Observation in the BaBar Experiment of a Narrow Meson in the $D_s^+\pi^0$ System at 2.32 GeV/c^2.

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Representing the BaBar Collaboration

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Outline.

- **Introduction.**
- **A few words on the BaBar experiment.**
- **Event selection.**
- **Observation of** $D_{sJ}^{*+}(2317) \rightarrow D_s^+\pi^0$
- **Search for other Decay modes:**
  $D_s^+\gamma$, $D_s^+\gamma\gamma$, $D_s^{*+}(2112)\gamma$, $D_s^+\pi^0\pi^0$, $D_s^+\pi^0\gamma$.
- **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.

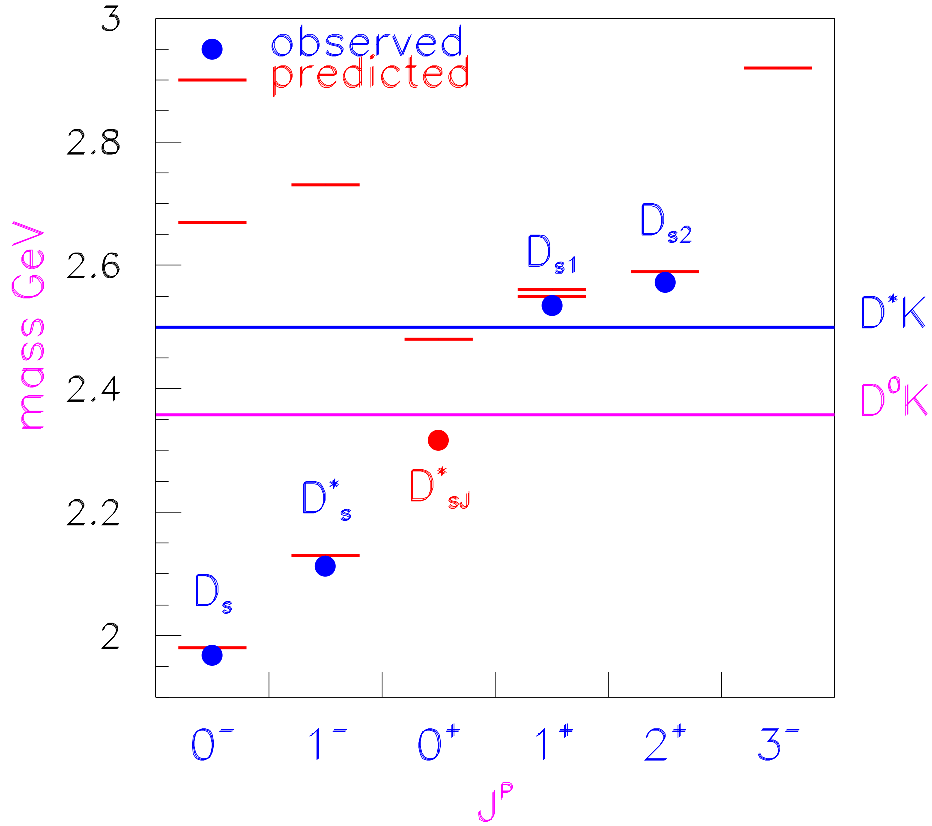
□ For example, the Godfrey-Isgur-Kokoski potential model predicts the $J^P = 0^+$ member at a mass of 2.48 GeV (DiPierro and Eichten at 2.487), with a width 270–990 MeV decaying mainly to $D^0 K$. The large width would make it difficult to observe.

□ However, if the mass of this state is below the $D^0 K$ threshold, it could be very narrow.

□ The model also predicts two 1^+ states at masses of 2.55 and 2.56 GeV (DiPierro and Eichten at 2.535 and 2.605). Only one of these two states has been observed up to now.

Spectroscopy of D_s mesons.

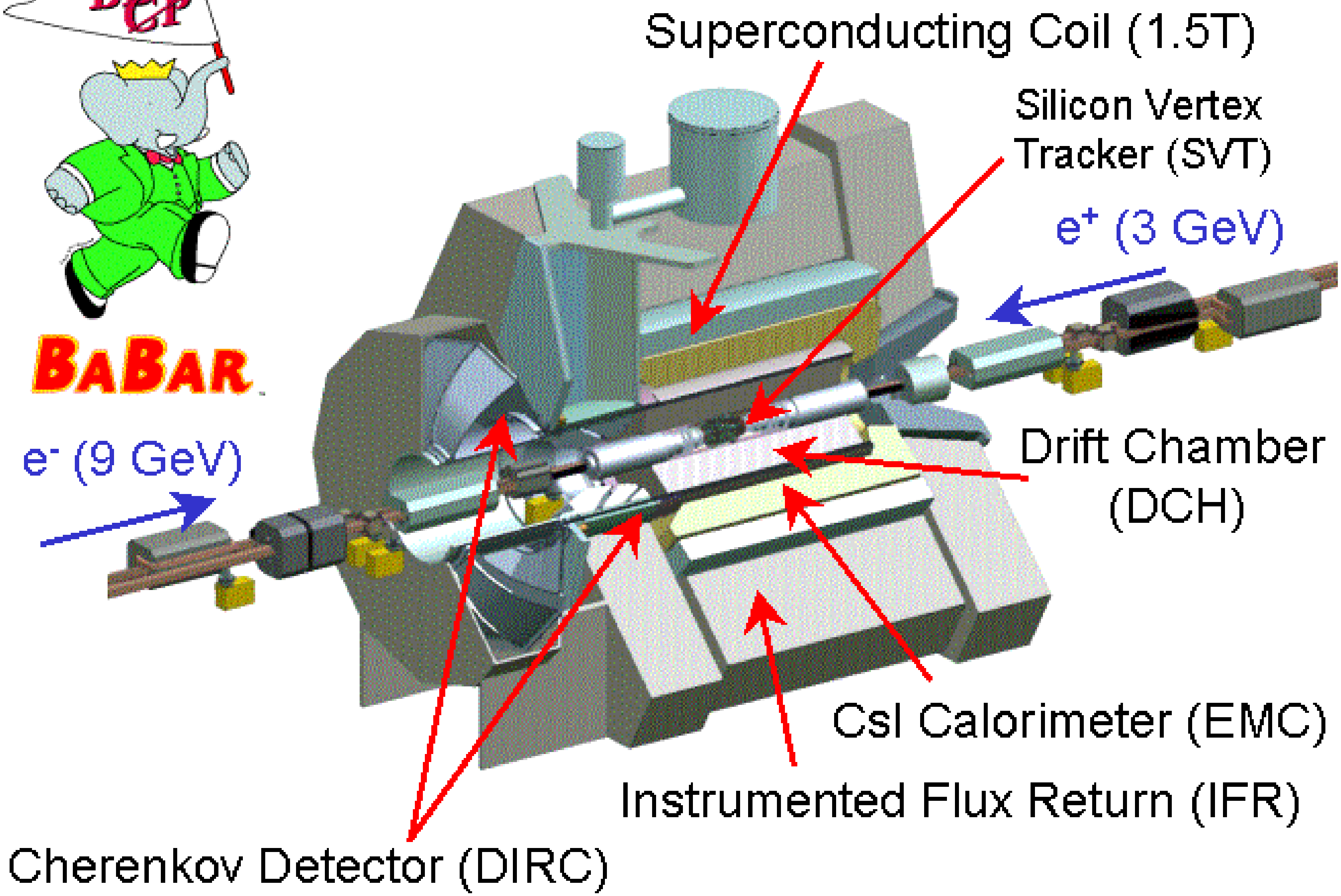
□ Potential model expectations and experimental status for D_s mesons.



□ Remarkably good agreement up to now.

□ Exception: the newly discovered state at 2.317 GeV.

BABAR Detector @ PEP-II



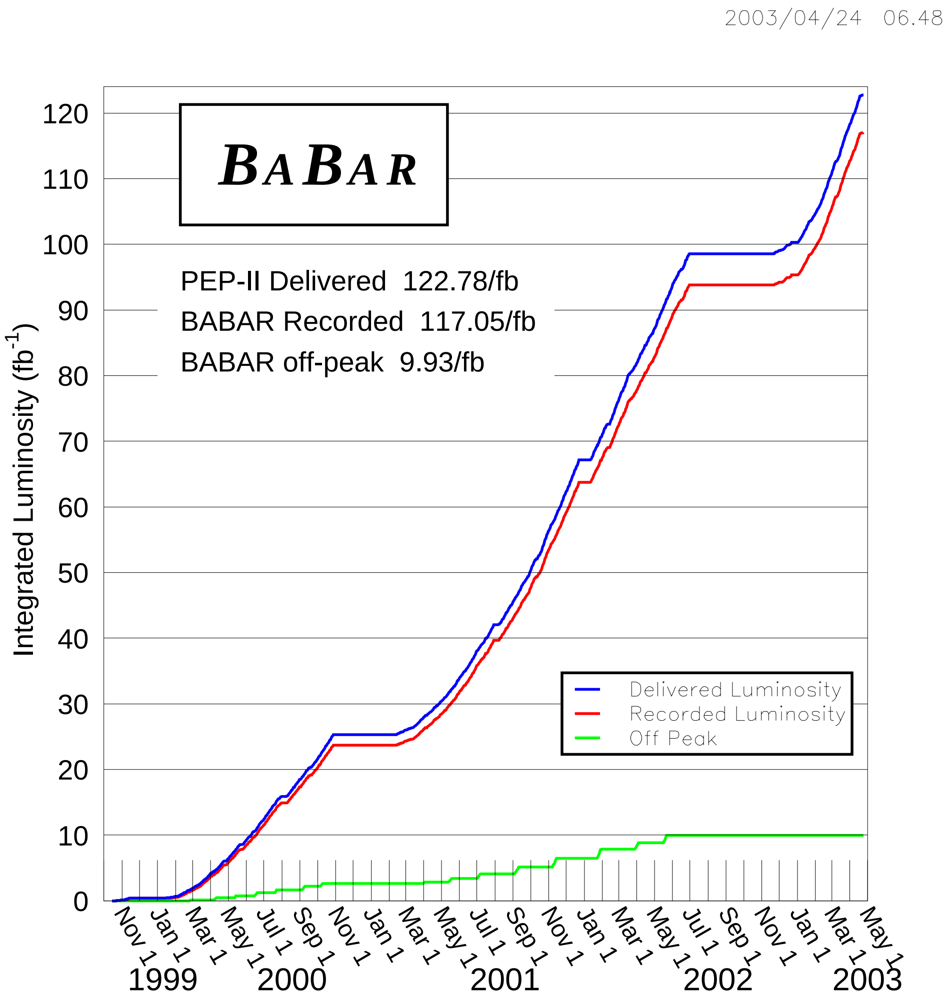
The BaBar Experiment.

□ 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.

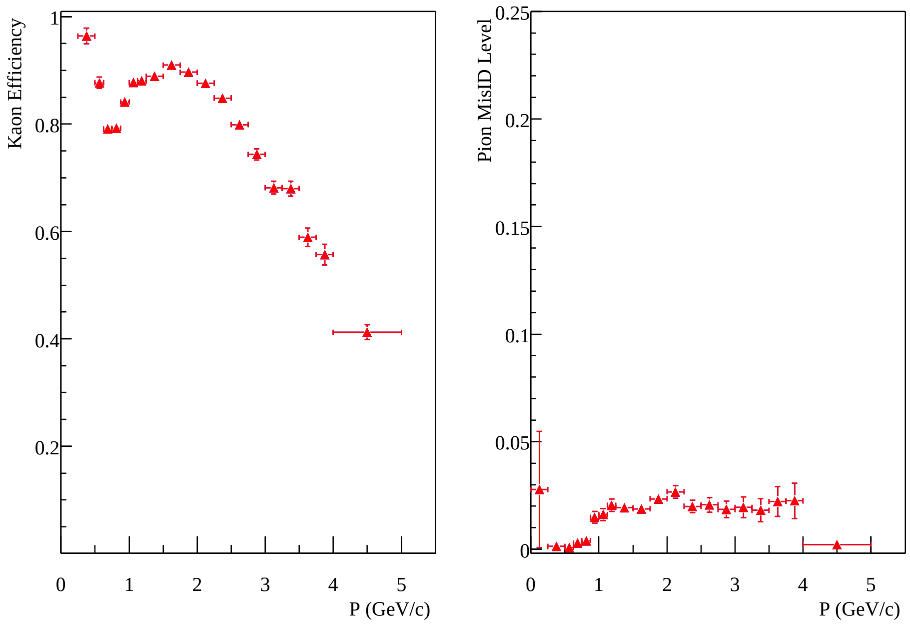


PID Performance.

