THE UNIVERSITY OF WARWICK

B physics at hadron colliders

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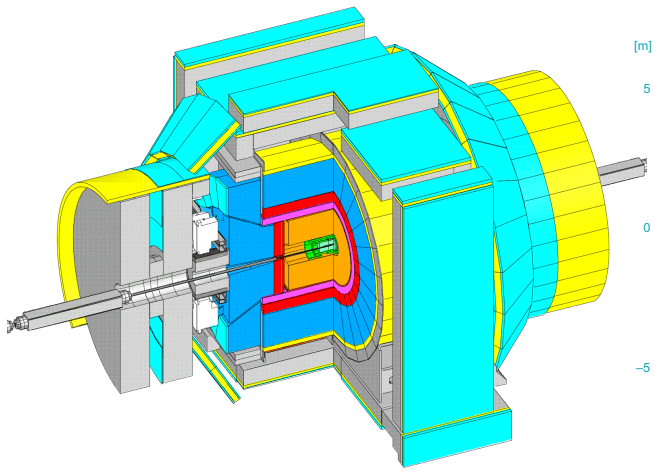
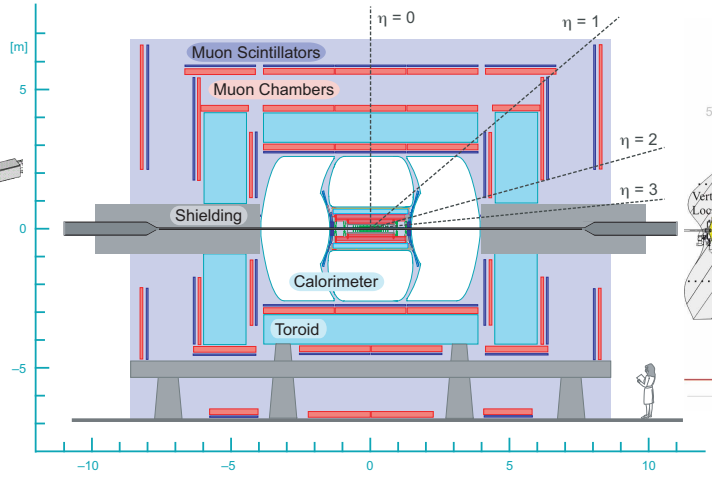
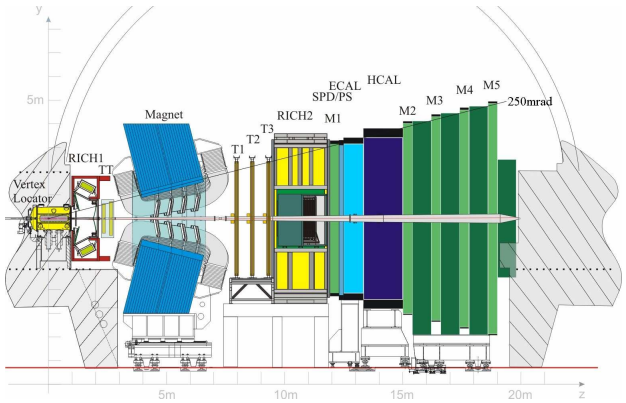






Introduction

- Experiments at Tevatron and LHC deliver many interesting results on heavy flavour
- In this talk I will concentrate only on those which are relevant for search and understanding of new physics
  - Testing our tools through *b*-hadron lifetimes
  - Getting SM CKM matrix (measurement of angle γ)
  - B_s mixing and CP violation
  - Rare decays, both hadronic and leptonic
  - Mixing and CP violation in charm
- With audience packed by high profile theorists I will skip most of the theory side

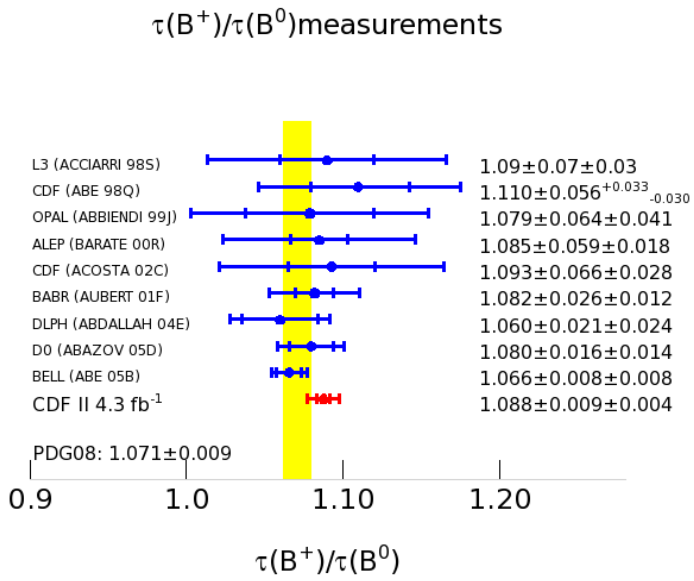
b hadron lifetimes

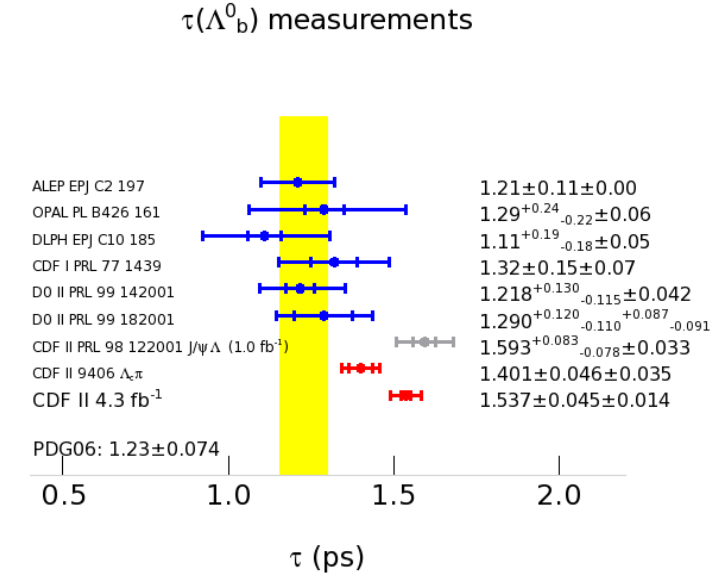
- Theory description of B mixing relies on HQE
- HQE also used to predict lifetimes
- Lifetimes dominated by tree level $b \to c$ transition
- Do not expect new physics to affect it
- Expectations:

$$\frac{\tau(B_s)}{\tau(B_d)} - 1 \in [-4 \times 10^{-3}; 0]$$

$$\frac{\tau(B^+)}{\tau(B_d)} - 1 = 0.044 \pm 0.024$$

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.88 \pm 0.05$$



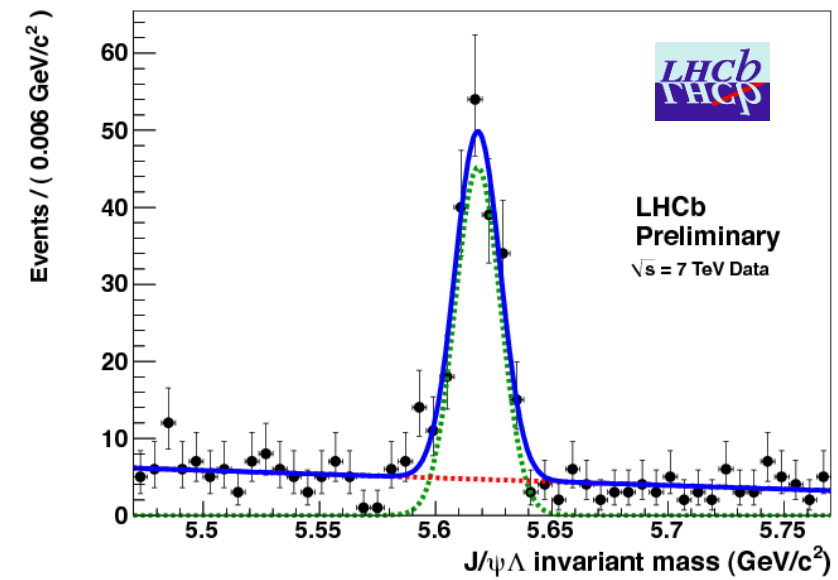


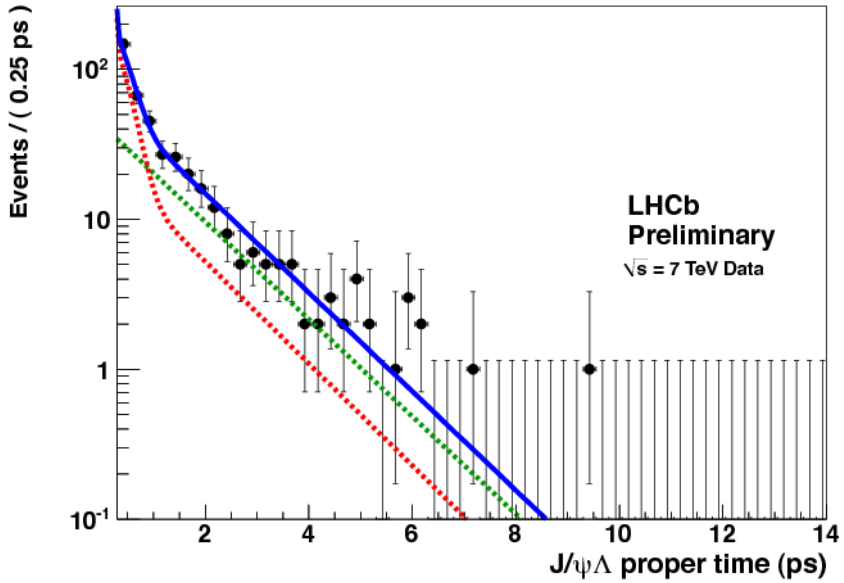
b hadron lifetimes

- Latest measurement performed by LHCb collaboration
- Uses about 6700 B^+, 2670+840 B^0 and 190 Λ_b signal events
- Measured lifetimes:

$$\tau(B^+) = 1.689 \pm 0.022 \pm 0.047 \text{ ps}$$
$$\tau(B^0) = 1.523 \pm 0.028 \pm 0.19 \text{ ps}$$
$$\tau(\Lambda_b) = 1.353 \pm 0.108 \pm 0.035 \text{ ps}$$

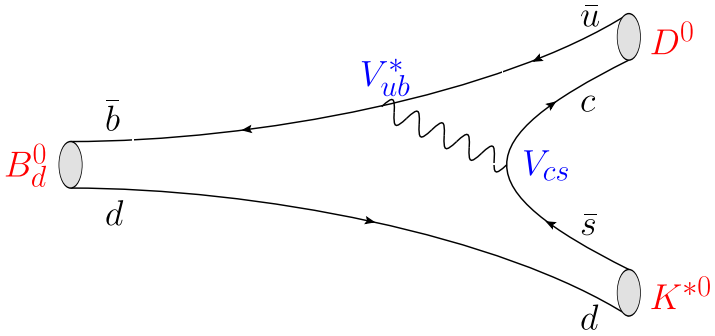
- Measurements consistent with previous ones
- Seems to prefer smaller Λ_b lifetime than CDF, but uncertainties are large
- HQE passes this test for the moment

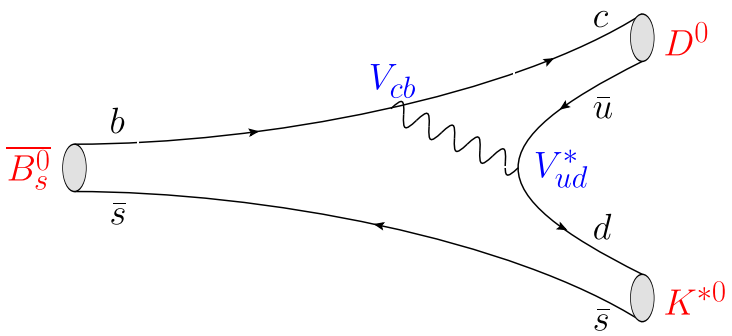




γ with trees

- Before we can start to talk about new physics, we need precise SM prediction
- Knowledge of CKM matrix is important here
- Need to determine CKM matrix from measurements where NP contribution is unlikely
- Measurements of the angle γ in tree level processes is important contribution to this
- Comes as CP violation from interference of



