Reanalysis of the $e^+e^- \to D^*\bar{D}^*\pi$ reaction and the claim for the $Z_c(4025)$ resonance

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Instituto de Física, Universidade de São Paulo, Brazil,

26-10-2013, Beihang University, China.

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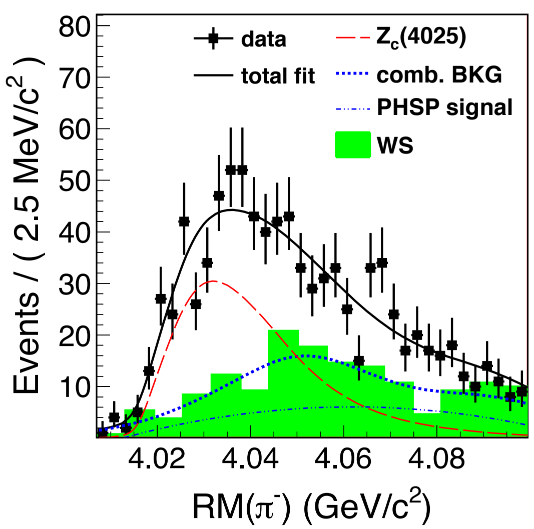
- BESIII claims the existence of a resonance in the reaction $e^+e^- \to (D^* \bar{D}^*)^{\pm}\pi^{\mp}$ at $\sqrt{s}$ = 4.26 GeV (arXiv:1308.2760 [hep-ex]).



Z_c(4025):
- Mass (4026.3±2.6±3.7) MeV
- width (24.8±5.6±7.7) MeV
- $I=1$, $J^P=1^+$ ($D^* \bar{D}^*$ in S-wave)

- Theoretical interpretations: 2^+ tetraquark state, 1^+ $D^* \bar{D}^*$ states using HQSS, QCD sum rules, pion exchange, etc.[1]

↓

Masses compatible with Z_c(4025), but large uncertainties

[1] Guo, Hidalgo-Duque, Nieves, PRD88,054007 (2013); Chen, Steele, Du, Zhu, arxiv: 1308.5060[hep-ph]. Cui, Liu, Huang, arxiv: 1308.3625 [hep-ph]; He, Liu, Sun, Zhu, arxiv: 1308.2999; Qiao, Tang, arxiv: 1308.3439 [hep-ph]

INTRODUCTION

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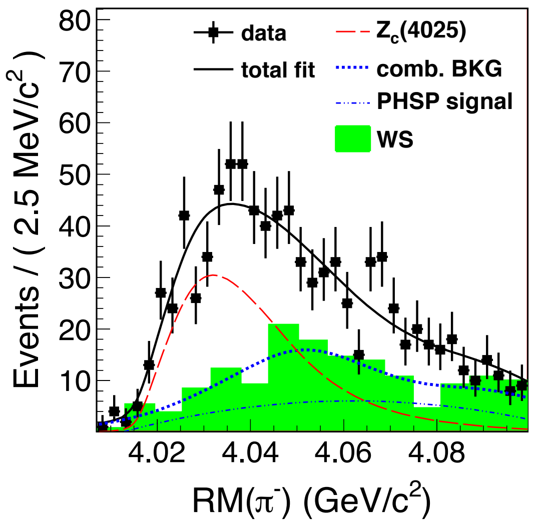

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- Peaks close to the threshold can be due to a state below the threshold (EPJA36,189; PLB719,388; arxiv:1306.6594 [hep-ph]).
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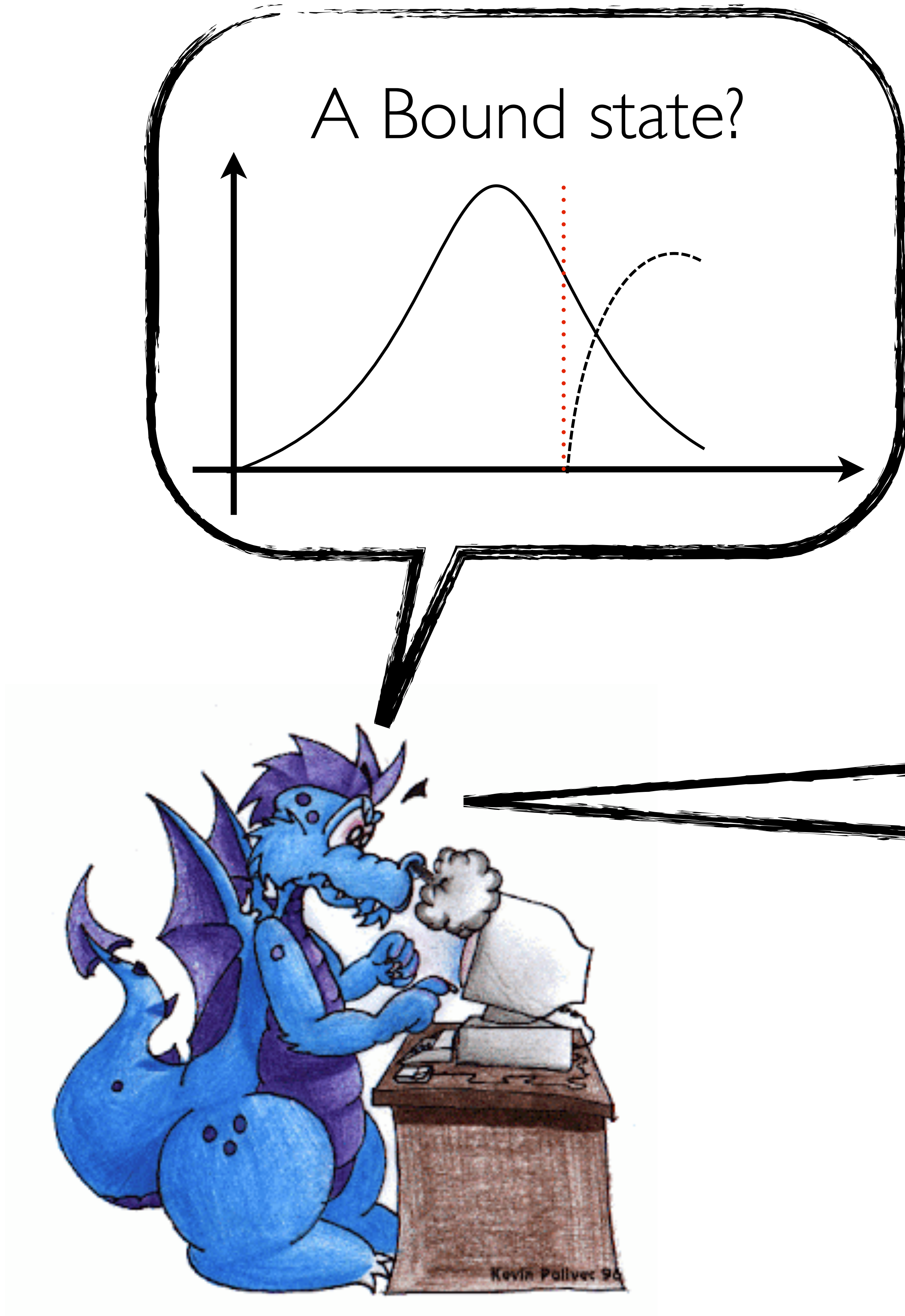
INTRODUCTION



