# Dalitz Analysis of Heavy Flavor decays.

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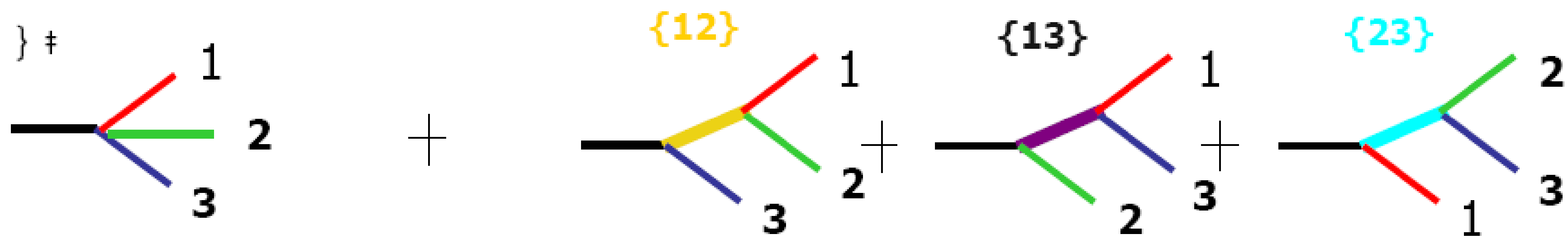
□ Summary.

- Dalitz plot analysis;
- Results from B decays;
- Scalar mesons from charm and charmonium decays;
- Conclusions;

# Dalitz plot analysis.

☐ The Dalitz plot analysis is the most complete method for extracting amplitudes and phases in charm and B three-body decays. D. Asner, hep-ex/0410014

☐ It assumes an Isobar model, which means that the decay is always mediated by a two-body resonance.




☐ Analyses are usually performed by unbinned maximum likelihood fits.

☐ The likelihood is parametrized as:

$$L = x \mid A_1 + c_2 A_2 e^{i\phi_2} + c_3 A_3 e^{i\phi_3} + \ldots \mid^2 + (1 - x) B$$

where $A_i$ and $\phi_i$ are amplitudes and phases for each contributions, all measured with respect to a reference amplitude.

☐ x is the signal fraction and B is the background.

# Dalitz plot analysis: Amplitudes.

- Amplitudes written as:

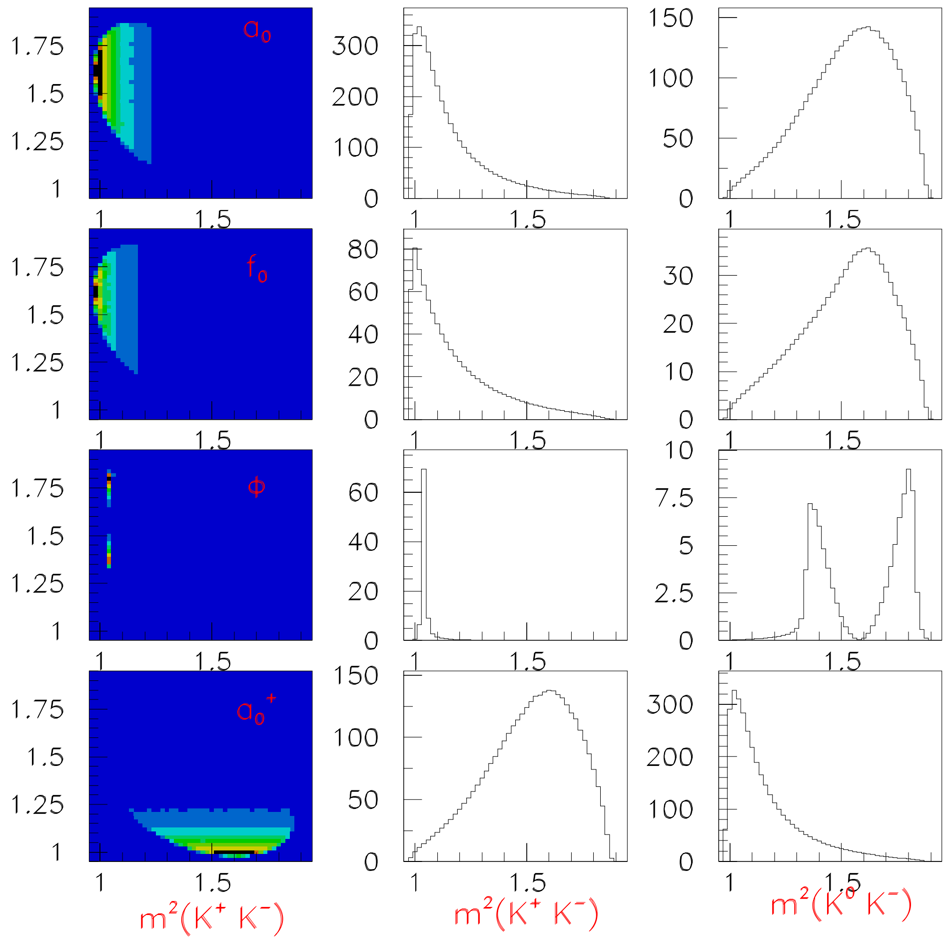
$$A_i = BW_i \times \Omega_i$$

where $BW_i$ are Relativistic Breit-Wigner and $\Omega_i$ describe the angular distributions.

- Standard procedure is to use the helicity formalism.
- Zemach tensors can also be used.
- All amplitudes normalized on the Dalitz plot.

# Dalitz plot analysis: Amplitudes.

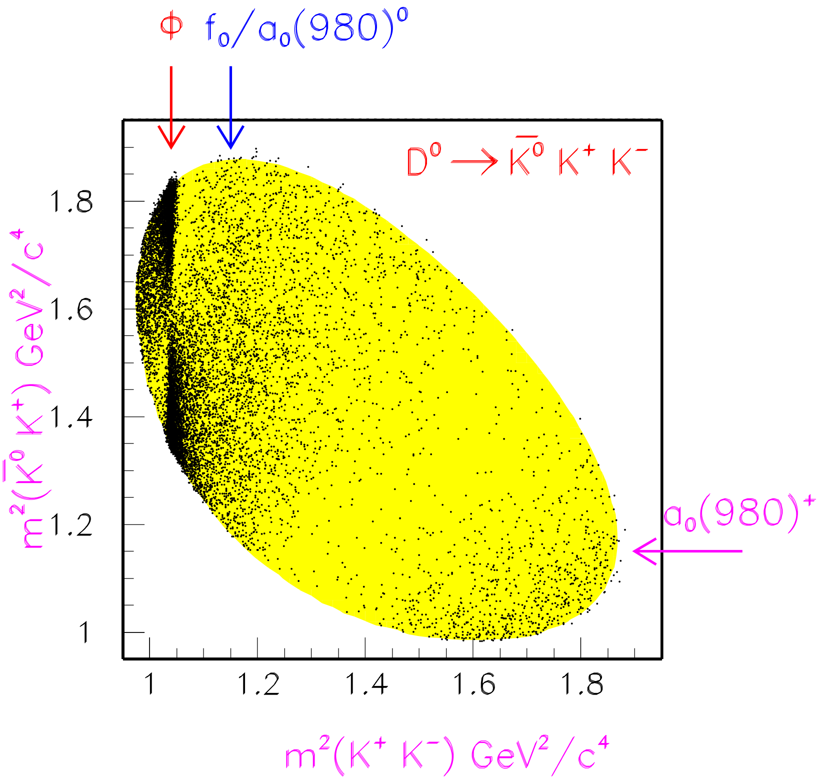
□ Example from charm decays: $D^0 \to \bar{K}^0 K^+ K^-$:

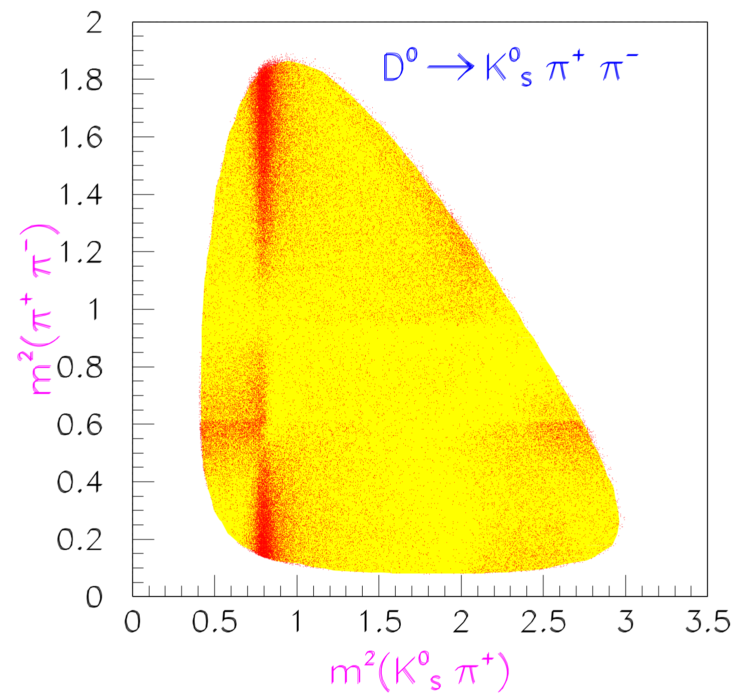



□ Spin of intermediate resonances clearly recognized.

