Latest Results from BESIII

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NSTAR 2013, 27\textsuperscript{th} – 30\textsuperscript{th} May, 2013
Peñiscola, Valencian Community (Spain)
Outline

➤ Introduction

➤ Selected recent results
  ● Charmonium transitions and decays
  ● “Exotic” charmonium states
  ● Excited baryon program

➤ Summary and Outlook

For details, see Wenlong’s talk @ parallel B5
BEPCII -- A High Luminosity Double-ring Collider
BEPCII and BESIII Detector

**BEPCII:**
- $\sqrt{s} : 2.0-4.6$ GeV
- Luminosity:
  - Design: $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$
  - Achieved: $\sim 7.08 \times 10^{32}$ cm$^{-2}$s$^{-1}$

**BESIII:**
- MDC: $\sigma_p/p = 0.5\%$ at $1$ GeV/c
- EMC: $\sigma_E/E = 2.5\%$ at $1$ GeV
- TOF: 80ps(barrel), 110ps(endcap)
- MUC: 9 layers RPC for barrel, 8 for endcap
BESIII Collaboration

~360 members
50 institutions from 11 countries

USA (6)
Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (12)
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab
Netherland: KVI/Univ. of Gröningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)
Seoul Nat. Univ.

Japan (1)
Tokyo Univ.

Pakistan (2)
Univ. of Punjab
COMSAT CIIT

China (28)
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ.
Zhongshan Univ., Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoqing Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
...
Physics in the Charm Region

- Charmonium physics:
  - Spectroscopy, transitions, decays
  - "Exotic" charmonium states
- Light hadron physics: (using charmonium as source to produce light hadrons)
  - meson & baryon spectroscopy
  - glueball & hybrid
- Open Charm physics:
- QCD & Tau physics:
  - ...

![Diagram of mass spectrum with states and transitions labeled.](image)
## BESIII Data Samples

<table>
<thead>
<tr>
<th>Energy</th>
<th>Topics (Highlight)</th>
<th>Analyzed</th>
<th>Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi$</td>
<td>light hadron</td>
<td>225M decays</td>
<td>1.2B decays</td>
</tr>
<tr>
<td>$\Psi'$</td>
<td>charmonium, light hadron</td>
<td>106M decays</td>
<td>600M decays</td>
</tr>
<tr>
<td>$\Psi(3770)$</td>
<td>open charm</td>
<td>2.9 fb$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$E_{cm} = 4010$ MeV</td>
<td>Exotic charmonium states</td>
<td>482pb$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$E_{cm} = 4260$ MeV</td>
<td>Exotic charmonium states</td>
<td>525pb$^{-1}$</td>
<td>2fb$^{-1}$ (ongoing)</td>
</tr>
<tr>
<td>$E_{cm} = 4360$ MeV</td>
<td>Exotic charmonium states</td>
<td></td>
<td>520pb$^{-1}$</td>
</tr>
</tbody>
</table>

* Other energy points for line scan studies, etc.
Charmonium Transitions and Decays

- EM transitions and decays: clean, relatively simple.
  - potential models
  - lattice QCD calculations
  - EFT
    - $\psi(2S) \rightarrow \gamma \eta_c'$
    - $J/\psi \rightarrow \gamma \gamma \gamma$
- Baryon-involving decays
  - test pQCD
  - helicity selection rules (HSR)
    - $\eta_c \rightarrow \text{Baryon + anti-Baryon}$
First Observation of $\psi' \rightarrow \gamma \eta_c'$

- Magnetic dipole transition, $\psi' \rightarrow \gamma \eta_c'$
  - $\eta_c' \rightarrow K_s K \pi / K^+ K^- \pi^0$
- $E_\gamma \sim 50$ MeV: high background
  - data driven technique
- Combined significance: $> 10 \sigma$
- Measure: $B(\psi' \rightarrow \gamma \eta_c') \times B(\eta_c' \rightarrow \bar{K}K \pi) = (2.98 \pm 0.57 \pm 0.48) \times 10^{-6}$

- Combined with BaBar measurement of $B(\eta_c' \rightarrow K K \pi)$ to obtain:
  $B(\psi' \rightarrow \gamma \eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$
- Consistent with potential model prediction: $(0.1-6.2) \times 10^{-4}$ [1]

Test of non-perturbative QCD with first order corrections

\[
R = \frac{\mathcal{B}(J/\psi \to 3\gamma)}{\mathcal{B}(J/\psi \to e^+ e^-)} = \frac{64(\pi^2 - 9)}{243 \pi} \alpha \left( 1 - 7.3 \frac{\alpha_s(r)}{\pi} \right)
\]

\[\alpha_s \sim 0.19 : R \sim 3.0 \times 10^{-4}\]

