In the last few years charm and charmonium spectroscopy has received a new revival due to the discovery of new unexpected particles.

New results on Spectroscopy from B-factories are coming from:

- B decays;
- Charm decays;
- Inclusive $e^+e^-$ interactions;
- $\gamma\gamma$ collisions;
- Initial State Radiation;

Important issue for spectroscopy: Exclusive or Semi-exclusive reactions.
Among the still unsolved questions heavy and light meson spectroscopy I will focus on:

- Completing the charm and charmonium spectrum;
- Solving the question of the existence of gluonium or hybrid states.
The recent discoveries in the charm spectrum put back into question the validity of the potential models. Therefore it is important to establish the complete spectrum of charm. The $\bar{c}u/d$ spectrum.

Where are the charm radial excitations?
The charm spectrum.

- The $\bar{c}s$ spectrum after the discovery of the $D_{sJ}$ states.

- Are there still unexpected particles to be found?
The new $D_{sJ}$ states.

- The new $D_{sJ}$ states have been interpreted as:
  - The missing $c\bar{s}$ states. For reasons still to understand potential models predict wrong masses.
  - 4-quark states or molecules. In this cases other states should be found. Some of them could be narrow.
  - The discovery of a new phenomenon such as Chiral Doubling? In this case again new states are expected to be found.
Narrow states can be extracted from continuum $e^+e^-$ annihilations using hard $p^*$ cuts. This is being done at current B-factories.

The BaBar discovery of the new $D_{sJ}$ states:
The process of isolating charm decays from continuum is quasi-exclusive: a large part of the non-$c$ and combinatorial background is removed by applying a high $p^*$ cut.

However, spin-parity analysis is impossible in continuum production except for a few cases.

Broad states cannot be isolated from continuum.

Presence of reflections from other narrow states.
Broad states can only be extracted from B decays. BELLE evidence for $D_0^*(2308) \rightarrow D^+\pi^-$ in $B^- \rightarrow D^+\pi^−\pi^−$. 

![Graph showing events distribution in $M_{D\pi}$]
It is important to establish the complete spectrum of charmonium.

Several states still missing. Are there hybrid charmonium states?
Charmonium hybrids.

- S. Godfrey: the existence of gluonium excitations in the hadron spectrum is one of the most important unanswered questions in hadron physics.
- Hybrid mesons $\psi_g$ consists of $\bar{c}cg$.
- The flux tube model predicts 8 states between 4 and 4.2 GeV.
- Lattice QCD calculations predict the $J^{PC} = 1^{-+}$ state between 4.04 and 4.4 GeV. The proximity of $D^*D$ thresholds could make it narrow.
- Some hybrids can have exotic quantum numbers such as:

\[
\psi_g(J^{PC} = 0^{+-}, 2^{+-}) \rightarrow J/\psi + (\pi^+\pi^-), \eta, \eta'
\]

\[
\psi_g(J^{PC} = 1^{-+}) \rightarrow \eta_c + (\pi^+\pi^-), \eta, \eta'
\]

- Some of these states could be produced in B decays.
- Hybrid mesons with $J^{PC} = 1^{--}$ could be looked for in $e^+e^-$ annihilations via ISR.
Charmonium spectrum.

- New charmonium states can be extracted from B decays:
- The $J/\psi \pi^+ \pi^-$ mass spectrum from B decays in BELLE from $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$:

![Mass spectrum graph]
But also $J^{PC} = \text{even}^{x+}$ can be obtained from $\gamma\gamma$ collisions.

The Observation of $\eta_c$ and $\eta_c(2S)$ from BaBar from $\gamma\gamma$.

$\gamma\gamma$ collisions are also an $\eta_c$ factory.
The Observation of $\chi_{c0}$ and $\chi_{c2}$ from BELLE in $\gamma\gamma$ collisions.

$\gamma\gamma$ collisions are also a $\chi_{c0,2}$ factory.
The $J^{PC} = 1^{--}$ charmonium states can be observed from ISR $e^+e^- \rightarrow \gamma J/\psi$.

The $J/\psi \rightarrow \pi^+\pi^-\pi^0$ from BaBar.

BaBar, for events having the ISR $\gamma$ reconstructed: 10 events per $fb^{-1}$. With $20ab^{-1}$: 200 K events. Similar to the actual BES statistics. A super B-factory is also a charmonium factory.
Lattice QCD predicts the scalar gluonium around 1.7 GeV:
Status of gluonium searches.

- Too many scalar mesons below 2. GeV.
- Two nonets? 4-quark states? Gluonium?
- Where is the scalar glueball?
- Many proposals.
  - Narrow: $f_0(1500)$, $f_0(1700)$.
  - Wide: $\sigma$.
- Information on some of these states, such as the existence of $k(800)$ and $\sigma$ can be extracted from existing data from charm decays.
- Unlikely to produce gluonium in charm decays.

<table>
<thead>
<tr>
<th></th>
<th>I = 1/2</th>
<th>I = 1</th>
<th>I = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k(800)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a_0(980)$</td>
<td></td>
<td>$f_0(980)$</td>
<td></td>
</tr>
<tr>
<td>$f_0(1370)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_0^*(1430)$</td>
<td>$a_0(1490)$</td>
<td>$f_0(1500)$</td>
<td></td>
</tr>
<tr>
<td>$f_0(1700)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_0^*(1950)$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The possibility of searching for gluonium in B decays has been suggested by the experimental measurement of a large decay rate for:

\[ B \to \eta' X, \quad B \to \eta' K \]

The diagram giving rise to these processes is:

\[ b \to sg \]

There are arguments in favour of a gluonic content of the \( \eta' \), therefore gluonium states may be produced in B decays.
The total rate $b \rightarrow sg$ has been calculated perturbatively:

$$B(b \rightarrow sg) = (2 - 5) \times 10^{-3}$$

One should look for:

$$B \rightarrow K^{(*)} \pi \pi, KK, \eta\eta, \eta\eta'$$

in searching for scalar or tensor states.

One should look for:

$$B \rightarrow K^{(*)} \eta \pi \pi, K\bar{K}\pi$$

in searching for pseudoscalar states.

P. Minkowski and W. Ochs hep-ph/0404194
Search for gluonium in B decays.

- Present data. Study of:
  \[ B \to K + \text{ scalar(tensor)} \]

- BELLE: \( \pi^+\pi^- \) mass spectrum in \( B^+ \to K^+\pi^+\pi^- \)

- Strong \( f_0(980) \) signal.

- Wide scalar structure around 1.3 GeV. \( f_0(1300) \)?

- No \( f_0(1500) \).
Search for gluonium in B decays.

- **BELLE**: $K^+K^-$ mass spectrum in $B^+ \rightarrow K^+K^+K^-$

- $f_0(1500)$ or $f_2'(1525)$?

- Actually very limited statistics in the search for the pseudoscalar gluonium in:

$$B \rightarrow K(\eta\pi\pi),(\eta\pi\pi)$$
Gluonium in double charmonium sample?

- Observation by BELLE of an unexpected large rate for:

\[ e^+ e^- \rightarrow J/\psi \eta_c \]

and

\[ e^+ e^- \rightarrow J/\psi (\bar{c}c) \]
This discovery has triggered some authors to suggest that this rate may be partly due to the presence of a gluonium state:

\[ e^+ e^- \rightarrow \bar{c}c gg \]

S. Brodsky et al., hep-ph/0305269
Conclusions

- A Super B-factory is also a $\tau/charm$ factory but also a charmonium factory.
- Charm, charmonium, light and exotic meson spectroscopy can receive new inputs and possibly new unexpected states could be found.