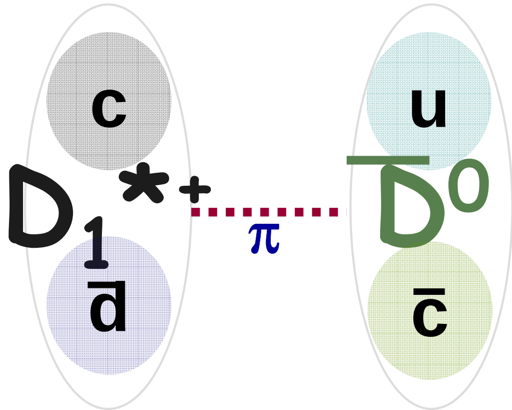
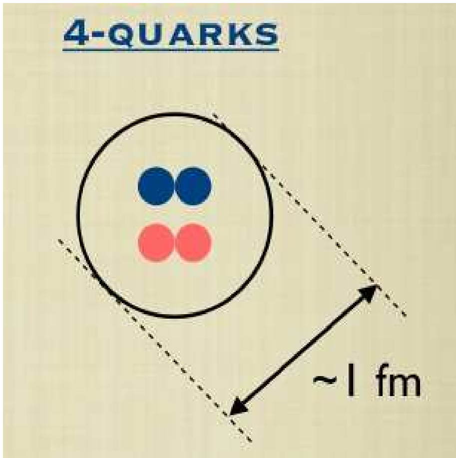
May 20-22, Charm2009, Leimen, Germany

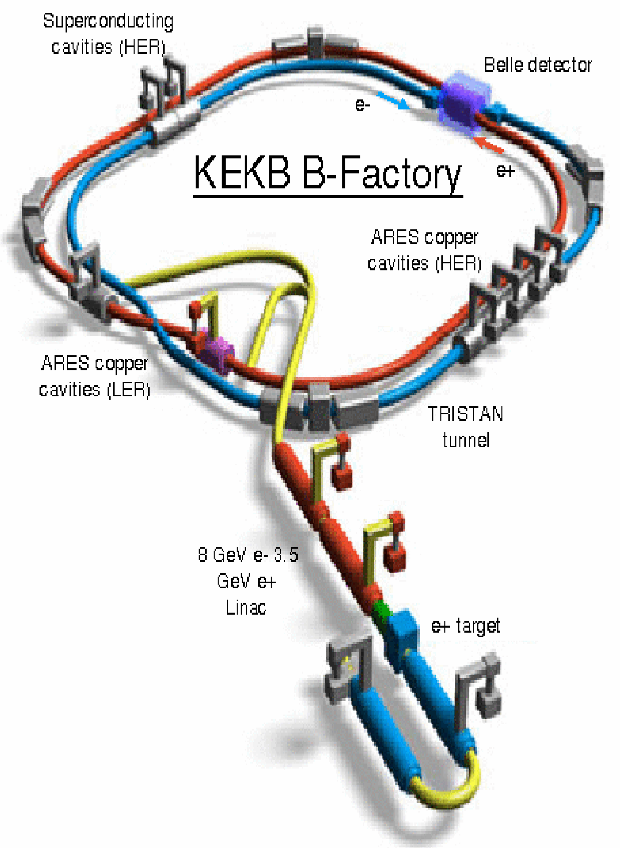
Z Observation at

Ruslan Chistov (ITEP, Moscow)
Representing
the Belle Collaboration

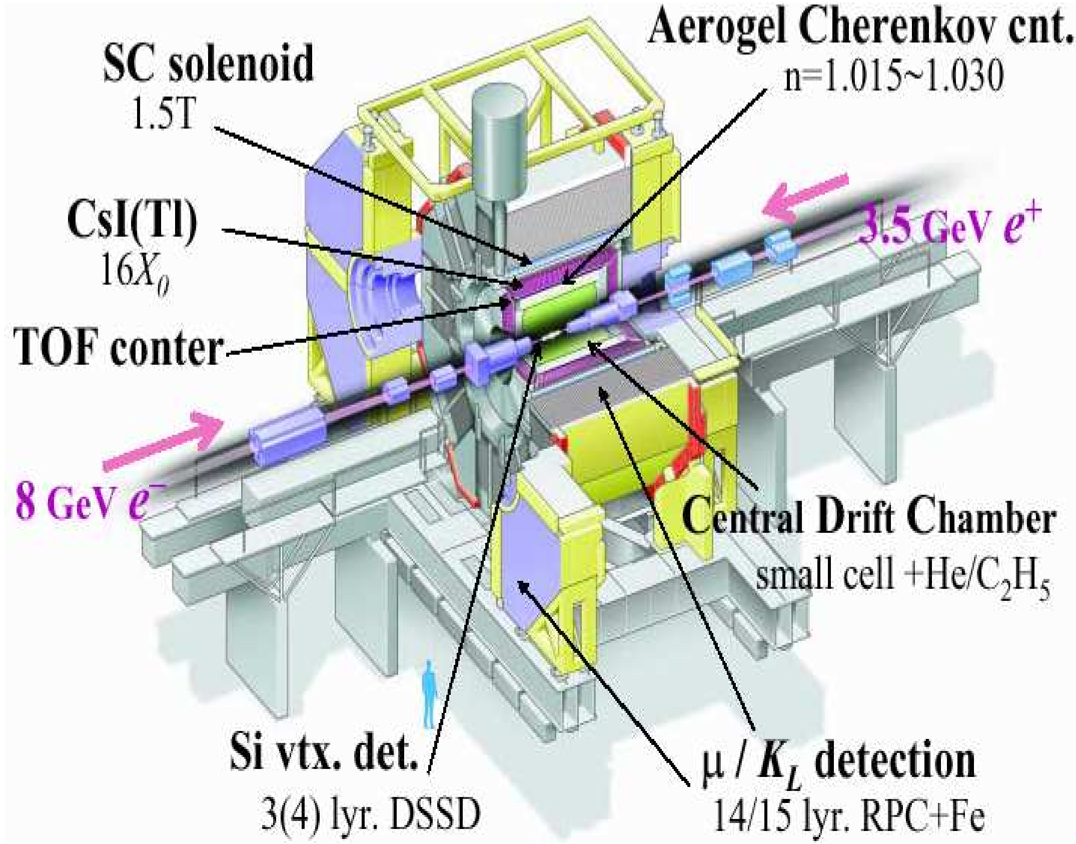


- Introduction
- Observation of
  $Z(4430)^+ \to \pi^+\psi'$ at Belle
- Observation of
  $Z^+_{1,2} \to \pi^+\chi_{c1}$ at Belle
- Update of $Z(4430)^+$ at Belle (NEW)
- Summary





$\mathcal{L}$ > 910 fb^{-1}

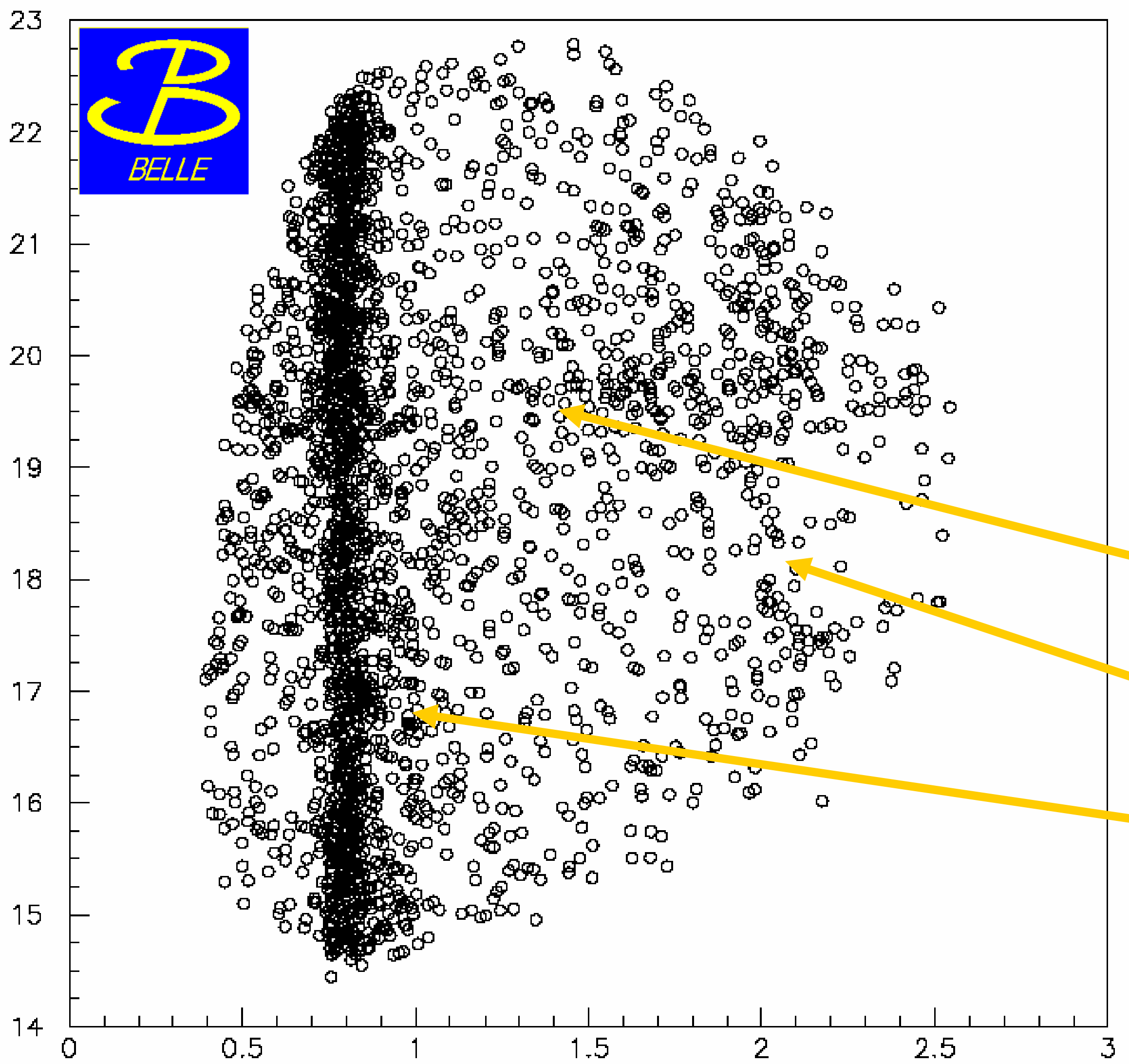


High *Luminosity* has permitted us to obtain unexpected results on charm spectroscopy, particularly with charmonium in the final state.

This has modified our understanding of known and predicted charmonia levels

Z(4430)$^+$ at Belle

PRL 100, 142001 (2008)



Study of $B \to K\pi^+\psi'$:

$\psi' \to l^+l^-$ and $J/\psi\pi^+\pi^-$ ($M(\pi\pi)>0.44$ GeV); B-candidates inv. mass is kinematically constrained to m_B (experim. resolution for $M(\psi'\pi^+)$~2.5 MeV);

