b-Physics Results by ATLAS and CMS

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$B_c^+ \to J/\psi D_s^+$ and $B_c^+ \to J/\psi D_s^{*+}$ at ATLAS

- B_c^+ can decay via a weak transition of either heavy quark and a weak annihilation, and provide a unique testing ground for various theoretical models

JHEP08(2022)087

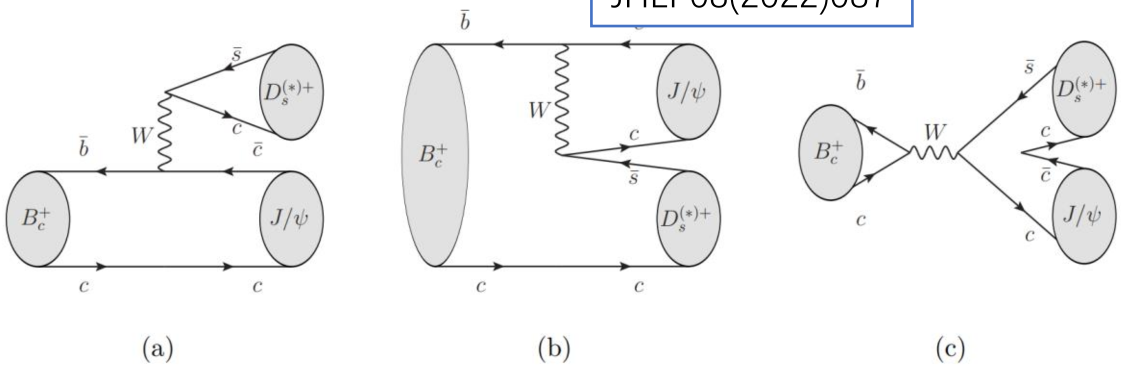


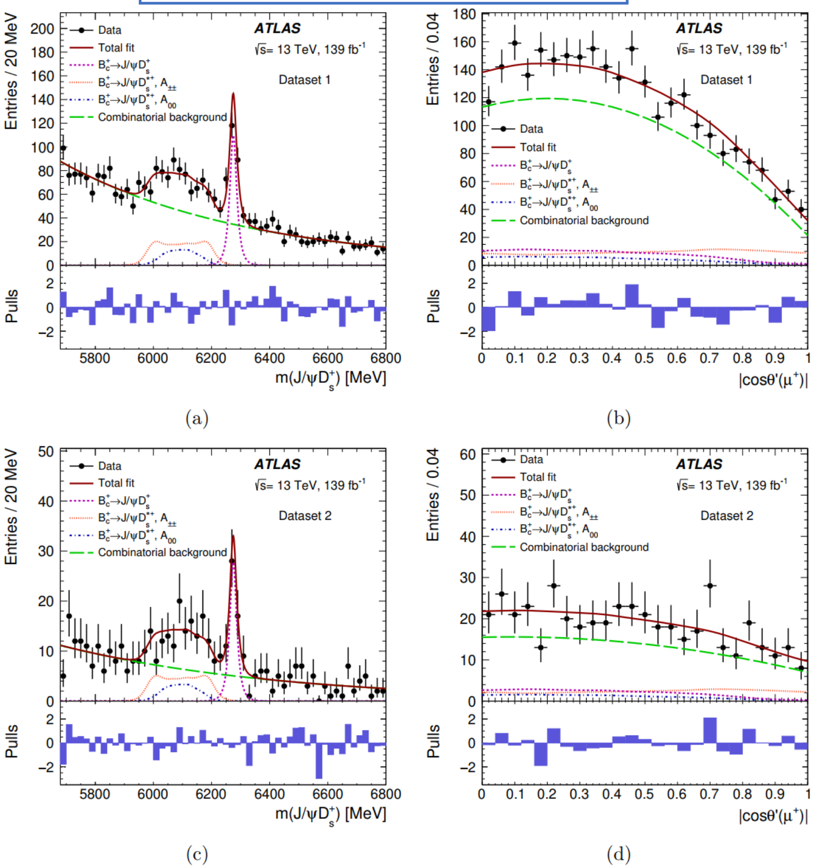
Figure 1. Feynman diagrams for $B_c^+ \to J/\psi D_s^{(*)+}$ decays: (a) colour-favoured spectator, (b) colour-suppressed spectator, and (c) annihilation topology.

