B Physics at CDF

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IOP HEPP meeting: Beauty Physics in the UK

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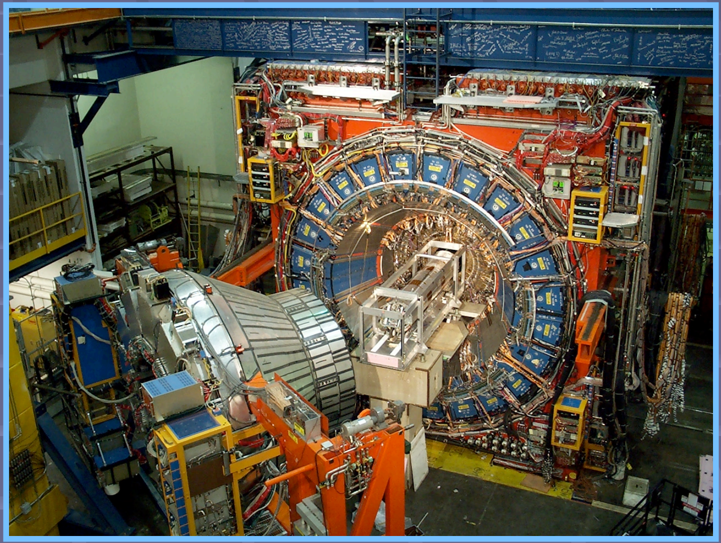
Overview

- Introduction
- The CDF detector
- B lifetimes
- B_s mixing and CPV
- B baryon results
- Further results
- Summary



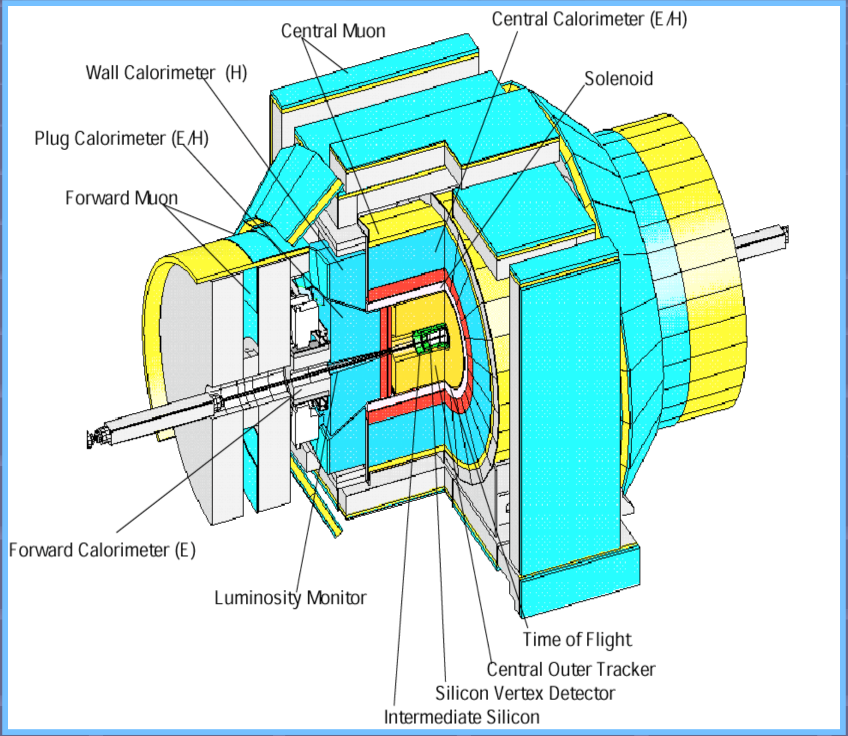
Introduction

- > 4 fb^{-1} of data written to tape
- Taking ~ 40pb^{-1} per week
  - c.f. Run-I total $\int Ldt$ = 110pb^{-1}
  - Up to 8.8fb^{-1} data could be provided by October 2010
- $p\bar{p}$ collisions have advantages and challenges for B physics:
  - Large cross sections - high yield
  - Large background - need sophisticated triggers
- Areas of interest:
  - B lifetimes
  - CP Violation
  - Discovery
  - Rare decays

CDF detector

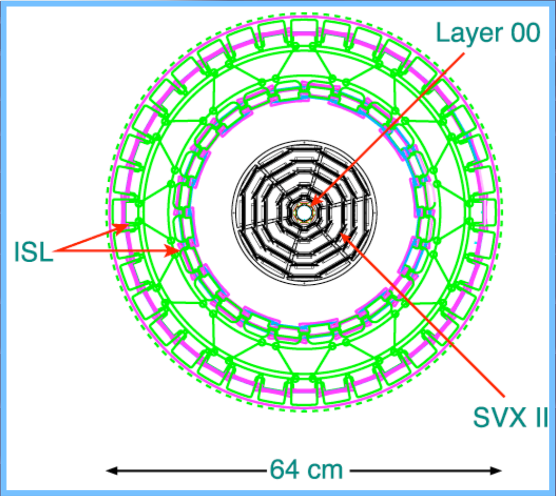
CDF strengths for B physics:

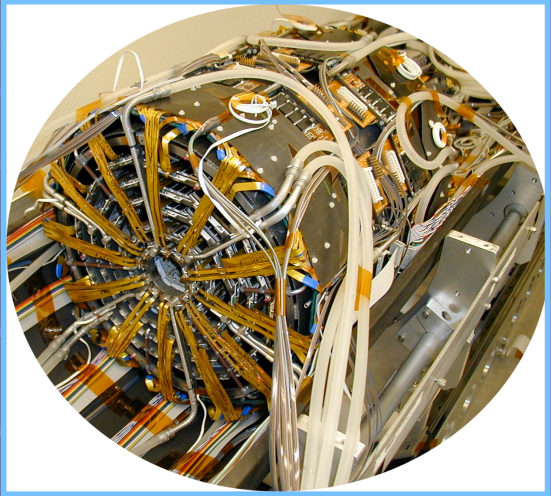
- Tracking
  - Central drift chamber and silicon vertex detector in 1.4T magnetic field
  - Excellent vertex resolution ~23μm
  - p_T resolution: $\sigma(p_T)/p_T^2 \sim 0.1\%$
- Particle ID
  - dE/dx: 1.5σ K-π separation at p>2GeV/c
  - TOF: 2σ K-π separation at p>1.5GeV/c
- Trigger:
  - J/ψ
  - Hadronic trigger - displaced vertex



The Silicon Vertex Detector

- Important component for B physics
- Silicon detector comprised of: SVX-II, ISL & L00
  - 7m^2 of Silicon sensors arranged as 8 concentric layers
  - 722,432 channels read-out by 5456 chips
- Provides precision tracking
  - Primary & displaced vertices
  - Innovative use of Silicon in hardware displaced vertex trigger



