Two new, strange, charmed mesons in BABAR.

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Representing the BaBar Collaboration

KEK Seminar

November 11, 2003

Outline.

- **Introduction.**
- **A few words on the BaBar experiment.**
- **Event 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 throughout all this work.)

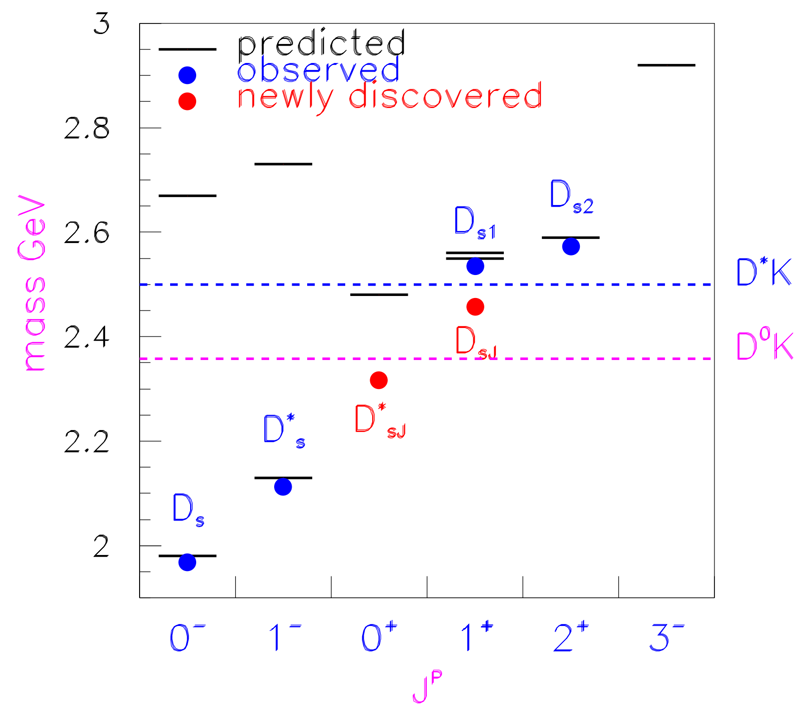
Introduction.

□ Up to six months ago, the spectrum of the $c\bar{s}$ D_s mesons still contained empty slots.

□ Potential models, such as the one from Godfrey-Isgur-Kokoski, predict 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.

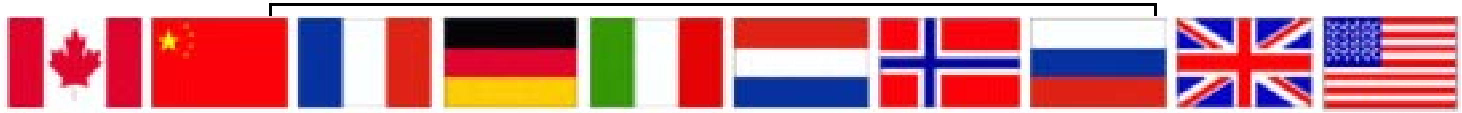
□ The model also predicts two 1^+ states at masses of 2.55 and 2.56 GeV.

□ Potential model expectations and experimental status for D_s mesons: ⟶



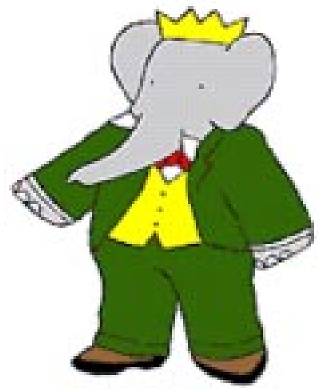
□ Remarkably good agreement up to now.

□ *Exception: the newly discovered states at 2.317 and 2.458 GeV/c^2 with $J^P = 0^+$ and 1^+ respectively as the most probable assignments.*



The BaBar Collaboration

10 countries
77 Institutions
~580 Physicists



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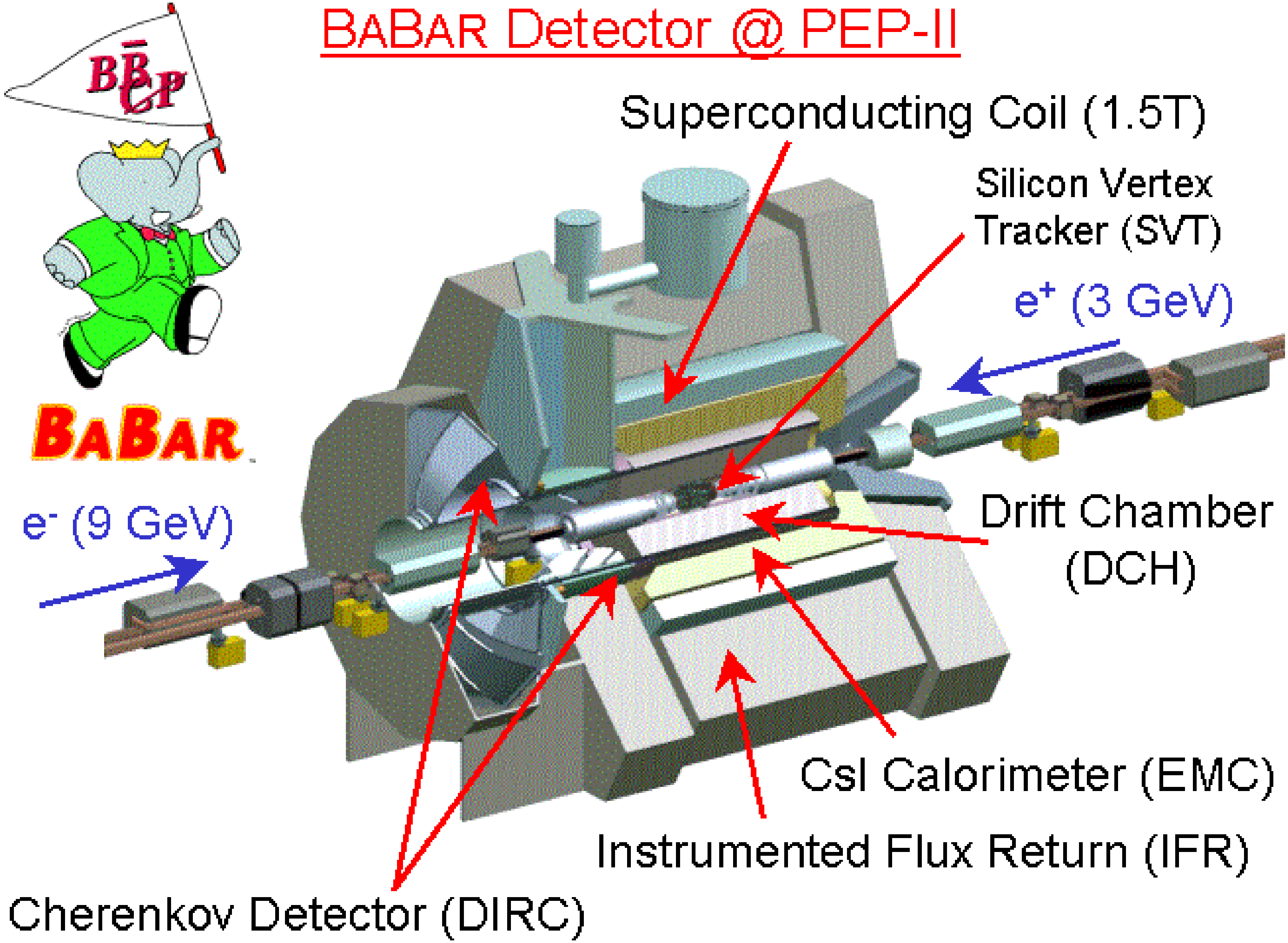
BABAR Detector @ PEP-II



