Measurement of the anomalous like-sign dimuon charge asymmetry with 9 fb^{-1} of $p\bar{p}$ collisions

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Outline

1. What do we measure, why and how?

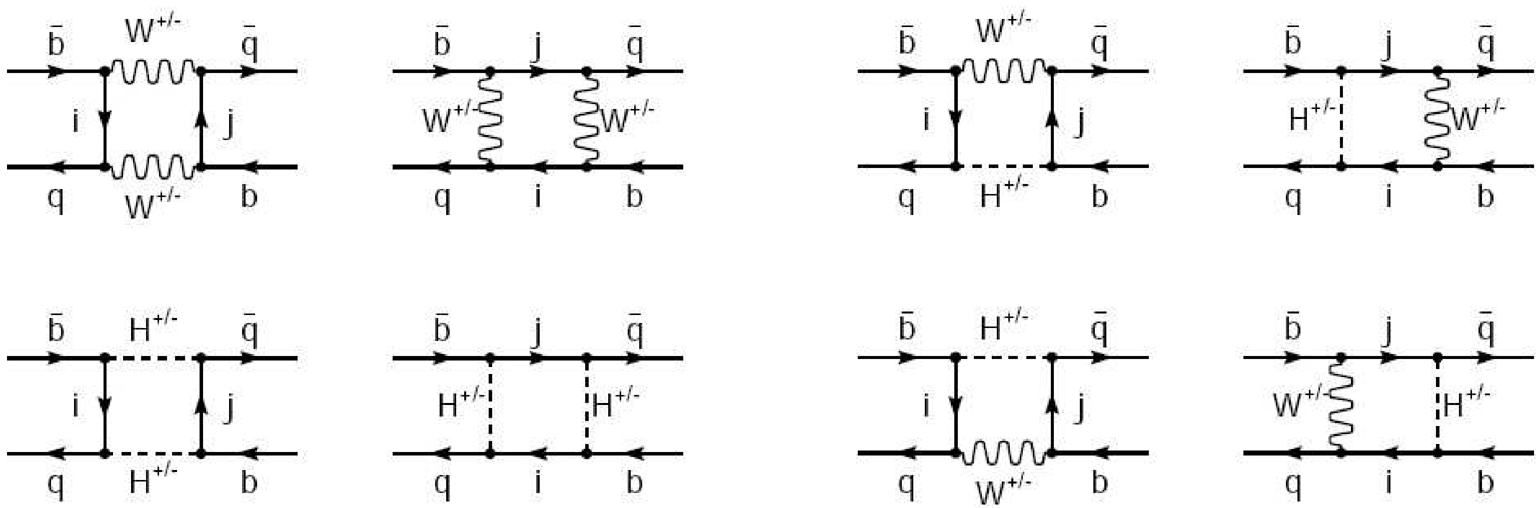
2. Results with 9.0 fb^{-1}

3. Cross-checks

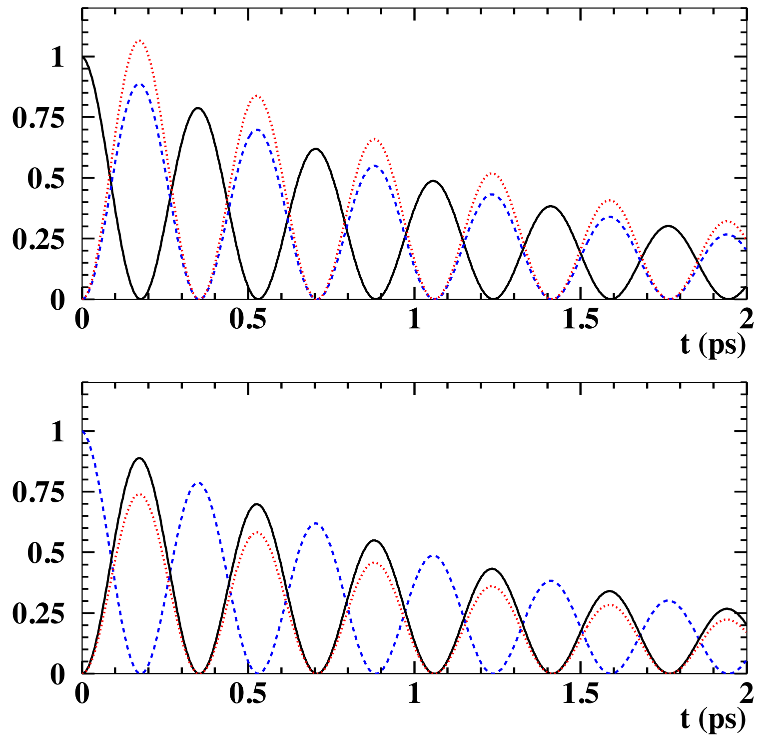
4. Dependence on the impact parameter

5. Conclusions

1. What do we measure, why and how?



$B_q^0 \leftrightarrow \bar{B}_q^0$ mixing is sensitive to new physics. $q = d, s$.



Top: Histogram of proper time of decays $B_s^0(s\bar{b}) \to \mu^+ X$ (continuous line), $B_s^0 \to \bar{B}_s^0 \to \mu^- X$ (dashed blue line if no CP violation, dotted red line if CP violation). Bottom: The same for $\bar{B}_s^0$ at $t = 0$.

At the Tevatron, b quarks are mostly created as $b\bar{b}$ pairs. To obtain a like-sign dimuon from semi-leptonic decay, one b hadron must decay to a "right sign" muon (i.e. a muon of the same sign as the original b quark), and the other b hadron must be a B_d^0 or B_s^0 that oscillates and decays to a "wrong sign" muon. For example

$$B^-(b\bar{u}) \to \mu^- X, \ B_s^0(s\bar{b}) \to \bar{B}_s^0 \to \mu^- X.$$

We measure the like-sign dimuon charge asymmetry of direct semileptonic B decays in $p\bar{p}$ collisions:

$$A^b_{\mathsf{sl}} \equiv \frac{N^{++}_{b\bar{b}} - N^{--}_{b\bar{b}}}{N^{++}_{b\bar{b}} + N^{--}_{b\bar{b}}},$$

$$A^b_{\mathsf{sl}} = C_d a^d_{\mathsf{sl}} + C_s a^s_{\mathsf{sl}},$$

$$a^q_{\mathsf{sl}} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q, \text{ with } q = d, s.$$

A^b_{sl} is obtained from the "raw" charge asymmetries

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-} \text{ , and } A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}.$$

Why measure A^b_{sl}?

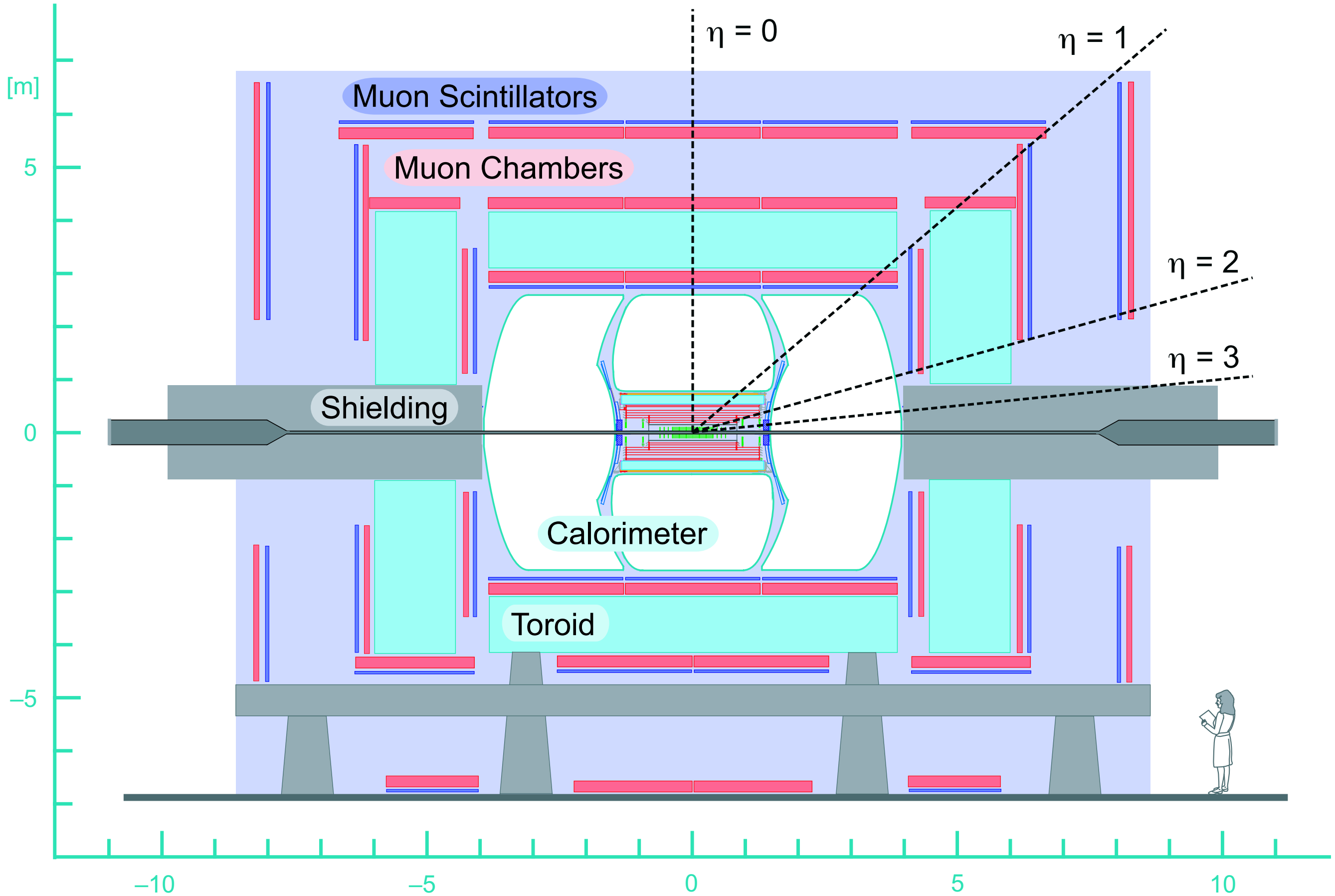
- In the Standard Model $A^b_{\mathrm{sl}} = (-0.028^{+0.005}_{-0.006})\% \approx 0$.