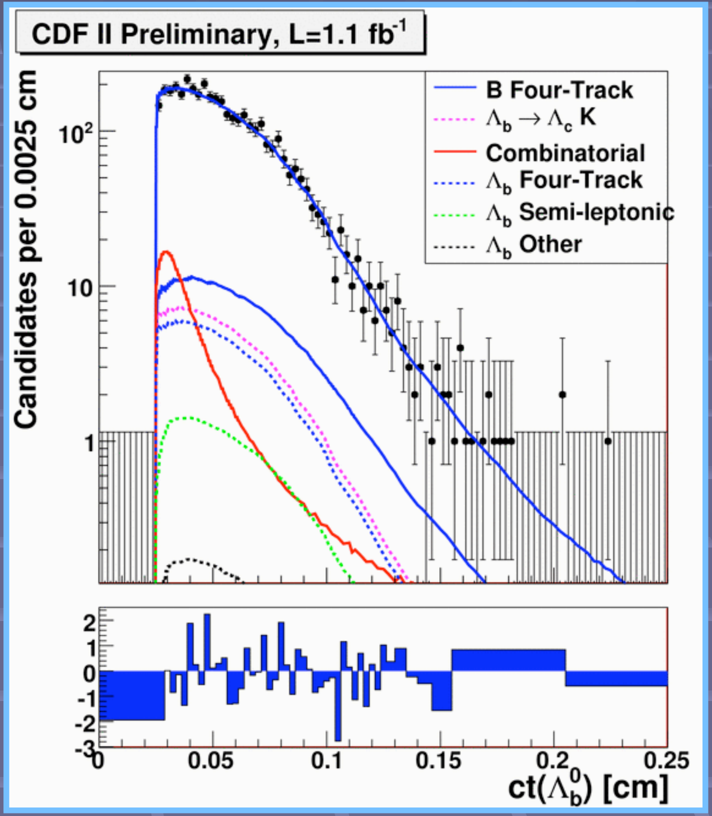


B Lifetimes

- Testing HQET - models lifetimes of hadrons containing at least one heavy quark such as *b*
- Expect $\tau(B^+) > \tau(B^0) \approx \tau(B_s{}^0) > \tau(\Lambda_b{}^0) \gg \tau(B_c{}^+)$

Λ_b Lifetime Measurement

- Λ_b lifetime measured in $\Lambda_b \rightarrow \Lambda_c\, \pi$
  - Sample collected using two displaced track trigger
- 2-stage fit:
  - First fit Λ_b mass
  - Second, unbinned maximum likelihood 2D fit of lifetime and error.
- More compatible with world average than previous result using $\Lambda_b \rightarrow J/\psi\Lambda$

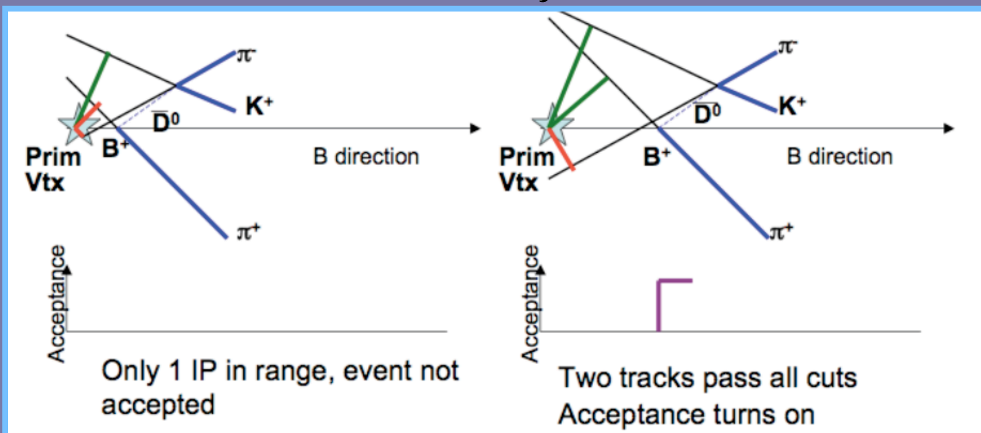


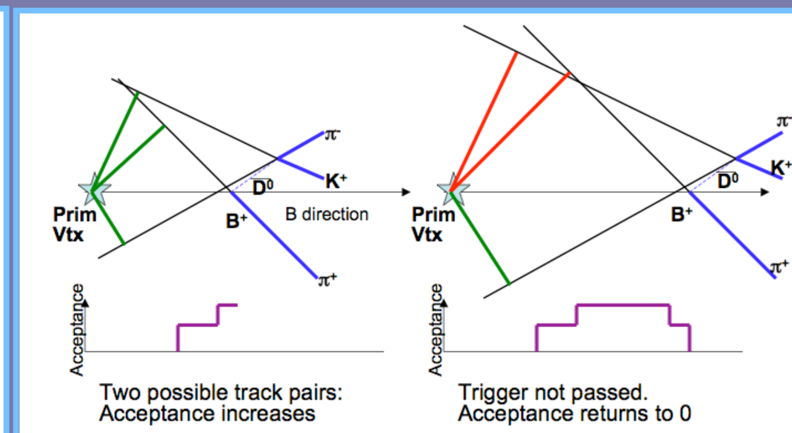
$c\tau(\Lambda_b^0)$ = 423 ± 14 (stat) ± 9 (syst) μm,
$c\tau(\Lambda_b^0)$ /c $\tau(B^0)$ = 0.92± 0.04

http://www-cdf.fnal.gov/physics/new/bottom/080703.blessed-lblcpi-ct

MC Free Measurement of B^+ Lifetime

- Uses new method for correcting trigger bias:
  - Acceptance function corrects for bias event-by-event
  - Converts impact parameter trigger into effective lifetime cut
  - No MC, so no systematic error due to simulation