Horizontal band

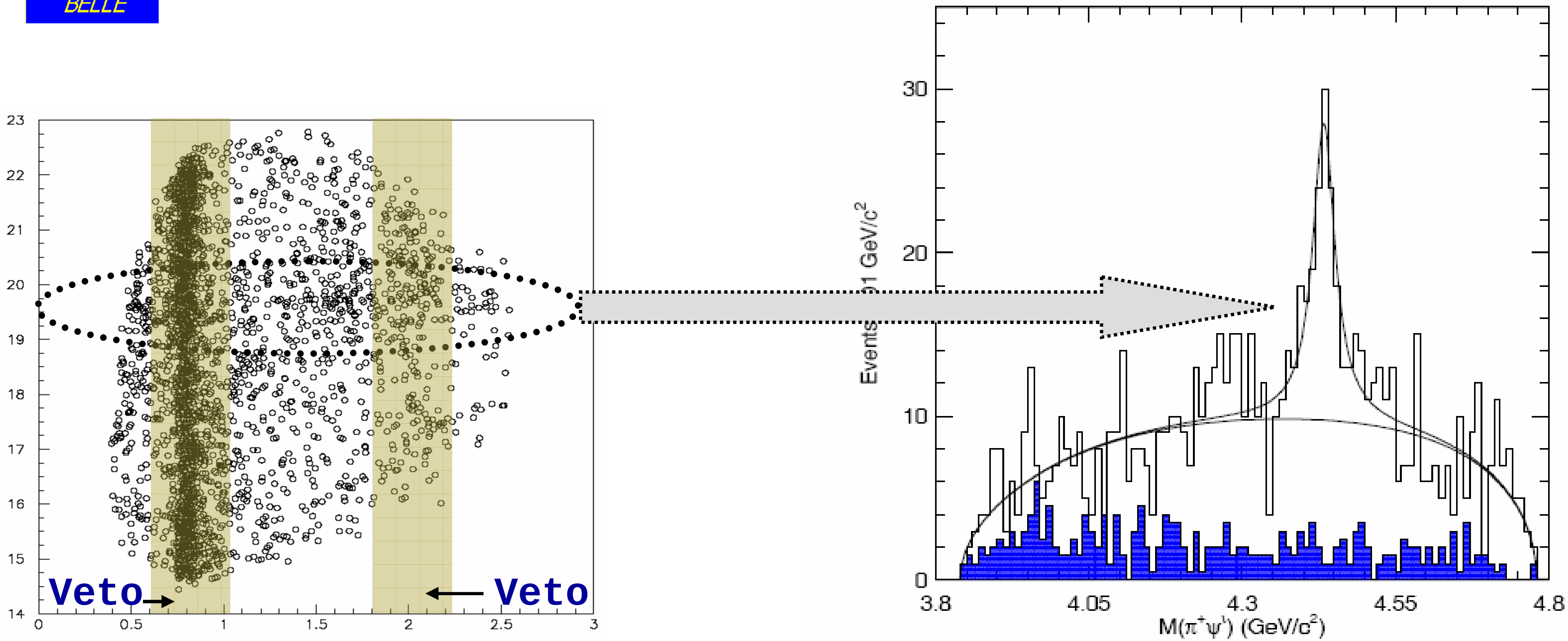
K*(1430)

K*(892)

Study it

$Z(4430)^+$ at Belle

PRL 100, 142001 (2008)



Fit: S-wave Breit-Wigner +
Background with kinematic thresholds

Cross-checks:
$Z(4430)^+$ is present in both ψ' subsamples

Total significance: 6.5 σ
M = (4433±4±1) MeV
$\Gamma = (44^{+17}_{-13}{}^{+30}_{-11})$ MeV
$Br(B \to KZ) \times Br(Z \to \psi(2S)\pi^+) = (4.1 \pm 1.0 \pm 1.3) \cdot 10^{-5}$

$Z(4430)^+$ at Belle

PRL 100, 142001 (2008)

$B^+ \rightarrow Z^+ K_s$ or $B^0 \rightarrow Z^- K^+$

$Z^\pm \rightarrow \psi(2S)\pi^\pm$

A variety of interpretations:

- threshold effect (J.L.Rosner 0708.3496, D.V.Bugg, 0709.1254);
- D^*D_1 molecular state (X. Liu *and* Y.R. Liu, 0711.0494);
- radially excited tetraquark (L.Maiani, A.D.Polosa, V.Riquer, 0708.3997);
- baryonium state (C.F.Qiao, 0709.4066);
- hadro-charmonium (S.Dubinskiy,M.B.Voloshin,0803.2224); …

Charged, I=1

Cannot be a conventional charmonium or hybrid state

Should contain light quarks in addition to cc.

The observation of Z(4430) has motivated us to continue the study of other $B \to (c\bar{c})\ \pi^+K^-$ decays

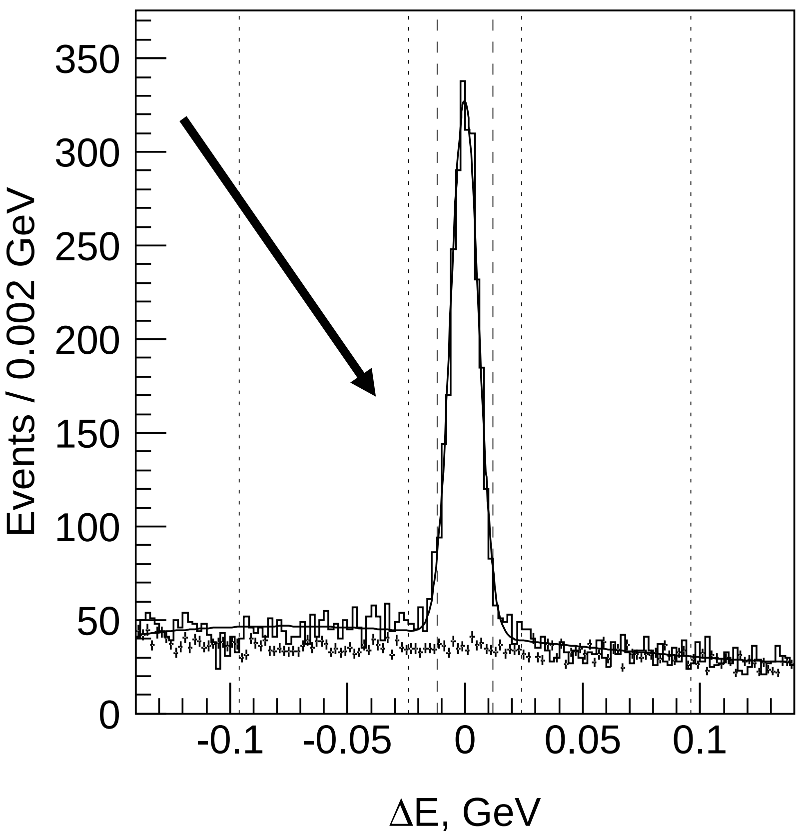
New charged Z's decaying into $\pi^+\chi_{c1}$

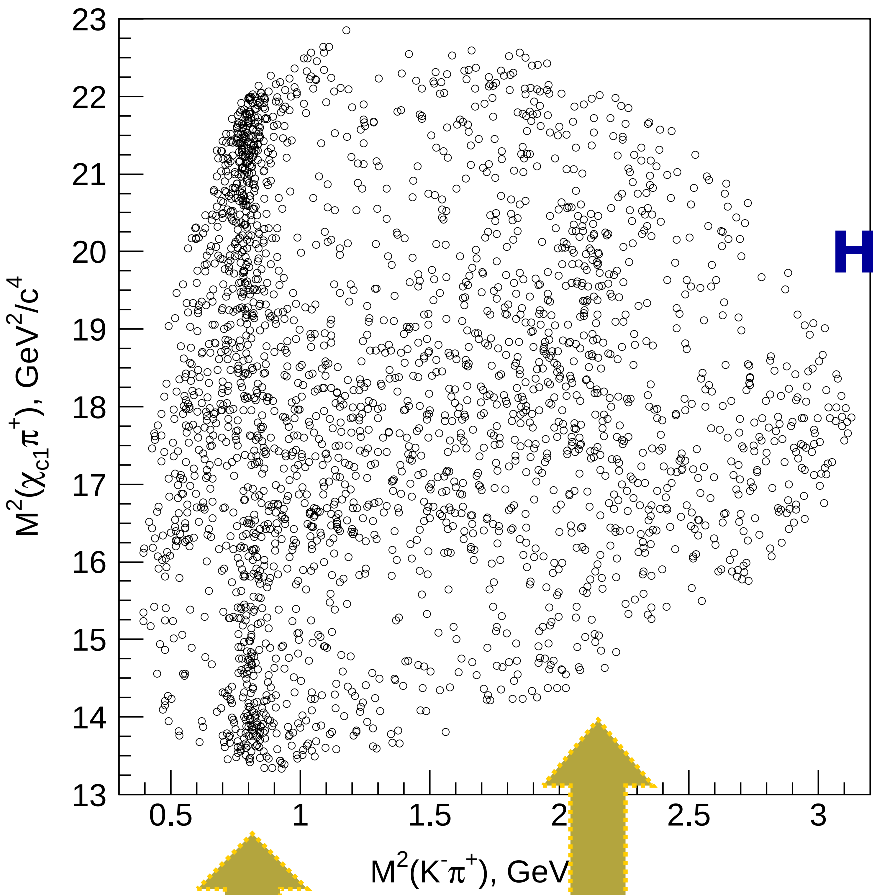
PRD 78, 072004 (2008)

Study of $B \to K^- \pi^+ \chi_{c1}$

Very simple selection, then look at DP:

B-signal





Horizontal band

Study it

K*(892)

K*(1430)

Isobar Fit to entire Dalitz Plot:

All known K*'s below 1900 MeV

κ + K*(892) +
K*(1410) + K^*_0(1430) +
K^*_2(1430) + K*(1680) +
K^*_3(1780) +
(Z's) + Interference

$K^-\pi^+\chi_{c1}$ Dalitz Plot Formalism

The decay $B\to K\pi\chi_{c1}$ is described by 6 variables, $M(\pi\chi_{c1})$, $M(K\pi)$, helicity angles $\theta_{\chi c1}$, $\theta_{J/\psi}$ and angles btw the production and decay planes $\varphi_{\chi c1}$, $\varphi_{J/\psi}$

Integrate over all angles; reconstruction efficiency is uniform over full angle ranges and interference terms between different χ_{c1} helicity states are negligibly small.

Fitting function:

$$F(s_x, s_y) = S(s_x, s_y) \times \epsilon(s_x, s_y) + B(s_x, s_y)$$

$$A_\lambda^R(s_x, s_y) = F_B^{(L_B)} \cdot \frac{1}{M_R^2 - s_R - iM_R\Gamma(s_R)} \cdot F_R^{(L_R)} \cdot T_\lambda \cdot \left(\frac{p_B}{m_B}\right)^{L_B} \cdot \left(\frac{p_R}{\sqrt{s_R}}\right)^{L_R}.$$

Amplitude for $B\to K\pi\chi_{c1}$ via 2-body intermediate res.R and χ_{c1} in hel.λ

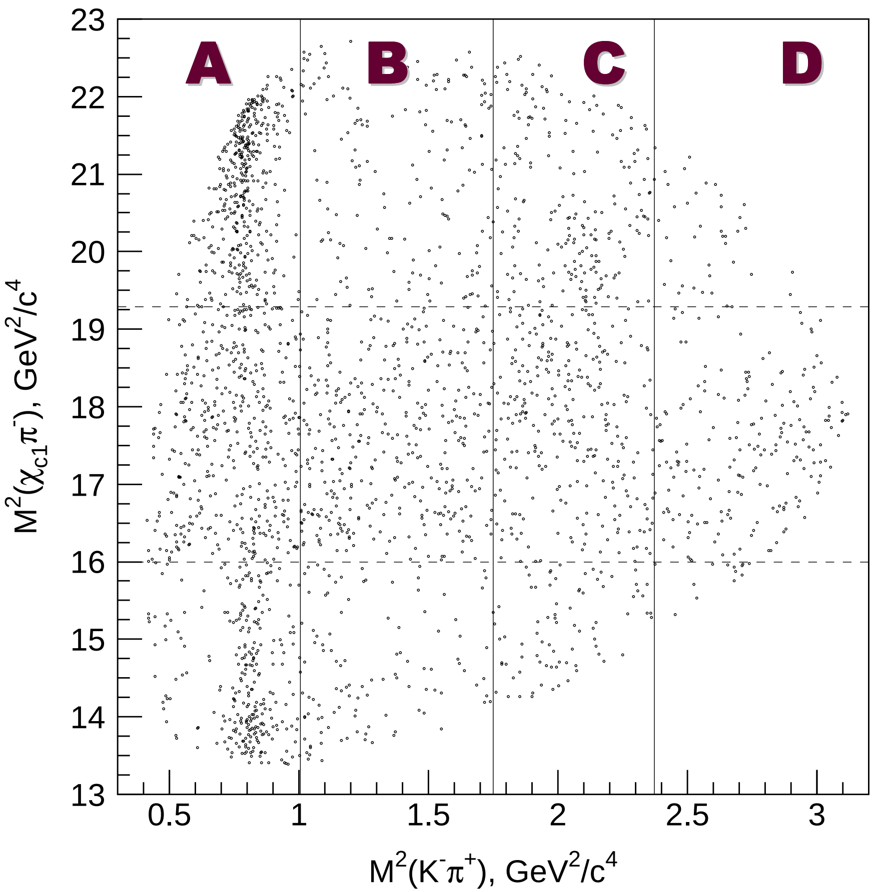
Angle dependent term:

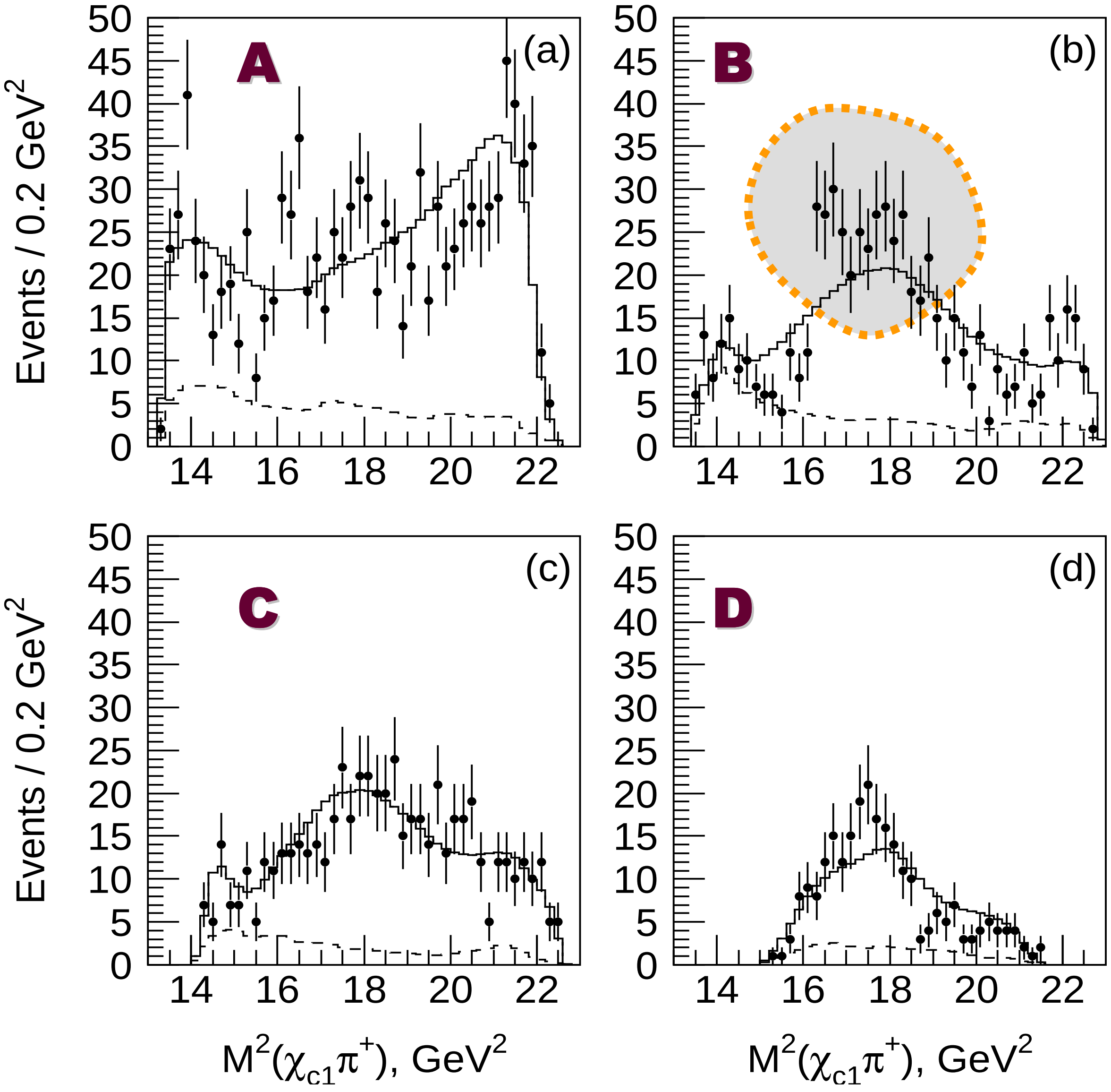
$$T_\lambda = d^J_{0\lambda}(\theta_{Z^+})$$

Signal event density

$$S(s_x, s_y) = \sum_{\lambda=-1,0,1} \left| \sum_{K^*} a_\lambda^{K^*} e^{i\phi_\lambda^{K^*}} A_\lambda^{K^*}(s_x, s_y) + \sum_{\lambda'=-1,0,1} d^1_{\lambda'\lambda}(\theta) a_{\lambda'}^{Z^+} e^{i\phi_{\lambda'}^{Z^+}} A_{\lambda'}^{Z^+}(s_x, s_y) \right|^2$$

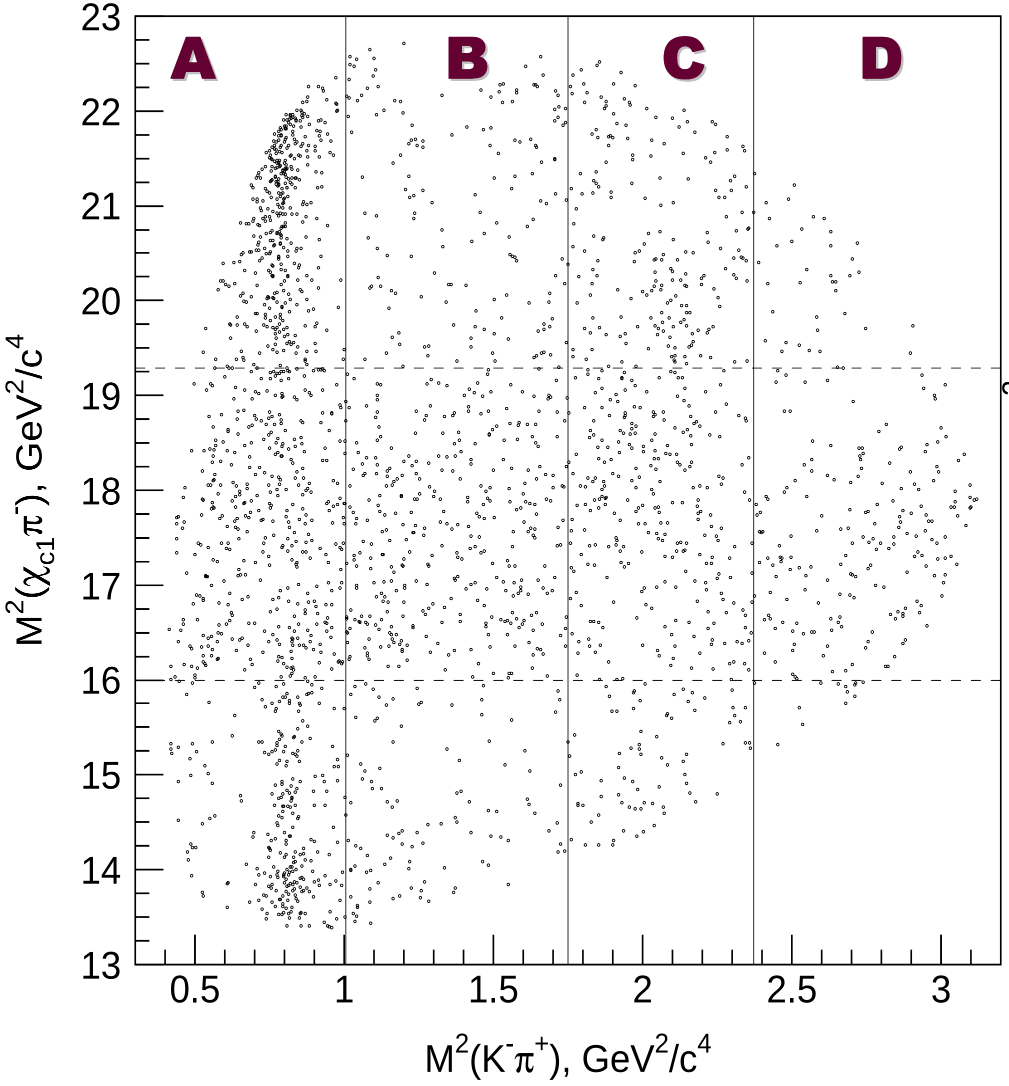
The fit results in DP slices without any Z's:

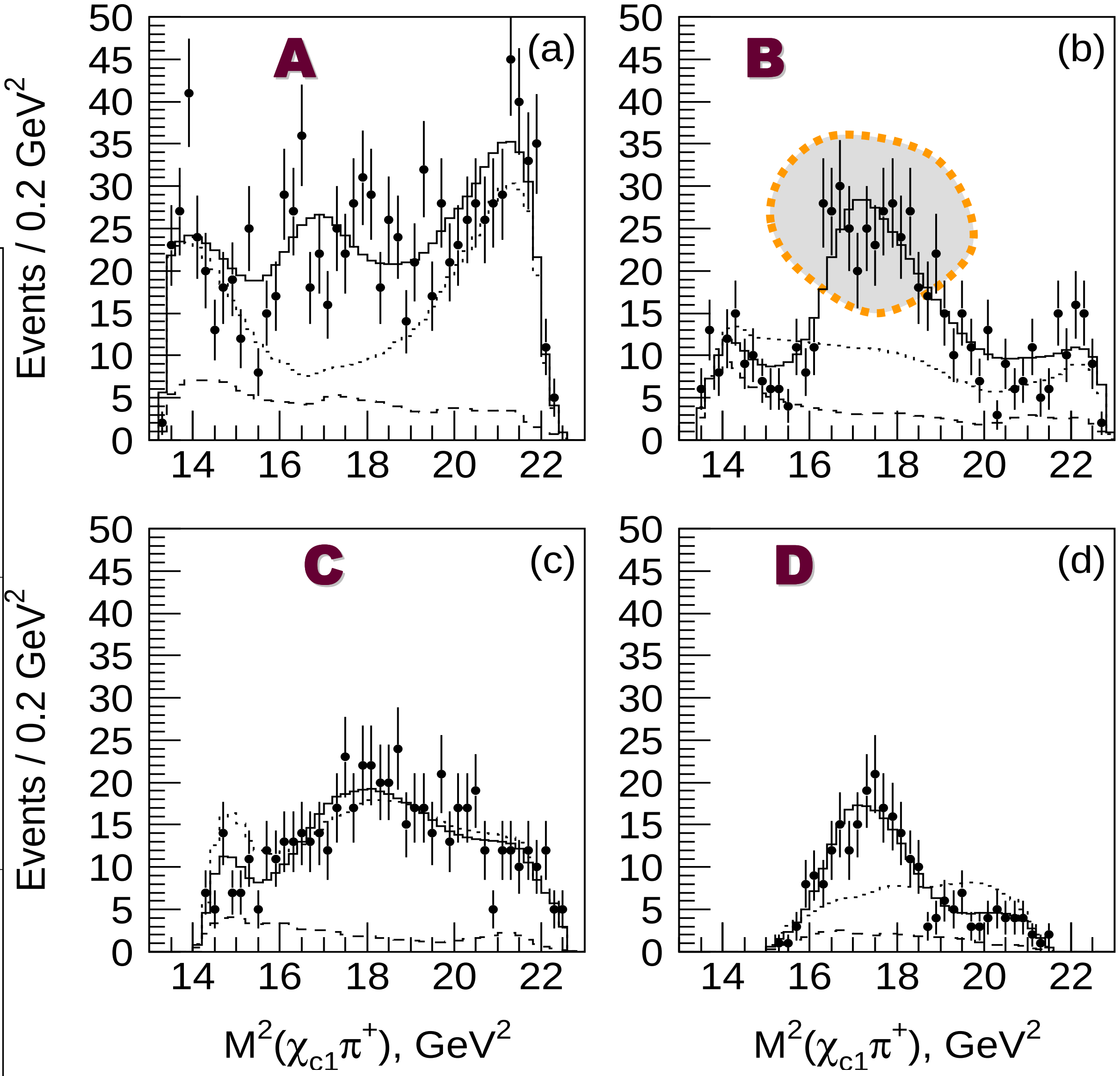




Confidence level of this fit: $3\text{x}10^{-10}$

The fit results in DP slices with one Z:

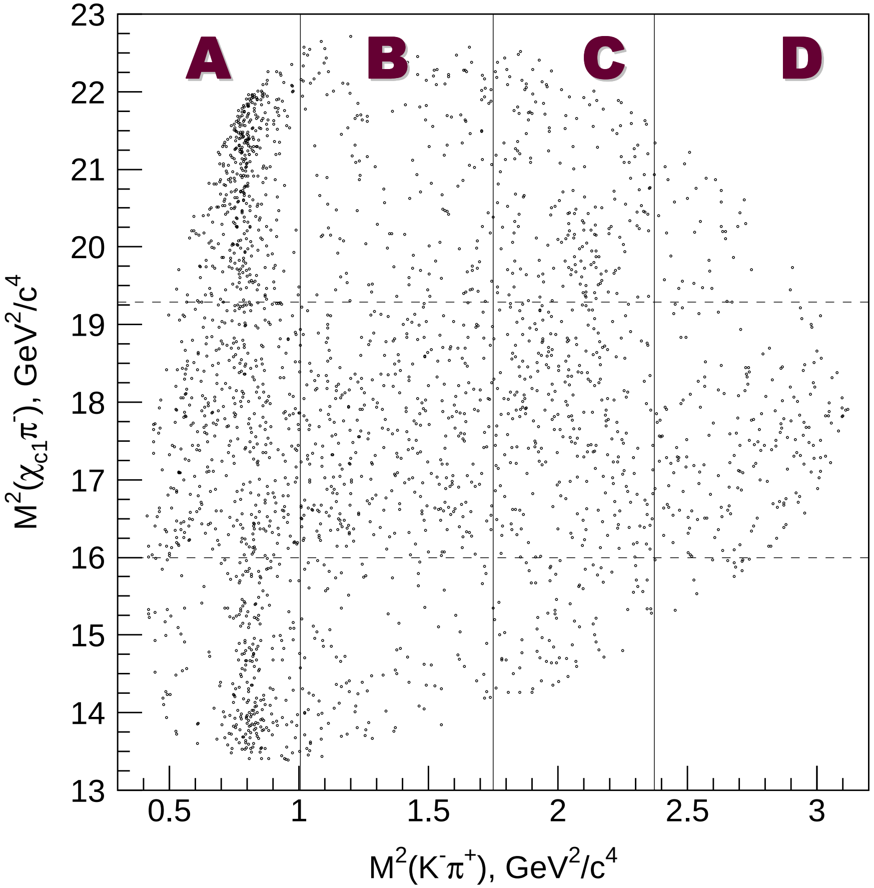


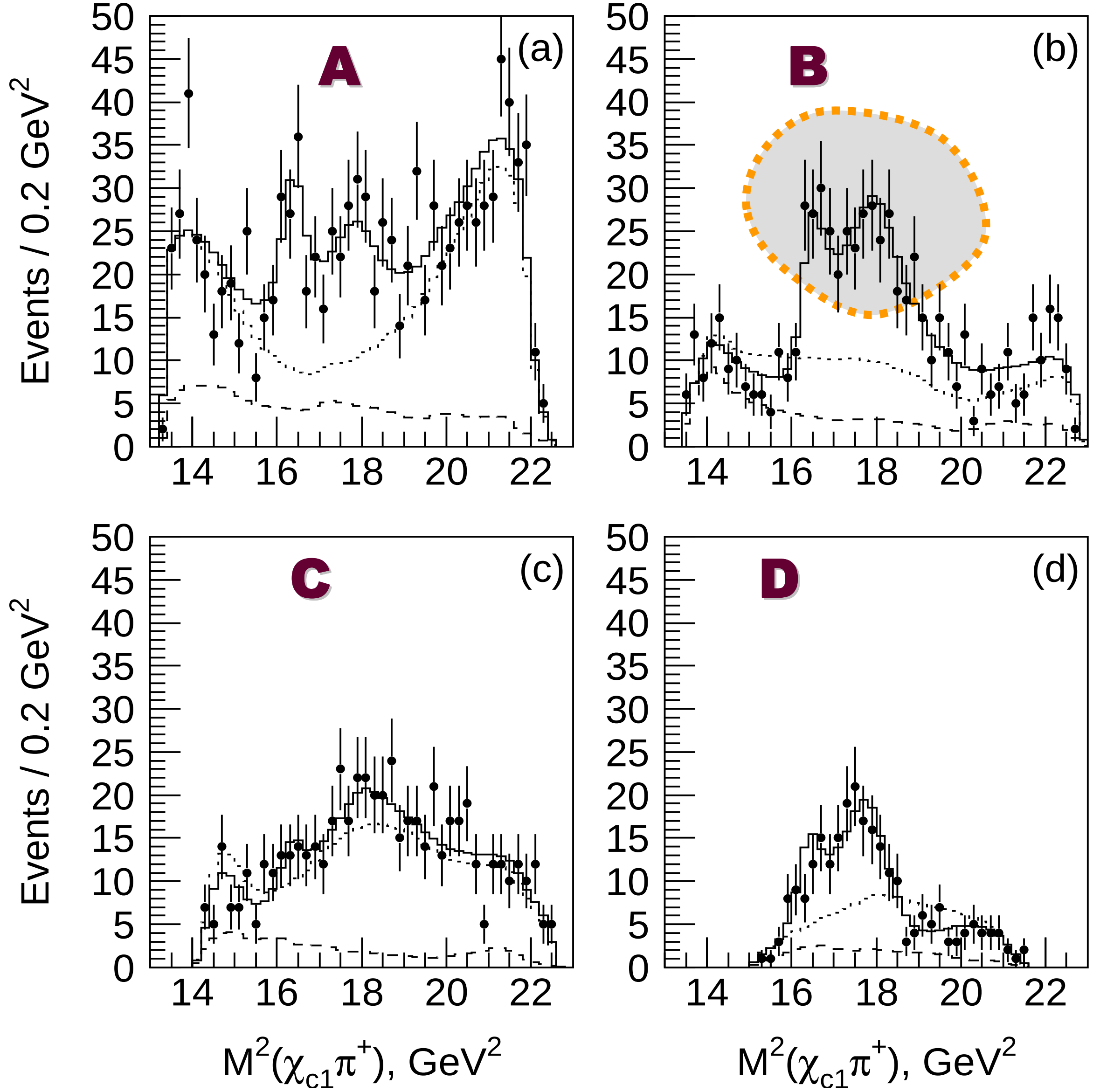


Confidence level of this fit: 0.5%

Try an additional Z

The fit results in vertical DP slices with two Z's:





Confidence level of this fit: 42%

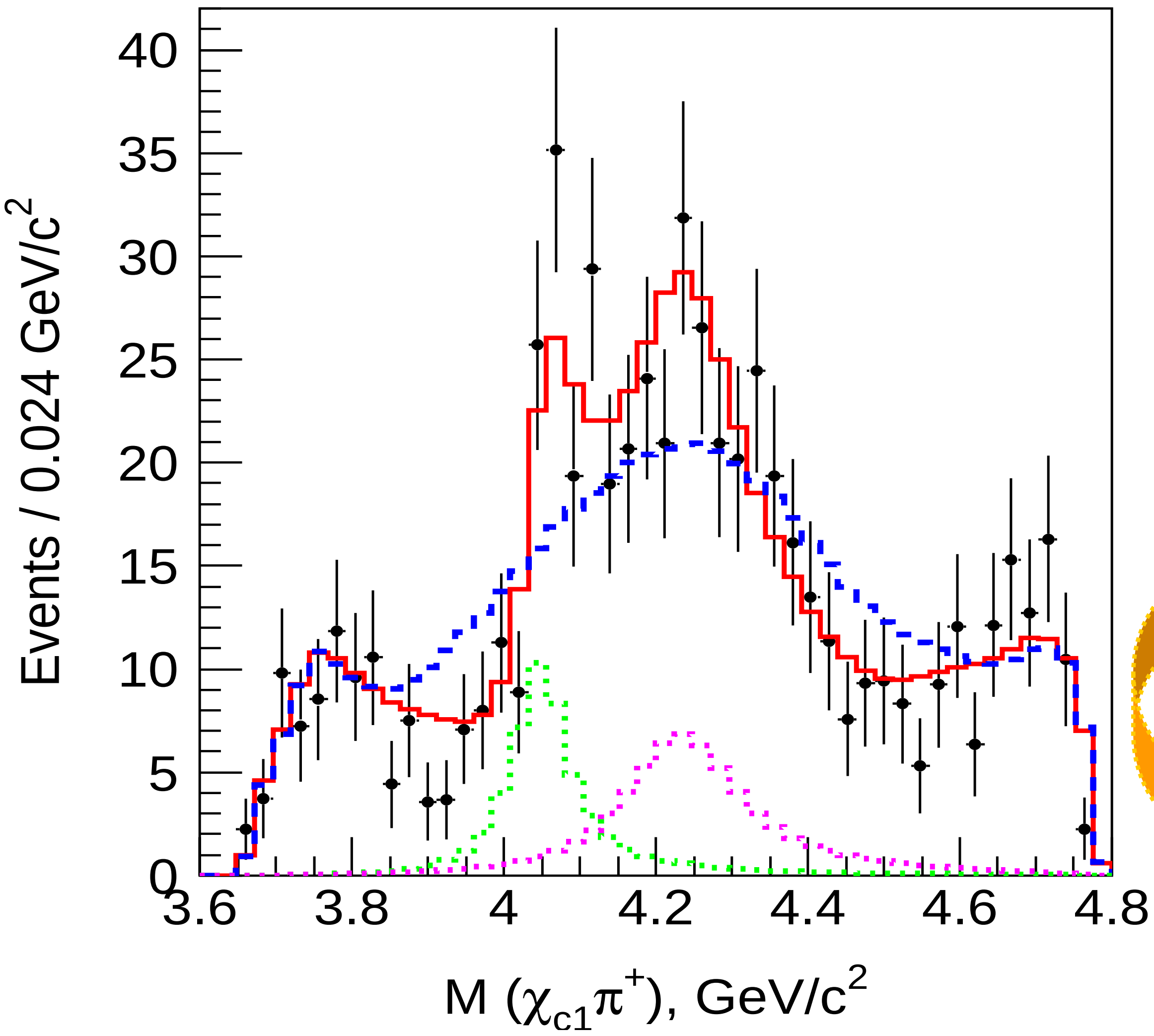
Systematics and significances (incl. d.o.f.) from various fit models:

TABLE II. Different fit models that are used to study systematic uncertainties and the significances of the single- and double-Z^+ hypotheses.

	Model	Significance of one Z^+	One Z^+ vs two Z^+	Significance of two Z^+
1	* default (see text)	10.7σ	5.7σ	13.2σ
2	no κ	15.6σ	5.0σ	16.6σ
3	no $K^*(1410)$	13.4σ	5.4σ	14.8σ
4	no $K_0^*(1430)$	10.4σ	5.2σ	14.4σ
5	no $K^*(1680)$	13.3σ	5.6σ	14.8σ
6	no $K_3^*(1780)$	12.9σ	5.6σ	14.4σ
7	add nonresonant $\chi_{c1}K^-$ term	9.0σ	5.3σ	10.3σ
8	add nonresonant $\chi_{c1}K^-$ term, no $K^*(1410)$	11.3σ	5.1σ	13.5σ
9	add nonresonant $\chi_{c1}K^-$ term, no $K^*(1680)$	11.4σ	5.3σ	13.7σ
10	add nonresonant $\chi_{c1}K^-$ term, no $K_3^*(1780)$	10.8σ	5.4σ	13.2σ
11	add nonresonant $\chi_{c1}K^-$ term, release constraints on κ mass & width	9.5σ	5.3σ	10.7σ
12	add nonresonant $\chi_{c1}K^-$ term, new K^* ($J=1$)	7.7σ	5.4σ	9.2σ
13	add nonresonant $\chi_{c1}K^-$ term, new K^* ($J=2$)	6.2σ	5.6σ	8.1σ
14	LASS parametrization of S-wave component	12.4σ	5.3σ	13.8σ

The worst case, but the param's of this new K* are far from those for all known K*'s

Parameters of the new EXOTIC $Z^+_{1,2} \to \pi^+ \chi_{c1}$ states and Mass($\pi^+\chi_{c1}$) distribution



No discrimination between J=0 or 1

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

with the product branching fractions of

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

are the same order as obtained for other, possibly exotic X,Y,Z states.