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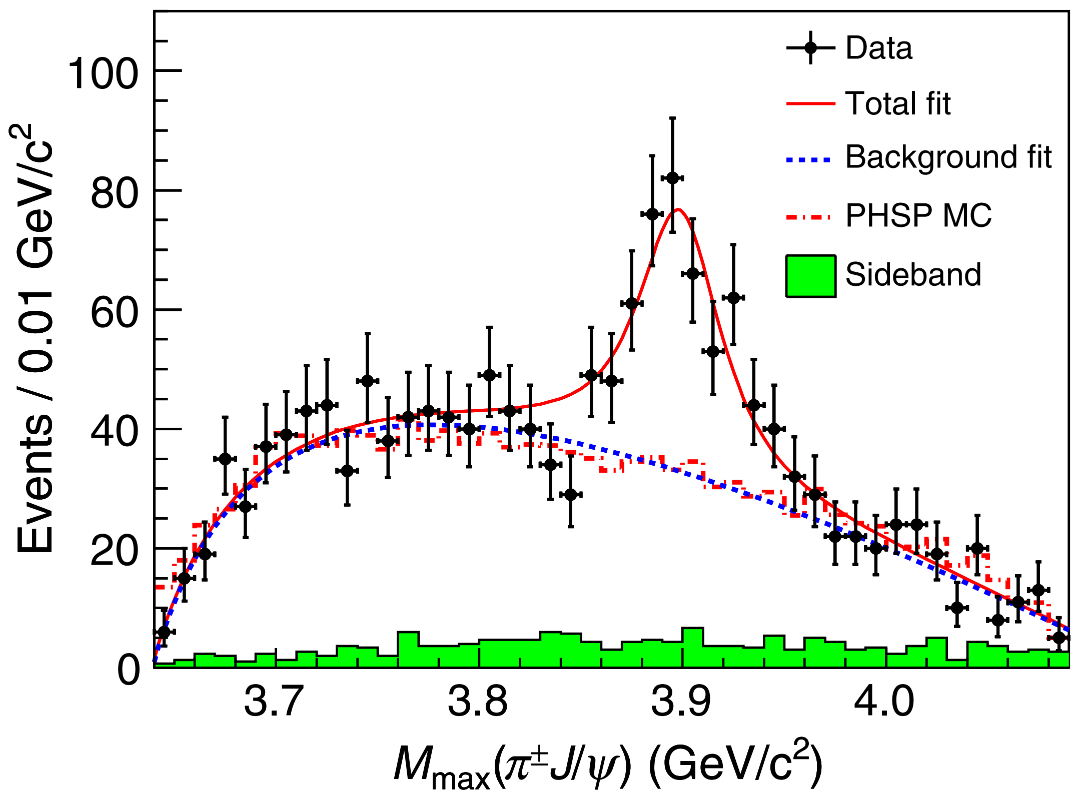
INTRODUCTION

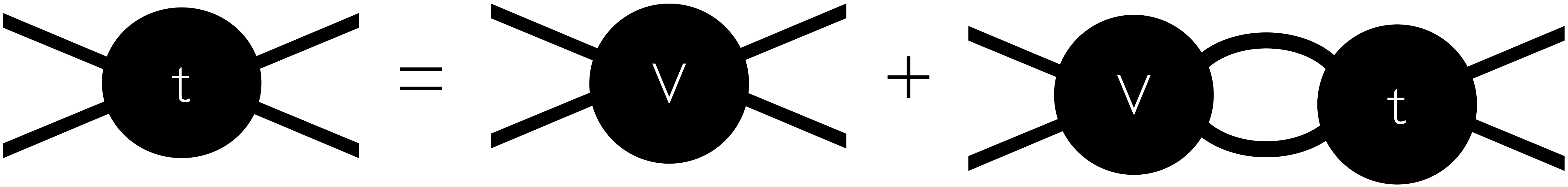
- If $J^P = 1^+$, Z_c can decay to π J/ψ. The process $e^+e^- \rightarrow \pi^+ \pi^- J/\psi$ at $\sqrt{s}$ = 4.26 GeV only shows the $Z_c(3900)$ (BESIII,PRL110,252001).



- A single channel with an energy independent potential can generate bound states, but not resonances (Yamagata-Nieves-Oset, PRD83, 014003).

THE $D^*\bar{D}^*$ SYSTEM

- Studied using effective field theories based on the hidden local symmetry and solving the Bethe-Salpeter equation (Molina, Oset, PRD80,114013).



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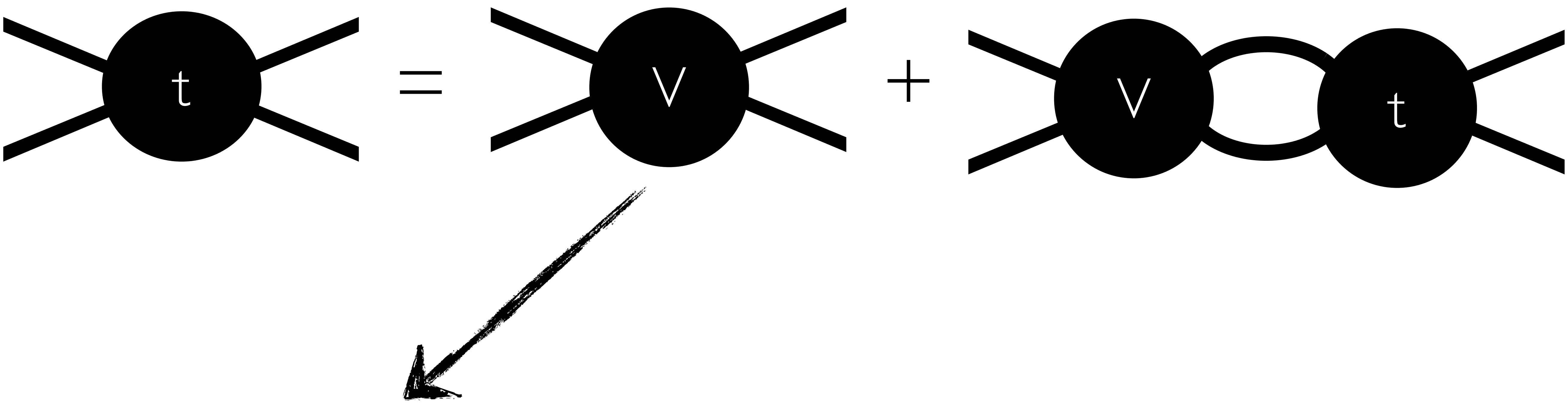

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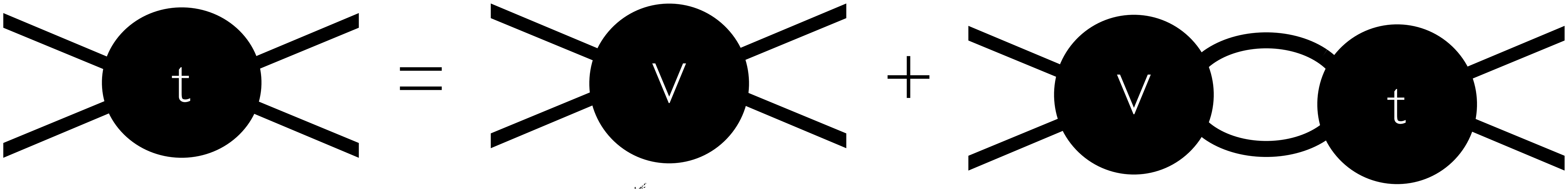

$$P^{(0)} = \frac{1}{3}\vec{\epsilon}\cdot\vec{\epsilon}'\delta_{km},$$

$$P^{(1)} = \frac{1}{2}\left(\epsilon_m\epsilon'_k - \epsilon_k\epsilon'_m\right),$$

$$P^{(2)} = \frac{1}{2}\left(\epsilon_m\epsilon'_k + \epsilon_k\epsilon'_m\right) - \frac{1}{3}\vec{\epsilon}\cdot\vec{\epsilon}'\delta_{km}$$

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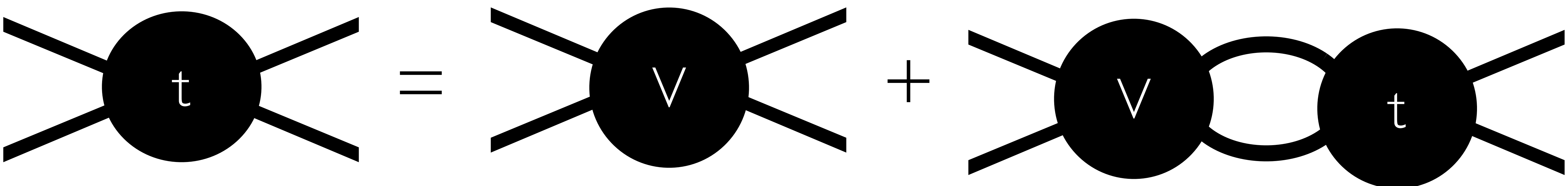

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Z_c ?

