CP Violation measurements at DØ experiment

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CP Violation (CPV)

- Today's matter dominated universe requires that CP violation must have occurred shortly after the big bang
- The Standard Model allows for CP violation, but the observed CP violation is tiny
- Search for CP violation may be the key to find a hint of new physics
- The D0 detector's wide muon coverage provides a unique opportunity to measure many CP violation related parameters in many decay modes (of B-mesons)

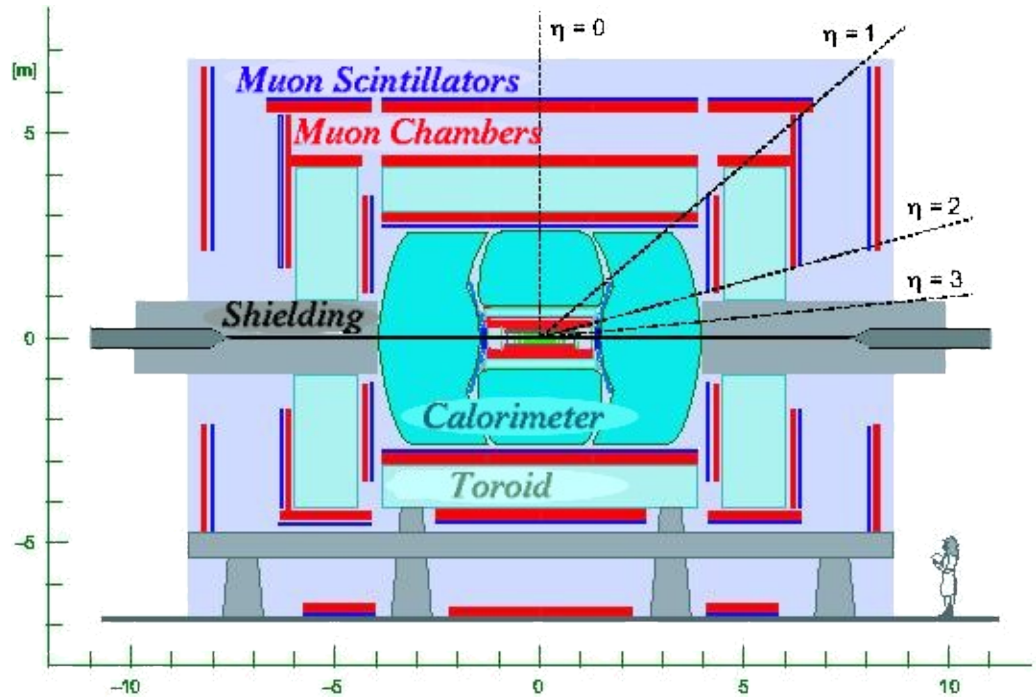
CPV at DØ

- Wide muon coverage |eta| =< 2
- Shielding along beam pipe to significantly reduce fake rate
- Initial state of B-mesons is CP-symmetric

~~production asymmetries~~

- Tracker is symmetric around the collision point

~~tracking asymmetries~~



In this talk, full D0 data set of 10.4 fb^{-1}

CPV at DØ

- Wide muon coverage |eta| =< 2
- Shielding along beam pipe to significantly reduce fake rate
- Initial state of B-mesons is CP-symmetric

production asymmetries

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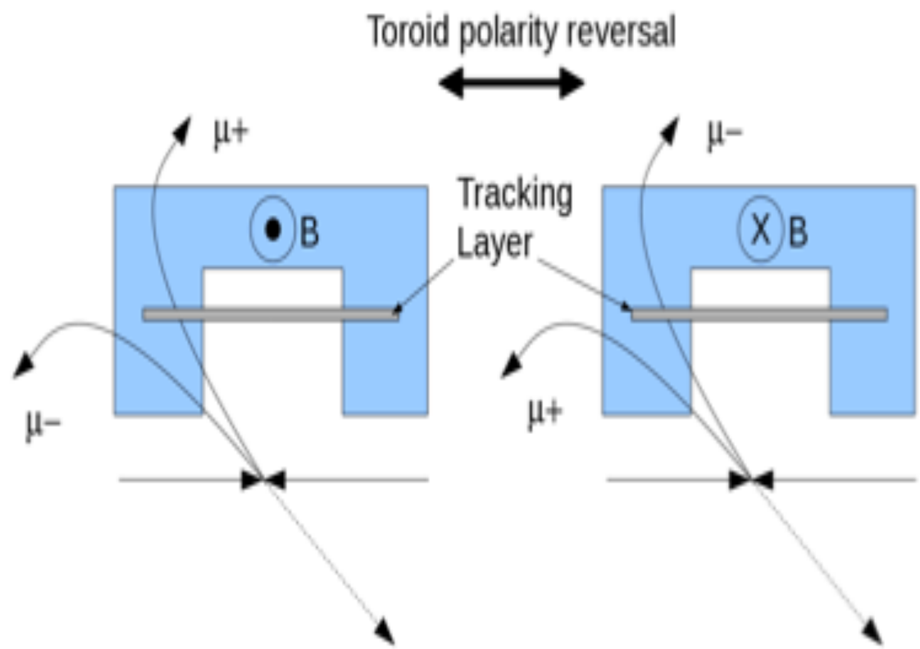
tracking asymmetries

