新强子态研究新进展

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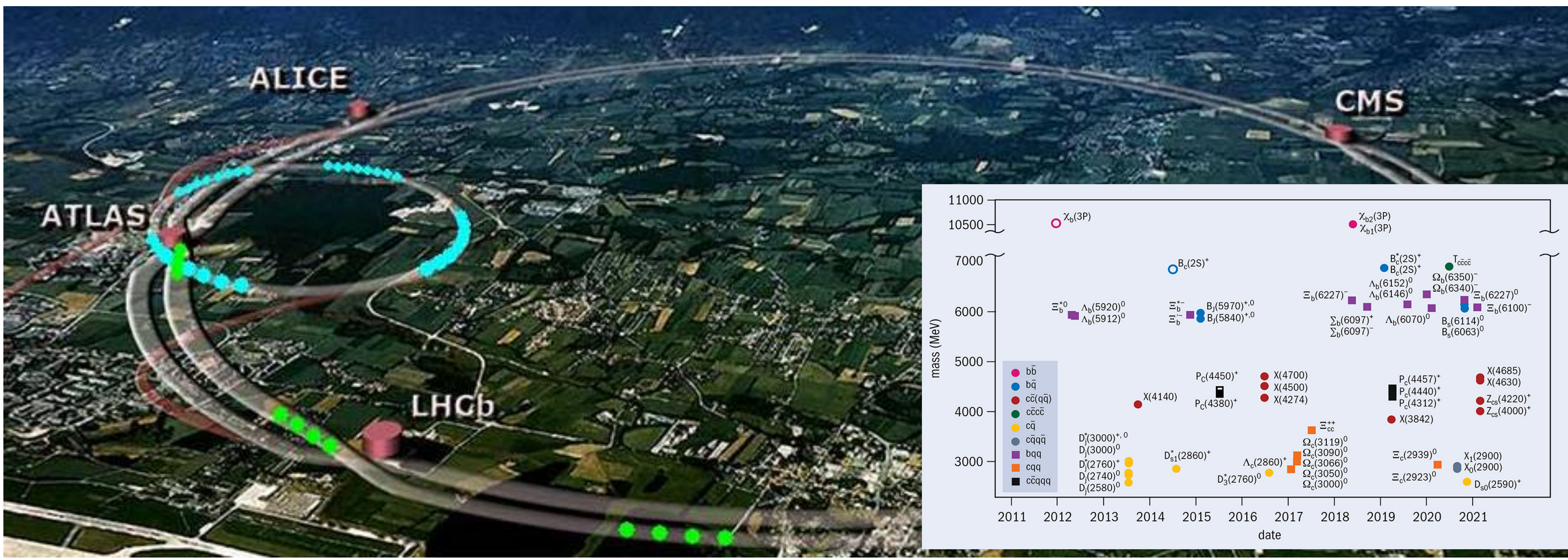
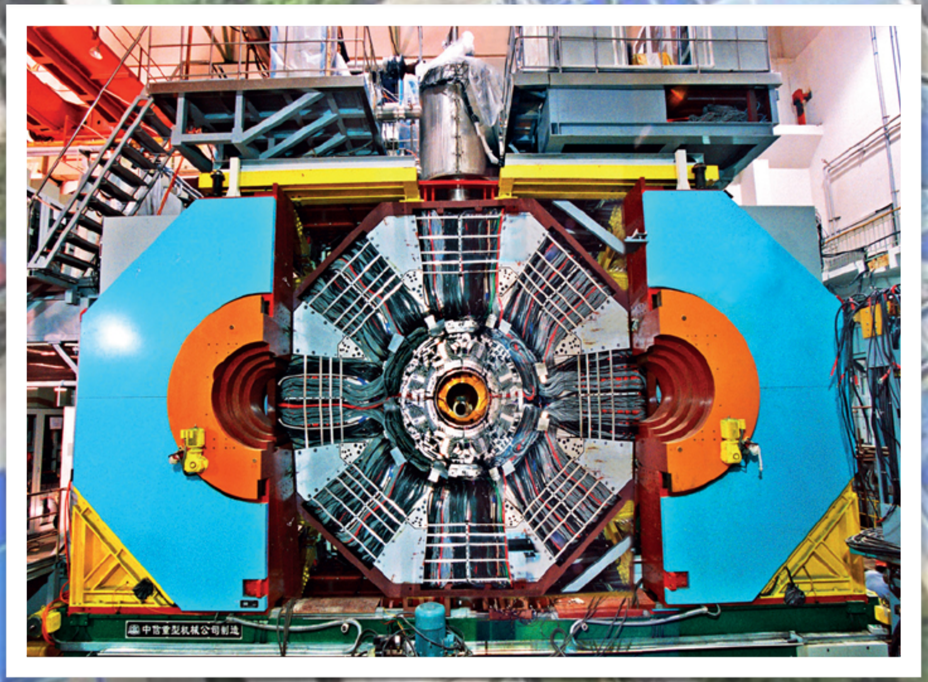
2023年度中国科学院理论物理前沿重点实验室年会
2023年6月2日

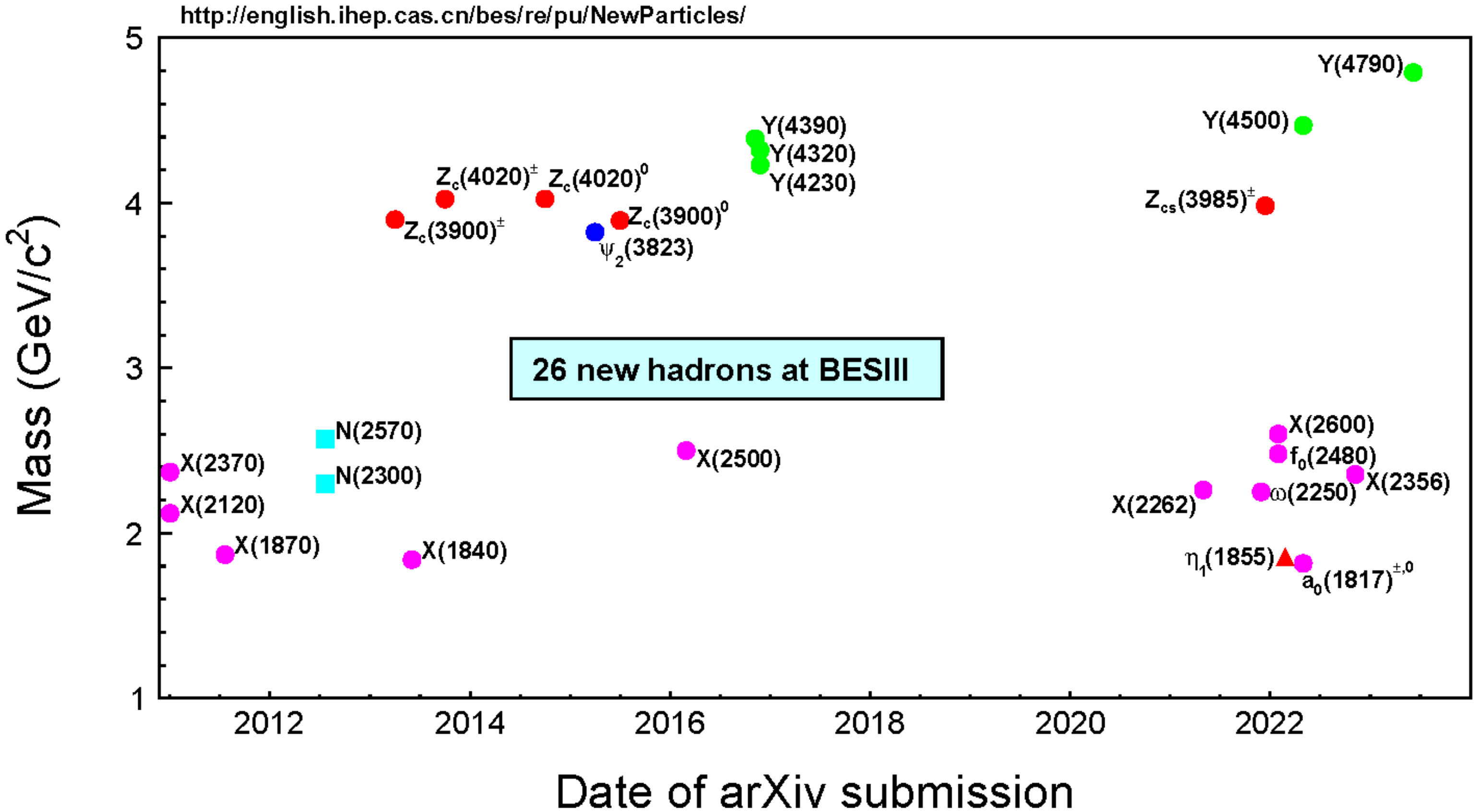
Outline

- Experimental status
- Pentaquark is alway a focused point
- Pay more attentions to the study of light hadron spectroscopy
- Summary-Never underestimate the ability of experiment

Experimental status



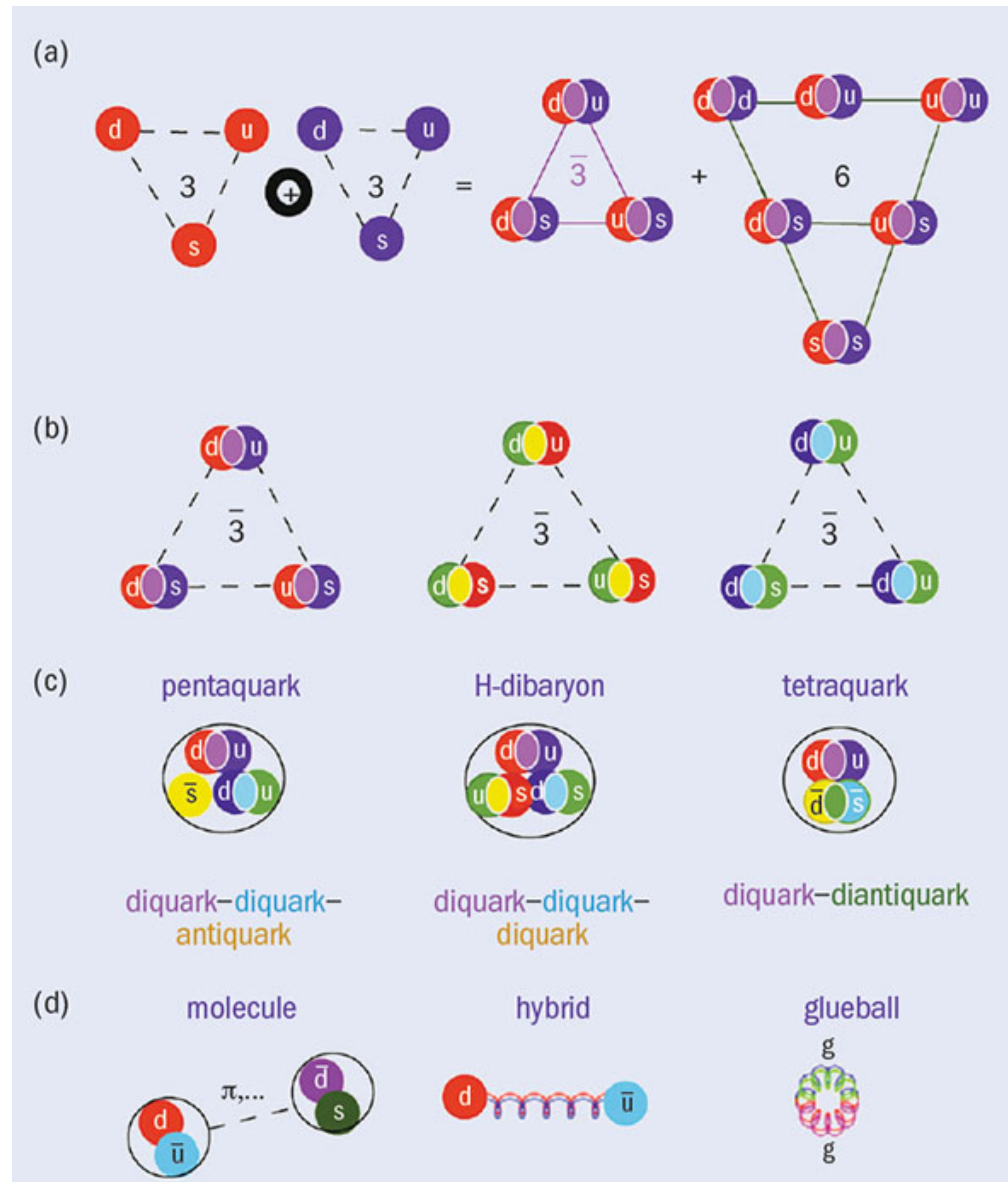




http://english.ihep.cas.cn/bes/re/pu/NewParticles/
26 new hadrons at BESIII
Mass (GeV/c2)
Date of arXiv submission
Y(4790)
Y(4500)
Y(4390)
Y(4320)
Y(4230)
Zc(4020)±
Zc(4020)0
Zc(3900)±
Zc(3900)0
ψ2(3823)
Zcs(3985)±
N(2570)
N(2300)
X(2370)
X(2120)
X(1870)
X(1840)
X(2500)
X(2600)
f0(2480)
X(2356)
X(2262)
ω(2250)
η1(1855)
a0(1817)±,0
1
2
3
4
5
2012
2014
2016
2018
2020
2022

