Properties of $\eta_b(1S)$ and $h_b(1P)$ at BABAR

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QWG2011:

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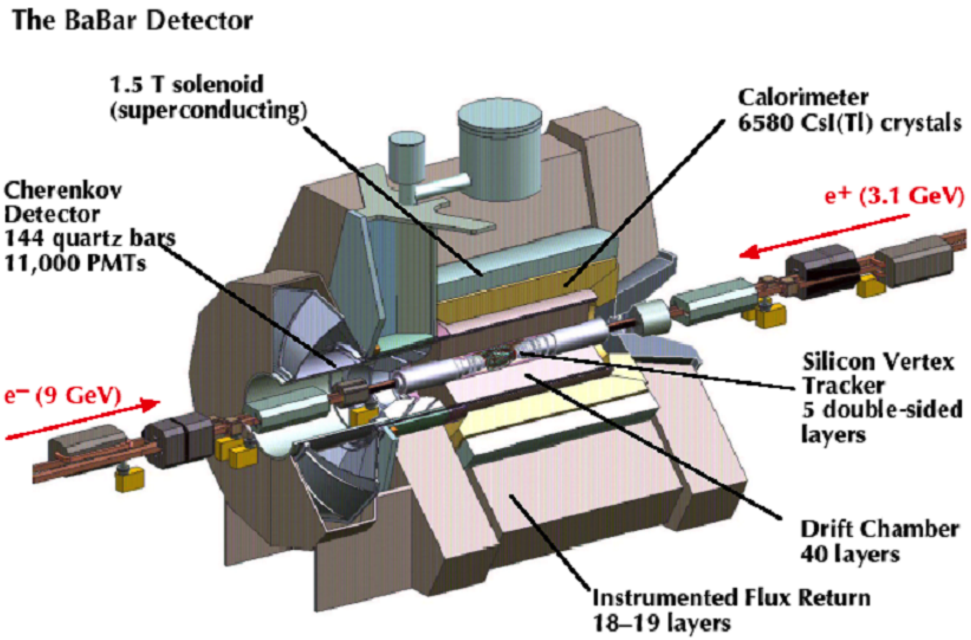
- Inclusive searches for the $h_b(1P)$ in
  - $\Upsilon(3S) \rightarrow \pi^+\pi^- X$
  - $\Upsilon(3S) \rightarrow \pi^0 X$
- search for $\eta_b(nS)$ in radiative $\Upsilon(3S)$ and $\Upsilon(2S)$ transitions using converted photons

BaBar experiment



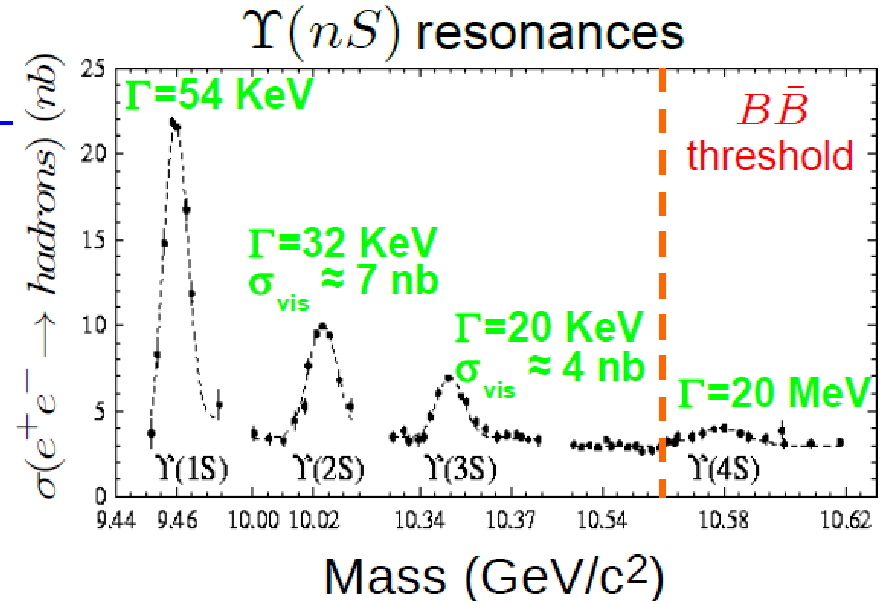
Υ(2S)	Υ(3S)	Υ(4S)	Υ(5S)
14 fb^{-1}	30 fb^{-1}	433 fb^{-1}	3.2 fb^{-1} (scan)

Most data taken at the Υ(4S)

dedicated running at the narrow Υ resonances

- 100 M Υ(2S)
- 122 M Υ(3S)

and a scan above the Υ(4S)

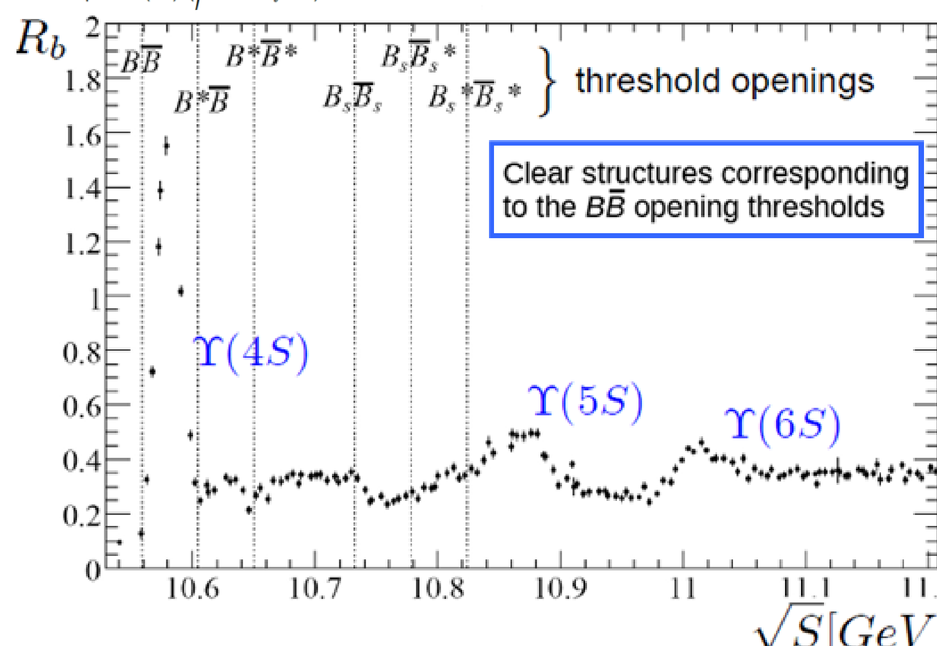


e^+e^- Cross Section Scan

PRL 102, 012001 (2009)

Precision scan in E_{CM} from 10.54 GeV to 11.20 GeV

- 5 MeV steps with 25 pb^{-1} at each step ($\int \mathcal{L} \approx 3.3\, fb^{-1}$)
- 8 steps at Υ(6S) ($\int \mathcal{L} \approx 0.6\, fb^{-1}$)



Expected $h_b(1P)$ properties

- Expected mass: $m_{h_b(1P)} = (m_{\chi_{b0}(1P)} + 3m_{\chi_{b1}(1P)} + 5m_{\chi_{b2}(1P)}) / 9 \approx 9900\ \mathrm{MeV}/c^2$

- Predicted production mechanisms
  - $\mathcal{B}(\Upsilon(3S) \to \pi^+\pi^- h_b(1P)) \sim 10^{-3} - 10^{-2}$ — Kuang et al., PRD 37,1210(1988)
  - $\mathcal{B}(\Upsilon(3S) \to \pi^0 h_b(1P)) \sim 10^{-3}$ — Voloshin, Sov, J. Nucl. Phys 43,1011(1986)
  - $R(\pi^0 h_b(1P) / \pi^+\pi^- h_b(1P)) = 0.05 - 20$

- Expected decay modes — Godfrey and Rosner, PRD 66, 014012 (2002)
  - $h_b(1P) \to ggg$ (57%), $\gamma\eta_b(1S)$ (41%), γgg (2%)

- Previous experimental limits
  - $\mathcal{B}(\Upsilon(3S) \to \pi^+\pi^- h_b(1P)) < 1.8 \times 10^{-3}$
  - $\mathcal{B}(\Upsilon(3S) \to \pi^0\ h_b(1P)) < 2.8 \times 10^{-3}$

