International Workshop on e^+e^- collisions from ϕ to ψ,
28 June 2017, Mainz

Recent results on XYZ physics from Belle

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Outline:

Observation of $\chi_{c0}(2P)$ candidate in $e^+e^- \to J/\psi\, D\bar{D}$ PRD95,112003(2017)

New measurement of $e^+e^- \to D^{(*)}\bar{D}^*$ via ISR NEW

$\Upsilon(4S) \to \pi^+\pi^- \Upsilon(1S,2S)$
$\Upsilon(4S) \to \eta\, \Upsilon(1S)$ NEW

Observation of $\chi_{c0}(2P)$ candidate

Reminder: X(3915) $B \to (J/\psi\ \omega)\ K$, $\gamma\gamma \to (J/\psi\ \omega)$ observed by Belle (2005), confirmed by BaBar

BaBar: $J^P = 0^+ \Rightarrow \chi_{c0}(2P)$ candidate PRD86,072002(2012)

Difficulties:

tiny width: 20 MeV, expect >100 MeV (190 MeV above S-wave threshold)
$D\bar{D}$ not seen $\Rightarrow \Gamma(J/\psi\ \omega) > 0.6\ \Gamma(D\bar{D})$
tiny 2^3P_2-2^3P_1 splitting: 8.8 ± 3.2 MeV (in $b\bar{b}$: 36 MeV)

Olsen PRD91,057501(2015)

Observation of an alternative $\chi_{c0}(2P)$ candidate in $e^+e^- \to J/\psi\ (D\bar{D})$

Belle PRD95,112003(2017)

X(3940) in $e^+e^- \to J/\psi\ (D\bar{D}^*)$

X(4160) in $e^+e^- \to J/\psi\ (D^*\bar{D}^*)$

$e^+e^- \to J/\psi\,(D\bar{D})$ ← $M_{rec} = \sqrt{[\underline{p}(e^+e^-) - \underline{p}(J/\psi) - \underline{p}(D)]^2}$

reconstructed

$J/\psi \to \mu^+\mu^-$, e^+e^-

$D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K_S\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^+$, $K^-\pi^+\pi^+$, $K_S\pi^+$, $K_S\pi^+\pi^0$, $K_S\pi^+\pi^+\pi^-$

Neural Networks. Variables: separation btw J/ψ and D vertices, angle btw D momentum and direction from J/ψ to D vertex, lepton PID, π^0 related: mass, helicity angle... $\Rightarrow$ v_i

Requirements on $M(J/\psi)$, $M(D)$, M_{rec} and v_i are chosen individually for each channel maximizing global Figure-of-Merit.

$$\frac{\sum_i N_{\rm sig}^{(i)}}{\frac{a}{2} + \sqrt{\sum_i N_{\rm bg}^{(i)}}}$$

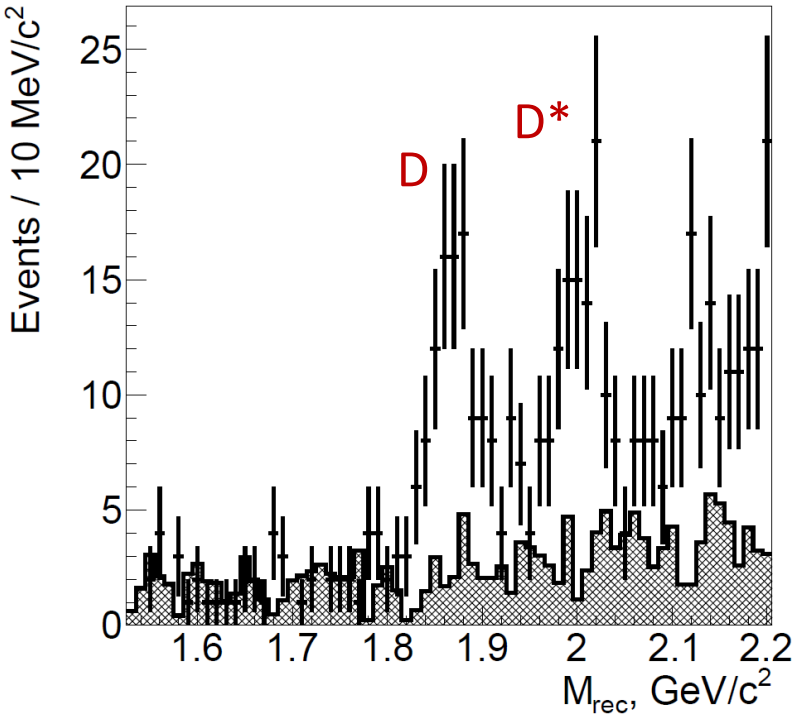
$\Rightarrow$ 103 selected events

Fraction of background? $\Rightarrow$ 3D fit in $M(J/\psi)$, $M(D)$ and M_{rec}

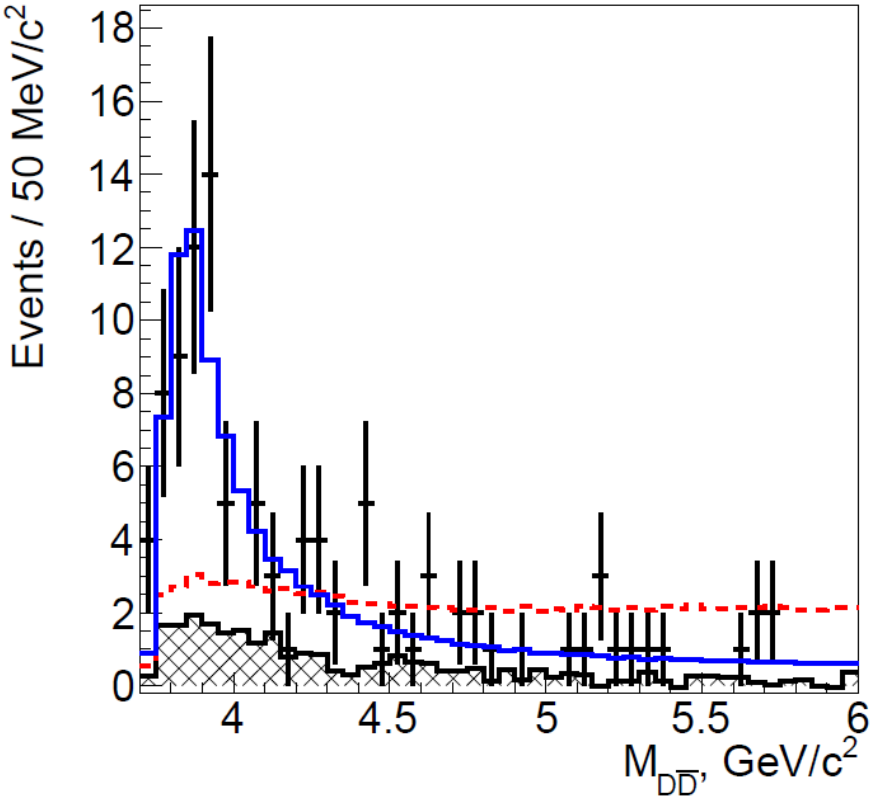
25 ± 2 background events

fit gives also normalization of sidebands

$e^+e^- \to J/\psi\,(D\bar{D})$



Sum over all D, J/ψ channels.
Sidebands describe background level well.



$\Rightarrow$ X*(3860)

$J^{PC} = 0^{++}, \cancel{1^{--}}, 2^{++}, \cancel{3^{--}}, \ldots$

C-parity

too high

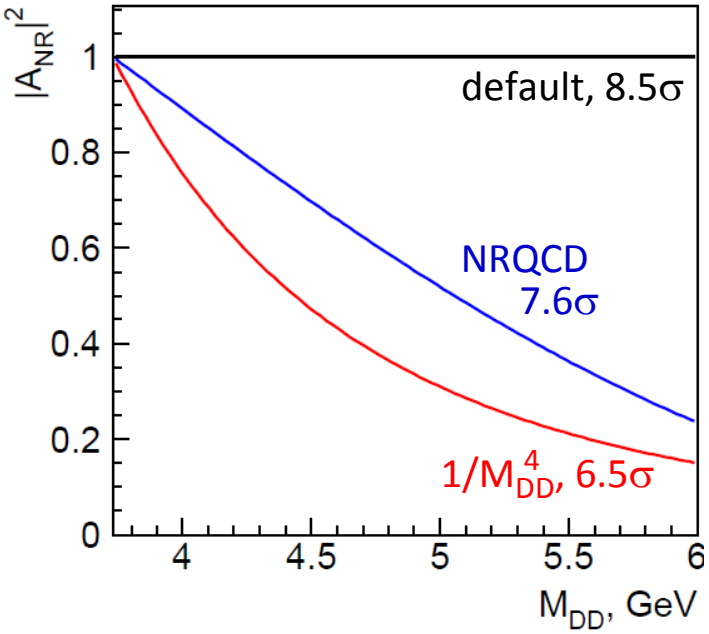
Amplitude analysis

In 6D phase space: $M_{D\bar{D}}, \theta_{\rm prod}, \theta_{J/\psi}, \theta_{X^*}, \varphi_{\ell^-}, \varphi_D$

Model: X* + non-resonant contribution

Blatt-Weisskopf ff

$$A_{X^*}(M) = \left(\frac{p(M)}{p(m)}\right)^L \frac{F_L(M)}{m^2 - M^2 - im\Gamma(M)}$$



