First MuonID Mexico Meeting

EXOTIC HADRONS IN HEAVY-ION COLLISIONS

Collision measured at ALICE detector (2014)

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Outlook

The interest on exotics

- *Beyond the quark model*
- *The compact vs. molecular “controversy”*

The X(3872)

- *The best studied and most intriguing exotic*
- *Lineshape analysis*

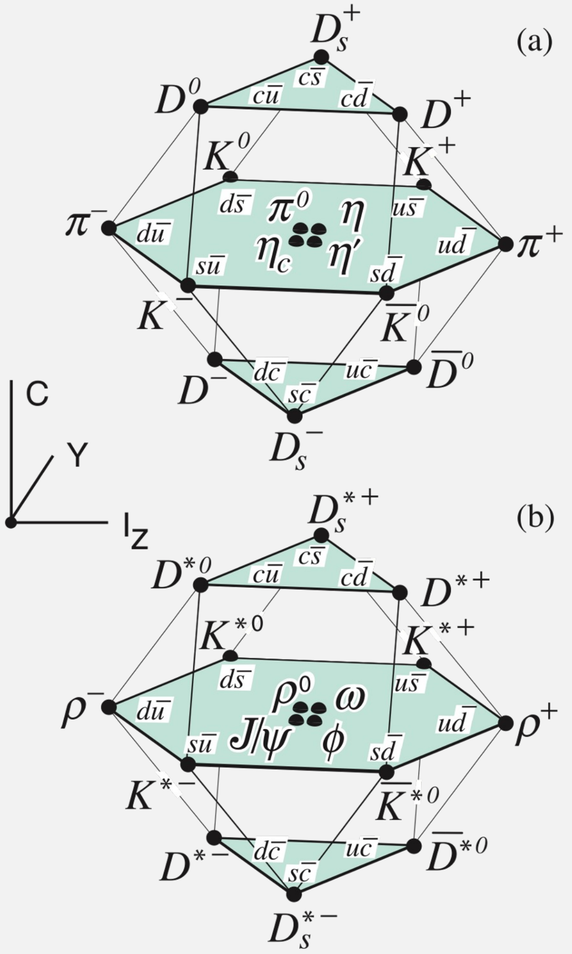
Heavy-ion collisions and exotics

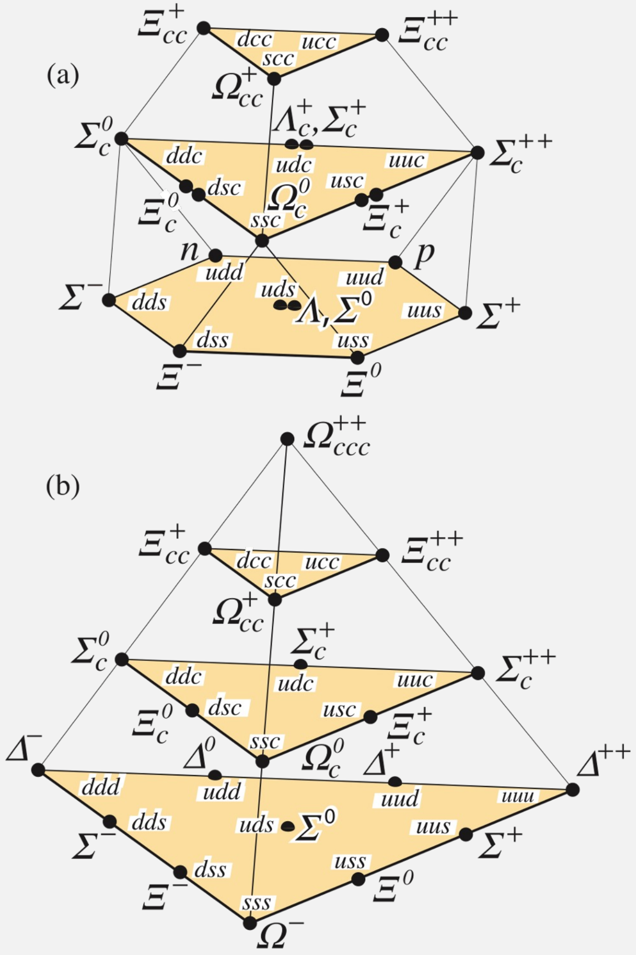
- *Prompt vs. non-prompt production*
- *Ultraperipheral production*

Takeaways

Quark model

G. Zweig, CERN-TH-401 (1964)
M. Gell-Mann, Phys. Lett. 8 (1964) 214
A. Petermann, Nucl. Phys. 63 (1965) 349





PDG, PTEP 2022 (2022) 083C01

Is that it?

PHYSICAL REVIEW D VOLUME 32, NUMBER 1 1 JULY 1985

Mesons in a relativized quark model with chromodynamics

Stephen Godfrey and Nathan Isgur
Department of Physics, University of Toronto, Toronto, M5S 1A7 Canada
(Received 12 December 1983; revised manuscript received 10 May 1985)

We show that mesons—from the π to the Υ—can be described in a unified quark model with chromodynamics. The key ingredient of the model is a universal one-gluon-exchange-plus-linear-confinement potential motivated by QCD, but it is crucial to the success of the description to take into account relativistic effects. The spectroscopic results of the model are supported by an extensive analysis of strong, electromagnetic, and weak meson couplings.

Problem: Why does this model work? Is there an underlying symmetry?

