New Spectroscopy from Charm and Beauty decays.

Antimo Palano

INFN and University of Bari

LNF Spring School, Frascati, May 16, 2005.

□ Summary.

- New Spectroscopy from B factories and fixed target experiments;
- Methods;
- Charmonium spectroscopy;
- Charm Spectroscopy;
- Light Meson Spectroscopy;
- Pentaquarks.

Introduction.

□ In the last few years Heavy and Light Meson Spectroscopy has received new interest due to the unexpected discovery of new states.

□ New particles/resonances have been found/proposed in the field of light scalar, charmed and charmonium mesons.

□ In particular, new results on Spectroscopy are coming from:

- B decays;
- Charm decays;
- Inclusive e^+e^- interactions;
- $\gamma\gamma$ collisions;
- Initial State Radiation;
- e^+e^- colliders;
- Fixed Target Experiments and hadron colliders;

Experiments.

- Two B-factories are currently collecting data:
- BaBar at PEP-II, Stanford, USA.
- BELLE at KEK, Tsukuba, Japan.

- Experiment running with e^+e^-:
- CLEO, at Cornell, USA.
- BES at Bejing.

- Several fixed target experiments are collecting or still analyzing data:
- FOCUS at Fermilab, USA.
- CDF at Fermilab, USA.
- E791 at Fermilab, USA.
- E835 at Fermilab, USA.

B decays.

- B mesons are extracted, at B-factories, from:

$$\Upsilon(4S) \rightarrow B^0 \bar{B}^0$$

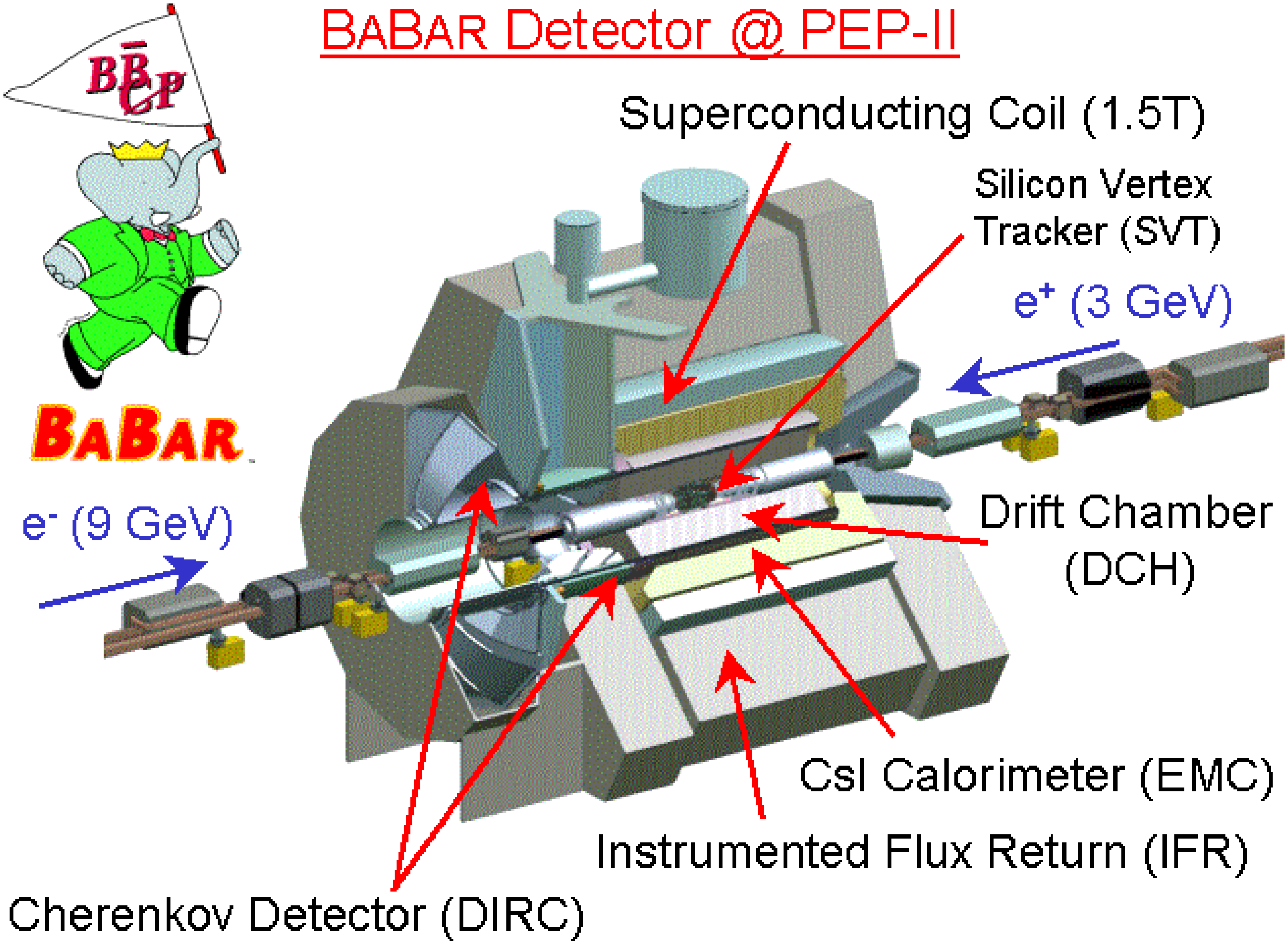
$$\Upsilon(4S) \rightarrow B^+ B^-$$

- Study of e^+e^- at the $\Upsilon(4S)$ energy: 10.58 GeV.

$$E_{e^-} = 9.0, E_{e^+} = 3.1, \beta\gamma = 0.56$$

- Asymmetric collider in order to produce a forward boost.

BaBar Detector @ PEP-II



Spectroscopy at B-factories.

□ The power of B-factories for spectroscopy is based on:

- Relatively small combinatorial in e^+e^- interactions.
- Good tracking and vertexing.
- Good Particle Identification.
- Detection of all possible final states, with charged tracks and γ's .
- Very high statistics.
  □ BELLE: 420 fb^{-1}
  □ BABAR: 250 fb^{-1} (restarting now from a long shutdown)

B decays.

- □ Use of the m_{ES} and ΔE variables.
- □ m_{ES}^2 (Energy Substituted Mass), is defined as the difference, in the e^+e^- center of mass system, between the squared Beam energy and the squared B momentum:

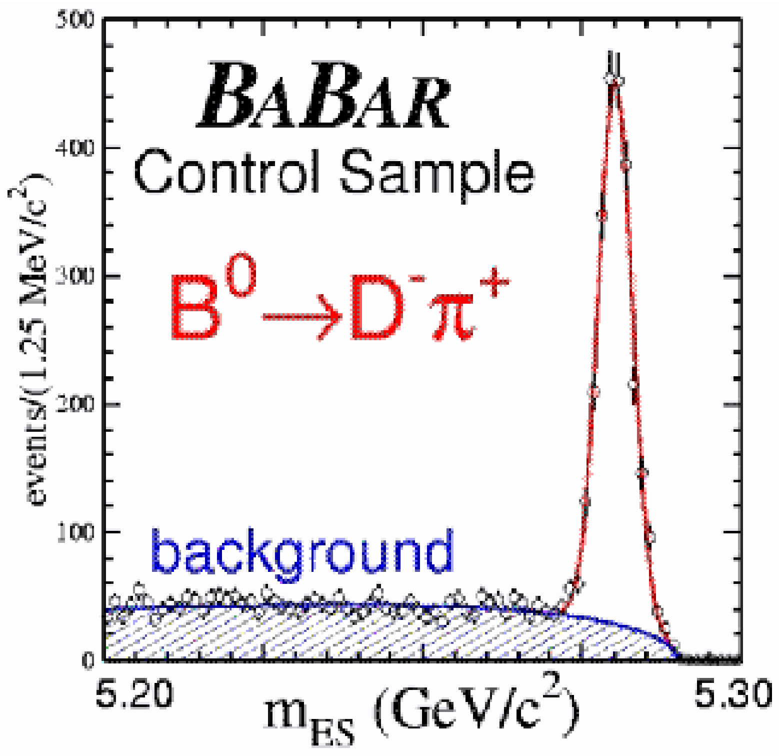
$$m_{ES} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2}$$

- □ ΔE is defined as the difference between the center of mass B and Beam energy:

$$\Delta E = E^*_B - E^*_{beam}$$

B mass

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$

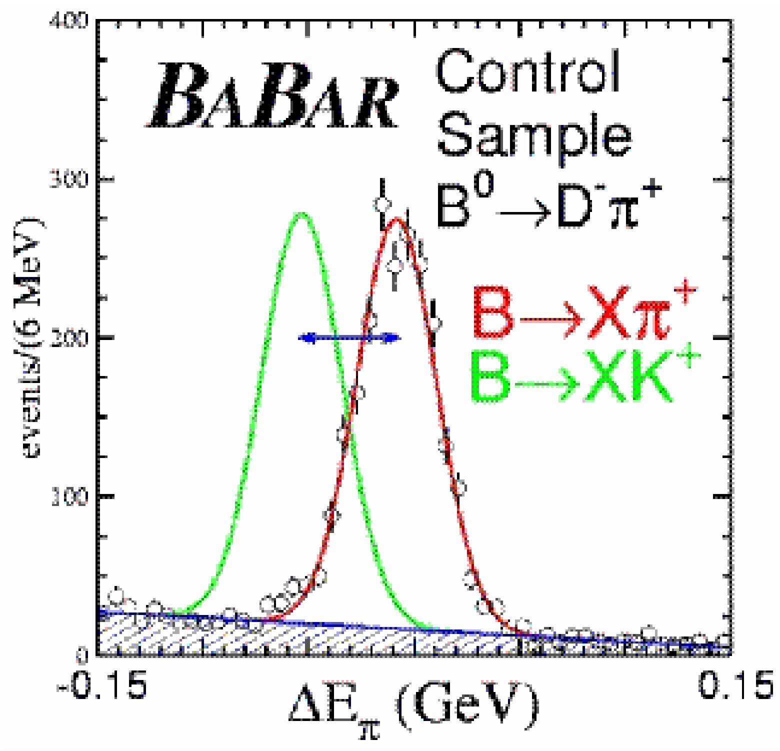


$\sigma(m_{ES}) \equiv 2.5 - 3\ \mathrm{MeV/c^2}$:

dominated by beam energy spread.

Missing Energy

$$\Delta E = E^{*}_{B} - E^{*}_{beam}$$

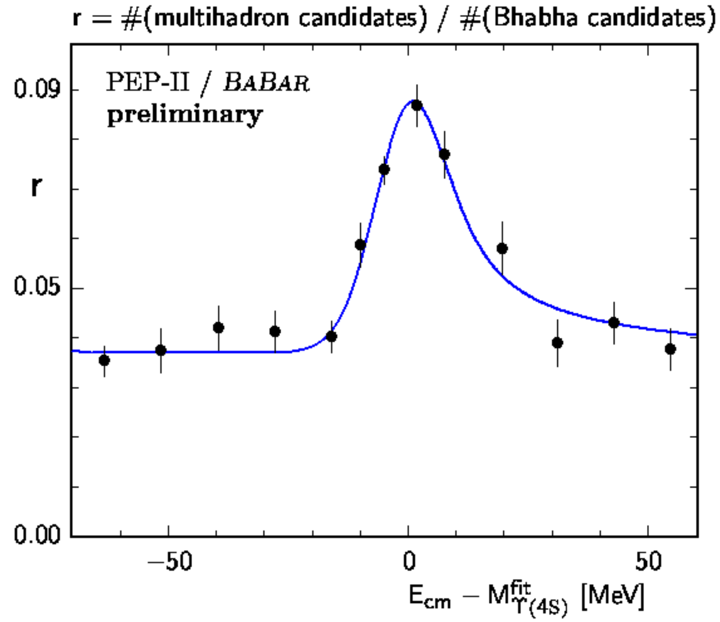


$\sigma(\Delta E) \equiv 15 - 80$ MeV:

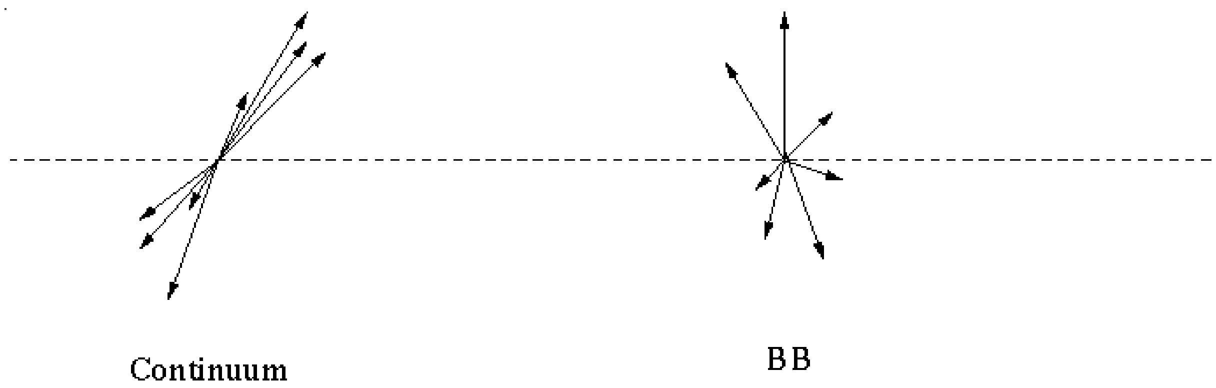
dominated by particle momenta.

Separation from continuum.

□ At B-factories, the $\Upsilon(4S)$ resonance sits on a consistent continuum background.



□ However one may use events shapes to remove continuum events which have a jet-like shape.



□ There are several ways of doing it. In this example two methods have been used:

- The ratio of the second Fox-Wolfram moment divided by the zeroth moment for the whole event, FW_{ev}. The Fox-Worfram moments H_l are defined as:

$$H_l = \sum_{i,j} \frac{\mid p_i \mid \cdot \mid p_j \mid}{E_{vis}^2} P_l(cos\theta_{ij})$$

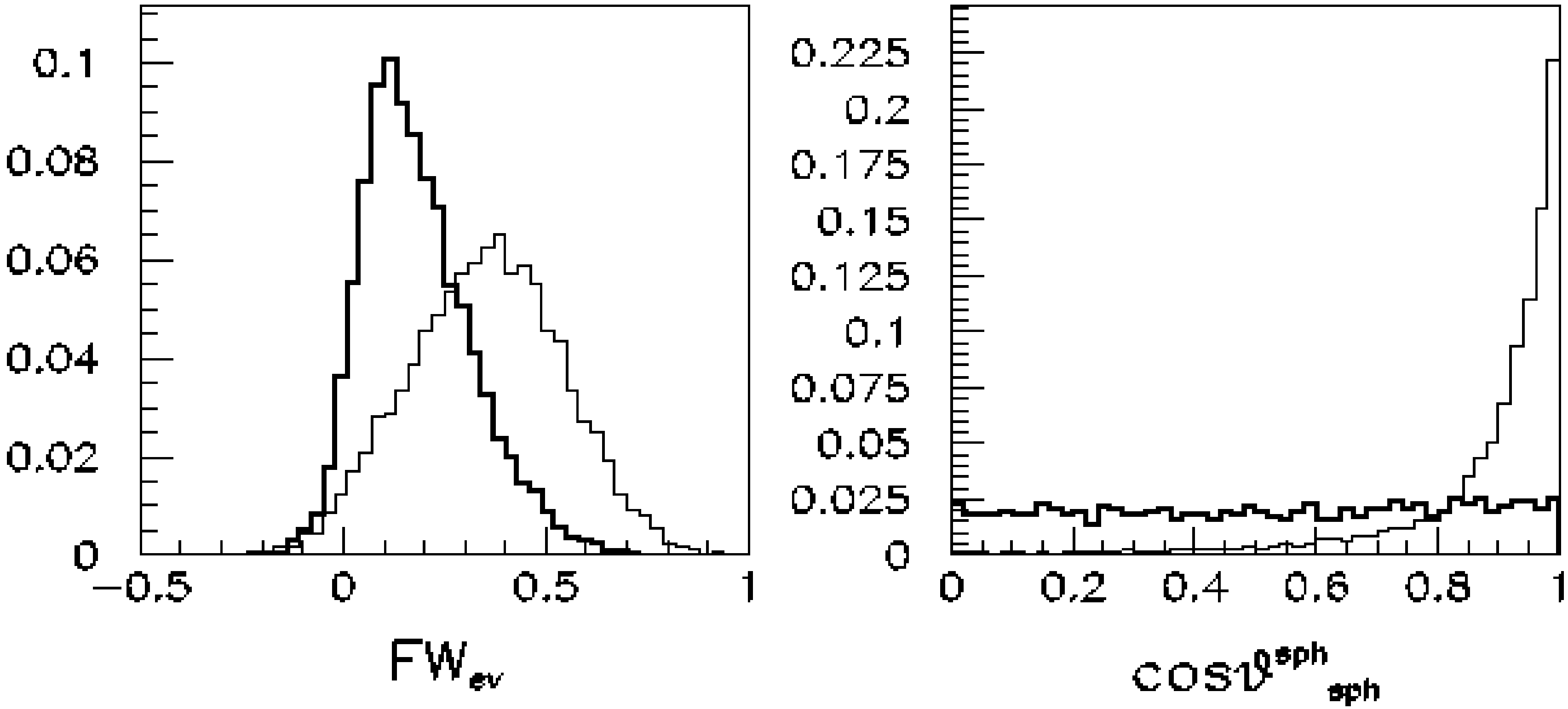
  where P_l are the Legendre polynomials, p_{ij} and θ_{ij} are particles momenta and opening angle's. E_{vis} is the event visible energy.

- The angle between the sphericity axis of the B with respect to that of the rest of the event $cos\theta_{sph}^{sph}$. The sphericity is defined as:

$$S = \frac{3}{2} min \frac{\sum_i p_{jT}^2}{\sum_j p_j^2}$$

  where p_T indicates the transverse momentum of the particle.

- Example of events separation. Monte Carlo simulation:
- Light: continuum, Thick: $B\bar{B}$.



Spectroscopy from B decays.

☐ Advantages:

- Very clean starting physical state: a spin 0 particle;
- Backgrounds moderately low;
- Suppression of high partial waves (usually J<3);
- Large phase space which allows to cover a large mass region.

☐ Disadvantages:

- Branching ratios for interesting channels rather low;
- Rather often, complicated final states.

B decays.

□ Several B decays useful for spectroscopy:

- Involving charm production.

  □ Search for excited charm states in:

$$B \to D^* \pi\pi$$

  □ Search for excited charm states in:

$$B \to D^* D(s) \pi$$

- Charmless.

  □ Study of (where $h = \pi, K$):

$$B \to 3h$$

- Charmonium.

  □ Study of:

$$B \to \psi X$$

Charm decays.

□ Charmed mesons decay to light hadrons, therefore a fundamental laboratory for studying light meson spectroscopy, especially for spin 0 and spin 1 mesons.

□ Cross sections for different processes, at the $\Upsilon(4S)$:

$e^+e^- \to$	σ (nb)
$b\bar{b}$	1.05
$c\bar{c}$	1.30
$s\bar{s}$	0.35
$u\bar{u}$	1.39
$d\bar{d}$	0.35
$\tau^+\tau^-$	0.94
$\mu^+\mu^-$	1.16
e^+e^-	≈ 40

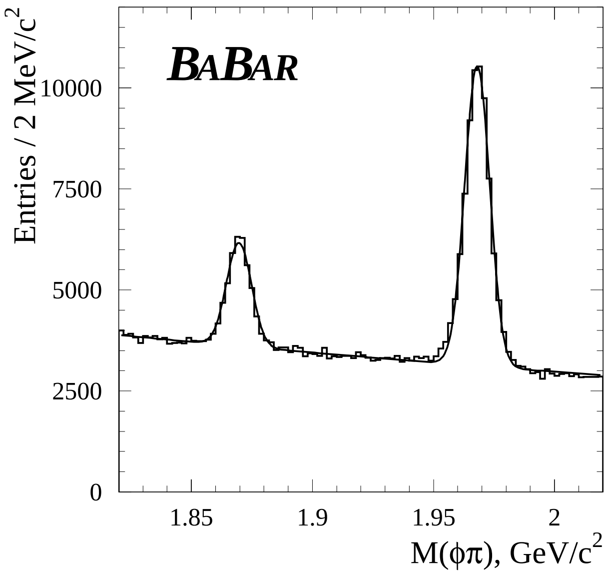
□ Inclusive Charm Physics is performed on events selected from continuum $e^+e^- \to \bar{c}c$

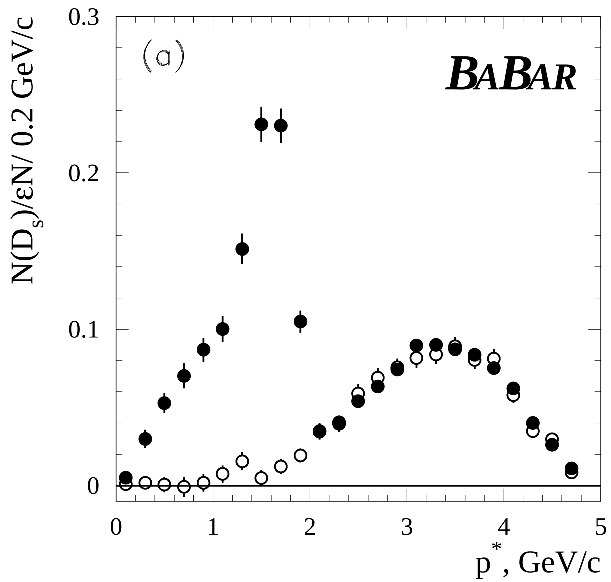
□ Very high statistics samples of charmed mesons actually available.

Study of D_s^+ in BaBar.

□ Example from BaBar: mass distribution and p^* momentum spectrum f or $D_s^+ \to \phi\pi^+$. BABAR,hep-ex/0201041

Filled/open points: normalized on/off peak data.





□ By using inclusive continuum events combinatorial background is strongly reduced.

□ Kinematical selection: the center of mass momentum $(p^*) > 2.5$ GeV/c.

Selection of Charmed mesons from continuum.

□ Alternatively, x_F is used instead of p^*. x_F defined as the ratio between the actual center of mass momentum and the maximum allowed momentum.

$$x_F = \frac{p^*}{p^*_{max}}$$

$$p^*_{max} = \sqrt{E^2_{beam} - M^2_D}$$

Selection of D^0 Charmed mesons from continuum.

- Use of the $D^{*+} \to \pi^+ D^0$ tag for D^0 decays.
- Example:

$$\begin{aligned} D^{*+} \to \; & D^0 \pi^+ \\ & \to \bar{K}^0 \pi^+ \pi^- \end{aligned}$$

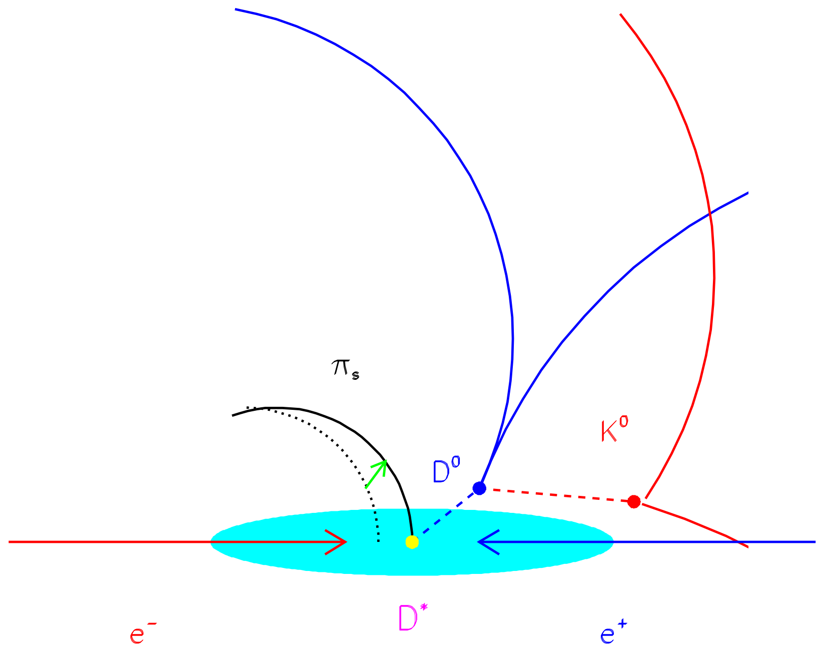
$$\begin{aligned} D^{*-} \to \; & \bar{D}^0 \pi^- \\ & \to K^0 \pi^+ \pi^- \end{aligned}$$

- Here the charge of the slow π gives the flavor of the D^0 and of the K^0.

Slow pion refit.

☐ Refitting of the slow pion.The momentum of the slow pion is usually below 500 MeV/c: badly measured.

☐ Cartoon of one event:



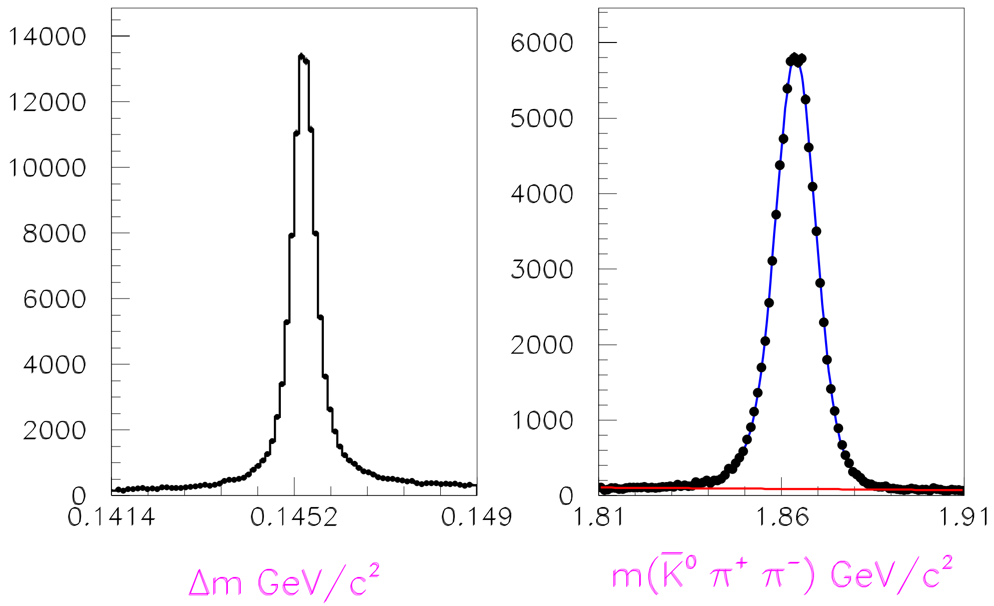
☐ Using the event vertex in the fit of the slow pion momentum improves the resolution.

The use of Δ m.

- Definition of Δm:

$$\Delta m = m(\bar{K}^0\pi^+\pi^-\pi_s^+) - m(\bar{K}^0\pi^+\pi^-)$$

- Selecting events in the Δm peak results in a clean selection of the D^0 signal.



Selection of D^+ Charmed mesons from continuum.

□ D^+ mesons can be isolated in an a rather efficient way by making use of their longer lifetime.

$$c\tau_{D^0} = 123\mu m; \quad c\tau_{D^+} = 311.8\mu m; \quad c\tau_{D_s^+} = 147\mu m$$

□ In some cases can be useful to use the tag:

$$D^{*+} \to \pi^0 D^+$$

□ This tag is rather inefficient because of the difficulty of detecting slow $\pi^0 \to \gamma\gamma$. The momentum of the slow π^0 is below 500 MeV/c.

□ Used in difficult cases, such as:

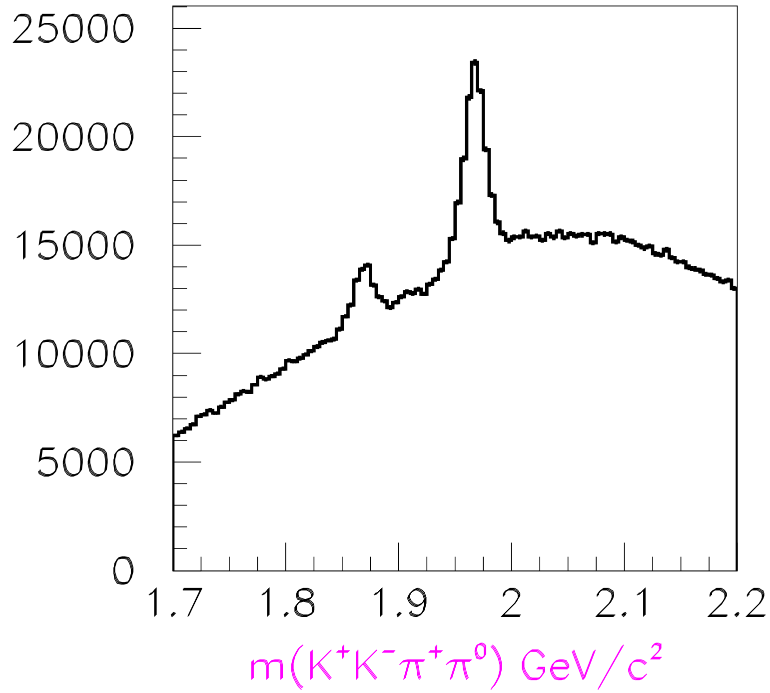
$$D^+ \to \pi^+ \pi^0$$

Selection of D_s^+ Charmed mesons from continuum.

- In this case can be useful to use the decay:

$$D_s^*(2112)^+ \rightarrow \gamma D_s^+$$

- Example from BaBar: combinatorial $K^+K^-\pi^+\pi^0$ mass distribution:



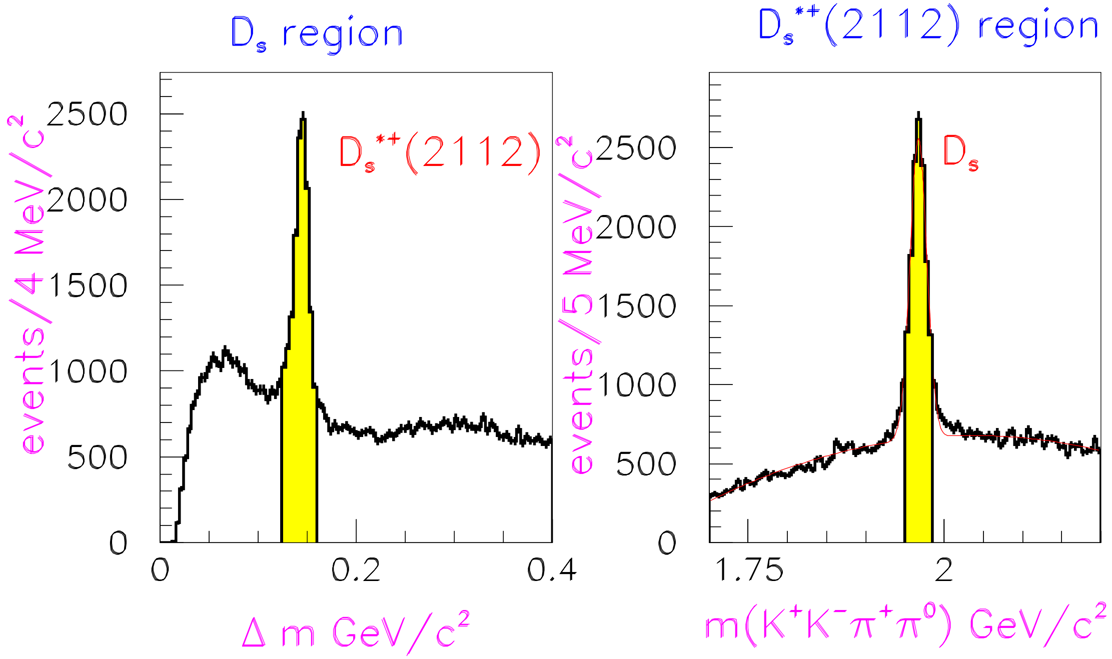
- Signals due to D^+ and D_s^+.

Δm selection.

□ Selecting events in the D_s^+ mass window results in a clear $D_s^{*+}(2112) \rightarrow \gamma D_s^+$ signal. Selecting events in the D_s^{*+} mass window results in a clear D_s^+ signal. Further kinematic cuts may further enhance the signal to background.