Angular parts: helicity formalism.

$$\mathrm{M} = (3862^{+26}_{-32}{}^{+40}_{-13})\ \mathrm{MeV}/c^2$$

$$\Gamma = (201^{+154}_{-67}{}^{+88}_{-82})\ \mathrm{MeV}$$

← significances include "look-elsewhere" effect

⇐ MC pseudoexperiments

0^{++} is favored over 2^{++} at 3.8σ

… at 2.5σ including systematics

X*(3860)

$\Rightarrow$ good $\chi_{c0}(2P)$ candidate

$M = (3862^{+26}_{-32}{}^{+40}_{-13})\ \mathrm{MeV}/c^2$

$\Gamma = (201^{+154}_{-67}{}^{+88}_{-82})\ \mathrm{MeV}$

$J^{PC} = 0^{++}$ are favored

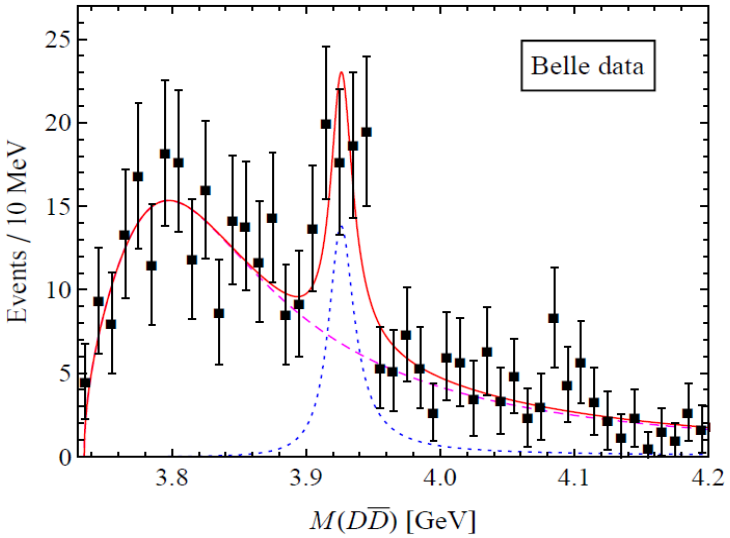
Seen in $D\bar{D}$

Guo, Meissner PRD86,091501(2012)

Bump near threshold in $\gamma\gamma \to D\bar{D}$ $\Leftarrow$ $\chi_{c0}(2P)$?

rough fit: $M = 3838$ MeV , $\Gamma = 211$ MeV

in agreement



What is X(3915) ? $\Rightarrow$ Unlikely $\chi_{c0}(2P)$.

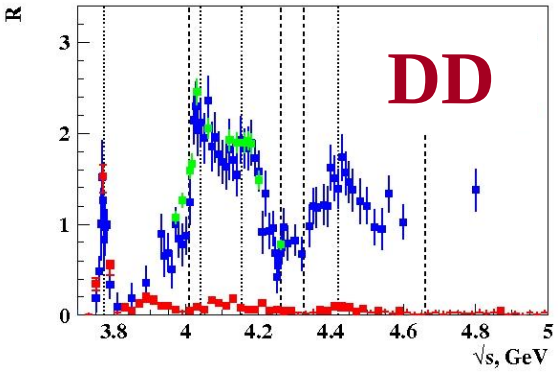
No more 0^{++} charmonia nearby are expected $\Rightarrow$ exotics.

Zhou, Xiao, Zhou PRL115,022001(2015)

J^{PC} measurement by BaBar is model dependent, X(3915) could be $\chi_{c2}(2P)$.

discussion – talk by Alexey Nefediev

Update of $e^+e^- \to D^{(*)+}D^{*-}$


DD
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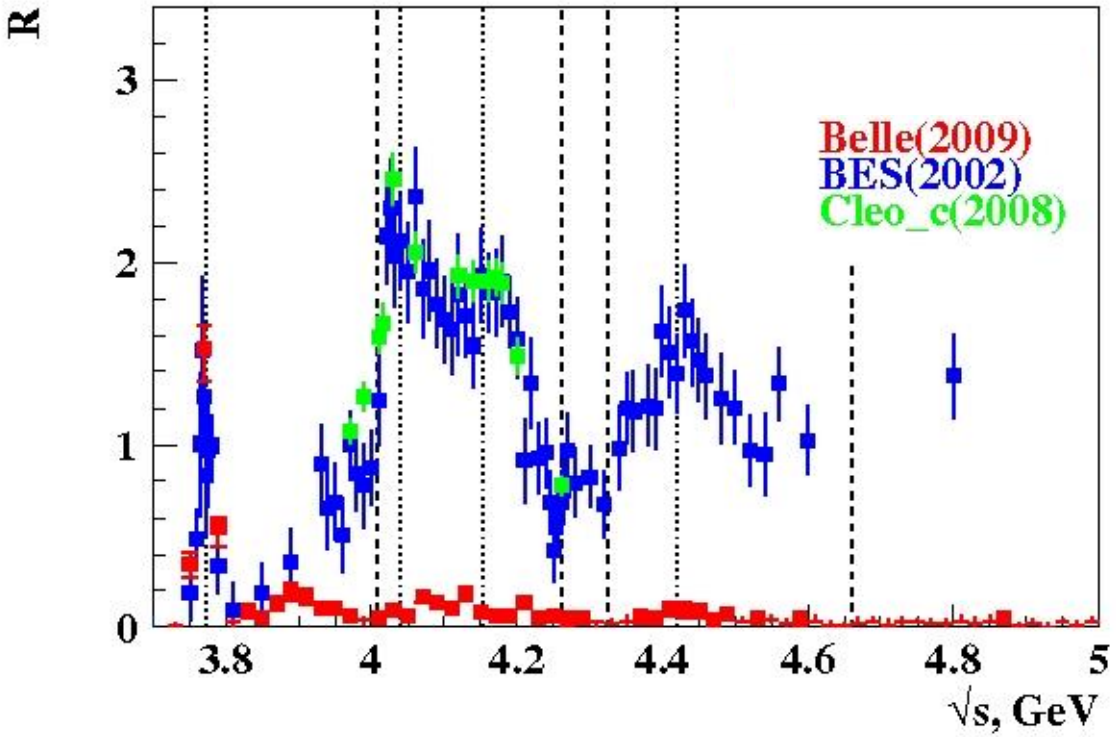
√s, GeV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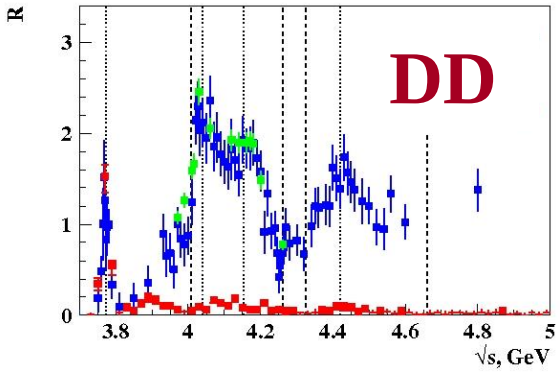
√s, GeV
Belle(2009)
BES(2002)
Cleo_c(2008)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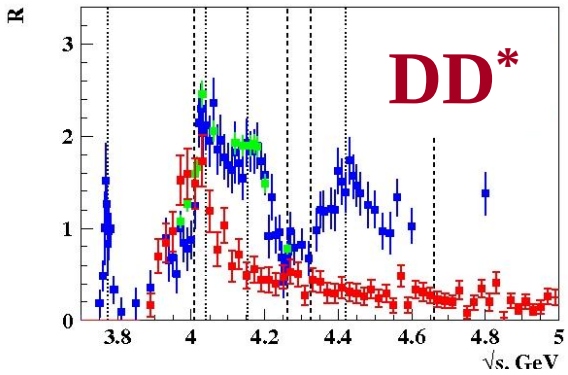
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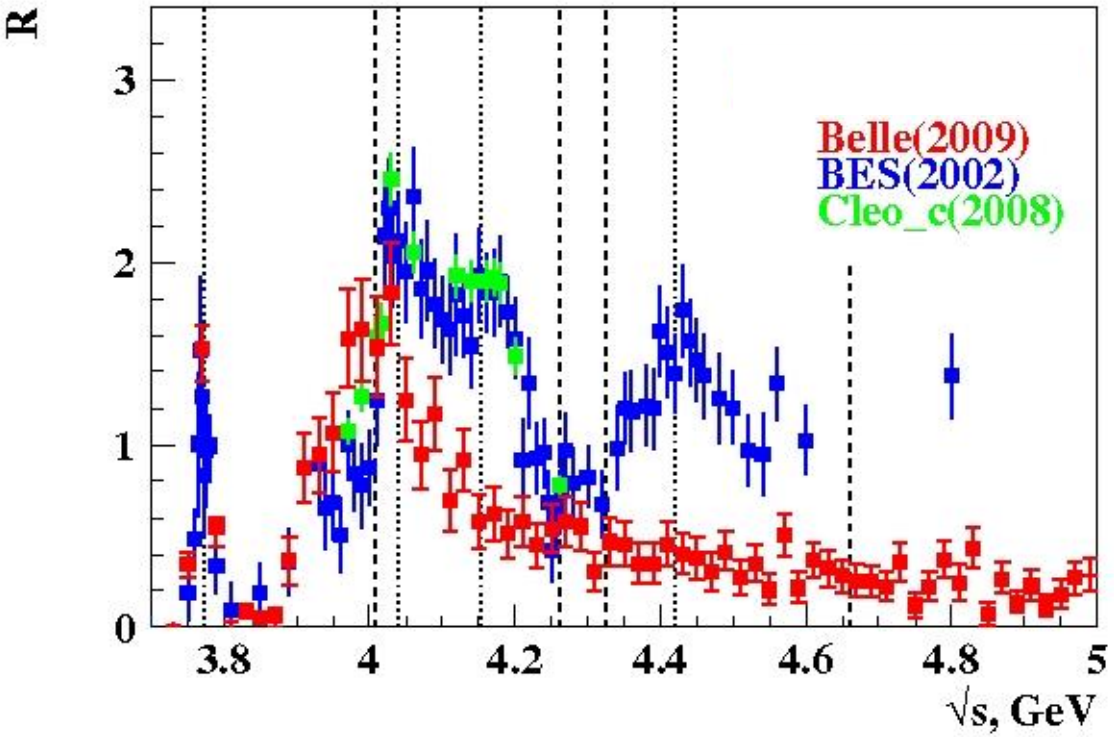
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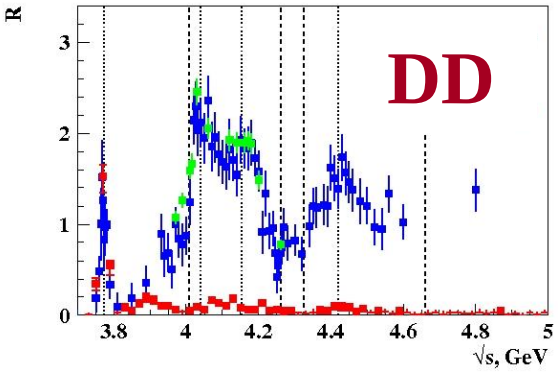
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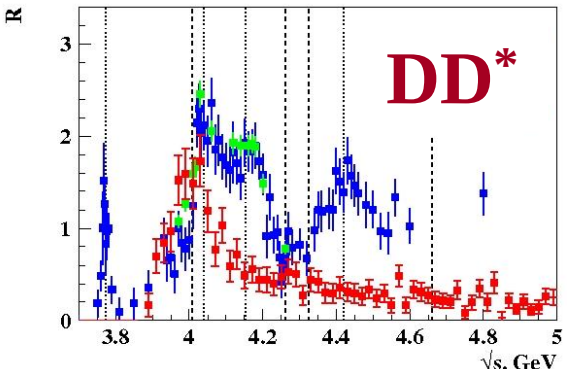
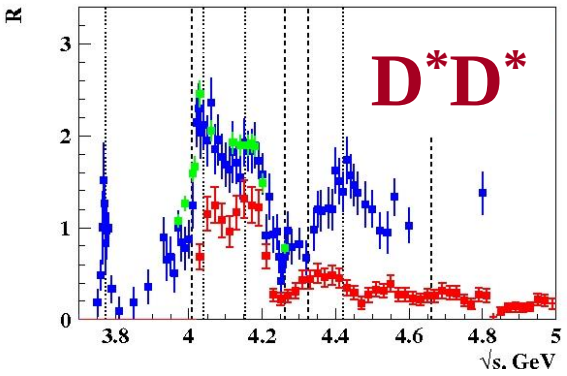
R
√s, GeV


