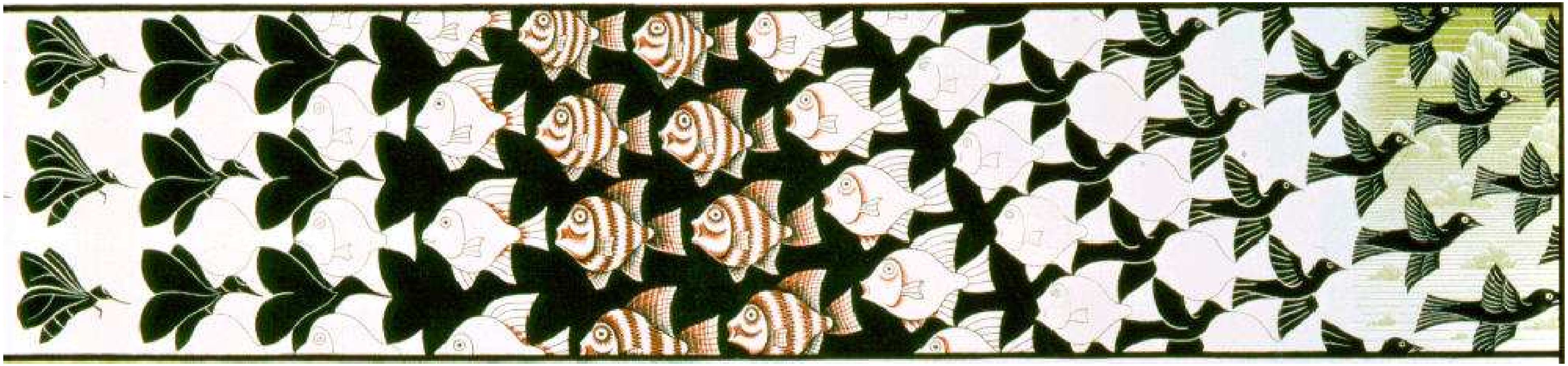
Charm 2009,
May 20-22
Leimen, Germany



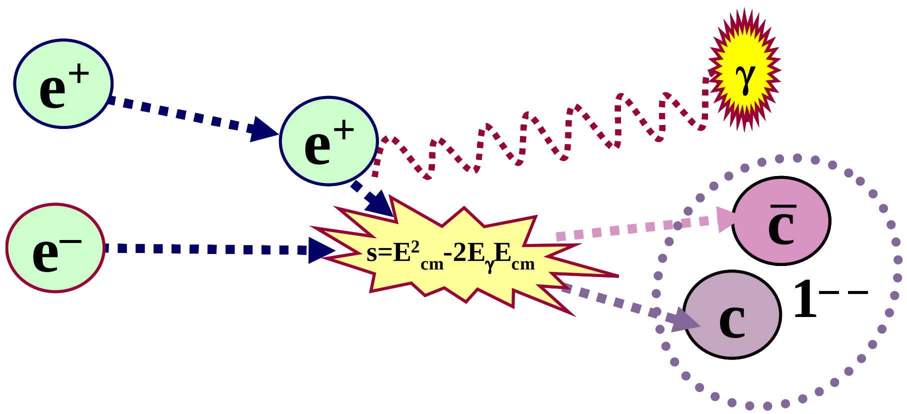
ISR e^+e^- to charm

Galina Pakhlova
ITEP, Belle collaboration

Two main reasons to measure e^+e^- annihilation to open charm

- To shed light on the nature of the charmoniumlike "1^{--} family" with masses above open charm threshold

- To provide model independent information on the parameters of the $J^{PC} = 1^{--}$ charmonium states spectrum above open charm threshold

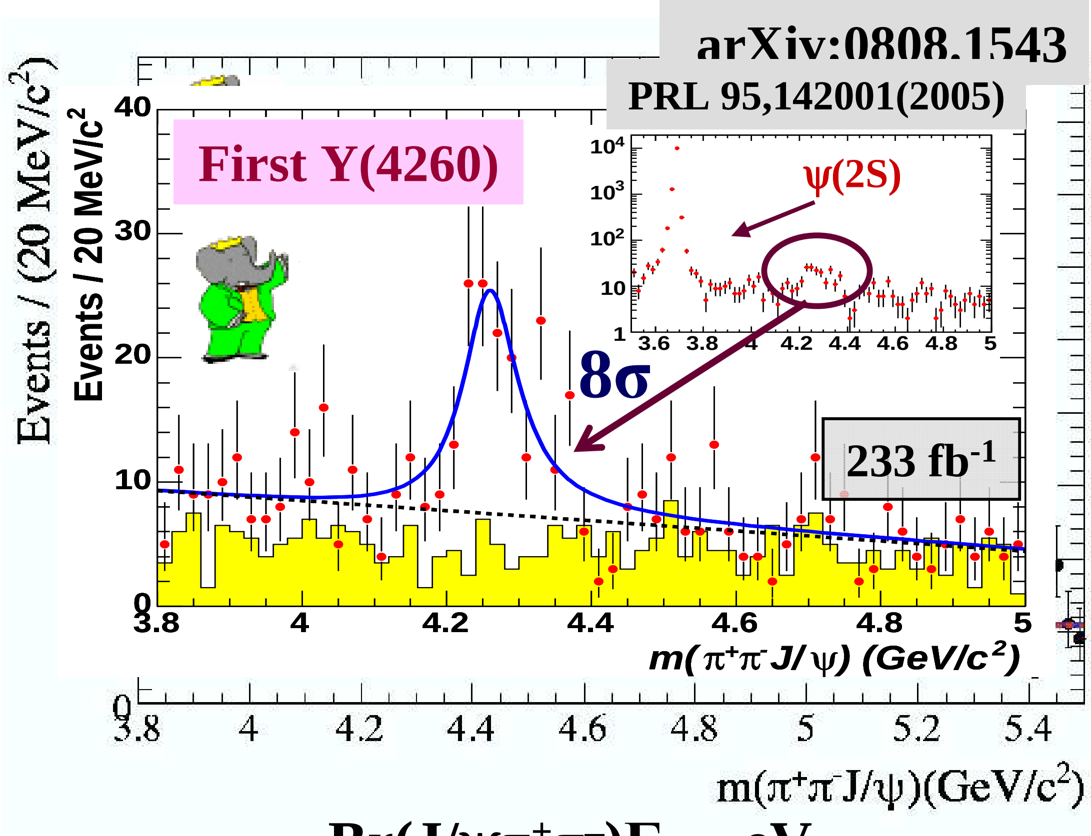


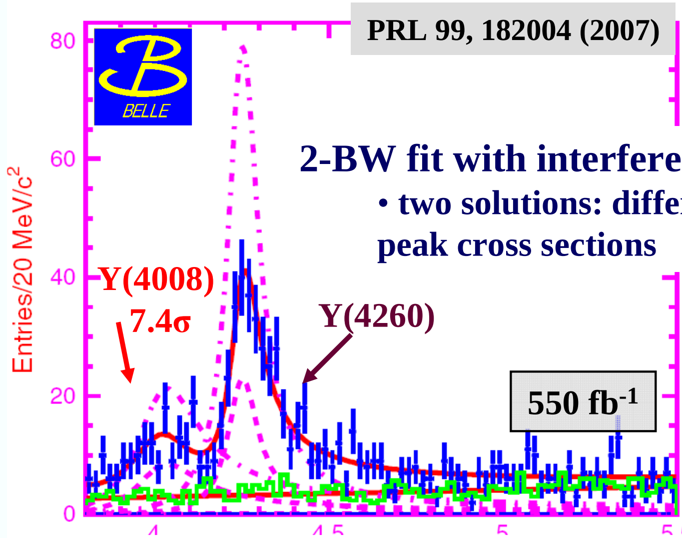
Three main reasons to use ISR at B factories

- Quantum numbers of final states are fixed $J^{PC} = 1^{--}$
- Continuous ISR spectrum:
  - access to the whole $\sqrt{s}$ interval
- α_{em} suppression compensated by huge luminosity
  - comparable sensitivity to energy scan (CLEOc, BES)

Charmoniumlike 1^{--} family

Two or one states in $e^+e^- \to J/\psi\pi^+\pi^-\gamma_{ISR}$?





