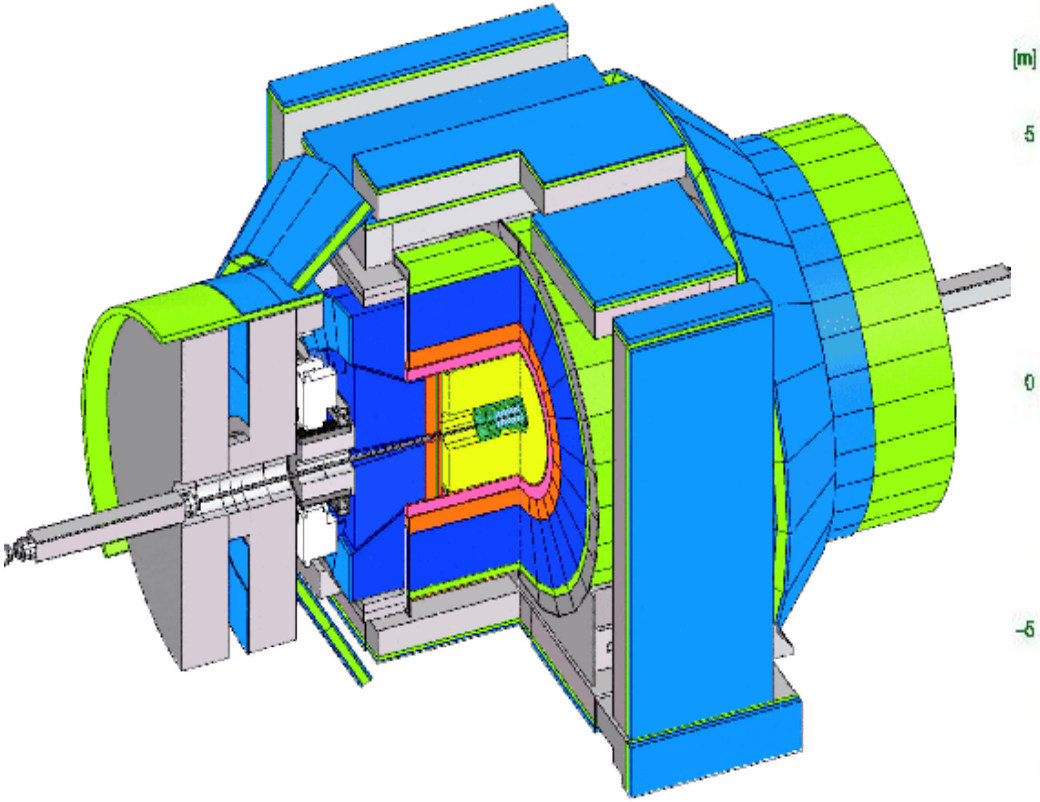
$\Omega^-_b \rightarrow J/\psi\ \Omega^-$

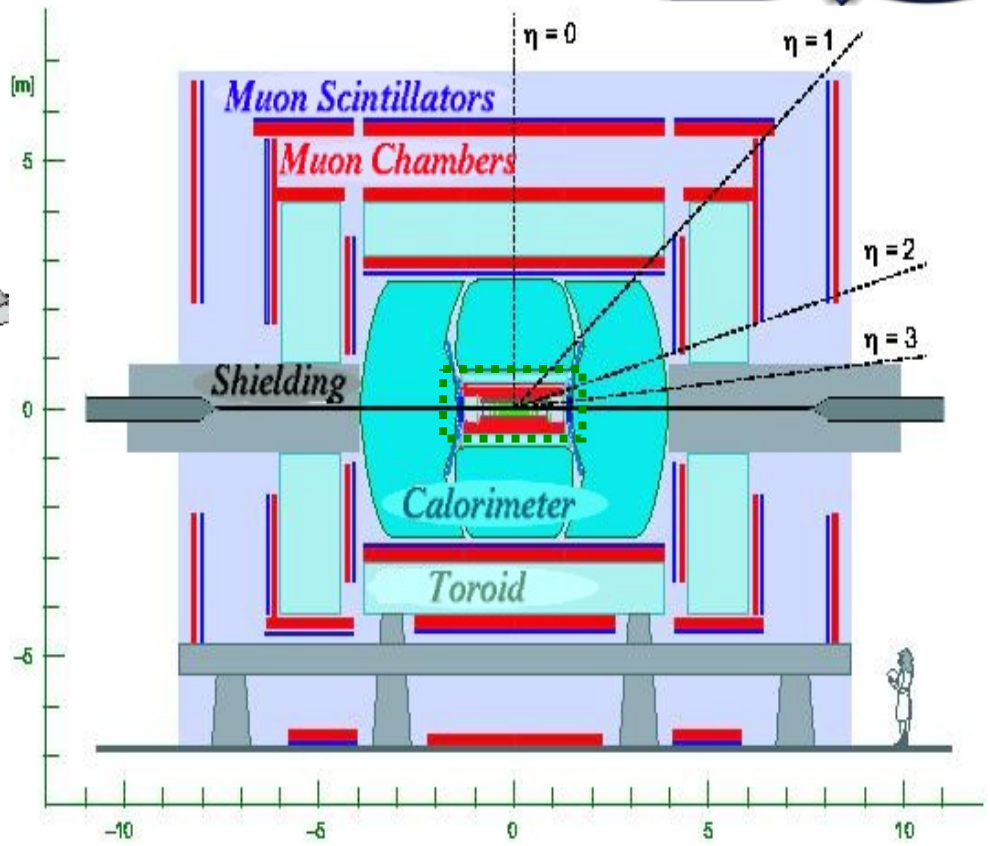


$\Omega^-_b \rightarrow \Omega^0_c\ \pi^-$ (hadronic)



CDF and D0 Detectors





Drift Chamber/Silicon detector
(R~1.4 m, 1.4 T B Field)
Excellent vertex/mass resolution
Tracker/Muon acceptance: $|\eta|<1$
Asymmetric design in tilted cells
Displaced vertex Trigger

Fiber Tracker/Silicon detector
(R~0.5 m, 2.0 T B Field)
Reduced mass resolution
Tracker/Muon acceptance: $|\eta|<2$
Regular reversal of magnetic field
cancels detector asymmetries

In this Talk

- B baryons properties (CDF)
  - Ξ^-_b and Ω^-_b mass and lifetime in J/ψ X modes
  - Ξ^-_b , Ξ^0_b and Ω^-_b mass in fully hadronic modes

- $B^+_c \rightarrow J/\psi\mu^+\nu$ relative cross section (CDF)

- Search for X(4140) (D0)

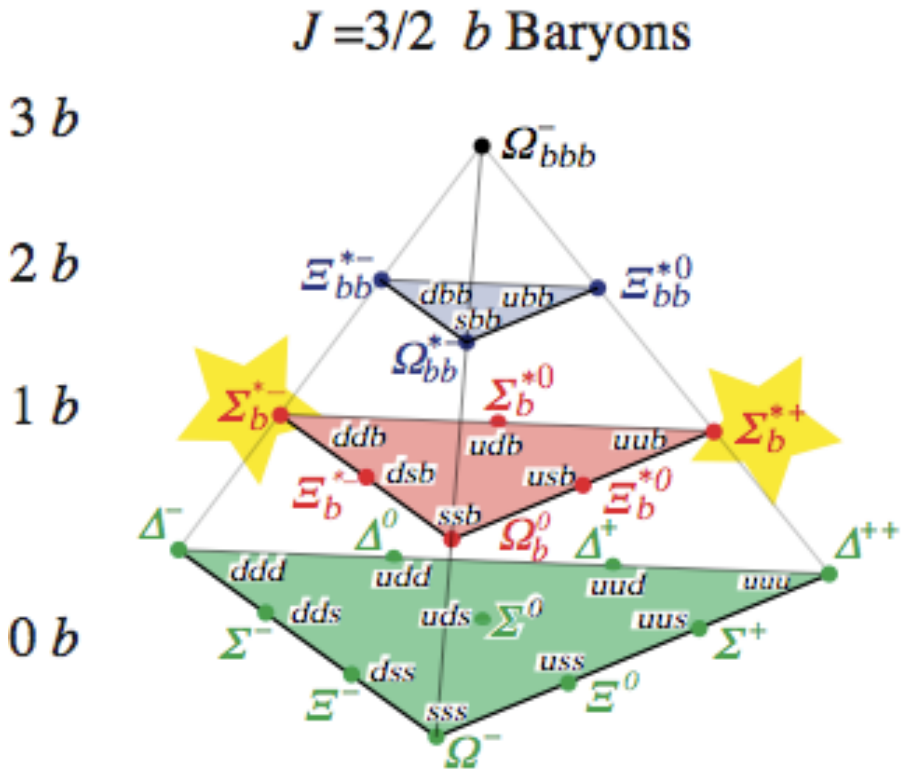
- Charm Mixing (CDF)

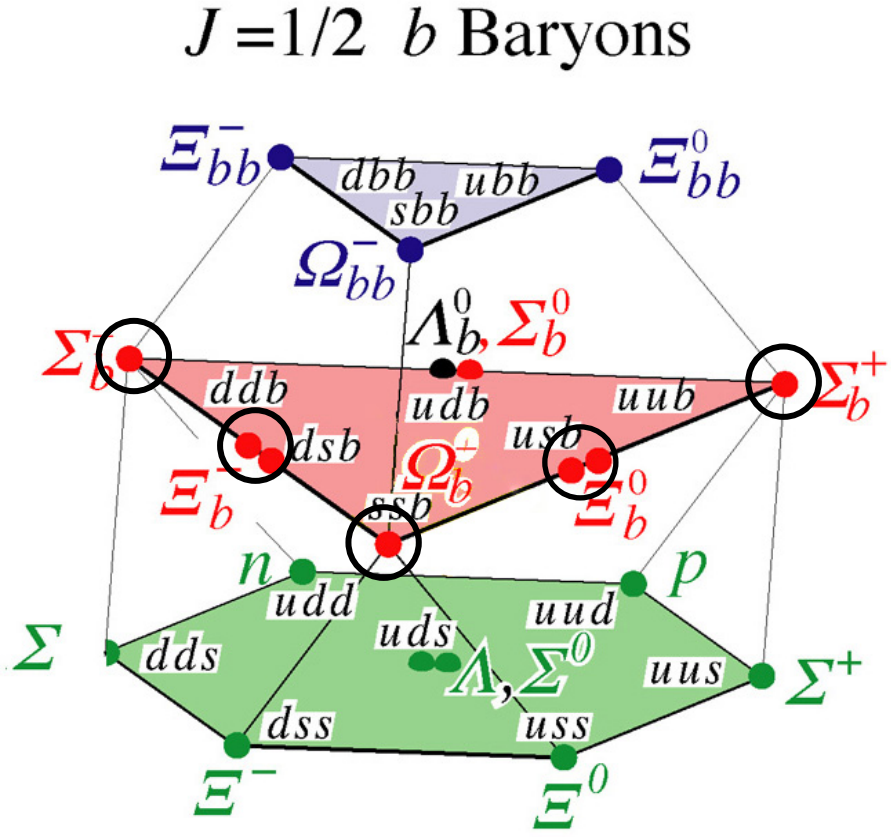
- Search for CP violation in b and c decays (D0)
  - direct CPV in $B^+ \rightarrow J/\psi K^+$ and $B^+ \rightarrow J/\psi\pi^+$
  - direct CPV in $D^+_s \rightarrow \phi\,\pi^+$

