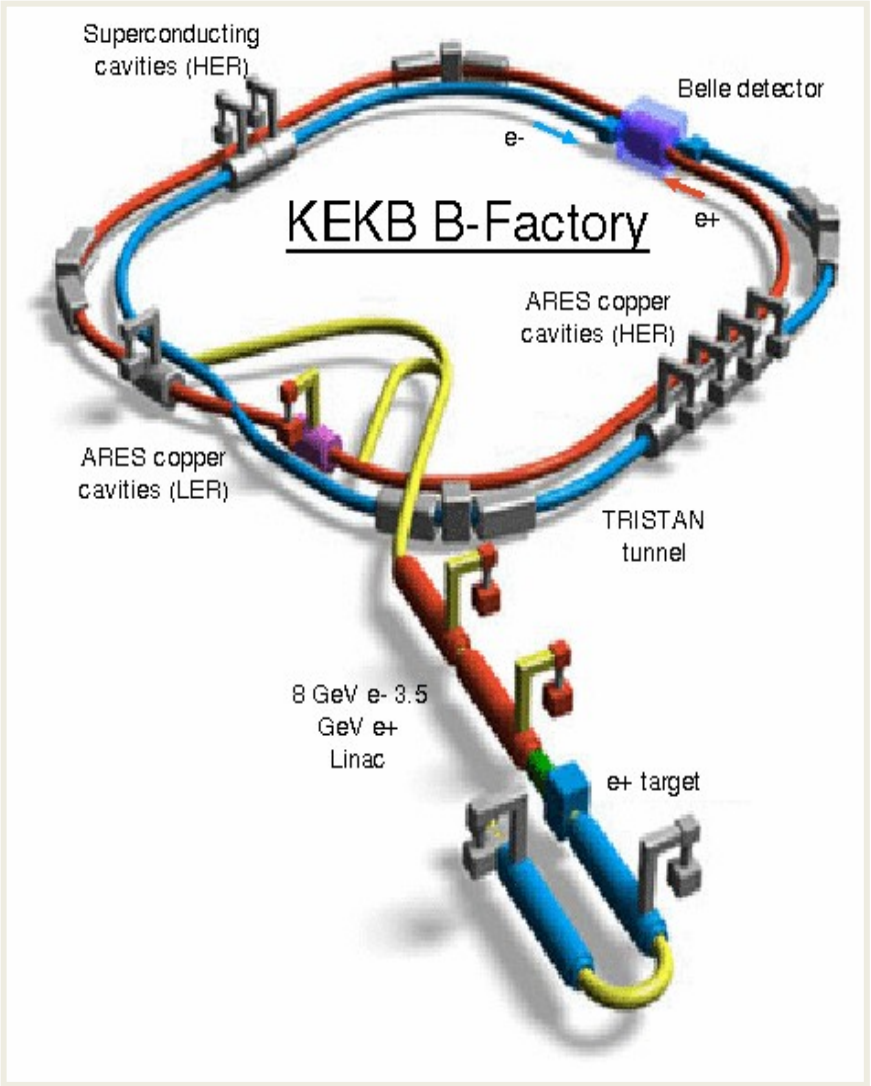
ISR Studies of the Charmonium Region at Belle

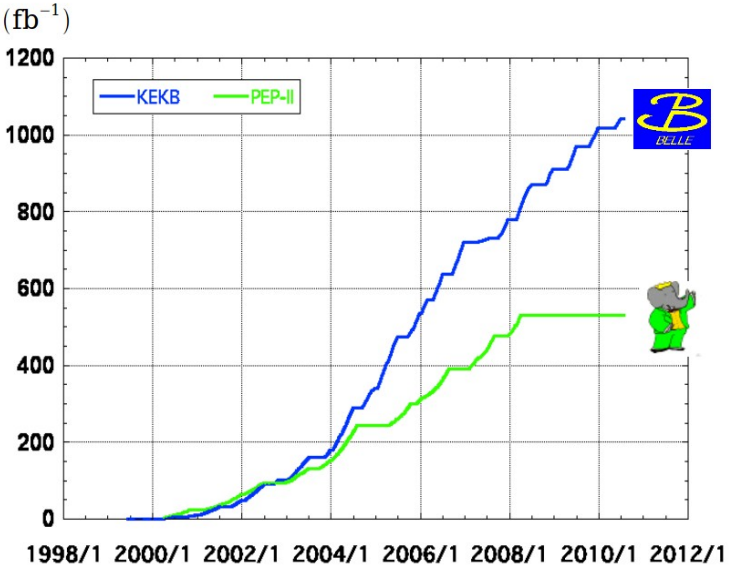
Timofey Uglov

MIPT

KEKB accelerator



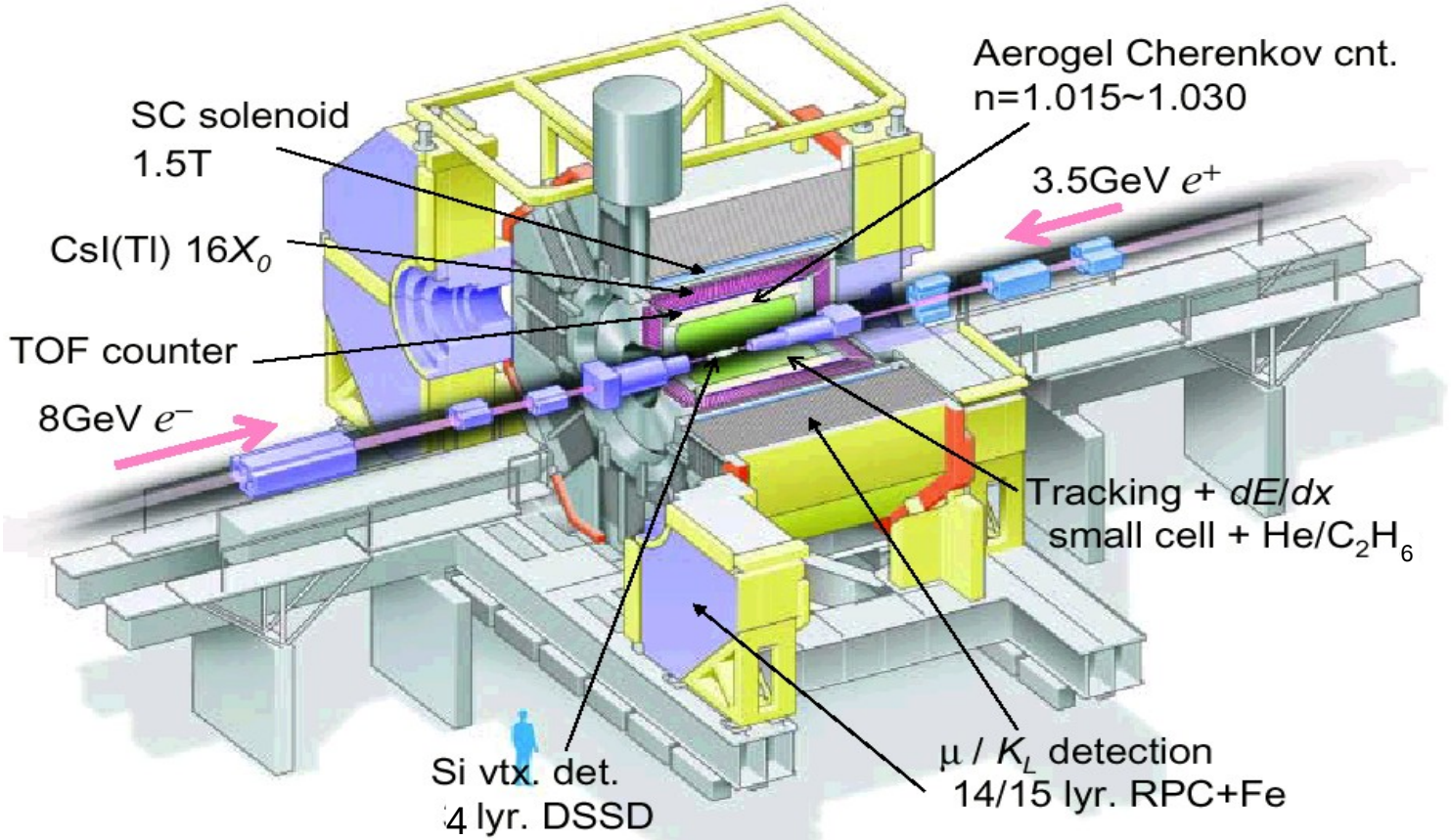
Integrated luminosity of B factories



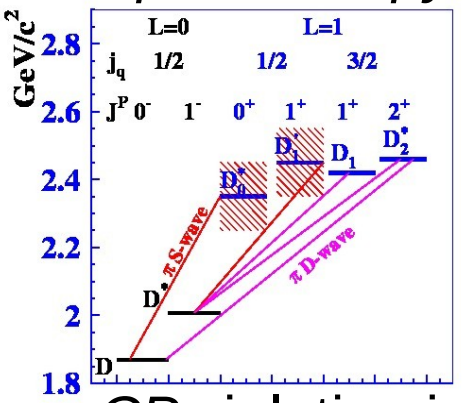
> 1 ab^{-1}
On resonance:
Υ(5S): 121 fb^{-1}
Υ(4S): 711 fb^{-1}
Υ(3S): 3 fb^{-1}
Υ(2S): 25 fb^{-1}
Υ(1S): 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
Υ(4S): 433 fb^{-1}
Υ(3S): 30 fb^{-1}
Υ(2S): 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

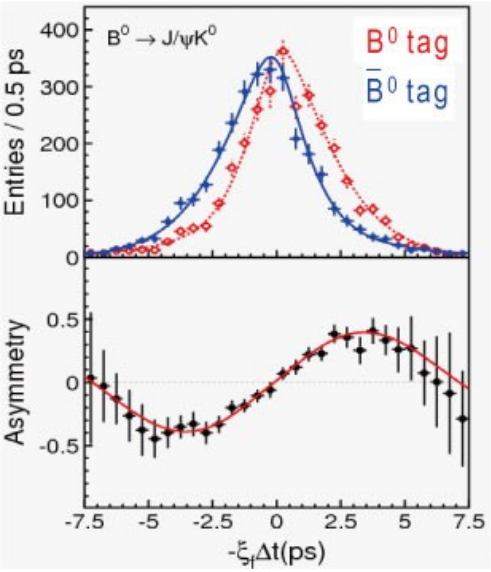
Belle achievements



Heavy hadrons spectroscopy



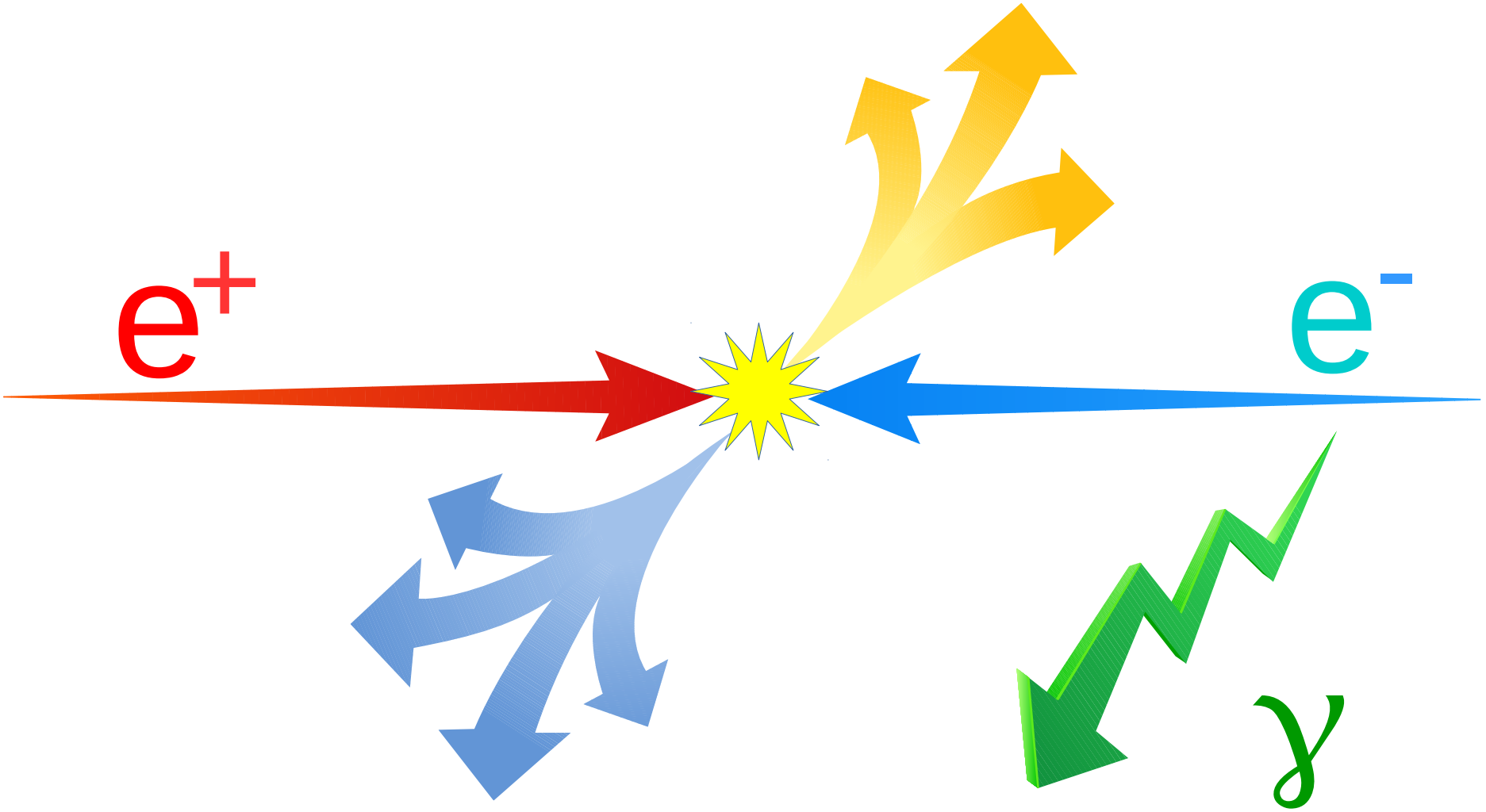
CP violation in B-mesons



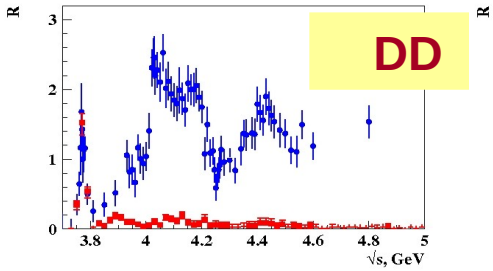
New charmonium-like states: X, Y, Z …

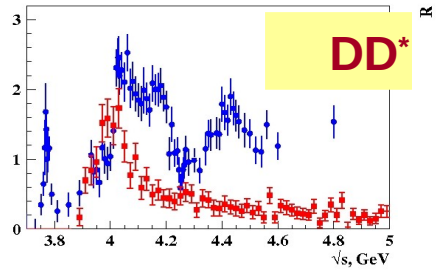
$\int \mathcal{L} dt > 1000\ fb^{-1}$

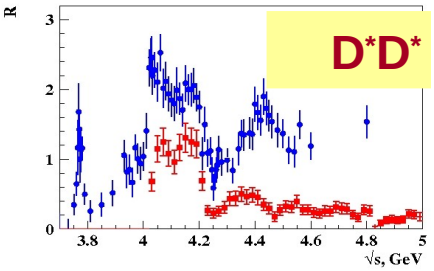
ISR measurements: technique

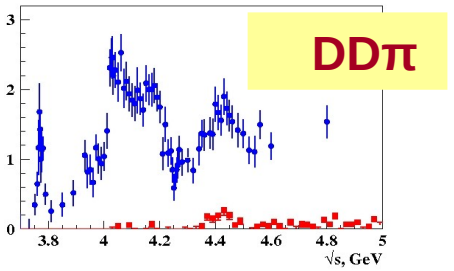


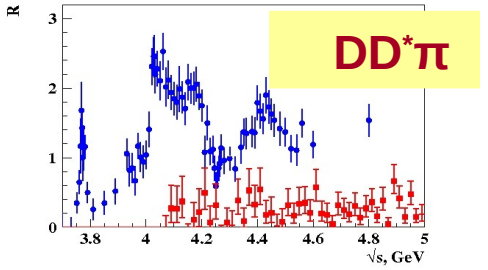
Open-charm cross-section

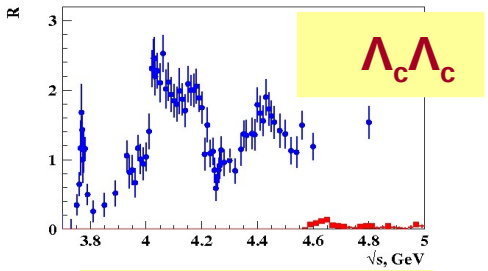


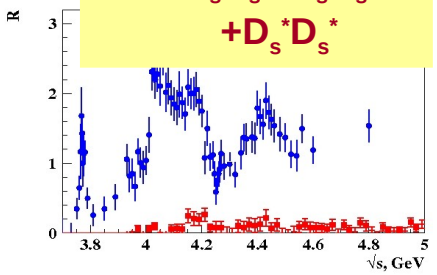




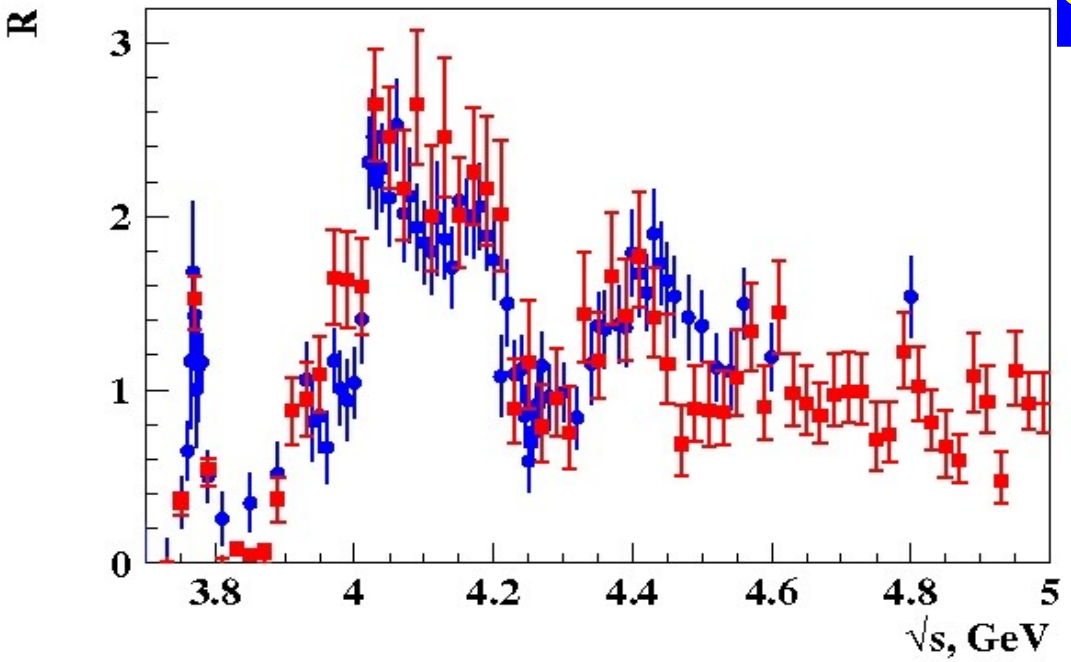






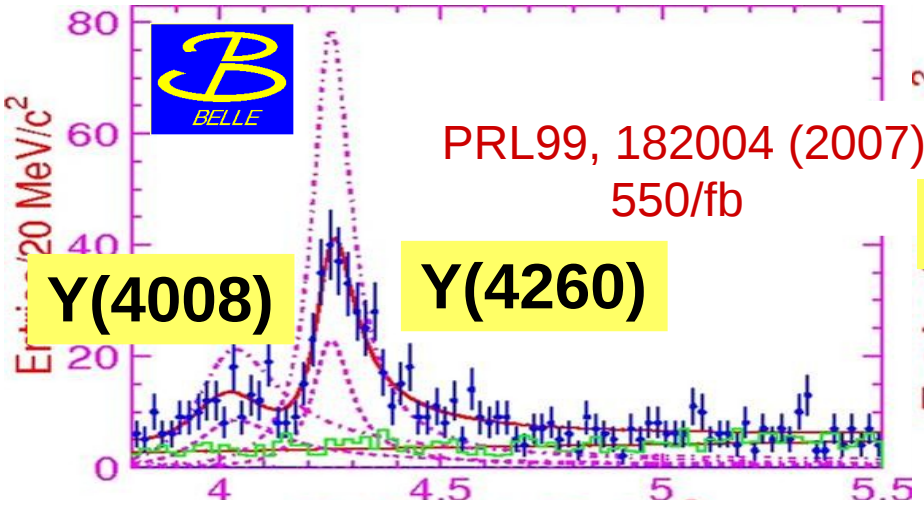


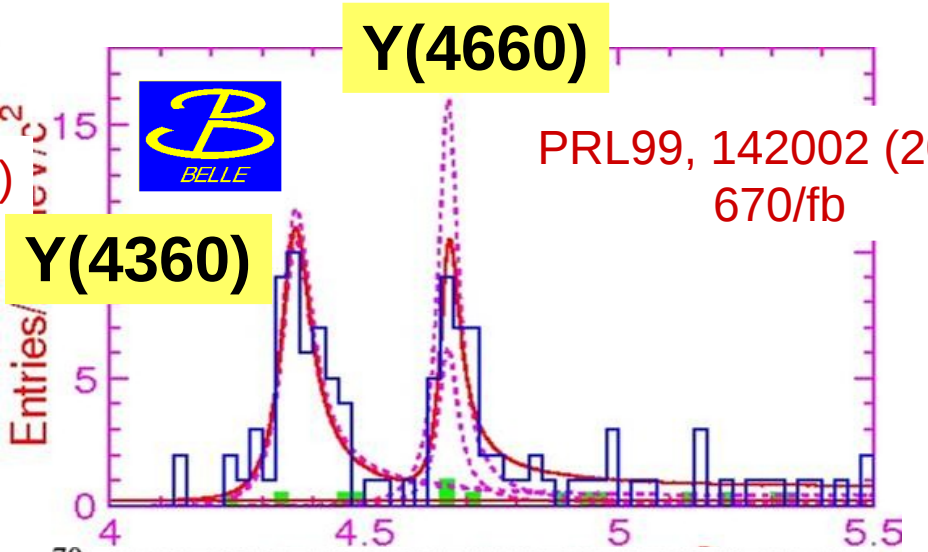
Exclusive cross sections contribution to the total cross section

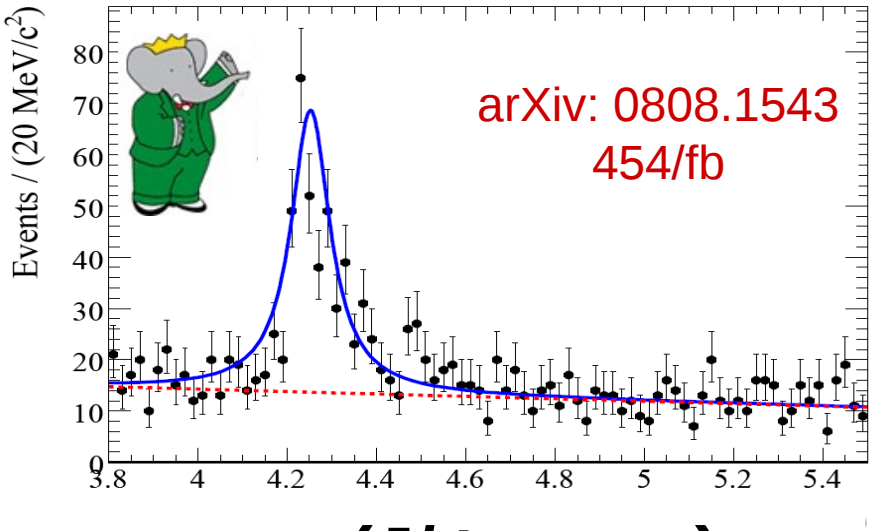


Contributions of D^+D^{*-}, $D^{*+}D^{*-}$, $D^0D^-\pi^+$ and $D^0D^{*-}\pi^+$ are scaled following isospin symmetry

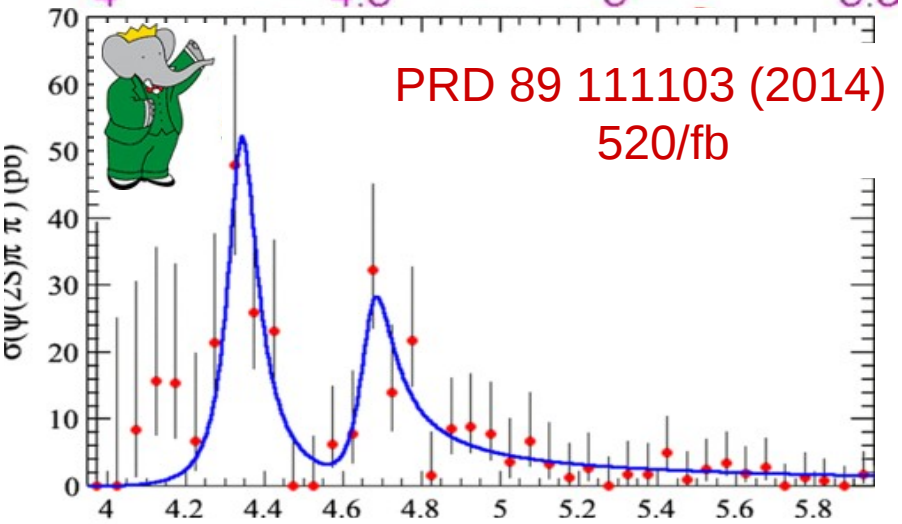
Hidden charm: 1^{--} Y-family







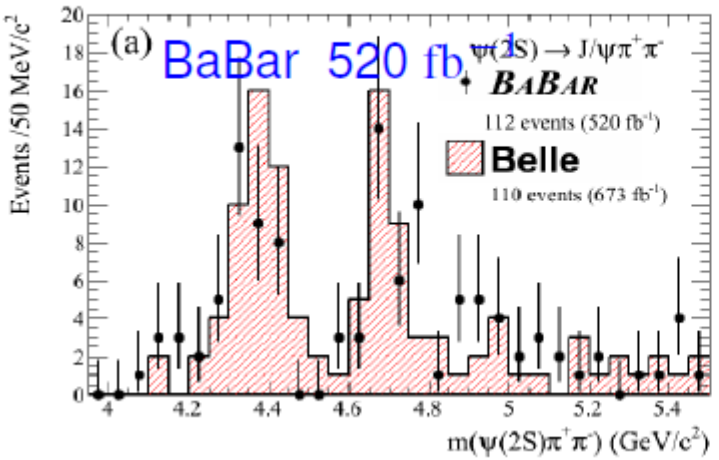
m(J/ψ π+π-)



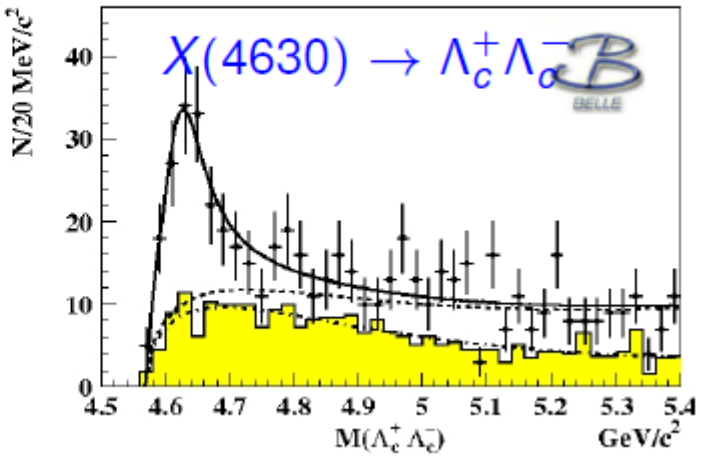
m(ψ(2S) π+π-)

Y-family puzzles

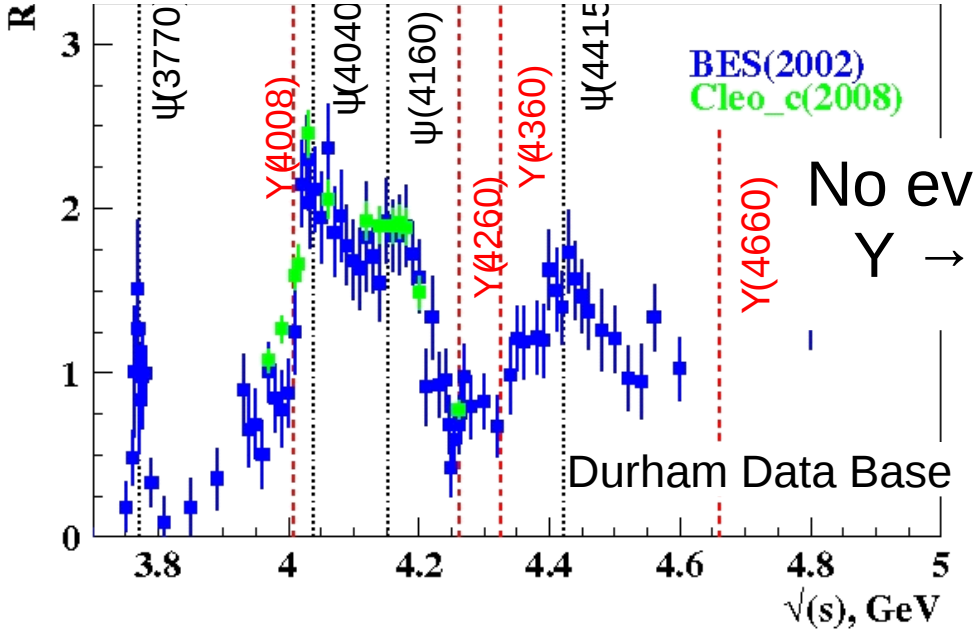
PRD89,111103(R)(2014)



PRL101,172001(2008)



Y(4660)=X(4630)
???

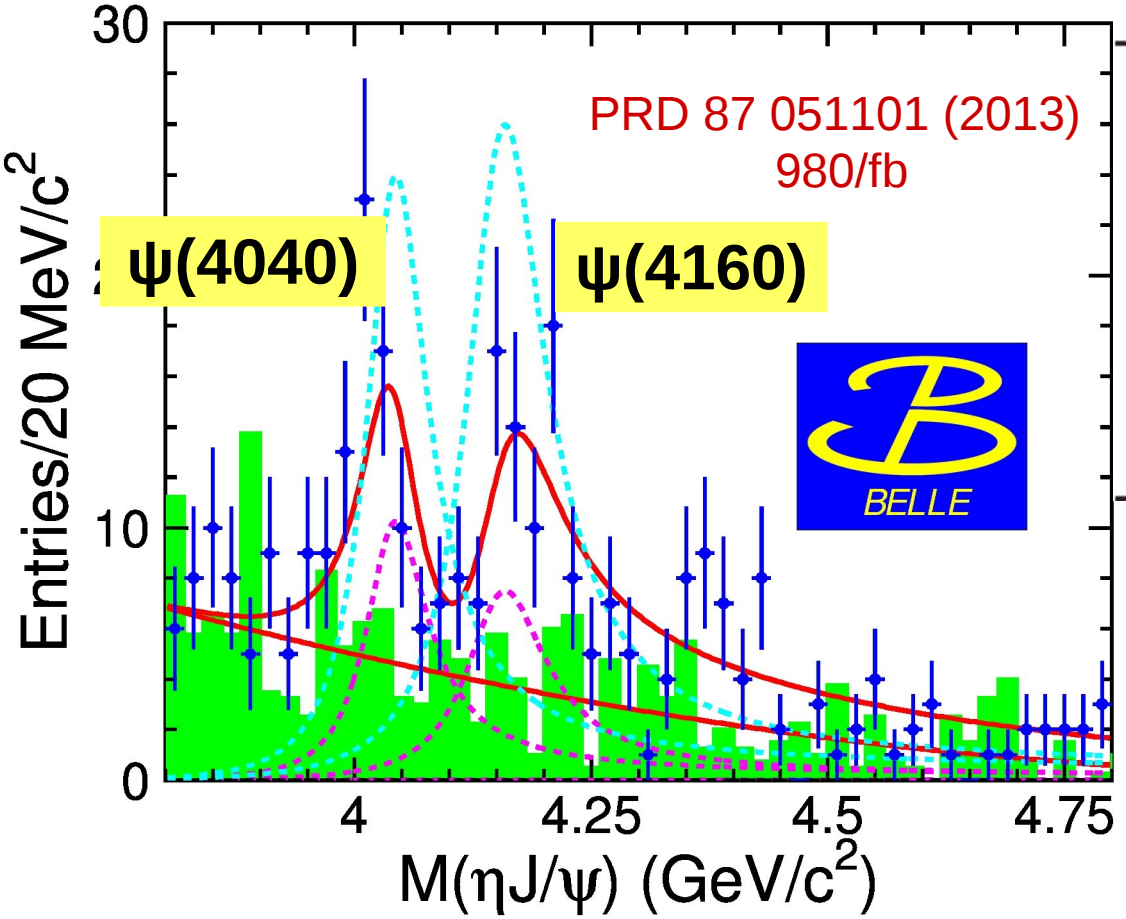


No evidence for
Y → hadrons

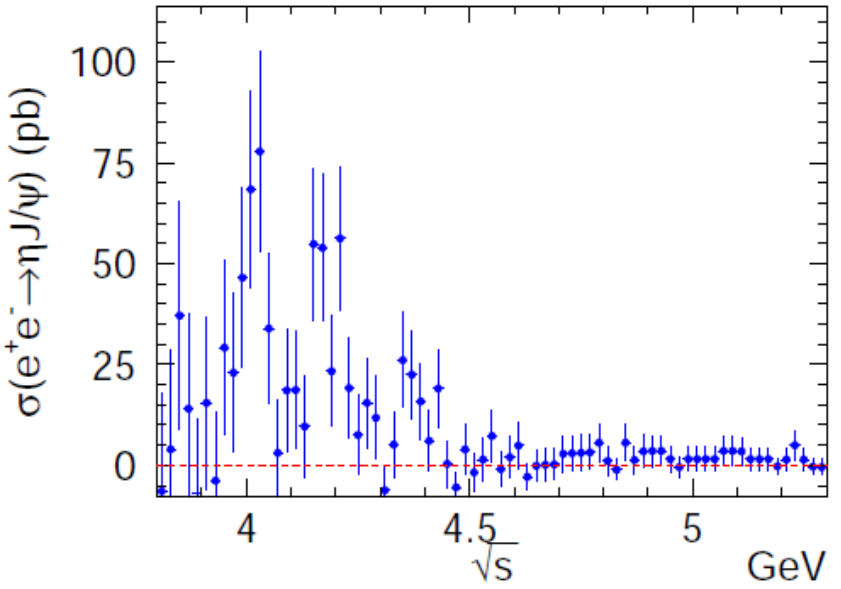
Reprocessed Belle data:
higher efficiency

Another hunt for Y

$e^+e^- \to J/\psi\,\eta + \gamma_{ISR}$

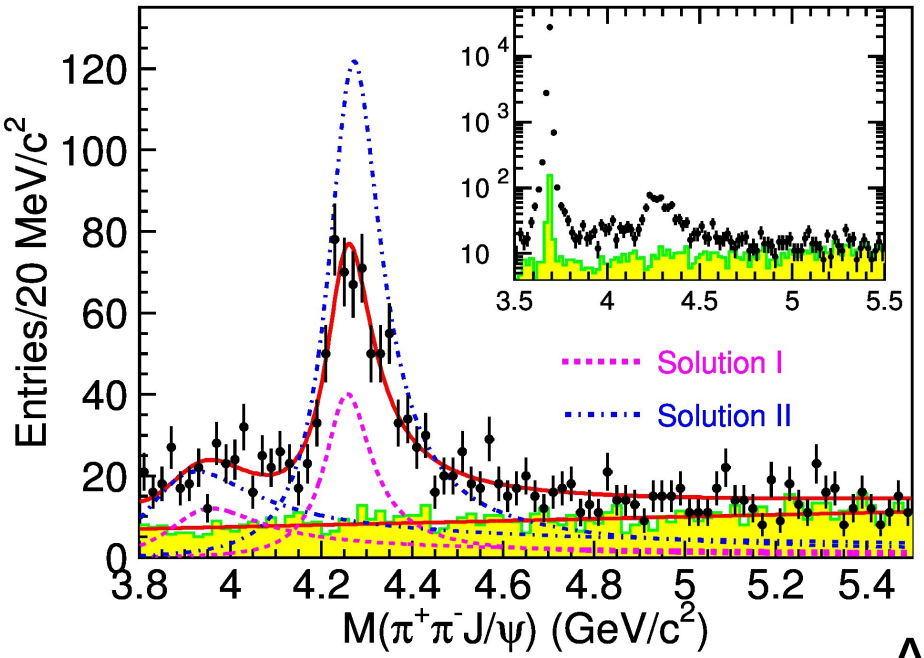


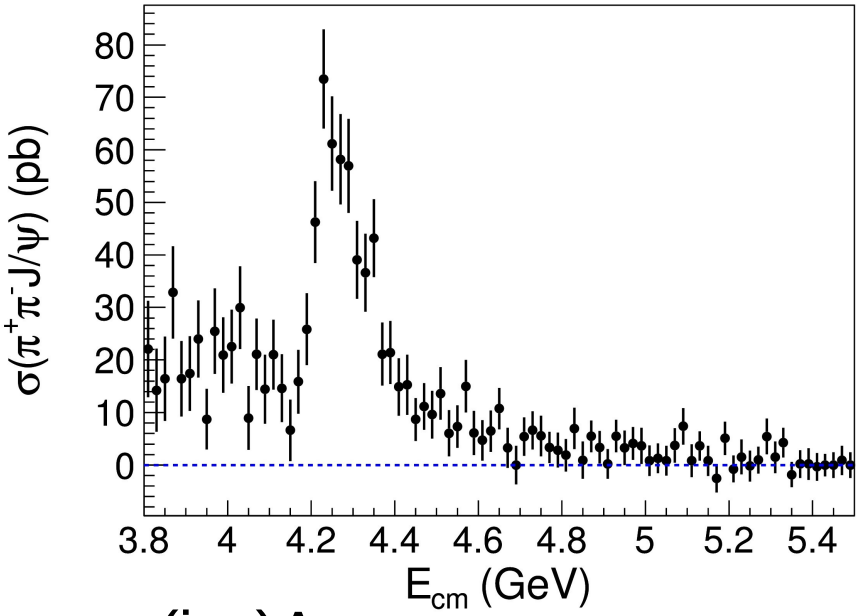
Parameters	Solution I	Solution II
$M_{\psi(4040)}$	4039 (fixed)	
$\Gamma_{\psi(4040)}$	80 (fixed)	
$\mathcal{B}\cdot\Gamma_{e^+e^-}^{\psi(4040)}$	$4.8 \pm 0.9 \pm 1.4$	$11.2 \pm 1.3 \pm 1.9$
$M_{\psi(4160)}$	4153 (fixed)	
$\Gamma_{\psi(4160)}$	103 (fixed)	
$\mathcal{B}\cdot\Gamma_{e^+e^-}^{\psi(4040)}$	$4.0 \pm 0.8 \pm 1.4$	$13.8 \pm 1.3 \pm 2.0$
ϕ	$336 \pm 12 \pm 14$	$251 \pm 4 \pm 7$



No evidence for
Y(4260), Y(4360), ψ(4415), or Y(4660)

$e^+e^- \to J/\psi\ \pi^+\pi^-\ +\ \gamma_{ISR}$





$A = A_1 + \exp(i\varphi_1)A_2$

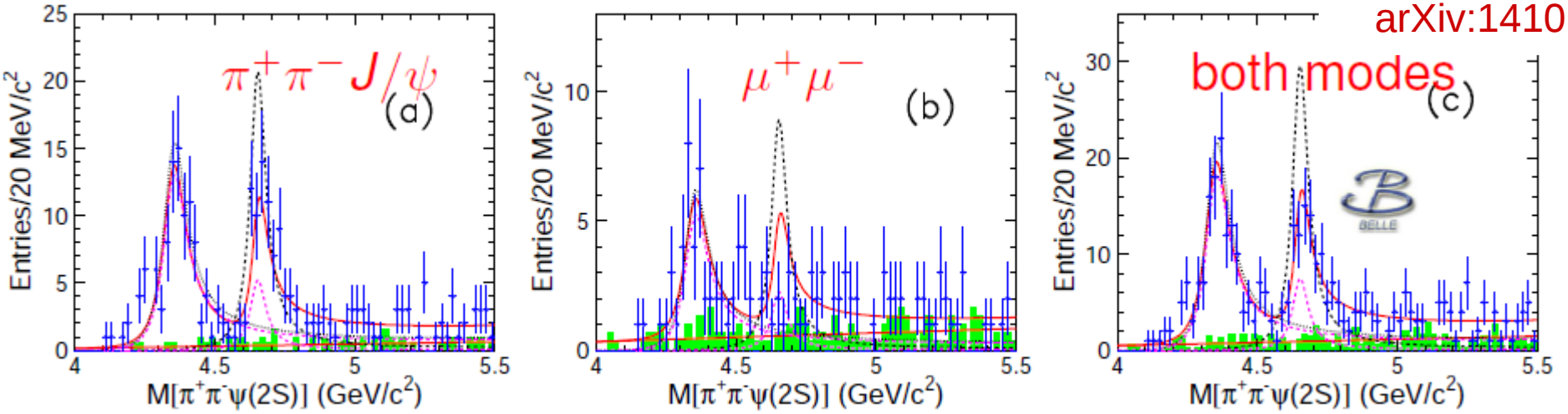
Y(4260) is observed

Y(4008) is confirmed

No structures found around D*D* threshold

Parameters	Solution I	Solution II
$M(R_1)$	$3890.8 \pm 40.5 \pm 11.5$	
$\Gamma_{\rm tot}(R_1)$	$254.5 \pm 39.5 \pm 13.6$	
$\Gamma_{ee}\mathcal{B}(R_1 \to \pi^+\pi^- J/\psi)$	$(3.8 \pm 0.6 \pm 0.4)$	$(8.4 \pm 1.2 \pm 1.1)$
$M(R_2)$	$4258.6 \pm 8.3 \pm 12.1$	
$\Gamma_{\rm tot}(R_2)$	$134.1 \pm 16.4 \pm 5.5$	
$\Gamma_{ee}\mathcal{B}(R_2 \to \pi^+\pi^- J/\psi)$	$(6.4 \pm 0.8 \pm 0.6)$	$(20.5 \pm 1.4 \pm 2.0)$
ϕ	$59 \pm 17 \pm 11$	$-116 \pm 6 \pm 11$

$e^+e^- \to \psi(2S)\ \pi^+\pi^-\ +\ \gamma_{ISR}$



arXiv:1410.7641

$A = A_1 + \exp(i\varphi_1)A_2$

Parameters	Solution I	Solution II
$M_{Y(4360)}$ (MeV/c^2)	$4347 \pm 6 \pm 3$	
$\Gamma_{Y(4360)}$ (MeV)	$103 \pm 9 \pm 5$	
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4360)}$ (eV)	$9.2 \pm 0.6 \pm 0.6$	$10.9 \pm 0.6 \pm 0.7$
$M_{Y(4660)}$ (MeV/c^2)	$4652 \pm 10 \pm 11$	
$\Gamma_{Y(4660)}$ (MeV)	$68 \pm 11 \pm 5$	
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4660)}$ (eV)	$2.0 \pm 0.3 \pm 0.2$	$8.1 \pm 1.1 \pm 1.0$
ϕ (°)	$32 \pm 18 \pm 20$	$272 \pm 8 \pm 7$

$\chi^2/ndf = 18.7/21$.

Add $\psi(2S) \to \mu^+\mu^-$ channel

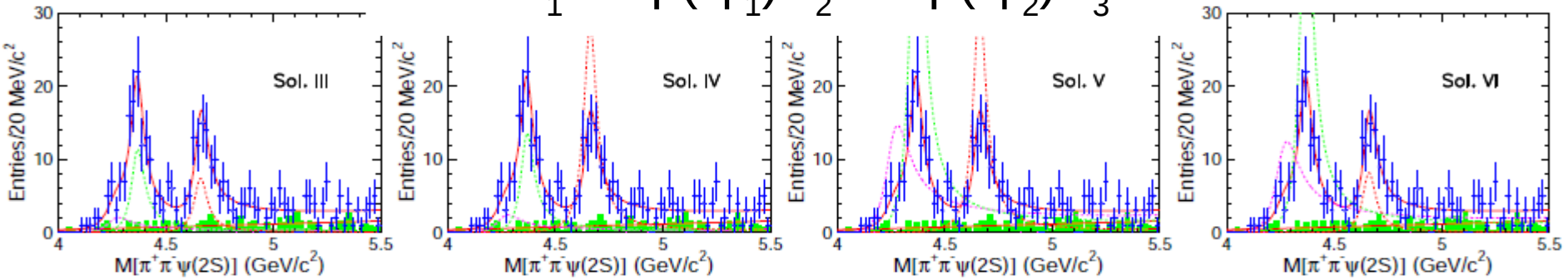
No signal above Y(4660)

Evidence for Y(4260) ?

$e^+e^- \to \psi(2S)\ \pi^+\pi^-\ +\ \gamma_{ISR}$

$$A = A_1 + \exp(i\varphi_1)A_2 + \exp(i\varphi_2)A_3$$

arXiv:1410.7641



Parameters	Solution I	Solution II	Solution III	Solution IV
$\mathcal{B}\cdot\Gamma^{e^+e^-}_{Y(4260)}$ (eV)	$1.5 \pm 0.6 \pm 0.4$	$1.7 \pm 0.7 \pm 0.5$	$10.4 \pm 1.3 \pm 0.8$	$8.9 \pm 1.2 \pm 0.8$
$M_{Y(4360)}$ (MeV/c^2)		$4365 \pm 7 \pm 4$		
$\Gamma_{Y(4360)}$ (MeV)		$74 \pm 14 \pm 4$		
$\mathcal{B}\cdot\Gamma^{e^+e^-}_{Y(4360)}$ (eV)	$4.1 \pm 1.0 \pm 0.6$	$4.9 \pm 1.3 \pm 0.6$	$21.1 \pm 3.5 \pm 1.4$	$17.7 \pm 2.6 \pm 1.5$
$M_{Y(4660)}$ (MeV/c^2)		$4660 \pm 9 \pm 12$		
$\Gamma_{Y(4660)}$ (MeV)		$74 \pm 12 \pm 4$		
$\mathcal{B}\cdot\Gamma^{e^+e^-}_{Y(4660)}$ (eV)	$2.2 \pm 0.4 \pm 0.2$	$8.4 \pm 0.9 \pm 0.9$	$9.3 \pm 1.2 \pm 1.0$	$2.4 \pm 0.5 \pm 0.3$
ϕ_1 (°)	$304 \pm 24 \pm 21$	$294 \pm 25 \pm 23$	$130 \pm 4 \pm 2$	$141 \pm 5 \pm 4$
ϕ_2 (°)	$26 \pm 19 \pm 10$	$238 \pm 14 \pm 21$	$329 \pm 8 \pm 5$	$117 \pm 23 \pm 25$

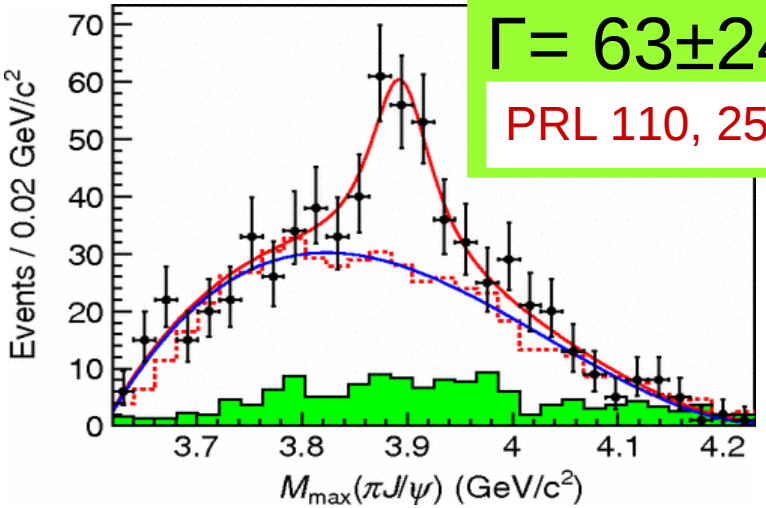
Almost the same fit quality for all four solutions ($\chi^2/n.d.f.$=14.8/19)
Significance of Y(4260)~2.4σ, but affects M and Γ of other Y's

$Z_c(3900)$ discovery

Belle

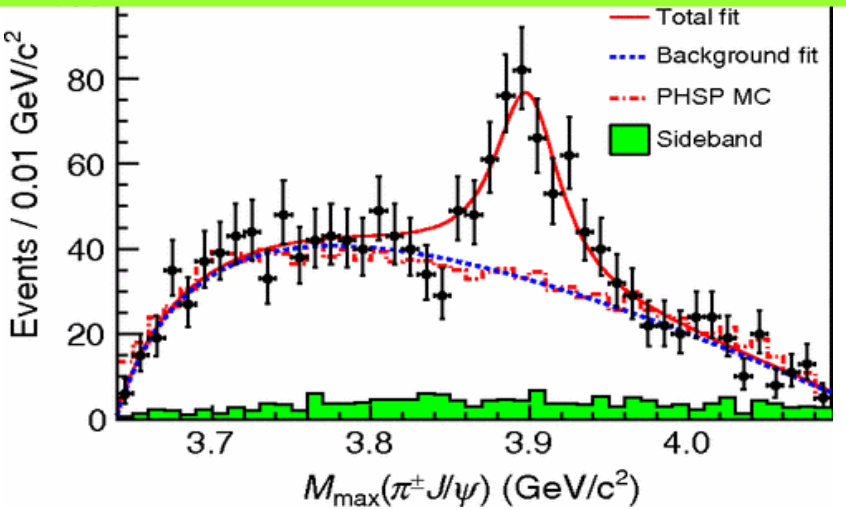
$M=3894.5\pm6.6\pm4.5$ MeV/c^2
$\Gamma= 63\pm24\pm26$ MeV
PRL 110, 252002 (2013)

$\Upsilon(4260)$
$\rightarrow Z(3900)\pi$
$\rightarrow J/\psi\pi\pi$



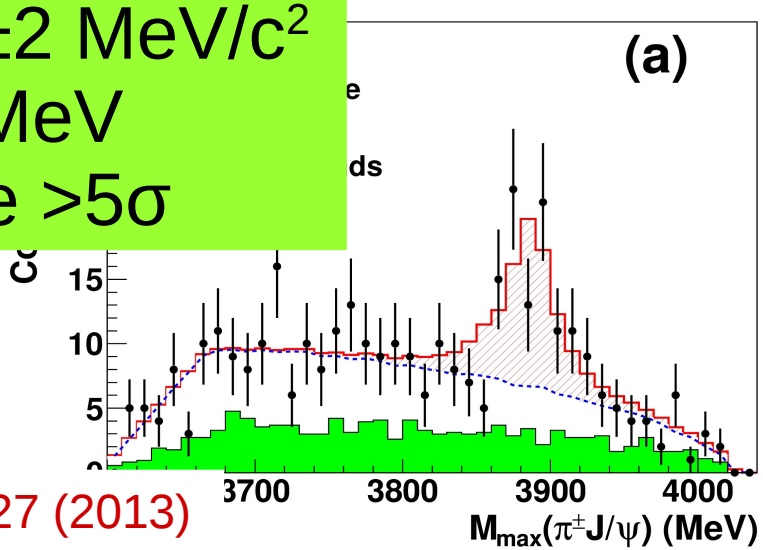
$M=3899.0\pm3.6\pm4.9$ MeV/c^2
$\Gamma= 46\pm10\pm20$ MeV
PRL 110, 252001 (2013)

BES III



$M=3886\pm4\pm2$ MeV/c^2
$\Gamma=37\pm4\pm8$ MeV
Significance >5σ

CLEO-c

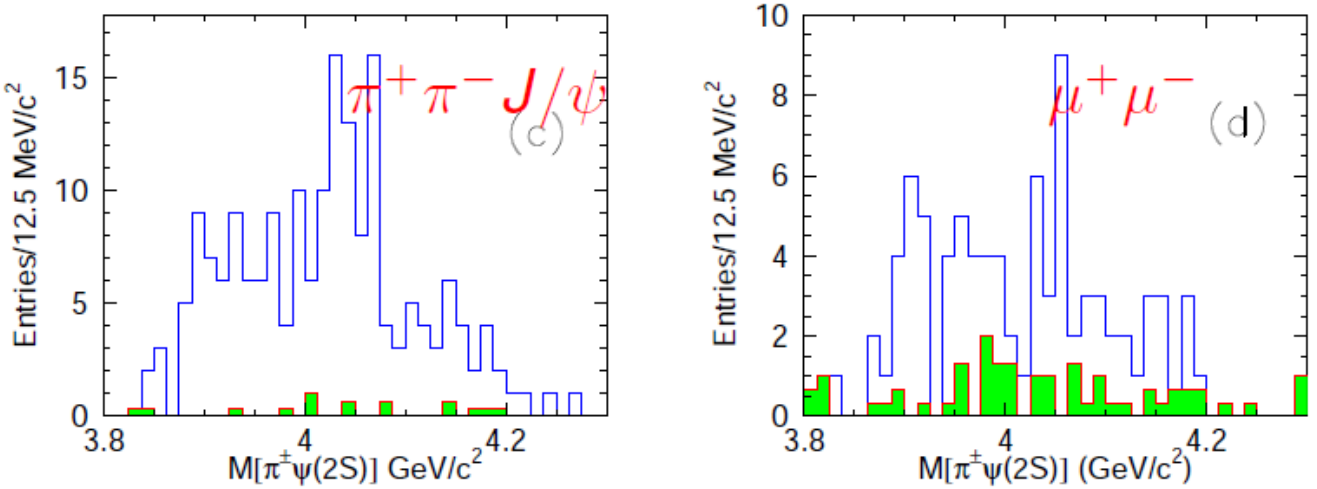


Phys. Lett. B 727 (2013)

$Z_c(4050)$?