□ Here:

$$\Delta m = m(K^+K^-\pi^+\pi^0\gamma) - m(K^+K^-\pi^+\pi^0)$$

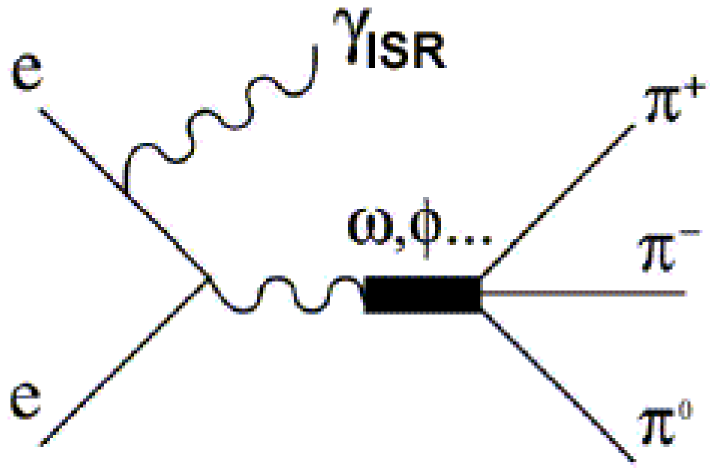


e^+e^- interactions with Initial State Radiation (ISR).

□ Another clean method for studying meson spectroscopy is that of the reaction:

$$e^+e^- \to \gamma + hadrons$$

where the photon emission is caused by Initial State Radiation (ISR).



□ This process can be used to measure the e^+e^- annihilation cross section over a wide range of center of mass energies.

□ This process produces only $J^{PC} = 1^{--}$ mesons, therefore information can be obtained on the structure of vector mesons.

e^+e^- interactions with Initial State Radiation (ISR).

- The angular distribution of the ISR γ and the ISR cross section are given by:

$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = W(s,x,\theta)\cdot\sigma_0(s(1-x)),$$

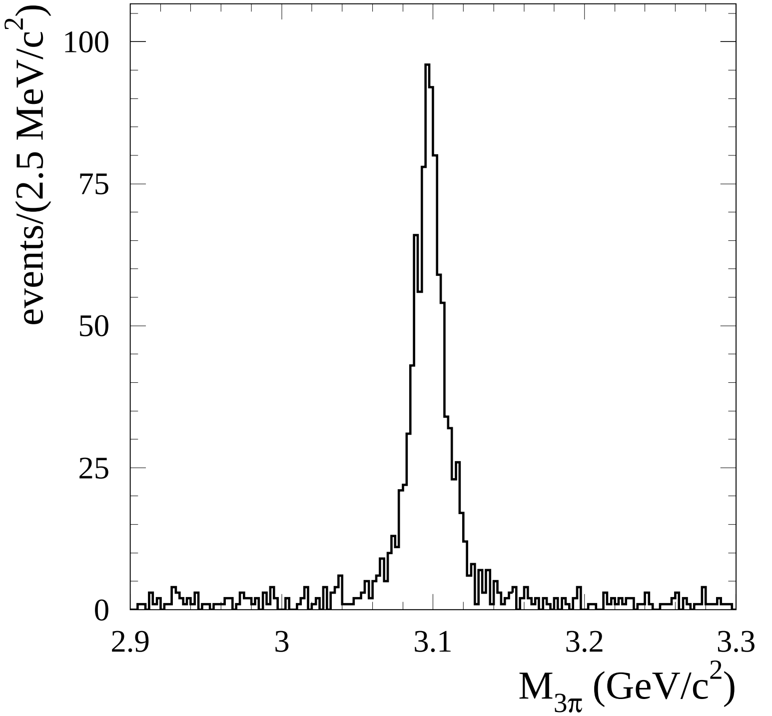
$$W(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right), \quad x = \frac{2E_\gamma}{\sqrt{s}}$$

- This gives a sharply peaked γ with an energy $E^* > 3$ GeV.

ISR production of J/ψ.

□ Example from BaBar.Study of: BABAR,hep-ex/0408078

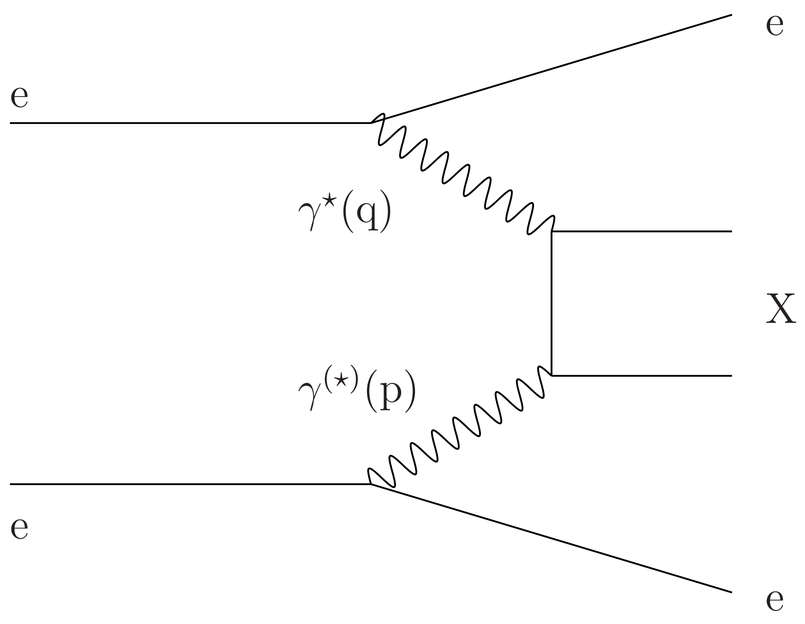
$$e^+e^- \to \gamma_{ISR}\ J/\psi$$
$$\to \pi^+\pi^-\pi^0$$



$\gamma\gamma$ collisions.

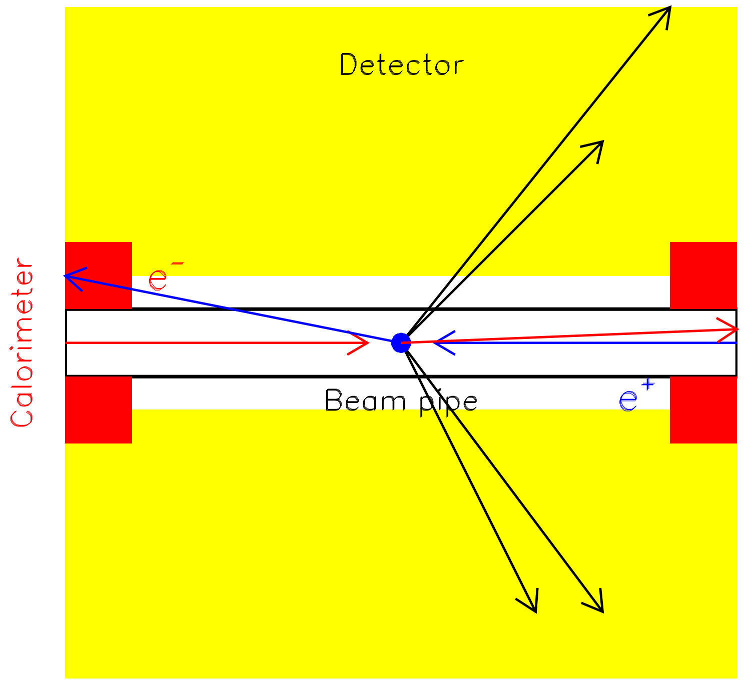
□ $\gamma\gamma$ collisions are a very clean source of meson resonances.

□ They are kinematically characterized by the 4-momentum transfer q^2, the mass of the virtually exchanged particles.



Tagged and untagged $\gamma\gamma$ collisions.

□ Normally the two exchanged γ's are virtual because most of the cross section has small q^2 (untagged events). In this case the γ's are on the mass shell and get lost in the detector beam pipe.

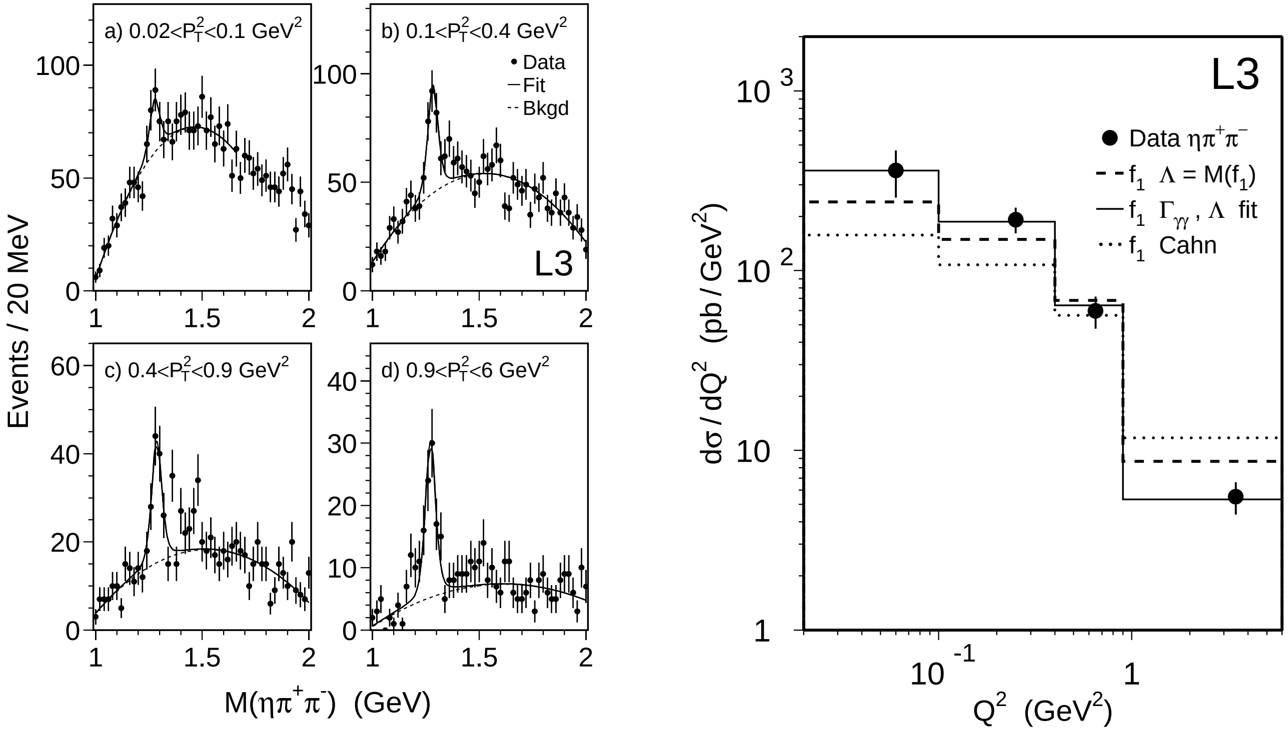


□ Tagged events have one of the two γ's massive (indicated with γ^*).

Spin 0 and Spin 1 resonances.

□ Landau-Yang theorem: vector states cannot be formed by two real photons.

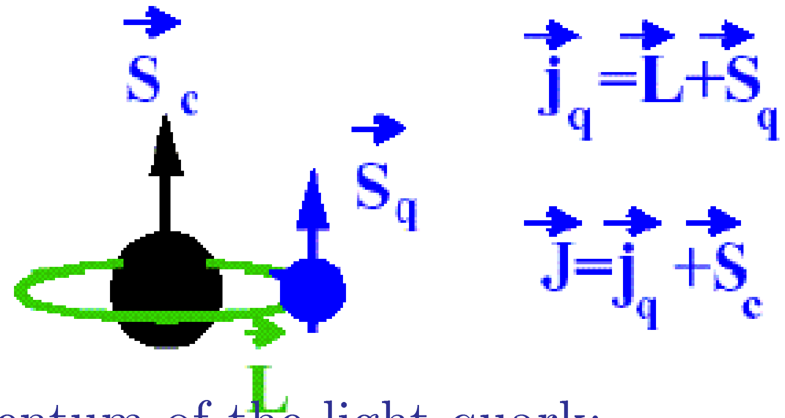
□ Data from L3: $\gamma\gamma \to \eta\pi^+\pi^-$. Formation of the $J^{PC} = 1^{++}$ meson $f_1(1285)$. p_T^2 is proportional to q^2. L3,hep-ex/0011035



□ $f_1(1285)$ signal mostly seen at high p_T.

Charm Spectroscopy.

- Potential model of the Charm spectrum:
- The ($\bar{c}u/d$ or $\bar{c}s$) systems are treated as the Hydrogen atom.



- Total angular momentum of the light quark:

$$j = S_q + L$$

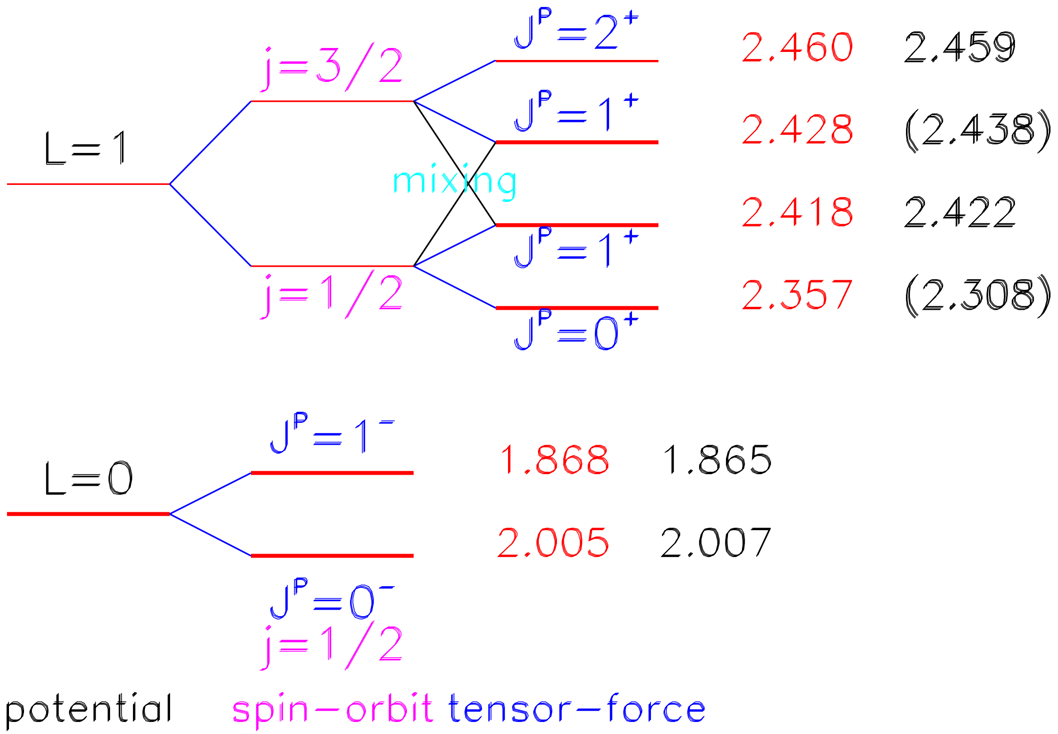
- Total Spin:

$$J = L + S_q + S_Q$$

$$P = (-1)^{L+1}; \qquad C = (-1)^{L+S}$$

Charm Spectroscopy.

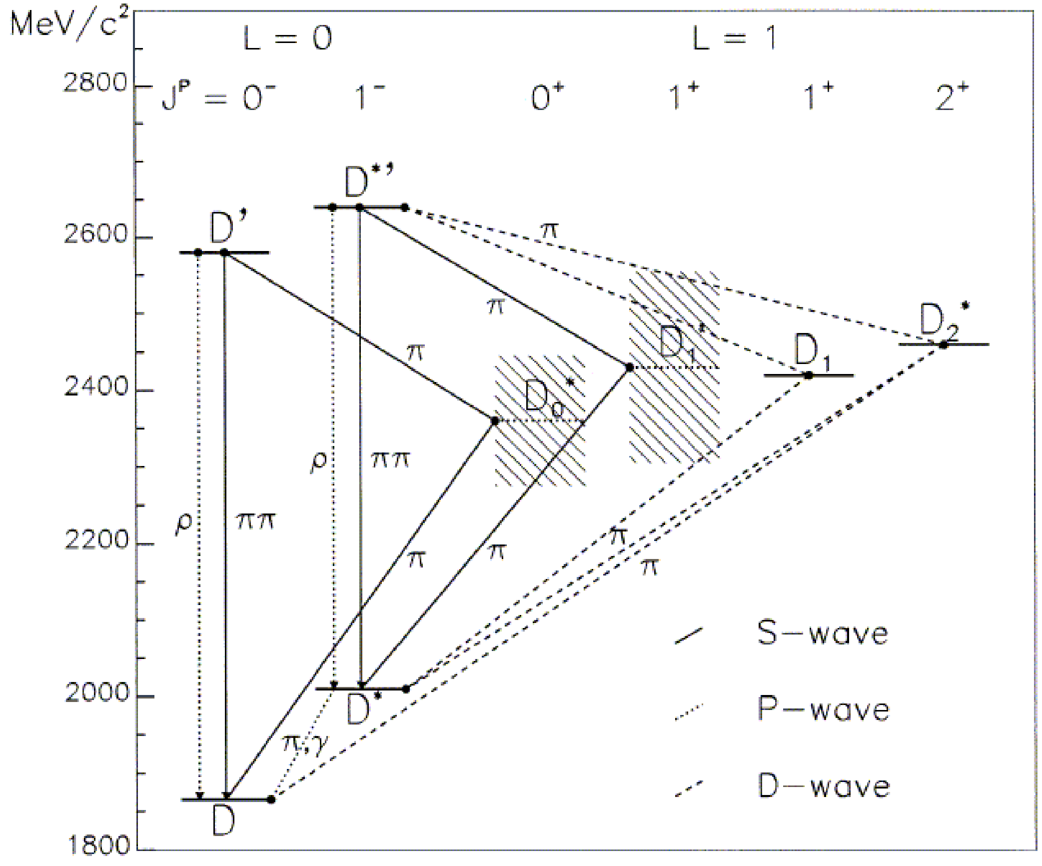
□ Spectrum of the $\bar{c}u$ states with prediction from Godfrey,Isgur,Kokoski (red) compared with experimental values (black):



□ States in () broad and found very recently.

Charm Spectroscopy.

□ The expected spectrum of D mesons:

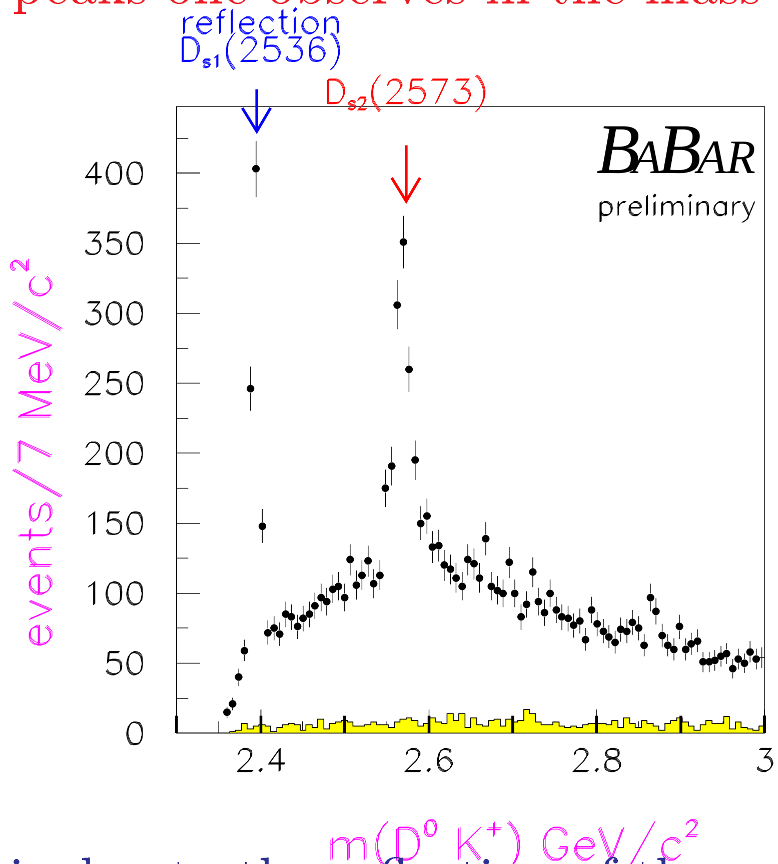


□ The broad states recently discovered. Radial excitations still missing.

The problem of the reflections.

□ The search for new charmed mesons in inclusive spectra is complicated by the problem of the reflections: not all the peaks one observes in the mass spectrum are due to particles.

□ A rather spectacular example is given by the D^0K^+ mass spectrum:



□ The first narrow peak in this spectrum is due to the reflection of the particle $D_{s1}(2536)^+ \to K^+D^*(2007)^0$.

□ Decay chain:

$$D_{s1}(2536)^+ \rightarrow K^+ \; D^*(2007)^0$$
$$\rightarrow D^0(\pi^0/\gamma)$$

□ The kinematics is such that combining the D^0 with the K^+ and ignoring the (π^0/γ) we still obtain a narrow peak (fake).

□ Conclusion: one has to be very careful before claiming for the discovery of a new particle.

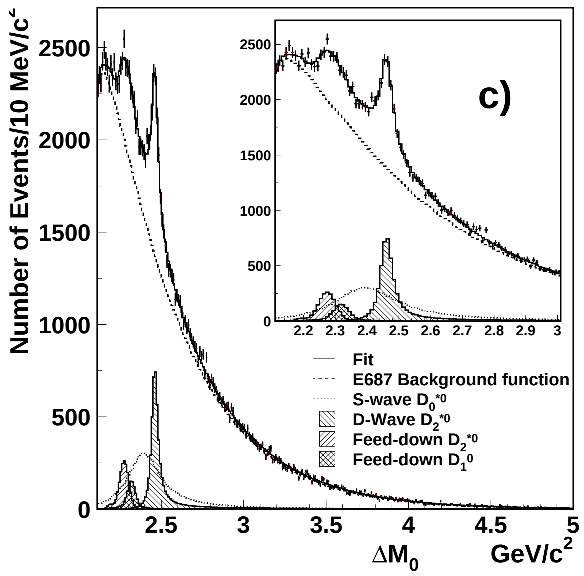
The evidence for the broad $c\bar{u}$ states.

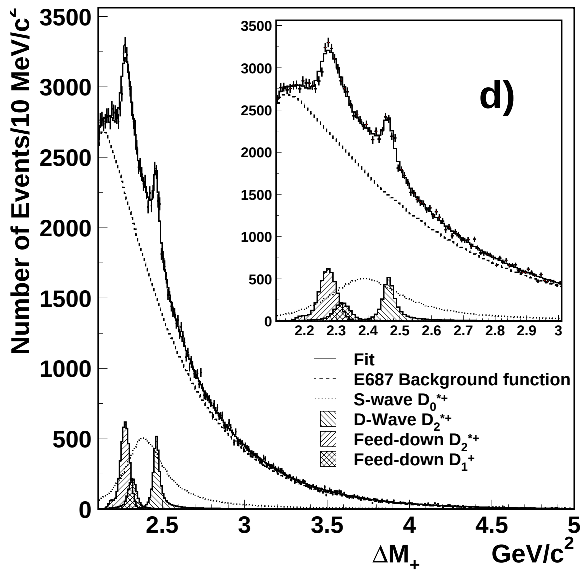
□ Two different approaches have been used to search for the missing broad $c\bar{u}$ states with $J^{PC} = 0^{++}$ and 1^{++}.

- Inclusive (FOCUS) (photo-production: γ N experiment);
- Exclusive, using B decays (BELLE);

Results from FOCUS.

□ This experiments studied the inclusive $D^0\pi^+$ and $D^+\pi^-$ mass spectra where $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$ and $D^+ \to K^-\pi^+\pi^+$.FOCUS,hep-ex/0312060





□ After having included the feed-downs and the $D_2^*(2464)$ signal, they need a further broad resonance to have a good fit to the data.

□ Resulting parameters for the broad state (interpreted as due to a $J^{PC} = 0^{++}$ resonance):

$$D^{*+} : m = 2403 \pm 14 \pm 35 \qquad \Gamma = 283 \pm 24 \pm 34 \quad MeV$$

$$D^{*0} : m = 2407 \pm 21 \pm 35 \qquad \Gamma = 240 \pm 55 \pm 59 \quad MeV$$

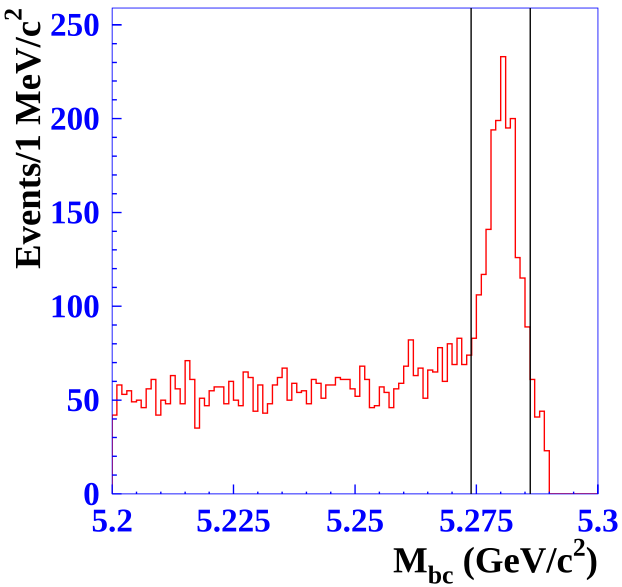
Results from BELLE.

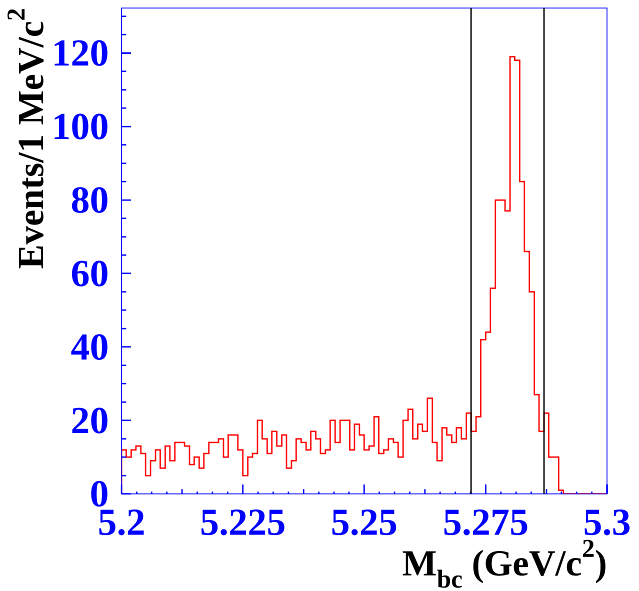
□ BELLE experiments studies the decays: BELLE,hep-ex/0307021

$$B^- \to D^+\pi^-\pi^-$$

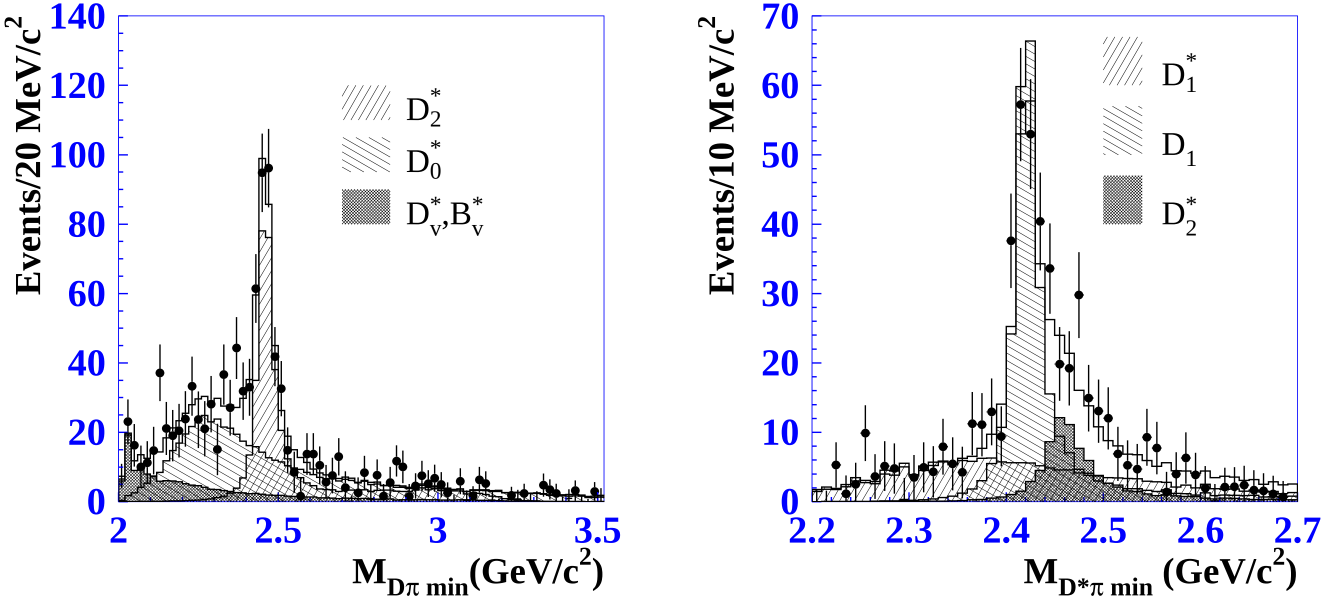
$$B^- \to D^{*+}\pi^-\pi^-$$

□ Important issue in this analysis is the low background. Beam constrained masses for the two channels.





□ They perform a Dalitz plot analysis of the B mesons three-body and four-body decays. Fitted projections on the $D\pi$ and $D^*\pi$ masses after background subtraction.



□ The resulting parameters for the scalar and axial broad states are the following:

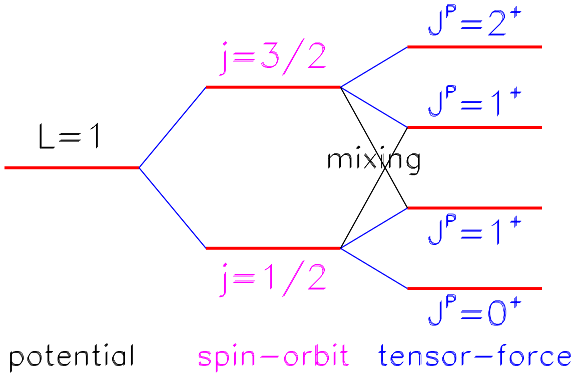
$$D_0^{*0} : m = 2308 \pm 17 \pm 15 \pm 28 \qquad \Gamma = 276 \pm 21 \pm 18 \pm 60 \quad MeV$$

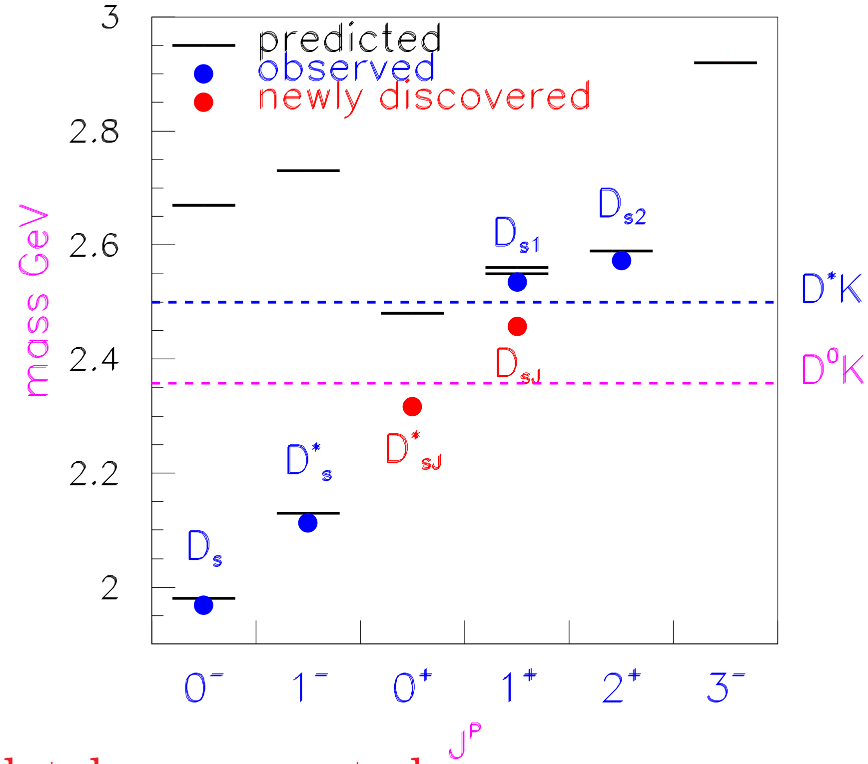
$$D_1 : m = 2427 \pm 26 \pm 20 \pm 15 \qquad \Gamma = 384^{+}107_{-75} \pm 24 \pm 70 \quad MeV$$

□ The mass of the D^{*0} is $\approx$ 100 MeV lower with respect to the FOCUS evaluation.

