Simultaneous Measurement of $\tau(B^\prime)$ and $\Delta m_d$ using Partially Reconstructed $B^0 \rightarrow D^{*+}l^-\nu$ decays

- Analysis Strategy
- Sample Composition
- PDF Description
- Fit Method
- MC Results
- Analysis Bias
- DT Results
- Systematic Errors
- Conclusions

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BAD 287
CONF-04/15 (ICHEP)

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Analysis Strategy (1)

\[ \bar{B}^0 \rightarrow D^{*+} l^- \nu \]

\[ \rightarrow D^0 \pi_s^+ \]

Partial Reconstruction:

- \( D^* \) identified only from \( \pi_s \)
- \( B^0 \) ~ at rest in Y rest frame

Selection Variable:

\[ M_{\nu}^2 = (M_{B^0} - E_{D^*} - E_l)^2 - (P_{D^*} + P_l)^2 \sim 0 \text{ for Signal} \]

From \( E_{\pi_s} , P_{\pi_s} \) parameterization

\[ 1^\pm \pi_s^\pm \]: right–charge correlation
\[ 1^\mp \pi_s^{\mp} \]: wrong–charge correlation

750K Peaking events (Run1+2)
Analysis Strategy (2)

**Tag Side**

\[ l^+ \]

\[ \Delta z \]

**Signal Side**

\[ l^- \]

\[ \pi^{*+} \]

**Signal Vertex:** \( l\pi^* + \text{Beam Spot (x,y), } \sigma_y \text{ (B.S.) inflated to 50\( \mu \)m (B motion)} \)

Combine \( P_l, P_{\pi^*} \), Prob Vtx \((l,\pi^*)\) in Likelihood Ratio \( \chi \)

**Tag Vertex:** \( l \text{ (Elbatag) (\( \varepsilon \sim 10\) %) +BS (x,y)} \)

\( P_l > 1 \text{ GeV/c (e) (1.1 GeV/c (\( \mu \)))} \)

Tag Lepton alone: No \( D^0 \) bias

Compute \( \Delta t = \Delta z / \beta \gamma \) (Boost Approx.)
**Analysis Strategy (3) (After ICHEP)**

- Multiple candidates events with additional $\pi^*$ from the Tag–$B^0$ decay chain originate a Selection Bias: look at $M_{\nu}^2$ on Tag–Side:
  
  $\pi^*$ from D*, Decay–Side Signal
  
  $\pi^*$ from D*, Decay–Side BKG

- Event removed if: $M_{\nu}^2 (\text{tag–side}) > -3$ GeV$^2$

![Graphs showing data distributions](image)

- $\pi^*$ not from D*

- Entries / 0.2 GeV$^2/c^4$

### Graph Descriptions:

1. **Left Graph:**
   - Title: Entries / 0.2 GeV$^2/c^4$
   - X-axis: MM$^2$ (GeV$^2/c^4$)
   - Y-axis: Entries / 0.2 GeV$^2/c^4$

2. **Right Graph:**
   - Title: Entries / 0.2 GeV$^2/c^4$
   - X-axis: MM$^2$ (GeV$^2/c^4$)
   - Y-axis: Entries / 0.2 GeV$^2/c^4$

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**Graph Analysis (Left):**

- The graph shows the distribution of entries for events with $\pi^*$ from D*, Decay–Side Signal.

**Graph Analysis (Right):**

- The graph shows the distribution of entries for events with $\pi^*$ from D*, Decay–Side BKG.