# Dalitz plots from charm decays.

□ $D^0$ decays from BaBar.



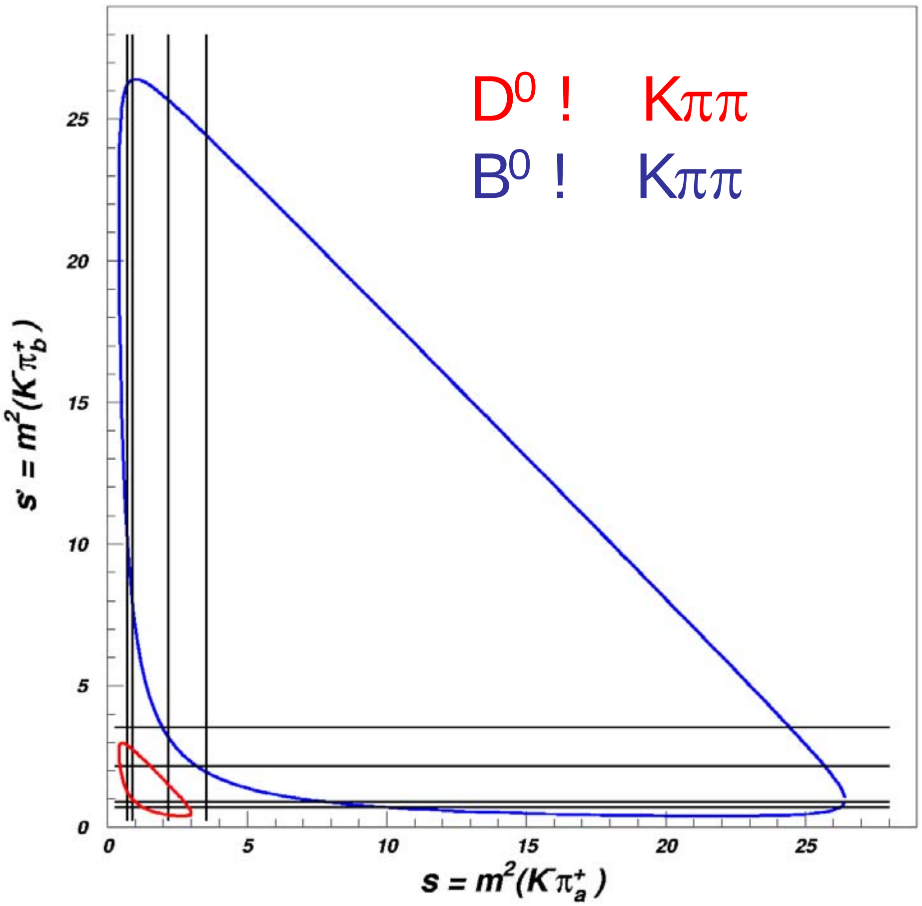




□ Presence of $\phi(1020)$ interfering with a threshold scalar $f_0/a_0(980)^0$ in $D^0 \to \bar{K}^0 K^+ K^-$.

□ Very complex structure in $D^0 \to \bar{K}^0 \pi^+ \pi^-$: up to 13 resonances.

# Dalitz plot analysis.

□ Difference in phase space between charm and B decays is huge.




□ Fractions computed as:

$$f_i = \frac{|c_i|^2 \int |A_i|^2 dm_x^2 dm_y^2}{\sum_{j,k} c_j c_k^* \int A_j A_k^* dm_x^2 dm_y^2}$$

□ Because of interferences the sum of the fractions does not add up to 1.

## Dalitz plot analysis: Background.

□ In some charm decays the background is consistent with being flat.

□ A Non Resonant contribution is often included:

$$c_{NR}e^{i\phi_{NR}}$$

□ In charm decays this contribution is small or consistent with zero.

□ Not possible in B decays.

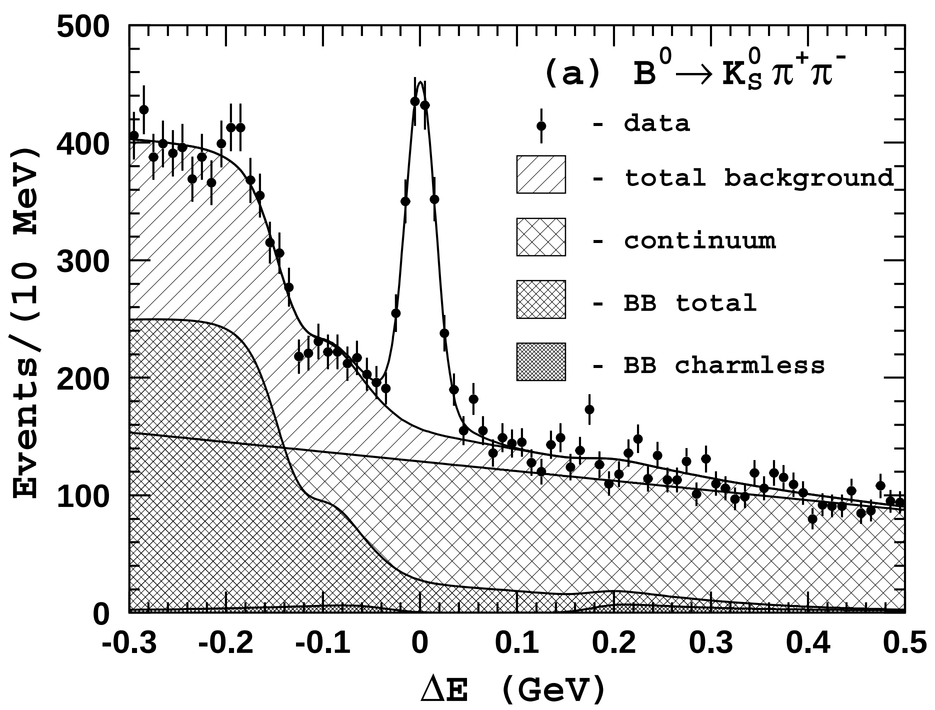
□ One problem from B decays is the presence of a sizeable background.

□ A background description is needed, possibly extrapolated from sidebands: difficult to distinguish from the true possible non resonant contribution.

□ Difficult to study interferences between signal and Non Resonant contribution.

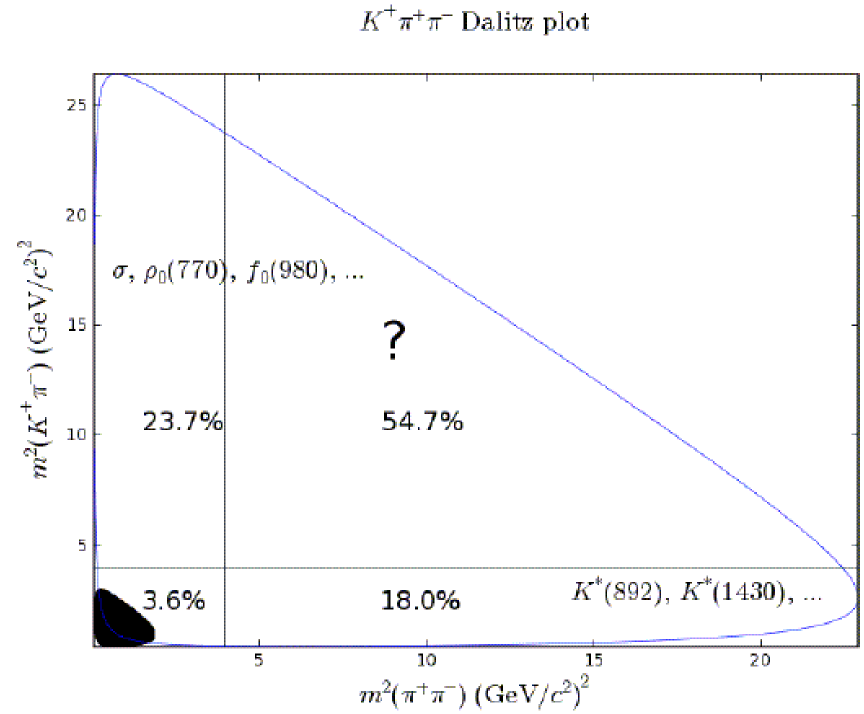
# Dalitz plot analysis: Background.

□ Example from BELLE: $\Delta E$ distribution from $B^0 \to K_S^0 \pi^+ \pi^-$.



# Background parametrization.

☐ 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.

