Observation of New Narrow D_s states.

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from the BaBar Collaboration

Outline.

- **Introduction.**
- **Events selection.**
- **Observation of** $D_{sJ}^{*+}(2317) \to D_s^+\pi^0$
- **Observation of** $D_{sJ}^{*+}(2458) \to D_s^{*+}\pi^0$
- **Comparison with other experiments.**
- **Theoretical work in progress.**
- **Conclusions and Outlook.**

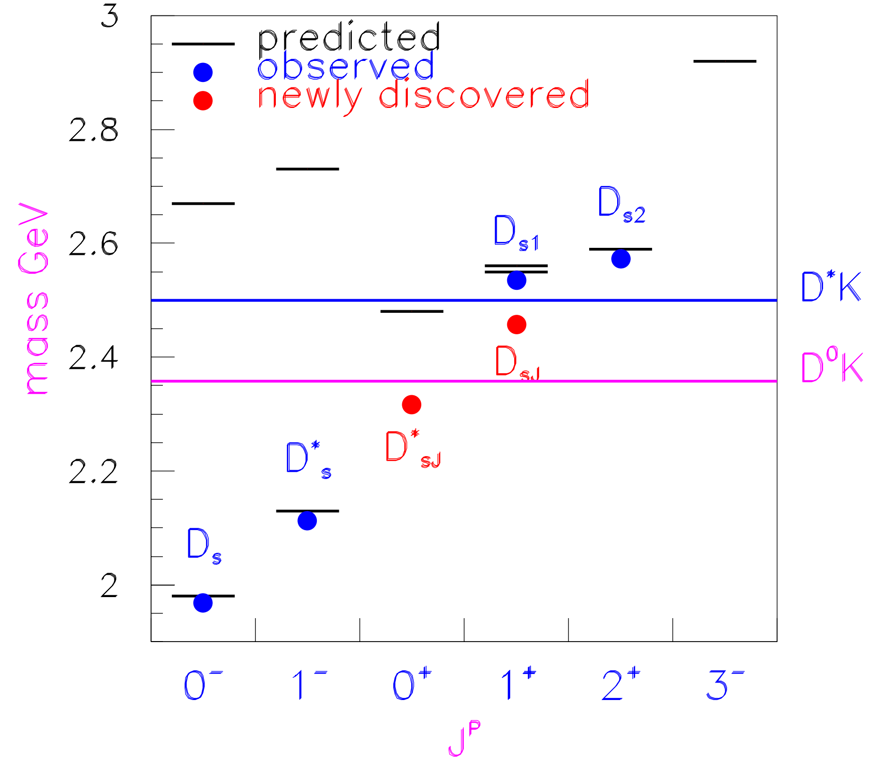
(Charge conjugation is implied through all this work.)

Introduction.

□ The expected spectrum of the $c\bar{s}$ D_s mesons still contains empty slots.

□ For example, the Godfrey-Isgur-Kokoski potential model predicts the $J^P = 0^+$ member at a mass of 2.48 GeV, with a width 270–990 MeV decaying mainly to D^0K. The large width would make it difficult to observe.

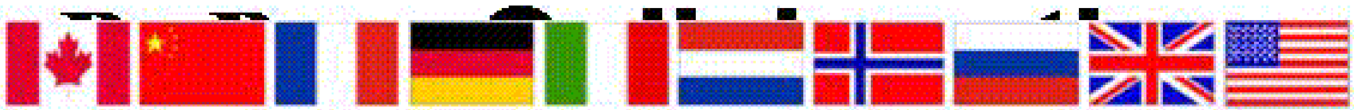
□ The model also predicts two 1^+ states at masses of 2.55 and 2.56 GeV.



□ Potential model expectations and experimental status for D_s mesons.

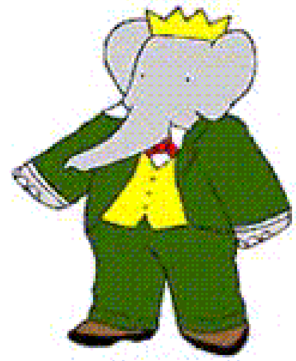
□ Remarkably good agreement up to now.

□ Exception: the newly discovered states at 2.317 and 2.458 GeV.



The BaBar Collaboration

10 countries
77 Institutions
~580 Physicists



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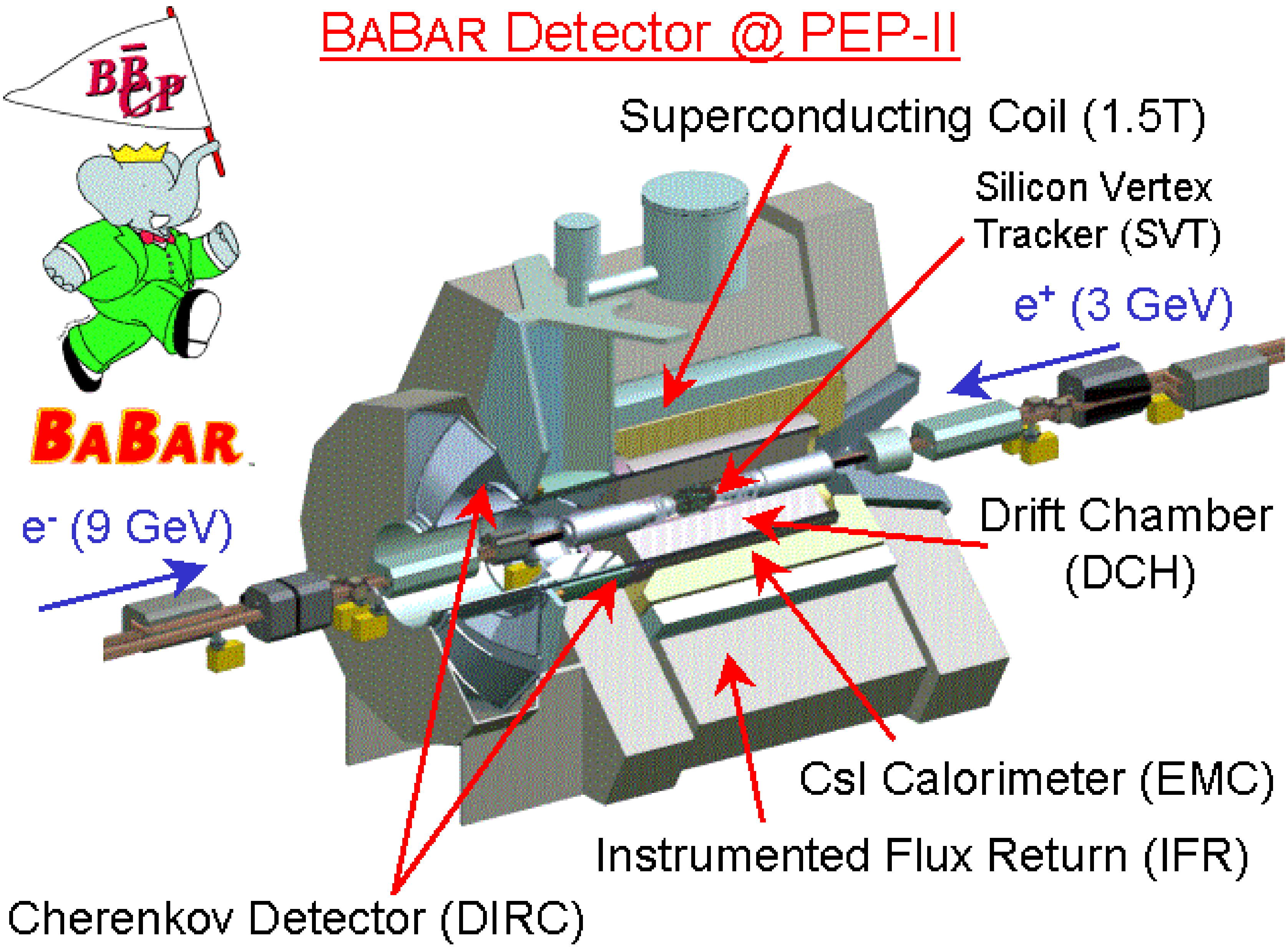


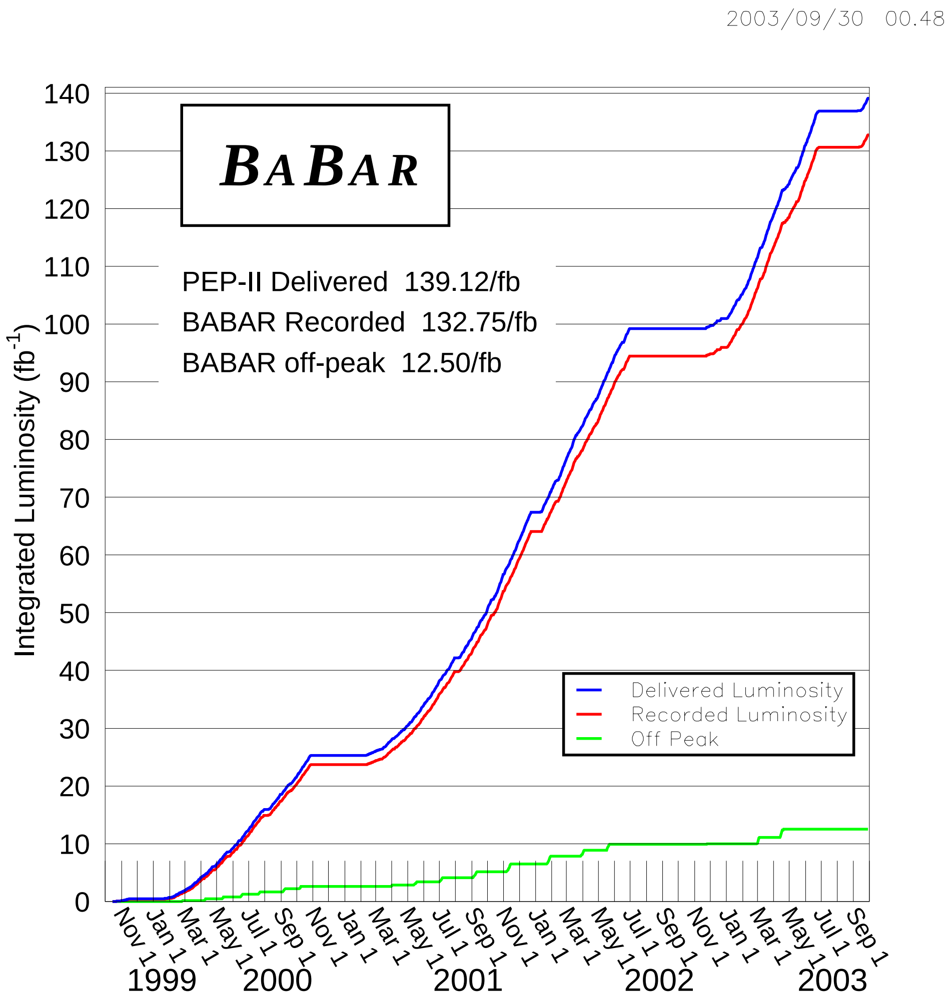
The BaBar Experiment.

☐ The power of BaBar for Charm Physics 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.

Data Set.

□ The data sample consists of 91.5 fb^{-1} (on and off peak) from the 1999-2002 data sample.

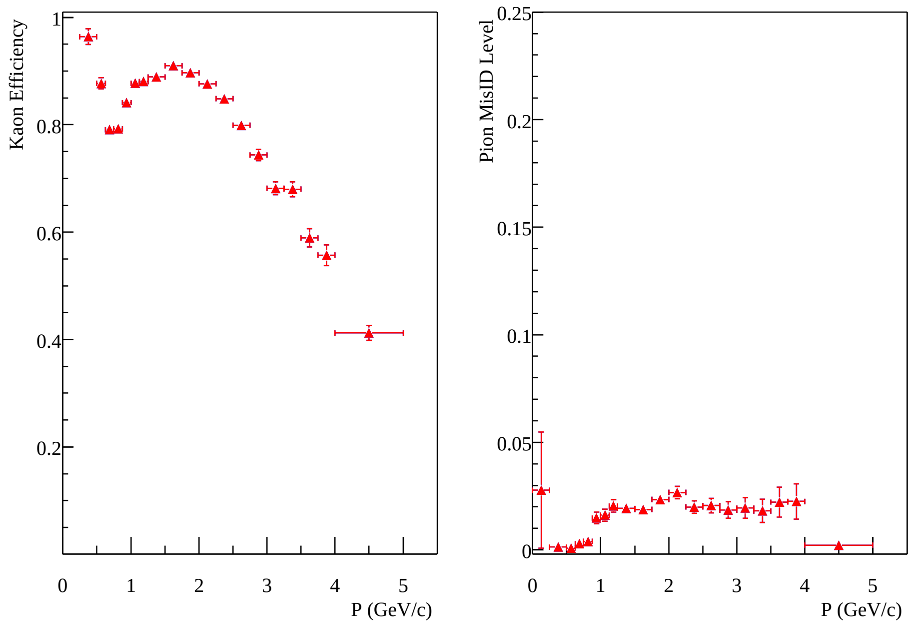


PID Performance.

□ Particle Identification obtained by combining dE/dx from the Drift Chamber and Silicon Vertex Detector with the DIRC information.

□ In the present analysis the PID algorithm used gives $\approx$ 90 % K identification efficiency with $\approx$ 2 % π mis-identification as K.

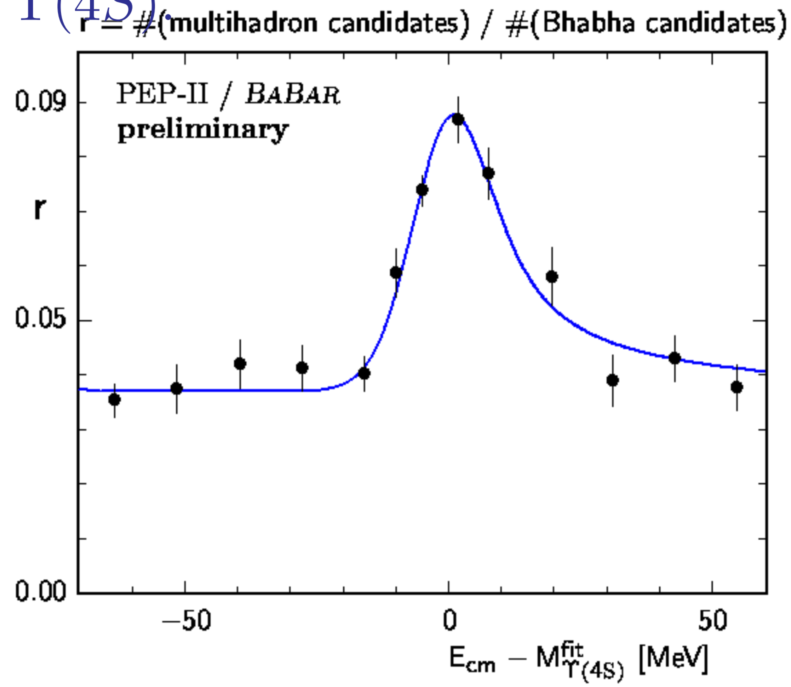
□ *Efficiency for K and π mis-identification as a function of lab. momentum.*



Charm Physics in BaBar.

- ☐ Cross Section Scan from BaBar in the region of the $\Upsilon(4S)$.
- ☐ The $\Upsilon(4S)$ Resonance sits on a large continuum background .
- ☐ Effective cross sections at the energy of the $\Upsilon(4S)$.

