Recent results on hadron states from LHCb

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2025/04/27

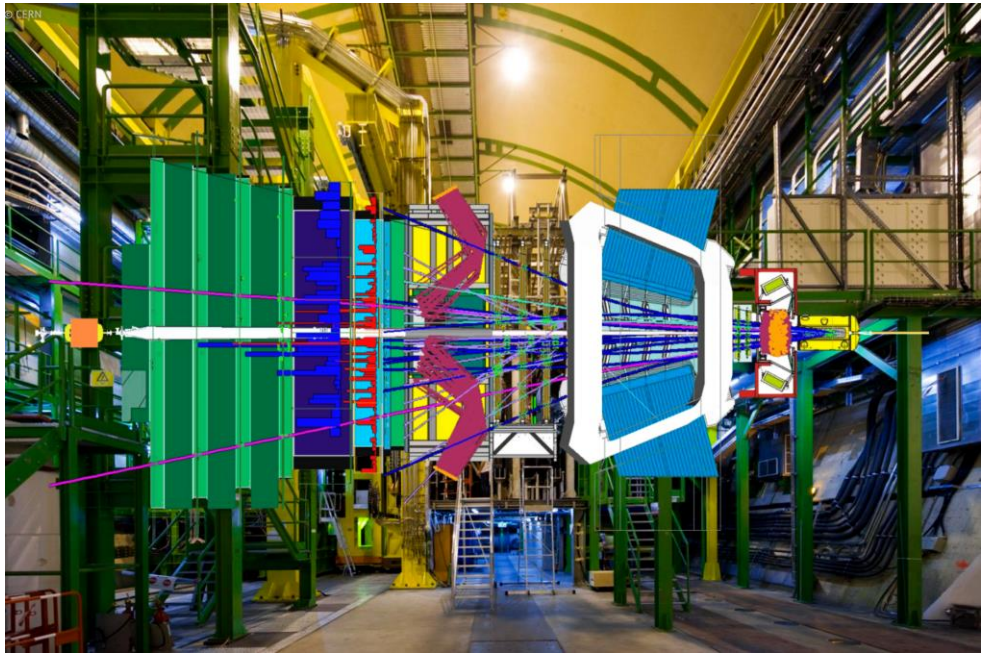
第5届LHCb前沿物理研讨会@武汉

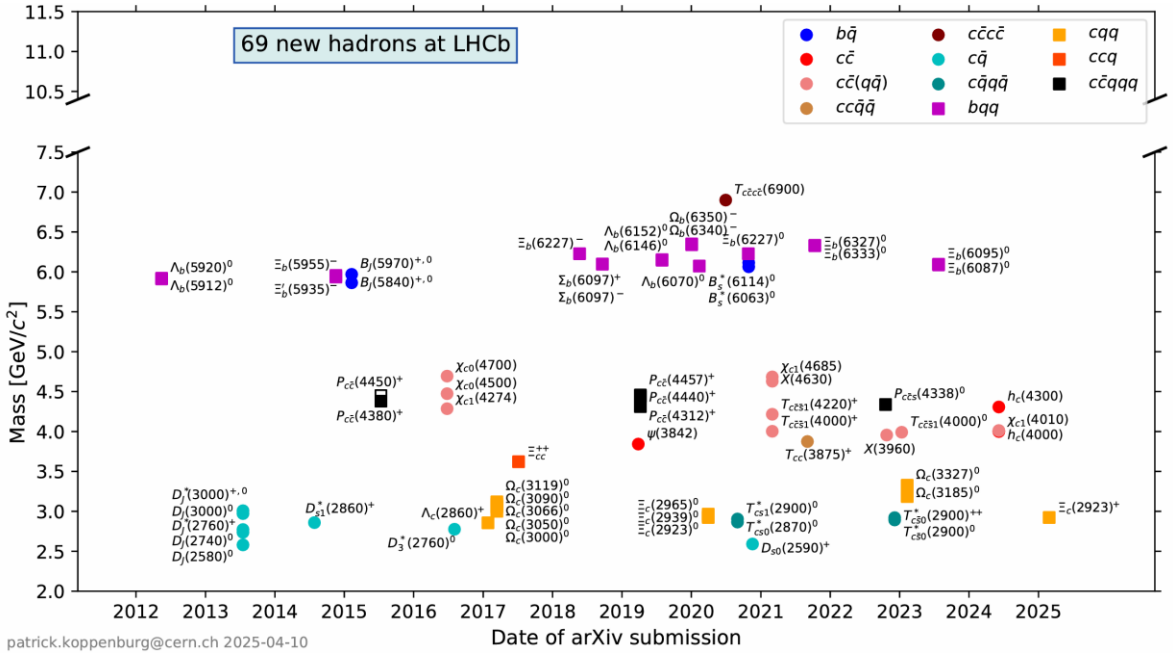
Hadrons @ LHCb

LHCb: a dedicated spectrometer to *b* or *c* hadrons

- excellent tracking and particle identification
- 9 fb^{-1} for Run1 (7-8 TeV) + Run2 (13 TeV)

The structure and properties of hadrons from QCD remains a challenge, non-perturbative effects involved

