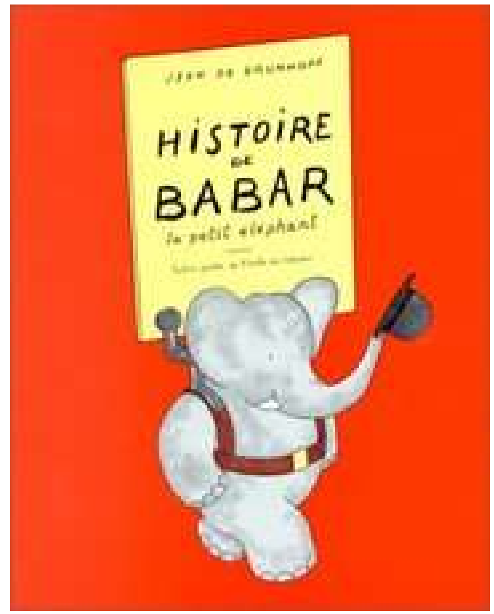
Charmonium Spectroscopy with

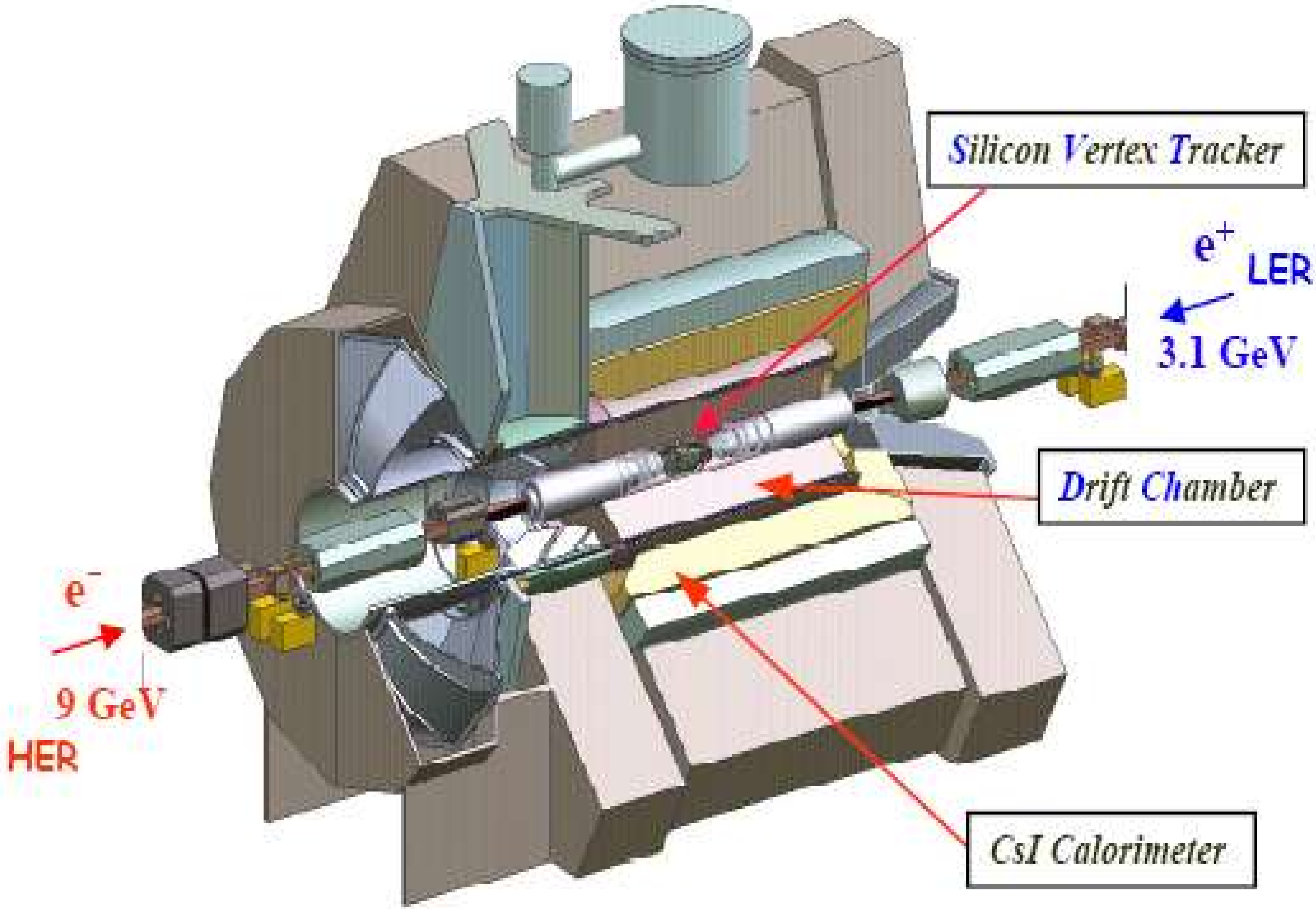


Brad Wogsland

The road ahead...

- The BaBar Detector
- Detecting Resonances
- So what is a Breit-Wigner?
- Another example: reconstructing the J/Psi resonance
- Charmonia
- X(3940)
- Y(3940)
- Y(4260)
- X(3872)
- Finding the isospin of the dipion subsystem in the decay of X(3872)
- Questions?
- Acknowledgementation

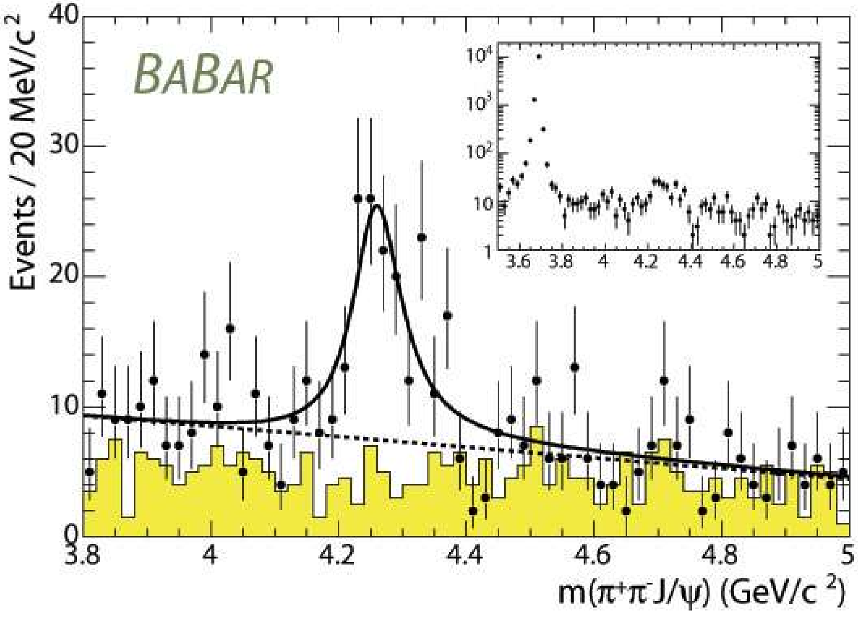
The BaBar Detector



For details see B. Aubert et al, *Nuclear Instruments and Methods in Physics Research* **A 479**, 1 (2002).

Detecting Resonances