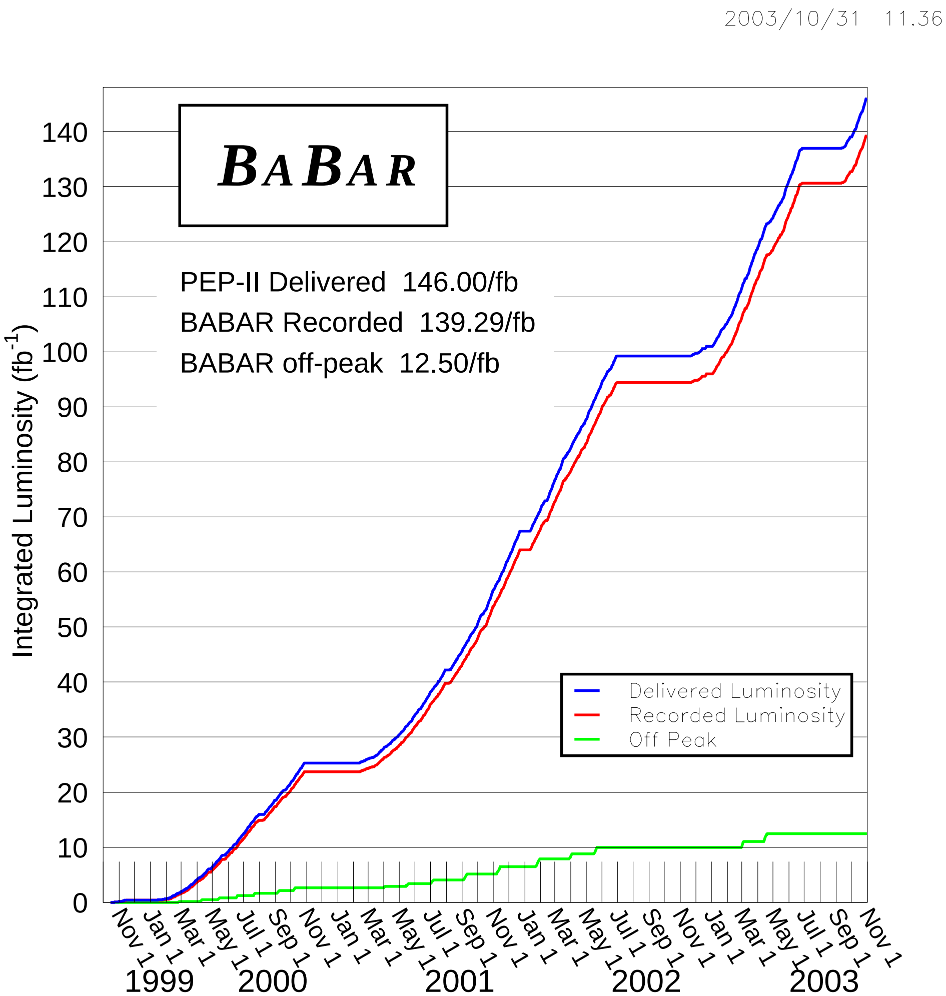
Charm Physics in BaBar.

□ The power of BaBar for Charm Physics is based on:

- Relatively small combinatoric background 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.

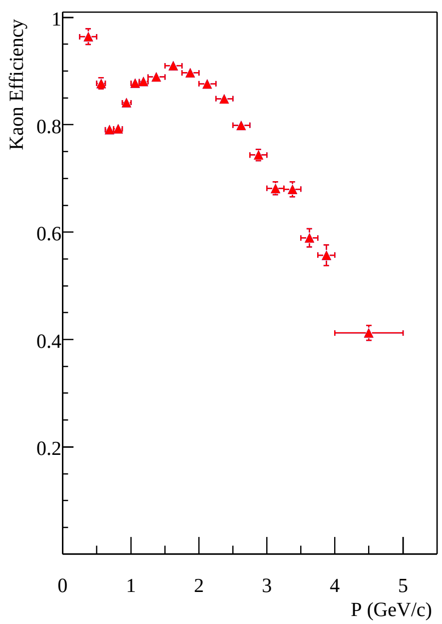


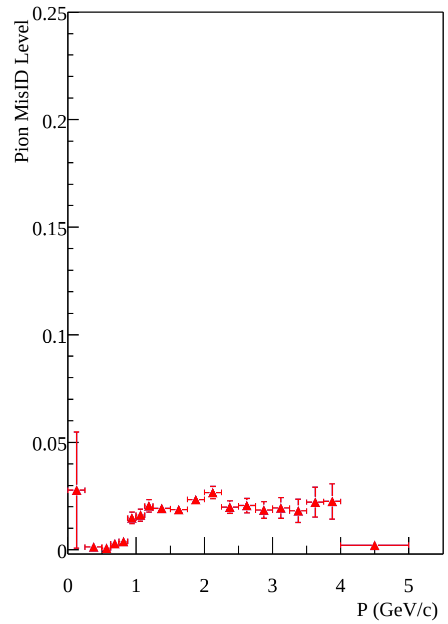
PID Performance.