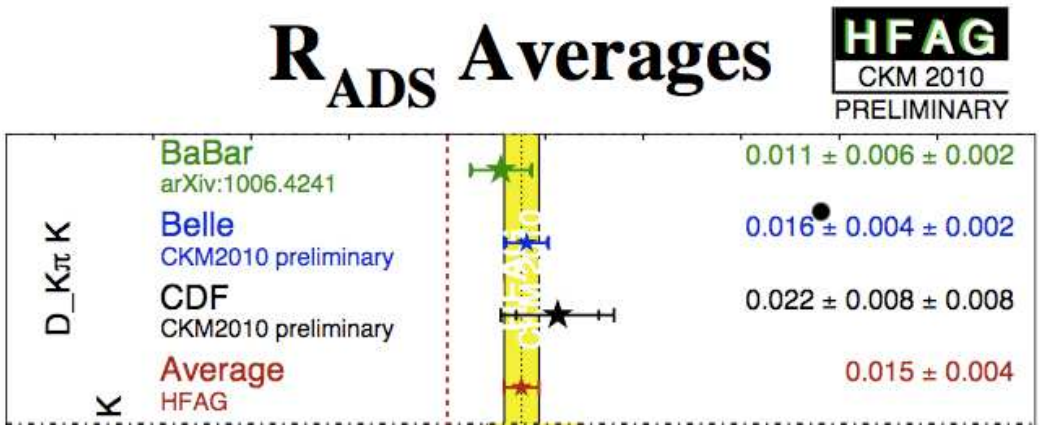


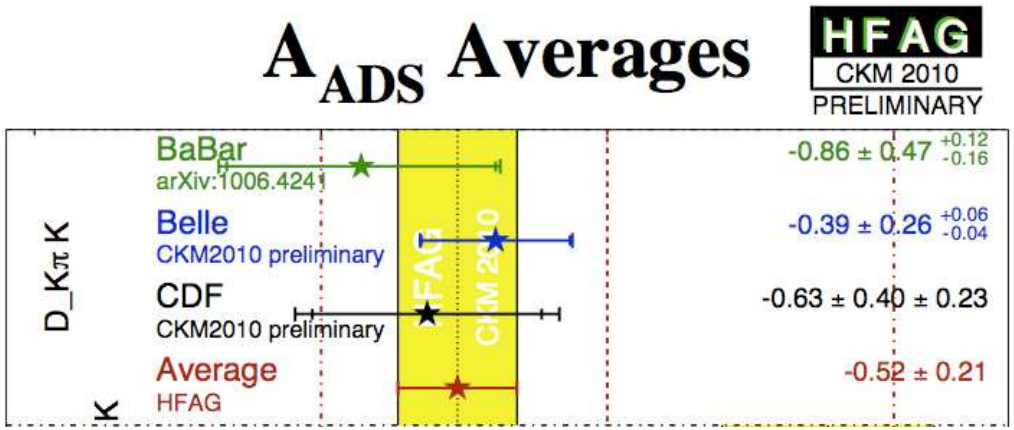
with D^0 and $\bar{D}^0$ decaying to common final state

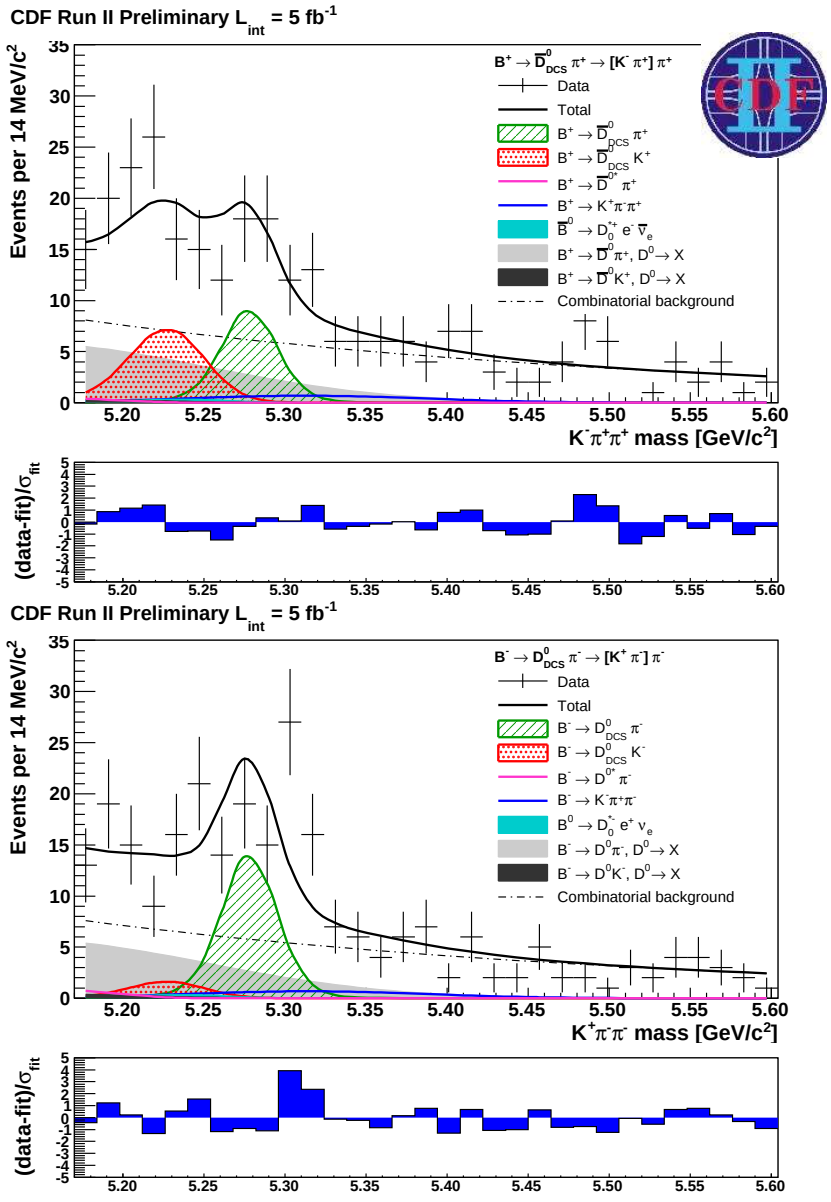
- Difficult because of small rate and/or small *CP* violation

γ with trees

- Start to see significant signals
- Reasonable precision compared to *B*-factories

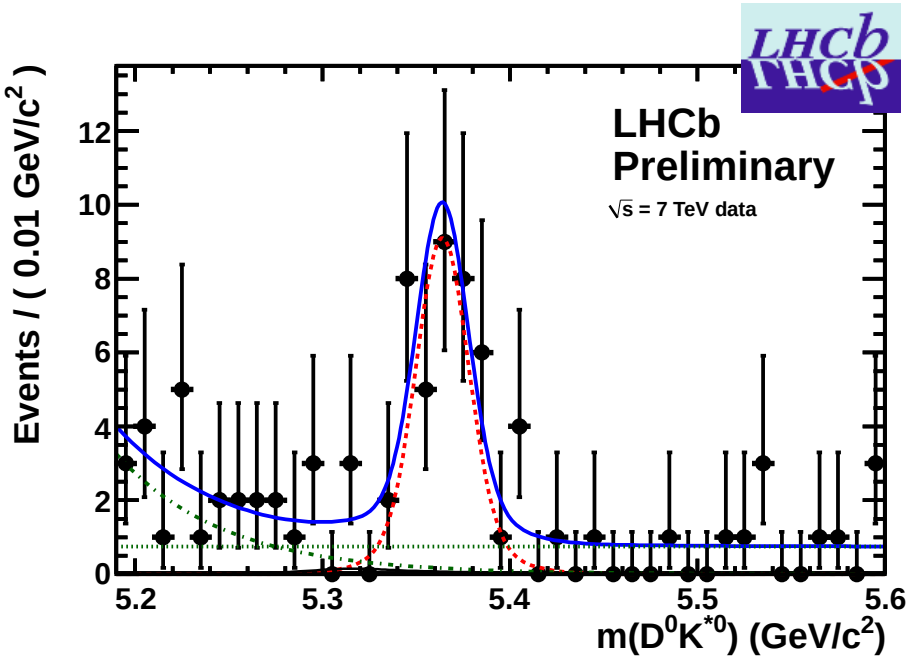






Future of γ with trees

- While CDF has some more data to analysis, real progress needs more than factor of 2 increase in statistics
- Clear task for LHCb
- Statistics at LHCb not large enough for measurement right now
- But can already study new decays and possibly important back-grounds
- First observation of $B_s \to D^0 K^{*0}$
- Significance over 9σ
- $\mathcal{B}(\bar{B}_s \to D^0 K^{*0})/\mathcal{B}(B^0 \to D^0 \rho) = 1.39 \pm 0.31 \pm 0.25$
- Trigger on hadronic states works well $\to$ good prospect for γ

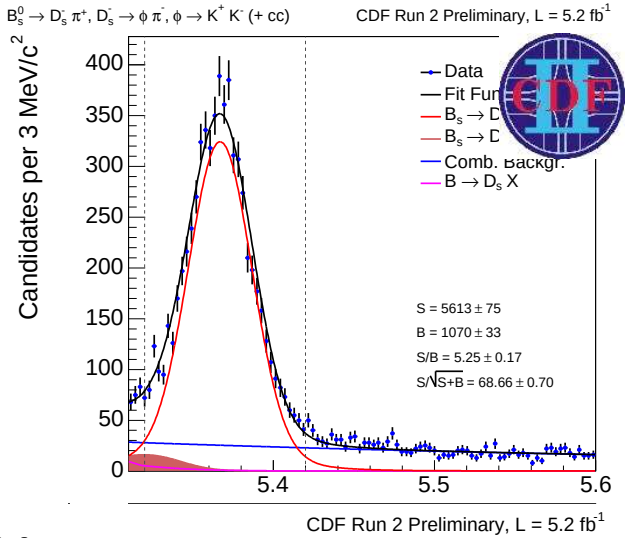


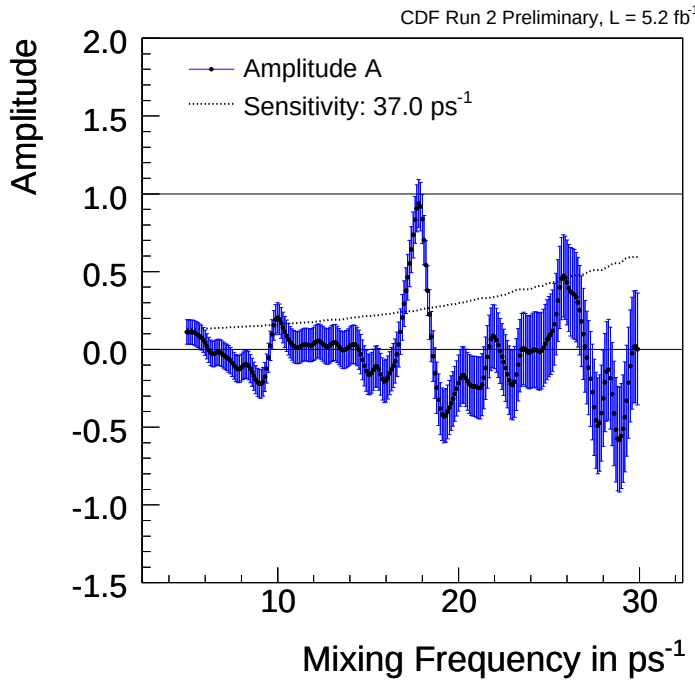
B_s mixing

- Provides two inputs for CPV in $B_s \to J/\psi\phi$
  - Mixing frequency Δm_s
  - Performance of flavour tagging
- Principle

$$A = \frac{N_{mix} - N_{unmix}}{N_{mix} + N_{unmix}} = A \cdot D \cos(\Delta m t)$$