BESIII

"Particle Zoo 2.0"—Exotic states



Recent observations of tetraquark and pentaquark

$P_{\psi s}^{\Lambda}(4338)$

LHCb

Model with J/ψΛ resonance

Amplitude contributions:

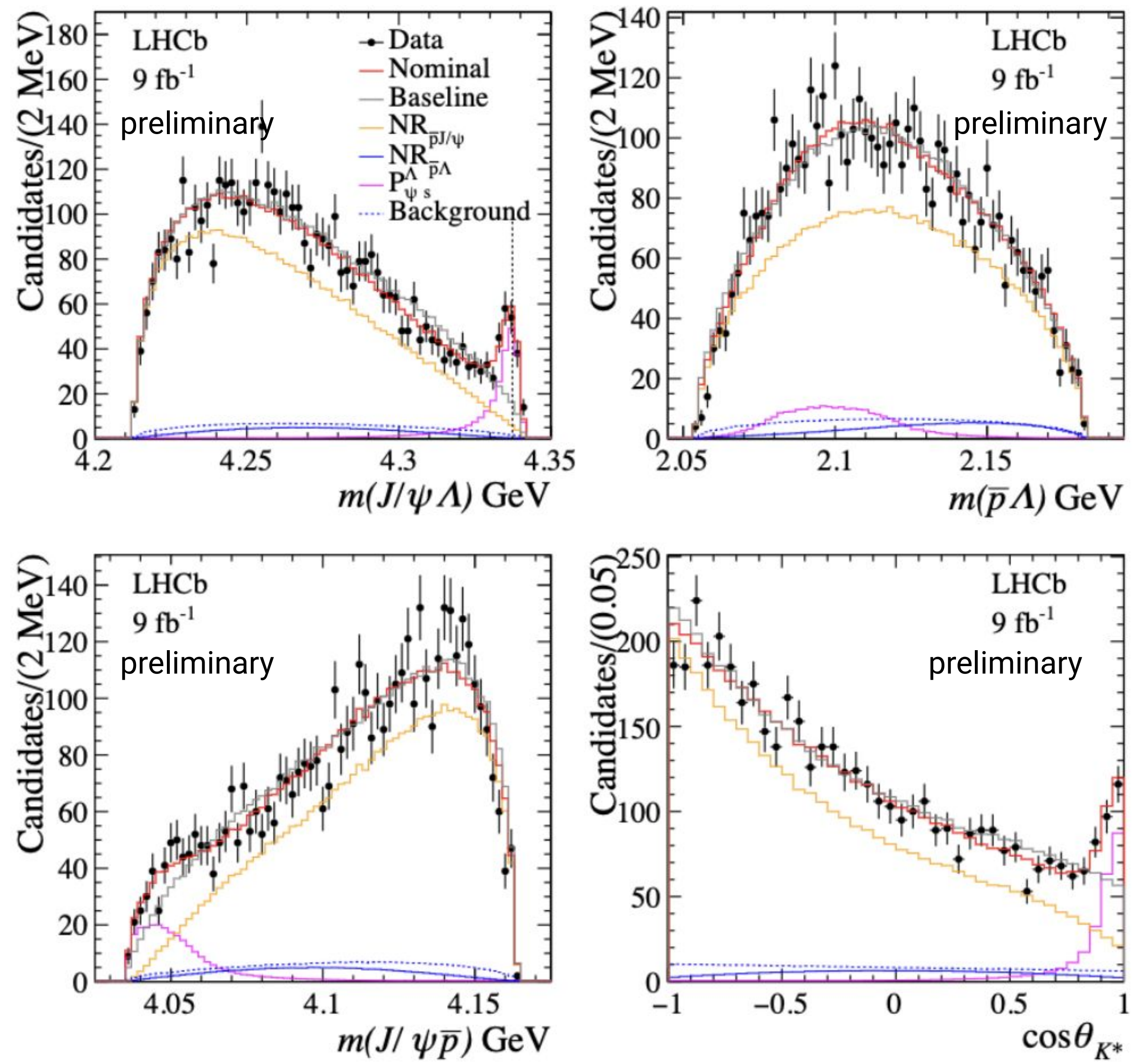
- $NR(\bar{p}\Lambda)$
- $NR(\bar{p}J/\psi)$
- $P_{\psi s}^{\Lambda}(J/\psi\Lambda)$

Fit results:

$m(P_{\psi s}^{\Lambda})$	$4338.2 \pm 0.7\ MeV$
$\Gamma(P_{\psi s}^{\Lambda})$	$7.0 \pm 1.2\ MeV$
$f\,(P_{\psi s}^{\Lambda})$	$12.5 \pm 0.7\%$

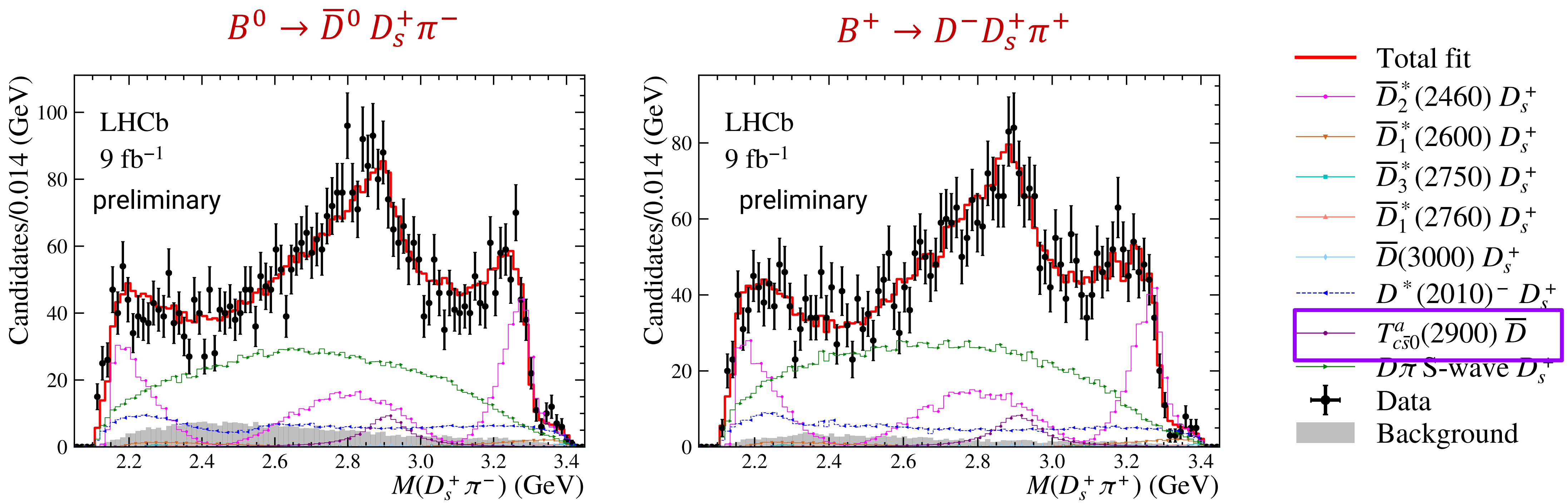
⇒ Spin-parity:
J = ½ determined
P = -1 favored, $½^+$ rejected @90% CL

From Wilks' theorem:
significance > 10 σ



$T^{a}_{c\bar{s}0}(2900)$

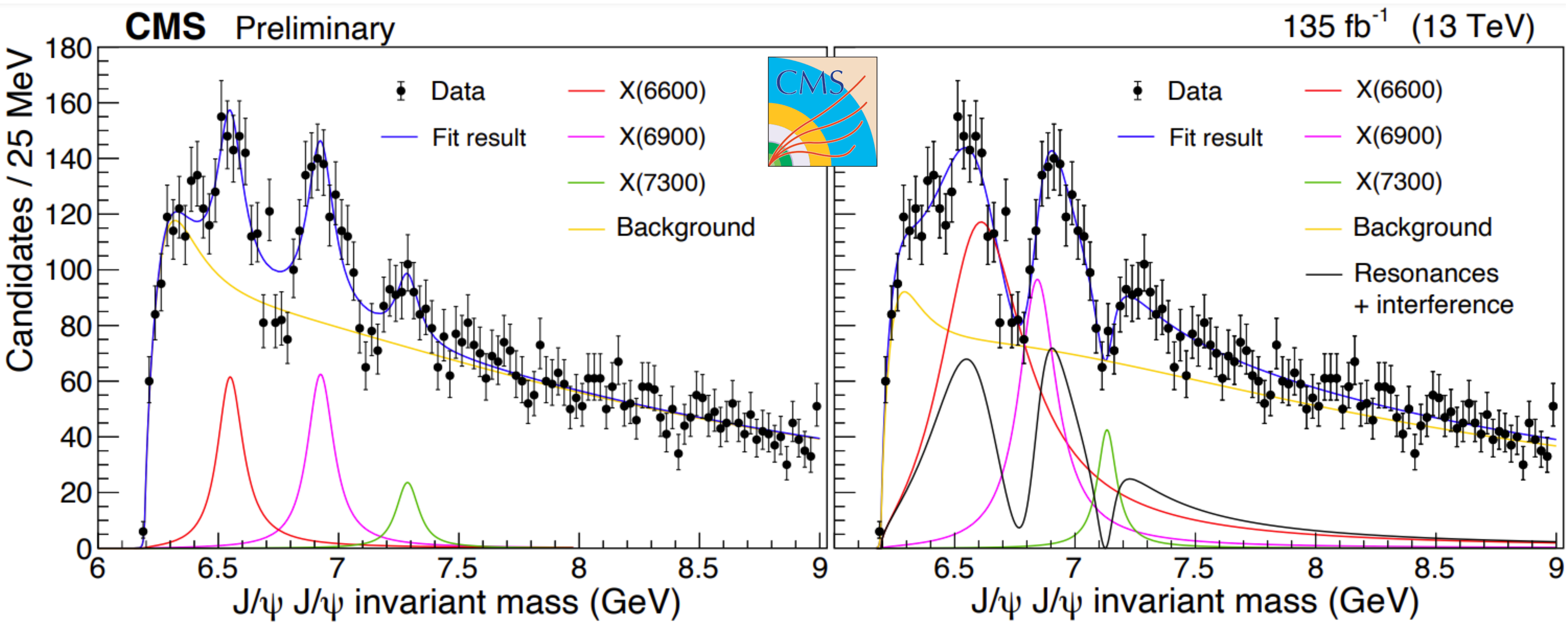
Fit with additional $T^{a}_{c\bar{s}0}(2900)^{++/0} \to D_s^+ \pi^{+/-}$



$M(D_s\pi)$ well described by adding a $J^P = 0^+$ $T^{a}_{c\bar{s}0}(2900)$ in each channel

- To test existence of potential partner of $T_{cs1}(2900)$
  - A second $D_s\pi$ resonance with $J^P = 1^-$ is not significant
- Additional resonances are tested but no improvement on the description

More peaks in di-J/ψ invariant mass spectrum



https://cms.cern/news/cms-observes-potential-family-tetra-quark-states-composed-only-charm-quarks

