BABAR

A. Calcaterra, R. de Sangro (Resp.), G. Finocchiaro, P. Patteri,
S. Martellotti, I. Peruzzi , M. Piccolo, M. Rama, A. Zallo

1 Introduction

The *BABAR* experiment has been running at the PEP-II asymmetric B factory of the SLAC National Laboratory (Stanford, USA) from 2001 to 2008, collecting a data sample corresponding to approximately $0.5\,\mathrm{ab}^{-1}$. The data were collected mostly at the CM energy corresponding to the $\Upsilon(4S)$ mass; large data sample were also obtained at the CM energy corresponding to the $\Upsilon(2S)$ and $\Upsilon(3S)$ resonances. The experiment has produced a wealth of important physics results, ranging from measurements of all three angles of the Unitarity triangle, to the discovery of the $D-\bar{D}$ mixing, the discovery of the η_b, the discovery of several interesting charm and charmonium states. The study of the ISR events, also pursued at *BABAR* has produced many important results in the energy range down hadron threshold production.

After the end of data taking the complete data set was reprocessed, and large amount of Monte Carlo events were generated and fully reconstructed. During 2012 the intense analysis period has not yet slowed down: this year the number of published paper was similar to that of 2011, while the number of contributed papers to international conferences even exceeded it. To date the *BABAR* analysis effort has resulted in more than 500 publications in Phys. Rev. Lett. or Phys. Rev. D.

The main activity of the LNF group in 2012 has been the pubblication of the paper on the combined final measurement of γ from *BABAR*, the pubblication of the analysis of $B \to D^{*+}D^{*-}$ selected with a partial reconstruction technique, and the start of a new physics analysis for the measurement of the Electric Dipole Moment of the τ lepton, the subject of a doctoral thesis of a new PHD student who joined the group. Members of the group have also been actively involved in the preparation of the *Physics of the B-Factories Book*, in collaboration with the Belle group, to illustrate the analysis strategies and the physics results of the B-factories. The book is now in the final review process internal to the two collaborations. We'll give a brief description of these activities in the next sections.

2 Physics of the B-factories book

Over the last decade BaBar and Belle have studied the physics of bottom and charm mesons, tau leptons, heavy quarkonium states, etc. that were produced at the PEP-II and KEKB e^+e^- storage rings. The two collaborations have developed increasingly sophisticated techniques for extracting the maximum amount of information from data. A project is ongoing to document all these techniques in a book, named *Physics of the B-Factories*. The book will provide descriptions of all of the techniques developed by the experiments and a comprehensive overview of the measurements. The editing of the book is in its final stage and the publication is currently expected to happen in 2013. One member of our group is co-author of the chapter on the measurement of the angle γ of the Unitarity Triangle, while another provided a written contribution to the chapter on the measurement of $\sin(2\beta)$.

3 Combined measurement of the CKM angle γ from $B \to D^{(*)}K^{(*)}$ decays

We have worked on the determination of the Cabibbo-Kobayashi-Maskawa CP-violating angle γ through the combination of various measurements involving $B^{\pm} \to DK^{\pm}$, $B^{\pm} \to D^{*}K^{\pm}$, and $B^{\pm} \to DK^{*\pm}$ decays performed by BaBar. Using up to 474 million $B\bar{B}$ pairs we obtain $\gamma = (69^{+17}_{-16})^{\circ}$ modulo 180°. The total uncertainty is dominated by the statistical component, with the experimental and Dalitz-amplitude-model systematic uncertainties amounting to $\pm 4^{\circ}$. The corresponding two-standard-deviation region is $41^{\circ} < \gamma < 102^{\circ}$. This result is inconsistent with $\gamma = 0$ with a significance of 5.9 standard deviations and it is competitive with the combinations performed by the LHCb and Belle experiments. The article has been accepted by Phys. Rev. D.

4 Measurement of $\sin 2\beta$ with partial reconstruction of B mesons to the $D^{*+}D^{*-}$decay

In 2012 this analysis has undergone a thorough review process, which resulted in its final publication at the end of the year. The analysis was presented for the first time at the ICHEP 2012 summer conference in Melbourne by a member of our group.

