Belle実験における$B \to D^0\bar{D}^{*0}K$崩壊を用いた$X(3872)$ラインシェイプ測定結果

(arXiv:2302.02127 [hep-ex]、Phys. Rev. D 投稿済み)

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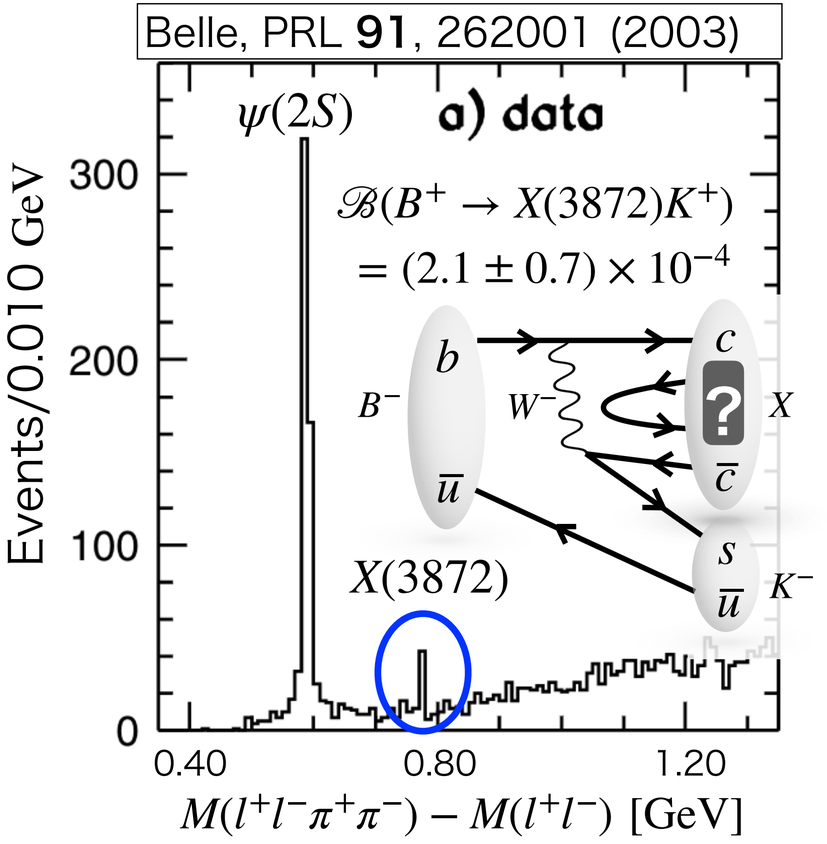
$X(3872)$

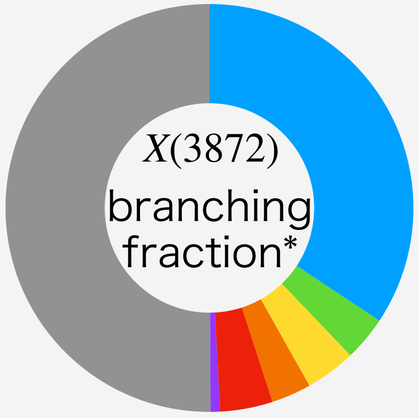
- $X(3872)$ is charmonium-like **exotic state** observed in $B \to J/\psi\pi^+\pi^- K$ decays at Belle.
  - Mass is inconsistent with predictions about standard charmonia from quark model.
  - Isospin $I = 1$ for $J/\psi\rho(\to \pi^+\pi^-)$ decay mode.
    → This state includes $u\bar{u}$ and $d\bar{d}$ components.

Belle, PRL **91**, 262001 (2003)



- Property:
  - Mass 3871.65 ± 0.06 MeV/c²
  - Width 1.19 ± 0.21 MeV
  - Quantum number $J^{PC} = 1^{++}$

Branching fraction observed to date



$D^0\overline{D}^{*0}$	(37 ± 9)%
$J/\psi\rho\ (\to \pi^+\pi^-)$	(3.8 ± 1.2)%
$J/\psi\omega$	(4.3 ± 2.1)%
$\chi_{c1}\pi^0$	(3.4 ± 1.6)%
$\psi(2S)\gamma$	(4.5 ± 2.0)%
$J/\psi\gamma$	(0.8 ± 0.4)%
Not seen	約46%

