UNIVERSITY OF Cincinnati

Study of Quarkonium(-like) States at Belle

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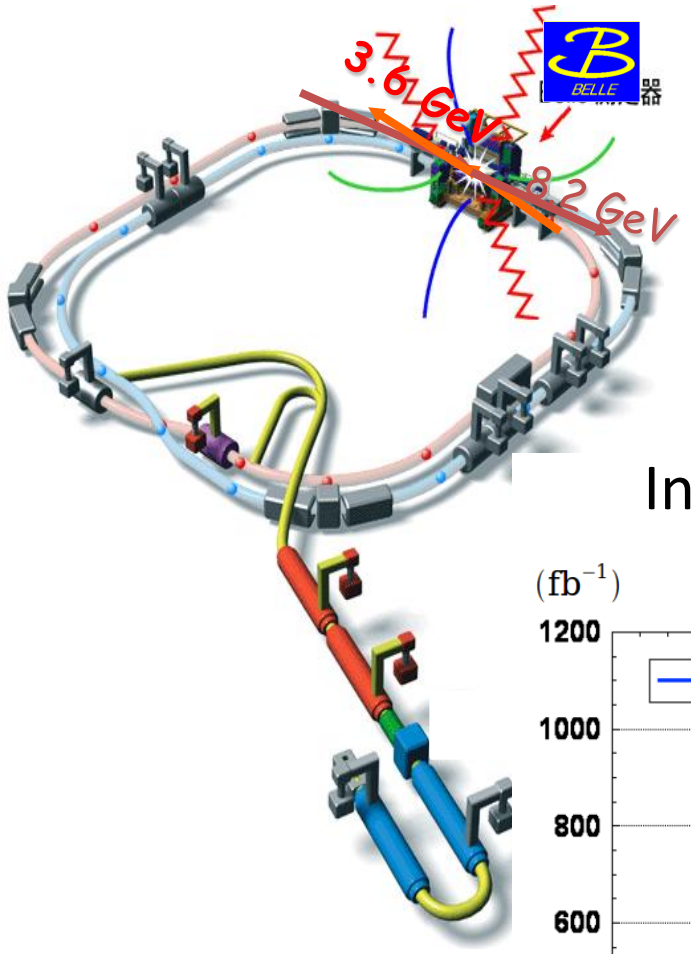
Deep Inelastic Scattering April, 2013

1. Bottomonium at $\Upsilon(5S)$ Preliminary Results
    1. Search for Z_b^0 in $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^0\pi^0$
2. Results in Charmonium
    1. Confirmation of Y(4008)
    2. Observation of $Z^{\pm}(3895)$

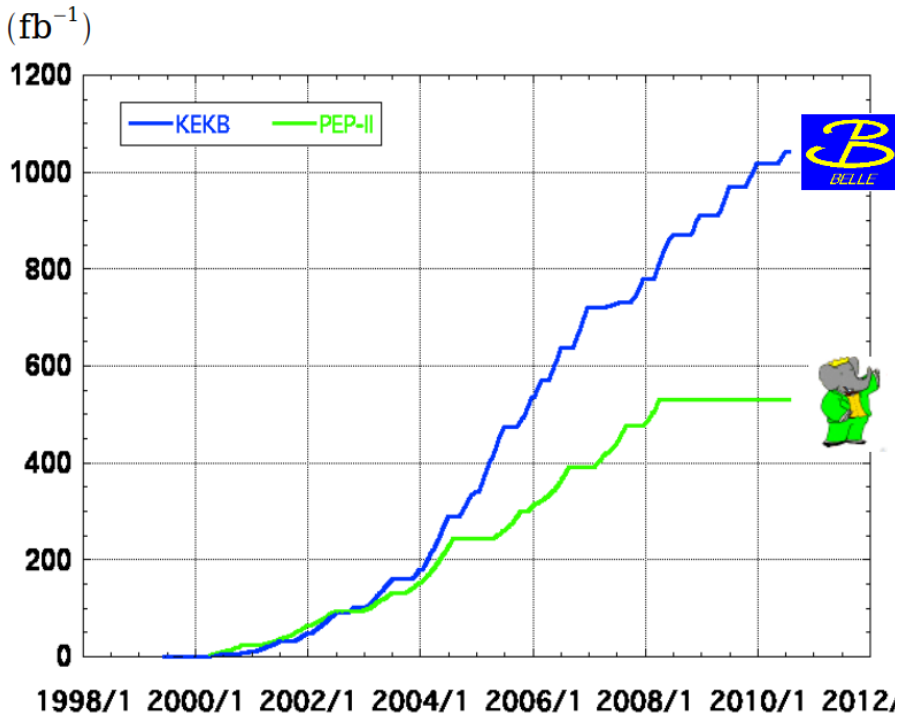


KEKb

Tsukuba, Japan

- Asymmetric e^+e^- storage rings

Integrated Luminosity



Res/E_{CM}(GeV)/lum

Υ(1S): 9.46, 5.75 fb^{-1}
Υ(2S): 10.02, 25 fb^{-1}
Υ(3S): 10.36, 2.95 fb^{-1}
Υ(4S): 10.58, 710.5 fb^{-1}
Υ(5S): 10.87, 121.4 fb^{-1}

