Observation a Family of All-Charm Tetra-Quark Candidates at CMS

张敬庆
南京师范大学

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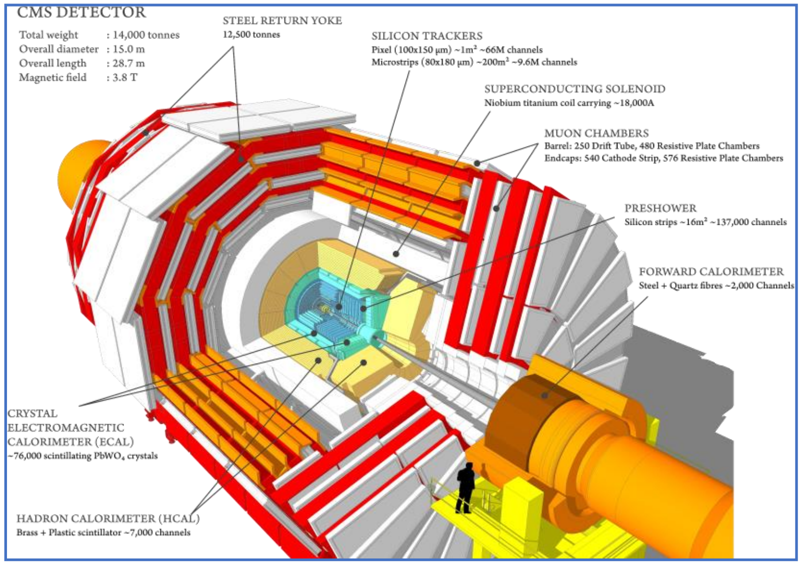
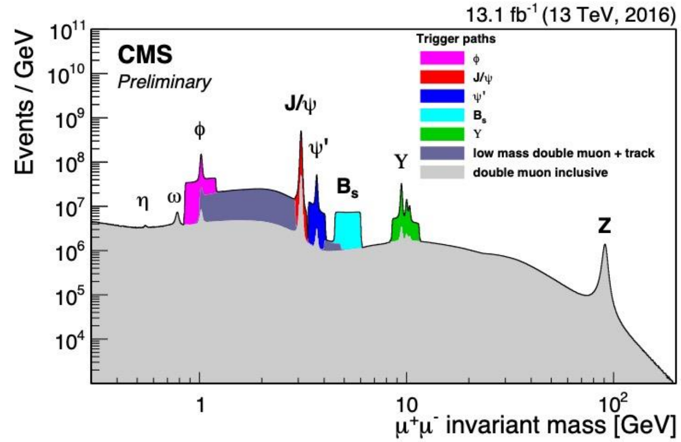
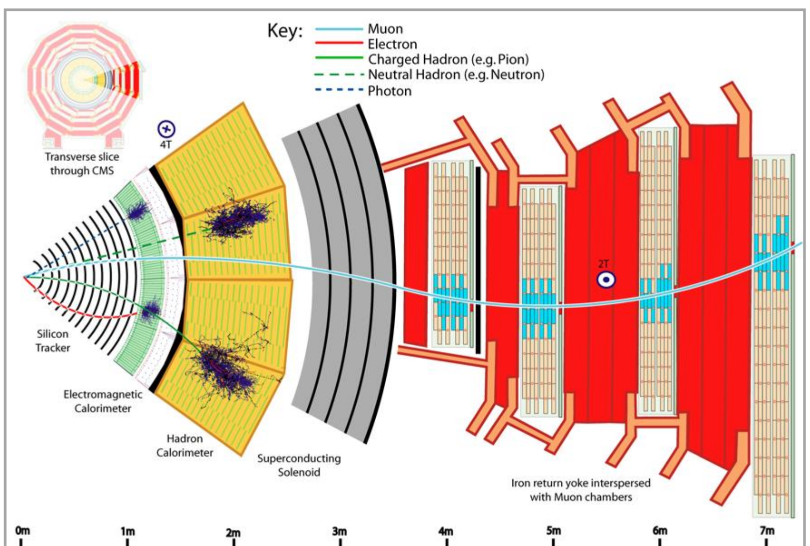
  CMS-PAS-BPH-24-003
- Spin-parity of all-charm tetraquarks

  CMS-PAS-BPH-24-002
- Summary

CMS detector





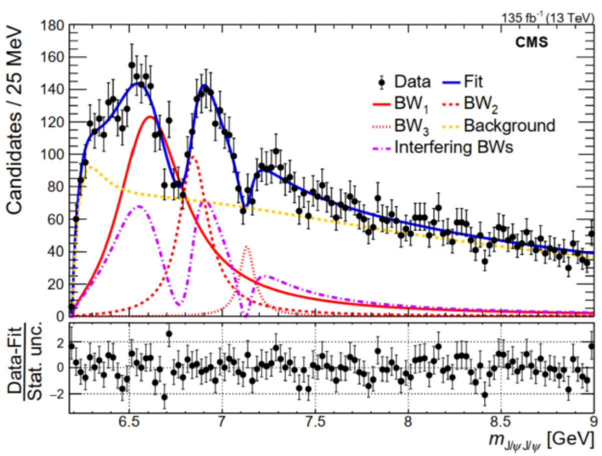


Excellent detector for (exotic) quarkonium

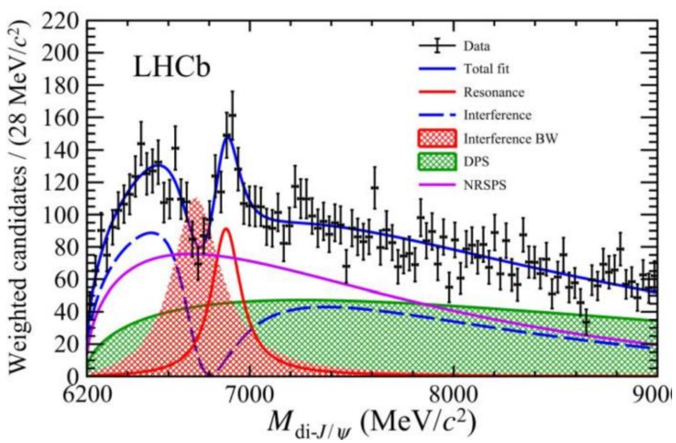
- Good muon system
  - High-purity muon ID, $\frac{\Delta m}{m}\sim 0.6\%$ for J/ψ
- Silicon tracking detector
  - B = 3.8 T, $\frac{\Delta p_T}{p_T}\sim 1\%$ & good vertex resolution
- Different triggers for different physic programs/purposes

The tetraquark candidates at LHC

- Structures in $J/\psi J/\psi$ mass spectrum at CMS, LHCb and ATLAS from the LHC run 2 data
- LHC starts run 3 in 2022
  → more data & more opportunity



PRL132.111901(2024)



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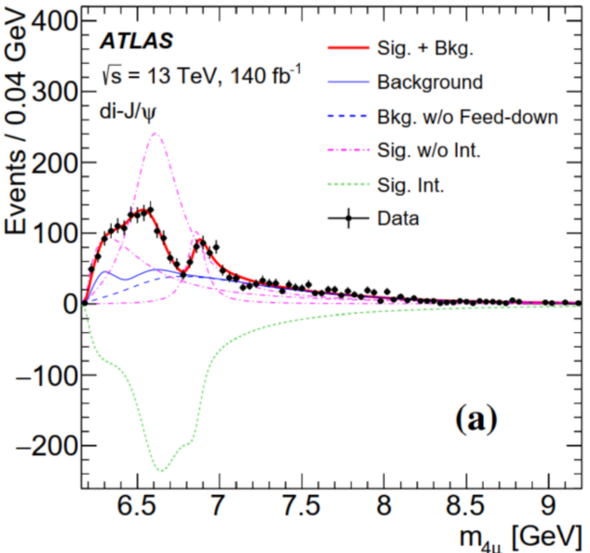


PRL131.151902(2023)

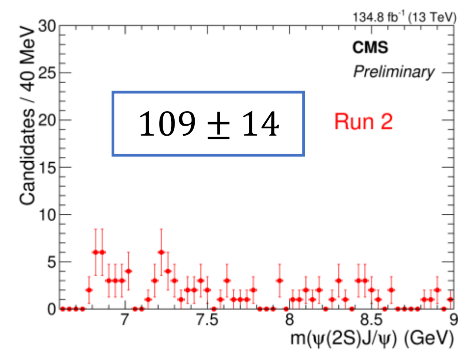
X(6900) and X(7100) in $J/\psi\psi(2S)$ at CMS

