

Heavy Flavour results from Tevatron

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On behalf of CDF and DØ collaborations

Moriond-EW conference,

la Thuile, 08 February 2012

Introduction

- For past 10 years the Tevatron has pioneered and established the role of hadron colliders for flavour physics
- It became the main source of results on B_s, B baryons, B_c
- Currently the experiments at Tevatron finalize their study and publish the results with the full statistics (up to 10 fb^{-1})
- In this talk the new results on:
  - Rare B decays B^0, $B_s \to \mu^+\mu^-$ (CDF)
  - $B_s \to J/\psi\, \varphi$ (CDF, DØ)
  - Dimuon charge asymmetry (DØ)
  - $A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$ (CDF)
  - Related measurement $B_s \to D_s^{(*)} D_s^{(*)}$ (CDF)

B^0 and $B_s \to \mu^+\mu^-$ (CDF)

- SM prediction (A. Buras *et al.*, arXiv:1012.2126) :

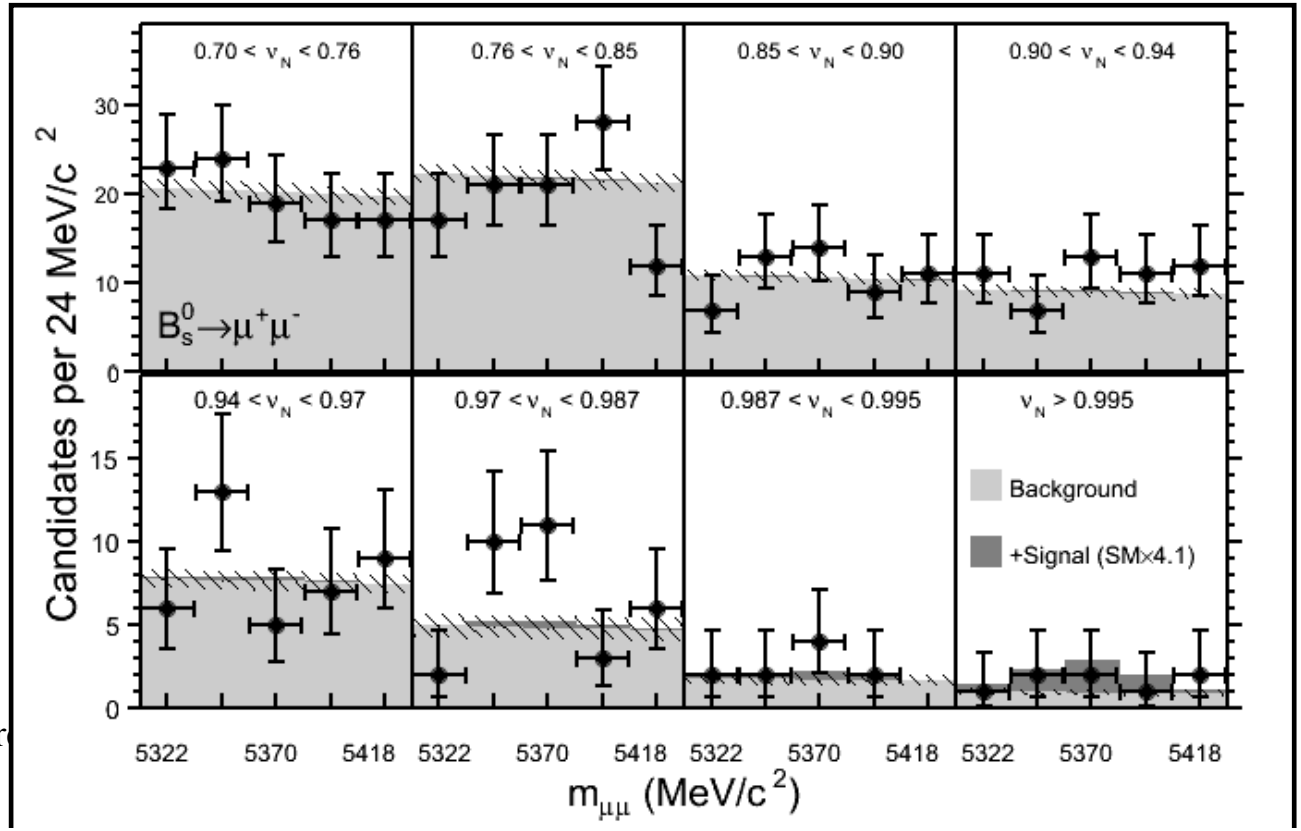
  Br $(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$

  Br $(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$

- New physics (e.g. mSUGRA) can significantly change this decay rate
- CDF presented in summer 2011 the analysis with 7 fb^{-1} (PRL 107, 191801 (2011) featuring an accumulation of signal-like events with ~2.5σ deviation from the background
- New CDF analysis includes the full Run2 statistics (9.6 fb^{-1})
- Given the interest to the previous result, the analysis of the remaining statistics is kept the same

$B_s \rightarrow \mu^+\mu^-$ (CDF)

- Excess of events for $\nu_{NN} > 0.97$
  - p-value (background + SM $B_s \rightarrow \mu^+\mu^-$ hypothesis) is 7.2%
  - Excess for $0.97 < \nu_{NN} < 0.987$ appears to be statistical fluctuation
  - p-value for two highest NN bins (bkg+SM $B_s \rightarrow \mu^+\mu^-$ hypothesis) is 22.4%
- Good consistency with the SM expectation



B^0 and $B_s \to \mu^+\mu^-$ Result (CDF)

- Obtained results (9.6 fb^{-1}) :

$$\mathrm{Br}(B_s \to \mu^+\mu^-) = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$$

$$\mathrm{Br}(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9} \; (3.8 \times 10^{-9}) \text{ at } 95\% \; (90\%) \text{ C.L.}$$

First double sided limit on Br ($B_s \to \mu^+\mu^-$)

$$0.8 \times 10^{-9} < \mathrm{Br}(B_s \to \mu^+\mu^-) < 3.4 \times 10^{-8} \text{ at } 95\% \text{ C.L.}$$

$$2.2 \times 10^{-9} < \mathrm{Br}(B_s \to \mu^+\mu^-) < 3.0 \times 10^{-8} \text{ at } 90\% \text{ C.L.}$$

- Consistent with other measurements:

Dzero : $\mathrm{Br}(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8}$ (95% CL)

LHCb : $\mathrm{Br}(B_s \to \mu^+\mu^-) < 1.4 \times 10^{-8}$ (95% CL)

CMS : $\mathrm{Br}(B_s \to \mu^+\mu^-) < 7.7 \times 10^{-9}$ (95% CL)

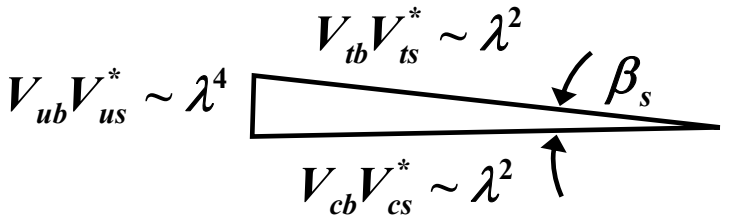
CP asymmetry

- CP asymmetry is a key ingredient for understanding the evolution of our universe
- The CP asymmetry contained in the SM is not sufficient to describe the observed abundance of matter in our world
- New sources of CP asymmetry are needed
- They should reveal themselves by the deviation of the observed CP asymmetry from the SM prediction

Decay $B_s \to J/\psi\,\varphi$

- It is a golden decay mode to measure CP asymmetry in B_s system
- CP asymmetry in $B_s \to J/\psi\varphi$ decay is described by the phase $\phi^{J/\psi\varphi}$
- Within the SM $\phi^{J/\psi\varphi}$ is related with the angle β_s of the (bs) unitarity triangle:

$$\phi^{J/\psi\varphi,SM} = -2\beta_s = 2\arg\left(-\frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*}\right) = -0.038 \pm 0.002$$

