Dalitz Plot Analysis of Heavy Quark Mesons Decays (3).

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Charmless B decays

□ These decay have been studied mostly for CP violation studies.

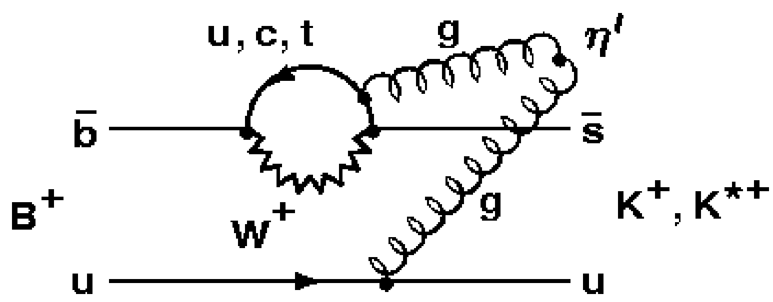
□ However there are issues related to the search for exotics.

□ The possibility of searching for gluonium in B decays has been suggested by the experimental measurement of a large decay rate for:

$$B \to \eta' X, \qquad B \to \eta' K$$

□ The diagram giving rise to these processes is:

$$b \to sg$$



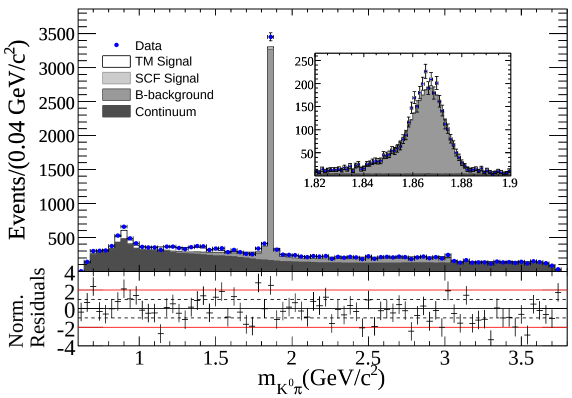
□ There are arguments in favour of a gluonic content of the η', therefore gluonium states may be produced in B decays.

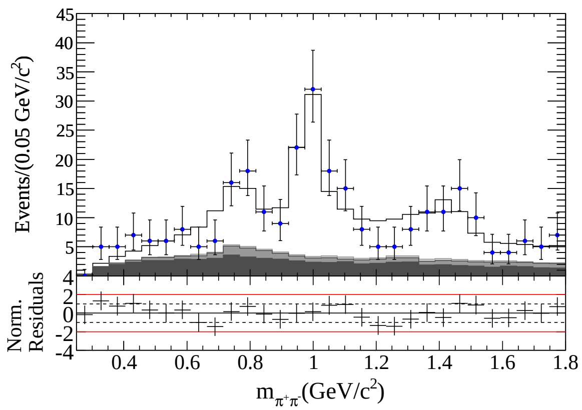
H. Fritzsch, Phys. Lett. B415 (1997) 83

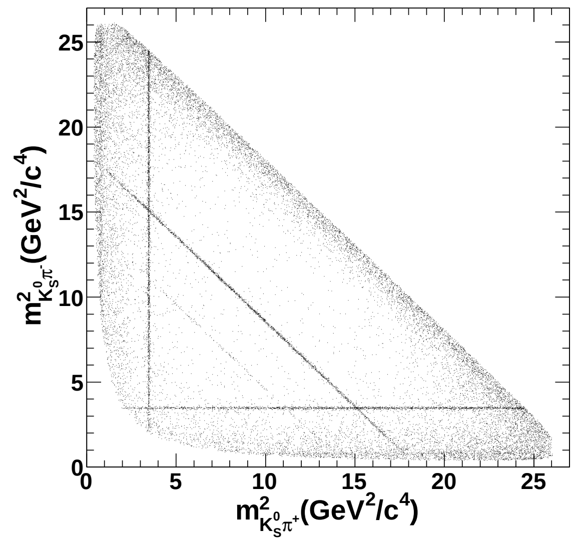
P. Minkowski and W. Ochs hep-ph/0404194

Selection of Charmless B decays

□ Another issue is related to the presence of narrow peaks coming from different processes which include charm and charmonium decays.





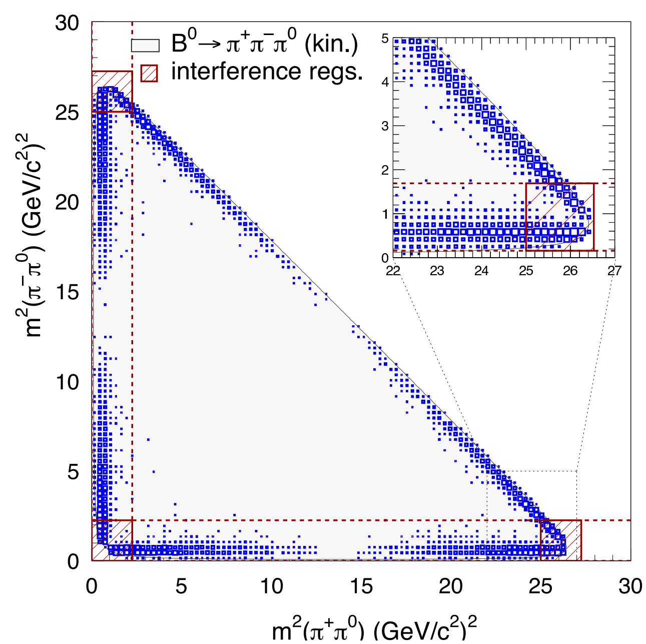


□ The narrow bands correspond to $D^{\mp}\pi^{\pm}$, $J/\psi K^0_S$ and $\psi(2S)K^0_S$ background events.

