Observation of the open-charm tetraquark state $T^*_{cs0}(2870)^0$ in the $B^- \to D^- D^0 K^0_S$ decay

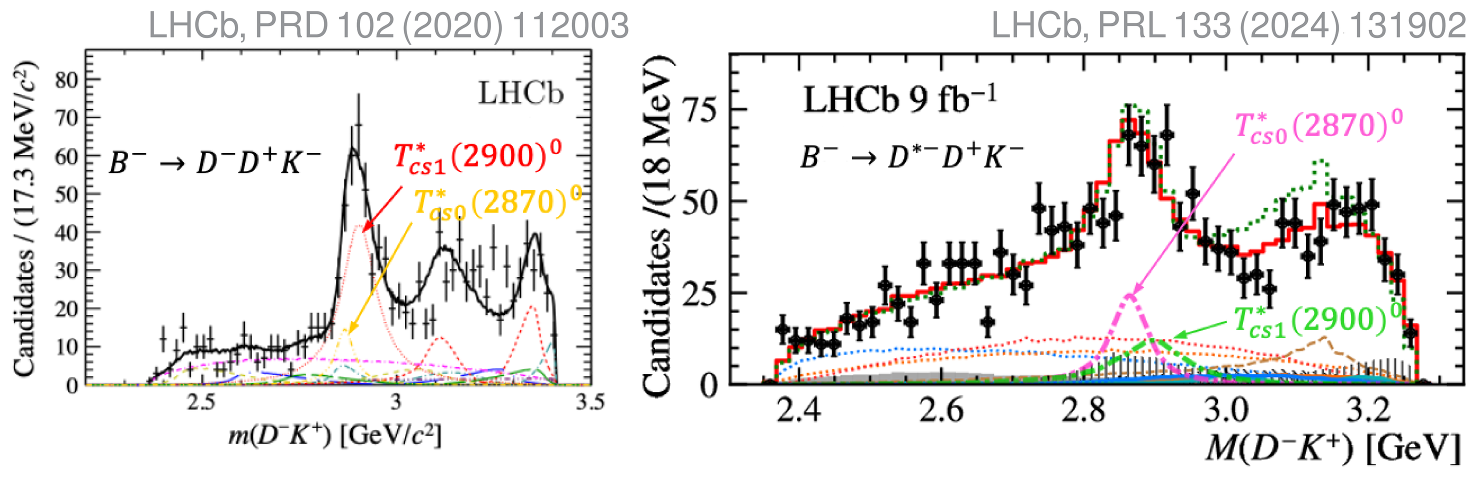
Tianwen Zhou on behalf of LHCb

School of Physics, Peking University, Beijing

1. Introduction

- Discoveries of open-charm tetraquark states $T^*_{cs0}(2870)^0$ and $T^*_{cs1}(2900)^0$ $(cs\bar{u}\bar{d})$
  - Firstly observed in the $B^- \to D^- D^+ K^-$ decay LHCb, PRD 102 (2020) 112003 LHCb, PRL 125 (2020) 242001
  - Confirmed in the same channel of the $B^- \to D^{*-} D^+ K^-$ decay

