

All charm tetraquarks at CMS

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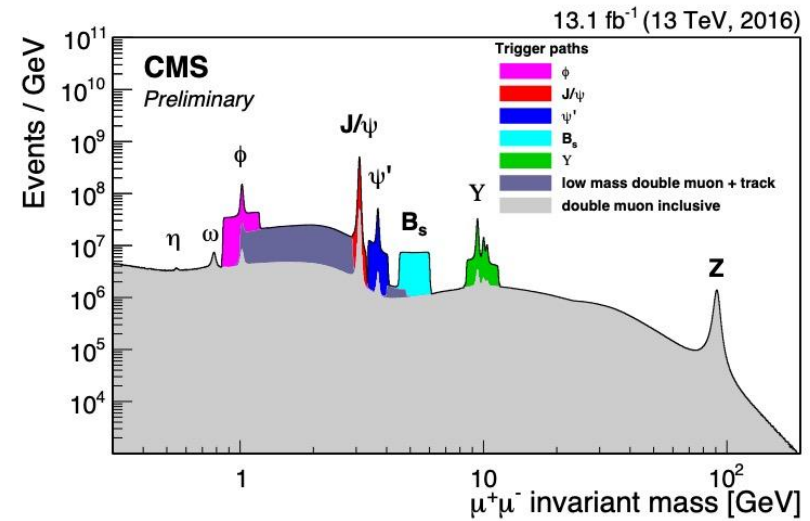
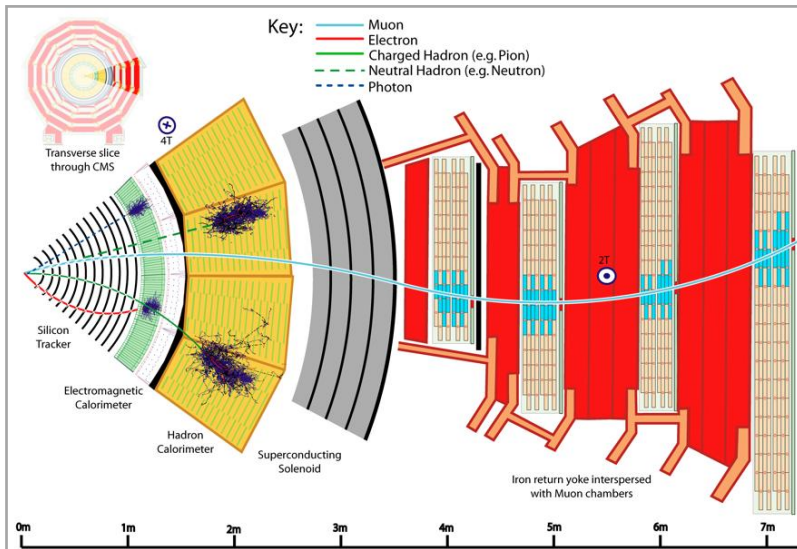
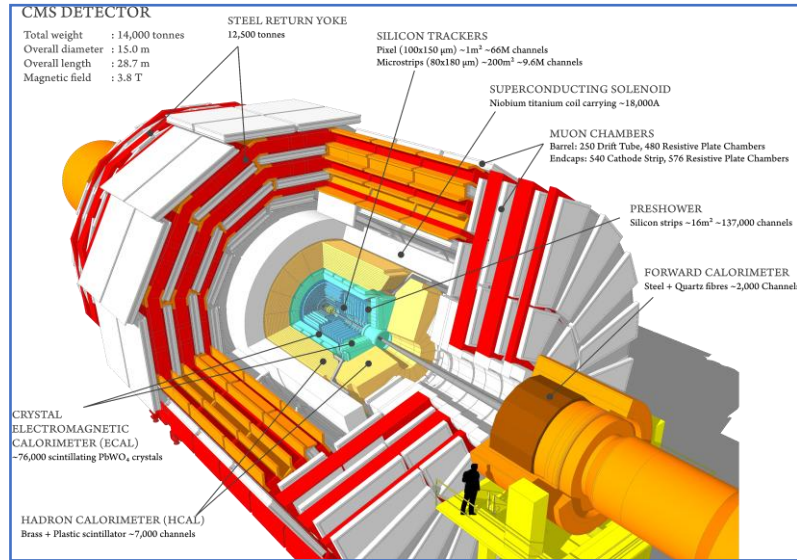
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2026.04.24-2026.04.28

Outline

- Spin-parity of all charm tetraquarks [Nature 648 \(2025\) 58](#)
- $X(6900)$ and $X(7100)$ in $J/\psi\psi(2S)$ [arxiv:2602.02252](#)
- All charm tetraquarks in $J/\psi J/\psi$ with CMS run 2 and run 3 data

[arxiv:2602.02252](#)

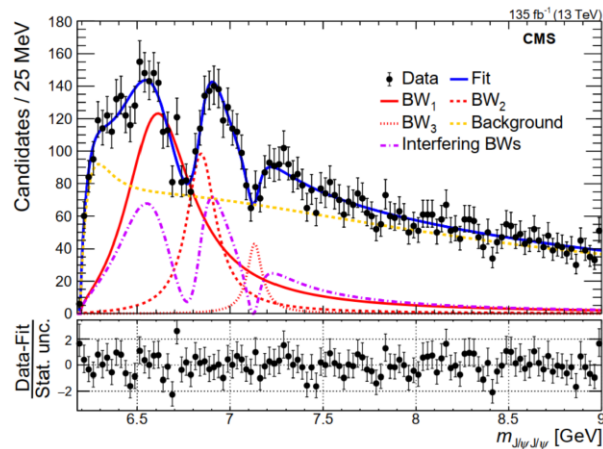
CMS detector



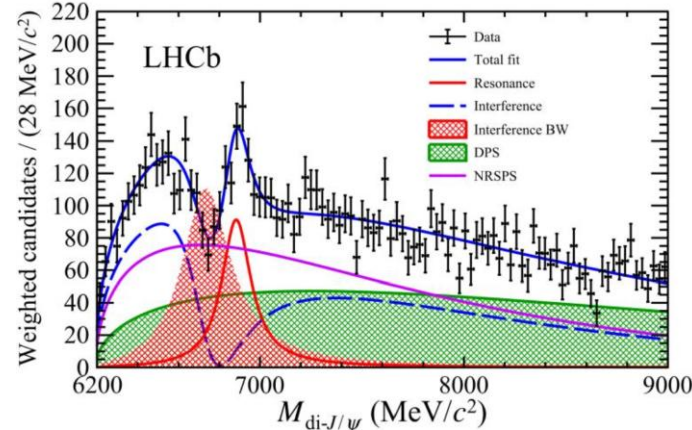
- Excellent detector for (exotic) quarkonium
- Good muon system
 - High-purity muon ID, $\frac{\Delta m}{m} \sim 0.6\%$ for J/ψ
- Silicon tracking detector
 - $B = 3.8 \text{ T}$, $\frac{\Delta p_T}{p_T} \sim 1\%$ & good vertex resolution
- Different triggers for different physics programs/purposes

The tetraquark candidates at LHC

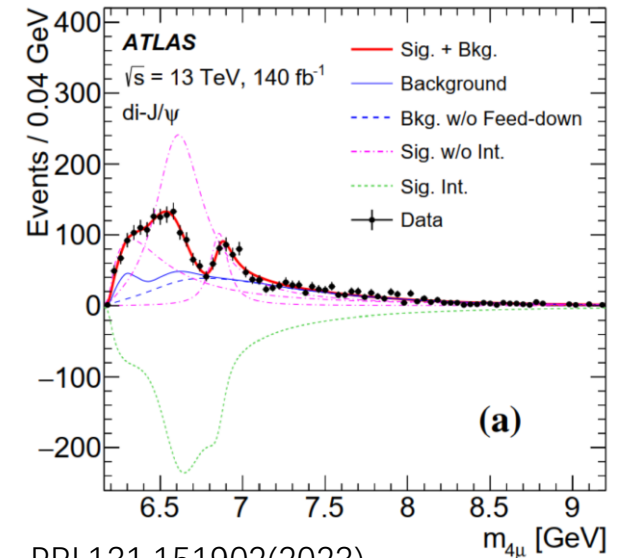
- Structures in $J/\psi J/\psi$ mass spectrum at CMS, LHCb and ATLAS from the LHC run 2 data
- Structures established but need more study to understand them



PRL132.111901(2024)



Sci.Bull.65(2020)23,1983-1993

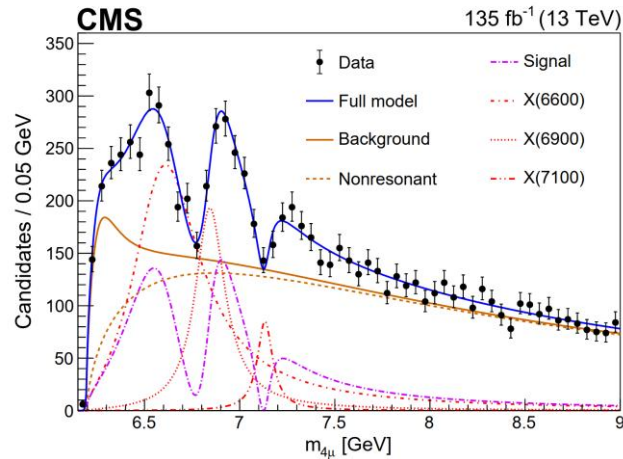


PRL131.151902(2023)

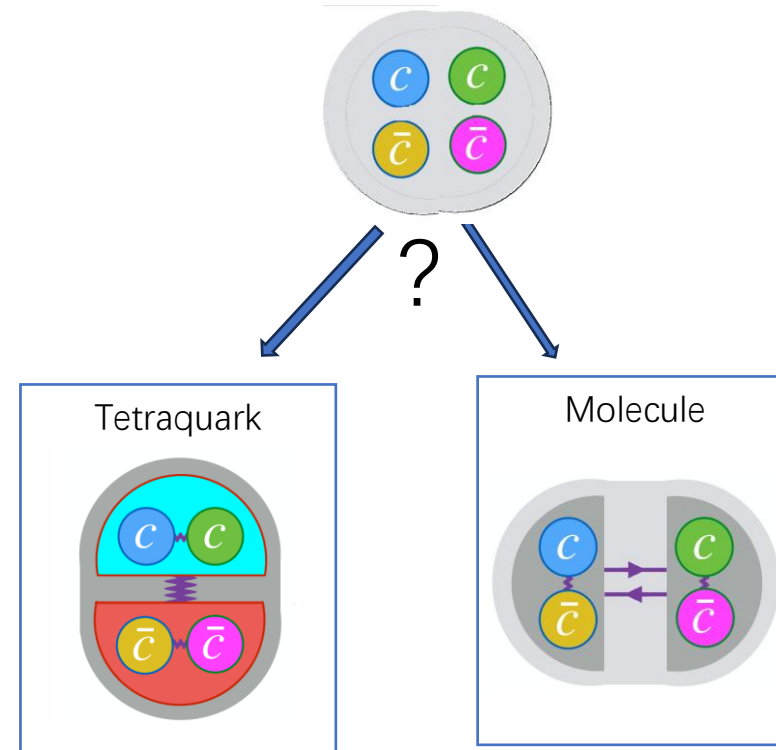
Internal Structure of the tetraquarks

Nature 648 (2025) 58

- Tetraquark candidates observed in experiments



$$X \rightarrow J/\psi J/\psi \rightarrow \mu^+ \mu^- \mu^+ \mu^-$$



- Don't know internal structure
 - Tetraquark, molecule, ...?
- Don't know spin-parity either
 - How to study their spin-parity?