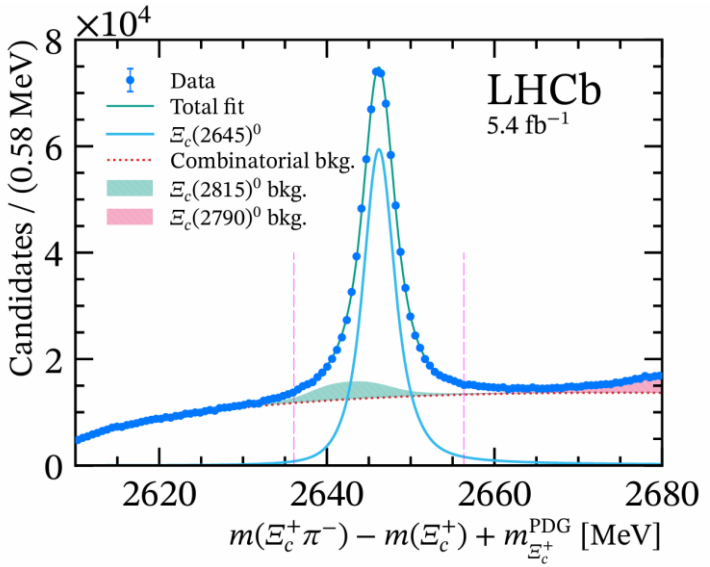


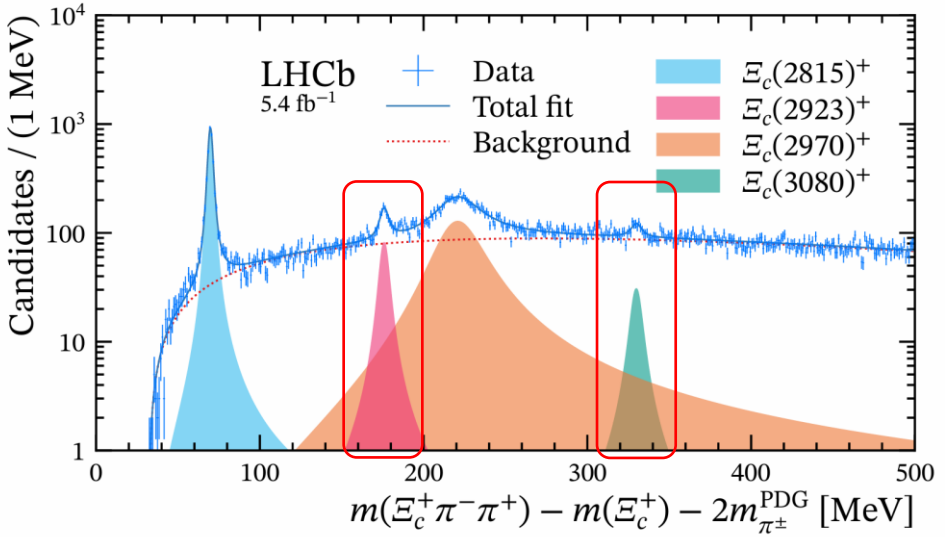


Observation of new baryons $\Xi_c(2923)^+$

arXiv:2502.18987

- Decay chain: $\Xi_c^{**+} \to \Xi_c(2645)^0\pi^+$, $\Xi_c(2645)^0 \to \Xi_c^+\pi^-$, $\Xi_c^+ \to pK^-\pi^+$
- Observed a new excited $\Xi_c(2923)^+$, as the isospin partner of $\Xi_c(2923)^0$
- Observe new decay mode: $\Xi_c(3080)^+ \to \Xi_c(2645)^0\pi^+$
- Measured precisely the $\Xi_c(2815)^+$ and $\Xi_c(2970)^+$
  - natural width of $\Xi_c(2970)^+$ twice as $\Xi_c(2965)^0$ state





$m[\Xi_c(2815)^+] = 2816.65 \pm 0.03 \pm 0.03 \pm 0.23\,\text{MeV},$
$\Gamma[\Xi_c(2815)^+] = 2.07 \pm 0.08 \pm 0.12\,\text{MeV},$

$m[\Xi_c(2923)^+] = 2922.8 \pm 0.3 \pm 0.5 \pm 0.2\,\text{MeV},$
$\Gamma[\Xi_c(2923)^+] = 5.3 \pm 0.9 \pm 1.4\,\text{MeV},$

$m[\Xi_c(2970)^+] = 2968.6 \pm 0.5 \pm 0.5 \pm 0.2\,\text{MeV},$
$\Gamma[\Xi_c(2970)^+] = 31.7 \pm 1.7 \pm 1.9\,\text{MeV},$

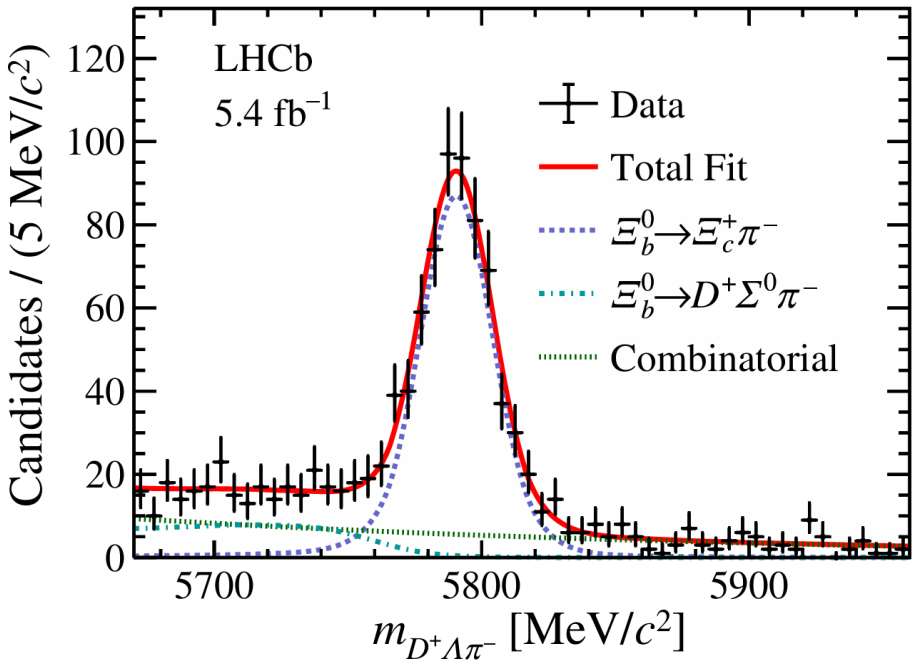
$m[\Xi_c(3080)^+] = 3076.8 \pm 0.7 \pm 1.3 \pm 0.2\,\text{MeV},$
$\Gamma[\Xi_c(3080)^+] = 6.8 \pm 2.3 \pm 0.9\,\text{MeV},$