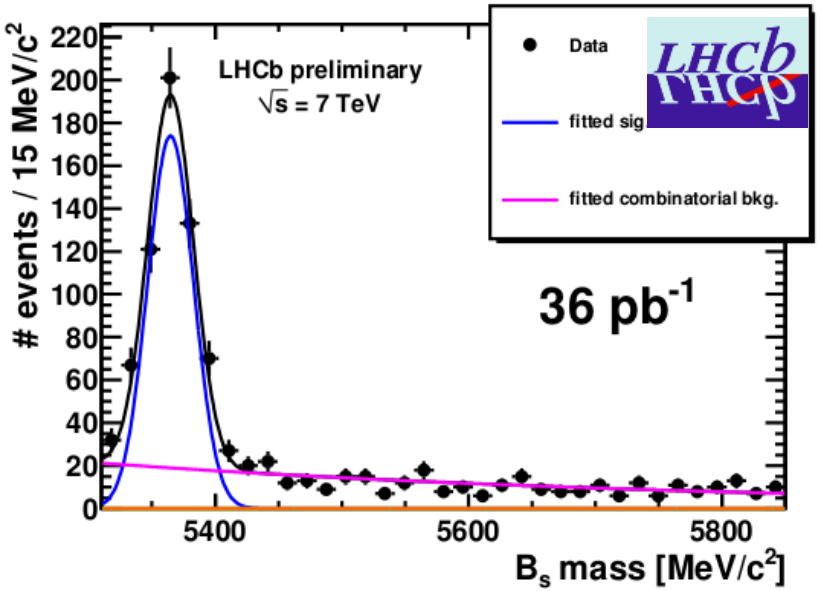
- Use decays:
  - $B_s \to D_s\pi$ with $D_s \to \phi\pi$, $D_s \to K^*K$, $D_s \to \pi\pi\pi$
  - $B_s \to D_s\pi\pi\pi$ with $D_s \to \phi\pi$
- In total $\approx$ 12900 signal events
- Total tagging power $\epsilon D^2 = 3.2 \pm 1.4\%$
- $\Delta m_s = 17.79 \pm 0.07(\text{stat})\ \text{ps}^{-1}$
- 1 fb^{-1}: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ \text{ps}^{-1}$

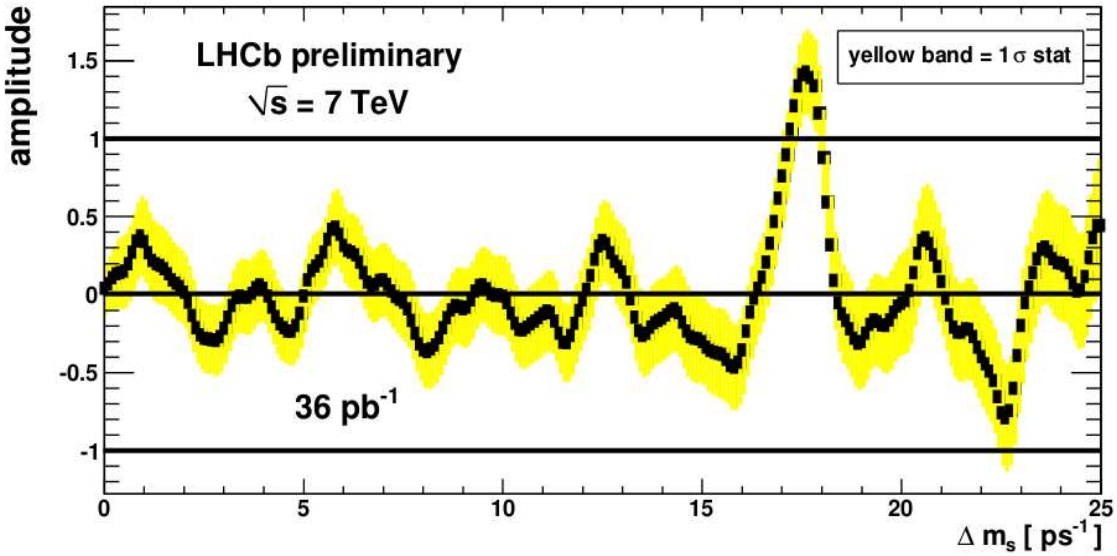




B_s mixing

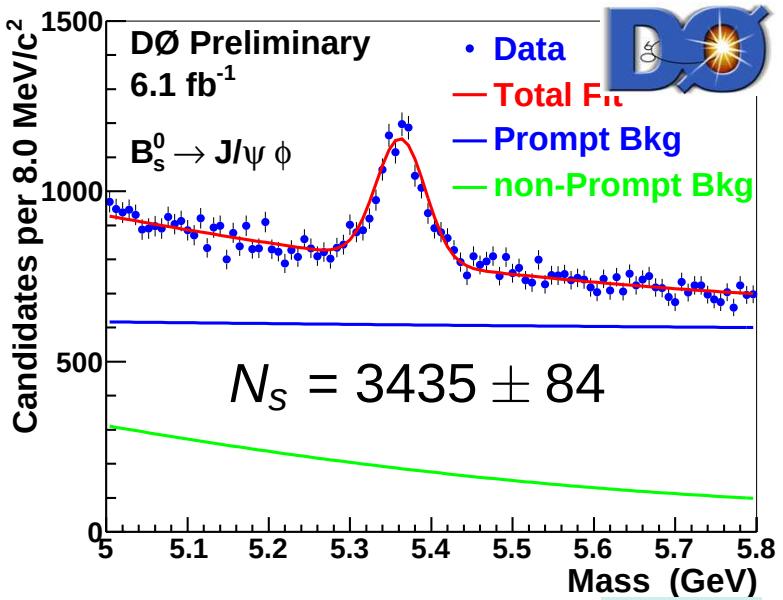
- LHCb uses $B_s \to D_s^-(K^+K^-\pi^-)(3)\pi$ decays
- About 1350 signal events
- Proper decay time about factor 2 better than CDF
- Opposite side tagging only
- $\Delta m_s = 17.63 \pm 0.11 \pm 0.04$ ps^{-1}
- Significance 4.6σ
- Tagging power 3.8$\pm$2.1%

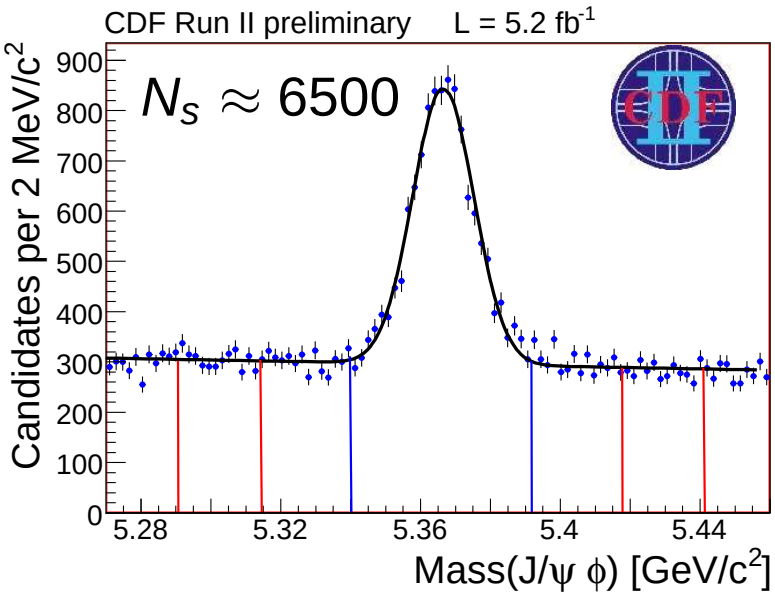


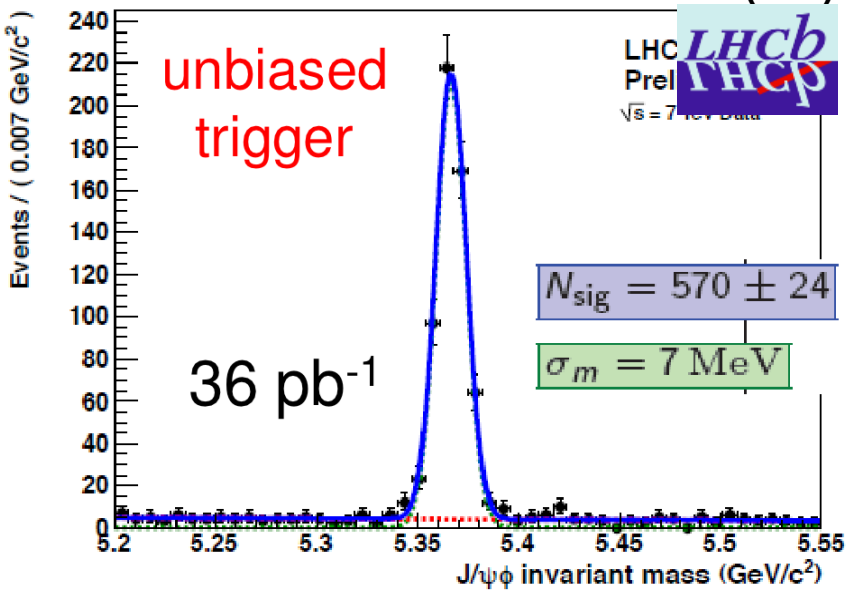


CPV in $B_s \to J/\psi\phi$

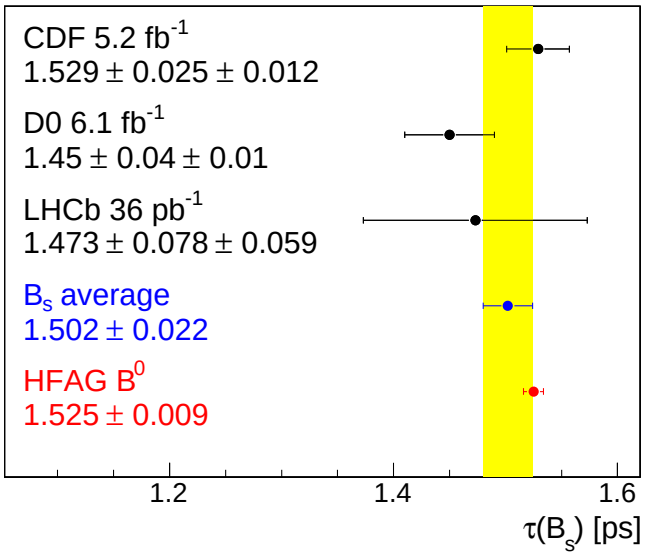
- Decay $B_s \to J/\psi\phi$ provides good laboratory to search for NP in B_s mixing phase
- Tevatron experiments updated last summer
- LHCb joins the game
- ATLAS and CMS on their way