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**Note:**

- The images are placeholders for actual graph visuals, which are described in the text.
Sample Composition (1)

- Run 1+2 Analysis 10 (~88 MBB); MC~2 X DATA
- Select events with $|\Delta t|<18$ ps, $\sigma\Delta t<3$ ps

Unmixed ($l^+l^-$)

- $M^2_{\nu}$ (for unmixed and mixed subsamples) fitted as a sum of:
  - Continuum (off-peak)
  - BB Combinatorial (MC)
  - $B^-$ Peaking BKG (MC); Isospin Conservation: $2/3$ of $B^-\rightarrow D^*\pi l\nu$ from $B^-$ decays
  - $B^0$ Signal (MC)
- $M^2_{\nu}>-2.5$GeV$^2$/c$^4$: Nevts ~ 70000 lepton tagged; f($B^0$ Signal)~65%
Sample Composition (2)

Background Fractions to be used in the $\Delta t$ fit:

$$f_{qq}^+(M^2_{\nu}), f_{BB}^+(M^2_{\nu}), f_{B-}^+(M^2_{\nu})$$

- $M^2_{\nu} < -4.5$ GeV$^2$/c$^4$:  
  $$f_{qq}^+(M^2_{\nu}) = 1 - f_{BB}^+(M^2_{\nu})$$
PDF Description

\( \mathcal{F}^\pm(\Delta t, \sigma \Delta t, M^2_v \mid \tau, \Delta m) = \)

\[
\begin{align*}
&f^+_{qq}(M^2_v) \mathcal{F}^+_{qq}(\Delta t, \sigma \Delta t) \otimes R(\delta \Delta t, \sigma \Delta t) \\
&+ f^+_{BB}(M^2_v) \mathcal{F}^+_{BB}(\Delta t, \sigma \Delta t) \otimes R(\delta \Delta t, \sigma \Delta t) \\
&+ S_{B^-}^* f^+_{B^-}(M^2_v) \mathcal{F}^+_{B^-}(\Delta t, \sigma \Delta t) \otimes R(\delta \Delta t, \sigma \Delta t) \\
&+ [1 - S_{B^-}^* f^+_{B^-}(M^2_v) - f^+_{BB}(M^2_v) - f^+_{qq}(M^2_v)] \\
&\ast \mathcal{F}^+_{B^0}(\Delta t, \sigma \Delta t \mid \tau, \Delta m) \otimes R(\delta \Delta t, \sigma \Delta t)
\end{align*}
\]

Continuum

Combinatorial

Peaking B^- 

B^0 Signal

\( f^+_i(M^2_v) : \text{fractions, } \mathcal{F}^+_{qq}(\Delta t, \sigma \Delta t) : \text{PDF, } S_{B^-}^* : \text{scale factor constr. to } 1 \pm 50\% \)

(\text{Isospin Assumption})

Resolution Function:

\[ R(\delta \Delta t, \sigma \Delta t) \sim (1 - f_w - f_o) \exp(-((\delta \Delta t - o_n)^2)/2(S_n \sigma \Delta t)^2) \]

\[ + f_w \exp(-((\delta \Delta t - o_w)^2)/2(S_w \sigma \Delta t)^2) \]

\[ + f_o \exp(-\delta \Delta t/2S_o^2) \]

Narrow

Wide

Outlier

\( \delta \Delta t = \Delta t(\text{measured}) - \Delta t(\text{true}) \)

Offset o_n, o_w adjusted for each sample; f_o, S_o, S_n (Comb.) \( \neq f_o, S_o, S_n \) (Signal)

Other Resolution Function parameters common to all samples
**Fit Method (1)**

- Fit to $\Delta t$ to determine simultaneously $\tau$, $\Delta m$ and dilution $D$, constrained to the fraction of mixed events:

\[
\frac{N_{\text{mix}}}{N_{\text{tot}}} = \chi_d(D) + \frac{(1-D)}{2}; \quad \chi_d = \frac{x^2}{(1+x^2)^2}; \quad x = \Delta m \tau
\]

- Binned (100/250 $\Delta t$ X 25/50 $\sigma \Delta t$) Maximum–likelihood fit to mixed and unmixed subsamples

- Likelihood value computed at the bin center / average in the bin

- Use all the events in the range $-10$ GeV$^2$/c$^4 < M^2 < 2$ GeV$^2$/c$^4$

(Assumption: Same PDFs in BKG/Signal regions for BB Combinatorial and Continuum)

