Status of exotic states at ATLAS

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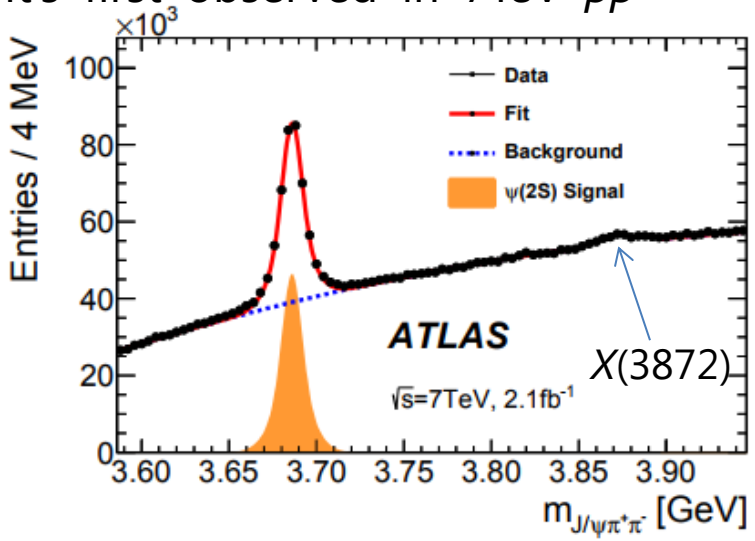
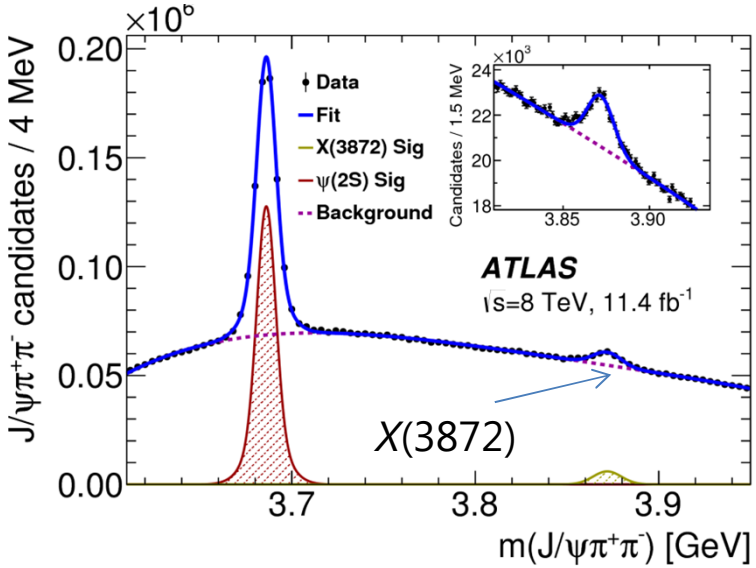
Contents