Suppress EM bkg. by using J/ψ from ψ’
Measure: \(B(J/\psi \rightarrow \gamma \gamma \gamma) = (11.3 \pm 1.8 \pm 2.0) \times 10^{-6}\)

BESIII + CLEOc: \(R = (1.95 \pm 0.37) \times 10^{-4}\)

Need radiative and relativistic correction

Evidence for ηc → γγ; complementary to two-photon fusion measurements
\(B(\eta_c \rightarrow \gamma \gamma) = (2.6 \pm 0.7 \pm 0.7) \times 10^{-4}\)
\[ \eta_c \rightarrow \text{Baryon + anti-Baryon} \]

- HSR prohibition

- Charmed-meson loop model explains \( \eta_c \rightarrow \text{ppbar, } \Lambda \Lambda \text{bar} \)

\[
J/\Psi \rightarrow \gamma \eta_c \quad \eta_c \rightarrow \begin{cases} \Sigma^+ \Sigma^- \\ \Xi^+ \Xi^- \end{cases}
\]
\[
\Sigma^+ \rightarrow p \pi^0 \\
\Xi^- \rightarrow \Lambda \pi^- \rightarrow p \pi^- \pi^-
\]

- Measurements:

\[
Br(\eta_c \rightarrow \Sigma^+ \Sigma^-) = (2.11 \pm 0.28 \pm 0.18 \pm 0.50) \times 10^{-3}
\]
\[
Br(\eta_c \rightarrow \Xi^+ \Xi^-) = (0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}
\]

- Charmed-meson loop prediction:

\[
Br(\eta_c \rightarrow \Sigma^+ \Sigma^-) = (0.51 - 1.00) \times 10^{-3}
\]
\[
Br(\eta_c \rightarrow \Xi^+ \Xi^-) = (0.48 - 0.96) \times 10^{-3}
\]
Charmonium Spectroscopy

Many charmonium states above \( \bar{D}D \) threshold discovered

Production in \( e^+e^- \) and B decay (Belle, BaBar, CDF, D0, CLEO)

Some are likely conventional \( cc \) states, e.g. \( \chi_{cJ}(2P) \)

Some have surprising properties

Many need confirmation (NC!), spin-parity determination and search for other states to complete the spectrum. Statistical capability of current B-factory data sets is limited

Complementary to light quark systems:
Is there evidence for gluonic degrees of freedom in the spectrum of charmonium?

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Review from Quarkonium Working Group

<table>
<thead>
<tr>
<th>State</th>
<th>( m ) (MeV)</th>
<th>( \Gamma ) (MeV)</th>
<th>( J^{PC} )</th>
<th>Year</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X(3872) )</td>
<td>3871.52±0.20</td>
<td>1.3±0.6</td>
<td>1++/2−−</td>
<td>2003</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt;2.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( X(3915) )</td>
<td>3915.6 ±3.1</td>
<td>28±10</td>
<td>0/2?+</td>
<td>2004</td>
<td>OK</td>
</tr>
<tr>
<td>( X(3940) )</td>
<td>3942^{+9}_{-8}</td>
<td>37^{+27}_{-17}</td>
<td>?+</td>
<td>2007</td>
<td>NC!</td>
</tr>
<tr>
<td>( G(3900) )</td>
<td>3943 ±21</td>
<td>52±11</td>
<td>1−−</td>
<td>2007</td>
<td>OK</td>
</tr>
<tr>
<td>( Y(4008) )</td>
<td>4008^{+121}_{-49}</td>
<td>226±97</td>
<td>1−−</td>
<td>2007</td>
<td>NC!</td>
</tr>
<tr>
<td>( Z_1(4050)^+ )</td>
<td>4051^{+24}_{-43}</td>
<td>82^{+51}_{-55}</td>
<td>?</td>
<td>2008</td>
<td>NC!</td>
</tr>
<tr>
<td>( Y(4140) )</td>
<td>4143.4 ±3.0</td>
<td>15^{+11}_{-7}</td>
<td>??+</td>
<td>2009</td>
<td>NC!</td>
</tr>
<tr>
<td>( X(4160) )</td>
<td>4156^{+29}_{-25}</td>
<td>139^{+113}_{-65}</td>
<td>??+</td>
<td>2007</td>
<td>NC!</td>
</tr>
<tr>
<td>( Z_2(4250)^+ )</td>
<td>4248^{+185}_{-45}</td>
<td>177^{+321}_{-72}</td>
<td>?</td>
<td>2008</td>
<td>NC!</td>
</tr>
<tr>
<td>( Y(4260) )</td>
<td>4263 ±5</td>
<td>108±14</td>
<td>1−−</td>
<td>2005</td>
<td>OK</td>
</tr>
</tbody>
</table>

