



中国科学院大学
University of Chinese Academy of Sciences

Latest Results of Exotic States from LHCb

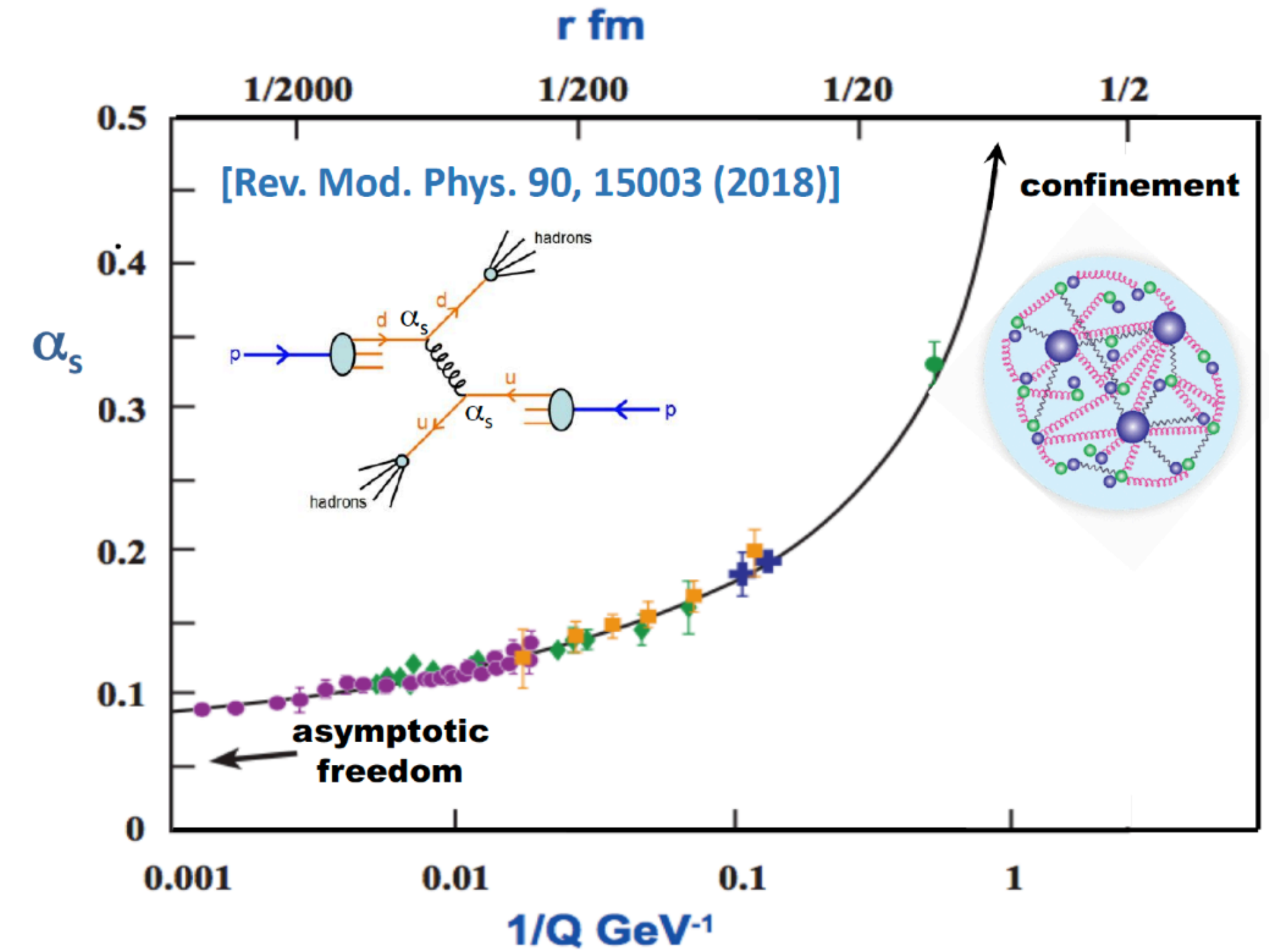
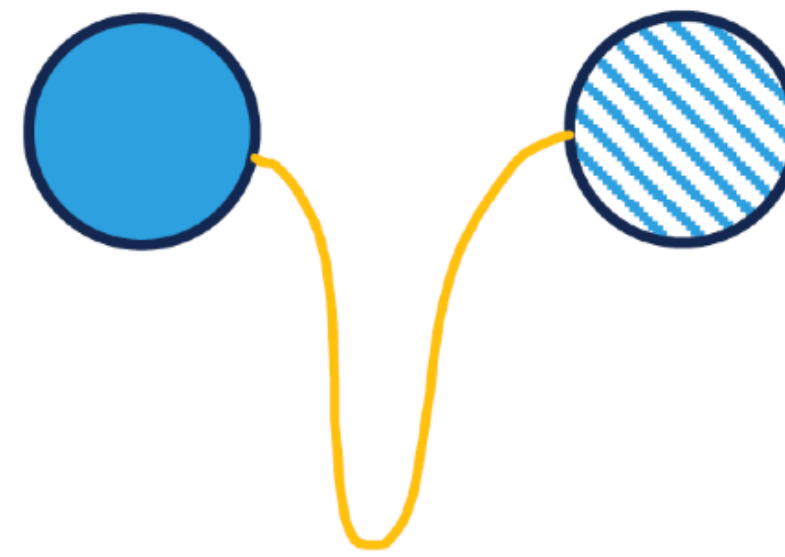
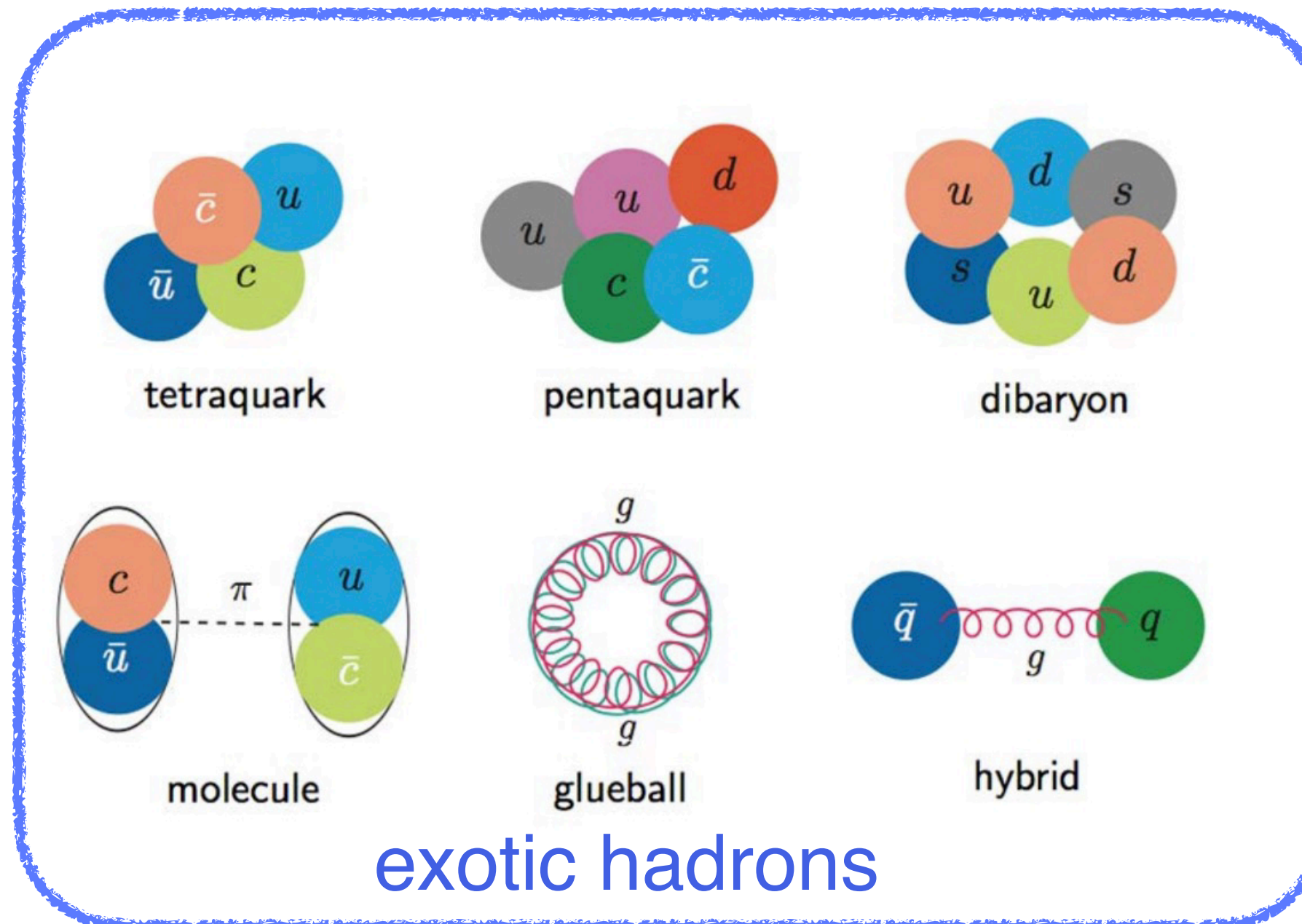
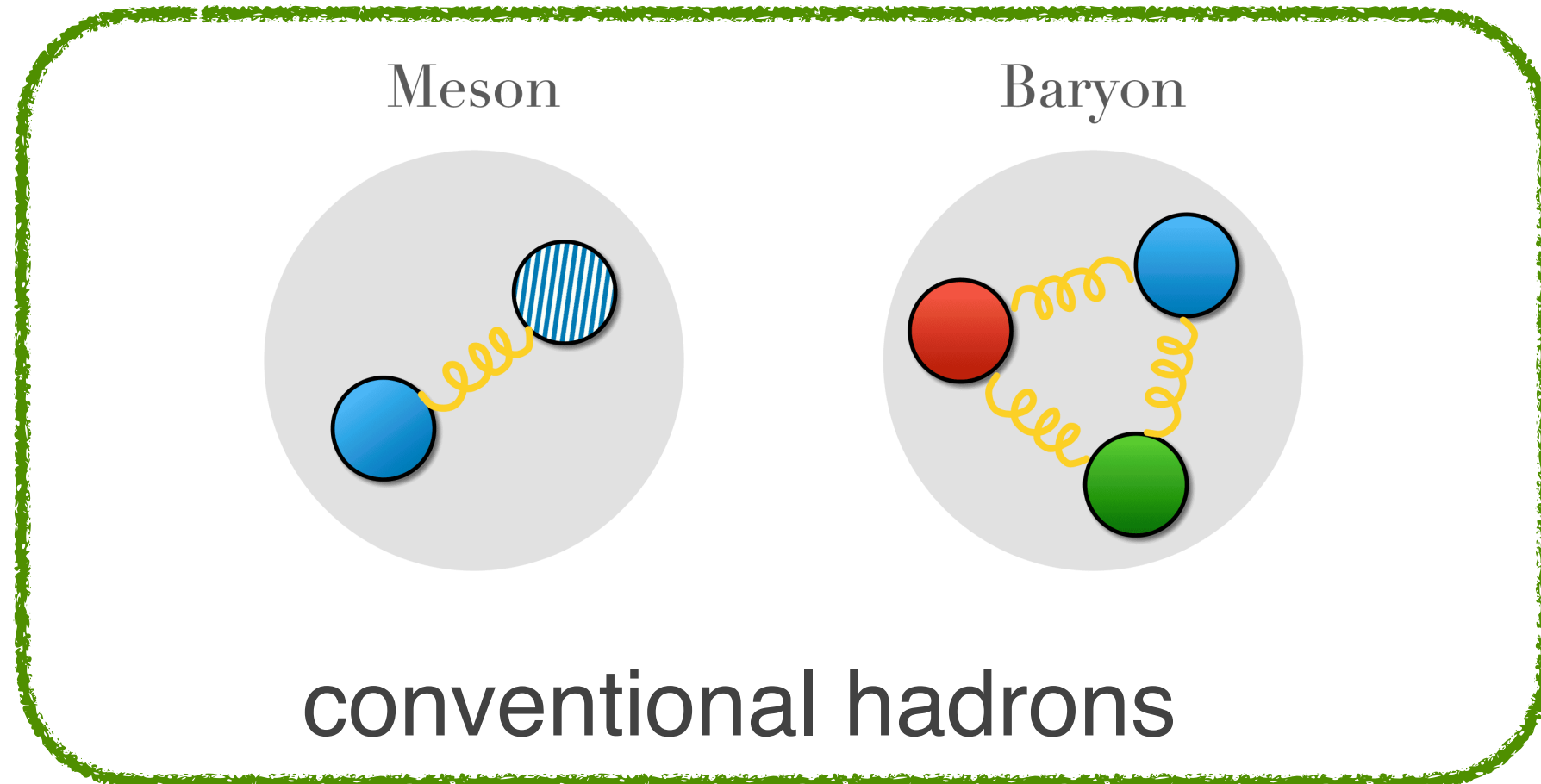
李佩莲

中国科学院大学

第九届强子谱和强子结构研讨会

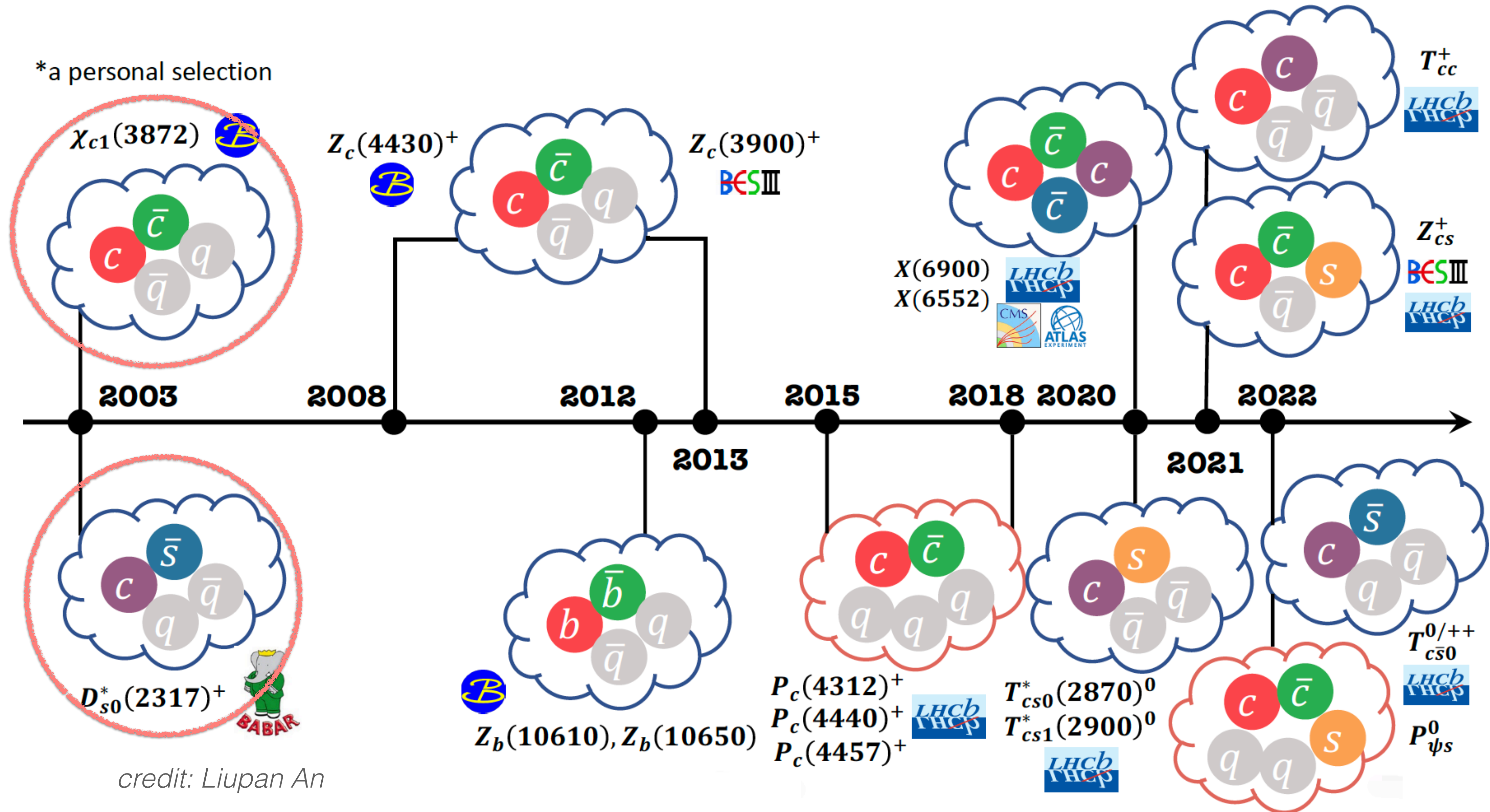
河南新乡, 2026.08.20

Hadron spectroscopy for QCD

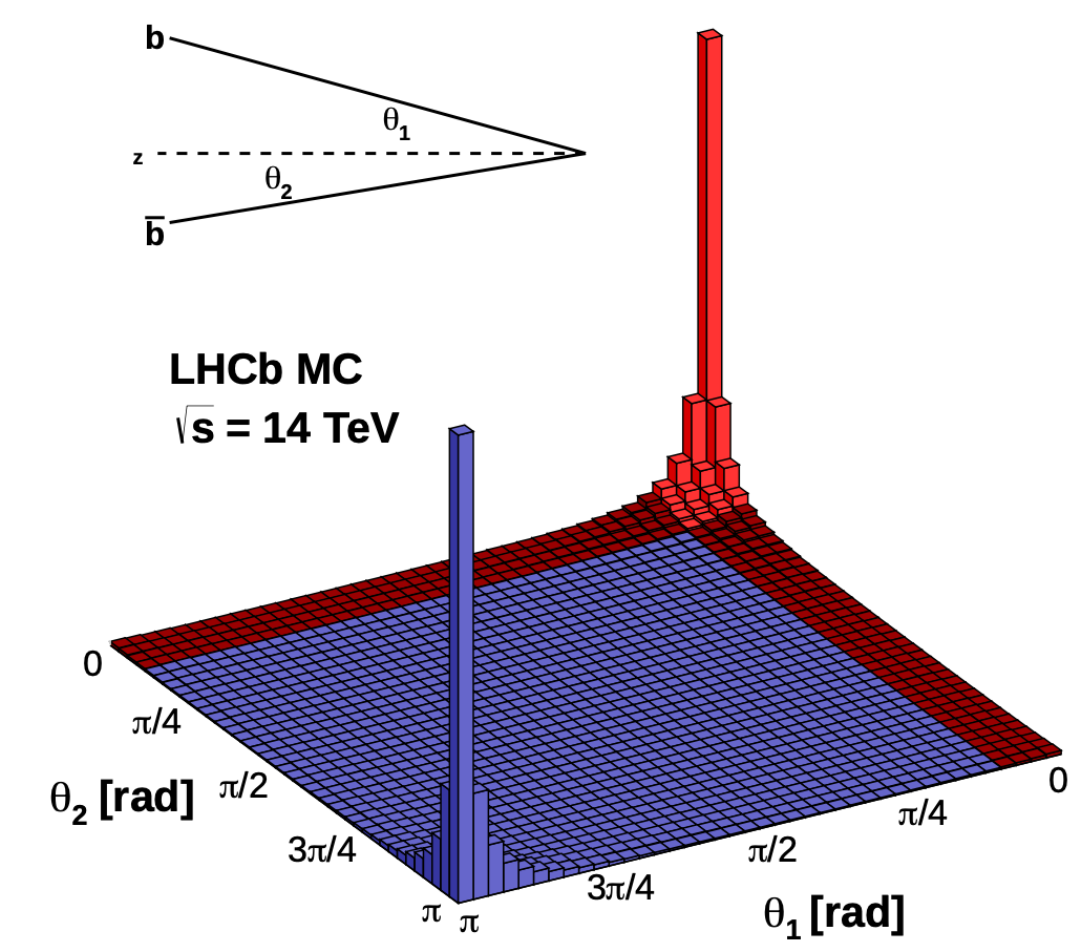
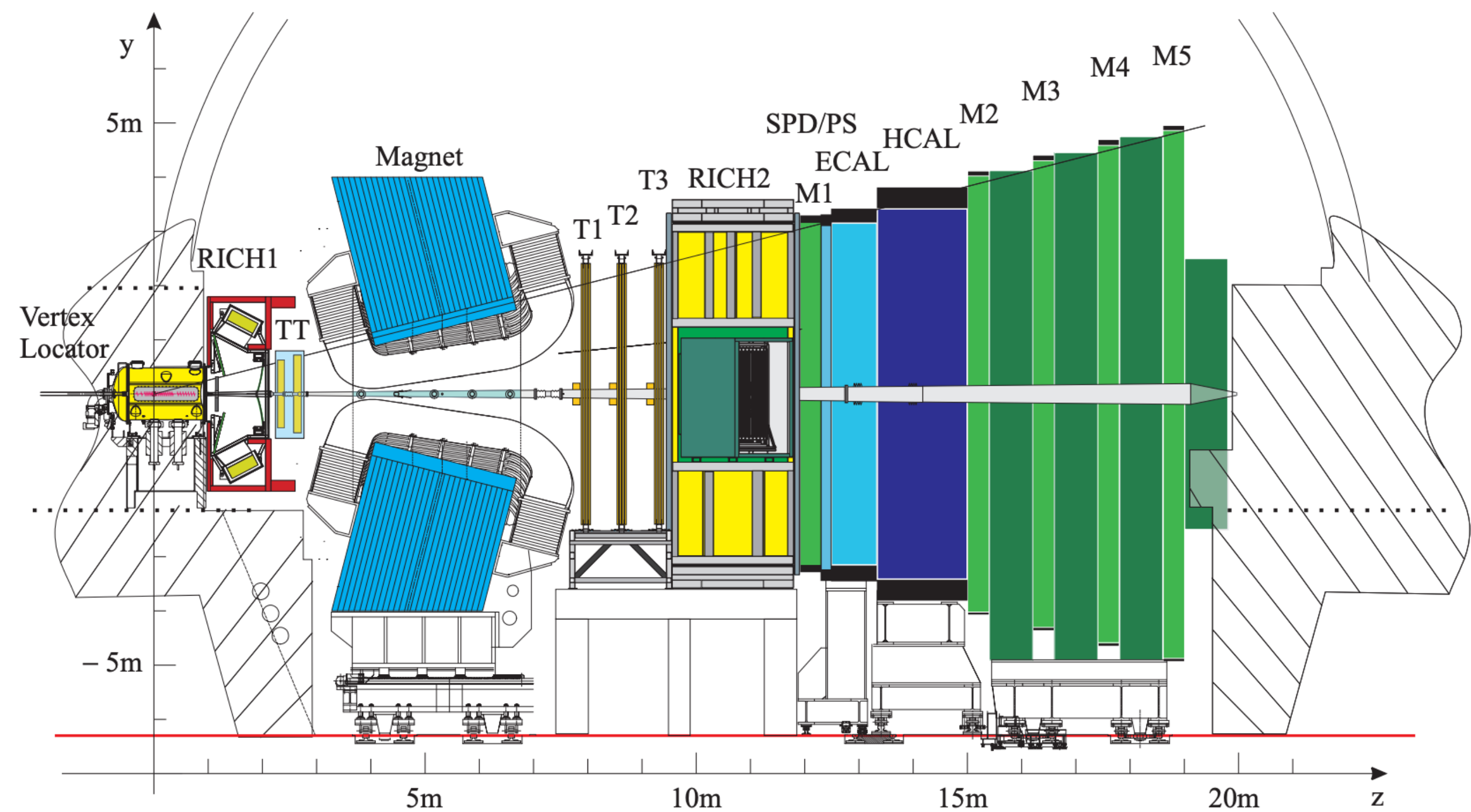


- Color confinement at low energy
 - clear indication from both experiments and Lattice QCD
 - believed to be related to increase of α_s at low energy, but never demonstrated analytically
- Exotic states provide inputs for further understanding of QCD

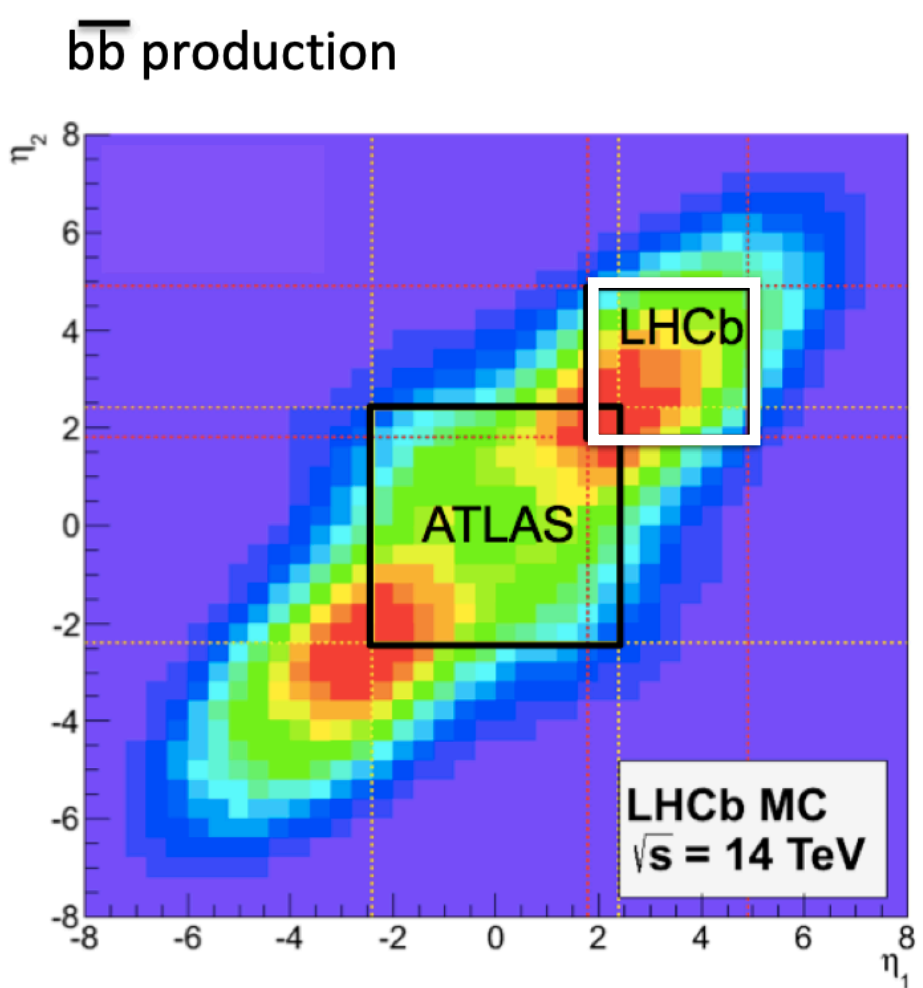
Timeline of heavy exotic hadrons



LHCb detector



$2 < \eta < 5$



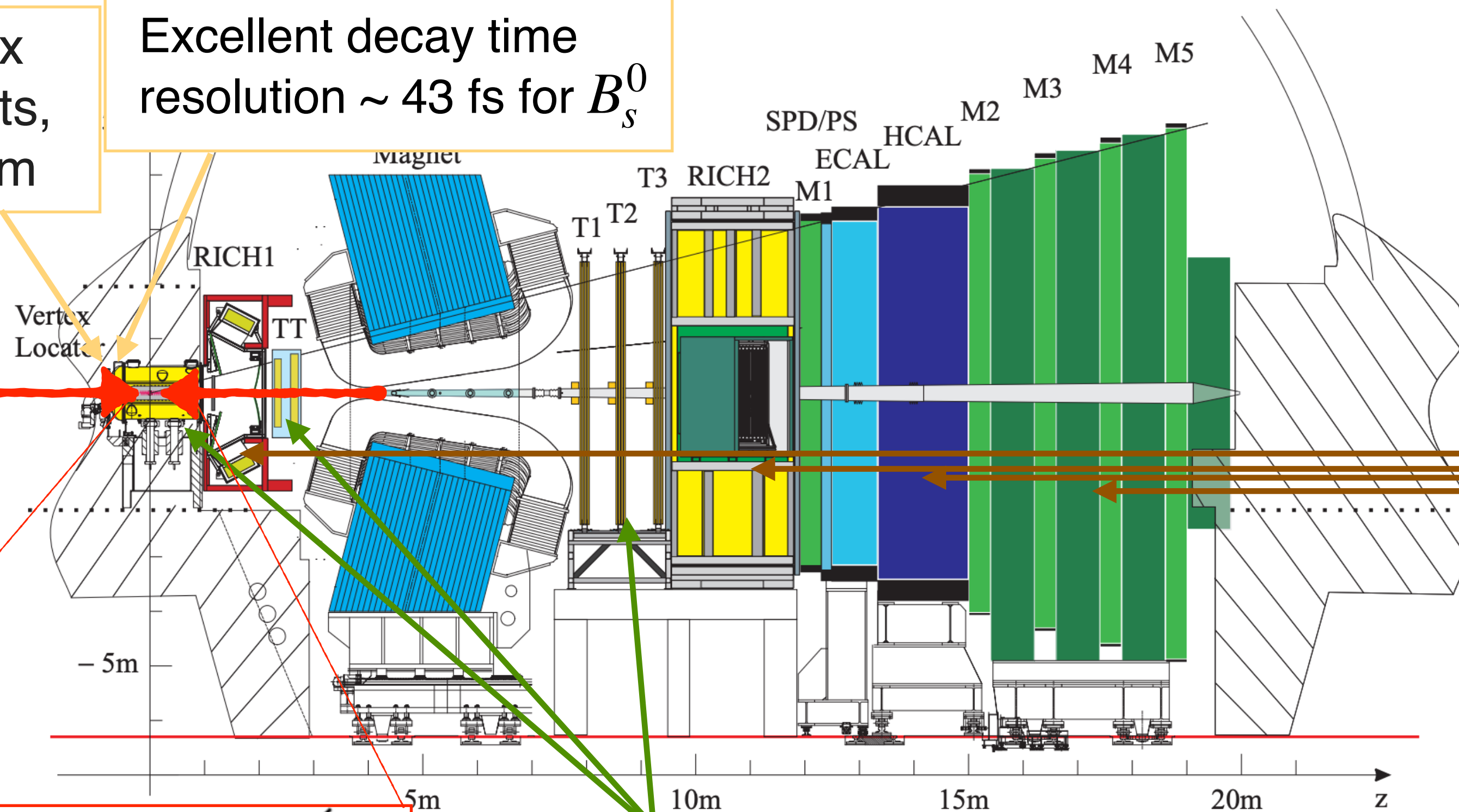
LHCb detector

- Daughters of b & c hadron decays: $p_T \sim \mathcal{O}(1 \text{ GeV}/c)$, flight distance $L \sim 1 \text{ mm}$

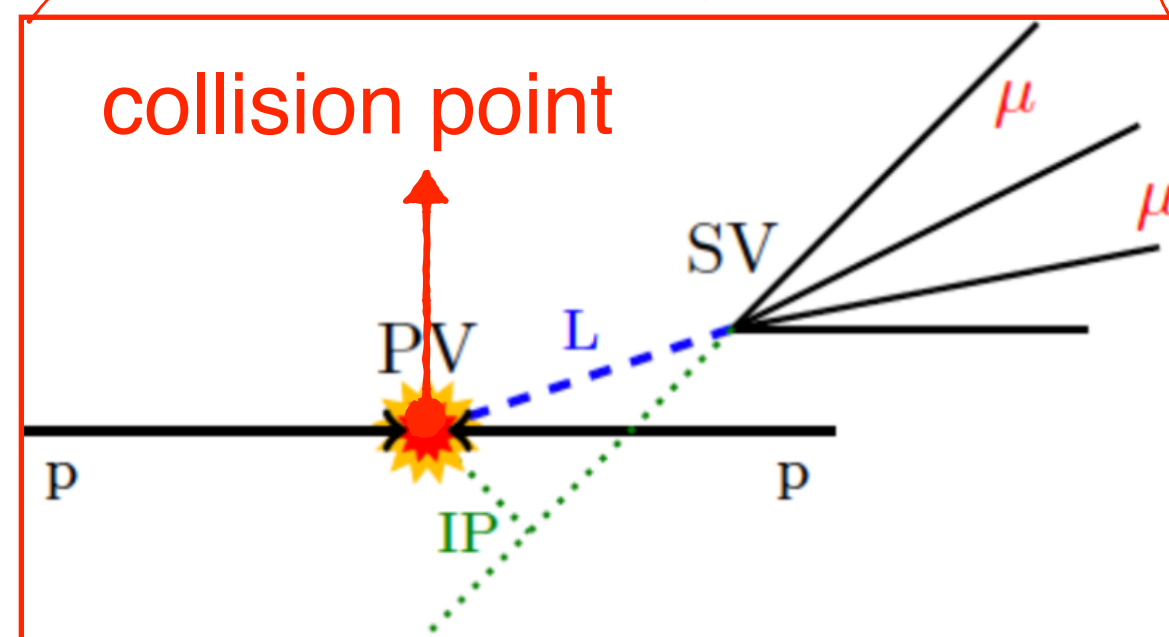
Precise vertex measurements,
 $\sigma(IP_x) \sim 35 \mu\text{m}$

Excellent decay time resolution $\sim 43 \text{ fs}$ for B_s^0

proton beam



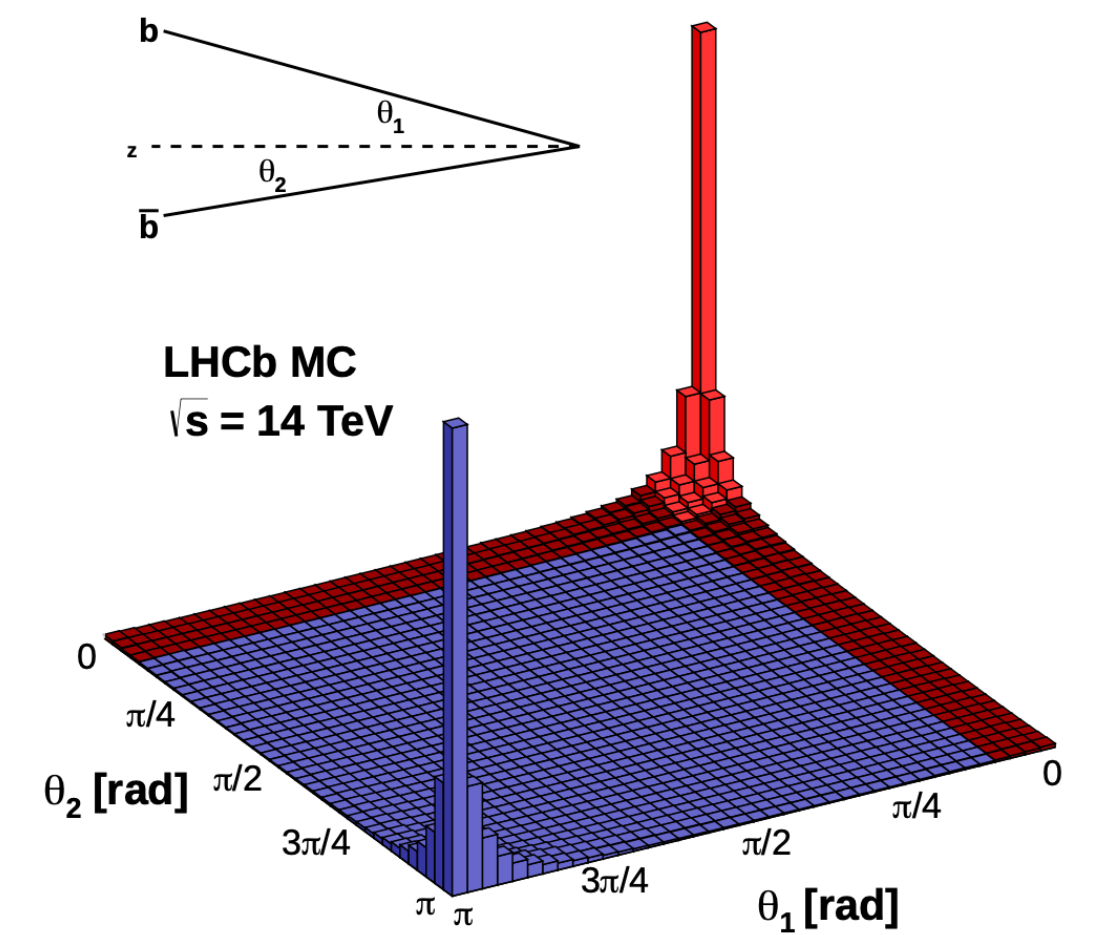
collision point



Excellent momentum resolution $\sim 0.5\%$

LHCb performance:
JINST 14 (2019) P04013

9 fb^{-1} Run 1+2 data
 $\sim 10^{11}$ b hadrons



$2 < \eta < 5$

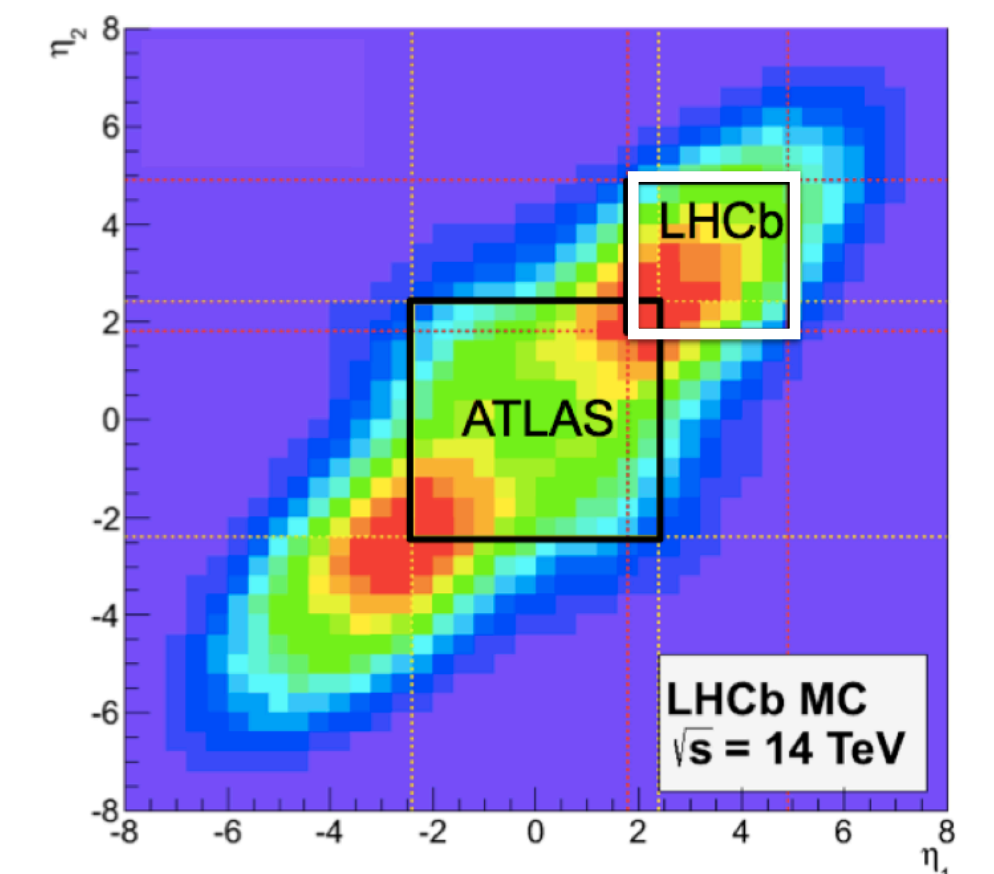
Excellent particle identification

$\epsilon(K) \approx 95\%$

misID $p(\pi \rightarrow K) \approx 5\%$

$\epsilon(\mu) \approx 97\%$

$b\bar{b}$ production

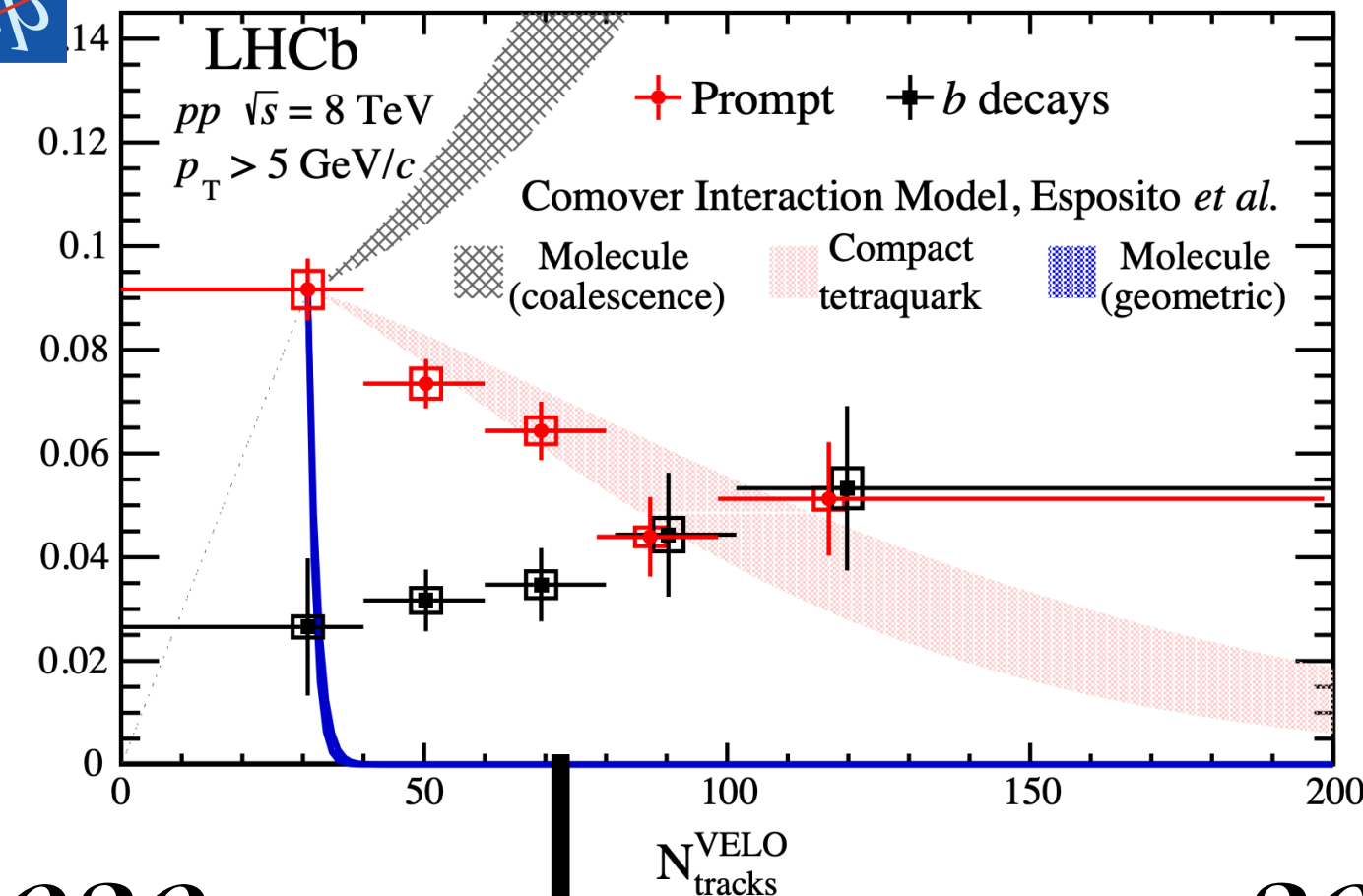


$\chi_{c1}(3872)$

PRL126(2021)092001

LHCb

$\sigma_{\chi_{c1}(3872)} \frac{B(\chi_{c1}(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\sigma_{\psi(2S)} \frac{B(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)}$



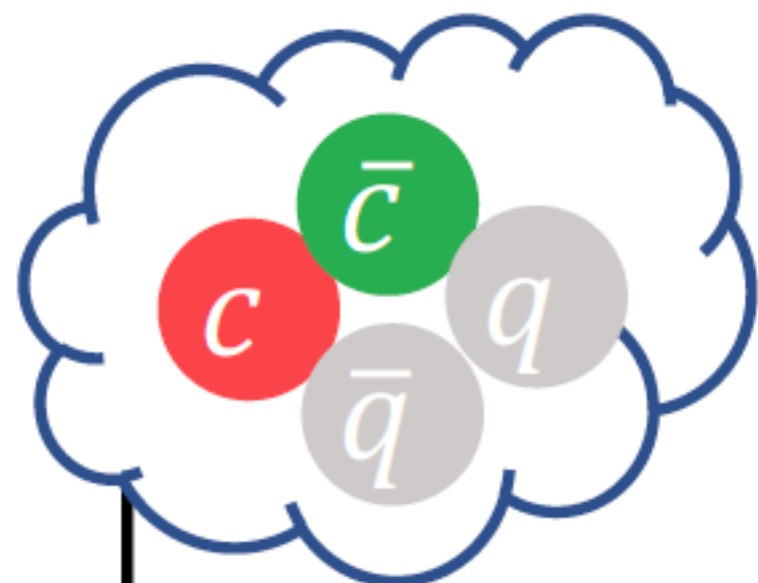
2020

2021

2024

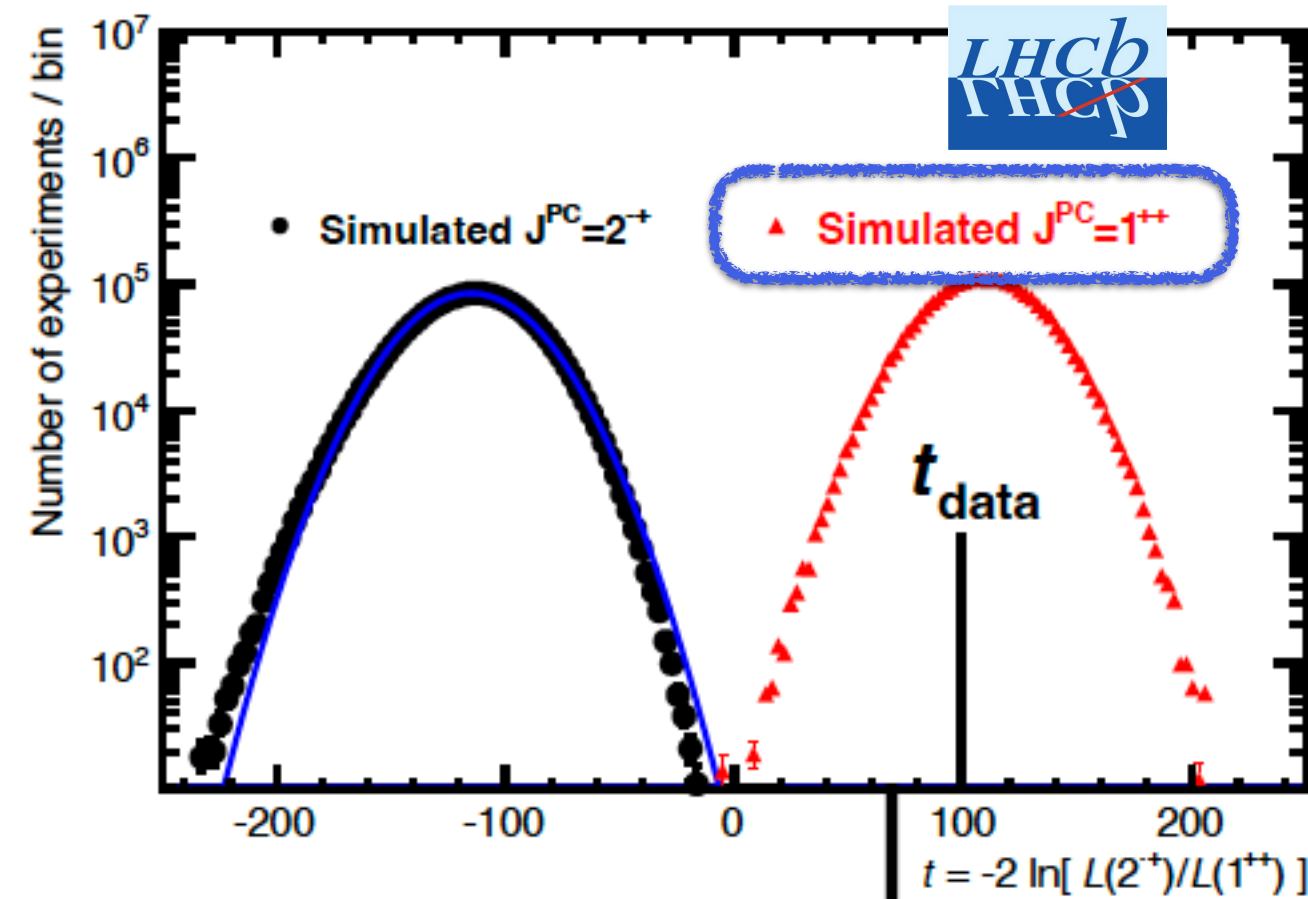
PRL132(2024)151903

$\chi_{c1}(3872)$



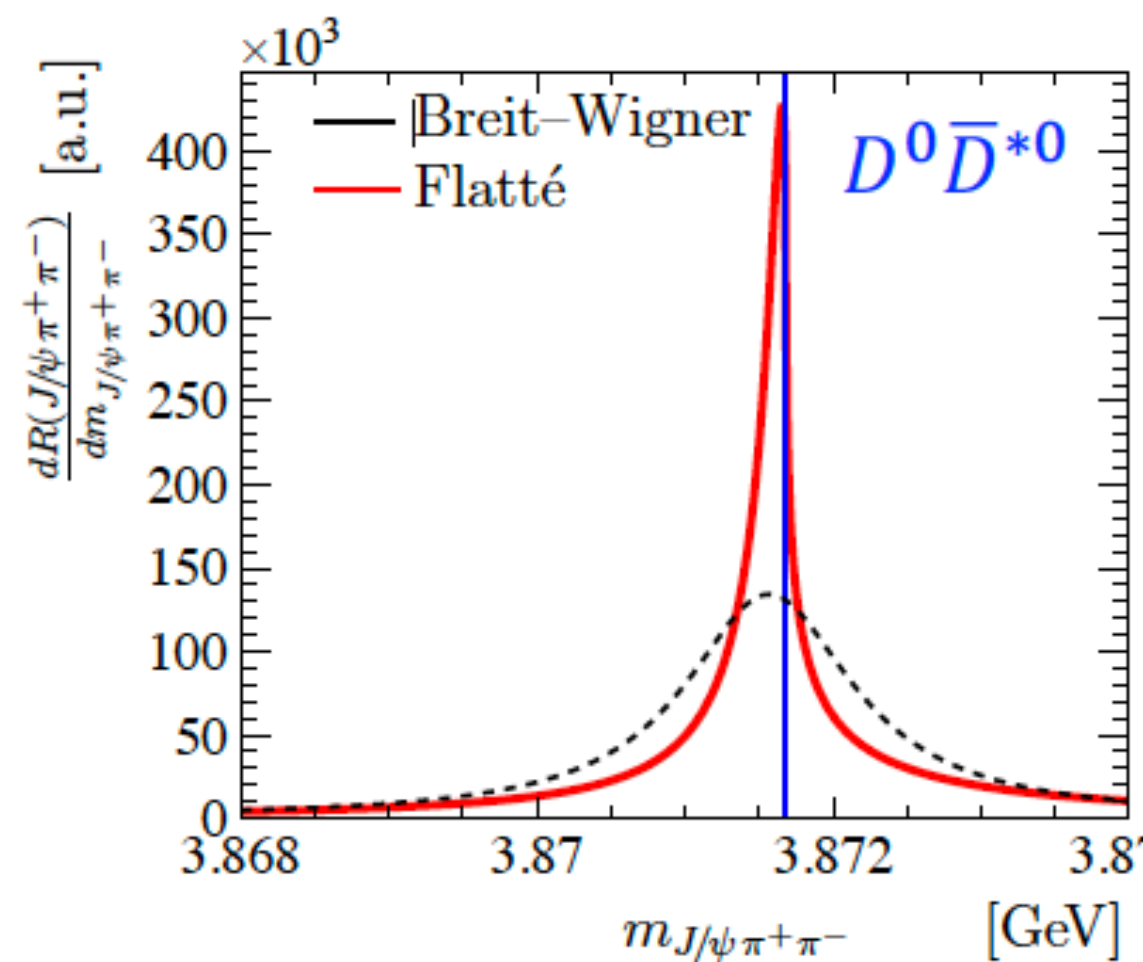
2003

PRL91(2003)262001

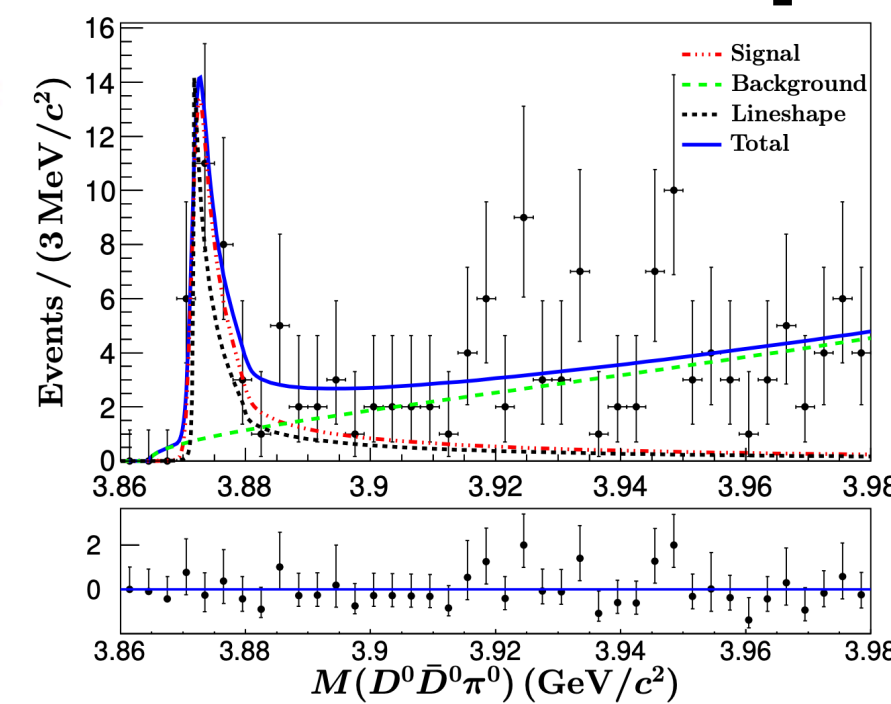
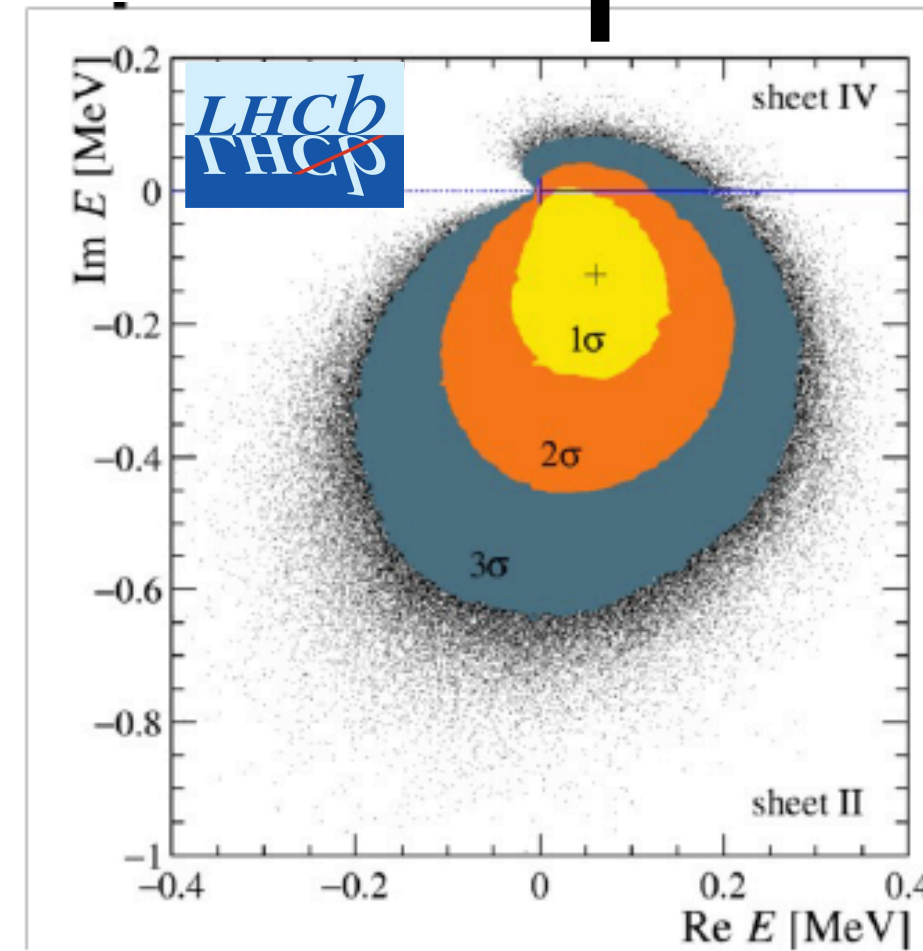


