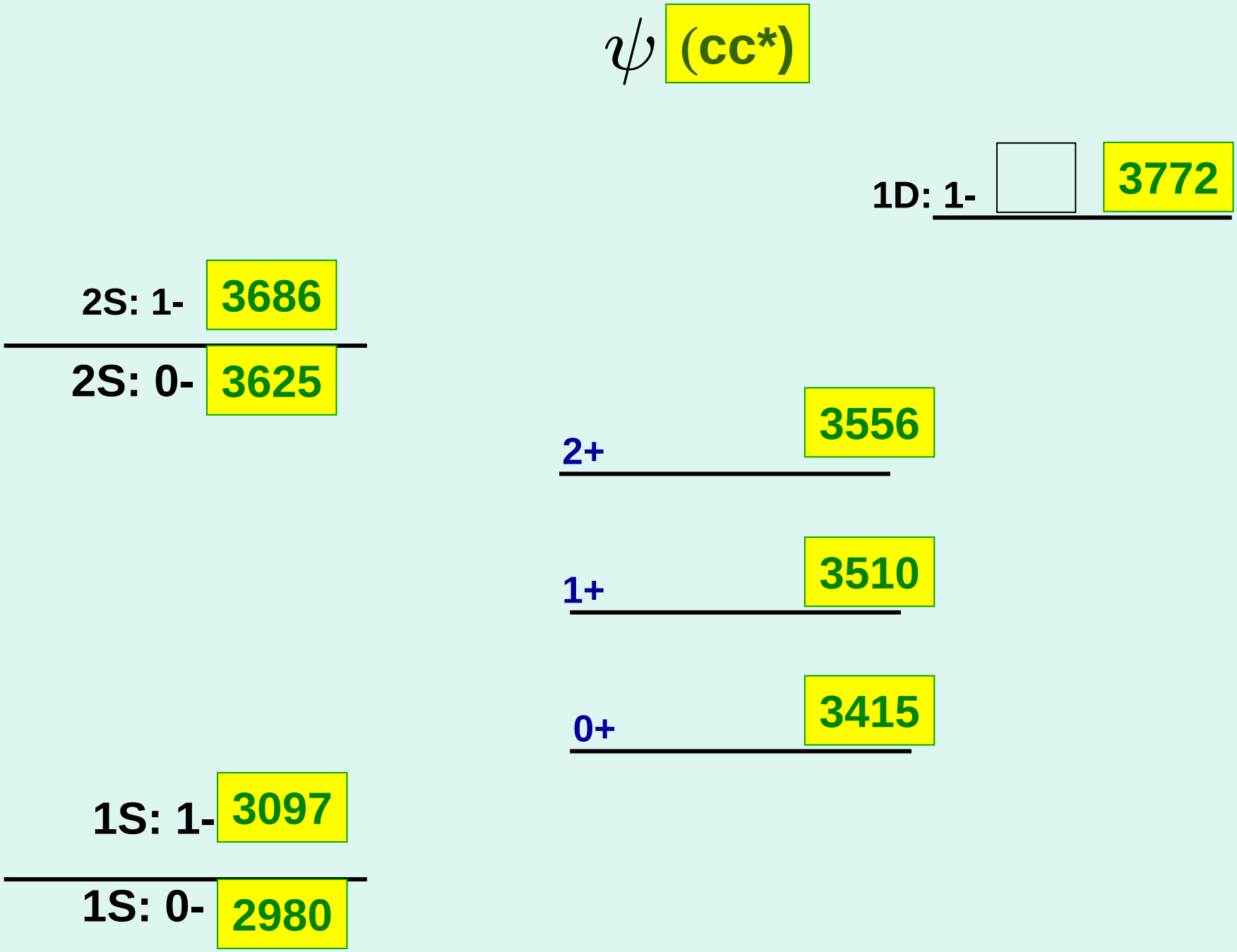
States outside the quark model:

3.Hybrids and 4…….

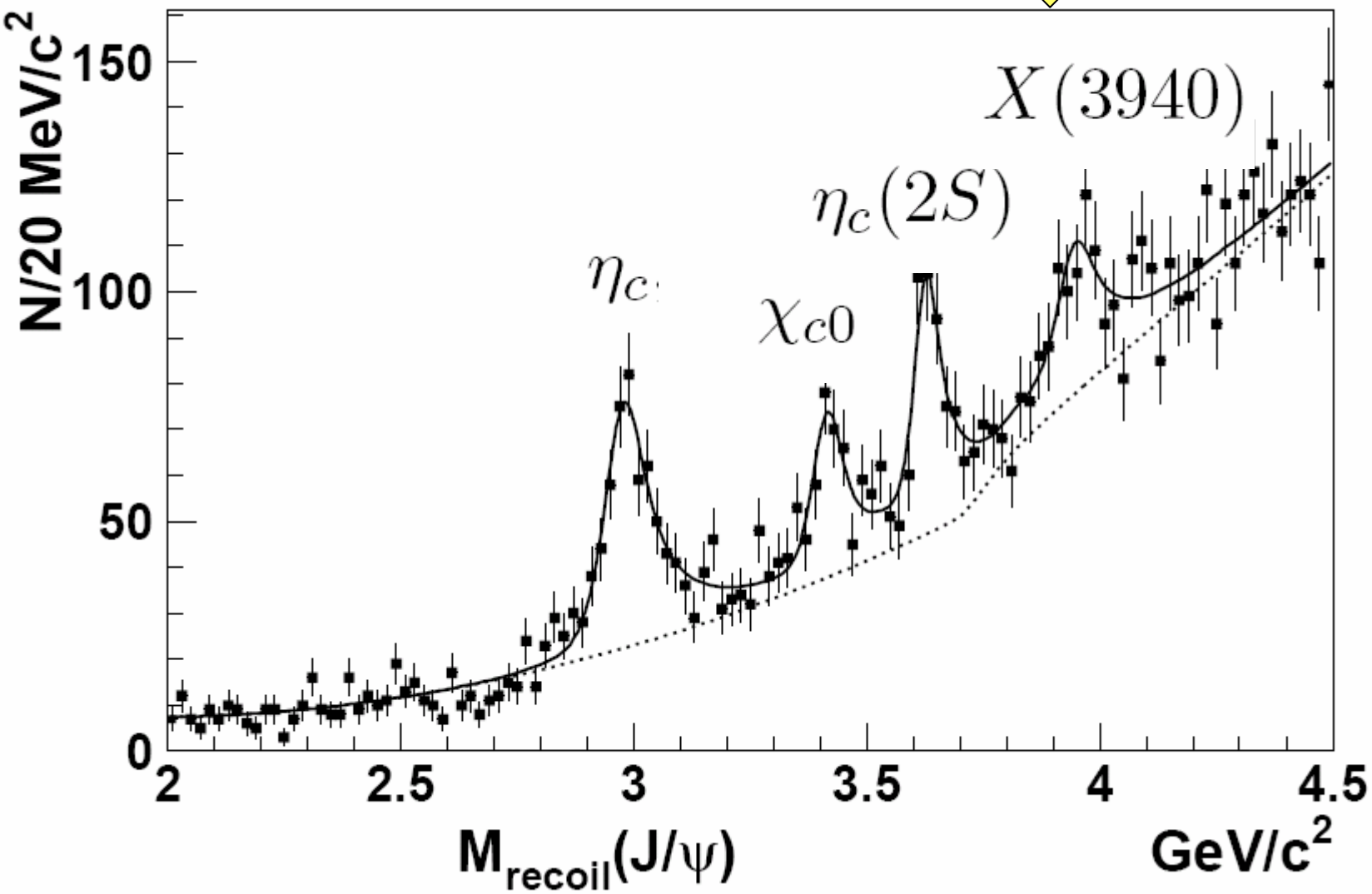

Weird + unusual charm


ψ (cc*)
1D: 1-
3772
2S: 1-
3686
2S: 0-
3625
2+
3556
1+
3510
0+
3415
1S: 1-
3097
1S: 0-
2980

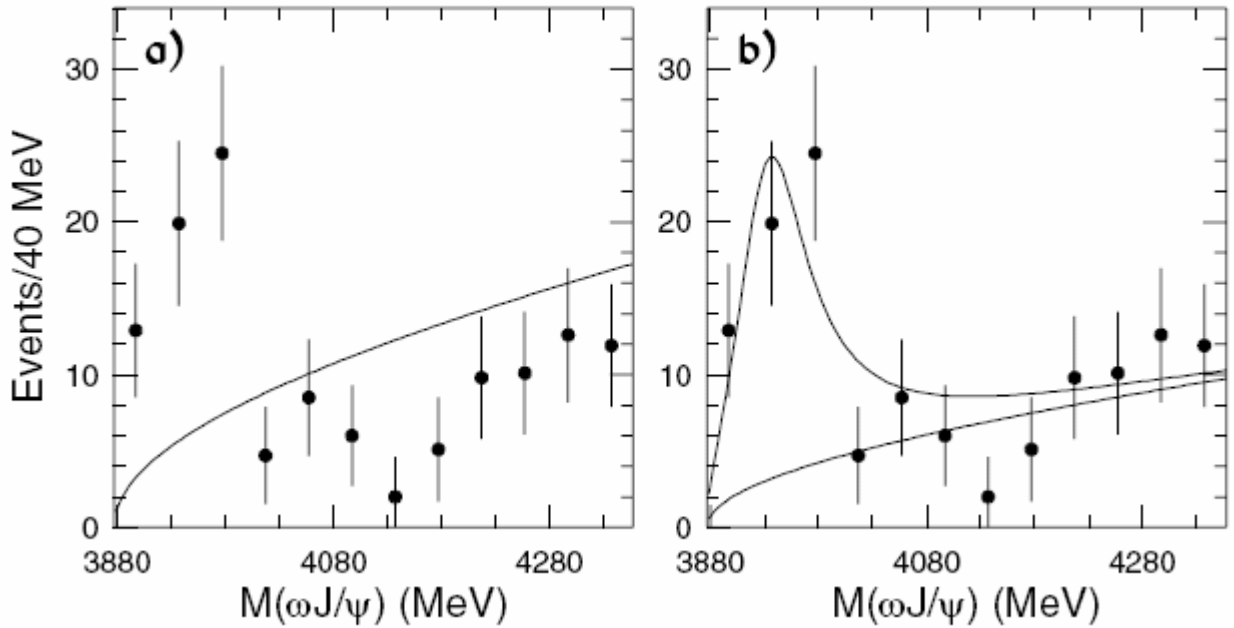
Belle

e+e- to ψ + X

???