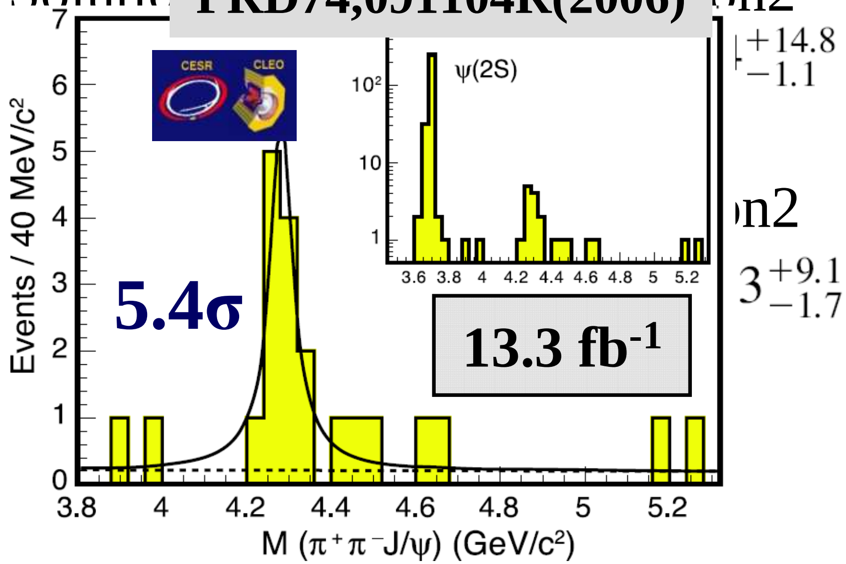
$Br(J/\psi\pi^+\pi^-)\Gamma_{ee}$, eV

Solutic ... on2

on2

$3^{+9.1}_{-1.7}$

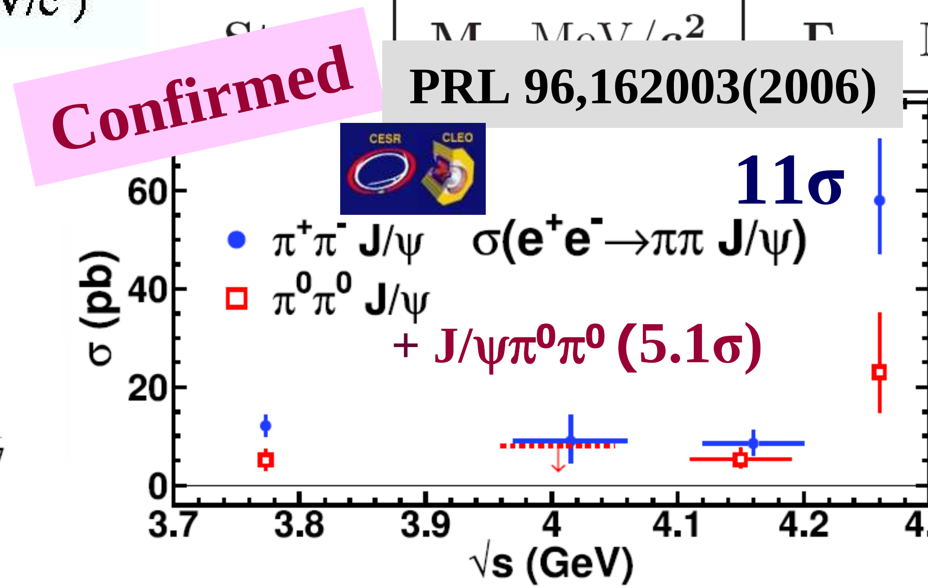
$^{+14.8}_{-1.1}$



Ab

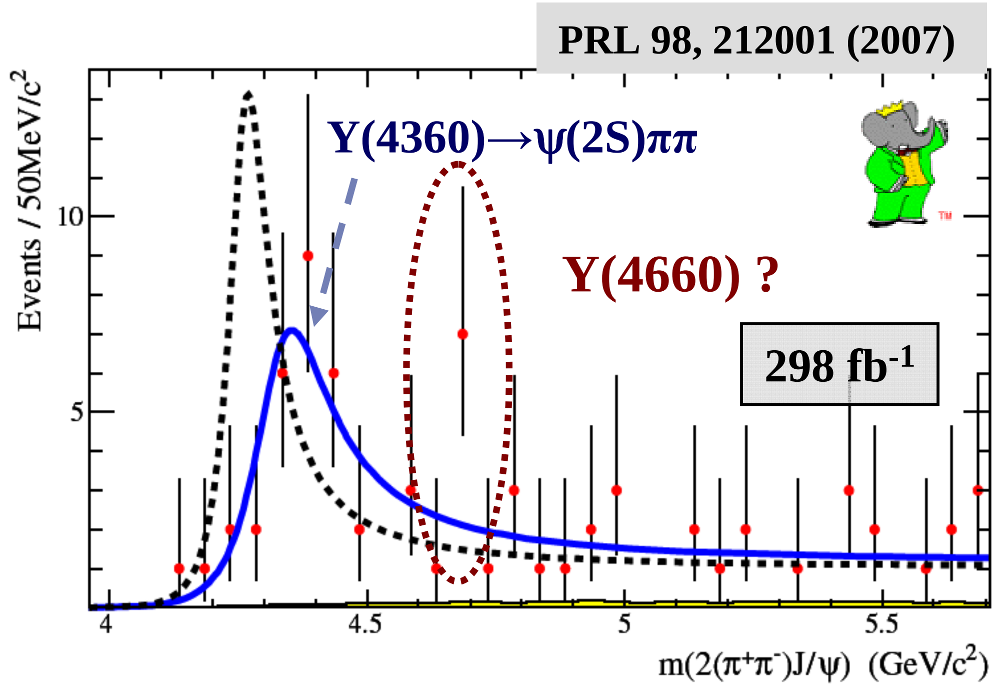
is

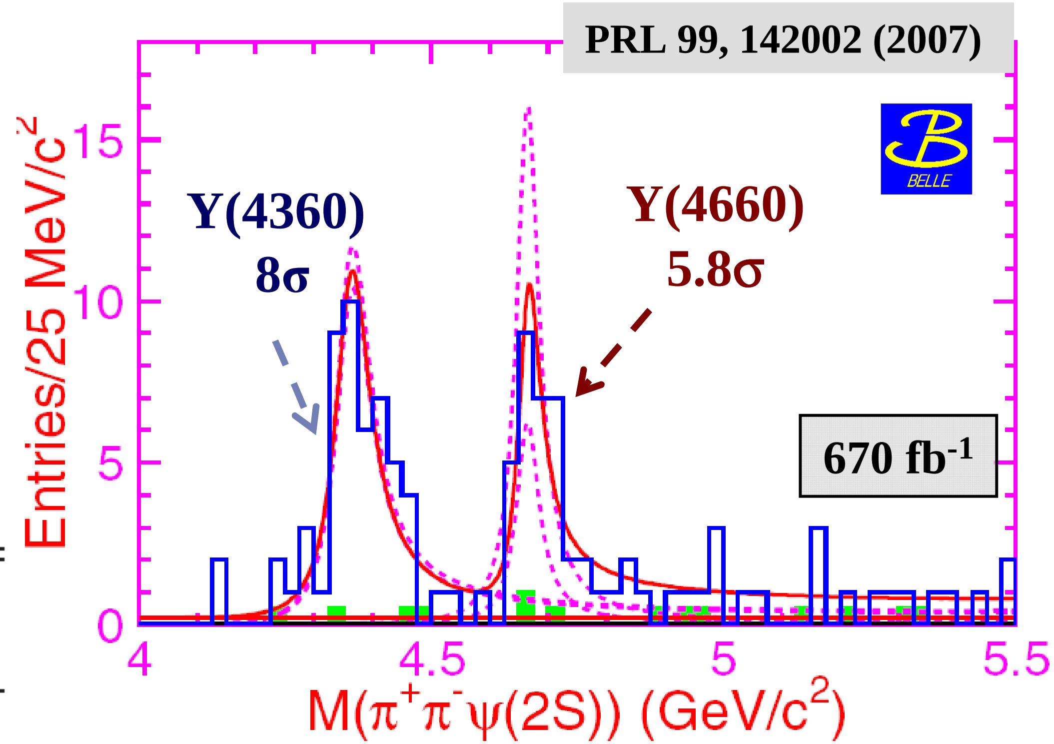
charmonium



St...	M, MeV/c^2	Γ, MeV
		± 87
		8^{+6}_{-4}
		8^{+4}_{-6}
		± 5
Y(4260)	$4247 \pm 12^{+17}_{-32}$	$108 \pm 19 \pm 10$

$e^+e^- \to \psi(2S)\,\pi^+\pi^-\,\gamma_{ISR}$
Y(4360), Y(4660) ...



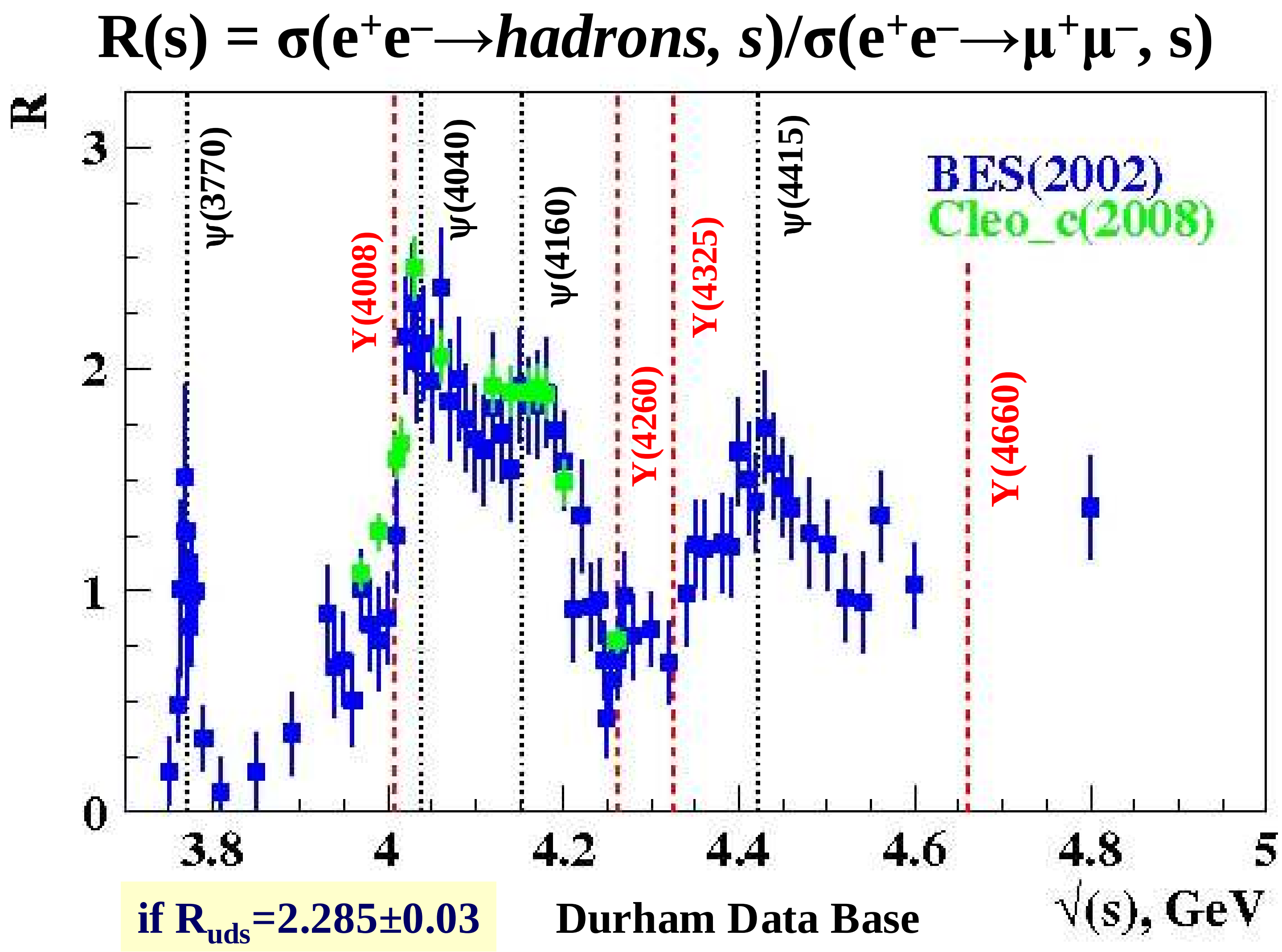


State	M, MeV/c^2	Γ_{tot}, MeV
Y(4360)	4324 ± 24	172 ± 33
Y(4360)	$4361 \pm 9 \pm 9$	$74 \pm 15 \pm 10$
Y(4660)	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$

2-BW fit with interference

Absence of open charm production is inconsistent with conventional charmonium

Y states vs inclusive cross section $e^+e^- \to hadrons$



- Peak positions for M(J/ψππ) & M(ψ(2S)ππ) significantly different
- Y(4260) mass corresponds to dip in inclusive cross section

Interpretations of Y states

Problem:

- **No room for Y states among conventional 1^{--} charmonium**

quark model S.Godfrey and N.Isgur PRD32,189 (1985)

  - $3^3S_1 = \psi(4040)$, $2^3D_1 = \psi(4160)$, $4^3S^1 = \psi(4415)$ **are measured**
  - masses of predicted 3^3D_1 (4520), 5^3S_1 (4760), 4^3D_1(4810) higher(lower) Y masses

Options

- $Y(4325) = 3^3D_1$, $Y(4660) = 5^3S_1$ with shifted masses

G.J Ding et al Phys.Rev.D77:014033 (2008)
A.M.Badalyan et al arXiv:0805.2291

- **Charmonium hybrids**

Zhu S.L.; Close F.E.; Kou E. and Pene O.

  - The lightest hybrid is expected by LQCD around 4.2 GeV
  - The dominant decays $Y(4260) \to D^{(*)}D^{(*)}\pi$, via virtual D^{**}

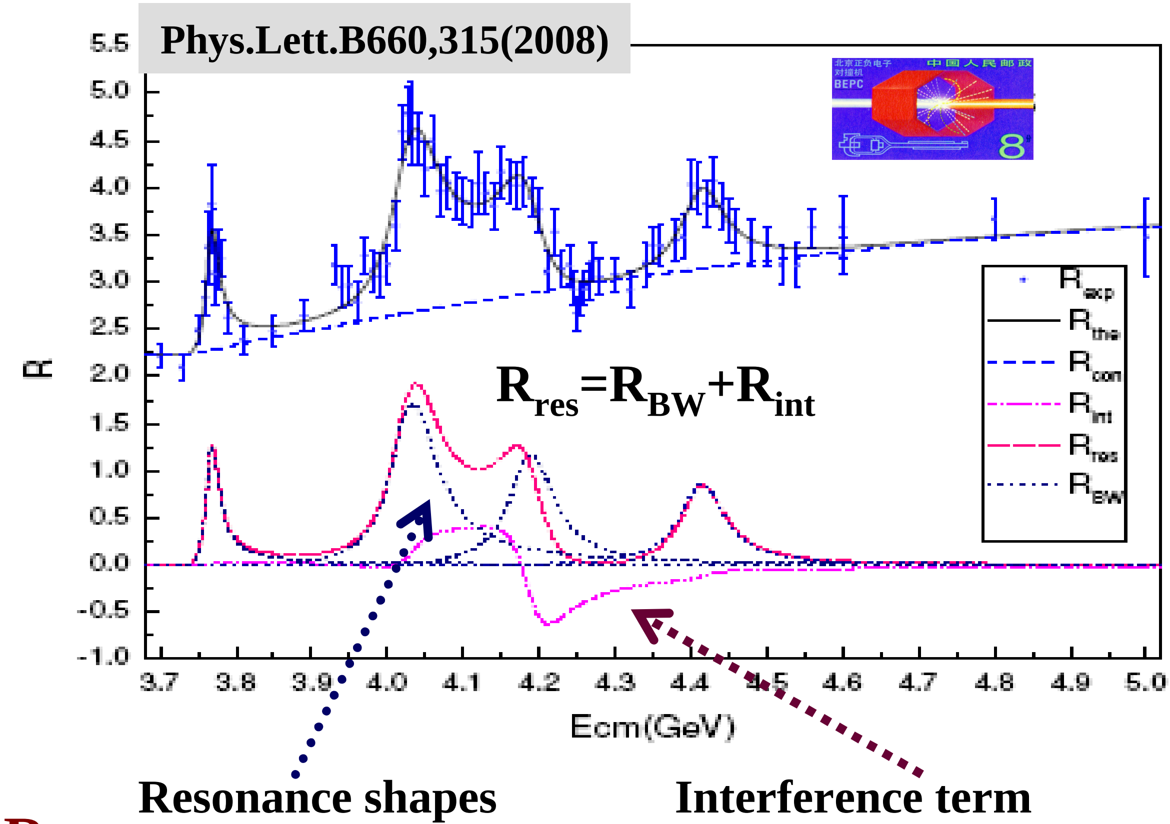
- **Hadro-charmonium**
  - Specific charmonium state “coated” by excited light-hadron matter

S.Dubinskiy, M.B.Voloshin, A.Gorsky

- **Multiquark states**
  - [cq][cq] tetraquark — *Maiani L., Riquer V., Piccinini F., Polosa A.D.*
  - DD_1 or D^*D^0 molecules — *Swanson E.; Rosner J.L., Close F.E.*