PRL110(2013)222001

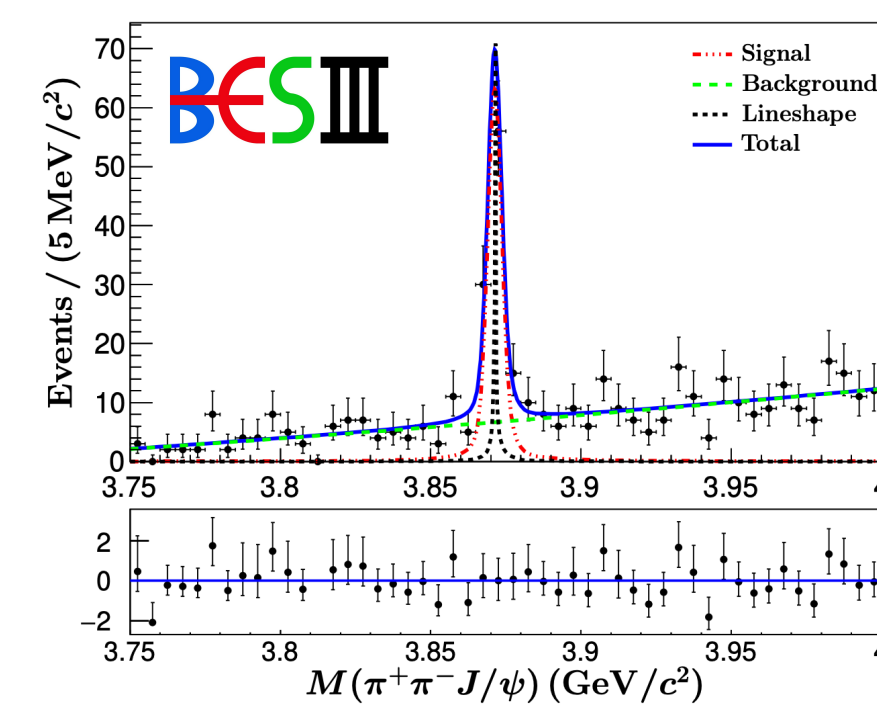
2013



PRD102(2020)092005



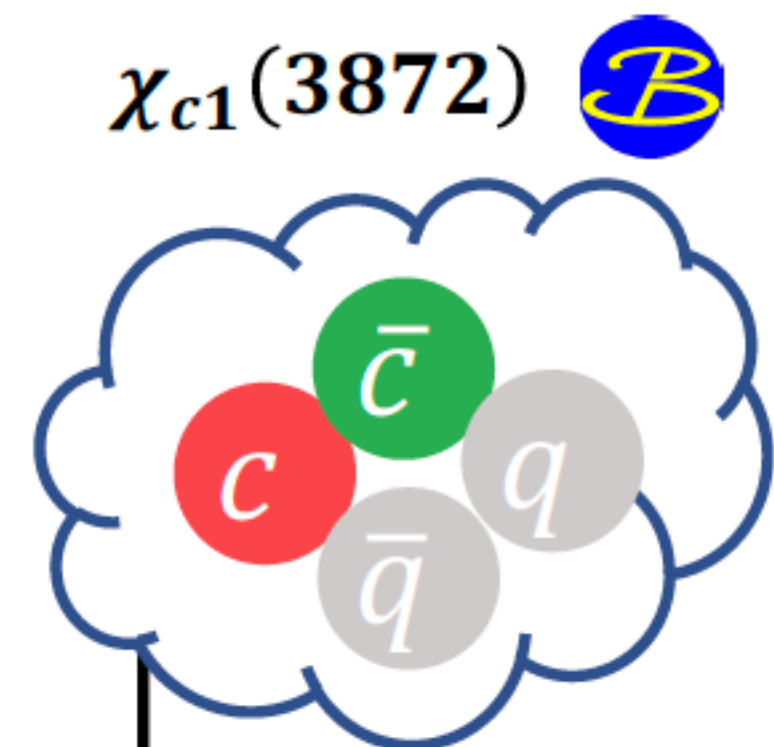
(a)



(b)

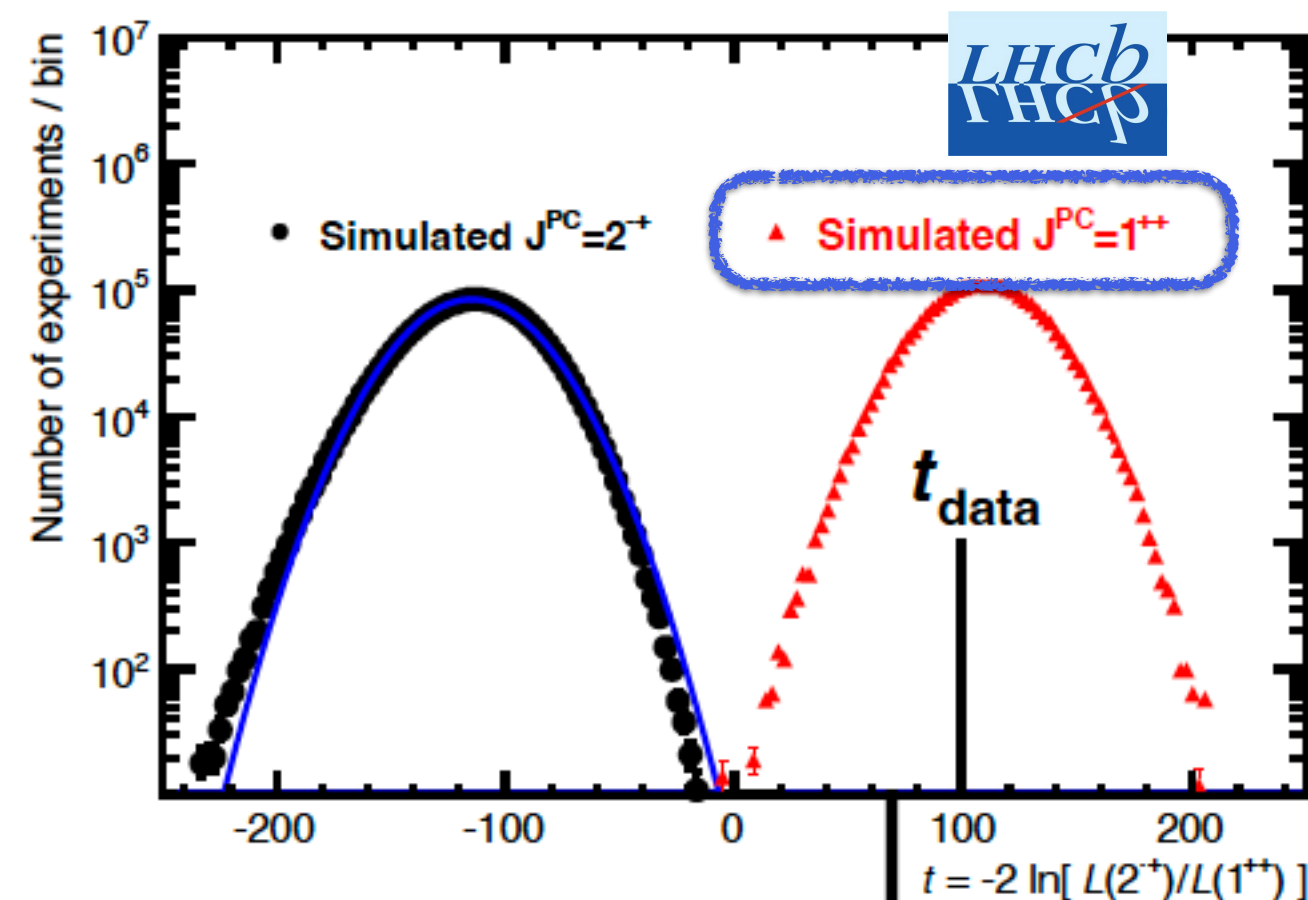
$$\frac{\Gamma(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}{\Gamma(X(3872) \rightarrow D^0 \bar{D}^{*0})} = 0.05 \pm 0.01_{-0.02}^{+0.01}$$

$\chi_{c1}(3872)$



2003

PRL91(2003)262001

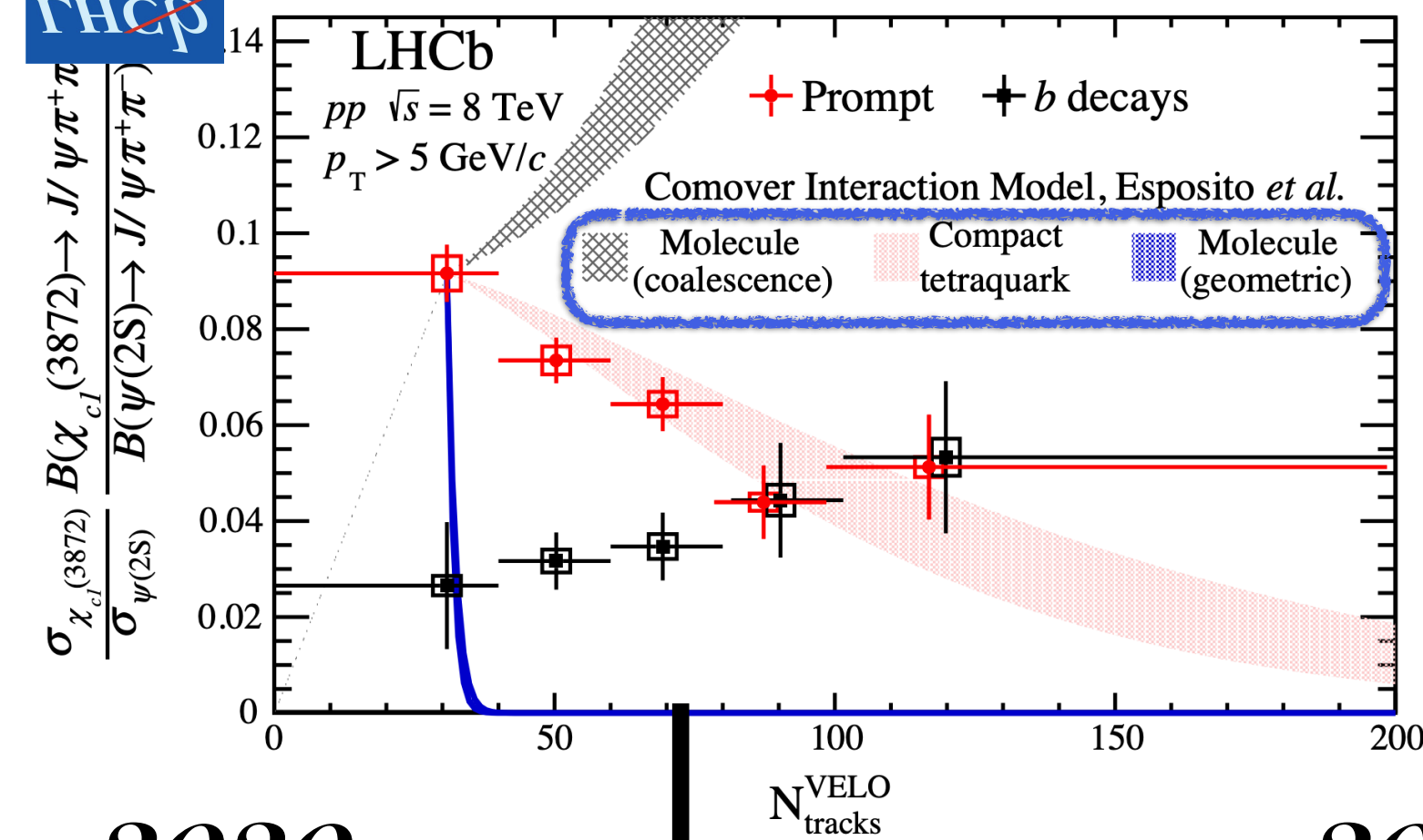


PRL110(2013)222001

2013

LHCb

PRL126(2021)092001

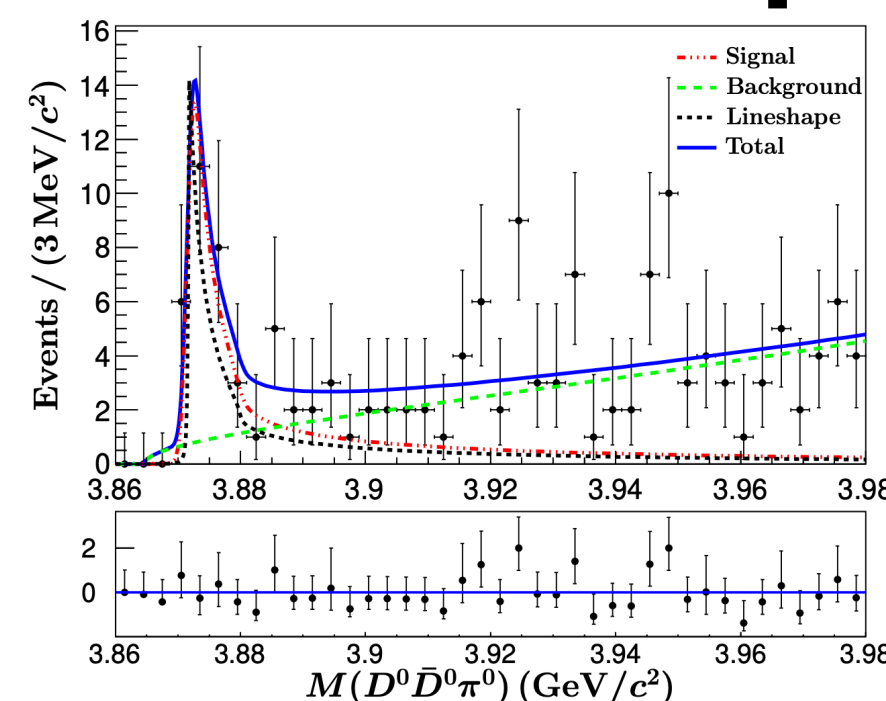
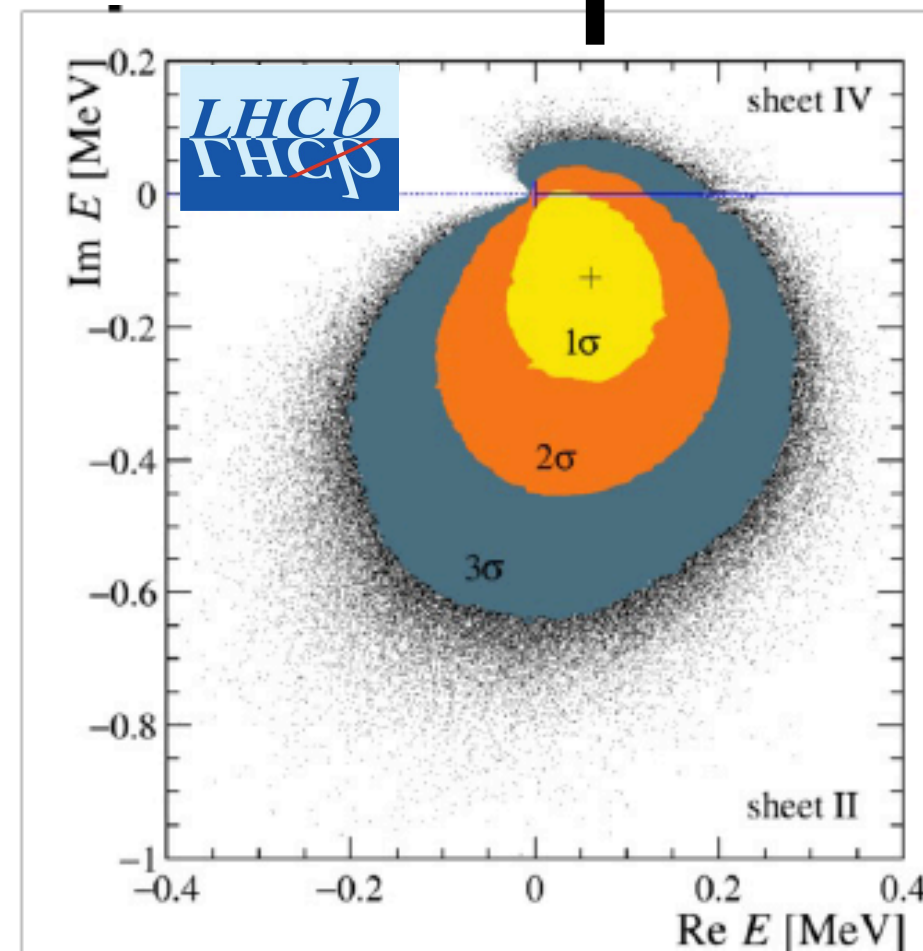
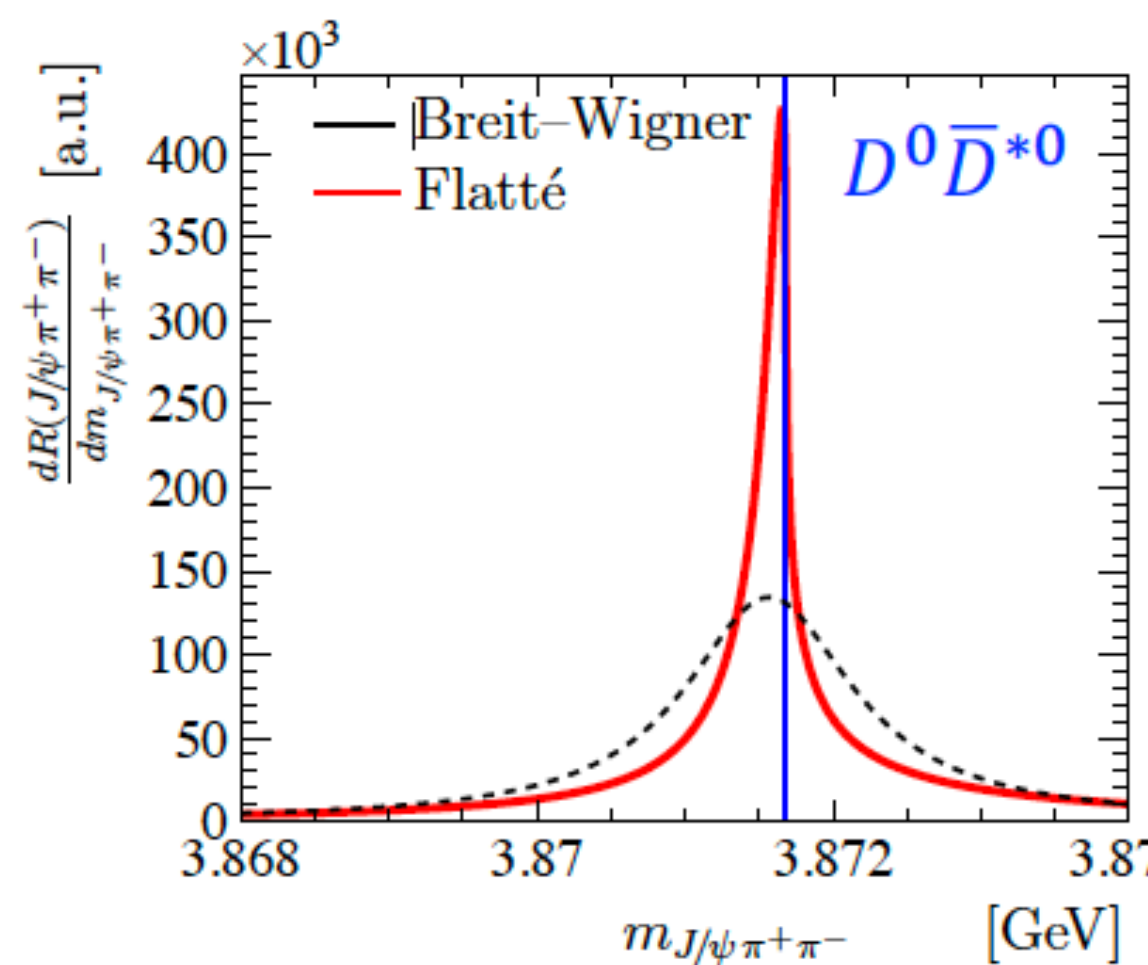
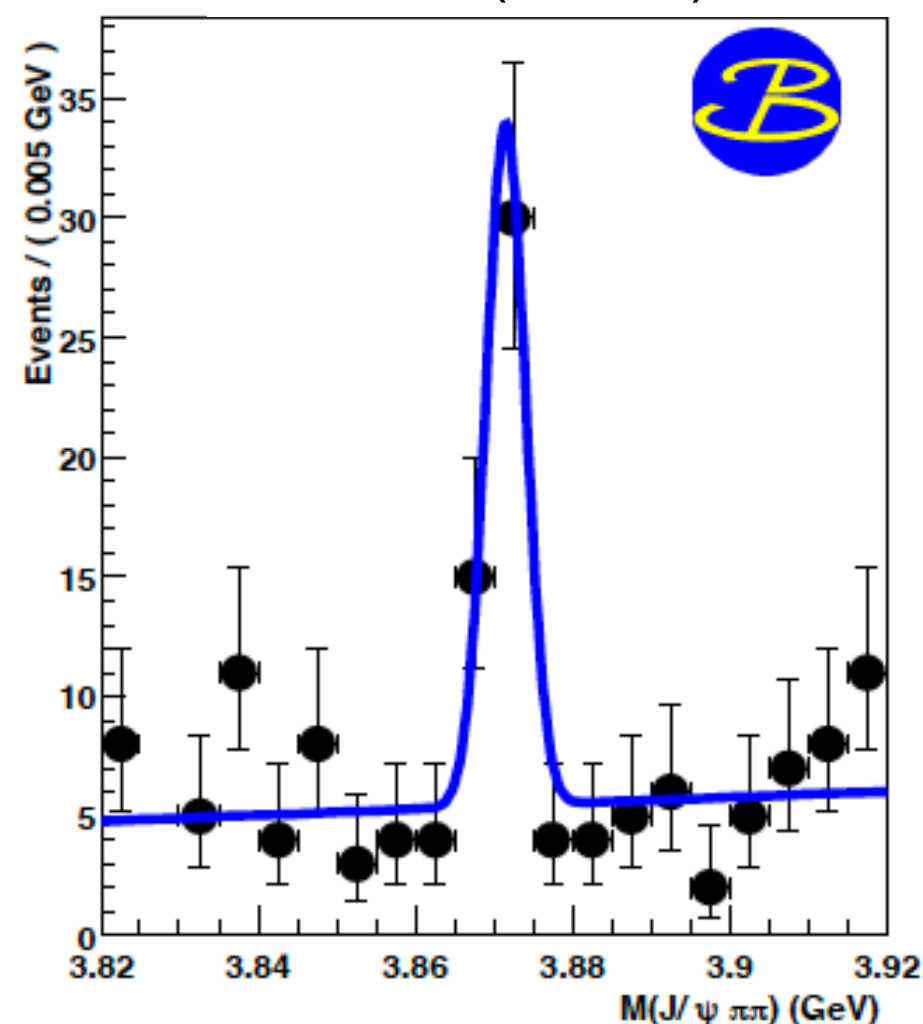


2020

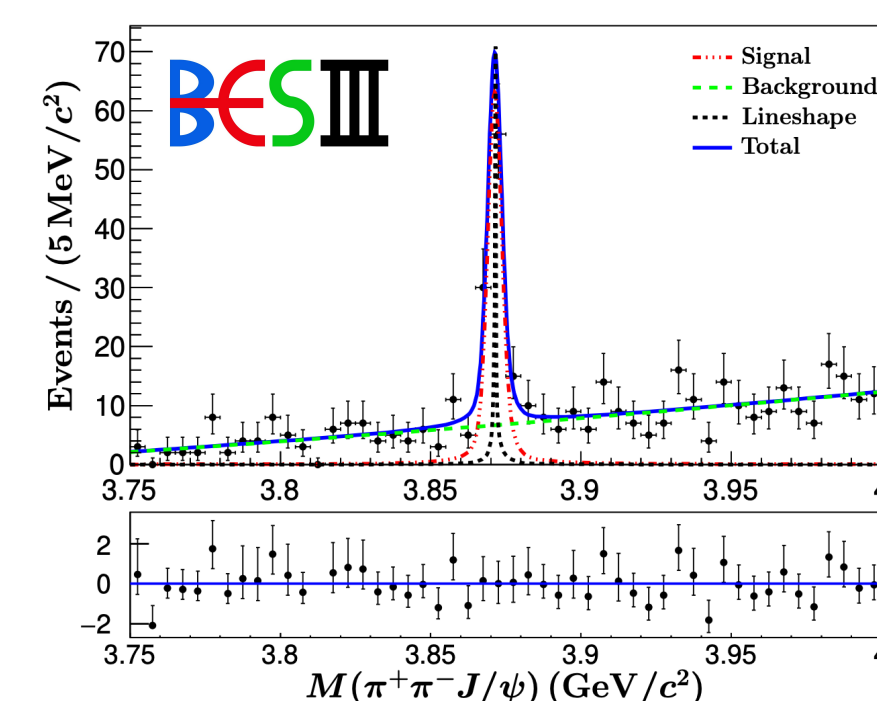
2021

2024

still under discussion!



(a)



(b)

$$\frac{\Gamma(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}{\Gamma(X(3872) \rightarrow D^0 \bar{D}^{*0})} = 0.05 \pm 0.01^{+0.01}_{-0.02}$$

PRD102(2020)092005

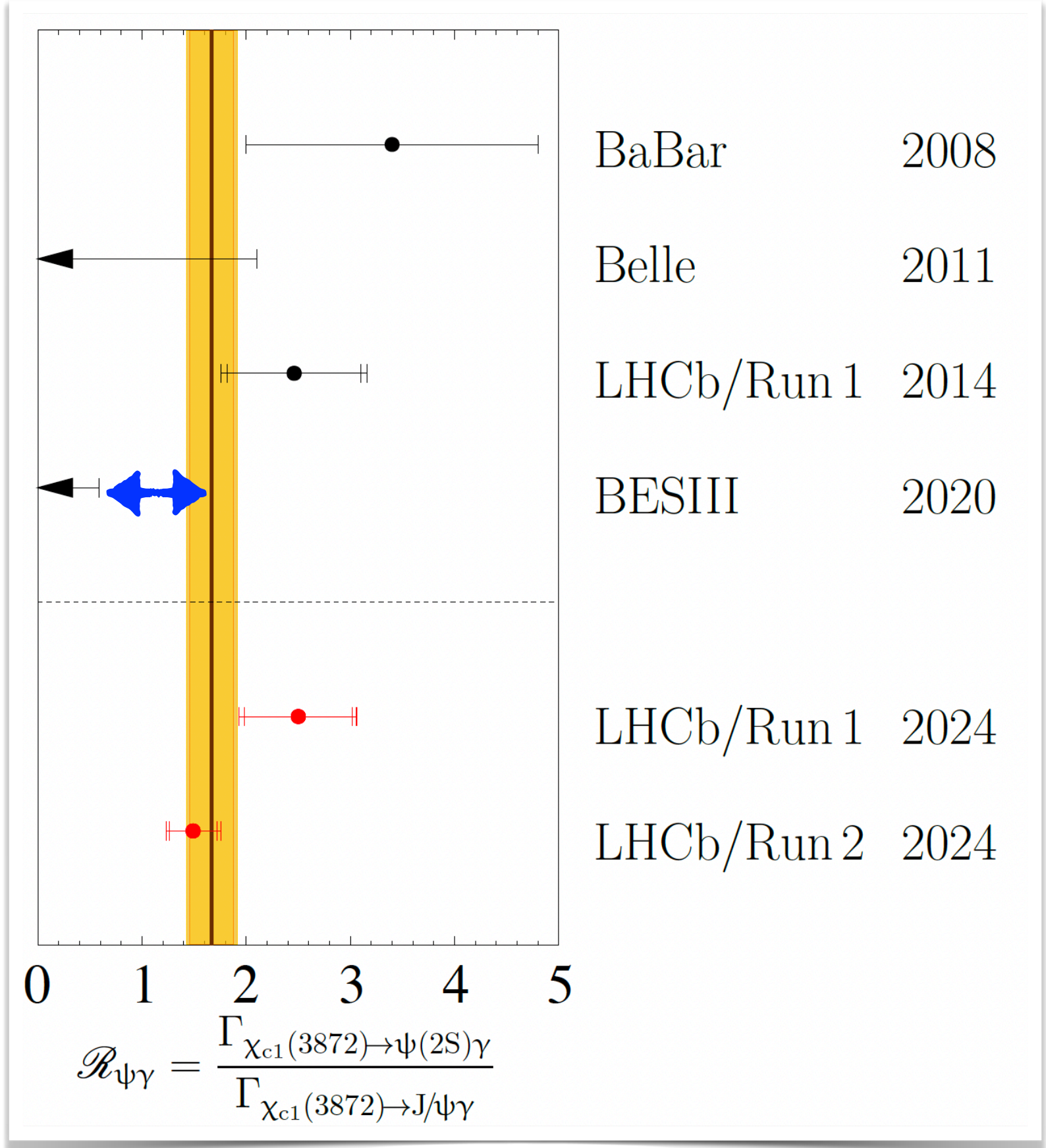
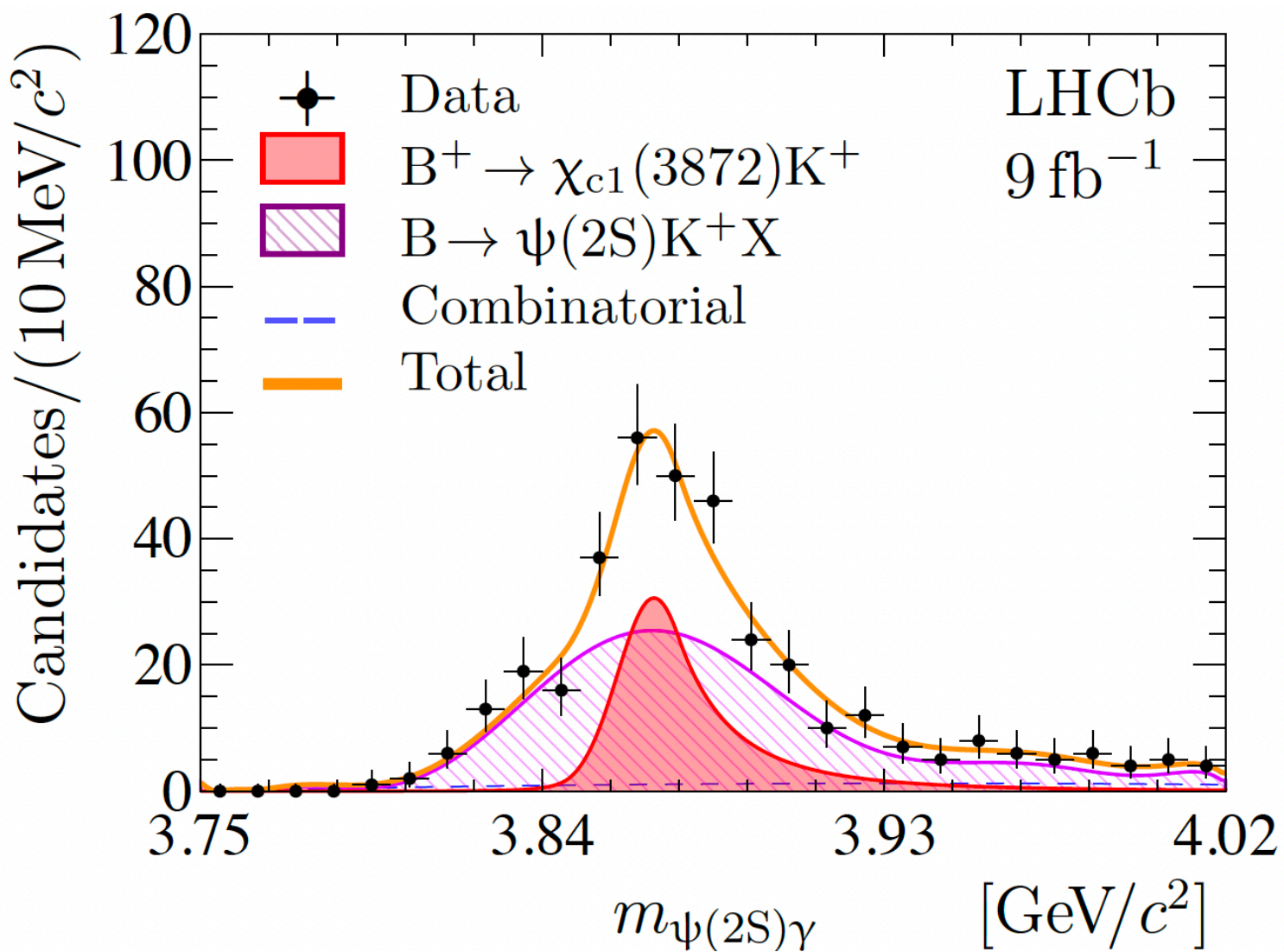
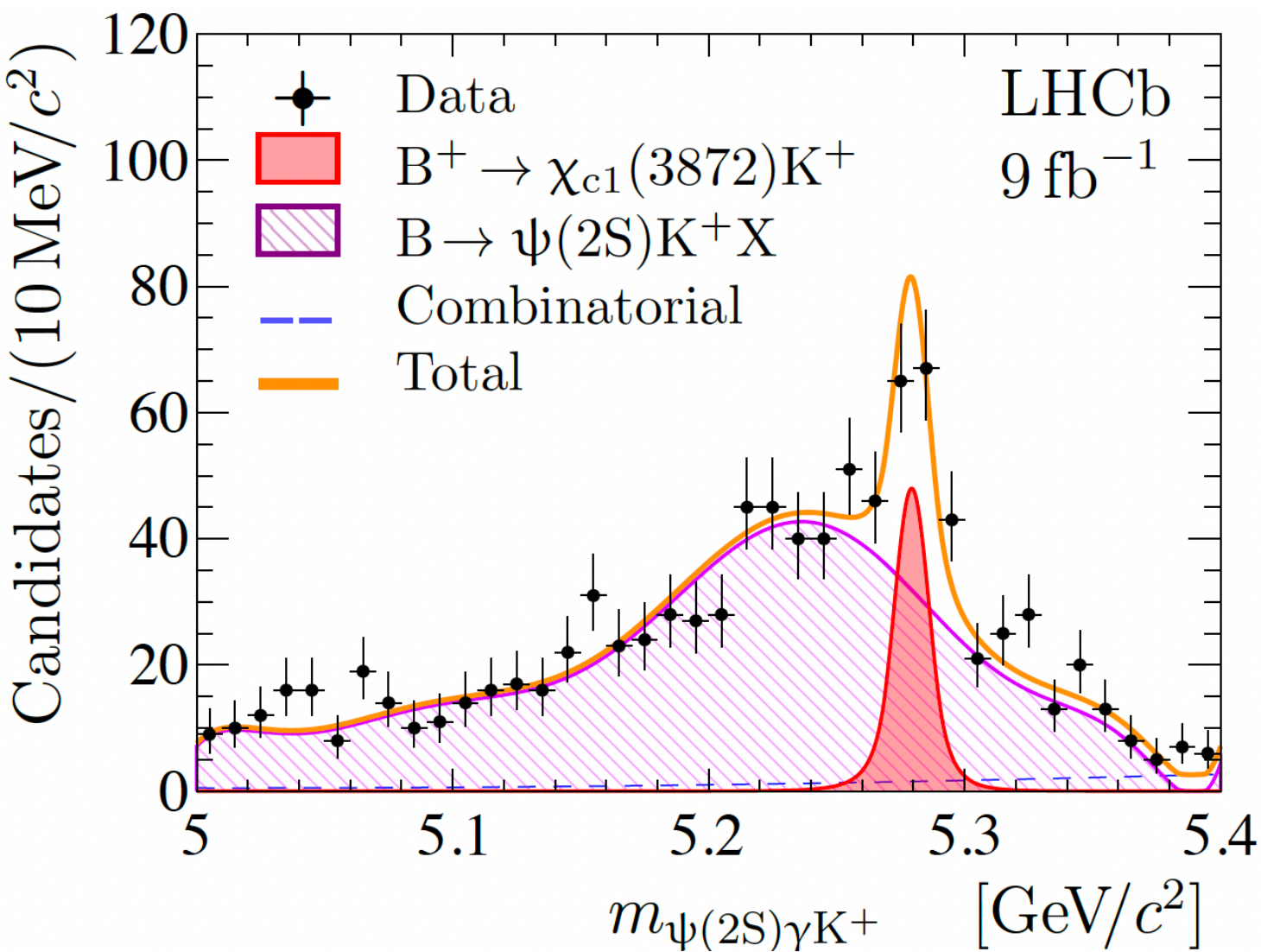
Radiative decays of $\chi_{c1}(3872)$

JHEP 11 (2024) 121

PRD109(2024)074009

- Ratio of the partial radiative decay widths into $\psi(2S)\gamma$ and $J/\psi\gamma \ll 1$ for a pure $D\bar{D}^*$ molecular
- $\chi_{c1}(3872) \rightarrow \gamma\psi(2S)$ observed for the first time in $B^+ \rightarrow \chi_{c1}(3872)K^+$ with 9 fb^{-1} pp collision data
- Inconsistent with pure $D\bar{D}^*$ molecular hypothesis but agree with many others:
conventional $c\bar{c}$ charmonium, $c\bar{c}q\bar{q}$ tetra quark, molecules mixed with a sizeable compact component

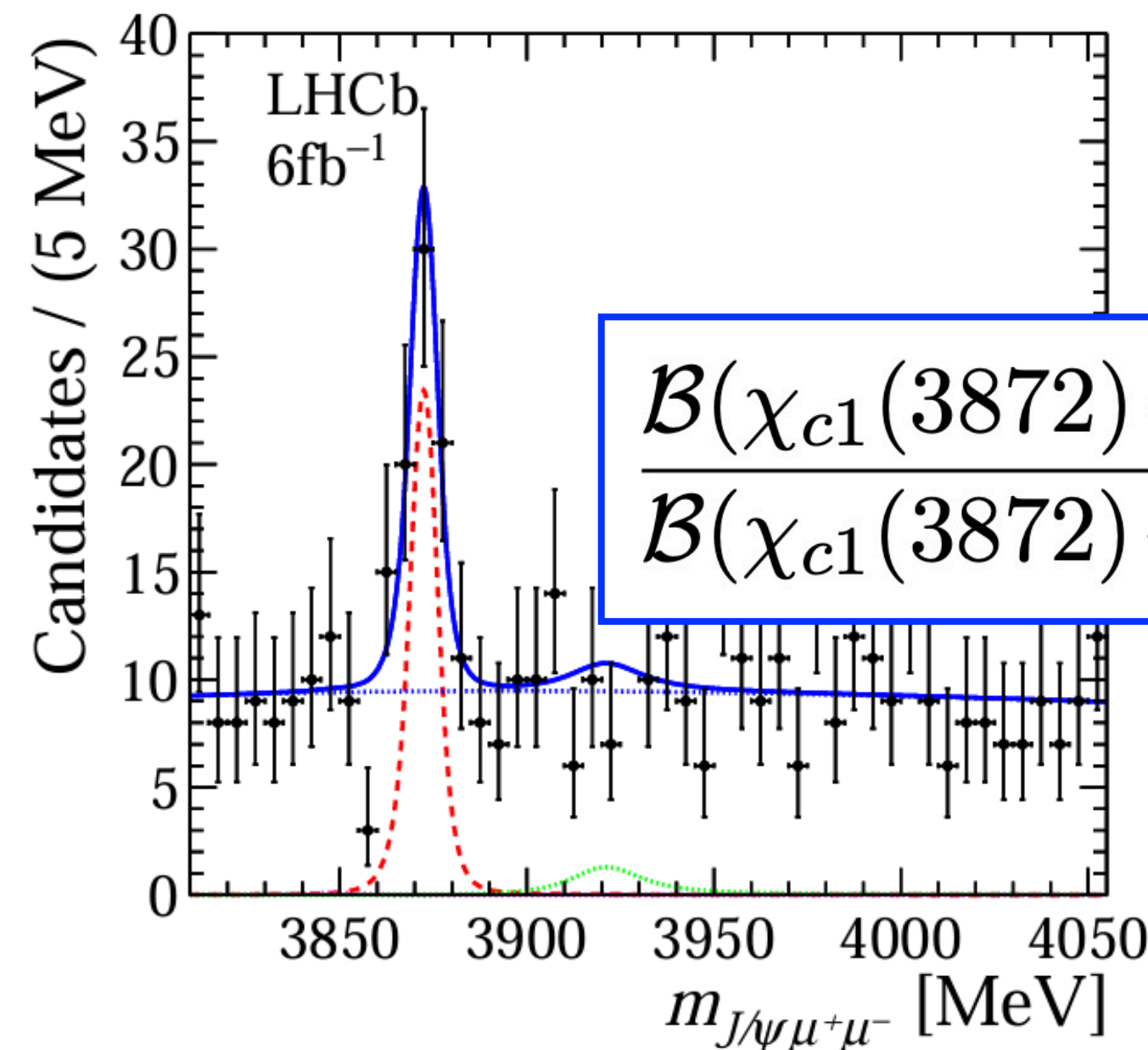
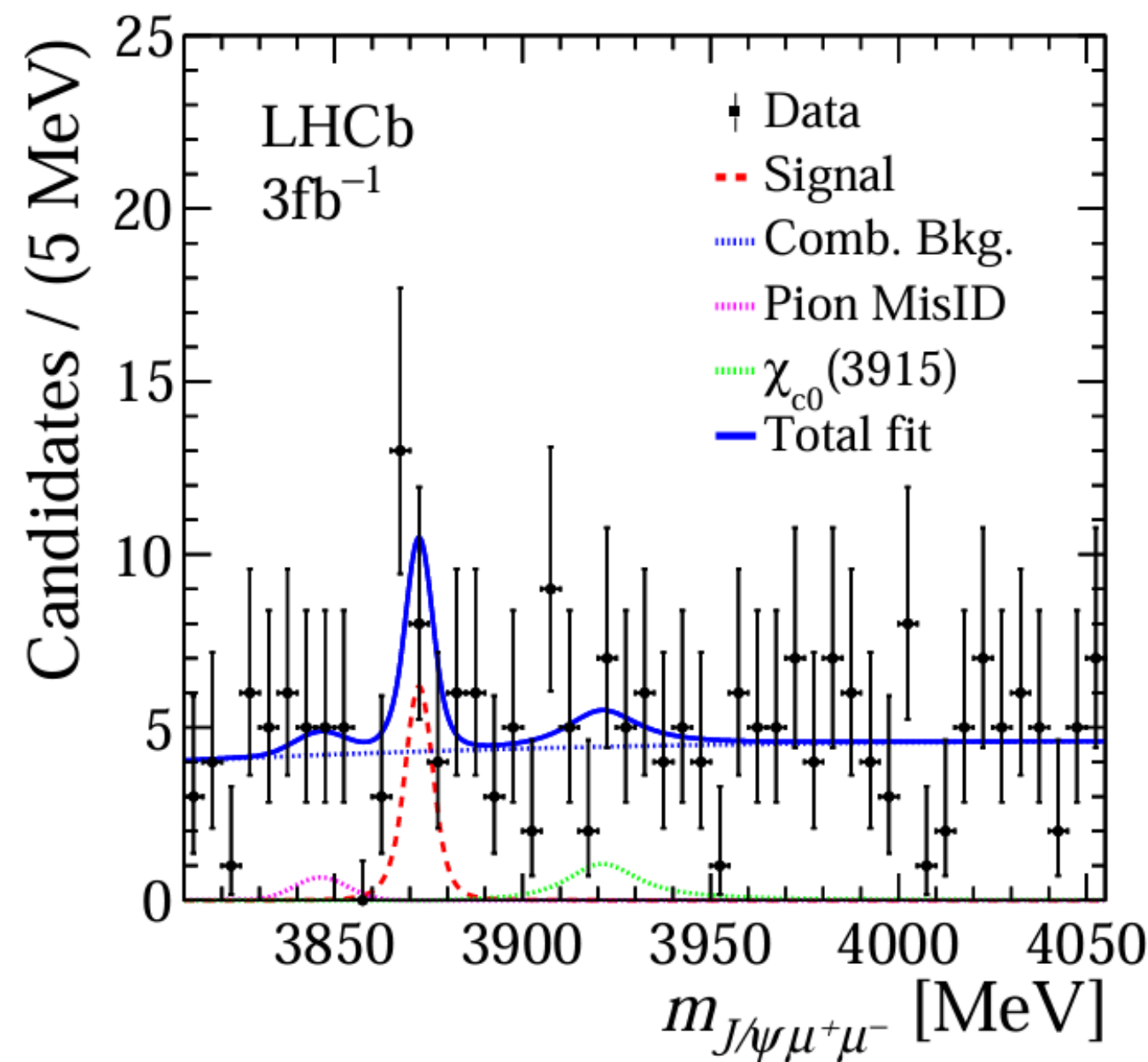
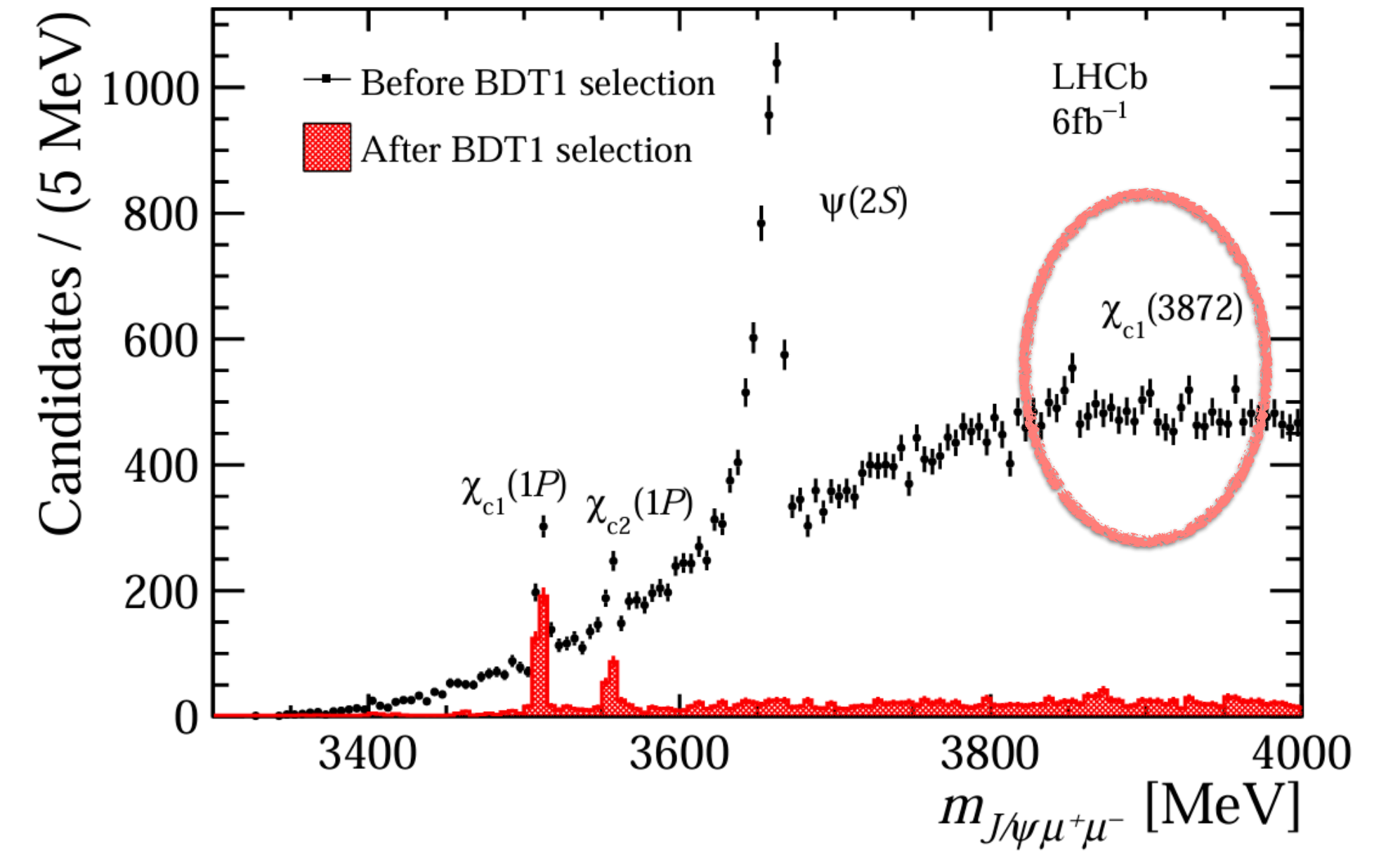
$$\frac{\Gamma_{\chi_{c1}(3872) \rightarrow \psi(2S)\gamma}}{\Gamma_{\chi_{c1}(3872) \rightarrow J/\psi\gamma}} = 1.67 \pm 0.21 \pm 0.12 \pm 0.04$$



Observation of $\chi_{c1}(3872) \rightarrow J/\psi \mu^+ \mu^-$

PRD113(2026)072019

- Several possible contributions to $\chi_{c1}(3872) \rightarrow J/\psi \mu^+ \mu^-$: virtual photon at low $m_{\mu\mu}$ or ρ/ω contribution at high $m_{\mu\mu}$
- Simultaneous search of $\chi_{c0}(3915)$
- 60 ± 11 $\chi_{c0}(3872)$ with significance $> 6\sigma$ using 9 fb^{-1} Runs 1+2 data



$$\frac{\mathcal{B}(\chi_{c1}(3872) \rightarrow J/\psi \mu^+ \mu^-)}{\mathcal{B}(\chi_{c1}(3872) \rightarrow J/\psi \pi^+ \pi^-)} = (1.68 \pm 0.32 \pm 0.05) \times 10^{-3}$$