LHCb, PRD 102 (2020) 112003 LHCb, PRL 133 (2024) 131902



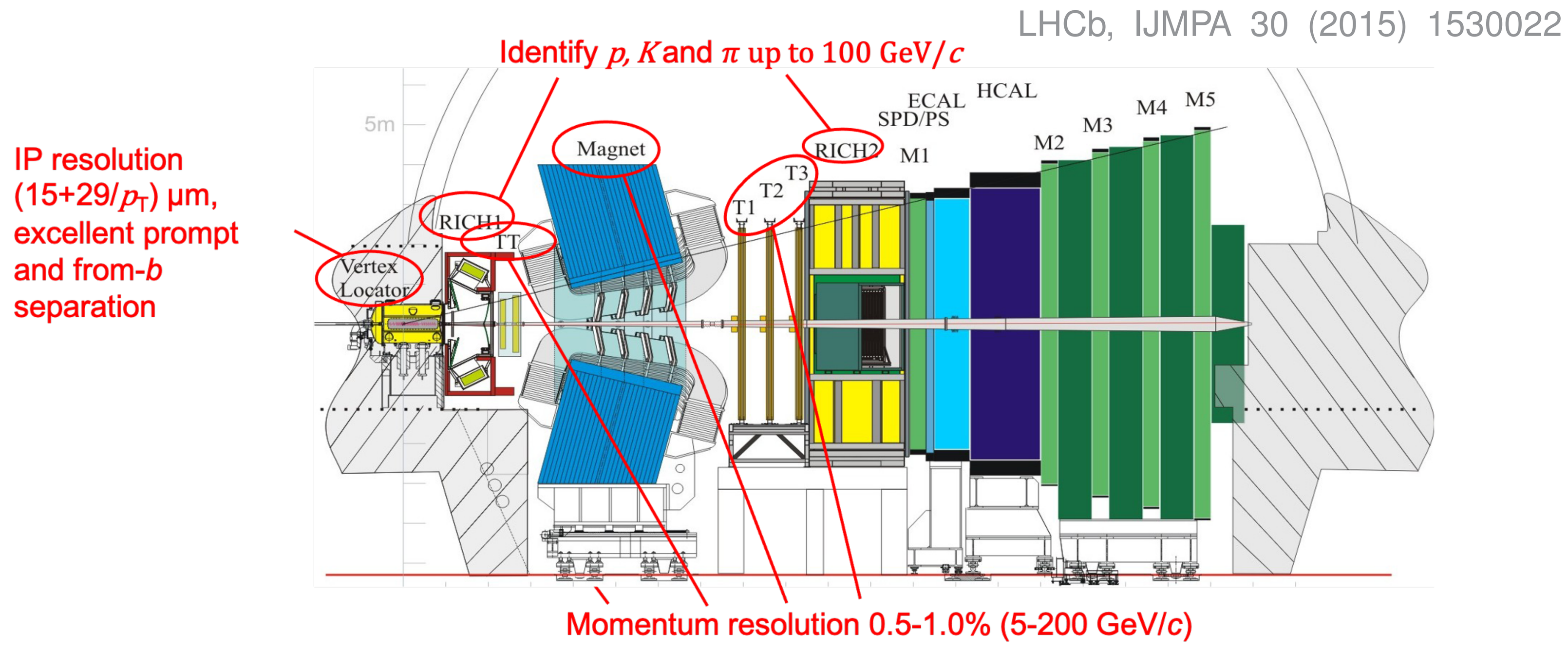
- There are multiple interpretations for their internal structures.
- $B^- \to D^- D^0 K^0_S$ decay: an ideal process to search for the T^{*0}_{cs} exotic states in the $D^0 K^0_S$ channel.

2. LHCb detector

- A single-arm forward spectrometer, covering the pseudorapidity range of $2 < \eta < 5$
- Study particles containing b or c quarks

LHCb, JINST 3 (2008) S08005

LHCb, IJMPA 30 (2015) 1530022



3. Signal extraction

- Dataset: LHCb Run1+Run2 data
- Selections: cut-based selections + MVA
- Mass fit to extract the signal yields:
  - Signal shape: $f \times Gaus(m, \sigma_1) + (1-f) \times Gaus(m, \sigma_2)$
  - Combinatorial background shape: exponential

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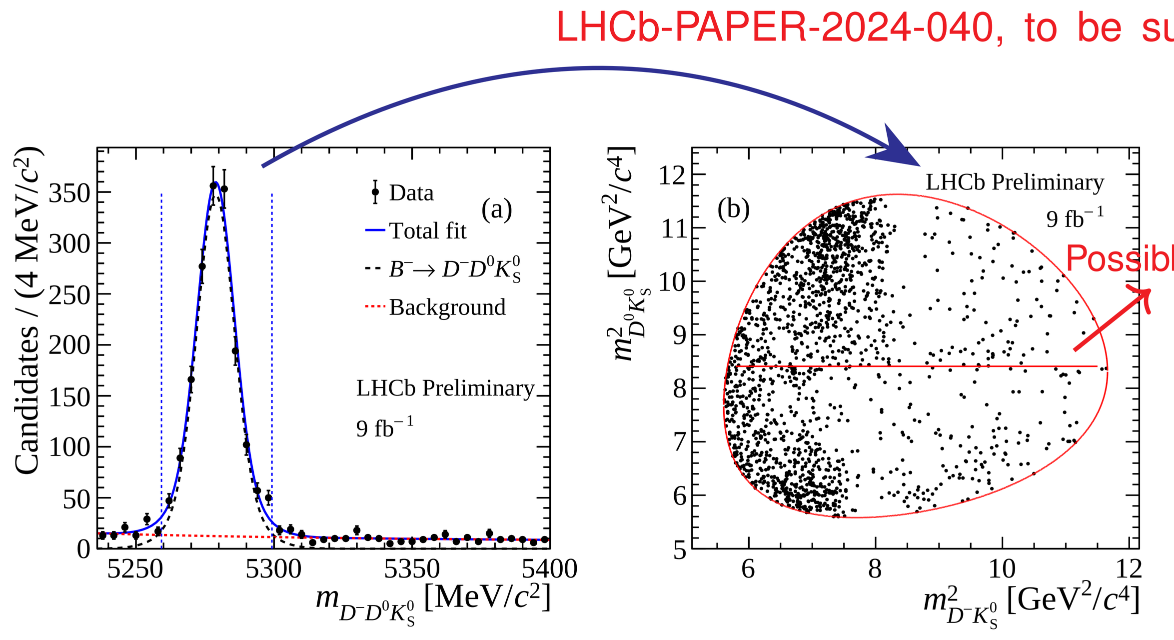

