A new measurement of $X(3872) \to D^0\bar{D}^{*0}$ at Belle

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@Hadron2023

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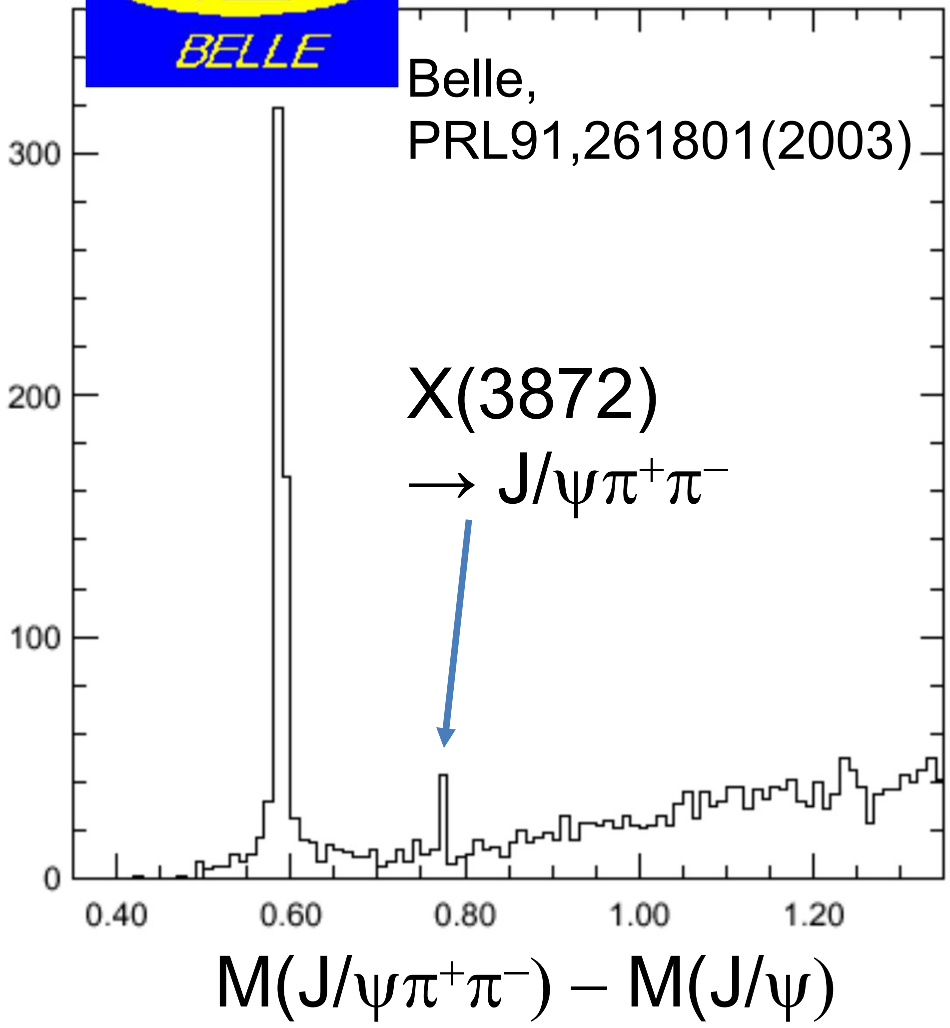
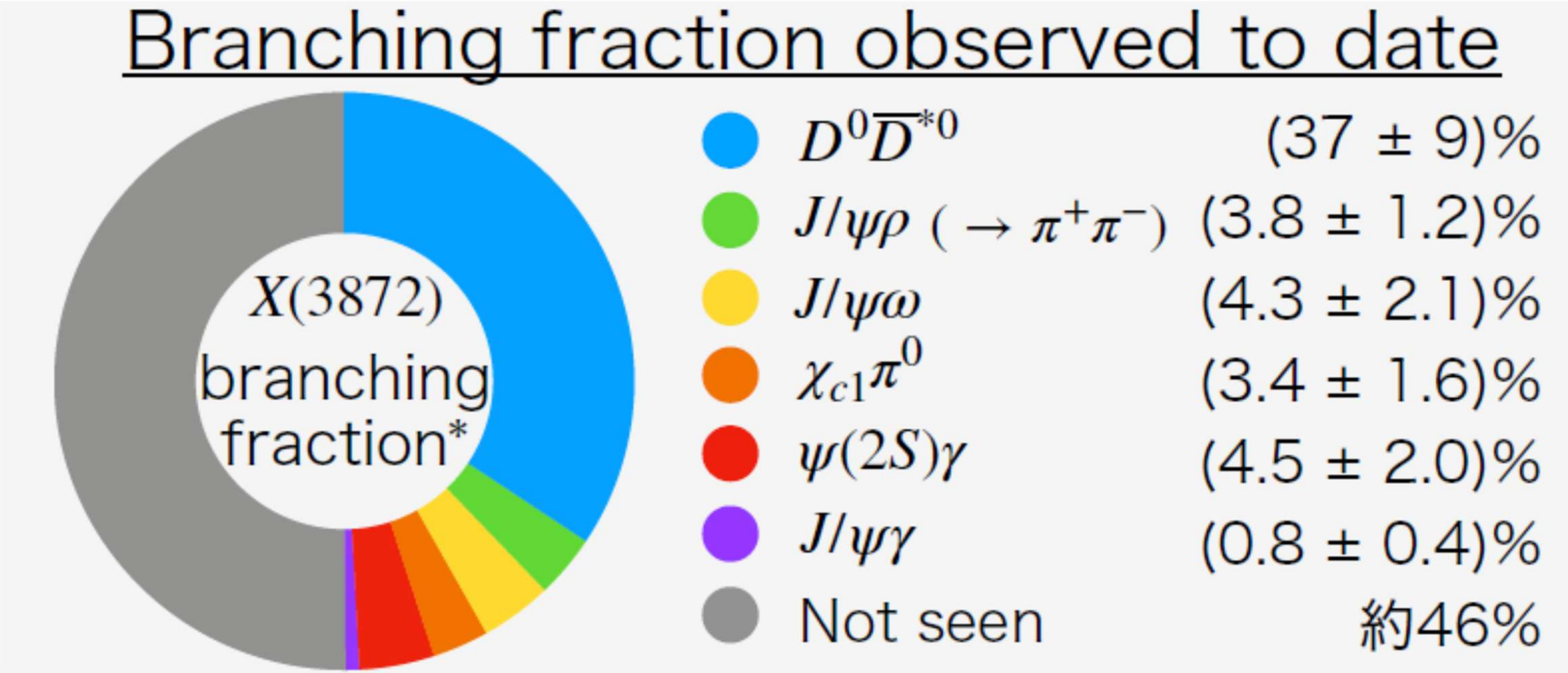
Introduction