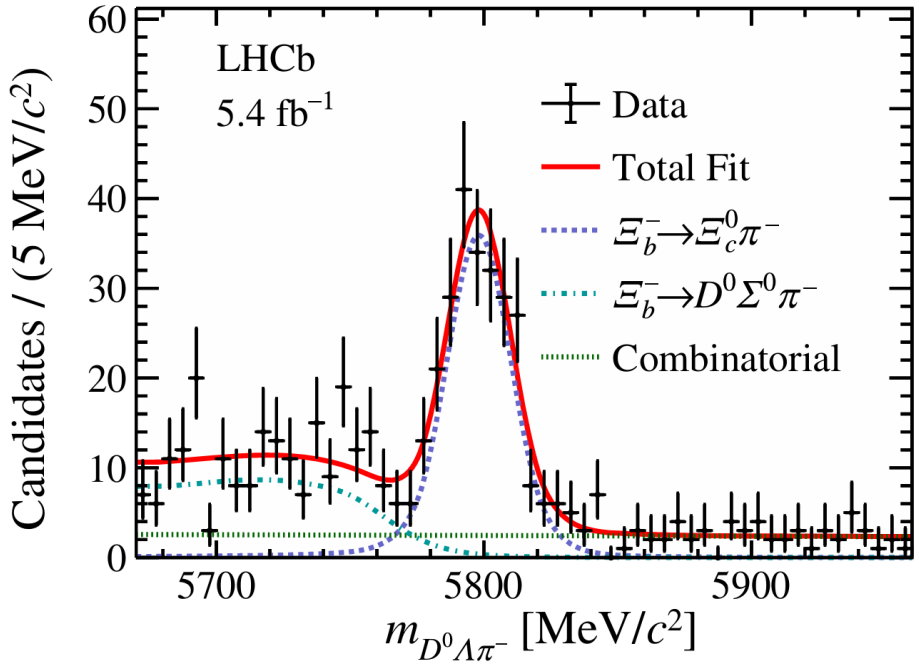
First determination of the J^P of $\Xi_c(3055)^{+(0)}$

Phys. Rev. Lett. 134 (2025) 081901

Amplitude analysis separately for $\Xi_b^{0(-)} \to \Xi_c^{**+(0)}\pi^-$, $\Xi_c^{**+(0)} \to D^{+(0)}\Lambda$

- signal weights extracted from $\Xi_b^{0(-)}$ mass fit
- first observation of $\Xi_b^{0(-)} \to \Xi_c(3055)^{+(0)}\pi^-$ in pp collisions





First determination of the J^P of $\Xi_c(3055)^{+(0)}$

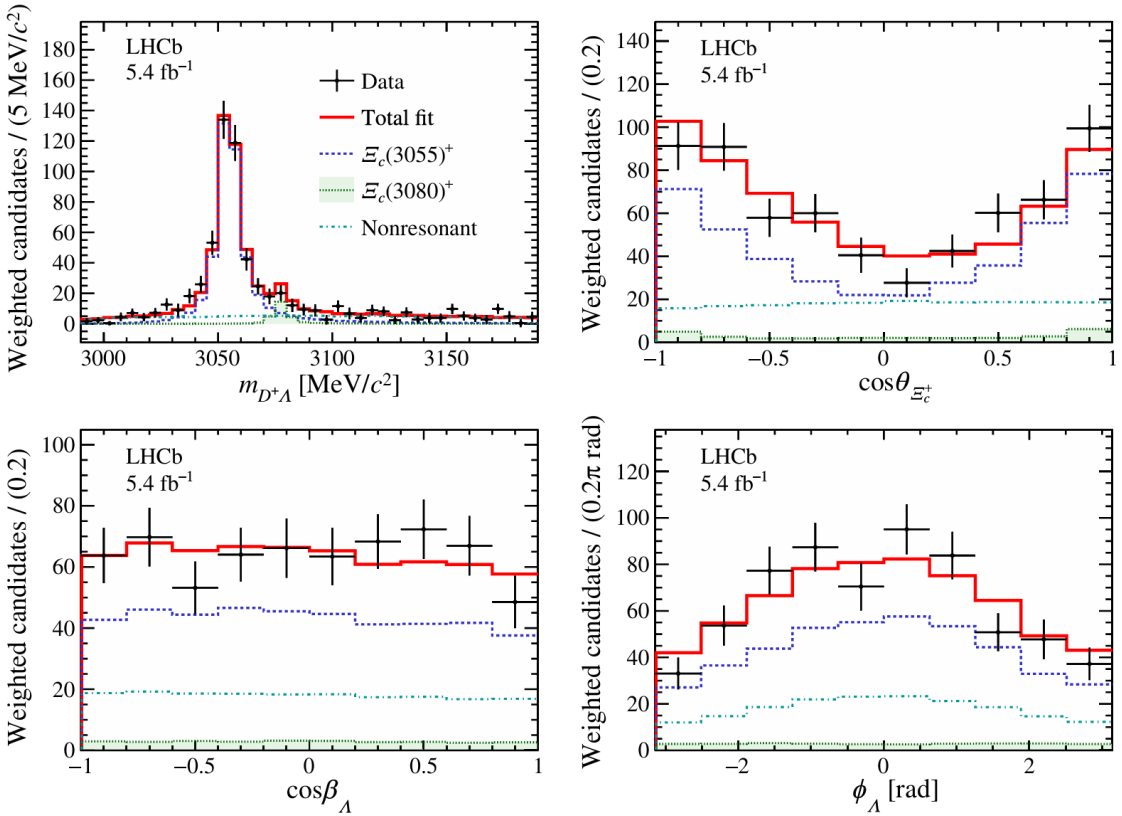
Phys. Rev. Lett. 134 (2025) 081901

Best fit combination gives $\Xi_c(3055)^{+(0)}$ $J^P = 3/2^+$ with significance 6.5σ (3.5σ)

- Measured mass and width agree with PDG value
- first time measured up-down asymmetries for $\Xi_b^{0(-)} \to \Xi_c(3055)^{+(0)}\pi^-$, $\alpha = -0.92 \pm 0.10 \pm 0.05$ $(-0.92 \pm 0.16 \pm 0.22)$, consistent with maximal parity violation

$$\alpha \equiv \frac{|H_{\lambda_{\Xi_b^0}=+1/2}|^2 - |H_{\lambda_{\Xi_b^0}=-1/2}|^2}{|H_{\lambda_{\Xi_b^0}=+1/2}|^2 + |H_{\lambda_{\Xi_b^0}=-1/2}|^2},$$

- Significance of $\Xi_c(3080)^{+(0)}$ 4.4σ (3.6σ)