... ... ... ... ... ... ... ... ... ... ... ...
Y(4260) and Y(4360)

- Y(4260), anomalous enhancement in \( J/\psi \pi \pi \) cross section discovered by BaBar in initial state radiation (ISR) \( e^+e^- \) production (confirmed by Belle and CLEO)

- Must be a 1\(^{-}\) state
  - overpopulates 1\(^{-}\) charmonium states
  - above \( \bar{D}D \) threshold but does not couple to \( \bar{D}D \) like others

- Similarly mysterious Y(4360) in \( \psi' \pi \pi \)

- Study at BESIII by collecting data at fixed \( E_{cm} = 4.26 \) and 4.36 GeV.
  - study systematically looking at many channels

\( \sigma(\pi^{+}\pi^{-}\bar{J}/\psi) \) (pb)

\[ \text{Belle Collaboration, arXiv:1304.0121} \]

\[ \text{BESIII arXiv:1303.5949} \]

\[ \text{ISR production (BaBar, Belle)} \]
\( Z_c(3900) \) in \( Y(4260) \rightarrow J/\psi \pi^+\pi^- \)

\( \sigma^B(e^+e^- \rightarrow \pi^+\pi^- J/\psi ) = 62.9 \pm 1.9 \pm 3.7 \text{ pb} \) agrees with Babar & Belle.

Observe structures in both \( \pi^+J/\psi \) and \( \pi^- J/\psi \) invariant mass spectra.
\( Z_c(3900) \) in \( Y(4260) \rightarrow J/\psi \pi^+\pi^- \)

- \( \pi^+\pi^- \) mass spectrum: \( f_0(980), \sigma(500) \), generate no peak in \( \pi^\pm J/\psi \) spectrum.

- \( \pi^\pm J/\psi \) mass spectrum: peak at 3.9GeV/c^2 (\( Z_c(3900) \)); the wider peak at low mass is a kinematic reflection of the \( Z_c(3900) \).
$Z_c(3900)$ in $Y(4260) \rightarrow J/\psi \pi^+ \pi^-$

BESIII arXiv: 1303.5949
Accepted by PRL

- Fit projection to obtain:
  - $M(Z_c) = 3899 \pm 3.6 \pm 4.9$ MeV/c$^2$
  - $\Gamma(Z_c) = 46 \pm 10 \pm 20$ MeV/c$^2$
  - Significance: $> 8\sigma$

At 4260 MeV production of $Z_c \pi^\pm$ is $(21.5 \pm 3.3)$% of the $J/\psi \pi^+ \pi^-$ cross section

- Couples to ccbar
- Has electric charge
- Interpretation:
  - 4-quark states?
  - DD* interaction at threshold?

- Confirmed by Belle(arXiv:1304.0121) in ISR
Y(4260) production and by Kam Seth (arXiv: 1304.3036) using 586 pb$^{-1}$ of CLEO data taken at a CM energy of 4170MeV.

307 ± 48 events.
The nature of $Z_c(3900)$?

From SPIRE HEP Database (17th, May)

1. **Tetraquarks**
   - arXiv: 1110.1333, 1303.6857
   - arXiv: 1304. (0345, 1301, 6433, 7080, 7816)

2. **Hadronic molecules**
   - arXiv: 1303.6608,
   - arXiv: 1304. (2882, 1850, 5748, 7467)

3. **Four quark state (1 or 2)**
   - arXiv: 1304.0380

4. **Meson loop**
   - arXiv: 1303.6355, 1304.4458

5. **Initial State Pion Emission (ISPE) model**
   - arXiv: 1303.6842, 1304.5845

With more data presently analysed, BESIII will be able to exclude various interpretations of the $Z_c(3900)$!
Excited Baryon Program using charmonium decays

Advantages of excited baryon study using charmonium decay:
1: Isospin filter: less states, less complicated.
\[ \psi (I = 0) \rightarrow p (I=1/2) \quad \bar{p} \pi^0 (I=1/2) \quad N^* \rightarrow \text{yes}, \quad \Delta^* \rightarrow \text{no} \]
2: Study by many decay channels, such as \( \pi^0N, \eta N, \eta' N, \omega N \ldots \)
3: Large statistics for charmonium states
4: Study of \( N^*, \Lambda^*, \Sigma^*, \Xi^* \)

See Wenlong’s talk @parallel B5
N* in $\psi' \rightarrow p \bar{p} \pi^0$


- Full partial wave analysis.
- Two new N* states observed.