- **S-wave charm meson thresholds** — *Lui X.*

Charmonium states contribution to inclusive cross section $e^+e^- \to hadrons$ above open charm threshold



Last BES fit to the inclusive R spectrum

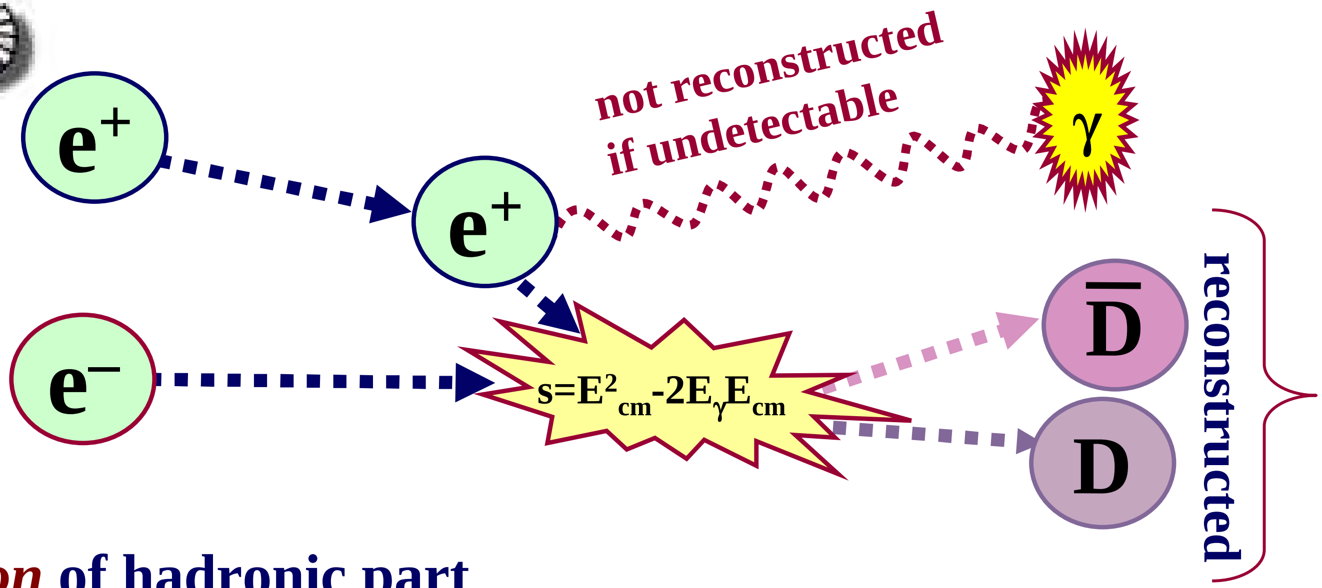
all possible two body decays of ψ(3770), ψ(4040), ψ(4160), ψ(4415) are included

Significant effect of interference : model dependent!!!

To reduce model dependence

need to measure exclusive cross sections to open charm final states

$e^+e^- \to DD$ via ISR with full reconstruction



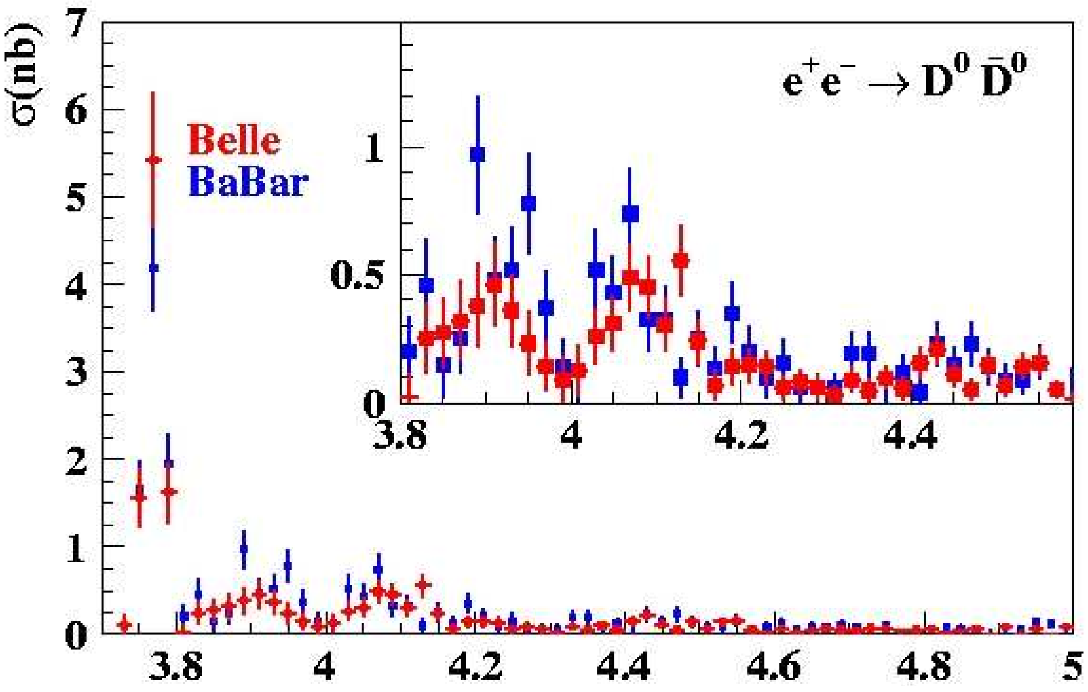
- *Full reconstruction* of hadronic part
- ISR photon detection is not required
  - but used if it is in the detector acceptance
- Translate measured DD mass spectrum to cross section

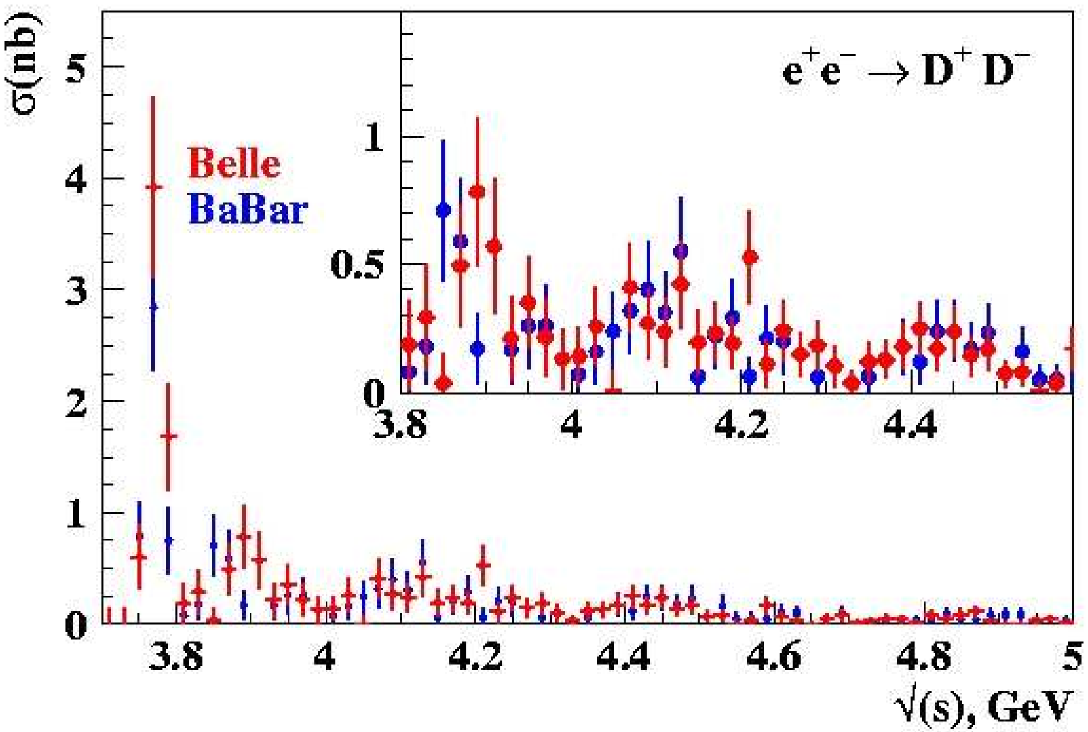
σ($e^+e^- \to DD$)

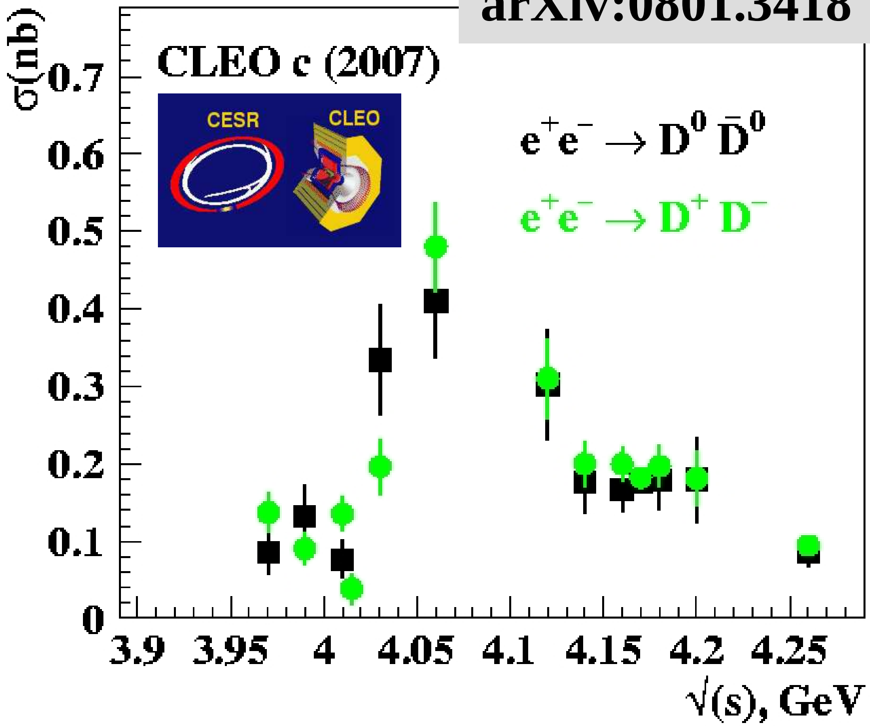
Phys.Rev.D77,011103(2008)

Phys.Rev. D76, 111105(2007)

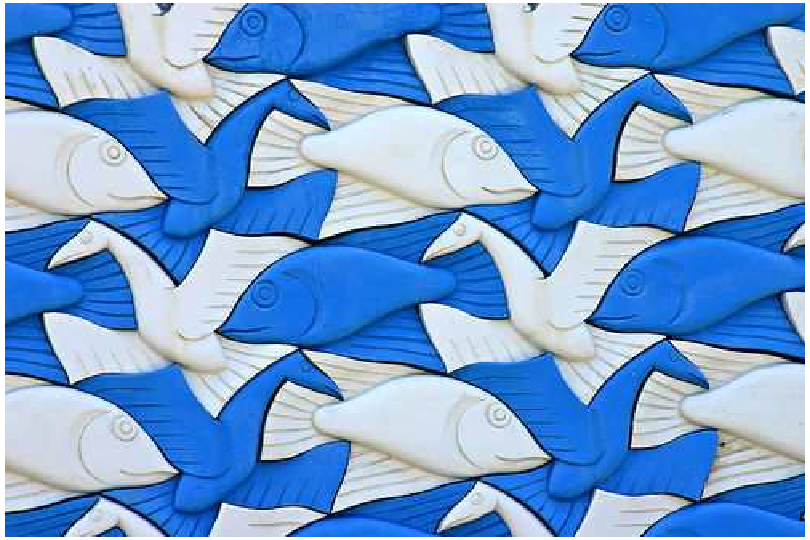
arXiv:0801.3418



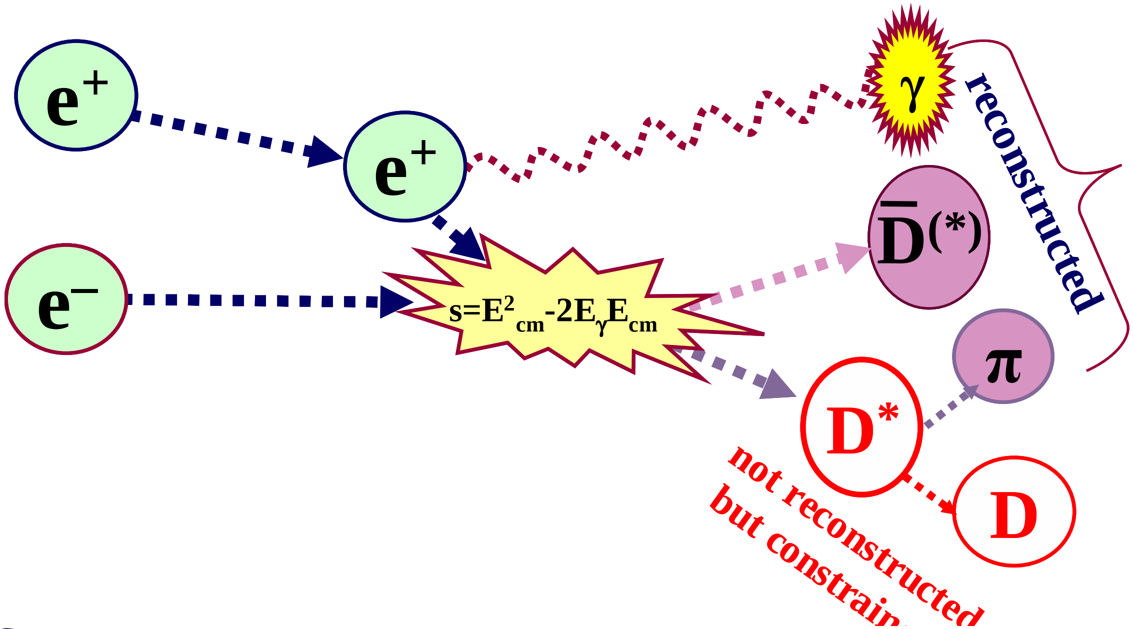




- Broad structure around 3.9 GeV
  - in *qualitative agreement* with coupled-channel model?
- Some structure at 4.0-4.2 GeV
  - Statistics are small …ψ(4040)? ψ(4160)?
- Hint of ψ(4415)