- All four combinations of magnet polarities

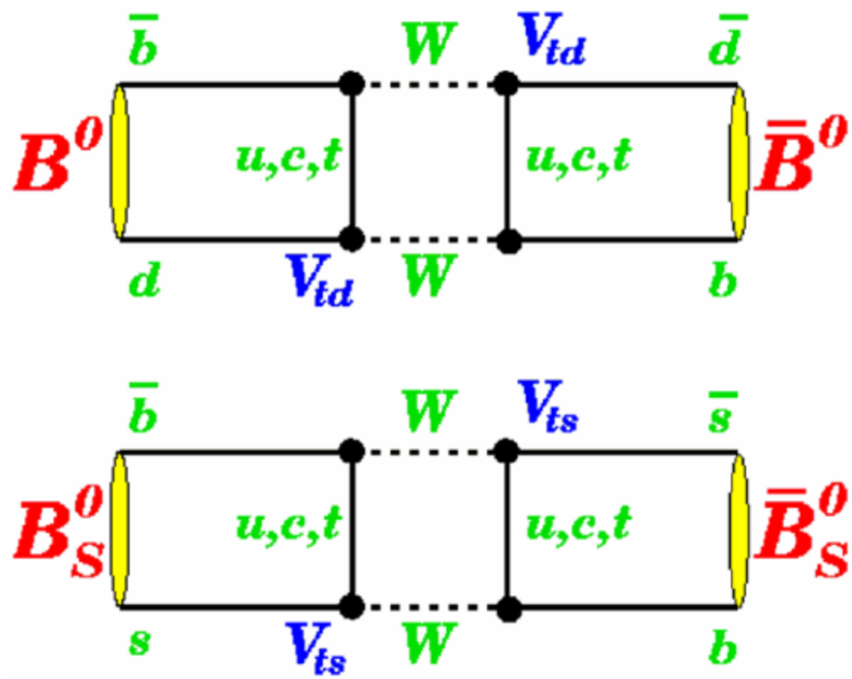
1^{st} order detector asymmetries



Regular reversal of solenoid (charge track) and toroid (muon) magnets performed at D0 during data recording

B-meson Mixing

- Neutral B-mesons oscillate between flavor eigenstates
  - ✓ particle ⇔ anti-particle
- The complex phase between mass and decay matrix elements
  - ✓ can produce asymmetry & CPV
- In SM, the complex phase as well as asymmetry values are small compared to experimental precision
- Any deviation from SM value
  - ✓ unambiguous signal of new physics



CPV in B-meson Mixing

semileptonic mixing asymmetry (for quark flavor, q)

$$a^q_{sl} = \frac{\Delta\Gamma_q}{\Delta M_q} tan(\phi_q) = \frac{\Gamma(\overline{B}^0_q \to B^0_q \to l^+X) - \Gamma(B^0_q \to \overline{B}^0_q \to l^-X)}{\Gamma(\overline{B}^0_q \to B^0_q \to l^+X) + \Gamma(B^0_q \to \overline{B}^0_q \to l^-X}$$

Flavor eigenstate M_{12} , $|\Gamma_{12}|$ and $arg(-M_{12}/\Gamma_{12})$

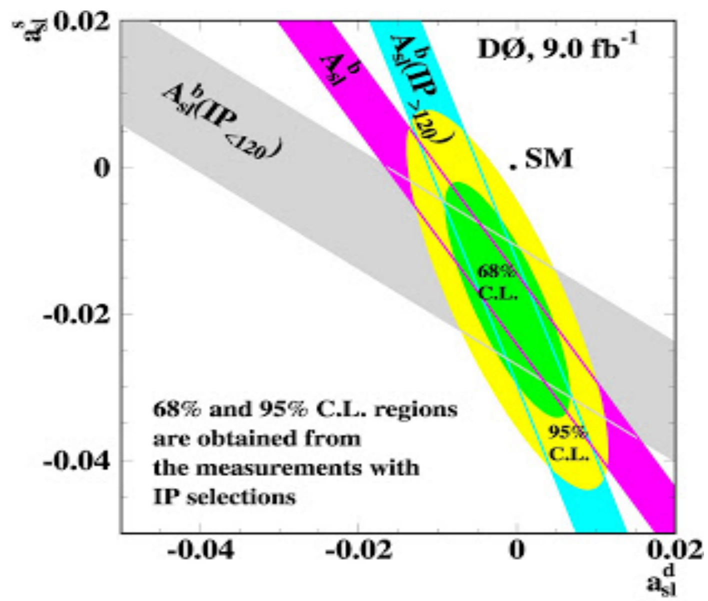
Mass eigenstate ΔM_q , $\Delta\Gamma_q$ and ϕ_q

$a^d_{sl} = (-0.041 \pm 0.006)\,\%$

$a^s_{sl} = (-0.0019 \pm 0.0003)\,\%$

Same charge dimuon asymmetry measurement at D0 has a significant discrepancy from the SM predicted value, the asymmetry is linear combination of a^s_{sl} & a^d_{sl}

See Peter Garbincius's talk in "Physics beyond the SM" session on Friday

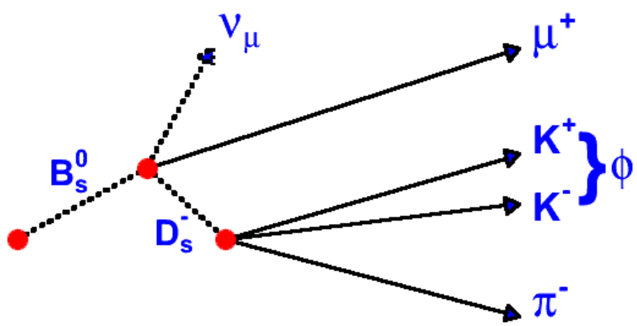


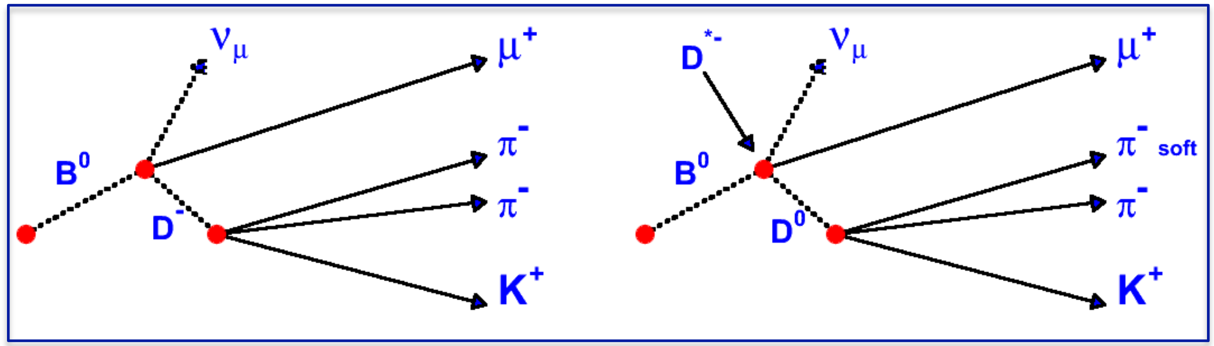
D0 uncorrelated measurements of a^s_{sl} & a^d_{sl} & direct CP violation asymmetry parameters are presented in this talk