See Wenlong’s talk @parallel B5
J/ψ → ω p ¯p

- No obvious p ¯p threshold enhancement
- B(J/ψ → ωX(p ¯p) → ω p ¯p) < 3.9*10^{-6}
- Disfavors Pure FSI interpretation
- No obvious structures in M_pω

pp bound state? glueball? FSI? …

arXiv: 1303.3040
Accepted by PRD
Summary and Outlook

- Diverse program of hadron physics ongoing at BESIII
  - new or more precise experimental tests of calculations of charmonium transitions and decays
  - an unexpected result in the charmonium spectrum: a charged charmonium-like state
  - many ongoing N* studies using J/ψ or ψ’ decay
- Expect vibrant program headed into the future:
  - already have at least 4X statistics in both J/ψ and ψ’ decays
  - analysis has started on E_{cm} = 4360 \text{ MeV}
  - expect 4X statistics at E_{cm} = 4260 \text{ MeV} by the end of summer
Thank you!
$J/\psi \rightarrow \omega \ \bar{p}p$

arXiv: 1303.3040
Accepted by PRD
pp mass threshold structure in $J/\psi \rightarrow \gamma \bar{p}p$

- Confirmed by BESIII, Chinese Physic C 34, 421(2010)

- PWA of $J/\psi \rightarrow \gamma p\bar{p}$ was first performed, PRL 108, 112003(2012)

Theoretical interpretation:
- conventional meson?
- $p\bar{p}$ bound state/multiquark
- glueball
- Final state interaction (FSI)
- ...

\[ J^{pc} = 0^{-+} \rightarrow >6.8\sigma \text{ better than other } J^{pc} \text{ assignments.} \]

\[ M = 1832^{+19}_{-5} \text{ (stat)}^{+18}_{-17} \text{ (syst)} \pm 19 \text{ (mod)} \text{MeV}/c^2 \]

\[ \Gamma = 13 \pm 20 \text{ (stat)}^{+11}_{-33} \text{ (syst)} \pm 4 \text{ (mod)} \text{MeV}/c^2 \text{ or } \Gamma < 76 \text{ MeV}/c^2 \text{ @90\% C.L.} \]

\[ B(J/\psi \rightarrow \gamma X(p\bar{p}))B(X(p\bar{p}) \rightarrow p\bar{p}) = (9.0^{+0.4}_{-1.1} \text{ (stat)}^{+1.5}_{-5.0} \text{ (syst)} \pm 2.3 \text{ (mod)}) \times 10^{-5} \]
Obviously different line shape of p\bar{p} mass spectrum near threshold from that in J/\psi decays.

**PWA results:**
- Significance of X(p\bar{p}) is > 6.9\sigma.
- The production ratio R:
  \[ R = \frac{B(\psi' \rightarrow \gamma X(p\bar{p}))}{B(J/\psi \rightarrow \gamma X(p\bar{p}))} \]
  \[ = (5.08^{+0.71}_{-0.45} \text{ (stat)}^{+0.67}_{-3.58} \text{ (syst)} \pm 0.12 \text{ (mod)})\% \]
- It is suppressed compared with “12% rule”.

**PWA Projection:**

---

5/31/12

Meson2012
N* in $\psi'$ $\rightarrow p \bar{p} \eta$

Two components:
1. $N(1535) \frac{1}{2}^-$
2. PHSP

A full PWA is performed.

PDG:
$M = 1.535 \pm 0.01 \text{GeV/c}^2$
$\Gamma = 125\sim175 \text{MeV/c}^2$

See Wenlong’s talk @parallel B5

BESIII arXiv: 1304.1973
For $\psi$ decay to baryons:

**Construction of PWA amplitudes.**

Rostov-Schrödinger covariant tensor formalism:

\[
\begin{align*}
\frac{1}{2} & \ N^+ \\
\frac{3}{2} & \ N^+ \\
L_{\text{mix}} = -i \gamma_{\mu} \bar{N} \Gamma R q & + \text{h.c.} \\
L_{\text{KVE}} = -g_{\epsilon} \bar{N} \Gamma_{\mu} N \psi^{\mu} & + i \frac{g_{\epsilon}}{M_N} \bar{N} \Gamma_{\mu} N \psi^{\mu} + \text{h.c.}
\end{align*}
\]

where

\[
\begin{align*}
\Gamma = & \ 2, \ \Gamma_{\mu} = x_{\mu} x_{\nu}, \ \Gamma_{\mu} = x_{\mu} x_{\nu} \text{ for } \frac{1}{2} - N^+, \\
\Gamma = & \ 2, \ \Gamma_{\mu} = x_{\mu} x_{\nu}, \ \Gamma_{\mu} = x_{\mu} x_{\nu} \text{ for } \frac{1}{2} - N^+.
\end{align*}
\]

Three basic elements for constructing amplitudes:

Wave functions, propagators, effective couplings.