□ 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 ≈ 90 % K identification efficiency with ≈ 2 % π mis-identification as K.

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



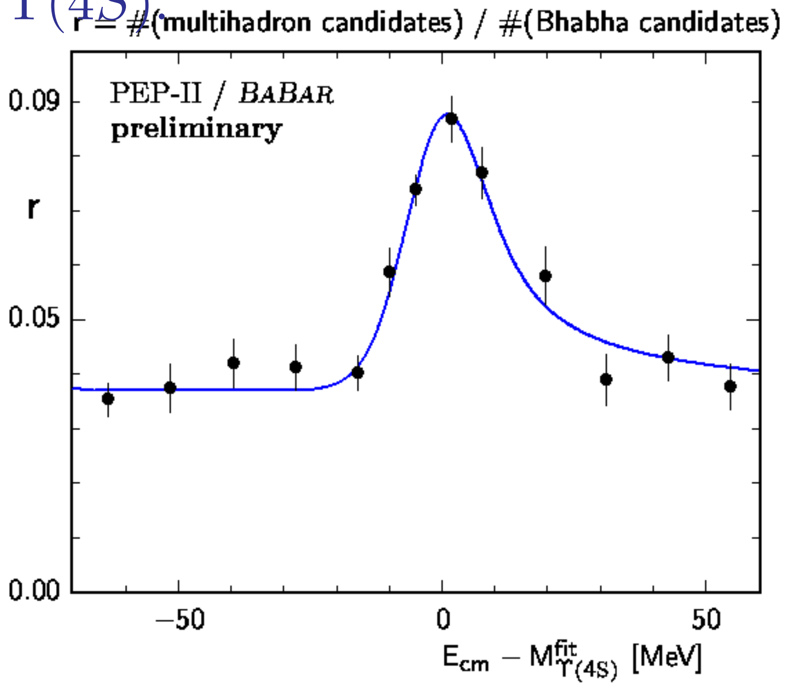
Charm Physics in BaBar.

□ 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



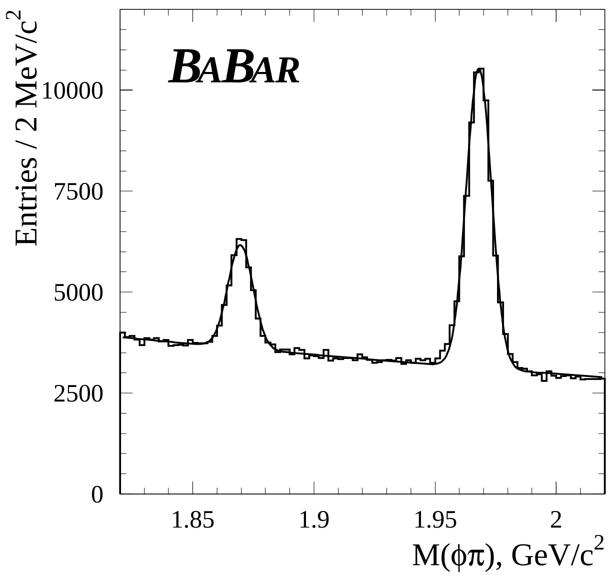
□ Charm Analyses are performed on data corresponding to continuum $\bar{c}c$ production.

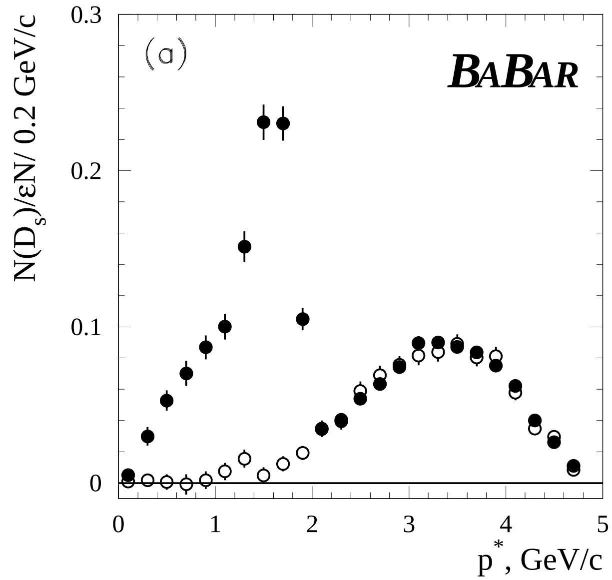
$$e^+e^- \rightarrow c\bar{c}$$

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:

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

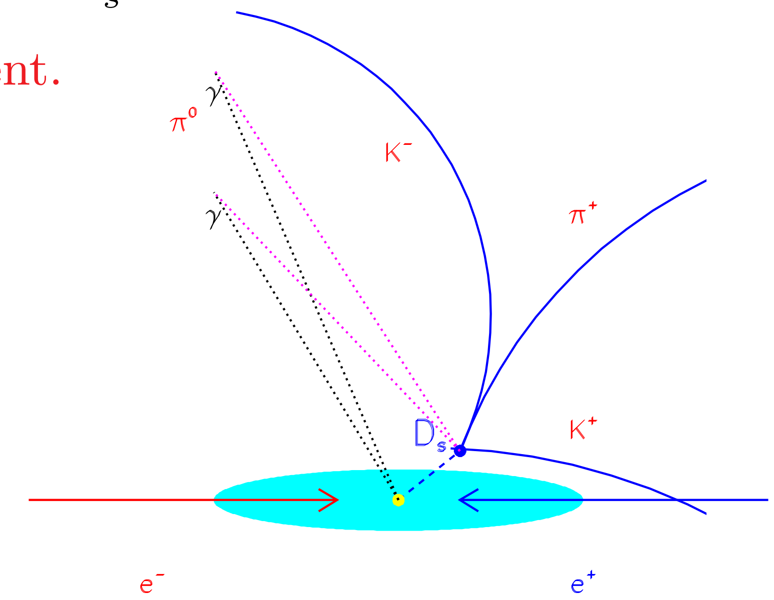
☐ This final state has been selected using the following procedure:

- 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 $D_s^+ \rightarrow K^+K^-\pi^+\pi^0$;
  - to the production vertex, to investigate the $D_s^+\pi^0$ mass distribution.

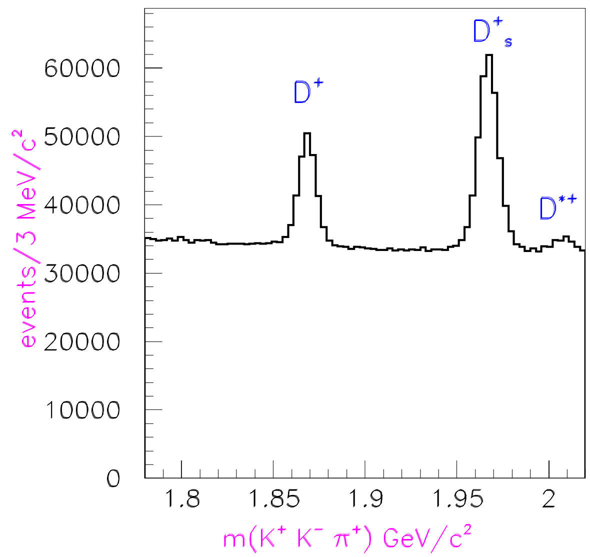
  □ Qualitative sketch, not to scale, of one event.

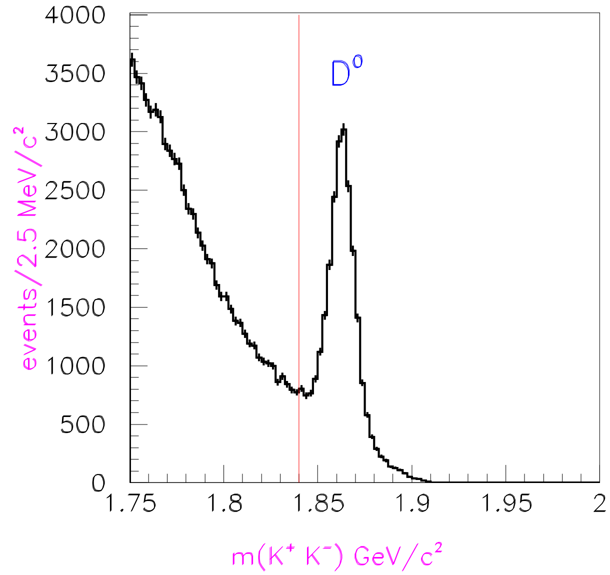


- Each $K^+K^-\pi^+\pi^0$ candidate must satisfy $p^* > 2.5$ GeV/c.

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

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





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

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

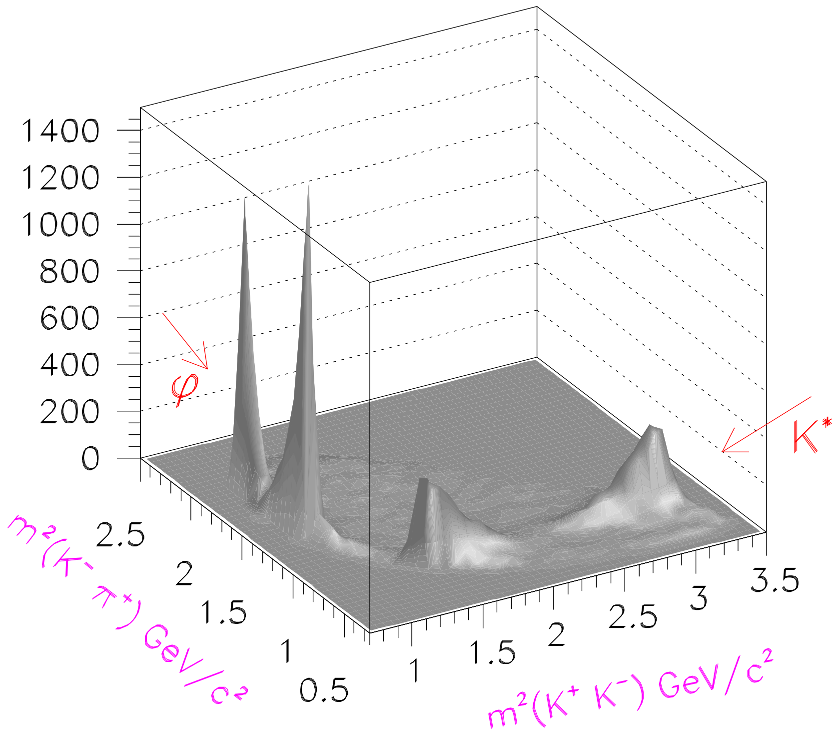
$$\to K^+K^-$$

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

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

The D_s^+ Dalitz plot.

