Status report on the like-sign dimuon charge asymmetry in $p\bar{p}$ collisions

and

Measurement of the direct CP asymmetry in $B^{\pm} \to J/\psi K^{\pm}$ and $B^{\pm} \to J/\psi \pi^{\pm}$ decays

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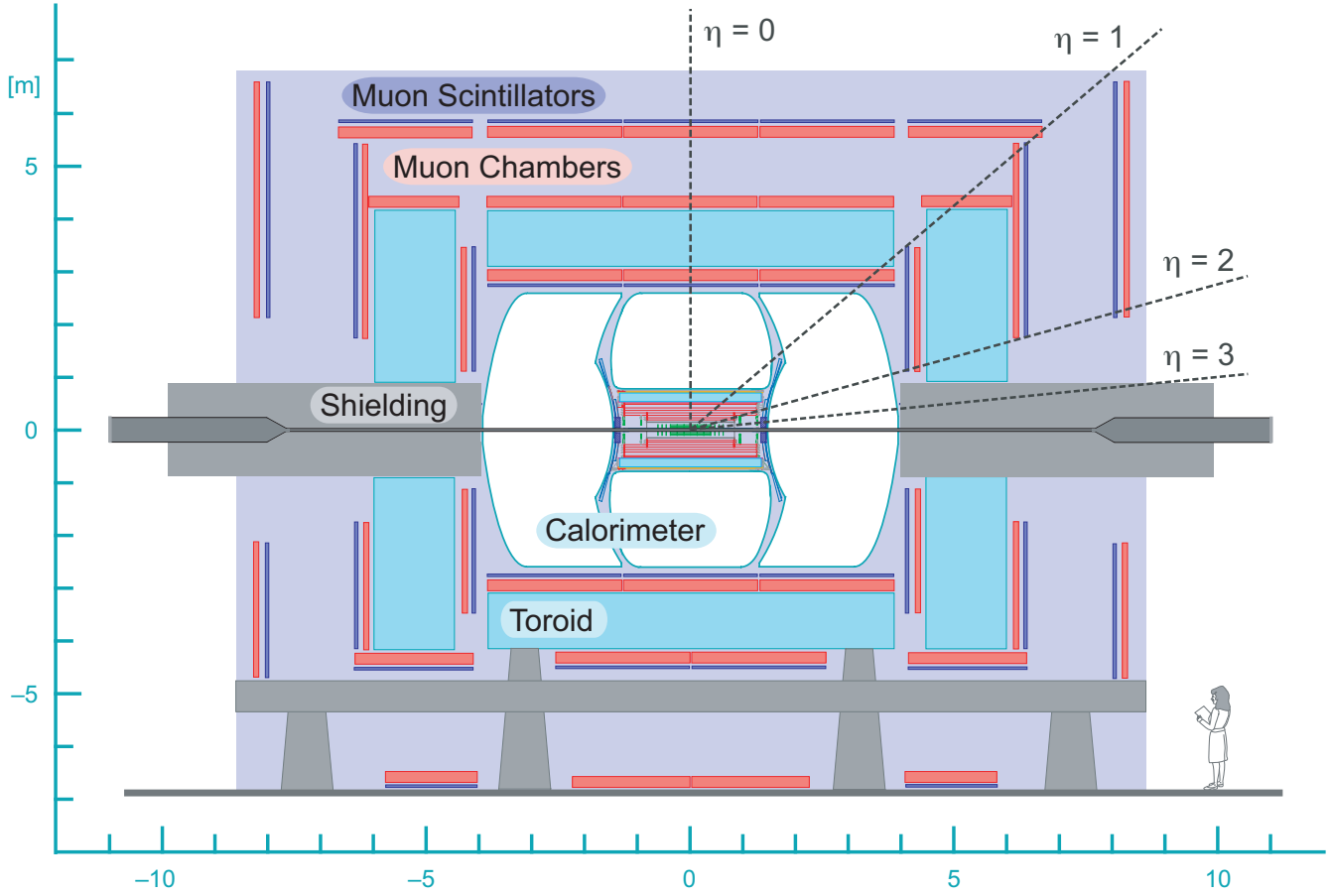
Representing the DØ Collaboration
Flavor Physics and CP violation (2013)



The DØ detector.