- Float all the Signal/Bkg parameters in the same fit
**Fit Method (2)**

- Validate in the simulation the resolution model and the measured tagging dilution comparing the generated $\tau$, $\Delta m$ values with the results of the fits using:
  - true $\Delta t$ and tagging (Selection Bias check)
  - true $\Delta z$ and tagging (Boost Approximation check)
  - true $\Delta z$ and experimental tagging (realistic dilution)
  - experimental $\Delta z$ and true tagging (resolution function)
  - experimental $\Delta z$ and tagging (realistic fit)

- Validate in the simulation every term in the PDF ($B^0$, $B^-$, Combinatorial) :
  - Add terms (one a time) and repeat the fit
  - Perform complete ($B^0+B^-+BB$) MC test
  - Check Continuum using off-peak events

- Fit the Real Data events

⇒ Total of 14 tests
Fit Method (4): $B^0$ Signal PDF

Tagging Lepton Sample: \{ b\rightarrow l, b\rightarrow c\rightarrow l, D^0 \rightarrow l \}

From tag B

From decay B

Tag B

Decay B

Cascade Lepton

Decay Lepton

Prompt Lepton

Cascade Lepton Tag Side

Decay Side

$\pi^*$
**MC Results (1): Prompt**

- **MC:** $\mathcal{D}_p \sim 0.97$
  
  Floated in the fit;

- **DT:** $\mathcal{D}_p \sim 0.99$

- $\mathcal{O}_N$, $\mathcal{O}_W$ compatible with zero

\[ \mathcal{F}_P^{\pm} = e^{-|\Delta t|/\tau} \left( 1 \pm \mathcal{D}_p \cos(\Delta m \Delta t) \right) \]

$\tau_B = 1.547 \pm 0.006$ ps

$\Delta m = 0.466 \pm 0.002$ ps$^{-1}$
**MC Results (2): Decay–Side Cascade**

- No information on mixing
- Effective D Lifetime $\tau_D$ floated
- Fraction $\alpha(\theta)^\pm$ from angle $l(tag) - \pi_s$

\[ \mathcal{F}^D = e^{-|\Delta t|/\tau_D} \]

\[ \alpha(\theta)^- \]

\[ \alpha(\theta)^+ \]

\[ \begin{array}{c}
\text{Unmixed} \\
\text{Mixed}
\end{array} \]

\[ \begin{array}{c}
\text{Unmixed} \\
\text{Mixed}
\end{array} \]
$MC$ Results (3): Tag−Side Cascade

\[ \mathcal{F}_{c}^{\pm} = e^{-|\Delta t|/\tau} \left( 1 \mp D_{c} \cos(\Delta m \Delta t) \right) \]

- $D_{c} = 0.65 \pm 0.08$ from PDG
- $B(b \to c \to l^{-})/(B(b \to c \to l^{+})+B(b \to \bar{c} \to l^{-}))$ fixed in the fit;
  (MC: $D_{c} = 0.545$)

- $\omega_{n} = -0.32 \pm 0.03$ ps; $\omega_{w} = -2.7 \pm 0.4$ ps due to D lifetime

- $\tau_{B} = 1.54 \pm 0.02$; $\Delta m = 0.441 \pm 0.014$ ps$^{-1}$
MC Results (4): Full $B^0$ Signal

- Float ratio cascade to prompt $f_{bcl}$

\[
\begin{align*}
\mathcal{F}_{-B0}^- &= (1 - \alpha(\theta)^-) \left\{ (1 - f_{bcl}) \mathcal{F}_p^-(\Delta t, \tau, \Delta m) \\
&+ f_{bcl} \mathcal{F}_c^-(\Delta t, \tau, \Delta m) \right\} \\
&+ \alpha(\theta)^- \mathcal{F}_D^-(\Delta t, \tau_D)
\end{align*}
\]

\[
\begin{align*}
\mathcal{F}_{+B0}^+ &= (1 - \alpha(\theta)^+) \left\{ (1 - f_{bcl}) \mathcal{F}_p^+(\Delta t, \tau, \Delta m) \\
&+ f_{bcl} \mathcal{F}_c^+(\Delta t, \tau, \Delta m) \right\} \\
&+ \alpha(\theta)^+ \mathcal{F}_D^+(\Delta t, \tau_D)
\end{align*}
\]