$Y(4360) \rightarrow \psi(2S)\ \pi^+\pi^-$

arXiv:1410.7641



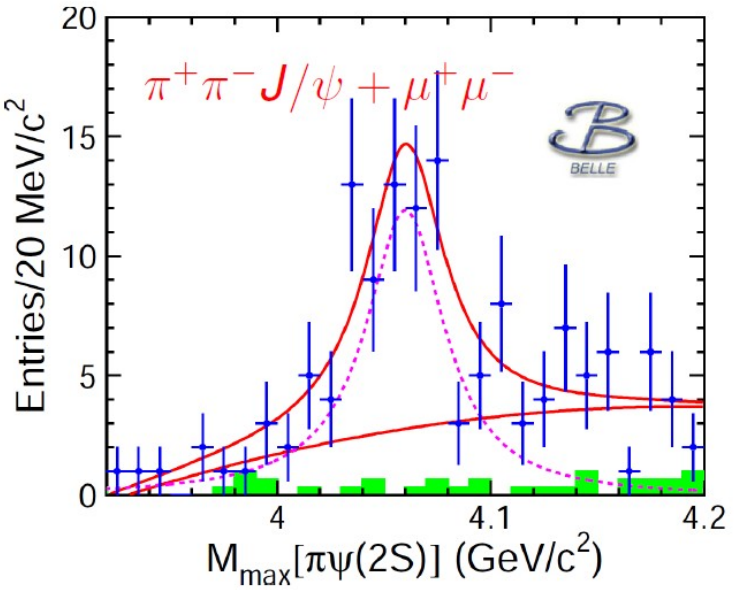
Y(4660) decay is dominated by $f_0(980)\psi(2S)$: no Z-like structures found

Excess in both channels near 4.05 MeV/c²

M=4054±3±1 MeV/c²

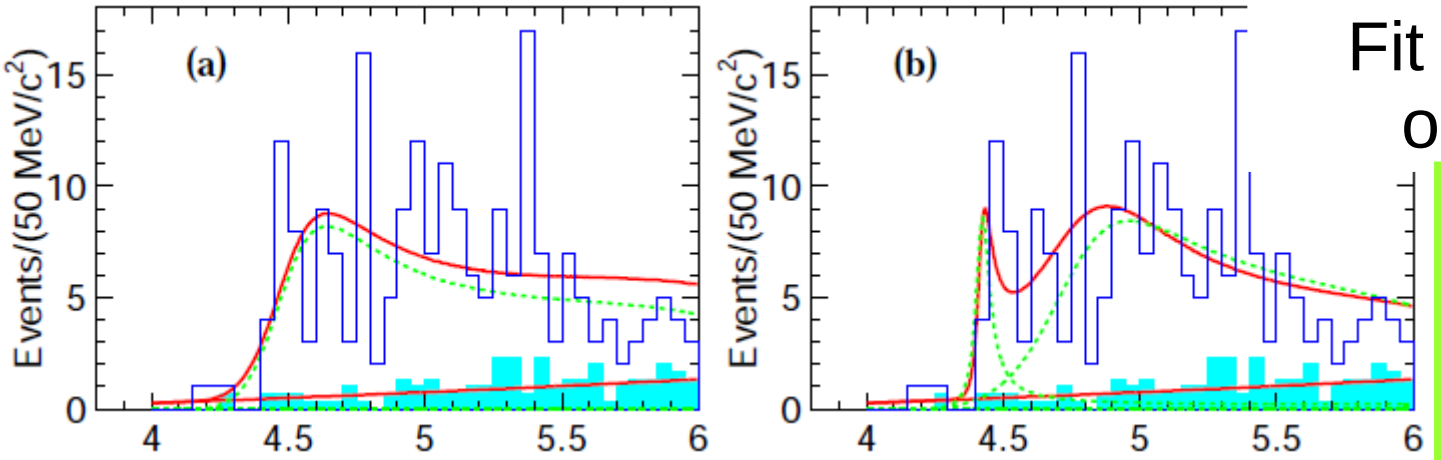
Γ=45±11±6 MeV

Significance 3.5σ



$e^+e^- \to J/\psi\ K^+K^-\ +\ \gamma_{ISR}$

PRD 89 072015 (2014)

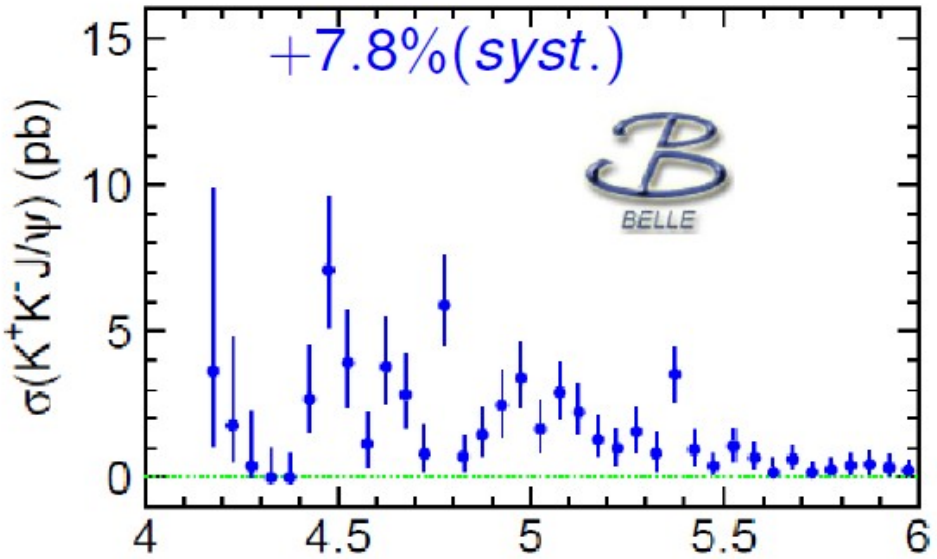


Fit with ψ(4415) + one resonance

M=4742±117±1 MeV/c^2

Γ=617±86 MeV

X^2/n.d.f.=30/11



No evidence for Z_{cs} resonance in KJ/ψ system

Summary

- Increased reconstruction efficiency and huge data sample allows Belle to improve latest results of the charmonium studies with ISR photon.
- In $e^+e^- \to J/\psi\ \pi^+\pi^- + \gamma_{ISR}$ channel Y(4008) and Y(4260) are confirmed; Y(4260) decay to a new Zc(3900) state is observed.
- In $e^+e^- \to \psi(2S)\ \pi^+\pi^- + \gamma_{ISR}$ channel Y(4360) and Y(4660) are confirmed; evidence for Y(4360) decay to a new Zc(4050) state is observed (3.5σ).
- Cross-sections for $e^+e^- \to J/\psi\ \pi^+\pi^-$, $e^+e^- \to \psi(2S)\ \pi^+\pi^-$, $e^+e^- \to J/\psi$ KK, $e^+e^- \to J/\psi\ \eta$ are measured
- New data from Belle2 could solve problems in charmonium region, clarify the nature of the exotic charmonia