B Baryons

For a long time totally a Tevatron field, now a rich legacy to LHC

- $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed in 2006
- Ξ_b^- observed in 2007
- Ω_b^- observed in 2008
- Ξ_b^0 observed in 2011





Ξ_b^-/Ω_b^- Reconstruction

Reconstruct Ξ_b^- and Ω_b^- in the decays

$\Xi_b^- \rightarrow J/\psi\, \Xi^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Xi^- \rightarrow \Lambda\pi^-$

$\Omega_b^- \rightarrow J/\psi\, \Omega^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Omega^- \rightarrow \Lambda K^-$

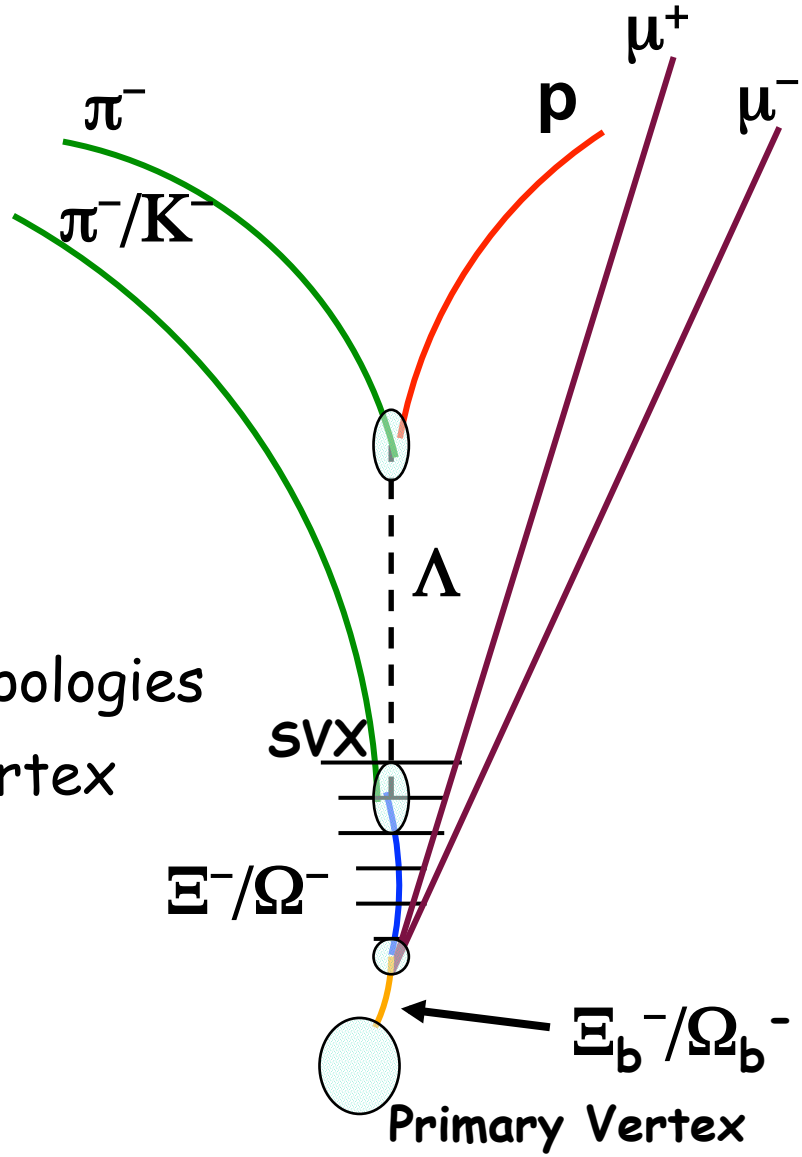
5-track, 3-vertex kinematic fit

$\mu^+\mu^-$ constrained to J/ψ mass

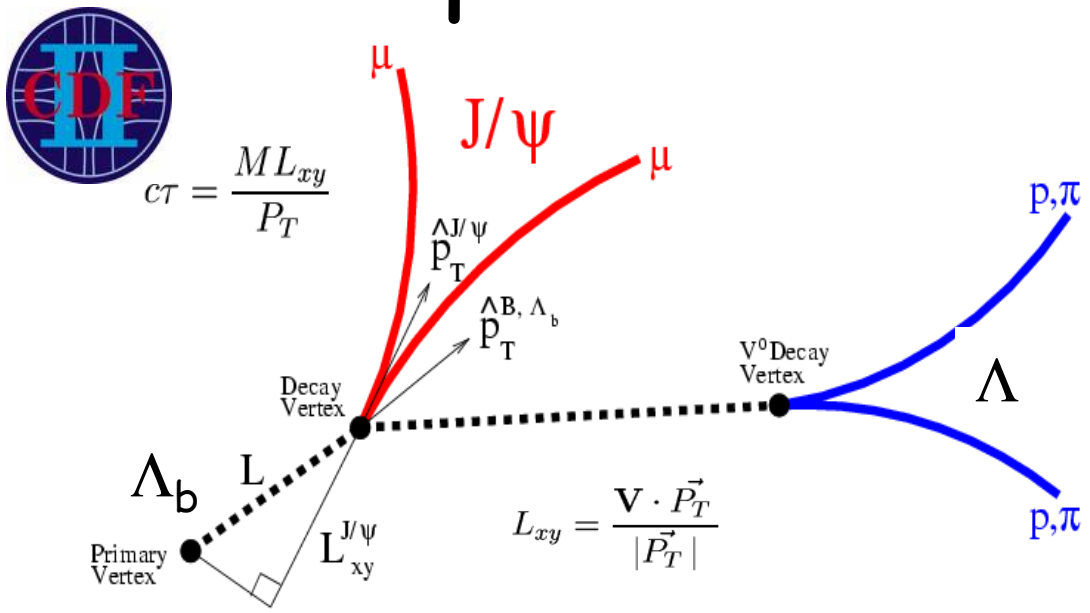
Trajectories constrained to appropriate topologies

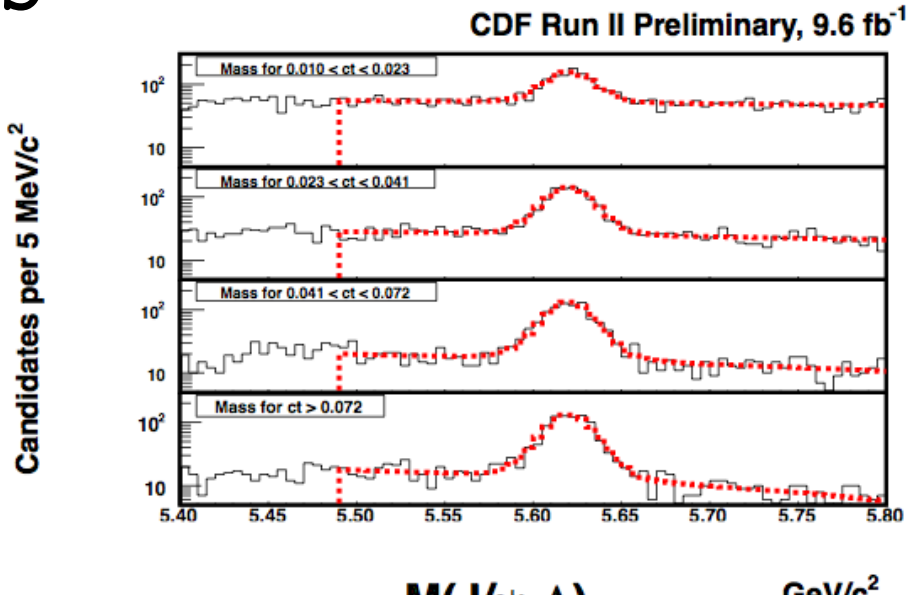
Reconstructed Ξ^-/Ω^- constrained to $\mu^+\mu^-$ vertex

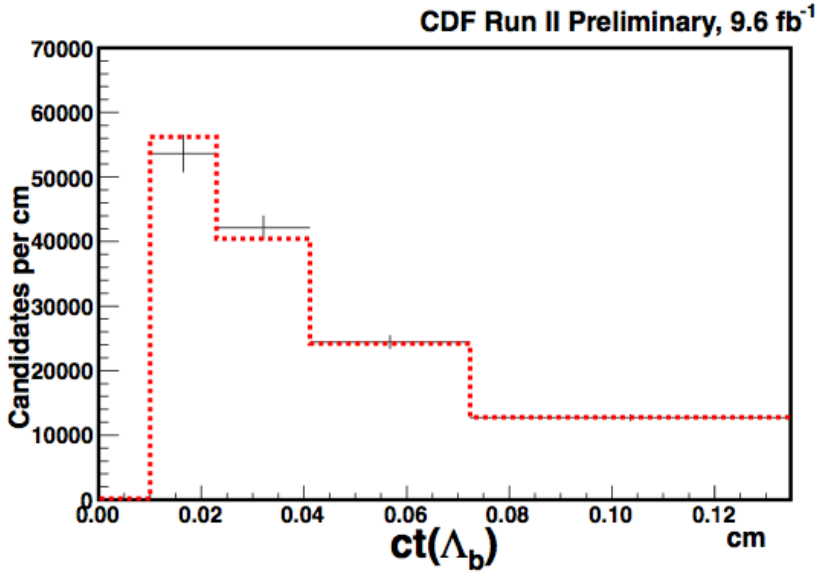
Long life of the Ξ^- and Ω^- leaves hits in the silicon detector (unique to baryons)