$e^+e^- \rightarrow$	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



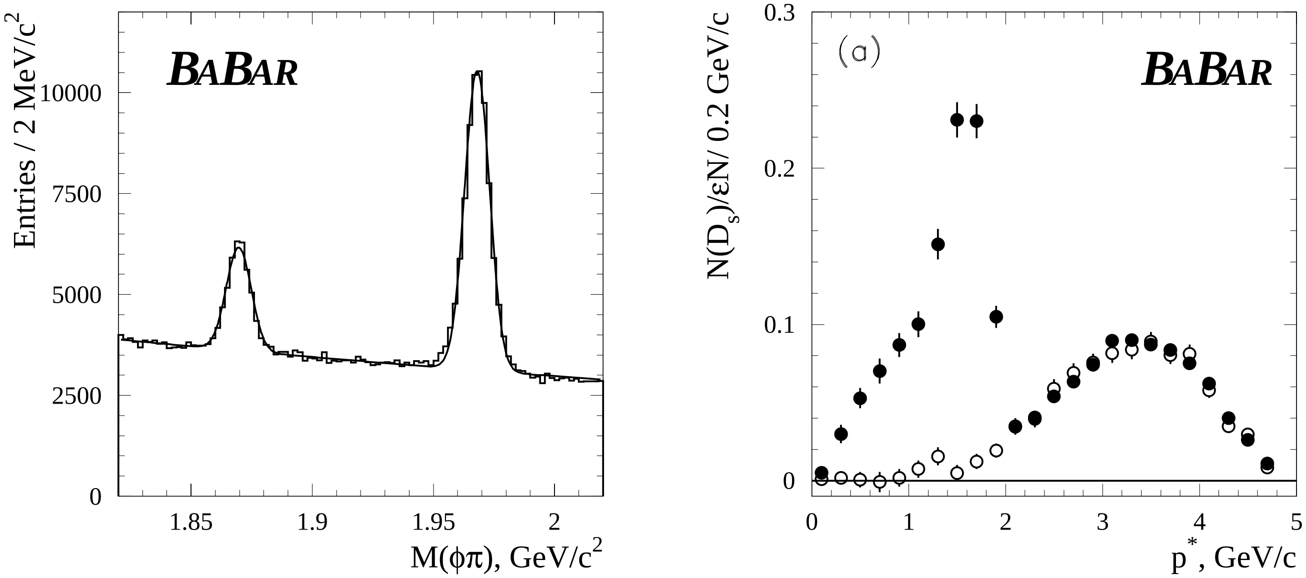
☐ Charm Analyses are performed on data corresponding to continuum $\bar{c}c$ production.

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

Study of D_s^+ in BaBar.

□ Example from BaBar: mass distribution and p^* momentum spectrum for $D_s^+ \to \phi\pi^+$.

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.

Data selection.

□ In this work we search for resonances decaying to:

$$D_s^+ \pi^0$$

□ D_s^+ mesons are selected through the $\phi\pi^+$ and $\overline{K^{*0}}K^+$ decay modes, therefore the final state to reconstruct is:

$$K^+K^-\pi^+\gamma\gamma \qquad (+c.c.)$$

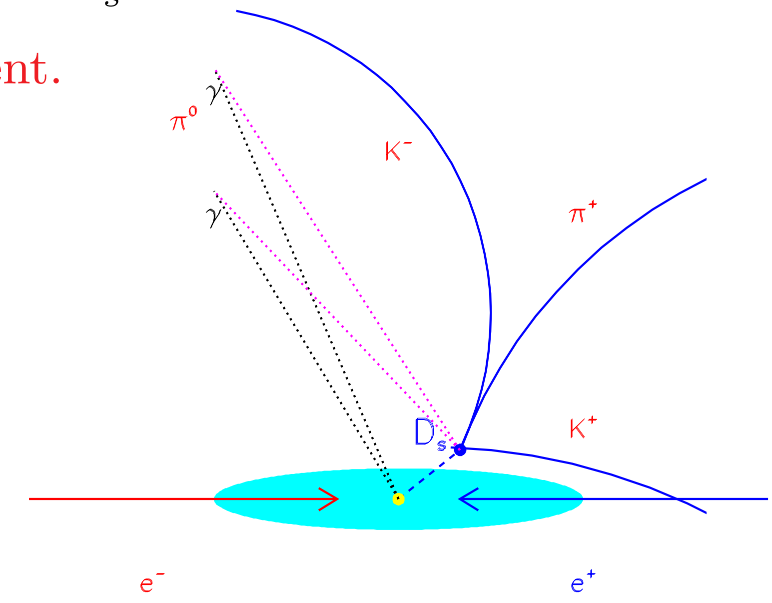
□ This final state has been selected using the following procedure:

- All combinations of three charged tracks with total charge $\pm$ 1, an identified K^+K^- pair, and a third track which is not a $K^\pm$, have been considered.
- Each D_s^+ candidate has been fitted to a common vertex requiring a fit probability > 0.1 %.
- The D_s^+ candidate was traced back to the interaction region in order to obtain the production vertex.

Data selection.

- All pairs of γ's, each γ having energy > 100 MeV, have been fitted to a π^0 with mass constraint and a probability cut > 1 % was applied.
- Each π^0 candidate has been fitted twice:
  - to the $K^+K^-\pi^+$ vertex, to investigate the decay mode $D_s^+ \to K^+K^-\pi^+\pi^0$;
  - to the production vertex, to investigate the $D_s^+\pi^0$ mass distribution.

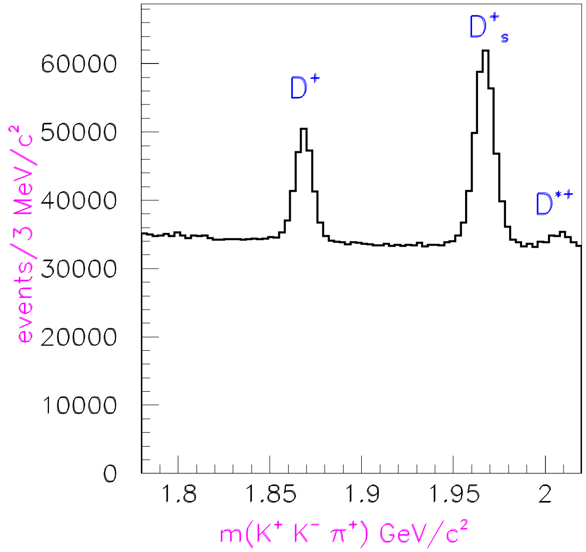
  □ Qualitative sketch, not to scale, of one event.

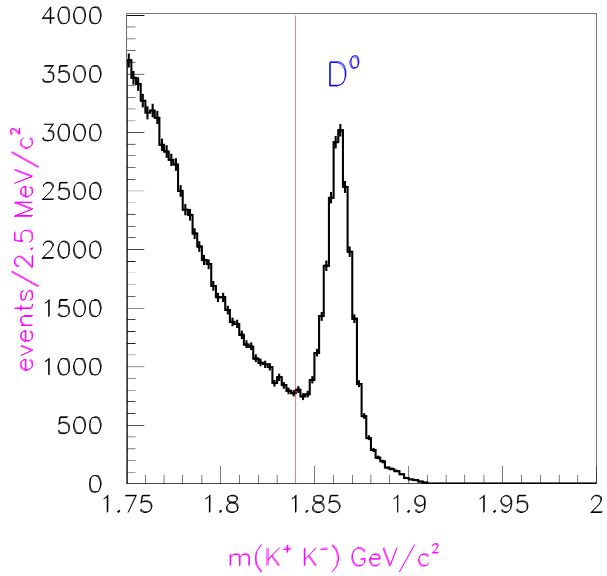


- Each $K^+K^-\pi^+\pi^0$ candidate must satisfy $p^* > 2.5$ GeV/c.

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

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





□ Presence also of a $D^{*+}(2010)$ signal:

$$D^{*+}(2010) \rightarrow \pi^+ D^0$$

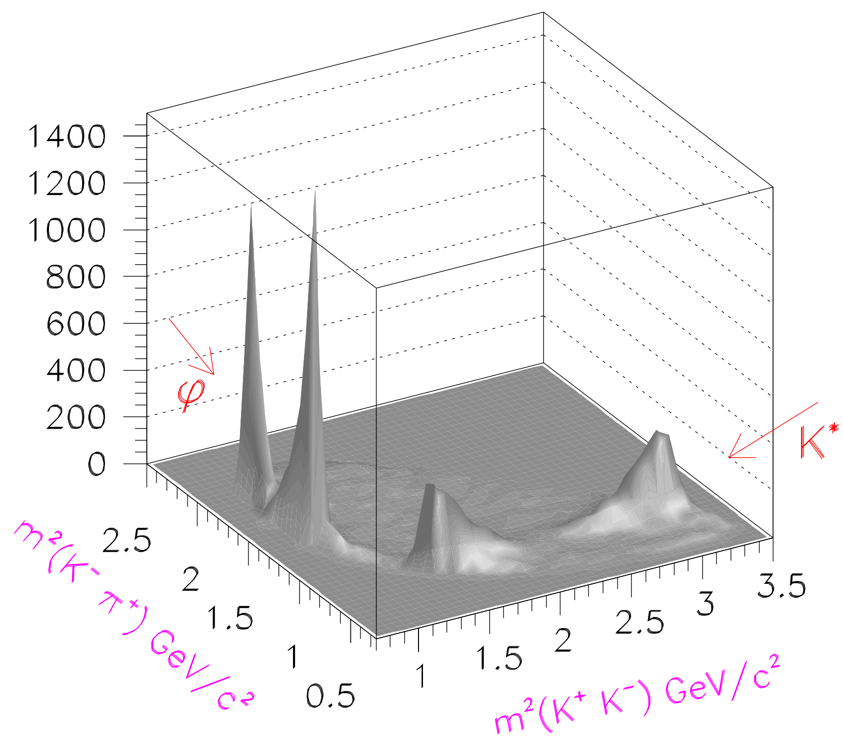
$$\rightarrow K^+K^-$$

removed requiring: $m(K^+K^-) < 1.84$ GeV.

□ $\approx 131 \times 10^3$ D_s^+ events above background.

The D_s^+ Dalitz plot.

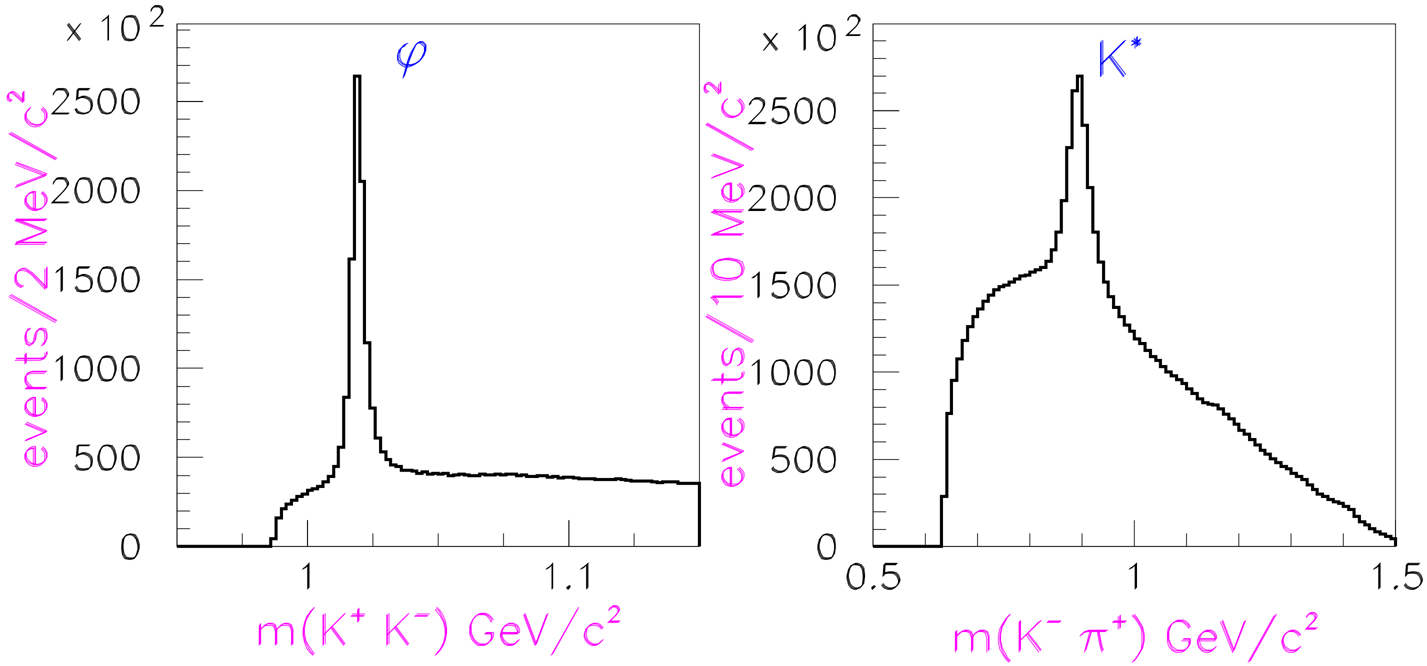
- D_s^+ signal enhanced by selecting the $\phi\pi^+$ and $\overline{K^{*0}}K^+$ decay modes.
- These two modes do not overlap, as shown by the D_s^+ Dalitz plot:



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

Selection of $\phi\pi^+$ and $\overline{K^{*0}}K^+$

□ Inclusive K^+K^- and $K^-\pi^+$ mass spectra:

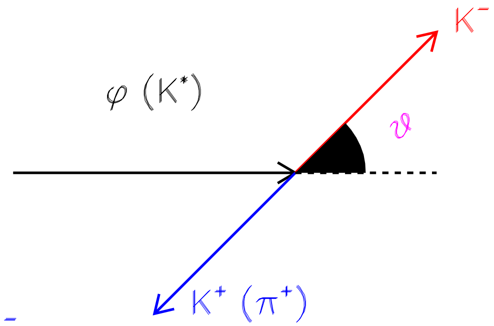


□ ϕ selected requiring: $\mid m(K^+K^-) - 1.019 \mid \leq 0.01 \quad GeV$

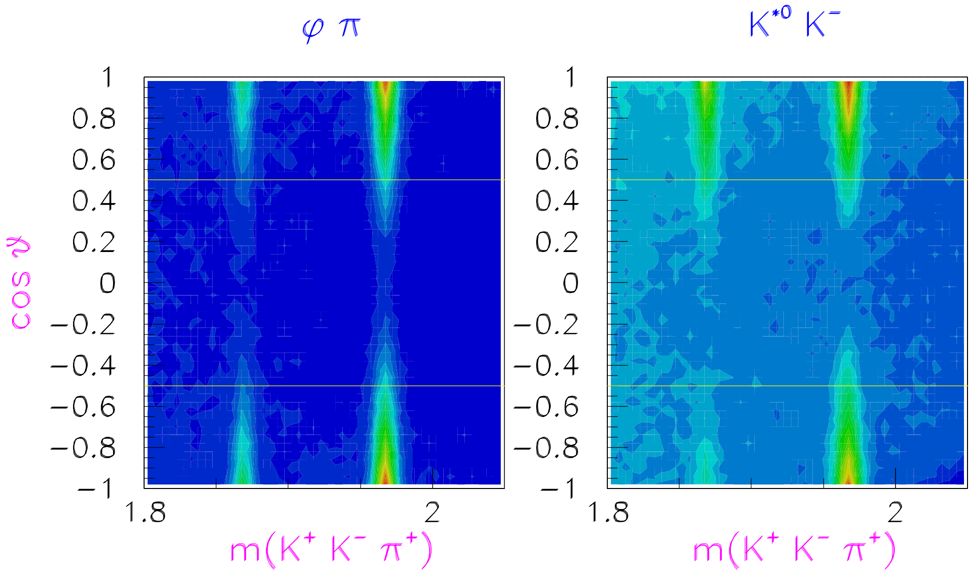
□ $\overline{K^{*0}}$ selected requiring: $\mid m(K^-\pi^+) - 0.896 \mid \leq 0.05 \quad GeV$

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.