If it is not forbidden, it is mandatory

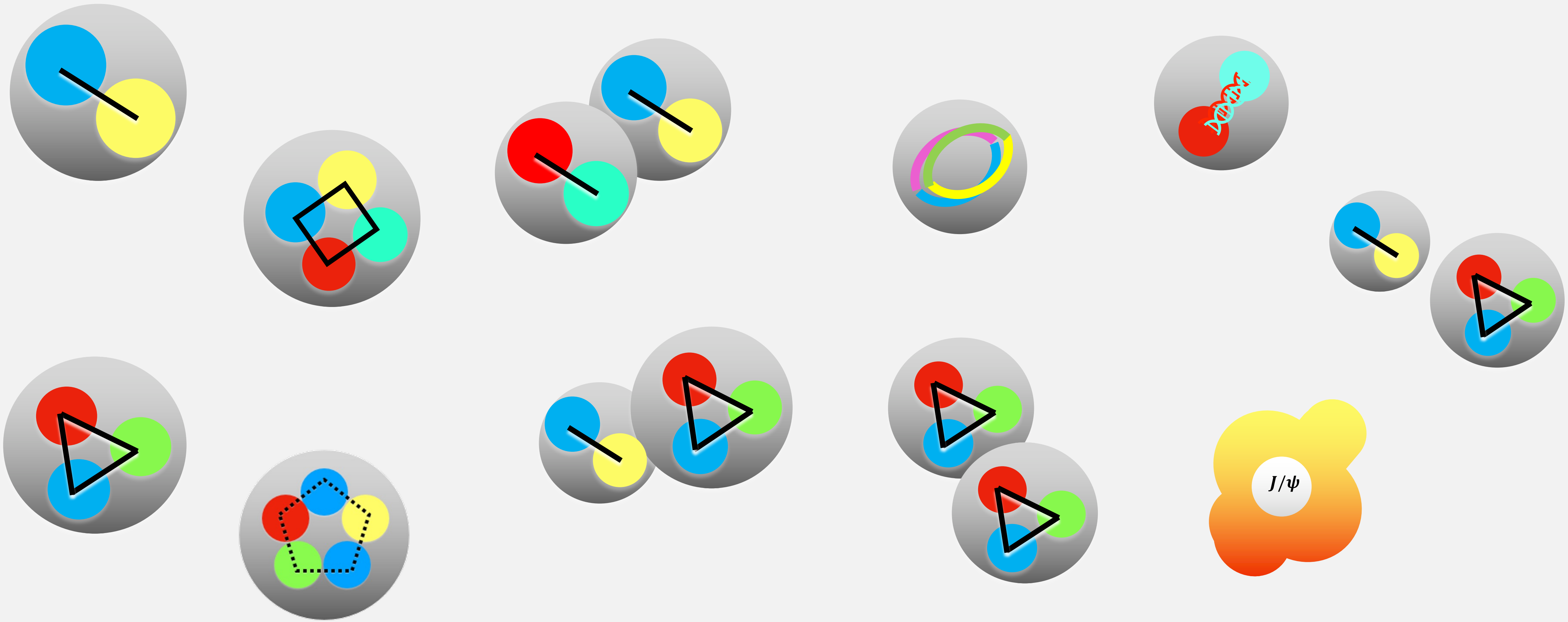
State superposition

$$|Meson\rangle = \alpha_0|\bar{q}q\rangle + \alpha_1|\bar{q}\bar{q}qq\rangle + \alpha_2|\bar{q}qg\rangle + \alpha_3|gg\rangle + \cdots$$

$$|Baryon\rangle = \alpha_0|qqq\rangle + \alpha_1|\bar{q}qqqq\rangle + \alpha_2|qqqg\rangle + \cdots$$

$$\sum_{i=0}^{\infty} |\alpha_i|^2 = 1$$

Understand resonances



Exotic hadron

Quantum numbers cannot be obtained by $q\bar{q}$ or qqq combinations

- *π_1 (hybrid candidate)*

Minimal quark content goes beyond $q\bar{q}$ or qqq

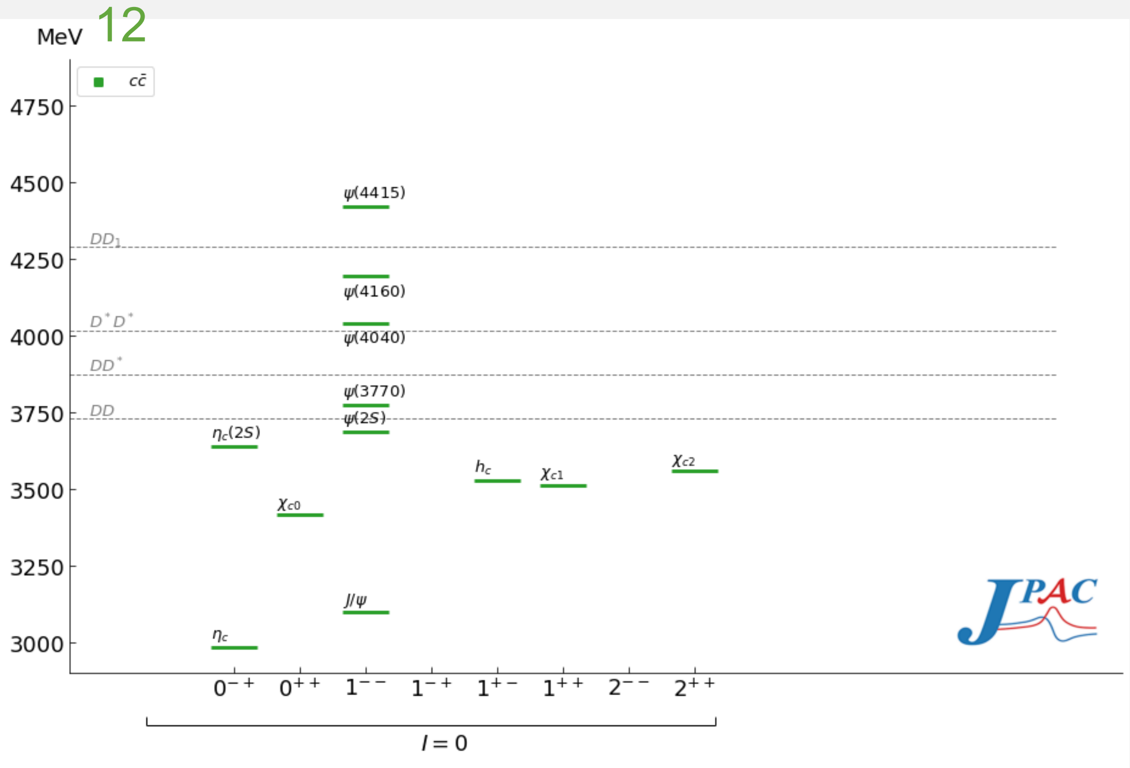
- *Tetraquarks, pentaquarks*

Minimal quark content is ordinary but has nonquark model properties

- *X(3872)*

Charmonia(-like)