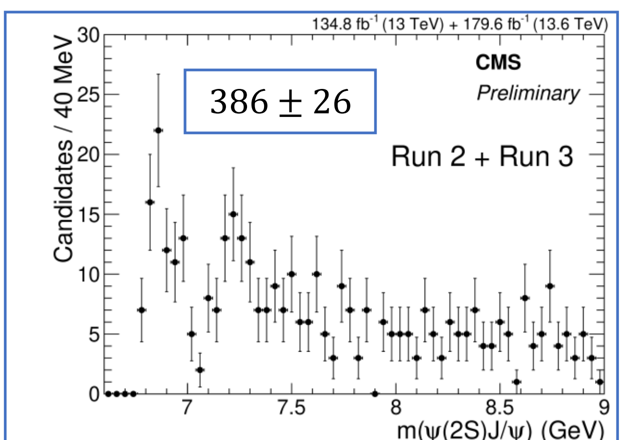
CMS-PAS-BPH-22-004

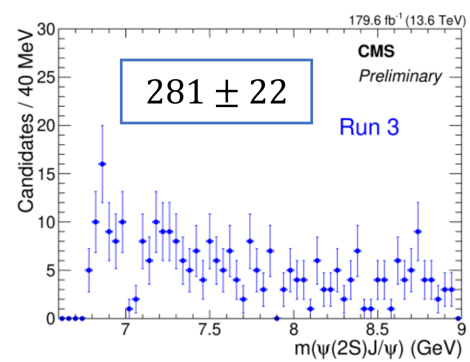
X(6900) and X(7100) in $J/\psi\psi(2S)$ at CMS

CMS-PAS-BPH-22-004

- J/ψ and $\psi(2S)$ reconstructed via $\mu^+\mu^-$
- 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}
- Trigger:
  - Run 2: 3 muons, pT > 5, 3, 3 GeV
  - Run 3: 2muons, pT > 4, 3 GeV



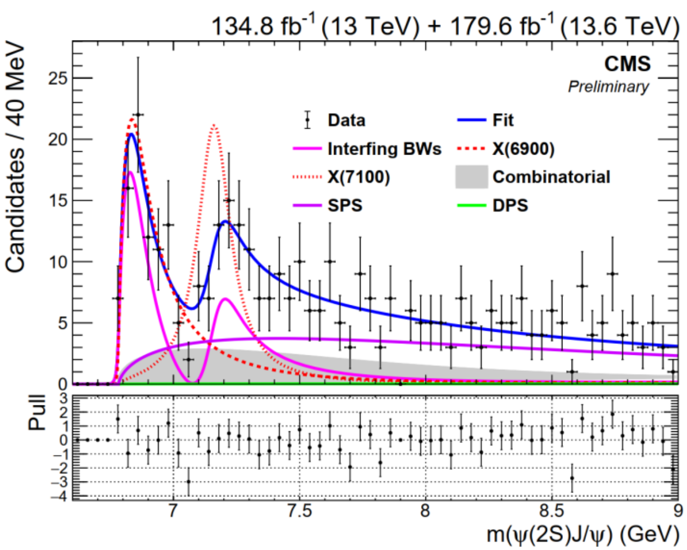




X(6900) and X(7100) in $J/\psi\psi(2S)$ at CMS

CMS-PAS-BPH-22-004

- 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
  - **7.9σ for X(6900), 4.0σ for X(7100)**
  - Impact from X(6600) [below threshold] considered in systematic uncertainty



Fit	Sample	Interf.		X(6600)	X(6900)	X(7100)
f_{i23}	$J/\psi\psi(2S)$	BW_2, BW_3	m :	—	$6876^{+46+110}_{-29-110}$	7169^{+26+74}_{-52-70}
			Γ :	—	$253^{+290+120}_{-100-120}$	$154^{+110+140}_{-82-160}$
f_{JJ} [1]	$J/\psi J/\psi$	BW_1, BW_2, BW_3	m :	6638^{+43+16}_{-38-31}	6847^{+44+48}_{-28-20}	7134^{+48+41}_{-25-15}
			Γ :	$440^{+230+110}_{-200-240}$	191^{+66+25}_{-49-17}	97^{+40+29}_{-29-26}

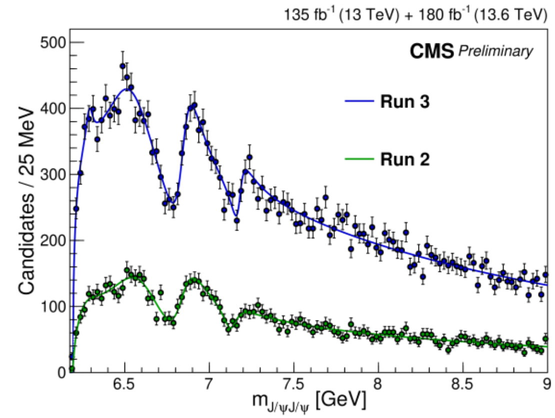
Observation of a family of all-charm tetraquark candidates at the LHC

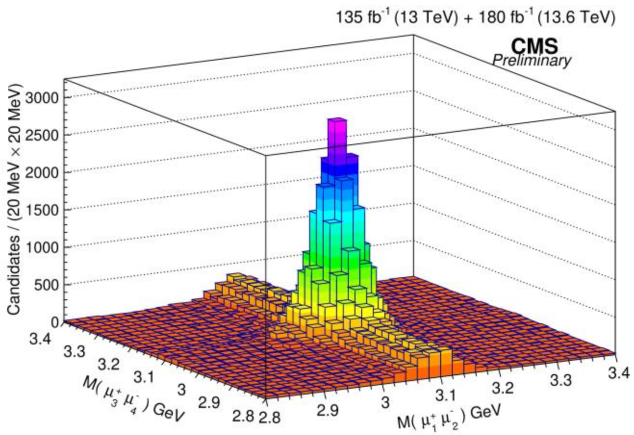
CMS-PAS-BPH-24-003

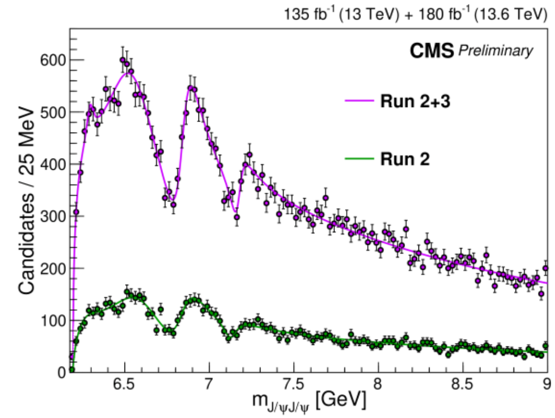
All-charm tetraquark candidates at CMS

CMS-PAS-BPH-24-003

- 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, $\mathbf{179.6}$ fb^{-1}
- Trigger:
  - Run 2: 3 muons, pT > 5, 3, 3 GeV
  - Run 3: 2muons, pT > 4, 3 GeV





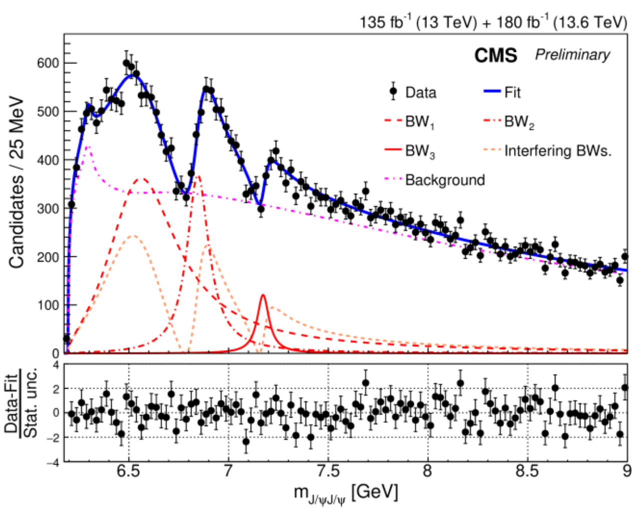


All-charm tetraquark candidates at CMS

CMS-PAS-BPH-24-003

- 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)
    - Background: NRSPS, DPS, combinatorial contribution,feeddown
  - Significance
    - 15.2σ for X(6600), 16.7σ for X(6900), and **7.7σ for X(7100)**
    - **9.9σ for interference (two dips),**

