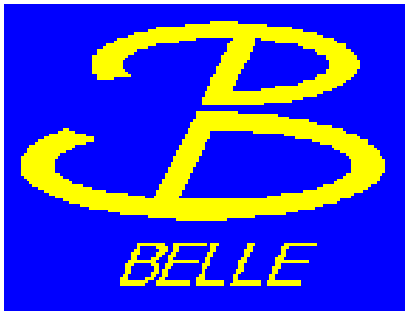


Y(2S) decays at Belle

Umberto Tamponi

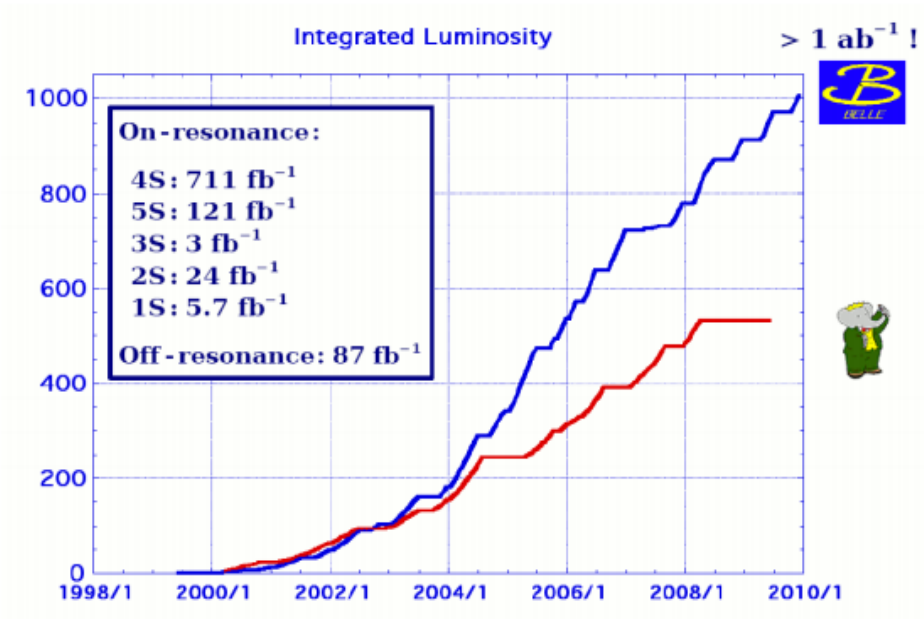
University of Torino and INFN Torino

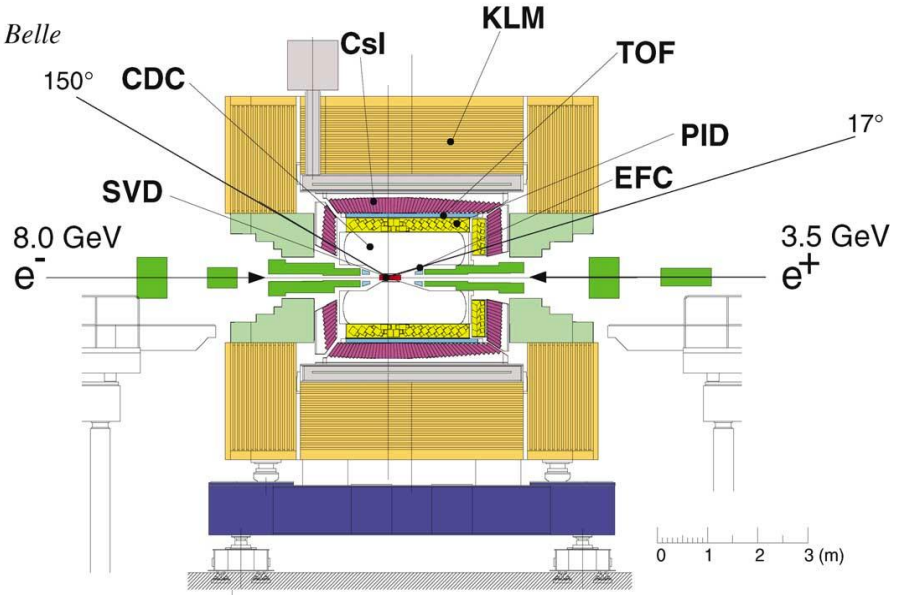
EPS2011, Grenoble, July 22 2011

Outline

- $\Upsilon(1S) \longrightarrow \gamma$ charmonium (Phys. Rev. D 82, 051504(R) (2010))
- $\Upsilon(2S) \longrightarrow \gamma$ charmonium (new)
- $\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$ (new)

Data samples @ Y(1S, 2S)

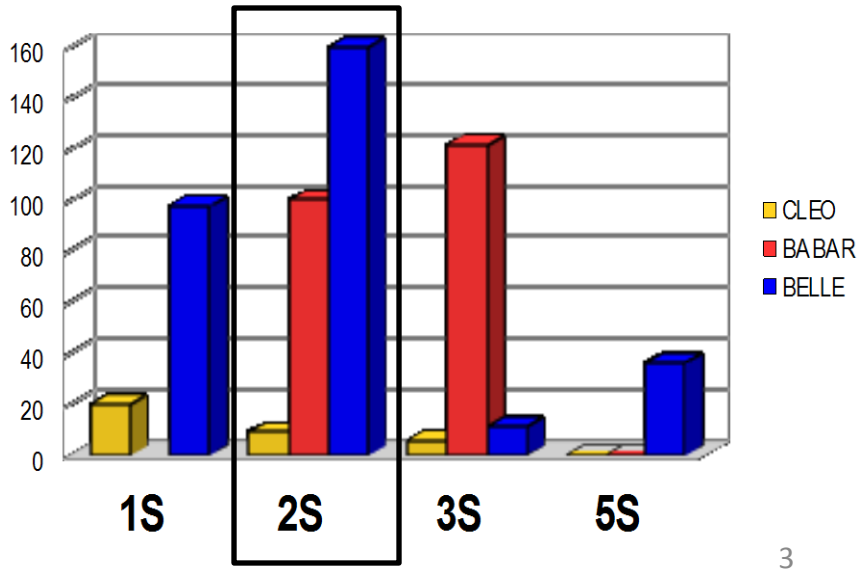




Y(2S) : 24 fb^{-1} (158 Million)

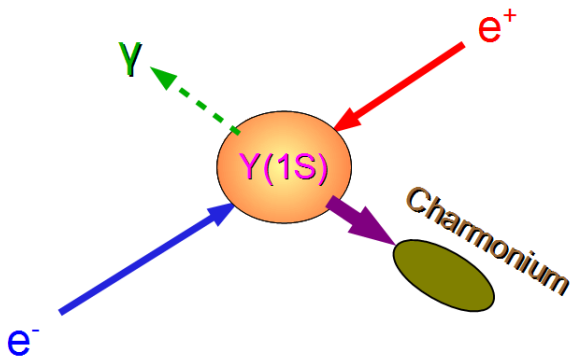
Y(1S) : 5.7 fb^{-1} (102 Million)

World largest samples



Y(1S) ⟶ γ charmonium

Ideal process to bridge bottomonium with charmonium within the same framework



KT Chao et al, (hep-ph/0701009) provides a very large set of NRQCD predictions on many interesting processes:

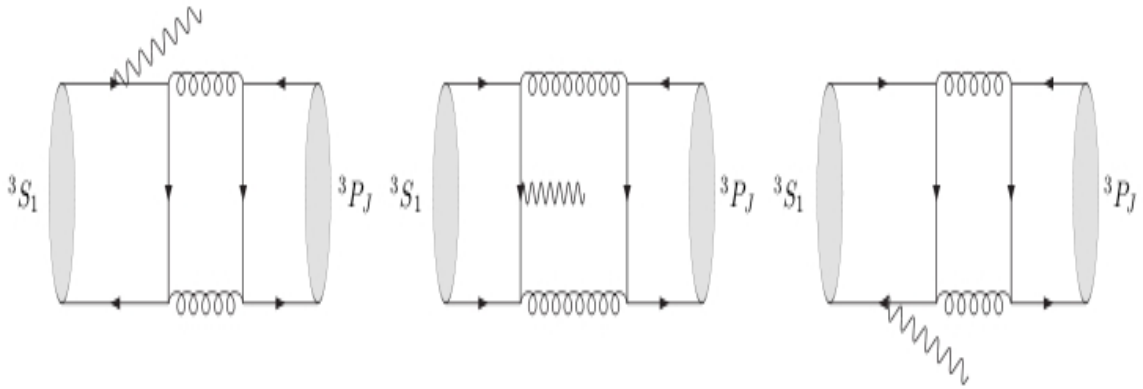
$\Upsilon(1S) \rightarrow \gamma\eta_c, \gamma\chi_c$

$\Upsilon(1S) \rightarrow \gamma f_J$

$\chi_{c,b}(1P) \rightarrow \gamma(\rho,\omega,\varphi)$

$\chi_b(1P) \rightarrow \gamma J/\psi$

$\eta_b(1P) \rightarrow \gamma J/\psi$



Significant corrections are expected from interference between QCD and QED amplitudes.

Besides these predictions, also recently discovered exotic charmonia (X3872,X3915,Y4140) deserve a search...

$\Upsilon(1S) \longrightarrow \gamma$ charmonium

- Phys. Rev. D 82, 051504(R) (2010)

$BF(\Upsilon(1S) \longrightarrow \gamma X(3872)) \times BF(X(3872) \longrightarrow \pi^+\pi^- J/\psi) < 0.16 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma X(3872)) \times BF(X(3872) \longrightarrow \pi^+\pi^-\pi^0 J/\psi) < 0.28 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma X(3915)) \times BF(X(3915) \longrightarrow \omega J/\psi) < 0.30 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma X(4140)) \times BF(X(4140) \longrightarrow \phi J/\psi) < 0.22 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma \chi_{c0}) < 65 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma \chi_{c1}) < 2.3 \times 10^{-5}$

$BF(\Upsilon(1S) \longrightarrow \gamma \chi_{c2}) < 0.76 \times 10^{-5}$

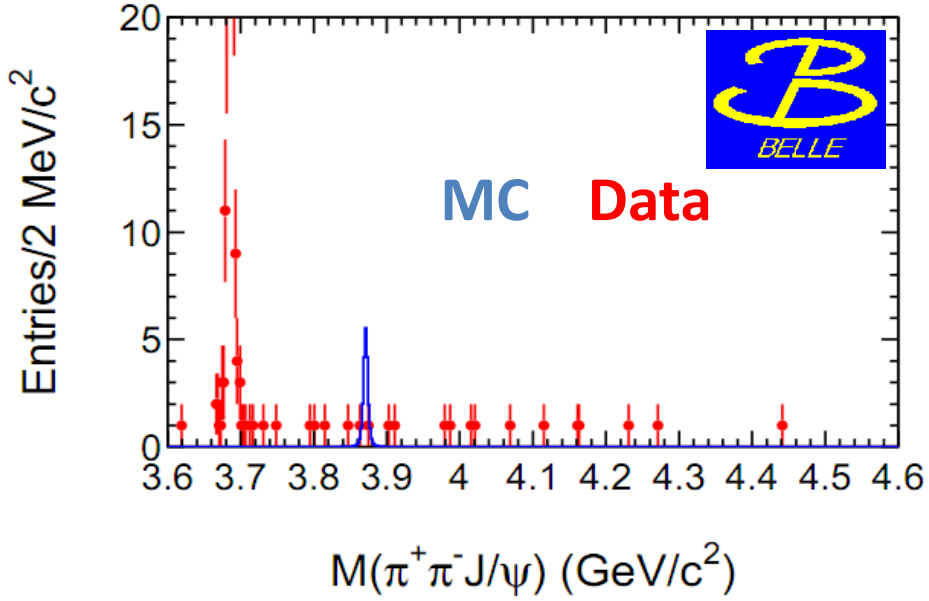
$BF(\Upsilon(1S) \longrightarrow \gamma \eta_c) < 5.7 \times 10^{-5}$

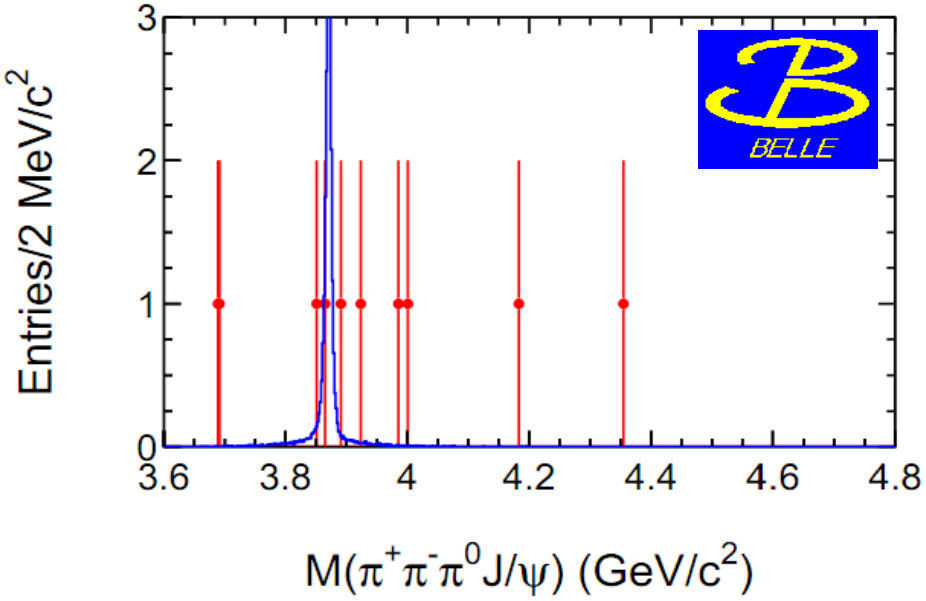
$\Upsilon(2S) \longrightarrow \gamma$ charmonium

- X(3872)
- X(3915)
- Y(4140)
- Y(4350)
- χ_{cJ}
- η_c
- $\gamma\ \psi\ (2S)$

$\Upsilon(2S) \longrightarrow \gamma\, X(3872)$

- $\pi^+\pi^-(\pi^0)J/\psi$ final states
- 4 prongs (+ 1 $\gamma\gamma$)
- Photon cut: $\cos(\theta)<0.9$, E > 3.5 GeV
- J/ψ mass fit



