New Particles

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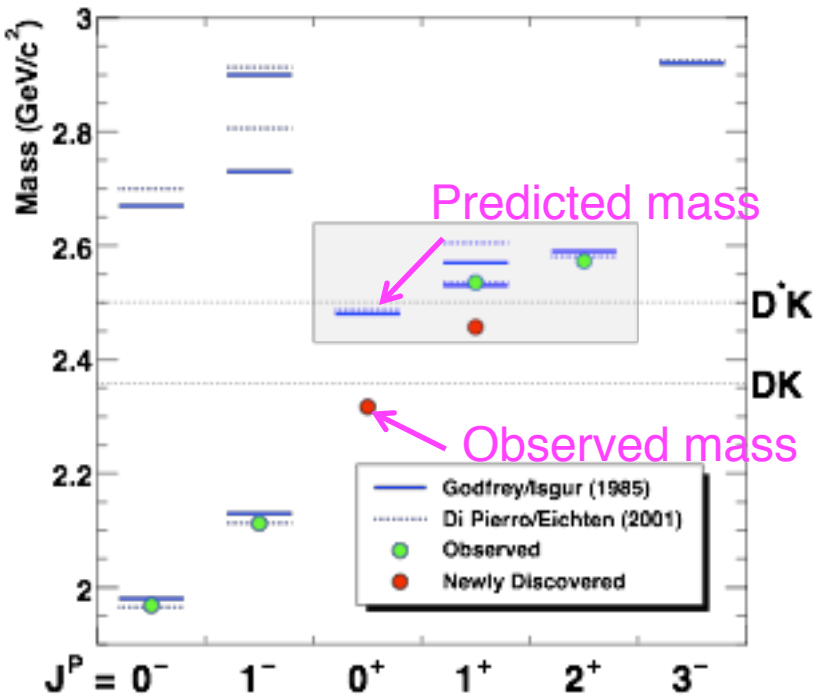
27-Oct-2008

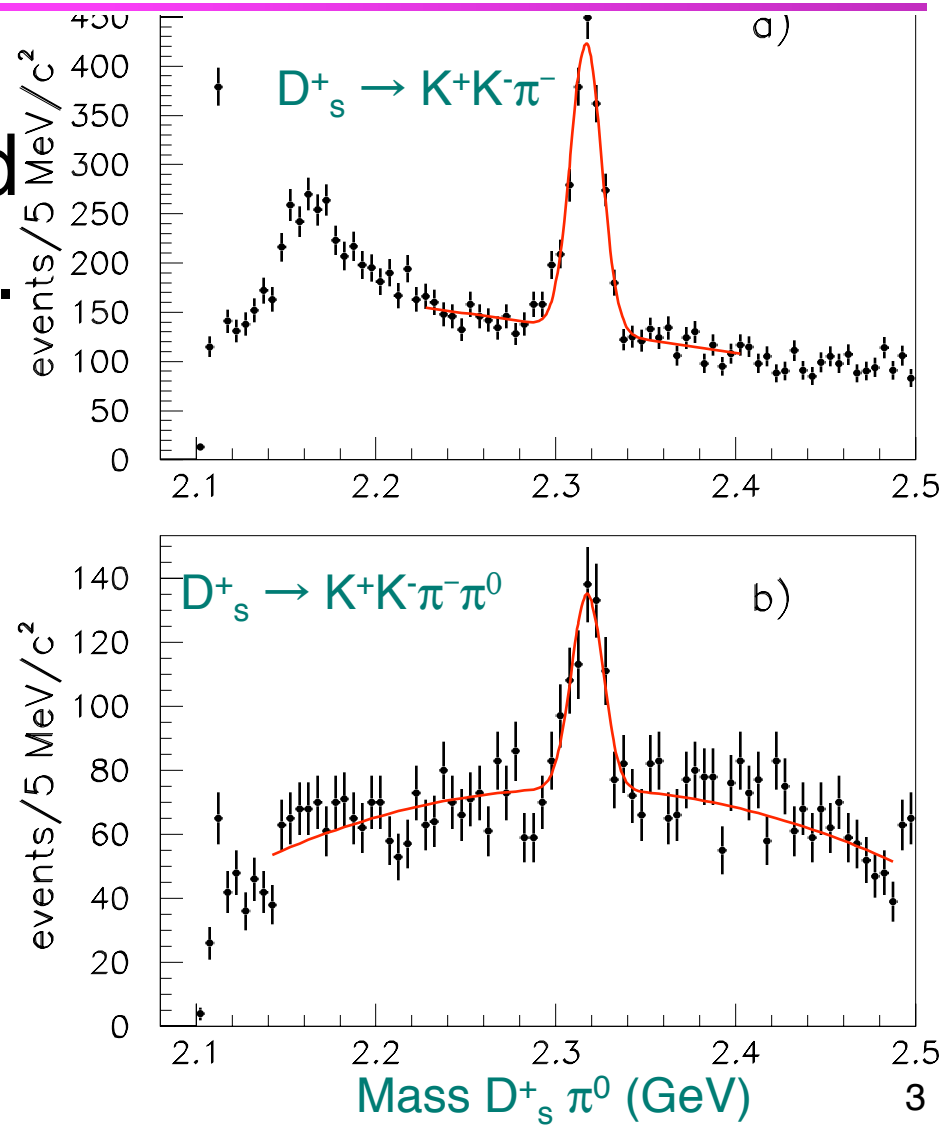
Physics Book

PRL 90:242001, 2003

$D^*_{s0}(2317)^+$

- Surprisingly light and narrow resonance found in $D^+_s\pi^0$ mass spectrum.

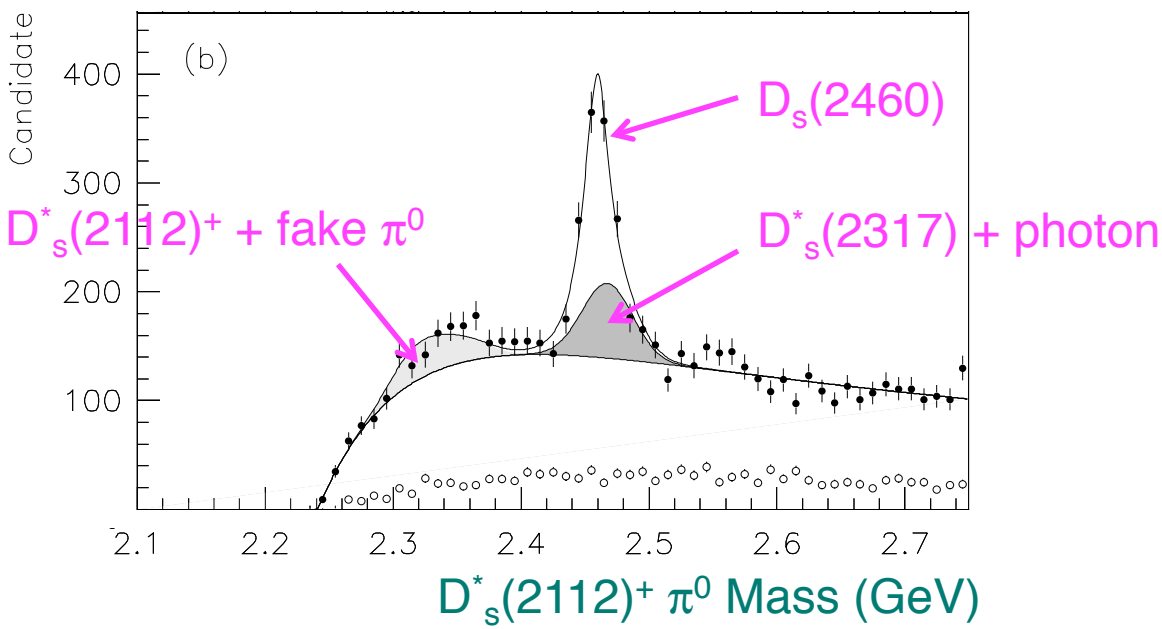




PRD 69:031101, 2004
PRL 97:222001, 2006

$D_{s1}(2460)^+$

- Shortly thereafter, second narrow state observed in $D^*_s(2112)^+ \pi^0$. Initial uncertainty: new particle? Or $D^*_s(2317)^+$ + random photon?



- More recently, another D_s meson at 2.86 GeV

BABAR Citations

1) **Observation of a narrow meson decaying to D+(s) pi0 at a mass of 2.32-GeV/c**2.**
By BABAR Collaboration (B. Aubert *et al.*). SLAC-PUB-9711, BABAR-PUB-03-011, Apr 2003. 7pp.
Press Release from SLAC.
Published in **Phys.Rev.Lett.90:242001,2003**.
e-Print: **hep-ex/0304021**

464 citations

TOPCITE = 250+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 464 times
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
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pdgLive (measurements quoted by PDG)
Press Release about this paper
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2) **Observation of CP violation in the B0 meson system.**
By BABAR Collaboration (B. Aubert *et al.*). SLAC-PUB-8904, BABAR-PUB-01-18, Jul 2001. 8pp.
Press release.
Published in **Phys.Rev.Lett.87:091801,2001**.
e-Print: **hep-ex/0107013**

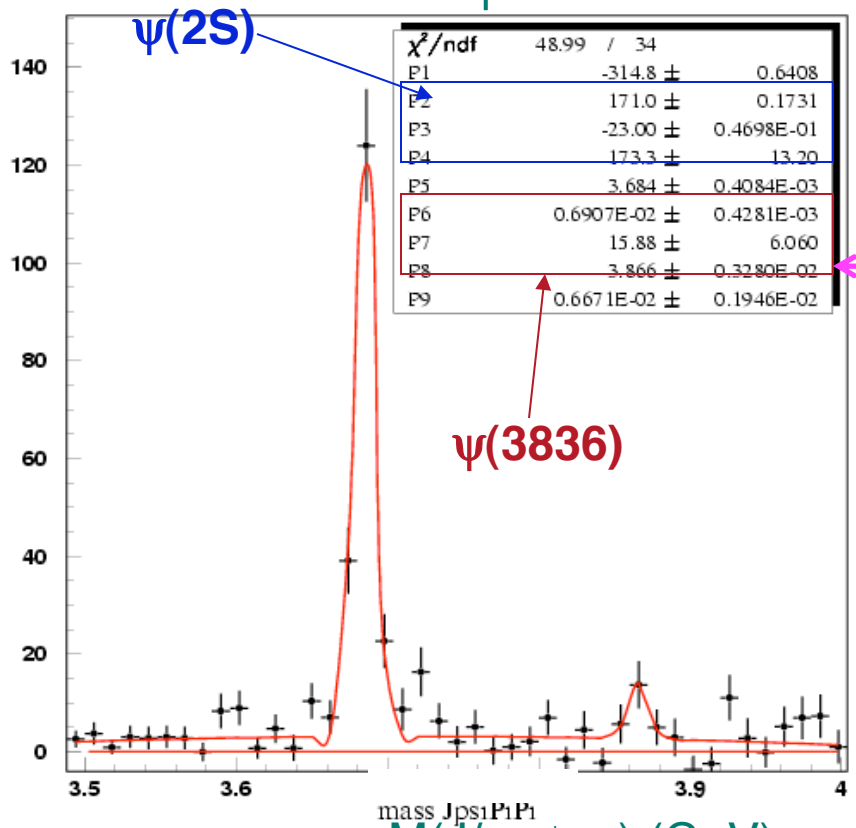
428 citations

TOPCITE = 250+
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 428 times

PRD 71:071103, 2005

X(3872)

