Determination of the spin and parity of all-charm tetraquarks at CMS

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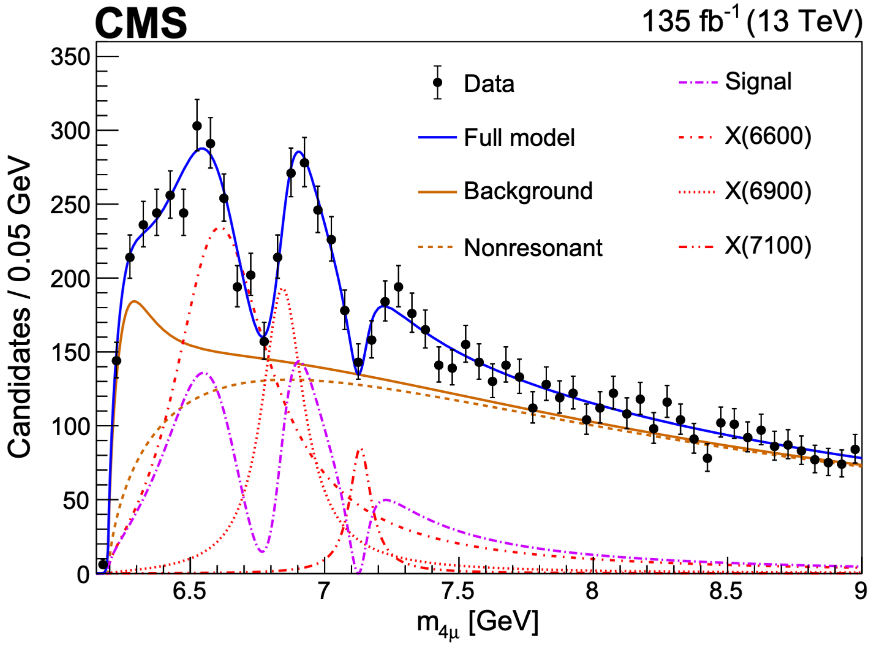
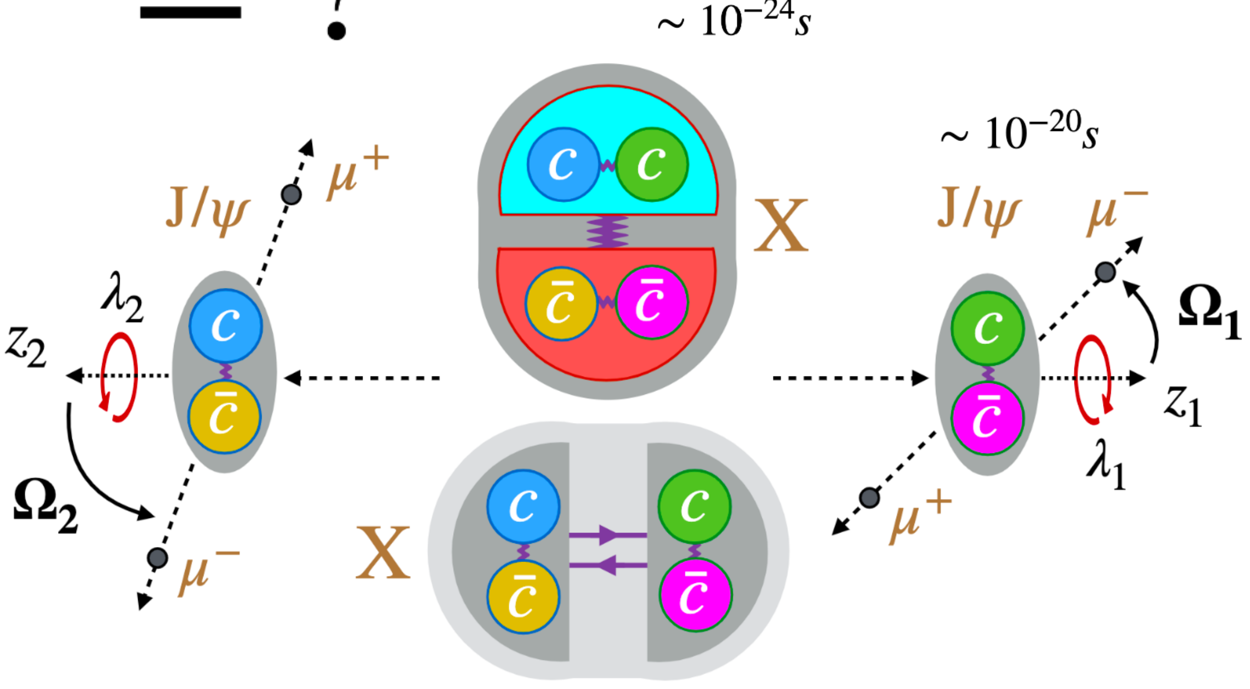
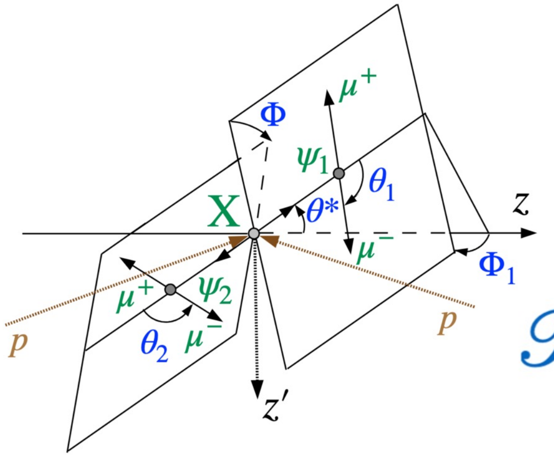
$J^{PC} = ?$