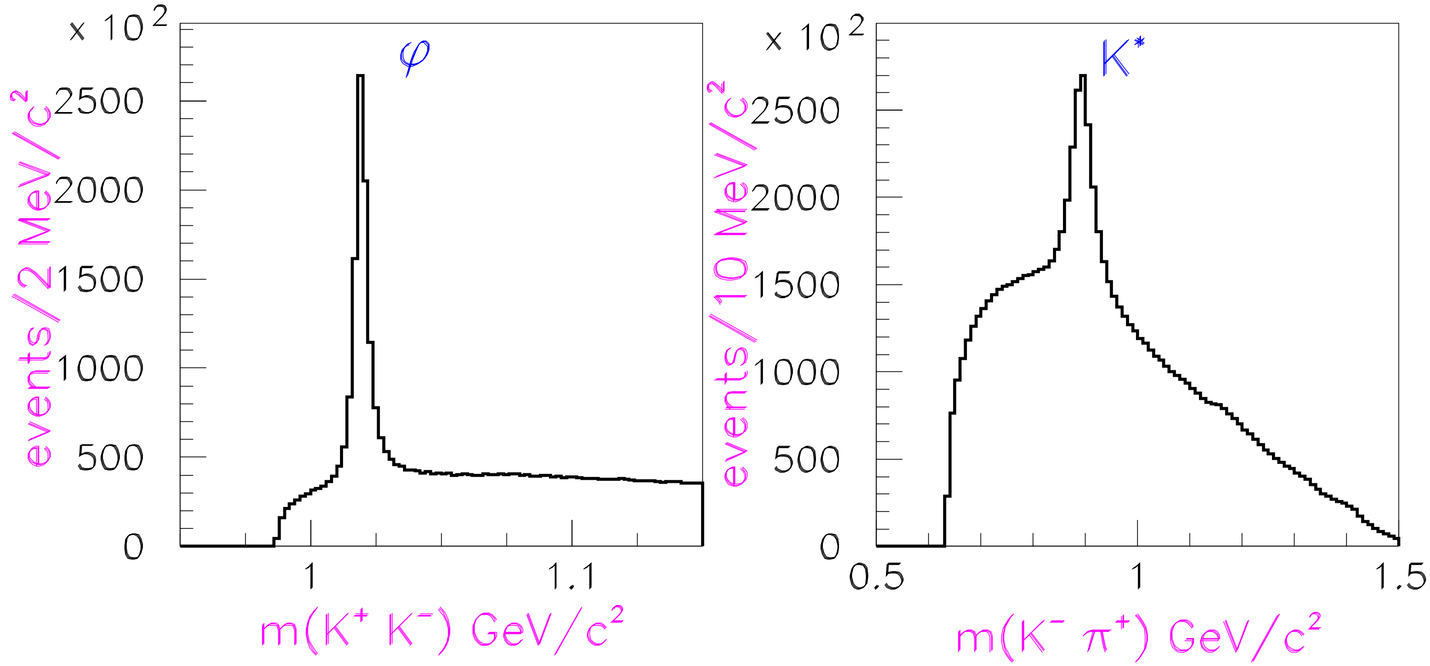
- D_s^+ signal enhanced by selecting the $\phi\pi^+$ and $\overline{K^{*0}}K^+$ decay modes.
- These two modes do not overlap, as shown by the D_s^+ Dalitz plot:



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

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

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

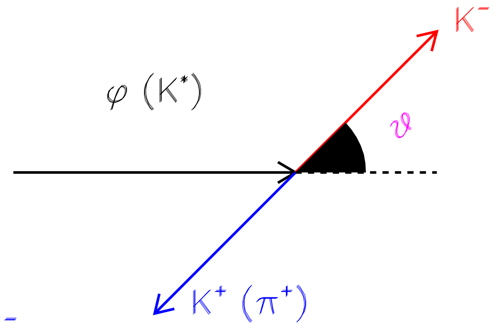


□ ϕ selected requiring: $| \, m(K^+K^-) - 1.019 \, | \leq 0.01 \quad GeV$

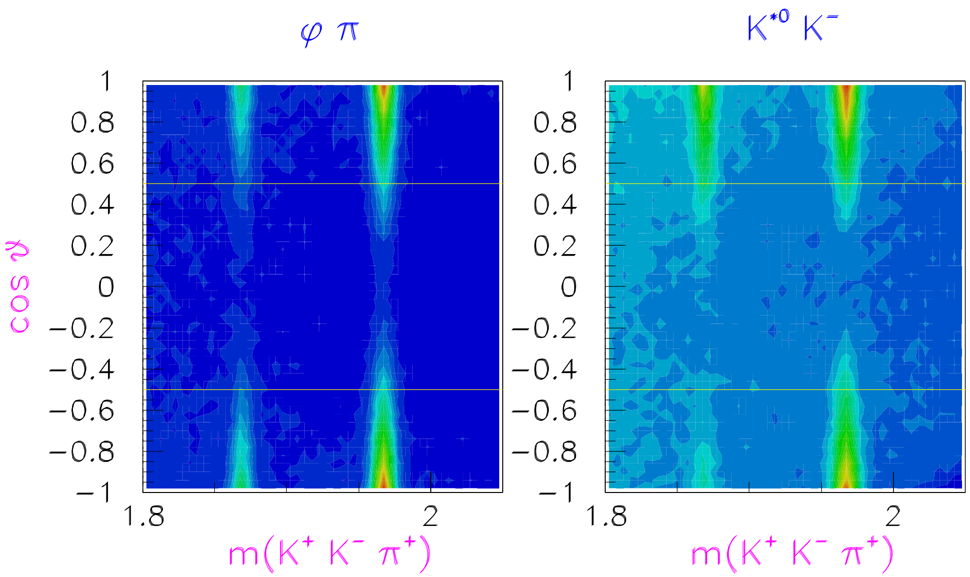
□ $\overline{K^{*0}}$ selected requiring: $| \, m(K^-\pi^+) - 0.896 \, | \leq 0.05 \quad GeV$

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.



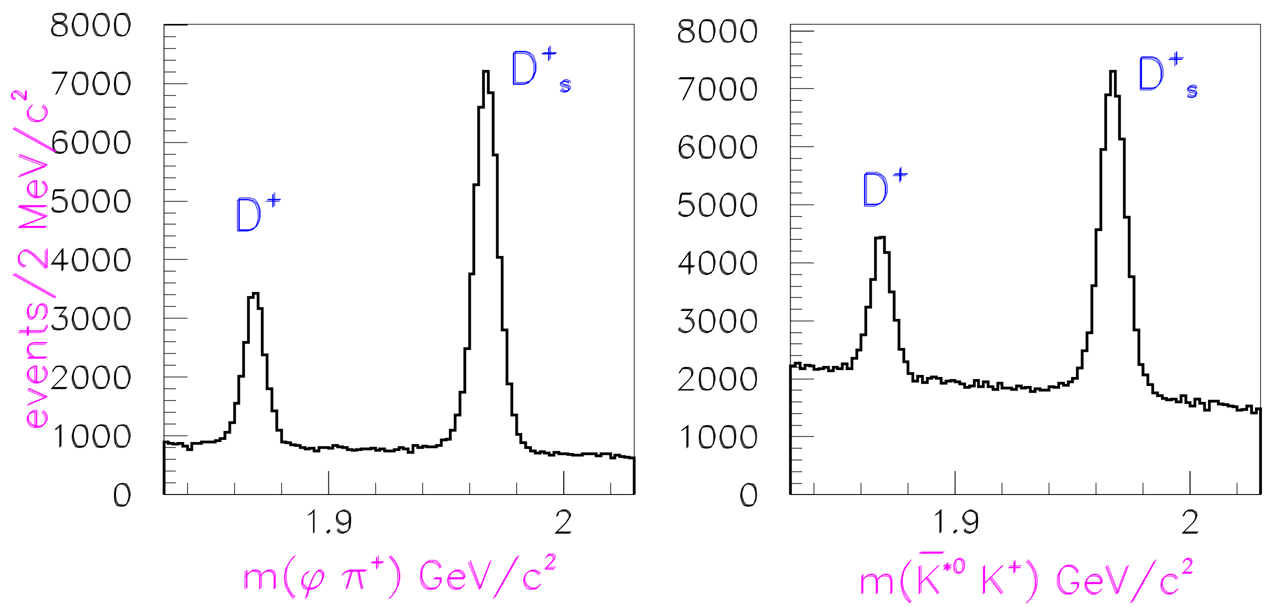
□ Scatter diagram of $cos\theta$ vs. $m(K^+K^-\pi^+)$:



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

Resulting mass spectra.

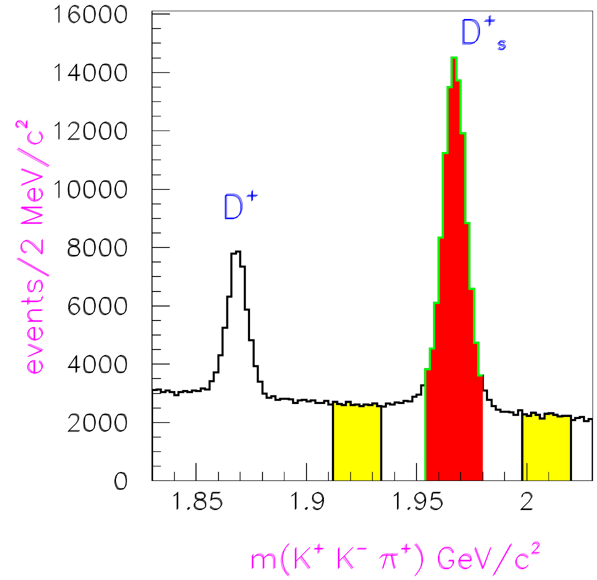
- Resulting $\phi\pi^+$ and $\overline{K^{*0}}K^+$ mass spectra:



- 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:

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

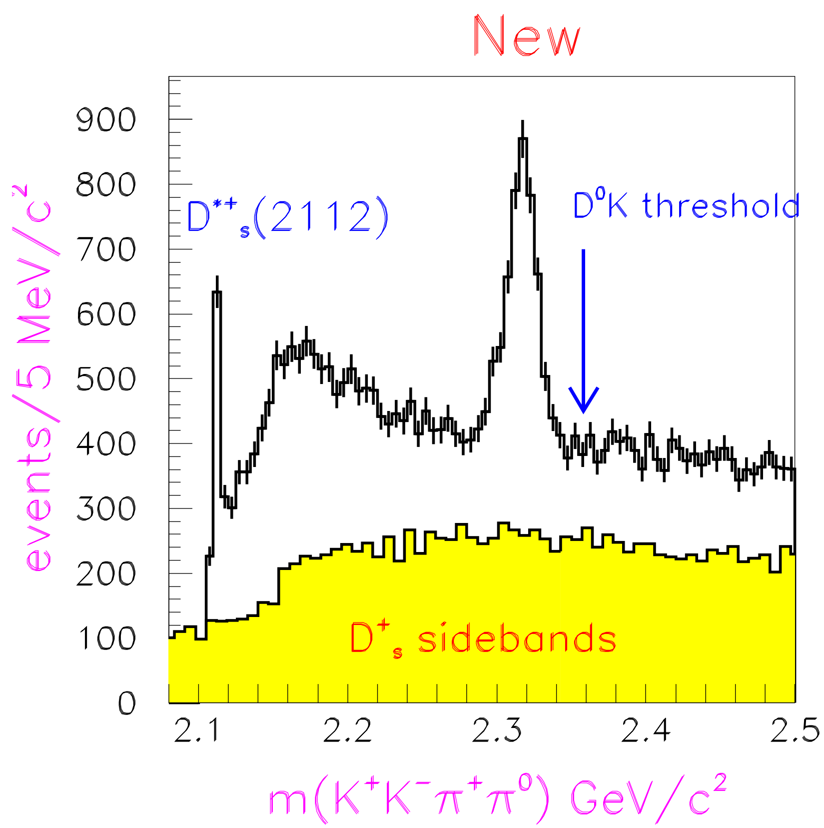
and two sideband regions as:

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

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

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

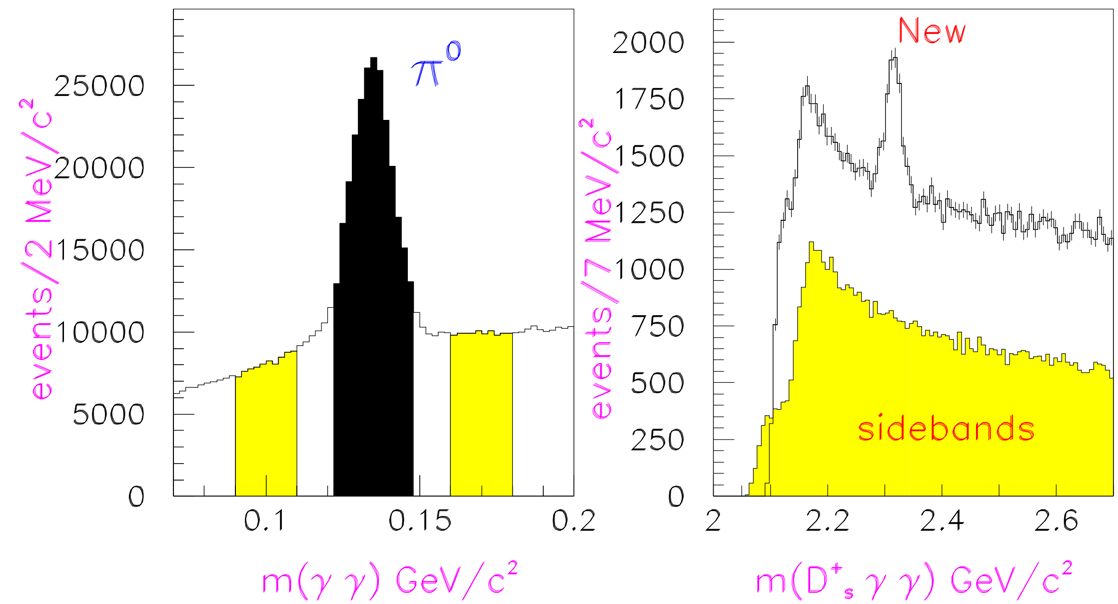
- □ Compare $(K^+K^-\pi^+)\pi^0$ mass spectra for the D_s^+ signal region and sidebands.
- □ We observe the known decay: $D_s^{*+}(2112) \to D_s^+\pi^0$.
- □ Totally unexpected large signal ($\approx$ 2200 events) at 2.32 GeV.



