Angular analysis of the $e^+e^- \to D^{(*)+}D^{*-}$ process near the open charm threshold with initial state radiation

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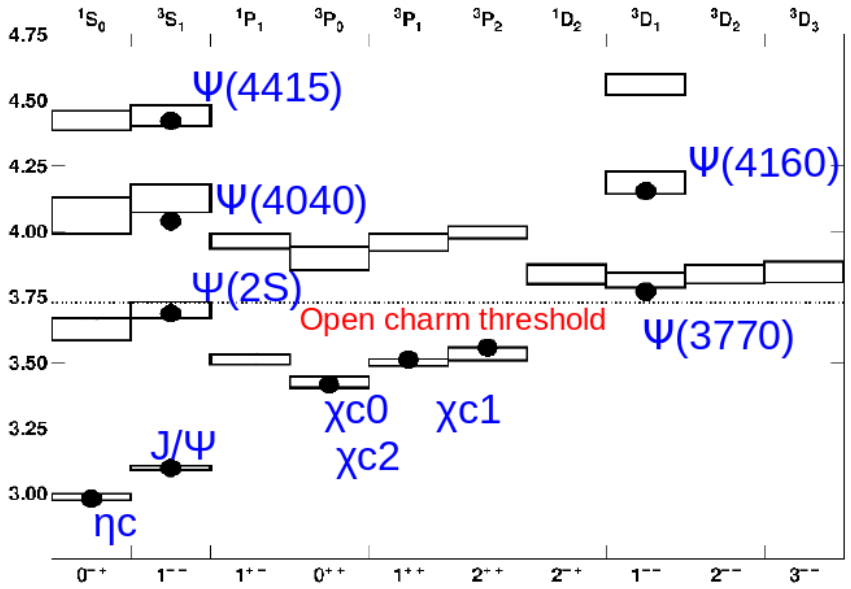
Spectrum of charmonium

- Vector states above open-charm threshold are not fully understood
- Parameters of ψ states obtained from $\sigma_{\mathrm{tot}}(e^+e^- \to \text{hadrons})$
  - are model-dependent
  - have large uncertainties
- Data collected should allow for coupled-channel analysis



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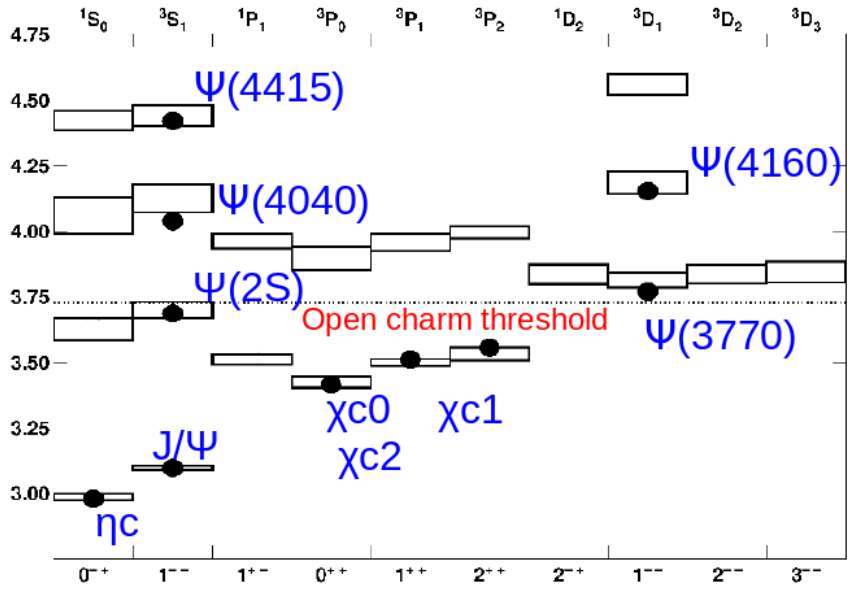
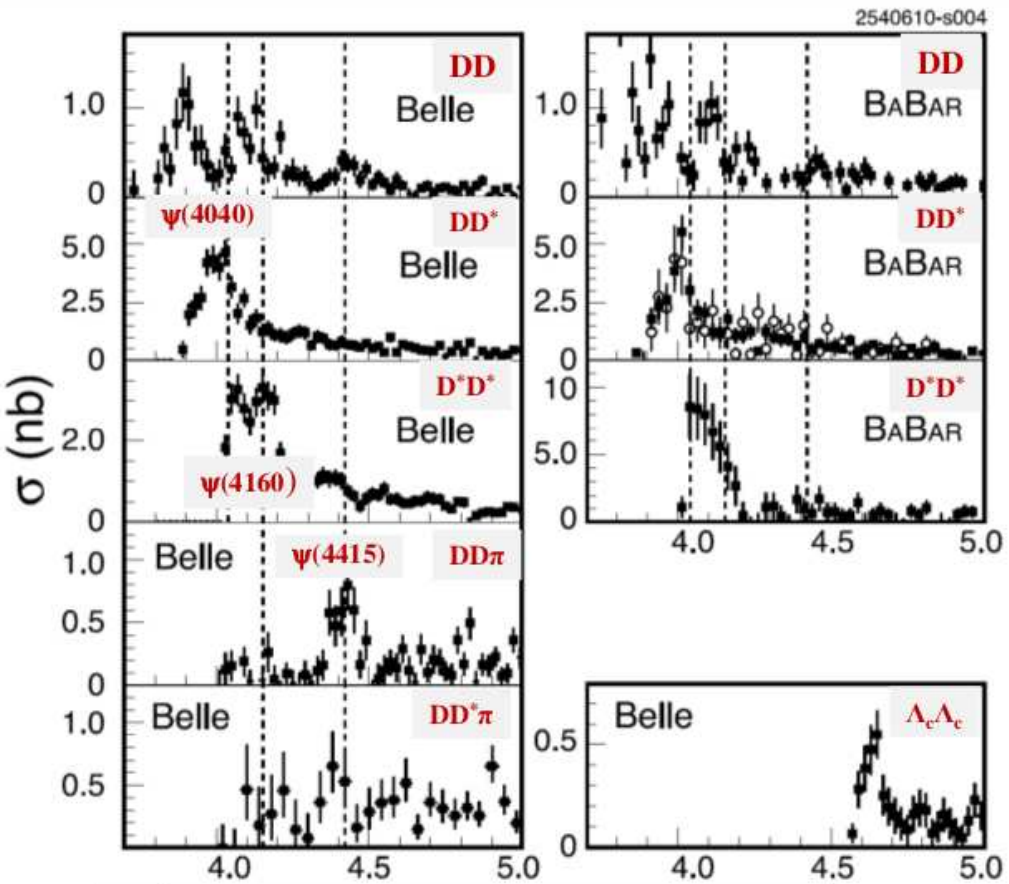


Solution $\Longrightarrow$ Measure exclusive cross sections

Comparison with previous results



- Belle [1-5] and BaBar [6,7] results agree with each other *(see last slide for references)*
- Statistics is too low to study the structure of the cross sections
- Sum of all measured excusive cross-section to open-charm channels saturates the total cross section