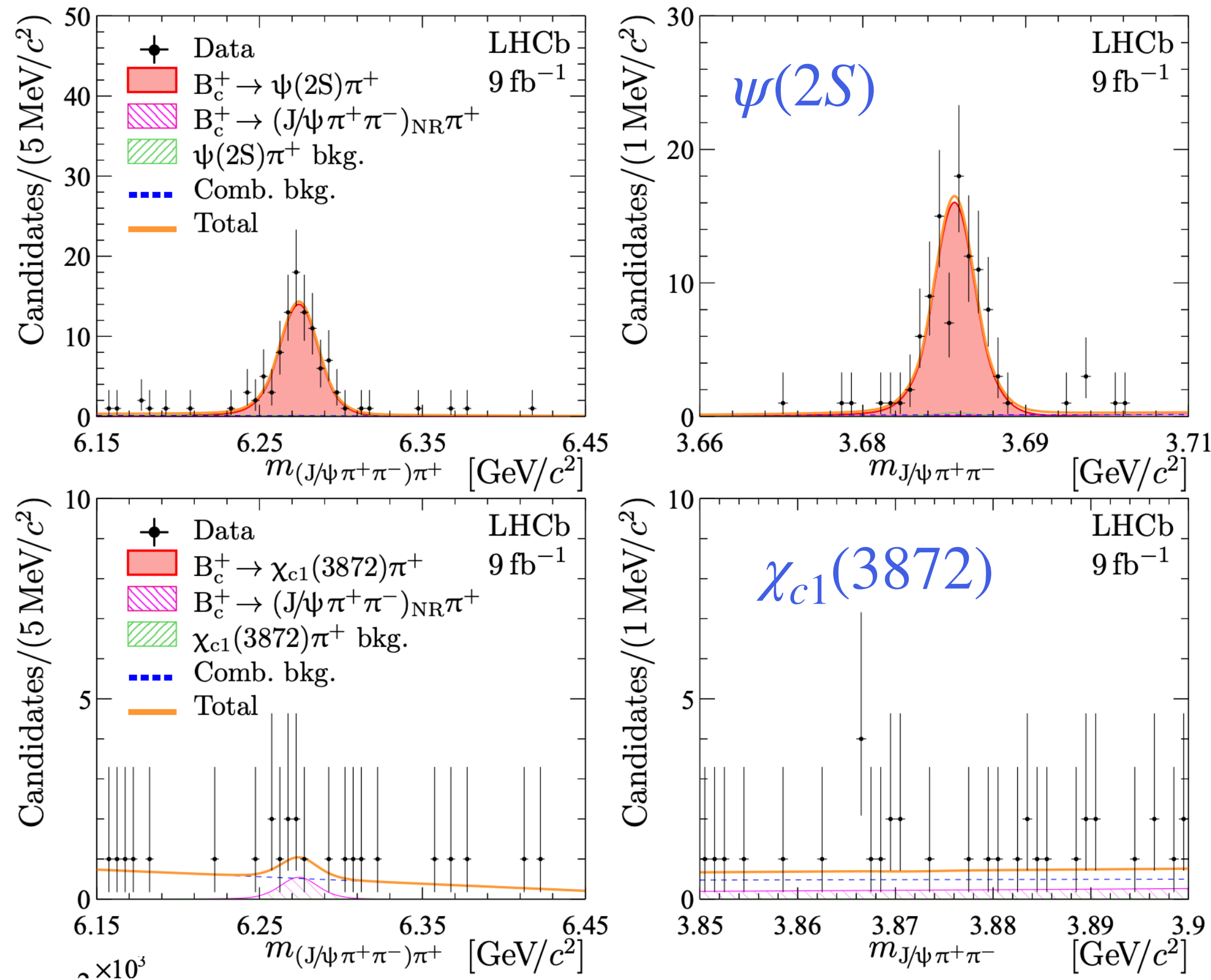
Search for $B_c^+ \rightarrow \chi_{c1}(3872)\pi^+$

JHEP 06 (2025) 13

- The compact-tetra quark interpretation of $\chi_{c1}(3872)$ predicts enhancement of $\mathcal{B}(B_c^+ \rightarrow \chi_{c1}(3872)\pi^+)$
- ATLAS reported significant enhancement of $\chi_{c1}(3872)$ production from B_c^+ , assuming short-lived contribution of non-prompt $\chi_{c1}(3872)$ to arise from B_c^+ decays

JHEP 01 (2017) 117

No signal observed from 9 fb^{-1} LHCb Run 1+2 data



$B_c^+ \rightarrow X_{c\bar{c}} \pi^+$ UL @90% CL

$B_s^0 \rightarrow X_{c\bar{c}} \pi^+ \pi^-$ [86]

$B_s^0 \rightarrow X_{c\bar{c}} \phi$ [41]

$B^+ \rightarrow X_{c\bar{c}} K^+$ [81]

$\Lambda_b^0 \rightarrow X_{c\bar{c}} p K^-$ [79]

$B^0 \rightarrow X_{c\bar{c}} K^{*0}$ [30]

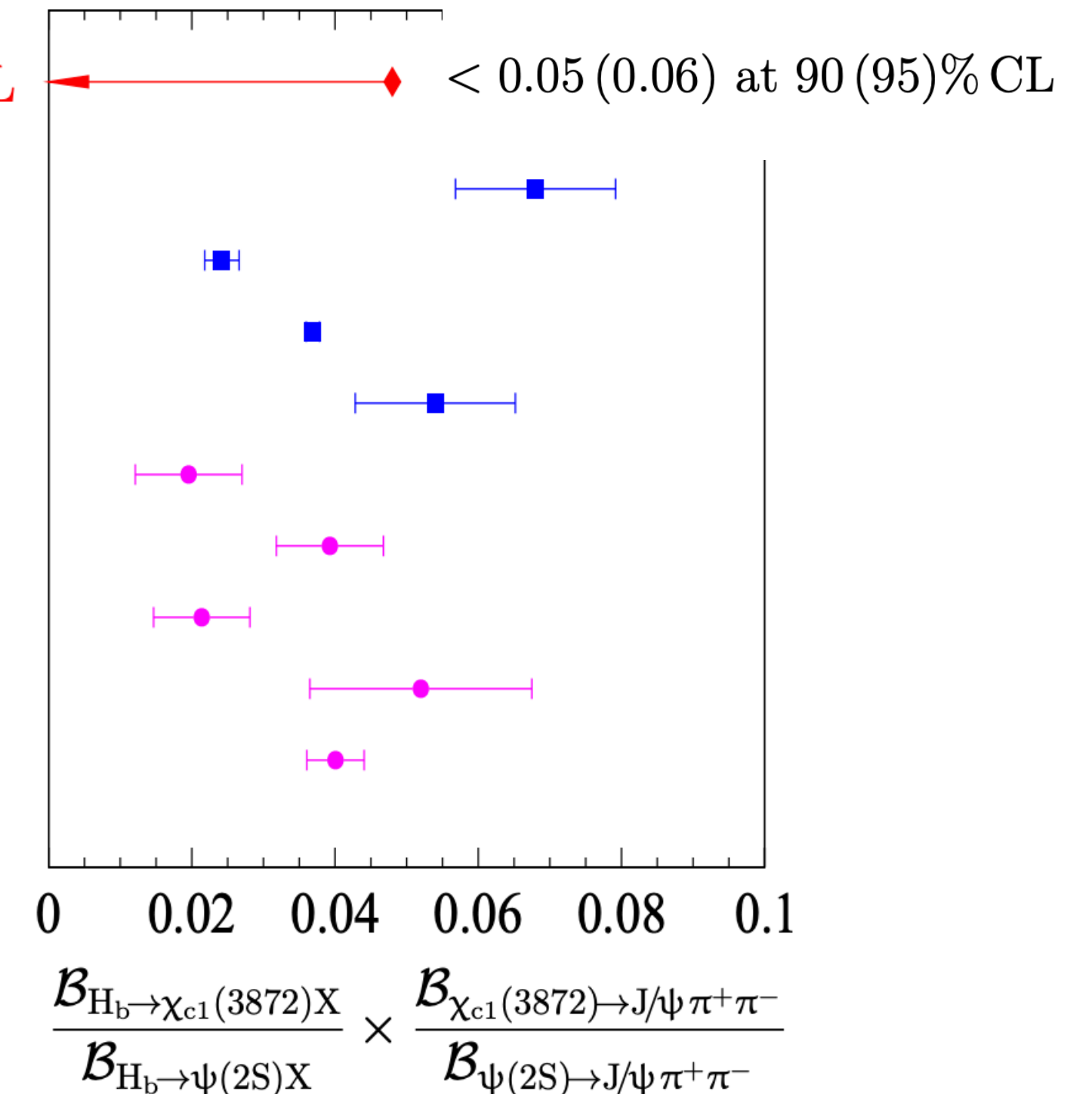
$B^0 \rightarrow X_{c\bar{c}} K^+ \pi^-$ [30]

$B^0 \rightarrow X_{c\bar{c}} K^0$ [30]

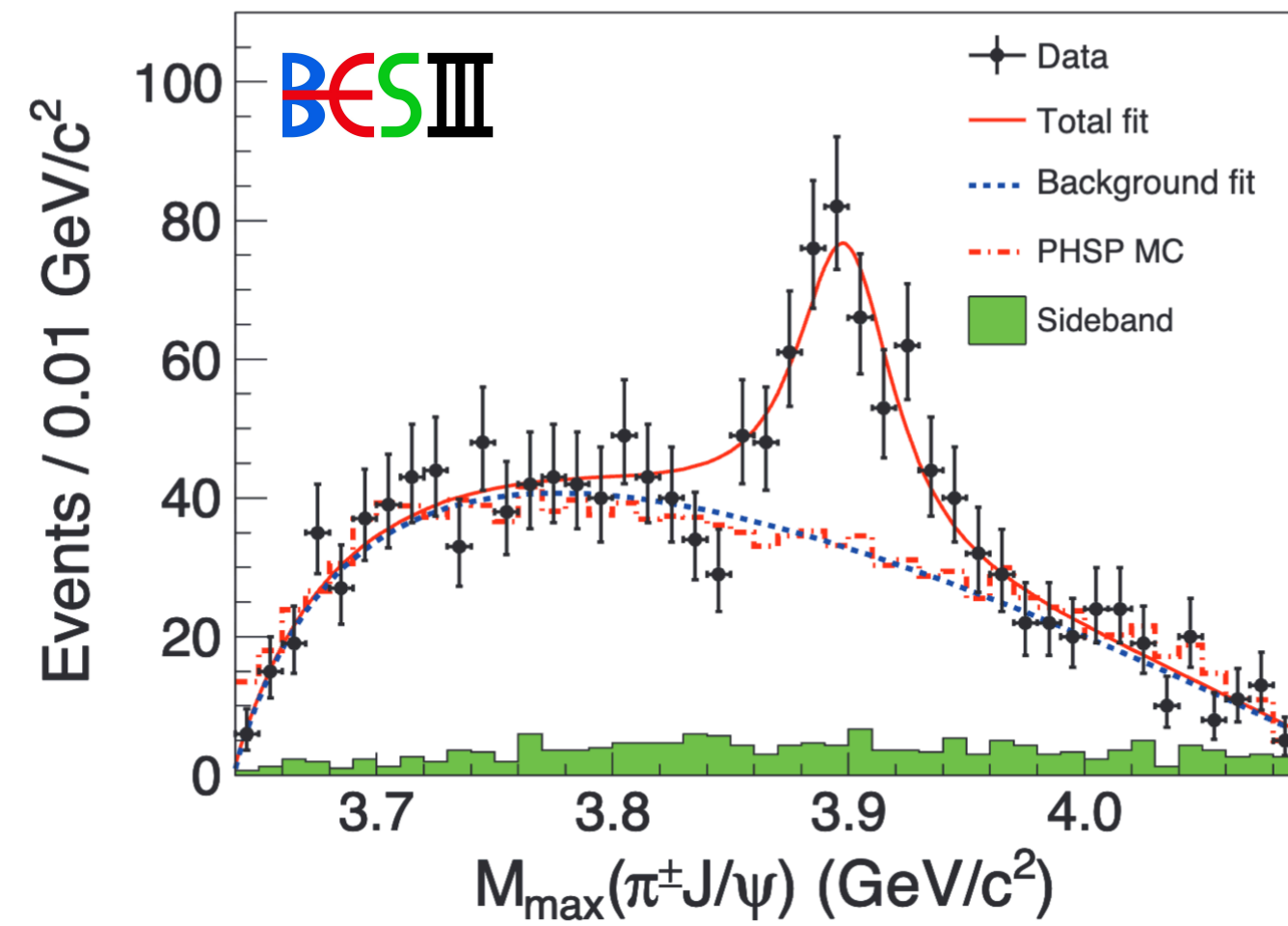
$B^+ \rightarrow X_{c\bar{c}} K^0 \pi^+$ [30]

$B^+ \rightarrow X_{c\bar{c}} K^+$ [30]

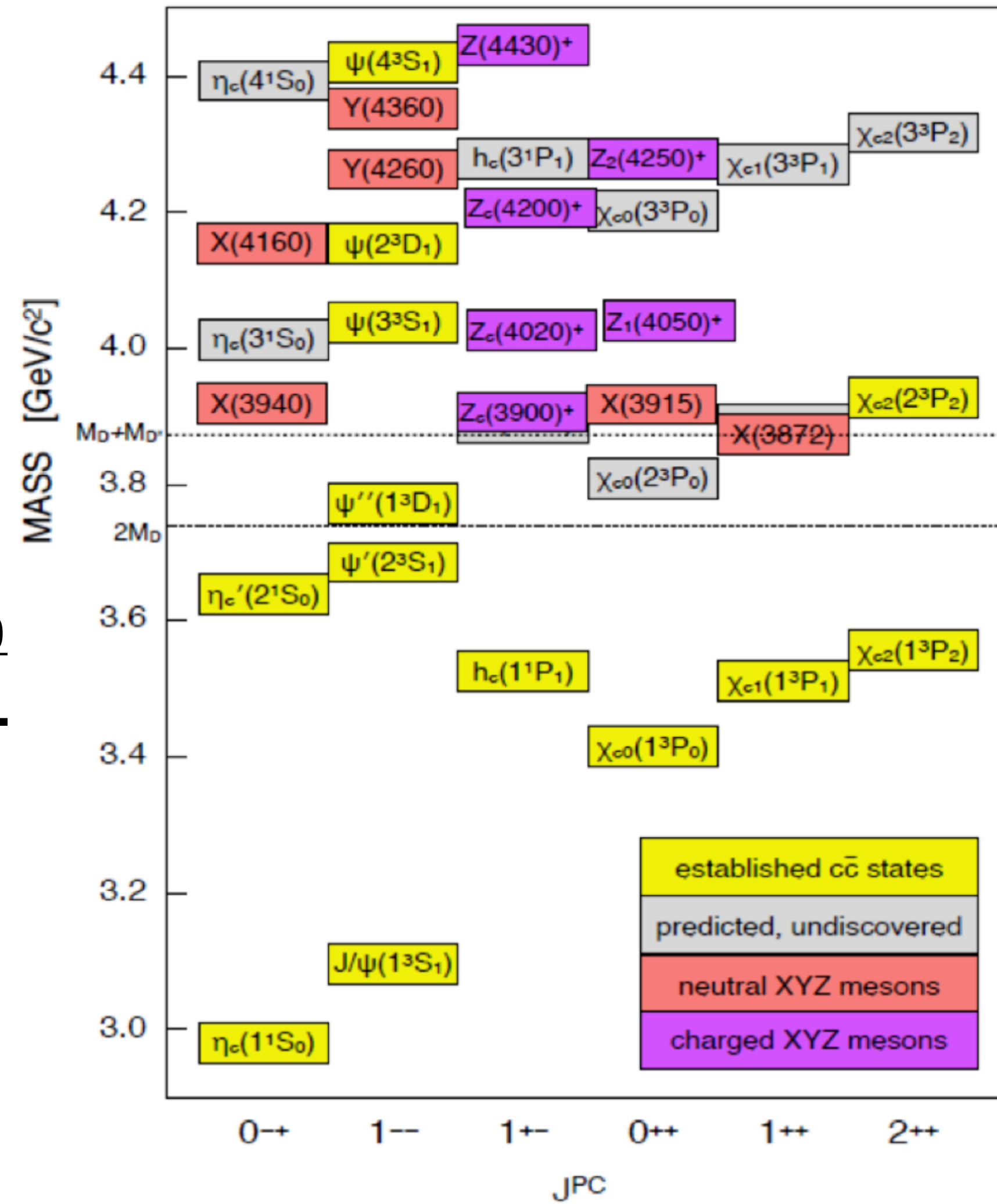
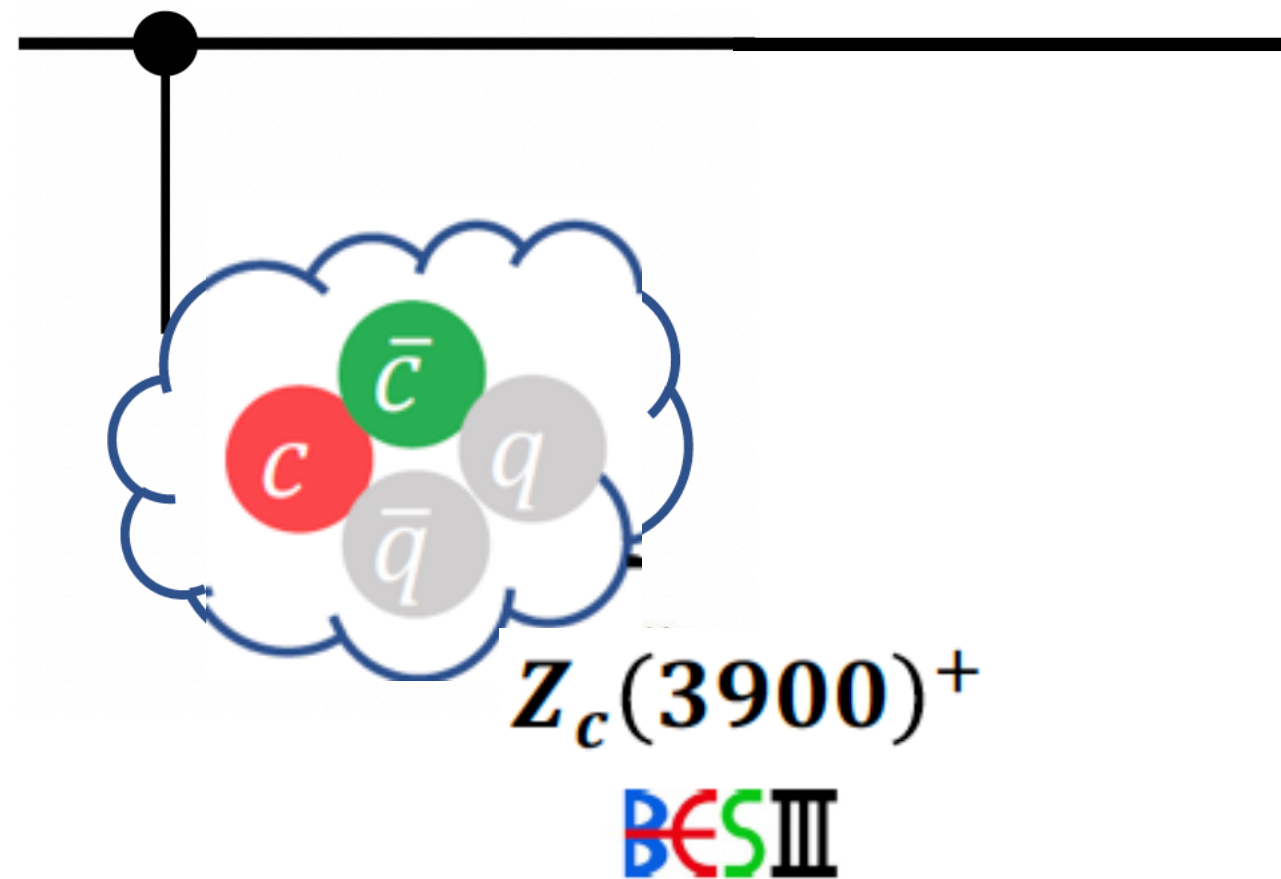
$X_{c\bar{c}} \equiv \chi_{c1}(3872) \text{ or } \psi(2S)$



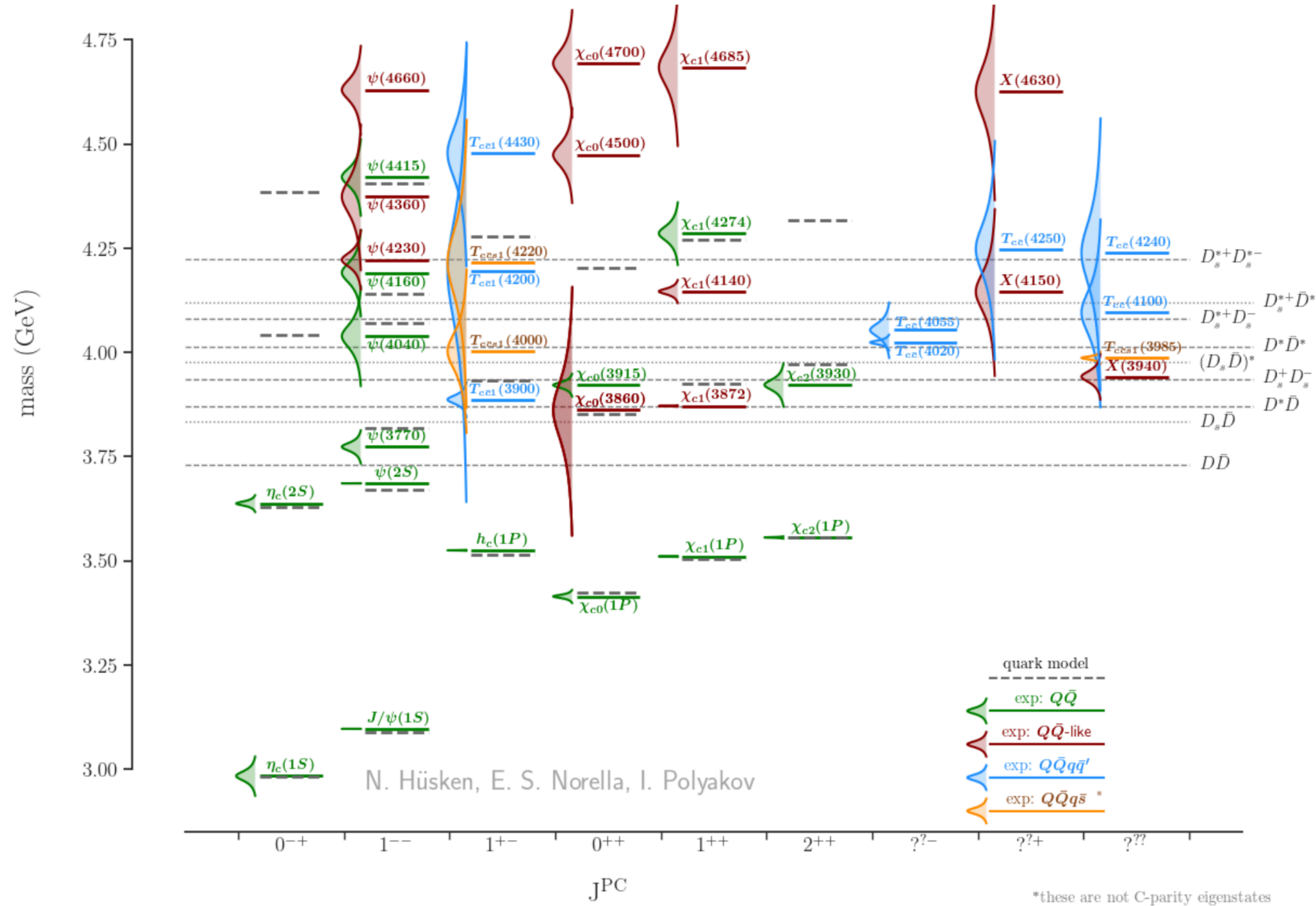
$T_{c\bar{c}}$ states



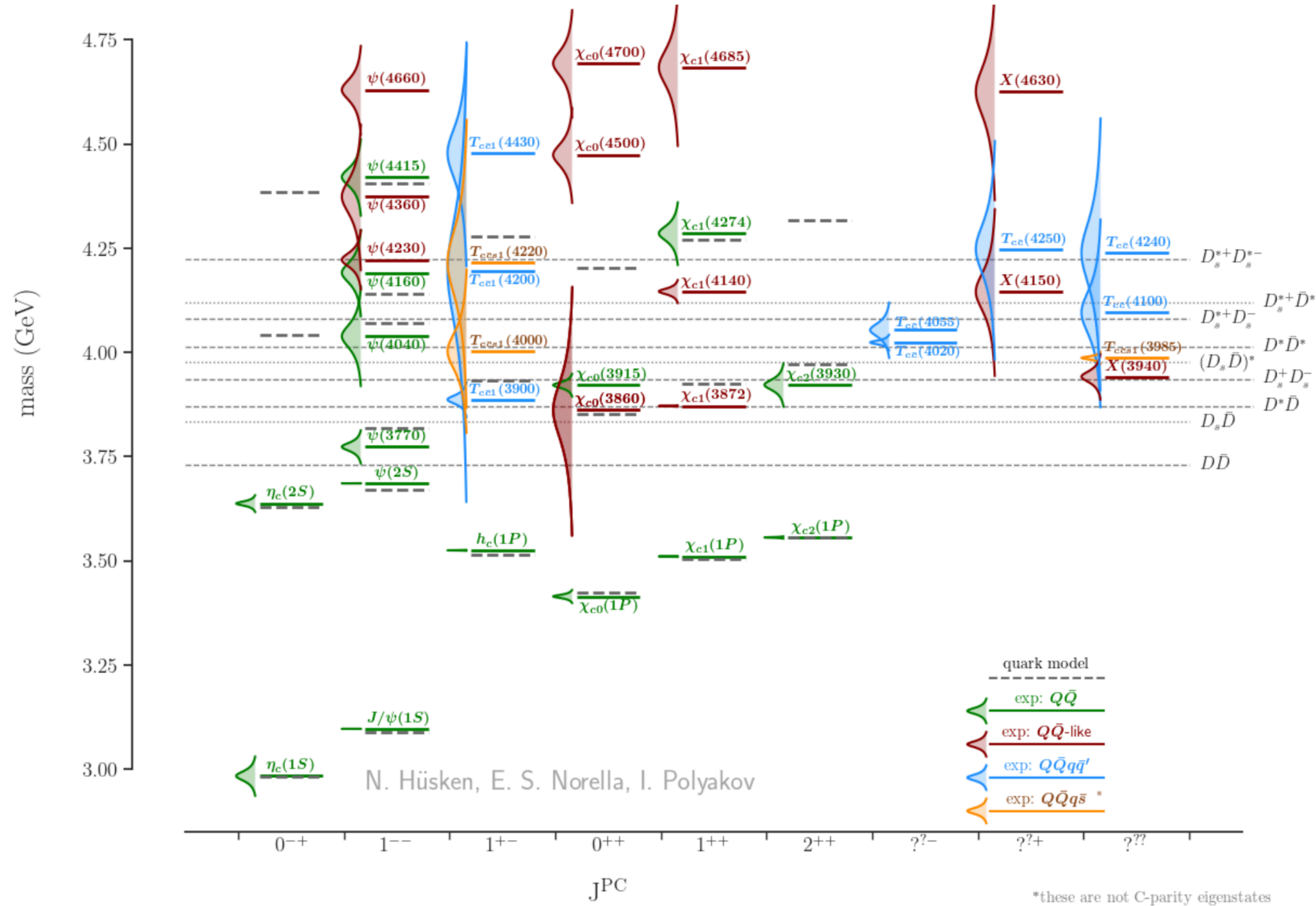
2013 PRL 110(2013)25200



$T_{c\bar{c}}$ states



$T_{c\bar{c}}$ states



- e^+e^- annihilation
- $e^+e^- \rightarrow J/\psi X$
- Decay from charmonium-like states
- b hadron decays
- Pomeron-induced process

BESIII

BELLE Belle II

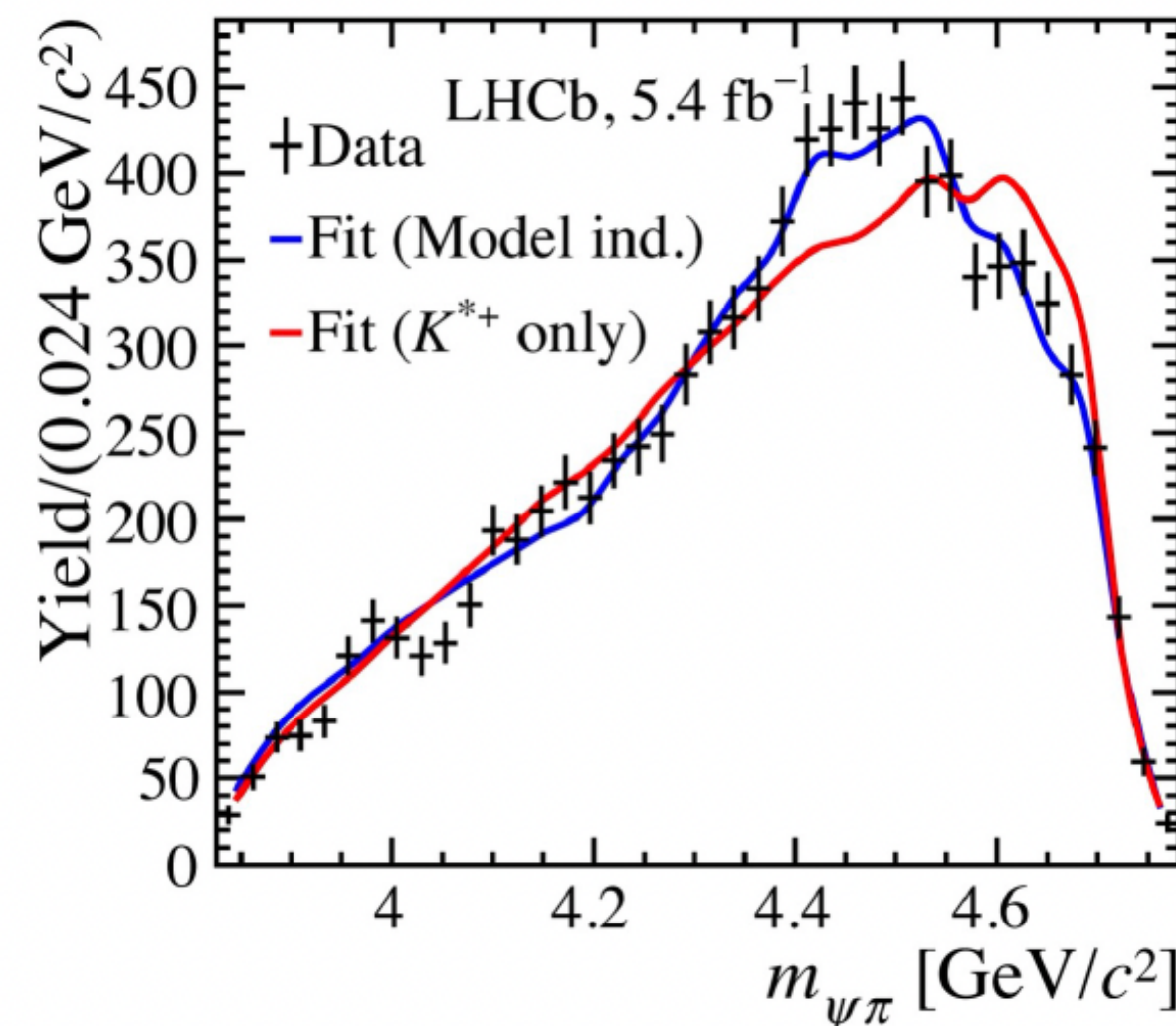
LHCb

Study of $T_{c\bar{c}1}(4430)^+$

PRD 113 (2026) L071101

- No consensus on the $T_{c\bar{c}1}(4430)^+$ nature since the first observation by Belle [PRL100\(2008\)142001](#)
- First full amplitude analysis of $B^+ \rightarrow \psi(2S)K_S^0\pi^+$ with 5.4 fb^{-1} LHCb data
- Both model-independent and model-dependent approaches tested
 - $T_{c\bar{c}1}(4430)^+$ needed, both BW & Flatte parametrisation considered

Model independent



- ✓ discrepancy resolved by adding $\psi(2S)\pi^+$ component which shows resonant behavior

Model dependent

✓ Breit Wigner:

$$M = 4.452 \pm 0.016^{+0.055}_{-0.033} \text{ GeV}$$

$$\Gamma = 0.174 \pm 0.019^{+0.083}_{-0.020} \text{ GeV}$$

$$f = (3.7 \pm 0.6^{+4.0}_{-0.7})\%$$

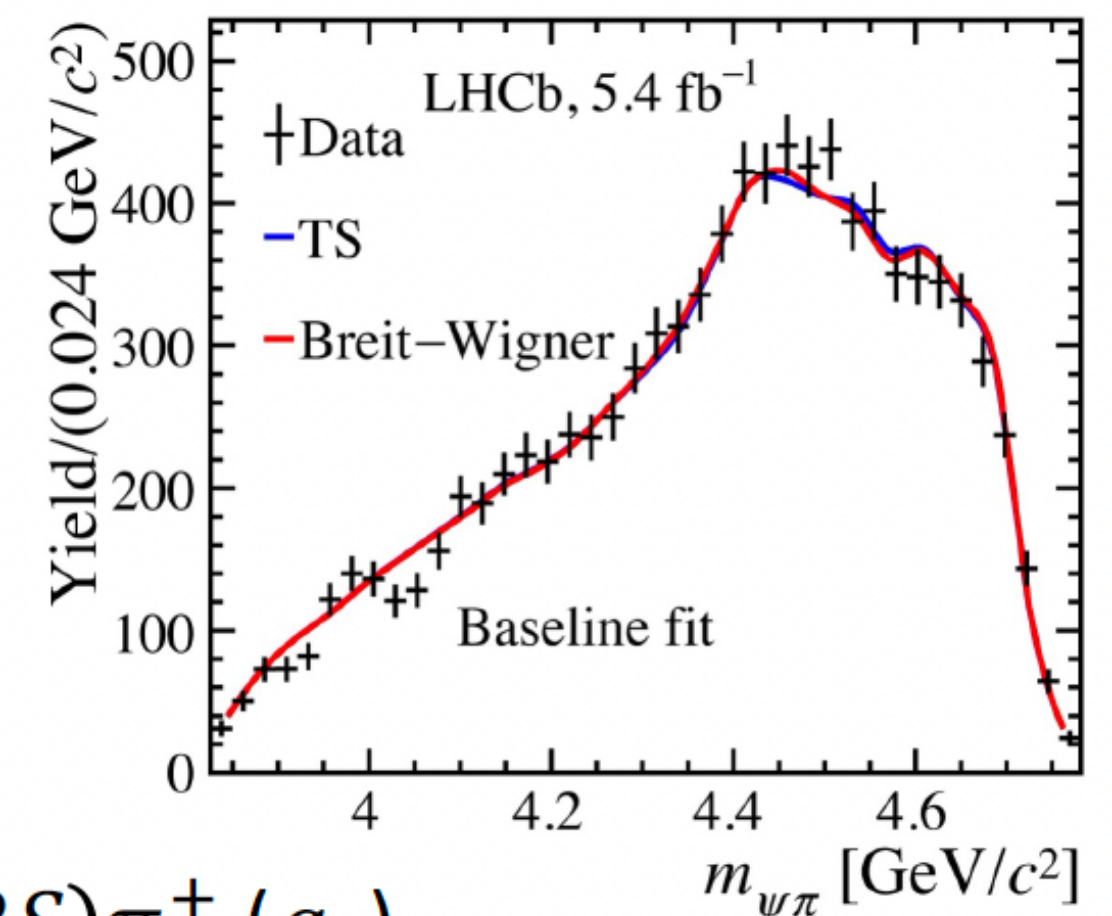
$$J^P = 1^+$$

consistent with $T_{c\bar{c}1}(4430)^+$

- ◆ **Molecular scenario:** Flatte model with coupling to $\bar{D}_1^*(2600)^0 D^+$ (g_2) and $\psi(2S)\pi^+$ (g_1)

$$g_2 = 0.00 \pm 1.78 \pm 2.81 \text{ GeV}/c^2, \left| \frac{g_2}{g_1} \right| < 6.8 @ 95\% \text{ CL}$$

- ◆ **Triangle singularity mechanism:** model incorporating singularity in $\psi(4230)K^{*+}\pi^+$ triangle diagram gives reasonable description

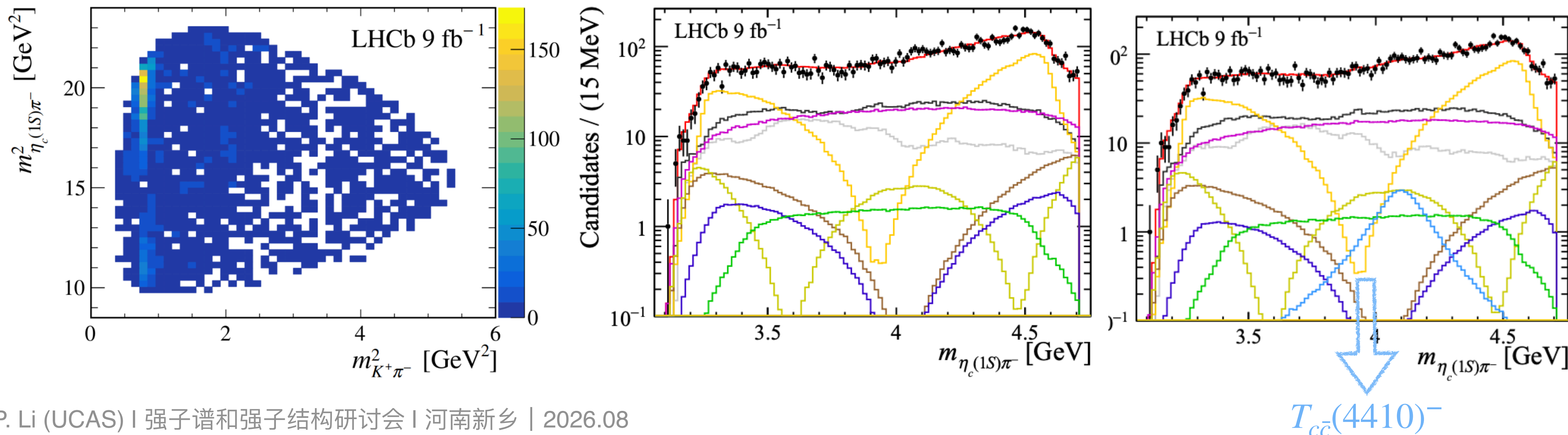


Search for $T_{c\bar{c}}(4410)^-$

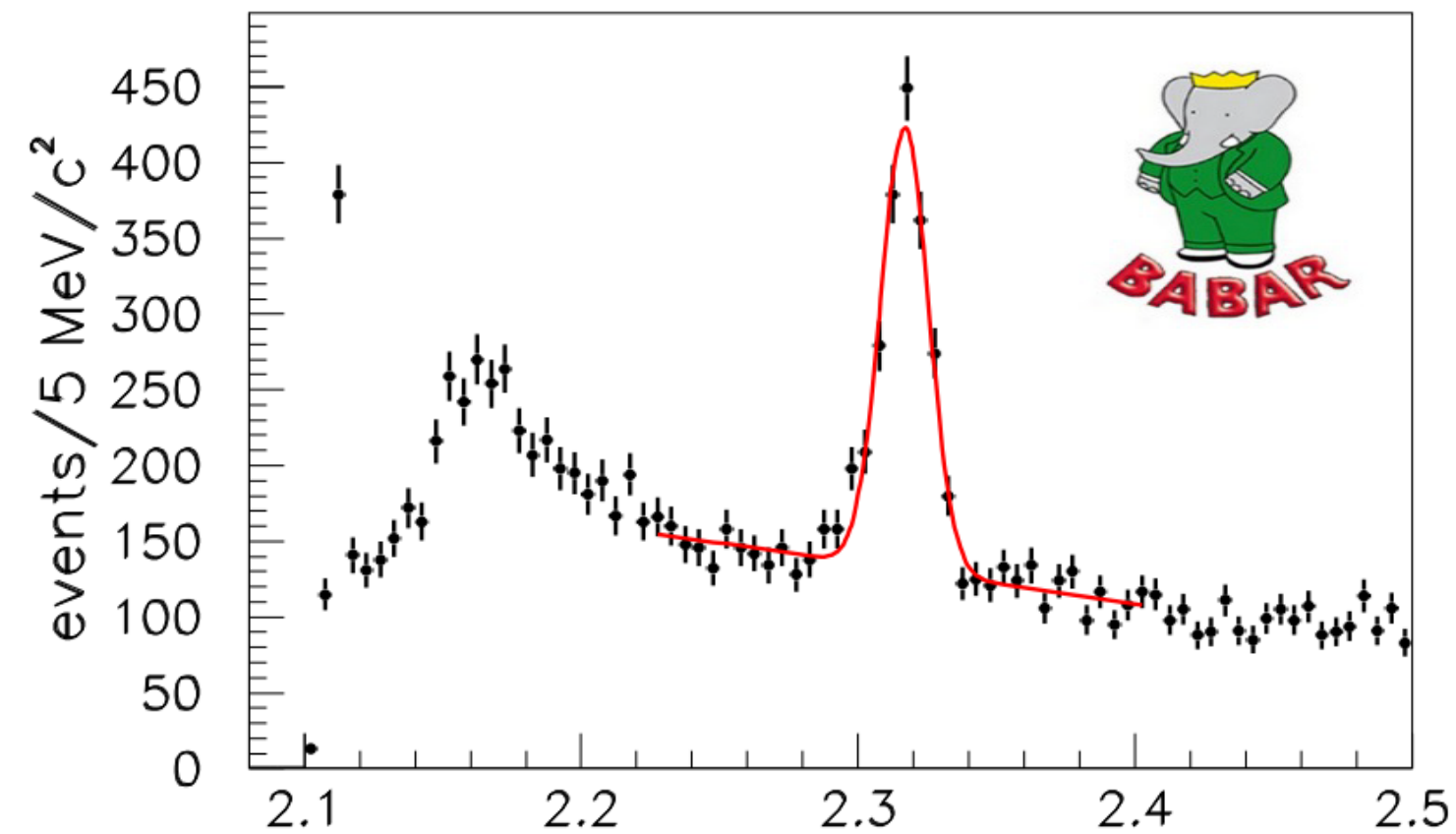
EPJC 86 (2026) 537

- Evidence (3.2σ) of $T_{c\bar{c}}(4410)^-$ was found in $B^0 \rightarrow \eta_c(1S)K^+\pi^-$ with 4.7 fb^{-1} LHCb data
 - $M = 4096 \pm 20^{+18}_{-22} \text{ MeV}$, $\Gamma = 152 \pm 58^{+60}_{-35} \text{ MeV}$ EPJC78(2018)1019
- Amplitude analysis of $B^0 \rightarrow \eta_c(1S)K^+\pi^-$ using 9 fb^{-1} Run 1 + 2 data
- $T_{c\bar{c}}(4410)^-$ is slightly preferred in the amplitude model, but significance less than 3σ when considering systematic uncertainties

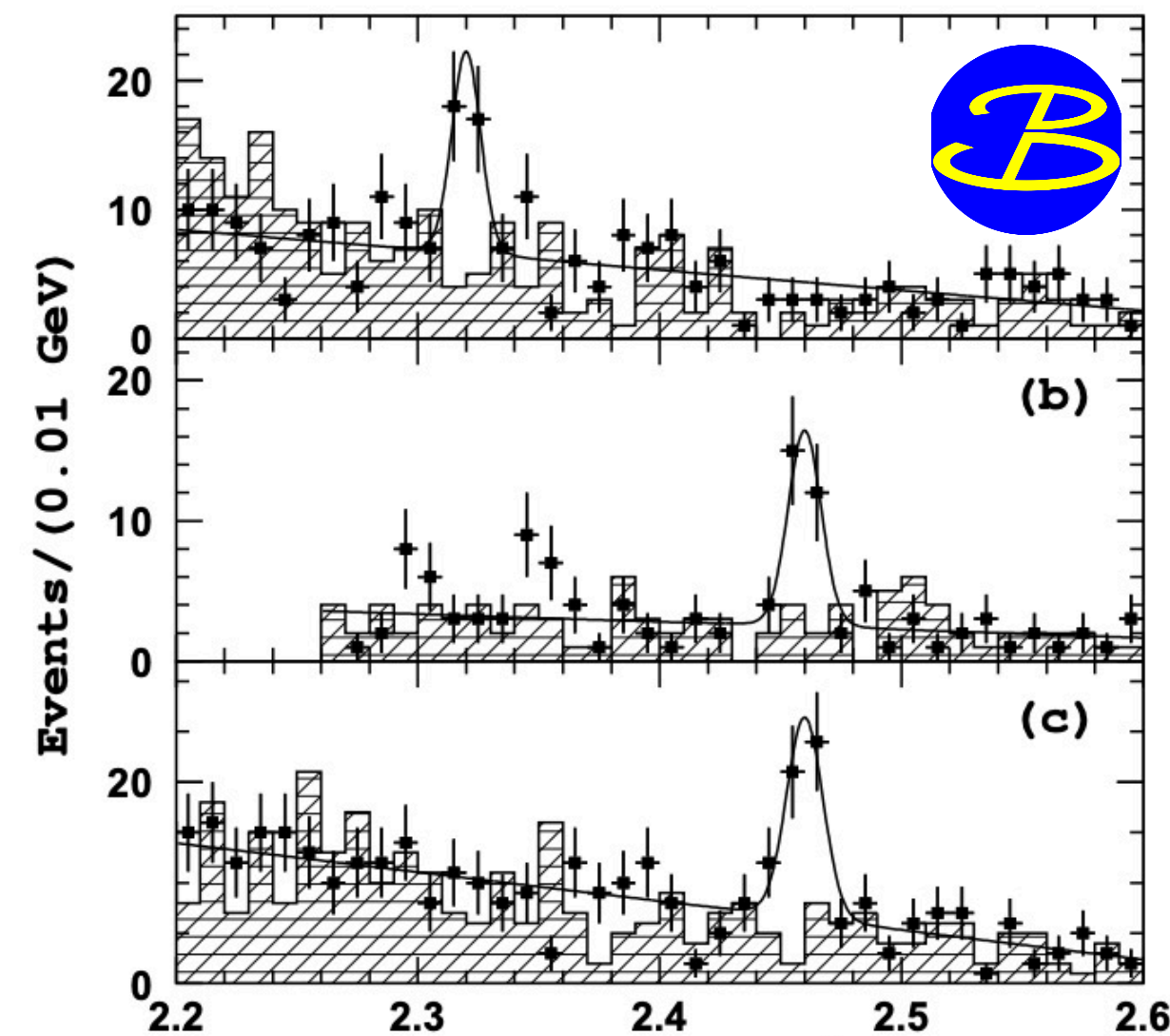
$$\mathcal{B}(B^0 \rightarrow \eta_c(1S)K^+\pi^-) = (5.82 \pm 0.20 \pm 0.23 \pm 0.55) \times 10^{-4}$$