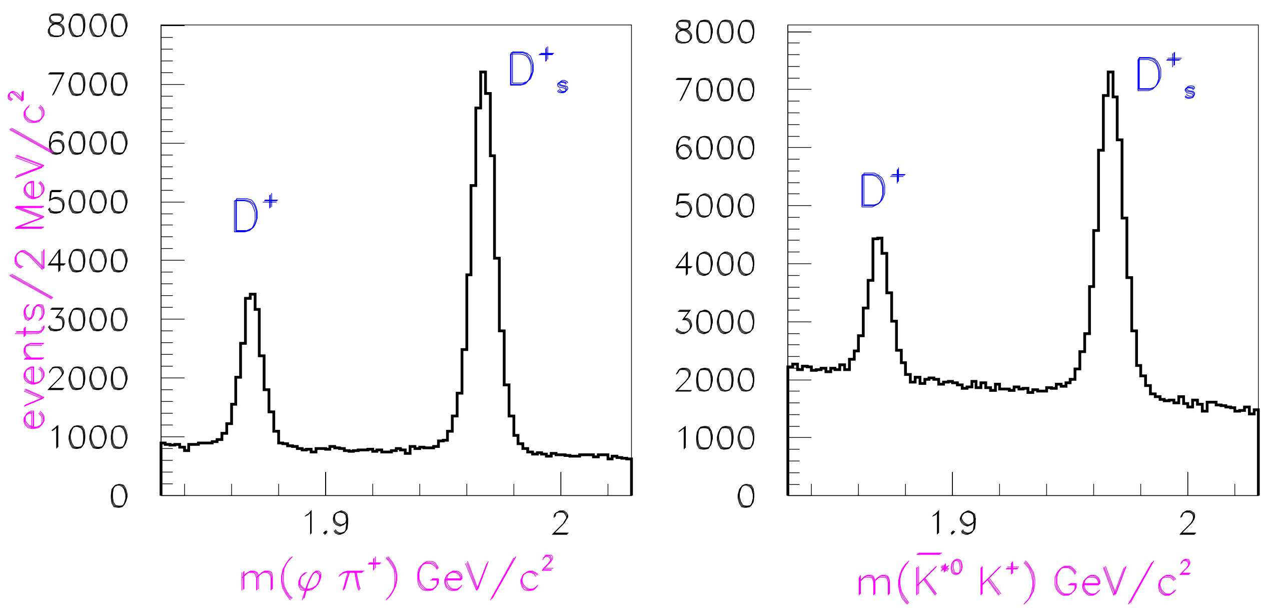
□ Scatter diagram of $cos\theta$ vs. $m(K^+K^-\pi^+)$:



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

Resulting mass spectra.

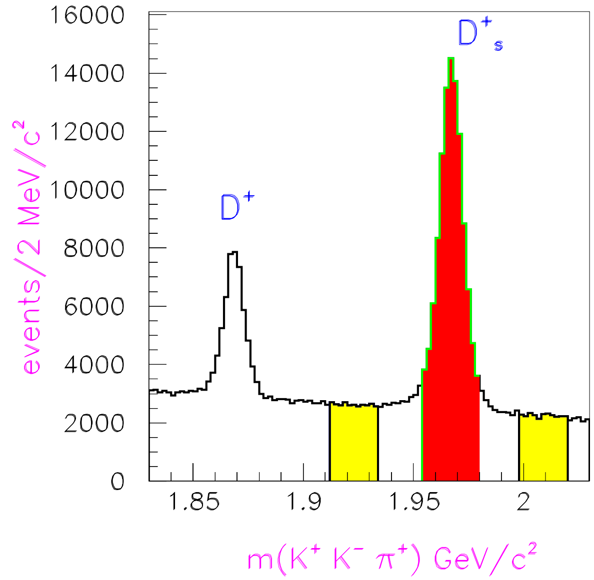
- Resulting $\phi\pi^+$ and $\overline{K^{*0}}K^+$ mass spectra:



- The two samples have 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:

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

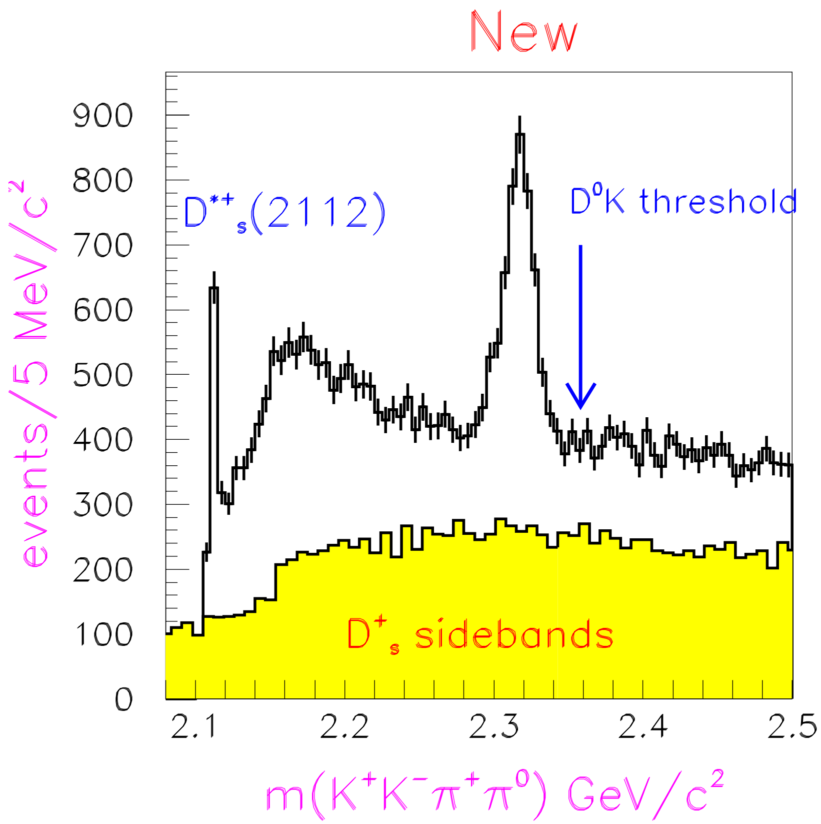
and two sideband regions as:

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

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

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

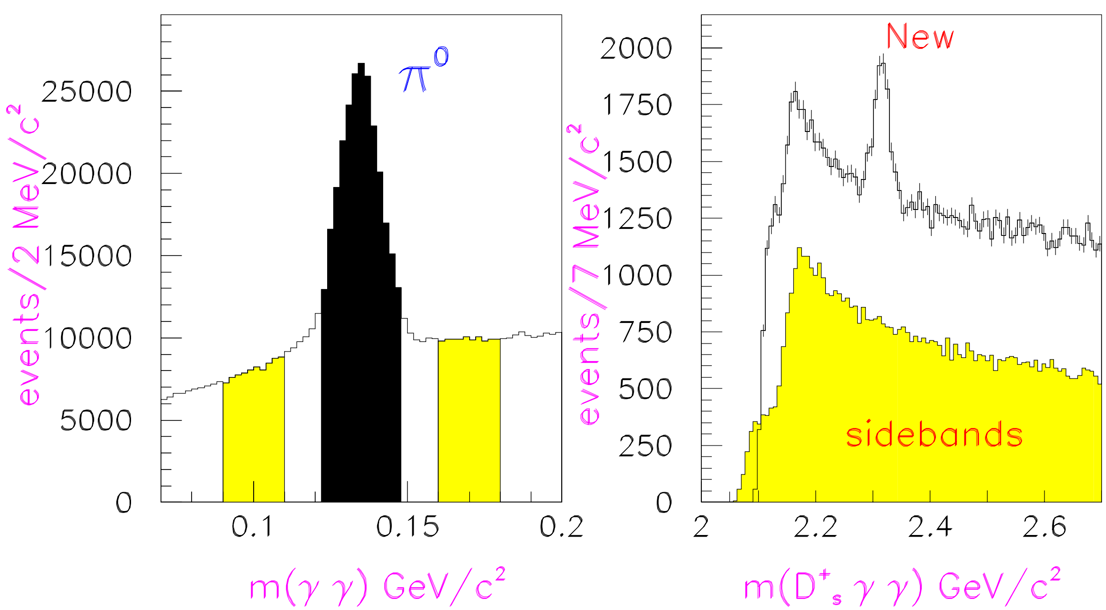
- □ Compare $(K^+K^-\pi^+)\pi^0$ mass spectra for the D_s^+ signal region and sidebands.
- □ We observe the known decay: $D_s^{*+}(2112) \to D_s^+\pi^0$.
- □ **Totally unexpected large signal ($\approx$ 2200 events) at 2.32 GeV.**



- □ No signals for the D_s^+ sidebands.

$D_s^+\gamma\gamma$ mass for π^0 signal and sidebands.

- Plot of the $\gamma\gamma$ effective mass defining π^0 signal and sideband regions.
- $D_s^+\gamma\gamma$ mass spectrum for the π^0 signal region.
- We make no use of the fitted π^0, use the 4-momentum of the γ pair.
- Same large signal at 2.32.
- $D^{*+}(2112)$ signal washed out because of "π^0" resolution.



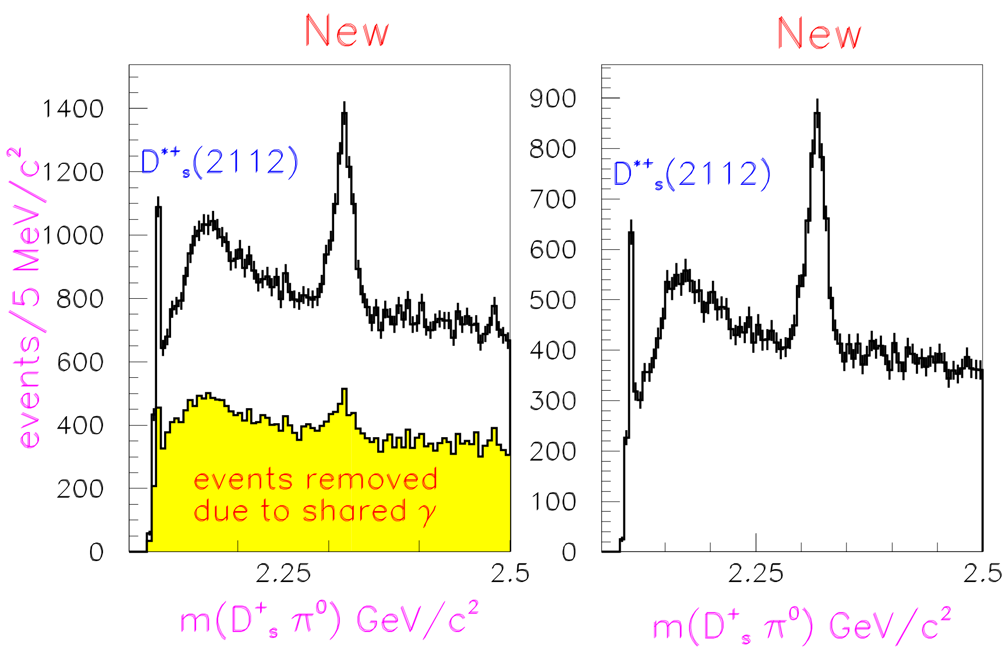
- π^0 sidebands: no signals.

$D_s^+ \pi^0$ 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 common 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:

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

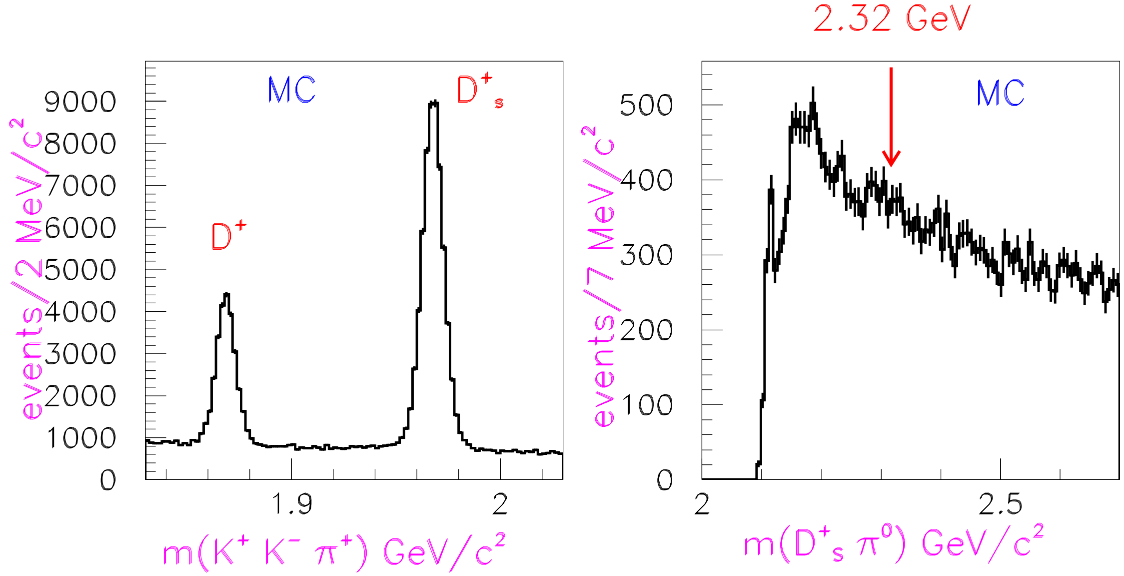
have been simulated using GEANT4. They have been reconstructed and analyzed using the same analysis procedure as that used for data.

□ The generated events contain all that is 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.