□ Particle Identification is 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.*

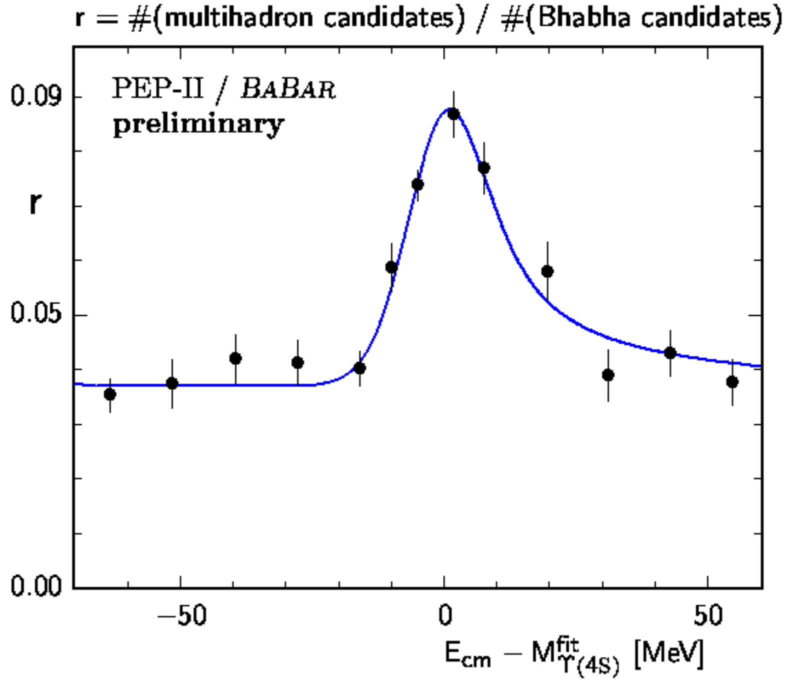




Charm Physics in BaBar.

- 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



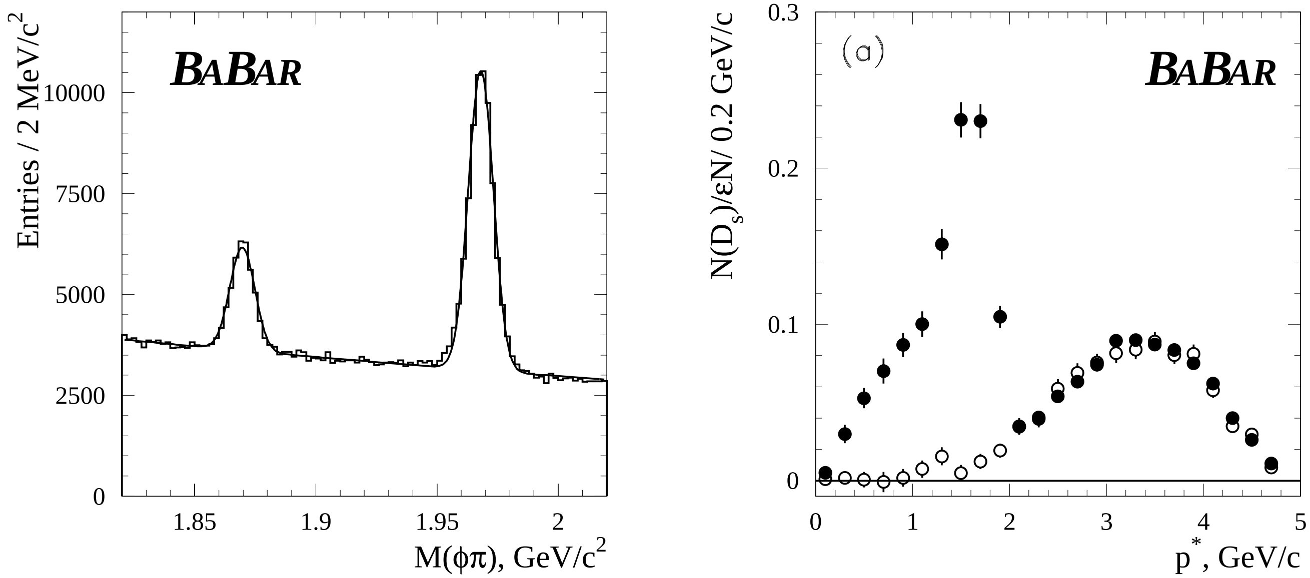
- Charm Analyses are performed on data corresponding to continuum $\bar{c}c$ production.

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

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:

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

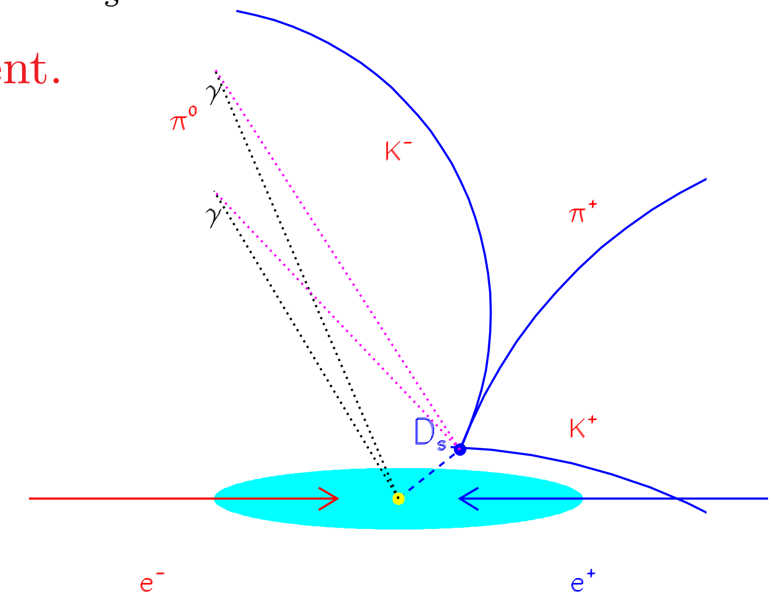
□ This final state has been selected using the following procedure:

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

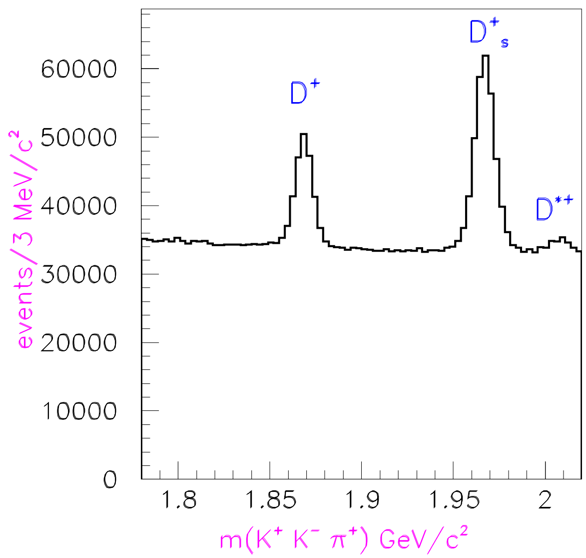
  □ Qualitative sketch, not to scale, of one event.