- Look for peaks in graph of number of events versus invariant mass of final state particles
- A Breit-Wigner fit to the resonance must be statistically significant (5 sigma) to be considered publishable
- The example at right is the Y(4260) resonance recently discovered at BaBar



So what is a Breit-Wigner?

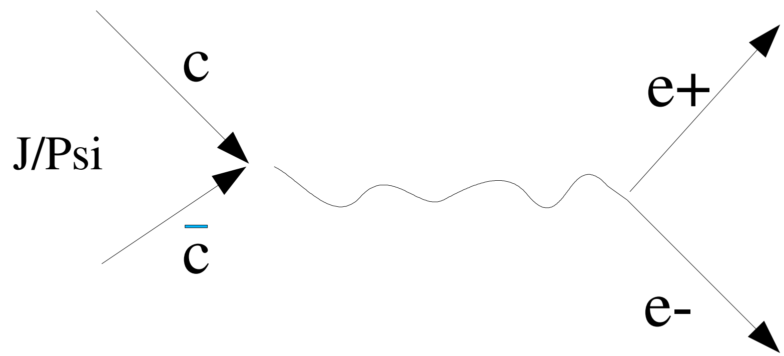
- “Invariant mass” means the square root of the Mandalstam variable s, that is, the sum of the interacting particles' 4-momenta, which is E_{CMS}, the energy in the center of mass frame
- Since the particles in most collider experiments are relativistic, the relativistic Breit-Wigner form is used:

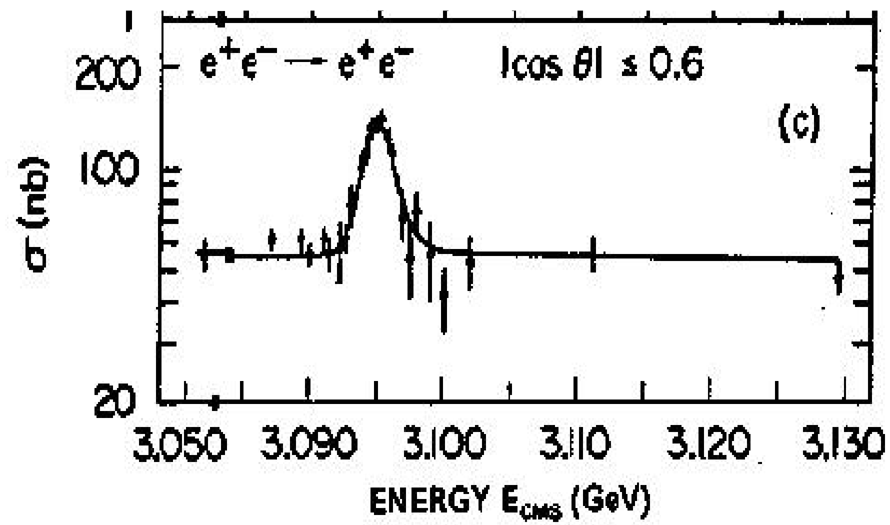
$$\frac{M_0^2 \text{gamma}^2}{(s - M_0^2)^2 + M_0^2 \text{gamma}^2}$$

- Where M_0 is the resonance's mass, s is the invariant mass and gamma is the resonance's width.
- Mathematicians call it a Cauchy distribution.

Eugene Wigner
1902 - 1995

Another example: reconstructing the J/Psi resonance

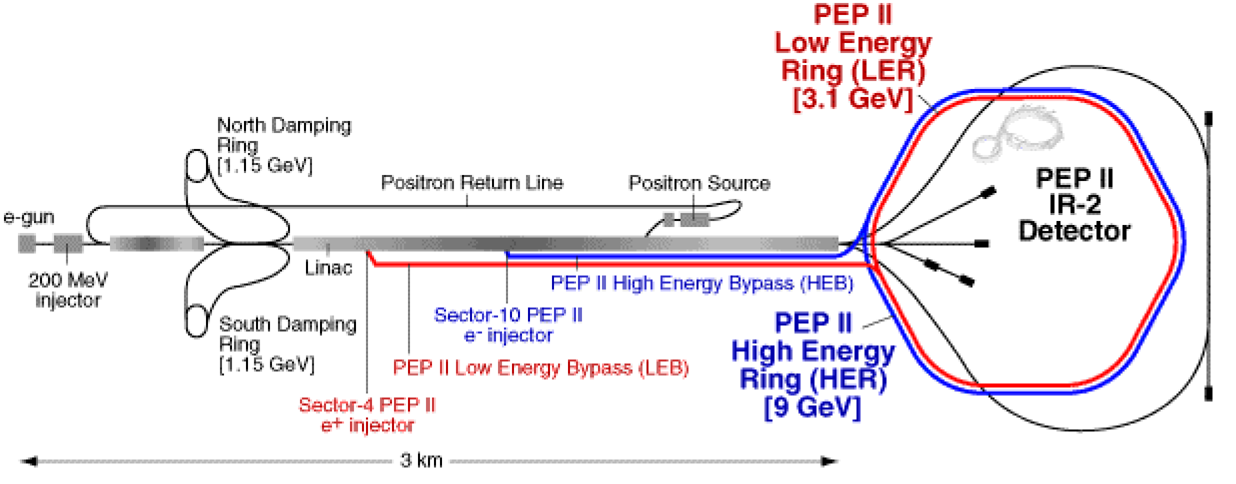




- J/Psi decays to e+e- about 6% of the time and electrons are easy to detect.
- Follow the particles trajectories backward through the detector to make sure they meet.
- Look at a number of such events and plot the invariant mass of the electron positron pair in bins.
- A peak appears around 3.1 GeV – fit a Breit-Wigner to it and look at the statistical significance.