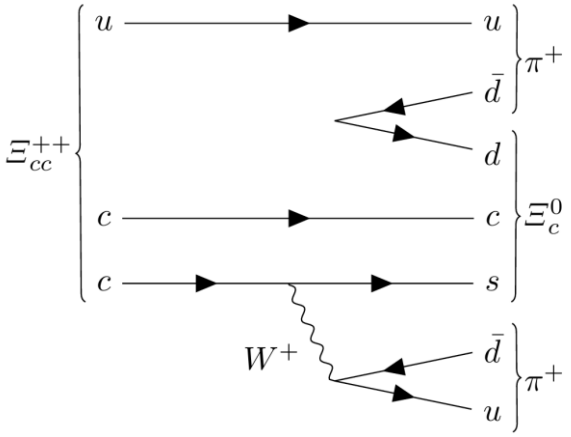
Observation of new decay $\Xi_{cc}^{++} \to \Xi_c^0 \pi^+ \pi^-$

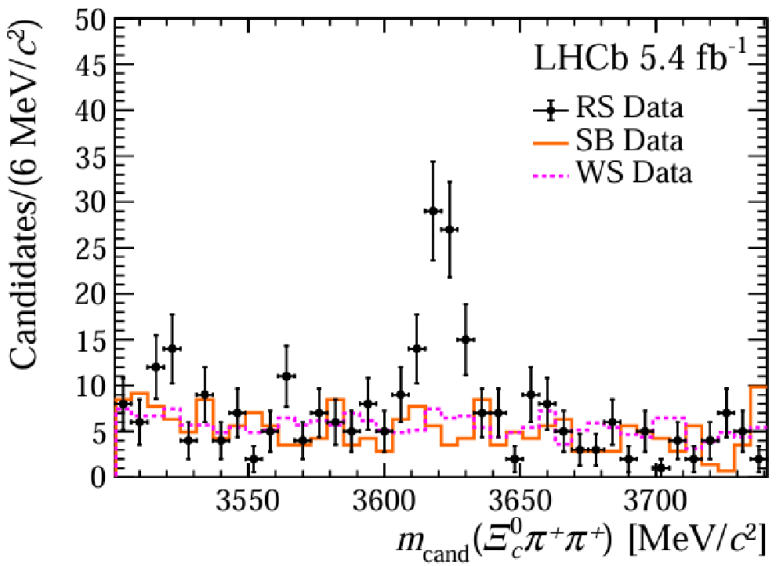
arXiv:2504.05063

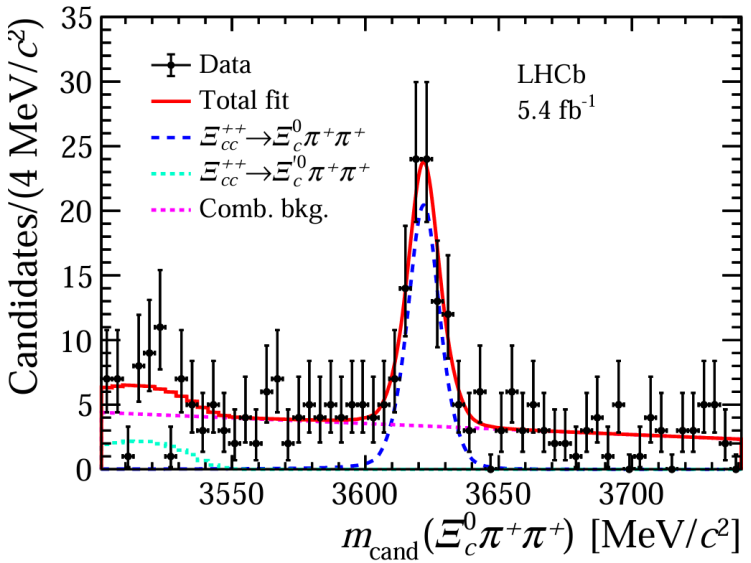
Observed ~ 80 signals for $\Xi_{cc}^{++} \to \Xi_c^0 \pi^+ \pi^-$ with significance of $>10\sigma$

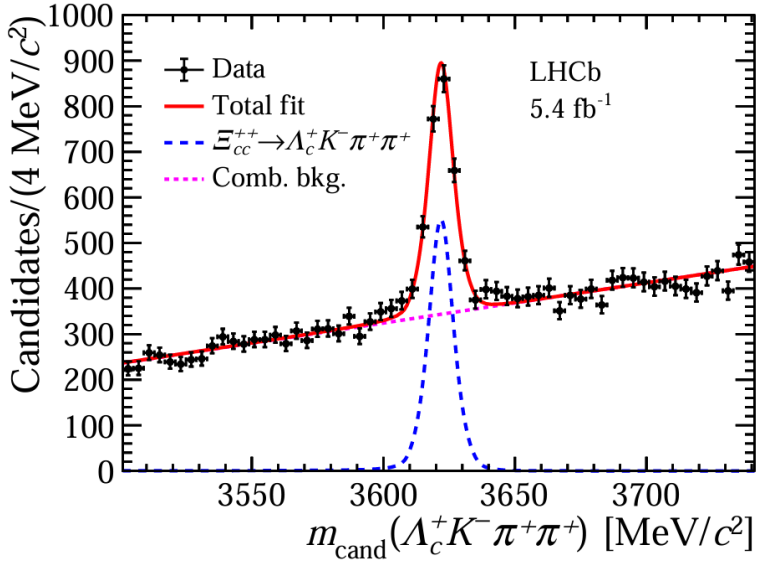
- measured Ξ_{cc}^{++} mass agree with known value
- no significant narrow Ξ_c^+ found in $\Xi_c^0 \pi^+$ spectrum
- branching ratio set related to $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^-$

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^0 \pi^+ \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)} = 1.37 \pm 0.18(\text{stat}) \pm 0.09(\text{syst}) \pm 0.35(\text{ext})$$









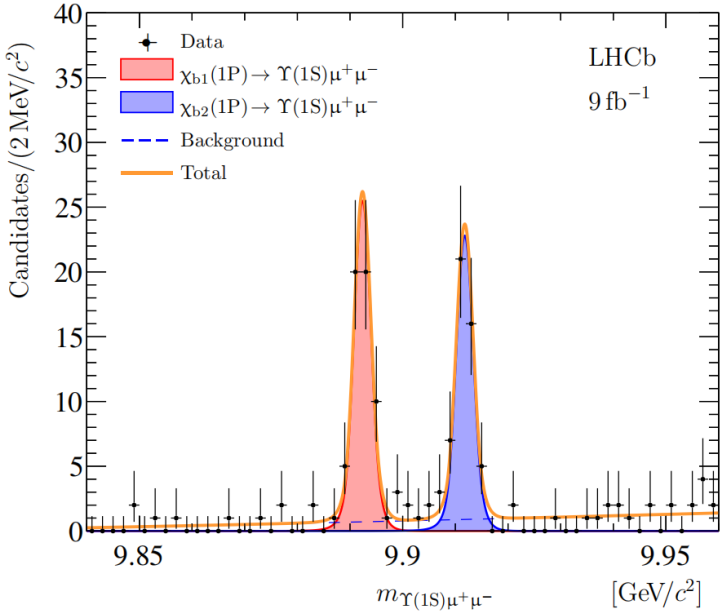
Observation of muonic Dalitz decays of χ_b meson