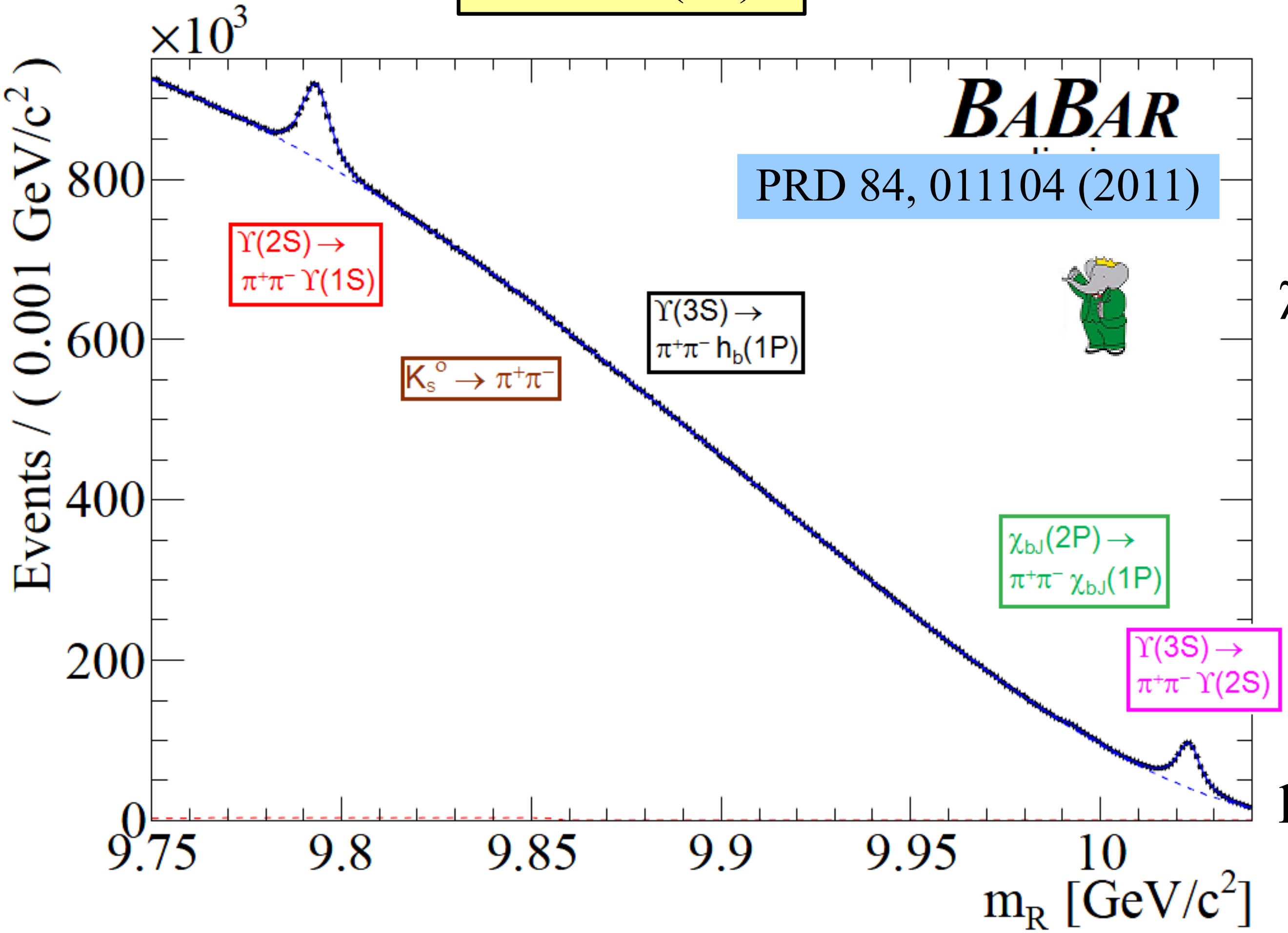
CLEO, PRD 43,1448(1991)
PRD 49, 40 (1994)

6 M $\Upsilon(3S)$

Search for $h_b(1P)$ in $\Upsilon(3S)\to\pi^+\pi^-(X)$

mass recoiling against the $\pi^+\pi^-$: $m_R^2 = (m_{\Upsilon(3S)} - E_{\pi\pi})^2 - P_{\pi\pi}^2$

122 M $\Upsilon(3S)$



χ^2 fit to signal components

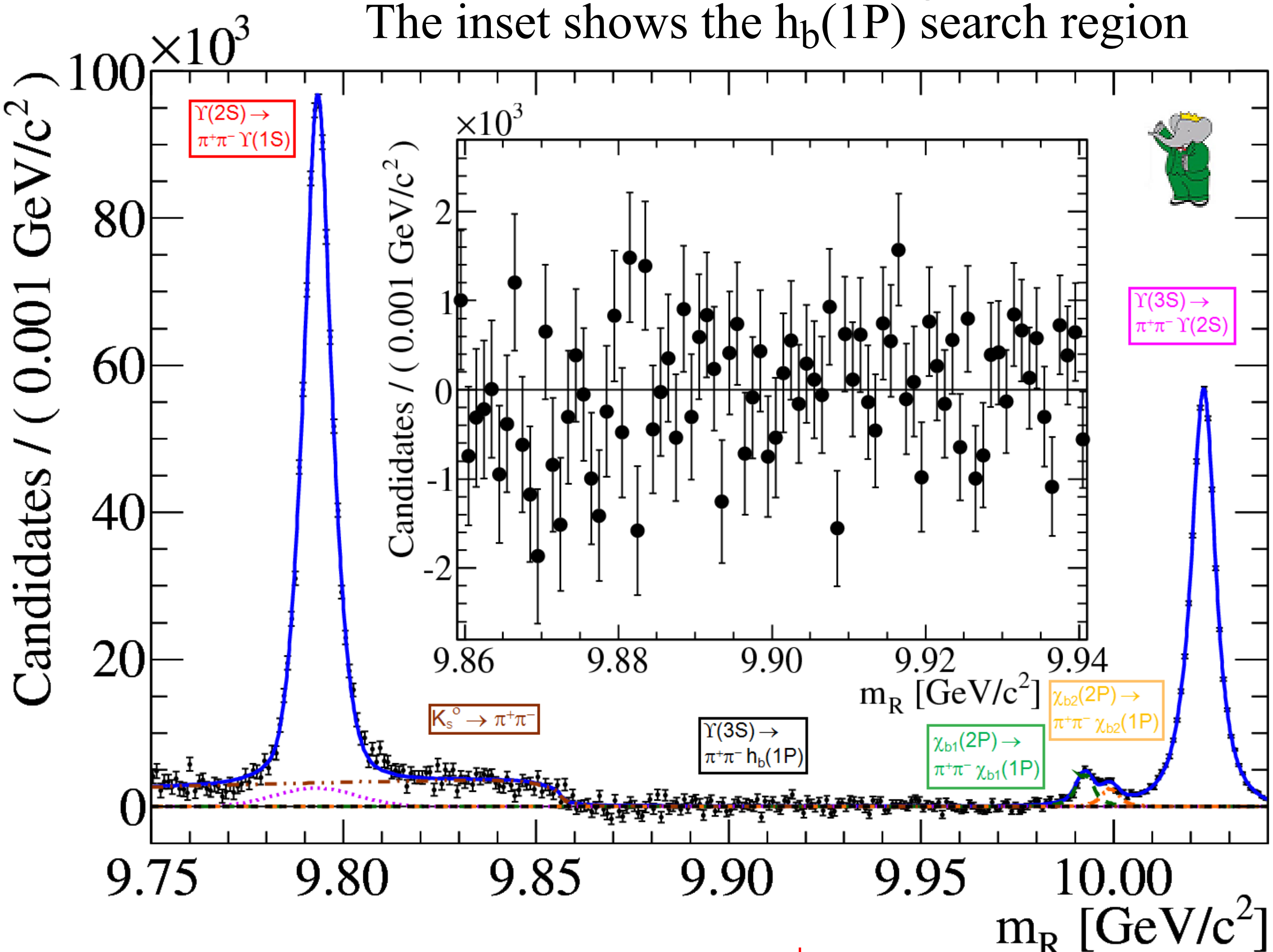
- $\Upsilon(3S)\to\pi^+\pi^-\, h_b(1P)$
- $\Upsilon(3S)\to\pi^+\pi^-\, \Upsilon(2S)$
- $\Upsilon(2S)\to\pi^+\pi^-\, \Upsilon(1S)$
- $\chi_b(2P)\to\pi^+\pi^-\chi_b(1P)$