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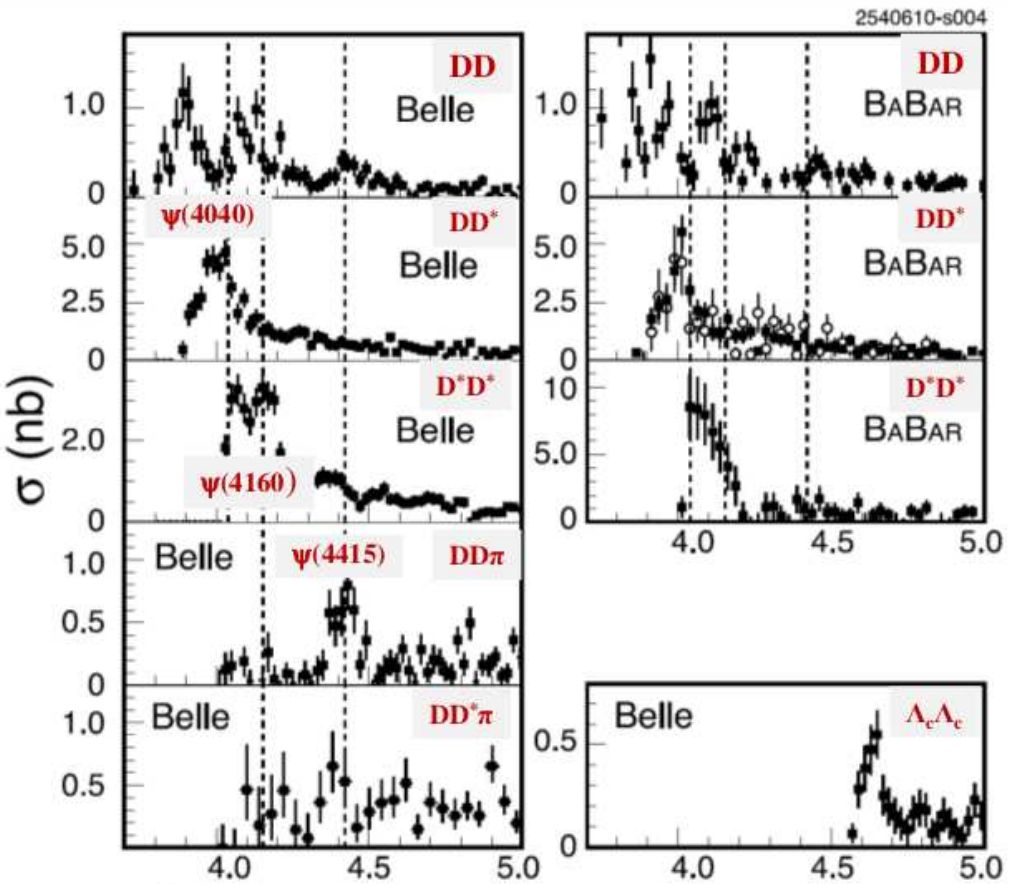

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- Statistics is too low to study the structure of the cross sections
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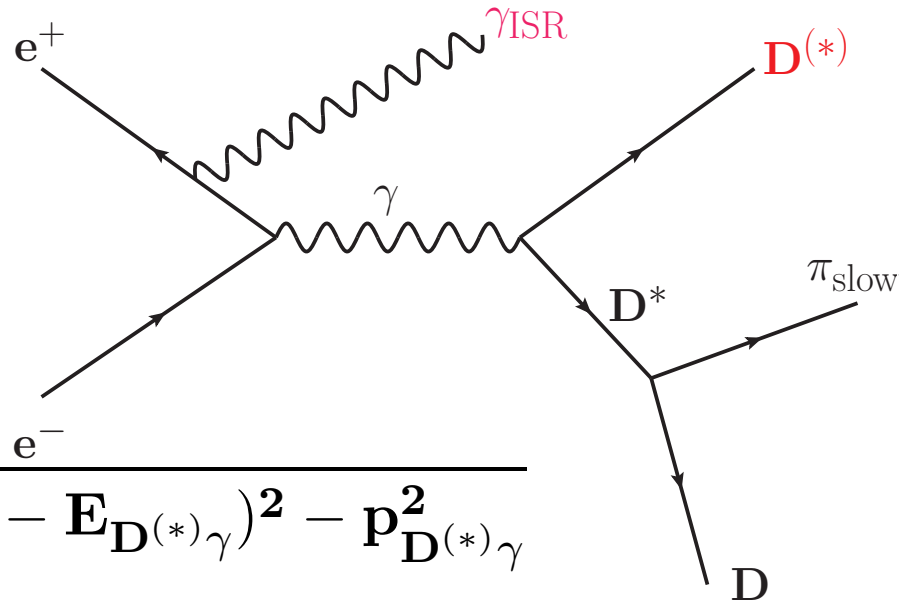
Goals:

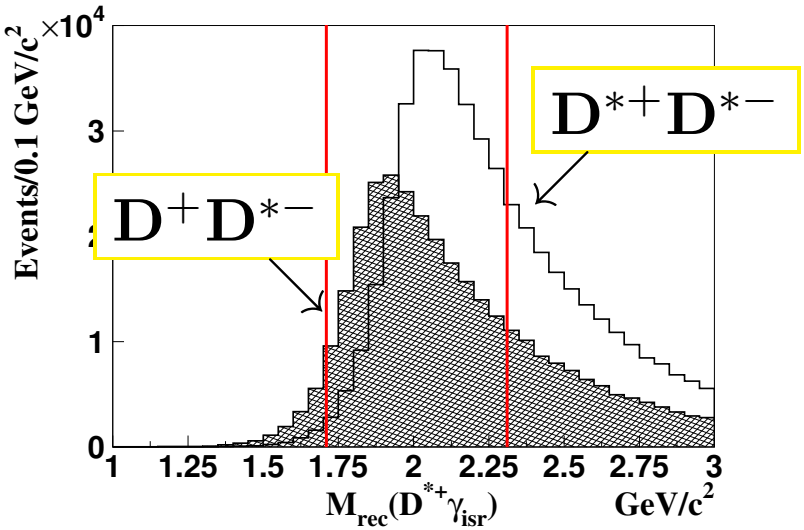
- To improve accuracy of cross section measurements
- To measure separately cross sections for all 3 possible helicity combinations (TT, LT, LL) for the $D^* \bar{D}^*$ final state

Method

- Partial reconstruction
- Reconstruct D^*, γ_{ISR}



$$M_{recoil}(D^{(*)}\gamma) = \sqrt{(E_{c.m.} - E_{D^{(*)}\gamma})^2 - p^2_{D^{(*)}\gamma}}$$



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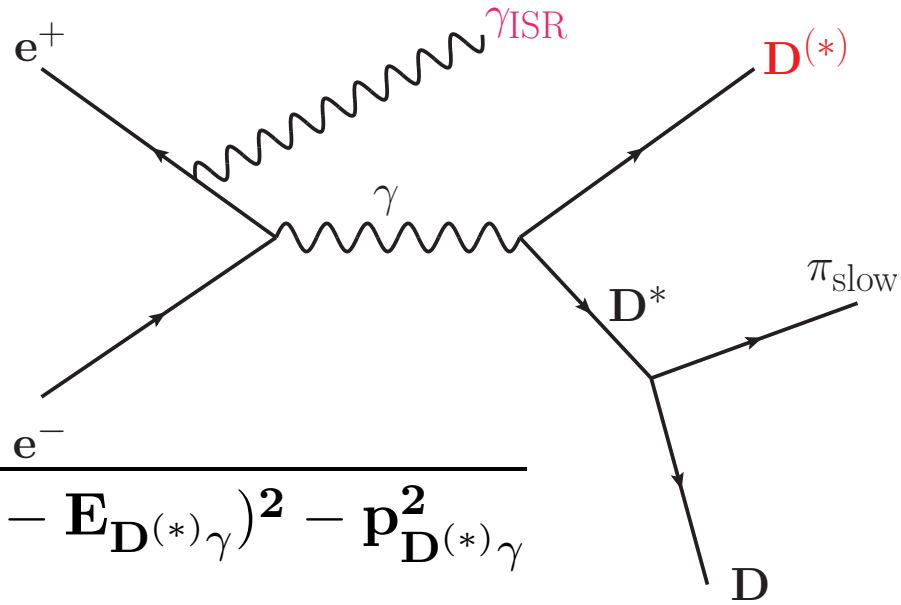