The discovery of the new D_s states.

□ Potential model expectations and experimental results for the P-wave D_s mesons:





□ Surprise: very large discrepancies. Completely unexpected.

□ As in the case of the $\bar{c}u$ mesons, the scalar and axial mesons where expected to be wide.

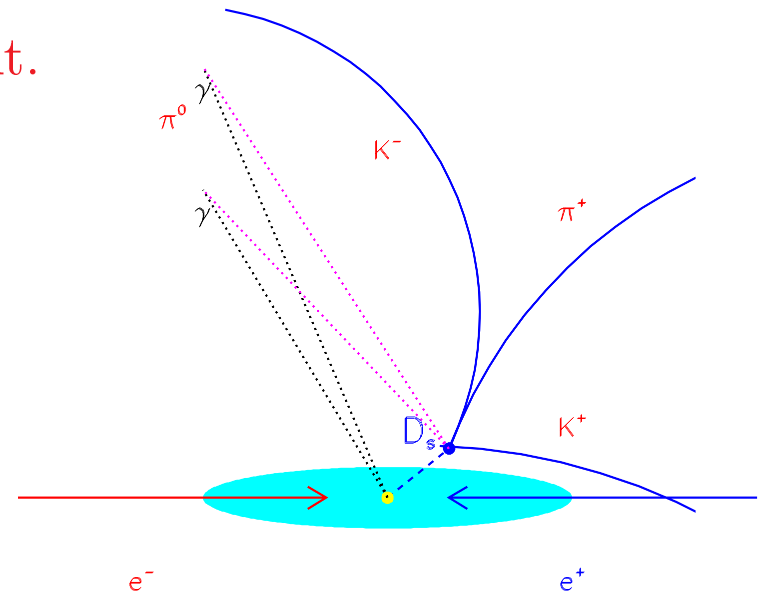
□ Experiment: they are very narrow and below their relative thresholds.

The discovery of the new D_s states.

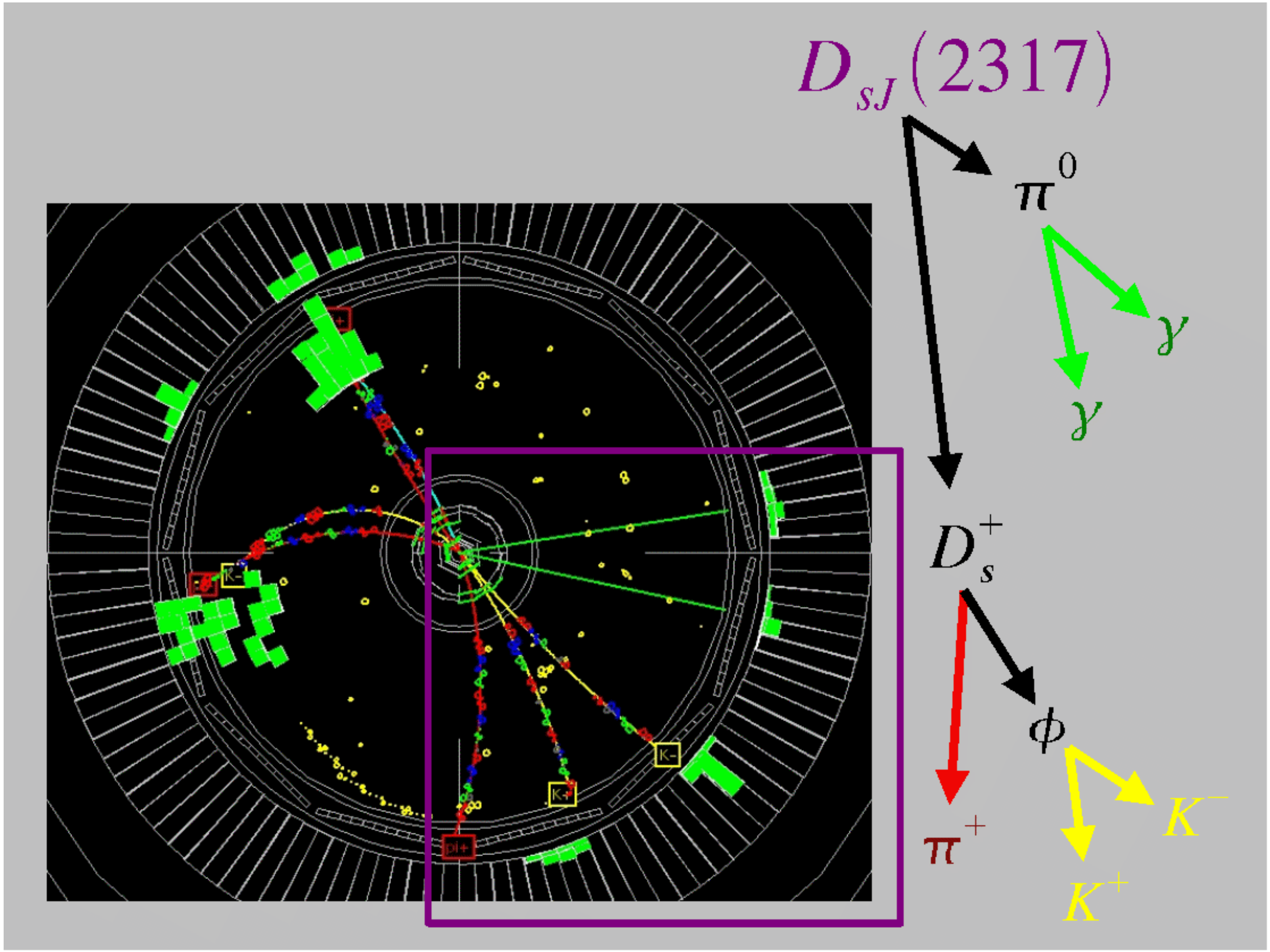
□ The discovery has been made by BaBar experiment in the study of the inclusive reaction: BABAR,hep-ex/0304021

$$\begin{aligned} e^+e^- \to \;& D_s^+\pi^0(+\gamma' s) \\ & \to K^+K^-\pi^+ \end{aligned}$$

□ Qualitative sketch, not to scale, of one event.

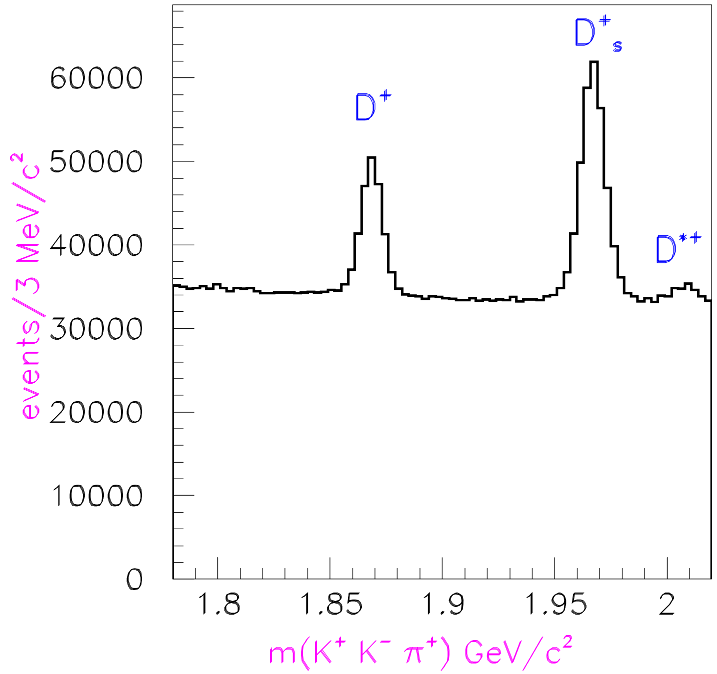


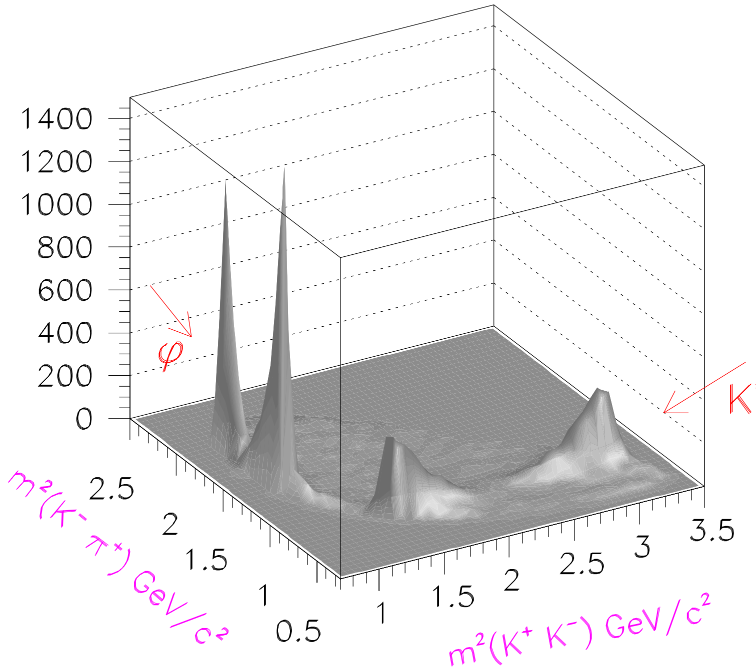
One real event.



D_s^+ selection: $K^+K^-\pi^+$ mass spectrum.

□ The total $K^+K^-\pi^+$ mass spectrum shows prominent D^+ and D_s^+ signals.





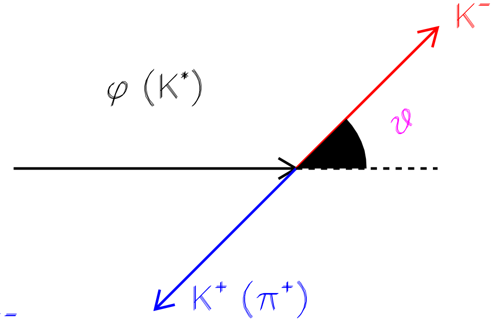
Real Data: $D_s^+ \rightarrow K^+K^-\pi^+$ *Dalitz plot*

tagged with $D_s^*(2112)^+ \rightarrow D_s^+\gamma$

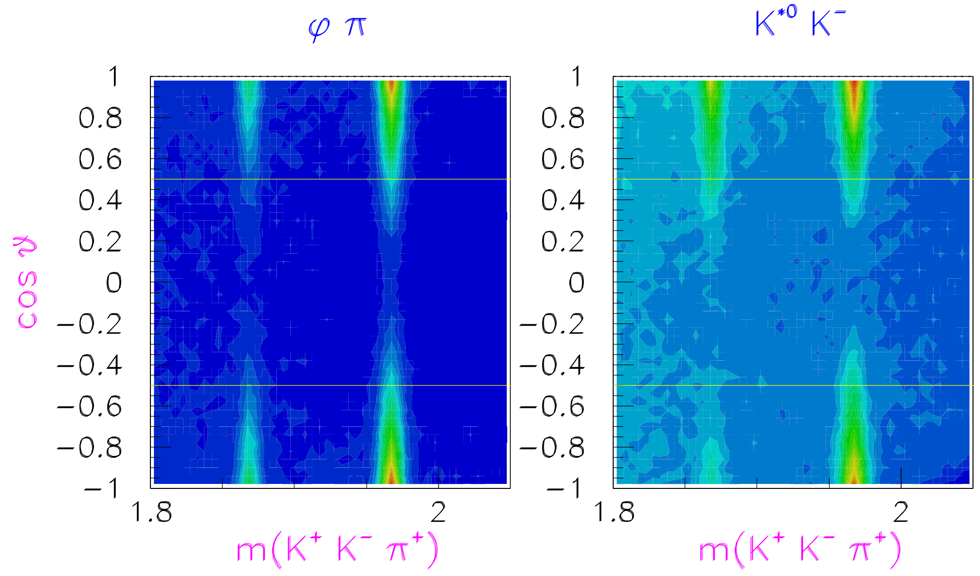
□ $cos^2\theta$ distribution in each vector meson band.

Use of D_s^+ angular distributions.

□ We define θ as the angle between the K^- and the ϕ ($\overline{K^{*0}}$) direction in the ϕ ($\overline{K^{*0}}$) rest frame.

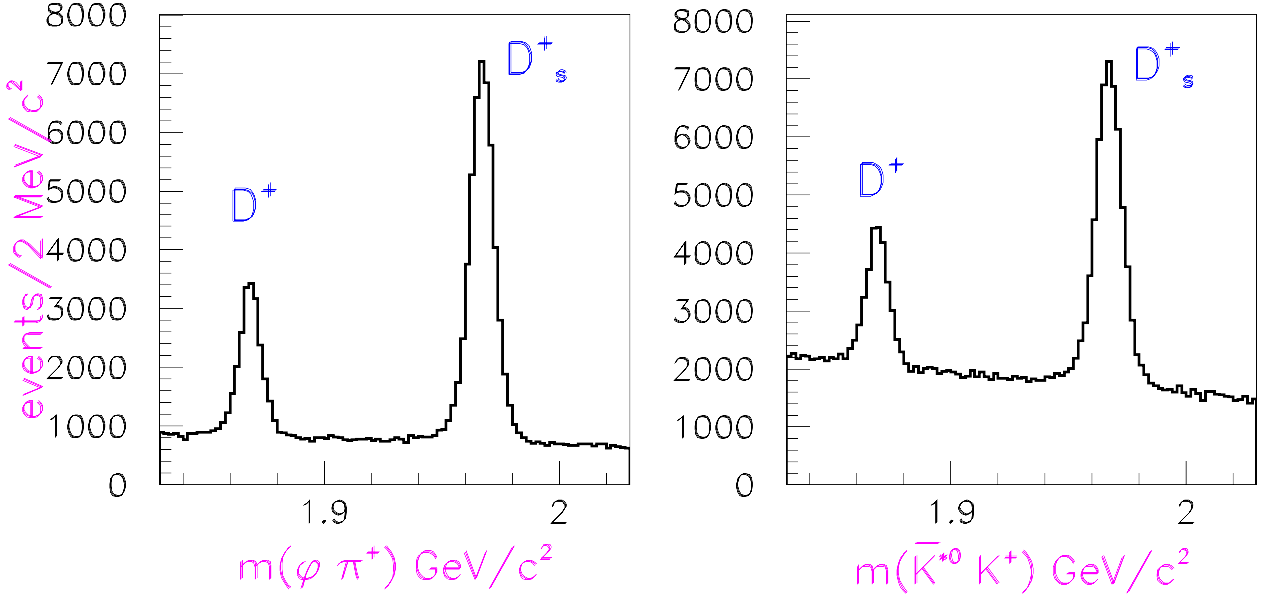


□ Scatter diagram of $cos\theta$ vs. $m(K^+K^-\pi^+)$:



□ Require $\mid cos\theta \mid > 0.5$ to enhance the D_s^+ signal (retains 87.5 % of signal).

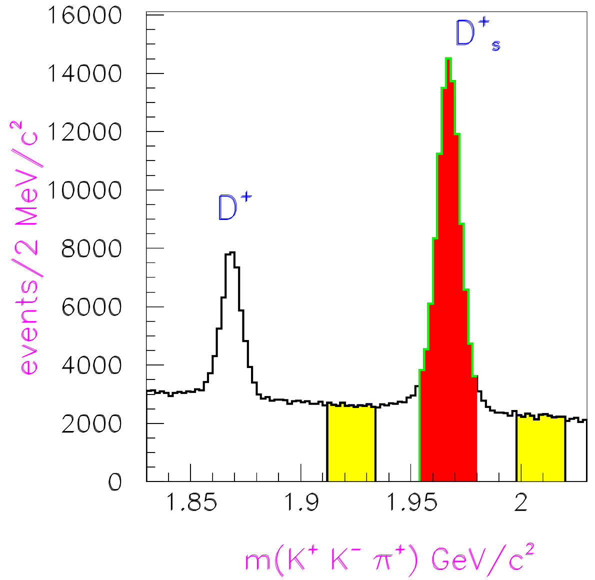
□ Resulting $\phi\pi^+$ and $\overline{K^{*0}}K^+$ mass spectra:



□ The two samples are of similar sizes.

Total $K^+K^-\pi^+$ mass spectrum.

□ Sum of the $\phi\pi^+$ and $\overline{K^{*0}}K^+$ contributions ($\approx$ 80 000 D_s^+ events above background):



□ We define the signal D_s^+ region as:

$$1.954 < m(K^+K^-\pi^+) < 1.980 \quad GeV$$

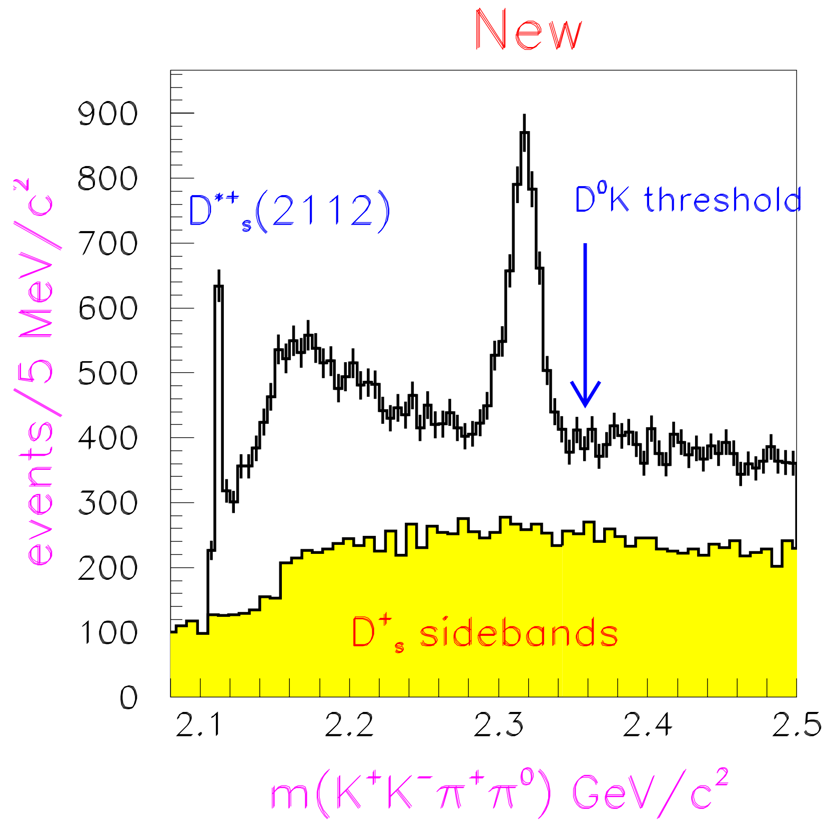
and two sideband regions as:

$$1.912 < m(K^+K^-\pi^+) < 1.934 \quad GeV$$

$$1.998 < m(K^+K^-\pi^+) < 2.020 \quad GeV$$

$D_s^+\pi^0$ mass spectrum.

- Compare $(K^+K^-\pi^+)\pi^0$ mass spectra for the D_s^+ signal region and sidebands.
- We observe the known decay: $D_s^*(2112)^+ \to D_s^+\pi^0$.
- **Totally unexpected large signal ($\approx$ 2200 events) at 2.32 GeV.**



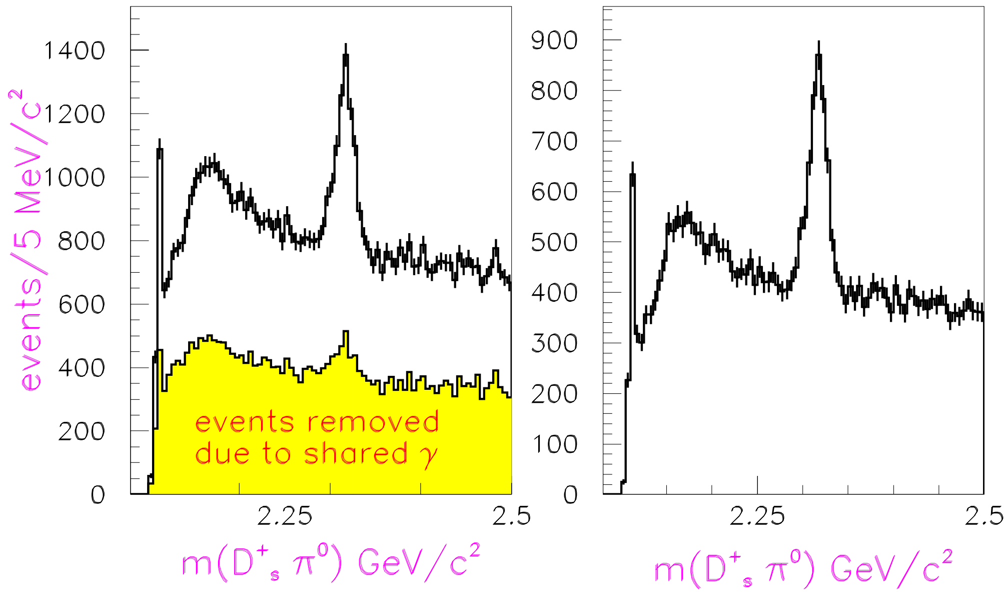
- No signals for the D_s^+ sidebands.

$D_s^+\pi^0$ mass spectrum.

□ No D_s^+ kinematic fit. Resolution improved by adding the decay particles' 3-momenta and calculating the D_s^+ energy using the D_s^+ PDG mass:

$$E_{D_s} = \sqrt{p^2 + m_{D_s}^2}$$

□ We require that each π^0 does not have either γ in comm on with any other π^0 candidate.



□ Remaining signal at 2.32 GeV contains 1948 ± 104 events.

Test using Monte Carlo simulation.

□ Monte Carlo events from the reaction:

$$e^+e^- \to \bar{c}c$$

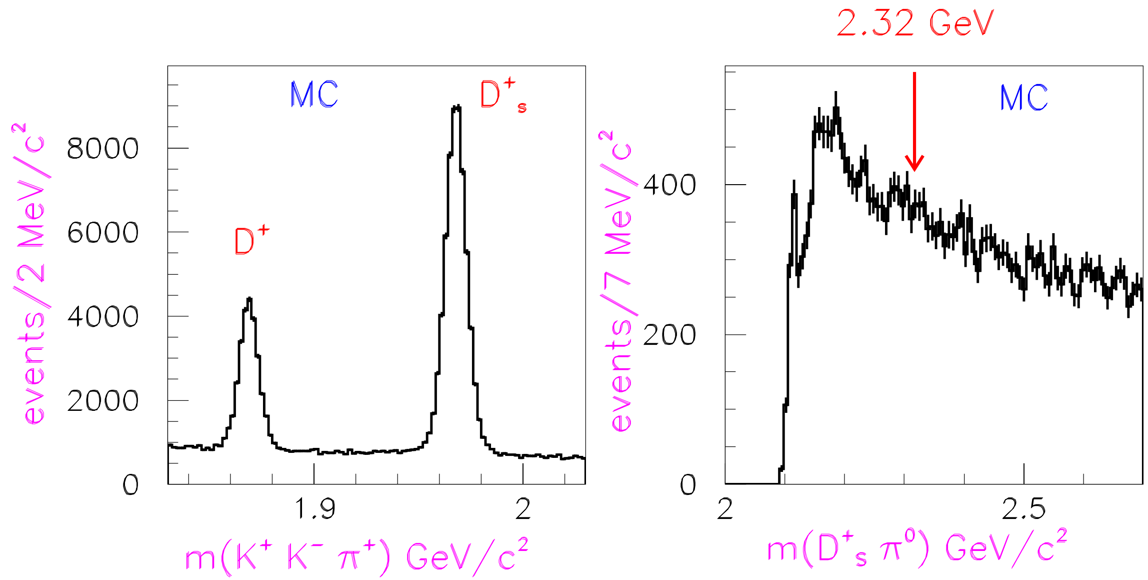
have been simulated using GEANT4. They have been reconstructed and analyzed using the same analysis procedure as that used for data.

□ The generated events contain all what was presently known about charm spectroscopy.

□ Analyzed $\approx 80 \times 10^6$ generated events.

Test using Monte Carlo simulation.

□ Sum of $\phi\pi^+$ and $\overline{K^{*0}}K^+$ mass distributions and $D_s^+\pi^0$ mass spectrum.



□ We observe the known decay: $D_s^*(2112)^+ \to D_s^+\pi^0$.

□ The $D_s^+\pi^0$ mass spectrum shows no significant signal in the 2.32 GeV mass region. We would expect $\approx$ 1400 events.

□ **We conclude that the 2.32 GeV structure is not due to reflections from known states.**

Study of $D_s^+ \to K^+K^-\pi^+\pi^0$.

- This D_s^+ decay channel has the same topology as $D_s^+\pi^0$ w ith $D_s^+ \to K^+K^-\pi^+$. It gives direct information on resolution and scale for $m(D_s^+\pi^0)$.
- A different D_s^+ decay mode with which to study $D_s^+\pi^0$.
- Uses the π^0 fitted to the $K^+K^-\pi^+$ vertex to reconstruct the D_s^+.
- We plot the distribution of:

$$\Delta m = m(K^+K^-\pi^+\pi^0\gamma) - m(K^+K^-\pi^+\pi^0)$$

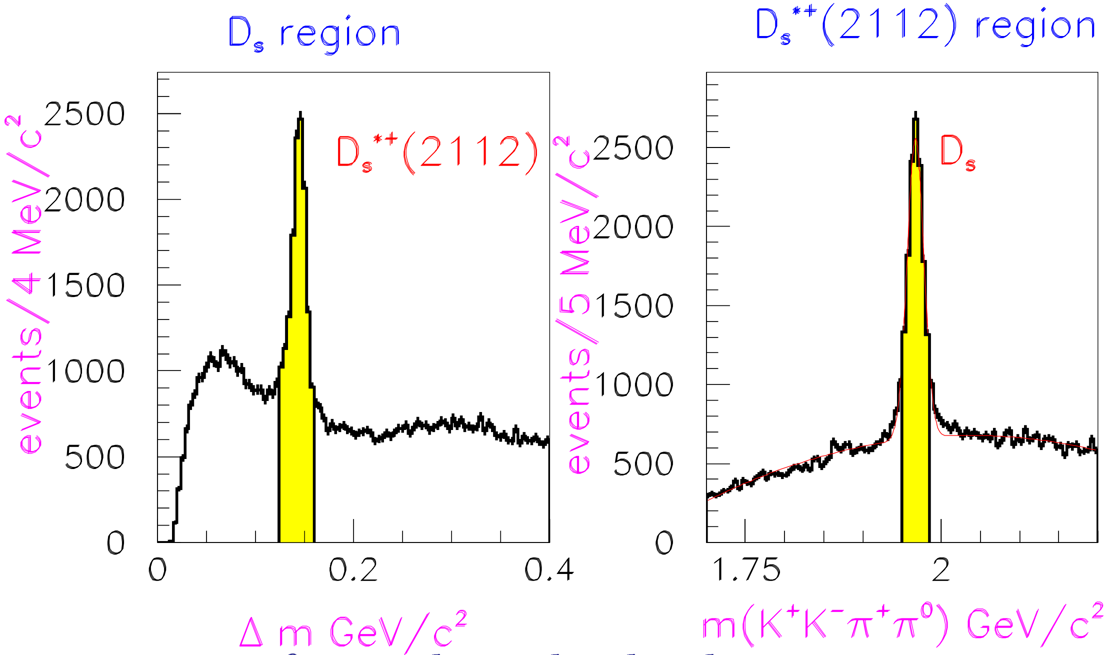
for the D_s^+ region, defined as:

$$1.95 < m(K^+K^-\pi^+\pi^0) < 1.985 \qquad GeV$$

- We plot the distribution of $m(K^+K^-\pi^+\pi^0)$ for the $D_s^*(2112)^+$ region, defined as:

$$0.124 < \Delta m < 0.160 \qquad GeV$$

Mass spectra.



- Fitted D_s^+ parameters from the 4-body decay:

$$m_{D_s \to K^+K^-\pi^+\pi^0} = 1967.4 \pm 0.2 \qquad MeV$$

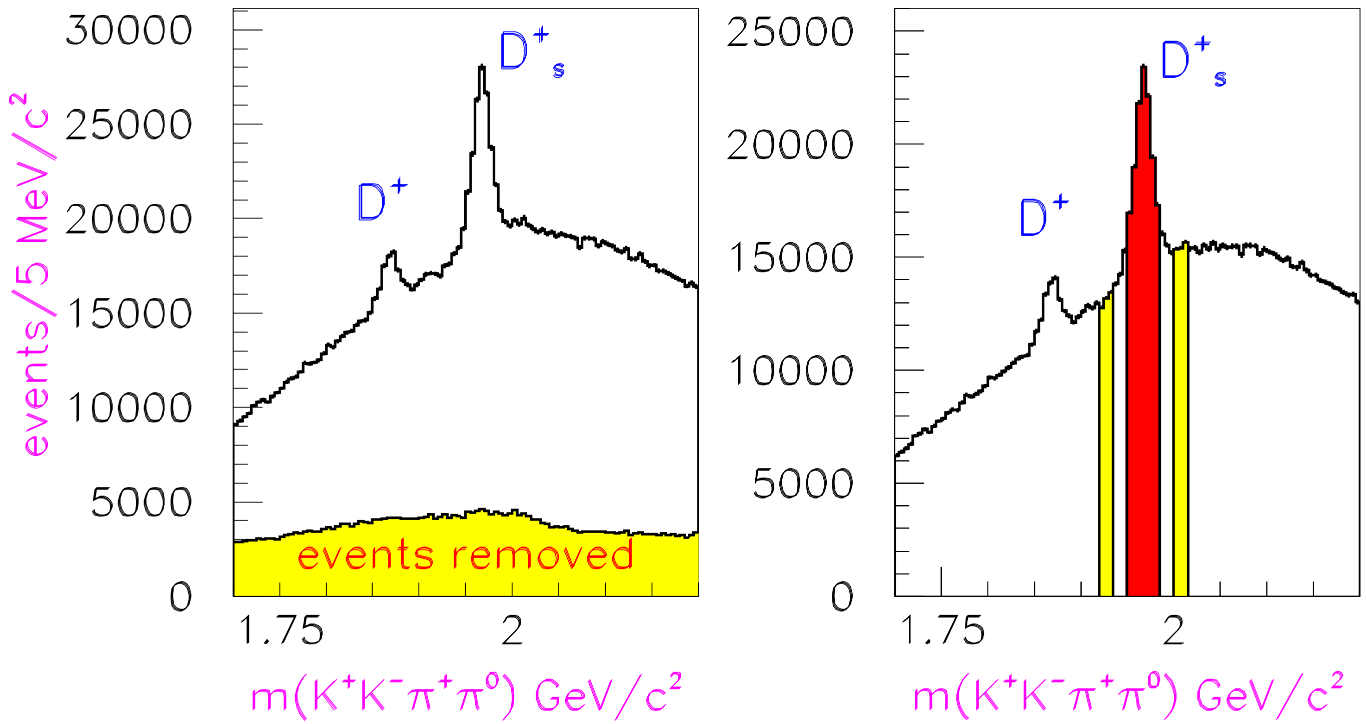
- To be compared with the fitted D_s^+ parameters from the 3-bod y decay:

$$m_{D_s \to K^+K^-\pi^+} = 1967.20 \pm 0.03 \qquad MeV$$

- No mass shift introduced by the presence of the π^0.

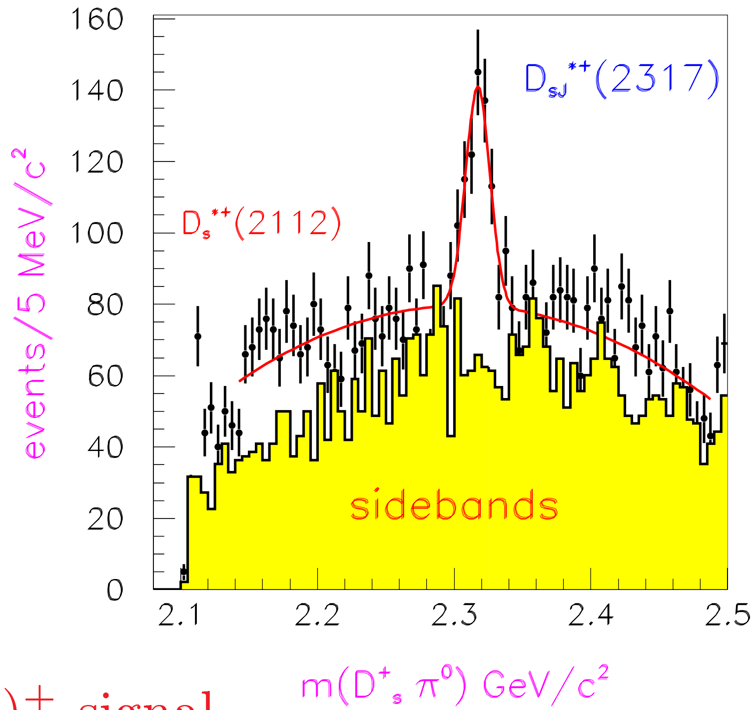
Selection of $D_s^+ \to K^+K^-\pi^+\pi^0$.