- New particles beyond the Standard Model can contribute to the box Feynman diagrams of $(B^0_q, \bar{B}^0_q)$ mixing even if these particles are not directly accessible at the Tevatron.

- Any significant deviation of the dimuon charge asymmetry A^b_{sl} from zero is unambiguous evidence of New Physics.

- At the Tevatron, the dimuon charge asymmetry is the most sensitive probe of some extensions of the Standard Model.

How?



The DØ detector.

Three methods to measure A_{sl}^b: $(a_S \equiv c_b A_{\mathrm{sl}}^b,\ A_S \equiv C_b A_{\mathrm{sl}}^b)$:

Inclusive muon sample (1 μ):

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-} = \sum_{i=0}^{5} f_\mu^i \{ f_S^i (a_S + \delta_i) + f_K^i a_K^i + f_\pi^i a_\pi^i + f_p^i a_p^i \}.$$

Like-sign dimuon sample (2 μ):

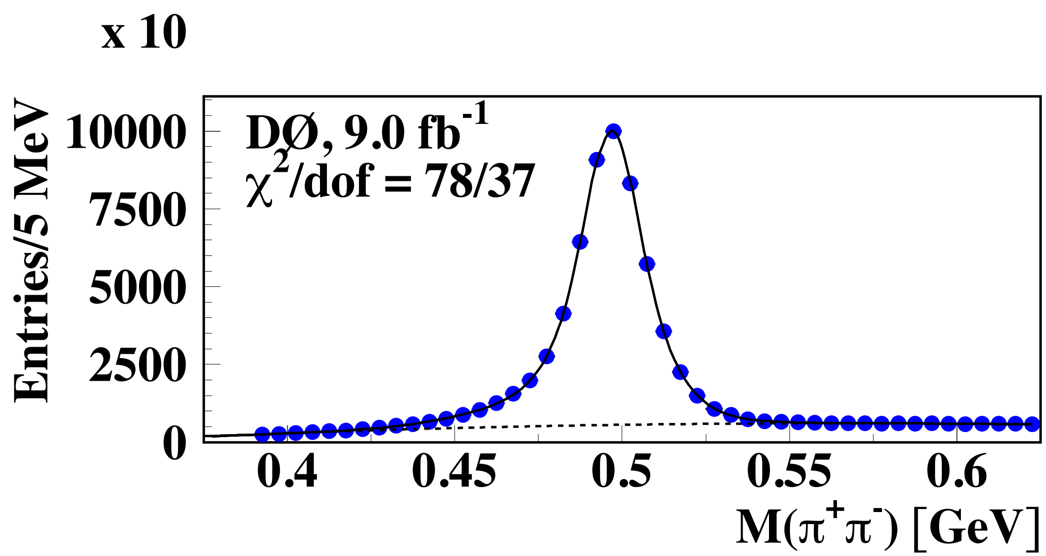
$$\begin{aligned} A &\equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \\ &= F_{SS} A_S + F_{SL} a_S + \sum_{i=0}^{5} F_\mu^i \{ (2 - F_{\mathrm{bkg}}^i) \delta_i \\ &\quad + F_K^i a_K^i + F_\pi^i a_\pi^i + F_p^i a_p^i \}. \end{aligned}$$

Combined: $A - \alpha a$. α chosen to minimize total uncertainty.

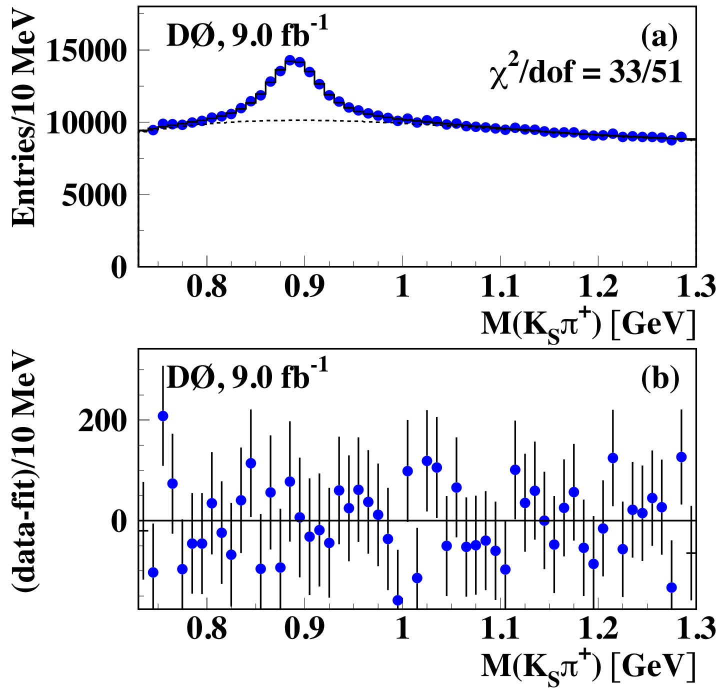
All parameters are measured with data as a function of p_T by reconstructing exclusive decays:

- f_K: $K^{*+} \to K_S \pi^+$, $K^{*0} \to \pi^- K^+ \to \mu^+$ and $K_S \to \pi^+ \pi^- \to \mu$.
- f_π: f_K, $K_S \to \pi^+ \pi^- \to \mu$, $\phi \to K^+ K^- \to \mu$ and n_π / n_K from MC.
- f_p: f_K, $\Lambda \to \pi^- p^+ \to \mu$, $\phi \to K^+ K^- \to \mu$ and n_p / n_K from MC.
- a_K: $K^{*0} \to \pi^- K^+ \to \mu^+$ and $\phi \to K^+ K^- \to \mu$.
- a_π: $K_S \to \pi^+ \pi^- \to \mu$.
- a_p: $\Lambda \to \pi^- p \to \mu$.
- δ: $J/\psi \to$ track track $\to \mu$.
- $R_K \equiv F_K / f_K$: $K^{*0} \to \pi^- K^+ \to \mu^+$ (null-fit method) and $K_S \to \pi^+ \pi^- \to \mu$.