- Mass (3960-3990) MeV
- width (120-170) MeV
- $I=1$, $J^P=2^+$

THE $D^*\bar{D}^*$ SYSTEM

- QCD sum rules (Khemchandani, Martínez Torres, Nielsen, Navarra et al., arxiv: 1310.0862 [hep-ph])

$$j_{\mu\nu}(x) = [\bar{c}_a(x)\gamma_\mu u_a(x)]\left[\bar{d}_b(x)\gamma_\nu c_b(x)\right]$$

$$\Pi_{\mu\nu\alpha\beta}(q^2) = i\int d^4x e^{iqx}\langle 0 \mid T\left[j_{\mu\nu}(x) j^\dagger_{\alpha\beta}(0)\right] \mid 0\rangle$$

$$\mathcal{P}^{(0)} = \frac{1}{3}\Delta^{\mu\nu}\Delta^{\alpha\beta},$$

$$\mathcal{P}^{(1)} = \frac{1}{2}\left(\Delta^{\mu\alpha}\Delta^{\nu\beta} - \Delta^{\mu\beta}\Delta^{\nu\alpha}\right),$$

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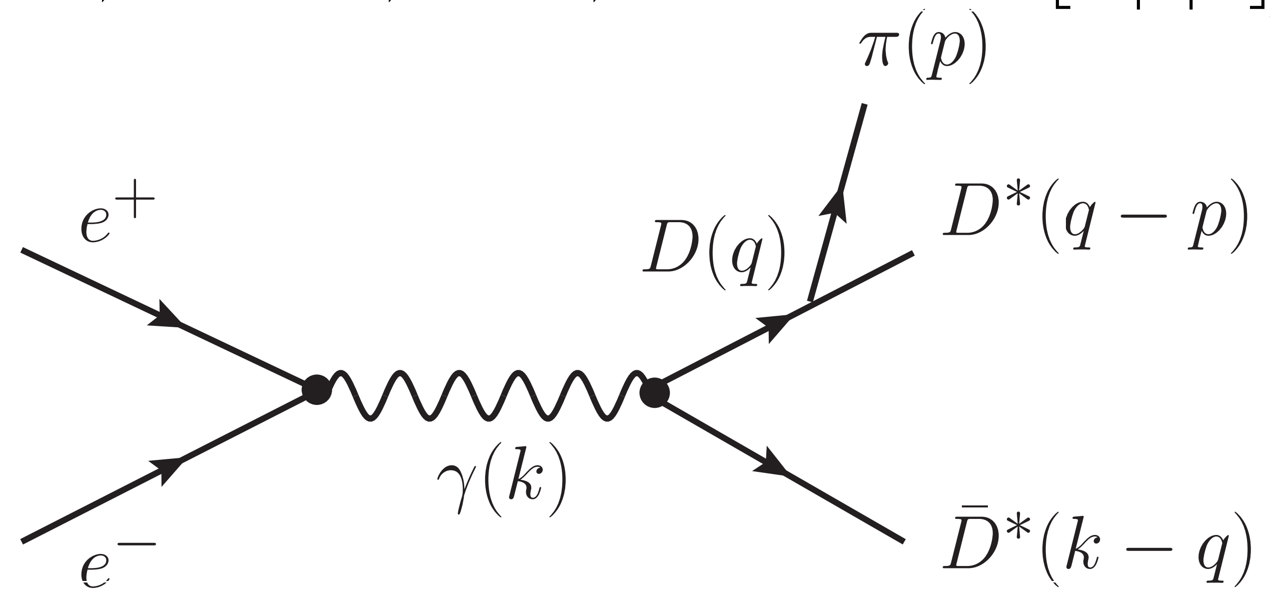
$$\Delta_{\mu\nu} \equiv -g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}.$$

- Results: three nearly spin degenerated states $(0^+, 1^+, 2^+)$ with masses 3950±100 MeV.

FORMALISM

- *D*-wave production of a 2^+ bound state (A. Martínez Torres, K. P. Khemchandani, F. S. Navarra, M. Nielsen, E. Oset, arXiv:1310.1119 [hep-ph])



$$t \propto k^0 \epsilon^{ijk} L_i q_j (q+p)_m \frac{1}{q^2 - m_D^2 + i\epsilon} \epsilon_k(\bar{D}^*) \epsilon_m(D^*)$$

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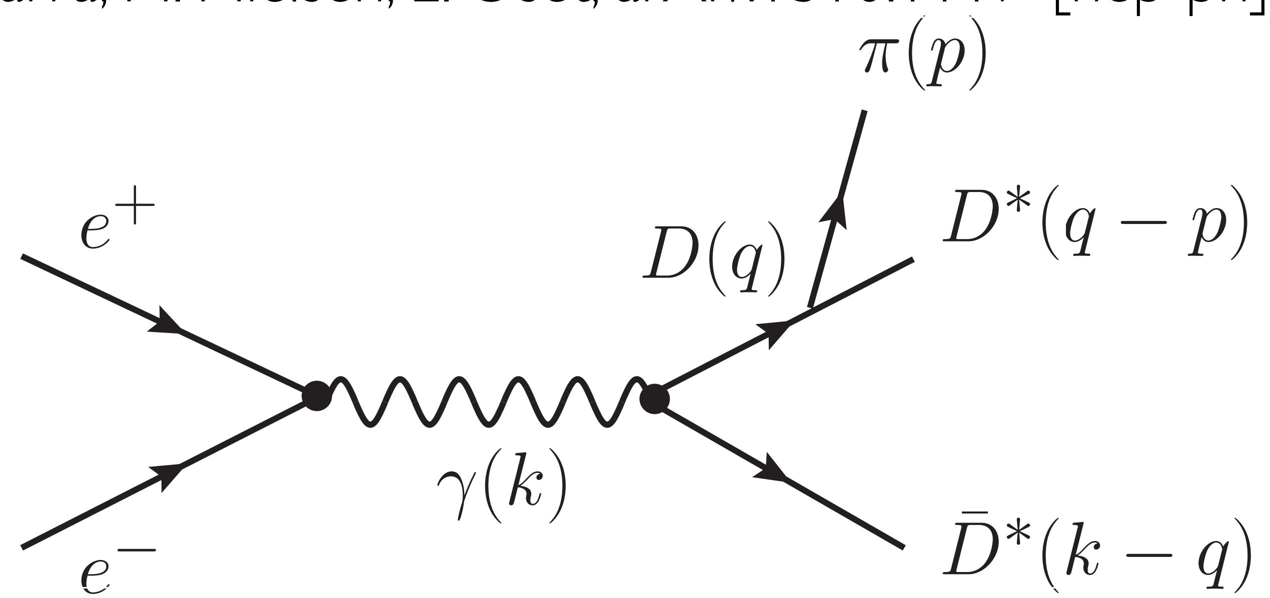

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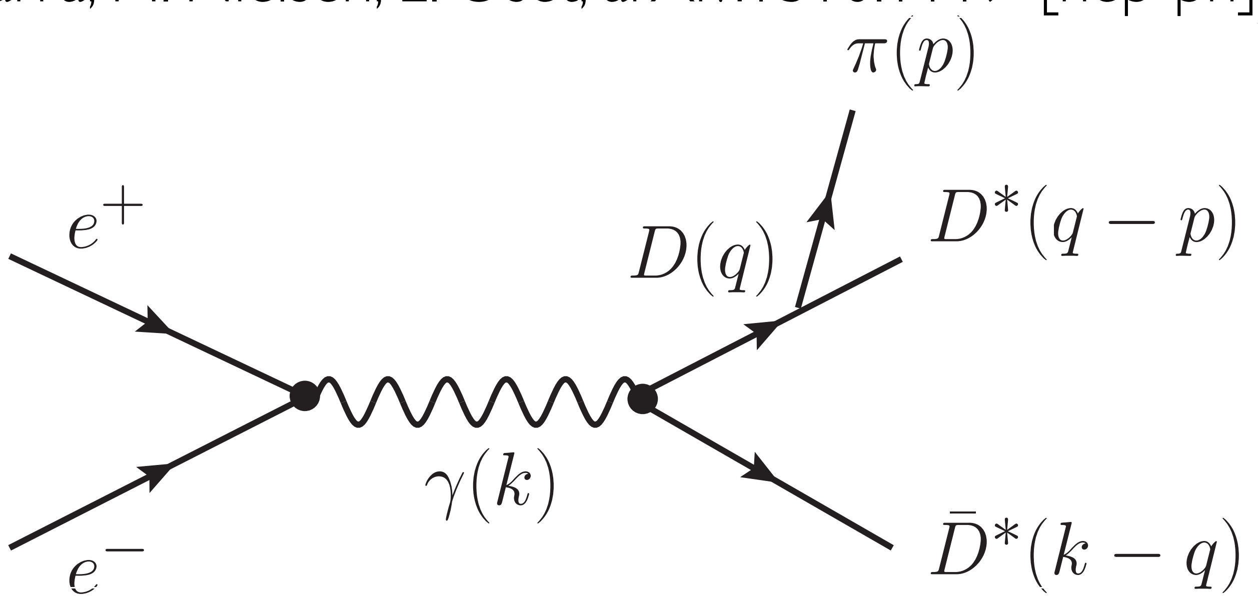