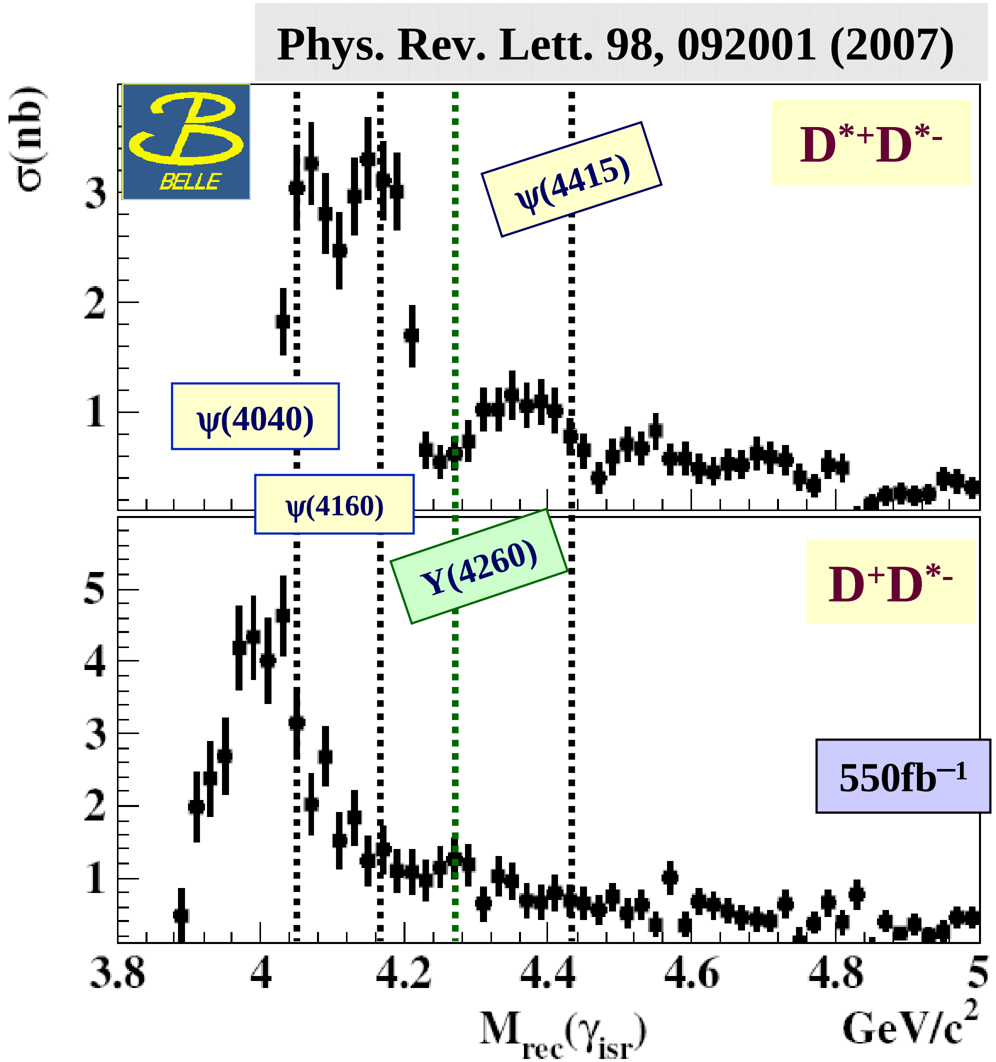
$e^+e^- \to D^{(*)}D^*$ via ISR with partial reconstruction

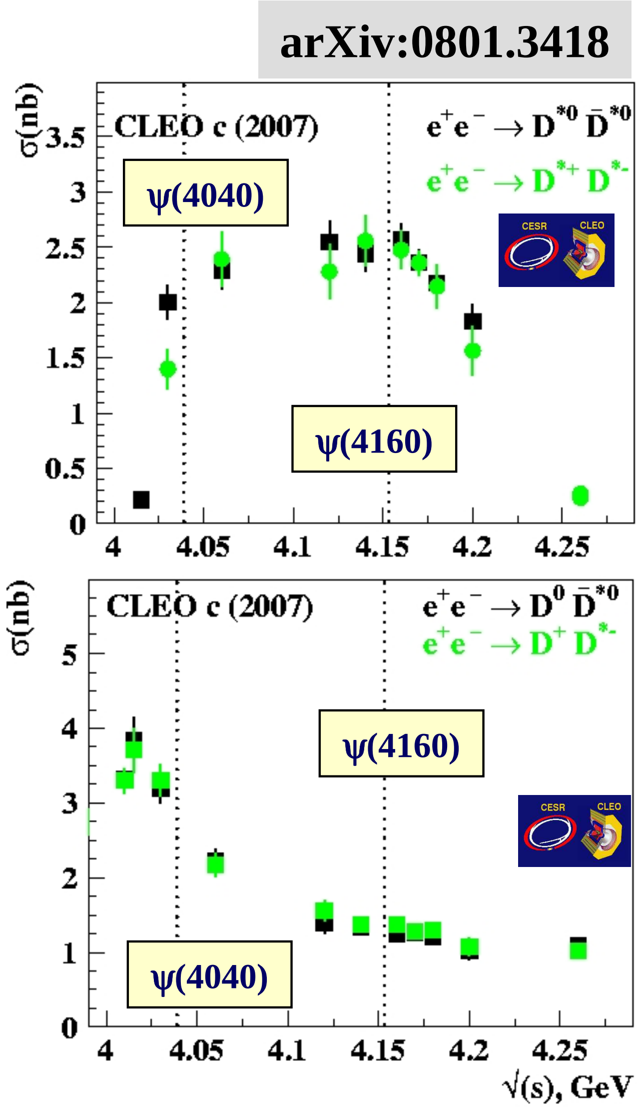


DD^* & D^*D^*

- D^* ***partial reconstruction***
  - increase eff ~ 10-20 times
- Detection of ISR photon
- Translate measured mass recoil against γ_{ISR} $\equiv D^{(*)}D^*$ mass spectrum to cross section

Exclusive $e^+e^- \to D^{(*)}D^*$ cross-sections



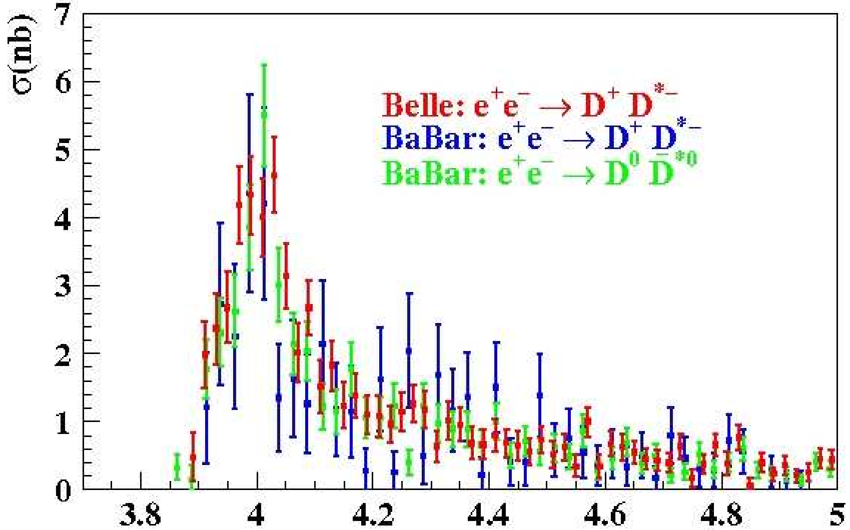


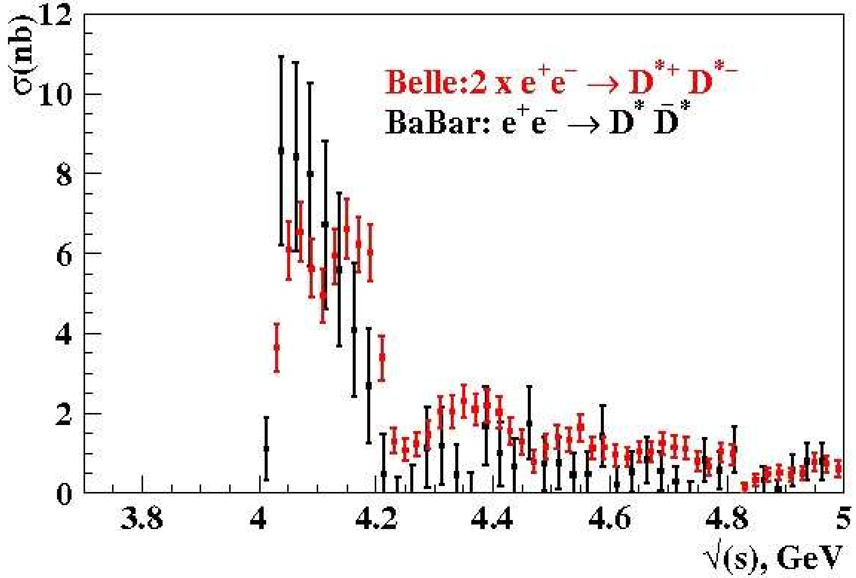
Backgrounds are reliably estimated from the data
Systematic errors ≈ statistical errors

Y(4260) signal

DD^* : hint, but not significant
D^*D^* : clear dip (similar to inclusive R)

Belle vs BaBar: $\sigma(e^+e^- \to D^{(*)}D^*)$





Phys. Rev. Lett. 98, 092001 (2007)