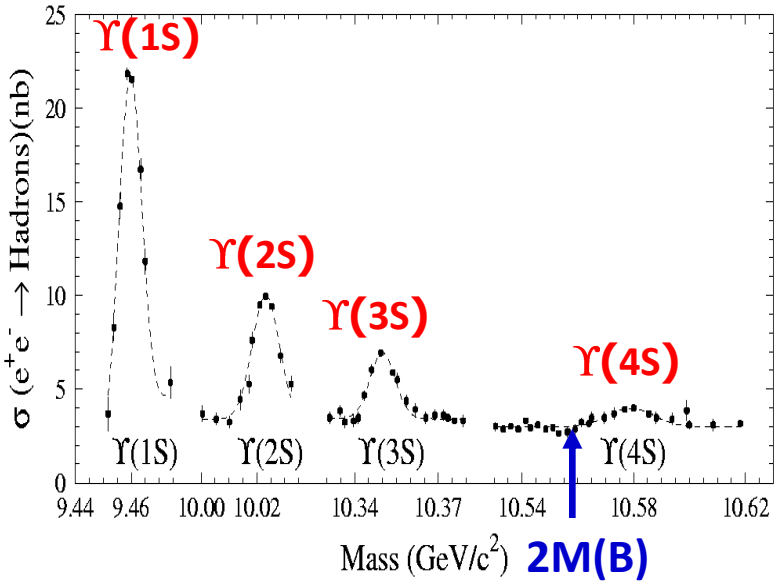
Off resonance/scan:
~100 fb^{-1}

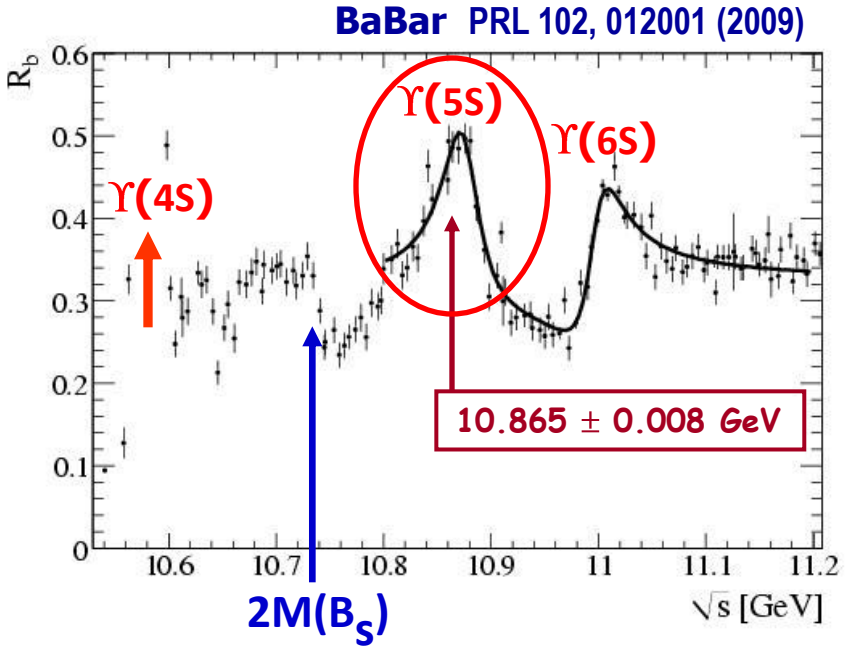
Υ(2S): 10.02, 14 fb^{-1}
Υ(3S): 10.36, 30 fb^{-1}
Υ(4S): 10.58, 433 fb^{-1}

Off resonance:
~54 fb^{-1}

Υ(nS)

Bottomonium ($b\bar{b}$) s=1, ℓ=0, $J^{PC}=1^{--}$





Υ(4S) just above $B\overline{B}$ threshold, 96% $B\overline{B}$ decays $\Rightarrow$B studies, CP violation, etc.

(Υ(5S)) just above $B_s^{(*)}\overline{B}_s^{(*)}$ threshold, ~60% $B^{(*)}\overline{B}^{(*)}X$, ~20% $B_s^{(*)}\overline{B}_s^{(*)}$, few bottomonia $\Rightarrow B_s$ studies

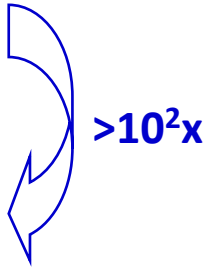
This talk

Puzzles of $\Upsilon(5S)$ decays

Anomalous production of $\Upsilon(nS)\,\pi^+\pi^-$

PRL100,112001(2008)

	Γ(MeV)
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019



Hypotheses

1. Rescattering $\Upsilon(5S) \to BB\pi^+\pi^- \to \Upsilon(nS)\pi^+\pi^-$
   Meng et al. Phys.Rev.D78:034022,2008

2. Tetraquark $\Upsilon(5S) \to T_{bb}\pi \to \Upsilon(nS)\pi^+\pi^-$
   Karliner et al. arXiv:0802.0649v2; Xiang Liu et al. Eur. Phys. J. C (2009) 61: 411–428; Yan-Rui Liu et al. Eur.Phys.J.C56:63-73,2008; N. Brambilla et al, Eur.Phys.J. C71 (2011) 1534; N. Brambilla et al. CERN Yellow Report, CERN-2005-005, Geneva: CERN, 2005.- 487 p.

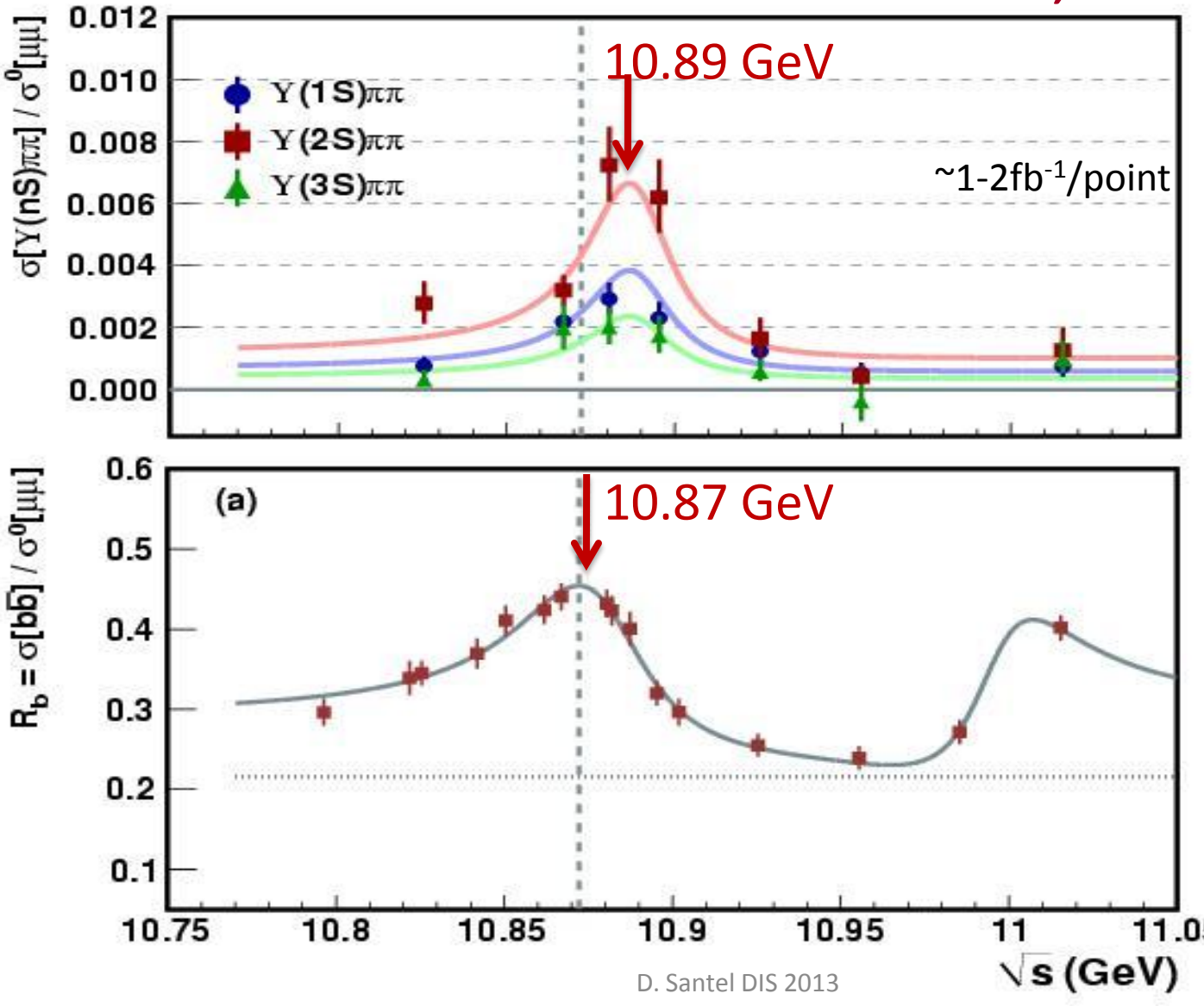
3. Exotic resonance Y_b near $\Upsilon(5S)$
   - analog of Y(4260) resonance with anomalous $\Gamma(J/\psi\,\pi^+\pi^-)$
   - Check shapes of R_b and $\sigma(\Upsilon\pi\pi)$ as function of E_{CM}