2003



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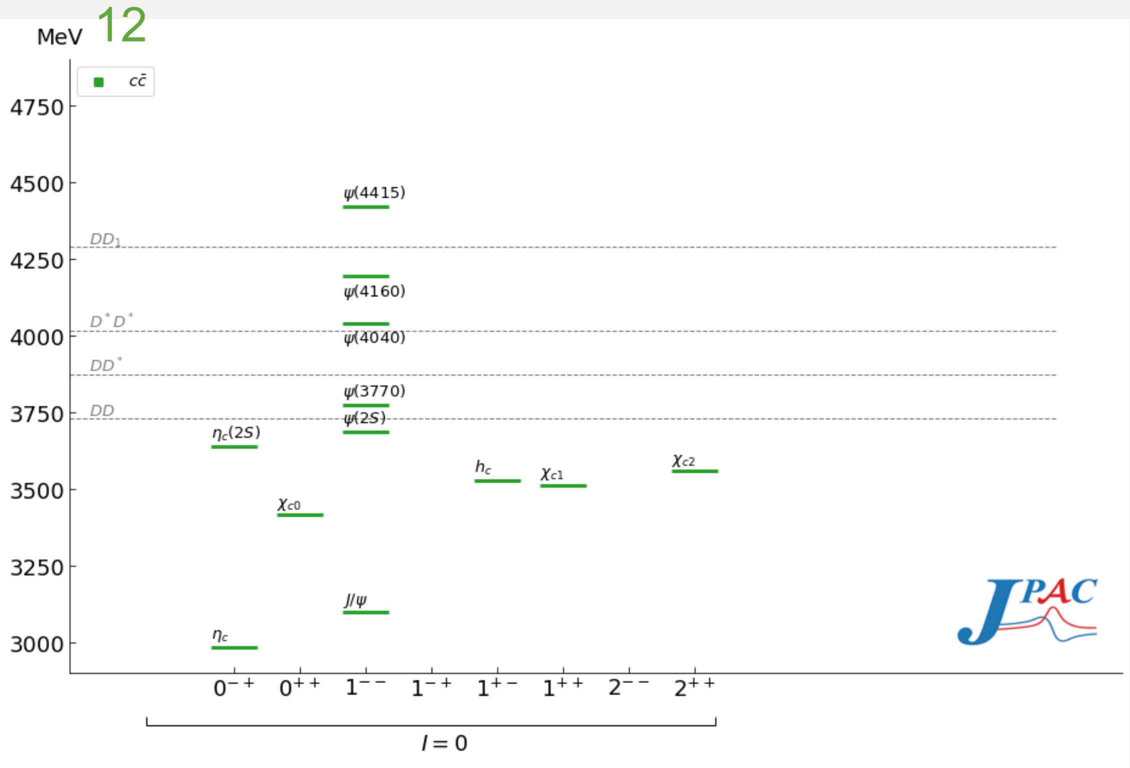
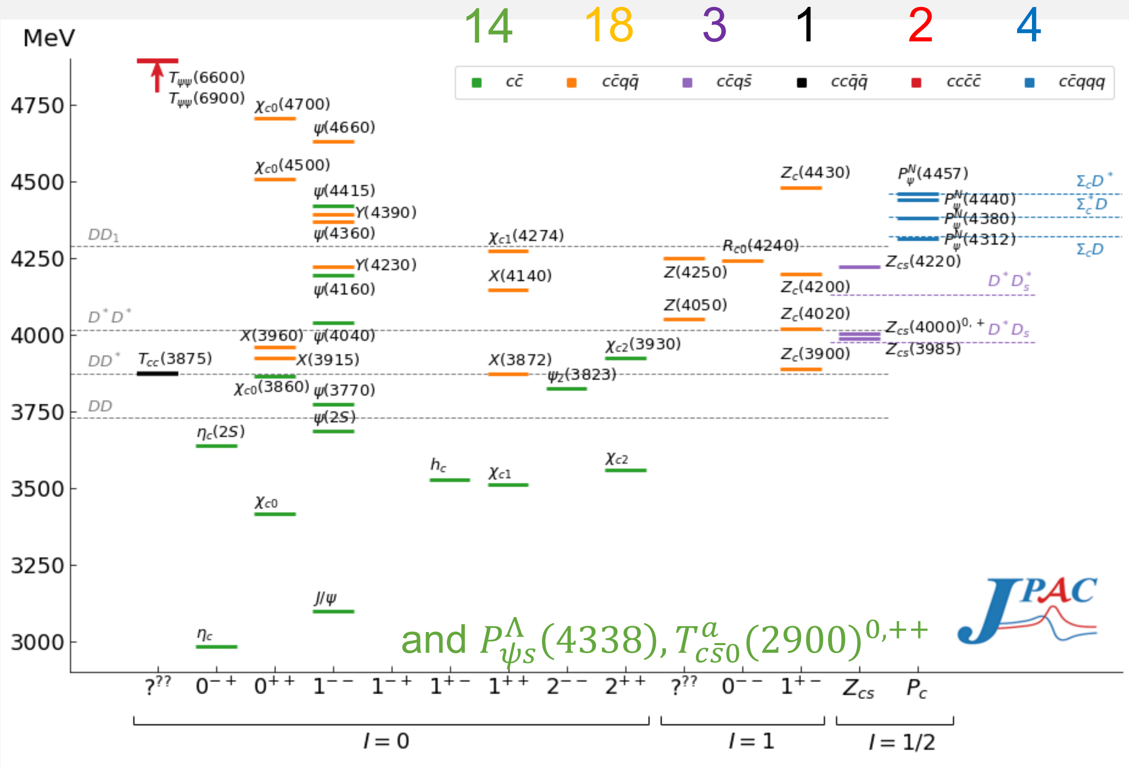


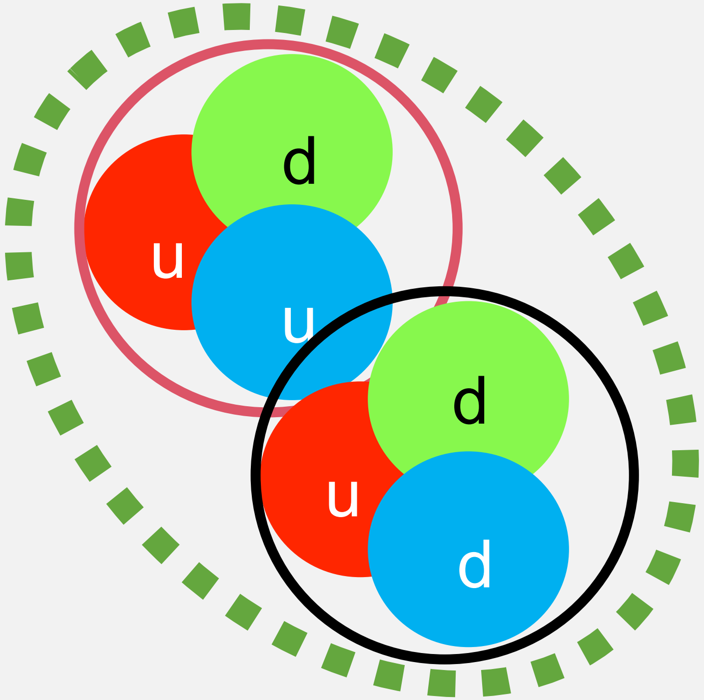
2022



Updated from JPAC, PPNP 127 (2022) 103981

Compact vs. molecular

Simplest hadron molecule: deuteron

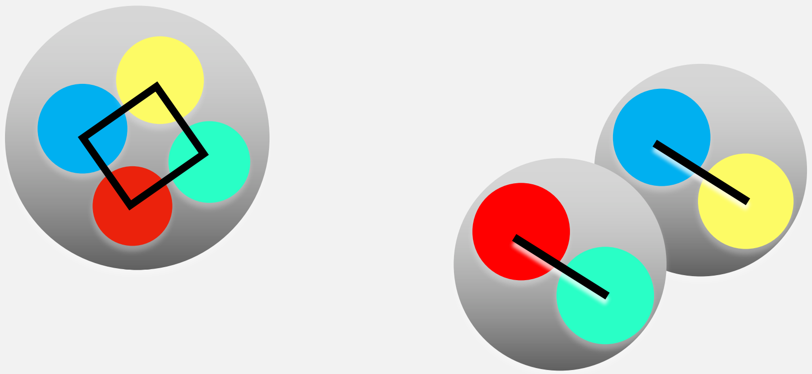


Weinberg, Phys. Rev. 137 (1965) B672

Relates to how the strong interaction confines quarks

How do quarks arrange themselves to generate a hadron

- *diquarks: quark-quark*
- *quark-antiquark*



The revolution: X(3872)

Three-body decays opened a new era in hadron spectroscopy

The X(3872) has ordinary quantum numbers compatible with a $c\bar{c}$ state, but…

VOLUME 91, NUMBER 26 PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2003

Observation of a Narrow Charmoniumlike State in Exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ Decays