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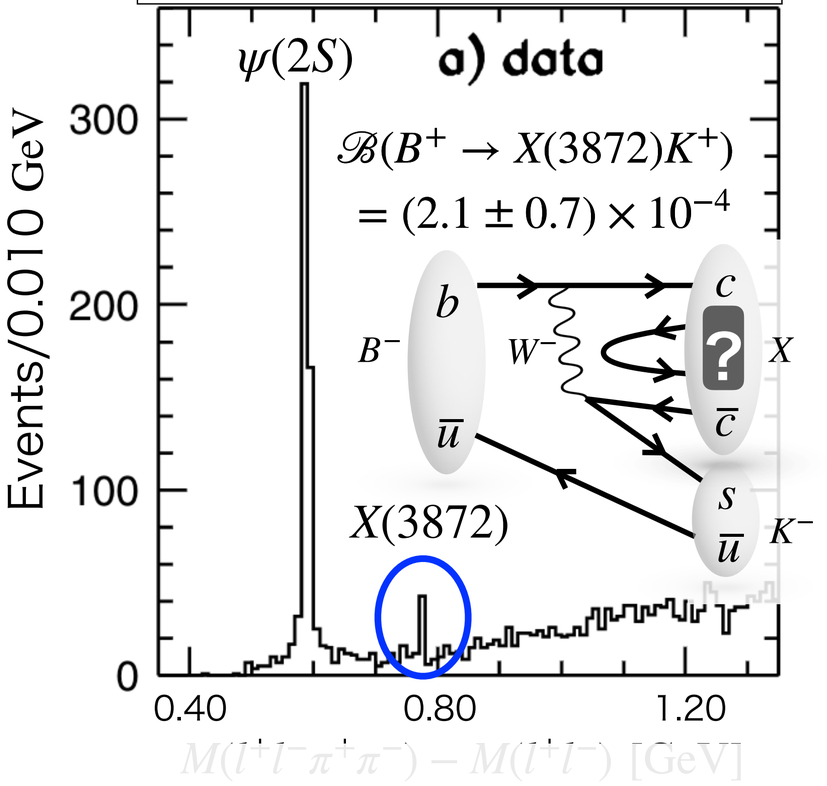


$X(3872) \to D^0\bar{D}^{*0}$ branching fraction is the largest. ←

Mass 3871.65 ± 0.06 MeV/c²

→ It coincides with $D^0\bar{D}^{*0}$ threshold.
(3871.69 ± 0.10 MeV/c²)

Quantum number $J^{PC} = 1^{++}$ → It couples with $D\bar{D}^*$ channel in S-wave.

$D^0\bar{D}^{*0}$	(37 ± 9)%

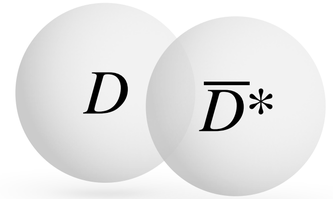
Coupling with $D\bar{D}^*$ state is indicated.

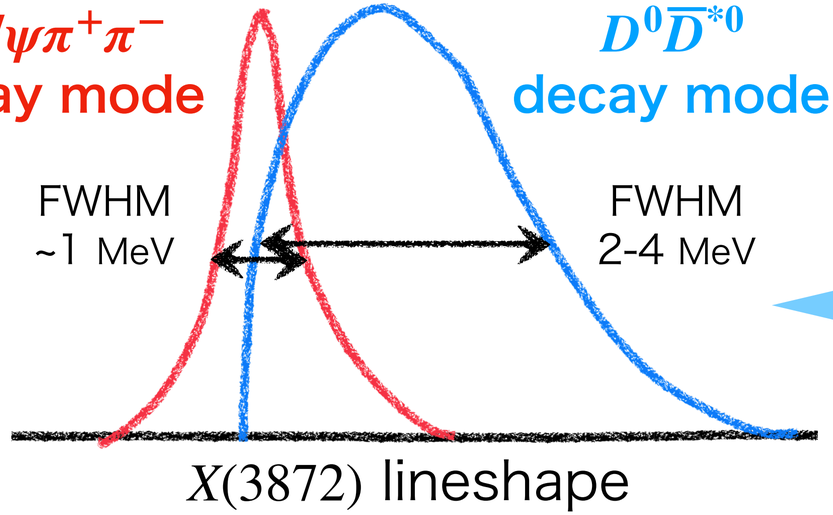
Structure and Lineshape Analysis

- Determining $X(3872) \to D\overline{D}^*$ coupling strength is important to discuss $X(3872)$ structure.
- It can be evaluated by lineshape measurement with
  - model to account for coupled channel effects (Flatte model).
  - $X(3872) \to D^0\overline{D}^{*0}$ decays corresponding to $D\overline{D}^*$ channel.