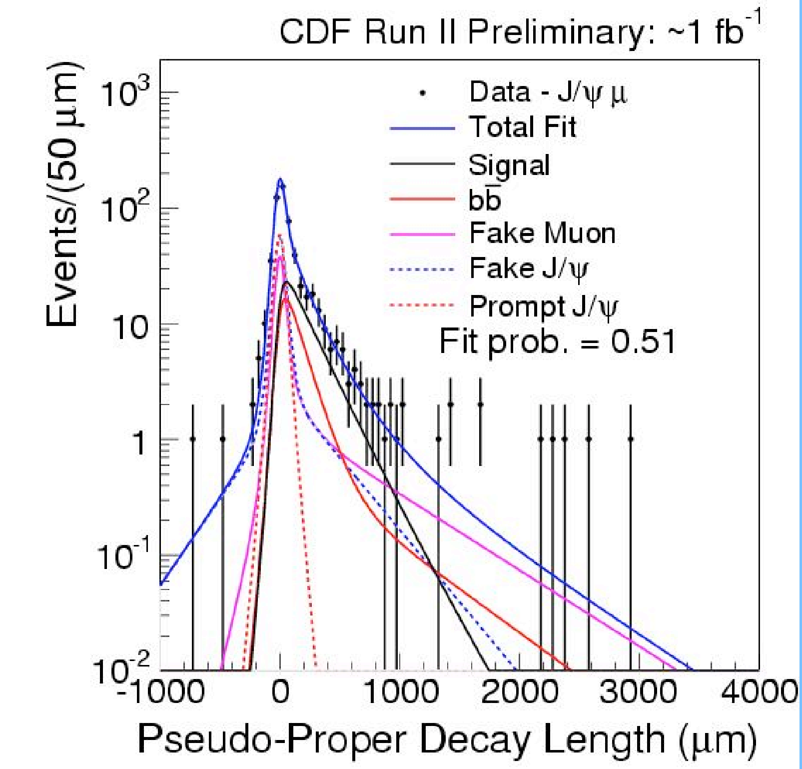


$c\tau(B^+) = 498.2 \pm 6.8$ (stat.) $\pm$ 4.5 (syst.) μm
($c\tau(B^+) = 491.1 \pm 3.3$ μm, PDG 2008)

http://www-cdf.fnal.gov/physics/new/bottom/080612.blessed-MCfree_Blifetime

B_c Lifetime Measurement

- Uses semileptonic modes:
  $B_c^{\pm} \rightarrow J/\psi + l^{\pm} + X$
- Fit e, μ channels separately, then combine likelihood
- Agrees with theoretical predictions

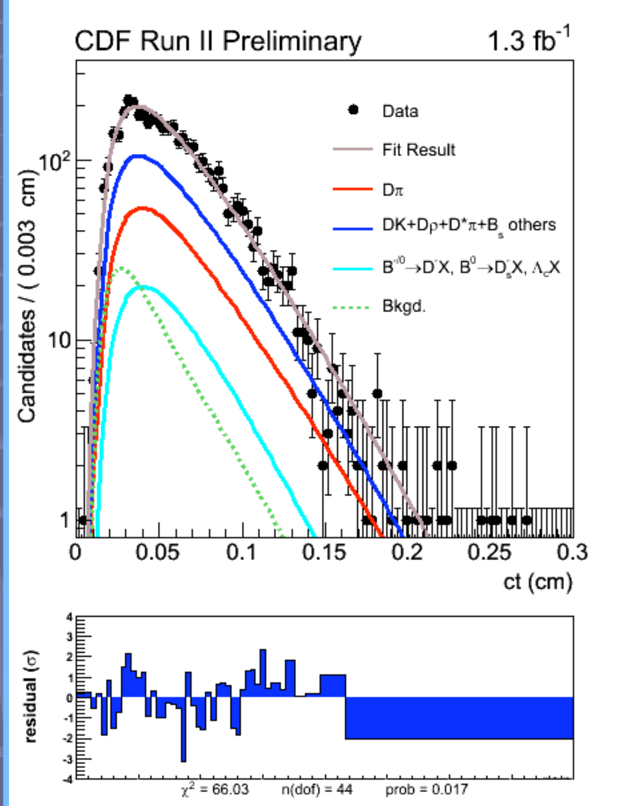


$c\tau(B_c^+) = 142 \pm 15\ (\text{stat}) \pm 6\ (\text{syst})\ \mu m$

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

$B_s \rightarrow D^*\pi X$ Lifetime Update

- Analysis of fully reconstructed mode in two-track trigger that exploits 2x additional statistics from partially reconstructed decays.
- Now agrees with HQET predictions that $c\tau(B_s^0) \sim c\tau(B^0)$



$c\tau(B_s^0) = 455 \pm 12$ (stat.) $\pm\ 7$ (syst.) μm

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

CPV in B_s System

- Sensitive to New Physics

Neutral B_s System

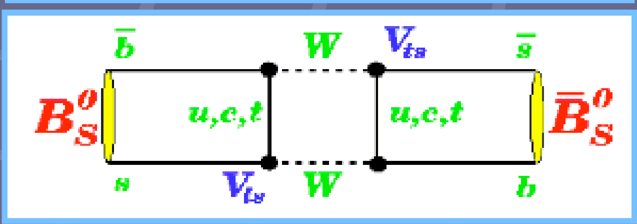
- B_s mixing governed by Schrödinger eqn.:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$

- Gives rise to 2 mass eigenstates, B_s^H and B_s^L.
- Study of CPV and oscillations give access to parameters of interest:

$$|B_s^H\rangle = p\,|B_s^0\rangle - q\,|\bar{B}_s^0\rangle$$

$$|B_s^L\rangle = p\,|B_s^0\rangle + q\,|\bar{B}_s^0\rangle$$



$\Delta m_s = m_H - m_L \approx 2|M_{12}|$

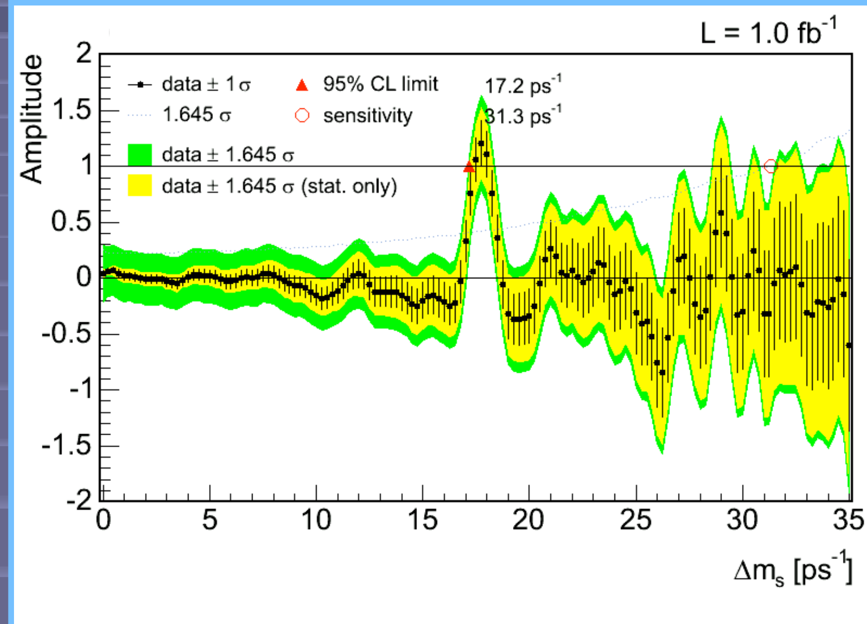
$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos(\varphi_s)$

$\varphi_s = \arg(-M_{12}/\Gamma_{12})$ ~0.004 in SM

$\beta_s^{J/\psi\,\varphi} = \arg(-V_{ts}V^*_{tb}/\,V_{cs}V^*_{cb})$ ~0.02 in SM

B_s Oscillations

- In 2006: First observation of B_s - $\bar{B}_s$ oscillation frequency.
- Fit oscillation amplitude, A, fixing Δm_s to a probe value.
  - Expect amplitude consistent with A=1 at true value of Δm_s.
- Mixing frequency constrains magnitude of possible NP
- Phase of any NP amplitude is unconstrained...
- Time evolution of $B_s \rightarrow J/\psi\ \varphi$ decays sensitive to NP phase:
  - Interference between decay and mixing + decay.