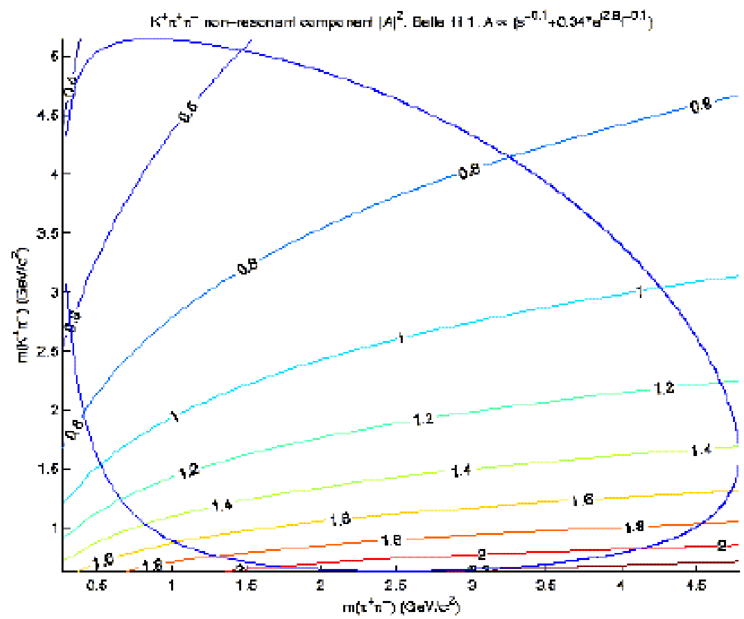
# Background parametrization.

□ Different phenomenological background paramerizations. Example:

$$A_{nr} = a_1^{nr} e^{-\alpha s_{13}} e^{i\delta_1^{nr}} + a_2^{nr} e^{-\alpha s_{23}} e^{i\delta_2^{nr}}$$

where $s_{13}$ and $s_{23}$ are the squared two-body effective masses.

□ This background accounts, for the $B^0 \to K_S^0 \pi^+ \pi^-$ case, to $41.9 \pm 5.2$ %.



# Dalitz plot analysis in B decays.

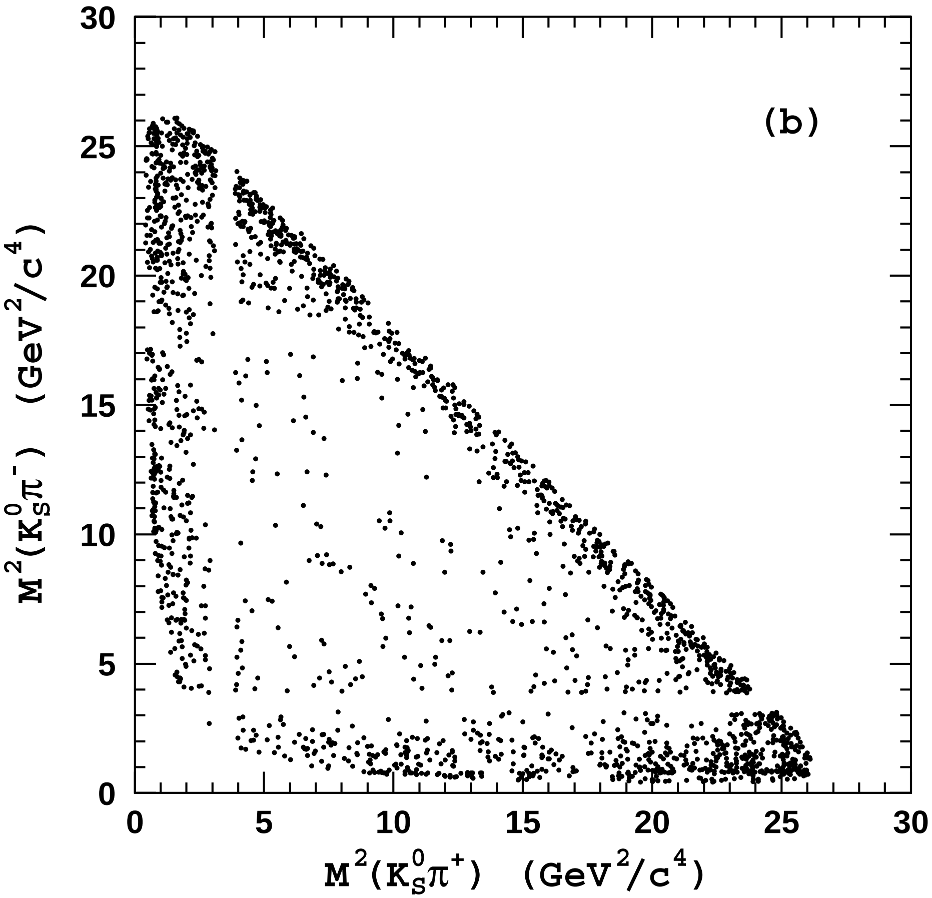
□ Many Dalitz analyses in B and charm decays are in progress.

□ Some projections from:

- $B^0 \longrightarrow K_S^0 \pi^+ \pi^-$
- $B^+ \longrightarrow K^+ \pi^+ \pi^-$
- $B^0 \longrightarrow K_S^0 K^+ K^-$
- $B^+ \longrightarrow \pi^+ \pi^+ \pi^-$

# Dalitz plot analysis of $B^0 \to K^0_S \pi^+ \pi^-$.

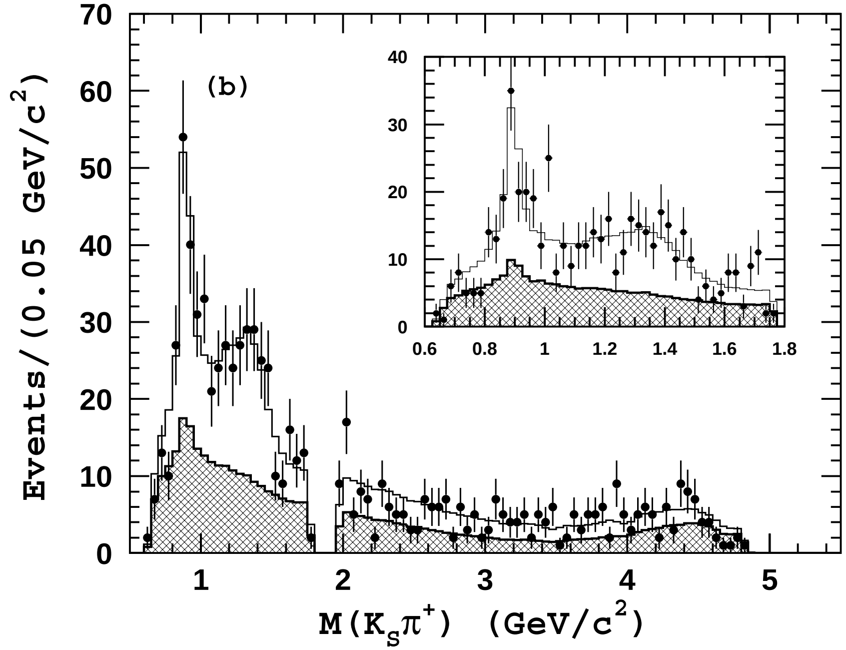
□ Data from BELLE ($357 fb^{-1}$): Dalitz plot.

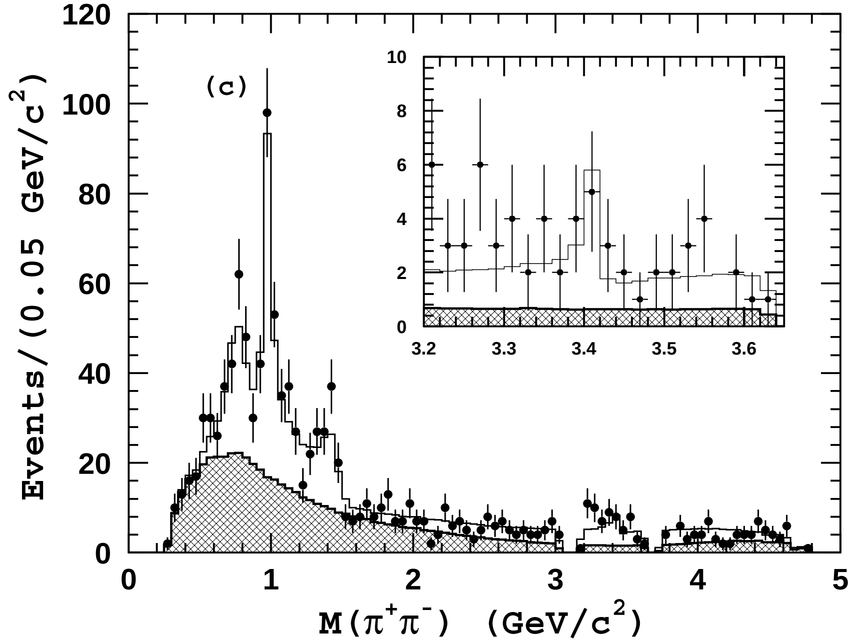



□ Cuts due to suppression of intermediate charm and charmonium decays.

# Dalitz plot analysis of $B^0 \to K_S^0 \pi^+ \pi^-$.

- $K_S^0 \pi^\pm$ and $\pi^+\pi^-$ mass spectra.