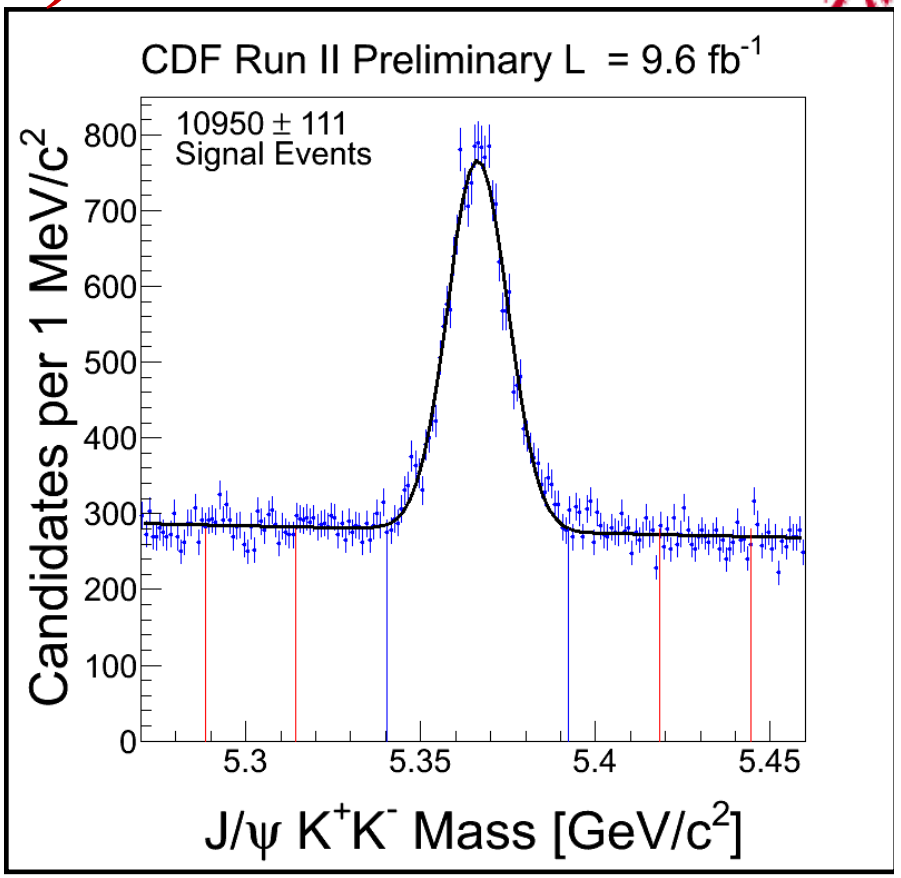


- $\phi^{J/\psi\varphi}$ can be significantly modified by the new physics contribution:

$$\phi^{J/\psi\varphi} = \phi^{J/\psi\varphi,SM} + \phi_s^{NP}$$

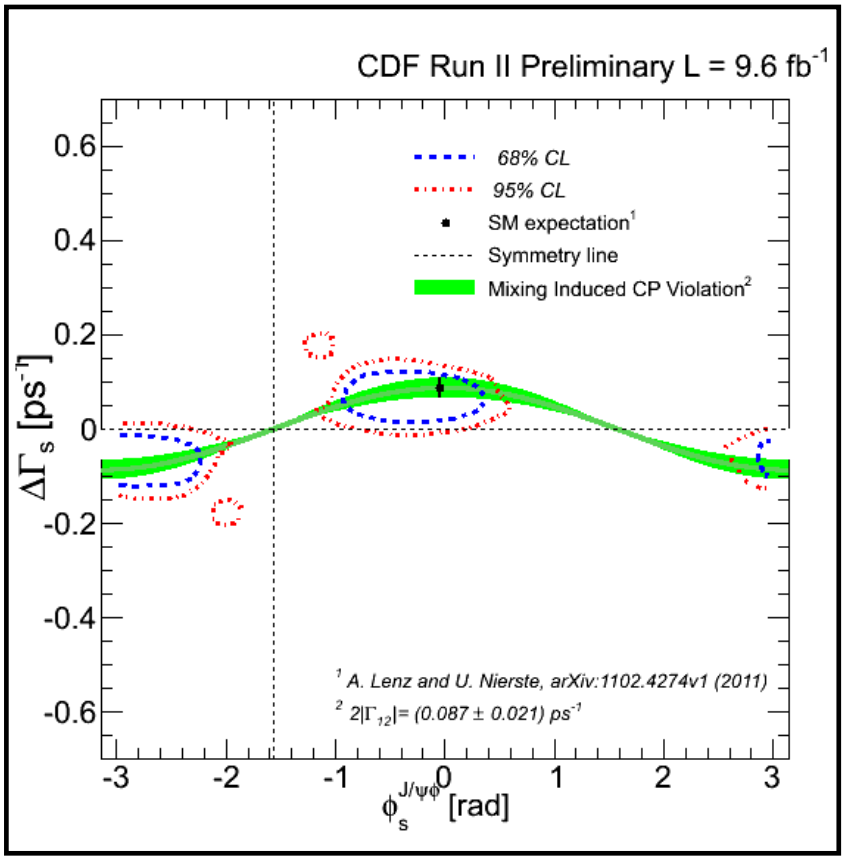
$B_s \rightarrow J/\psi\, \varphi$ (CDF)

- Full statistics (9.6 fb^{-1}) analyzed
- ~10950 signal events
- Analysis is similar to the previous measurement with a part of statistics
  - arXiv: 1112.1726
- Both opposite and same side flavour tagging calibrated in data
  - Opposite side: $\varepsilon D^2 = (1.39 \pm 0.01)\%$ recalibrated for the full data set
  - Same side: $\varepsilon D^2 = (3.2 \pm 1.4)\%$, calibrated and used for ~half of statistics
    - This degrades the statistical resolution of φ_s by no more than 15%



$B_s \to J/\psi\,\varphi$ result (CDF)

- Result of angular analysis consistent with SM prediction
  - p-value of the SM hypothesis is 54%
- Result on $\Delta\Gamma_s$ and Γ_s are still finalized
- Obtained value of $\beta_s = -\varphi_s^{J/\psi\varphi}/2$ is:



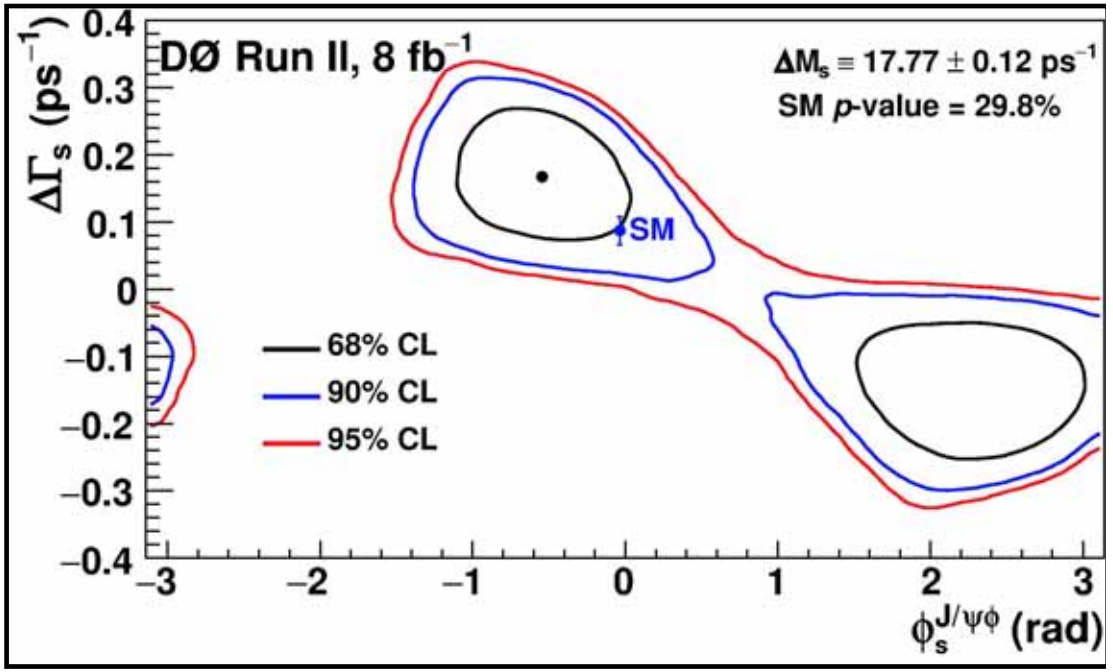
$$\beta_s^{J/\psi\varphi} \in [-\pi/2,-1.51] \cup [-0.06,0.30] \cup [1.26,\pi/2] \ \text{(68\% C.L.)}$$

$B_s \rightarrow J/\psi\,\varphi$ (DØ)

- 8.0 fb^{-1} of data analyzed
- 6500 signal events
- Only the opposite flavour tagging is used
- *p*-value for the SM point is 29.8%

arXiv:1109.3166

$$\tau_s = 1.443^{+0.038}_{-0.035}\ \text{ps}$$
$$\Delta\Gamma_s = 0.163^{+0.065}_{-0.064}\ \text{ps}^{-1}$$
$$\phi_s = -0.55^{+0.38}_{-0.36}$$



Dimuon charge asymmetry A^b_{sl} (DØ)