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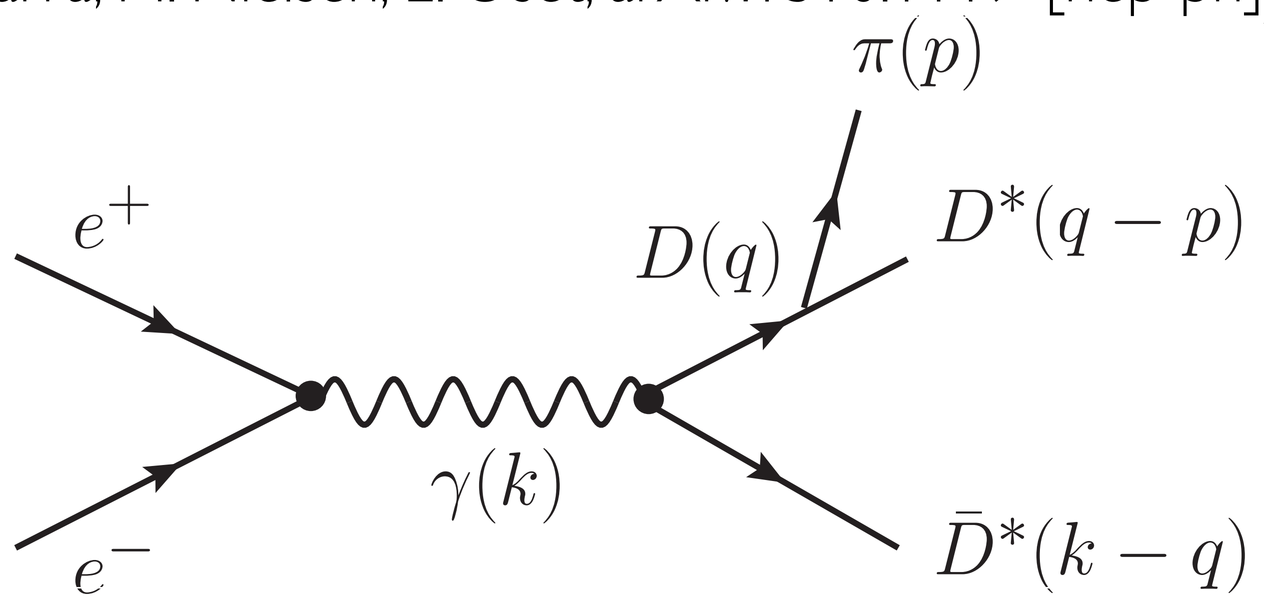

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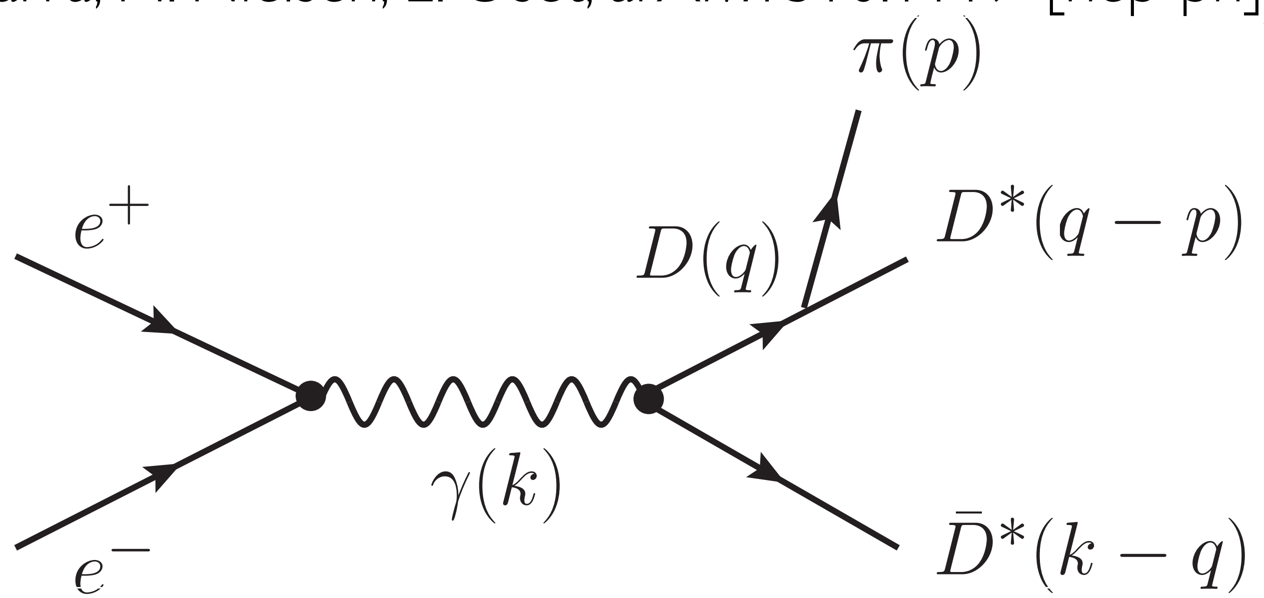

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contains S=2

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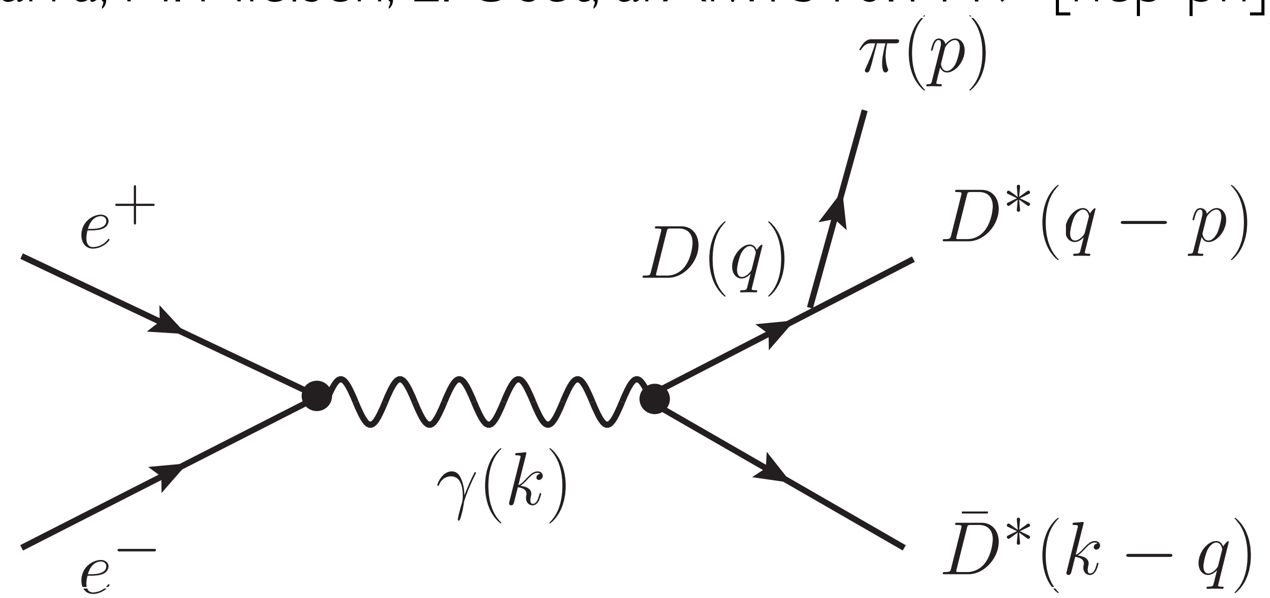

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D-wave   contains S=2

- The *D*-wave character and the spin 2 structure is preserved upon interaction of the final $D^*\bar{D}^*$ states

FORMALISM

- Invariant mass distribution:

$$\frac{d\sigma}{dM_{D^*\bar{D}^*}} = \frac{m_e^2}{s\sqrt{s}} p\tilde{q} \left(|T|^2 F_L + B \right) + \mathrm{WS}$$