The parameters S, C are extracted from the CP and tag side vertices time difference Δt distribution of events selected using event topology and kinematic cuts. In fig. 1 we show the

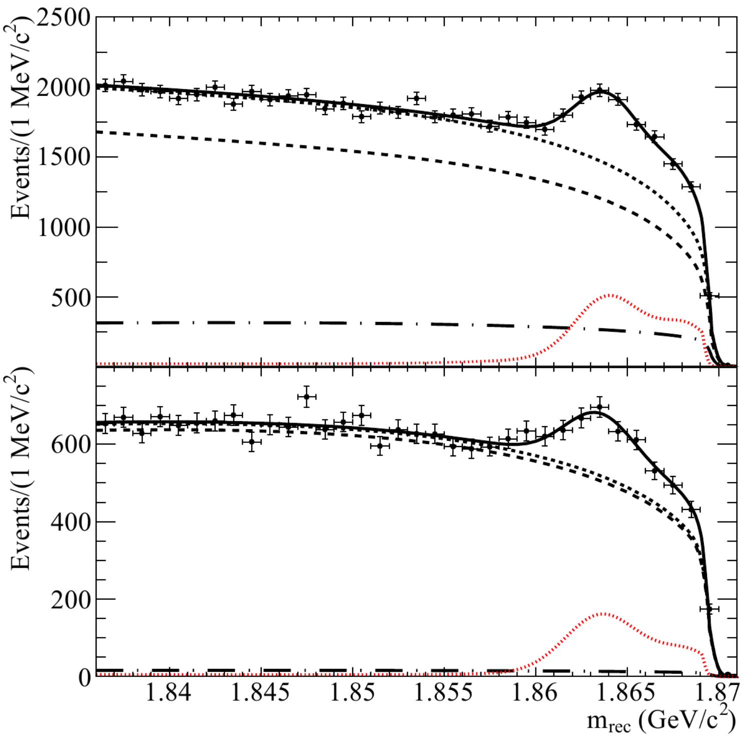

Figure 1: Result of the kinematical fit of kaon (top) and lepton (bottom) tagged data events, with PDF's overlaid: total PDF (solid line), total background ($B\overline{B}$ + continuum, short-dashed line), $B\overline{B}$ combinatorial background (dashed line), continuum u, d, s, c background (dot-dashed line) and signal (dotted red line).

recoil mass distribution of the full *BABAR* dataset (black crosses), corresponding to $\approx 435\ fb^{-1}$ of integrated luminosity. The presence of an excess of events in the signal region is evident.

We fit the data with a PDF (black curve), made of a signal component (red) plus a continuum (green) and $B\bar{B}$ (blue) combinatorial background component. We find a total of 3843 ± 397 (1128 ± 218) events in the kaon (lepton) sample. We fit the time distribution in the data, whose

