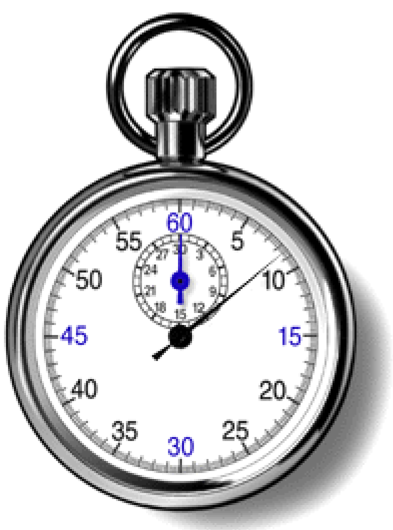
B Hadron Properties at the Tevatron

HCP2008
May 29, 2008



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on behalf of the D0 and CDF Collaborations

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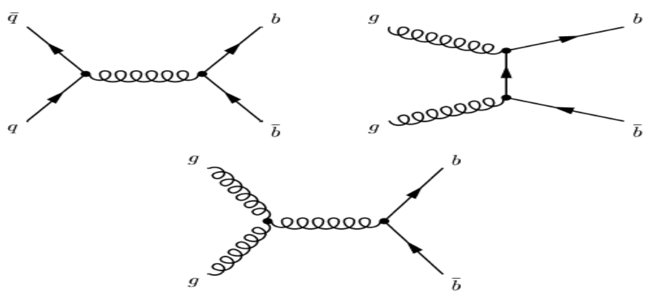
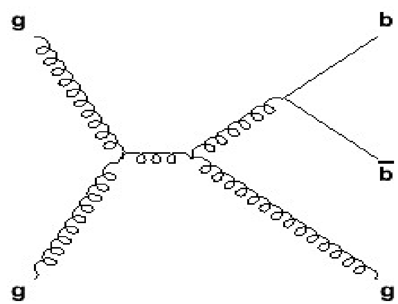
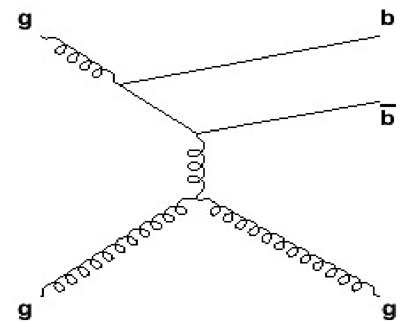
B Physics at the Tevatron







Large bb(bar) cross section, but still 1/1000 of total inelastic cross section

Dependant on triggers to get to B events (J/ψ, displaced vertices, leptons)

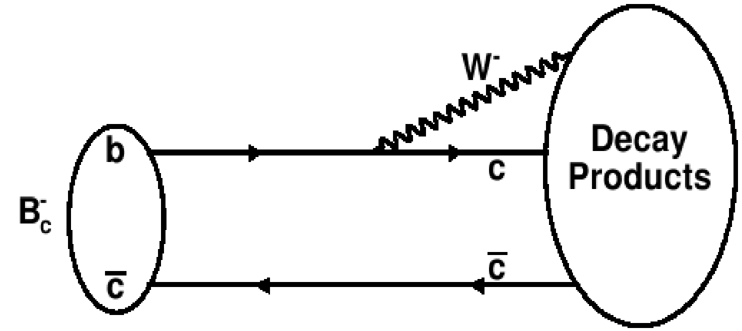
Many states only accessible at Tevatron: B_c Λ_b Σ_b Ξ_b...

B physics probes many aspects of theory:

1) CKM Matrix
2) QCD parameters
3) BSM processes
4) Effective field theories – HQET, NRQCD, lattice QCD...

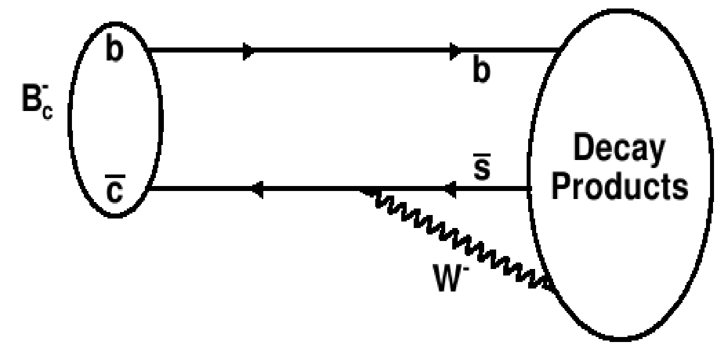
The B_c Meson

Two heavy (b and c) quarks, but decays weakly = unique laboratory for physics



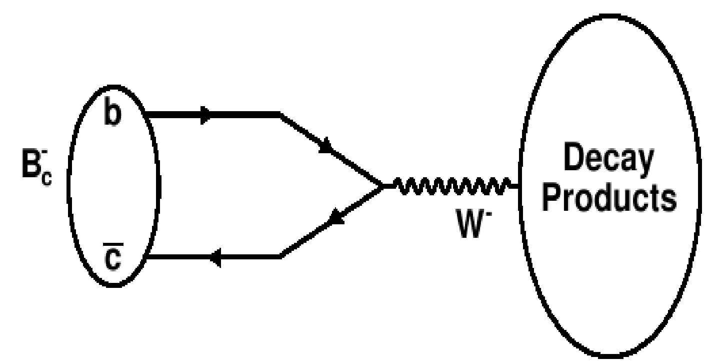
Mass – potential models and lattice QCD calculations

Decay – both quarks contribute to width, expect shorter lifetime than B mesons, lots of decay modes



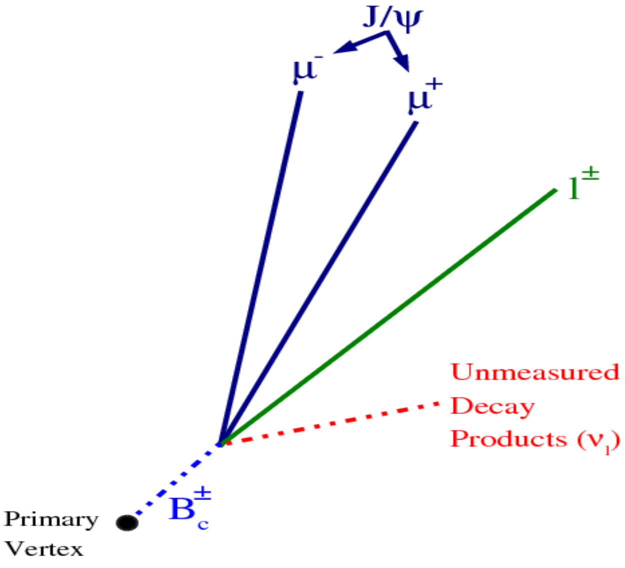
Theory predicts τ~0.5 ps, but large uncertainties and model to model variation

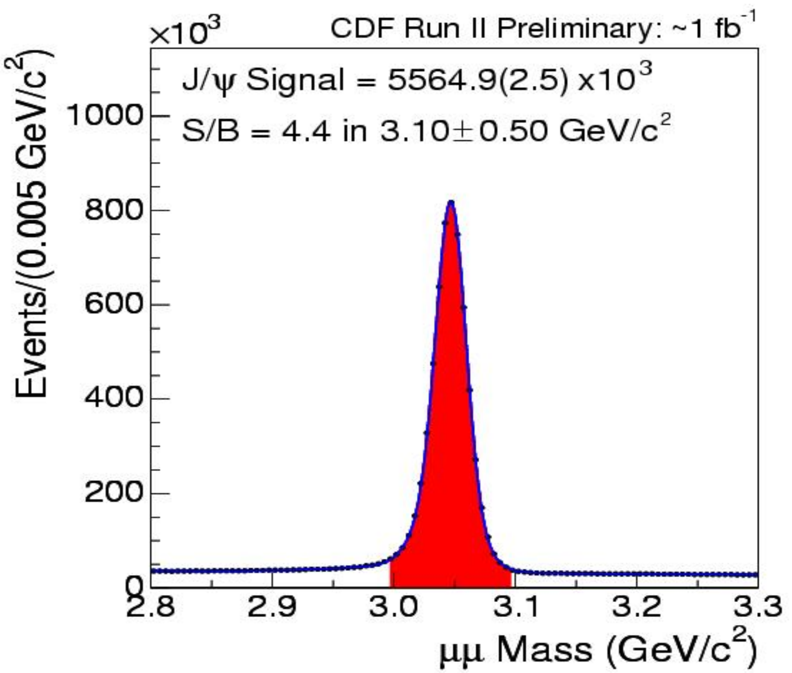
Weak decay of b quark -> final states with J/ψ (nice signature for experiment)



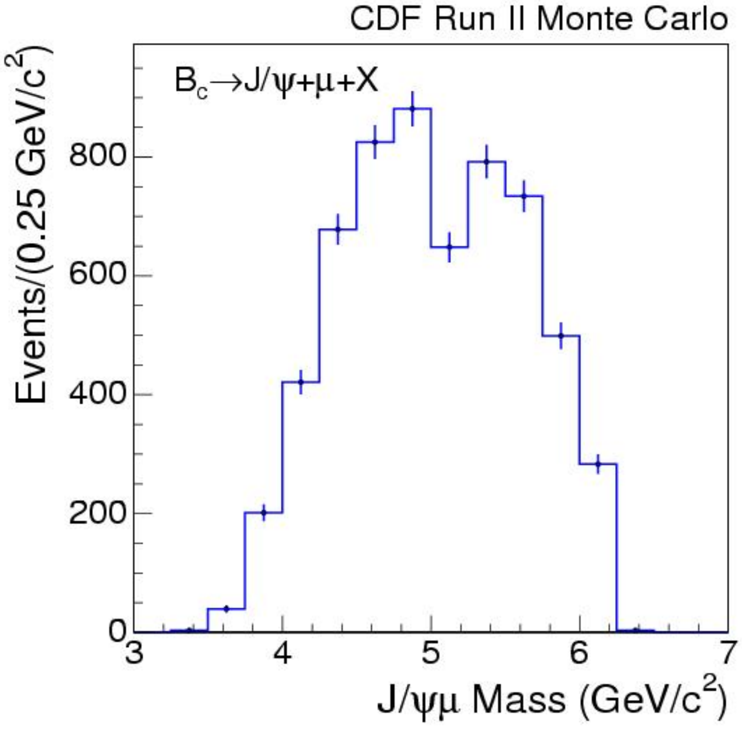
Lifetime in B_c->J/ψ+l+X (CDF)

- Select tri-lepton events
  - 2 muons reconstruct to J/ψ mass ~5.5 million candidates
  - 3^{rd} lepton from same vertex: 1935 electron candidates
    572 muon candidates
- Model missing momentum in signal events
- Model tri-lepton backgrounds
- Likelihood minimization of lifetime distribution using signal and background models

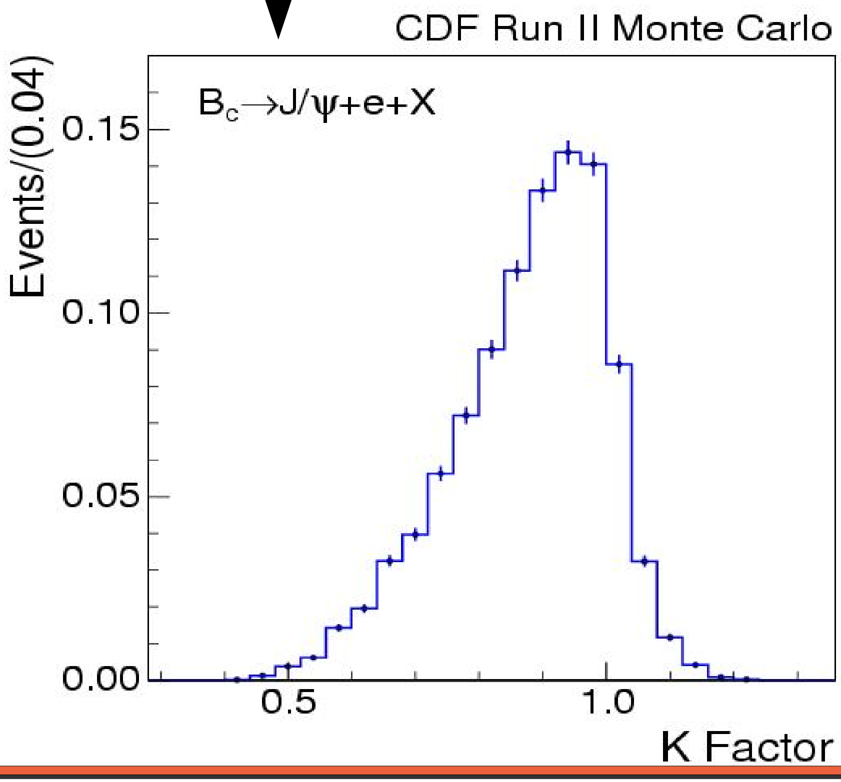




Signal Model



- Missing neutrino means broad J/ψ+l mass window for signal: 4-6 GeV/c^2
- Also means missing momentum when measuring lifetime
- Correct using "K" factor from MC of B_c decays