- B_c^+ to $J/\psi D_s^+$and $J/\psi D_s^{*+}$ decays are observed by LHCb and ATLAS, while weak annihilation contribution is discussed only in a few papers, PRD90(2014)114030, IJMPA33(2018)1850044
- ATLAS improved the precision of the measurements of these two decays, using 139 fb^{-1} data collected at $\sqrt{s}$ = 13 TeV

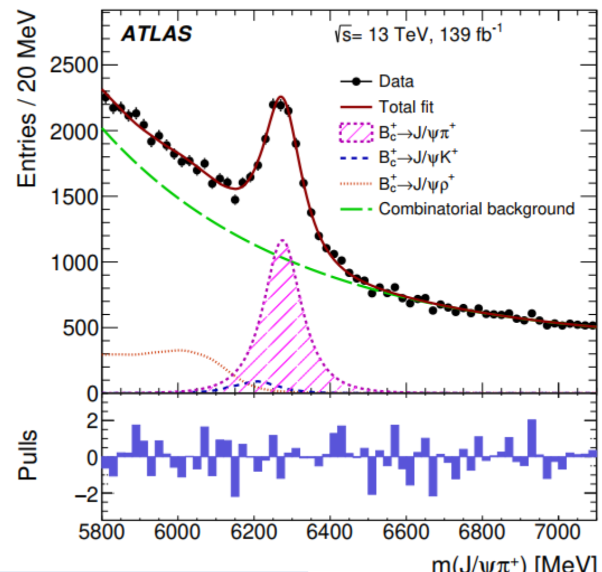
$B_c^+ \to J/\psi D_s^+$ and $B_c^+ \to J/\psi D_s^{*+}$ at ATLAS

- 2D fit to $m(J/\psi D_s^+)$: $|cos\theta'(\mu^+)|$ is applied to extract signal yields, and transverse polarization fraction in $B_c^+ \to J/\psi D_s^{*+}$
- Branching fractions are measured relative to $B_c^+ \to J/\psi \pi^+$

Fit to signal channels



Fit to reference channel



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$B_c^+ \to J/\psi D_s^+$ and $B_c^+ \to J/\psi D_s^{*+}$ at ATLAS

- Precision improved branching fraction ratio measurements
  - Consistent with earlier ATLAS and LHCb measurements
  - Consistent with a QCD relativistic potential model calculation

$$R_{D_s^+/\pi^+} = \frac{B(B_c^+ \to J/\psi D_s^+)}{B(B_c^+ \to J/\psi \pi^+)} = 2.76 \pm 0.33 \pm 0.29 \pm 0.16$$

$$R_{D_s^{*+}/\pi^+} = \frac{B(B_c^+ \to J/\psi D_s^{*+})}{B(B_c^+ \to J/\psi \pi^+)} = 5.33 \pm 0.61 \pm 0.67 \pm 0.32$$

$$R_{D_s^{*+}/D_s^+} = \frac{B(B_c^+ \to J/\psi D_s^{*+})}{B(B_c^+ \to J/\psi D_s^+)} = 1.93 \pm 0.24 \pm 0.09$$

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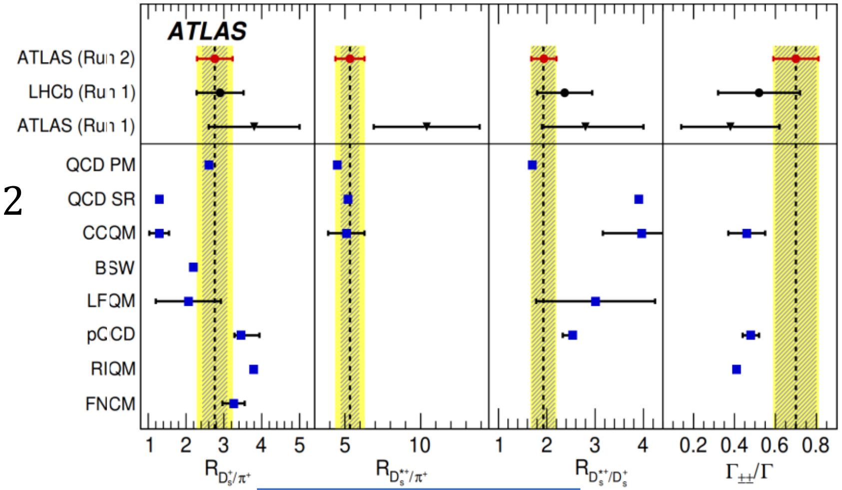