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

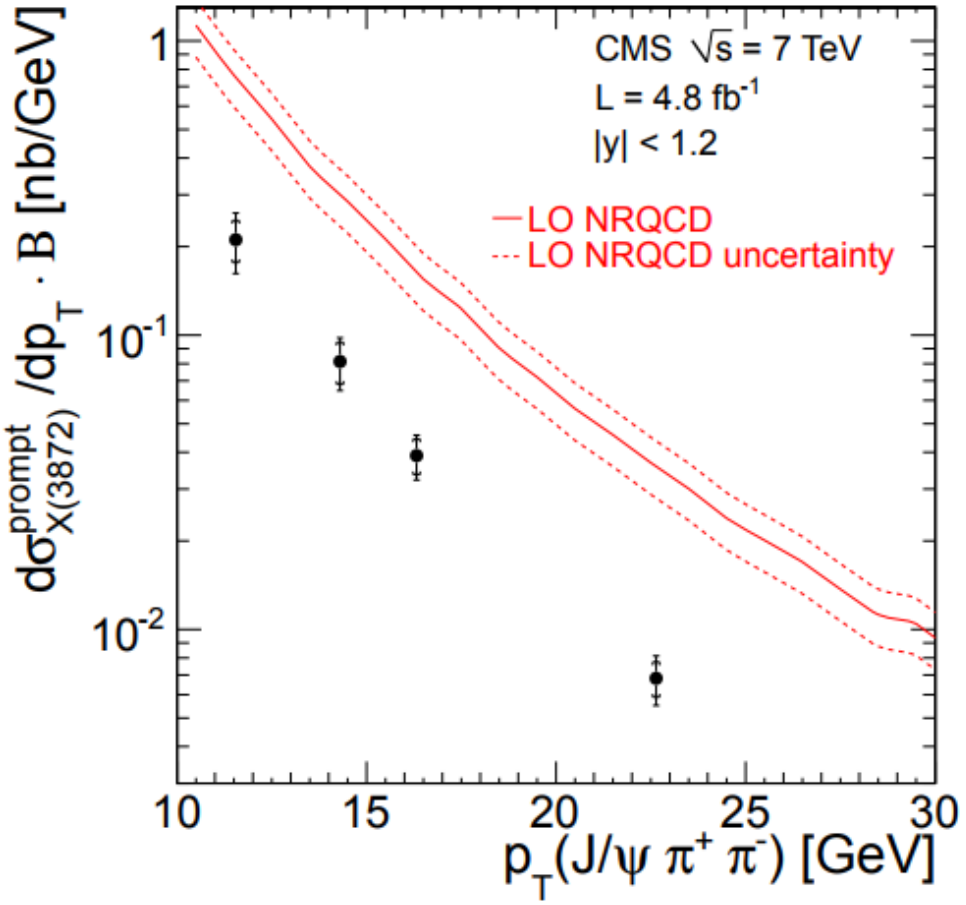
2. Search for X_b and other hidden beauty states in $\pi^+\pi^- Y(1S)$ final state;

- 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 $D^0\overline{D}^{*0}$ molecule appears too high compared to data;



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- Later reinterpretation of X(3872) structure, assumig it's a mixture of $D^0\overline{D}^{*0}$ molecule and $\chi_{c1}(2P)$ state showed much better agreement with data;