$D\overline{D}^*$ coupling strength

Loosely bound or virtual states



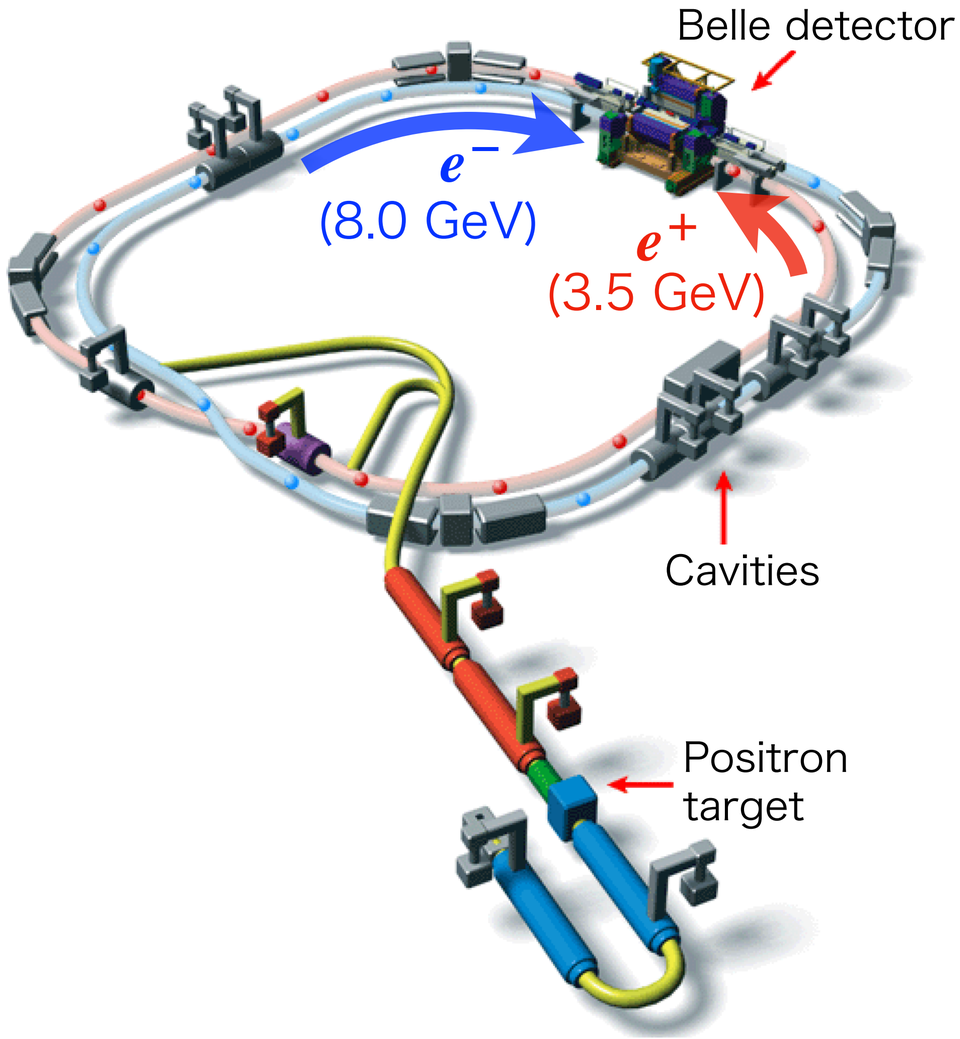


$X(3872)$ lineshape

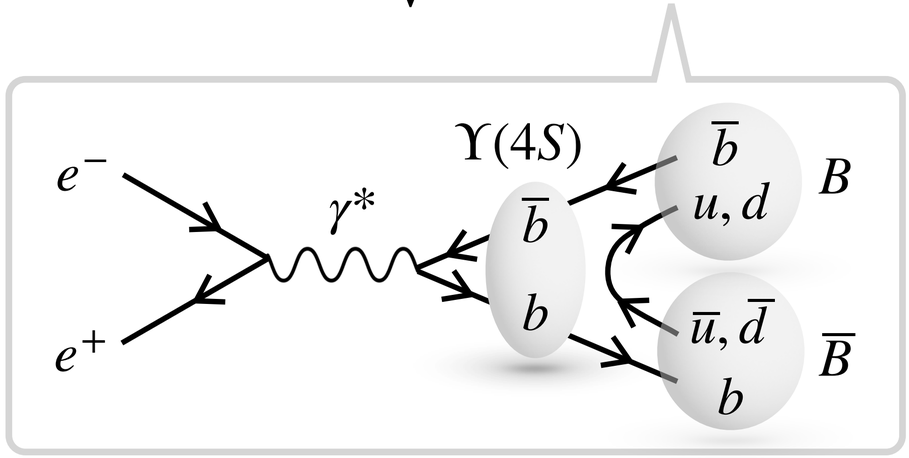
- **Wider lineshape**
  because of phase space and threshold effect
- **Better mass resolution**
  thanks to small Q-value (~100 keV, ~1/20 of $J/\psi\pi^+\pi^-$)
- **Belle experiment is suitable**
  because $D^{*0} \to D^0\gamma, D^0\pi^0$ can be reconstructed.

We aim to measure $X(3872) \to D^0\overline{D}^{*0}$ signal lineshape using Belle full data.