Check procedure: Λ_b mass/lifetime





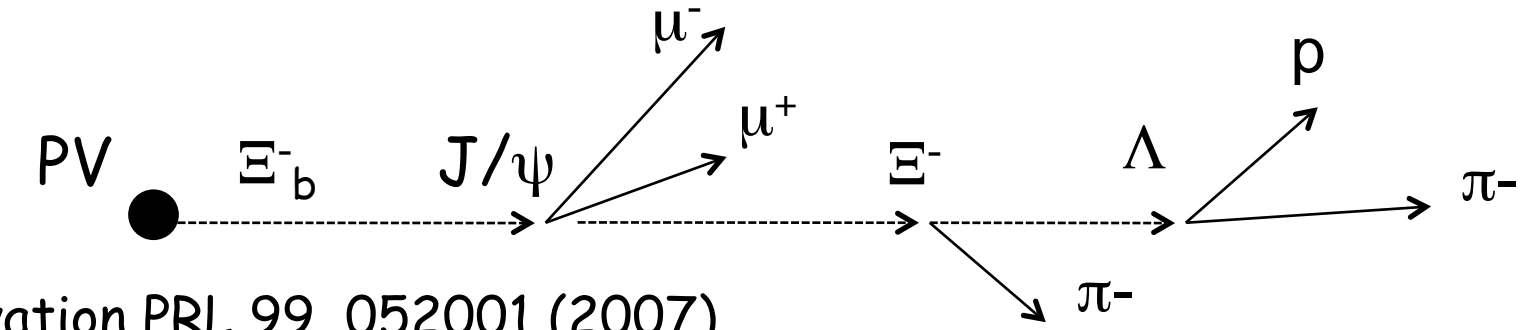


Binned lifetime fit distributions

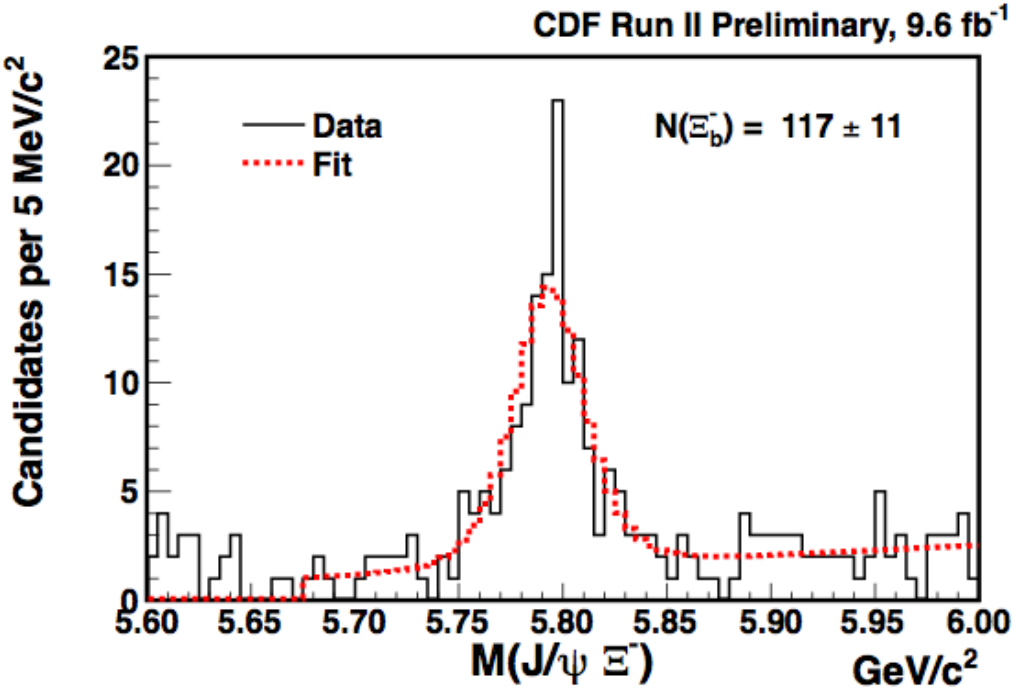
- Each bin comes from an independent fit to the mass distribution
- Dashed lines are fit projections

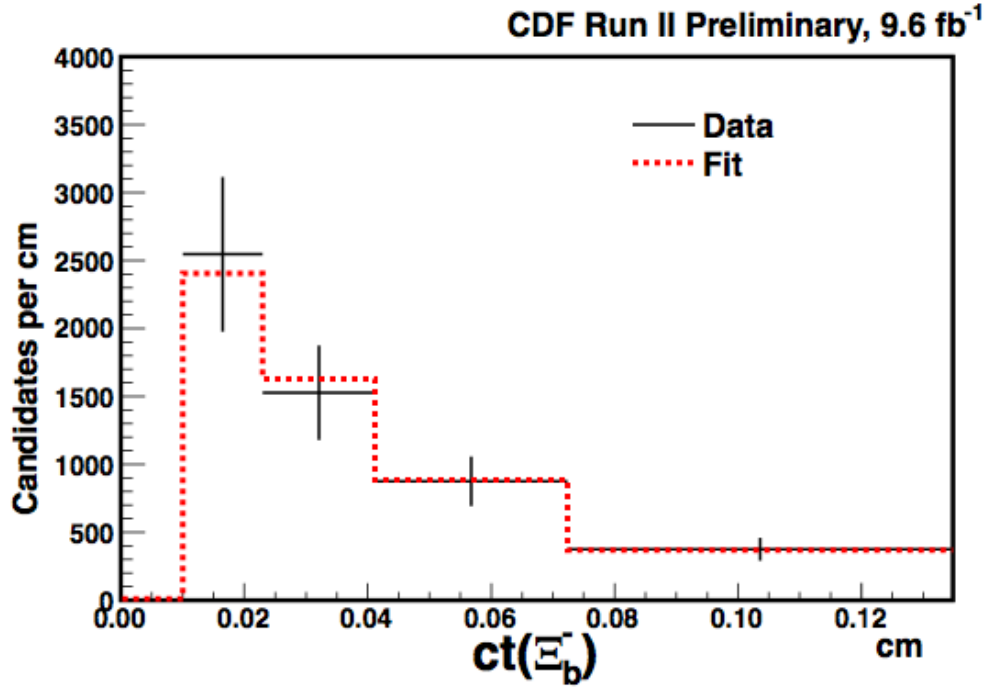
Mass (Λ_b): 5620.14 ± 0.31(stat) ± 0.40(syst) MeV/c2
Lifetime (Λ_b): 1.565 ± 0.035(stat) ± 0.020(syst) ps

Ξ^-_b mass and lifetime



Ξ^-_b Observation PRL 99, 052001 (2007)





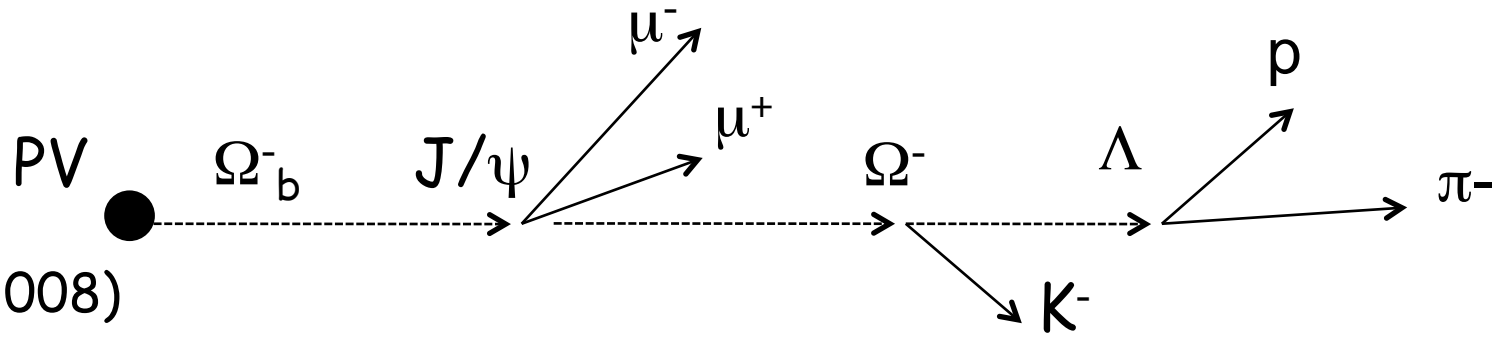
Mass (Ξ^-_b): 5791.6 ± 2.0(stat) ± 0.40(syst) MeV/c^2
Lifetime (Ξ^-_b): 1.36 ± 0.15(stat) ± 0.02(syst) ps
LHCb: 5795.8 ± 0.9(stat) ± 0.40(syst) MeV/c^2