The square Dalitz plot

□ A common feature of Dalitz plot analyses of B-meson decays to charmless final states is that both the signal events and the combinatorial $e^+e^- \rightarrow q\overline{q}$ $(q = u, d, s, c)$ continuum background events populate the kinematic boundaries of the Dalitz plot. This is due to the low masses of the final state particles compared with the B mass.

□ Large variations occurring over small areas of the Dalitz plot are difficult to describe in detail



□ The boundaries of the Dalitz plot are particularly important since it is here that the interference between light meson resonances occurs and hence they are the regions with the greatest sensitivity to relative phases.

The square Dalitz plot

□ A solution that was adopted by some analyses is to apply a transformation to the kinematic variables that maps the Dalitz plot into a rectangle: the so-called *Square Dalitz plot* (SDP).

□ Such a transformation avoids the curved edge of bins on the boundary, which simplifies the use of non-parametric PDFs (histograms) to model the distribution of events over the Dalitz plot. Moreover, the transformation is required to expand the regions of interference to generally ease parameterization; for instance, equal size bins cover this region in more detail.

□ For $B^0 \to \pi^+\pi^-\pi^0$ analysis, the SDP is obtained by the transformation:

$$ds_+\, ds_- \;\longrightarrow |\det J|\, dm'\, d\theta'. \tag{1}$$

□ The variable s_+ (s_-) is the square invariant mass of the π^+ (π^-) and the π^0. The new coordinates are.

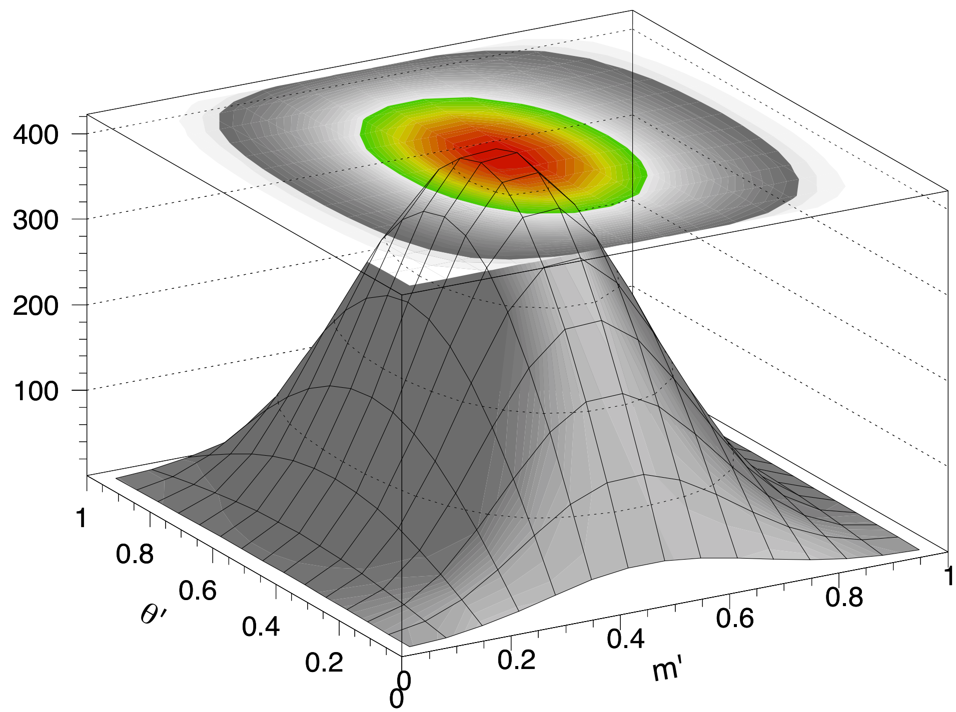
$$m' \equiv \frac{1}{\pi} \arccos\left(2\frac{m_0 - m_0^{\min}}{m_0^{\max} - m_0^{\min}} - 1\right),\;\; \theta' \equiv \frac{1}{\pi}\theta_0, \tag{2}$$

where $m_0 = \sqrt{s_0}$ is the invariant mass of the charged particles, $m_0^{\max} = m_{B^0} - m_{\pi^0}$ and $m_0^{\min} = 2m_{\pi^+}$ are the kinematic limits of m_0, θ_0 is the helicity angle of the ρ^0 resonance, which decays to the two charged pions, and J is the Jacobian of the transformation. Both new variables range between 0 and 1. The determinant of the Jacobian is given by

$$|\det J| \;=\; 4\,|\mathbf{p}_+^*||\mathbf{p}_0^*|\, m_0 \cdot \frac{\partial m_0}{\partial m'} \cdot \frac{\partial \cos\theta_0}{\partial \theta'}\;\;, \tag{3}$$

where $|\mathbf{p}_+^*| = \sqrt{E_+^* - m_{\pi^+}^2}$ and $|\mathbf{p}_0^*| = \sqrt{E_0^* - m_{\pi^0}^2}$, and where E_+^* (E_0^*) is the energy of the π^+ (π^0) defined in the $\pi^+\pi^-$ rest frame.

