Time Dependent Measurements with BABAR at PEP II

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for the BABAR Collaboration

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The BABAR Collaboration

9 Countries
72 Institutions
554 Physicists

Canada [4/16]
U of British Columbia
McGill U
U de Montréal
U of Victoria

China [1/6]
Inst. of High Energy Physics, Beijing

France [5/50]
LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris 6/7
Ecole Polytechnique
CEA, DAPNIA, CE–Saclay

Germany [3/21]
U Rostock
Ruhr U Bochum
Technische U Dresden

USA [35/276]
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UC, Los Angeles
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INFN and U Torino
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U of Edinburgh
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway, University of London
U of Manchester
Rutherford Appleton Laboratory

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CP violation arises in Standard Model through a single phase in the CKM matrix

\[ V = \begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix} = \begin{pmatrix}
    1 - \frac{1}{2} \lambda^2 & \lambda & A\lambda^3 (\rho - i\eta) \\
    -\lambda & 1 - \frac{1}{2} \lambda^2 & A\lambda^2 \\
    A\lambda^3 (1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix} + O(\lambda^4) \]

Unitarity of \( V \) requires e.g. \( V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \)

Can be represented as “unitarity” triangle in the complex plane

\( \mathbf{CP} \) violating asymmetries \( A(\Delta t) \) in \( B^0 \) decays measure \( \alpha, \beta, \gamma \)
**CP Violation**

**CP violation from interference between decays with and without mixing**

\[
\lambda_{f_{CP}} = \frac{q}{p} \frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}} = \eta_{f_{CP}} |\lambda_{f_{CP}}| e^{-2i\phi_{CP}}
\]

\[
\lambda_{f_{CP}} \neq \pm 1 \implies \text{Prob}(\bar{B}^0_{\text{phys}}(t) \rightarrow f_{CP}) \neq \text{Prob}(B^0_{\text{phys}}(t) \rightarrow f_{CP})
\]

**Time–dependent CP Observable:**

\[
A_{f_{CP}}(t) = \frac{\Gamma(\bar{B}^0_{\text{phys}}(t) \rightarrow f_{CP}) - \Gamma(B^0_{\text{phys}}(t) \rightarrow f_{CP})}{\Gamma(\bar{B}^0_{\text{phys}}(t) \rightarrow f_{CP}) + \Gamma(B^0_{\text{phys}}(t) \rightarrow f_{CP})} = C_{f_{CP}} \cdot \cos(\Delta m_{B_d} t) + S_{f_{CP}} \cdot \sin(\Delta m_{B_d} t)
\]

\[
C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}, \quad S_{f_{CP}} = \frac{-2 \text{Im}\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}
\]

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Experimental Technique

\[ \Delta t \approx \Delta z / \langle \beta \gamma \rangle c \]

\[ B^0_{\text{rec}} = B^0_{\text{flav}} \quad \text{(flavor eigenstates)} \rightarrow \text{lifetime, mixing analyses} \]

\[ B^0_{\text{rec}} = B^0_{\text{CP}} \quad \text{(CP eigenstates)} \rightarrow \text{CP analysis} \]
Asymmetric machine: 9 GeV $e^-$ on 3.1 GeV $e^+$

Center of mass energy: $M_{Y(4S)} = 10.58$ GeV

Boost of $Y(4S)$ in lab frame: $\beta \gamma = 0.56$
PEP II RECORDS:
Luminosity $4.3 \times 10^{33}$ cm$^{-2}$ s$^{-1}$
8 hours integrated $102$ pb$^{-1}$
24 hours $278$ pb$^{-1}$

**BABAR**
logging efficiency $> 95%$

Summer conferences dataset: 32M BB pairs
The BABAR Detector

1.5T solenoid

DIRC (PID)
144 quartz bars
11000 PMs

EMC
6580 CsI(Tl) crystals

Drift Chamber
40 stereo layers

Silicon Vertex Tracker
5 layers, double sided strips

e⁺ (3.1 GeV)

e⁻ (9 GeV)