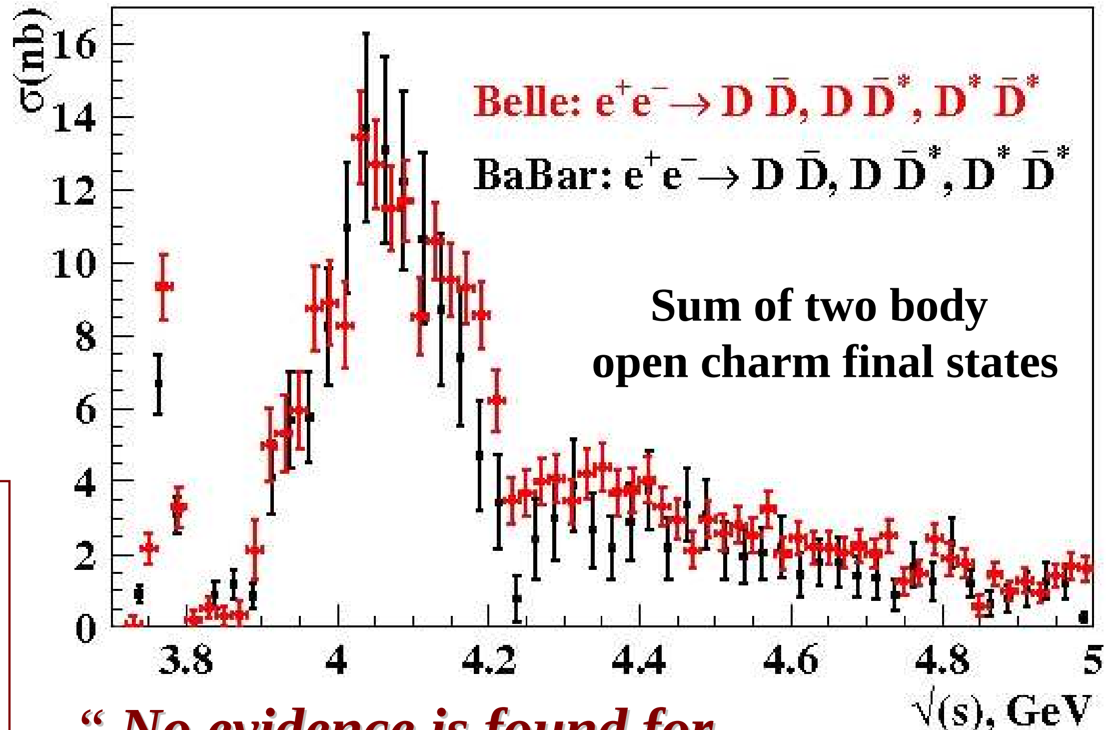
New

384 fb^{-1} arXiv:0903.1597

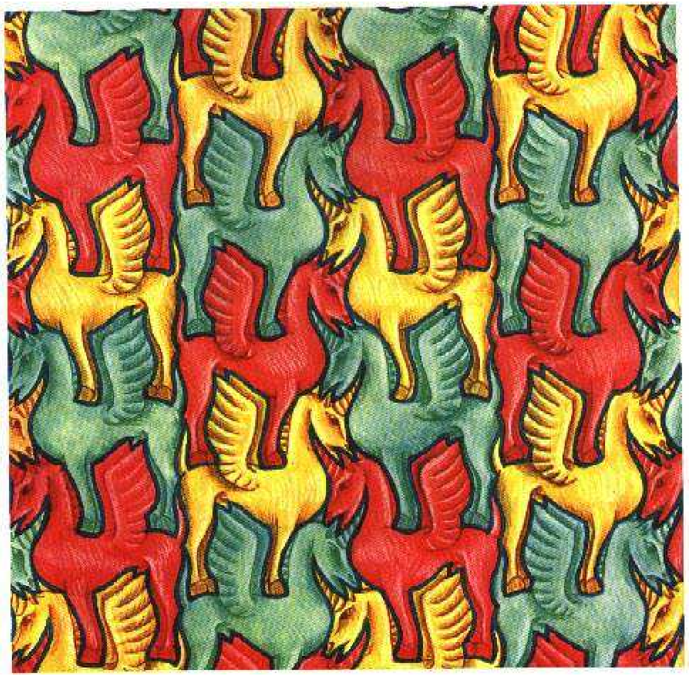
- Full reconstruction of hadronic part
- Both charged and neutral final states
- Fit by sum of ψ states with fixed masses&widths from PDG

$$\frac{\mathcal{B}(Y(4260) \to D^* \overline{D})}{\mathcal{B}(Y(4260) \to J/\psi \pi^+ \pi^-)} < 34$$

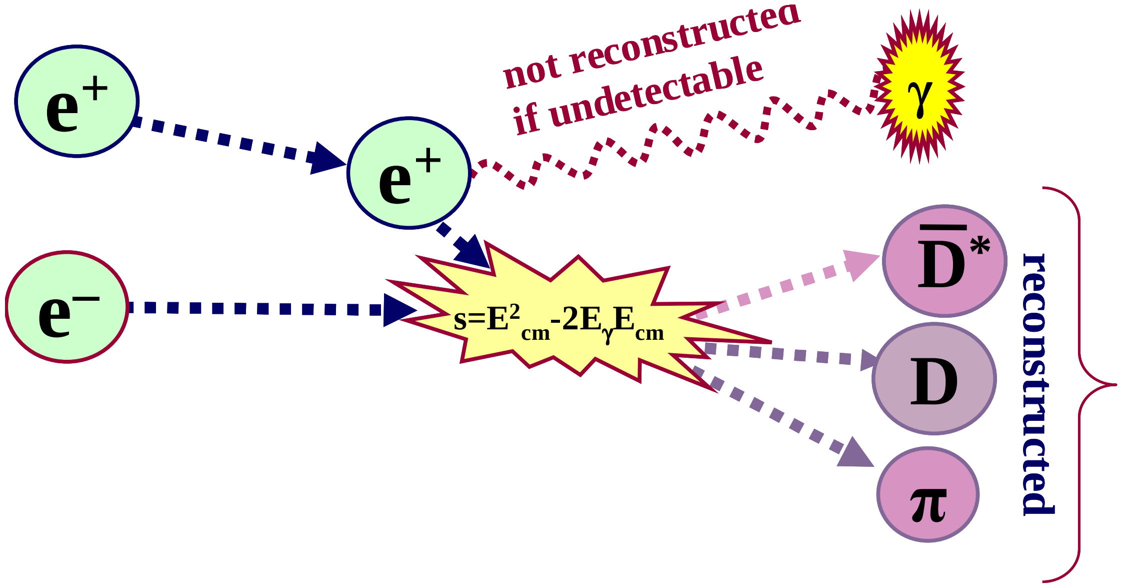
$$\frac{\mathcal{B}(Y(4260) \to D^* \overline{D}^*)}{\mathcal{B}(Y(4260) \to J/\psi \pi^+ \pi^-)} < 40$$



" No evidence is found for Y(4260) decays to DD, DD* or D*D*… "



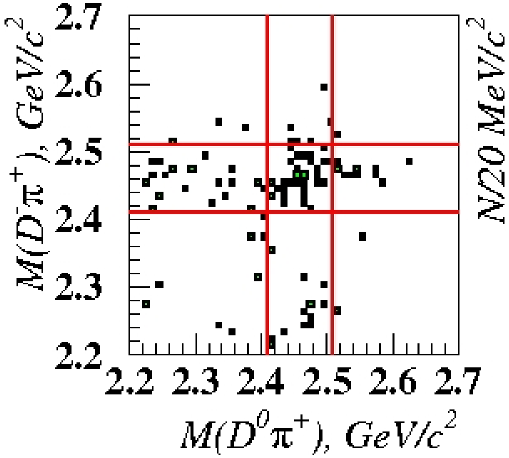
Three body final states

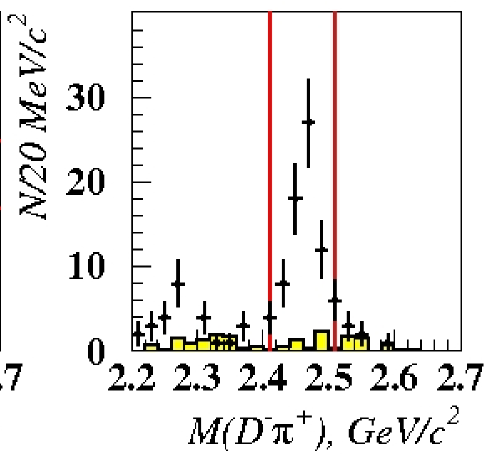


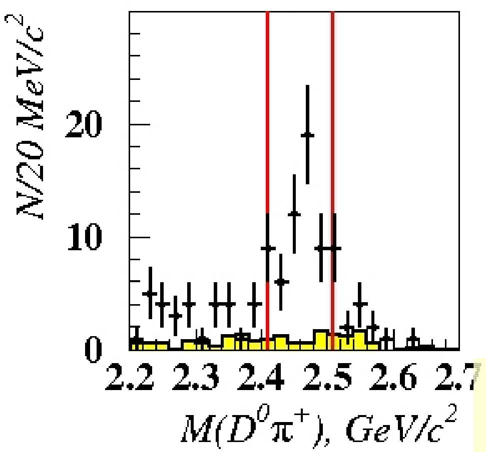
$D^0\, D^{(*)-}\, \pi^+$

- ***Full reconstruction*** **of hadronic part**
- **ISR photon detection is not required**
  - **but used if it is in the detector acceptance**
- **Translate measured $DD^{(*)}\pi$ mass spectrum to cross section**

Resonant structure in $\psi(4415) \to D^0 D^- \pi^+$







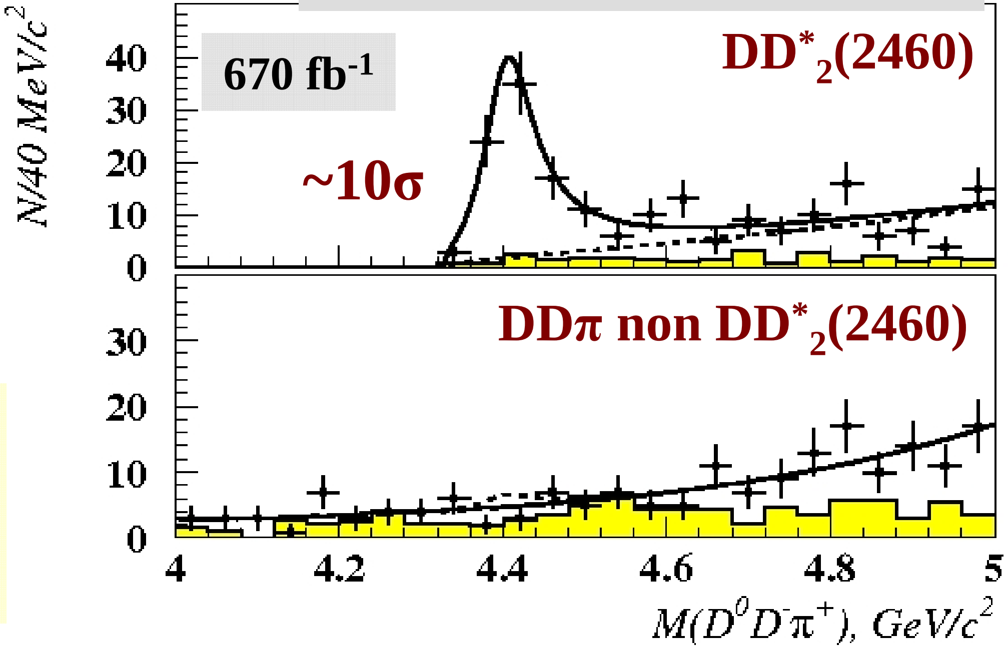
$M(D^0\pi^+)$ vs $M(D^-\pi^+)$ from $\psi(4415)$ region

- Clear $D^*_2(2460)$ signals
- No non-$D^*_2(2460)$ contribution

$M = 4411 \pm 7$ MeV
$\Gamma_{tot} = 77 \pm 20$ MeV
$N_{ev} = 109 \pm 25$

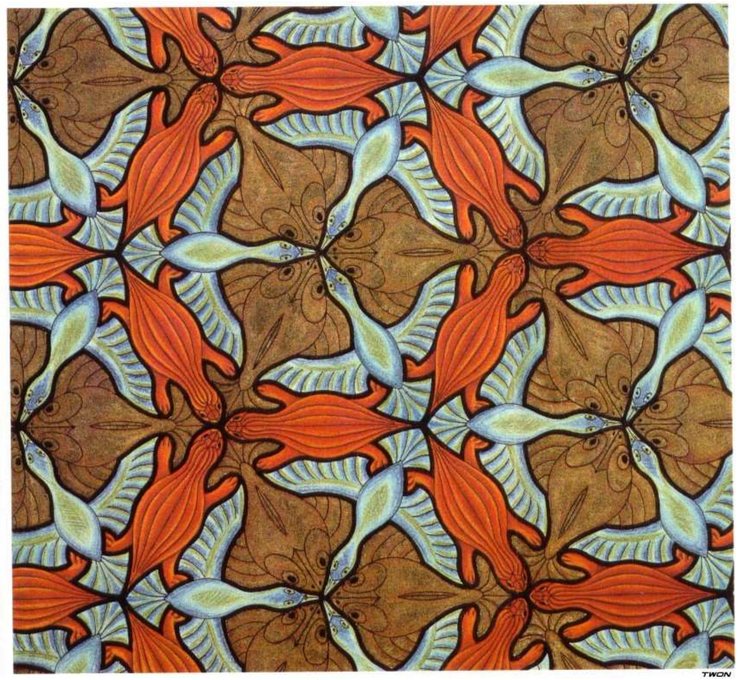
Consistent with BES,
Phys.Lett.B660,315(2008)
PDG06, Barnes at.al
Phys. Rev. D72, 054026 (2005)

Phys.Rev.Lett.100,062001(2008)

