Dalitz Plot Analysis of Heavy Quark Mesons Decays (4). The question of Z^+ resonances.

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Introduction.

□ Belle Experiment claims for the discovery of exotic charged charmonium states in B decays. $Z^+(4430) \to \psi(2S)\pi^+$ observed the decay $B \to \psi(2S)K\pi$ (Phys. Rev. Lett. 100, 142001, (2008)),(Phys. Rev. D 80, 031104(R) (2009))

□ Further $Z_1(4050)^+$ and $Z_2(4250)^+$ observed in the decay to $\chi_{c1}\pi^+$ in $B \to \chi_{c1}K\pi$ (Phys.Rev.D 78, 072004, (2008))

□ BaBar published the search for $Z^+(4430) \to \psi(2S)\pi^+$ with negative results (Phys. Rev. D 79, 112001 (2009)).

□ BaBar published the search for $Z_1(4050)^+$ and $Z_2(4250)^+$ in $B \to \chi_{c1}K\pi$ with negative results (Phys. Rev. D .

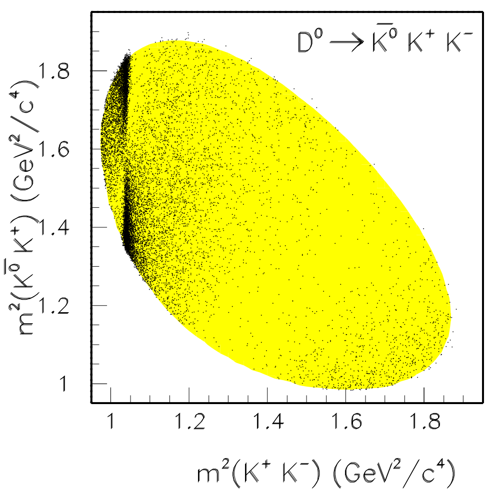
□ No signal was also observed in the $J/\psi\pi$ system in the study of the $B \to J/\psi K\pi$ decay.

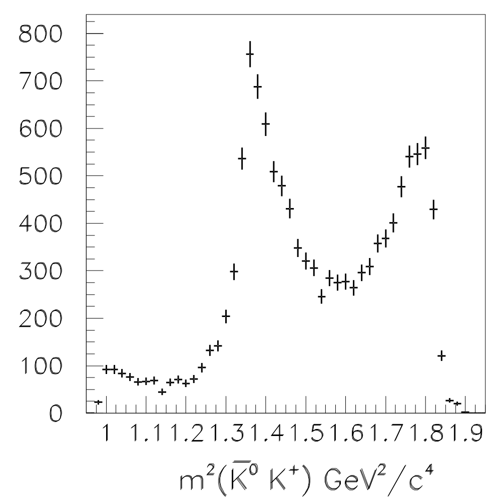
□ A lot of theoretical and experimental discussion. A charged charmonium state is not a simple $q\bar{q}$ meson.

Introduction.

□ Main points of discussion are:

- Interference effects between amplitudes in 3-body B decay Dalitz plots produce peaks in quasi-two-body mass projections which may not be due to real states.
  A dramatic demonstration comes from charm decays. Dalitz plot of $D^0 \to \bar{K}^0 K^+ K^-$ and projection along the $\bar{K}^0 K^+$ axis: structures are not due to resonances.

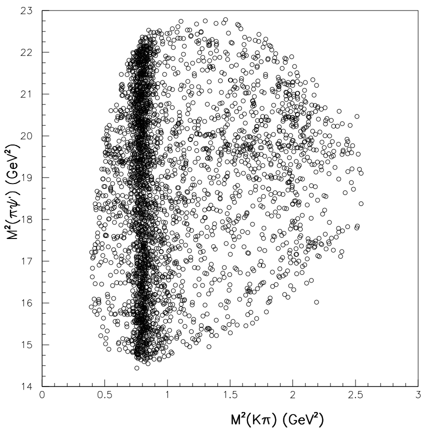


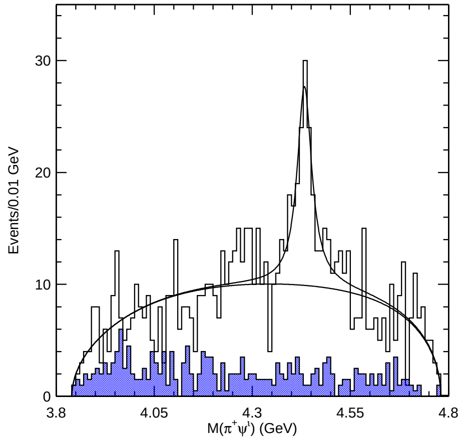


- The angular structures in $B \to \psi(2S) K\pi$ and $B \to \chi_{c1} K\pi$ decays are very complex and cannot be described by only two variables as it is done in a simple Dalitz plot analysis See BaBar analysis of $B \to J/\psi K pi$ (arXiv:hep-ex/0411016).

Belle observation of $Z^+(4430)$.

□ They select events of the type $B \to K\pi^+\psi'$, where the ψ' decays either to $\ell^+\ell^-$ or $\pi^+\pi^- J/\psi$ with $J/\psi \to \ell^+\ell^-$ ($\ell = e$ or μ). Both charged and neutral ($K^0_S \to \pi^+\pi^-$) kaons are used.
□ Dalitz plot and $\pi^+\psi'$ mass spectrum with K^* veto.