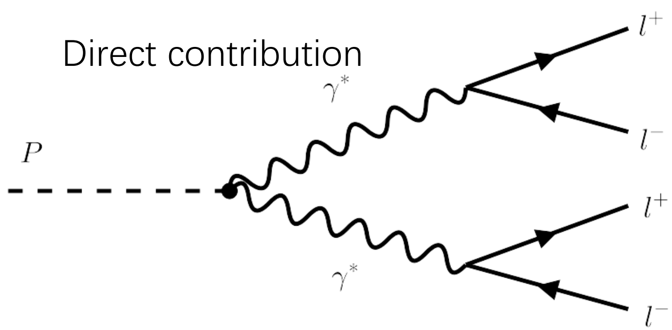
JHEP08(2022)087

- The fraction of transverse polarization in $B_c^+ \to J/\psi D_s^{*+}$ decay
  - $\Gamma_{\pm\pm}/\Gamma = 0.70 \pm 0.10 \pm 0.04$ JHEP08(2022)087
  - Agree with 2/3 --- expected from naive spin-counting considerations

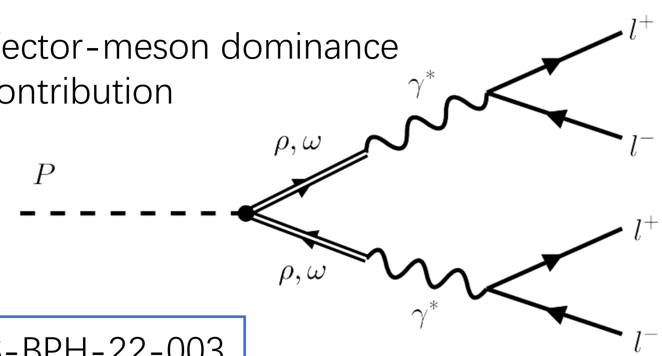
First observation of the rare 4μ decay of η at CMS

- The double-Dalitz decay, $\eta \rightarrow \mu^+\mu^-\mu^+\mu^-$, proceeds via internal conversion of two photons into 4 muons

Direct contribution



Vector-meson dominance contribution



CMS-PAS-BPH-22-003

- It can serve as precision test of the SM
- It offers sensitivity to new physics
- It contributes to the hadronic light-by-light component of the muon anomalous magnetic moment a_μ

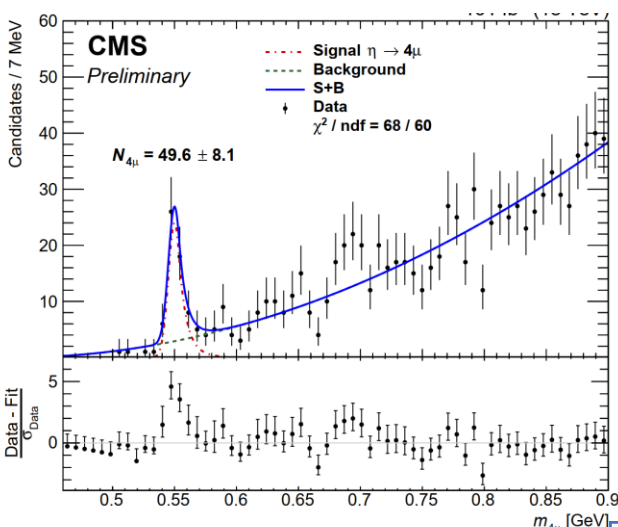
First observation of the rare 4μ decay of η at CMS

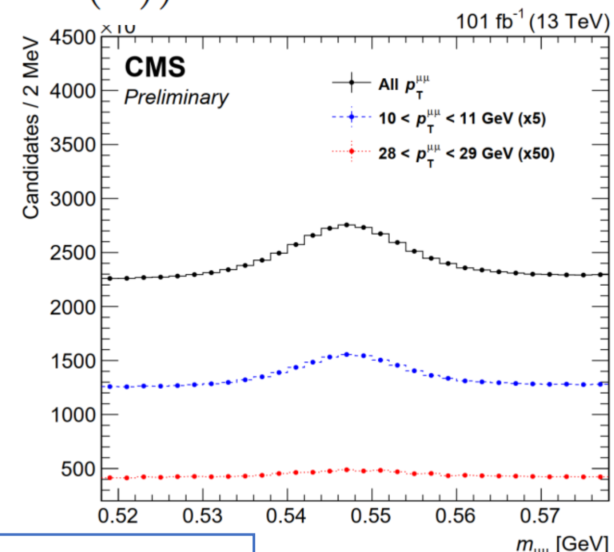
- CMS observed the double-Dalitz decay $\eta \to \mu^+\mu^-\mu^+\mu^-$ for the first time, using data collected at $\sqrt{s}$ = 13 TeV in 2017 and 2018, with high rate triggers
- The branching fraction is measured relative to $\eta \to \mu^+\mu^-$

