Les Rencontres de Physique de la Vallee d'Aoste
1-7 March 2008, La Thuile, Aosta Valley, Italy

Hot topics at Belle

Roman Mizuk (ITEP, Moscow)

XYZ mesons

Dalitz analyses of $B \to K \pi^+ \psi'$ and $B \to K \pi^+ \chi_{c1}$

Charmonium renaissance: XYZ mesons

S.L.Olsen, 0901.2371

state	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes	Observed by:
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	e^+e^- (ISR), $J/\psi \to \eta Y_s(2175)$	BaBar, BESII, Belle
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$,$\gamma J/\psi$, $D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$	Belle, CDF, D0, BaBar
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$	Belle
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$	Belle
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \to KY(3940)$	Belle, BaBar
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	Belle
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$	Belle
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	BaBar, CLEO, Belle
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^-\psi'$	e^+e^-(ISR)	BaBar, Belle
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^-\psi'$	e^+e^-(ISR)	Belle
$Z_1(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm\chi_{c1}$	$B \to KZ_1^\pm(4050)$	Belle
$Z_2(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm\chi_{c1}$	$B \to KZ_2^\pm(4250)$	Belle
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm\psi'$	$B \to KZ^\pm(4430)$	Belle
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^-\Upsilon(1,2,3S)$	$e^+e^- \to Y_b$	Belle

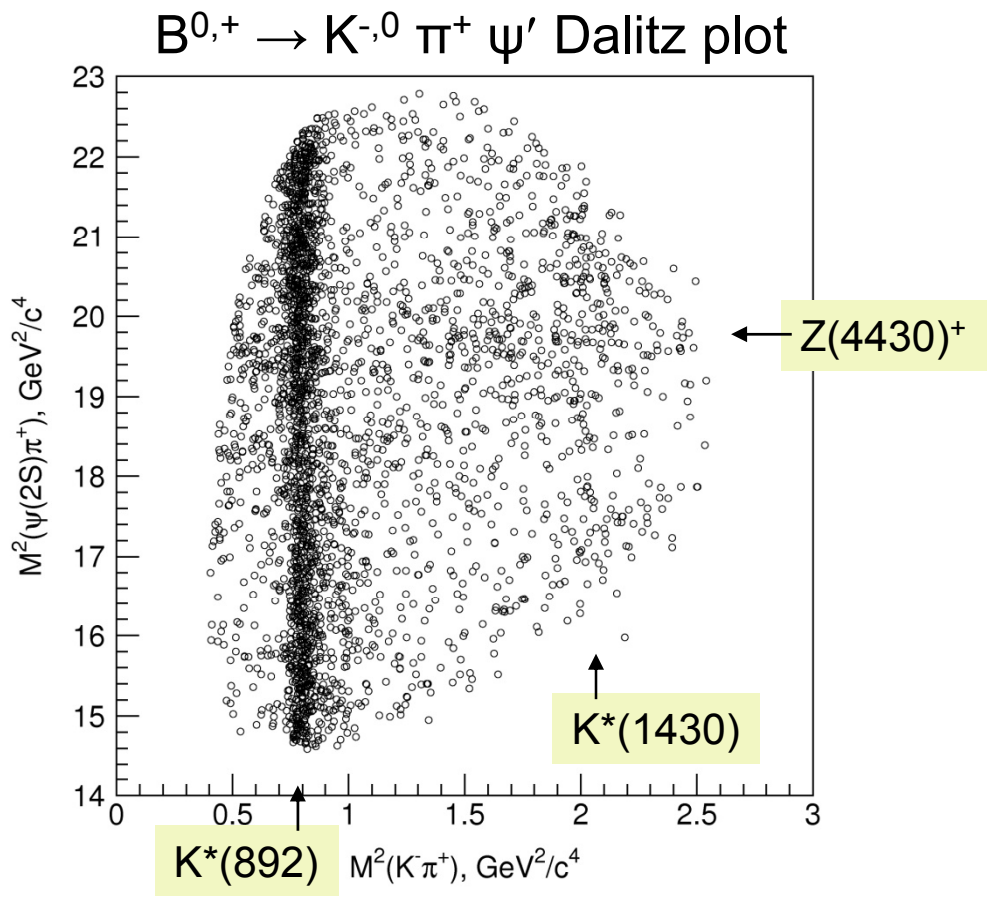
Final states with c and $\underline{c}$, but do not fit expectations for unfilled $c\underline{c}$ levels.

Exotic? tetraquark $|cq\underline{c}q\rangle$, molecule $D\underline{D}$, hybrid $|c\underline{c}g\rangle$.

Manifestly exotic: $Z(4430)^+ \to \pi^+\psi'$ and $Z_1(4050), Z_2(4250) \to \pi^+\chi_{c1} \Leftrightarrow |cu\underline{c}d\rangle$.

Observation of $Z(4430)^+ \to \pi^+ \psi'$

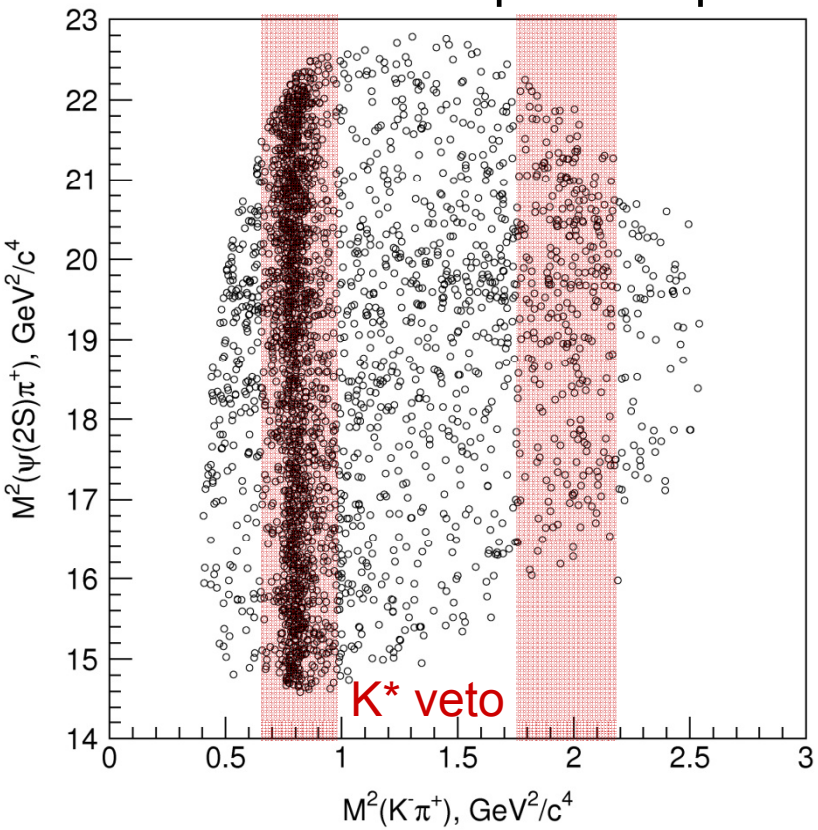
Belle, PRL100,142001



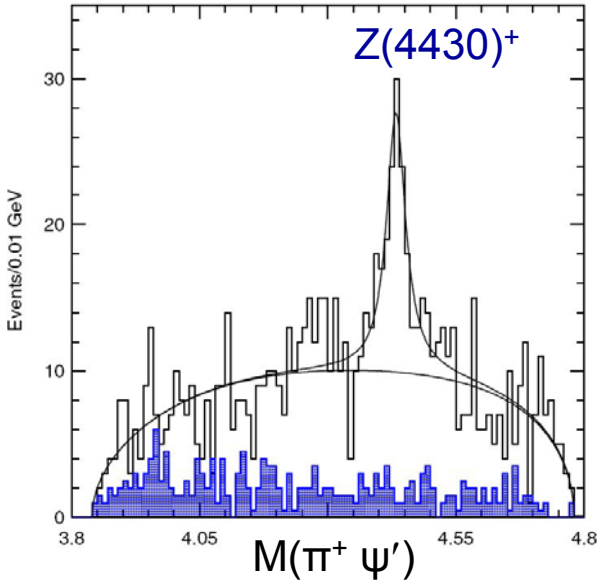
Observation of $Z(4430)^+ \to \pi^+\psi'$