ATLAS is joining this party

arXiv: 2304.08962

di-J/ψ	model A	model B
m_0	$6.41 \pm 0.08^{+0.08}_{-0.03}$	$6.65 \pm 0.02^{+0.03}_{-0.02}$
Γ_0	$0.59 \pm 0.35^{+0.12}_{-0.20}$	$0.44 \pm 0.05^{+0.06}_{-0.05}$
m_1	$6.63 \pm 0.05^{+0.08}_{-0.01}$	—
Γ_1	$0.35 \pm 0.11^{+0.11}_{-0.04}$	
m_2	$6.86 \pm 0.03^{+0.01}_{-0.02}$	$6.91 \pm 0.01 \pm 0.01$
Γ_2	$0.11 \pm 0.05^{+0.02}_{-0.01}$	$0.15 \pm 0.03 \pm 0.01$
$\Delta s/s$	$\pm 5.1\%^{+8.1\%}_{-8.9\%}$	—
J/ψ+$\psi(2S)$	**model α**	**model β**
m_3 or m	$7.22 \pm 0.03^{+0.01}_{-0.03}$	$6.96 \pm 0.05 \pm 0.03$
Γ_3 or Γ	$0.09 \pm 0.06^{+0.06}_{-0.03}$	$0.51 \pm 0.17^{+0.11}_{-0.10}$
$\Delta s/s$	$\pm 21\% \pm 14\%$	$\pm 20\% \pm 12\%$

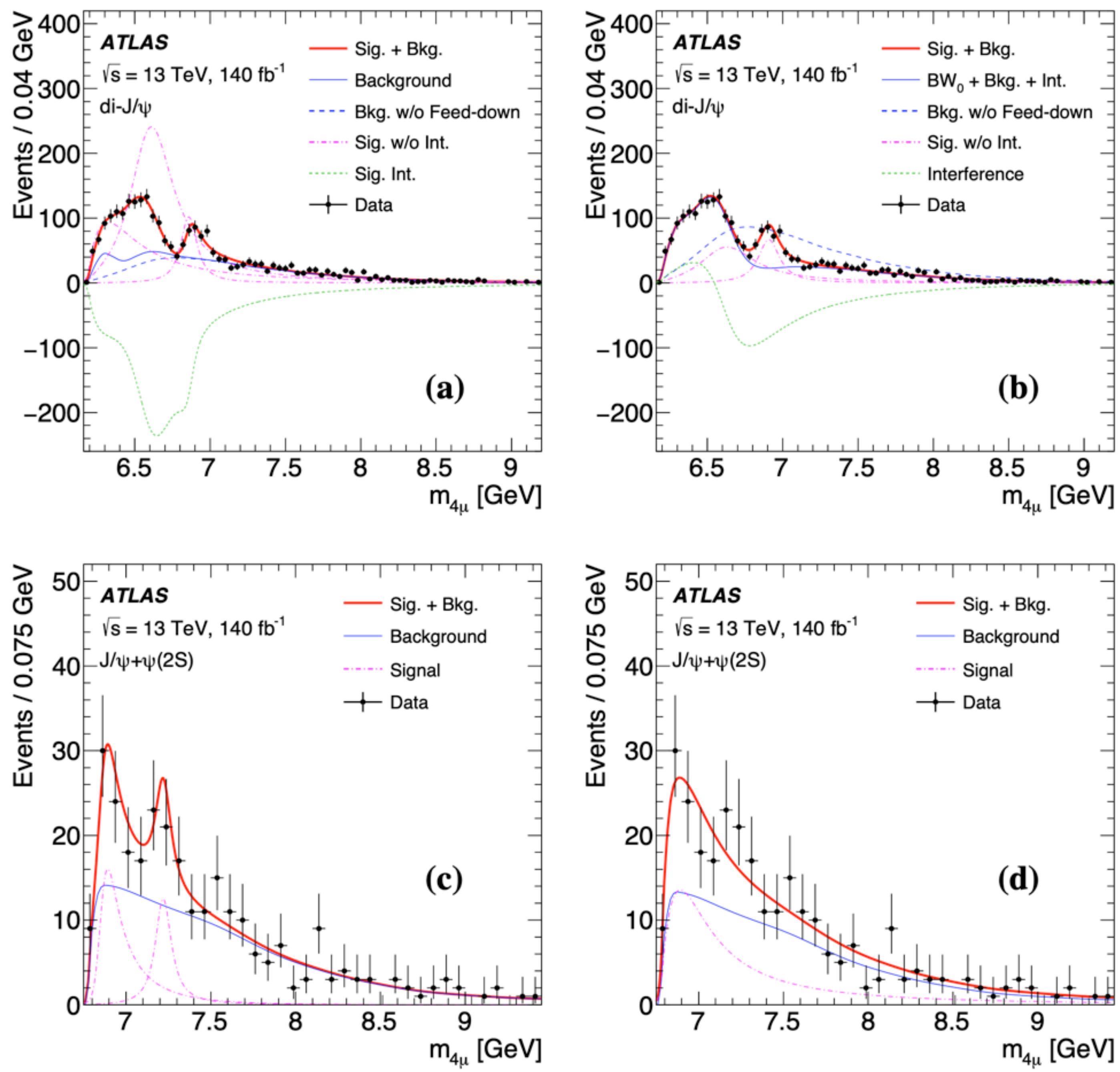
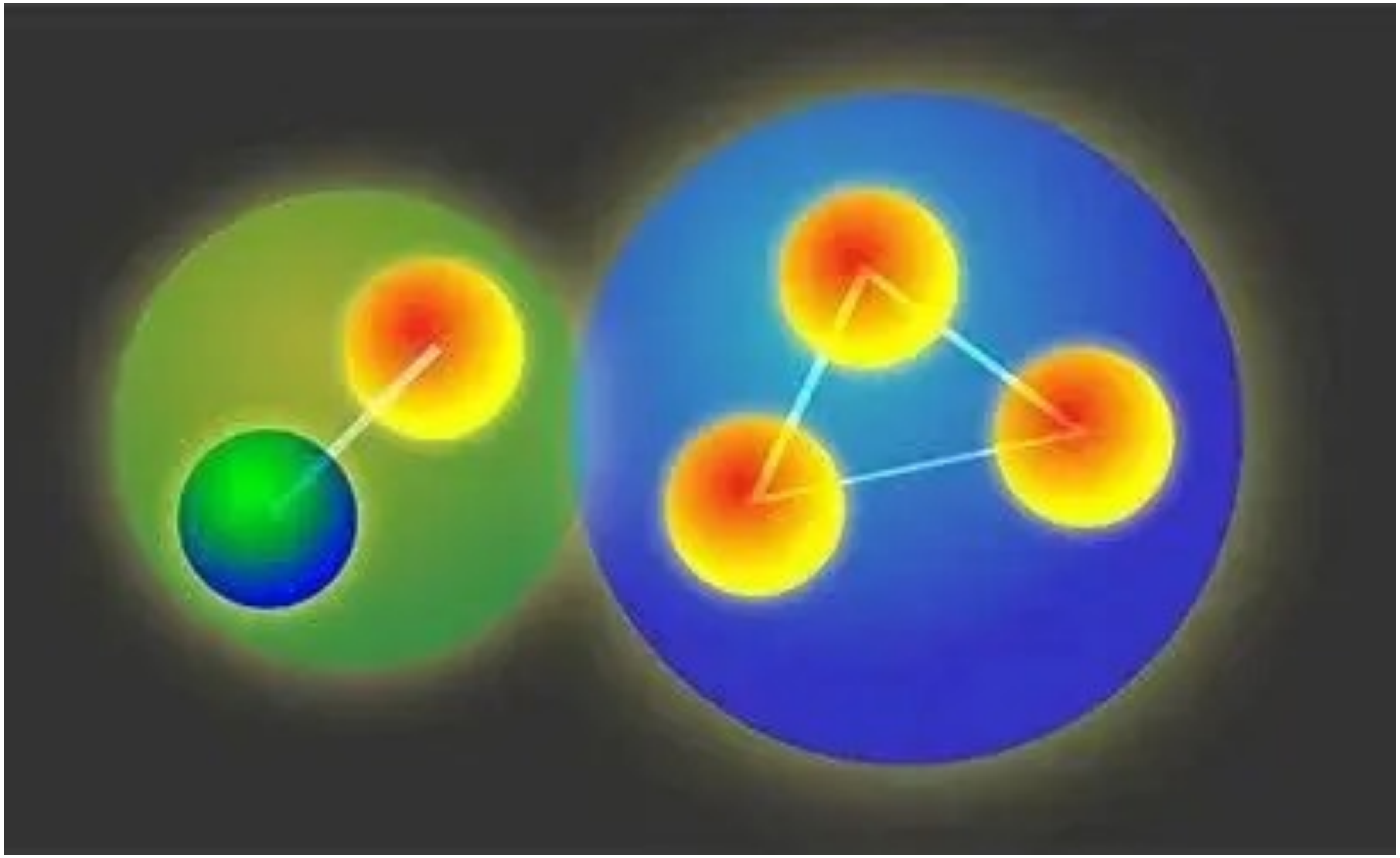


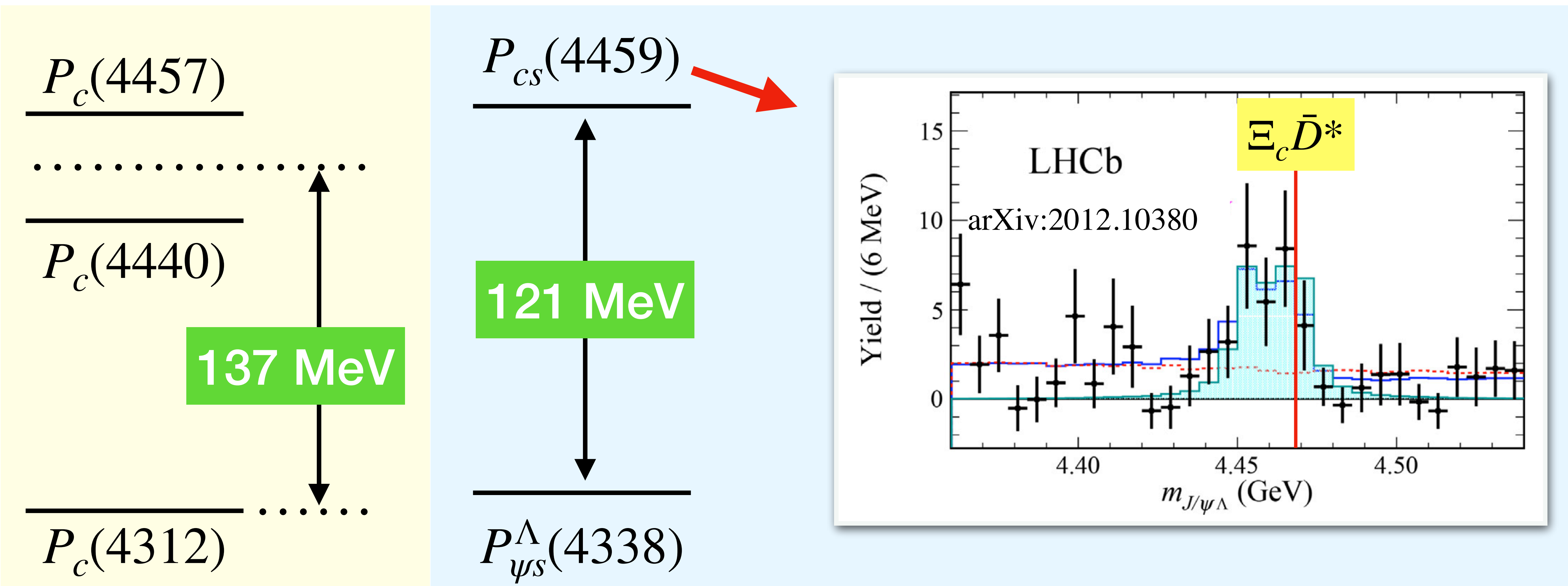
Figure 1: The fit to the mass spectra in the signal regions in the di-J/ψ (a,b) and J/ψ+$\psi(2S)$ (c,d) channels. Fit results for models A (a), B (b), α (c) and β (d) are shown. The purple dash-dotted lines represent the components of individual resonances, and the green short dashed ones represent the interferences among them.