  and is consistent to SM predication

$$\frac{\mathcal{B}_{4\mu}}{\mathcal{B}_{2\mu}} = (0.9 \pm 0.1\,(\text{stat}) \pm 0.1\,(\text{syst})) \times 10^{-3}$$

$$\mathcal{B}(\eta \to 4\mu) = (5.0 \pm 0.8\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.7\,(\mathcal{B})) \times 10^{-9}$$

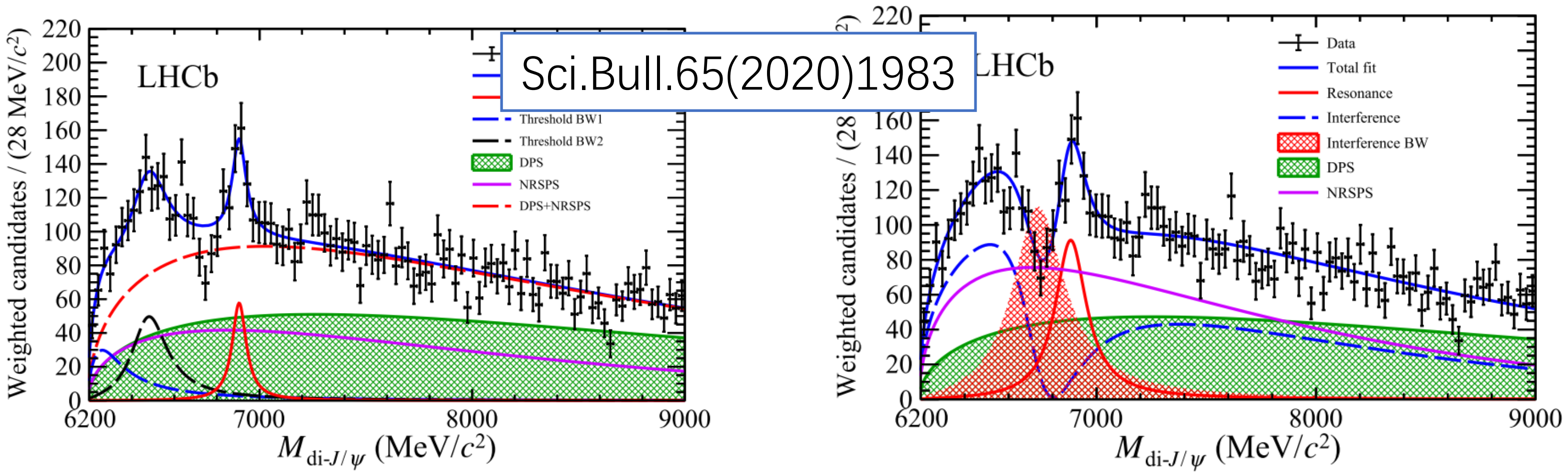




CMS-PAS-BPH-22-003

Di-J/ψ resonances

- Exotic hadrons which are not in $q\bar{q}$ or qqq configurations are expected in QCD theory
- Many candidates are reported in experiments since the discovery of the X(3872) by Belle
- Exotic hadrons containing four charm are discussed in various theoretical models. A such candidate, the X(6900) is first reported by LHCb in 2020