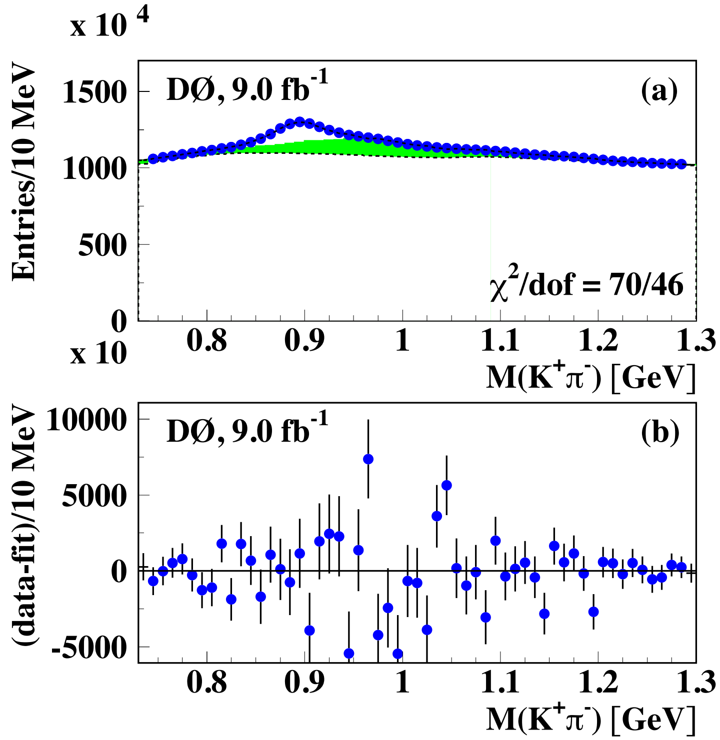
Example: fits to obtain f_K



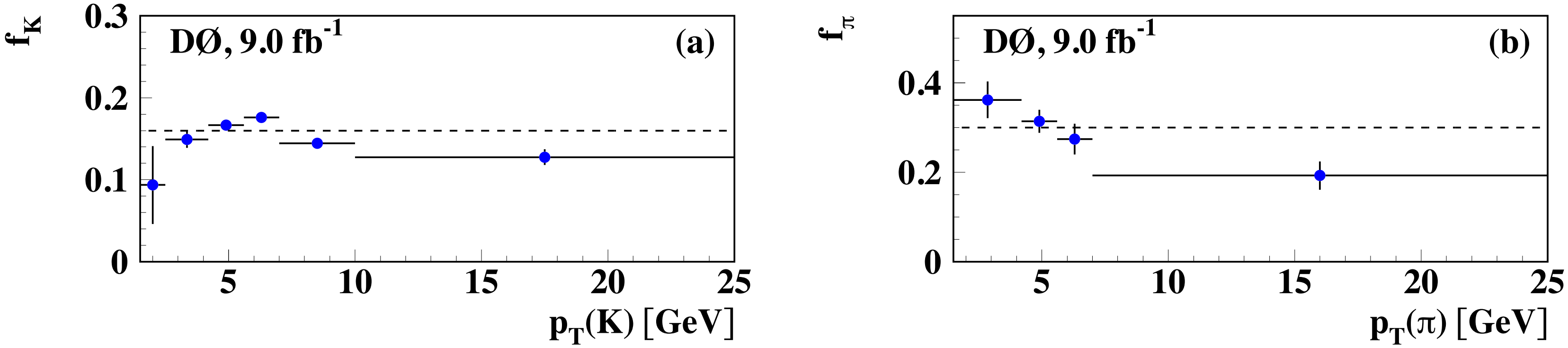
$K_S \to \pi^+\pi^- \to \mu$ candidates with $4.2 < p_T(K_S) < 5.6$ GeV in the inclusive muon sample.



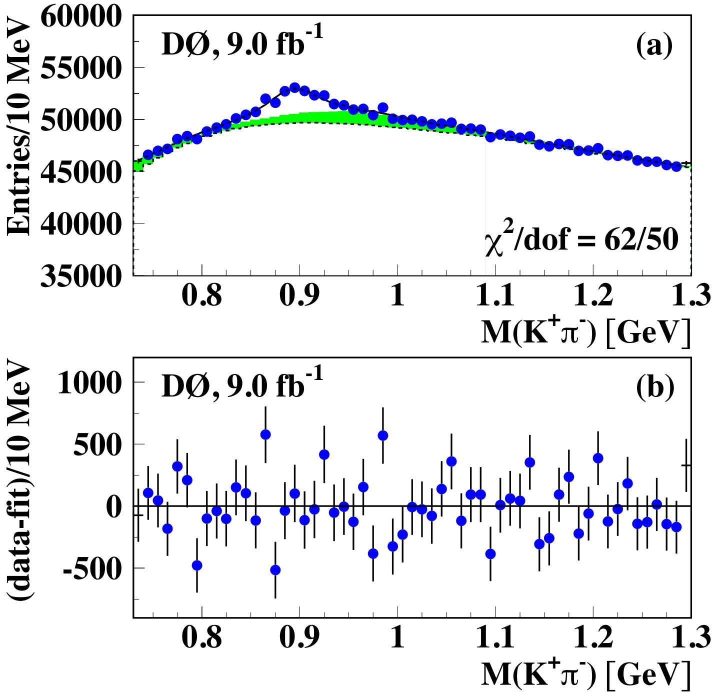
$K^{*+} \rightarrow \pi^+ K_S \rightarrow \pi\pi \rightarrow \mu$ candidates with 4.2 $< p_T(K_S) <$ 5.6 GeV in the inclusive muon sample.



$K^{*0} \to \pi^- K^+ \to \mu^+$ candidates with $4.2 < p_T(K^+) < 5.6$ GeV in the inclusive muon sample. Green: $\rho^0 \to \pi^+\pi^-$ events.

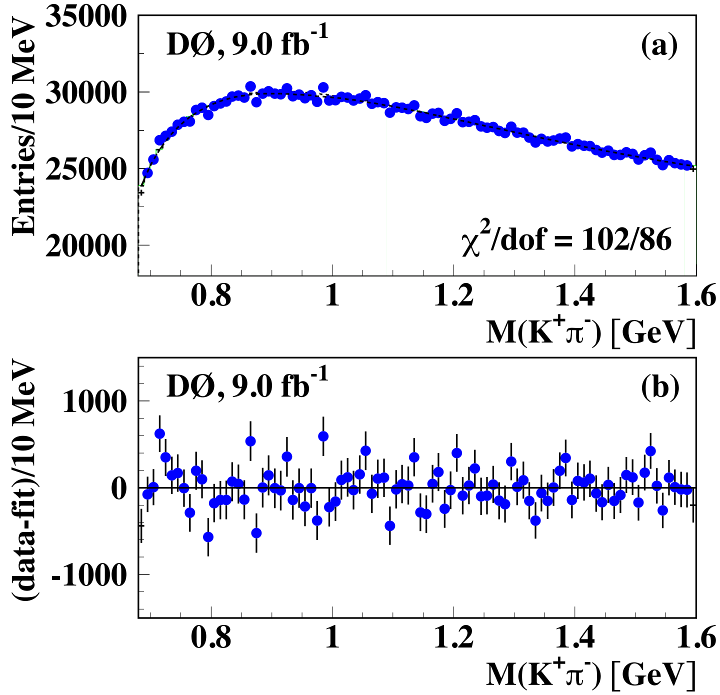


The fraction of (a) $K \to \mu$ tracks, and (b) $\pi \to \mu$ tracks in the inclusive muon sample as a function of the track transverse momentum p_T.



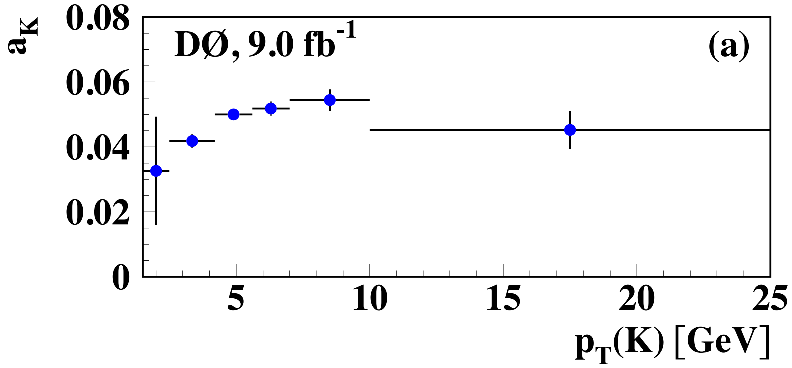
$K^{*0} \to \pi^- K^+ \to \mu^+$ candidates with $4.2 < p_T(K^+) < 5.6$ GeV in the like-sign dimuon sample. Green: $\rho^0 \to \pi^+\pi^-$ events.

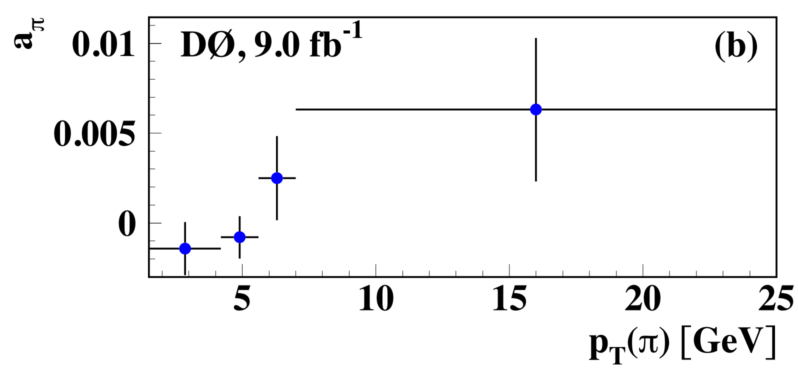
Null-fit to obtain $R_K = F_K/f_K$



$K^+\pi^-$ invariant mass distribution of a weighted difference of histograms for inclusive muons and like-sign dimuons for $4.2 < p_T(K^+) < 5.6$ GeV.

The K^+ has a longer inelastic interaction length in the calorimeter than K^-, and therefore has more time to decay. This results in a positive charge asymmetry a_K of the kaon decay background. a_K is measured with the data in two independent channels: $K^{*0} \to \pi^- K^+ \to \mu^+$ and $\phi \to K^+ K^- \to \mu$.





The asymmetries (a) a_K, and (b) a_π as a function of the kaon or pion p_T.

Contribution of different background sources to the observed asymmetry in the inclusive muon and like-sign dimuon samples. Only the statistical uncertainties are given. $a - a_{\rm bkg} = f_S c_b A^s_{\rm sl}$, $A - A_{\rm bkg} = (F_{SS} C_b + F_{SL} c_b) A^s_{\rm sl}$.