plus smooth background

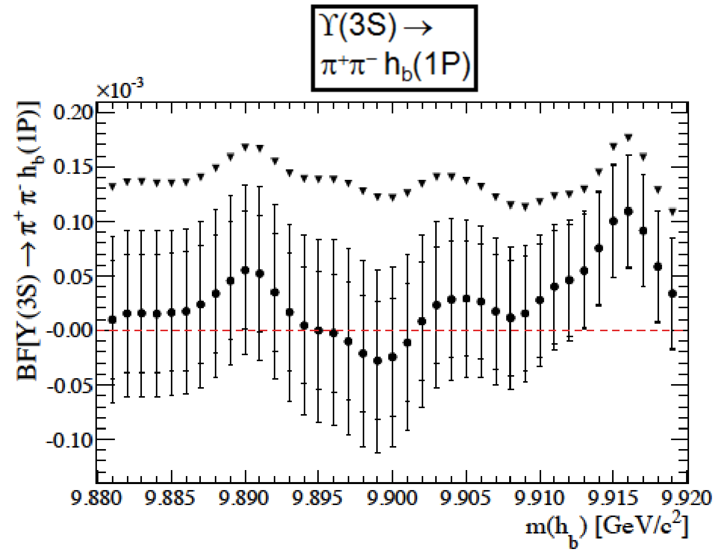
- non-peaking combinatorial
- $K^0\to\pi\pi$

Results

fit result, with smooth background subtracted.
The inset shows the $h_b(1P)$ search region



PRD 84, 011104 (2011)



central value and 90% CL UL as a function of h_b mass

No evidence for $\Upsilon(3S)\rightarrow\pi^+\pi^-\,h_b(1P)$:

$\mathcal{B}(\Upsilon(3S)\rightarrow\pi^+\pi^-\,h_b(1P)) < 1.2\times10^{-4}$ (90%CL)

x10 improvement over previous CLEO limit PRD 43,1448(1991)

disfavours some theory predictions e.g.
Kuang et al., PRD 37,1210 (1988)
Tuan, Mod. Ph.L. A7,3527 (1992)

Evidence for $\Upsilon(3S) \to \pi^0 h_b(1P)$

Preliminary

122 M $\Upsilon(3S)$

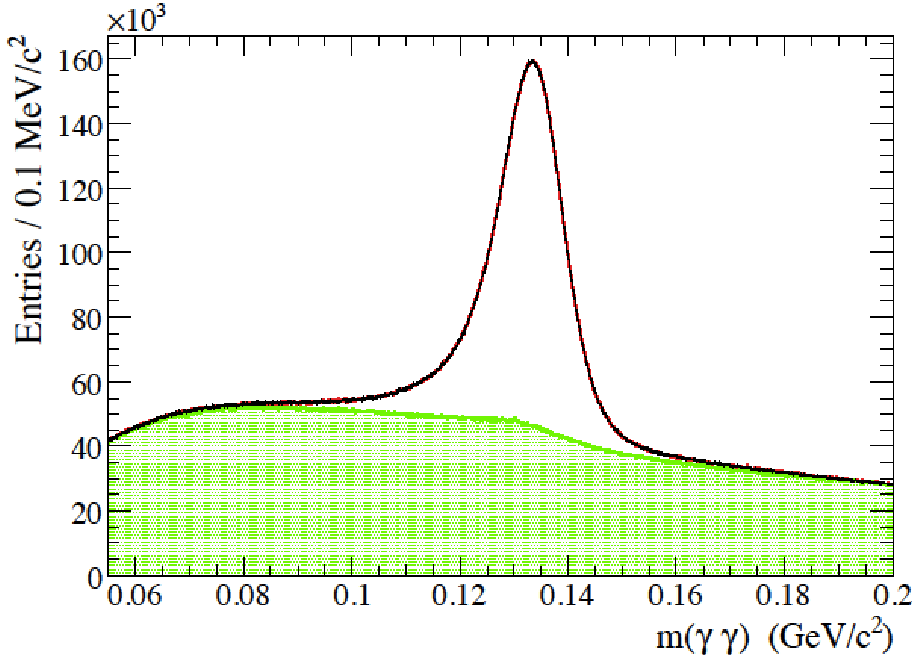
Select events with a π^0 and a photon

Require E_γ to be compatible with $h_b \to \gamma\eta_b(1S)$ (dominant decay mode)

arXiv:1102.4565

In each bin of $m_{recoil} = \sqrt{(m_{\Upsilon(3S)} - E^*_{\pi^0})^2 - P^{*2}_{\pi^0}}$

- perform a fit to the $\gamma\gamma$ inv. mass distribution to determine the number of π^0 in that bin



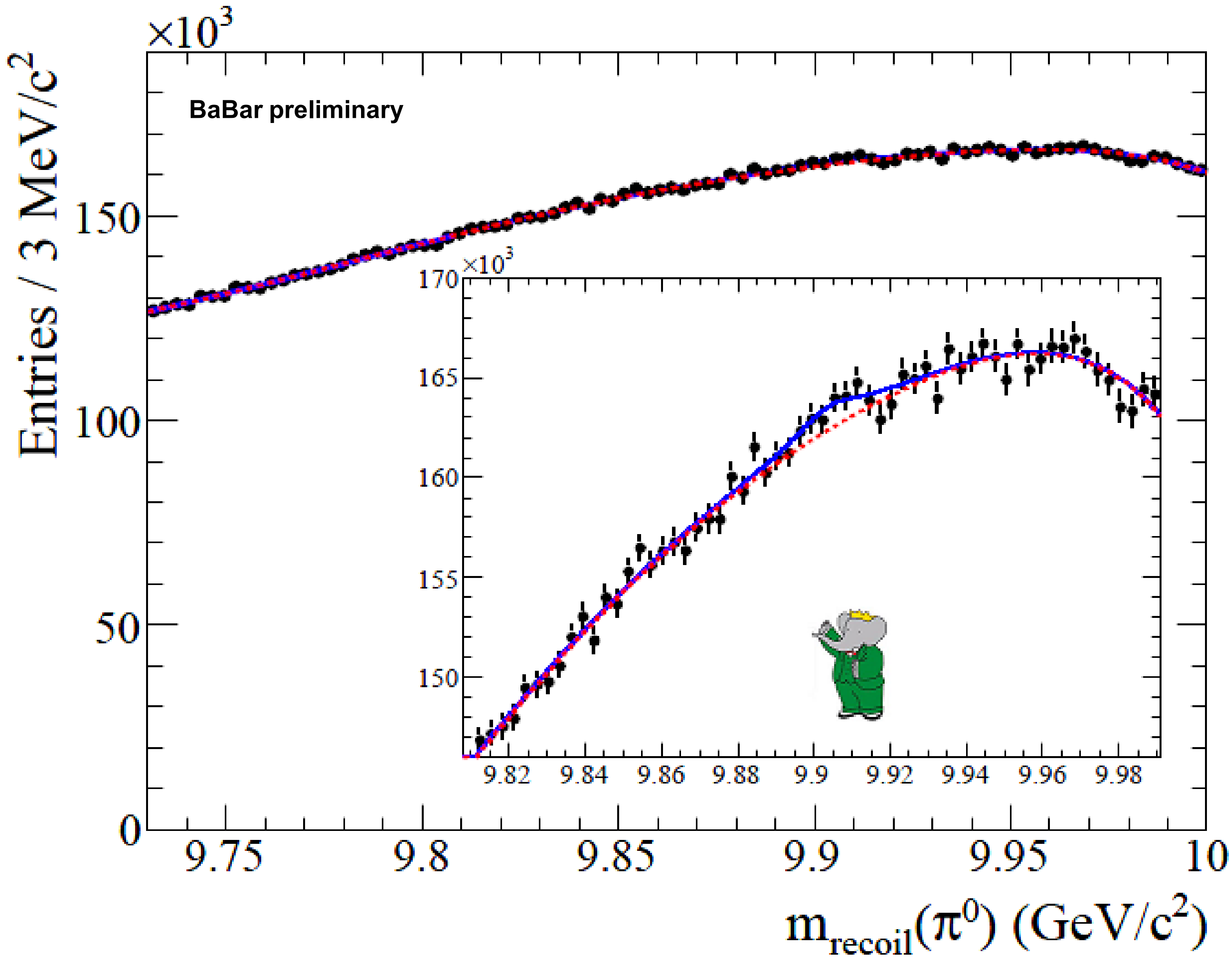
to obtain the distribution of the number of events recoiling against a π^0 as a function of m_{recoil}