Pentaquark is always a focused point



Similarity between P_c and P_{cs}

F.L. Wang, Xiang Liu, Phys.Lett.B 835(2022)137583



$$\Xi_b^- \to J/\psi \Lambda K$$

Emergence of molecular-type characteristic spectrum of hidden-charm pentaquark with strangeness embodied in the $P_{\psi s}^{\Lambda}(4338)$ and $P_{cs}(4459)$

F.L. Wang, Xiang Liu, Phys.Lett.B 835(2022)137583

$\Xi_c'\bar{D}$

$J^P = 1/2^-$

Λ	E	r_{RMS}
1.45	-0.29	4.92
1.65	-4.62	1.65
1.84	-12.14	1.10

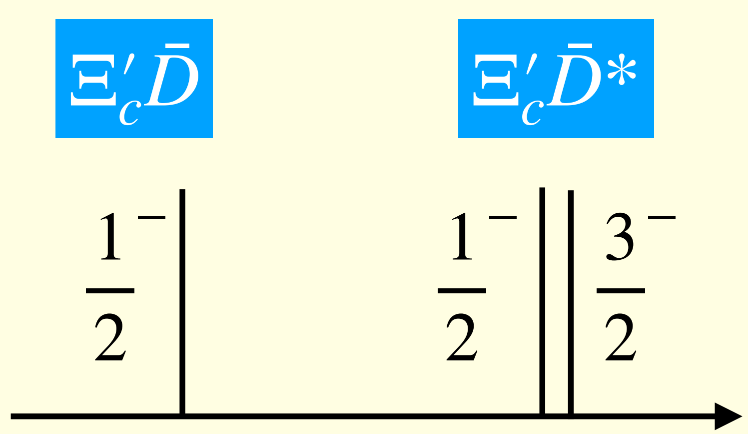
$\Xi_c'\bar{D}^*$

$J^P = 1/2^-$

Λ	E	r_{RMS}	$P\left({}^2S_{\frac{1}{2}}/{}^4D_{\frac{1}{2}}\right)$
0.92	-0.50	4.02	99.63/0.37
0.97	-4.18	1.64	99.45/0.55
1.02	-11.90	1.06	99.45/0.55

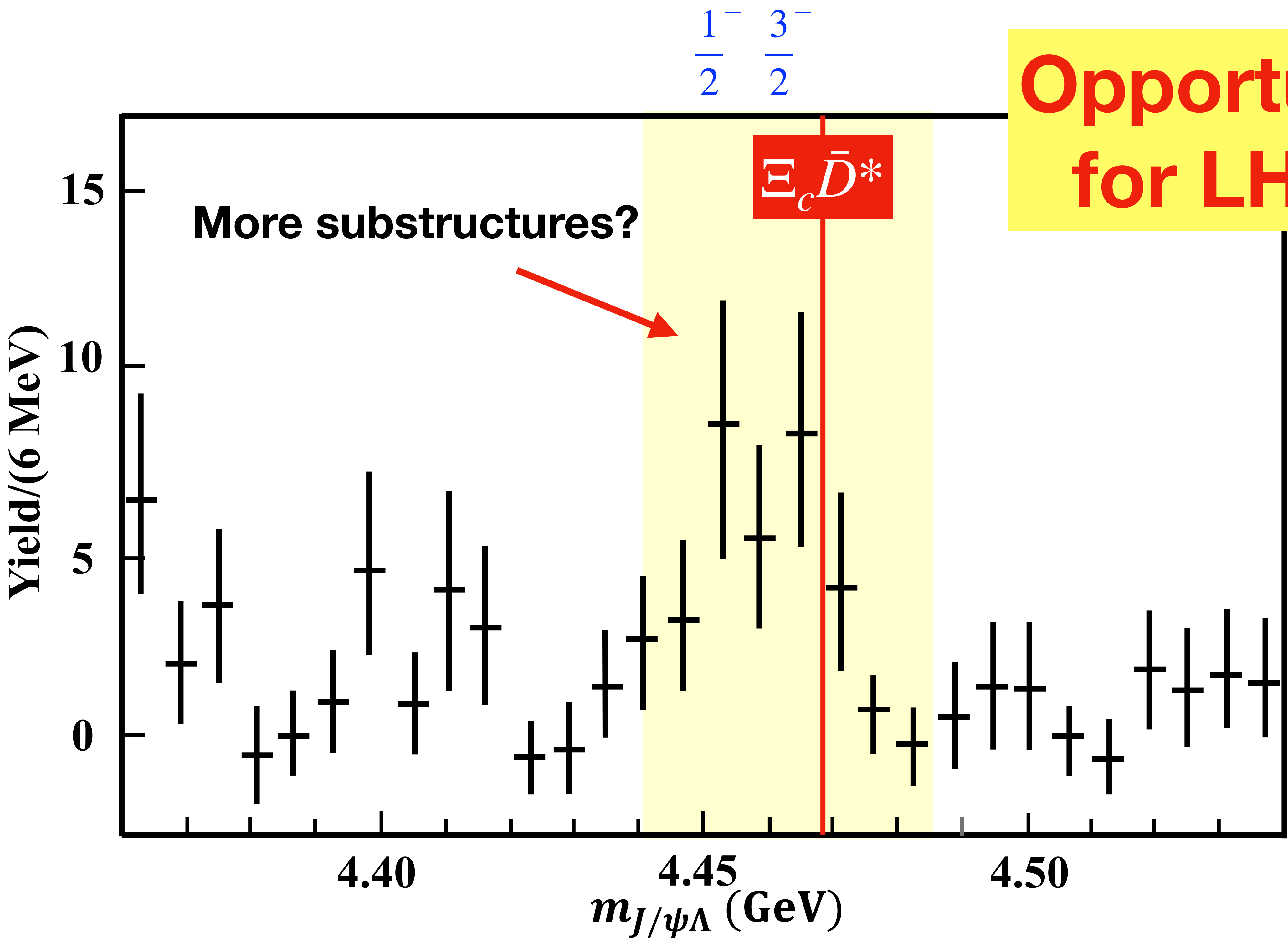
$J^P = 3/2^-$

Λ	E	r_{RMS}	$P\left({}^4S_{\frac{3}{2}}/{}^2D_{\frac{3}{2}}/{}^4D_{\frac{3}{2}}\right)$
1.63	-0.33	4.87	98.49/0.17/1.18
2.09	-4.79	1.75	96.63/0.32/3.05
2.55	-12.42	1.21	95.65/0.35/4.00



Characteristic spectrum

Test it with more precise data



Opportunity for LHCb

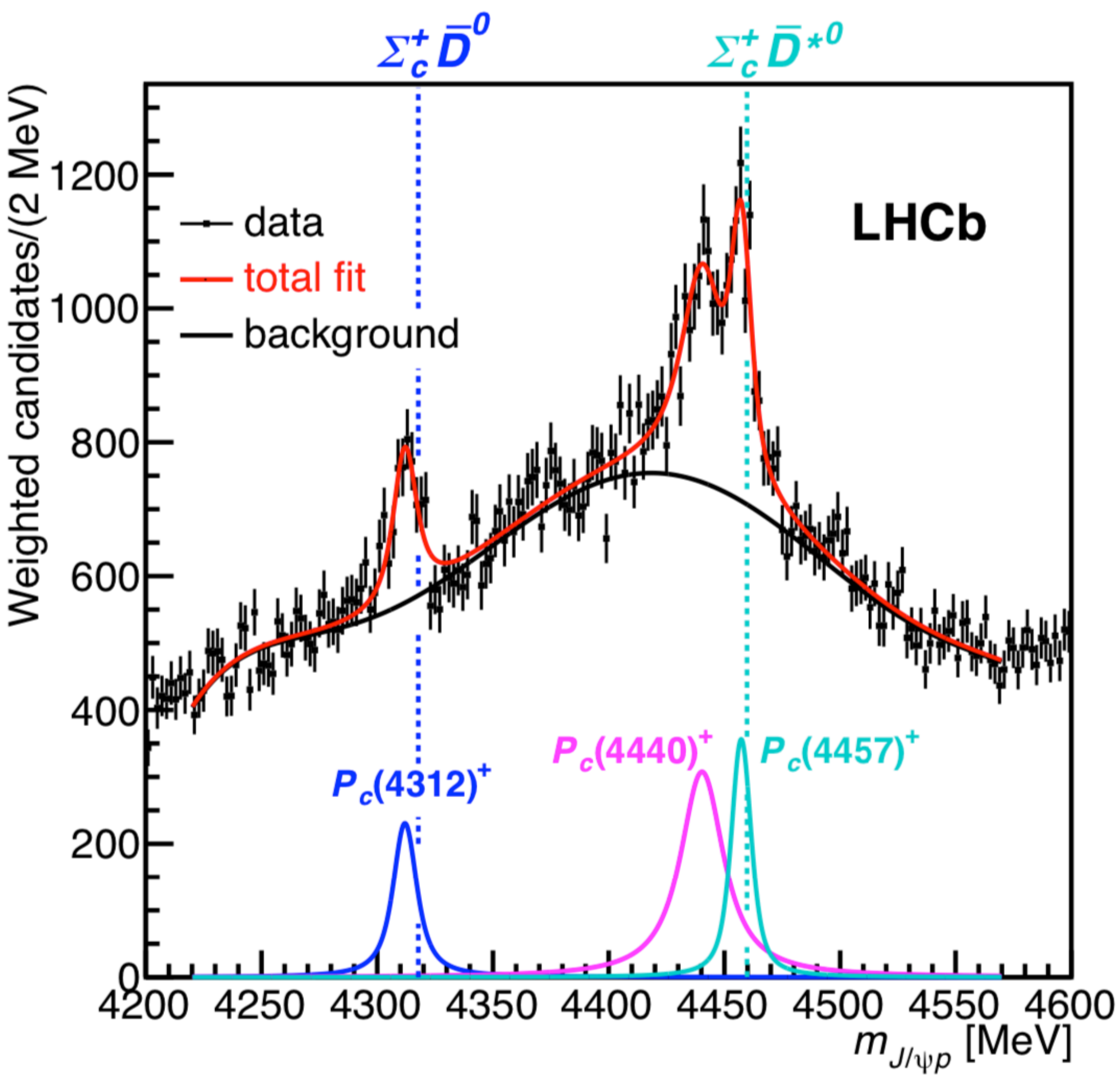
PHYSICAL REVIEW LETTERS 122, 222001 (2019)

Editors' Suggestion | Featured in Physics

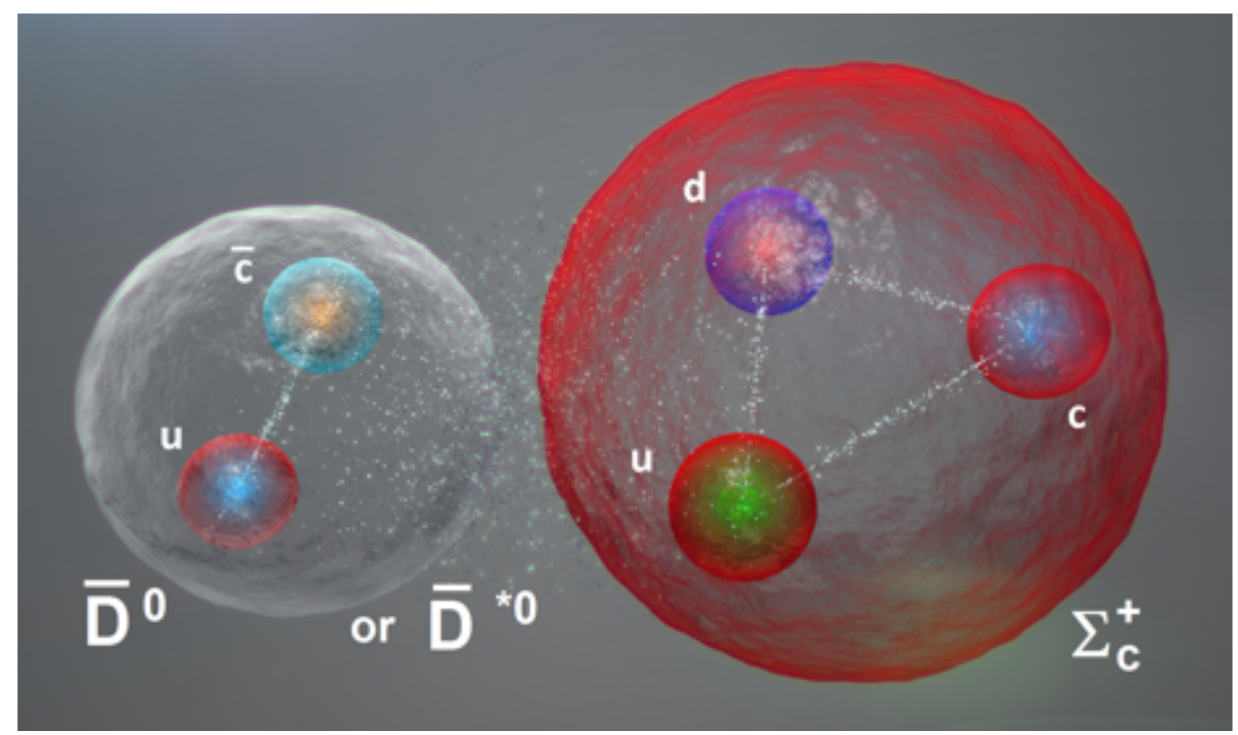
Observation of a Narrow Pentaquark State, $P_c(4312)^+$, and of the Two-Peak Structure of the $P_c(4450)^+$