DD*
R
√s. GeV


D*D*
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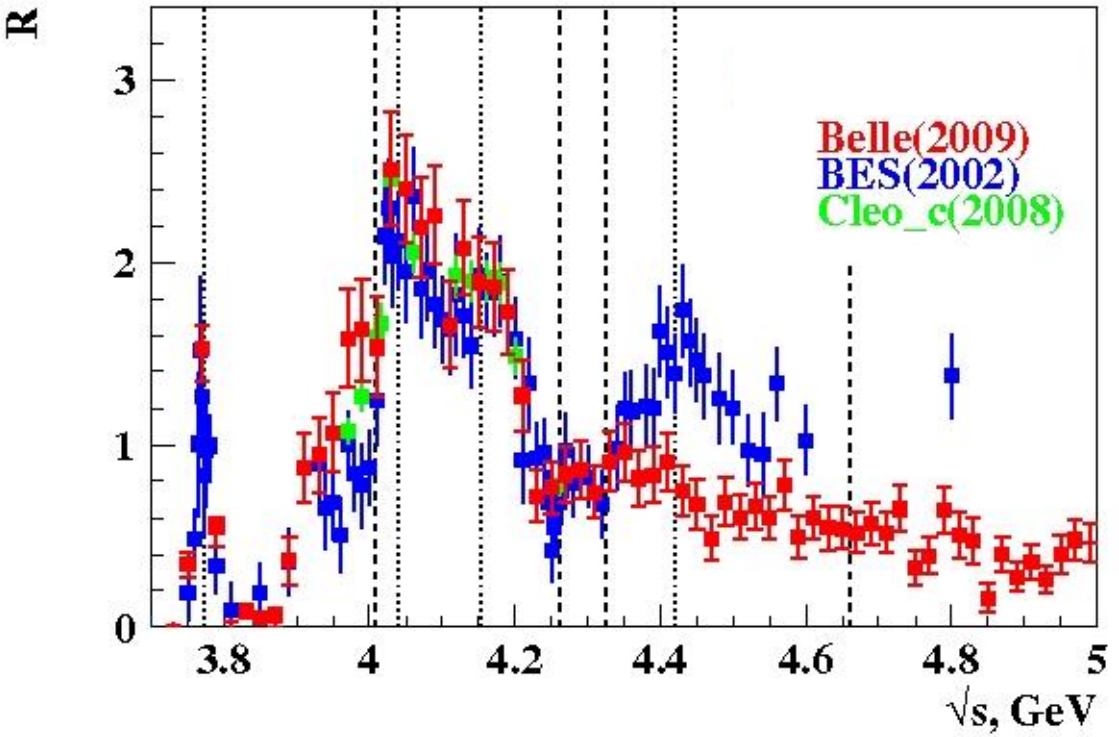
√s. GeV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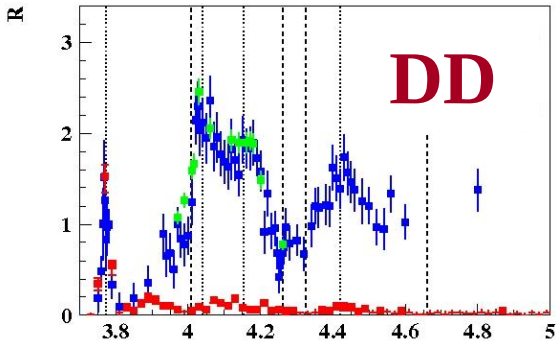
Belle(2009)
BES(2002)
Cleo_c(2008)
√s, GeV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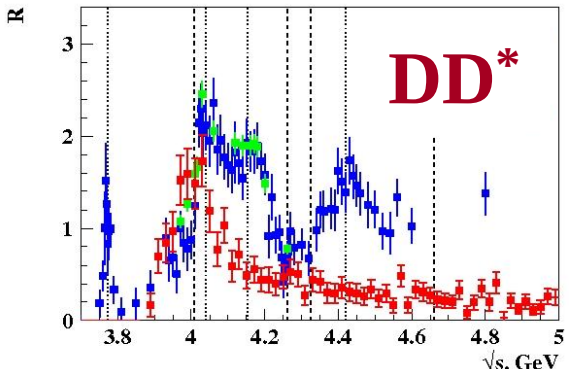
√s, GeV