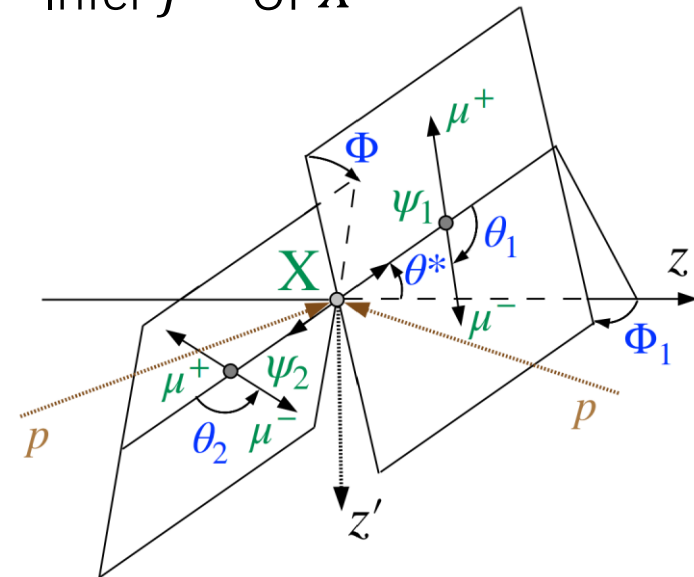
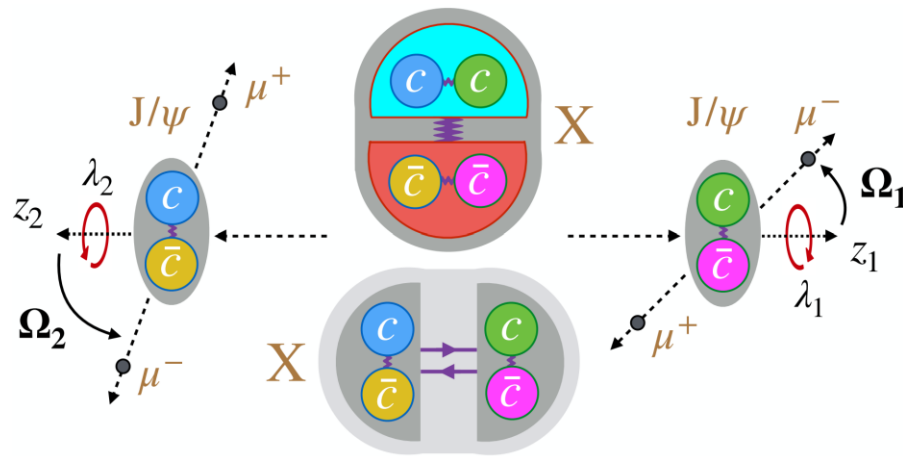
Infer spin-parity of X

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- Infer J^{PC} of X from angular distributions
- Theory
 - $A(X \rightarrow VV)$ depends on J_X^{PC} polarization of J/ψ
 - $A(X \rightarrow VV)$ determines angular distributions

- Experiment

- Measure angular distributions of $J/\psi, \mu$ etc.
- Infer J^{PC} of X



Lorentz invariant amplitude

- Expect three resonances to have the same tensor structure

$$A(X_{J=0} \rightarrow V_1 V_2) = \left(a_1(q^2) m_V^2 \epsilon_1^* \epsilon_2^* + a_2(q^2) f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3(q^2) f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

recall (22 years):
 $B \rightarrow \varphi K^*$ expect A_{00}
 found ~50% A_{++}
 Higgs (12 years):
 $H \rightarrow 4\ell \Rightarrow 0_m^+$

0_m^+

$A_{00} = A_{++} = A_{--}$ at $2m_{J/\psi}$ threshold

A_{00} at large m_X $A_{++} = A_{--}$

0_h^+

0^-

$A_{++} = -A_{--}$

arXiv:1001.3396

empirical form factors ($m_{4\mu}^2$)

$$A(X_{J=1} \rightarrow V_1 V_2) = \left(b_1(q^2) \left[(\epsilon_1^* q)(\epsilon_2^* \epsilon_X) + (\epsilon_2^* q)(\epsilon_1^* \epsilon_X) \right] + b_2(q^2) \epsilon_{\alpha\mu\nu\beta} \epsilon_X^\alpha \epsilon_1^{*\mu} \epsilon_2^{*\nu} \tilde{q}^\beta \right)$$

1^-

$A_{+0} = -A_{0+} = A_{-0} = -A_{0-}$

1^+

$A_{+0} = -A_{0+} = -A_{-0} = A_{0-}$

Helicities (0, -) of two J/ψ

more for spin-2

Simplification in angular analysis

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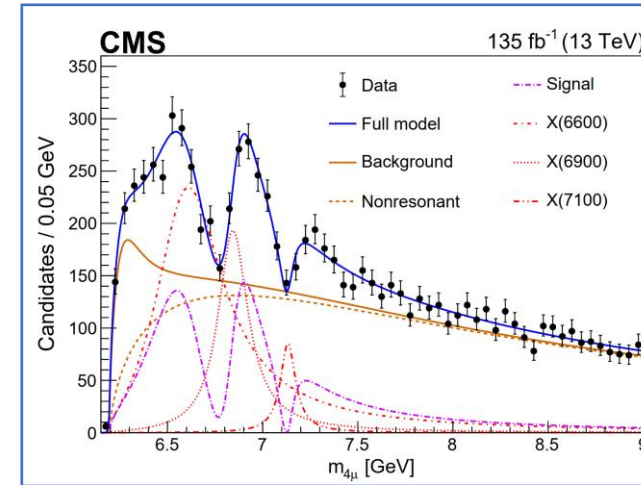
- Full amplitude analysis possible, but very complex

$$\mathcal{P}(\Phi, \theta_1, \theta_2; m_{4\mu}) \propto |A(X \rightarrow VV)|^2$$

- Simplification in angular analysis

(1) Same properties of **3 resonances**:

$$\mathcal{P}(m_{4\mu}, \vec{\Omega}) = \underbrace{\mathcal{P}(m_{4\mu})}_{\text{empirical}} \cdot \underbrace{T(\vec{\Omega} | m_{4\mu})}_{\text{angular}}$$



(2) Pairwise tests of J_X^P hypotheses i and j :

[arXiv:1208.4018](https://arxiv.org/abs/1208.4018)

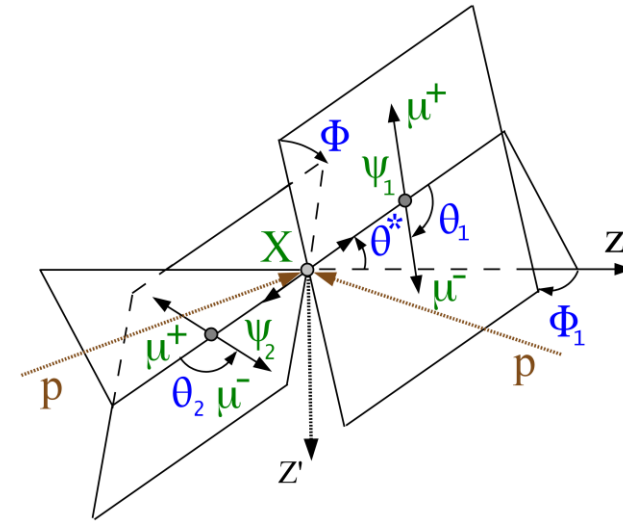
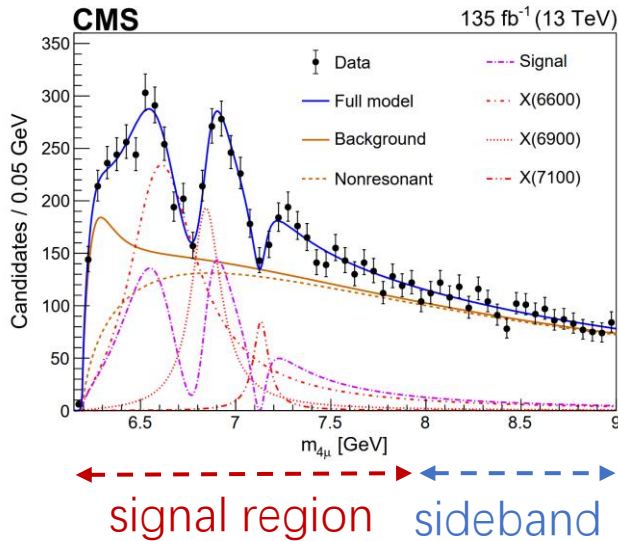
$$\text{MELA } \mathcal{D}_{ij}(\vec{\Omega} | m_{4\mu}) = \frac{\mathcal{P}_i(\vec{\Omega} | m_{4\mu})}{\mathcal{P}_i(\vec{\Omega} | m_{4\mu}) + \mathcal{P}_j(\vec{\Omega} | m_{4\mu})}$$

1 optimal observable \Leftarrow Higgs boson discovery and spin-parity

- Final 2D model: $\mathcal{P}_{ijk}(m_{4\mu}, \mathcal{D}_{ij}) = \mathcal{P}_k(m_{4\mu}) \cdot T_{ijk}(\mathcal{D}_{ij} | m_{4\mu})$

Analysis of data

- Two dimensions ($m_{4\mu}, D_{ij}$) analysis: $\mathcal{P}_{ijk}(m_{4\mu}, \mathcal{D}_{ij}) = \mathcal{P}_k(m_{4\mu}) \cdot T_{ijk}(\mathcal{D}_{ij} | m_{4\mu})$
 - Event selection from observation paper [Phys. Rev. Lett. 132 \(2024\) 111901](#)
 - BKG: data sideband & MC simulation with Pythia
 - $m_{4\mu}$ shapes: [Phys. Rev. Lett. 132 \(2024\) 111901](#)
 - Decay angles Φ, θ_1, θ_2 to identify $D_{ij}(\Phi, \theta_1, \theta_2; m_{4\mu})$



All steps till here prepared blinded

Hypothesis test of 0^- vs. 2_m^+

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- Hypothesis test for $j = 0^-$ vs. $i = 2_m^+$

		Observed		Expected	
		p -value	Z-score	p -value	Z-score
0^- vs 2_m^+	0^-	2.7×10^{-13}	7.2	6.5×10^{-14}	7.4
	2_m^+	0.42	0.2	0.5	0