Belle, PRL100,142001

$B^{0,+} \to K^{-,0}\,\pi^+\,\psi'$ Dalitz plot



projection with K* veto applied



$$M = (4433 \pm 4 \pm 2)\,\mathrm{MeV}/c^2$$
$$\Gamma = (45^{+18+30}_{-13-13})\,\mathrm{MeV}$$

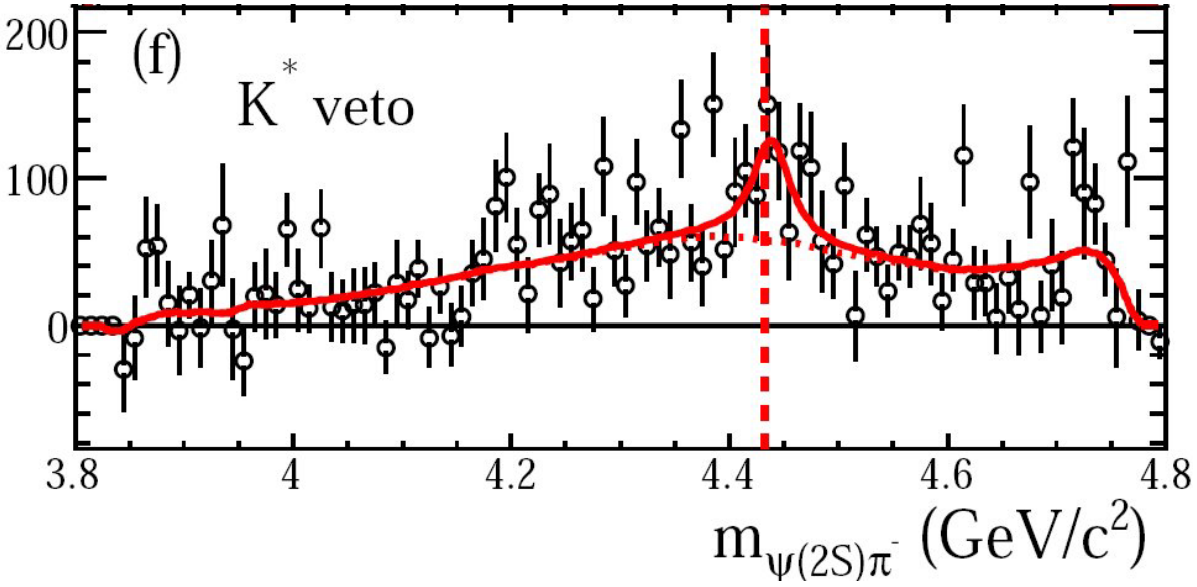
$$\mathcal{B}(\bar{B}^0 \to K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \to \pi^+\psi') = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$

Significance 6.5σ.

Interference of L=0,1,2 waves in $K\pi^+$ system can not produce such a narrow structure.

Search for $Z(4430)^+$ by BaBar

BaBar, 0811.0564
submitted to PRD



"No significant $Z(4430)^+$ signal"

$Z(4430)^+$ significance 1.9σ M,Γ are floating
3.1σ M,Γ are fixed to Belle measurement

"More complicated background shape than assumed by Belle."

⇔ Motivation for $B \to K \pi^+ \psi'$ Dalitz analysis.

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

First presented at QWG08.

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

Amplitude = sum over quasi two-body contributions

Breit-Wigner $\times$ angular dependence

Consider intermediate resonances

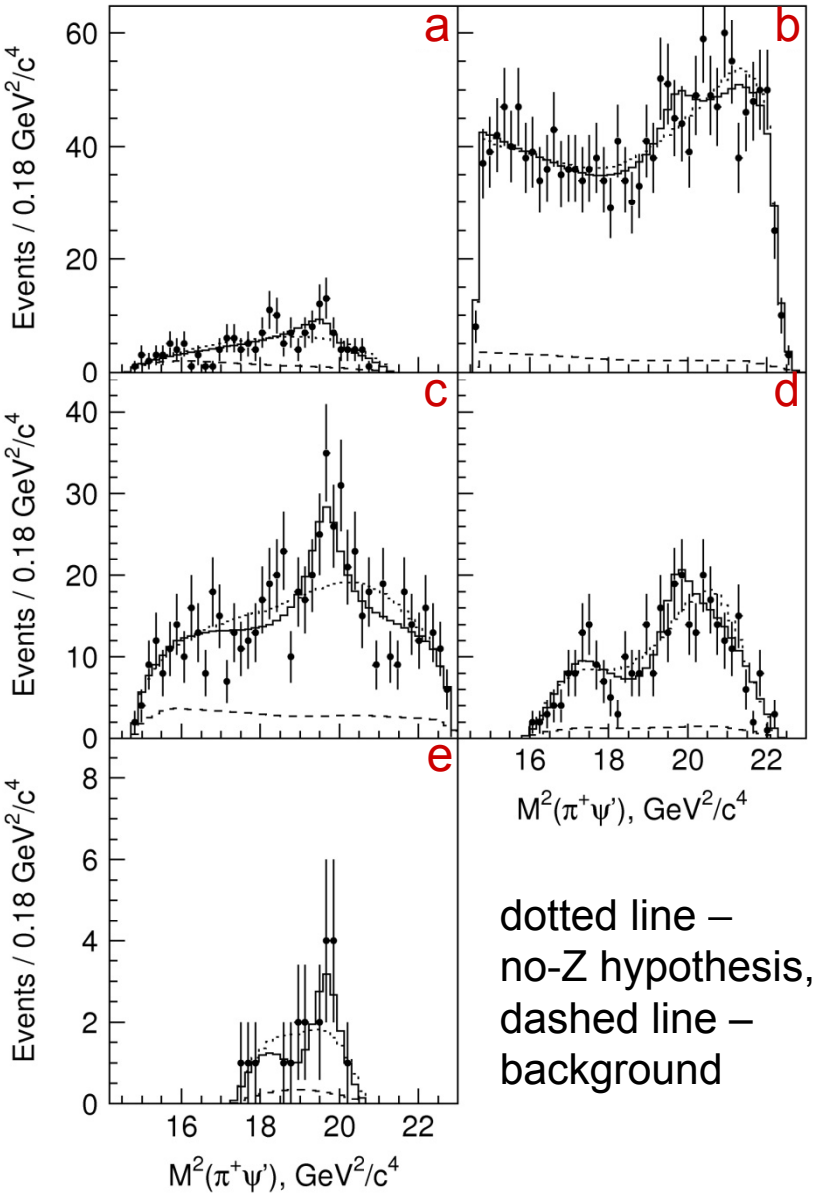
κ, $K^*(892)$, $K^*(1410)$, $K_0(1430)$, $K_2(1430)$, $K^*(1680)$,
$Z(4430)^+ \to \pi^+ \psi'$

Fit function is corrected for efficiency and background.