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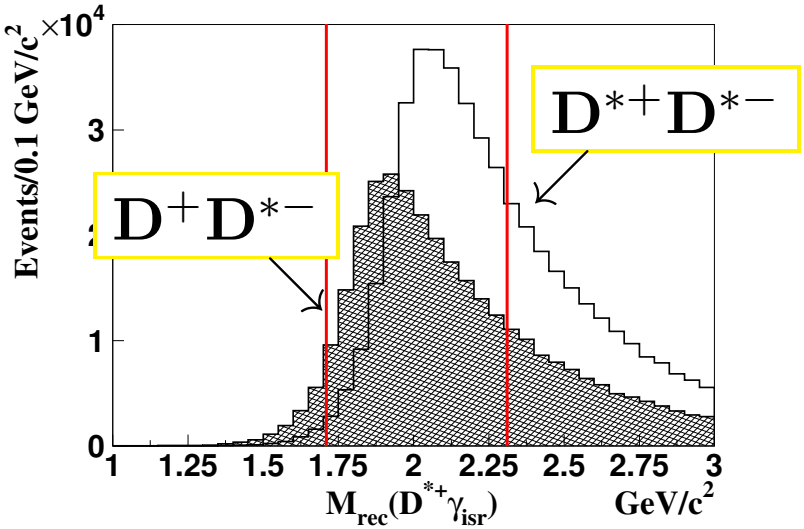
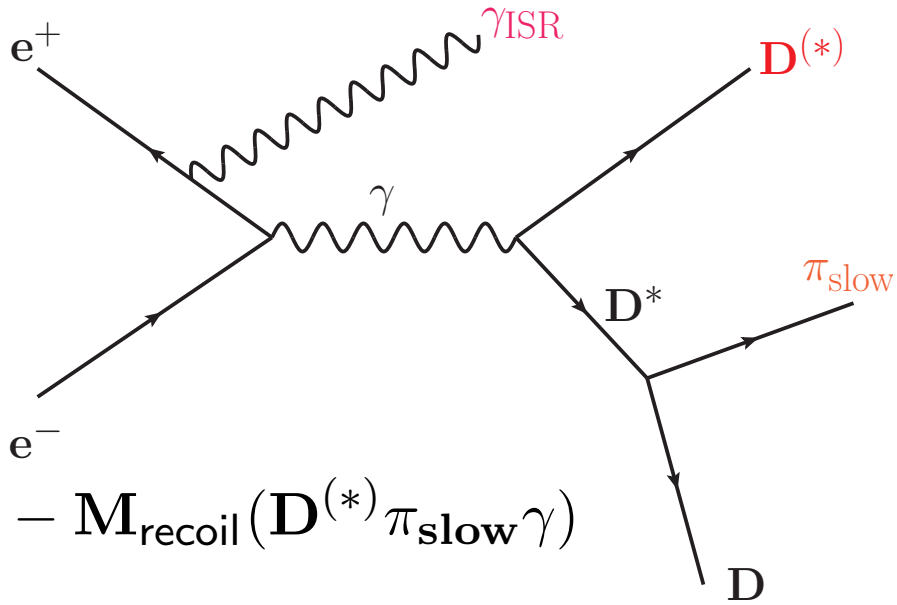


Problem: Cannot distinguish between D, D^* and D^{**} in the final state

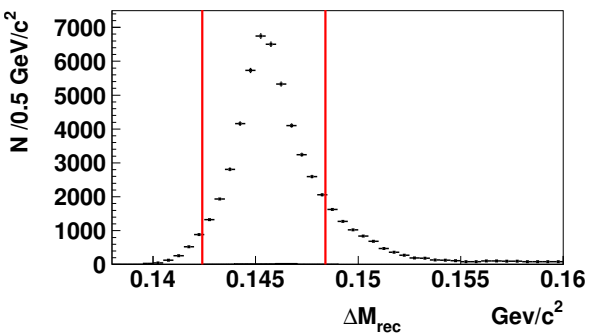
Method

- Partial reconstruction
- Reconstruct $\mathbf{D}^*$, γ_{ISR} and $\pi_{\mathbf{slow}}$



$$\Delta M_{\mathrm{recoil}} = M_{\mathrm{recoil}}(D^{(*)}\gamma_{\mathrm{ISR}}) - M_{\mathrm{recoil}}(D^{(*)}\pi_{\mathbf{slow}}\gamma)$$

$e^+e^- \to D^+D^{*-}$

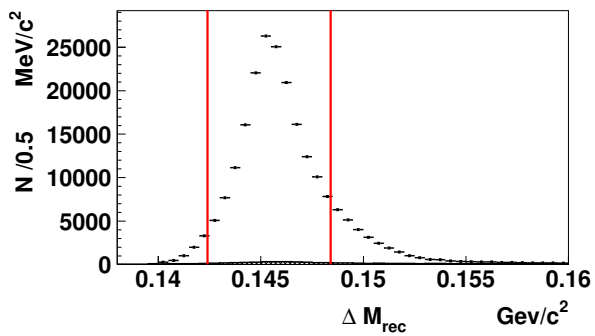


Recoil mass difference $\Delta M_{\mathrm{recoil}}$

cut:

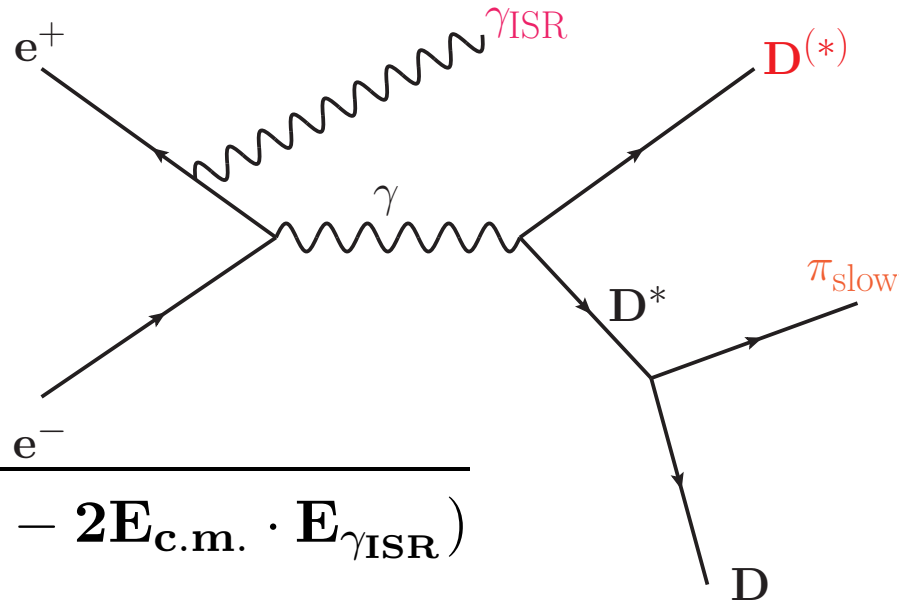
$\pm 3 MeV/c^2$

$e^+e^- \to D^{*+}D^{*-}$



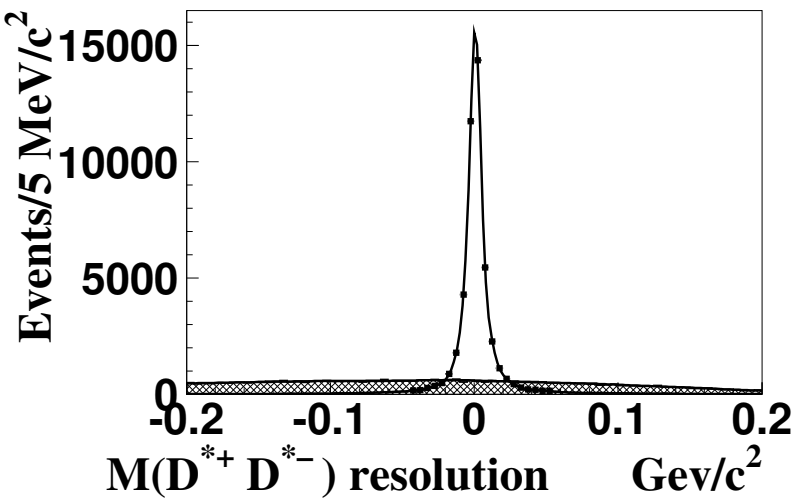
Method

- Partial reconstruction
- Reconstruct $\mathbf{D^*}$, γ_{ISR} and $\pi_{\mathbf{slow}}$
- $\mathbf{M(D^{(*)+}D^{*-}) \equiv M_{recoil}(\gamma_{ISR})}$



$$\mathbf{M_{recoil}(\gamma_{ISR}) = \sqrt{(E^2_{c.m.} - 2E_{c.m.} \cdot E_{\gamma_{ISR}})}}$$

Refit $M_{\mathrm{recoil}}(D^{(*)}\gamma_{\mathrm{ISR}})$ to D^* mass to improve the $M_{\mathrm{recoil}}(\gamma_{\mathrm{ISR}})$ resolution



$\mathbf{M_{recoil}(\gamma_{ISR})}$ resolution:

Before re-fit — hatched histogram

After re-fit — solid line

Comparison with previous analysis

- Increased data sample: 547 fb^{-1} $\Longrightarrow$ 951 fb^{-1}
- Additional modes for D reconstruction $\Longrightarrow$ $\mathbf{D^0}$ decay channels:
- Extended signal region for $M_{\text{recoil}}(D^{(*)}\gamma_{\text{ISR}})$

$$|(M_{\text{recoil}}(D^{(*)+}\gamma_{\text{ISR}}) - M(D^{*-}))| < \cancel{200}\ 300\ \text{MeV}/c^2$$

- $\sigma[e^+e^- \to D^{(*)+}D^{*-}] = \dfrac{dN/dM}{\eta_{\text{tot}}(M) \cdot dL/dM}$

  dL/dM up to second-order QED corrections

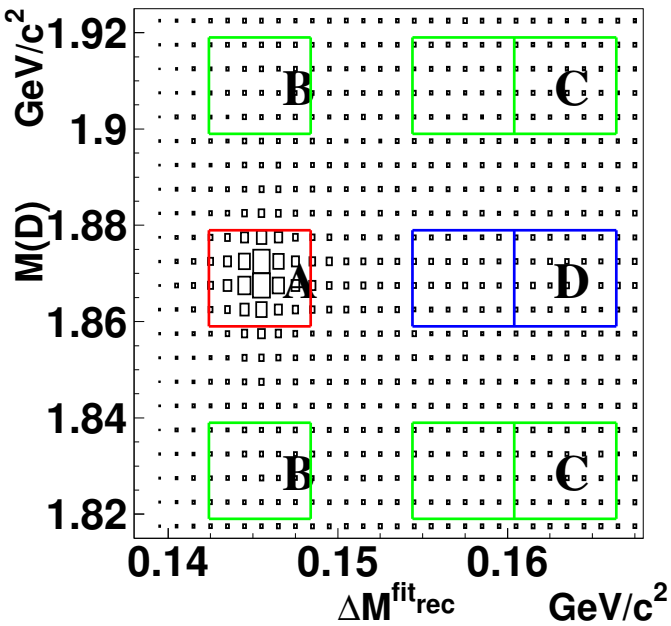
  (Kuraev & Fadin (1985))

1. $K^-\pi^+$
2. K^-K^+
3. $K^-\pi^-\pi^+\pi^+$
4. $K^0_S\pi^+\pi^-$
5. $K^-\pi^+\pi^0$
6. $K^0_SK^+K^-$
7. $K^0_S\pi^0$
8. $K^-K^+\pi^-\pi^+$
9. $K^0_S\pi^+\pi^-\pi^0$

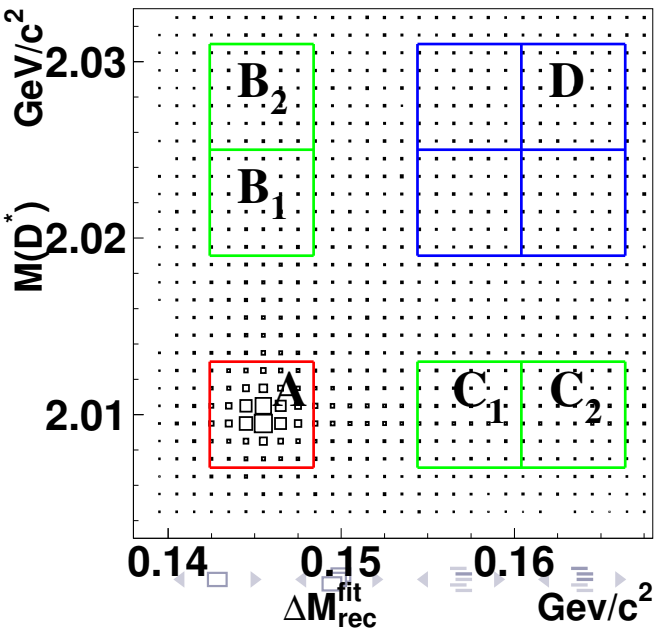
Backgrounds

1. Combinatorial background under the reconstructed $D^{(*)+}$ peak
2. Real $D^{(*)+}$ mesons and a combinatorial π_{slow}
3. Both the $D^{(*)+}$ meson and π_{slow} are combinatorial
4. Reflections from the processes $e^+e^- \to D^{(*)+}D^{*-}\pi^0\gamma_{\text{ISR}}$ where the π^0 is lost
5. Contribution of the $e^+e^- \to D^{(*)+}D^{*-}\pi^0_{\text{fast}}$ where the hard π^0_{fast} is misidentified as γ_{ISR}