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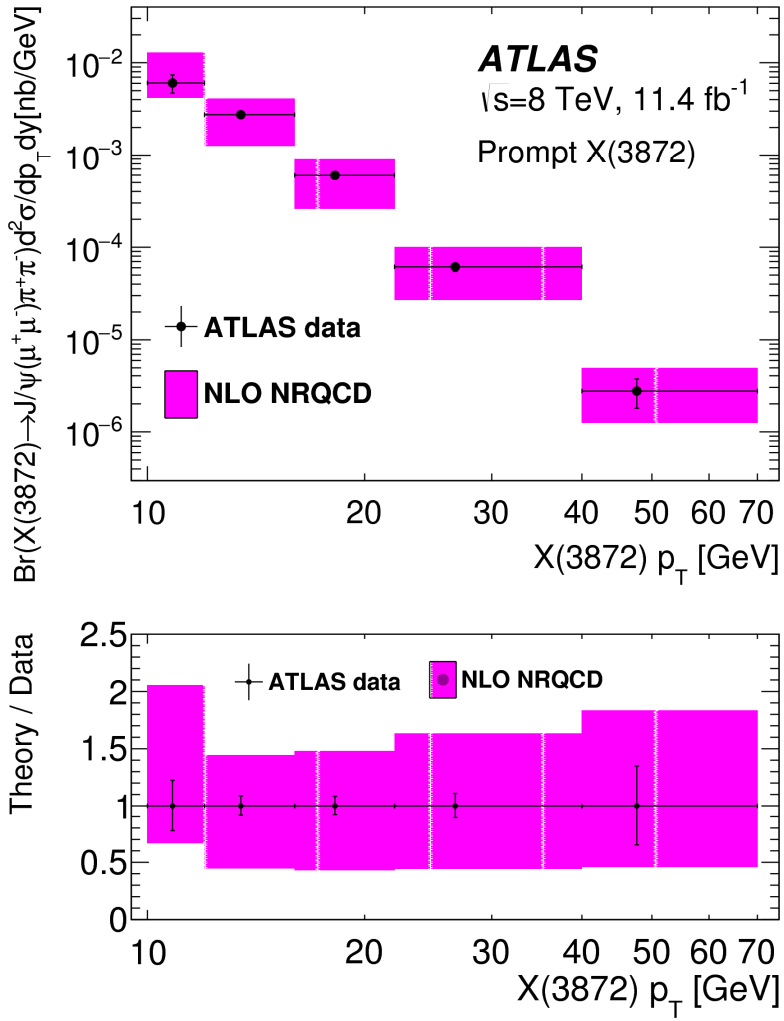
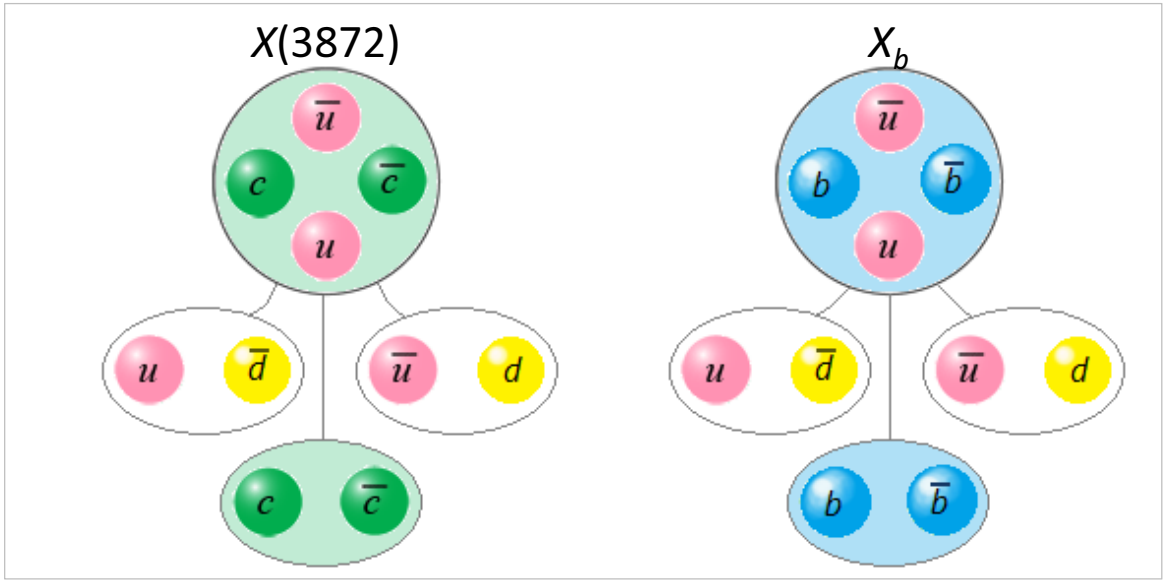


- Cross-section of the prompt production of X(3872); it's well described by the NRQCD prediction, assuming X(3872) to be a mixture of $D^0\overline{D}^{*0}$ molecule and χ_{c1}(2P) state, with domination of χ_{c1}(2P).