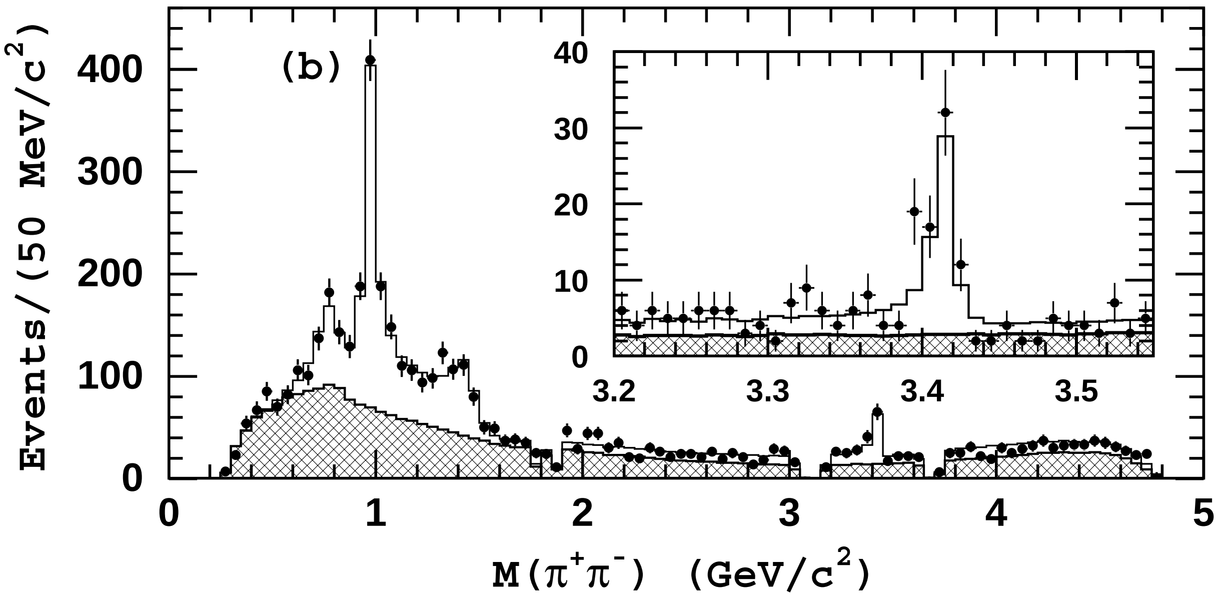



- Decays dominated by spin 0 and spin 1 resonances.
- Presence of $K^*(890)$ and $K_0^*(1430)$ resonances in $K\pi$.
- Presence of $\rho(770)$ and $f_0(980)$ and $f_0(1300)$ resonances in $\pi\pi$.

# Dalitz plot analysis of $B^+ \to K^+\pi^+\pi^-$.

□ Data from BELLE (386 $fb^{-1}$) : $\pi^+\pi^-$ projection. Similar features, presence of $\rho(770)$ and $f_0(980)$ and $f_0(1300)$ resonances.




□ Need for an extra $K\pi$ S-wave. Using the $\kappa(800)$ the fit improves but not possible to extract its parameters.

□ Evidence for direct CP violation at level of 3.9 $\sigma$ in:

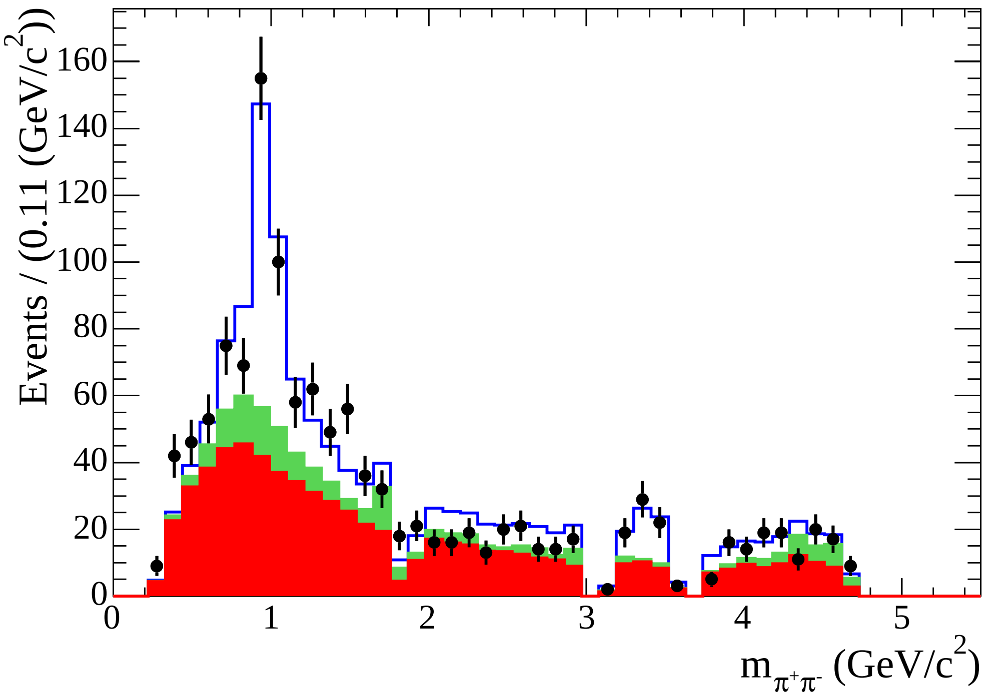
$$B^{\pm} \to \rho(770)K^{\pm}$$

# Dalitz plot analysis of $B^+ \to K^+\pi^+\pi^-$.

□ Data from BABAR (205 $fb^{-1}$): $\pi^+\pi^-$ projection. Similar features, presence of $\rho(770)$ and $f_0(980)$.

□ Not clear $f_0(1300)$.

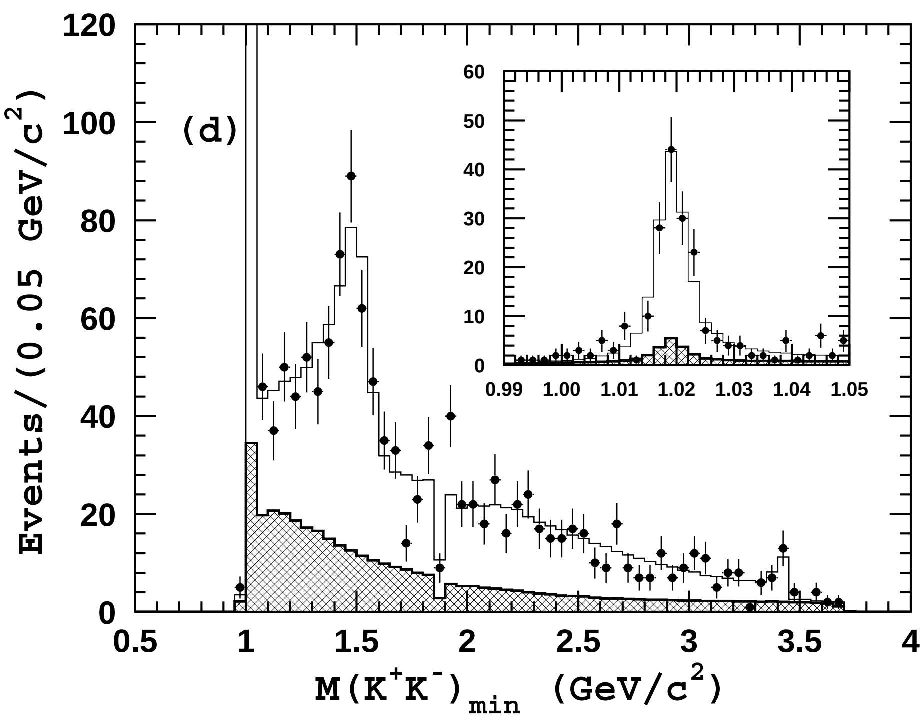
□ $K\pi$ S-wave parametrized according to the LASS fit to the S-wave $K\pi$ data.




□ CP asymmetry at level of 2.4 $\sigma$.

# Dalitz plot analysis of $B^+ \to K^+K^+K^-$.

□ Data from BELLE (140 $fb^{-1}$): $K^+K^-$ projection.

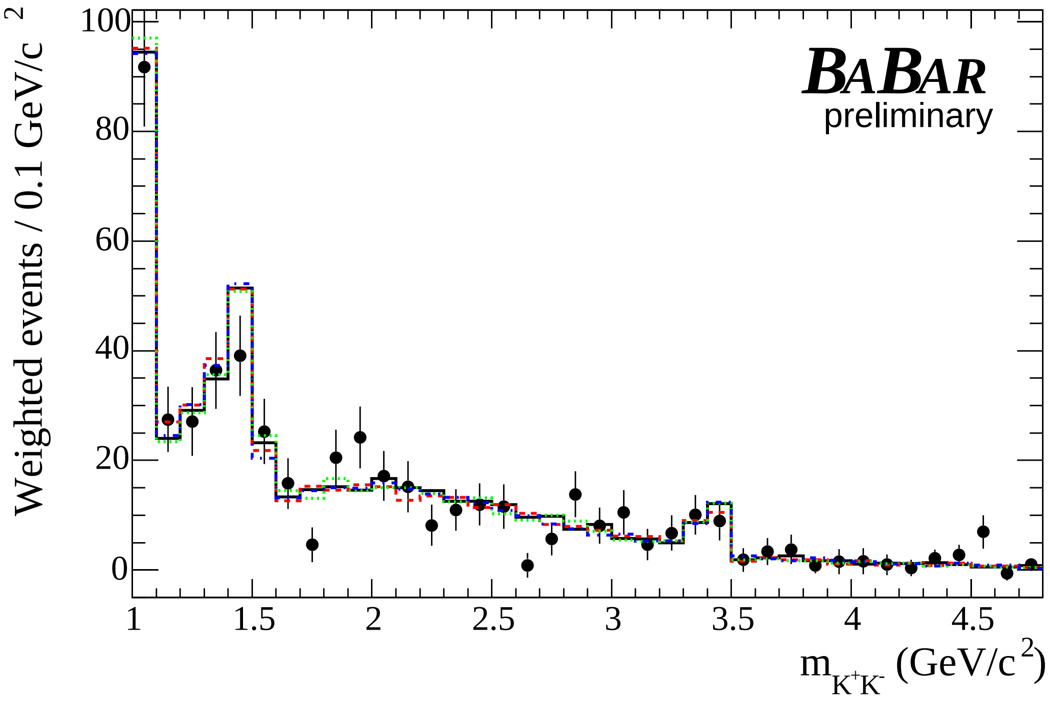



□ Presence of $f_0(1500)$? Analysis prefers a scalar resonance.