- ☐ Combinatorial $K^+K^-\pi^+\pi^0$ effective mass.
- ☐ Require at least one 2-body mass in a vector meson resonance region [ϕ, K^* or ρ].



The $D_s^+\pi^0$ effective mass for $D_s^+ \to K^+K^-\pi^+\pi^0$.

- $D_s^+\pi^0$ spectrum for the D_s^+ signal region and sidebands.



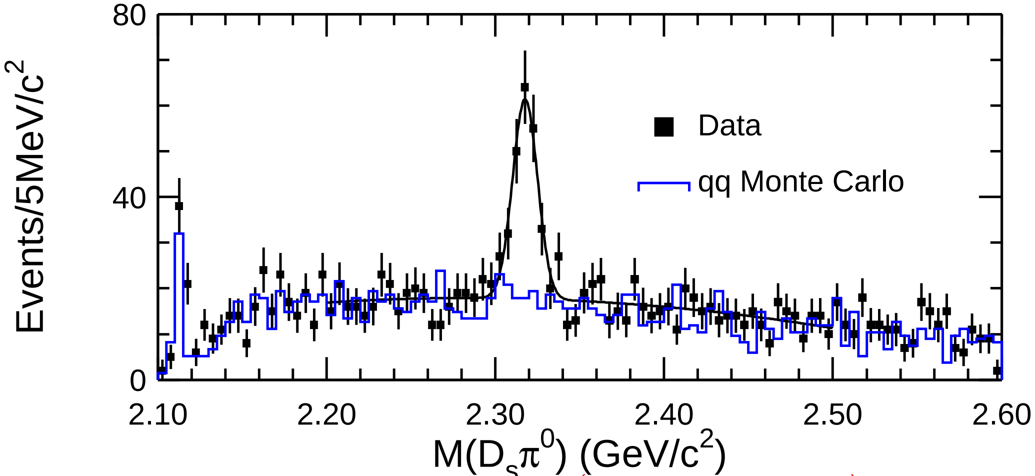
- There is a $D_s^*(2112)^+$ signal.
- No signals for the D_s^+ sideband regions.
- **There is a clear $D*_J\ (2317)^+$ signal with the following parameters:**

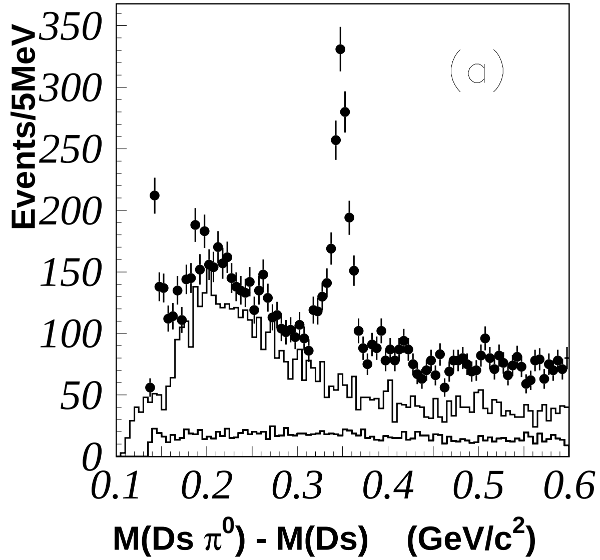
$$m = 2317.6 \pm 1.3 \quad MeV \qquad \sigma = 8.8 \pm 1.1 \quad MeV$$

- Consistent with the values obtained using the $D_s^+ \to K^+K^-\pi^+$ decay mode.

Confirmation of $D^{*}_{sJ}(2317)^{+}$ by other experiments.

CLEO 13.5 fb^{-1} **BELLE** 86.9 fb^{-1}





□ Confirmation by CLEO (hep-ex/0305017):

$\Delta m = 350.0 \pm 1.2\,(\text{stat}) \pm 1.0\,(\text{syst})$ MeV, N=155 ± 23

□ Confirmation by BELLE (hep-ex/0307052):

$\Delta m = 348.7 \pm 0.5\,(\text{stat})$ MeV, $N = 761 \pm 44$

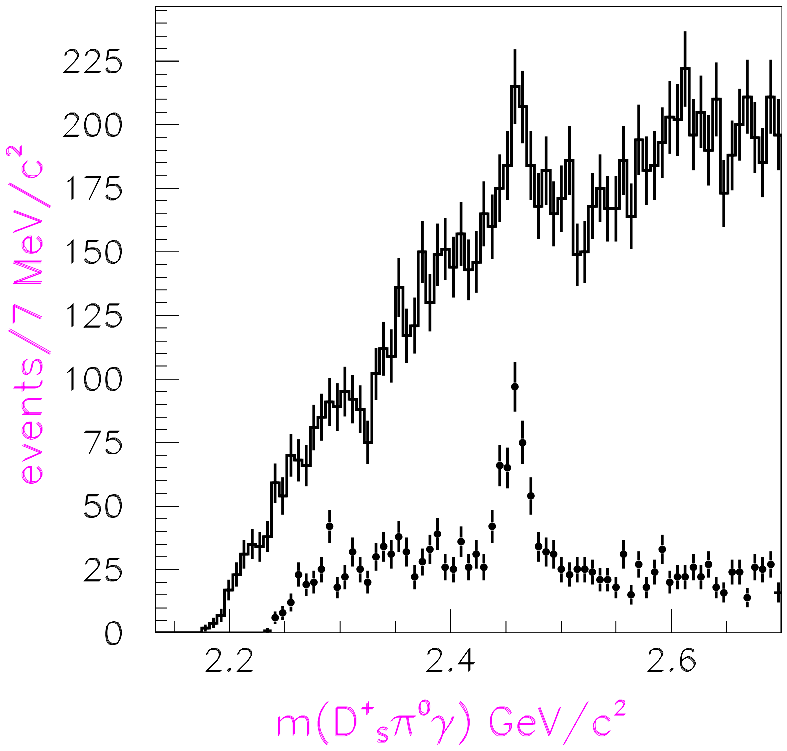
□ In good agreement with BaBar (91.5 fb^{-1}):

$\Delta m = 348.4 \pm 0.4\,(\text{stat})$ MeV, $N = 1948 \pm 104$.

Both CLEO and BELLE use only the $D_s^+ \to \phi\pi^+$ *decay mode.*

Study of $m(D_s^+\pi^0\gamma)$ by BaBar.

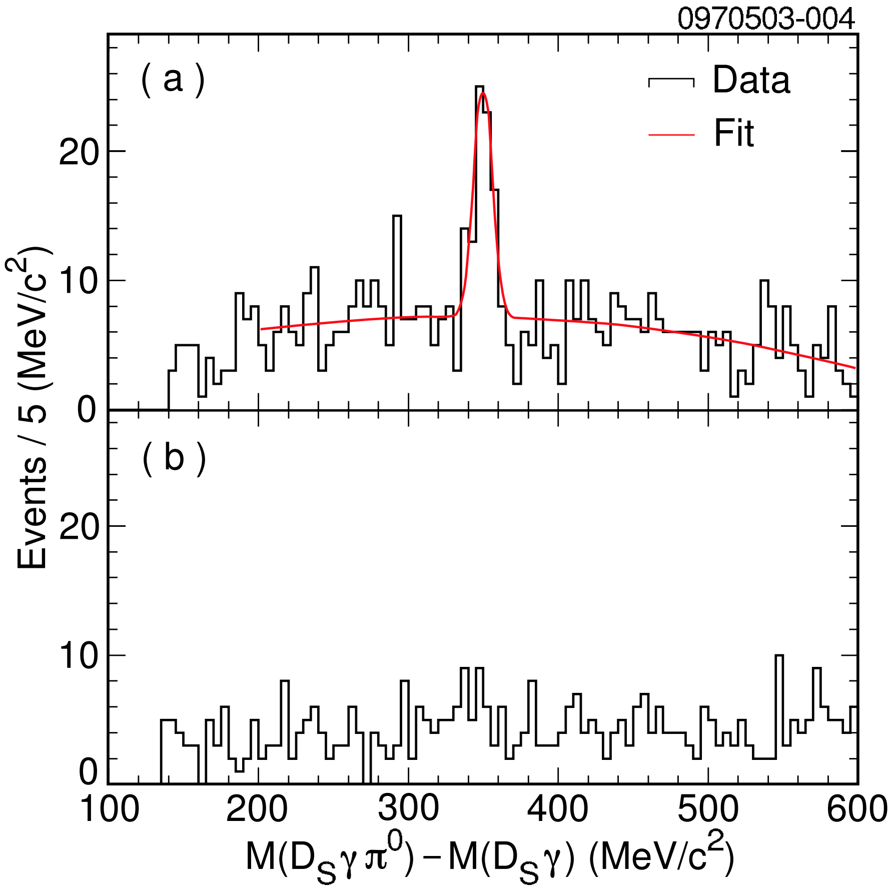
□ BaBar published the following $D_s^+\pi^0\gamma$ without claiming for the discovery of a new state:



□ Dots: $D_s^*(2112)^+\pi^0$ mass distribution.

$D_{sJ}(2458)^+$: results from other experiments.

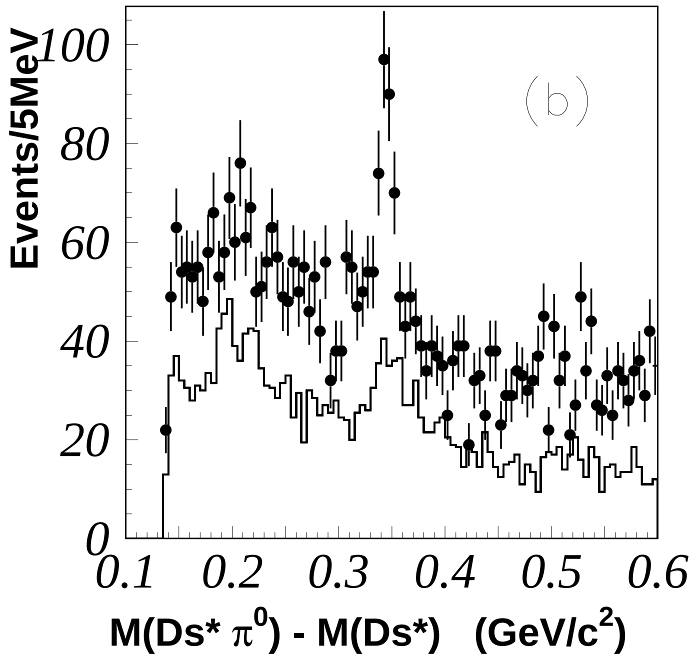
CLEO 13.5 fb^{-1}



$\Delta m = 349.8 \pm 1.3$ MeV$/c^2$

$N = 41 \pm 12$

BELLE 86.9 fb^{-1}

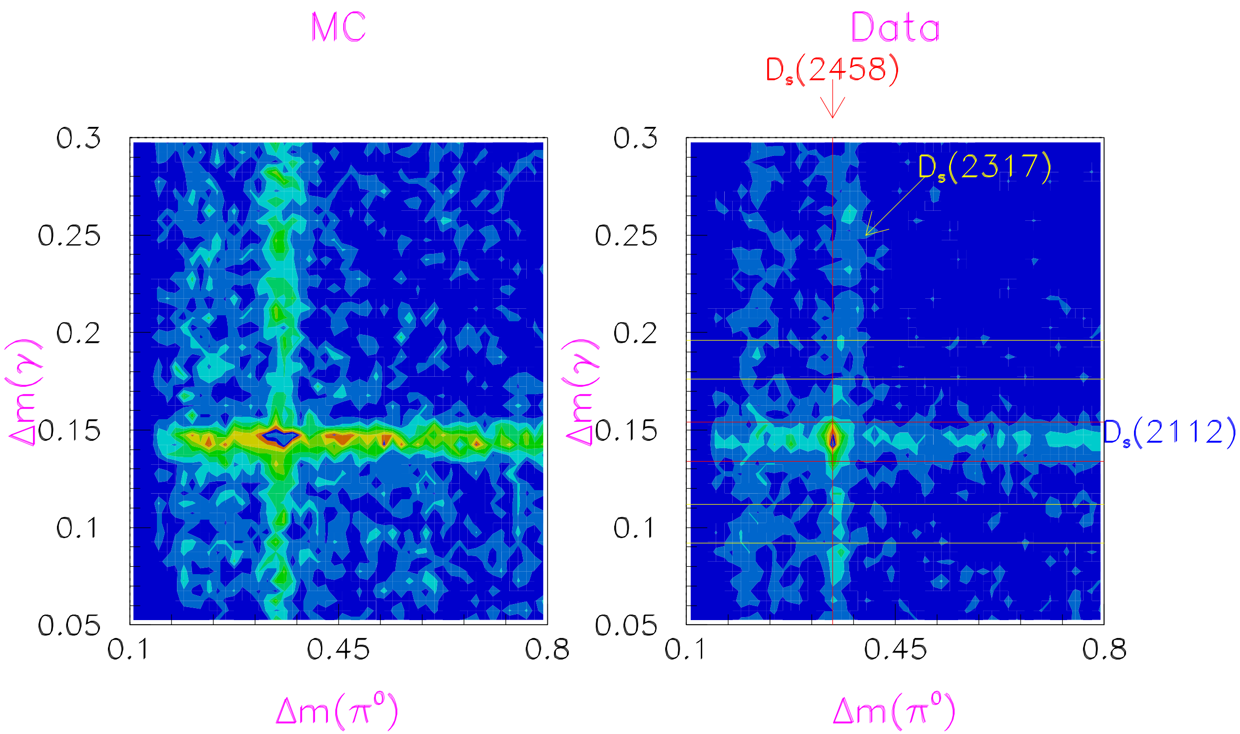


$\Delta m = 345.4 \pm 1.3$ MeV$/c^2$

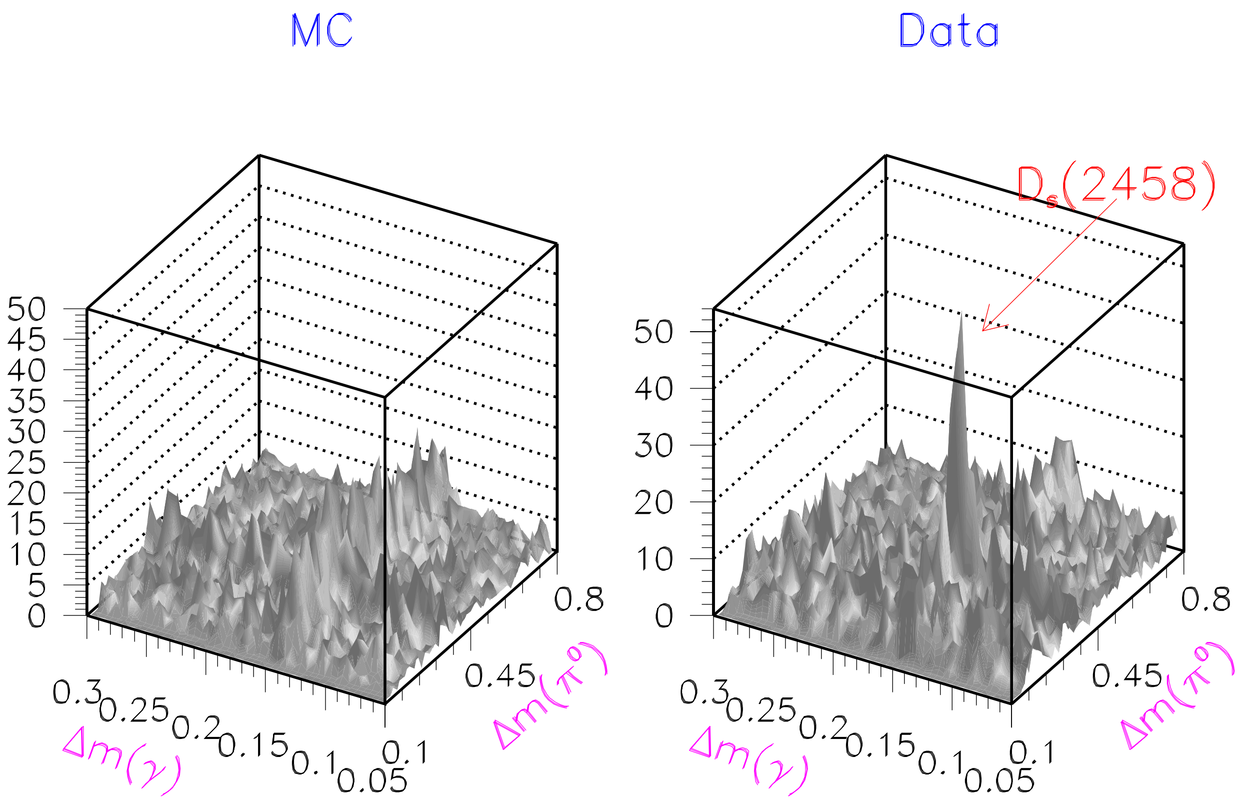
$N = 126 \pm 25$

Study of $m(D_s^+\pi^0\gamma)$

□ In an inclusive environment, the scatter diagrams of $\Delta m(\gamma) = m(D_s^+\gamma) - m(D_s^+)$ vs. $\Delta m(\pi^0) = m(D_s^+\pi^0\gamma) - m(D_s^+\gamma)$ exhibit bands due to $D_s^*(2112)^+$ and $D_{sJ}^*(2317)^+$ which cross near $m(D_s^+\pi^0\gamma)$= 2.46 GeV. BABAR,hep-ex/0310050



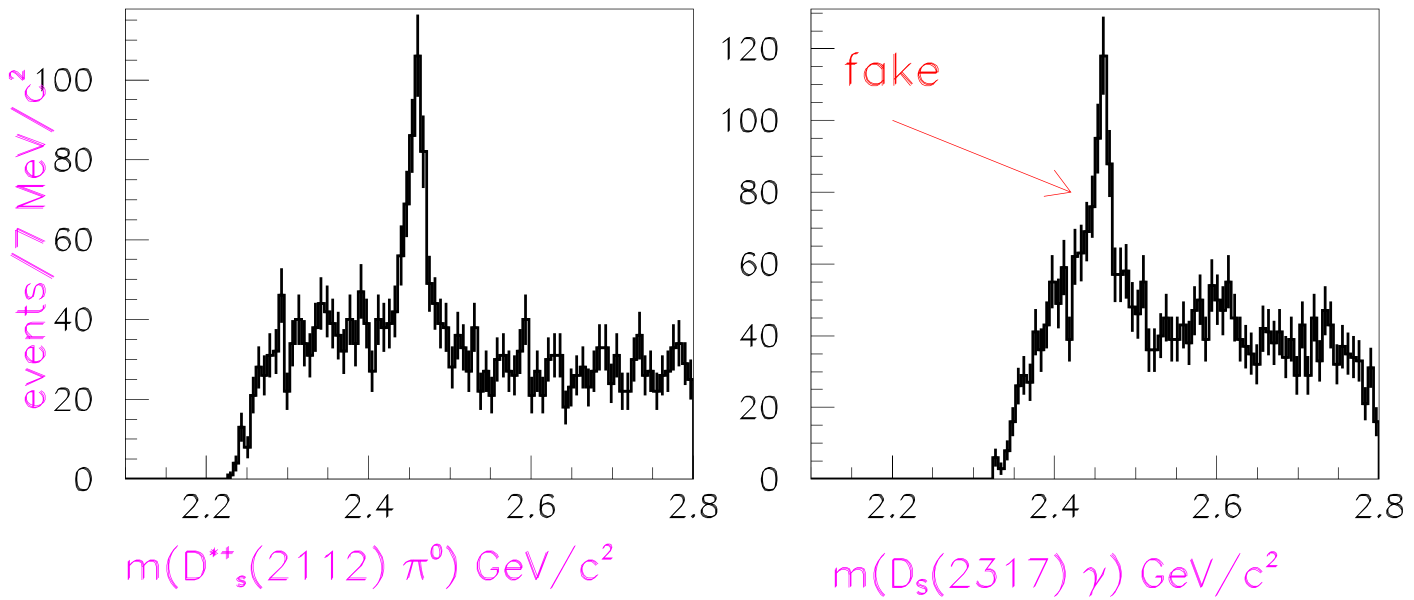
The same as Lego plot.



☐ Excess of events in the data but not in the Monte Carlo.

Mass distributions.

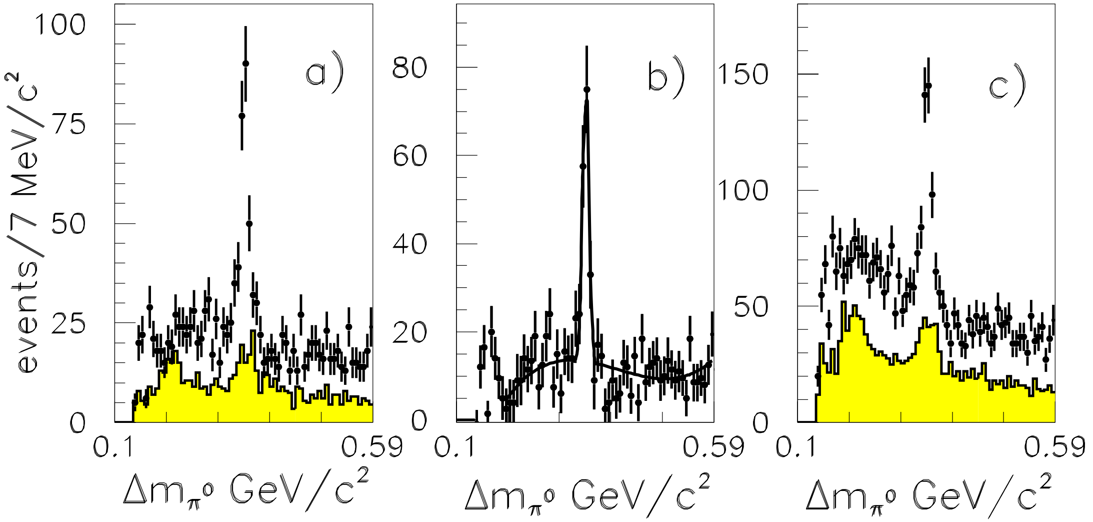
□ Data: $D_s^*(2112)^+\pi^0$ and $D_{sJ}^*(2317)^+\gamma$ mass distributions.



□ Structures at ≈ 2.46 GeV in both $D_s^*(2112)^+\pi^0$ an d $D_{sJ}^*(2317)^+\gamma$. At this level, not possible to separate them.

Extraction of the $D_{sJ}(2458)^+$ signal.

- Subtract directly the sidebands in the Δm scatterplot:



- Fitted parameters:

$$\Delta m(\pi^0) = 344.6 \pm 1.2$$

- Background peaking at slightly higher mass ($\approx$ 5 MeV).
- Background particularly enhanced when the π^0 veto is removed (c).
- Possible reason of a mass discrepancy with CLEO.

Channel Likelihood fit.

□ In order to isolate the signal from backgrounds we have performed a Channel Likelihood fit of the $D_s^+\pi^0\gamma$ system.

P.E. Condon and P.L. Cowell, Phys. Rev. D9, 2558 (1974)

□ The fit describes the system as due to a superposition of non-interfering resonances in the $D_s^+\pi^0\gamma$, $D_s^+\pi^0$ and $D_s^+\gamma$ systems.

□ The Likelihood function is therefore written as:

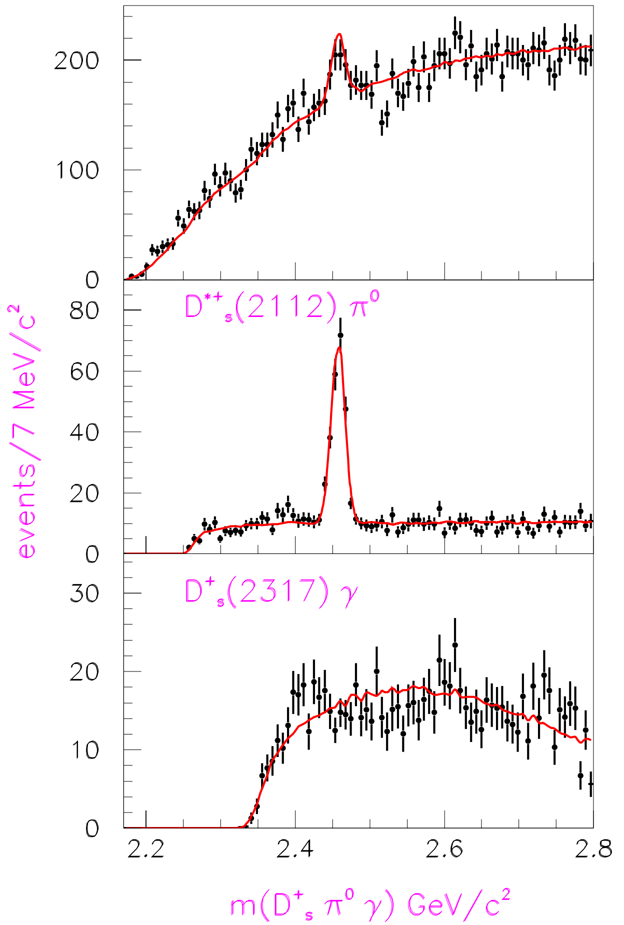
$$L = x_1 P_1 + x_2 P_2 + ... + (1 - x_1 - x_2 - ...)$$

where x_i are the fitted fractions and P_i are normalized Probability Density Functions. The P_i are described in terms of Gaussians which describe the different resonant contributions.

Channel Likelihood fit projections.

□ The fit computes, for each event, a probability to belong to a given contributing channel. The weighted distributions therefore automatically take into account all the reflections.

□ $D_s^+\pi^0\gamma$ mass distribution weighted by $D_s^*(2112)^+$ and $D_{sJ}(2317)^+$:



□ **$D_{sJ}(2458)^+$ signal in $D_s^*(2112)^+\pi^0$.**

□ **No $D_{sJ}(2458)^+$ signal in $D_{sJ}(2317)^+\gamma$.**

Results from the Channel Likelihood fit.

- $D_{sJ}(2458)^+$ parameters from a Likelihood scan:

$$m(D_{sJ}(2458)^+) = 2458 \pm 1(stat.) \pm 1(syst.) \quad MeV/c^2$$

$$\sigma = 8.5 \pm 1.0 \quad MeV/c^2$$

- Statistical significance: $\approx 10\ \sigma$.
- Decay rates:

$$N(D_{sJ}(2458)^+ \to D_s^*(2112)^+\pi^0) = 195 \pm 26$$

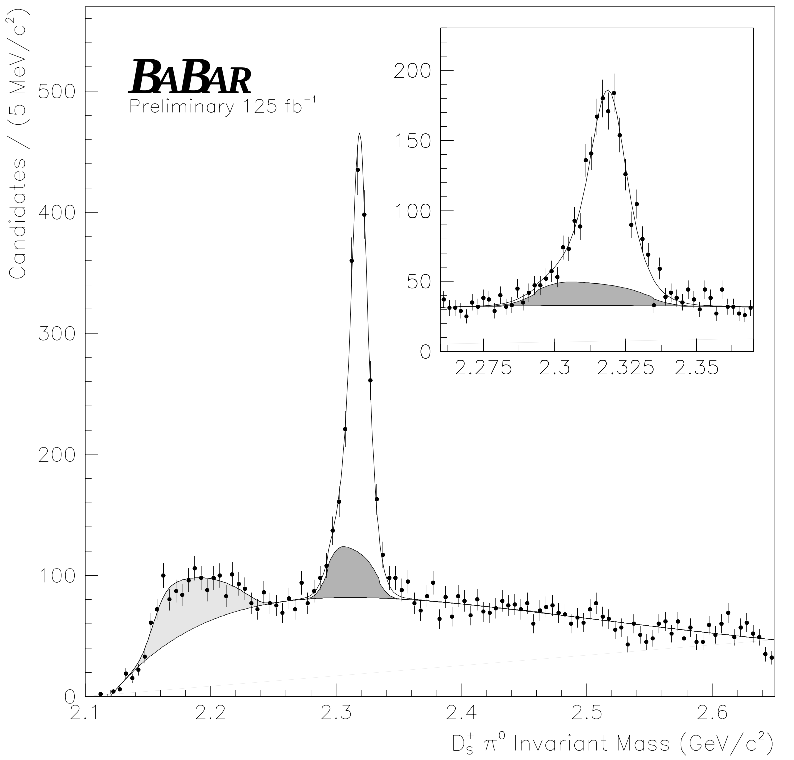
$$N(D_{sJ}(2458)^+ \to D_{sJ}^*(2317)^+\gamma) = 0 \pm 22$$

- Correcting for efficiency we derive the following upper limit:

$$\frac{D_{sJ}(2458)^+ \to D_{sJ}^*(2317)^+\gamma}{D_{sJ}(2458)^+ \to D_s^*(2112)^+\pi^0} < 0.22 \qquad 95\% \quad c.l.$$

Distortion of the $D_s(2317)$ line shape.

□ $D_s^+\pi^0$ mass spectrum with expected contribution from $D_s(2458)^+$ (upgrade of the analysis to 125 fb^{-1} BABAR,hep-ex/0408067.



□ Taken into account in fitting the mass spectrum.

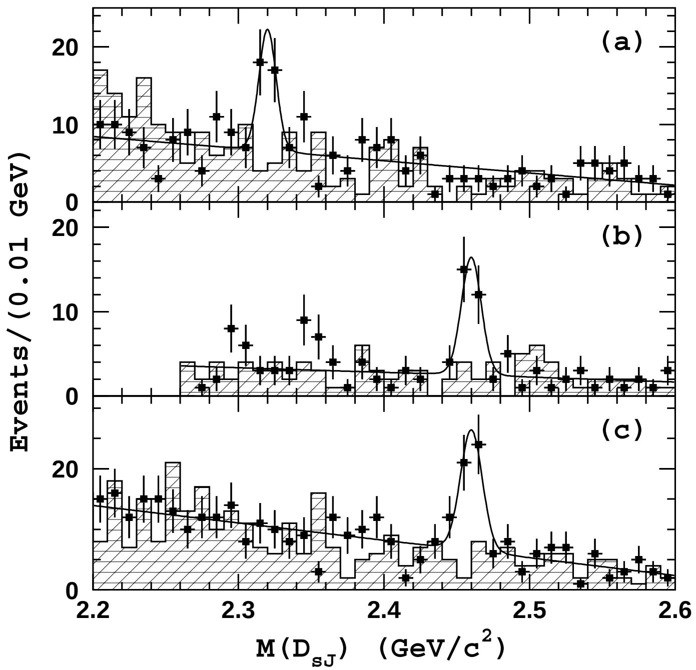
Results from B decays.

☐ Observation of:

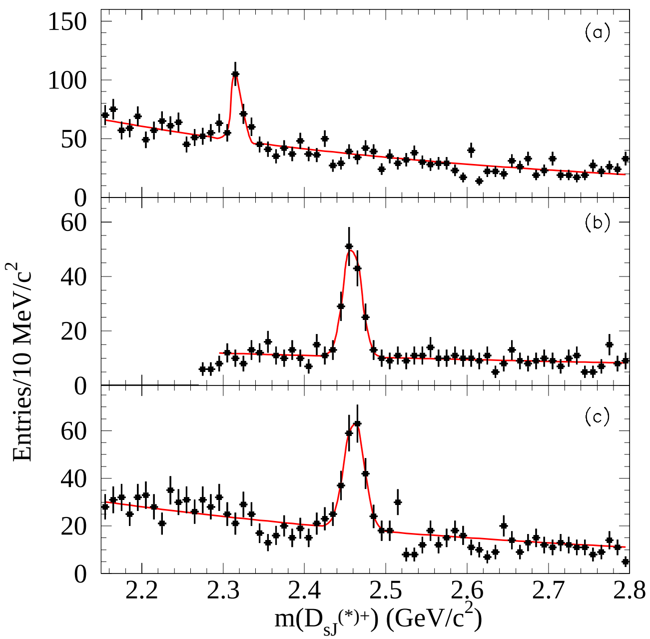
$$B \to D D_{sJ}^{*}(2317)^{+} \quad B \to D D_{sJ}(2458)^{+}$$

BELLE,hep-ex/0308019;BABAR,hep-ex/0408041

BELLE



BABAR

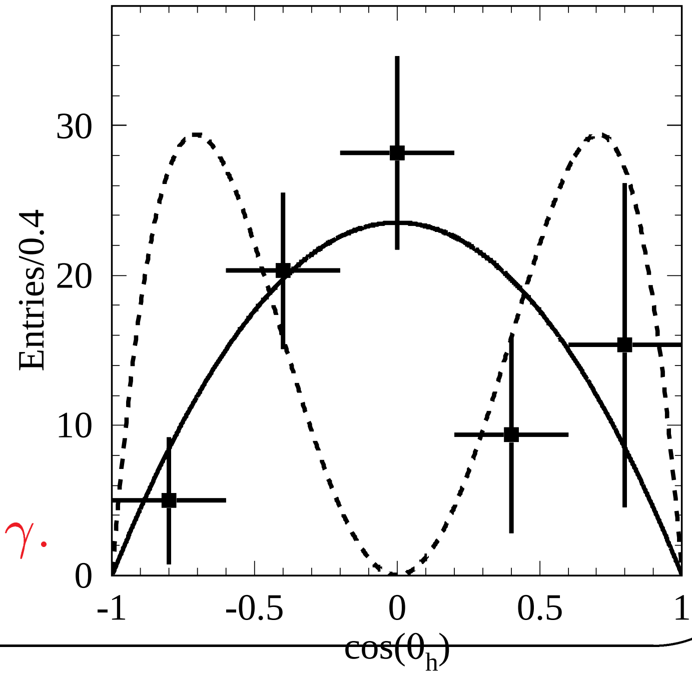


Results from B decays.