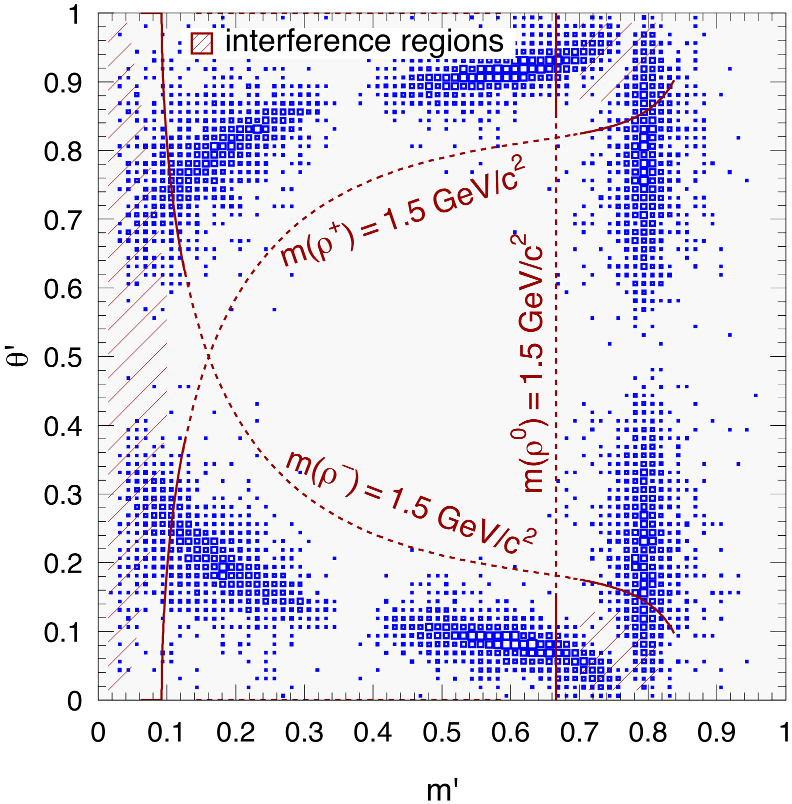
□ The figure shows the determinant of the Jacobian as a function of the SDP parameters m' and θ'. If the events in the nominal Dalitz plot were distributed according to a uniform (non-resonant) three-body phases space, their distribution in the SDP would match the plot of $|\det J|$.



The square Dalitz plot

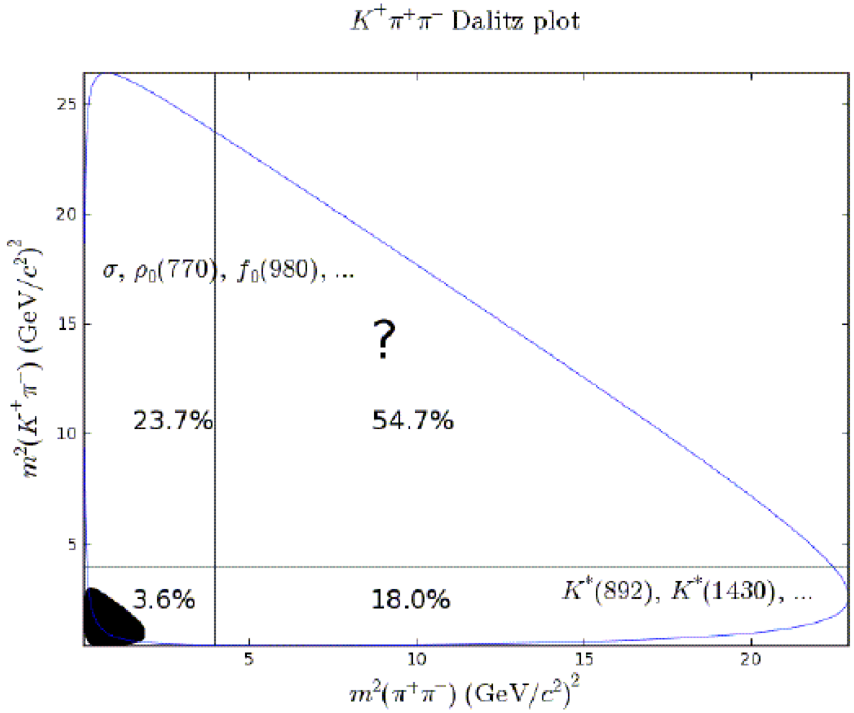
□ The effect of the transformation is illustrated in the figure which displays the nominal and square Dalitz plots for simulated signal events generated with Monte Carlo.

□ The benefits of the SDP that are explained above are clearly visible in this figure. To simplify the comparison, hatched areas showing the interference regions between ρ bands and dashed isocontours $\sqrt{s_{+,-,0}} = 1.5\ \mathrm{GeV}/c^2$ have been superimposed on both Dalitz plots.



Non-Resonant contribution.

- In B decays there is a large unknown region on the Dalitz plot.



- Can be populated by background.
- But also unknown resonances. Light mesons spectroscopy known only up to a mass of $\approx$ 2 GeV.

Non-Resonant contribution.

□ An additional feature seen in three-body chermless decays is a large broad "nonresonant" (NR) contribution.

□ Several analyses have found that a uniform-phase-space model is insufficient to describe the NR term, and have instead parameterized it with an empirical model.

□ The NR term has been taken to be purely K^+K^- S-wave in $B^+ \to K^+K^-K^+$, while smaller $K^+K_S^0$ and $K^-K_S^0$ S-wave terms have been seen in $B^0 \to K^+K^-K_S^0$ which correspond effectively to higher-order K^+K^- partial waves (arXiv:1201.5897).

□ Because the NR contribution dominates much of the available phase space, it is crucial to study its angular distribution if one wishes to have an accurate description of the Dalitz plot.

□ Some BaBar analyses modeled $B^+ \to K^+K^-K^+$ with an exponential model given by

$$F_{NR}(s_{ab}, s_{bc}) = e^{\alpha s_{ab}} + e^{\alpha s_{bc}} \; , \tag{4}$$

where the symmetrization is explicit. α is a parameter to be determined empirically. This model consists purely of K^+K^- S-wave decays.