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CM momentum

D^* momentum in $D^*\bar{D}^*$ rest frame

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CM momentum

$$T = \frac{A}{M_{D^*\bar{D}^*}^2 - M_R^2 + iM_R\Gamma_R}$$

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phase space background

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CM momentum

D* momentum
in D*$\overline{\text{D}}$* rest frame

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phase space background

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p: CM momentum

$\tilde{q}$: D* momentum in D$^*\overline{\text{D}}^*$ rest frame

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B: phase space background

WS: combinatorial backgrounds (D$^+$ with a π of the wrong charge)

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CM momentum

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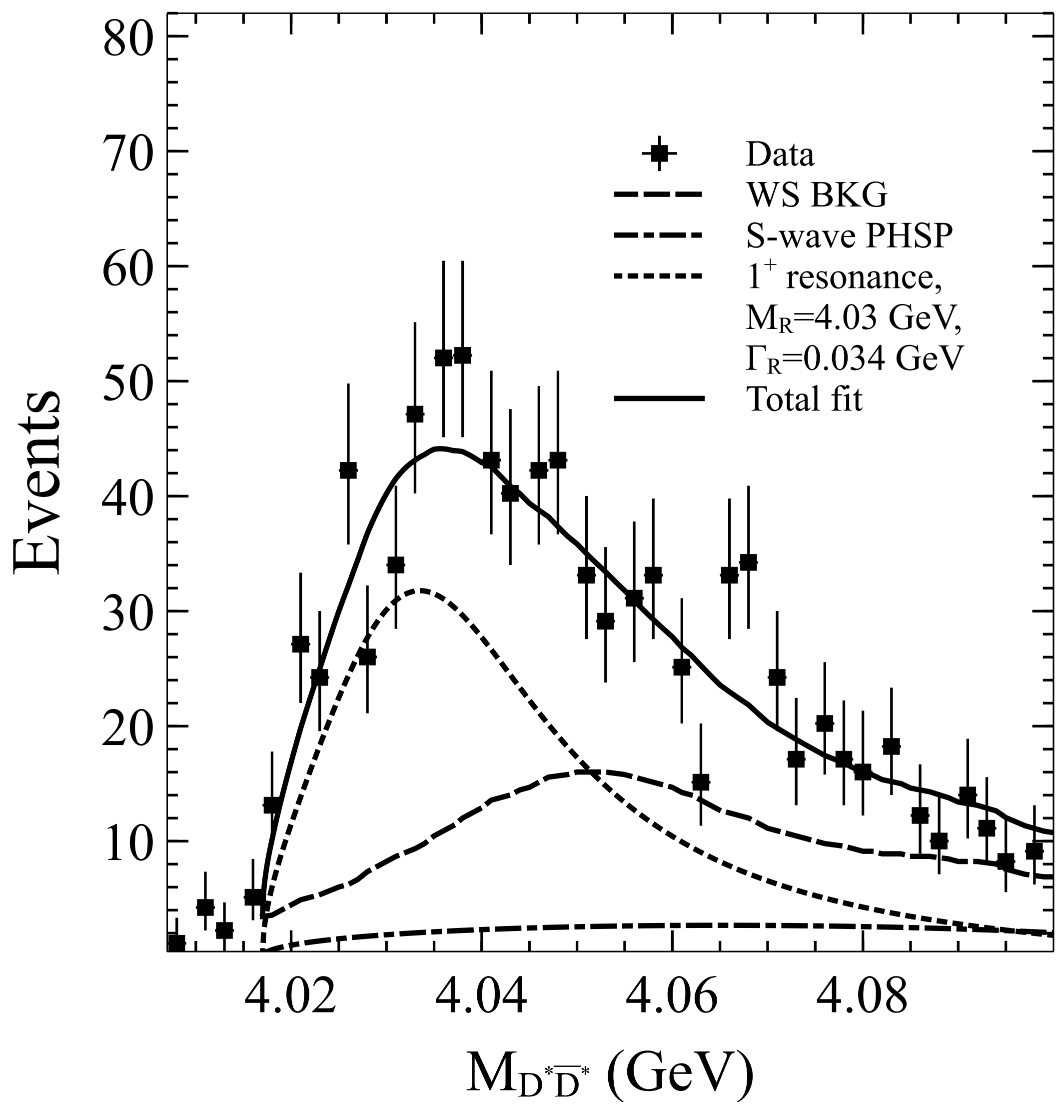
phase space background

combinatorial backgrounds (D^+ with a π of the wrong charge)

- We consider A, B, M_R, Γ_R as parameters and perform a fit to the data.
- Good fit: χ^2/n.d.o.f ~1 (BES III experiment: χ^2/n.d.o.f = 0.92)

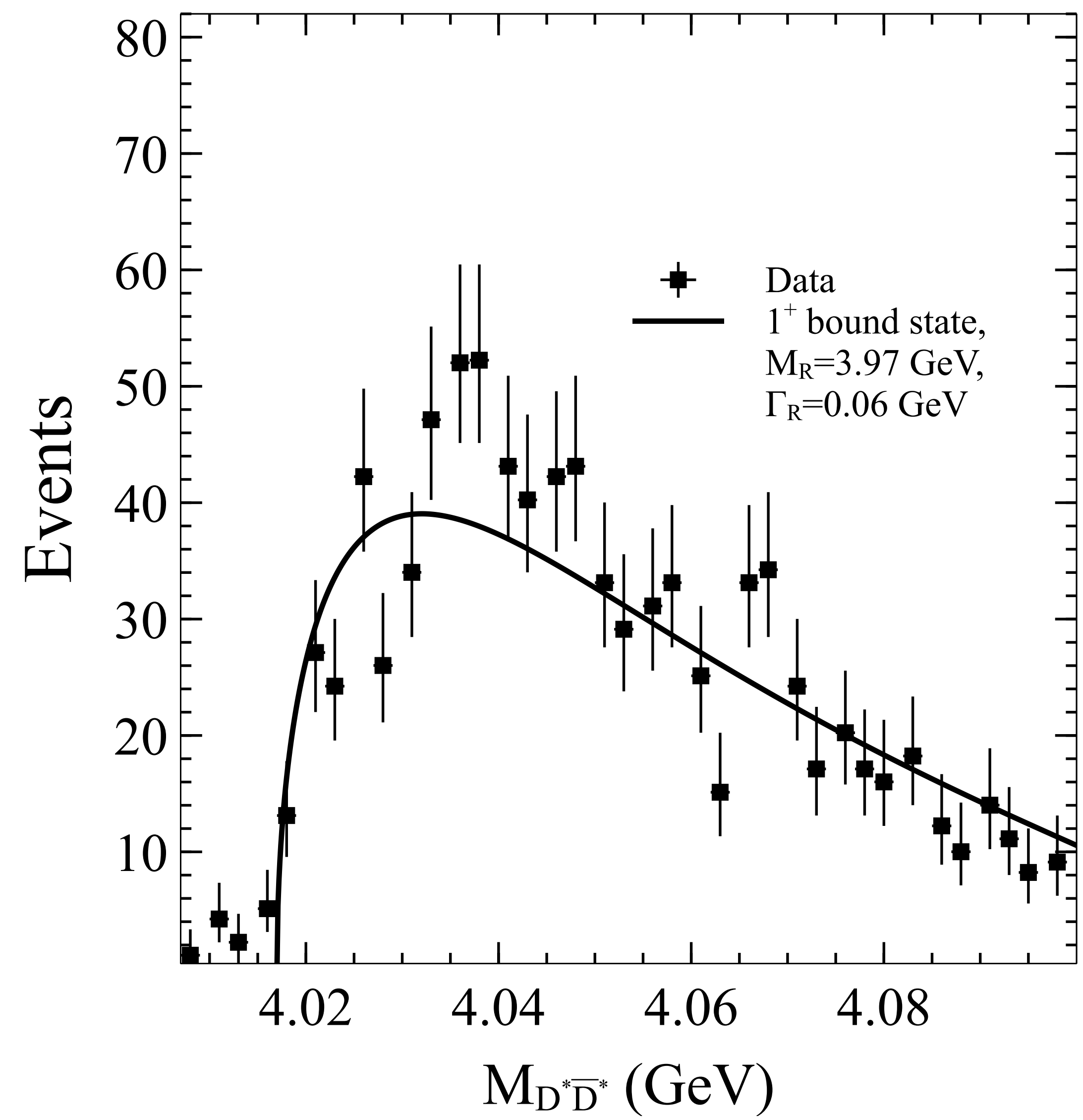
RESULTS

As BESIII



1^+ resonance produced in S-wave
(M=4030 MeV, Γ=34 MeV)