Status report on the like-sign dimuon charge asymmetry in $p\bar{p}$ collisions

1. Motivation: (in 1992!)
CP violation in mixing of B^0 and B_s^0

Example:

$$p\bar{p} \to b\bar{b}X \to B^- B^0 X \to B^- \bar{B}^0 X \to \mu^-\mu^- X,$$
$$p\bar{p} \to \bar{b}bX \to B^+ \bar{B}^0 X \to B^+ B^0 X \to \mu^+\mu^+ X.$$

$$A \equiv \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)};\ \ a \equiv \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)}$$

$$A_{CP} \equiv A - A_{\text{bkg}};\ \ a_{CP} = a - a_{\text{bkg}}.$$

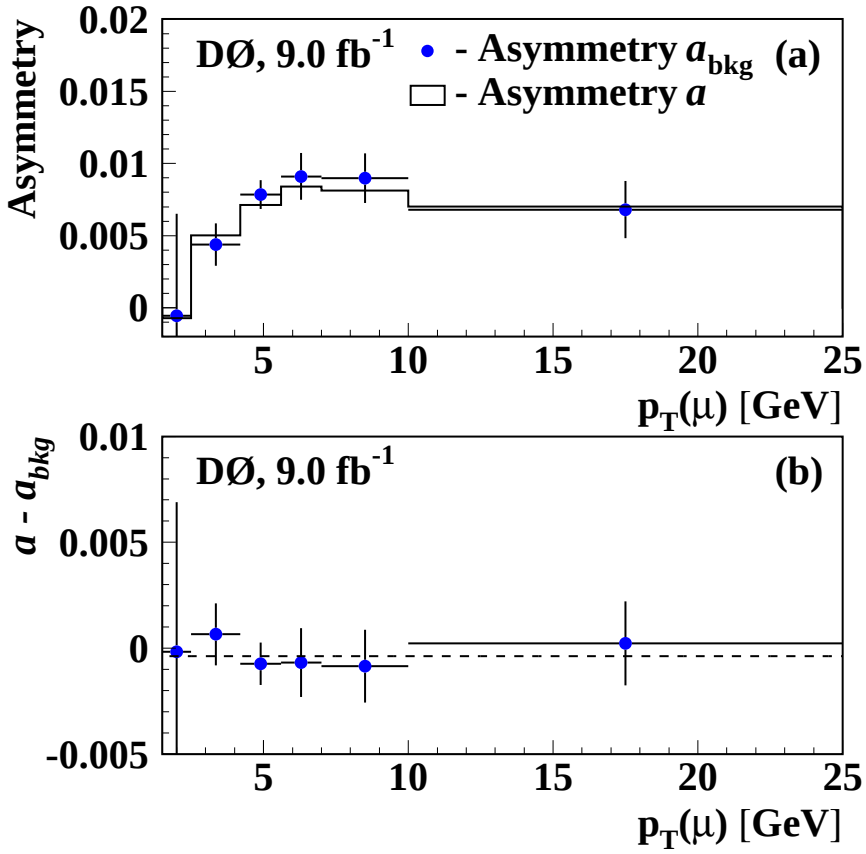
Model independent asymmetries: A_{CP} and a_{CP} are normalized to all muons, while the normalizations of A_S and a_S exclude muons from kaon and pion decay.

2. History

Residual asymmetry $A_{CP} = A - A_{\text{bkg}}$ measured with different integrated luminosities $\int Ldt$.