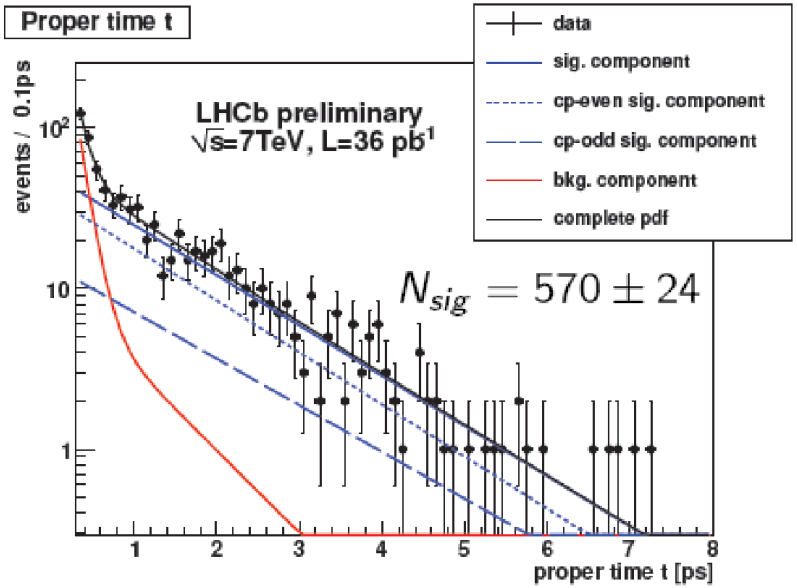


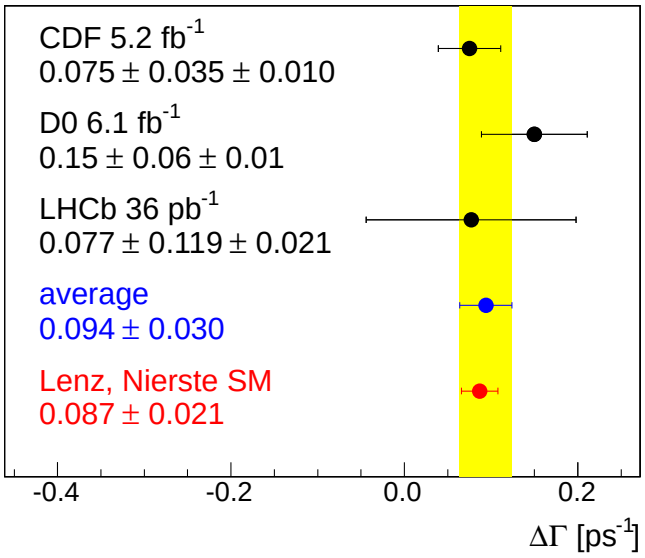


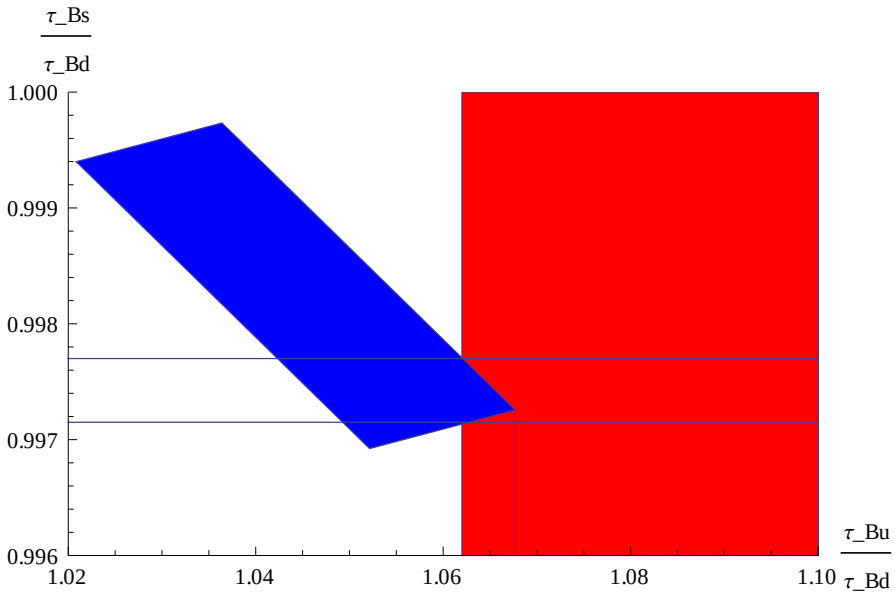


B_s lifetime and $\Delta\Gamma_s$

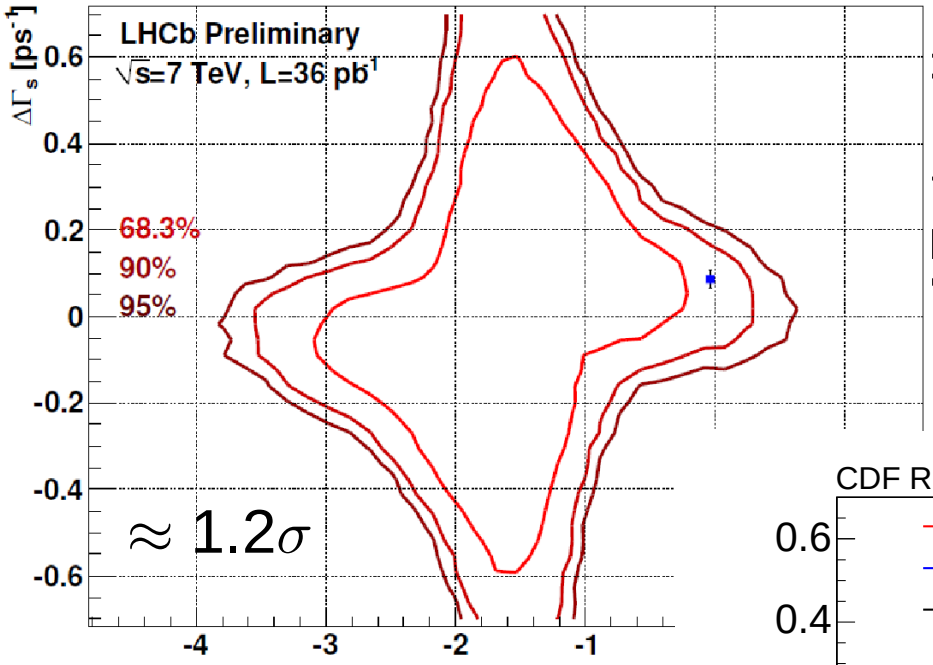


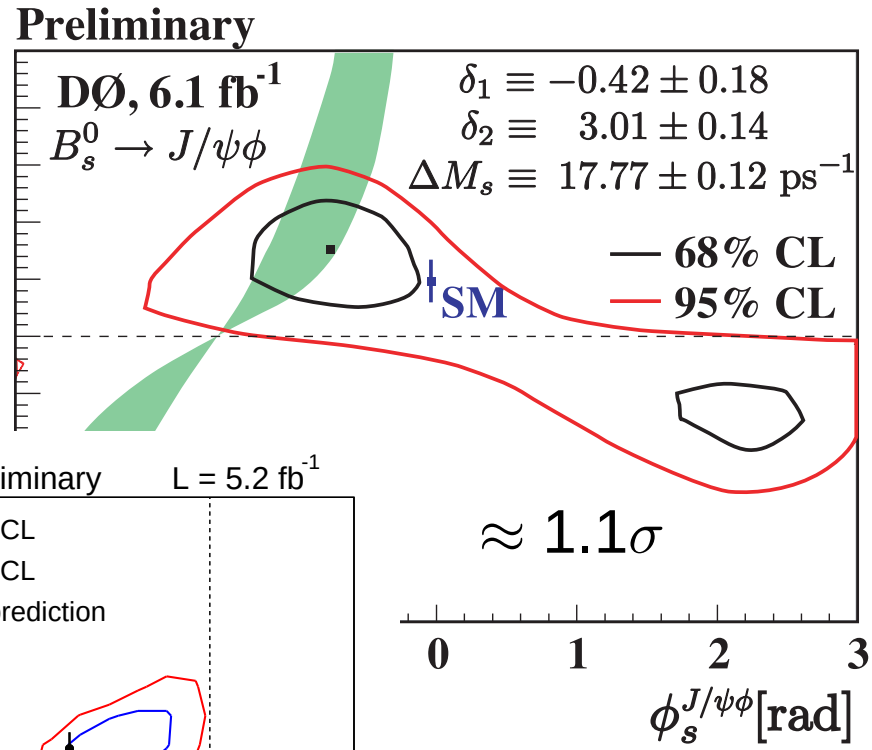


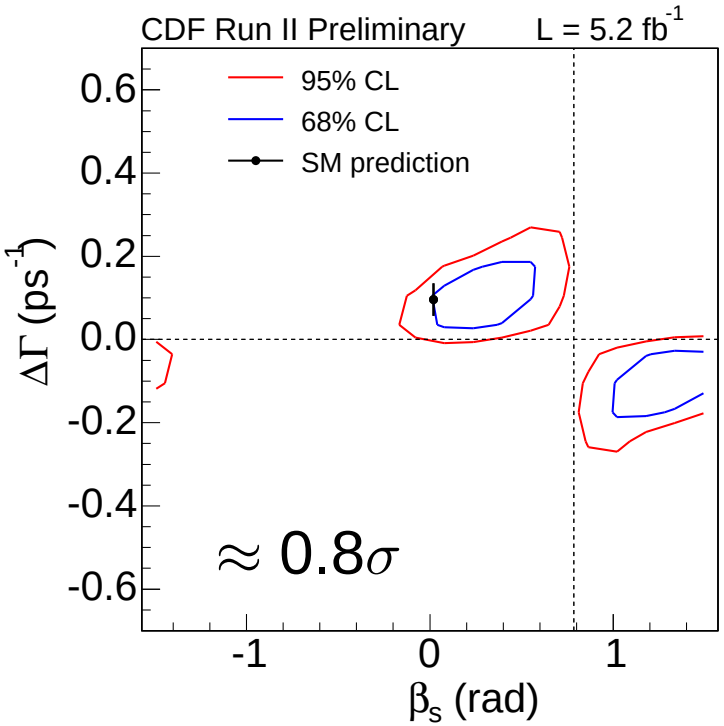




CPV in $B_s \to J/\psi\phi$

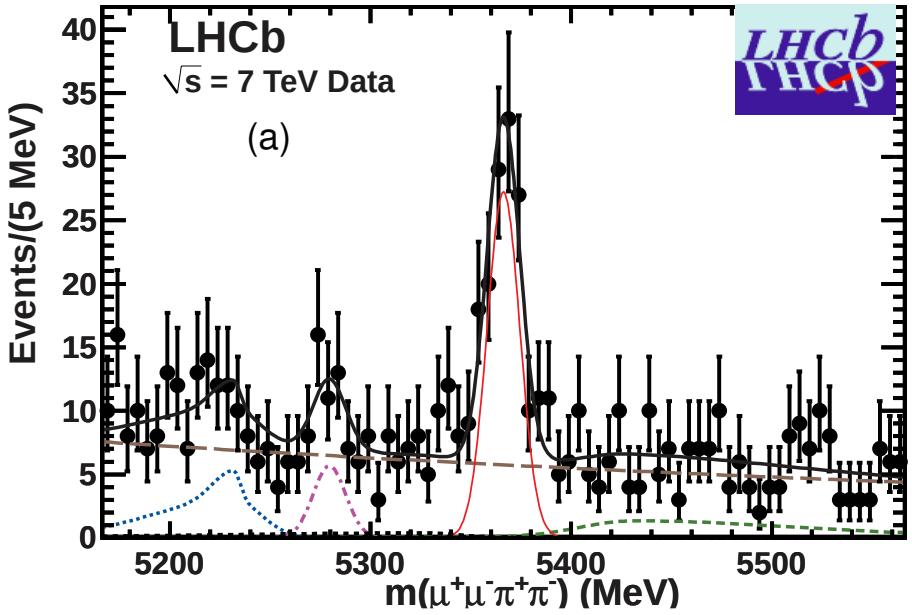


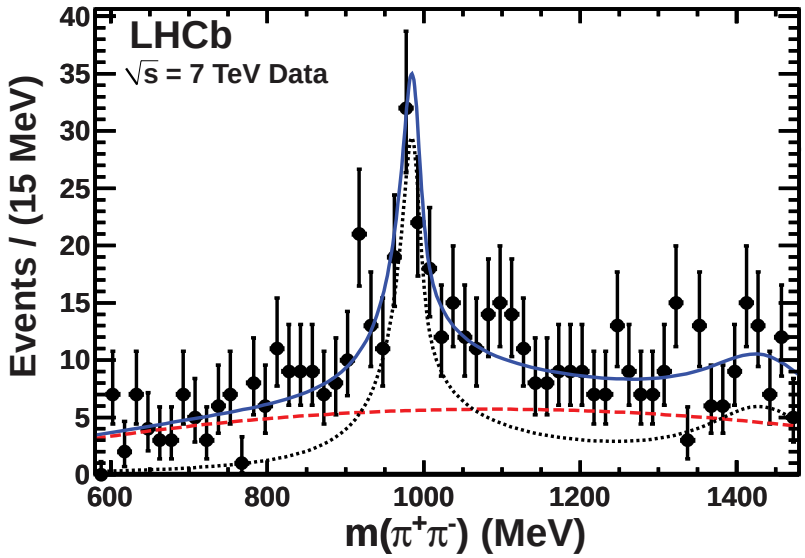




Observation of $B_s \to J/\psi f_0(980)$

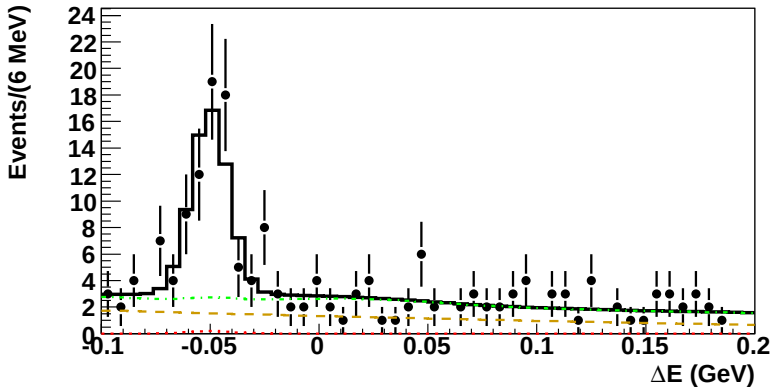
- Since first $B_s \to J/\psi\phi$ CPV measurements there was discussion of s-wave
- Neglecting it can bias result
- Decay $B_s \to J/\psi f_0(980)$ provides good test of s-wave
- Expect $R_{f_0/\phi}$ in region 0.1–0.5
- Since it is CP-odd eigenstate, can in future
  - Measure lifetime and contribute to $\Delta\Gamma$
  - Measure CPV in B_s system without angular analysis