- □ 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.



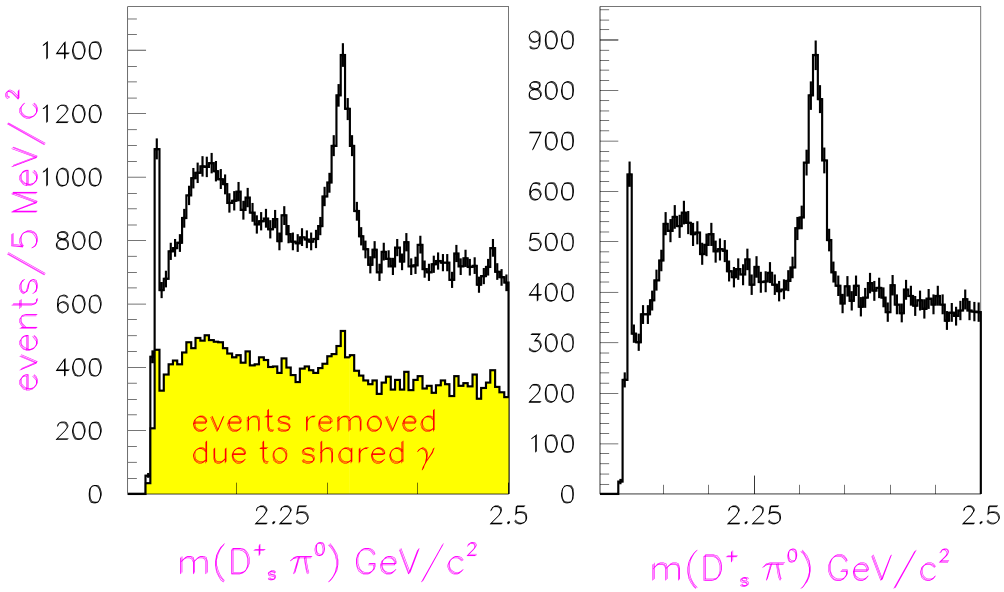
- π^0 sidebands: no signals.

$D_s^+\pi^0$ 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:

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

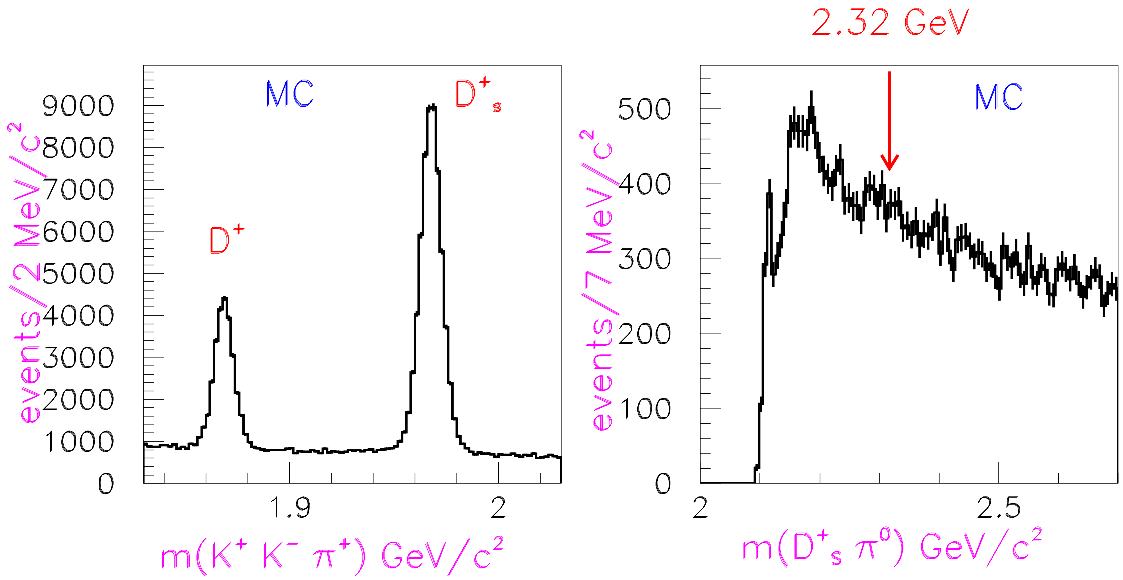
have been simulated using GEANT4. They have been reconstructed and analyzed using the same analysis procedure as that used for data.

□ 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.



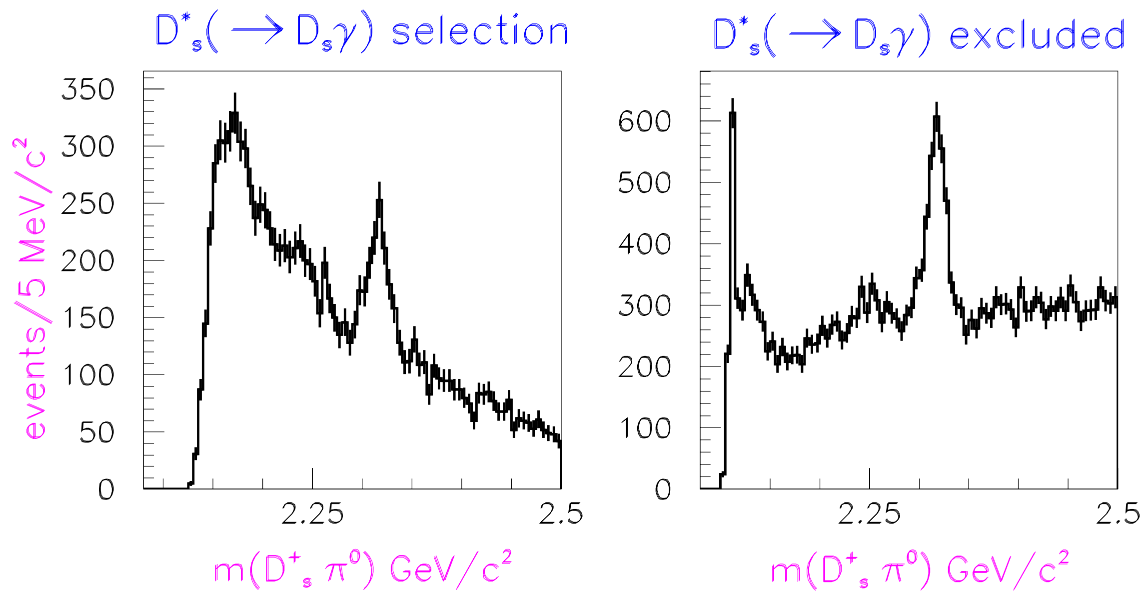
□ We observe the known decay: $D_s^{*+}(2112) \rightarrow D_s^+\pi^0$.

□ 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 $D_s^+\gamma_{1,2}$.

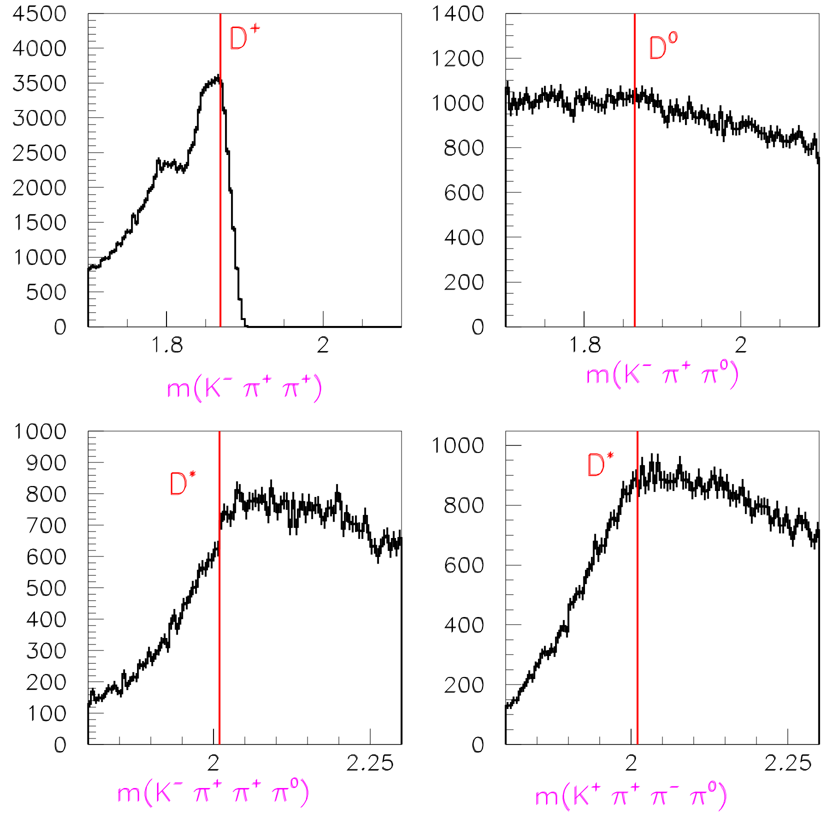


□ Anti-selecting $D_s^{*+}(2112)(\rightarrow D_s^+\gamma)$, the 2.32 GeV signal survives: it is not due to $D_s^{*+}(2112)$ reflection.

□ The wide structure at $\approx$ 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.



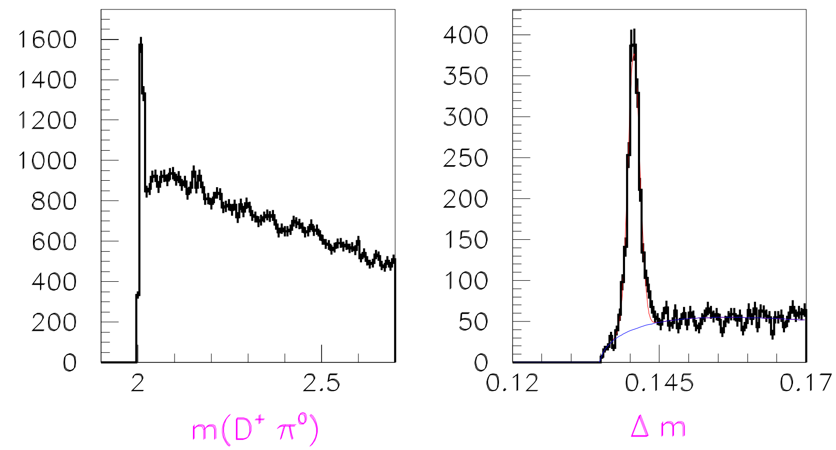
- No D^+, D^0 or D^{*+} signals are observed.

Is there anything similar in $D^+\pi^0$?

- Selecting events in the D^+ mass region:

$$1.859 < m(K^+K^-\pi^+) < 1.877 \quad GeV$$

we obtain the following $m(D^+\pi^0)$ and $\Delta m = m(K^+K^-\pi^+\pi^0) - m(K^+K^-\pi^+)$ distributions.