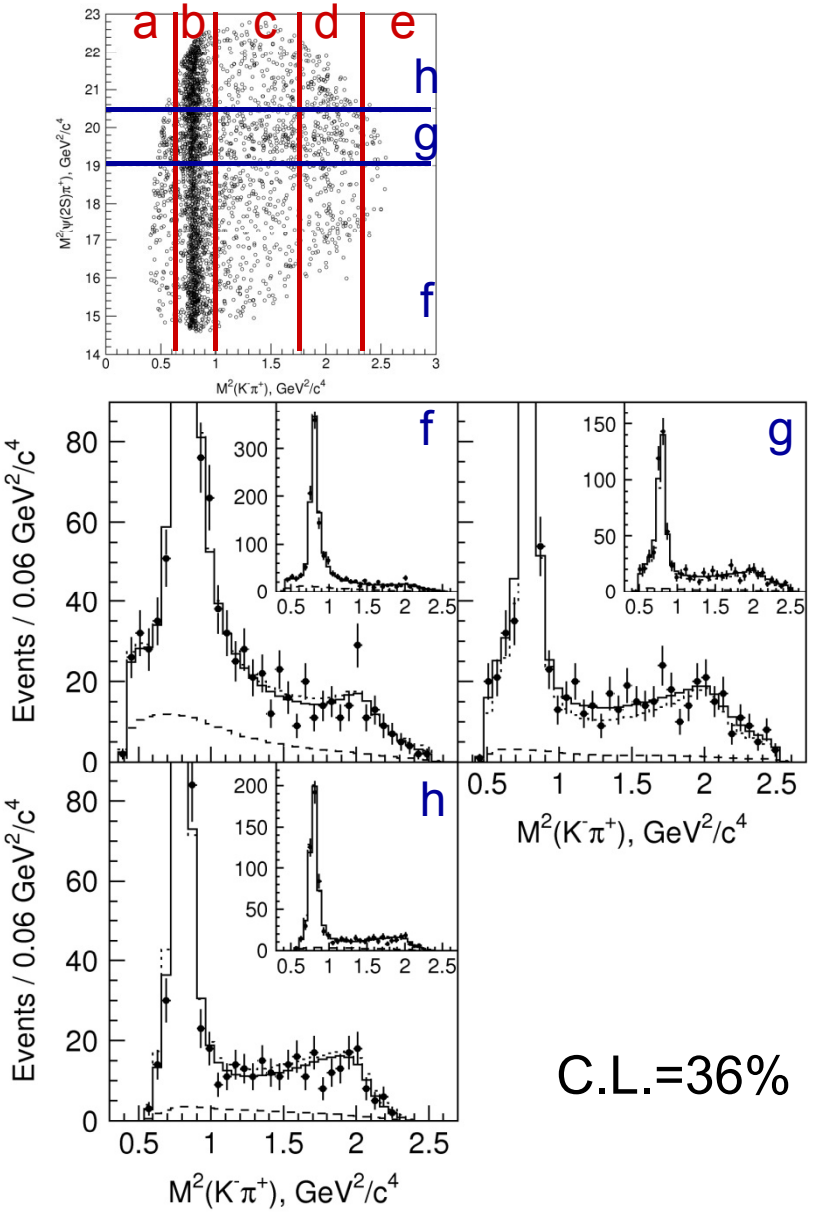
$605 fb^{-1}$

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

Results of B → K π⁺ ψ′ Dalitz plot fit

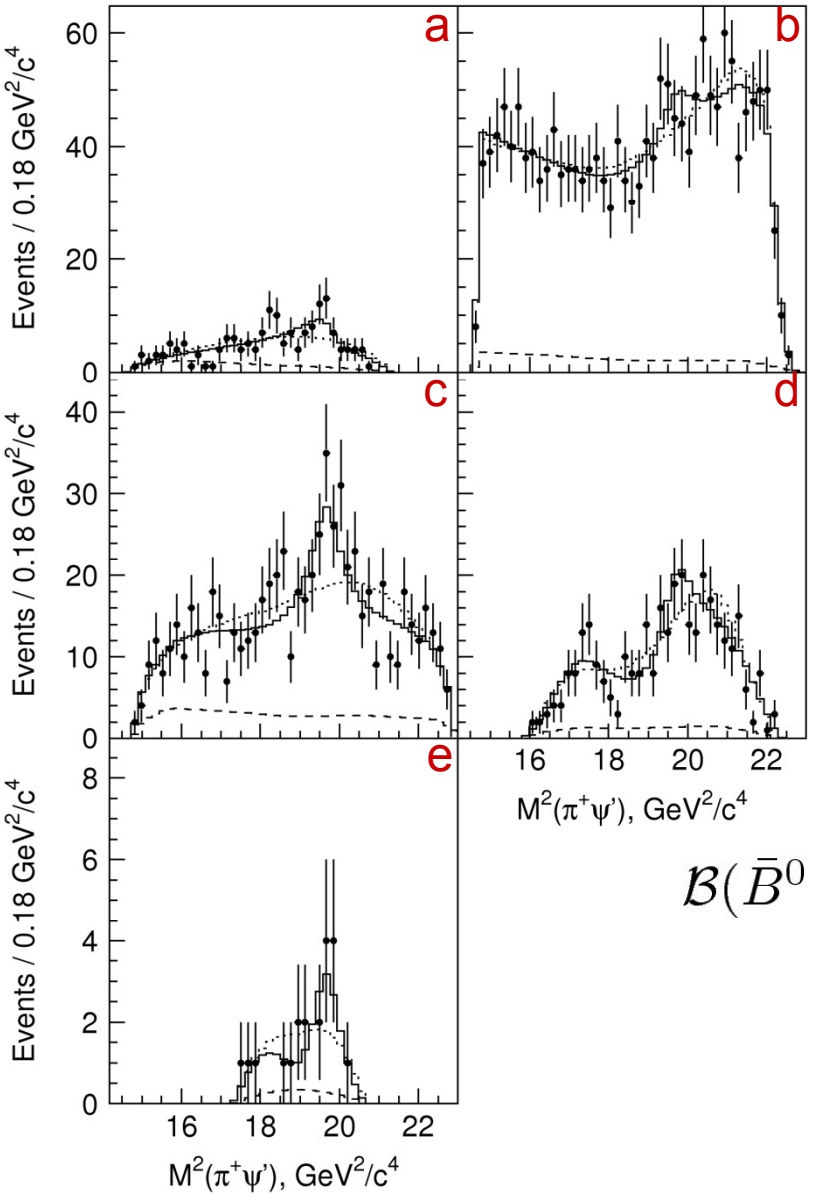


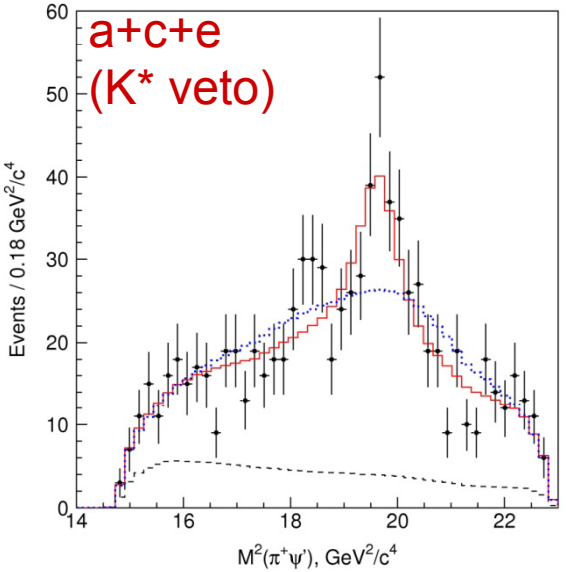
dotted line – no-Z hypothesis, dashed line – background



C.L.=36%

Results of B → K π⁺ ψ′ Dalitz plot fit





Preliminary

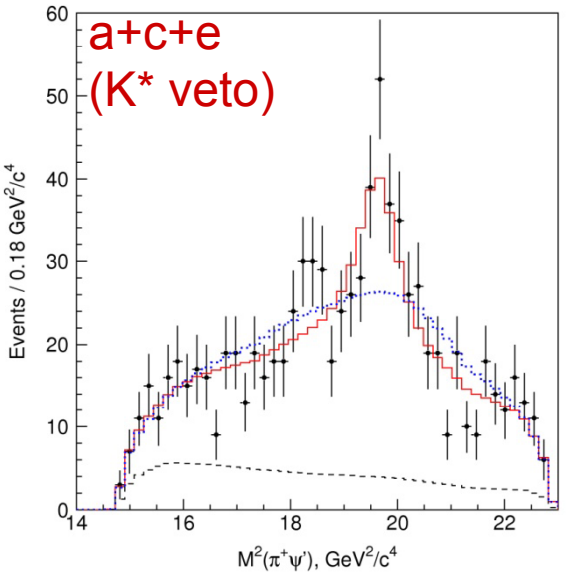
Dalitz analysis results

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

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

Significance 6.4σ

Results of B → K π⁺ ψ′ Dalitz plot fit



Previous measurement

$$M = (4433 \pm 4 \pm 2)\,\mathrm{MeV}/c^2$$
$$\Gamma = (45^{+18+30}_{-13-13})\,\mathrm{MeV}$$

Dalitz analysis results

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

$$\mathcal{B}(\bar{B}^0 \to K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \to \pi^+ \psi')$$
$$= (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$
$$= (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5}$$

Significance 6.5σ

Significance 6.4σ

Dalitz analysis results agree with previous Belle measurement.