□ Some clustering of events in a horizontal band is evident in the upper half of the Dalitz plot near $M^2(\pi\psi') \simeq 20$ GeV^2.
□ To study these events with the effects of the known $K\pi$ resonant states minimized, they restrict the analysis to the events with $|M(K\pi) - m_{K^*(890)}| \geq 0.1$ GeV and $|M(K\pi) - m_{K_2^*(1430)}| \geq 0.1$ GeV (K^* veto).
□ Fitting the resulting $\pi^+\psi'$ mass spectrum with a Breit-wigner they obtain the following parameters

$$M = (4433 \pm 4(\text{stat}) \pm 2(\text{syst}))\ \text{MeV},\ \ \Gamma = (45^{+18}_{-13}(\text{stat})^{+30}_{-13}(\text{syst}))\ \text{MeV}$$

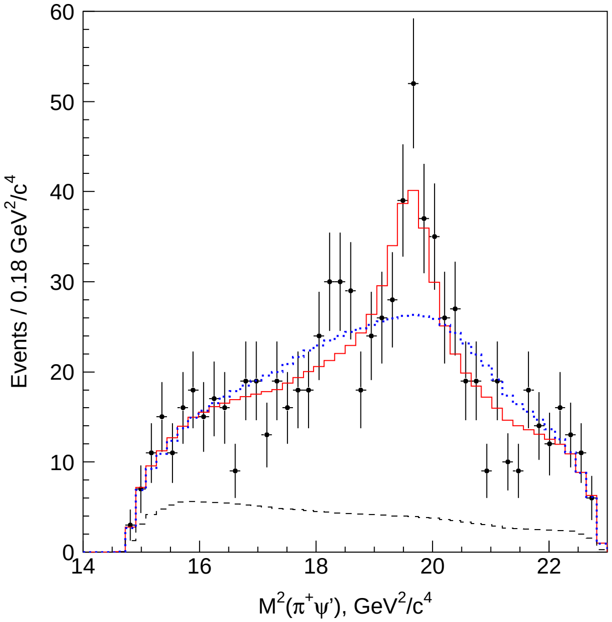
□ commenting that Γ is too narrow to be caused by interference effects in the $K\pi$ channel.
□ The statistical significance of the observed peak is 6.5σ.

Belle observation of $Z^+(4430) \to \psi(2S)\pi^+$. Dalitz analysis

- Belle re-analyzed the $B \to \psi(2S)K\pi$ data using a Dalitz analysis (arXiv:0905.2869).
- They confirm the signal for $Z^+(4430) \to \psi(2S)\pi^+$ with a mass:

$$M = (4443^{+15}_{-12}{}^{+19}_{-13})\,\mathrm{MeV}/c^2,\ \Gamma = (107^{+86}_{-43}{}^{+74}_{-56})\,\mathrm{MeV}$$

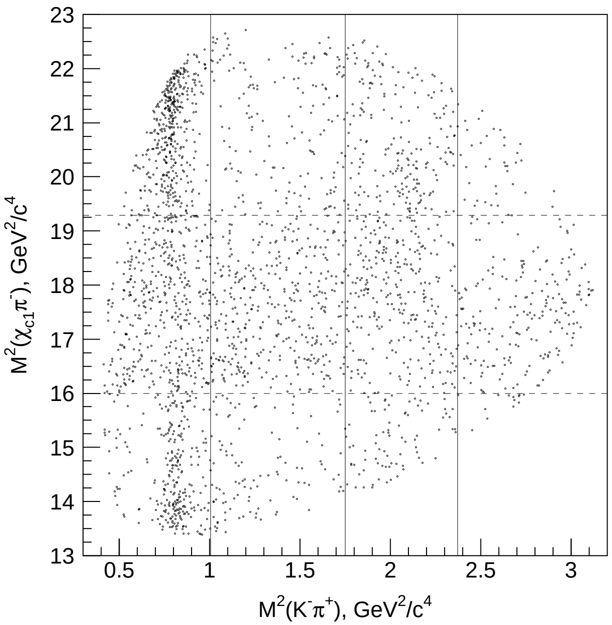
- A somewhat larger width.



Belle observation of $Z_1(4050)^+$ and $Z_2(4250)^+$. Dalitz analysis

□ Belle reconstructed the decay $B \to K^-\pi^+\chi_{c1}$ with the χ_{c1} reconstructed in the $J/\psi\gamma$ decay mode and the J/ψ reconstructed in the $\ell^+\ell^-$ decay mode.

□ Dalitz plot and $M(\pi^+\chi_{c1})$ showing the new Z resonances.



□ In the Dalitz analysis the decay $B \to K^-\pi^+\chi_{c1}$ is described by six variables.

□ They take these to be $M(\pi^+\chi_{c1})$, $M(K^-\pi^+)$, the χ_{c1} and J/ψ helicity angles ($\theta_{\chi_{c1}}$ and $\theta_{J/\psi}$), and the angle between the χ_{c1} (J/ψ) production and decay planes $\phi_{\chi_{c1}}$ ($\phi_{J/\psi}$).

□ Then they analyze the $B \to K^-\pi^+\chi_{c1}$ decay process after integrating over the angular variables $\theta_{\chi_{c1}}$, $\theta_{J/\psi}$, $\phi_{\chi_{c1}}$ and $\phi_{J/\psi}$.

□ They perform a **binned likelihood fit** to the Dalitz plot distribution.

□ The angular function T_λ is obtained using the helicity formalism.

□ For the $B \to K^*(\to K^-\pi^+)\chi_{c1}$ decay

$$T_\lambda = d^J_{\lambda\,0}(\theta_{K^*}), \tag{1}$$

where J is the spin of the K^* resonance; θ_{K^*} is the helicity angle of the K^* decay.

□ For the $B \to K^- Z^+(\to \pi^+\chi_{c1})$ decay

$$T_\lambda = d^J_{0\,\lambda}(\theta_{Z^+}), \tag{2}$$

where J is the spin of the Z^+ resonance and θ_{Z^+} is the helicity angle of the Z^+ decay.

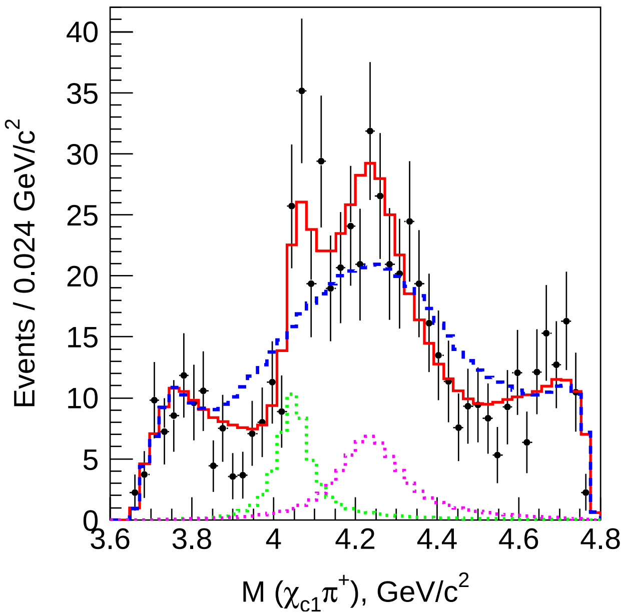
□ The resulting expression for the signal event density function is