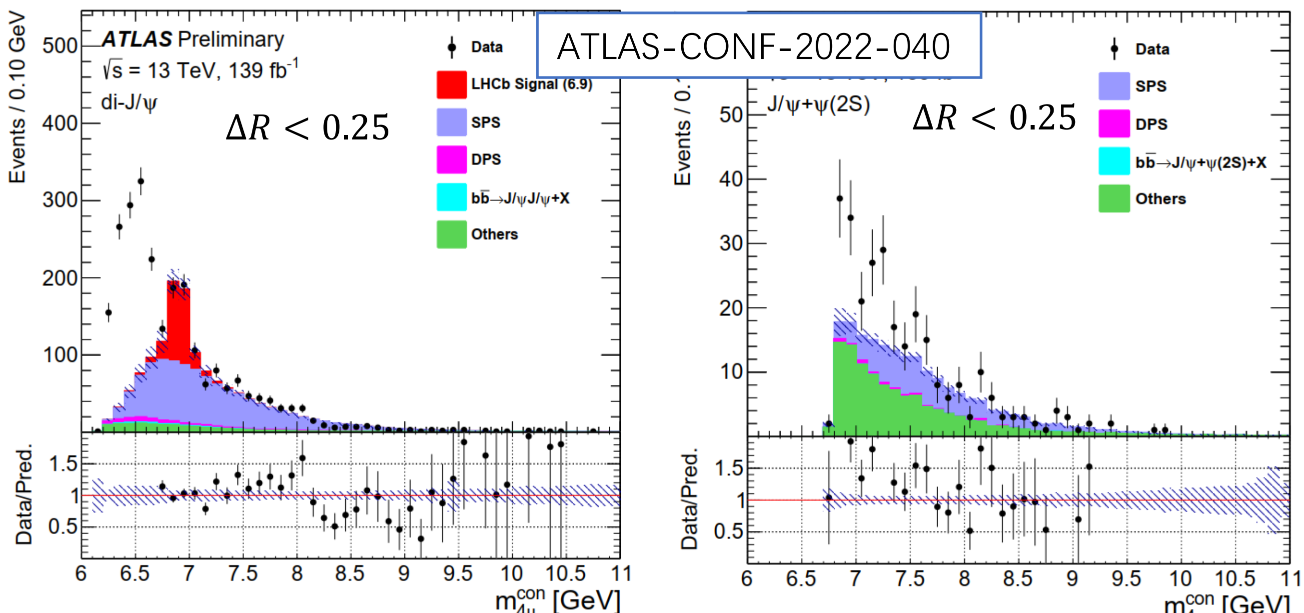


Sci.Bull.65(2020)1983

- ATLAS and CMS collected good data to study Di-J/ψ structures

Di-J/ψ resonances at ATLAS

- ATLAS studied the Di-J/ψ mass spectrum using 139 fb^{-1} data collected in 2015-2018 at $\sqrt{s}$ = 13 TeV
- $\Delta R < 0.25$ for signal region, and $\Delta R > 0.25$ for control region
- Single parton scattering (SPS) and double parton scattering (DPS) backgrounds are modeled by MC simulations, and corrected according to data in control region
- Obvious structures in di-J/ψ and $J/\psi\psi(2S)$ mass distributions



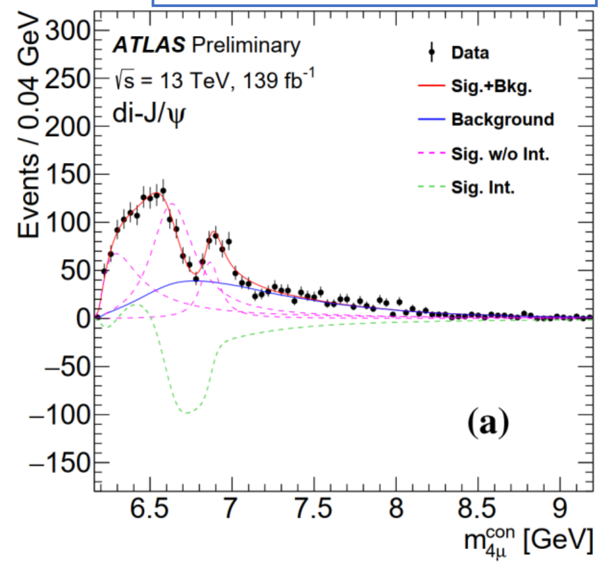
Di-J/ψ resonances at ATLAS

- Three interfering BWs for di-J/ψ signal structures
  - The third one consistent with LHCb
  - Significance is $\mathbf{10\sigma}$

(GeV)	m_0	Γ_0	m_1	Γ_1
di-J/ψ	$6.22 \pm 0.05^{+0.04}_{-0.05}$	$0.31 \pm 0.12^{+0.07}_{-0.08}$	$6.62 \pm 0.03^{+0.02}_{-0.01}$	$0.31 \pm 0.09^{+0.06}_{-0.11}$
	m_2	Γ_2		
	$6.87 \pm 0.03^{+0.06}_{-0.01}$	$0.12 \pm 0.04^{+0.03}_{-0.01}$		