signal region — sideband





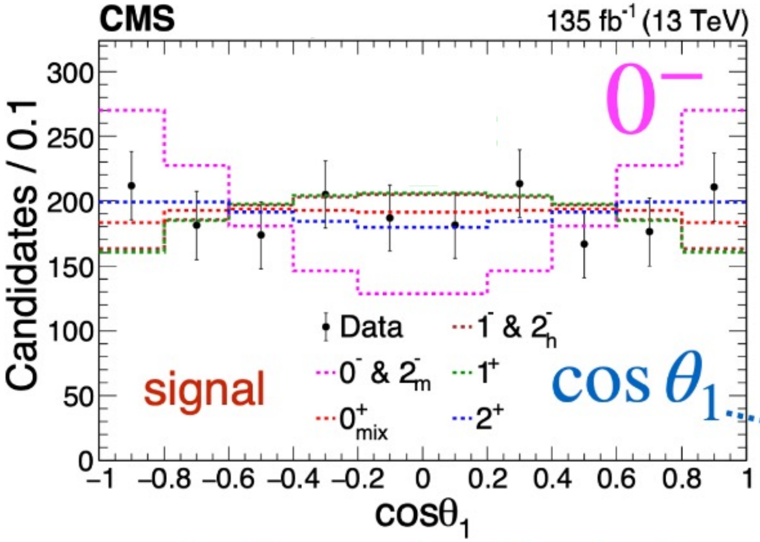
$\mathscr{P}(\Phi, \theta_1, \theta_2; m_{4\mu})$

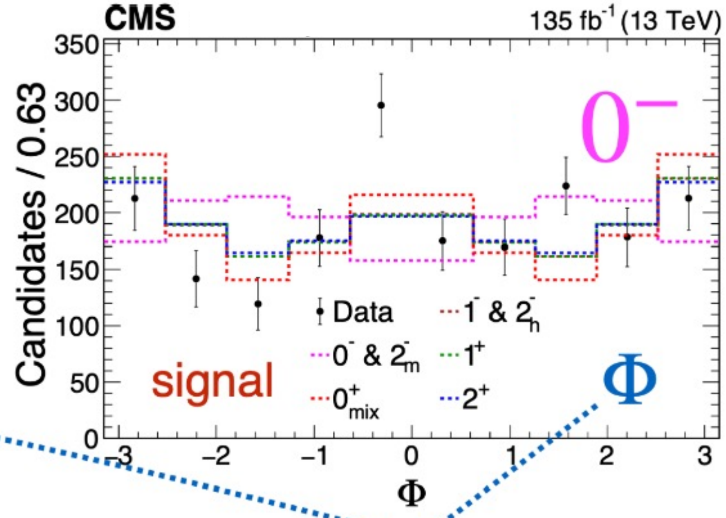
λ_1	decay helicity amplitudes	λ_2	
←	A_{++}	→	$J_X = 0$
→	A_{--}	←	$J_X = 0$
0	A_{00}	0	$J_X = 0$
←	A_{+0}	0	$J_X = 1$
0	A_{0+}	→	$J_X = 1$
→	A_{-0}	0	$J_X = 1$
0	A_{0-}	←	$J_X = 1$
←	A_{+-}	←	$J_X \geq 2$
→	A_{-+}	→	$J_X \geq 2$

($J_X \geq 2$ applies to all amplitudes.)