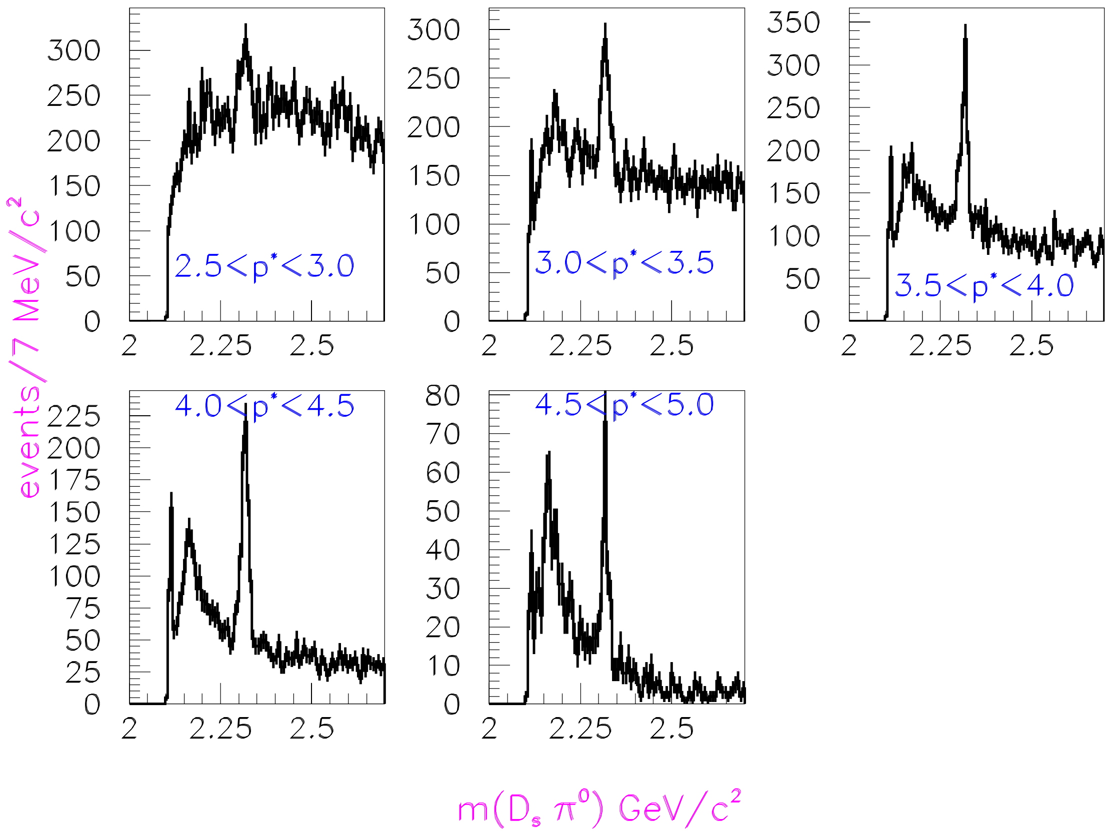
- Apart from a $D^{*+}(2010)$ signal, no other structure is observed.
- The fitted Δm values are:

$$\Delta m = 140.67 \pm 0.05 \quad MeV \qquad \sigma = 1.02 \pm 0.06 \quad MeV$$

to be compared with $\Delta m = 140.64 \pm 0.10$ MeV from PDG.

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^*.

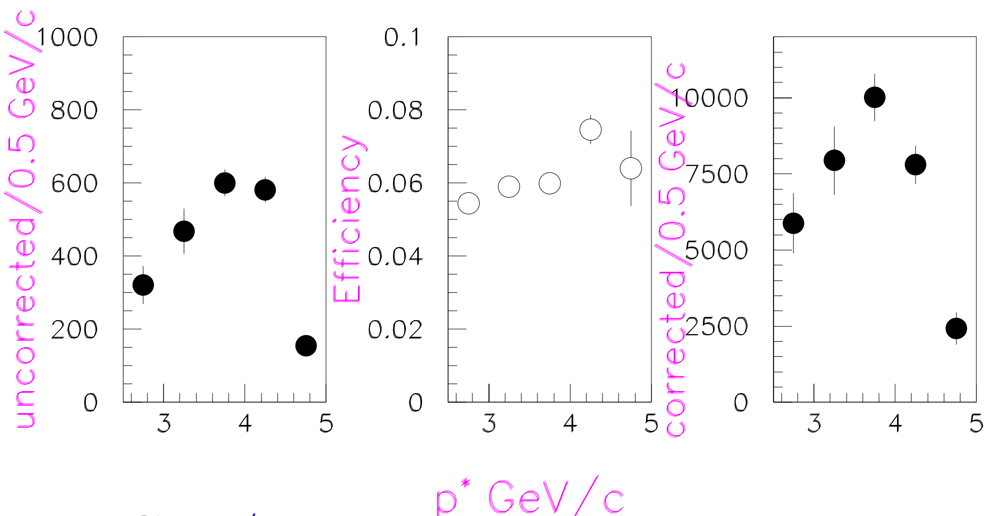
□ The signal to background ratio can be improved by means of a p^* selection.

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.

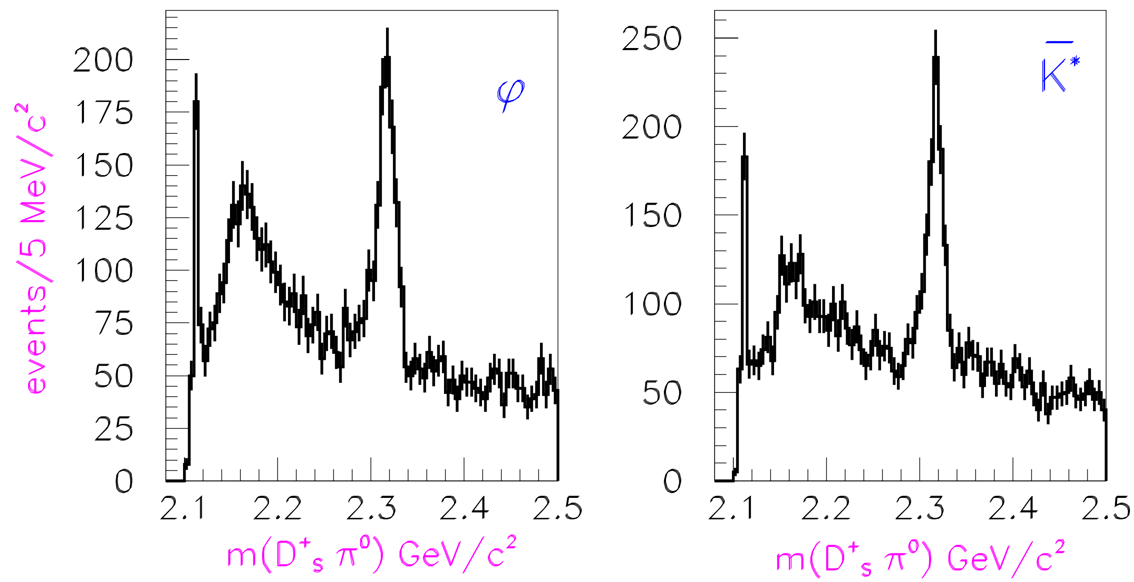
□ Uncorrected and corrected p^* distributions.



□ Maximum at ≈ 3.9 GeV/c.

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

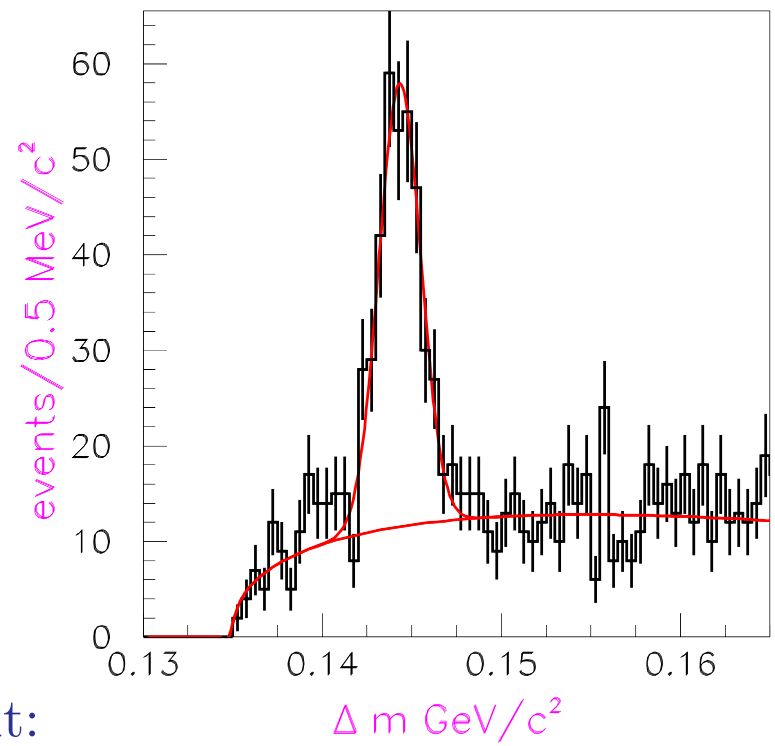
- $D_s^+\pi^0$ mass spectra separated for ϕ and $\overline{K^{*0}}$ subsamples.
- Required $p^* > 3.5$ GeV/c.



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

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

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



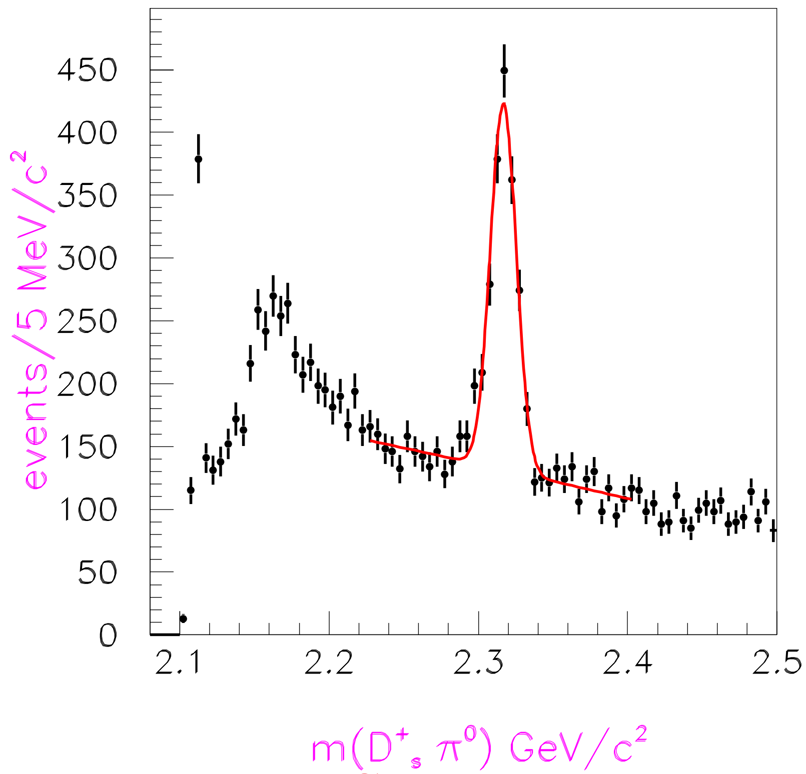
- Results from the fit:

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

- 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.

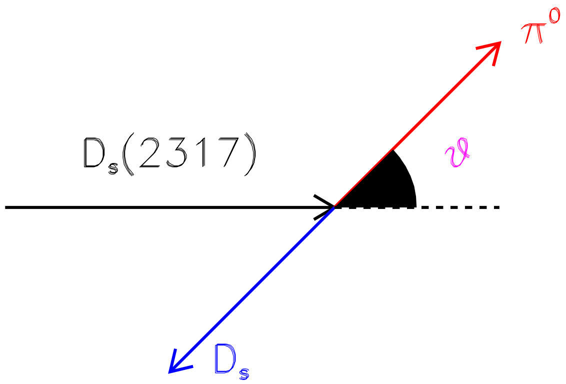
$$m = 2316.8 \pm 0.4 \quad GeV \qquad \sigma = 8.6 \pm 0.4 \qquad MeV$$

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

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

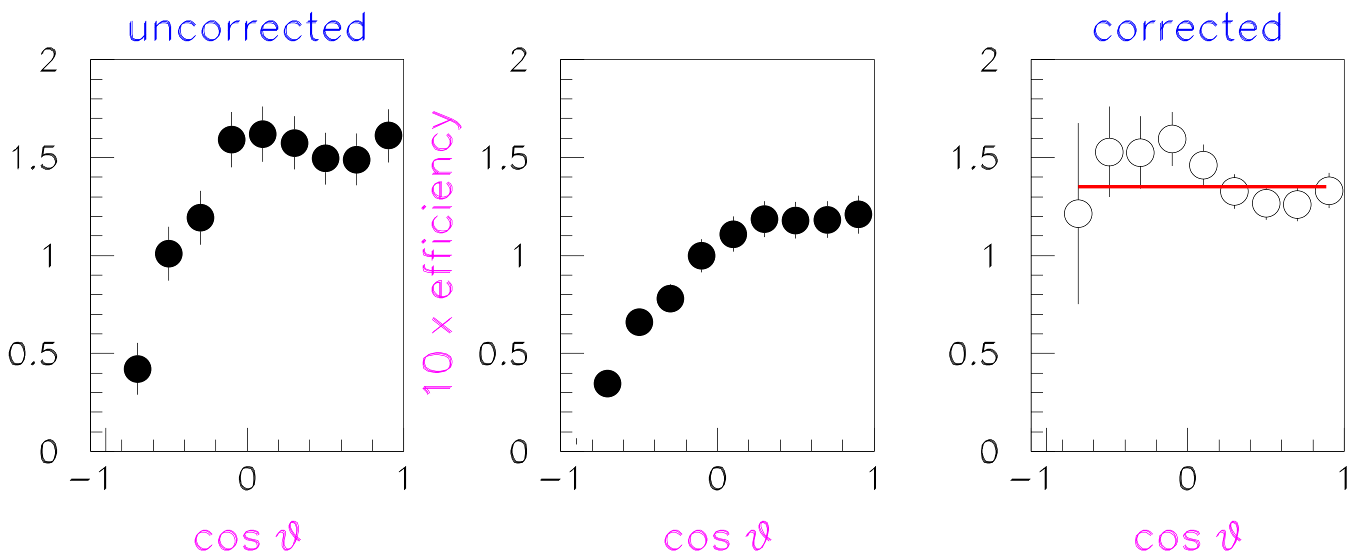
□ In the case of polarized production, the decay angular distribution can give information on the spin of the particle.