$\mathbf{10\sigma}$
Consistent with LHCb

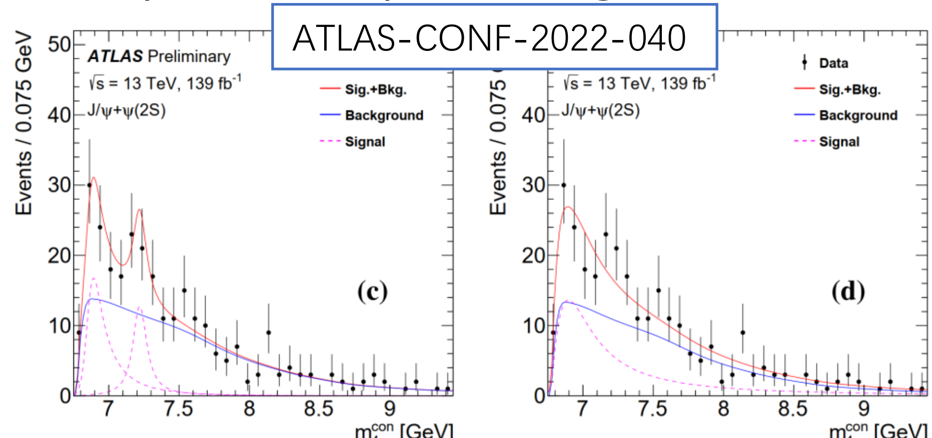
ATLAS-CONF-2022-040



- Di-J/ψ signal structure + single BW (model A), or single BW (model B) for $J/\psi\psi(2S)$ signals
  - Model A, 4th BW is evident (3.2σ)
  - Model B, the signal BW is $\mathbf{4.3\sigma}$

	m_3	Γ_3
model A	$7.22 \pm 0.03^{+0.02}_{-0.03}$	$0.10^{+0.13+0.06}_{-0.07-0.05}$
model B	$6.78 \pm 0.36^{+0.35}_{-0.54}$	$0.39 \pm 0.11^{+0.11}_{-0.07}$

ATLAS-CONF-2022-040



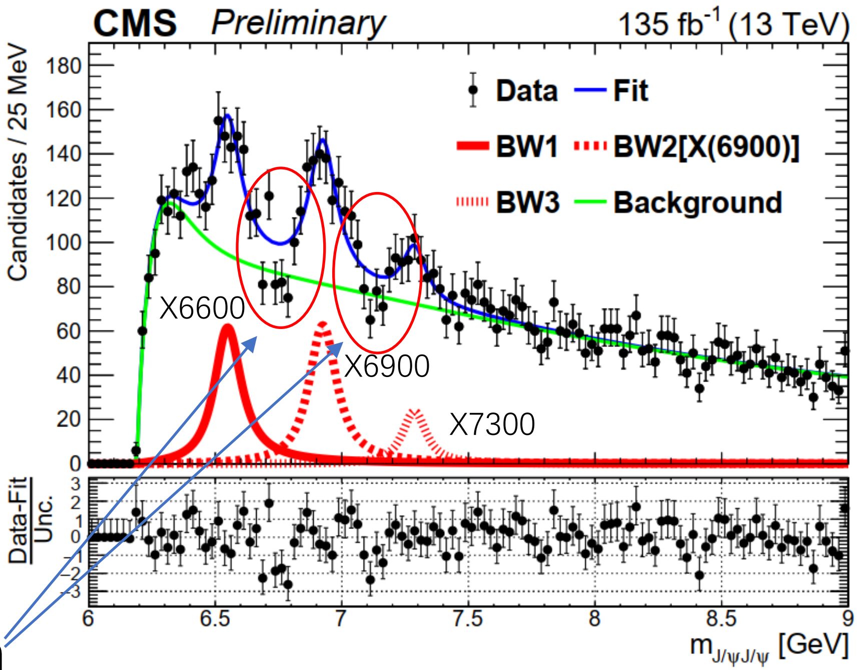
Di-J/ψ resonances at CMS

- CMS studied the di-J/ψ mass using 135 fb^{-1} data collected in 2016-2018 at $\sqrt{s}$ = 13 TeV
- Background: NRSPS, NRDPS, a near threshold BW (*ad-hoc* BKG)
- Non-interference fit
  - BKG + three BWs

	X(6600)	X(6900)	X(7300)
	BW1	BW2	BW3
m	$6552 \pm 10 \pm 12$	$6927 \pm 9 \pm 5$	$7287 \pm 19 \pm 5$
Γ	$124 \pm 29 \pm 34$	$122 \pm 22 \pm 19$	$95 \pm 46 \pm 20$
N	474 ± 113	492 ± 75	156 ± 56