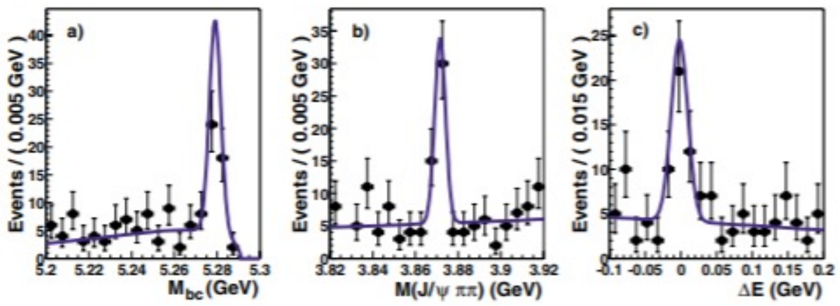
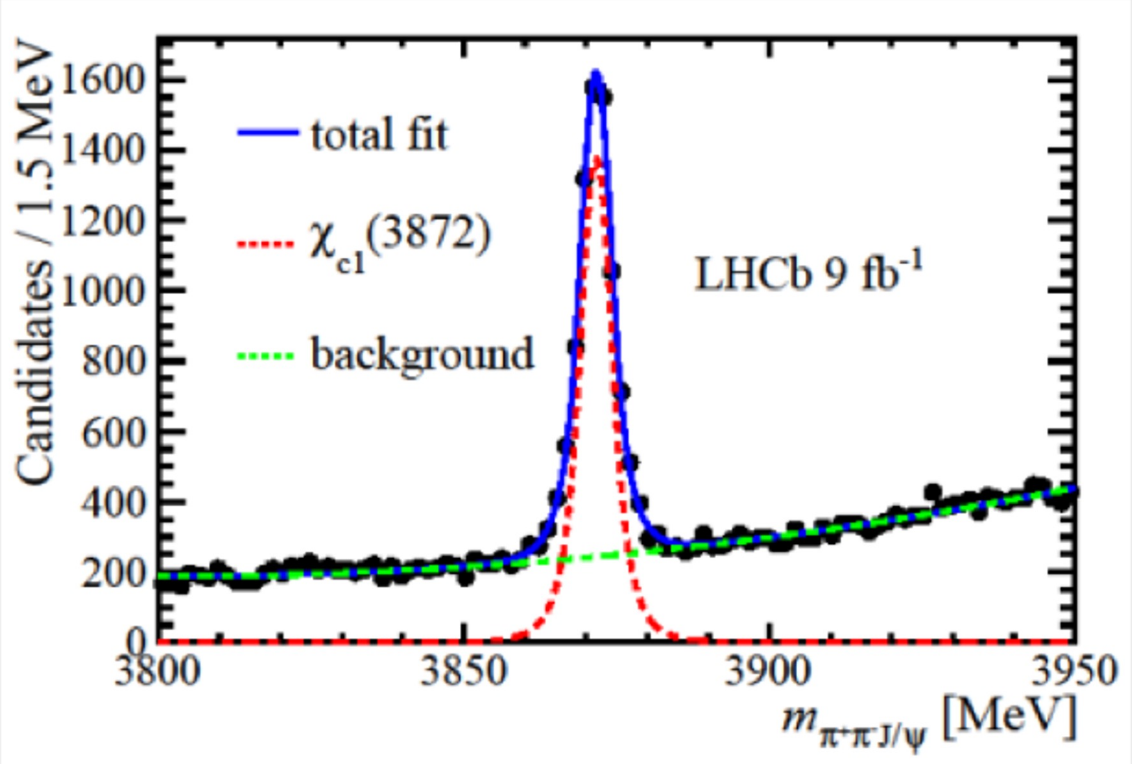


FIG. 2 (color online). Signal-band projections of (a) M_{bc}, (b) $M_{\pi^+\pi^- J/\psi}$, and (c) ΔE for the $X(3872) \to \pi^+\pi^- J/\psi$ signal region with the results of the unbinned fit superimposed.

Most cited physics paper from Belle >2000

Why is X(3872) exotic?

$B^+ \to K^+ X(3872) \to K^+ J/\psi\, \pi^- \pi^+$



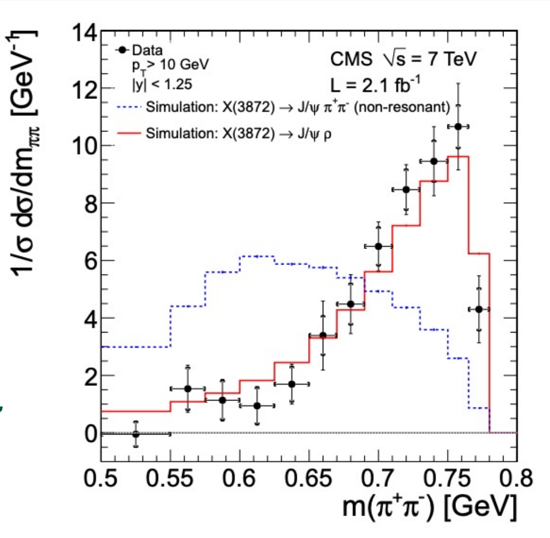
$X(3872) \to J/\psi\, \rho \to J/\psi\, \pi^- \pi^+$
$X(3872) \to J/\psi\, \omega \to J/\psi\, \pi^- \pi^+$

ρ violates isospin
ω respects isospin

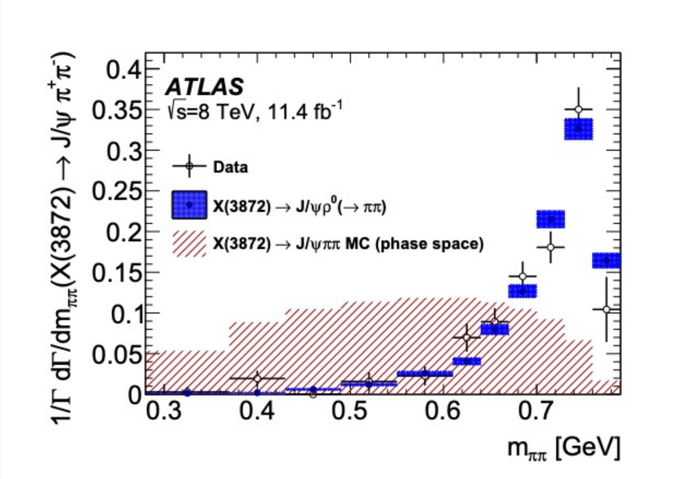
If it were a quark-antiquark state you expect ω to dominate

