Status of exotic states at ATLAS

I. Yeletskikh
Joint Institute for Nuclear Research, Dubna

On behalf of the ATLAS Collaboration
1. Production measurements of $X(3872)$ in $J/\psi \pi^+\pi^-$ channel: ATLAS and CMS results;

2. Search for $X_b$ and other hidden beauty states in $\pi^+\pi^- \Upsilon(1S)$ final state;
Production measurements of $X(3872) \to J/\psi \pi^+\pi^-$

- $X(3872)$ is discovered by BELLE in 2003; at ATLAS, it’s first observed in 7TeV $pp$-collisions (JHEP 1409 (2014) 079);

- Cross-section and production ratios measurements are important in revealing the internal structure of the $X(3872)$ as well as reference point for other analyses;

- Cross sections predicted for $X(3872)$ in theory are considerably different for different models of it’s internal structure;

- ATLAS performed measurement of the differential cross sections for the production of $\psi(2S)$ and $X(3872)$, using 11.4/fb of proton-proton collisions at 8TeV in the $J/\psi \pi^+\pi^-$ final state (JHEP 01 (2017) 117);
The first measurement of the differential cross section of the prompt \(X(3872)\) production was made by CMS (using 7TeV \(pp\)-collisions data);

Cross-section of the prompt production of \(X(3872)\) is compared to the NRQCD theoretical prediction;

Theoretical cross section, calculated assuming \(X(3872)\) to be a \(D^0 \bar{D}^{*\,0}\) molecule appears too high compared to data;

Later reinterpretation of \(X(3872)\) structure, assumig it’s a mixture of \(D^0 \bar{D}^{*\,0}\) molecule and \(\chi_{c1}(2P)\) state showed much better agreement with data;
Cross-section of the prompt production of $X(3872)$; it’s well described by the NRQCD prediction, assuming $X(3872)$ to be a mixture of $D^0 \bar{D}^{*0}$ molecule and $\chi_{c1}(2P)$ state, with domination of $\chi_{c1}(2P)$. 
The heavy-quark symmetry suggests the existence of the hidden-beauty partners of the hidden-charm exotic states;

- $X_b$ is a hypothetical bottomonium partner of the well-studied $X(3872)$ state;
- Discovery of $X_b$ can shed light on the structure of these exotic states;

- Decay mode $X_b \rightarrow \pi^+\pi^- Y(1S)$ is an analogue for the $X(3872)$ discovery mode: $\pi^+\pi^- J/\psi$, however, it can be suppressed by G-parity conservation, which is broken for charmonium decays;
- Different theoretical models suggest mass of $X_b$ in the range $10492 – 10682$ MeV
- $\pi^+\pi^- Y(1S)$ channel is interesting w.r.t. studies of higher bottomonium states (e.g., $Y(4S)$, $Y(5S)$) and exotic structures in their decays (ref. Phys. Rev. Lett. 108, 122001)

Search for $X_b$ in $\pi^+\pi^- Y(1S)$ final state
Search for $X_b$ in $\pi^+\pi^-\Upsilon(1S)$ final state

- Search for $X_b$ is performed by ATLAS with 16.2/fb of 8TeV $pp$ collisions data (Phys.Lett. B740 (2015) 199);
- The $\pi^+\pi^-\Upsilon(1S)$ invariant mass distribution shows visible peaks for $\Upsilon(2S)$, $\Upsilon(3S)$, but no other signal candidates;
- Expected Number of $X_b$ events is determined relative to the number of $\Upsilon(2S)$ events:

$$N = N_{2S} \cdot R \cdot \frac{A}{A_{2S}} \cdot \frac{\epsilon}{\epsilon_{2S}},$$

$$R \equiv \frac{(\sigma B)}{(\sigma B)_{2S}}$$

is the relative $X_b$ production rate;

- The analogous ratio for $X(3872)$ was observed to be 6.56% (JHEP04 (2013) 154);
- In the absence of signal, the limit is set on the value of $R$ depending of $X_b$ mass;
Limit on the relative production rate of the $X_b$ signal together with 1σ, 2σ uncertainty bands. $\Upsilon(2S)$ and $\Upsilon(3S)$ signal regions are excluded.

- Limit ranges in **0.8%-4.0%**.
- Band at the right – shift of the limit under alternative $X_b$ spin-alignment scenarios;

- Observed $p$-value in the no-signal hypothesis (solid);
- Expected $p$-values for the different $X_b$ production rates;
- Fits to $\Upsilon(10860)$ and $\Upsilon(11020)$ reveal no significant signals;
Search for $X_b$ in $\pi^+\pi^-Y(1S)$ final state

Search for $X_b$ has also been performed by CMS (20.7/fb 8TeV), with no significant signal.

- Distributions of selected events over $M(\pi^+\pi^-Y(1S))$ (left);
- Limit on the relative production rate of the $X_b$ signal (top);
- Limit ranges in 0.9%-5.4%.

Conclusions and future plans

- $X(3872)$ state is observed at ATLAS, the differential cross sections for its prompt and non-prompt production are measured;
- These measurements make model of mixed $D^0\bar{D}^{*0}$ molecule and $\chi_{c1}(2P)$ state preferable in the theory of $X(3872)$ internal structure; the results are consistent with CMS measurements;
- The searches for bottomonium partner of $X(3872)$, called $X_b$, are performed at ATLAS and CMS; no evidence for signal is observed; both experiments set limit on the $X_b$ production rate over $\Upsilon(2S)$ production at the level of 0.8%-4.0% (ATLAS) and 0.9-5.4% (CMS);

- New experimental searches at LHC are motivated by the DØ report of the $X(5568)$ state in $B_s\pi^\pm$ invariant mass – in hadronic and semileptonic channels of $B_s$ decays;
- Many future opportunities are suggested by the charmonium pentaquark discovery by LHCb, e.g., existence of charmonium strange pentaquark states, existence of bottomonium partners, etc.
- Analysis of $B$-hadron decays is a perspective strategy in the searches for new charmonium exotic states. Increase of statistics in Run II data is important for LHC to gain in sensitivity for new exotics;
Backup slides
• From the theoretical point of view, the $X_b \rightarrow \pi^+\pi^- Y(1S)$ decays are suppressed due to G-parity conservation, which is broken in the case of charmonium decays;
• In this sense, the complete analogy between $X_b$ and $X(3872)$ is broken.

• Taking this in mind, another perspective channels for $X_b$ search are $X_b \rightarrow Y(1S)\omega$ and $X_b \rightarrow Y(1S)\varphi$ as well as $X_b \rightarrow Y(1S)\chi_b$;
• Analyses in these channels are in different stages of progress now, though they present some experimental challenges, in particular, the efficient detection of the $\chi_b$ (e.g. in $\chi_b \rightarrow Y\gamma$);
Search for structure in $B_s \pi^\pm$ invariant mass

In December 2016, DØ collaboration published the evidence for a narrow structure $X(5568)$ in the decay $X(5568) \rightarrow B_s^0 \pi^\pm$, $B_s^0 \rightarrow J/\psi (\mu^+\mu^-)\phi(K^+K^-)$


$X(5568)$ is a tetraquark candidate, composed of two quarks and two antiquarks of four different flavors: $b,s,u,d$

Using fixed background shape they extracted:
$m = 5567.8 \pm 2.9 \text{(stat)} +0.9 - 1.9 \text{(syst)} \text{MeV}$,
$\Gamma = 21.9 \pm 6.4 \text{(stat)} + 5.0 - 2.5 \text{(syst)} \text{MeV}$,

significance $5.1\sigma$, and number of signal events $N = 133 \pm 31$