      9.7σ for 6750 MeV dip, 6.5σ for 7150 MeV dip



		X(6600)	X(6900)	X(7100)
		BW_1	BW_2	BW_3
Interference	m (MeV)	$6593\,^{+15}_{-14} \pm 25$	$6847\,^{+10}_{-10} \pm 15$	$7173\,^{+9}_{-10} \pm 13$
(Run 2+Run 3)	Γ (MeV)	$446\,^{+66}_{-54} \pm 87$	$135\,^{+16}_{-14} \pm 14$	$73\,^{+18}_{-15} \pm 10$
Interference	m (MeV)	$6638\,^{+43+16}_{-38-31}$	$6847\,^{+44+48}_{-28-20}$	$7134\,^{+48+41}_{-25-15}$
(Run 2 [12])	Γ (MeV)	$440\,^{+230+110}_{-200-240}$	$191\,^{+66+25}_{-49-17}$	$97\,^{+40+29}_{-29-26}$

reconstructed as $J/\psi J/\psi$ instead of $J/\psi J/\psi\pi\pi$

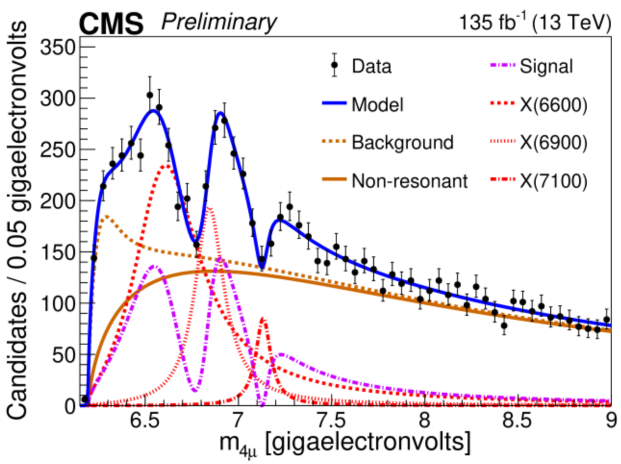
Spin and symmetry properties of all-charm tetraquarks

CMS-PAS-BPH-24-002

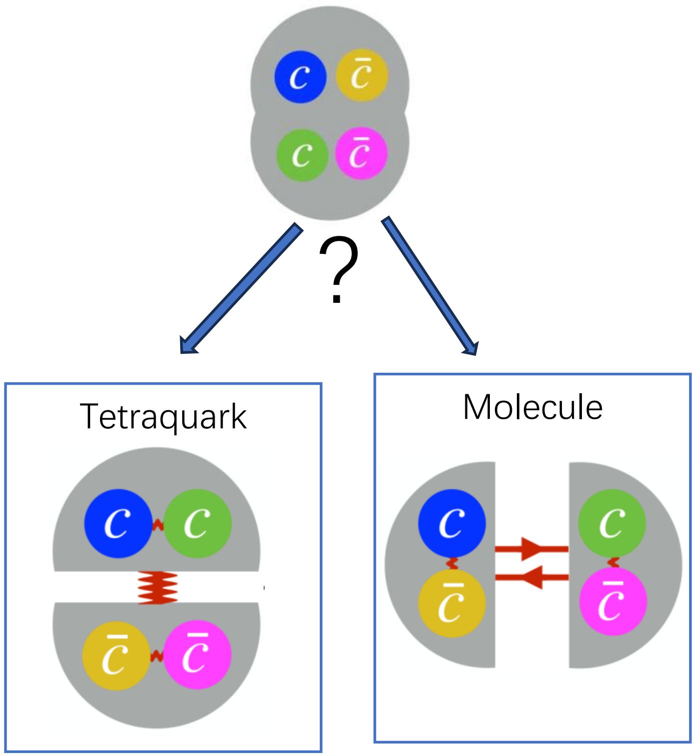
Internal Structure of the tetraquarks

CMS-PAS-BPH-24-002

- Tetraquark candidates observed in experiments



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

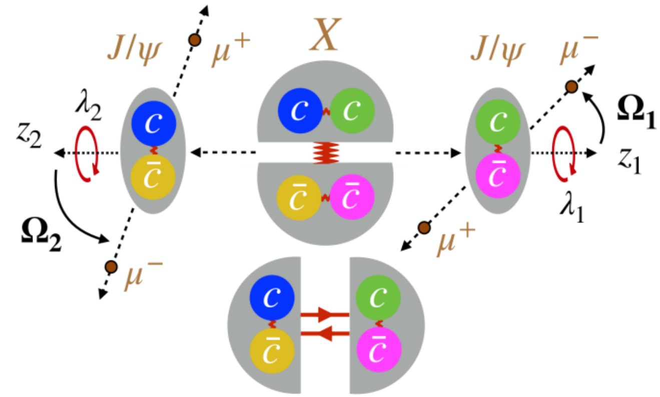


- Tetraquark, molecule, ···?
- Spin-parity study could help
  - How to study their spin-parity?

Angular distribution and spin polarization

[CMS-PAS-BPH-24-002]

- Infer J^{PC} of X from
  - spin polarizations of J/ψ mesons
  - angular distributions of muons
- Helicity and angular distribution



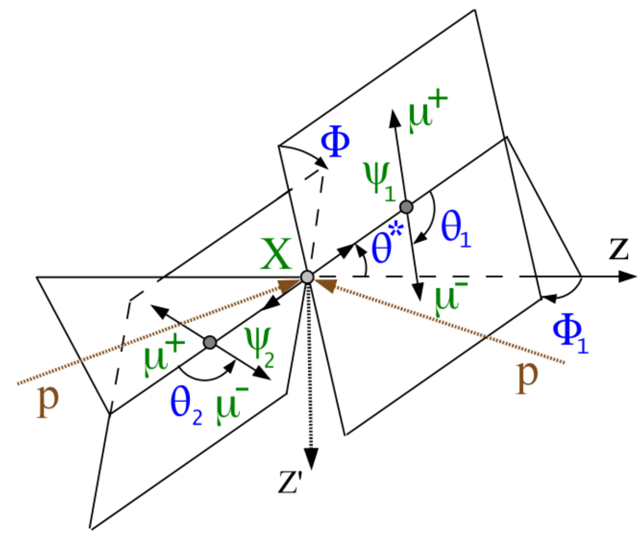
For $1 \rightarrow 2$ decay process

$$\langle \Omega, \lambda_1, \lambda_2 | S | Jm \rangle = \sqrt{\frac{(2J+1)}{4\pi}} D^{J*}_{m,\lambda_1-\lambda_2}(\Omega) A_{\lambda_1\lambda_2},$$

Wigner D function (angular distribution)

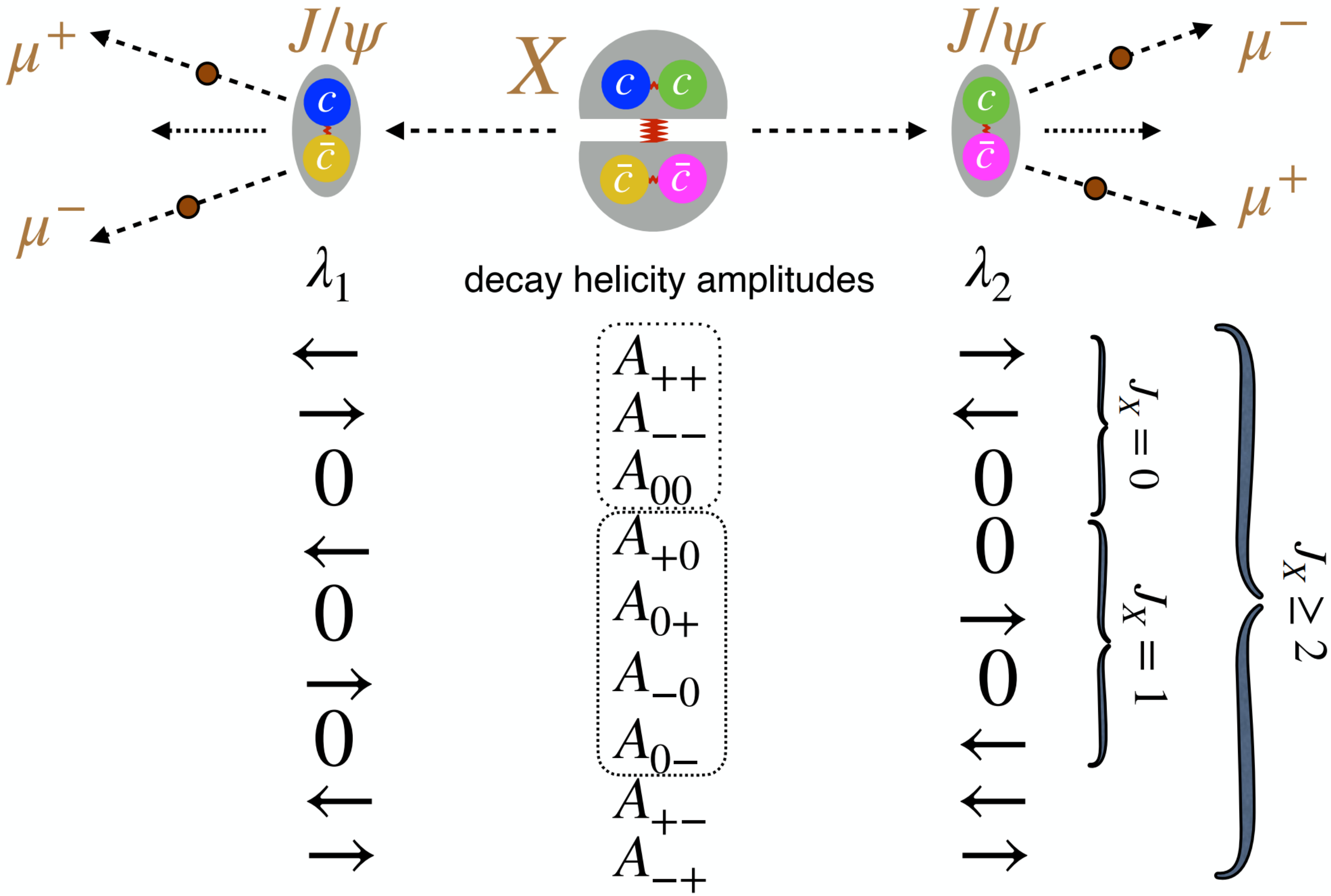
Polar and azimuthal angles of final states