- □ Spin Analysis in B decays. Plot of the helicity angle θ_h.
- □ Study of the decay:

$$B^+ \to \bar{D}^0 D_{sJ}^+(2458)(\to D_s\gamma)$$

□ θ_h is the angle between the D_{sJ} momentum in the B rest frame and the D_s^+ momentum in the D_{sJ} rest frame.



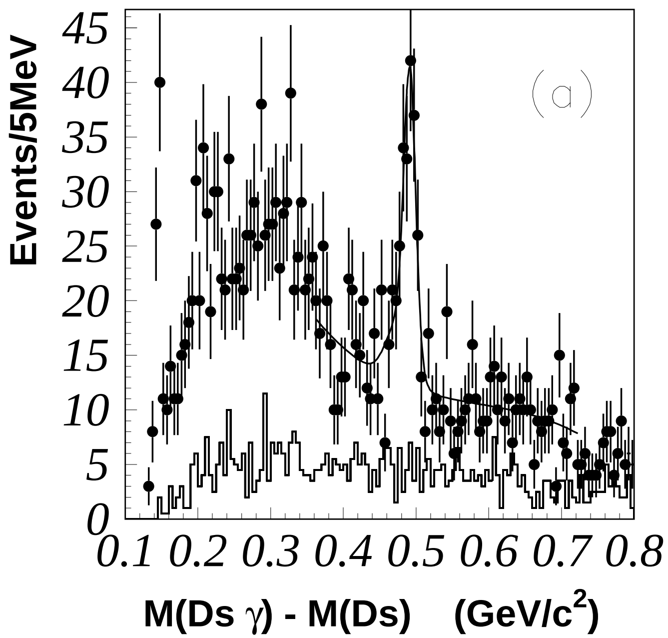
- □ Curves are for J=1 (solid) and J=2 (dashed).
- □ J=0 ruled out by parity and angular momentum conservation because $D_{sJ}^+(2458) \to D_s^+\gamma$.

Radiative decays from continuum.

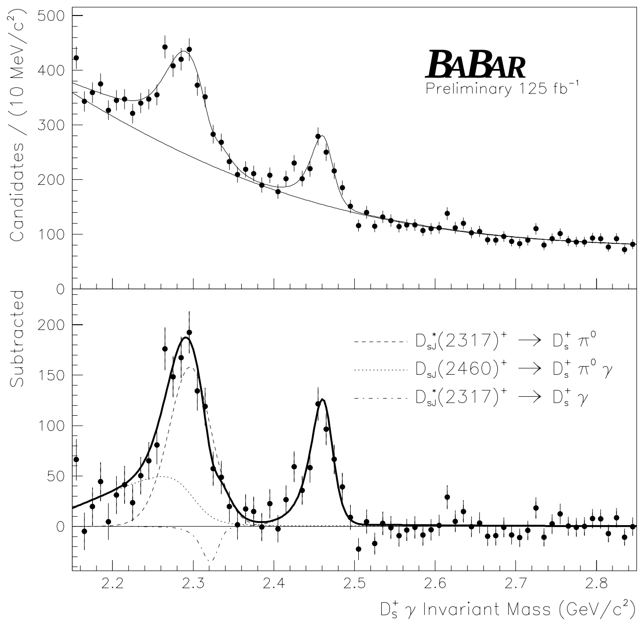
☐ Observation of:

$$D_{sJ}(2458)^+ \to D_s^+ \gamma$$

BELLE

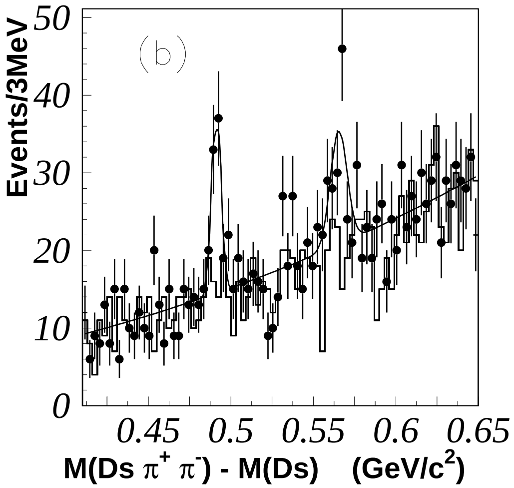


BABAR

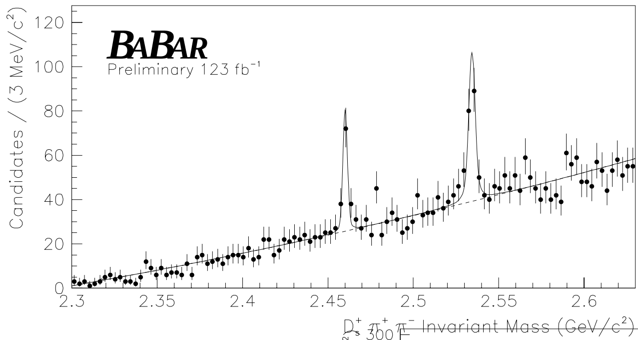


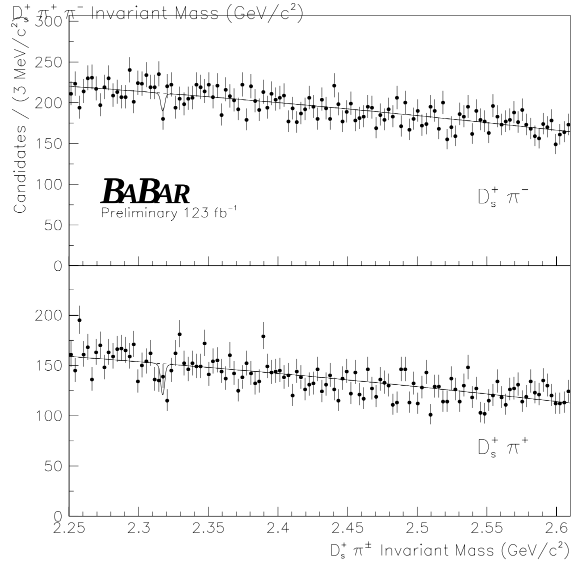
Search for structure in $D_s^+\pi^+\pi^-$ and $D_s^+\pi^\pm$.

BELLE



BABAR

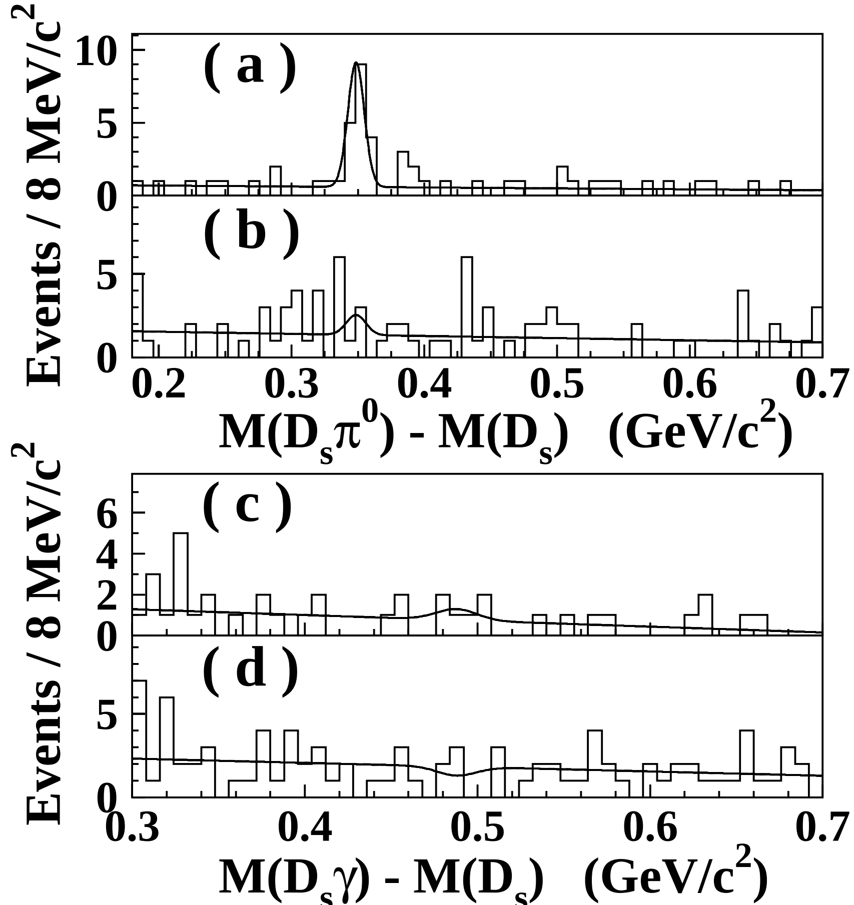


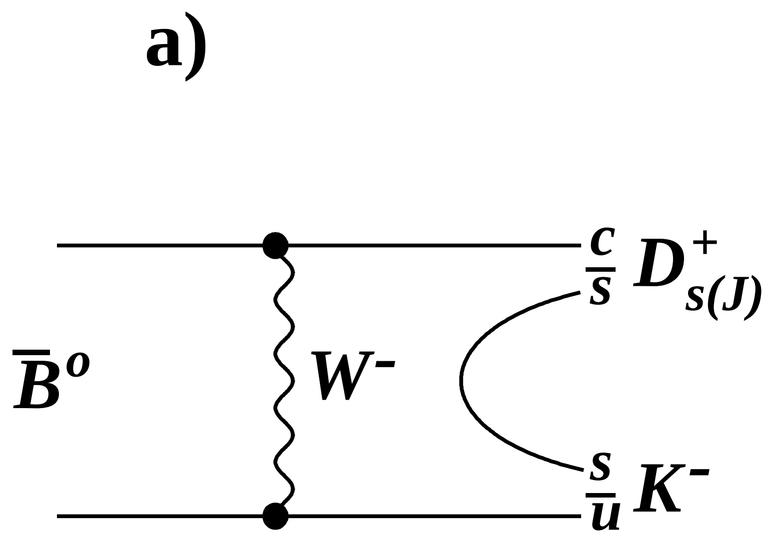


- □ Observation of $D_{sJ}^+(2458)$ and $D_s^+(2536)$.
- □ No structure observed so far in $D_s^+\pi^\pm$.

Observation of $B \to D_{sJ}(2317)K$.

- □ Discovered by BELLE. BELLE, hep-ex/0409026
- □ Important because it could be the clear evidence for an annihilation diagram.





- □ No evidence for $B \to D_{sJ}(2458)K$.

Experimental Summary.

□ The measured width of these states is consistent with the experimental resolution, which implies a small intrinsic width ($\Gamma < 10$ MeV).

□ The $D_{sJ}(2317)^+$ structure is not observed in:

$$D_s^+\gamma, D_s^+\gamma\gamma, D_s^*(2112)^+\gamma, D_s^+\pi^+\pi^-, D_s^+\pi^0\gamma, D_s^+\pi^+, D_s^+\pi^-$$

□ The quantum numbers of $D_{sJ}(2317)^+$ are consistent with being $J^P = 0^+$.

□ The quantum numbers of $D_{sJ}(2458)^+$ have been measured to be $J^P = 1^+$.

Experimental Summary.

□ The mass of the $D^*_{sJ}(2317)^+$ is 40 MeV/c^2 below D^0K threshold.

□ The mass of the $D_{sJ}(2458)^+$ is 44 MeV/c^2 below $D^{0*}K$ threshold.

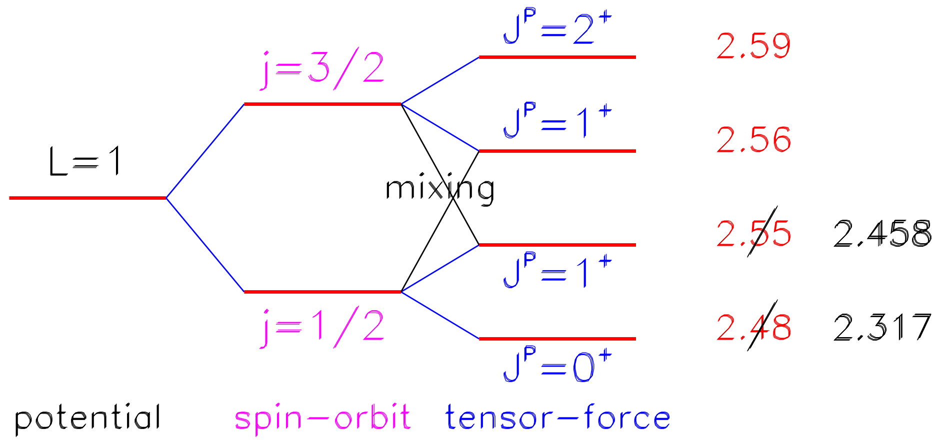
□ If the isospin of these states is I=0, since the $D_s^+\pi^0$ and $D_s^{*+}\pi^0$ systems have isospin I=1, these decays violate isospin conservation. This would explain the small widths.

□ In this case it is possible that this isospin violating decay proceeds via $\eta - \pi^0$ mixing, as proposed by Cho and Wise. Phys.Rev. D49 (1994) 6228.

What can these states be?

□ Potential Models before $D^*_{sJ}(2317)^+$ predicted masses too high.

S. Godfrey and N. Isgur, Phys. Rev. D32 (1985) 189, S. Godfrey and R. Kokoski, Phys. Rev. D43 (1991) 1679.



□ After discovery of $D^*_{sJ}(2317)^+$ a class of potential models has some difficulty fitting all states and getting decay patterns right.

R. Cahn and J. Jackson, hep-ph/0305012, S. Godfrey, hep-ph/0305012, P. Colangelo and F. De Fazio, hep-ph/0305140.

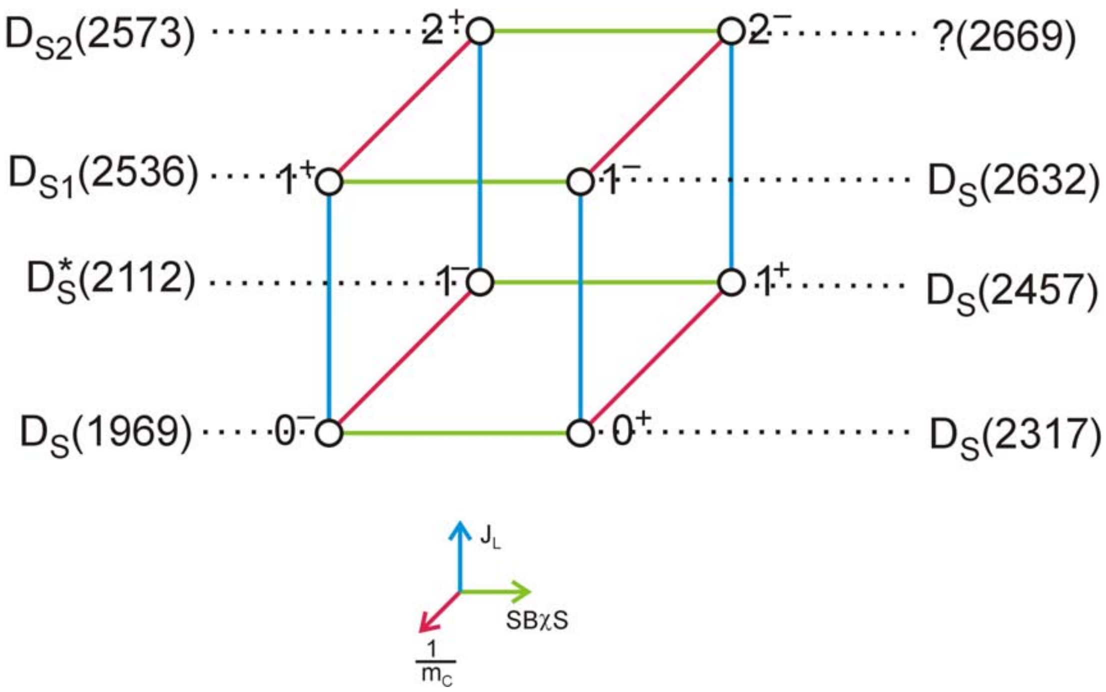
□ Perhaps with new potentials all charm, non-charm mesons can be fit.

□ Also QCD Lattice calculations are in trouble: the mass for a scalar $c\bar{s}$ is expected to be higher than that measured.

G. Bali, hep-ph/0305209.

□ Chiral symmetry models predict the observed pattern: the splitting of $D^*_{sJ}(2317)^+$ and $D_{sJ}(2458)^+$ is about the same as $D_s(1969)^+ - D^*_s(2112)^+$. Predict many decay modes, including radiative decay of $D_{sJ}(2458)^+$.

W. Bardeen et al., hep-ph/0305049; M.A. Nowak, hep-ph/0407272



What can these states be?

□ Four-quark states or molecules:
T.Barnes, F. Close, H. Lipkin (hep-ph/0305025), Cheng and Hou hep-ph/0305038,K. Terasaki hep-ph/0305213, A. Szczepaniak hep-ph/0305060

□ Ordinary $c\bar{s}$ states still there to be found.

□ Expect in this case a large variety of new states with I=0 and I=1.

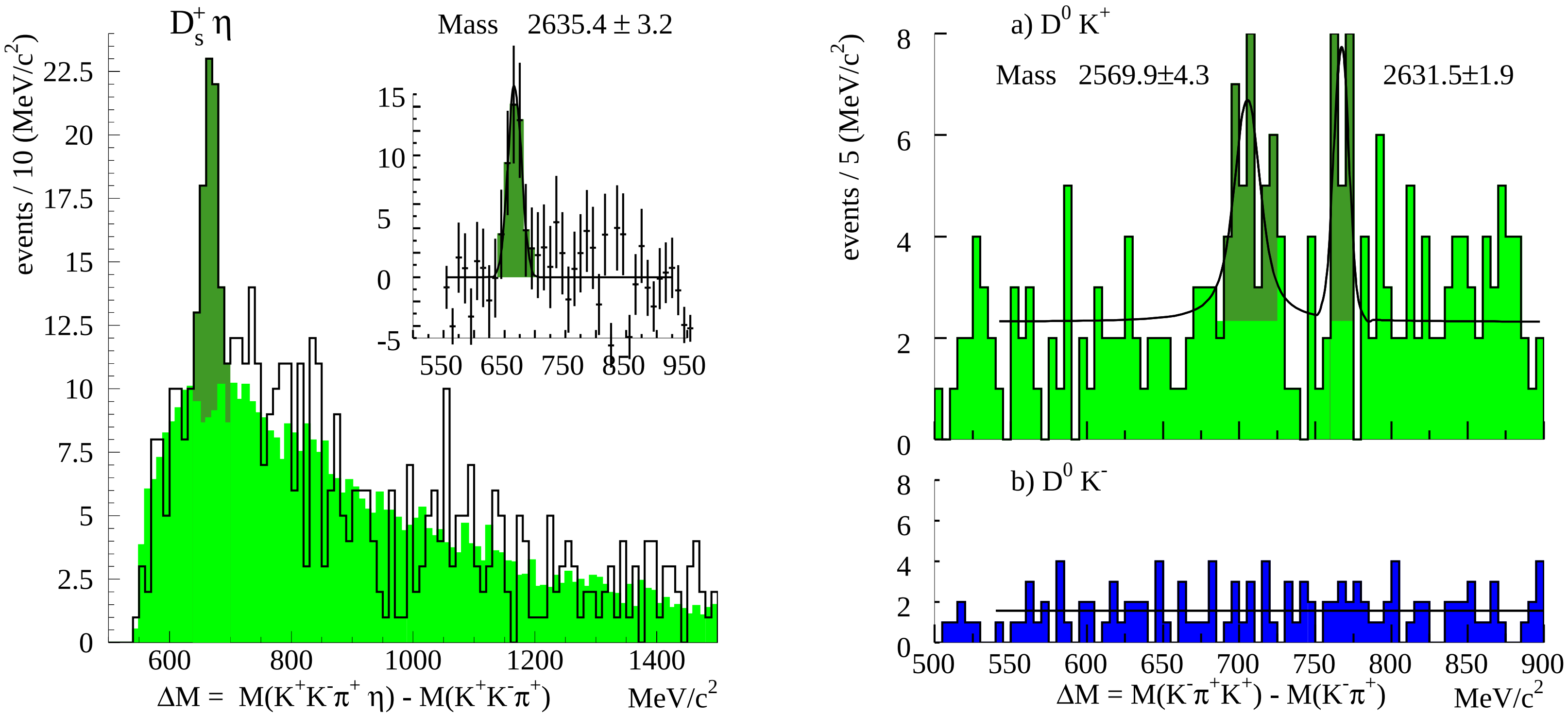
The Selex claim for a discovery of $D_s(2632)$.

☐ SELEX experiment, at Fermilab, uses a 600 GeV/c hyperon beam on nuclei.

SELEX,hep-ex/0406045

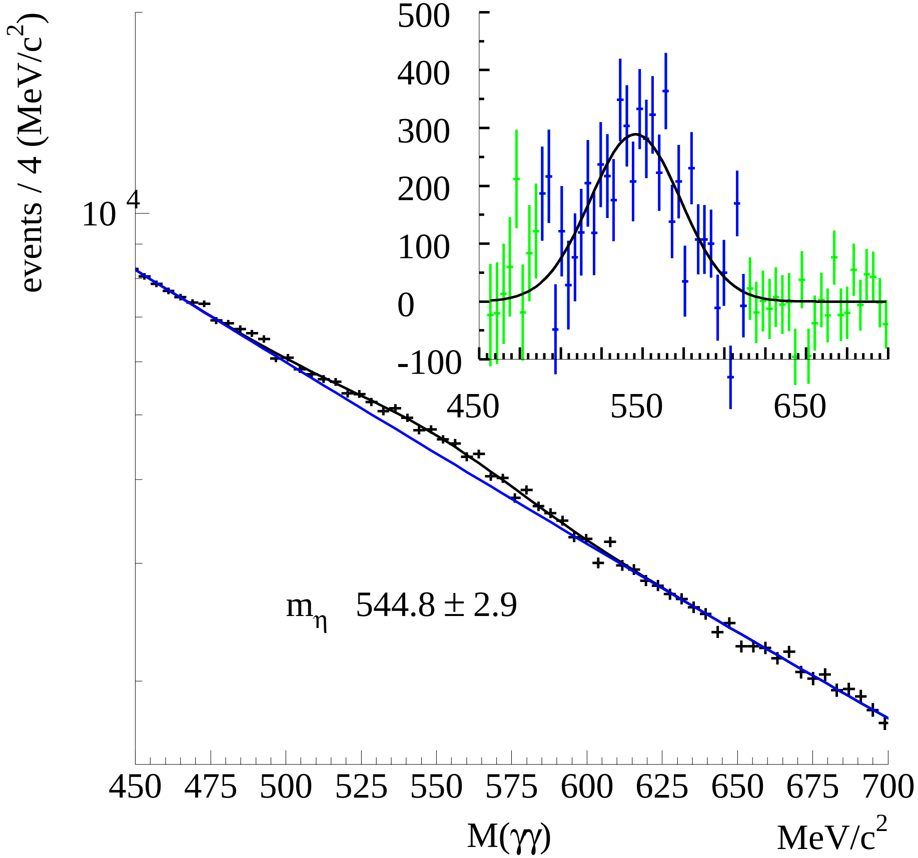
☐ Starting with a sample of 544 $D_s^+ \to K^+K^-\pi^+$ events they claim for a structure in the $D_s^+\eta$ mass spectrum and D^0K^+ mass spectra:

$$m(D_s(2632)) = 2635 \pm 3 \quad MeV$$



The Selex claim for a discovery of $D_s(2632)$.

□ The SELEX η signal:

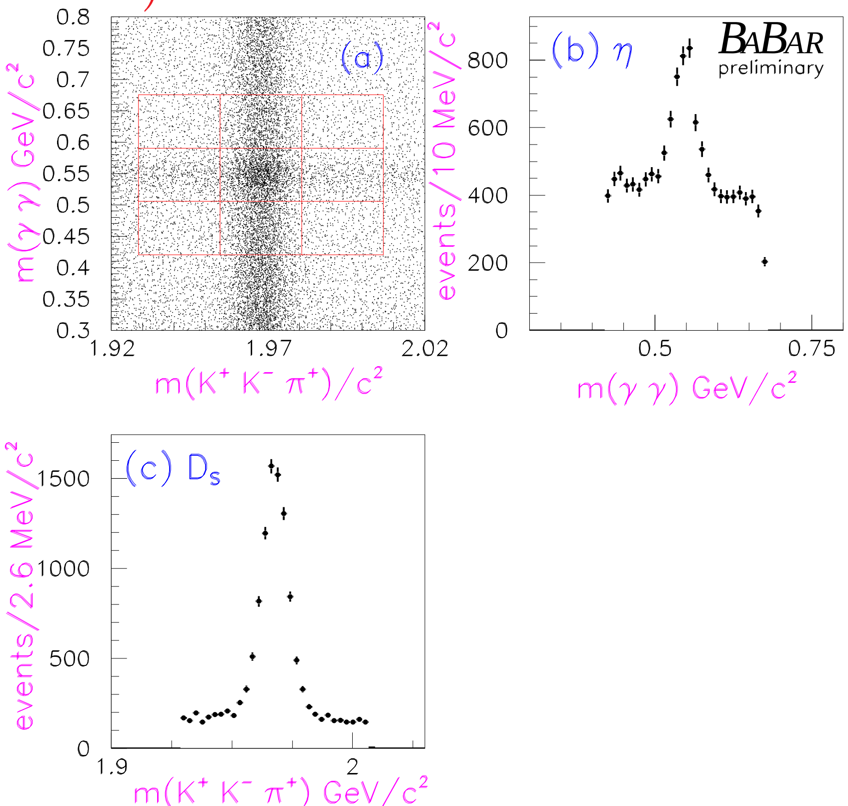


□ They measure that 55 % of all the observed D_s^+ are coming from the decay of this particle.

BaBar Search for $D_s(2632)$.

□ BaBar experiment has used a sample of 196 000 D_s^+ events, and 3900 η's. BABAR,hep-ex/0408087

□ The scatter diagram $m(\gamma\gamma)$ vs. $m(K^+K^-\pi^+)$ shows an excess of events in the $D_s^+\eta$ region.



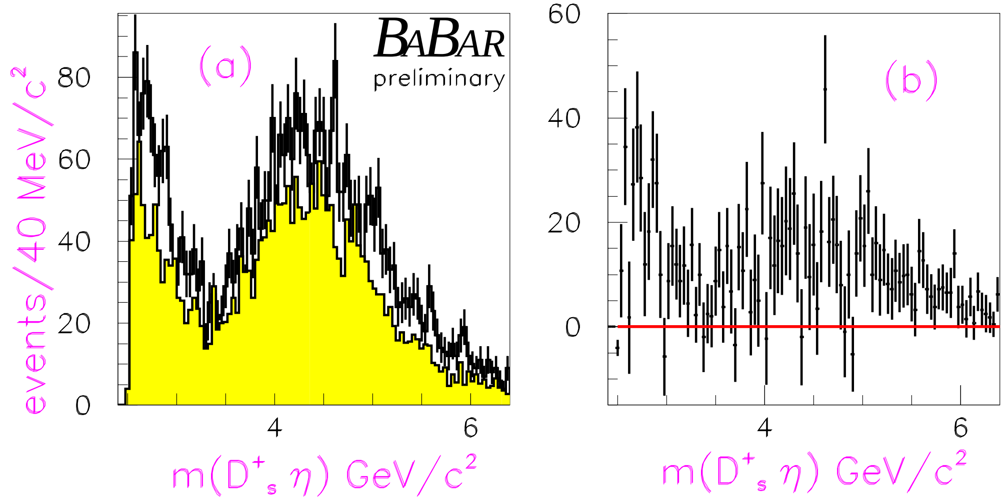
□ Excess computed using the 9 tiles method:

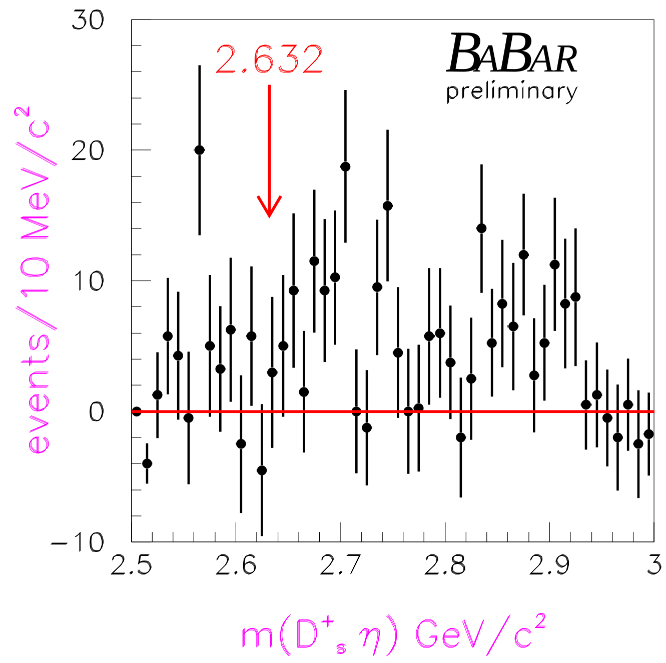
$$N = N_5 - 0.5 * (N_1 + N_3 + N_7 + N_9) + 0.25 * (N_2 + N_4 + N_6 + N_9)$$

where N_i are the events in each of the 9 tiles numbered from left to right and from bottom to top.

BaBar Search for $D_s(2632)$.

- ☐ The data show that a fraction of the D_s^+ and η are in opposite jets (uncorrelated).
- ☐ The $D_s^+\eta$ mass spectrum does not show any signal in the $D_s^+(2632)$ region.

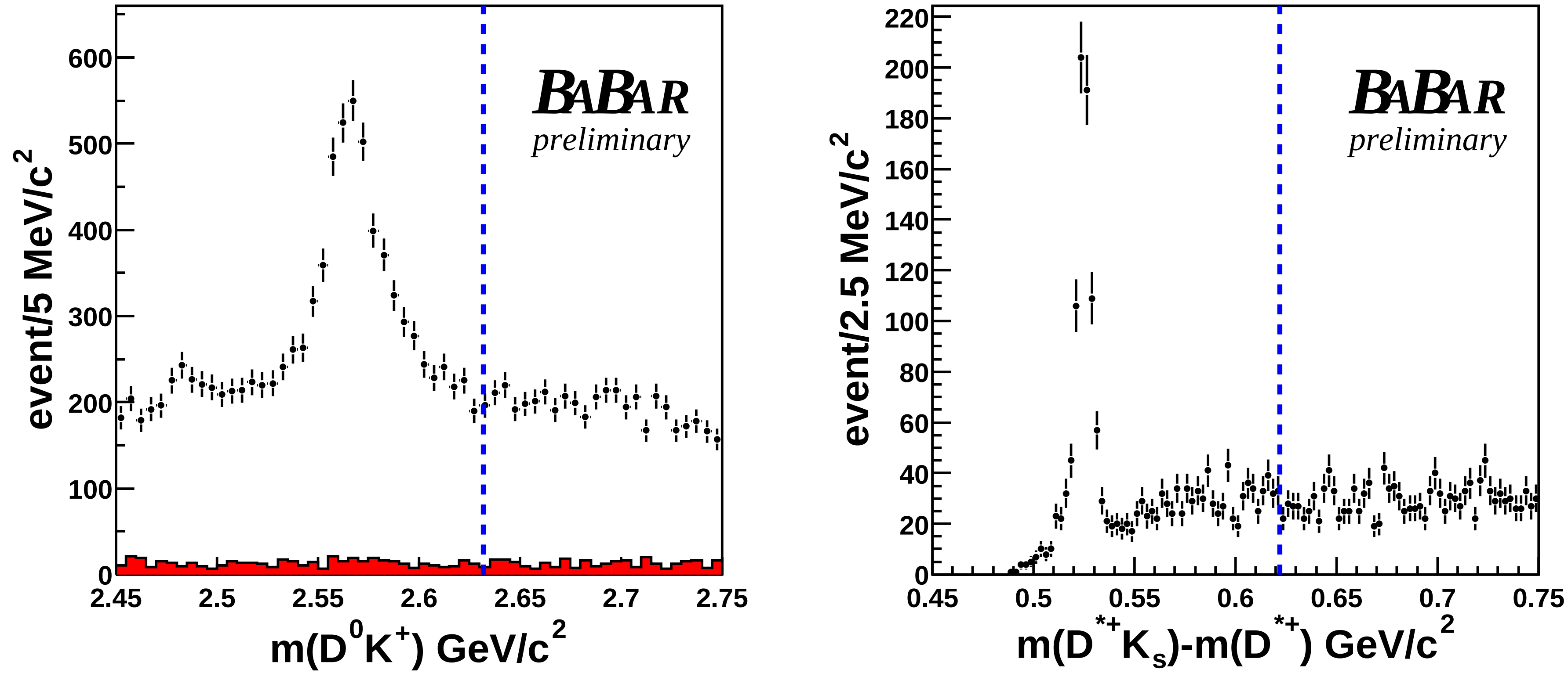




- ☐ No evidence for $D_s(2632)$.