$\int Ldt$	asymmetry A_{CP}	*	(DO), Phys.Rev. D
1.0 fb^{-1}	$(-0.280 \pm 0.130 \pm 0.090)\%$	1.7σ	**74**, 092001 (2006)
6.1 fb^{-1}	$(-0.252 \pm 0.088 \pm 0.092)\%$	3.2σ	**82**, 032001 (2010)
9.0 fb^{-1}	$(-0.276 \pm 0.067 \pm 0.063)\%$	3.9σ	**84**, 052007 (2011)
10.5 fb^{-1}	?	$?\sigma$	(2013)

* Discrepancy with A_{CP}^{mix}(SM) only



The closure test with inclusive muons.

3. CPV in interference of B^0

Example:
$p\bar{p} \to b\bar{b}X \to B^- B^0 X \to B^- D^+ D^- X$; $B^- \to \mu^- X$; $D^- \to \mu^- X$,
$p\bar{p} \to \bar{b}bX \to B^+ \bar{B}^0 X \to B^+ D^+ D^- X$; $B^+ \to \mu^+ X$; $D^+ \to \mu^+ X$.

$D^+ D^-$ is CP-even.

$$\frac{d\Gamma(\bar{B}^0 \to D^+ D^-)}{dt} \propto \exp(-\Gamma_d t)\,[1 + S \sin(\Delta m_d t)]\,,$$
$$\frac{d\Gamma(B^0 \to D^+ D^-)}{dt} \propto \exp(-\Gamma_d t)\,[1 - S \sin(\Delta m_d t)]\,.$$

For this decay $\bar{B}^0(B^0) \to D^+D^-$:

$$A_S^{\text{int}} = S\frac{x_d}{1+x_d^2}.$$

This asymmetry is numerically LARGE because
$S = -\sin(2\beta) = 0.679 \pm 0.020$ and $x_d \equiv \Delta m_d/\Gamma_d = 0.770 \pm 0.008$.

CPV in interference does not contribute to a_{CP}.

Comparison between experiment (2011) and the standard model for B^0 and B_s^0:

$$\begin{aligned} a_S &= (-0.063 \pm 0.079 \pm 0.141)\%, \\ a_S^{\text{mix}}(\text{SM}) &= (-0.006 \pm 0.015)\%, \\ a_S^{\text{int}}(\text{SM}) &= (-0.000 \pm 0.000)\%. \\ A_S &= (-0.383 \pm 0.092 \pm 0.102)\%, \\ A_S^{\text{mix}}(\text{SM}) &= (-0.011 \pm 0.002)\%, \\ A_S^{\text{int}}(\text{SM}) &= (-0.045 \pm 0.016)\%. \end{aligned}$$

What is the cause of this discrepancy?

Recent experiments:

(after (Heavy Flavor Averaging Group), arXiv:1207.1158 (2012))

$a^d_{\rm sl} = +0.0068 \pm 0.0047$ V.M. Abazov *et al.* (DØ Collaboration), Phys. Rev. D **86**, 072009 (2012).

$a^s_{\rm sl} = -0.0104 \pm 0.0074$ V.M. Abazov *et al.* (DØ Collaboration), Phys. Rev. Lett. **110**, 011801 (2013).

$a^s_{\rm sl} = -0.0024 \pm 0.0063$ LHCb Collaboration, Conference report LHCb-CONF-2012-022 (2012)

$a^d_{\rm sl} = 0.0006 \pm 0.0017 \pm 0.0034$ BaBar at Beauty conference (2013), not included in next slide

4. Experimental constraints

Contributions to A_S allowed by experiments:
(compare with $A_S = (-0.383 \pm 0.092 \pm 0.102)\%$)