R. Aaij *et al.*[*]
(LHCb Collaboration)

(Received 6 April 2019; published 5 June 2019)



2019年高精度的实验数据支持分子态构型



PHYSICAL REVIEW D **106**, L111501 (2022)

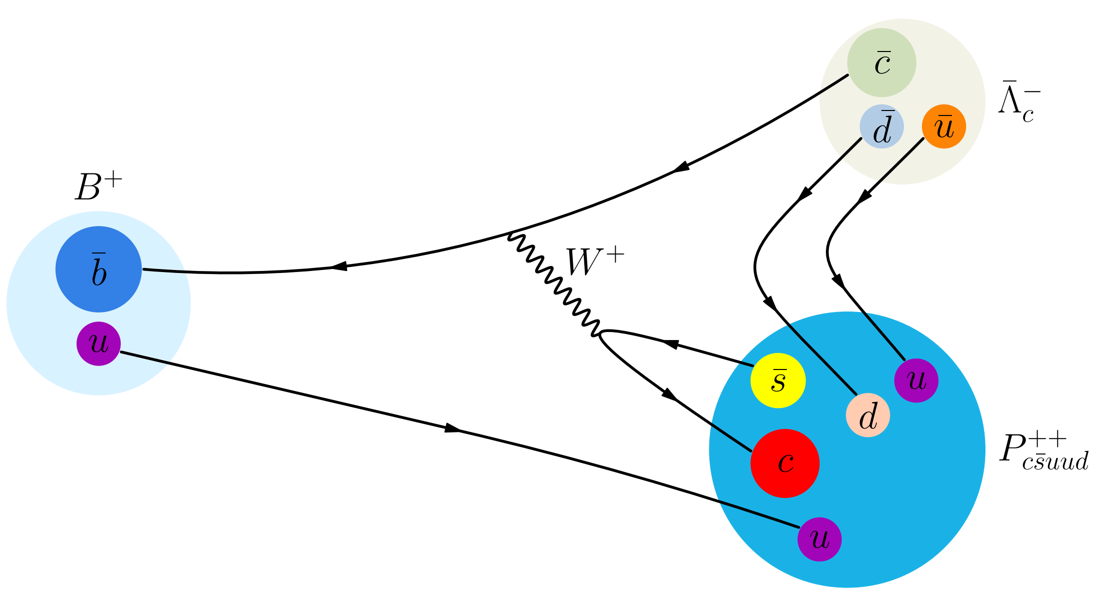
Letter

Discovery of $T^{a}_{c\bar{s}0}(2900)^{0,++}$ implies new charmed-strange pentaquark system

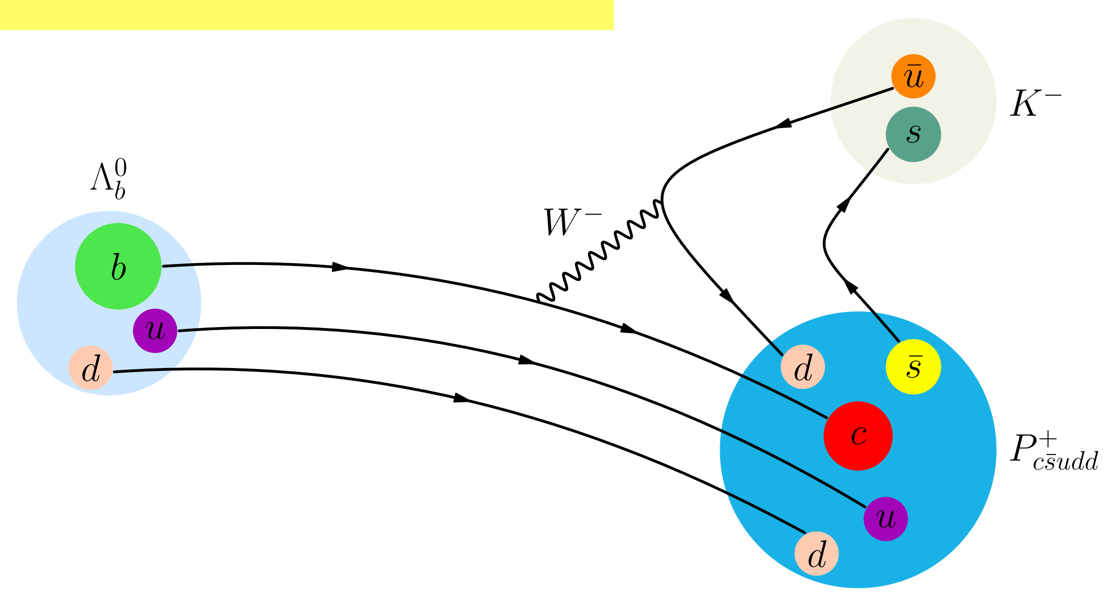
Hong-Tao An,[1,2,*] Zhan-Wei Liu,[1,2,3,†] Fu-Sheng Yu,[3,4,5,‡] and Xiang Liu[1,2,3,§]

Inspired by the very recently discovered tetraquark states $T^{a}_{c\bar{s}0}(2900)^{0,++}$ from the LHCb Collaboration, we predict the existence of a new charmed-strange pentaquark system, $c\bar{s}nnn$, which is closely connected to $c\bar{s}n\bar{n}$ by exchanging $\bar{n}$ into nn with $n = u, d$. Especially, it is suggested to experimentally search for the predicted new pentaquark system via the weak decays of B mesons or b baryons, with the support from the study of the mass spectrum and the decay properties. The predicted new pentaquark system must attract extensive attention from experimentalists and theorists when it constructs the "particle zoo 2.0" in the near future.

让我们拭目以待!



$B^+ \to P^{++}_{c\bar{s}uud}\,\bar{\Lambda}_c^-$



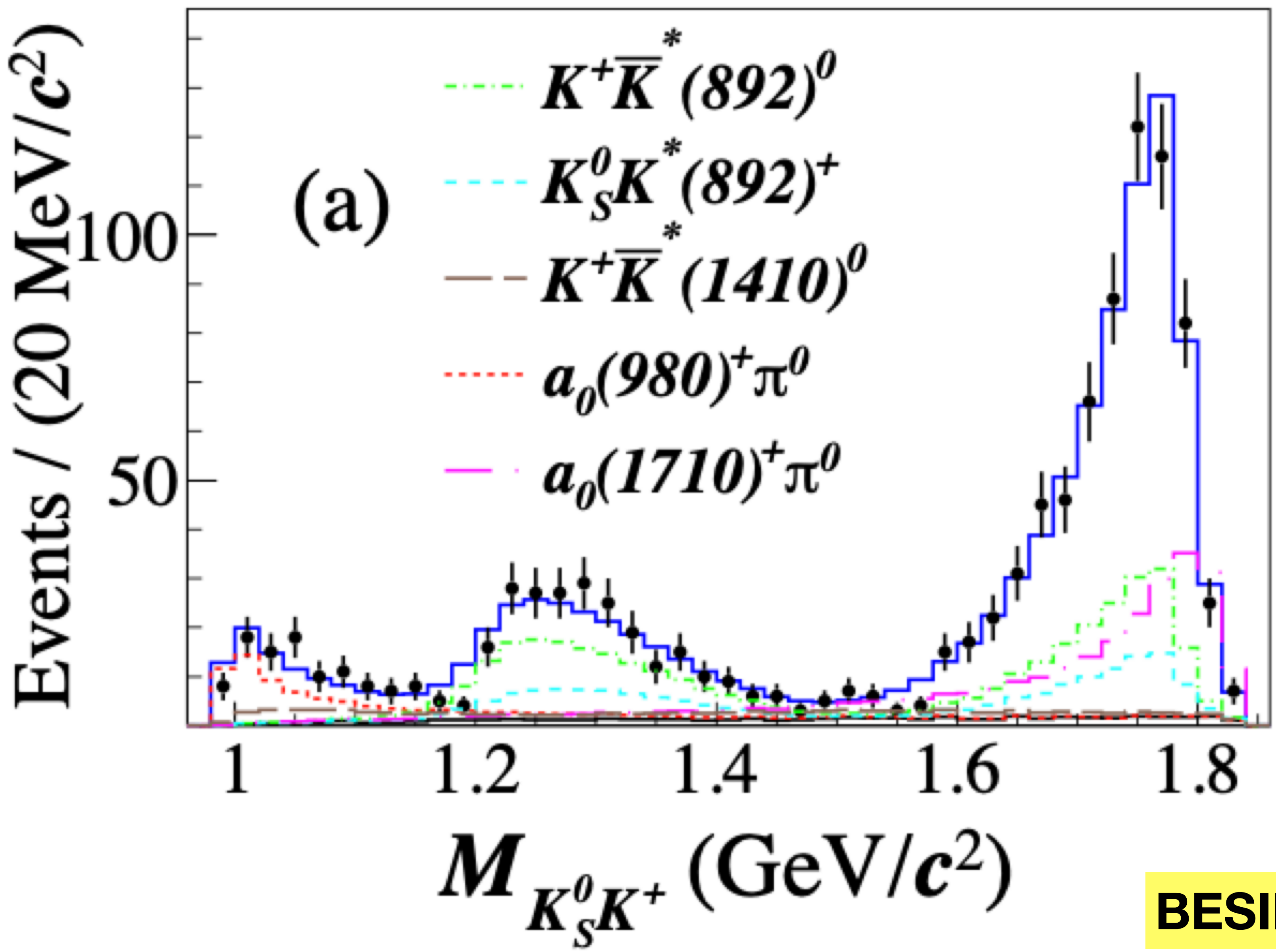
$\Lambda_b^0 \to P^{+}_{c\bar{s}udd}\,K^-$

Pay more attentions to the study of light hadron spectroscopy

Observation of $a_0(1710)^+ \to K^0_S K^+$ in study of the $D_s^+ \to K^0_S K^+ \pi^0$ decay

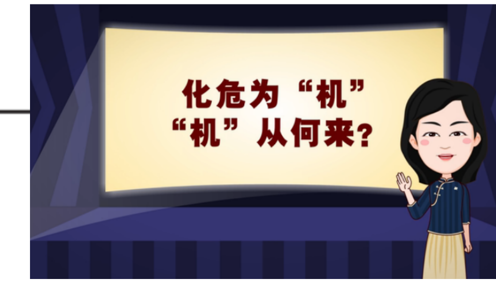
Challenge for $f_0(1710)$ as glueball

$$M = 1.817 \pm 0.008(\text{stat}) \pm 0.020(\text{syst})\ \text{GeV}$$
$$\Gamma = 0.097 \pm 0.022(\text{stat}) \pm 0.015(\text{syst})\ \text{GeV}$$



BESIII, arXiv:2204.09614

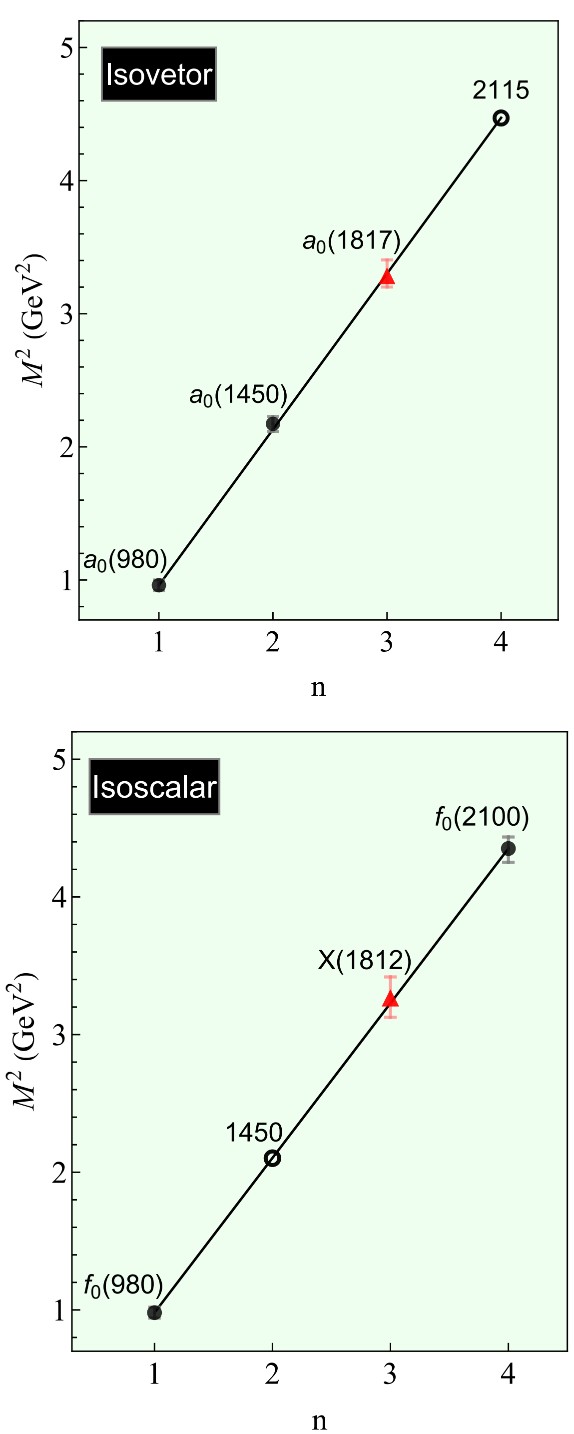
PHYSICAL REVIEW D **105,** 114014 (2022)