   Hou et al., Phys.Rev.D74:017504,2006
   Ali et al. Phys.Rev.Lett.104:162001,2010

Search for Anomalous Structure: Energy Scan

- R_b peaks at 10.87, $\sigma(\Upsilon\pi\pi)$ peaks at 10.89

PRD82,091106R(2010)



$\sigma[\Upsilon(nS)\pi\pi]/\ \sigma[\mu\mu]$

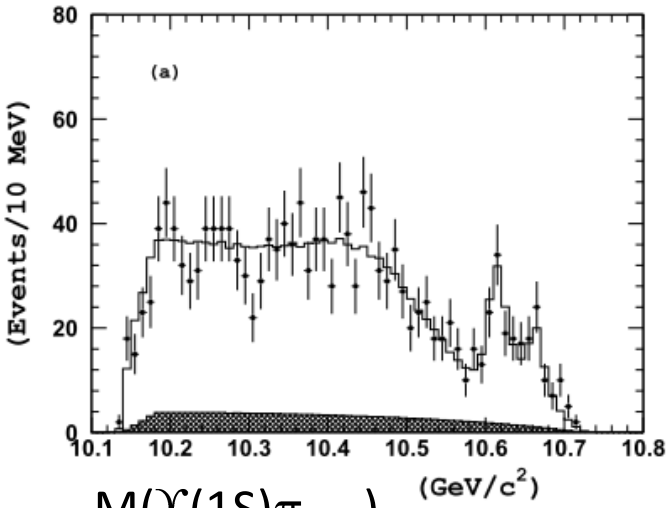
Define R_b:
$\sigma[bb]/\ \sigma[\mu\mu]$

$\sqrt{s}(GeV)$

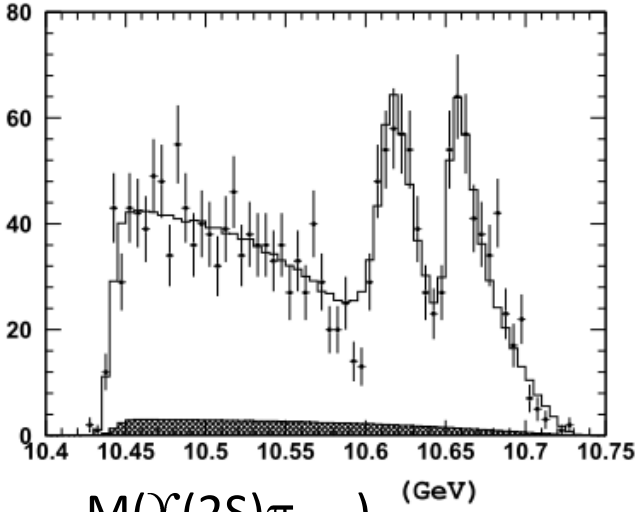
Observation of Charged $Z_b(10610)$, $Z_b(10650)$

PRL 108, 122001 (2012)

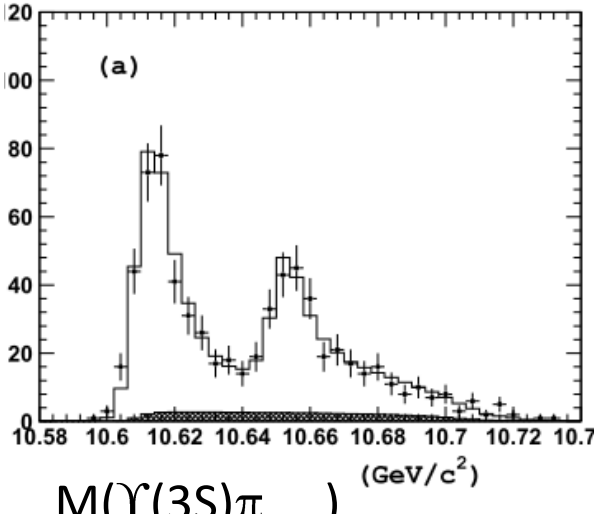
- $\Upsilon(5S) \rightarrow Z_b\pi^{\pm} \rightarrow h_b(nP)\pi^+\pi^-$ (n=1,2)
- $\Upsilon(5S) \rightarrow Z_b\pi^{\pm} \rightarrow \Upsilon(mS)\pi^+\pi^-$ (m=1,2,3)
- Average over 5 channels:
  - $Z_b(10610)$: M = 10607.2±2 MeV Γ=18.4±2.4 MeV
  - $Z_b(10650)$: M = 10652.2±1.5 MeV Γ=11.5±2.2 MeV