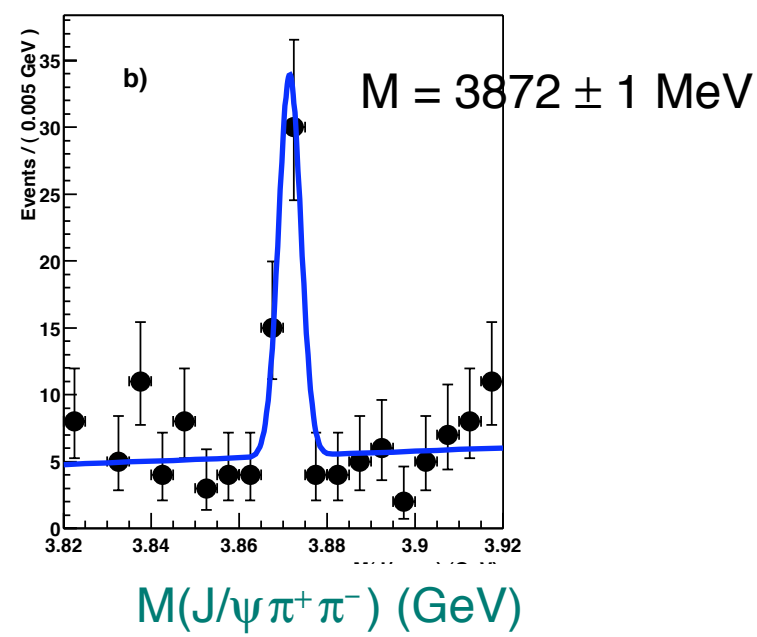
$B^+ \rightarrow J/\psi\pi^+\pi^- K^+$



AWG meeting June 2003 motivation: background to $J/\psi\ K_L$; test factorization…

Mass = 3866 ± 6

Belle, later that summer

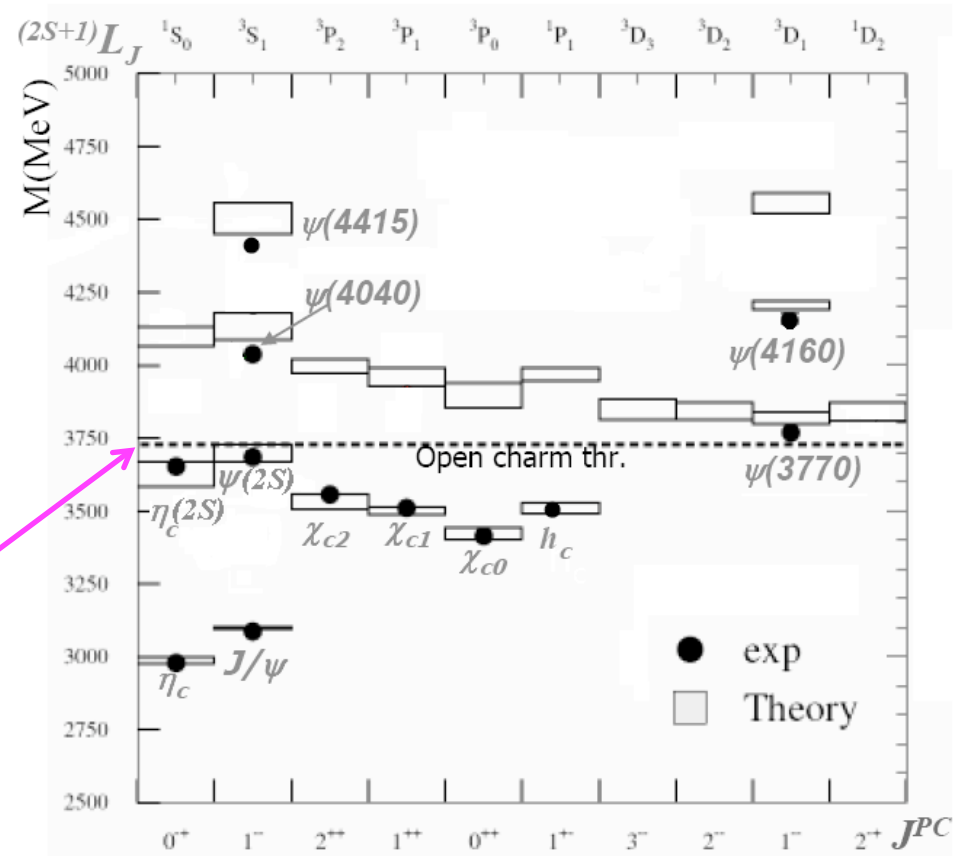


Charmonium

- Two heavy quarks, spins ↑↓ or ↑↑ + orbital angular momenta ⇒ mass spectrum of states is basically calculable

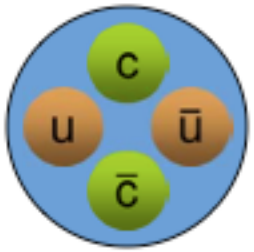
Below $D\bar{D}$ threshold states are narrow; above, generally broad

Charmonium spectrum pre-X(3872)



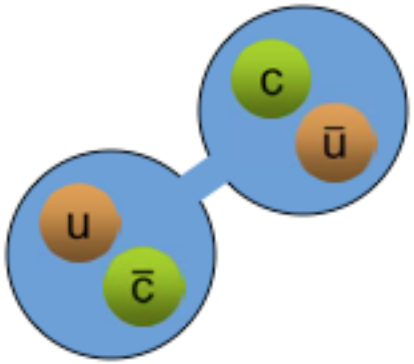
Alternatives

tetraquark



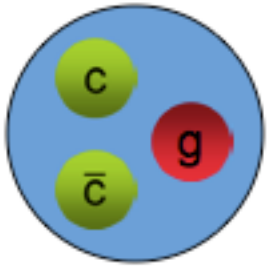
also [c $\bar{d}$ $\bar{c}$ d] 2nd neutral state
[c $\bar{u}$ $\bar{c}$ d] charged partner

DD* molecule



$M_X = 3872.2 \pm 0.8$ MeV;
$M(D^0\bar{D}^{*0}) = 3871.81 \pm 0.36$ MeV

hybrid

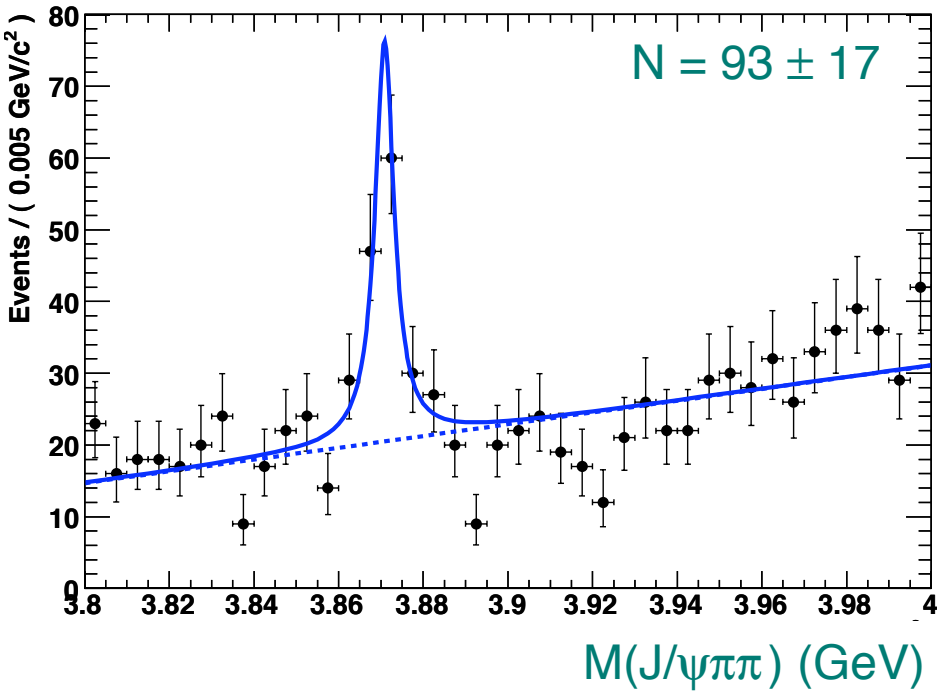


- Distinguish between alternatives by mass; branching fractions; charged or neutral partners; quantum numbers.

