Observation of a family of all-charm tetraquarks at CMS

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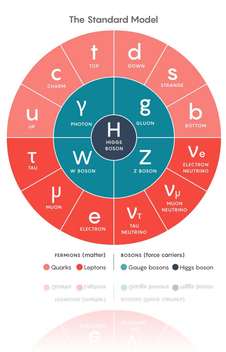
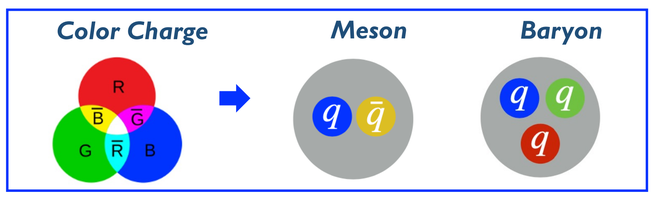
on behalf of the CMS Collaboration

Quark model and Exotic hadron

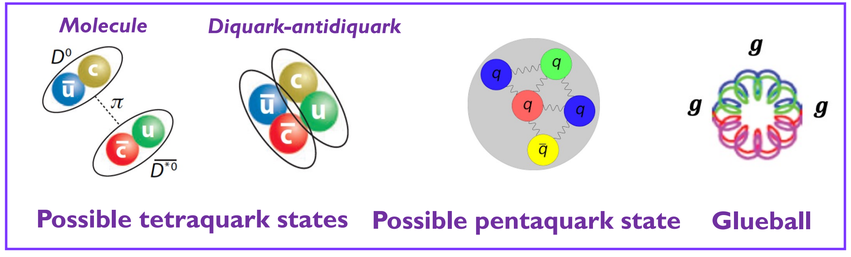


- 1964: Gell-Mann & Zweig → hadrons = meson or baryon
- Possible tetraquark & pentaquark states
- QCD allows exotic hadrons: hybrids, glueballs

Quark model



"Exotic" hadron



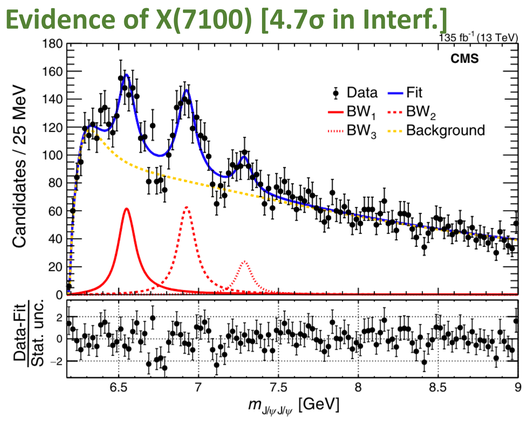
Prospects: A family of all-charm tetraquarks?

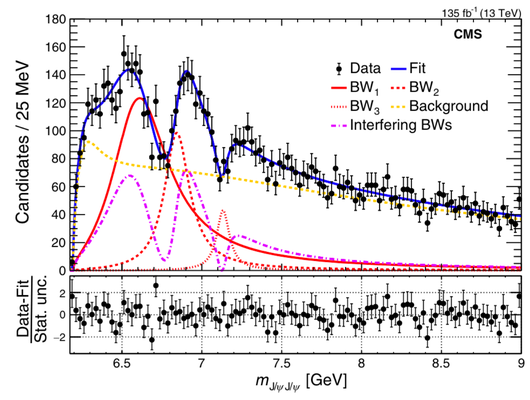
CMS report 3 tetracharm candidates

- X(6900) [all 3 LHC exps]
- X(6600) observed with 7σ
- Evidence of X(7100) [4.7σ in Interf.]

CMS adopt "3-way" interference model

- Threshold BW (non-interfering) + three interfering BWs
- Interference for each individual dip < 4σ





With CMS Run III data

ALL states over 5σ ?
Interference over 5σ ?

→ *Same J^{PC} ?*
> 200 MeV mass splittings ==> Radial excitations ?

A radial family of all-charm tetraquarks with same J^{PC} ?