Instrumented Flux Return
iron / RPCs (muon / neutral hadrons)

SVT:
97% efficiency, 15 μm z hit resolution (inner layers, perp. tracks)

SVT+DCH:
σ(\(\rho_T\))/\(\rho_T\) = 0.13 % × \(\rho_T\) + 0.45 %, σ(\(z_0\)) = 65 @ 1 GeV/c

DIRC:
K−π separation 4.2 σ @ 3.0 GeV/c 2.5 σ @ 4.0 GeV/c

EMC:
σ\(E/E\) = 2.3 %×\(E^{−1/4}\) + 1.9 %

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**Analysis Strategy**

*CP* time-dependent asymmetries:
Reconstruct the *B* decay to *CP* eigenstates and tag the flavor of the other *B*

Select *B*<sub>tag</sub> events by using mainly leptons and kaons from hadronic decays

Select *B*<sub>rec</sub> events

Measure the mistag fractions *w* and determine dilutions *D*=1−2*w*

Measure Δ*z* between *B*<sub>tag</sub> and *B*<sub>rec</sub> to determine the signed time difference Δ*t* between the decays

Determine the Δ*z* resolution function

**LIFETIMES**
All particle detected

Total E, p in Y(4S) frame: $E^*_B$, $p^*_B$

Kinematic variables for signal and background estimates:

\[ \Delta E = E^*_B - \sqrt{s}/2 \]
\[ \sigma \sim 7-40 \text{ MeV} \]

\[ m_{ES} = \sqrt{(s/4 - p^*_B^2)} \]
\[ \sigma \sim 3 \text{ MeV} \]
Flavor Eigenstates

Reconstruction of flavor eigenstates for lifetimes and mixing

\[ B^0 \rightarrow D^{(*)-}\pi^+, \ D^{(*)-}\rho^+, \ D^{(*)-}a_1^+, J/\Psi K^0 \]

\[ B^- \rightarrow D^{(*)0}\pi^-, J/\Psi K^-, \Psi(2S) \]
**CP eigenstates** \( \eta_{CP} = -1 \) and \( J/\Psi \ K^* \)

\[
\begin{align*}
B^0 & \to J/\Psi \ K^0_S \ (\pi^+\pi^-) \\
B^0 & \to J/\Psi \ K^0_S (\pi^0\pi^0) \\
B^0 & \to J/\Psi (2S) \ K^0_S \\
B^0 & \to \chi_{c1} \ K^0_S \\
B^0 & \to J/\Psi \ K^{*0} \ (K^0_S \pi^0)
\end{align*}
\]

\( N = 728 \)

Purity 95%

\( J/\Psi \ K^* \) angular analysis to evaluate the effective \( CP \) due to the 2 components of the final state
Neutral clusters not consistent with $\gamma$, $\pi^0$ or noise are $K_L$ candidates.

B mass constraint is imposed.
### Tagging Algorithm

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>Charge of fastest electron (muon) with $p^* &gt; 1.0(1.1)$ GeV/c</td>
</tr>
<tr>
<td>Kaon</td>
<td>Total charge of identified kaons</td>
</tr>
<tr>
<td>NT1</td>
<td>Neural Network, $</td>
</tr>
<tr>
<td>NT2</td>
<td>Neural Network, $0.2 &lt;</td>
</tr>
</tbody>
</table>

**Neural network** exploits information carried by non-identified leptons and kaons, soft pions from $D^*$ decays.
**Tagging Algorithm**

**Kaon ID**  
uses SVT and DCH $dE/dx$ and DIRC Cherenkov angle

**Lepton ID**  
Typical Tight Electron selection (EMC based) :
92% efficiency above 500 MeV with 0.1% $\pi$ misID  
Typical Tight Muon selection (IFR based) :
75% efficiency above 1.5 GeV with 3% $\pi$ misID