- 2D parameterization:

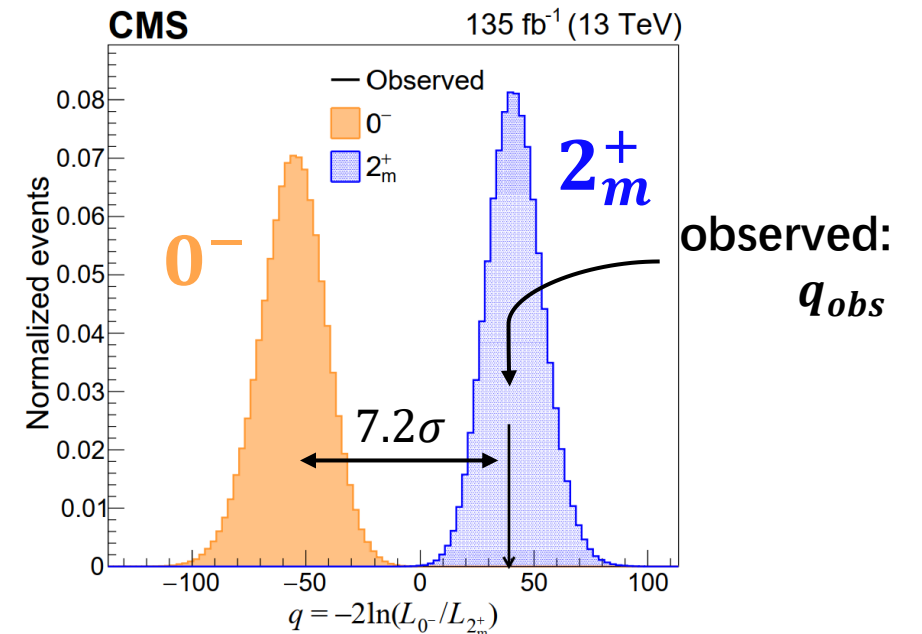
$$\mathcal{P}_{ijk}(m_{4\mu}, \mathcal{D}_{ij}) = \mathcal{P}_k(m_{4\mu}) \cdot T_{ijk}(\mathcal{D}_{ij} | m_{4\mu})$$

- Test statistics:

$$q = -2\ln(\mathcal{L}_{J_i^P} / \mathcal{L}_{J_j^P})$$

- Confidence level:

$$CL_s = \frac{P(q \geq q_{\text{obs}} | J_j^P + \text{bkg})}{P(q \geq q_{\text{obs}} | J_i^P + \text{bkg})}$$



Hypothesis test of J_i^P vs. J_j^P

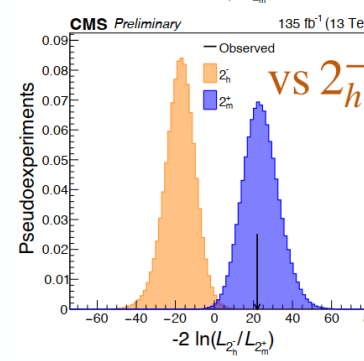
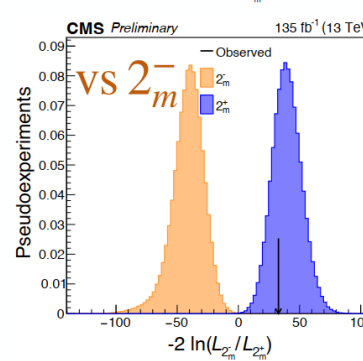
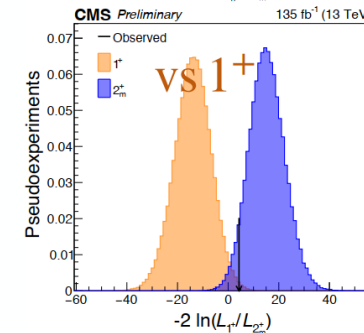
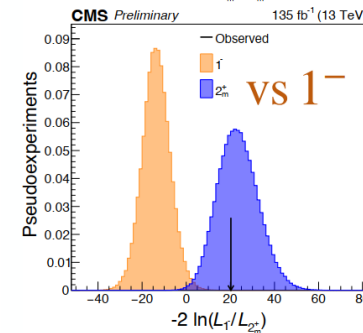
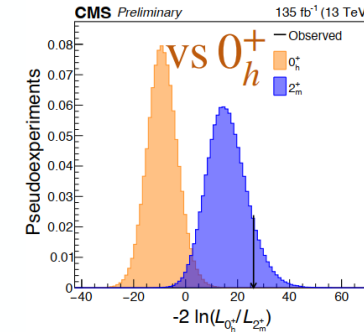
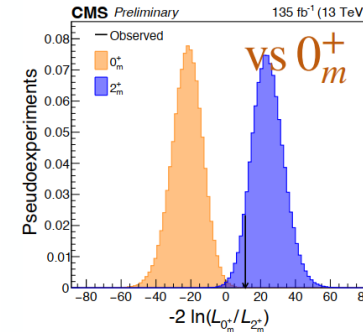
- Combined 2D fit: $\mathcal{P}_{ijk}(m_{4\mu}, \mathcal{D}_{ij})$

➤ $J^P = 2_m^+$ model survives

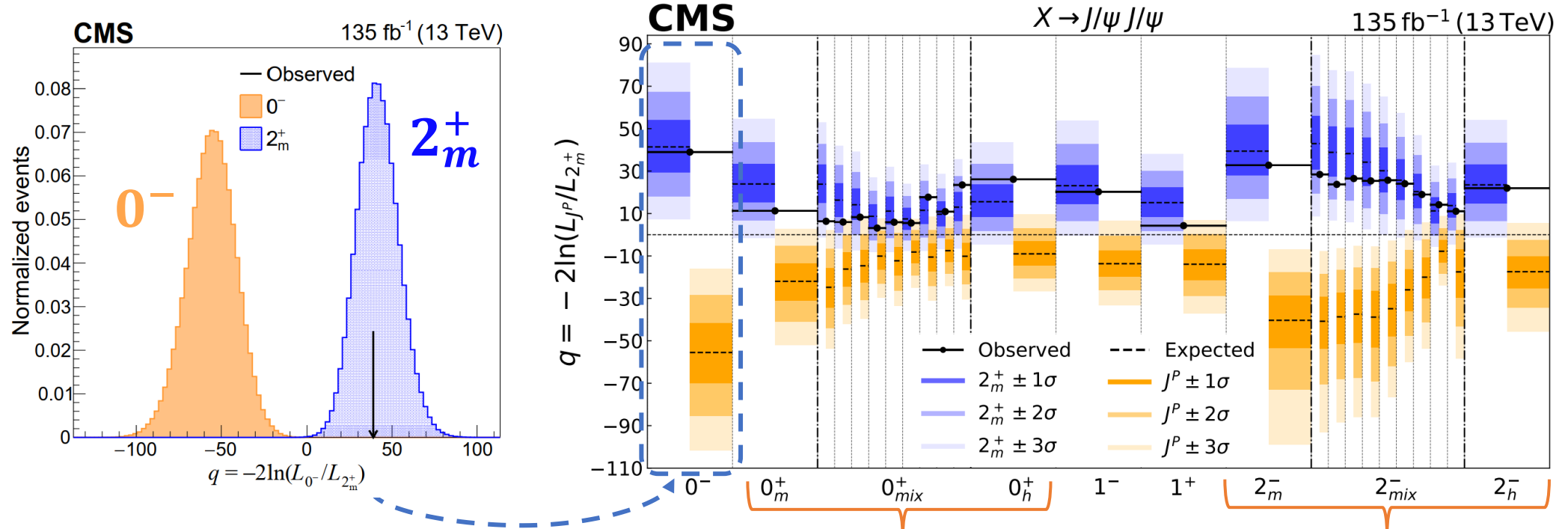
J_i^P	p -value	Z-score reject J_i^P
0^-	2.7×10^{-13}	7.2
0_m^+	4.3×10^{-5}	3.9
0_{mix}^+	1.4×10^{-2}	2.2
0_h^+	3.1×10^{-9}	5.8
1^-	8.0×10^{-8}	5.2
1^+	4.7×10^{-3}	2.6
2_m^-	4.1×10^{-12}	6.8
2_{mix}^-	6.5×10^{-4}	3.2
2_h^-	2.2×10^{-8}	5.5

mix

mix



Summary of results



- Data consistent with **2⁺⁺**, inconsistent with **others**
 - $PC = ++$
 - $J \neq 1$ at > 99% CL; $J \neq 0$ at 95% CL
 - $J > 2$ possible, but highly unlikely, require $L \geq 2$
 - $J = 2$ consistent, rare in nature, naively expected $J = 0$

Scan of two **2⁻⁺** (11 steps)

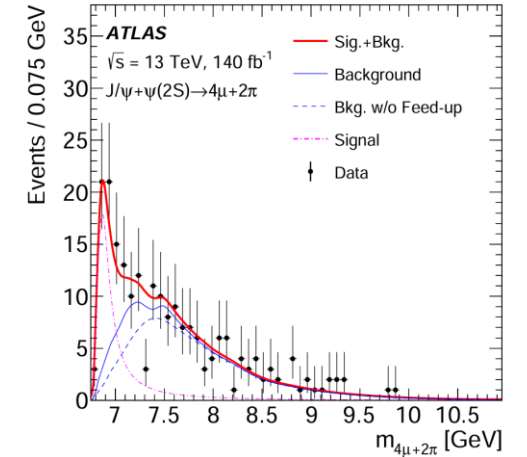
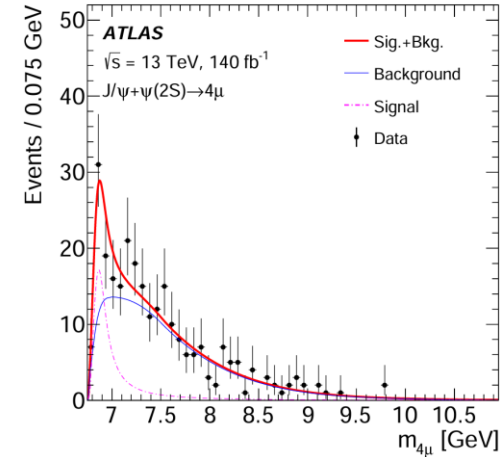
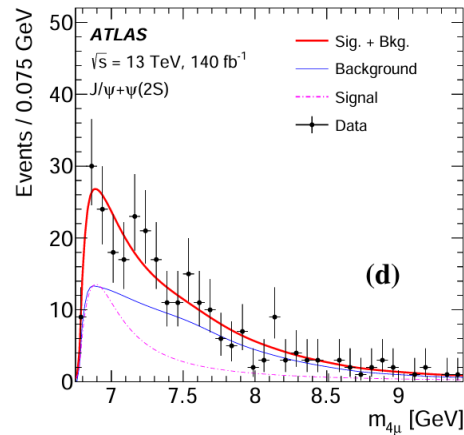
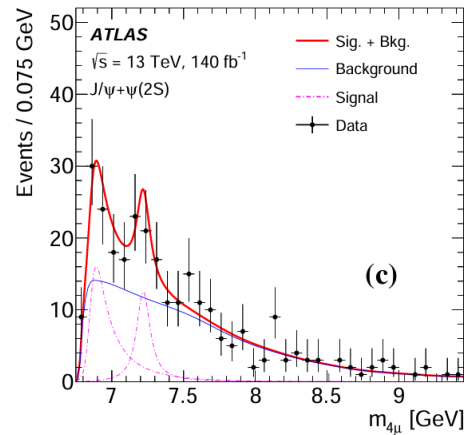
-- No interference (different spin projections)