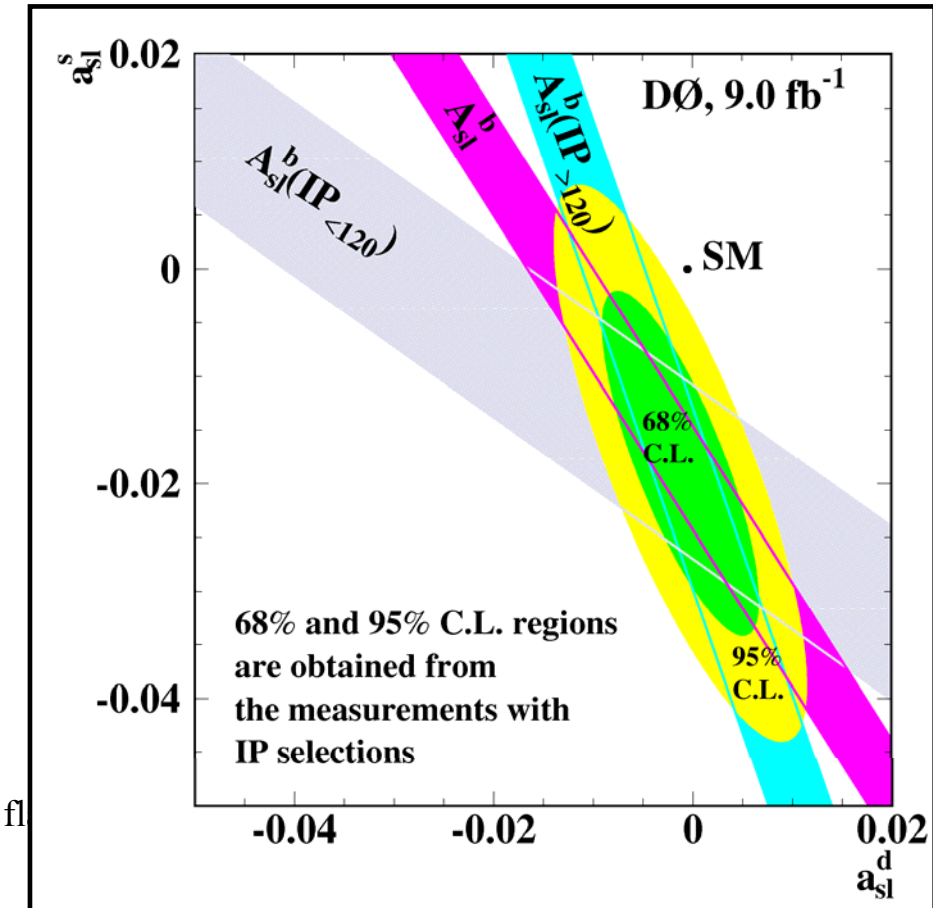
$$A^b_{sl} \equiv \frac{N^{++}_b - N^{--}_b}{N^{++}_b + N^{--}_b}$$

- DØ collaboration observes 3.9σ deviation from the SM prediction in the value of A^b_{sl} using 9 fb^{-1} of data

$$A^b_{sl} = (-0.787 \pm 0.172\,(\text{stat}) \pm 0.093\,(\text{syst}))\%$$

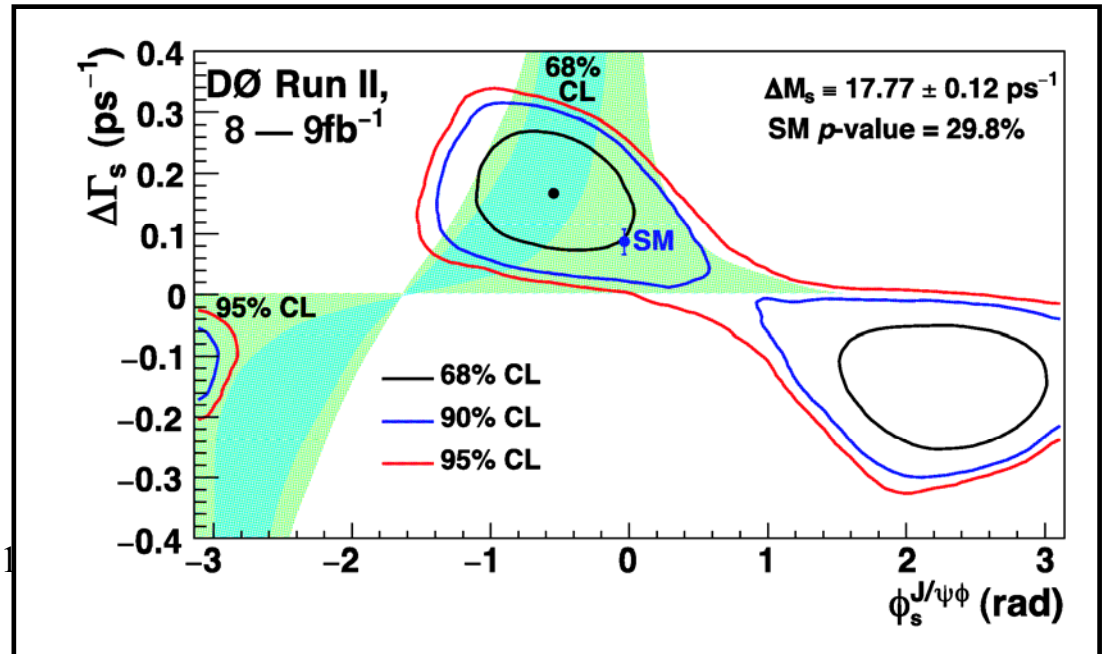
- A^b_{sl} contains contributions of semileptonic charge asymmetries a^d_{sl} and a^s_{sl}
- The separate values of a^d_{sl} and a^s_{sl} are obtained from the study of the muon impact parameter dependence of A^b_{sl}

$$a^d_{sl} = (-0.12 \pm 0.52)\%$$
$$a^s_{sl} = (-1.81 \pm 1.06)\%$$



Comparison with other measurements

- Combining dimuon asymmetry with DØ measurement of a^s_{sl} and world average value of a^d_{sl} we get: $\boxed{a^s_{sl} = (-0.89 \pm 0.62)\%}$
- Relation with the CP violating phase ϕ_s measured in $B_s \rightarrow J/\psi\varphi$ decay: $\boxed{a^s_{sl} = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s}$
- This result is in good agreement with the $B_s \rightarrow J/\psi\varphi$ study of DØ and other collaborations



CP asymmetry in $D^0 \to K^+K^-, \pi^+\pi^-$

- CP violation in single Cabibbo suppressed D^0 decays at O(1%) level signals the new physics contribution
- CDF previously measured $A_{CP}(K^+K^-)$ and $A_{CP}(\pi^+\pi^-)$ with 6 fb^{-1}:

$$\text{CDF}: A_{CP}(\pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$$
$$A_{CP}(K^+K^-) = (-0.24 \pm 0.22 \pm 0.10)\%$$

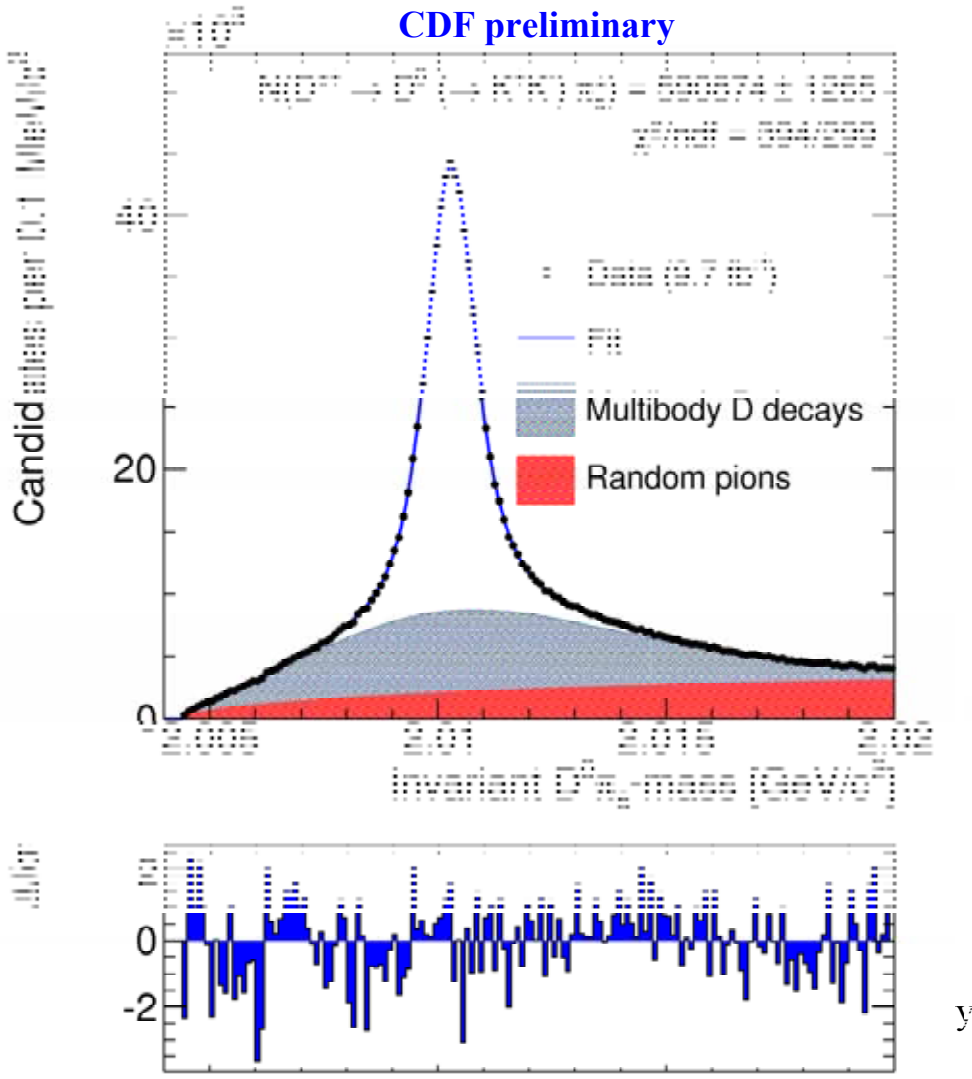
- New analysis uses the full data set (9.6 fb^{-1}) and is optimized for the measurement of $\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$
  - motivated by the recent LHCb measurement:

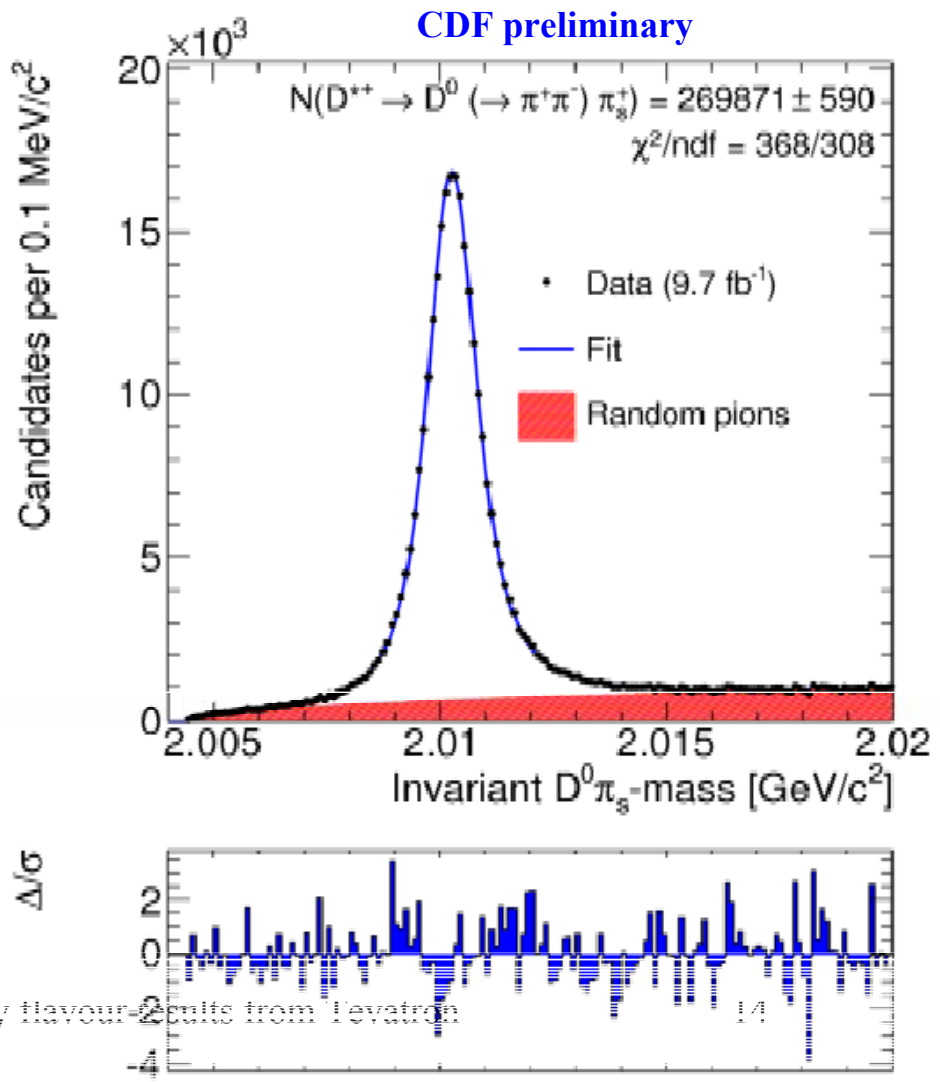
$$\text{LHCb}: \Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.82 \pm 0.21 \pm 0.11)\%$$

  - In the difference of asymmetries many systematic uncertainties cancel and the selection cuts were loosened to increase the statistics
  - In total 550K $D^0 \to \pi^+\pi^-$ decays and 1.21M $D^0 \to K^+K^-$ decays selected

Selected signal $D^0 \to K^+K^-, \pi^+\pi^-$

- The plots show the signal in $D^0 \to K^+K^-, \pi^+\pi^-$ decays
- Statistics in $\overline{D}^0 \to K^+K^-, \pi^+\pi^-$ decays is about the same





CP asymmetry in $D^0 \to K^+K^-, \pi^+\pi^-$

- Measured value:

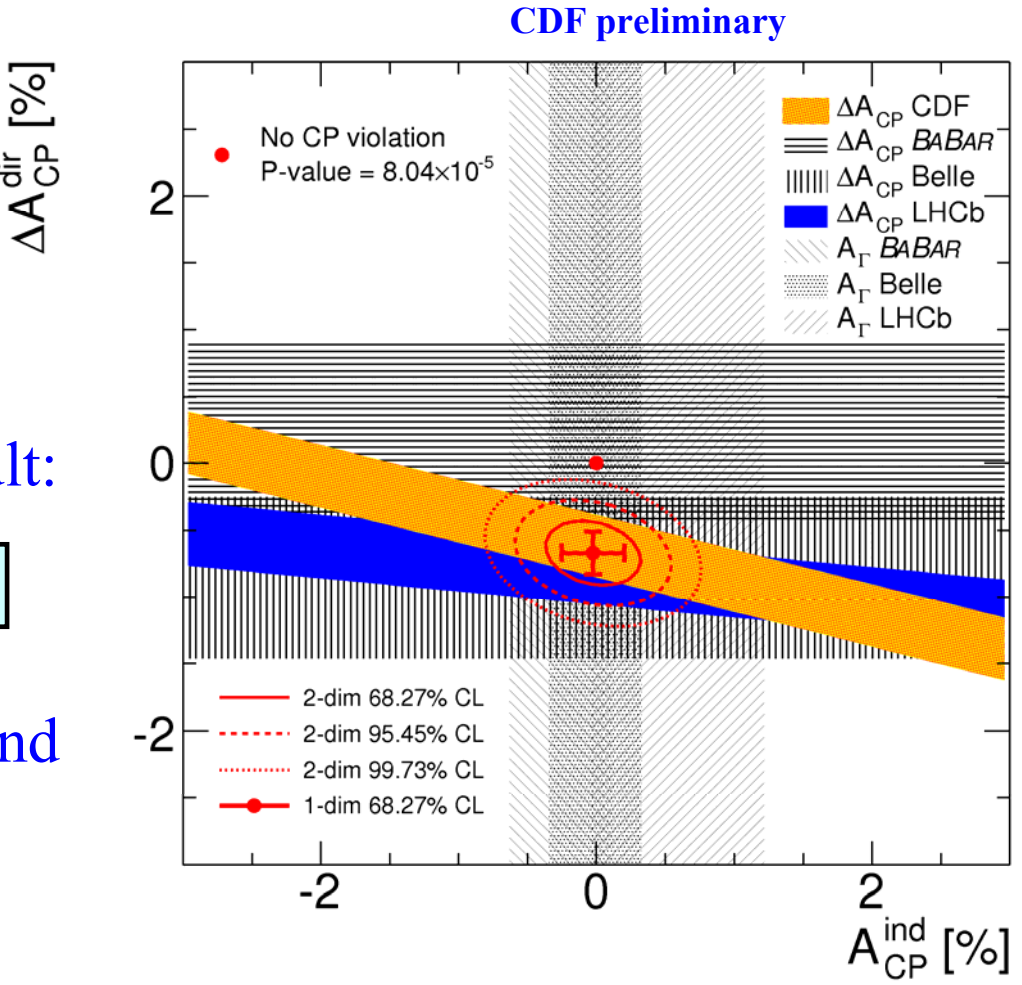
$$\textbf{CDF}: \Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$$

  - 2.7 σ deviation from zero

- Consistent with the LHCb result:

$$\textbf{LHCb}: \Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$$

- The combination of the CDF and LHCb results gives ~3.8σ deviation from zero.