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

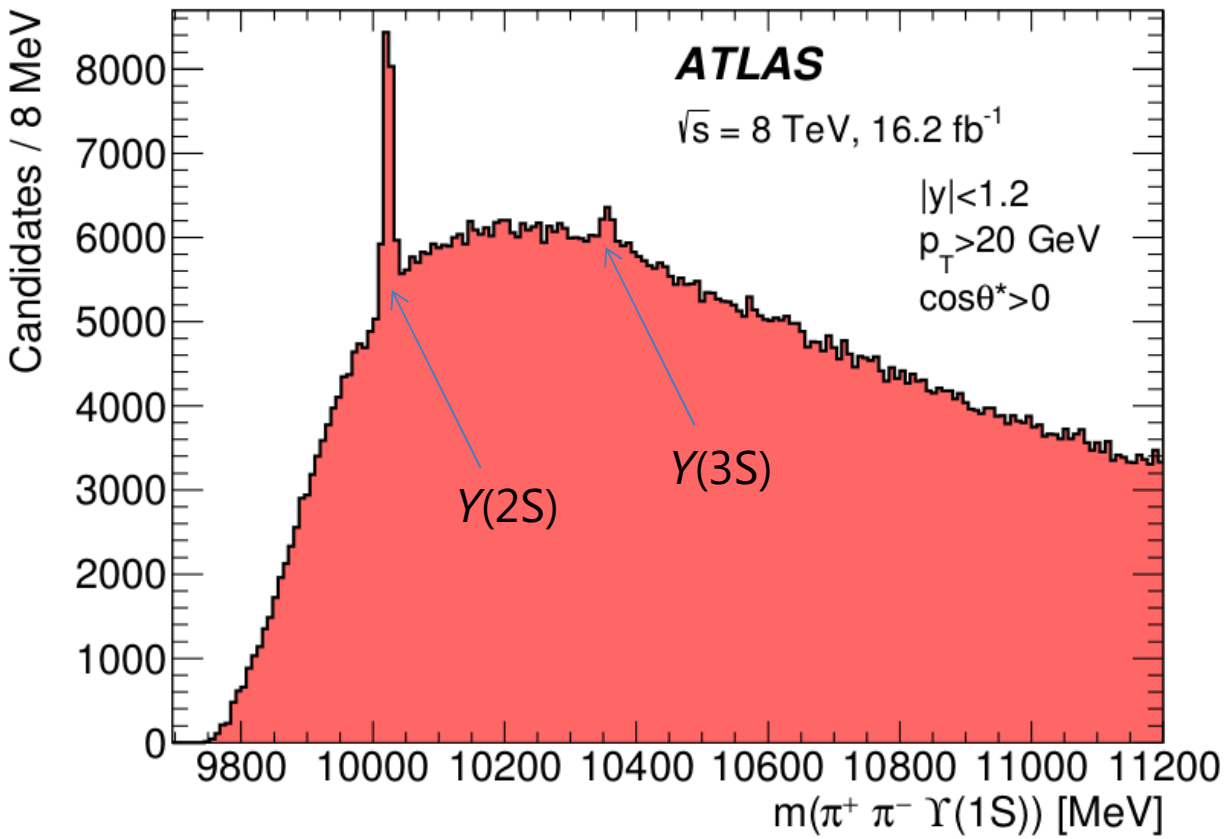
- The heavy-quark symmetry suggests the existence of the hidden-beauty partners of the hidden-charm exotic states;
- X_b is a hypothetical bottomonium partner of the well-studied $X(3872)$ state;
- Discovery of X_b can shed light on the structure of these exotic states;



- Decay mode $\boldsymbol{X_b \to \pi^+\pi^- Y(1S)}$ is an analogue for the X(3872) discovery mode: $\boldsymbol{\pi^+\pi^- J/\psi}$, 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**
- $\boldsymbol{\pi^+\pi^- Y(1S)}$ 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)

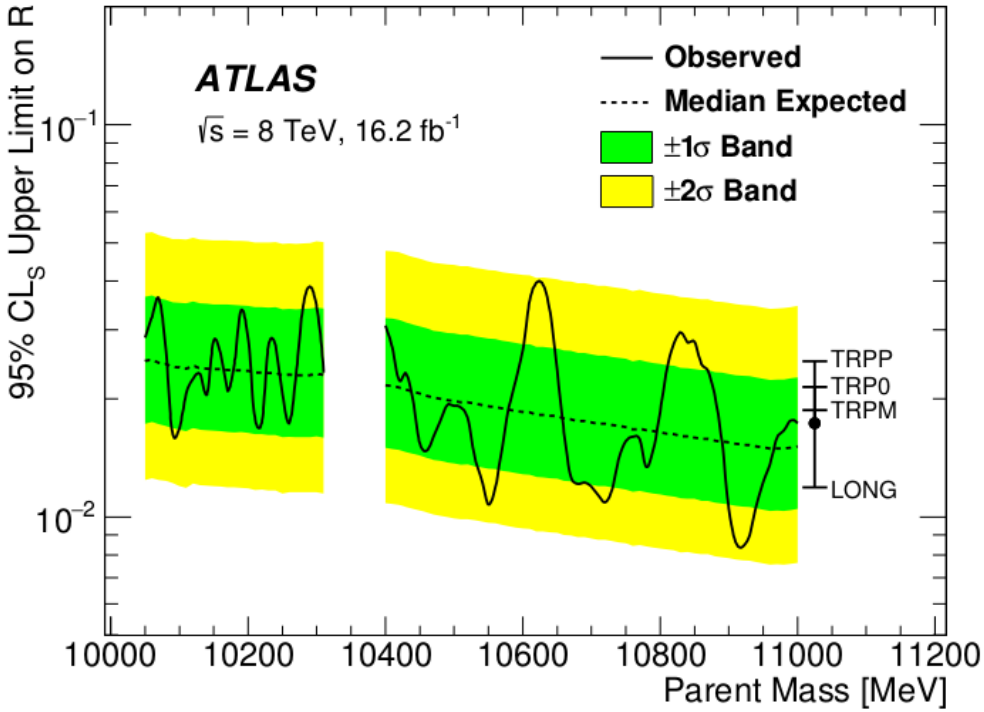
- Search for X_b is performed by ATLAS with 16.2/fb of 8TeV *pp* collisions data (Phys.Lett. B740 (2015) 199);
- The $\pi^+\pi^- Y$(1S) invariant mass distribution shows visible peaks for *Y*(2S), *Y*(3S), but no other signal candidates;
- Expected Number *of* X_b events is determined relative to the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