- MC requires assumptions about B_c production spectrum and branching fractions

Tri-lepton Backgrounds

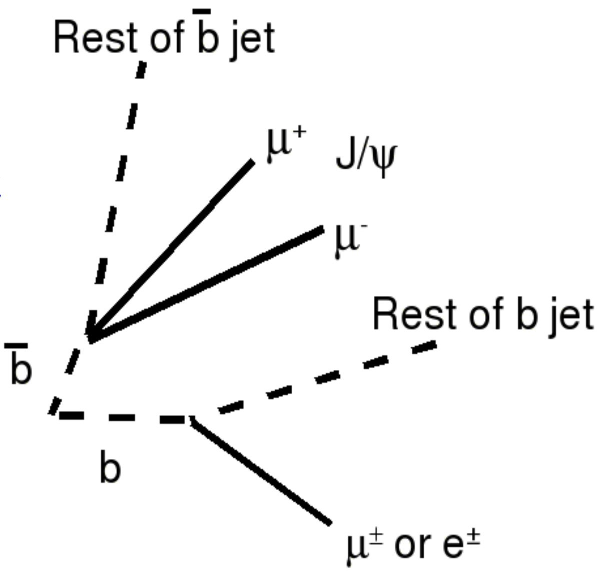
Small B_c production compared to bb(bar) or cc(bar) -> rare events can be significant backgrounds:

1) J/ψ continuum background with third lepton – easily modeled from J/ψ mass sidebands

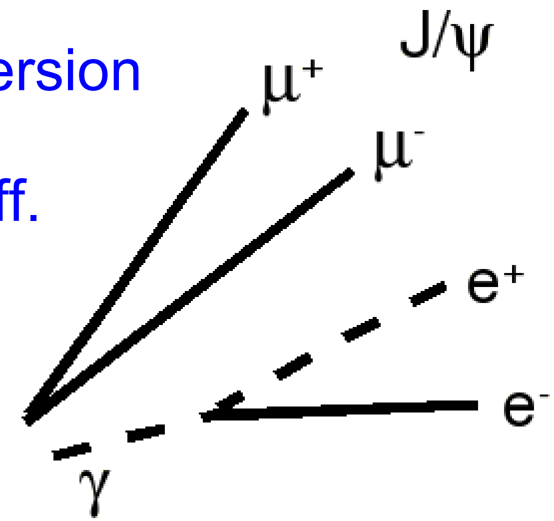
2) Hadrons faking third lepton – estimate fake rates for π, K from D^*->$D^0(\pi K)\pi$ and p from Λ->pπ

3) J/ψ and lepton faking vertex (lepton from other b jet or photon conversion)

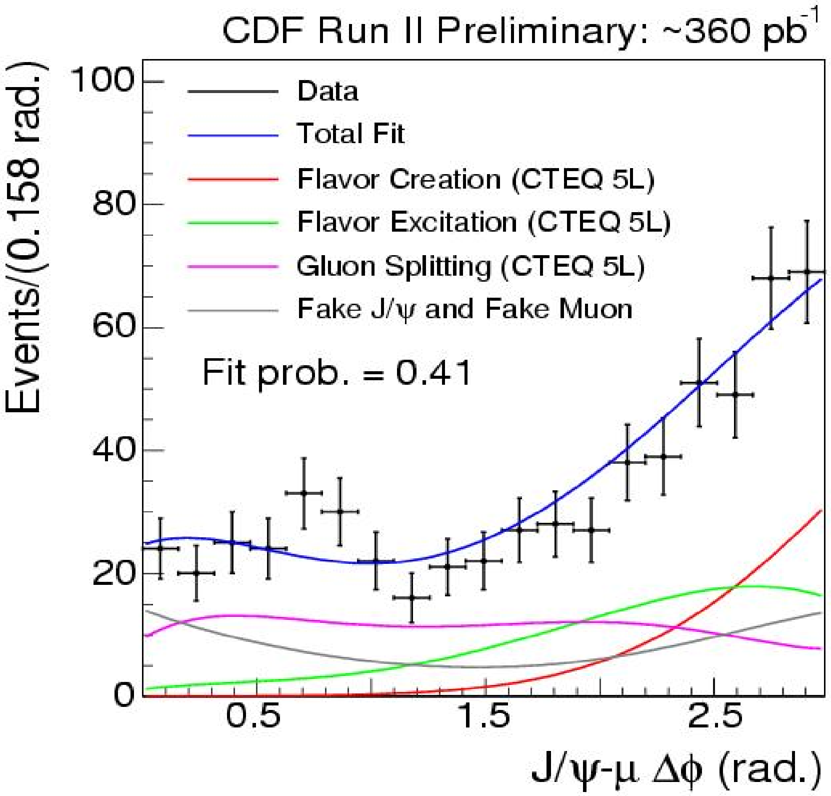
Model with MC



ID conversion partner, model eff.

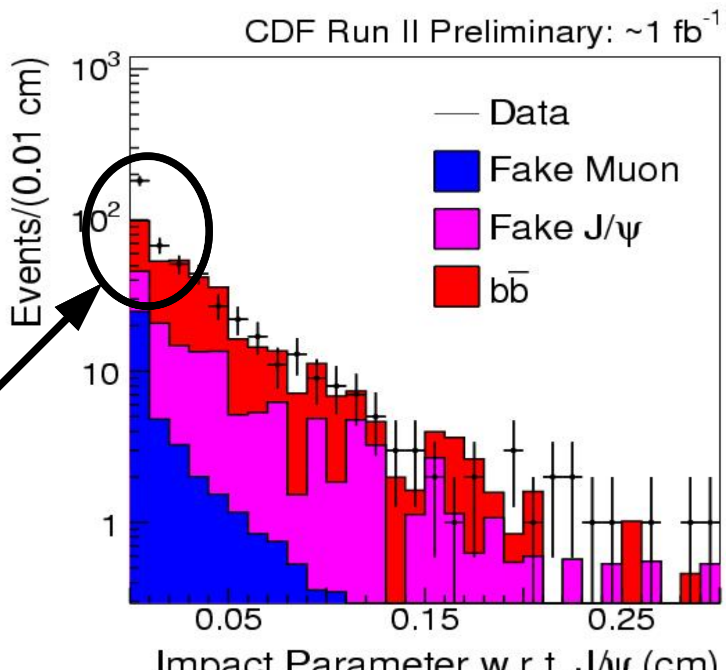


More on bb(bar) Background

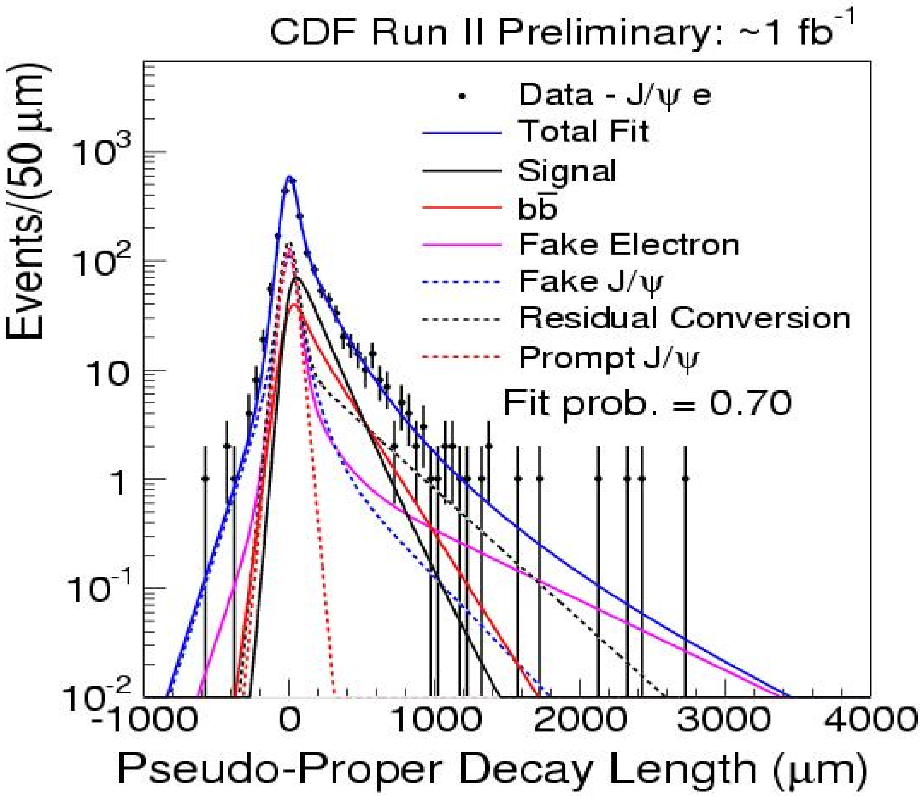


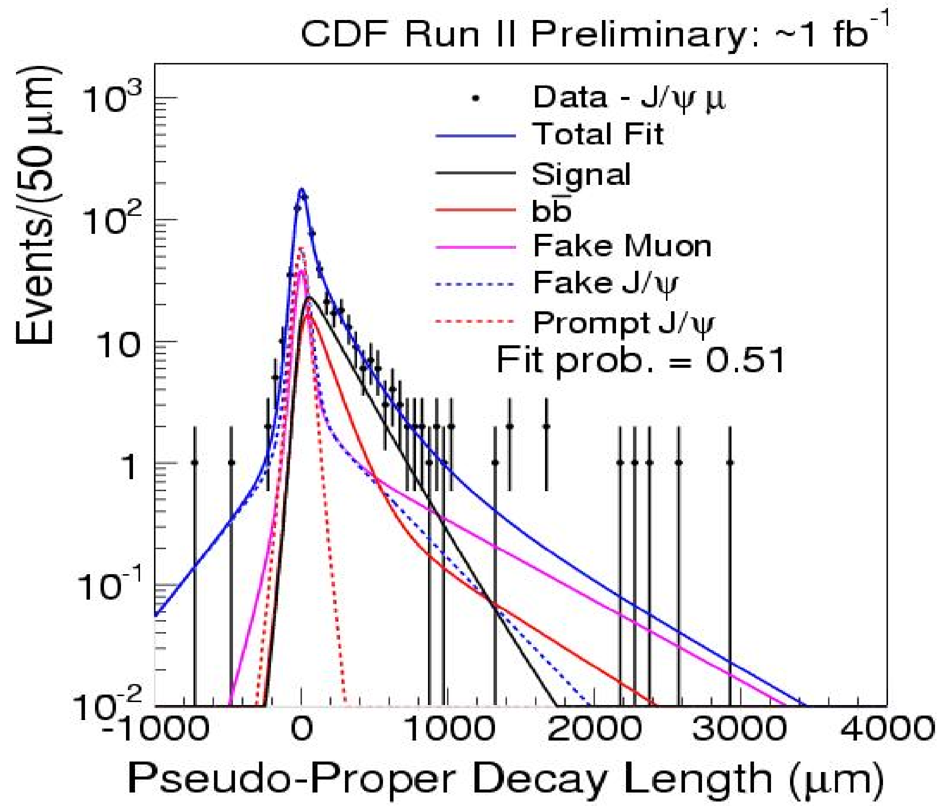
- Realistic MC for bb(bar) background
- Uncertainties in the pp(bar)->bb(bar) production
- Tune Pythia sample using fit to $\Delta\phi$ (J/ψ–μ) in data with no J/ψ–μ vetex requirements (left)
- Double check agreement with data using impact parameter of third muon with respect to J/ψ vertex