Scan mixture of two **0⁺⁺** amp. (11 steps)

-- Constructive interf. most conservative

X(6900) and X(7100) in $J/\psi\psi(2S)$

- ATLAS



[PhysRevLett131.151902](https://arxiv.org/abs/1311.1519)
 3σ of X(7100)

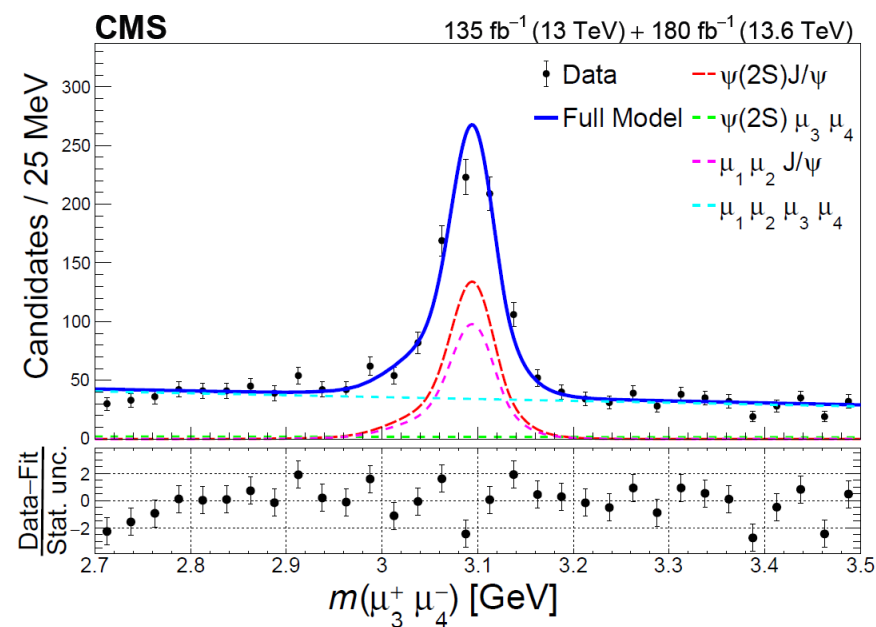
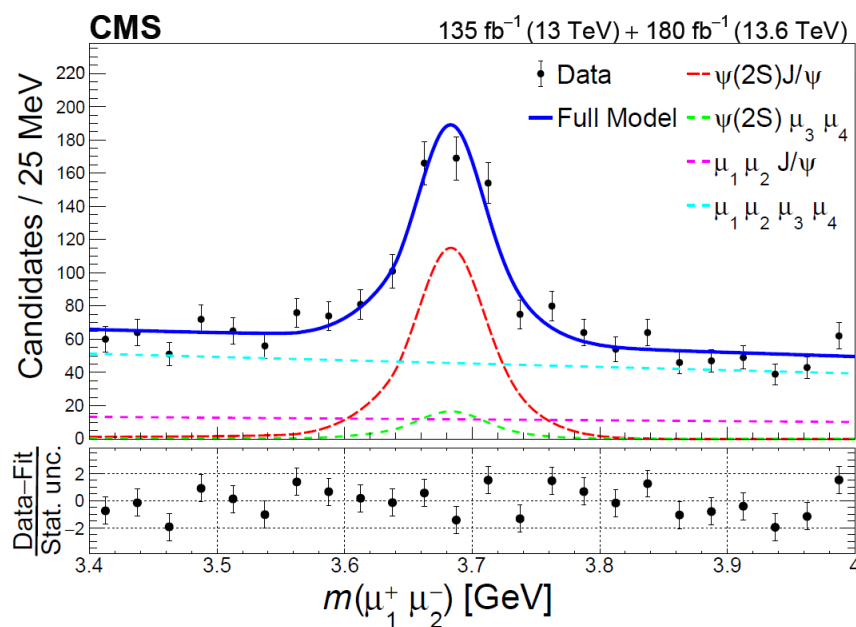
[arxiv:2509.13101](https://arxiv.org/abs/2509.13101)
No X(7100)

- How about CMS's data

X(6900) and X(7100) in $J/\psi\psi(2S)$

arxiv:2602.02252

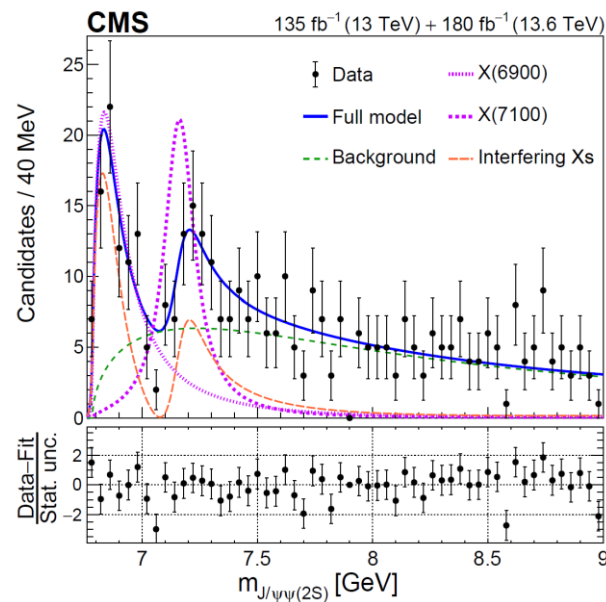
- Dataset:
 - 135 fb CMS data taken in 2016, 2017, and 2018 LHC runs (13 TeV)
 - 180 fb CMS data taken in 2022, 2023, and 2024 LHC runs (13.6 TeV)
- J/ψ and $\psi(2S)$ reconstructed via $\psi \rightarrow \mu^+ \mu^-$



X(6900) and X(7100) in $J/\psi\psi(2S)$ at CMS

arxiv:2602.02252

- X(6900) and X(7100) in $J/\psi\psi(2S)$
 - Data fit
 - Signal: X(6900), X(7100) and their interference
 - Background: NRSPS, DPS, combinatorial contribution
 - **$> 8\sigma$ for X(6900), $> 4.0\sigma$ for X(7100)**
 - Impact from X(6600) [below threshold] considered in systematic uncertainty



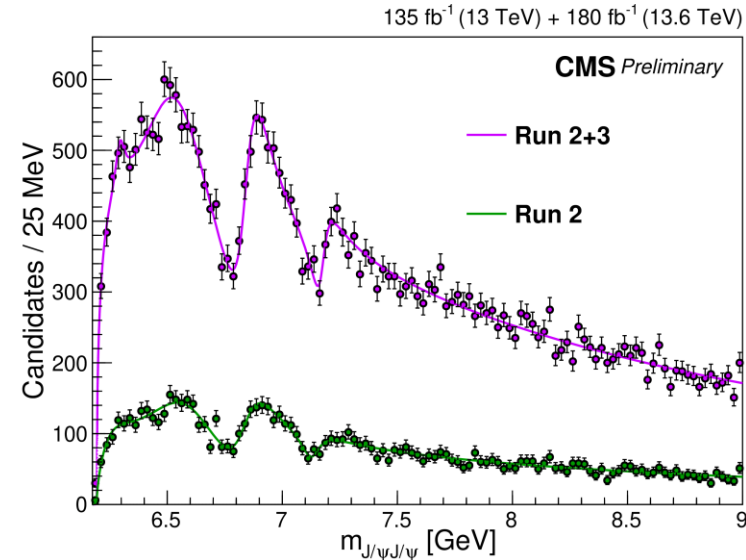
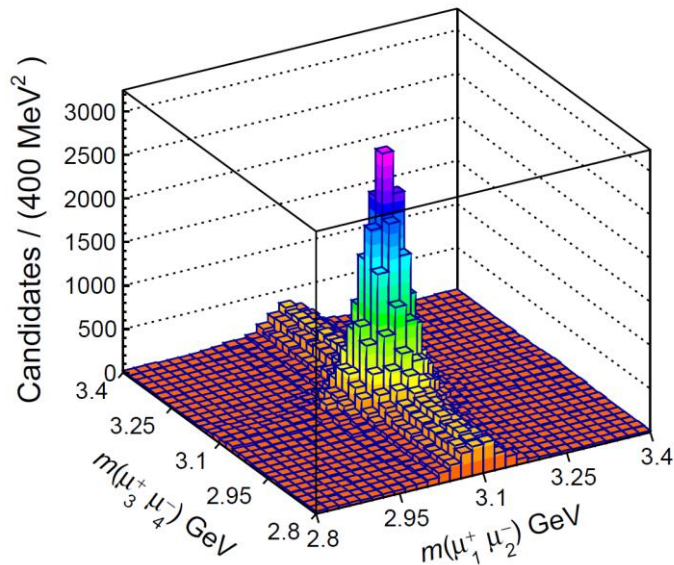
	X(6600)	X(6900)	X(7100)
$J/\psi\psi(2S)$: Run 2+3			
Mass	—	$6876^{+46+111}_{-29-112}$	7169^{+26+80}_{-52-72}
Width	—	$253^{+290+140}_{-100-134}$	$154^{+110+140}_{-82-181}$

More details see Liangliang Chen's [talk](#)

All-charm tetraquarks at CMS

arxiv:2602.02252

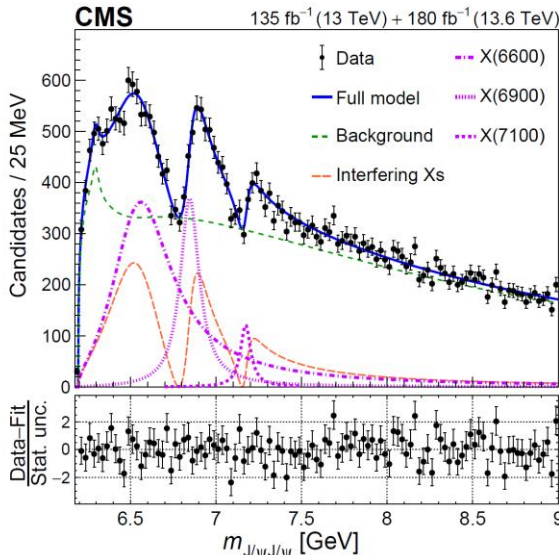
- Tetraquark candidates observed in $J/\psi J/\psi$ mass at CMS
 - J/ψ reconstructed via its $\mu^+ \mu^-$ decays
- Data (314 fb^{-1})
 - 2016-2018 (run 2): 13 TeV, 134.8 fb^{-1}
 - 2022-2024 (run 3): 13.6 TeV, 179.6 fb^{-1}