Evidence for $\Upsilon(3S)\to\pi^0 h_b(1P)$

Preliminary

122 M $\Upsilon(3S)$

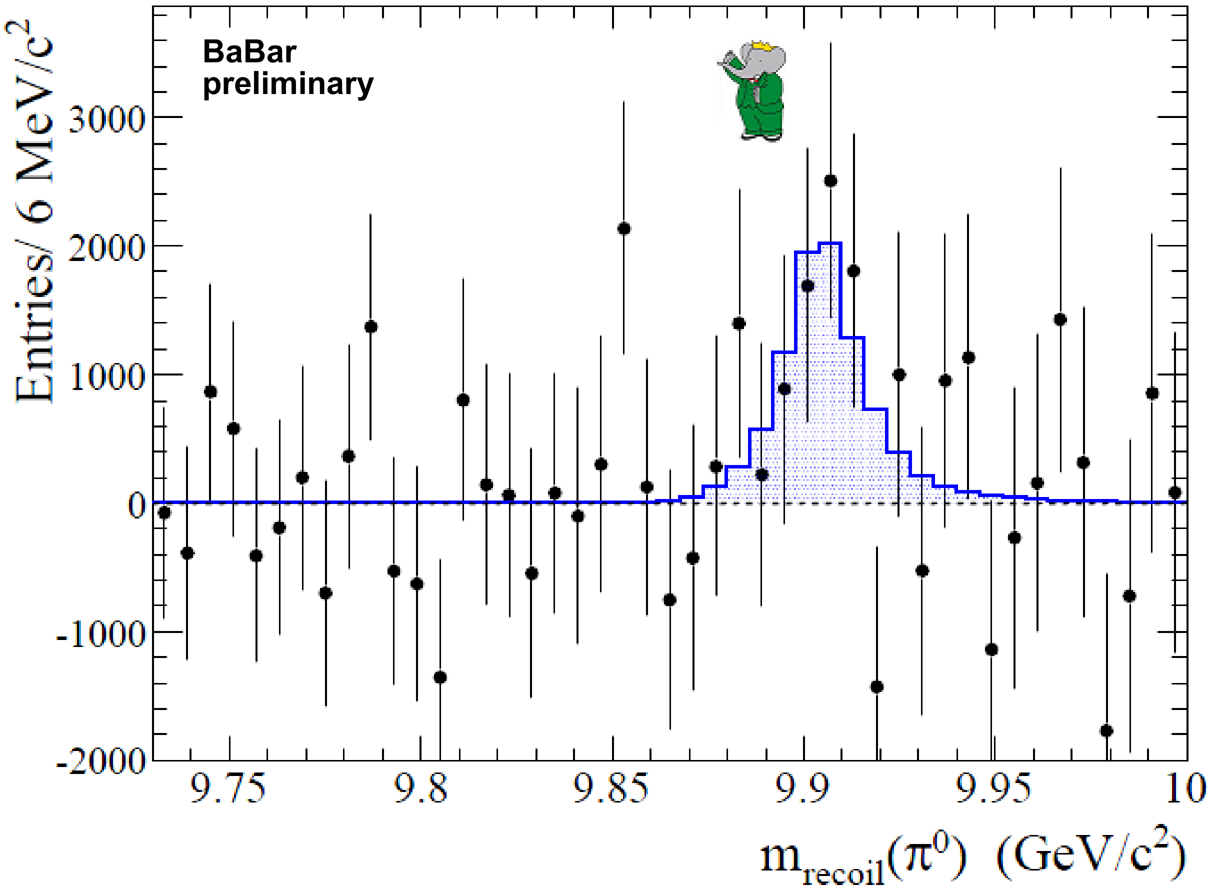
arXiv:1102.4565



Evidence for $\Upsilon(3S)\to\pi^0 h_b(1P)$ Preliminary

122 M $\Upsilon(3S)$

$m_{recoil}(\pi^0)$ background subtracted



arXiv:1102.4565

9145±2804 signal events

$M(h_b)$= (9902±4(stat)±1(syst)) MeV/c^2

consistent with predictions

Statistical significance

(from $\sqrt{\Delta\chi^2}$): 3.2 σ

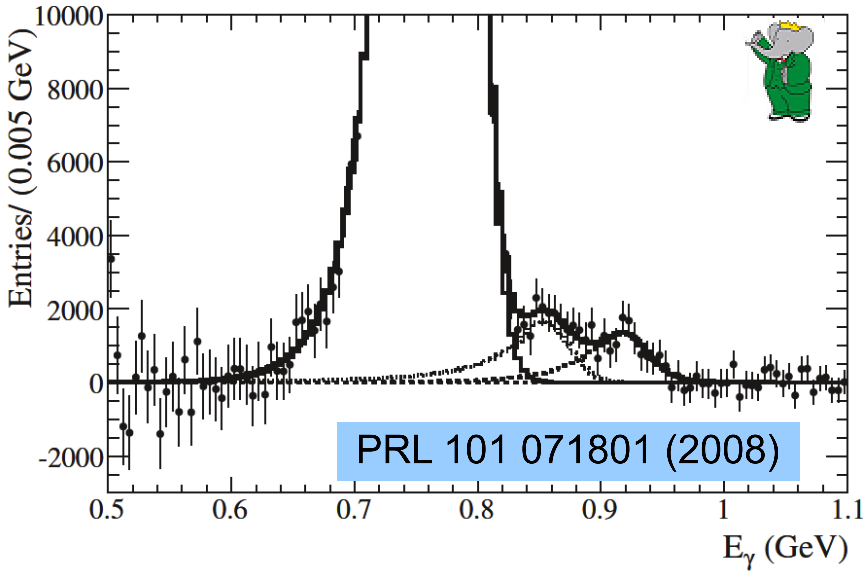
including systematic error: 3.0 σ

$\mathcal{B}(\Upsilon(3S)\to\pi^0\, h_b(1P))\times\mathcal{B}(h_b(1P)\to\gamma\eta_b(1S))$=(3.7±1.1±0.7) ×$10^{-4}$

evaluated at the expected mass value
$M(h_b)$=9900 MeV/c^2

Bottomonium radiative transitions with converted photons

- In the $\Upsilon(nS)\rightarrow\gamma\eta_b(1S)$ transition the photon energy is close to the energy of $\chi_{bJ}(2P)$ transition photons and ISR photon from $e^+e^-\rightarrow\gamma_{ISR}\Upsilon(1S)$



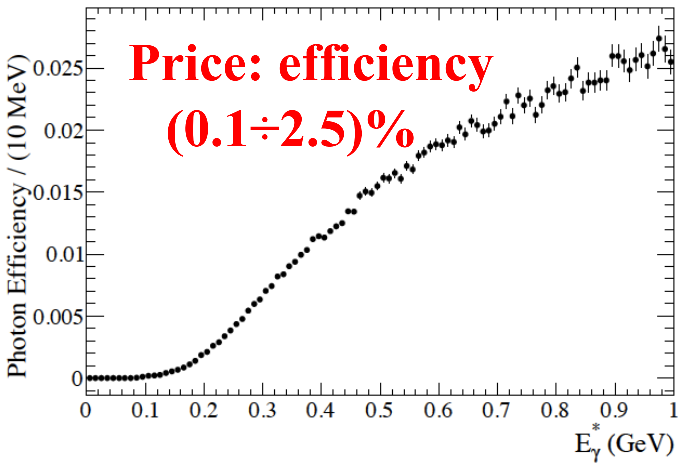
- $\Gamma(\eta_b(1S))$=5-15 MeV

 using estimates of $\Gamma_{\gamma\gamma}(\eta_b(1S))$=(0.2-0.7) keV and

$$\frac{\Gamma_{\gamma\gamma}(\eta_b)}{\Gamma_{gg}(\eta_b)} = \frac{9}{2} Q_b^4 \frac{\alpha_{em}^2}{\alpha_s^2}\left(1 - 7.8\frac{\alpha_s}{\pi}\right)$$