Excess from signal



B_c Lifetime Results





Electron Channel: $\tau = 0.403^{+0.060}_{-0.053}(stat.)\ ps$

Muon Channel: $\tau = 0.597^{+0.11}_{-0.09}(stat.)\ ps$

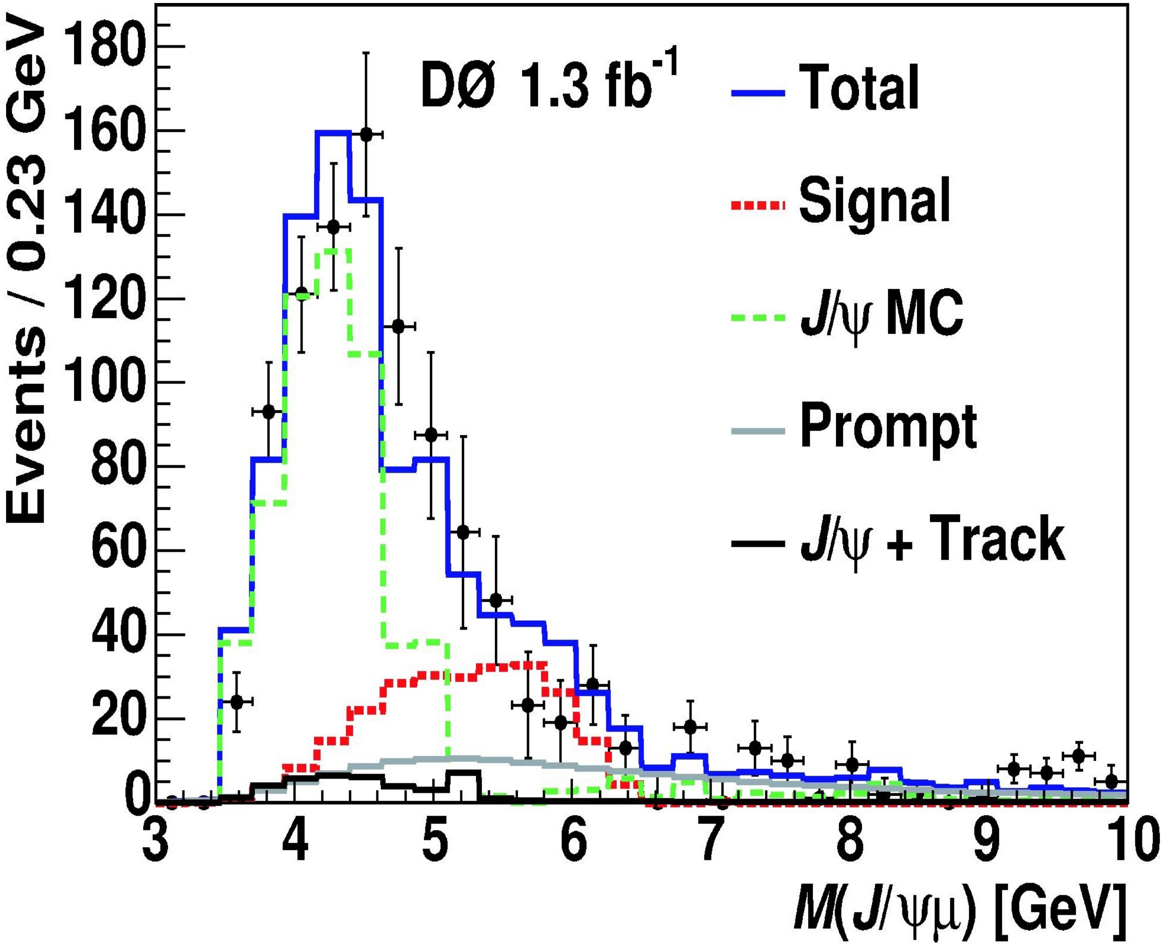
Combined Result: $\boxed{\tau = 0.476^{+0.053}_{-0.049}(stat.) \pm 0.018(syst.)\ ps}$

http://www-cdf.fnal.gov/physics/new/bottom/080327.blessed-BC_LT_SemiLeptonic/

B_c Lifetime (D0)

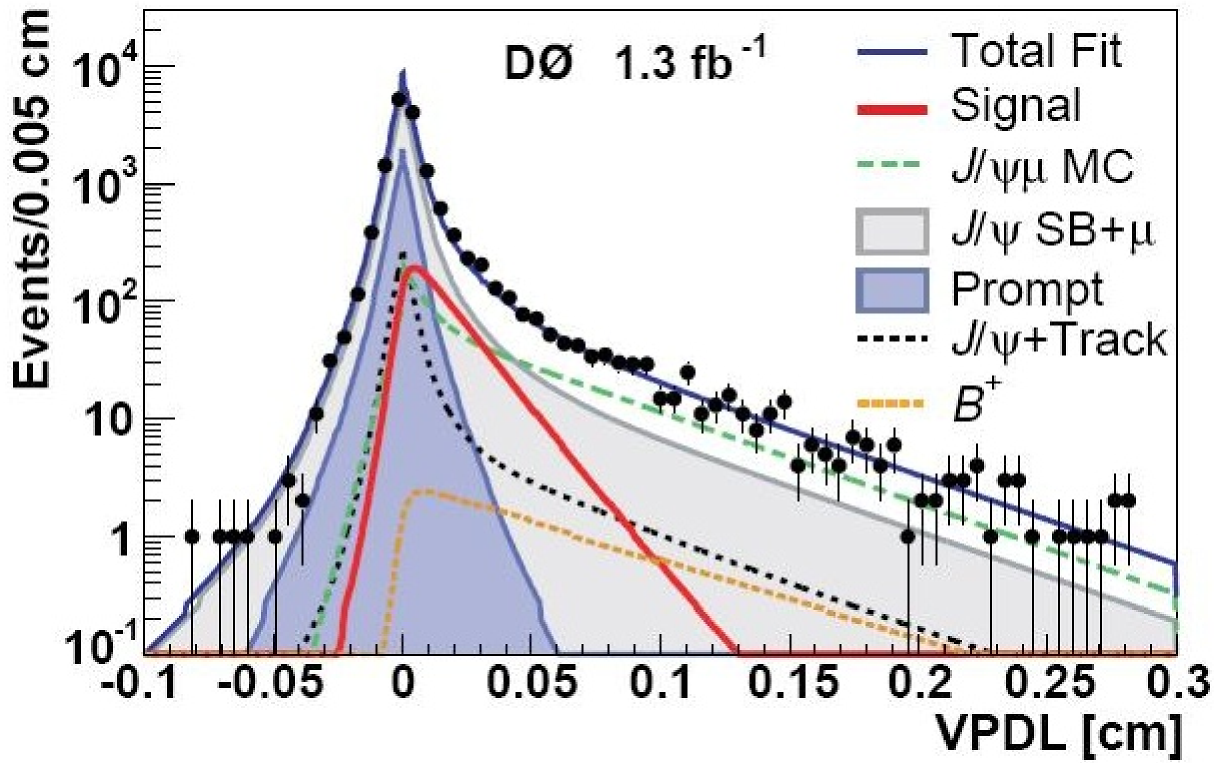
- Measurement using $B_c \to J/\psi(\mu\mu)+\mu+X$ decays
- D0 has excellent muon acceptance -> good match with 3 μ final state

- Similar backgrounds as CDF measurement
- Simultaneous mass, lifetime fit to help constrain backgrounds
- Requires K factors to model missing momentum (similar to CDF analysis)



B_c Lifetime Result

- 14753 $J/\psi+\mu$ candidate events
- Fit returns B_c yield of 881±80 events



Result with 1.3 fb^{-1} of data:

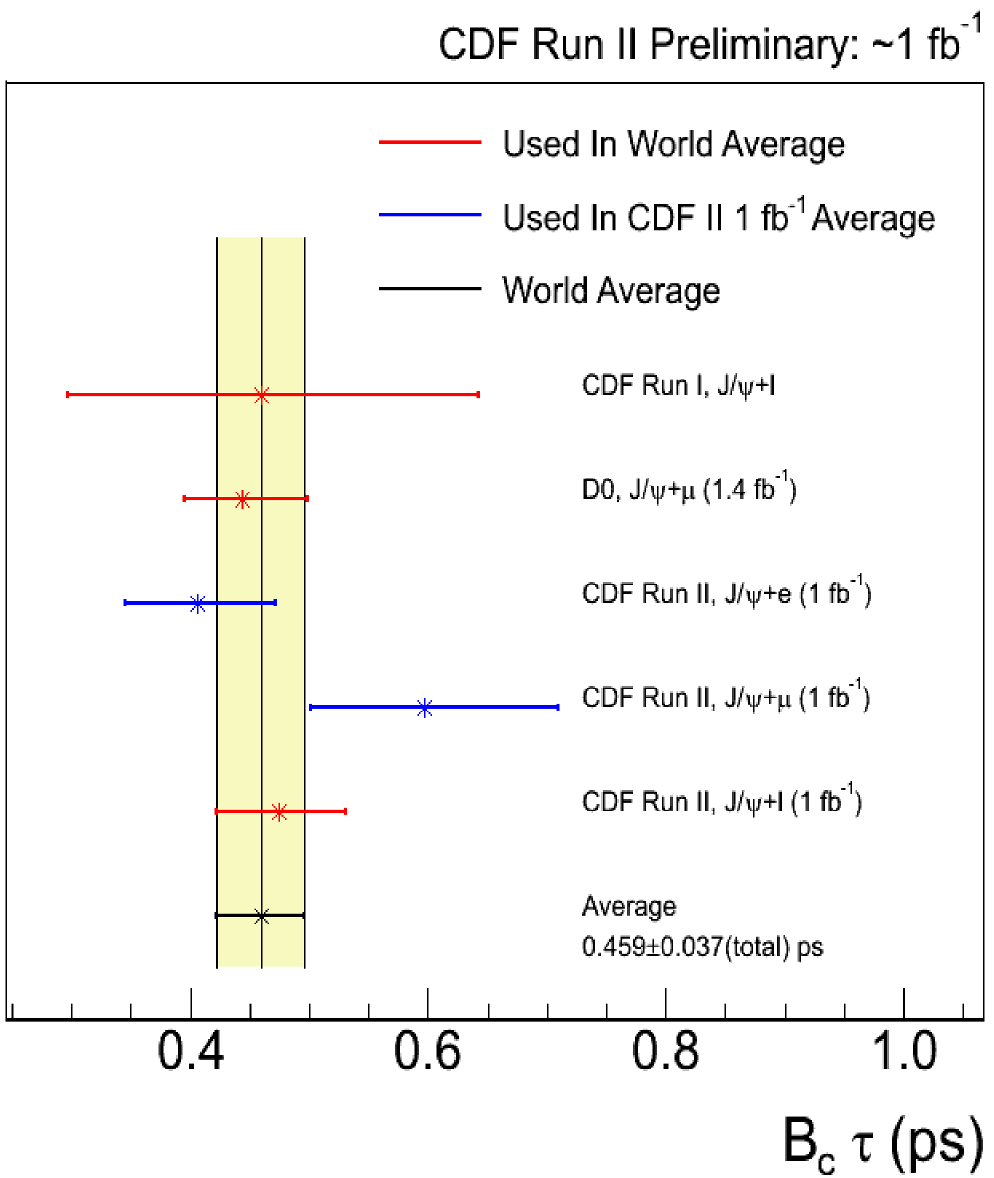
$$\tau = 0.448^{+0.038}_{-0.036}(stat.) \pm 0.032(syst.)\ ps$$

Mass templates are primary source of systematic uncertainty

World best measurement

arXiv:0805:2614v1[hep-ex]

B_c Lifetime Summary



Speaker's world average of B_c lifetime results:

$\tau = 0.459 \pm 0.037$ ps

Compares to theoretical predictions that range (central values):

$\tau = 0.47 – 0.59$ ps

arXiv:hep-ph/0006104
Phy Rev. D 64, 14003 (2001)
Phy Lett. B 452, 129 (1999)
hep-ph/0002127 (and references within)

B_c Mass (D0)

- Using $B_c^{\pm} \to J/\psi(\mu\mu)+\pi^{\pm}$ - fully reconstructed = precise mass measurement
- Expect BR ~0.1 of semileptonic modes

- Cuts optimized on:

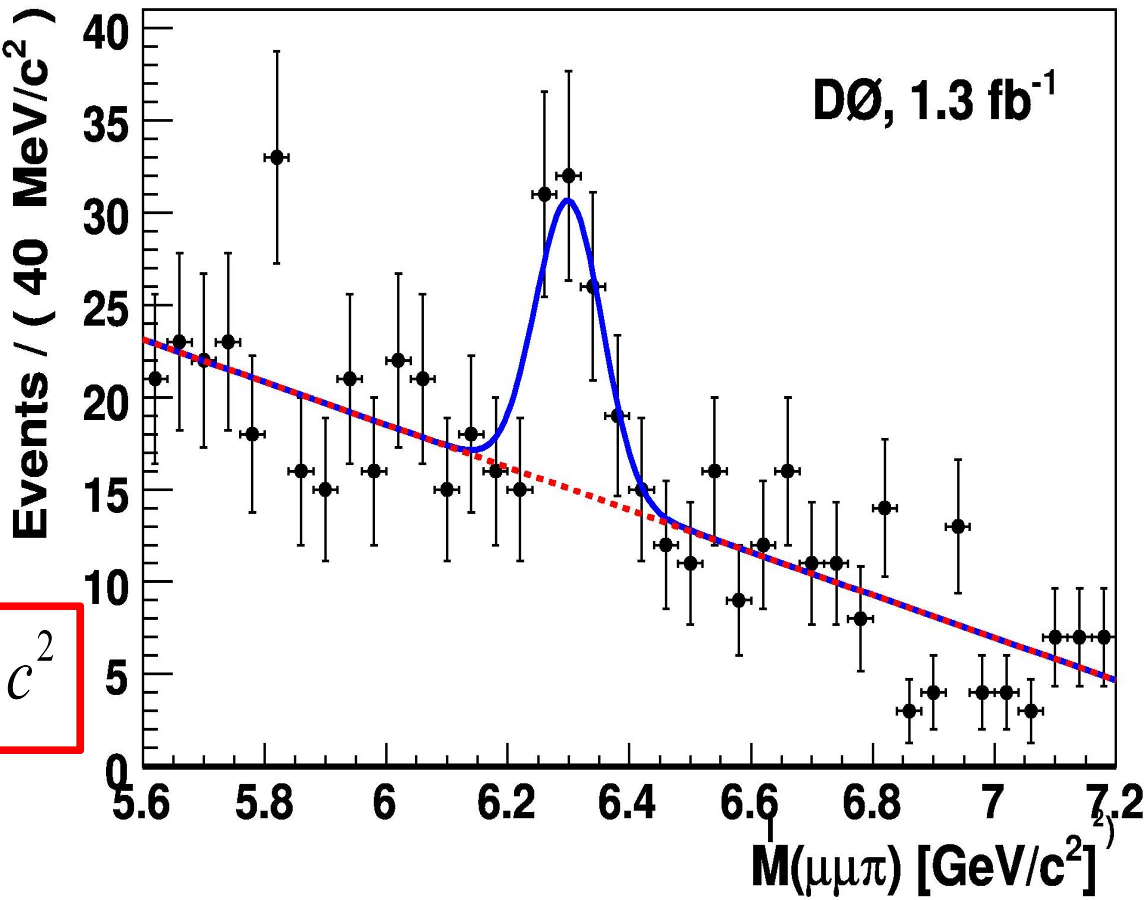
  Stage 1 - $B_u^{\pm} \to J/\psi+K^{\pm}$ (data)