Process	Allowed A_S
Mixing of B^0	$(+0.062 \pm 0.073)\%$
Mixing of B_s^0	$(-0.111 \pm 0.093)\%$ *
Interference of B^0	$(-0.045 \pm 0.016)\%$ (SM)
Interference of B_s^0	$(-0.0009 \pm 0.0003)\%$ (SM)
CPV in $b \to c\bar{c}q$ decays	$(+0.000 \pm 0.001)\%$
$a_{(b)}$ in $b \to \mu X$ decays	$(-0.17 \pm 0.43)\%$
$a_{(c)}$ in $c \to \mu X$ decays	$(-0.07 \pm 0.19)\%$

G. Borissov and B. Hoeneisen, Phys. Rev. D **87**, 074020 (2013)
*From $B_s^0 \to J/\psi\phi$, assuming that new physics CPV is not cancelled by penguin contributions, $a_{\mathrm{sl}}^s = (-0.01 \pm 0.05)\%$, and this entry becomes negligible.

5. Interpretation

$$
\begin{aligned}
A_S &= A_S^{\text{int}} + A_S^{\text{mix}} + ?, \\
A_S^{\text{int}} &= A_S^{\text{int}}(\text{SM}) \frac{\Delta\Gamma_d}{\Gamma_d}, \\
A_S^{\text{mix}} &= C_b A_{\text{sl}}^b, \\
A_{\text{sl}}^b &= C_d a_{\text{sl}}^d + C_s a_{\text{sl}}^s, \\
a_{\text{sl}}^q &= \frac{\Delta\Gamma_q}{\Delta m_q} \tan(\phi_q^{12}),
\end{aligned}
$$

The measurements as a function of impact parameter constrain a_{sl}^d, a_{sl}^s and $\Delta\Gamma_d$ (and ?).

6. Questions (instead of Conclusions!)

- $\Delta\Gamma_d/\Gamma_d$(SM) is estimated to be $(0.42 \pm 0.08)\%$. Is it possible that $\Delta\Gamma_d/\Gamma_d \approx 1\%$ or 2% due to low energy, non-perturbative contributions?

- Is it possible that we are still missing other significant standard model contributions to A_{CP}?

- Are we seeing hints of new physics? Confirmation by other experiments are necessary.

Measurement of the direct CP asymmetry in $B^{\pm} \to J/\psi K^{\pm}$ and $B^{\pm} \to J/\psi \pi^{\pm}$ decays.

- Data: 10.4fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

- Decay: $p\bar{p} \to b\bar{b}X \to B^+X \to J/\psi K^+X$; $J/\psi \to \mu^+\mu^-$.

- $B^+ \to J/\psi K^+$ has tree and penguin diagrams with the same weak phase. Hence $|A^{J/\psi K}| < 0.3\%$ in the standard model. Good to search for new physics CP violation.

- The hadron is assigned the kaon mass.