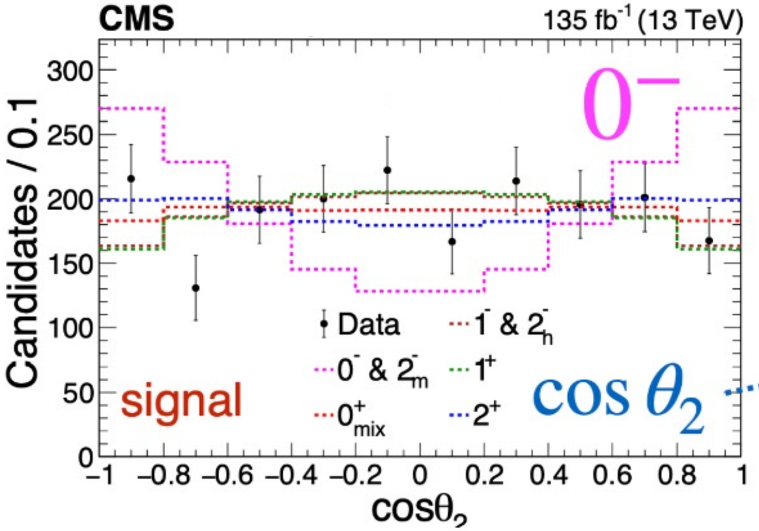
Decay Angles

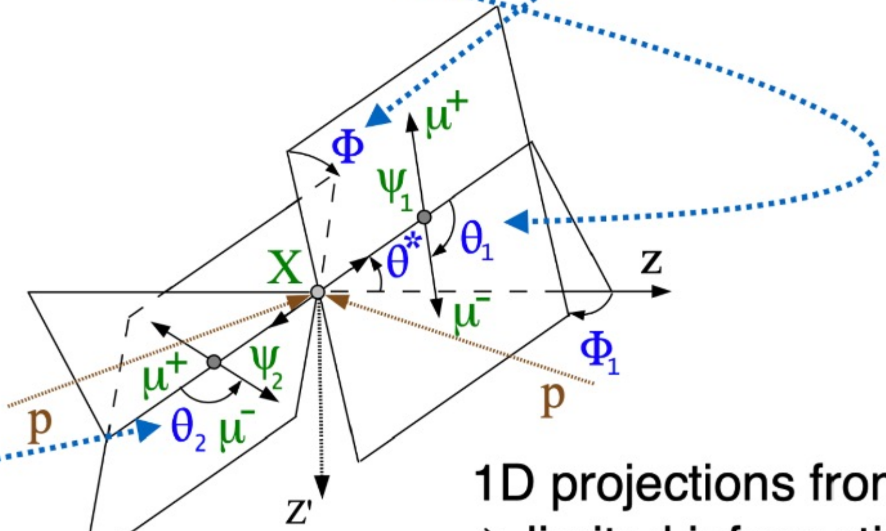
decay angles (consistency check): distinguish models