$M(\Upsilon(1S)\pi_{max})$



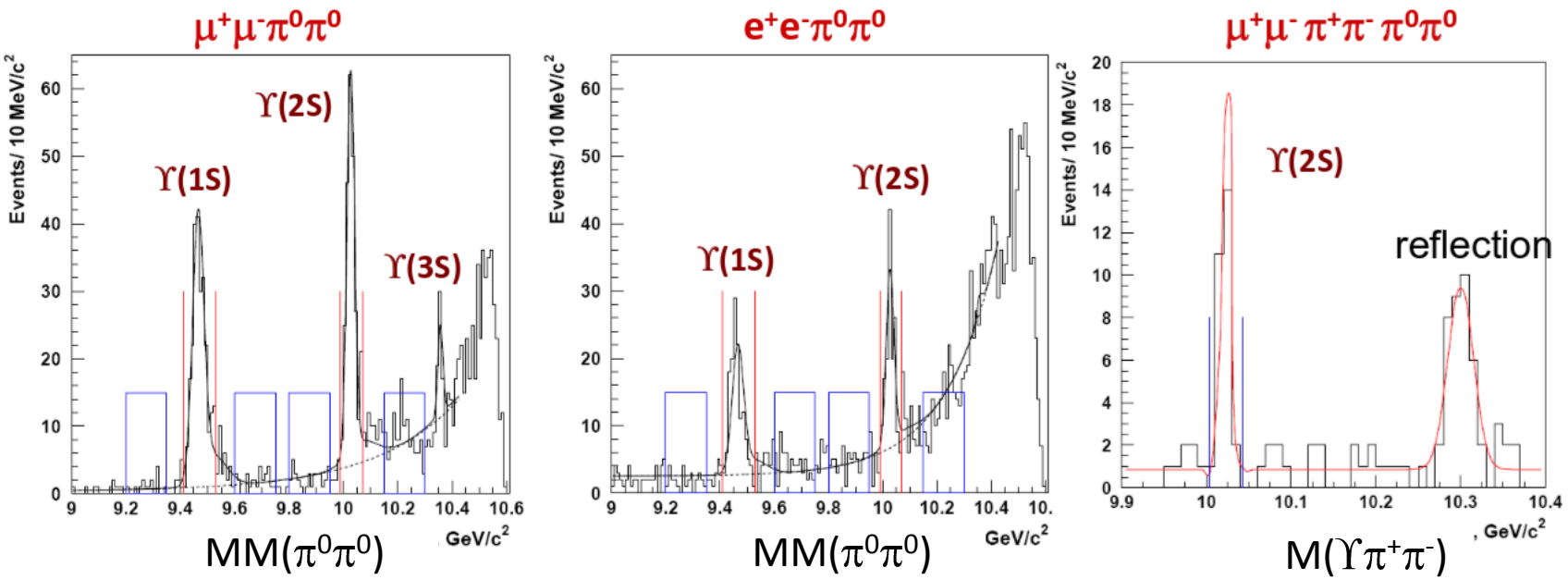
$M(\Upsilon(2S)\pi_{max})$



$M(\Upsilon(3S)\pi_{max})$

Search for Z_b^0: "$\Upsilon(5S)$"$\rightarrow\Upsilon(nS)\pi^0\pi^0$

$\Upsilon(1,2,3S)\rightarrow\mu^+\mu^-, e^+e^-$ $\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^+\pi^-$



$$MM(\pi^0\pi^0) = \sqrt{(E_{\Upsilon(5S)} - E^*_{\pi^0\pi^0})^2 - p^{*2}_{\pi^0\pi^0}}$$

PRELIMINARY

arXiv:1207.4345

BF[$\Upsilon(5S)\rightarrow\Upsilon(1S)\pi^0\pi^0$] = $(2.25\pm0.11\pm0.20)\ 10^{-3}$

BF[$\Upsilon(5S)\rightarrow\Upsilon(2S)\pi^0\pi^0$] = $(3.79\pm0.24\pm0.49)\ 10^{-3}$

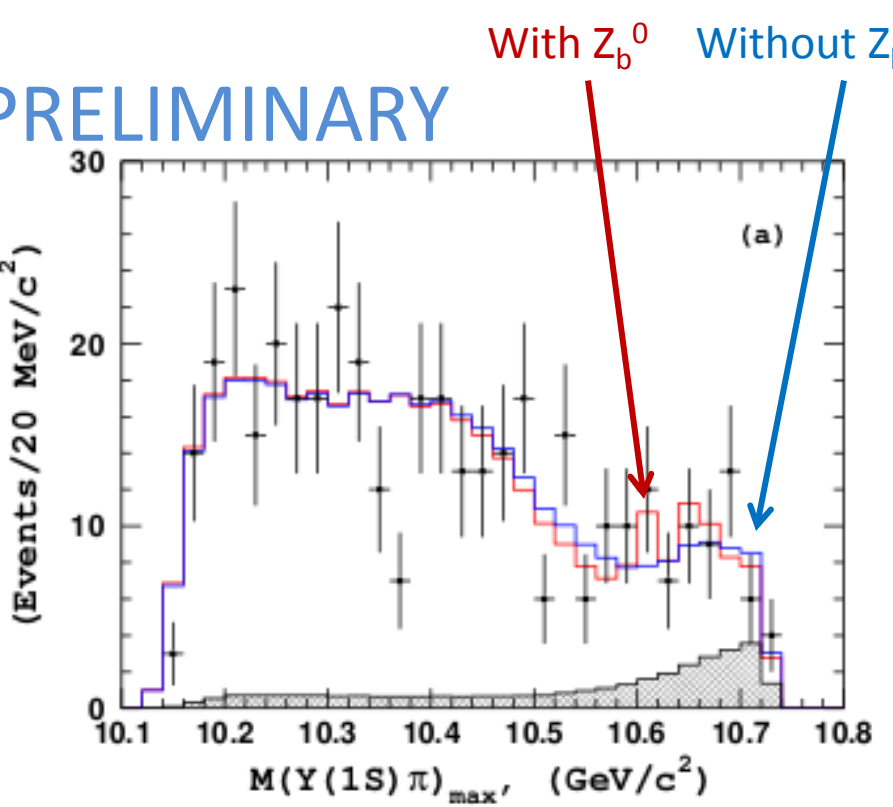
Consistent with 1/2 of $\Upsilon(5S)\rightarrow\Upsilon(nS)\pi^+\pi^-$

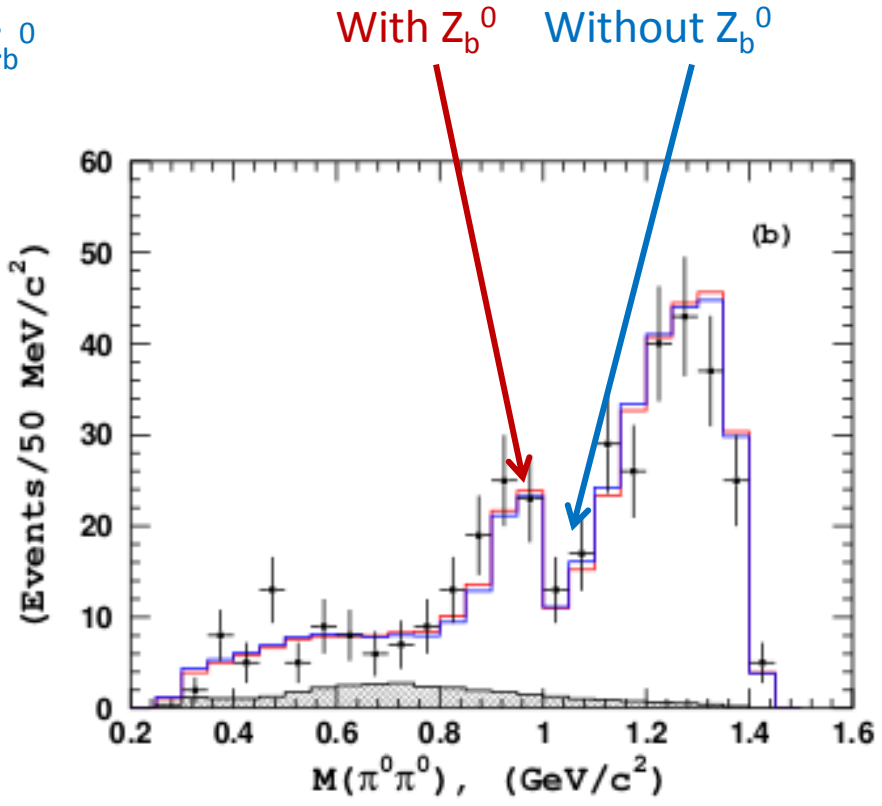
Dalitz Analysis of "$\Upsilon(5S)$"$\rightarrow\Upsilon(1S)\pi^0\pi^0$