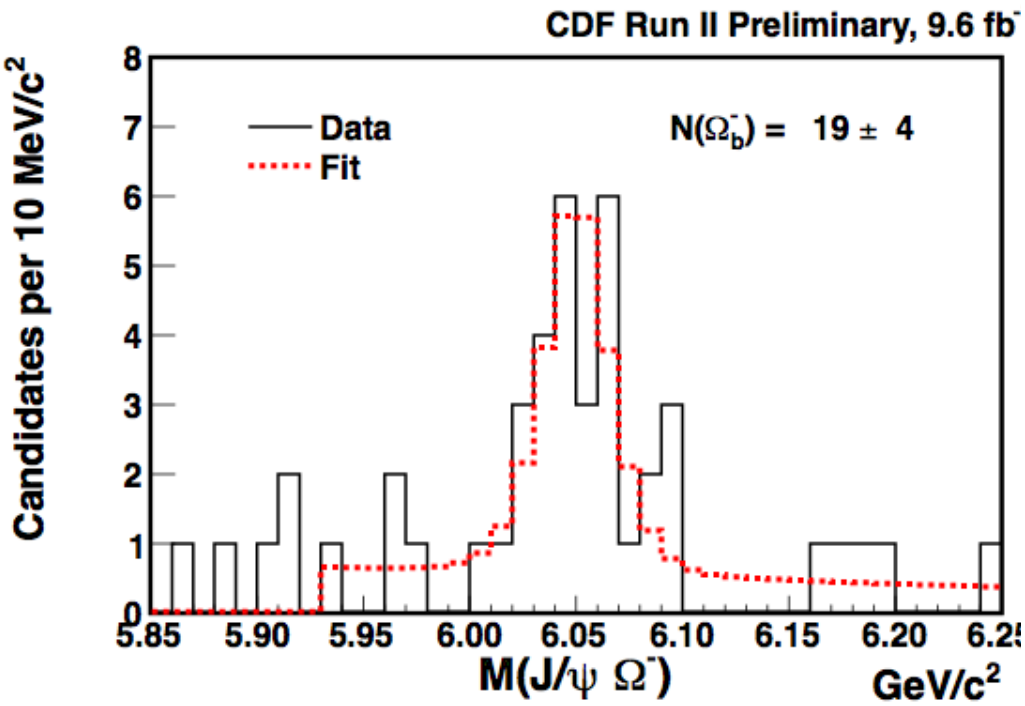
Ω^-_b mass and lifetime

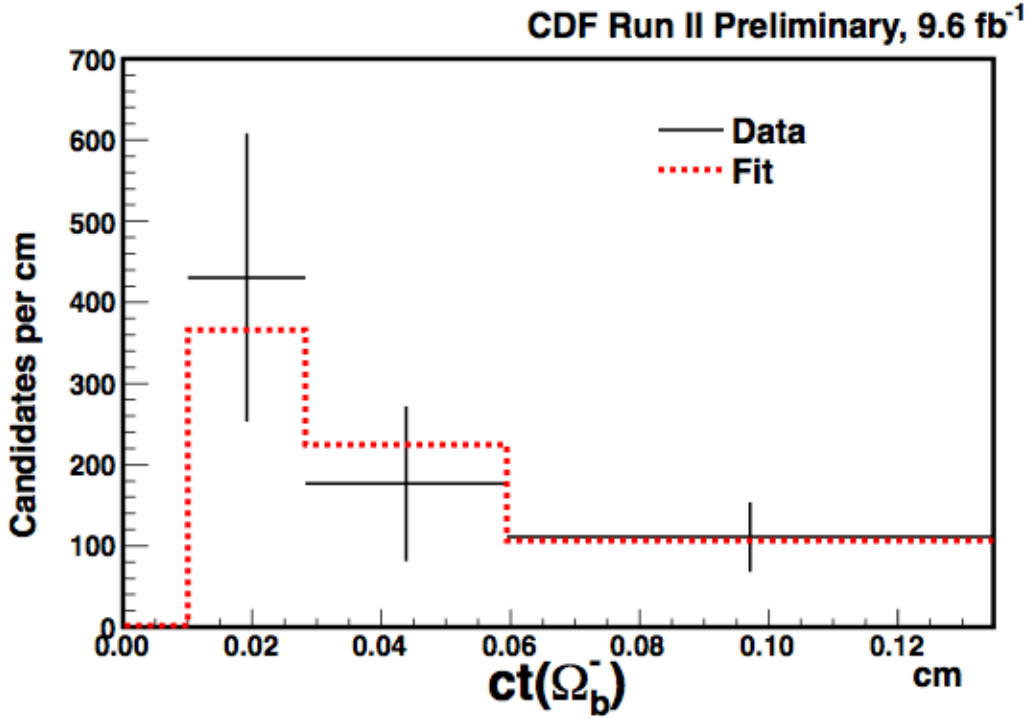
Observation

PRL 101, 232002 (2008)

PRD 80, 072003 (2009)





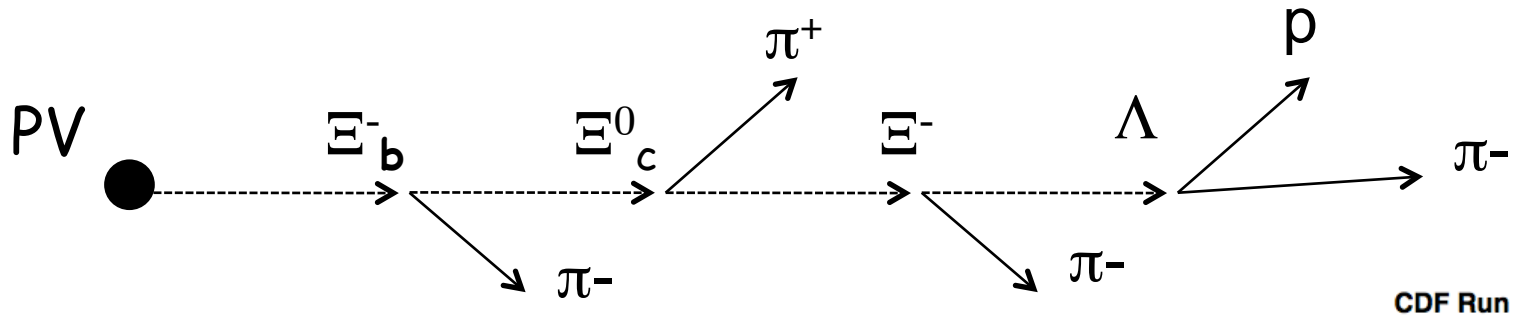


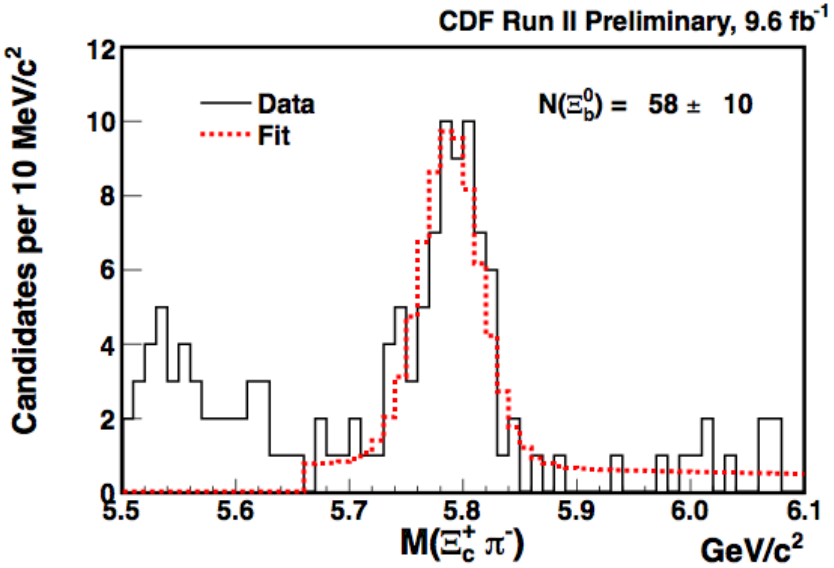
Mass (Ω^-_b): 6051.4 ± 4.2(stat) ± 0.5(syst) MeV/c^2

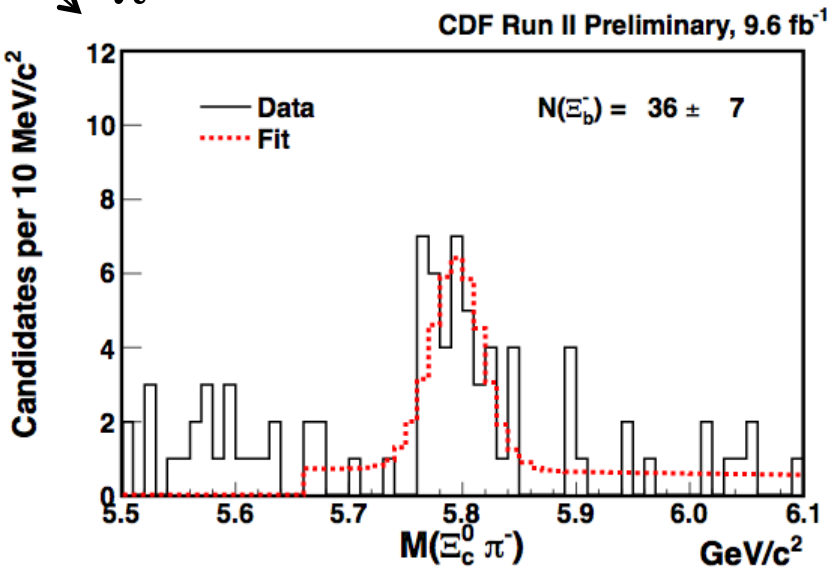
Lifetime (Ω^-_b): 1.77 +0.55 -0.41(stat) ± 0.02(syst) ps

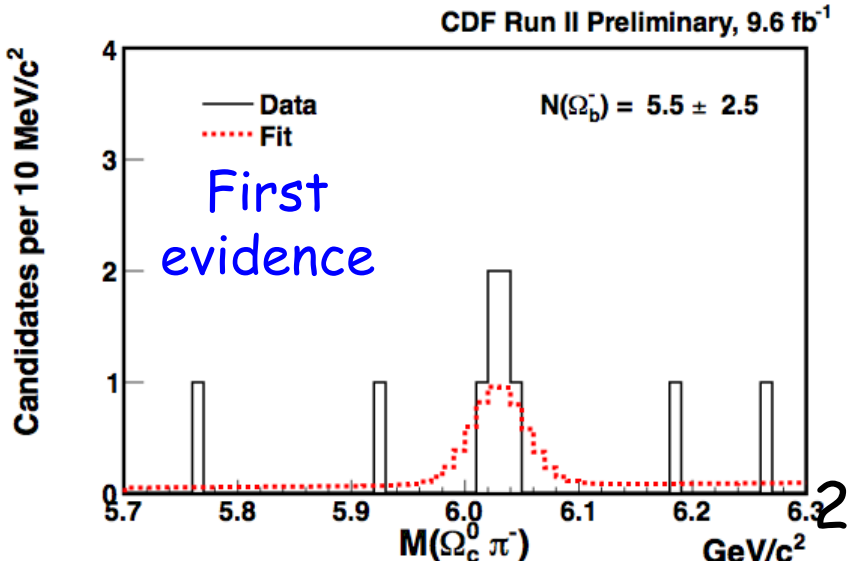
LHCb: 6046.0 ± 2.2(stat) ± 0.5(syst) MeV/c^2

Evidence for $\Omega^-_b \to \Omega^0_c \pi^-$ (hadronic)