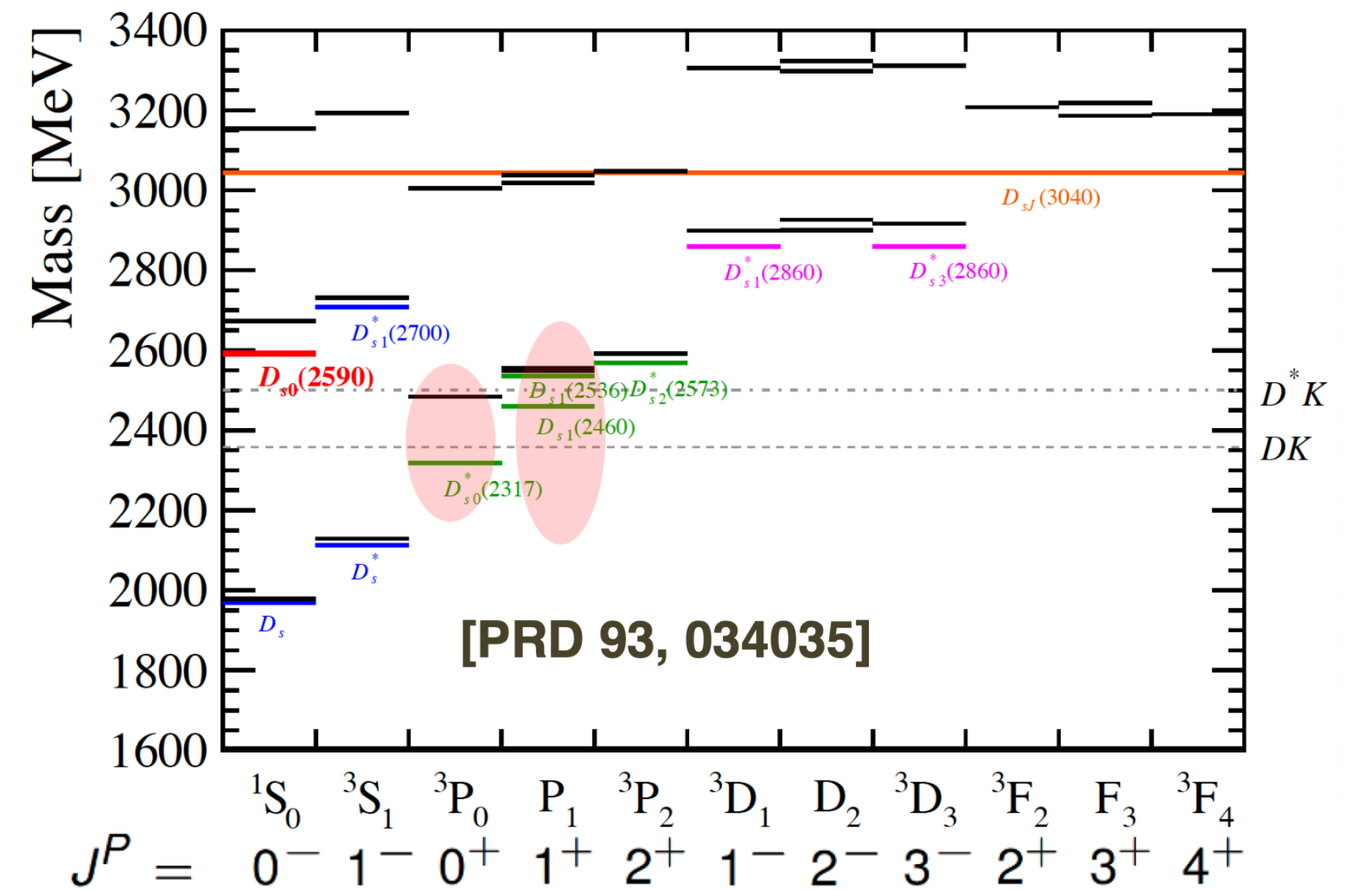
Puzzle in $D_s^\pm$ spectroscopy



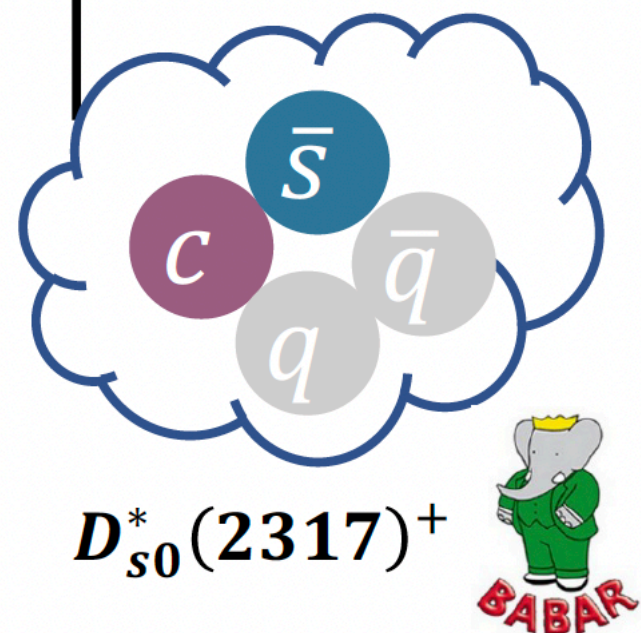
PRL90(2003)242001



PRL90(2003)262002

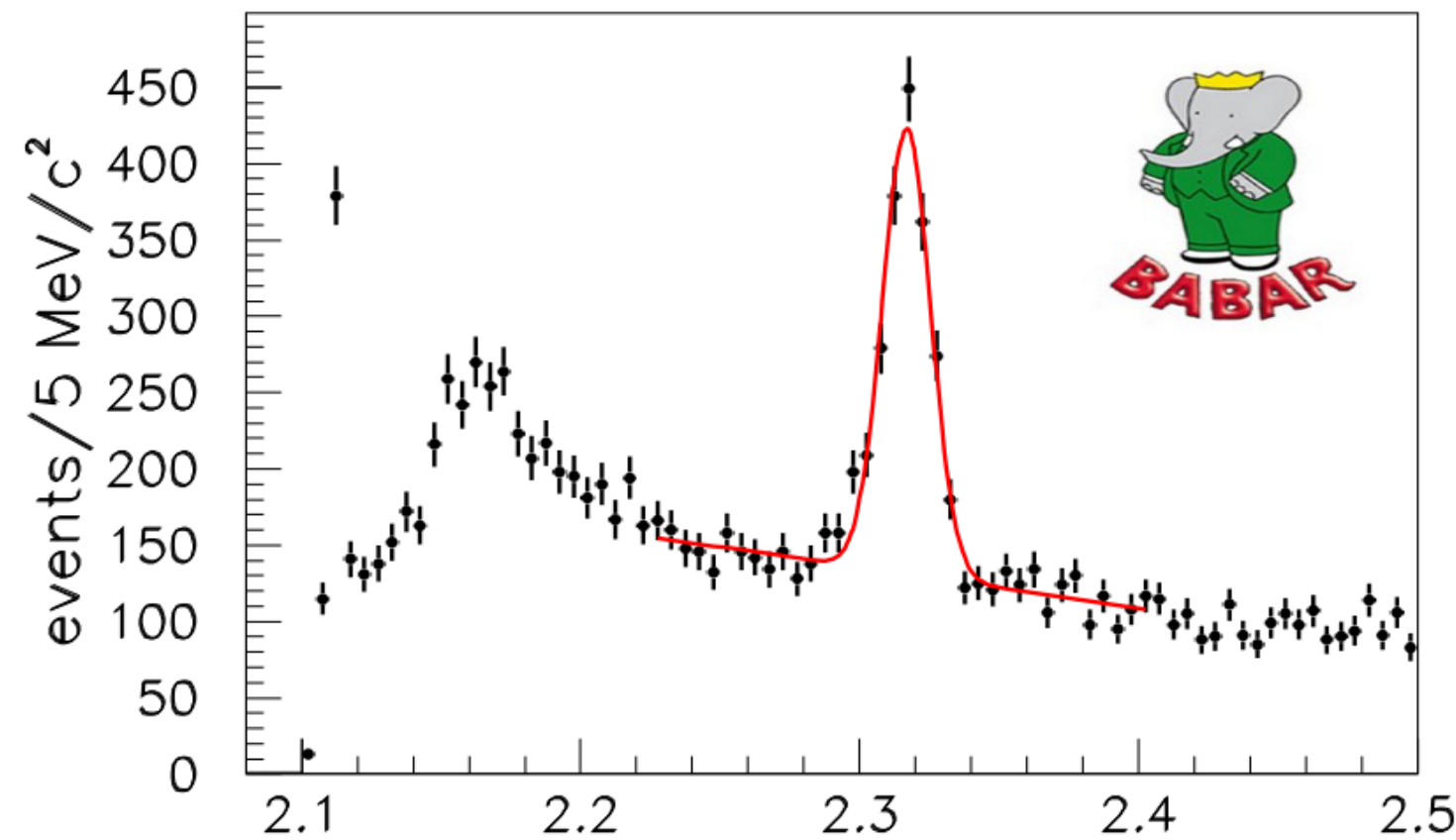


2003

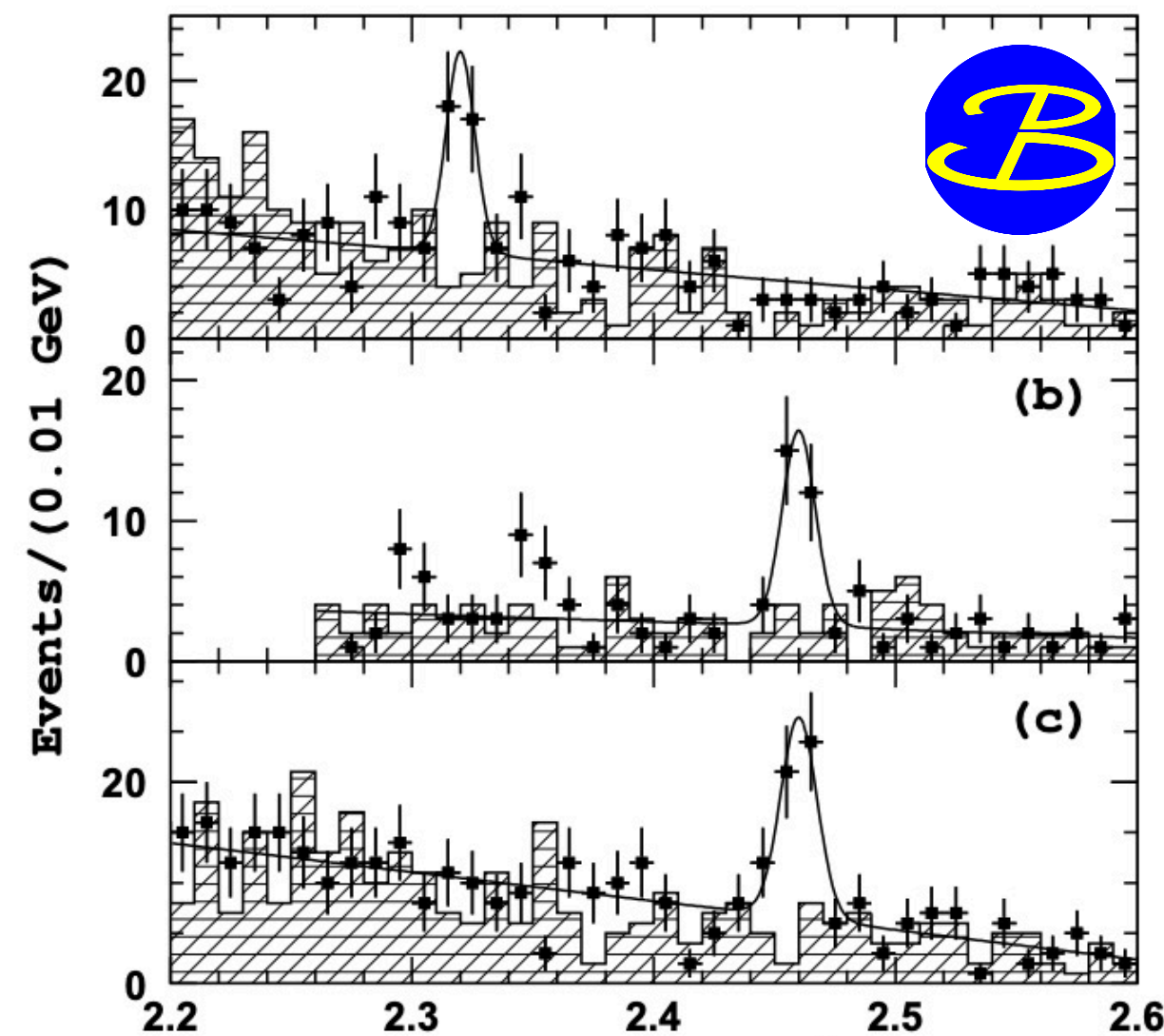


$D_{s0}^*(2317)^+$

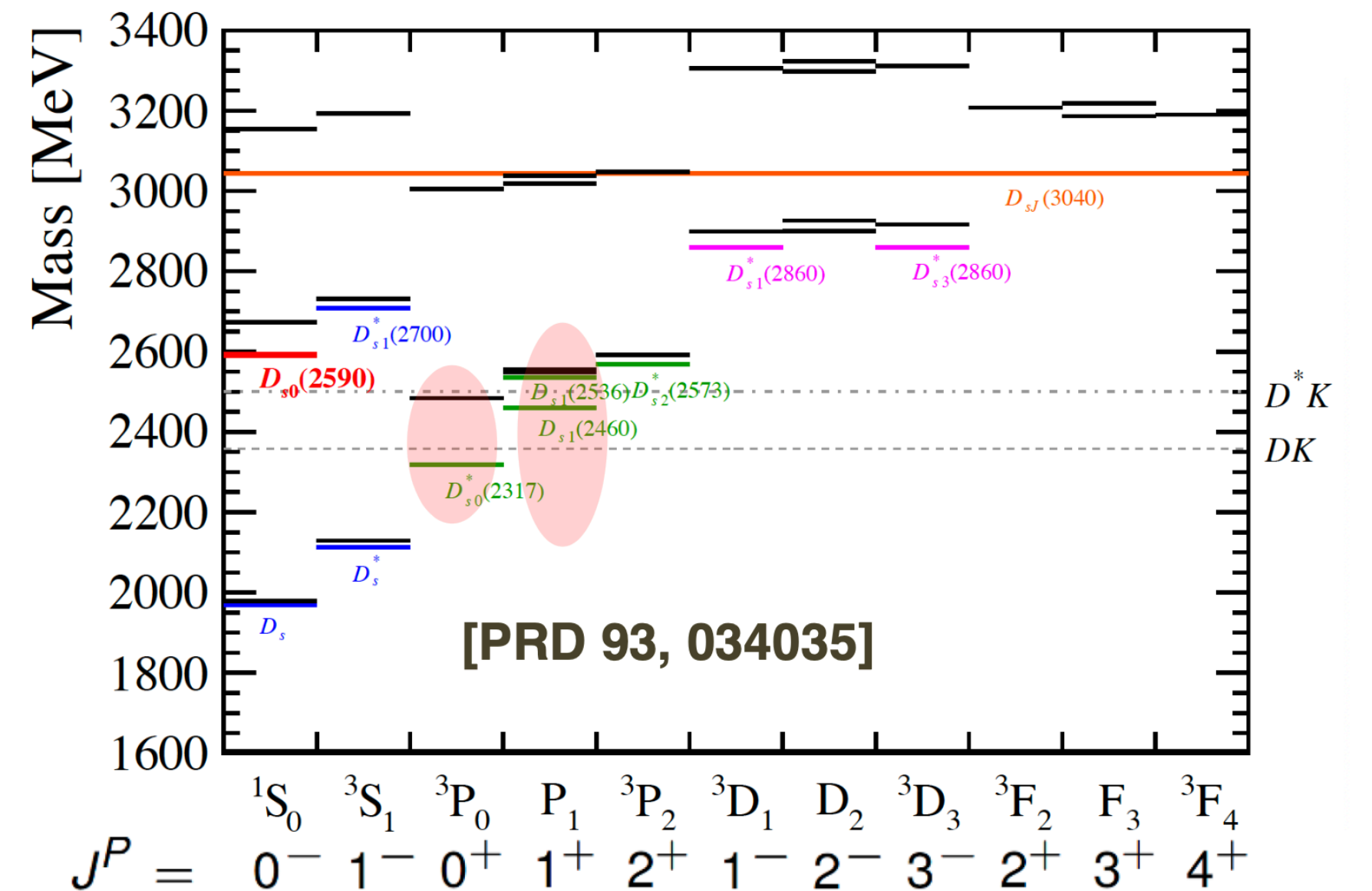
Puzzle in $D_s^\pm$ spectroscopy



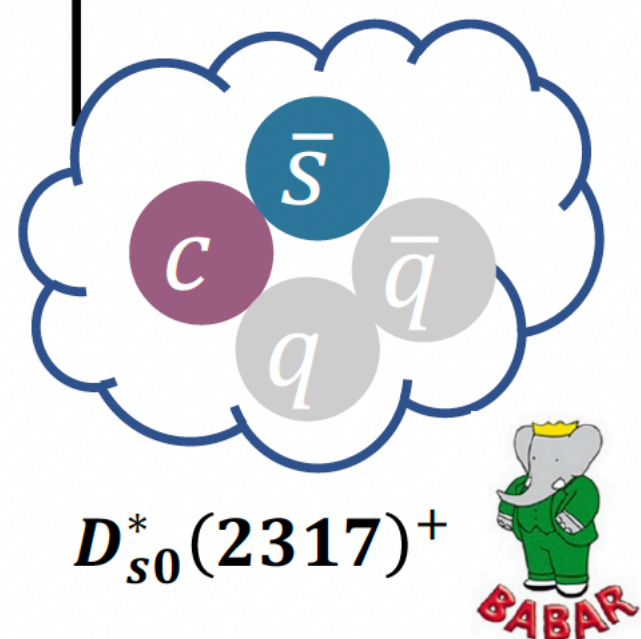
PRL90(2003)242001



PRL90(2003)262002



2003

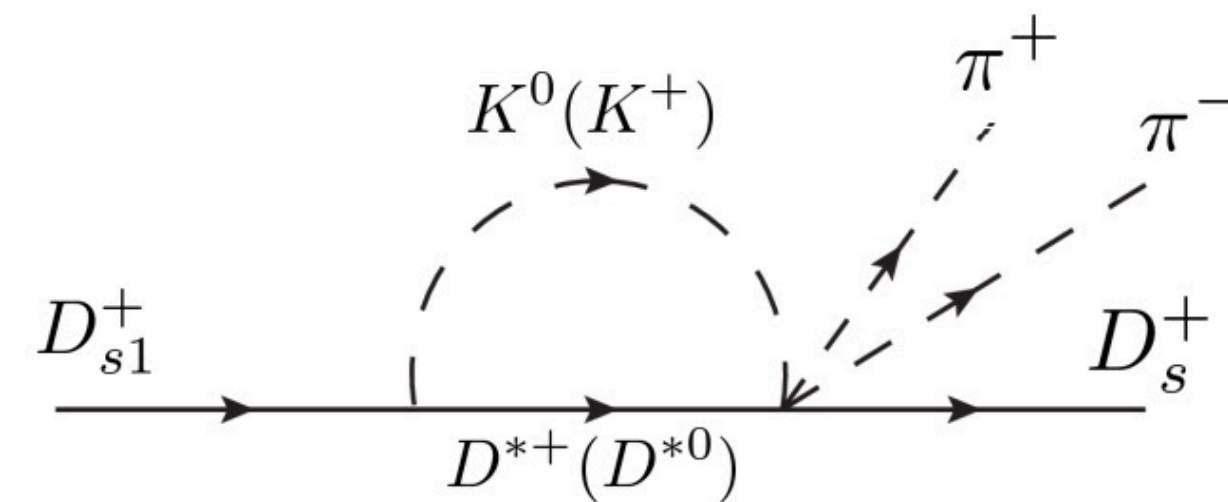


- $D_{s0}^*(2317)^\pm$ and $D_{s1}(2460)^\pm$ are considered candidates of (DK, D^*K) molecules

- Masses ~ 100 MeV below predictions

- Isospin-violating decay $D_s^{(*)+} \pi^0$

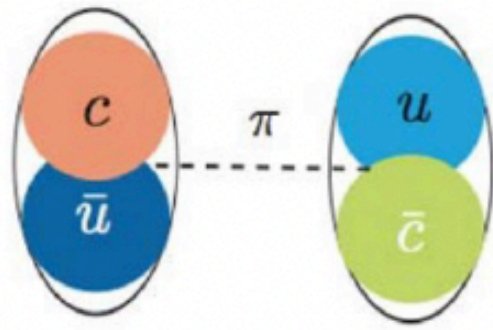
Commun. Theor. Phys.75 055203



- Double-bump line shape in $m(\pi\pi)$ from $D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$ if as D^*K molecule

$T_{c\bar{s}}$ states at LHCb

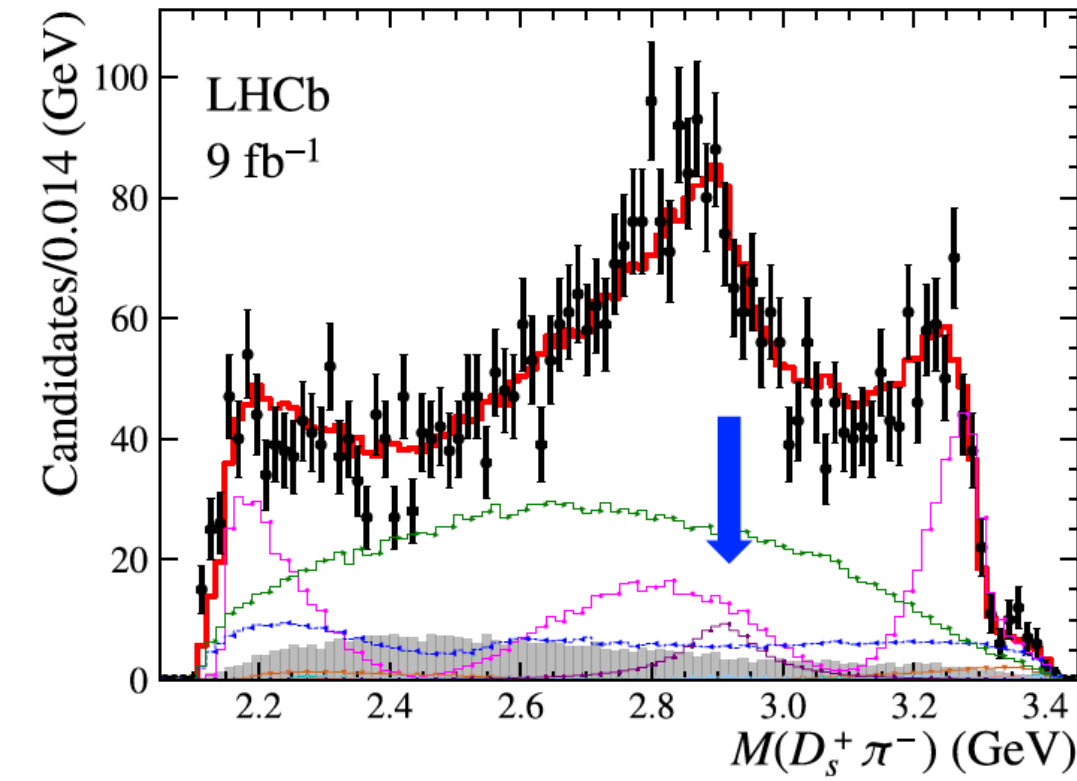
Hadron molecule



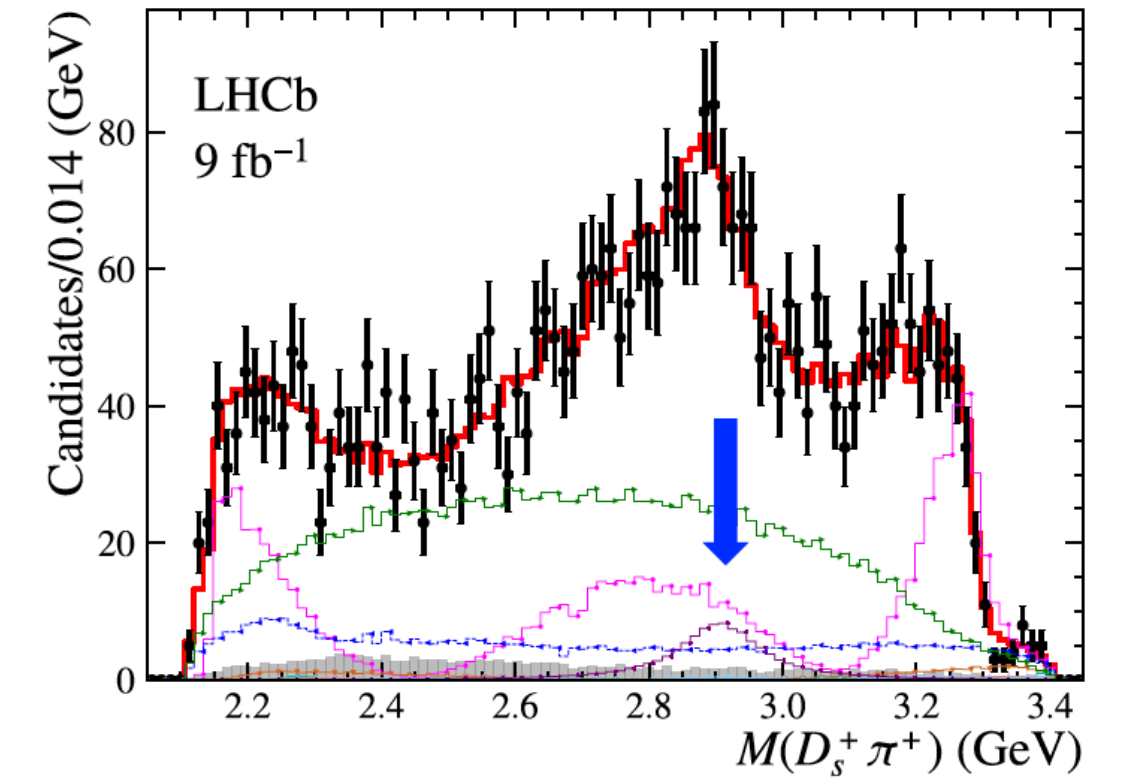
$$\begin{aligned} D_{s0}^*(2317)^+ &\rightarrow DK \\ D_{s1}(2460)^+ &\rightarrow D^*K \\ T_{c\bar{s}0}^*(2900)^{0/++} &\rightarrow D^*K^* \end{aligned}$$

$\Rightarrow$ partners expected, may couple to $D_s^+ \pi^\pm$

$$T_{c\bar{s}0}^*(2900)^0$$

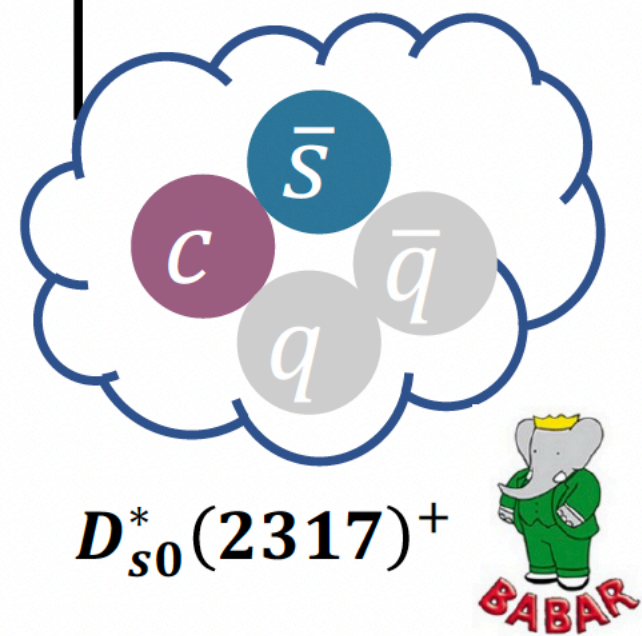


$$T_{c\bar{s}0}^*(2900)^{++}$$

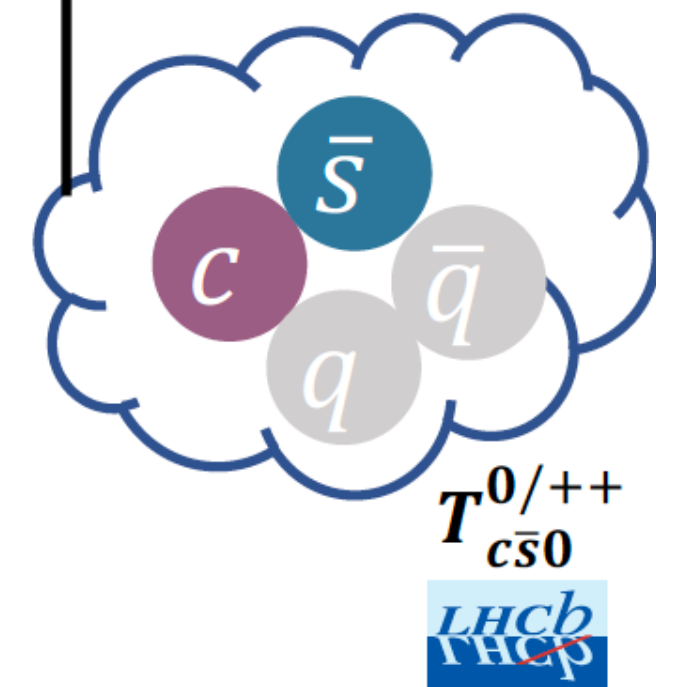


PRL131(2023)041902

2003

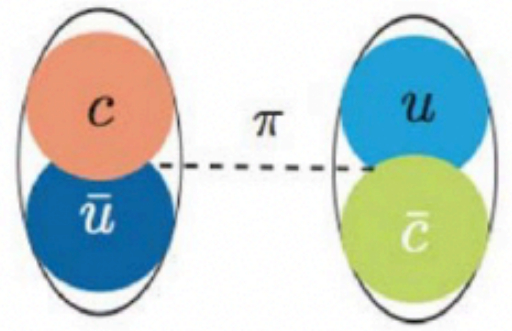


2022



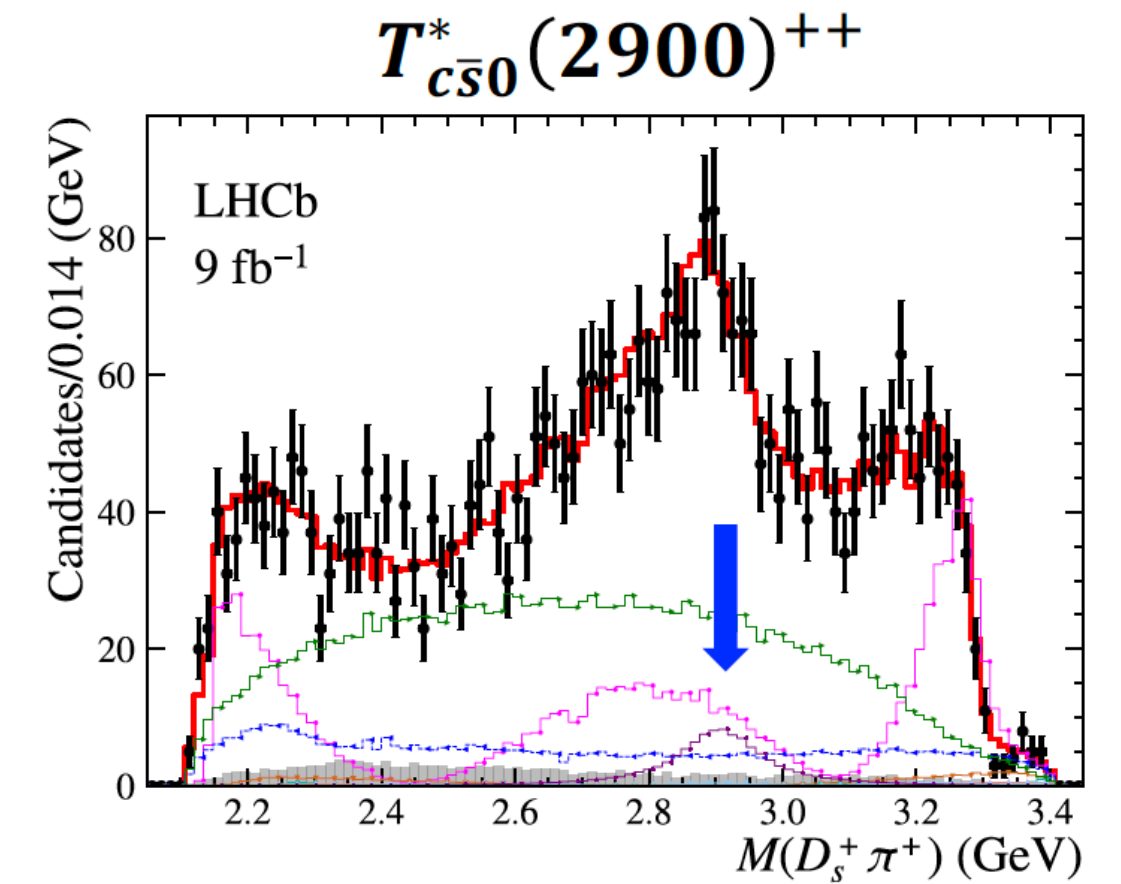
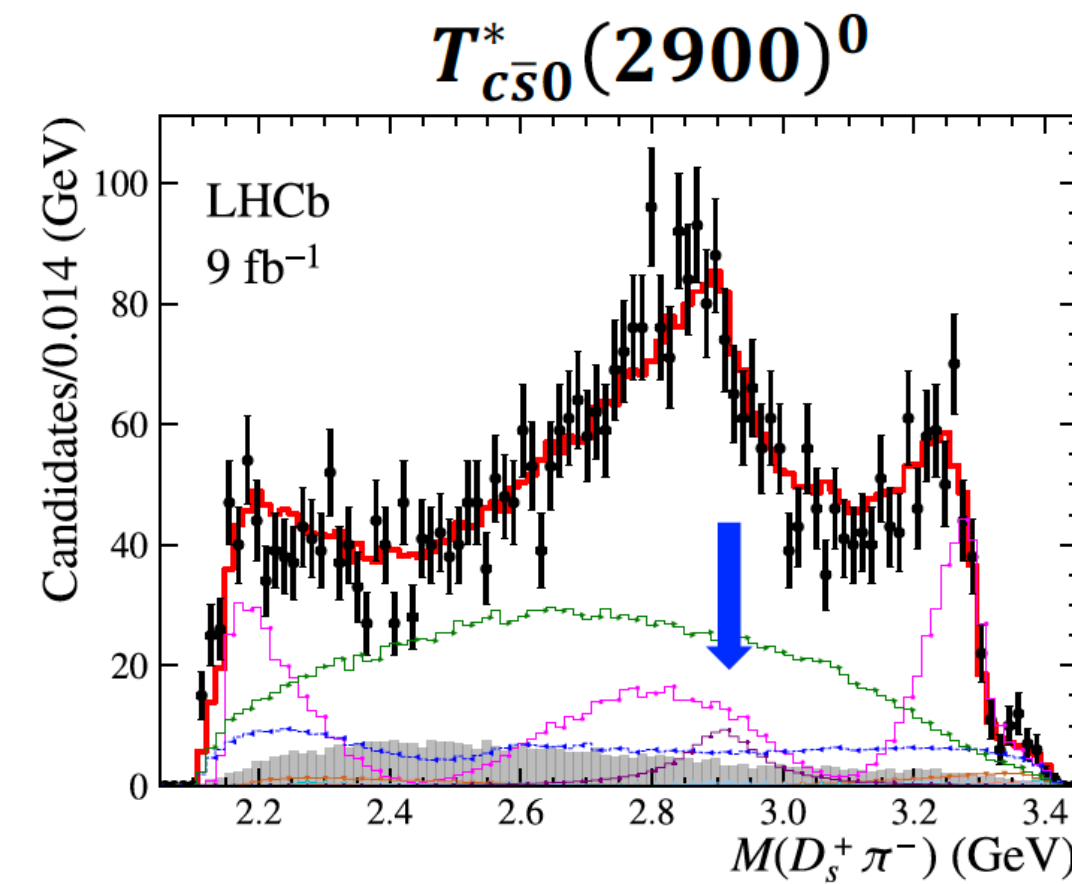
$T_{c\bar{s}}$ states at LHCb

Hadron molecule



$D_{s0}^*(2317)^+ \rightarrow DK$
 $D_{s1}(2460)^+ \rightarrow D^*K$
 $T_{c\bar{s}0}^*(2900)^{0/++} \rightarrow D^*K^*$

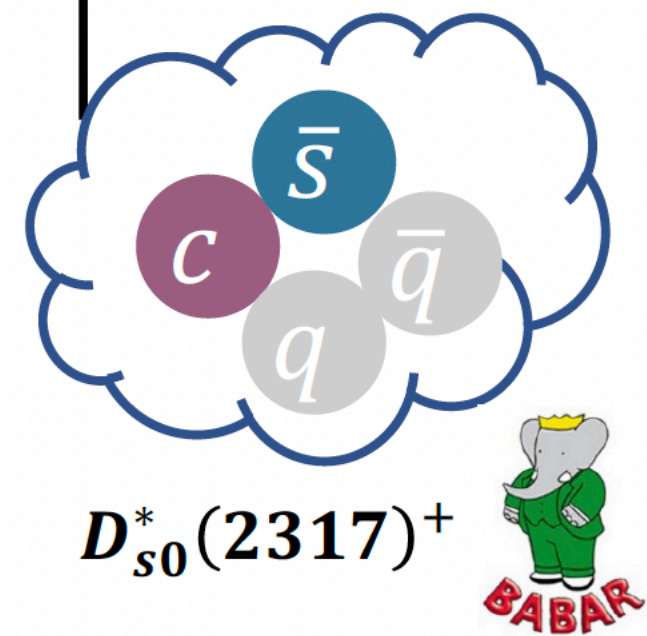
$\Rightarrow$ partners expected, may couple to $D_s^+ \pi^\pm$



PRL131(2023)041902

2003

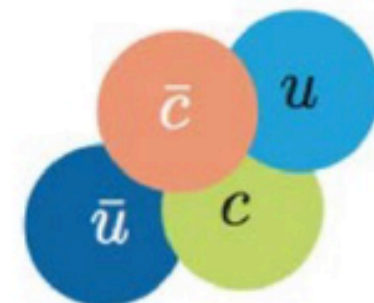
2022



Compact multiquark

PRD 110 (2024)034014

$S_{33}(2335 \pm 100) \rightarrow \bar{D}^0 K^0, K^+ K^0 \pi^-$ (weak decay)



$S_{11}(2367 \pm 10) \rightarrow \bar{D}_s^- \pi^-$

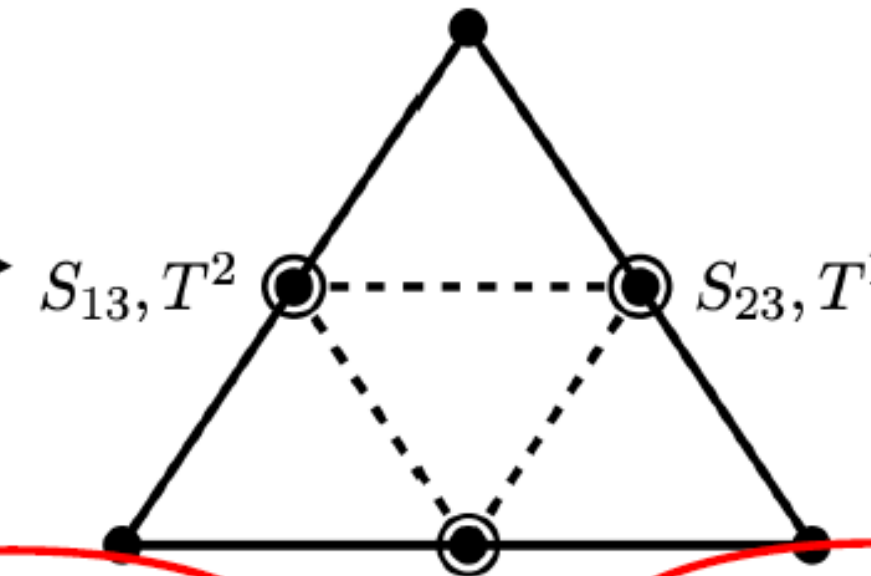
$D_{s0}^{*-}(2317)$

+ second state

$S_{22}(2367 \pm 10) \rightarrow \bar{D}_s^- \pi^+$

radial excitation

$S_{33} = X_0(2900)$



$S_{11} = D_{s0}^{*-}(2900)$

S_{12}, T^3

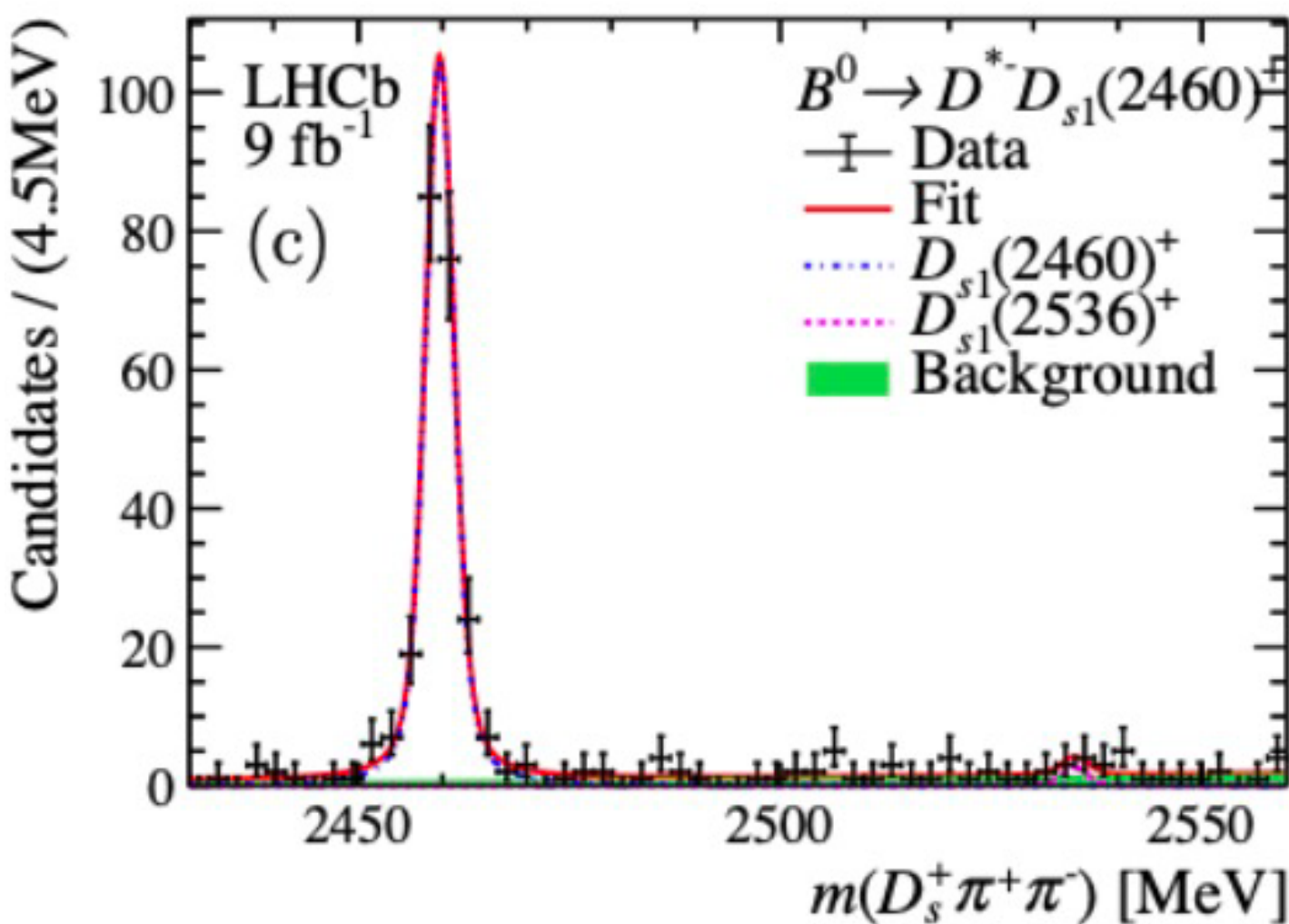
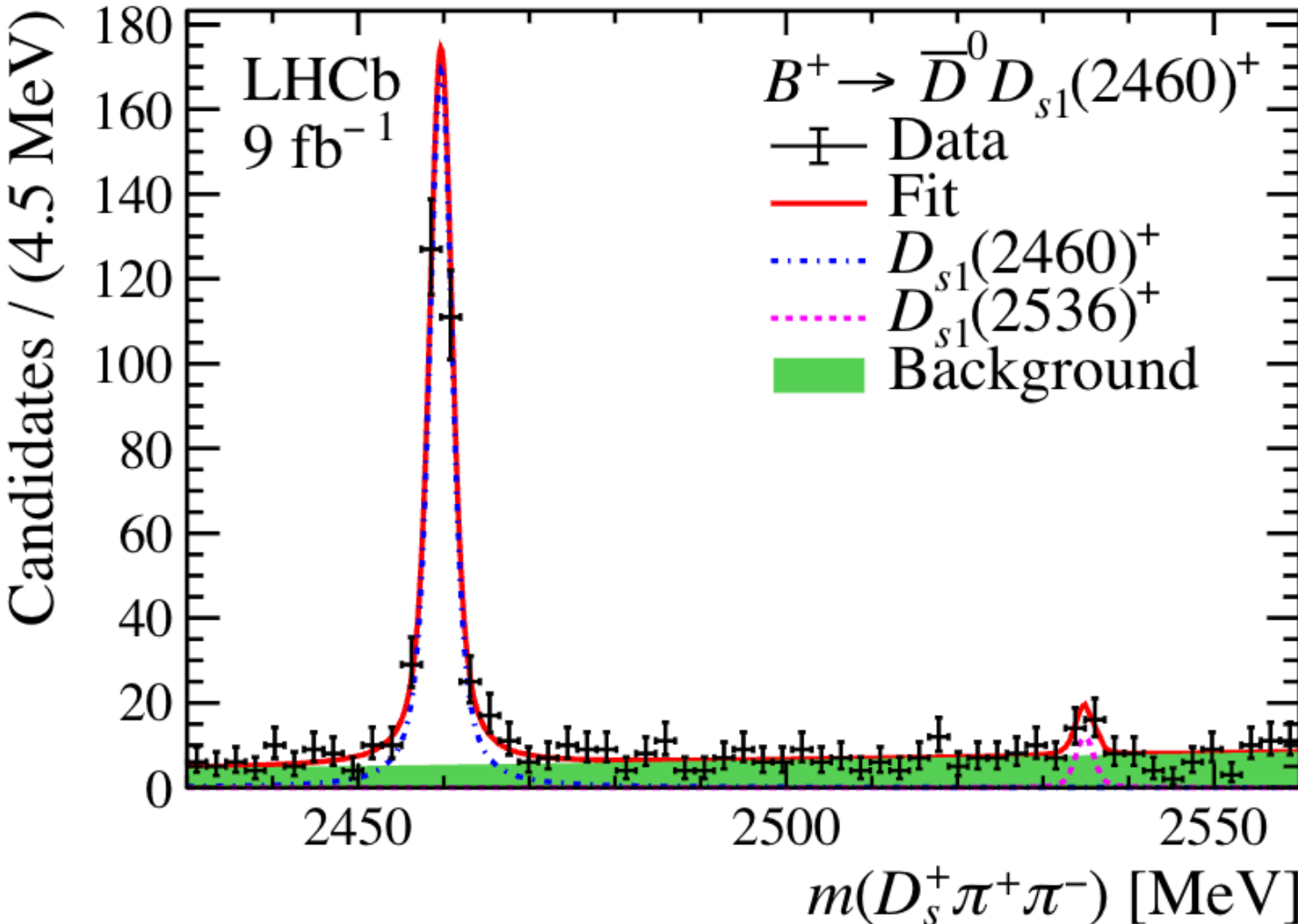
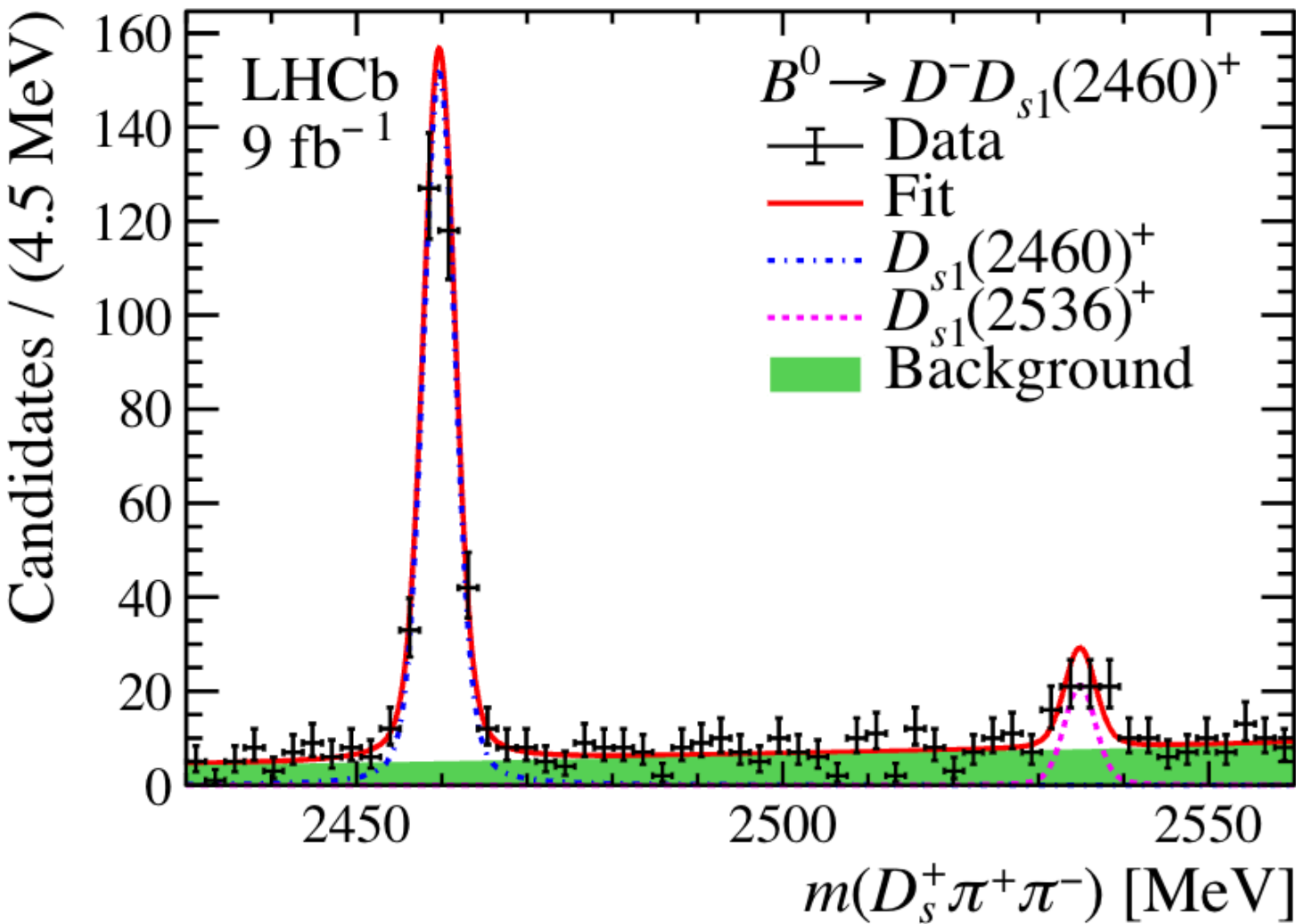
$S_{22} = D_{s0}^0(2900)$



- Isospin partners of $D_{s0}^*(2317)$ proposed inspired by $T_{c\bar{s}}(2900)^{++/0} \rightarrow D_s^+ \pi^{+/-}$

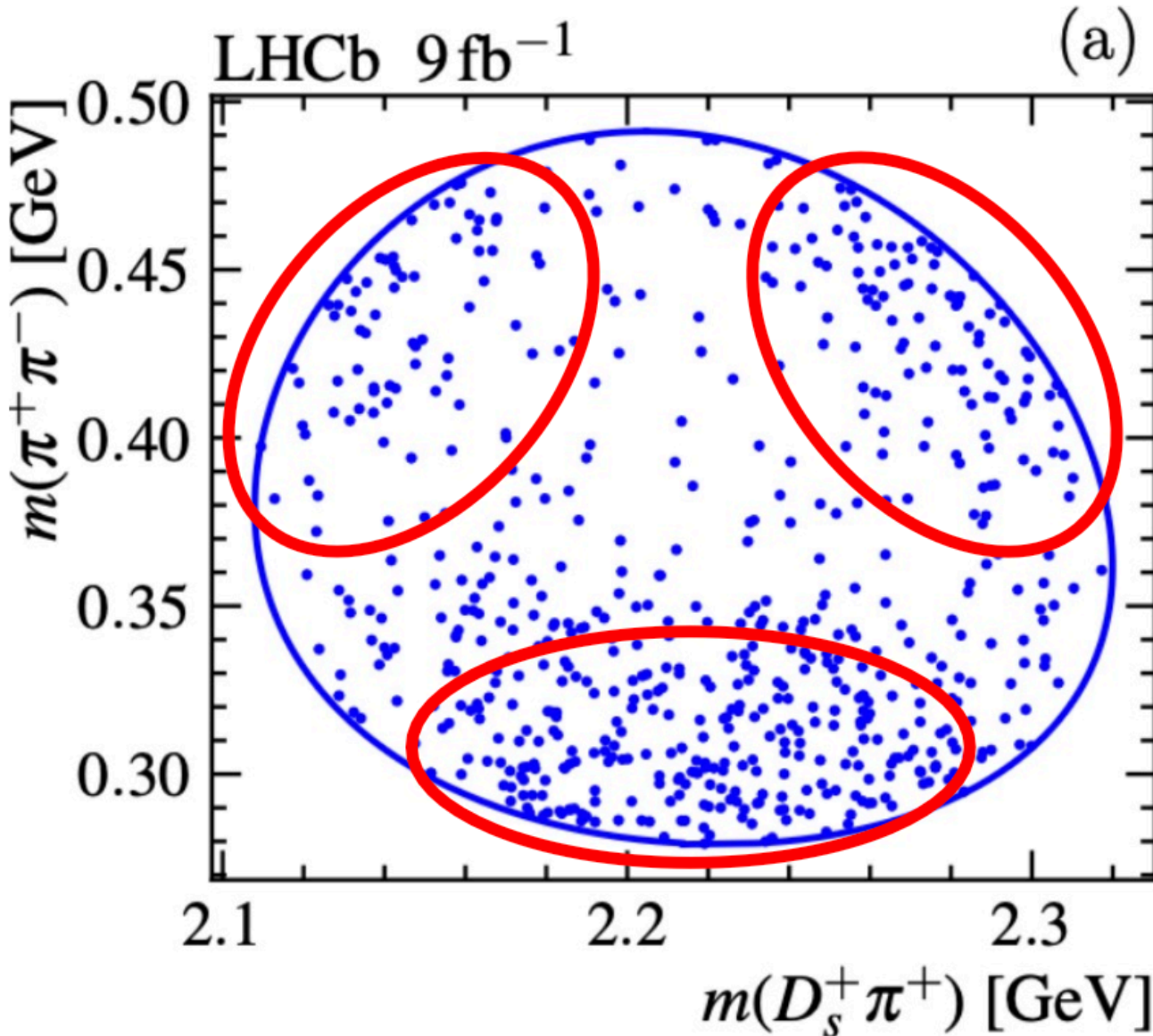
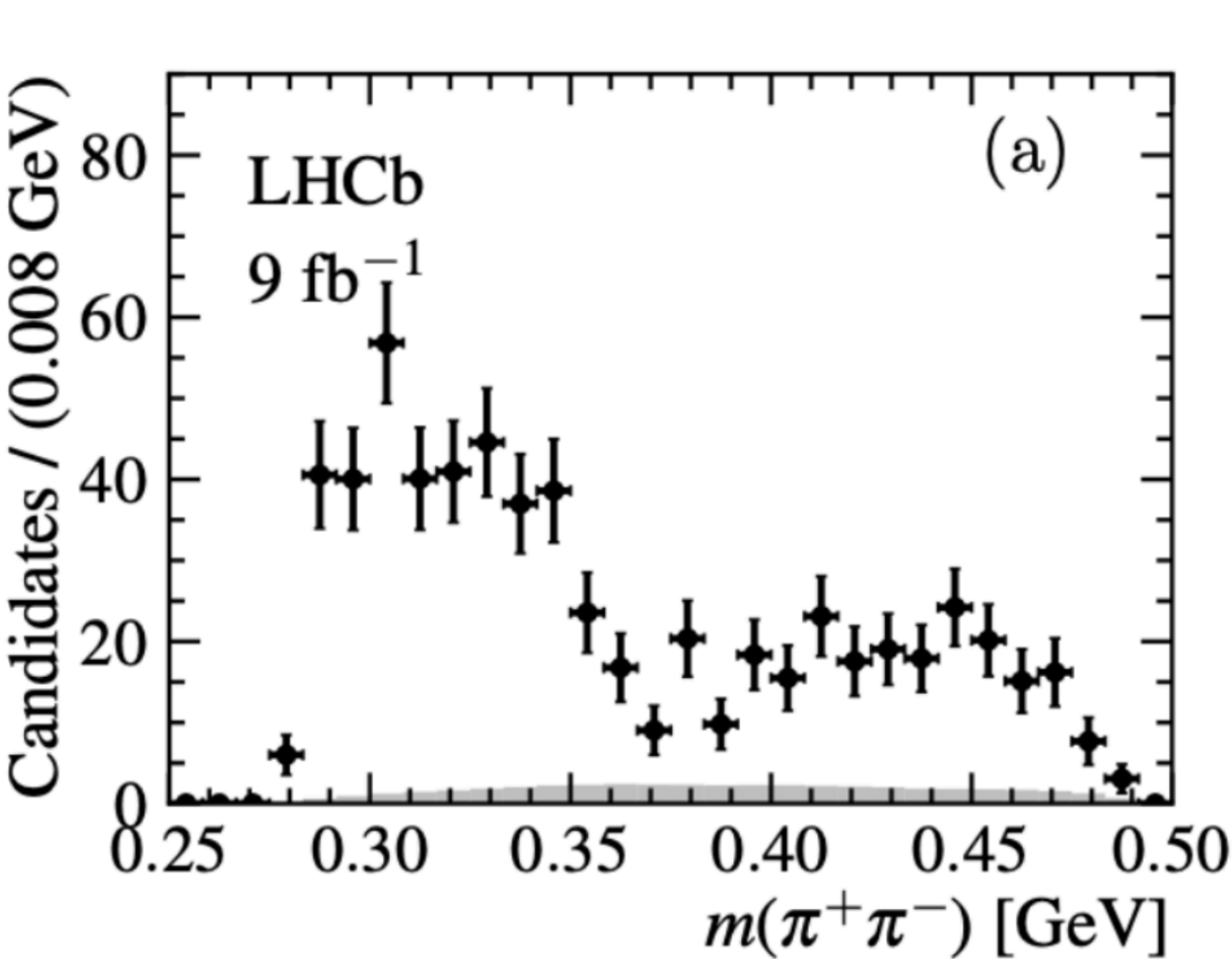
Study of $D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$

Sci.Bull. 70(2025)1432–1444



Channel	Signal yield
$B^0 \rightarrow D^- D_s^+ \pi^+ \pi^-$	305 ± 20
$B^+ \rightarrow \bar{D}^0 D_s^+ \pi^+ \pi^-$	279 ± 18
$B^0 \rightarrow D^{*-} D_s^+ \pi^+ \pi^-$	205 ± 14

$\sim 800 D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$



Study of $D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$

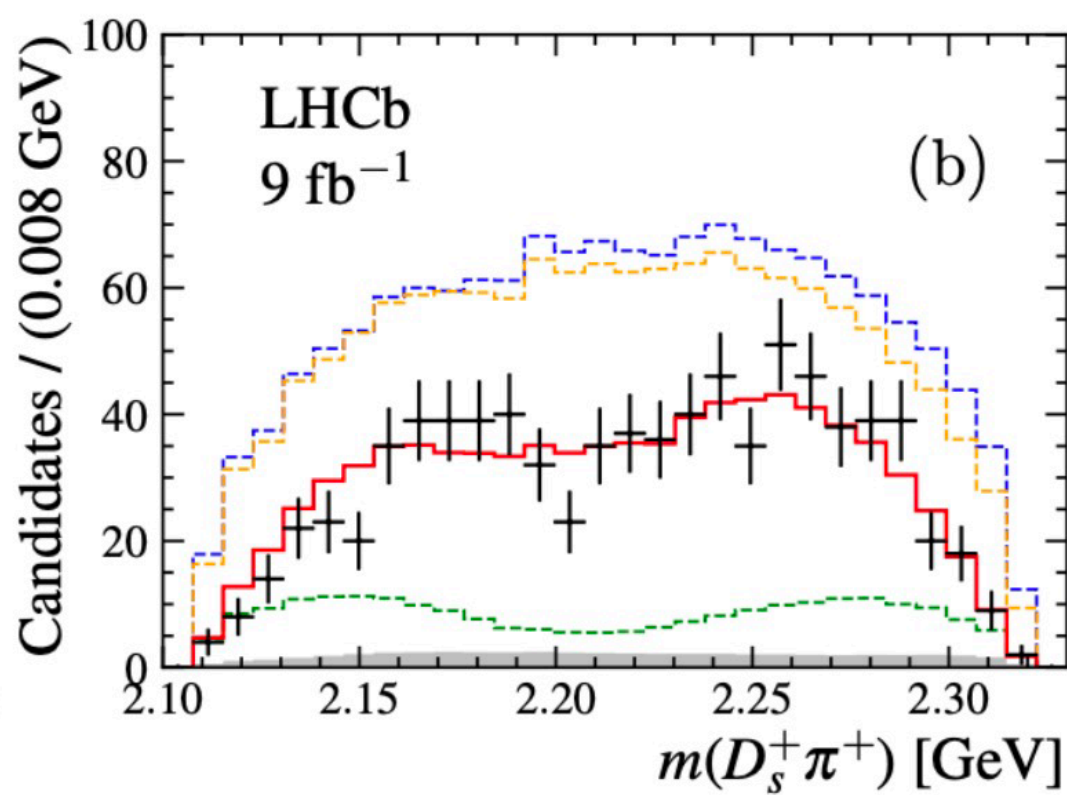
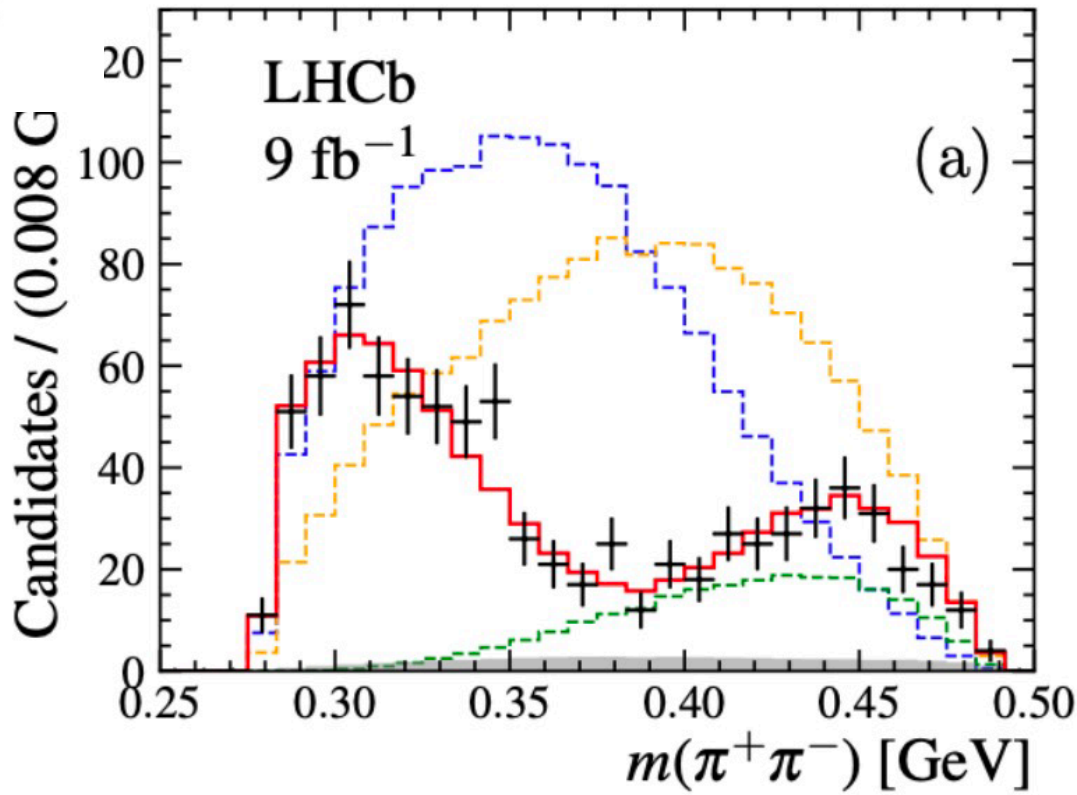
Sci.Bull. 70(2025)1432–1444

Two models describe data equally well!