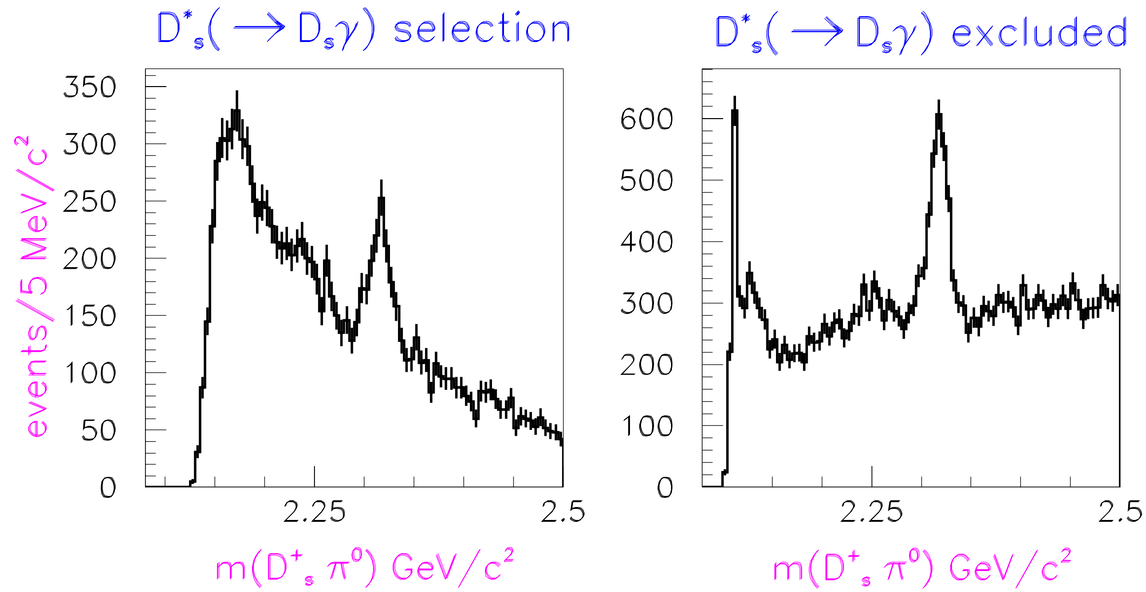
□ We observe the known decay: $D_s^{*+}(2112) \rightarrow D_s^+\pi^0$.

□ 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.

Is the 2.32 GeV structure due to $D_s^{*+}(2112)$ reflection?

□ We use the γ's from the π^0 candidate to compute the mass $D_s^+\gamma_{1,2}$.

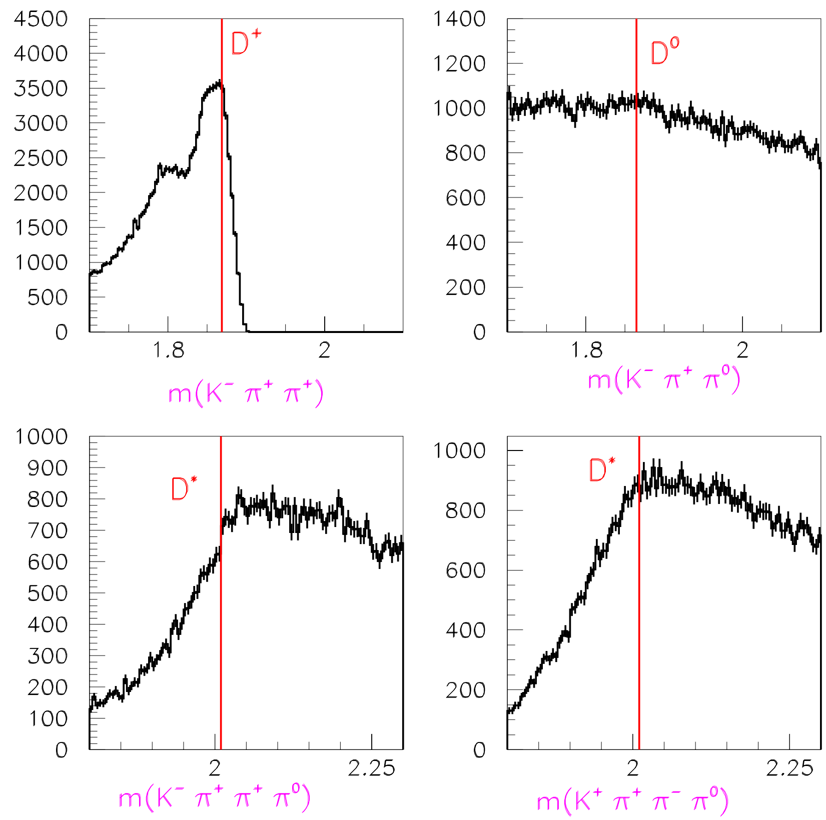


□ Anti-selecting $D_s^{*+}(2112)(\rightarrow D_s^+\gamma)$, the 2.32 GeV signal survives: it is not due to $D_s^{*+}(2112)$ reflection.

□ The wide structure at ≈ 2.17 GeV is due to $D_s^{*+}(2112) \rightarrow D_s^+\gamma$ when a second γ yields a γ pair in the π^0 signal region.

Tests for π mis-identification and D^* reflections.

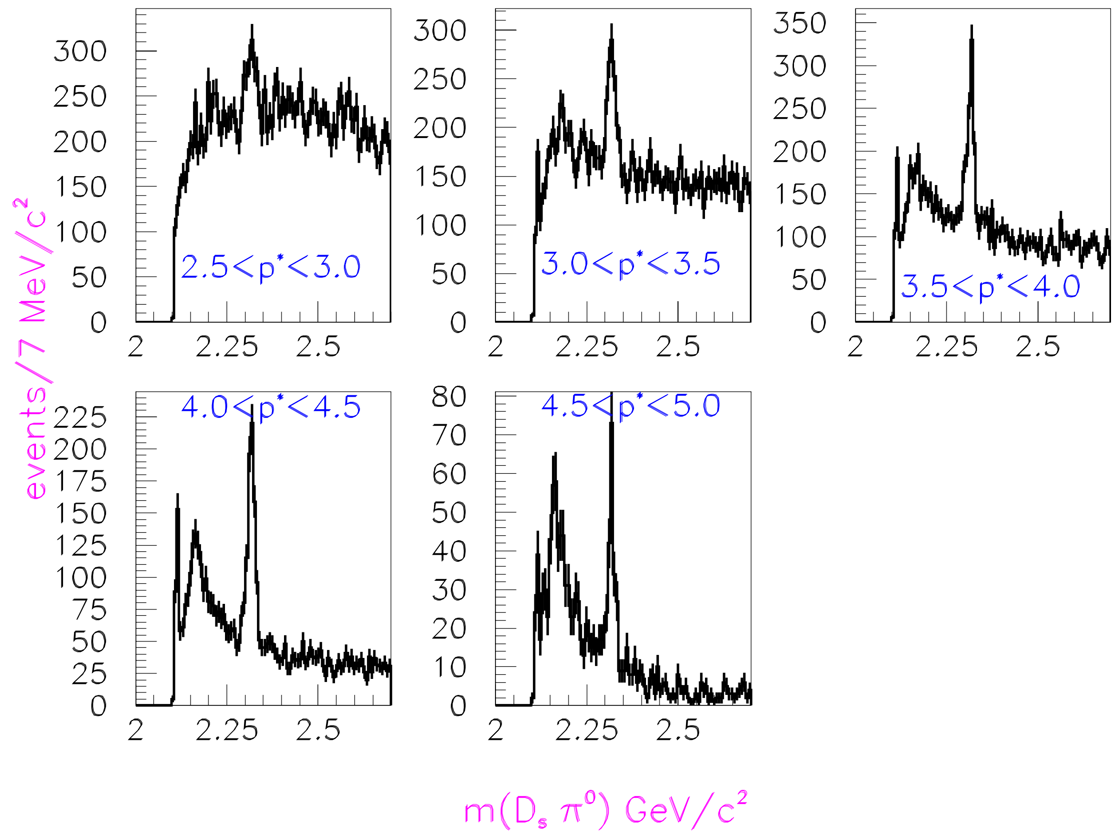
- Events in the D_s^+ signal region are selected.
- Charged π mass given to one of the kaons.
- The resulting 3- and 4-particle mass distributions are as shown.



- No D^+, D^0 or D^{*+} signals are observed.

The $p^*(D_s^+\pi^0)$ dependence of the 2.32 GeV signal.

□ $D_s^+\pi^0$ mass spectrum in slices of p^*.

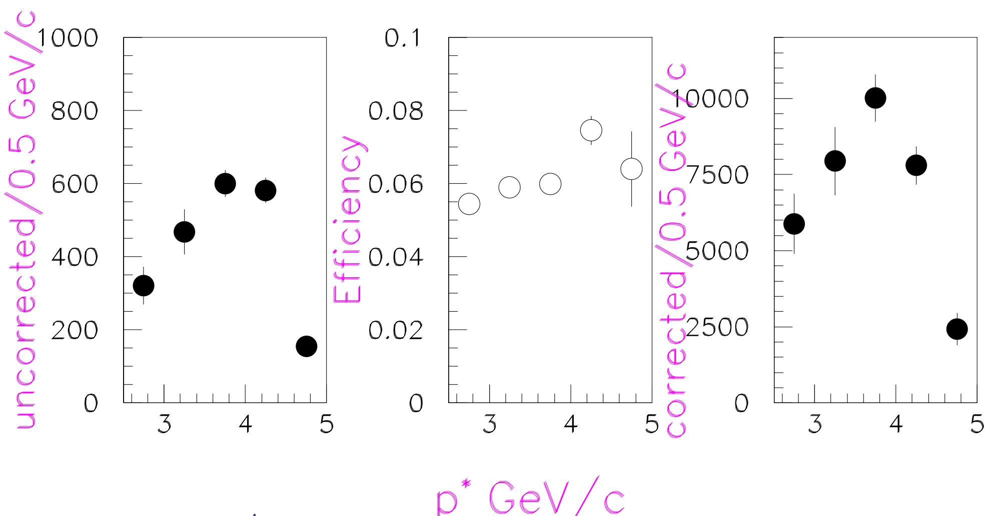


□ The 2.32 GeV signal is present in all the p^* regions. Signal to background increases with increasing p^*.

□ The signal to background ratio can be improved by means of a p^* selection.

The p^* dependence of the 2.32 GeV signal.

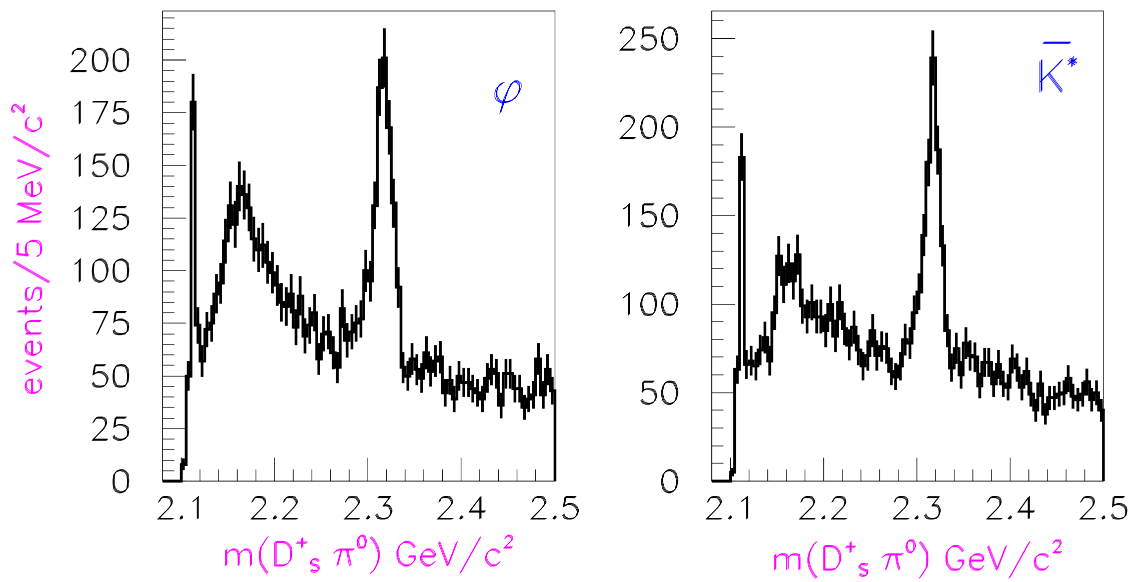
- The 2.32 GeV signal yield has been obtained as a function of p^* by fitting a Gaussian signal+polynomial background to the $D_s^+\pi^0$ mass distributions for each p^* interval.
- The efficiency as a function of p^* has been obtained using Monte Carlo simulation.
- Uncorrected and corrected p^* distributions.



- Maximum at ≈ 3.9 GeV/c.

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

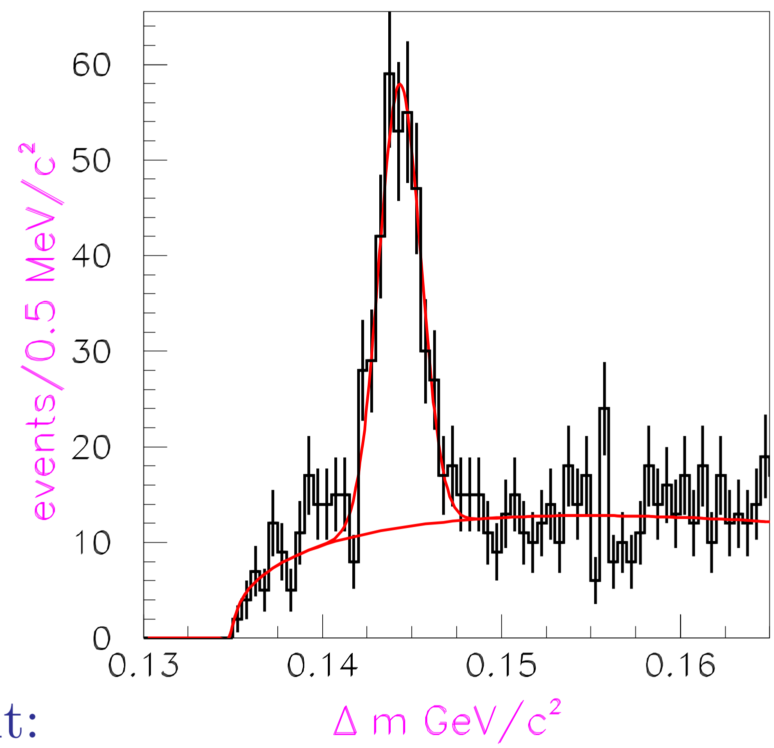
- $D_s^+\pi^0$ mass spectra separated for ϕ and $\overline{K^{*0}}$ subsamples.
- Required $p^* > 3.5$ GeV/c.



- $D_s^{*+}(2112)$ and 2.32 GeV signals present in both distributions with similar strengths.

Fit to the $D_s^{*+}(2112) \to D_s^+ \pi^0$ signal.

□ Plot of: $\Delta m = m(K^+K^-\pi^+\pi^0) - m(K^+K^-\pi^+)$ in the threshold region.



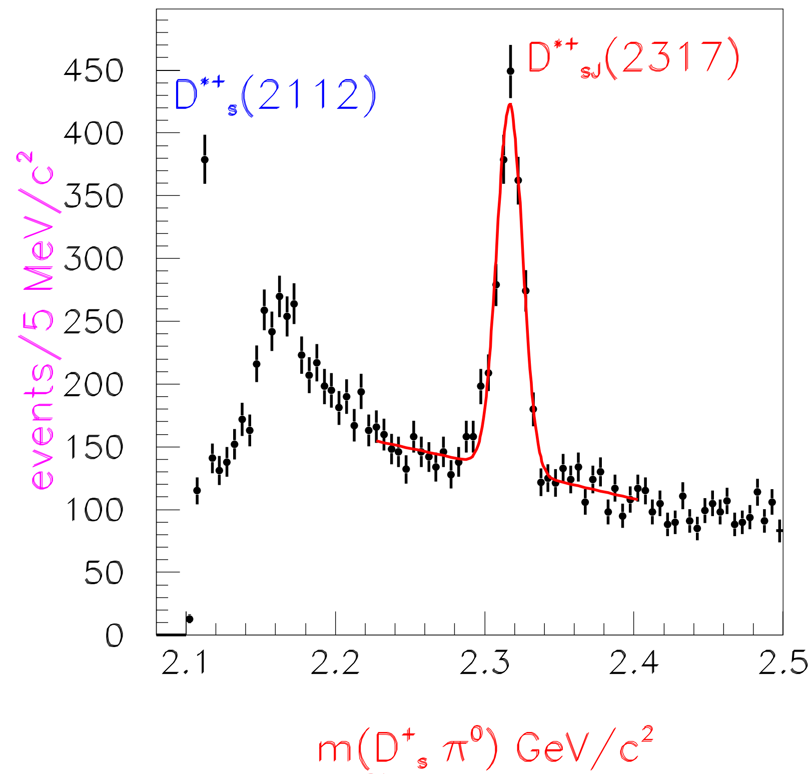
□ Results from the fit:

$$\Delta m = 144.3 \pm 0.1 \quad MeV \qquad \sigma = 1.16 \pm 0.01 \quad MeV$$

□ To be compared with PDG: $\Delta m = 143.8 \pm 0.4$ MeV.