Systematics of $B \to K \pi^+ \psi'$ Dalitz plot fit

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	$6.5\,\sigma$

$Z(4430)^+$ significance exceeds 5.4σ for all fit models.

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

Branching fractions

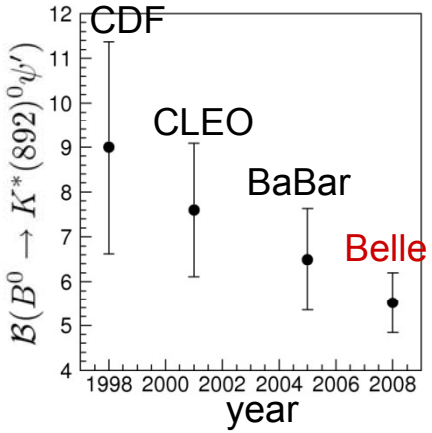
$$\mathcal{B}(\bar{B}^0 \to K^-\pi^+\psi') = (5.68 \pm 0.13 \pm 0.42) \times 10^{-4}$$

$$(5.57 \pm 0.16) \times 10^{-4} \quad \text{BaBar, 0811.0564}$$

(stat.)

$$\mathcal{B}(B^0 \to K^*(892)^0\psi') = (5.52^{+0.35+0.53}_{-0.32-0.58}) \times 10^{-4}$$

$$(7.2 \pm 0.8) \times 10^{-4} \quad \text{PDG}$$



Fraction of K*(892) which are longitudinally polarized

$$f_L = (44.8^{+4.0+4.0}_{-2.7-5.3})\%$$

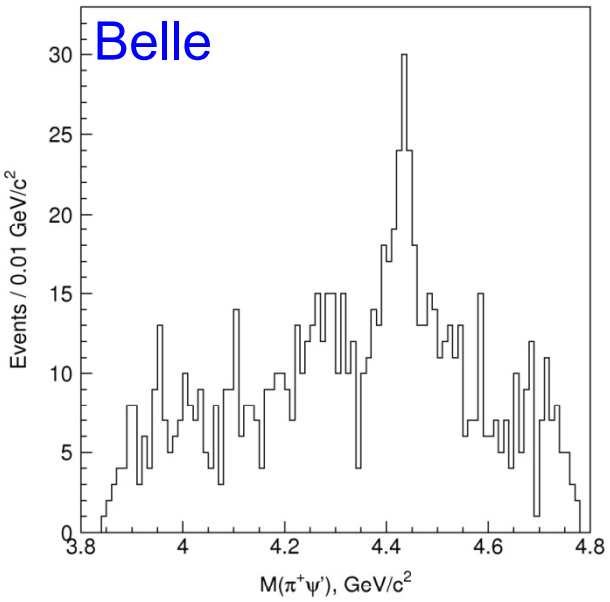
$$0.45 \pm 0.11 \pm 0.04 \quad \text{CLEO, PRD63,031103}$$

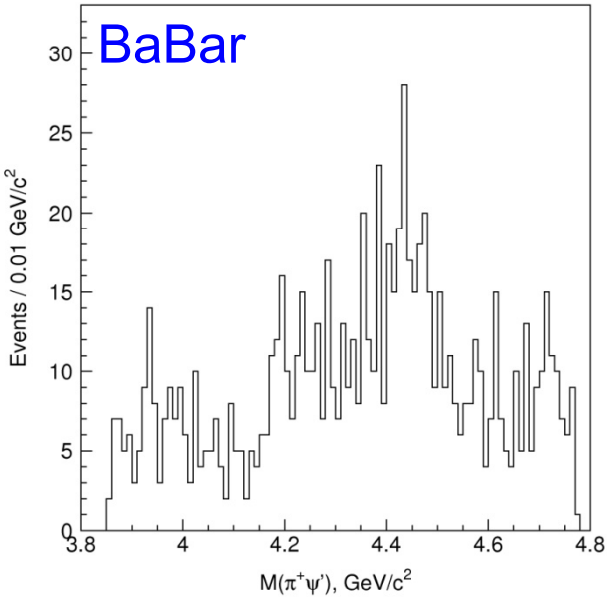
These are the first measurements based on Dalitz analysis.

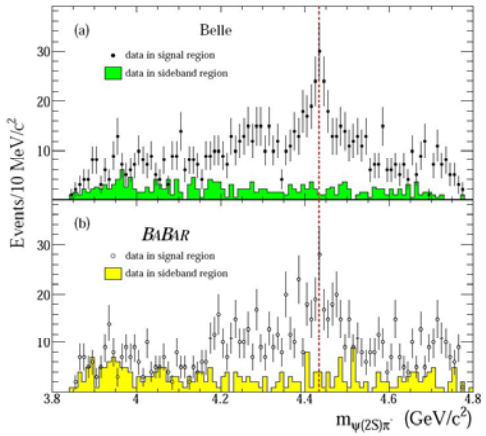
Comparison with BaBar

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:







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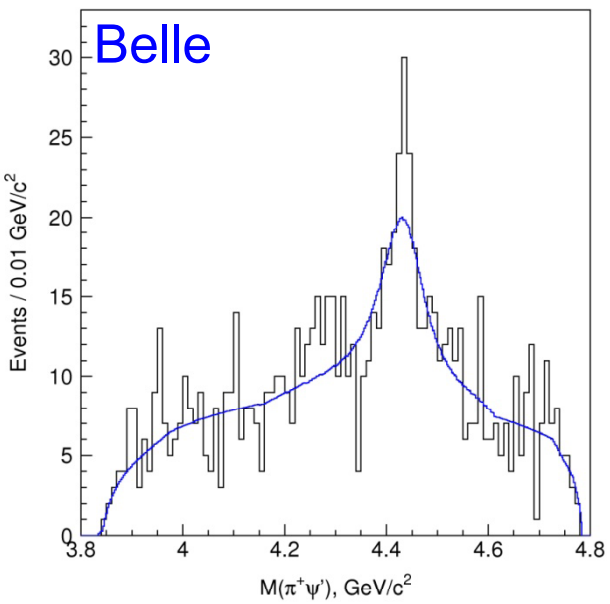
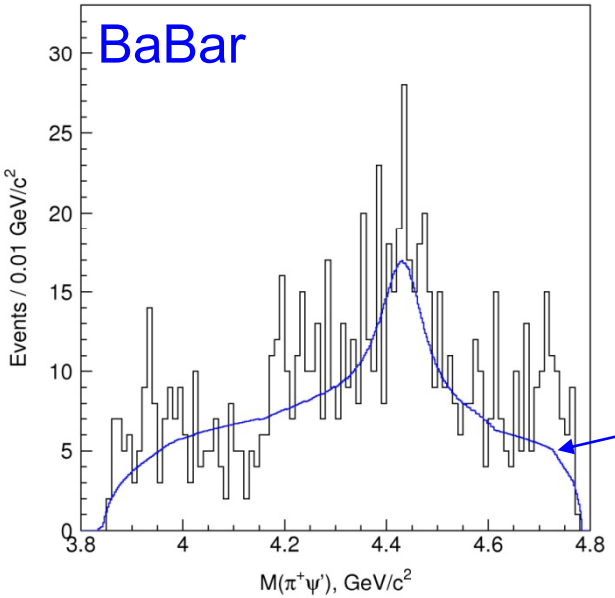




Result of Dalitz fit scaled down by 1.18 to account for smaller statistics @ BaBar.