  Stage 2 - $B_c^{\pm} \to J/\psi+\pi^{\pm}$ (MC)

Measurement with 1.3 fb^{-1}:

54±12 Signal Events

$$\boxed{M = 6300 \pm 14\,(stat) \pm 5\,(syst)\ MeV/c^2}$$



arXiv:0802.4258[hep-ex]

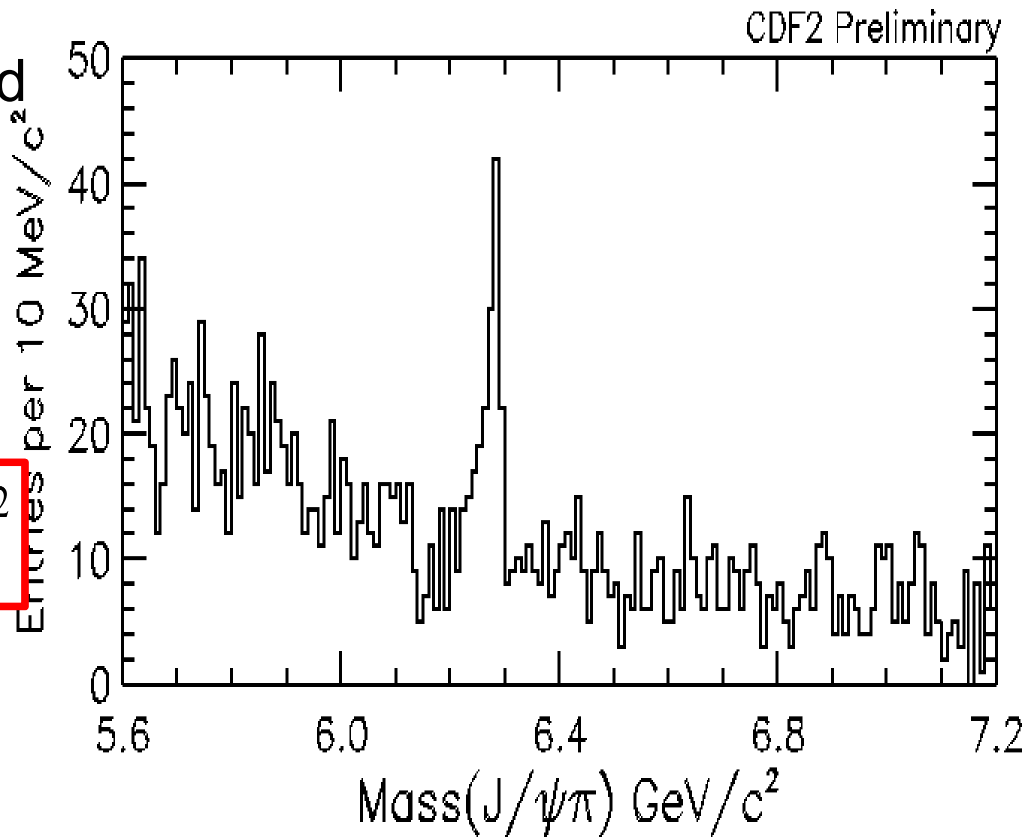
B_c Mass (CDF)

- CDF $B_c^{\pm} \to J/\psi(\mu\mu)+\pi^{\pm}$ has been updated
- Cuts optimized on $B_u^{\pm} \to J/\psi + K^{\pm}$
- Most recent update with 2.4 fb^{-1}:

108±15 Signal Events

$$M = 6275.6 \pm 2.9(stat) \pm 2.5(syst)\ MeV/c^2$$

PRL 100, 182002 (2008)



Theory:

M = $6304 \pm 12^{+18}_{-0}$ MeV/c² (lattice QCD)

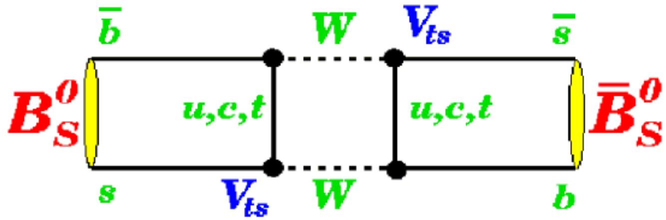
PRD 65, 034001 (2002)

M = 6247-6286 MeV/c² (non-rel. potential models)

PRD 70, 054017 (2004)

Lifetime in the pipeline

B_s Lifetime Intro



- Mass eigenstates B_s^H and B_s^L – decay widths Γ_H and Γ_L
- Define: $\Delta\Gamma = \Gamma_L - \Gamma_H$ and $\Gamma_S = (\Gamma_H + \Gamma_L)/2$
- Assuming no CP violation, two kinds of measurements:

1) Flavor specific – measure a single exponential for Γ_H and Γ_L

Actually measure:

$$\tau(B_s^0)_{\rm fs} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}.$$

$B_s \to D_s + \pi$

$B_s \to J/\psi + \phi$

2) Measure $\Delta\Gamma$ and Γ_S directly – identify the CP eigenstates (angular analysis of decays)

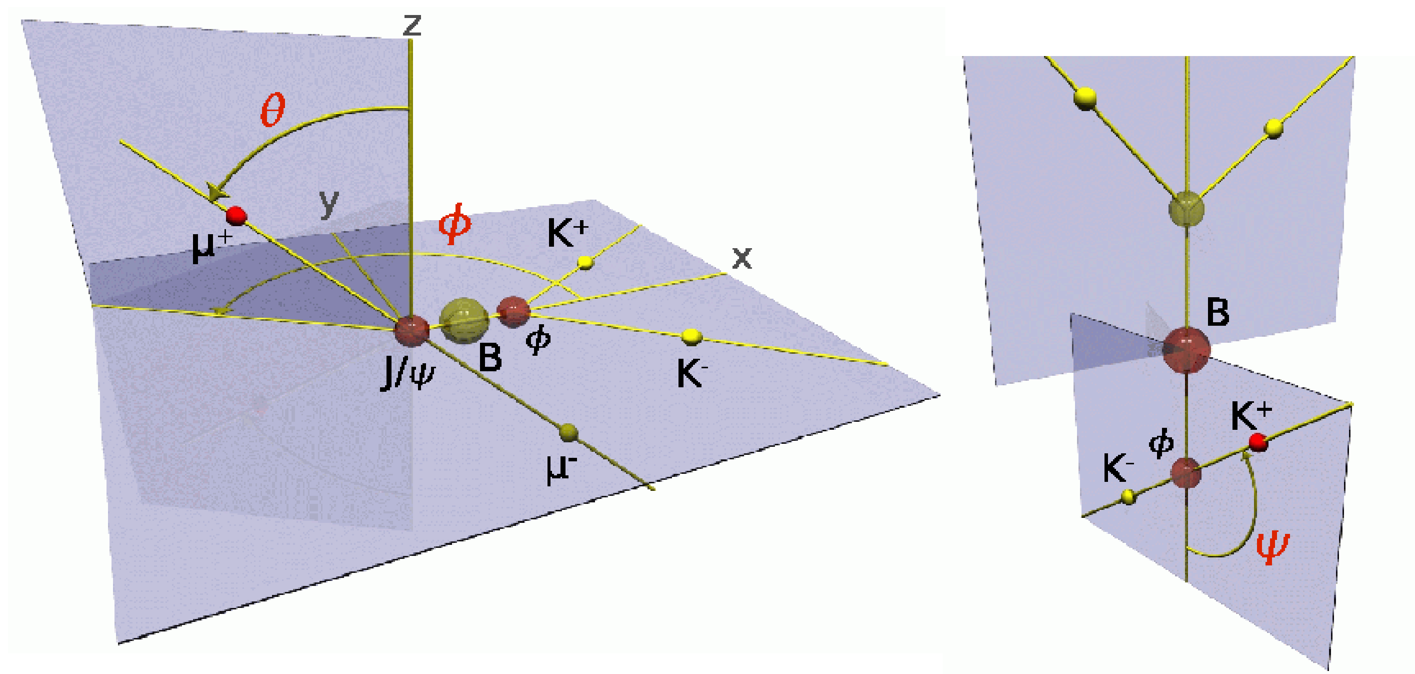
- Heavy quark expansion predicts τ_s/τ_d = 1.0±0.02 (τ_d=1.530±0.009 ps)

PRD 70, 094031 (2004)

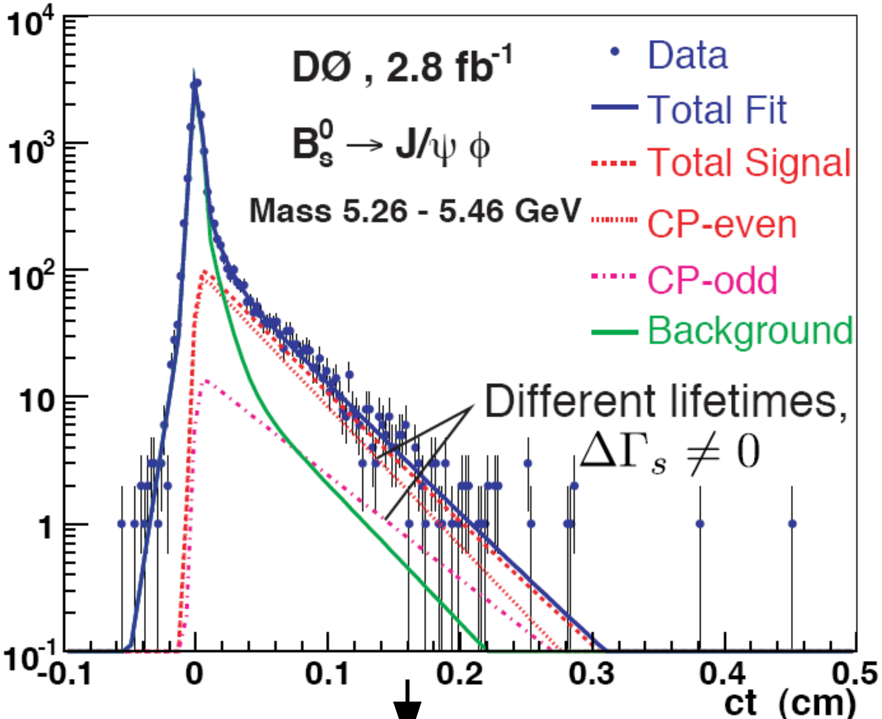
B_s->J/ψ+φ Angular Analysis

- Include angles describing decay in fit for τ and ΔΓ
- For no CPV - B_s^H=CP odd B_s^L=CP even
- Pseudo scalar->vector+vector: S,D wave (CP even) and P wave (CP odd)
- Angular distributions constrains CP even and CP odd components

Transversity Basis



B_s Lifetime in B_s->J/ψ+φ



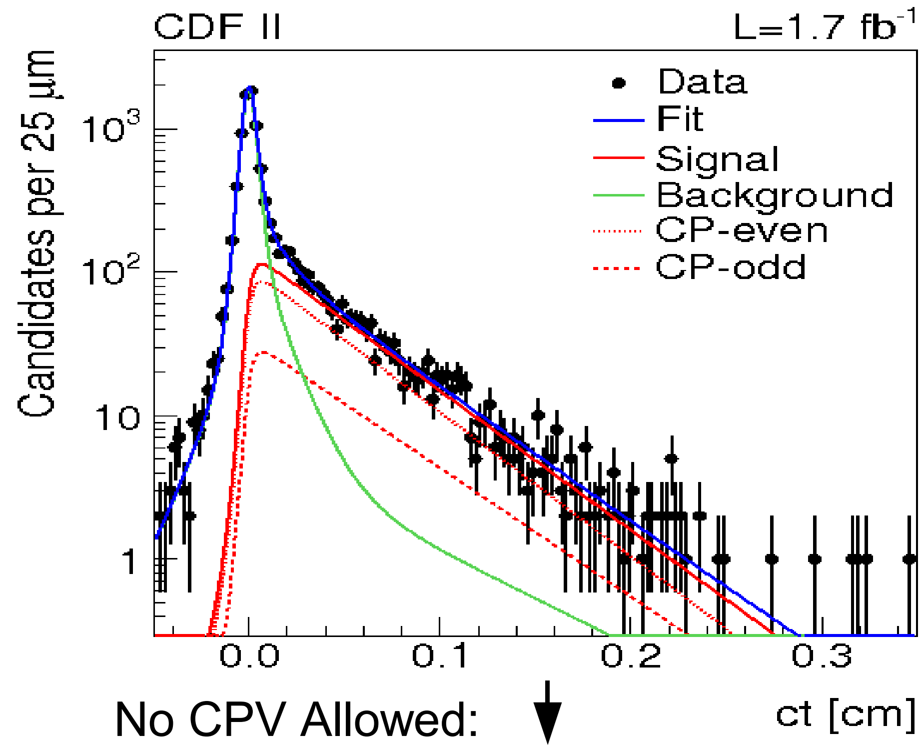
CPV Allowed:

$$\tau = 1.52 \pm 0.05\,(stat) \pm 0.01\,(syst)\ \ ps$$
$$\Delta\Gamma = 0.19 \pm 0.07\,(stat)^{+0.02}_{-0.01}\,(syst)\ \ ps^{-1}$$