Kwong, Mackenzie, Rosenfeld, Rosner, PRD 37, 3210 (1988)

Use converted photons ($\gamma\rightarrow e+e-$) to improve resolution (e.g.: 25 → 5 MeV)



arXiv:1104.5254

(accepted by PRD)

The spectrum of radiative transitions from $\Upsilon(3S)$ is very rich, many overlapping lines

Deconvolving the individual contributions has been the main difficulty in earlier measurements

Improved measurement of many radiative transitions
See P. Kim talk on Friday

Converted photon energy spectra

arXiv:1104.5254

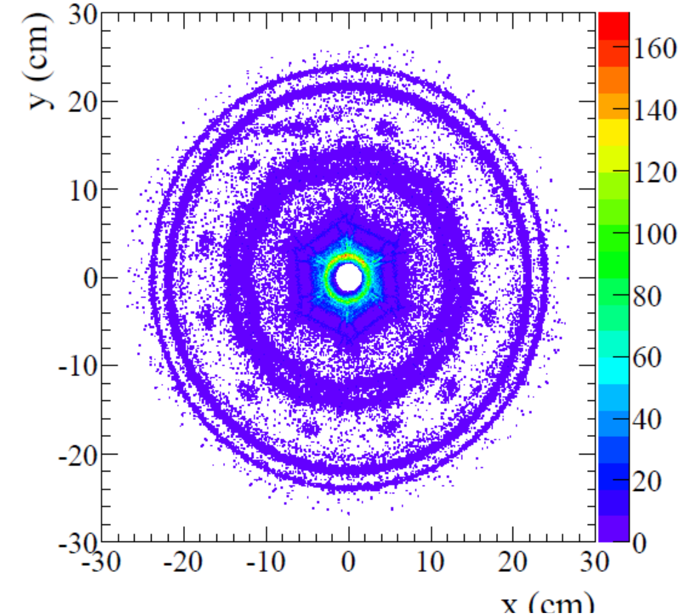
(accepted by PRD)

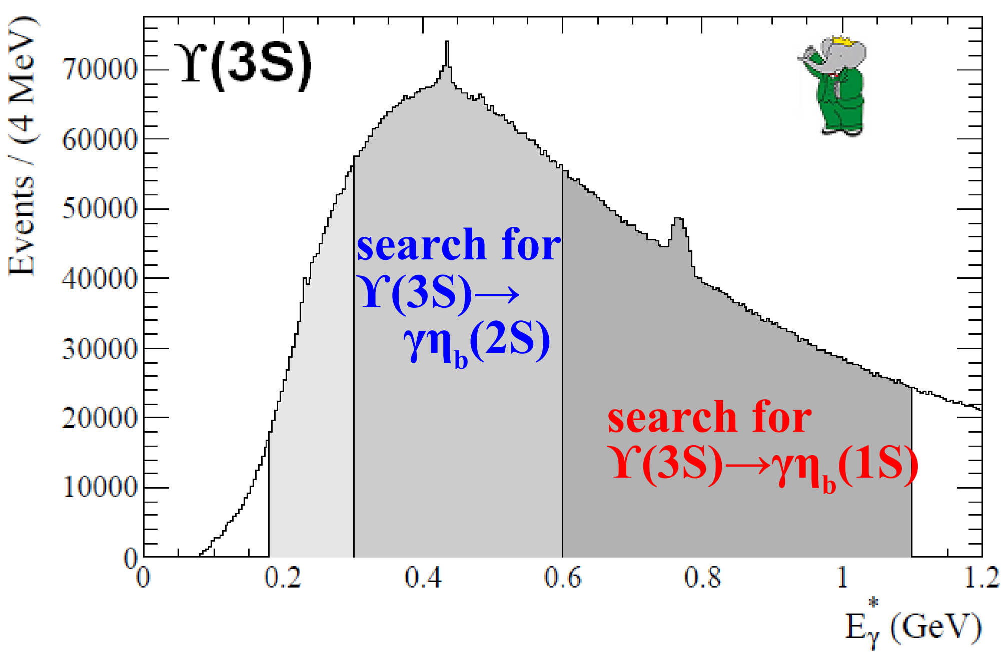
Converted photons are reconstructed from pair of tracks, selected with χ^2 fitter, m_γ, ρ_γ

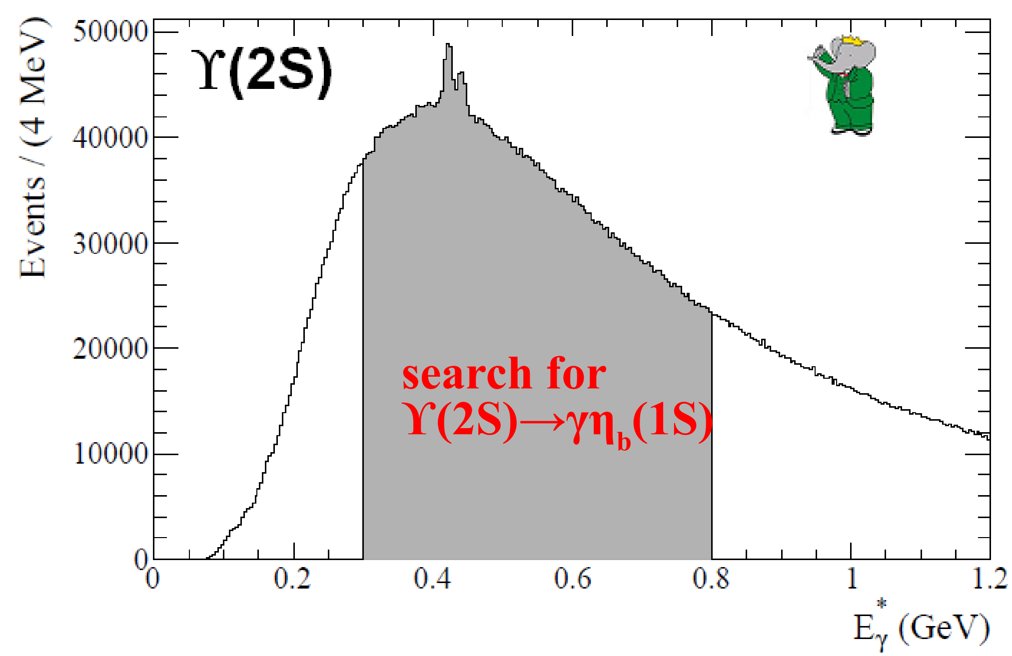
Additional cuts: $|\cos\theta_{thrust}|$, N_{tracks}, π^0 veto

Fit E^*_γ spectrum in four regions of interest

1) $\Upsilon(3S)$: $180 < E^*_\gamma < 300$ MeV
2) $\Upsilon(3S)$: $300 < E^*_\gamma < 600$ MeV
3) $\Upsilon(3S)$: $600 < E^*_\gamma < 1100$ MeV
4) $\Upsilon(2S)$: $300 < E^*_\gamma < 800$ MeV