### Tagging Performance

<table>
<thead>
<tr>
<th>Tagging category</th>
<th>Fraction of tagged events $\epsilon$ (%)</th>
<th>Wrong tag fraction $w$ (%)</th>
<th>$Q = \epsilon(1-2w)^2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton</td>
<td>10.9 ± 0.3</td>
<td><strong>8.9 ± 1.3</strong></td>
<td>7.4 ± 0.5</td>
</tr>
<tr>
<td>Kaon</td>
<td>35.8 ± 0.5</td>
<td>17.6 ± 1.0</td>
<td>15.0 ± 0.9</td>
</tr>
<tr>
<td>NT1</td>
<td>7.8 ± 0.3</td>
<td>22.0 ± 2.1</td>
<td>2.5 ± 0.4</td>
</tr>
<tr>
<td>NT2</td>
<td>13.8 ± 0.3</td>
<td>35.1 ± 1.9</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>ALL</td>
<td><strong>68.4 ± 0.7</strong></td>
<td><strong>35.1 ± 1.9</strong></td>
<td><strong>26.1 ± 1.2</strong></td>
</tr>
</tbody>
</table>
Exploit full power of the SVT and of the kinematic and vertexing constraints

\[ \sigma_z(B_{\text{rec}}) = 70 \, \mu m \text{ (core } \sigma_z(B_{\text{erec}}) = 45 \, \mu m, \text{ fraction 80\%)} \]

**Vertexing Algorithm**

- **B_{\text{rec}}** is fully reconstructed while **B_{\text{tag}}** is only partially reconstructed
- Reconstruct **B_{\text{rec}}** vertex from charged **B_{\text{rec}}** daughters

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Vertexing Algorithm

Determine $B_{\text{tag}}$ vertex from charged tracks not belonging to $B_{\text{rec}}$ vertex and momentum, beam spot and $Y(4S)$ momentum.

$\sigma_{\Delta z} = 190 \, \mu m$ (core $\sigma_{\Delta z} = 110 \, \mu m$, fraction 65%)

97% efficiency (including 1–prong tags)

$\Delta t$ resolution function measured from data ($B_{\text{flav}}$ sample)
event–by–event $\sigma(\Delta t)$ from vertex errors

Resolution function $R(\Delta t)$: 2 models:
- Sum of 3 Gaussians (mixing + CP analyses)
- Lifetime–like bias (lifetime analysis)

Simultaneous unbinned maximum likelihood fit to $B^0/B^+$ samples
19 free parameters:
- $\tau(B^+)$ and $\tau(B^0)$
- $\Delta t$ signal resolution
- Empirical background description

Background parameters determined from $m_{ES}$ sideband
Lifetimes Measurement

Precision measurement:
2% statistical error
1.5% systematic error

\[ \tau_0 = 1.546 \pm 0.032 \pm 0.022 \text{ ps} \]

\[ \tau_\pm = 1.673 \pm 0.032 \pm 0.022 \text{ ps} \]

\[ \tau_\pm / \tau_0 = 1.082 \pm 0.026 \pm 0.011 \]
Fitting Strategy

Same strategy for mixing and $\sin^2 \beta$ measurements:
perform a global fit to all the events that can carry information

- **Mixing**: tagged flavour eigenstates
- **$\sin^2 \beta$**: tagged flavour and $CP$ eigenstates

Extract as many parameters as possible from data

<table>
<thead>
<tr>
<th>Parameter</th>
<th># parameters</th>
<th>Sensitive events</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sin^2 \beta$</td>
<td>1</td>
<td>$CP$</td>
<td>Only in $CP$ fit</td>
</tr>
<tr>
<td>$\Delta m_d$</td>
<td>1</td>
<td>flavor</td>
<td>Only in mixing</td>
</tr>
<tr>
<td>$w$ &amp; $\Delta w$</td>
<td>8</td>
<td>flavor and $CP$</td>
<td></td>
</tr>
<tr>
<td>$\Delta t$ resolution</td>
<td>16</td>
<td>flavor and $CP$</td>
<td></td>
</tr>
<tr>
<td>Background $\tau$</td>
<td>6</td>
<td>sidebands</td>
<td></td>
</tr>
<tr>
<td>Background $w$</td>
<td>8</td>
<td>sidebands</td>
<td></td>
</tr>
<tr>
<td>Background $\Delta t$</td>
<td>6</td>
<td>sidebands</td>
<td></td>
</tr>
</tbody>
</table>