Charmonia

- J/Psi and Psi' resonances first discovered at SLAC in 1974.
- Explained as bound states of quark-antiquark pair (meson)of new “charm” quark.
- 11 charmonia now known.
- Several more good candidates now being studied...



Charmonia

- 2 particle system like hydrogen.
- Therefore quantum mechanics "simple"like hydrogen, but QCD potential unknown.
- Many use modified Coulomb plus linear potential which gives good results with the right parameters.
- T.Barnes et al, *Phys.Rev.* **D72**, 054026 (2005). a good recent reference to this theory.

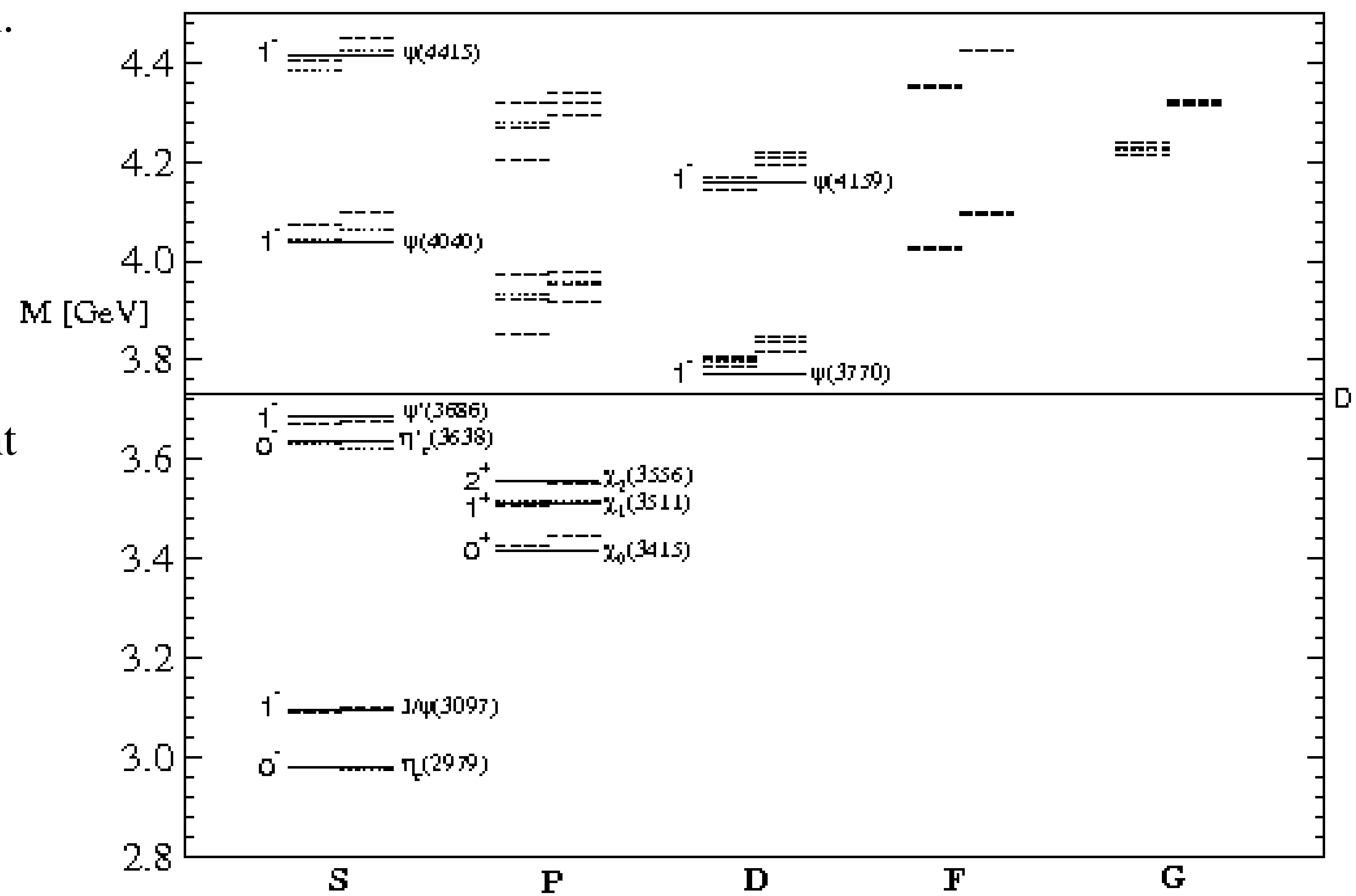


TABLE I: Experimental and theoretical spectrum of $c\bar{c}$ states. The experimental masses are PDG averages, which are rounded to 1 MeV and assigned equal weights in the theoretical fits. For the 2^1S_0 $\eta_c'(3638)$ we use a world average of recent measurements [86].

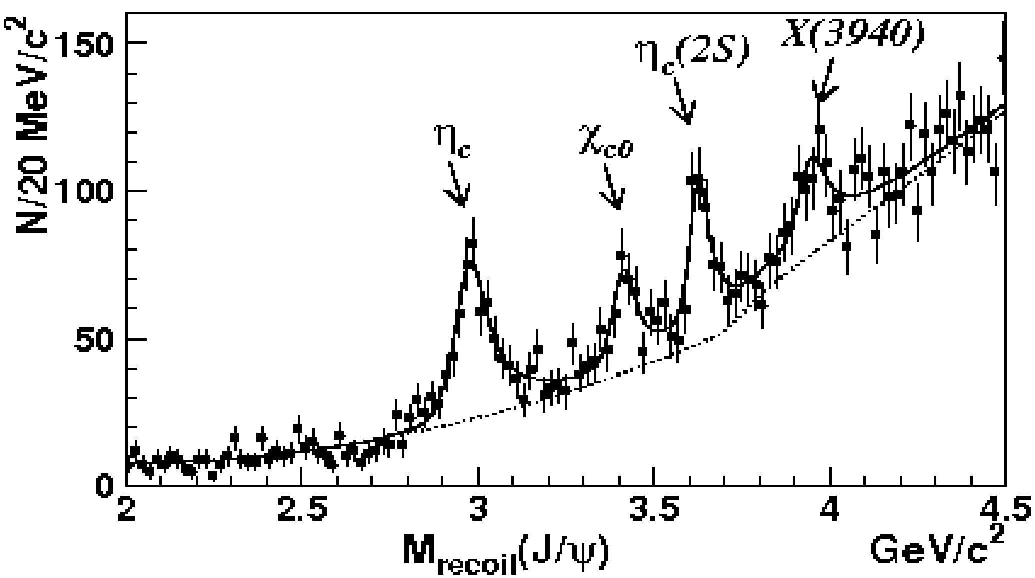
Multiplet	State	Expt.	Input (NR)	Theor. NR	Theor. GI
1S	$J/\psi(1^3S_1)$	3096.87 ± 0.04	3097	3090	3098
	$\eta_c(1^1S_0)$	2979.2 ± 1.3	2979	2982	2975
2S	$\psi'(2^3S_1)$	3685.96 ± 0.09	3686	3672	3676
	$\eta_c'(2^1S_0)$	3637.7 ± 4.4	3638	3630	3623
3S	$\psi(3^3S_1)$	4040 ± 10	4040	4072	4100