Fit to the $D_s^+\pi^0$ mass spectrum in the 2.32 GeV region.

- Require $p^* > 3.5$ GeV/c.



- Fit with a polynomial and a single Gaussian.

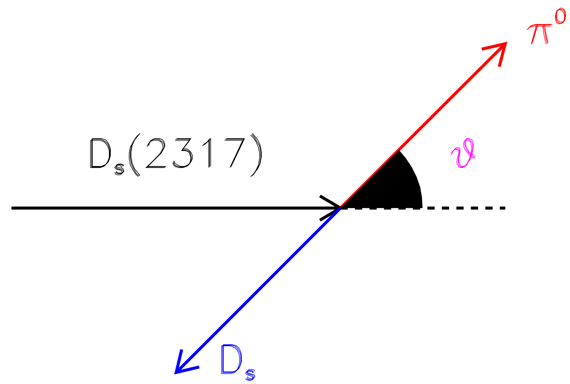
$$m = 2316.8 \pm 0.4 \quad MeV \qquad \sigma = 8.6 \pm 0.4 \qquad MeV$$

- *Statistical errors only.* We refer to this state as $D_{sJ}^{*+}(2317)$ from here on.

$D_{sJ}^{*+}(2317)$ **Decay Angular distribution.**

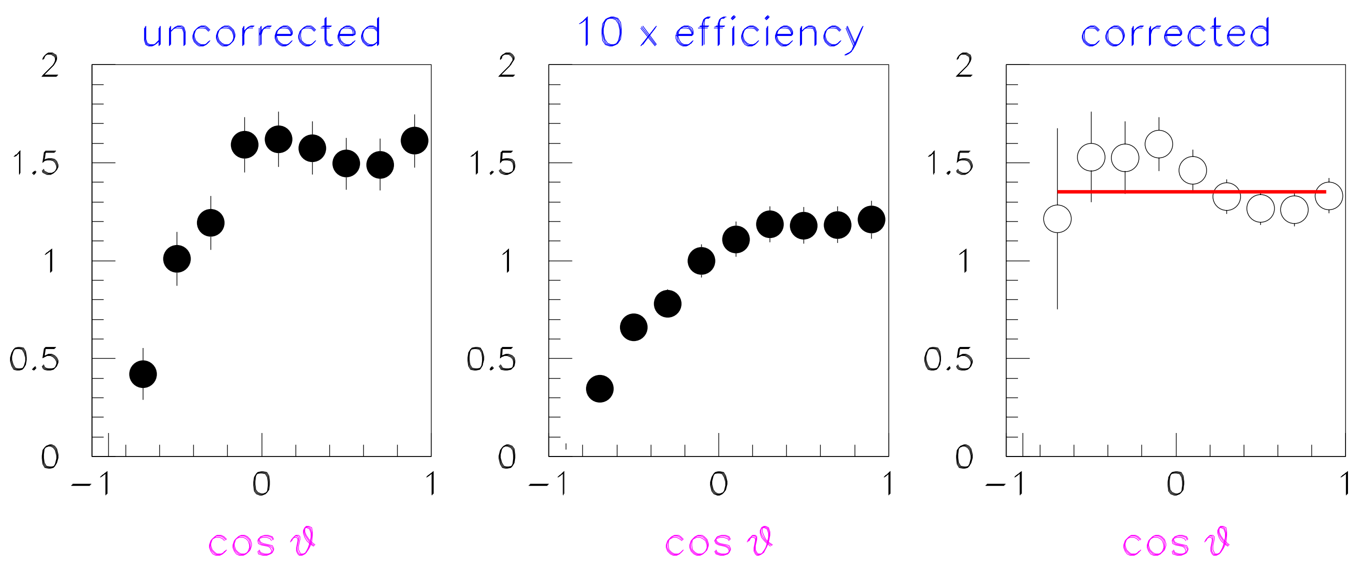
□ In the case of polarized production, the decay angular distribution can give information on the spin of the particle.

□ We have computed the distribution of the π^0 angle with respect to the $D_s^+\pi^0$ direction (in the overall c.m.) in the $D_s^+\pi^0$ rest frame.



$D_{sJ}^{*+}(2317)$ Decay Angular distribution.

□ The $D_s^+\pi^0$ mass spectrum has been fitted in 10 slices of $\cos\,\theta$. We plot the yield, the efficiency and the corrected angular distribution (in arbitrary units).



□ The corrected distribution in $cos\theta$ is consistent with being flat (43 % probability).

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

□ This D_s^+ decay channel has the same topology as $D_s^+\pi^0$ with $D_s^+ \to K^+K^-\pi^+$. 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:

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

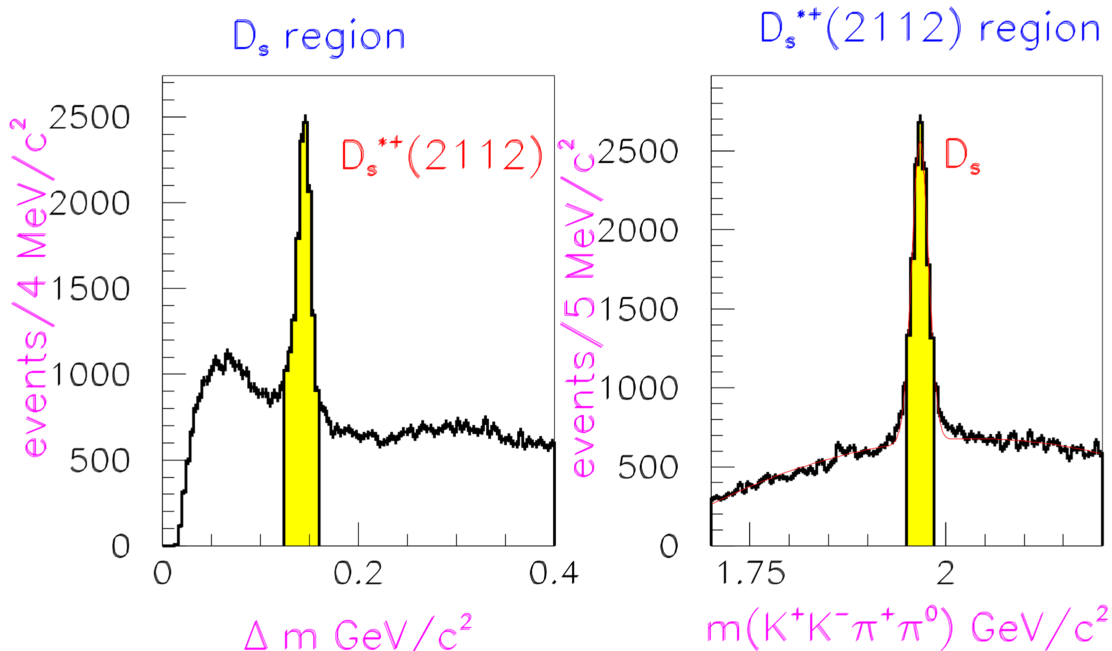
for the D_s^+ region, defined as:

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

□ 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:

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

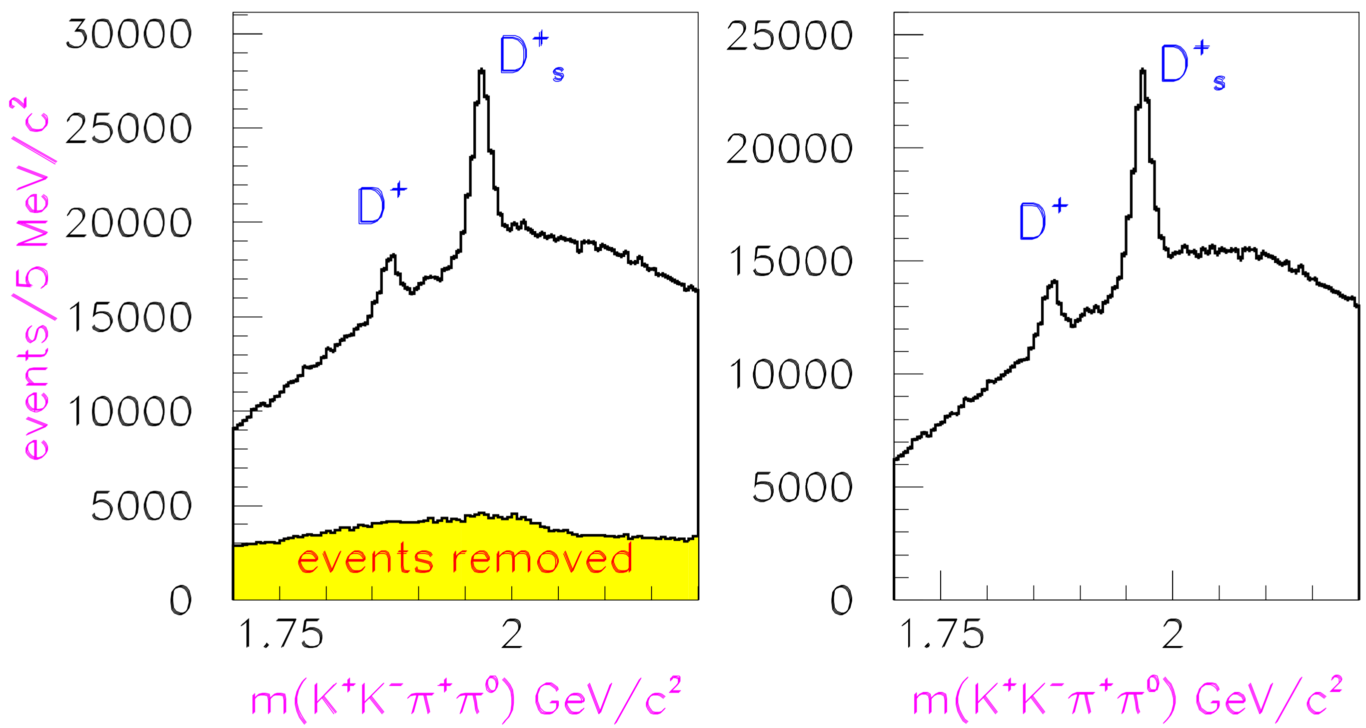
□ To be compared with the fitted D_s^+ parameters from the 3-body decay:

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

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

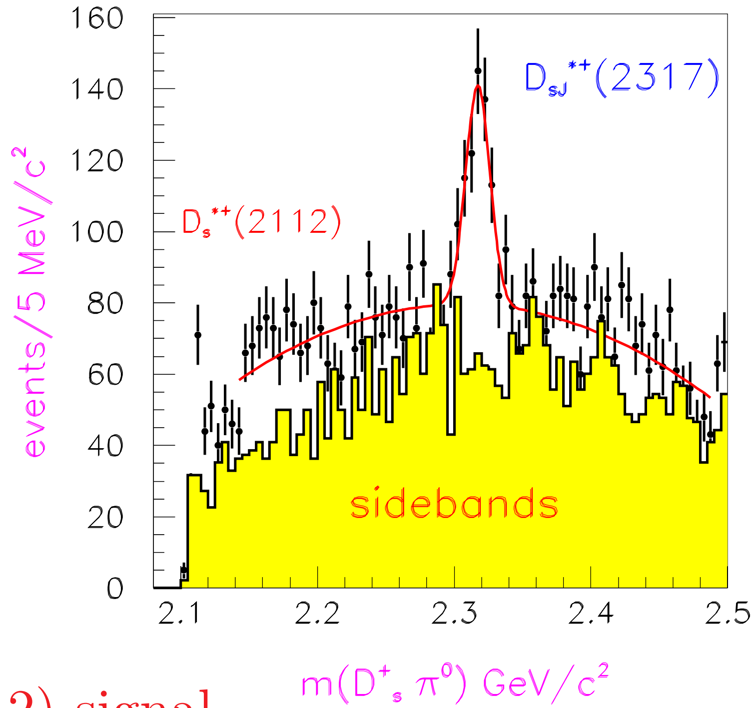
Selection of $D_s^+ \to K^+K^-\pi^+\pi^0$.

- □ 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.



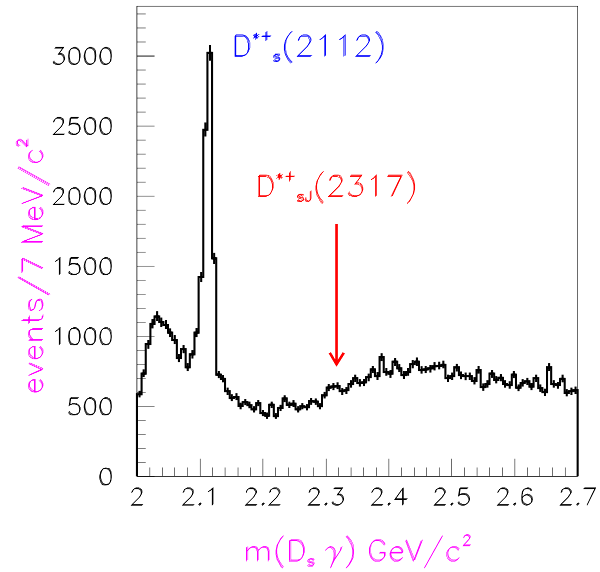
- There is a $D^{*+}(2112)$ signal.
- No signals for the D_s^+ sideband regions.
- There is a clear $D_J^{*+}(2317)$ signal with the following parameters:

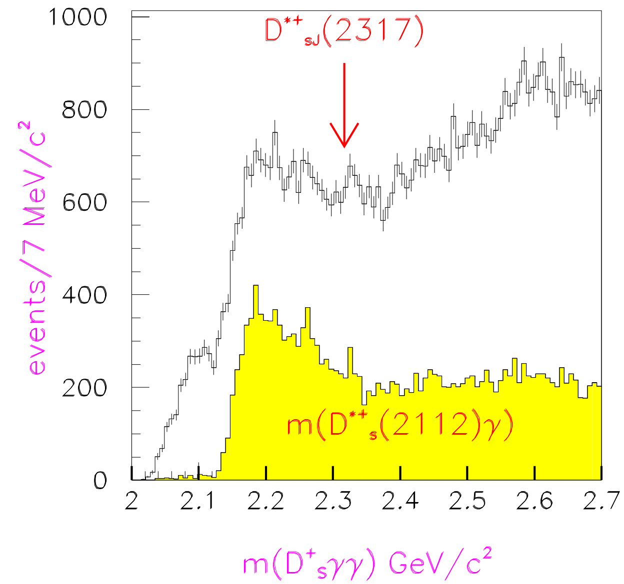
$$m = 2317.6 \pm 1.3 \quad MeV \qquad \sigma = 8.8 \pm 1.1 \quad MeV$$

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

Search for other $D_{sJ}^{*+}(2317)$ decay modes.