□ If $f_0(1500)$, something wrong in its branching fractions.

# Dalitz plot analysis of $B^0 \to K_S^0 K^+ K^-$.

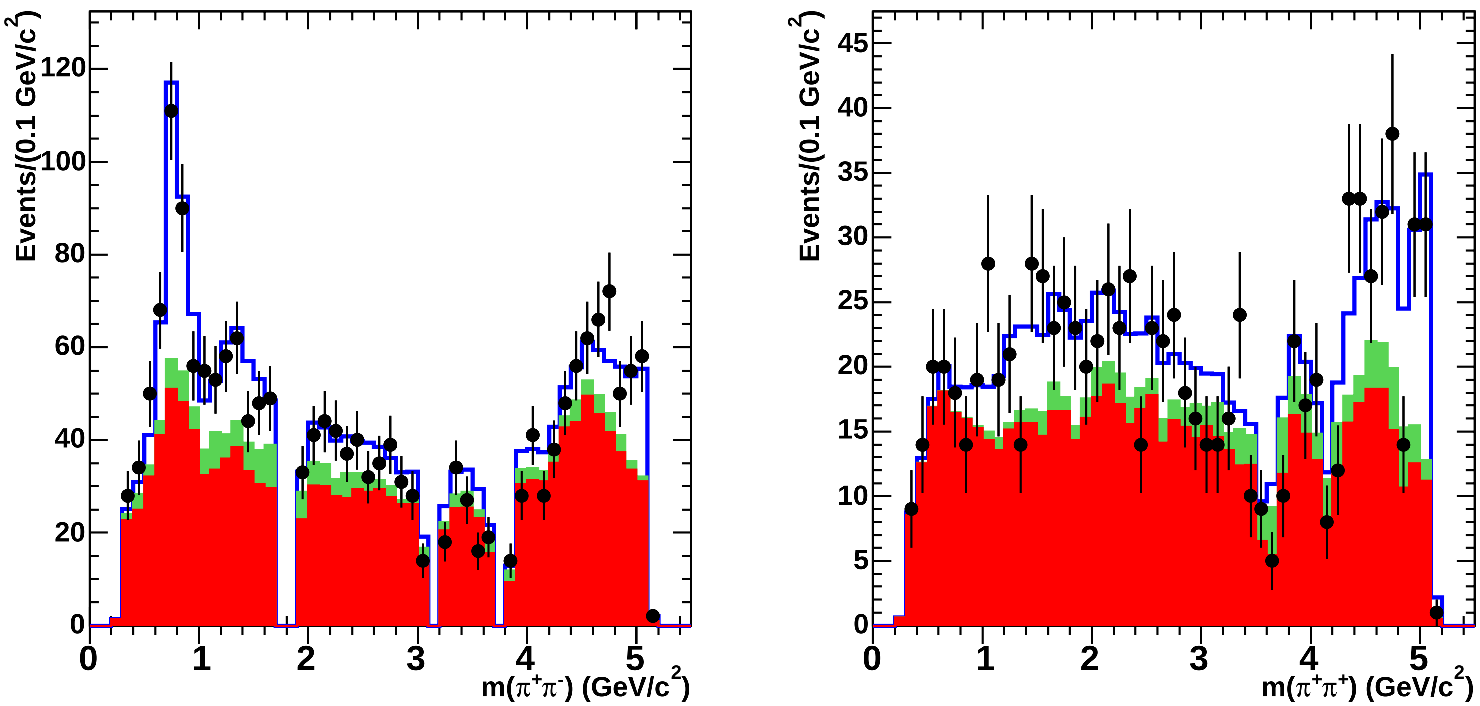
□ Data from BABAR (215 $fb^{-1}$): $K^+K^-$ projection.




□ Presence of $f_0(1500)$? Analysis prefers a scalar resonance.

# Dalitz plot analysis of $B^+ \to \pi^+\pi^+\pi^-$.

□ Data from BABAR (210 $fb^{-1}$): $\pi^+\pi^-$ projection.



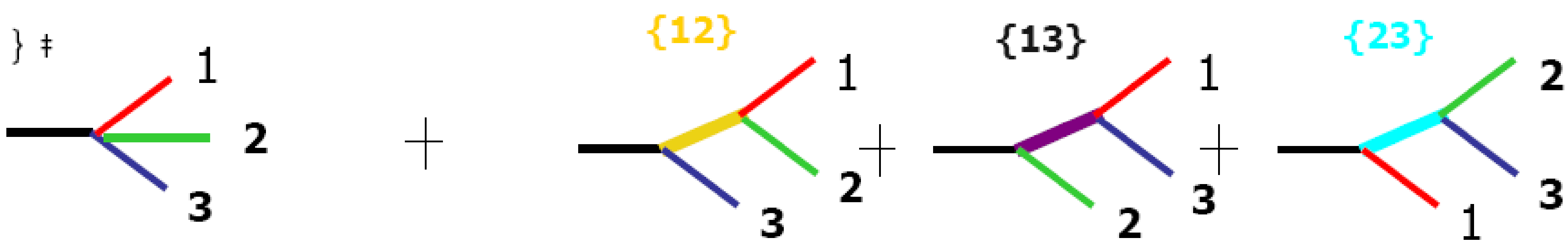

□ Decay dominated by $\rho^0(770)$.

# Unresolved Issues.

- ☐ Many other Dalitz analyses in progress.
- ☐ Uncertainties dominated by the poor knowledge of many aspects of light meson spectroscopy.
- ☐ Small scalar contribution below the $\phi$ in $B^0 \to K_S^0 K^+ K^-$? Issue related to the $f_0(980)$ parameters. Strong $f_0(980)$ signal observed in $B^0 \to K_S^0 \pi^+ \pi^-$
- ☐ What is the state $f_X(1500)$?
- ☐ What about the $\pi^+\pi^-$ S-wave? Does the $\sigma(500)$ exists?
- ☐ What about the $K\pi$ S-wave? Does the $\kappa(800)$ exists?
- ☐ Not possible to resolve these issues within B decays.
- ☐ Need information from other sources such as charm or charmonium decays.

# Charm decays.

- Charmed mesons are produced with high statistics in B-factories.
- Some three-body charm decays can be very simple and produce useful information on scalar and vector mesons.




- In some cases decay channels can be switched off by physics.
- Examples:

$$D^+ \to K^- \pi^+ \pi^+, \qquad D^+ \to \pi^+ \pi^+ \pi^-, \qquad D_s^+ \to \pi^+ \pi^+ \pi^-$$

can give useful information on the structure of the S-wave in the $K\pi$ and $\pi\pi$ final states.

- D meson decay to resonances coupled to $u\bar{u} + d\bar{d}$, $D_s$ mesons to $s\bar{s}$.

# Charmonium decays.

□ $J/\psi$ radiative and hadronic decays are also a reach source of information on scalar mesons.

□ Radiative $J/\psi$ decays could be a source of gluonium, hadronic $J/\psi \to \omega h^+ h^-$ and $J/\psi \to \phi h^+ h^-$ can give information on states coupled to $u\bar{u} + d\bar{d}$ and $s\bar{s}$ states.

# Status of scalar mesons.

□ Too many scalar mesons below 2. GeV.

| I = 1/2 | I = 1 | I = 0 |
|---|---|---|
| $k(800)$ | | $\sigma$ |
| | $a_0(980)$ | $f_0(980)$ |
| | | $f_0(1370)$ |
| $K_0^*(1430)$ | $a_0(1490)$ | $f_0(1500)$ |
| | | $f_0(1700)$ |
| $K_0^*(1950)$ | | |

□ Two nonets? 4-quark states? Gluonium?

□ Where is the scalar glueball?

□ Many proposals.

Narrow: $f_0(1500)$, $f_0(1700)$.

Wide: $\sigma$.

