Exotic Spectroscopy Experimental overview

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Beyond the "standard spectroscopy"

- Search for states with 2 quarks+"something else"
  - New forms of aggregation
  - Expected but never identified!!!
- Hybrids: $q\bar{q}$+n gluons
  - Lowest state 1^{-+} (forbidden for quarkonium)
  - Dominant decay $H \rightarrow DD^{**}$
- Tetraquarks: $[qq'][\bar{q}\bar{q}']$
  - Large amount of states
  - small widths also above threshold
- Molecules: $M[q\bar{q}]M[q'\bar{q}']$
  - Smaller number of states but still small widths also above threshold

Search for resonances:
- with non-quarkonium J^{PC}
- unnaturally small widths
- not null charge: clear indication of something new going on

Building a new spectroscopy

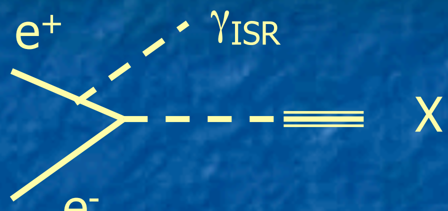
1. Find structures
2. Measure quantum numbers (mass, JPC from production and decay properties)
3. “walks like a dog, smells like a dog …”
   - Several possible scenarios (hybrids, molecules, tetraquarks,…)
4. Quantify models and fit data to it
5. Search missing states to complete the picture

Strong interplay between theory and experiment

Experiments

- $e^+e^- \rightarrow$ Charmonium (CLEO-c, BES)
  - L~10^{33}/cm^2/s
  - E=3.0-4.3 GeV
- $e^+e^- \rightarrow$ Y(4S): (BaBar, Belle, CLEO)
  - L~10^{34}/cm^2/s
  - Charmonium in B decays, ISR and $\gamma\gamma$ production
    - Capability to measure J^{PC} also in production
- pp colliders (CDF, D0)
  - High Xsection $\rightarrow$ copious production
  - Extremely high backgrounds

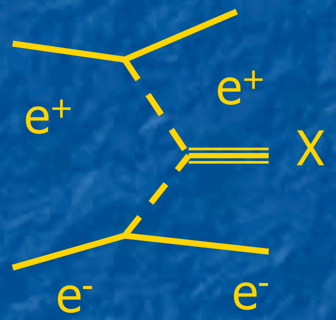
Measuring the quantum numbers



- Production:
  - ISR only produces with same quantum numbers as the photon ($J^{PC}=1^{--}$)
  - $\gamma\gamma$ only produces with C=+
  - Double charmonium production

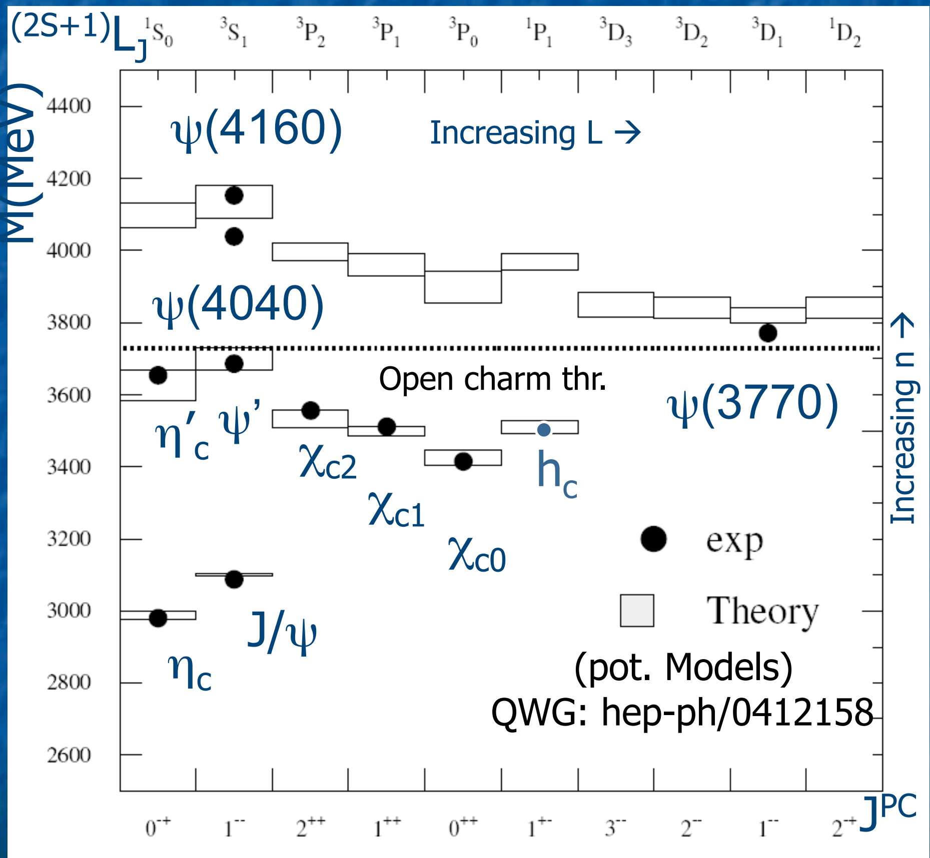
    $e^+e^- \to \gamma^* \to X_{cc}^1 X_{cc}^2$

    Possible only if quantum numbers of the two charmonia can be combined to give a 1^{--}.



- Decay:
  - Angular distributions of decay products depend on J^P.
  - Strong decay into C eigenstates (C_1 and C_2) implies $C=C_1{*}C_2$
  - Selection rules
    - Conservation of J
    - Conservation of P,C in strong and electromagnetic decays

Charmonium: state of the art



Basically all states below the open charm threshold are observed and explained

The new Charmonium zoology

- X(3872)
- The 3940 Family
- The 4150 Family
- The 1-- family
- The charged states

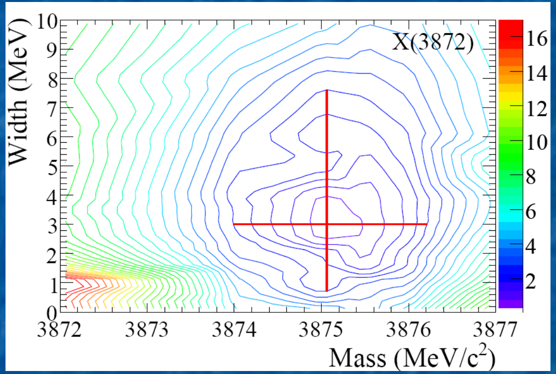
C=+

X(3872)

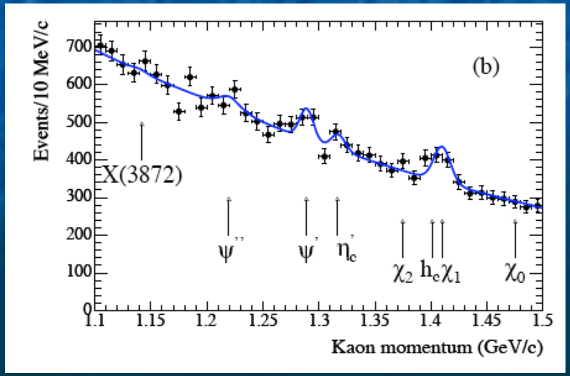
- Best known new state, M~3872 MeV, $J^{CP}=1^{++}$
- Only seen in B decays so far ($B\to XK$)
- Possiility to measure absolute BF and widths. Bayesian likelihood combination of:
  - Product $BF(B\to XK) x BF(X\to f)$
    - $f = J/\psi\pi\pi, D^{*0}D^0, J/\psi\gamma, \psi(2S)\gamma, J/\psi\pi^+\pi^-\pi^0, \chi_c\gamma, \gamma\gamma, J/\psi\eta$
  - Measured Γ (BaBar)

$$\Gamma = (3.6^{+4.6}_{-2.3} \pm 0.9)\,MeV$$

$\Delta\chi^2$



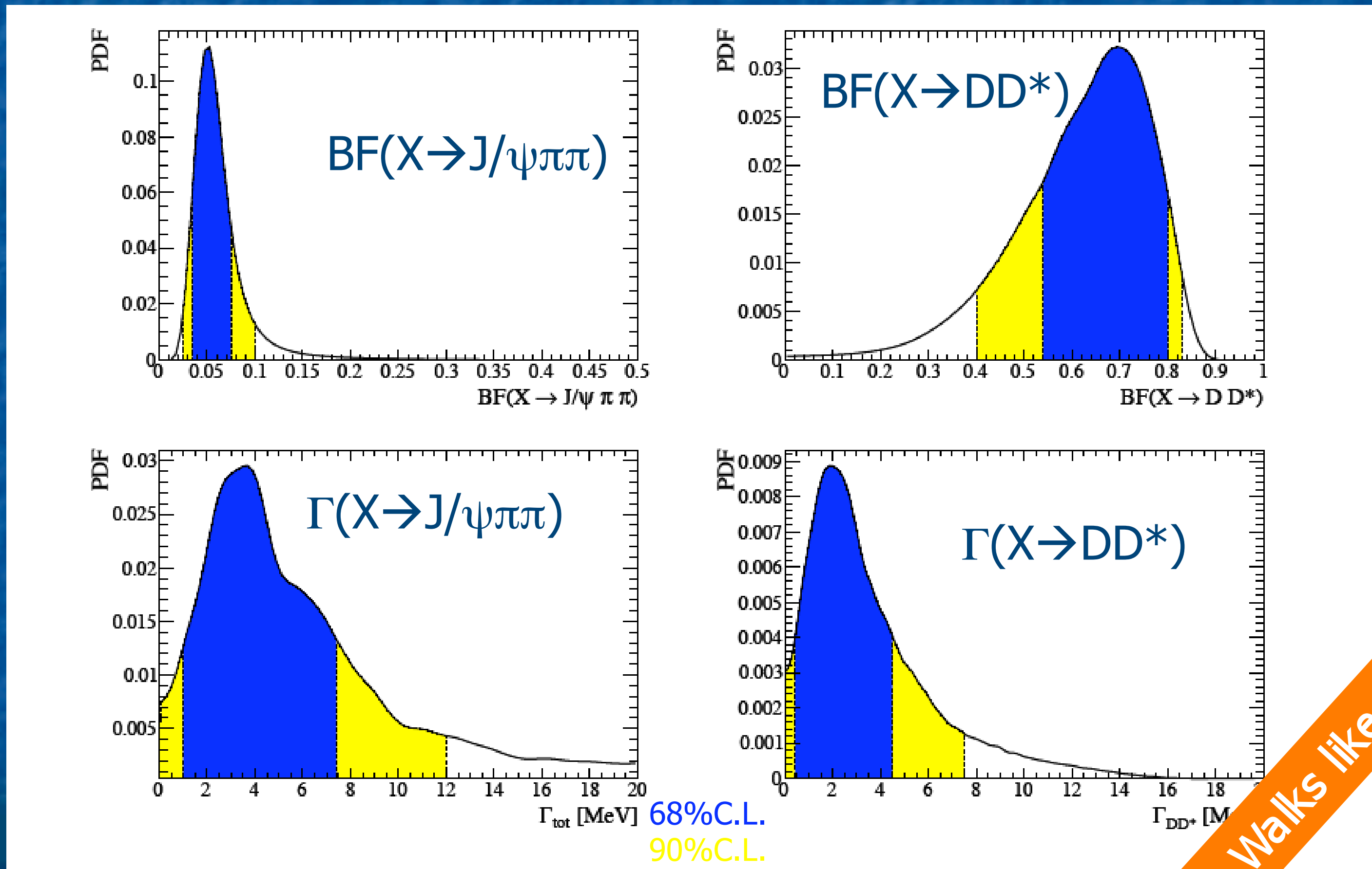
  - Upper limit on $BF(B\to XK)$ from K inclusive spectrum on the recoil of fully reconstructed B decays (BaBar).



2. Measure quantum numbers

Work in progress
Drenska, RF, Piccinini, Polosa, Renga, Sabelli

Combined BF and widths



3. Walks like a dog (?)

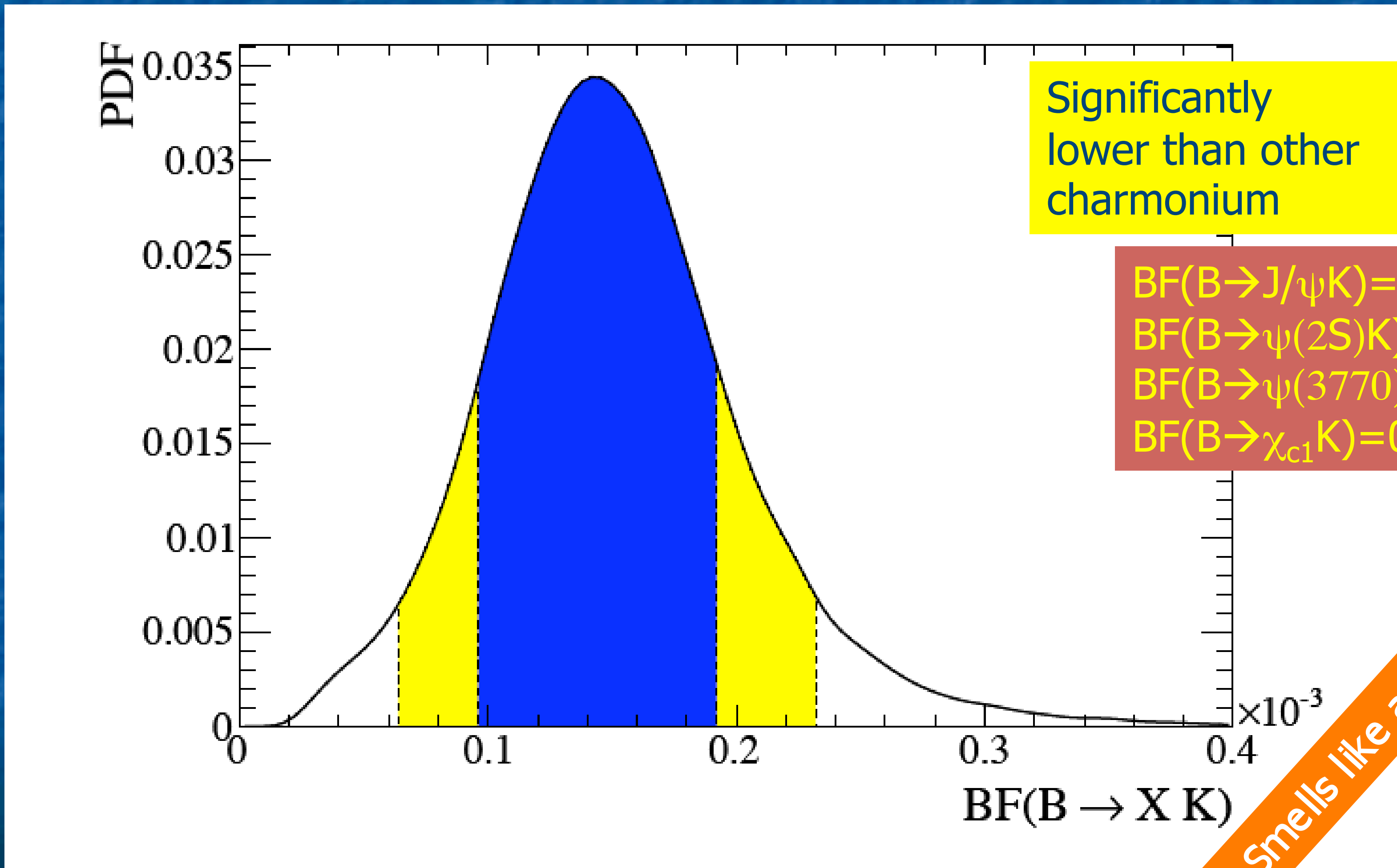
Large DD* BF and Γ : Prob(Γ(X→DD*)<Γ(D*)=0.7%

Test against molecular nature

Summary of BF

B Decay mode	X decay mode	B_{fit}	$B/B_{J/\psi\pi\pi}$
$XK^{\pm}$	$X \to J/\psi\pi\pi$	$[0.035, 0.075]$	N/A
XK^{0}	$X \to J/\psi\pi\pi$	–	N/A
$XK^{\pm}$	$X \to D^{*0}D^{0}$	$[0.54, 0.8]$	$[3.9, 18.9]$
XK^{0}	$X \to D^{*0}D^{0}$	–	–
XK	$X \to J/\psi\gamma$	$[0.0075, 0.0195]$	$[0.19, 0.32]$
XK	$X \to \psi(2S)\gamma$	$[0.03, 0.09]$	$[0.75, 1.55]$
XK	$X \to \gamma\gamma$	< 0.0004	< 0.0078
XK	$X \to J/\psi\eta$	< 0.098	< 1.9
XK	$X \to J/\psi\pi\pi\pi^{0}$	$[0.015, 0.08]$	$[0.45, 1.44]$

BF(B→XK)

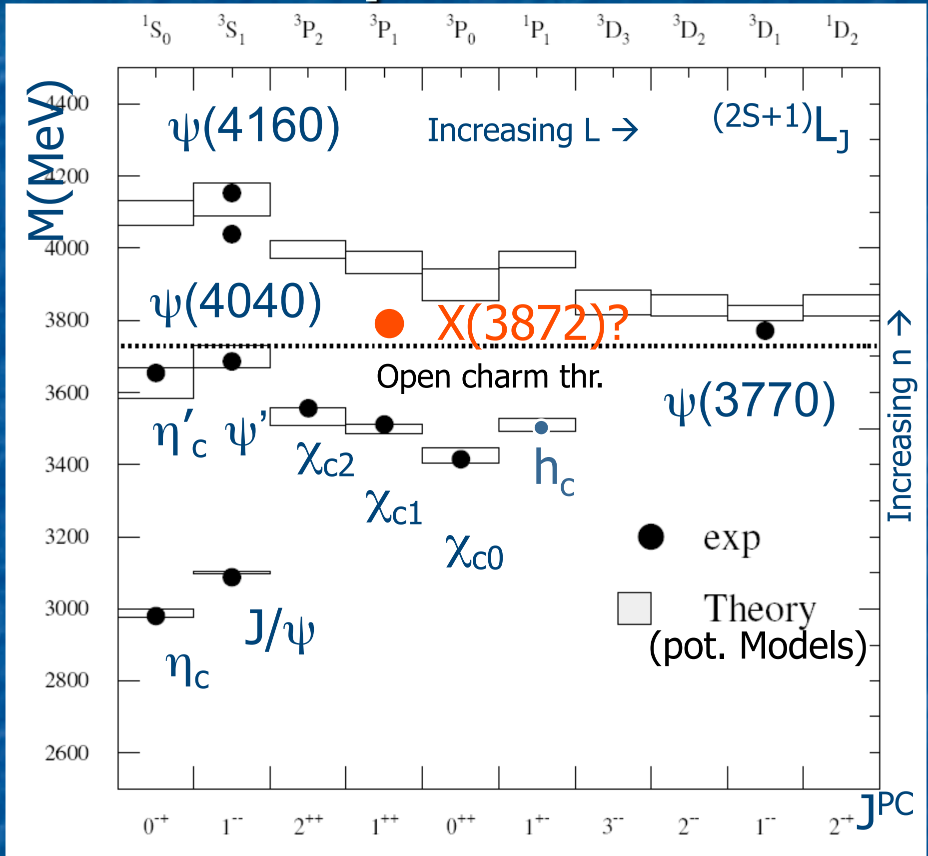


Significantly lower than other charmonium

BF(B→J/ψK)=10^{-3}
BF(B→ψ(2S)K)=0.65 10^{-3}
BF(B→ψ(3770)K)=0.5 10^{-3}
BF(B→χ_{c1}K)=0.5 10^{-3}