$$S(s_x, s_y) = \sum_{\lambda=-1,0,1} \Big| \sum_{K^*} a^{K^*}_\lambda e^{i\phi^{K^*}_\lambda} A^{K^*}_\lambda(s_x, s_y) + \sum_{\lambda'=-1,0,1} d^1_{\lambda'\lambda}(\theta)\, a^{Z^+}_{\lambda'} e^{i\phi^{Z^+}_{\lambda'}} A^{Z^+}_{\lambda'}(s_x, s_y)\Big|^2, \tag{3}$$

where a^R_λ and ϕ^R_λ are the normalizations and phases of the amplitudes for the intermediate resonance R and χ_{c1} helicity λ. The phase $\phi_0^{K^*(892)}$ is fixed to zero.

Belle observation of $Z_1(4050)^+$ and $Z_2(4250)^+$. Dalitz analysis

- They fit with one or two resonances.



- The mass and width of the Z^+ found from the fit are

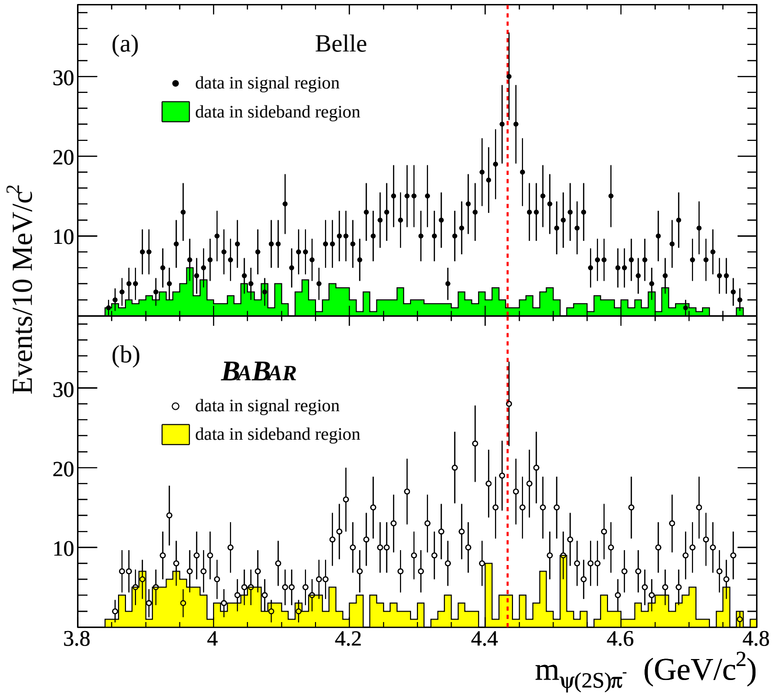
$$M = (4150^{+31}_{-16})\ \text{MeV}/c^2 \text{ and } \Gamma = (352^{+99}_{-43})\ \text{MeV};$$

- When fitted with two Breit-Wigner resonance amplitudes, the resonance parameters are

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

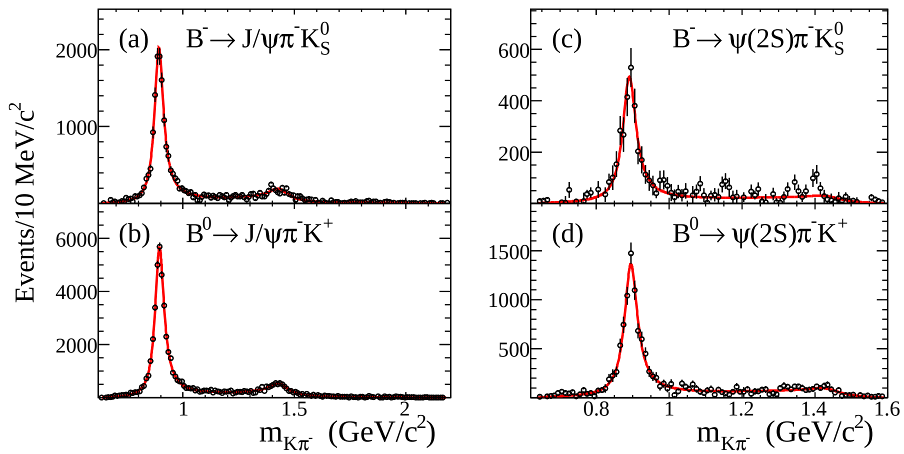
BaBar analysis of $B \to \psi(2S) K \pi$

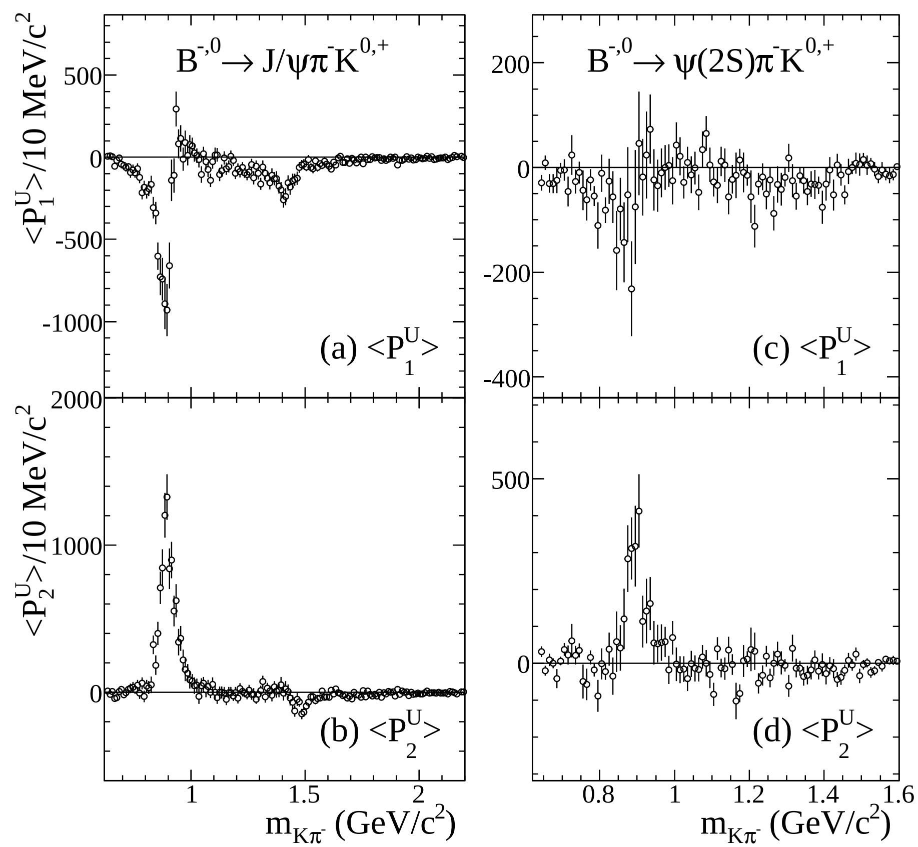
- Babar made use of a different approach (arXiv:0811.0564).
- First we observe that *BaBar* and Belle data are consistent.