Belle Experiment

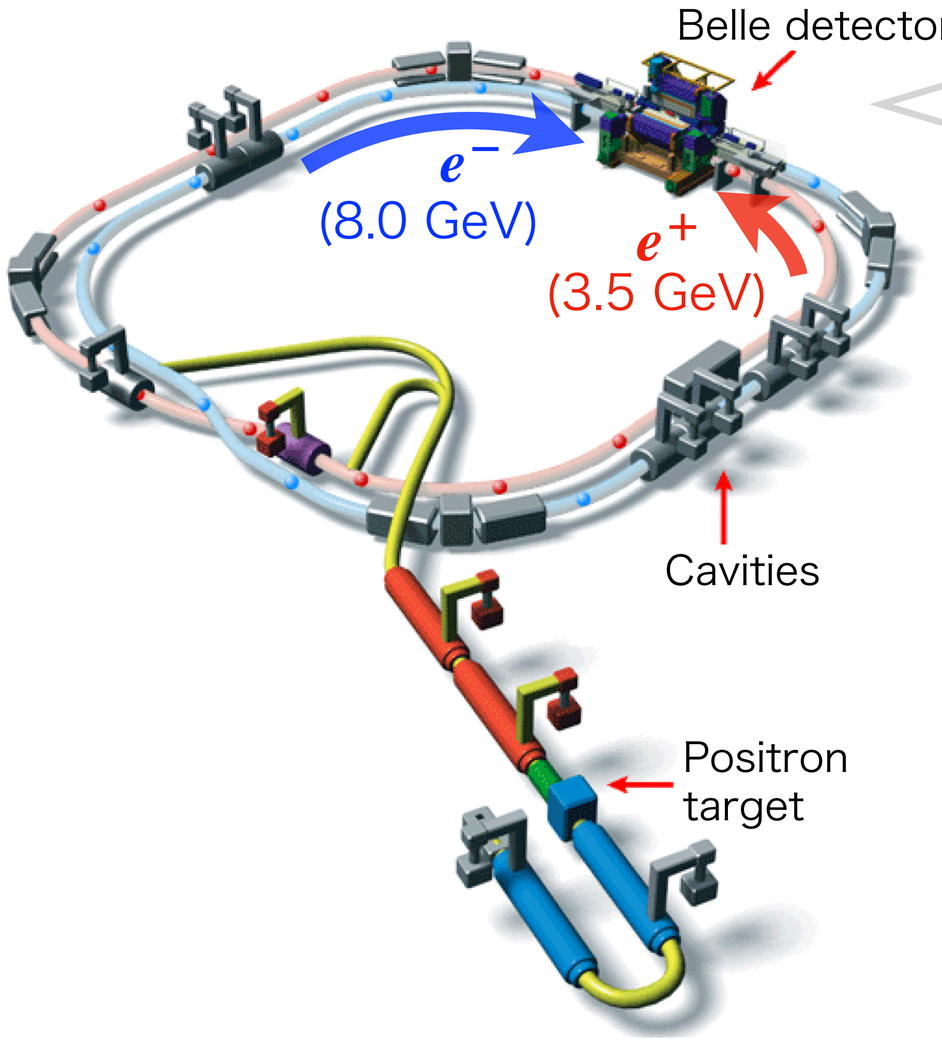


- Electron-positron collider (KEKB)
- Data was collected from 1999 to 2010.
  - 711fb^{-1} data at $\sqrt{s} =$ **10.58 GeV**

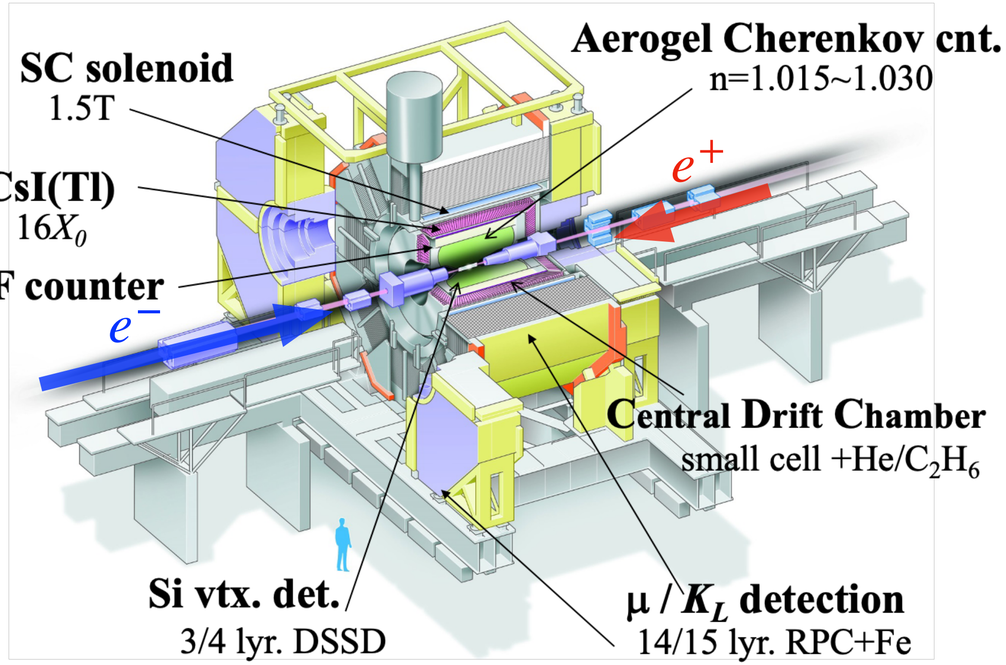


→ Includes $\begin{cases} 7.72 \times 10^8\ B\overline{B} \text{ pairs} \\ 1.8 \times 10^5\ B \to (X(3872) \to D^0\overline{D}^{*0})K \text{ decays.} \end{cases}$

Belle Experiment



General-purpose detector: Belle

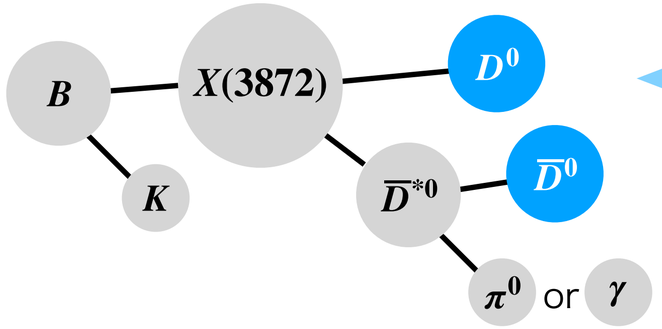


π^+, K^+, p, e^-, μ^-, γ can be detected in wide momentum region.