3. Smells like a dog (?)

The X(3872) puzzle



Charmonium:

- Cons
  - narrow to be above threshold
  - large BF in isospin violating $J/\psi\rho$
  - low BF(B→XK)

Molecules:

- Pros
  - Close to threshold
  - favors DD* decays
- Cons
  - above threshold!
  - narrow
  - hard to match production Xsections in pp

Tetraquark :

- Pros:
  - explains small width
  - Any mass allowed
- Cons:
  - Several unobserved states predicted

Omitting dozens of theory references

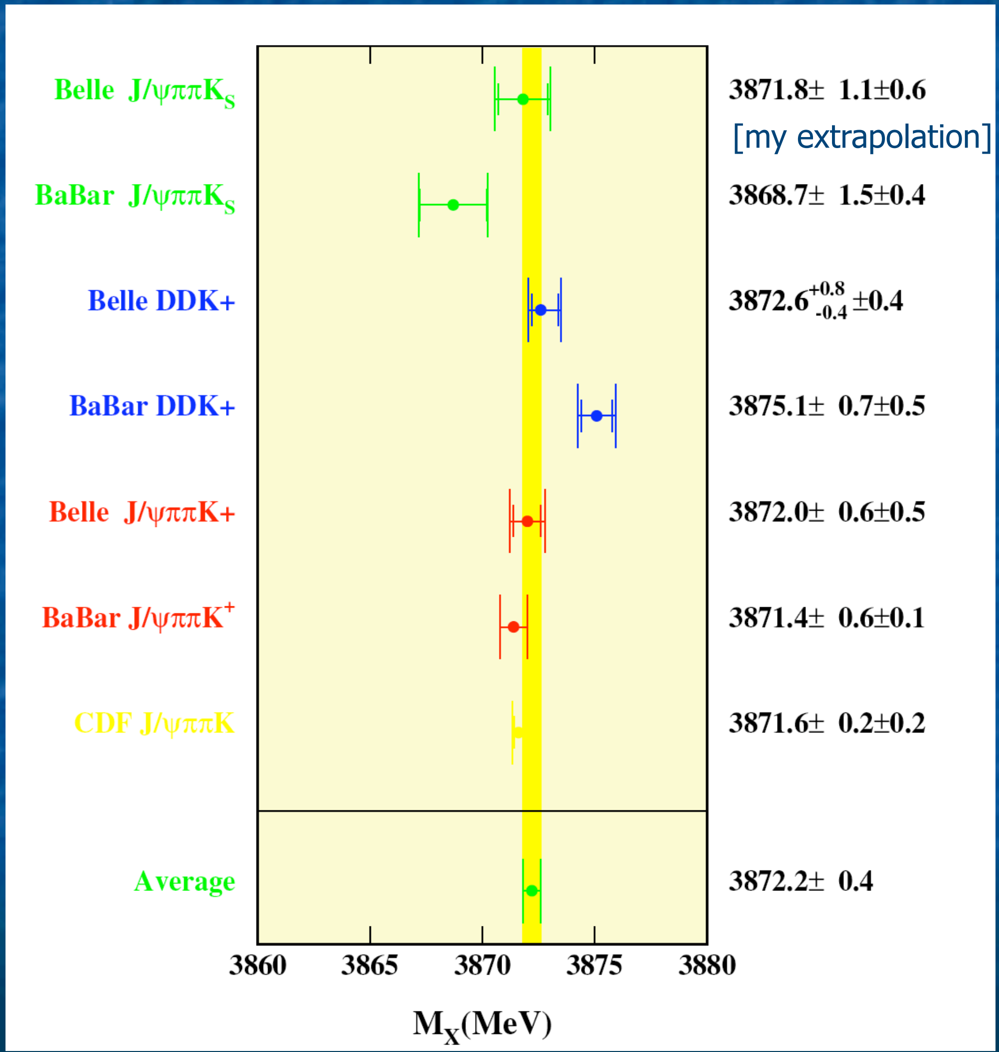
X(3872) mass in several final states

Poor agreement among mass measurements:
<u>$X \rightarrow J/\psi\pi\pi$ and $X \rightarrow DD^{(*)}$ differ by ~3.5σ</u>

TWO STATES? X(3872) & X(3876) ?

Predicted by tetraquark model
(but why so close to threshold?)

PRL 103:152001,2009
CDF inclusive $J/\psi\pi\pi$
$\Delta M < 3.2$ MeV @90%C.L.



The new Charmonium zoology

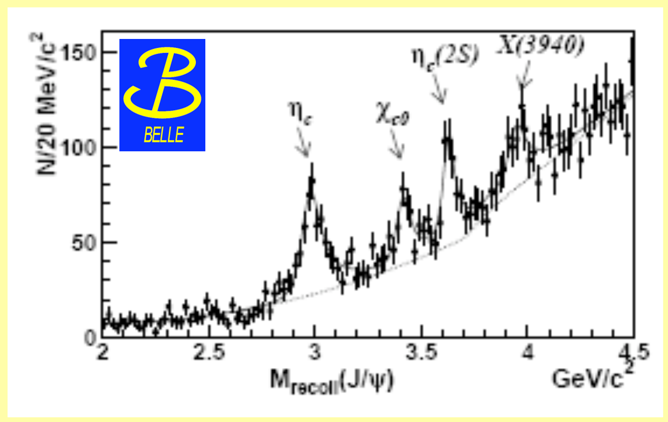
- X(3872)
- The 3940 Family
- The 4150 Family
- The 1-- family
- The charged states

C=+

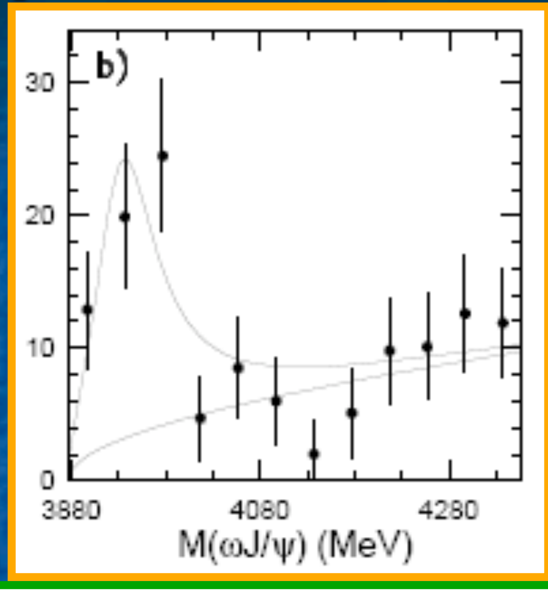
The 3940 family

PRL 94, 182002 (2005)
PRL 101, 082001 (2008)

PRL 98, 082001 (2007)

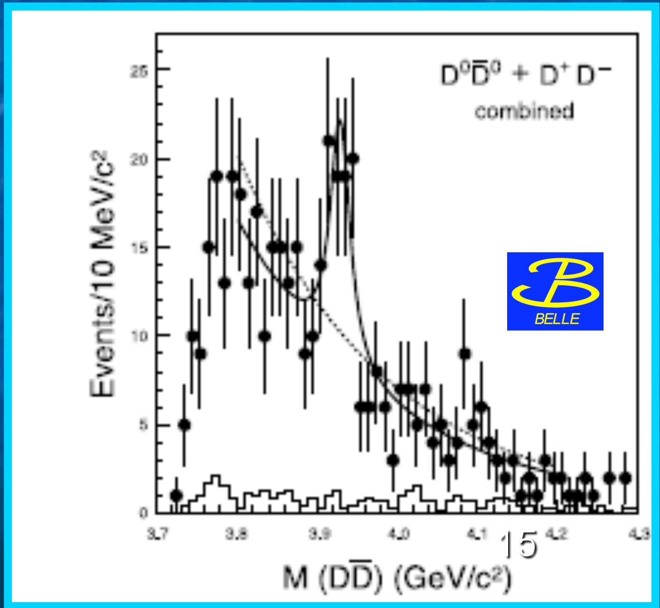


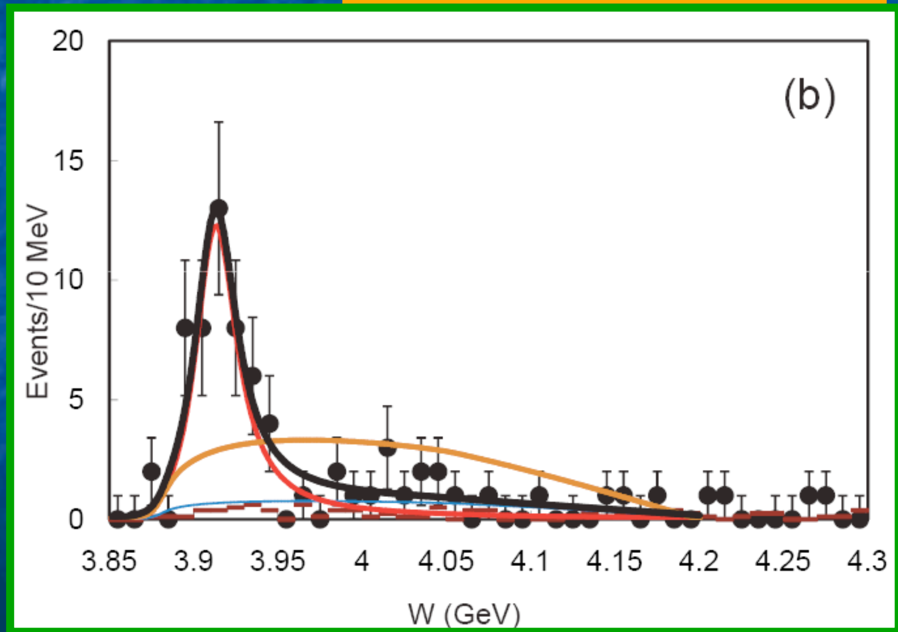
B→YK
Y(3940)→J/ψω



e$^+$e$^-$ →J/ψ X
X(3940)→DD*

PRL 96, 082003 (2006)

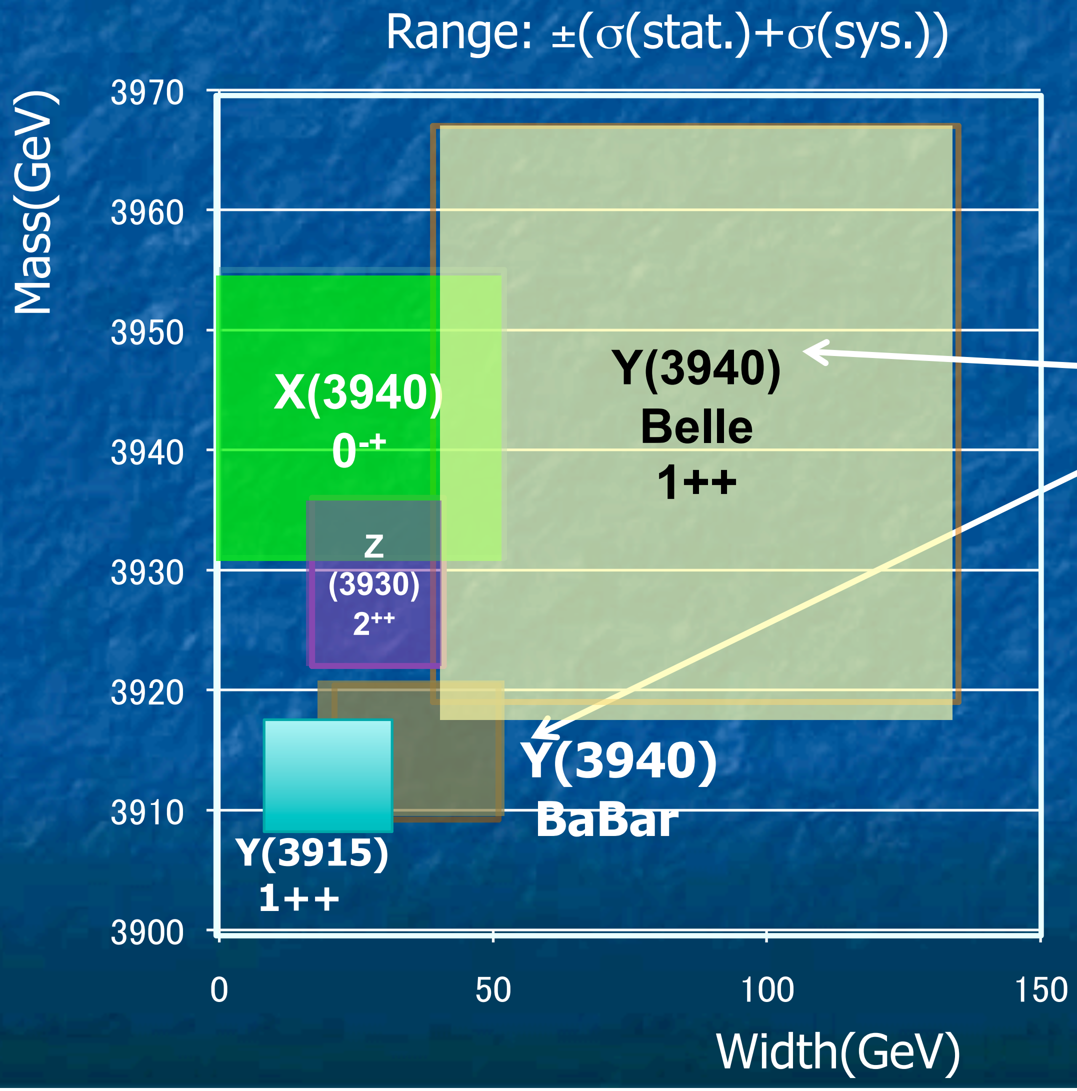




γγ->Z Z(3940)→DD

γγ->Y Y(3915)→J/ψω

The 4 states near 3940



Better analysis of the J/ψ ω mass spectrum needed!!

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} C=+

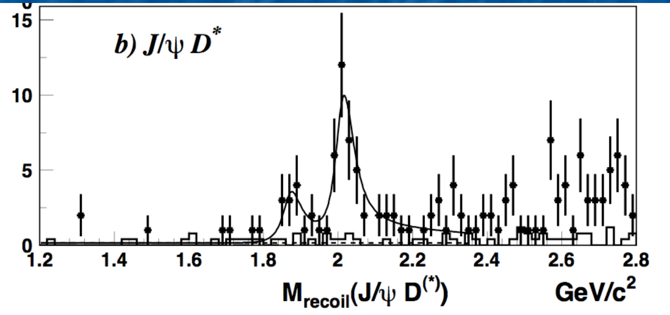
PRL 100:202001,2008

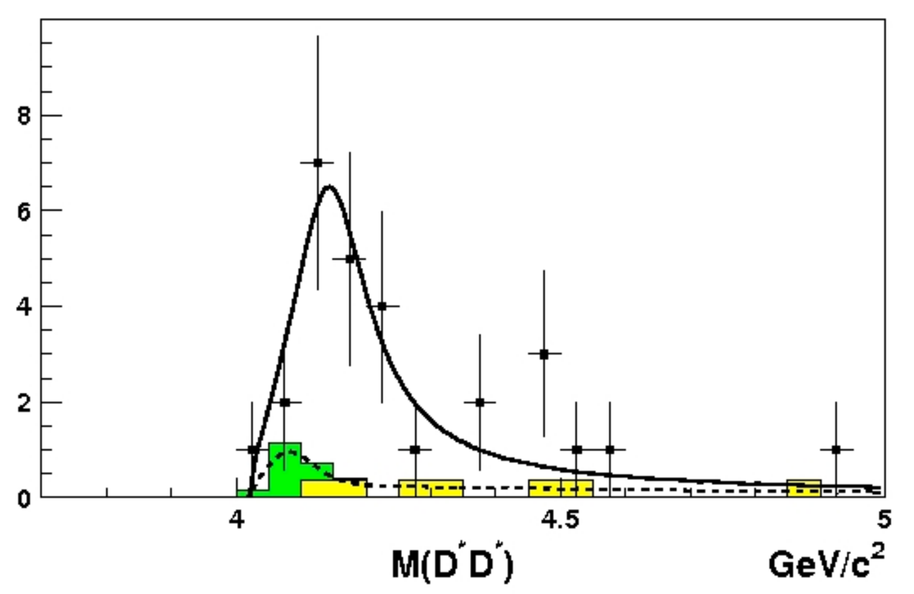
X(4160)

- Produced in e+e- → J/ψ X(4160)
- Observed in X(4160)→D*D* with partial reco technique $J^{PC}=0^{\pm+}, 2^{\pm+}$

$e^+ e^- \rightarrow J/\psi\ D^* D^*$

reconstructed





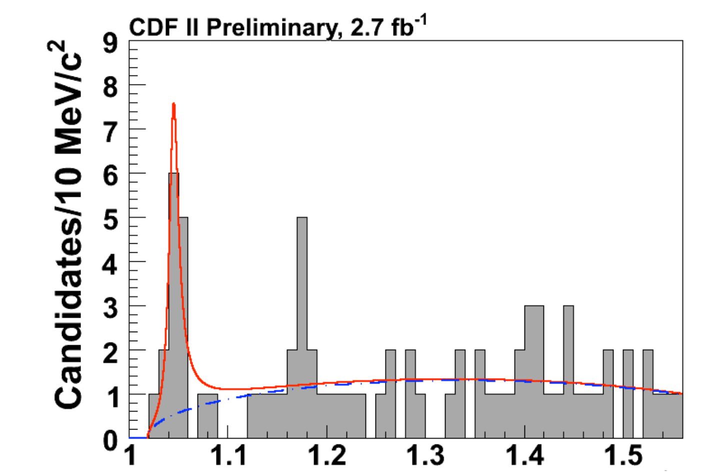
$M = 4156\ ^{+25}_{-20} \pm 15\,\mathrm{MeV}$

$\Gamma_{tot} = 137\ ^{+111}_{-61} \pm 21\,\mathrm{MeV}$

Y(4140)

PRL 102:242002,2009

Search for B→YK Y→J/ψφ



$\Delta M = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$

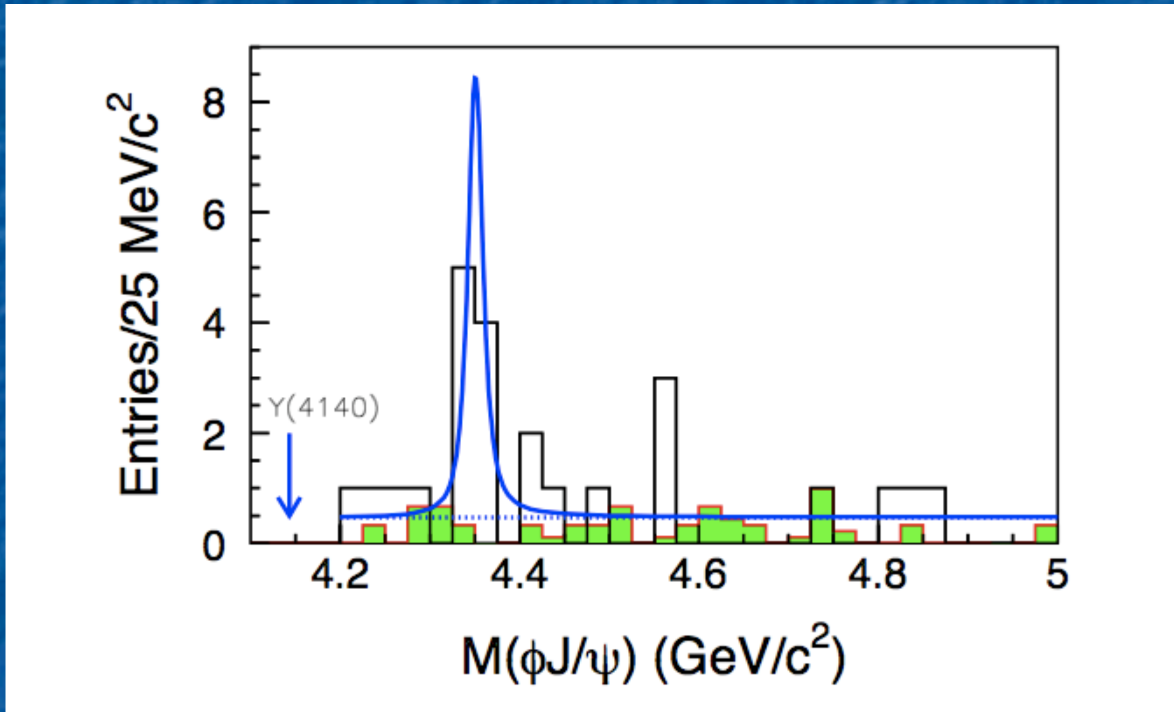
M: 4143.0 ± 2.9 ± 1.2 MeV,
Γ: 11.7 $^{+8.3}_{-5.0}$ ± 3.7MeV,
Signif. > 3.8σ