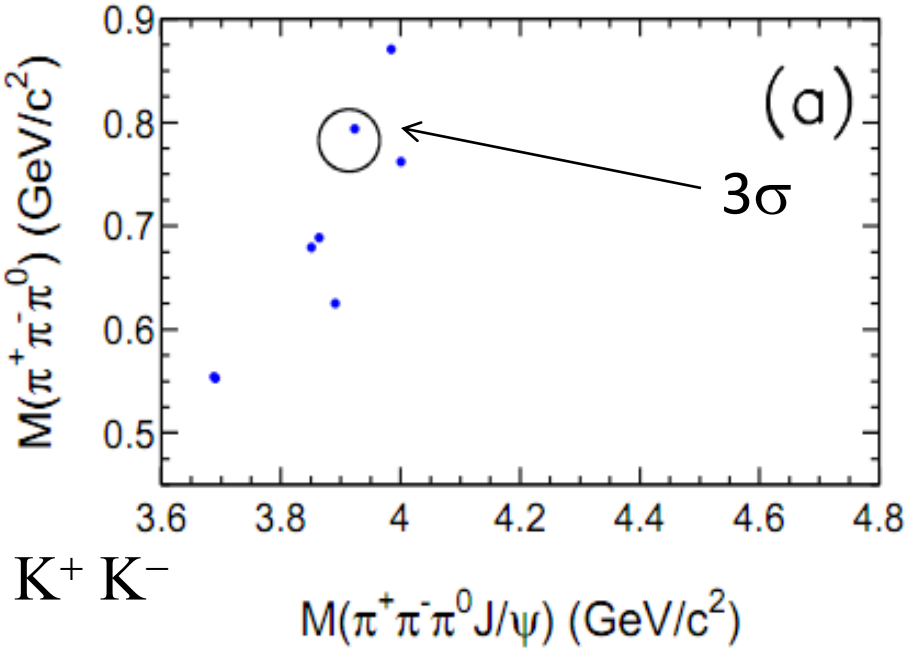


$BF(\Upsilon(2S) \longrightarrow \gamma\, X(3872)) \times BF(X(3872) \longrightarrow \pi^+\pi^- J/\psi) < 0.8 \times 10^{-6}$

$BF(\Upsilon(2S) \longrightarrow \gamma\, X(3872)) \times BF(X(3872) \longrightarrow \pi^+\pi^-\pi^0 J/\psi) < 2.4 \times 10^{-6}$

$Y(2S) \longrightarrow \gamma X(3915), \gamma Y(4140), \gamma X(4350)$

- $X(3915) \longrightarrow \omega J/\psi; \quad \omega \longrightarrow \pi^+\pi^-\pi^0$
- Same criteria used for X(3872)
- One event observed



- $Y(4170), X(4350) \longrightarrow \phi J/\psi; \quad \phi \longrightarrow K^+ K^-$
- No events observed

$$BF(Y(2S) \longrightarrow \gamma Y(4140)) \times BF(Y(4140) \longrightarrow \phi J/\psi) < 1.2 \times 10^{-6}$$

$$BF(Y(2S) \longrightarrow \gamma X(4350)) \times BF(X(4350) \longrightarrow \phi J/\psi) < 1.3 \times 10^{-6}$$

$$BF(Y(2S) \longrightarrow \gamma X(3915)) \times BF(X(3915) \longrightarrow \omega J/\psi) < 2.8 \times 10^{-6}$$

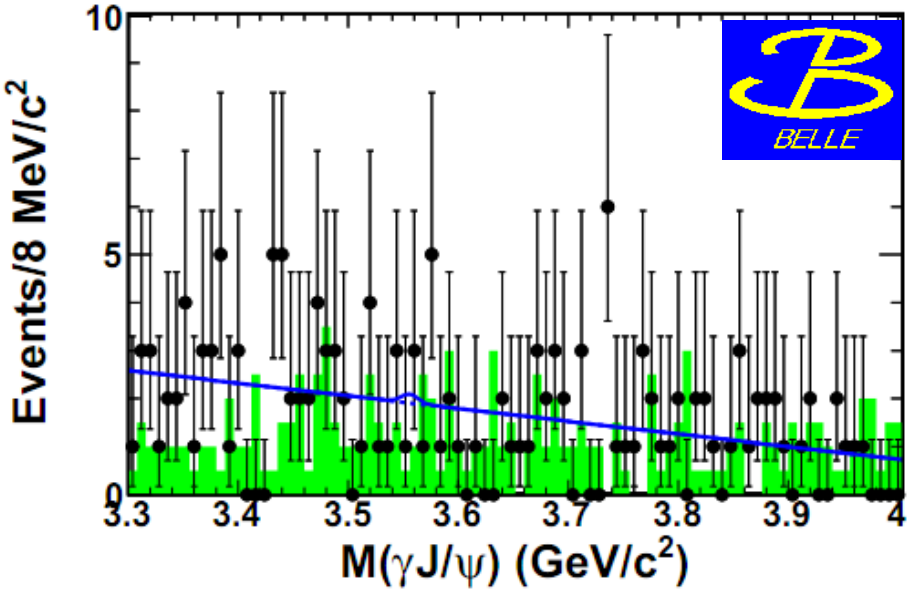
$\Upsilon(2S) \longrightarrow \gamma\, \chi_{cJ}$

Event selection:

– χ_{cJ} detected in $\gamma\, J/\psi$ final state
- 2 leptons, opposite charge
- 2 photons, E > 150 MeV,
- FSR cut: $\theta^*(l\gamma) > 18°$

Main Backgrounds:

- Bhabha scattering
- χ_{cJ} from $\psi(2S)$ ISR production



$BF(\Upsilon(2S) \longrightarrow \gamma\, \chi_{c0}) < 8.5 \times 10^{-4}$

$BF(\Upsilon(2S) \longrightarrow \gamma\, \chi_{c1}) < 3.6 \times 10^{-6}$

$BF(\Upsilon(2S) \longrightarrow \gamma\, \chi_{c2}) < 1.2 \times 10^{-6}$

$\Upsilon(2S) \longrightarrow \gamma\, \eta_c$

5 channels:

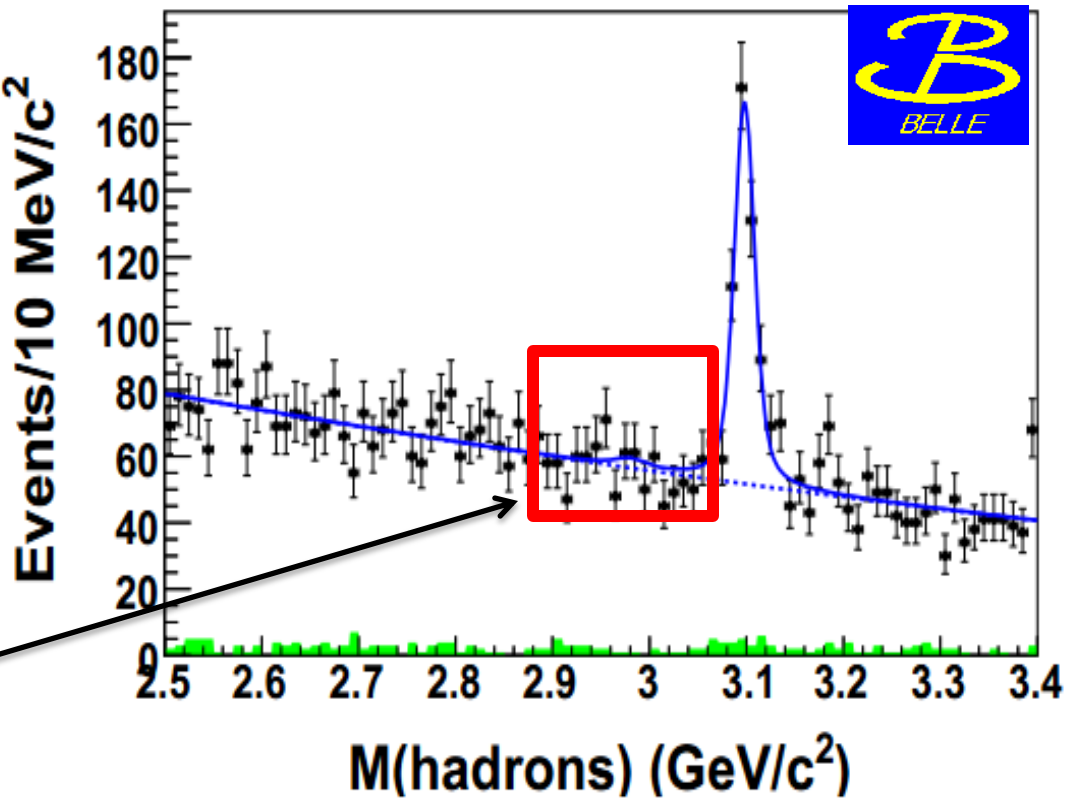
$K_S\, K^-\, \pi^+$ +c.c.;

$K^+K^-\pi^+\pi^-$;

$2(K^+K^-)$; $2(\pi^+\pi^-)$; $3(\pi^+\pi^-)$

Event selection:

- 4, 6 prongs, no net charge
- E_γ > 3.5 GeV
- π and K PID



no η_c evidence

$$BF(\Upsilon(2S) \longrightarrow \gamma\, \eta_c) < 2.7 \times 10^{-5}$$

$\Upsilon(2S) \longrightarrow \gamma_R X \longrightarrow \gamma_R \gamma \Psi(2S)$

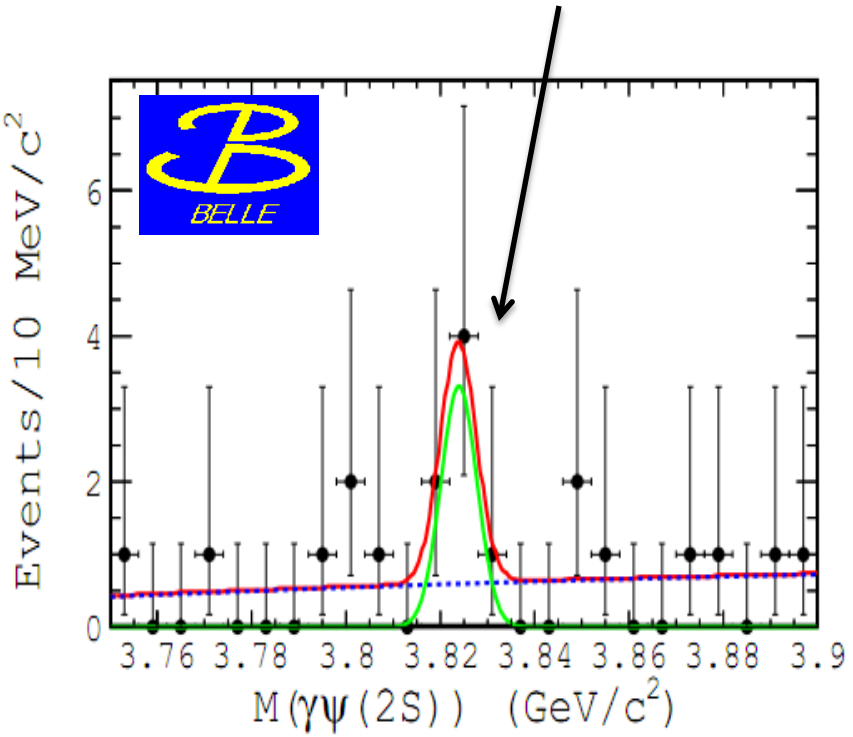
– C-even states above $\psi(2S)$ can decay to $\gamma\ \psi(2S)$
– $\psi(2S)$ reconstructed in $\pi^+\pi^- J/\psi$
– Main background from $\psi(2S)$ ISR production

Event selection:

$E_{high} > 3.5$ GeV, $E_{low} > 75$ MeV
π PID
$-0.5 < M^2_{rec}(\gamma_l \psi(2S)) < 1.5 (GeV/c^2)^2$

No significant signal

2.5 σ excess at 3.824±0.002 GeV



$$\mathcal{B}(\Upsilon(2S) \to \gamma X(3824)) \times (X(3824) \to \gamma\psi(2S)) < 1.2 \times 10^{-5}$$

$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$

$\Upsilon(nS) \longrightarrow \eta\, \Upsilon(1S)$

$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$:

- Theoretical predictions: $\mathcal{B} \approx 8.0 \cdot 10^{-4}$
- CLEO observed (5.3 σ with 1.3 fb^{-1}) : $\mathcal{B} = (2.1^{+0.7}_{-0.6} \pm 0.3) \cdot 10^{-4}$

(PRL 101, 192001)

$\Upsilon(3S) \longrightarrow \eta\, \Upsilon(1S)$:

- Theoretical predictions: $\mathcal{B} \approx 6.5 \times 10^{-4}$
- CLEO: $\mathcal{B} < 1.8 \times 10^{-4}$ with 1.3 fb^{-1} (PRL 101, 192001)

$\Upsilon(4S) \longrightarrow \eta\, \Upsilon(1S)$:

BaBar: $\mathcal{B} \approx 2.5 \times \mathcal{B}(\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-)$ (PRD 78, 112002)

Measure the $\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$ with the 24 fb^{-1} Belle sample

$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$: backgrounds

Event reconstruction:

η detected in either $\gamma\gamma$ or $\pi^+\pi^+\pi^0$

$\Upsilon(1S)$ detected in $\mu^+\mu^-$ and e^+e^-

Backgrounds:

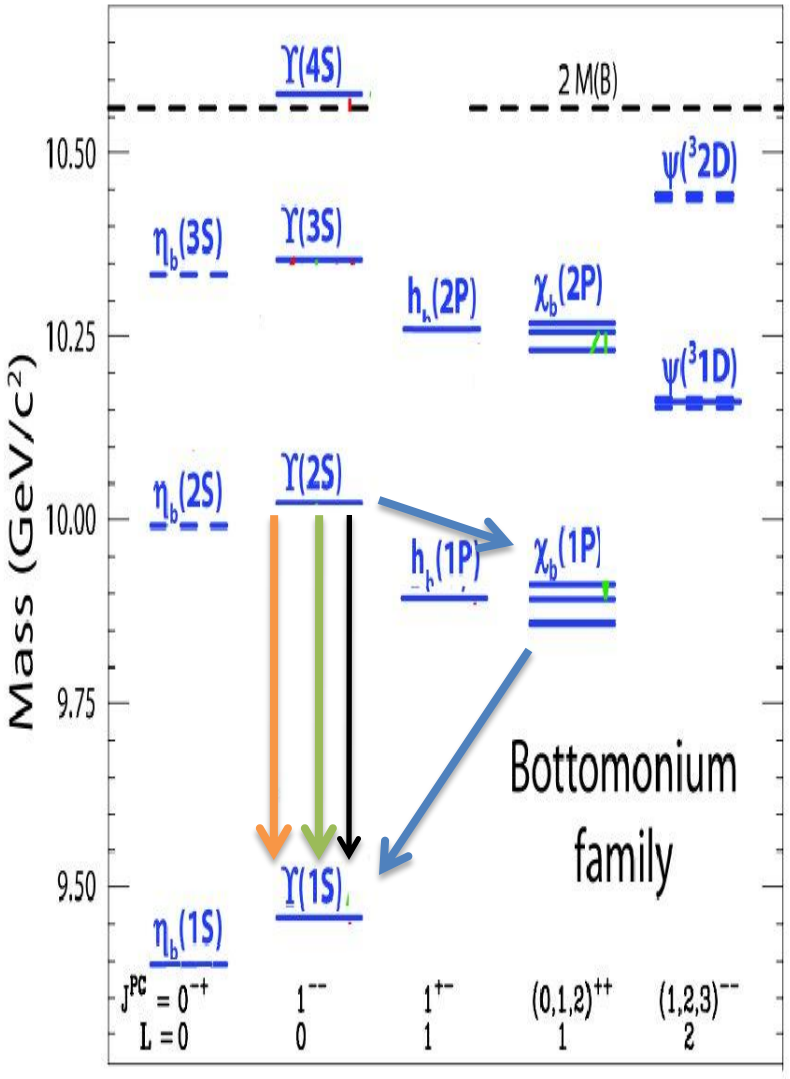
$\Upsilon(2S) \longrightarrow \pi^+\pi^-\Upsilon(1S)$ (BR = 18.1%)

$\Upsilon(2S) \longrightarrow \pi^0\pi^0\Upsilon(1S)$ (BR = 9.0 %)

$\Upsilon(2S) \longrightarrow \gamma\, \chi_{bj} \longrightarrow \Upsilon(1S)\, \gamma\gamma$ (BR= 0.2%)

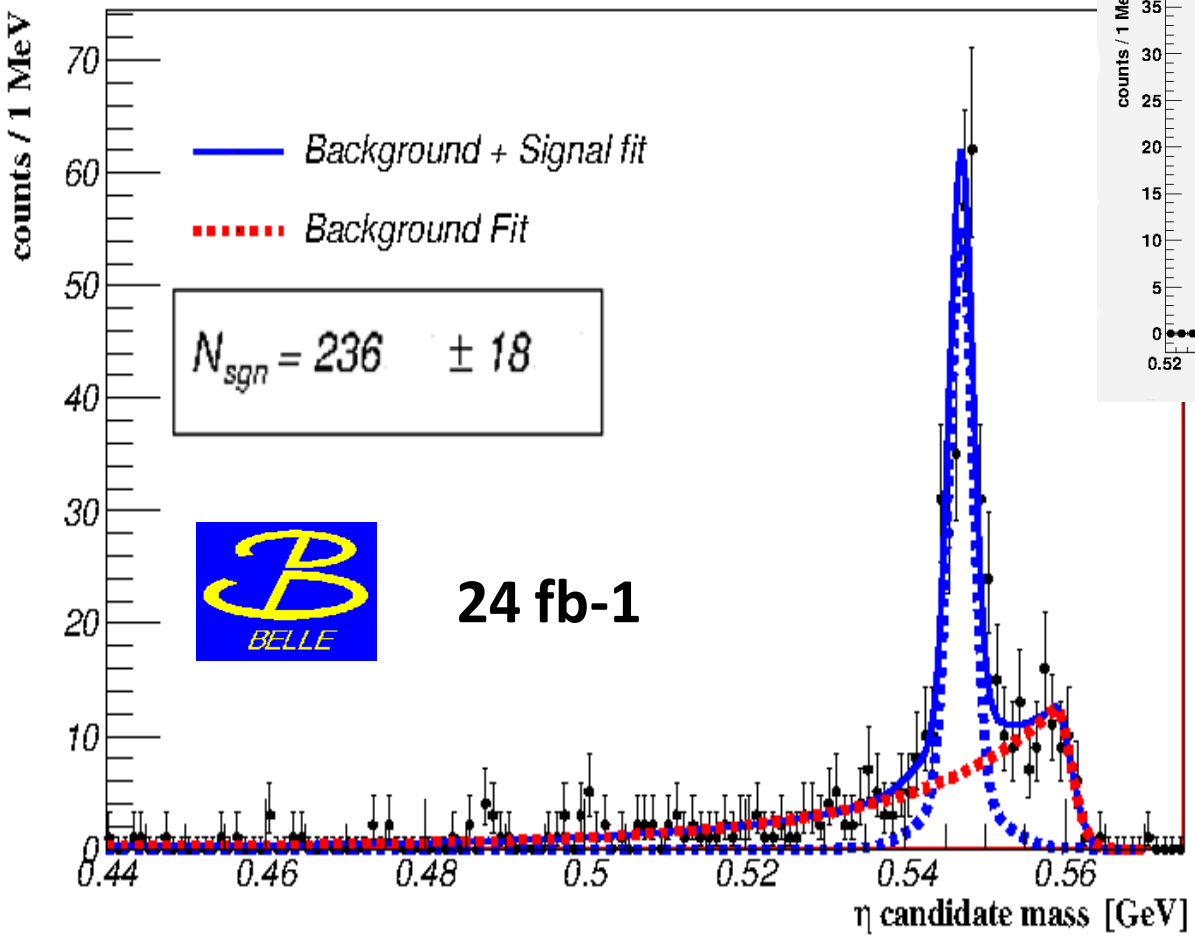
Radiative Bhabha scattering ($\gamma\gamma$ mode)

S/B ratio 10^{-4}

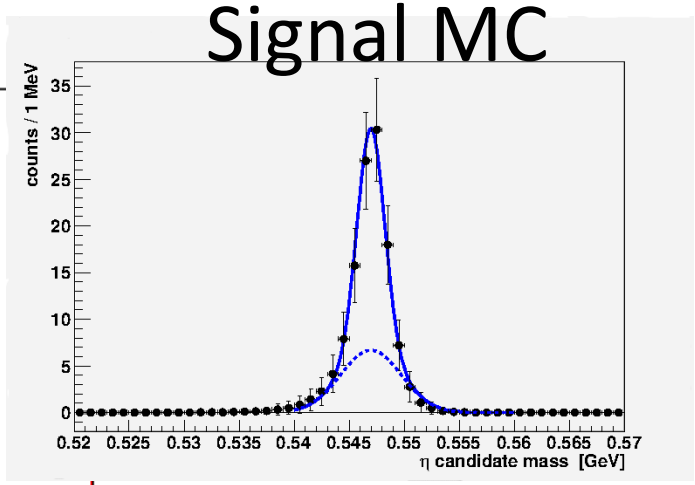


Y(2S) $\longrightarrow \eta$ Y(1S) : Fit

- Signal parameters fixed by MC, only the number of events is left free
- Background parameters free, range and shape fixed by MC



Signal MC



Main cuts:

57 MeV < E <220 MeV (3π)

180 MeV < E <360 MeV (2γ)

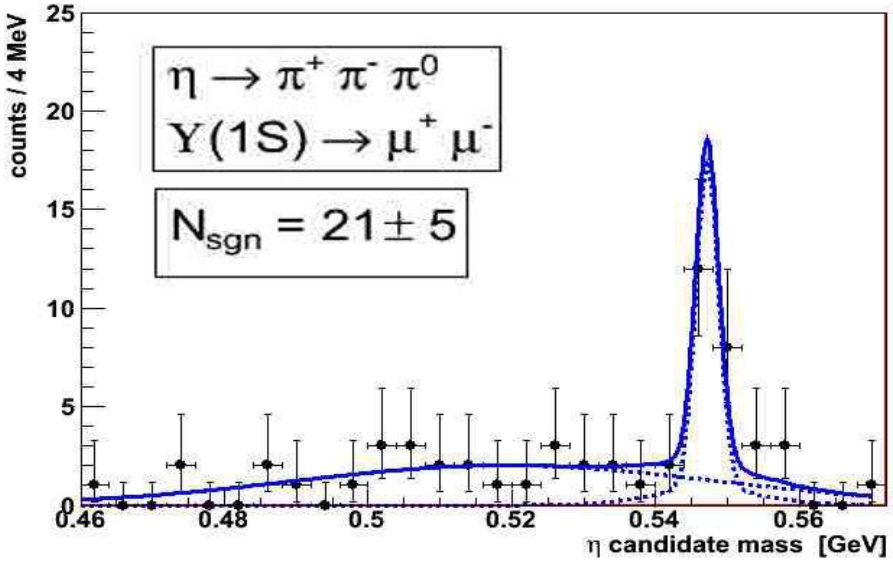
$\theta(\gamma l)>200$ mrad (FSR tag)