Br($B_s \to D_s^{(*)} D_s^{(*)}$) (CDF)

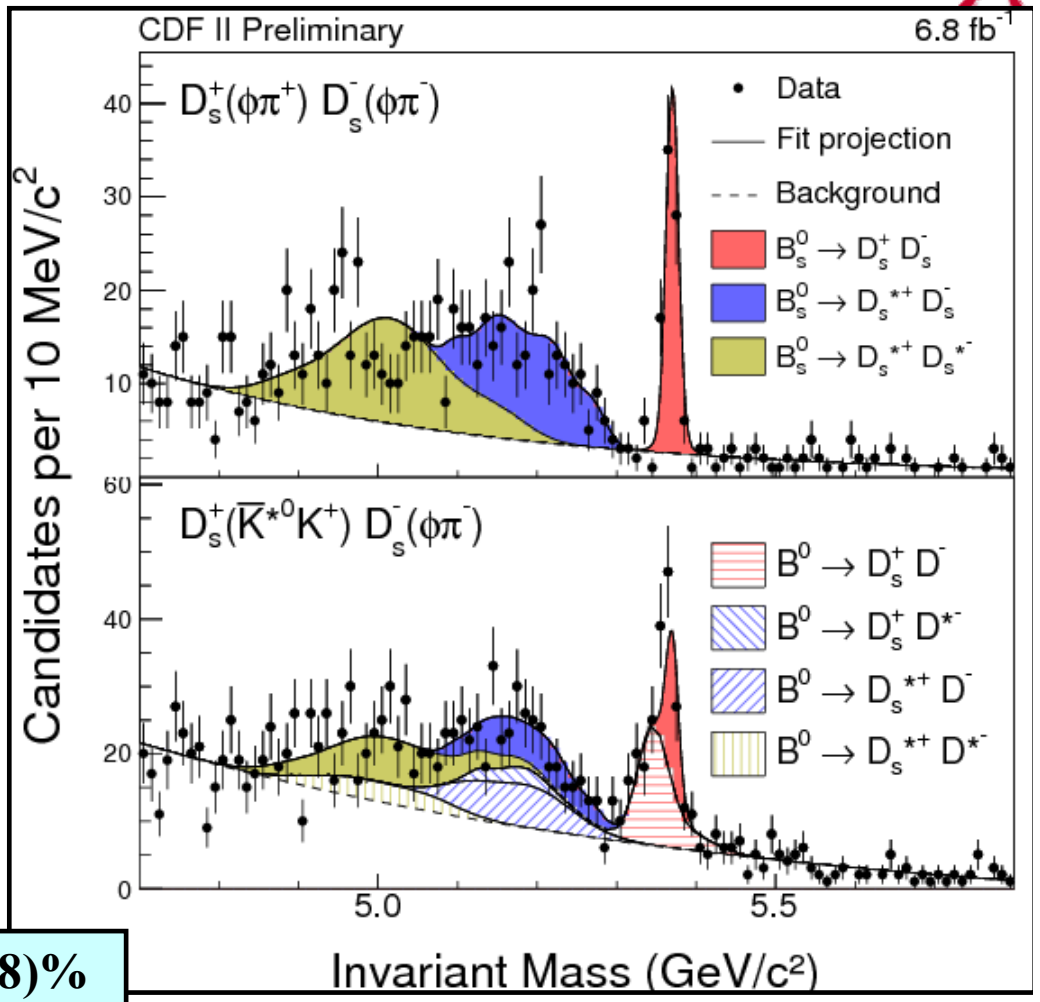
- CDF reconstructs semi-exclusive decays

$$B_s \to D_s^+ D_s^-$$
$$B_s \to D_s^{*+} D_s^- + D_s^+ D_s^{*-}$$
$$B_s \to D_s^{*+} D_s^{*-}$$

with $D_s \to \varphi\pi$ or $D_s \to K^*K$

- 750 decays Br($B_s \to D_s^{(*)} D_s^{(*)}$) reconstructed in total
- Result:

$$\mathrm{Br}(B_s \to D_s^+ D_s^-) = (0.49 \pm 0.06 \pm 0.05 \pm 0.08)\%$$
$$\mathrm{Br}(B_s \to D_s^{*\pm} D_s^{\mu}) = (1.13 \pm 0.12 \pm 0.09 \pm 0.19)\%$$
$$\mathrm{Br}(B_s \to D_s^{*+} D_s^{*-}) = (1.75 \pm 0.19 \pm 0.17 \pm 0.29)\%$$



Br($B_s \to D_s^{(*)} D_s^{(*)}$)

- First evidence of this decay is obtained by DØ:

$$\mathrm{Br}\,(B_s \to D_s^{(*)} D_s^{(*)}) = 0.035 \pm 0.010 \pm 0.011$$

- Confirmed by Belle:

$$\mathrm{Br}\,(B_s \to D_s^{(*)} D_s^{(*)}) = 0.0685^{+0.0153+0.0179}_{-0.0130-0.0180}$$

- New CDF measurement has significantly better precision:

$$\mathrm{Br}\,(B_s \to D_s^{(*)} D_s^{(*)}) = 0.0338 \pm 0.0025 \pm 0.0030 \pm 0.0056\,(\mathrm{norm})$$

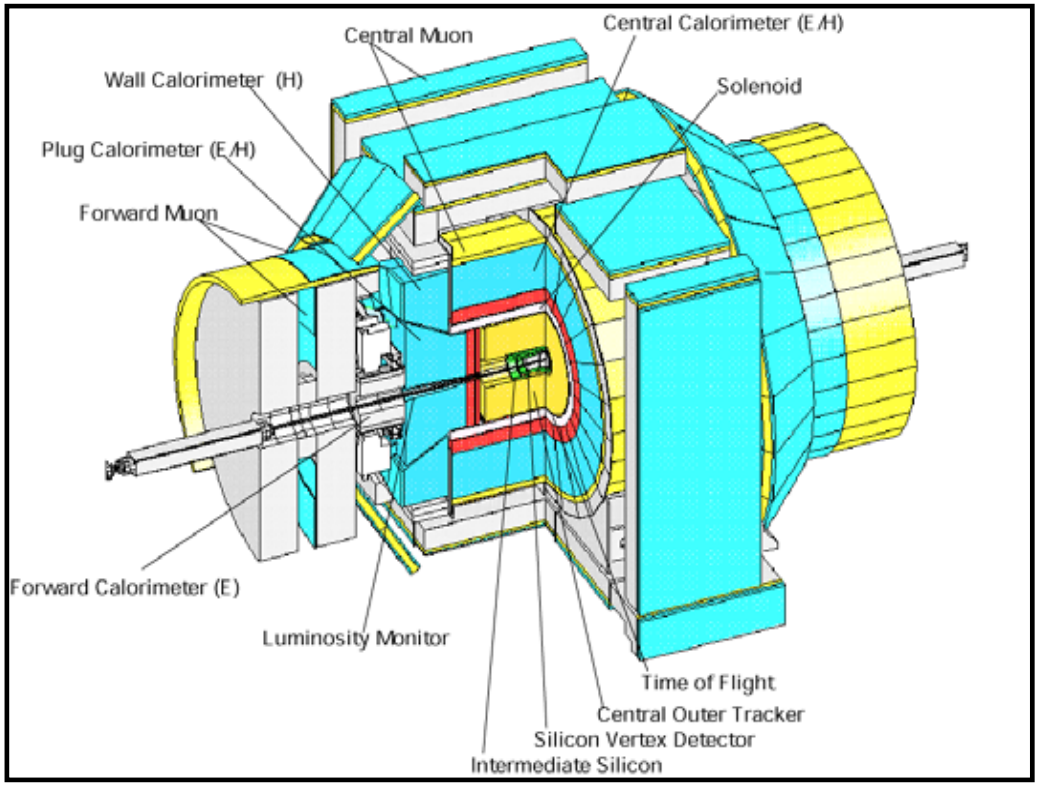
Summary

- Experiments at Tevatron finalize the analysis of their full statistics
- New results are presented in:
  - B^0, $B_s \to \mu^+\mu^-$ (CDF)
  - $B_s \to J/\psi\, \varphi$ (CDF, DØ)
  - Dimuon charge asymmetry (DØ)
  - $A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$ (CDF)
  - Related measurement $B_s \to D_s^{(*)} D_s^{(*)}$ (CDF)
- Tevatron experiments produced many more interesting results in heavy flavour physics
  - See online web pages of the CDF and DØ experiments:
    - http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
    - http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