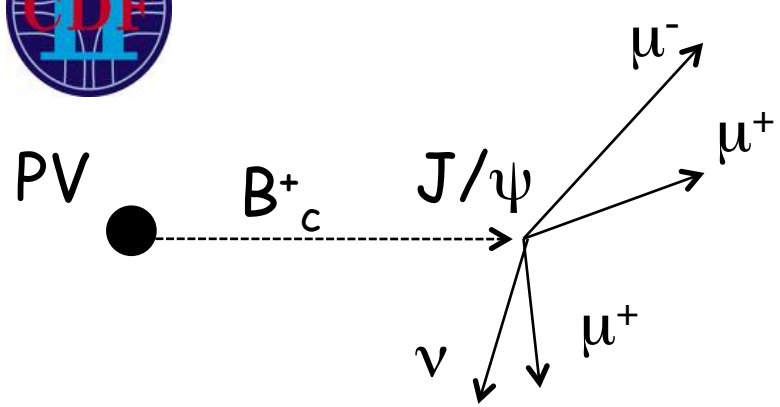




Ξ_b^0, Ξ_b^- observation in the hadronic sample
PRL 107, 102001 (2011)

Mass(Ξ^-_b): 5796.5 ±4.7(stat) ±0.95(syst) MeV/c^2
Mass(Ξ^0_b): 5791.6 ±5.0(stat) ±0.73(syst) MeV/c^2
Mass(Ω^-_b): 6040 ±8(stat) ±2(syst) MeV/c^2

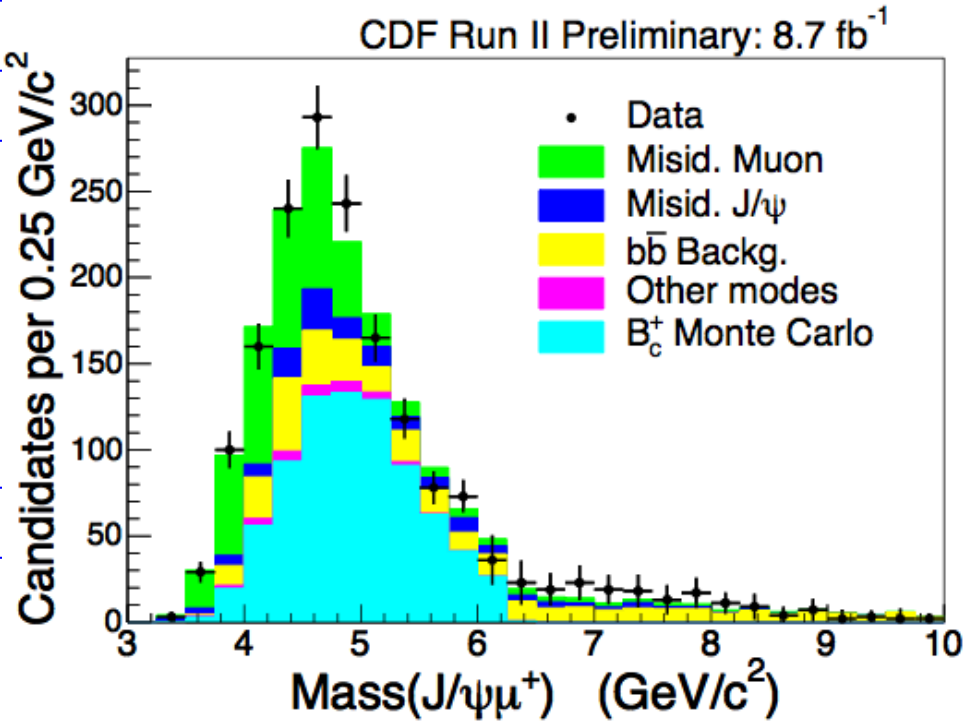
$B^+_c \to J/\psi\mu^+\nu$ relative cross section



Cross sec. measured relative to $B^+ \to J/\psi K^+$ (same number of charged tracks)

$$\frac{\sigma(B^+_c) \times BR(B^+_c \to J/\psi\mu^+\nu)}{\sigma(B^+) \times BR(B^+ \to J/\psi K^+)} = \frac{N(B^+_c)}{N(B^+)} \times \varepsilon_{rel}$$

	3-4 GeV/c^2	4-6 GeV/c^2	6-10 GeV/c^2
B_c^+ candidates	132±11.5	1370±37.0	208±14.4
Misidentified J/ψ	11.5±2.4	96.5±6.9	25.0±3.5
Misidentified Muon	86.7	344.4	32.1
Double Fake	-5.1	-19.0	-5.2
$b\bar{b}$ Background	12.4±2.4	178.6±12.4	110.4±10.7
Other decay modes	2.6±0.1	30.0±0.2	0
Total background	108.1 ± 3.4	630.5 ± 14.2	162.3 ± 11.3
B_c^+ Excess	23.9±12.0	739.5±39.6	45.7±18.3
B_c^+ Monte Carlo, (scaled to signal region)	22.6±0.6	739.5±3.7	27.6±0.6



$B^+_c \to J/\psi\mu^+\nu$ relative cross section

Systematic errors due to
- B^+_c background estimate
- Relative efficiency estimate

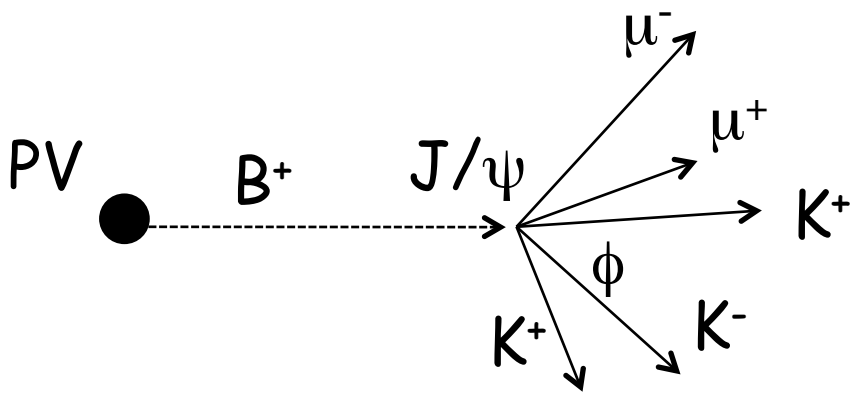
B_c^+ background	Systematic uncertainty
Misidentified J/ψ	not used
Misidentified Muon	$^{+9.6}_{-16.5}$
Double fake	$^{+0.5}_{-0.9}$
$b\bar{b}$ background	± 5.8
Other decay modes	± 16.3
Total	$^{+19.8}_{-23.9}$

	$\Delta\epsilon_{rel}$
B_c^+ lifetime	$^{+0.134}_{-0.147}$
B_c^+ spectrum	$^{+0.356}_{-0.303}$
B^+ spectrum	± 0.055
XFT	± 0.070
CMUP efficiency	$^{+0.092}_{-0.087}$
Total systematics	$^{+0.401}_{-0.359}$

Quantity	Value
$N(B_c^+ \to J/\psi\mu^+\nu)$	739.5 ± 39.6(stat) $^{+19.8}_{-23.9}$(sys)
$N(B^+ \to J/\psi K^+)$	14338 ± 125 (stat)
ϵ_{rel}	4.093 ± 0.038(stat)$^{+0.401}_{-0.359}$(sys)
$\frac{\sigma(B_c^+)BR(B_c^+\to J/\psi\mu^+\nu)}{\sigma(B^+)BR(B^+\to J/\psi K^+)}$	0.211 $\pm$ 0.012 (stat) $^{+0.021}_{-0.020}$ (sys)

Search for X(4140)

Question of existence of the narrow X(4140) resonance in the $J/\psi\phi$ spectrum of the $B^+ \to J/\psi\phi K^+$ decay is still open.