Analysis Overview

Decay modes analyzed:

$B_s^0 \to \mu^+ \nu D_s^- X$ $\quad$ $B^0 \to \mu^+ \nu D^{*-} X$ $\quad$ $B^0 \to \mu^+ \nu D^- X$





Raw asymmetry, extracted by counting signal yields

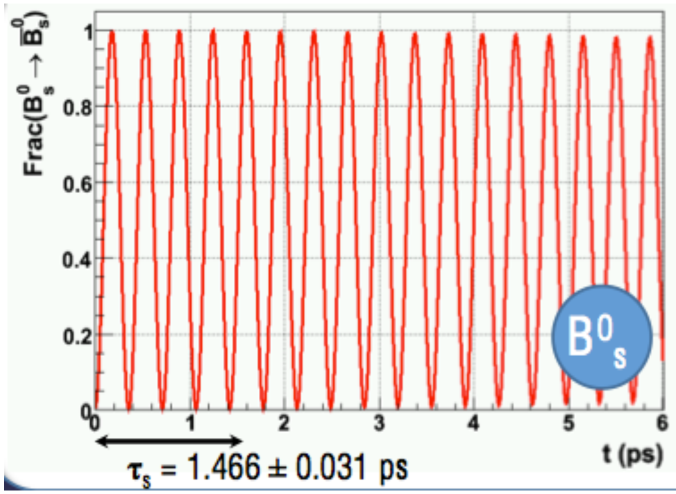
Background asymmetry, extracted for μ, K & π

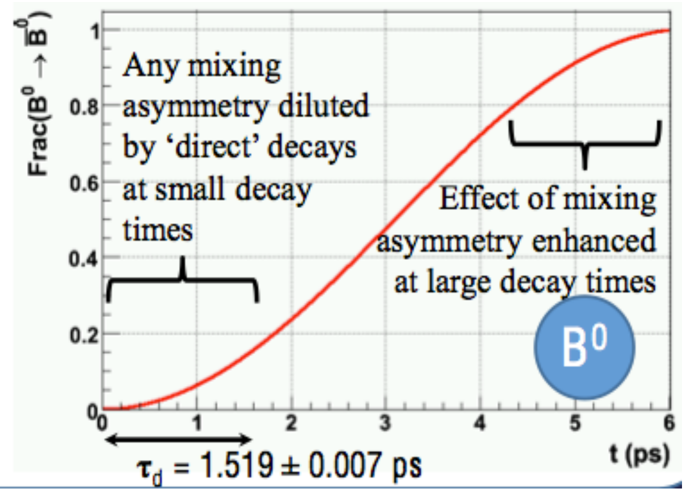
$$a_{sl}^q = \frac{A - A_{BG}}{F^{osc}_{B^0_{(s)}}}$$

Fraction of reconstructed signal from oscillated B-mesons

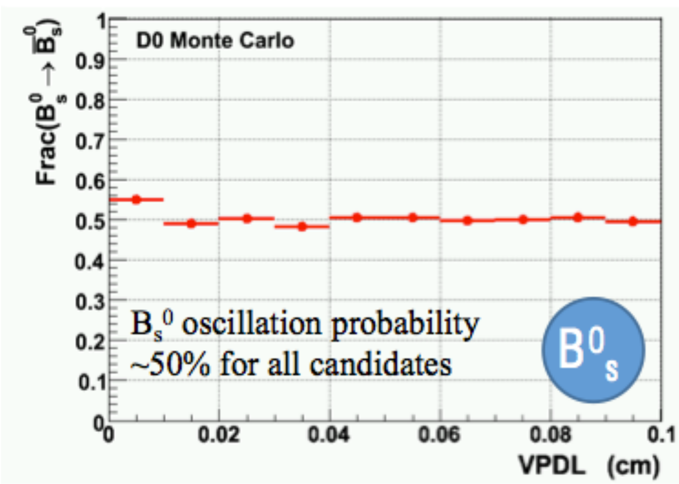
Time Dependence

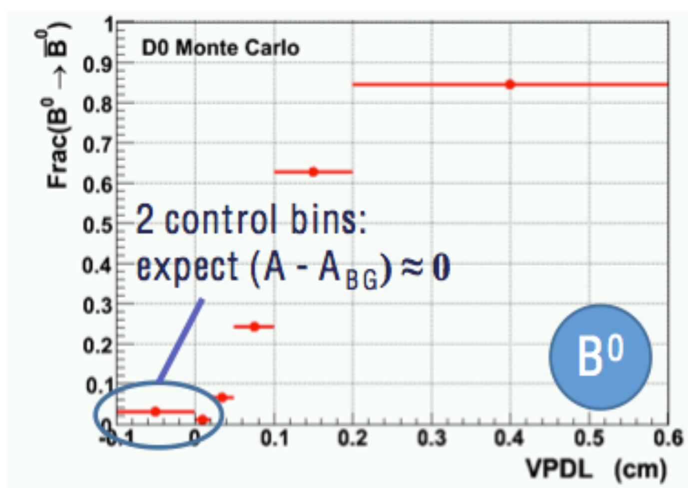
$F^{osc}_{B^0_{(s)}} = 0.465 \pm 0.017$ **: Determined by MC, using VPDL**





Time ➔ VPDL (visible proper decay length) ; missing neutrino distorts time measurement





B^0 asymmetries in 6 bins of VPDL

B_s^0 data not divided in VPDL bins

Background asymmetries :kaon

Largest asymmetry due to charged kaons

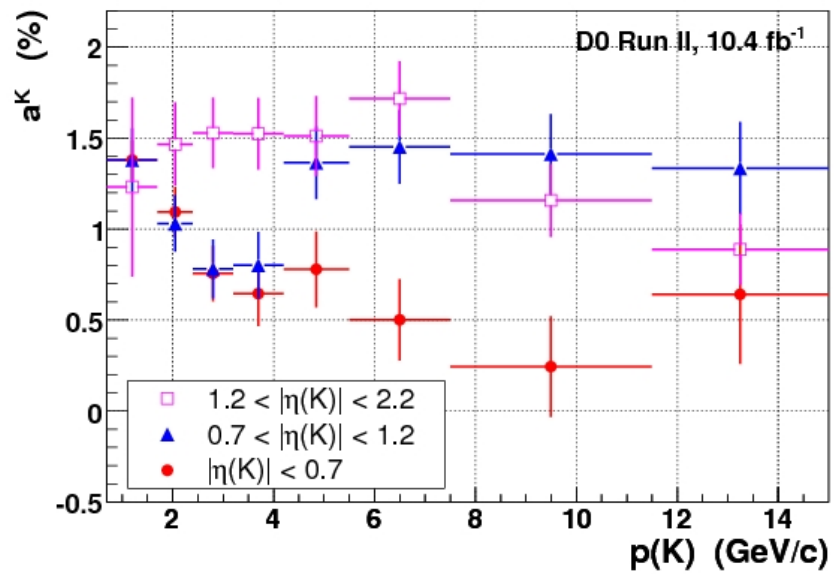
K^+ has a smaller interaction cross-section with respect to its counterpart i.e. K^-

$K^-N \rightarrow Y\pi$ @ $p(K) = 1$ GeV

$K^+N \rightarrow$ ✗

$\sigma(K^-d) \approx 80mb$

$\sigma(K^+d) \approx 33mb$



K^+ has a higher track reconstruction efficiency due to its longer path length in the tracker

Inherent physics asymmetry!

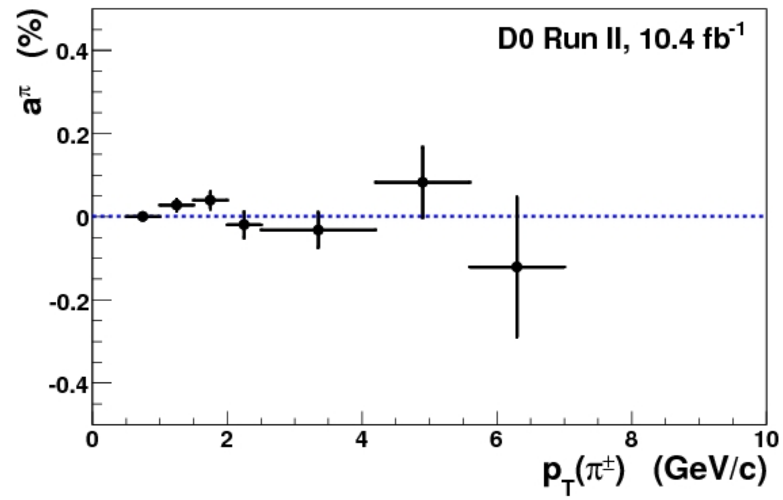
Kaon reconstruction asymmetry measurement is data driven using:

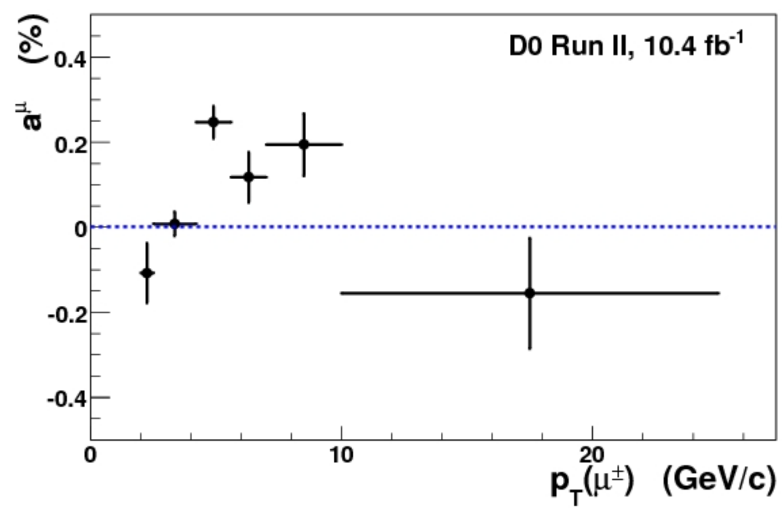
$$K_0^* \rightarrow K^\pm \pi^\mp$$

0.5% ➔ 1.5% depending on (p_K, $|\eta_K|$) bin

Background asymmetries :pion, muon

- Pion and muon related asymmetries are mostly driven by detector effects
- Approximately 10 times smaller compared to kaon asymmetries
- Both asymmetries are measured using data driven methods;
  - Pion reconstruction asymmetry measured using $K_s^0 \to \pi^+\pi^- and \;\; K^{*+} \to K_s^0\pi^+$
  - Muon reconstruction asymmetry measured using $J/\psi \to \mu^+\mu^-$





Raw Asymmetries: B_s^0

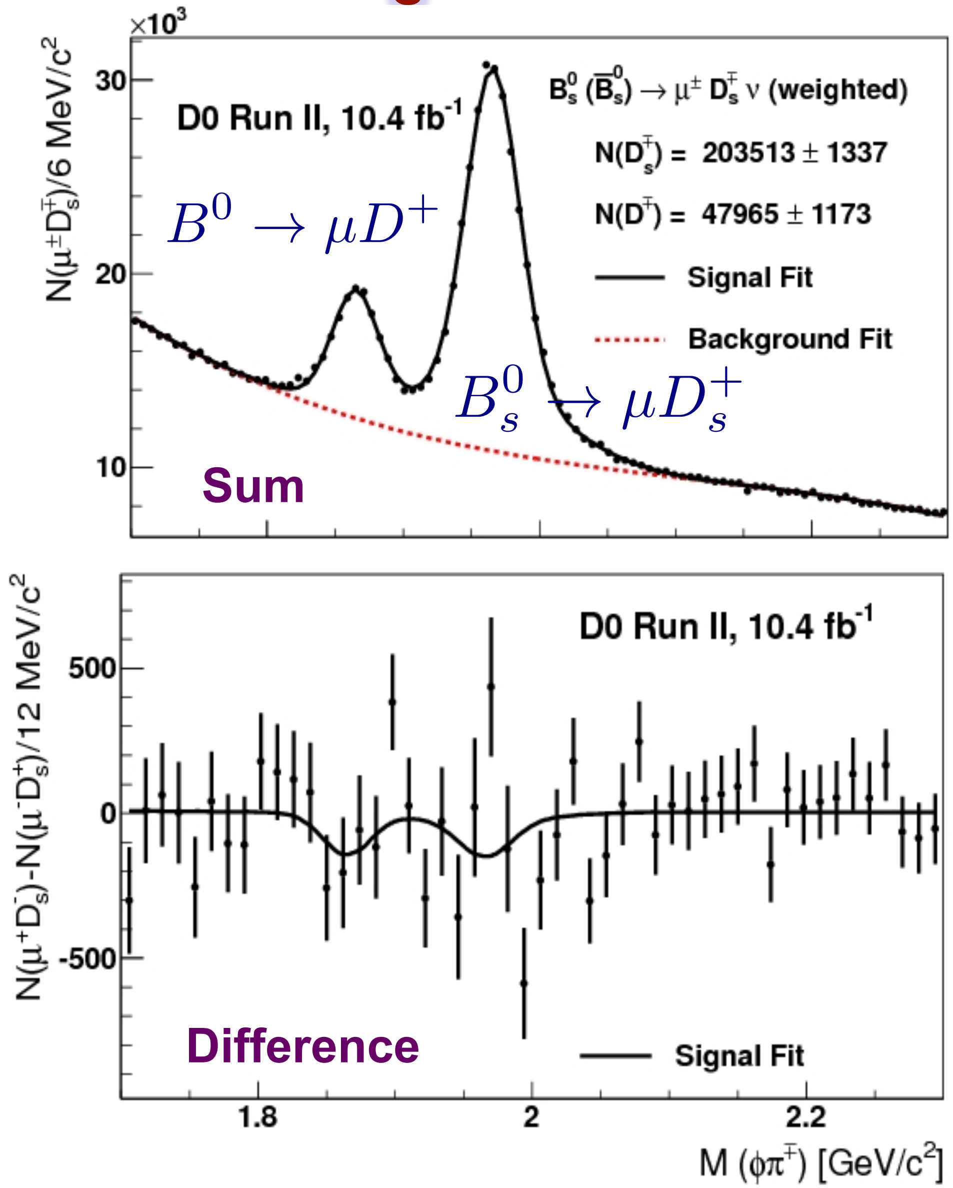
Simultaneous fit to sum and difference

$$A = \frac{N_{\mu^+ D^{(*)-}_{(s)}} - N_{\mu^- D^{(*)+}_{(s)}}}{N_{\mu^+ D^{(*)-}_{(s)}} + N_{\mu^- D^{(*)+}_{(s)}}} \equiv \frac{N_{diff}}{N_{sum}}$$