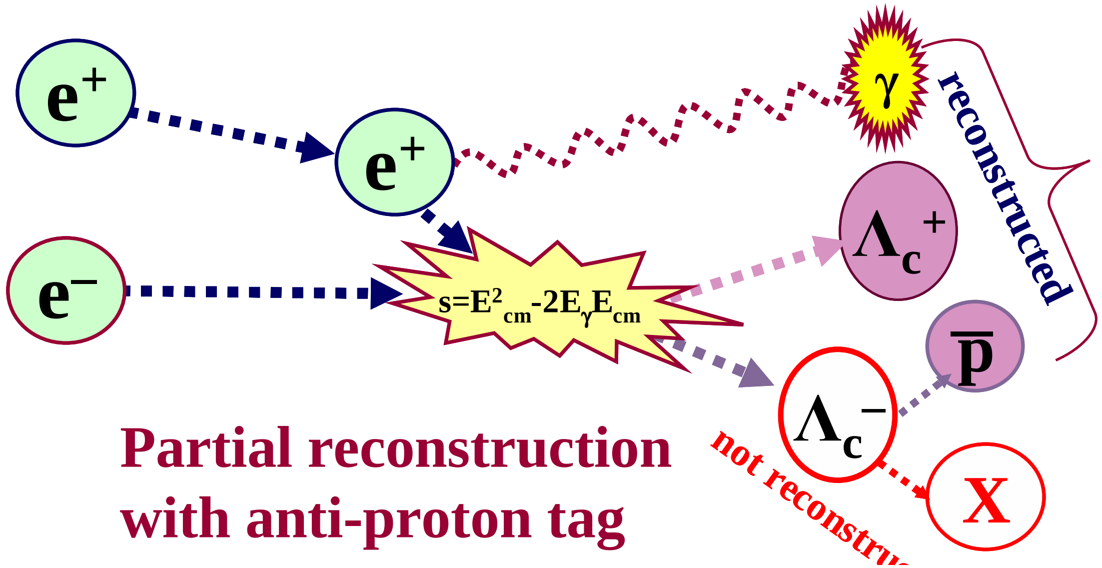


$\sigma(e^+e^- \to \psi(4415)) \times Br(\psi(4415) \to DD^*_2(2460)) \times Br(D^*_2(2460) \to D\pi) = (0.74 \pm 0.17 \pm 0.07)$nb

$Br(\psi(4415) \to D(D\pi)_{non\ D2(2460)}) / Br(\psi(4415) \to DD^*_2(2460)) < 0.22$



The first charm baryons final state

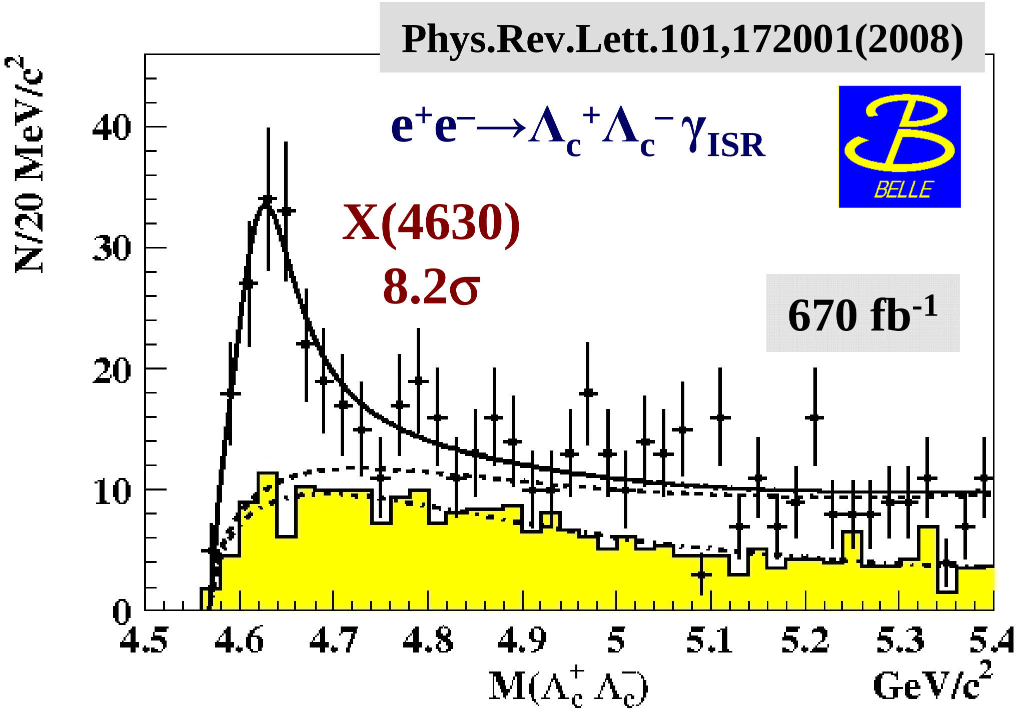


Partial reconstruction with anti-proton tag

- **Reconstruct Λ_c^+**
- **Use anti-proton tag from inclusive $\Lambda_c^- \to p^- X$**

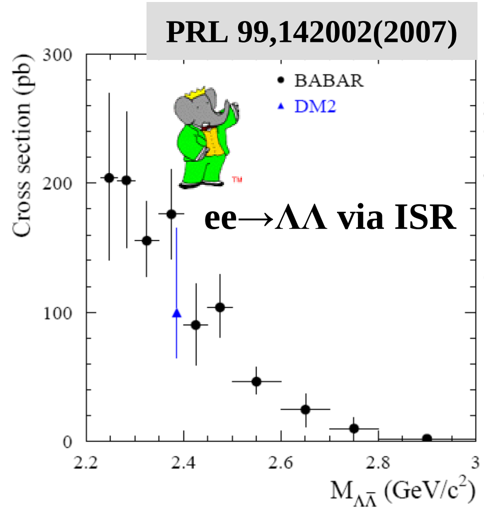
  $Br(\Lambda_c^+ \to pX) = (50 \pm 16)\%$

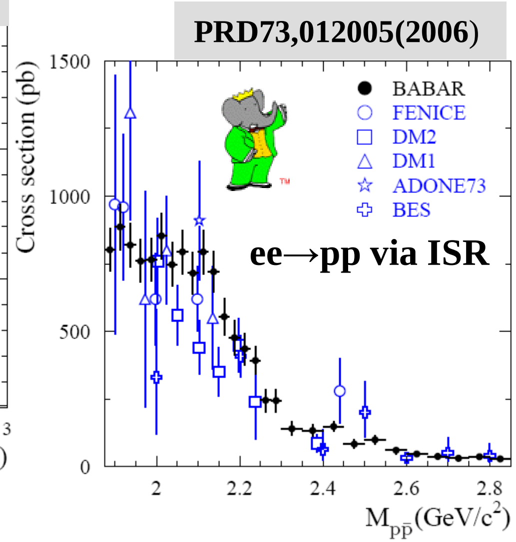
  - **combinatorial background suppressed by ≈ 10**
- **Detect the high energy ISR photon**
- **Translate measured mass recoil against $\gamma_{ISR} \equiv \Lambda_c^+ \Lambda_c^-$ mass spectrum to cross section**



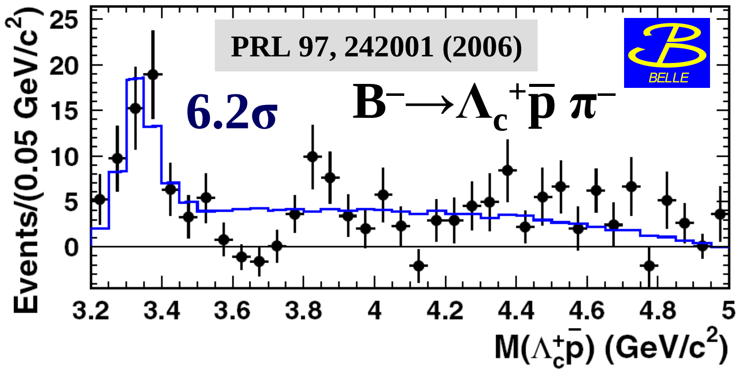
$e^+e^- \to \Lambda_c^+\Lambda_c^-\gamma_{ISR}$

- no peak-like structure





- dibaryon threshold effect
  - like in B→pΛπ, J/ψ→γpp

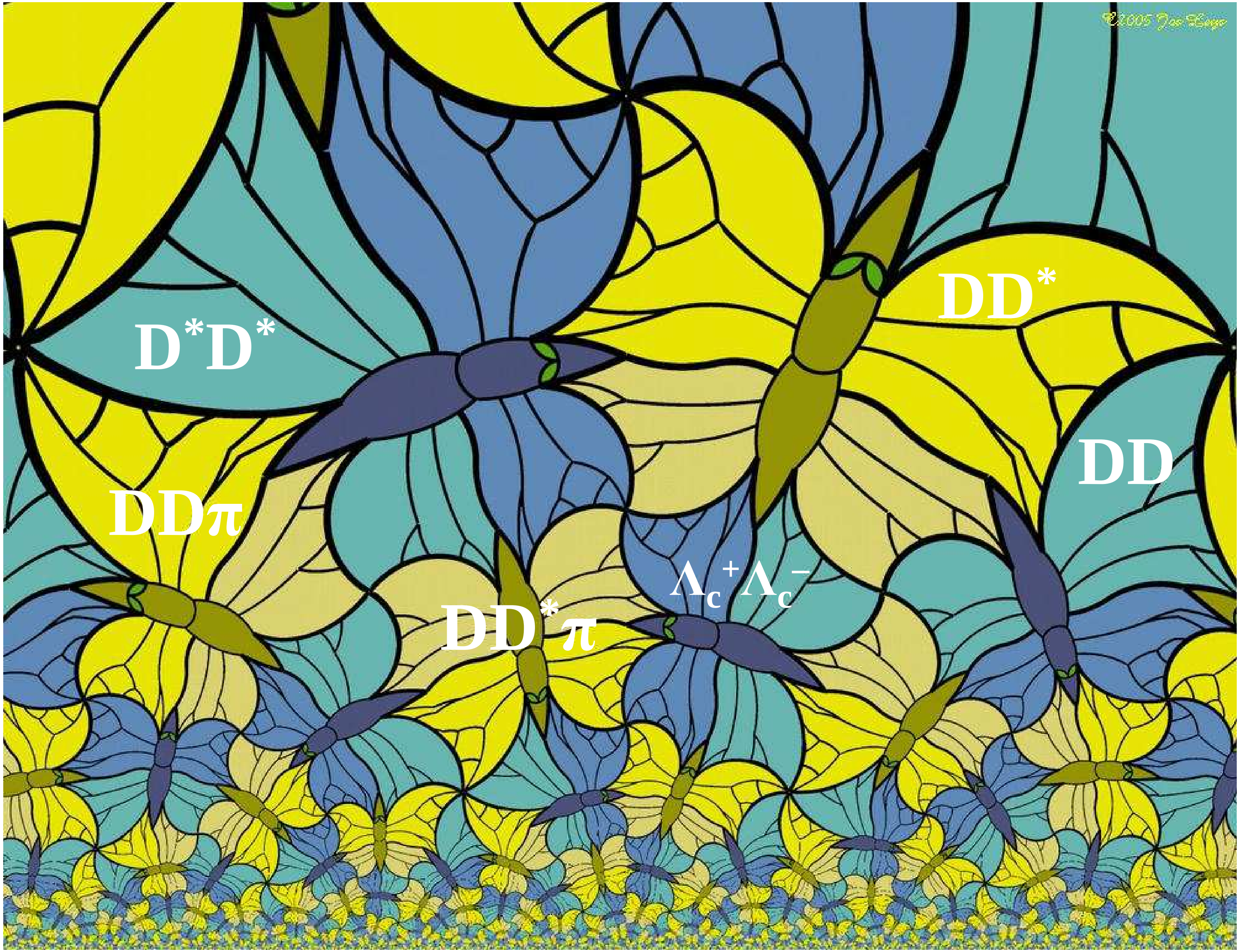


- 5^3S_1 charmonium state
  - in some models $M(5^3S_1)$ ~4670MeV
- Other interpretations

Interpretations for the new X(4630)