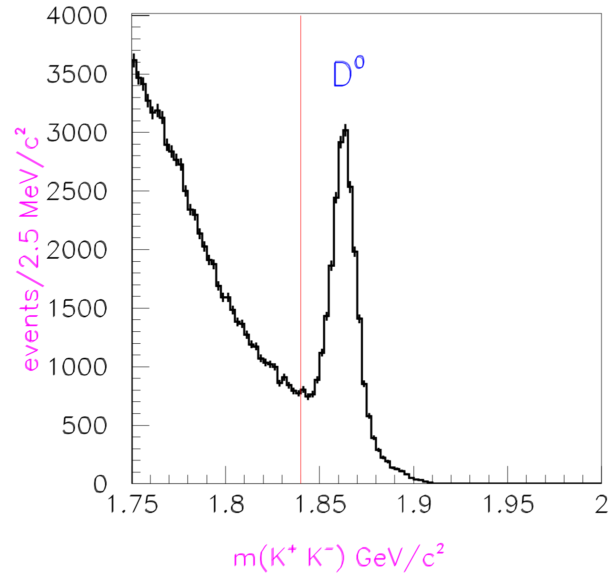


- Each $K^+K^-\pi^+\pi^0$ candidate must satisfy $p^* > 2.5$ GeV/c.

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

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





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

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

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

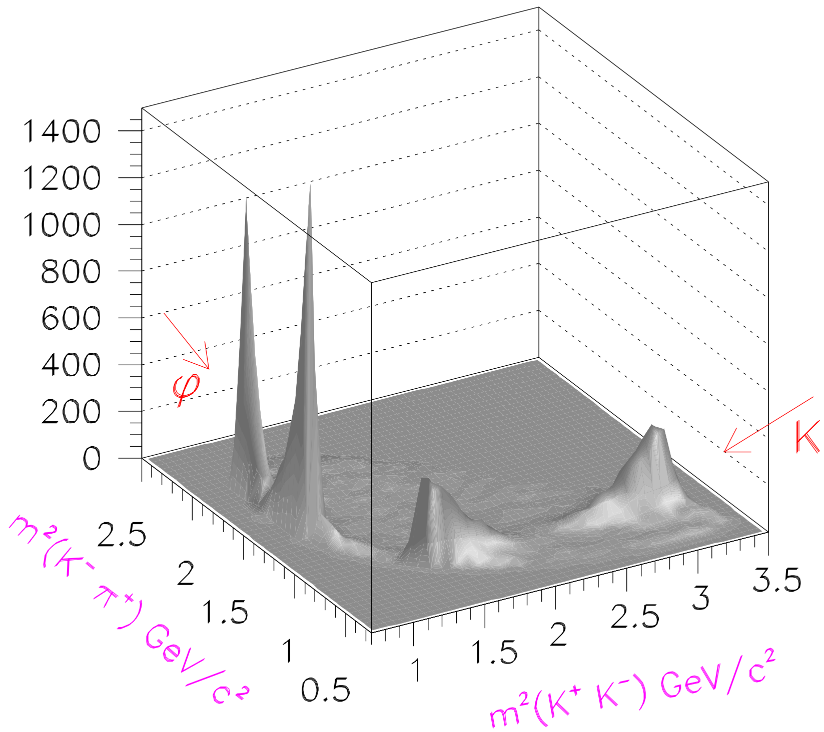
removed requiring: $m(K^+K^-) < 1.84$ GeV.

□ $\approx 131 \times 10^3$ 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:

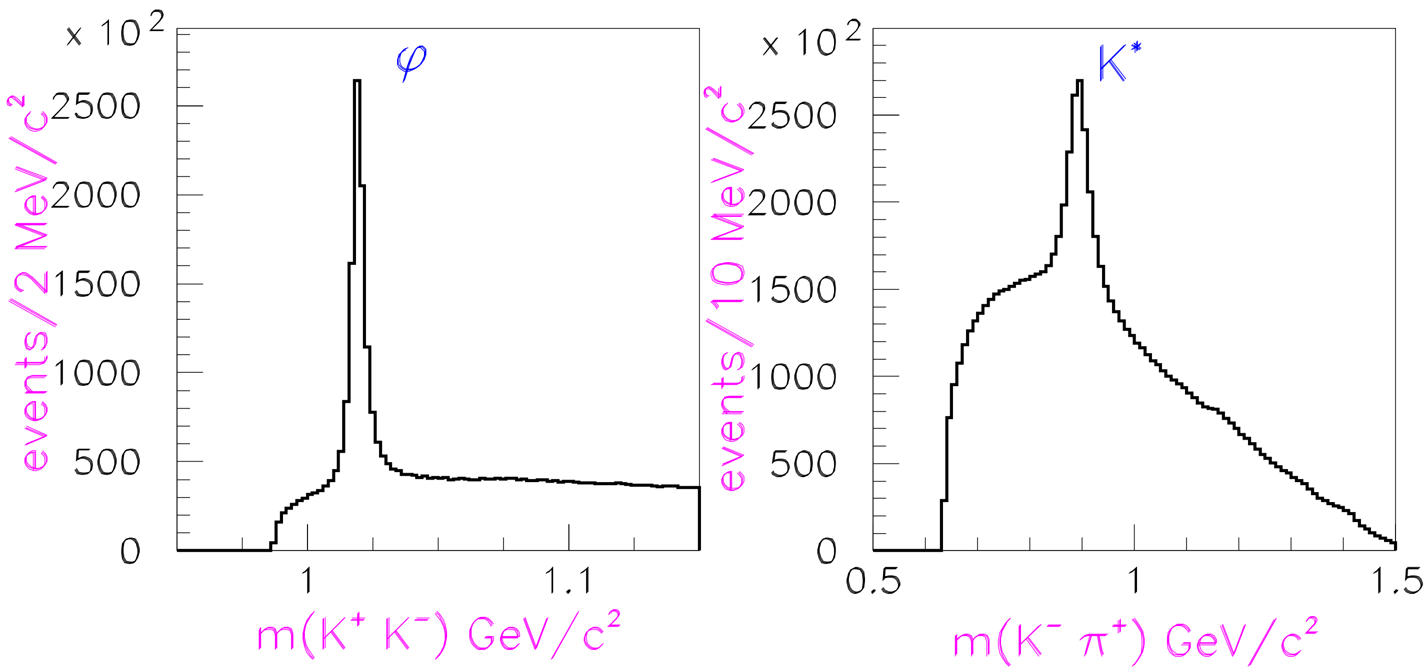
Real Data: $D_s^+ \to K^+K^-\pi^+$ Dalitz plot tagged with $D_s^*(2112)^+ \to D_s^+\gamma$



