Search for exotics at BABAR

July 29th, 2014 | Elisabetta Prencipe(*), Forschungszentrum Jülich (Germany) | ICNPF 2014, Kolymbari (Greece)

(*) Previously addressed at JGU University of Mainz (Germany)
Outline

Recent results will be introduced.
Selected topics:

- Analysis of the rare decay $B^{\pm,0} \rightarrow J/\psi \ K K K^{\pm,0}$
- Analysis of $B^0 \rightarrow J/\psi \phi$
- Analysis of $\eta_c \rightarrow K K \eta$ and $\eta_c \rightarrow K K \pi^0$ via 2-photon interactions
- Radiative transitions involving $\chi_{bj}(1P, 2P)$

arXiV: 1407.7244 [hep-ex]
In arXiV since h. 00:00, 29th July 2014

PRD 89, 112004 (2014)

Draft in preparation

Elisabetta Prencipe
ICNPF 2014, Koymbari
The BABAR experiment

Located at SLAC (California)
Runs: from 1999 to 2008
\( e^+e^- \) asymmetric collider
\(-0.9 < \cos \theta^* < 0.85\)
operating at the c.m. energy of 
Y(4S), then Y(2S) and Y(3S).

- Optimized for studies of CP violation
- High luminosity achieved \( \Rightarrow \) rare decay studies
- High production rate of \( cc \) \( \Rightarrow \) charmonium studies
- Run at Y(2S) and Y(3S) \( \Rightarrow \) bottomonium studies

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Strangeness in Charmonium

\[ b \rightarrow c\bar{s}s \]
Analysis $B \to J/\psi KK(K):$ motivation

- $B \to J/\psi K K K$: rare $B$ decay, Cabibbo suppressed, predicted $BF \sim 10^{-5}$
- $K^+K^-$ contribution expected to be dominated from $\phi$ [$BF(\phi \to K^+K^-) \sim 49.5\%$]
- $B \to J/\psi \phi K$: three body decay, gluon rich process $\Rightarrow$ ideal place to look for exotics
- It could proceed also via quasi-2-body decay, $B \to Y_g (\bar{c}c\bar{s}s)K, Y_g \to J/\psi\phi$
- If any $Y_g$ exists, expected mass $< 4.3$ GeV/c$^2$ (threshold DD$^{**}$)
- $B^0 \to J/\psi\phi$: transition $b\bar{d} \to \bar{c}c\bar{s}s$ rescattering process $\Rightarrow$ no signal expected

B $\to$ $J/\psi K K K$ via strange sea quark

B $\to$ $J/\psi K K K$ via gluon coupling

$B^0 \to J/\psi\phi$: rescattering diagram
Analysis $B \rightarrow J/\psi KK(K)$: “old” measurements

- Old BaBar publication: PRL 91 (2003) 071801, 51 fb$^{-1}$
- Today: 424 fb$^{-1}$, 470M $B\bar{B}$: expected much higher precision in BF measurements, and possibility to look at the invariant mass distributions

Old BaBar publication: PRL 91 (2003) 071801, 51 fb$^{-1}$

Today: 424 fb$^{-1}$, 470M $B\bar{B}$: expected much higher precision in BF measurements, and possibility to look at the invariant mass distributions

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Channel</th>
<th>B.R. $(10^{-5})$</th>
<th>PDG12 average $(10^{-5})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar</td>
<td>$B^\pm \rightarrow J/\psi K^\pm$</td>
<td>$4.4 \pm 1.4 \pm 0.5$</td>
<td>$5.2 \pm 1.7$</td>
</tr>
<tr>
<td>CLEO-II</td>
<td>$B^0 \rightarrow J/\psi K^0$</td>
<td>$8.8_{-3.0}^{+3.5} \pm 1.3$</td>
<td></td>
</tr>
<tr>
<td>BaBar</td>
<td>$B^0 \rightarrow J/\psi K^0$</td>
<td>$10.2 \pm 3.8 \pm 1.0$</td>
<td>$9.4 \pm 2.6$</td>
</tr>
<tr>
<td>CLEO-II</td>
<td>$B^0 \rightarrow J/\psi K^0$</td>
<td>$8.8_{-3.0}^{+3.5} \pm 1.3$</td>
<td></td>
</tr>
</tbody>
</table>

$B^0 \rightarrow J/\psi \phi$ UL$<9.2 \times 10^{-6}$

No update until 2014!