→ Key of D^{*0} reconstruction

Event Reconstruction, Selection and Detector Response

Reported in JPS 2021 annual meeting (15aU1-1)



D^0 candidates are reconstructed in six decay modes with higher reconstruction efficiency and purity:

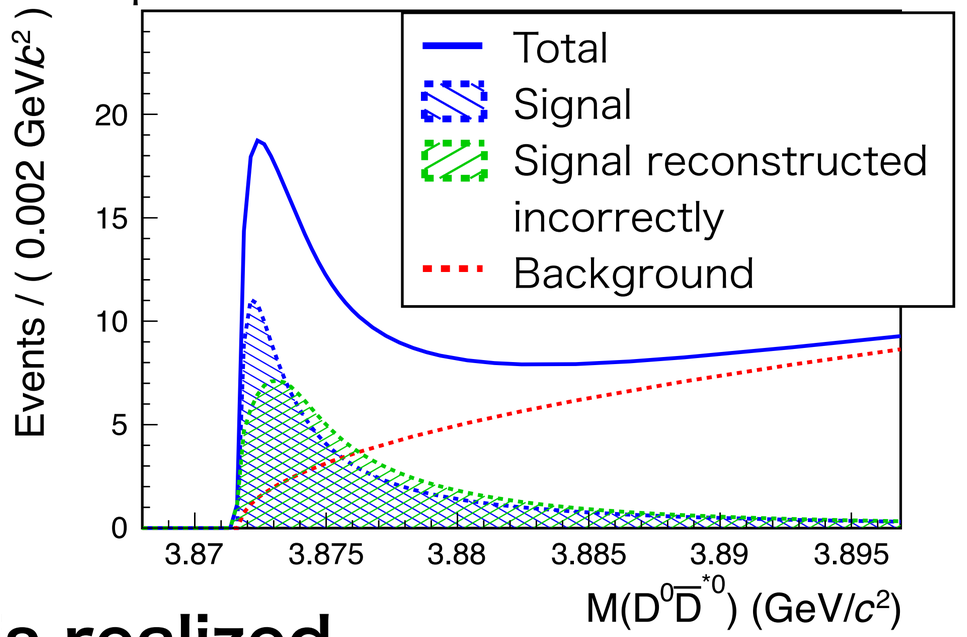
$K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$, $K^0_S\pi^+\pi^-$, $K^0_S\pi^+\pi^-\pi^0$, K^-K^+

- Compared with previous study using $X(3872) \to D^0\overline{D}^{*0}$ decays at Belle,

  PRD **81**, 031103 (2010)

  - Signal efficiency is improved by a factor of 1.9.
  - Mass-dependent signal efficiency and mass resolution are convolved.

Expected distribution for $D^{*0} \to D^0\pi^0$



More precise lineshape measurement is realized.

Flatte Model and Fit Method

- Breit-Wigner formula expanded to account for coupled channel effects
- Definition with respect to energy difference from $D^0\overline{D}^{*0}$ threshold E :

C. Hanhart et. al., PRD **76** 034007 (2007)

$$f(E) = \frac{g k_{D^0\overline{D}^{*0}}}{\left| E - E_f + \frac{i}{2}\left[\Gamma_0 + \Gamma_{J/\psi\rho}(E) + \Gamma_{J/\psi\omega}(E) + g\left(k_{D^0\overline{D}^{*0}} + k_{D^+D^{*-}}\right)\right]\right|^2}$$

Mass difference from $D^0\overline{D}^{*0}$ threshold

Partial widths for radiative, $J/\psi\rho$, and $J/\psi\omega$ decays

Coupling to $D\overline{D}^*$ channel
… g : Coupling constant to $D\overline{D}^*$ channel
… k_a : Momentum for channel a

($k_{D^0\overline{D}^{*0}} = \sqrt{2\mu E}$
μ is reduced mass)

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Partial widths for radiative, $J/\psi\rho$, and $J/\psi\omega$ decays

Coupling to $D\overline{D}^*$ channel

… g : Coupling constant

Requirements from definition :

(Area under lineshape ∝ Branching fraction)

- $\Gamma_{J/\psi\omega}$ is fixed by world-average $\mathcal{B}(X(3872) \to J/\psi\omega)$.
- g is softly constrained by $\mathcal{B}(X(3872) \to D^0\overline{D}^{*0})$ calculated from signal yield obtained by the fit.