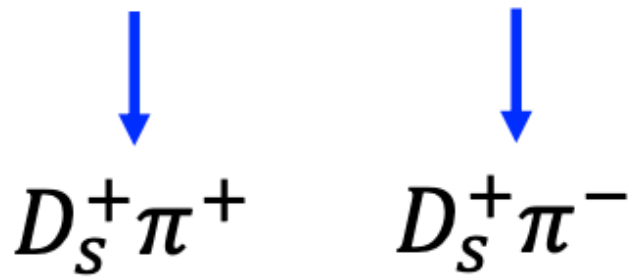
- $f_0(500) + f_0(980) + f_2(1270)$
 - Large contribution from $f_0(980)$ and $f_2(1270)$ despite beyond phase space limit
 - Can't be rejected, but **implausible**

Resonance	Mass (MeV)	Width (MeV)	FF (%)
$f_0(500)$	$376 \pm 9 \pm 16$	$175 \pm 23 \pm 16$	$197 \pm 35 \pm 23$
$f_0(980)$	945.5	167	$187 \pm 38 \pm 43$
$f_2(1270)$	1275.4	186.6	$29 \pm 2 \pm 1$

--- $f_0(500)$
--- $f_0(980)$
--- $f_2(1270)$
■ Background
— Total fit
+ Data



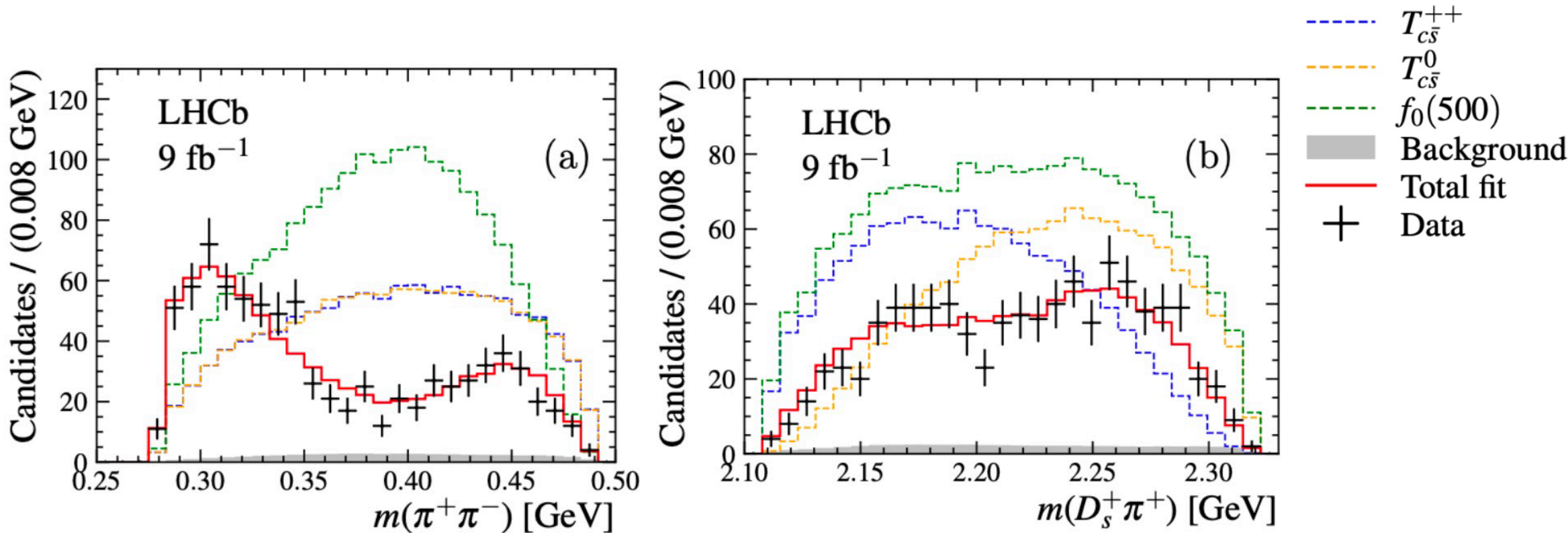
- $f_0(500) + T_{c\bar{s}}^{++} + T_{c\bar{s}}^0$ (new exotics)



Consistent with isospin symmetry

$T_{c\bar{s}}$ masses $\sim D_{s0}^*(2317)^+$, but different widths

Resonance	Mass (MeV)	Width (MeV)	FF (%)
$f_0(500)$	$472 \pm 32 \pm 19$	$226 \pm 24 \pm 18$	$237^{+51}_{-43} \pm 42$
$T_{c\bar{s}}$	$2328 \pm 12 \pm 12$	$96 \pm 16^{+170}_{-23}$	$151^{+31}_{-33} \pm 25$

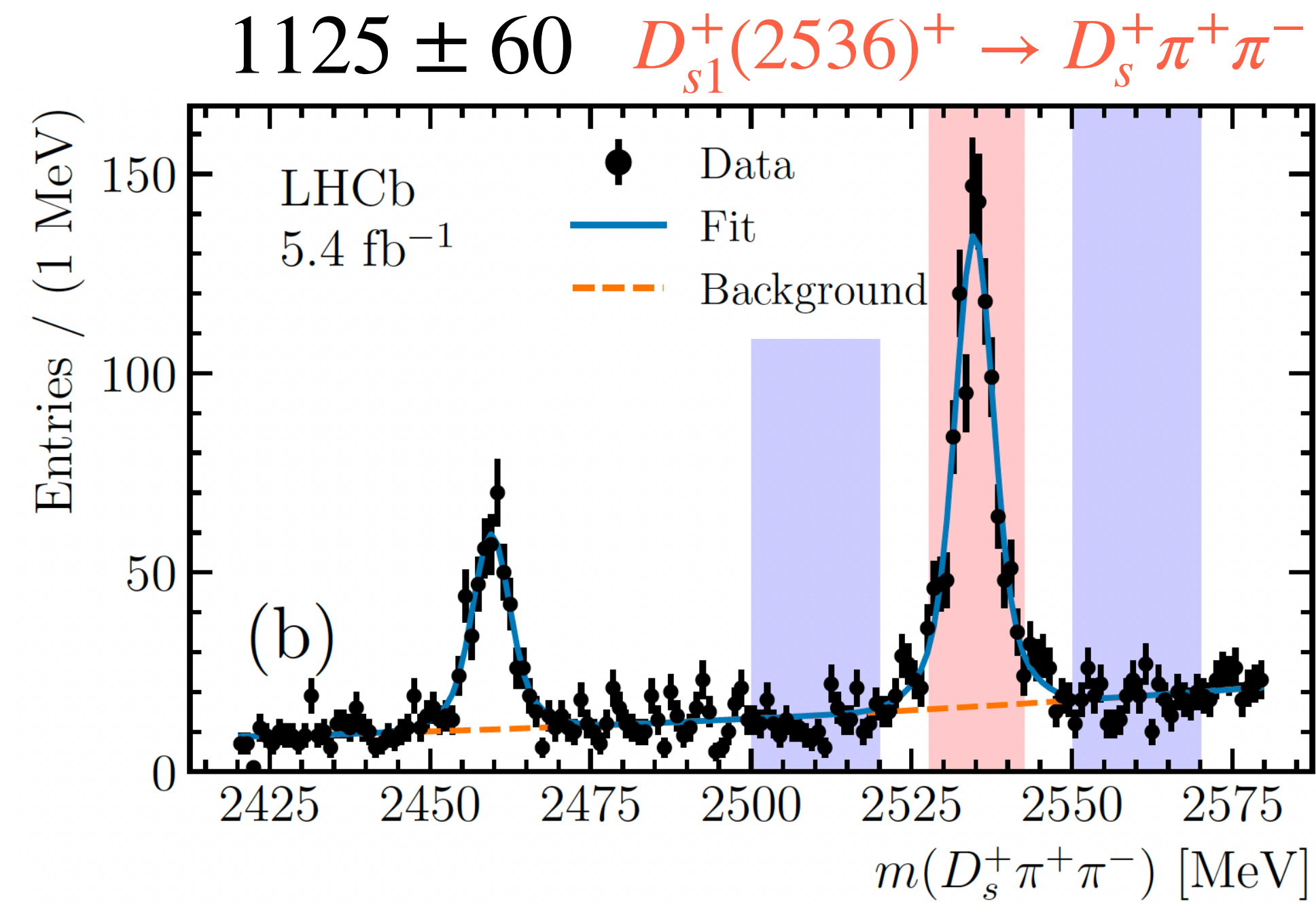
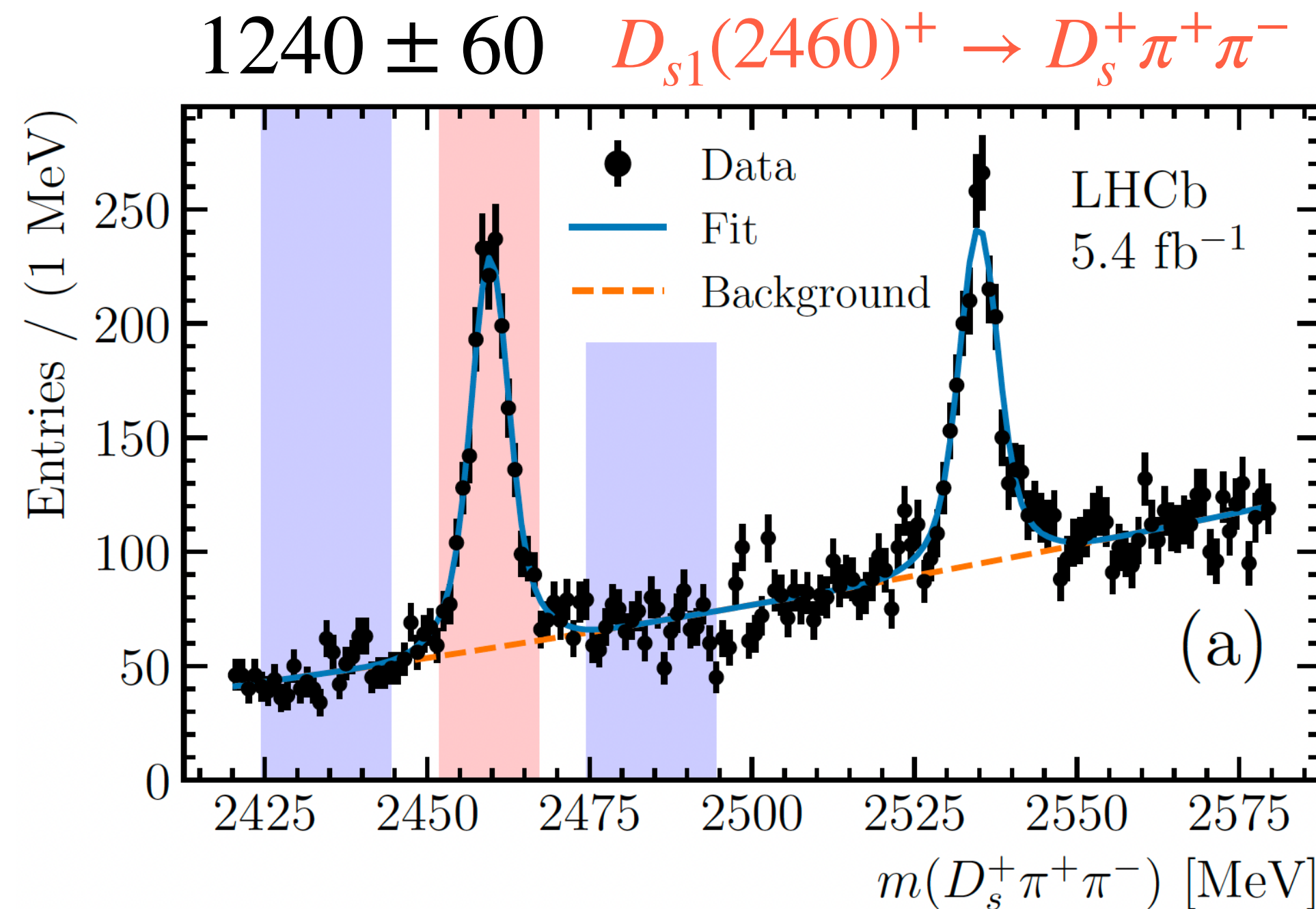


μ -tagged $D_{s1}(2460)^+/D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$

arXiv:2608.10826

- $D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$ from μ -tagged $B \rightarrow D_{s1}(2460)^+ (\bar{D}^{(*)}) \rightarrow \mu \bar{\nu} X_\mu$ predominately
- $D_{s1}^+(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$ mostly from $\bar{B}_s^0 \rightarrow D_{s1}(2536)^+ \mu^- \bar{\nu}_\mu$
- $D_{s1}^+(2536)^+$ was assumed to be either a conventional $c\bar{s}$ meson or D^*K molecule
- Branching fraction of $D_{s1}^+(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$ measured for the first time w.r.t $D_{s1}^+(2536)^+ \rightarrow D^+ K^+ \pi^-$

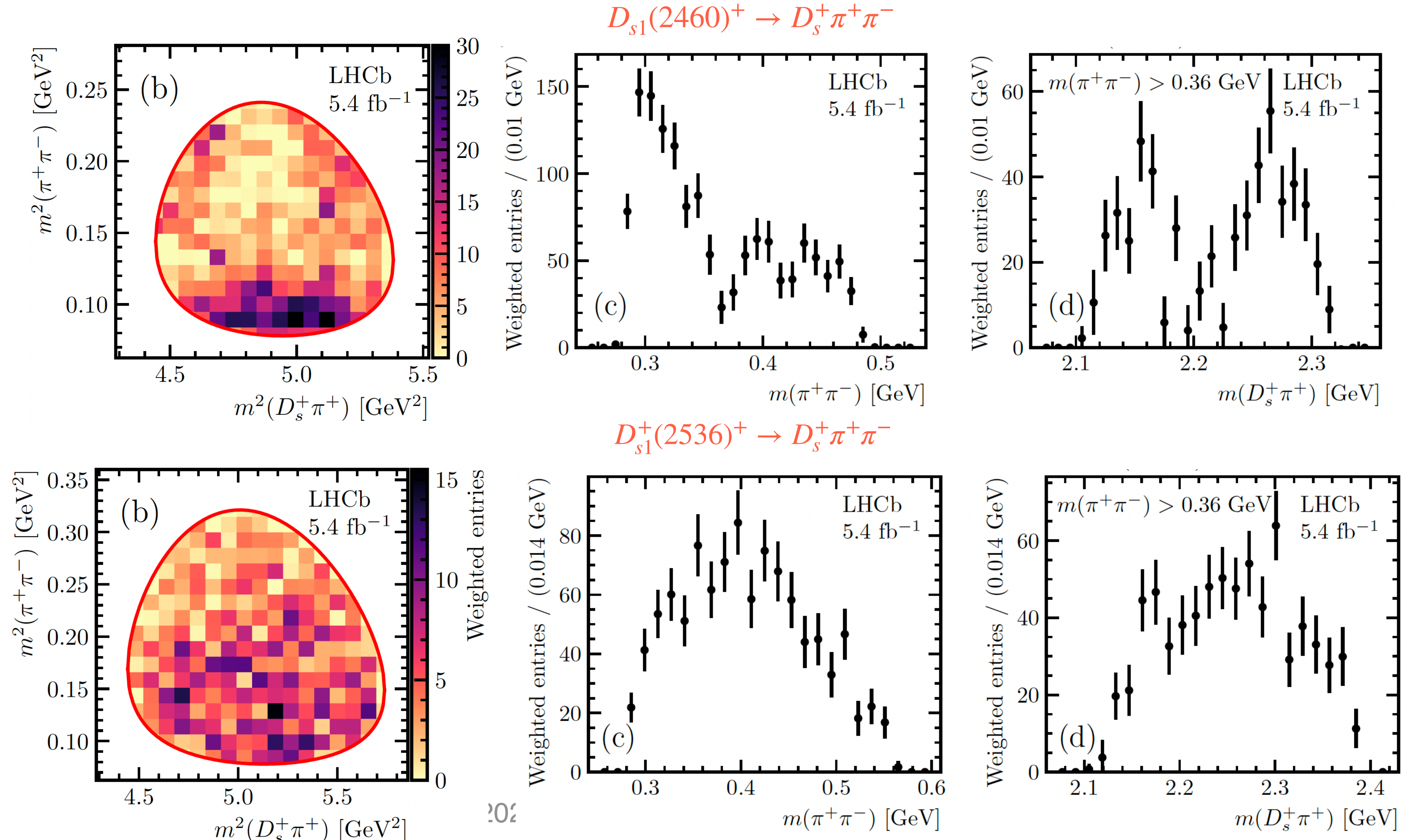
$$\frac{\mathcal{B}(D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-)}{\mathcal{B}(D_{s1}(2536)^+ \rightarrow D^+ K^+ \pi^-)} = 1.57 \pm 0.08 \pm 0.09 \pm 0.17$$



μ -tagged $D_{s1}(2460)^+/D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$

[arXiv:2608.10826](https://arxiv.org/abs/2608.10826)

- Significant different Dalitz plots suggests differences in the internal structure of the two states

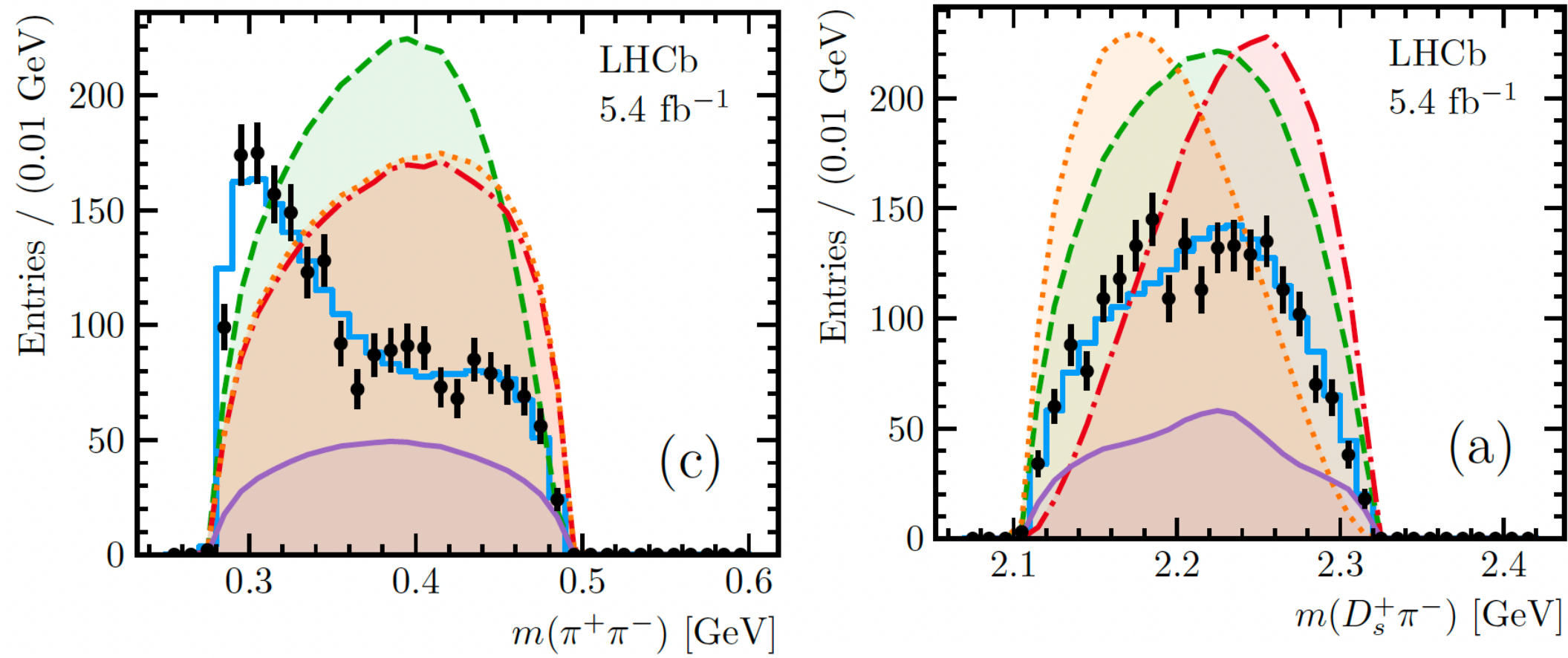


μ -tagged $D_{s1}(2460)^+/D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$

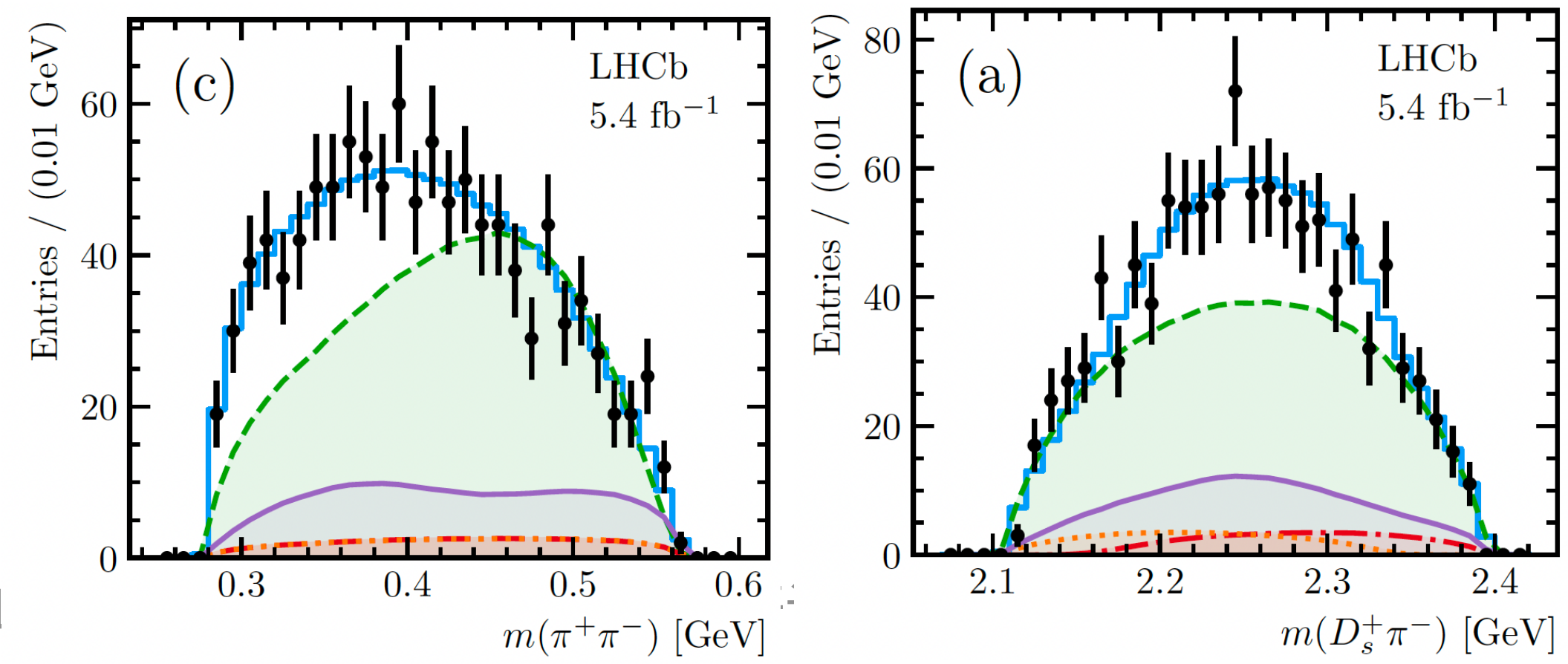
arXiv:2608.10826

- A simultaneous amplitude analysis of $D_{s1}(2460)^+$ and $D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$
- Baseline model same as in previous analysis of $B \rightarrow DD\pi\pi$ $-2 \ln \mathcal{L}^{(\text{comb})} = -2 \ln \mathcal{L}^{(2460)} - 2 \ln \mathcal{L}^{(2536)}$

$D_{s1}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-$



$D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$



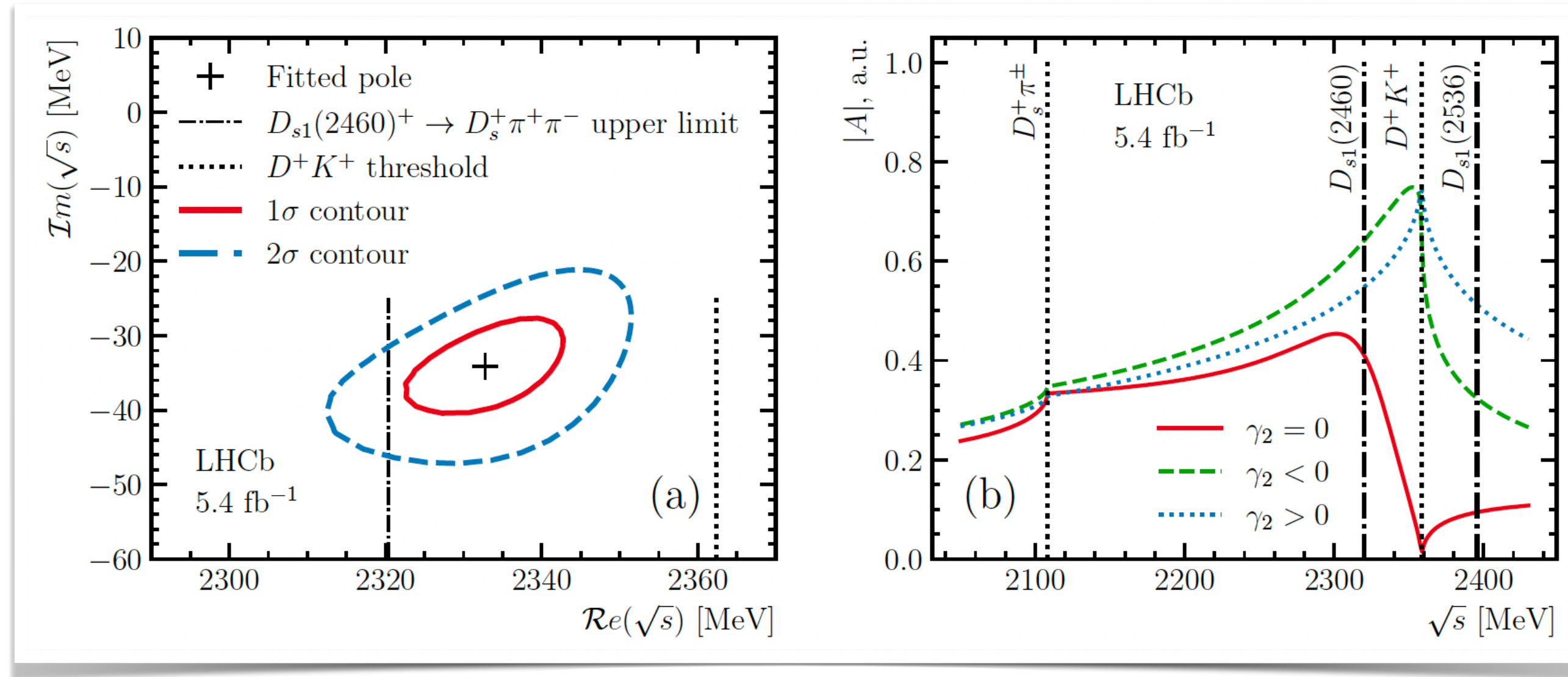
Legend: Fit (blue line), $T_{c\bar{s}0}^{*++}$ (red dashed line), Background (purple line), $f_0(500)$ (green dashed line), $T_{c\bar{s}0}^{*0}$ (orange dotted line), Data (black dots with error bars).

Model	$-\Delta \log \mathcal{L}$	N_{par}	χ^2_{2460}	χ^2_{2536}
1. $f_0(500)$, $f_2(1270)$	73.7	6	146.5	114.5
2. $f_0(500)$, $f_0(980)$, $f_2(1270)$	-2.5	10	61.9	73.8
3. QMI $\pi\pi$, $f_2(1270)$	44.8	12	106.2	109.1
4. $f_0(500)$, RBW $T_{c\bar{s}0}^*$	-3.1	8	64.6	67.8
5. $f_0(500)$, RBW $T_{c\bar{s}1}^*$	-7.3	12	61.5	62.7
6. $f_0(500)$, SLA $T_{c\bar{s}0}^*$	0	8	67.0	71.1
7. $f_0(500)$, SLA $T_{c\bar{s}0}^*$, no isosymmetry	-2.7	12	63.1	69.8
8. $f_0(500)$, SLA $T_{c\bar{s}0}^*$, $\gamma_2 \neq 0$	-2.7	9	64.0	68.5
9. $f_0(500)$, Tri(D^*K)	4.0	6	77.4	69.2
10. $f_0(500)$, Tri(DK^*)	12.7	6	89.7	71.2
11. $f_0(500)$, Tri(D^*K) in $D_{s1}(2460)^+$, Tri(DK^*) in $D_{s1}(2536)^+$	4.9	6	75.0	69.7
12. $f_0(500)$, SLA $T_{c\bar{s}0}^*$ only in $D_{s1}(2460)^+$	13.1	6	69.0	82.6
13. QMI $\pi\pi$, SLA $T_{c\bar{s}0}^*$	-8.3	14	56.4	63.7
14. QMI $\pi\pi$, SLA $T_{c\bar{s}0}^*$ only in $D_{s1}(2460)^+$	1.4	12	68.5	67.7
15. $f_0(500)$, $f_2(1270)$, SLA $T_{c\bar{s}0}^*$	-5.9	12	62.4	67.2
16. $f_0(500)$, $f_2(1270)$, SLA $T_{c\bar{s}0}^*$ only in $D_{s1}(2460)^+$	5.8	10	67.7	75.7
17. $f_0(500)$, $f_2(1270)$ in $D_{s1}(2536)^+$, SLA $T_{c\bar{s}0}^*$ in $D_{s1}(2460)^+$	6.0	8	69.8	74.6

μ -tagged $D_{s1}(2460)^+/D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$

[arXiv:2608.10826](https://arxiv.org/abs/2608.10826)

- Evidence of exotic contributions to the $D_s^+ \pi^\pm$ channel with the pole below DK threshold
- Favour scenarios of $D_{s1}(2460)^+$ decay containing a sizeable near-threshold $D_s^+ \pi$ component consistent with a DK molecular configuration
- Less strong in $D_{s1}(2536)^+$ but still disfavour a single $\pi\pi - S$ amplitudes



Parameter	Value
γ	$-298^{+25}_{-35} \pm 29$
β	$156^{+20}_{-16} \pm 17$
$m(f_0(500))$ [MeV]	$528^{+50}_{-30} \pm 41$
$\Gamma(f_0(500))$ [MeV]	$268^{+36}_{-28} \pm 31$
$\mathcal{F}(f_0(500))_{2460}$ (%)	$293 \pm 53 \pm 113$
$\mathcal{F}(T_{c\bar{s}0}^*)_{2460}$ (%)	$257 \pm 31 \pm 62$
$\mathcal{F}(f_0(500))_{2536}$ (%)	$102 \pm 23 \pm 9$
$\mathcal{F}(T_{c\bar{s}0}^*)_{2536}$ (%)	$6.6 \pm 2.1 \pm 2.8$
$\mathcal{R}e(\sqrt{s_0})$ [MeV]	$2333 \pm 9 \pm 11$
$\mathcal{I}m(\sqrt{s_0})$ [MeV]	$-34 \pm 6 \pm 7$

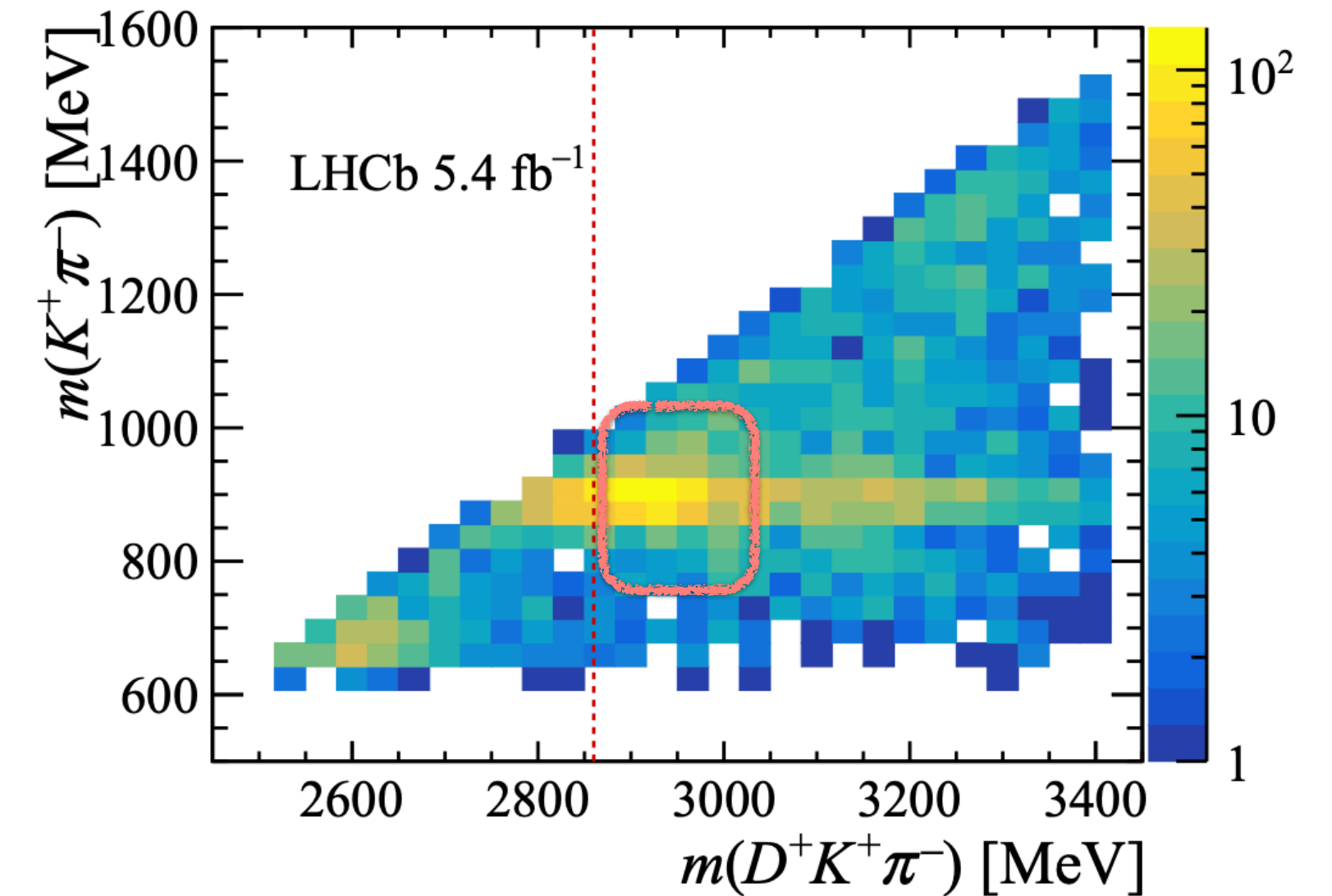
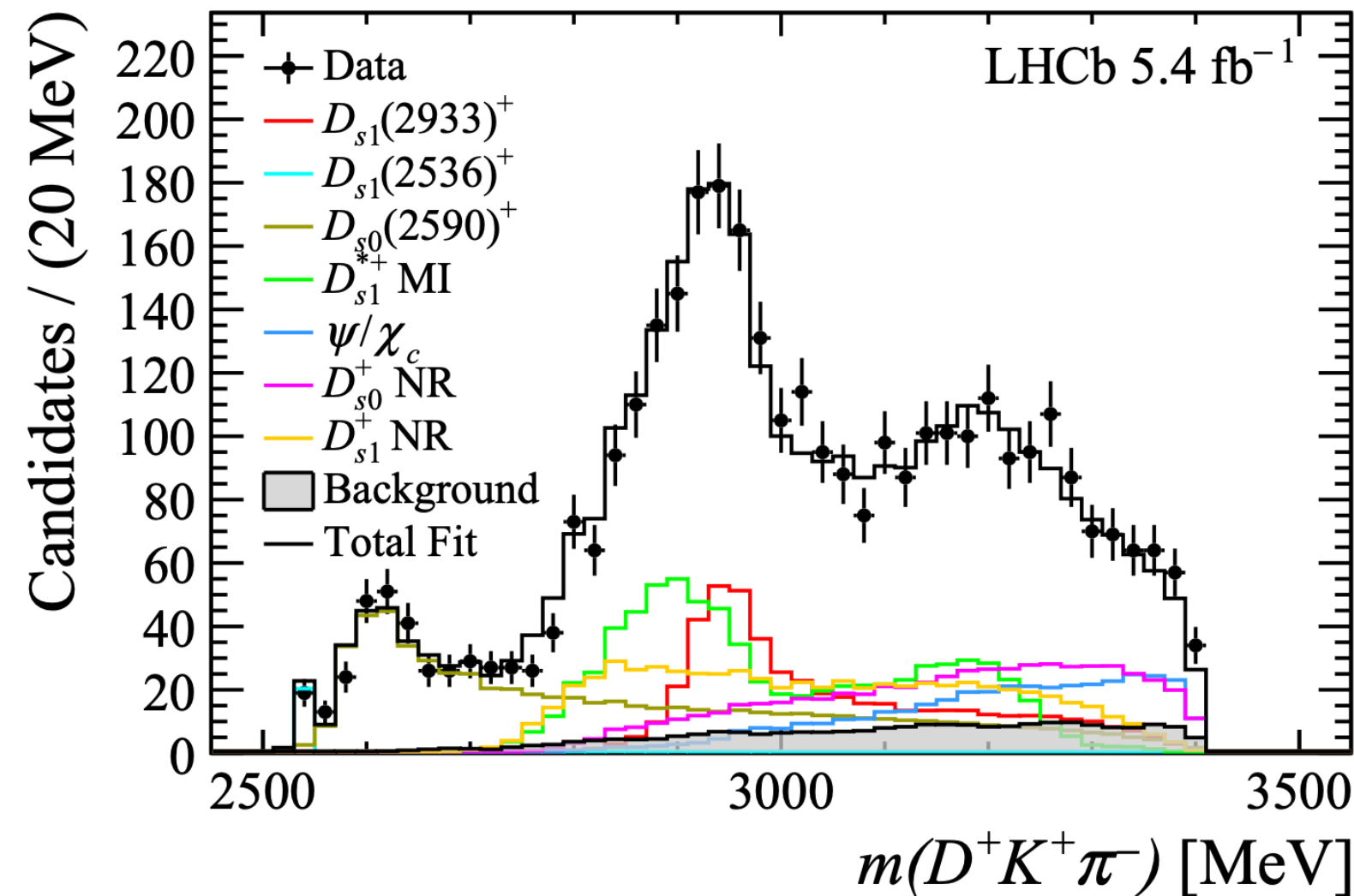
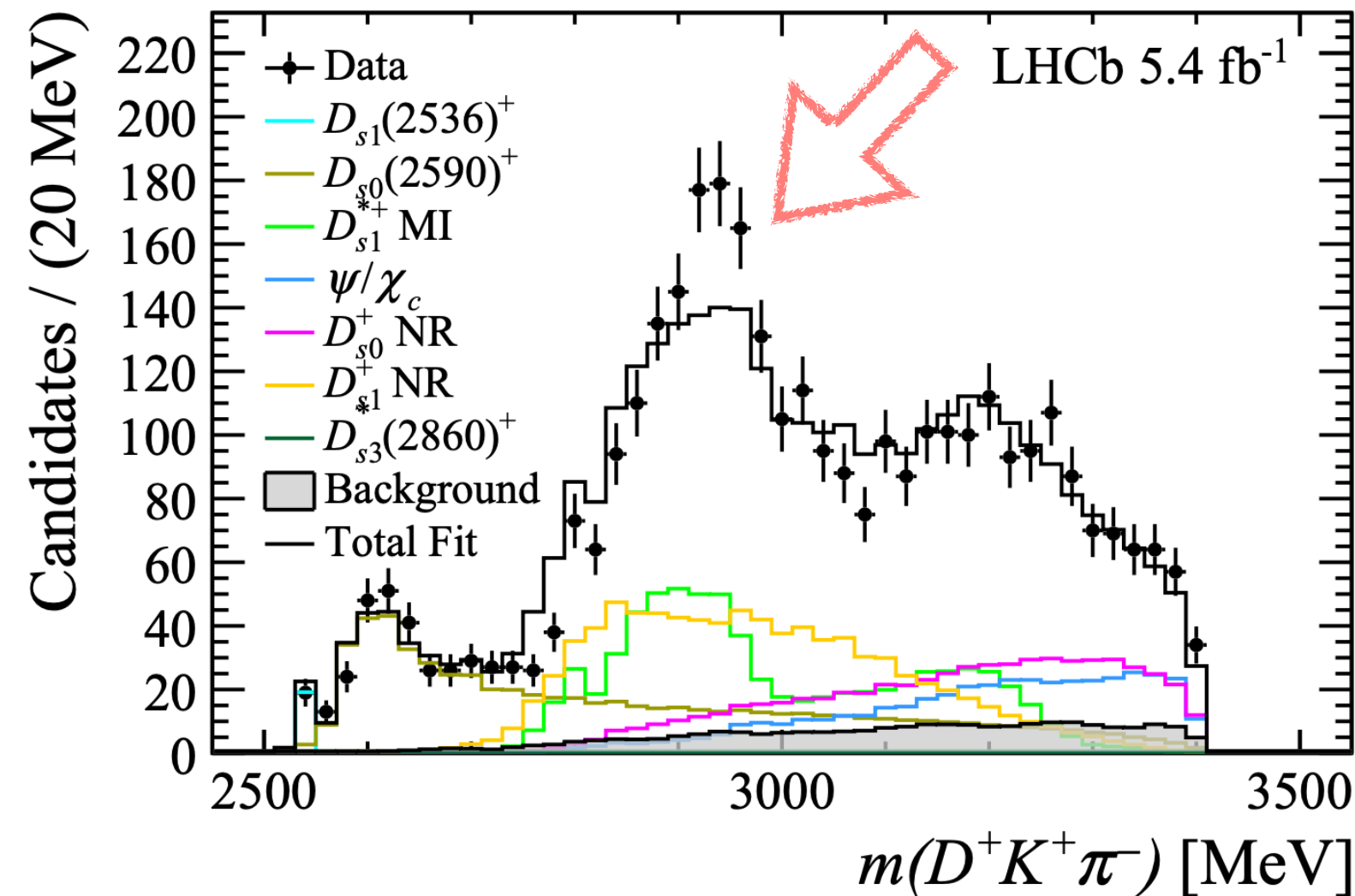
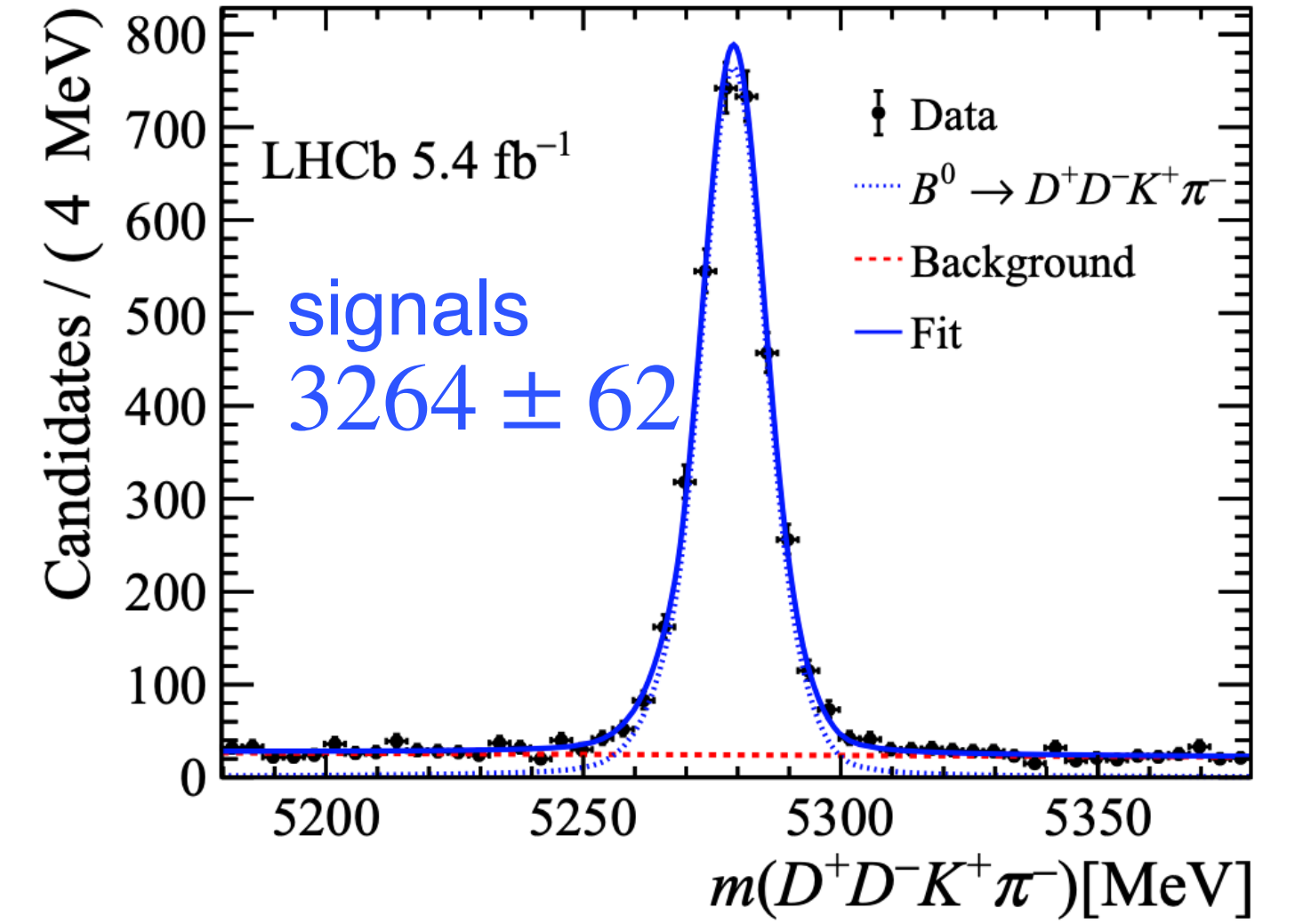
$$\mathcal{R}_{\text{SLA}}(m) = \frac{\beta^2 \rho_{DK}(m) + i\gamma_2(i\gamma \rho_{DK}(m) - 1)}{\beta^2 \rho_{DK}(m) \rho_{D_s\pi}(m) + (i\gamma \rho_{DK}(m) - 1)(i\gamma_2 \rho_{D_s\pi}(m) - 1)}$$