Source	inclusive muon	like-sign dimuon
$(f_K a_K$ or $F_K A_K) \times 10^2$	$+0.776 \pm 0.021$	$+0.633 \pm 0.031$
$(f_\pi a_\pi$ or $F_\pi A_\pi) \times 10^2$	$+0.007 \pm 0.027$	-0.002 ± 0.023
$(f_p a_p$ or $F_p A_p) \times 10^2$	-0.014 ± 0.022	-0.016 ± 0.019
$[(1 - f_{\rm bkg})\delta$ or $(2 - F_{\rm bkg})\Delta] \times 10^2$	-0.047 ± 0.012	-0.212 ± 0.030
$(a_{\rm bkg}$ or $A_{\rm bkg}) \times 10^2$	$+0.722 \pm 0.042$	$+0.402 \pm 0.053$
$(a$ or $A) \times 10^2$	$+0.688 \pm 0.002$	$+0.126 \pm 0.041$
$[(a - a_{\rm bkg})$ or $(A - A_{\rm bkg})] \times 10^2$	-0.034 ± 0.042	-0.276 ± 0.067

Heavy quark decays. Note: we now take χ_0 form LEP.

	Process	Weight
T_1	$b \to \mu^- X$	$w_1 \equiv 1.$
T_{1a}	$b \to \mu^- X$ (nos)	$w_{1a} = (1-\chi_0)w_1$
T_{1b}	$\bar{b} \to b \to \mu^- X$ (osc)	$w_{1b} = \chi_0 w_1$
T_2	$b \to c \to \mu^+ X$	$w_2 = 0.096 \pm 0.012$
T_{2a}	$b \to c \to \mu^+ X$ (nos)	$w_{2a} = (1-\chi_0)w_2$
T_{2b}	$\bar{b} \to b \to c \to \mu^+ X$ (osc)	$w_{2b} = \chi_0 w_2$
T_3	$b \to c\bar{c}q$ with $c \to \mu^+ X$ or $\bar{c} \to \mu^- X$	$w_3 = 0.064 \pm 0.006$
T_4	$\eta, \omega, \rho^0, \phi(1020), J/\psi, \psi' \to \mu^+\mu^-$	$w_4 = 0.021 \pm 0.002$
T_5	$b\bar{b}c\bar{c}$ with $c \to \mu^+ X$ or $\bar{c} \to \mu^- X$	$w_5 = 0.013 \pm 0.002$
T_6	$c\bar{c}$ with $c \to \mu^+ X$ or $\bar{c} \to \mu^- X$	$w_6 = 0.675 \pm 0.101$

Dilution factors: $c_b = 0.061 \pm 0.007$, $C_b = 0.474 \pm 0.032$.

Improvements (since Phys. Rev. D 82, 032001, (2010))

- To increase the number of events, the $|p_z|$ cut is lowered from 6.4 GeV to 5.4 GeV.

- To lower the $K \to \mu$ and $\pi \to \mu$ backgrounds, the χ^2 of the match of track parameters obtained with the central detector and outer muon system is reduced from 40 to 12 (with 4 d.o.f.).

- The measurement of f_K is improved: $K_S \to \pi\pi \to \mu$ (muon required for same sample composition as $K \to \mu$).

- The measurement of $R_K \equiv F_K/f_K$ is done in two independent channels: $K^{*0} \to \pi^- K^+ \to \mu^+ X$ (with the null-fit method), and the new channel $K_S \to \pi\pi \to \mu$.

- The data set is increased from 6.1 fb^{-1} to 9.0 fb^{-1}.

2. Results with 9.0 fb^{-1}

- From 1 μ (2.041×10^9 muons):
  $A^b_{\text{sl}} = (-1.04 \pm 1.30 \text{ (stat)} \pm 2.31 \text{ (syst)})$ %.

- From 2 μ (6.019×10^6 like-sign dimuons):
  $A^b_{\text{sl}} = (-0.808 \pm 0.202 \text{ (stat)} \pm 0.222 \text{ (syst)})$ %.

- Combined (from $A - \alpha a$ with $\alpha = 0.89$):
  $A^b_{\text{sl}} = (-0.787 \pm 0.172 \text{ (stat)} \pm 0.093 \text{ (syst)})$ %.

- $A^b_{\mathsf{sl}} = (-0.787 \pm 0.172\ (\mathsf{stat}) \pm 0.093\ (\mathsf{syst}))\ \%$.
  This measurement disagrees with the prediction of the Standard Model by 3.9 standard deviations.

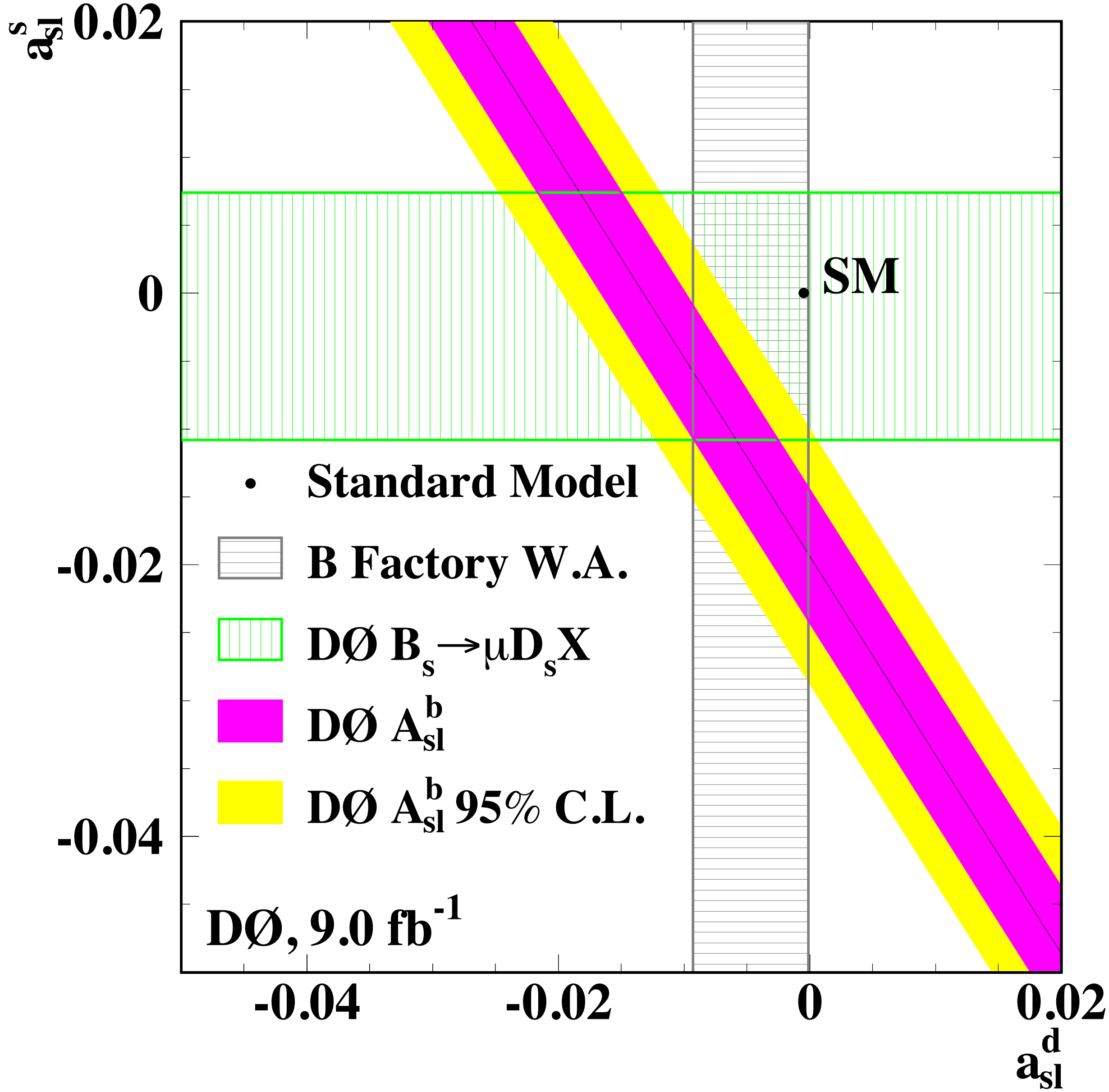
- The charge asymmetry of like-sign dimuon events after subtracting all background contributions from the raw charge asymmetry is:

$$\begin{aligned} A_{\mathsf{res}} &\equiv (A - \alpha a) - (A_{\mathsf{bkg}} - \alpha a_{\mathsf{bkg}}) \\ &= (-0.246 \pm 0.052\ (\mathsf{stat}) \pm 0.021\ (\mathsf{syst}))\%. \end{aligned}$$

  This quantity does not depend on the interpretation in terms of the charge asymmetry of semileptonic decays of B mesons. This measurement disagrees with the prediction of the Standard Model by 4.2 standard deviations.

Sources of uncertainty on A^b_{sl}. The first nine rows contain statistical uncertainties, the next four rows contain systematic uncertainties.