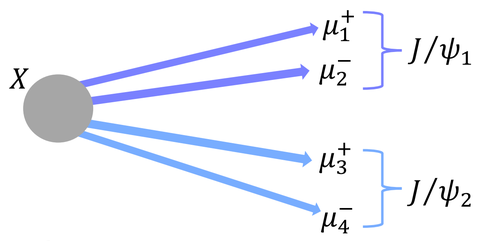
Data and Event Selection

❖ Datasets

Run II: 135 fb^{-1} in 2016~2018 @13TeV

Run III: 180 fb^{-1} in 2022~2024 @13.6TeV

❖ Event Selection



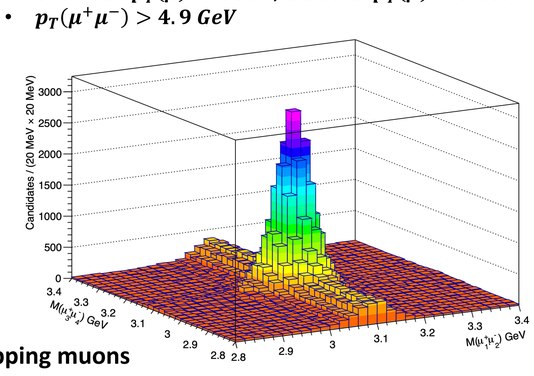
❑**Single muon:**
- Soft muon ID
- $|\eta(\mu)| \leq 2.4$

❑**Single J/ψ:**
- $2.95 < M(J/\psi) < 3.25\ GeV$
- $prob_{vtx}(J/\psi) > 0.1\%$
  $M(\mu^+\mu^-)$ *constrained to* $M(J/\psi)$
- Final mass window cut for J/ψ candidate:
  $|M(\mu^+\mu^-) - M(J/\psi)| < 3\rho\sigma$

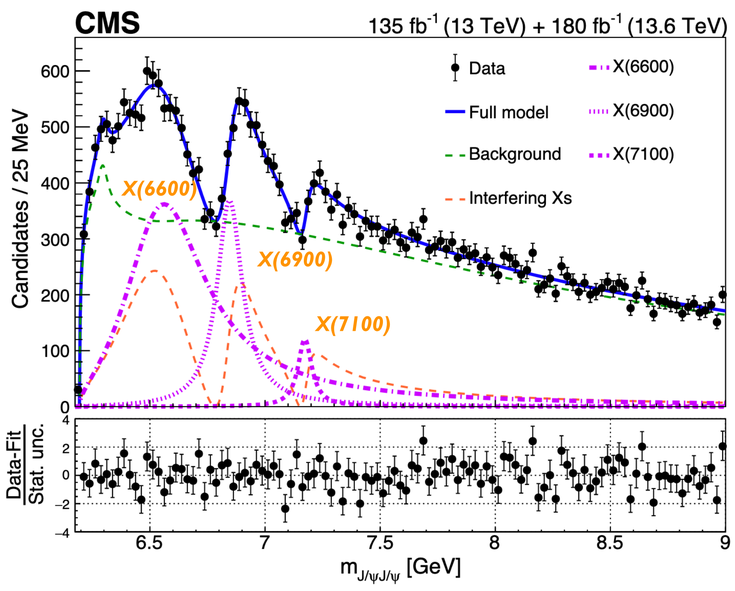
❑**Four muons:**
- 4μ charge zero
- $prob_{vtx}(4\mu) > 0.5\%$
- $prob_{vtx}(J/\psi J/\psi) > 0.1\%$

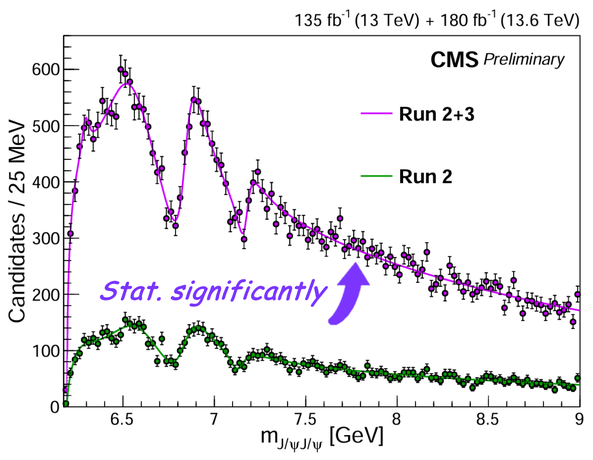
❑**Multiple candidates treatment:**
- Select best combination from one 4μ based on
  $\chi^2_m = \left(\frac{m_1(\mu^+\mu^-) - M_{J/\psi}}{\sigma_{m_1}}\right)^2 + \left(\frac{m_2(\mu^+\mu^-) - M_{J/\psi}}{\sigma_{m_2}}\right)^2$
- Keep duplicate combination if have non-overlapping muons

