Observation of an excess of di-charmonium events in the four-muon final state with the ATLAS detector

LHCC, 27th November, 2023

A search is made for potential $c\bar{c}c\bar{c}$ tetraquarks decaying into a pair of charmonium states in the four muon final state. Two decay channels, J/ψ+$J/\psi \rightarrow 4\mu$ and J/ψ+ψ(2S) $\rightarrow 4\mu$, are studied. Statistically significant excesses with respect to backgrounds dominated by the single parton scattering are seen in the di-J/ψ channel consistent with a narrow resonance at 6.9 GeV and a broader structure at lower mass. A statistically significant excess is also seen in the J/ψ+ψ(2S) channel.

Introduction

- The quark model was proposed by Gell-Mann and Zweig sixty years ago
- Exotic hadrons were predicted at the same time as conventional $q\bar{q}$ mesons and qqq baryons
- Lack of observations of full-heavy tetraquarks which can make the theory-experiment comparison easier
  - First proposal of full-charm tetraquark (1975): Prog. of Theor. Phys., Vol 54, No. 2
  - The first calculation of the full-charm tetraquark mass (1981): Z. Phys. C 7 (1981) 317
  - First observation of potential full-charm tetraquark X(6900) (2020): LHCb Science Bulletin 65 (2020) 1983

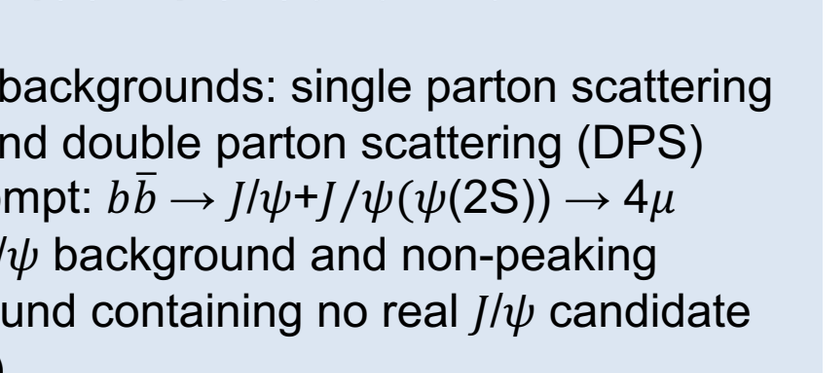
Signal and backgrounds

- Signal process:
  tetraquark $\rightarrow J/\psi$+J/ψ or J/ψ+ψ(2S) $\rightarrow 4\mu$
- Backgrounds:
  - Prompt backgrounds: single parton scattering (SPS) and double parton scattering (DPS)
  - Non-prompt: $b\bar{b} \rightarrow J/\psi$+$J/\psi(\psi(2S)) \rightarrow 4\mu$
  - Single J/ψ background and non-peaking background containing no real J/ψ candidate (Others)
  - In the di-J/ψ channel, the feed-down from J/ψ+ψ(2S) channel to di-J/ψ channel is treated as an additional background