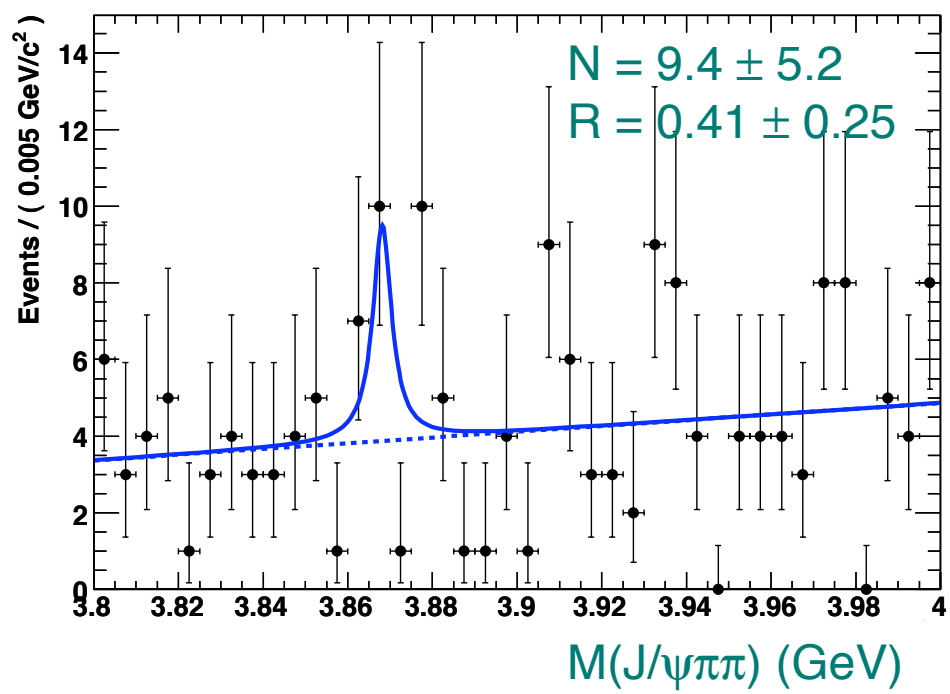
PRD 77:111101, 2008

$X(3872) \to J/\psi\pi^+\pi^-$

$B^+ \to X^0 K^+$



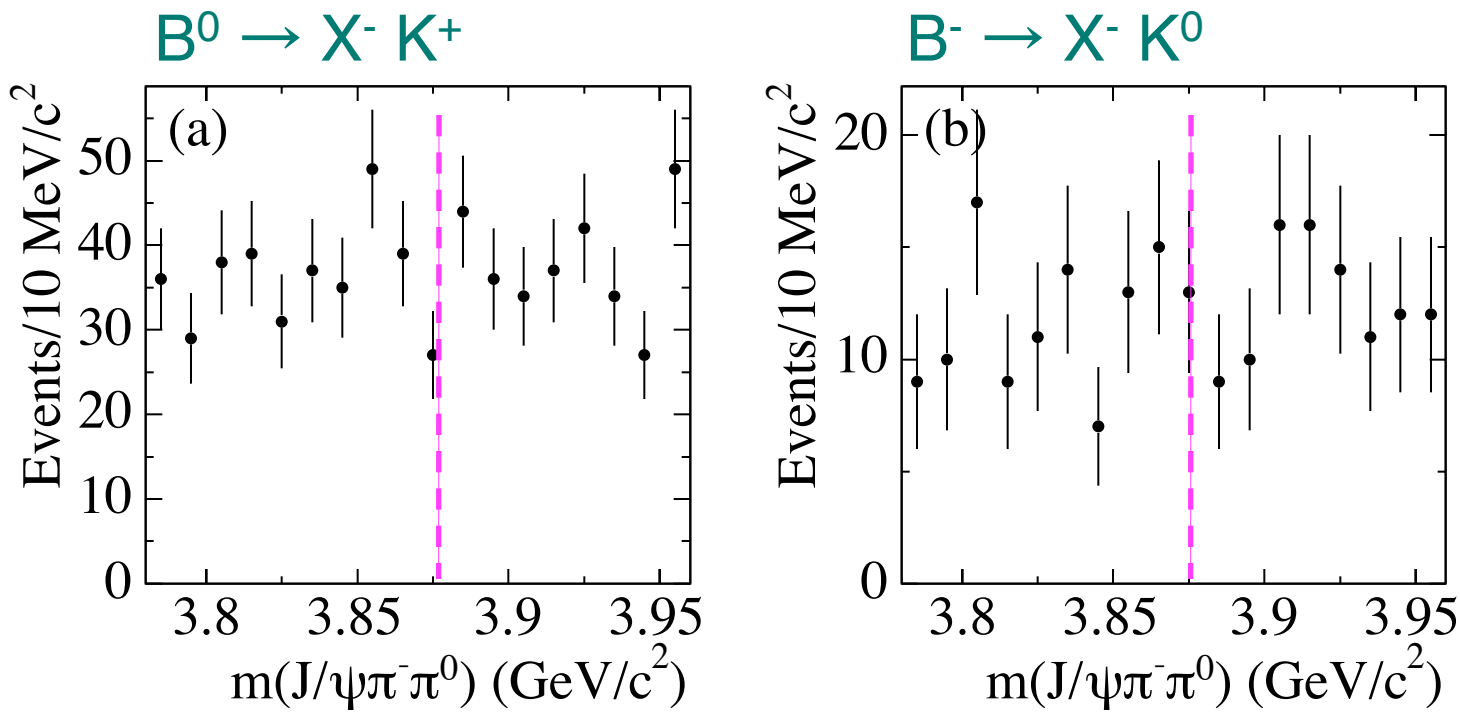
$B^0 \to X^0 K^0$



- Are these the same X^0? $\Delta m = 2.7 \pm 1.6$ MeV.
- Is the decay $X \to J/\psi\rho, \rho \to \pi^+\pi^-$?
  If so, $X \to J/\psi\, \pi^0\pi^0$ forbidden.

PRD 71: 031501, 2005

Charged Partner

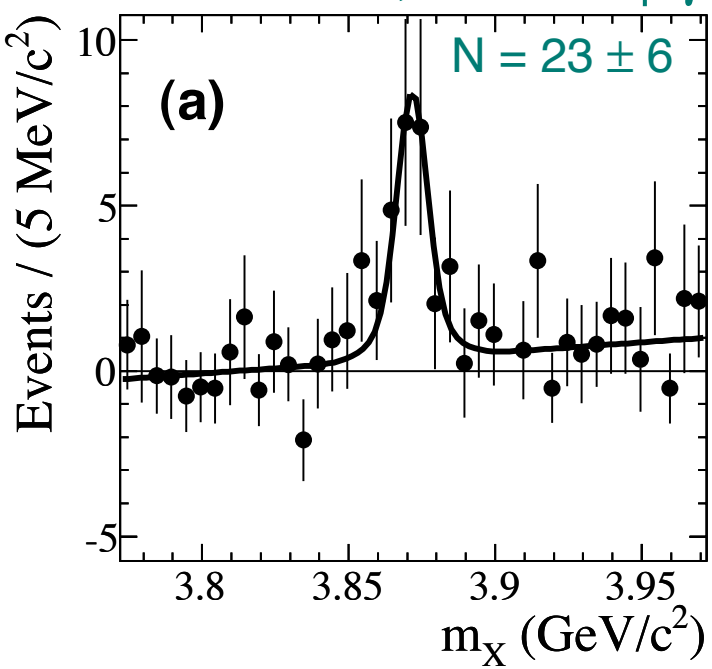


- Would seem to rule out tetraquark interpretation
  $B^0 \to X^- K^+ < 5.4 \times 10^{-6}$ vs
  $B^+ \to X^0 K^+ = (11.4 \pm 2.0) \times 10^{-6}$

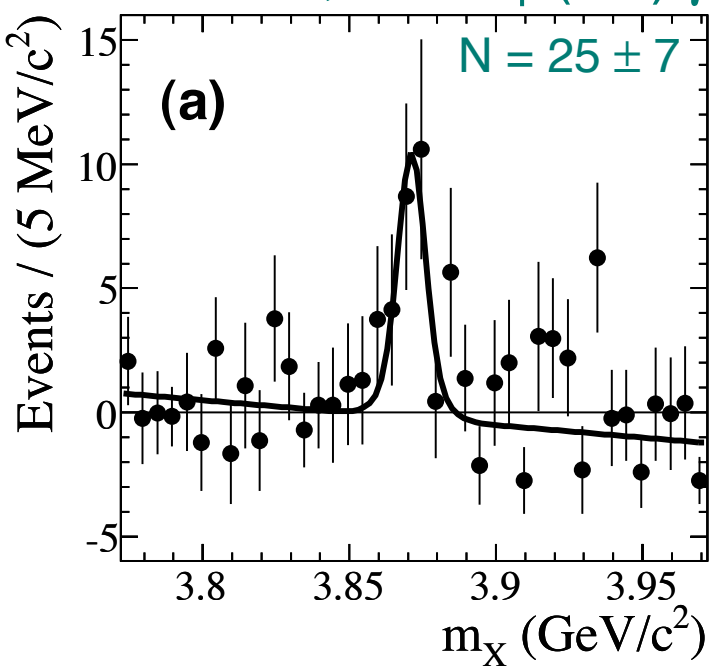
PRD 74:071101, 2006
0809.0042 [hep-ex]

$X(3872) \to J/\psi\gamma$ or $\psi(2S)\gamma$

$B^+ \to X K^+$, $X \to J/\psi\gamma$



$B^+ \to X K^+$, $X \to \psi(2S)\gamma$

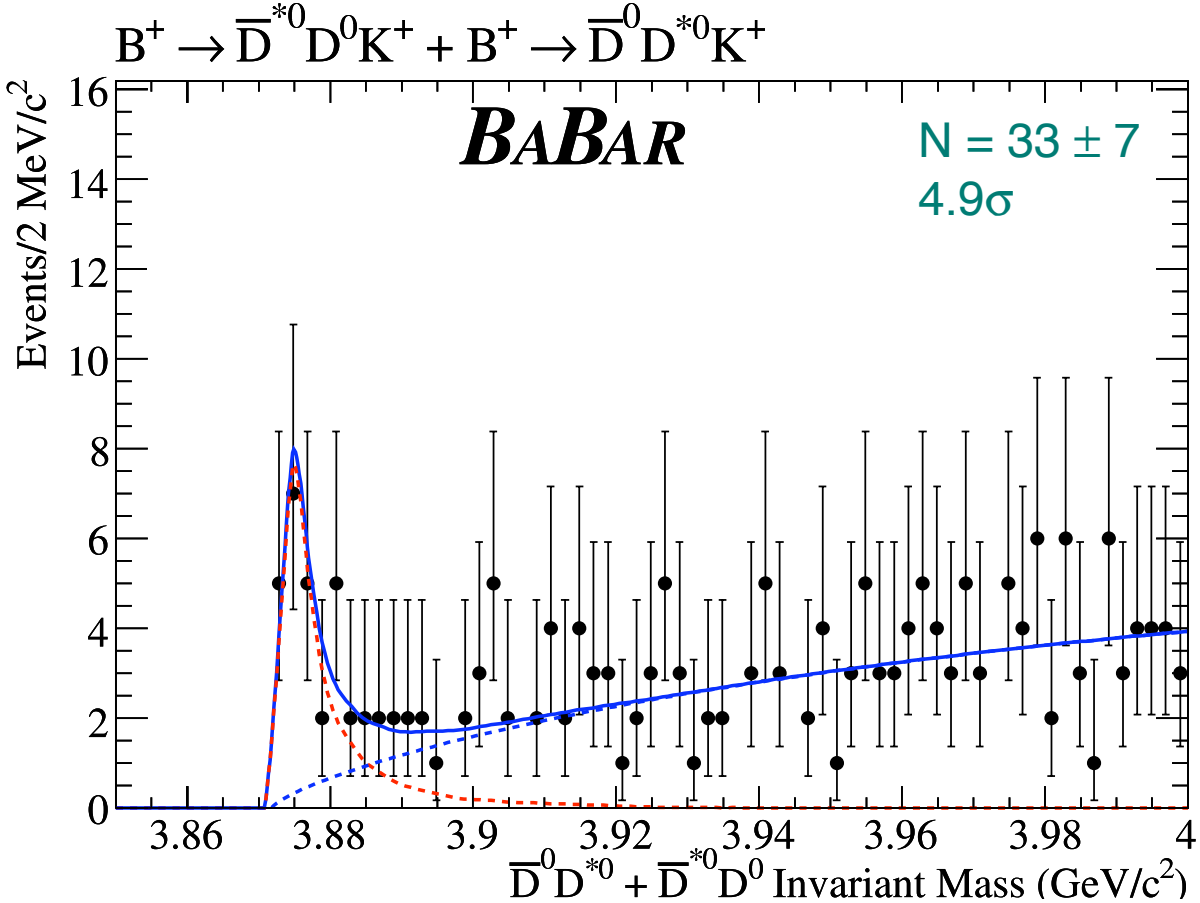


$X \to \psi(2S)\gamma / X \to J/\psi\gamma = 3.5 \pm 1.4$; $X \to \psi(2S)\gamma / X \to J/\psi\pi^+\pi^- = 1.1 \pm 0.4$

- Establishes one quantum number: C = +1
- $X \to \psi(2S)\gamma$ suppressed for $D^0\bar{D}^{*0}$ molecule?