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

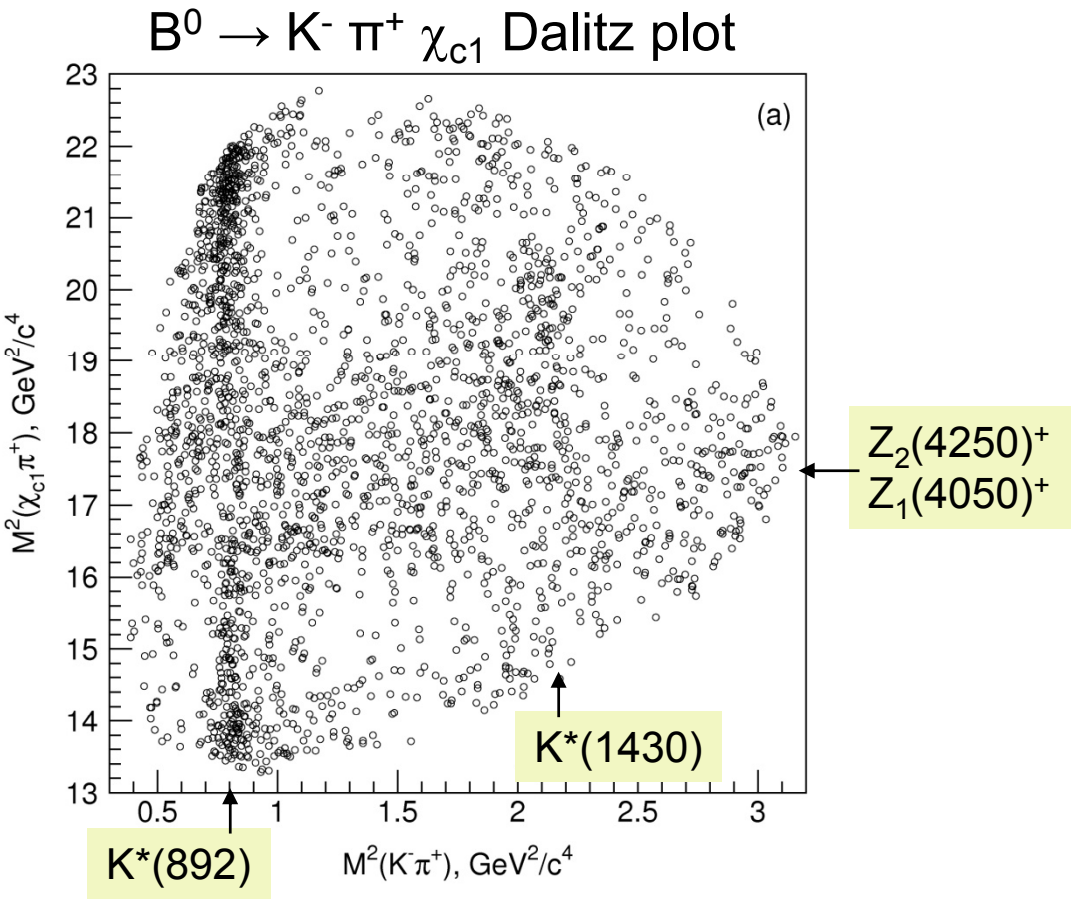
⇔ assumption about background is crucial.

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

Dalitz analysis is preferable.

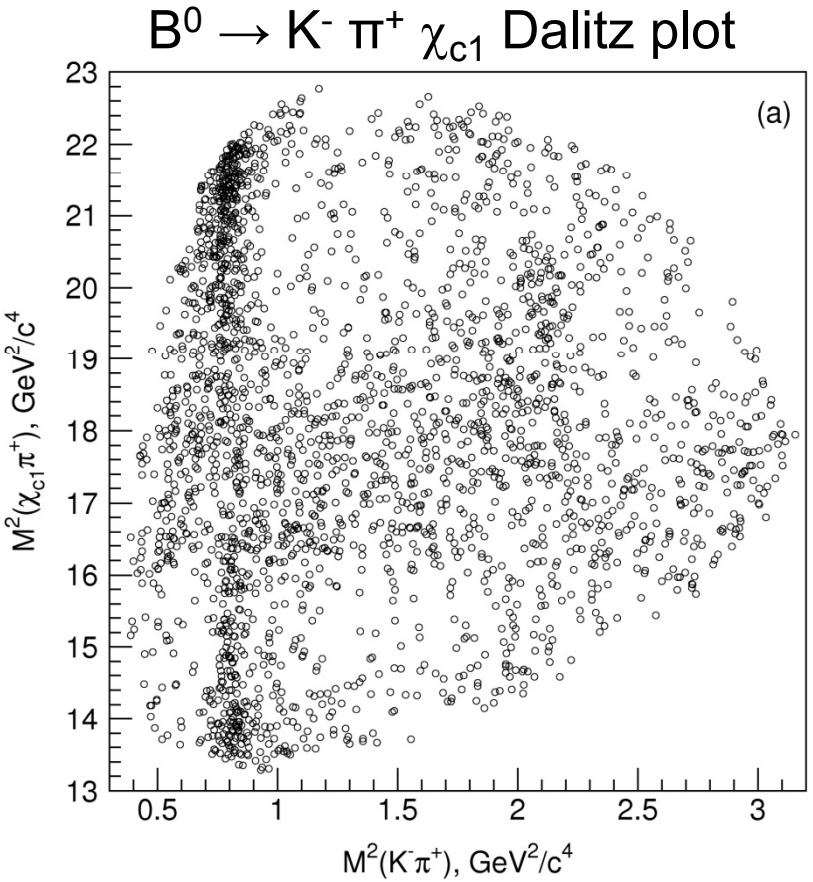
Dalitz plot analysis of $B^0 \to K^- \pi^+ \chi_{c1}$