- ☐ Require that the γ is not part of any π^0 candidate.
- ☐ Require $p^*_{D_s\gamma} > 3.5$ GeV/c.

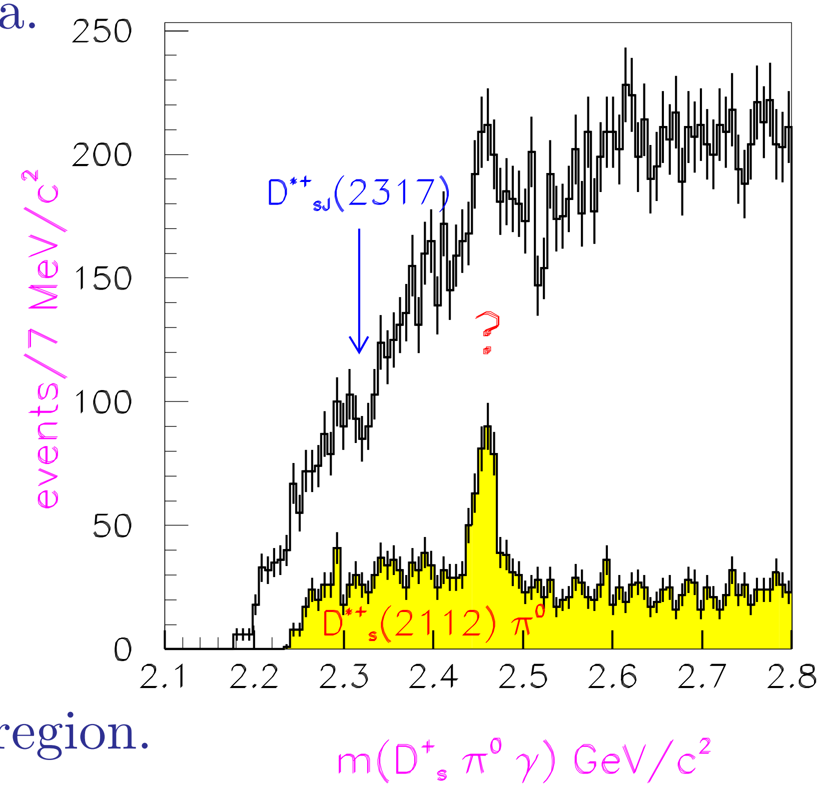




- ☐ At the present level of statistics.
  - No significant $D_{sJ}^{*+}(2317)$ signal in the $D_s^+\gamma$ mass spectrum.
  - No significant $D_{sJ}^{*+}(2317) \to D_s^+\gamma\gamma$ decay.
  - No significant $D_{sJ}^{*+}(2317) \to D_s^{*+}(2112)\gamma$ decay.

Search for $D_{sJ}^{*+}(2317)$ decay to $D_s^+\pi^0\gamma$.

- Require $p^*_{D_s\pi^0\gamma} > 3.5$ GeV/c.
- Require the π^0 lab. momentum > 300 MeV/c.
- Neither γ from a π^0 can be part of any other π^0.
- The bachelor γ cannot belong to any π^0 candidate.
- $D_s^+\pi^0\gamma$ and $D_s^{*+}(2112)\pi^0$ mass spectra.



- No significant signal in the 2.32 GeV region.
- Possible structure at ≈ 2.46 GeV.

Could the $D_{sJ}^{*+}(2317)$ signal be due to the decay of a narrow state at 2.46 GeV in $D_s^+\pi^0\gamma$?

□ If we assume the existence of a narrow state, the $X^+(2460)$ which decays to $D_s^{*+}(2112)\pi^0$, the kinematic cross-over would result in a narrow signal in $m(D_s^+\pi^0)$ near 2.32 GeV.

□ Two ways to test this hypothesis:

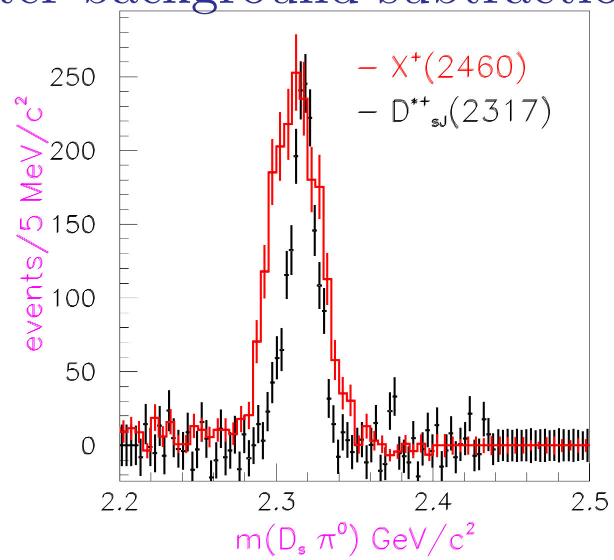
- The $D_{sJ}^{*+}(2317)$ lineshape.
- Comparison of the $D_{sJ}^{*+}(2317)/X^+(2460)$ relative rates for data and $X^+(2460)$ Monte Carlo simulation.

The $D_{sJ}^{*+}(2317)$ lineshape.

□ Use of Monte Carlo simulation of:

$$e^+e^- \to X^+(2460) \qquad\qquad + X_{recoil}$$
$$\to D_s^{*+}(2112)\pi^0$$

□ Comparison between the $X^+(2460)$ reflection from Monte Carlo and the $D_{sJ}^{*+}(2317)$ data signal after background subtraction.



□ Conclusion: the $D_{sJ}^{*+}(2317)$ lineshape does not agree with that expected from $X^+(2460)$ reflection.

$D_{sJ}^{*+}(2317)/X^+(2460)$ **ratio.**

□ The second test is to compute the ratio $D_{sJ}^{*+}(2317)/X^+(2460)$ for data and Monte Carlo for $X^+(2460) \to D_s^{*+}(2112)\pi^0$ with no D_{sJ}^{*+} generated.

□ For $p^* > 3.0$ GeV/c:

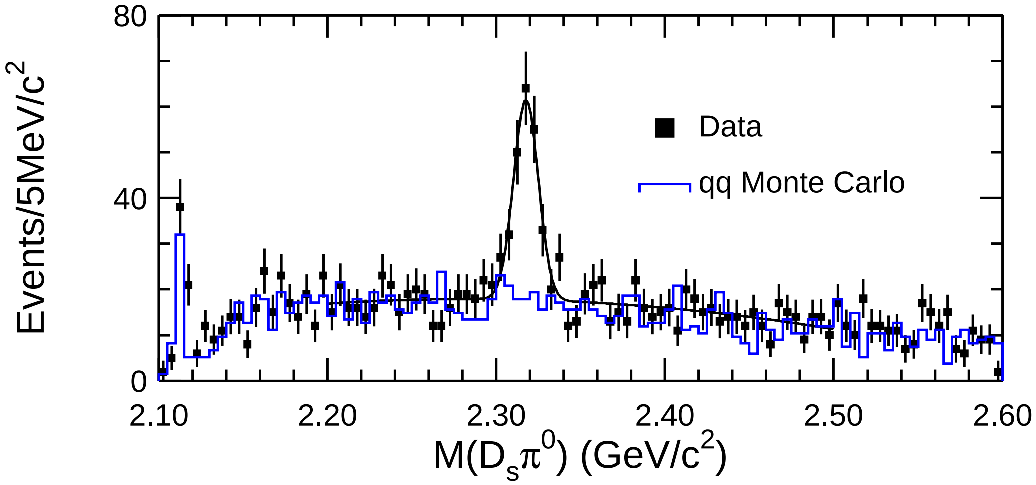
$$\frac{N(D_{sJ}^{*+}(2317))/N(X^+(2460))(Data)}{N(D_{sJ}^{*+}(2317))/N(X^+(2460))(MC)} = 5.4 \pm 0.3$$

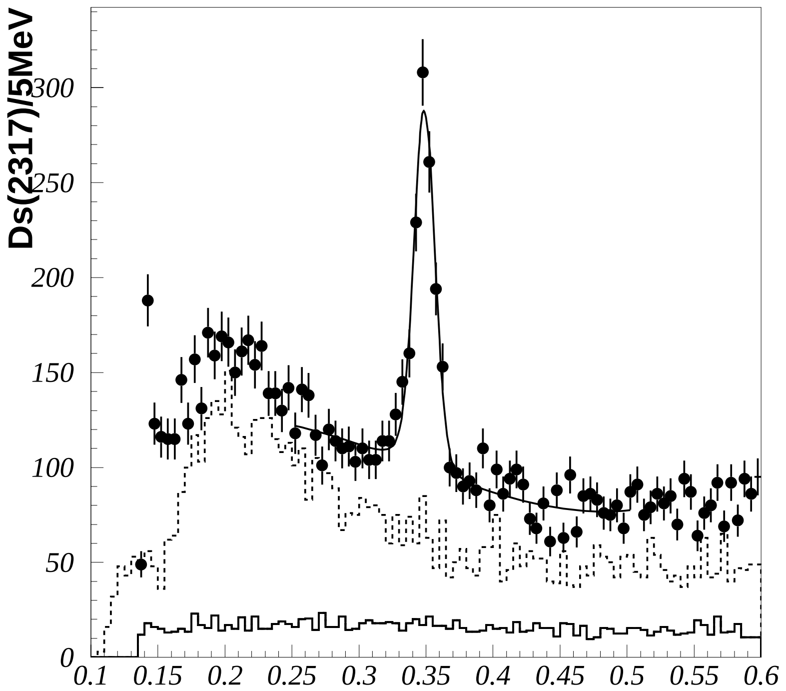
□ In the data we find ≈ 5 times more $D_{sJ}^{*+}(2317)$ events than expected from a Monte Carlo simulation with only $X^+(2460)$ production.

□ Conclusion: the relative rates disagree with the hypothesis that the $D_{sJ}^{*+}(2317)$ signal is due entirely to production of a state at ≈ 2.46 GeV which decays to $D_s^{*+}(2112)\pi^0$.

Confirmation of $D_{sJ}^{+}(2317)$ by other experiments.

CLEO 13.5 fb^{-1} | **BELLE 78 fb^{-1}**



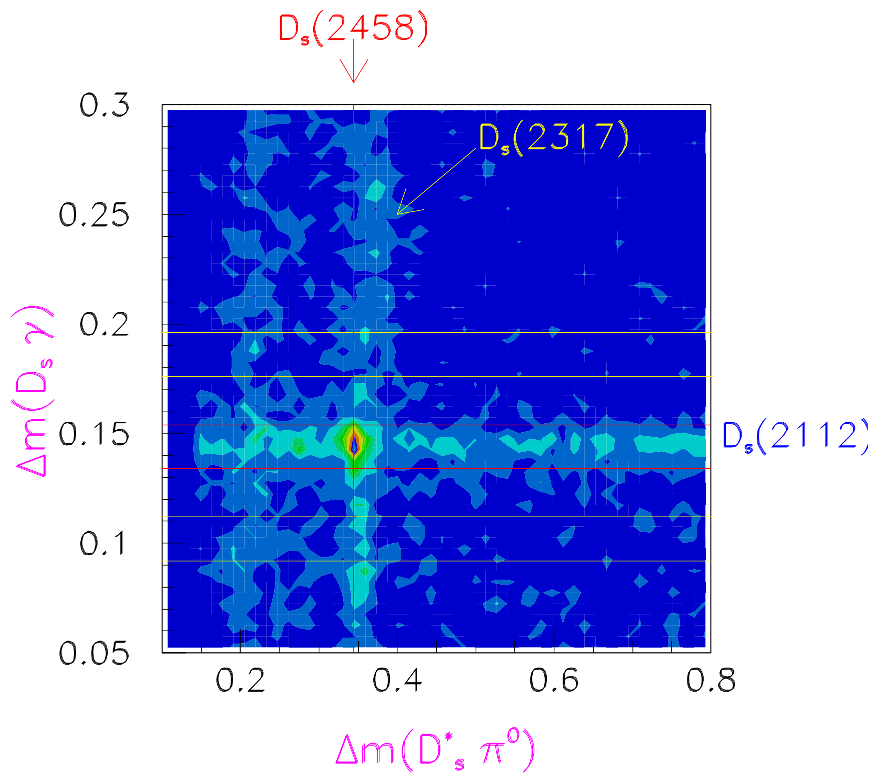


- □ **Confirmation by CLEO:** $\Delta m = 350.3 \pm 1.0 \quad MeV, \quad N = 231 \pm 30$
- □ **Confirmation by BELLE:** $\Delta m = 348.9 \pm 0.5, \quad N = 643 \pm 50$
- □ **In good agreement with BaBar (91.5 fb^{-1}):**

$\Delta m = 348.4 \pm 0.4 \quad MeV, \quad N = 1948 \pm 104$.

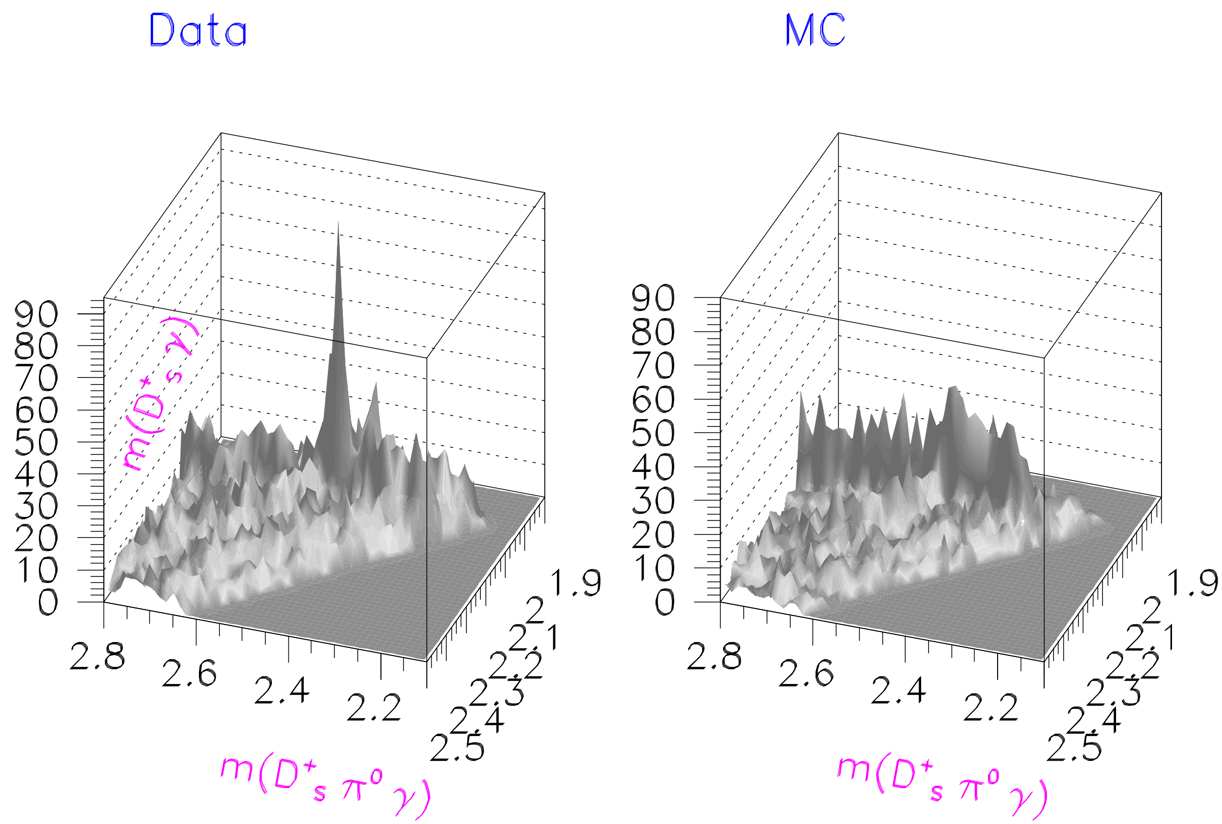
The 2.46 GeV region of $m(D_s^+\pi^0\gamma)$: a new particle or an artefact of kinematics?