Helicity amplitude



J/ψ polarizations

CMS-PAS-BPH-24-002



J/ψ polarizations

CMS-PAS-BPH-24-002

- Symmetries:

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

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

— P & C conserved in QCD:

X with definite J^{PC}

$C = +1$

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

$J_X = 0$: A_{++}, A_{--}, A_{00}

$J_X = 1$: A_{+0}, A_{0+}, A_{-0}, A_{0-}

$J_X \geq 2$: A_{+-}, A_{-+}

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

Lorentz invariant amplitude

CMS-PAS-BPH-24-002

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

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

0_m^+ 0_h^+ 0^-

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

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

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

recall (22 years):
$B \to \varphi K^*$ expect A_{00}
found ~50% A_{++}

Higgs (12 years):
$H \to 4\ell \Rightarrow 0_m^+$

arXiv:1001.3396

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

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

1^- 1^+

more for spin-2

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

Simplification in angular analysis

[CMS-PAS-BPH-24-002]

- Full amplitude analysis possible, but very complex

$$\langle \Omega, \lambda_1, \lambda_2 | S | Jm \rangle = \sqrt{\frac{(2J+1)}{4\pi}} D^{J*}_{m,\lambda_1-\lambda_2}(\Omega) A_{\lambda_1\lambda_2},$$

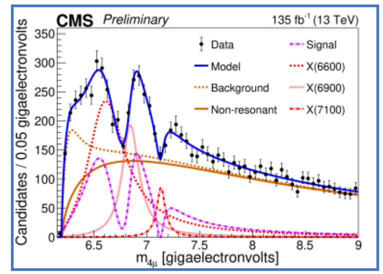
$+$

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

$\to A_{\lambda_1\lambda_2}$ $\quad 0^+_m \quad 0^+_h \quad 0^-$

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

- Simplification in angular analysis



(1) Same properties of 3 resonances:

$$\mathscr{P}(m_{4\mu}, \overrightarrow{\Omega}) = \mathscr{P}(m_{4\mu}) \cdot T(\overrightarrow{\Omega}\,|\,m_{4\mu})$$

empirical   angular

(2) Pairwise tests of J_X^P hypotheses i and j: [arXiv:1208.4018]

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

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

- Final 2D model:

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

Data analysis

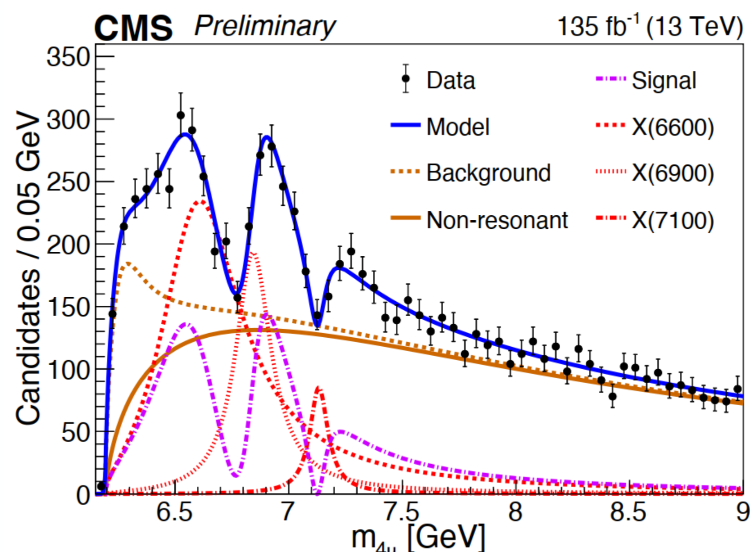
CMS-PAS-BPH-24-002

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

— trigger $\mu^+\mu^-\mu^\pm$
$p_T > 3\,\mathrm{GeV}, p_T > 5\,\mathrm{GeV}$

— reco $(\mu^+\mu^-)(\mu^+\mu^-)$
$p_T > 2\,\mathrm{GeV}, |\eta| < 2.4$

— mass / vertex - constrained fit



signal region sideband

- Background: data sideband & MC simulation with **Pythia**

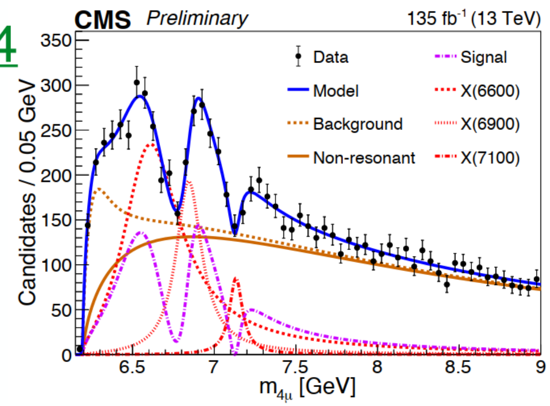
— $J/\psi J/\psi$ single- and double-parton scattering

— empirical threshold enhancement (signal-like MC)

Variables in the analysis

CMS-PAS-BPH-24-002

(1) $m_{4\mu}$ spectrum $X \to 4\mu$ — arXiv:2306.07164



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

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

for $J = 0$ exact

for $J = 1,2,..$ depends on production mechanism

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

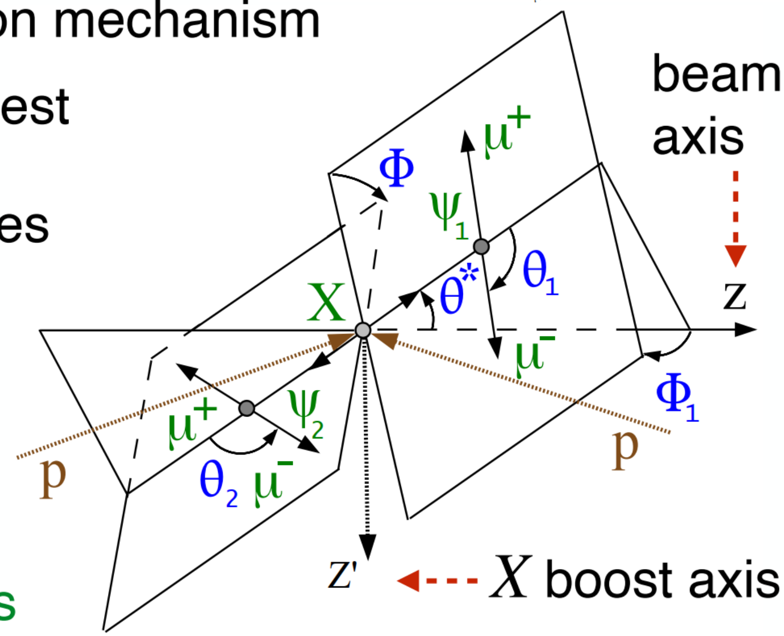
(4) Φ_1, θ^* or Φ'_1, θ'^* production angles