- X(3872) (aka $\chi_{c1}(3872)$) -- very famous exotic state
  - Narrow width
  - On the DD^* threshold
  - Violates isospin in $J/\psi\rho$ vs $J/\psi\omega$ decays
  - $J^{PC}=1^{++}$
- S-wave DD^* molecule?
  - Mixed with charmonium?



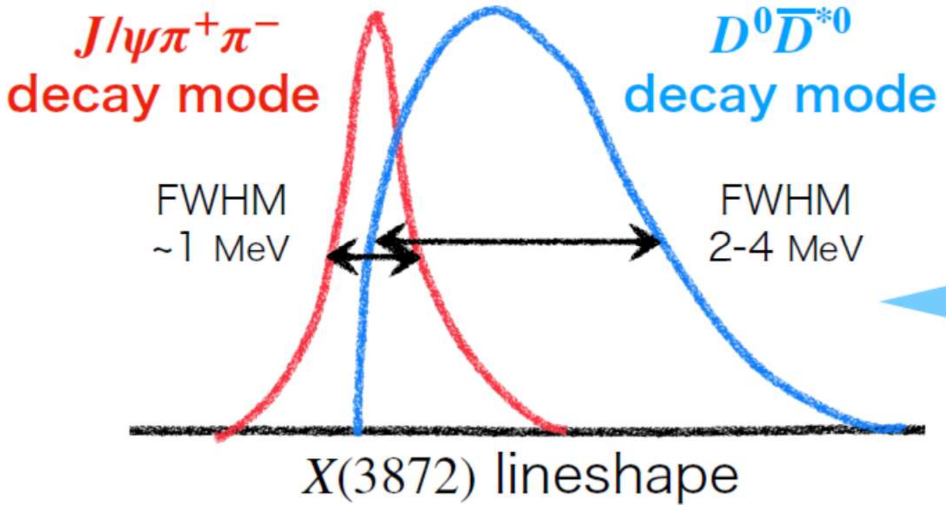
Coupling with DD*



- $D^0\overline{D}^{*0}$ decay has the largest BR
  → Coupling to the DD* channel is strong