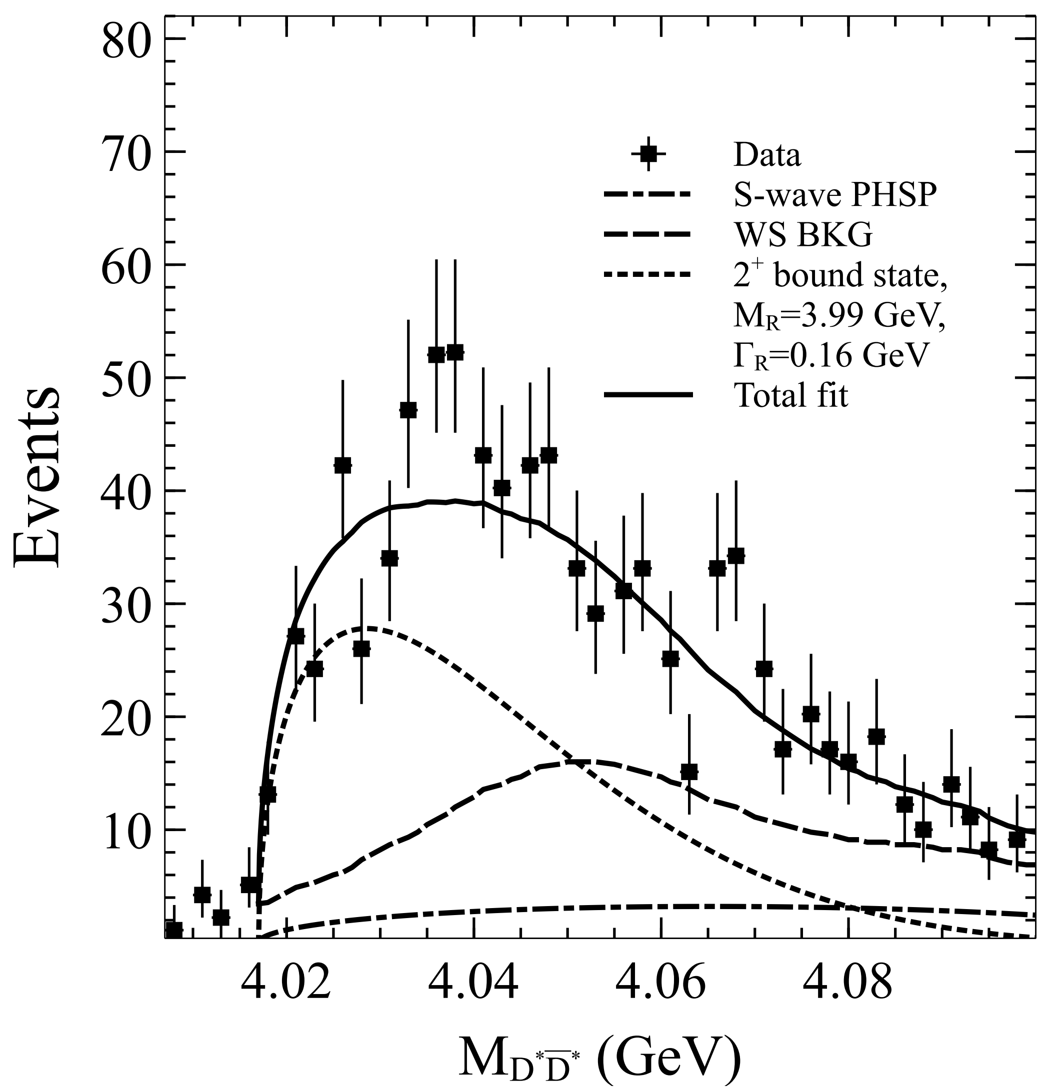
Alternative



1^+ bound state produced in S-wave
(M=3970 MeV, Γ=60 MeV)

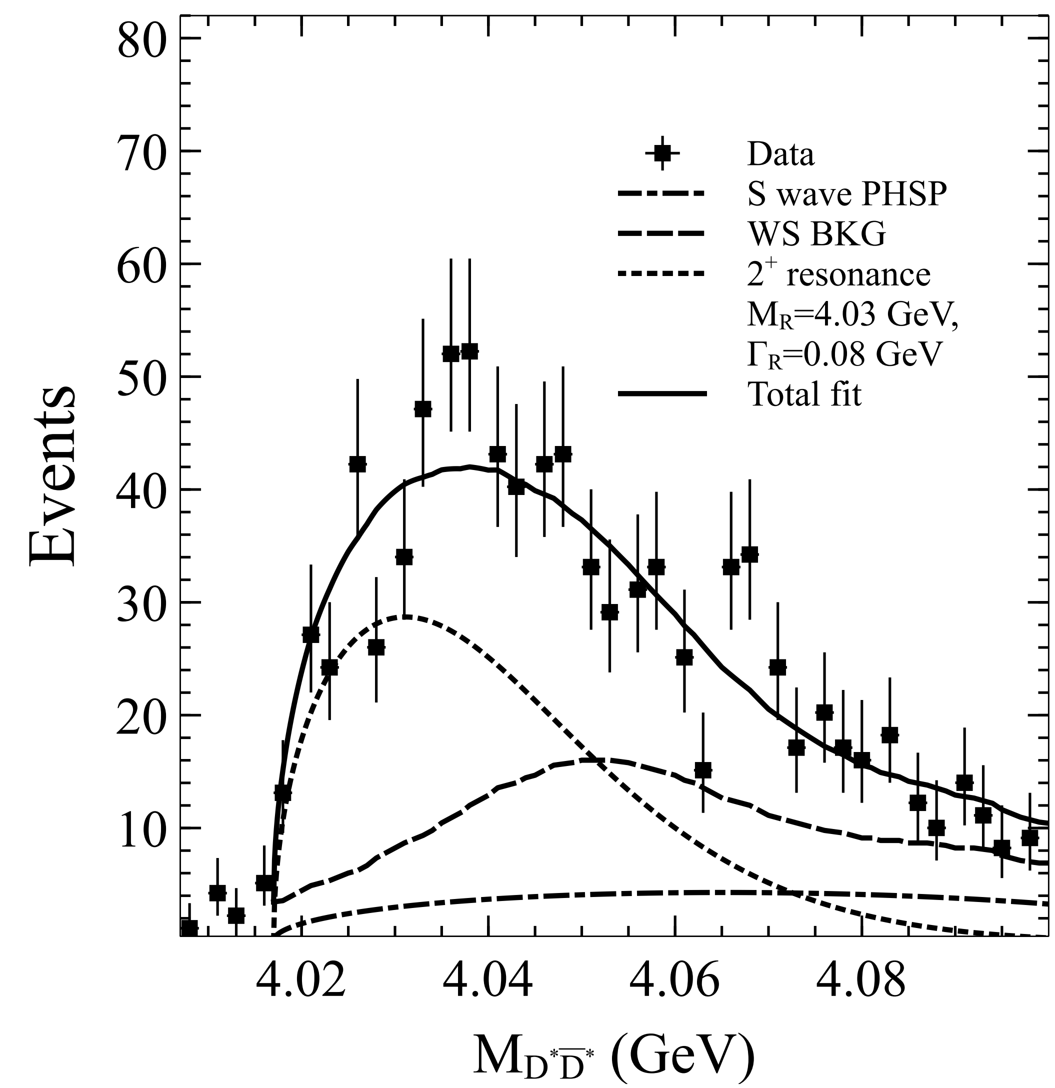
RESULTS

Alternative



2^+ bound state produced in *D*-wave (M=3990 MeV, *Γ*=160 MeV)