- Confirmation of X(6900), 9.4σ
- Observation of X(6600), 6.5σ
- Evidence of X(7300), 4.1σ
- Data demands better description

CMS-PAS-BPH-21-003



Di-J/ψ resonances at CMS

- A possible way to describe the dips is the interference
- Interference fit
  - BKG + three interfering BWs

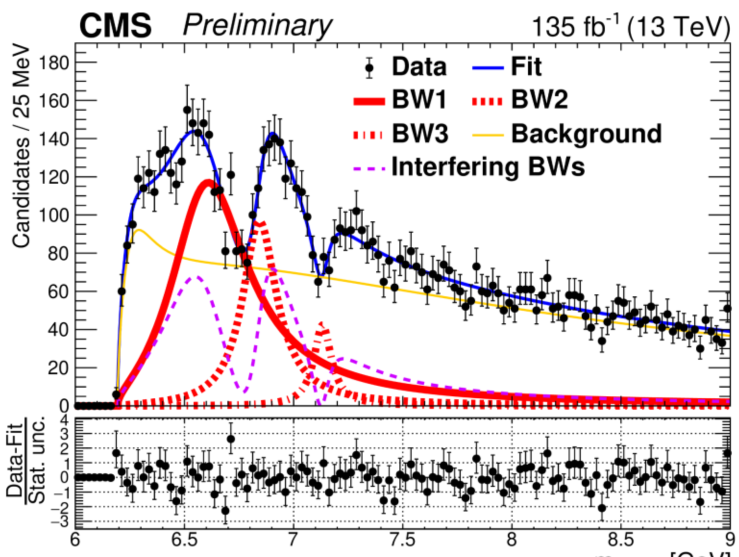
$$|r_1 \exp(i\phi_1)\, BW_1 + BW_2 + r_3 \exp(i\phi_3)\, BW_3|^2$$

  - Describes data well

CMS-PAS-BPH-21-003 (cern.ch)

		X(6600) BW1	X(6900) BW2	X(7300) BW3
Interference	m [MeV]	6638^{+43+16}_{-38-31}	6847^{+44+48}_{-28-20}	7134^{+48+41}_{-25-15}
	Γ [MeV]	$444^{+226+109}_{-199-235}$	191^{+66+25}_{-49-17}	97^{+40+29}_{-29-26}

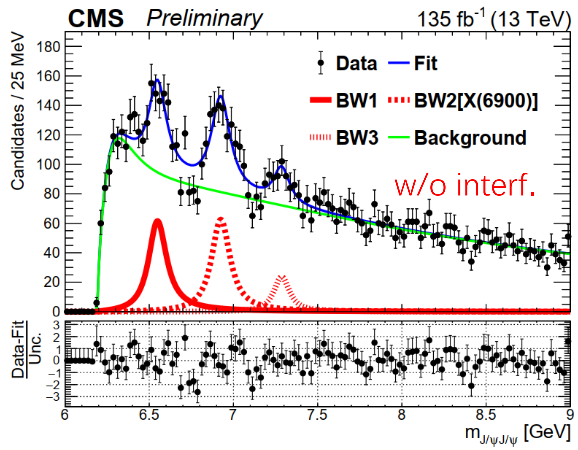
- Implication of interf. result
  - Same J^{PC}
  - Large mass diff. – 200-300 MeV indicates radial excitation

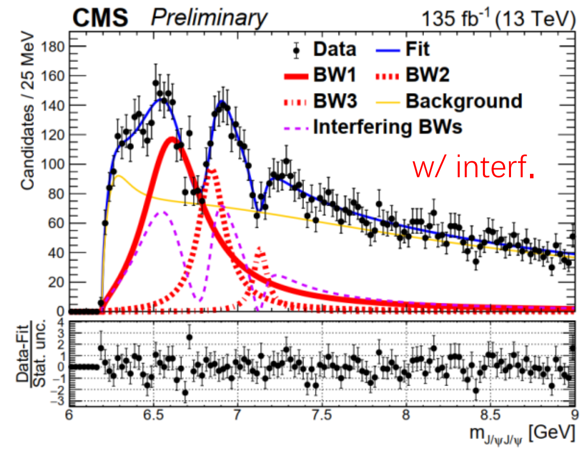


CMS-PAS-BPH-21-003 (cern.ch)