$\tau_B = 1.548 \pm 0.006 \text{ ps}$; $\Delta m = 0.470 \pm 0.002 \text{ ps}^{-1}$
**MC Results (5): Peaking $B^-$**

- Exponential term:
  $\tau_{B^-} = 1.671 \pm 0.018$ ps (MC: 1.65 ps)

- Overall fraction constrained to $1 \pm 0.5$
  (Isospin Conservation Assumption)

- Decay–Side Cascade treatment similar to $B^0$ Signal by means of $\alpha_{B^-}(\theta)^\pm$

B$^0$+B$^-$ Resonant Fit:

- $\tau_B = 1.540 \pm 0.006$ ps;
- $\Delta m = 0.469 \pm 0.003$ ps$^{-1}$
- $S_{B^-} = 0.8 \pm 0.1$
**MC Results (6): BB Combinatorial (After ICHEP)**

Strategy similar to Signal Treatment:
Fit independently each Combinatorial BKG Component and then add together all the terms, according to their relative fractions:

- **B^0 BKG**: prompt leptons, cascade decay–side, cascade tag–side
- **B^+ BKG**: prompt leptons, cascade decay–side, cascade tag–side

- Same PDF for B^0/B^+ cascade decay–side
- Same PDF for B^+ prompt leptons/cascade tag–side

Advantages:
- All the parameters have a clear physical meaning;
- Check the stability of the results adding one component after another;
- Comparison between the fitted values and the MC predictions (eventual discrepancies can be used in the systematics evaluation)
MC Results (/): BB Combinatorial

- Compare the fitted component in the BKG global fit (blue) with the corresponding subsample result (red)

Fractions assumed from MC

Free Fractions (apart $\alpha^+_{\text{BKG}}$)

1 $\sigma$ effect
**MC Results (8): BB Combinatorial**

- **Parameters**: 13 floated (apart resolution); 5 fixed ($D_C$, $\tau_{B^-}$, $\alpha^+_{BKG,B^-}$, $\alpha^+_{BKG,B0}$, $f_{w, Dtag}$)

- **Assumption of same PDF in the BKG/Signal regions successfully checked by**: 
  - Compatibility of the fitted parameters values in the two regions
  - Kolmogorov test
  - Compatibility of MC global fit results using fixed BKG/Signal region combinatorial parameters
  - Different BKG region definitions in MC global fit

\[ M_{\nu}^2 < -4.5 \text{ GeV}^2/c^4 : \text{BKG Region} \]

\[ M_{\nu}^2 > -4.5 \text{ GeV}^2/c^4 : \text{Signal Region} \]
**MC Results (7): Global Fit**

B^0 + B^- + BB with 30 floated parameters (including resolution)

\[ \tau_B = 1.554 \pm 0.007 \text{ ps}; \Delta m = 0.464 \pm 0.004 \text{ ps}^{-1}; \rho = -1.4\% \]
**Analysis Bias (1)**

True $\Delta t$/True tag

$\tau = 1.550 \pm 0.004$

$\Delta m = 0.4691 \pm 0.0010$

CHECK: Selection

Generated: $\tau = 1.548$ ps; $\Delta m = 0.472$ ps$^{-1}$

True $\Delta z$/True tag

1.555 $\pm$ 0.004

0.4657 $\pm$ 0.0011

Boost Appr.