Interpretation

- Possible $J^{PC}=0^{++},1^{-+},2^{++}$
- Non Charmonium J^{CP} → hybrid (lowest state predicted ~4100 MeV)
- Another 'edge' state, better candidate molecule

Y(4140) in γγ → X(4350)

PRL104:112004,2010



M: 4350 ± 5 MeV,

Γ: 13 $^{+18}_{-9}$ ± 4MeV,

Signif. = 3.2σ

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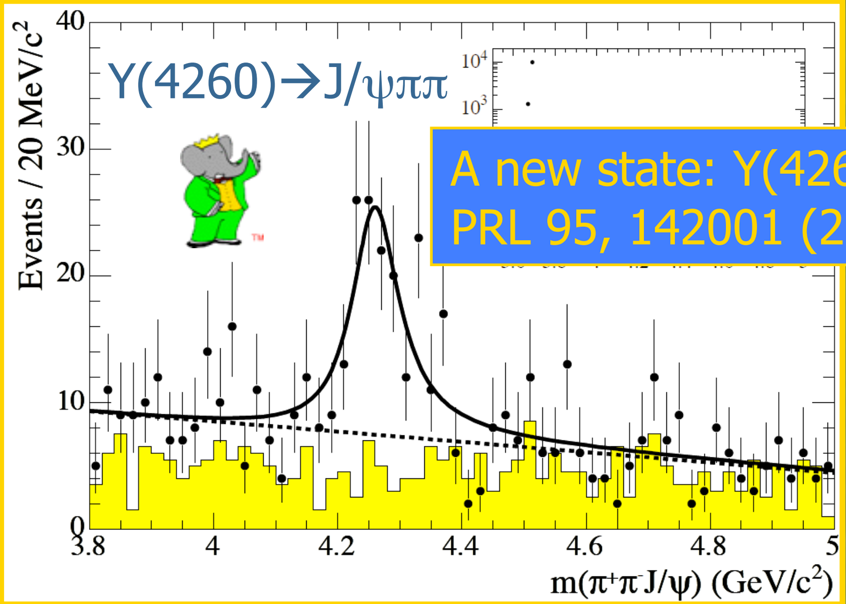
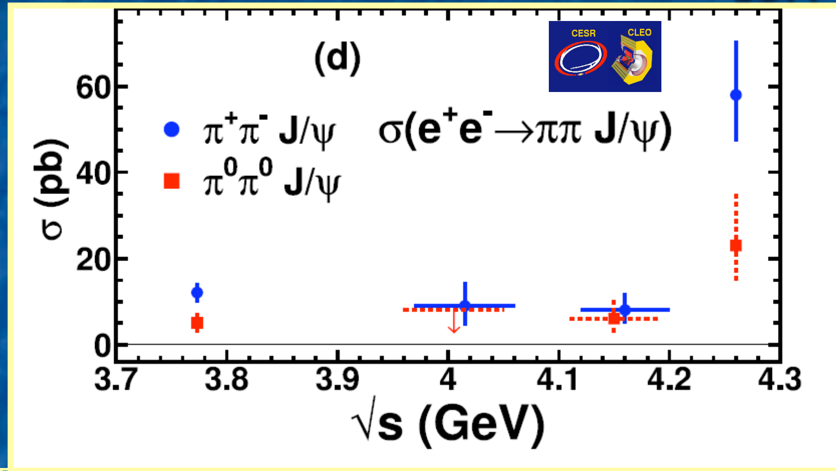
C=+

The 1^{--} family

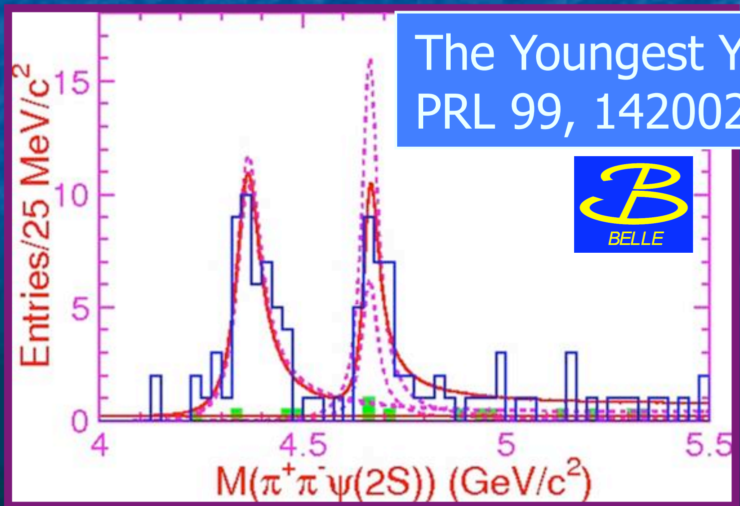
Several resonances observed in $e^+e^- \rightarrow Y\gamma_{ISR}$



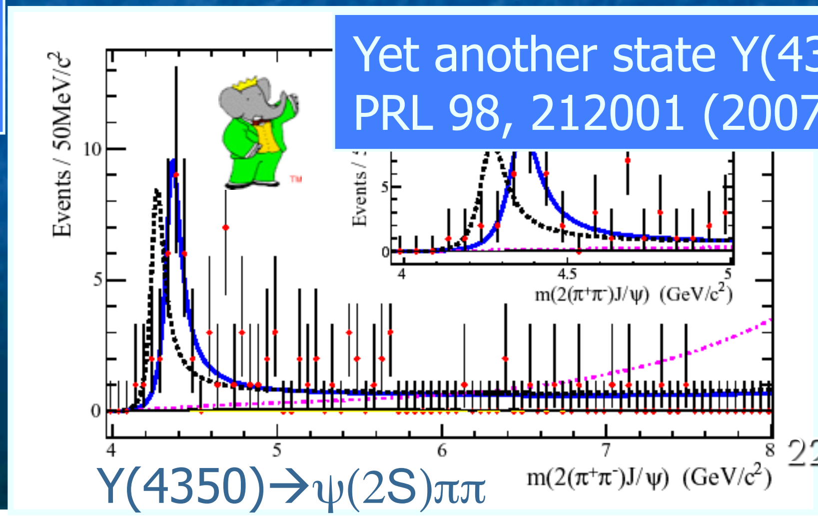
A new state: Y(4260)
PRL 95, 142001 (2005)



Confirmation + $J/\psi\pi^0\pi^0$:
CLEO PRD74, 091104 (2006)
CLEO-c PRL 96, 162003 (2006)



The Youngest Y(4660)
PRL 99, 142002 (2007)



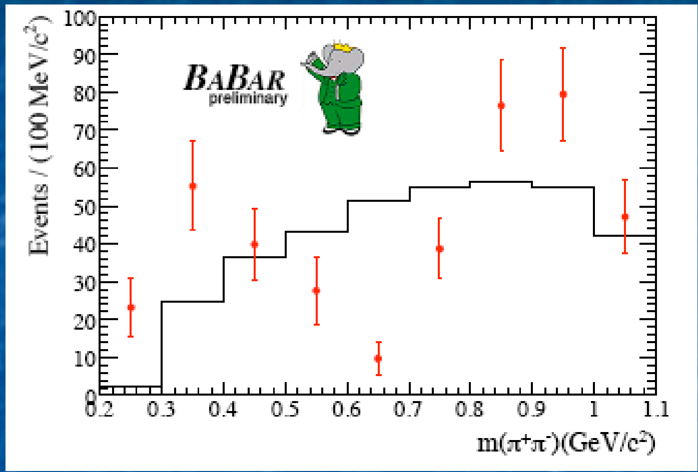
Yet another state Y(4350)
PRL 98, 212001 (2007)

$Y(4350)\rightarrow\psi(2S)\pi\pi$

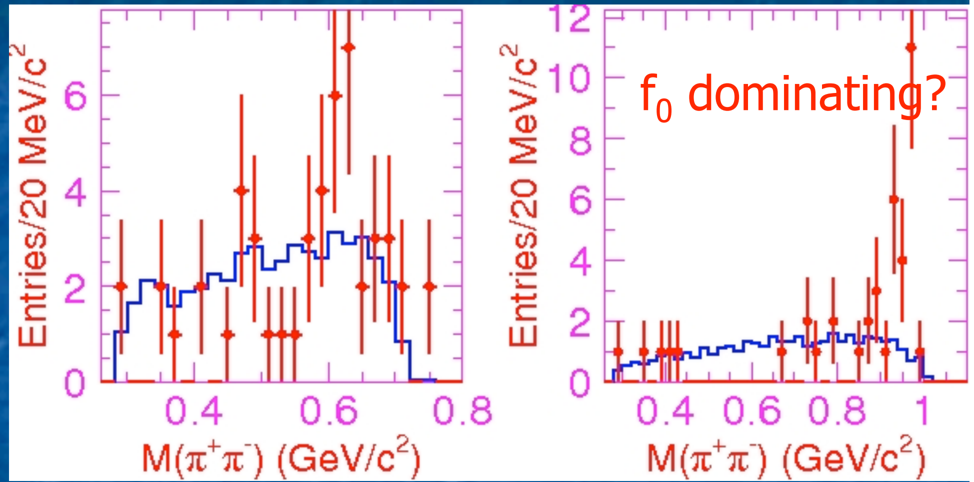
DECAY PROPERTIES

$\pi^+\pi^-$ invariant mass

Y(4260)



Y(4350) Y(4660)



Also, why would Y(4350) and Y(4660) prefer $\psi(2S)\pi\pi$?

Radial or orbital excitation of tetraquarks would prefer $\psi(2S)$

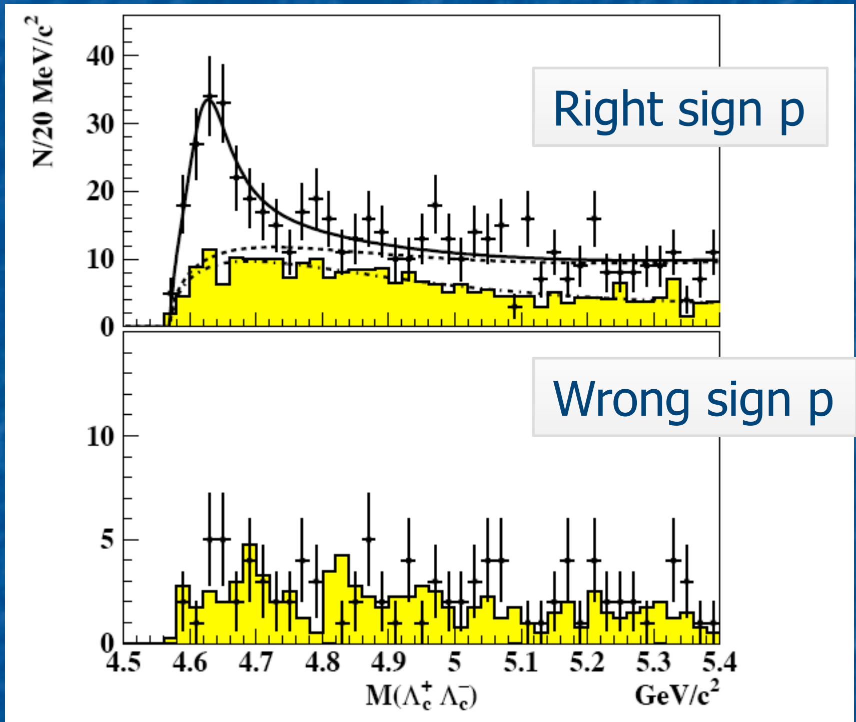
n_r	ℓ	R(J/ψ – ψ)
1	1	0.07
0	3	0.2
0	1	3.5

Cotugno, RF, Polosa, Sabelli
PRL 104, **132005 (2010)**

PRL101,172001 (2008)

Y(4660)→$\Lambda_c \Lambda_c$

- Search for ISR $e^+e^- \to \Lambda_c \Lambda_c \gamma$ events

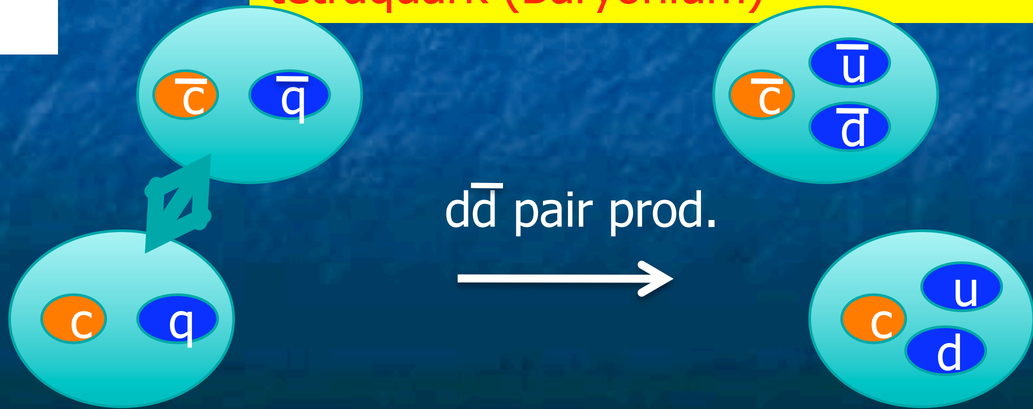


Cotugno, RF, Polosa, Sabelli
PRL104, 132005 (2010)

- simultaneous fit to $\psi(2S)\pi\pi$ and $\Lambda_c \Lambda_c$ modes has good χ^2
- M=4661±9 MeV Γ=61±23 MeV
- Large preference of the baryonic decay model!

$$\mathcal{B}(Y_B \to \Lambda_c \bar{\Lambda}_c)/\mathcal{B}(Y_B \to \psi(2S)\pi\pi) = 117 \pm 44$$

Y(4660) good candidate for a tetraquark (Baryonium)



The new Charmonium zoology

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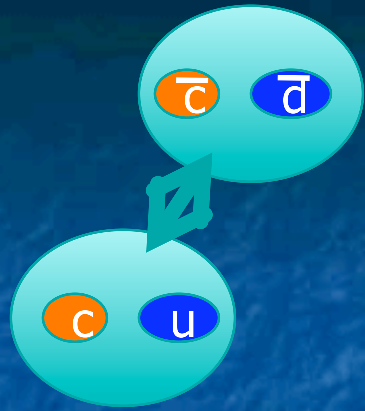
C=+

The Z(4430)$^+$



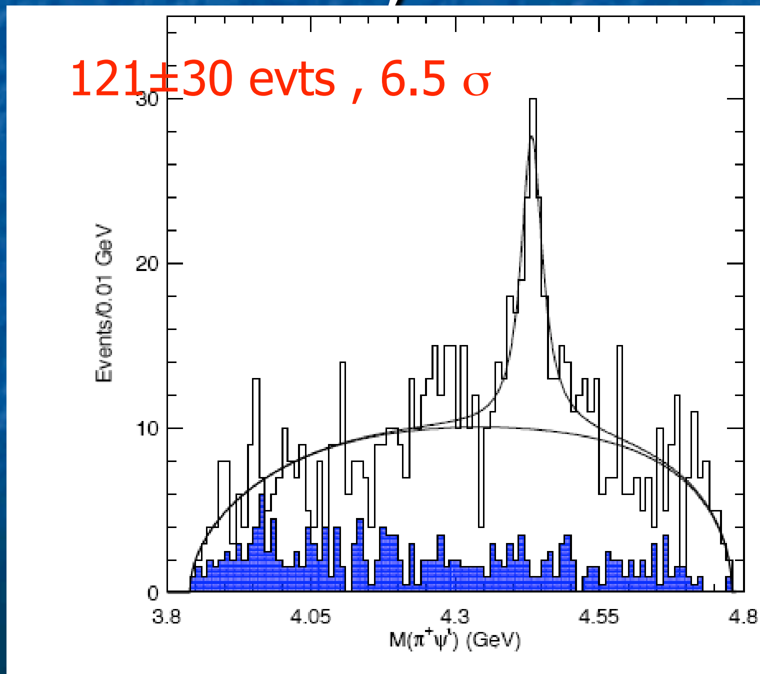
- Charged states a strong prediction of the tetra-quark model
- First observed by Belle in PRL100, 142001 (2008)
- Search for $Z^{\pm} \rightarrow$

J/ψ or $\psi(2S) + \pi^{\pm}$

In $B \rightarrow \psi\pi^{\pm}K$ decays

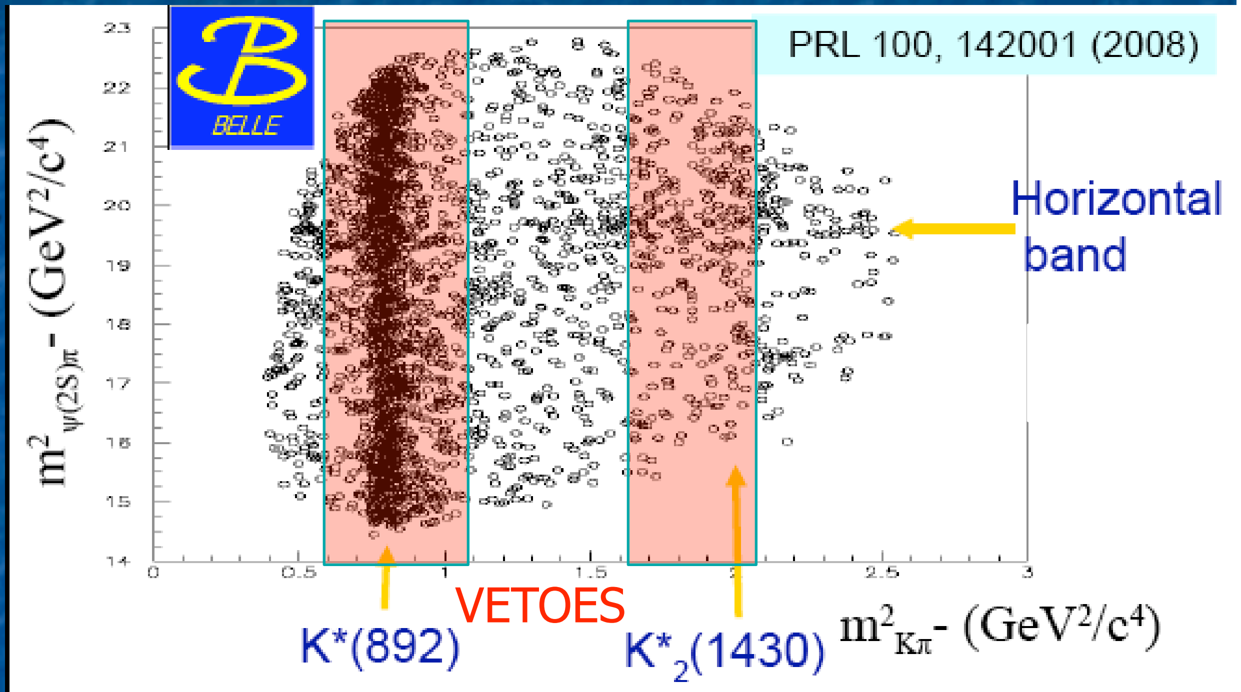
M=4433±4±2 MeV

$\Gamma=45^{+18}_{-13}{}^{+30}_{-13}$ MeV



Criticisms to "discovery analysis"