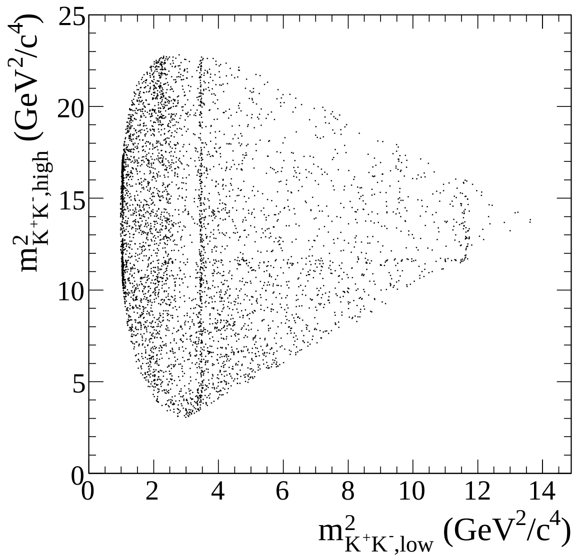
□ The most recently published $B^0 \to K^+K^-K_S^0$ analyses by Belle and BaBar both used what is called an *extended exponential model*. This model adds $K^+K_S^0$ and $K^-K_S^0$ exponential terms:

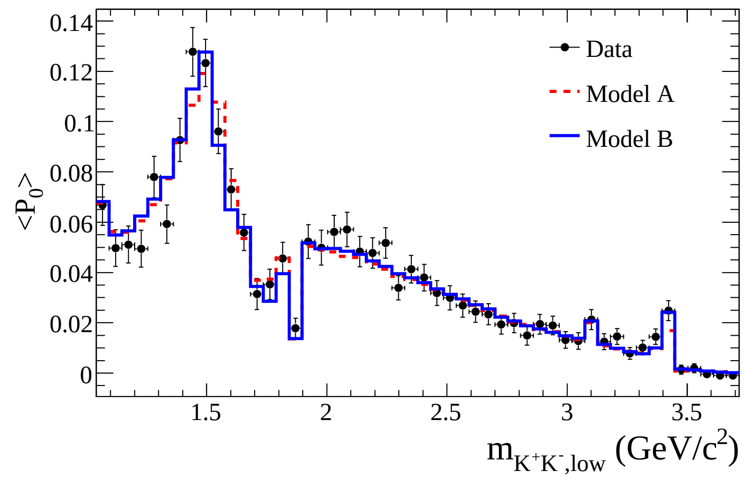
$$A^-_{NR}(s_{ab}, s_{bc}) = a_{12}e^{\alpha s_{ab}} + a_{13}e^{\alpha s_{ac}} + a_{23}e^{\alpha s_{bc}} \tag{5}$$

$$\overline{\mathcal{A}}_{NR}(s_{ab}, s_{bc}) = a_{12}e^{\alpha s_{ab}} + a_{13}e^{\alpha s_{bc}} + a_{23}e^{\alpha s_{ac}} \tag{6}$$

Example from $B^+ \to K^+K^-K^+$.

□ Dalitz plot from *BABAR* (arXiv:1201.5897).



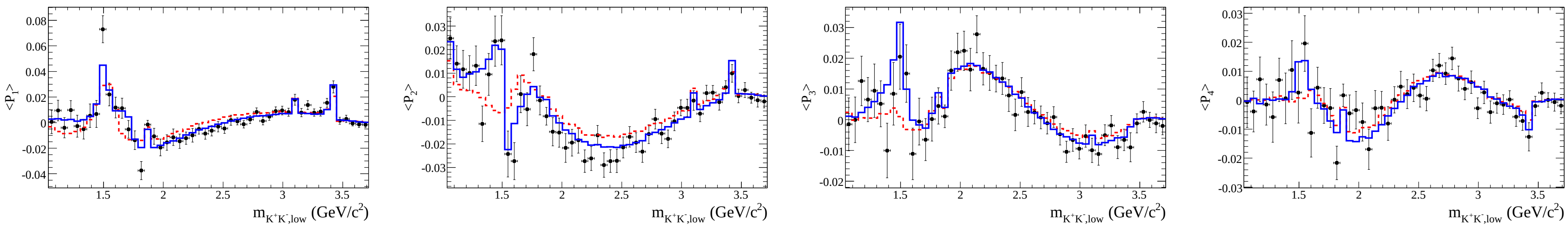


□ Signals are from $\phi(1020)$, $f_0(1500)/f_2'(1525)$, D^0 and χ_{c0}.

□ One important goal is to understand the nature of the so-called $f_X(1500)$ resonance seen in several previous analyses.

□ Both *BABAR* and Belle have modeled this resonance as a scalar particle, but while *BABAR* has found its mass and width to be inconsistent with any established resonance, Belle has found a mass and width consistent with the $f_0(1500)$.

Angular moments from $B^+ \to K^+K^-K^+$.

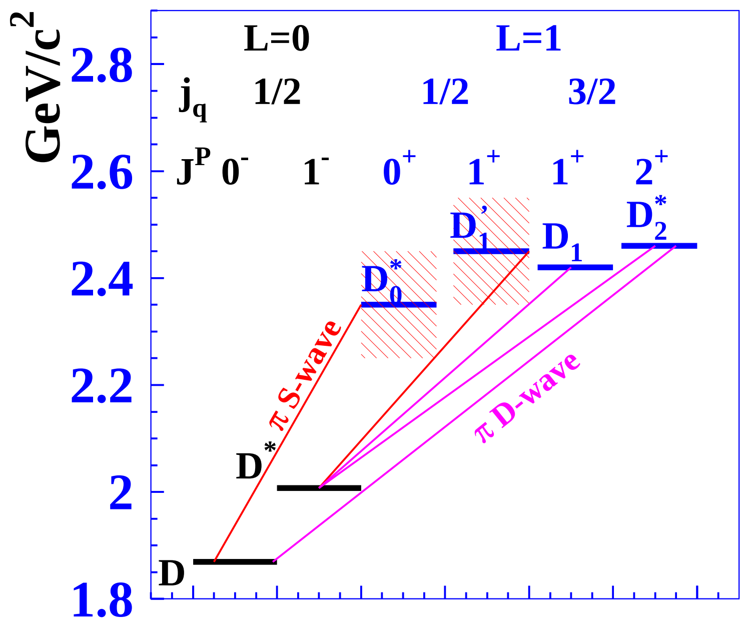


□ They conclude that the hypothetical particle $f_X(1500)$ is not a single scalar resonance, but instead can be described by the sum of the well-established resonances $f_0(1500)$, $f_2'(1525)$, and $f_0(1710)$.