No CPV Allowed:

$$\tau = 1.53 \pm 0.06\,(stat)\ \ ps$$
$$\Delta\Gamma = 0.14 \pm 0.07\,(stat)\ \ ps^{-1}$$

arXiv:/0802.2255[hep-ex]



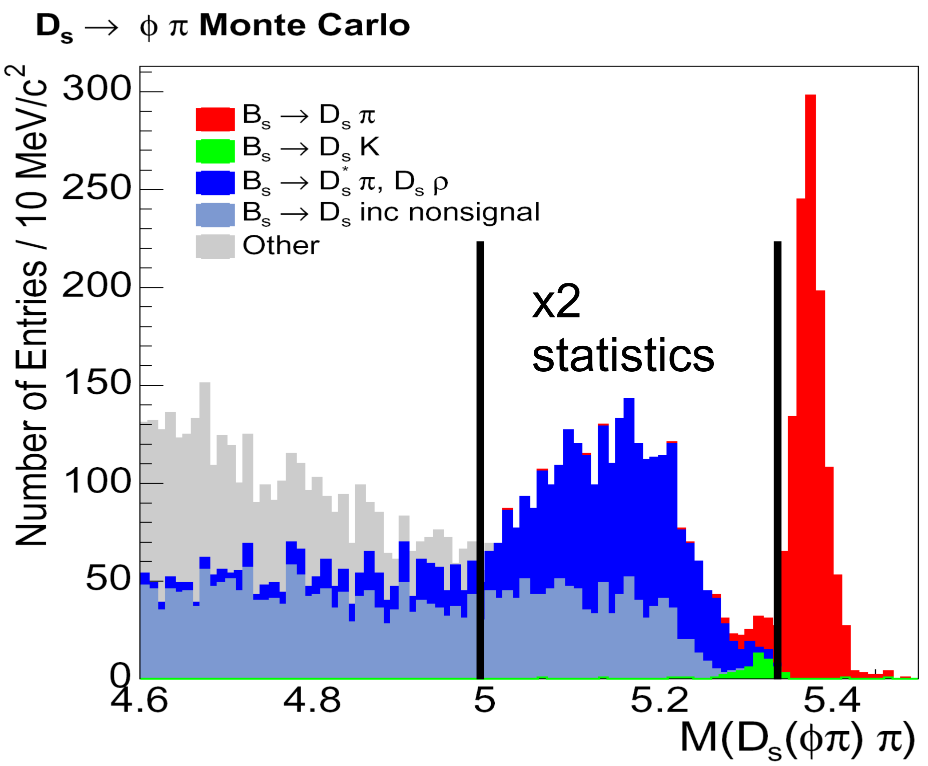
No CPV Allowed:

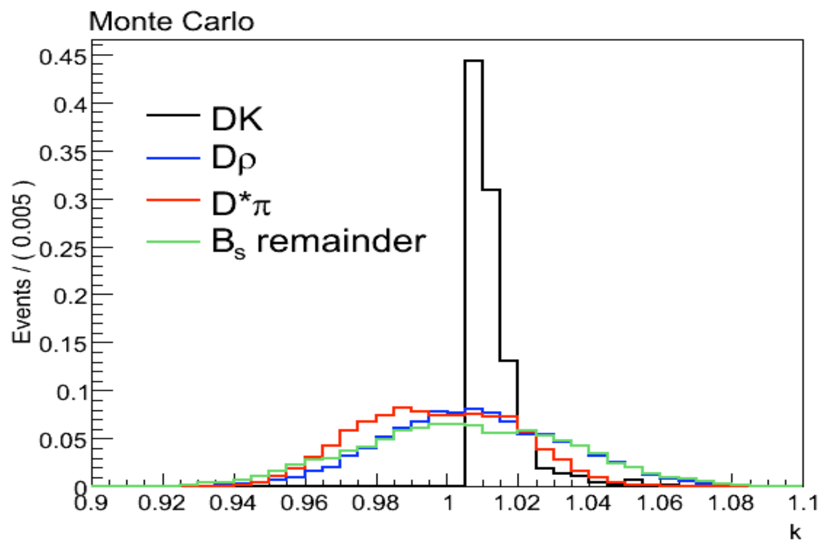
$$\tau = 1.52 \pm 0.04\,(stat) \pm 0.02\,(syst)\ \ ps$$
$$\Delta\Gamma = 0.08 \pm 0.06\,(stat) \pm 0.01\,(syst)\ \ ps^{-1}$$

PRL 100, 121803 (2008)

B_s Lifetime in $B_s \to D_s^-(\phi\pi)+\pi^++X$ (CDF)

- Flavor specific lifetime using $B_s \to D_s^-(\phi\pi)+\pi^++X$
  - Combines fully reconstructed and partially reconstructed modes
  - $B_s \to D_s^-(\phi\pi)+\pi^+$ and $B_s \to D_s^-(\phi\pi)+\rho^+(\pi^+\pi^0)$ dominate
  - Partially reconstructed give >x2 statistics

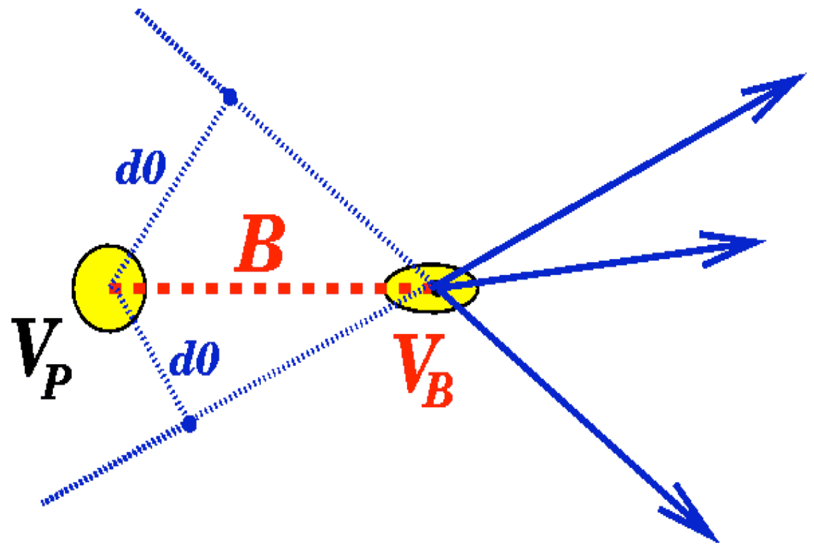




- Partially reconstructed decays -> model missing momentum in lifetimes (K factors)

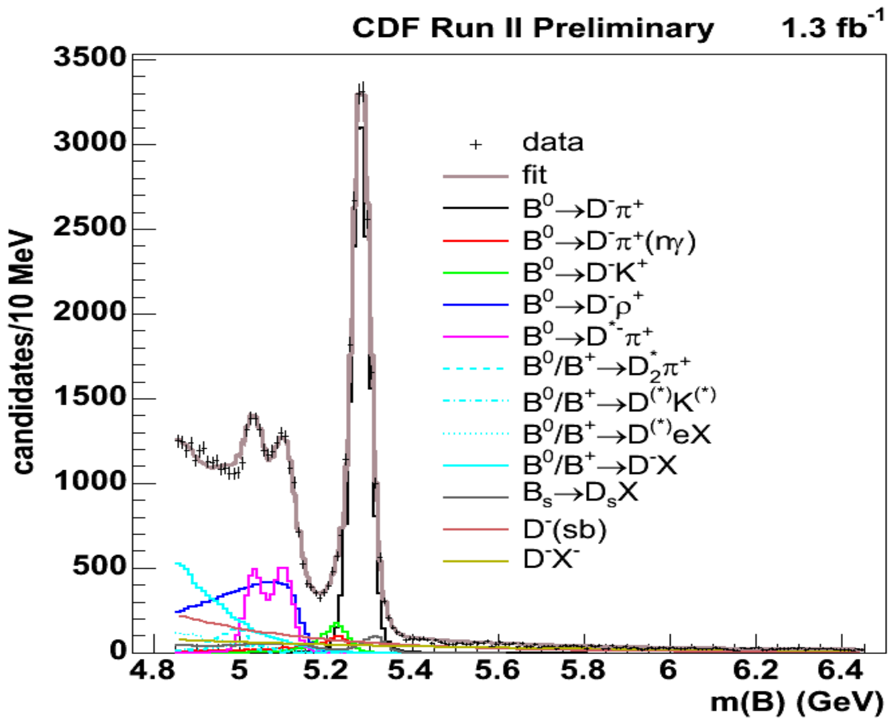
Hadronic Trigger an Sample

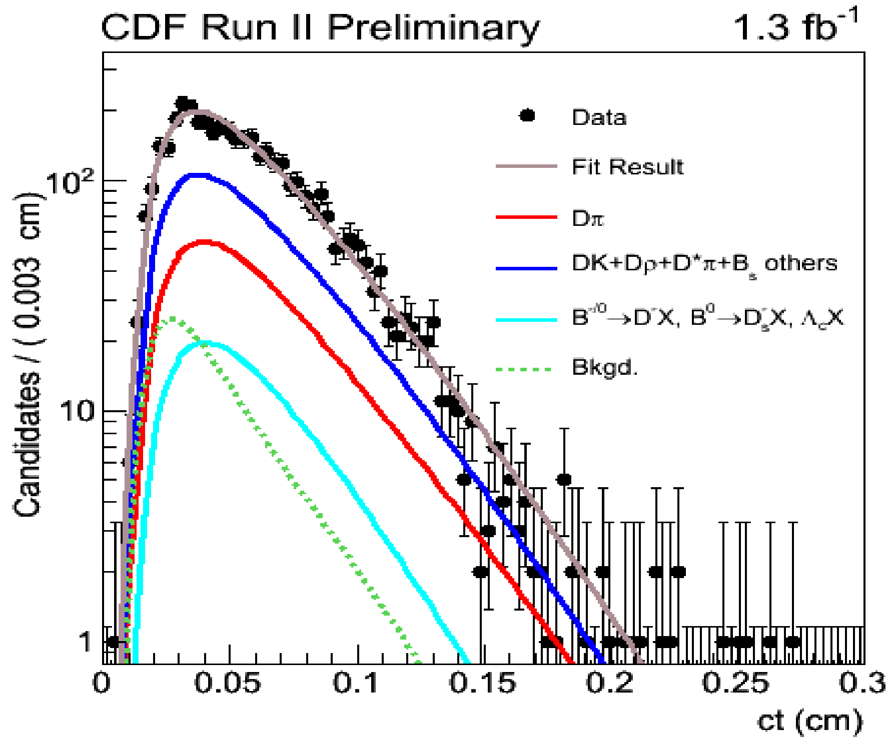
- Events are triggered using the displaced vertex trigger
  - Two tracks with 120 μm < d0 < 1 mm
  - Intersection >200 μm from primary vertex
- Introduces bias to lifetime
- Model with efficiency function from MC
- Check fitting procedure with other samples:
  - $B^0 \rightarrow D^-(K^+\pi^-\pi^-)\,\pi^+$
  - $B^0 \rightarrow D^{*-}(D^0(K^+\pi^-)\pi^-)\,\pi^+$
  - $B^+ \rightarrow D^0(K^+\pi^-)\,\pi^+$



- ~1100 fully reconstructed events
- ~2000 partially reconstructed events

B_s Lifetime Result





Two steps to lifetime fit:

1) Fit of the mass distribution to set the relative fractions of decay modes

2) Likelihood minimization to fit ct distribution and extract lifetime

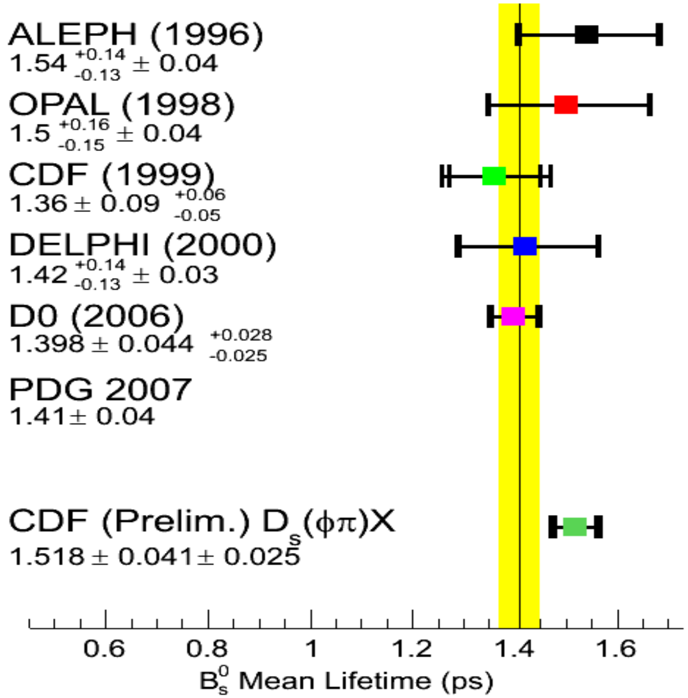
$$\boxed{\tau = 1.518 \pm 0.041\,(stat.) \pm 0.025\,(syst.)\ ps}$$