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



A Comparison with Monte Carlo Simulation.

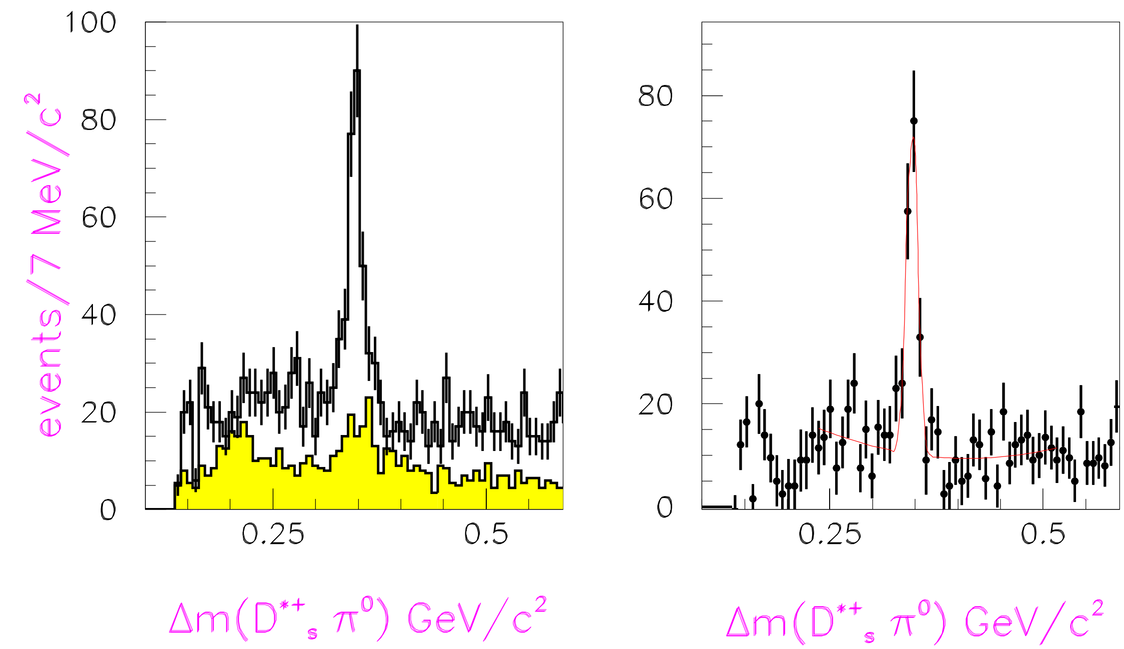
□ Lego plot of $D_s^+\gamma$ vs. $D_s^+\pi^0\gamma$ for Data and Monte Carlo which contains no $D_{sJ}^+(2458)$ resonance.



□ Strucure at ≈ 2.46 GeV in the Data only.

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

□ Subtract directly the sidebands in the Δm plane:



□ Fitted parameters:

$$\Delta m(D_s^{*+}(2112)\pi^0) = 344.6 \pm 1.2 \qquad MeV$$

□ Background peaking at a slightly higher mass.

Channel Likelihood Fit.

☐ We have performed a Maximum Likelihood fit of the $D_s^+\pi^0\gamma$ system using the technique of the Channel Likelihood.

☐ The fit describes the $D_s^+\pi^0\gamma$ system in terms of resonances in the $D_s^+\pi^0\gamma$, $D_s^+\pi^0$ and $D_s^+\gamma$ final states and phase space.

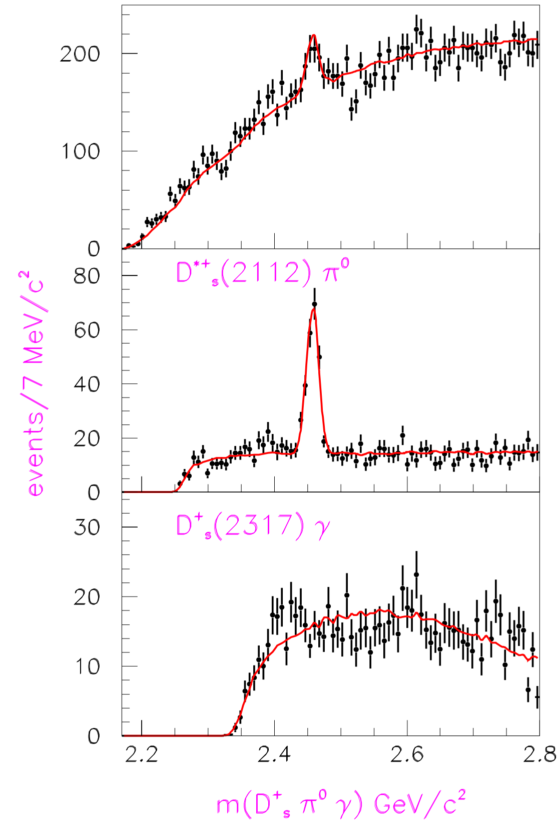
☐ The Likelihood function is of the form:

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

where x_i are the fractions for each final state and P_i are normalized Probability Density Functions. P_i are Gaussians describing the different contributing resonances.

Channel Likelihood Fit Projections.

□ The fit allows to obtain weighted distributions. In this way the reflections are automatically removed.



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

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

Results from the Channel Likelihood Fit.

- $D_s^+(2458)$ parameters:

$$m(D_s^+(2458)) = 2458 \pm 1 \quad MeV/c^2$$

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

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

$$N(D_s^+(2458) \rightarrow D_s^{*+}(2112)\pi^0) = 180 \pm 22$$

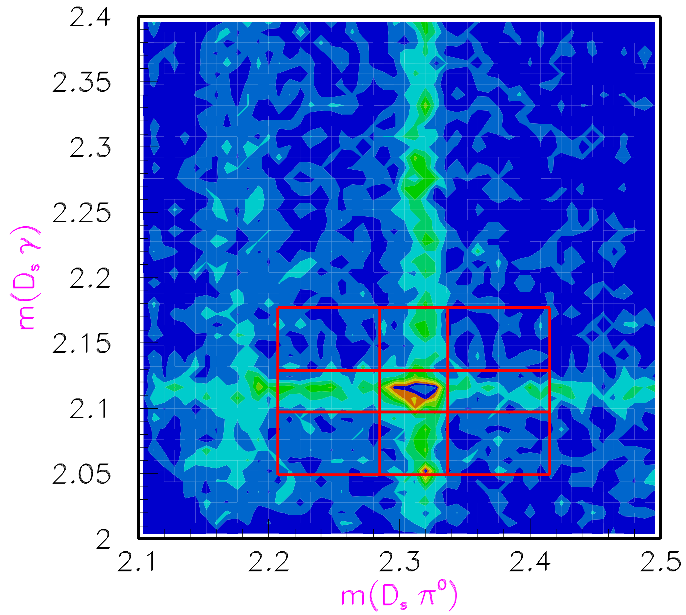
$$N(D_s^+(2458) \rightarrow D_{sJ}^{*+}(2317)\gamma) = 0 \pm 19$$

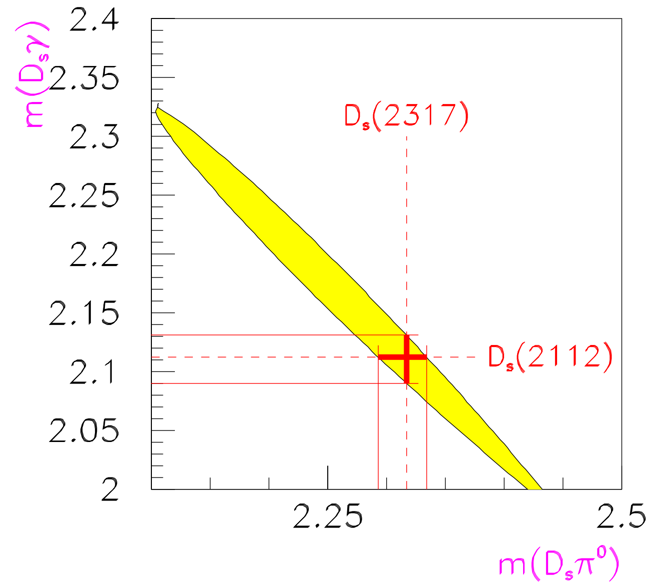
- Correcting for efficiency, we obtain the following upper limit:

$$\frac{D_s^+(2458) \rightarrow D_{sJ}^{*+}(2317)\gamma}{D_s^{*+}(2112)\pi^0} < 0.2 \quad 95\% \qquad C.L.$$

The method of the 9 tiles.

□ Consider the $m(D_s^+\gamma)$ vs. $m(D_s^+\pi^0)$ scatter diagram:





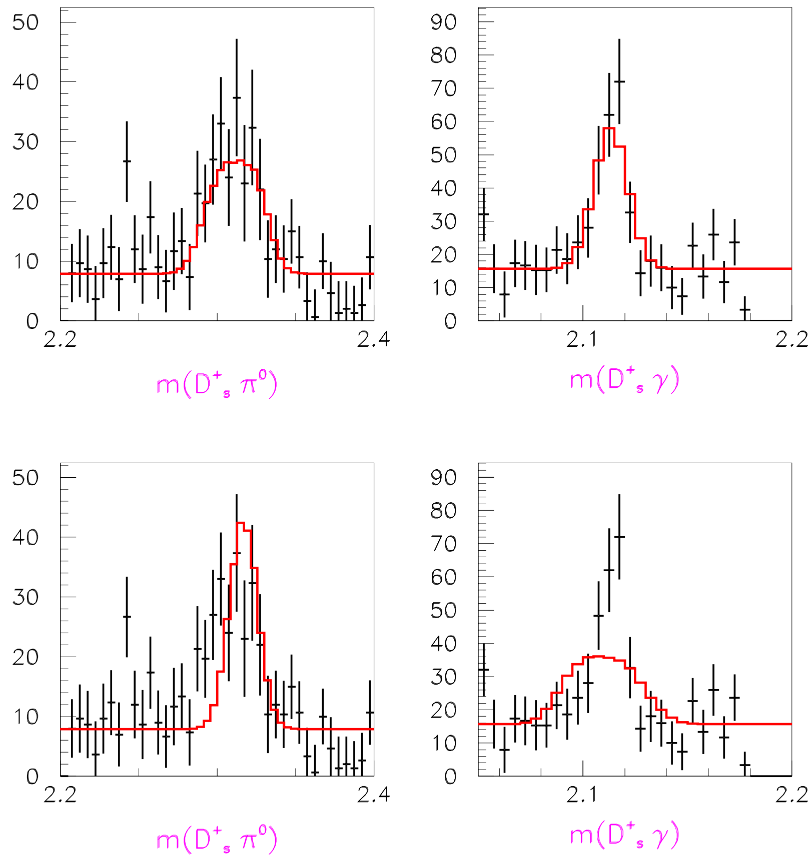
□ Subtracting the adjacent tiles, the $D_{sJ}^+(2458)$ "Dalitz plot" projections on the two axis can be extracted.

$D_{sJ}^{+}(2458)$ projections.

- $D_{sJ}^{+}(2458)$ projections compared with Monte Carlo simulations for:

$$D_{sJ}^{+}(2458) \to D_s^{*+}(2112)\pi^0$$

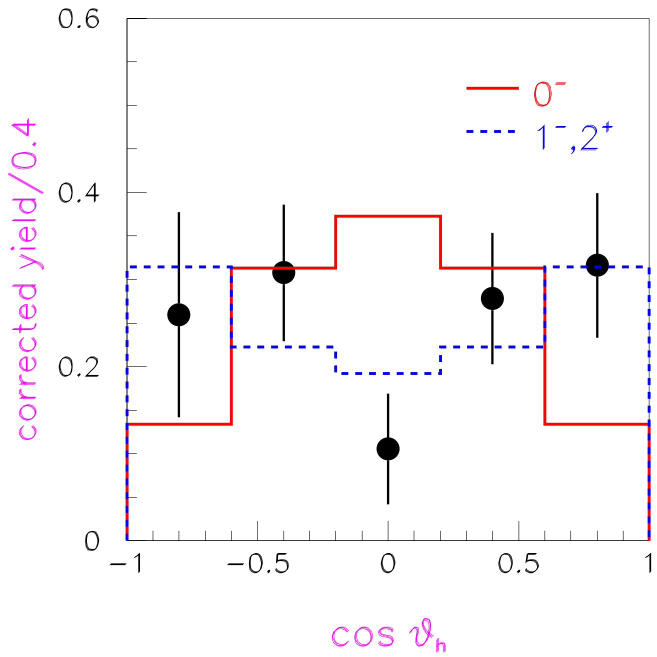
$$D_{sJ}^{+}(2458) \to D_{sJ}^{*+}(2317)\gamma:$$



- $D_{sJ}^{+}(2458) \to D_s^{*+}(2112)\pi^0$ decay clearly favoured.

Angular analysis.

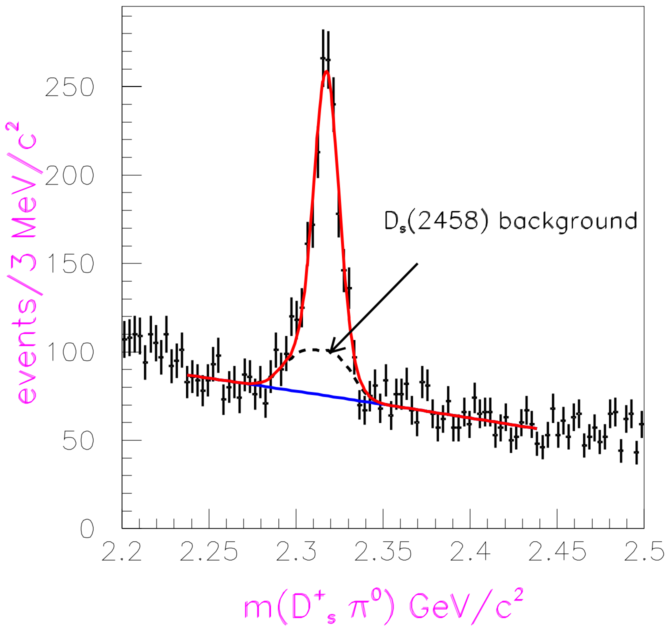
□ Distribution of the helicity angle θ of the γ with respect to the $D_s^{*+}(2112)$ direction in the $D_{sJ}^+(2458)$ rest frame.



□ Inconsistent with $J^P = 0^-$.