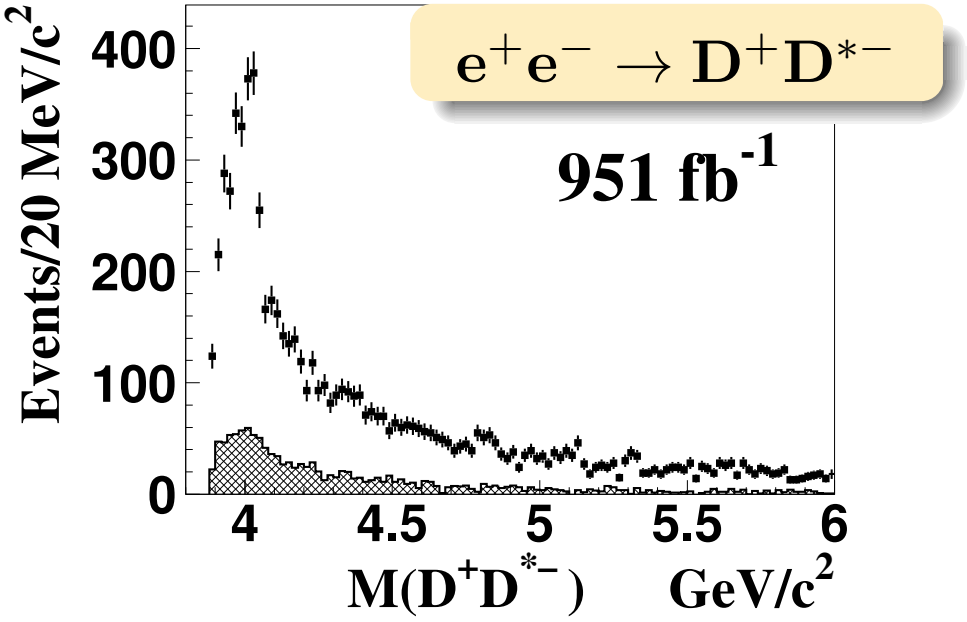
$\mathbf{e^+e^- \to D^+D^{*-}}$

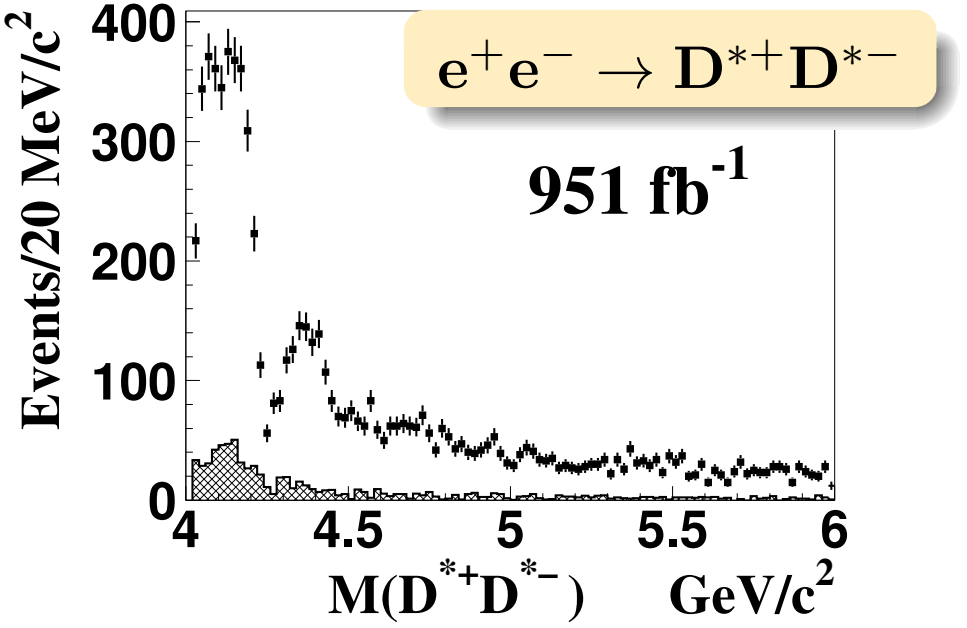


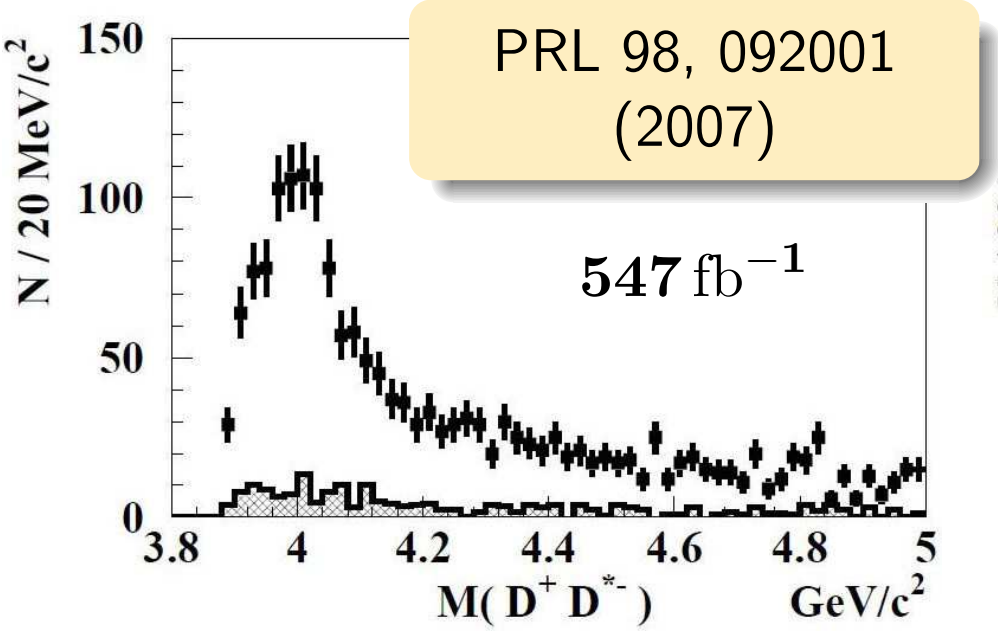
$\mathbf{e^+e^- \to D^{*+}D^{*-}}$

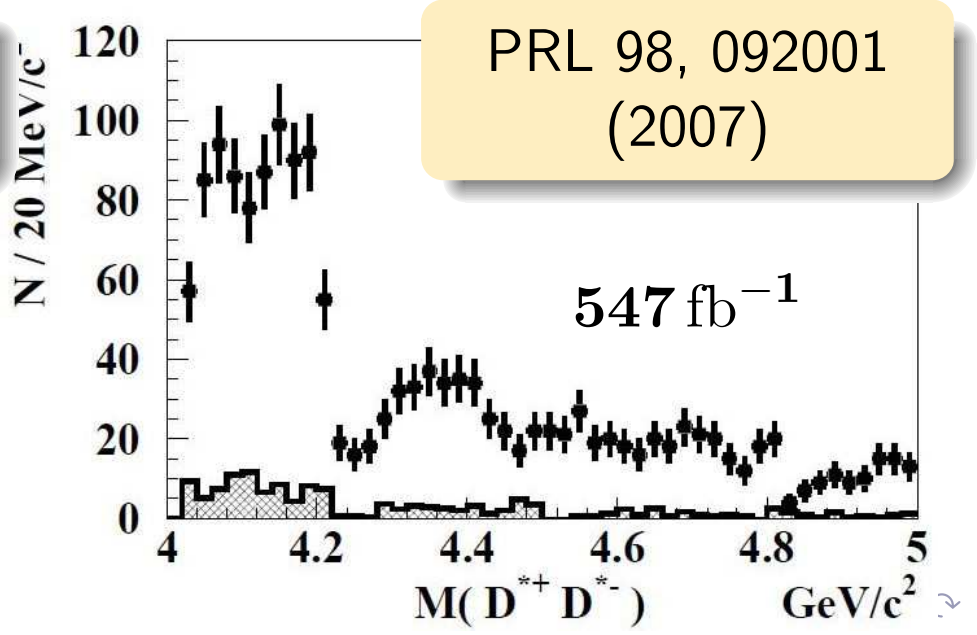


Mass spectra



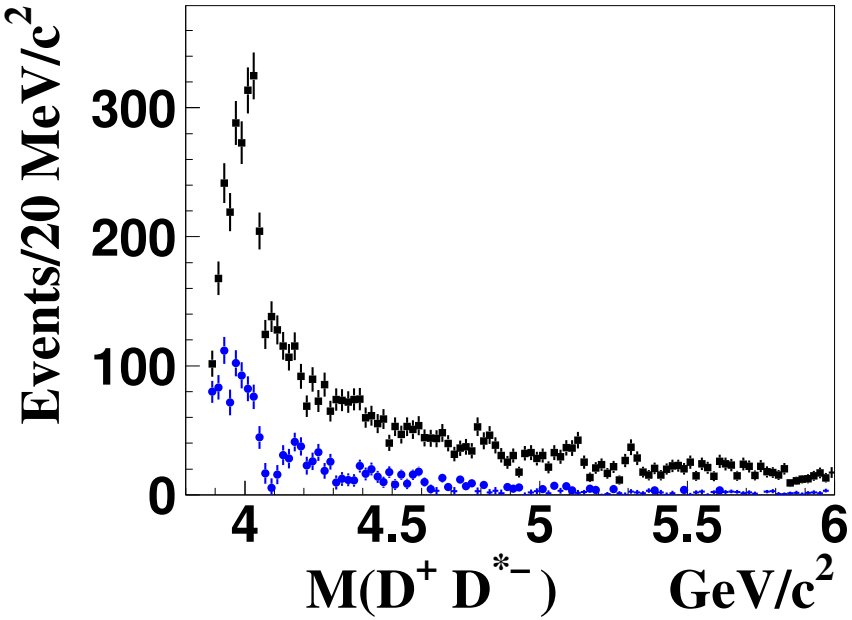




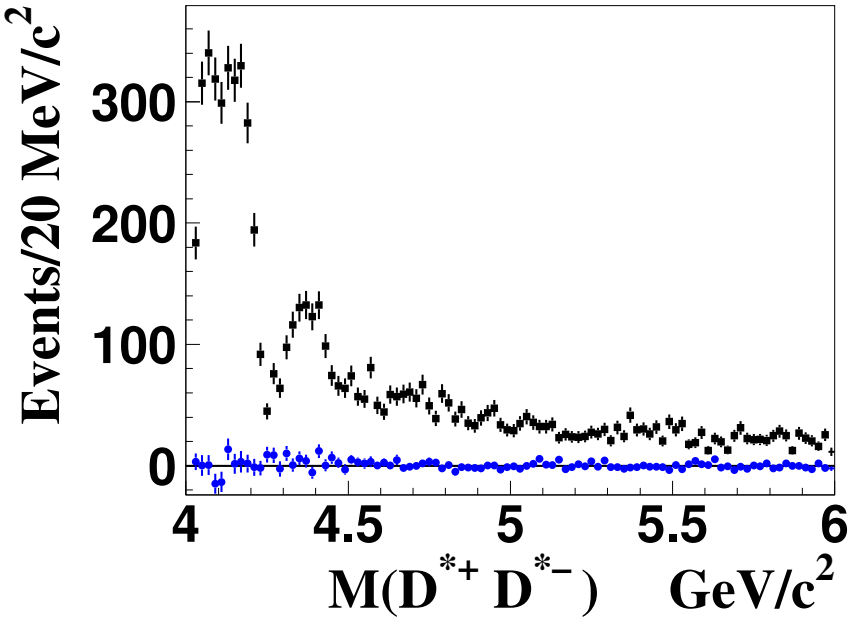


Reflection from the processes $e^+e^- \to D^{(*)+}D^{*-}\pi^0\gamma_{ISR}$

$e^+e^- \to D^+D^{*-}$