BaBar measurements dominate the PDG measurements since 2003
$B \rightarrow J/\psi KK(K)$: BF strategy

- **B channels under study:** $B^\pm$ and $B^0$
- **$K^+K^-$ invariant mass in the full range [0.98;1.69] GeV/c$^2$

### PDG2012

<table>
<thead>
<tr>
<th>decay channel</th>
<th>BR</th>
<th>$J^G$ ($J^{PC}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0(980) \rightarrow K^+K^-$</td>
<td>seen</td>
<td>$1^-(0^{++})$</td>
</tr>
<tr>
<td>$f_0(980) \rightarrow K^+K^-$</td>
<td>seen</td>
<td>$0^+(0^{++})$</td>
</tr>
<tr>
<td>$\phi(1020) \rightarrow K^+K^-$</td>
<td>$(48.9 \pm 0.5)%$</td>
<td>$0^-(1^{--})$</td>
</tr>
<tr>
<td>$f_2(1270) \rightarrow K^+K^-$</td>
<td>$(4.6 \pm 0.4)%$</td>
<td>$0^+(2^{++})$</td>
</tr>
<tr>
<td>$a_2(1320) \rightarrow K^+K^-$</td>
<td>$(4.9 \pm 0.8)%$</td>
<td>$1^-(2^{++})$</td>
</tr>
<tr>
<td>$f_2^{'}(1525) \rightarrow K^+K^-$</td>
<td>$(88.8 \pm 3.1)%$</td>
<td>$0^+(2^{++})$</td>
</tr>
<tr>
<td>$\phi(1680) \rightarrow K^+K^-$</td>
<td>seen</td>
<td>$0^-(1^{--})$</td>
</tr>
</tbody>
</table>

Several resonant states decaying to $K^+K^-$. Expected dominant meson ($\rightarrow K^+K^-$) in these $B$ decays: $\phi$

- **Measurement of BF$s$:**
  - blind analysis (large MC samples) to check consistency of fit methods
  - unbinned maximum likelihood fit of $m_{ES}$ (gaussian fit for signal yield; Argus function to parametrize the background). Double check with $\Delta E$ fit is performed

$$m_{ES} = \sqrt{E_{beam}^* - p_{beam}^*}$$

$$\Delta E = E_{beam}^* - \sqrt{s}/2$$

- $K^+K^-$ invariant mass in the full range, then we restrict to the $\phi$ mass region

- **$J/\psi$ reconstructed to $e^+e^-$ and $\mu^+\mu^-$; mass constrained

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$B \rightarrow J/\psi KKK$: fits for BF measurements

- No BF measurements in the PDG until 2014

$B^\pm \rightarrow J/\psi KKK^\pm$

$B^0 \rightarrow J/\psi KKK^0_S$

arXiv: 1407.7244 [hep-ex]
$K^+K^-$ invariant mass

- $B^\pm \to J/\psi KK^\pm$
- $B^0 \to J/\psi KK^0_S$

- $\phi$ mass region selected to study $B \to J/\psi \phi K$
- $\phi$ meson dominant over the $K^+K^-$ combinations
- One-to-one correspondence between $B$ candidate and $\phi$ candidate
- Observation of good signal, small background

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$B \rightarrow J/\psi\phi(K)$: fits for BF measurements

$B^\pm \rightarrow J/\psi\phi K^\pm$

$B^0 \rightarrow J/\psi\phi K^0_S$

$B^0 \rightarrow J/\psi\phi$

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**B → J/ψKK(K): BF results**

TABLE I: Event yields, BF measurements ($\mathcal{B}$) and efficiencies ($\epsilon$) for the different final states. The yields re-weighted by the average efficiency ($\bar{\epsilon}$) evaluated on PHSP MC distributions, and the yields re-weighted by the efficiency from the Dalitz plots ($\epsilon_D$) are reported. BF measurements with the two different efficiency methods are compared for the channel $B^+ \rightarrow J/\psi K^+ K^- K^+$ ($B^+_{KKK}$), $B^+ \rightarrow J/\psi \phi K^+$ ($B^+_{\phi K}$), $B^0 \rightarrow J/\psi K^- K^+ K^0_S$ ($B^0_{KKK_S}$), and $B^0 \rightarrow J/\psi \phi K^0_S$ ($B^0_{\phi K_S}$). The $B^0 \rightarrow J/\psi \phi$ ($B^0_{\phi}$) UL at 90% c.l. is listed at the end of the table.