Source	1μ	2μ	combined
A or a (stat)	0.00068	0.00121	0.00132
f_K (stat)	0.00472	0.00064	0.00028
R_K (stat)	N/A	0.00059	0.00065
$P(\pi \to \mu)/P(K \to \mu)$	0.00181	0.00023	0.00008
$P(p \to \mu)/P(K \to \mu)$	0.00323	0.00026	0.00002
A_K	0.00458	0.00052	0.00037
A_π	0.00802	0.00067	0.00030
A_p	0.00584	0.00050	0.00020
δ or Δ	0.00377	0.00087	0.00067
f_K (syst)	0.02310	0.00204	0.00007
R_K (syst)	N/A	0.00068	0.00072
π, K, p multiplicity	0.00067	0.00019	0.00017
c_b or C_b	0.00121	0.00052	0.00056
Total statistical	0.01304	0.00202	0.00172
Total systematic	0.02313	0.00222	0.00093
Total	0.02656	0.00300	0.00196


a_{sl}^{s}
0.02
0
-0.02
-0.04
SM
Standard Model
B Factory W.A.
DØ $B_s \rightarrow \mu D_s X$
DØ A_{sl}^{b}
DØ A_{sl}^{b} 95% C.L.
DØ, 9.0 fb^{-1}
-0.04
-0.02
0
0.02
a_{sl}^{d}

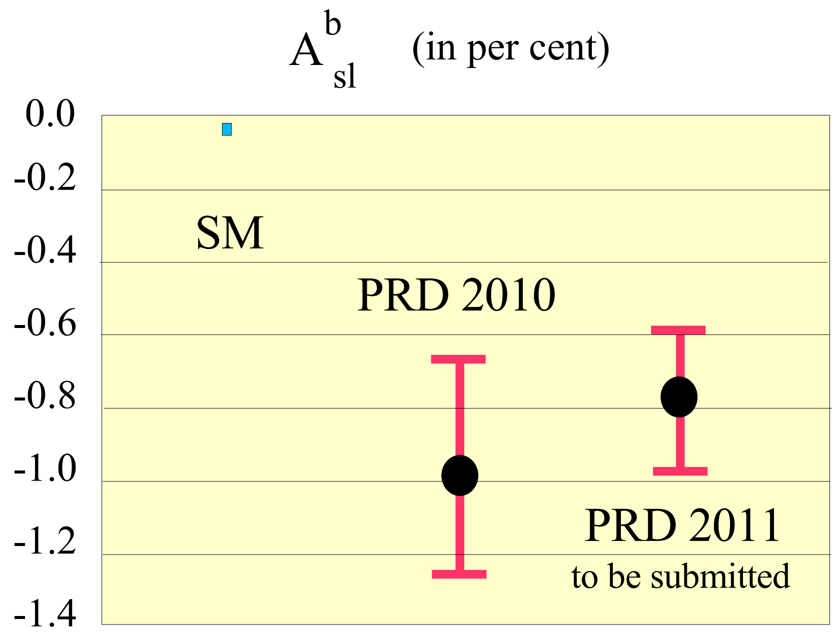
History

- Phys. Rev. D 82, 032001, (2010),
  Phys. Rev. Lett. 105, 081801 (2010), 6.1 fb^{-1}:
  $A^b_{\mathrm{sl}} = (-0.957 \pm 0.251\ (\mathrm{stat}) \pm 0.146\ (\mathrm{syst}))\ \%$, 3.2$\sigma$ from SM.

- This measurement (2011) with same 6.1 fb^{-1} data set:
  $A^b_{\mathrm{sl}} = (-0.891 \pm 0.204\ (\mathrm{stat}) \pm 0.128\ (\mathrm{syst}))\ \%$, 3.6$\sigma$ from SM.
  Significance of difference from measurement with 9.0 fb^{-1}
  (accounting for common events): 0.74σ.

- This measurement (2011) with 9.0 fb^{-1}:
  $A^b_{\mathrm{sl}} = (-0.787 \pm 0.172\ (\mathrm{stat}) \pm 0.093\ (\mathrm{syst}))\ \%$, 3.9σ from SM.

- This measurement (2011) with last 2.9 fb^{-1}:
  $A^b_{\text{sl}} = (-0.600 \pm 0.335\ \text{(stat)} \pm 0.188\ \text{(syst)})\ \%$.
  Significance of difference from measurement with 9.0 fb^{-1} (accounting for common events): 0.57σ.



Comparison of measurements of A_{sl}^{b}.

Comparison of directly measured background subtracted asymmetries

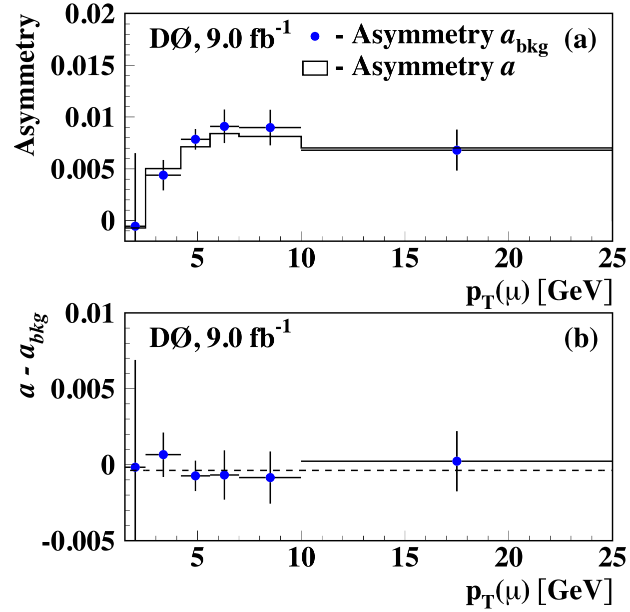
(before dividing by the dilution factor which depends on the physics interpretation in terms of $B_q \bar{B}_q$ mixing and semi-leptonic decay):

- Phys. Rev. D 74, 092001 (2006), Eq. (11), 1 fb^{-1}:
  $A = (-0.28 \pm 0.13 \text{ (stat)} \pm 0.09 \text{ (syst)})\%$.

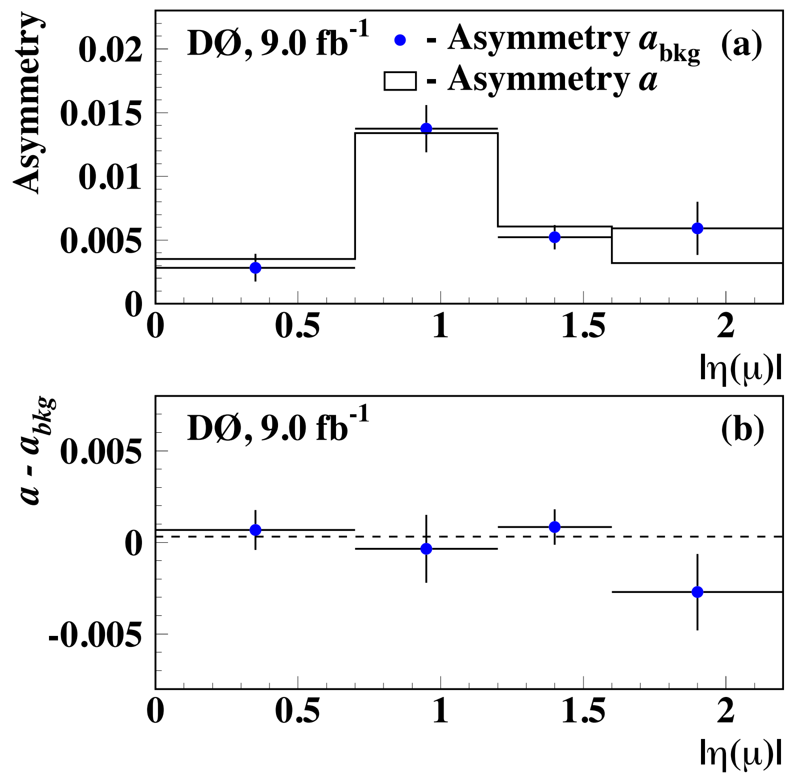
- This measurement, (2011), 9.0 fb^{-1}:
  $A_{\text{res}} = (-0.246 \pm 0.052 \text{ (stat)} \pm 0.021 \text{ (syst)})\%$.

All measurements are consistent.

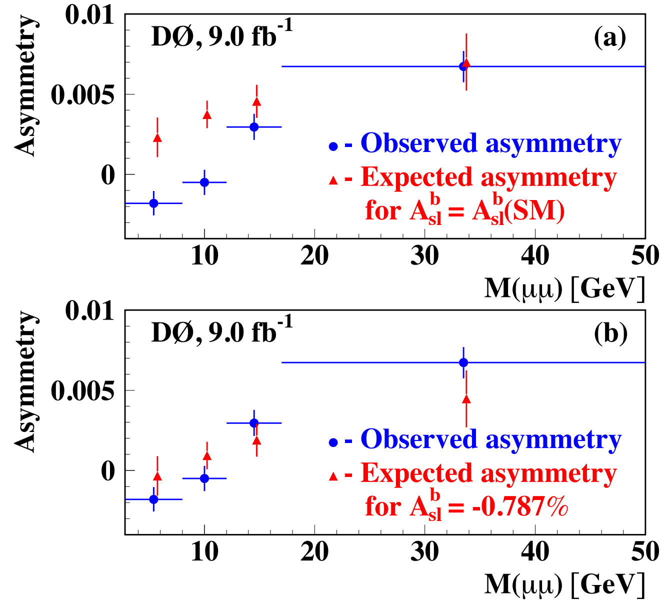
3. Cross-checks



The asymmetry a_{bkg} (points with error bars, total uncertainties are shown), as expected from our measurements of the fractions and asymmetries of the background processes, is compared to the measured asymmetry a of the inclusive muon sample as a function of p_T. The asymmetry from CP violation is negligible compared to the background in the inclusive muon sample.