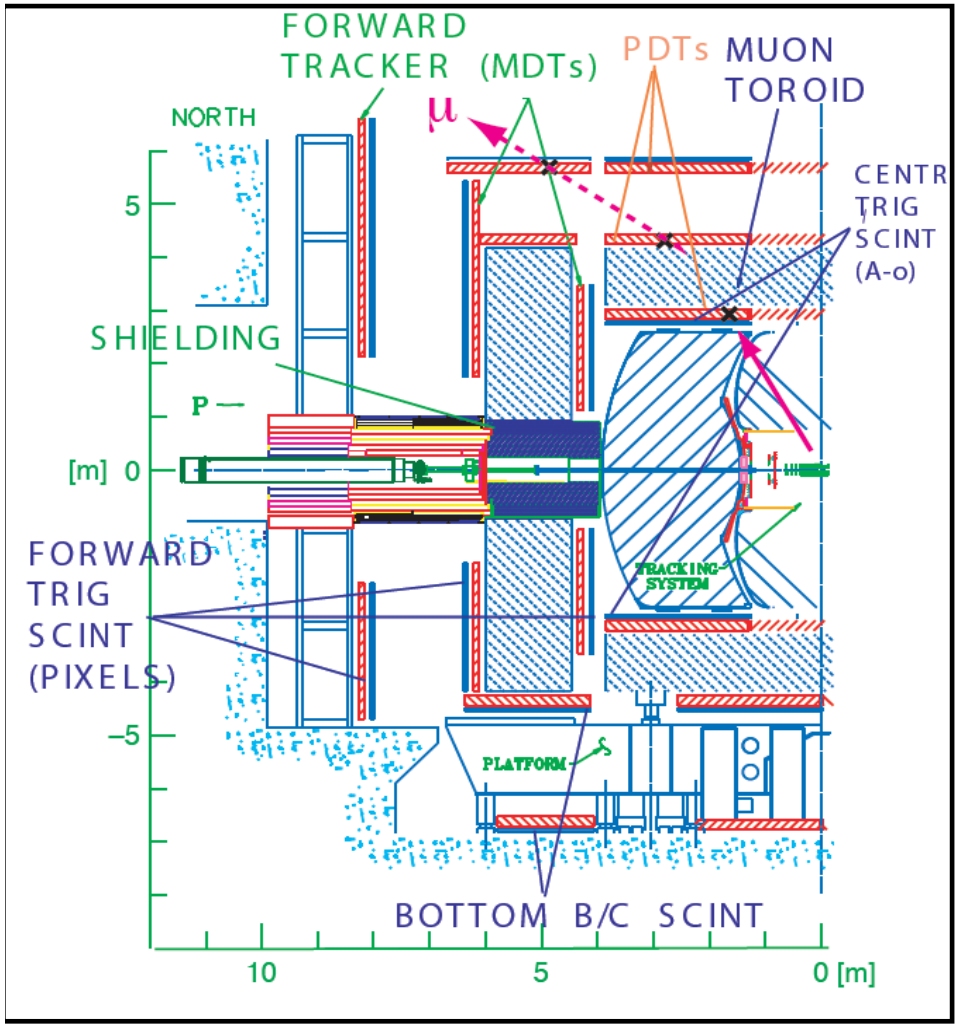
Backup

CDF detector for *B* physics

- Silicon detector (SVX):
  - 5 double sided layers, $|\eta|<2$;
  - Radius: from 2.5 to 10 cm;
  - L00 at r~1.5 cm;
- Drift chambers (COT)
  - 96 layers; $|\eta| < 2$;
  - Radius from 44 to 132 cm;
- Magnetic field 1.4 T;
- Muon identification
  - trigger up to $|\eta| < 1$;
- Time-of-flight detectors provides particle ID



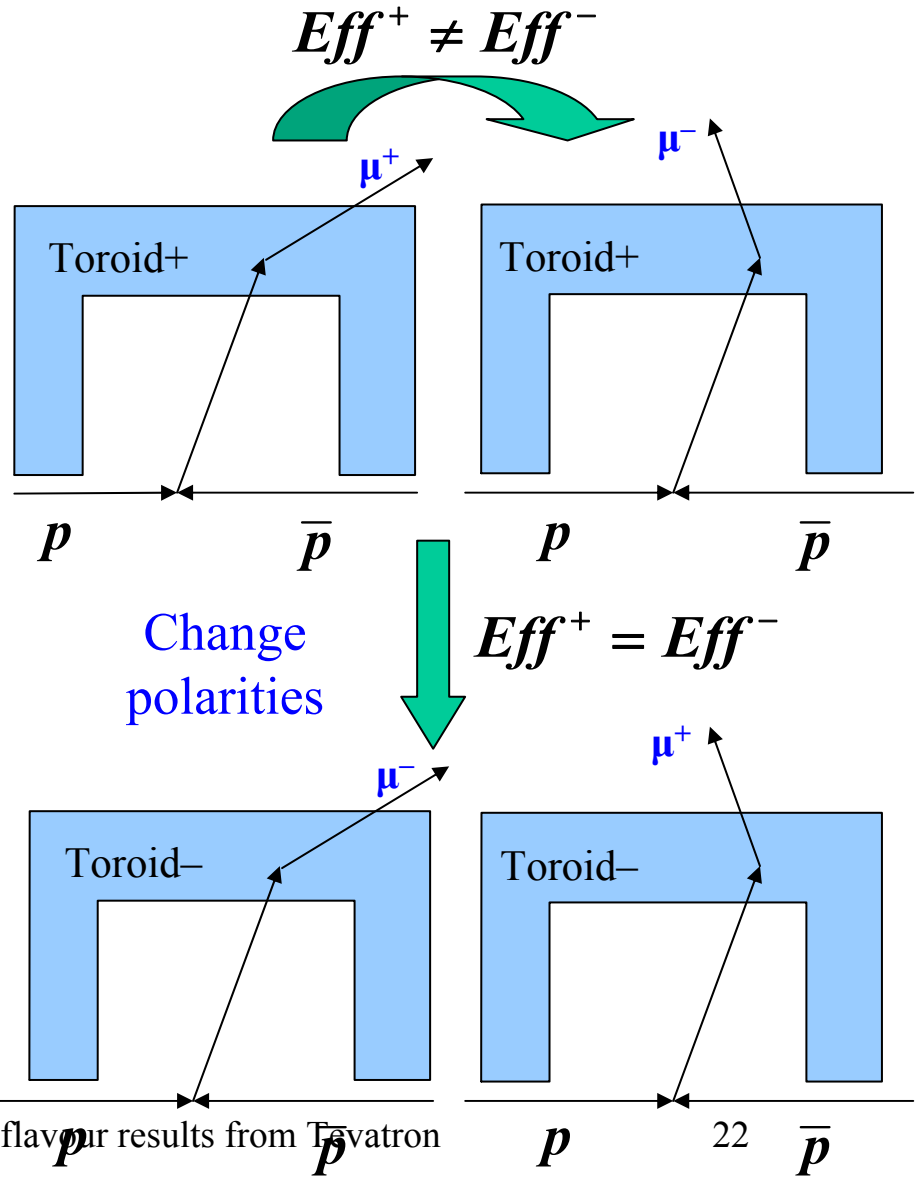
DØ detector for *B* physics



- Silicon detector (SMT):
  - 4 mainly double sided layers;
  - $|\eta| < 2$;
  - L0 at r=1.6 cm;
- Silicon Fibre Tracker (CFT):
  - 8 layers, $|\eta| < 2$;
  - Radius: 20 – 50 cm
- Muon system:
  - 3 layers + Toroid;
  - Large acceptance $|\eta| < 2.2$;
  - Scintillator layers for trigger;
  - Cosmic ray rejection;
  - Low punch-through;
  - Local measurement of muon charge and momentum;

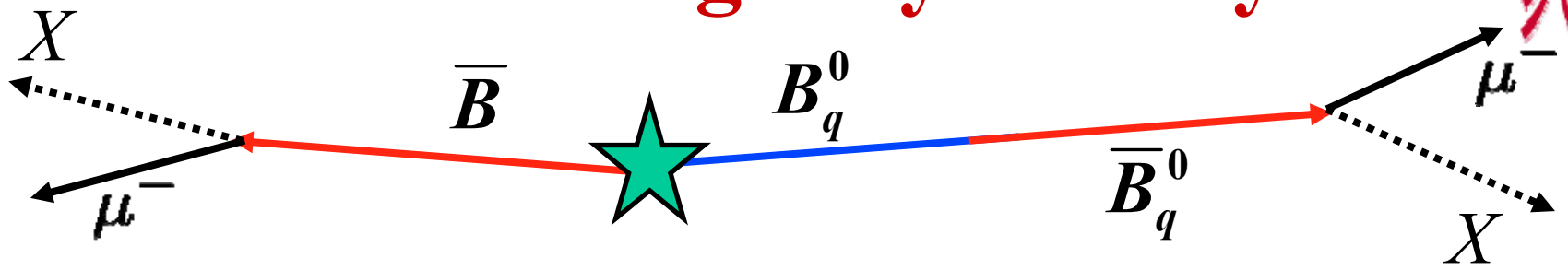
DØ: Reversing Magnet Polarities

- Polarities of DØ solenoid and toroid are reversed regularly;
- Trajectory of the negative particle becomes exactly the same as the trajectory of the positive particle with the reversed magnet polarity;
- This cancels the difference in the reconstruction efficiency between positive and negative particles;