<table>
<thead>
<tr>
<th>$B$ channel</th>
<th>Event yield</th>
<th>$\bar{\epsilon}$ (%)</th>
<th>Corrected yield ($\bar{\epsilon}$)</th>
<th>Corrected yield ($\epsilon_D$)</th>
<th>$\mathcal{B}$ (×10^{-5}) calculated with $\bar{\epsilon}$</th>
<th>$\mathcal{B}$ (×10^{-5}) calculated with $\epsilon_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+_{KKK}$</td>
<td>290±22</td>
<td>17.96±0.04</td>
<td>1615±122</td>
<td>1904±144</td>
<td>5.86±0.44 (stat)±0.24 (sys)</td>
<td>6.91±0.52 (stat)±0.28 (sys)</td>
</tr>
<tr>
<td>$B^+_{\phi K}$</td>
<td>189±14</td>
<td>16.28±0.04</td>
<td>1161±86</td>
<td>1396±103</td>
<td>4.21±0.31 (stat)±0.13 (sys)</td>
<td>5.06±0.37 (stat)±0.15 (sys)</td>
</tr>
<tr>
<td>$B^0_{KKK_S}$</td>
<td>68±13</td>
<td>11.31±0.04</td>
<td>586±115</td>
<td>639±125</td>
<td>3.07±0.59 (stat)±0.13 (sys)</td>
<td>3.35±0.66 (stat)±0.15 (sys)</td>
</tr>
<tr>
<td>$B^0_{\phi K_S}$</td>
<td>41±7</td>
<td>10.73±0.04</td>
<td>382±65</td>
<td>406±69</td>
<td>2.00±0.34 (stat)±0.05 (sys)</td>
<td>2.13±0.36 (stat)±0.06 (sys)</td>
</tr>
<tr>
<td>$B^0_{\phi}$</td>
<td>6±4</td>
<td>31.12±0.07</td>
<td>19±13</td>
<td>–</td>
<td>&lt;0.101</td>
<td>–</td>
</tr>
</tbody>
</table>

- The difference between the case A) and B) is due to the $K^+K^-$ correction in the Dalitz structure
\[ R_+ = \frac{\mathcal{B}(B^+ \to J/\psi K^+ K^- K^+)}{\mathcal{B}(B^+ \to J/\psi K^+)} = 1.39 \pm 0.15 \pm 0.07 \]

\[ R_0 = \frac{\mathcal{B}(B^0 \to J/\psi K^+ K^- K^0_s)}{\mathcal{B}(B^0 \to J/\psi K^0_s)} = 1.54 \pm 0.40 \pm 0.08 \]

\[ R_\phi = \frac{\mathcal{B}(B^0 \to J/\psi K^0_s)}{\mathcal{B}(B^+ \to J/\psi K^+)} = 0.48 \pm 0.09 \pm 0.02 \]

\[ R_{2K} = \frac{\mathcal{B}(B^0 \to J/\psi K^+ K^- K^0_s)}{\mathcal{B}(B^+ \to J/\psi K^+ K^- K^+)} = 0.52 \pm 0.09 \pm 0.03 \]

- BF in agreement with the prediction of the quark spectator model
- \( K^+ K^- \) contribution to BF outside the \( \phi \) mass region: first measurement
- Old Babar measurement on \( B \to J/\psi K \) confirmed, now with \( >4 \) times precision
  ⇒ currently highest world precision of these BF measurements!

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**B → J/ψKKK: search for exotics**