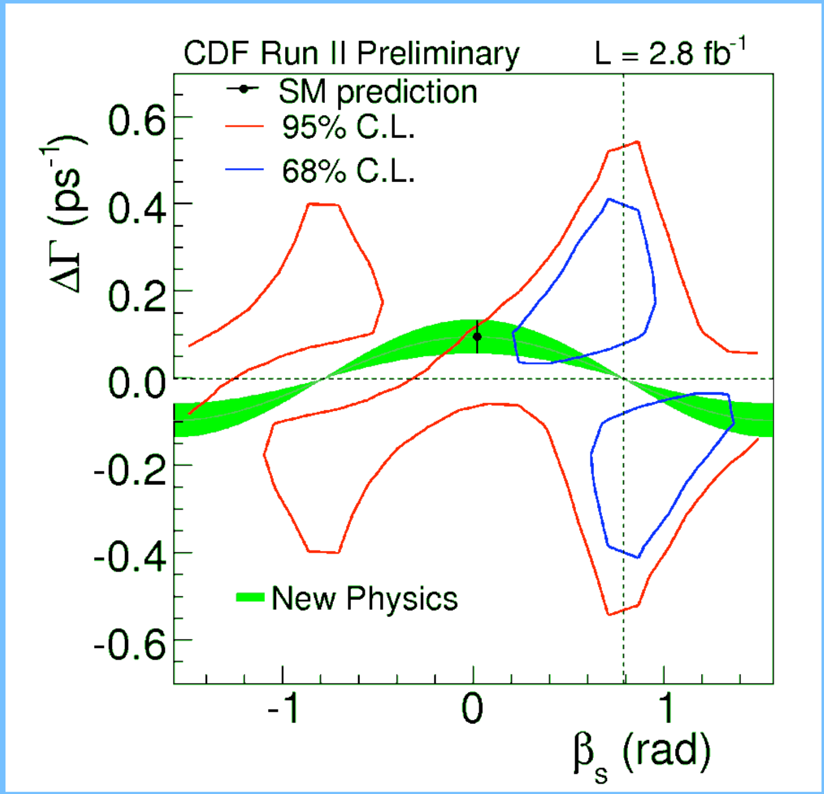


Δm_s= 17.77 ± 0.10(stat) ± 0.07(sys) ps^{-1}

PRL 97, 242003, 2006

Sensitivity to New Physics: $\beta_s^{J/\psi\varphi}$ and $\Delta\Gamma$

- Flavour tagged $B_s^0 \to J/\psi\varphi$ finds 1.8σ (p-value = 7%) discrepancy with SM for $\beta_s^{J/\psi\varphi}$
- Still compatible with a statistical fluctuation, but similar effect observed by D0
- Increased statistics may provide evidence for NP…
- Recent updated analysis with 2.8fb^{-1} improves precision of published 1.3fb^{-1} result.



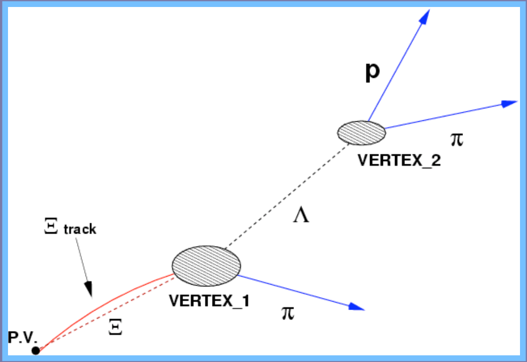
http://www-cdf.fnal.gov/physics/new/bottom/080724.blessed-tagged_BsJPsiPhi_update_prelim

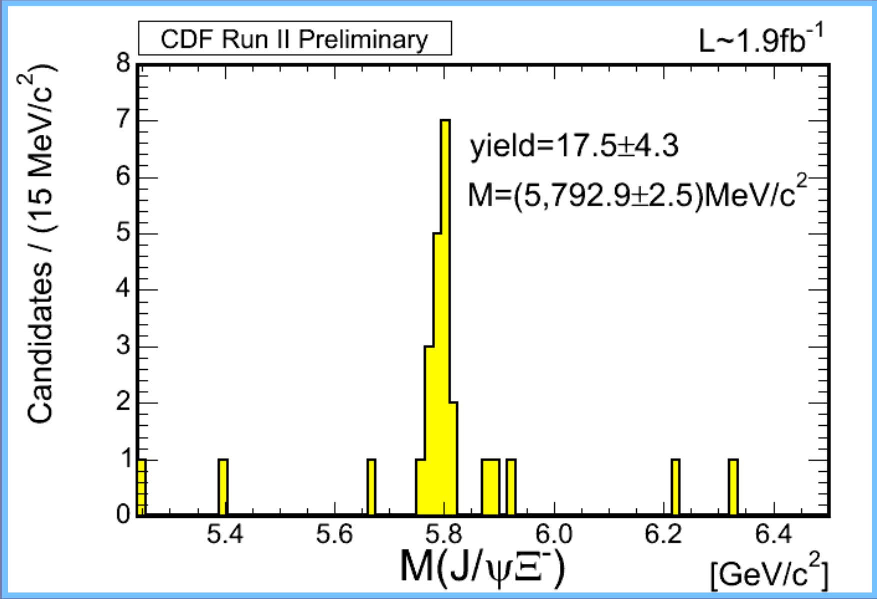
B Baryon Observations at CDF

Ξ_b Observation and mass measurement

- "Cascade B" first observed at the Tevatron in 2007
- Uses fully reconstructed decay:

$\Xi_b^- \rightarrow J/\psi\,\Xi^- \rightarrow [\mu^+\mu^-][\Lambda^0\pi^-],\ \Lambda^0 \rightarrow p\pi^-$





$m(\Xi_b) = 5792.9 \pm 2.5\ (\text{stat.}) \pm 1.7(\text{syst.})\ \text{MeV}/c^2$

- Statistical significance of Ξ_b signal is $>7\sigma$

PRL 99, 052002, 2007

More results

- Search for FCNC rare decays $B_{s(d)} \rightarrow \mu^+\mu^-$ *($2fb^{-1}$)*

  $BR(B_s \rightarrow \mu^+\mu^-) < 5.8 \times 10^{-8}$ @95% CL
  $BR(B_d \rightarrow \mu^+\mu^-) < 1.8 \times 10^{-8}$ @95% CL