BaBar analysis of $B \to \psi(2S)K\pi$

□ $K\pi$ mass spectra and Y_L^0 Legendre polynomials for $B \to \psi(2S)K\pi$ and $B \to \psi K\pi$.





□ $K\pi$ mass spectra and Y_L^0 Legendre polynomials are similar between $B \to \psi K\pi$ and $B \to \psi(2S)K\pi$.

Fits to the $K\pi$ mass spectra.

□ Binned χ^2 fits to the background-subtracted and efficiency-corrected $K\pi$ mass spectra in terms of S, P, and D wave a mplitudes.

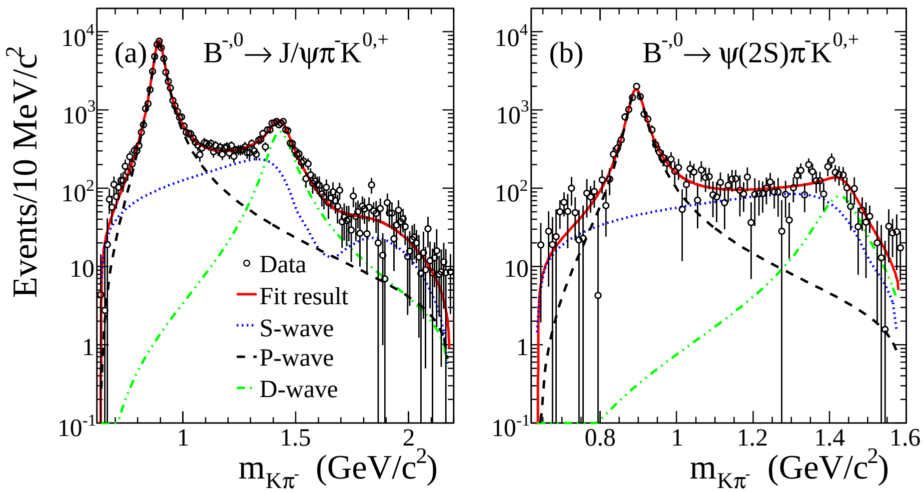
□ Fitting function:

$$\frac{dN}{dm_{K\pi}} = N \times \left[f_S \left(\frac{G_S}{\int G_S dm_{K\pi}} \right) + f_P \left(\frac{G_P}{\int G_P dm_{K\pi}} \right) + f_D \left(\frac{G_D}{\int G_D dm_{K\pi}} \right) \right]$$

□ where the fractions f are such that: $f_S + f_P + f_D = 1$.

□ The P- and D-wave intensities are expressed in terms of relativistic Breit-Wigner with parameters fixed to the PDG values f or $K^*(892)$ and $K_2^*(1430)$ respectively.

□ For S-wave contribution has been described by the LASS parametrization.



□ Notice the Log. scale. Notice also a discrepancy between the the data and the LASS representation of the threshold region.

Description of the $\psi(2S)\pi$ mass spectrum.

☐ A localized structure in the $\psi(2S)\pi$ mass spectrum shows its effect in high L Legendre polynomial moments $< Y_L^0 >$.

☐ The BaBar analysis attempts to describe the $\psi(2S)\pi$ mass distribution using the information from the $K\pi$ system only using Legendre polynomials from $B \to \psi K\pi$ or the $B \to \psi(2S)K\pi$

☐ *They also limit L to its minimum possible value.*

☐ They generate a large number of MC events according to the following model.

- $B \to \psi(2S)K\pi$ events are generated according to phase-space.
- Label $w_{m(K\pi)}$ the weight corresponding to the fit to the $K\pi$ mass projection.
- Incorporate the measured $K\pi$ angular structure by giving weight w_L to each event according to the expression:

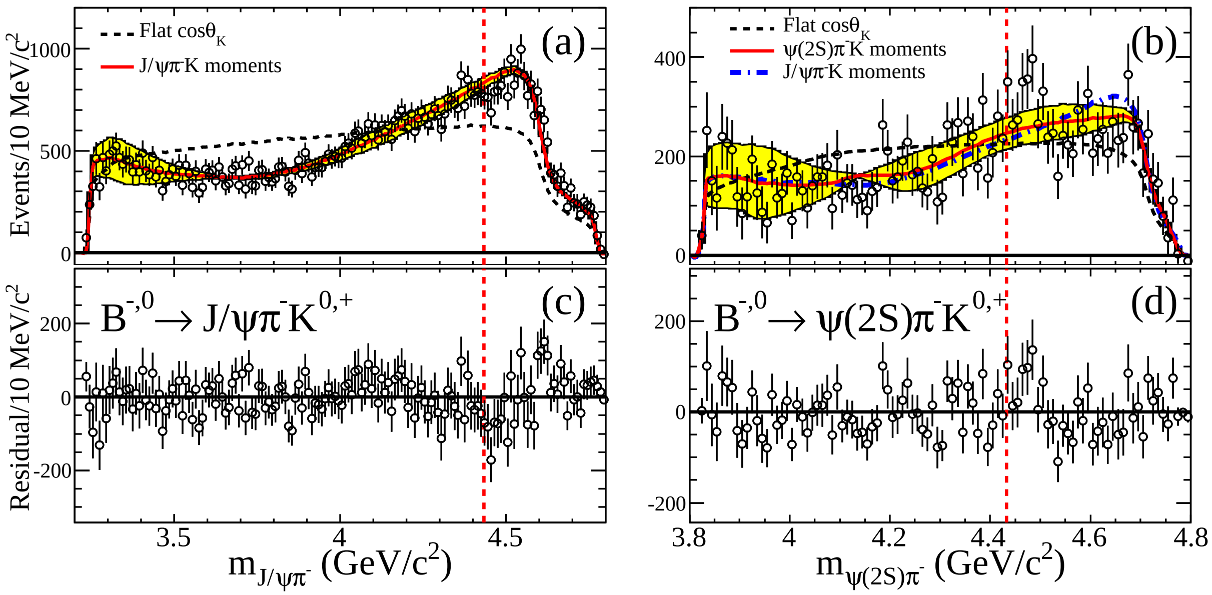
$$w_L = \sum_{i=0}^{L_{max}} < Y_i^N > Y_i^0(\cos\theta)$$

  where $Y_i^N = Y_i^0/n$ are the normalized moments. The Y_i^N are evaluated for the $m(K\pi)$ value by linear interpolation over consecutive $m(K\pi)$ mass intervals.
- The total weight is thus:

$$w = w_{m(K\pi)} \cdot w_L$$

Data-MC comparison.

□ The generated distributions, weighted by the total weight w, are then normalized to the number of data events after background-subtraction and efficiency-correction.



□ The simulation is performed using the $B \rightarrow J/\psi K\pi$ or $B \rightarrow J/\psi K\pi$ data.

□ Both simulations describe the data well.

□ No need for additional Z resonances.

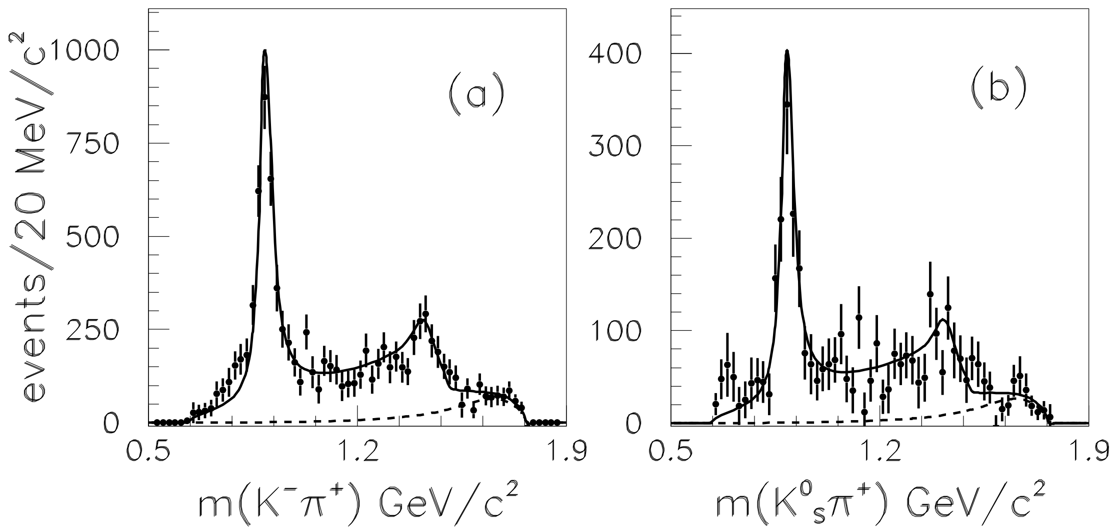
□ Areas in color describe the spread due to the statistical uncertainty on the Legendre polynomials.

Study of $B \to \chi_{c1} K\pi$.

□ A slighly modified analysis was performed for the study of $\overline{B}^0 \to \chi_{c1} K^- \pi^+$ and $B^+ \to \chi_{c1} K^0_S \pi^+$ (arXiv:1111.5919) by BABAR.

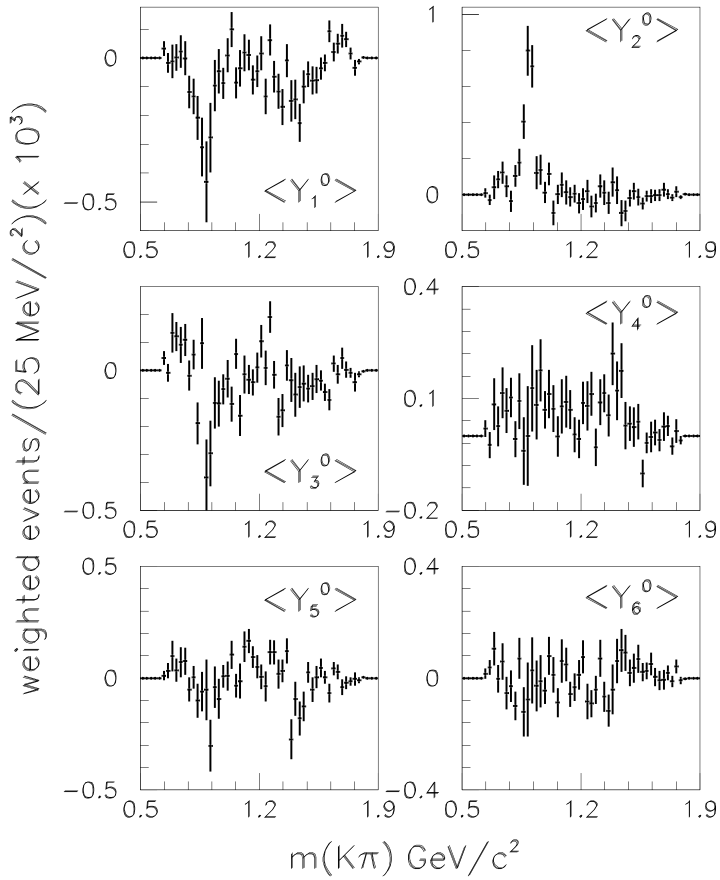
□ The fit to the $K\pi$ mass distributions in this case require a small P-wave contribution from $K^*(1680)$ ($\approx$ 10 %), not present in the $B \to J/\psi K\pi$ decays or $B \to \psi(2S) K\pi$.