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

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

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

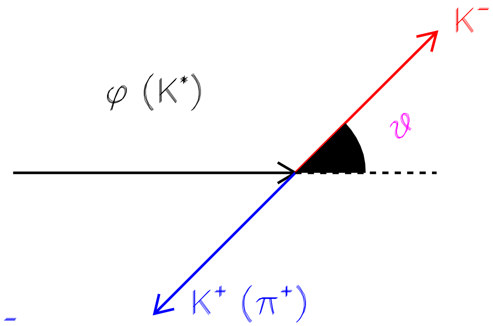


- ϕ selected requiring: $| m(K^+K^-) - 1.019 | \leq 0.01 \quad GeV$

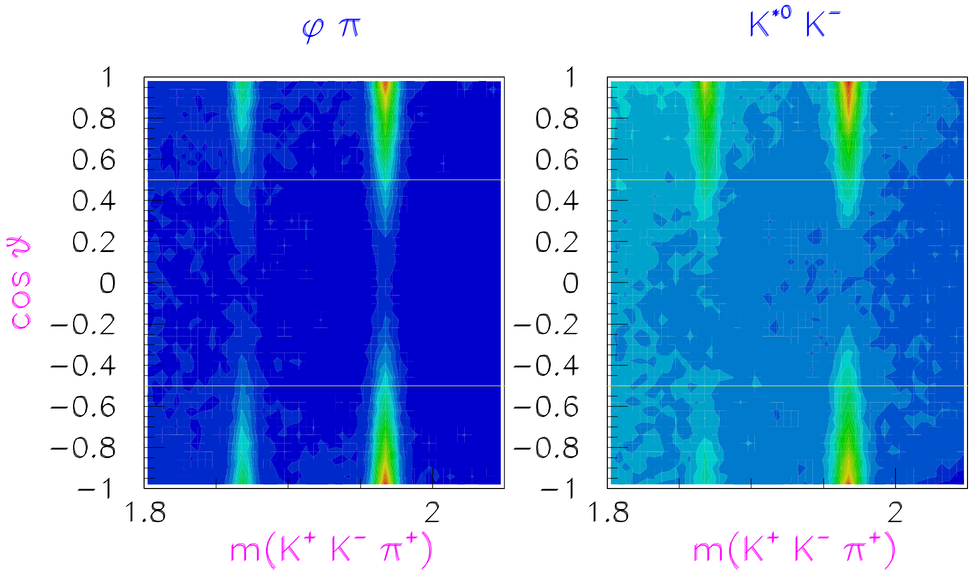
- $\overline{K^{*0}}$ selected requiring: $| m(K^-\pi^+) - 0.896 | \leq 0.05 \quad GeV$

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.



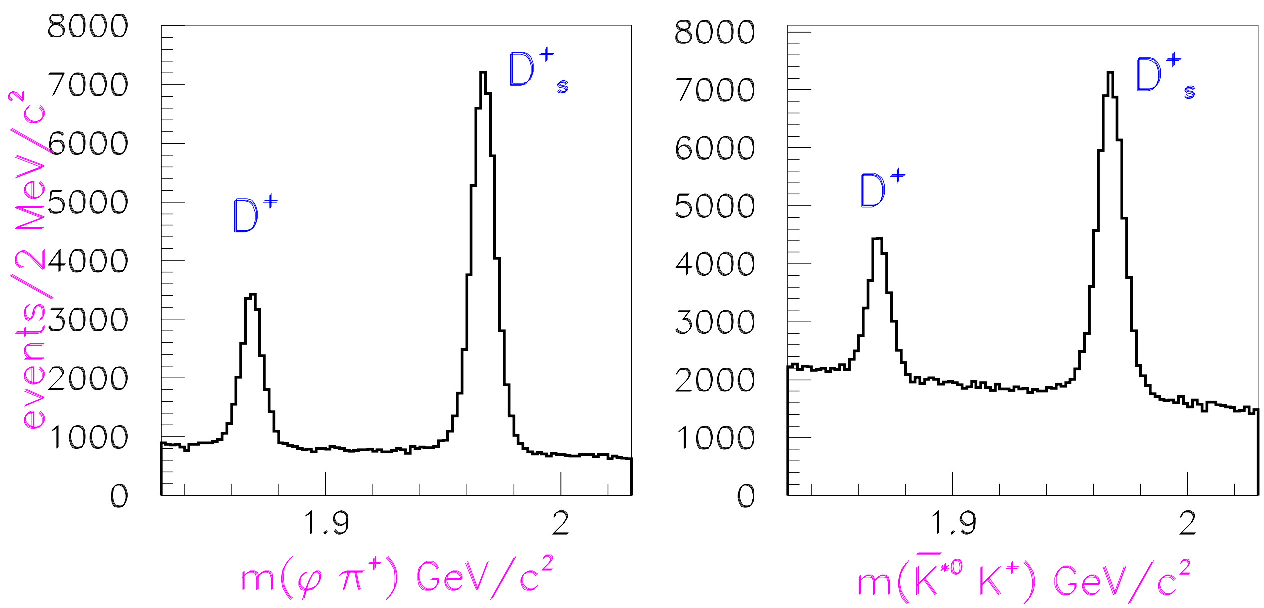
□ Scatter diagram of $cos\theta$ vs. $m(K^+K^-\pi^+)$:



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

Resulting mass spectra.

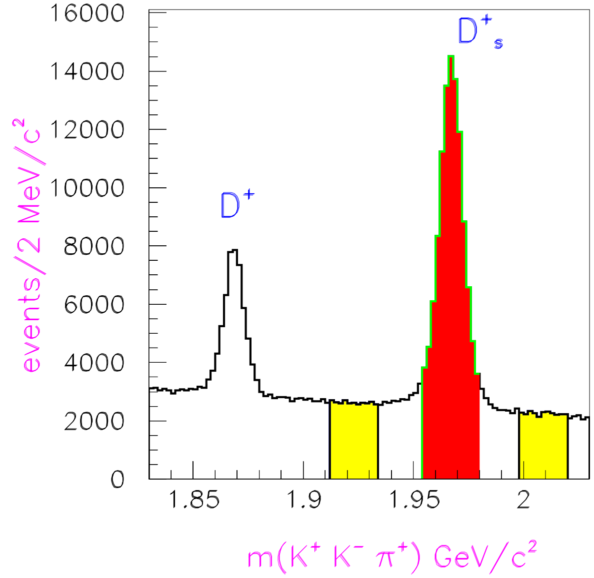
☐ Resulting $\phi\pi^+$ and $\overline{K^{*0}}K^+$ mass spectra:



☐ The two samples 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:

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

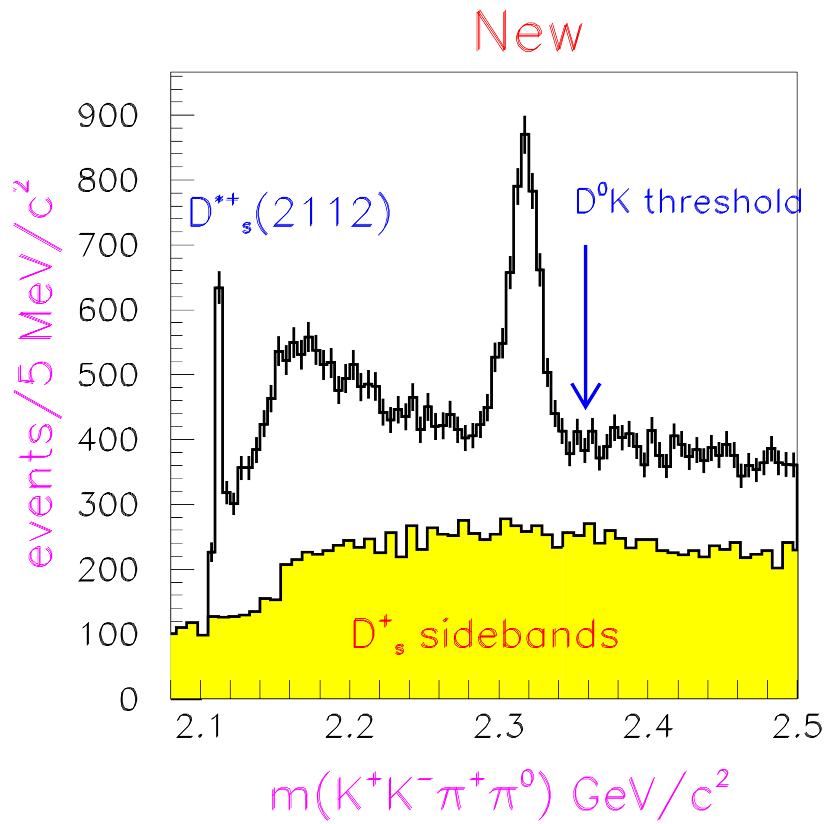
and two sideband regions as:

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

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

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

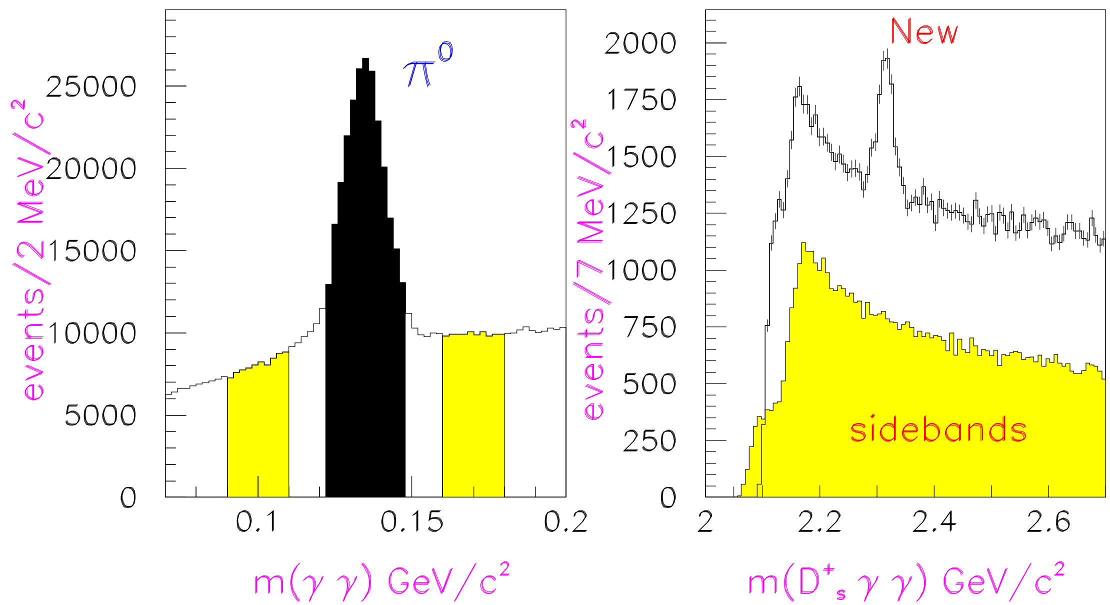
- Compare $(K^+K^-\pi^+)\pi^0$ mass spectra for the D_s^+ signal region and sidebands.
- We observe the known decay: $D_s^*(2112)^+ \rightarrow D_s^+\pi^0$.
- **Totally unexpected large signal ($\approx$ 2200 events) at 2.32 GeV.**



- 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 GeV.**
- $D_s^*(2112)^+$ signal washed out because of "π^0" resolution.



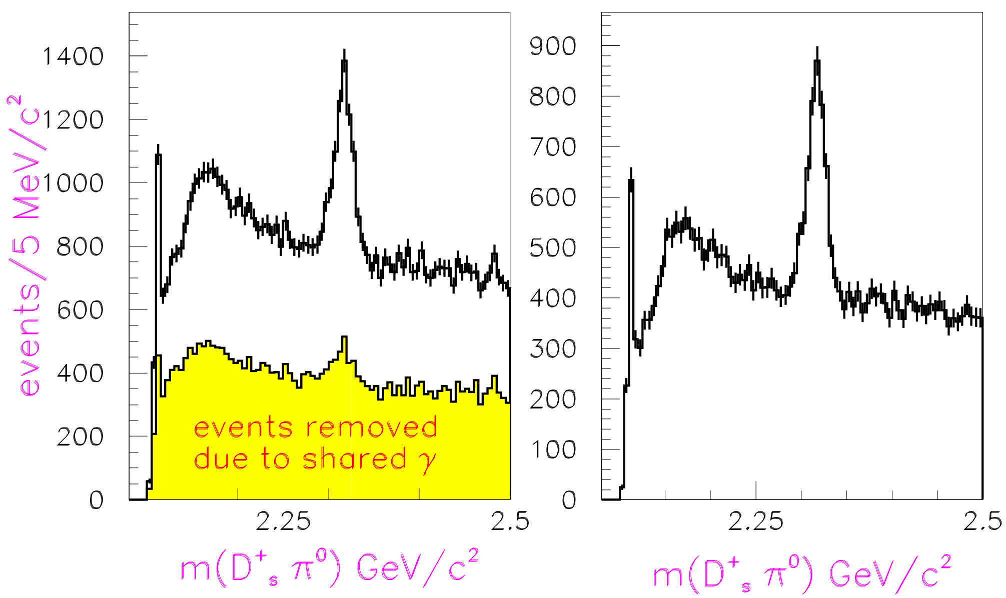
- π^0 sidebands: no signals.