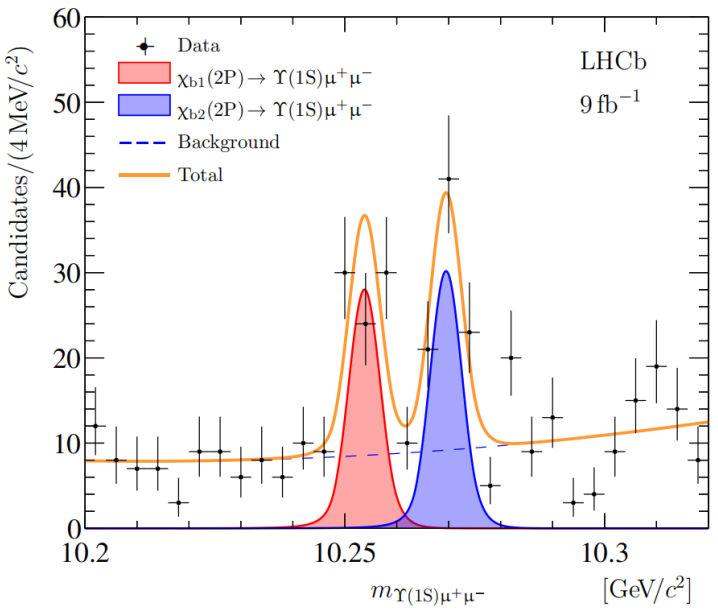
JHEP 10 (2024) 122

First observation of the $\chi_{b1}(1P)$, $\chi_{b2}(1P)$, $\chi_{b1}(2P)$ and $\chi_{b2}(2P)$ muonic Dalitz decays

- significance $>5\sigma$ for all states
- Most precise measurements of $\chi_{b1}(1P)$

$$m_{\chi_{b1}(1P)} = 9\,892.50 \pm 0.26 \pm 0.10 \pm 0.10\,\mathrm{MeV}/c^2\,,$$
$$m_{\chi_{b2}(1P)} = 9\,911.92 \pm 0.29 \pm 0.11 \pm 0.10\,\mathrm{MeV}/c^2\,,$$
$$m_{\chi_{b1}(2P)} = 10\,253.97 \pm 0.75 \pm 0.22 \pm 0.09\,\mathrm{MeV}/c^2\,,$$
$$m_{\chi_{b2}(2P)} = 10\,269.67 \pm 0.67 \pm 0.22 \pm 0.09\,\mathrm{MeV}/c^2\,,$$





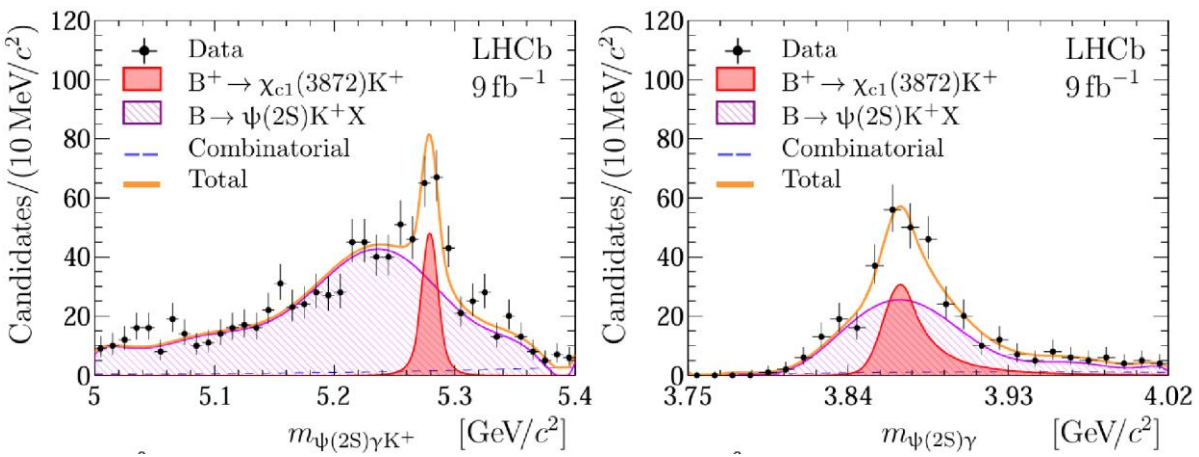
Radiative decay of $\chi_{c1}(3872)$

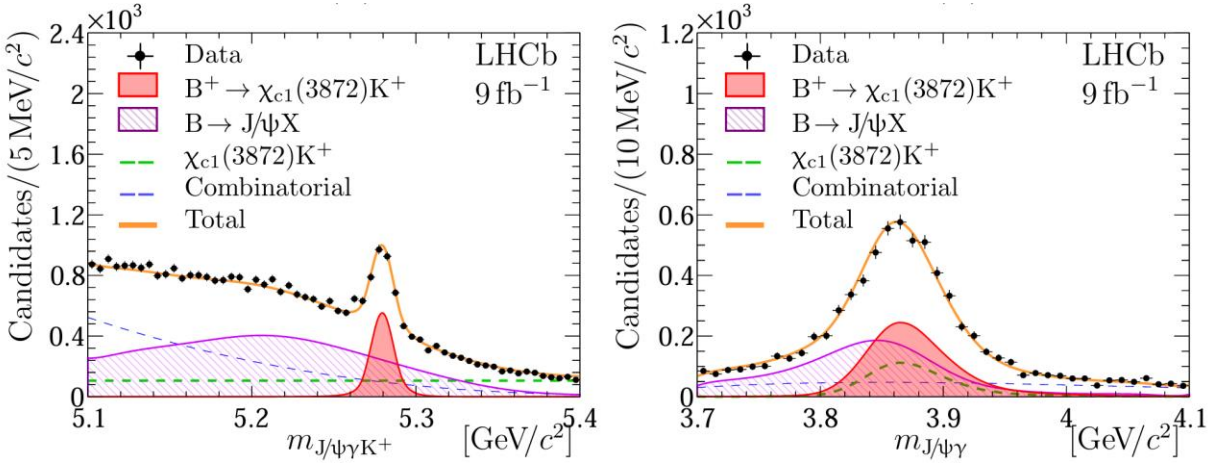
JHEP 11 (2024) 121

First observed $\chi_{c1}(3872) \to \psi(2S)\gamma$ via study of $B^+ \to \psi(2S)\gamma K^+$, with significance of 4.8σ ($6.0\,\sigma$) for Run1 (Run2)