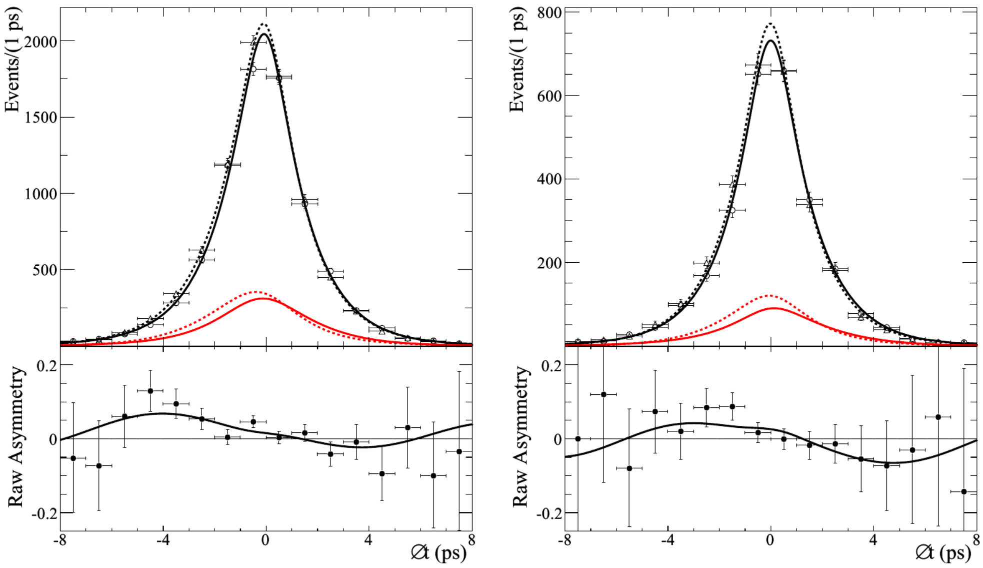

Figure 2: Top: Δt distribution for B^0 (dashed) and $\overline{B}^0$ (solid) for kaon(left plot) and lepton(right plot) tags; the lower curves are the corresponding signal PDFs. Bottom: corresponding raw time-dependent CP asymmetry. Only data in the restricted signal region $m_{\mathrm{rec}} > 1.860\ \mathrm{GeV}/c^2$ are shown.

result we show in fig. 2 where we plot the time difference distribution of data events for the full collected sample, and the corrisponding raw CP asymmetry for the lepton and kaon tag samples. The final result is:

$$\begin{aligned} C &= +0.12 \pm 0.11 \\ S &= -0.42 \pm 0.16 \end{aligned} \quad \text{kaon tags,}$$

$$\begin{aligned} C &= +0.20 \pm 0.15 \\ S &= -0.21 \pm 0.20. \end{aligned} \quad \text{lepton tags.}$$

The combined statistical and systematic errors are:

$$C = +0.15 \pm 0.09 \pm 0.05 \quad (1)$$

$$S = -0.34 \pm 0.12 \pm 0.09, \quad (2)$$

This measurement reduces the error of the previous BaBar measurement performed with fully reconstructed $D^{*+}D^{*-}$final states by $\approx 25\%$.

A description of this analysis and its results have been included in the B-Factories legacy book.

5 Measurement of the τ lepton Electric Dipole Moment in the $e^+e^- \to \tau^+\tau^-$ production

The search for a CP violation signature arising from an electric dipole moment (EDM) different from zero of the τ lepton is searched in the $e^+e^- \to \tau^+\tau^-$ reaction with Babar data. This analysis started in 2012 with the study of the τ EDM measurement algorithms and methods on Monte Carlo samples.

The EDM gives a tree level contribution to the τ-pairs production cross section; the corresponding Feynman diagrams are shown Fig.3. Taking into account the EDM contribution in the

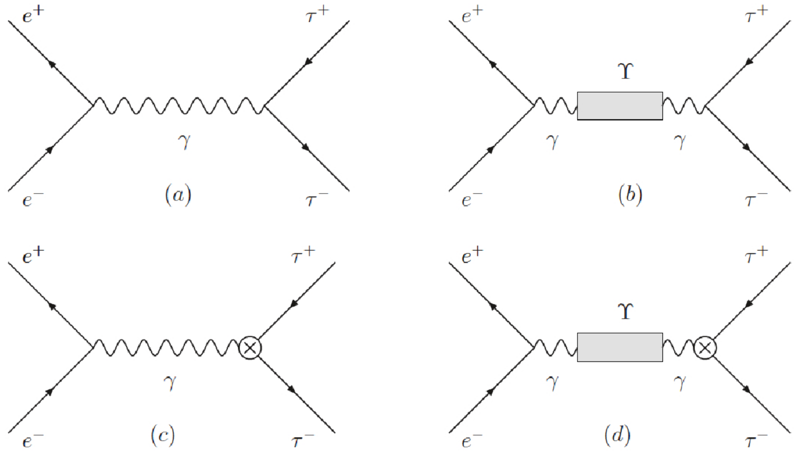

Figure 3: Diagrams. (a) direct γ exchange. (b) Υ production. (c) EDM in γ exchange. (d) EDM at the Υ-peak.