Structure and Lineshape Analysis

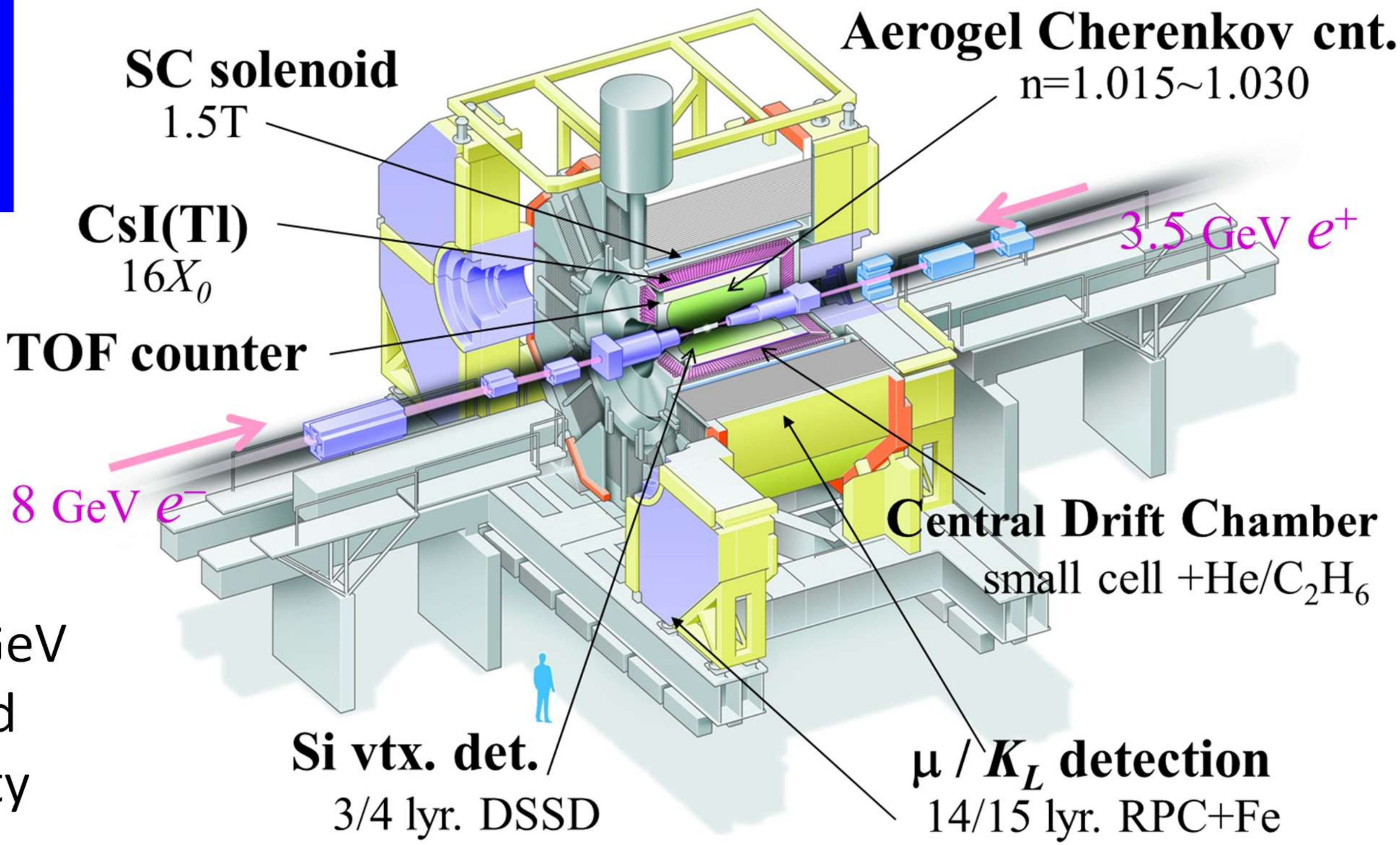
- Determining $X(3872) \to DD^*$ coupling strength is important to discuss the structure.
  - Strong coupling → Molecular state (loosely bound or virtual)



- **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.

- Study of $X(3872) \to D^0\overline{D}^{*0}$ lineshape
  - Flatte model: coupled channel effect

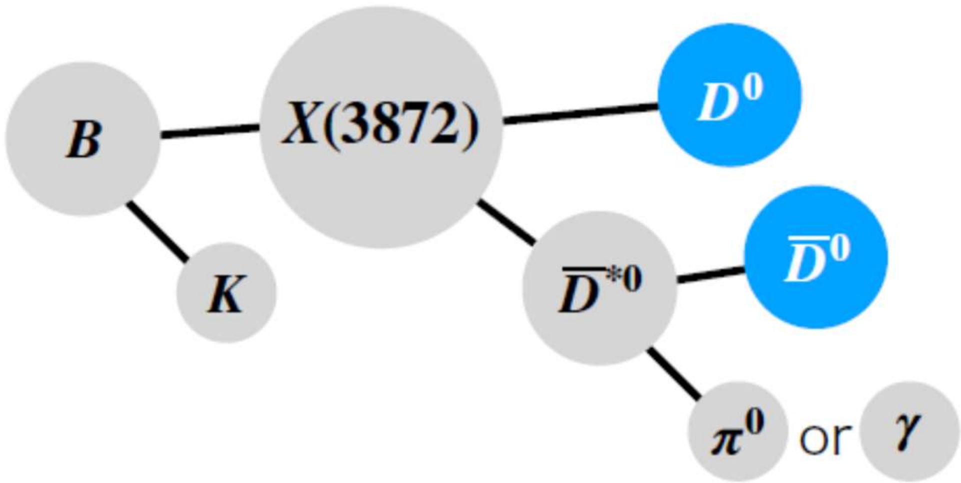
Belle experiment

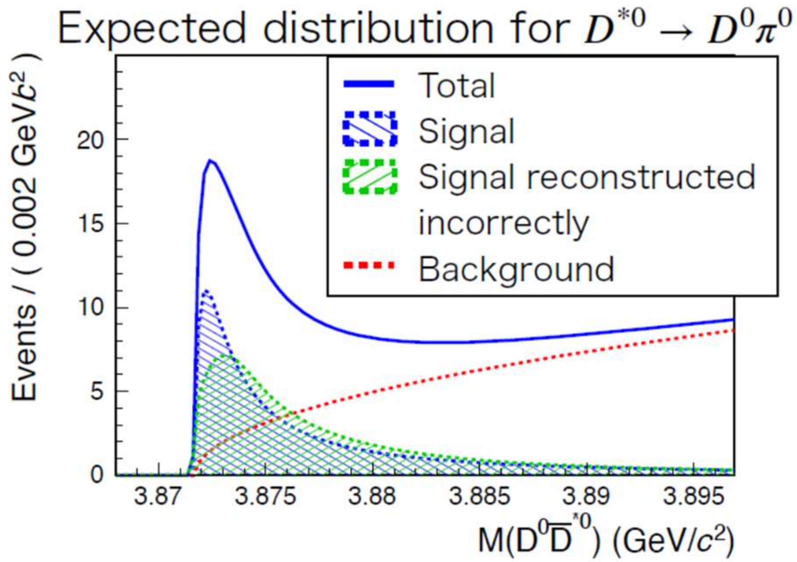


- √s~10.6 GeV
- Integrated Luminosity ~ 1 ab^{-1}

- Almost 4π, good momentum resolution ($\Delta p/p\sim 0.1\%$), EM calorimeter, PID & Si Vertex detector
- 7.72x10^8 $B\bar{B}$ pairs, 1.8x10^5 $B \rightarrow (X(3872) \rightarrow D^0\bar{D}^{*0})K$ decays