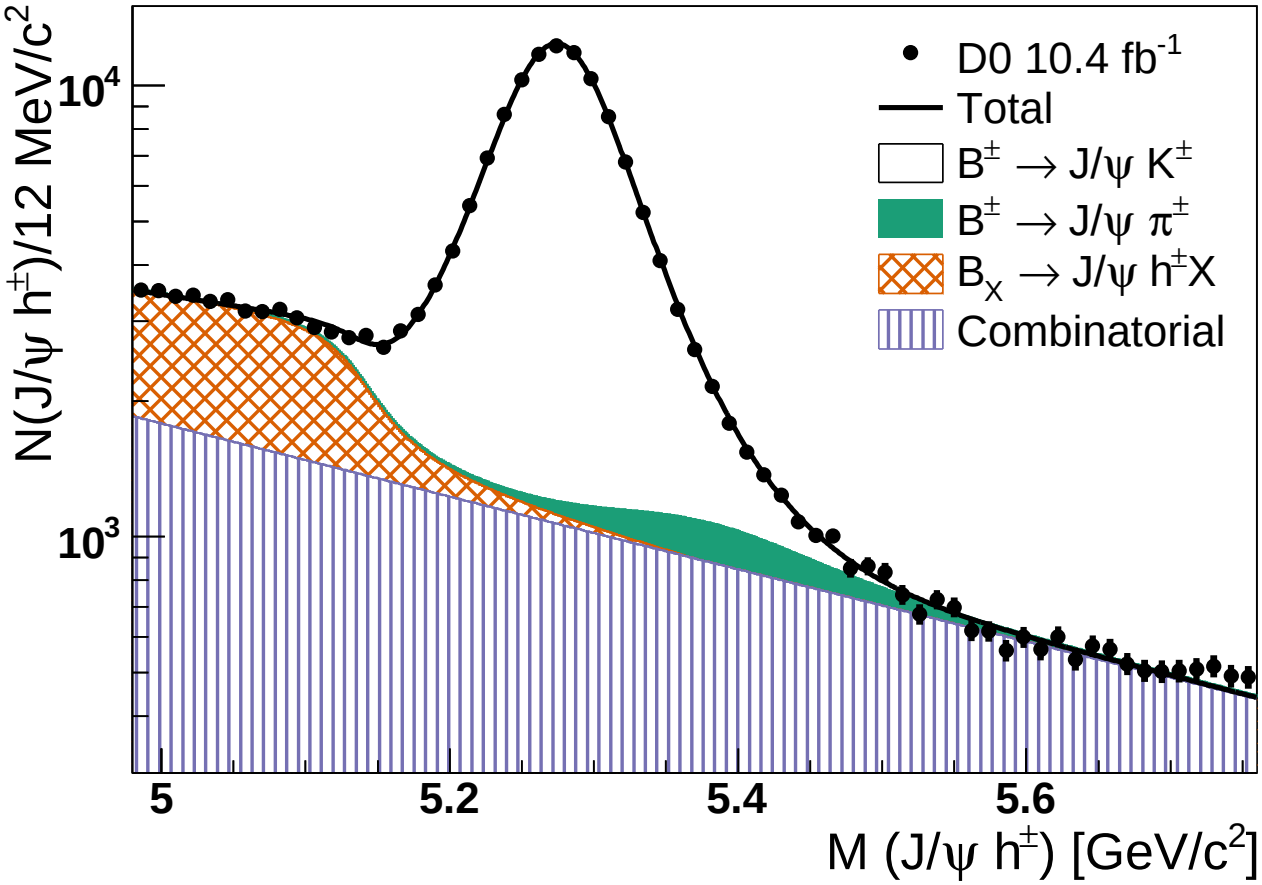
- Signal selection: Cut based + multivariate (likelihood ratio method).

- Unbinned maximum likelihood fit with $\mathcal{L} = (1 - q_h A_{\text{raw}}^{J/\psi K}) G_K(m) + (1 - q_h A_{\text{raw}}^{J/\psi \pi}) G_\pi(m) + (1 - q_h A_T) T(m) + (1 - q_h A_E) E(m)$.