Changing Magnet polarities is an important feature of DØ detector, which reduces significantly the systematics in CP asymmetry measurements

Dimuon charge asymmetry



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

- Both B_d and B_s contribute in $A^b_{\rm sl}$:

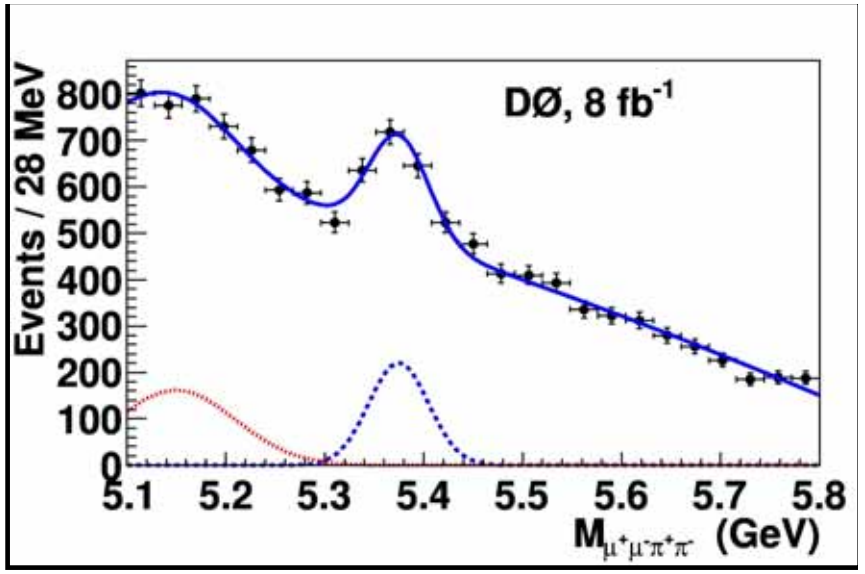
$$A_{sl}^b = (0.506 \pm 0.022) a_{sl}^d + (0.494 \pm 0.022) a_{sl}^s$$

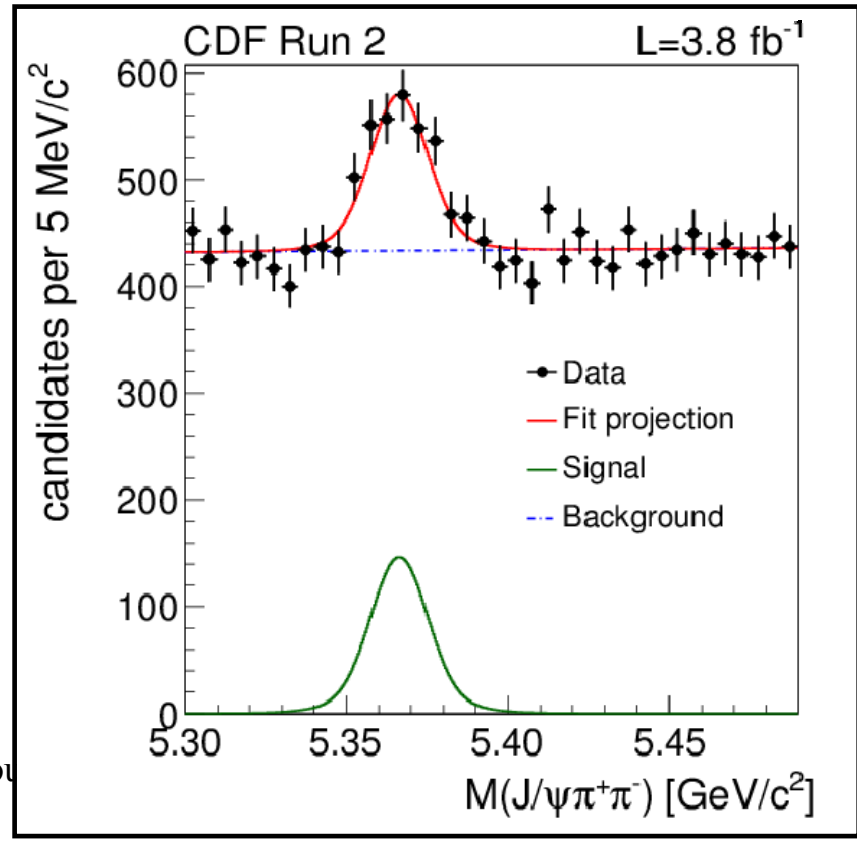
  - $a^q_{\rm sl}$ is the charge asymmetry of "wrong sign" semileptonic B^0_q ($q = d,s$) decays:

$$a_{sl}^q \equiv \frac{\Gamma(\overline{B}_q^0 \to \mu^+ X) - \Gamma(B_q^0 \to \mu^- X)}{\Gamma(\overline{B}_q^0 \to \mu^+ X) + \Gamma(B_q^0 \to \mu^- X)}; \quad q = d, s$$

Decay $B_s \rightarrow J/\psi f_0$

- This decay can provide complementary information on the CP violation in B_s system
  - The final system is a pure CP-odd Eigen-state, and the angular analysis is not required to measure the CP violation
- This decay was first observed by the LHCb experiment, shortly followed by Belle confirmation
- Both DØ and CDF collaboration confirm the observation of this decay





Decay $B_s \to J/\psi\, f_0$

- All experiments report the measurement of the branching fraction rate:

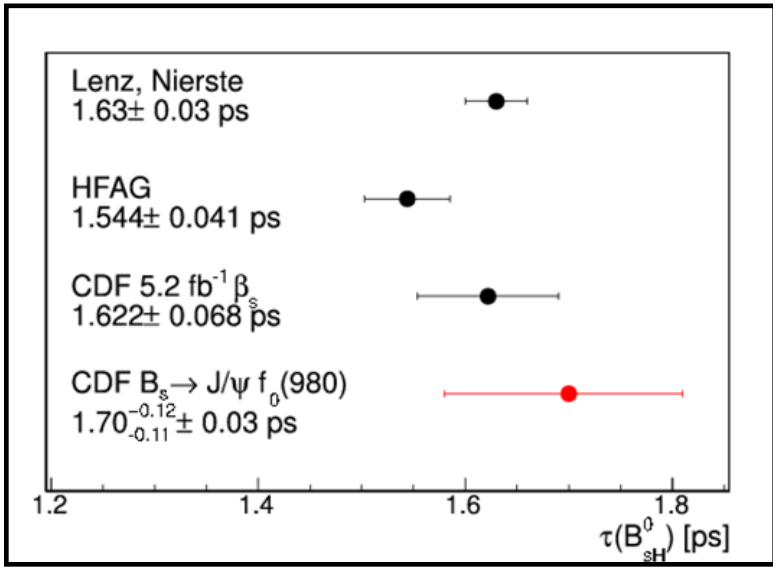
$$R_{f_0/\phi} = \frac{Br(B_s^0 \to J/\psi\, f_0)Br(f_0 \to \pi^+\pi^-)}{Br(B_s^0 \to J/\psi\phi)Br(\phi \to K^+K^-)}$$

$$R_{f_0/\phi} = 0.275 \pm 0.041 \pm 0.061 \ \text{(Dzero)}$$

$$R_{f_0/\phi} = 0.257 \pm 0.020 \pm 0.014 \ \text{(CDF)}$$

- In addition, CDF also measures the B_s lifetime in this state:

$$\tau(B_s \ \text{CP-odd}) = 1.70^{+0.12}_{-0.11} \pm 0.03 \ \text{ps} \ \text{(CDF)}$$



Other CP asymmetry results

- CP asymmetry in $B_s \to \varphi\varphi$ decay:

$$\text{CDF}: A_u = (-0.7 \pm 6.4 \pm 1.8)\%$$
$$A_v = (-12.0 \pm 6.4 \pm 1.6)\%$$

- CP asymmetry in D^0 decays:

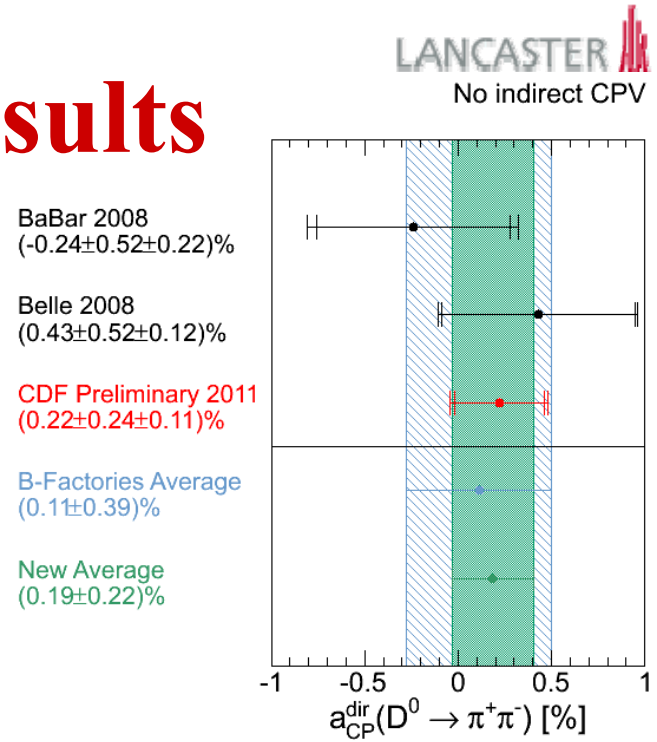
$$\text{CDF}: A_{CP}(\pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$$
$$A_{CP}(K^+K^-) = (-0.24 \pm 0.22 \pm 0.10)\%$$

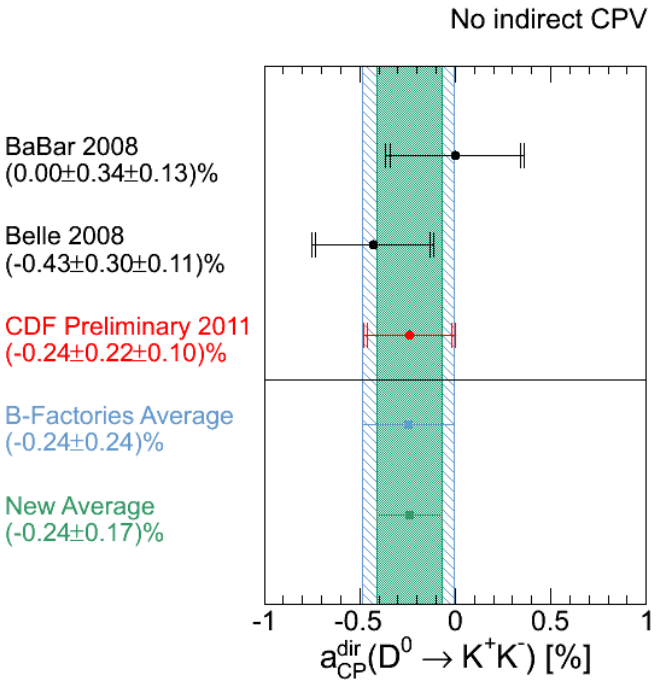
- Consistent with the recent claim by LHCb of the evidence of CP violation in D^0 decays

$$\text{LHCb}: \Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$
$$= (-0.82 \pm 0.21 \pm 0.11)\%$$

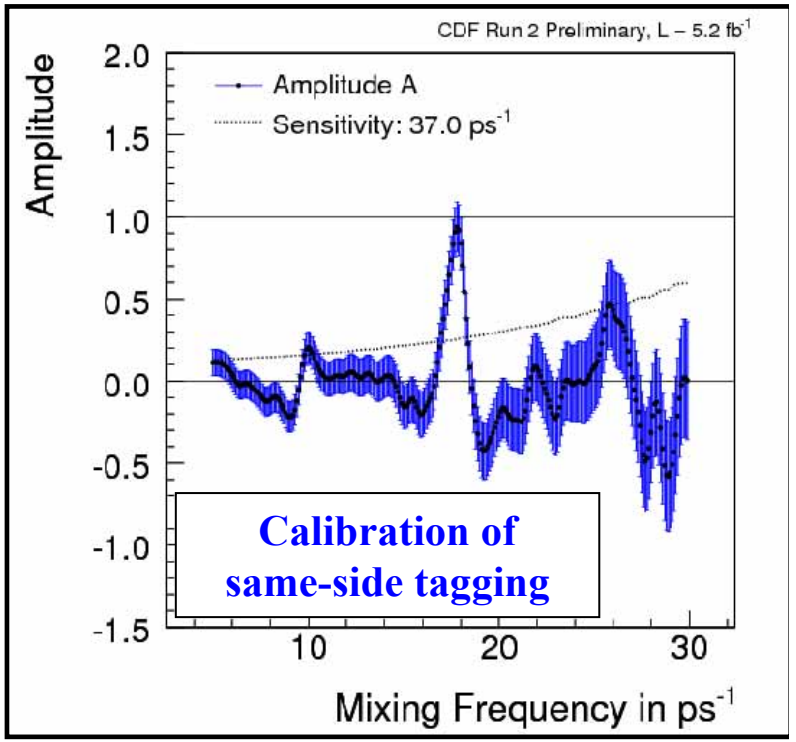
- CP asymmetry in $D^0 \to K_S\pi^+\pi^-$ decay

$$\text{CDF}: A_{CP} = (-0.05 \pm 0.57 \pm 0.54)\%$$



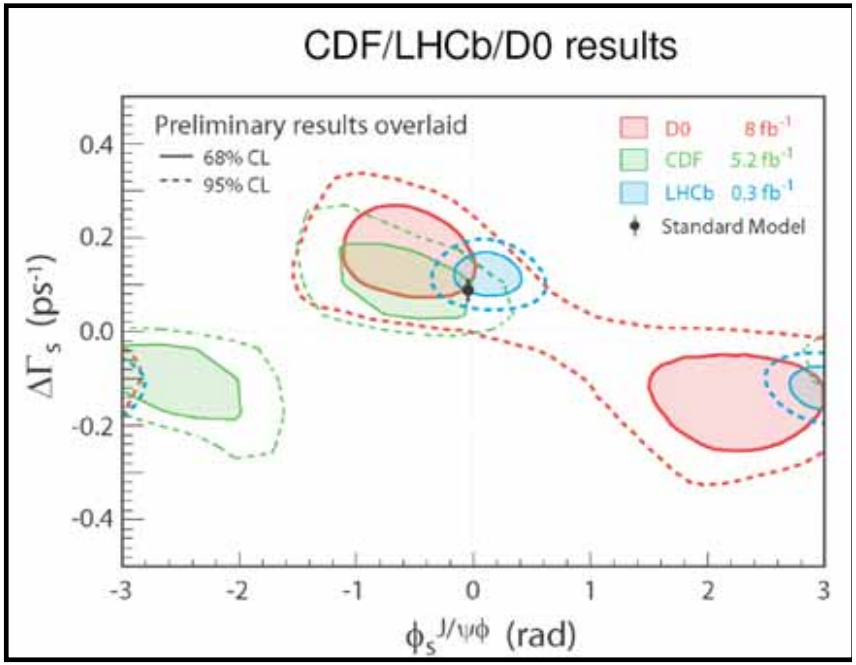


$B_s \rightarrow J/\psi\ \varphi$ (CDF)



Comparison between experiments

- The comparison plot includes the previous CDF result obtained with ~1/2 of statistics
- The results of CDF and DØ agree with each other and with a recent measurement by LHCb



Summary

- New measurement of Br(B^0,$B_s \to \mu^+\mu^-$) (CDF):

$$\mathbf{Br}(B_s \to \mu^+\mu^-) = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$$

$$\mathbf{Br}(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9} (3.8 \times 10^{-9}) \text{ at } 95\% (90\%) \text{ C.L.}$$

- First double-sided limit on this branching fraction:

$$0.8 \times 10^{-9} < \mathbf{Br}(B_s \to \mu^+\mu^-) < 3.4 \times 10^{-8} \text{ at } 95\% \text{ C.L.}$$

$$2.2 \times 10^{-9} < \mathbf{Br}(B_s \to \mu^+\mu^-) < 3.0 \times 10^{-8} \text{ at } 90\% \text{ C.L.}$$

- New results in $B_s \to J/\psi\, \varphi$ study from CDF and DØ
  - Result is consistent with the SM prediction
- 3.9σ deviation in the dimuon charge asymmetry (DØ):

$$A_{sl}^b = (-0.787 \pm 0.172\,(\text{stat}) \pm 0.093\,(\text{syst}))\%$$

- CP asymmetry in $D^0 \to K^+K^-$, $\pi^+\pi^-$ decays (CDF):

$$\text{CDF}: \Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$$

  - Consistent with the LHCb result

Summary (cont.)

- New measurement of Br($B_s \to D_s^{(*)} D_s^{(*)}$)

$$\mathbf{Br}\,(B_s \to D_s^{(*)} D_s^{(*)}) = 0.0338 \pm 0.0025 \pm 0.0030 \pm 0.0056\,(\mathrm{norm})$$

- Tevatron experiments produced much more interesting results in heavy flavour physics
  - See online web pages of the CDF and DØ experiments:
    - http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
    - http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm