Anomalous like-sign dimuon asymmetry

\[ Y \]

\[ \mu^+ \]

\[ B^0 \]

\[ \overline{B}^0 \]

\[ B^0 \]

\[ X \]

\[ A_{sl}^b \equiv \frac{N_{b}^{++} - N_{b}^{--}}{N_{b}^{++} + N_{b}^{--}} \]

\[ = C_d a_{sl}^d + C_s a_{sl}^s \]

where \( a_{sl}^q = \frac{\Delta \Gamma_q}{\Delta M_q} \tan \phi_q \)

\[ \text{arxiv.org:1106.6308 PRD 84 052007 (2011)} \]

\( C_{d(s)} \) is the fraction of \( B_d(B_s) \) events in the data sample.
\[ A_{sl}^b = (-0.787 \pm 0.172 \text{(stat)} \pm 0.093 \text{(syst)}) \% \]

- Anomalous Dimuon - 3.9\(\sigma\) deviation from SM expectations
- Split the data (blue band, grey band):
  \[ a_{sl}^d = (-0.12 \pm 0.52)\% , \]
  \[ a_{sl}^s = (-1.81 \pm 1.06)\% . \]
- Need to investigate in as many different ways as possible.

**SM Prediction**

\[ a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4} , \]
\[ a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5} . \]
Semi-leptonic Charge asymmetries

\[ a_{sl}^q = \frac{\Gamma (\bar{B}_q^0 \rightarrow B_q^0 \rightarrow \ell^+\nu X) - \Gamma (B_q^0 \rightarrow \bar{B}_q^0 \rightarrow \ell^-\bar{\nu} \bar{X})}{\Gamma (\bar{B}_q^0 \rightarrow B_q^0 \rightarrow \ell^+\nu X) + \Gamma (B_q^0 \rightarrow \bar{B}_q^0 \rightarrow \ell^-\bar{\nu} \bar{X})} \]

\[ a_{sl}^q = \frac{A - A_{bg}}{F_{B_q^0}^{osc}} \]

\[ A = \frac{N(\mu^+ D_{q}^{(*)-}) - N(\mu^- D_{q}^{(*)+})}{N(\mu^+ D_{q}^{(*)-}) + N(\mu^- D_{q}^{(*)+})} \]

- Use lepton charge to identify the B-meson flavour
- Correct for detector and physics background asymmetries
- Scale by the fraction of mixed events (using MC simulations)
- Assume no production asymmetry, no direct CP violation in charged D-mesons or B-meson semileptonic decay, only CP violation in mixing for B mesons.
Kaon Corrections

- \( K^+ \) and \( K^- \) have very different interaction cross sections
- Use the decay \( K^* \rightarrow K\pi \) to measure the asymmetry as a function of momentum and \( \eta \)

![Graph](image-url)
Residual Muon and Track Asymmetries

- The residual muon $p_T$ dependent reconstruction asymmetry between +ve and -ve tracks is measured using $J/\psi \rightarrow \mu\mu$ in a tag and probe analysis.

- Tracking asymmetry studied with $K_s \rightarrow \pi\pi$, $K^* \rightarrow K_s\pi$, plus other resonances showing no measurable correction

- See <0.05% effects in MC for pions - apply as a systematic
Select Data Sample from 10.4 fb\(^{-1}\)

Extract raw asymmetry by fitting \(D_s\) resonance in the invariant mass spectrum:

\[
A = \frac{N_{\mu^+D_s^-} - N_{\mu^-D_s^+}}{N_{\mu^+D_s^-} + N_{\mu^-D_s^+}},
\]

Correct for residual muon and tracking reconstruction asymmetries.

Correct for dilution.

Unblind after corrections are finalised.

No need for kaon correction.
The raw asymmetry $A$

- Non-lifetime biasing cuts + Log Likelihood ratio cut
- Blinded sensitivity tests performed
- Sum and difference fitted simultaneously
- $F(\text{sum}) = F_s(D_s) + F_s(D) + F_b$
- $F(\text{diff}) = AF_s(D_s) + A_DF_s(D) + A_bF_b$

$$A = \left[ -0.40 \pm 0.33 \text{ (stat.)} \right] \% \pm 0.05 \text{ (syst.)}$$

- Apply corrections of

$$A_{bg} = \left[ 0.11 \pm 0.06 \text{ (syst.)} \right] \%$$
• Model $\mu D_q$ events with Pythia, EvtGen, & Geant
• Weight events to match
  • $B$ meson lifetimes and mixing parameters
  • $B_s$ fraction that have mixed is essentially 50%.
• In $B_s$ analysis contamination from oscillated $B_d$’s is 0.5%
  (assuming a 1% asymmetry in $B_d$ implies a 0.005% effect)

\[
P\left( B^0_s \rightarrow \bar{B}^0_s \right) = \frac{1}{2} \left[ 1 - \frac{\cos(\Delta M_s \cdot t)}{\cosh(\Delta \Gamma_s \cdot t)} \right], \quad P\left( B^0_d \rightarrow \bar{B}^0_d \right) = \frac{1}{2} \left[ 1 - \frac{\cos(\Delta M_d \cdot t)}{\cosh(\Delta \Gamma_d \cdot t)} \right]
\]

\[
F^{OSC}_{B^0_s} = 0.465 \pm 0.017
\]
\( a_{s1}^s = [-1.08 \pm 0.72 \text{ (stat)} \pm 0.17 \text{ (syst)}] \% \),

- World’s best measurement
- Consistent with like-sign dimuon result
- Submitted to PRL and will appear on arXiv on Sunday night

http://www-d0.fnal.gov/Run2Physics/WWW/results/final/B/B12D/
Comparison with LHCb

- New preliminary LHCb result released today

\[ a^s_{sl}(\text{LHCb}) = (-0.24 \pm 0.63) \% \]

- All results are consistent

- \( \chi^2 = 0.77/1 \text{ dof for } a^s_{sl} \) combination

- Average of \( B_s^0 \to \mu^+ D_s^- \) results:

\[ a^s_{sl}(B_s^0 \to \mu D_s) = (-0.60 \pm 0.48) \% \]
\( a^{d_{sl}} \) in \( B_d^0 \rightarrow \mu^+D^{(*)-} \)

- Measure \( a^{d_{sl}} \) in two channels in a binned lifetime analysis.

\[
B_d^0 \rightarrow \mu^+\nu D^- X
\]

\[
B_d^0 \rightarrow \mu^+\nu D^{*-} X
\]

### Lifetime Bins

| Bin Range       | Count       |
|-----------------|-------------|
| -0.10 - 0.00 cm |             |
| 0.00 - 0.02 cm  |             |
| 0.02 - 0.05 cm  |             |
| 0.05 - 0.10 cm  |             |
| 0.10 - 0.20 cm  |             |
| 0.20 - 0.60 cm  |             |

### D0 MC, Preliminary

![Graph showing oscillation parameters](image_url)
Measure $a_{s\ell}$ in two channels in a binned lifetime analysis.

\[ B_d^0 \rightarrow \mu^+ \nu D^- X \quad \text{and} \quad B_d^0 \rightarrow \mu^+ \nu D^{*-} X \]

Use the first two lifetime bins as a control region to test corrections as expect no mixing.
Mass Distributions - 0.10 - 0.20 cm

\[ B_d^0 \rightarrow \mu^+ \nu D^- X \]

\[ B_d^0 \rightarrow \mu^+ \nu D^{*-} X \]
Extract $a_{sl}^d$

$$B_d^0 \rightarrow \mu^+ \nu D^- X$$

$$B_d^0 \rightarrow \mu^+ \nu D^*^- X$$

$$a_{sl}^d (\mu D) = [0.53 \pm 0.63 \text{ (stat.)} \pm 0.16 \text{ (syst.)}] \%$$

$$a_{sl}^d (\mu D^*) = [1.32 \pm 0.62 \text{ (stat.)} \pm 0.16 \text{ (syst.)}] \%$$

Weighted Average

$$a_{sl}^d = [0.93 \pm 0.45 \text{ (stat.)} \pm 0.14 \text{ (syst.)}] \%$$
Combination of D0 Results

- Combine all three D0 measurements (including correlations)

\[
\begin{align*}
\alpha_s^{s_{11}} &= (-1.81 \pm 0.56) \% \\
\alpha_s^d &= (0.22 \pm 0.30) \% \\
\rho &= -0.50
\end{align*}
\]

- p-value(SM) = 0.29% 3.0 standard deviations
  \(\chi^2 = 4.66/2 \text{ dof}\)

- \(\alpha_s^{s_{11}}\) is 3.2 standard deviations from zero
Including B-Factory $a_{sl}^d$

- Average new D0 result with HFAG PDG 2012 average of B-Factory results:
  