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

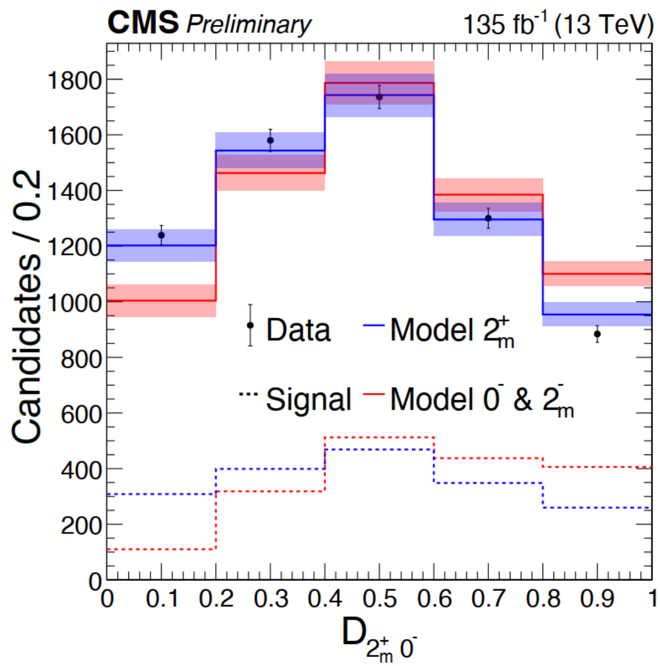


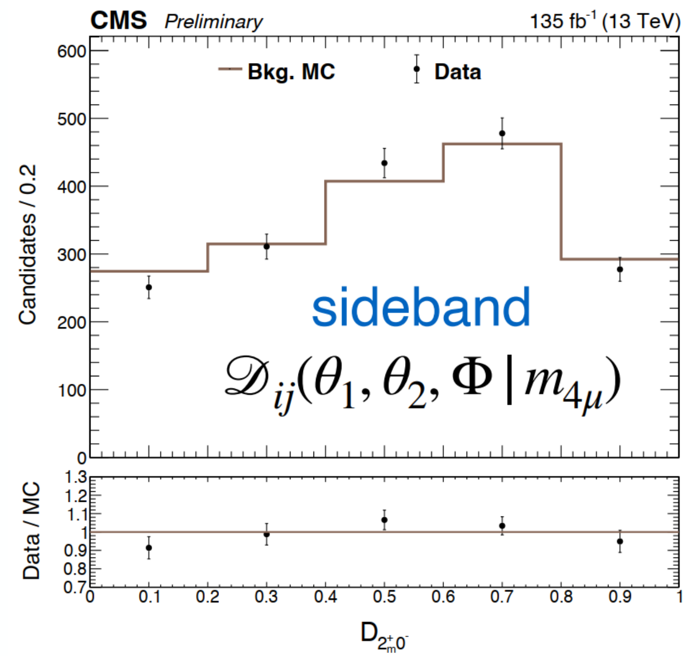
All steps till here prepared blinded

Optimal Observables

CMS-PAS-BPH-24-002

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





sideband

$\mathscr{D}_{ij}(\theta_1, \theta_2, \Phi \,|\, m_{4\mu})$

optimal observable

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

1D projections from 2D
⇒ limited information

background model from MC
control in sidebands
systematic variations

Hypothesis tesf of $\mathbf{0^{-}}\ \boldsymbol{vs.}\ \mathbf{2_{m}^{+}}$

CMS-PAS-BPH-24-002

- 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}^{+}	4.2×10^{-1}	0.2	0.50	0.0

2D parameterization:

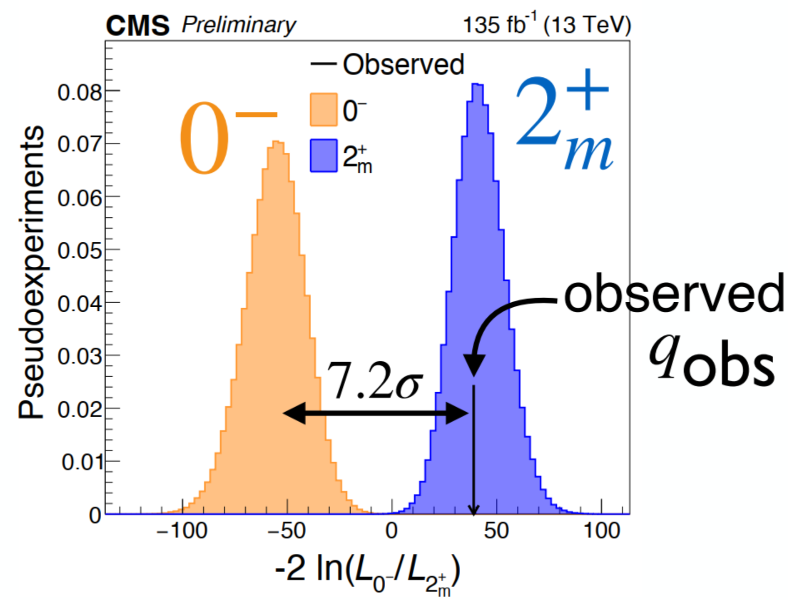
$$\mathscr{P}_{ijk}(m_{4\mu}, \mathscr{D}_{ij}) = \mathscr{P}_{k}(m_{4\mu}) \cdot T_{ijk}(\mathscr{D}_{ij} \,|\, m_{4\mu})$$

— test statistic:

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

— 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

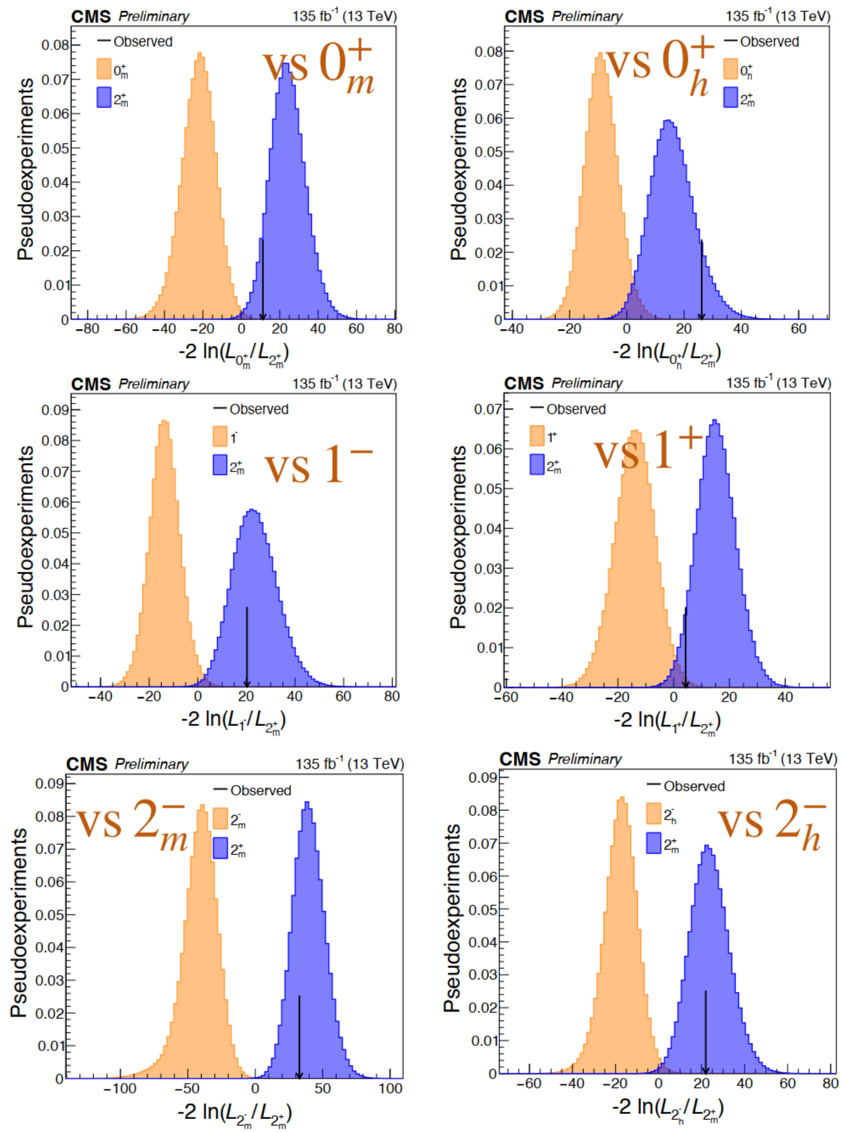
CMS-PAS-BPH-24-002

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

J_X^P	p-value	Z-score reject J_X^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