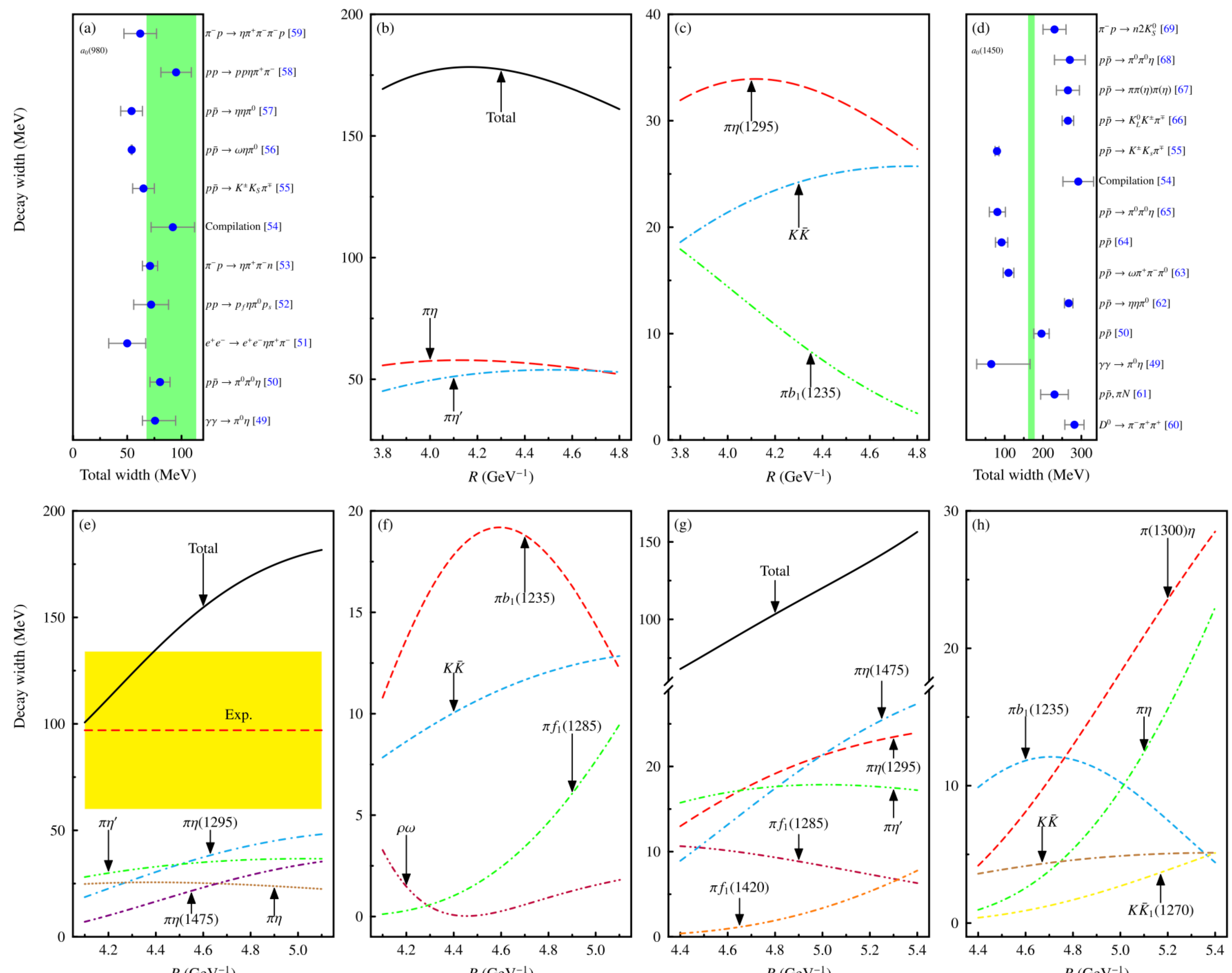


It is safe to assign $f_0(1710)$ as glueball

Newly observed $a_0(1817)$ as the scaling point of constructing the scalar meson spectroscopy

Dan Guo,[1,2,*] Wei Chen,[4,†] Hua-Xing Chen,[5,‡] Xiang Liu,[1,2,3,7,§] and Shi-Lin Zhu[6,∥]





促使BESIII实验组重新调整了文章的表述

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Observation of an a_0-like State with Mass of 1.817 GeV in the Study of $D_s^+ \to K_S^0 K^+ \pi^0$ Decays

M. Ablikim *et al.* (BESIII Collaboration)

Phys. Rev. Lett. **129**, 182001 – Published 28 October 2022

Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

Using e^+e^- annihilation data corresponding to an integrated luminosity of $6.32\,\mathrm{fb}^{-1}$ collected at center-of-mass energies between 4.178 and 4.226 GeV with the BESIII detector, we perform the fi amplitude analysis of the decay $D_s^+ \to K_S^0 K^+ \pi^0$ and determine the relative branching fractions ar phases for intermediate processes. We observe an a_0-like state with mass of 1.817 GeV in its dec $K_S^0 K^+$ for the first time. In addition, we measure the ratio $\{\mathscr{B}[D_s^+ \to \bar{K}^*(892)^0 K^+]/\mathscr{B}[D_s^+ \to \bar{K}^0 K^*(892)^+]\}$ to be $2.35^{+0.42}_{-0.23\,\mathrm{stat}} \pm 0.10_{\mathrm{syst}}$. Finally, we provid precision measurement of the absolute branching fraction $\mathscr{B}(D_s^+ \to K_S^0 K^+ \pi^0) = (1.46 \pm 0.06_{\mathrm{stat}} \pm 0.05_{\mathrm{syst}})\%$.

实验在前 理论在后

在BESIII正式发表的PRL论文中引用了我们的理论工作

Construct light hadron spectroscopy always on the road

BABAR-PUB-22/001
SLAC-PUB-17694

BaBar, arXiv:2207.10340

Study of the reactions $e^+e^- \to K^+K^-\pi^0\pi^0\pi^0$, $e^+e^- \to K^0_S K^\pm\pi^\mp\pi^0\pi^0$, and $e^+e^- \to K^0_S K^\pm\pi^\mp\pi^+\pi^-$ at center-of-mass energies from threshold to 4.5 GeV using initial-state radiation

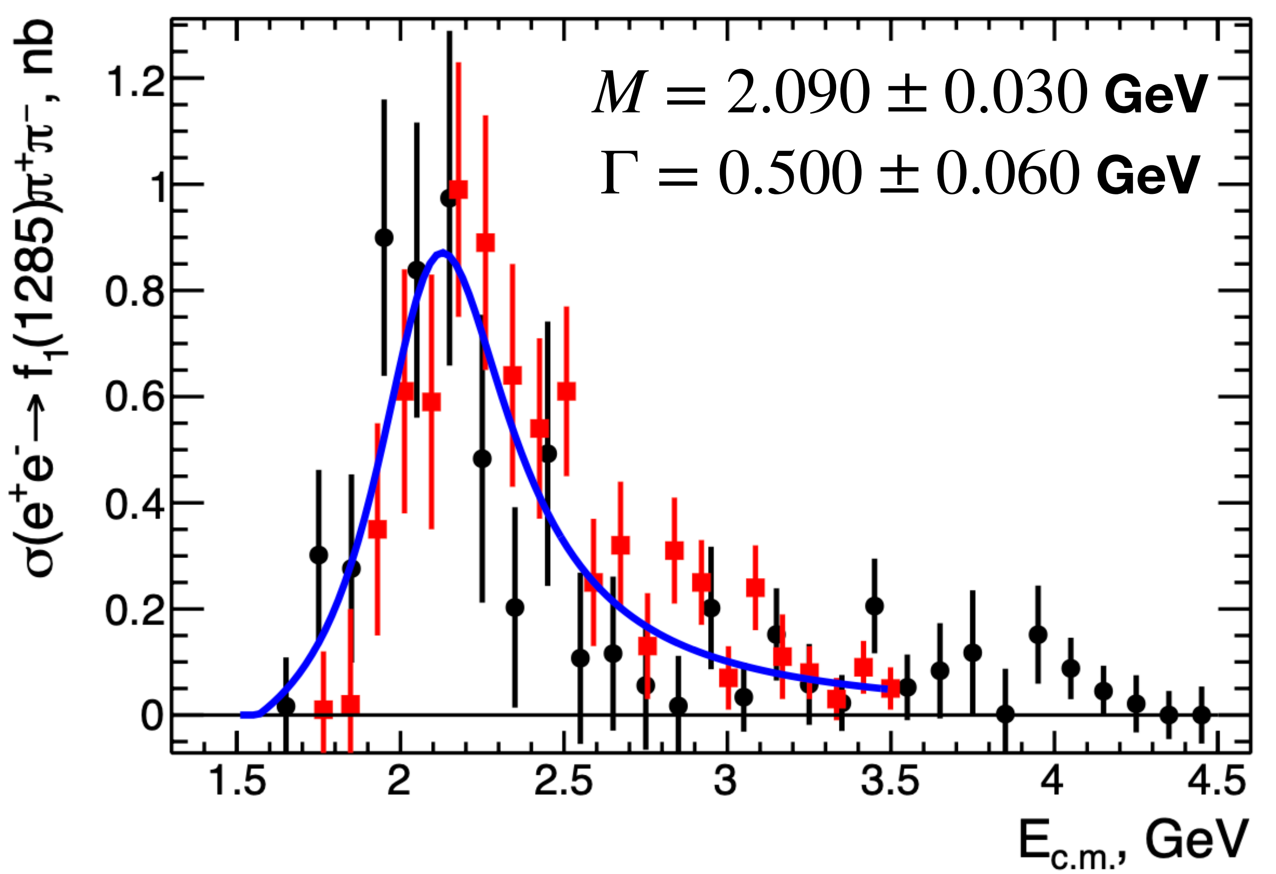
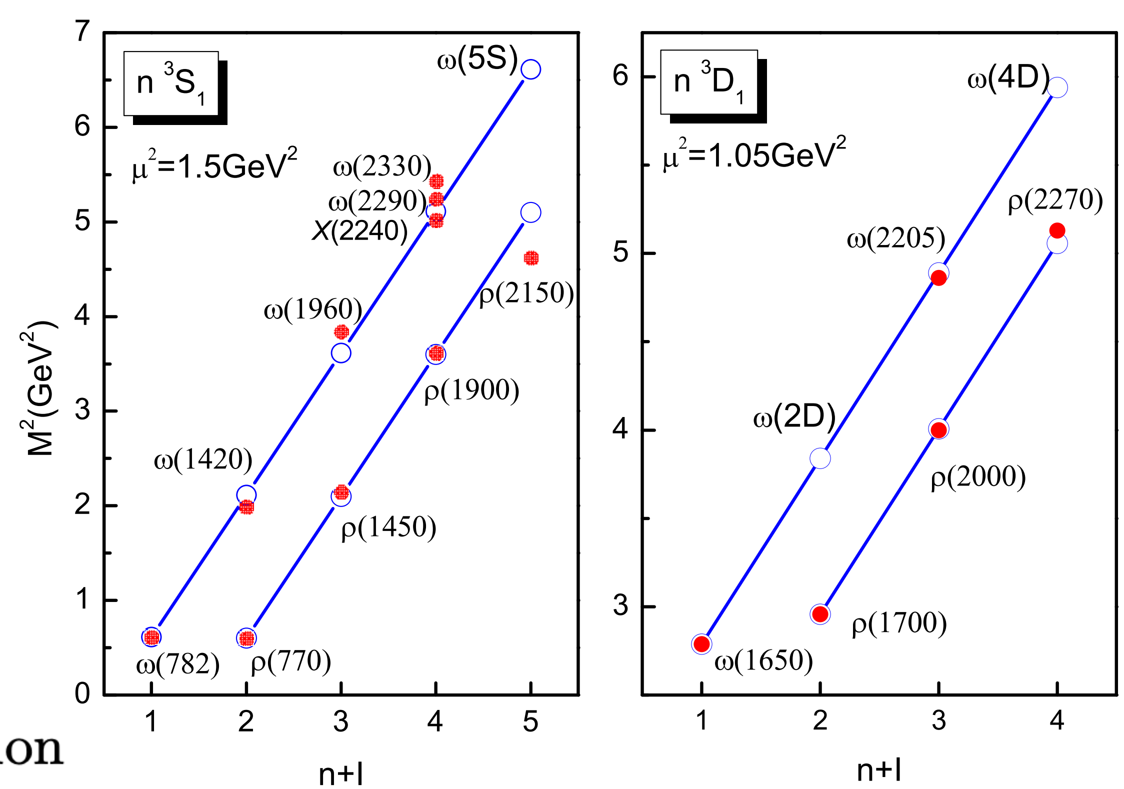


FIG. 13: The measured $e^+e^- \to f_1(1285)\pi^+\pi^-$ cross section from the present analysis (dots) in comparison with previous measurement (squares) [12]. The solid curve is fit explained in the text.