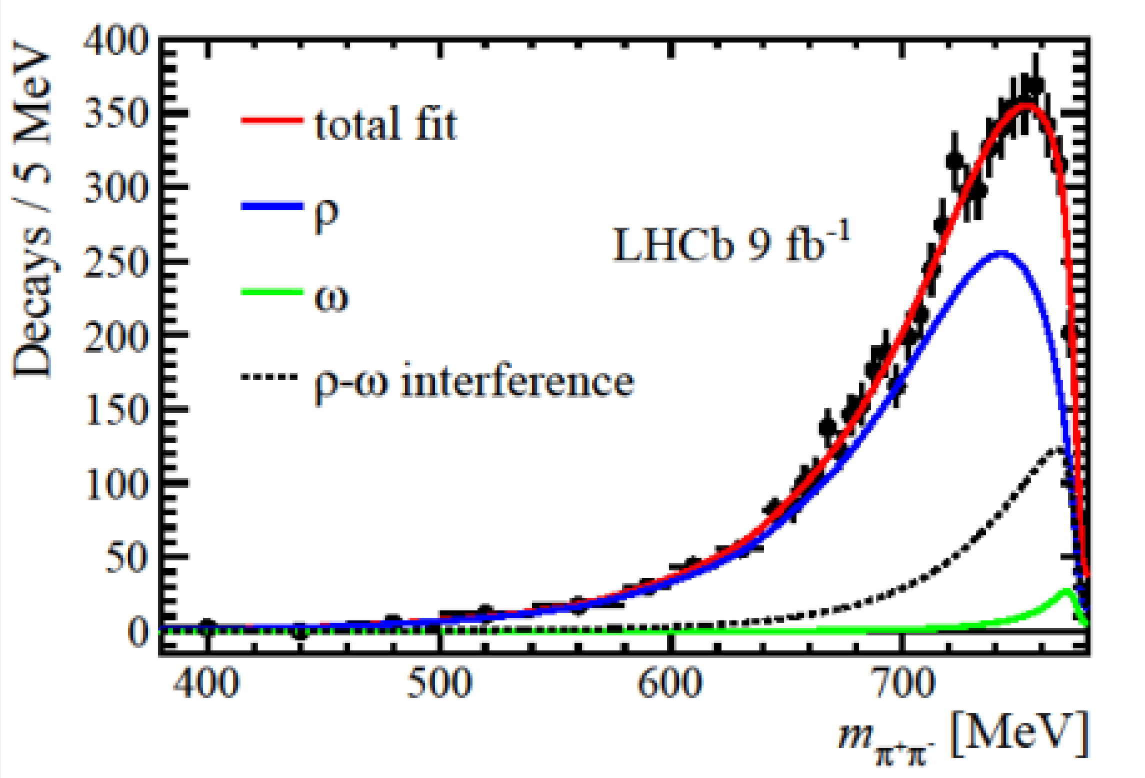
Data from LHCb, 2204.12597 [hep-ex]

Lineshape analysis: ρ is the dominant component



CMS, JHEP 04 (2013) 154
ATLAS, JHEP 01 (2017) 117



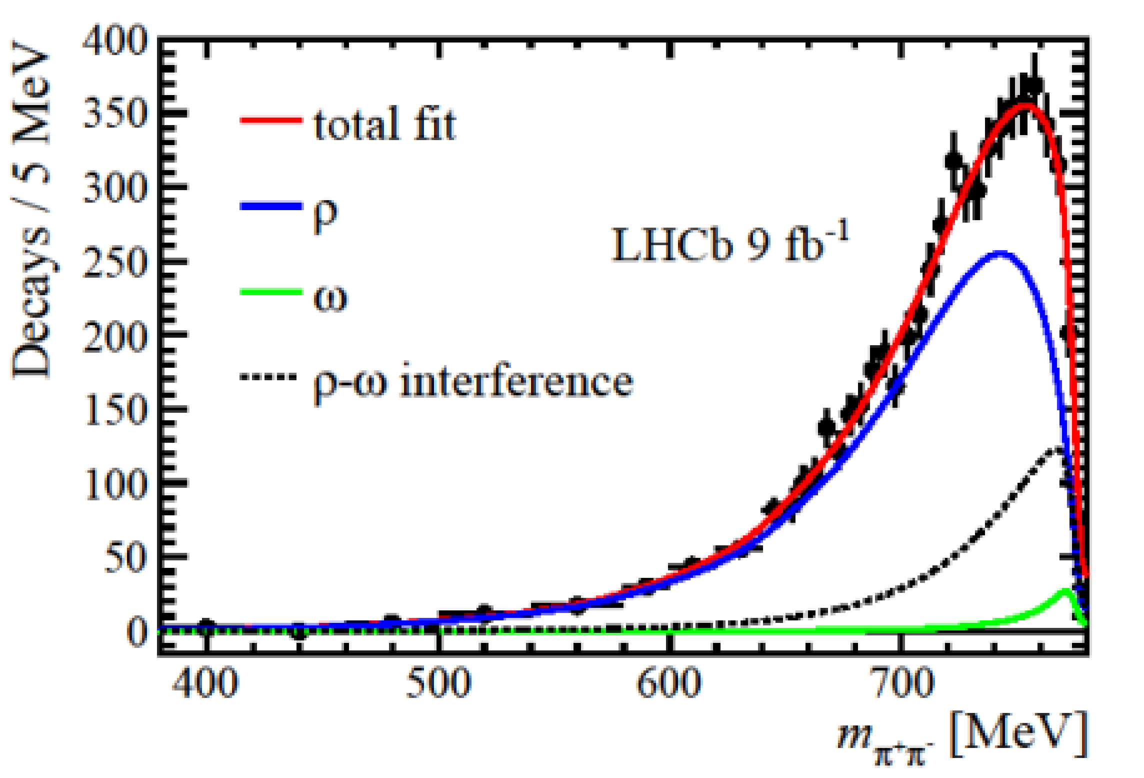


LHCb, 2204.12597 [hep-ex]

Lineshape analysis: ρ is the dominant component

$$\mathcal{M} = \frac{p_\pi(s)}{p_\pi(m_\rho)} \{\mathrm{BW}^{\mathrm{GS}}(s, m_\rho, \Gamma_\rho)\ [1 + A_\omega^{\mathrm{GS}}\, e^{i\phi_\omega}\, \mathrm{BW}_\omega(s, m_\omega, \Gamma_\omega)] + A_{\rho'}^{\mathrm{GS}}\, e^{i\phi_{\rho'}}\, \mathrm{BW}^{\mathrm{GS}}(s, m_{\rho'}, \Gamma_{\rho'})\}$$

$$R_\omega^{all} = 0.214 \pm 0.023 \pm 0.020$$
$$R_\omega^0 = 0.019 \pm 0.04 \pm 0.003$$
$$R_{\omega/\rho}^0 = 0.025 \pm 0.006 \pm 0.005$$