Lagrangian, the cross section of the $e^+e^- \to \tau^+\tau^-$ process is proportional to the squared spin density matrix:

$$\mathcal{M}^2_{prod} = \mathcal{M}^2_{SM} + Re(d_\tau)\mathcal{M}^2_{Re} + Im(d_\tau)\mathcal{M}^2_{Im} + |d_\tau|^2\mathcal{M}^2_{d^2}.$$

For the EDM measurement we adopt the same method used in previous existing measurements by the ARGUS and Belle experiments, the so-called optimal observable method, which maximizes the sensitivity to d_τ. The optimal observables are defined as:

$$\mathcal{O}_{Re} = \frac{\mathcal{M}^2_{Re}}{\mathcal{M}^2_{SM}}, \quad \mathcal{O}_{Im} = \frac{\mathcal{M}^2_{Im}}{\mathcal{M}^2_{SM}}. \tag{3}$$

The matrix elements $\mathcal{M}^2_i = \mathcal{M}^2_i(\vec{k}, \vec{S}_\pm)$ depend on the τ^+ momentum $\vec{k}$ and on the τ^+ and τ^- spin vectors $\vec{S}_\pm$ in the τ-pair rest frame. The complete reconstruction of these quantities is prevented by the presence of undetectable neutrinos in τ decays. The final state in which both τ's decay hadronically in $\tau^\pm \to \pi^\pm\nu$ has been analysed. The τ momentum measurement algorithm and the spin reconstruction formula have been studied and verified. The mean values of the optimal observables $\langle\mathcal{O}_{Re}\rangle$ and $\langle\mathcal{O}_{Im}\rangle$ are linear functions of d_τ:

$$\langle\mathcal{O}_{Re}\rangle = a_{Re} \cdot Re(d_\tau) + b_{Re}, \quad \langle\mathcal{O}_{Im}\rangle = a_{Im} \cdot Im(d_\tau) + b_{Im}. \tag{4}$$

In order to extract the value of d_τ from the observable means measured on the data, we have to know the coefficients a_j and the offsets b_j. The parameters a_j and b_j are extracted from the correlations between $\langle \mathcal{O}_{Re} \rangle$ ($\langle \mathcal{O}_{Im} \rangle$) and $Re(d_\tau)$ ($Im(d_\tau)$) extracted by a full Monte Carlo (MC) simulation including the detector simulation with acceptance effects and event selection efficiency. The slopes a_j represent the real and imaginary EDM sensitivity, the offsets b_j represent the difference from zero of the observable mean when $d_\tau = 0$.

This EDM measurement method and the EDM sensitivity evaluation have been tested on a preliminary signal MC sample with no detector effects. Distributions of the real and imaginary optimal observables for $\tau^+\tau^- \to \pi^+\pi^-\nu_\tau\bar{\nu}_\tau$ events, from a MC sample with about the same statistics expected for Babar data, are shown in Fig.4. In Fig.5 the correlations between the

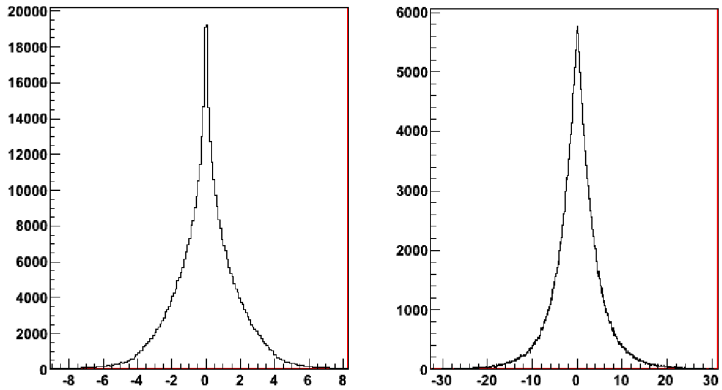

Figure 4: Optimal observables distribution for $\tau^+\tau^- \to \pi^+\pi^-\nu_\tau\bar{\nu}_\tau$ events. Left: O_{Re}; right: O_{Im}.

observable means $\langle O_{Re} \rangle$ and $\langle O_{Im} \rangle$ and d_τ of this MC sample are shown.