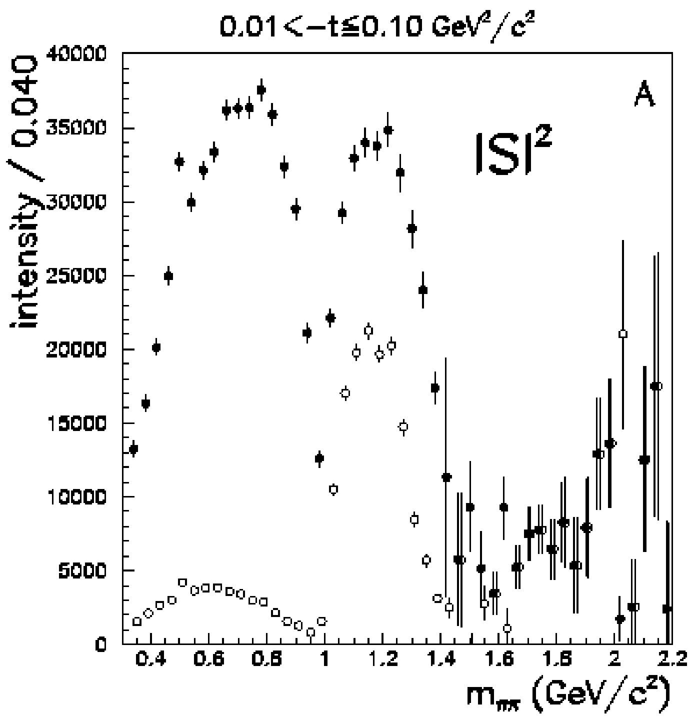
□ Information on some of these states, such as the existence of $k(800)$ and $\sigma$ can be extracted from existing data from charm or charmonium decays.

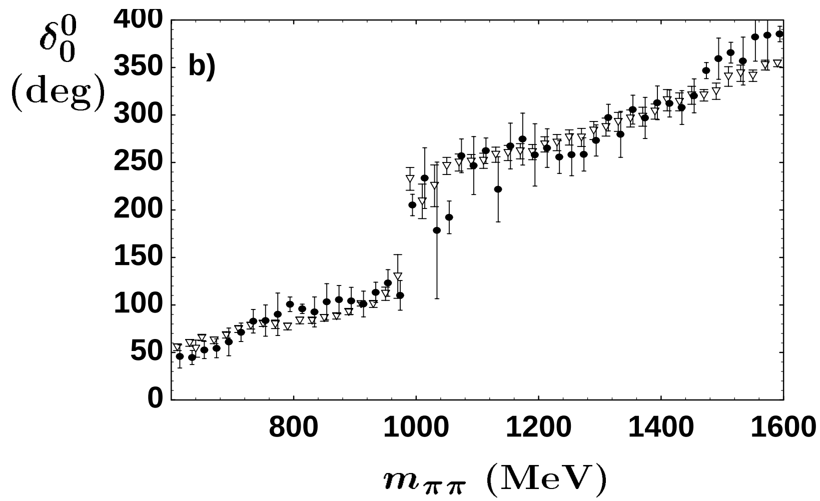
□ Unlikely to produce gluonium in charm decays.

# The evidence for $\sigma(500)$.

□ The $\pi\pi$ amplitude and phase has been measured in:

$$\pi^- p \to \pi\pi n$$



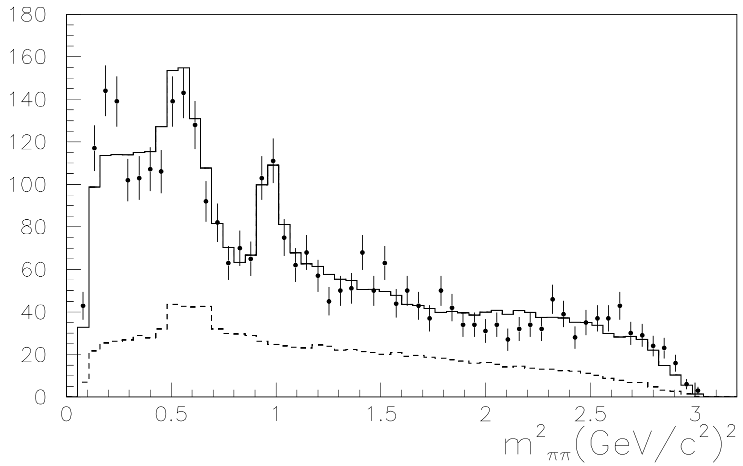



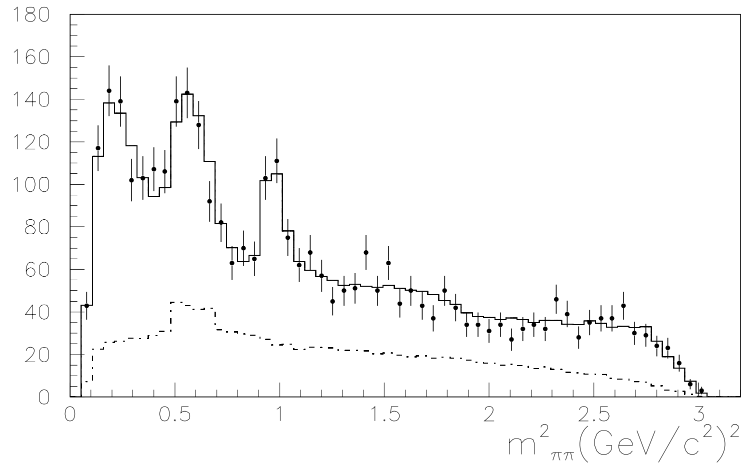

□ Slowly moving phase: a broad resonance? $\sigma(500)$?

# The evidence for $\sigma(500)$.

□ The existence of the $\sigma(500)$ has been triggered again by the Dalitz Plot analysis of $D^+ \to \pi^+\pi^+\pi^-$ (E791).

□ In order to obtain a good fit of the Dalitz plot they need to introduce a new wide scalar resonance:



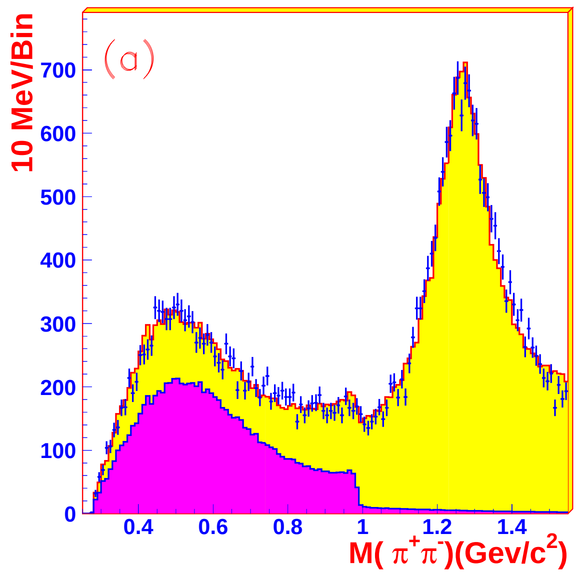

$$m = 478 \pm 24 \pm 17 \quad MeV$$

$$\Gamma = 324 \pm 41 \pm 21 \quad MeV$$

# The evidence for $\sigma(500)$.

□ BES: study of $J/\psi \to \omega\pi^+\pi^-$. Large threshold scalar enhancement. If fitted using a Breit-Wigner:

$$m = 526 \pm 15, \qquad \Gamma = 535 \pm 50 \quad MeV$$




□ However, no phase motion measured.

## The $f_0(980)$ resonance.

□ The $f_0(980)$ resonance has been discovered many years ago but has still uncertain parameters and interpretations because is just sitting at the $K\bar{K}$ threshold and strongly coupled to the $\pi\pi$ and $K\bar{K}$ final states.

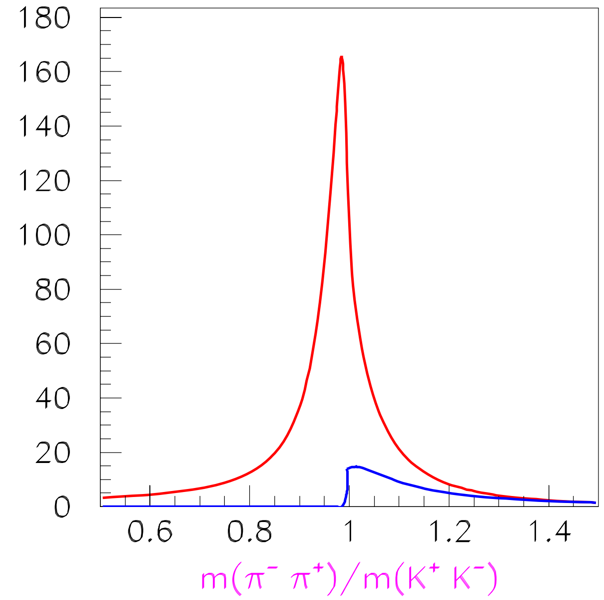
□ Many good data exist on its $\pi\pi$ projection.

□ A few good data on its the $K\bar{K}$ projection, complicated by the presence of the $a_0(980)$ resonance.