True $\Delta z$/Meas tag

1.555 $\pm$ 0.004

0.4648 $\pm$ 0.0013

Dilution

Meas $\Delta z$/True tag

1.542 $\pm$ 0.005

0.4711 $\pm$ 0.0017

Resolution
Analysis Bias (2)

B⁰ Signal Sample:

- Event Selection/Fit Procedure (True Δt, True tag vs Generated Values):
  \[ \delta \tau = +0.0017 \pm 0.0043 \text{ ps}; \quad \delta \Delta m = -0.0029 \pm 0.0010 \text{ ps}^{-1} \]  
  (ICHEP: +0.016 ± 0.005)  
  (fit effect, \[ \delta \chi_d = 0.0007 \pm 0.0011 \])

- Boost Approximation (True Δz, True tag vs True Δt, True tag):
  \[ \delta \tau = +0.0054 \text{ ps}; \]
  \[ \delta \Delta m = -0.0034 \text{ ps}^{-1} \]

- Full B⁰ Signal Sample with realistic resolution and tagging 
  (Meas. Δz, Meas. tag vs True Δt, True tag):
  \[ \delta \tau = -0.0014 \pm 0.0036 \text{ ps}; \]
  \[ \delta \Delta m = +0.0009 \pm 0.0015 \text{ ps}^{-1} \]
Analysis Bias (3)

Adding Background:

• B⁻ Peaking (Total Resonant Sample vs B⁰ Signal Sample):
  \[ \delta \tau = -0.0082 \pm 0.0031 \text{ ps}; \]
  \[ \delta \Delta m = -0.0014 \pm 0.0021 \text{ ps}^{-1} \]

• Combinatorial BKG Parameterization (Global Sample vs Resonant Sample):
  \[ \delta \tau = +0.014 \pm 0.0033 \text{ ps}; \]
  \[ \delta \Delta m = -0.0042 \pm 0.0024 \text{ ps}^{-1} \]

→ Total (Global MC Fit vs Generated Values):
  \[ \delta \tau = +0.0065 \pm 0.0072 \text{ ps}; \]
  \[ \delta \Delta m = -0.0076 \pm 0.0037 \text{ ps}^{-1} \]

→ Results on Real Data to be Corrected by:

\[ \tau = \tau_{\text{meas.}} - (0.0065 \pm 0.0072) \text{ ps} \]
\[ \Delta m = \Delta m_{\text{meas.}} + (0.0076 \pm 0.0037) \text{ ps}^{-1} \]
DT Results (1): Continuum

- Test on off-peak events
- Pure lifetime term with non zero offset

\[ \tau_{qq} = 0.36 \pm 0.06 \text{ ps} \]
\[ \omega_n = \omega_w = -0.01 \pm 0.05 \text{ ps} \]
32 floated parameters (including resolution)

\[ \tau_B = XXX \pm 0.0098 \text{ ps}; \Delta m = XXX \pm 0.0049 \text{ ps}^{-1}; \rho = +4.9\% \]
**Systematic Errors (1)**

- Sample Composition: Vary BB below the peak by $\pm$ 2.3%
- Analysis Bias: Statistical error of the Full Monte Carlo Fit Result
- Vary PDF fixed parameters ($\tau_{B^-}=1.671\pm0.018$ ps, $\mathcal{D}_c=0.65\pm0.08$)
- Vary offset of outlier PDF; adopt flat PDF
- Vary fraction of decay–side cascade by its statistical error
- Vary bin size, use average value of the Likelihood in the bin
- Vary $\Delta t$, $\sigma \Delta t$ cut
- Alignment, $z$–scale, boost: *at present* from fully reco $D^{*+} l^- \nu$ analysis


**Systematic Errors (2) (ICHEP)**

Table 2: Systematic uncertainties.