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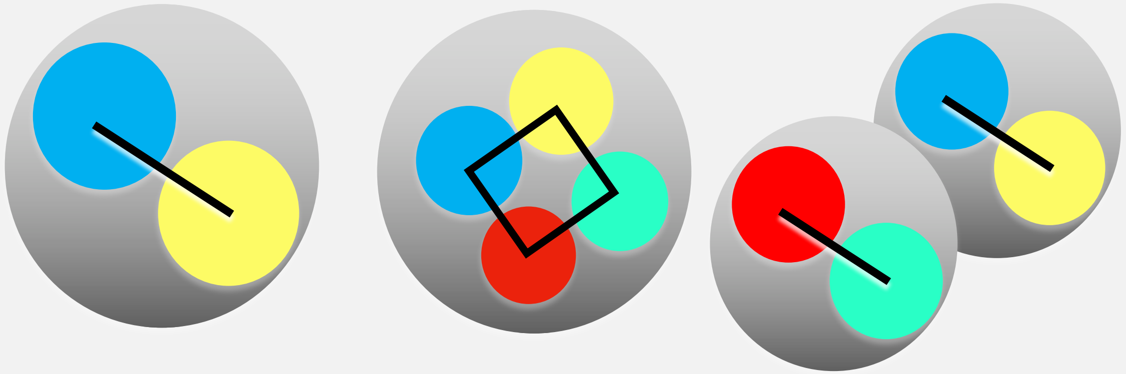
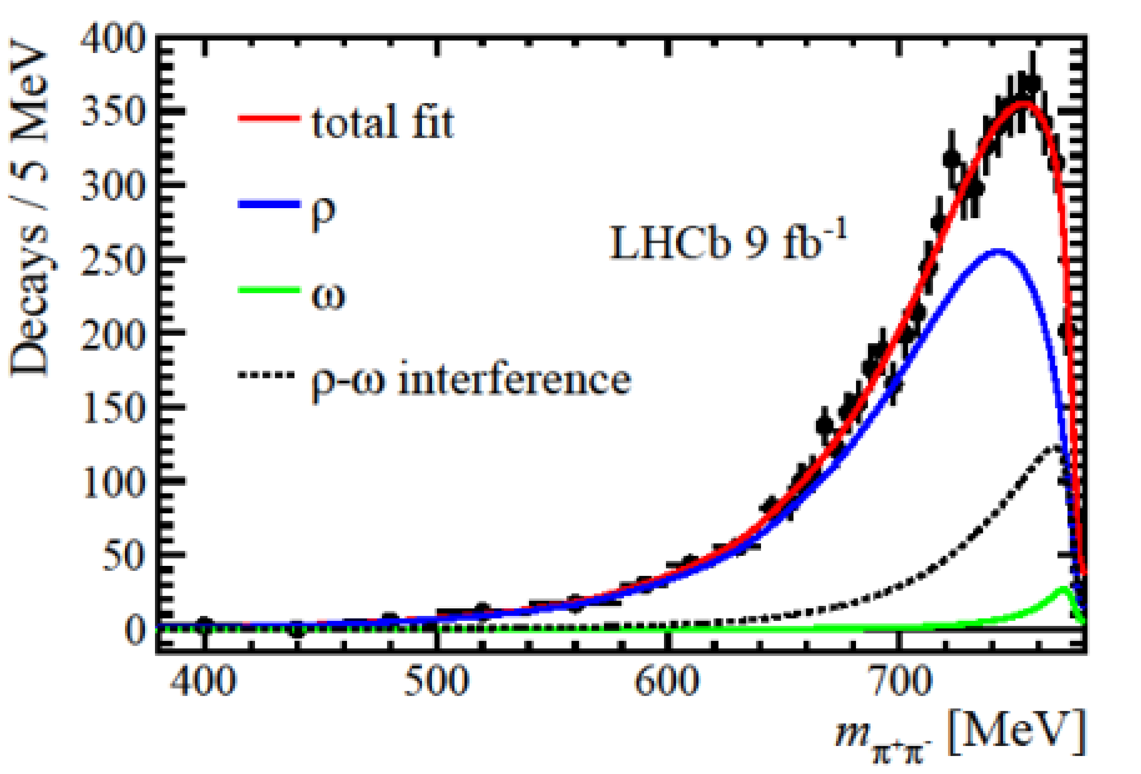
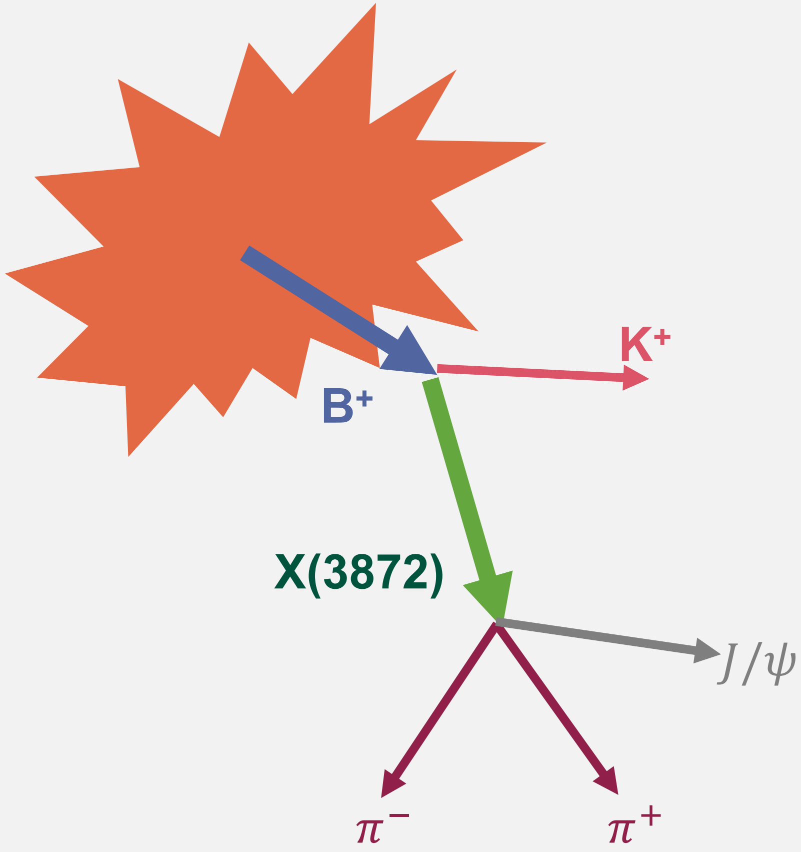
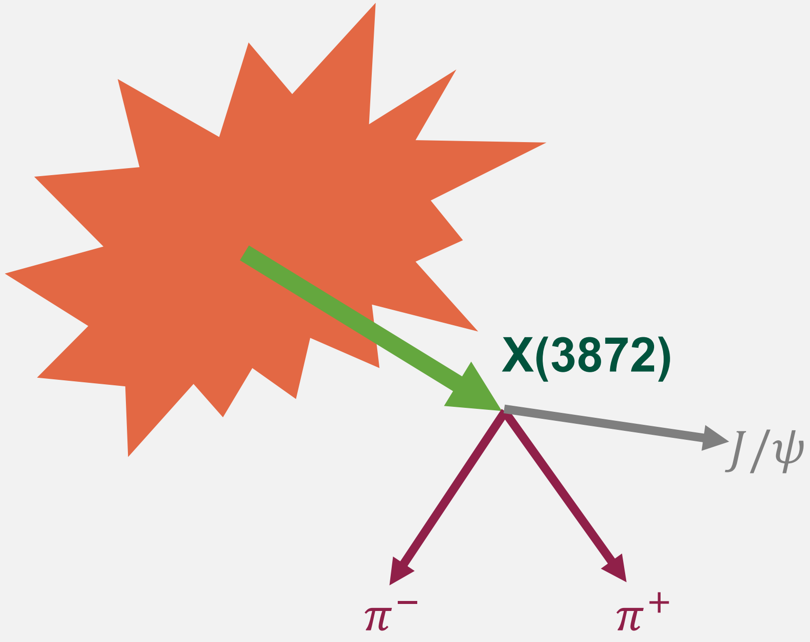




LHCb, 2204.12597 [hep-ex]