  PRL 100,101802, 2008

- Properties of X(3872): *($2.4fb^{-1}$)*
  - Nature of particle still being investigated
  - Precise mass measurement:

    $m(X(3872)) = 3871.61 \pm 0.16\ (stat) \pm 0.19\ (syst)\ MeV/c^2$

  - Observed in decay $X(3872) \rightarrow J/\psi\pi^+\pi^-$

    http://www-cdf.fnal.gov/physics/new/bottom/080724.blessed-X-Mass

- Mass and width measurement of orbitally excited (L=1) B^{**0} mesons. *($1.7fb^{-1}$)*

  $m(B_1) = 5725.3^{+1.6}_{-2.2}\ (stat)\ ^{+1.4}_{-1.5}\ (syst)\ MeV/c^2$

  $m(B^*_2) = 5740.2^{+1.7}_{-1.8}\ (stat)\ ^{+0.9}_{-0.8}\ (syst)\ MeV/c^2$

  http://www-cdf.fnal.gov/physics/new/bottom/070726.blessed-bss/

- And many more…http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

Summary

- CDF has highly successful B physics program
  - competitive (B^0 and B^+ modes) and complementary (B_s, B_c, baryons) to B factories.
- First analysis of flavour-tagged $B_s \rightarrow J/\psi\varphi$ decays shows 1.8σ fluctuation w.r.t SM - possible hint of New Physics
- Discovery of new resonances, and world best results of lifetimes, masses and other properties.
- Shown results based on samples which will be doubled to tripled in a year’s time - will keep having an impact in forthcoming years…

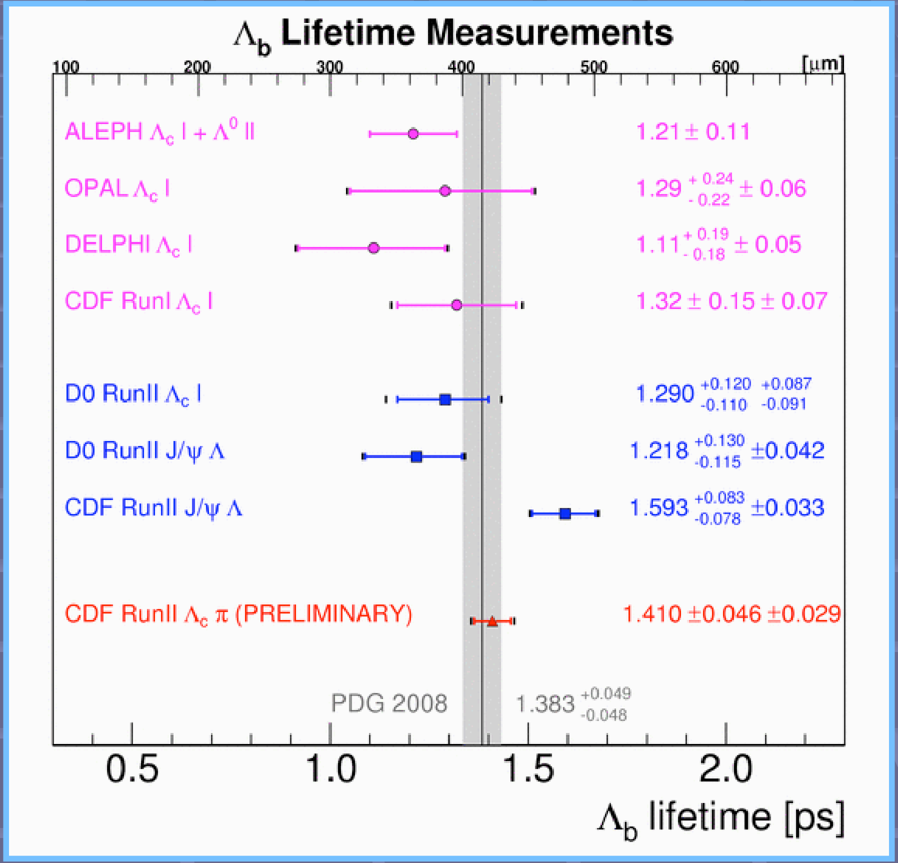
Backup Slides

B_s studies at CDF

- High yield of $B_s \rightarrow J/\psi\ \varphi$
  - Important channel for CPV studies
  - Interference between mixing and decays yields phase measurements
- Tagging performance:
  - Opposite side tagger $\varepsilon D^2 \sim 1.2\%$
  - Same side tagger $\varepsilon D^2 \sim 3.6\%$ (in B_s)
    - Uses PID (TOF, dE/dx)

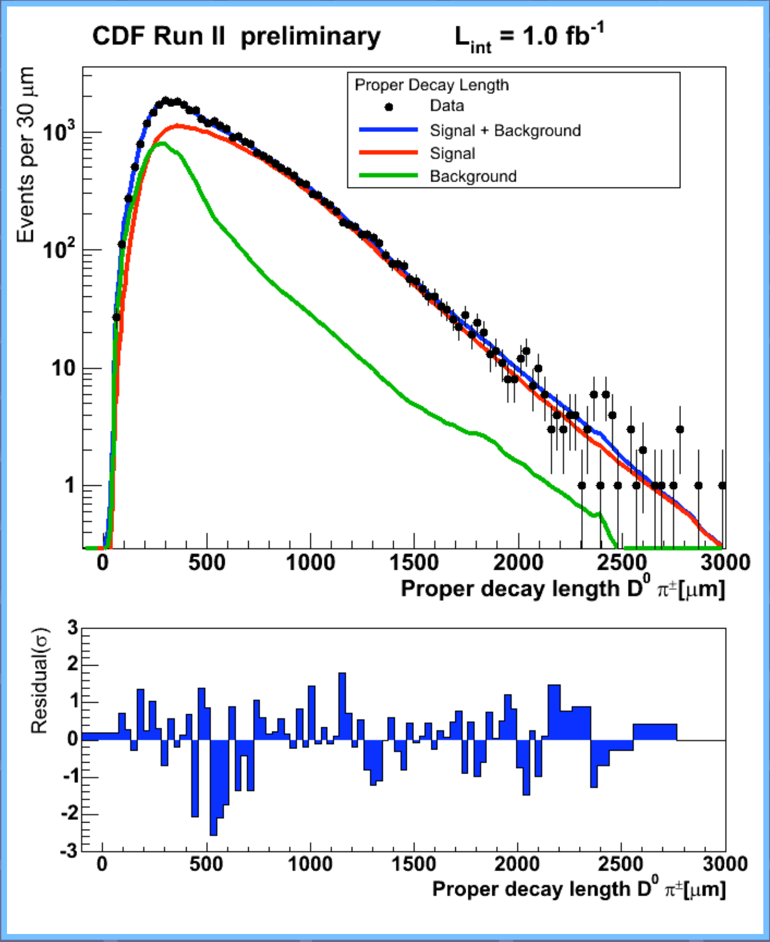
Λ_b Lifetime backup

- 1.1fb^{-1} lumi
- Displaced track trigger dataset
- Not exponential due to trigger bias - corrected for using MC simulation leading to 9μm systematic.