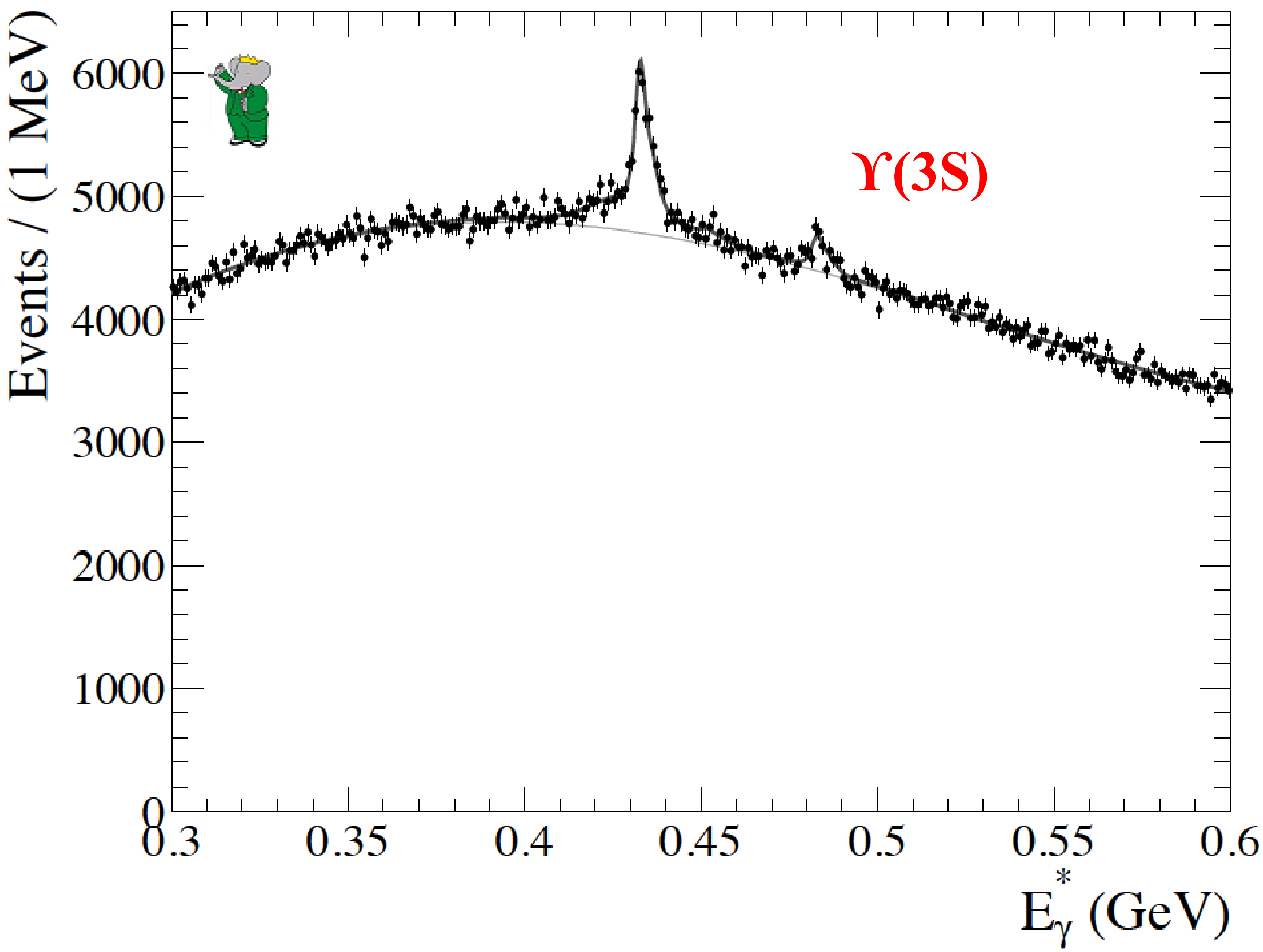
$\Upsilon(3S)$ - $300<E^*_\gamma<600$ MeV

arXiv:1104.5254

(accepted by PRD)

Complex spectrum

- 3 signal transitions for $\Upsilon(3S)\rightarrow\gamma\ \chi_{bJ}(1P)$
- 3 overlapping Doppler-broadened transitions for $\chi_{bJ}(1P)\rightarrow\gamma\Upsilon(1S)$, shape depends on the path to $\chi_{bJ}(1P)$

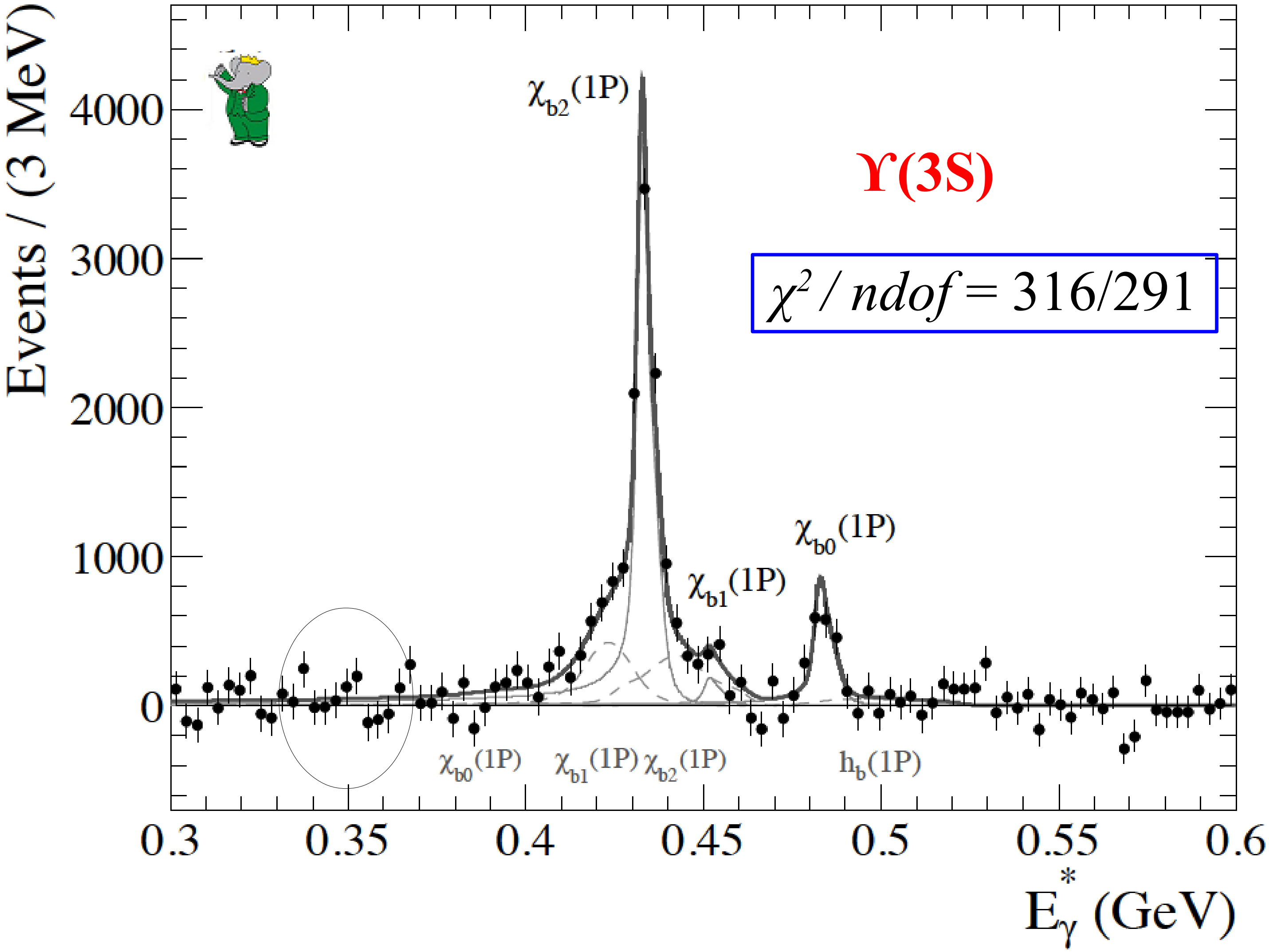


binned χ^2 fit to sum of smooth component plus signal components

$\Upsilon(3S)$ - $300<E^*_\gamma<600$ MeV

arXiv:1104.5254

(accepted by PRD)



subtracting the smooth background

try to add an $\eta_b(2S)$ signal component

$$\mathcal{B}(\Upsilon(3S) \to \gamma\eta_b(2S)) < 1.9 \times 10^{-3}$$ (90% CL)

consistent with CLEO (a factor 2 less stringent)

PRL 94, 032001 (2005).