- Signal box selected: $m_{ES}>5.27$ GeV/c²; $|\Delta E|<30$ MeV (B⁺) and $|\Delta E|<25$ MeV (B⁰)
- Mass resolution at the J/ψφ threshold: 2 MeV/c²
- Search for resonant states in J/ψKK, J/ψK, KKK
- J/ψφ invariant mass gained more attention because of several recent publications
- J/ψ and φ are vectors: high spin contribution expected
- Efficiency as function of the invariant mass must be taken into account
- In our fit: mass and width fixed to the CDF values (first publication on res. structure)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ref</th>
<th>$M_{X(4140)}$ [MeV/c²]</th>
<th>$\Gamma_{X(4140)}$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>PRL102.242002(2009)</td>
<td>4143.0 ± 2.9 ± 1.2</td>
<td>11.7^{+8.3}_{-5.0} ± 3.7</td>
</tr>
<tr>
<td>CDF</td>
<td>arXiv:1101.6058</td>
<td>4143.4^{+2.9}_{-3.0} ± 0.6</td>
<td>15.2^{+10.4}_{-6.1} ± 2.5</td>
</tr>
<tr>
<td>LHCb</td>
<td>PRD85,091103(2012)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CMS</td>
<td>PRB734,261(2014)</td>
<td>4148.0 ± 2.4 ± 6.3</td>
<td>28^{+15}_{-11} ± 19</td>
</tr>
<tr>
<td>D0</td>
<td>PRD89,012004(2014)</td>
<td>4159.0 ± 4.3 ± 6.6</td>
<td>19.9 ± 12.6^{+1.0}_{-8.0}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ref</th>
<th>$M_{X(4270)}$ [MeV/c²]</th>
<th>$\Gamma_{X(4270)}$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>arXiv:1101.6058</td>
<td>4274.4^{+8.4}_{-6.7} ± 1.9</td>
<td>32.3^{+21.1}_{-15.3} ± 7.6</td>
</tr>
<tr>
<td>LHCb</td>
<td>PRD85,091103(2012)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CMS</td>
<td>PRB734,261(2014)</td>
<td>4313.8 ± 5.3 ± 7.3</td>
<td>38^{+30}_{-15} ± 16</td>
</tr>
<tr>
<td>D0</td>
<td>PRD89,012004(2014)</td>
<td>≈ 4360</td>
<td>30 (fixed)</td>
</tr>
</tbody>
</table>

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The controversial picture of $m_{J/\psi}$
**B → J/ψϕK: reconstruction efficiency**

- Efficiency lower at the J/ψϕ mass threshold due to the difficulty to reconstruct low momentum kaon
- Charged B channel more sensitive to the efficiency change at the J/ψϕ threshold compared to B^0 channel, due to the poorer ϕ (→K^+K^-)reconstruction
$B \to J/\psi \phi K$: invariant mass fit

- Unbinned maximum likelihood fit
- 2 Breit-Wigner + PHSP function re-weighted by 2D-efficiency map from Dalitz plots
- Central value and width of the Breit-Wigners are fixed in the fit
- Background estimated from $\Delta E$ sidebands

Background evaluated with $\Delta E$ sidebands

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$B \rightarrow J/\psi \phi K$: mass fit results

<table>
<thead>
<tr>
<th>Channel</th>
<th>Fit</th>
<th>$f_X(4140)$ (%)</th>
<th>$f_X(4270)$ (%)</th>
<th>2D $\chi^2/\nu$</th>
<th>1D $\chi^2/\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+$</td>
<td>A</td>
<td>9.2 ± 3.3</td>
<td>10.6 ± 4.8</td>
<td>12.7/12</td>
<td>6.5/20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>9.2 ± 2.9</td>
<td>0.0</td>
<td>17.4/13</td>
<td>15.0/17</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.0</td>
<td>10.0 ± 4.8</td>
<td>20.7/13</td>
<td>19.3/19</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>0.0</td>
<td>0.0</td>
<td>26.4/14</td>
<td>34.2/18</td>
</tr>
<tr>
<td>$B^0 + B^+$</td>
<td>A</td>
<td>7.3 ± 3.8</td>
<td>12.0 ± 4.9</td>
<td>8.5/12</td>
<td>15.9/19</td>
</tr>
</tbody>
</table>

Our fit:
- S-wave relativistic Breit-Wigners;
- non-resonant contribution represented by a constant term;
- no interference allowed between the fit components;
- small bkg from $\Delta E$ sidebands, consistent with PHSP behavior (incorporated in the non-resonant PHSP term);
- high spin contribution expected, but angular term non included due to poor statistics (we assume that the resonances decay isotropically)

\[
\begin{aligned}
\text{fit without resonances (phase space):} & \quad \chi^2/\text{ndof} = 26.4/14 \\
\text{fit with two resonances (parameters fixed to CDF):} & \quad \chi^2/\text{ndof} = 12.7/12 \\
n f_X(4140) = (9.2\pm3.3\pm4.7)\%, & \quad f_X(4270) = (10.6\pm4.8\pm7.1)\% \\
n f_X(4140) = (13.2\pm3.8\pm6.8)\%, & \quad f_X(4270) = (10.9\pm5.2\pm7.3)\%
\end{aligned}
\]