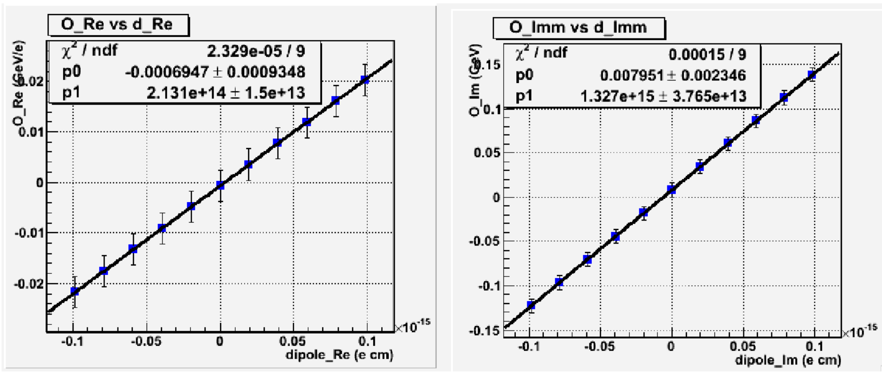

Figure 5: Correlation between the observable means $\langle O_{Re} \rangle$ (left) and $\langle O_{Im} \rangle$ (right) and d_τ for the analysed MC sample. Fit results are shown, p0 is the offset b_j and p1 is the slope, corresponding to the EDM sensitivity a_j.

The statistical sensitivity (one σ) to the $Re(d_\tau)$ expected with the full babar data sample extrapolated from the correlation plot (Fig.5, left) is $0.14 \cdot 10^{-16} ecm$, one order of magnitude higher than the one reached by Belle. The systematic uncertainties are now under evaluation with the ongoing analysis on the full realistic MC sample with detector acceptance and background effects included. We are confident to improve the present Belle experimental measurements.

6 List of Conference Talks in Year 2012

1. "CP Violation in Mixing at $B\scriptstyle{A}\displaystyle B\scriptstyle{AR}$", R. de Sangro ($B\scriptstyle{A}\displaystyle B\scriptstyle{AR}$ Collaboration)
   International Conference on High Energy Physics, 4-11 July 2012, Melbourne, Australia.

References

1. **"Search for di-muon decays of a low-mass Higgs boson in radiative decays of the $\Upsilon(1S)$"**, J. P. Lees *et al.* , Phys. Rev. D 87, **031102**, (2013) (R)
2. **"Measurement of $D^0 - \bar{D}^0$ Mixing and CP Violation in Two-Body D^0 Decays"**, J. P. Lees *et al.* , Phys. Rev. D **87**, 012004 (2013)
3. **"Study of high-multiplicity 3-prong and 5-prong tau decays at BABAR"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 092010 (2012).
4. **"Study of the baryonic B decay $B^- \to \Sigma_c^{++}\bar{p}\pi^-\pi^-$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 091102 (2012).
5. **"Measurement of the Time-Dependent CP Asymmetry of Partially Reconstructed $B^0 \to D^{*+}D^{*-}$ Decays"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 112006 (2012).
6. **"Branching fraction and form-factor shape measurements of exclusive charmless semileptonic B decays, and determination of $|V_{ub}|$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 092004 (2012).
7. **"The branching fraction of $\tau^- \to \pi^- K_S^0 K_S^0 (\pi^0)\nu_\tau$ decays"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 092013 (2012).
8. **"A search for the decay modes $B^{+-} \to h^{+-}\tau^{+-}l$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 012004 (2012).
9. **"Observation of Time Reversal Violation in the B^0 Meson System"**, J. P. Lees *et al.* , Phys. Rev. Lett. **109**, 211801 (2012).
10. **"Measurement of B($B \to X_s\gamma$), the $B \to X_s\gamma$ photon energy spectrum, and the direct CP asymmetry in $B \to X_{s+d}\gamma$ decays"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 112008 (2012).
11. **"Precision Measurement of the $B \to X_s\gamma$ Photon Energy Spectrum, Branching Fraction, and Direct CP Asymmetry $A_{CP}(B \to X_{s+d}\gamma)$"**, J. P. Lees *et al.* , Phys. Rev. Lett. **109**, 191801 (2012).
12. **"Study of $X(3915) \to J/\psi\omega$ in two-photon collisions"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 072002 (2012).
13. **"Exclusive Measurements of $b \to s\gamma$ Transition Rate and Photon Energy Spectrum"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 052012 (2012).
14. **"Search for the decay modes $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, and $D^0 \to e\mu$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 032001 (2012).
15. **"Improved Limits on B^0 Decays to Invisible Final States and to $\nu\bar{\nu}\gamma$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 051105 (2012).