Dalitz analysis of $B \to K^- \pi^+ \psi'$

Data sample from original analysis is used

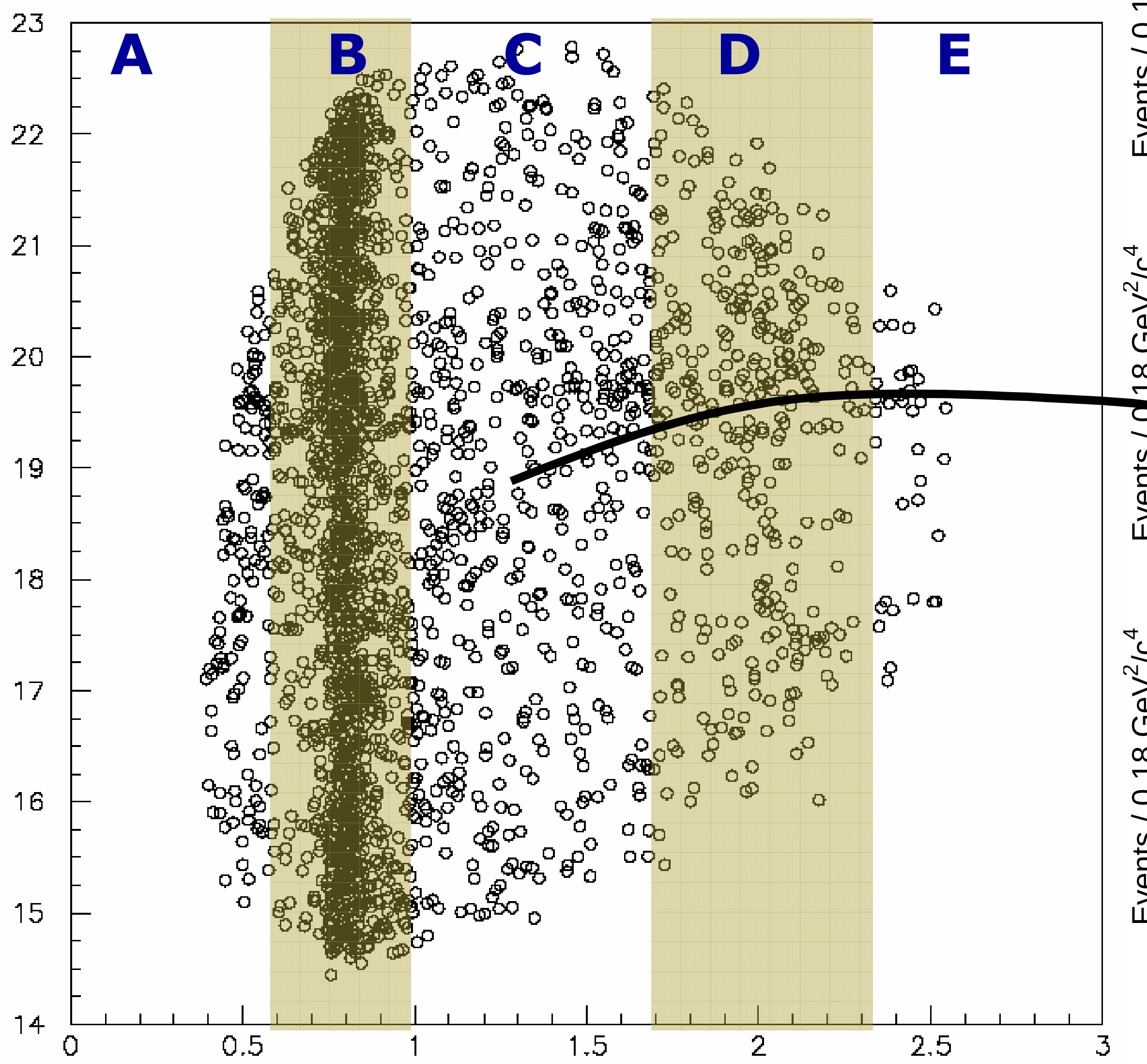
The same fitting technique as in $B \to K\pi\chi_{c1}$ is used

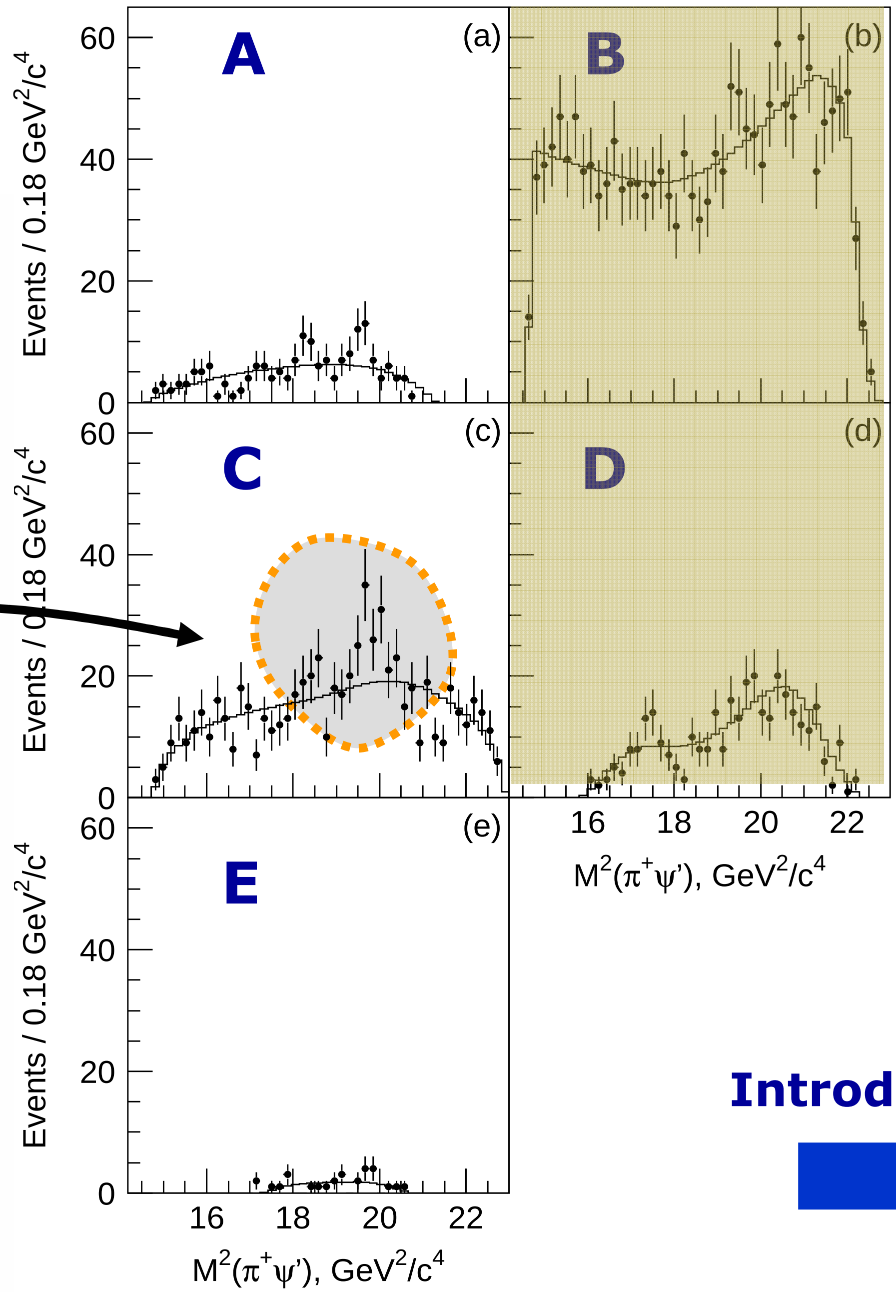
New results on $Z(4430)^+$

Submitted to PRD(RC), arXiv:0905.2869

Dalitz Plot slices:

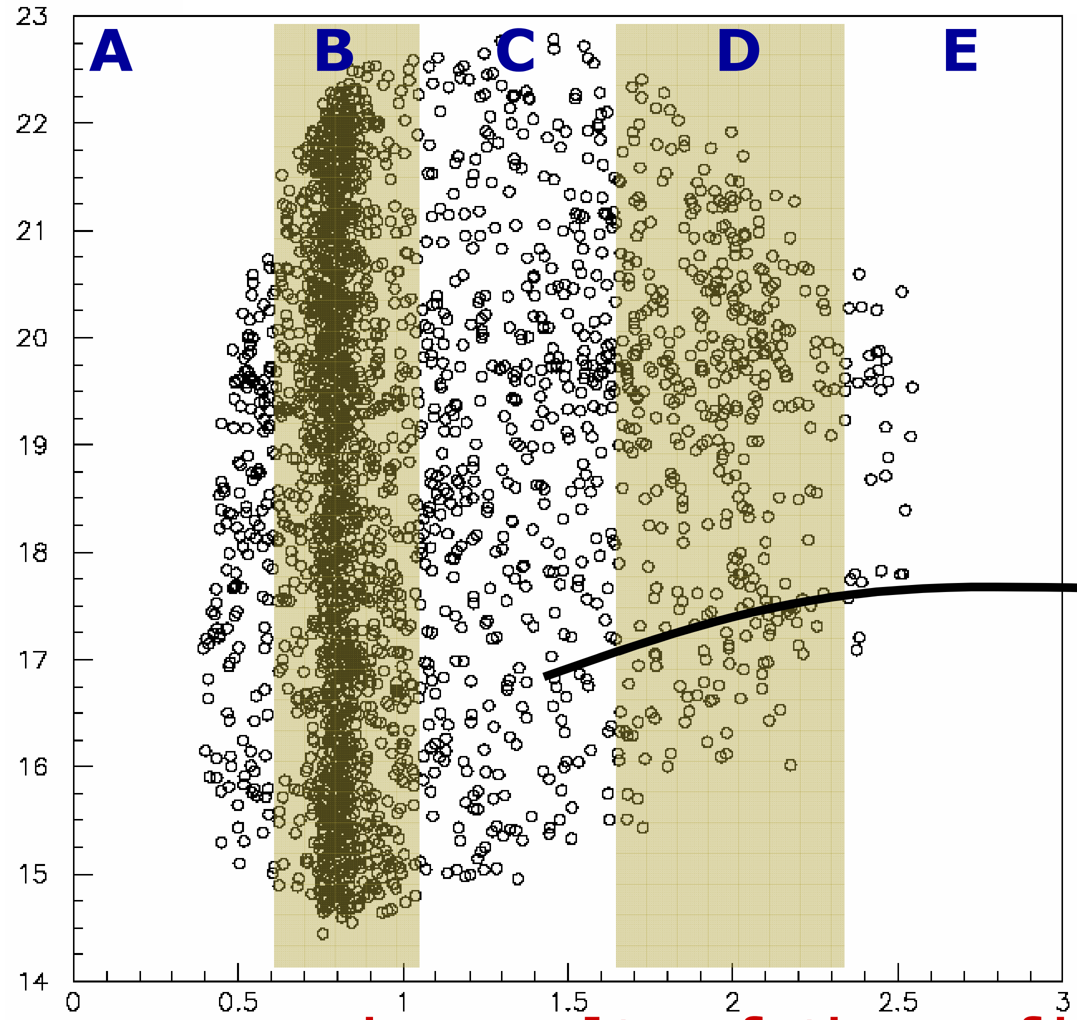
Fit without a Z resonance: CL=0.1%

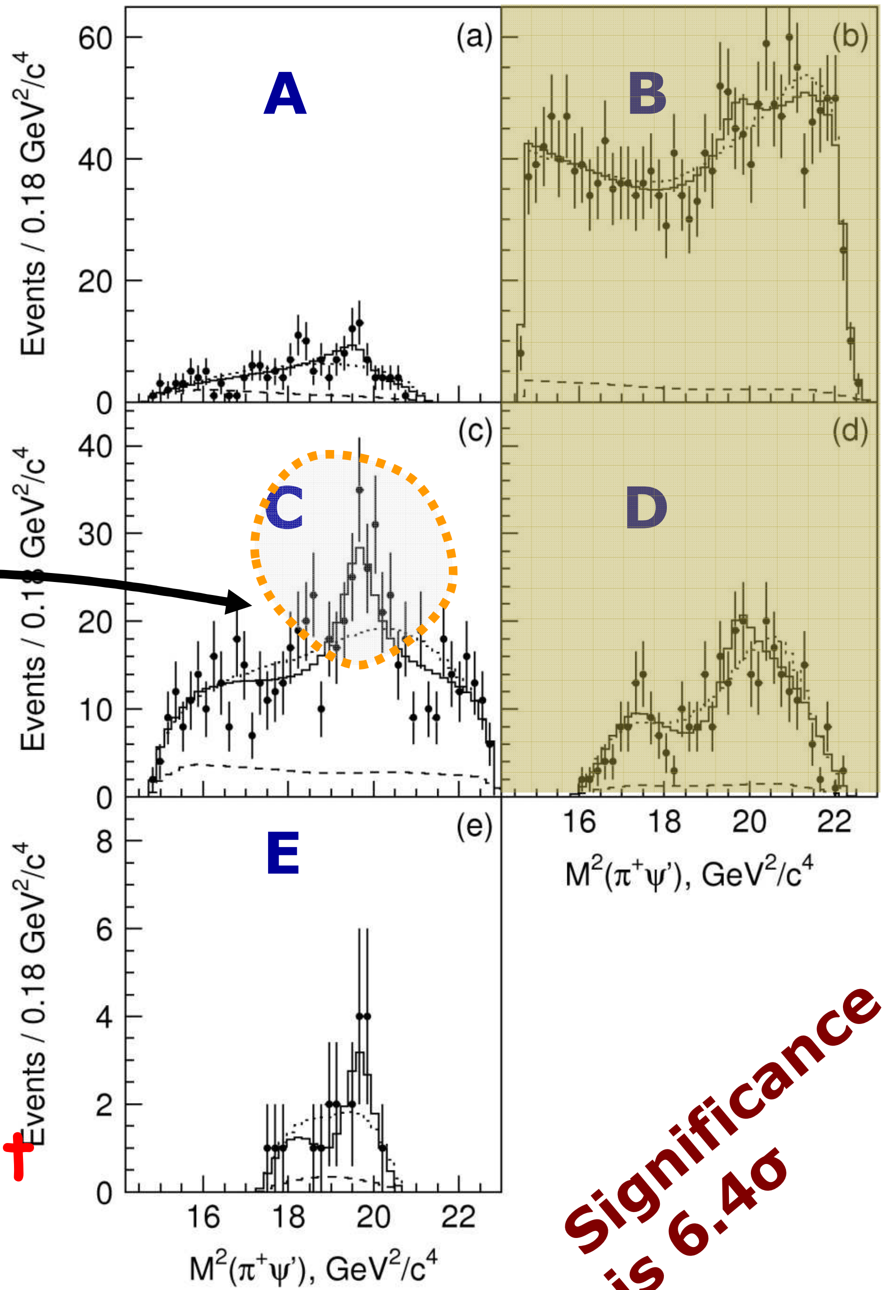




Introduce Z

NEW results on $Z(4430)^+$ from Dalitz plot fit





The results of the DP fit in its slices with Z:

Confidence Level of the fit WITH $Z(4430)^+$ is 36%

Significance of Z is 6.4σ

Different fit models and the significance of $Z(4430)^+$

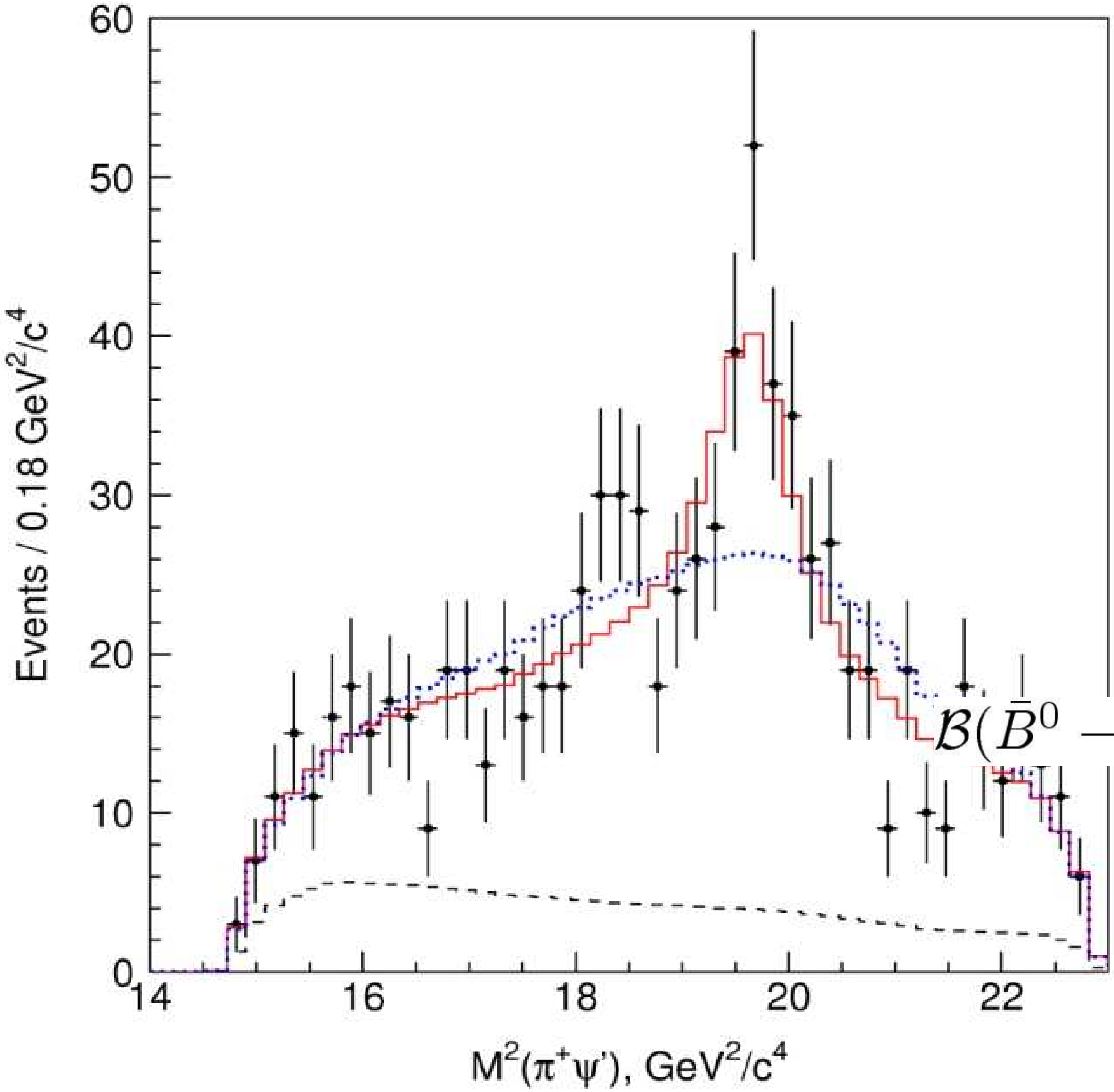
Model	Significance
default	$6.4\,\sigma$
no $K_0^*(1430)$	$6.6\,\sigma$
no $K^*(1680)$	$6.6\,\sigma$
release constraints on κ mass & width	$6.3\,\sigma$
new K^* $(J=1)$	$6.0\,\sigma$
new K^* $(J=2)$	$5.5\,\sigma$
add non-resonant $\psi' K^-$ term	$6.3\,\sigma$
add non-resonant $\psi' K^-$ term, release constraints on κ mass & width	$5.8\,\sigma$
add non-resonant $\psi' K^-$ term, new K^* $(J=1)$	$5.5\,\sigma$
add non-resonant $\psi' K^-$ term, new K^* $(J=2)$	$5.4\,\sigma$
add non-resonant $\psi' K^-$ term, no $K^*(1410)$	$6.3\,\sigma$
add non-resonant $\psi' K^-$ term, no $K^*(1680)$	$6.6\,\sigma$
LASS parameterization of S-wave component	$6.5\,\sigma$

Assume $J_{Z(4430)}=0$. No fit improvement for $J_{Z(4430)}=1$.

Significance of $Z(4430)^+$ in different fit models is always larger than 5σ

Updated parameters of Z(4430)$^+$ from Dalitz plot fit

Sum of 3 slices (K*'s veto)



Belle confirms the original result on Z(4430)$^+$

$$M = (4443^{+15+17}_{-12-13})\ \mathrm{MeV}/c^2$$
$$\Gamma = (109^{+86+57}_{-43-52})\ \mathrm{MeV}$$

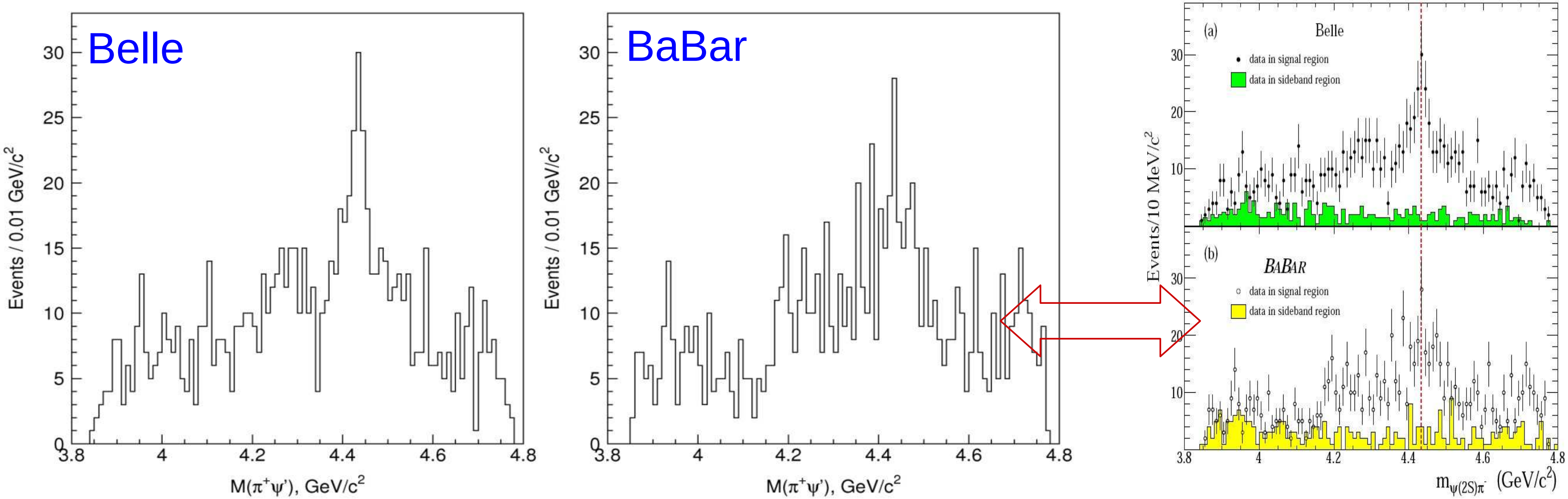
$$\mathcal{B}(\bar{B}^0 \to K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \to \pi^+\psi') = (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5}$$

Width is larger than original but uncertainties are large

Comparison with BaBar *(arXiv:0811.0564)*

BaBar paper: Belle and BaBar data **are statistically consistent**.

⇔ peak in $M(\pi^+\psi')$ is present also in BaBar data with similar to Belle shape:



Why different significances are reported? (6.4σ Belle vs. 1.9–3.1σ BaBar)

⇔ assumption about background is crucial.

20

Summary of Belle results on charged Z's

- **2007: Belle observed first charged charmoniumlike state, $Z(4430)^+$ decaying into $\psi'\pi^+$**

- **2008: Belle continued the study of $B \to K\pi(c\bar{c})$ decays and observed two new charged charmonium~~l~~ike states $Z(4050)^+$ and $Z(4250)^+$, decaying into $\pi^+\chi_{c1}$**

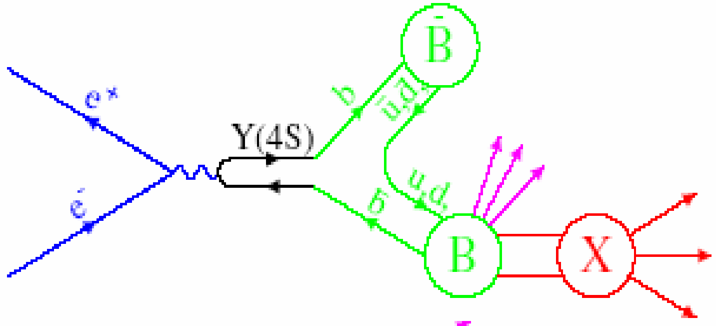
- **Update on $Z(4430)^+$:**
Dalitz Plot analysis confirms original observation. The $Z(4430)^+$ has a significance of 6.4σ. The parameters of $Z(4430)^+$ from the DP analysis agree and supersede previous Belle measurement. BaBar has not confirmed $Z(4430)^+$ production so far.

These states have similar character: have non-zero electric charge and decay into ordinary charmonia and π^+.
The current options for their nature include tetraquark, molecular type states and hadro-charmonium.

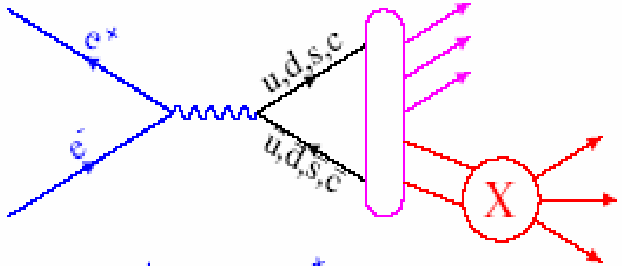
Back-up slides

The mechanisms of new particle production at B-factories

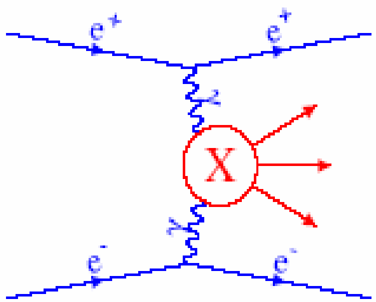
From B-decays, e.g.
$B^+ \to X(3872)K^+$



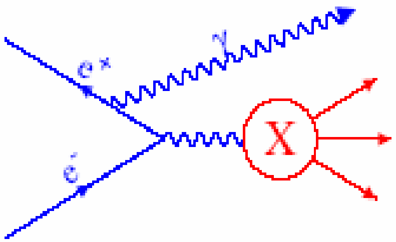
In double charmonium production, e.g. $e^+e^- \to J/\psi\ X(3940)$



In $\gamma\gamma$ fusion,
e.g. $\gamma\gamma \to \eta_c(2S)$ or $\gamma\gamma \to Z(3930)$



In radiative return, e.g.
$e^+e^- \to \gamma_{ISR}Y(4260) \to J/\psi\ \pi^+\pi^-$



Can charged Z be in principle produced here?