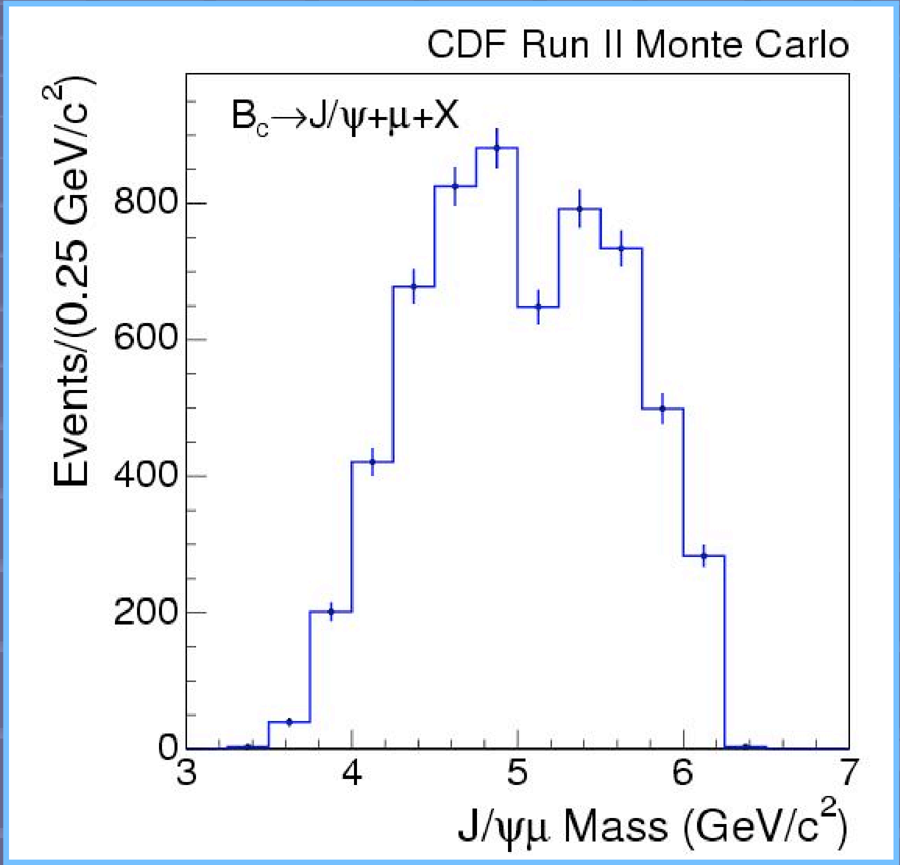
MC free method backup

- 1.0fb^{-1} lumi, 24200 ± 200 sig. events
- $B^+ \rightarrow D^0\pi$
- Impact parameter trigger - intrinsically biases the lifetime measurement
- Event by event decay kinematics used to correct for bias - acceptance function converts applied IP cuts to lifetime cuts for each event.
- 1st measurement to correct bias without MC
- Applicable to future experiments with IP trigger, eg LHCb



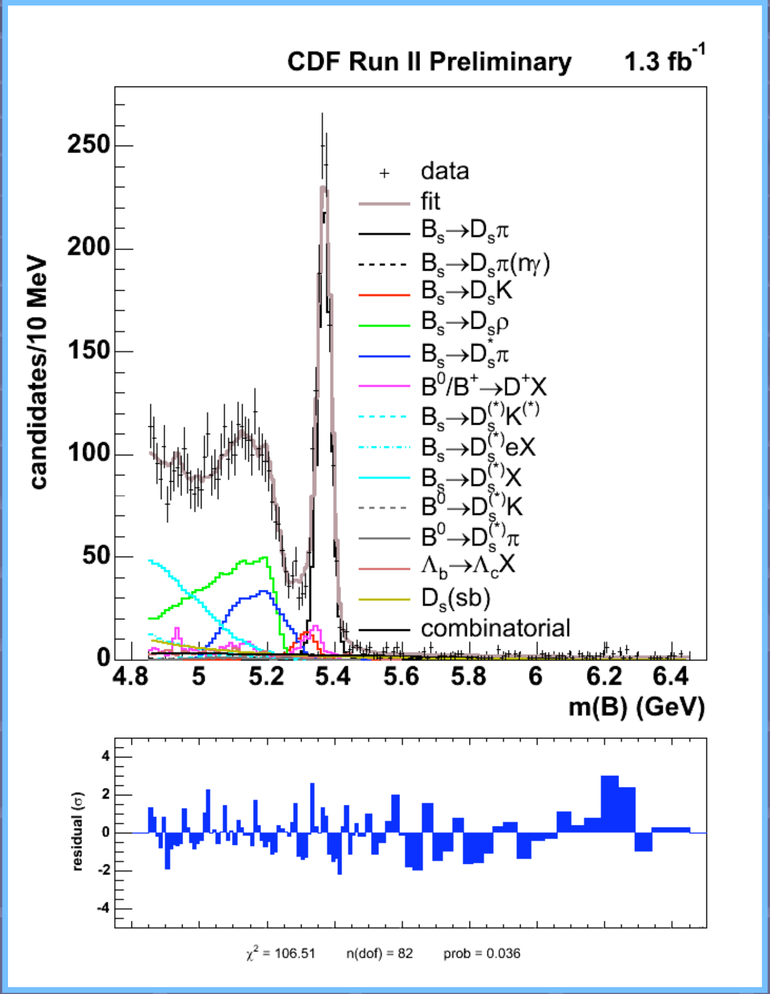
B_c Lifetime backup

- 1 fb^{-1}
- $J/\psi \rightarrow \mu\mu$ trigger has no lifetime bias
- Challenge is dealing with bkg model - missing ν so no mass peak - difficult to discriminate between sig and bkg. See MC mass plot.
- Analyse J/ψ + l candidates in inverse mass range 4-6GeV/c^2 (B_c expected region)