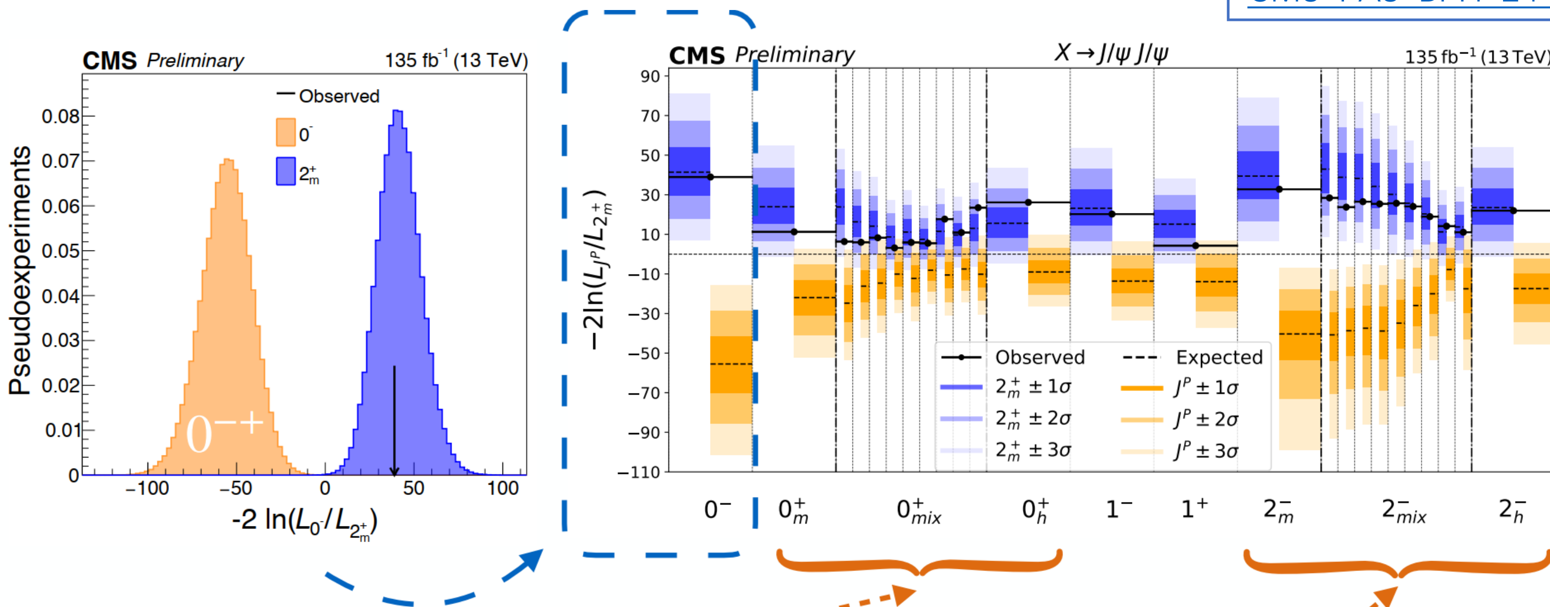
mix

mix



Summary of results

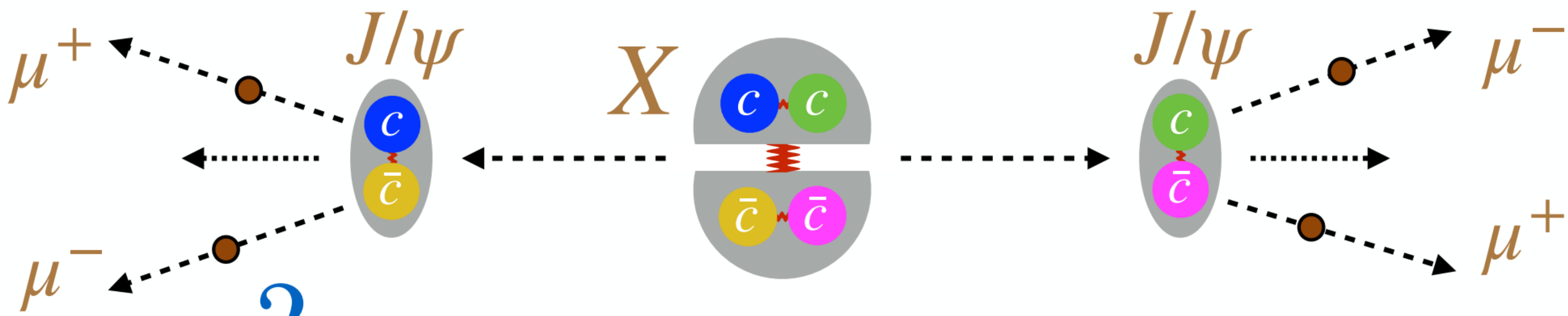
CMS-PAS-BPH-24-002



- Scan mixture of two 0^{++} amplitudes (11 steps)
  — constructive interference most conservative
- Scan mixture of two 2^{-+} amplitudes (11 steps)
  — no interference (different spin projections)
- Data are consistent with a 2^{++} model, inconsistent with others

Summary of results

CMS-PAS-BPH-24-002



? $(c\bar{c})_{s=1} + (c\bar{c})_{s=1}$

? $(cc)_{s=1} + (\bar{c}\bar{c})_{s=1} \Rightarrow L = 0\ (\mathrm{n}S): \ S = 2 \Rightarrow$ $J^{PC} = 2^{++},\ n = (1,)2,3,4,...$

- 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 $J = 0$

Summary

- X(6900) & X(7100) seen in $J/\psi\psi(2S)$ at CMS
  - **7.9$\boldsymbol{\sigma}$ for X(6900), $\mathbf{4.0}\boldsymbol{\sigma}$ for X(7100)**
- X(6600), X(6900), X(7100) in $J/\psi J/\psi$ at CMS
  - **$> \mathbf{5}\boldsymbol{\sigma}$ for each**; **$> \mathbf{5}\boldsymbol{\sigma}$ for interference. (vs. no-interf.)**
- J^{PC} of the three X
  - **PC = ++**
  - $J \neq \mathbf{1}$ at > 99% CL
  - $J \neq \mathbf{0}$ at > 95% CL
  - $J > 2$ possible, but highly unlikely, require $L \geq 2$
  - **$\boldsymbol{J} = \mathbf{2}$ consistent**, rare in nature, naively expected J = 0

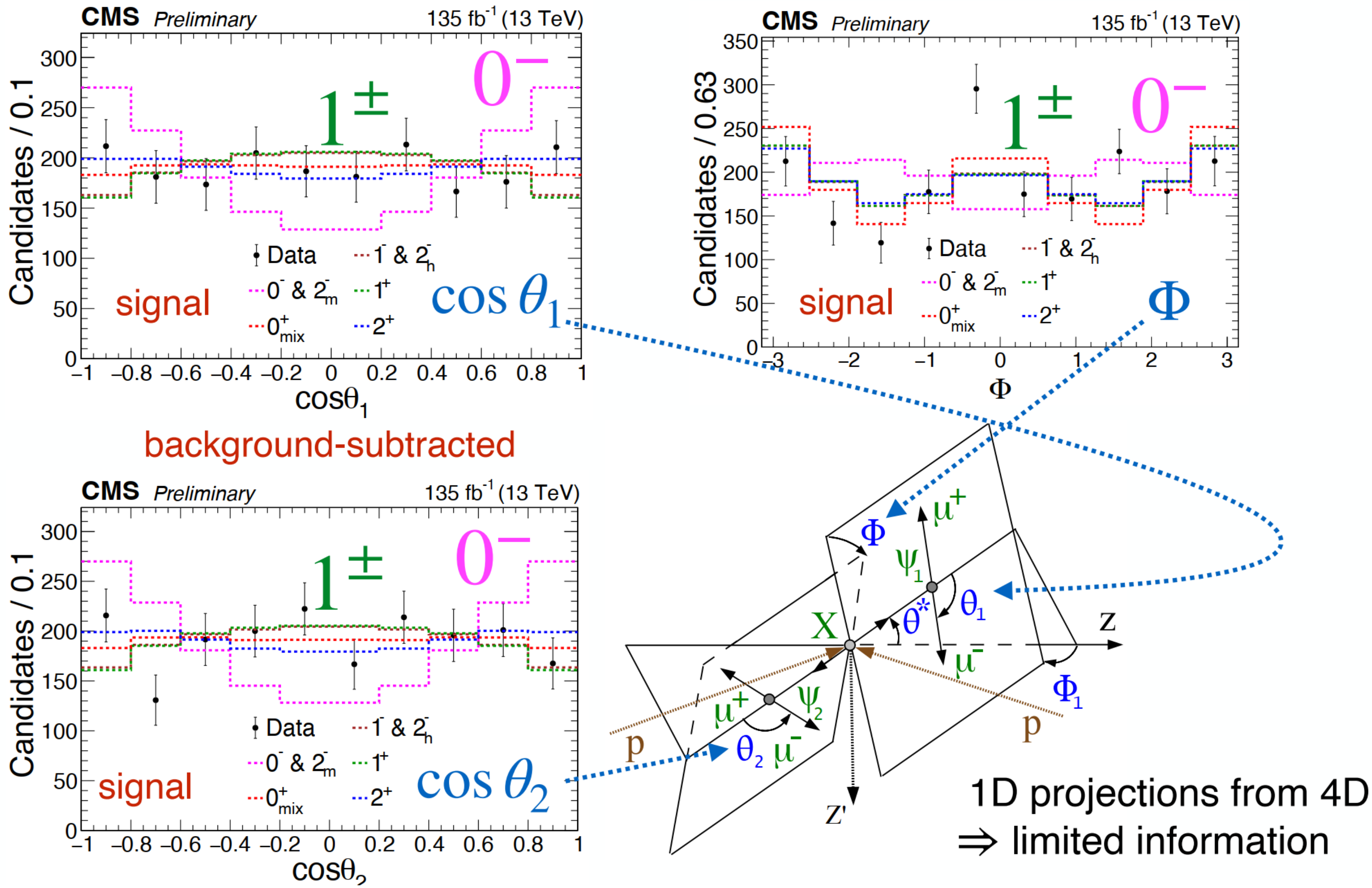
Thanks!