Yes

yet unknown ($e^+e^- \to X^+Y^-$??)

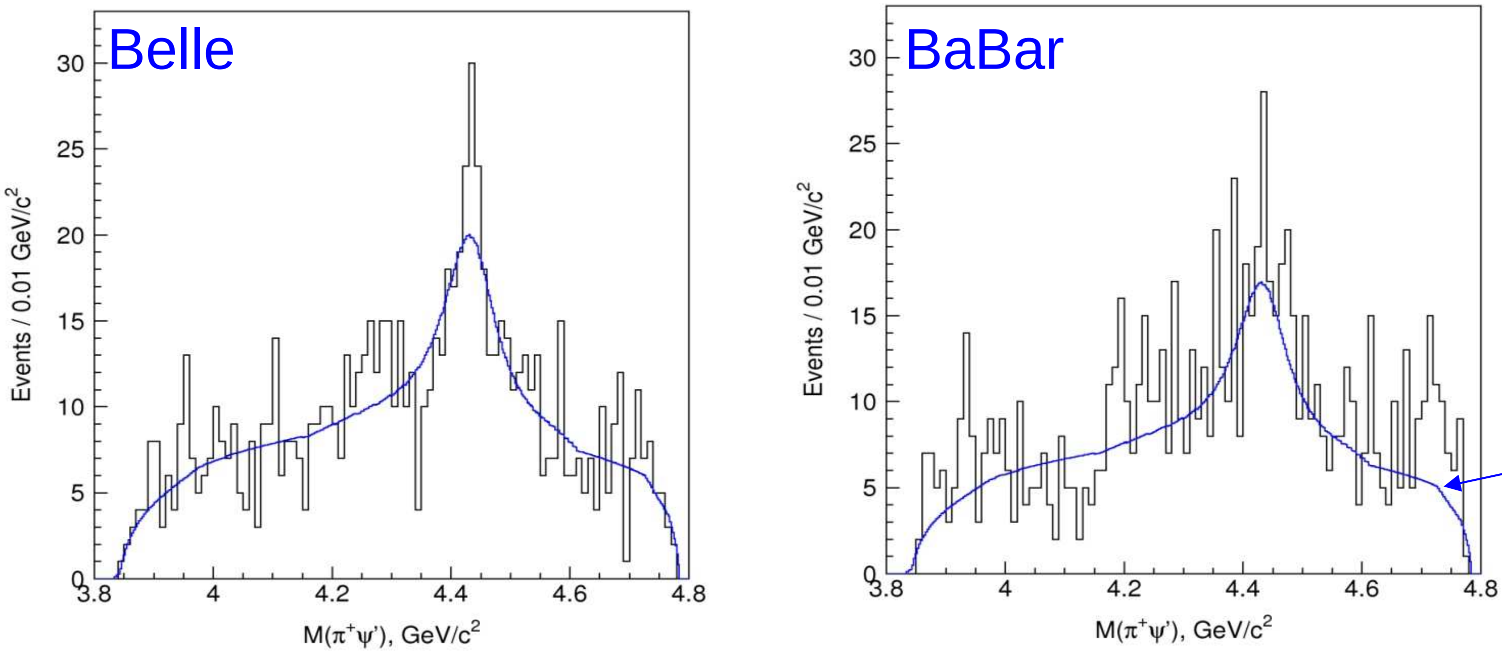
No

No

Since only neutrals can be produced

Comparison with BaBar

BaBar paper: Belle and BaBar data are statistically consistent.
⇔ peak in $M(\pi^+\psi')$ is present also in BaBar data with similar to Belle shape:



Result of Dalitz fit scaled down by 1.18 to account for smaller statistics @ BaBar.

From talk by Roman Mizuk at LaThuile'09

Why different significances are reported? (6.4σ Belle vs. 1.9–3.1σ BaBar)

⇔ assumption about background is crucial.

BaBar method is a simplification of amplitude analysis with a lot of (unphysical?) freedom in description of background.

Dalitz analysis is preferable.

Formalism of $B \to K^- \pi^+ \chi_{c1}$ Dalitz analysis

Integrate over ψ' decay angles
$\Leftrightarrow$ interference between different χ_{c1} helicity states vanish
$\Leftrightarrow$ consider χ_{c1} as stable

Amplitude = sum over quasi two-body contributions

Breit-Wigner $\times$ angular dependence

Consider intermediate resonances

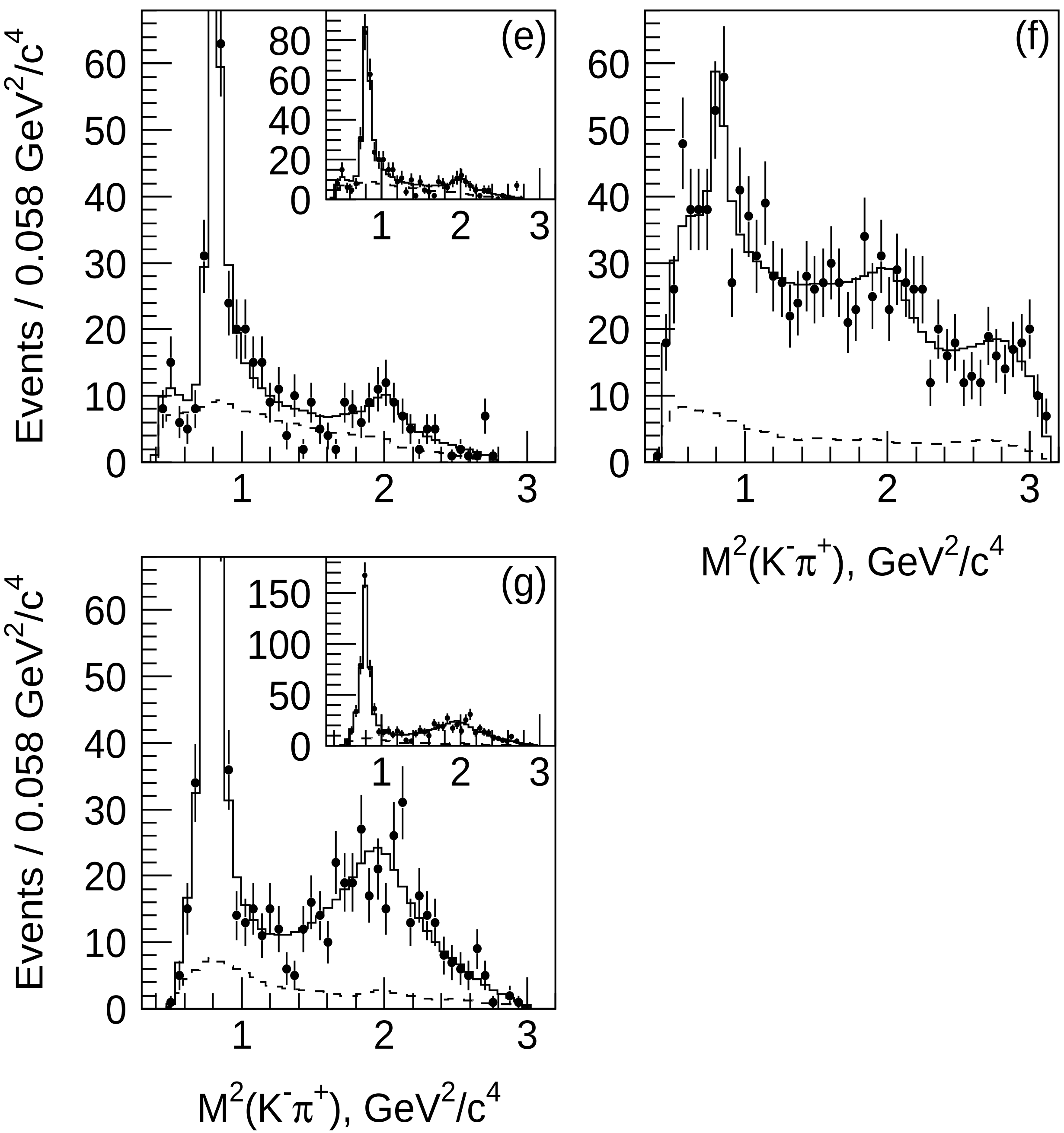
κ, $K^*(892)$, $K^*(1410)$, $K_0(1430)$, $K_2(1430)$, $K^*(1680)$,
Z('s)$^+$

Fit function is corrected for efficiency and background.

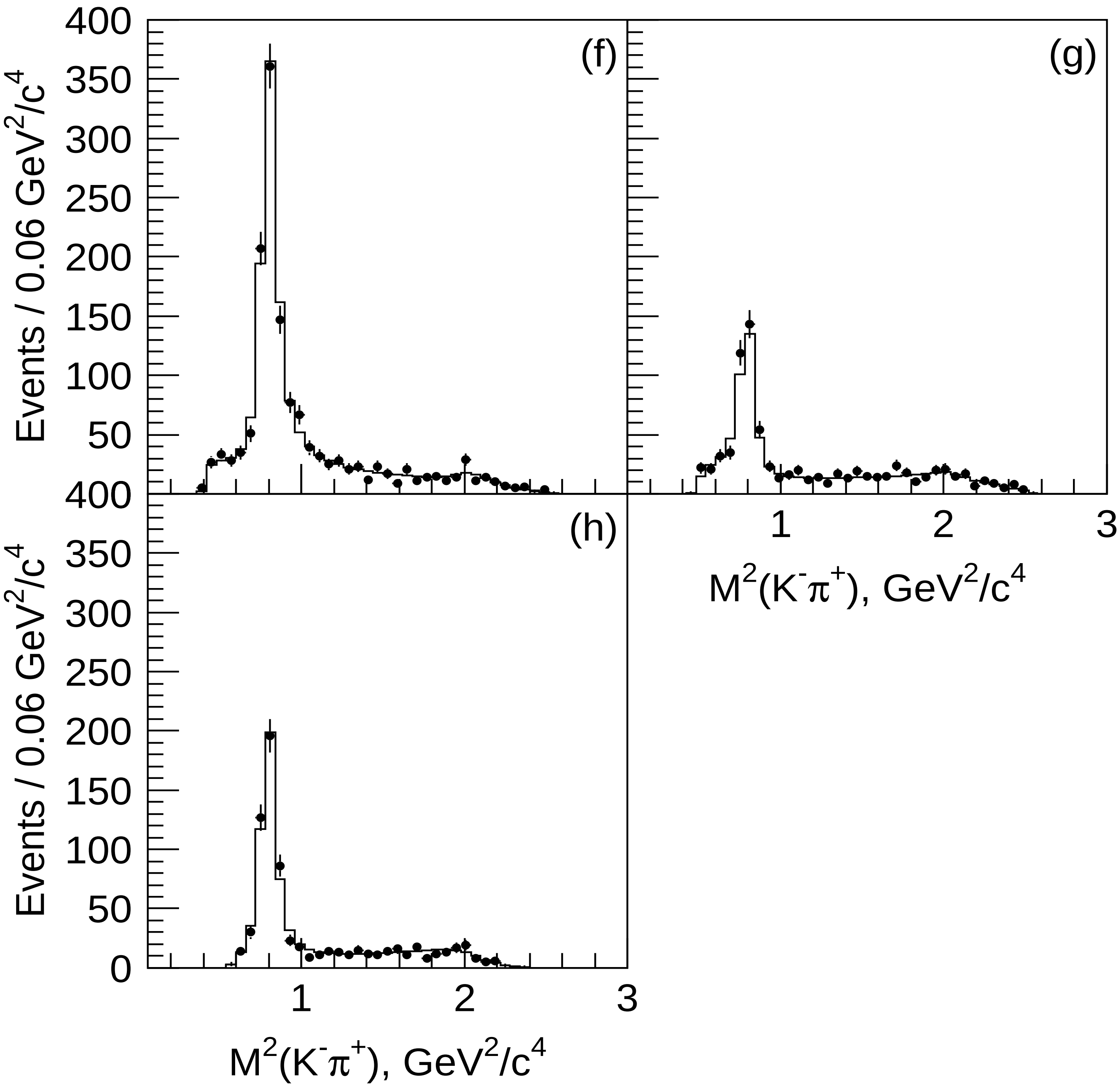
605fb^{-1}

Use the same data sample as in $Z(4430)^+$ observation paper.