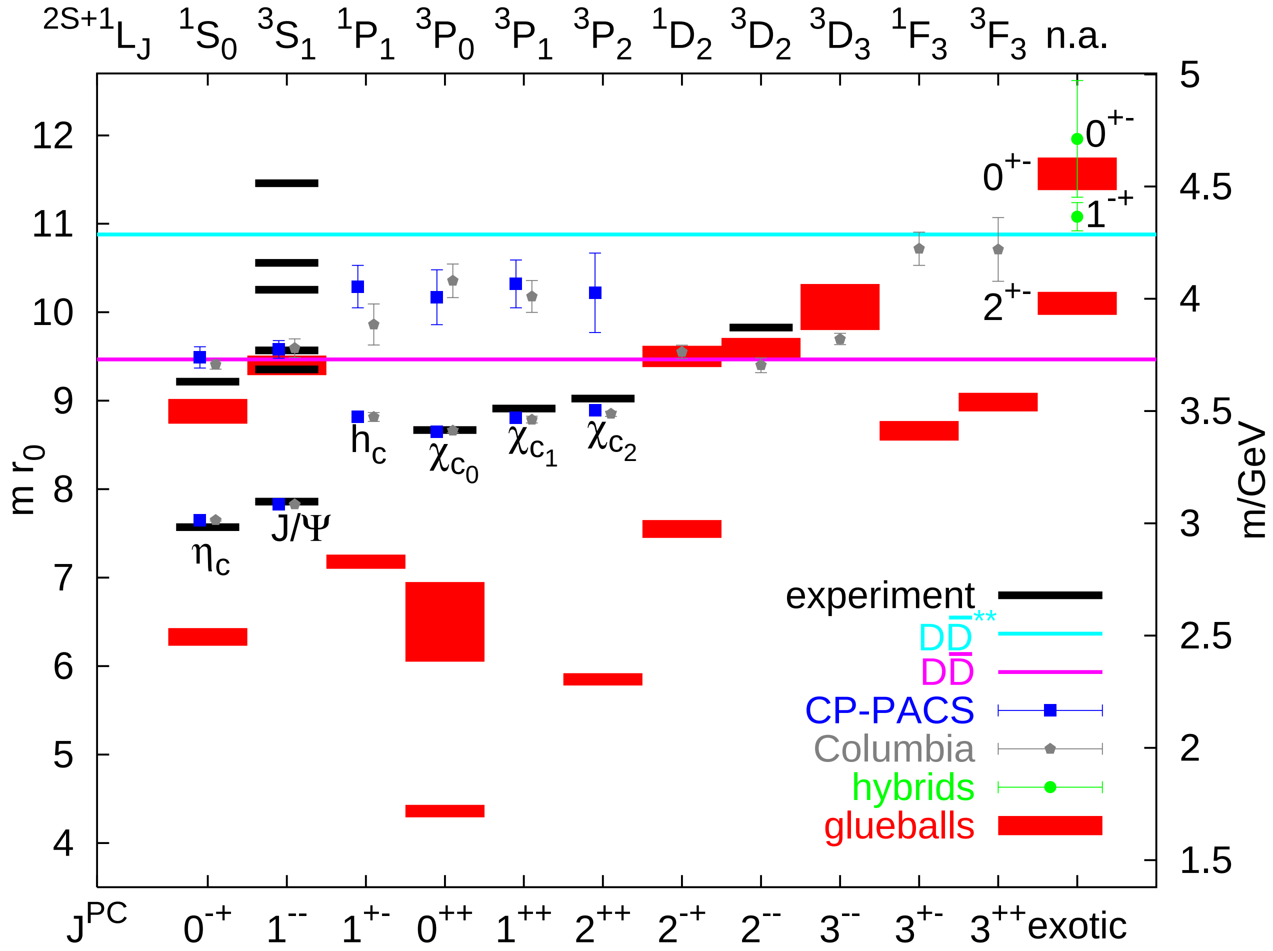
BaBar Search for $D_s(2632)$.

□ No evidence is also found for any signal in the D^0K^+ or $D^{*+}K_S^0$ mass distributions.



The Charmonium spectrum.

- It is important to establish the complete spectrum of charmonium.



- Many narrow radial excitations.
- Several states still missing.

News in the Charmonium spectrum.

□ New developments include the evidences/observations of:

$$\eta_c(2S), h_c, X(3870)$$

□ Not very much data exists on charmonium decays above the $D^{(*)}D^{(*)}$ thresholds.

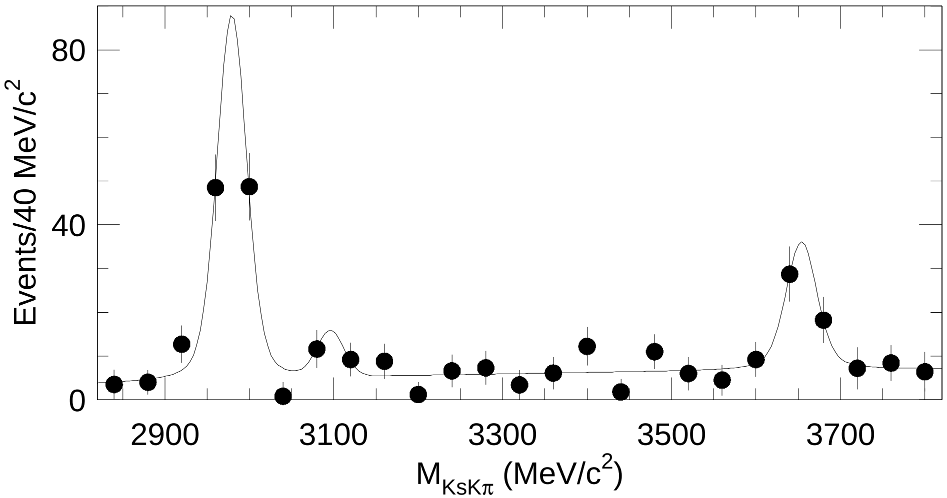
Evidence for $\eta_c(2S)$ in BELLE.

□ The 2^1S_0 state, the $\eta_c(2S)$ has been evidenced by BELLE in the study of B decays: BELLE,hep-ex/0206002

$$B^+ \to K^+\eta_c(2S) \quad and \quad B^0 \to K^0_S\eta_c(2S)$$

where:

$$\eta_c(2S) \to K^0_S K^\pm \pi^\mp$$



□ Cuts have been performed to remove contaminations from B decays to $D^0 \to K^-\pi^+$ and $D_s^+ \to K^0_S K^+$.

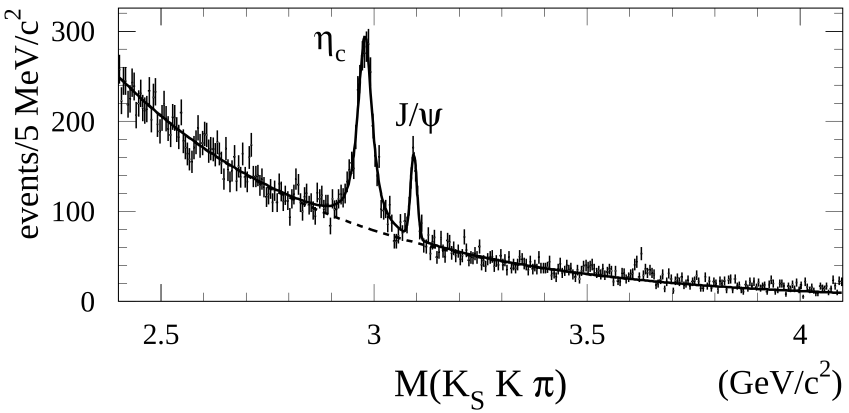
□ The mass of the $\eta_c(2S)$ was measured as:

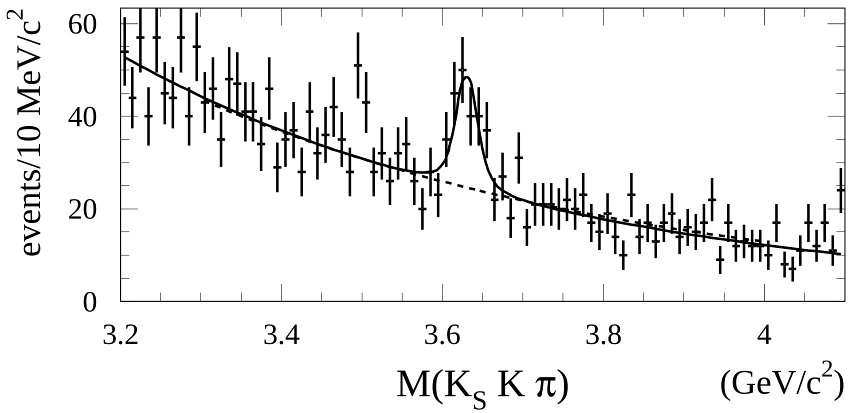
$$m = 3654 \pm 6 \pm 8 \quad MeV$$

Observation of $\gamma\gamma \to \eta_c(2S)$ by BABAR.

□ The Observation of η_c and $\eta_c(2S)$ from BaBar from $\gamma\gamma$.

BABAR,hep-ex/0311038





□ The mass of the $\eta_c(2S)$ is lower than the BELLE measurement:

$$m = 3630.8 \pm 3.4 \pm 1 \quad MeV$$

□ The $\eta_c(2S)$ has also been observed by CLEO with mass:

$$m = 3642.9 \pm 3.1 \pm 1.5 \quad MeV$$

The search for h_c.

□ The state h_c ($J^{PC} = 1^{+-}, 1^1P_1$) has been searched for in several experiments. It could decay to:

$$J/\psi\pi^0, \quad \eta_c\gamma$$

□ Experiment E835 studies resonances formation in $\bar{p}p$ annihilations at FERMILAB.

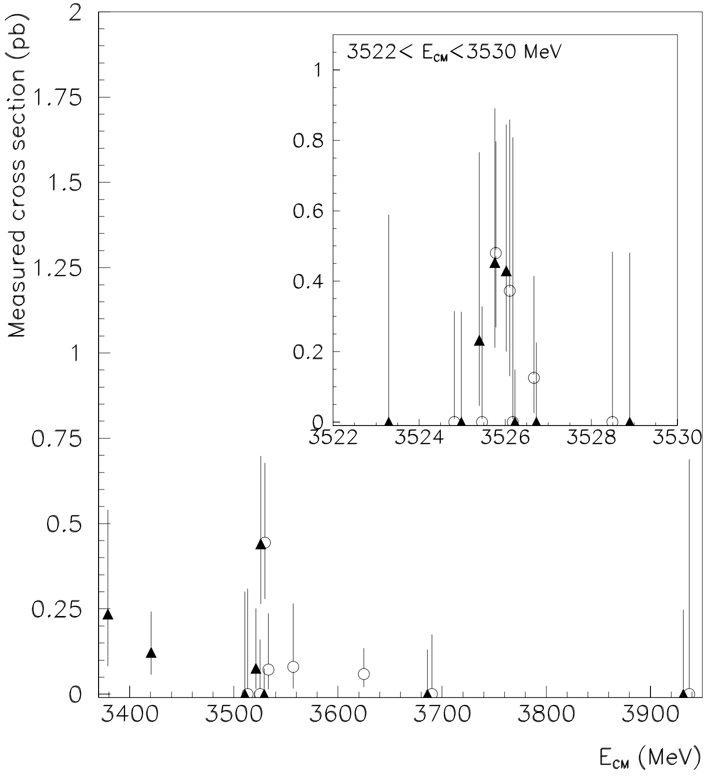
□ No evidence for h_c in:(E835,hep-ex/0410085)

$$\bar{p}p \to h_c \to J/\psi\pi^0$$

The evidence for h_c in E835.

- 23 candidates in (a 3σ effect):

$$\bar{p}p \to h_c \to \eta_c\gamma \\ \to \gamma\gamma$$



$$m = 3525.8 \pm 0.2 \pm 0.2 \quad MeV$$

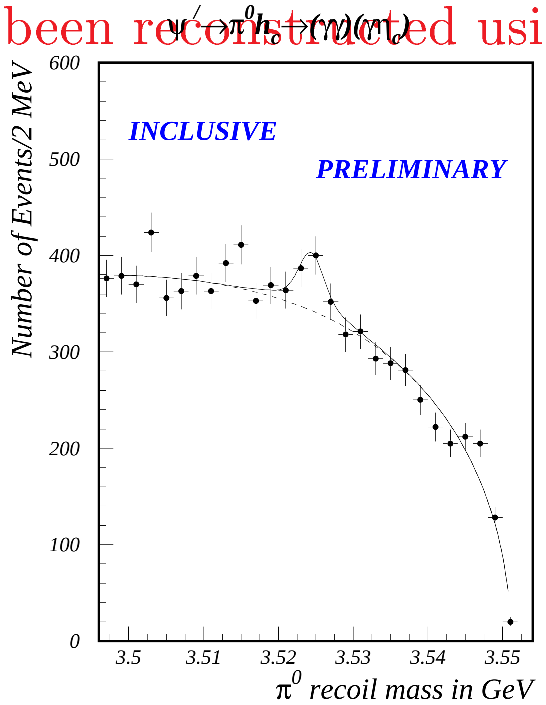
The search for h_c by CLEO.

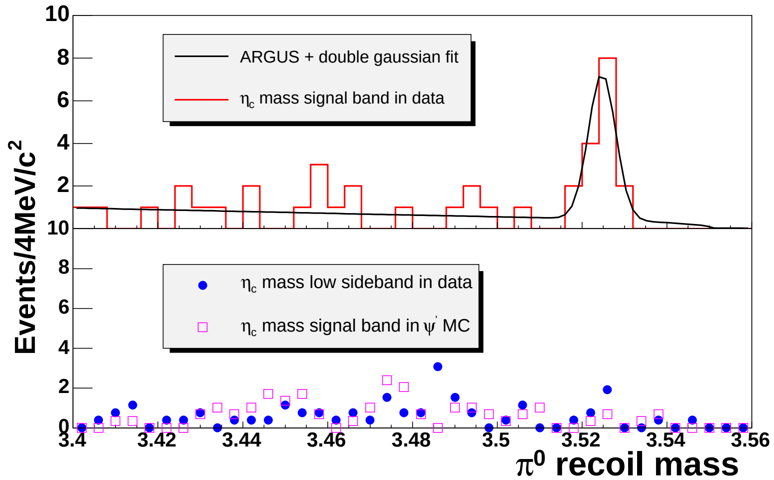
□ CLEO experiment has searched for h_c using $\approx 3 \times 10^6$ $\psi'(3686)$ decays.

CLEO,hep-ex/0410090

$$\psi' \to \pi^0 hc$$
$$\to \gamma\eta_c$$

□ Two analyses have been performed inclusive, and exclusive (where the η_c has been reconstructed using many decay modes).





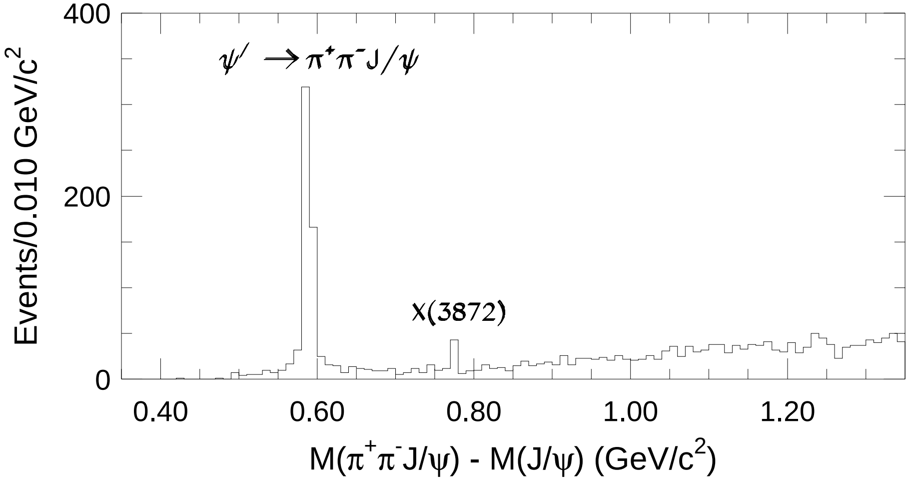
$$m = 3524.4 \pm 0.9 \quad MeV$$

□ Significance is $\approx 5\sigma$.

The observation of $X(3872)$.

□ BELLE experiment has discovered a narrow charmonium state in BELLE,hep-ex/0309032:

$$B^+ \to K^+ J/\psi\pi^+\pi^-$$



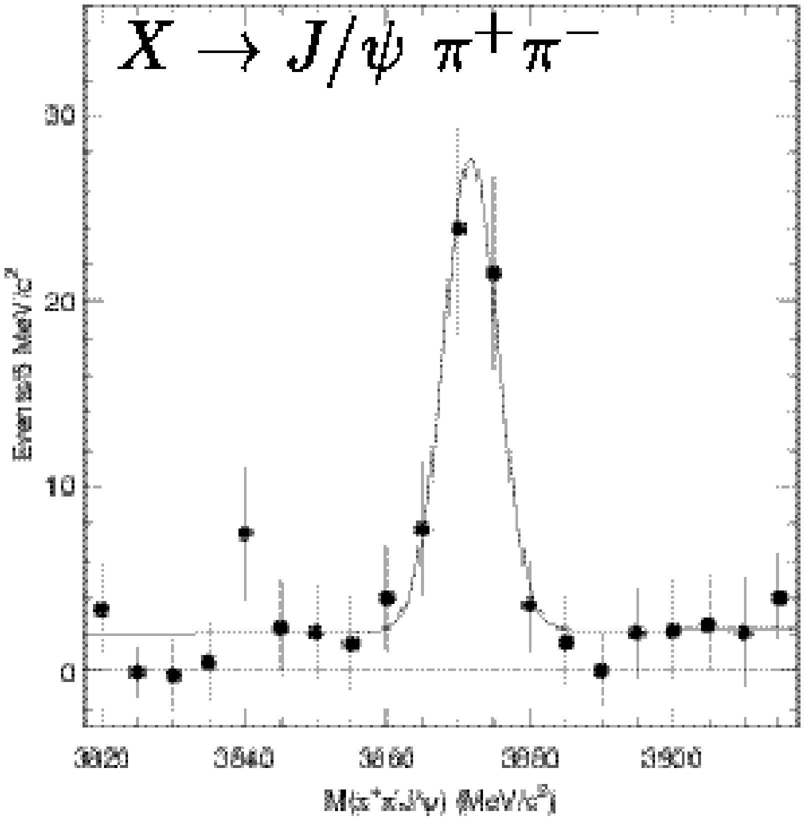
$$m = 3872 \pm 0.6 \pm 0.5 \quad MeV$$

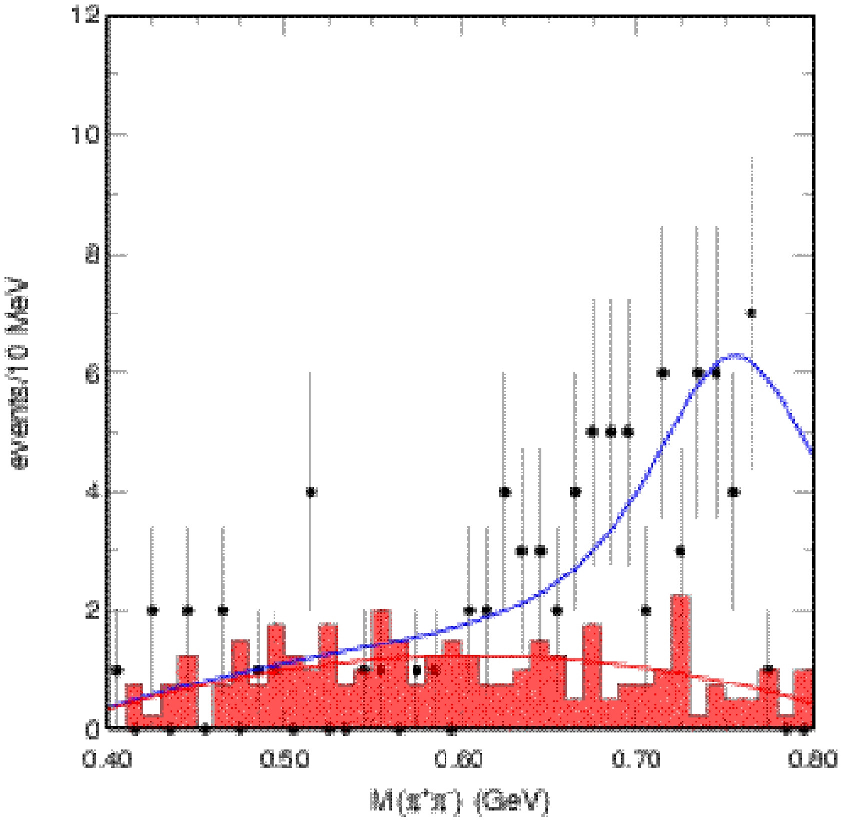
□ Confirmed by BaBar, CDF and D0.

The observation of $X(3872)$.

Last update on 253 fb^{-1} shows that the $\pi^+\pi^-$ spectrum is compatible with being:

$$X(3872) \to J/\psi\rho^0(770)$$





A new charmonium state?

□ Several tests performed in searching for other decay modes.

$$J^{PC} = 2^{--}, 1^{+-}, 2^{-+}, 1^{++}, 3^{--}, 0^{+}, 1^{-}, 2^{+}$$

excluded.

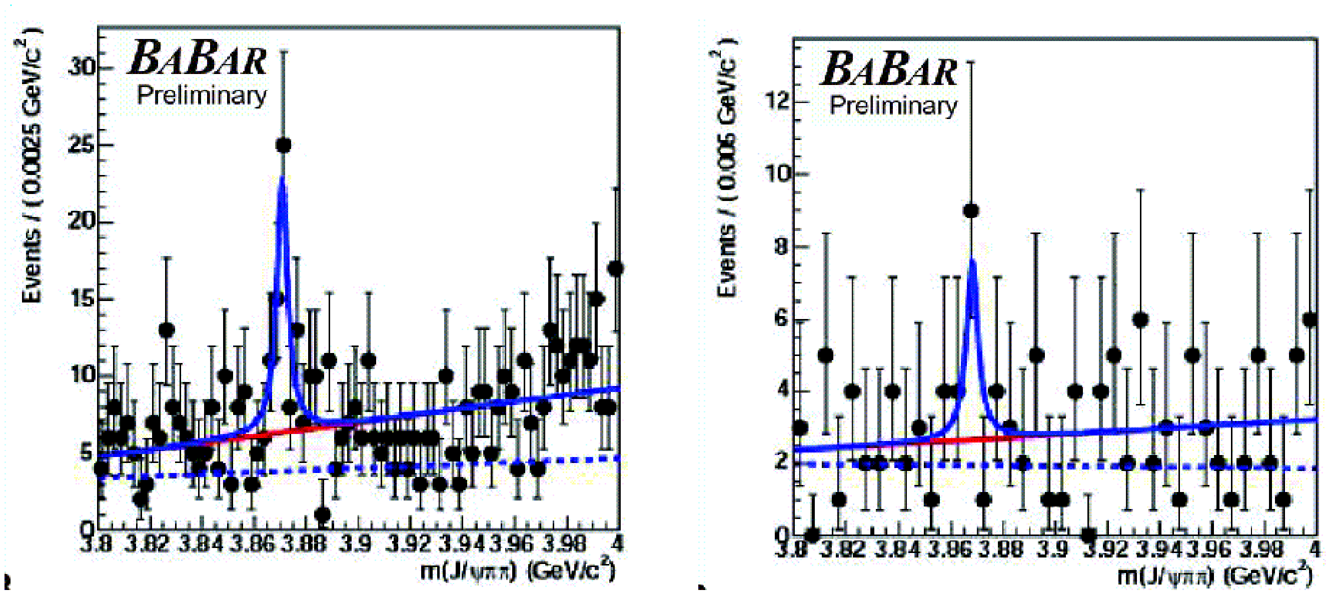
□ Some models suggest:

- $D^0 \bar{D}^{(*)} K$ molecule;
- Diquark-antidiquark;

Results from BaBar.

□ Study of $B^+ \to X(3872)K^+$ and $B^0 \to X(3872)K^0_s$ from BaBar.J.

Coleman(BABAR),Moriond QCD 2005



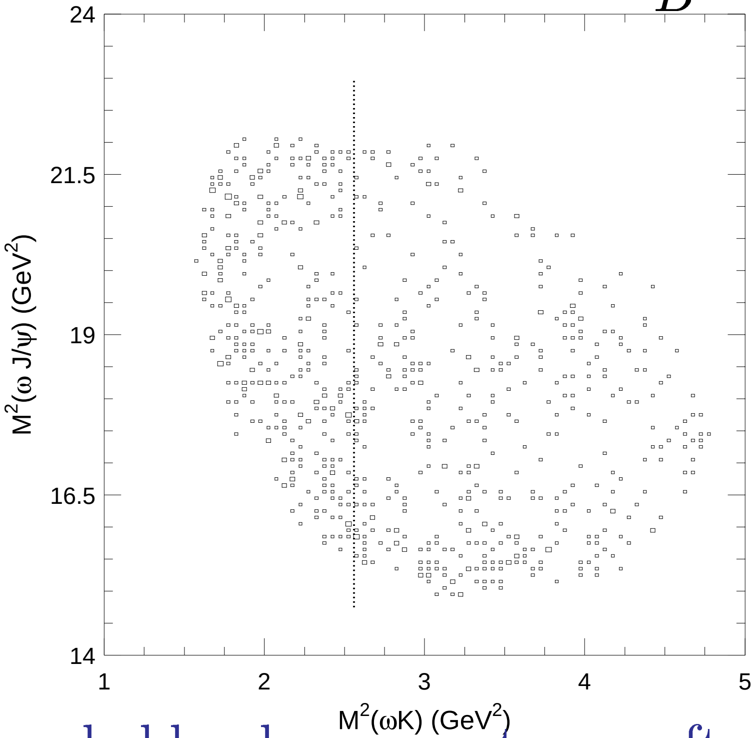
□ Measure:

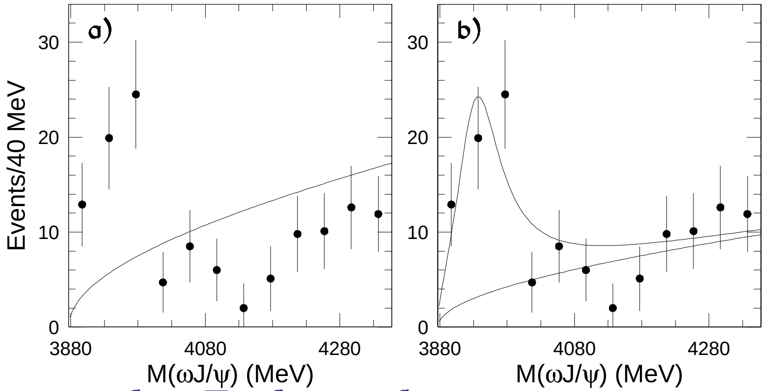
$$\frac{B^0 \to XK^0}{B^+ \to XK^+} = 0.61 \pm 0.36 \pm 0.07$$

A threshold enhancement in $J/\psi\omega$.

□ BELLE experiment has shown a threshold enhancement in the $J/\psi\omega$:BELLE,hep-ex/0408126

$B^+ \to K^+ J/\psi\omega$





□ Threshold enhancement seen ofter a cut on the Dalitz plot.

□ Not clear its resonance origin.

□ Not clear if related to X(3872).

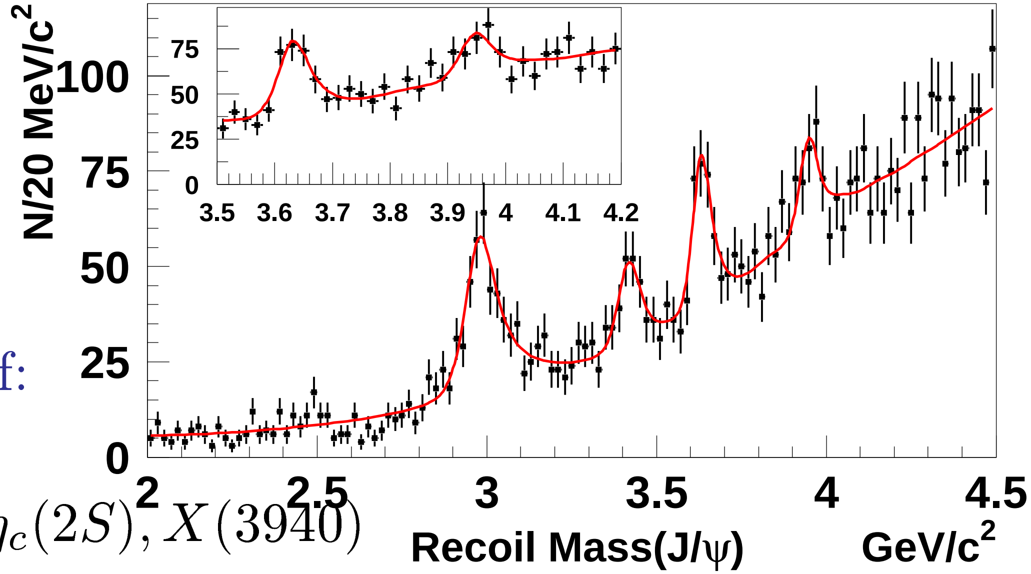
Double $\bar{c}c$.