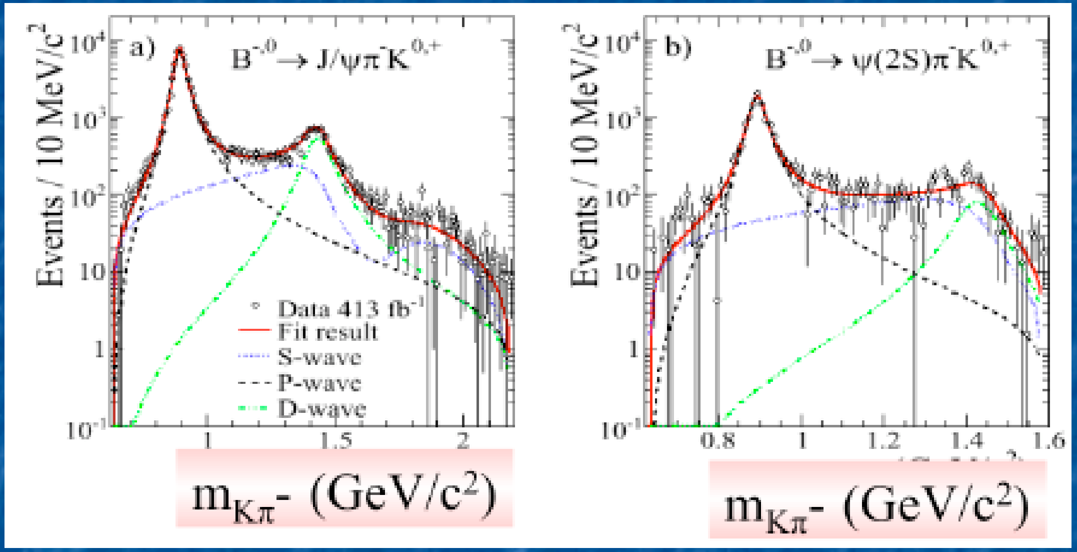
- Only "global" efficiency correction
- Poor treatment of 3-body decays (cut away dominant resonances – no interference/ reflections)



- Arbitrary choice of background shape

BaBar Analysis

- Event-by-event efficiency correction
- Describe the Kπ system in detail
  - Mass



  - Angular distributions fitted with Legendre Polynomials

BaBar results

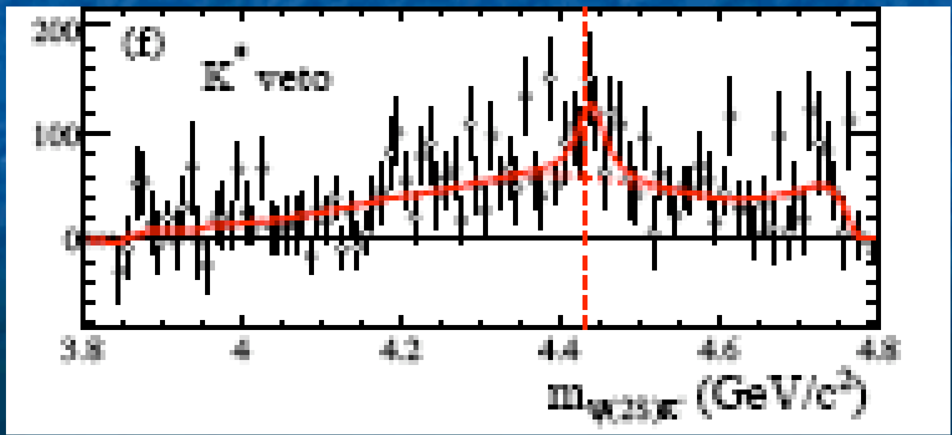
- Fitting without vetoes

  m=4476±8 MeV/c^2; Γ=32±16 MeV; signal size: 2.7 σ

[offset of 43±9 MeV w.r.t. Belle]

- Same vetoes as Belle

  m=4439±8 MeV/c^2; Γ=41±33 MeV; signal size 1.9 σ

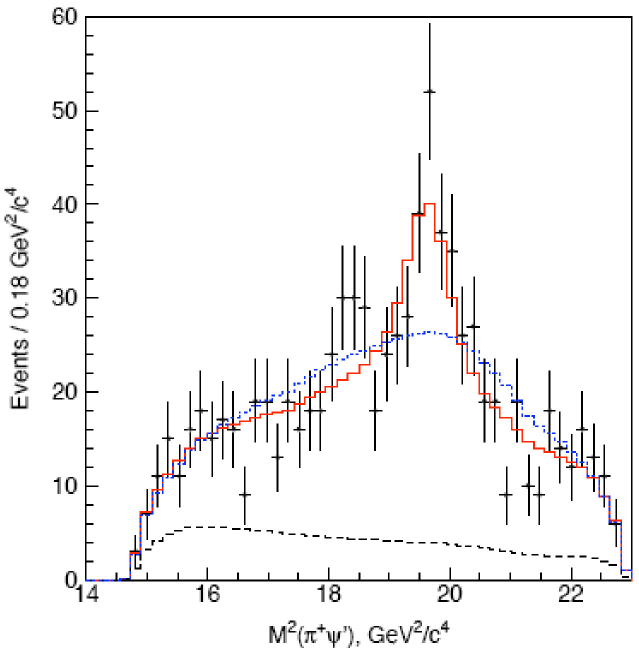


Conclusions:
• mistreatement of background might enhance significance
• veto might bias signal mass measurement

arXiv:0905.2869

Belle Dalitz Plot Analysis

- Belle's observation confirmed, but errors increase
- Including ψ(2S)W



W=	Fit fraction (%)	Significance
$Z(4430)^+$	$5.7^{+3.1}_{-1.6}$	$6.4\,\sigma$
κ	$4.1^{+3.4}_{-1.1}$	$1.5\,\sigma$
$K^*(892)$	$64.8^{+3.8}_{-3.5}$	large
$K^*(1410)$	$5.5^{+8.8}_{-1.5}$	$0.5\,\sigma$
$K_0^*(1430)$	5.3 ± 2.6	$1.3\,\sigma$
$K_2^*(1430)$	$5.5^{+1.6}_{-1.4}$	$3.1\,\sigma$
$K^*(1680)$	$2.8^{+5.8}_{-1.0}$	$1.2\,\sigma$

$m=4443^{+24}_{-18}$ MeV
$\Gamma=109^{+113}_{-71}$ MeV

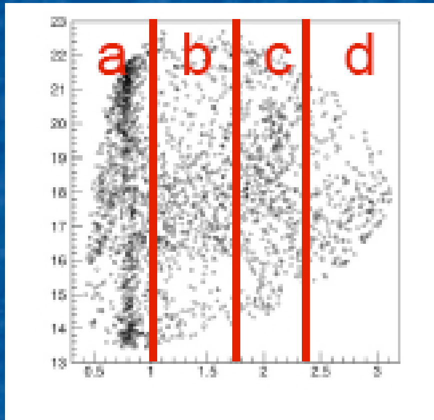
$$\mathcal{B}(\bar{B}^0 \to K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \to \pi^+ \psi')$$

$$= (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5}$$

CFR. BaBar excludes 3.1 10–5 @90%C.L.

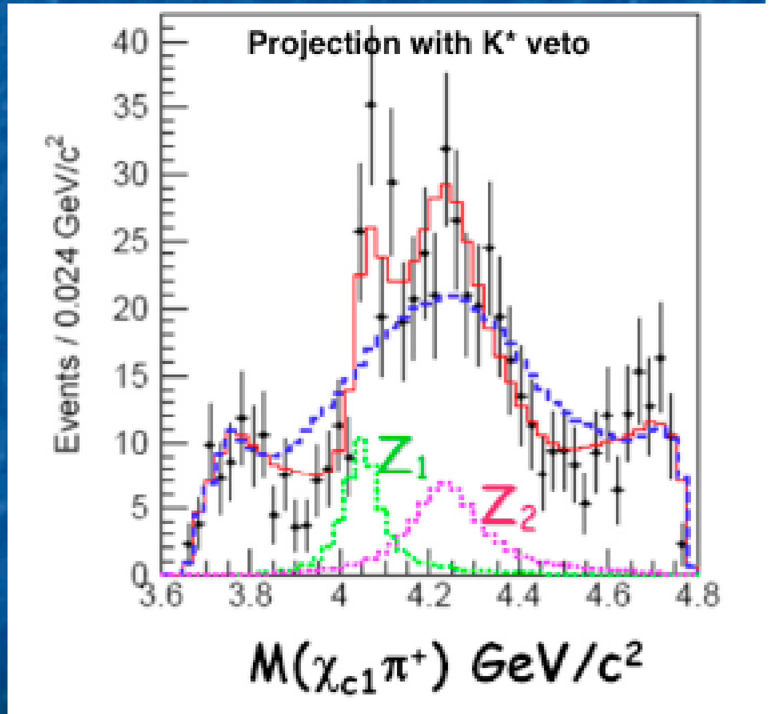
PRD 78, 072004 (2008)

Z^1 and $Z^2 \rightarrow \chi_{c1}\pi$



b+d

Same analysis strategy



$$M_1 = (4051 \pm 14^{+20}_{-41})\ \mathrm{MeV}/c^2,$$
$$\Gamma_1 = (82^{+21+47}_{-17-22})\ \mathrm{MeV},$$
$$M_2 = (4248^{+44+180}_{-29-35})\ \mathrm{MeV}/c^2,$$
$$\Gamma_2 = (177^{+54+316}_{-39-61})\ \mathrm{MeV},$$

$$\mathcal{B}(\bar{B}^0 \to K^- Z_1^+) \times \mathcal{B}(Z_1^+ \to \pi^+ \chi_{c1}) = (3.0^{+1.5+3.7}_{-0.8-1.6}) \times 10^{-5},$$
$$\mathcal{B}(\bar{B}^0 \to K^- Z_2^+) \times \mathcal{B}(Z_2^+ \to \pi^+ \chi_{c1}) = (4.0^{+2.3+19.7}_{-0.9-0.5}) \times 10^{-5}.$$

$J^P=1^-$ assuming L=0

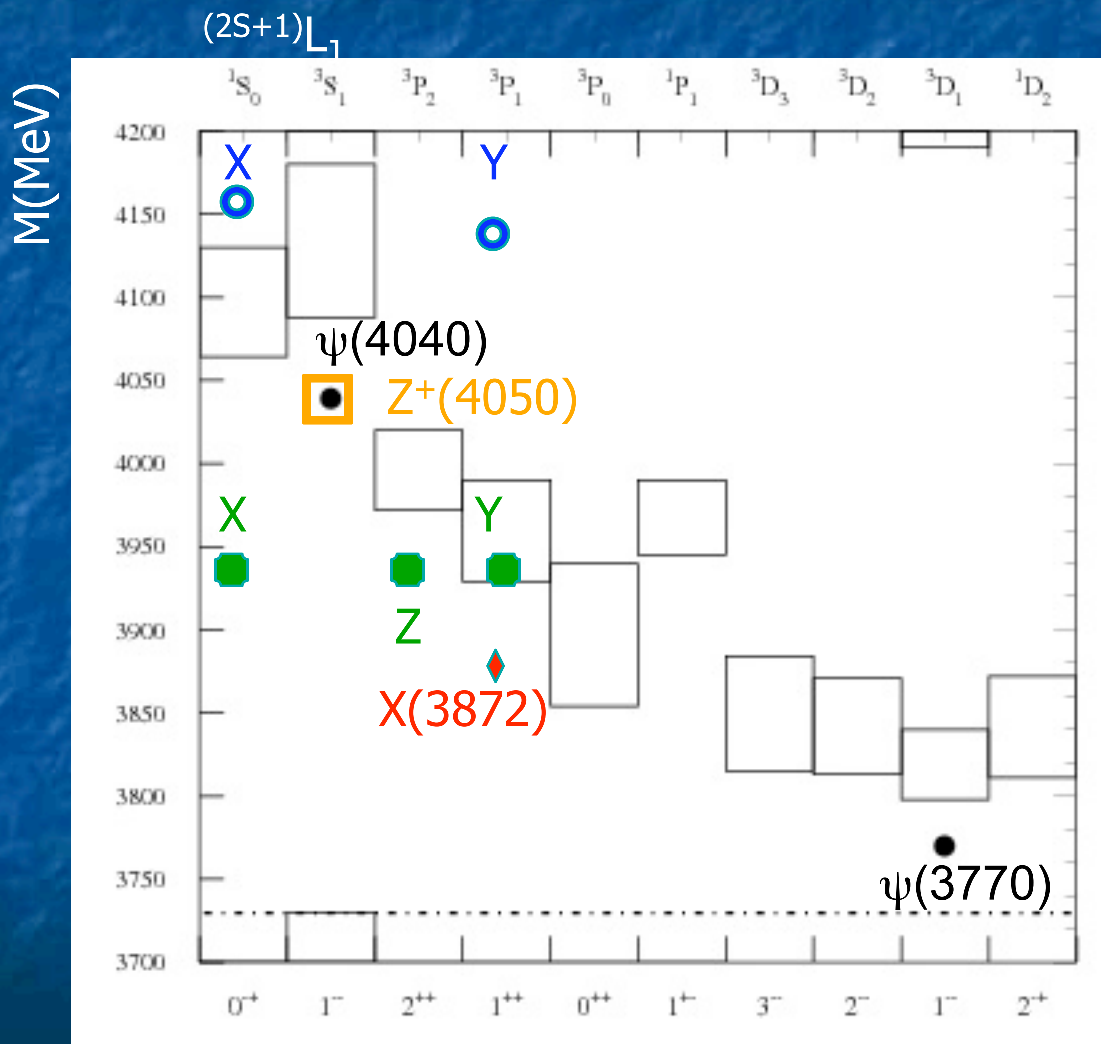
Summary (I)

ψ(4040) and Z±(4050) and isospin triplet?!?

X(4140): candidate $\eta_c(3S)$
Y(4160): candidate hybrid

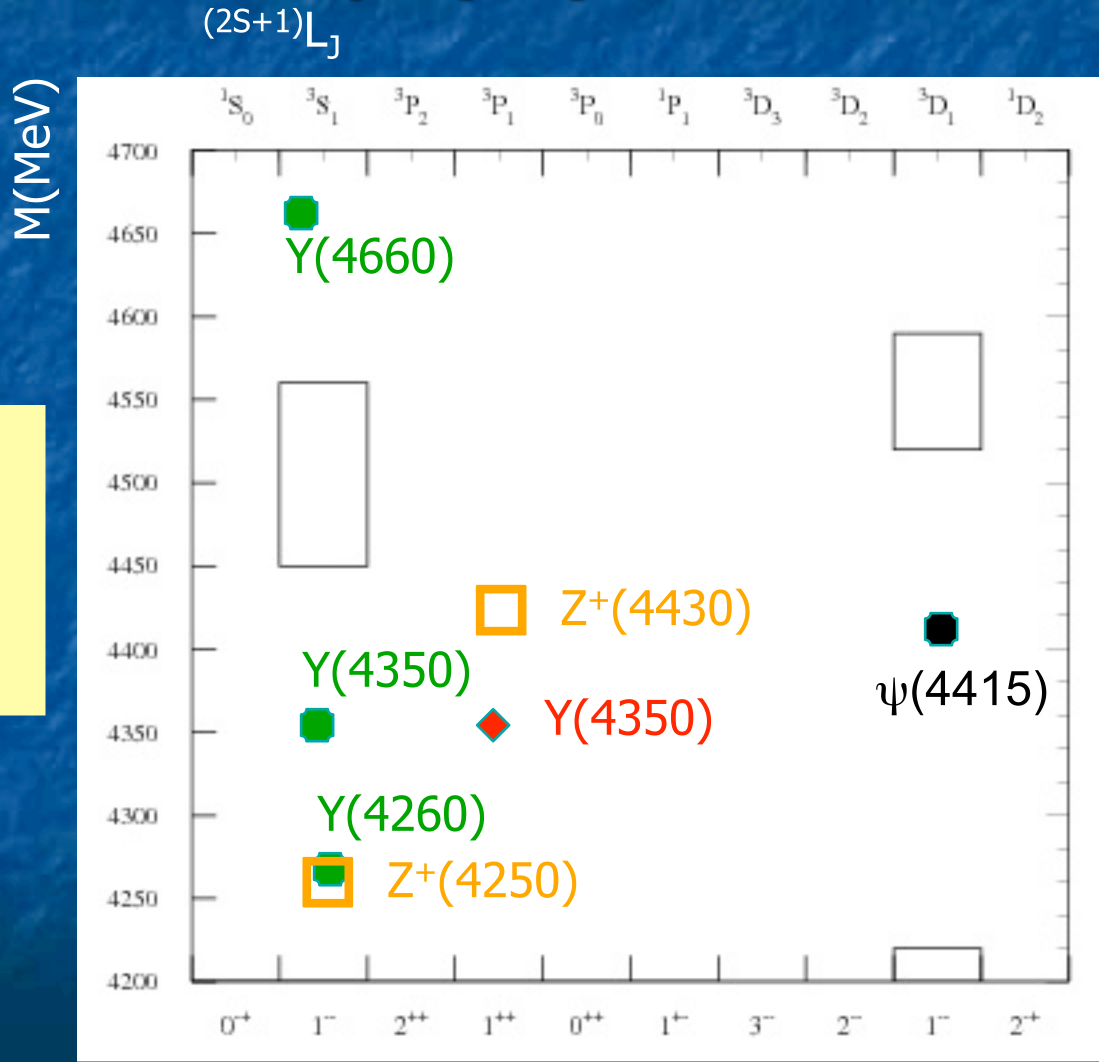
3940 family:
X candidate tetraquark
Y,Z candidate $\chi(2P)_{1,2}$

X: the most debated (tetraquark vs DD* molecule)



Summary (II)

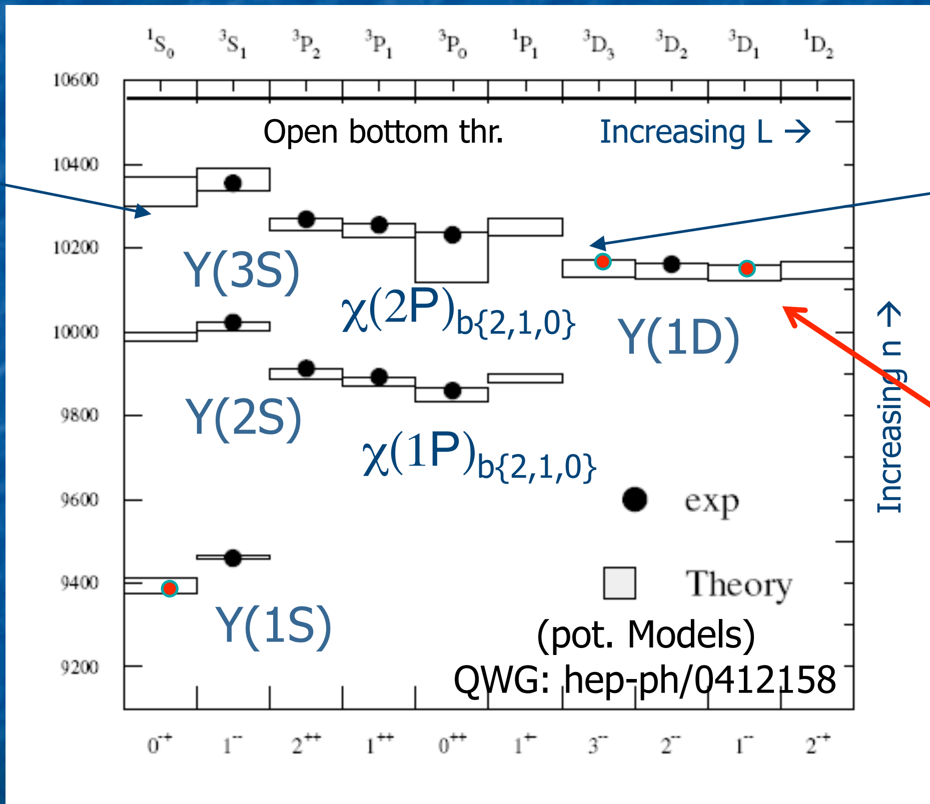
1⁻⁻ family:
Y(4660) best tetraquark candidate
Y(4260) and Z±(4250) an isospin triplet?!?