New determination of $D_s^+(2317)$ parameters.

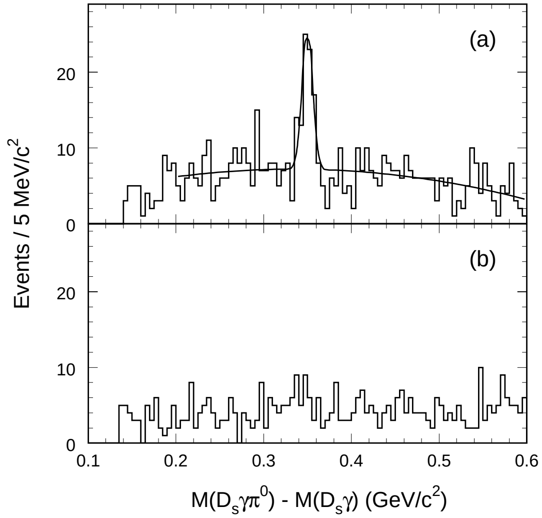
□ Once known the $D_{sJ}^+(2458)$ parameters using Monte Carlo simulations we can estimate the expected background under the $D_s^+(2317)$ signal:



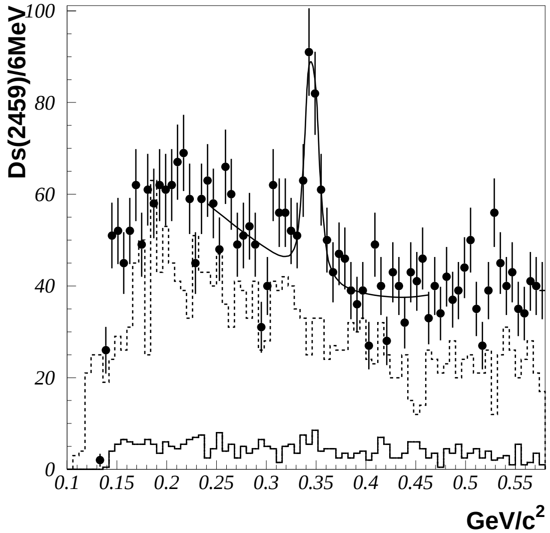
□ Resulting $D_s^+(2317)$ parameters:

$$m = 2317.3 \pm 0.4, \qquad \sigma = 7.3 \pm 0.2 \quad MeV/c^2$$

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



- CLEO: No peaking background.
- $\Delta m = 349.8 \pm 1.3 \quad MeV,\ N = 41 \pm 12$

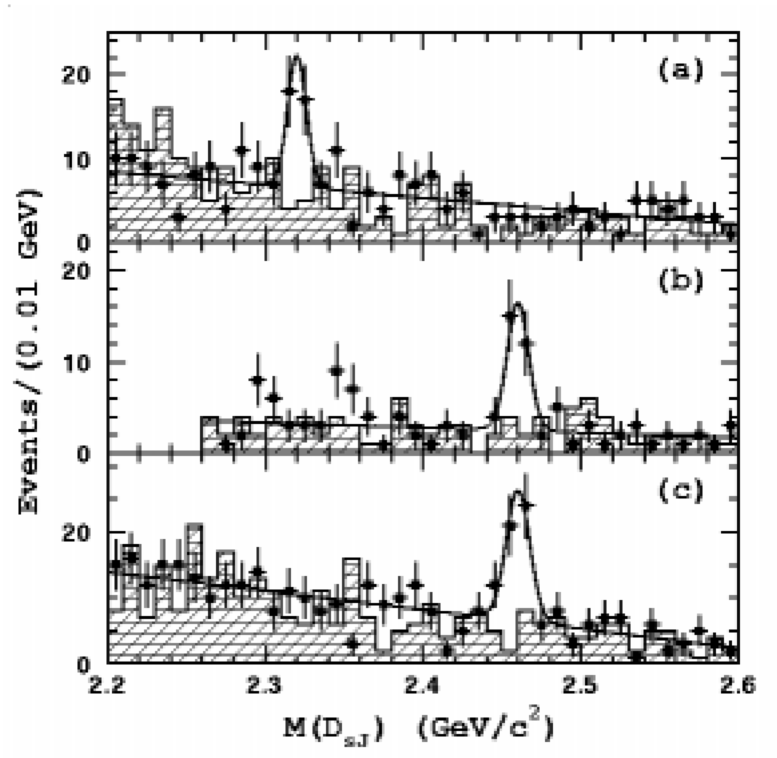


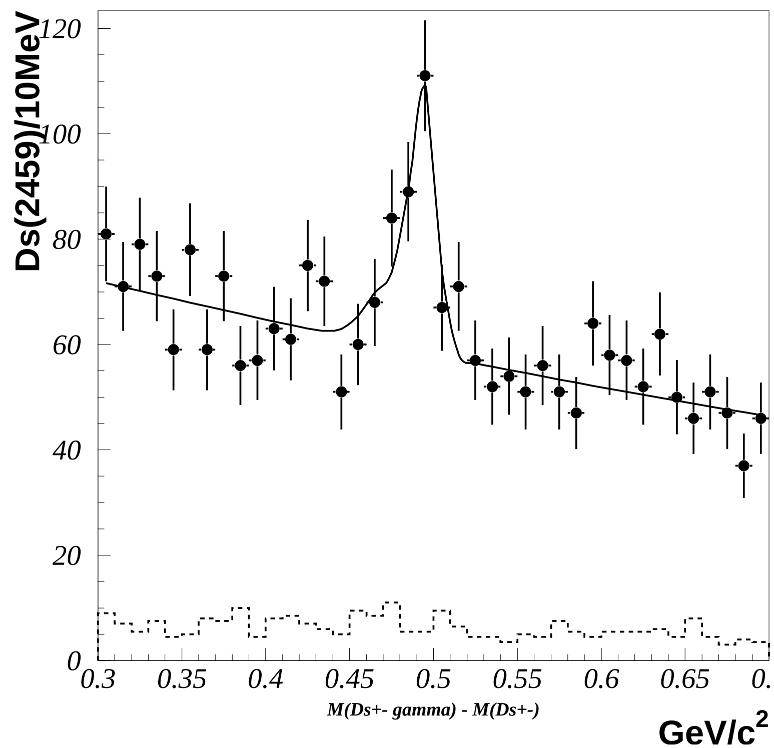
- BELLE: $\Delta m = 345.4 \pm 1.3 \quad MeV,\ N = 79 \pm 18$

B decays from BELLE.

□ Evidence for:

$$B \to DD_{sJ}(2317) \qquad B \to DD_{sJ}(2458) \qquad D_{sJ}(2458) \to D_s\gamma(continuum)$$

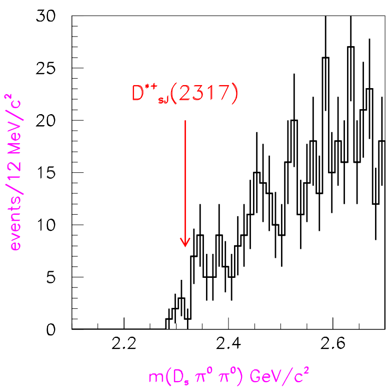


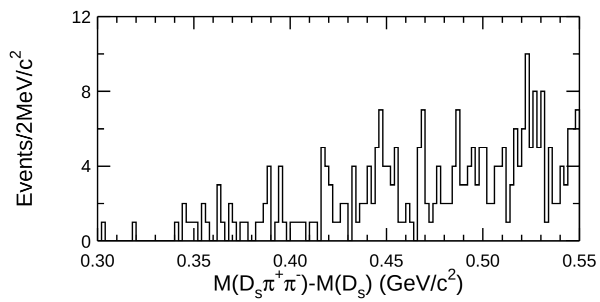


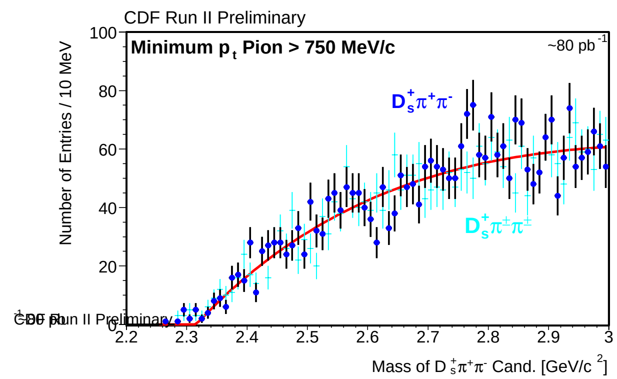
□ Evidence for $D^+_{sJ}(2458) \to D^+_s\gamma$ from continuum and in B decays: $J^P = 1^+$ favoured.

Search for structure in $D_s^+\pi\pi$.

BABAR | **CLEO** | **CDF (80 pb^{-1})**







- □ No structures in $D_s^+\pi\pi$.
- □ No structures in $D_s^+\pi$.

Experimental Summary ($D_{sJ}^{*+}(2317)$).

☐ A large ($\approx$ 2200 events), narrow signal has been discovered by BaBar experiment in the inclusively-produced $D_s^+\pi^0$ mass distribution for the D_s^+ decay modes:

$$D_s^+ \to K^+K^-\pi^+, \qquad D_s^+ \to K^+K^-\pi^+\pi^0$$

☐ The fitted mass value is:

$$m = 2317.3 \pm 0.4(stat) \pm 1.0(syst) \qquad MeV/c^2$$

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

☐ The structure is not observed in the $D_s^+\gamma$, $D_s^+\gamma\gamma$, $D_s^{*+}(2112)\gamma$, $D_s^+\pi^0\pi^0$ nor $D_s^+\pi^0\gamma$ mass distributions.

☐ The quantum numbers are consistent with being $J^P = 0^+$, but other natural spin-parity assignments cannot be excluded.

☐ This observation has been confirmed by CLEO and BELLE experiments in both continuum and B decays.

Experimental Summary ($D_{sJ}^+(2458)$).

□ BaBar has also shown first the evidence of structure in the $D_s^+\pi^0\gamma$ mass distribution at $\approx$ 2.46 GeV. However, the complexity of the overlapping kinematics of the $D_s^{*+}(2112) \to D_s^+\gamma$ and $D_{sJ}^{*+}(2317) \to D_s^+\pi^0$ has required a detailed careful study, in order to arrive at a definive conclusion.

□ CLEO experiment observes $D_s^+(2463)$ state (hep-ex/0305100) which has also been confirmed by BELLE.

□ The analysis reported here by BaBar experiment reports the observation of a state at 2.458 GeV decaying to $D^{*+}(2112)\pi^0$. The parameters of this state are the following:

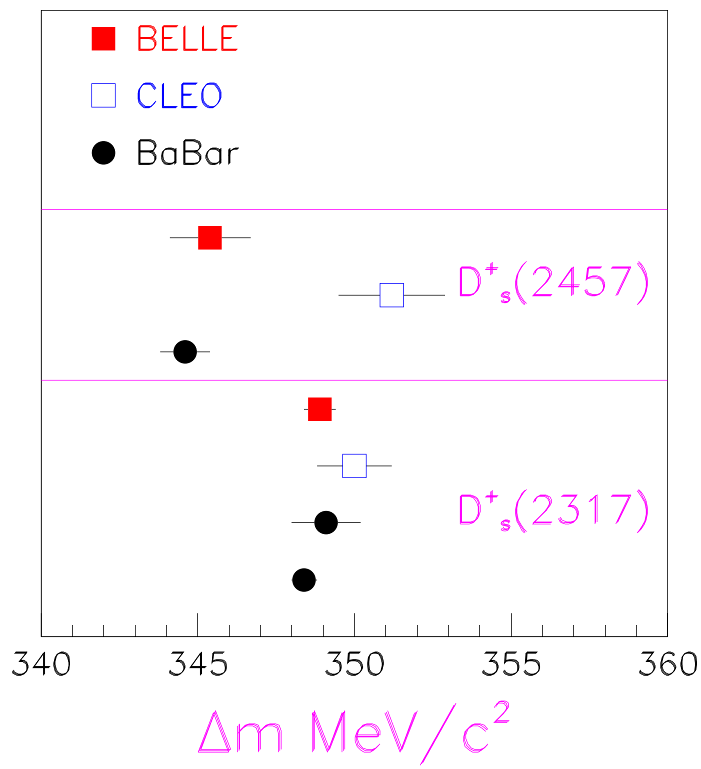
$$\Delta m = 346.2 \pm 0.9 \quad MeV$$

$$m(D_{sJ}^+(2458)) = 2458.0 \pm 1.0(stat) \pm 1.0(syst) \qquad MeV/c^2$$

□ The width is consistent with experimental resolution.

Experimental Summary ($D^+_{sJ}(2458)$).

□ Comparison between the three esperiments:



□ The spin analyses support the possibility that $D^+_{sJ}(2458)$ has $J^P = 1^+$.

□ This is also supported by the BELLE observation of $D^+_{sJ}(2458) \to D^+_s \gamma$.

Experimental Summary.

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

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

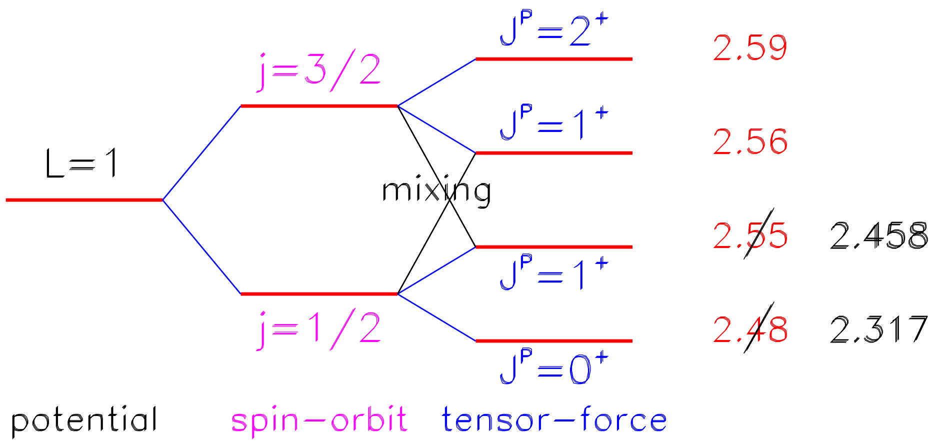
□ If the isospin of these states is I=0, since the $D_s^+ \pi^0$ and $D_s^{*+} \pi^0$ systems have isospin I=1, these decays violate isospin conservation. This would explain the small widths.

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

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, bottom mesons can be fit.

□ Also QCD Lattice calculations are in troubles: the mass for a scalar $c\bar{s}$ expected to be higher than what measured.
G. Bali,hep-ph/0305209).

□ Chiral symmetry models.
□ Predict observed pattern: splitting of $D_{sJ}^{*+}(2317)$ and $D_{sJ}^{+}(2458)$ is same as $D_s^+(1869)) - D_s^{*+}(2112)$. Predict many decay modes, including radiative decay of $D_{sJ}^{+}(2458)$
W. Bardeen et al., hep-ph/0305049.

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.

How can we decide?

- Measure radiative decays.
- Measure transitions with dipion emission.
- Find still more states.

Conclusions and Outlook.

□ The BaBar discovery of a narrow D_s^+ state has open a new window in particle physics.

□ This discovery will have a large impact on the spectroscopy of the charmed and beauty mesons.

□ Large experimental and theoretical activity is in progress.