- These results are background corrected.
- Small background: purity 89% ($B^+$) and 82% ($B^0$)
- $\chi^2$ of fits acceptable in all cases: no hypothesis should be rejected
**B → J/ψϕK: fractions**

X(4140) and X(4270) on 422.5 fb⁻¹ integrated luminosity: <2σ effect (within sys. uncertainties)

No additional structures are shown in the other invariant mass systems

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ref</th>
<th>f_{X(4140)} [%]</th>
<th>f_{X(4270)} [%]</th>
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<td>arXiv:1101.6058</td>
<td>14.9 ± 2.9 ± 2.4</td>
<td>&lt; 7</td>
</tr>
<tr>
<td>LHCb</td>
<td>PRD85,091103(2012)</td>
<td>13.4 ± 3.0 (*)</td>
<td>19 ± 7 ± 4</td>
</tr>
<tr>
<td>CMS</td>
<td>PRB734,261(2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D0</td>
<td>PRD89,012004(2014)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) estimated from the number of signal events quoted
What happens if we re-weight data (not the fit function) by the Dalitz efficiency?

(a) Average efficiency distribution as a function of the $J/\psi \phi$ mass for $B^+ \rightarrow J/\psi \phi K^+$

(b) Efficiency corrected $J/\psi \phi$ for the combined $B^+$ and $B^0$ samples

(c) Efficiency corrected and background subtracted $J/\psi \phi$ mass spectrum for the combined $B^+$ and $B^0$ samples

Significance < 2 $\sigma$ within systematic uncertainties
$B \rightarrow J/\psi \phi K: \text{comparison (I)}$

What did we learn from the other experiments? The result of the analysis of $m(J/\psi \phi)$ is still controversial.

- **LHCb and CMS**
  - LHCb: 275.2 events
  - CMS: scaled 0.150

- **D0 and CMS**
  - D0: 203.3 events
  - CMS: scaled 0.143

- **CDF and CMS**
  - CDF: 93.0 events
  - CMS: scaled 0.040

CDF Coll., PRL 102, 242002 (2009); LHCb Coll., PRD 85, 091103 (2010); D0 Coll., PRD 89, 012004 (2014); CMS Coll., PRB 734, 261 (2014)

More details: see poster session, 2th of August, poster n. 11

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$B \rightarrow J/\psi \phi K$: comparison (II)

Note: BABAR re-weighed data ($B^0 + B^\pm$); other experiments: only $B^\pm$, only $J/\psi \rightarrow \mu \mu$
Search for new resonances via $\gamma \gamma$ interactions
**Dalitz analysis** $\eta_c \rightarrow K^+K^-\eta/\pi^0$

- 2-photon interactions: $e^+e^-$ interact and emit a quasi-real photon, which can form resonances.
- **Clear signature**: $J=0^\pm, 2^\pm, \ldots$; the resonant state (if any) cannot be vector
- In BABAR resonant states are observed in 2-photon interactions: $X(3915)$, ...
- Low $p_t$ respect to the beam axis
- Final state emitted along the beam direction

$\eta_c(nS)$ decays not well known

$$\sum B(\eta_c(1S)) \approx 20\%; \quad \sum B(\eta_c(2S)) \approx 5\%$$

- Advantage of this search in BaBar: large event yield
- Excellent S/B: non-resonant hadronic cross section is small
Search for exotic states in $\eta_c$ decays

- BES III showed:
  - $6.7 \pm 3.2$ events for $\eta_c(nS) \rightarrow K^+K^-\eta$
  - $54.9 \pm 9.2$ events for $\eta_c(nS) \rightarrow K^+K^-\pi^0$

- No publication exists on Dalitz plot analysis of $\eta_c$ to 3 pseudo-scalar mesons
  - $\eta_c(1S) \rightarrow K^+K^-\eta$: 1145 events
    First observation
  - $\eta_c(2S) \rightarrow K^+K^-\eta$: 47 events
    First evidence
  - $\eta_c(1S) \rightarrow K^+K^-\pi^0$: 4518 events
  - $\eta_c(2S) \rightarrow K^+K^-\pi^0$: 178 events