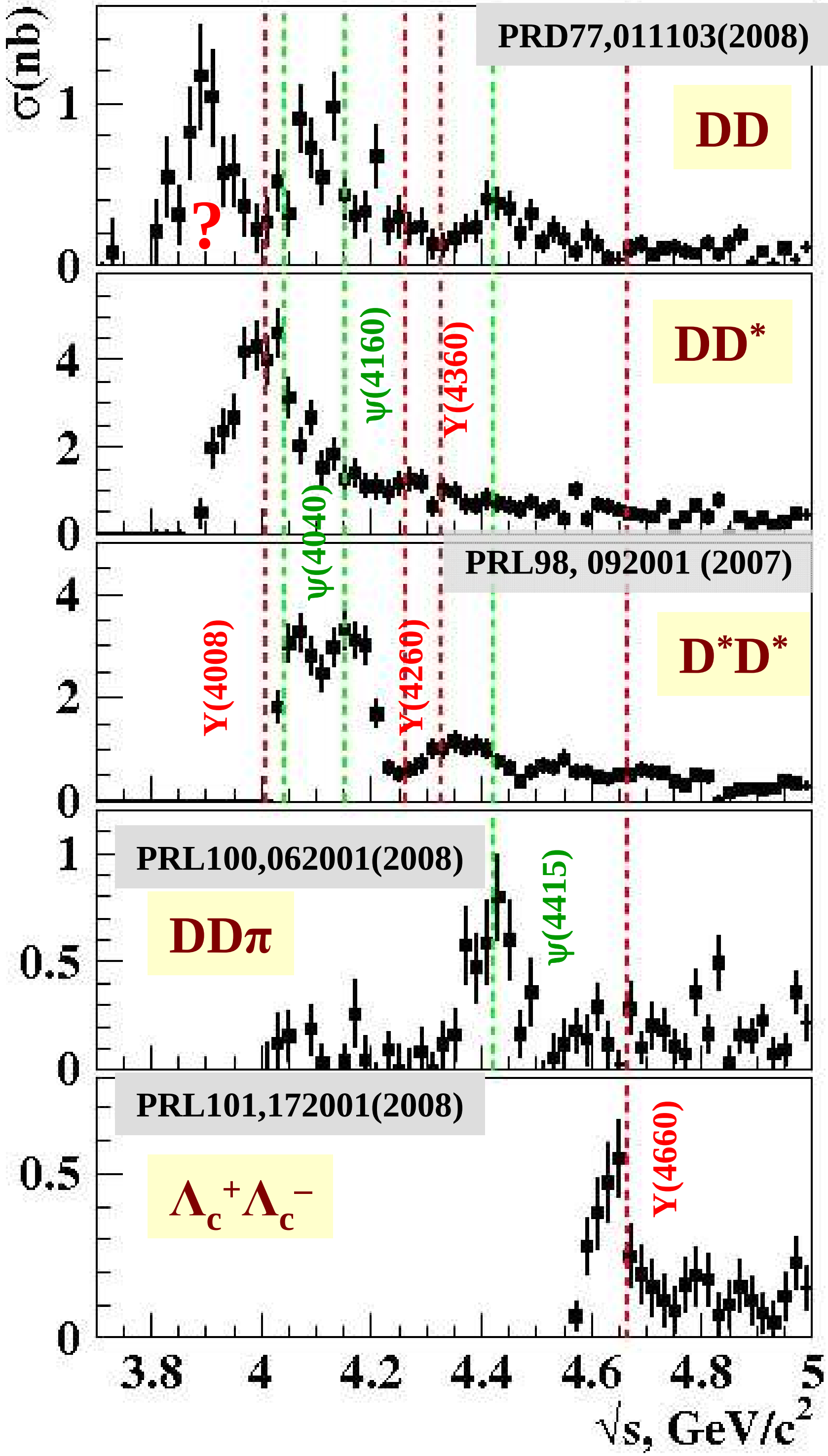
- X(4630) ≡ Y(4660)? $J^{PC}=1^{--}$

State	M, MeV/c^2	Γ_{tot}, MeV
X(4630)	4634^{+8+5}_{-7-8}	92^{+40+10}_{-24-21}
Y(4660)	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$

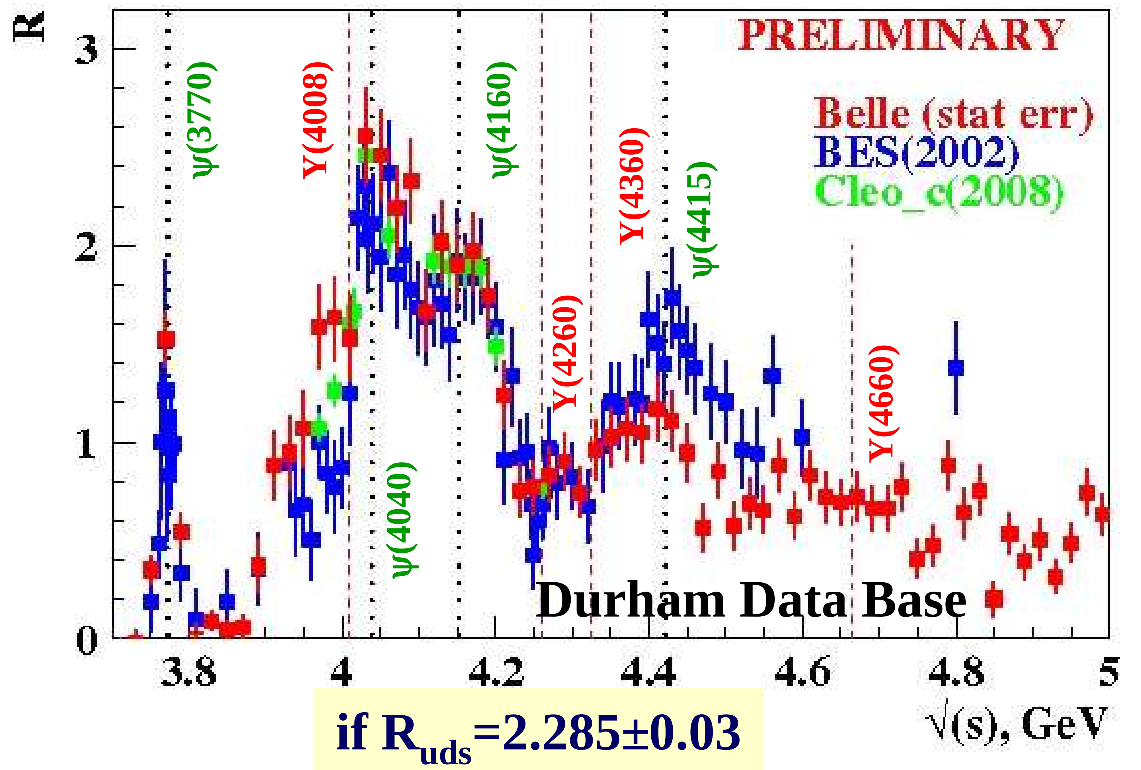


Contribution to the inclusive cross section

σ(e⁺e⁻→open charm) via ISR



Belle: Sum of all measured exclusive contributions



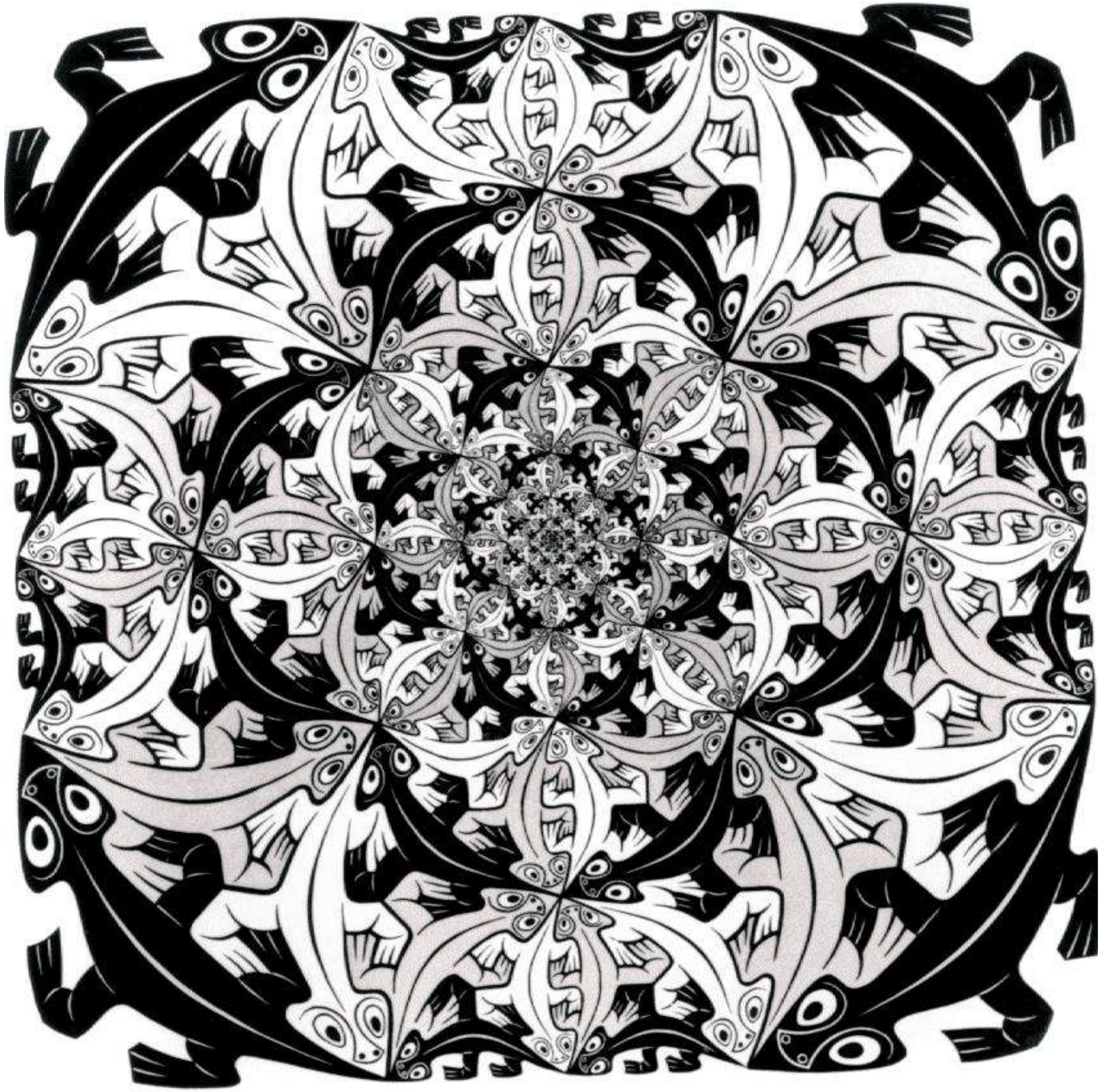
Y states vs exclusive cross sections

- Y(4008) mass coincides with DD^* peak
- Y(4260) mass corresponds to dip in D^*D^* cross-sect
- Y(4660) mass is close to $\Lambda_c^+\Lambda_c^-$ peak
- Enhancement near 3.9 GeV in ee→DD *coupled channel effect?*