$\Upsilon(3S)$ - $600<E^*_\gamma<1100$ MeV

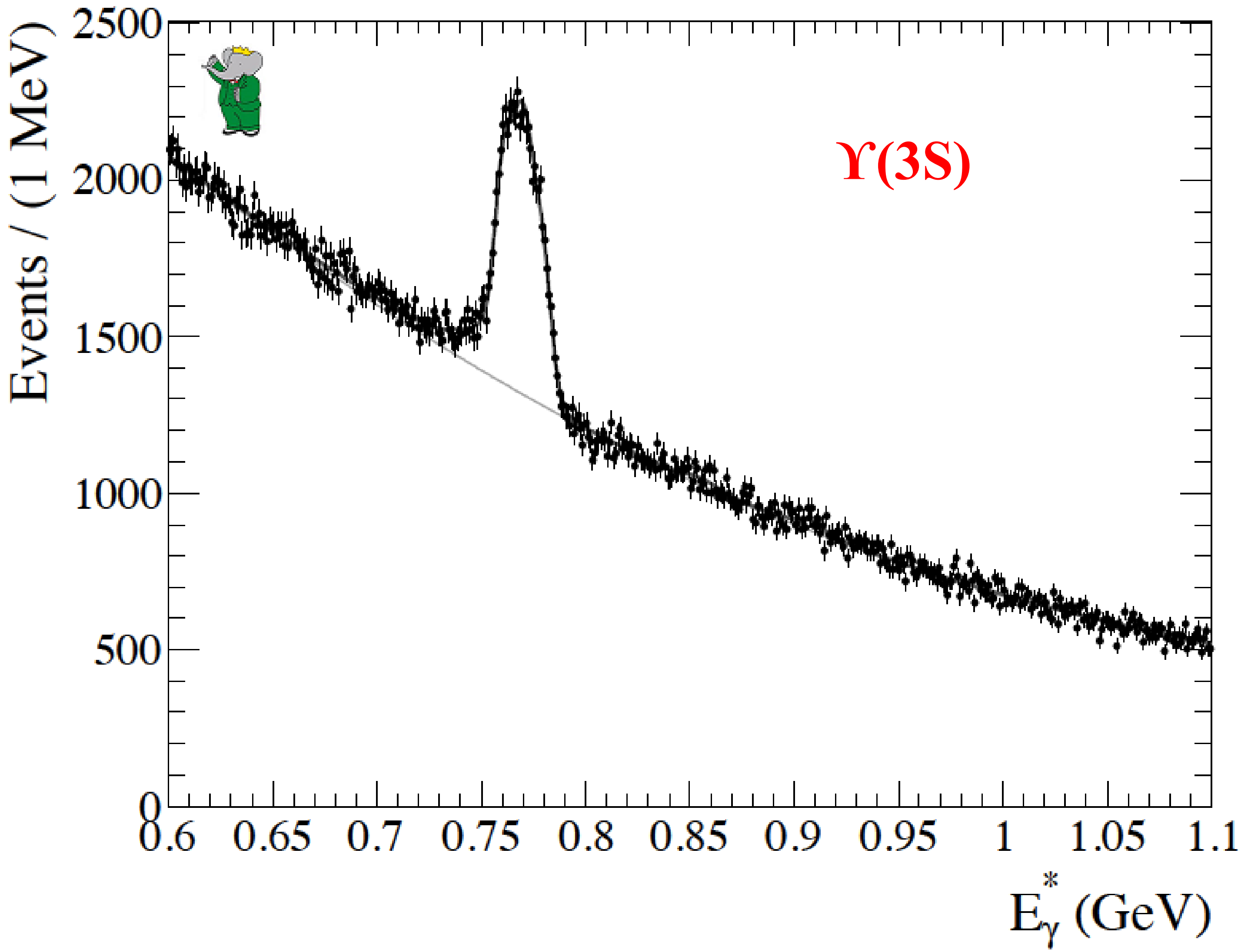
arXiv:1104.5254

(accepted by PRD)

Expect

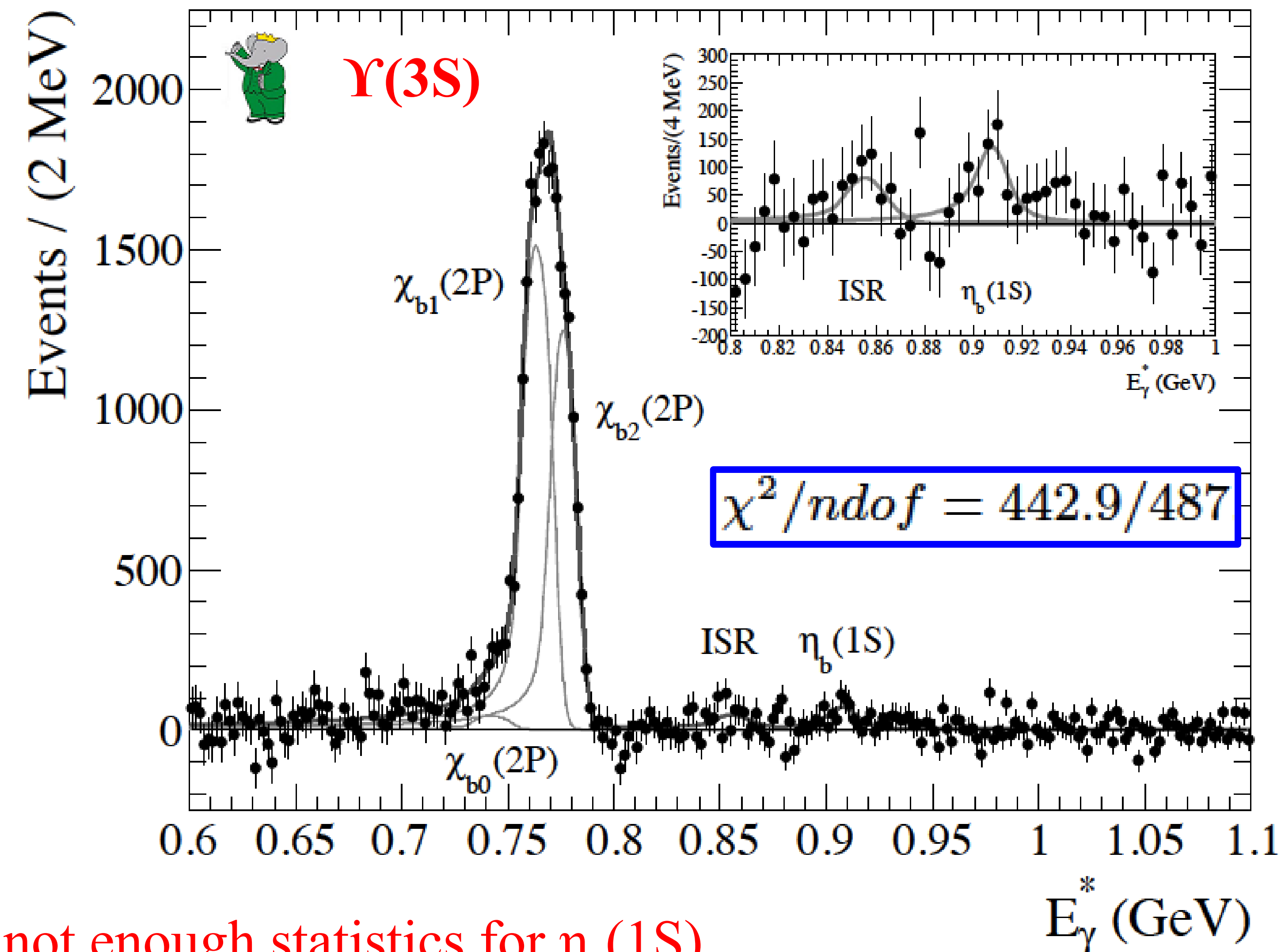
3 signal overlapping transitions for $\chi_{bJ}(2P)\to\gamma\Upsilon(1S)$

$\Upsilon(3S)\to\gamma\eta_b(1S)$ and photon from ISR $\Upsilon(1S)$ production



binned χ^2 fit to sum of smooth component plus signal components

$\Upsilon(3S)$ - $600 < E^*_\gamma < 1100$ MeV



arXiv:1104.5254

(accepted by PRD)

subtracting the smooth background component

not enough statistics for $\eta_b(1S)$

$\mathcal{B}(\Upsilon(3S) \rightarrow \gamma\eta_b(1S) < 8.5 \times 10^{-4}$ (90% CL)

(for $\eta_b(1S)$ mass floating)