	$\eta_c(3^1S_0)$			4043	4064
4S	$\psi(4^3S_1)$	4415 ± 6	4415	4406	4450
	$\eta_c(4^1S_0)$			4384	4425
1P	$\chi_2(1^3P_2)$	3556.18 ± 0.13	3556	3556	3550
	$\chi_1(1^3P_1)$	3510.51 ± 0.12	3511	3505	3510
	$\chi_0(1^3P_0)$	3415.3 ± 0.4	3415	3424	3445
	$h_c(1^1P_1)$	see text		3516	3517
2P	$\chi_2(2^3P_2)$			3972	3979
	$\chi_1(2^3P_1)$			3925	3953
	$\chi_0(2^3P_0)$			3852	3916
	$h_c(2^1P_1)$			3934	3956
3P	$\chi_2(3^3P_2)$			4317	4337
	$\chi_1(3^3P_1)$			4271	4317
	$\chi_0(3^3P_0)$			4202	4292
	$h_c(3^1P_1)$			4279	4318
1D	$\psi_3(1^3D_3)$			3806	3849
	$\psi_2(1^3D_2)$			3800	3838
	$\psi(1^3D_1)$	3769.9 ± 2.5	3770	3785	3819
	$\eta_{c2}(1^1D_2)$			3799	3837
2D	$\psi_3(2^3D_3)$			4167	4217
	$\psi_2(2^3D_2)$			4158	4208
	$\psi(2^3D_1)$	4159 ± 20	4159	4142	4194
	$\eta_{c2}(2^1D_2)$			4158	4208
1F	$\chi_4(1^3F_4)$			4021	4095
	$\chi_3(1^3F_3)$			4029	4097
	$\chi_2(1^3F_2)$			4029	4092
	$h_{c3}(1^1F_3)$			4026	4094
2F	$\chi_4(2^3F_4)$			4348	4425
	$\chi_3(2^3F_3)$			4352	4426
	$\chi_2(2^3F_2)$			4351	4422
	$h_{c3}(2^1F_3)$			4350	4424
1G	$\psi_5(1^3G_5)$			4214	4312
	$\psi_4(1^3G_4)$			4228	4320
	$\psi_3(1^3G_3)$			4237	4323
	$\eta_{c4}(1^1G_4)$			4225	4317