$D_s^+\pi^0$ 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:

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

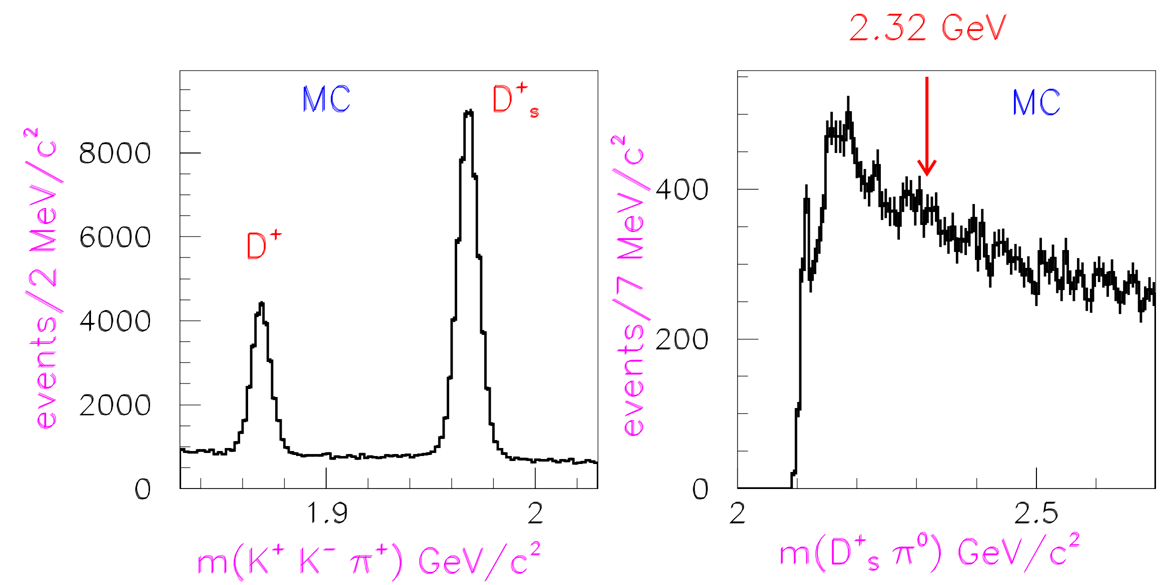
have been simulated using GEANT4. They have been reconstructed and analyzed using the same analysis procedure as that used for data.

□ The generated events contain all 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.



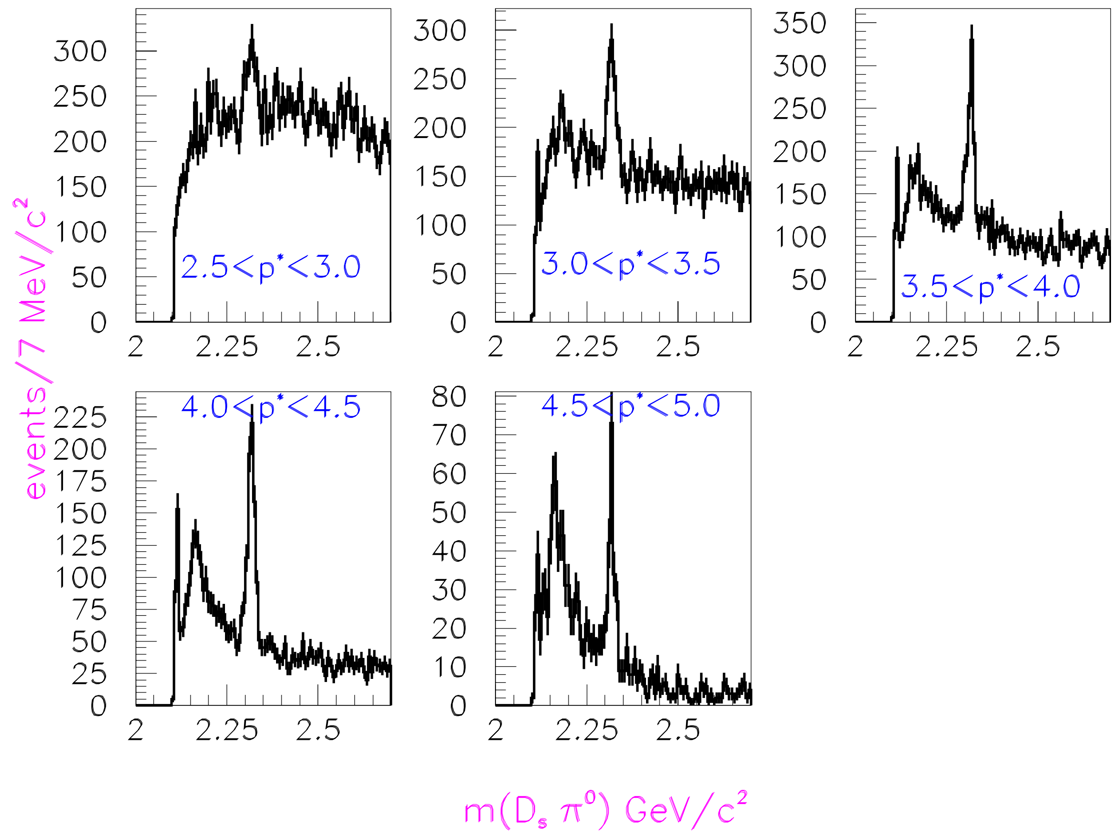
□ We observe the known decay: $D_s^*(2112)^+ \rightarrow D_s^+\pi^0$.

□ 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.**

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^*.