$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- Z_b^0 signal is not statistically significant
  - Not excluded

PRELIMINARY





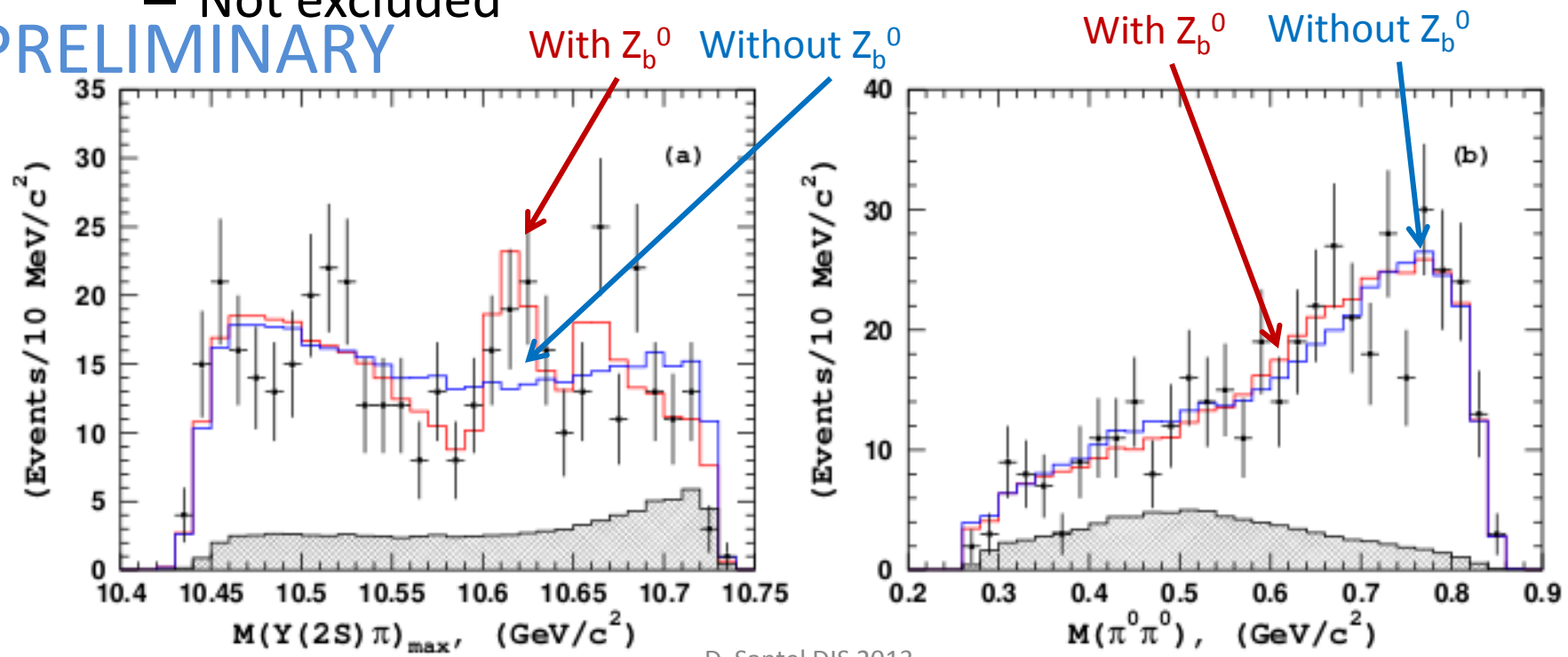
arXiv:1207.4345

Dalitz Analysis of "$\Upsilon(5S)$"$\rightarrow\Upsilon(2S)\pi^0\pi^0$

$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- $Z_b^0(10610)$ signal has statistical significance 5.3σ, 4.9σ with systematics
  - M=10609$\pm$8.6$\pm$6 MeV (Z_b^+ M = 10607.2$\pm$2 MeV)
- $Z_b^0(10650)$ not statistically significant (~2σ)
  - Not excluded

PRELIMINARY



arXiv:1207.4345

Charmonium-like Particles

Many identified:

- Y(4260) in $e^+e^- \to \gamma_{isr}\, J/\psi\pi^+\pi^-$ (BaBar) PRL 95, 142001 (2005)
- $Z(4430)^{\pm} \to \psi(2S)\pi^{\pm}$ in $B \to \psi(2S)K\pi$ (Belle) PRL 100, 142001 (2008)
- Two charged Zs $\to \chi_{c1}\pi^{\pm}$ in $B \to \chi_{c1}K\pi$ PRD 78, 072004 (2008)
- Y(4008)? (Belle) PRL 99, 182004 (2007)
  - BaBar attributed structure below Y(4260) to exponentially decreasing non-resonant $J/\psi\pi^+\pi^-$

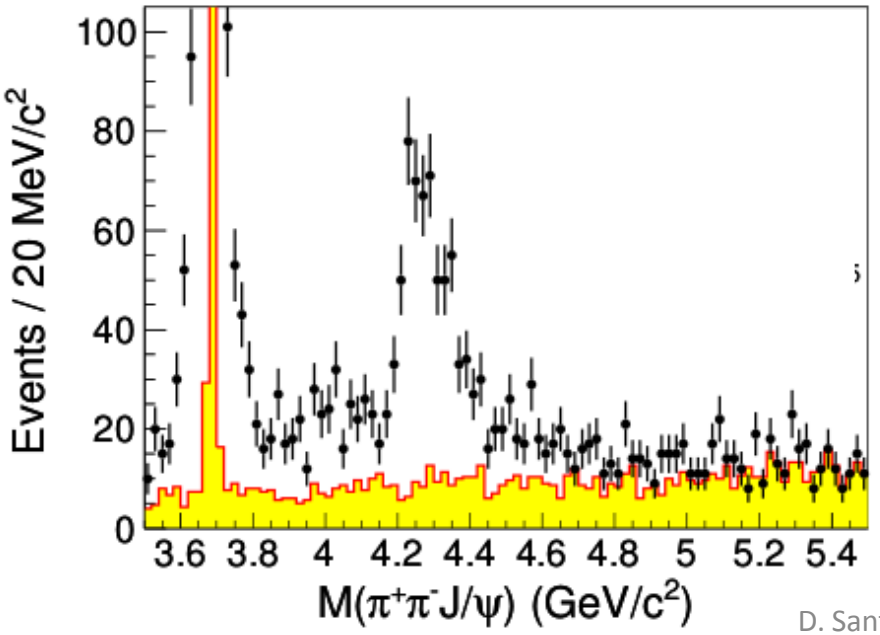
- Bottomonium-like: Two charged Z_bs $\to \Upsilon(nS)\pi^{\pm}$ in "$\Upsilon(5S)$" $\to \Upsilon(nS)\pi^+\pi^-$ (Belle) PRL 108, 122001 (2012)