Backup

Decay angles

CMS-PAS-BPH-24-002

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



Production: p_T and p_z of X

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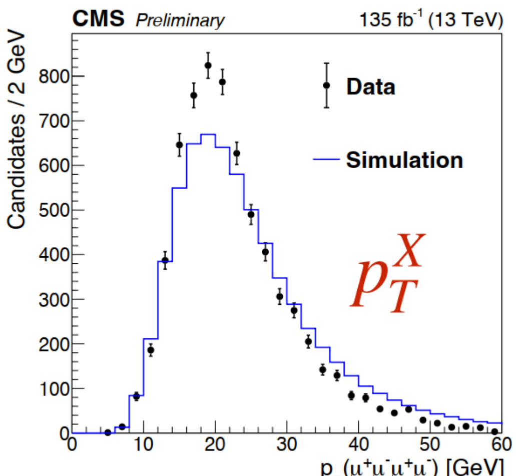
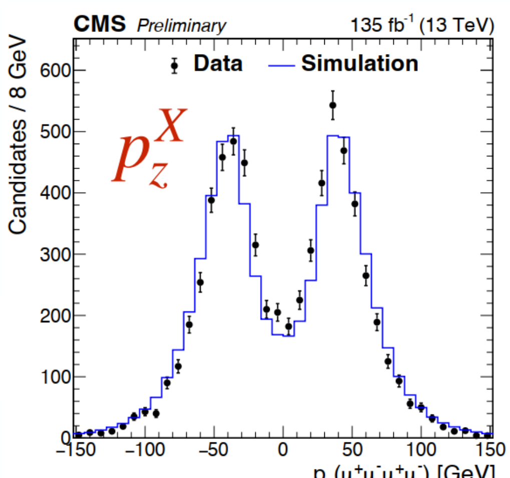
— empirical model to reproduce p_T^X and p_z^X in data





— 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

Production angles

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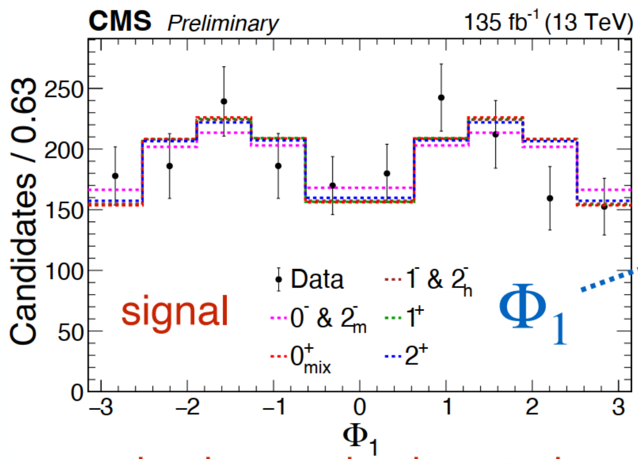
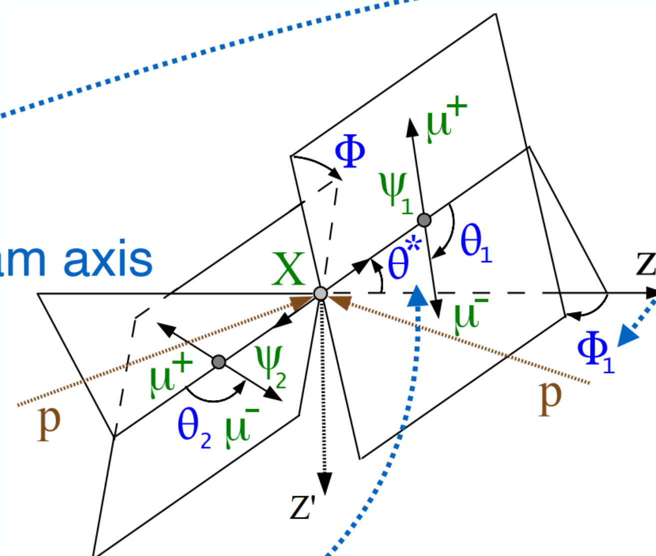
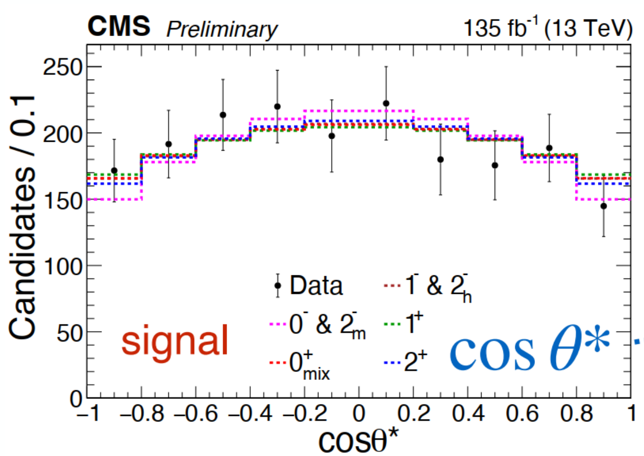
(4) production angles consistent with unpolarized resonances