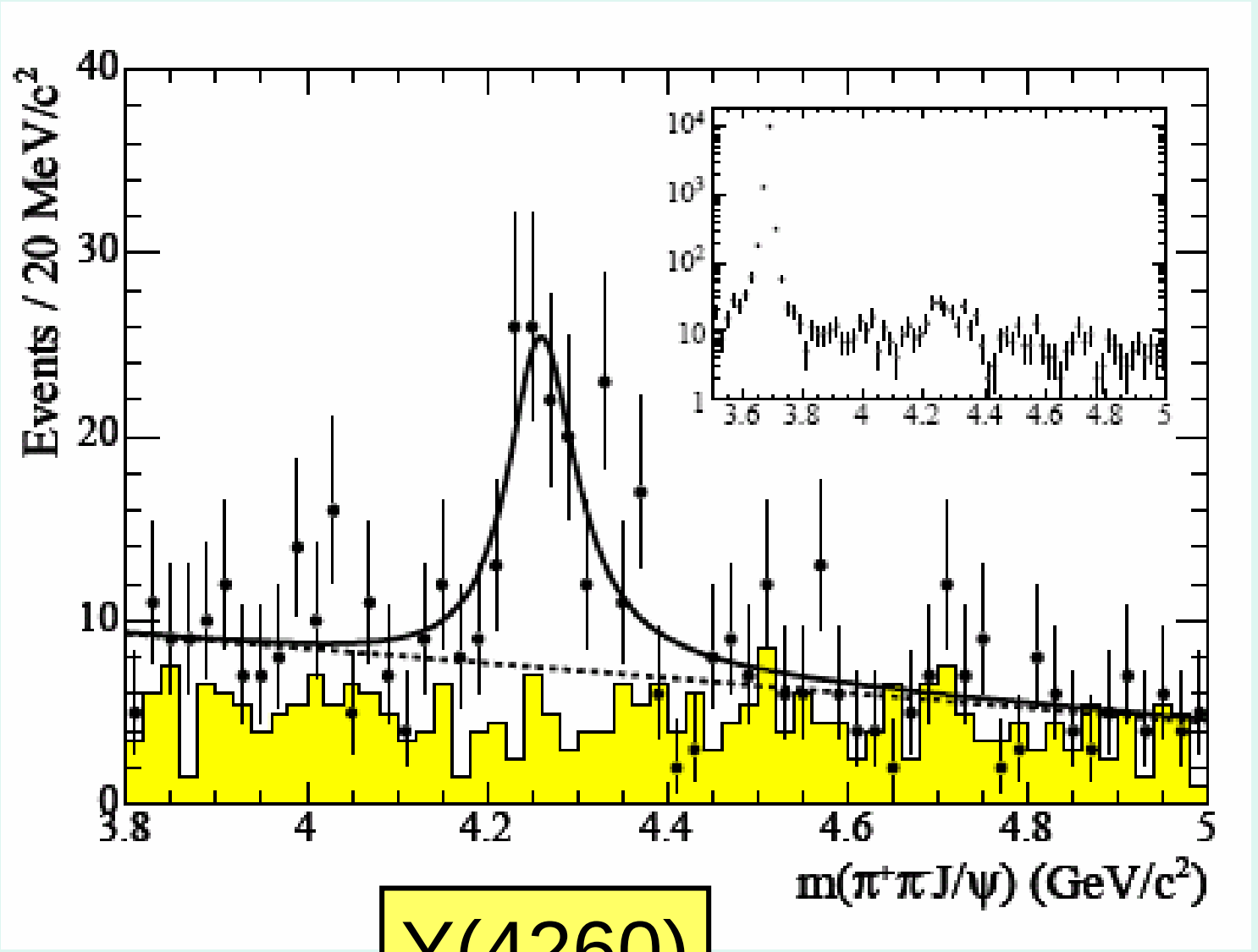
Claim of Hybrid Charmonium by BELLE



$$\mathcal{B}(B \to KY(3940))\mathcal{B}(Y(3940) \to \omega J/\psi) = (7.1 \pm 1.3 \pm 3.1) \times 10^{-5},$$

Is this the same as X(3940)?
Is it hybrid charmonium as claimed?
….possibly not, but this might be…….

e+e- \to psi pi pi BaBar sees new vector cc*



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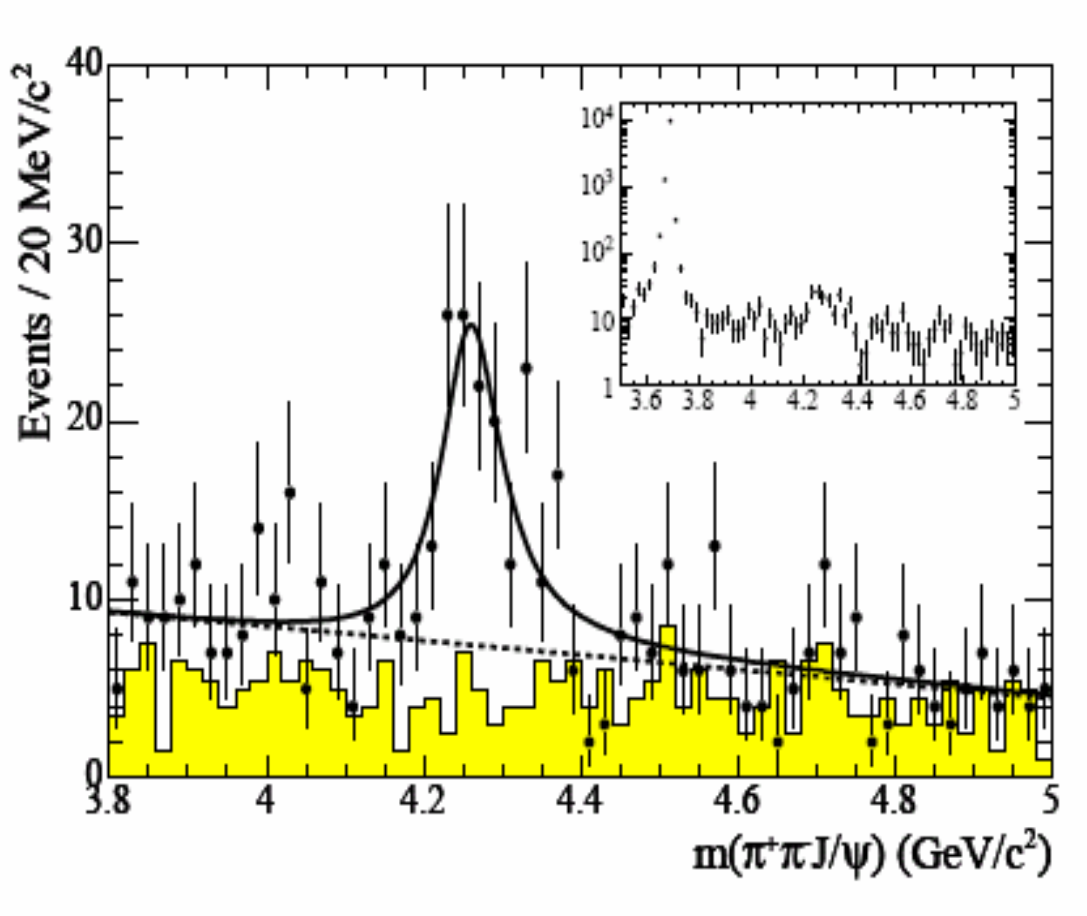

Y(4260)