□ S-wave contribution larger than in $B \to J/\psi K\pi$ decays, where is $\approx$ 16 %.



The $K\pi$ Legendre polynomial moments.

- Add $\overline{B}^0$ and B^+ data. Weight the events by the $Y_L^0(cos\theta)$ Legendre polynomials.
- Efficiency-corrected and background-subtracted distributions.



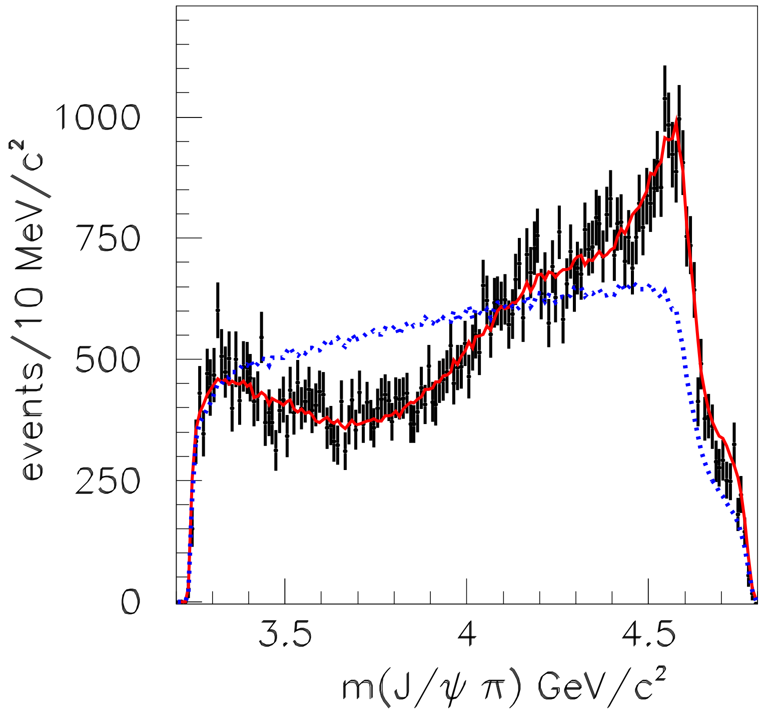
- We observe the S-P interference in the $< Y_1^0 >$ moment.
- Significant enhancement in Y_1^0 at ≈ 1.7 GeV indicating the presence of a P-wave.
- We observe the presence of the spin-1 $K^*(890)$ in the $< Y_2^0 >$ moment.
- We have evidence for the spin-2 $K_2^*(1430)$ resonance in the $< Y_4^0 >$ moment.
- $< Y_6^0 >$ is consistent with zero.

MC simulations: $B \to J/\psi K\pi$

- We test the method on $B \to J/\psi \pi K$ where there is no evidence for narrow or broad Z resonances.
- We vary L_{max} between 4 and 6 and obtain the best description of the data with $L_{max} = 5$.

L_{max}	χ^2/NDF
4	223/152
5	162/152
6	180/152

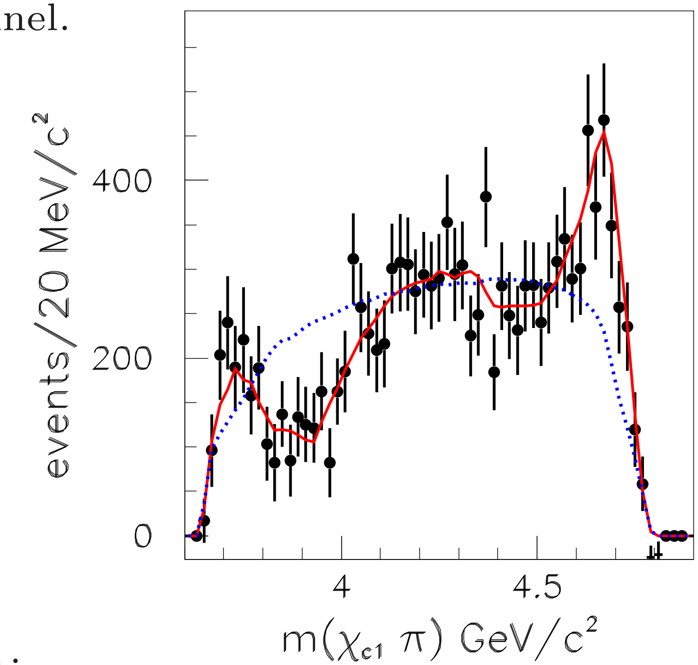
- MC/data comparison, the dotted line shows the effect of removing the angular w_L weight.



MC simulations: $B \to \chi_{c1} K\pi$

□ Similar results are obtained for the $B \to \chi_{c1} K\pi$ channel.

L_{max}	χ^2/NDF
4	53/58
5	46/58
6	49/58
"mixed"	63/58



□ *$B \to J/\psi K\pi$ and $B \to \chi_{c1} K\pi$ data can be described using a similar approach.*

□ **This indicates that there is no need for additional resonant structure in order to describe the $\chi_{c1}\pi$ mass distribution.**

□ We also use a "mixed" Legendre polynomial composition, using $L_{max} = 3$ for $m(K\pi) < 1.2$ GeV and $L_{max} = 4$ above.

□ This is justified by the fact that only spin 0 and spin 1 resonances are present in the low mass region.

□ This representation also gives an excellent description of the $\overline{B}^0 \to \chi_{c1} K\pi$ data.