The new Bottomonium zoology

Bottomonium: state of the art

η_b (x2) completely missing



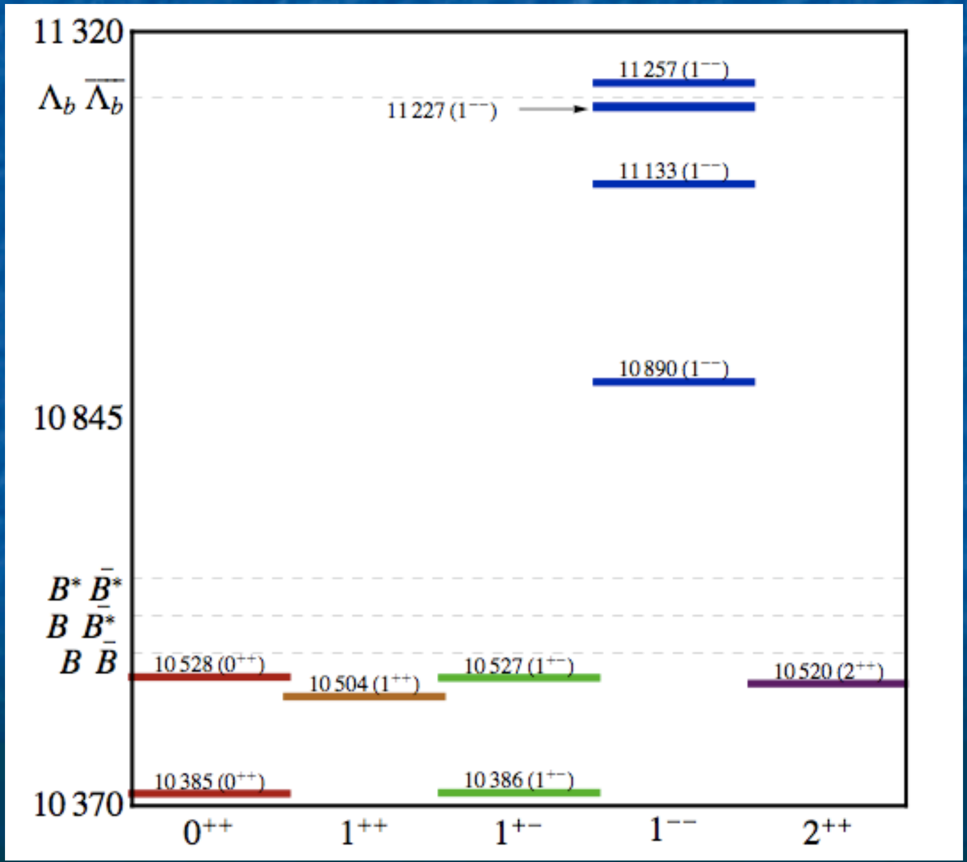
2 h_b states and a D state are narrow but not observed

Recent Observations: η_b, ^3D_J

5 narrow resonances still missing !

Exotic states

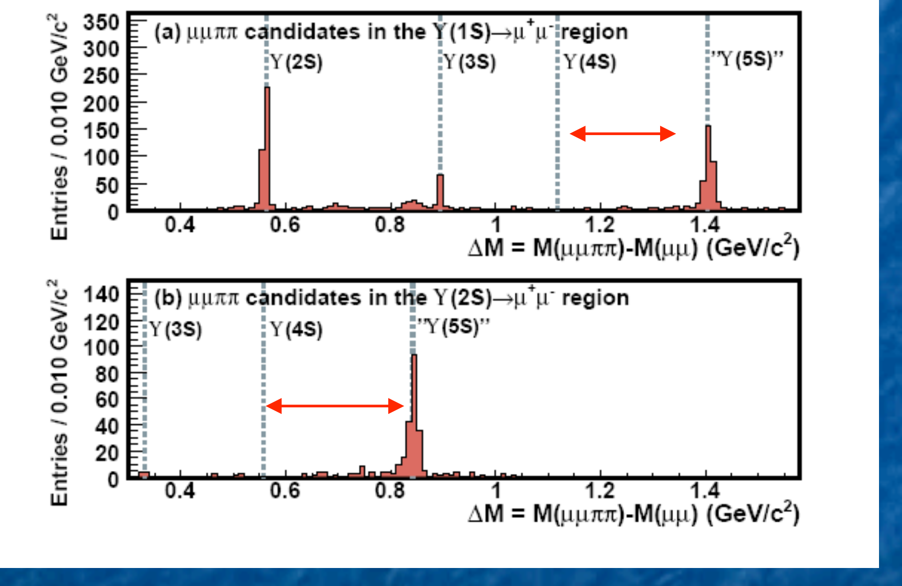
- Several unexpected 1^{--} charmonium-like states [Y(4260),Y(4350),Y(4660)] have been observed decaying into J/ψ or $\psi(2S)$ and two pions
  - Exotic particles, candidates for tetraquarks and hybrids / new spectroscopy in general
- Sitting at their center of mass allowa a much better understanding of their decay properties → Mostly sensible to 1^{--} states



Expected tetraquark spectrum
PLB684:28,2010

Tetraquark candidates: Y(5S)

Recent observation from Belle of unusual behaviour of Y(5S) in its decay to Y(nS)ππ
➔ Y(5S) good tetraquark candidate
➔ Expect to see other resonances with such an eccess

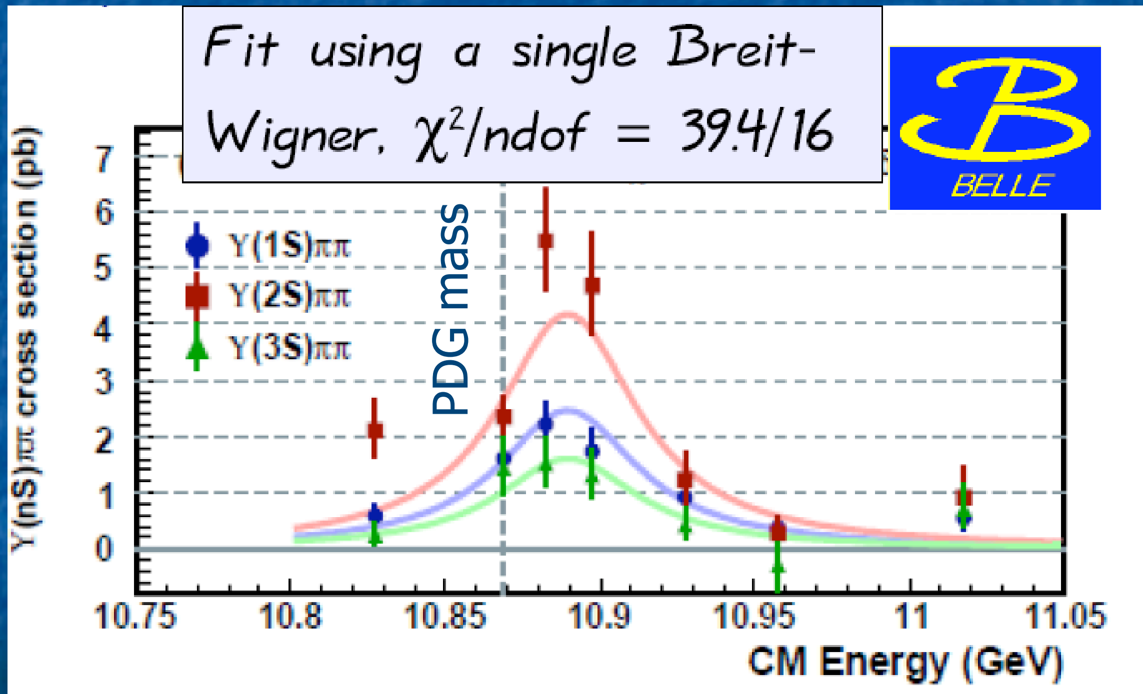


Belle: L=21fb^{-1} @ Y(5S)

- This measurement also tells us that σ*BF(Y$_b$→Υ(1S)ππ) ≤10 pb

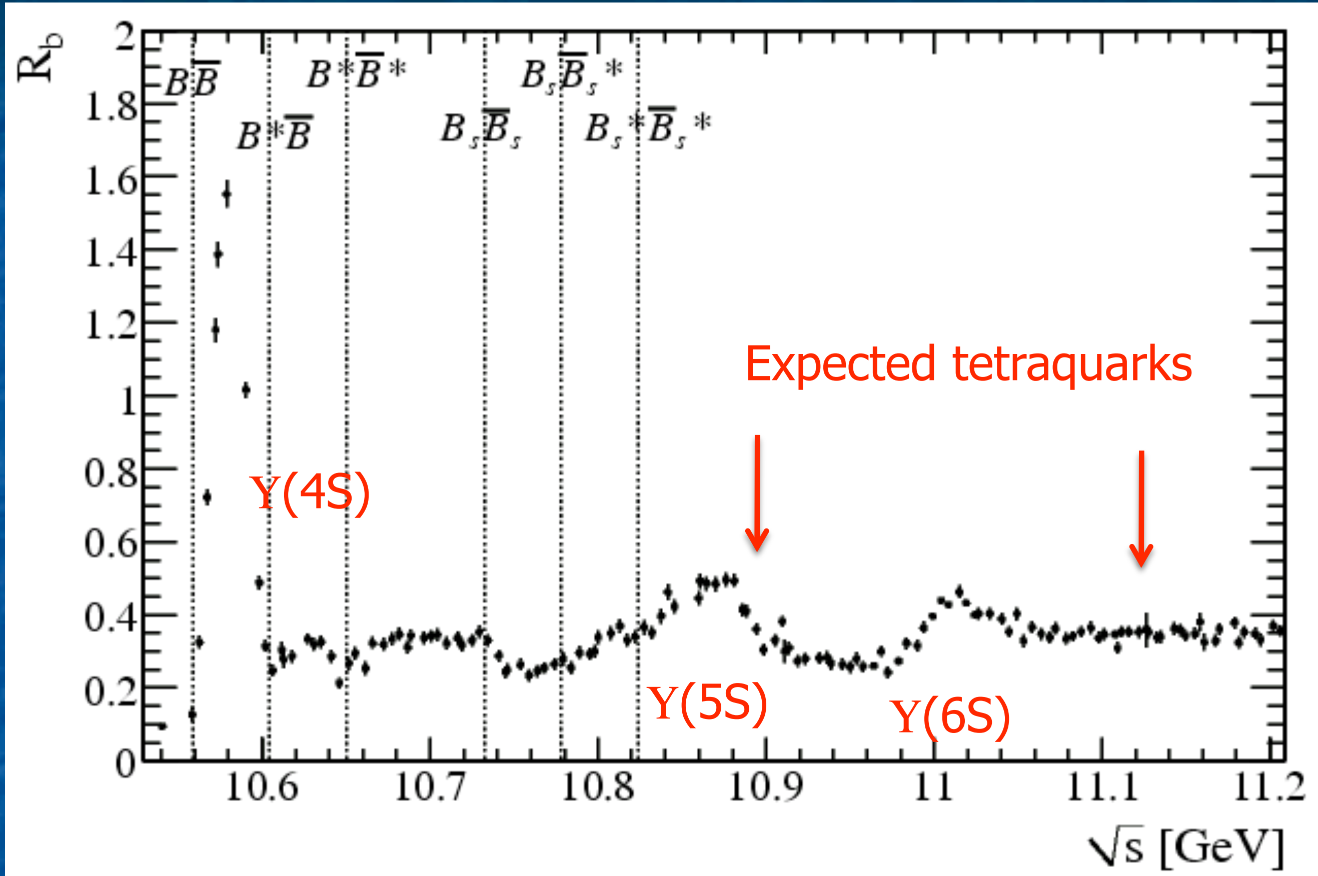
Scan around Υ(5S)

- Search for $\Upsilon \rightarrow \Upsilon(nS)\pi\pi$ in analogy to $Y \rightarrow \psi\pi\pi$



M_Υ=(10889±2) MeV Γ_Υ=(55±9) MeV

Scan between Υ(4S) and $\Lambda_b\Lambda_b$



PRL 102, 012001 (2009)

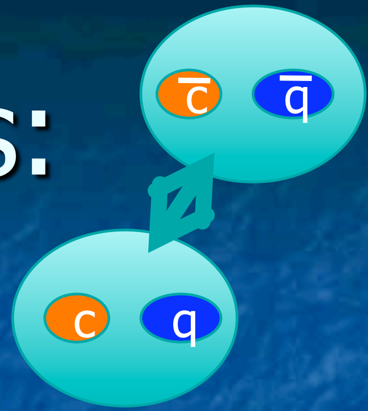
Main result: Υ(5,6S) inconsistent with PDG

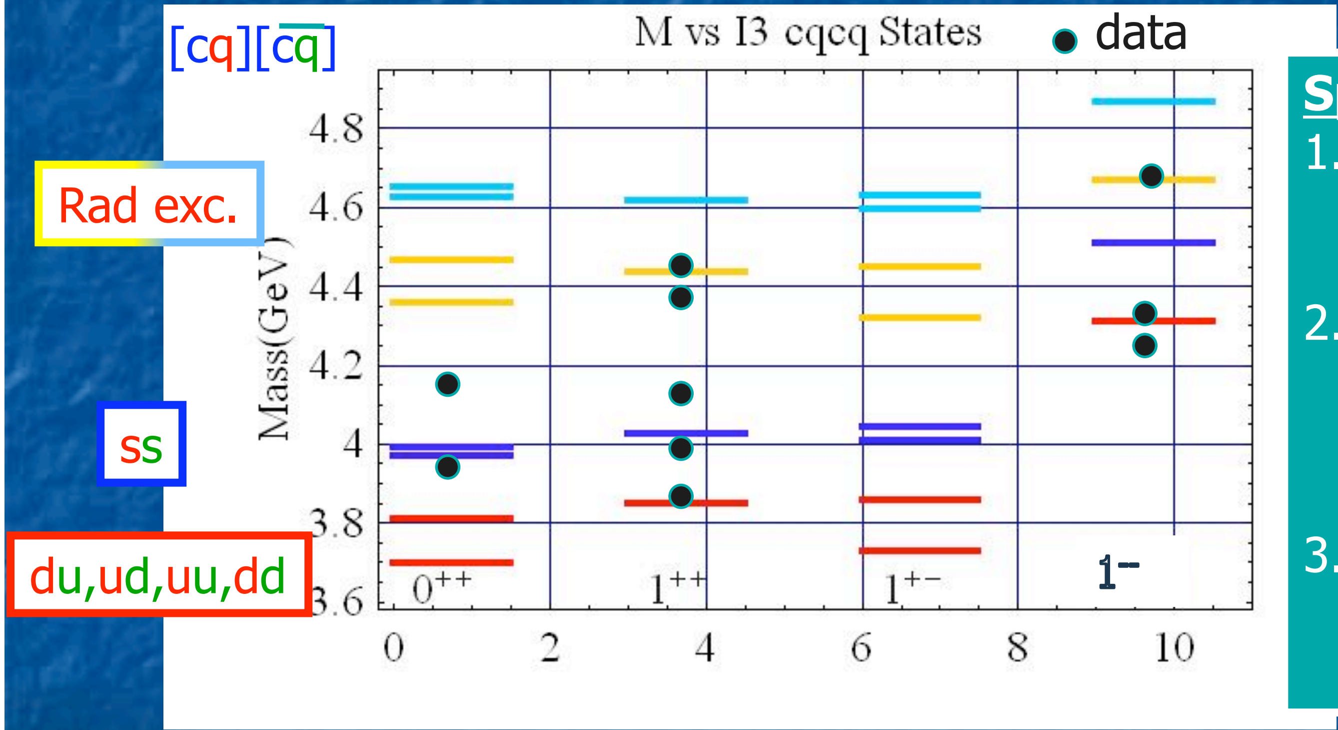
	$\Upsilon(5S)$	$\Upsilon(6S)$
$M[MeV]$	10876 ± 2	10960 ± 2
$\Gamma[MeV]$	43 ± 4	37 ± 3
$\phi[rad]$	2.11 ± 0.12	0.12 ± 0.07
$M_{PDG}[MeV]$	10865 ± 8	11019 ± 8
$\Gamma_{PDG}[MeV]$	110 ± 13	79 ± 16

Towards a global picture

" 'tis a long way to go! "

Interpretative hazards: tetraquarks





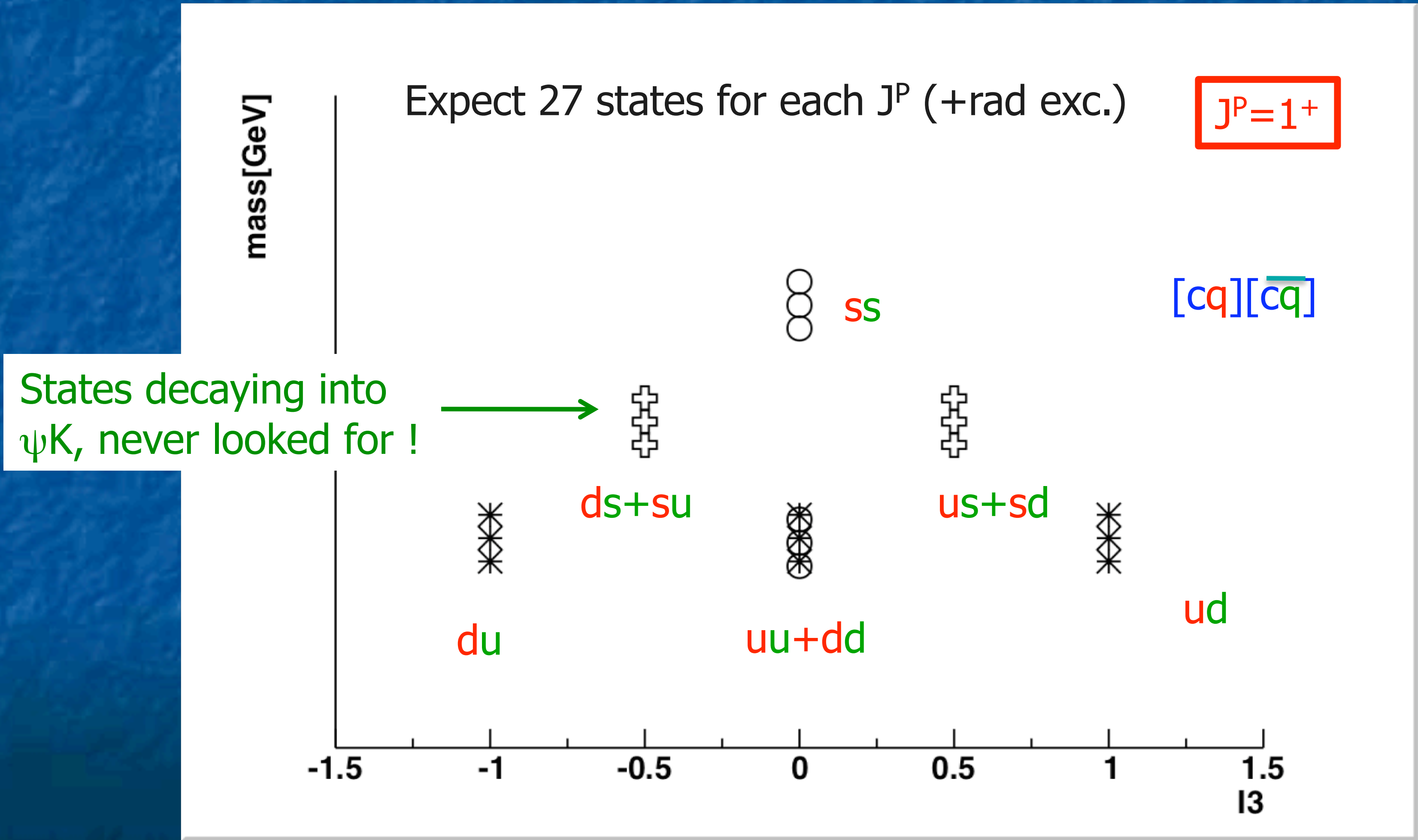
Spectra based on :