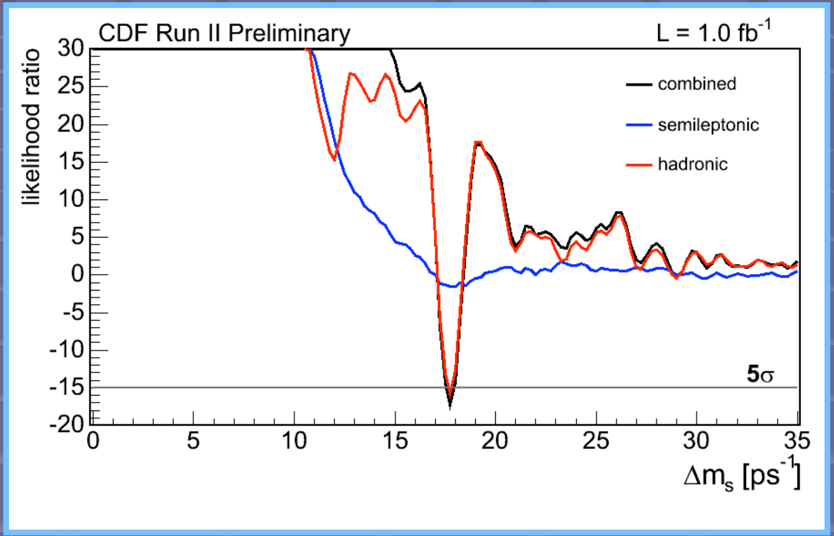
B_s Lifetime backup

- $1.3 fb^{-1}$
- Uses MC to correct for TTT bias
- 1100 fully reconstructed $B_s \rightarrow D^-_s (\varphi\pi^-) \pi^+$
- Similar number of partially reconstructed B_s candidates eg. $B_s \rightarrow D^-_s \rho^+ (\pi^+\pi^0)$ where π^0 is not reconstructed - come from actual B_s so can contribute to lifetime.
- Treated like semileptonic events.
- Uncertainty due to missing tracks or misaligned masses can be accounted for and included in likelihood formula.



B_s mixing backup

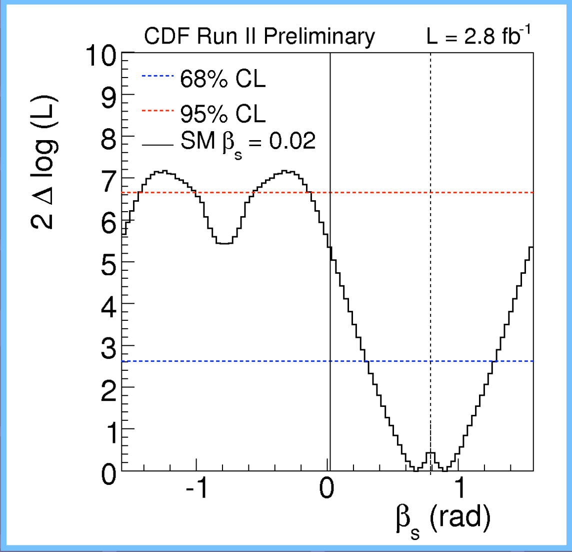
- $1.0 fb^{-1}$
- 5600 fully reconstructed hadronic B_s decays
- 3100 partially reconstructed hadronic B_s decays
- 61500 partially reconstructed semileptonic B_s decays
- Measure probability, as function of proper decay time, that B_s decays with same or opposite flavour as the flavour at production. Gives signal peak for B_s - B_s oscillations.
- Probability of random fluctuations causing this = $8 \times 10^{-8} > 5\sigma$

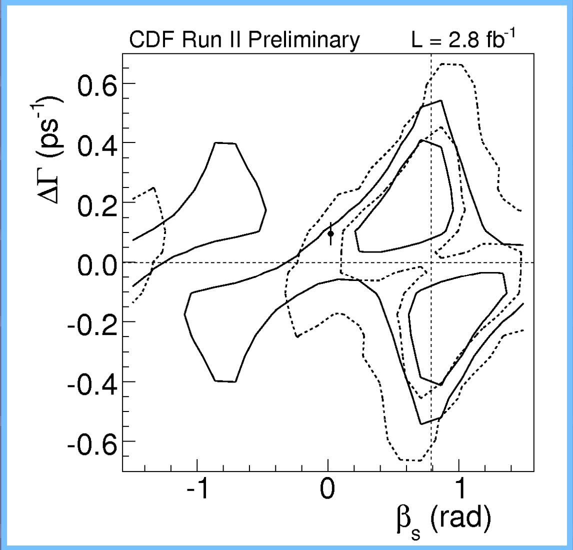


Log of ratio of likelihoods for A=1 and A=0 vs. osc. frequency

$\beta_s^{J/\psi\varphi}$ and $\Delta\Gamma$ backup

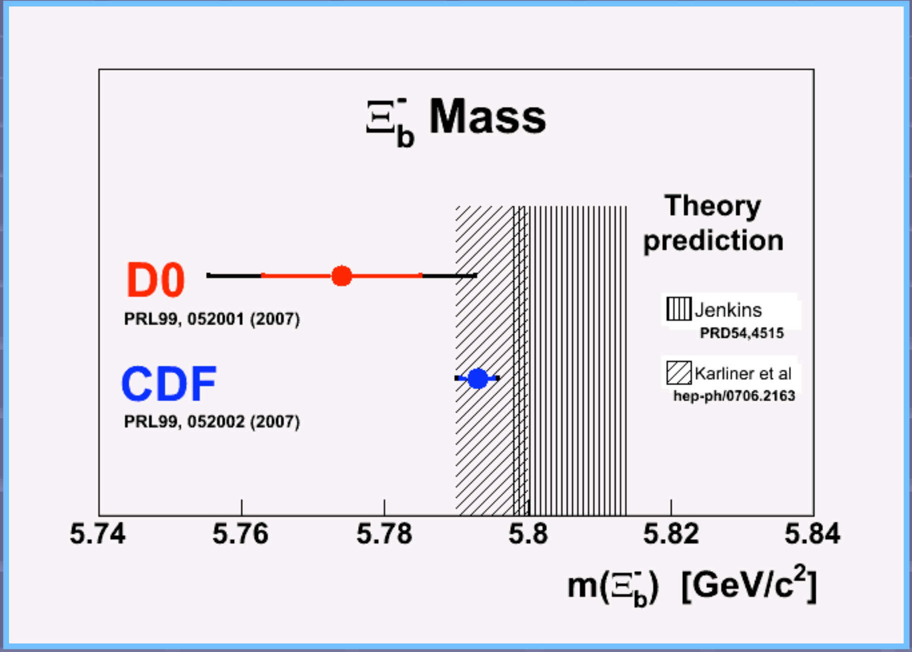
- 3150 sig. events - currently lacking PID in 2nd half of dataset
- Feldman-Cousins likelihood ratio used to determine confidence level for 20x40 grid evenly spaced in β_s , $\Delta\Gamma$.
- 2 minima due to exact symmetry in transformation: $2\beta_s \to \pi - 2\beta_s$, $\Delta\Gamma \to -\Delta\Gamma$, $\delta_{//} \to 2\pi - \delta$, $\delta_{perp} \to 2\pi - \delta_{perp}$ can be removed by applying constraints to appropriate ranges
  - approx. symmetries remain -> still local minima and since log likelihood fn is non-parabolic not possible to give meaningful point estimates.