❑**HLT Trigger:**
- HLT_Dimuon0_Jpsi3p5_Muon2
  - Level 1 requirements: 3 muons
  - $2.95 < M(\mu^+\mu^-) < 3.25\ GeV$
  - $p_T(\mu) > 3.5\ GeV$
- HLT_DoubleMu4_3_LowMass
  - Level 1 requirements: 2 muons
  - $0.2 < M(\mu^+\mu^-) < 8.5\ GeV$
  - one muon $p_T(\mu) > 4\ GeV$, the other $p_T(\mu) > 3\ GeV$
  - $p_T(\mu^+\mu^-) > 4.9\ GeV$



CMS Run II & III interference fit result





Params [MeV]	Run II&III Interf.	Run II Interf.
M(BW1)	$6593^{+15}_{-14} \pm 25$	6638^{+43+16}_{-38-31}
Γ(BW1)	$446^{+66}_{-54} \pm 87$	$440^{+230+110}_{-200-240}$
M(BW2)	$6847 \pm 10 \pm 15$	6847^{+44+48}_{-28-20}
Γ(BW2)	$135^{+16}_{-14} \pm 14$	191^{+66+25}_{-49-17}
M(BW3)	$7173^{+9}_{-10} \pm 13$	7134^{+48+41}_{-25-15}
Γ(BW3)	$73^{+18}_{-15} \pm 10$	97^{+40+29}_{-29-26}

X(6600) ~ 15σ

X(6900) ~ 17σ

X(7100) ~ 8σ

Interf of BW12~ 10σ

Interf of BW23~ 7σ

VS. Run II result:

Stat. unc. X1/3; Syst. unc. X1/2

Interference Fit Model

❖ **Signal shape:** Relativistic Breit-Wigner

❖ **Background component:** NRSPS+NRDPS+Comb+Feeddown+BW0

❖ **Interference model:**

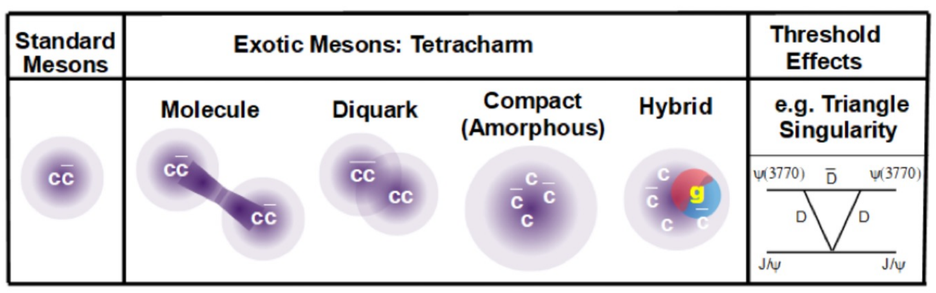
$$Pdf(m) = N_{X_0} \cdot |BW_0|^2 \otimes R(M_0)$$
$$+N_{X \text{ and interf}} \cdot |r_1 \cdot e^{i\phi_1} \cdot BW_1 \otimes R(M_1) + BW_2 \otimes R(M_2) + r_3 \cdot e^{i\phi_3} \cdot BW_3 \otimes R(M_3)|^2$$
$$+N_{\text{NRSPS}} \cdot f_{\text{NRSPS}}(m) + N_{\text{DPS}} \cdot f_{\text{DPS}}(m)$$
$$+N_{\text{Feeddown}} \cdot f_{\text{Feeddown}}(m) + N_{\text{Comb}} \cdot f_{\text{Comb}}(m)$$

- ✓ **All states and dips well above 5σ !**
- ✓ **Quantum interference among structures validated!**
- ✓ **Large mass splittings (> 250MeV) exist, with improved precision**

Summary and Discussion

Update $J/\psi J/\psi$ result with the addition of Run III data

- ✓ The first analysis including 2024 Data among LHC 3 exps
- ✓ Include Feed-down and combinatorial background
- ✓ Update parameterization of Run II&III background



A family of all-charm tetraquarks !!!

- X(6600), X(6900), and X(7100) well above 5σ
  ==> Comparisons possible
- Quantum interference among structures validated well above 5σ
  ==> States have common J^{PC}
- Large mass splittings, more precisely
  ==> radial family of states

CMS is painting a coherent and compelling picture of J/ψ J/ψ structures!

Reference

[1] M. Gell-Mann, "A schematic model of baryons and mesons", Phys. Lett. 8 (1964) 214.

[2] G. Zweig, "An SU(3) model for strong interaction symmetry and its breaking", 1964. CERN-TH-401.

[3] M. Y. Barabanov et al., "Diquark correlations in hadron physics: Origin, impact and evidence", Prog. Part. Nucl. Phys. 116 (2021) 103835.

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