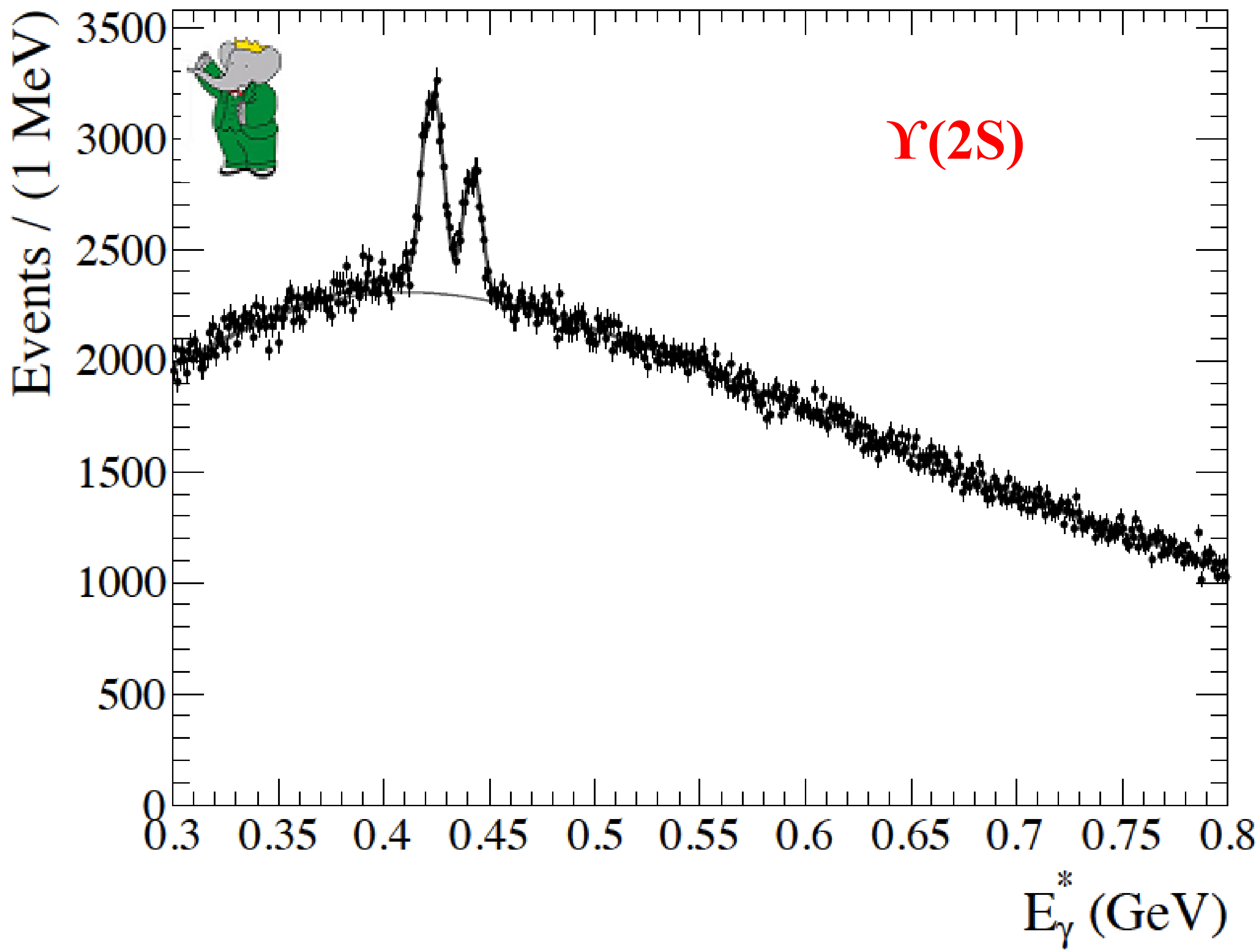
consistent with our previous result

PRL 101 071801 (2008)

$\Upsilon(2S)$ - $300<E^*_\gamma<800$ MeV

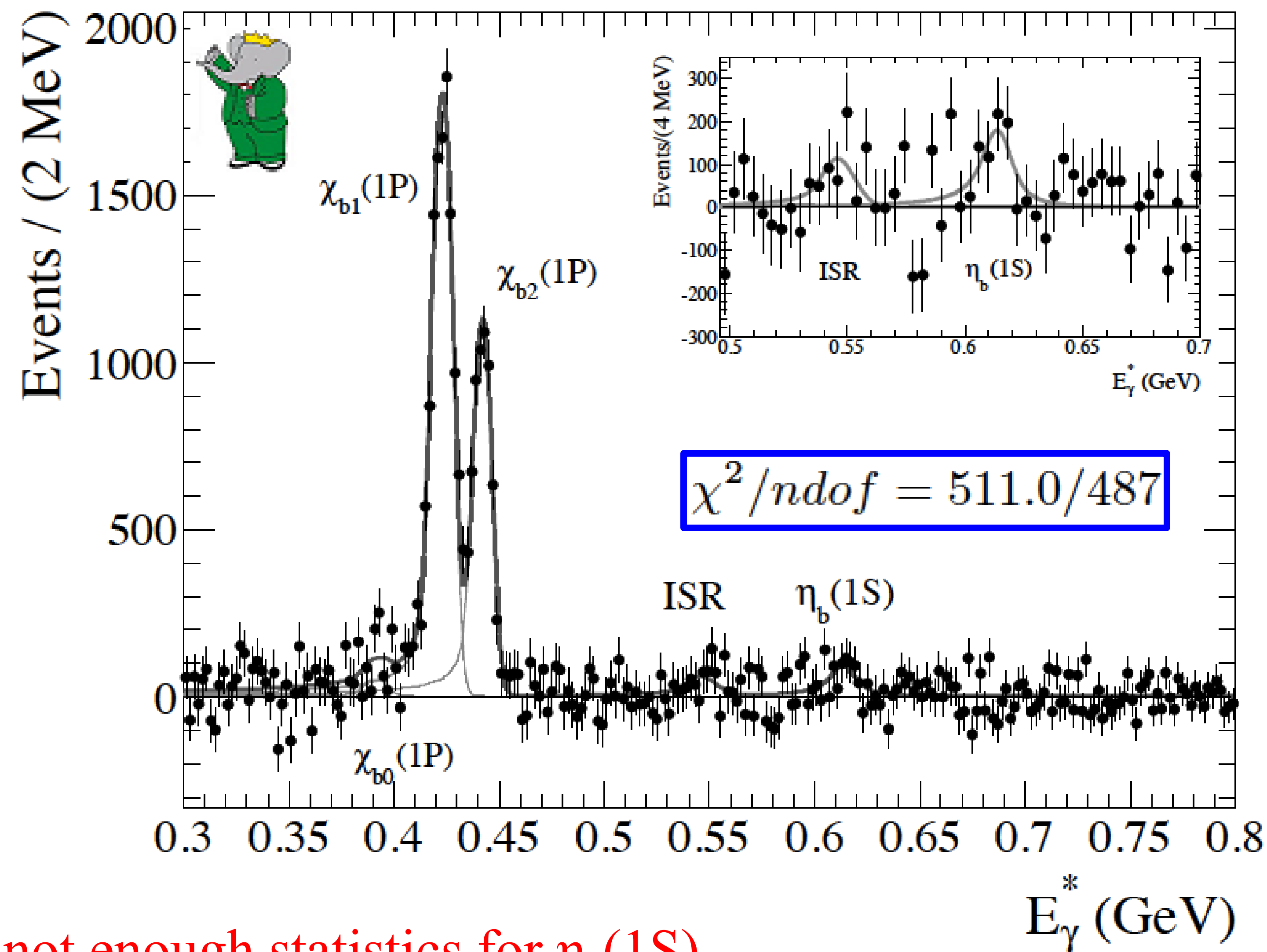
arXiv:1104.5254
(accepted by PRD)

Expect
3 signal transitions for $\chi_{bJ}(1P)\rightarrow\gamma\Upsilon(1S)$
$\Upsilon(2S)\rightarrow\gamma\eta_b(1S)$ and photon from ISR $\Upsilon(1S)$ production



binned χ^2 fit to sum of smooth component plus signal components

$\Upsilon(2S)$ - $300<E^*_\gamma<800$ MeV



arXiv:1104.5254

(accepted by PRD)

subtracting the smooth background component

not enough statistics for $\eta_b(1S)$

$$\mathcal{B}(\Upsilon(2S) \to \gamma\eta_b(1S)) < 0.21\%$$ (90% CL)

(for $\eta_b(1S)$ mass floating)
consistent with our previous result
PRL 103 161801 (2009)

Conclusions

- no evidence for $\Upsilon(3S)\rightarrow\pi^{+}\pi^{-} h_b(1P)$
- evidence for $\Upsilon(3S)\rightarrow\pi^{0} h_b(1P)$
  - mass compatible with expectation
  - branching ratio values marginally discriminating between different calculations
- Not enough statistics to observe $\eta_b(nS)$ in the converted photon spectrum, but with the larger statistics at super B-factories it could be a valid strategy
  - by-product: very precise measurements of a number of hadronic and radiative decays

see Peter Kim's talk on Friday