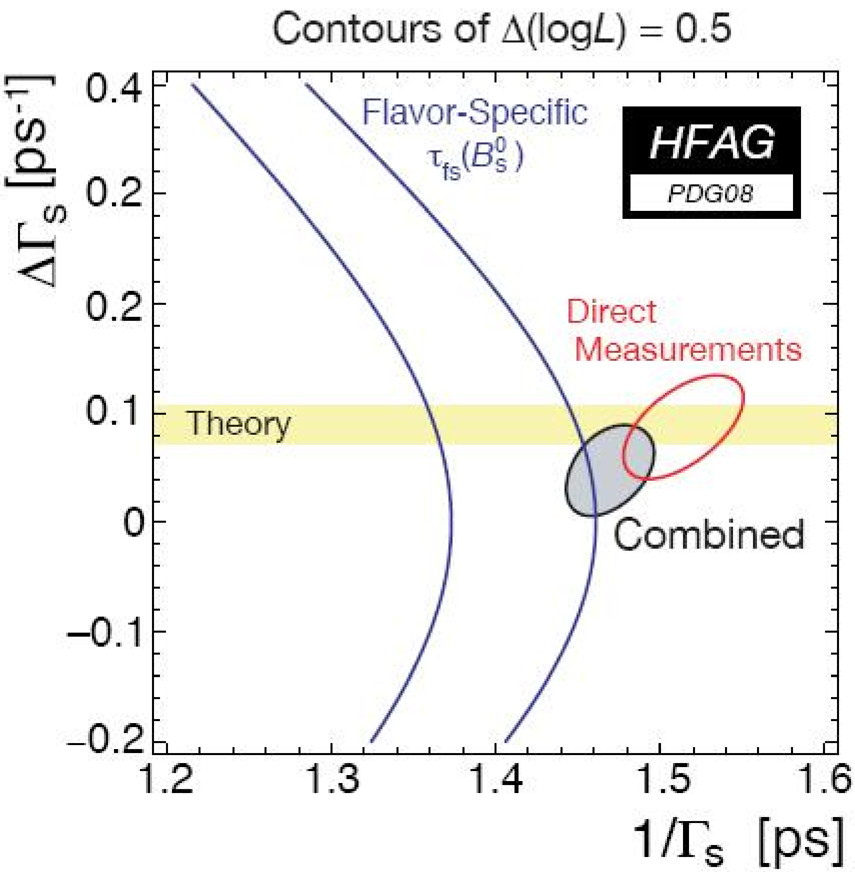
*World best flavor specific

080207.blessed-bs-lifetime/http://www-cdf.fnal.gov/physics/new/bottom/

B_s Lifetime Summary

- D_s+π+X contributions to flavor specific world average
- Larger values consistent with J/ψ+φ results





- HFAG for PDG 2008 includes CDF J/ψ+φ
- Recent results suggest τ_s/τ_d ~1
  - τ_s/τ_d = 0.939±0.021 as of HFAG 2007
  - Recall τ_s/τ_d = 1.0±0.02 from HQE

J/ψ Polarization (CDF)

- NRQCD predicts S-wave quarkonium should be transversely polarized for sufficiently large p_T

- Define quantity $\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$

PRL 99, 132001 (2007)

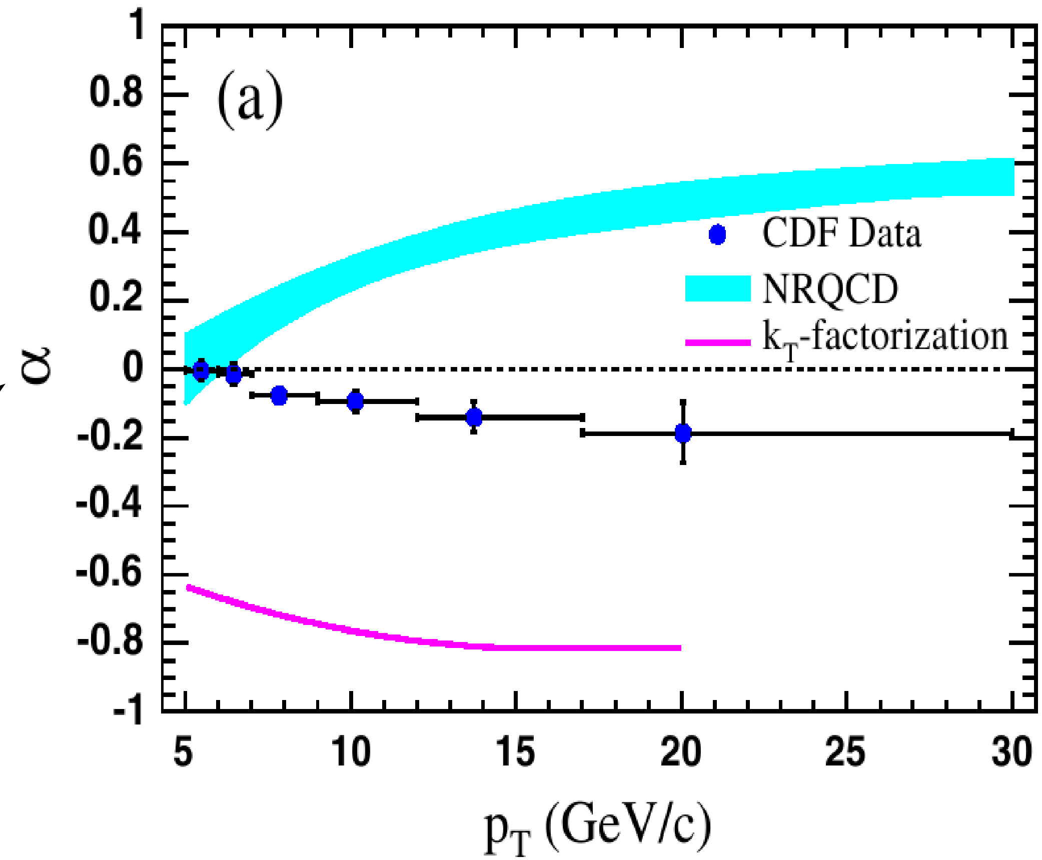
- And cosθ* (angle between μ^+ in J/ψ rest frame and J/ψ in lab):

$$\frac{dN}{d(\cos\theta^*)} \propto 1 + \alpha \cos^2\theta^*$$

- With 0.8 fb^{-1} of data CDF looks at prompt J/ψ polarization (~800,000 candidates)

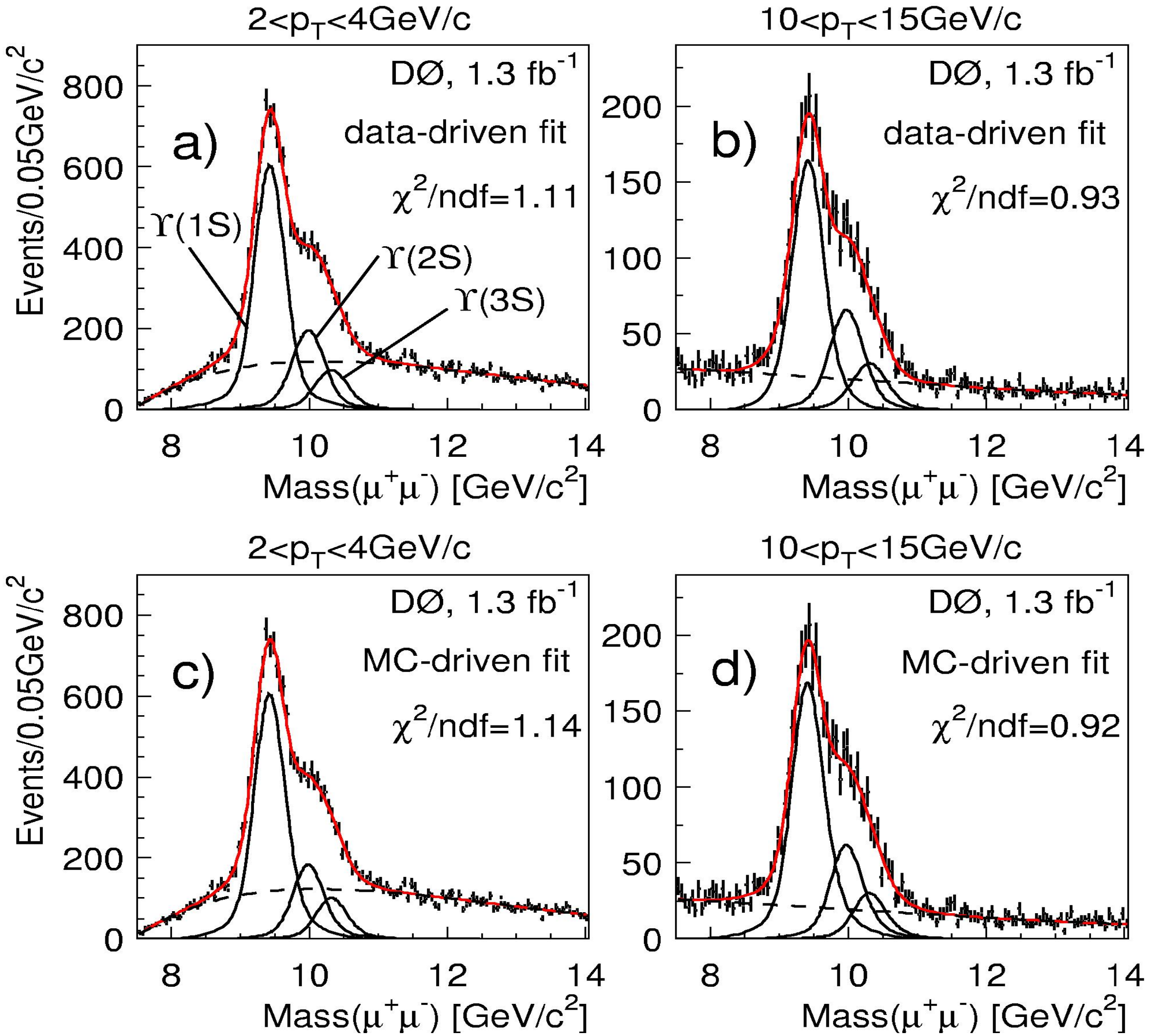
- Fit cosθ* to extract α

- See opposite of NRQCD prediction



Υ(nS) Polarization (D0)

- Fit di-muon mass in p_T and $\cos\theta^*$ bins for Υ(nS) normalizations
- Two types of mass fits
  - Data driven – all parameters determined by fit
  - MC driven – asymmetric tail from MC (used for normalizations)
- ~260,000 Υ(nS) events



arXiv:0804.7299[hep-ex]

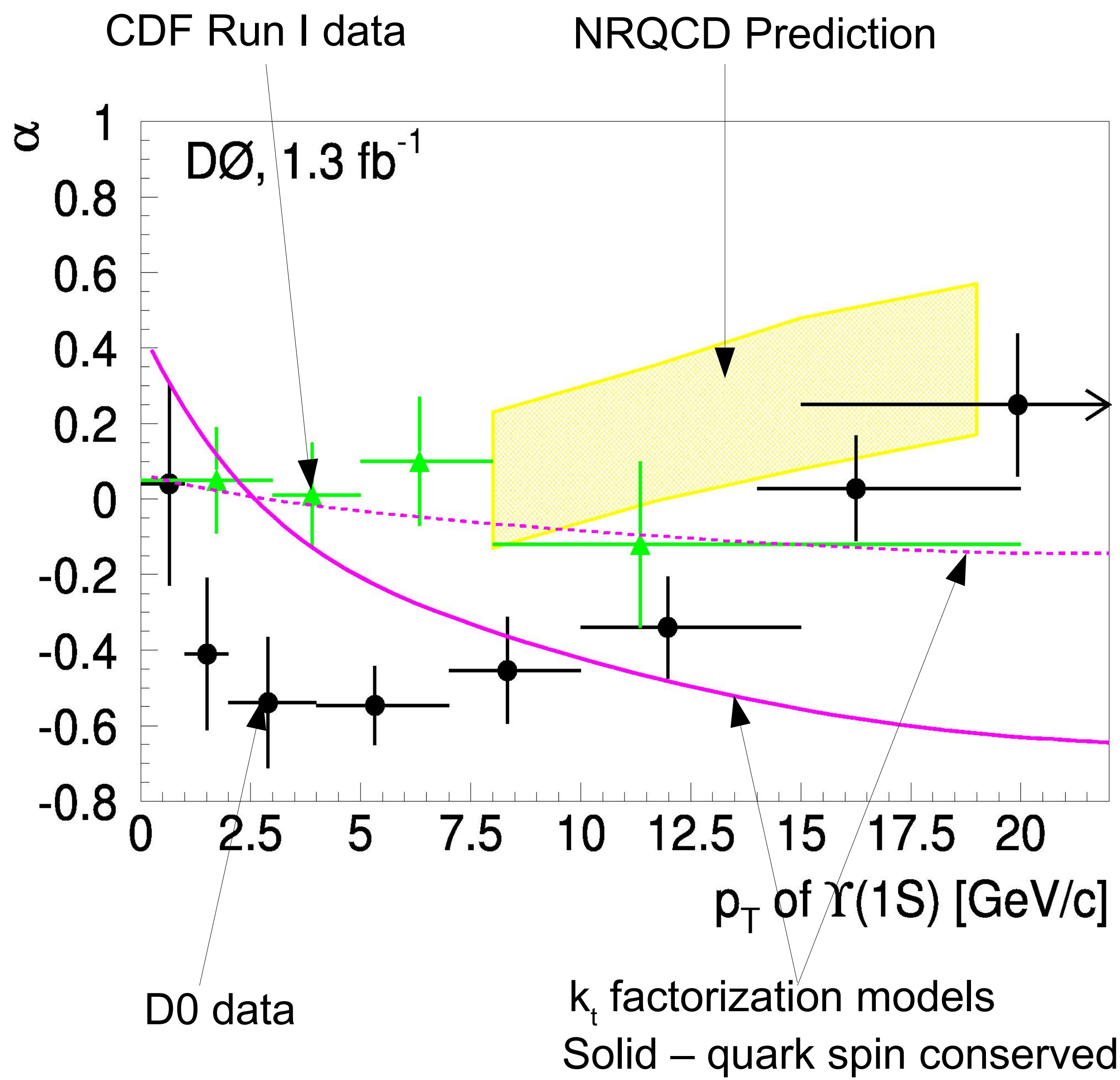
α for 1S State Compared to Models

- Measure α from $\cos\theta^*$
- See α>1 at high p_T but:

  1) Disagreement with CDF Run 1 measurement

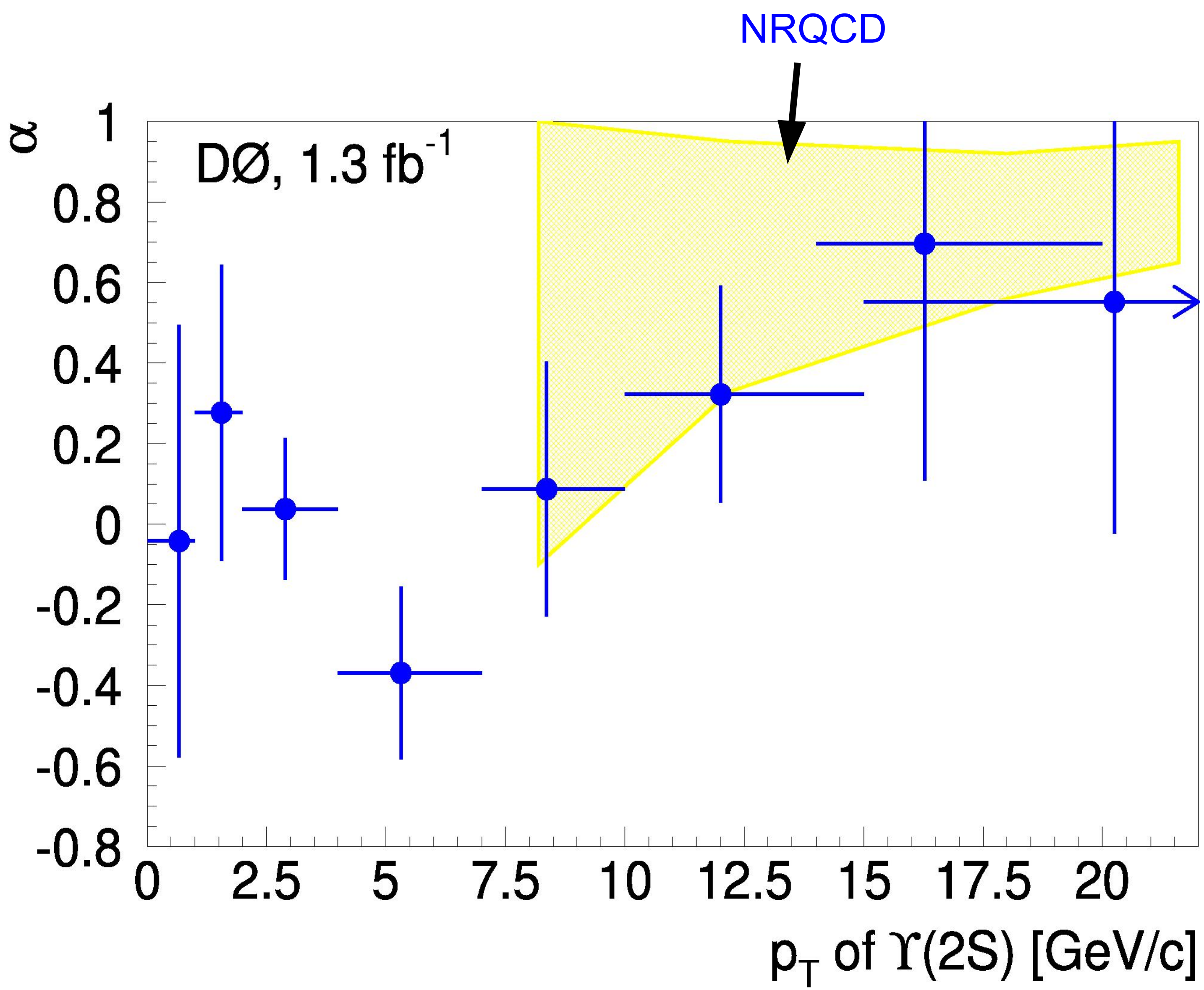
  2) Not a good match to NRQCD or k_t factorizatoin

- CDF Run II result would help understand data discrepancy
- Continued work on theoretical models

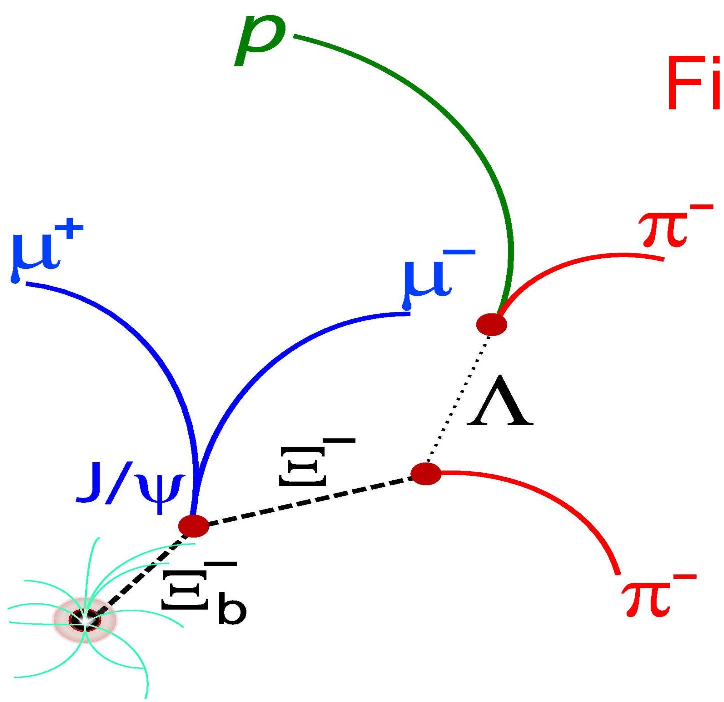


Υ(2S) Polarization

- Also measure α for Υ(2S)
- Good agreement with NRQCD



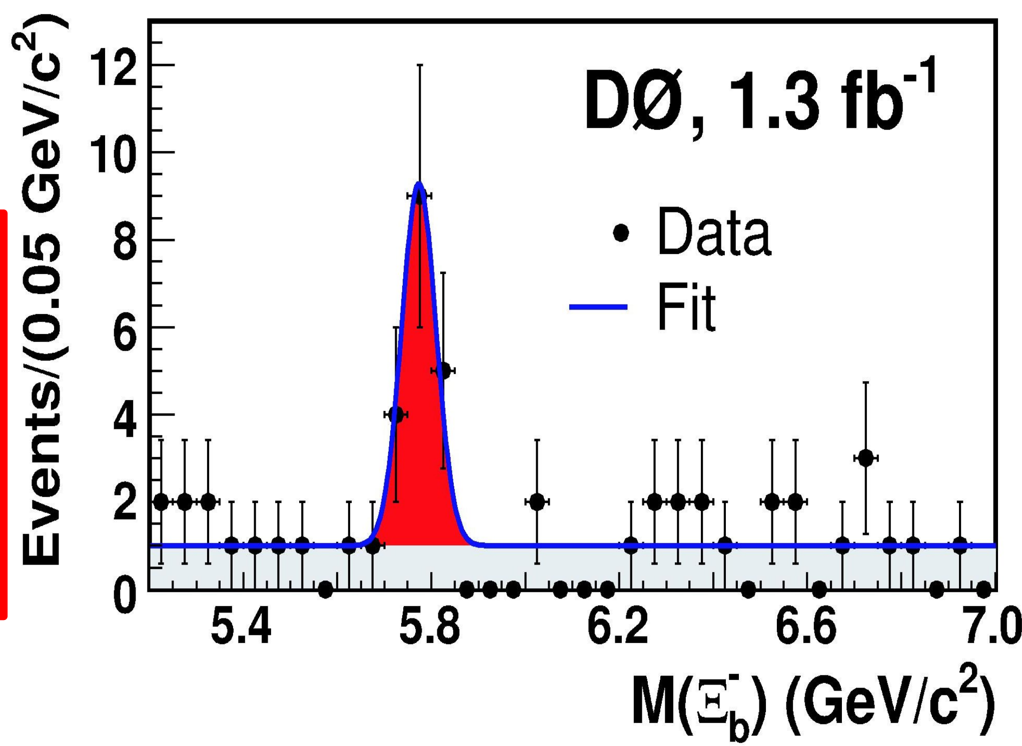
Ξ_b Observation and Mass (D0)



First direct observation of Ξ_b (dsb) by D0

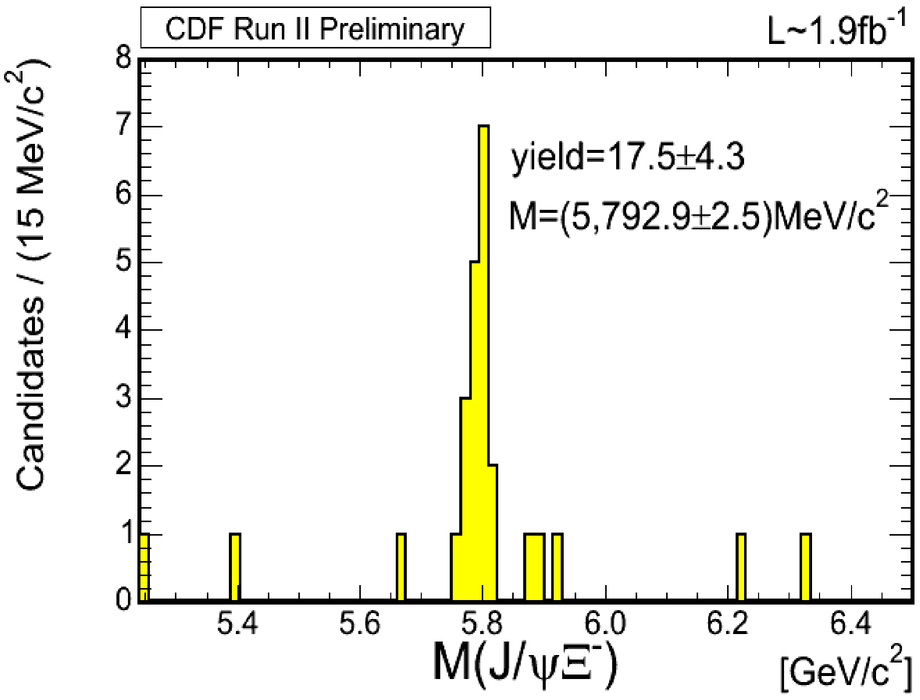
- Decay channel - $\Xi_b^- \to J/\psi(\mu\mu)+\Xi(\Lambda\pi^-)$
- 1.3 fb^{-1} of integrated lumi.
- Ξ and Λ decay lengths ~ cm

$$15.2 \pm 4.4(stat)^{+1.9}_{-0.4}\ events$$
$$5.5\sigma\ significance$$
$$M = 5.774 \pm 0.011(stat) \pm 0.015(syst)\ GeV/c^2$$



PRL 99, 052001 (2007)