New Result on Y(4260) and Y(4008)

Belle Preprint 2013-6
arXiv:1304.0121

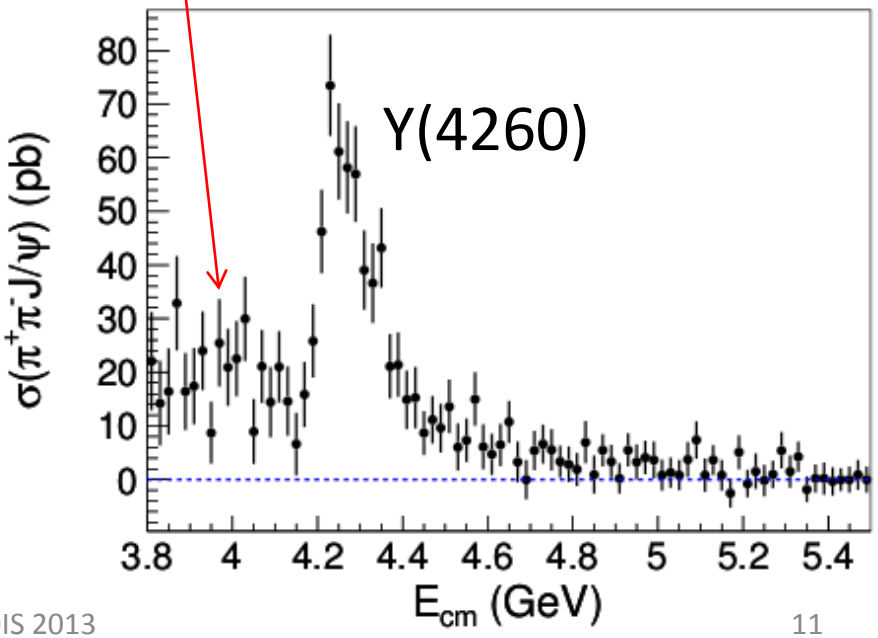
- Look for structure in Y(4260) $\rightarrow J/\psi\pi^+\pi^-$
  - Full 967 fb^{-1} Belle data set

Signal Normalized sideband



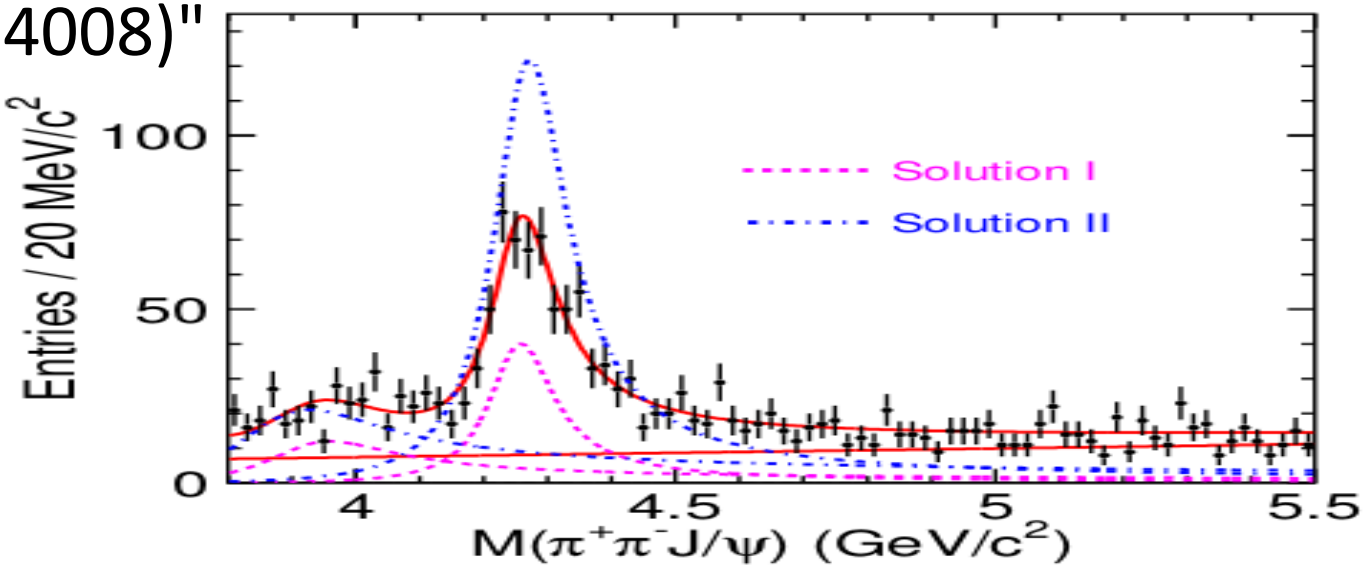
"Y(4008)"

Background-subtracted cross-section



New Result on Y(4260) and Y(4008)

- Fit of $M(\pi^+\pi^- J/\psi)$ to two coherent resonances, Y(4260) and "Y(4008)"



$M(R1) = 3980.8 \pm 40.5 \pm 11.5$ MeV
$\Gamma(R1) = 254.5 \pm 39.5 \pm 13.6$ MeV

"Y(4008)"