# Extracting the $f_0(980)$ parameters.

□ The $f_0(980)$ lineshape is determined by:

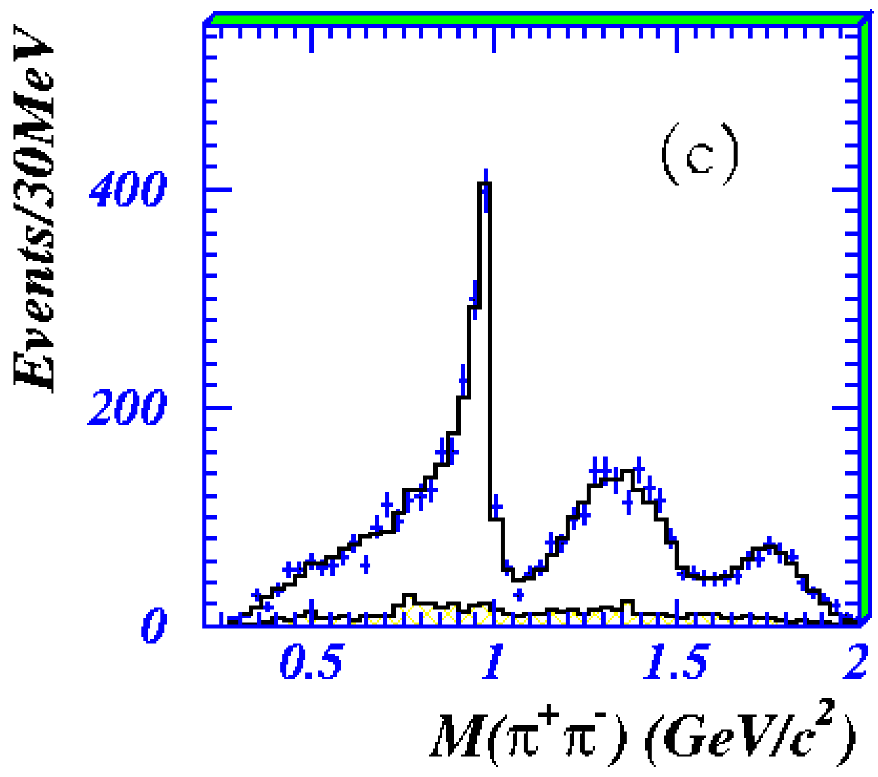
- Its coupling to the $K\bar{K}$ final state;
- The interference with other wide scalar resonances;
- Resolution effects related to both the relatively narrow width and the presence of thresholds;

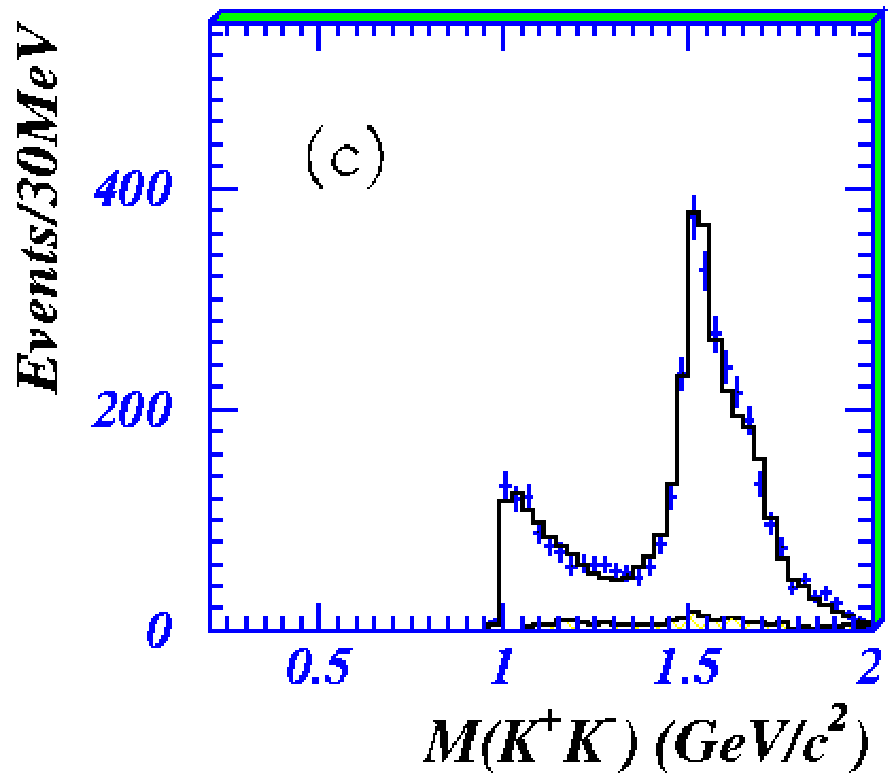


# $J/\psi$ decays.

- First analyses performed by MarkIII and DM2. Recent analysis from BES.
- Study of:

$$J/\psi \to \phi\pi^+\pi^- \qquad and \qquad J/\psi \to \phi K^+K^-$$



□ Here the $f_0(980)$ amplitude has been fitted to the Flatté form:

$$f = \frac{1}{M^2 - s - i m_0 (g_1 \rho_{\pi\pi} + g_2 \rho_{K\bar{K}})}. \quad (1)$$

□ $\rho$ is Lorentz invariant phase space, $2k/\sqrt{s}$, where $k$ refers to the $\pi$ or $K$ momentum in the rest frame of the resonance.

□ The result is:

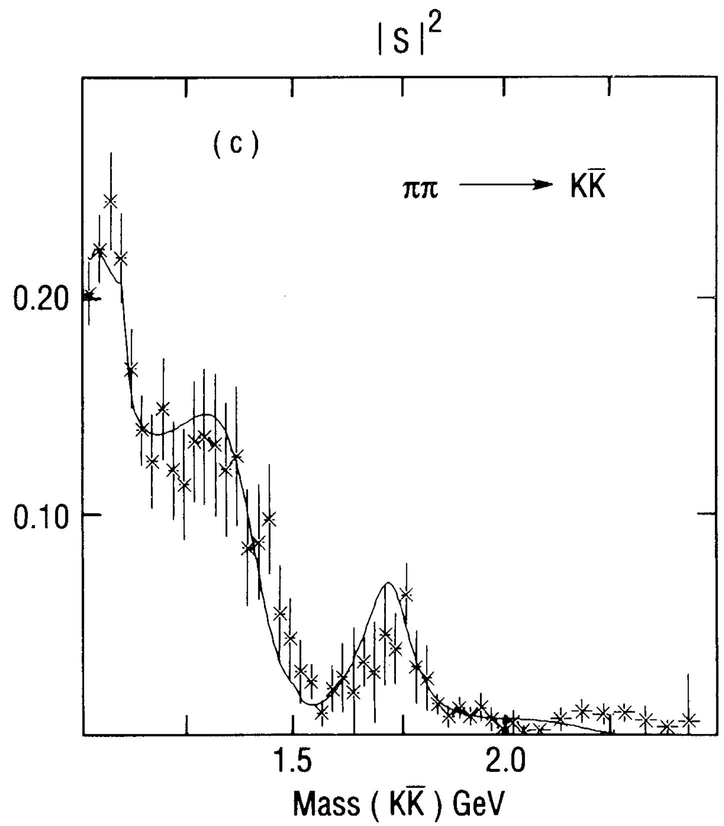
$g_2/g_1 = 4.21 \pm 0.25$ (stat) $\pm 0.21$ (syst).

□ Values are:

$M = 965 \pm 8 \pm 6$ MeV/c$^2$, $g_1 = 165 \pm 10 \pm 15$ MeV/c$^2$.

# What the $f_X(1500)$ can be?

□ No signal in the S-wave from $\pi^- p \to K_S^0 K_S^0 n$.

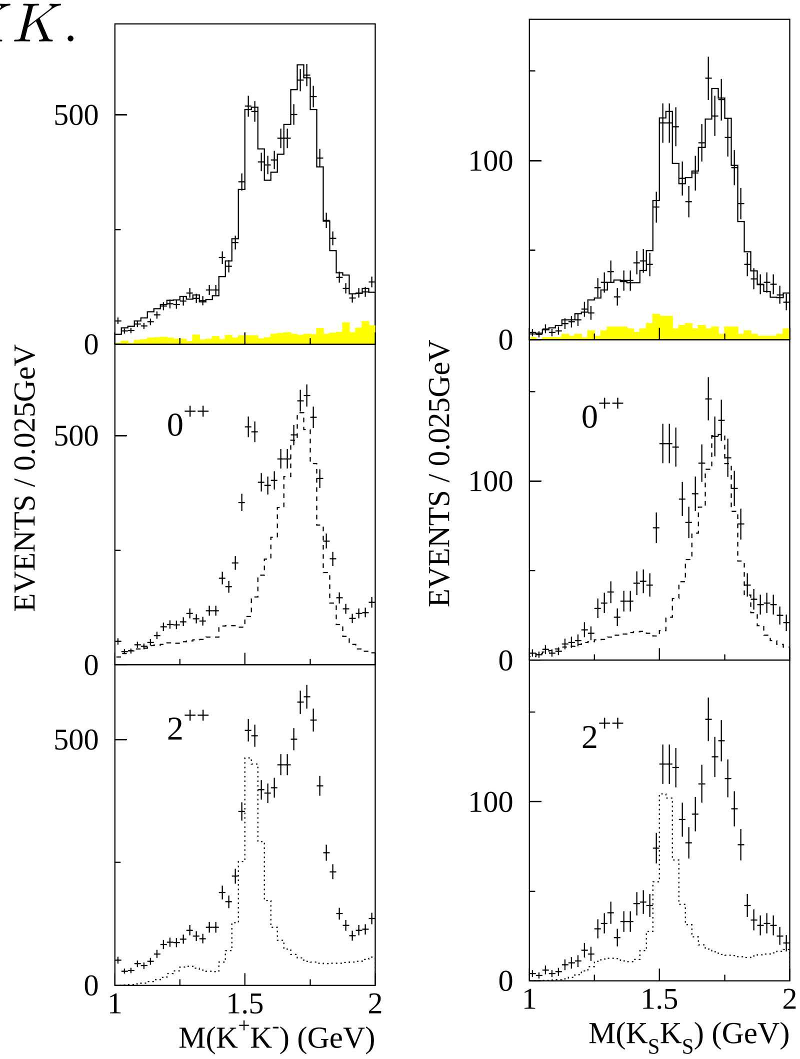



□ Some $f_0(1400)$ signal.