Belle, PRD78,072004



Dalitz plot analysis of $B^0 \to K^- \pi^+ \chi_{c1}$

Belle, PRD78,072004



Same approach as for $B^0 \to K^- \pi^+ \psi'$

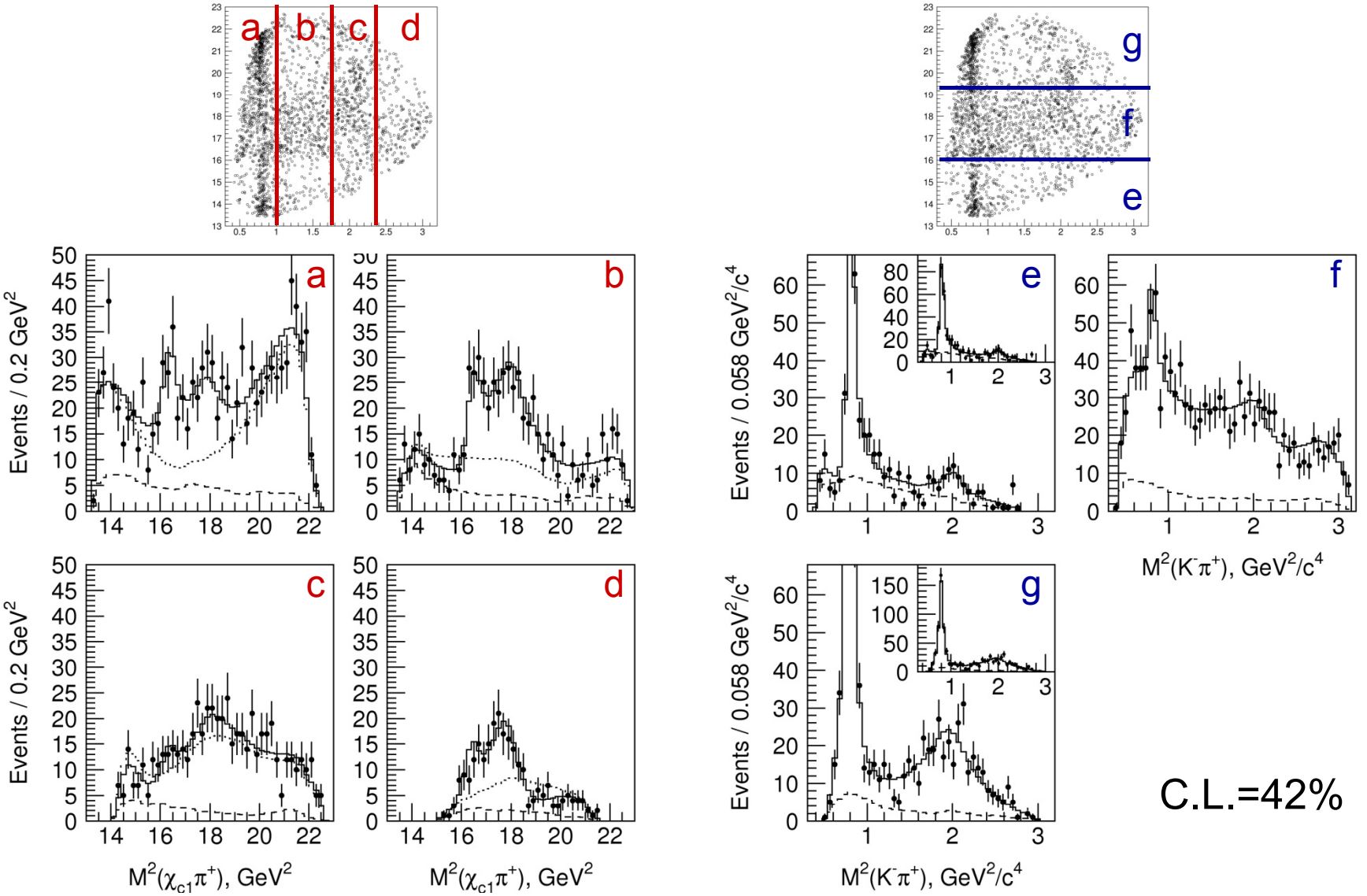
Integrate over χ_{c1} decay angles

Consider intermediate

κ, $K^*(892)$, $K^*(1410)$, $K_0(1430)$, $K_2(1430)$, $K^*(1680)$, $K^*_3(1780)$, $Z^+ \to \pi^+ \chi_{c1}$

Results of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

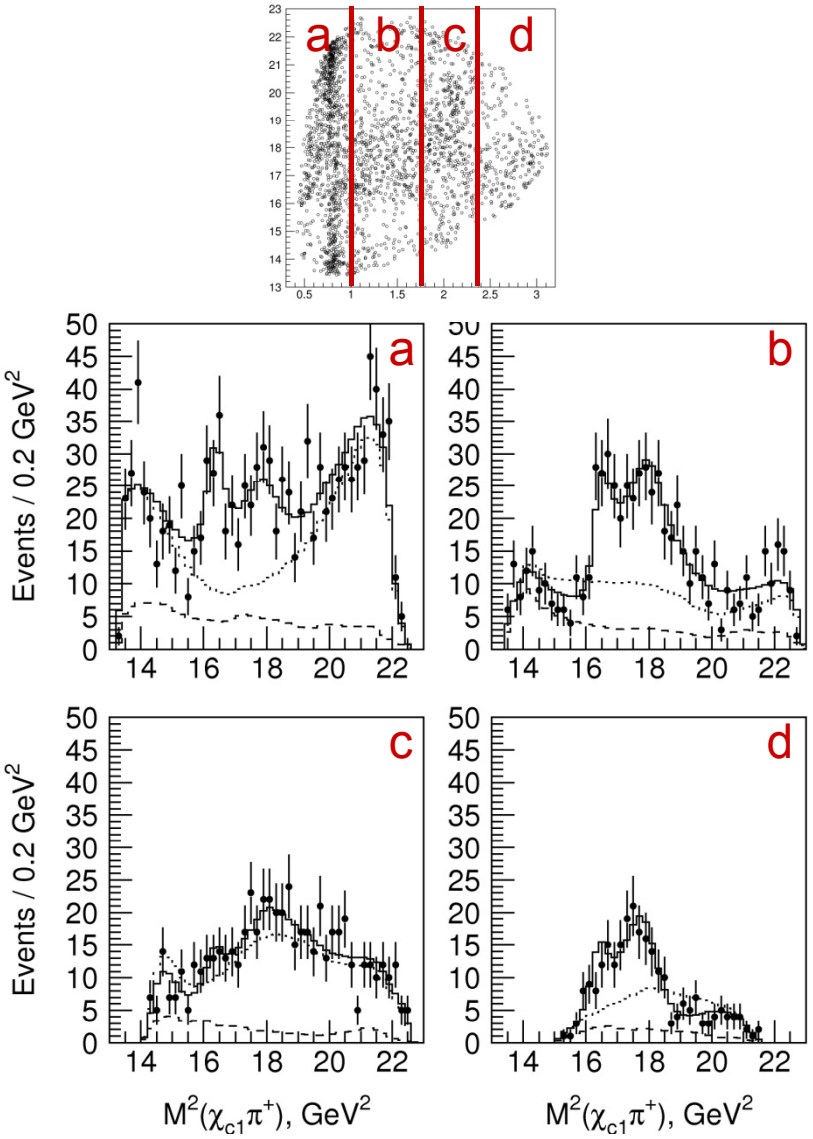
Fit model: all low-lying K* + two ($\pi^+ \chi_{c1}$) resonances



C.L.=42%

Results of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

Fit model: all low-lying K* + two ($\pi^+ \chi_{c1}$) resonances



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

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

$\Leftrightarrow$ $Z_1(4050)^+$ and $Z_2(4250)^+$

Systematics of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

Model	Significance of one Z^+	One Z^+ vs. two Z^+	Significance of two Z^+
default	$10.7\,\sigma$	$5.7\,\sigma$	$13.2\,\sigma$
no κ	$15.6\,\sigma$	$5.0\,\sigma$	$16.6\,\sigma$
no $K^*(1410)$	$13.4\,\sigma$	$5.4\,\sigma$	$14.8\,\sigma$
no $K_0^*(1430)$	$10.4\,\sigma$	$5.2\,\sigma$	$14.4\,\sigma$
no $K^*(1680)$	$13.3\,\sigma$	$5.6\,\sigma$	$14.8\,\sigma$
no $K_3^*(1780)$	$12.9\,\sigma$	$5.6\,\sigma$	$14.4\,\sigma$
add non-resonant $\chi_{c1}K^-$ term	$9.0\,\sigma$	$5.3\,\sigma$	$10.3\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, no $K^*(1410)$	$11.3\,\sigma$	$5.1\,\sigma$	$13.5\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, no $K^*(1680)$	$11.4\,\sigma$	$5.3\,\sigma$	$13.7\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, no $K_3^*(1780)$	$10.8\,\sigma$	$5.4\,\sigma$	$13.2\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, release constraints on κ mass & width	$9.5\,\sigma$	$5.3\,\sigma$	$10.7\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, new K^* $(J=1)$	$7.7\,\sigma$	$5.4\,\sigma$	$9.2\,\sigma$
add non-resonant $\chi_{c1}K^-$ term, new K^* $(J=2)$	$6.2\,\sigma$	$5.6\,\sigma$	$8.1\,\sigma$
LASS parameterization of S-wave component	$12.4\,\sigma$	$5.3\,\sigma$	$13.8\,\sigma$

Significance of $Z_1(4050)^+$ and $Z_2(4250)^+$ is high.

Assume $J_{Z1}=0$, $J_{Z2}=0$. No fit improvement for $J_{Z1}=1$ / $J_{Z2}=1$.

Conclusions

From Dalitz plot analysis of B → K π⁺ ψ′ we find signal of Z(4430)⁺ → π⁺ ψ′

$$M = (4443^{+15+17}_{-12-13})\,\mathrm{MeV}/c^2$$
$$\Gamma = (109^{+86+57}_{-43-52})\,\mathrm{MeV}$$
$$\mathcal{B}(\bar{B}^0 \to K^- Z(4430)^+) \times \mathcal{B}(Z(4430)^+ \to \pi^+ \psi') = (3.2^{+1.8+5.3}_{-0.9-1.6}) \times 10^{-5}$$

Significance 6.4σ

These results agree with and supersede our previous measurement.