1. Quark constituent model (as in Maiani et al,
2. orbital excitations based on Chew-Frautschi as in hep-ph/0602128
3. radial excitations taken from standard charmonium

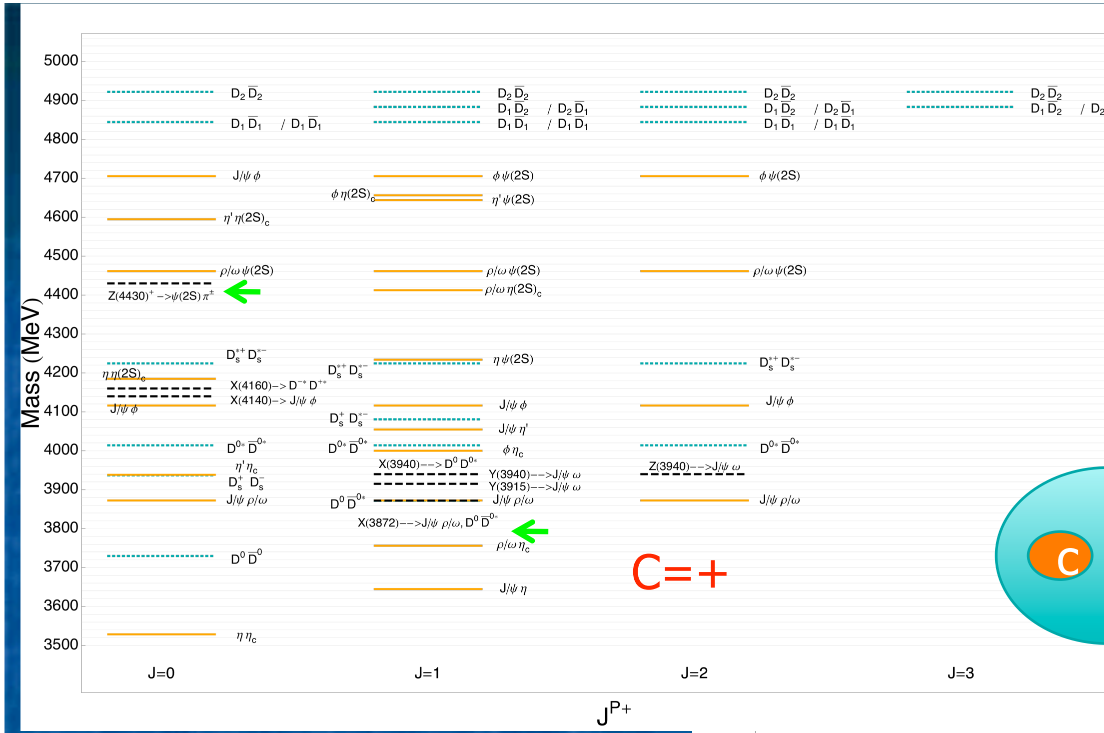
O(100 MeV) uncertainties

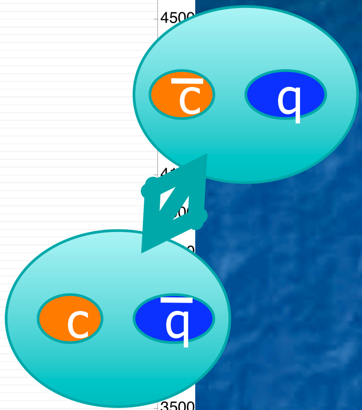
Work in progress
Drenska, RF, Piccinini, Polosa, Renga, Sabelli

The Real challenge of tetraquarks



Interpretative hazards: molecules





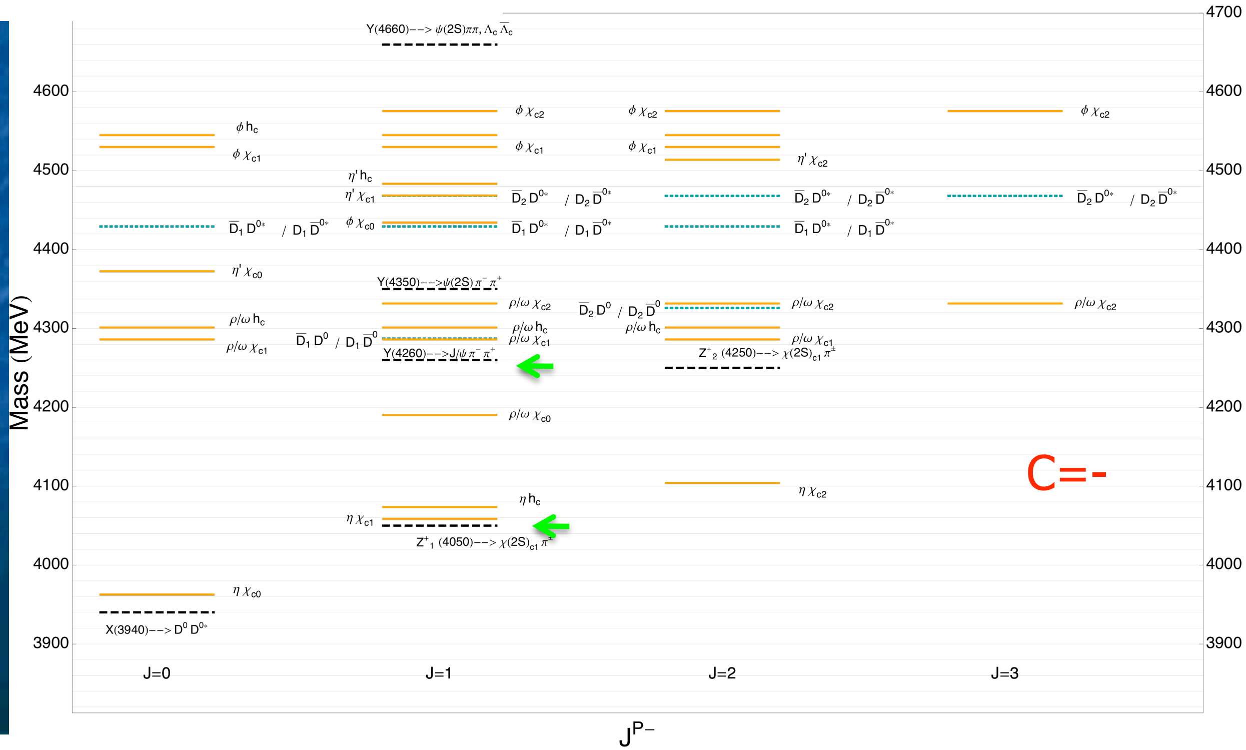
Legenda

------- charm – charm

_____ charmonium - light

- - - - - data

Interesting states: right below a threshold (→)



Outlook

B decays	JPC	J/ψππ	J/ψω	J/ψγ	J/ψφ	J/ψη	ψ(2S)ππ	ψ(2S)ω	ψ(2S)γ	χcγ	pp	ΛΛ	ΛcΛc	DD	DD*	D*D*	Ds(*)Ds(*)	γγ
X(3872)	1++ [2-+]	S	S*	S	N/A	N/S	N/A	N/A	S	N/S	M/F	M/F	N/A	N/A	S	N/A	N/A	N/S
X,Y (3940)	0−+	M/F	S	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	N/S	N/A	N	N
Z(3940)	2++	M/F	S?^	N/S	N/A	N/A	N/A	N/A	M/F	N/A	M/F	M/F	N/A	M/F	M/F	N/A	N	N
Y(4140)	JP+	M/F	M/F	N	S	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
X(4160)	0P+	M/F	M/F^	N	M/F	N/A	N	N/A	N	N/A	M/F	M/F	N/A	M/F	N	N	N	N
Y(4260)	1−−	S	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
X(4350)	JP+	M/F	M/F^	N	M/F	N/A	N	N	N	N/A	M/F	M/F	N/A	N	N	N	N	N
Y(4350)	1−−	M/F	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	N/A	N	N	N	N	N/A
Y(4660)	1−−	N	N/A	N/A	N/A	M/F	N	N/A	N/A	N	M/F	M/F	M/F^^	N	N	N	N	N/A

ISR	JPC	J/ψππ	ψ(2S)ππ	J/ψη	χcγ	pp	ΛΛ	ΛcΛc	DD	DD*	D*D*	Ds(*)Ds(*)
Y(4260)	1−−	S	N/S	N/S	N/S	N/S	M/F	N/A	N/S	N/S	N/S	N
Y(4350)	1−−	N/S	S	M/F	M/F	M/F	M/F	N/A	M/F	M/F	M/F	N
Y(4660)	1−−	N/S	S	M/F	M/F	M/F	M/F	S	M/F	M/F	M/F	N

legenda

- S: seen
- M/F: missing fit
- N/S: not seen
- N: not searched
- N/A: not applicable
- N/F: not feasible

pp incl	JPC	J/ψππ	J/ψω	J/ψγ	J/ψφ	J/ψη	ψ(2S)ππ	ψ(2S)ω	ψ(2S)γ	χcγ	pp	ΛΛ	ΛcΛc	DD	DD*	D*D*	Ds(*)Ds(*)
X(3872)	1++ [2-+]	S	N	N/F	N/A	N/A	N/A	N/A	N/F	N/A	N	N	N/A	N/A	N	N/A	N/A
X,Y (3940)	0−+ [JP+](1)	N/S	N	N/F	N/A	N/A	N/A	N/A	N/F	N/A	N	N	N/A	N	N	N/A	N
Z(3940)	2++	N/S	N	N/F	N/A	N/A	N/A	N/A	N/F	N/A	N	N	N/A	N	N	N	N
Y(4140)	JP+	N	N	N/F	N	N/A	N	N/A	N/F	N/A	N	N	N/A	N	N	N	N
X(4160)	0P+	N	N	N/F	N	N/A	N	N/A	N/F	N/A	N	N	N/A	N	N	N	N
Y(4260)	1−−	N	N/A	N/A	N/A	N	N	N/A	N/A	N/F	N	N	N/A	N	N	N	N
X(4350)	JP+	N	N	N/F	N	N/A	N	N	N/F	N/A	N	N	N/A	N	N	N	N
Y(4350)	1−−	N	N/A	N/A	N/A	N	N	N/A	N/A	N/F	N	N	N/A	N	N	N	N
Y(4660)	1−−	N	N/A	N/A	N/A	N	N	N/A	N/A	N/F	N	N	N	N	N	N	N

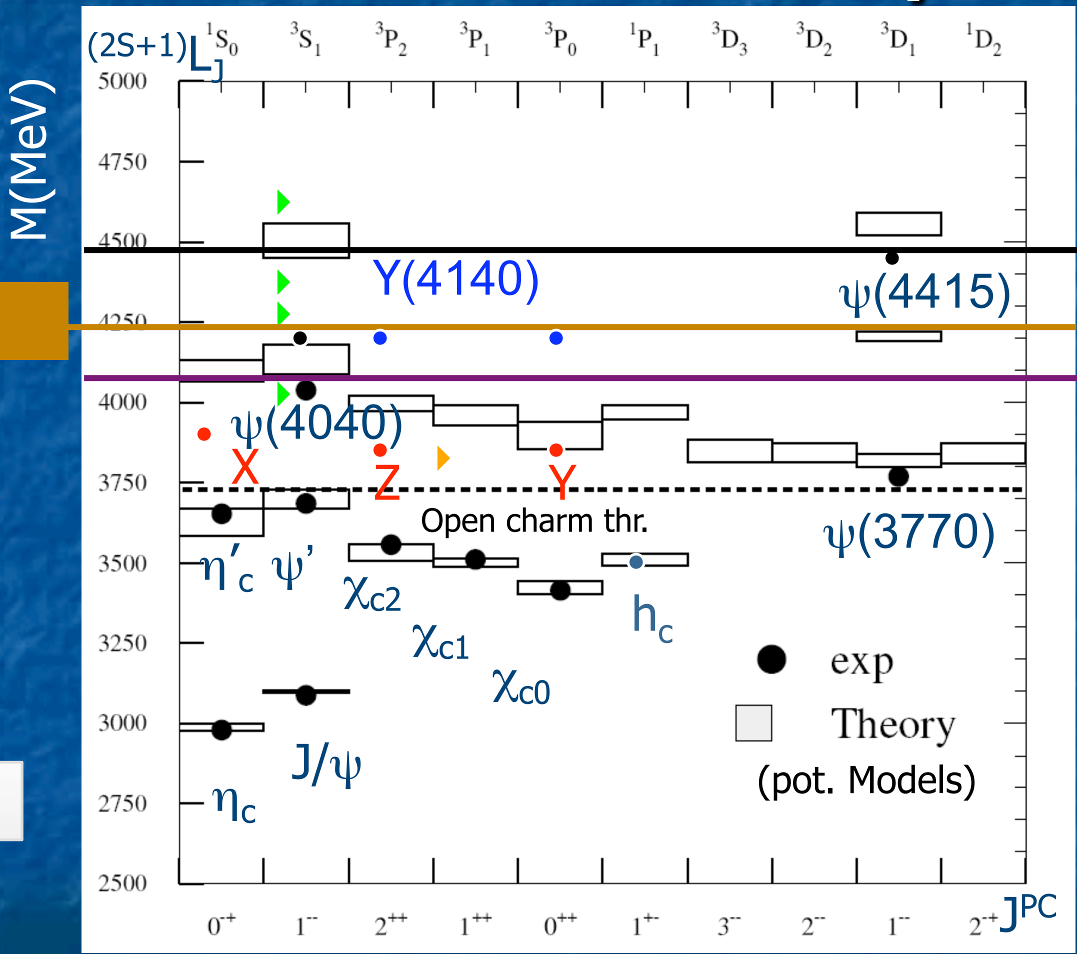
Plenty of states seen with low stat and in only one channel
➔ next generation [SuperB(elle)?] needed

backup

More on the
1^{--} family

Summary

The charged candidates



Z(4430)

Z(4250)

Z(4050)

X(3872) never ending story

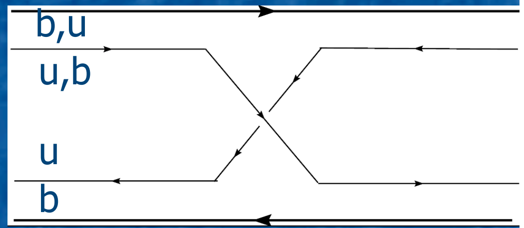
One more member of the 3940 family

X(4160)

New state from CDF
Good Hybrid candidate

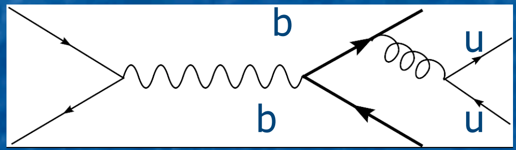
Properties of possible exotic states

- $J^{PC}=1^{--}$: could be produced in e^+e^- collisions
- Masses (obtained scaling from Charmonium to Bottomonium)
  - $Y(4260) \rightarrow Y_b(10610)$
  - $Y(4350) \rightarrow Y_b(10700)$
  - $Y(4660) \rightarrow Y_b(11010)$



- Width (dominated by this diagram in tetraquark/molecules)
  Independent from the heavy quark: $\Gamma(Y_b)\sim\Gamma(Y)=50\text{-}150$MeV

Most likely



- Decay channels
  - Easiest to detect: $Y_b \rightarrow \Upsilon X$ ($X=\pi\pi, \pi^0\pi^0, \pi\pi\pi^0$, KK, π^0, η)
  - Because of the same graph estimate $BF(Y_b \rightarrow \Upsilon\pi\pi) \sim (Y \rightarrow \psi\pi\pi)$ (if mediated by single meson)
- Production cross-section
  - Smaller than Y because of charge ($\sigma(e^+e^- \rightarrow Y_b) \sim \sigma(e^+e^- \rightarrow Y)/4$)
  - Smaller than regular bottomonium because need to produce more than just two quarks

→ Expect $\sigma(e^+e^- \rightarrow Y_b)BF(Y_b \rightarrow \Upsilon\pi\pi) \sim \sigma(e^+e^- \rightarrow Y)BF(Y \rightarrow \psi\pi\pi)/4$ ~25pb (or less if $Y_b \rightarrow \Upsilon\pi\pi$ not mediated by a single meson)

Confirmation of Y(3940) (B→KωJ/ψ)

$\omega \to \pi^+\pi^-\pi^0$

New result, based on 350 fb^{-1}:

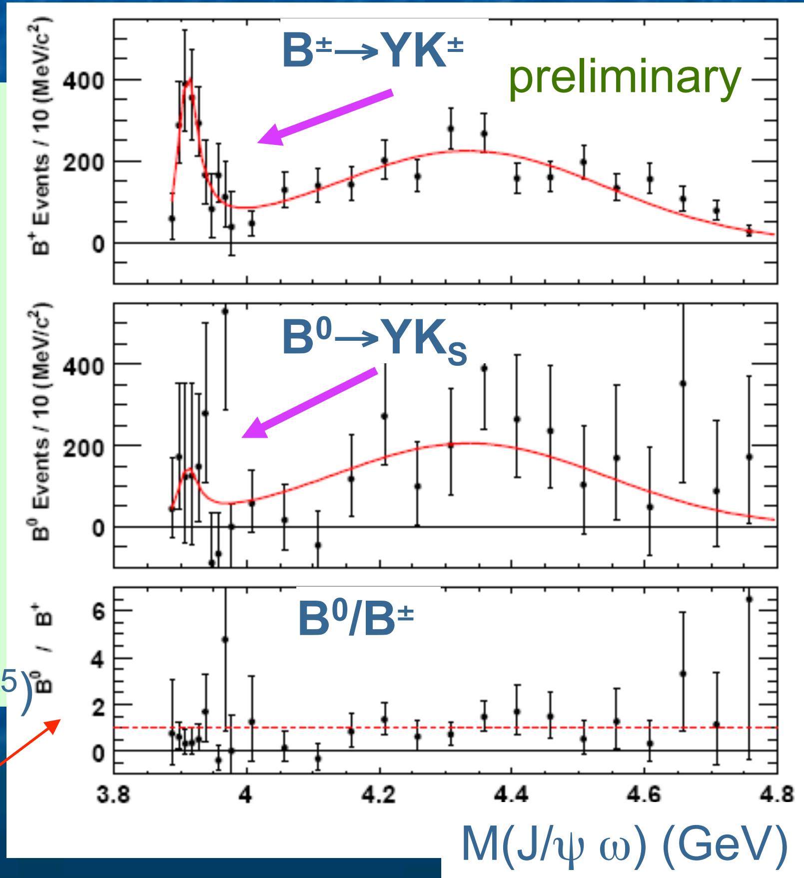
$$M(Y) = (3914.3^{+3.8}_{-3.4}(stat)^{+1.6}_{-1.6}(syst))\ \mathrm{MeV/c^2},$$
$$\Gamma(Y) = (33^{+12}_{-8}(stat)^{+0.6}_{-0.6}(syst))\ \mathrm{MeV}.$$

Belle's evidence for B→YK, Y→J/ψω confirmed

- ~30MeV lower mass than Belle's
- Narrower width
- Clear demonstration of decay into ω
- Preliminary BF estimate similar to Belle's (~10^{-5})

Y(3940) closer to X(3940)
Can they be the same state?