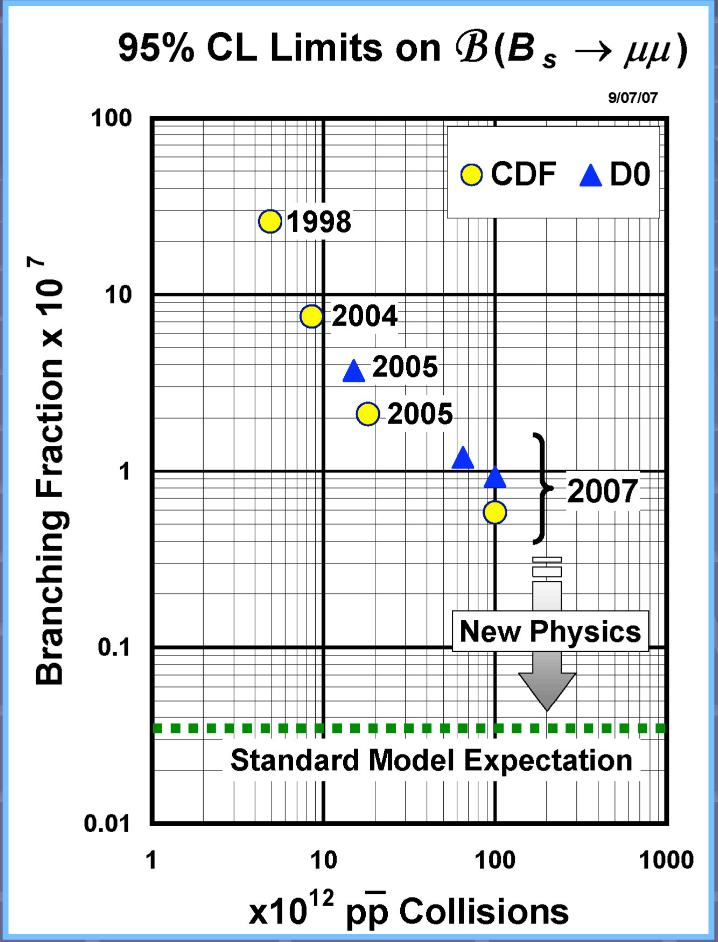
Ξ_b Backup

- $1.9 fb^{-1}$
- Apply to $\Xi_b^- \to J/\psi \Xi^-$ signal - same strategy was applied to $B_c \to J/\psi\, \pi$ observation
- Reduce bkg and increase vtx precision by using Ξ tracked in SVX.
- Use of Ξ track, turns 5 track final state ($\mu\mu\pi p\pi$) into 3 track vertex ($\mu\mu\Xi$) which is analagous to the state in $B^+ \to J/\psi K^+$
- Optimise cuts to get best $B^+ \to J/\psi K^+$ signal



$B_{s(d)} \rightarrow \mu^+\mu^-$ Backup

- FCNC decays suppressed in SM, only occur through higher order diagrams
- SM predicts BR~3.8×10^{-9}
  - This is > 1 order of magnitude smaller than current experimental sensitivity
- Various extensions (eg. MSSM, Minimal Flavour Violating) to SM predict enhancement of 1-3 orders of magnitude to this branching ratio



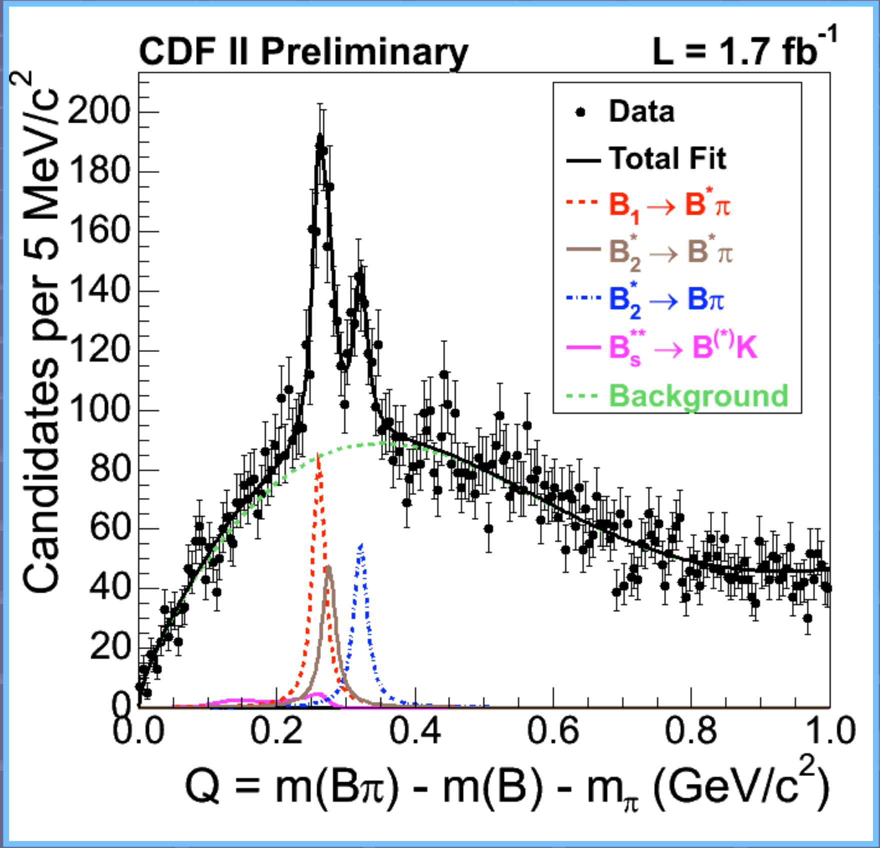
X(3872) Backup

- Does observed X(3872) signal stems from two states?
  - Fit the mass signal with a Breit-Wigner function convoluted with a resolution function determined from simulation.
  - Both functions contain width scale factor that is a free parameter in the fit
  - sensitive to the shape of the mass signal.
- Measured width scale factor is compared to values seen in pseudo experiments which assume two states with given mass difference and ratio of events.
- The resolution in the simulated events is corrected for the difference between data and simulation measured for the $\psi(2s)$
- Results consistent with single mass state

$\Delta m < 3.6$ MeV/c^2 at 95% CL

B^{**0} mesons Backup

- 4 orbitally excited B** states:
  - J_l = 1/2 (J = 0, 1) are B^*_0 and B^*_1 - not yet observed
  - J_l = 3/2 (J = 1,2) are B_1 and B^*_2
  - J_l = total angular momentum of the light quark (d, u)
- Currently most precise measurement of narrow B^{**0} masses



$\Gamma(B_2{}^{*0}) = 22.7^{+3.8}_{-3.2}$ (stat.) $^{+3.2}_{-10.2}$ (syst.)