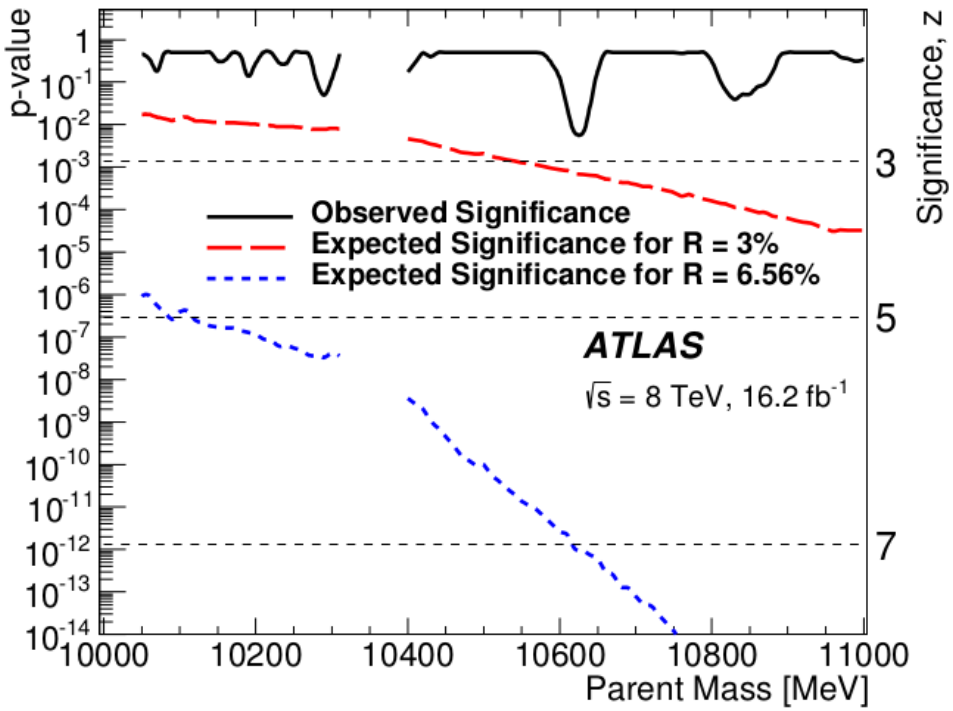
$$N = N_{2S} \cdot R \cdot \frac{\mathcal{A}}{\mathcal{A}_{2S}} \cdot \frac{\epsilon}{\epsilon_{2S}},$$



$R \equiv (\sigma\mathcal{B})/(\sigma\mathcal{B})_{2S}$ 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;