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (MeV/c$^2$)</th>
<th>$\Gamma$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c \rightarrow K^+K^-\eta$</td>
<td>$2984.1 \pm 1.1 \pm 2.1$</td>
<td>$34.8 \pm 3.1 \pm 4.0$</td>
</tr>
<tr>
<td>$\eta_c \rightarrow K^+K^-\pi^0$</td>
<td>$2979.8 \pm 0.8 \pm 3.5$</td>
<td>$25.2 \pm 2.6 \pm 2.4$</td>
</tr>
<tr>
<td>$\eta_c(2S) \rightarrow K^+K^-\eta$</td>
<td>$3635.1 \pm 5.8 \pm 2.1$</td>
<td>11.3 (fixed)</td>
</tr>
<tr>
<td>$\eta_c(2S) \rightarrow K^+K^-\pi^0$</td>
<td>$3637.0 \pm 5.7 \pm 3.4$</td>
<td>11.3 (fixed)</td>
</tr>
</tbody>
</table>
BF measurements

<table>
<thead>
<tr>
<th>Channel</th>
<th>Event yield</th>
<th>Weights</th>
<th>$\mathcal{R}$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c \rightarrow K^+ K^- \pi^0$</td>
<td>$4518 \pm 131 \pm 50$</td>
<td>$17.0 \pm 0.7$</td>
<td>$0.571 \pm 0.025 \pm 0.051$</td>
<td>$32 \sigma$</td>
</tr>
<tr>
<td>$\eta_c \rightarrow K^+ K^- \eta \ (\eta \rightarrow \gamma \gamma)$</td>
<td>$853 \pm 38 \pm 11$</td>
<td>$21.3 \pm 0.6$</td>
<td>$0.602 \pm 0.032 \pm 0.065$</td>
<td>$21 \sigma$</td>
</tr>
<tr>
<td>$B(\eta_c \rightarrow K^+ K^- \eta)/B(\eta_c \rightarrow K^+ K^- \pi^0)$</td>
<td>$292 \pm 20 \pm 7$</td>
<td>$31.2 \pm 2.1$</td>
<td>$0.523 \pm 0.040 \pm 0.083$</td>
<td>$14 \sigma$</td>
</tr>
<tr>
<td>$\eta_c \rightarrow K^+ K^- \eta \ (\eta \rightarrow \pi^+ \pi^- \pi^0)$</td>
<td>$178 \pm 29 \pm 39$</td>
<td>$14.3 \pm 1.3$</td>
<td>$0.82 \pm 0.21 \pm 0.27$</td>
<td>$3.7 \sigma$</td>
</tr>
<tr>
<td>$B(\eta_c \rightarrow K^+ K^- \eta)/B(\eta_c \rightarrow K^+ K^- \pi^0)$</td>
<td>$47 \pm 9 \pm 3$</td>
<td>$17.4 \pm 0.4$</td>
<td>$2.5 \sigma$</td>
<td>$4.9 \sigma$</td>
</tr>
<tr>
<td>$\eta_c(2S) \rightarrow K^+ K^- \eta$</td>
<td>$88 \pm 27 \pm 23$</td>
<td></td>
<td></td>
<td>$2.5 \sigma$</td>
</tr>
<tr>
<td>$\eta_c(2S) \rightarrow K^+ K^- \pi^0$</td>
<td>$2 \pm 5 \pm 2$</td>
<td></td>
<td></td>
<td>$0.0 \sigma$</td>
</tr>
</tbody>
</table>

$\eta_c(1S)$
\[ \mathcal{R}(\eta_c) = \frac{B(\eta_c \rightarrow K^+ K^- \eta)}{B(\eta_c \rightarrow K^+ K^- \pi^0)} = 0.571 \pm 0.025 \pm 0.051 \]

BESIII: $0.46 \pm 0.24$

$\eta_c(2S)$
\[ \mathcal{R}(\eta_c(2S)) = \frac{B(\eta_c(2S) \rightarrow K^+ K^- \eta)}{B(\eta_c(2S) \rightarrow K^+ K^- \pi^0)} = 0.82 \pm 0.21 \pm 0.27 \]
Dalitz plot: $\eta_c(1S) \rightarrow K^+K^-\eta$