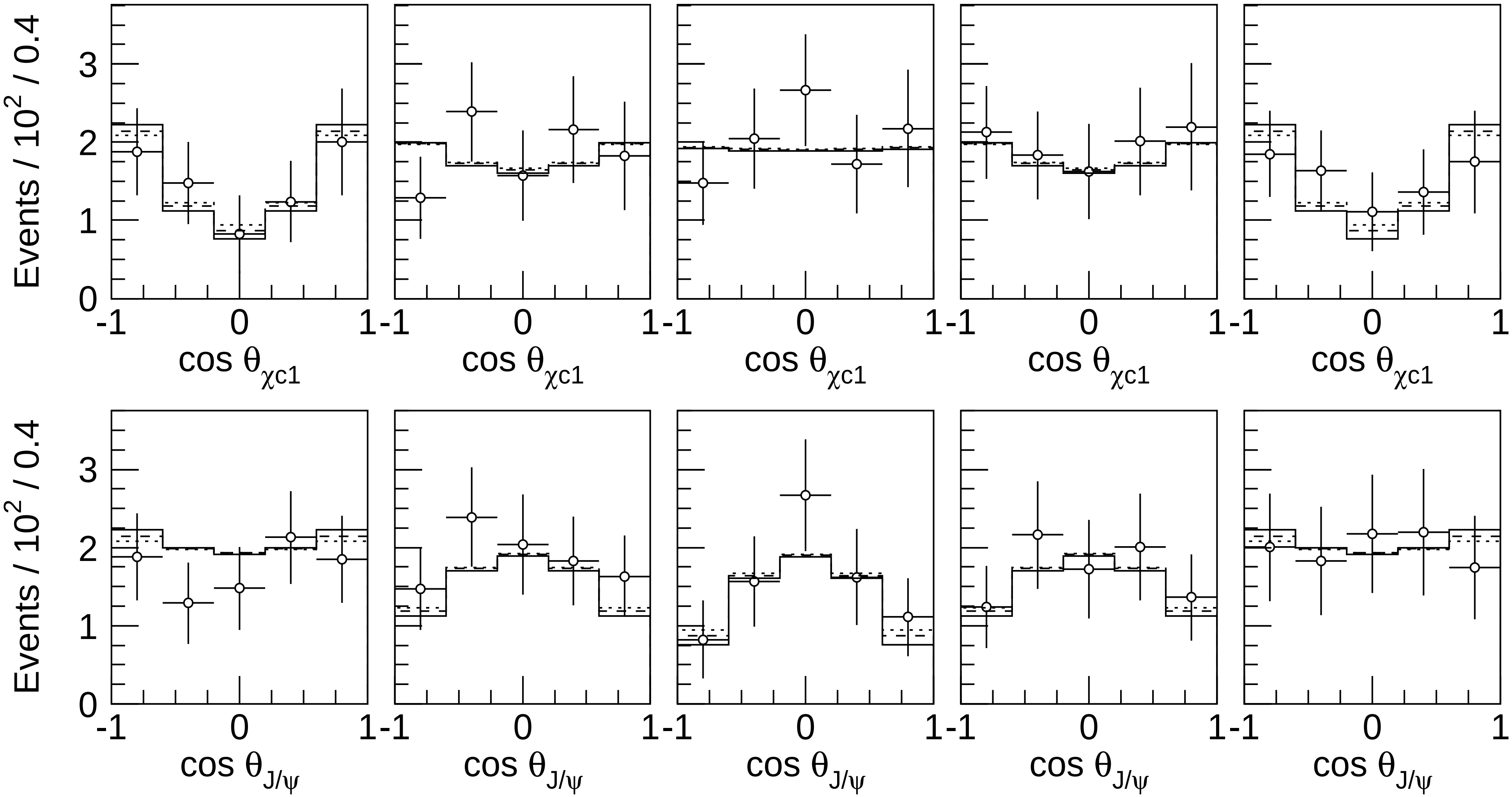
M(Kπ) description in $B \to K\pi^+\chi_{c1}$



M(Kπ) description in $B \to K\pi^+\psi'$

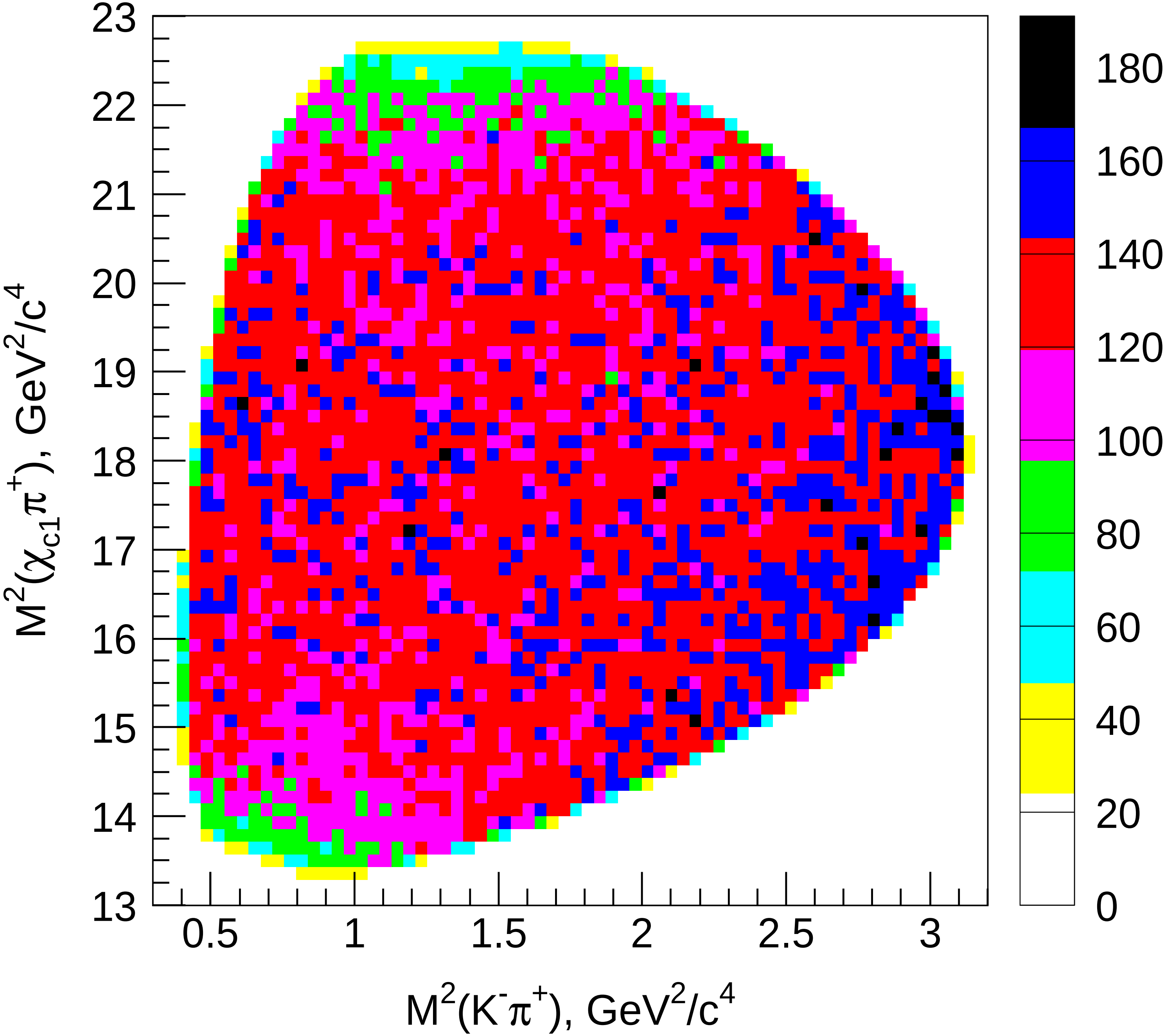


Cross-Check: angular distributions of the χ_{c1} and J/ψ in $B \to K\pi^+\chi_{c1}$

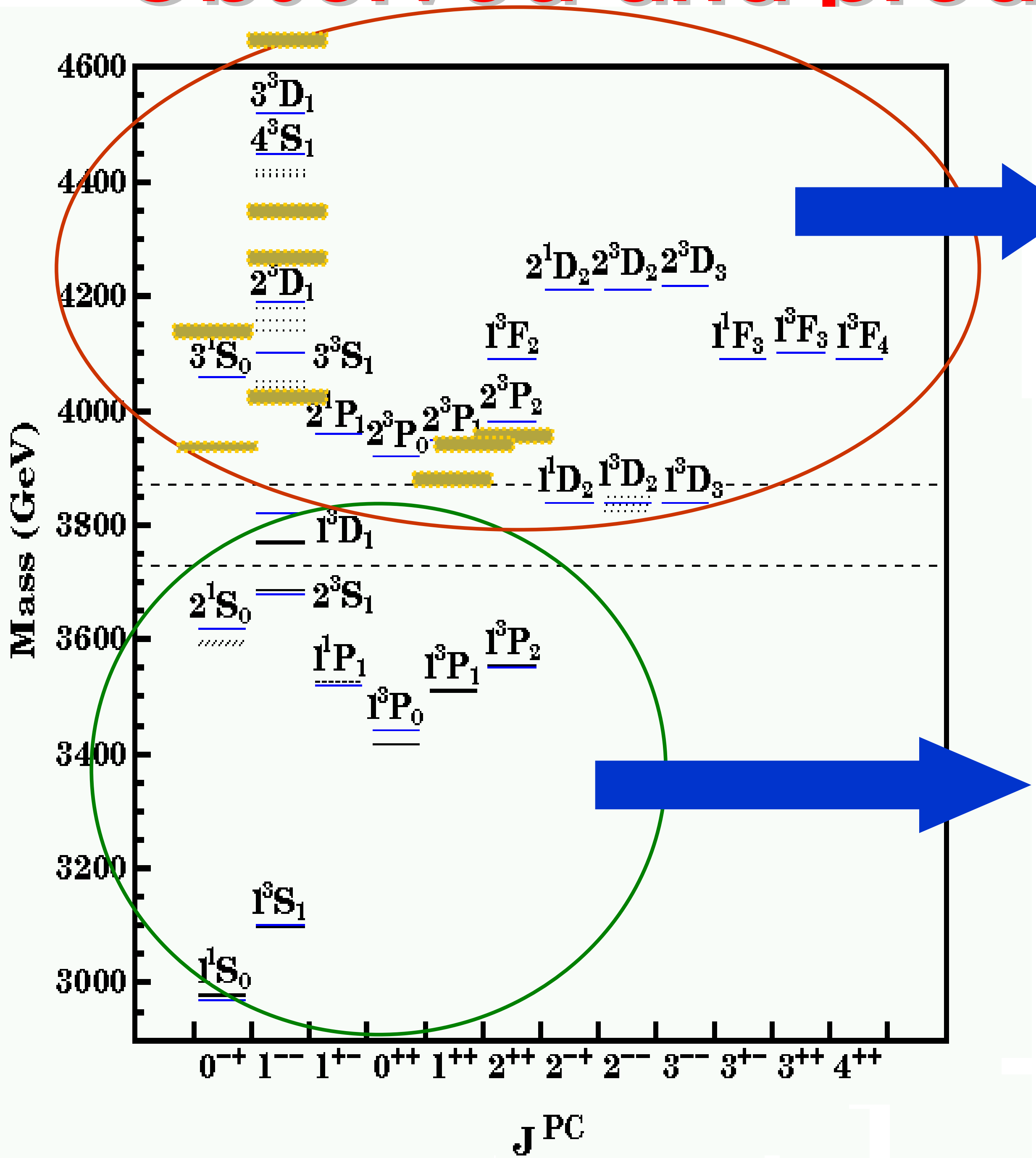


Data and predictions from the default fit model agree very well and little discrimination between spin 0 and 1

Dalitz Plot efficiency in $B \to K^- \pi^+ \chi_{c1}$



Observed and predicted charmonia



A number of unexpected exotic states above $D\bar{D}^{(*)}$ thresholds that do not fit into available $c\bar{c}$ slots

Described well the observed spectrum of $c\bar{c}$ states