□ *We will use this "mixed" representation for computing upper limits on Z production.*

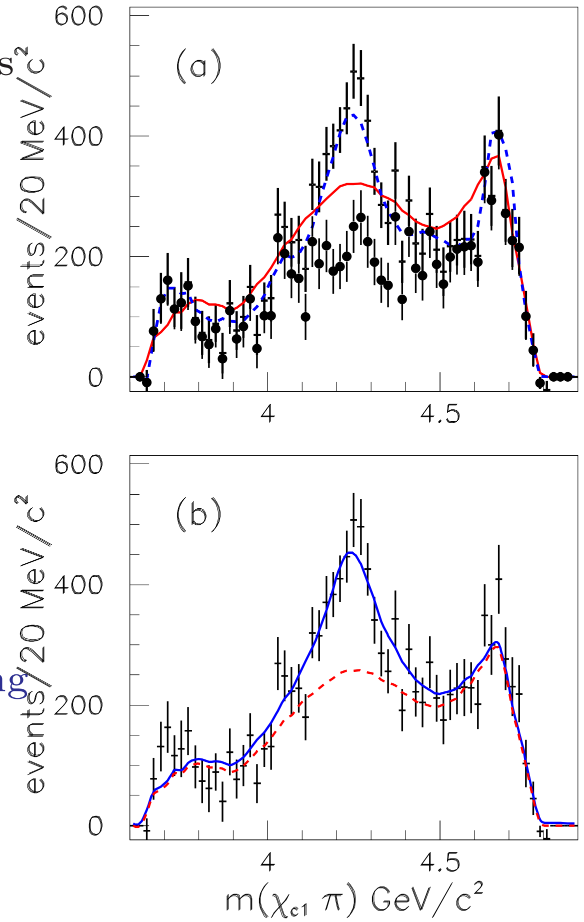
How would a Z resonance show up?

□ We artificially add a ≈ 25% contribution of a scalar $Z_2(4250)^+ \to \chi_{c1}\pi$ resonance in the $\overline{B}^0 \to \pi^+ K^- \chi_{c1}$ data.

□ These MC toy events are obtained from MC data, weighted by a Breit-Wigner.

□ We then compute Legendre polynomial moments for the whole sample and predict the $\chi_{c1}\pi$ mass spectrum using the same algorithm as for real data.

□ Using the "mixed" method, the resulting MC simulation does not describe the MC data well: $\chi^2/NDF = 140/58$



□ *black dots indicate the* $B^0 \to \pi^- K^+ \chi_{c1}$ *data, crosses indicate the total sample.*

□ In (a) The dashed curve shows a simulation with $L_{\max} = 15$.

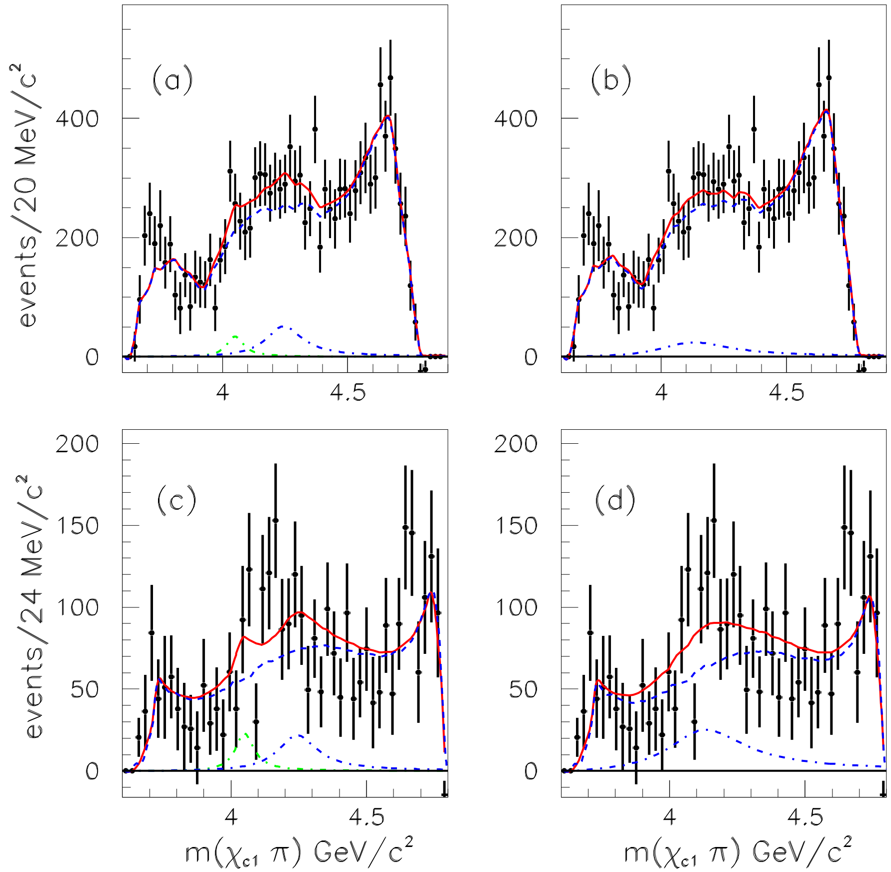
□ In (b) the fit incorporates a Breit-Wigner lineshape describing the $Z_2(4250)^+$.

□ The dashed curve represents the background model from the "mixed" simulation.

Search for Z resonances.

- We now fit the $\chi_{c1}\pi$ mass spectrum using the following model:
- *Assume the prediction from the MC simulation ("mixed") as background.*
- *Include two scalar Breit-Wigner with parameters fixed to the Belle measurements.*
- Fit the full data set (Total).

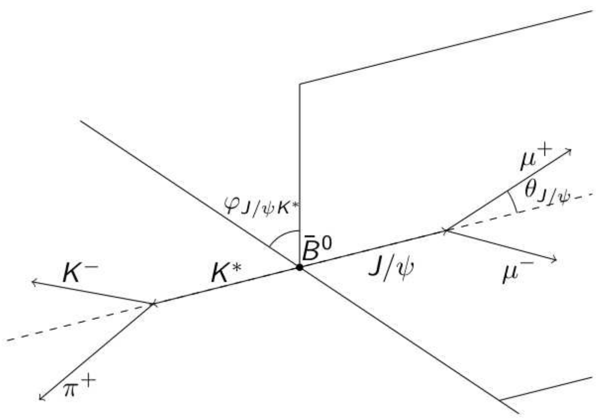
Data	Resonance	N_σ	Fraction (%)
a) Total	$Z_1(4050)^+$	1.1	1.6 ± 1.4
	$Z_2(4250)^+$	2.0	4.8 ± 2.4
b) Total	$Z(4150)^+$	1.1	4.0 ± 3.8
c) Window	$Z_1(4050)^+$	1.2	3.5 ± 3.0
	$Z_2(4250)^+$	1.3	6.7 ± 5.1
d) Window	$Z(4150)^+$	1.7	13.7 ± 8.0