Require

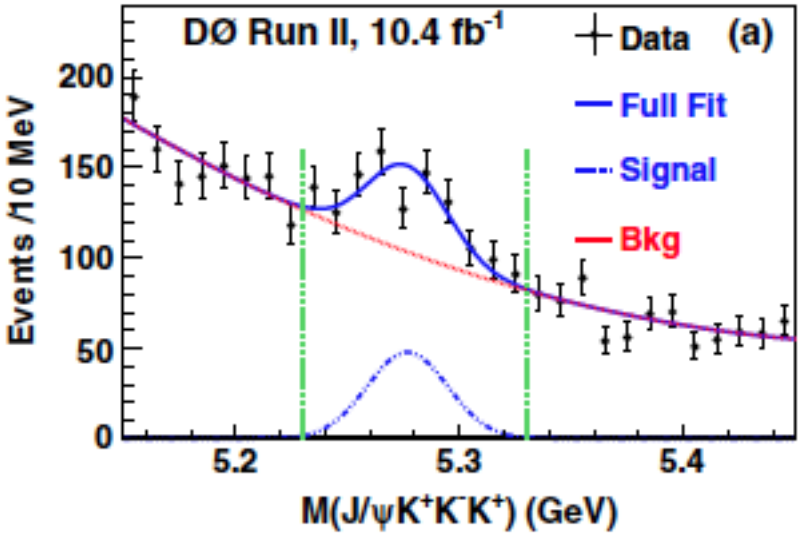
$L_{xy}(B^+) > 250\ \mu m$

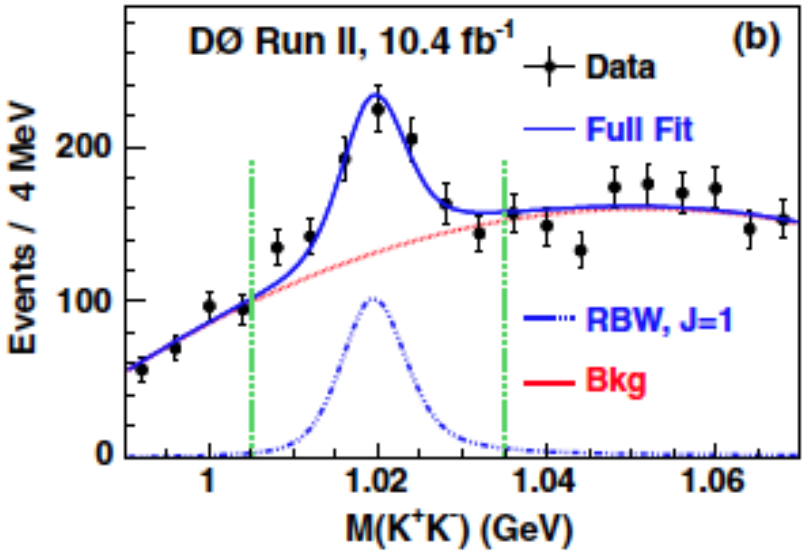
$p_T(B^+) > 7\ GeV/c$

$d(J/\psi\phi) < 50\ \mu m$

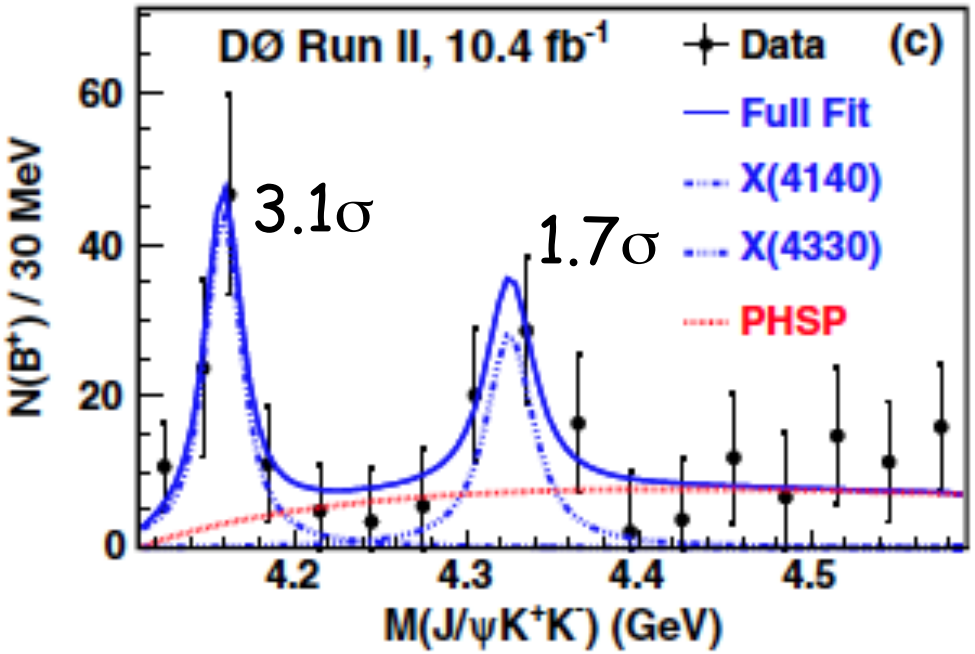
$1.005 < m(\phi) < 1.035\ GeV/c^2$

Estimate 215 ±37 B^+ events





Search for X(4140)



- CDF: 3.8σ evidence
- Belle: No evidence
- LHCb: No evidence
- CMS: >5σ observation

3.1σ evidence for the X(4140)

Mass

4159 ±4.3(stat) ±6.6(syst) MeV/c^2

Width

19.9 ±12.6(stat) ±8(syst) MeV/c^2

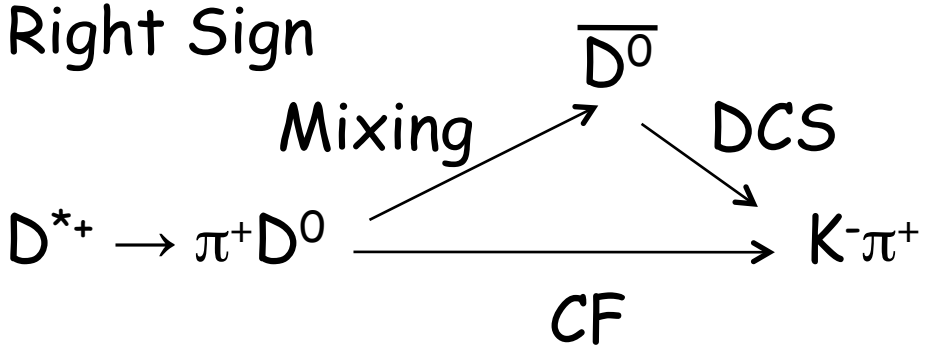
PRD89, 012004 (2014)

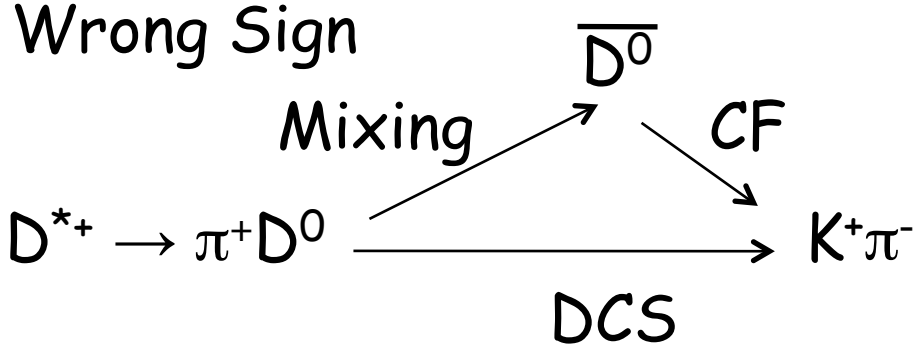
$$\frac{BR(B^+ \to X(4140)K^+)}{BR(B^+ \to J/\psi\phi K^+)} = [19 \pm 7(stat) \pm 4(syst)]\ \%$$

Charm Mixing

- Compare rate of wrong-sign $D^0 \rightarrow K^+\pi^-$ decays to right-sign $D^0 \rightarrow K^-\pi^+$ decays

  - Tag flavor at production with $D^{*+} \rightarrow D^0\pi^+$ decays
  - Wrong sign events can come from mixing or double Cabibbo suppressed (DCS) decays
  - DCS decays are time independent

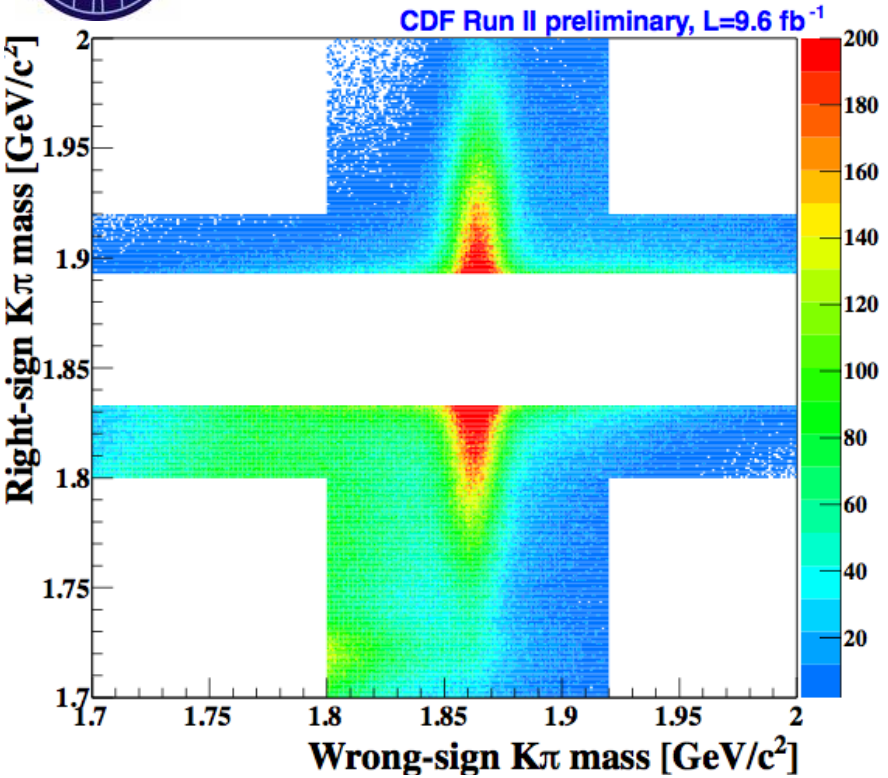




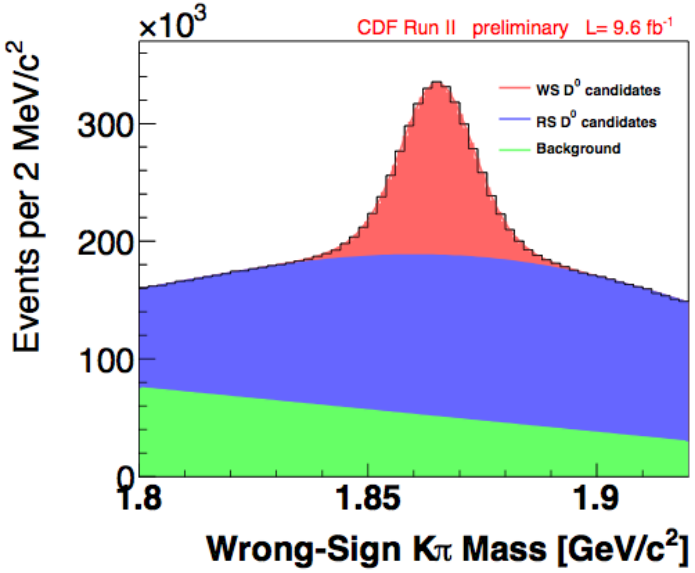
- If no CP violation and small mixing ($x,y \ll 1$):

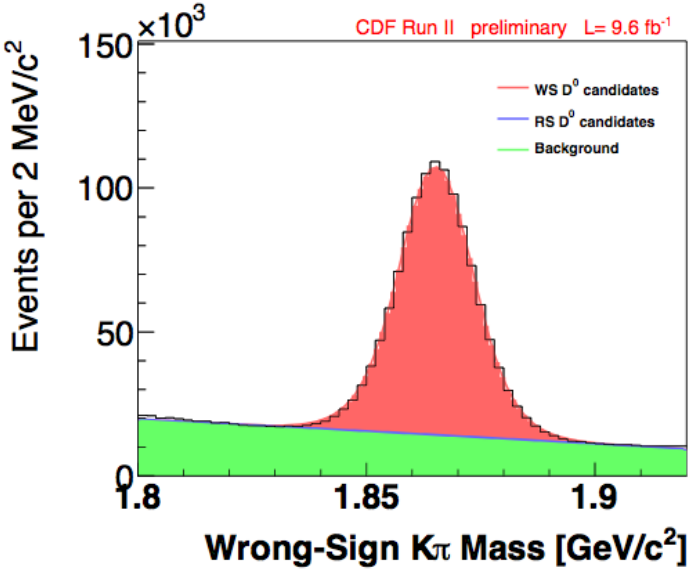
$$R(t/\tau) = R_D + \sqrt{R_D}\, y' \times (t/\tau) + 1/4 \times (x'^2 + y'^2) \times (t/\tau)^2$$