Signal yield $N_s = 1544 \pm 42$, signal purity $f_s = (92.6 \pm 0.6)\%$

4. Amplitude model

- For the $B \to R(\to ab)c$ decay, helicity amplitude is $\mathcal{M}_R(m_{ab}, \theta_{ab}|\vec{\omega})$
- Signal PDF:

$$\mathcal{P}_s(m_{ab}, \theta_{ab}|\vec{\omega}) = \frac{\epsilon(m_{ab}, \theta_{ab})}{I(\vec{\omega})} \left|\sum_R \mathcal{M}_R(m_{ab}, \theta_{ab}|\vec{\omega})\right|^2$$

- Efficiency map $\epsilon(m_{ab}, \theta_{ab})$: derived from simulation samples
- Background PDF $\mathcal{P}_b$: derived from the high B mass region of data
- Log-likelihood for the amplitude fit:

$$\ln \mathcal{L} = \sum_j \ln \left[f_s \mathcal{P}_s(m^j_{ab}, \theta^j_{ab}|\vec{\omega}) + (1-f_s)\mathcal{P}_b(m^j_{ab}, \theta^j_{ab}) \right] \quad f_s \text{ is fixed}$$

5. Fit strategy

- Null hypothesis model (H_0): only known D^{*-}_{sJ} resonances + NRs
- Add new T^{*0}_{cs} states in the model to find the nominal one (H_1) resulting in the largest $\Delta \ln \mathcal{L} \equiv \ln \mathcal{L}(H_1) - \ln \mathcal{L}(H_0)$.
- Significance of T^{*0}_{cs} is estimated using pseudo-experiments.

6. Results

- The nominal model: known D^{*-}_{sJ} resonances + NRs + $T^{*0}_{cs0}(J^P = 0^+)$

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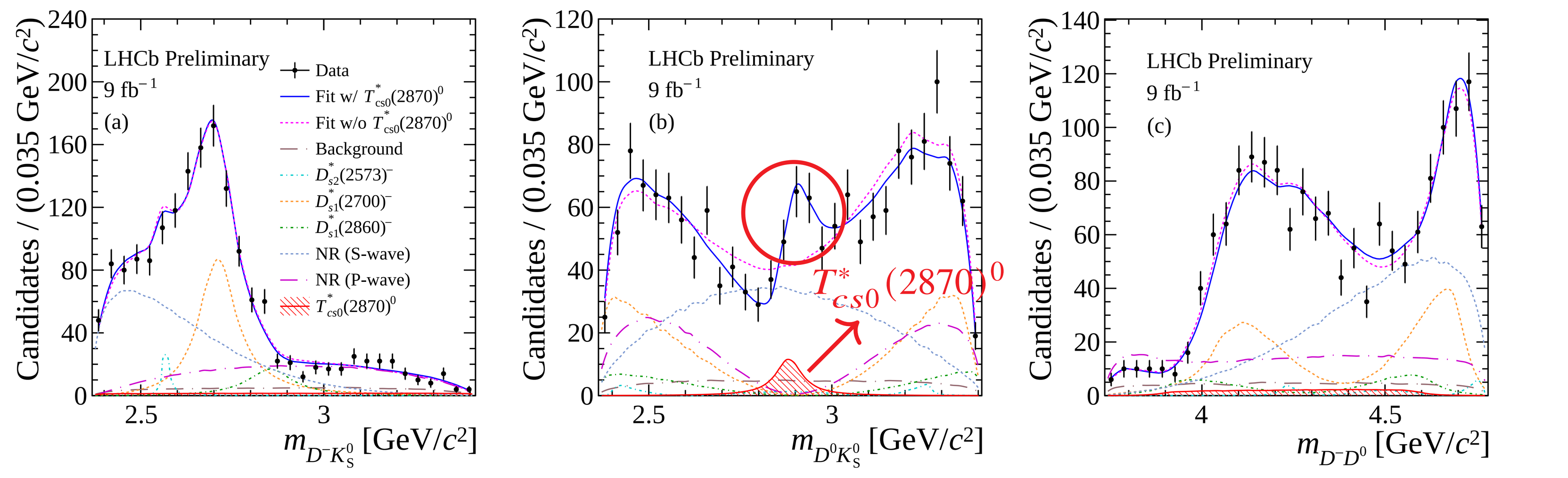