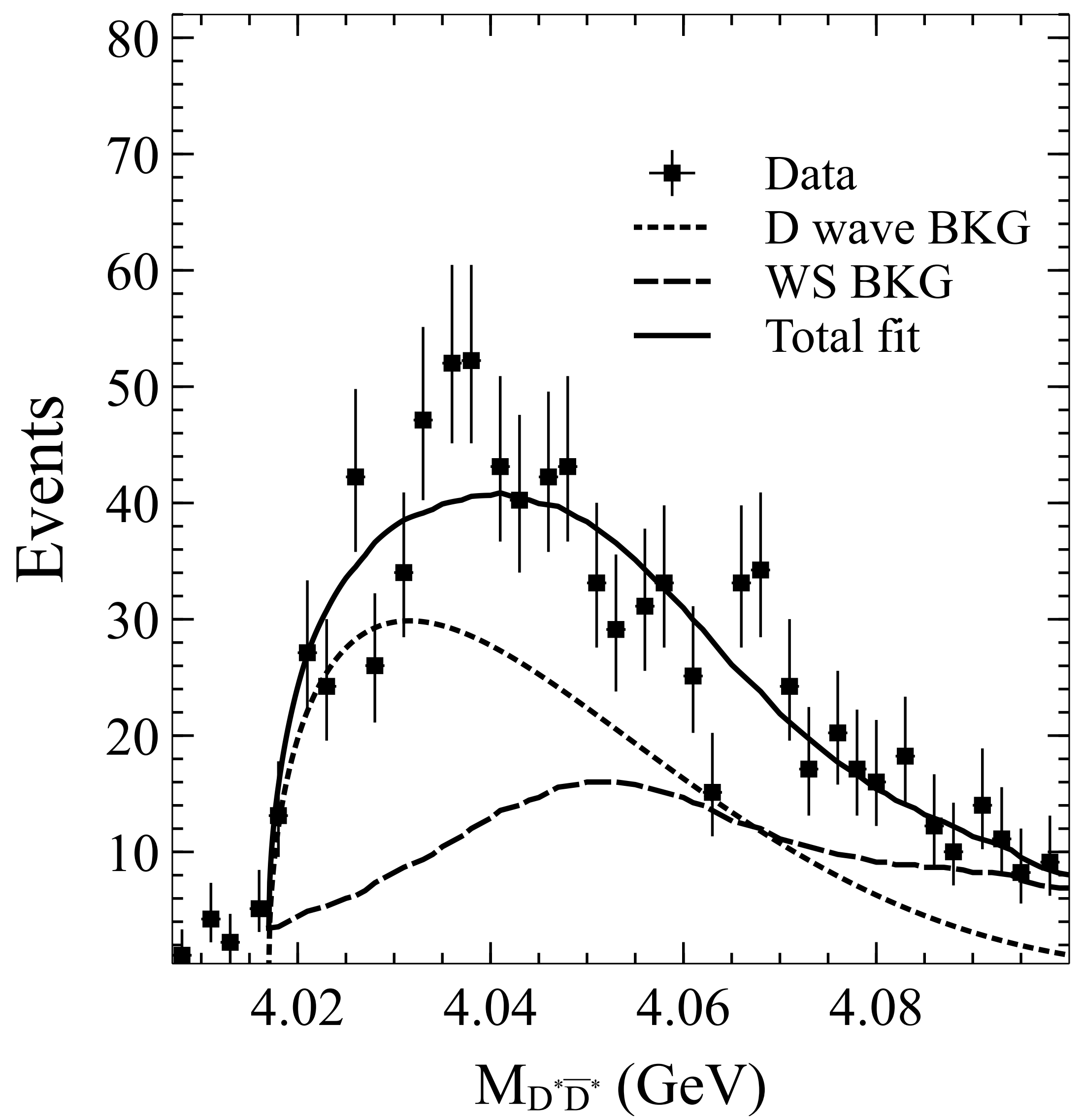
Alternative



2^+ resonance produced in *D*-wave (M=4030 MeV, *Γ*=80 MeV)

RESULTS

Alternative

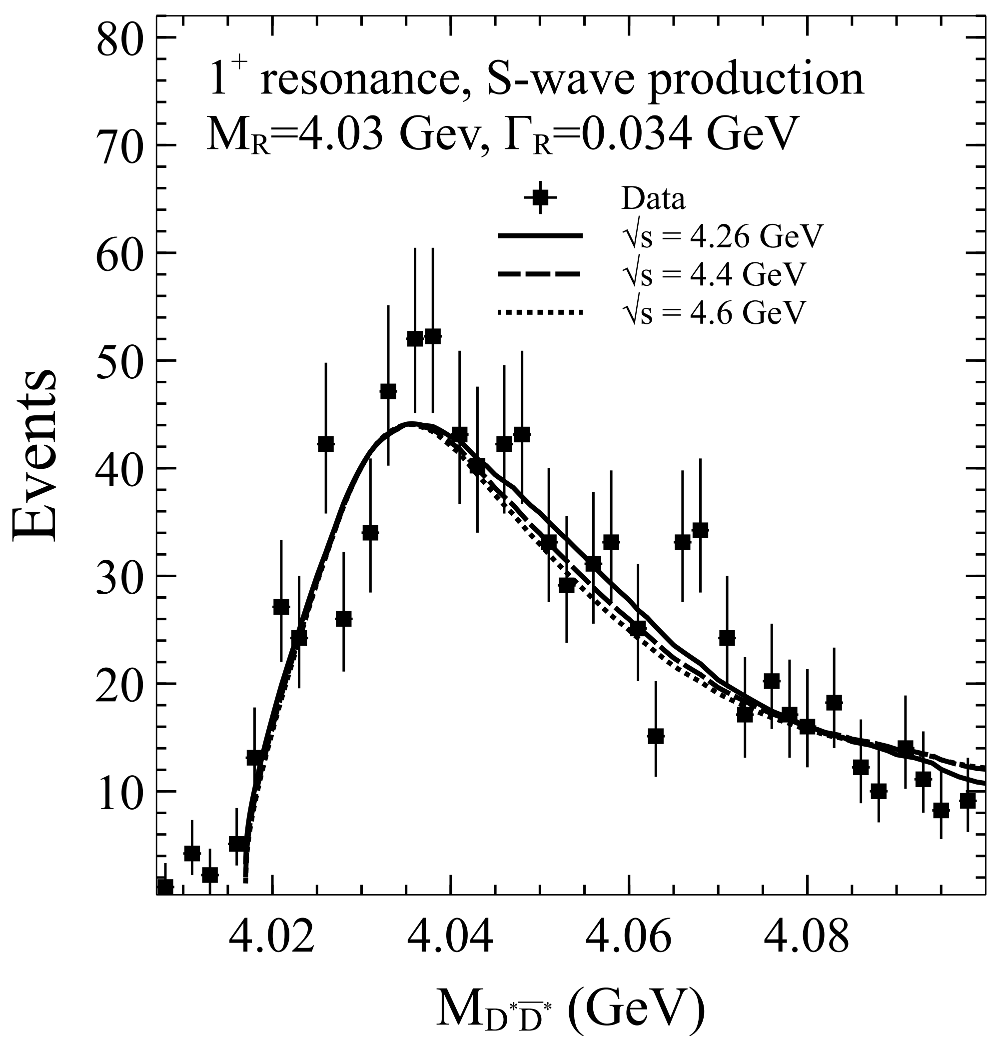


D-wave background

RESULTS

- Is there a way to know which of the different options is responsible for the signal found? ➡ Change CM energy

As BESIII



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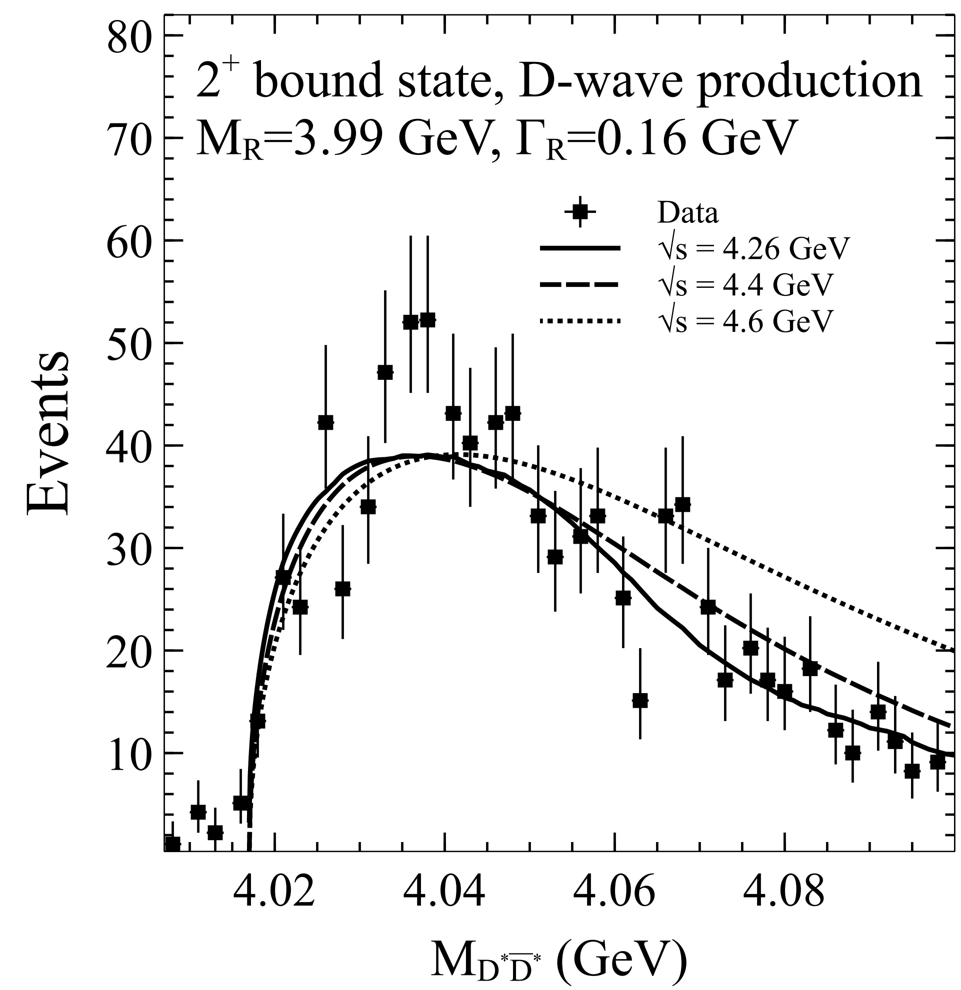