$e^+e^- \to D^{*+}D^{*-}$



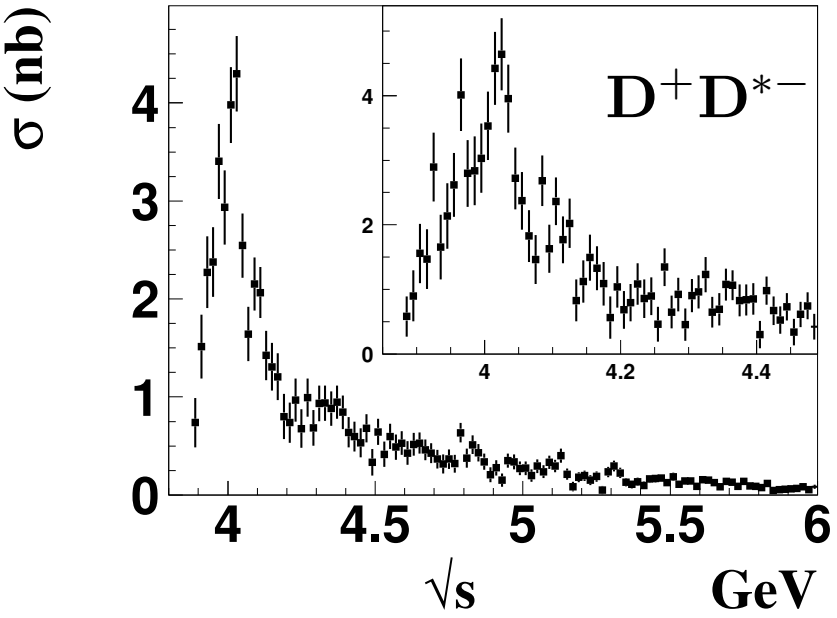
Background (blue points) from

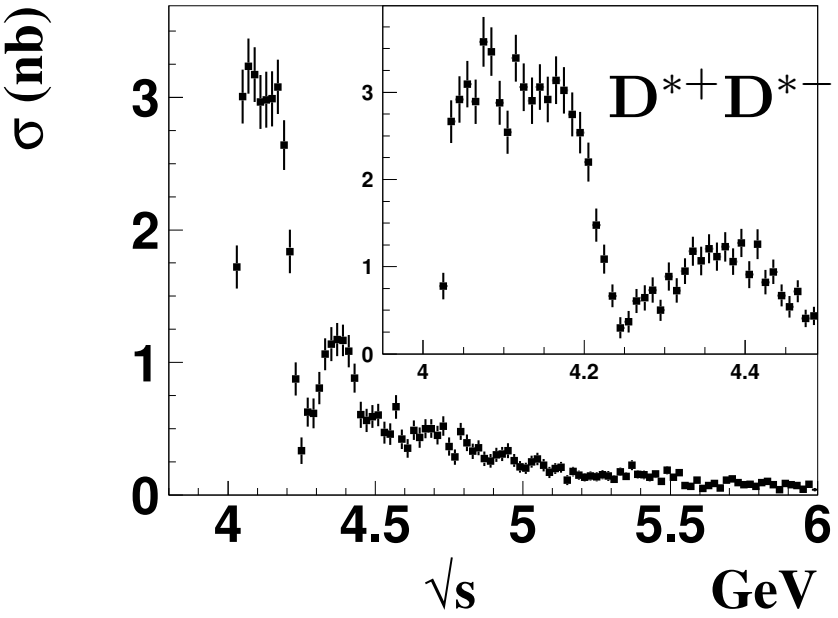
$$e^+e^- \to D^{(*)+}D^{*-}\pi^0_{\text{miss}}\gamma_{\text{ISR}}$$

is evaluated from the isospin-conjugated process

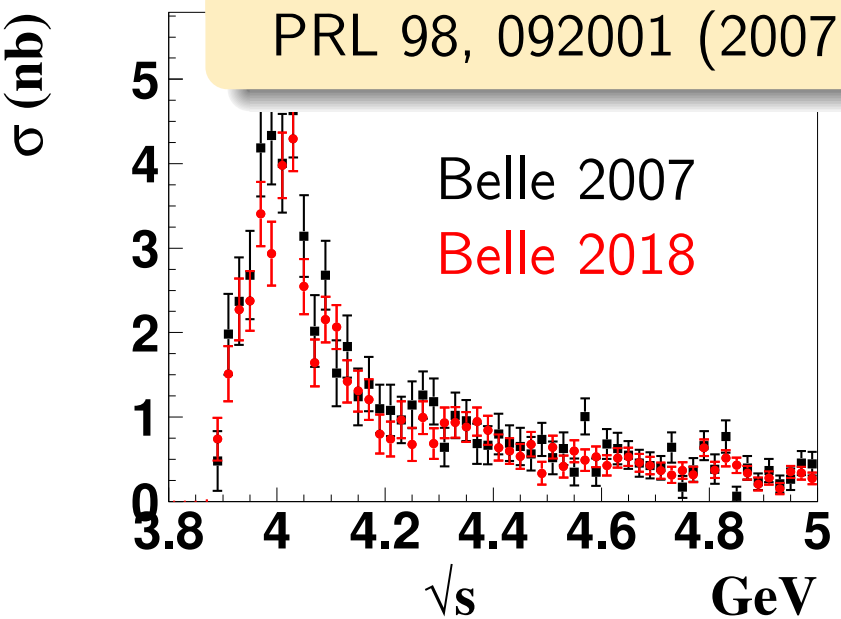
$$e^+e^- \to D^{(*)0}D^{*-}\pi^+_{\text{miss}}\gamma_{\text{ISR}}$$

with the reconstruction of $D^{(*)0}$, π^-_{slow} and γ_{ISR}





PRL 98, 092001 (2007)