$(\gamma_2 = 0)$

Observation of $D_{s1}^+(2933)^0 \rightarrow D^+ K^+ \pi^-$

arXiv: 2604.21257

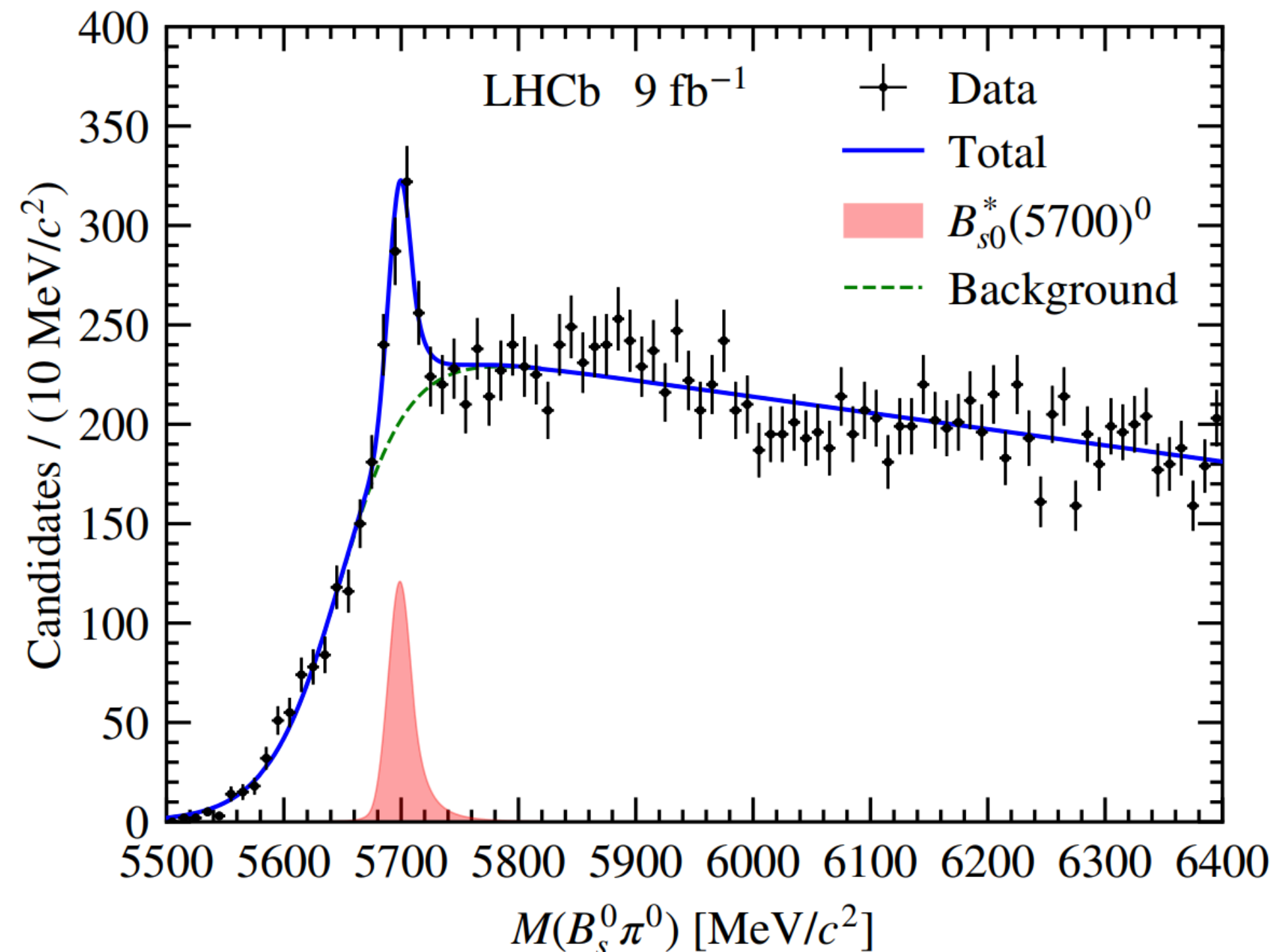
- Observe $D_{s1}^+(2933)^0 \rightarrow D^+ K^+ \pi^-$ from $B^0 \rightarrow D^+ D^- K^+ \pi^-$ ($>10 \sigma$)
 - $M = 2933_{-5}^{+6}(\text{stat.})_{-3}^{+4}(\text{syst.}) \text{ MeV}$, $\Gamma = 72_{-12}^{+18}(\text{stat.})_{-10}^{+7}(\text{syst.}) \text{ MeV}$
 - $J^P = 1^+$ preferred
- Compatible with a conventional state $D_s(2P_1^{(\prime)})^+$, the first radial excitation of P-wave D_s system ($D_{s1}(2460)^+/D_{s1}(2536)^+$), but mass lower than potential model predictions



Discovery of narrow beauty-strange state $B_{s0}^*(5700)^0$

LHCb-PAPER-2026-021 in preparation

- Observation of $B_s^*(5700)^0 \rightarrow \pi^0 B_s^0$ using Runs 1+2 data
 - $M = 5698.9 \pm 1.5 \pm 0.6 \pm 0.1 \text{ MeV}$, $\Gamma < 9.8(11.8) \text{ MeV}$ at 90(95) % CL
 - Mass $\sim 130 \text{ MeV}$ below quark model prediction
- Mass splitting $m(B_{s0}^0(5700)^0) - m(B_s^0) = 332 \text{ MeV}$, similar as in $D_{s0}(2317)^+$





第 136 期 HAPOF: LHCb 实验上 $B_{s0}^*(5700)^0$ 介子的首次观测

报告人: 安刘攀 博士 主持人: 陈殿勇 教授

会议地址: <https://meeting.tencent.com/dm/SCjPU0FWfBw>

腾讯会议: 463-549-470 2026 年 08 月 21 日 (周五) 15:00

摘要: 奇特强子态是探索强相互作用非微扰特性的重要窗口。2003年, BaBar 和 CLEO 实验先后发现 $D_{s0}^*(2317)^+$ 和 $D_{s1}(2460)^+$ 介子, 因二者性质与夸克模型预言存在显著差异, 引发巨大关注, 被广泛认为是奇特强子态的候选者。在底介子体系中寻找它们的对应态并确定其性质, 对检验和深化强相互作用理论至关重要。近期, LHCb 实验在 $B_s^0 \pi^0$ 不变质量谱中首次观测到了 $B_{s0}^*(5700)^0$ 介子, 为回应这一理论关切提供了重要实验依据。本次报告将围绕这一发现进行详细介绍与讨论。

报告人: 安刘攀, 北京大学物理学院助理教授。2013年本科毕业于清华大学。2018年获清华大学博士学位。先后在意大利国家核物理研究所佛罗伦萨实验室(INFN Firenze)和欧洲核子研究中心(CERN)从事博士后研究工作, 2023年加入北京大学。长期在LHCb实验上从事重味强子谱学和产生机制研究, 在奇特强子态、重味强子谱学和重夸克偶素产生机制等方面主导完成了多项科研成果, 包括全粲四夸克态 $X(6900)$ 和 B_c^+ 介子轨道激发态的首次发现, 及近期发布的 Ω_{cc}^+ 重子和 $B_{s0}^*(5700)^0$ 介子的首次观测。现任LHCb实验副物理协调人。



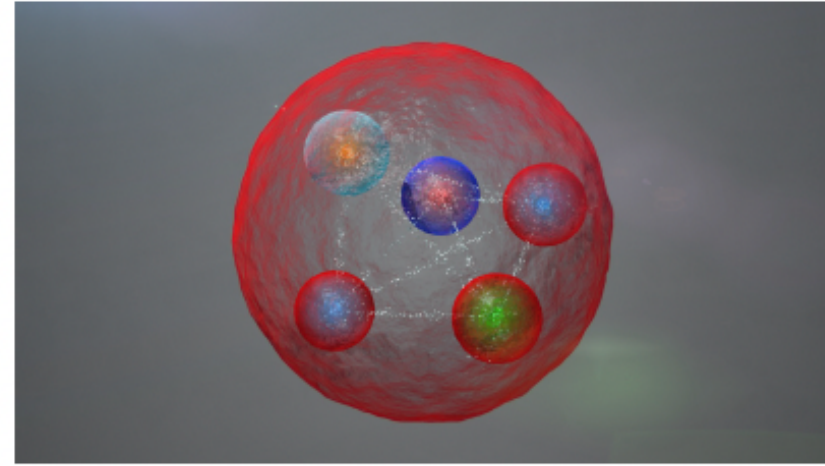
顾问委员: (按姓氏拼音排序)

陈莹 (中国科学院高能物理研究所), 高原宁 (北京大学), 李海波 (中国科学院高能物理研究所), 梁作堂 (山东大学), 刘川 (北京大学), 吕才典 (中国科学院高能物理研究所), 马建平 (中国科学院理论物理研究所), 彭海平 (中国科学技术大学), 乔从丰 (中国科学院大学), 沈肖雁 (中国科学院高能物理研究所), 许怒 (中国科学院近代物理所), 苑长征 (中国科学院高能物理研究所), 张鲁西 (中国科学院理论物理研究所), 张宗桦 (中国科学院高能物理研究所), 赵光达 (北京大学), 赵强 (中国科学院高能物理研究所), 赵政国 (中国科学技术大学), 郑汉青 (四川大学), 郑阳恒 (中国科学院大学), 朱世琳 (北京大学), 邹冰松 (清华大学)

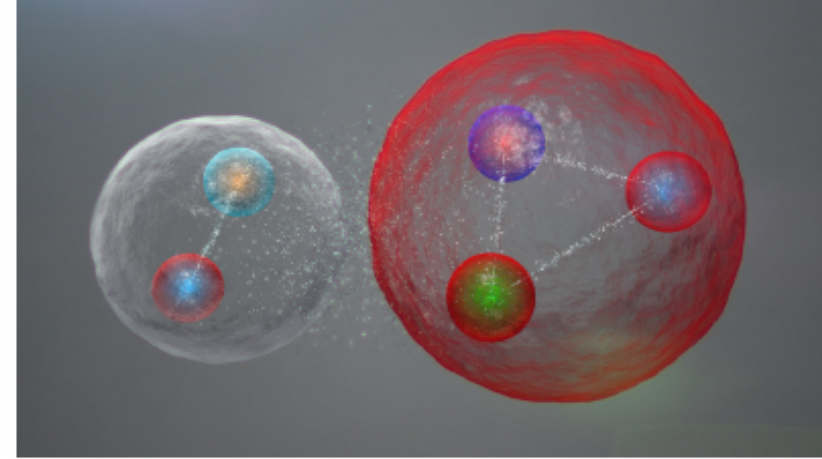
特别鸣谢: 本届论坛由彭桓武理论物理创新研究中心支持

More in Liupan's seminar tomorrow

Pentaquark studies at LHCb

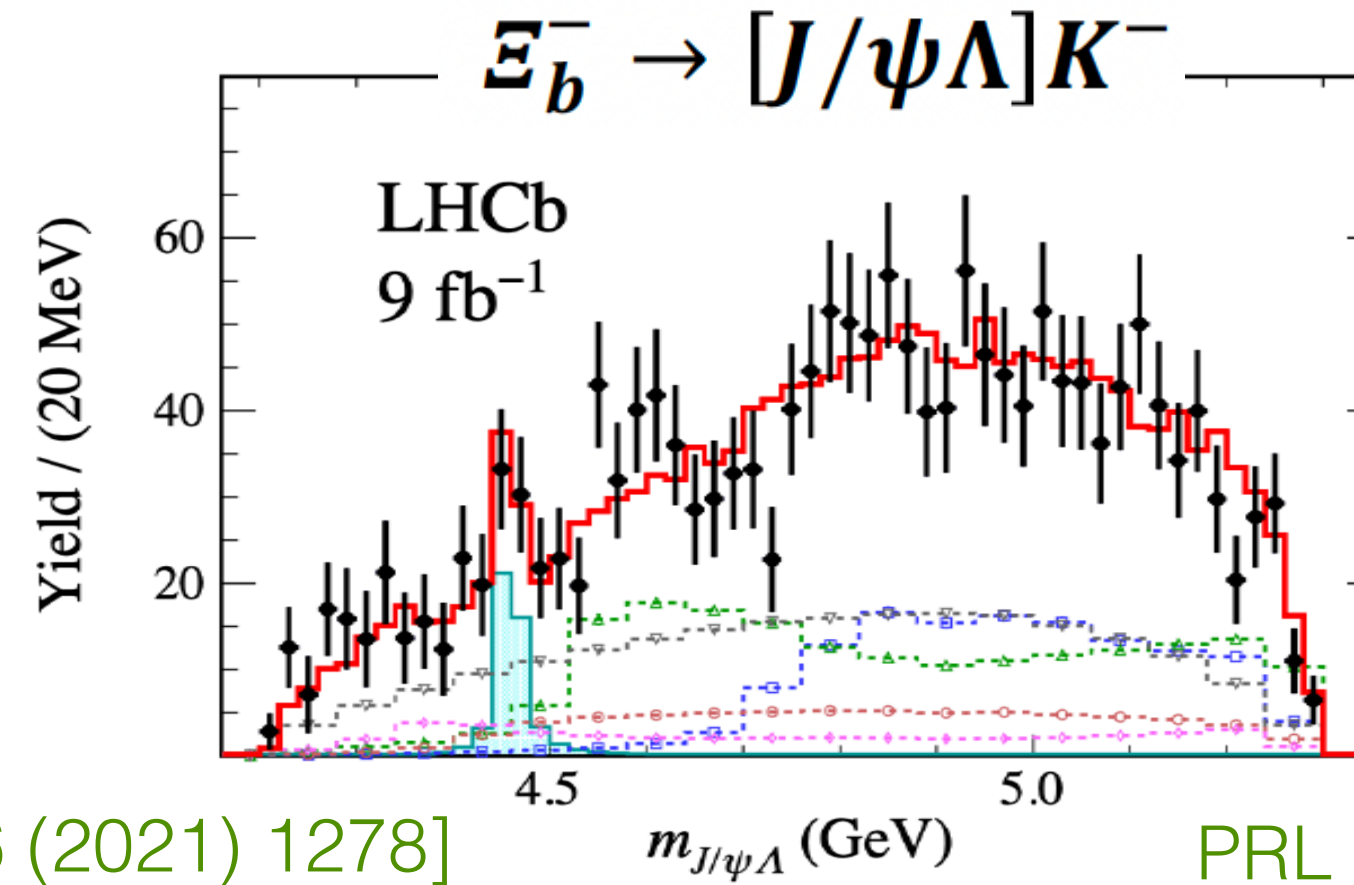


vs.

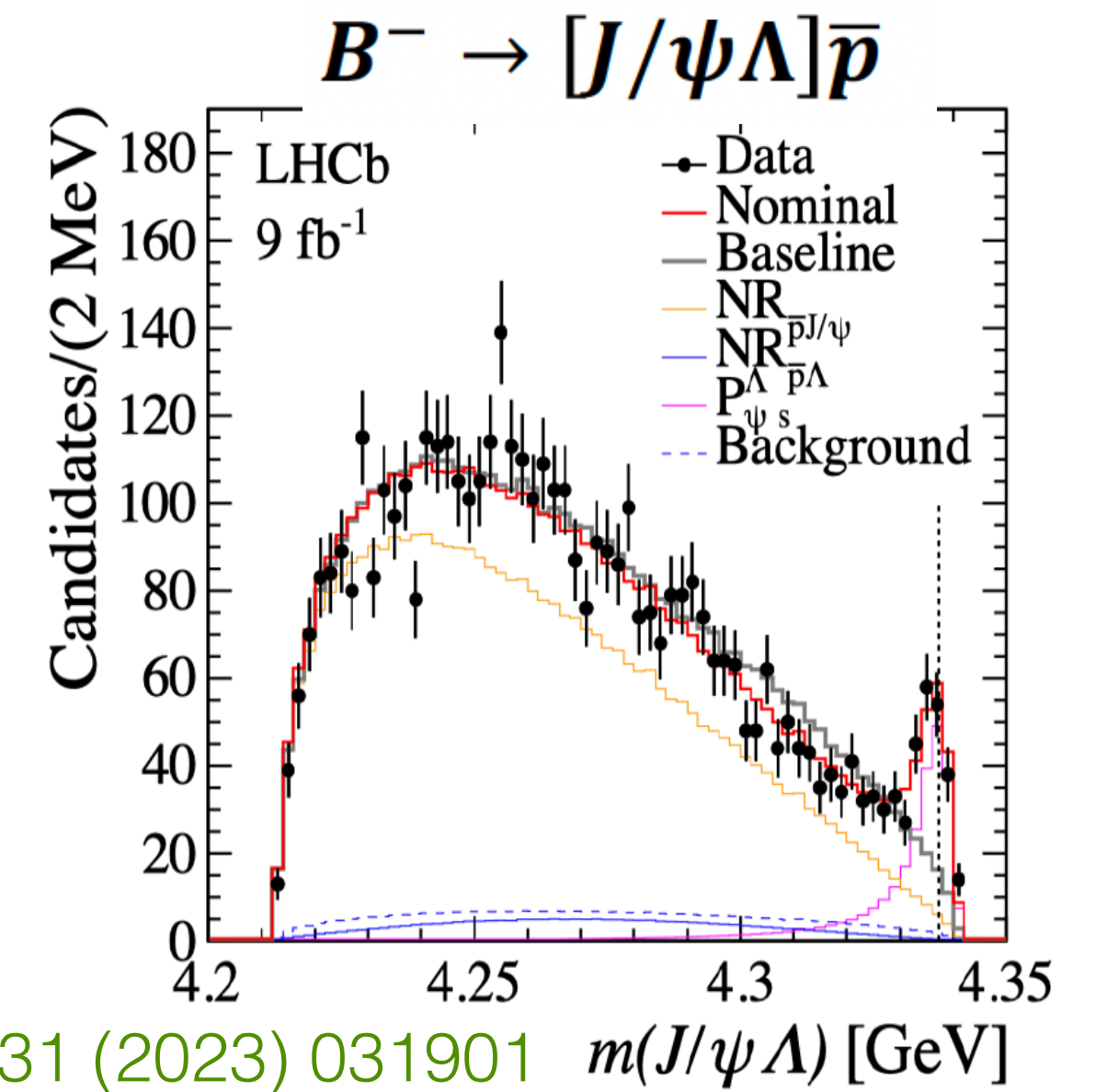


binding scheme → decay modes

Science Bulletin 66 (2021) 1278]



PRL 131 (2023) 031901

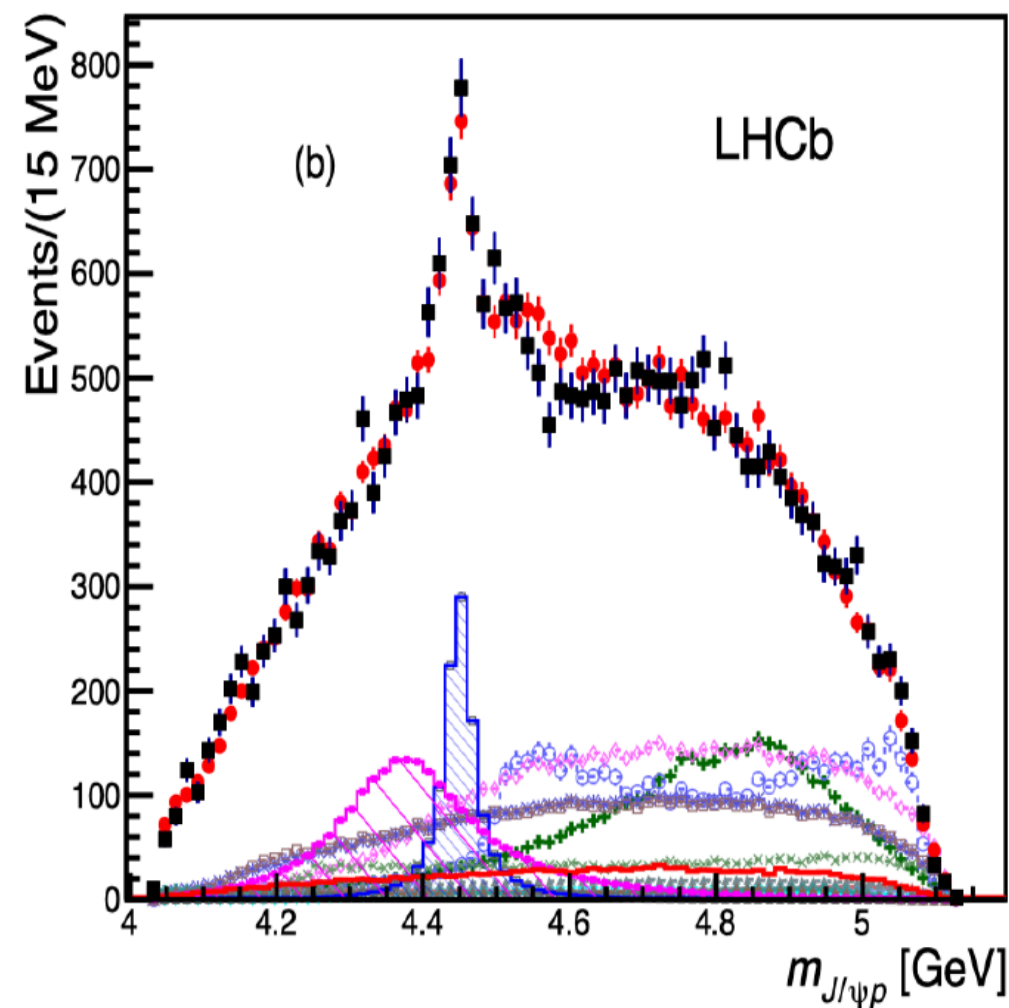


2015

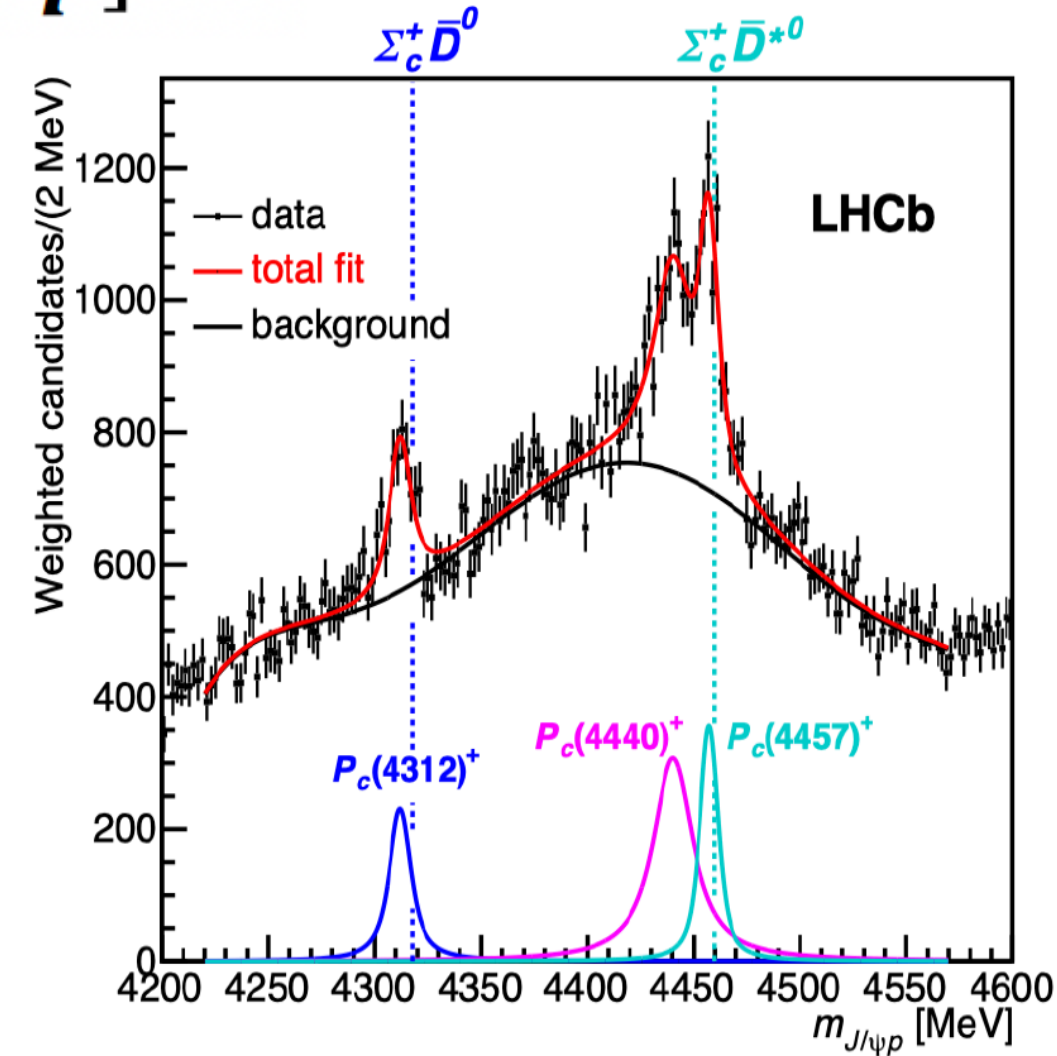
2018

2022

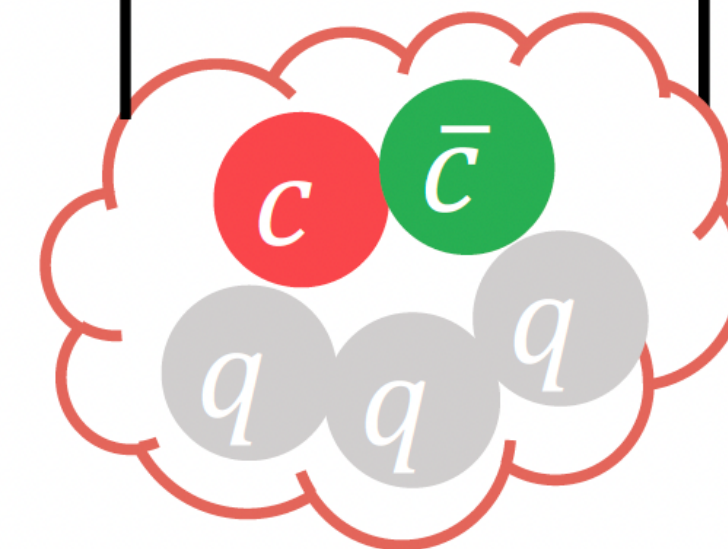
$$\Lambda_b^0 \rightarrow [J/\psi p]K^-$$



PRL 115 (2015) 072001]

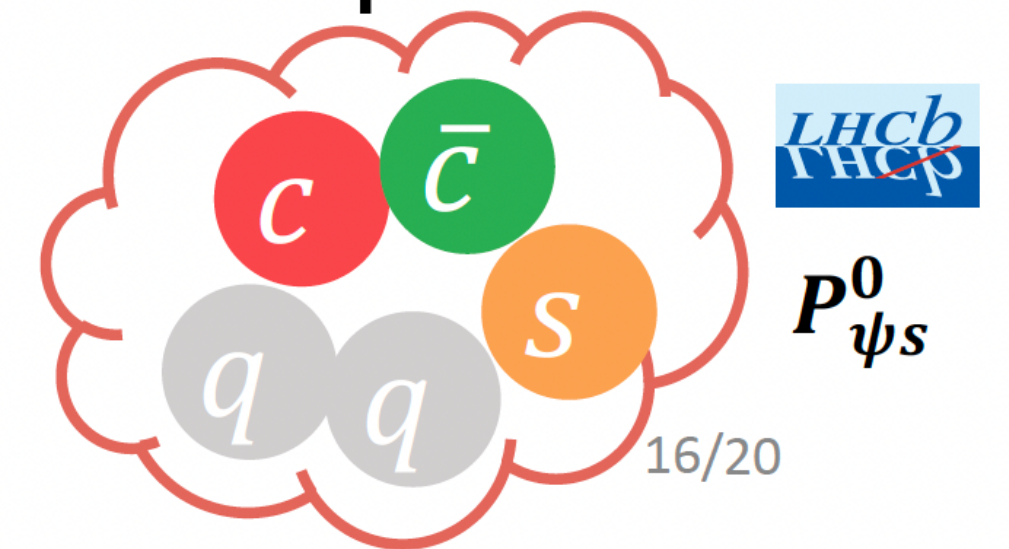


PRL 122 (2019) 222001



$P_c(4312)^+$
 $P_c(4440)^+$
 $P_c(4457)^+$

1 An



$P_{\psi s}^0$

16/20

Search for more pentaquark

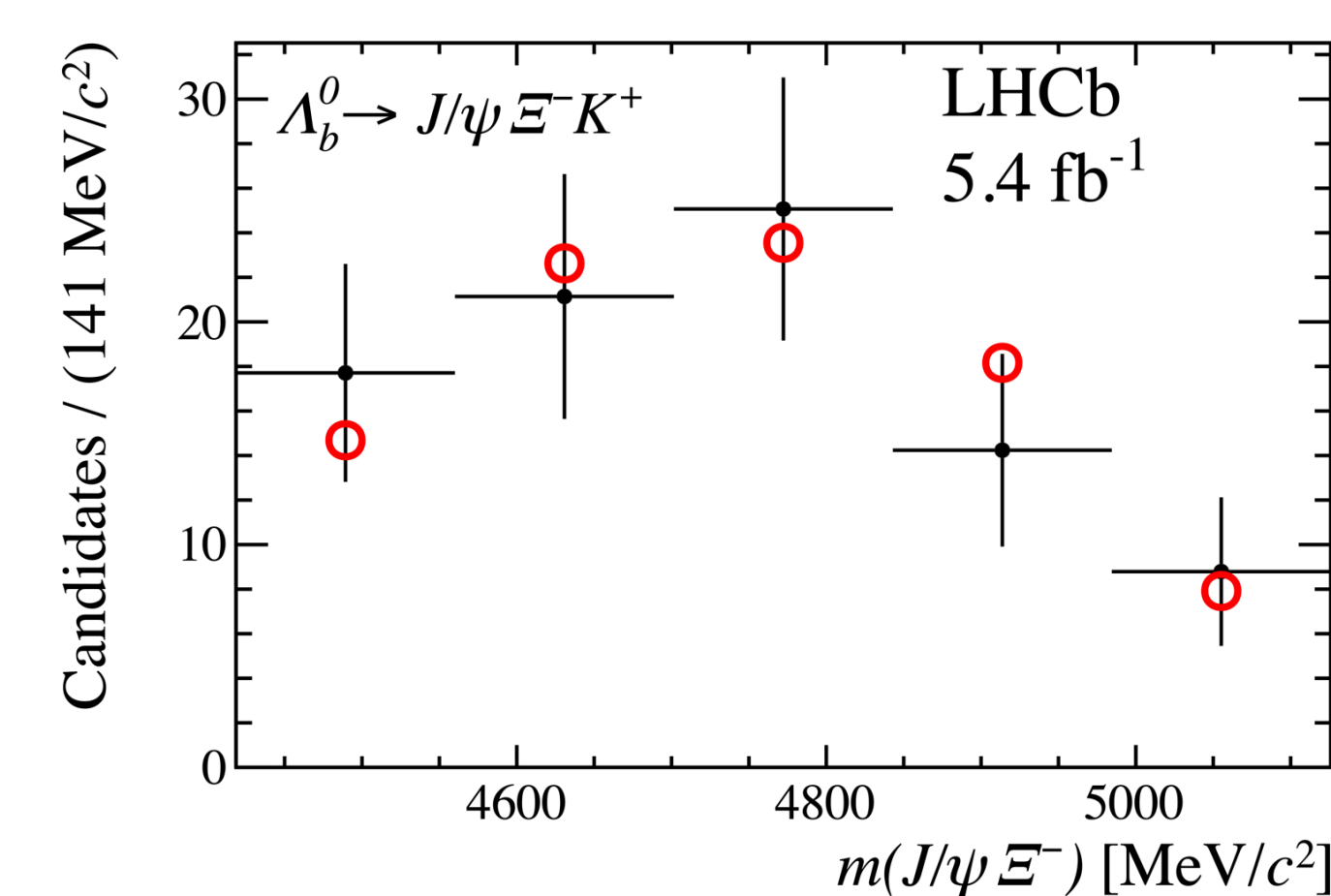
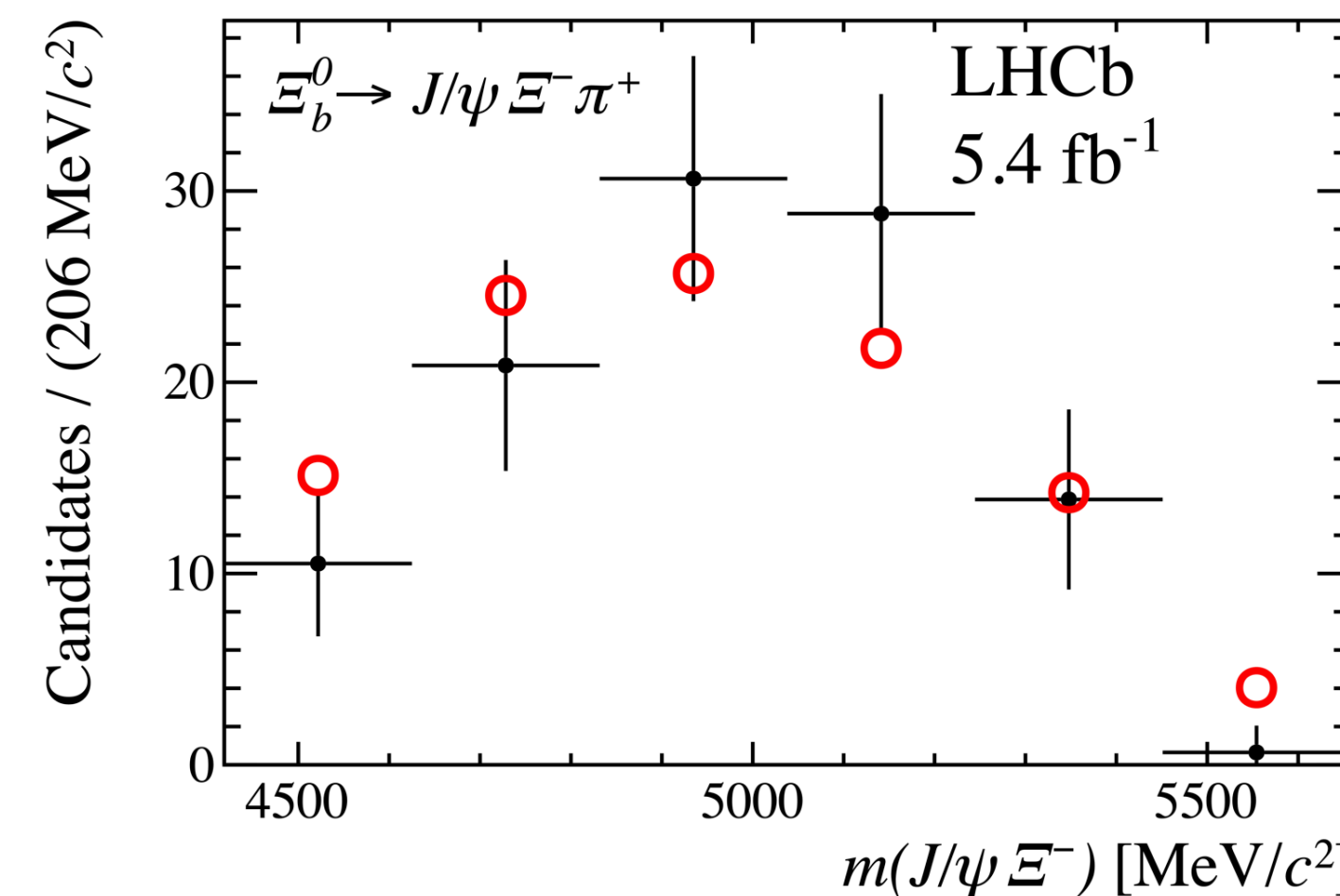
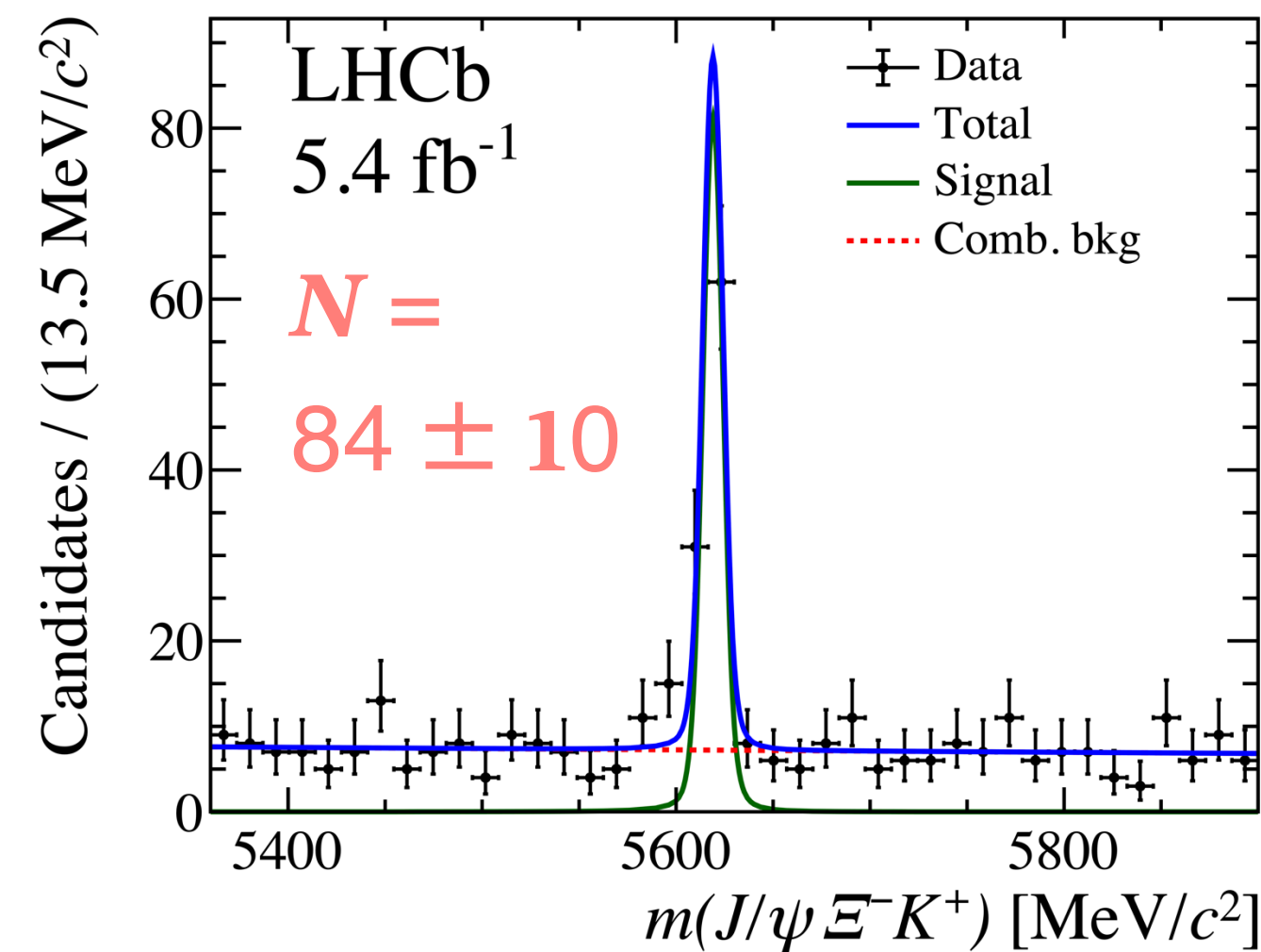
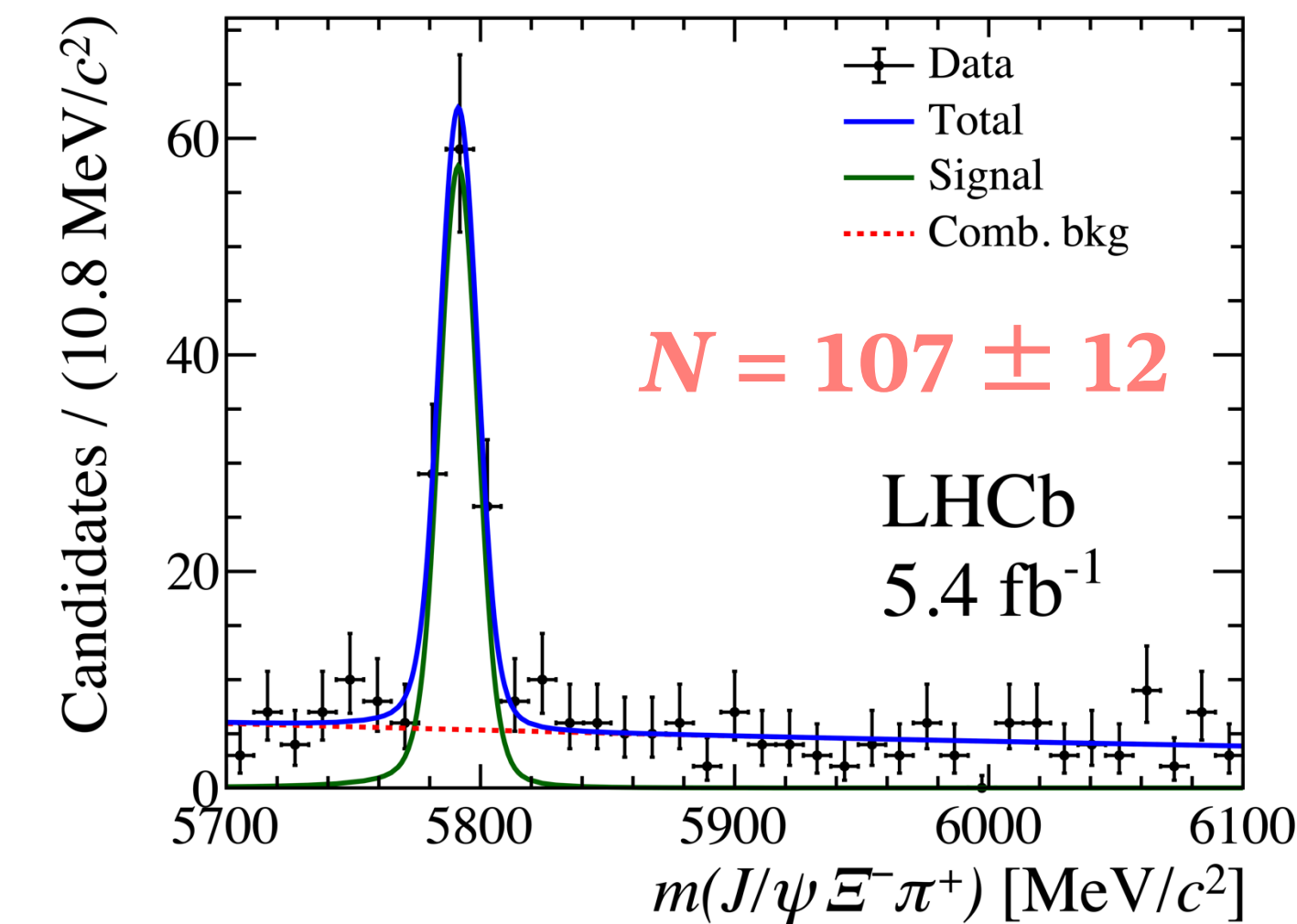
EPJC 85 (2025) 812

$$J/\psi p \rightarrow c\bar{c}uud$$

$$J/\psi \Lambda \rightarrow c\bar{c}\textcolor{red}{s}ud$$

?

$$J/\psi \Xi \rightarrow c\bar{c}\textcolor{red}{s}s u/d$$



- First observation of $\Xi_b^0 \rightarrow J/\psi \Xi^- \pi^+$
- Most precise measurement of $\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi \Xi^- K^+)$

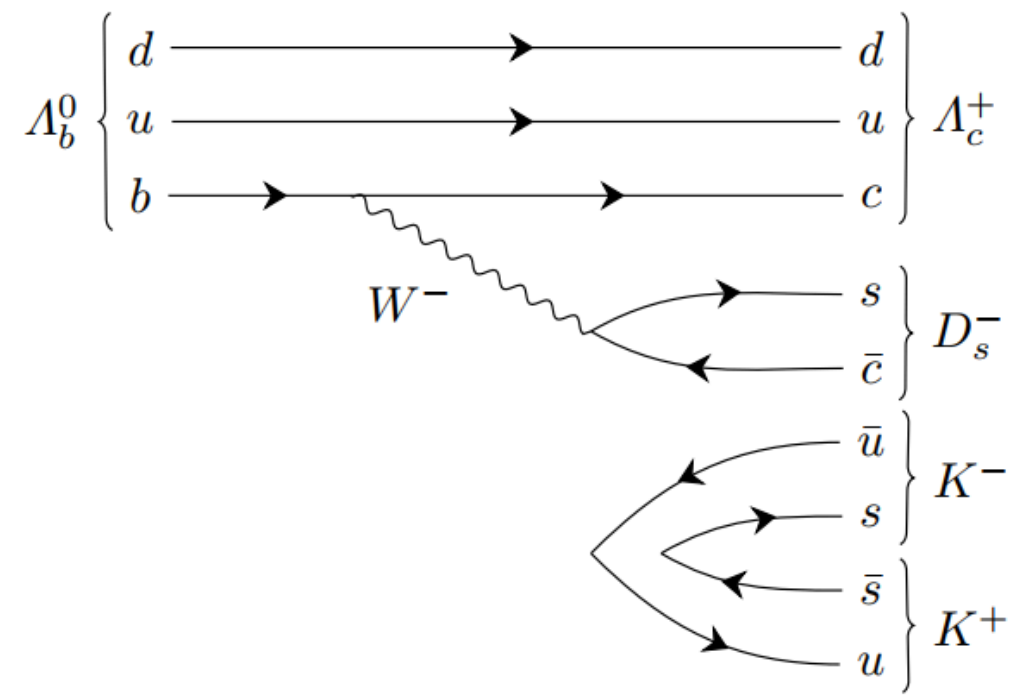
$$\frac{\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi \Xi^- K^+)}{\mathcal{B}(\Lambda_b^0 \rightarrow J/\psi \Lambda)} = (1.17 \pm 0.14 \pm 0.08) \times 10^{-2}$$

$$\frac{\mathcal{B}(\Xi_b^0 \rightarrow J/\psi \Xi^- \pi^+)}{\mathcal{B}(\Xi_b^0 \rightarrow J/\psi \Xi^-)} = (11.9 \pm 1.4 \pm 0.6) \times 10^{-2}$$

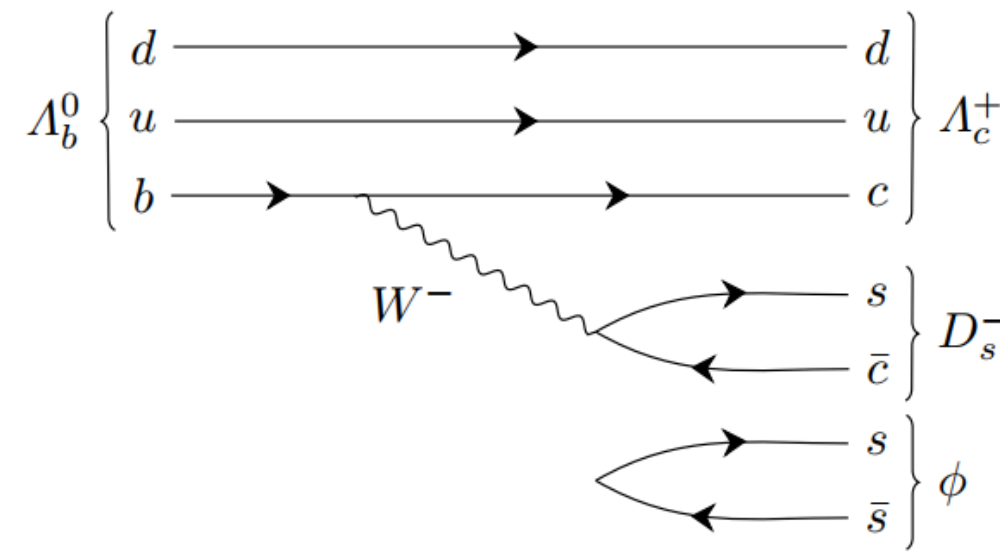
- Larger stats. needed for amplitude analysis

Search of pentaquark via open charm modes

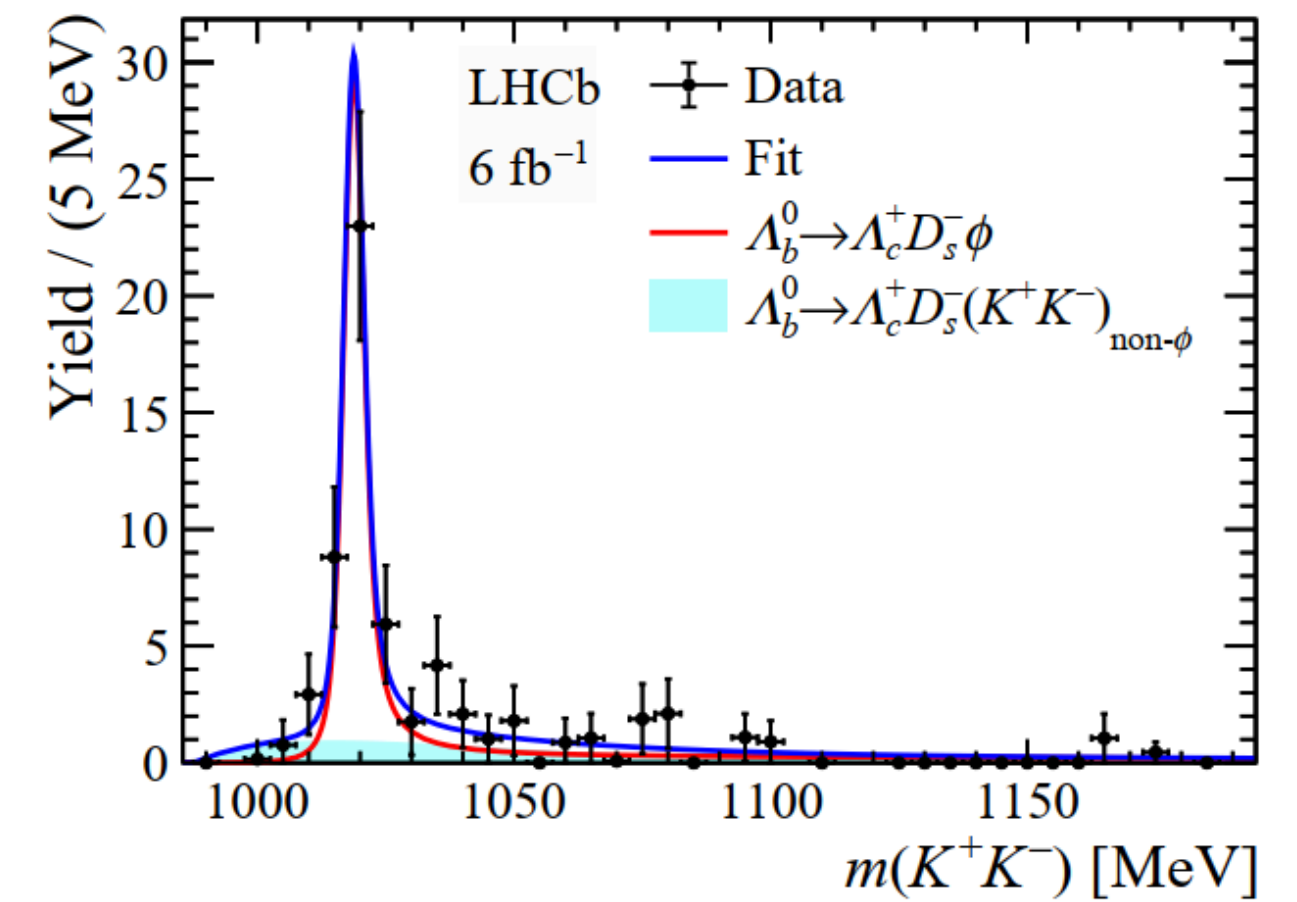
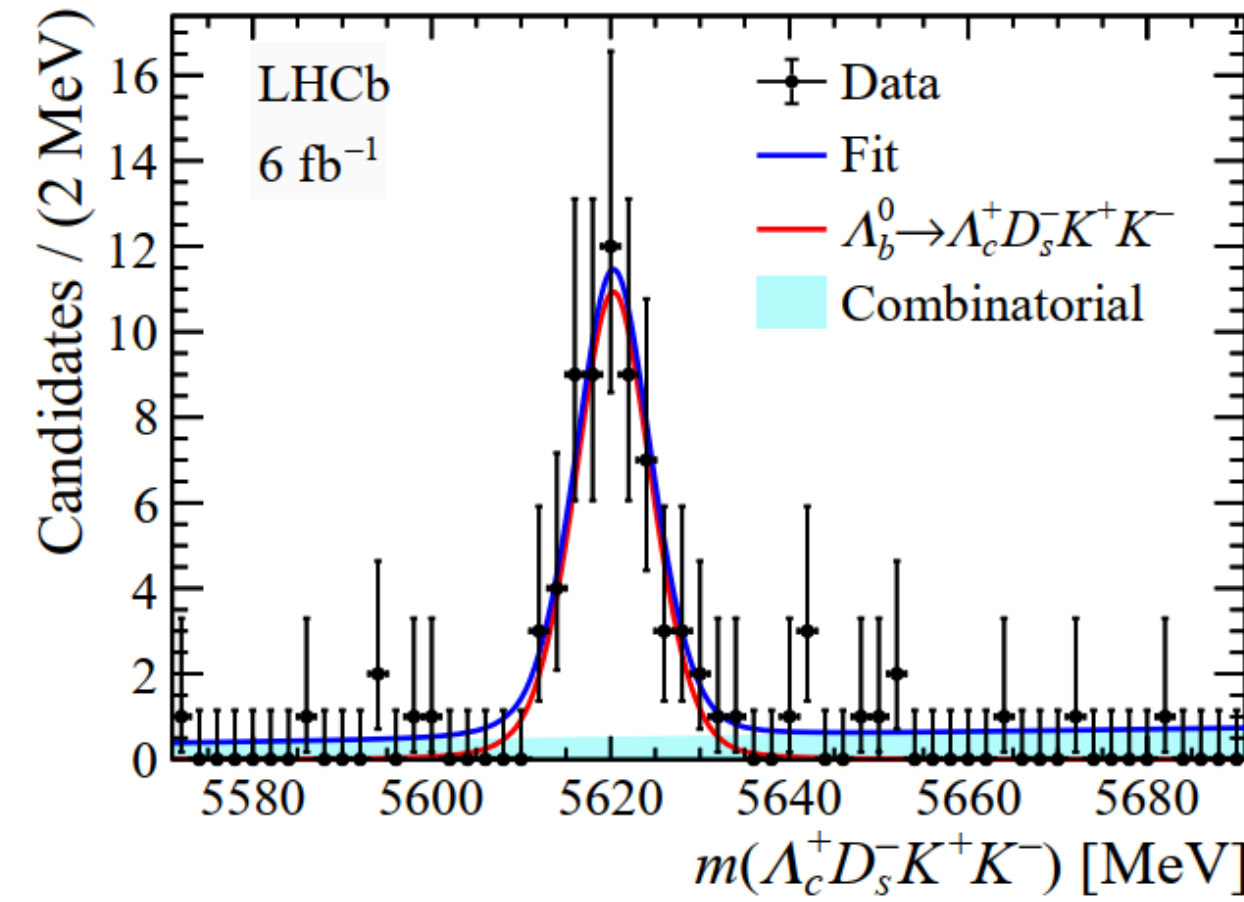
PRD112 (2025) 052013