The same, but as a function of the absolute value of muon pseudorapidity $|\eta(\mu)|$.



The observed and expected like-sign dimuon charge asymmetries in bins of dimuon invariant mass. The expected asymmetry is shown for (a) $A^b_{\rm sl}$ = SM value, and (b) $A^b_{\rm sl} = -0.787$ %.

More cross-checks (see paper for numerical details):

- Different running periods
- Tighter muon selection
- Lower background (by tightening χ^2 match between central detector and outer muon system track parameters).
- Lower impact parameter cut from 0.300 to 0.012 cm.
- Only low luminosity events.

- Invariant mass of the 2 muons greater than 12 GeV (instead of 2.8 GeV).

- Only muons with $p_T > 4.2$ GeV.

- Only muons with $p_T < 7.0$ GeV.

- Only muons in part of the ϕ range.

- Only muons in part of the η range (several tests).

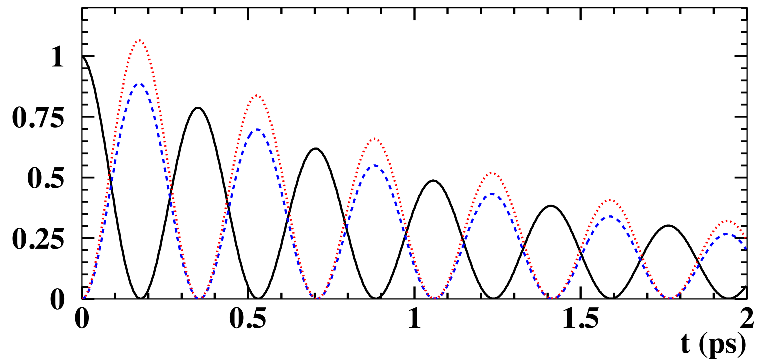
- Tests with different trigger requirements.

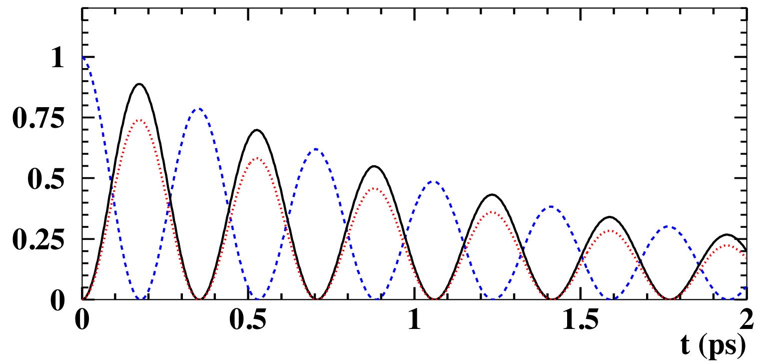
4. Dependence on the impact parameter

Additional measurements are made applying an impact parameter (*IP*) cut on each muon.

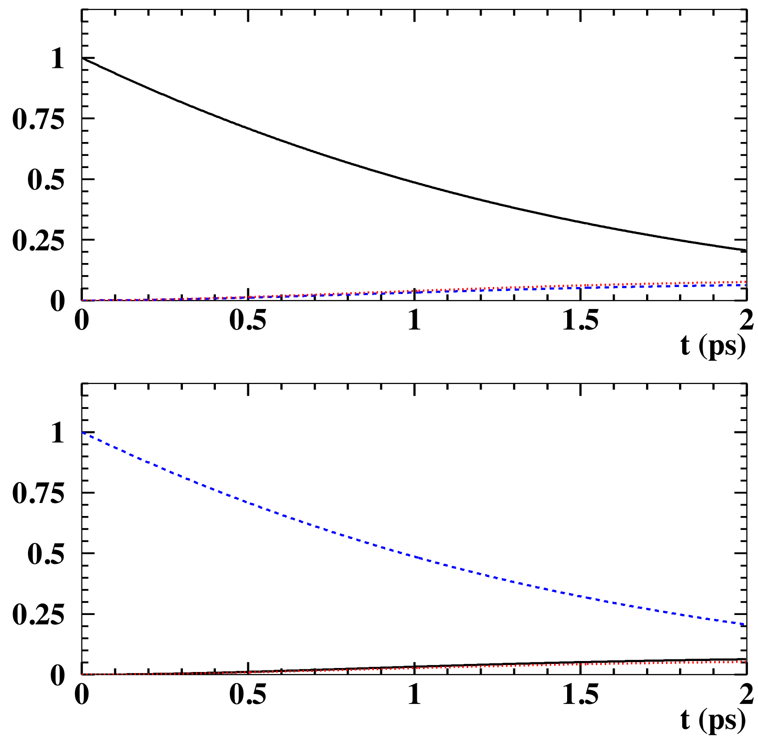
IP is the distance of closest approach of the muon track to the primary vertex projected onto the plane transverse to the $p\bar{p}$ beams.

The dependence of $A^b_{\mathrm{sl}} = C_d a^d_{\mathrm{sl}} + C_s a^s_{\mathrm{sl}}$ on *IP* can reveal the origin of the asymmetry because C_d and C_s depend on *IP*.

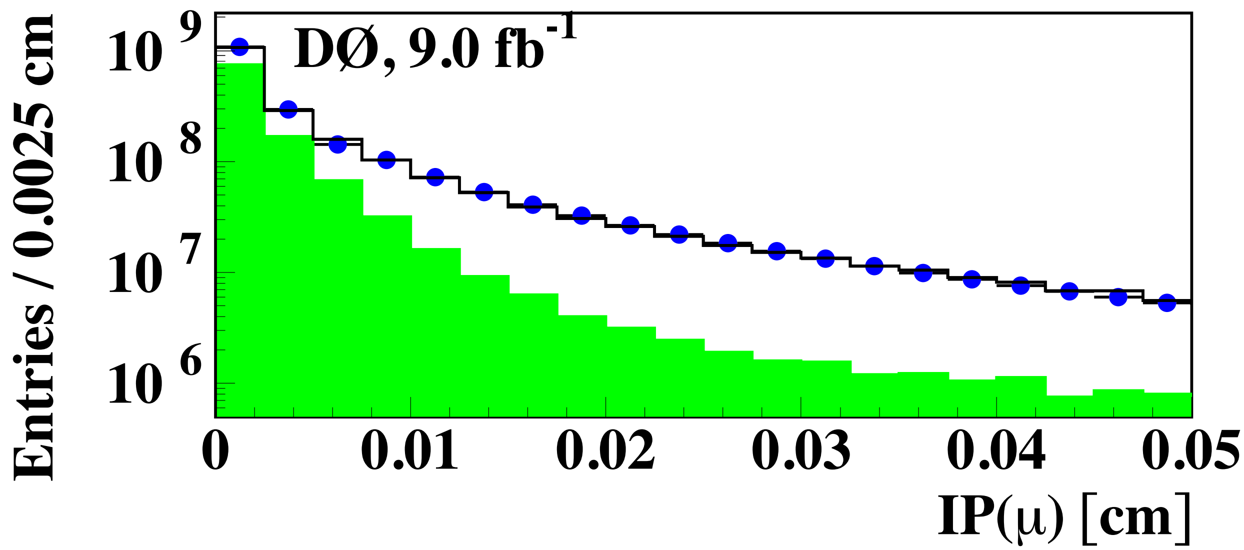




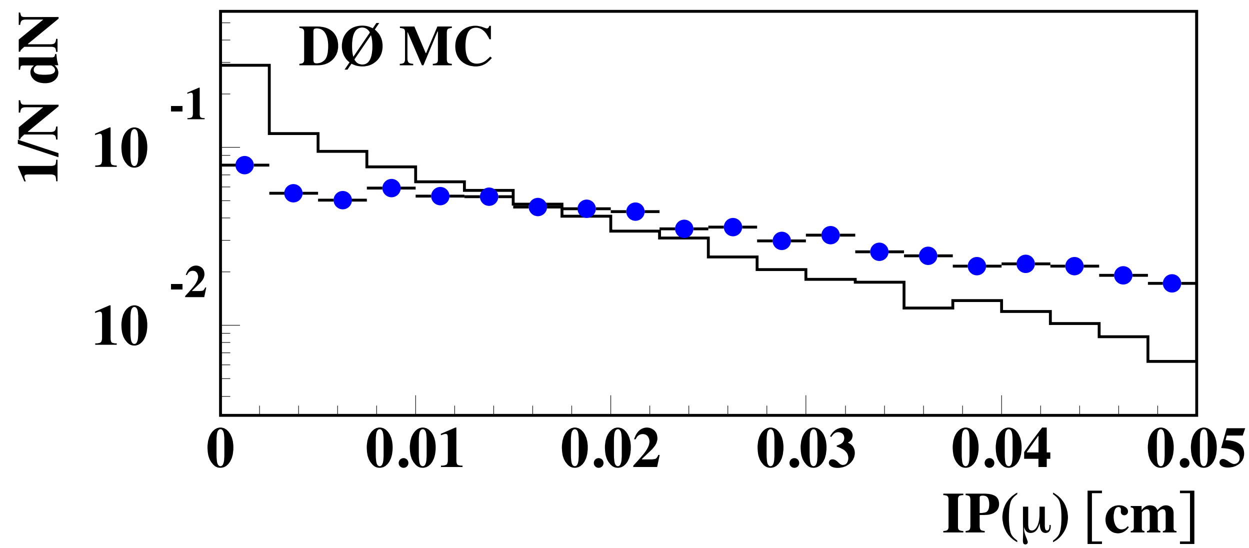
Top: Histogram of proper time of decays $B_s^0 \to \mu^+ X$ (continuous line), $B_s^0 \to \bar{B}_s^0 \to \mu^- X$ (dashed line if no CP violation, dotted red line if CP violation).
Bottom: The same for $\bar{B}_s^0$ at $t = 0$.