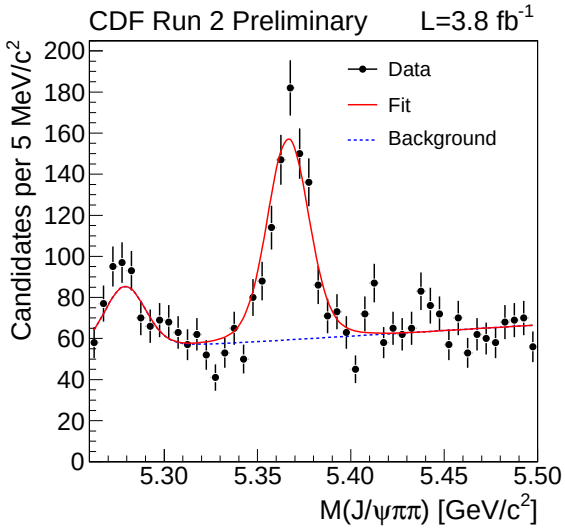


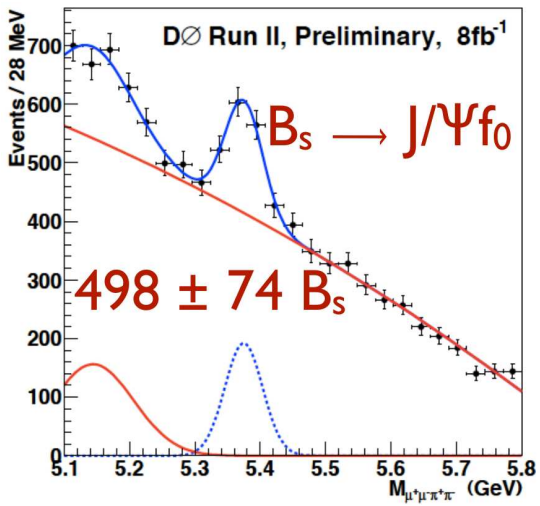


Observation of $B_s \to J/\psi f_0(980)$

- LHCb: $R_{f_0/phi} = 0.252^{+0.046\ +0.027}_{-0.032\ -0.033}$
- CDF: $R_{f_0/phi} = 0.292 \pm 0.020 \pm 0.017$
- DØ: $R_{f_0/phi} = 0.210 \pm 0.032 \pm 0.036$
- Belle: $\mathcal{B}(B_s \to J/\psi f_0(980), f_0 \to \pi^+\pi^-) = 1.16^{+0.31\ +0.15\ +0.26}_{-0.19\ 0.17\ -0.18} \times 10^{-4}$



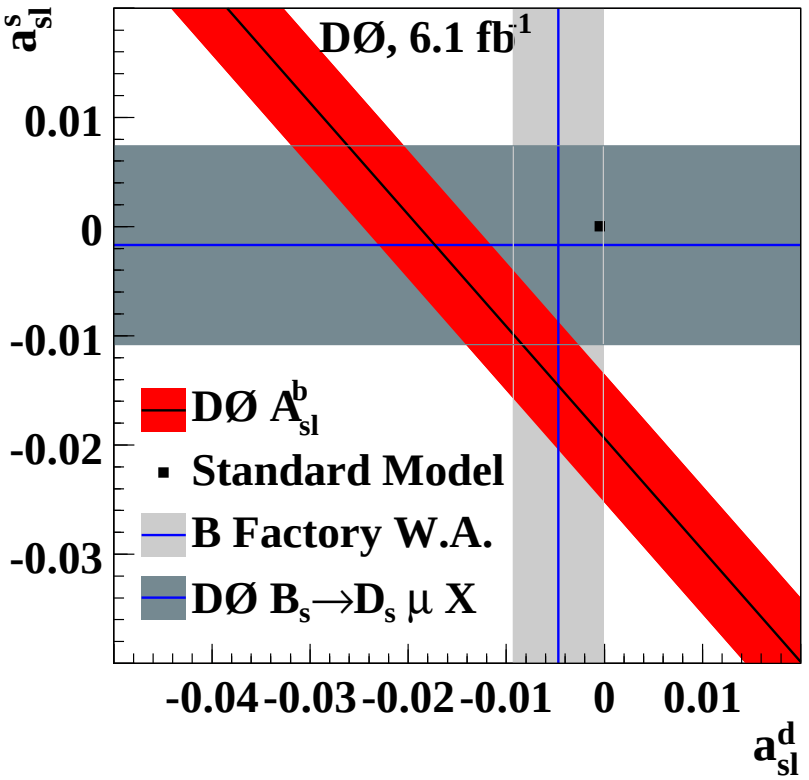




A_{SL}

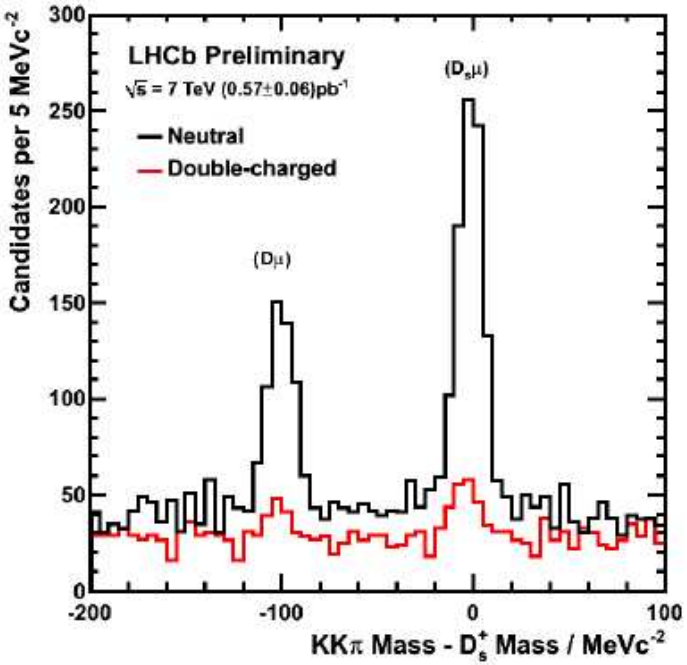
- Alternative way to look for NP in mixing phase is to measure A_{fs}
- Connected to phase by $A_{fs} = \Delta\Gamma_q / \Delta m_q \tan\phi_q$
- Traditionally measured using:
  - Semileptonic decays
  - Same charge dimuons
- Recent measurement by DØ
- Measures $A_{fs}^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$
- Mixture of B^0 and B_s effect
- SM prediction
  $A_{fs}^b = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$
- Result: $(-96 \pm 25 \pm 15) \times 10^{-4}$

arXiv:1005.2757

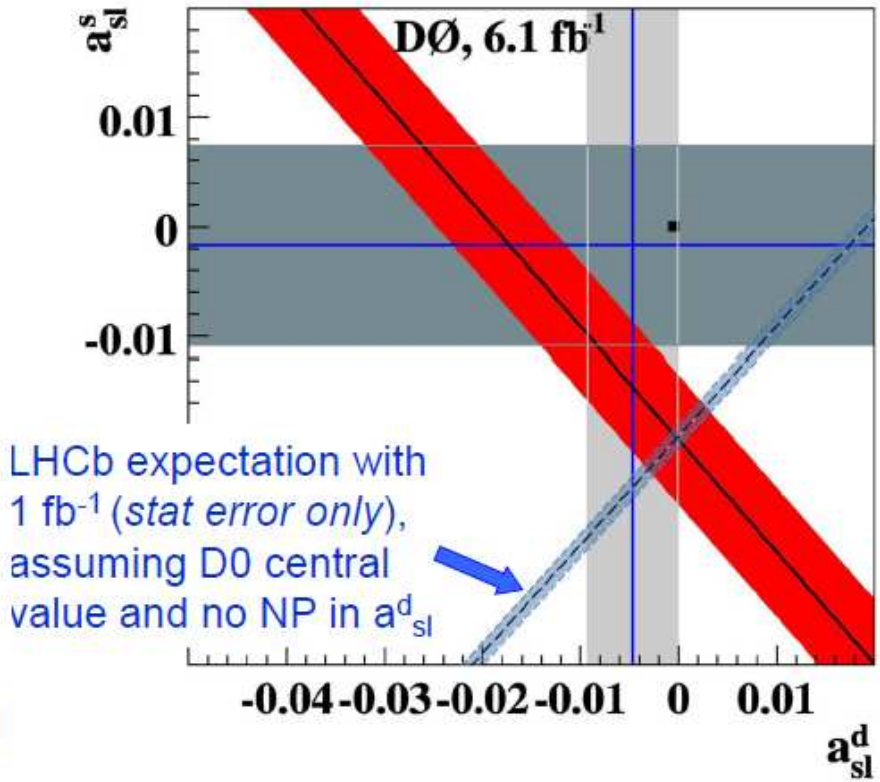


A_{SL}

- LHCb plans to measure difference $a^s_{SL} - a^d_{SL}$ using same final state ($B_s \to D_s(KK\pi)\mu\nu$ and $B^0 \to D(KK\pi)\mu\nu$)
- This suppresses detector effects
- Provides complementary information