All-charm tetraquarks at CMS

arxiv:2602.02252

- X(6600), X(6900), X(7100) in $J/\psi J/\psi$ at CMS
 - Data fit
 - Signal: Coherent sum of X(6600), X(6900), X(7100)
 - BKG: NRSPS, DPS, combinatorial contribution, feeddown
 - Significance
 - $> 5\sigma$ for each of X(6600), X(6900), and X(7100)
 - $> 5\sigma$ for interference (two dips)
 - $> 5\sigma$ for each single dip: 6750 MeV dip, and 7150 MeV dip



		X(6600)	X(6900)	X(7100)
$J/\psi J/\psi$: Run 2 [15]	Mass	6638^{+43+16}_{-38-31}	6847^{+44+48}_{-28-20}	7134^{+48+41}_{-25-15}
	Width	$440^{+230+110}_{-200-240}$	191^{+66+25}_{-49-17}	97^{+40+29}_{-29-26}
$J/\psi J/\psi$: Run 2+3	Mass	$6593^{+15}_{-14} \pm 25$	$6847 \pm 10 \pm 15$	$7173^{+9}_{-10} \pm 13$
	Width	$446^{+66}_{-54} \pm 87$	$135^{+16}_{-14} \pm 14$	$73^{+18}_{-15} \pm 10$
$J/\psi \psi(2S)$: Run 2+3	Mass	—	$6876^{+46+111}_{-29-112}$	7169^{+26+80}_{-52-72}
	Width	—	$253^{+290+140}_{-100-134}$	$154^{+110+140}_{-82-181}$

Feeddown: e.g., $X \rightarrow J/\psi \psi(2S) \rightarrow J/\psi J/\psi \pi \pi$ is reconstructed as $J/\psi J/\psi$ instead of $J/\psi J/\psi \pi \pi$

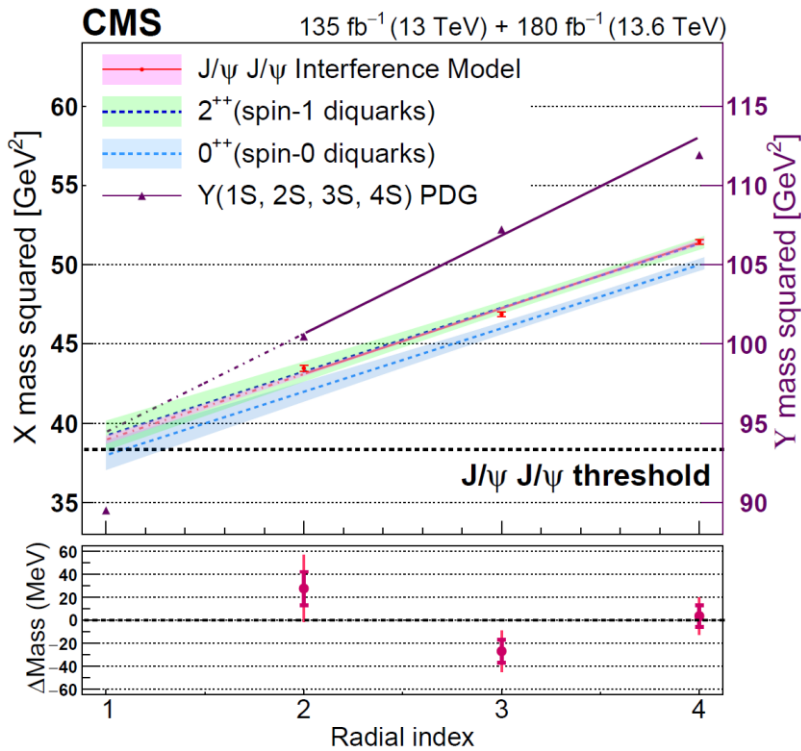
Patterns among the triplets

arxiv:2602.02252

- Regge theory: $n_r = \beta M^2 + \beta_0$
 $n_r = n - 1$, radial quantum number n

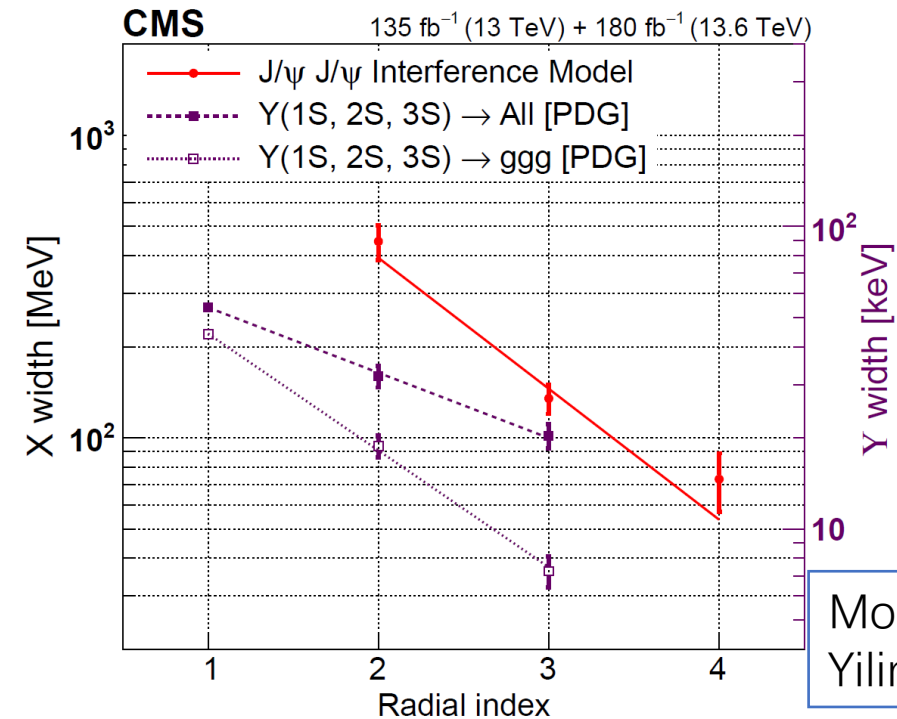
- X widths decreases with radial excitation, exponentially

Regge trajectories of X and Y



Good agreement with spin-1 diquark 0⁺⁺ or 2⁺⁺ state

Width trends of X and Y



More details see Yilin Zhou's [talk](#)

In **Y** family, $b\bar{b}$ quark-antiquark annihilation predominantly
 A similar exponential width trend with annihilation partial width of **Y** family

Summary

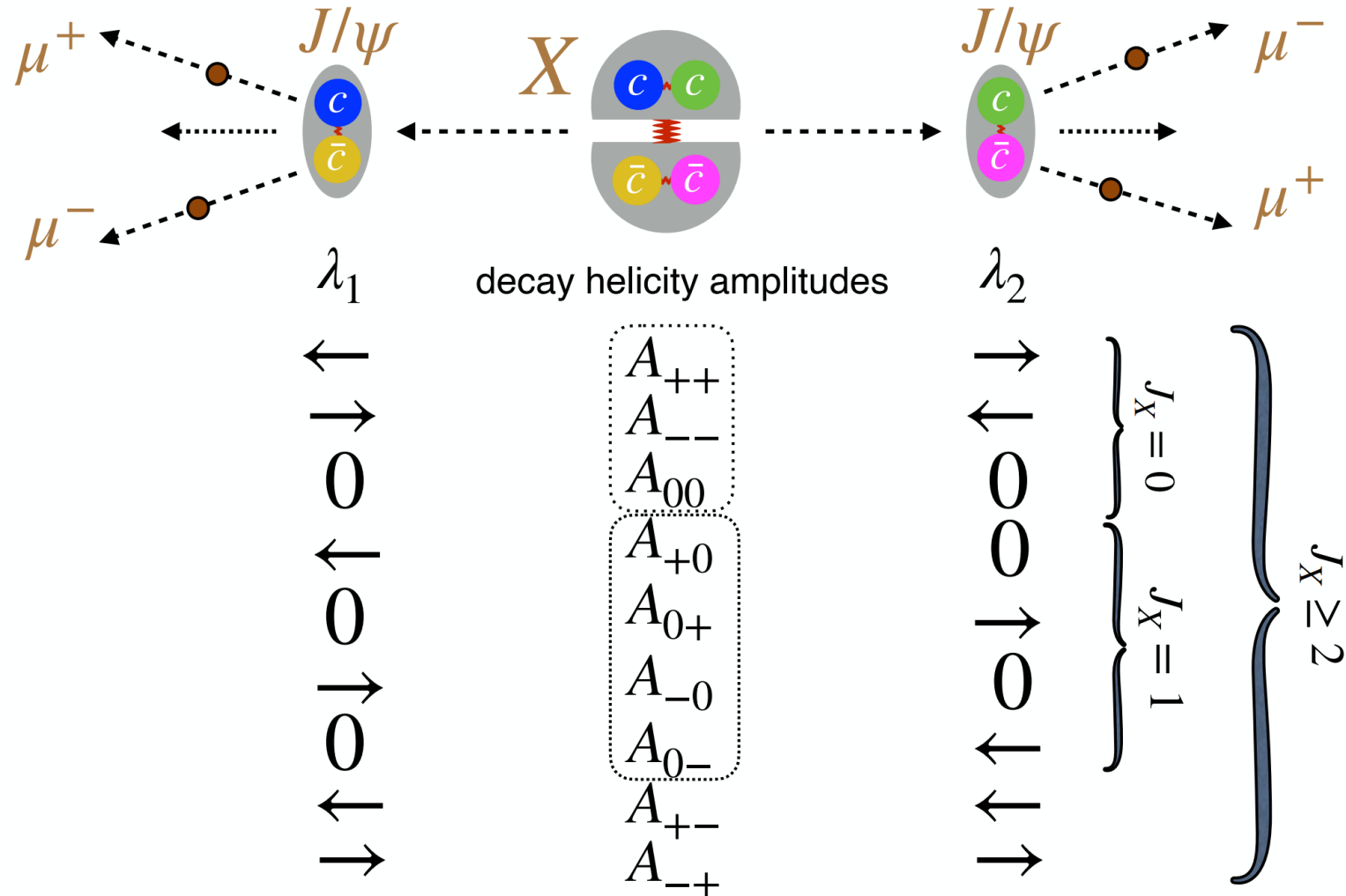
- Spin-parity analysis of the tetraquarks at CMS
 - Data consistent with 2^{++}
 - Exclude spin 0 and spin 1 at 99% and 95% CL
- Observation of X(6900) in $J/\psi\psi(2S)$, and evidence of X(7100) in $J/\psi\psi(2S)$
- Observation of X(7100) in $J/\psi J/\psi$, and interference greater than 5σ