As you can see, theorists have left us with a lot of states still to be found!

Charmonia

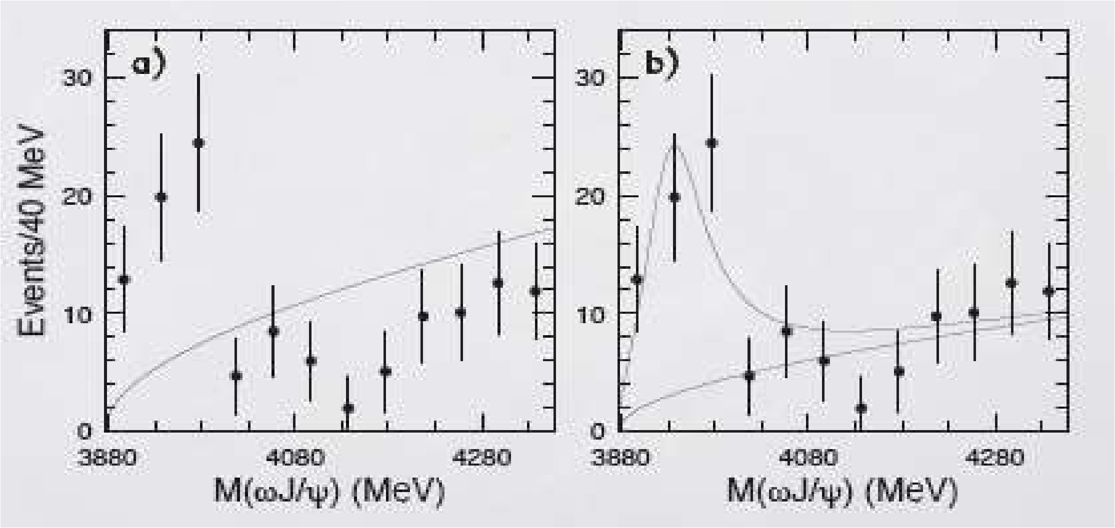
- New resonances observed at B meson factories like X(3872), X(3940), Y(3940) and Y(4260) are possible candidates for these unobserved states.
- Every resonance discovered brings with it a new puzzle though, because the decay channel, quantum numbers and mass must all be fit into the theory.
- But physicists like puzzles...