PRD 77:011102, 2008

$X(3872) \rightarrow D^0 \bar{D}^{*0}$



Tremendous effort to correctly handle impact of threshold on mass and width

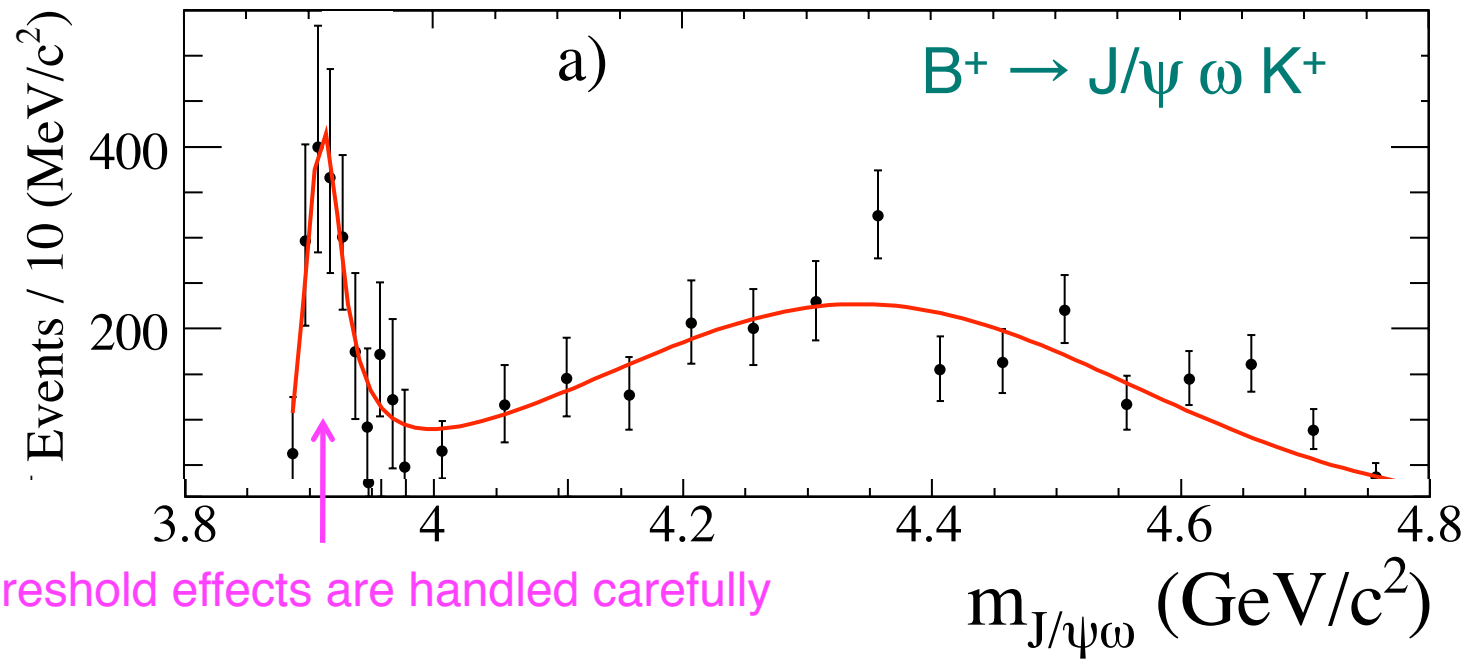
- Mass is 4σ higher than $J/\psi\pi^+\pi^-$, but could be threshold effect.

What is the X(3872)?

- CDF angular analysis: $J^{PC} = 1^{++}$ or 2^{-+}. Belle analysis favors 1^{++}.
  - 1^{++}: would favor molecule;
  - 2^{-+}: would favor charmonium;
  - but decay rates are also relevant.
- Still an open question…

PRL 101:082001, 2008

$Y(3940) \to J/\psi\,\omega$



Threshold effects are handled carefully

M = 3915 ± 4 MeV (vs M = 3943 ± 20 MeV Belle)

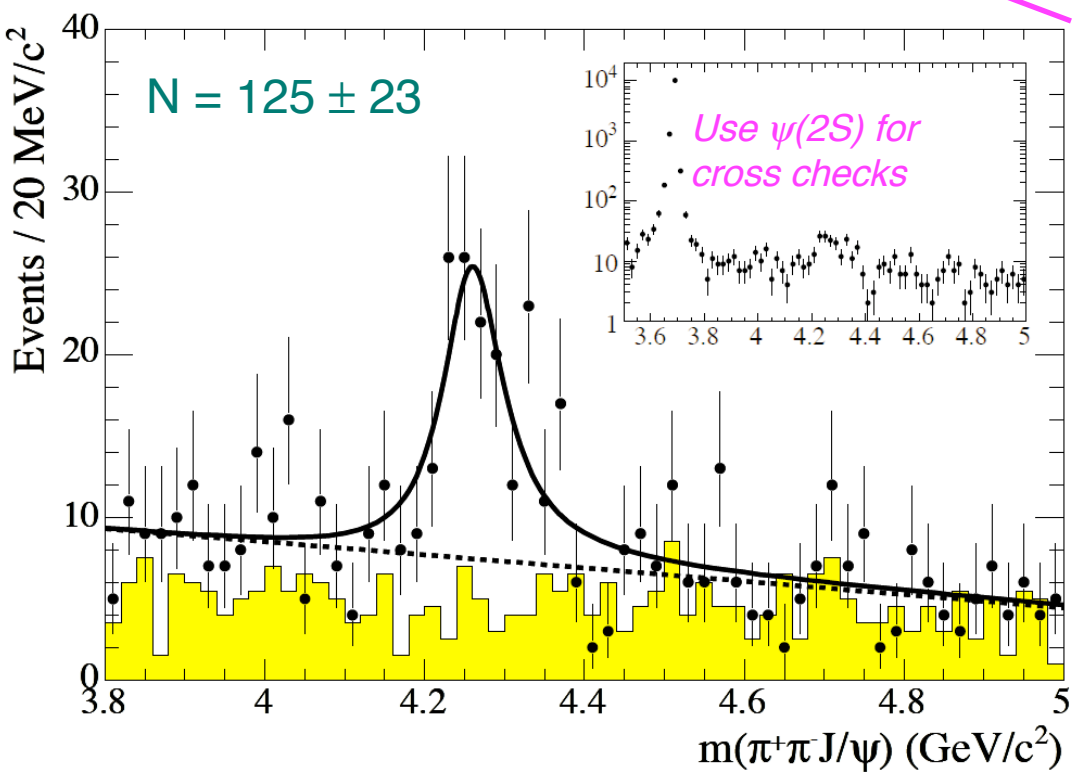
- May be $\chi_{c1}(2P)$, standard charmonium,
  - » might expect larger DD* decay rate and radiative decays

PRL 95:142001, 2005

Y(4260)

- ISR production: $e^+e^- \to (\gamma)\pi^+\pi^- J/\psi \Rightarrow J^{PC} = 1^{--}$.