Largest correlation with $\sin^2 \beta$ $\approx 12\%$
Simultaneous likelihood fit to each tagging category; mixed and unmixed events with common resolution function

\[ \frac{1}{4} e^{-\Gamma |\Delta t|} \left[ 1 \pm (1-2w) \cos(\Delta m_d \Delta t) \right] \otimes R(\Delta t;a) \]

Allows extraction of mistag rates and resolution parameters

(preliminary)
\[ \Delta m_d = 0.519 \pm 0.020\,(\text{stat}) \pm 0.016\,(\text{syst}) \, \text{ps}^{-1} \]
CP Analysis: Time Distributions

**perfect**
flavor tagging &
time resolution

\[ -B^0 \text{ tag} \]
\[ \overline{B}^0 \text{ tag} \]

**realistic**
mis-tagging probability &
finite time resolution

\[ -B^0 \text{ tag} \]
\[ \overline{B}^0 \text{ tag} \]

\[
f_{CP,\pm}(\Delta t) = \left\{ \frac{e^{-|\Delta t|/\tau_{B_d}}}{2\tau_{B_d}} \times \left( 1 \mp \eta f (1 - 2w) \sin 2\beta \sin(\Delta m_{B_d} \Delta t) \right) \right\} \otimes R
\]

"\( f_{CP,+} \) \( \Leftrightarrow \) \( B^0_{\text{tag}} = B^0 \)

"\( f_{CP,-} \) \( \Leftrightarrow \) \( B^0_{\text{tag}} = \overline{B}^0 \)

Same mis-tagging probabilities \( w \) and
time-resolution function \( R(\Delta t) \) as from mixing
$\eta_{CP} = +1$  Time Distributions
$\sin^2 \beta = 0.59 \pm 0.14$

Null results in flavor samples

Consistency of CP channels $P(\chi^2) = 8\%$

Goodness-of-fit: $P(L_{\text{max}}>L_{\text{obs}})>27\%$
Corrected Asymmetries

\[ \sin 2\beta \text{ fitted in bins of } \Delta t \]

\[ \sin 2\beta \text{ fitted in bins of } \Delta t \text{ and multiplied by } \sin(\Delta m_d \Delta t) \]
Signal resolution and vertexing = 0.03
Resolution model, outliers, SVT residual misalignment

Tagging = 0.03
Studies of possible differences between $B_{CP}$ and $B_{\text{flavor}}$ samples

Backgrounds = 0.02 (overall)
Signal probability, peaking background, $CP$ content of background

Total = 0.05 for full sample

<table>
<thead>
<tr>
<th></th>
<th>$K_{S}$</th>
<th>$K_{L}$</th>
<th>$K^{*0}$</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sys</td>
<td>0.05</td>
<td>0.10</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Total Stat</td>
<td>0.15</td>
<td>0.34</td>
<td>1.01</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Interpretation of the Results

One solution for $\beta$ is consistent with measurements of sides of Unitarity Triangle

$|V_{ub}/V_{cb}|$, $|e_K|$, $\Delta m_d$, $\Delta m_s/\Delta m_d$, $\Delta m_d$, $|V_{us}/V_{cd}|$

Höcker et al, hep-ex/0104062
(but many other recent global CKM matrix analyses)
World Average

Assumes uncorrelated systematic errors
**$\sin^2 \beta$ projections**

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{Graph showing total luminosity (fb$^{-1}$) and $\sin^2 \beta$ error over years.}
\end{figure}

**$BaBar$ will collect $\sim 0.5 \text{ ab}^{-1}$ by 2005**

$BaBar$ will then measure $\sin^2 \beta$ at the $\sim 0.05$ level

Assuming similar improvements for Belle and CDF,

the world will know $\sin^2 \beta$ at the $\sim 0.03$ level by 2005
**CP violation in $B^0 \rightarrow \pi^+\pi^-$ decays**