Decay mode	$\mathcal{B}(B^+ \to K^+K^-K^+) \times FF_j$ (10^{-6})
$\phi(1020)K^+$	$4.48 \pm 0.22^{+0.33}_{-0.24}$
$f_0(980)K^+$	$9.4 \pm 1.6 \pm 2.8$
$f_0(1500)K^+$	$0.74 \pm 0.18 \pm 0.52$
$f_2'(1525)K^+$	$0.69 \pm 0.16 \pm 0.13$
$f_0(1710)K^+$	$1.12 \pm 0.25 \pm 0.50$
$\chi_{c0}K^+$	$1.12 \pm 0.15 \pm 0.06$
NR	$22.8 \pm 2.7 \pm 7.6$
NR (S-wave)	$52^{+23}_{-14} \pm 27$
NR (P-wave)	$24^{+22}_{-12} \pm 27$

Charm spectroscopy in B decays.

- Important information has been obtained from the study of B decays to open charm.
- Measurement of the parameters of broad resonances.
- The lower spectrum of D_J mesons.



- Discovery of new charmed mesons.

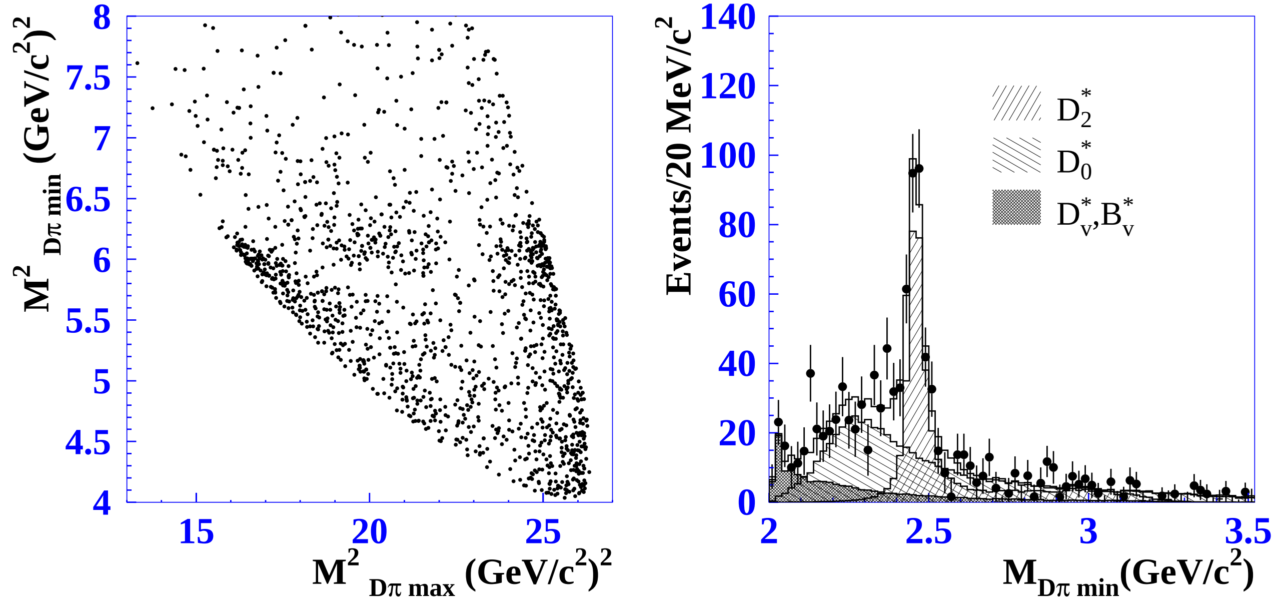
Charm spectroscopy in B decays.

□ The production of neutral $D^{\star\star}$ was studied through full Dalitz-plot analysis of $B^- \to D^+\pi^-\pi^-$ and $B^- \to D^{\star+}\pi^-\pi^-$ three-body decays.

□ In the three-body $B^- \to D^+\pi^-\pi^-$ reaction the $D\pi$ can form either a tensor meson D_2^{*0} or a scalar state D_0^{*0}.

□ In addition, two virtual contributions were considered: produced off-shell D_v^{*0} which could decay to contributing as $B^- \to D_v^{*0}\pi^- \to D^+\pi^-\pi^-$, and a virtual B^{*0} giving $B \to B_v^{*0}\pi$ with $B_v^{*0} \to D\pi$.

□ Data from Belle (hep-ex/0307021)



□ Broad resonance parameters.

$D_0^{*0} \to D^+\pi^- : 2308 \pm 17 \pm 15 \pm 28, \Gamma = 276 \pm 21 \pm 18 \pm 60\ MeV$

Charm spectroscopy in B decays.

□ A similar analysis has been performed by BABAR on a Dalitz plot analysis of $B^- \to D^+\pi^-\pi^-$ decays (arXiv:0901.1291).