Event selection

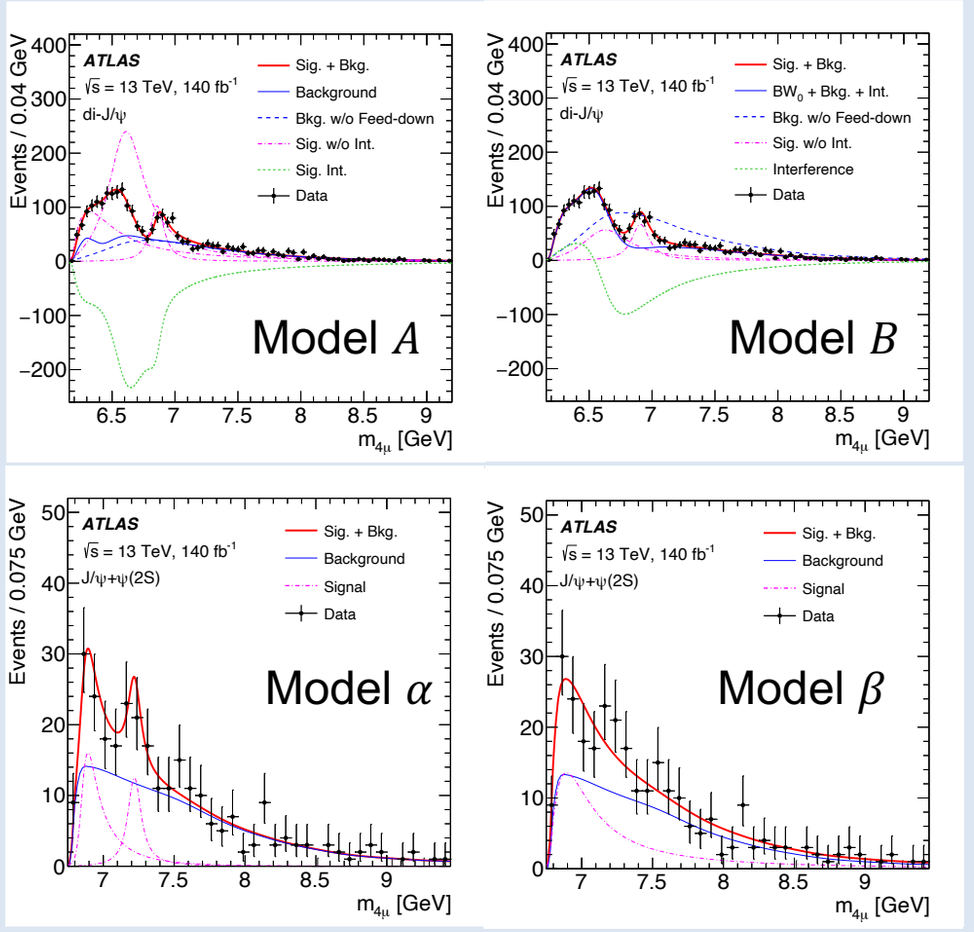
- J/ψ and ψ(2S) mass window requirement to reduce Others background
- Vertex fit quality and L_{xy} requirements to reduce non-prompt background

Signal region	Control region	Non-prompt region
Di-muon or tri-muon triggers, oppositely charged muons from each charmonium, *loose* muons, $p_{\mathrm{T}}^{1,2,3,4} > 4, 4, 3, 3$ GeV and $\lvert\eta_{1,2,3,4}\rvert < 2.5$ for the four muons, $m_{J/\psi} \in [2.94, 3.25]$ GeV, or $m_{\psi(2S)} \in [3.56, 3.80]$ GeV, Loose vertex requirements $\chi^2_{4\mu}/N < 40$ $(N = 5)$ and $\chi^2_{\text{di-}\mu}/N < 100$ $(N = 2)$,		
Vertex $\chi^2_{4\mu}/N < 3$, $L_{xy}^{4\mu} < 0.2$ mm, $\lvert L_{xy}^{\text{di-}\mu}\rvert < 0.3$ mm, $m_{4\mu} < 11$ GeV,		Vertex $\chi^2_{4\mu}/N > 6$,
$\Delta R < 0.25$ between charmonia	$\Delta R \geq 0.25$ between charmonia	or $\lvert L_{xy}^{\text{di-}\mu}\rvert > 0.4$ mm



Results

- In the di-J/ψ channel, the peak around 6.9 GeV is consistent with the LHCb observed X(6900), with significance far above 5σ
- In the J/ψ+ψ(2S) channel, the signal significance is $4.7\sigma(4.3\sigma)$ for model $\alpha(\beta)$. In model α , the significance of the 2nd peak (7.2 GeV) reaches 3.0σ



di-J/ψ	model A	model B
m_0	$6.41 \pm 0.08^{+0.08}_{-0.03}$	$6.65 \pm 0.02^{+0.03}_{-0.02}$
Γ_0	$0.59 \pm 0.35^{+0.12}_{-0.20}$	$0.44 \pm 0.05^{+0.06}_{-0.05}$
m_1	$6.63 \pm 0.05^{+0.08}_{-0.01}$	—
Γ_1	$0.35 \pm 0.11^{+0.11}_{-0.04}$	
m_2	$6.86 \pm 0.03^{+0.01}_{-0.02}$	$6.91 \pm 0.01 \pm 0.01$
Γ_2	$0.11 \pm 0.05^{+0.02}_{-0.01}$	$0.15 \pm 0.03 \pm 0.01$
$\Delta s/s$	$\pm 5.1\%^{+8.1\%}_{-8.9\%}$	—
J/ψ+ψ(2S)	model α	model β
m_3	$7.22 \pm 0.03^{+0.01}_{-0.04}$	$6.96 \pm 0.05 \pm 0.03$
Γ_3	$0.09 \pm 0.06^{+0.06}_{-0.05}$	$0.51 \pm 0.17^{+0.11}_{-0.10}$
$\Delta s/s$	$\pm 21\%^{+25\%}_{-15\%}$	$\pm 20\% \pm 12\%$

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