  $a_{sl}^d = (-0.05 \pm 0.56)\% \quad \text{arXiv:1207.1158}$

- Combination of two values of $a_{sl}^d$ has $\chi^2 = 1.79$ so we scale up the uncertainty

- Combine with D0 dimuon and $a_{sl}^s$
  
  \[
  a_{sl}^s = (-1.63 \pm 0.56)\% \\
  a_{sl}^d = (0.02 \pm 0.30)\% \\
  \rho = -0.51
  \]

- p-value(SM) = 0.26%, $\chi^2 = 2.06/2$ dof 2.90 standard deviations from SM

Before these analyses

\[
  a_{sl}^d = (-0.12 \pm 0.52)\%, \\
  a_{sl}^s = (-1.81 \pm 1.06)\%.
\]
• Presented new measurements of $a^d_{s1}$ and $a^s_{s1}$ in exclusive final states.

• Both are the world’s most precise single experiment measurements.

$$a^s_{s1} = [-1.08 \pm 0.72 \text{ (stat)} \pm 0.17 \text{ (syst)}] \%,$$

$$a^d_{s1} = [0.93 \pm 0.45 \text{ (stat.)} \pm 0.14 \text{ (syst.)}] \%$$

• Both measurements are consistent with the anomalous like-sign dimuon charge asymmetry

• Combined value of $a^s_{s1}$ is significantly different from the SM (-1.63 ± 0.56)% : 2.91 standard deviations from zero.

• Final update on anomalous like-sign dimuon asymmetry this summer (effectively doubling statistics for IP measurement).
Combination with LHCb

- Combine with D0 and B-Factory average $a_{sl}^d$.

$$a_{sl}^s = (-1.02 \pm 0.42)\%$$
$$a_{sl}^d = (-0.15 \pm 0.29)\%$$
$$\rho = -0.40$$

- $p$-value(SM) = 1.3%
  2.5 standard deviations
  $$\chi^2 = 4.00/2 \text{ dof}$$

- $a_{sl}^s$ is 2.5 standard deviations from zero
Backup
Combination Details

- Page 15: Only using D0 Results

- Make full use of the correlations between uncertainties of the IP dependence of the like sign dimuon anomalous like-sign dimuon charge asymmetry.

- The $a^d_{sl}$ and $a^s_{sl}$ measurements are assumed to be independent as they are dominated by the statistical uncertainty (There is correlation in some of the systematic uncertainties).

$$a^q_{sl} = \frac{|p/q|^2_{d(s)} - |q/p|^2_{d(s)}}{|p/q|^2_{d(s)} + |q/p|^2_{d(s)}}$$
• Page 16: D0 Anomalous Dimuon Asymmetry, D0 $a_{d_{sl}}$ and $a_{s_{sl}}$ and B-factory combination of $a_{d_{sl}}$.

• We combine the D0 and B-Factory values of $a_{d_{sl}}$ before carrying out the 2-D combination.

• Combination of two values of $a_{d_{sl}}$ has $\chi^2 = 1.79$ so we scale up the uncertainty by $\sqrt{1.79}$ as is used in the PFG. I.e. $
\sqrt{(1.79)} \times 0.36\% = 0.48\%$

• The combined D0 and B-Factory values of $a_{d_{sl}}$ is:

$$a_{d_{sl}} = (0.52 \pm 0.48)\%$$
Combination Details

• Page 16: D0 Anomalous Dimuon Asymmetry, D0 $a^d_{sl}$ and $a^s_{sl}$ and B-factory combination of $a^d_{sl}$.

• Current HFAG average has uncertainties of $a^d_{sl}$: 0.33% and $a^s_{sl}$: 0.64% including previous D0 measurements.

• Our combination

\[
\begin{align*}
  a^s_{sl} &= (-1.63 \pm 0.56) \% \\
  a^d_{sl} &= (0.02 \pm 0.30) \% \\
  \rho &= -0.51 \\
  |q/p|_s &= 1.0082 \pm 0.0028 \\
  |q/p|_d &= 0.9999 \pm 0.0015
\end{align*}
\]
- HFAG PDG 2012 average of B-Factory results: $a_{sl}^d = (-0.05 \pm 0.56)\%$

  $a_{sl}^s = (-0.88 \pm 0.42)\%$
  $a_{sl}^d = (-0.37 \pm 0.30)\%$
  $\rho = -0.42$

- p-value(SM) = 0.69%
  2.7 standard deviations
  $\chi^2 = 1.57/2$ dof

- $a_{sl}^s$ is 2.1 standard deviations from zero