(a) The nonresonant K^+K^- process

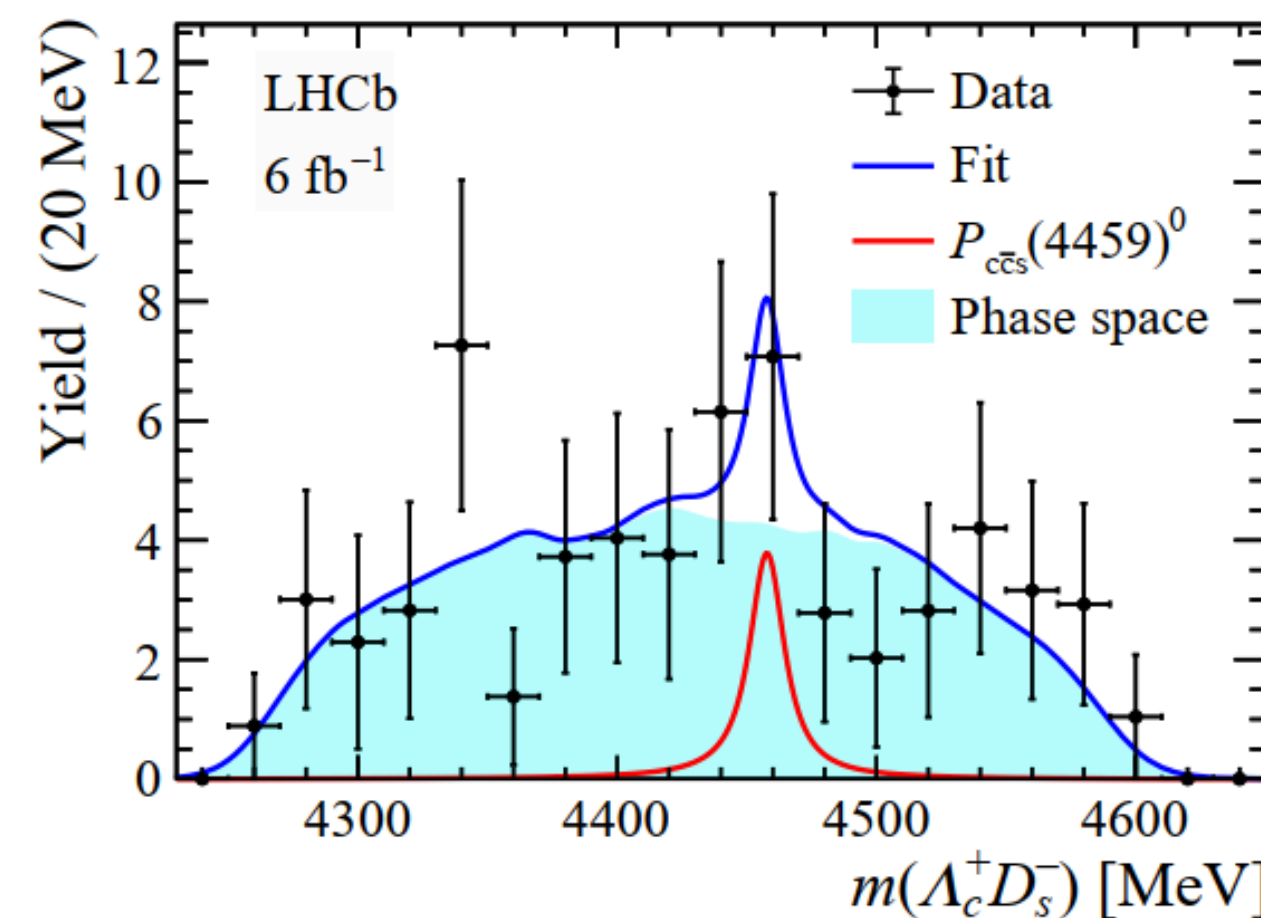
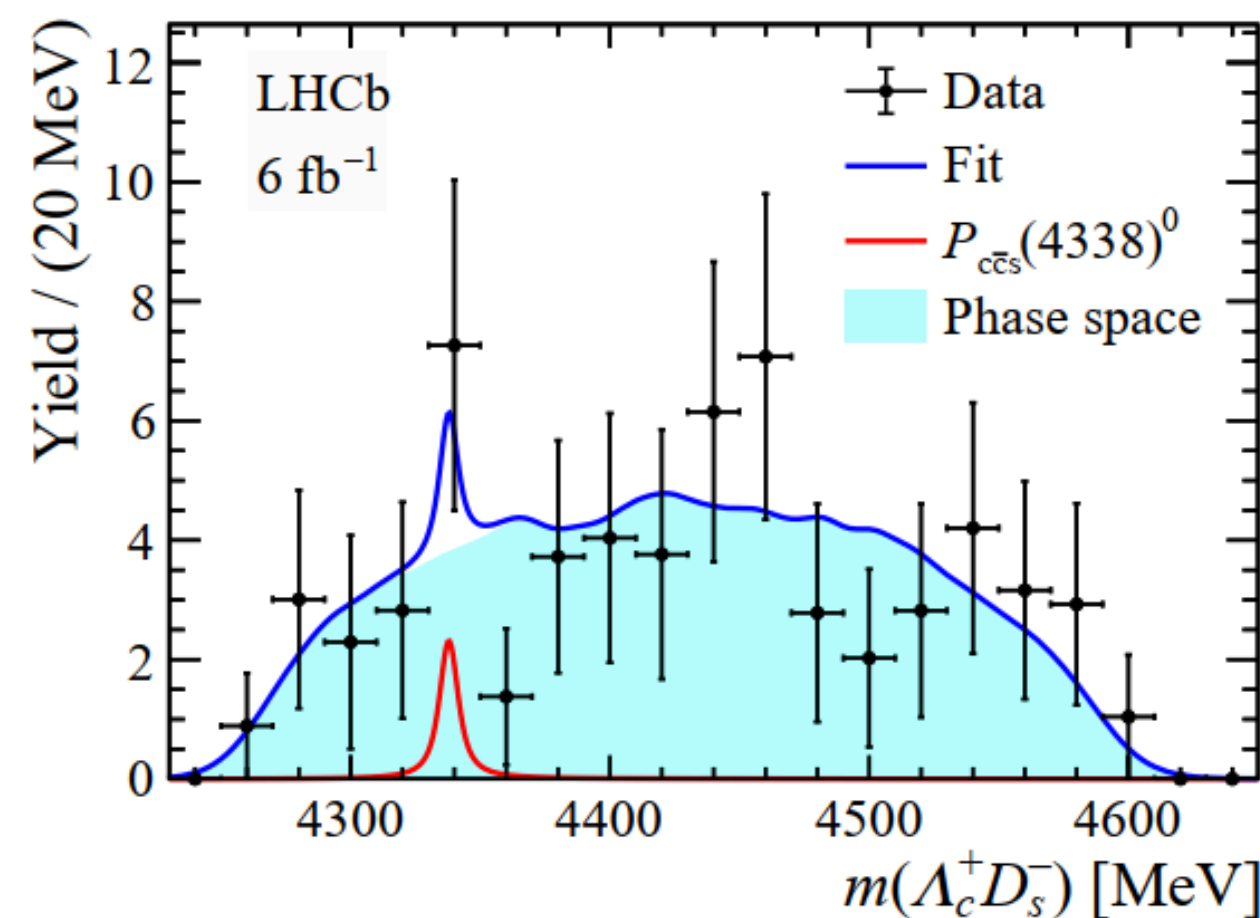


(b) The ϕ -dominated process



$$\mathcal{R}_{P_{c\bar{c}s}^0} \equiv \frac{\mathcal{B}(\Lambda_b^0 \rightarrow P_{c\bar{c}s} K^+ K^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^- K^+ K^-)} \cdot \mathcal{B}(P_{c\bar{c}s}^0 \rightarrow \Lambda_c^+ D_s^-)$$

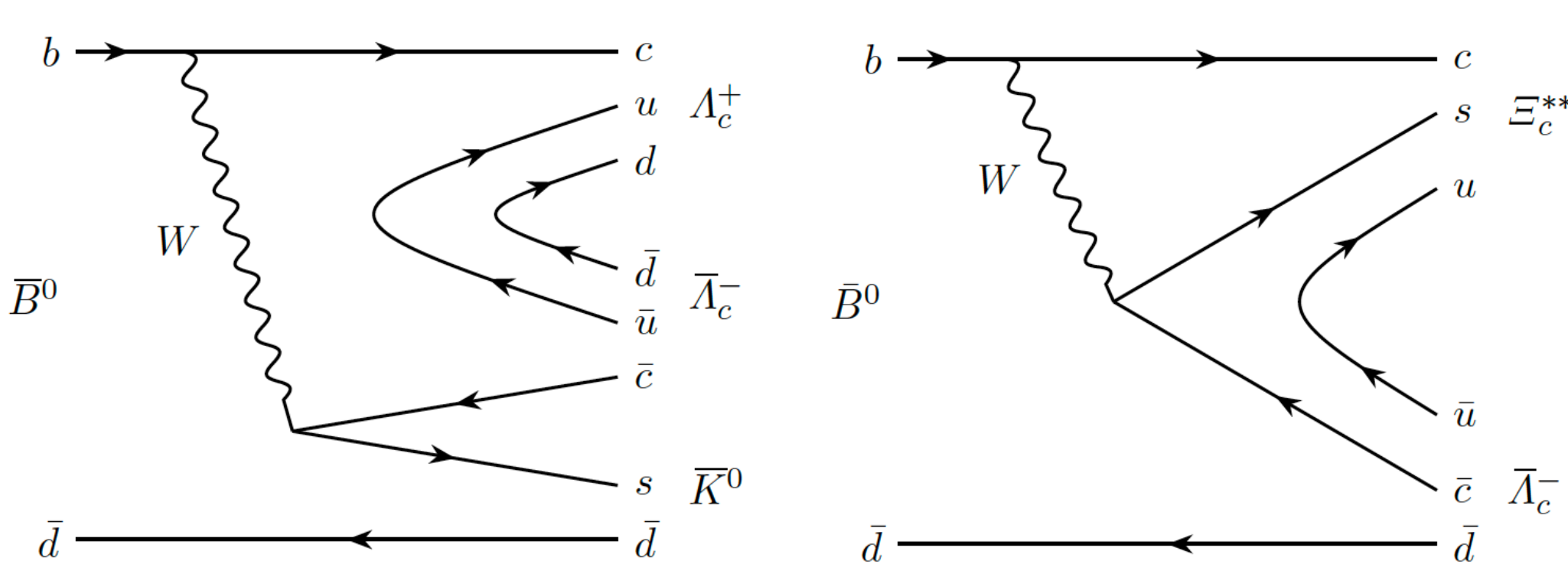
$$\frac{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^- K^+ K^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ D_s^-)} = 0.0141 \pm 0.0019 \pm 0.0012$$



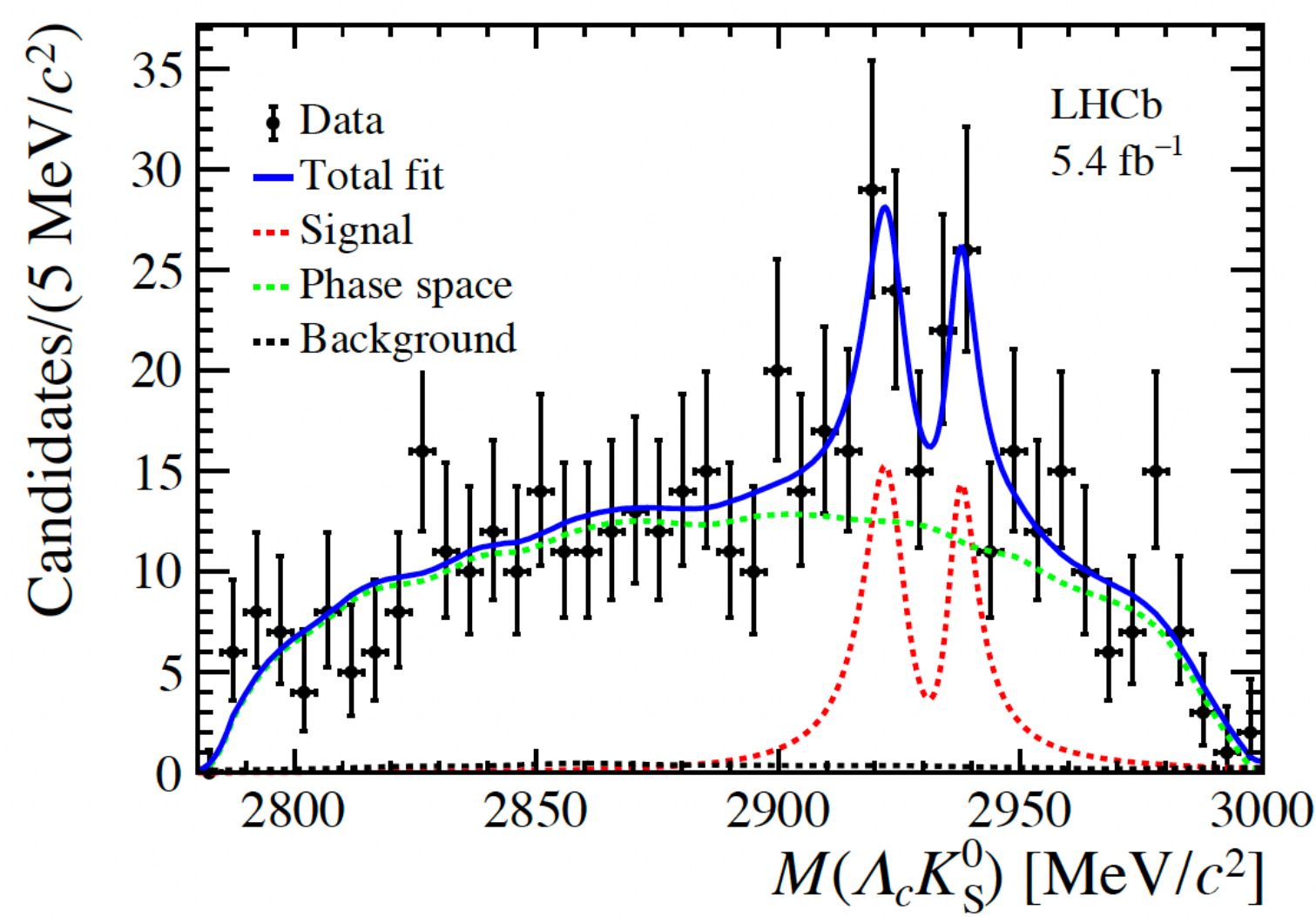
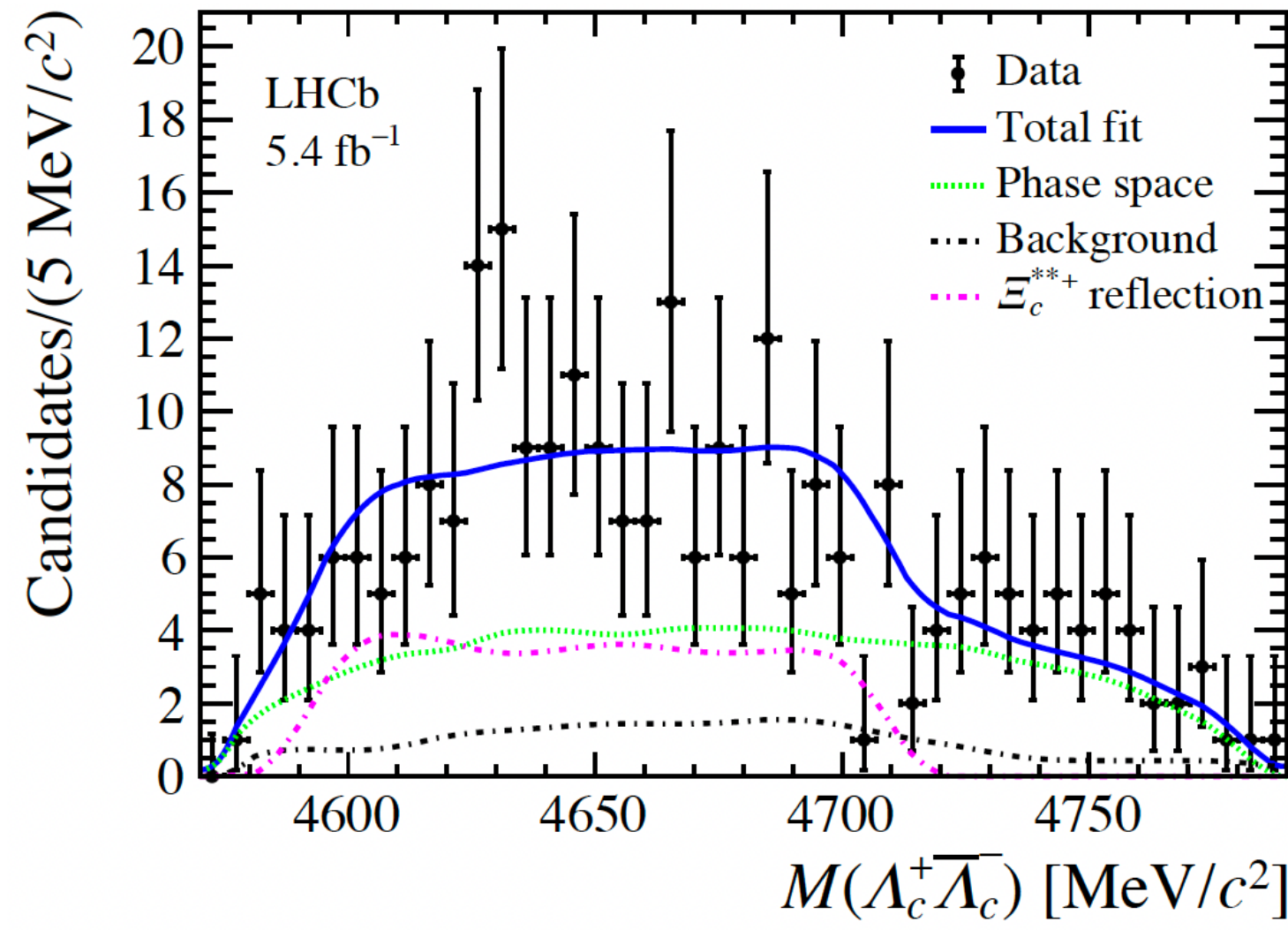
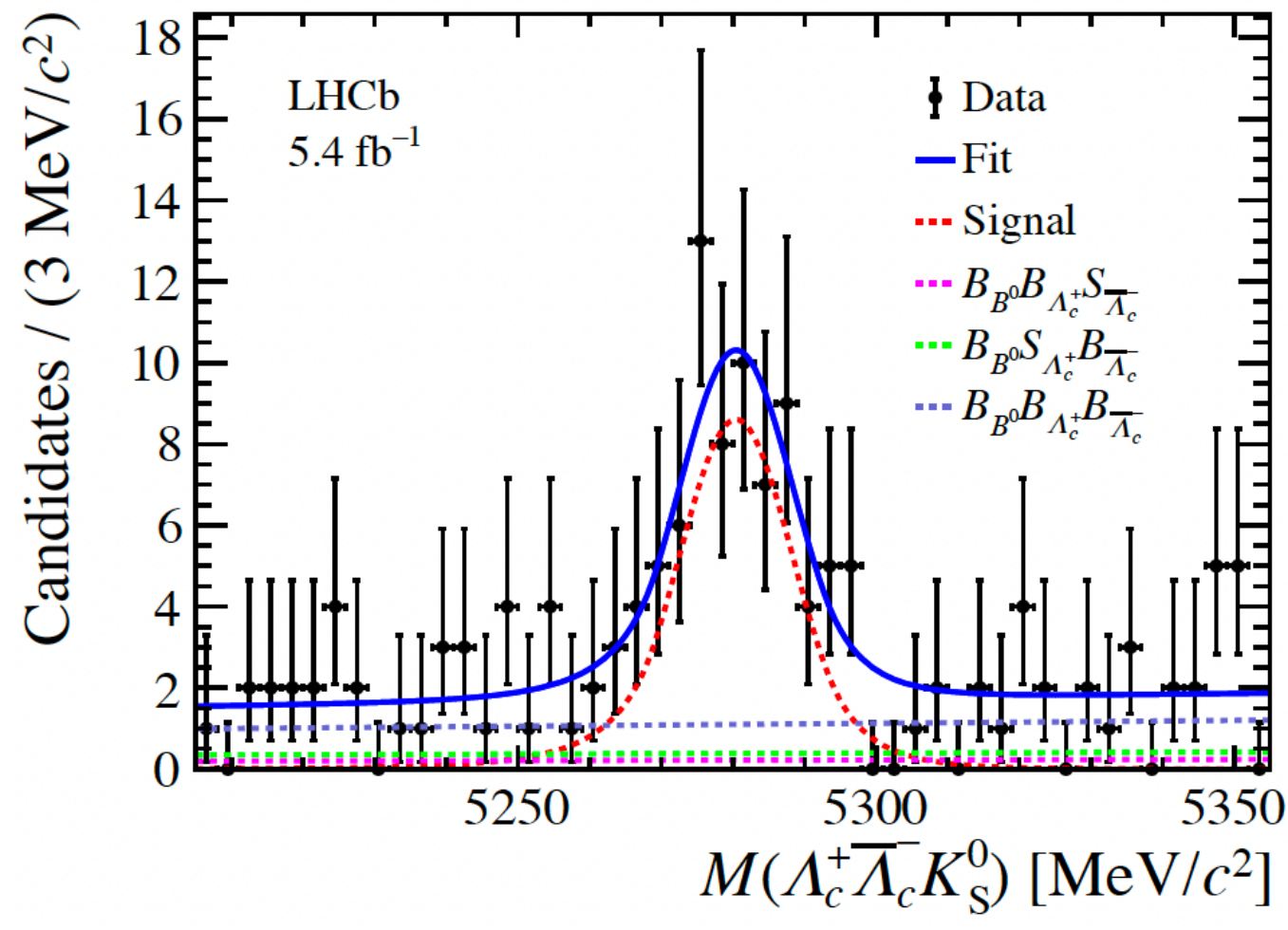
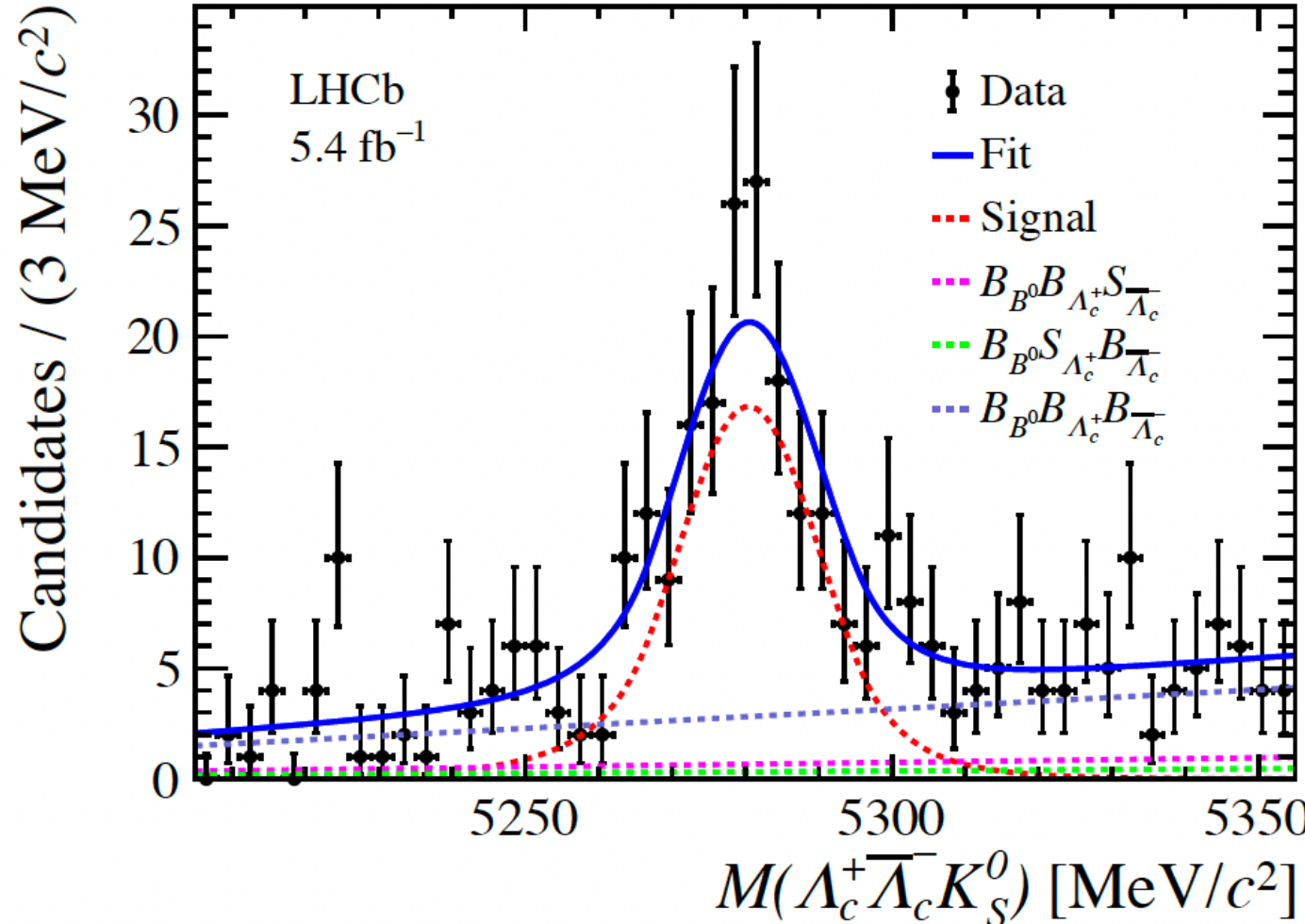
- Upper limits on 95% (90%) CLs:
- $\mathcal{R}(P_{c\bar{c}s}(4338)^0) < 0.12$ (0.10)
- $\mathcal{R}(P_{c\bar{c}s}(4459)^0) < 0.20$ (0.17)

Search of hexaquark states

PRD 114, (2026) 012012



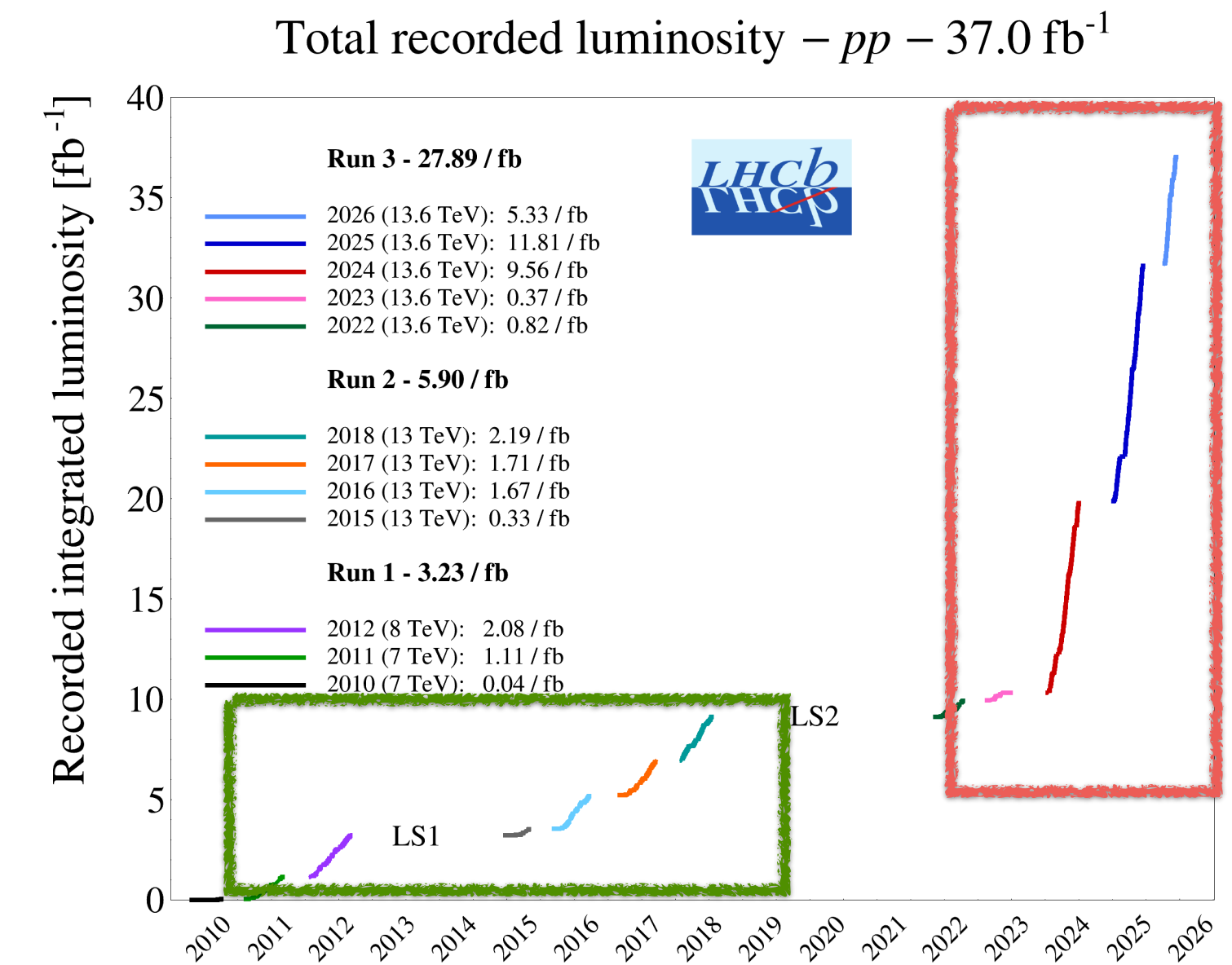
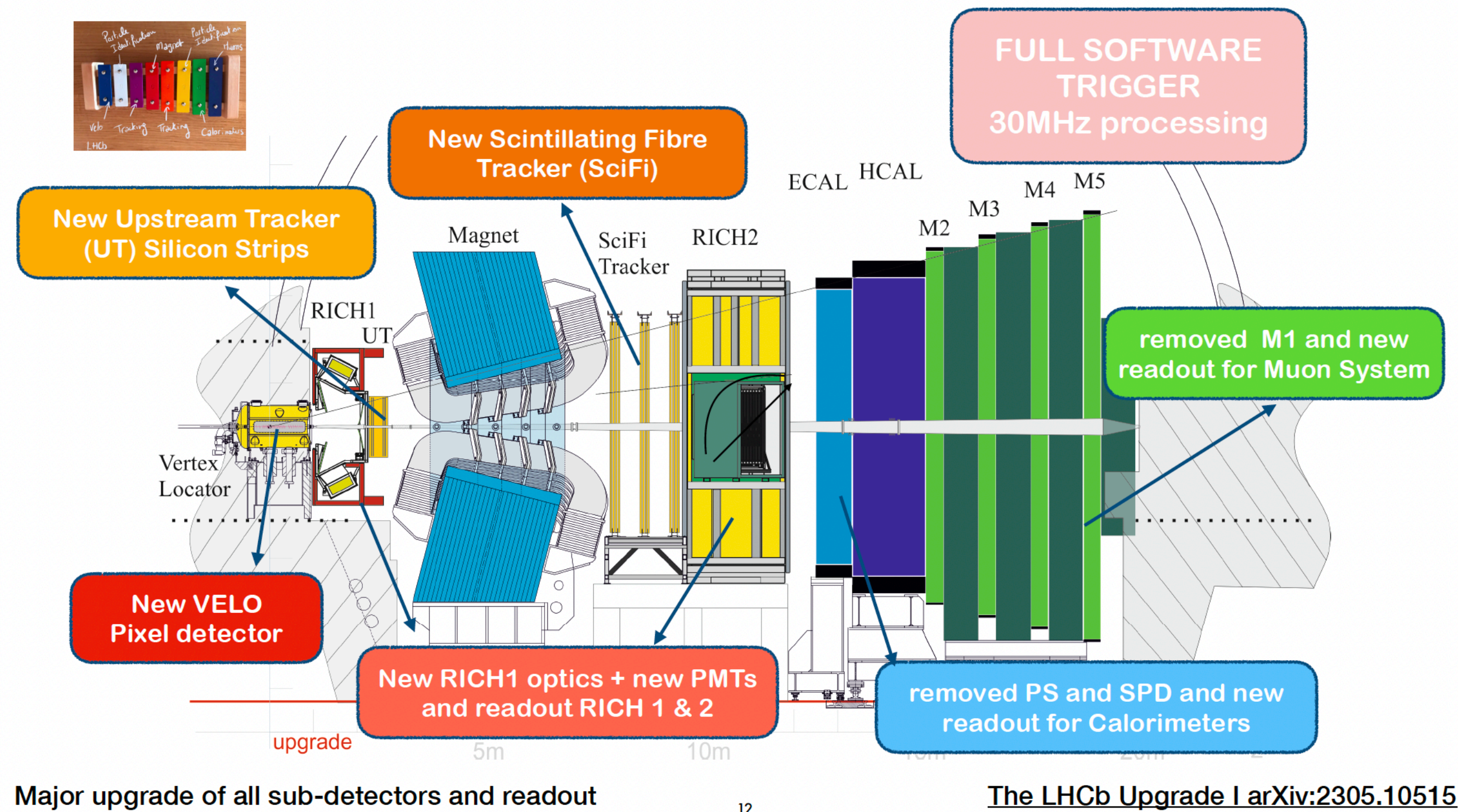
$$\frac{\mathcal{B}(B^0 \rightarrow \Lambda_c^+ \bar{\Lambda}_c^- K_S^0)}{\mathcal{B}(B^+ \rightarrow \Lambda_c^+ \bar{\Lambda}_c^- K^+)} = 0.53 \pm 0.05 \pm 0.05$$



- Evidence of $\Xi_c(2923)^+$ and $\Xi_c(2939)^+$
- a significance of 3.9σ
- no significant structure seen in $\Lambda_c^+ \bar{\Lambda}_c^-$

State	Mass [MeV/c ²]	Width [MeV/c ²]
$\Xi_c(2923)^+$	$2923.1 \pm 1.8 \pm 0.8$	$11.6 \pm 5.2 \pm 2.6$
$\Xi_c(2939)^+$	$2937.5 \pm 1.6 \pm 0.9$	$7.1 \pm 4.1 \pm 2.4$

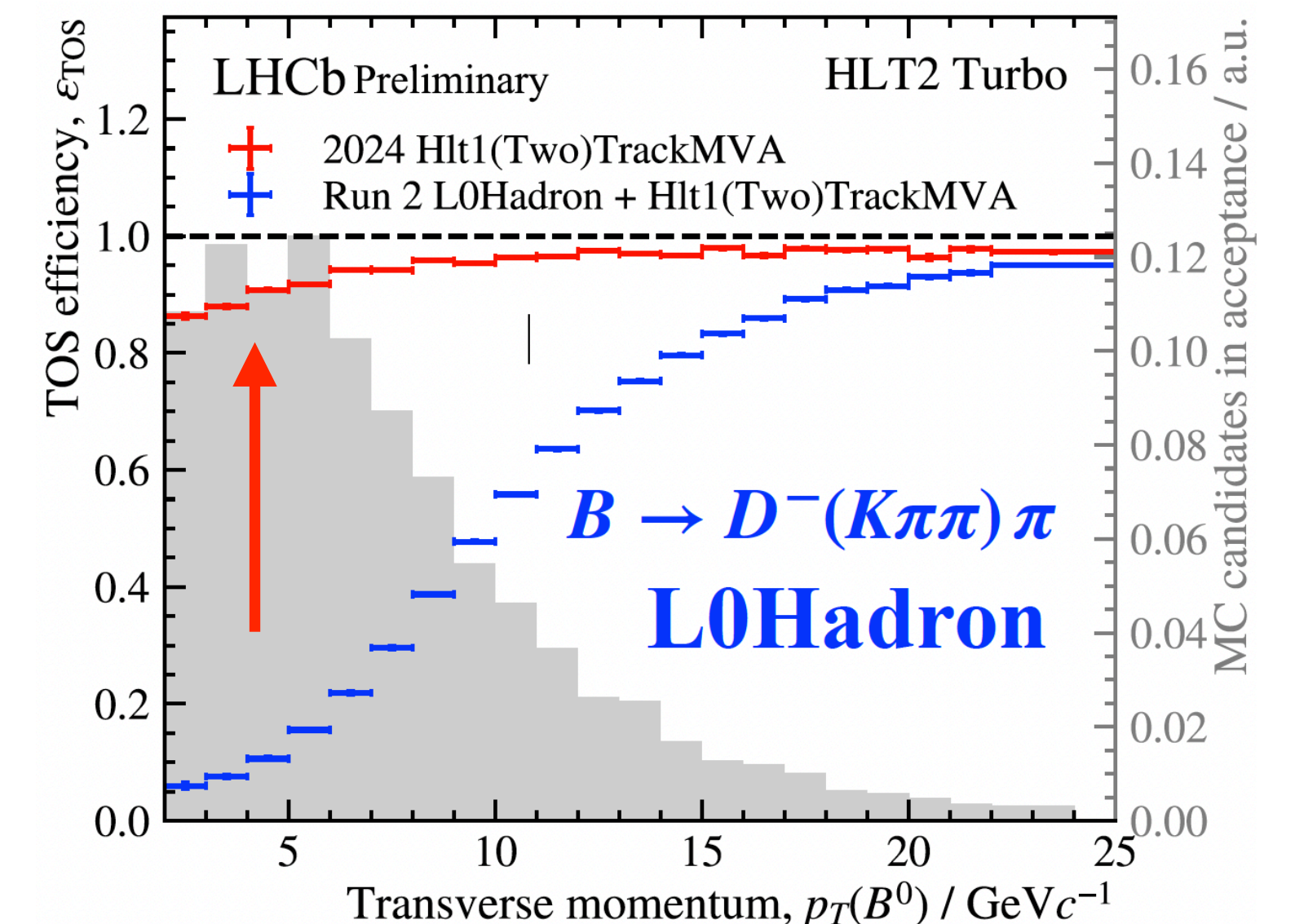
Very active analyses with Run 3 data



Fully new detector with purely software-based trigger system
2~4x increase in efficiency of hadronic decays

Run 3 : 27.89 fb^{-1} (3x than Runs 1+2)

Great potential for further understanding of these exotic states



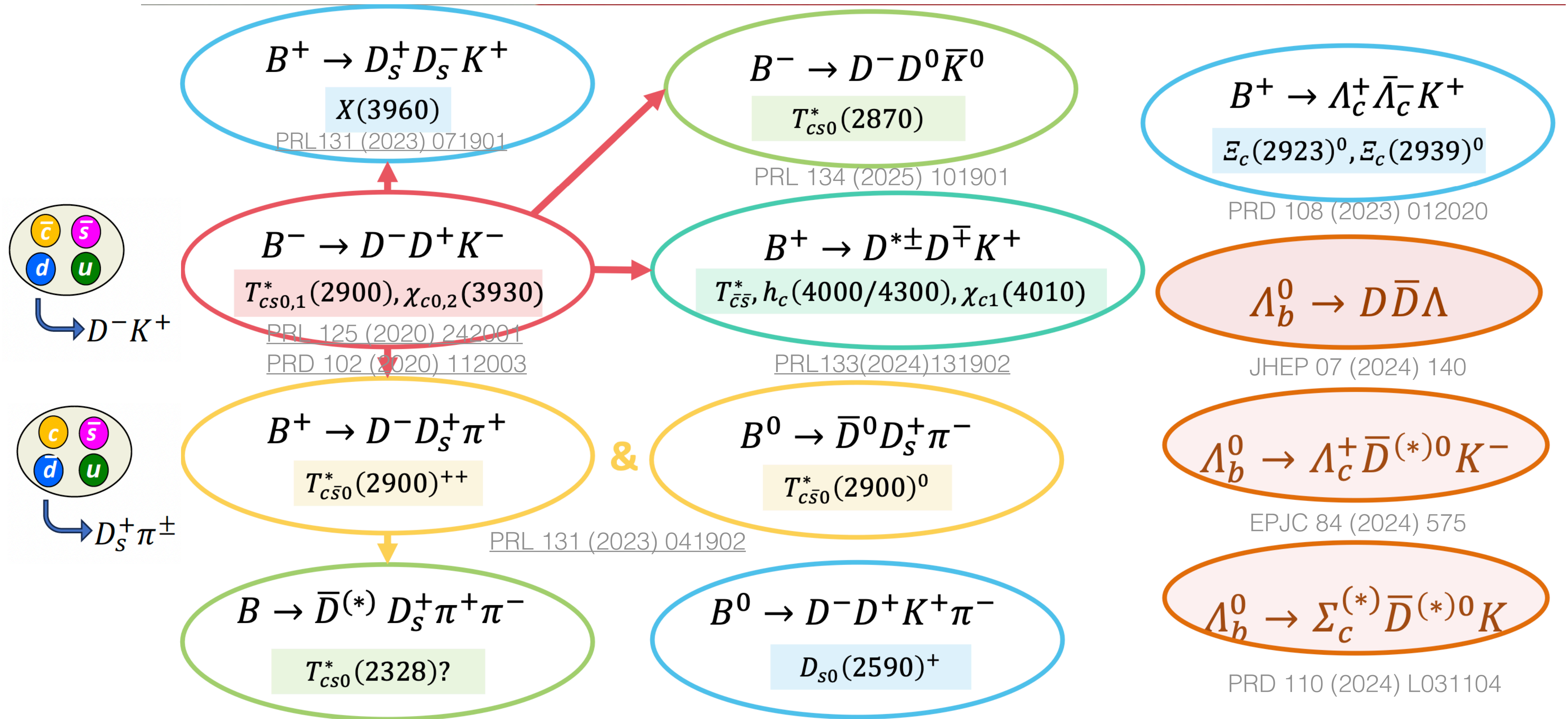
Summary

- LHCb provides huge pp collision samples for study of heavy exotic states
- **Charmonium-like states:**
 - Radiative decays and search of new decays of $\chi_{c1}(3872)$
 - Observation and searches of various $T_{c\bar{c}}$ states
- **Open-charm tetraquark states:** further study of $D_{s1}(2460)$ and $D_{s1}(2536)$ decays
- Continuous searches of pentaquark & hexaquark states
- LHCb **Run 3 collected 3x more data** than Runs 1+2, providing great potential for further investigation of the various exotic states

stay tuned!

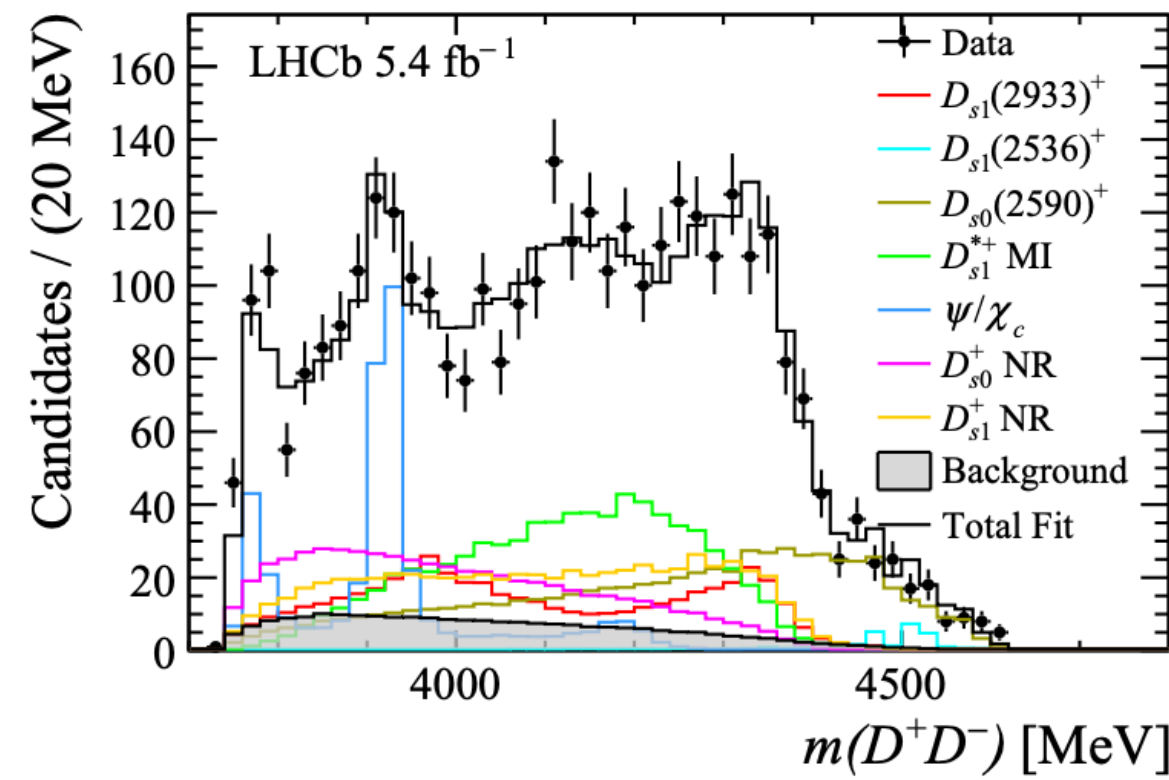
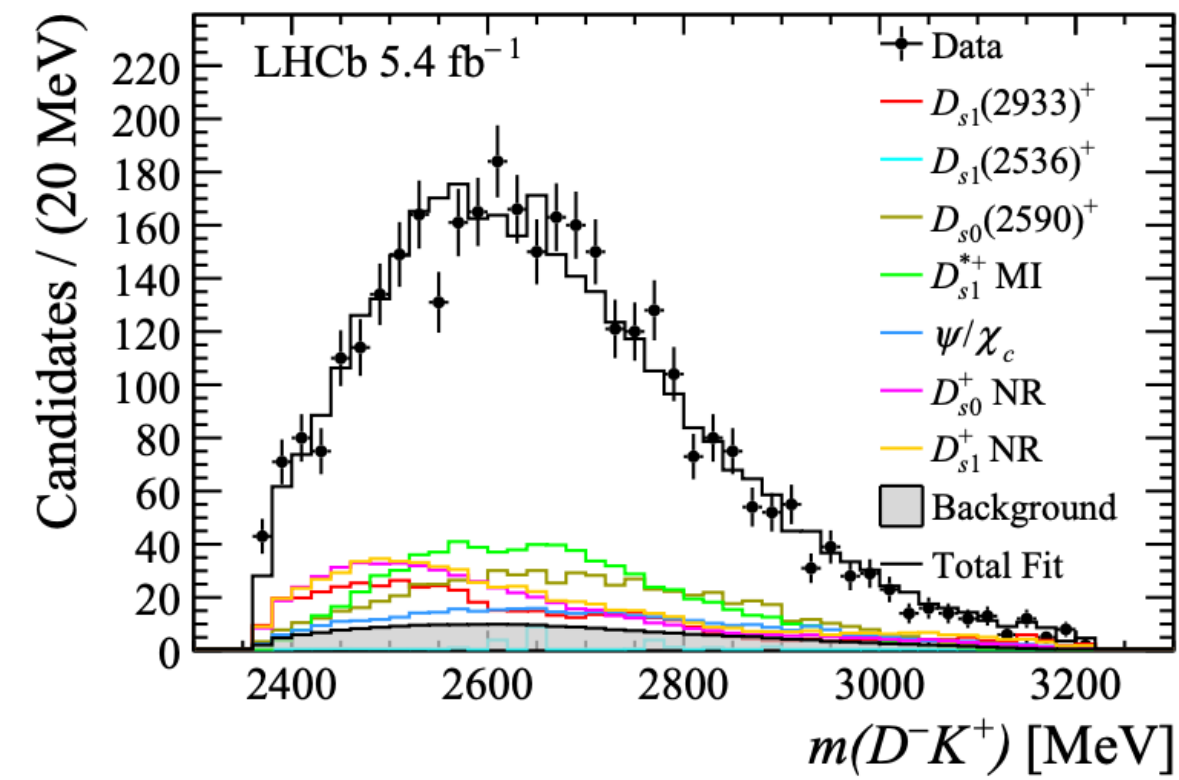
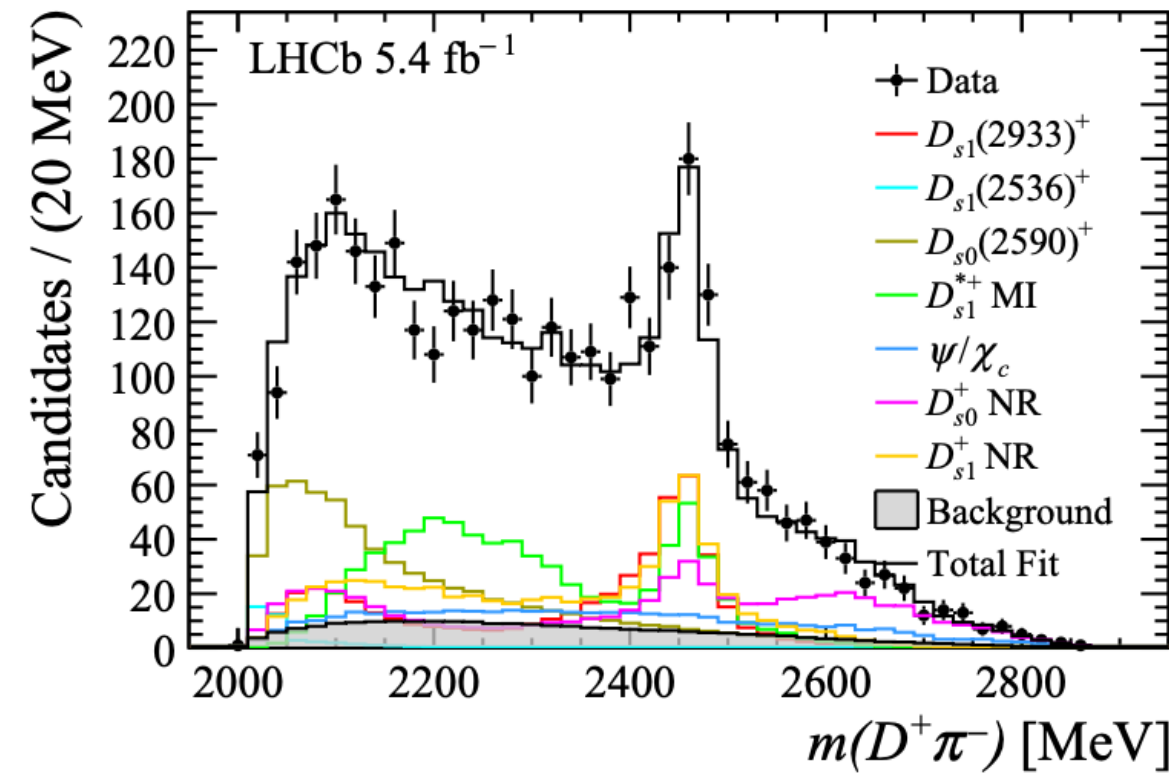
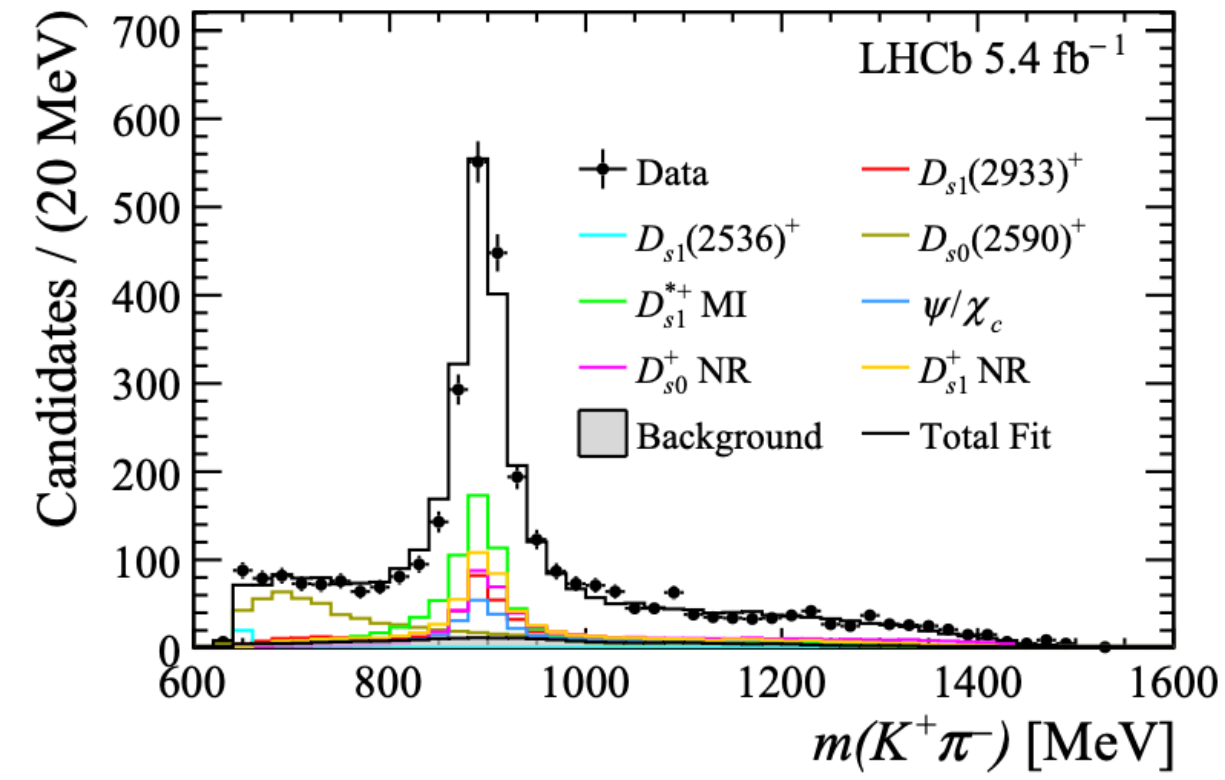