Same for B_d^0 (top) and $\bar{B}_d^0$ (bottom) at $t = 0$. Applying an IP cut can enrich the sample in oscillating B_d^0's (shown in red).



The muon impact parameter (*IP*) distribution in the inclusive muon sample (dots). The solid line represents the muon *IP* distribution in simulation. The shaded histogram is the contribution from K, π and p background muons in simulation.



The normalized impact parameter (*IP*) distribution for muons produced in oscillating decays of B_d^0 mesons (dots) and B_s^0 mesons (solid histogram) in simulation.

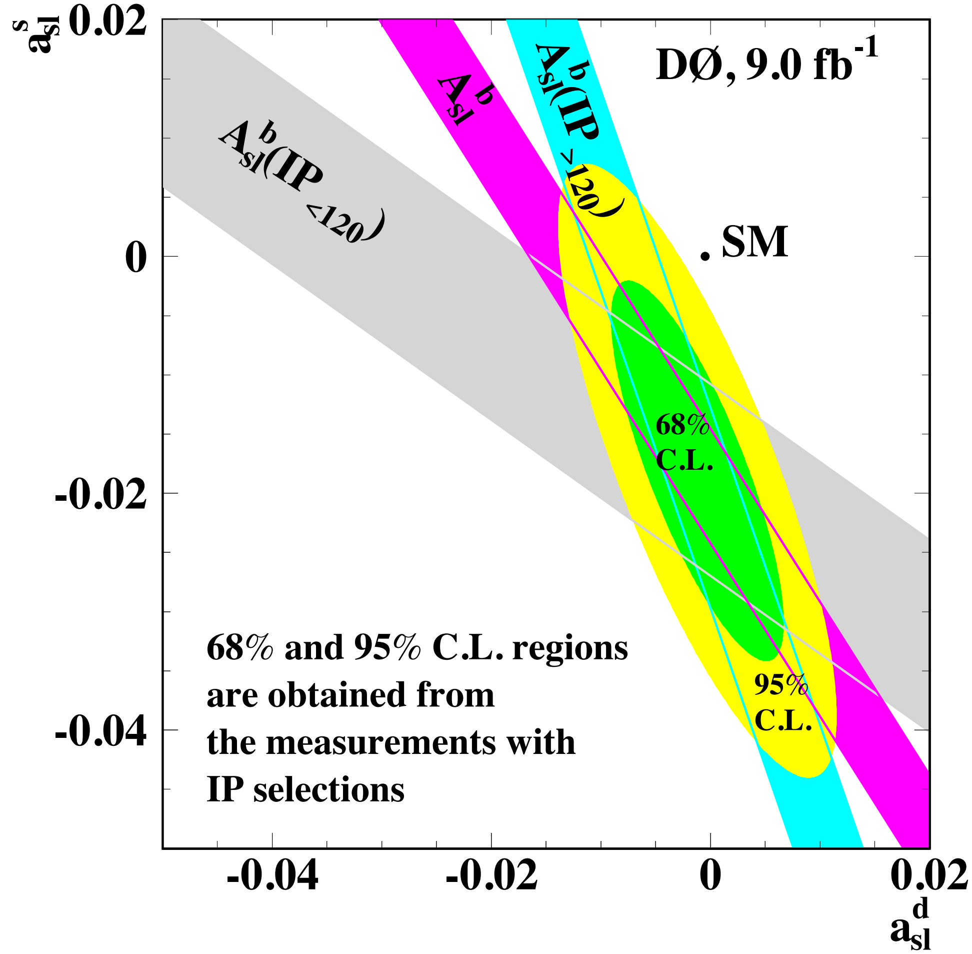
Input quantities for the measurement of $A_{\rm sl}^b$ using the muons with impact parameter (*IP*) above and below 120 μm. Only the statistical uncertainties are given.

Quantity	$IP_{>120}$	$IP_{<120}$
$f_K \times 10^2$	5.19 ± 0.37	17.64 ± 0.27
$f_\pi \times 10^2$	5.65 ± 0.40	34.72 ± 1.86
$f_p \times 10^2$	0.05 ± 0.03	0.45 ± 0.20
$F_K \times 10^2$	4.48 ± 4.05	21.49 ± 0.62
$F_\pi \times 10^2$	4.43 ± 3.95	40.47 ± 2.26
$F_p \times 10^2$	0.03 ± 0.05	0.59 ± 0.23
$f_S \times 10^2$	89.11 ± 0.88	47.18 ± 2.03
$F_{\rm bkg} \times 10^2$	8.94 ± 8.26	62.56 ± 3.07
$F_{SS} \times 10^2$	91.79 ± 7.65	53.66 ± 2.68
$a \times 10^2$	-0.014 ± 0.005	$+0.835 \pm 0.002$
$a_{\rm bkg} \times 10^2$	$+0.027 \pm 0.023$	$+0.864 \pm 0.049$
$A \times 10^2$	-0.529 ± 0.120	$+0.555 \pm 0.060$
$A_{\rm bkg} \times 10^2$	-0.127 ± 0.093	$+0.829 \pm 0.077$

Mixing probability χ_d obtained in simulation and the coefficients C_d and C_s for different muon selections.

Selection	$\chi_d(MC)$	C_d	C_s
all	0.186 ± 0.002	0.594 ± 0.022	0.406 ± 0.022
$IP < 50\mu$m	0.059 ± 0.002	0.316 ± 0.021	0.684 ± 0.021
$IP < 80\mu$m	0.069 ± 0.002	0.351 ± 0.022	0.649 ± 0.022
$IP < 120\mu$m	0.084 ± 0.002	0.397 ± 0.022	0.603 ± 0.022
$IP > 50\mu$m	0.264 ± 0.004	0.674 ± 0.020	0.326 ± 0.020
$IP > 80\mu$m	0.299 ± 0.004	0.701 ± 0.019	0.299 ± 0.019
$IP > 120\mu$m	0.342 ± 0.004	0.728 ± 0.018	0.272 ± 0.018

Selection	Sample	A^b_{sl} $\times 10^2$	Uncertainty $\times 10^2$ statistical	systematic
All events	1μ	−1.042	1.304	2.314
	2μ	−0.808	0.202	0.222
	comb.	−0.787	0.172	0.093
$IP < 50\mu$m	1μ	−3.244	4.101	7.466
	2μ	−2.837	0.776	1.221
	comb.	−2.779	0.674	0.694
$IP > 50\mu$m	1μ	−0.171	0.343	0.311
	2μ	−0.593	0.257	0.074
	comb.	−0.533	0.239	0.100
$IP < 80\mu$m	1μ	−1.293	3.282	5.841
	2μ	−1.481	0.541	0.810
	comb.	−1.521	0.458	0.501
$IP > 80\mu$m	1μ	−0.388	0.280	0.179
	2μ	−0.529	0.285	0.048
	comb.	−0.742	0.226	0.091
$IP < 120\mu$m	1μ	−1.654	2.774	4.962
	2μ	−1.175	0.439	0.590
	comb.	−1.138	0.366	0.323
$IP > 120\mu$m	1μ	−0.422	0.240	0.121
	2μ	−0.818	0.342	0.067
	comb.	−0.579	0.210	0.094



Measurements of A^b_{sl} with *IP* $> 120\mu$m and *IP* $< 120\mu$m, and corresponding 68% and 95% confidence level regions in the $(a^d_{\text{sl}}, a^s_{\text{sl}})$ plane. Also shown is the measurement with no *IP* cut.

From $IP > 120\mu$m and $IP < 120\mu$m we measure

$$a_{\mathsf{sl}}^{d} = -0.0012 \pm 0.0051,$$

$$a_{\mathsf{sl}}^{s} = -0.0181 \pm 0.0104,$$

with correlation $\rho_{ds} = -0.782$.