□ The Dalitz plot for these events is shown in the figure and is symmetric in the $D\pi$ masses because of the two identical pions. The distribution clearly evidences the nodes structure of the spin-2 $D^*(2460)^+$.

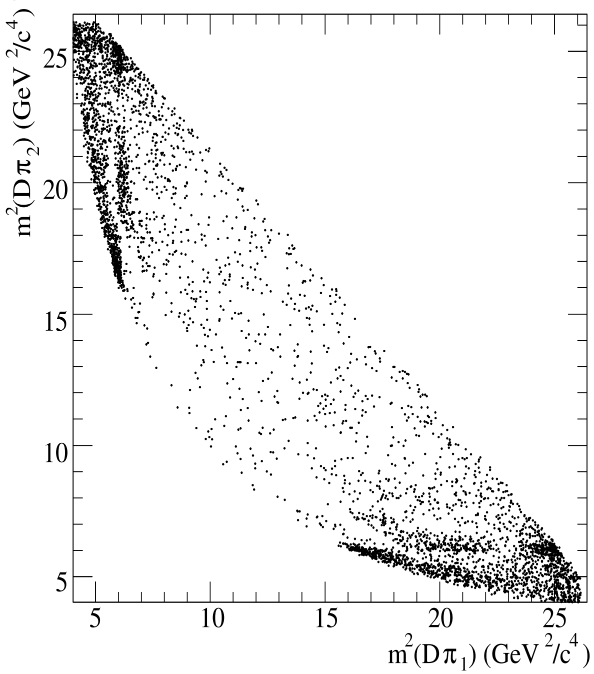
□ We also observe an accumulation of events in the $D\pi$ threshold region. These events are attributed by the Dalitz analysis to the presence of a large fraction of D_0^*.

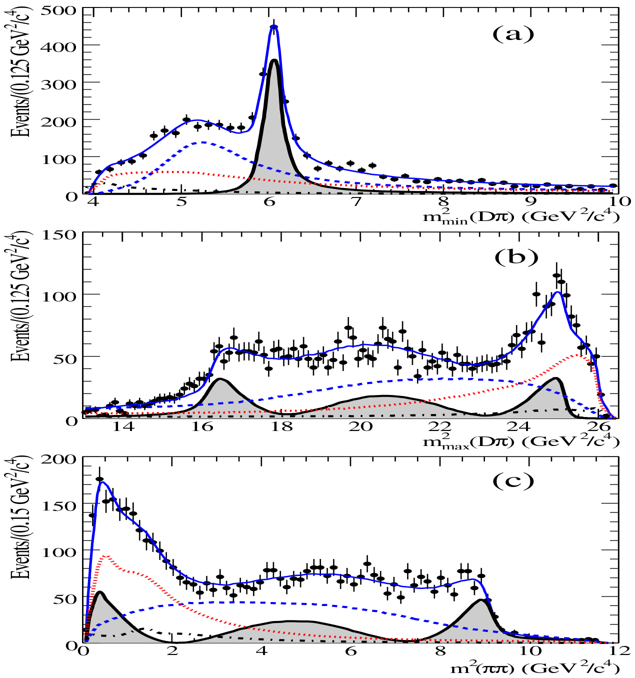
□ In conclusion, the analysis of the $B^- \to D^+\pi^-\pi^-$ Dalitz plot using the isobar model confirms the existence of a narrow D_2^{*0} and a broad D_0^{*0} resonances.

□ The mass and width of D_0^{*0} are determined to be:

$m_{D_0^{*0}} = (2297 \pm 8 \pm 5 \pm 19)$ MeV/

$\Gamma_{D_0^{*0}} = (273 \pm 12 \pm 17 \pm 45)$ MeV





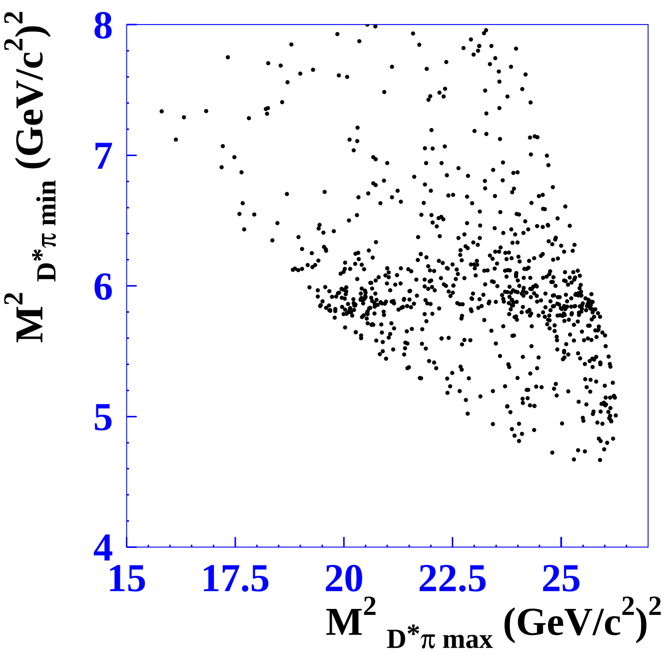
Charm spectroscopy in B decays.