□ 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 θ. We plot the yield, the efficiency and the corrected angular distribution (in arbitrary units).



□ The corrected distribution in *cosθ* 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^+.

☐ Here we adopt the following strategy:

- First we isolate a clean $D_s^+ \to K^+K^-\pi^+\pi^0$ signal requiring the presence of the decay chain:

$$D_s^{*+}(2112) \to \gamma D_s^+ \\ \to K^+K^-\pi^+\pi^0$$

- Then we use the information obtained from this study to improve the quality of the selection of the inclusive $D_s^+ \to K^+K^-\pi^+\pi^0$ decay.

Study of $D_s^+ \to K^+K^-\pi^+\pi^0$ from $D_s^{*+}(2112)$.

□ The selection of this final state proceeds through the following steps.

- γ's from this π^0 not in common with any other π^0 candidate.
- Require $p^*_{K^+K^-\pi^+\pi^0\gamma} > 3.5 \quad GeV/c$.
- Require the π^0 lab. momentum, $p_{\pi^0} > 300$ MeV/c.
- Increase the π^0 fit probability requirement to be $> 10\%$.
- We plot the distribution of:

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

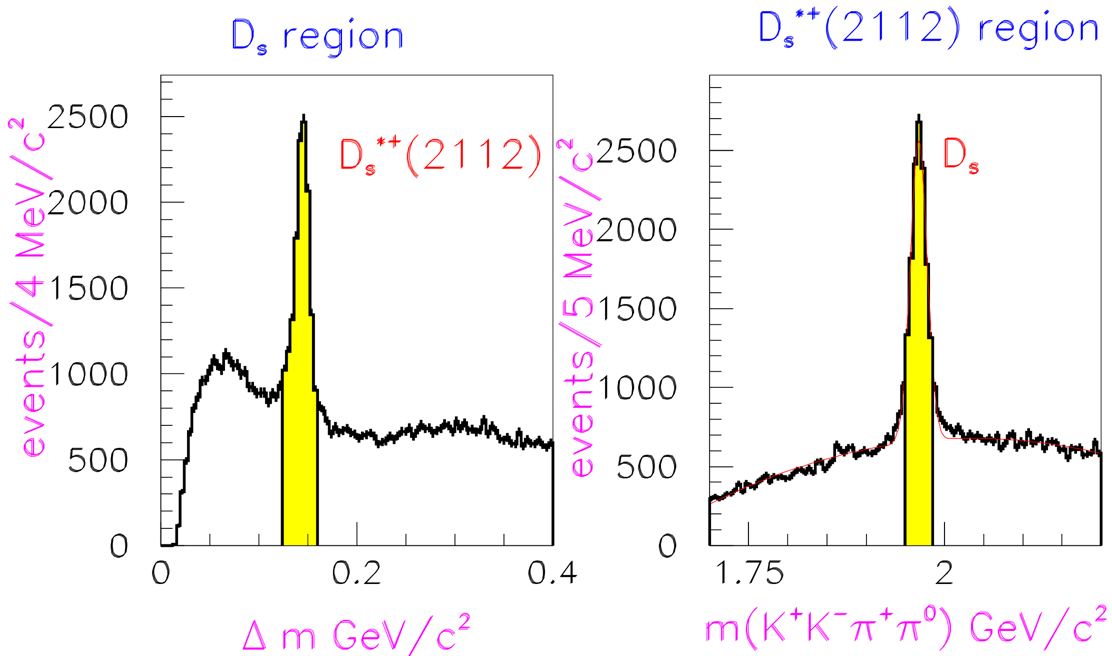
  for the D_s^+ region, defined as:

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

- 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:

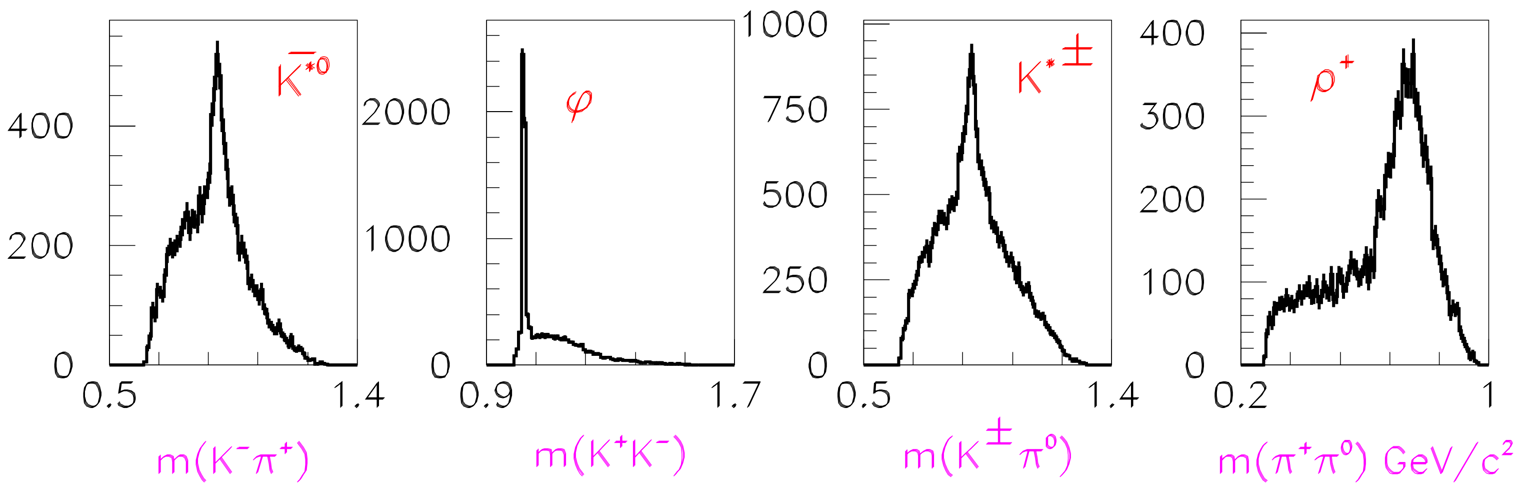
$$m_{D_s \to K^+K^-\pi^+} = 1967.20 \pm 0.03 \qquad MeV$$

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

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

□ Study of the D_s^+ from $D_s^{*+}(2112) \to \gamma D_s^+$.

□ Sub-resonance structure in this D_s^+ decay:

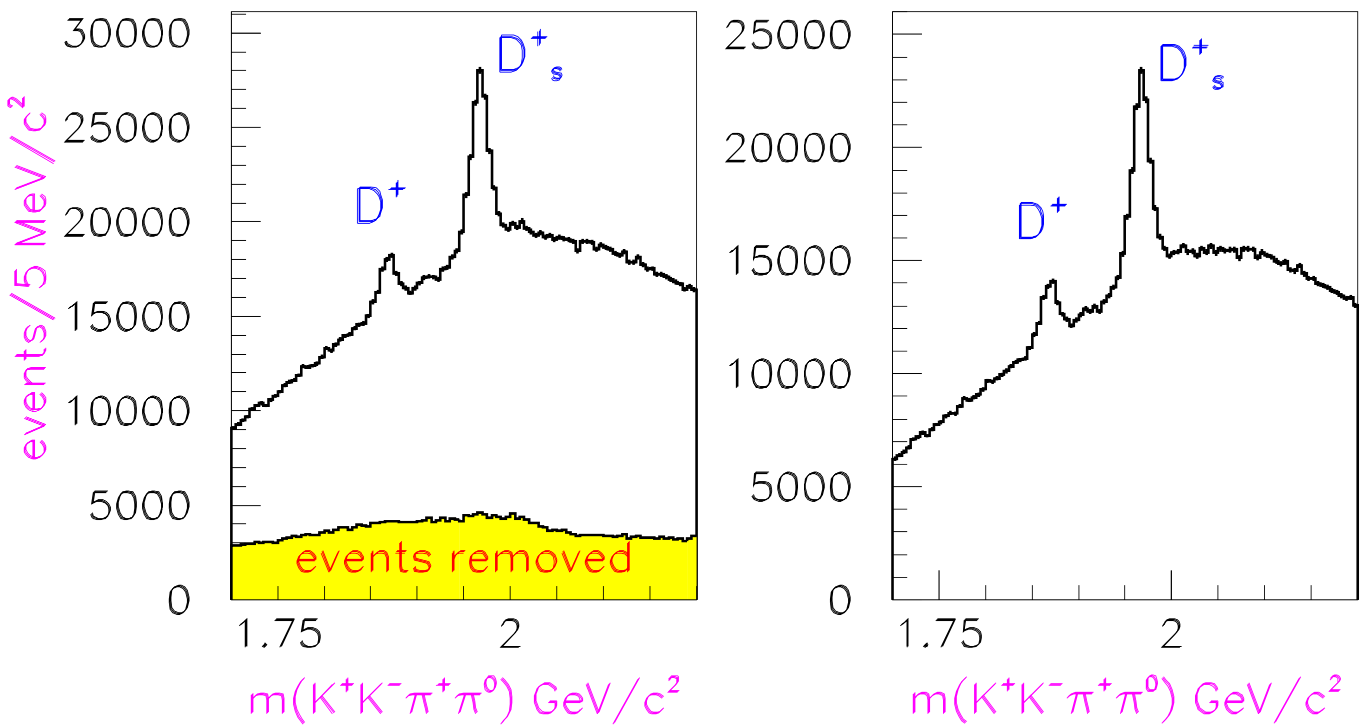


□ Decay dominated by intermediate vector meson resonances. Improved signal to background for D_s^+ by requiring ϕ, K^* or ρ subresonant structure.

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].

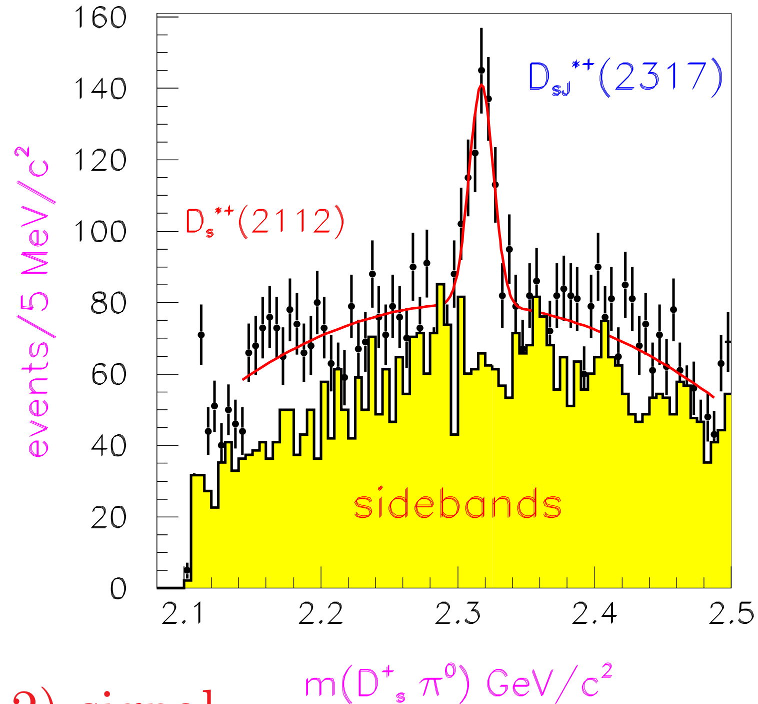


Selection of the $D_s^+\pi^0$ with $D_s^+ \to K^+K^-\pi^+\pi^0$.