No sign of established
3S/2D(4040/4160)
4S(4400)
in the psi pipi data

Y(4260) thus seems anomalous

Also no place
for extra cc* state

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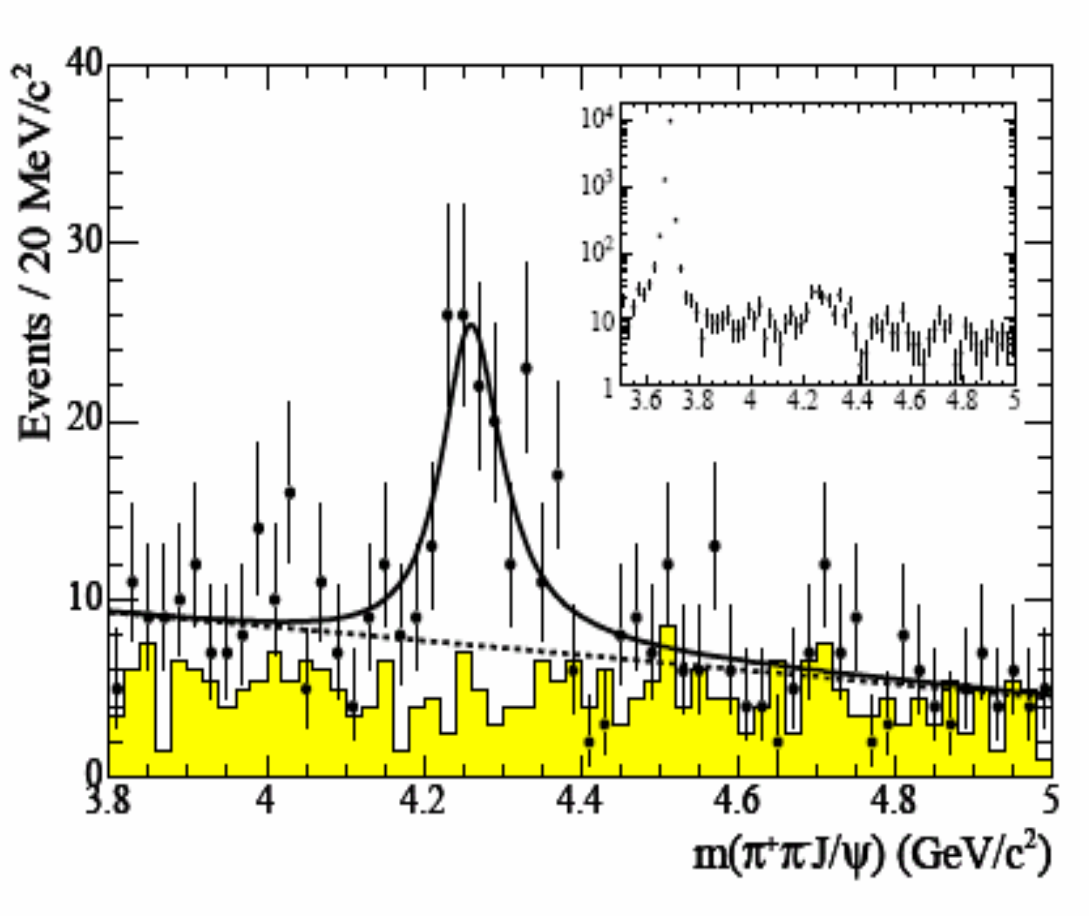

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Also no place
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\Gamma(ee) 5-80eV
Compare \sim 1 keV !!

Y(4260) Three Possibilities

$$Y(4260) = ([cs]_{S=0}[\bar{c}\bar{s}]_{S=0})_{\mathrm{P-wave}}$$

Maiani et al

$Y(4260)$ **as hybrid charmonium**

FC + Page

Y(4260) = Non resonant S-wave threshold

FC worry

Experimental distinctions…….later

Potentials;
Lattices;
Flux Tubes
and hybrid mesons

$\Upsilon(b\bar{b})$ ψ (cc*)