Thanks

Backup

J/ψ polarizations

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J/ψ polarizations

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- Symmetries:

- angular momentum: $|\lambda_1 - \lambda_2| \leq J$

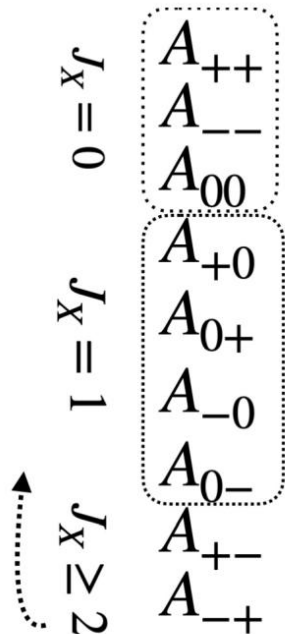
- P & C conserved in QCD:

X with definite J^{PC}

- identical J/ψ bosons $A_{\lambda_1\lambda_2} = (-1)^J A_{\lambda_2\lambda_1}$

$C = +1$

$A_{\lambda_1\lambda_2} = P(-1)^J A_{-\lambda_1-\lambda_2}$



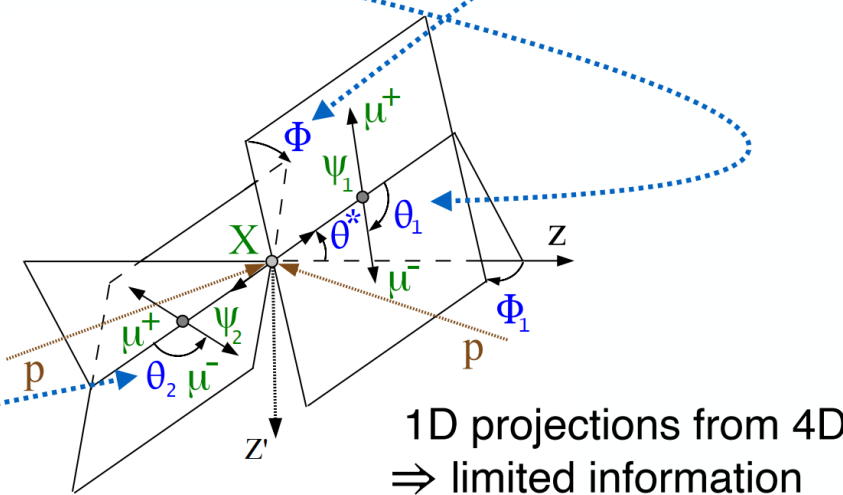
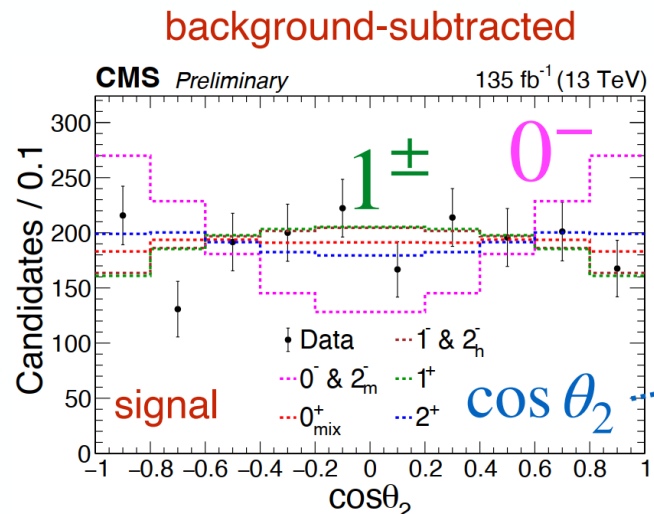
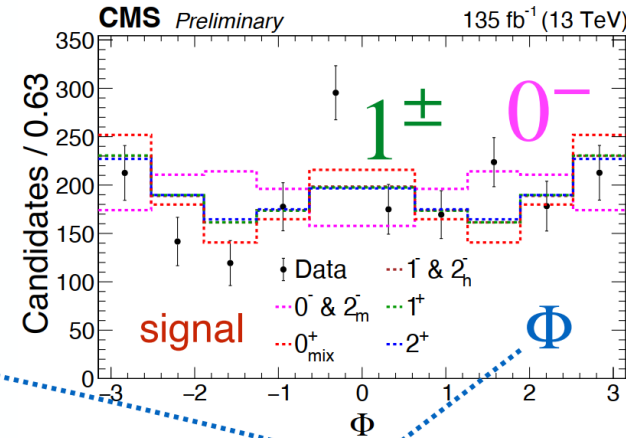
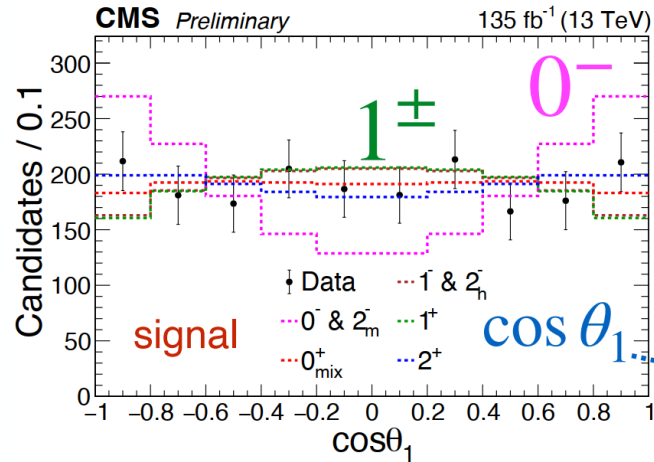
Test 8+ J_X^P models:

0^{-+}	0^-	$A_{++} = -A_{--}$
0^{++}	0_m^+ and 0_h^+	$A_{++} = A_{--}$ and A_{00} ← note 2 d.o.f.
1^{-+}	1^-	$A_{+0} = -A_{0+} = A_{-0} = -A_{0-}$
1^{++}	1^+	$A_{+0} = -A_{0+} = -A_{-0} = A_{0-}$
2^{-+}	2_m^- and 2_h^-	$A_{++} = -A_{--}$ and $A_{+0} = A_{0+} = -A_{-0} = -A_{0-}$ ← note 2 d.o.f.
2^{++}	2_m^+	$A_{++} = A_{--}, A_{00}, A_{+0} = A_{0+} = A_{-0} = A_{0-},$ and $A_{+-} = A_{-+}$

note 4 d.o.f. for 2^{++} , test one model

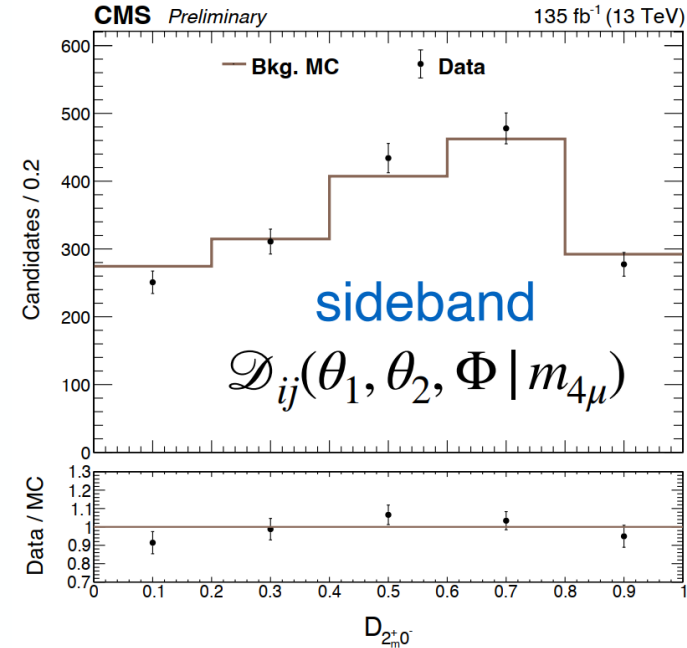
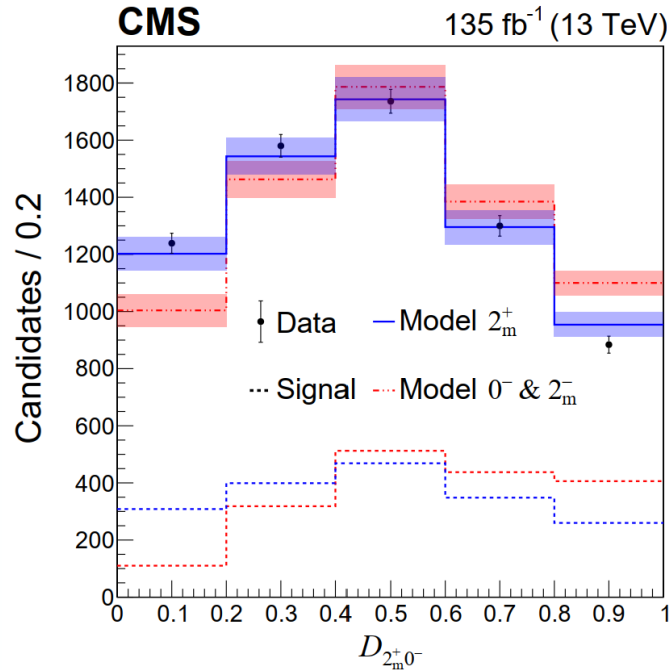
Decay angles

- Production angles not use – consistent with unpolarized
- Decay angles (consistency check): **distinguish** models



Optimal Observables

- 1D projection of data, optimal for $j = 0^-(2_m^-)$ vs $i = 2_m^+$



optimal observable

MELA
$$\mathcal{D}_{ij}(\vec{\Omega} | m_{4\mu}) = \frac{\mathcal{P}_i(\vec{\Omega} | m_{4\mu})}{\mathcal{P}_i(\vec{\Omega} | m_{4\mu}) + \mathcal{P}_j(\vec{\Omega} | m_{4\mu})}$$