X(3940)



- First observed by Belle in 2004.
- Seen in the channel B->J/Psi D D*
- Actually observed as peak in the invariant mass of the recoiling J/Psi

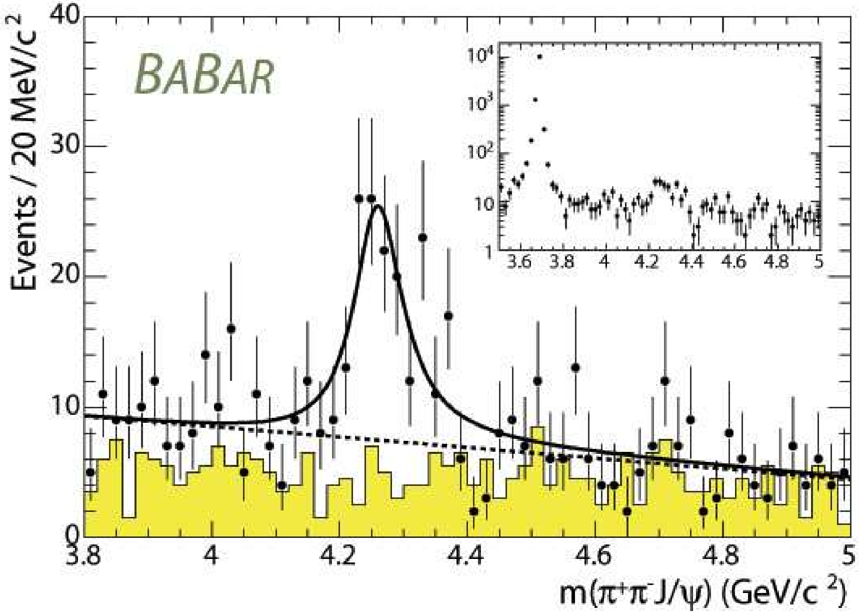
Y(3940)



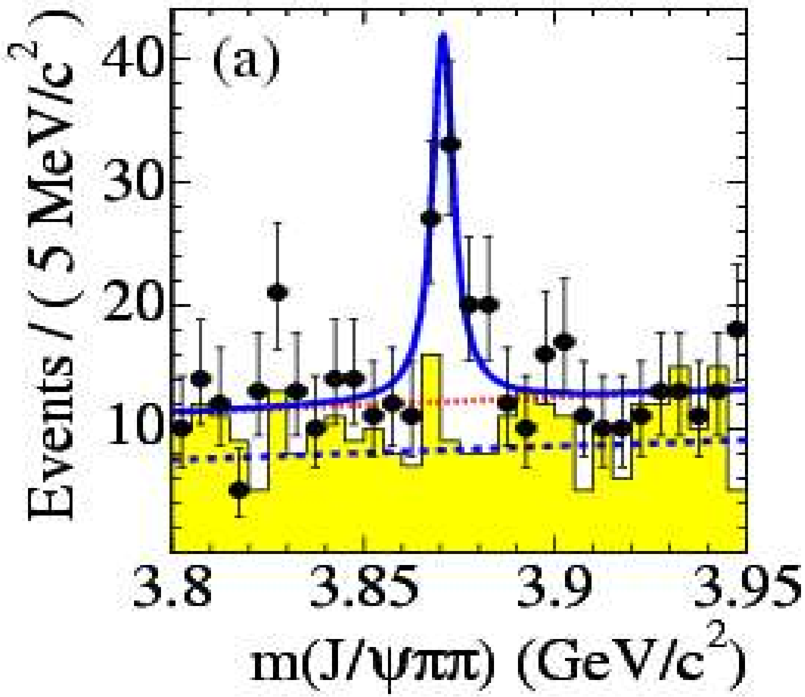
- First observed by Belle (that other B meson factory in Japan)
- Seen in the channel J/Psi omega

Y(4260)

- First observed at BaBar in 2005.
- Seen in ISR in the J/Psi pi^+ pi^- channel
- Quantum numbers: $J^{PC} = 1^{--}$
- Probably a hybrid meson, not charmonium