1D: 1- ☐ 3772

2S: 1- 10023 3686

Empirically =
Linear potential
V(r) = kr

Flux tube model

2+ 9913 3556

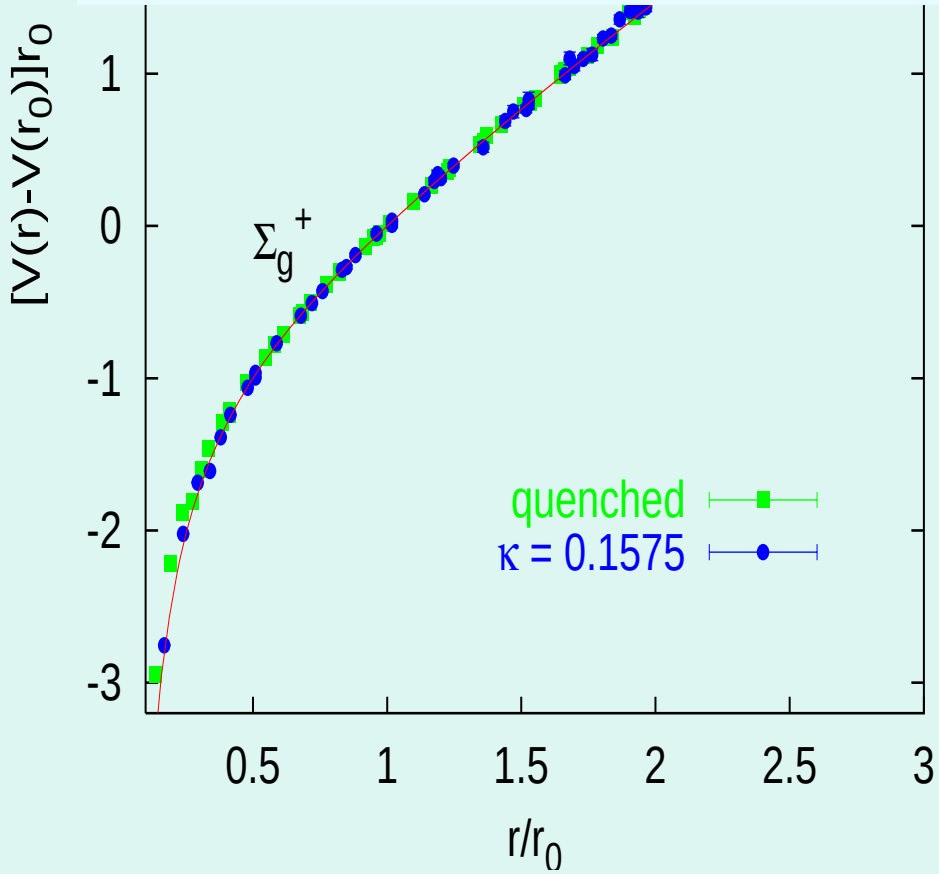
1+ 9893 3510

0+ 9860 3415

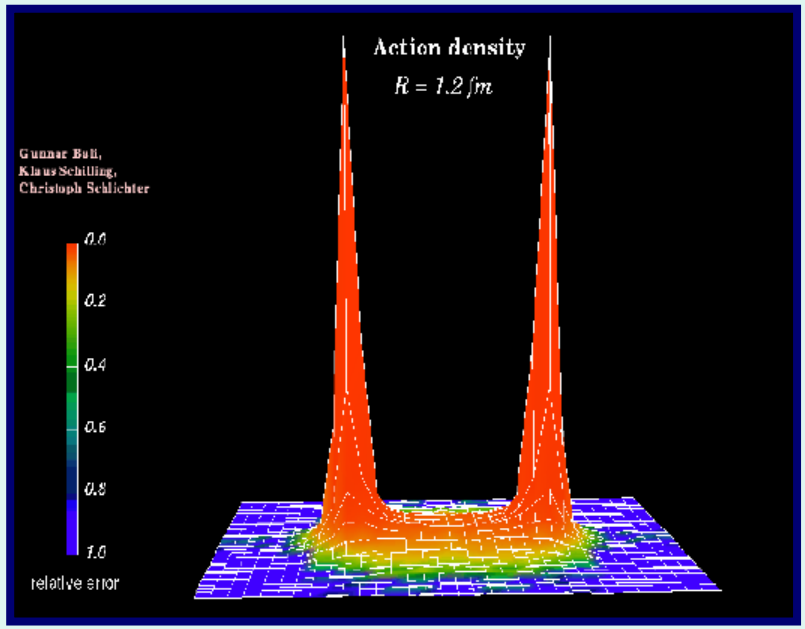
1S: 1- 9460 3097

Narrow below MM threshold

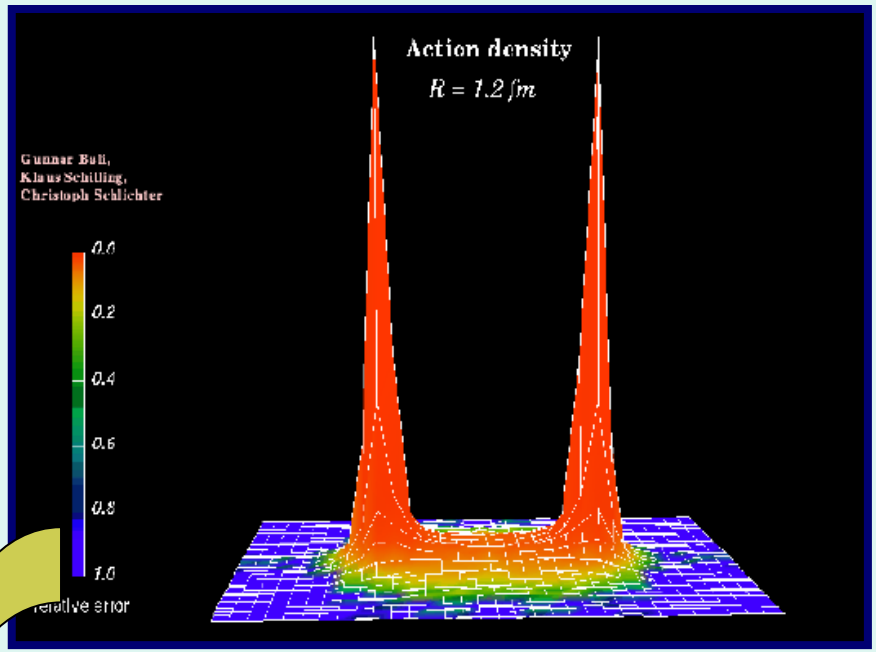
Lattice Linear Potential

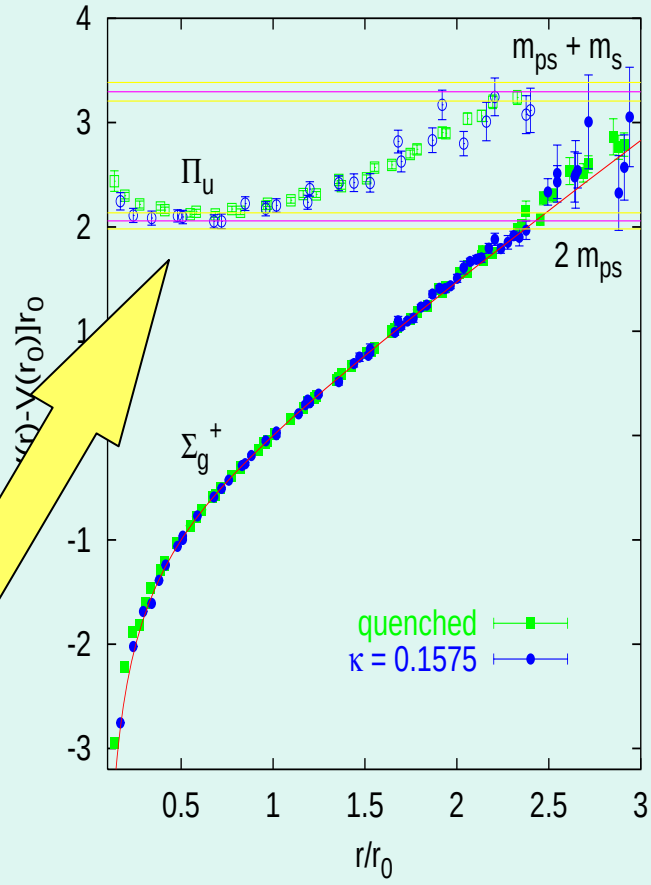


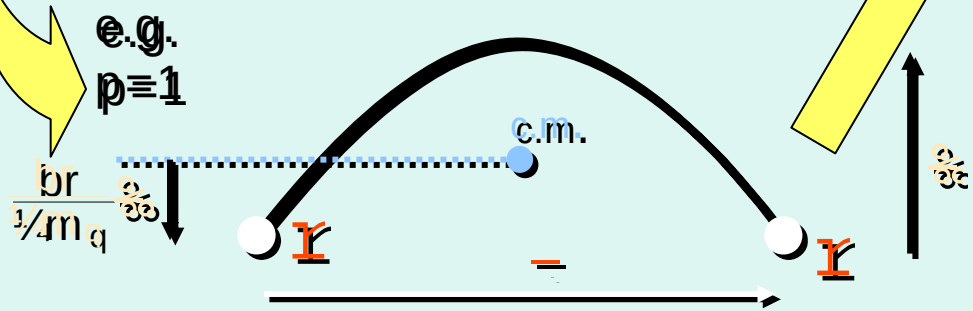
Linear flux tube



Gluonic hybrid mesons



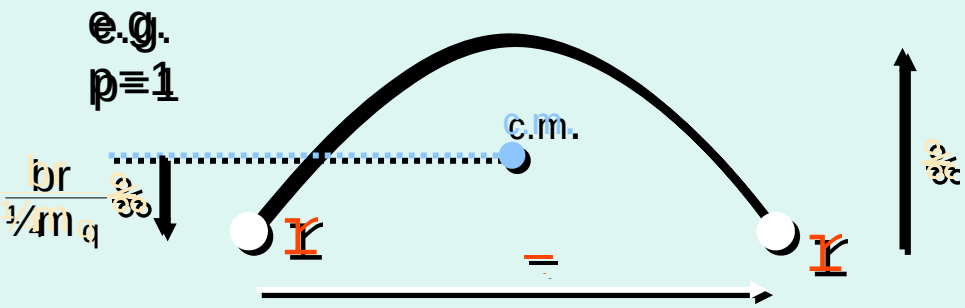




Exciting the flux tube

Lattice and model agree spectrum; decays in FT not yet lattice

flux-tube degrees-of-freedom



Costs about 1 to 1.5GeV energy to excite phonon "pi/R"
Hybrid nn* @ 2GeV; Hybrid cc* @ 4-4.5GeV

TABLE I. Predicted 1^{-+} Hybrid Masses.

state	mass (GeV)	model
$H_{u,d}$	1.3-1.8	bag model
	1.8-2.0	flux tube model
	2.1-2.5	QCD sum rules (most after 1984)

1-+ signals:

resonant? (Pennington); hybrid or molecule? (Klempt)

E1 photoproduction of hybrids gamma p to n H^+ \sim 50% relative to conventional mesons (Isgur; FC Dudek)

- **2+- also expected**. Diffractive Photoproduction!! Should exceed 1-+ strength. JeffersonLab@12GeV; HERA

Predicted 1-+ Hybrid masses (without spin splittings)

H_c	≈ 3.9	adiabatic bag model
	4.2-4.5	flux tube model
	4.1-5.3	QCD sum rules (most after 1984)
	4.19(3) $\pm$ sys.	HQLGT

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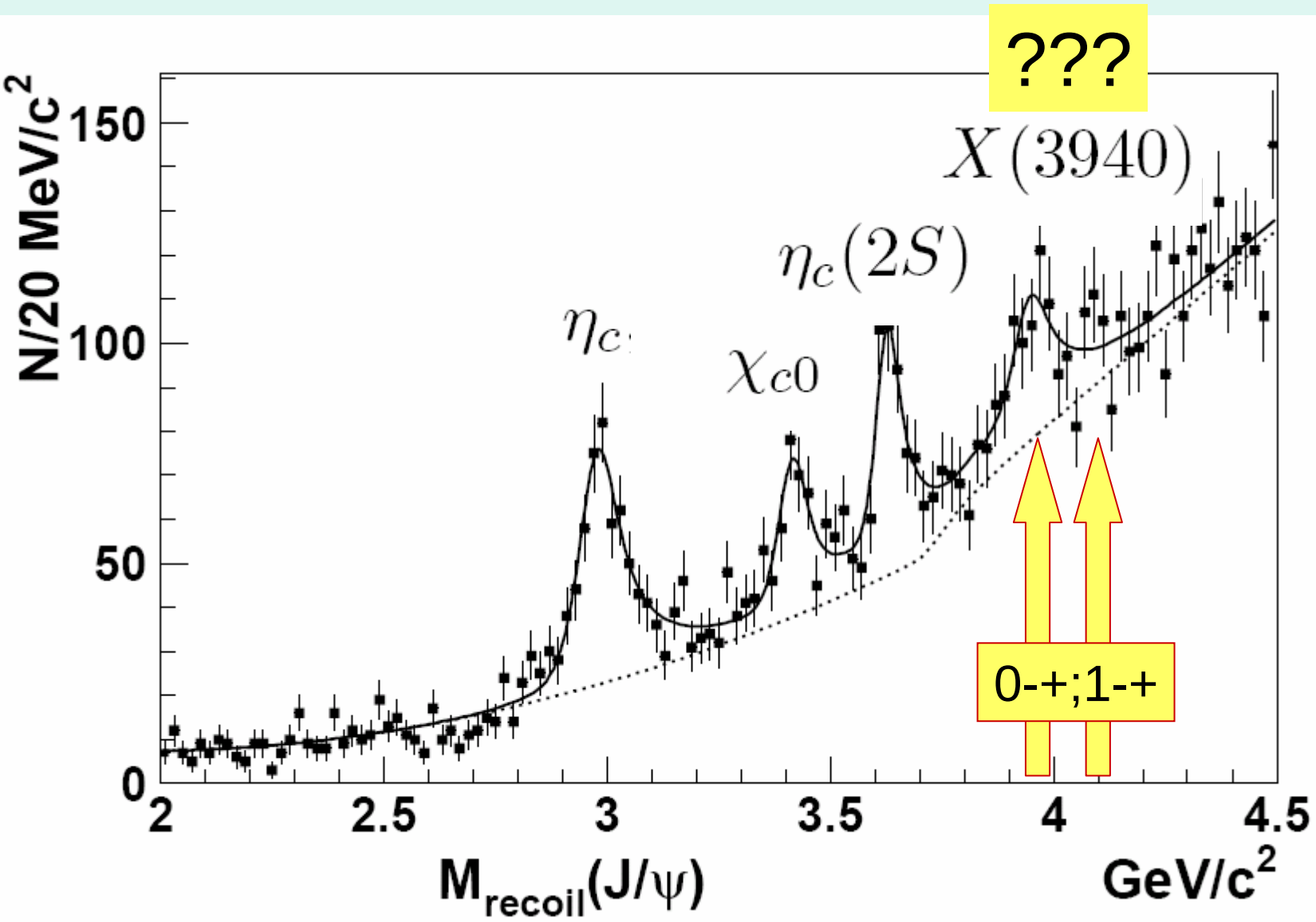
	4.1-5.3	QCD sum rules (most after 1984)
	4.19(3) $\pm$ sys.	HQLGT

Spin hyperfine splittings

1- - (4.25) Y(4260?)
1- + (4.1) HQLGT
0- + (3.95) X(3940?)

Belle

e+e- to ψ + X



e+e- \to \psi + (cc*)

What does theory expect?

Braaten and Lee;

Burns FC Swanson

Braaten pQCD applied to exclusive:

Claims it works but…….