Isospin cons.



X(4160)→ D*D*

BELLE

Obtain $J/\psi D^{(*)}D^{(*)}$ samples through kinematic separation, look at m(D(*)D(*)) after background subtraction:

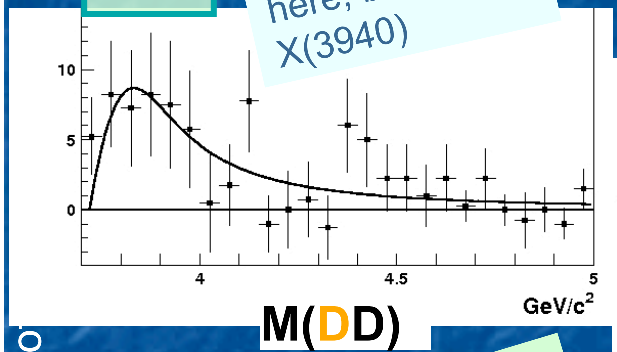
$e^+ e^- \rightarrow J/\psi\ D^{(*)}D^{(*)}$

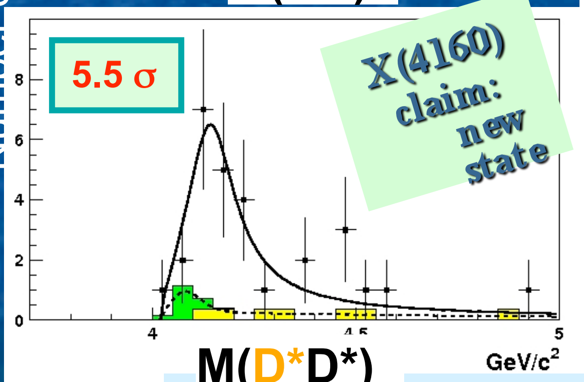
reconstructed

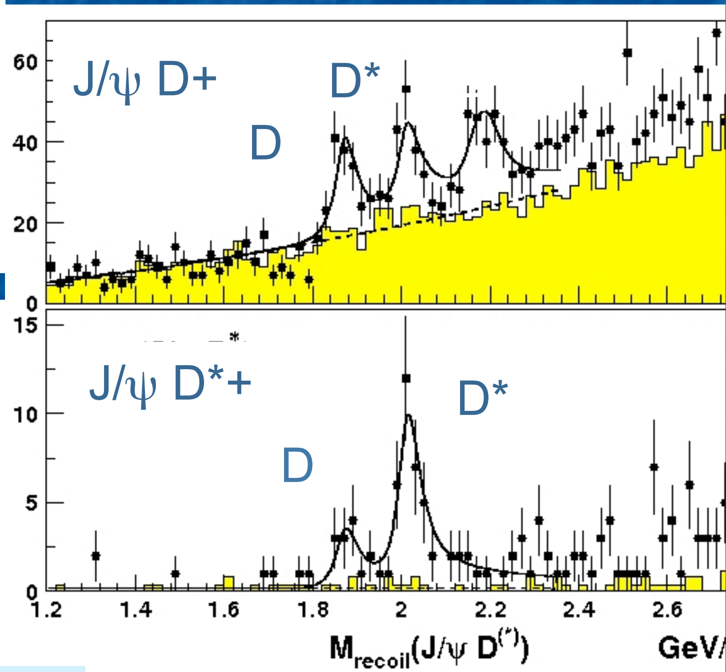
Inferred (Recoil mass)

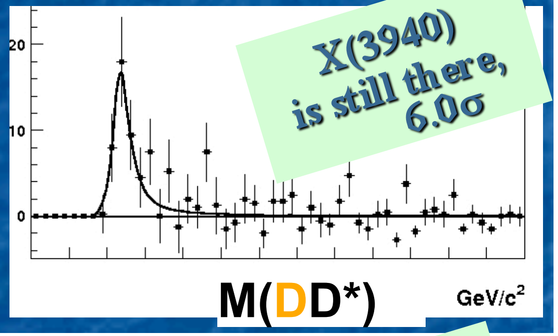
BELLE-CONF-0705

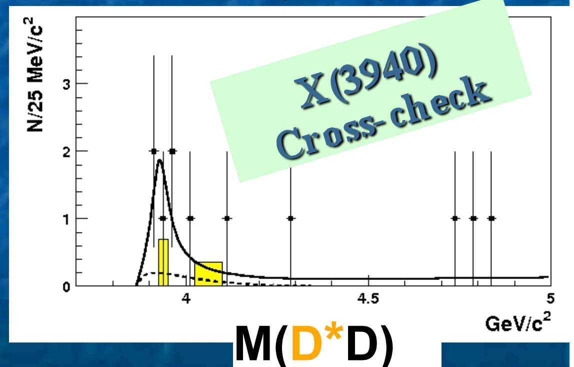
M = 3942 ±6 MeV
Γ_{tot} =37 ±12 MeV
N_{ev}= 52 ±11







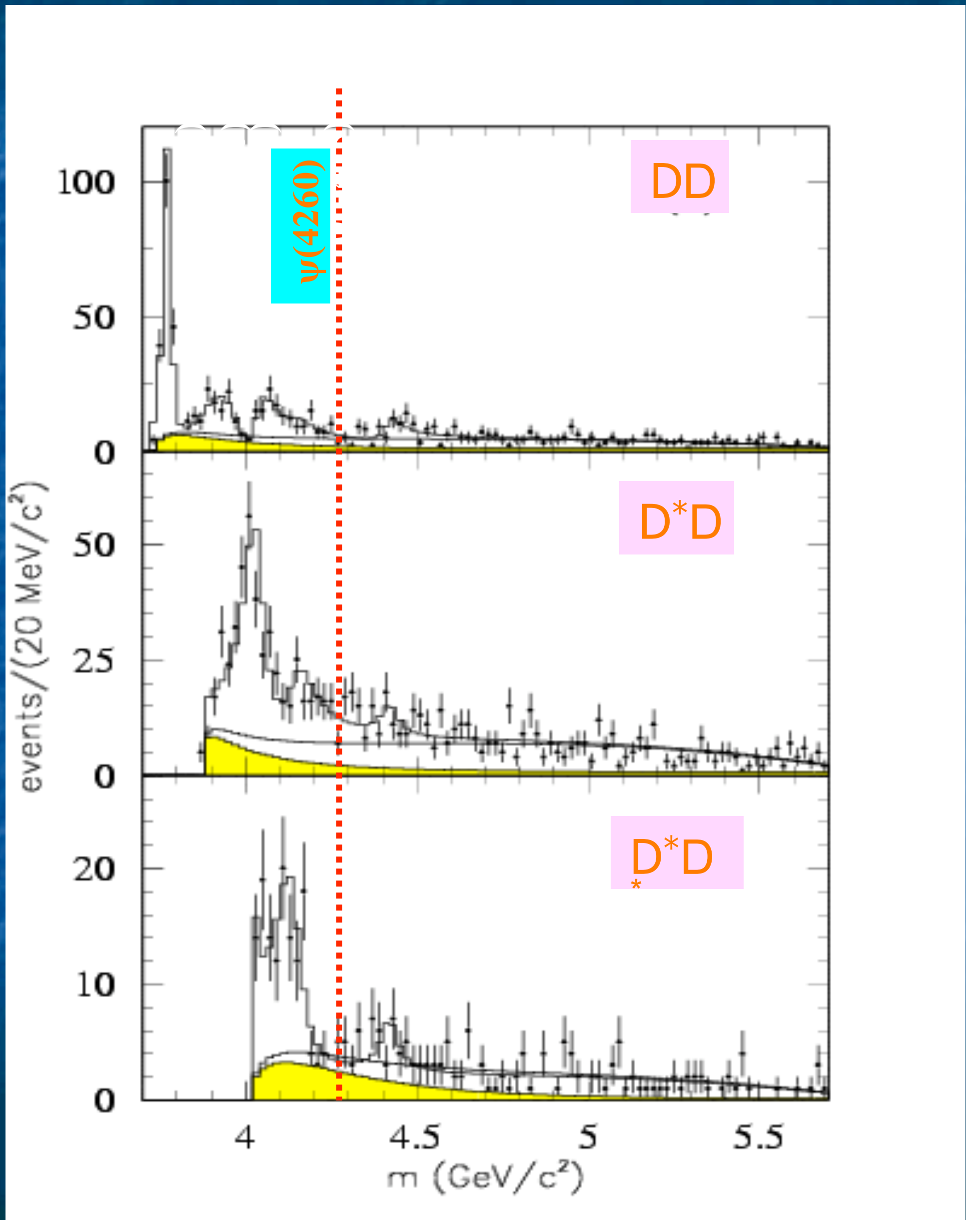




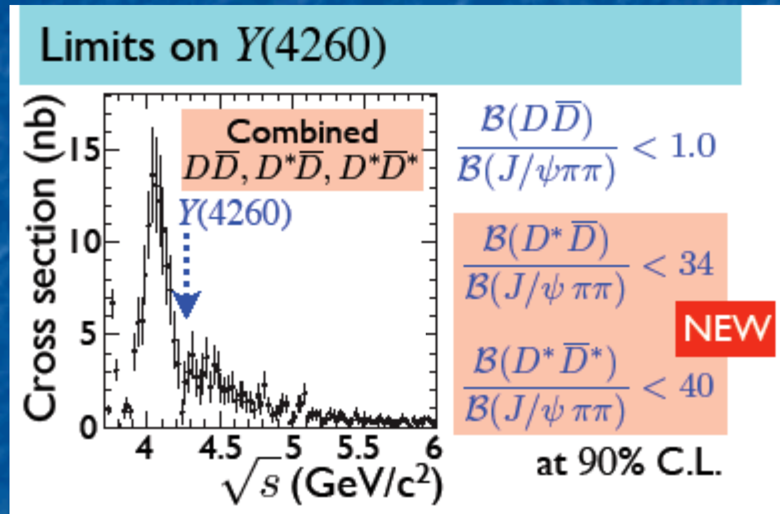
M = 4156 $^{+25}_{-20}$ ±15MeV
Γ_{tot} = 37 $^{+111}_{-61}$ ±21MeV
N_{ev}= 24 $^{+12}_{-8}$

⟹ One more particle to explain …
$J^{CP}=0^{-+}$ not excluded ($\eta_c(3S)$)

ISR search for Y(4260)→ $D^{(*)}D^{(*)}$



Y(4260) is 1^{--} charmonium state
→ should decay **predominantly** to DD, D^*D, and D^*D^*

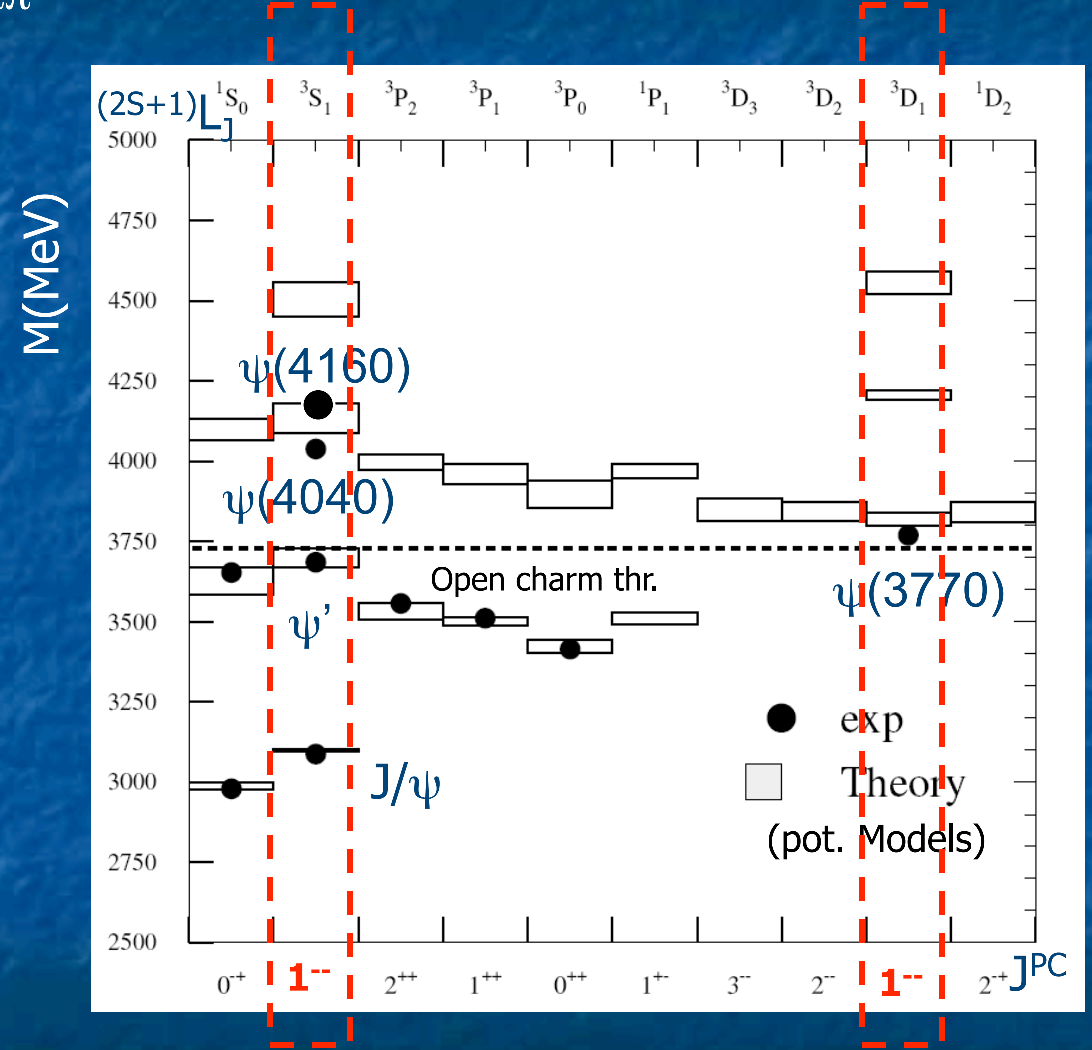


BaBar: PRD 79, 092001 (2009), 384

1^{--} family: recap

Only seen in ψ (2S)$\pi\pi$

4660
4350
4260

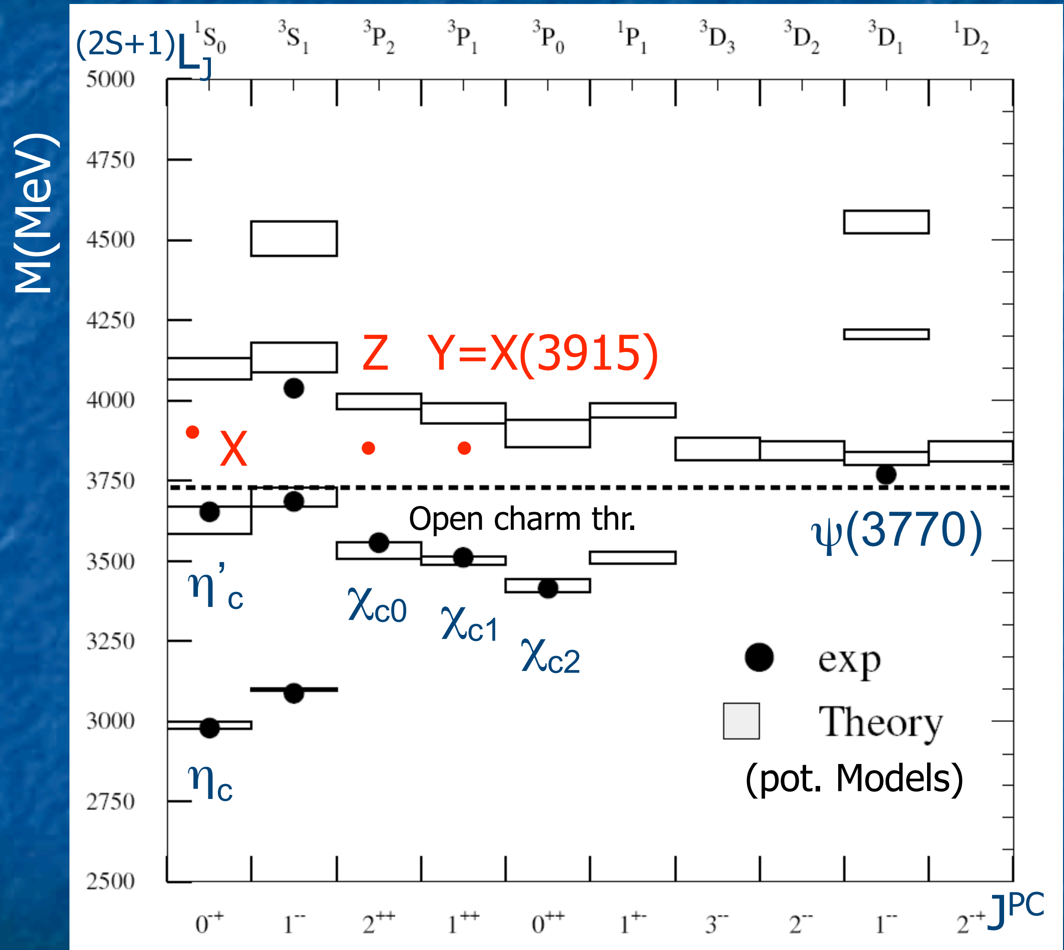


- Not matching any potential model prediction
- Too narrow

"new physics"?

4260 can be fit by a tetraquark model (decaying into $J/\psi f_0$ ...) or a hybrid (with $g \rightarrow \pi\pi$)

"Just" charmonium states?

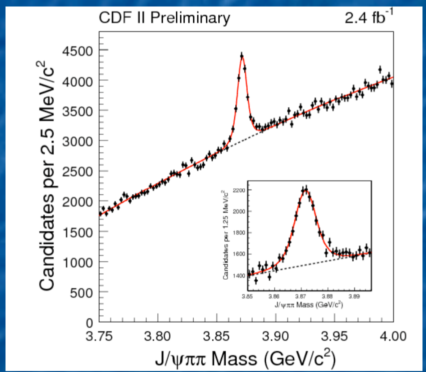


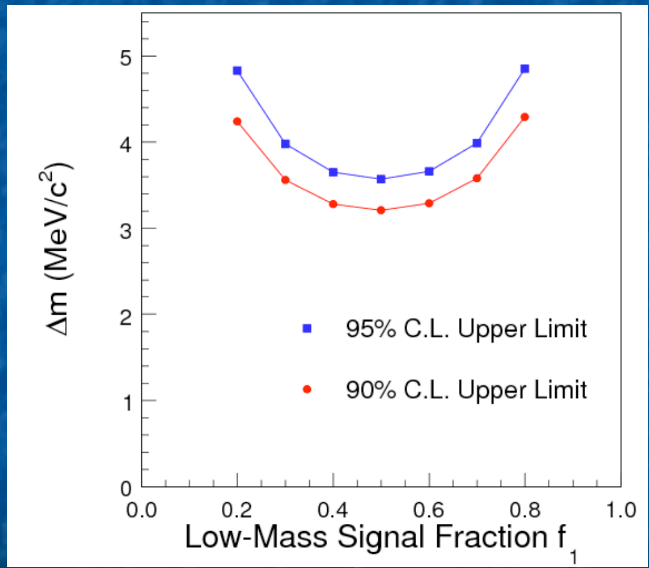
- Poor match with predictions
  - Above threshold?
- If X≠Y, difficult to explain absence of Y→open charm
  - Hybrid?