DD*
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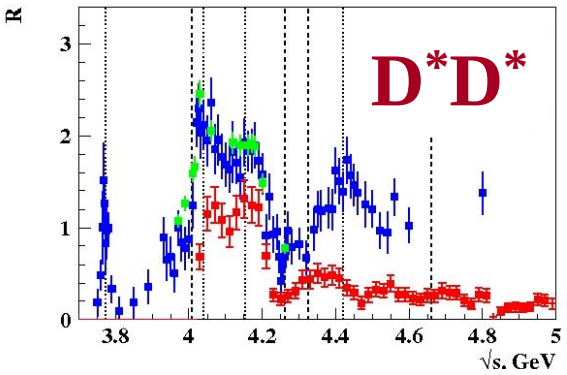
√s, GeV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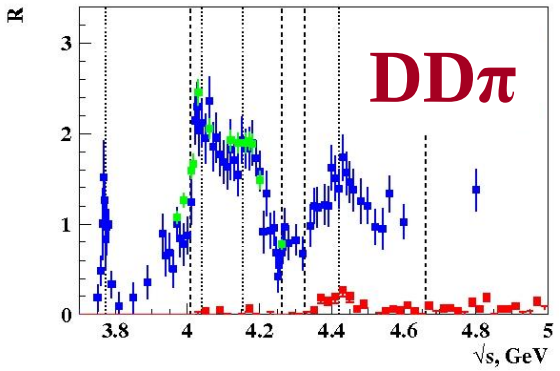
√s, GeV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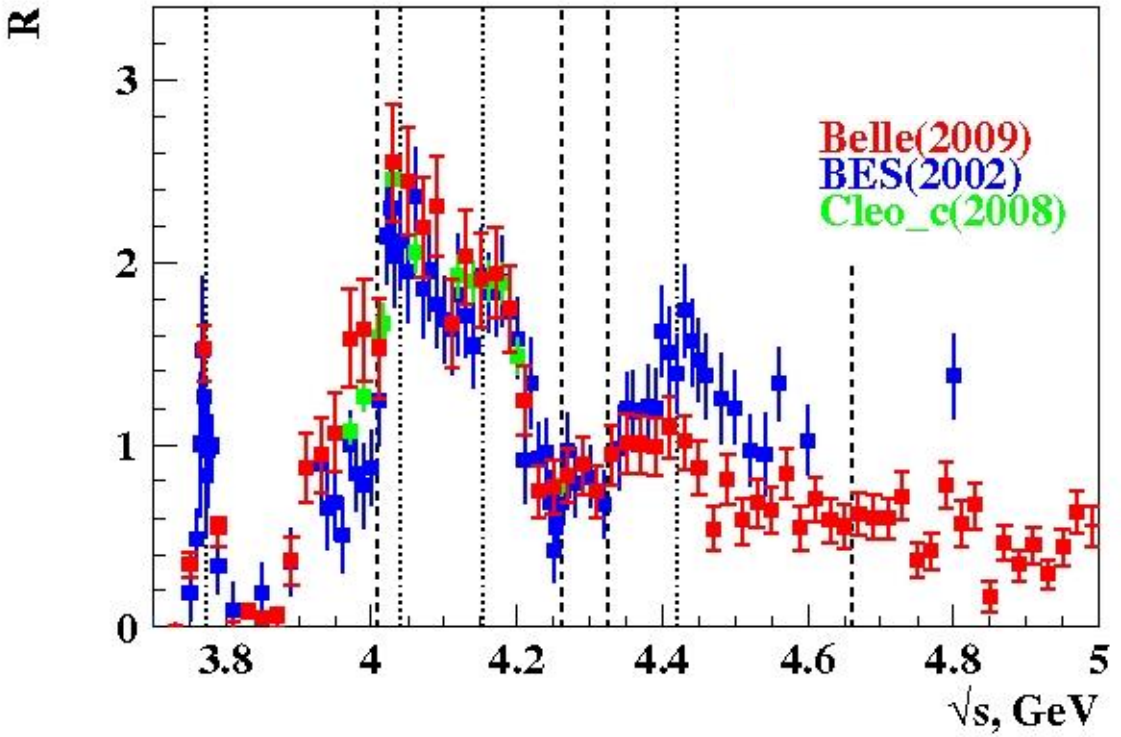
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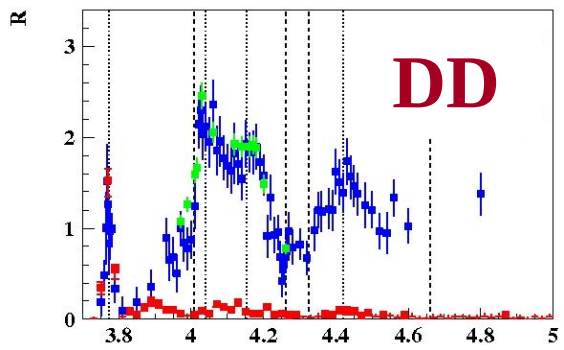
Belle(2009)
BES(2002)
Cleo_c(2008)
√s, GeV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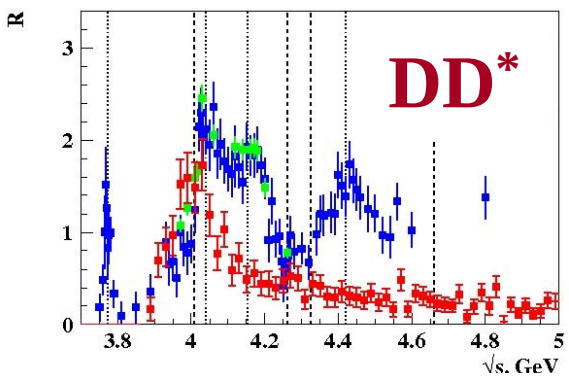
DD*
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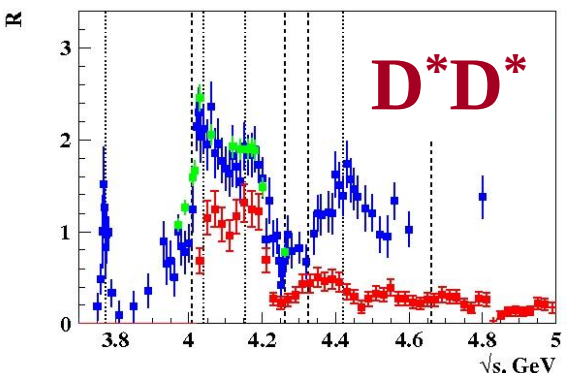
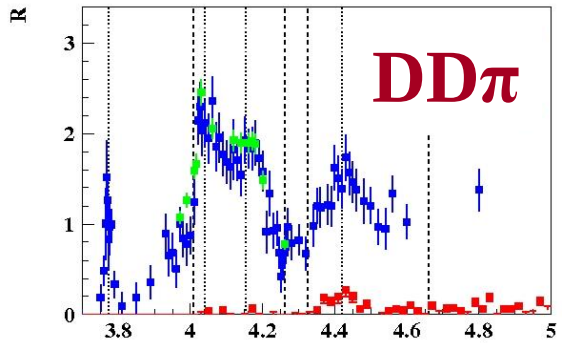
√s, GeV


D*D*
R
√s, GeV


DDπ
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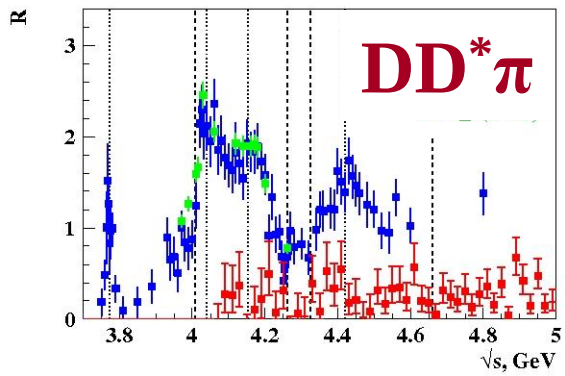
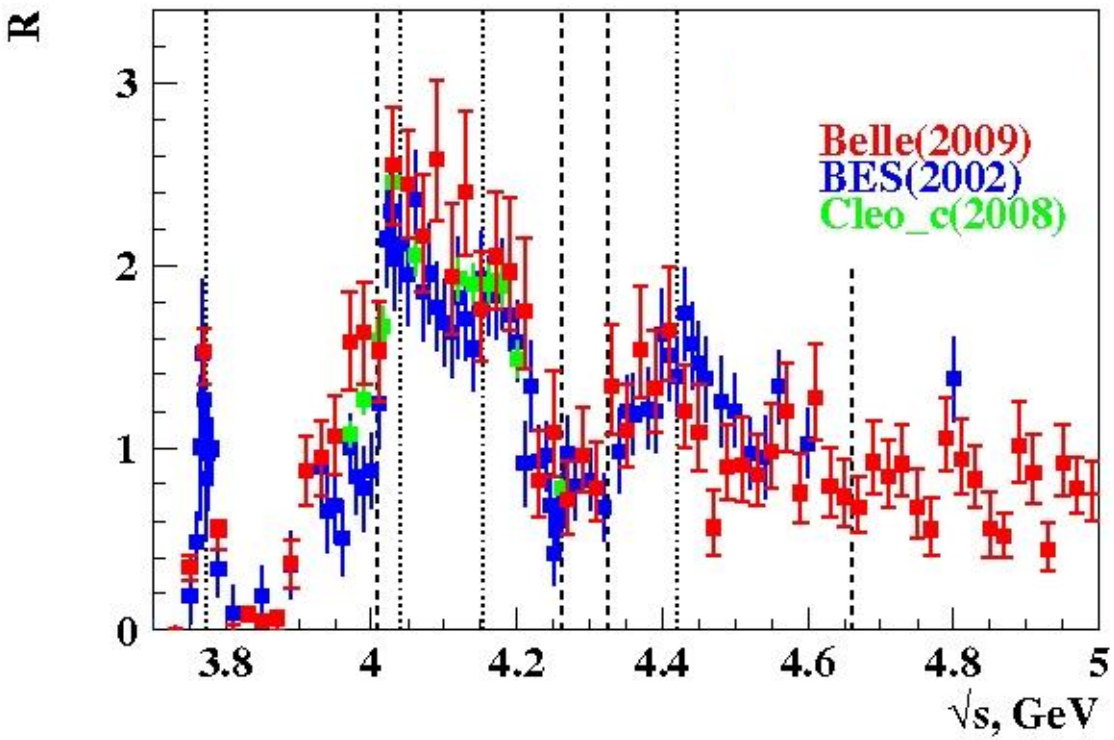