$$F(sum) = F_s(D_s) + F_s(D) + F_b$$

$$F(diff) = AF_s(D_s) + A_D F_s(D) + A_b F_b$$

$$A = [-0.40 \pm 0.33 \pm 0.05]\%$$

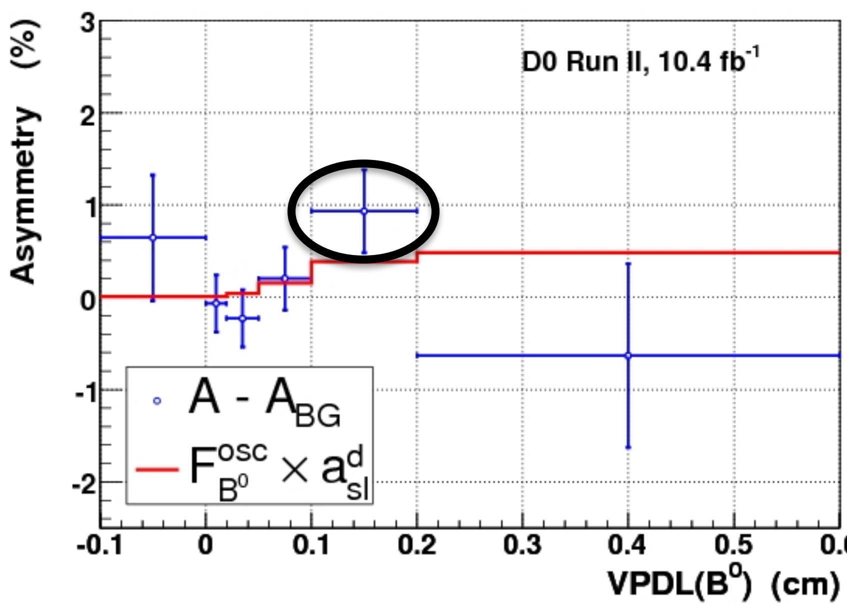


Asymmetry in background region is consistent with zero

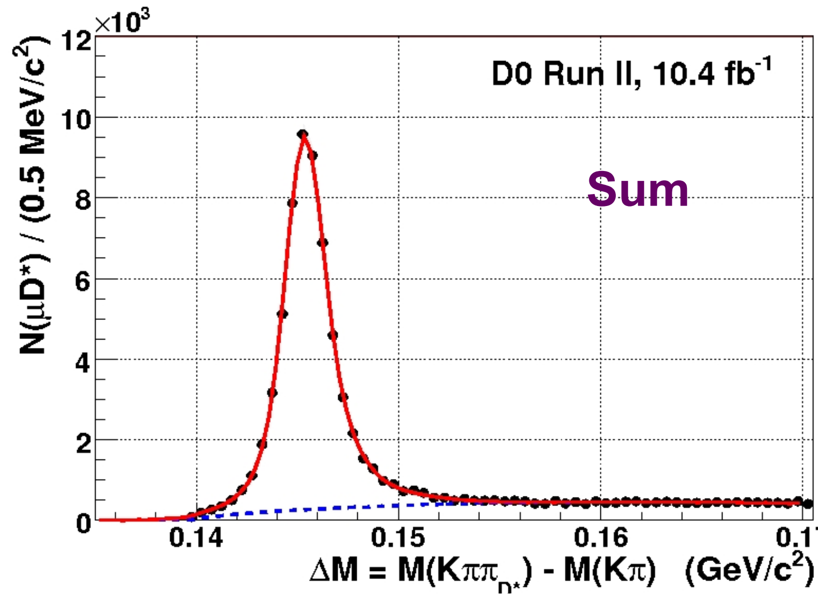
~~track reconstruction asymmetry~~

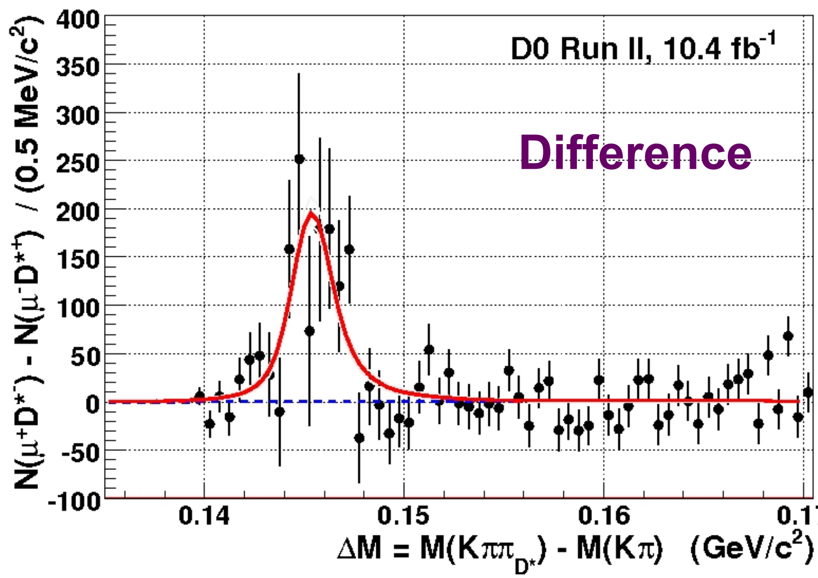
Raw Asymmetries: B^0

- B^0 data divided into 6 VPDL bins
- The 5th VPDL bin, 0.1→0.2 cm is most sensitive to D* channel



The difference showing expected large raw asymmetry due to kaon reconstruction asymmetry





Results

- Using B_s^0 data, we obtain the time integrated value of :

$$a_{sl}^{s} = [-1.12 \pm 0.74(stat) \pm 0.17(syst)]\%$$

  - consistent with D0 dimuon asymmetry result and with SM
  - This result supersedes previous worlds-best measurement (D0, 2009)
  - LHCb measurement: $a_{sl}^{s} = [-0.06 \pm 0.50 \pm 0.36]\%$ arXiv:1308.1048

- With two analyzed B^0 channels, where data divided in VPDL bins, we measure:

$$a_{sl}^{d} = [0.68 \pm 0.45(stat) \pm 0.14(syst)]\%$$

  - Above measured value is consistent with SM prediction
  - BABAR measurement: $a_{sl}^{d} = [0.06 \pm 0.17 \pm 0.34]\%$ arXiv:1305.1575

Direct CPV in $B^{\pm} \rightarrow J/\psi h^{\pm}$

Direct CPV in $B^{\pm} \rightarrow J/\psi h^{\pm}$

$$A^{J/\psi h} = \frac{\Gamma(B^- \to J/\psi h^-) - \Gamma(B^+ \to J/\psi h^+)}{\Gamma(B^- \to J/\psi h^-) + \Gamma(B^+ \to J/\psi h^+)}$$

"h" stand for hadron, either kaon or pion, D0 has analyzed both decay mode

- $B^{\pm} \rightarrow J/\psi h^{\pm}$ provides a clean test for direct CPV
- For $B^{\pm} \rightarrow J/\psi K^{\pm}$, the SM predicts that the tree and penguin contributions have the same weak phase and thus no direct CPV is expected O(0.1%)
- For $B^{\pm} \rightarrow J/\psi \pi^{\pm}$ decays could have CPV effects of a few percent

Current best measurements:

$$A^{J/\psi K} = (-0.76 \pm 0.55)\%(Belle, 2010)$$

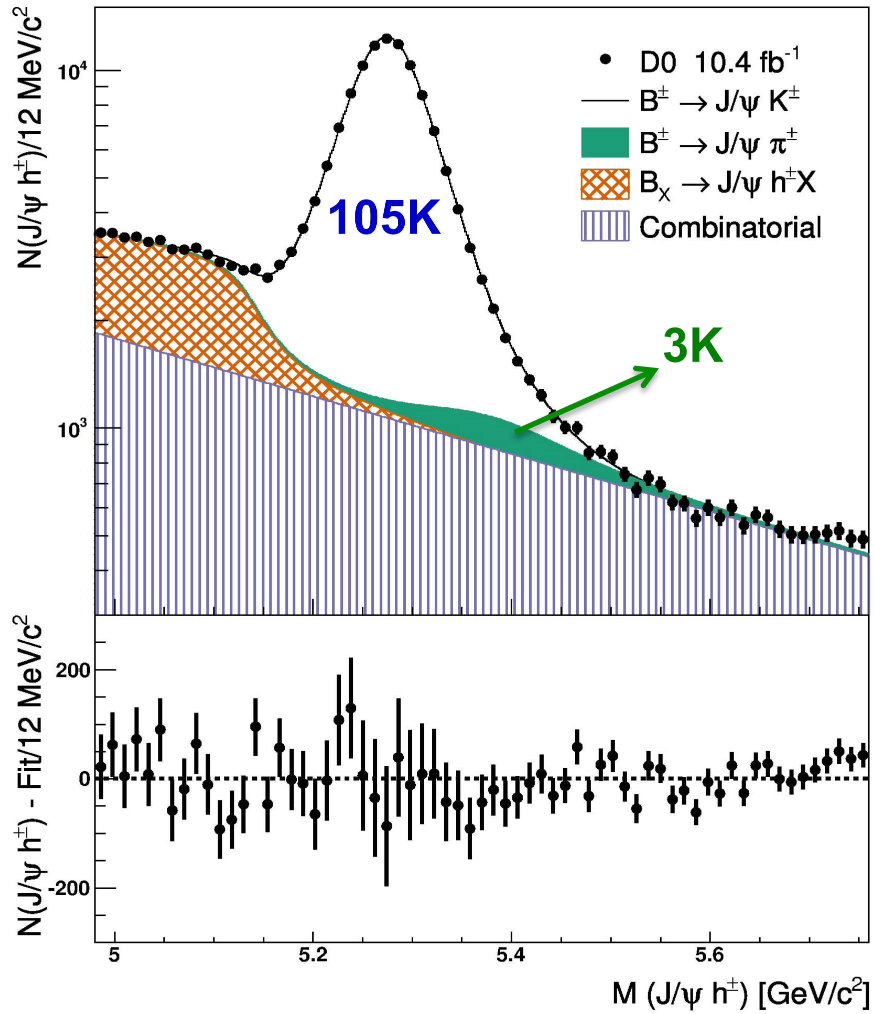
$$A^{J/\psi \pi} = (-0.5 \pm 2.9)\%(LHCb, 2012)$$