- 2D fit simultaneously to extract B^+ and $\chi_{c1}(3872)$
- signal and background shapes studied in simulation

- Relative BF : $$\mathscr{R}_{\psi\gamma} = \frac{N_{B^+\to(\chi_{c1}(3872)\to\psi(2S)\gamma)K^+}}{N_{B^+\to(\chi_{c1}(3872)\to J/\psi\gamma)K^+}} \times \frac{\varepsilon_{B^+\to(\chi_{c1}(3872)\to J/\psi\gamma)K^+}}{\varepsilon_{B^+\to(\chi_{c1}(3872)\to\psi(2S)\gamma)K^+}} \times \frac{\mathcal{B}_{J/\psi\to\mu^+\mu^-}}{\mathcal{B}_{\psi(2S)\to\mu^+\mu^-}}$$





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

JHEP 11 (2024) 121

stat. syst. ext.

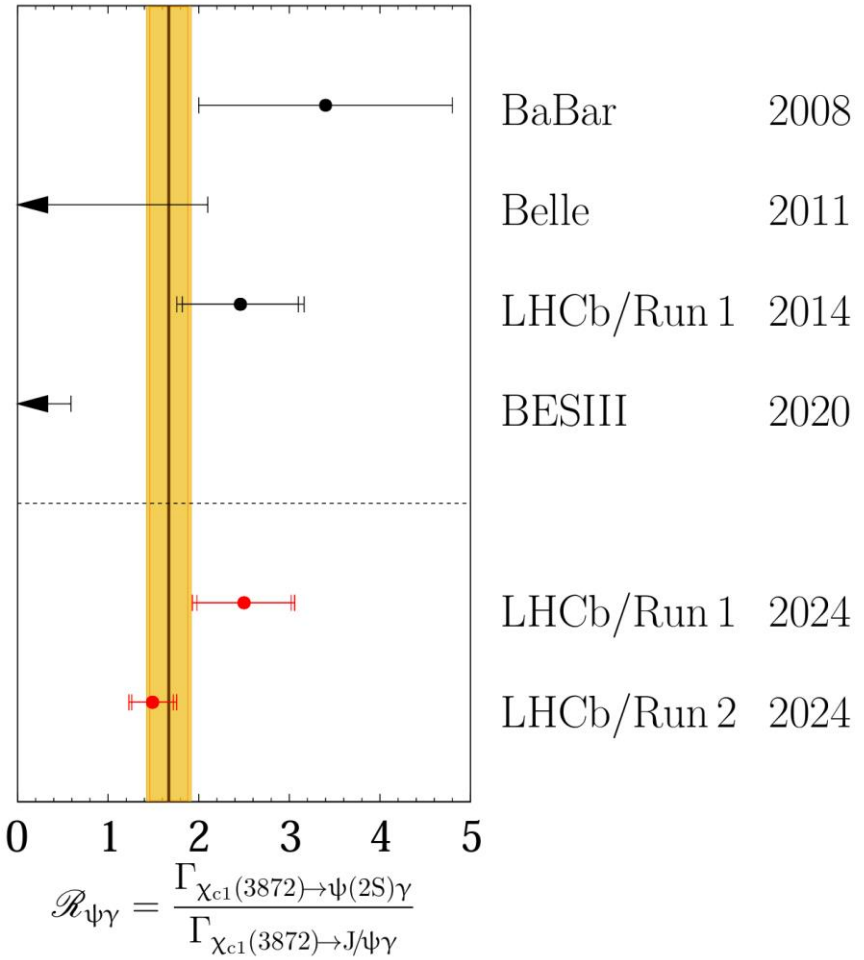
$$\mathscr{R}_{\psi\gamma} = 1.67 \pm 0.21 \pm 0.12 \pm 0.04$$

- The large measured R value are more inclined to the theoretical predictions of compact charmonium or tetraquark component

  i.e. PhysRevD 75,014005

- Pure $D\bar{D}^*$ molecular hypothesis is questionable, but small admixture of $c\bar{c}$ component is sufficient to explain the data