16. **"Search for resonances decaying to $\eta_c\pi^+\pi^-$ in two-photon interactions"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 092005 (2012).

17. **"Evidence for an excess of $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ decays"**, J. P. Lees *et al.* , Phys. Rev. Lett. **109**, 101802 (2012).

18. **"Precise Measurement of the $e^+e^- \to \pi^+\pi^-(\gamma)$ Cross Section with the Initial-State Radiation Method at BABAR"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 032013 (2012).

19. **"Measurement of Branching Fractions and Rate Asymmetries in the Rare Decays $B \to K^{(*)}l^+l^-$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 032012 (2012).

20. **"Study of the reaction $e^+e^- \to J/\psi\pi^+\pi^-$ via initial-state radiation at BaBar"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 051102 (2012).

21. **"Search for lepton-number violating processes in $B^+ \to h^-l^+l^+$ decays"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 071103 (2012).

22. **"Search for Low-Mass Dark-Sector Higgs Bosons"**, J. P. Lees *et al.* , Phys. Rev. Lett. **108**, 211801 (2012).

23. **"Study of CP violation in Dalitz-plot analyses of $B^0 \to K^+K^-K^0_S$, $B^+ \to K^+K^-K^+$, and $B^+ \to K^0_SK^0_SK^+$"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 112010 (2012).

24. **"Initial-State Radiation Measurement of the $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ Cross Section"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 112009 (2012).

25. **"B^0 meson decays to ρ^0K^{*0}, f_0K^{*0}, and ρ^-K^{*+}, including higher K^* resonances"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 072005 (2012).

26. **"Study of $\bar{B} \to X_u\ell\bar{\nu}$ decays in $B\bar{B}$ events tagged by a fully reconstructed B-meson decay and determination of $\|V_{ub}\|$"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 032004 (2012).

27. **"Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ states in $\bar{B}^0 \to \chi_{c1}K^-\pi^+$ and $B^+ \to \chi_{c1}K^0_S\pi^+$"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 052003 (2012).

28. **"Observation and study of the baryonic B-meson decays B to D(*) p pbar (pi) (pi)"**, P. del Amo Sanchez *et al.* , Phys. Rev. D **85**, 092017 (2012).

29. **"Amplitude analysis and measurement of the time-dependent CP asymmetry of $B^0 \to K^0_SK^0_SK^0_S$ decays"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 054023 (2012).

30. **"Search for the Decay $D^0 \to \gamma\gamma$ and Measurement of the Branching Fraction for $D^0 \to \pi^0\pi^0$"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 091107 (2012).

31. **"Search for $\bar{B} \to \Lambda_c + Xl^-\nu_l$ Decays in Events With a Fully Reconstructed B Meson"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 011102 (2012).

32. **"A Measurement of the Semileptonic Branching Fraction of the B_s Meson"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 011101 (2012).

33. **"Search for CP Violation in the Decay $\tau^- \to \pi^-K^0_S(\geq 0\pi^0)\nu_\tau$"**, J. P. Lees *et al.* , Phys. Rev. D **85**, 031102 (2012), [Erratum-ibid. D **85**, 099904 (2012)]

34. **"Cross Sections for the Reactions $e^+e^- \to K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, and $K^+K^-K^+K^-$ Measured Using Initial-State Radiation Events"**, J. P. Lees *et al.* , Phys. Rev. D **86**, 012008 (2012).