- ☐ Each π^0 candidate can be from the D_s^+ decay or can be the bachelor π^0.
- ☐ Neither γ from a π^0 candidate can be part of any other π^0 candidate.
- ☐ Require $p^*(D_s^+\pi^0) > 3.5$ GeV/c.
- ☐ Require that the lab. momentum of each $\pi^0 > 300$ MeV/c.

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.

Experimental Resolution.

□ Require $p^* > 3.0$ GeV/c. Comparison between $D_s^{*+}(2112)$ width in Monte Carlo and data:

$$Data: \quad \sigma = 6.6 \pm 0.1 \quad MeV$$

$$MC: \quad \sigma = 5.7 \pm 0.1 \quad MeV$$

□ The Monte Carlo is too optimistic by a factor 1.16.

□ Monte Carlo width for $D_{sJ}^{*+}(2317)$ (produced with $\Gamma = 0$):

$$\sigma = 7.7 \pm 0.2 \quad MeV$$

□ Scaling by a factor 1.16, we expect $\sigma = 8.9$ MeV.

□ For $D_{sJ}^{*+}(2317)$ we find (for $p^* > 3.0$ GeV/c):

$$\sigma = 9.0 \pm 0.4 \quad MeV$$

□ We conclude that the observed $D_{sJ}^{*+}(2317)$ width is consistent with the experimental resolution, i.e. the intrinsic width is small ($\Gamma < 10$ MeV).

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

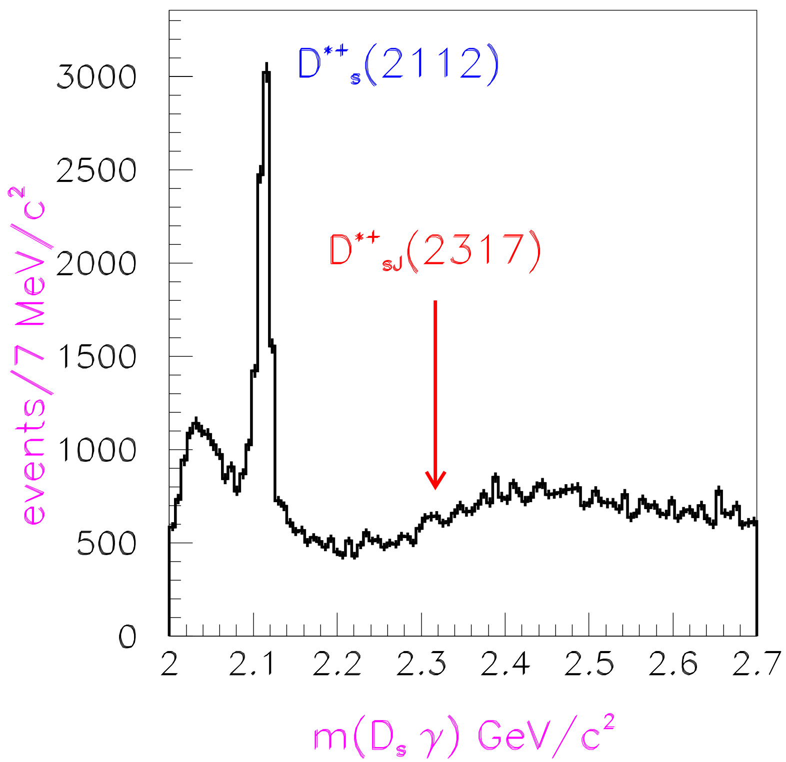
□ We have searched for other $D_{sJ}^{*+}(2317)$ decay modes.

□ In particular we have studied the following mass spectra:

- $D_s^+\gamma$;
- $D_s^+\gamma\gamma$;
- $D_s^{*+}(2112)\gamma$;
- $D_s^+\pi^0\pi^0$;
- $D_s^+\pi^0\gamma$.

Search for the $D_s^+\gamma$ decay mode of the $D_{sJ}^{*+}(2317)$.

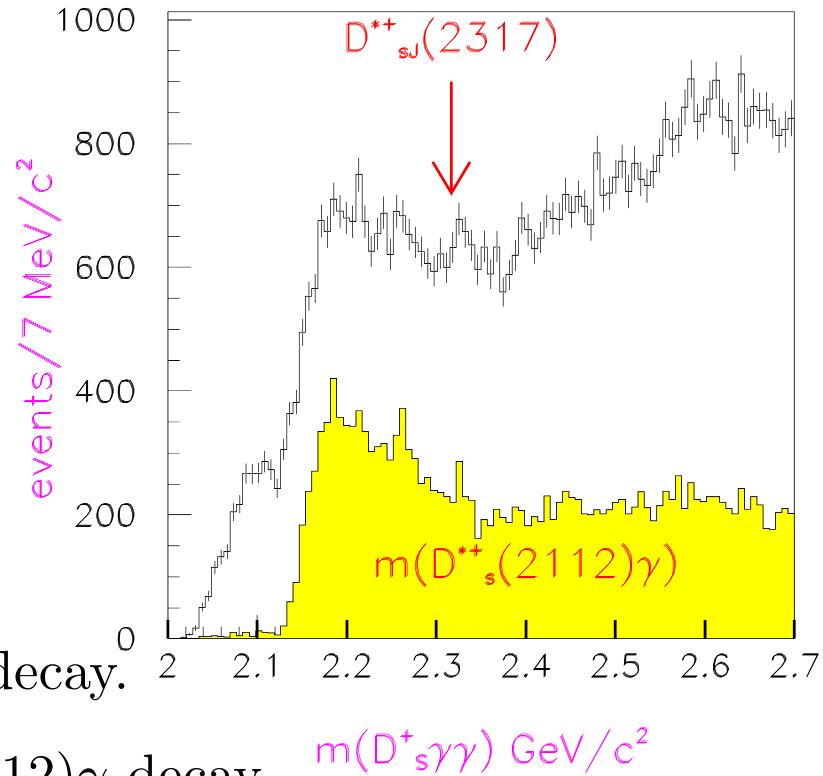
- ☐ Require that the γ is not part of any π^0 candidate.
- ☐ Require $p^*_{D_s\gamma} > 3.5$ GeV/c.
- ☐ $D_s^+\gamma$ mass spectrum.



- ☐ No significant $D_{sJ}^{*+}(2317)$ signal in the $D_s^+\gamma$ mass spectrum.

Search for $D_{sJ}^{*+}(2317)$ decay to $D_s^+\gamma\gamma$ and $D_s^{*+}(2112)\gamma$.

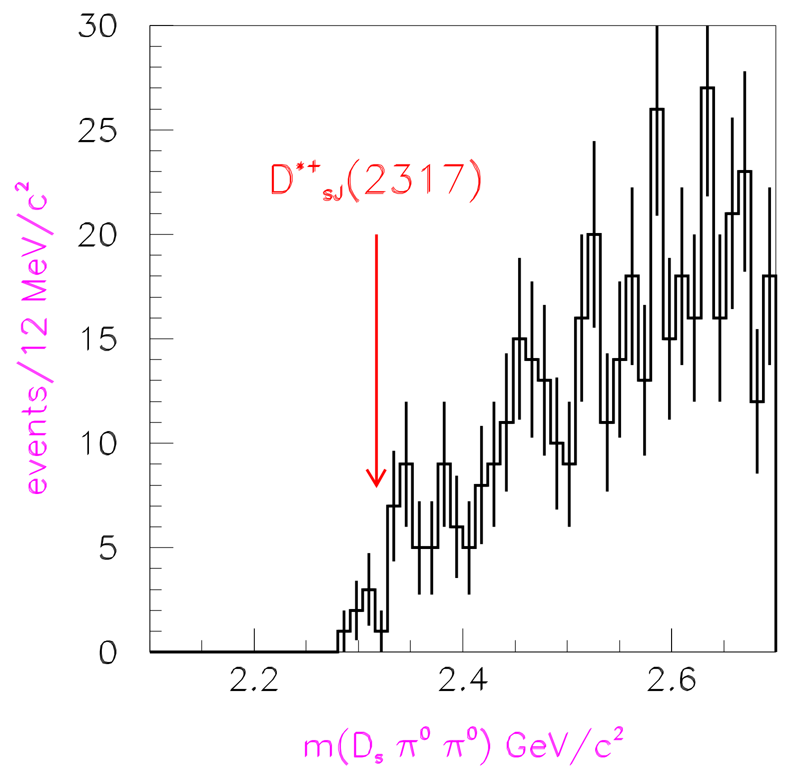
- Select events with $p^* > 3.5$ GeV/c.
- Exclude any γ which is part of a π^0 candidate.



- At the present level of statistics.
  - No significant $D_{sJ}^{*+}(2317) \rightarrow D_s^+\gamma\gamma$ decay.
  - No significant $D_{sJ}^{*+}(2317) \rightarrow D_s^{*+}(2112)\gamma$ decay.
- The wide bump at ≈2.18 GeV is due to the combination of the $D_s^{*+}(2112)$ with another γ in the same event.

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

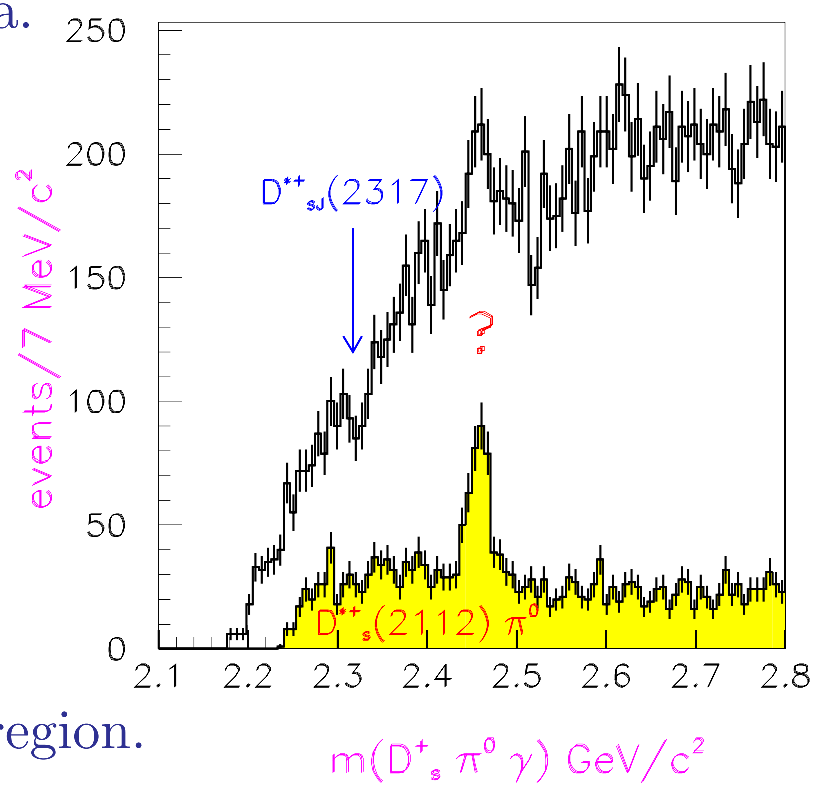
- Neither γ from a π^0 can be part of any other π^0.
- Require $p^* > 3.0$ GeV/c.



- Limited statistics. No prominent structure at the mass of $D_{sJ}^{*+}(2317)$.