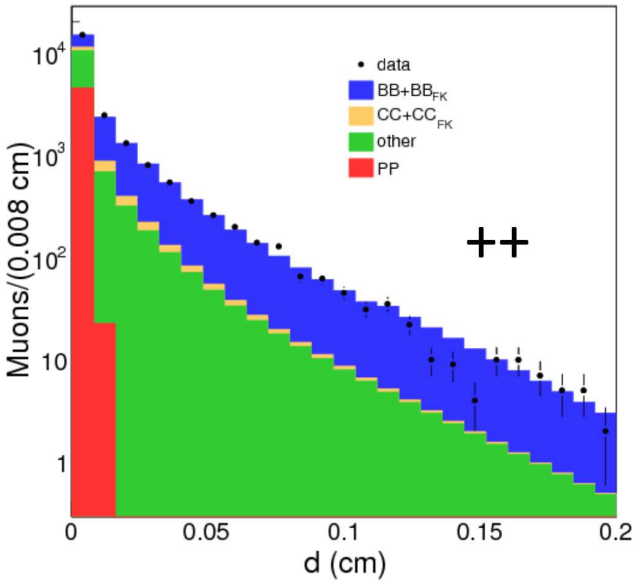


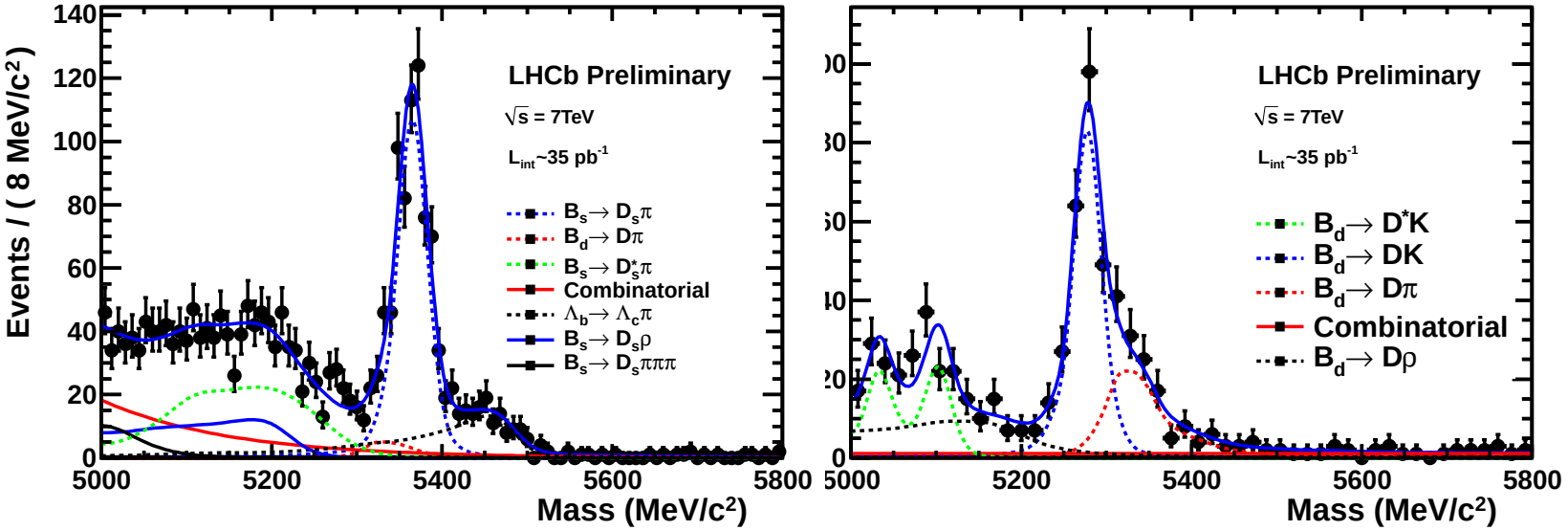
Events already being accumulated



Fragmentation

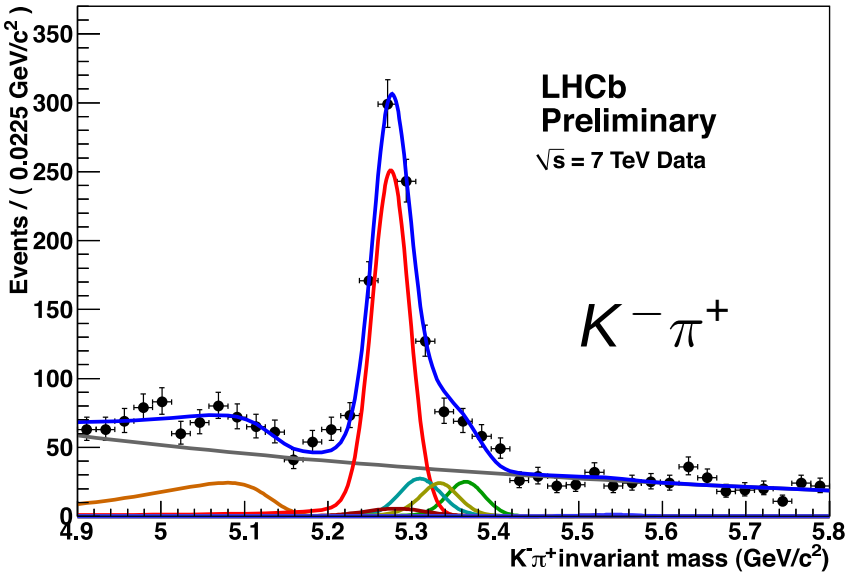
- Interpretation of A_{SL} needs f_s/f_d
- Long-standing discrepancy between LEP and Tevatron
- New CDF measurement of $\overline{\chi} = 0.126 \pm 0.008$ in agreement with LEP
- LHCb: $f_s/f_d = 0.245 \pm 0.017 \pm 0.025$
- Perhaps f_s/f_d at the end universal

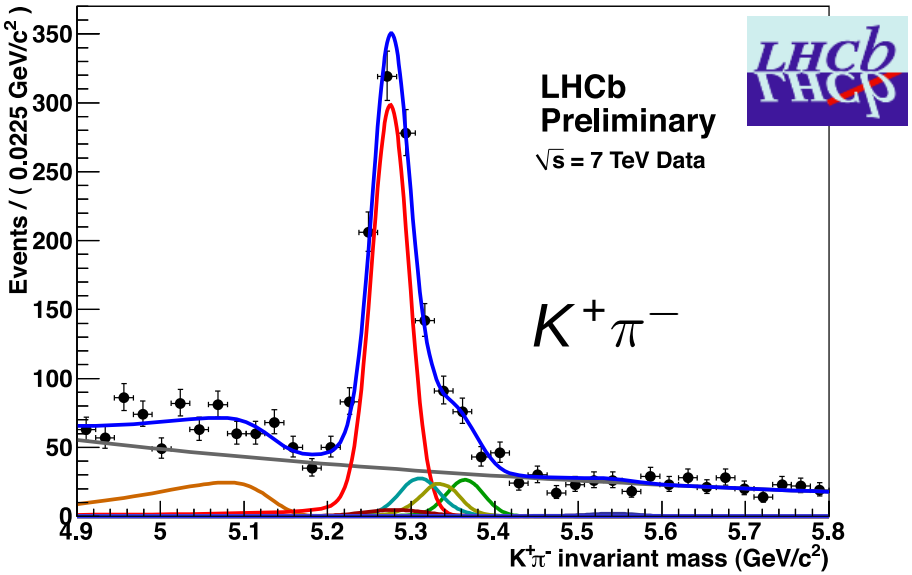




$B \to hh$

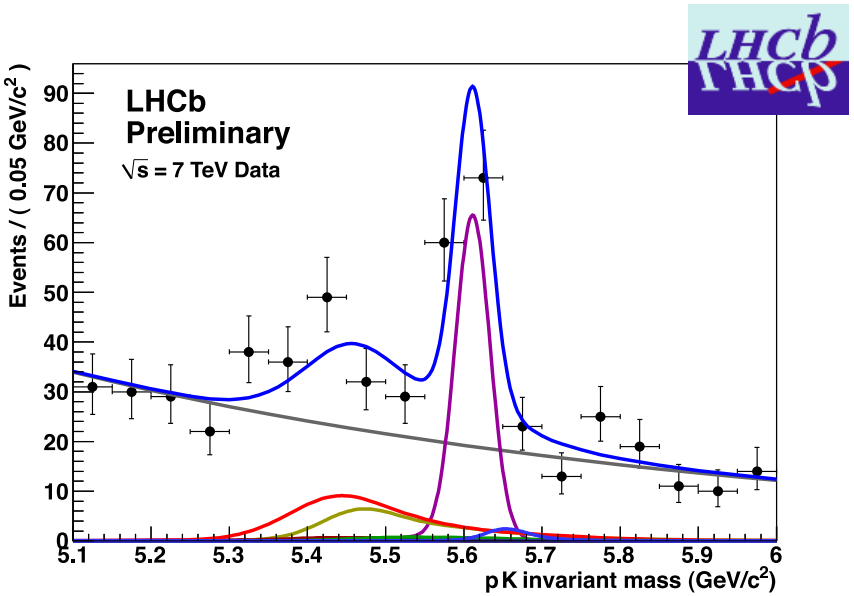
- Charmless two body b hadron decays provide rich output
- Lot of excitement in past from CP violation difference between $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$
- Latest result from LHCb
- 1447 ± 50 $B^0 \to K^+\pi^-$+cc events, 52 ± 10 $B_s \to K^-\pi^+$+cc
- CDF 1 fb^{-1} yields are ≈ 2400 and ≈ 140

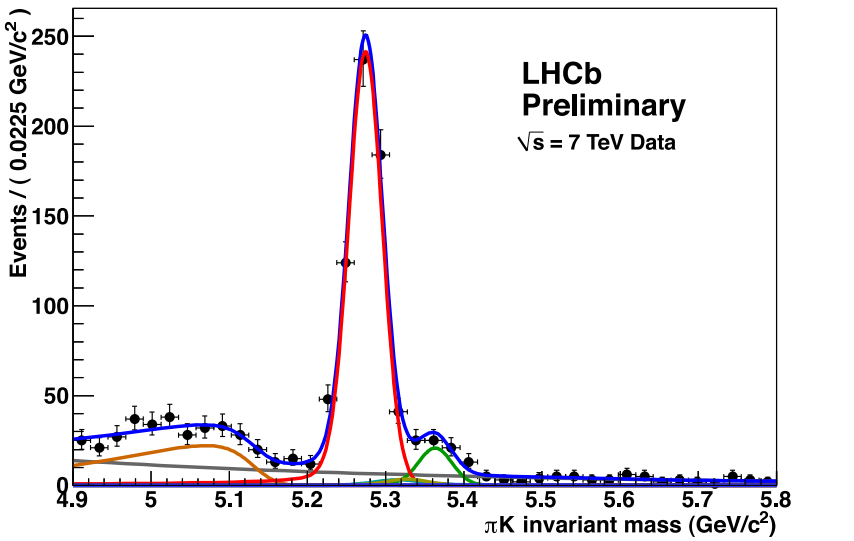




$B \to hh$

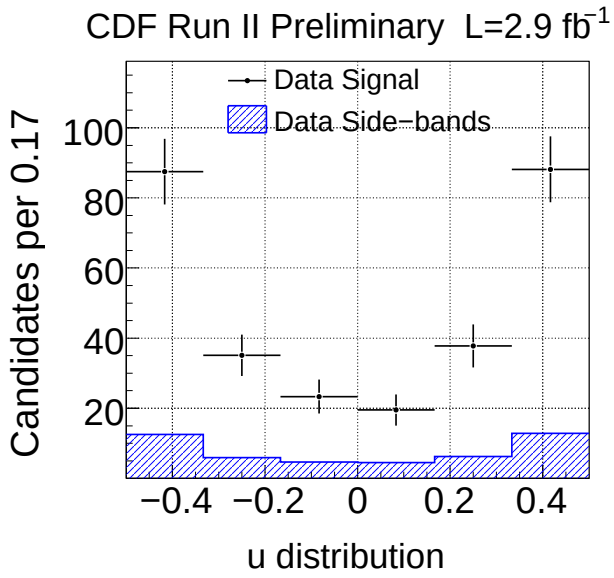
- LHCb results:
  - $A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008$
  - $A_{CP}(B_s \to K^-\pi^+) = 0.15 \pm 0.19 \pm 0.02$
- Compare to
  - HFAG $A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.011}$
  - CDF $A_{CP}(B_s \to K^-\pi^+) = 0.39 \pm 0.15 \pm 0.08$
- While B-factories analysed most of their data, CDF has $\approx$ 8 fb^{-1} available and LHCb collects data quickly