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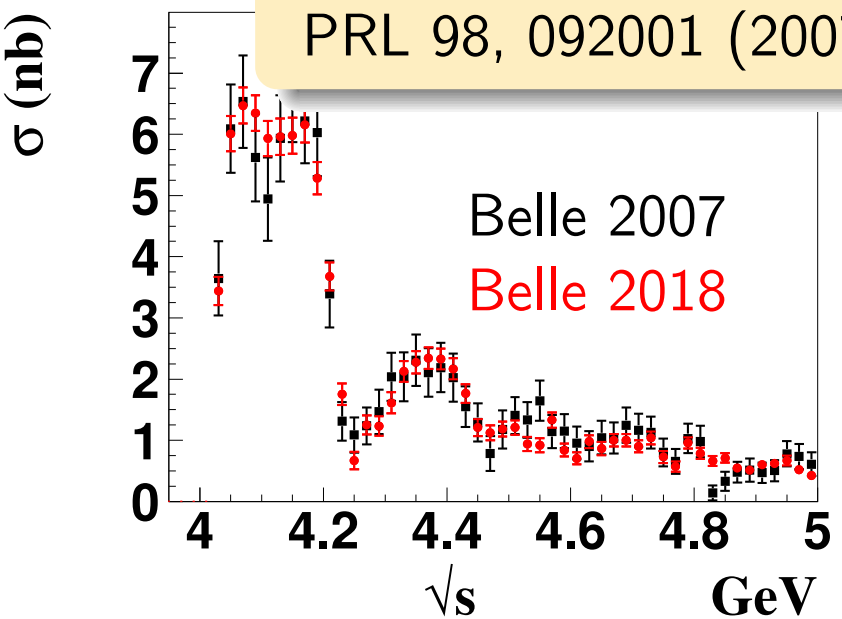
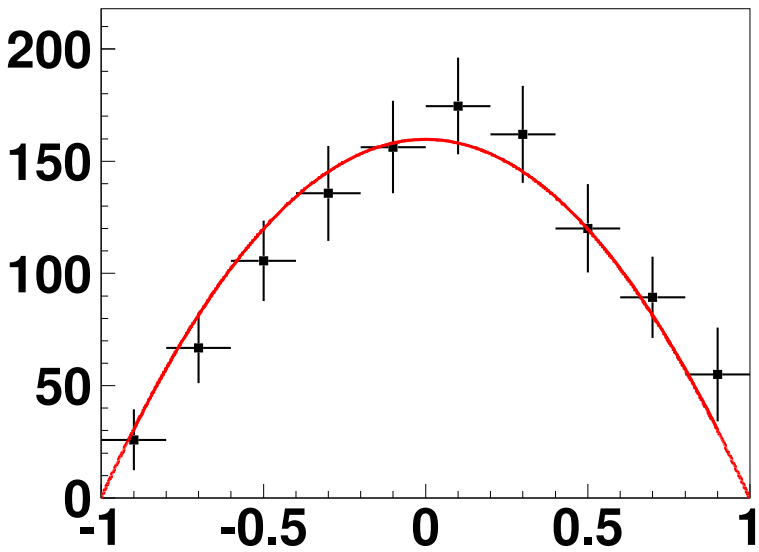
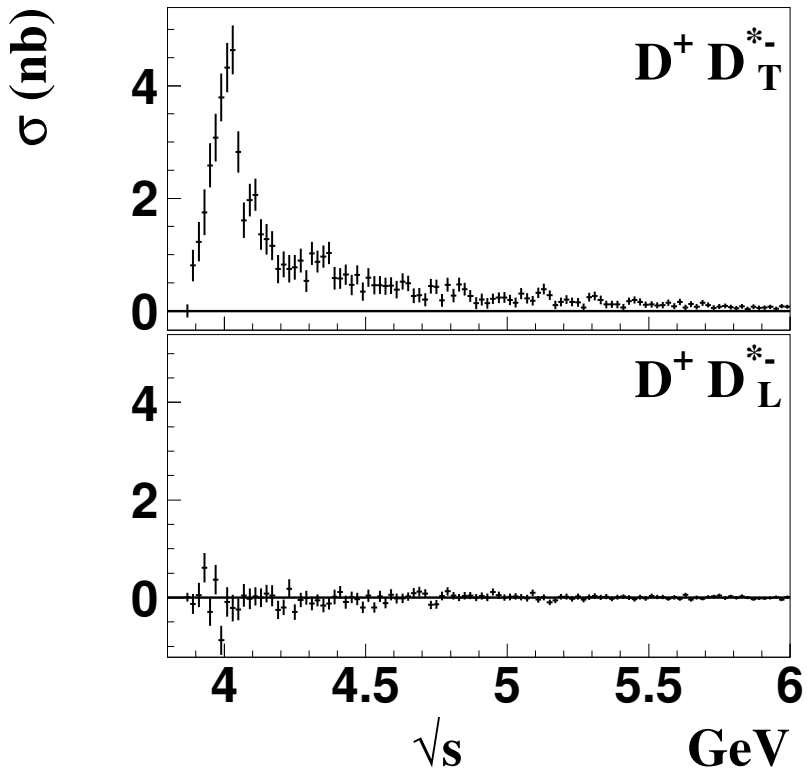


Angular analysis of the process $e^+e^- \to D^+D^{*-}$

- Study D^* helicity angle distribution in each bin of $M(D^+D^{*-})$
- D^* are transversely polarized
  $\Longrightarrow$ Check method

$$4.05 < M(D^+D^{*-}) < 4.3\mathrm{GeV}/c^2$$





$$f_L = \sigma_L \cdot \cos^2\theta$$
$$f_T = \sigma_T \cdot (1 - \cos^2\theta)$$

$$F(\cos\theta) = \eta(\cos\theta) \cdot dM/dL \cdot (f_L + f_T)$$

Angular analysis of the process $e^+e^- \to D^{*+}D^{*-}$

- Study of the D^* helicity angle distribution in each bin of $M(D^{*+}D^{*-})$
- Helicity composition of the $D^{*+}D^{*-}$ final state:

$$\mathbf{D}^{*+}_{\mathrm{T}}\mathbf{D}^{*-}_{\mathrm{T}},\ \mathbf{D}^{*+}_{\mathrm{T}}\mathbf{D}^{*-}_{\mathrm{L}} \text{ and } \mathbf{D}^{*+}_{\mathrm{L}}\mathbf{D}^{*-}_{\mathrm{L}}$$