- $M(T^{*0}_{cs0}) = 2883 \pm 11 \pm 7$ MeV/c^2, $\Gamma(T^{*0}_{cs0}) = 87^{+22}_{-47} \pm 6$ MeV.
- The significance of the $T^{*0}_{cs0}(J^P = 0^+)$ state is $5.3\,\sigma$ after accounting for systematic uncertainties.
- The T^{*0}_{cs0} state is identical to the $T^*_{cs0}(2870)^0$ state observed in the D^+K^- mass spectrum of the $B^- \to D^- D^+ K^-$ decay.
- No significant $T^{*0}_{cs1}(J^P = 1^-)$ state is found.

7. Check of isospin invariance

Quantities used to check the isospin invariance between $T^{*0}_{cs} \to D^0 \bar{K}^0$ and $T^{*0}_{cs} \to D^+ K^-$ decays:

- Relative decay width $R_I(T^{*0}_{cs}) \equiv \Gamma(T^{*0}_{cs} \to D^0 \bar{K}^0)/\Gamma(T^{*0}_{cs} \to D^+ K^-) \approx 1$

$$R_I(T^{*0}_{cs}) = \frac{\mathcal{B}(B^- \to D^- D^0 \bar{K}^0) \mathrm{FF}(T^{*0}_{cs} \to D^0 K^0_S)}{\mathcal{B}(B^- \to D^- D^+ K^-) \mathrm{FF}(T^{*0}_{cs} \to D^+ K^-)}$$

- Ratio of the fit fractions

$$R_{\mathrm{FF}}(D^0 K^0_S) \equiv \mathrm{FF}(T^{*0}_{cs1} \to D^0 K^0_S)/\mathrm{FF}(T^{*0}_{cs0} \to D^0 K^0_S)$$

$$R_{\mathrm{FF}}(D^+ K^-) \equiv \mathrm{FF}(T^{*0}_{cs1} \to D^+ K^-)/\mathrm{FF}(T^{*0}_{cs0} \to D^+ K^-)$$

$$R_{\mathrm{FF}}(D^0 K^0_S / D^+ K^-) \equiv R_{\mathrm{FF}}(D^0 K^0_S)/R_{\mathrm{FF}}(D^+ K^-) \approx 1$$

Results:

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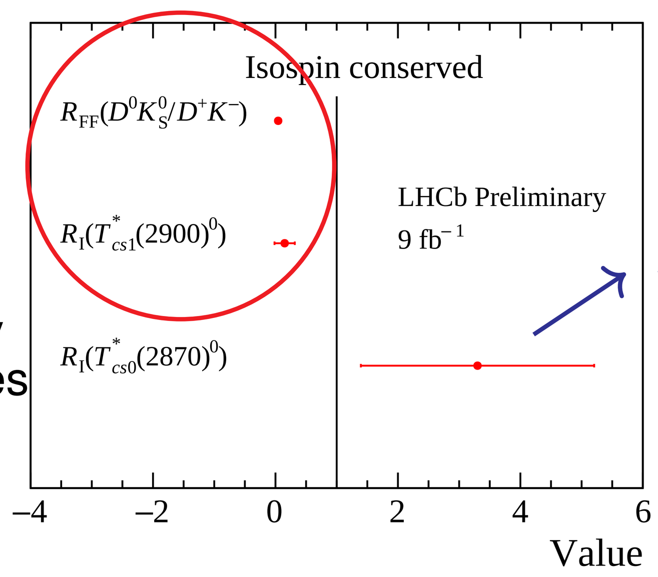
Indicate a violation of isospin invariance for $T^{*0}_{cs1} \to D^0 \bar{K}^0 / D^+ K^-$

May be caused by triangle singularities

May be a genuine state not having a definite isospin



Isospin invariance for $T^{*0}_{cs0} \to D^0 \bar{K}^0 / D^+ K^-$

8. Summary

- The $T^*_{cs0}(2870)^0$ state is observed in a new decay mode $D^0 K^0_S$ in the $B^- \to D^- D^0 K^0_S$ decay.
- The mass and width of the $T^*_{cs0}(2870)^0$ state are measured.
- No significant T^{*0}_{cs1} state with $J^P = 1^-$ is observed in the $B^- \to D^- D^0 K^0_S$ decay.
- Isospin invariance is checked, and an isospin violation between the $T^*_{cs1}(2900)^0 \to D^0 \bar{K}^0$ and $T^*_{cs1}(2900)^0 \to D^+ K^-$ decays is indicated.

Contact: tianwen.zhou@cern.ch