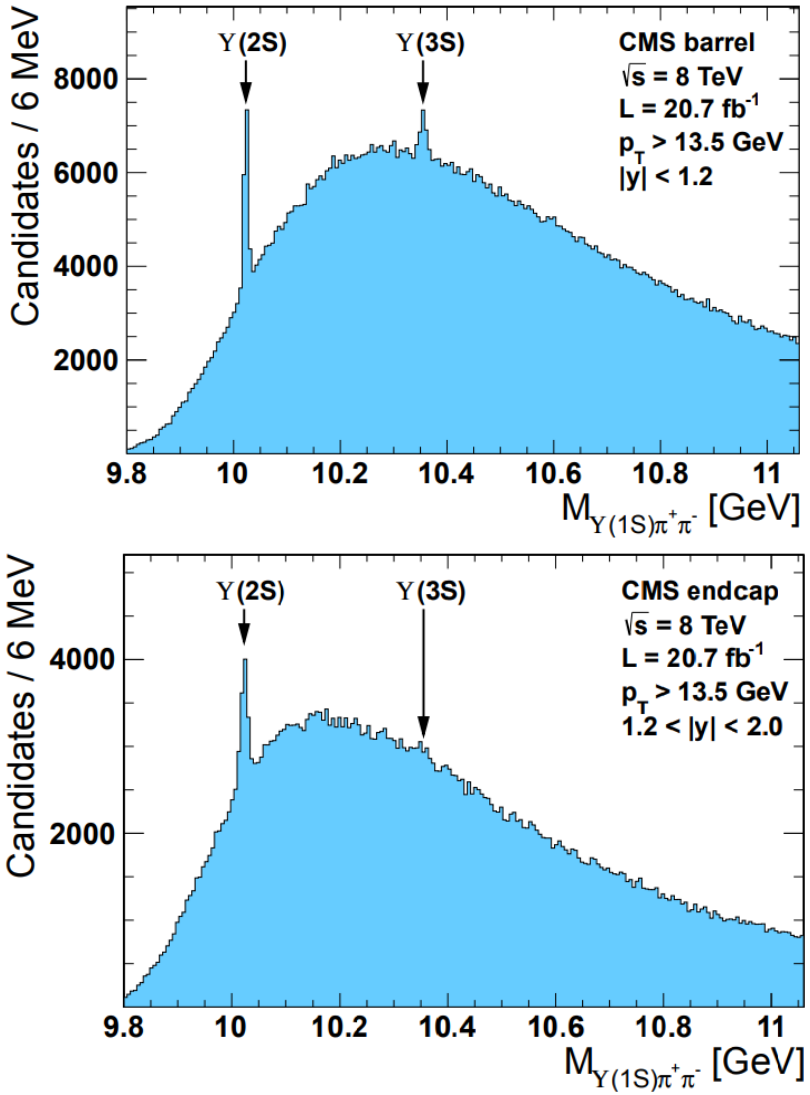




- Limit on the relative production rate of the X_b signal together with 1σ, 2σ uncertainty bands. Y(2S) and Y(3S) signal regions are excluded.
- Limit ranges in **0.8%-4.0%.**
- Band at the right – shift of the limit under alternative X_b spin-alignment scenarios;

- Observed p-value in the no-signal hypothesis (solid);
- Expected p-values for the different X_b production rates;
- Fits to Y(10860) and Y(11020) reveal no significant signals;

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



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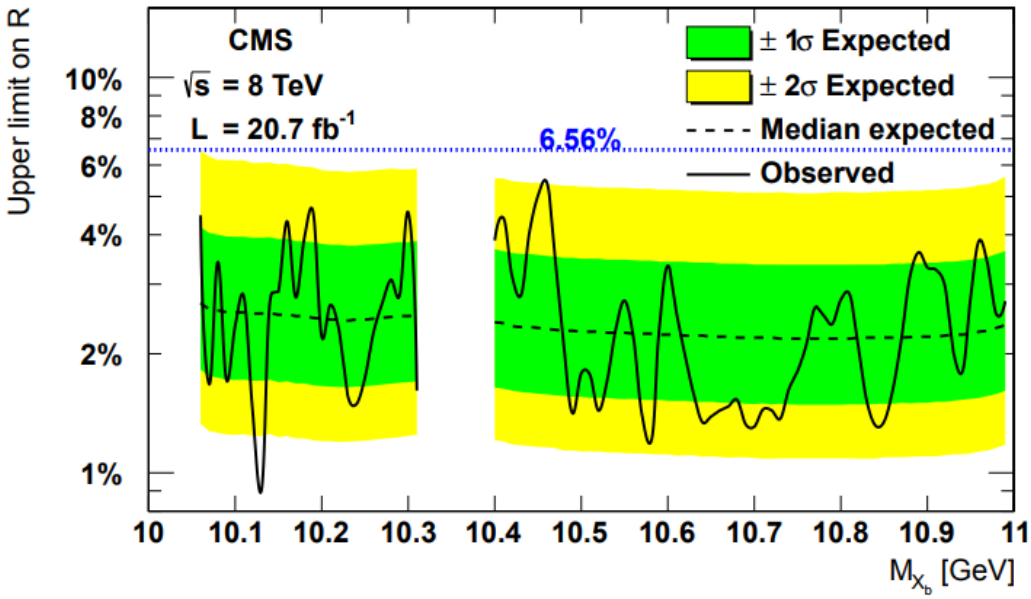