<table>
<thead>
<tr>
<th>Final state</th>
<th>Fraction %</th>
<th>Phase (radians)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0(1500)\eta$</td>
<td>23.7 ± 7.0 ± 1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>$f_0(1710)\eta$</td>
<td>8.9 ± 3.2 ± 0.4</td>
<td>2.2 ± 0.3 ± 0.1</td>
</tr>
<tr>
<td>$K_0(1430)^+K^-$</td>
<td>16.4 ± 4.2 ± 1.0</td>
<td>2.3 ± 0.2 ± 0.1</td>
</tr>
<tr>
<td>$f_0(2200)\eta$</td>
<td>11.2 ± 2.8 ± 0.5</td>
<td>2.1 ± 0.3 ± 0.1</td>
</tr>
<tr>
<td>$K_0^*(1950)^+K^-$</td>
<td>2.1 ± 1.3 ± 0.2</td>
<td>-0.2 ± 0.4 ± 0.1</td>
</tr>
<tr>
<td>$f_0(1525)\eta$</td>
<td>7.3 ± 3.8 ± 0.4</td>
<td>1.0 ± 0.1 ± 0.1</td>
</tr>
<tr>
<td>$f_0(1350)\eta$</td>
<td>5.0 ± 3.7 ± 0.5</td>
<td>0.9 ± 0.2 ± 0.1</td>
</tr>
<tr>
<td>$f_0(980)\eta$</td>
<td>10.4 ± 3.0 ± 0.5</td>
<td>-0.3 ± 0.3 ± 0.1</td>
</tr>
<tr>
<td>NR</td>
<td>15.5 ± 6.9 ± 1.0</td>
<td>-1.2 ± 0.4 ± 0.1</td>
</tr>
<tr>
<td>Sum</td>
<td>100.0 ± 11.2 ± 2.5</td>
<td></td>
</tr>
<tr>
<td>$\chi^2/\nu$</td>
<td>87/65</td>
<td></td>
</tr>
</tbody>
</table>

First evidence of $K_0^*(1430)^\pm \rightarrow K^\pm\eta$ seen as a peak

Elisabetta Prencipe

ICNPF 2014, Koymbari
Dalitz plot: $\eta_c(1S) \rightarrow K^+K^-\pi^0$

$K^\pm\pi^0$ dominated by $K_0^*(1430)$

<table>
<thead>
<tr>
<th>Final state</th>
<th>Fraction %</th>
<th>Phase (radians)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_0^*(1430)^+K^-$</td>
<td>$33.8 \pm 1.9 \pm 0.4$</td>
<td>$0.$</td>
</tr>
<tr>
<td>$K_0^*(1950)^+K^-$</td>
<td>$6.7 \pm 1.0 \pm 0.3$</td>
<td>$-0.67 \pm 0.07 \pm 0.03$</td>
</tr>
<tr>
<td>$a_0(980)\pi^0$</td>
<td>$1.9 \pm 0.1 \pm 0.2$</td>
<td>$0.38 \pm 0.24 \pm 0.02$</td>
</tr>
<tr>
<td>$a_0(1450)\pi^0$</td>
<td>$10.0 \pm 2.4 \pm 0.8$</td>
<td>$-2.4 \pm 0.05 \pm 0.03$</td>
</tr>
<tr>
<td>$a_2(1320)\pi^0$</td>
<td>$2.1 \pm 0.1 \pm 0.2$</td>
<td>$0.77 \pm 0.20 \pm 0.04$</td>
</tr>
<tr>
<td>$K_2^*(1430)^+K^-$</td>
<td>$6.8 \pm 1.4 \pm 0.3$</td>
<td>$-1.67 \pm 0.07 \pm 0.03$</td>
</tr>
<tr>
<td>NR</td>
<td>$24.4 \pm 2.5 \pm 0.6$</td>
<td>$1.49 \pm 0.07 \pm 0.03$</td>
</tr>
<tr>
<td>Sum</td>
<td>$85.8 \pm 3.6 \pm 1.2$</td>
<td></td>
</tr>
<tr>
<td>$\chi^2/\nu$</td>
<td>$212/130$</td>
<td></td>
</tr>
</tbody>
</table>

Elisabetta Prencipe

ICNPF 2014, Koymbari
$K_0^*(1430)$ properties

- $M = 1438 \pm 8 \pm 4$ MeV/$c^2$
  in agreement with LASS

- $\Gamma = 210 \pm 20 \pm 12$ MeV
  $\approx 3\sigma$ smaller than LASS result
  294±23 LASS
  270±80 (PDG average)

$$\frac{\mathcal{B}(K_0^* \to \eta K)}{\mathcal{B}(K_0^* \to \pi K)} = 0.092 \pm 0.025^{+0.010}_{-0.025}$$
Radiative Y(nS) transitions
Radiative $\Upsilon(nS)$ decays: motivation