Belle and BaBar data are consistent, Z(4430)⁺ peak is present in both.
Peak significance crucially depends on assumed background shape.

Belle – full Dalitz analysis

BaBar – simplified approach, freedom in background description

~~"Z(4430)⁺ is ruled out by BaBar."~~

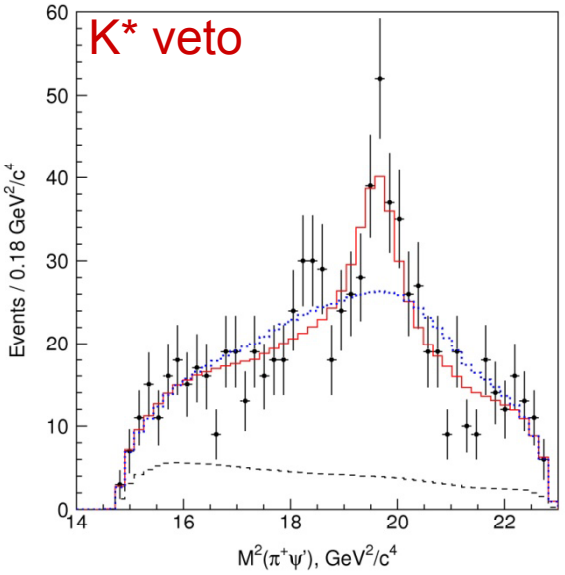
From Dalitz plot analysis of B → K π⁺ χ_{c1} we observe two new states

$Z_1(4050)$, $Z_2(4250) \to \pi^+ \chi_{c1}$

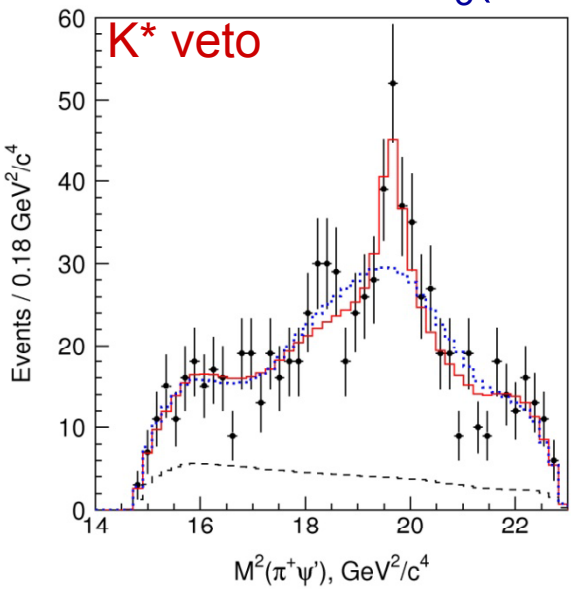
Back-up

Other fits of B → K π⁺ ψ′ Dalitz plot

default model



default model + $K^*_3(1780)$



Significance of $Z(4430)^+$ 6.4σ → 4.7σ if $K^*_3(1780)$ is included in default model.

We measure $\mathcal{B}(B \to K_3^*(1780)\psi') \simeq 0.5 \times \mathcal{B}(B \to K^*(982)\psi')$

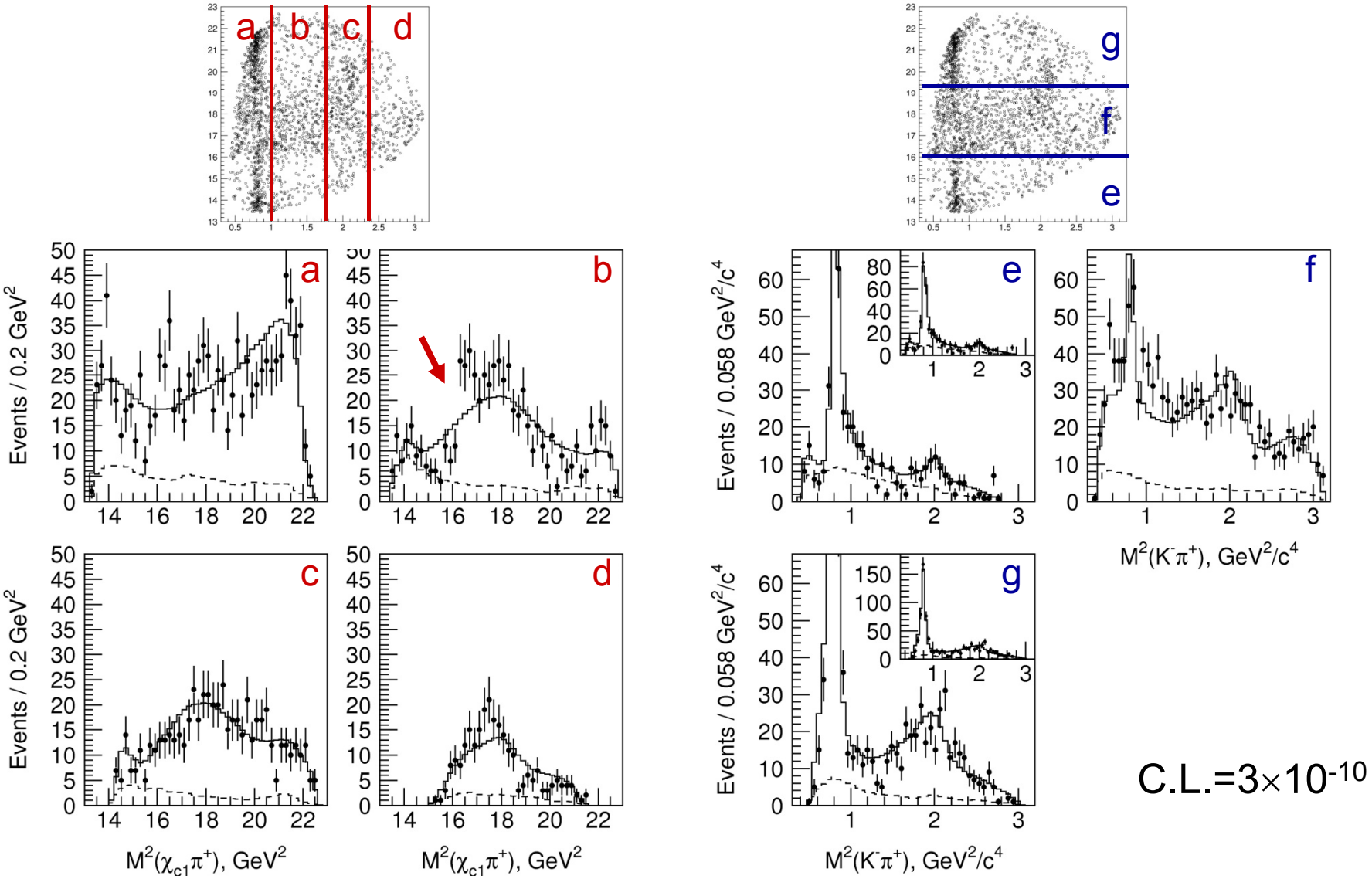
$K^*_3(1780)$ is
- 180MeV $\left(1.2\,\Gamma_{K_3^*(1780)}\right)$ above kinematic limit
- suppressed by centrifugal barrier with L≥2

BR is anomalously high and would imply non-trivial dynamics in manifestly exotic $K^*_3(1780)\psi'$ channel ⇒ 4.7σ is underestimate.

Toy MC: large measured $K^*_3(1780)$ fraction can happen due to stat. fluctuation.