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

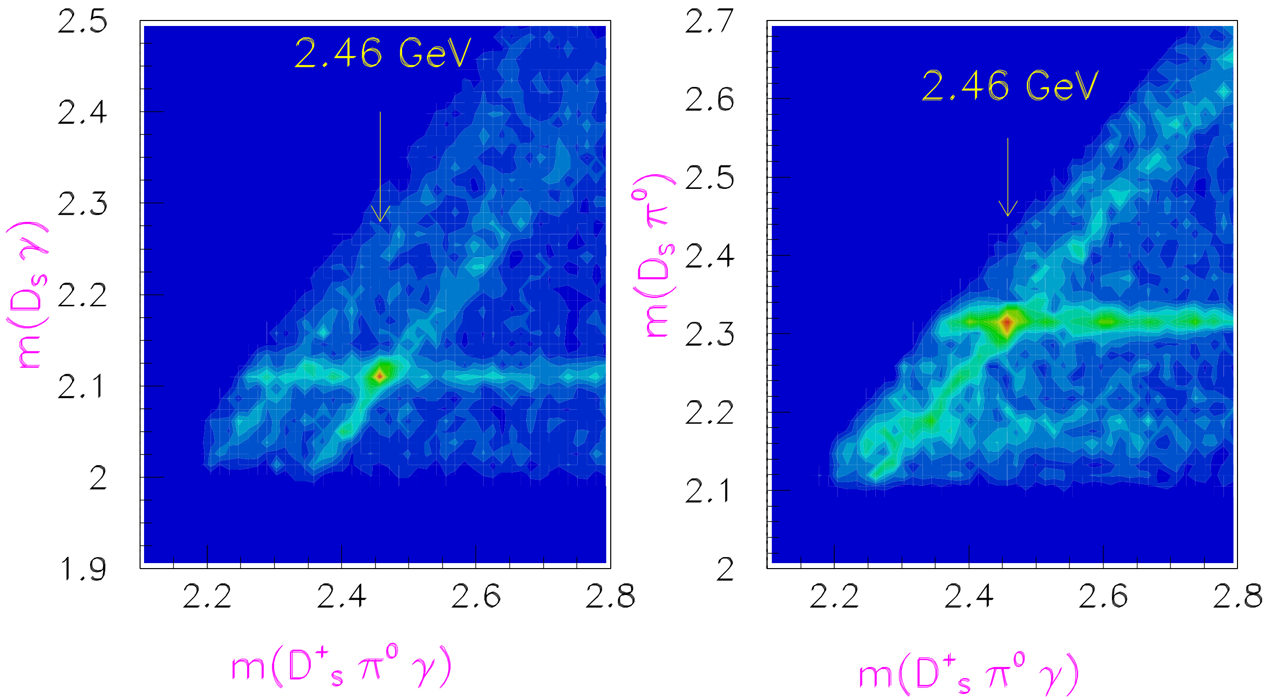
- Require $p^*_{D_s\pi^0\gamma} > 3.5$ GeV/c.
- Require the π^0 lab. momentum > 300 MeV/c.
- Neither γ from a π^0 can be part of any other π^0.
- The bachelor γ cannot belong to any π^0 candidate.
- $D_s^+\pi^0\gamma$ and $D_s^{*+}(2112)\pi^0$ mass spectra.



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

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

□ The scatter diagrams of $m(D_s^+\gamma)$ and $m(D_s^+\pi^0)$ vs. $m(D_s\pi^0\gamma)$ exhibit bands due to $D_s^{*+}(2112)$ and $D_{sJ}^{*+}(2317)$ which cross near $m(D_s^+\pi^0\gamma)$= 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 just discussed would result in a narrow signal in $m(D_s^+\pi^0)$ near 2.32 GeV.

□ Two ways to test this hypothesis:

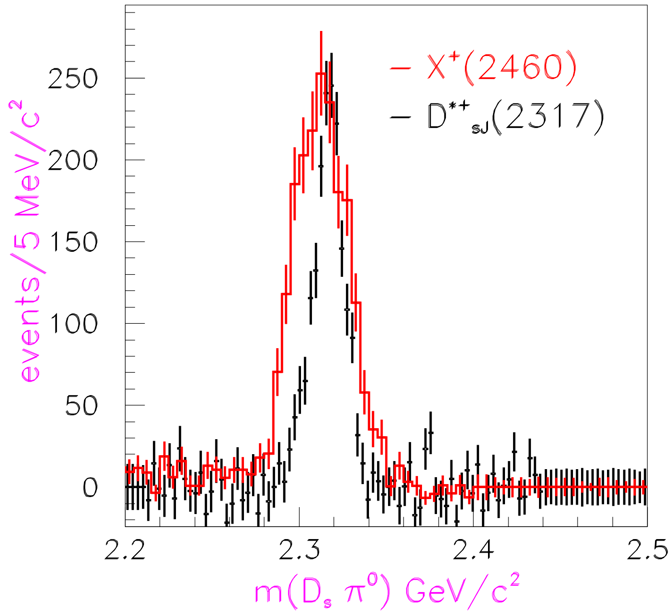
- The $D_{sJ}^{*+}(2317)$ lineshape.
- Comparison of the $D_{sJ}^{*+}(2317)/X^+(2460)$ relative rates for data and $X^+(2460)$ Monte Carlo simulation.

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

□ Use of Monte Carlo simulation of:

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

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



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

□ Fitting the reflection with a Gaussian we obtain the following parameters:

$$m = 2312.6 \pm 0.6 \quad MeV \qquad \sigma = 15.1 \pm 0.5 \quad MeV$$

to be compared with those of the signal:

$$m = 2317.0 \pm 0.4 \quad MeV \qquad \sigma = 9.0 \pm 0.4 \quad MeV$$

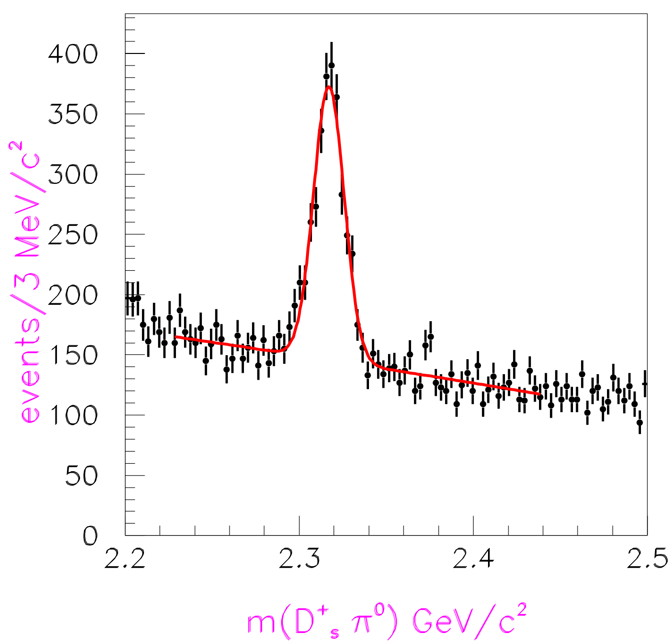
□ The reflection is wider and shifted: the shift can be removed by increasing the mass of the $X^+(2460)$ but the width cannot be reduced to ≈ 9 MeV.

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

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

□ A further test consists in checking whether the $D_{sJ}^{*+}(2317)$ is well-described by a single Gaussian.

□ $D_s^+\pi^0$ mass spectrum in 3 MeV bins for $p^* > 3.0$ GeV/c.



□ A single Gaussian fit has a probability of 67 %; for two Gaussians the fit probability is 87%.

□ Conclusion: the $D_s^{*+}(2317)$ lineshape is consistent with a single Gaussian.

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

□ The second test is to compute the ratio $D_{sJ}^{*+}(2317)/X^+(2460)$ for data and Monte Carlo for $X^+(2460) \rightarrow D_s^{*+}(2112)\pi^0$ 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 ≈ 6 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 $D_s^{*+}(2112)\pi^0$.

Experimental Summary.

□ A large (≈ 2200 events), narrow signal has been observed in the inclusively-produced $D_s^+\pi^0$ mass distribution for the D_s^+ decay mode:

$$D_s^+ \rightarrow K^+K^-\pi^+$$

□ The signal is also observed for the D_s^+ decay mode:

$$D_s^+ \rightarrow K^+K^-\pi^+\pi^0$$

□ The fitted mass value is:

$$m = 2316.8 \pm 0.4 \qquad MeV/c^2 \qquad (statistical \quad error \quad only)$$

The mass scale uncertainty is very conservatively estimated to be $\pm 3\ MeV/c^2$*.*

□ 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 spin-parity assignments cannot be excluded.

□ There is a small peak in the $D_s^+ \pi^0 \gamma$ mass distribution at ≈ 2.46 GeV. However, a complex kinematic configuration exists at this mass value due to overlap of $D_{sJ}^{*+}(2317)$ and $D_s^{*+}(2112)$ resonance bands, so that this region requires careful study. This work is underway at present.

□ The possibility that the $D_{sJ}^{*+}(2317)$ signal might result entirely from the production of an $X^+(2460)$ state decaying to $D_s^{*+}(2112)\pi^0$ has been explored and excluded.

Physics Summary.

□ We have observed a state at 2.32 GeV/c^2 whose measured width is consistent with the mass resolution, therefore $\Gamma < 10$ MeV.

□ To date, this state has been seen only in $D_s^+ \pi^0$.

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

□ Assuming parity conservation, this state decays to two pseudoscalar mesons. The parity of the final state is therefore:

$$P = \eta_{D_s} \eta_\pi (-1)^L = (-1)(-1)(-1)^J$$

where L=orbital angular momentum =J, since D_s and π^0 have spin 0. Therefore this state has natural spin-parity:

$$P = (-1)^J \qquad i.e. \quad J^P = 0^+, 1^-, 2^+, 3^-, ...$$

Physics Summary.

□ $J^P = 0^+$ seems to be the most likely spin-parity assignment. This is supported by the absence of a signal in $D_s^+\gamma$ and $D_s^+\pi^0\pi^0$.

□ In this hypothesis, the decay of $D_{sJ}^{*+}(2317)$ to $D_s^{*+}(2112)\gamma$ is allowed, but absent in the data with the present level of statistics.

□ If the isospin of this state is I=0, since the $D_s^+\pi^0$ system has isospin I=1, this decay violates isospin conservation. This would explain the small width.

□ Work is in progress to search for $D_s^+\pi^\pm$ decay modes.

What can this state be?

□ A multi-quark state (conjectured by N. Isgur and H. Lipkin).

□ An isospin conserving decay of a multiquark state should have a rather large width. Meson candidates for 4-quark states presently are:

$$f_0(980) \to (\pi\pi)/(K\bar{K}) \qquad \Gamma = 40 - 100 \quad MeV$$

$$a_0(980) \to (\eta\pi)/(K\bar{K}) \qquad \Gamma = 50 - 100 \quad MeV$$

where no isospin violation is involved in these decays.

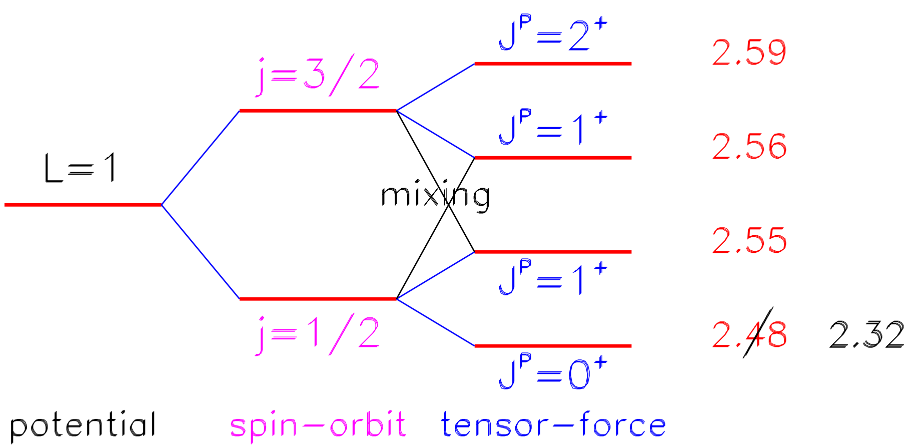
□ In the hypothesis of a multi-quark or a DK bound state, $D_{sJ}^{*+}(2317)$ should have I=0 in order to account for the small width.

What can this state be?

□ The 2.32 GeV state can be the missing P wave $c\bar{s}$ state with $J^P = 0^+$.

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

□ Potential models predict the following pattern for P wave D_s mesons:



□ Our result disagrees with expectations. The mass, width and decay modes for this state are quite different from those expected.

□ Most likely these models need modification.

Backup slides

$D_s^+\pi^0\gamma$ Monte Carlo simulations.

□ Monte Carlo simulation $e^+e^- \to \bar{c}c$ with included the new $D_{sJ}^{*+}(2317)$.

□ The scatter diagrams of $m(D_s^+\gamma)$ and $m(D_s^+\pi^0)$ vs. $m(D_s\pi^0\gamma)$ exhibit also in this case bands due to $D_s^{*+}(2112)$ and $D_{sJ}^{*+}(2317)$ which cross near $m(D_s^+\pi^0\gamma)$= 2.46 GeV.