  i.e. PhysLettB 2015 0213



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

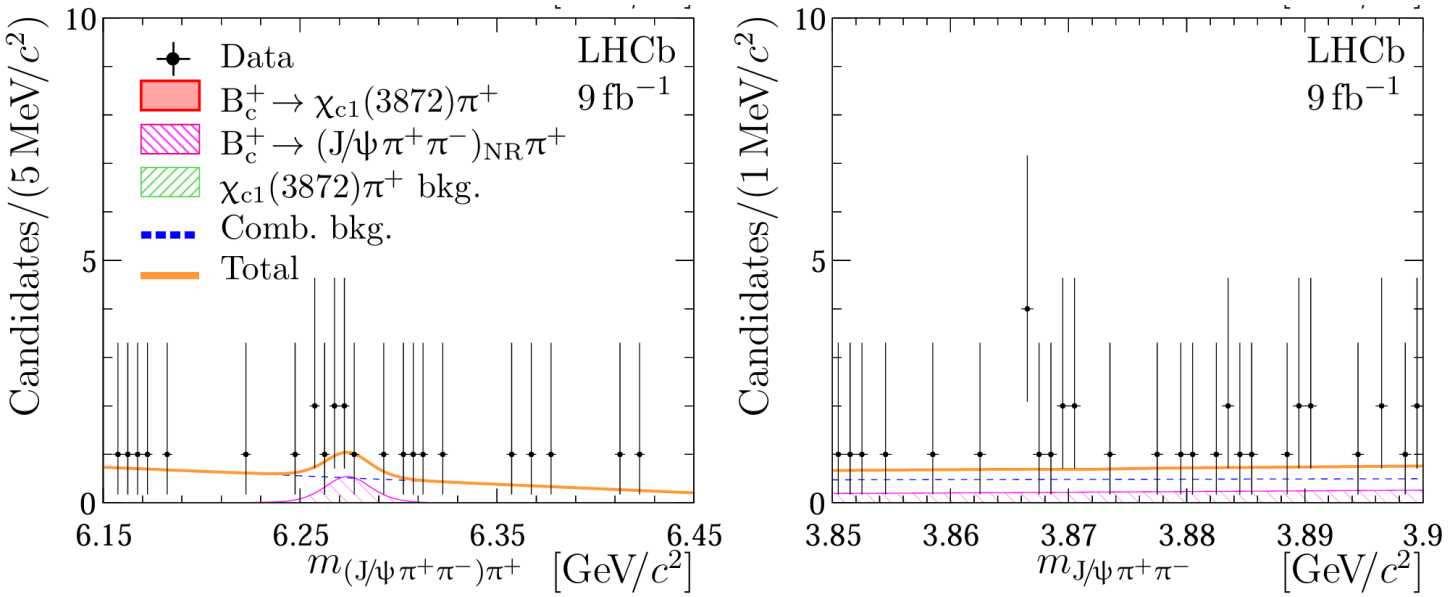
arXiv: 2503.20039

Production cross-sections of $\chi_{c1}(3872)$ measurement from ATLAS indicates the short-lived contribution arise from the decays of B_c^+

$$\frac{\sigma_{pp\to B_c^+ X} \times \mathcal{B}_{B_c^+\to\chi_{c1}(3872)X}}{\sigma_{pp\to b\bar{b}X} \times \mathcal{B}_{b\to\chi_{c1}(3872)X}} = (25 \pm 13 \pm 2 \pm 5)\,\%\,, \qquad \text{JHEP 01 (2017) 117}$$

LHCb search for $B_c^+ \to \chi_{c1}(3872)\pi^+$ with full Run1+2 data

- no significant signal is observed, upper limit set related to $B_c^+ \to \psi(2S)\pi^+$



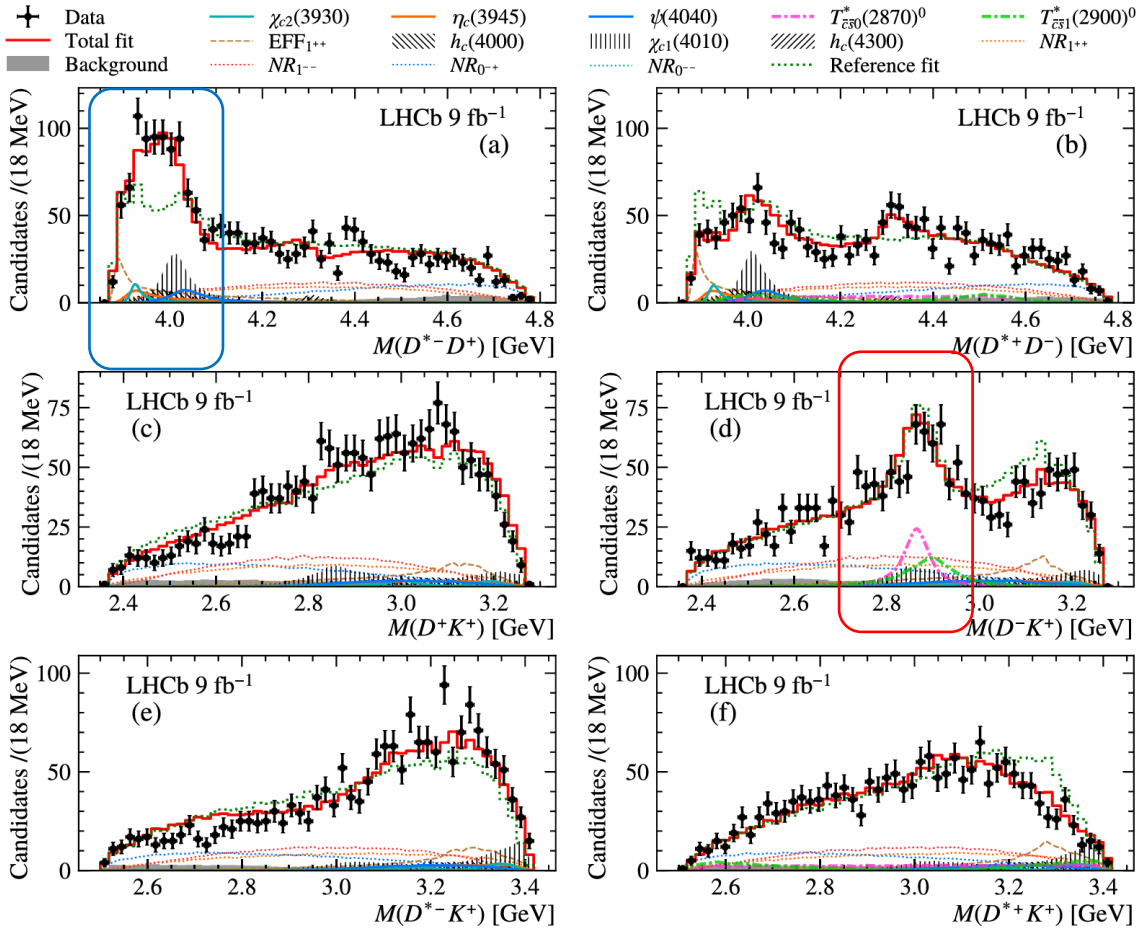
$$\mathcal{R}_{\psi(2S)}^{\chi_{c1}(3872)} = \frac{\mathcal{B}_{B_c^+\to\chi_{c1}(3872)\pi^+}}{\mathcal{B}_{B_c^+\to\psi(2S)\pi^+}} \times \frac{\mathcal{B}_{\chi_{c1}(3872)\to J/\psi\pi^+\pi^-}}{\mathcal{B}_{\psi(2S)\to J/\psi\pi^+\pi^-}}$$

$< 0.05\ (0.06)$ @ 90% (95%) **C.L**

Confirmation of T^*_{cs} in $B^+ \to D^{*+}D^-K^+$

The first open-charm tetraquarks $T^*_{cs0}(2870)^0$ and $T^*_{cs1}(2900)^0$ observed in $B^+ \to D^+D^-K^+$, confirmed in $B^+ \to D^{*+}D^-K^+$