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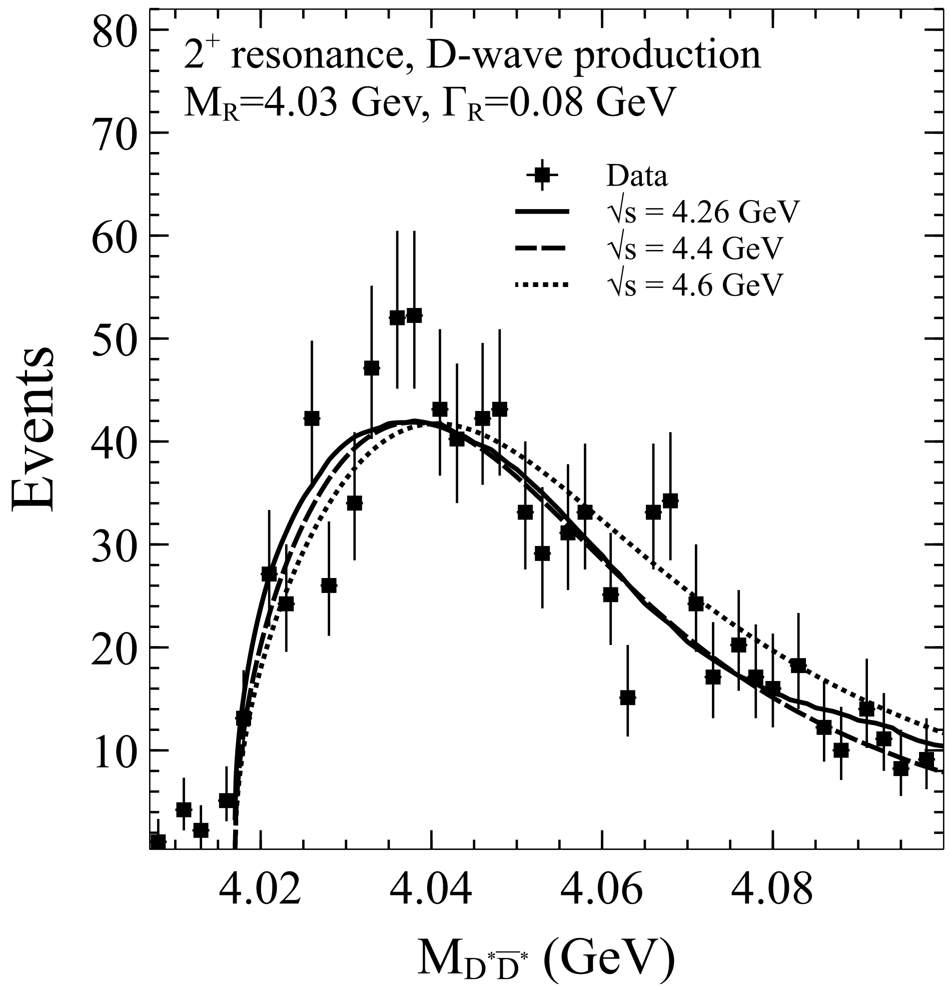

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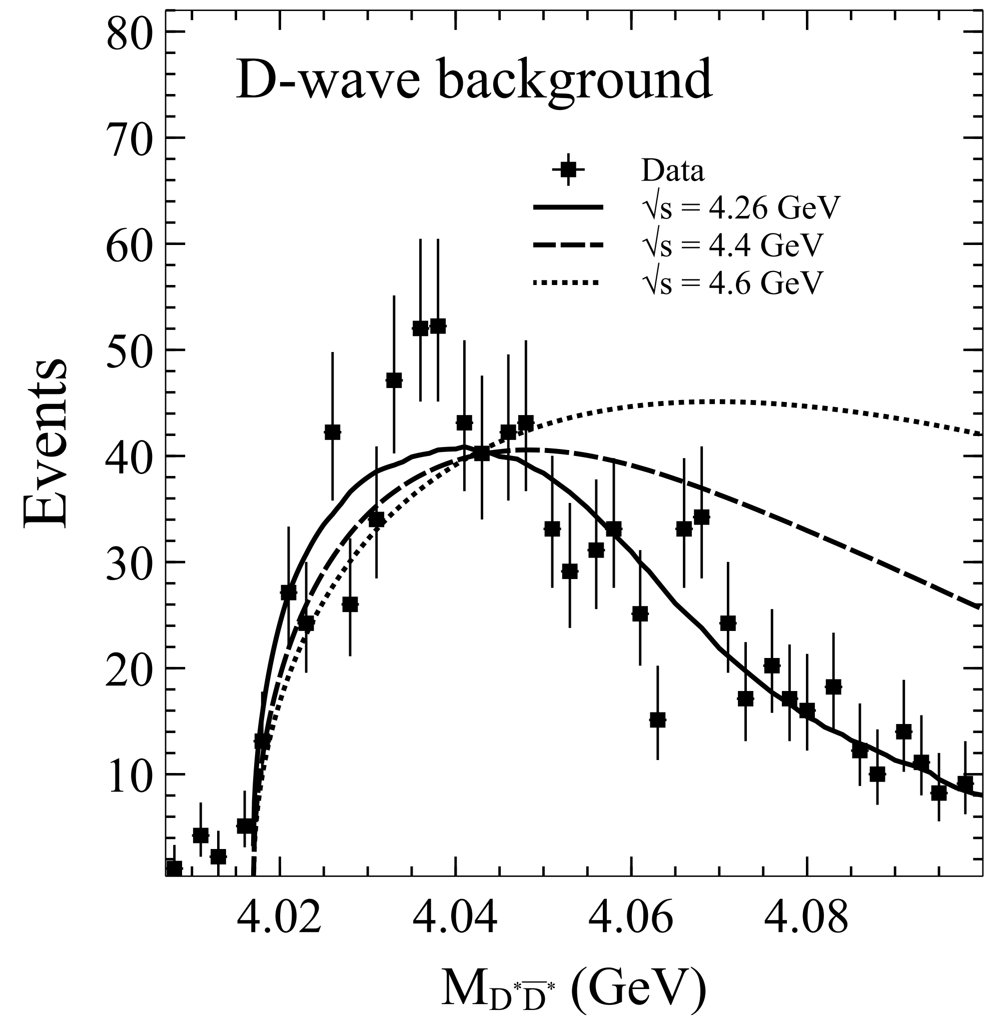

D-wave background

CONCLUSIONS

- We have obtained the $D^* \bar{D}^*$ invariant mass distribution associated to the $e^+e^- \rightarrow (D^* \bar{D}^*)^{\pm}\pi^{\mp}$ reaction.
- We have found that the signal related to a the $Z_c(4025)$ can also correspond to a 2^+ bound state, a 2^+ resonance or just to a *D*-wave background.
- All of them are equally plausible.
- Studying the dependence of the invariant mass distribution with the CM energy it could be possible to distinguish between a resonance (1^+ or 2^+) and a 2^+ bound state.