Observe 25% of γ

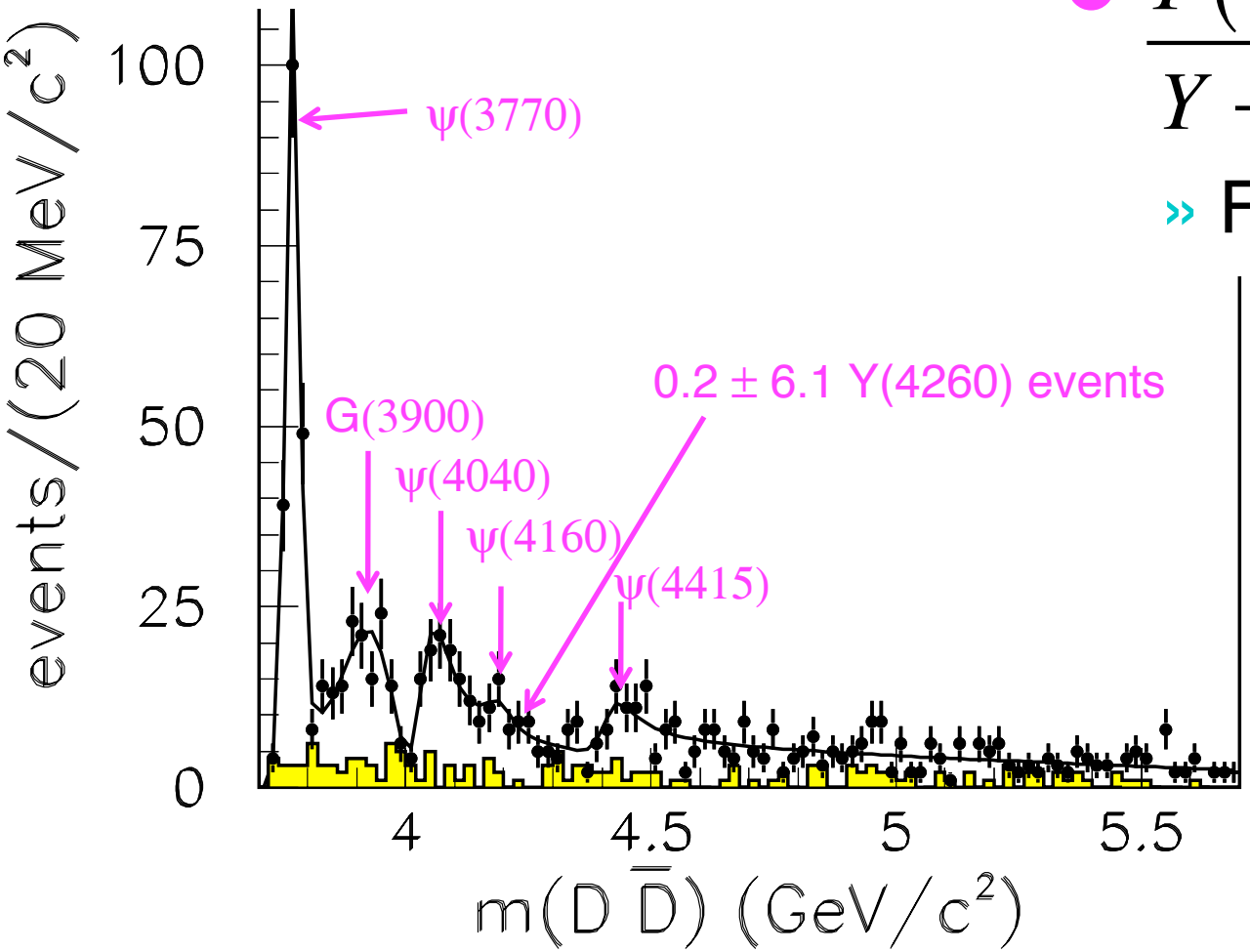


- All 1^{--} states accounted for in charmonium spectrum

PRD 76:111105, 2007

$Y(4260) \to D\bar{D}$

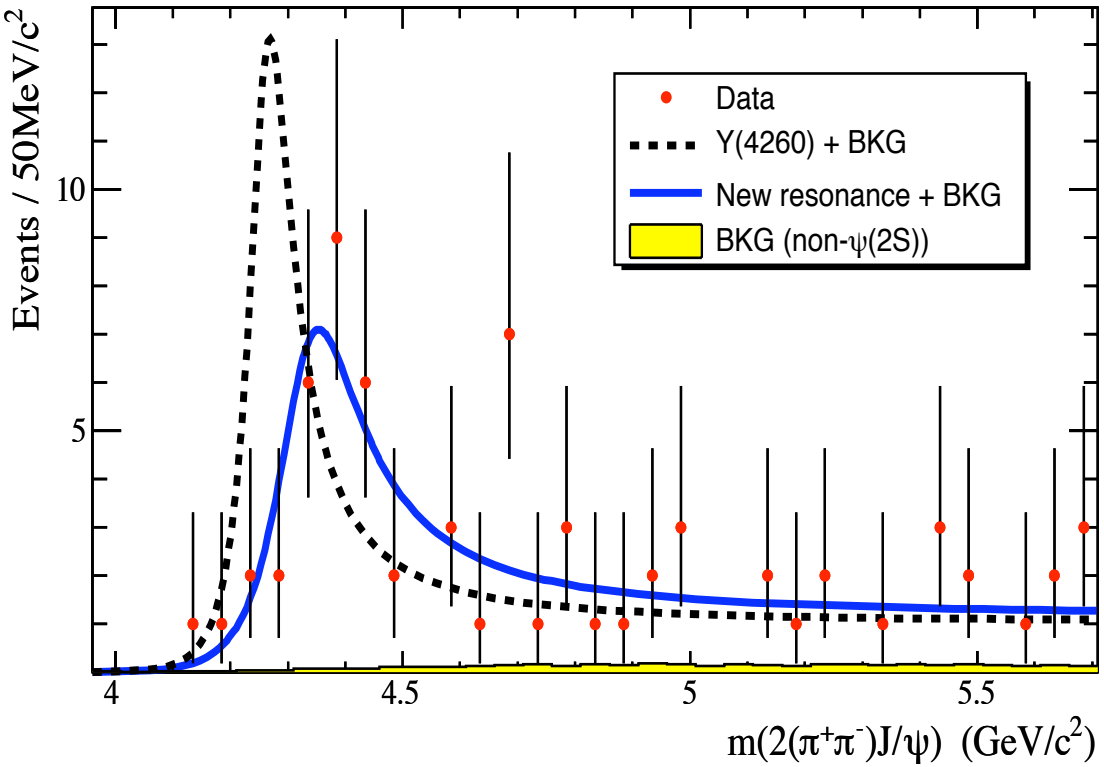
Mass of $D\bar{D}$ produced in ISR



- $$\frac{Y(4260) \to D\bar{D}}{Y \to \pi^+\pi^- J/\psi} < 1$$
  - For ψ(3770), ≈ 450.

PRL 98:212001, 2007

Y(4324)

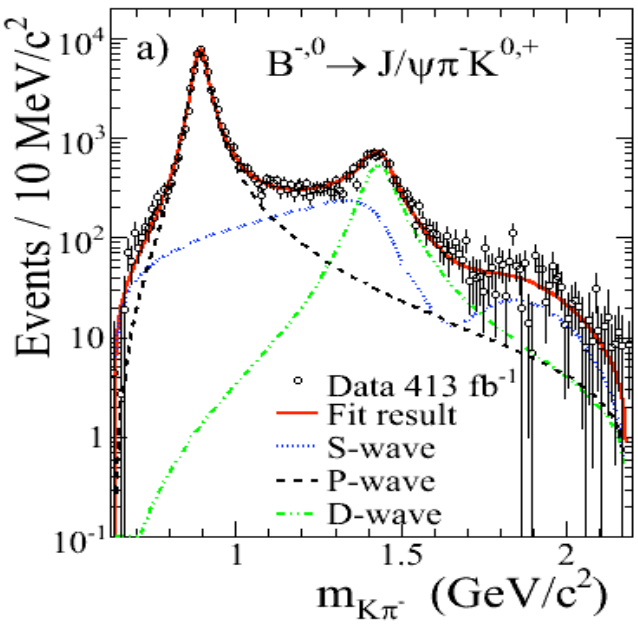


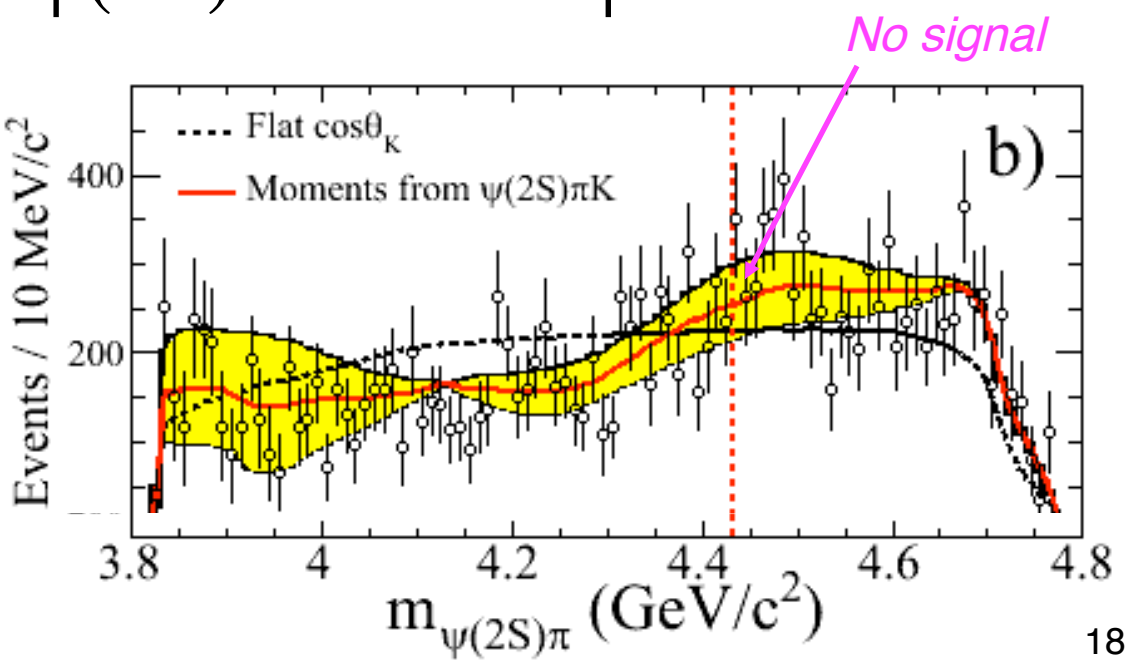
- Broad resonance in ISR production of $\pi^+\pi^-\psi(2S)$. Also $J^{PC} = 1^{--}$.

- Hybrid 1^{--} states expected. Lightest consistent with 4.26 GeV. Expect other hybrids, some with non-standard J^{PC} such as 1^{-+}.

$Z(4430)^-$

- Study $B \rightarrow \psi \pi^- K$ to look for $Z(4430)^-$ seen by Belle in $\psi(2S)\pi^-$. Would be four-quark state.
- Huge effort to understand $K \pi^-$ mass & angular distributions. Both $\psi(2S) \pi^-$ and $J/\psi \pi^-$.





To be submitted to PRD

BABAR-Analysis-Document 2049, v11
BABAR-PUB-08/xxx
SLAC-PUB-xxxx
hep-ex/xxxx

Search for the $Z(4430)^-$ at *BABAR*

B. Aubert,[1] M. Bona,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1] E. Prencipe,[1] X. Prudent,[1] V. Tisserand,[1] J. Garra Tico,[2] E. Grauges,[2] L. Lopez[ab],[3] A. Palano[ab],[3] M. Pappagallo[ab],[3] G. Eigen,[4] B. Stugu,[4] L. Sun,[4] G. S. Abrams,[5] M. Battaglia,[5] D. N. Brown,[5] R. N. Cahn,[5] R. G. Jacobsen,[5] L. T. Kerth,[5] Yu. G. Kolomensky,[5] G. Lynch,[5] I. L. Osipenkov,[5] M. T. Ronan,[5,*] K. Tackmann,[5] T. Tanabe,[5] C. M. Hawkes,[6] N. Soni,[6] A. T. Watson,[6] H. Koch,[7] T. Schroeder,[7] D. Walker,[8] D. J. Asgeirsson,[9] B. G. Fulsom,[9] C. Hearty,[9] T. S. Mattison,[9] J. A. McKenna,[9] M. Barrett,[10] A. Khan,[10] V. E. Blinov,[11] A. D. Bukin,[11] A. R. Buzykaev,[11] V. P. Druzhinin,[11] V. B. Golubev,[11] A. P. Onuchin,[11] S. I. Serednyakov,[11] Yu. I. Skovpen,[11] E. P. Solodov,[11] K. Yu. Todyshev,[11] M. Bondioli,[12] S. Curry,[12] I. Eschrich,[12] D. Kirkby,[12] A. J. Lankford,[12] P. Lund,[12] M. Mandelkern,[12] E. C. Martin,[12] D. P. Stoker,[12] S. Abachi,[13] C. Buchanan,[13] H. Atmacan,[14] J. W. Gary,[14] F. Liu,[14] O. Long,[14] G. M. Vitug,[14] Z. Yasin,[14] L. Zhang,[14] V. Sharma,[15] C. Campagnari,[16] T. M. Hong,[16] D. Kovalskyi,[16] M. A. Mazur,[16] J. D. Richman,[16] T. W. Beck,[17] A. M. Eisner,[17] C. J. Flacco,[17] C. A. Heusch,[17] J. Kroseberg,[17] W. S. Lockman,[17] A. J. Martinez,[17] T. Schalk,[17] B. A. Schumm,[17] A. Seiden,[17] M. G. Wilson,[17] L. O. Winstrom,[17] C. H. Cheng,[18] D. A. Doll,[18] B. Echenard,[18] F. Fang,[18] D. G. Hitlin,[18] I. Narsky,[18] T. Piatenko,[18] F. C. Porter,[18] R. Andreassen,[19] G. Mancinelli,[19] B. T. Meadows,[19] K. Mishra,[19] M. D. Sokoloff,[19] P. C. Bloom,[20] W. T. Ford,[20] A. Gaz,[20] J. F. Hirschauer,[20] M. Nagel,[20] U. Nauenberg,[20] J. G. Smith,[20] K. A. Ulmer,[20] S. R. Wagner,[20] R. Ayad,[21,†] A. Soffer,[21,‡] W. H. Toki,[21] R. J. Wilson,[21] E. Feltresi,[22] A. Hauke,[22] H. Jasper,[22] M. Karbach,[22] J. Merkel,[22] A. Petzold,[22] B. Spaan,[22] K. Wacker,[22] M. J. Kobel,[23] R. Nogowski,[23] K. R. Schubert,[23] R. Schwierz,[23] A. Volk,[23] D. Bernard,[24] G. R. Bonneaud,[24] E. Latour,[24] M. Verderi,[24] P. J. Clark,[25] S. Playfer,[25] J. E. Watson,[25]