Prompt vs. non-prompt resonance production

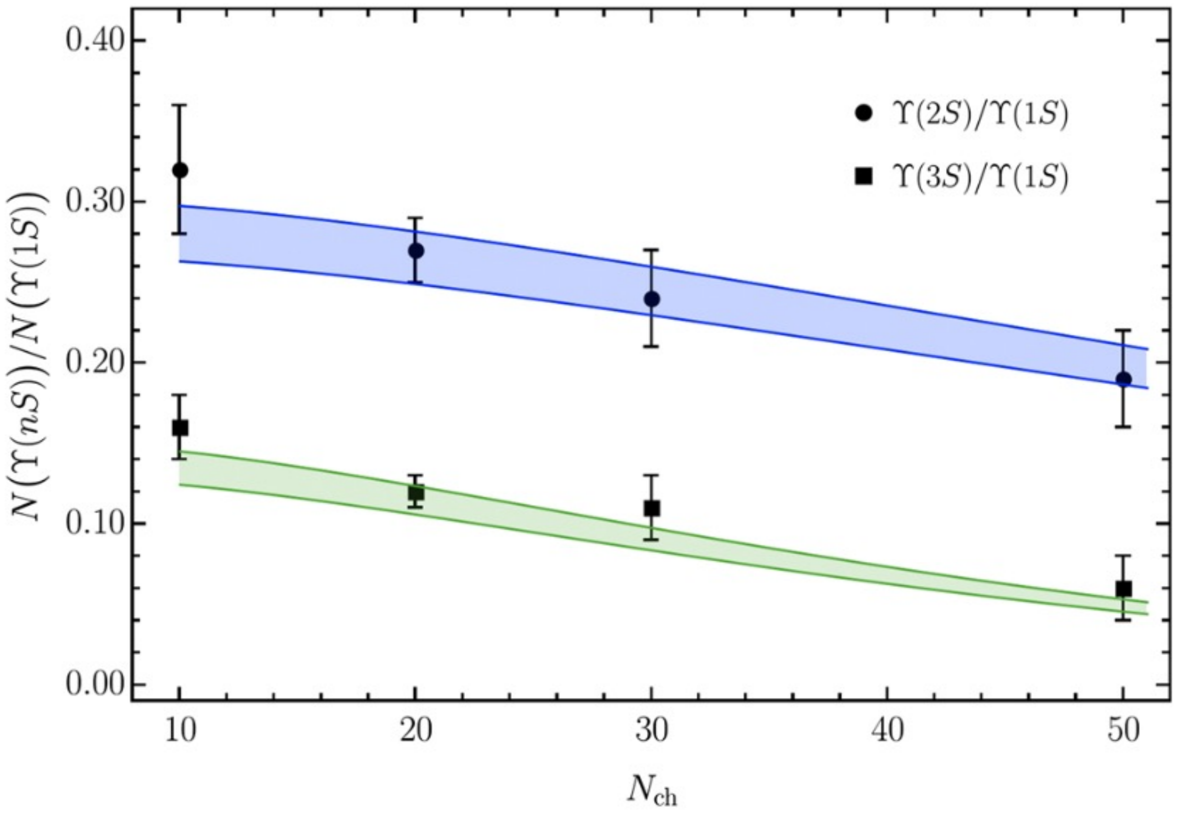




Estimating the size of states studying their behavior when immersed in QCD matter

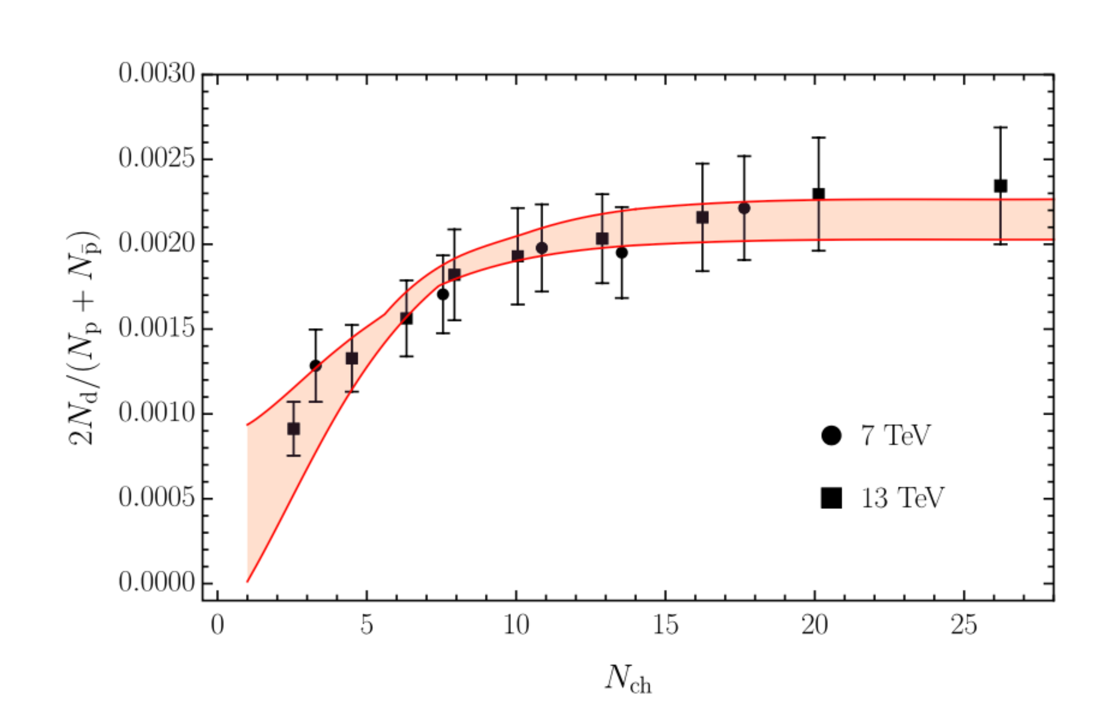
Bottomonia in high multiplicity

Under the assumption that the bottomonia are compact (which is most likely correct)