Extracting clean WS signal

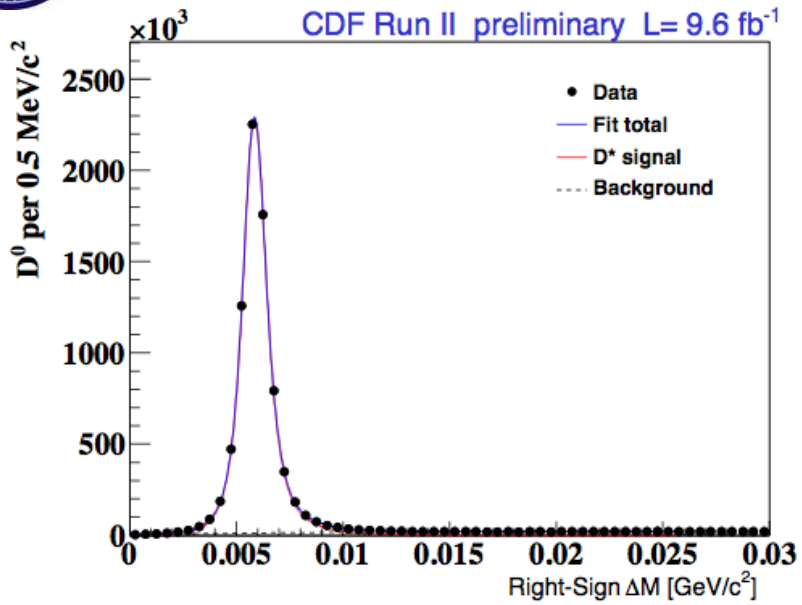


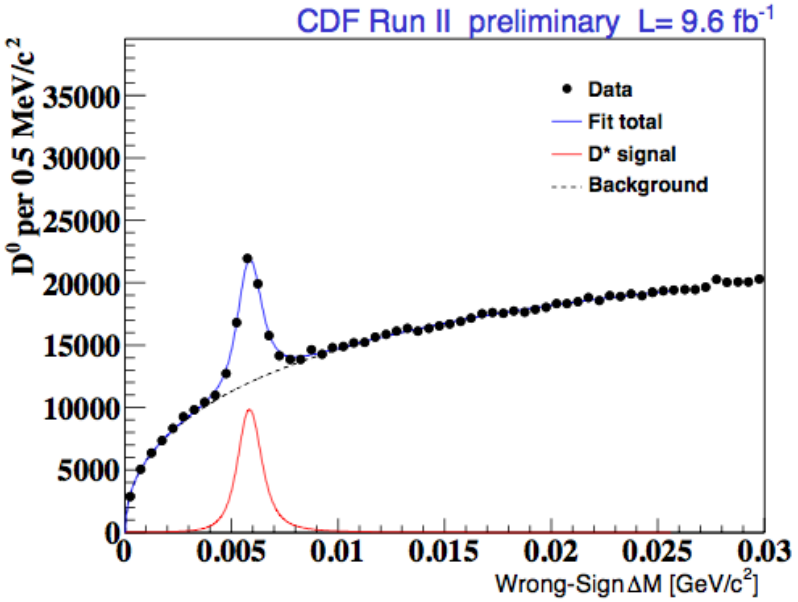
- WS signal contaminated by large background due to wrong charge assignment in RS decays
- Remove WS candidates consistent with RS hypothesis and vice versa
  - 96 % of background removed
  - 78 % efficient on signal





D^{*+} reconstruction

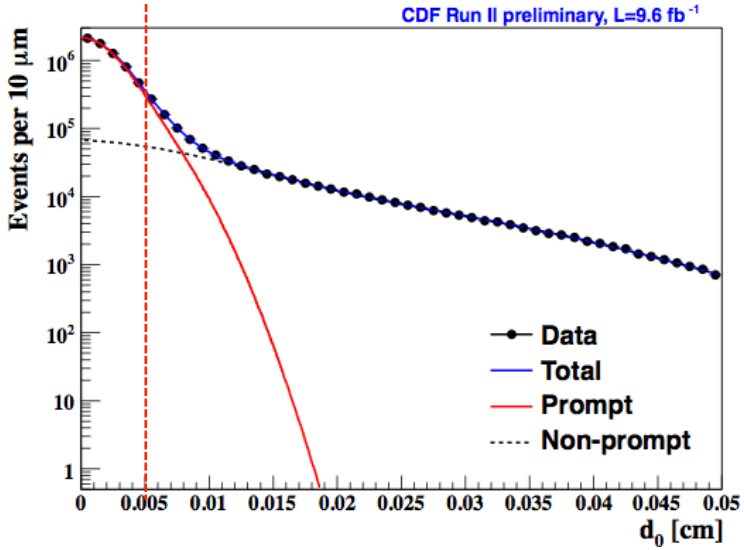




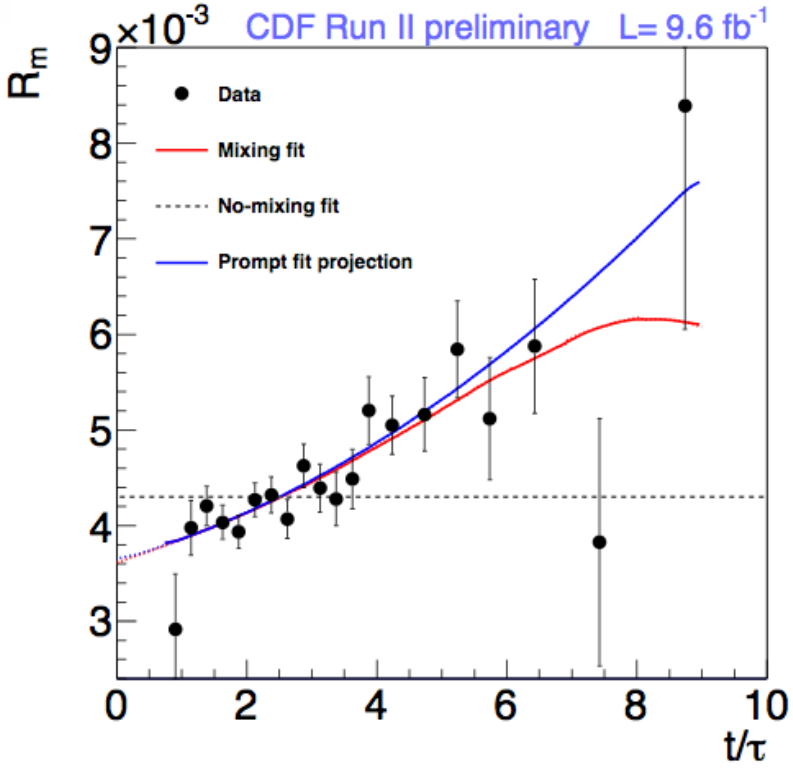
- The D^0 yields are determined in 20 bins of decay time, and 60 bins of $\Delta m = m(K\pi\pi_{tag}) - m(K\pi) - m(\pi)$, for RS and WS

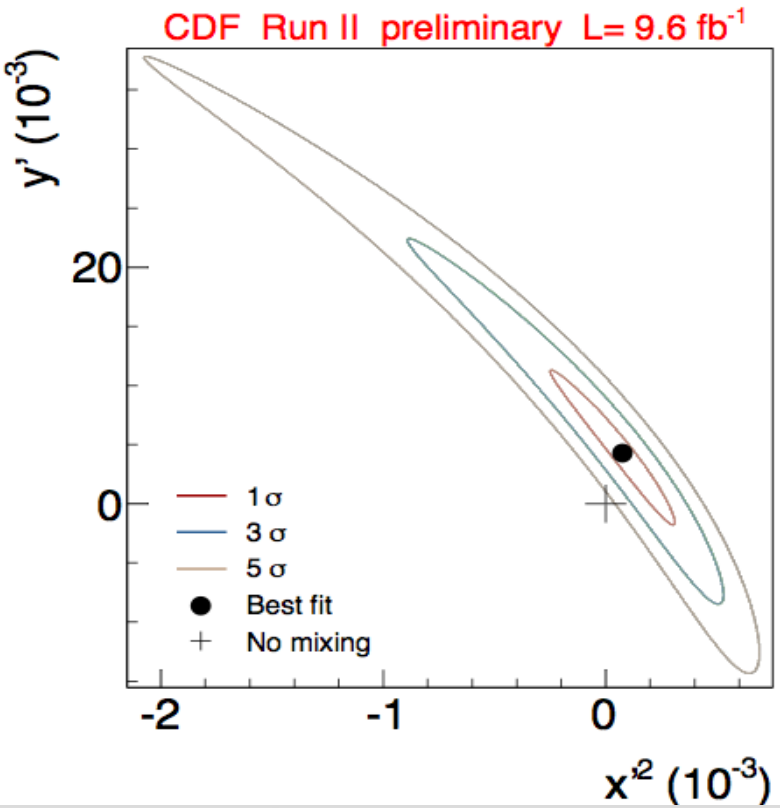
- Correction needed for B decay component, which generates a larger apparent lifetime

- Use D^0 impact parameter



D^0 Mixing measurement





Fit type	χ^2/ndf	Parameter	Fitted values $\times 10^{-3}$	Correlation coefficient R_D	y'	x'^2
Mixing	16.91/17	R_D	3.51 ± 0.35	1	-0.967	0.900
		y'	4.3 ± 4.3		1	-0.975
		x'^2	0.08 ± 0.18			1
No-mixing	58.75/19	R_B	4.30 ± 0.06			

D^0 mixing is observed at 6.1σ, mixing parameters are compatible with other experiments

PRL 111, 231802 (2013)

Direct CPV in $B^+ \to J/\psi K^+$, $B^+ \to J/\psi \pi^+$

No effect expected in $b \to scc$ ($J/\psi K$), possible in $b \to dcc$ ($J/\psi \pi$)