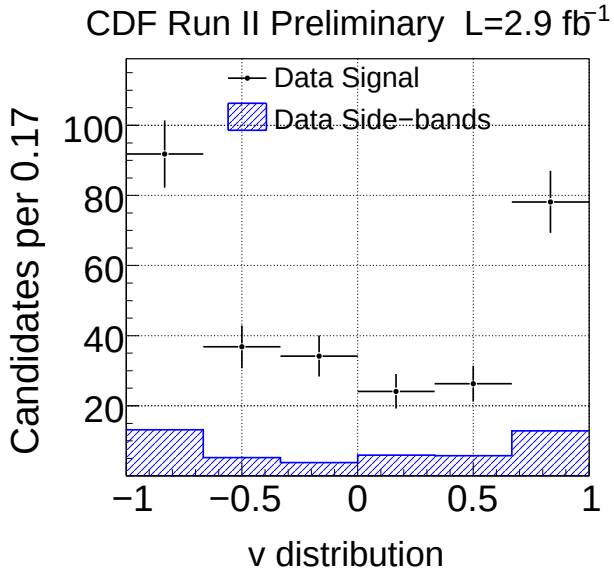




$B_s \to \phi\phi$ tripple products

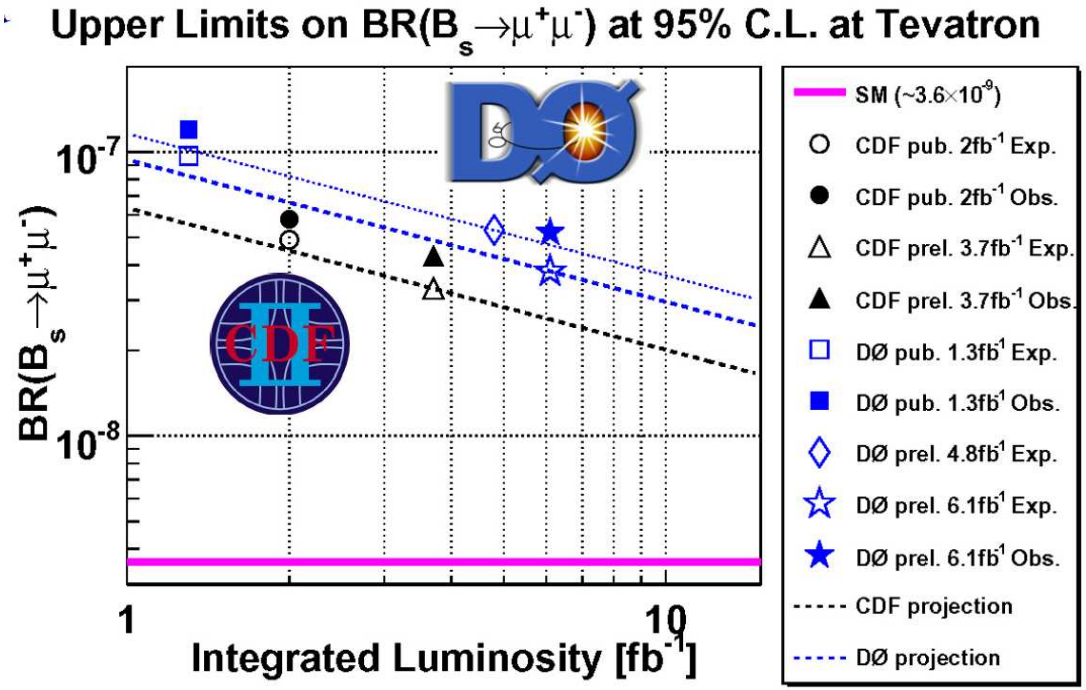
- $P \to VV$ allows to look to T violation through tripple products
- Interference between CP-odd and CP-even amplitudes
- $u = \cos\phi \sin\phi$ is related to $A_{||}A_{\perp}$
- $v = \sin(c \cdot \phi)$ where $c = \text{sign}(cos\theta_1 \cos\theta_2)$ is related to $A_0 A_{\perp}$
- Measure $A_x = \frac{\Gamma(x>0)-\Gamma(x<0)}{\Gamma(x>0)+\Gamma(x<0)}$
- Results:
  - $A_u = -0.007 \pm 0.064 \pm 0.018$
  - $A_v = -0.120 \pm 0.064 \pm 0.016$
- I think experiments can do many more of these if there is interest





$B_s \to \mu^+\mu^-$

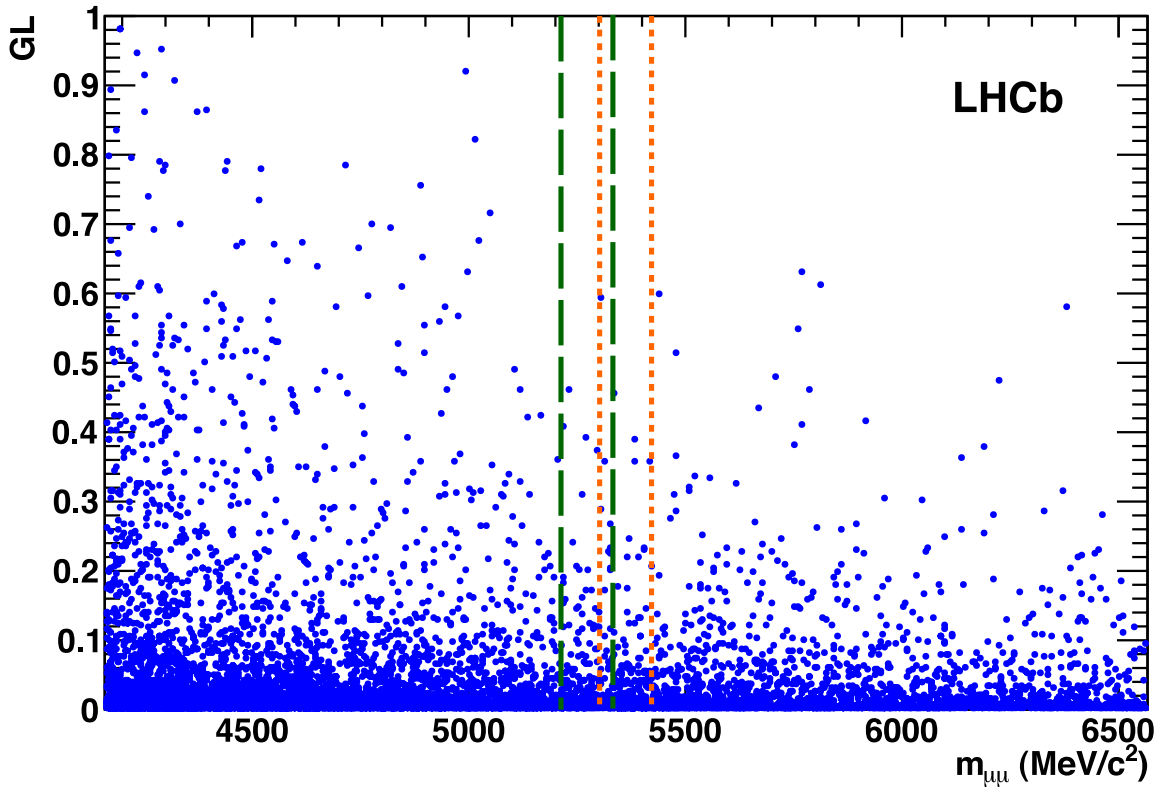
- FCNC decays are good probes of NP
- $B_s \to \mu\mu$ one of the most watched
- SM prediction (A.J.Buras, hep-ph/0904.4917): $(3.6 \pm 0.3) \times 10^{-9}$
- NP can enhance it by huge factors
- Hard constraints on NP even without seeing signal



- CDF Preliminary, 3.7 fb^{-1}: $< 4.3 \cdot 10^{-8}$ at 95% C.L.
- DØ Preliminary, 6.1 fb^{-1}: $< 5.2 \cdot 10^{-8}$ at 95% C.L.

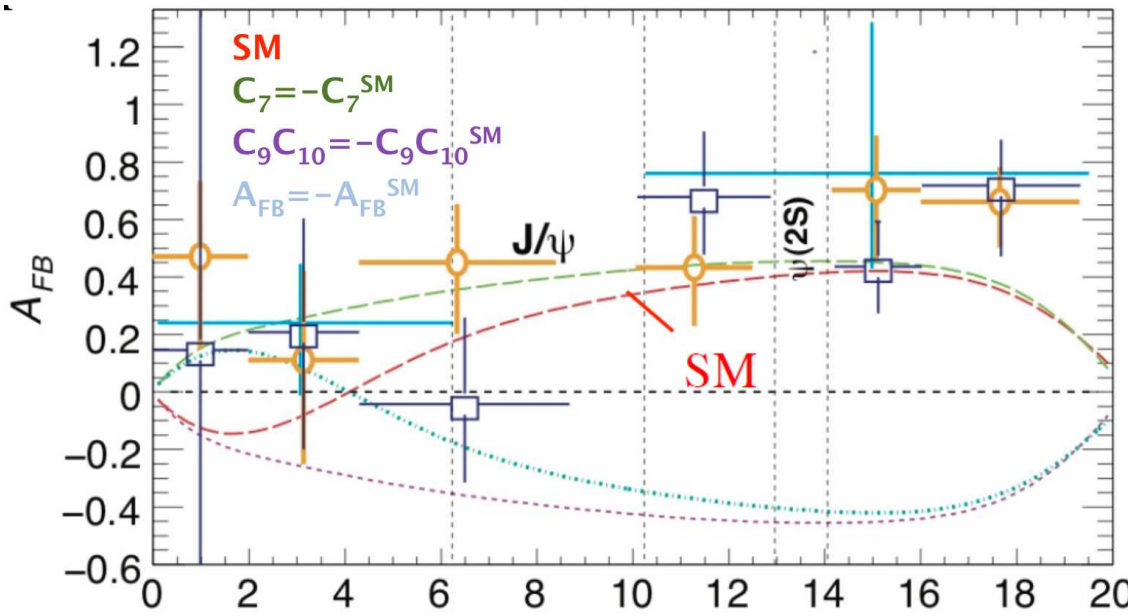
$B_s \to \mu^+\mu^-$

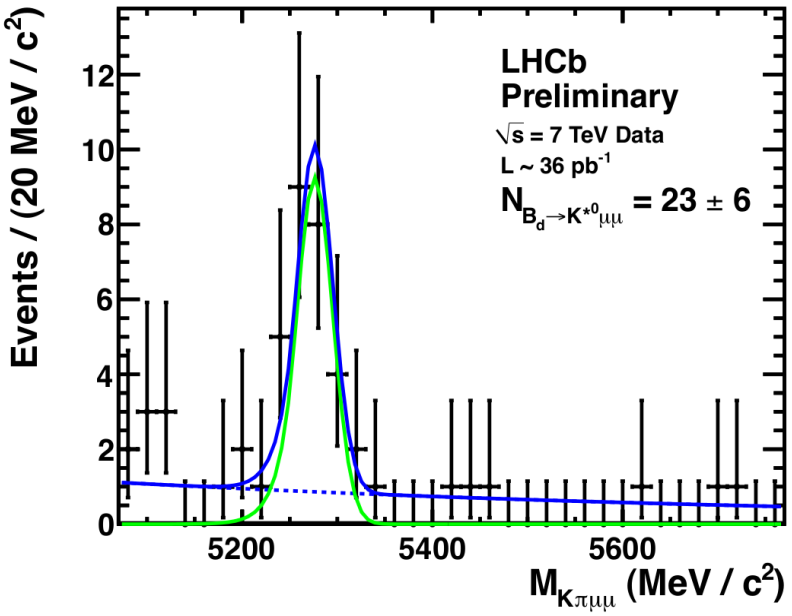
- LHCb submitted its first result in March
- Use more than one decay to normalise
- $< 5.6 \cdot 10^{-8}$ at 95% C.L.