Vector light meson



Our knowledge of light hadron spectroscopy is helpful to establish exotic states

Model with only K^*

$P_{\psi s}^{\Lambda}(4338)$

Amplitude contributions:

- $NR(\bar{p}\Lambda)$
- $K^{*+}_{2,3,4}$ → peaks out of phsp, no obvious contribution in $\bar{p}\Lambda$ distribution

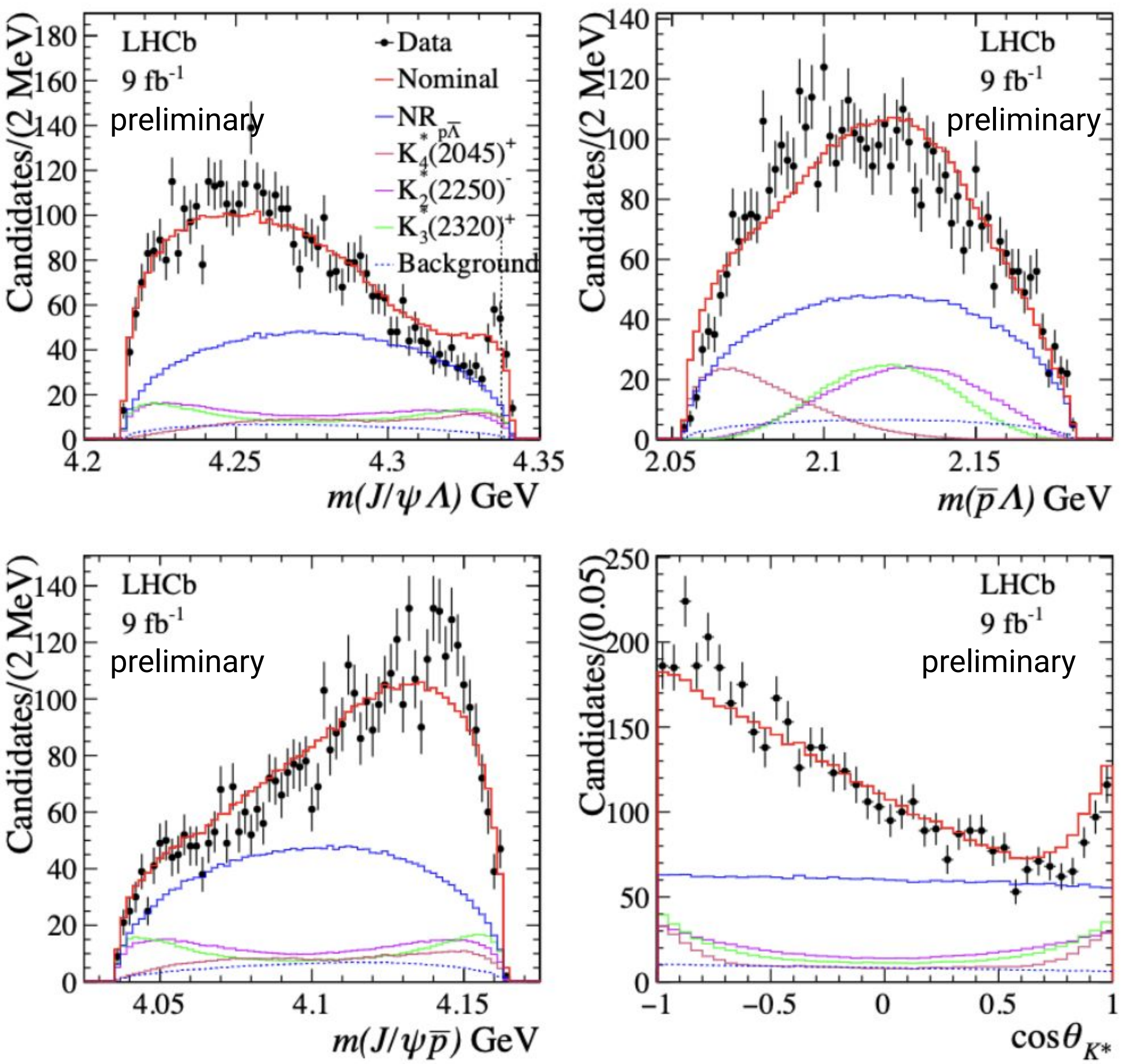
Resonance	Mass (MeV)	Natural width (MeV)	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

PDG 2020

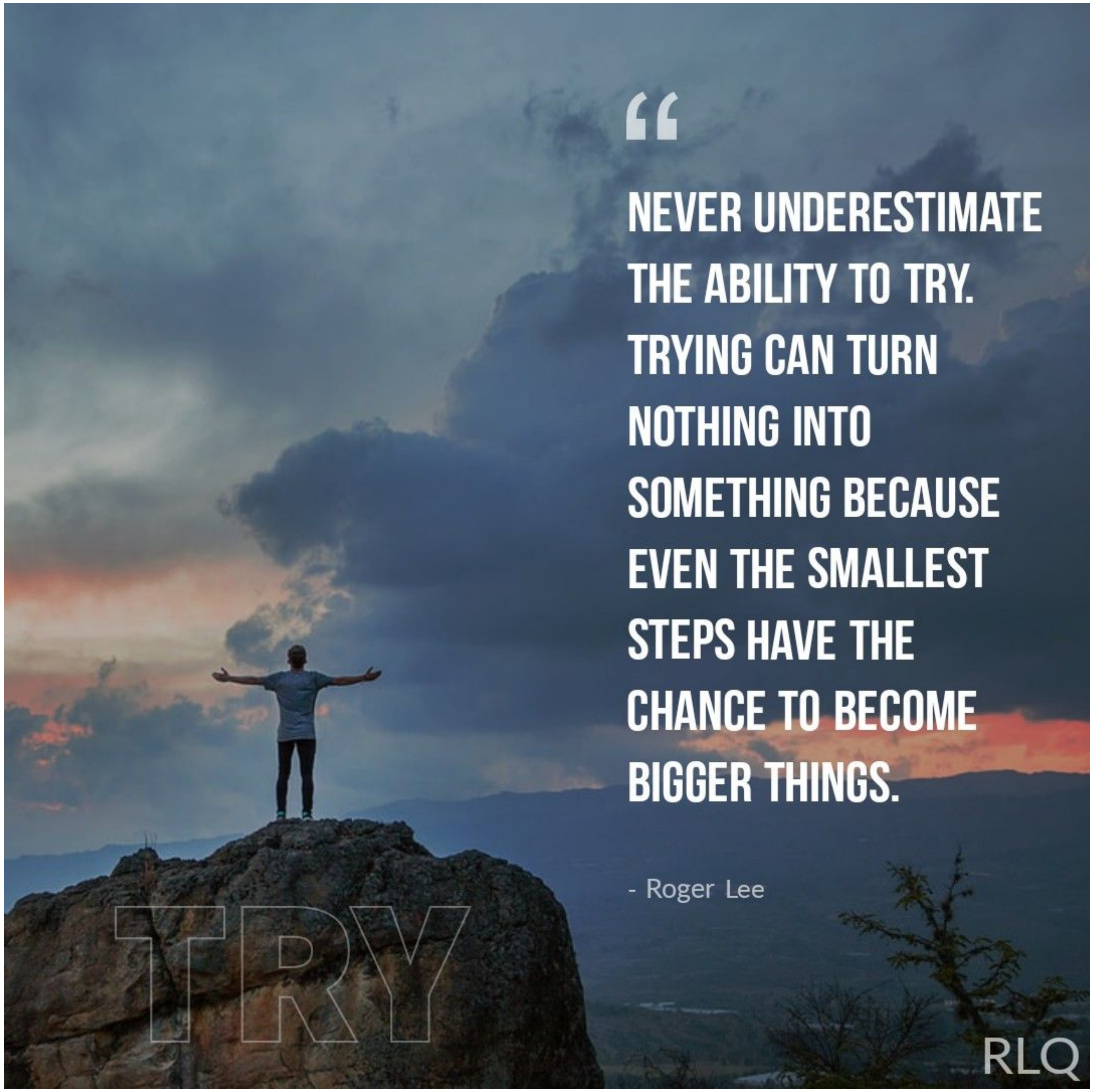
Model with K^* cannot describe data

Goodness-of-fit test

$$\chi^2/ndf = 123/33$$



Summary—Never underestimate the ability of experiment



PHYSICAL REVIEW D **104**, 034036 (2021)

EXAMPLE

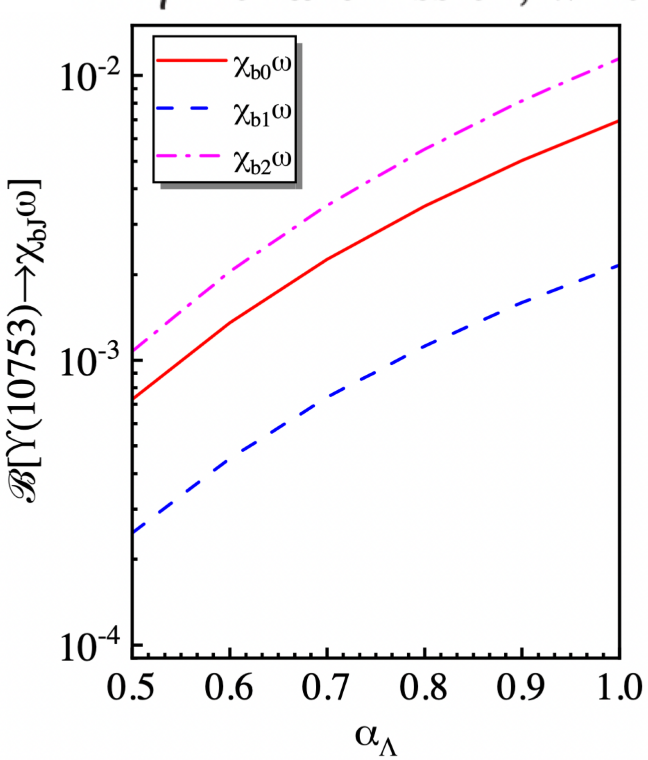
Hidden-bottom hadronic decays of $\Upsilon(10753)$ with a $\eta^{(\prime)}$ or ω emission

Yu-Shuai Li,[1,2,§] Zi-Yue Bai,[1,2,†] Qi Huang,[3,4,‡] and Xiang Liu[1,2,4,*]

[1]*School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China*
[2]*Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics of CAS, Lanzhou 730000, China*
[3]*University of Chinese Academy of Sciences (UCAS), Beijing 100049, China*
[4]*Lanzhou Center for Theoretical Physics and Frontier Science Center for Rare Isotopes, Lanzhou University, Lanzhou 730000, China*

(Received 29 June 2021; accepted 11 August 2021; published 31 August 2021)

In this work, we propose the 4S-3D mixing scheme to assign the $\Upsilon(10753)$ into the conventional bottomonium family. Under this interpretation, we further study its hidden-bottom hadronic decays with a $\eta^{(\prime)}$ or ω emission, which include $\Upsilon(10753) \to \Upsilon(1S)\eta^{(\prime)}$, $\Upsilon(10753) \to h_b(1P)\eta$, and $\Upsilon(10753) \to \chi_{bJ}\omega$
ince the $\Upsilon(10753)$ is above the $B\bar{B}$ threshold, the coupled-channel effect cannot
lculating partial decay widths of these $\Upsilon(10753)$ hidden-bottom decays, we apply
nism. Our result shows that these discussed decay processes own considerable
an order of magnitude of 10^{-4}–10^{-3}, which can be accessible at Belle II and other