Analysis Method

- Same analysis technique as used to measure a^q_{sl}
- Reweighted data based on magnet polarity; fitted with unbinned maximum likelihood fit to the "sum" and "difference" to extract raw asymmetry
- Correct for the background asymmetry

$$A^{J/\psi h}_{raw} = \frac{N_{J/\psi h^-} - N_{J/\psi h^+}}{N_{J/\psi h^-} + N_{J/\psi h^+}}$$

$$A^{J/\psi h} = A^{J/\psi h}_{raw} + A_h$$



Fit to Difference

Raw asymmetries:

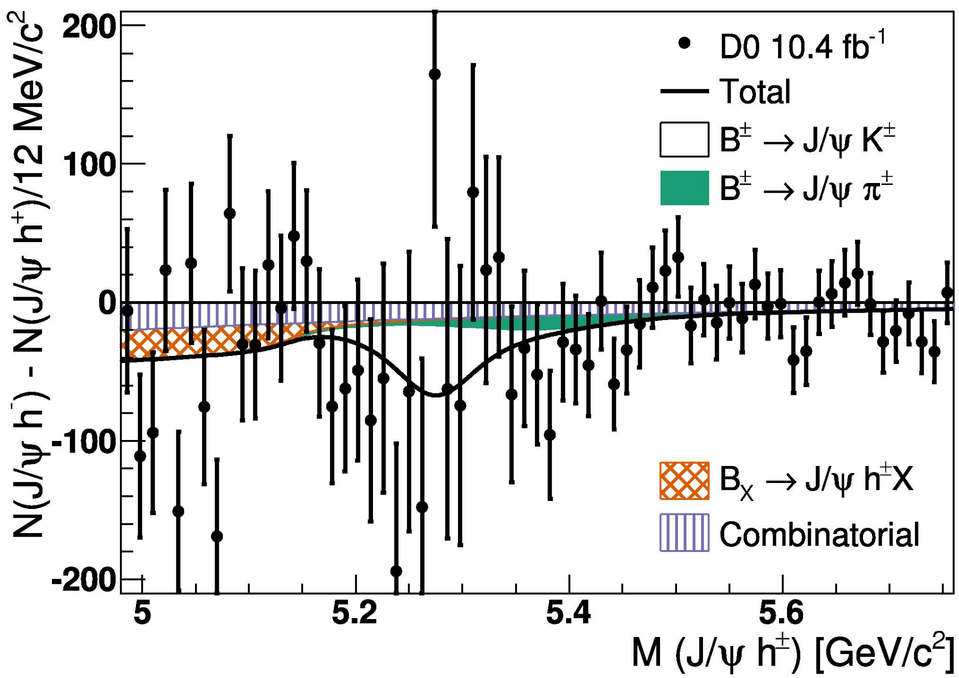
$$A_{raw}^{J/\psi K} = [-0.46 \pm 0.36(stat) \pm 0.05(syst)]\%$$

$$A_{raw}^{J/\psi \pi} = [-4.2 \pm 4.4(stat) \pm 1.8(syst)]\%$$

BG asymmetries: Standard kaon and pion reconstruction asymmetries in kinematic bins

$$A_{BG}^{J/\psi K} = [1.05 \pm 0.04]\%$$

$$A_{BG}^{J/\psi \pi} = [0.00 \pm 0.05]\%$$



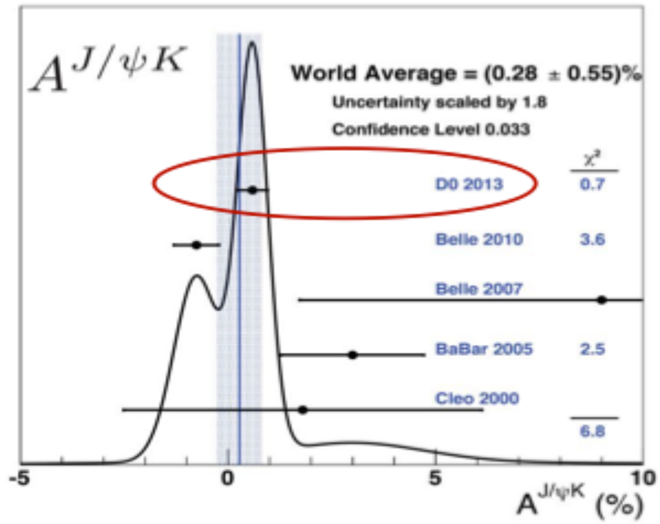
Systematic errors are determined for different fitting models and ranges