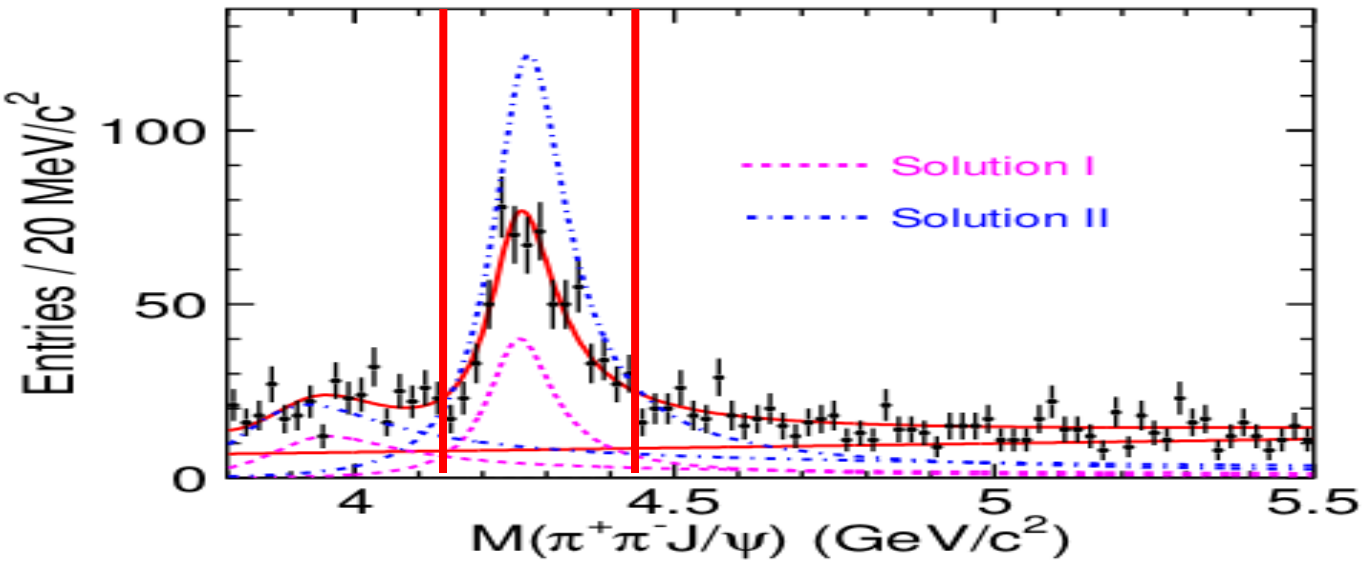
$M(R2) = 4258.6 \pm 8.3 \pm 12.1$ MeV
$\Gamma(R2) = 134.1 \pm 16.4 \pm 5.5$ MeV

Y(4260)

Two solutions for relative phase:
$\phi = 59 \pm 17 \pm 11$ $\quad -116 \pm 6 \pm 11$

Belle Preprint 2013-6
arXiv:1304.0121

Select Y(4260) Events

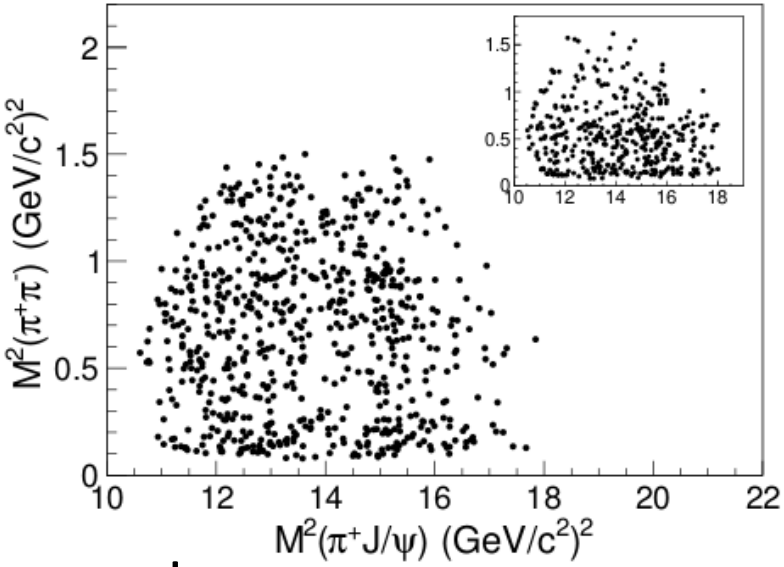


- Select 4.15 GeV < M($\pi^+\pi^-$J/ψ) < 4.45 GeV

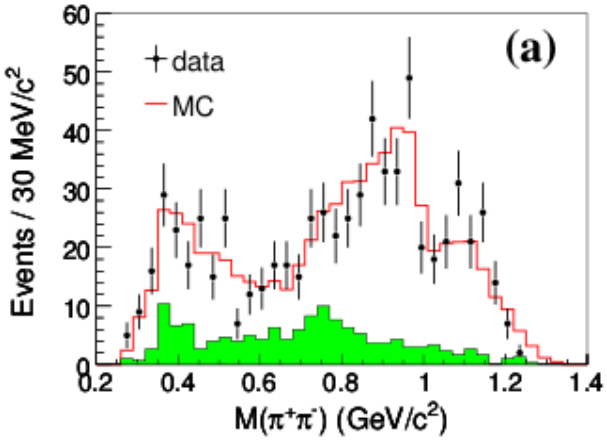
Dalitz Distribution of Y(4260)→J/ψππ

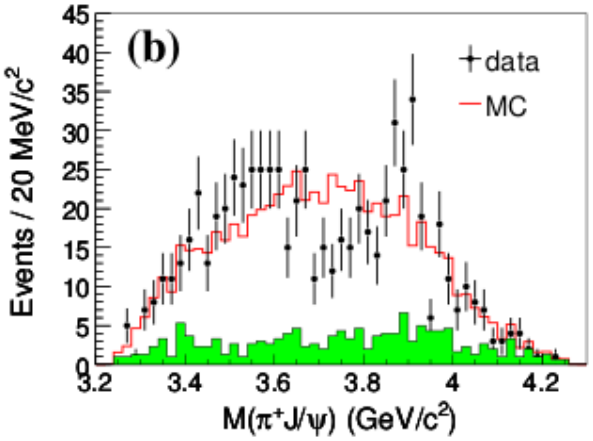
Belle Preprint 2013-6
arXiv:1304.0121

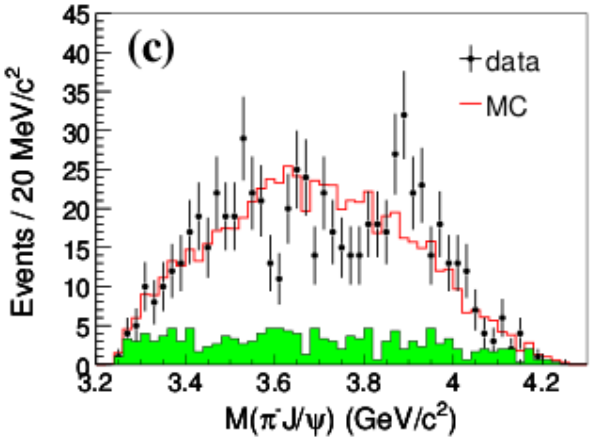
- Structures in M($\pi^+\pi^-$) consistent with known resonances: $f_0(500)$, $f_0(980)$, $f_2(1270)$ (MC, Red histogram)
- Additional structure in M($\pi^{\pm}$J/ψ)