- Distributions of selected events over M($\pi^+\pi^- Y(1S)$) (left);
- Limit on the relative production rate of the X_b signal (top);
- Limit ranges in **0.9%-5.4%.**

Conclusions and future plans

- X(3872) state is observed at ATLAS, the differential cross sections for it's prompt and non-prompt production are measured;
- These measurements make model of mixed $D^0\overline{D}^{*0}$ molecule and χ_{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 Y(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

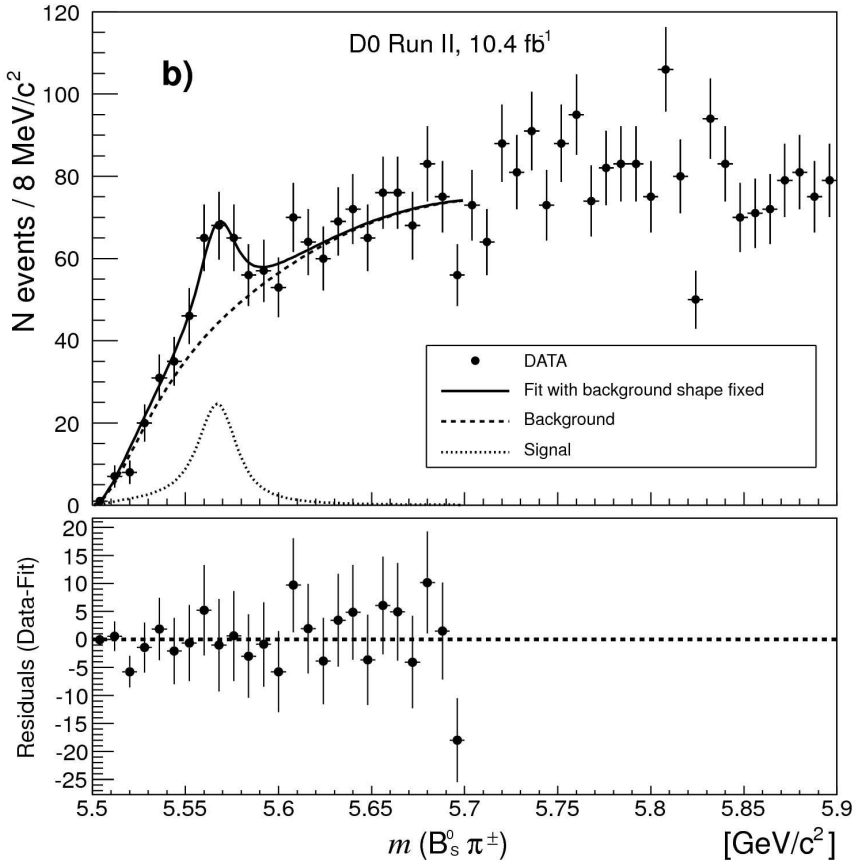
- From the theoretical point of view, the $X_b \to \pi^+\pi^- Y(1S)$ decays are suppressed due to G-parity conservation, which is broken in the case of charmonium decays;
- In this sense, the complete analogy between X_b and $X(3872)$ is broken….

- Taking this in mind, another perspective channels for X_b search are $X_b \to Y(1S)\omega$ and $X_b \to Y(1S)\varphi$ as well as $X_b \to Y(1S)\chi_b$;
- Analyses in these channels are in different stages of progress now, though they present some experimental challenges, in particular, the efficient detection of the χ_b (e.g. in $\chi_b \to Y\gamma$);

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 $X(5568) \rightarrow B_s^0\,\pi^{\pm}$, $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\varphi(K^+K^-)$

Phys. Rev. Lett. 117, 022003 (2016)



$X(5568)$ 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 ± 2.9(stat) +0.9−1.9(syst) MeV ,
Γ = 21.9 ± 6.4(stat) +5.0−2.5(syst) MeV,

significance 5.1σ, and number of signal events
N = 133 ± 31