- Generally well predicted from phenomenological models
  PRD 84 (2011) 094501

- Measure BF and mass splitting for radiative transition using BaBar $\Upsilon(2S)$ and $\Upsilon(3S)$ data

- BaBar sample: 14 fb$^{-1}$ $\Upsilon(2S)$; 28 fb$^{-1}$ $\Upsilon(3S)$

- Analysis measure:
  $\Upsilon(3S) \rightarrow \gamma \chi_{b\perp}(2P), \chi_{b\perp}(2P) \rightarrow \gamma \Upsilon(1S, 2S)$
  $\Upsilon(1S, 2S) \rightarrow \mu^+\mu^-$
  $3S \rightarrow 2P \rightarrow 1S, 3S \rightarrow 2P \rightarrow 1S$

  $\Upsilon(2S) \rightarrow \gamma \chi_{b\perp}(1P), \chi_{b\perp}(1P) \rightarrow \gamma \Upsilon(1S), \Upsilon(1S) \rightarrow \mu^+\mu^-$
  $2S \rightarrow 1P \rightarrow 1S$

  $\Upsilon(3S) \rightarrow \gamma \chi_{b\perp}(1P), \chi_{b\perp}(1P) \rightarrow \gamma \Upsilon(1S), \Upsilon(1S) \rightarrow \mu^+\mu^-$
  $3S \rightarrow 1P \rightarrow 1S$

- Event samples:
  - 2 calorimeter photons;
  - 1 calorimeter $\gamma$, one $\gamma$ from conversion
2 calorimeter photons

$Y(3S) \rightarrow \gamma \chi_{b1}(2P) \rightarrow \gamma Y(2S)$

$\chi_{b2}(2P)$

$\chi_{b1}(2P)$

$Y(3S) \rightarrow \gamma \chi_{b1}(2P) \rightarrow \gamma Y(1S)$

$\chi_{b2}(2P)$

$\chi_{b1}(2P)$

$\chi_{b0}(2P)$

$Y(2S) \rightarrow \gamma \chi_{b1}(1P) \rightarrow \gamma Y(1S)$

$\chi_{b2}(1P)$

$\chi_{b1}(1P)$

$\chi_{b0}(1P)$
1 $\gamma$ from conversion, 1 $\gamma$ from calorimeter

$Y(2S) \rightarrow \gamma \chi_b(1P) \rightarrow \gamma Y(1S)$

$Y(3S) \rightarrow \gamma \chi_b(1P) \rightarrow \gamma Y(1S)$

$Y(3S) \rightarrow \gamma \chi_b(2P) \rightarrow \gamma Y(2S)$

$Y(3S) \rightarrow \gamma \chi_b(2P) \rightarrow \gamma Y(1S)$
Summary

- New exciting results from BABAR in charmonium and bottomonium spectroscopy
- Search for hybrids in the B decays: $B^{±,0} \rightarrow J/\psi KKK^{±,0}$ (charged and neutral B)
  - All $K^+K^-$ inv mass range under exam for the *first time*: no main structure is evident
  - $K^+K^-$ inv mass restricted to $\phi$ meson in $[1.004;1.034]$ GeV/c$^2$:
    - $J/\psi K$ and KKK systems PHSP distributed;
    - $J/\psi\phi$ system shows a non-PHSP behaviour
- Search for $X(4140)$ and $X(4270)$ in $J/\psi\phi$ inv mass system: no evidence.
- UL are set up compatible with LHCb, and compatible with BF set up from CDF, CMS, D0.
- Interpretation of $J/\psi\phi$ inv mass system is difficult, because:
  - dynamics of $J/\psi$ and $\phi$ (vectors) interaction is complicated: full Dalitz analysis needed;
  - different hypotheses for explaining the presence of a non-PHSP behavior at the threshold
  - BABAR results consistent with other experiments within uncertainties.
- New BF set up: currently highest world precision
- Non resonant $K^+K^-$ contribution to the BF of $B \rightarrow J/\psi KKK$: *first measurement*
- **First observation** of $K^*_0(1430)$ in the Dalitz analysis of $\eta_c \rightarrow KK\eta$ via $\gamma\gamma$ interaction
- **Best evidence** for $\chi_{b1}(nP) \rightarrow \gamma Y$ transition
Thank you for your attention!