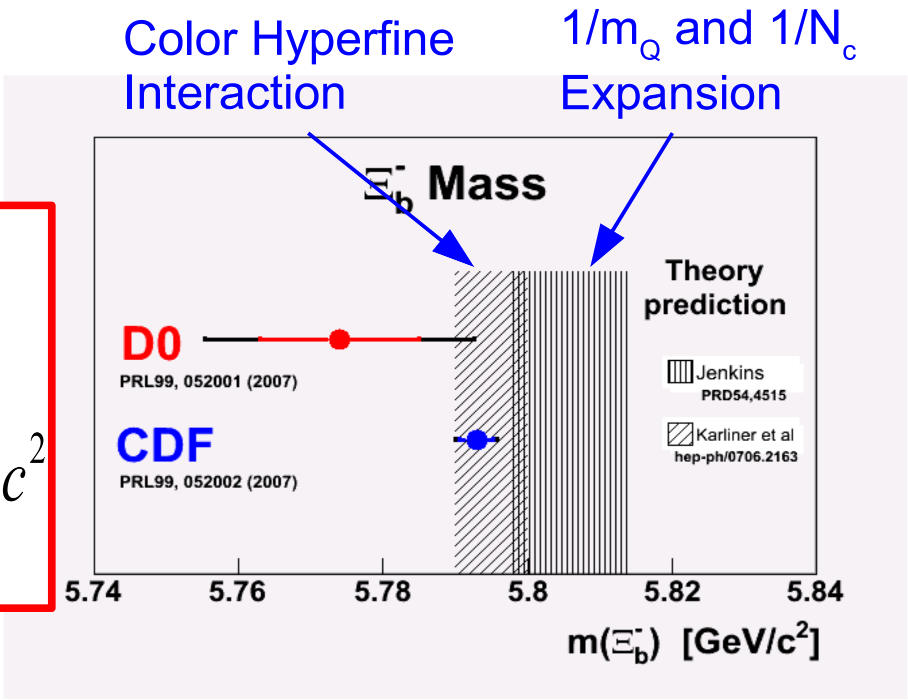
Ξ_b at CDF



- Similar to D0 analysis
- 1.9 fb^{-1} of integrated lumi.
- Reconstruct Ξ track in silicon – cut down on backgrounds
  - 5 track final state becomes 3 track final state

$$17.5 \pm 4.3 \; events$$
$$7.7\sigma \;\; significance$$
$$M = 5.7929 \pm 0.0025(stat) \pm 0.0017(syst) \; GeV/c^2$$

PRL 99, 052002 (2007)



Conclusions

- D0 and CDF are making many exciting measurements
- In Run II we have greatly improved the precision in B_c measurements – start to feed back to models
- Recent B_s lifetime measurements suggest $\tau_s/\tau_d = 1$
- Mystery of the quarkonium polarization
- Exciting direct observation of the Ξ_b
- Many interesting topics not covered in this talk: Λ_b, Σ_b, orbitally excited B mesons, etc.

http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm
http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

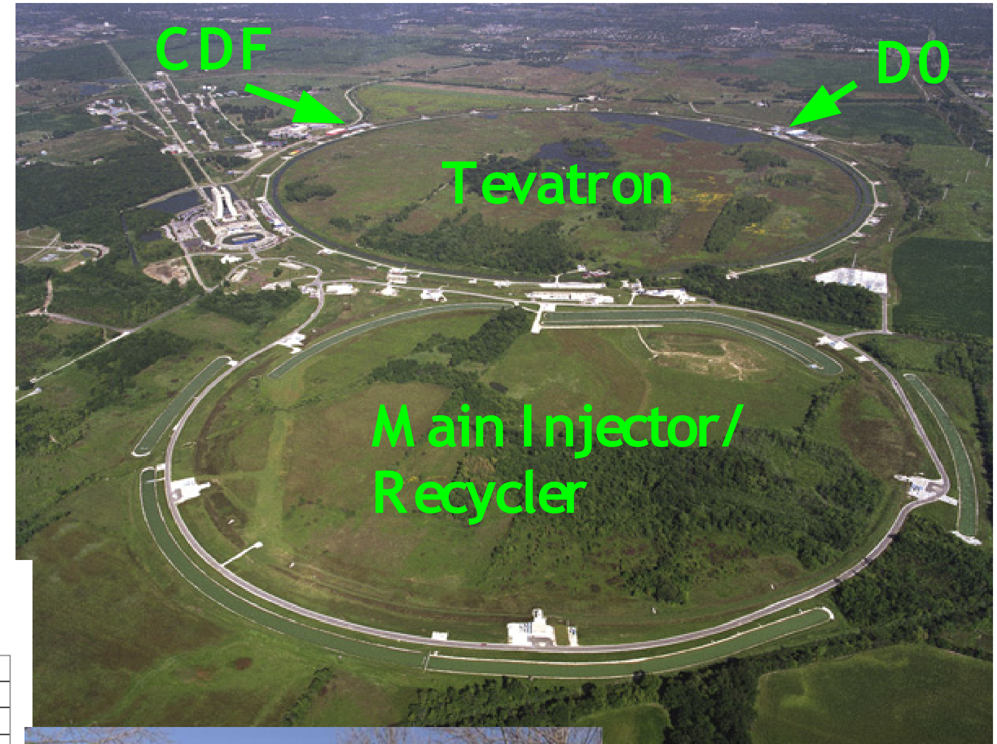
Extra Slides

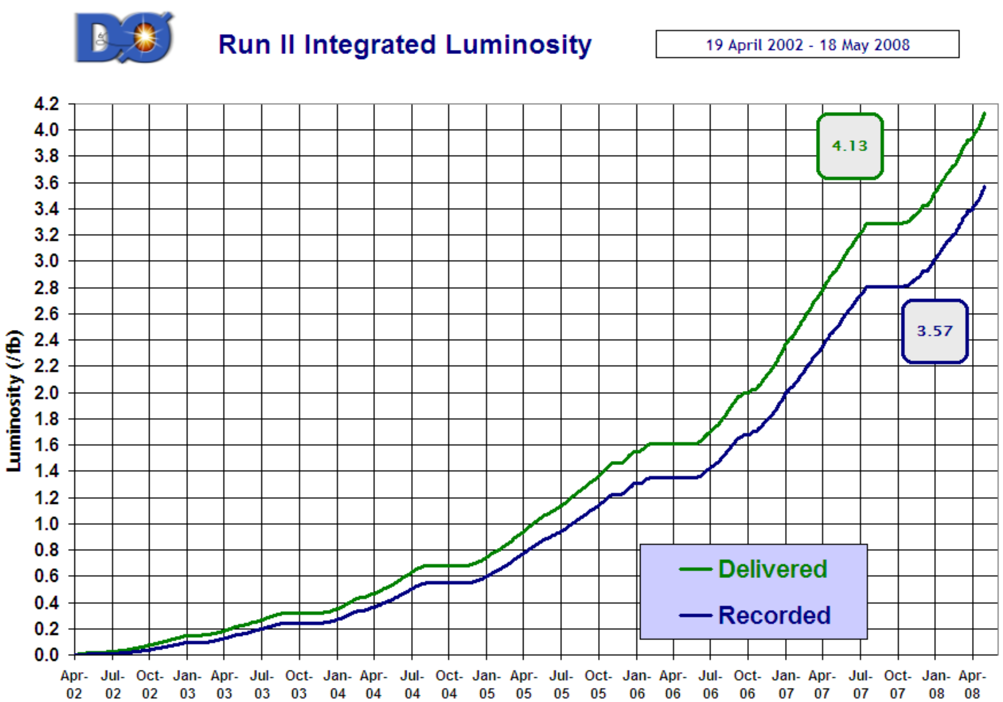
The Tevatron

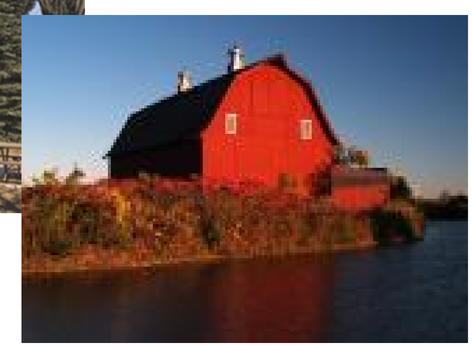
pp(bar) collisions at sqrt(s)=1.96 TeV

Peak instantaneous luminosities of 3×10^{32} $cm^{-2}s^{-1}$

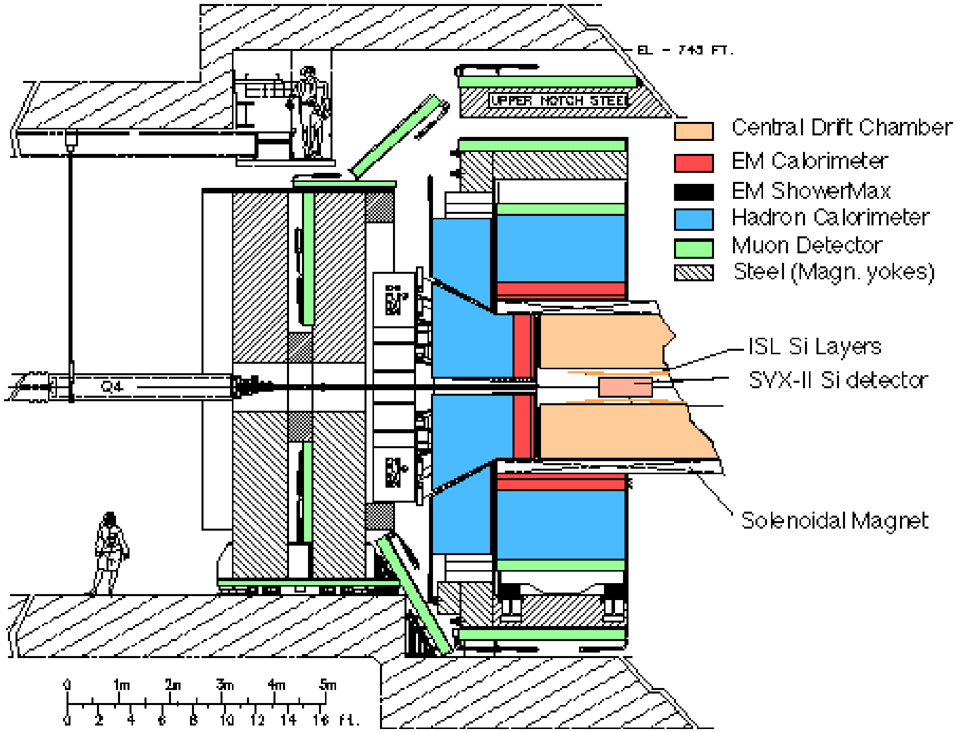
~4 fb^{-1} delivered so far

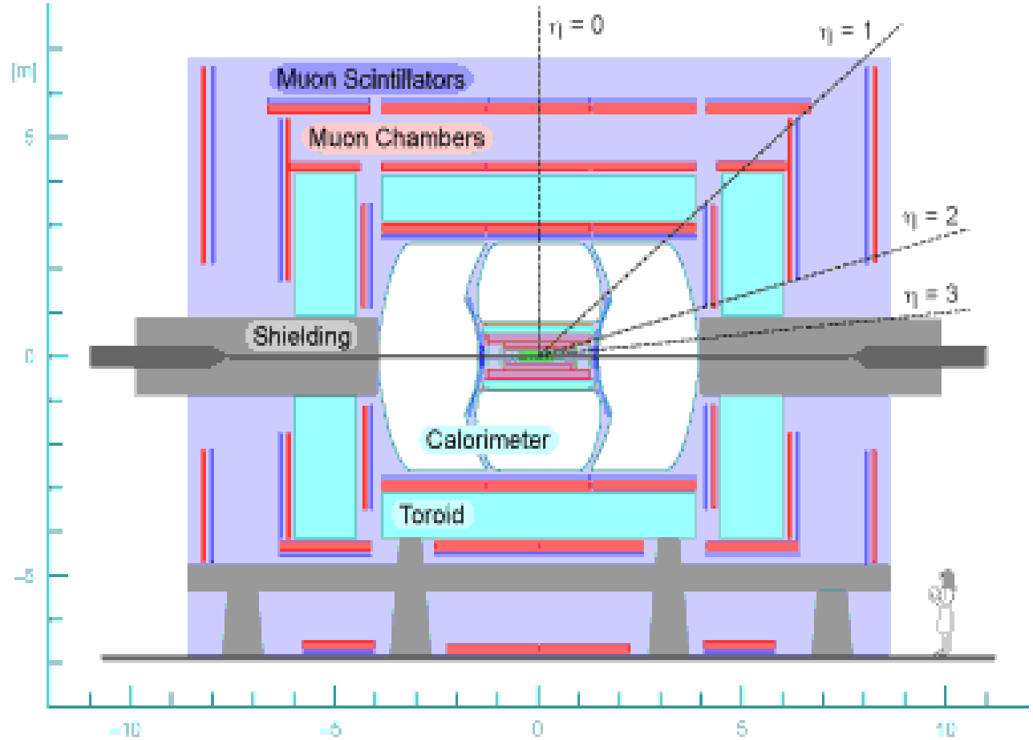






CDF & D0 Detectors





Complementary Strengths

CDF

- Precision tracking
  - Mass – $\delta p_T/p_T = 0.0015\ p_T$
  - Position – σ_{ct} ~ 25 mm
- Particle ID with time-of-flight, dE/dx

D0

- Muon Coverage
- Forward tracking

Coverage to $|\eta| = 2$

- Addition of inner silicon layer