If short range, expect \psi + hybrid similar to \psi = \chi (P-wave cc* states)

Tim Burns looking at this in flux tube model

Problem: cant understand the pattern of “ordinary”cc*

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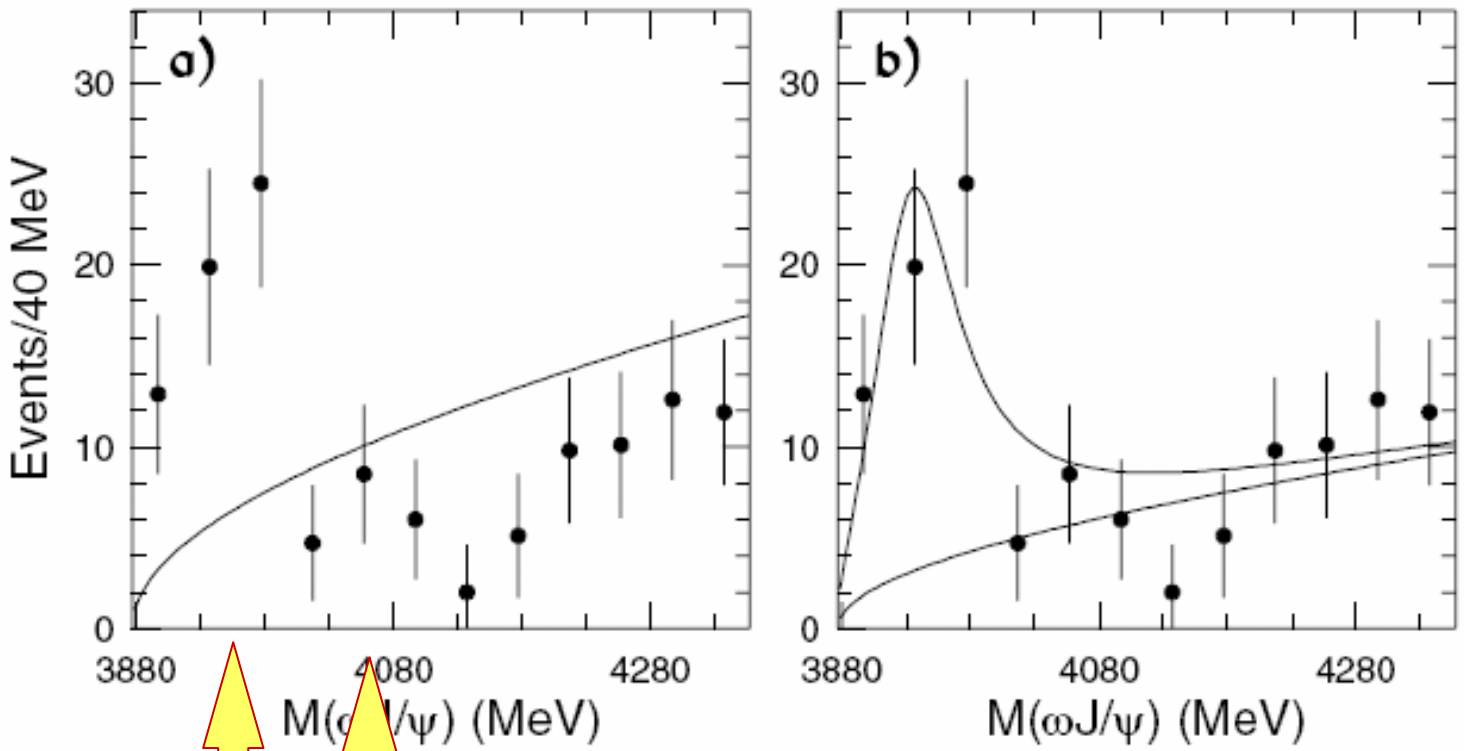
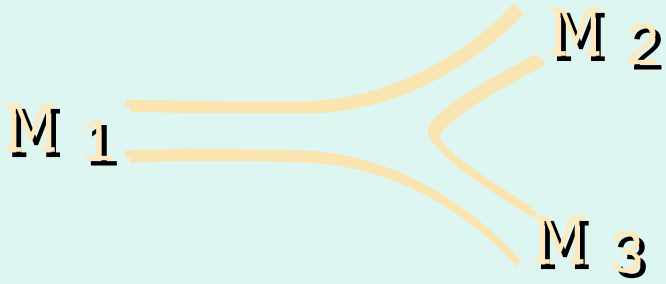


0-+;1-+

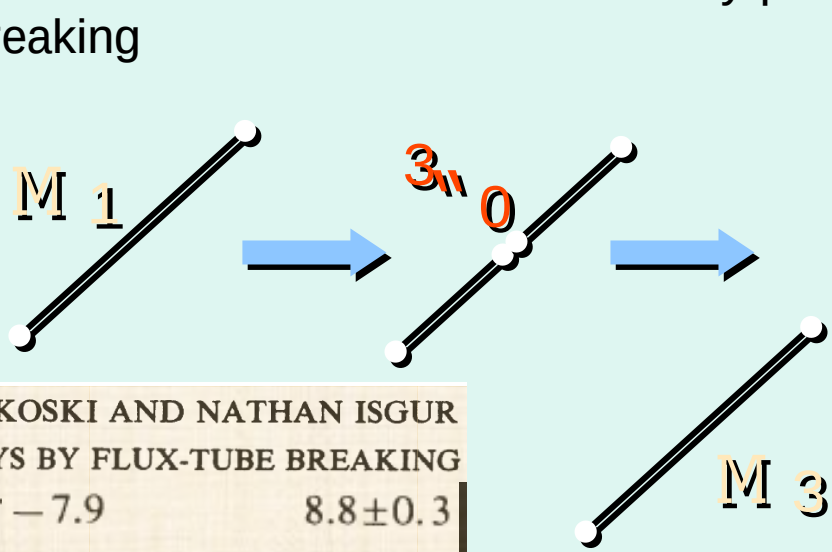
Statistics resolve if 0,1,2 structures and J^PC

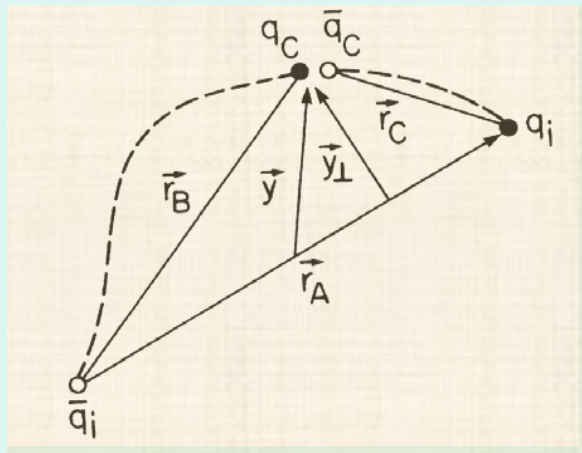
Decays in the Flux-Tube model

- there is a reasonably successful model of conventional meson decays called $^3P_0$ - because a $q\bar{q}$ pair is produced with these quantum numbers



- within the flux-tube model this decay process is realised by flux-tube breaking





RICHARD KOKOSKI AND NATHAN ISGUR
MESON DECAYS BY FLUX-TUBE BREAKING

$A_2 \to (\pi\pi)_\rho \pi$	-7.9	8.8 ± 0.3
$A_2 \to \eta\pi$	$+4.1$	4.0 ± 0.1
$A_2 \to K\bar{K}$	-2.8	2.3 ± 0.1

Hybrid Decays

- the same model can be applied to hybrids – the only difference is that the initial state has a tube phonon excited
- the angular momentum carried by the phonon has to go into the two-meson end state
  - leads to a selection rule that hybrids will not decay to a pair of *S* - wave mesons

    e.g. $\mathcal{H} \not\to$ $\mathcal{H} \not\to$ $\mathcal{H} \not\to$
  - the dominant decays are found to be to *S* + *P* e.g. $\mathcal{H} \to w_1$
- this hierarchy of decays has become the “folklore” of the hybrid hunters

F.E. Close, P.R. Page/Nuclear Physics B 443 (1995) 233–254

$$\pi f_1 : \pi b_1 : \pi\rho : \eta\pi : \eta'\pi = 60 : 170 : 5 - 20 : 0 - 10 : 0 - 10$$

hybrid decay?

	FTM Ref [?] 1.9GeV	FTM Ref[?] 2.0 GeV	Lattice Ref [?] 2.0 GeV
$\Gamma(\pi_1 \to b_1\pi)_S$	100	70	400 ± 120
$\Gamma(\pi_1 \to b_1\pi)_D$	30	30	
$\Gamma(\pi_1 \to f_1\pi)_S$	30	20	90 ± 60
$\Gamma(\pi_1 \to f_1\pi)_D$	20	25	

TABLE I: Comparison of flux tube and lattice predict[illegible]s for π_1 decays.