Event Reconstruction, Selection and Detector Response

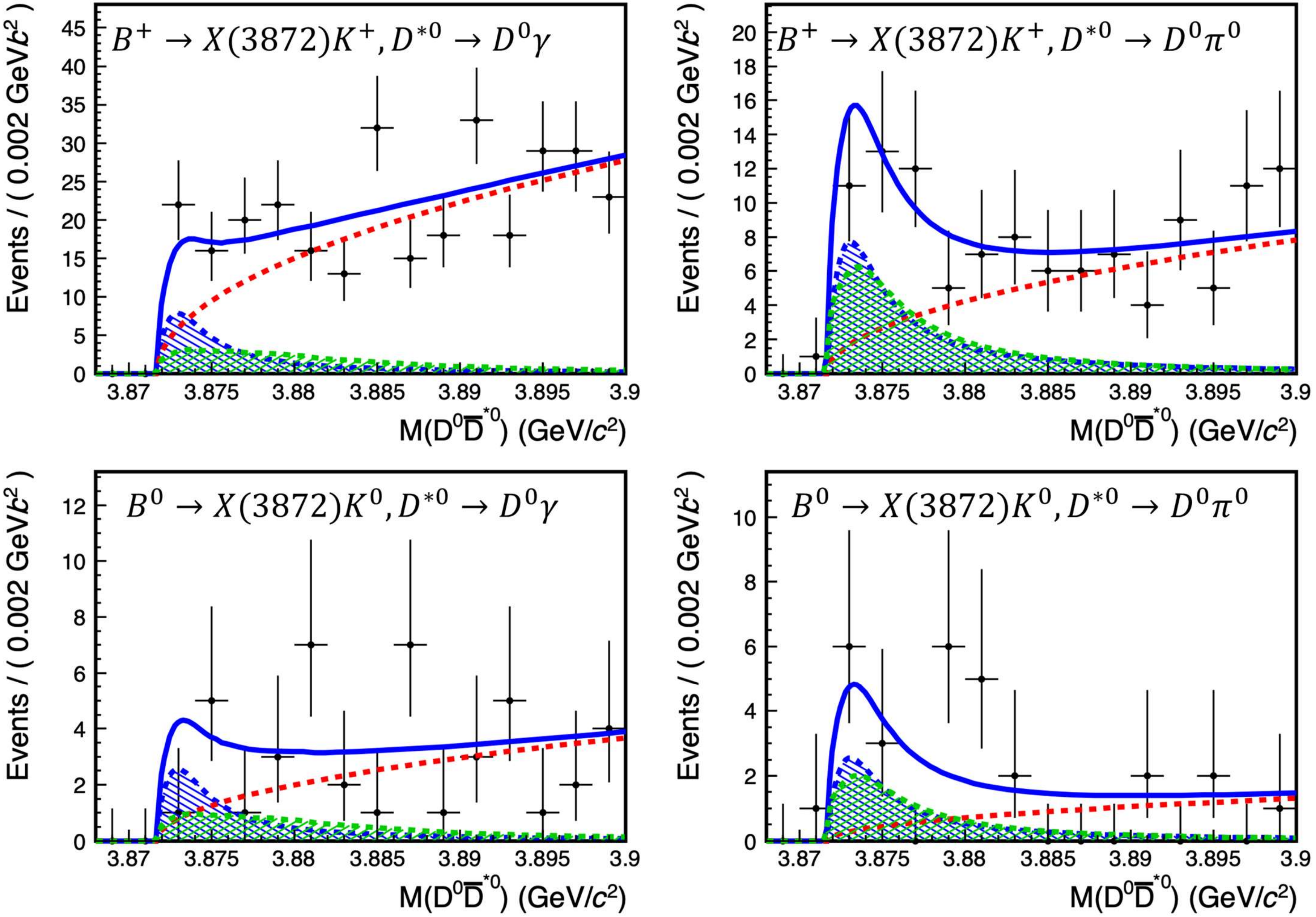




- D^0 candidates are reconstructed in six decay modes
  - $K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^-, K_S^0\pi^+\pi^-\pi^0, K^-K^+$
  - Signal efficiency is improved by a factor of 1.9 from the previous Belle measurement: [PRD 81, 031103 (2010)]

Result

[arXiv:2302.02127, PRD in press]