Results of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

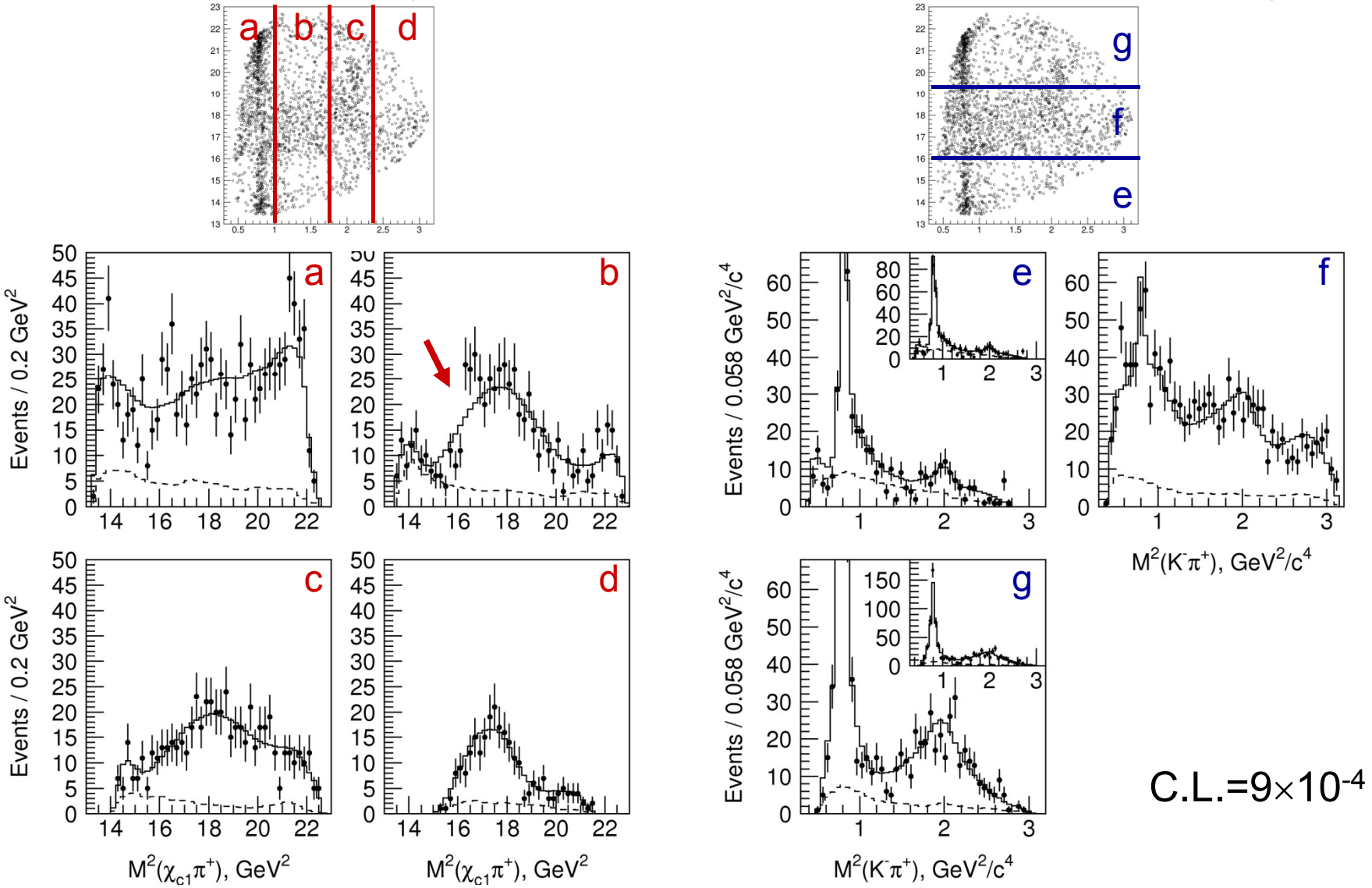
Fit model: all low-lying K* resonances



C.L.=3×10^{-10}

Results of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

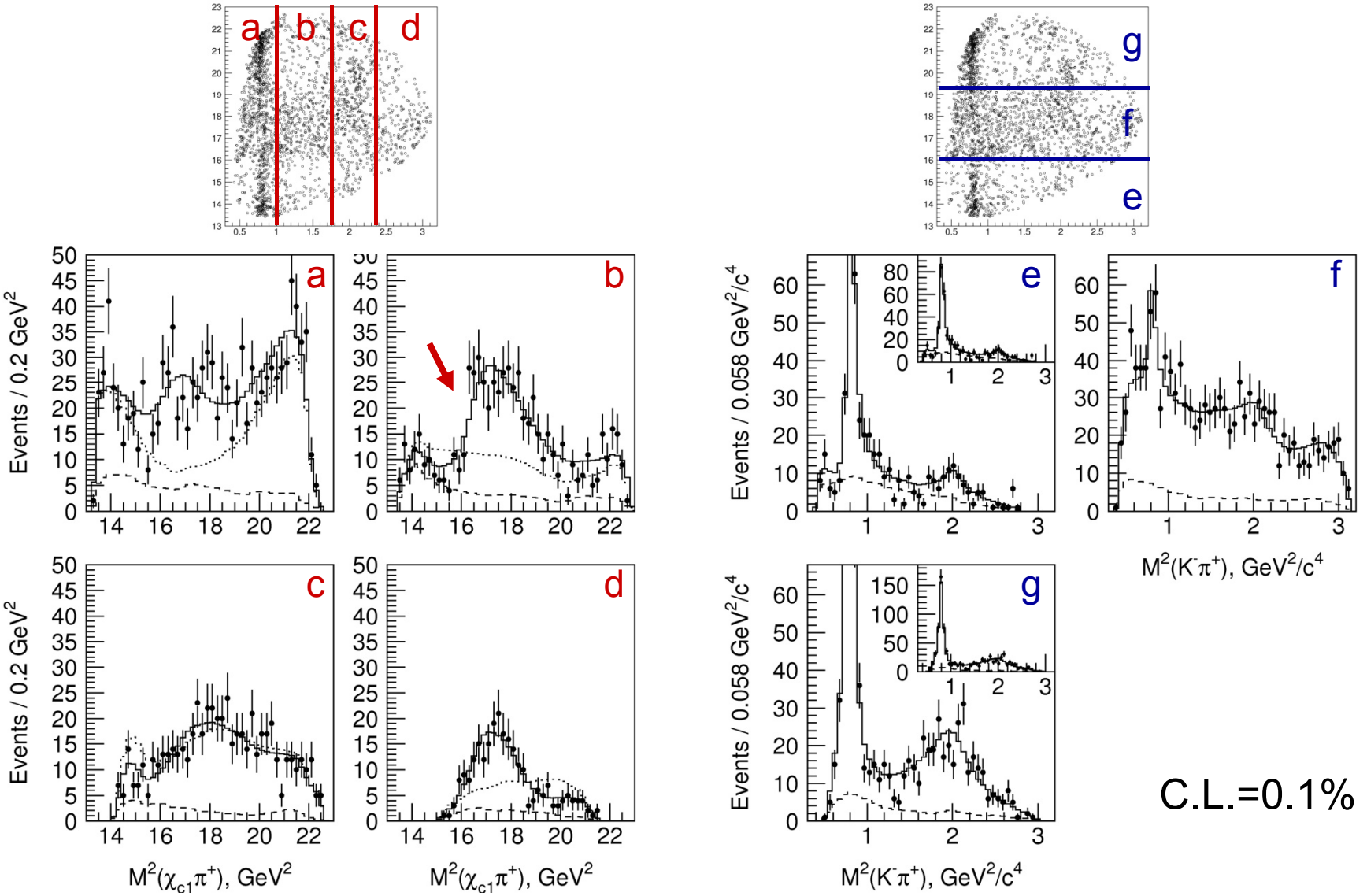
Fit model: all low-lying K* resonances + non-res. term + new K* (J=2)
(best description of data w/o exotic resonances)



C.L.=9×10^{-4}

Results of $B^0 \to K^- \pi^+ \chi_{c1}$ Dalitz plot fit

Fit model: all low-lying K* + ($\pi^+ \chi_{c1}$) resonance



C.L.=0.1%