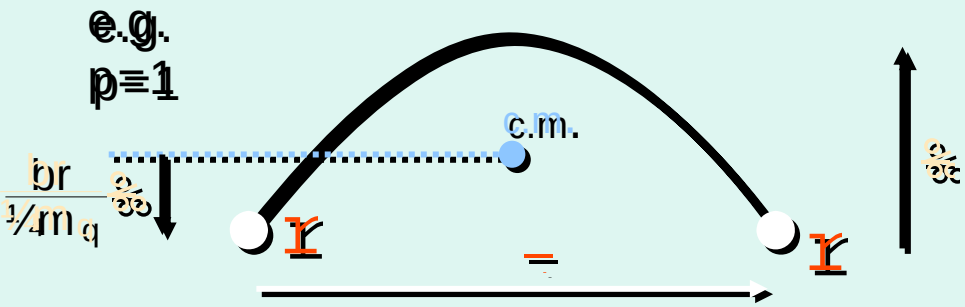
$$\langle \omega\pi|\sigma\cdot\nabla|b_1\rangle = S(k)$$

$$\langle b_1\pi|\sigma\cdot\nabla|\pi_1\rangle = \sqrt{2}\frac{\kappa\sqrt{b}}{\beta}S(k)$$

$$\langle f_1\pi|\sigma\cdot\nabla|\pi_1\rangle = \frac{1}{\sqrt{2}}\frac{\kappa\sqrt{b}}{\beta}S(k)$$

$$\frac{\Gamma(\pi_1 \to b_1\pi)}{\Gamma(\pi_1 \to f_1\pi)} = 4$$

flux-tube breaking and decays



Break tube: S+P states yes; S+S suppressed

S+S = 0 for hybrid charmonium

(FC + Page predictions 1995)

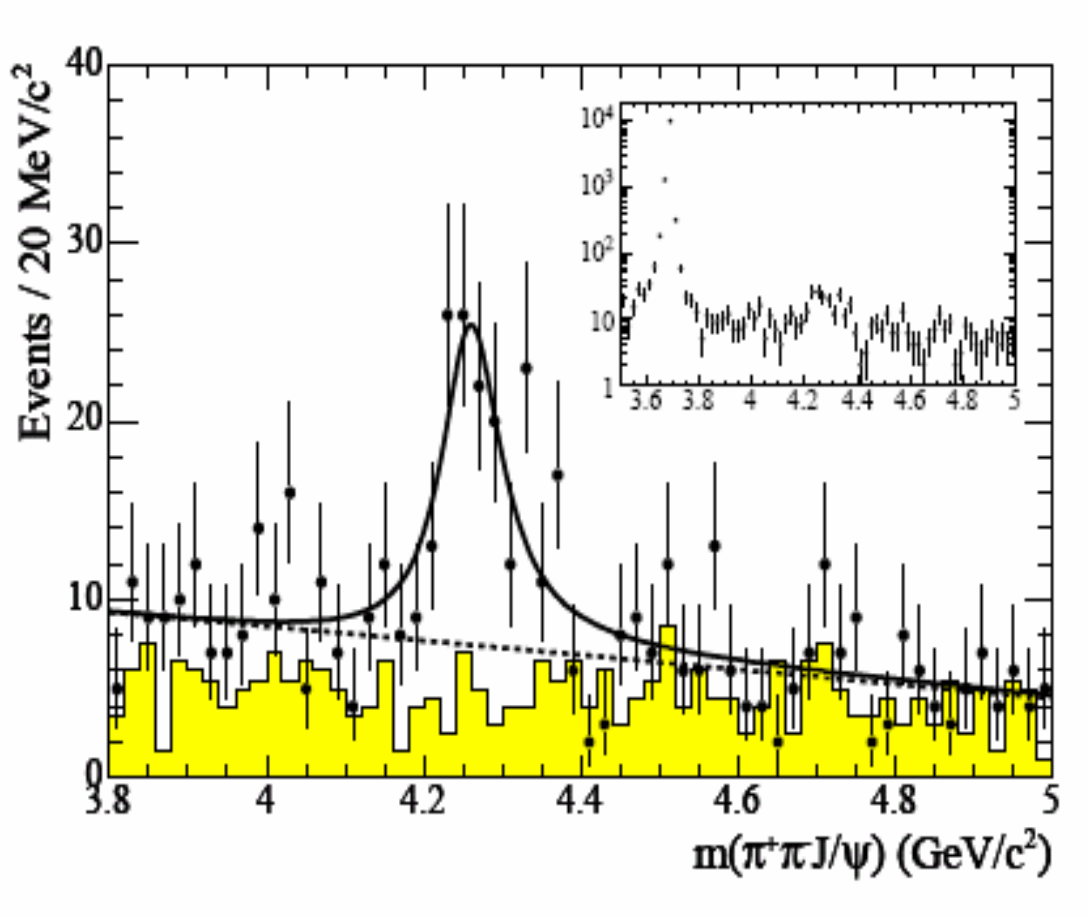
Look for DD_{0,1}; a bit of DD* and absence of DD or D*D* and of DsDs or Ds*Ds*

\psi f_0; \psi pipi; \chi \eta; h_c \eta also

Finally the anomalous vector cc*:

Y(4260)

e+e- \to psi pi pi BaBar sees new vector cc*



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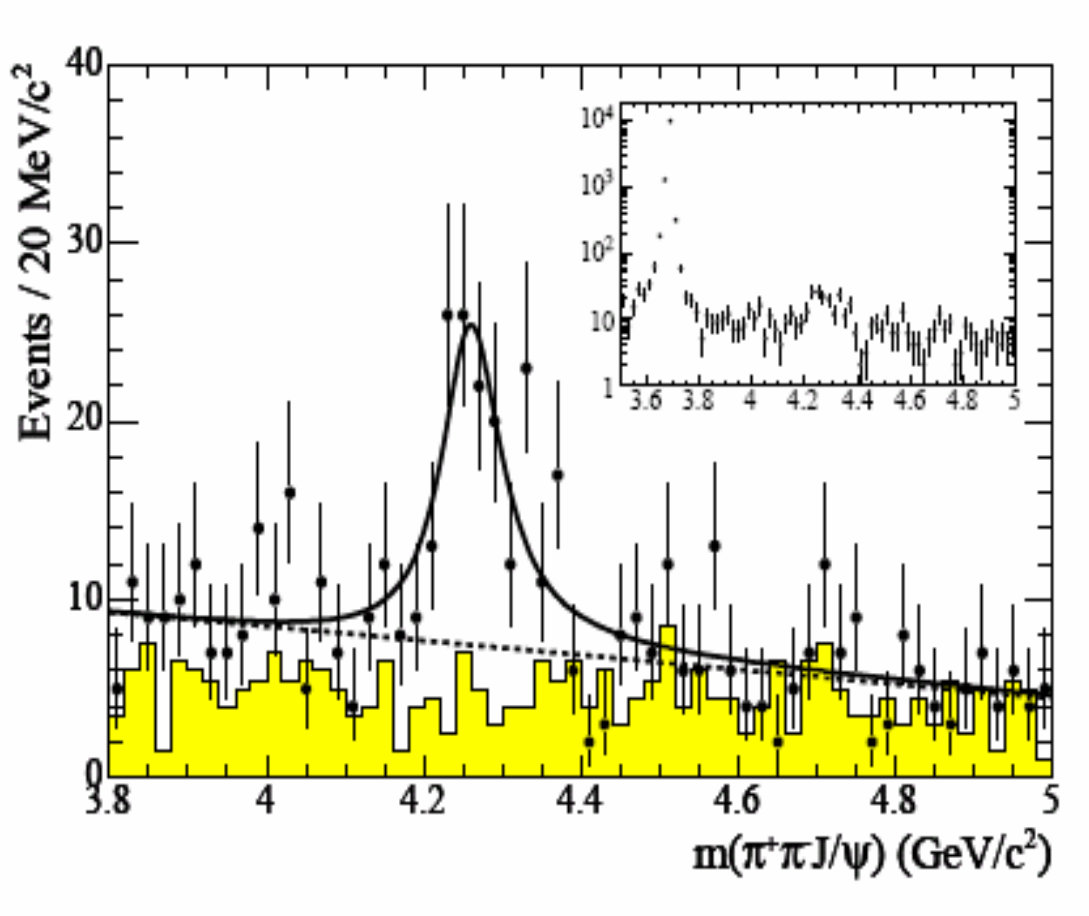