To obtain stable fit results,

E_f, Γ_0, $\Gamma_{J/\psi\rho}$ are fixed based on previous study using $J/\psi\pi^+\pi^-$ decays at LHCb experiment

PRD **102**, 092005 (2020)

→ Only g is floated

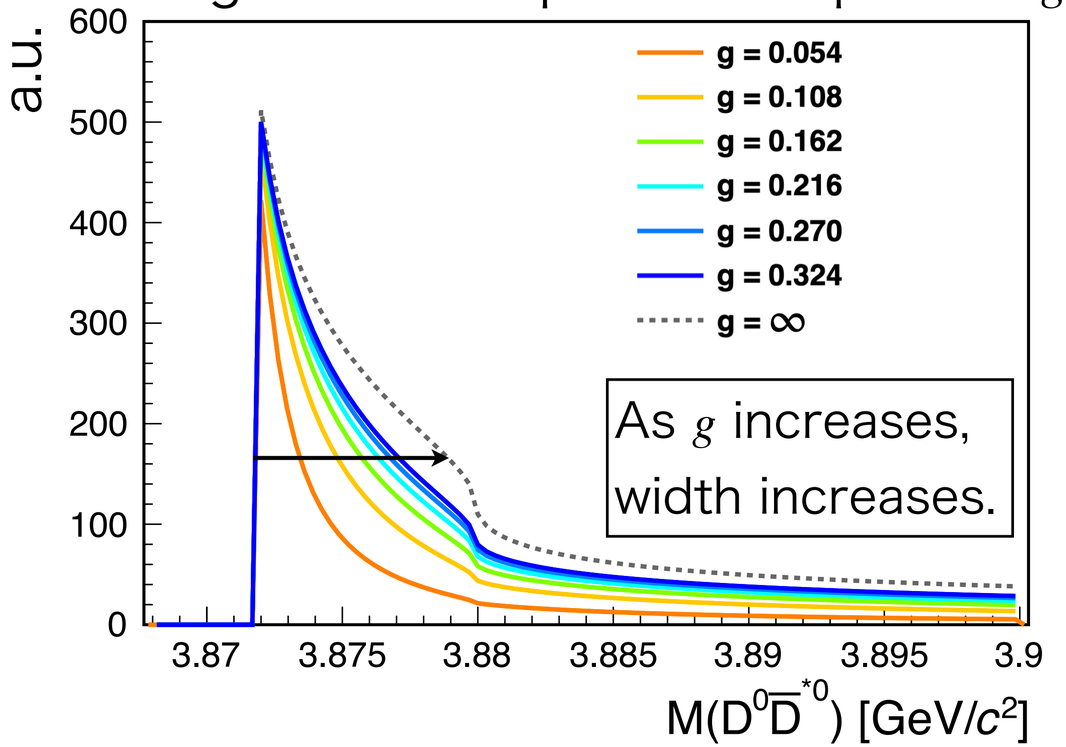
Fit Bias

- Lineshape converges to a fixed form for $g \gg 0$.

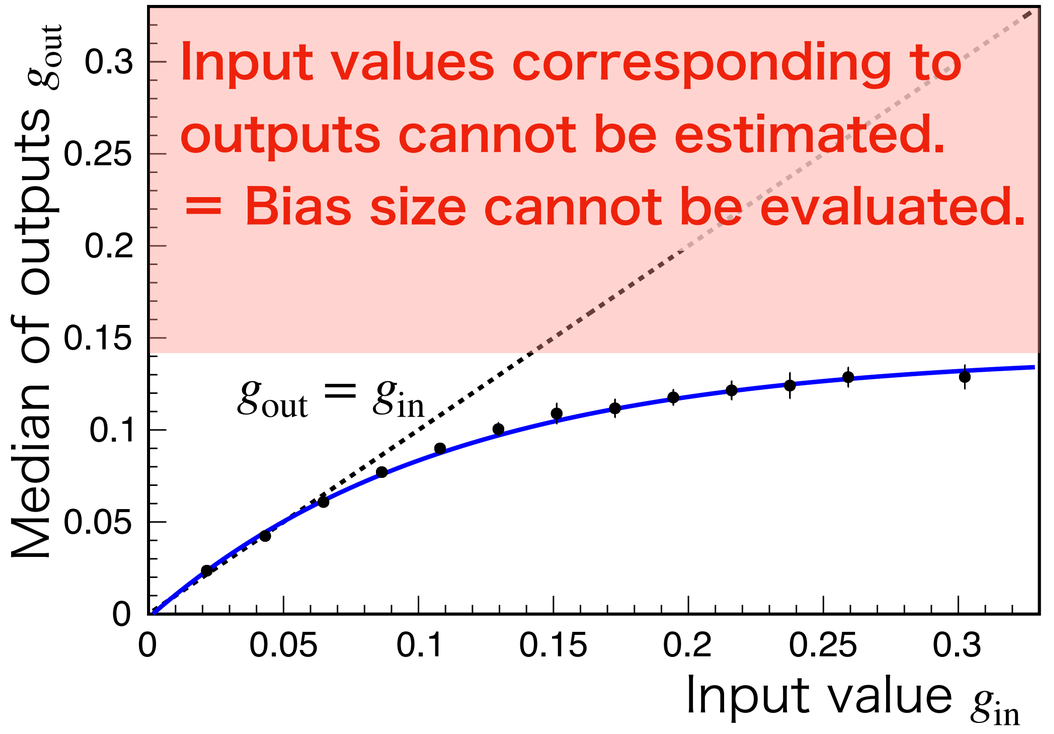
  → For this small sample size, g is likely to be underestimated.