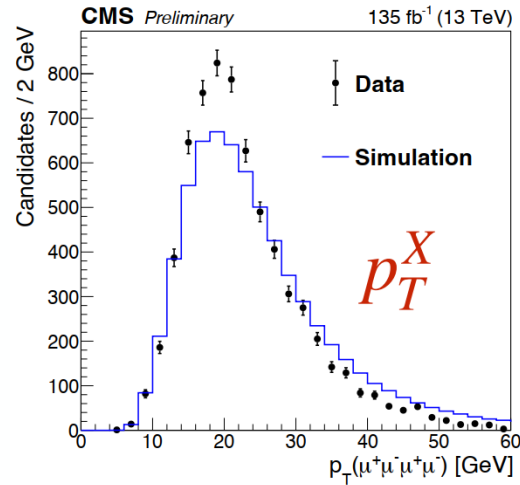
1D projections from 2D
 \Rightarrow limited information

background model from MC
 control in sidebands
 systematic variations

Production: p_T and p_z of X

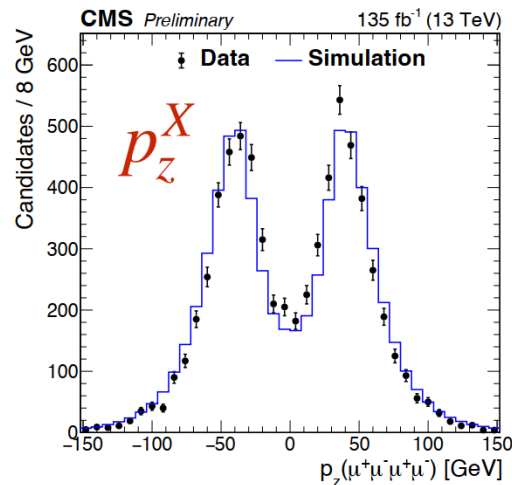
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- empirical model to reproduce p_T^X and p_z^X in data



- tune **Pythia** to match p_T^X in **sideband** and **signal region**

- fine-tune re-weighting p_T^X

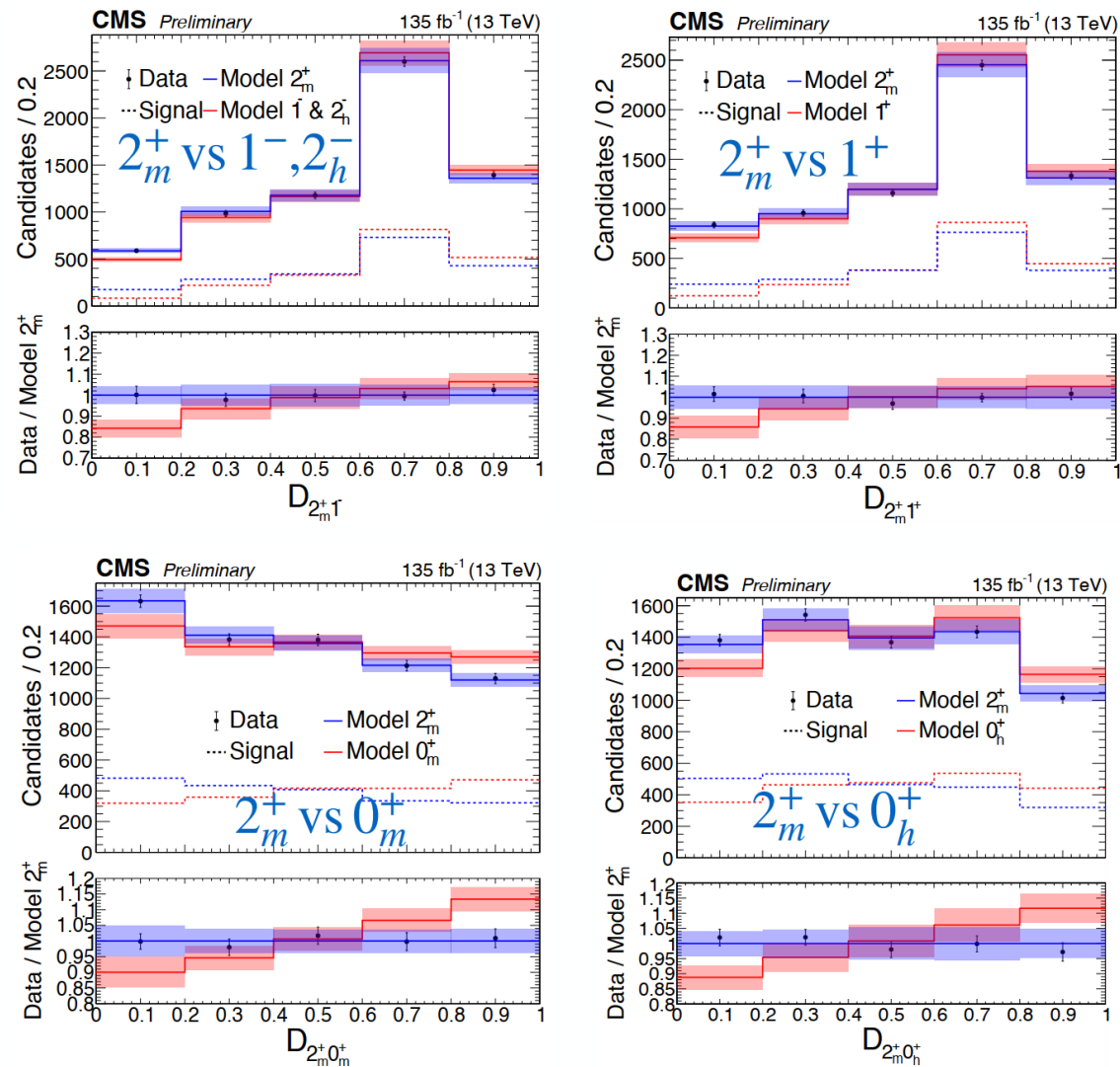


- residual p_T^X and p_z^X consistency tests coverage in systematics

- essential to model **detector acceptance**

Simulation:
JHUGen + Pythia

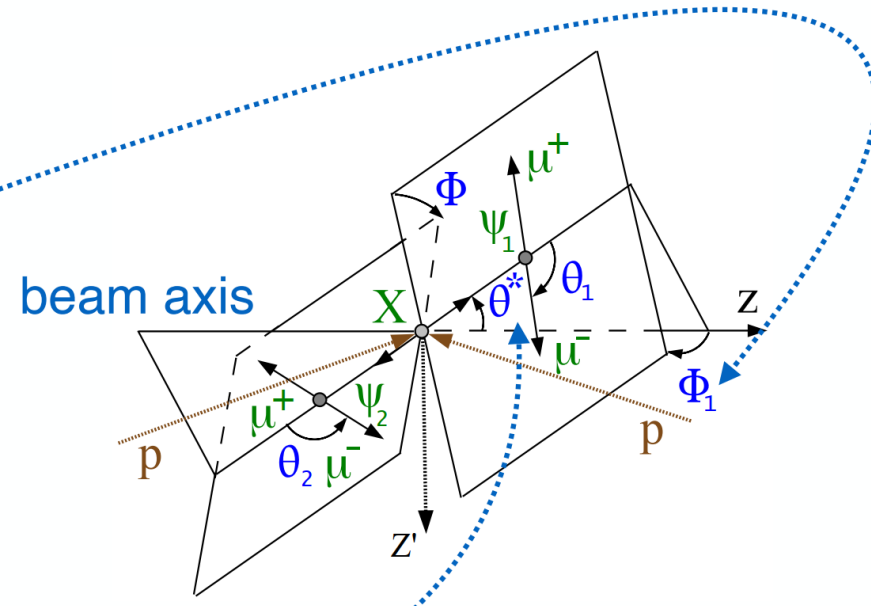
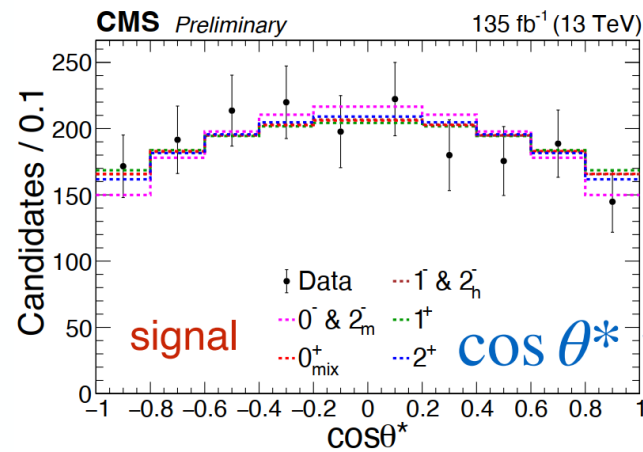
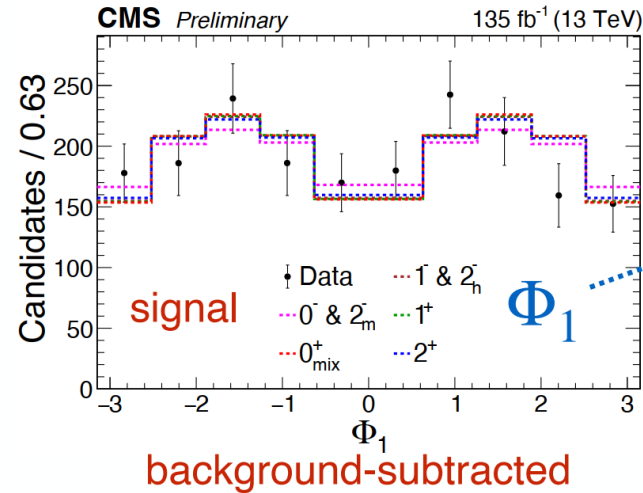
Discriminant



Production angles

(4) production angles consistent with **unpolarized** resonances

with respect to the **beam axis**



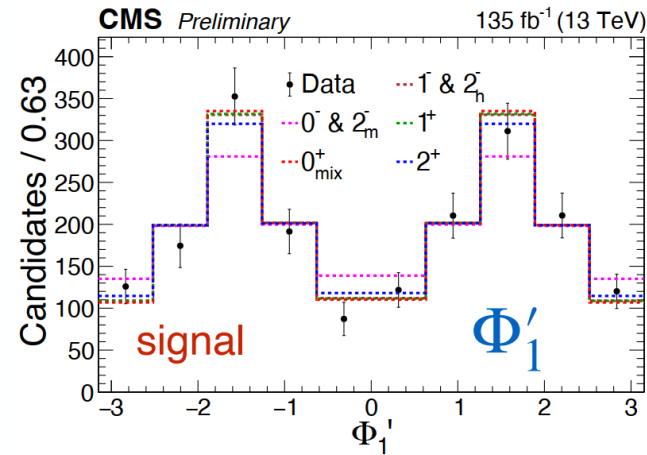
acceptance effects
⇒ distributions not flat