background-subtracted

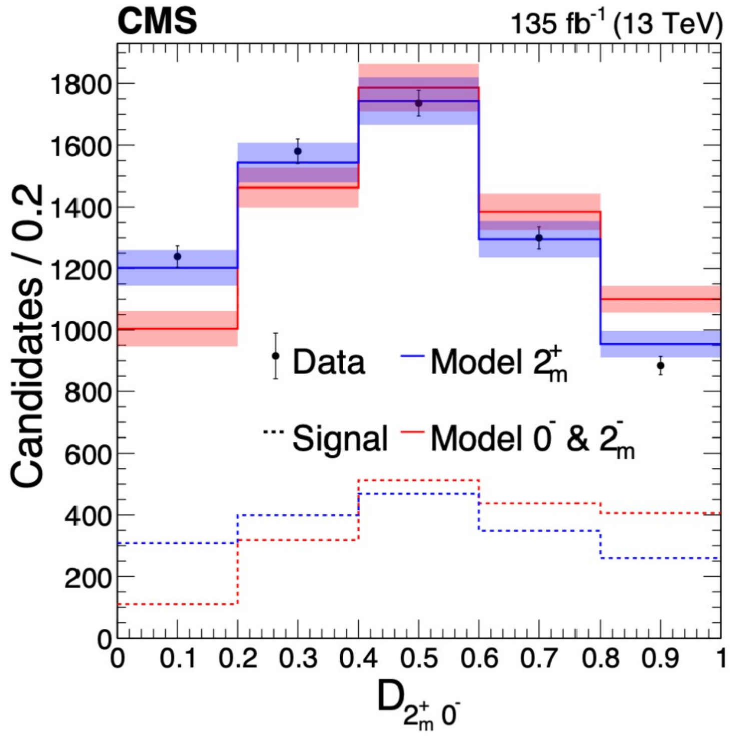


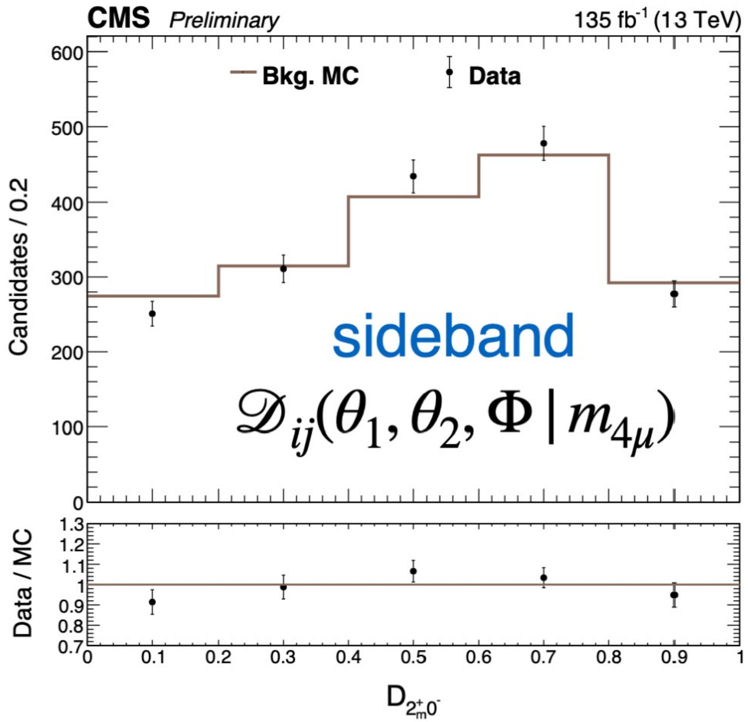


1D projections from 4D
⇒ limited information

Optimal Observable

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





background model from MC
control in sidebands
systematic variations

optimal observable

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

1D projections from 2D
⇒ limited information

2D parameterization:

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

Statistical Analysis

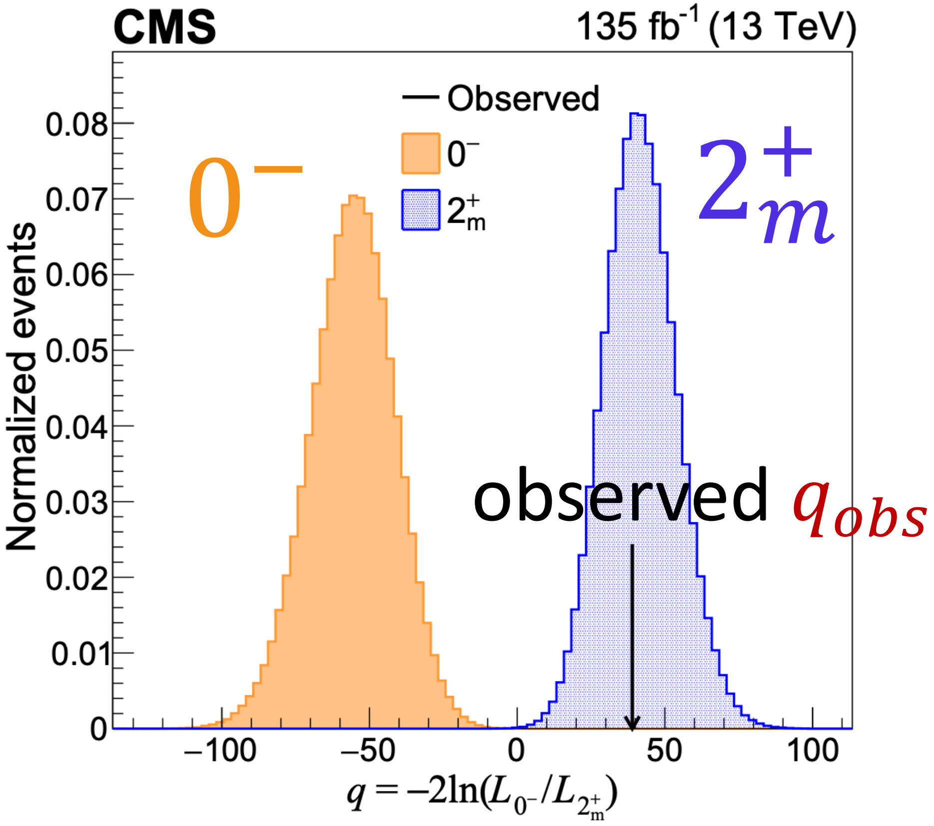
- Hypothesis test with toy MC for $J_1^P = 2_m^+$ vs $J_2^P = 0^-$
- Test statistic $q = -2\ln(\mathcal{L}_{J_2^P}/\mathcal{L}_{J_1^P})$
- Consistency of data with J_1^P/J_2^P using p-value:

$$p = P(q \le q_{obs}|J_1^P + bkg)$$
$$p = P(q \ge q_{obs}|J_2^P + bkg)$$

- Significance:
  Converted from p-value
  via Gaussian one-sided tail integral

- Confidence level

$$CL_s = \frac{P(q \ge q_{obs}|J_2^P + bkg)}{P(q \ge q_{obs}|J_1^P + bkg)}$$



		Observed p-value	Observed Z-score	Expected p-value	Expected 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

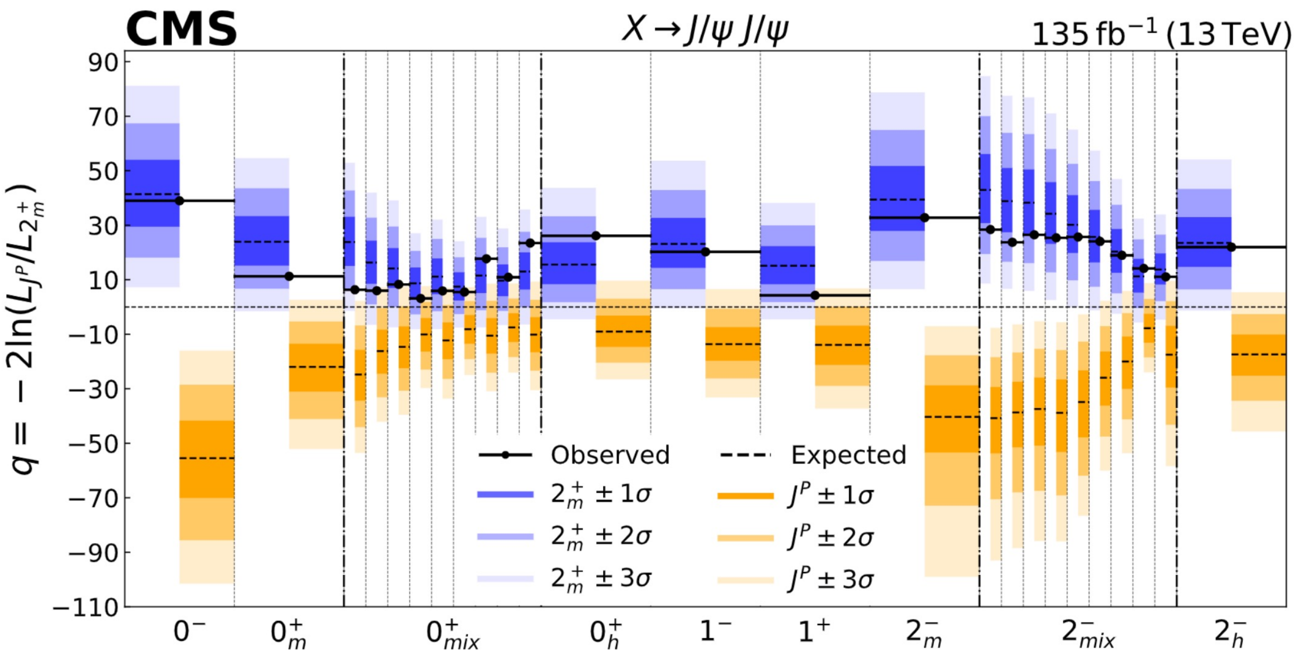
Summary

- Combine 2D fit: $\mathscr{P}_{ijk}(m_{4\mu}, \mathscr{D}_{ij})$
  - $J^P = 2^+_m$ model survives

J^P_X	p-value	Z-score reject J^P_X
0^-	2.7×10^{-13}	7.2
0^+_m	4.3×10^{-5}	3.9
$0^+_{\rm mix}$	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
$2^-_{\rm mix}$	6.5×10^{-4}	3.2
2^-_h	2.2×10^{-8}	5.5

mix

mix



J^{PC} analysis of exotic hadron decays at LHC (production-independent)

- consistent picture: set of 3 exotic teraquark resonances with the same J^{PC} $n = (1,)2,3,4$
- $PC = ++$ very certain
- $J \neq 1$ 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 $J = 0$