Result

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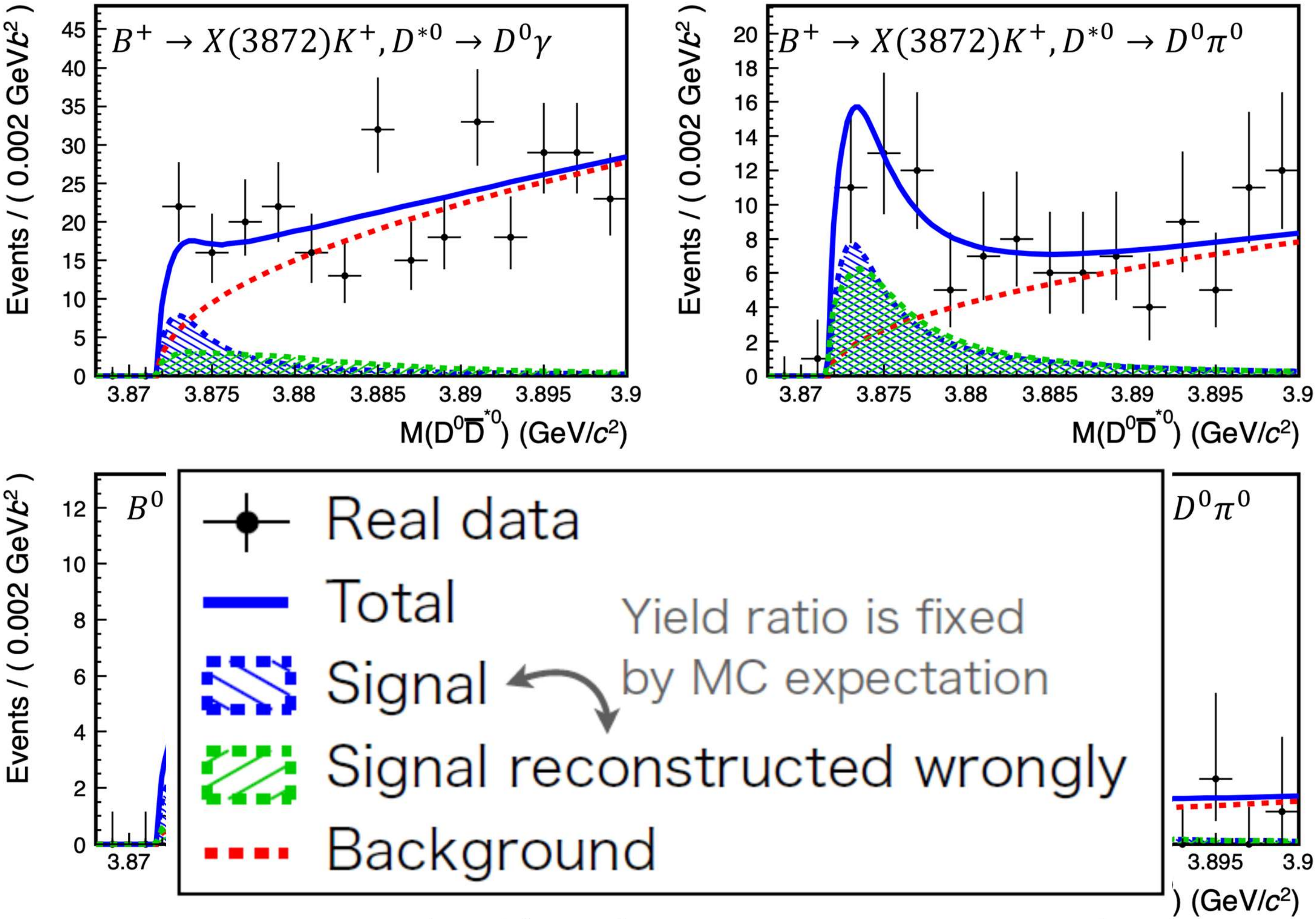


Fit 1 (Breit-Wigner)

- Significance: 7.5σ in total
- First observation from the B^0 channel (5.2σ)
- Branching ratios

$$\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to D^0\overline{D}^{0*}) = (0.97^{+0.21}_{-0.18} \pm 0.10) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to X(3872)K^0)/\mathcal{B}(B^+ \to X(3872)K^+) = 1.34^{+0.47+0.10}_{-0.40-0.12}$$

- Mass & width

$$m = 3873.71^{+0.56}_{-0.50} \pm 0.13 \text{ MeV}/c^2$$

$$\Gamma = 5.2^{+2.2}_{-1.5} \pm 0.4 \text{ MeV}$$

- All are consistent with and improved from the previous Belle result [PRD81.031103 (2010)]

Fit 2 (Flatte)

- A Flatte-like model by Hanhart et al.
  - Used in LHCb analysis for the J/ψππ channel [PRD 102, 092005 (2020)]

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

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

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)