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SLAC-PUB-xxxx
hep-ex/xxxx

The Z(4430)⁻ does not exist

~~Search for the Z(4430)⁻ at *BABAR*~~

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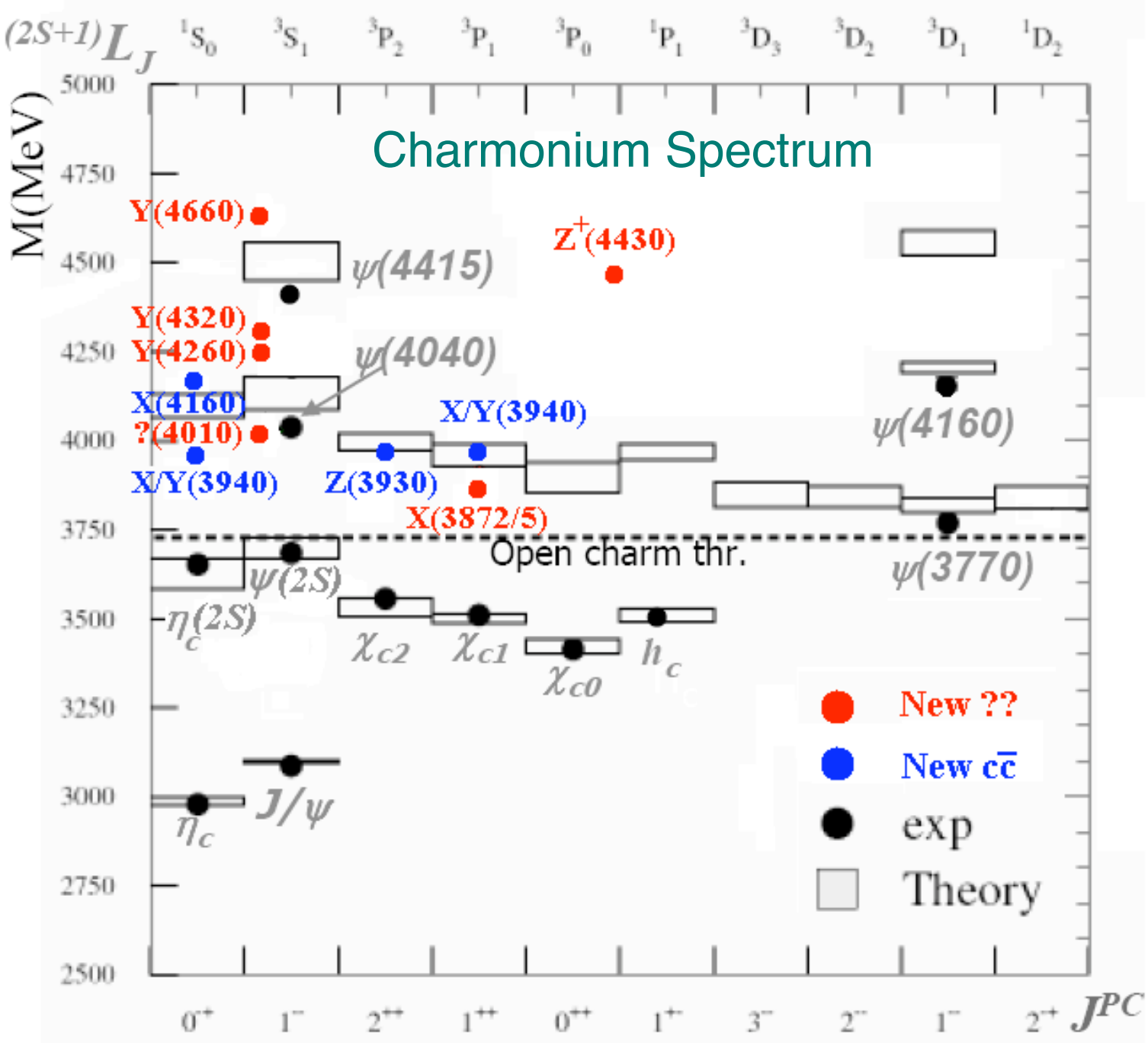
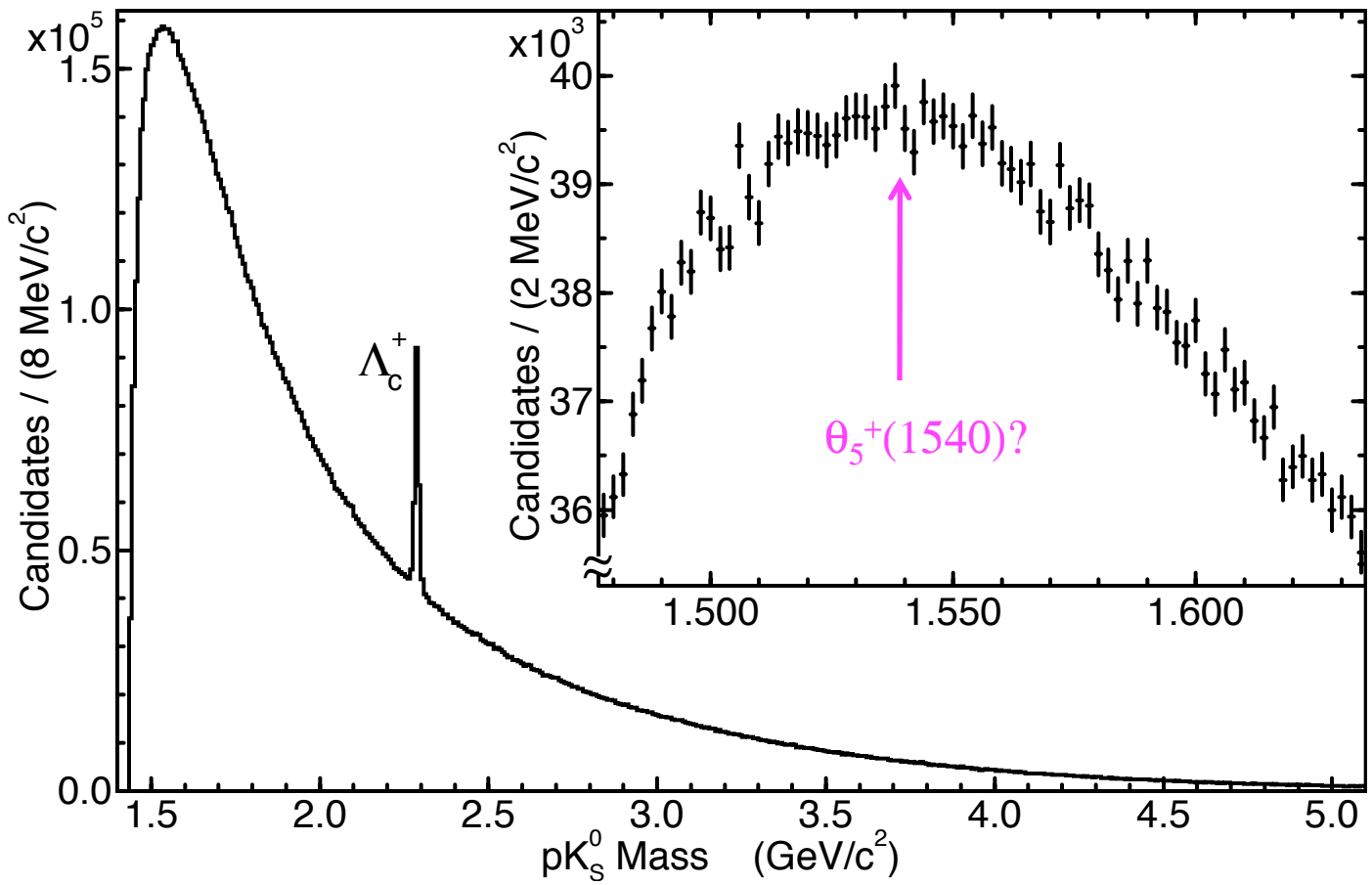
Charmonium Spectrum