(1) $\frac{3}{2} \ N^+$

Wave function:

\[
\psi_{\nu}(P, \bar{p}) = \frac{1}{\lambda_{\nu}} \left( \frac{1}{\bar{p}^2} \right)^{1/2} \bar{p}^\nu \psi(P, \bar{p}) u(p)
\]

Propagators:

\[
P_{\mu\nu} = \frac{P^2 - m^2 + i\epsilon}{\left( P^2 - m^2 + i\epsilon \right)^2} \left[ \delta_{\mu\nu} - \frac{1}{5} \bar{y}_{\mu} 1 y_{\nu} - \frac{8}{15} \bar{y}_{\mu} 1 y_{\nu} + \frac{4}{15} \bar{y}_{\mu} 1 y_{\nu} \right]
\]

Effective couplings:

(1) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]

(2) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]

(3) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]

(4) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]

(5) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]

(6) \[
\begin{align*}
1 \rightarrow N \ ar{N} \\
\bar{N} \rightarrow N, \ N
\end{align*}
\]
Kinematic reflections

- Resonant peaks
- Broad reflection
- $M^2(\pi^- J/\psi)$
- $M^2(\pi^+ J/\psi)$
- Counts
- Counts
- $1$-$D$
Figure 1. Charmed hadron loop diagrams that describe the long-distance transitions in $J_{c\bar{c}} \rightarrow p \bar{p}$. 
Helicity Selection Rule

According to the perturbative method of QCD, V.L. Chmyrak et al. have ever obtained the asymptotic behavior for some exclusive processes, e.g.

\[ BR_{J/\psi}(\lambda) \rightarrow h_1(\lambda_1)h_2(\lambda_2) \sim \left( \frac{\alpha_{QCD}^2}{m_c^2} \right)^{\lambda_1 + \lambda_2 + 2} \]


The leading order will contribute when \( \lambda_1 + \lambda_2 = 0 \), while the helicity configurations that do not satisfy this relation will be suppressed.

An alternative description of this selection rule with the quantum number named “naturalness”

\[ \sigma \equiv P(-1)^J \]

The selection rule requires that

\[ \sigma_{\text{initial}} = \sigma_1 \sigma_2 \]

Take the process \( J/\psi \rightarrow VP \) as an example

\[ M_{J/\psi}(\lambda_1) \rightarrow V(\lambda_2) P(\lambda_3) \propto \epsilon_{\mu\nu\alpha\beta} P_{\lambda_1}^{\mu} \epsilon_{\psi}(p, \lambda_2) P_{\lambda_3}^{\nu} \epsilon_{V}(p, \lambda_4) \]

In the rest frame of initial state, if \( \lambda_1 = 0, \epsilon_\psi \) can be approximately expressed as a linear combination of the final state momenta. Then the contraction of the Lorentz indices will result in a vanishing amplitude.

S and P-wave Charmonium Decays

<table>
<thead>
<tr>
<th>( \eta_c )</th>
<th>PP</th>
<th>PV</th>
<th>VV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi_{c0} )</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>( \chi_{c1} )</td>
<td>(√)</td>
<td>ε</td>
<td>(√)</td>
</tr>
<tr>
<td>( \chi_{c2} )</td>
<td>(ε)</td>
<td>√</td>
<td>(√)</td>
</tr>
</tbody>
</table>

Inconsistent with exp.

Zhao et al. 0812.4902
Zhang et al. PRL102, 172001

T. Feldmann & P. Kroll
PRD62, 074006 (2000)

\[ BR(\chi_{c1} \rightarrow K^{*0} \bar{K}^{*0}) = (1.6 \pm 0.4) \times 10^{-3} \quad \text{PDG} \]

- \( \bar{B}B \) represents the \( J^P=1/2^+ \) octet baryon-antibaryon pairs
- These processes also violate the helicity selection rule
- Some attempts have been made to understand this contradiction
  - quark-diquark model M. Anselmino et al.
  - quark mass correction F. Murgia; M. Anselmino et al.
  - mixing with glueball M. Anselmino et al.
  - quark pair creation model R.G. Ping et al.