DD*π
R
√s, GeV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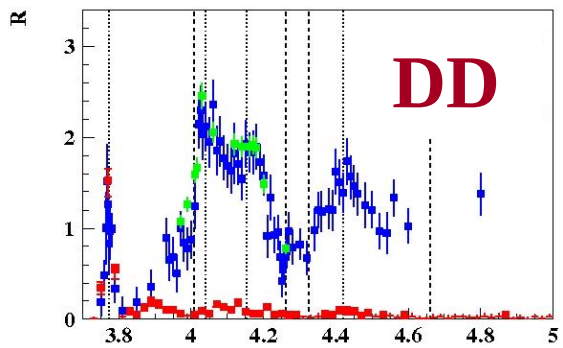
√s, GeV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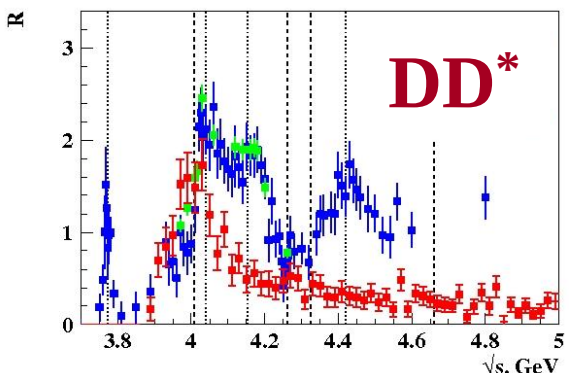
√s, GeV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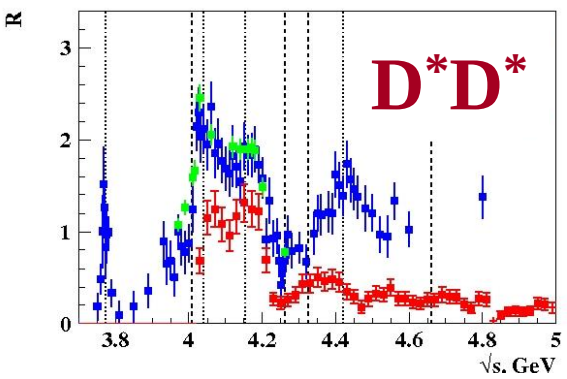
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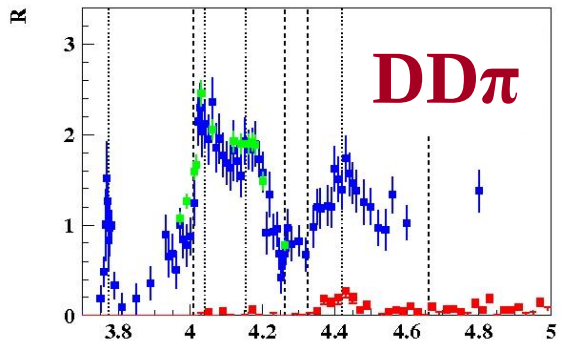
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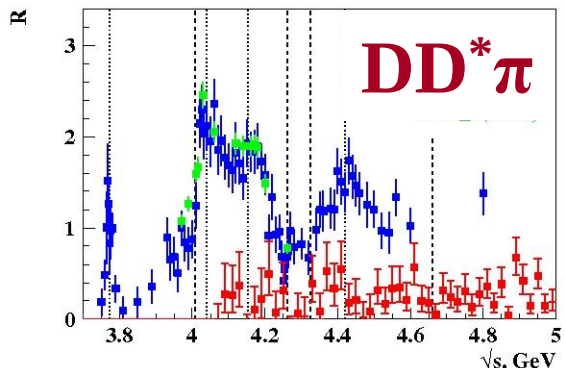
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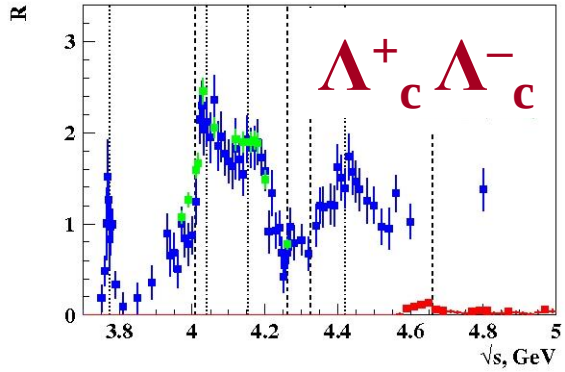
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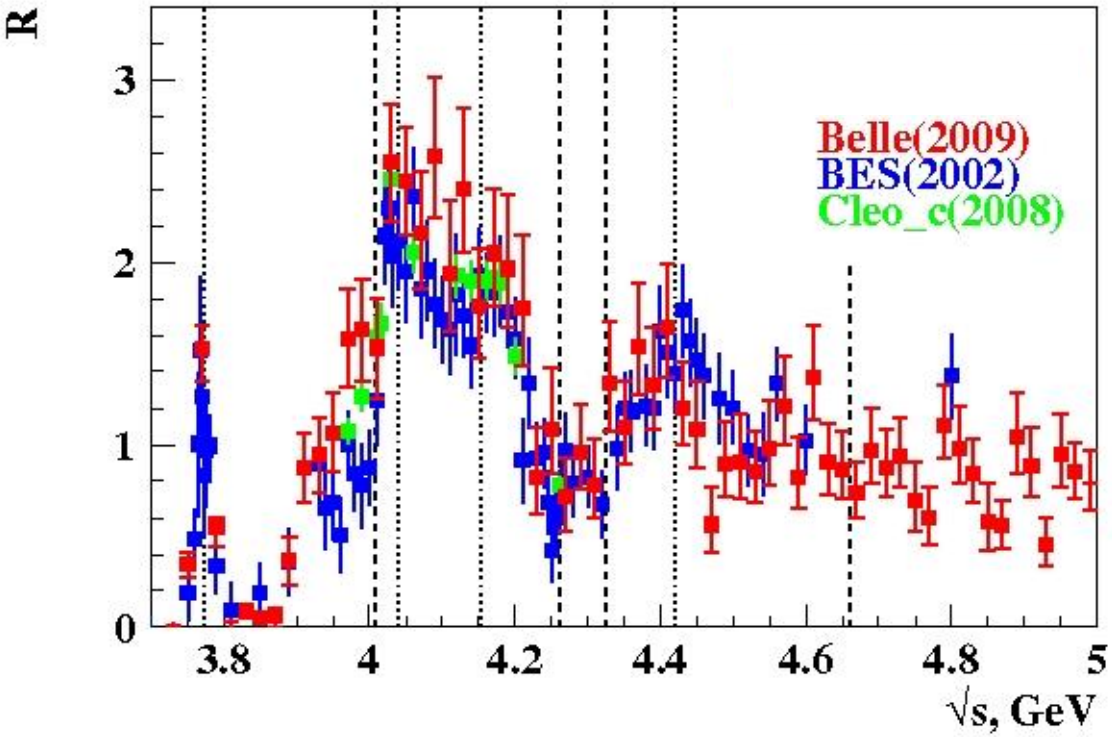
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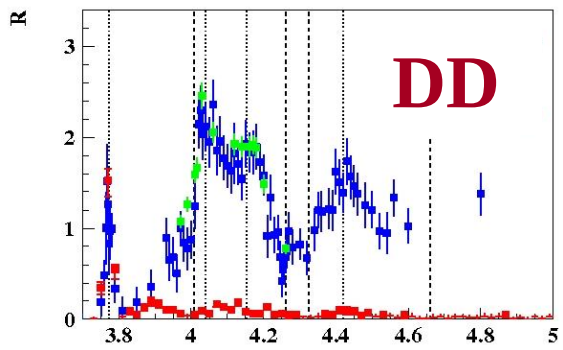
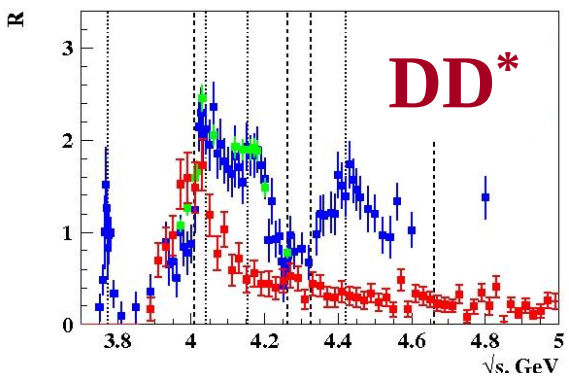
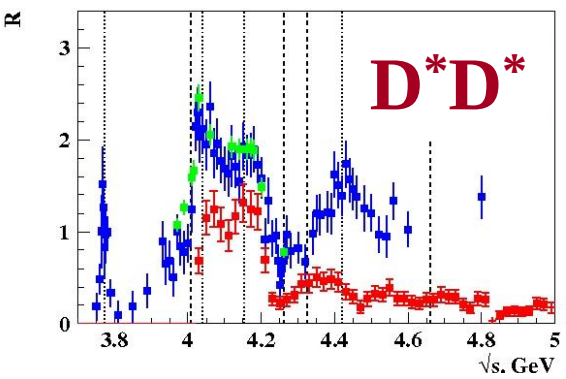
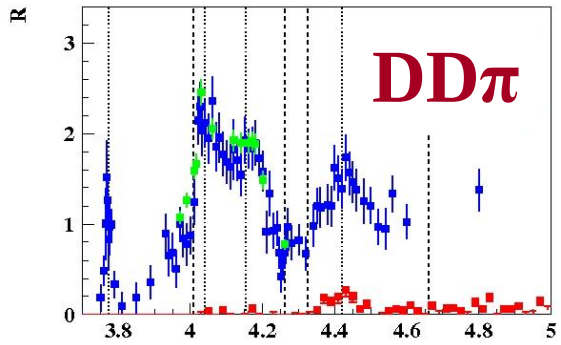
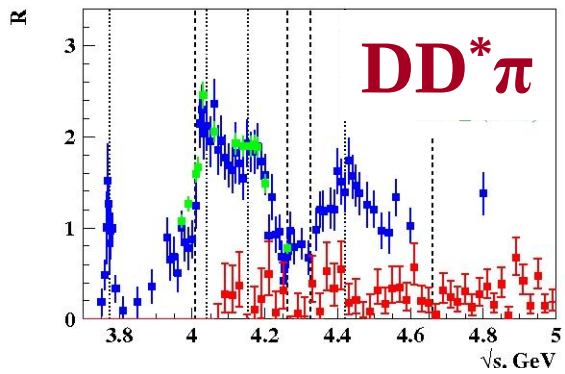
Belle(2009)
BES(2002)
Cleo_c(2008)
√s, GeV