PRL 95:042002, 2005

Pentaquarks

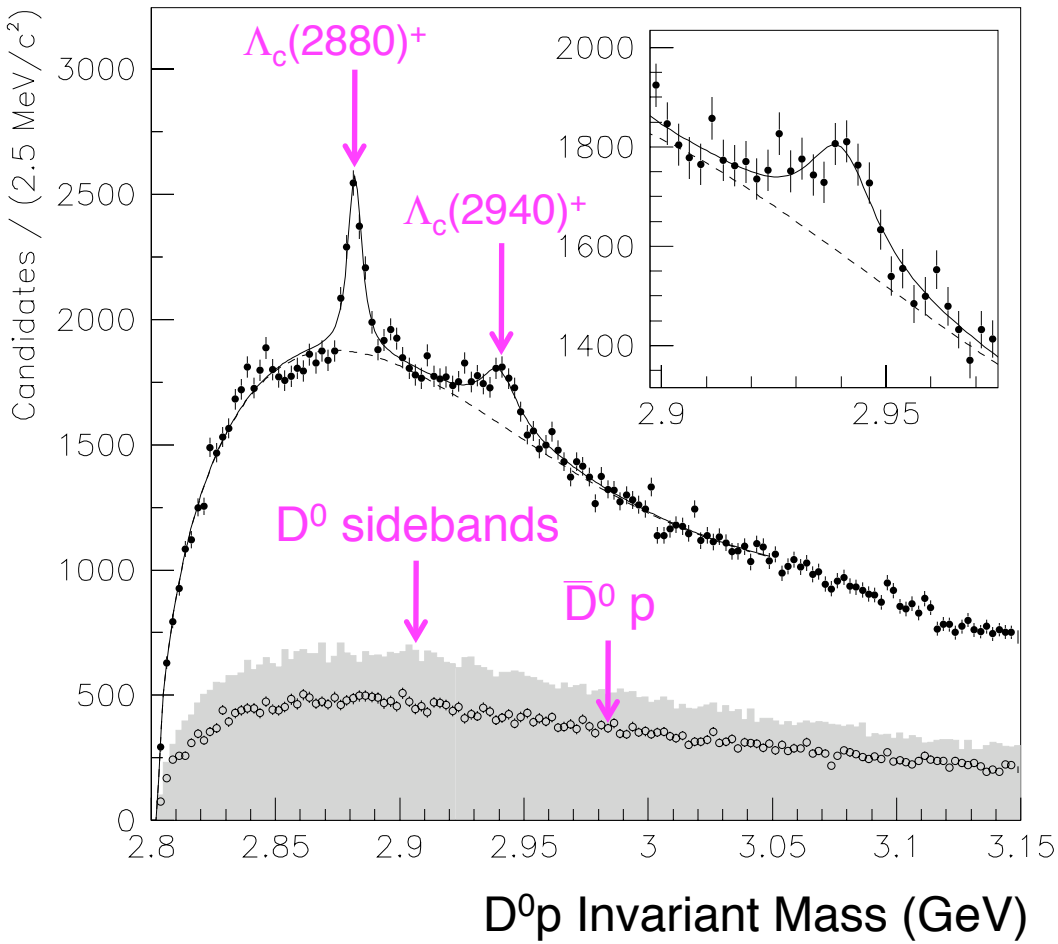
- BABAR failed to discover Pentaquarks.



PRL 98:012001, 2007

$\Lambda_c(2940)^+$

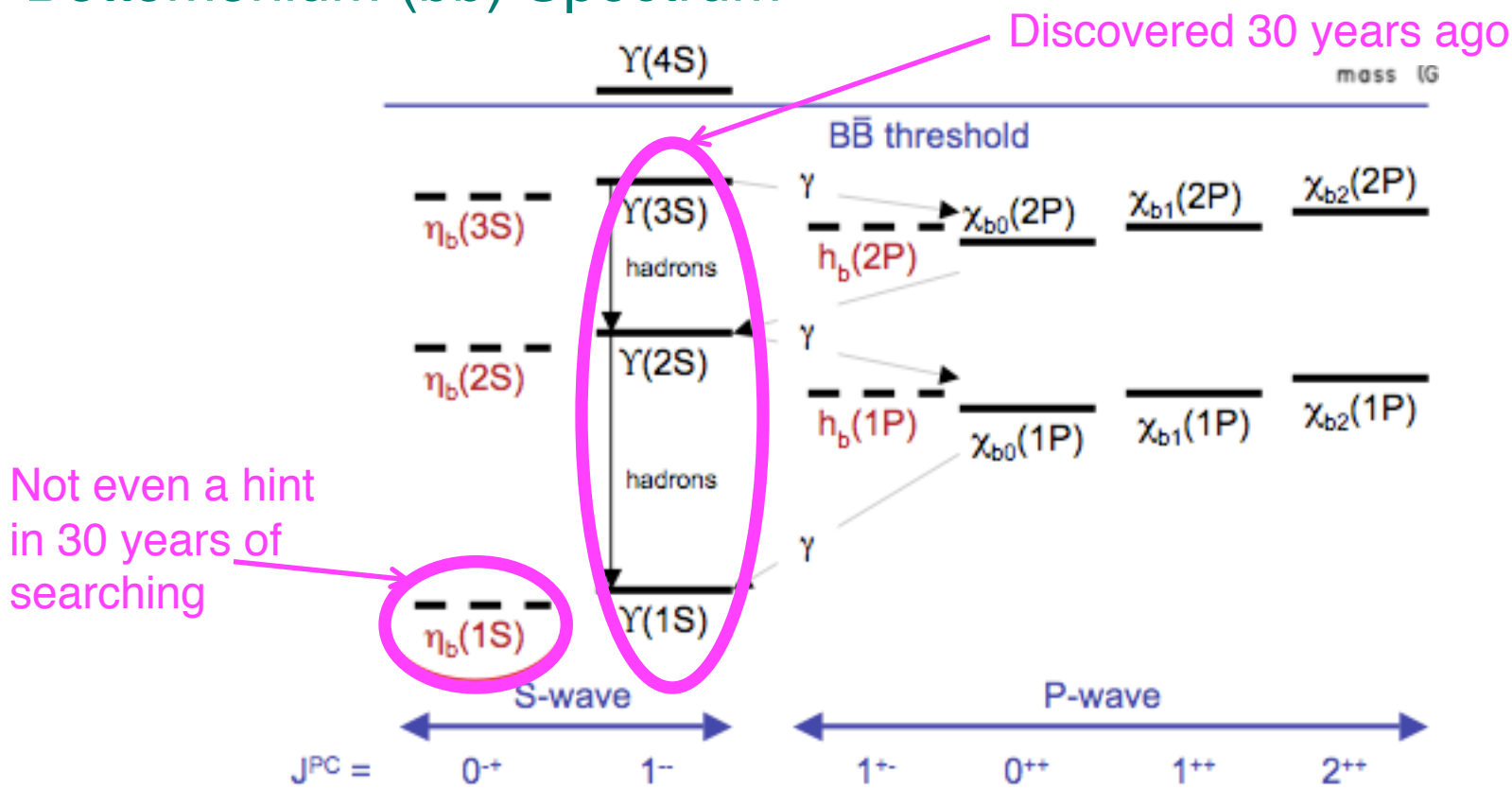
- A new charm baryon decaying to p D^0 (not pD^+)



$M = 2939.8 \pm 1.3 \pm 1.0$ MeV
$\Gamma = 17.5 \pm 5.2 \pm 5.9$ MeV

Observation of the η_b

Bottomonium ($b\bar{b}$) Spectrum



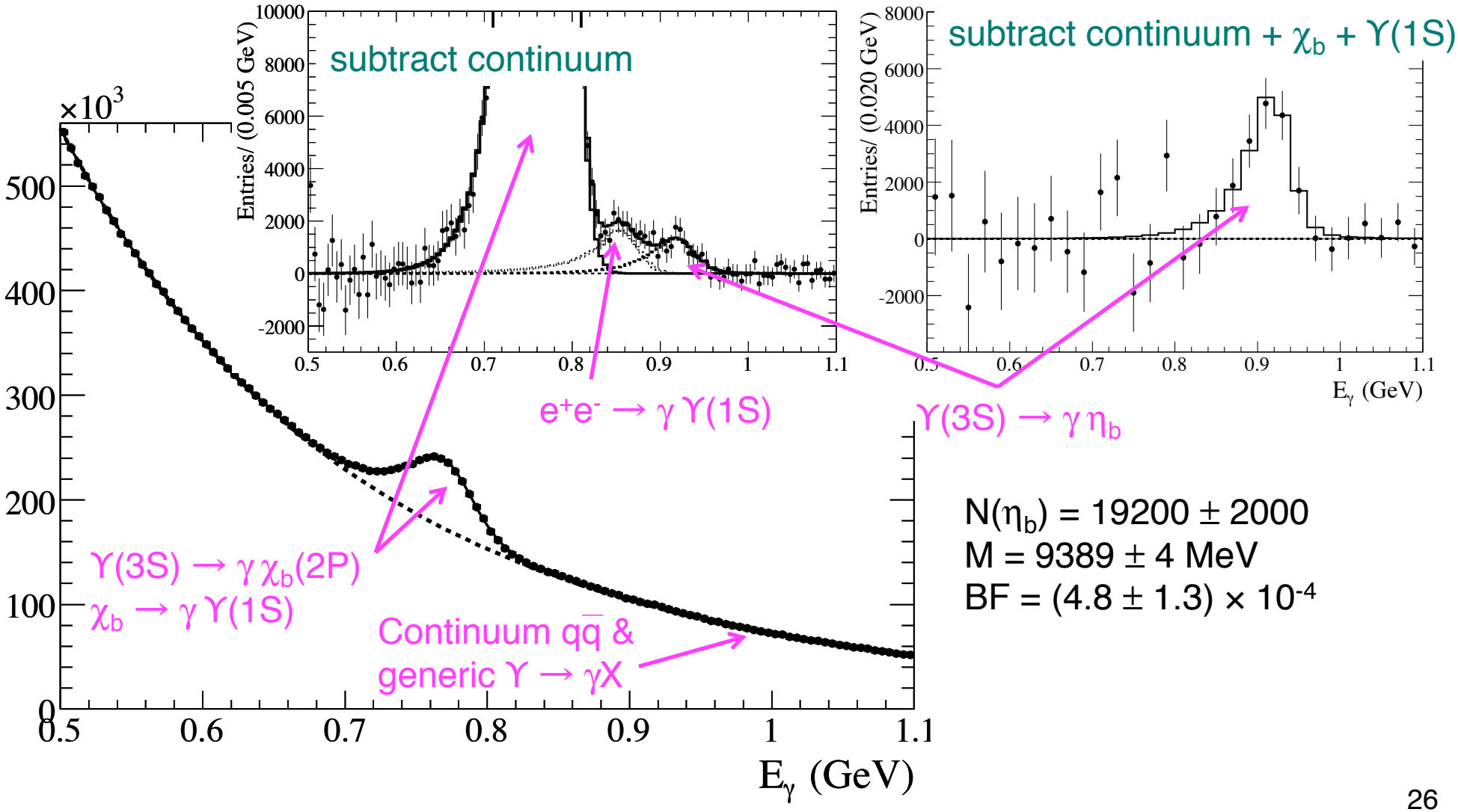
- QCD should be able to explain $\Upsilon(1S)/\eta_b$ mass difference (20–100 MeV).

Analysis Method

- $\Upsilon(3S) \rightarrow \gamma\,\eta_b$
- Look for photon only. E_γ = 911 MeV if $M(\eta_b)$ = 9.4 GeV.
- Problem: many other photons. Particular issue is $e^+e^- \rightarrow \gamma\Upsilon(1S)$ (E_γ= 856 MeV). Depending on $M(\eta_b)$, detector resolution leads to significant overlap with signal.