# What the $f_X(1500)$ can be?

□ Small S-wave from LASS in $K^- p \to K^+ K^- \Lambda$.

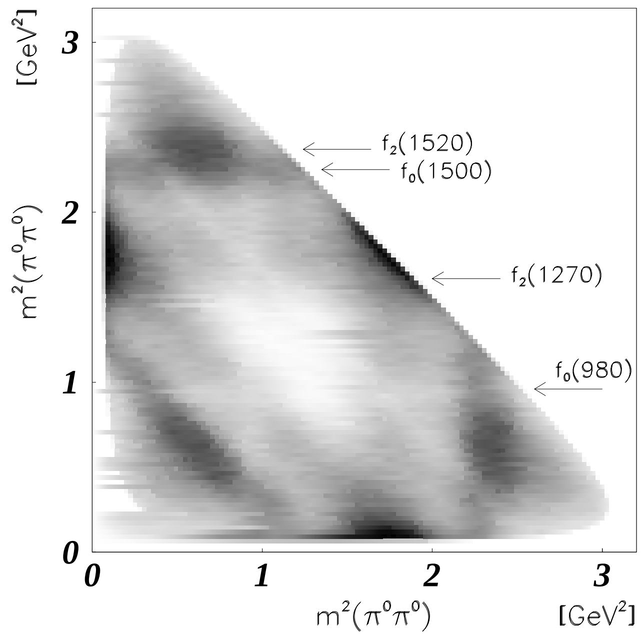
Blue□ No signal in $J/\psi$ decays to $\gamma K\bar{K}$ or $\omega K\bar{K}$.



# The $f_0(1500)$.

□ $f_0(1500)$ (M=1509±10,$\Gamma = 116 \pm 17$ MeV) was discovered by Crystal Barrel in $\bar{p}p$ annihilations at rest.

$$\bar{p}p \to \pi^0\pi^0\pi^0, \bar{p}p \to \eta\eta\pi^0, \bar{p}p \to \eta'\eta\pi^0, \bar{p}p \to K_L^0 K_L^0 \pi^0$$

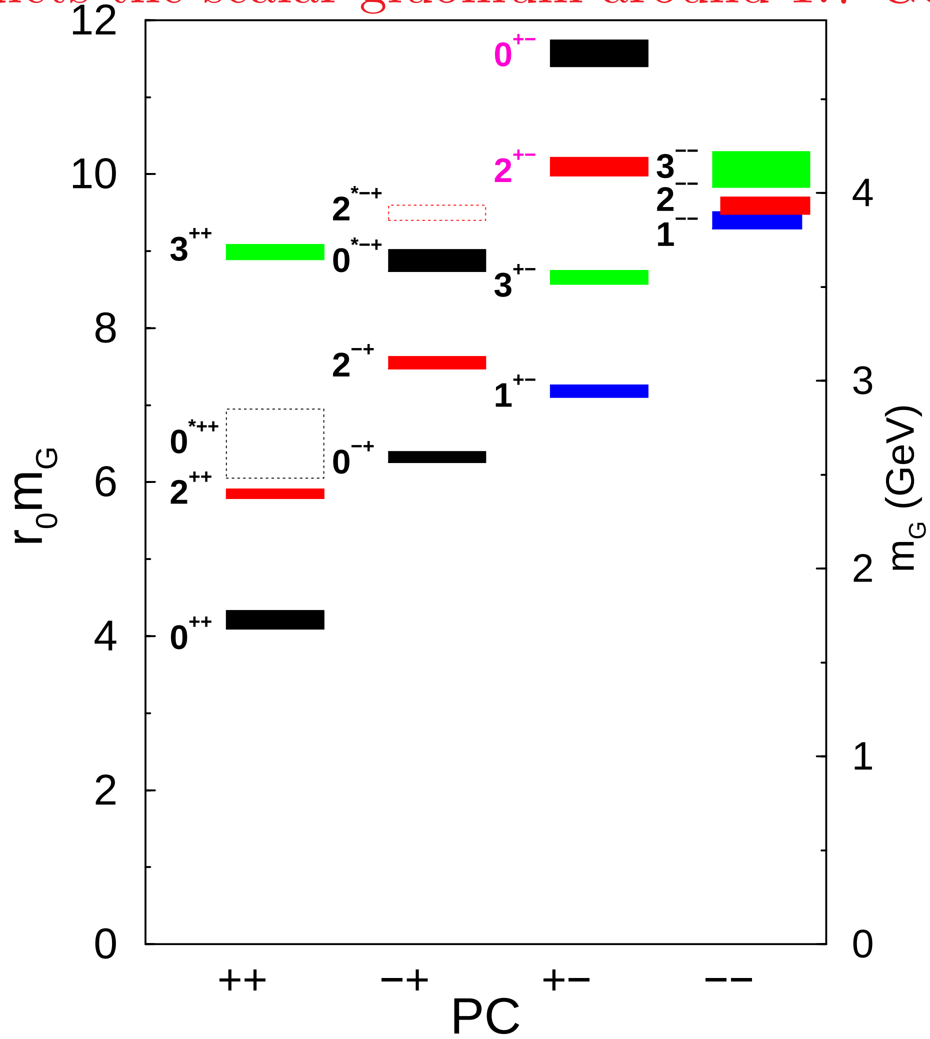



□ Rates:

$$\pi\pi : K\bar{K} : \eta\eta : \eta\eta' = (5.1 \pm 2.0) : (0.71 \pm 0.21) : (1.0) : (1.3 \pm 0.5)$$

# Gluonium?

□ Lattice QCD predicts the scalar gluonium around 1.7 GeV:



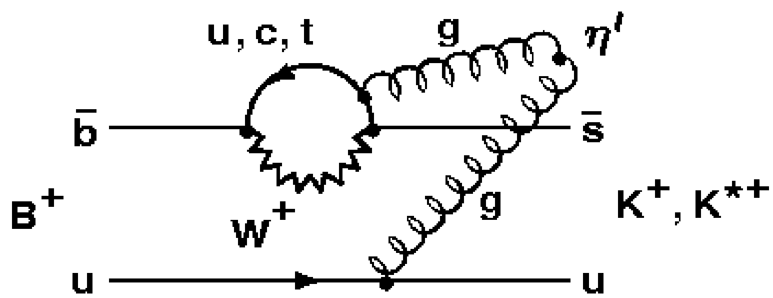
# Search for gluonium in B decays.

□ 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 $\eta'$, therefore gluonium states may be produced in B decays.

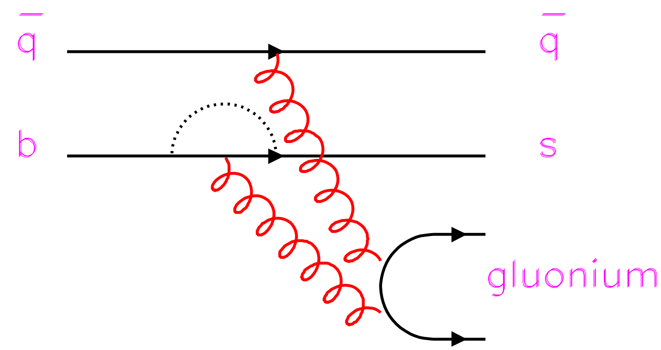
□ The total rate $b \to sg$ has been calculated perturbatively:

$$B(b \to sg) = (2 - 5) \times 10^{-3}$$

□ One should look for:

$$B \to K^{(*)}\pi\pi, KK, \eta\eta, \eta\eta'$$

in searching for scalar or tensor states.




H. Fritzsch, Phys. Lett. B415 (1997) 83
P. Minkowski and W. Ochs hep-ph/0404194

# Conclusions.

□ The study of charmless B decays is a new window where it is possible to search for New Physics but also to have new inputs to solve old puzzles related to light meson spectroscopy.

□ Useful information for studying B decays can be extracted from the high statistics study of charm and charmonium states.