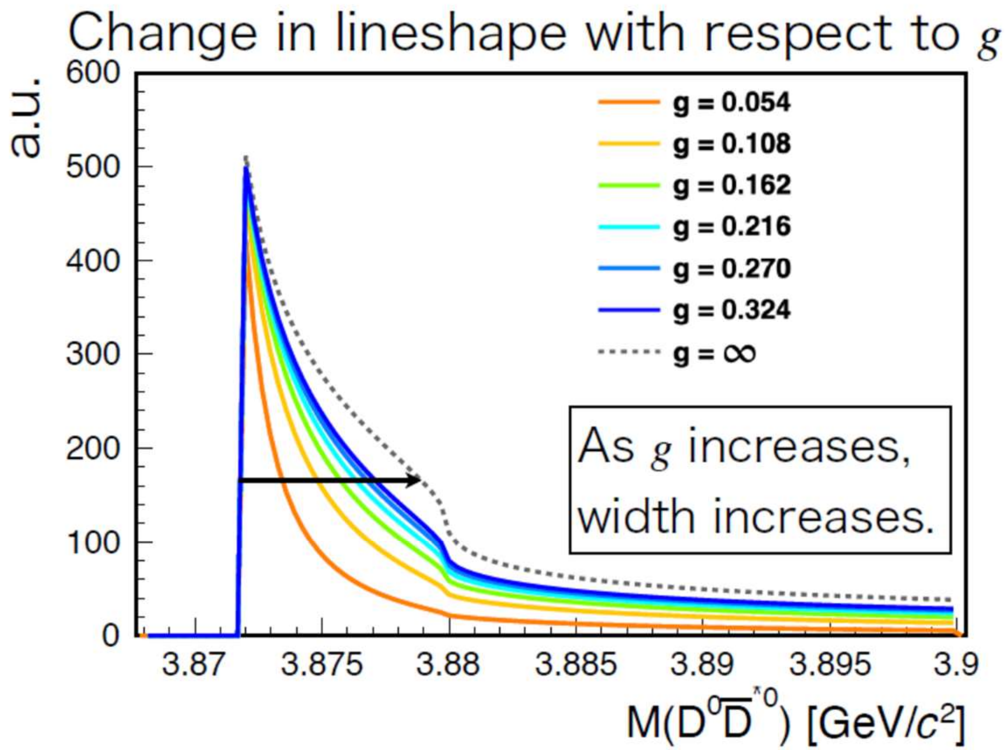
Constraints

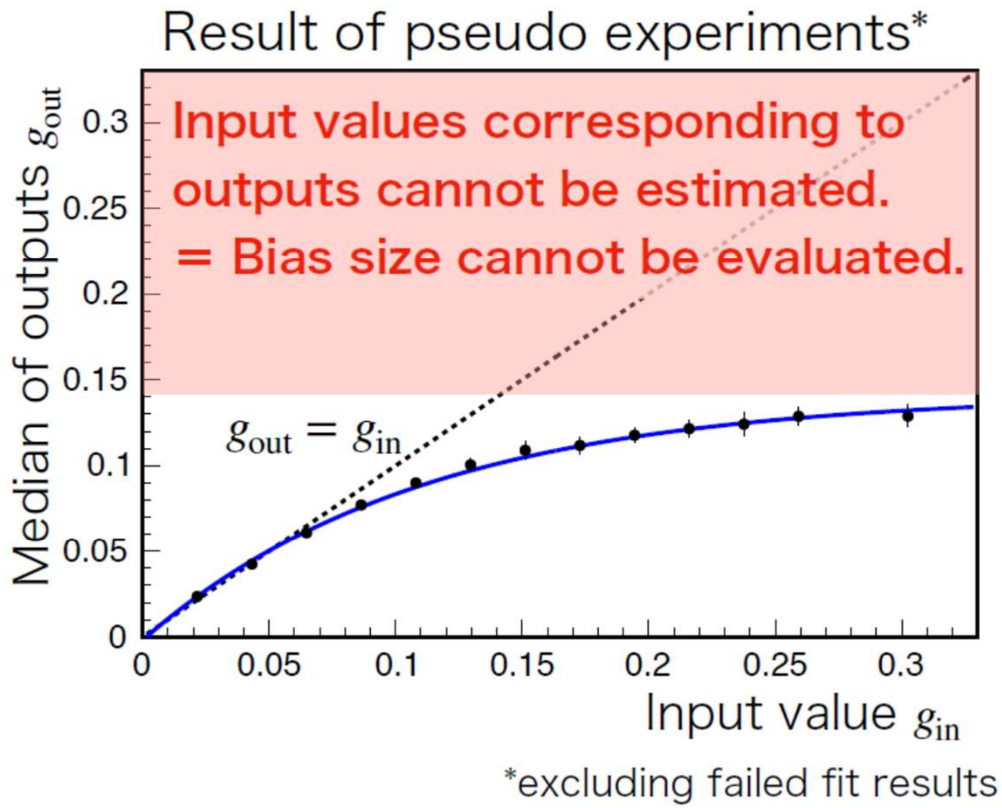
- Fit does not converge w/o constraints due to poor statistics
  - $\Gamma_{J/\psi\omega}$ is fixed by world-average BR
  - E_f, Γ_0, and $\Gamma_{J/\psi\rho}$ are fixed based on LHCb result [PRD 102, 092005 (2020)]
    $\frac{dg}{dE_f} = -15.11\ \mathrm{GeV}^{-1}, f_\rho = 1.8 \times 10^{-3}, \Gamma_0 = 1.4\ \mathrm{MeV}$
    (uncertainties are considered)