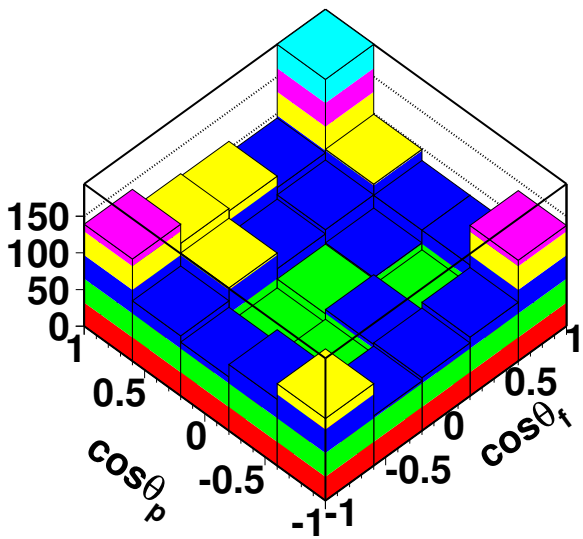
  - $D^*_{\mathrm{T}} \equiv$ transversely polarized D^* meson
  - $D^*_{\mathrm{L}} \equiv$ longitudinally polarized D^* meson
- Total cross section

$$\sigma = \sigma_{\mathrm{TT}} + \sigma_{\mathrm{TL}} + \sigma_{\mathrm{LL}}$$

$$f = \eta(c_1, c_2) \cdot dL/dM \cdot (f_{LL} + f_{TL} + f_{TT}) + f_{\mathrm{bg}}$$

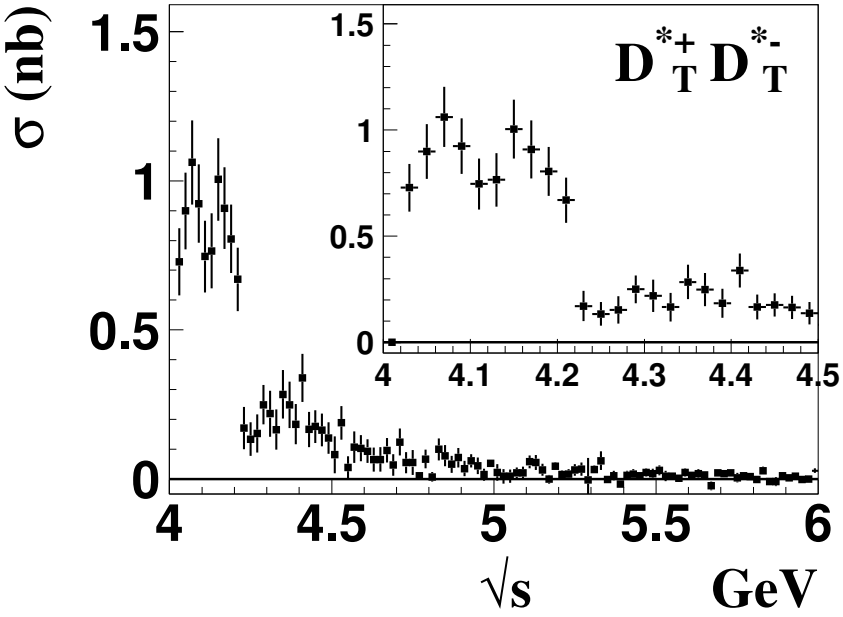
$c_1 \equiv \cos\theta_f \qquad c_2 \equiv \cos\theta_p$

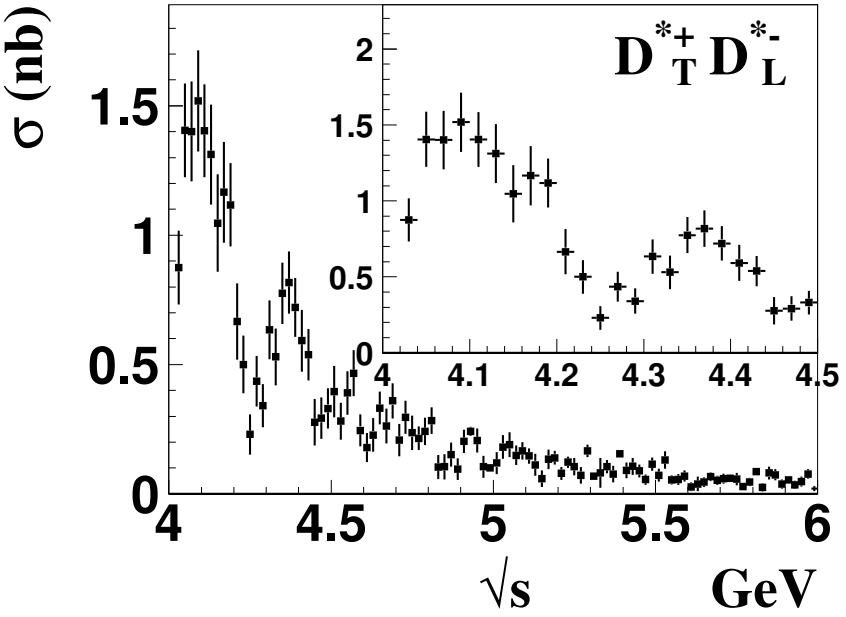
θ's are D^*'s helicity angles

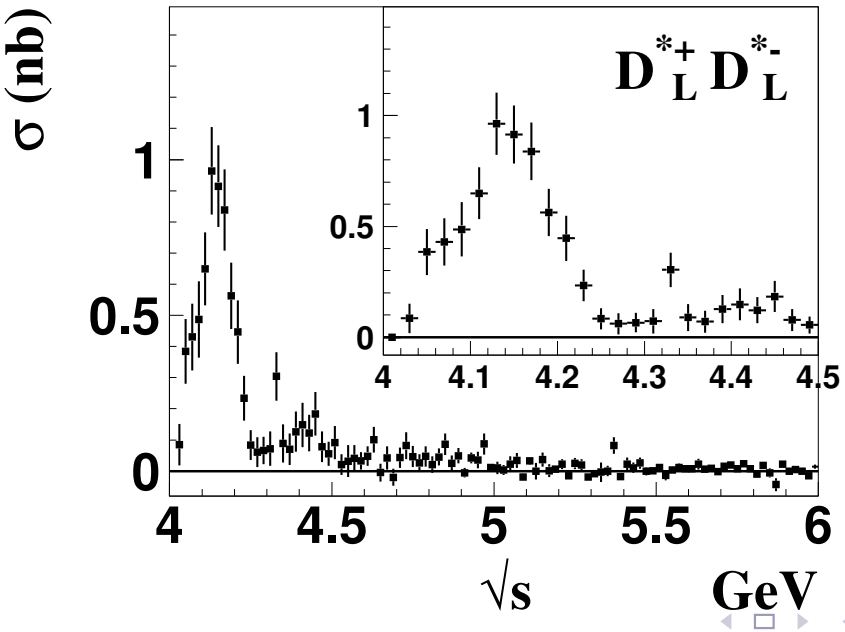


$$\begin{aligned} f_{TT} &= \sigma_{TT} \cdot (1 - c_1^2) \cdot (1 - c_2^2) \\ f_{TL} &= \sigma_{TL} \cdot \left((1 - c_1^2) \cdot c_2^2 + c_1^2 \cdot (1 - c_2^2)\right) \\ f_{LL} &= \sigma_{LL} \cdot c_1^2 \cdot c_2^2 \end{aligned}$$

Fit results







Conclusions

- We measured the exclusive cross sections of the $e^+e^- \to D^+D^{*-}$ and $e^+e^- \to D^{*+}D^{*-}$ processes
- The accuracy of the cross section measurements is increased
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Thank you for your attention!

References

1. Phys. Rev. D**77**,011103 (2008)
2. Phys. Rev. Lett.**98**, 092001 (2007)
3. Phys. Rev. Lett.**100**, 062001 (2007)
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