PRL 125 (2020) 242001
PRD 102 (2020) 112003
PRL 134 (2025) 101901



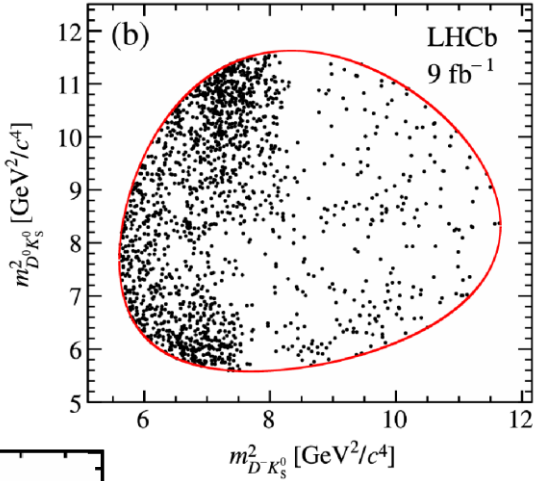
Component	$J^{P(C)}$
$EFF_{1^{++}}$	1^{++}
$\eta_c(3945)$	0^{-+}
$\chi_{c2}(3930)^\dagger$	2^{++}
$h_c(4000)$	1^{+-}
$\chi_{c1}(4010)$	1^{++}
$\psi(4040)^\dagger$	1^{--}
$h_c(4300)$	1^{+-}
$T^*_{\bar{c}\bar{s}0}(2870)^{0,\dagger}$	0^+
$T^*_{\bar{c}\bar{s}1}(2900)^{0\dagger}$	1^-
$NR_{1^{--}}(D^{*\mp}D^\pm)$	1^{--}
$NR_{0^{--}}(D^{*\mp}D^\pm)$	0^{--}
$NR_{1^{++}}(D^{*\mp}D^\pm)$	1^{++}
$NR_{0^{-+}}(D^{*\mp}D^\pm)$	0^{-+}

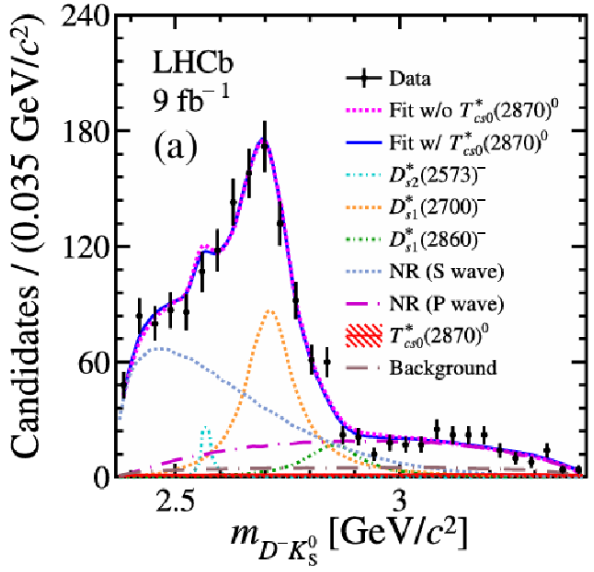
Open-charm tetraquark in $B^- \to D^- D^0 K_S^0$

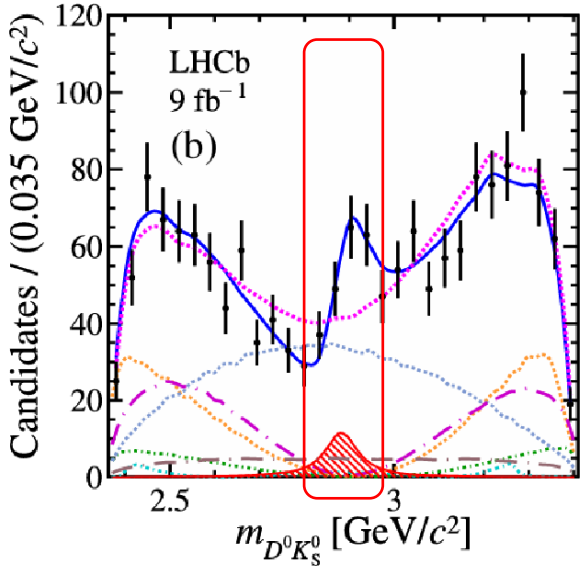
PRL 134 (2025) 101901

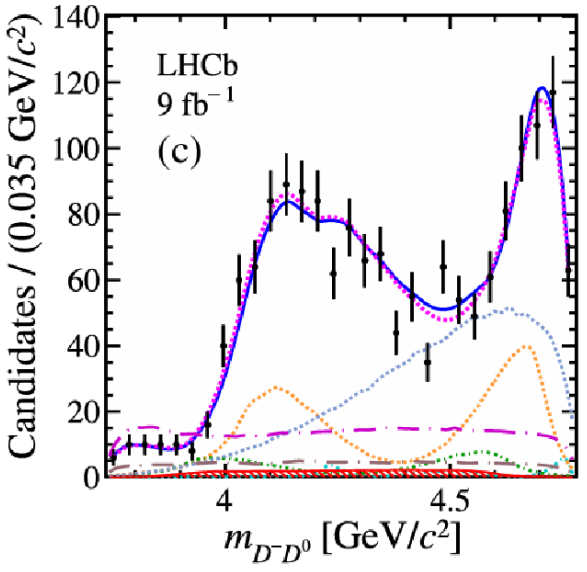
Observation of $T_{cs0}^*(2870)^0 \to D^0 K_S^0$ in $B^- \to D^- D^0 K_S^0$ amplitude analysis

- $T_{cs0}^*(2870)^0$ with $J^P = 0^+$ observed in $D^0 K_S^0$ final state, with significance of 5.3σ
- consistent with $T_{cs0}^*(2870)^0$ in $B^- \to D^- D^+ K^-$ analysis
  - isospin symmetry Phys.Rev.D102, 112003 (2020)
- No evidence of $T_{cs1}^*(2900)^0 \to D^0 K_S^0$ found
  - isospin violation









Conclusion and prospects

- LHCb is very active in the field of hadron state research, fast collected:
  - new excited baryons
  - amplitude analysis for exotic states
  - new decay modes for hadrons
- Lots of excellent Run3 data already!

party is going on…