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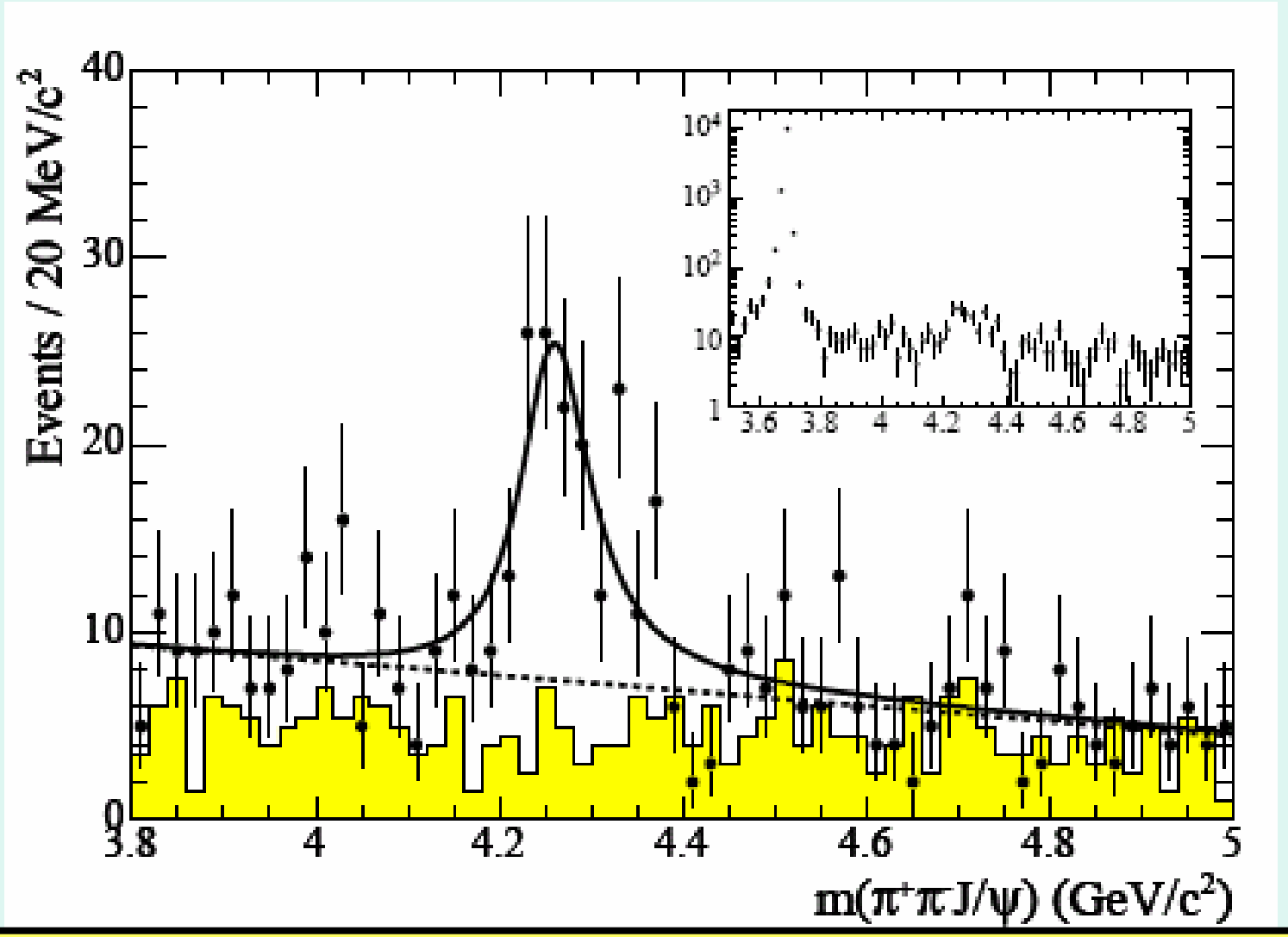
\Gamma(e+e-) 5 to 80 **eV**

e+e- \to psi pi pi BaBar sees new vector cc*



But width 90MeV dominantly psi pipi !

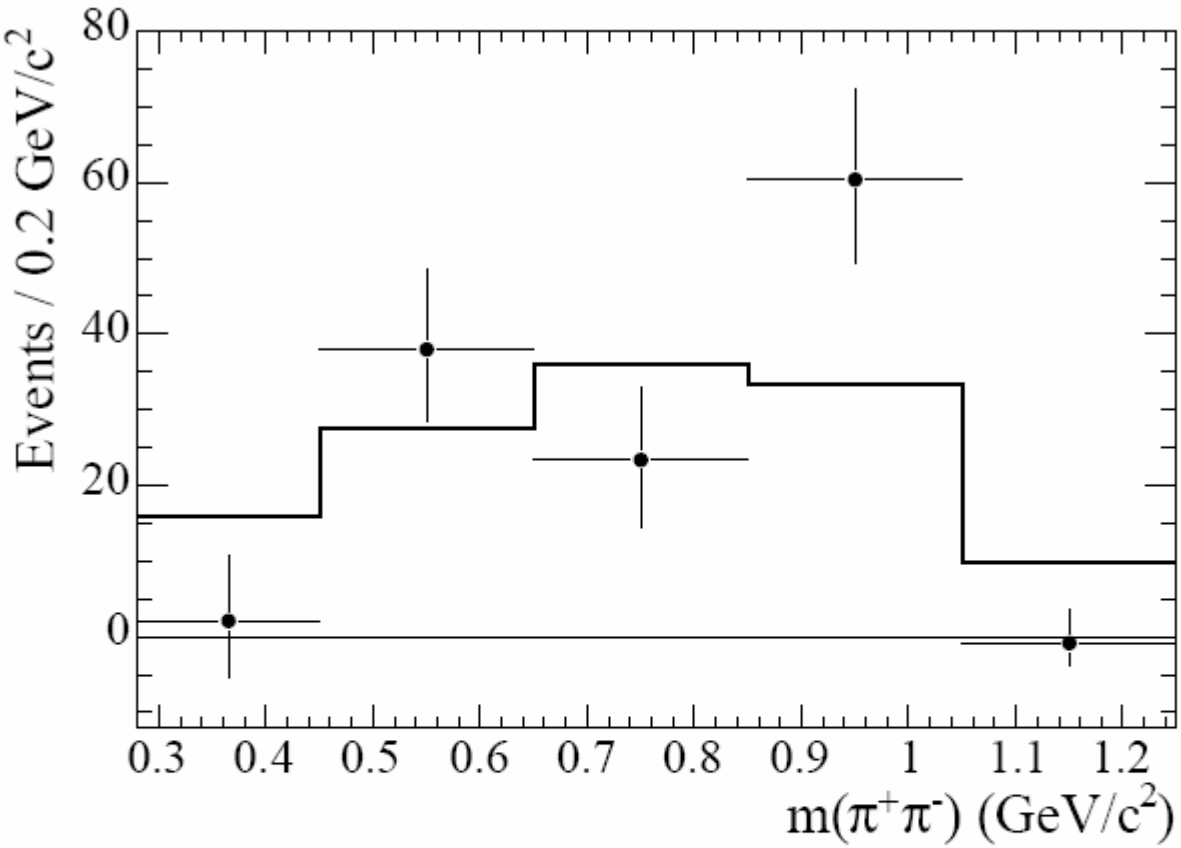
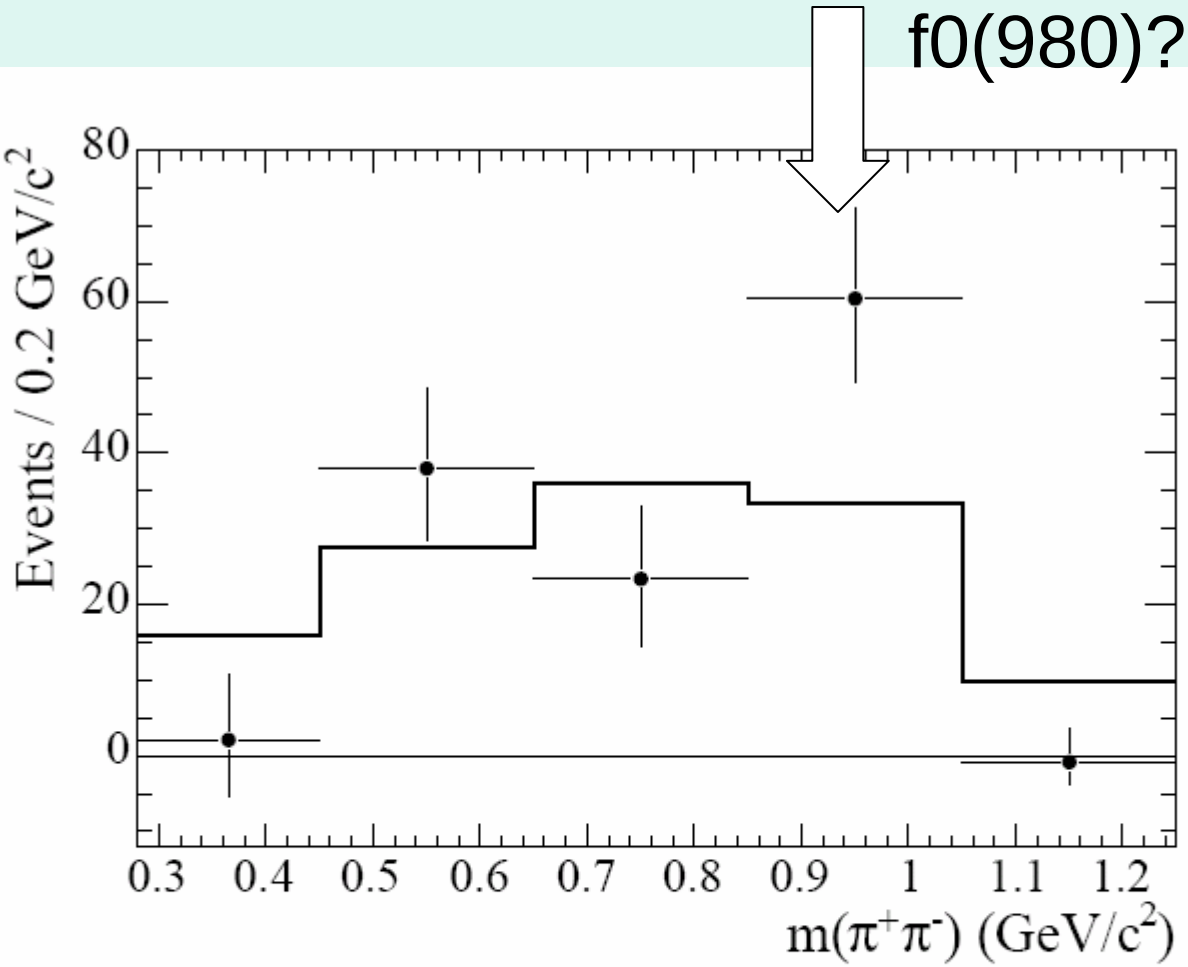


FIG. 3: The dipion mass distribution for $Y(4260) \to \pi^+\pi^- J/\psi$ data is shown as points with error bars. The histogram shows the distribution for Monte Carlo events where $Y(4260) \to \pi^+\pi^- J/\psi$ is generated according to an S-wave phase space model.