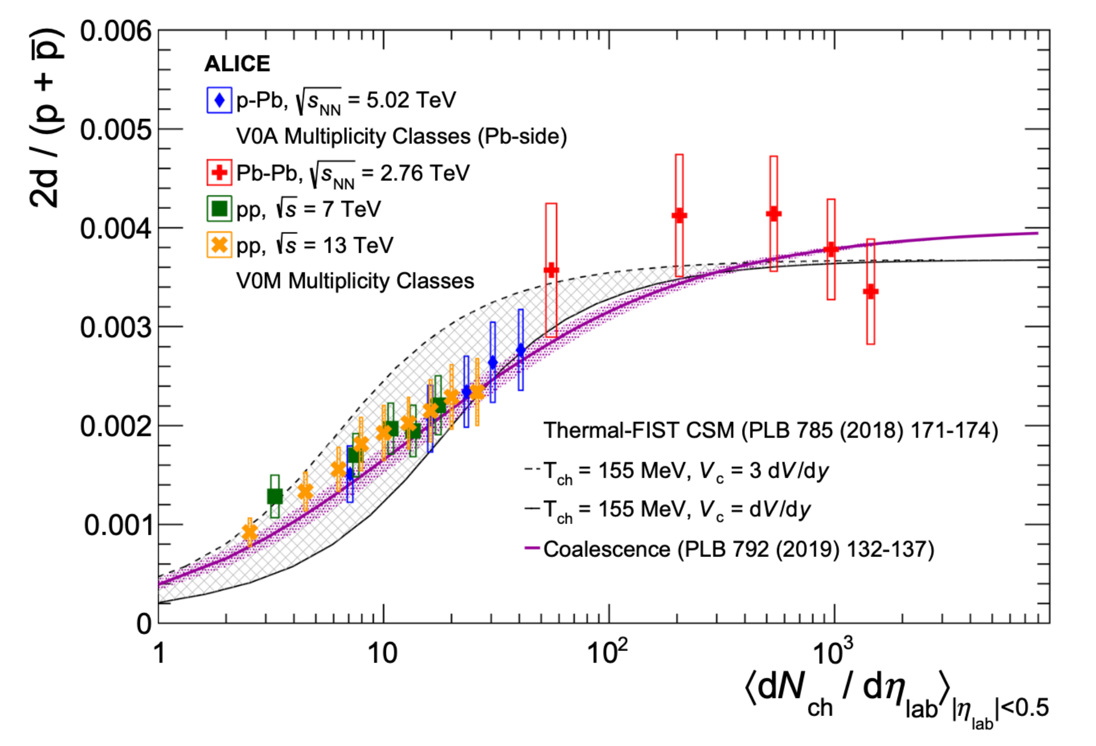


Esposito et al, EPJC 81 (2021) 229
Data from CMS, JHEP 04 (2014) 103

The deuteron in high-multiplicity



Esposito et al, EPJC 81 (2021) 229

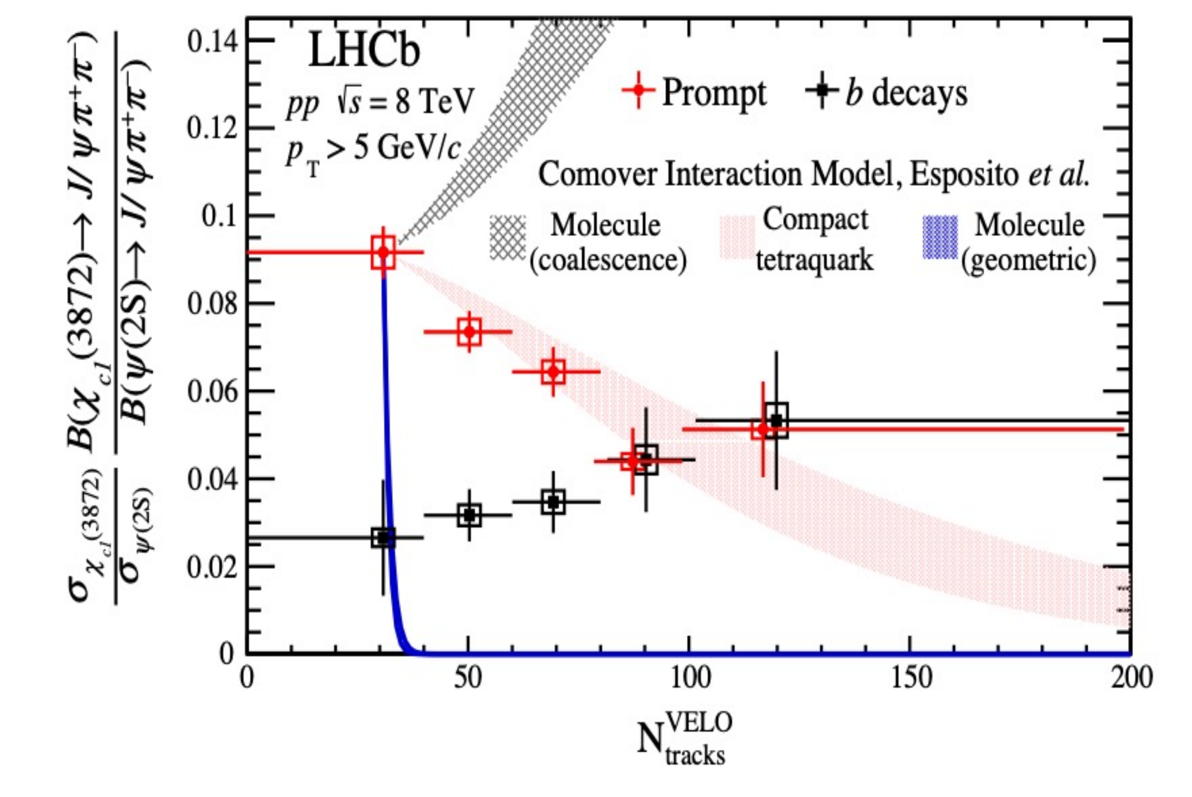


ALICE, PLB 794 (2019) 50
ALICE, EPJC 80 (2020) 889

The X(3872) in high multiplicity

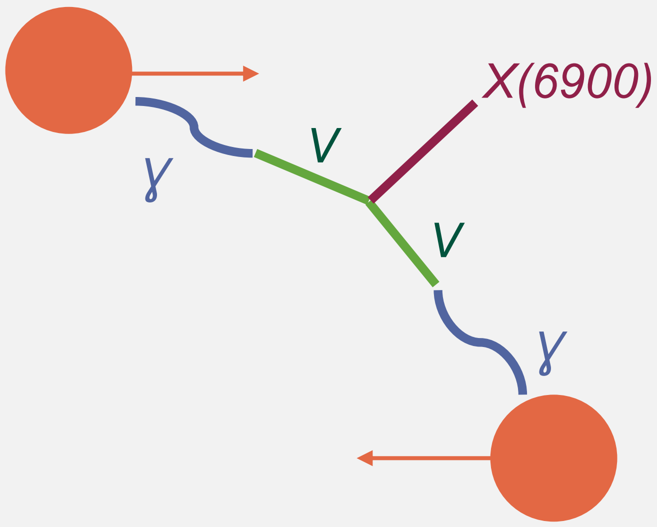
Ratio of X(3872) vs. ψ(2S) for $J/\psi\,\pi^-\pi^+$ as a function of the number of tracks reconstructed in the VELO at 8 TeV and forward pseudorapidity

- *Tetraquark of diameter 1.3 fm*



LHCb, PRL 126 (2021) 092001
Theory from Esposito et al, EPJC 81 (2021) 229

Ultra-peripheral heavy-ion collisions



Particularly interesting would be the X(6900) which could be produced copiously in this process

State, J^{PC}	$\Gamma_{\gamma\gamma}/\mathcal{B}_\psi$ (eV)	$\sigma(\text{PbPb} \to \text{PbPb}X)/\mathcal{B}_\psi$ (nb)
$X(6900)$, 0^{++}	$\sim$104	$\sim$282
$X(6900)$, 2^{++}	$\sim$86	$\sim$1165

Esposito et al., PRD 104 (2021) 114029

ALICE can keep contributing to hadron spectroscopy

- *Revealing resonance dynamics from high-multiplicity processes*
- *Discovery and confirmation of resonances from ultra-peripheral production*