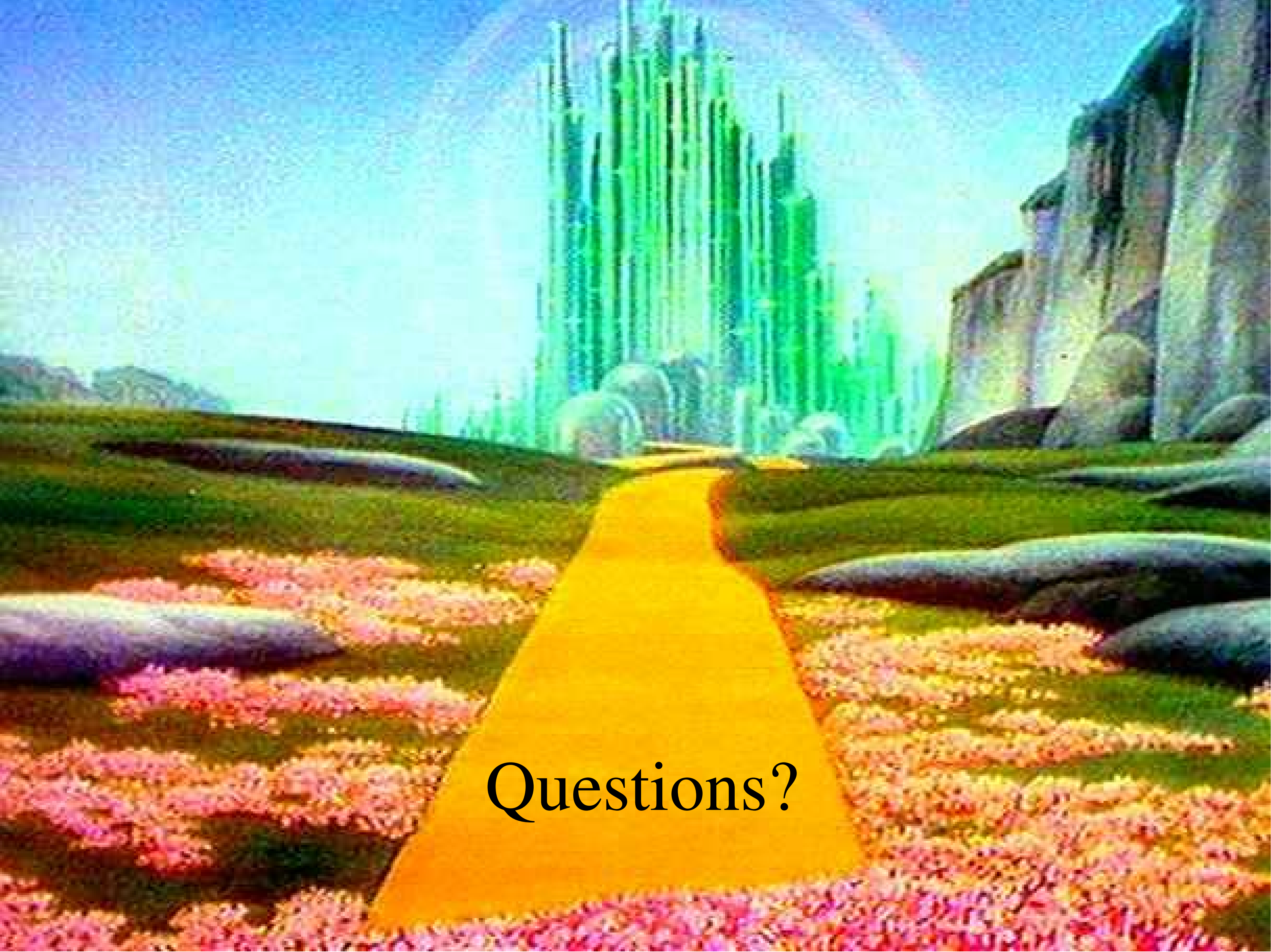
X(3872)



- First discovered at Belle
- First observed as a resonance in the channel J/Psi pi$^+$ pi $^-$
- Most theorists think it's not charmonium, but a strongly bound molecule of 2 D mesons

Finding the isospin of the dipion subsystem in the decay of X(3872)

- Idea of Voloshin (Phys. Lett. B 579, 316 (2004)).
- The ratio R of the branching fractions of the X decay with neutral pions to that of the X decay with charged pions (X is neutral) can tell us the isospin of the dipion subsystem
- If R=0, then I=1, if R=.5, then I=0. (For Psi' it is R'=.60+-.05)
- Belle reports a 90% CL limit of R<1.3R' – which doesn't resolve anything
- BaBar reports . . . (coming soon)


Questions?

Acknowledgementation

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