☐ Observation by BELLE of an unexpected large rate for: BELLE, hep-ex/0205104

$$e^+e^- \to J/\psi(\bar{c}c)$$

☐ Study of the missing mass to $e^+e^- -> J/\psi$ with $J/\psi \to l^+l^-$.

$$m_{recoil} = \sqrt{(\sqrt{s} - E^*_{J/\psi})^2 - p^{*2}_{J/\psi}}$$



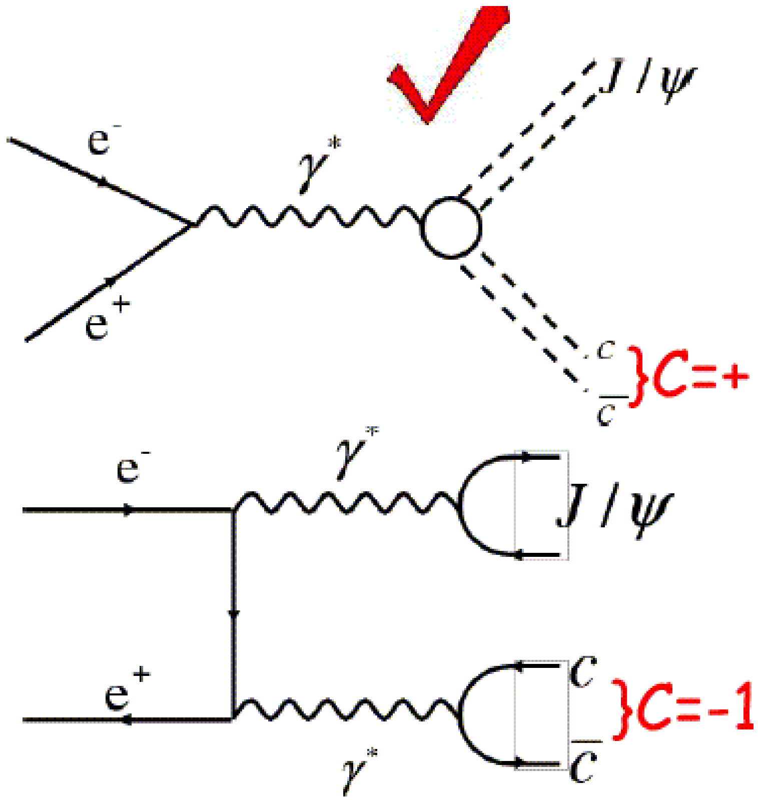
☐ Observed peaks at the positions of:

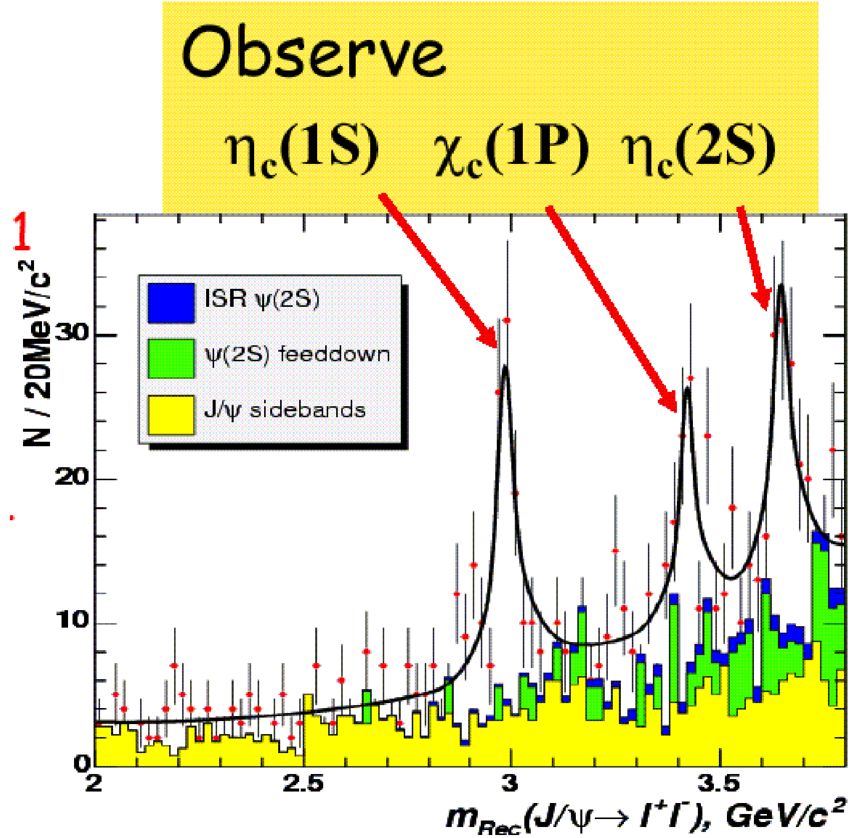
$$\eta_c, \chi_{c0}, \eta_c(2S), X(3940)$$

☐ X(3940) unknown object.

Double $\bar{c}c$.

- ☐ Result confirmed by BaBar.
- ☐ Two diagrams are possible:

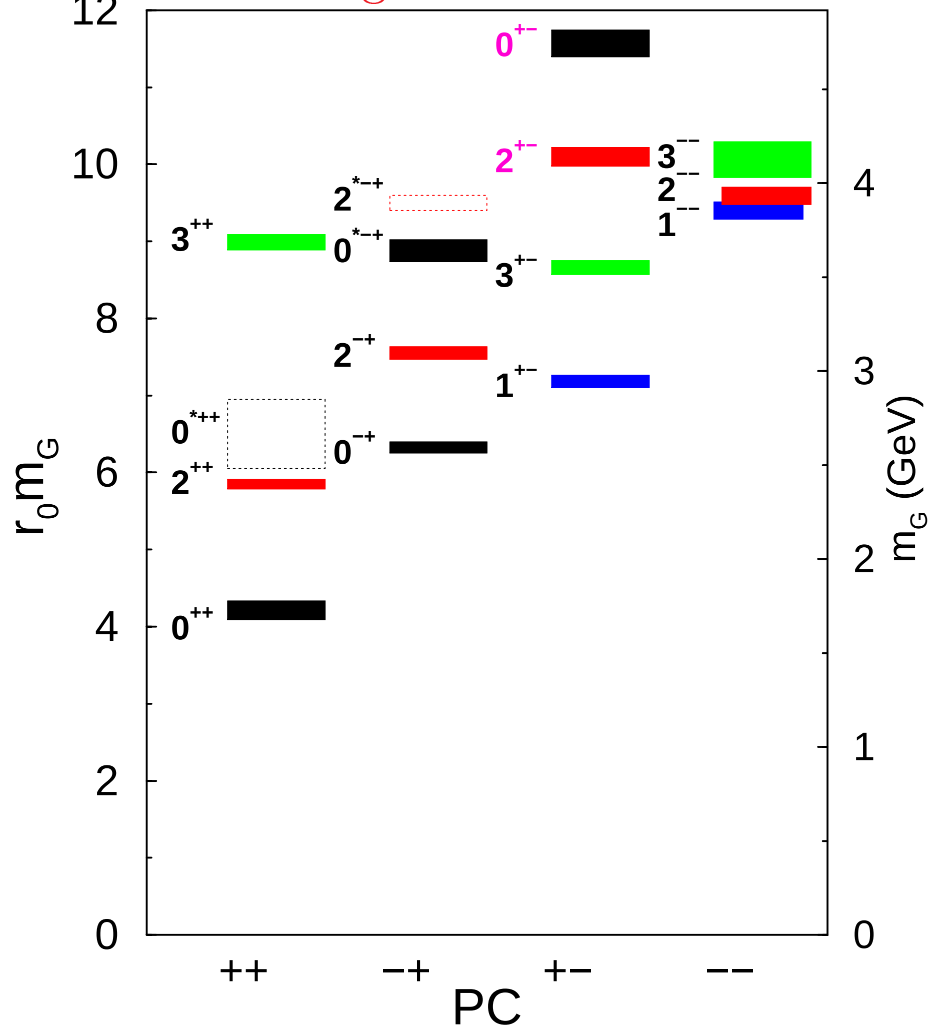




- ☐ Observed only C=+ states.

Light Meson spectroscopy.

□ Lattice QCD predicts the scalar gluonium around 1.7 GeV:



Status of gluonium searches.

□ Too many scalar mesons below 2. GeV.

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

□ Two nonets? 4-quark states? Gluonium?

□ Where is the scalar glueball?

□ Many proposals.

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

Wide: σ.

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

□ Unlikely to produce gluonium in charm decays.

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.

□ The likelihood is parametrized as:

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

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

□ x is the signal fraction. (1 - x) is the Non Resonant contribution, in most analysis consistent with zero.

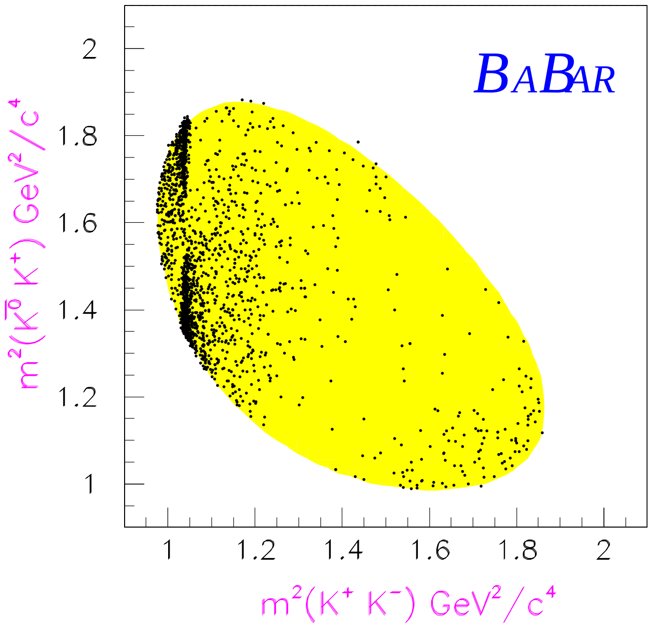
□ Most of charm decays go through intermediate two-body resonance production.

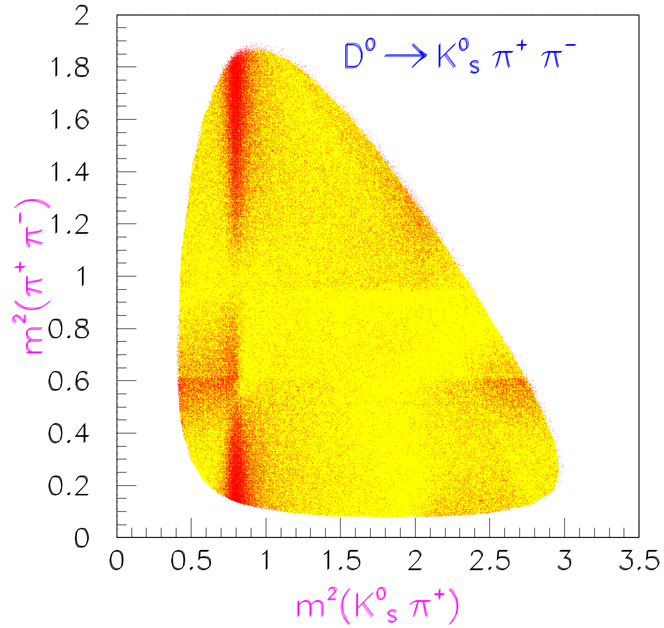
□ Because of interferences the sum of the fractions does not add up to 1.

Dalitz plot analysis.

□ Many analyses done or in progress. Examples from BaBar:

BABAR,hep-ex/0207089 $D^0 \to \bar{K}^0 K^+ K^-$ $D^0 \to \bar{K}^0 \pi^+ \pi^-$





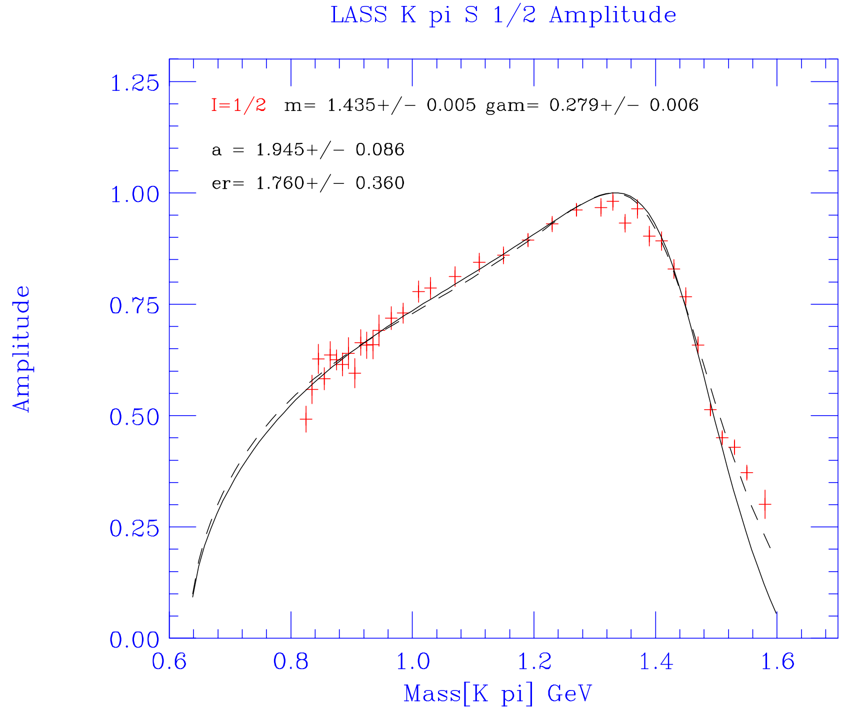
□ In some cases a rather simple structure. Clear interference of the $\phi(1020)$ with respect to $a_0(980)$ in $D^0 \to \bar{K}^0 K^+ K^-$.

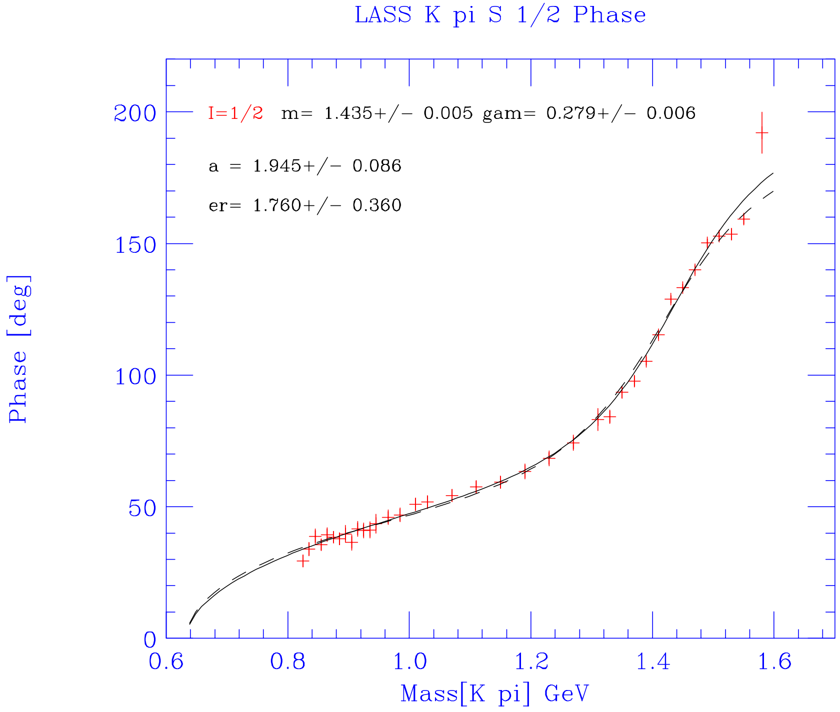
□ Very complex structure in $D^0 \to \bar{K}^0 \pi^+ \pi^-$: up to 13 resonances.

The evidence for $\kappa(800)$.

□ The $K\pi$ S-wave amplitude and phase has been studied by LASS experiment in the reaction: D.Aston et al., NPB296,1988,493

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





□ No need to introduce $k(800)$.

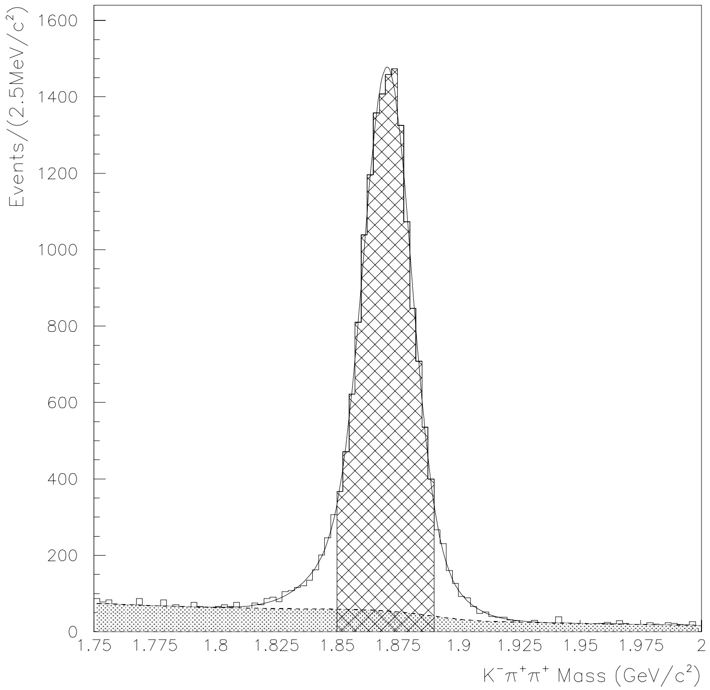
The evidence for $\kappa(800)$ from E791.

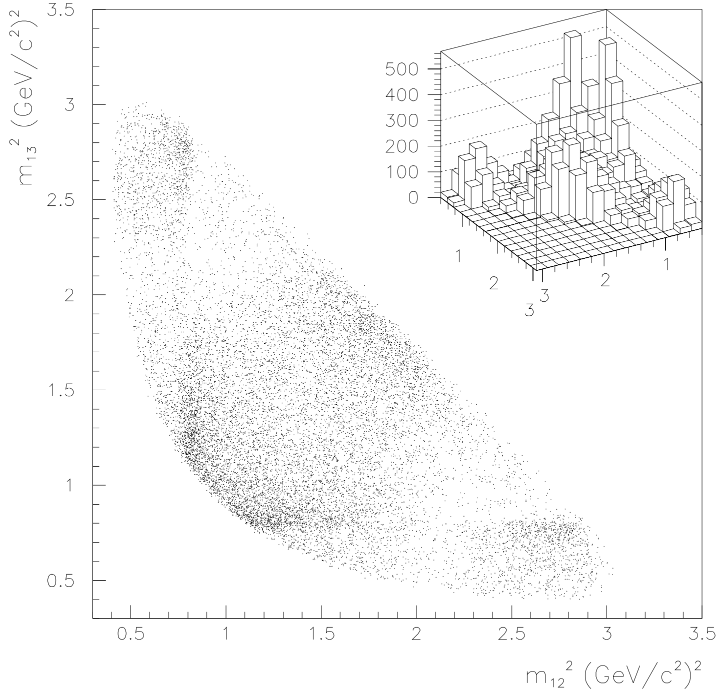
□ Experiment E791 at Fermilab has studied $\approx$ 15000 events from:

E791,hep-ex/0204018

$$D^+ \to K^-\pi^+\pi^+$$

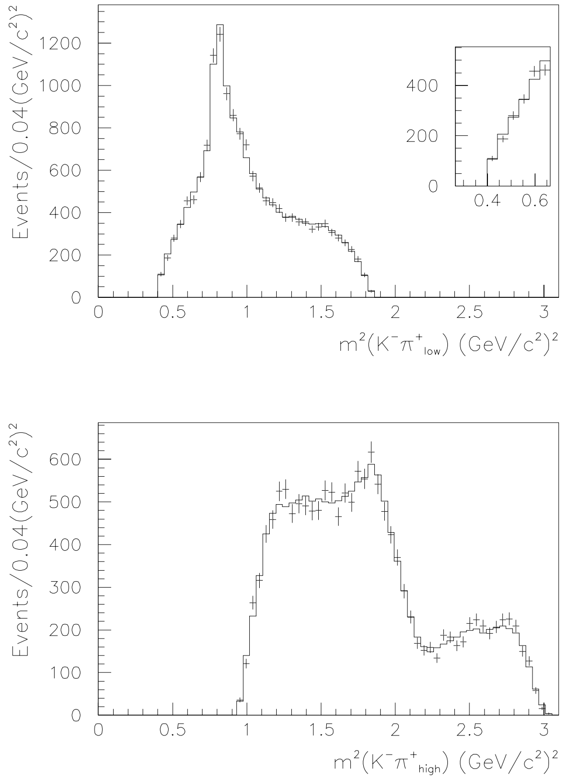
□ Mass spectrum and Dalitz plot.





The evidence for $\kappa(800)$ from E791.

- □ In order to fit the Dalitz plot a large Non Resonant contribution is needed.
- □ Or, better, a new low mass scalar resonance.



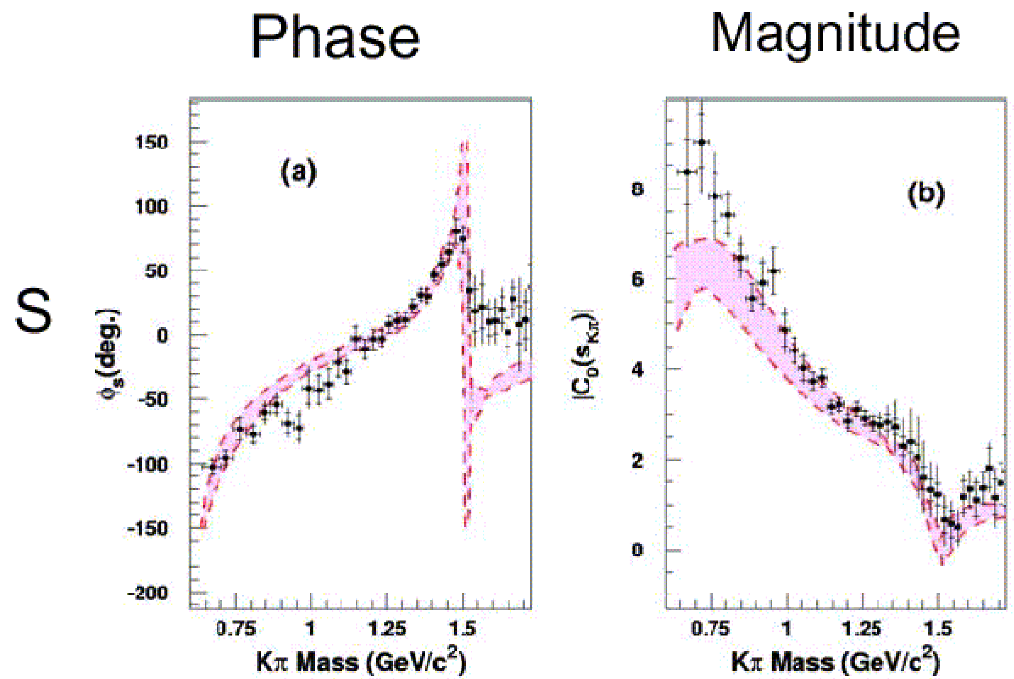
$$m = 797 \pm 19 \pm 42 \quad MeV, \qquad \Gamma = 410 \pm 43 \pm 85 \quad MeV$$

A different approach: Partial Wave analysis.

- A new method has been developed by E791. B.Meadows, Moriond QCD, 2005
- The scalar contribution is left free in the Dalitz plot analysis in terms of a complex number:

$$c_{m(K\pi)}e^{i\phi_{m(K\pi)}}$$

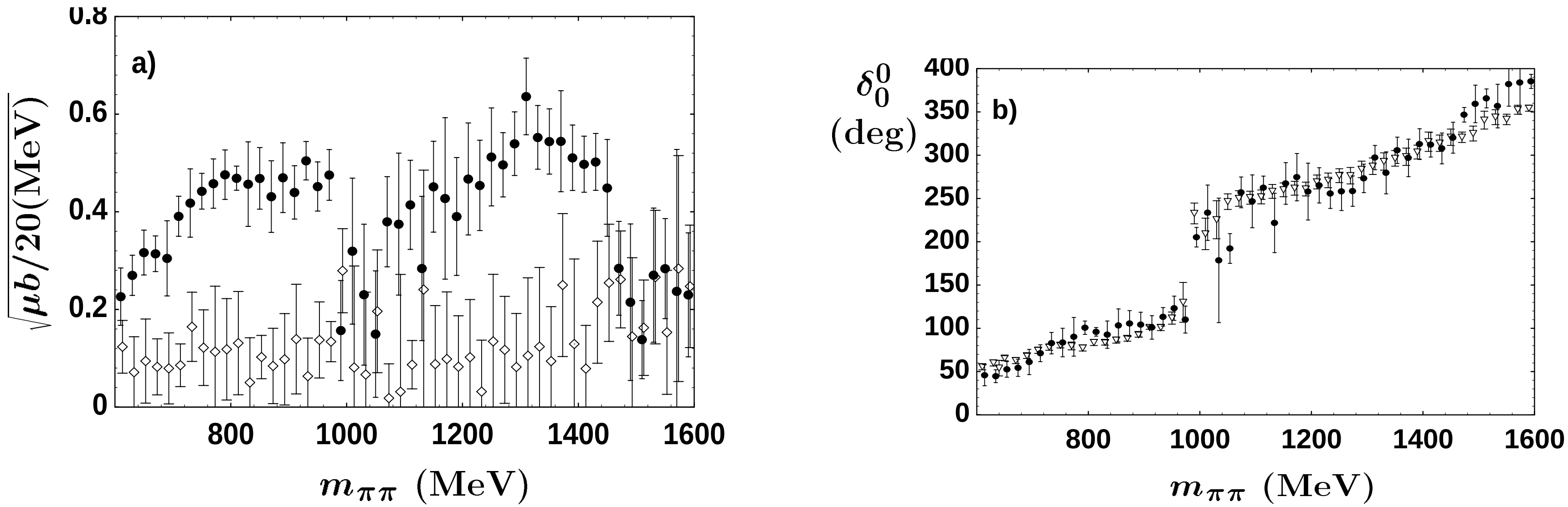
- The fit measures amplitude and phase as a function of the $K\pi$ mass.



The evidence for $\sigma(500)$.

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

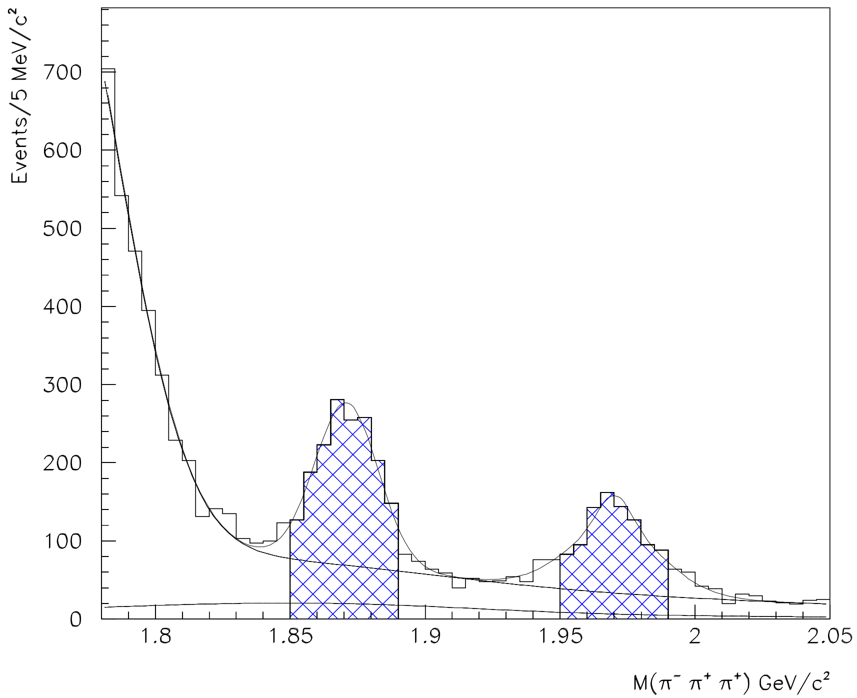
$$\pi^- p \to \pi^+ \pi^- n$$



The evidence for $\sigma(500)$.

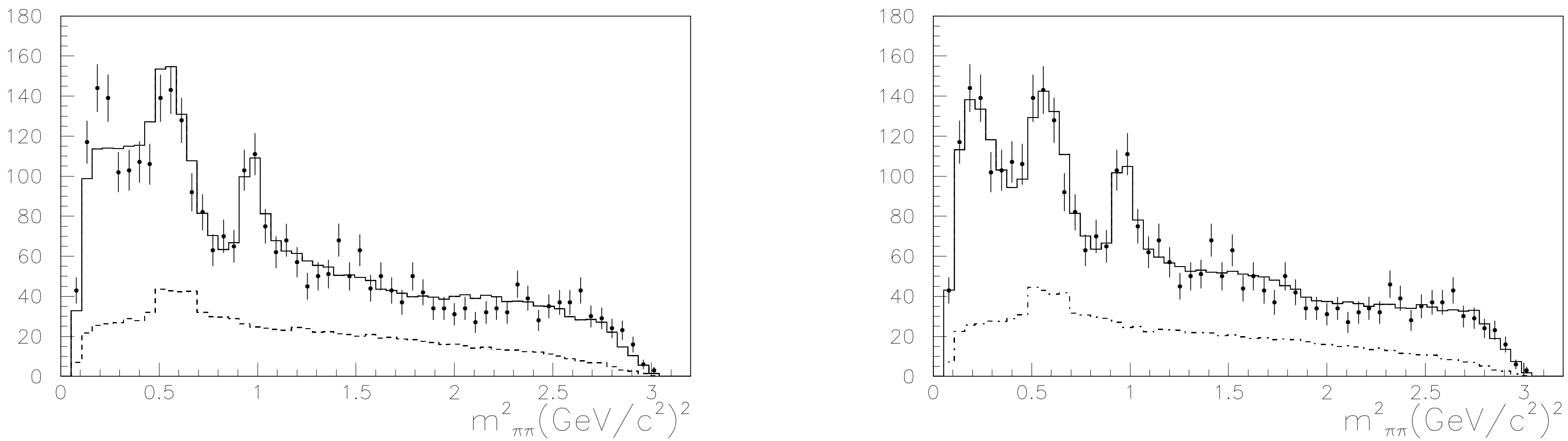
- Experiment E791 at Fermilab has studied $\approx$ 1200 events from: hep-ex/0011042

$$D^+ \to \pi^- \pi^+ \pi^+$$



The evidence for $\sigma(500)$.

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



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

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

A different approach: the K-matrix formalism.

□ Transition Matrix written as: K.Peters, hep-ph/0412069

$$T = (I - iK\rho)^{-1}K$$

$$K_{ij} = \sum_{\alpha} \frac{\gamma_{i\alpha}\gamma j\alpha m_\alpha \Gamma_\alpha}{m_\alpha^2 - m^2} + c_{ij}m^2$$

where the index ij extends to the different decay channels and the sum is over all the K matrix poles.

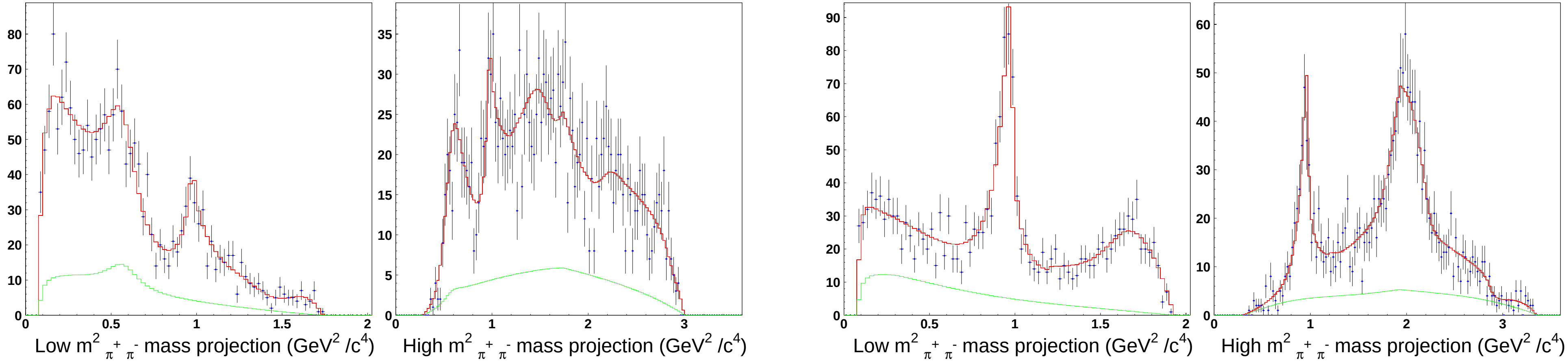
□ This approch respects unitariety.

□ Algorithm makes use of all existing data in a global fit.

□ The whole resulting S-wave used in the Dalitz plot analysis.

K-matrix fits to charm decays.

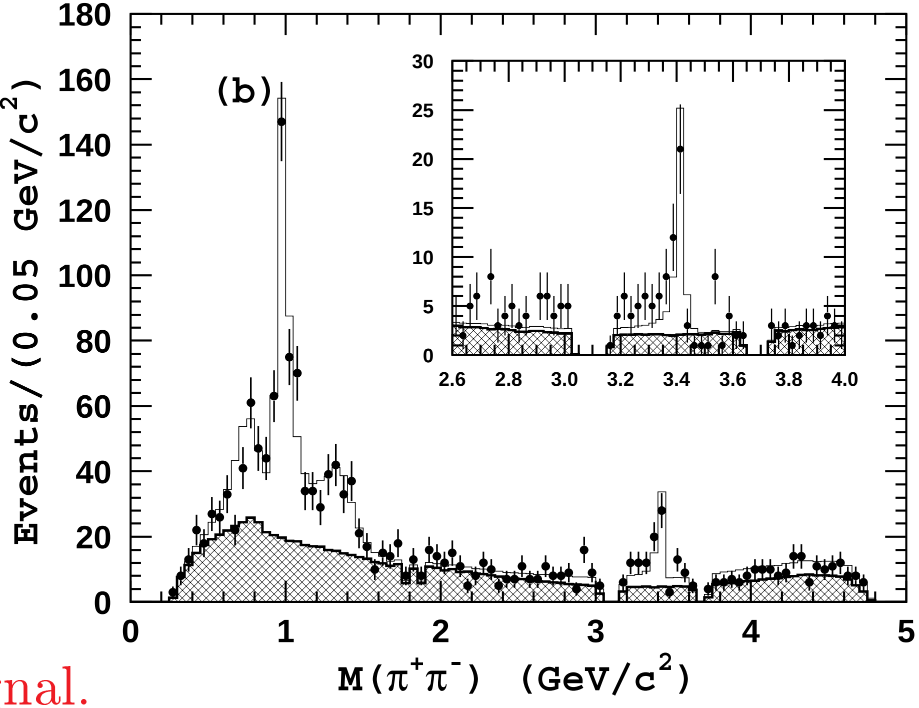
- FOCUS: Analysis of $D^+ \to \pi^+\pi^+\pi^-$ and $D_s^+ \to \pi^+\pi^+\pi^-$ FOCUS,hep-ex/0312040



- No need for a σ.