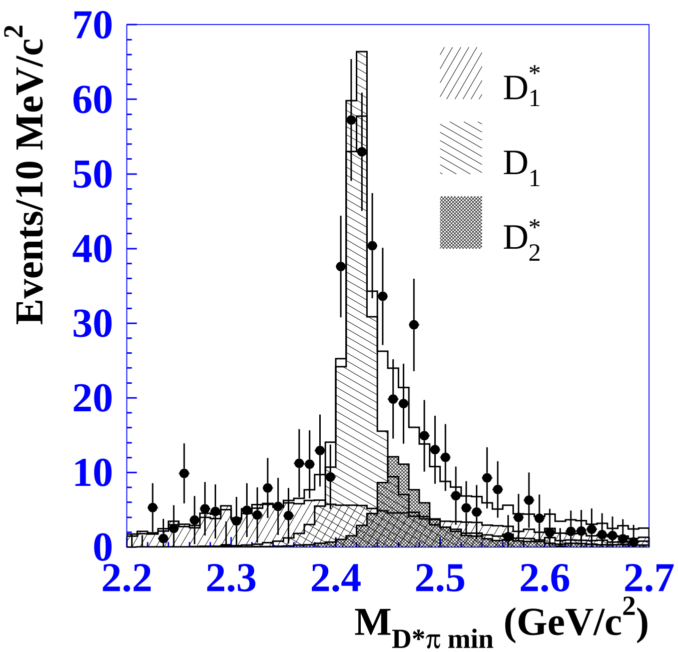
☐ The $B^- \to D^{\star +}\pi^-\pi^-$ Dalitz plot for signal region events, Belle (hep-ex/0307021).

☐ Final state of the $B^- \to D^{\star +}\pi^-\pi^-$ contains a vector particle therefore, assuming the $D^\star$ width to be negligible, in addition to two $D^\star\pi$ invariant squared masses there are two other variables chosen to specify the final state: the angle α between pions from the $D^\star$ and $D^{\star\star}$ decay in the $D^\star$ rest frame ($D^\star$ helicity angle) and the azimuthal angle γ of the pion from the $D^\star$ and relative to the $B \to D^\star\pi\pi$ decay plane.

☐ Broad resonance parameters.

$D_1^{\prime 0} \to D^{\star +}\pi^- 2427 \pm 26 \pm 20 \pm 15, \Gamma = 384^{+107}_{-75} \pm 24 \pm 70\ MeV$



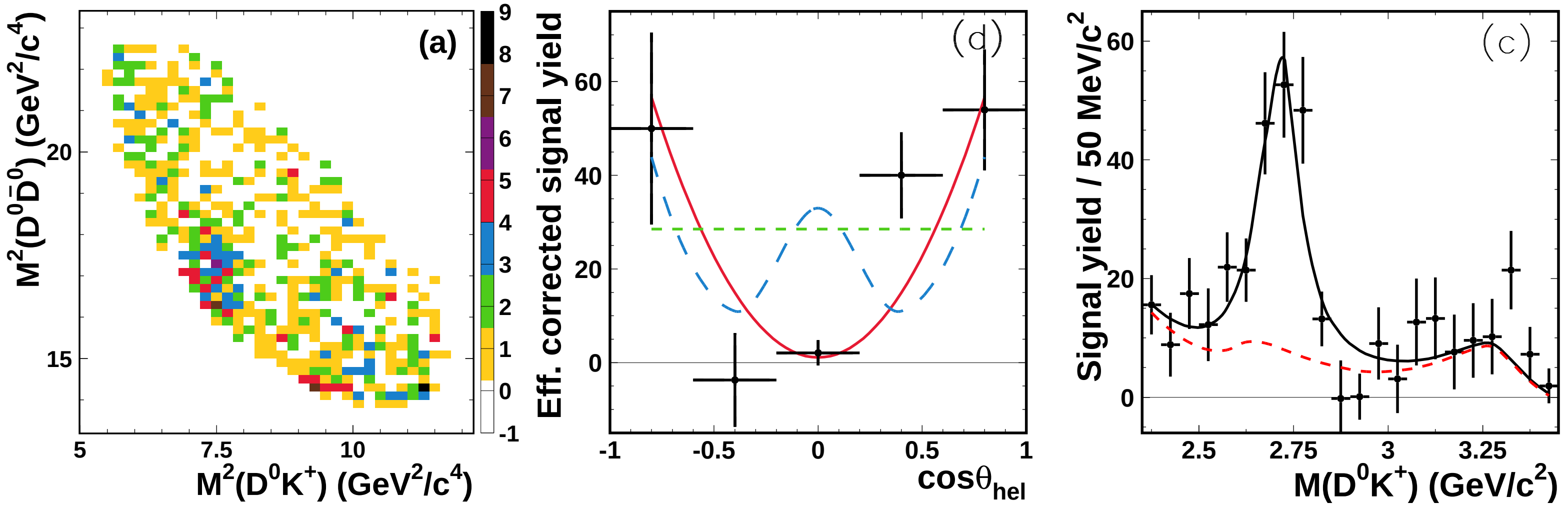


Charm spectroscopy in B decays.

□ Belle reports the observation of a new D_{sJ} meson produced in $B^+ \to \bar{D}^0 D_{sJ} \to \bar{D}^0 D^0 K^+$ (arXiv:0707.3491).

□ This state has a mass of $M = 2708 \pm 9^{+11}_{-10}$ MeV/c^2, a width $\Gamma = 108 \pm 23^{+36}_{-31}$ MeV/c^2 and a 1^- spin-parity.

□ They need to include an exponential form $a \times \exp\left[-\alpha M^2(D^0K^+)\right]$ to describe a threshold enhancement in the data.



Light meson spectroscopy in B decays.

□ Another possibility of using the Dalitz analysis is to perform a mass dependent Partial Wave Analysis. See the unpublished PhD thesis on BABAR data (http://www.infn.it/thesis/PS/getfile.php?filename=563-Monorchio-dottorato.ps).