PRL 101:071801, 2008

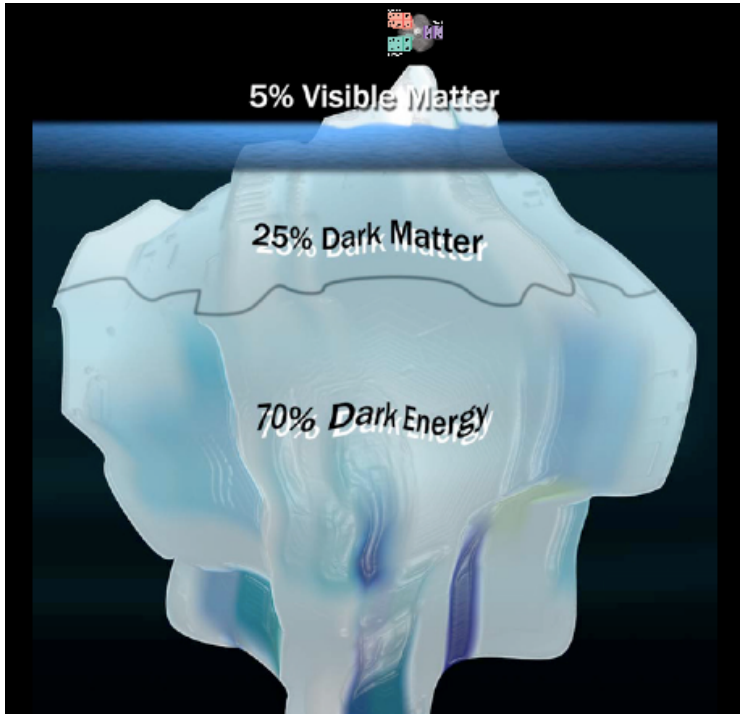
Observed Spectrum

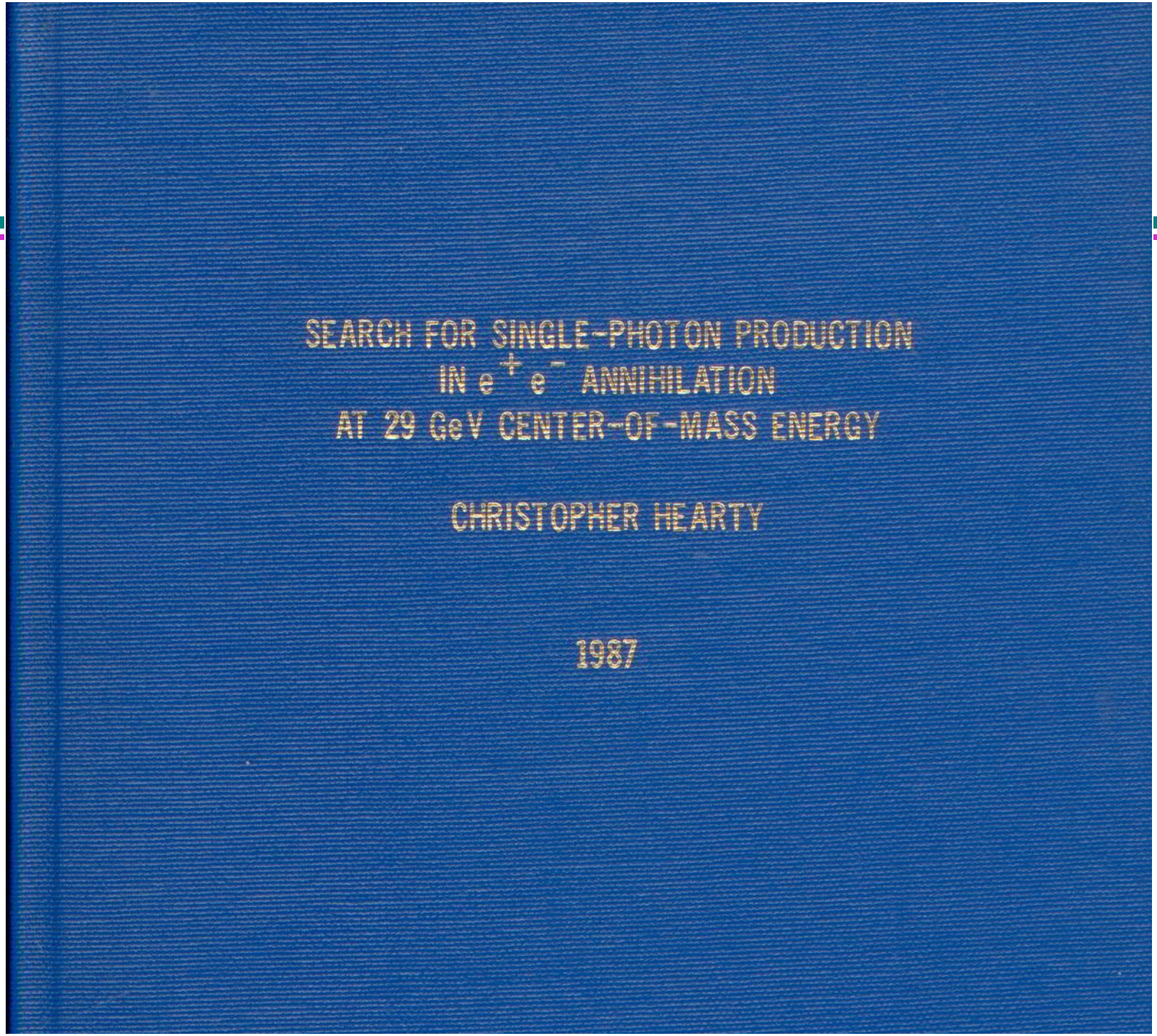


$N(\eta_b) = 19200 \pm 2000$
$M = 9389 \pm 4$ MeV
$BF = (4.8 \pm 1.3) \times 10^{-4}$

Light Higgs A^0

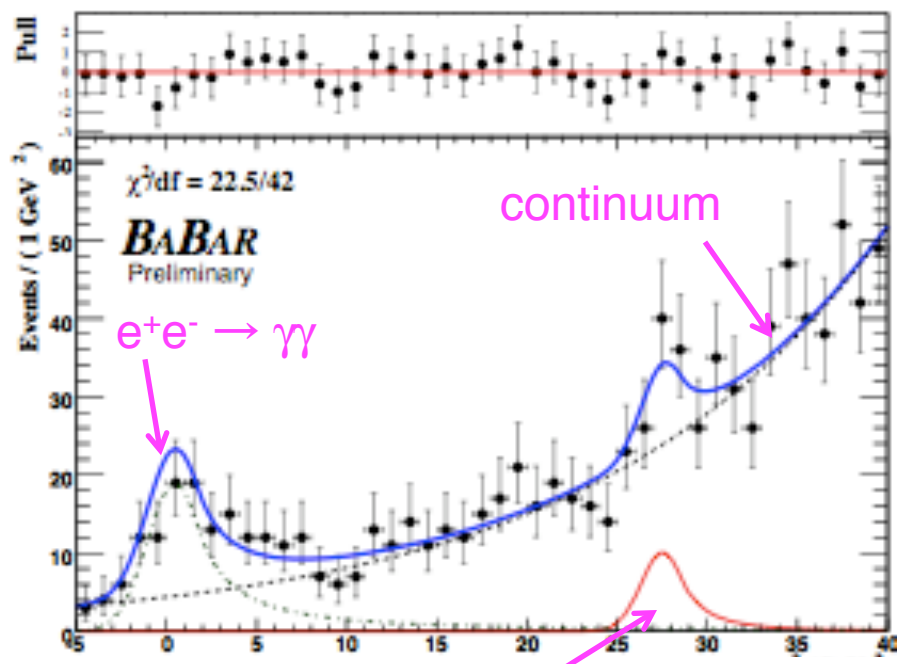
- Many extensions to the standard model include a light higgs: $\Upsilon \rightarrow \gamma A^0$. BF as large as 10^{-4}.
- If dark matter particle χ is also light, then $A^0 \rightarrow \chi\chi$ may be dominant
  $\Rightarrow$ final state is γ + "nothing"



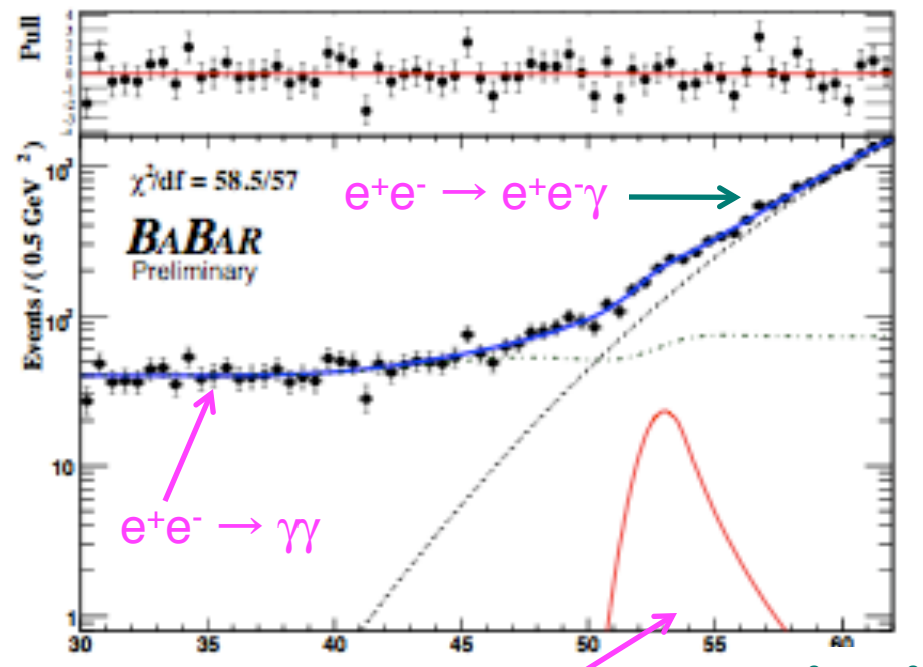

SEARCH FOR SINGLE-PHOTON PRODUCTION
IN e^+e^- ANNIHILATION
AT 29 GeV CENTER-OF-MASS ENERGY
CHRISTOPHER HEARTY
1987

$A^0 \rightarrow$ invisible

- Enabled by extensive modifications to trigger.



37 ± 15 events at M_A = 5.2 GeV



119 ± 71 events at M_A = 7.275 GeV

- 90% CL upper on BF $(0.2 - 32) \times 10^{-6}$

Summary

- Although not a big part of our original physics plan, new particle searches (and discoveries) have become one of the most exciting parts of the BABAR program.
- The Υ running has produced new opportunities.

- *Apologies to anyone whose analysis I neglected, and thanks to everyone who helped with the slides, even if they didn't know it.*