Dalitz plot analysis of B decays.

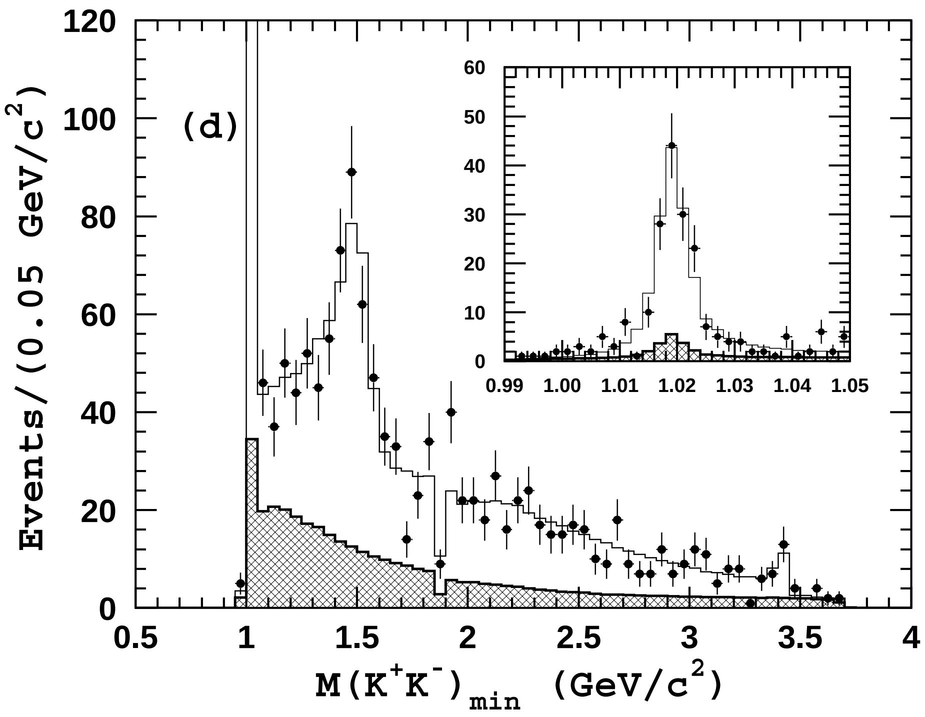
- ☐ BELLE: $\pi^+\pi^-$ mass spectrum in $B^+ \to K^+\pi^+\pi^-$. BELLE,hep-ex/0412066



- ☐ Strong $f_0(980)$ signal.
- ☐ Wide scalar structure around 1.3 GeV. $f_0(1300)$?
- ☐ No $f_0(1500)$.

Dalitz plot analysis of B decays.

- □ BELLE: K^+K^- mass spectrum in $B^+ \to K^+K^+K^-$



- □ $f_0(1500)$ or $f_2'(1525)$?

Pentaquarks: pathological science strikes back?

□ In 1953 I. Langmuir gave a lecture on Pathological Science: a number of good scientists reporting wrong results. D.R.O. Morrison (CERN/EP 90-36, 15 March 1990)

□ Three phases:

- Phase I: The original report is quickly confirmed;
- Phase II: about the same number of positive and negative results;
- Phase III: Avalanche of negative results.

□ Examples of pathological science could be:

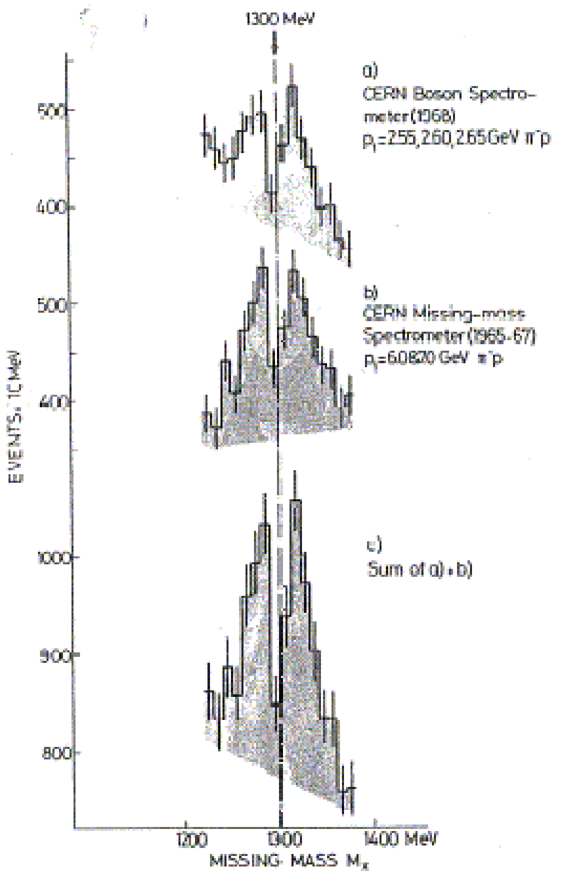
- A_2 splitting;
- Baryonium;
- Cold Fusion;

The A_2 splitting.

☐ The study of $\pi^- p \to pX^-$
The missing mass spectrum showed a dip at the mass of the A_2 resonance:

☐ Confirmed by a different experiment.

$\pi^- p \to p X^-$
(Chikovani et al. 1965-7)
(Benz, Chikovani et al. 1968)



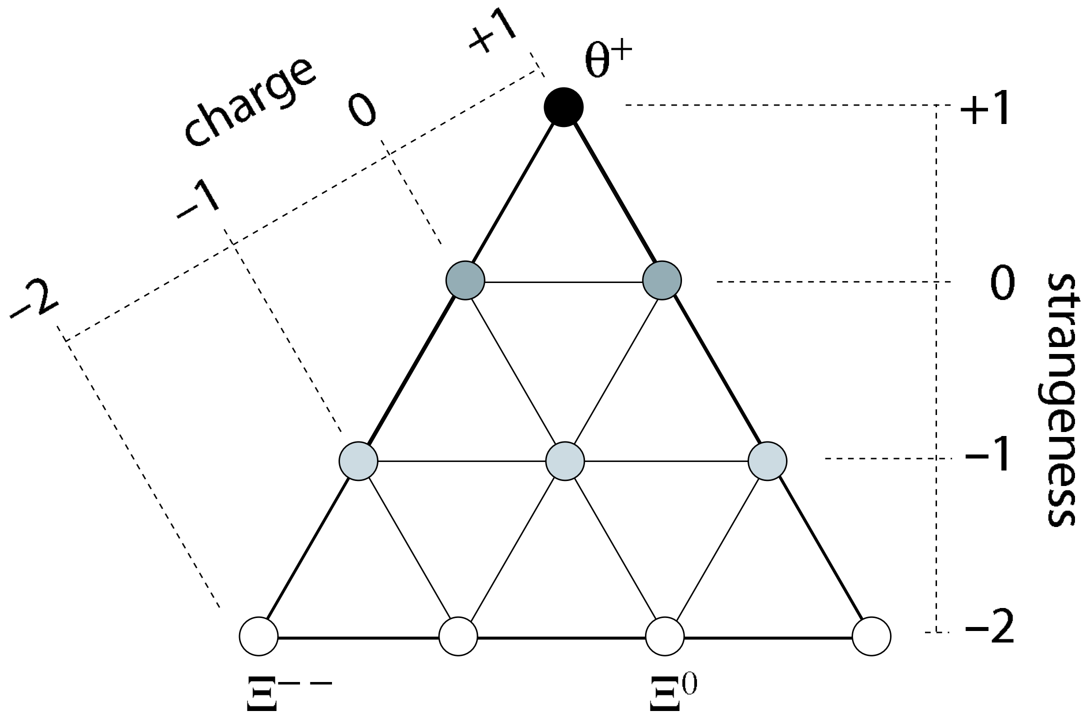
☐ Other experiments did not find the effect.

☐ For the baryonium case see:

A. Ferrer et al., The European Physical Journal C, Volume 10, Number 2 (1999) 249.

Pentaquarks.

☐ Predictions of pentaquarks: D. Diakonov et al.,hep-ph/9703373



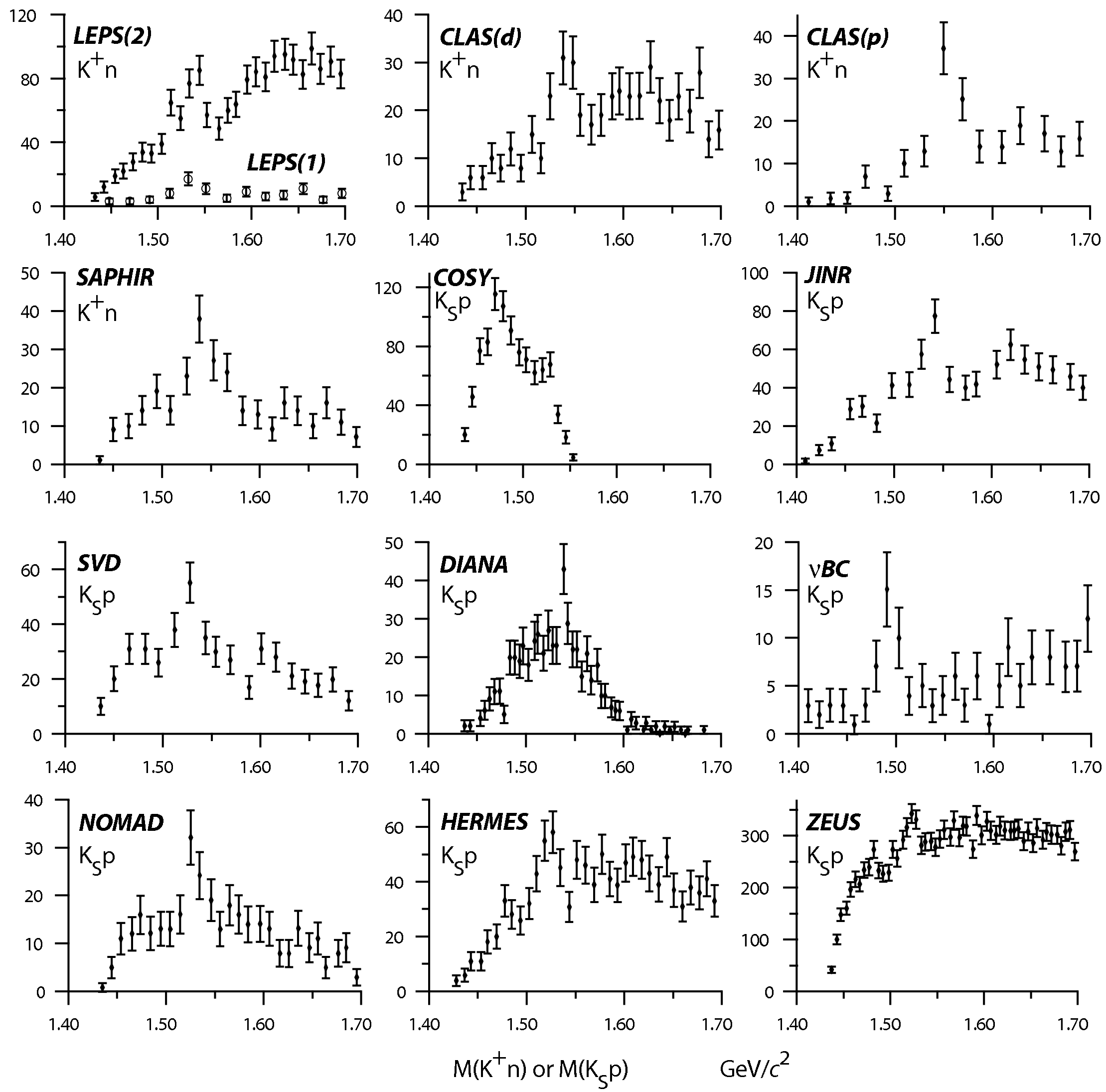
☐ Expected states:

$$\theta^+ = uudds, \Xi_5^{--} = ddss\bar{u}, \Xi_f^0 = udss\bar{,}\theta_c = uudd\bar{c}d$$

□ Positive evidences for pentaquarks: (from A. Dzierba et al., hep-ex/0412077)

Experiment	Reaction	State	Mode
LEPS(1)	$\gamma C_{12} \to K^+ K^- X$	θ^+	$K^+ n$
LEPS(2)	$\gamma d \to K^+ K^- X$	θ^+	$K^+ n$
CLAS(d)	$\gamma d \to K^+ K^- (n) p$	θ^+	$K^+ n$
CLAS(p)	$\gamma p \to K^+ K^- \pi^+ (n)$	θ^+	$K^+ n$
SAPHIR	$\gamma p \to K^0_S K^+ (n)$	θ^+	$K^+ n$
COSY	$pp \to \Sigma^+ K^0_S p$	θ^+	$K^0_S p$
JINR	$p(C_3 H_8) \to K^0_S p X$	θ^+	$K^0_S p$
SVD	$pA \to K^0_S p X$	θ^+	$K^0_S p$
DIANA	$K^+ Xe \to K^0_S p (Xe)'$	θ^+	$K^0_S p$
νBC	$\nu A \to K^0_S p X$	θ^+	$K^0_S p$
NOMAD	$\nu A \to K^0_S p X$	θ^+	$K^0_S p$
HERMES	quasi-real photoproduction	θ^+	$K^0_S p$
ZEUS	$ep \to K^0_S p X$	θ^+	$K^0_S p$
NA49	$pp \to \Xi \pi X$	Ξ_5	$\Xi \pi$
H1	$ep \to (D^* p) X$	θ_c	$D^* p$

The positive evidence.



□ Different ways of computing the statistical significance.

$$s/\sqrt{(b)}, s/\sqrt{s+b}, s/\sqrt{s+2b}$$

where s=signal, b=background.

□ Backgrounds of unknown shape. Unknown production mechanism.

□ Published significances range between 4.3 and 7.8 σ.

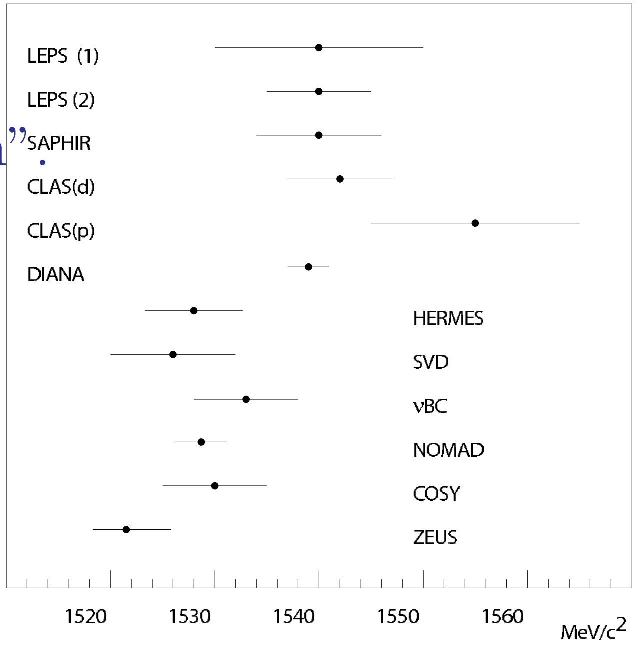
□ $s/\sqrt{s+b}$ ranges between 3.1 and 6.4 σ.

□ $s/\sqrt{s+2b}$ ranges between 2.4 and 4.7 σ.

□ No experiment has a compelling evidence,

□ only the cumulative result prompt the “observation”.

□ Mass of the θ^+.



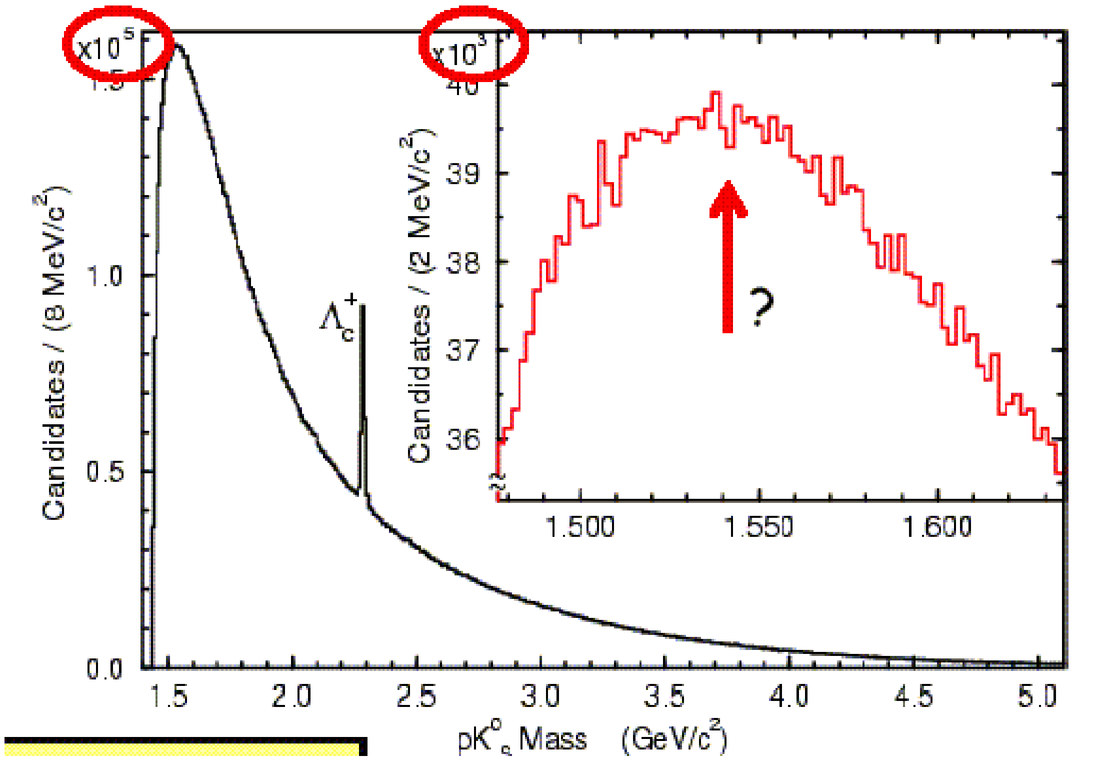
The negative evidence.

□ A list of negative results:

Experiment	Search Reaction	θ^+	Ξ_5	θ_c
ALEPH	Hadronic Z decays	$\Downarrow$	$\Downarrow$	$\Downarrow$
BaBar	$e^+e^- \to \Upsilon(4S)$	$\Downarrow$	$\Downarrow$	–
BELLE	$KN \to PX$	$\Downarrow$	–	$\Downarrow$
BES	$e^+e^- \to J/\psi(\psi(2S) \to \theta\bar{\theta}$	$\Downarrow$	–	$\Downarrow$
CDF	$p\bar{p} \to PX$	$\Downarrow$	$\Downarrow$	$\Downarrow$
COMPASS	$\mu^+(^6LiD) \to PX$	$\Downarrow$	$\Downarrow$	–
DELPHI	Hadronic Z decays	$\Downarrow$	–	–
E690	$pp \to PX$	$\Downarrow$	$\Downarrow$	–
FOCUS	$\gamma p \to PX$	$\Downarrow$	$\Downarrow$	$\Downarrow$
HERA-B	$pA \to PX$	$\Downarrow$	$\Downarrow$	–
HyperCP	$(\pi^+, K^+, p)Cu \to PX$	$\Downarrow$	–	–
LASS	$K^+p \to K^+n\pi^+$	$\Downarrow$	–	–
L3	$\gamma\gamma \to \theta\bar{\theta}$	$\Downarrow$	–	–
PHENIX	$AuAu \to PX$	$\Downarrow$	–	–
SELEX	$(\pi, p, \Sigma)p \to PX$	$\Downarrow$	–	–
SPHINX	$pC(N) \to \theta^+C(N)$	$\Downarrow$	–	–
WA89	$\Sigma^-N \to PX$	–	$\Downarrow$	–
ZEUS	$ep \to PX$	$\Uparrow$	$\Downarrow$	$\Downarrow$

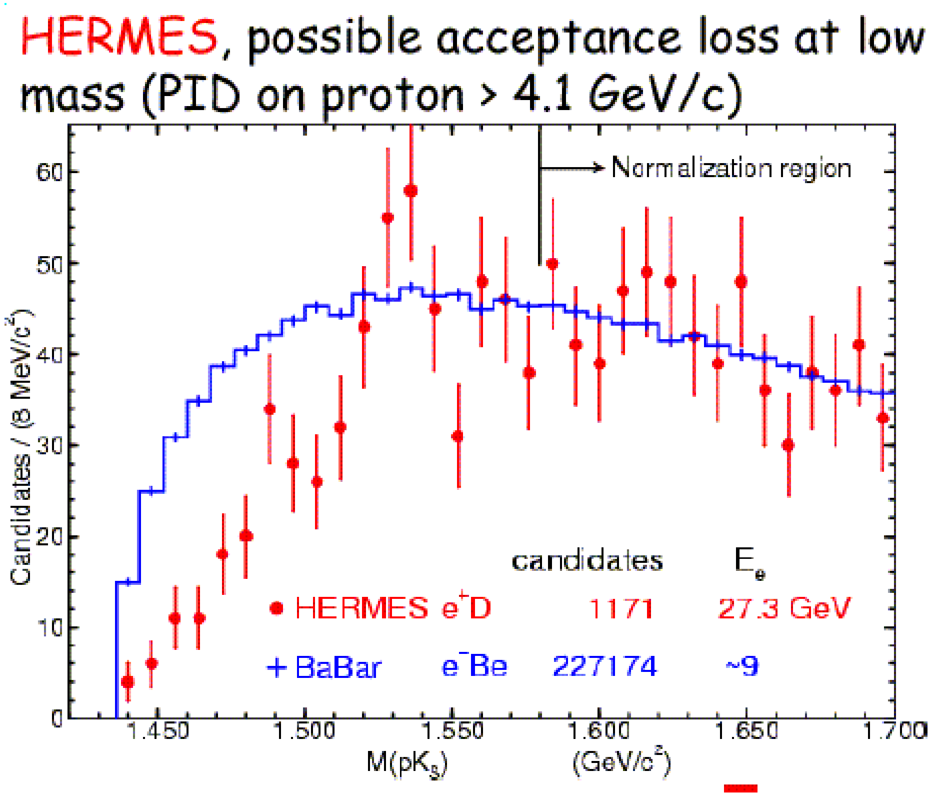
Some distribution of negative evidences: pK_s^0

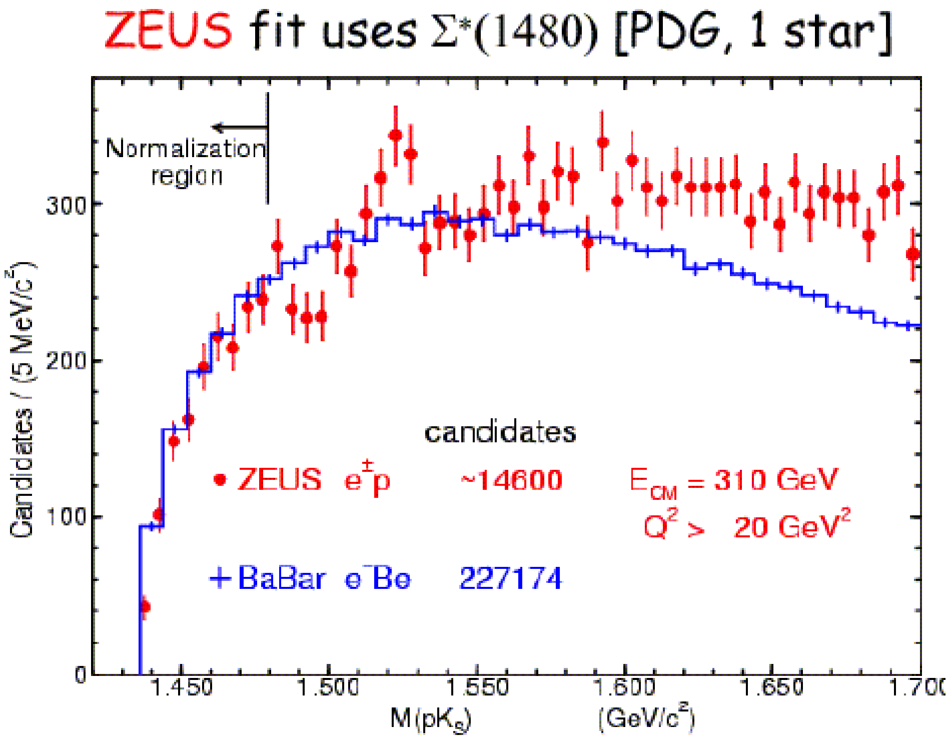
□ BaBar: pK_s^0 mass spectrum in e^+e^- annihilations.{BABAR,hep-ex/0502004}



Some distribution of negative evidences.

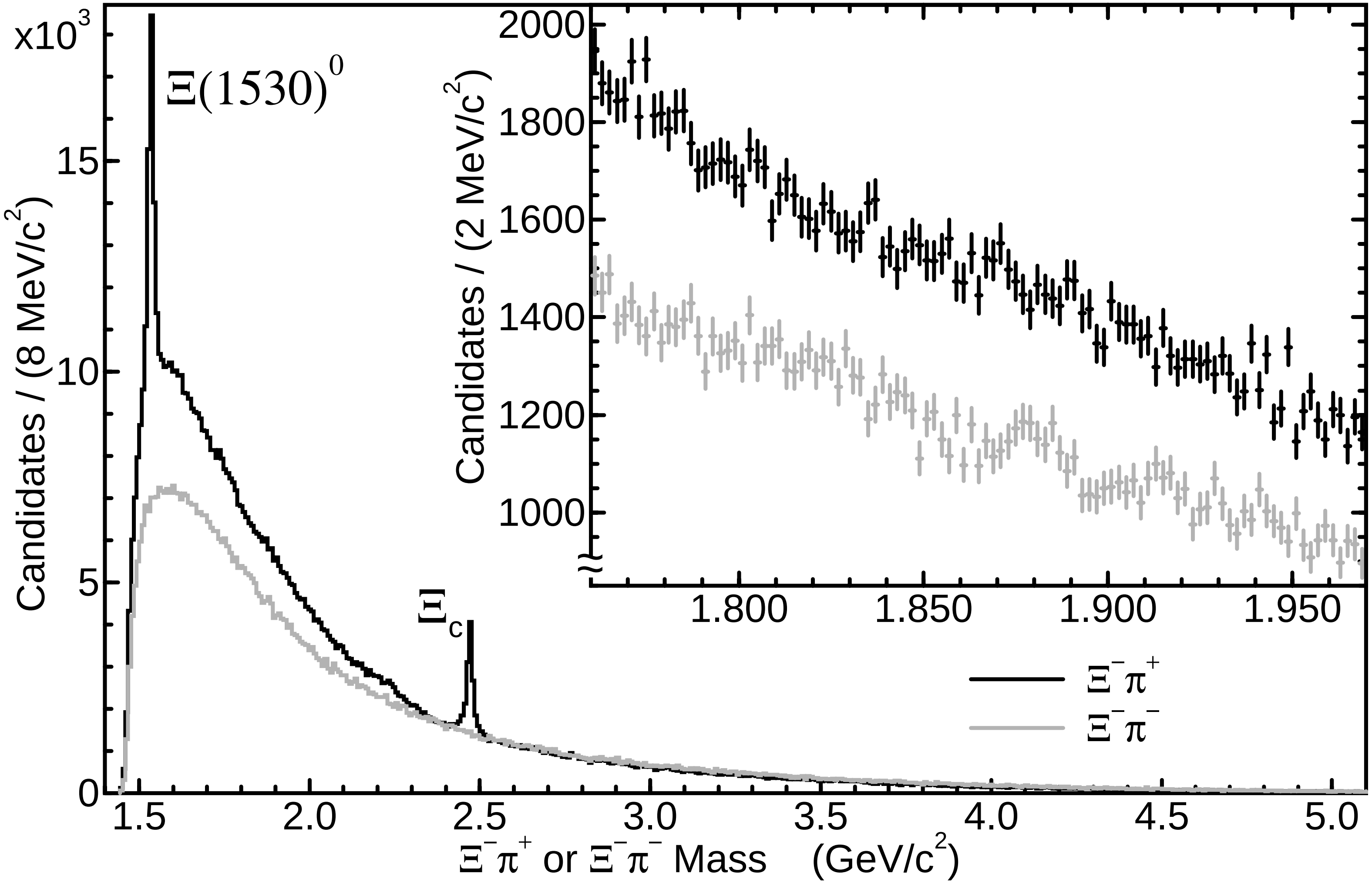
☐ BaBar. Comparison with other experiments:





Some distribution of negative evidences: $\Xi\pi$.

□ BaBar.



Future.

□ Data collection and analysis is continuing.

□ There is some prospect for a super B-factory somewhere.

□ Spectroscopy is foundamental for testing the quark model and QCD.

□ S. Godfrey: the existence of gluonium excitations in the hadron spectrum is one of the most important unanswered questions in hadron physics.

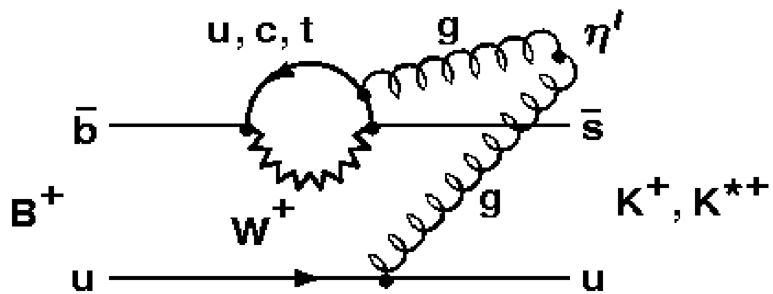
Search for gluonium in B decays.

□ 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 η', 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.

□ One should look for:

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

in searching for pseudoscalar states.

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

Charmonium hybrids.

□ Hybrid mesons ψ_g consists of $\bar{c}cg$.

□ The flux tube model predicts 8 states between 4 and 4.2 GeV.

□ Lattice QCD calculations predict the $J^{PC} = 1^{-+}$ state between 4.04 and 4.4 GeV. The proximity of D^*D thresholds could make it narrow.

□ Some hybrids can have exotic quantum numbers such as:

$$\psi_g(J^{PC} = 0^{+-}, 2^{+-}) \to J/\psi + (\pi^+\pi^-), \eta, \eta'$$

$$\psi_g(J^{PC} = 1^{-+}) \to \eta_c + (\pi^+\pi^-), \eta, \eta'$$

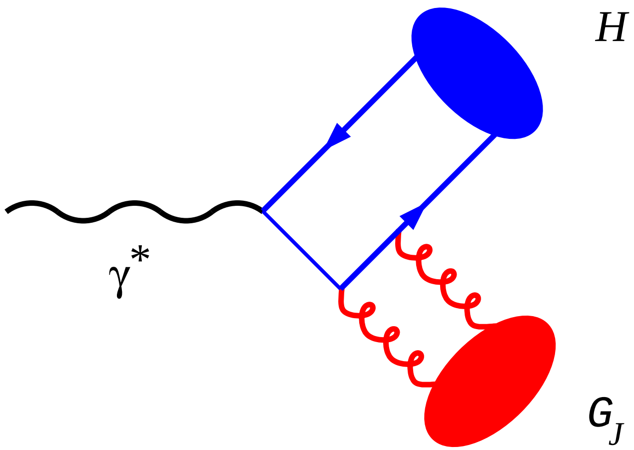
□ Some of these states could be produced in B decays.

□ Hybrid mesons with $J^{PC} = 1^{--}$ could be looked for in e^+e^- annihilations via ISR.

Gluonium in double charmonium sample?

This discovery has triggered some authors to suggest that this rate may be partly due to the presence of a gluonium state:

$$e^+e^- \to \bar{c}cgg$$



S. Brodsky et al., hep-ph/0305269