<table>
<thead>
<tr>
<th>Source</th>
<th>Variation</th>
<th>$\delta \tau_B$</th>
<th>$\delta \Delta m_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) $B\bar{B}$ fraction</td>
<td>$\pm 2.3%$</td>
<td>$\pm 0.0010$</td>
<td>$\pm 0.0010$</td>
</tr>
<tr>
<td>(b) Analysis bias</td>
<td>-</td>
<td>$\pm 0.0072$</td>
<td>$\pm 0.0037$</td>
</tr>
<tr>
<td>(c) $\tau_{B^-}$</td>
<td>$1.671\pm0.018$</td>
<td>$\pm 0.0019$</td>
<td>$\pm 0.0010$</td>
</tr>
<tr>
<td>(d) $\mathcal{D}_{C\ell}$</td>
<td>$0.65\pm0.08$</td>
<td>$\pm 0.0053$</td>
<td>$\pm 0.0005$</td>
</tr>
<tr>
<td>(e) z scale</td>
<td>-</td>
<td>$\pm 0.0060$</td>
<td>$\pm 0.0020$</td>
</tr>
<tr>
<td>(f) PEP-II boost</td>
<td>-</td>
<td>$\pm 0.0015$</td>
<td>$\pm 0.0005$</td>
</tr>
<tr>
<td>(g) Alignment</td>
<td>-</td>
<td>$\pm 0.0056$</td>
<td>$\pm 0.0030$</td>
</tr>
<tr>
<td>(h) Beam spot position</td>
<td>-</td>
<td>$\pm 0.0050$</td>
<td>$\pm 0.0010$</td>
</tr>
<tr>
<td>(i) Decay-side tags</td>
<td>-</td>
<td>$\pm 0.0025$</td>
<td>$\pm 0.0015$</td>
</tr>
<tr>
<td>(j) Binning</td>
<td>-</td>
<td>$\pm 0.0017$</td>
<td>$\pm 0.0021$</td>
</tr>
<tr>
<td>(k) Outlier</td>
<td>-</td>
<td>$\pm 0.0013$</td>
<td>$\pm 0.0021$</td>
</tr>
<tr>
<td>(l) $\Delta t$ and $\sigma_{\Delta t}$ cut</td>
<td>-</td>
<td>$\pm 0.0076$</td>
<td>$\pm 0.0032$</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$\pm 0.0157$</td>
<td>$\pm 0.0072$</td>
</tr>
</tbody>
</table>

New

\[
\tau_B = (XXX \pm 0.0098 \pm 0.016) \text{ ps}; \\
\Delta m = (XXX \pm 0.0049 \pm 0.0072) \text{ ps}^{-1}
\]
To do before Publication

- Re-Evaluation of the Systematic Errors using the new Event Selection and the new Combinatorial BKG Parameterization;
- Re-Validation of the Fit by Toy Monte Carlo;
- Cross Checks & further Systematic Errors evaluation:
  - Vary PDF Combinatorial BKG fixed parameters;
  - Alignment, $z$–scale, beam spot with our analysis setup;
  - Cut on selection variable $\chi$;
  - Use GEXP model for the Tag–Side Cascade sample
Conclusions

A very competitive preliminary result:

<table>
<thead>
<tr>
<th></th>
<th>$\Delta m$</th>
<th>$\tau_{B^0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar Hadronic</td>
<td>0.516±0.016±0.010</td>
<td>1.546±0.032±0.022</td>
</tr>
<tr>
<td>BaBar Dilepton</td>
<td>0.493±0.012±0.009</td>
<td>−</td>
</tr>
<tr>
<td>BaBar D*lv (P.R.)</td>
<td>−</td>
<td>1.529±0.012±0.029</td>
</tr>
<tr>
<td>BaBar D*π (P.R.)</td>
<td>−</td>
<td>1.533±0.034±0.033</td>
</tr>
<tr>
<td>BaBar D*lv</td>
<td>0.492±0.018±0.013</td>
<td>1.523±0.024±0.022</td>
</tr>
<tr>
<td>World Average</td>
<td>0.502±0.007</td>
<td>1.536±0.014</td>
</tr>
<tr>
<td>This Analysis</td>
<td>xxx±0.0049±0.0072</td>
<td>xxx±0.010±0.016</td>
</tr>
</tbody>
</table>