Di-J/ψ resonances at CMS

- Compare to theoretical calculations





CMS-PAS-BPH-21-003 (cern.ch)

arxiv:2108.04017

P-wave

1^1P_1	1^{--}	363.9	320.3	-366.7	337.5	-14.4	0	0	-2.6	6553	-	-
1^3P_0	0^{-+}	356.7	320.2	-366.7	337.5	-7.2	-56.9	-43.1	-2.6	6460	6398.1	$\eta_c(1S)\chi_{c0}(1P)$
1^3P_1	1^{-+}	356.6	320.3	-366.7	337.5	-7.2	-28.4	21.5	-2.7	6554	6494.1	$\eta_c(1S)\chi_{c1}(1P)$
1^3P_2	2^{-+}	356.6	320.2	-366.7	337.5	-7.2	28.4	-2.1	-2.4	6587	6539.6	$\eta_c(1S)\chi_{c2}(1P)$
1^5P_1	1^{--}	342.4	320.4	-366.7	337.5	7.2	-85.3	-30.2	-2.7	6459	6508.8	$\eta_c(1S)h_{c1}(1P)$
1^5P_2	2^{--}	342.2	320.2	-366.7	337.5	7.2	-28.4	30.2	-2.5	6577	6607.6	[illegible]
1^5P_3	3^{--}	342.3	320.3	-366.7	337.5	7.2	56.9	-8.6	-2.5	6623	6653.[illegible]	
2^1P_1	1^{--}	414.7	688.7	-263.4	548.6	-11.2	0	0	-1.6	6925	-	
2^3P_0	0^{-+}	410.0	689.6	-263.4	548.6	-5.6	-46.2	-34.5	-1.7	6851	-	
2^3P_1	1^{-+}	410.0	689.6	-263.4	548.6	-5.6	-23.1	17.2	-1.6	6926	-	
2^3P_2	2^{-+}	410.0	689.6	-263.4	548.7	-5.6	23.1	-3.4	-1.7	6951	-	
2^5P_1	1^{--}	398.7	689.5	-263.4	548.6	-5.6	-69.3	-24.2	-1.7	6849	-	
2^5P_2	2^{--}	398.7	689.5	-263.4	548.6	5.6	-23.1	24.2	-1.5	6944		
2^5P_3	3^{--}	398.8	689.7	-263.4	548.6	5.6	46.2	-6.9	-1.6	6982		
3^1P_1	1^{--}	479.8	982.2	-215.5	727.8	-9.3	0	0	-1.1	7221		
3^3P_0	0^{-+}	475.2	982.7	-215.5	727.7	-4.6	-41.9	-31.0	-1.2	7153		
3^3P_1	1^{-+}	475.1	982.6	-215.5	727.7	-4.6	-20.9	15.5	-1.2	7220		
3^3P_2	2^{-+}	475.1	982.6	-215.5	727.8	-4.6	20.9	-3.1	-1.0	7243		
3^5P_1	1^{--}	465.9	982.8	-215.5	727.7	4.6	-62.8	-21.7	-1.2	7150		
3^5P_2	2^{--}	465.7	982.6	-215.5	727.8	-4.6	-20.9	21.7	-1.1	7236		
3^5P_3	3^{--}	465.8	982.6	-215.5	727.8	4.6	41.9	-6.2	-1.1	7271	-	-

w/o interf.

BW1: 6552 MeV
BW2: 6927 MeV
BW3: 7287 MeV

w/ interf.

BW1 (MeV)	BW2 (MeV)	BW3 (MeV)
6638	6847	7134

S-wave

…ates	J^P	Mass($n=1$)	Mass($n=2$)	Mass($n=3$)	Mass($n=4$)
	0^{++}	6055^{+69}_{-74}	6555^{+36}_{-37}	6883^{+27}_{-27}	7154^{+22}_{-22}
	2^{++}	6090^{+62}_{-66}	6566^{+34}_{-35}	6890^{+27}_{-26}	7160^{+21}_{-22}
	0^{++}	5984^{+64}_{-67}	6468^{+35}_{-35}	6795^{+26}_{-26}	7066^{+21}_{-22}

NuclPhysB966(2021)115393

- Radial excited P-wave states (like J/ψ series)?
- Radial excited S-wave states?
- Theoretical situation difficulty & confusing
  - Important next step: measure J^{PC} to clarify

Summary

- ATLAS and CMS have collected large dataset which can be used for b and quarkonium/light hadron study
- Latest results from B_c^+ and η decays are presented
- Resonant structures in the di-J/ψ ($J/\psi\psi(2S)$) mass distribution are studied by ATLAS and CMS, and the X(6900) are confirmed by ATLAS and CMS

Thanks for your attention