Projections of Dalitz parameters





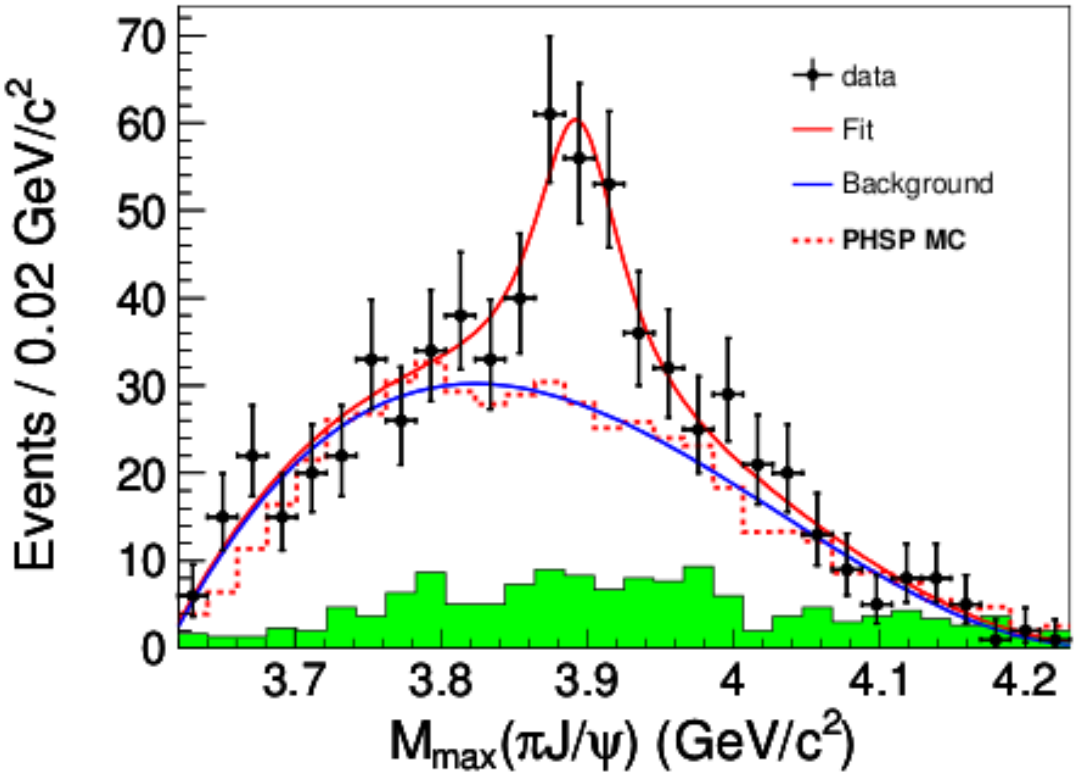


Unbinned Maximum Likelihood Fit to $M_{max}(\pi J/\psi)$

- Unbinned ML fit of single S-wave BW to $M_{max}(\pi J/\psi)$
- New resonance $Z(3895)^{\pm}$ is observed with 5.2σ significance

$M = 3894.5 \pm 6.6 \pm 4.5$ MeV

$\Gamma = 63 \pm 24 \pm 26$ MeV



$M_{max}(\pi J/\psi)$ = Max of $M(\pi^{+}J/\psi)$ or $M(\pi^{-}J/\psi)$

Also seen at BES

M = 3899.0 ± 3.6 ± 4.9 MeV

Γ= 46 ± 10 ± 20 MeV

arXiv:1303.5949

Belle Preprint 2013-6

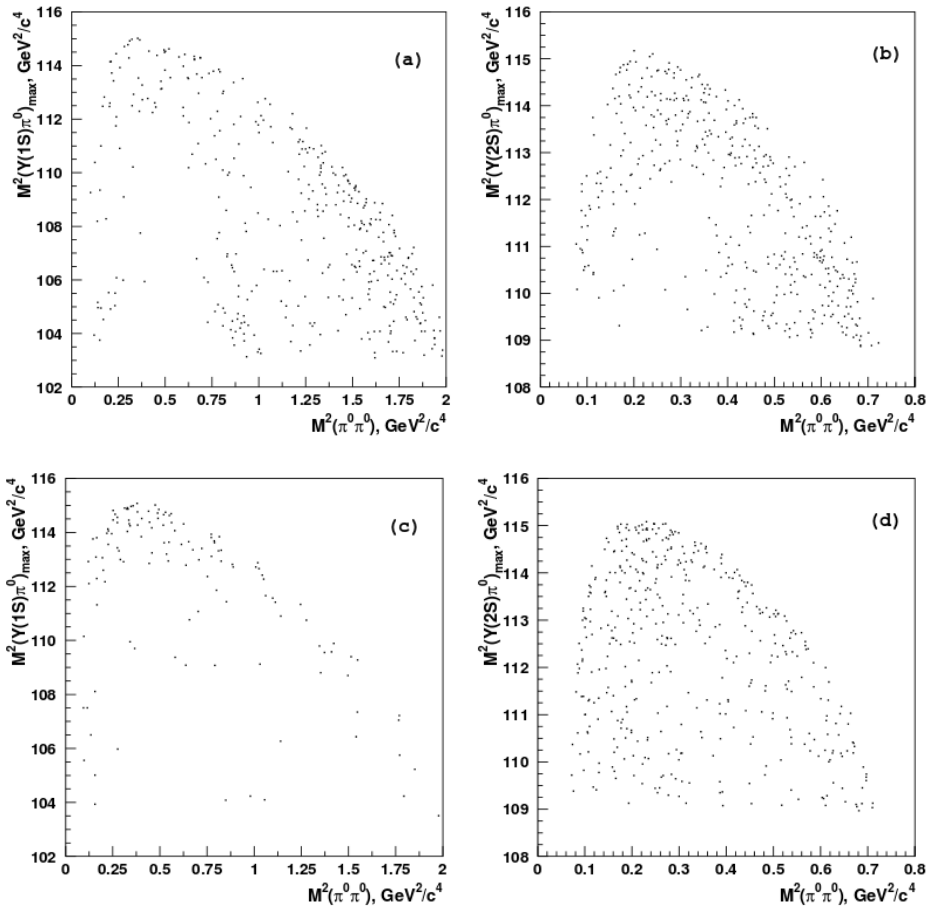
arXiv:1304.0121

Summary

- Neutral Z_b searched for in "$\Upsilon(5S)$"$\rightarrow\Upsilon(nS)\pi^0\pi^0$
  - Evidence for $Z_b^0(10610)$ with 4.9σ significance in $\Upsilon(5S)\rightarrow\Upsilon(2S)\pi^0\pi^0$ PRELIMINARY
- $\sigma(J/\psi\pi^+\pi^-)$ measured in the region 3.8-5.5 GeV
  - New results for "Y(4008)" and Y(4260)
- $Z(3895)^{\pm}$ observed in $Y(4260)\rightarrow J/\psi\pi^{\pm}$ with 5.2σ significance

Backups

Dalitz Analysis of $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^0\pi^0$



International Collaboration: Belle

BINP
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Fu-Jen Catholic U.
U. of Giessen
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Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

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ITEP
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KEK
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Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
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U. of Melbourne

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National United U.
Nihon Dental College
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Nova Gorica
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC

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Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
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U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

13 countries, 57 institutes, ~400 collaborators