ψ(4415) still some unaccounted-for decay channels

Charm strange final states contribution to be factor of 10 less

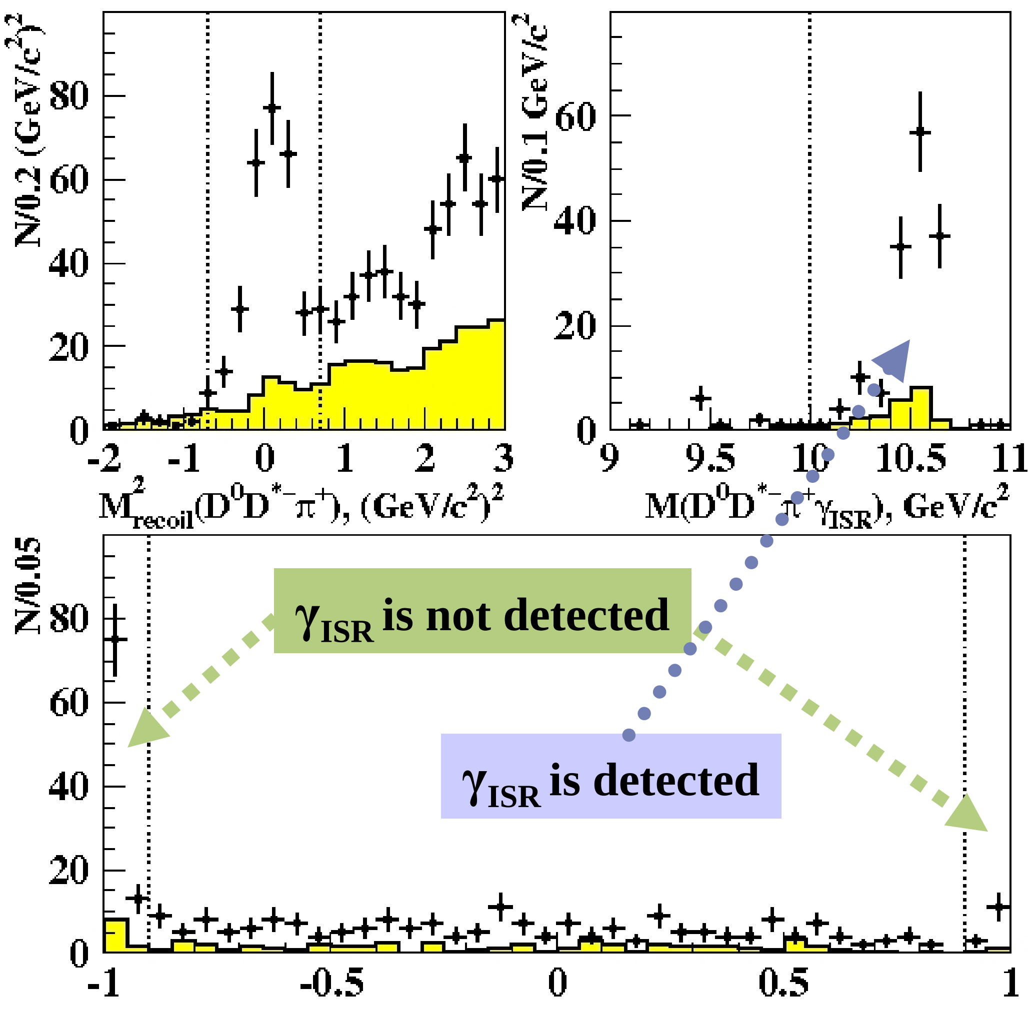
Galina Pakhlova



Searching for hybrids via their favorite decay modes

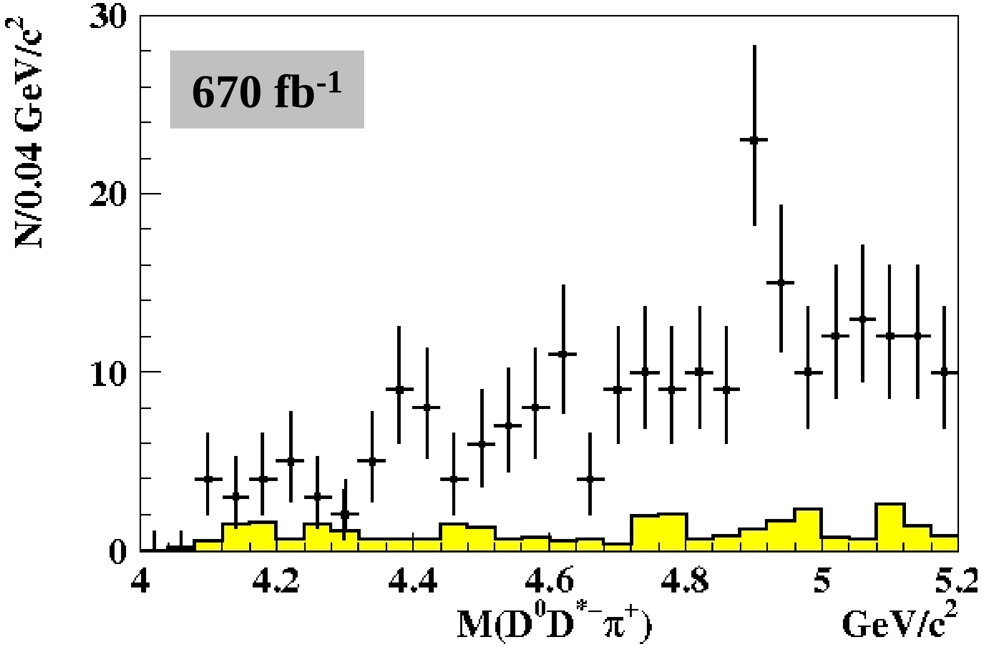
New

$e^+e^- \to D^0 D^{*-} \pi^+$ at $\sqrt{s} \sim 4-5$ GeV via ISR



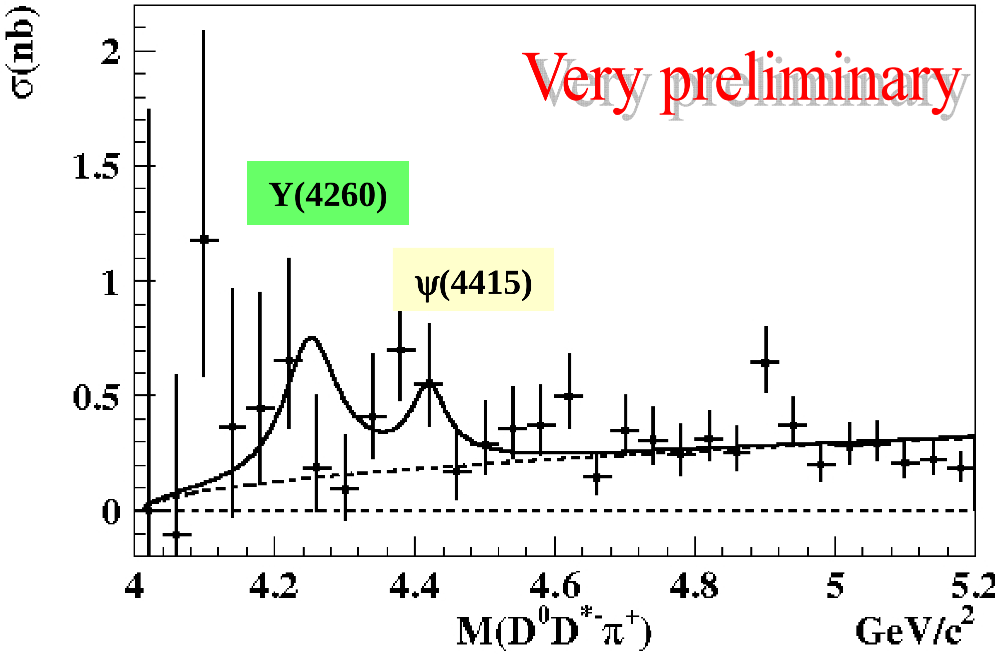
Consistent with ISR production

- Full reconstruction
- No extra tracks
- Detection of γ_{ISR} is not required
  - if γ_{ISR} is detected
  - $M(D^0 D^{*-} \pi^+ \gamma_{ISR})$ is required ~ Ecm



- Combinatorial bgs are estimated from sidebands D and D^*
- Other bgs are small and taken into account
- *Small efficiency at threshould*

Exclusive $e^+e^- \to D^0 D^{*-}\pi^+$ cross-section



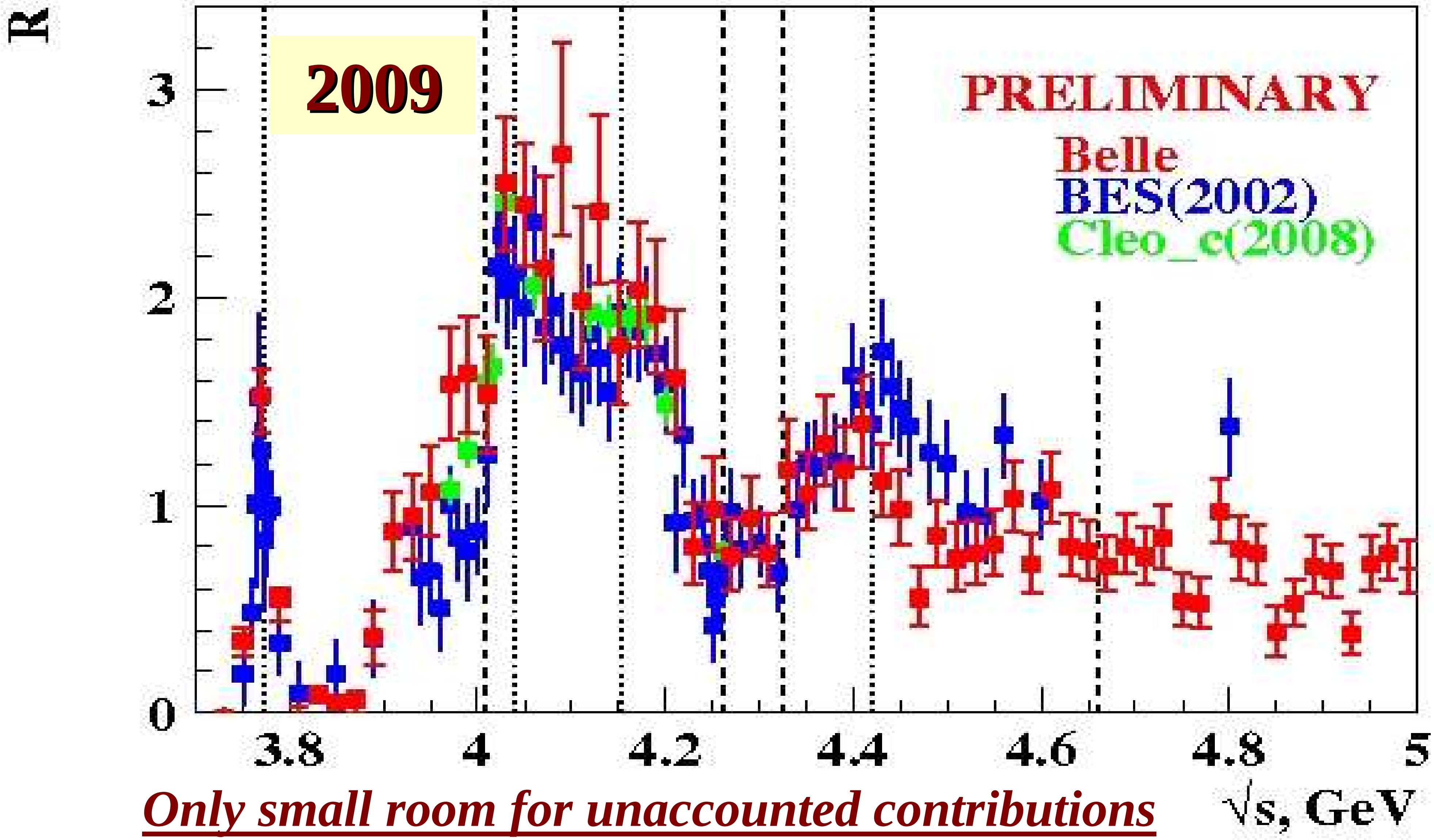
- No evident structures: only UL's !!!
- Baseline fit:
  - RBW for ψ(4415) & threshold function for non-resonant contribution without interference between amplitudes
- To obtain limits on $X \to D^0 D^{*-}\pi^+$, X=Y(4260), Y(4360), Y(4660), X(4630) perform four fits each with one of the X states, ψ(4415) and non-resonant contribution
- Fix masses and total widths from PDG

Interference could increase these UL's by factors of 2−4 depending on the final state (for destructive solutions)

$\sigma(e^+e^- \to \psi(4415)) \times Br(\psi(4415) \to D^0 D^{*-}\pi^+) < 0.8$ nb at 90% CL
$Br(\psi(4415) \to D^0 D^{*-}\pi^+) < 11$ % at 90% CL

UL at 90% CL		$Y(4260)$	$Y(4360)$	$Y(4660)$	$X(4630)$
$\sigma(e^+e^- \to X) \times \mathcal{B}(X \to D^0 D^{*-}\pi^+)$	nb	0.62	0.83	0.55	0.40
$\mathcal{B}_{ee} \times \mathcal{B}(X \to D^0 D^{*-}\pi^+)$	$\times 10^{-6}$	0.76	1.08	0.81	0.59
$\mathcal{B}(X \to D^0 D^{*-}\pi^+)/\mathcal{B}(X \to \pi^+\pi^- J/\psi)$		15			
$\mathcal{B}(X \to D^0 D^{*-}\pi^+)/\mathcal{B}(X \to \pi^+\pi^- \psi(2S))$			11	42	

Belle: Sum of all measured exclusive contributions



Only small room for unaccounted contributions

- **Charm strange final states?**

Limited inclusive data above 4.5 GeV

- **Charm baryons final states?**

In conclusion

Six exclusive open charm final states were measured

DD, $DD\pi$, $DD^{*}\pi$, $D^{*}D$, $D^{*}D^{*}$, $\Lambda_c\Lambda_c$

- **Their sum is close to $e^{+}e^{-} \rightarrow$ hadrons**
- **Belle & BaBar & Cleo_c cross section measurements are consistent with each other in corresponding energy ranges**

- **$D^{*}D^{*}$ (main contribution)**
  - **complicated shape of cross section**
  - **clear dip at $M(D^{*}D^{*}) \sim 4260$GeV (similar to inclusive R)**
- **DD^{*} (main contribution)**
  - **broad peak at threshold (shifted relative to 4040 GeV)**
- **DD**
  - **complicated shape of cross section**
  - **broad enhancement ~ 3.9 GeV – coupled channel effect?**
- **$DD\pi$**
  - **$\psi(4415)$ signal observed, dominated by $\psi(4415)\rightarrow DD_2\,(2460)$**
- **$DD^{*}\pi$**
  - **No evidend structures observed**

In charm meson final states no evident peaks corresponding to members of charmoniumlike 1^{--} family are found !

- **$\Lambda_c\Lambda_c$**
  - ***Enhancement at threshold, quantum numbers, mass and width are consistent with Y(4660)***

In conclusion
for theory

All presented cross sections can be found in <u>Durham Data Base</u>

<u>Please, don't use our plots and a ruler!</u>

Theoretical efforts to describe charm components of inclusive cross-section are kindly requested!