→ Only g is floated

Fit bias

- Lineshape converges to a fixed form for large g

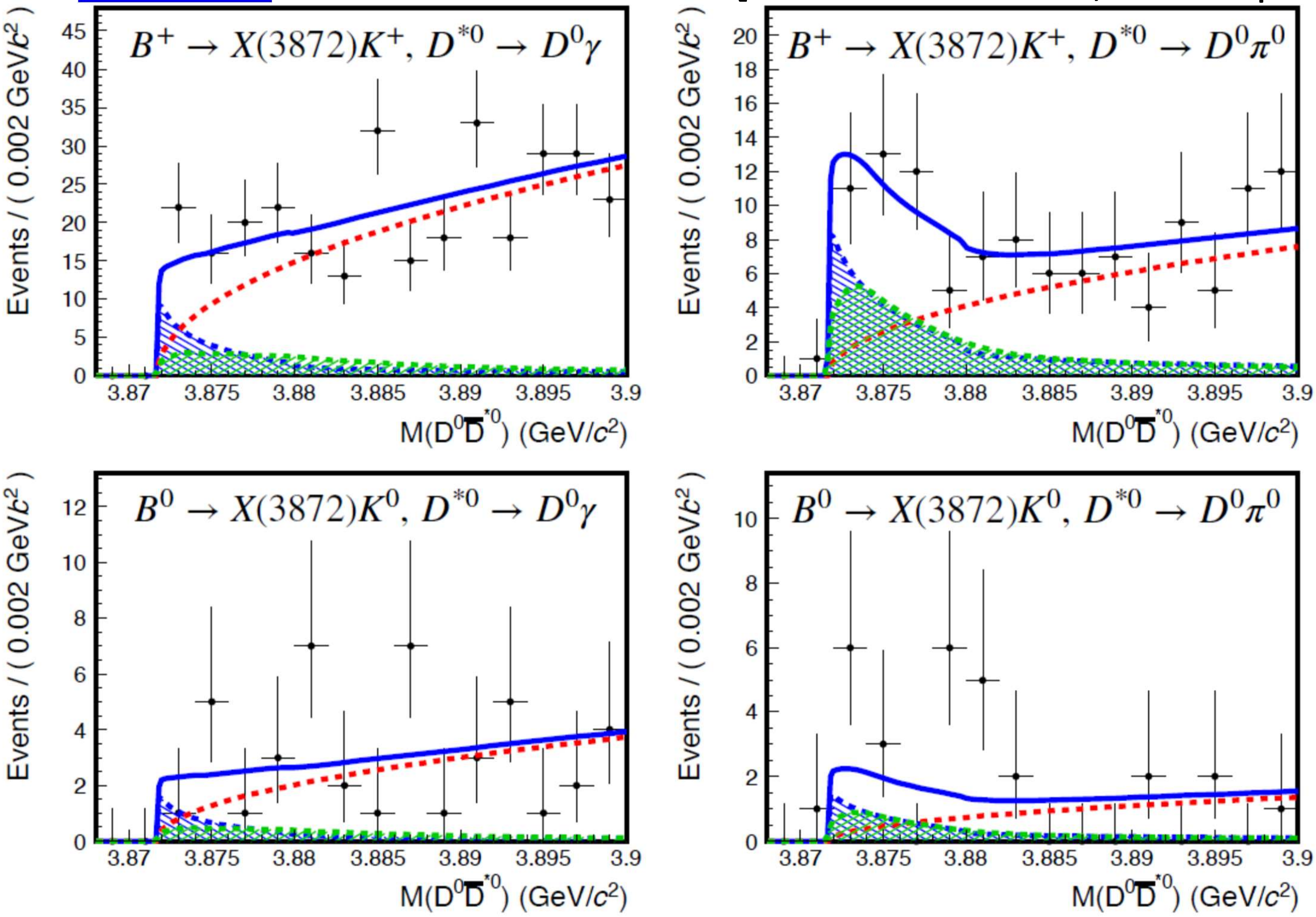




→ Only lower limit can be obtained for large g

Fit result

[arXiv:2302.02127, PRD in press]