background-subtracted

with respect to the beam axis





acceptance effects

⇒ distributions not flat

Production angles

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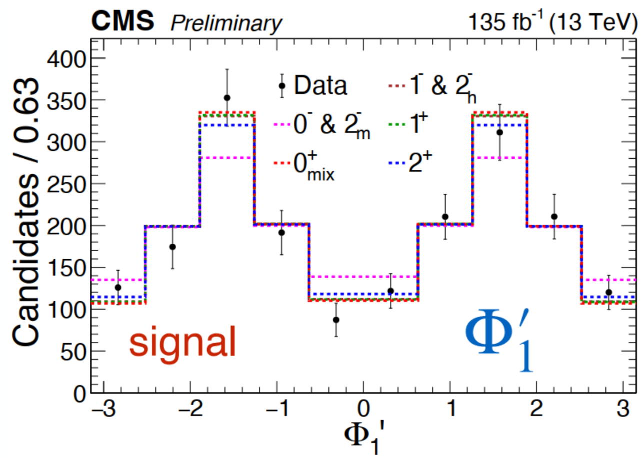
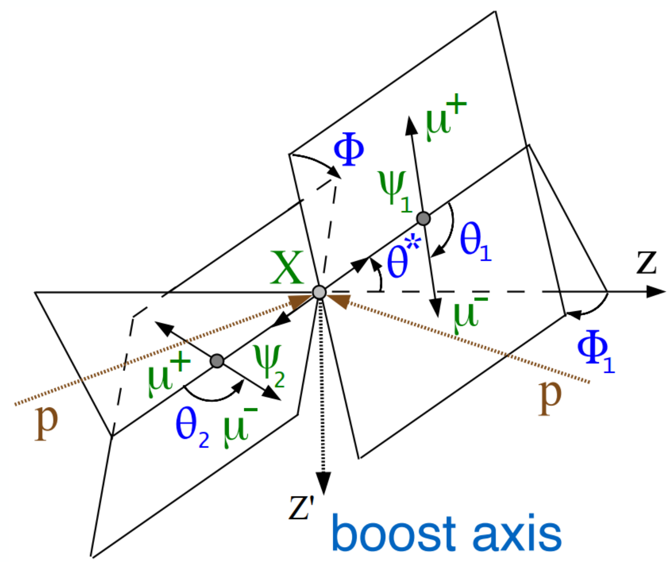
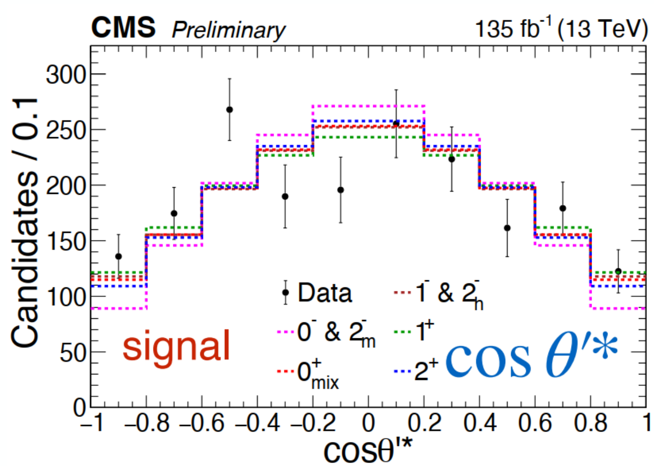
(4) production angles consistent with unpolarized resonances



with respect to the boost axis

does not prove unpolarized





Lorentz invariant amplitude

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

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

0_m^+ 0_h^+ 0^-

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

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

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

recall (22 years):
$B \to \varphi K^*$ expect A_{00}
found ~50% A_{++}

Higgs (12 years):
$H \to 4\ell \Rightarrow 0_m^+$

arXiv:1001.3396

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

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

1^- 1^+

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

more for spin-2

Lorentz invariant amplitude

CMS-PAS-BPH-24-002

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

arXiv:1001.3396

$$A(X_{J=2}\to V_1V_2) = 2c_1(q^2)t_{\mu\nu}f^{*1,\mu\alpha}f^{*2,\nu\alpha} + 2c_2(q^2)t_{\mu\nu}\frac{q_\alpha q_\beta}{\Lambda^2}f^{*1,\mu\alpha}f^{*2,\nu,\beta}$$
$$+c_3(q^2)\frac{\tilde q^\beta \tilde q^\alpha}{\Lambda^2}t_{\beta\nu}(f^{*1,\mu\nu}f^{*2}_{\mu\alpha}+f^{*2,\mu\nu}f^{*1}_{\mu\alpha}) + c_4(q^2)\frac{\tilde q^\nu \tilde q^\mu}{\Lambda^2}t_{\mu\nu}f^{*1,\alpha\beta}f^{*(2)}_{\alpha\beta}$$
$$+m_V^2\left(2c_5(q^2)t_{\mu\nu}\epsilon_1^{*\mu}\epsilon_2^{*\nu} + 2c_6(q^2)\frac{\tilde q^\mu q_\alpha}{\Lambda^2}t_{\mu\nu}\left(\epsilon_1^{*\nu}\epsilon_2^{*\alpha}-\epsilon_1^{*\alpha}\epsilon_2^{*\nu}\right) + c_7(q^2)\frac{\tilde q^\mu \tilde q^\nu}{\Lambda^2}t_{\mu\nu}\epsilon_1^*\epsilon_2^*\right)$$
$$+c_8(q^2)\frac{\tilde q_\mu \tilde q_\nu}{\Lambda^2}t_{\mu\nu}f^{*1,\alpha\beta}\tilde f^{*(2)}_{\alpha\beta} + c_{10}(q^2)\frac{t_{\mu\alpha}\tilde q^\alpha}{\Lambda^2}\epsilon_{\mu\nu\rho\sigma}q^\rho \tilde q^\sigma\left(\epsilon_1^{*\nu}(q\epsilon_2^*)+\epsilon_2^{*\nu}(q\epsilon_1^*)\right),$$

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. $A_{00}, A_{++} = A_{--}; A_{+0} = A_{0+} = A_{-0} = A_{0-}; A_{+-} = A_{-+}$ unique 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 $J \geq 2$)

Discriminant

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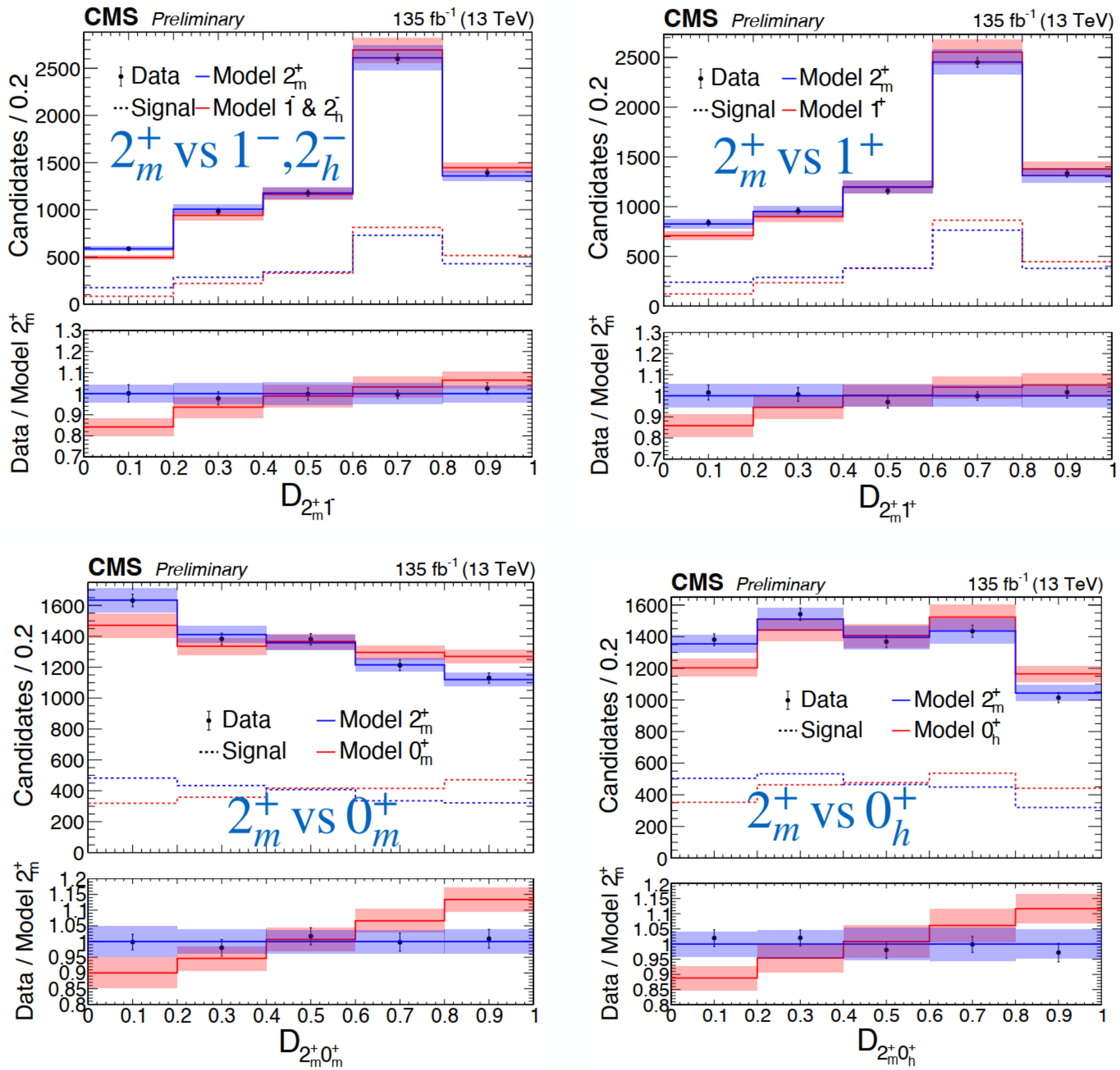

Results of J^P $vs. 2_m^+$

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- 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 $0^+, 1^+$