### Decay distributions $f_+(f_-)$ when tag = $B^0(B^0)^-$

$$f_\pm(\Delta t) = \frac{e^{(-\Delta t/\tau)}}{4\tau} [1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t)]$$

### Tree diagram

```
          u
           |
        W  q_b\rightarrow b
           |
          d
```

### Penguin diagram

```
          u
           |
        W  q\rightarrow b
           |
          u
```

### For single weak phase

$$\lambda \equiv \frac{q}{p} \frac{A_\bar{f}}{A_f} = \eta_f e^{-2i(\beta+\gamma)} = \eta_f e^{2i\alpha}$$

$C_{\pi\pi} = 0, S_{\pi\pi} = \sin 2\alpha$

### For additional weak phase

$|\lambda| \neq 1 \Rightarrow$ must fit for direct CP

$\text{Im} (\lambda) \neq \sin 2\alpha \Rightarrow$ need to relate asymmetry to $\alpha$

$C_{\pi\pi} \neq 0, S_{\pi\pi} = \sin 2\alpha_{\text{eff}}$
**CP violation in \( B^0 \rightarrow \pi^+\pi^- \) decays**

**L= 30.4 fb\(^{-1}\)**

97% of candidates is background

**Signal Yields:**

- \( \pi^+\pi^- \): \( 65 \pm 12^{+11}_{-11} \)
- \( K^+\pi^- \): \( 217 \pm 18 \)
- \( K^+K^- \): \( 4.3 \pm 6.3^{+4.3}_{-4.3} \)
Extended ML fit to the BRs and \( CP \) done simultaneously:

- tagging, dilutions, \( R(\Delta t) \) like in \( \sin 2\beta \) analysis
- background from continuum + need to discriminate between \( \pi \) and \( K \):
  - discriminating variables (\( m_{ES}, \Delta E, Fisher, \theta_c^1, \theta_c^2, \Delta t \))

Results:

\[
S(\pi^+\pi^-) = 0.03^{+0.53}_{-0.56} \text{ (stat)} \pm 0.11 \text{ (syst)} \\
C(\pi^+\pi^-) = -0.25^{+0.45}_{-0.47} \text{ (stat)} \pm 0.14 \text{ (syst)}
\]
We have established $CP$ violation at $4\sigma$ level with $\sin 2\beta = 0.59 \pm 0.14 \pm 0.05$

Probability is $< 3 \times 10^{-5}$ to observe an equal or larger value if no $CP$ violation exists

Corresponding probability for the $\eta_{CP} = -1$ modes is $2 \times 10^{-4}$

Probability of $J/\Psi K_L$ and $J/\Psi K_S$ having the same $\eta_{CP}$ is $< 0.1\%$

We have measured with high precision the $B^0/\bar{B}^0$ and $B^\pm$ lifetimes

$\tau_0 = 1.546 \pm 0.032 \pm 0.022 \text{ ps}$ \hspace{0.5cm} $\tau_\pm = 1.673 \pm 0.032 \pm 0.022 \text{ ps}$ \hspace{0.5cm} and

$\tau_\pm /\tau_0 = 1.082 \pm 0.026 \pm 0.011$, and the $B^0 - \bar{B}^0$ oscillation frequency

$\Delta m_d = 0.519 \pm 0.020 \pm 0.016 \text{ ps}^{-1}$

We have presented the first asymmetry measurement using $B^0 \rightarrow \pi\pi$
Golden Channel: $B^0 \rightarrow J/\psi \ K^0_{S/L}$

Theoretically cleanest way to measure $\sin^2 \beta$

Quark Subprocess $b \rightarrow c\bar{c}s$

$\bar{B}^0 \rightarrow J/\psi \ K^0$
$B^0 \rightarrow J/\psi \ K^0$

$B^0_{CP=-1} \rightarrow J/\psi \ K^0_S$
$B^0_{CP=+1} \rightarrow J/\psi \ K^0_L$