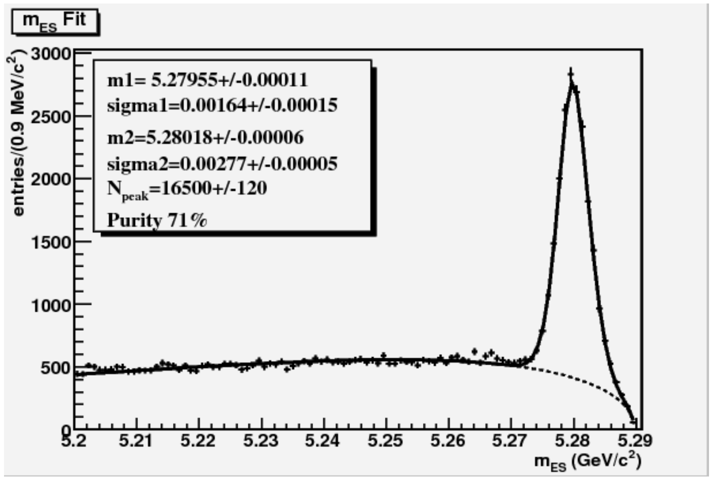
□ We study the decay:

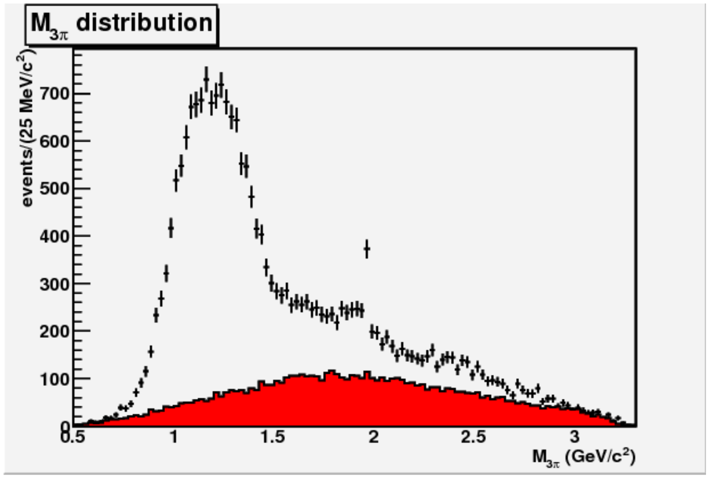
$$B^0 \to D^{*+}(\pi^+\pi^-\pi^-)$$

divide the $(\pi^+\pi^-\pi^-)$ mass spectrum in slices and perform a Dalitz analysis in each slice.

□ Then plot the resulting yields for each partial wave as a function of the $(\pi^+\pi^-\pi^-)$ mass.

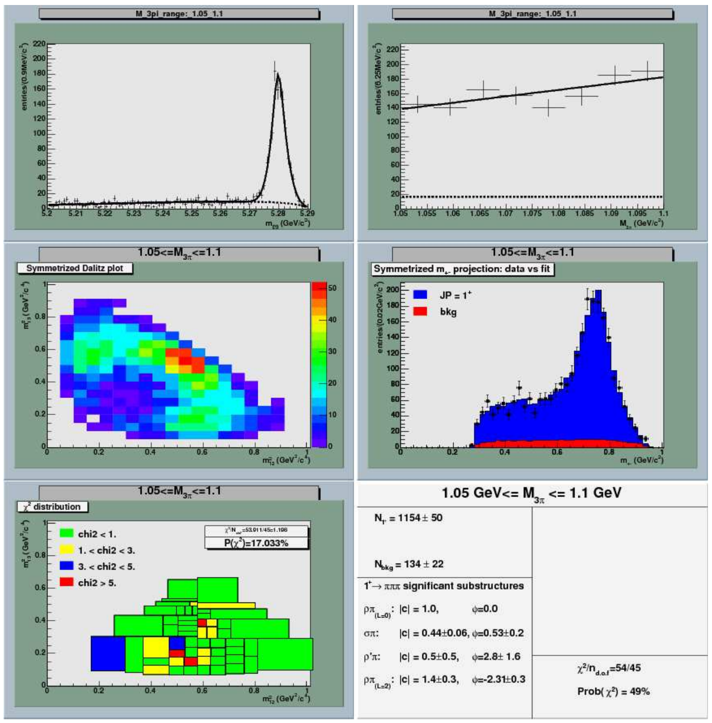
□ B^0 signal and $(\pi^+\pi^-\pi^-)$ mass spectrum with background in red.

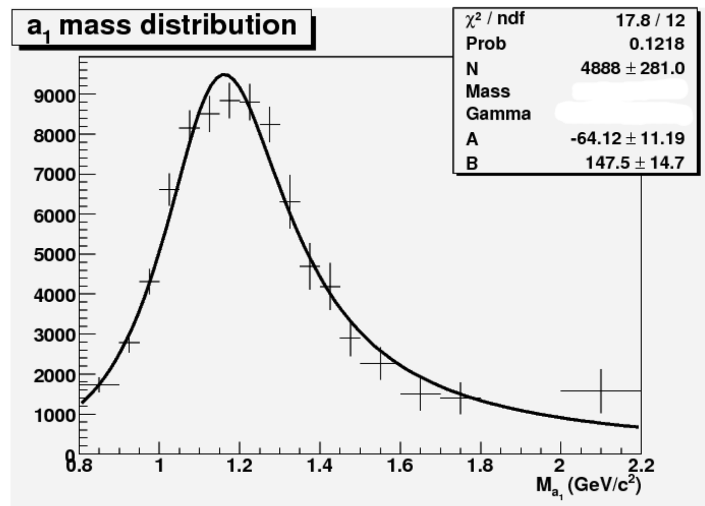




Light meson spectroscopy in B decays.

□ An example of a Dalitz analysis in a $(\pi^+\pi^-\pi^-)$ mass range.





□ The Dalitz analysis allows to measure partial branching fractions and lineshapes for each partial wave.

□ Plot of the $J^P = 1^+$ amplitude with a nice $a_1(1260)^+$ signal.