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Feasibility study of the spin-parity analysis for $J/\psi J/\psi$ structures at CMS

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Exotic hadrons

- Standard model QCD allows the existence of exotic hadrons: tetraquarks, pentaquarks, hybrids or glueballs. [1]

- Spin-parity is important to understand the nature of such exotic hadrons.

Exotic candidates in $J/\psi J/\psi$

- In theory: first mentioned in 1975 in [2], and first calculated in 1981 [3].

- In experiments: LHCb [4], **CMS [5]**, and ATLAS [6].

- J^P unknown -- determination is strongly needed.

Amplitudes of $gg, q\bar{q} \to X \to J/\psi J/\psi$

- Amplitudes with different J^P from couplings [7,8]

$$A(X \to VV) = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(a_1 g_{\mu\nu}m_X^2 + a_2 q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right)$$

$J^P = 0^-$ $J^P = 0^+$

$$A(X \to VV) = g_1^{(1)}\left[(\epsilon_1^*q)(\epsilon_2^*\epsilon_X) + (\epsilon_2^*q)(\epsilon_1^*\epsilon_X)\right] + g_2^{(1)}\epsilon_{\alpha\mu\nu\beta}\epsilon_X^\alpha \epsilon_1^{*\mu}\epsilon_2^{*\nu}\tilde{q}^\beta$$

$J^P = 1^-$ $J^P = 1^+$

Characteristics of helicity angles

- Definition
- $0^\pm$ angular distribution ($\Phi_1, cos\theta^*$ flat and not shown)

Spin-parity discriminant

- Discriminant for J^P separation in Matrix Element Likelihood Approach (MELA) [9]

- Amplitude and Probability

$$\mathcal{P}_{J^P} = |A_{J^P}(X \to VV)|^2$$

- Discriminant

$$D_{J^P=0^-} = \frac{\mathcal{P}_{0+}}{\mathcal{P}_{0+} + c \cdot \mathcal{P}_{0-}}$$

Template pdf

- Produce 2D template pdf $p(m_{4\mu}, D_{J^P})$ using MC

$\mathscr{P}_{0+}(m_{4\mu}, D_{JP})$ $\mathscr{P}_{0-}(m_{4\mu}, D_{JP})$ $\mathscr{P}_{bkg}(m_{4\mu}, D_{JP})$

Spin-parity separation

- Simple model for now:

  only X + background

- Separation of J^P:

  0^+ vs. 0^-

- Model and Likelihood:

$$\mathcal{L}_1 = \exp(-n_{sig} - n_{bkg})\prod_i (n_{sig}\mathcal{P}_{0-}(m_{4\mu}, D_{J^P}) + n_{bkg}\mathcal{P}_{bkg}(m_{4\mu}, D_{J^P}))$$

$$\mathcal{L}_2 = \exp(-n_{sig} - n_{bkg})\prod_i (n_{sig}\mathcal{P}_{0+}(m_{4\mu}, D_{J^P}) + n_{bkg}\mathcal{P}_{bkg}(m_{4\mu}, D_{J^P}))$$

- Significance of J^P separation for 0^+ vs. 0^-:

$$\mathcal{S} = \sqrt{-2\ln \mathcal{L}_1/\mathcal{L}_2}$$

Summary and outlook

- Applicable J^P separation approach [8]
- Test higher spin models: $J = 1, 2$
- Test multiple resonances and their interference

Reference

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