Fit result

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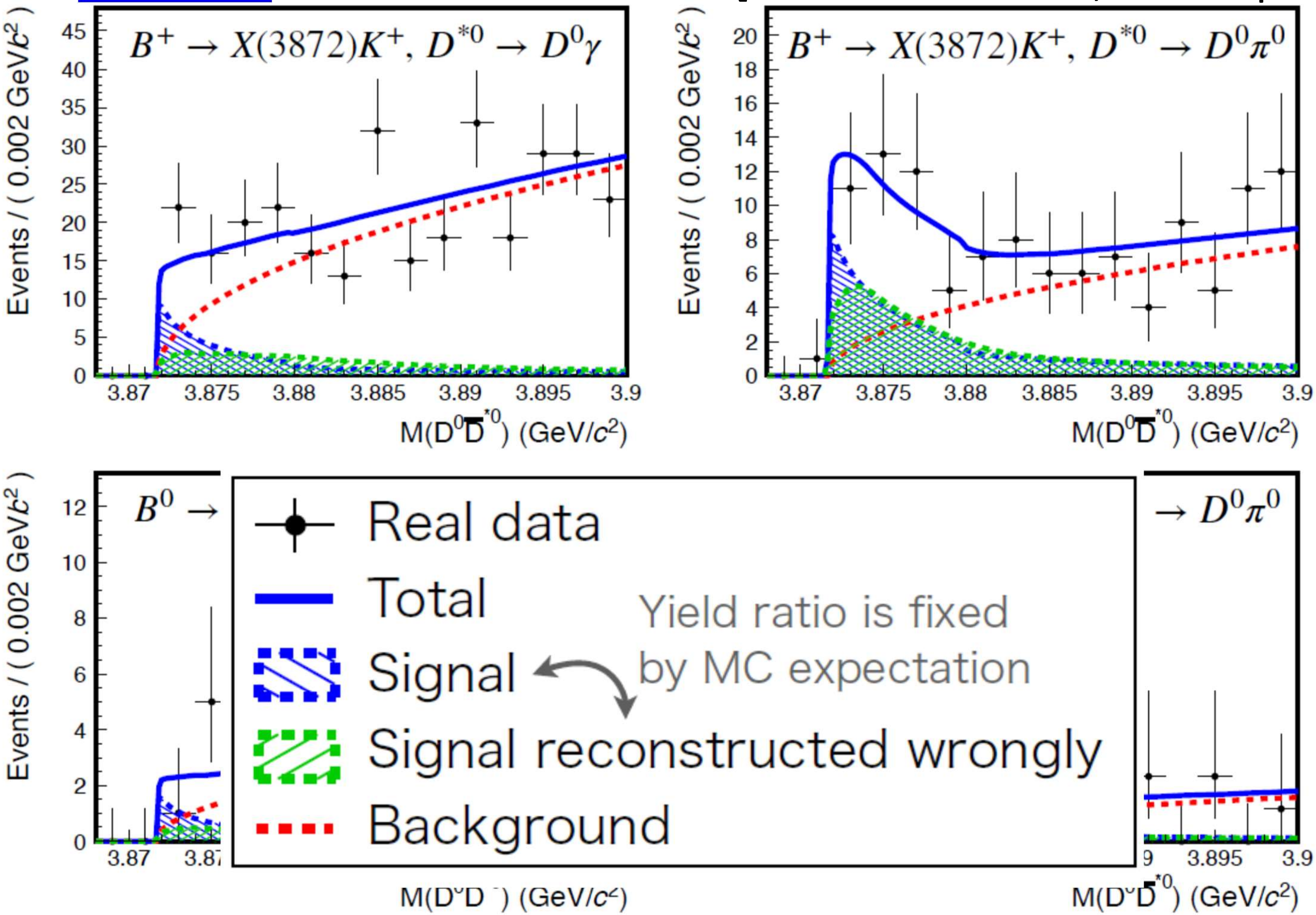
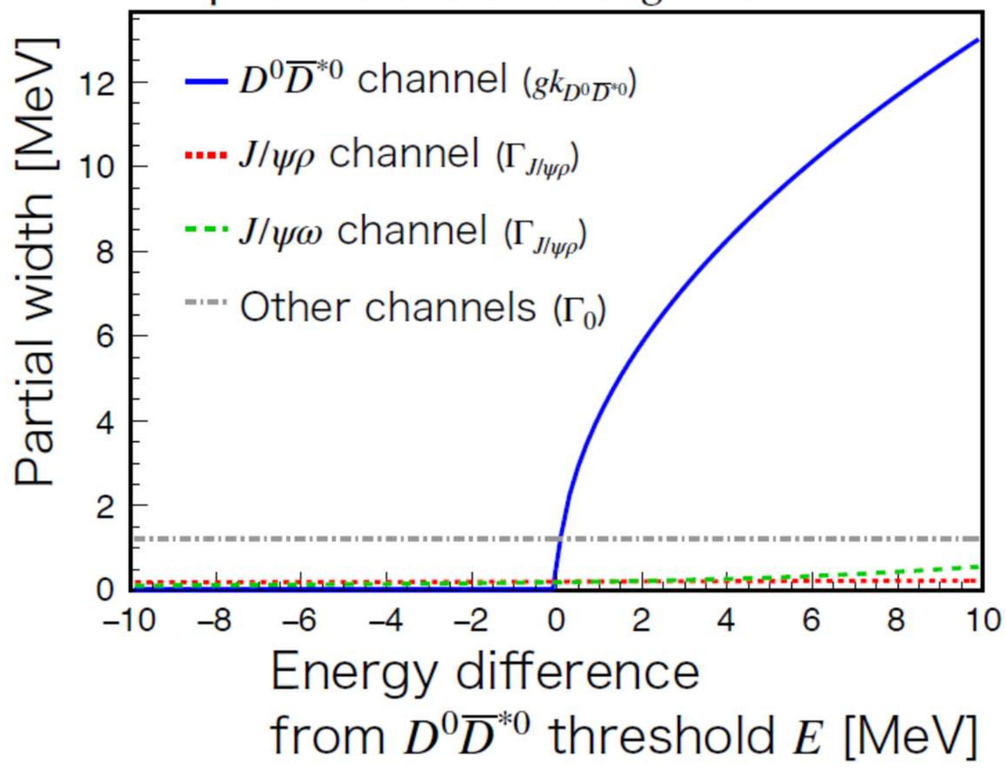


Result and discussion

- Fit result: $g = 0.29^{+2.69}_{-0.15}$ (stat. only)
  → Lower limit: $g > 0.094$ (90% CL)
  including systematic uncertainty
- Partial width for $D^0\overline{D}^{*0}$ channel is rather large
- According to Fermi's golden rule, the limit corresponds to
  $|\mathcal{M}| > 5.9$ GeV

Energy-dependent
partial width for $g = 0.094$



Summary & Prospect

- Using the Belle full data, we performed lineshape analysis for $X(3872) \to D^0\overline{D}^{*0}$
  - Obtained $g > 0.094$ (90% CL), corresponding to decay matrix element $|\mathcal{M}|$ > 5.9 GeV

- Statistics limited → ~x50 Larger statistics expected with Belle II
- Even better sensitivity can be obtained by analyzing $J/\psi\pi\pi$ decay (from Belle II or LHCb) simultaneously.
  → Determination of $X(3872) \to D^0\overline{D}^{*0}$ coupling

Exotic hadron mini-symposium in JPS-APS meeting in Hawaii

- JPS-APS Hawaii meeting: Oct. 7-12
- "Physics of Exotic Hadrons — From Discovery to Understanding“
- Calling for contributed talks until July 7th

- If you are interested, please visit https://indico.frib.msu.edu/event/66