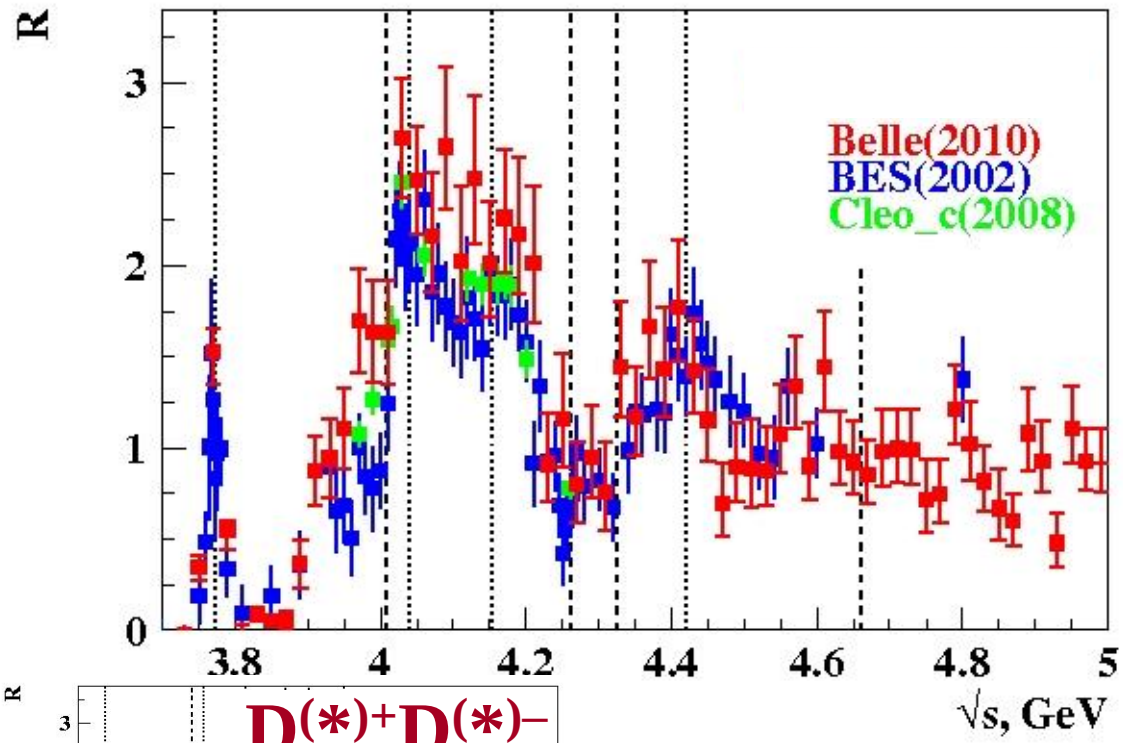


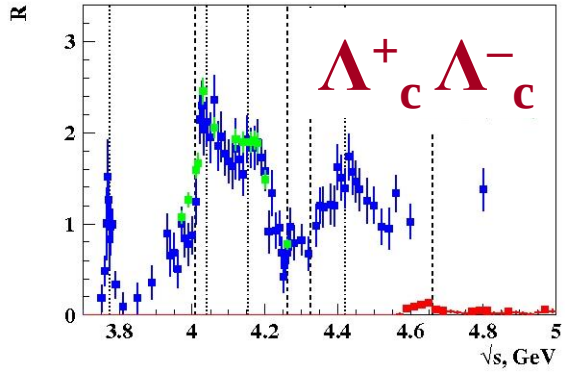


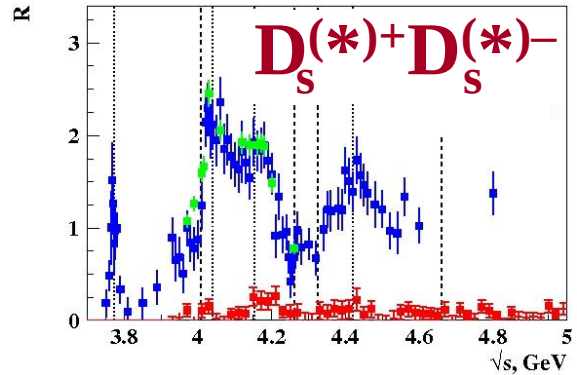












Total $c\bar{c}$ cross-section is decomposed into open charm channels

Coupled-channel analysis

Uglov, Kalashnikova, Nefediev, Pakhlova, Pakhlov JETP Lett.105,1(2017)

Goals:

masses of $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$
couplings of resonances to $D\bar{D}$, $D\bar{D}^*$, $D^*\bar{D}^*$, $D\bar{D}_2$ channels

Results / conclusions:

good description of data is achieved
accuracy in parameters of ψ states is poor
– errors in cross sections are big
– no information on $D^*\bar{D}^*$ polarization

Need an update of cross section measurements

Improvements in the update:

more data (factor 1.7)

implement standalone tracking in vertex detector

$\Rightarrow$ efficiency for low momentum tracks $\times 2$

more D^0, D^+ channels

Method: same as in previous publication

Belle PRL98,092001(2007)

$$e^+e^- \to D^{(*)+}D^{*-}\,\gamma_{ISR}$$
$$\hookrightarrow D^0\pi^-$$

D meson from D* is not reconstructed

Resolutions: $M_{rec}(D^{(*)}\,\gamma_{ISR})$ ~300 MeV

$M_{rec}(D^{(*)}\,\gamma_{ISR}) - M_{rec}(D^{(*)}\,\pi\,\gamma_{ISR})$ 1.4 MeV

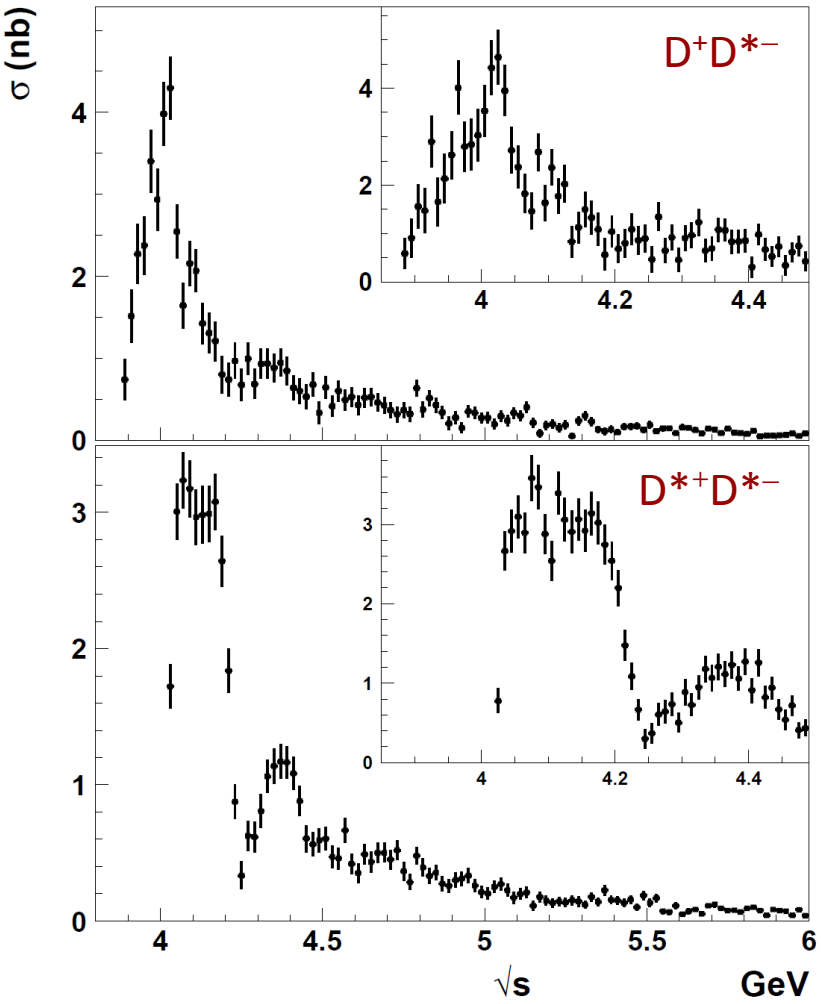
$D\bar{D}$ channel is coming later

need full reconstruction

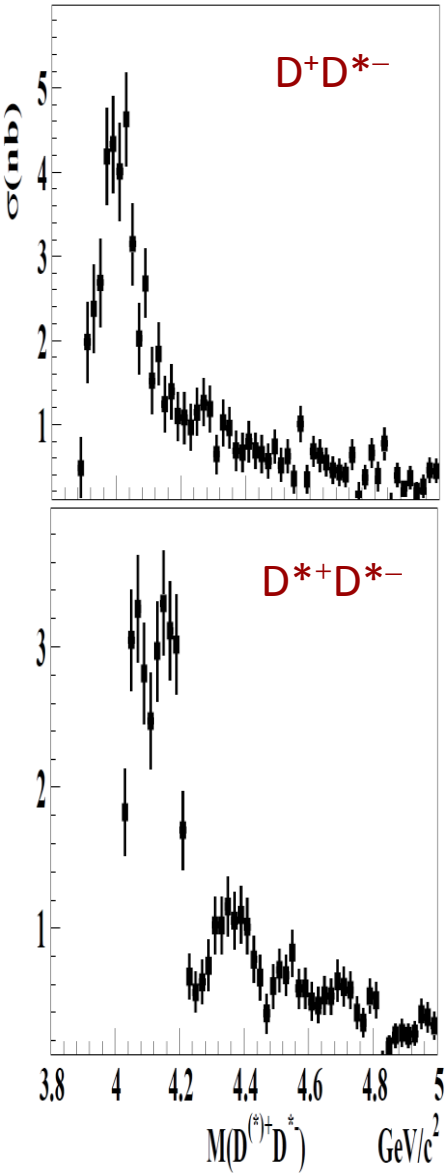
feed-down: first measure $D^{(*)}\bar{D}^*$

Cross sections of $e^+e^- \to D^{(*)+}D^{*-}$

preliminary



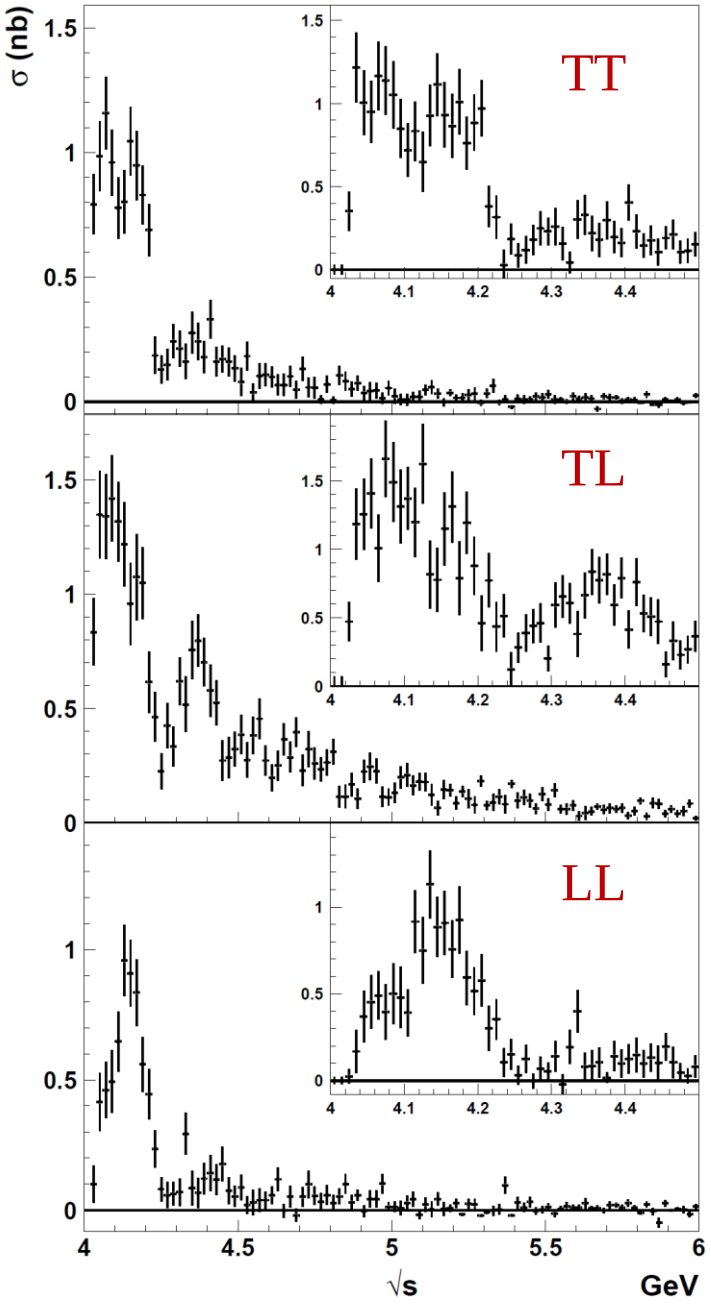
Belle PRL98,092001(2007)



In agreement with previous measurements, accuracy up to ×2 better.

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

preliminary



D* helicities	λ_1	λ_2	
	± 1	± 1	TT
	± 1	0	TL
	0	0	LL

In each energy bin perform 2D fit

$\cos\theta_1$ vs. $\cos\theta_2$

Cross sections have different shapes.

TL is the only non vanishing at high $\sqrt{s}$, as expected.

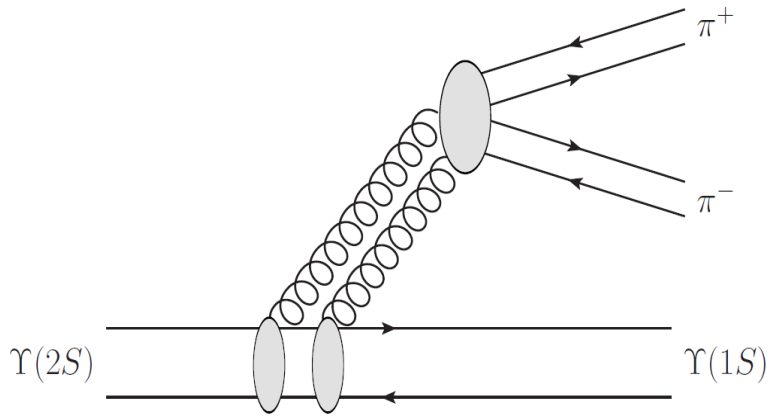
Grozin, Neubert PRD55,272(1997)

It is of interest to perform coupled-channel analysis of new results.

Hadronic transitions from $\Upsilon(4S)$

Hadronic transitions in bottomonia

Transition	Partial width (keV)
$\Upsilon(2S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	5.7 ± 0.5
$\Upsilon(1S)\,\eta$	$(9.3 \pm 1.5) \times 10^{-3}$
$\Upsilon(3S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	0.89 ± 0.08
$\Upsilon(1S)\,\eta$	$< 2 \times 10^{-3}$
$\Upsilon(2S)\,\pi^+\pi^-$	0.57 ± 0.06
$\Upsilon(4S) \to$	BaBar (2008)
$\Upsilon(1S)\,\pi^+\pi^-$	1.7 ± 0.2
$\Upsilon(1S)\,\eta$	4.0 ± 0.8
$\Upsilon(2S)\,\pi^+\pi^-$	1.8 ± 0.3
$h_b(1P)\,\eta$	45 ± 7

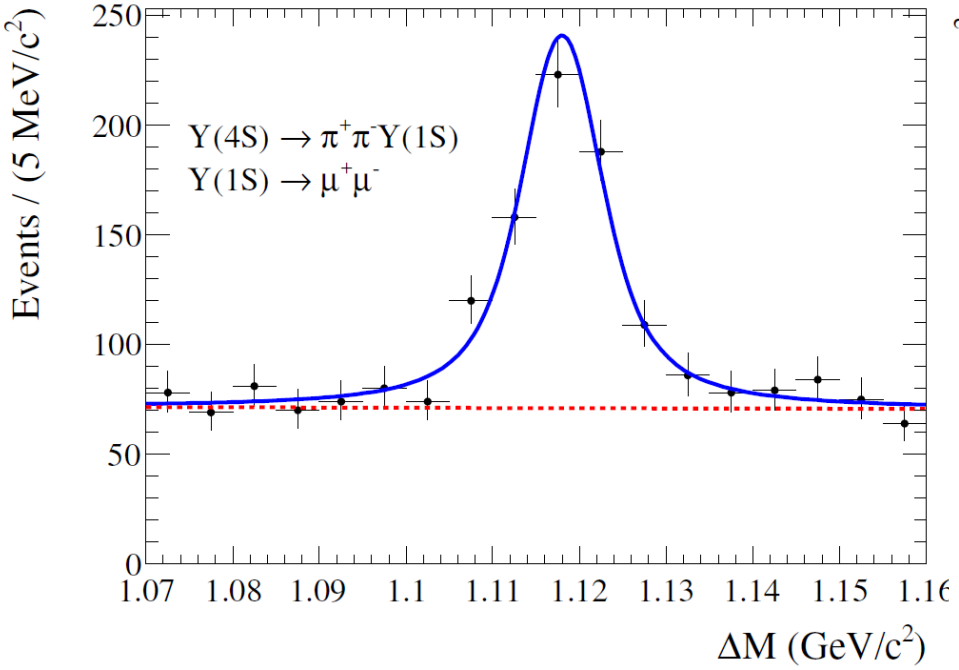


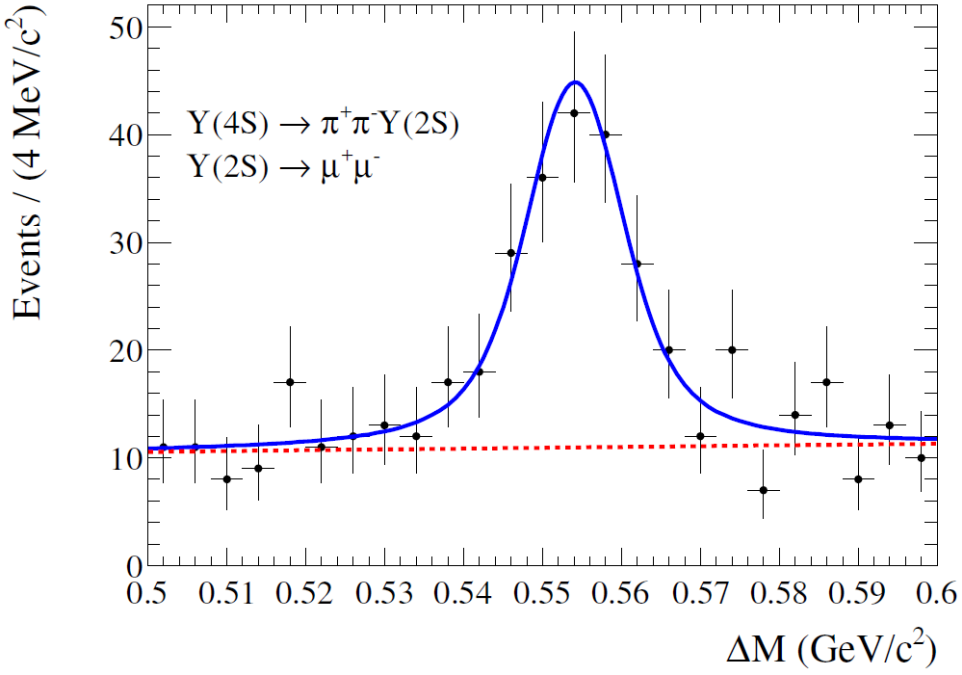
$\pi^+\pi^-$ transitions: E1E1 gluons

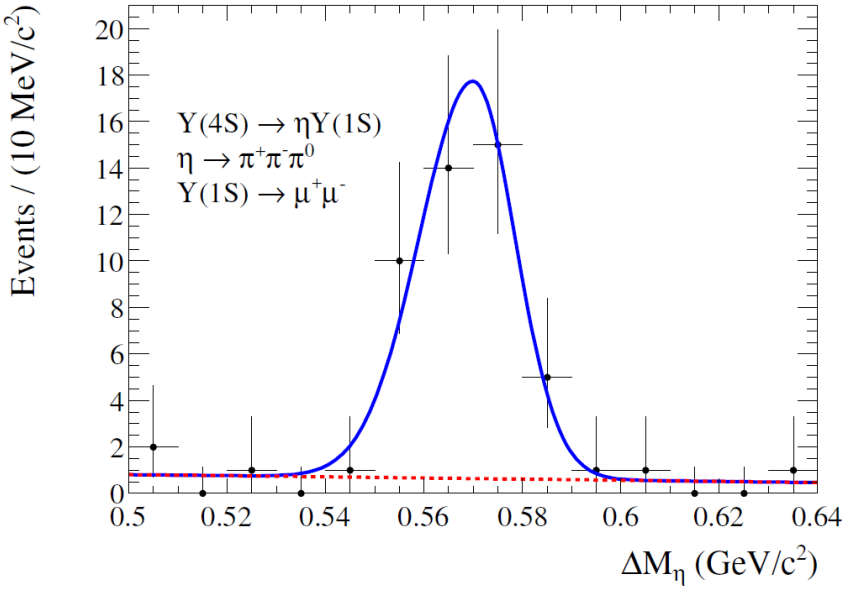
η transitions: E1M2, require spin-flip of b quark strongly suppressed

Results on $\Upsilon(4S) \to \Upsilon(1S)\eta$, $\Upsilon(2S)\pi^+\pi^-$ remained unconfirmed $\Rightarrow$ study at Belle

Hadronic transitions from $\Upsilon(4S)$







$$\Delta M = M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)$$

Very clear signals

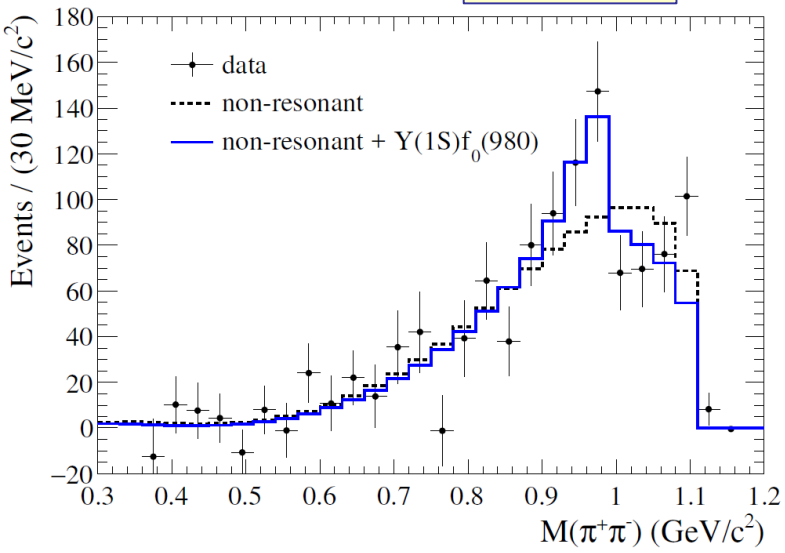
Results

Measurement	Result	PDG value [17]
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$	$(8.2 \pm 0.5 \pm 0.4) \times 10^{-5}$	$(8.1 \pm 0.6) \times 10^{-5}$
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S))$	$(7.9 \pm 1.0 \pm 0.4) \times 10^{-5}$	$(8.6 \pm 1.3) \times 10^{-5}$
$\mathcal{B}(\Upsilon(4S) \to \eta\Upsilon(1S))$	$(1.70 \pm 0.23 \pm 0.08) \times 10^{-4}$	$(1.96 \pm 0.28) \times 10^{-4}$
$\mathcal{R}$ as in Eq. 1	$2.07 \pm 0.30 \pm 0.11$	2.41 ± 0.42

agreement

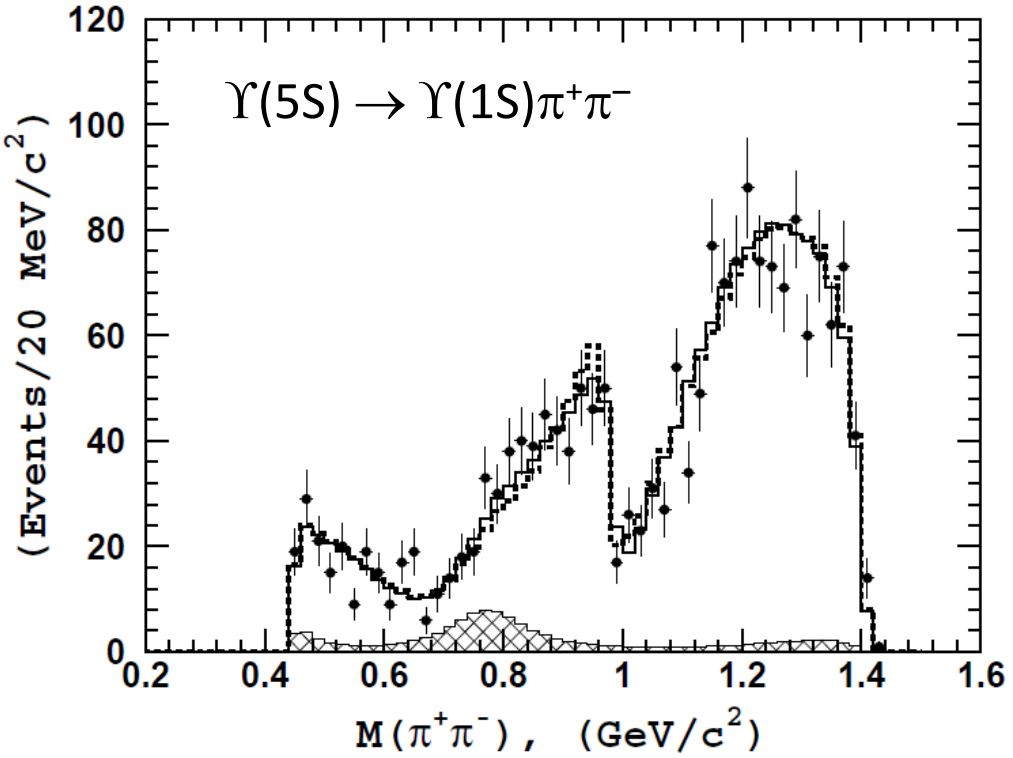
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$

$M(\pi^+\pi^-)$



Significance of

$\Upsilon(4S) \to \Upsilon(1S)f_0(980)$ is 2.8σ



Conclusions

Observation of X*(3860)

$\Rightarrow$ good $\chi_{c0}(2P)$ candidate

$$M = (3862^{+26+40}_{-32-13})\ \mathrm{MeV}/c^2$$

$$\Gamma = (201^{+154+88}_{-67-82})\ \mathrm{MeV}$$

$J^{PC} = 0^{++}$ are favored

Update of $e^+e^- \to D^{(*)+}D^{*-}$

accuracy improved by a factor of 2

cross sections for different polarizations are measured

Hadronic transitions from $\Upsilon(4S)$

BaBar result on $\Upsilon(4S) \to \Upsilon(1S)\eta$ is confirmed

hint of $\Upsilon(4S) \to \Upsilon(1S)\ f_0(980)$