  (For example, failure in determining maximum likelihood point and upper statistical uncertainty)

Change in lineshape with respect to g

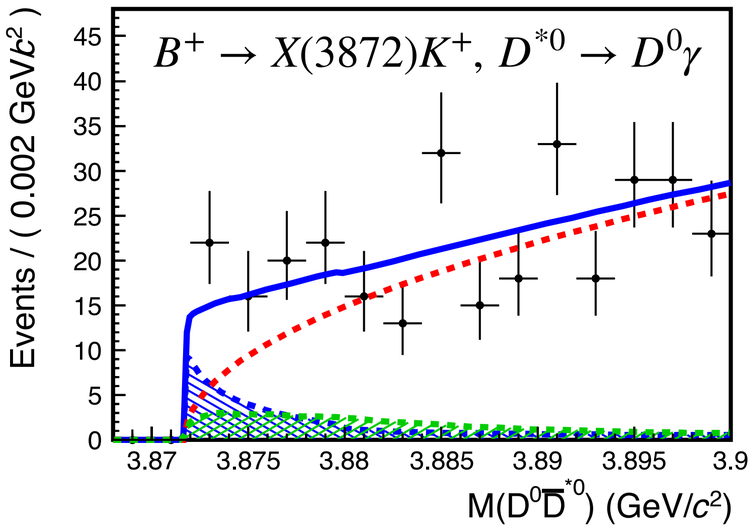


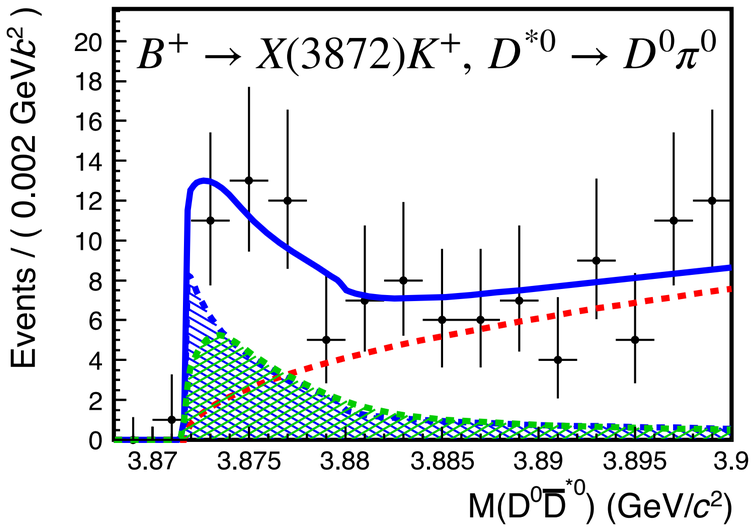
Result of pseudo experiments*

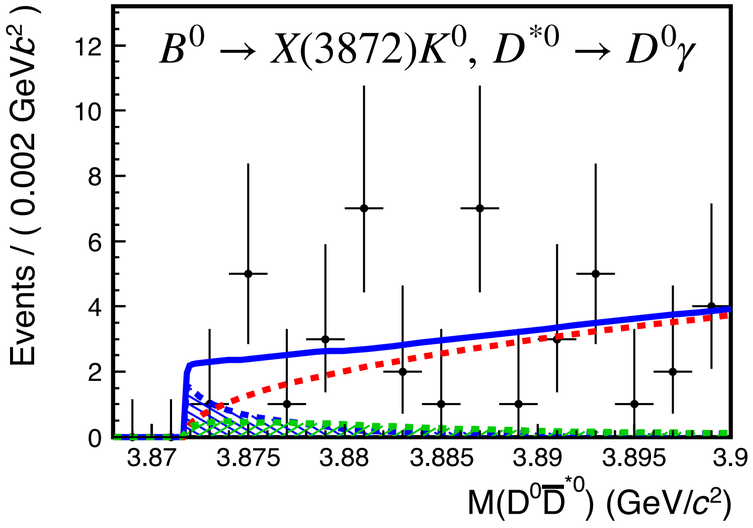


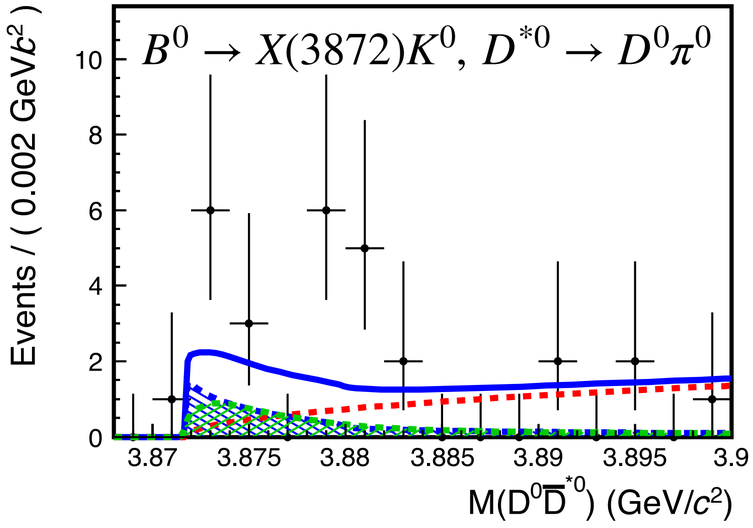
*excluding failed fit results

Fit to Data Using Flatte Model









Real data
Total
Signal
Signal reconstructed wrongly
Background

Yield ratio is fixed by MC expectation

- Fitted g is $0.29\ ^{+2.69}_{-0.15}$ (stat.).