5. Conclusions

- We have completed a new measurement of the like-sign dimuon charge asymmetry, with improvements in the data selection and analysis techniques, and a larger data set of 9.0 fb^{-1}.

- We obtain
  $A^b_{\text{sl}} = (-0.787 \pm 0.172\ (\text{stat}) \pm 0.093\ (\text{syst}))\ \%$.
  This measurement disagrees with the prediction of the standard model by 3.9 standard deviations.

- The dependence of A^b_{sl} on *IP* is consistent with the hypothesis of a new source of CP violation in the mixing of B^0_d and B^0_s mesons.

- This result is in agreement with previous measurements of A^b_{sl} at DØ (1), a^d_{sl} at B factories (2), a^s_{sl} at DØ (3), and with measurements of ϕ_s from $B^0_s \to J/\psi\phi$ decays at CDF (4) and DØ (5).

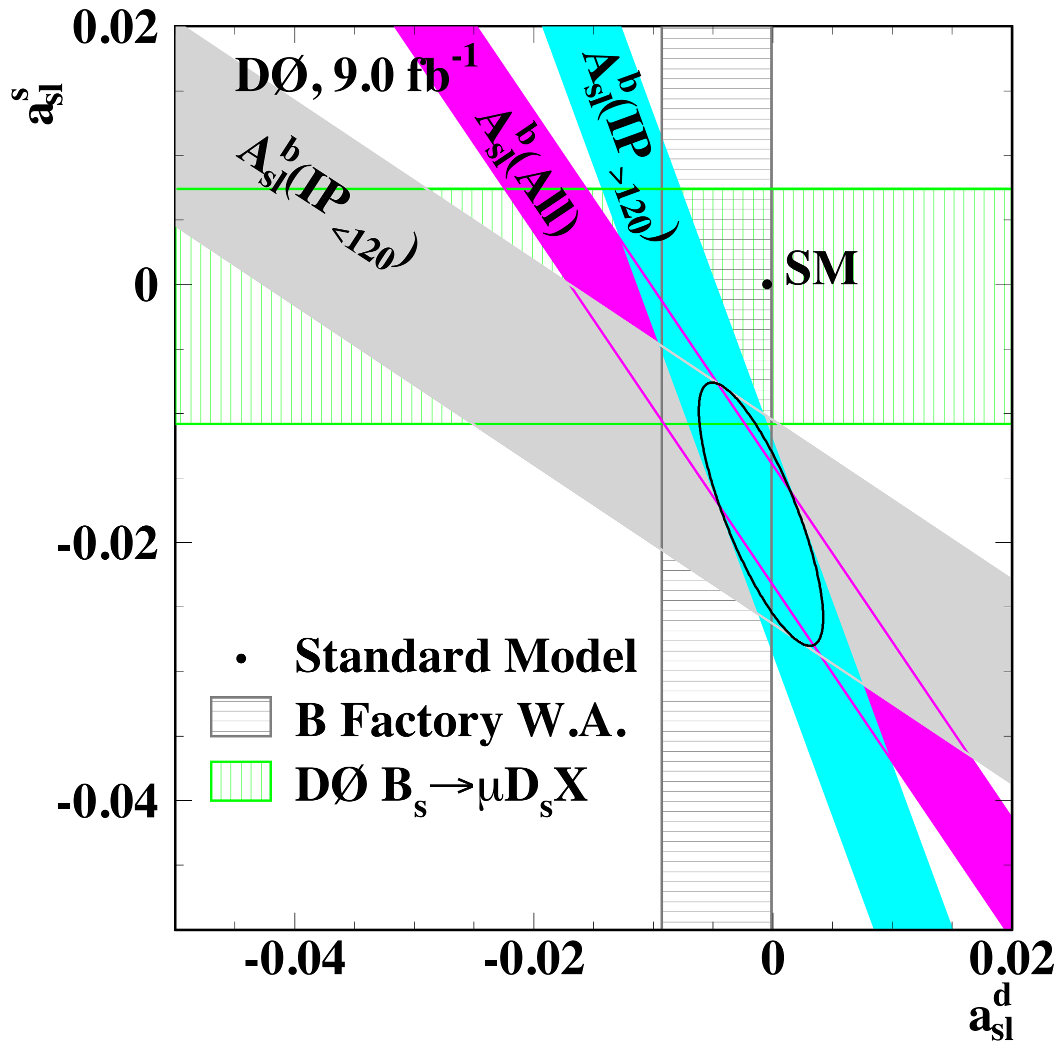
(1) Phys. Rev. D 74, 092001 (2006), Phys. Rev. D 82, 032001, (2010),

(2) E. Barberio *et al.* (HFAG), arXiv:0808.1297 [hep-ex] (2008),

(3) V.M. Abazov *et al.* (DØ Collaboration), Phys. Rev. D 82, 012003 (2010),

(4) T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. 100, 161802 (2008),

(5) V.M. Abazov *et al.* (DØ Collaboration), Phys. Rev. Lett. 101, 241801 (2008).



Ellipse for 1D 1σ ($\Delta\chi^2 = 1.0$) from $IP > 120\mu$m and $IP < 120\mu$m only.

Appendix: Theory

If CPT is a symmetry,

$$i\frac{d}{dt}\left(\begin{array}{c} B_s(t) \\ \bar{B}_s(t) \end{array}\right) = \left(\left[\begin{array}{cc} m & M_{12}^s \\ M_{12}^{s*} & m \end{array}\right] - \frac{i}{2}\left[\begin{array}{cc} \Gamma & \Gamma_{12}^s \\ \Gamma_{12}^{s*} & \Gamma \end{array}\right]\right)\left(\begin{array}{c} B_s(t) \\ \bar{B}_s(t) \end{array}\right).$$

The eigenvalues are

$$M_s + \frac{1}{2}\Delta M_s - \frac{i}{2}(\Gamma_s - \frac{1}{2}\Delta\Gamma_s),$$
$$M_s - \frac{1}{2}\Delta M_s - \frac{i}{2}(\Gamma_s + \frac{1}{2}\Delta\Gamma_s),$$

where $\Delta M_s > 0$ by definition.

The CP-violating phase is

$$\phi_s \equiv \arg\left(-\frac{M_{12}^s}{\Gamma_{12}^s}\right).$$

The observables are M_s, Γ_s, ϕ_s,

$$\Delta M_s = 2\left|M_{12}^s\right|, \qquad \Delta\Gamma_s = 2\left|\Gamma_{12}^s\right|\cos\phi_s,$$

$$a_{\mathrm{sl}}^s = \Im\frac{\Gamma_{12}^s}{M_{12}^s} = \frac{\left|\Gamma_{12}^s\right|}{\left|M_{12}^s\right|}\sin\phi_s = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s.$$

The semileptonic charge asymmetry is

$$a_{\mathsf{sl}}^{s} \equiv \frac{N(\bar{B}_s \to f) - N(B_s \to \bar{f})}{N(\bar{B}_s \to f) + N(B_s \to \bar{f})},$$

where f is a flavor specific final state to which only B_s can decay.

$$A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

$$A_{\mathsf{sl}}^{b} = \frac{f_d \chi_d a_{\mathsf{sl}}^{d} + f_s \chi_s a_{\mathsf{sl}}^{s}}{f_d \chi_d + f_s \chi_s} = (0.506 \pm 0.043) a_{\mathsf{sl}}^{d} + (0.494 \pm 0.043) a_{\mathsf{sl}}^{s}.$$

New Physics may change the Standard Model $M_{12}^{SM,s}$ to:

$$M_{12}^s \equiv M_{12}^{SM,s} \cdot \Delta_s = M_{12}^{SM,s} \cdot |\Delta_s| \, e^{i\phi_s^\Delta}.$$

$$\phi_s = \phi_s^{SM} + \phi_s^\Delta = 0.0042 \pm 0.0014 + \phi_s^\Delta,$$

$$\Delta M_s = \Delta M_s^{SM} \cdot |\Delta_s| = (19.30 \pm 6.74) \text{ ps}^{-1} \cdot |\Delta_s|$$

$$\Delta\Gamma_s = 2\,|\Gamma_{12}^s| \cos\phi_s = (0.096 \pm 0.039) \text{ ps}^{-1} \cdot \cos\phi_s,$$

$$\frac{\Delta\Gamma_s}{\Delta M_s} = \frac{|\Gamma_{12}^s|}{\left|M_{12}^{SM,s}\right|} \cdot \frac{\cos\phi_s}{|\Delta_s|} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\cos\phi_s}{|\Delta_s|},$$

$$a_{\text{sl}}^s = \frac{|\Gamma_{12}^s|}{\left|M_{12}^{SM,s}\right|} \cdot \frac{\sin\phi_s}{|\Delta_s|} = (4.97 \pm 0.94) \cdot 10^{-3} \cdot \frac{\sin\phi_s}{|\Delta_s|}.$$

From Alexander Lenz and Ulrich Nierste, hep-ph/0612167, November 2007.

The ϕ_s obtained from fits to $B_s \to J/\psi\phi$ is slightly different:

$$\phi_s = -2\beta_s^{SM} + \phi_s^{\Delta},$$

where

$$\beta_s^{SM} \equiv \arg \frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} = 0.019 \pm 0.001.$$