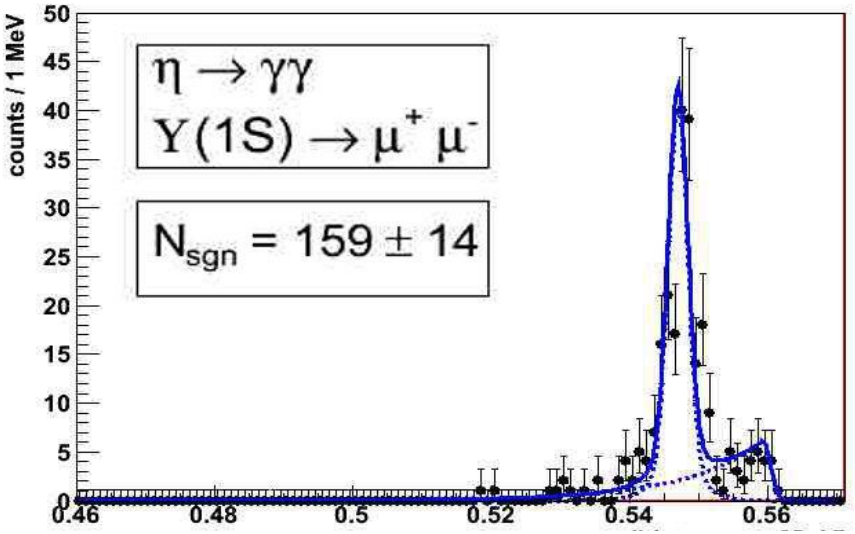
Y(1S) and Y(2S) mass constraints

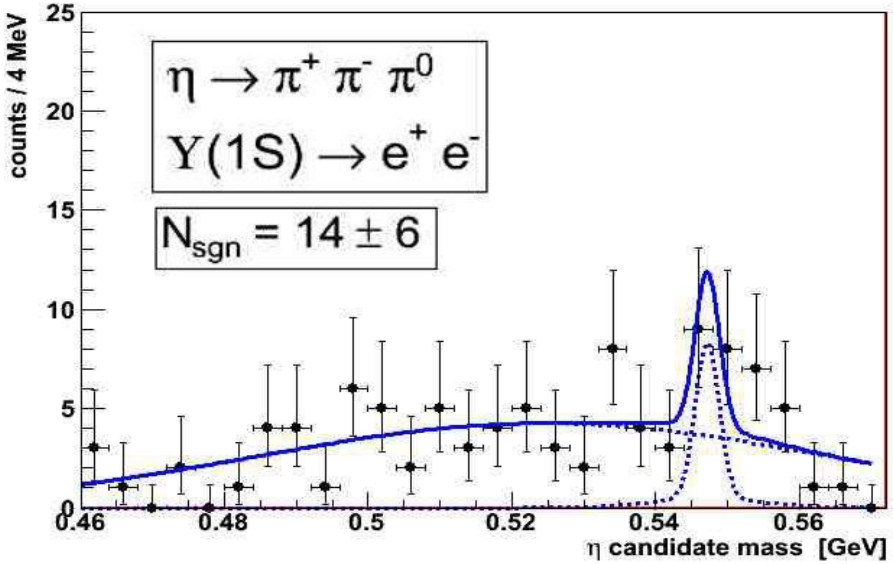
Bhabha veto

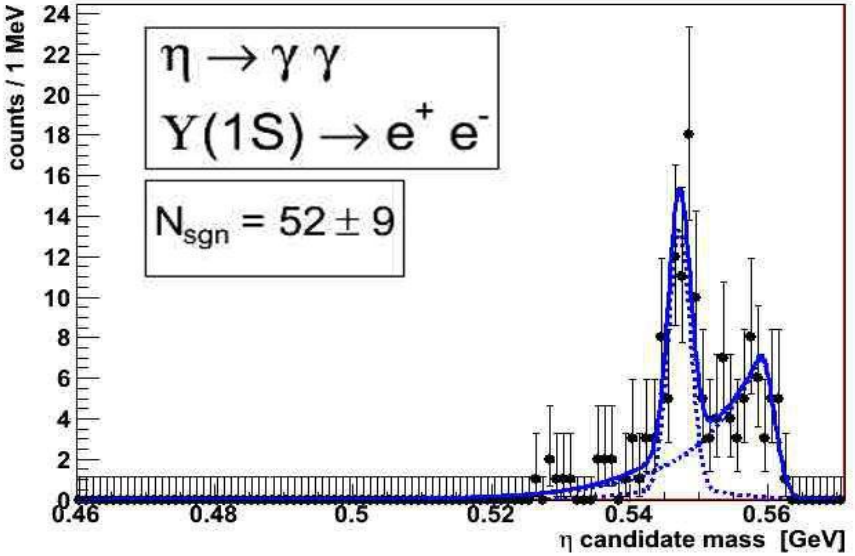
$\mathrm{Cos}(\theta(\pi\pi))<0.6$

$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$: Fit on subsamples

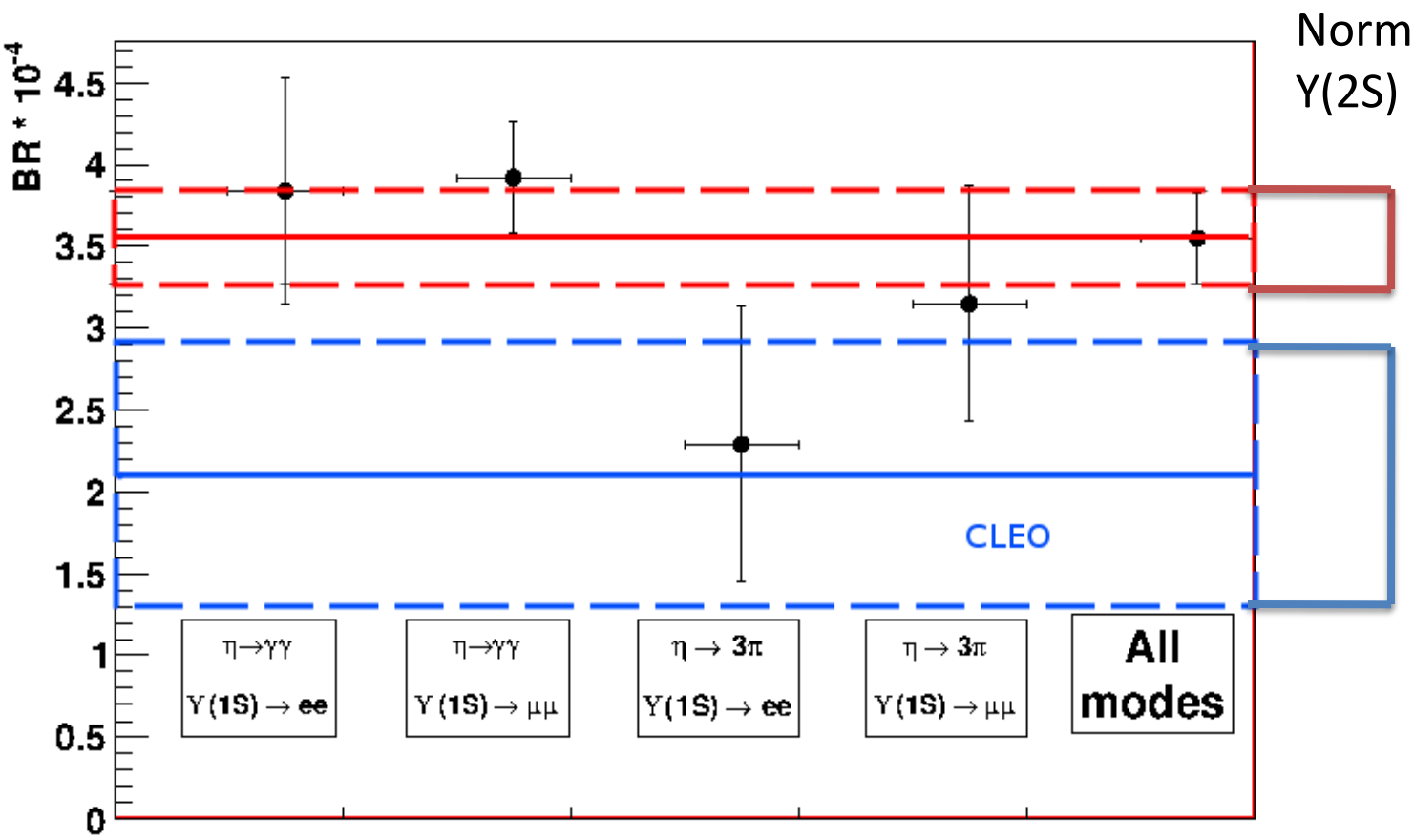








$\Upsilon(2S) \longrightarrow \eta\,\Upsilon(1S)$: Branching Ratio



Normalization sample:
$\Upsilon(2S) \longrightarrow \pi^+\pi^-\Upsilon(1S)$

BELLE

CLEO

1.6 σ

$$\mathcal{B}(\Upsilon(2S) \to \eta\Upsilon(1S)) = (3.55 \pm 0.28(stat) \pm 0.40(syst)) \cdot 10^{-4}$$

Y(2S) @ Belle summary

- Upper limits to **radiative** transitions between Y(2S) and charmonia have been reported
- No evidence of transitions to X(3872), X(3915), Y(4140) or X(4350) was found
- No clear evidence of transtions to charmonia above ψ(2S) was found
- Confirmed CLEO observation of Y(2S) $\longrightarrow$ Y(1S) η with significance $>10\sigma$ and

$$\mathcal{B}(\Upsilon(2S) \to \eta\Upsilon(1S)) = (3.55 \pm 0.28(stat) \pm 0.40(syst)) \cdot 10^{-4}$$

- Looking for Y(2S) $\longrightarrow$ Y(1S) π^0

Backup slides

$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$: event selection

Leptons:

2 tracks, same PID opposite charge

9 GeV < M(ll) < 9.8 GeV

P* > 4 GeV

Pions:

$\cos(\theta(\pi\pi))<0.6$

Photons:

57 MeV < E <220 MeV (3p)

180 MeV < E <360 MeV (3p)

$\theta(\gamma l)>200$ mrad (FSR tag)