Are there two X→J/ψππ ?

arXiv:0807.3699

- CDF with largest sample investigates the mass distribution for two resonances closeby

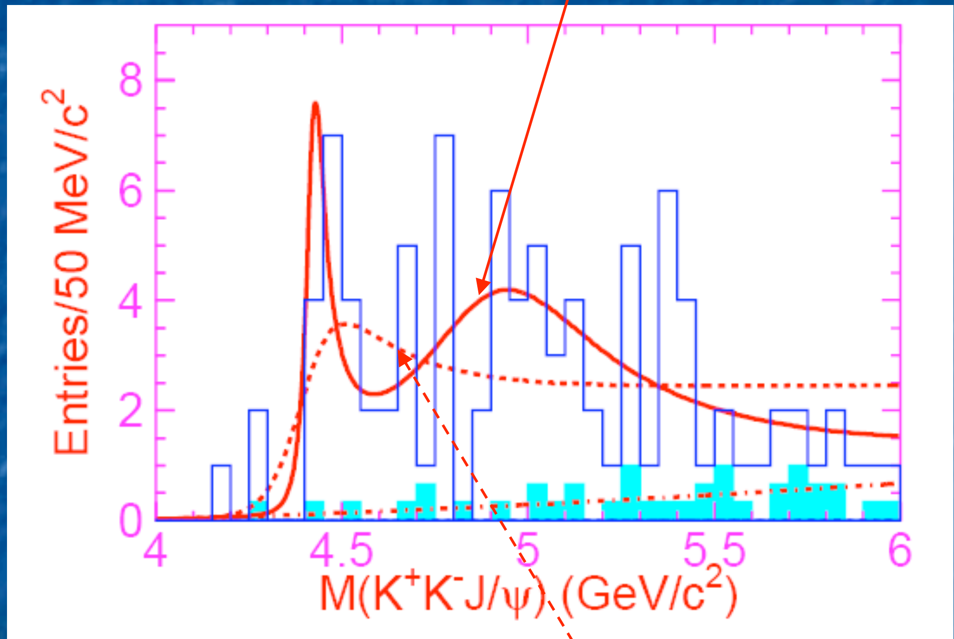




ΔM<3.2 MeV @90%C.L. ← Fitted mass difference as a function of first gaussian fraction

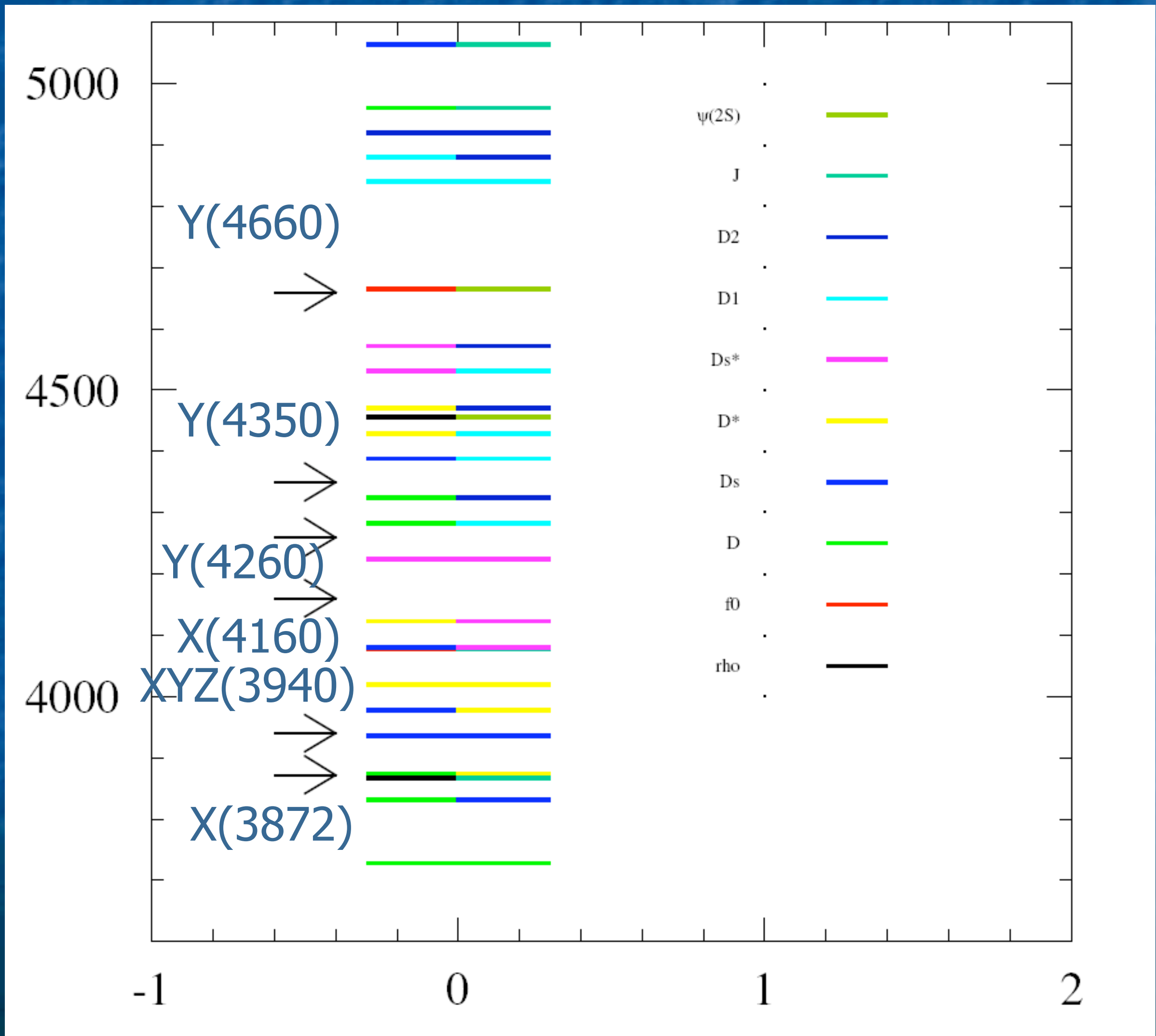
Fits to J/ψ KK invariant mass

'Standard ' y(4415) + 1 BW:
M = (4875±132) MeV
Γ = (630±126) MeV

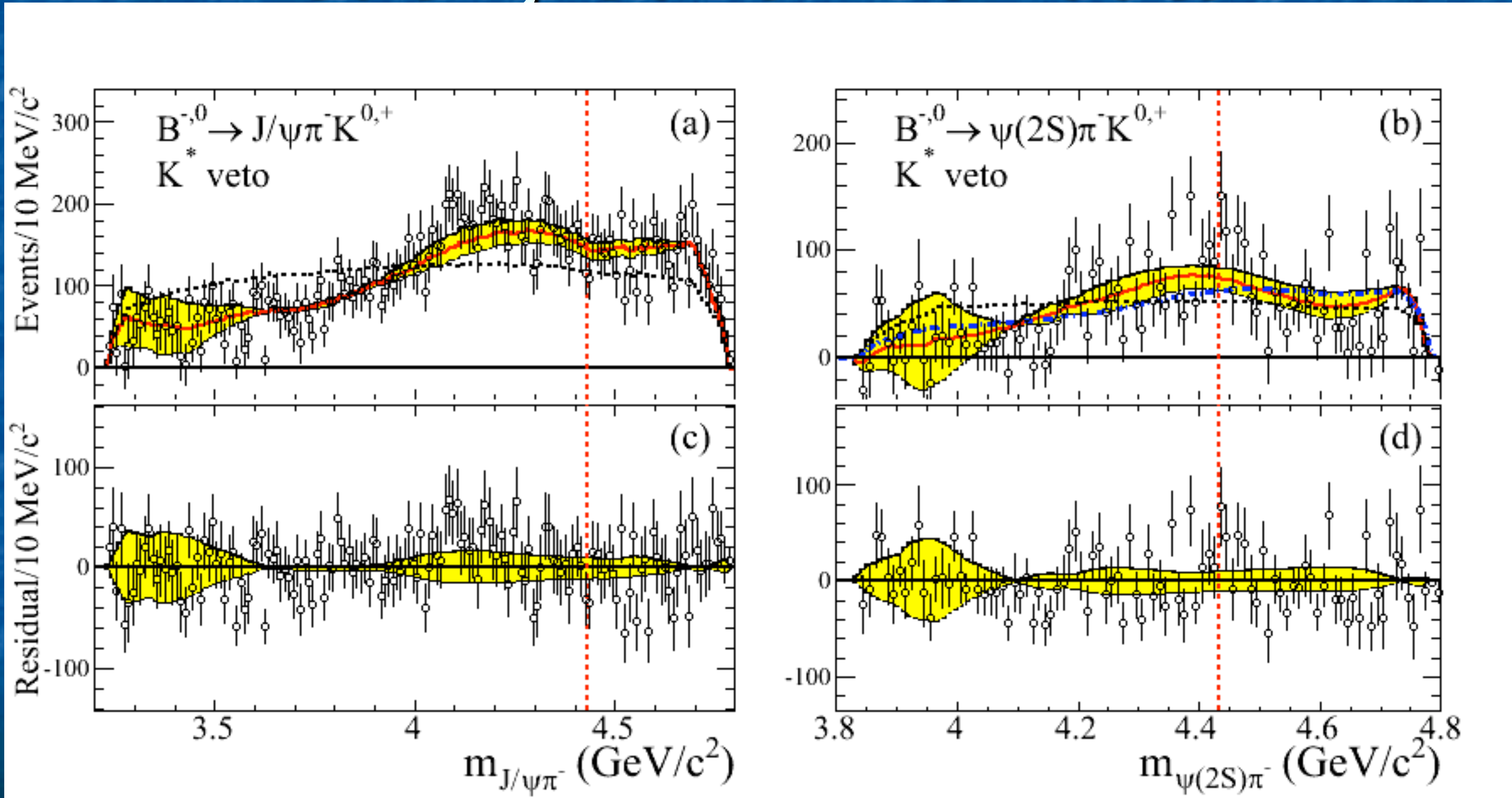


single BW:
M = (4430±38) MeV
Γ = (254±49) MeV

Thresholds and new states

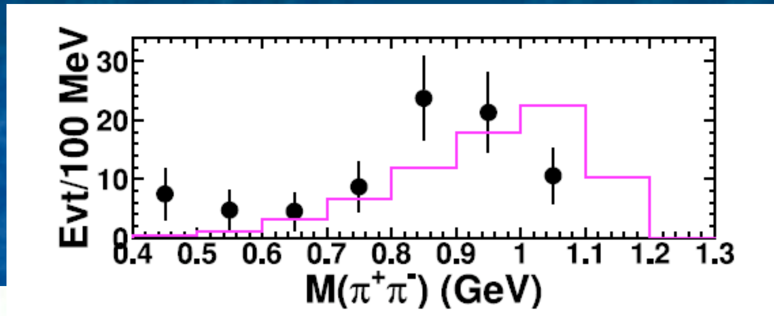


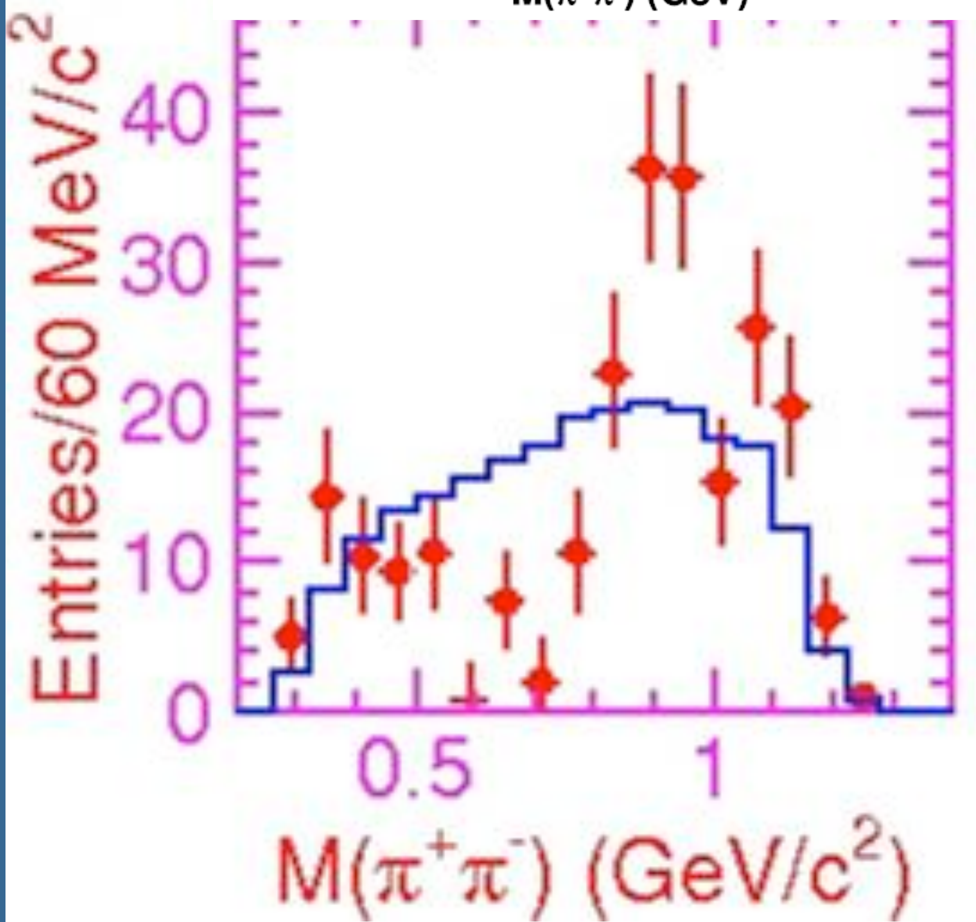
Comparison of BaBar background with data



Same "veto" definition as Belle

CLEO and Belle on 4260



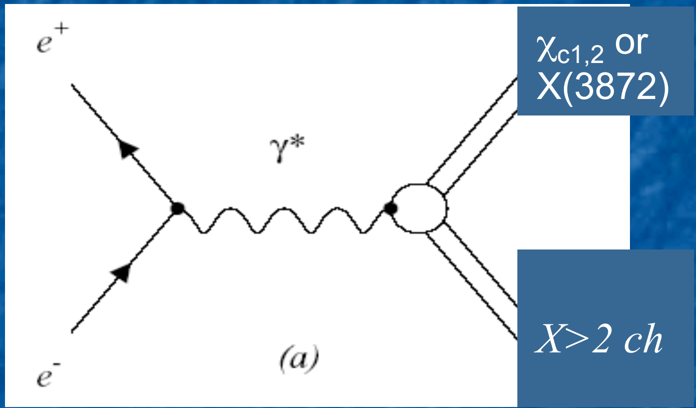


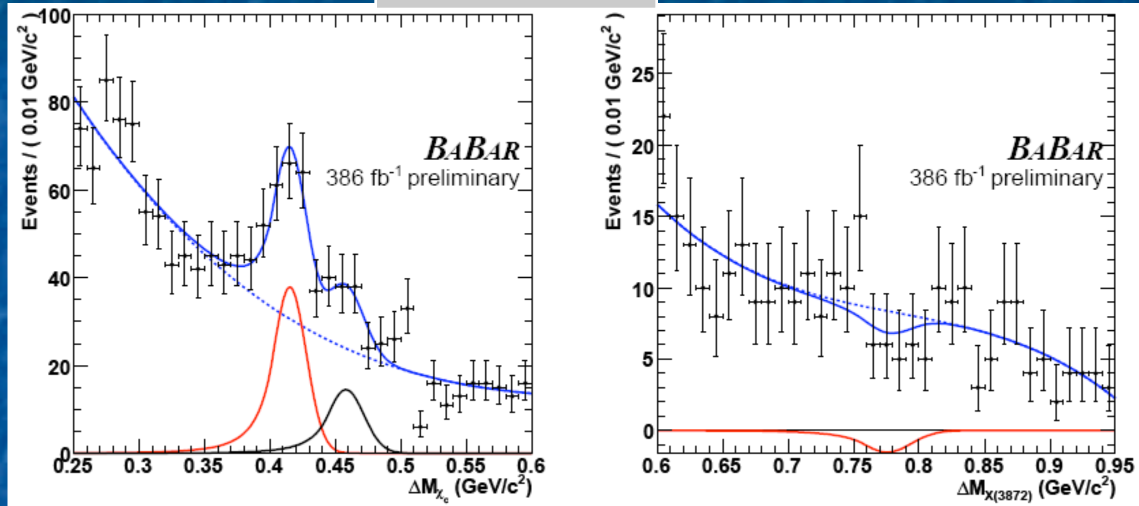
Search for $X(3872) \rightarrow J/\psi\, \gamma$ in continuum

386fb^{-1}

arXiv:0707.1633

J/ψ production observed in continuum while no evidence of χ_c states.





χ_c production is consistent with the expected contributions from prompt $\psi(2S)$ production feed-down to χ_c: no evidence of prompt $\chi_{c1,2}$

$$\sigma(e^+e^- \rightarrow \chi_{c1,direct}X) \cdot \mathcal{B}(X \rightarrow (N_{ch} > 2)) = (41.1 \pm 18.0 \pm 20.6)\ \text{fb}$$
$$(< 77\ \text{fb @90\% } C.L.),$$
$$\sigma(e^+e^- \rightarrow \chi_{c2,direct}X) \cdot \mathcal{B}(X \rightarrow (N_{ch} > 2)) = (23.2 \pm 27.7 \pm 26.1)\ \text{fb}$$
$$(< 79\ \text{fb @90\% } C.L.).$$

No evidence of X(3872) production in e^+e^- annihilation.

$$\sigma(e^+e^- \rightarrow X(3872)X) \cdot \mathcal{B}(X(3872) \rightarrow \gamma J/\psi) \cdot \mathcal{B}(X \rightarrow (N_{ch} > 2))$$
$$= (-2.7 \pm 3.7 \pm 1.0)\ \text{fb} \quad (< 5.1\ \text{fb @90\% } C.L.).$$

Samples used in results

Experiments

$58M J/\psi$, $14M \psi(2S)$

- $e^+e^- \rightarrow$ Charmonium (CLEO-c, BES-II)

  $3M \psi(2S)$, $1.8 M \psi(3770)$

  - $L \sim 10^{33}/cm^2/s$
  - E=3.0-4.3 GeV

$657M \Upsilon(4S)$

- $e^+e^- \rightarrow \Upsilon(4S)$: (BaBar, Belle, CLEO)

  $383M \Upsilon(4S)$ — $1.5M \Upsilon(1S)$, $1.9M \Upsilon(2S)$, $1.7M \Upsilon(3S)$, $9M \Upsilon(4S)$

  - $L \sim 10^{34}/cm^2/s$
  - Charmonium in B decays, ISR and $\gamma\gamma$ production
    - Capability to measure J^{PC} also in production
- pp colliders (CDF, D0)

  2.4bf-1 — $1.3\ fb^{-1}$

  - High Xsection $\rightarrow$ copious production
  - Extremely high backgrounds

Disclamers:
- time is very short $\rightarrow$ could not cover everything
- theory statements are indicative