Study of $H_b \rightarrow D^{(*)}\bar{D}h(h)$



Observation of $D_{s1}^+(2933)^0 \rightarrow D^+ K^+ \pi^-$

arXiv: 2604.21257



Component	Fit fraction (%)
$B^0 \rightarrow D^- D_{s1}(2536)^+, D_{s1}(2536)^+ \rightarrow K^+ (D^+ \pi^-)_S$	$1.0^{+0.1+0.6}_{-0.3-0.4}$
$B^0 \rightarrow D^- D_{s0}(2590)^+, D_{s0}(2590)^+ \rightarrow D^+ (K^+ \pi^-)_S$	$21.5^{+0.4+2.5}_{-2.1-0.6}$
$B^0 \rightarrow D^- D_{s1}(2933)^+, D_{s1}(2933)^+ \rightarrow K^+ (D^+ \pi^-)_S$	$2.4^{+0.5+0.4}_{-0.7-1.3}$
$B^0 \rightarrow D^- D_{s1}(2933)^+, D_{s1}(2933)^+ \rightarrow D^+ K_1^*(892)^0$	$8.9^{+1.8+2.4}_{-2.1-1.8}$
$B^0 \rightarrow D^- D_{s1}(2933)^+, D_{s1}(2933)^+ \rightarrow K^+ D_2^*(2460)^0$	$7.0^{+6.0+3.0}_{-3.0-3.7}$
$B^0 \rightarrow D^- D_{s1}^* \text{ MI}, D_{s1}^* \text{ MI} \rightarrow D^+ K_1^*(892)^0$	$18.0^{+0.9+0.4}_{-2.4-2.0}$
$B^0 \rightarrow D^- D_{s1}^* \text{ MI}, D_{s1}^* \text{ MI} \rightarrow K^+ D_2^*(2460)^0$	$4.7^{+0.8+0.4}_{-0.5-0.3}$
$B^0 \rightarrow D^- D_{s0}^+ \text{ NR}, D_{s0}^+ \text{ NR} \rightarrow D^+ K_1^*(892)^0$	$8.4^{+2.2+1.9}_{-0.8-0.9}$
$B^0 \rightarrow D^- D_{s0}^+ \text{ NR}, D_{s0}^+ \text{ NR} \rightarrow D^+ K_1^*(1410)^0$	$1.6^{+1.1+0.7}_{-0.3-0.9}$
$B^0 \rightarrow D^- D_{s0}^+ \text{ NR}, D_{s0}^+ \text{ NR} \rightarrow D^+ K_2^*(1430)^0$	$1.0^{+0.5+0.9}_{-0.3-0.1}$
$B^0 \rightarrow D^- D_{s0}^+ \text{ NR}, D_{s0}^+ \text{ NR} \rightarrow K^+ D_2^*(2460)^0$	$1.9^{+0.5+0.3}_{-0.6-0.9}$
$B^0 \rightarrow D^- D_{s0}^+ \text{ NR}, D_{s0}^+ \text{ NR} \rightarrow K^+ D_1^*(2600)^0$	$1.5^{+0.8+0.4}_{-0.3-0.4}$
$B^0 \rightarrow D^- D_{s1}^+ \text{ NR}, D_{s1}^+ \text{ NR} \rightarrow D^+ K_1^*(892)^0$	$10.0^{+2.2+1.8}_{-1.1-1.2}$
$B^0 \rightarrow D^- D_{s1}^+ \text{ NR}, D_{s1}^+ \text{ NR} \rightarrow K^+ D_2^*(2460)^0$	$6.0^{+6.5+2.6}_{-3.0-4.4}$
$B^0 \rightarrow D^- D_{s1}^+ \text{ NR}, D_{s1}^+ \text{ NR} \rightarrow K^+ D_1^*(2600)^0$	$2.5^{+0.6+0.6}_{-0.5-0.4}$
$B^0 \rightarrow (K^+ \pi^-)_S \chi_{c0}(3915), \chi_{c0}(3915) \rightarrow D^+ D^-$	$6.7^{+0.1+0.4}_{-2.2-1.1}$
$B^0 \rightarrow K_1^*(892)^0 \chi_{c0}(3915), \chi_{c0}(3915) \rightarrow D^+ D^-$	$0.9^{+0.5+0.3}_{-0.3-0.1}$
$B^0 \rightarrow K_1^*(892)^0 \chi_{c2}(3930), \chi_{c2}(3930) \rightarrow D^+ D^-$	$0.7^{+0.4+0.2}_{-0.3-0.2}$
$B^0 \rightarrow K_1^*(892)^0 \psi(3770), \psi(3770) \rightarrow D^+ D^-$	$2.3^{+0.5+0.4}_{-0.4-0.5}$
$B^0 \rightarrow K_2^*(1430)^0 \psi(3770), \psi(3770) \rightarrow D^+ D^-$	$0.9^{+0.4+0.0}_{-0.3-0.3}$
$B^0 \rightarrow K_1^*(892)^0 \psi(4040), \psi(4040) \rightarrow D^+ D^-$	$0.9^{+0.6+0.7}_{-0.3-0.3}$
$B^0 \rightarrow K_1^*(892)^0 \psi(4160), \psi(4160) \rightarrow D^+ D^-$	$0.9^{+0.7+1.8}_{-0.1-0.3}$
Total	$109.7^{+12.4+7.5}_{-5.4-9.5}$

μ -tagged $D_{s1}(2460)^+/D_{s1}(2536)^+ \rightarrow D_s^+ \pi^+ \pi^-$

[arXiv:2608.10826](#)

Table 2: Lineshape models used for $\pi^+ \pi^-$ and $D_s^+ \pi^\pm$ amplitudes.

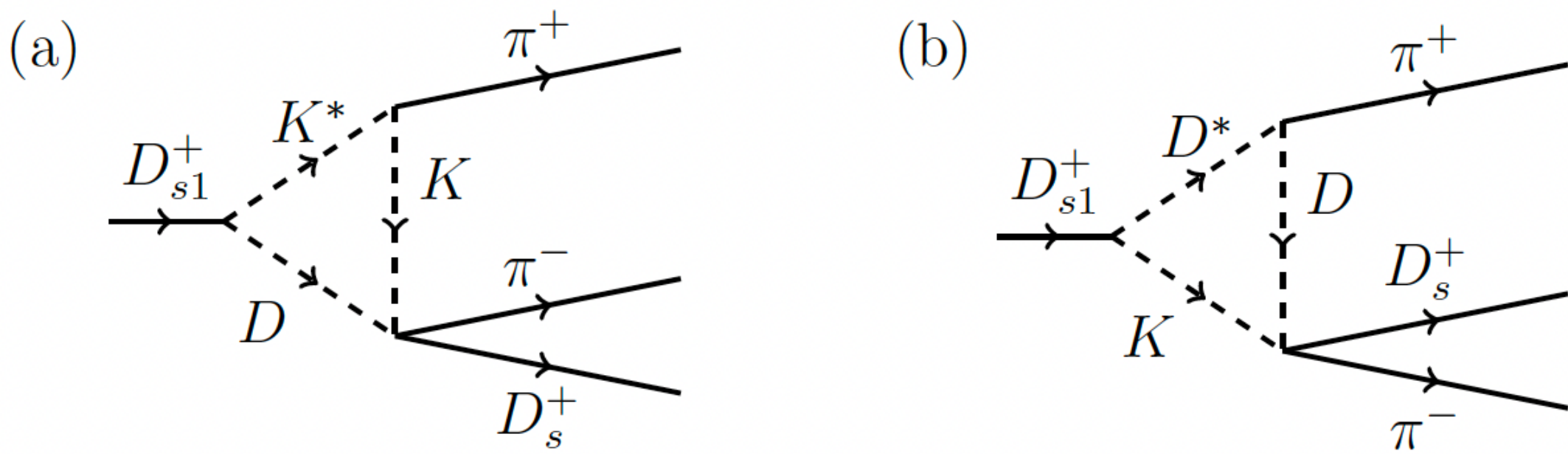
Channel	Resonances	Lineshape models
$\pi^+ \pi^-$	$f_0(500)$, $f_0(980)$, $f_2(1270)$ $f_0(500)$	Breit–Wigner (baseline) Quasi model-independent
$D_s^+ \pi^\pm$	$T_{c\bar{s}0}^*$, $T_{c\bar{s}1}^*$ $T_{c\bar{s}0}^*$ $T_{c\bar{s}0}^*$	Breit–Wigner Scattering-length approximation (baseline) $D^* K$ and DK^* triangle diagrams

$$\rho = \text{diag}(\rho_{DK}(m), \rho_{D_s\pi}(m)), \tag{8}$$

$$\rho_{AB}(m) = \frac{1}{16\pi} \frac{\sqrt{[m^2 - (m_A + m_B)^2][m^2 - (m_A - m_B)^2]}}{m^2}, \tag{9}$$

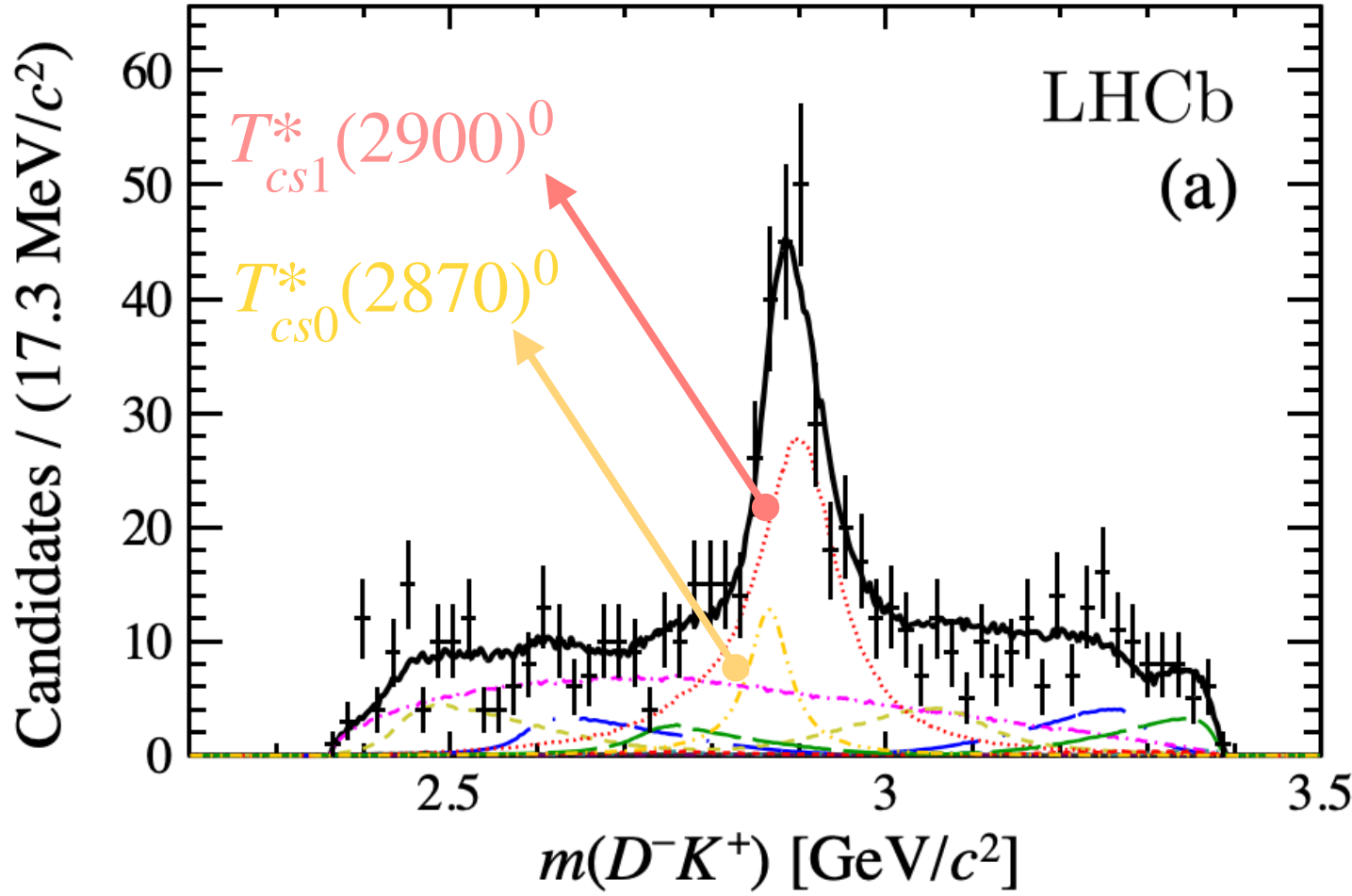
analytically continued below threshold using $\sqrt{x} = +i\sqrt{|x|}$. The constant K -matrix is

$$\mathcal{K} = \begin{pmatrix} \gamma & \beta \\ \beta & \gamma_2 \end{pmatrix}, \tag{10}$$

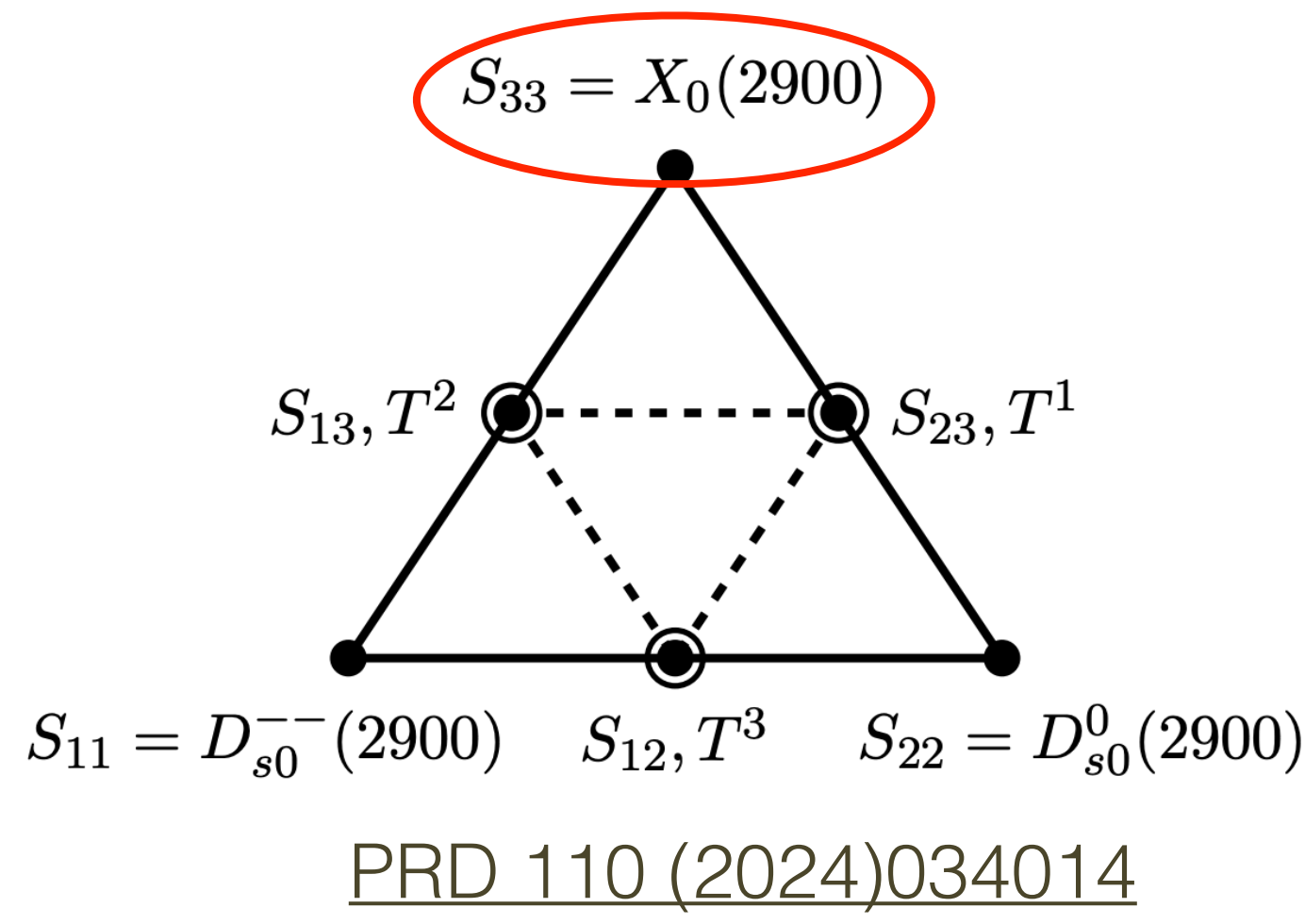


T_{cs} states at LHCb

$B^+ \rightarrow D^+ D^- K^+$



- $\psi(3770) \rightarrow D^+ D^-$
 - $\chi_{c0}(3930) \rightarrow D^+ D^-$
 - $\chi_{c2}(3930) \rightarrow D^+ D^-$
 - $\psi(4040) \rightarrow D^+ D^-$
 - $\psi(4160) \rightarrow D^+ D^-$
 - $\psi(4415) \rightarrow D^+ D^-$
 - $X_0(2900) \rightarrow D^- K^+$
 - $X_1(2900) \rightarrow D^- K^+$
 - Nonresonant
- PRL125(2020)242001
PRD102(2020)112003



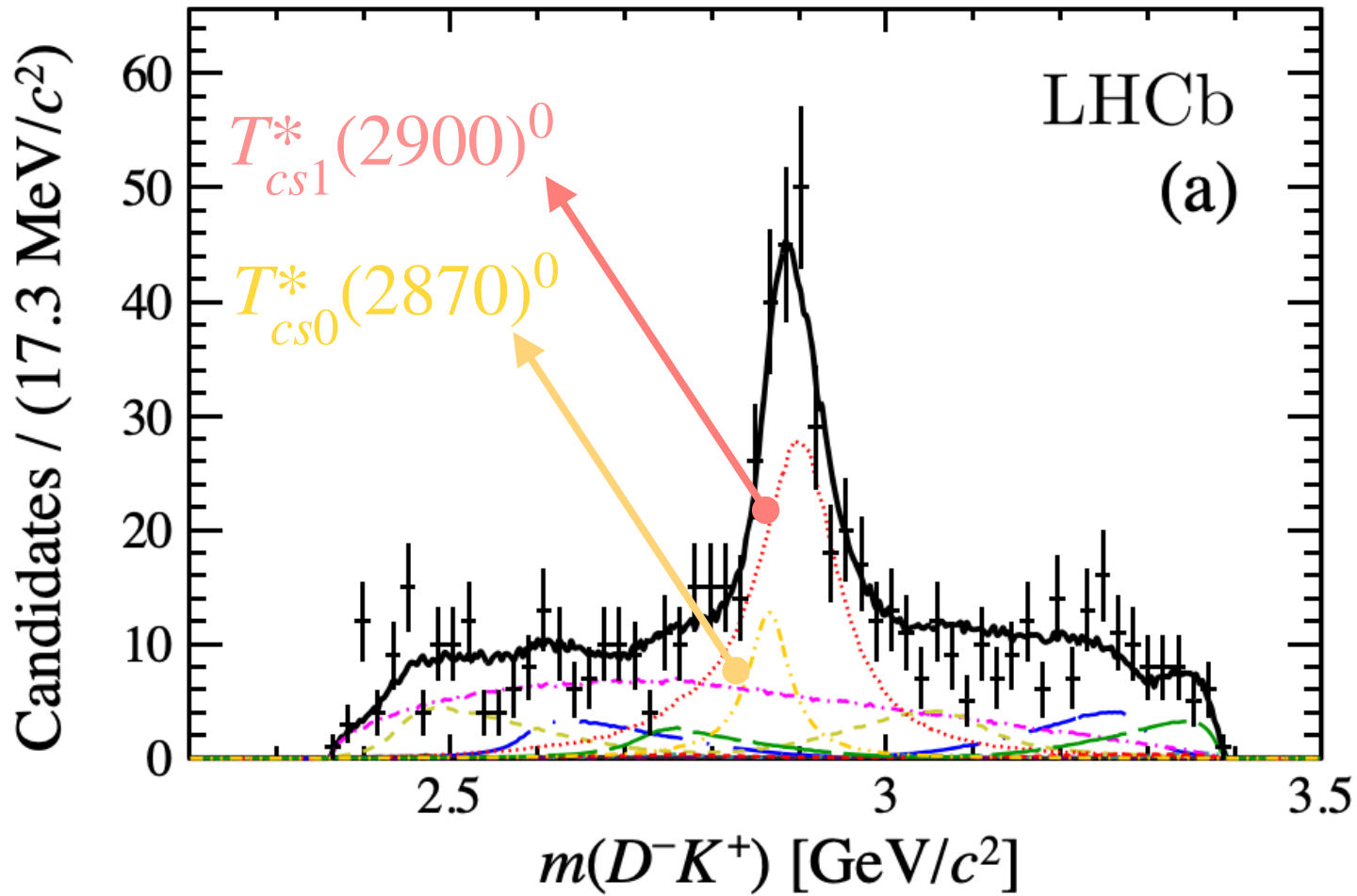
2020



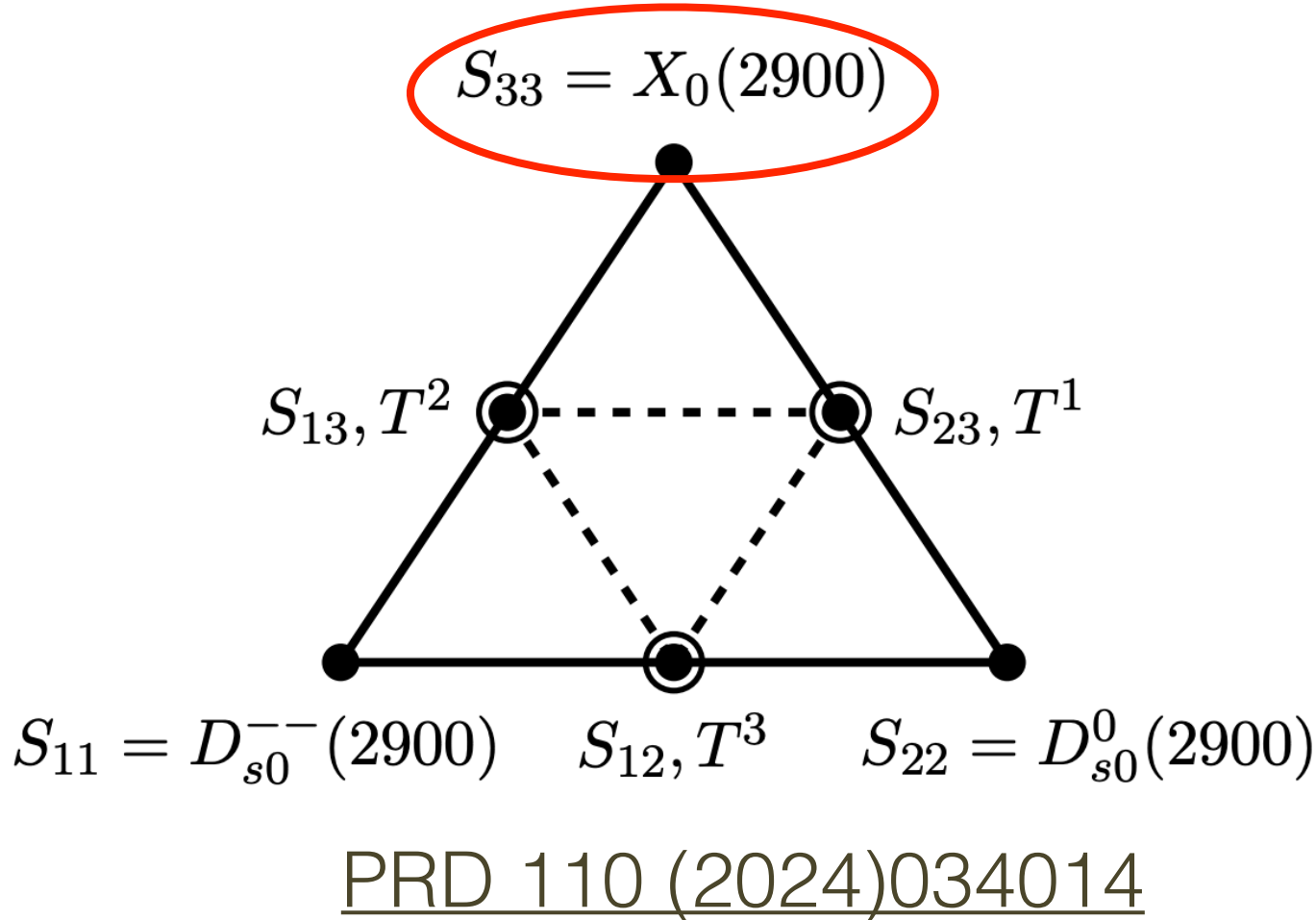
$T_{cs0}^*(2870)^0$
 $T_{cs1}^*(2900)^0$

T_{cs} states at LHCb

$B^+ \rightarrow D^+ D^- K^+$



- $\psi(3770) \rightarrow D^+ D^-$
 - $\chi_{c0}(3930) \rightarrow D^+ D^-$
 - $\chi_{c2}(3930) \rightarrow D^+ D^-$
 - $\psi(4040) \rightarrow D^+ D^-$
 - $\psi(4160) \rightarrow D^+ D^-$
 - $\psi(4415) \rightarrow D^+ D^-$
 - $X_0(2900) \rightarrow D^- K^+$
 - $X_1(2900) \rightarrow D^- K^+$
 - Nonresonant
- PRL125(2020)242001
- PRD102(2020)112003



2020

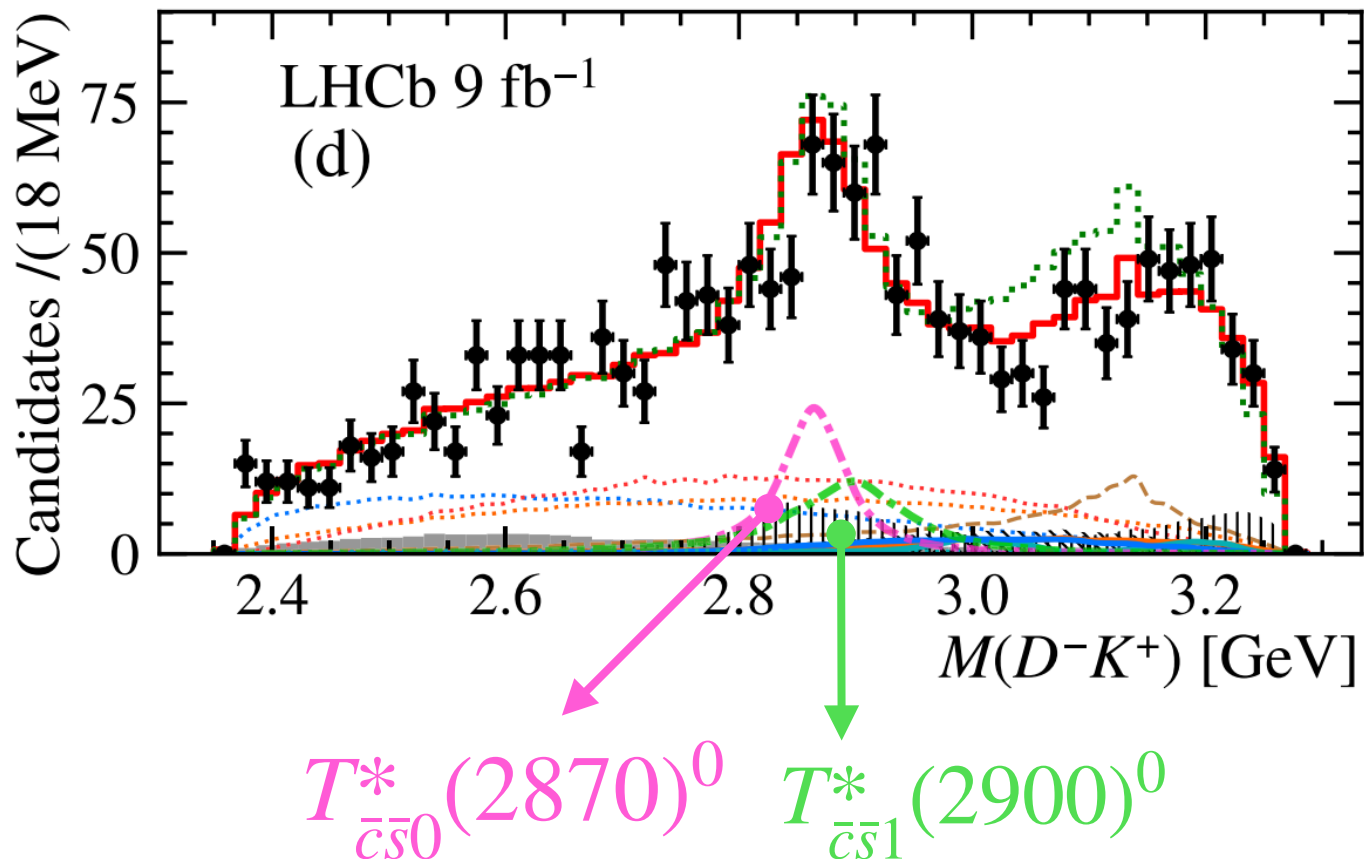


$T_{cs0}^*(2870)^0$

$T_{cs1}^*(2900)^0$

LHCb

$B^+ \rightarrow D^{*+} D^- K^+$



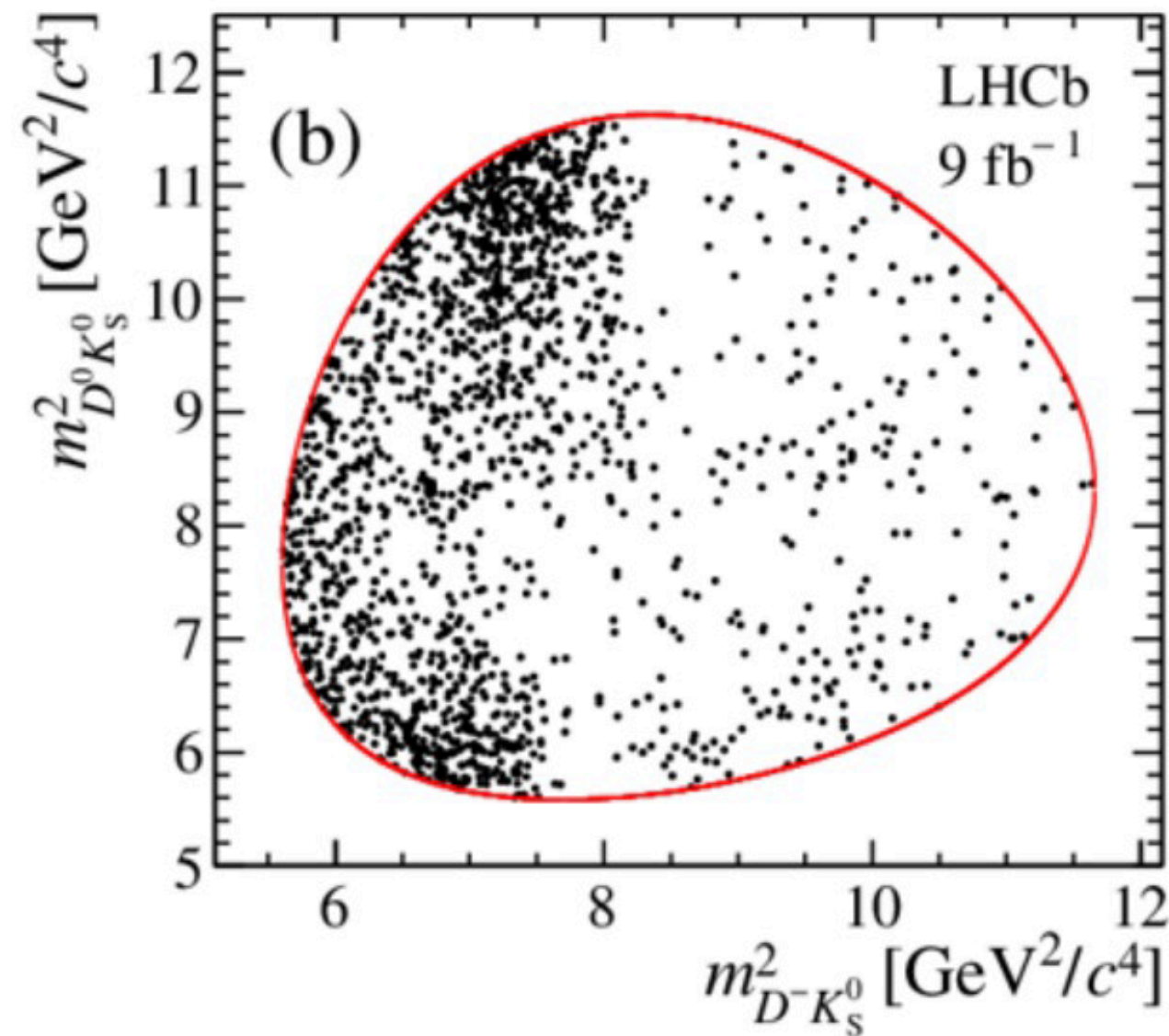
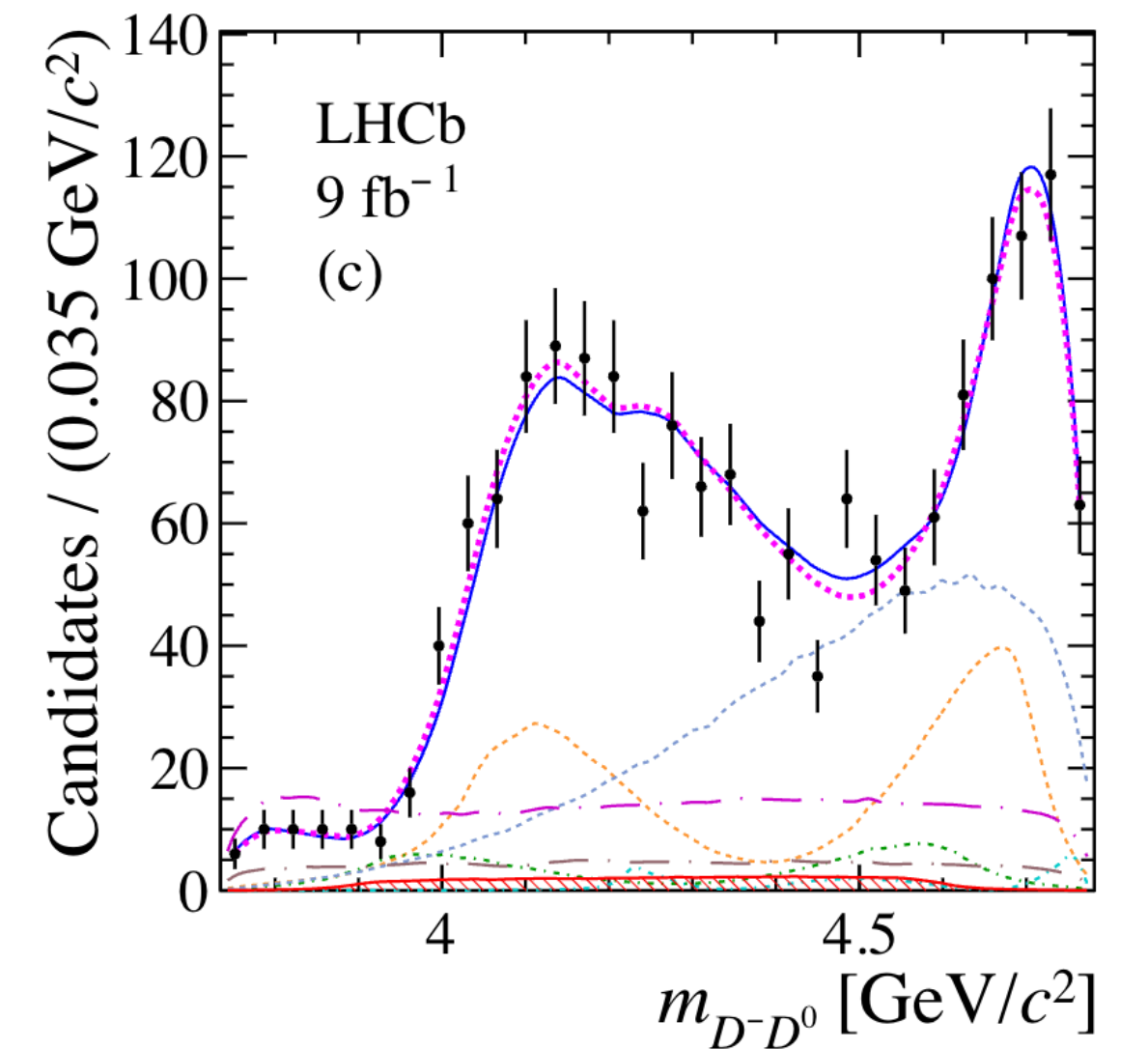
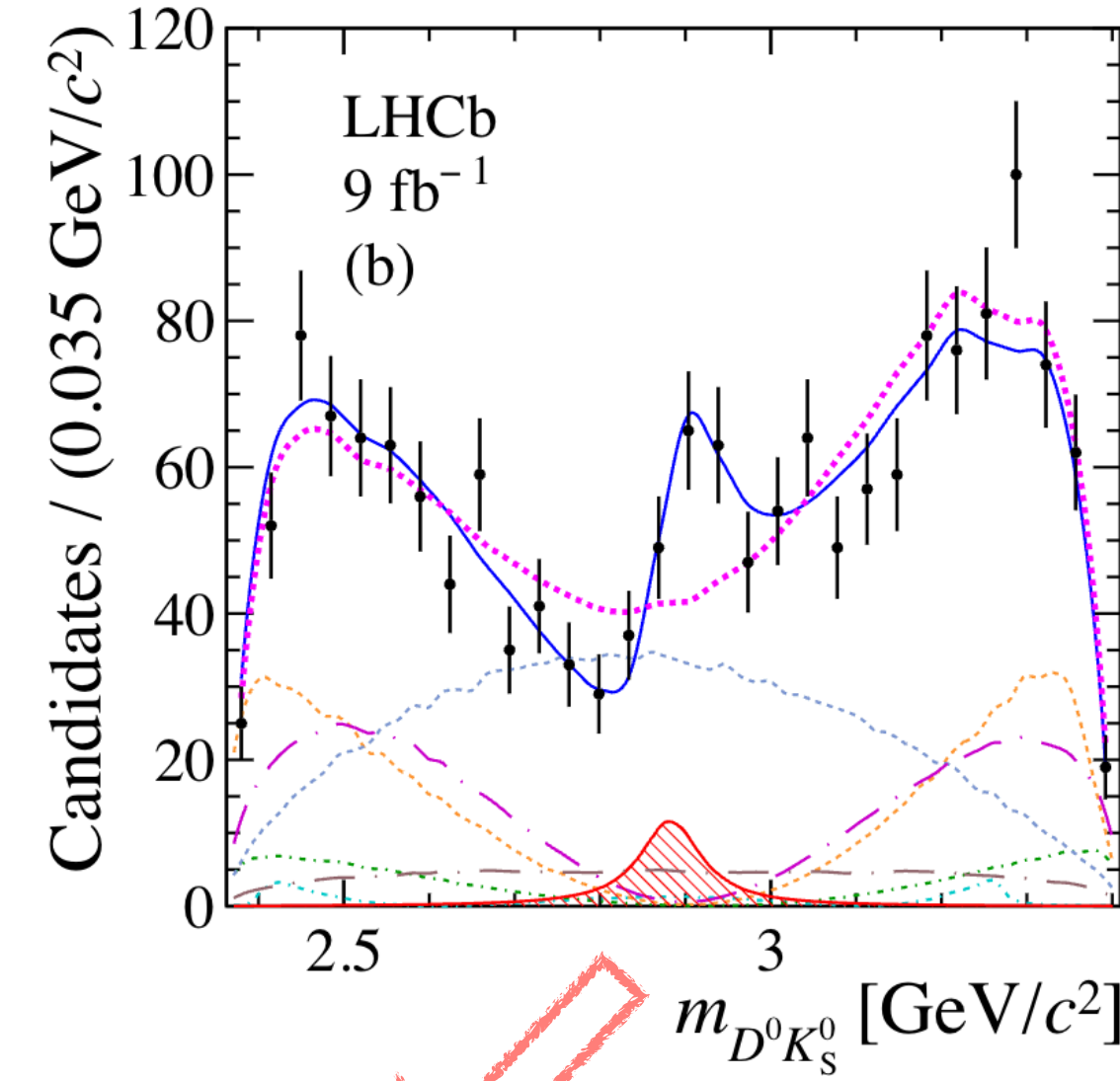
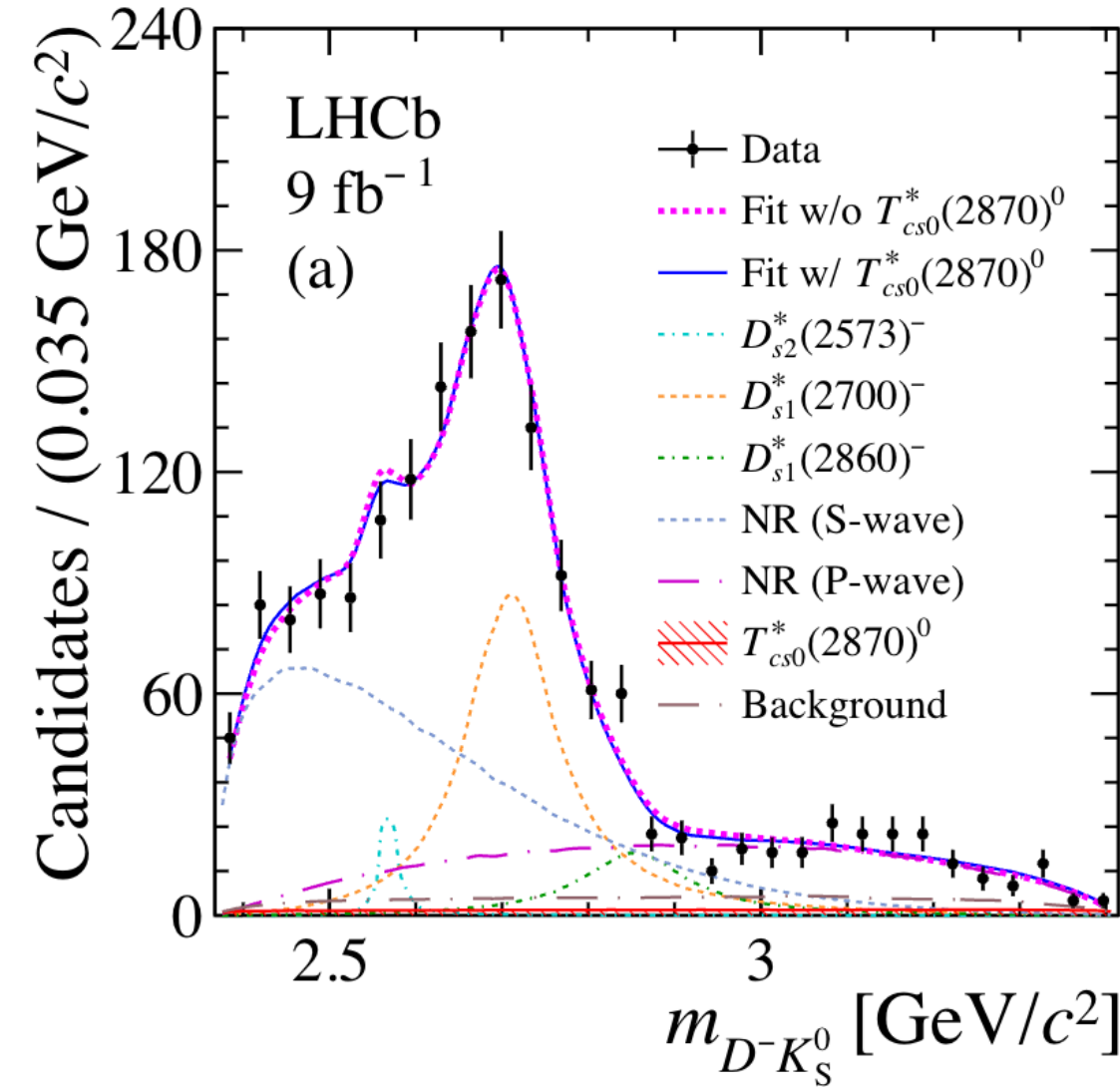
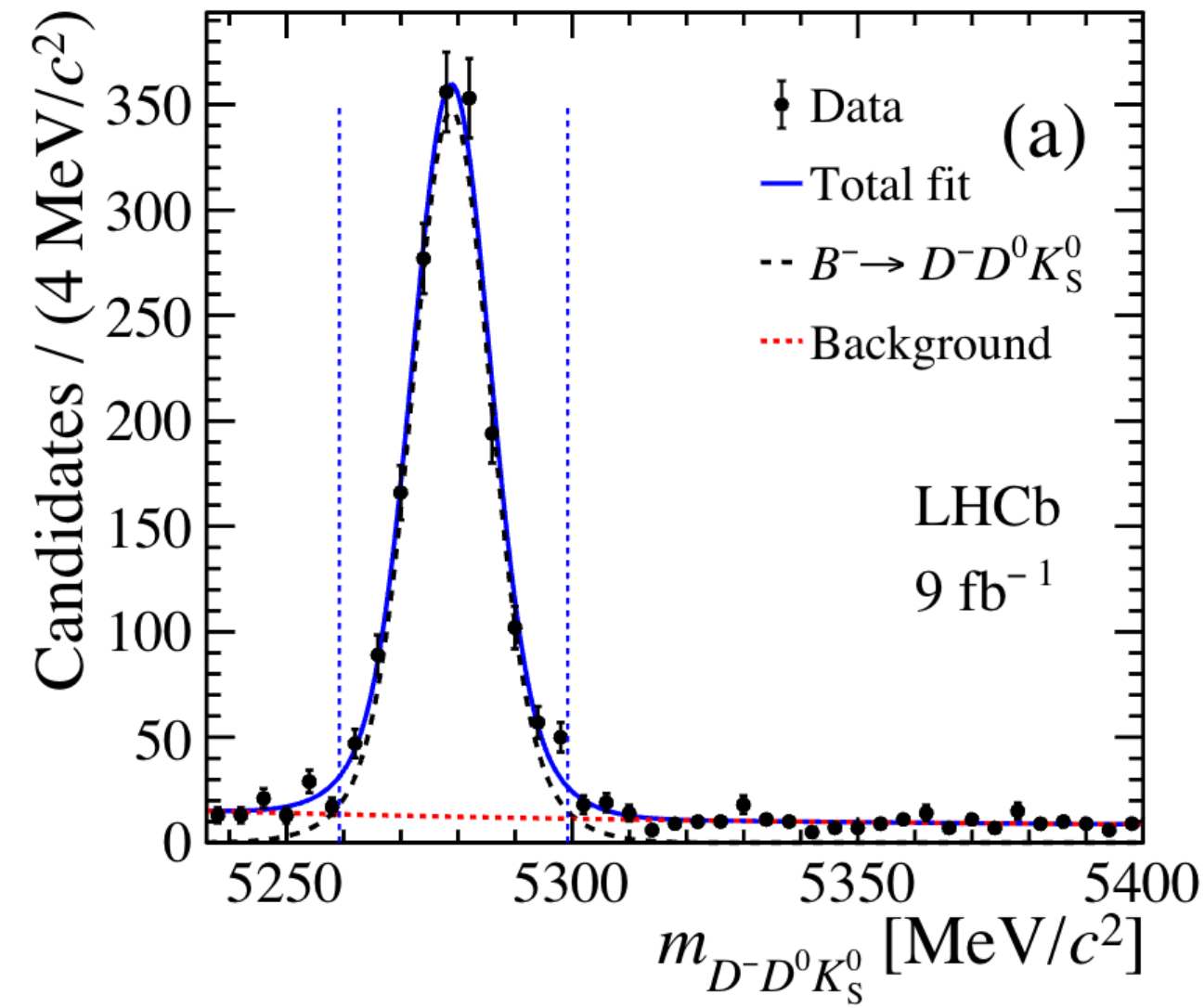
Property	This work	Previous work
$T_{cs0}^*(2870)^0$ mass [MeV]	$2914 \pm 11 \pm 15$	2866 ± 7
$T_{cs0}^*(2870)^0$ width [MeV]	$128 \pm 22 \pm 23$	57 ± 13
$T_{cs1}^*(2900)^0$ mass [MeV]	$2887 \pm 8 \pm 6$	2904 ± 5
$T_{cs1}^*(2900)^0$ width [MeV]	$92 \pm 16 \pm 16$	110 ± 12
$\mathcal{B}(B^+ \rightarrow T_{cs0}^*(2870)^0 D^{(*)+})$	$(4.5^{+0.6}_{-0.8} {}^{+0.9}_{-1.0} \pm 0.4) \times 10^{-5}$	$(1.2 \pm 0.5) \times 10^{-5}$
$\mathcal{B}(B^+ \rightarrow T_{cs1}^*(2900)^0 D^{(*)+})$	$(3.8^{+0.7}_{-1.0} {}^{+1.6}_{-1.1} \pm 0.3) \times 10^{-5}$	$(6.7 \pm 2.3) \times 10^{-5}$
$\frac{\mathcal{B}(B^+ \rightarrow T_{cs0}^*(2870)^0 D^{(*)+})}{\mathcal{B}(B^+ \rightarrow T_{cs1}^*(2900)^0 D^{(*)+})}$	$1.17 \pm 0.31 \pm 0.48$	0.18 ± 0.05

PRL133(2024)131902

Observation of $T_{cs0}^*(2870)^0 \rightarrow D^0 K_S^0$

$$B^- \rightarrow D^- D^0 K_S^0 \quad (N_{sig} = 1540 \pm 40)$$

PRL 134(2025)101901



- $T_{cs0}^*(2870)^0 \rightarrow D^0 K_S^0$ (5.3 σ significance)
 - $M = 2883 \pm 11 \pm 8 \text{ MeV}/c^2$, $\Gamma = 87_{-47}^{+22} \pm 17 \text{ MeV}$
 - $J^P = 0^+$ preferred
- No evidence for $T_{cs1}^*(2900)^0 \rightarrow$ isospin violation between $D^0 K_S^0$ and $D^+ K^-$