Single weak phase = no direct CP Violation $|\lambda_{J/\psi K^0_{S,L}}|=1$

$$A_{J/\psi K^0_{S,L}}(t) = -\eta_{J/\psi K^0_{S,L}} \cdot \sin 2\beta \cdot \sin (\Delta m_{B_d} t)$$

Experimentally: clear signature relatively high branching fractions
Run 1 – Run 2 comparison

Run 1

- PRL modes
- J/ΨKL: 0.33±0.18
- J/ΨK*0: 0.71±0.42
- χcKs: 1.30±1.20
- Ψ(2S)Ks: 3.60±0.4
- Average: 0.46±0.18

Run 2

- PRL modes
- J/ΨKL: 0.83±0.23
- J/ΨK*0: 0.68±0.58
- χcKs: 0.20±1.60
- Ψ(2S)Ks: 1.14±1.25
- J/ΨKs2π0: 1.90±1.20
- Average: 0.82±0.22

Sin2β

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**Run 1 – Run 2 comparison**

<table>
<thead>
<tr>
<th>mode</th>
<th>sin2β run1</th>
<th>N_{ev} run1</th>
<th>sin2β run2</th>
<th>N_{ev} run2</th>
<th>R_{ev}</th>
<th>Δ_{12}</th>
<th>R_{exp}</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/ψ K_{s}⁰ (π⁺π⁻)</td>
<td>0.23 ± 0.24</td>
<td>305</td>
<td>0.72 ± 0.27</td>
<td>169</td>
<td>1.37</td>
<td>0.49 ± 0.36</td>
<td>1.19</td>
</tr>
<tr>
<td>J/ψ K_{s}⁰ (π⁰π⁰)</td>
<td>0.13 ± 0.65</td>
<td>82</td>
<td>1.62 ± 0.74</td>
<td>42</td>
<td>1.26</td>
<td>1.49 ± 0.98</td>
<td>1.23</td>
</tr>
<tr>
<td>ψ(2S)K_{s}⁰ (π⁺π⁻)</td>
<td>0.31 ± 0.49</td>
<td>64</td>
<td>1.16 ± 1.21</td>
<td>28</td>
<td>1.08</td>
<td>0.85 ± 1.31</td>
<td>0.61</td>
</tr>
<tr>
<td>χ_c1K_{s}⁰ (π⁺π⁻)</td>
<td>—</td>
<td>29</td>
<td>1.14 ± 1.25</td>
<td>17</td>
<td>1.44</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>J/ψ K^{*0} (K_{s}⁰π⁰)</td>
<td>1.26 ± 1.22</td>
<td>60</td>
<td>0.15 ± 1.62</td>
<td>23</td>
<td>0.94</td>
<td>-1.11 ± 2.0</td>
<td>1.20</td>
</tr>
<tr>
<td>J/ψ K_{L}⁰</td>
<td>0.71 ± 0.42</td>
<td>288</td>
<td>0.68 ± 0.58</td>
<td>142</td>
<td>1.21</td>
<td>-0.03 ± 0.72</td>
<td>1.03</td>
</tr>
<tr>
<td>J/ψ K_{s}⁰ + ψ(2S)K_{s}⁰</td>
<td>0.32 ± 0.18</td>
<td>739</td>
<td>0.83 ± 0.23</td>
<td>381</td>
<td>1.27</td>
<td>0.51 ± 0.29</td>
<td>1.09</td>
</tr>
<tr>
<td>all</td>
<td>0.45 ± 0.18</td>
<td>816</td>
<td>0.82 ± 0.22</td>
<td>433</td>
<td>1.31</td>
<td>0.37 ± 0.29</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Table 35: comparison between run1 and run2 results. Number of events are also compared. \( R_{ev} = \frac{N_{2L_1}}{N_{1L_2}} \) is the ratio of the number of events per \( fb^{-1} \), \( Δ_{12} \) is the difference between the two runs while \( R_{exp} = \frac{\sigma_1}{\sigma_2} \sqrt{\frac{N_1}{N_2}} \)

30% efficiency improvement for all K_{S} modes
15% improvement due to vertexing/alignment
Change in central value \( \sim 1.8\sigma \) in uncorrelated error