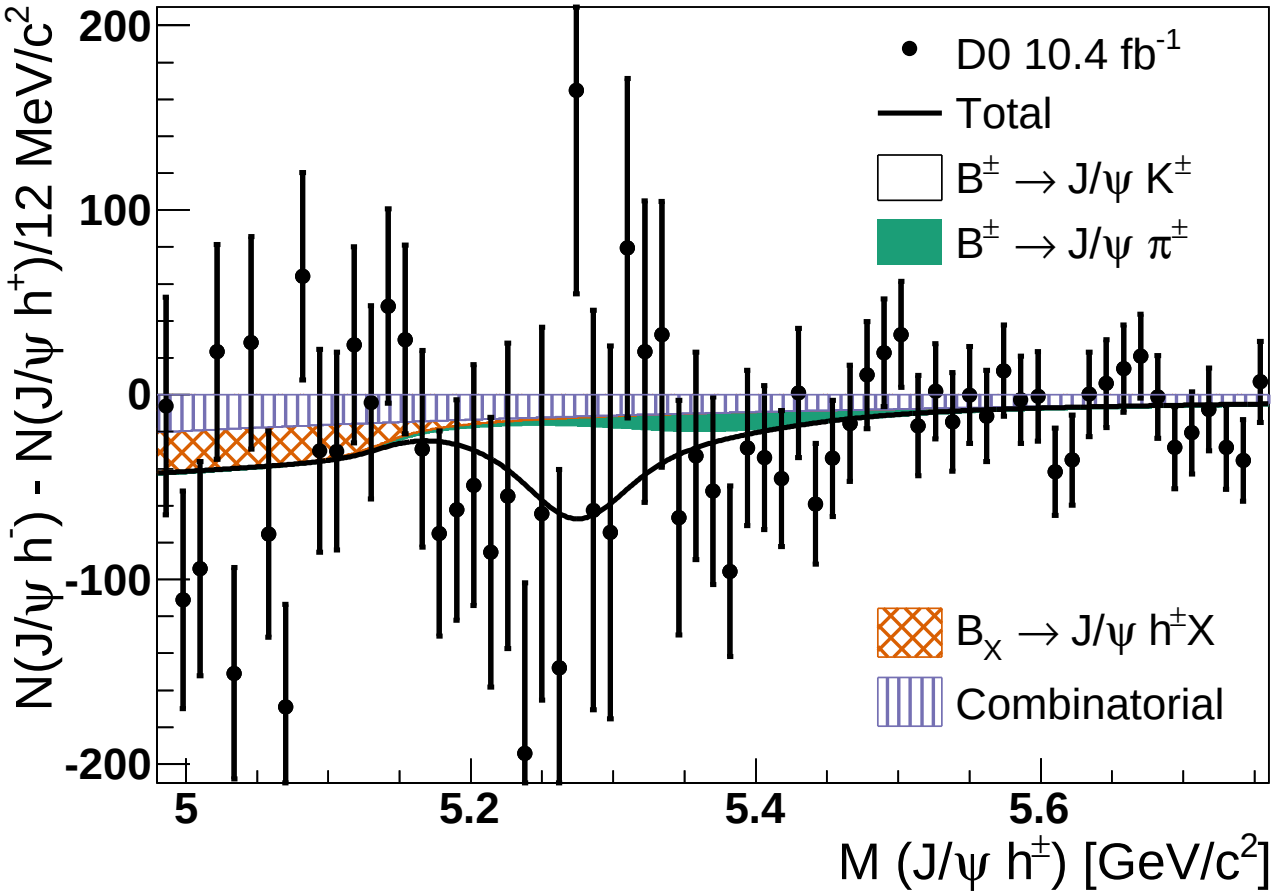
- $G_K(m)$: double gaussians with widths and normalizations free, and widths linearly dependent on kaon energy.
  $G_\pi(m)$ is an image of $G_K(m)$ shifted by $m_\pi \to m_K$.
  $T(m)$: threshold function for partially reconstructed $B_X \to J/\psi h^+ X$.
  $E(m)$: exponential function for combinatorial background.

- $A_{\text{raw}}^{J/\psi K} = [-0.46 \pm 0.36 \text{ (stat)} \pm 0.046 \text{ (syst)}]\%$,