In 2021, we predicted $\Upsilon(10753) \to \chi_{bJ}\omega$ with sizable branching ratios

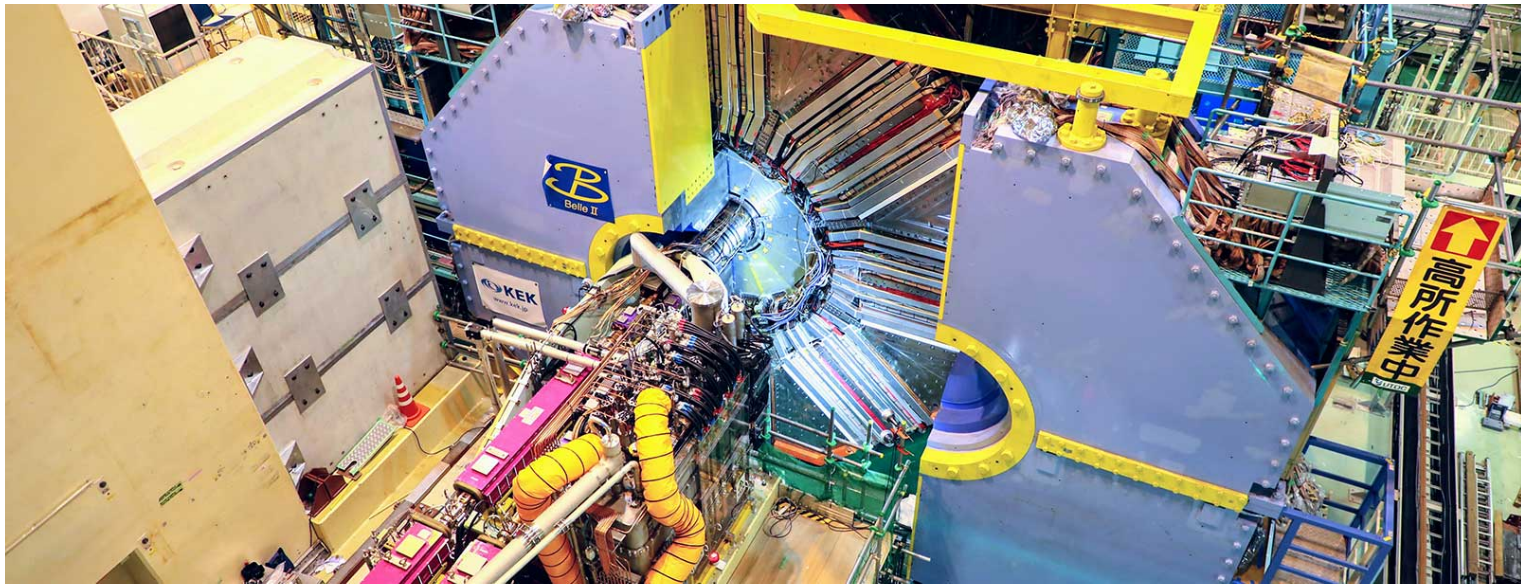
First analysis of Belle II energy scan data

Qingping Ji (Henan Normal University)

(On behalf of the Belle II Collaboration)

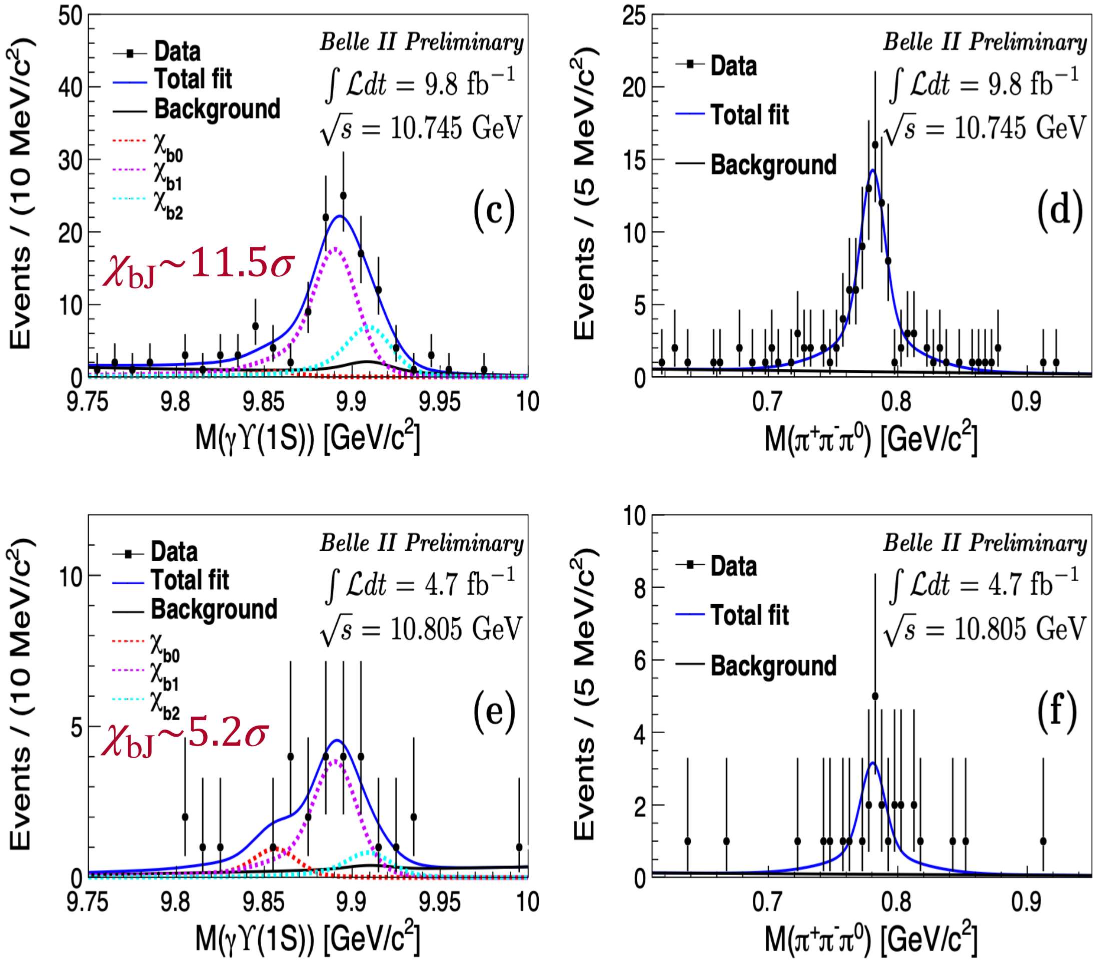
ICHEP 2022 BOLOGNA

ICHEP 2022 XLI International Conference on High Energy Physics Bologna (Italy)



New for ICHEP !

Observation of $e^+e^- \to \omega\chi_{bJ}$



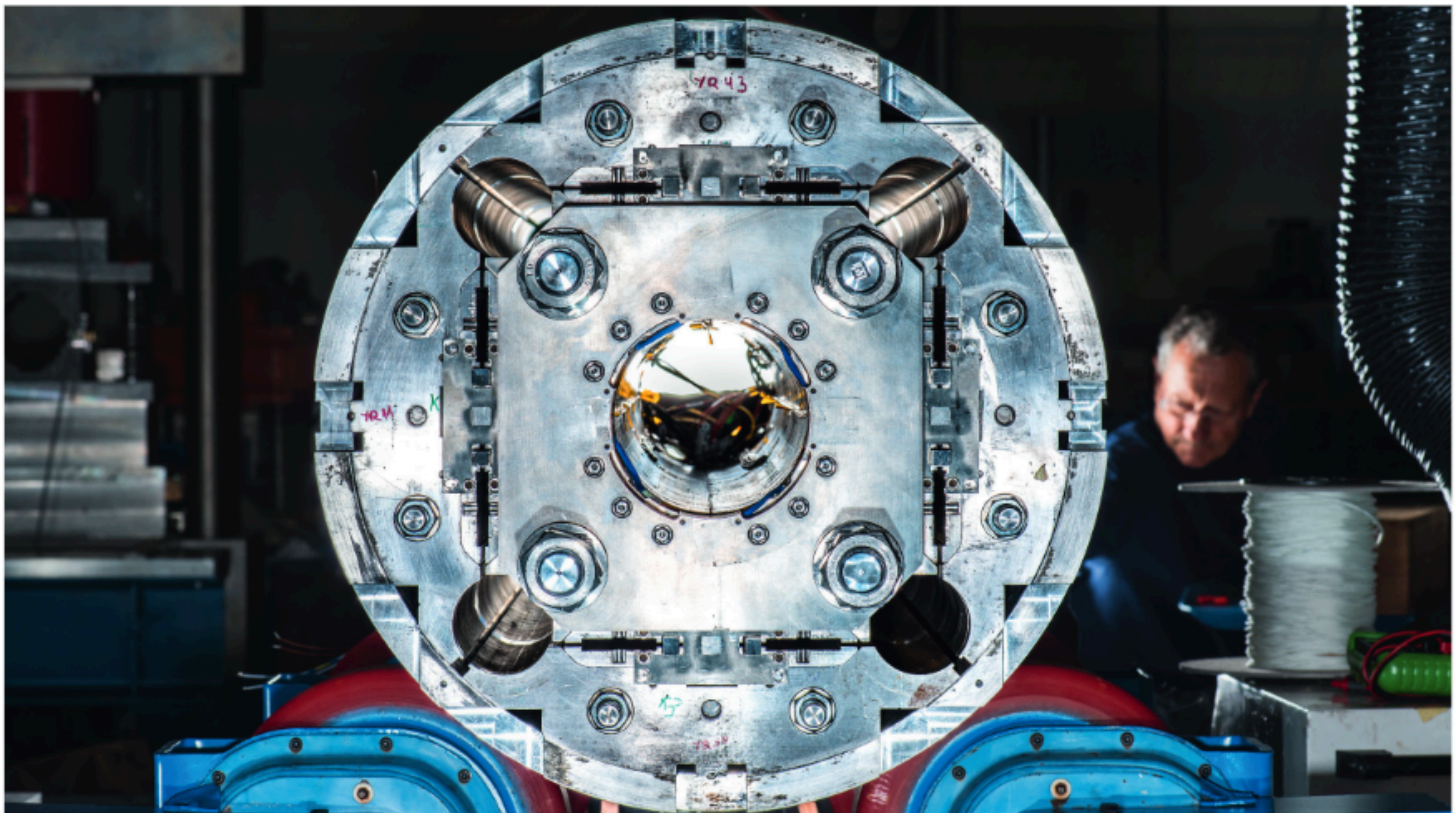
Two dimensional unbinned maximum likelihood fit to $M(\gamma\Upsilon(1S))$ and $M(\pi^+\pi^-\pi^0)$.

Channel	$\sqrt{s}$ (GeV)	$N^{\text{sig.}}$	$\sigma_B^{(\text{up})}$ (pb)
$e^+e^- \to \omega\chi_{b1}$	10.745	$68.9^{+13.7}_{-13.5}$	$3.6^{+0.7}_{-0.7}$ (stat.) $\pm$ 0.4 (syst.)
$e^+e^- \to \omega\chi_{b2}$		$27.6^{+11.6}_{-10.0}$	$2.8^{+1.2}_{-1.0}$ (stat.) $\pm$ 0.5 (syst.)
$e^+e^- \to \omega\chi_{b1}$	10.805	$15.0^{+6.8}_{-6.2}$	1.6 @ 90% C.L.
$e^+e^- \to \omega\chi_{b2}$		$3.3^{+5.3}_{-3.8}$	1.5 @ 90% C.L.

No evident signal are found at $\sqrt{s} = 10.710$ GeV.

The High-Luminosity LHC:
a new horizon for science and technology

The High-Luminosity LHC (HL-LHC) is a major upgrade of the Large Hadron Collider (LHC). The LHC collides tiny particles of matter (protons) at an energy of 13 TeV in order to study the fundamental components of matter and the forces that bind them together. The High-Luminosity LHC will make it possible to study these in more detail by increasing the number of collisions by a factor of between five and ten.



Prototype of a quadrupole magnet for the High-Luminosity LHC. (Image: Robert Hradil, Monika Majer/ProStudio22.ch)

Thank you for your attention!