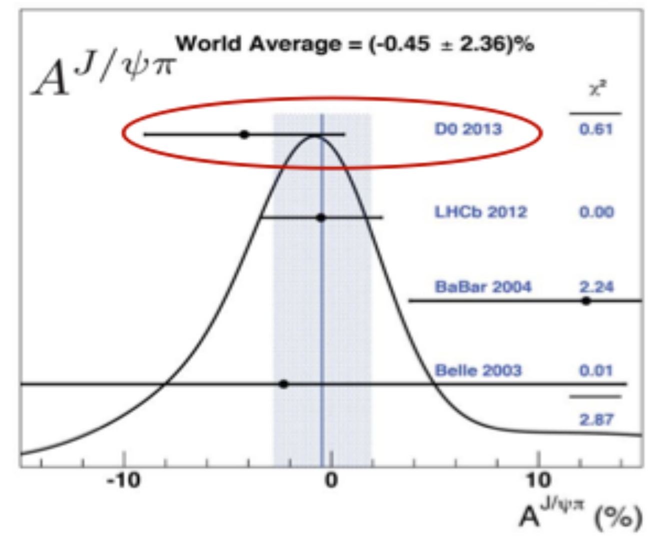
Results

$$A^{J/\psi K} = [0.59 \pm 0.36(stat) \pm 0.08(syst)]\%$$

$$A^{J/\psi \pi} = [-4.2 \pm 4.4(stat) \pm 1.8(syst)]\%$$

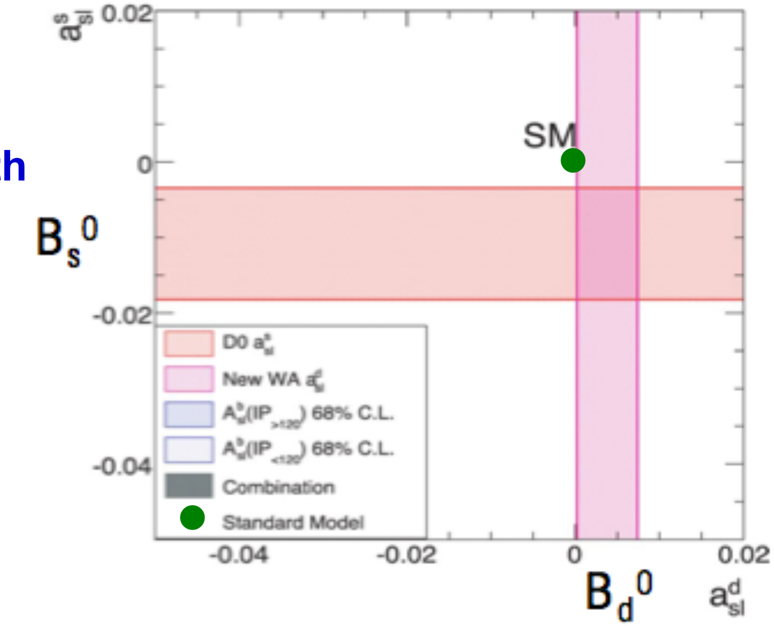
- **Most precise measurement of $A^{J\psi K}$, consistent with zero and SM prediction**
- **Competitive direct measurement of $A^{J/\psi\pi}$, consistent with zero**





Summary

- Measurement of asymmetry parameters related with CPV have been performed using D0 full data set
- Semi leptonic asymmetry publications
  PRD 86, 072009 (2012) & PRL 110, 011801 (2013)
- Direct CP violation $B^{\pm} \rightarrow J/\psi h^{\pm}$ publication :
  PRL 110, 241801 (2013)
- Our results are consistent with the SM predicted values and dimuon asymmetry results
- Many of our results are world's best precise measurement OR competitive



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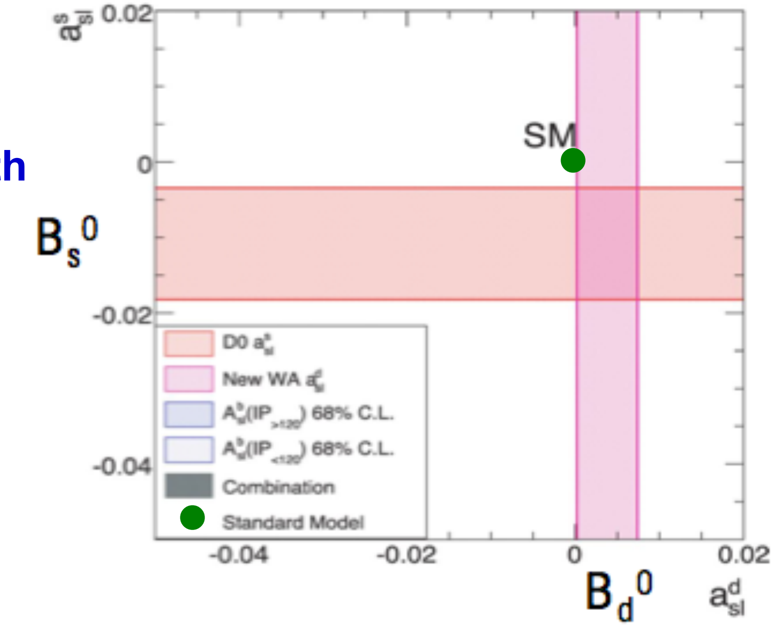
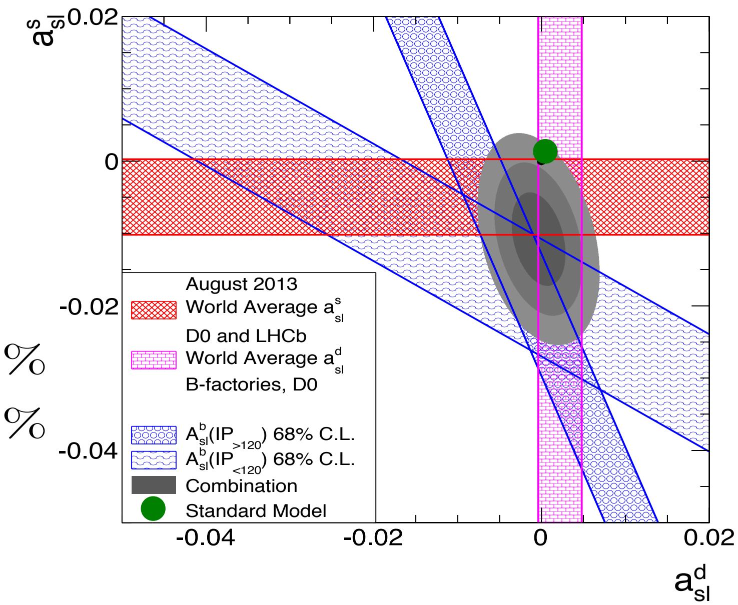
- Combine with D0 and B-factory a^d_{sl} and D0 like sign dimuon charge asymmetry

$$a^s_{\rm sl} = (-1.08 \pm 0.42)\ \%$$
$$a^d_{\rm sl} = (-0.04 \pm 0.21)\ \%$$
$$\rho = -0.32$$





Thank you!

a^d_{sl} by channel