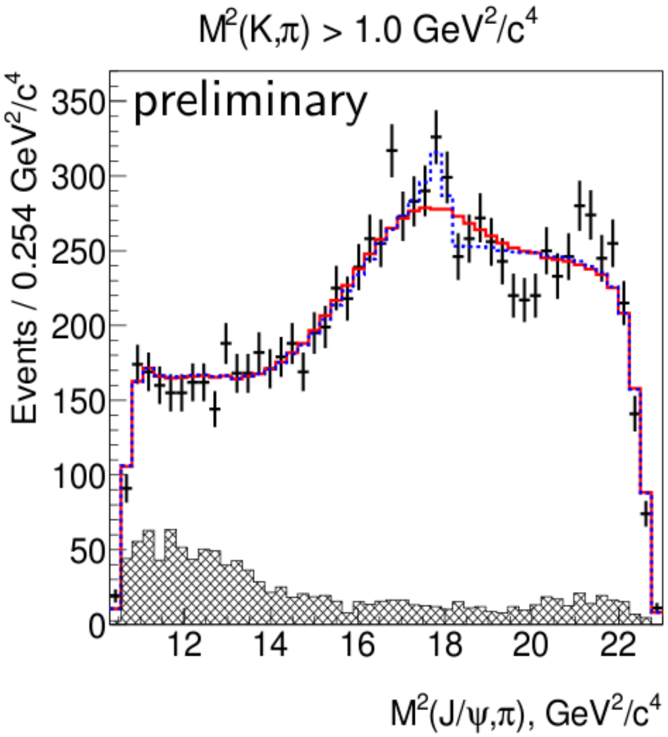
Search for Z in $B \to J/\psi K pi$.

□ Belle experiment has recently performed a more complete Dalitz analysis of $B \to J/\psi K pi$ (K. Chilikin, Talk at CHARM2012, 16 May 2012).

Model: angular variables



The variables considered are Dalitz variables $M^2(K,\pi)$, $M^2(J/\psi,\pi)$ and angles $\theta_{J/\psi}$, $\varphi_{J/\psi K^*}$.



□ No significant signal of Z^+ is found.

Not the end of the story.

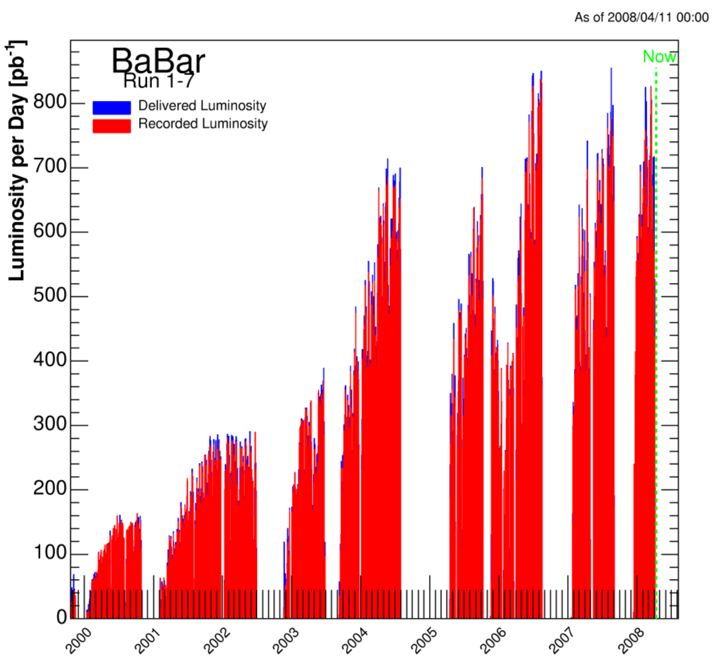
☐ New results from Belle:

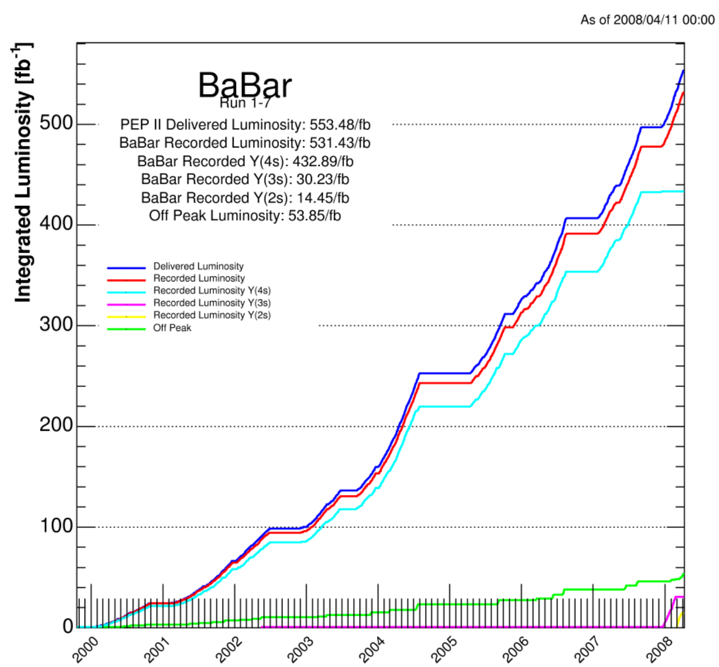
Observation of two charged bottomonium-like resonances in $\Upsilon(5S)$ decays. arXiv:1110.2251

☐ As we have seen previously confirmation of results is an essential ingredient of science and scientific method.

☐ However, tha BaBar/Belle competition is broken here because BaBar has no data on $\Upsilon(5S)$ decays.

☐ In April 2008 the $B - factory$ program at SLAC has been sharply interrupted and closed.





☐ Confirmation from LHCb?

☐ Much later in time: Super-B factories?