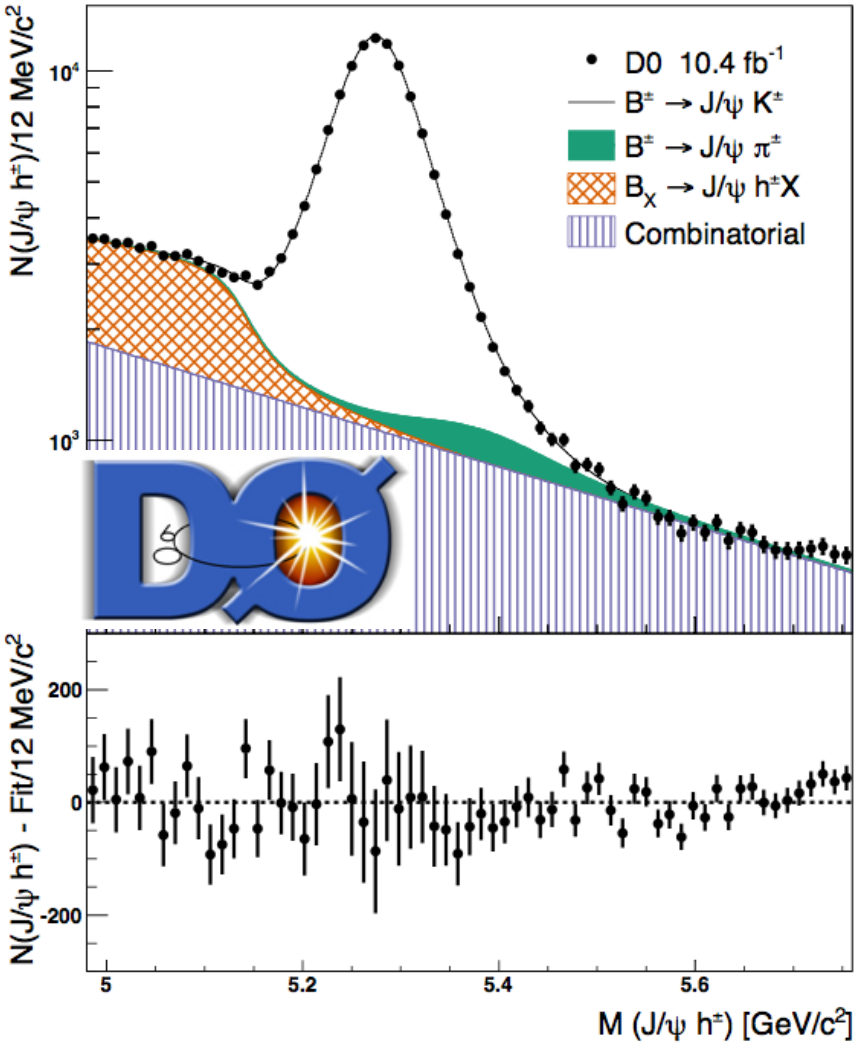
$$A(J/\psi X) = A(J/\psi X)_{RAW} + A(X)$$

Correction in rec. asym. between X^+ and X^-

Raw asym. between rec. B^+ and B^-

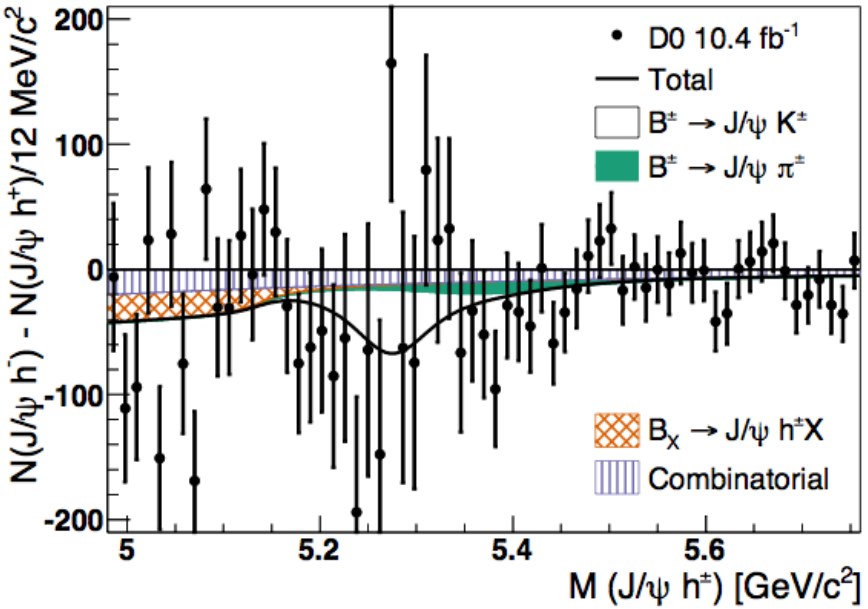
- Regular reversal of magnetic field minimizes $A(\pi)$
- $A(K)$ measured in $K^{*0} \to K^+\pi^-$

Event selection chosen to minimize statistical uncertainty on $A(J/\psi K)_{RAW}$



Direct CPV in $B^+ \to J/\psi K^+$, $B^+ \to J/\psi \pi^+$

Type of uncertainty	$A^{J/\psi K}$ (%)	$A^{J/\psi \pi}$ (%)
Statistical	0.36	4.4
Mass range	0.022	0.55
Fit function	0.011	0.69
$\Delta A_{\text{tracking}}$	0.05	0.05
ΔA_K	0.043	n/a
Total systematic uncertainty	0.07	0.9
Total uncertainty	0.37	4.5



$A(J/\psi K)$ = [0.59 ±0.36(stat) ±0.07(syst)] %
with a 1 % correction due to K^+/K^- asymmetry

$A(J/\psi \pi)$ = [-4.2 ±4.4(stat) ±0.9(syst)] %

PRL 110, 241801 (2013)

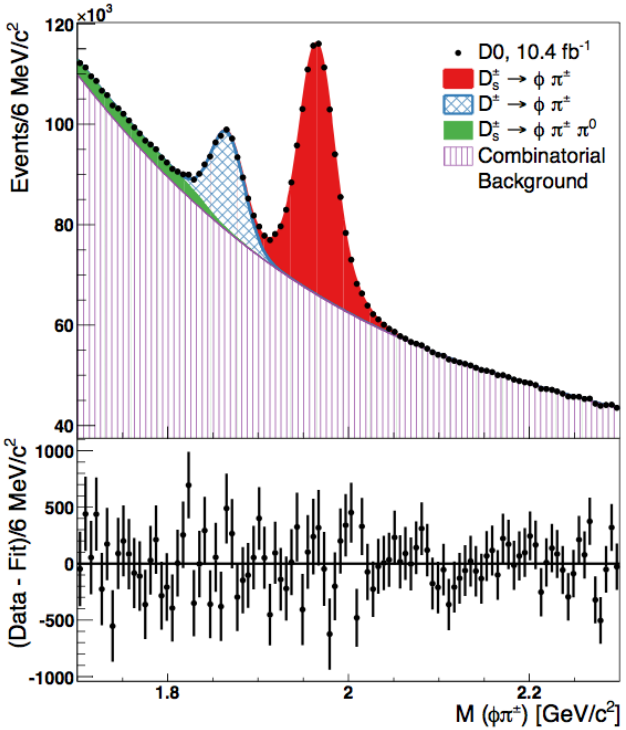
Direct CPV in $D^+_s \to \phi\pi^+$

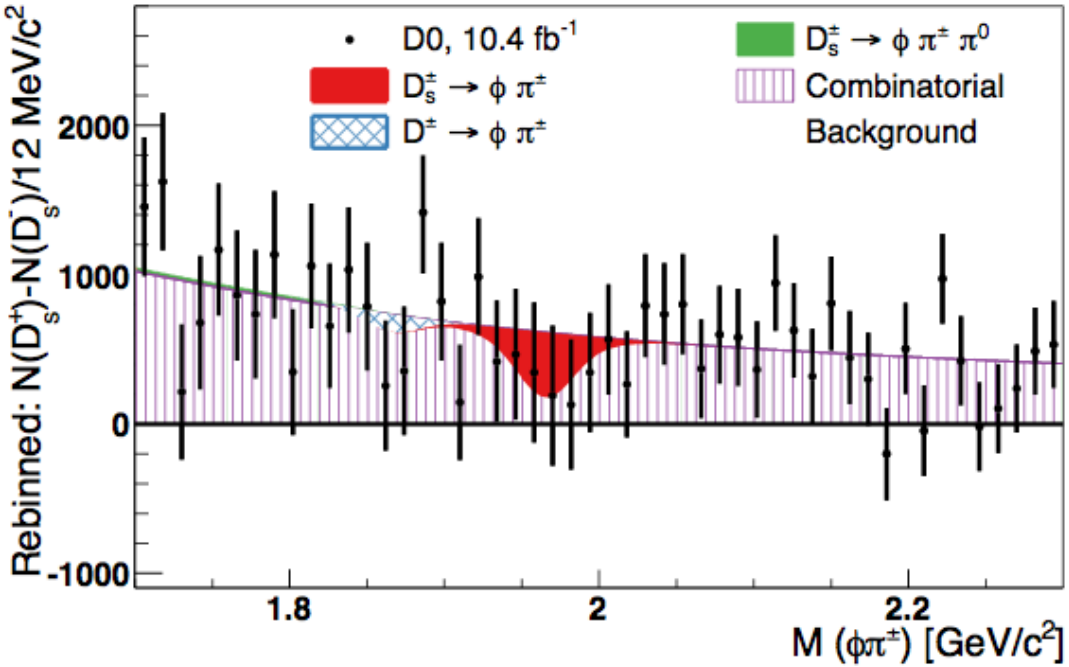
SM predicts non-existent CPV in this decay mode

$$A(\phi\pi^+) = A(\phi\pi^+)_{RAW} - A_{DET} - A_{PHYS}$$

RAW asym. from a simultaneous fit of sum/diff distributions

A_{DET} = -0.08% from data, A_{PHYS} = 0.02% from MC





World's best

A_{CP} = [-0.38 ±0.26(stat) ±0.08(syst)] %

arXiv:1312.0741

accepted by PRL

Conclusions

- CDF and D0 have been first class players in the field of heavy flavor physics for 20 years, with >150 papers
- Our results have been complementary and competitive with B-Factories in term of precision
- After showing that precision Heavy Flavor Physics is possible at hadron colliders, we are now leaving a rich legacy to LHC and future B-Factories
- But, still more to come with full Tevatron statistics