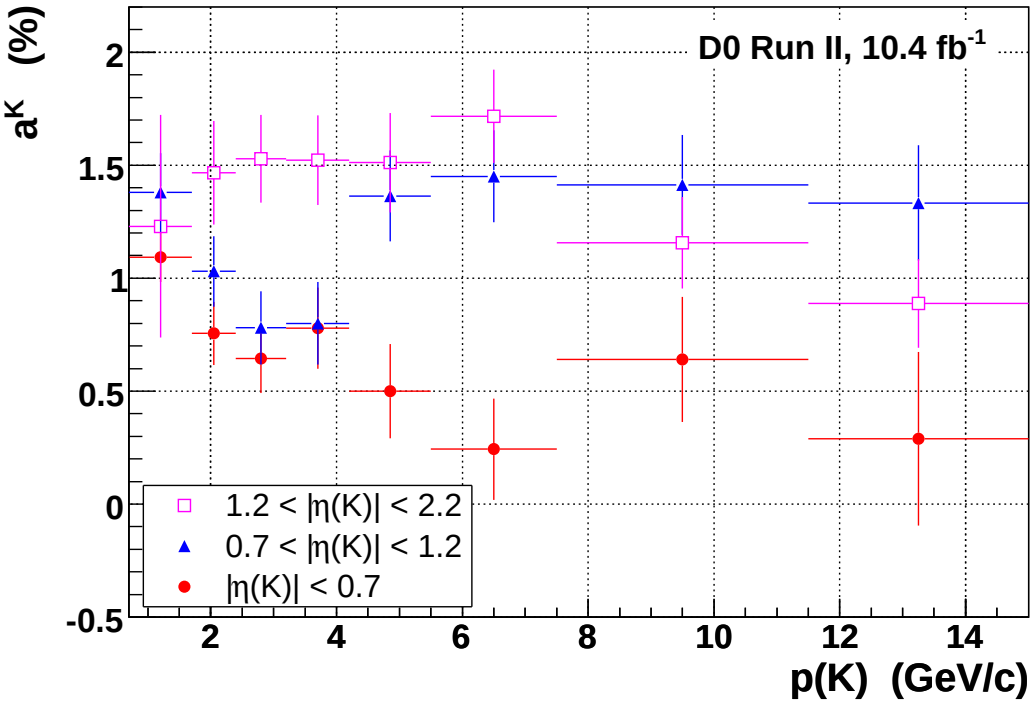
  $A_{\text{raw}}^{J/\psi \pi} = [-4.2 \pm 4.4 \text{ (stat)} \pm 1.82 \text{ (syst)}]\%$.



Projection of fit onto the sum distribution. $\chi^2/DOF = 76/47$.



Projection of fit onto the difference distribution. $\chi^2/DOF = 59/61$.



Kaon correction, $A_K = [+1.046 \pm 0.043$ (stat)], is measured with data reconstructing $K^{*0} \to K^+\pi^-$ decays (with same track requirements).

Conclusions

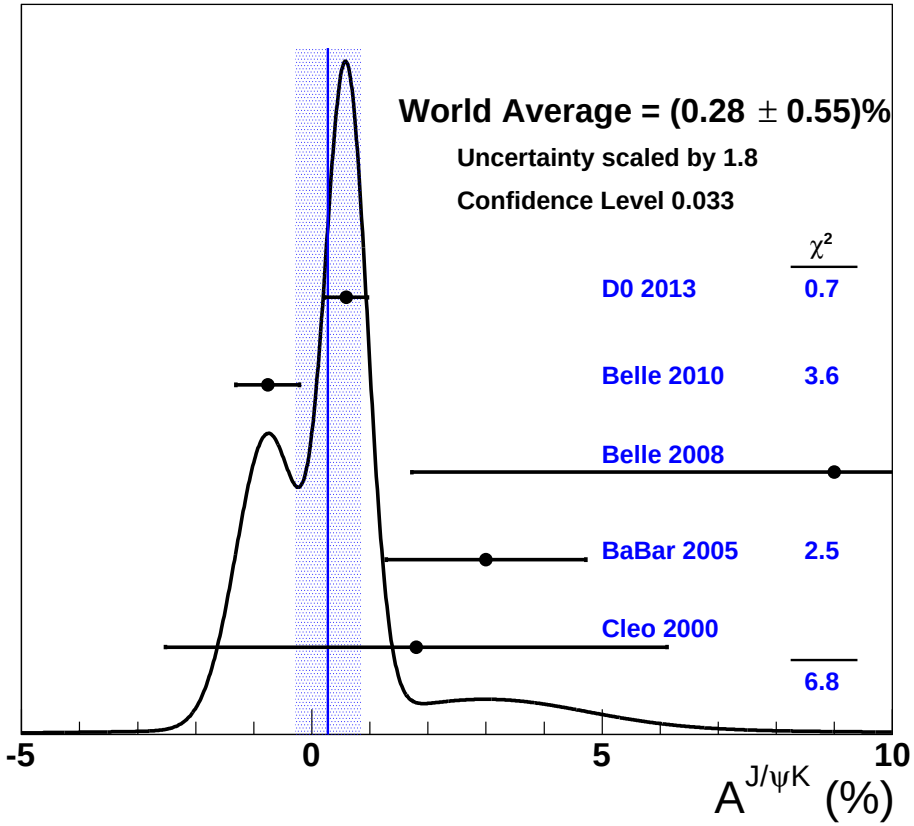
- Final results:

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

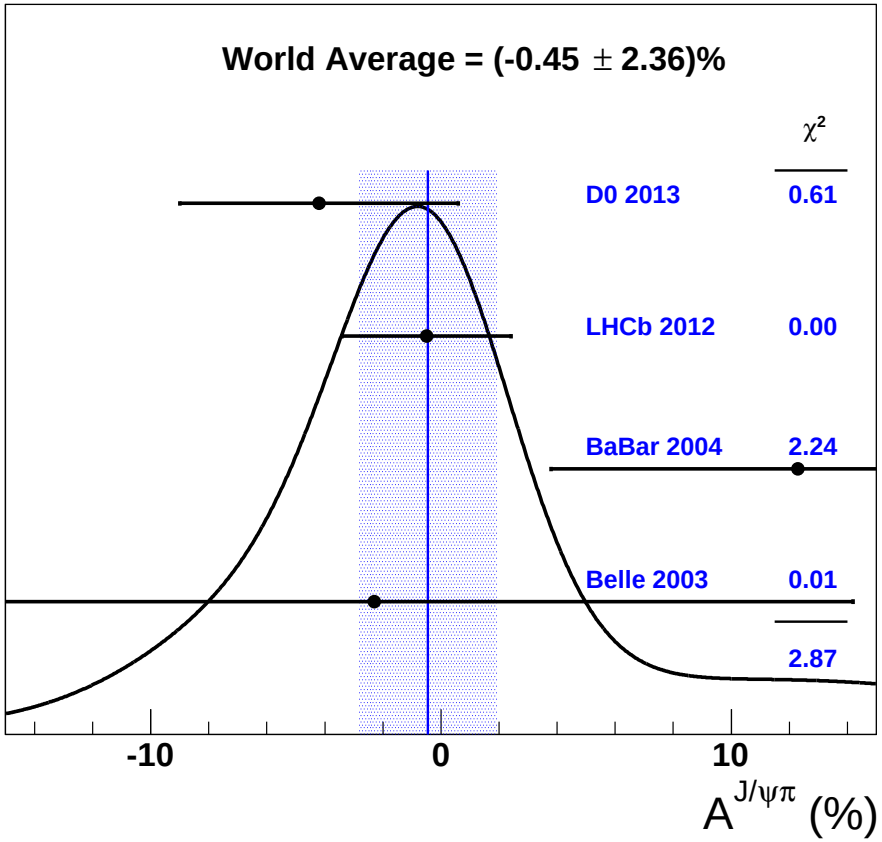
$$A^{J/\psi \pi} = [-4.2 \pm 4.4 \text{ (stat)} \pm 1.8 \text{ (syst)}]\%.$$

- There is agreement with the standard model

arXiv:1304.1655; Submitted to Phys. Rev. Lett.



World average of $A^{J/\psi K}$ using the PDG procedure.



World average of $A^{J/\psi\pi}$ using the PDG procedure.