$\cos(\theta(\gamma\gamma))<-0.88$ $(\gamma\gamma)$

Kinematic fit

Double mass constrain on $\Upsilon(2S)$ and $\Upsilon(1S)$

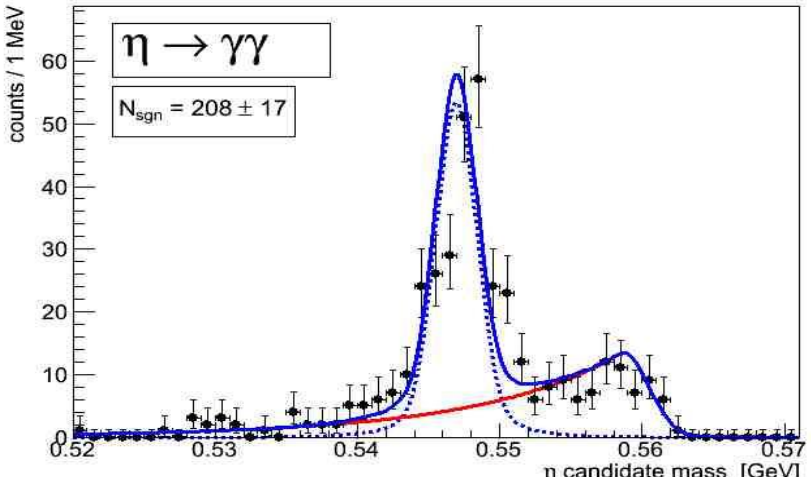
Final cuts

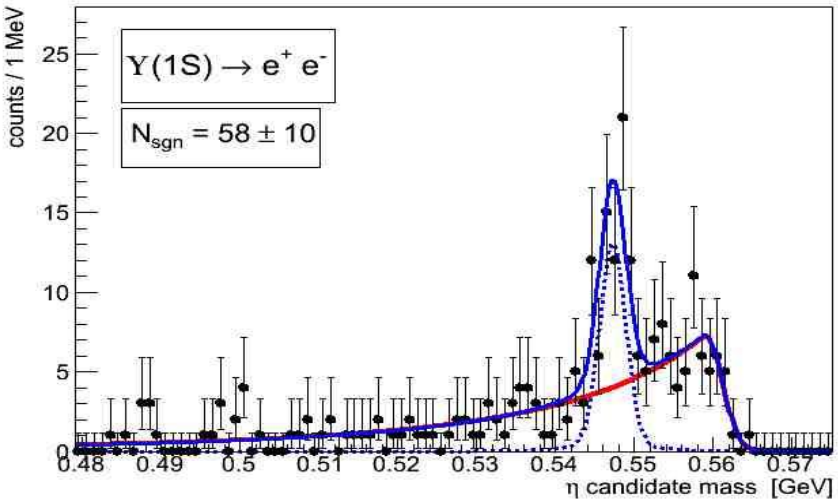
Bhabha veto

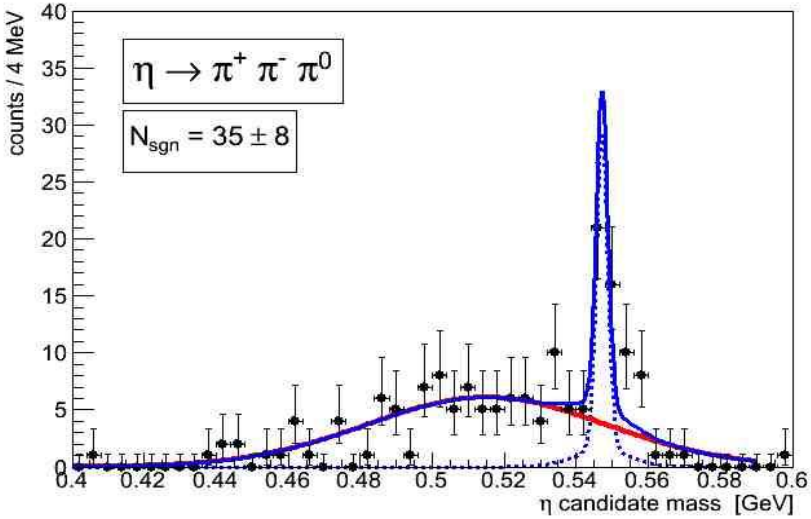
Event closure

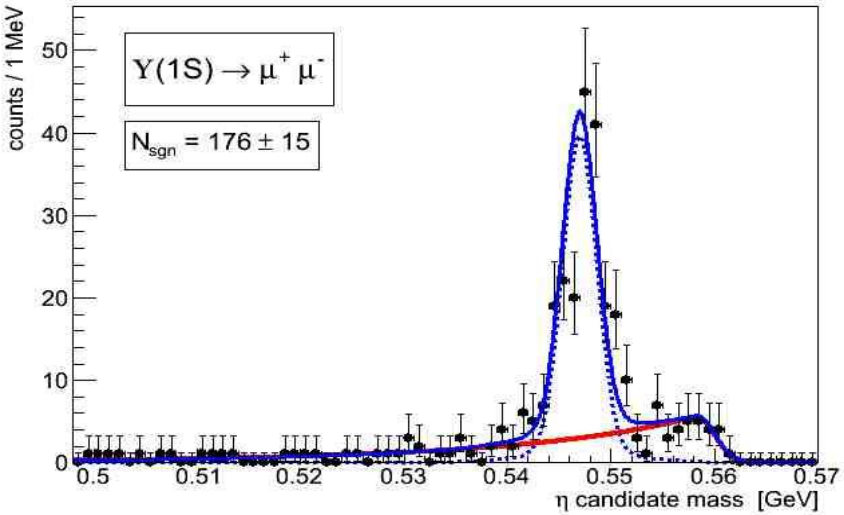
Kin. Fit χ^2

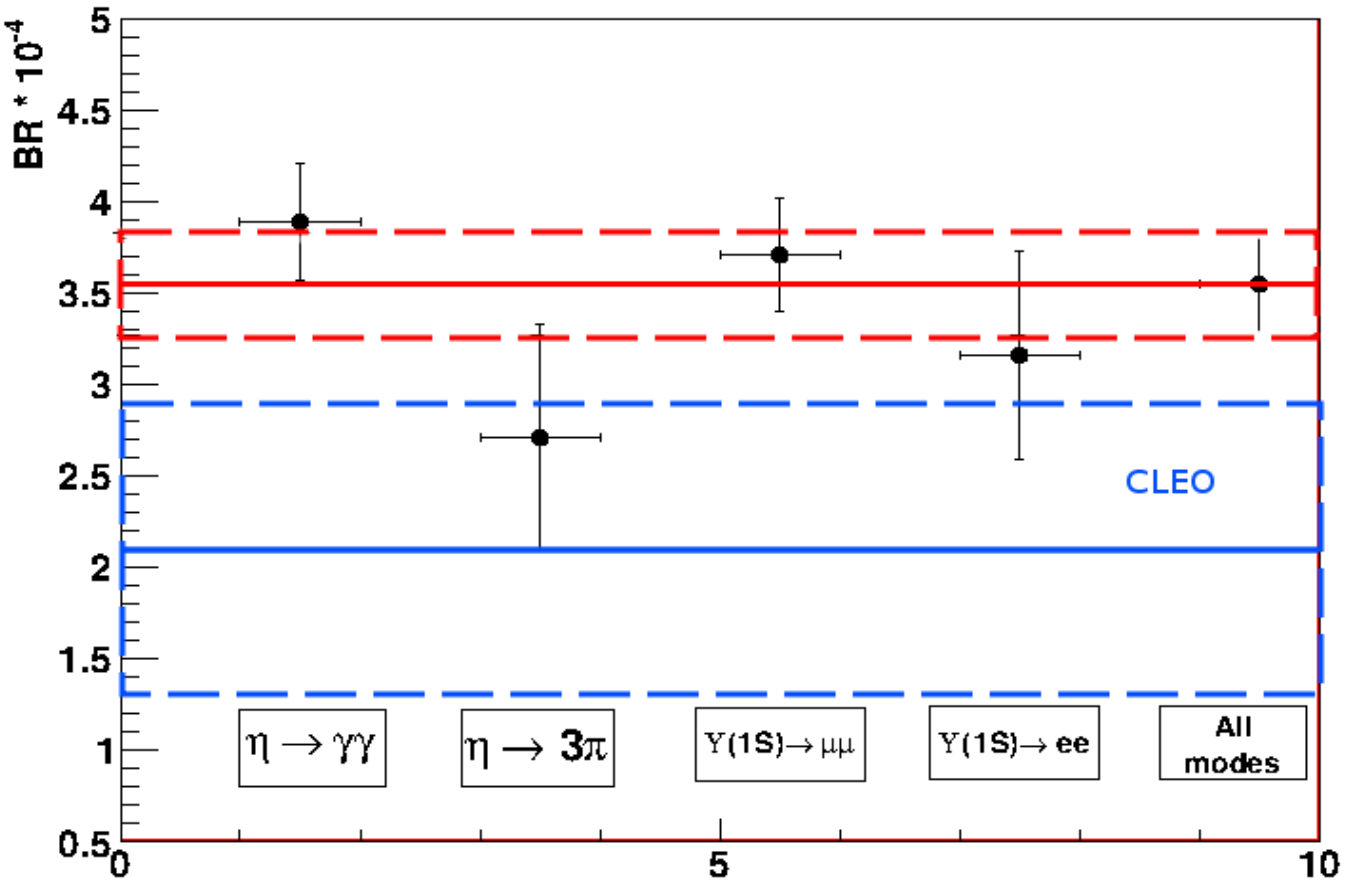
$\Upsilon(2S) \longrightarrow \eta\, \Upsilon(1S)$: Fit on subsamples










BR * 10^-4
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
5
10
CLEO
η → γγ
η → 3π
Υ(1S)→ μμ
Υ(1S)→ ee
All modes