- CDF is working on update, expected limit $\approx 2 \cdot 10^{-8}$ at 95% C.L.
- LHC collects data quickly, so improvements expected soon
- We enter territory where we might start to see excess

$B^0 \to K^* l^+ l^-$ advertiser



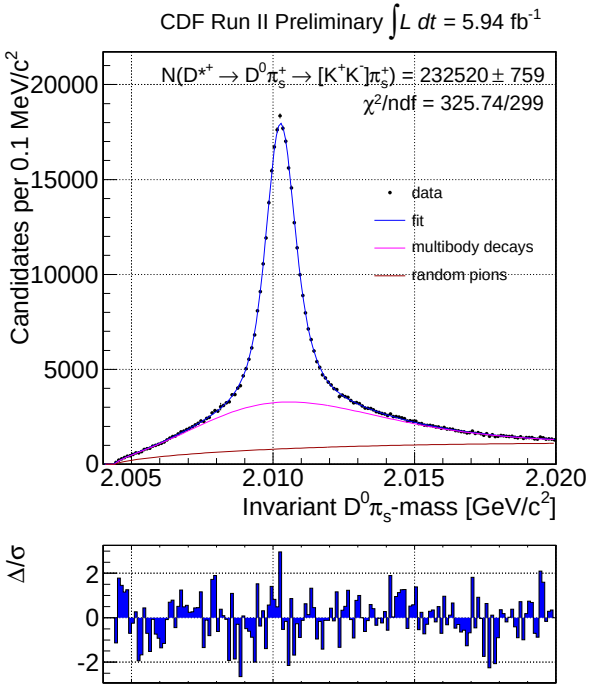


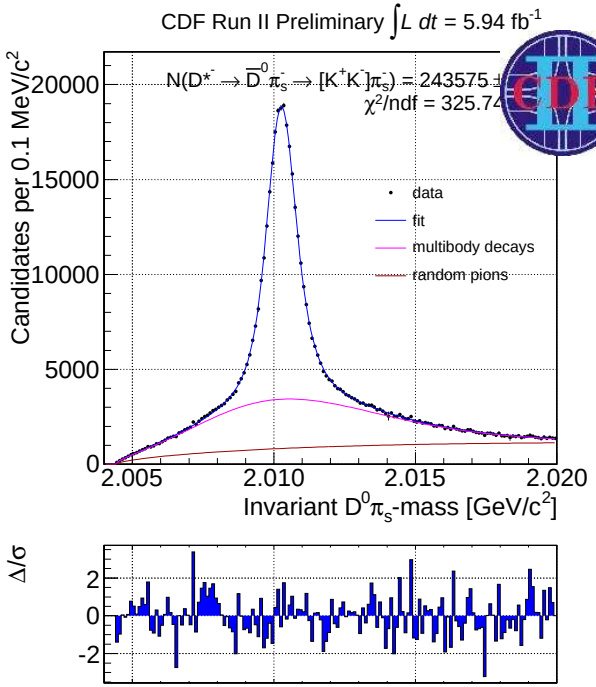
Belle, BABAR, CDF

- While Belle and BABAR analysed most of data, CDF has still significant amount
- CDF is working on update, probably summer time scale
- LHCb established first signal and should have interesting statistics in summer

CPV in charm sector

- In charm sector probe down type quarks in loops
- In SM CP violation is tiny (at most 5×10^{-3})
- Any indication of CPV in charm at the level of 1% $\Rightarrow$ new physics
- Best measurements in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$
- Difference $A_{CP}(KK) - A_{CP}(\pi\pi)$ sensitive to direct CPV





$\approx 476k\ D^0 \to K^+K^-$

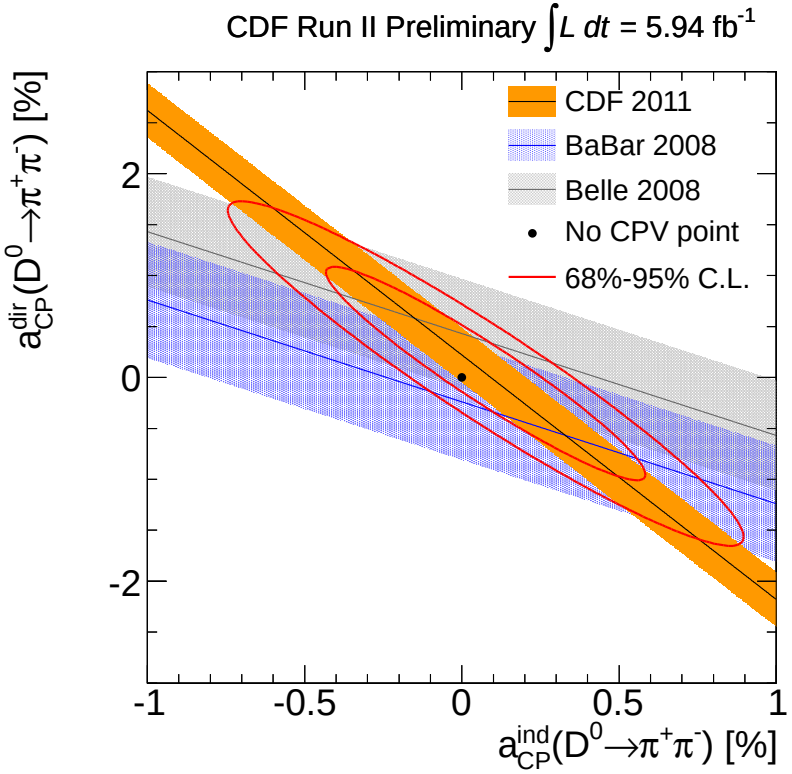
$\approx 217k\ D^0 \to \pi^+\pi^-$

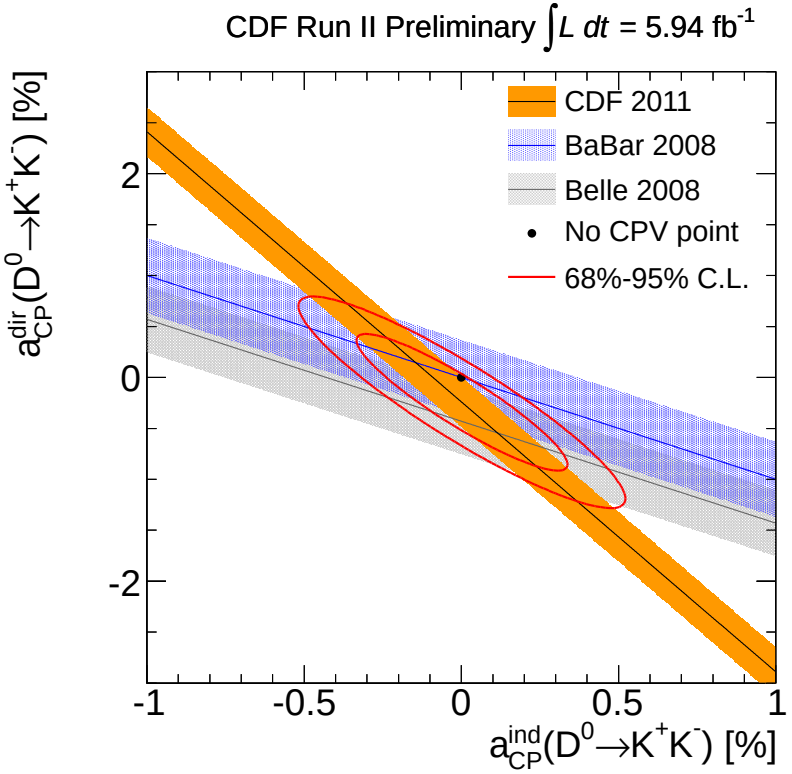
$A_{CP}(KK) = [-0.24 \pm 0.22 \pm 0.10]\%$

$A_{CP}(\pi\pi) = [+0.22 \pm 0.24 \pm 0.11]\%$

CPV in charm sector

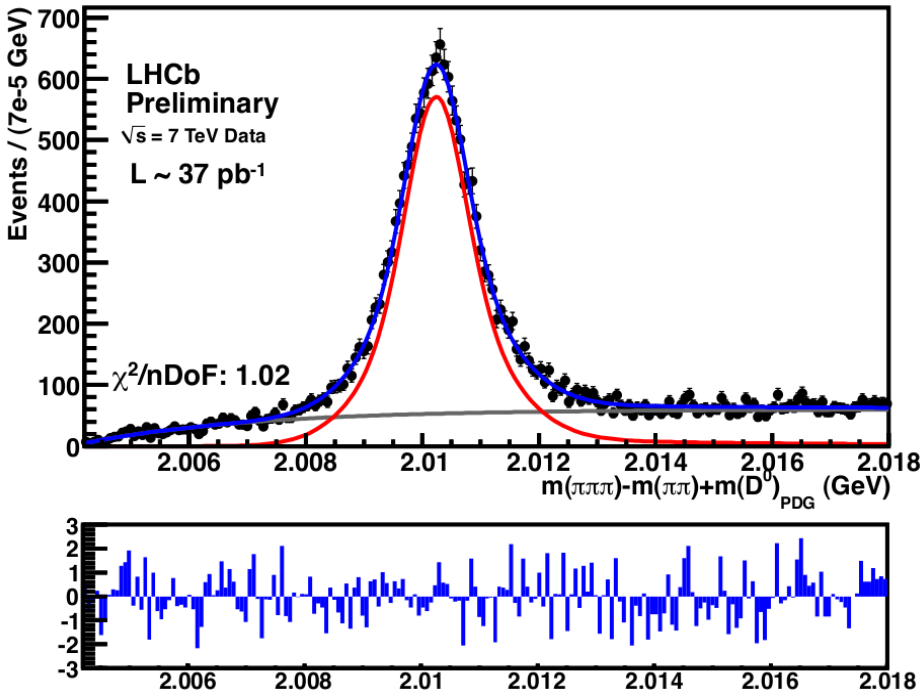
$$A_{CP}(h^+h^-) \approx a_{CP}^{dir} + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}$$

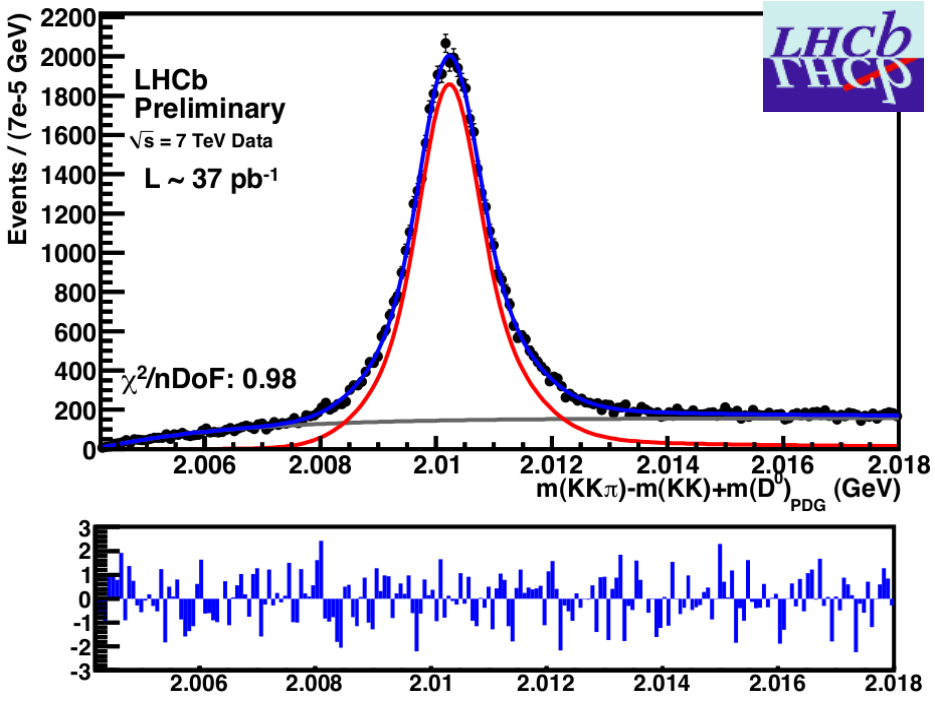




Trigger bias gives complementary information and helps in gaining precision

CPV in charm sector





- $A_{CP}(KK) - A_{CP}(\pi\pi) = [-0.28 \pm 0.70 \pm 0.25]\%$
- Expect 5 times better with this year data
- Many other analyses on way
- In decays $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ we are approaching region where CPV is not anymore unambiguous sign of NP

Outlook

- There is much more, which I could not cover in short time
- Check out latest results at:
  - http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm
  - https://lhcb.web.cern.ch/lhcb/temporary/LHCb_Results.html
- Tevatron still to analyse about half of their data
- LHCb expects to integrate 1 fb^{-1} this year