→ It is in the region where the fit bias cannot be evaluated.

- Lower limit including systematics uncertainty

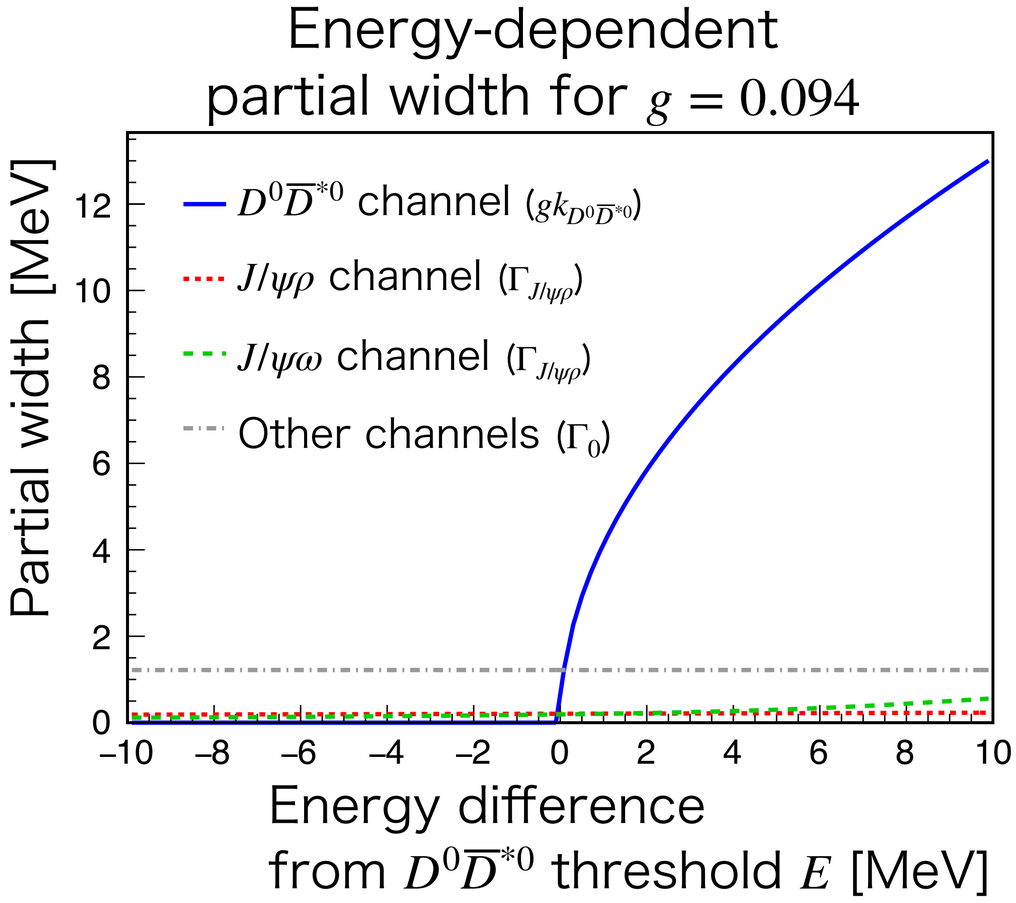
$g > 0.094$ (90% credibility)

Discussion

$g > 0.094$ (90% credibility)

- Partial width for $D^0\overline{D}^{*0}$ channel
  is $> O(1)$ MeV. (Apparent width is a few MeV.)
  → Impact of $D\overline{D}^*$ state on $X(3872)$ is large.

- According to Fermi's golden rule,
  the limit corresponds to
  limit of matrix element $|\mathscr{M}| > 5.9$ GeV



Summary

- $X(3872)$ lineshape analysis is important to reveal its structure.
- Using Belle full data, we performed lineshape analysis with
  "$X(3872) \to D^0\overline{D}^{*0}$ decays" × "model including coupled channel effects".
  - Coupling strength to $D\overline{D}^*$ channel is obtained as $g > 0.094$ (90% credibility).
  - The impact of $D\overline{D}^*$ state is large, and it corresponds to matrix element $|\mathscr{M}| > 5.9$ GeV.

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- Prospect; Uncertainty due to statistics is dominant in this analysis.
  ⋯ Statistics uncertainty and fit bias

→ It can be reduced using datas to be acquired at Belle II (× 50 that of Belle by ~2035).

Sensitivity is improved more by analyzing $J/\psi\pi^+\pi^-$ decays sample simultaneously.