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The mass coincides with the $D_1(2420)D$ threshold:

The decay modes $\psi\sigma/\eta$, $\psi f_0(980)/a_0(980)$ appear to dominate:

$\Gamma(Y(4260) \to e^+e^-)$ *is much smaller than all other* 1^{--} *charmonia:*

$$5.5\ eV \leq \Gamma(Y(4260) \to e^+e^-) \lesssim 62\ eV,$$

$\Gamma(Y(4260) \to \psi\pi^+\pi^-)$ *is much larger than all* 1^{--} *charmonia:*

$$\Gamma(Y(4260) \to \psi\pi^+\pi^-) \gtrsim 7.8\ MeV.$$

All consistent with **predictions** for hybrid charmonium

FC+Page 1995

Four Quark Interpretation of $Y(4260)$

L. Maiani* and V. Riquer†
Università di Roma 'La Sapienza' and I.N.F.N., Roma, Italy

F. Piccinini‡
I.N.F.N. Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica, via A. Bassi, 6, I-27100, Pavia, Italy

A.D. Polosa§
Dip. di Fisica, Università di Bari and I.N.F.N., Bari, Italy

$$Y(4260) = \left([cs]_{S=0}[\bar{c}\bar{s}]_{S=0}\right)_{\mathrm{P-wave}}$$

$$\Gamma_Y(D_s\bar{D}_s) >> \Gamma_Y(D\bar{D})$$

Dominant $D_s\bar{D}_s$ decay is quite a distinctive signature of the validity of the present model.

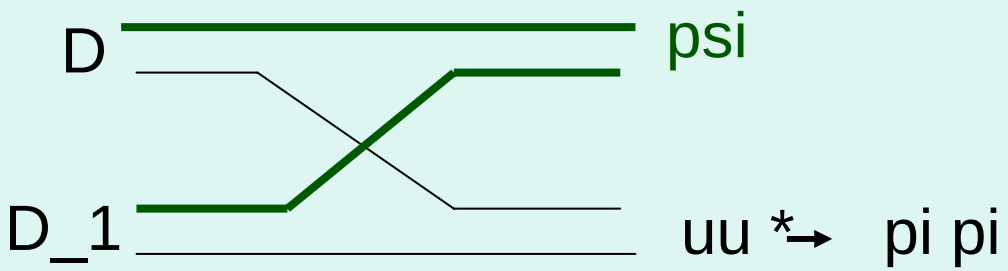
This is a clear distinction with hybrid for which this is ~ zero

Is it really a resonance?

e+e- ⇒ DD_1

is first S-wave charm threshold and occurs \sim 4.2 GeV !

S-wave, relative mom \sim 0;
DD_1 interchange constituents to make psi pipi “strongly”
(c.f. Swanson model of 3872 DD* \to psi omega)



e+e- ⇒ Ds Ds_1 ⇒ psi KK should show similar

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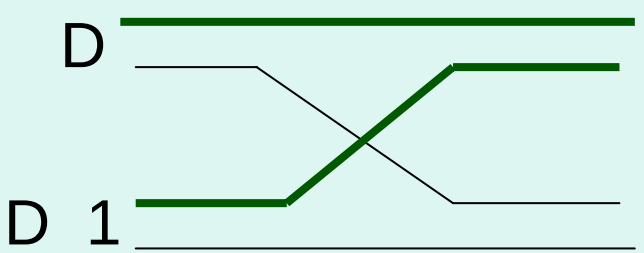

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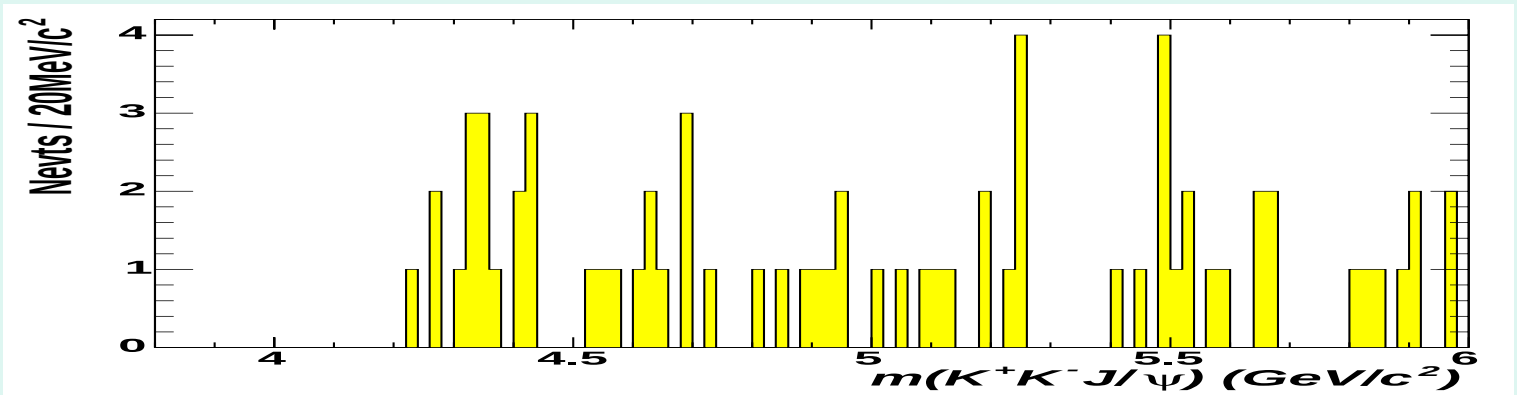
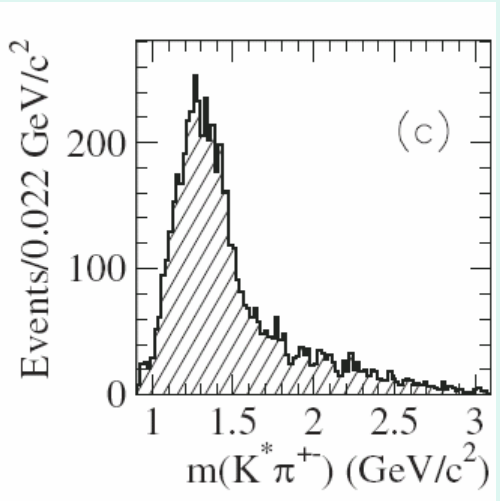


Lou

PHYSICAL REVIEW D 71, 052001 (2005)

$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, and $K^+K^-K^+K^-$ cross sections at center-of-mass energies 0.5–4.5 GeV measured with initial-state radiation

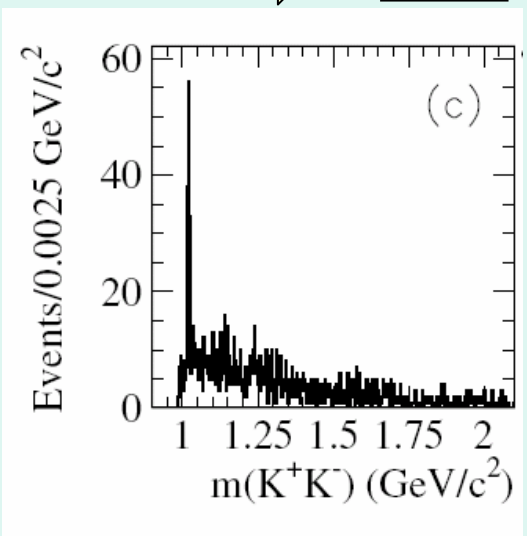
e+e- → KK_1

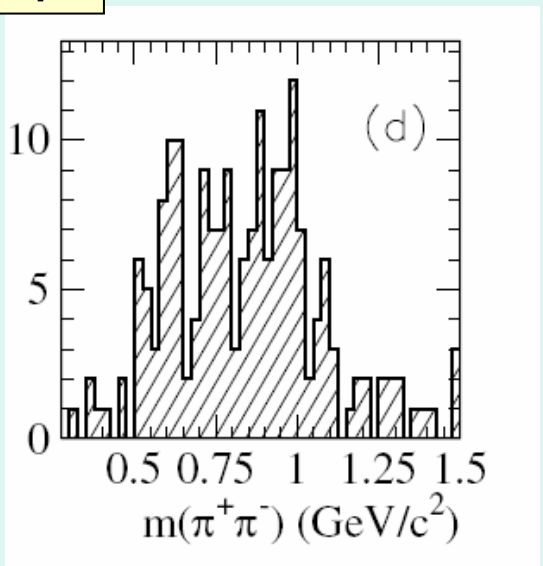


Future need to do:
Compare this with the DD_1 / psi pipi case:

M(pipi);
phi (psi) polarisation

→ phi pi pi





Maiani

SUMMARY AT MILOS

- BR for strong and e.m. decays of X(3872) still known to 30-40%: more precision and more channels are crucial!
- D^0 $Dbar^0$ π^0 channel is very important to tell molecule from 4quarks
- X(3940): is there $\rho\psi$ decay?
- Y(4260): observation of D_s $D_s$bar vs D D_1 decay will tell the difference, validating or disproving 4q or hybrid (or both!)
- The search of other 1^{--} in the 3900-4000 region could be fruitful

Close

Psi polarisation test
HQ symmetry would imply no psi; but also no 4260
For m_c DD_1 threshold and below D*D_0

Y(4260) Two Possibilities

$$Y(4260) = ([cs]_{S=0}[\bar{c}\bar{s}]_{S=0})_{\mathrm{P-wave}}$$

Maiani

$$Y(4260) \textbf{ as hybrid charmonium}$$

Close

DD_1 and not DsDs for hybrid

DsDs and not DD_1 for tetraquark

→ Experiment can decide