Production angles

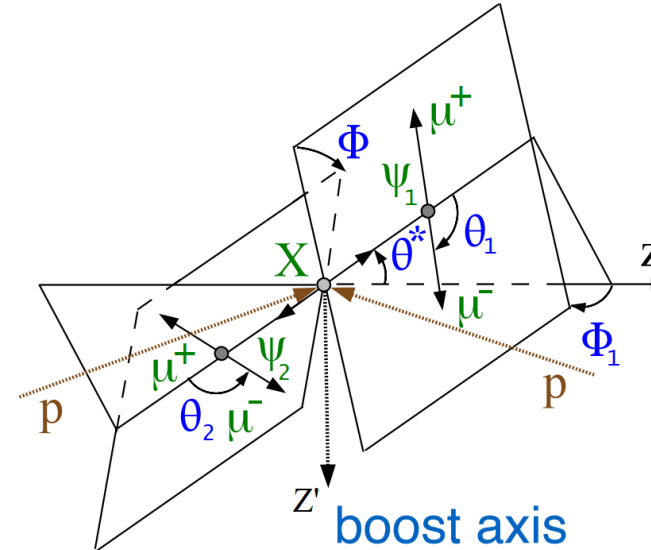
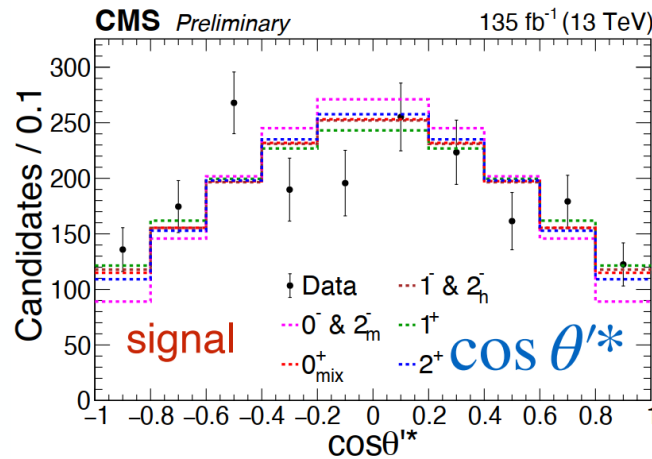
(4) production angles consistent with **unpolarized** resonances

with respect to the **boost axis**

does not prove **unpolarized**



background-subtracted



Lorentz invariant amplitude

- Expect three X resonances to have the same **tensor structure**:

$$A(X_{J=0} \rightarrow V_1 V_2) = \left(a_1(q^2) m_V^2 \epsilon_1^* \epsilon_2^* + a_2(q^2) f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3(q^2) f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

recall (22 years):
 $B \rightarrow \varphi K^*$ expect A_{00}
 found ~50% A_{++}
 Higgs (12 years):
 $H \rightarrow 4\ell \Rightarrow 0_m^+$

0_m^+

0_h^+

0^-

$A_{00} = A_{++} = A_{--}$ at $2m_{J/\psi}$ threshold

A_{00} at large m_X $A_{++} = A_{--}$

$A_{++} = -A_{--}$

[arXiv:1001.3396](https://arxiv.org/abs/1001.3396)

empirical **form factors** ($m_{4\mu}^2$)

$$A(X_{J=1} \rightarrow V_1 V_2) = \left(b_1(q^2) \left[(\epsilon_1^* q)(\epsilon_2^* \epsilon_X) + (\epsilon_2^* q)(\epsilon_1^* \epsilon_X) \right] + b_2(q^2) \epsilon_{\alpha\mu\nu\beta} \epsilon_X^\alpha \epsilon_1^{*\mu} \epsilon_2^{*\nu} \tilde{q}^\beta \right)$$

1^-

1^+

more for spin-2

$A_{+0} = -A_{0+} = A_{-0} = -A_{0-}$

$A_{+0} = -A_{0+} = -A_{-0} = A_{0-}$

Lorentz invariant amplitude

- Expect three X resonances to have the same **tensor structure**:

$$\begin{aligned}
 A(X_{J=2} \rightarrow V_1 V_2) = & 2c_1(q^2) t_{\mu\nu} f^{*1,\mu\alpha} f^{*2,\nu\alpha} + 2c_2(q^2) t_{\mu\nu} \frac{q_\alpha q_\beta}{\Lambda^2} f^{*1,\mu\alpha} f^{*2,\nu,\beta} \\
 & + c_3(q^2) \frac{\tilde{q}^\beta \tilde{q}^\alpha}{\Lambda^2} t_{\beta\nu} (f^{*1,\mu\nu} f_{\mu\alpha}^{*2} + f^{*2,\mu\nu} f_{\mu\alpha}^{*1}) + c_4(q^2) \frac{\tilde{q}^\nu \tilde{q}^\mu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} f_{\alpha\beta}^{*(2)} \\
 & + m_V^2 \left(2c_5(q^2) t_{\mu\nu} \epsilon_1^{*\mu} \epsilon_2^{*\nu} + 2c_6(q^2) \frac{\tilde{q}^\mu q_\alpha}{\Lambda^2} t_{\mu\nu} (\epsilon_1^{*\nu} \epsilon_2^{*\alpha} - \epsilon_1^{*\alpha} \epsilon_2^{*\nu}) + c_7(q^2) \frac{\tilde{q}^\mu \tilde{q}^\nu}{\Lambda^2} t_{\mu\nu} \epsilon_1^* \epsilon_2^* \right) \\
 & + c_8(q^2) \frac{\tilde{q}_\mu \tilde{q}_\nu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} \tilde{f}_{\alpha\beta}^{*(2)} + c_{10}(q^2) \frac{t_{\mu\alpha} \tilde{q}^\alpha}{\Lambda^2} \epsilon_{\mu\nu\rho\sigma} q^\rho \tilde{q}^\sigma (\epsilon_1^{*\nu} (q\epsilon_2^*) + \epsilon_2^{*\nu} (q\epsilon_1^*)),
 \end{aligned}$$

arXiv:1001.3396

2_m^-

$(A_{++} = -A_{--})$

2_h^-

$(A_{+0} = A_{0+} = -A_{-0} = -A_{0-})$

2_m^+ – minimal representative model including all amplitudes:

4 d.o.f. $A_{00}, A_{++} = A_{--}, A_{+0} = A_{0+} = A_{-0} = A_{0-}, A_{+-} = A_{-+}$ for 2^{++} (or $J \geq 2$)

21%
9%
47%
23%

basis of 2^{++} could be equivalent to $2_m^+, 0_m^+, 0_h^+, 1^+$

if data consistent with $2_m^+ \Rightarrow$ unambiguously 2^{++} (or $J \geq 2$)

Results of J^P vs. 2_m^+

- Full set of results, compared to 2_m^+

$P = -1$

		Observed		Expected	
		p-value	Z-score	p-value	Z-score
0^- vs 2_m^+	0^-	2.7×10^{-13}	7.2	6.5×10^{-14}	7.4
	2_m^+	4.2×10^{-1}	0.2	0.50	0.0
0_m^+ vs 2_m^+	0_m^+	4.3×10^{-5}	3.9	5.6×10^{-9}	5.7
	2_m^+	7.2×10^{-2}	1.5	0.50	0.0
0_{mix}^+ vs 2_m^+	0_{mix}^+	1.4×10^{-2}	2.2	8.4×10^{-4}	3.1
	2_m^+	1.7×10^{-1}	1.0	0.50	0.0
0_h^+ vs 2_m^+	0_h^+	3.1×10^{-9}	5.8	8.5×10^{-5}	3.8
	2_m^+	9.0×10^{-1}	-1.3	0.50	0.0
1^- vs 2_m^+	1^-	8.0×10^{-8}	5.2	6.4×10^{-9}	5.7
	2_m^+	3.8×10^{-1}	0.3	0.50	0.0
1^+ vs 2_m^+	1^+	4.7×10^{-3}	2.6	2.7×10^{-5}	4.0
	2_m^+	5.2×10^{-2}	1.6	0.50	0.0
2_m^- vs 2_m^+	2_m^-	4.1×10^{-12}	6.8	3.9×10^{-14}	7.5
	2_m^+	2.8×10^{-1}	0.6	0.50	0.0
2_{mix}^- vs 2_m^+	2_{mix}^-	6.5×10^{-4}	3.2	1.5×10^{-4}	3.6
	2_m^+	3.1×10^{-1}	0.5	0.50	0.0
2_h^- vs 2_m^+	2_h^-	2.2×10^{-8}	5.5	6.3×10^{-9}	5.7
	2_m^+	4.3×10^{-1}	0.2	0.50	0.0

– $J^{PC} = 2^{++}$
most likely

– $J > 2$ possible
but highly unlikely
require $L \geq 2$

– $J \neq 0$ at $> 95\%$ CL

– $J \neq 1$ at $> 99\%$ CL

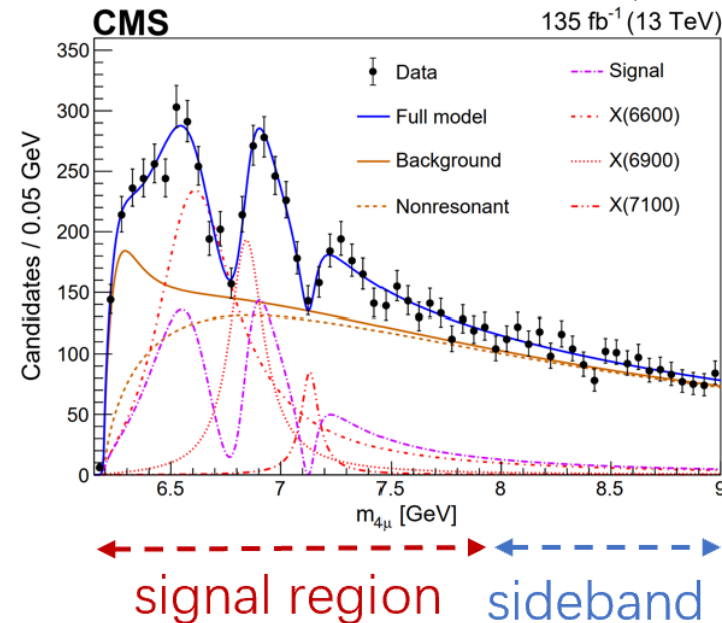
– $P \neq -1$ very certain
(exclude J^{-+} including $J \geq 3$)

- Recall: 2^{++} can have a mixture of 2_m^+ and look-alike of $0^+, 1^+$

Data analysis

(1) empirical $m_{4\mu}$ spectrum \rightarrow for **signal** and **background**

- trigger $\mu^+\mu^-\mu^\pm$
 $p_T > 3 \text{ GeV}, p_T > 5 \text{ GeV}$
- reco $(\mu^+\mu^-)(\mu^+\mu^-)$
 $p_T > 2 \text{ GeV}, |\eta| < 2.4$
- mass / vertex - constrained fit



- Background: **data** sideband & **MC** simulation with **Pythia**
 - $J/\psi J/\psi$ single- and double-parton scattering
 - empirical threshold enhancement (signal-like MC)

Variables in the analysis

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(1) $m_{4\mu}$ spectrum $X \rightarrow 4\mu$ — [arXiv:2306.07164](https://arxiv.org/abs/2306.07164)

(2) p_T and p_Z of $X \rightarrow 4\mu$ — match to data

(3) polarization J_z or $J_{z'}$ of X — unpolarized

for $J = 0$ exact

for $J = 1, 2, \dots$ depends on production mechanism

— vary J_z or $J_{z'}$ systematics or test

(4) Φ_1, θ^* or Φ'_1, θ'^* production angles

flat for unpolarized — test in data

non-flat for polarized

do not use in the primary analysis

(5) Φ, θ_1, θ_2 decay angles — analysis

All steps till here
prepared blinded