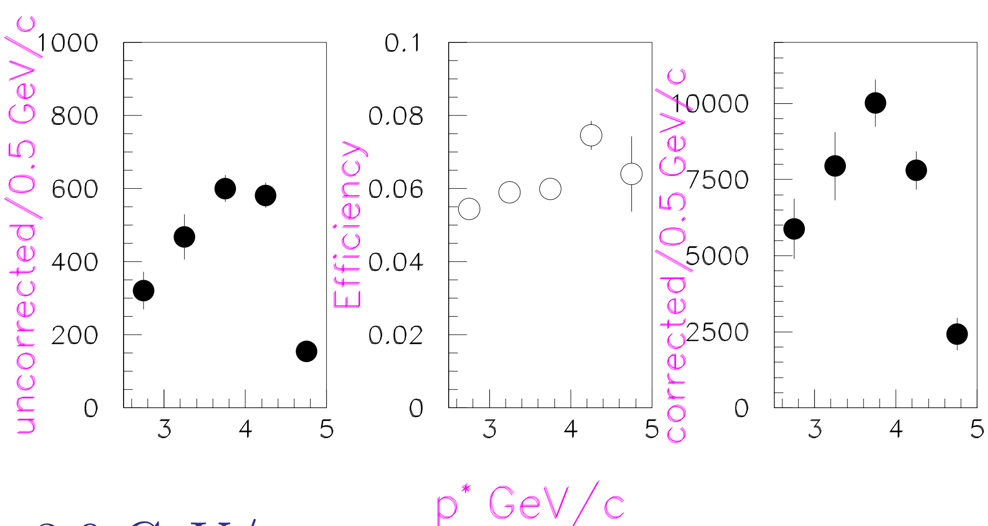
□ The signal to background ratio can be improved by means of a p^* selection.

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.

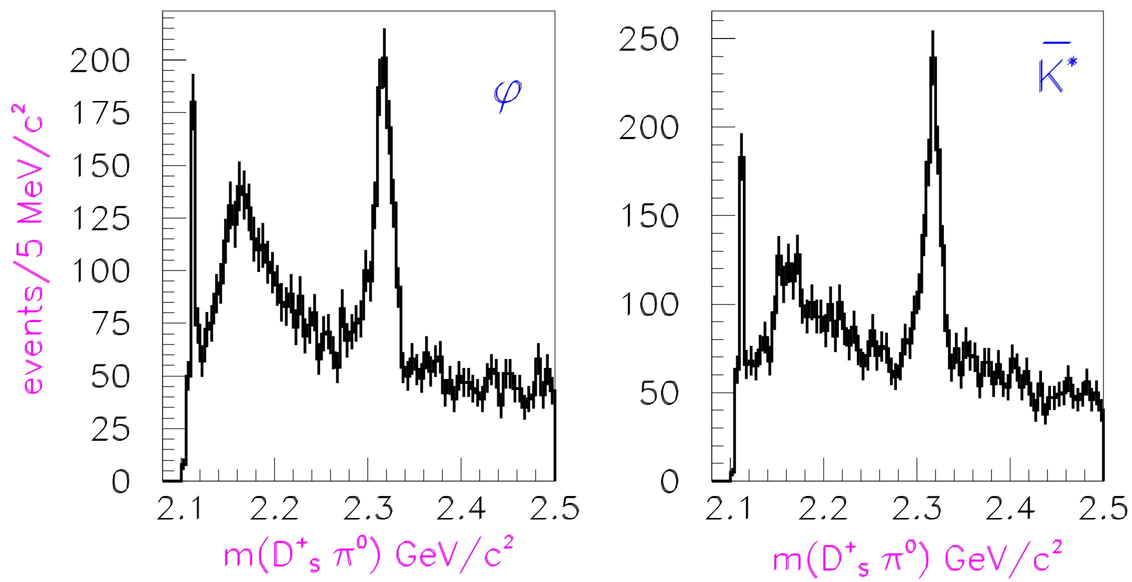
□ Uncorrected and corrected p^* distributions.



□ 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.

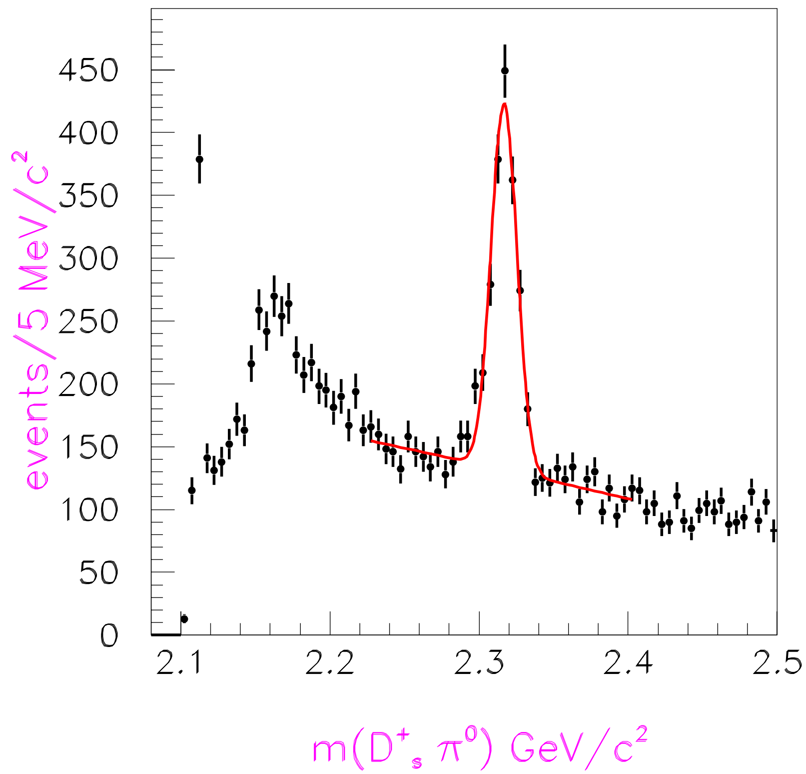


- $D_s^*(2112)^+$ and 2.32 GeV signals present in both distributions with similar strengths.

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

□ Require $p^* > 3.5$ GeV/c.

We will fit this spectrum again later.



□ Fit with a polynomial and a single Gaussian.

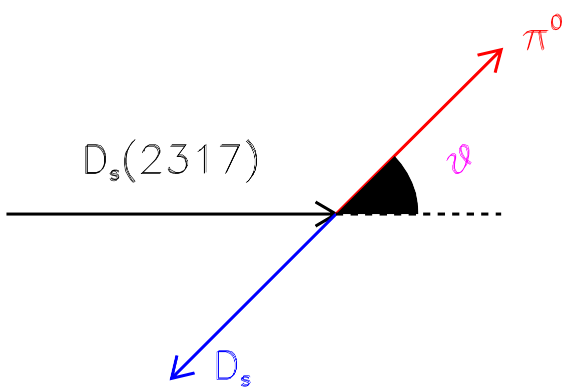
$$m = 2316.8 \pm 0.4 \quad GeV \qquad \sigma = 8.6 \pm 0.4 \qquad MeV$$

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

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

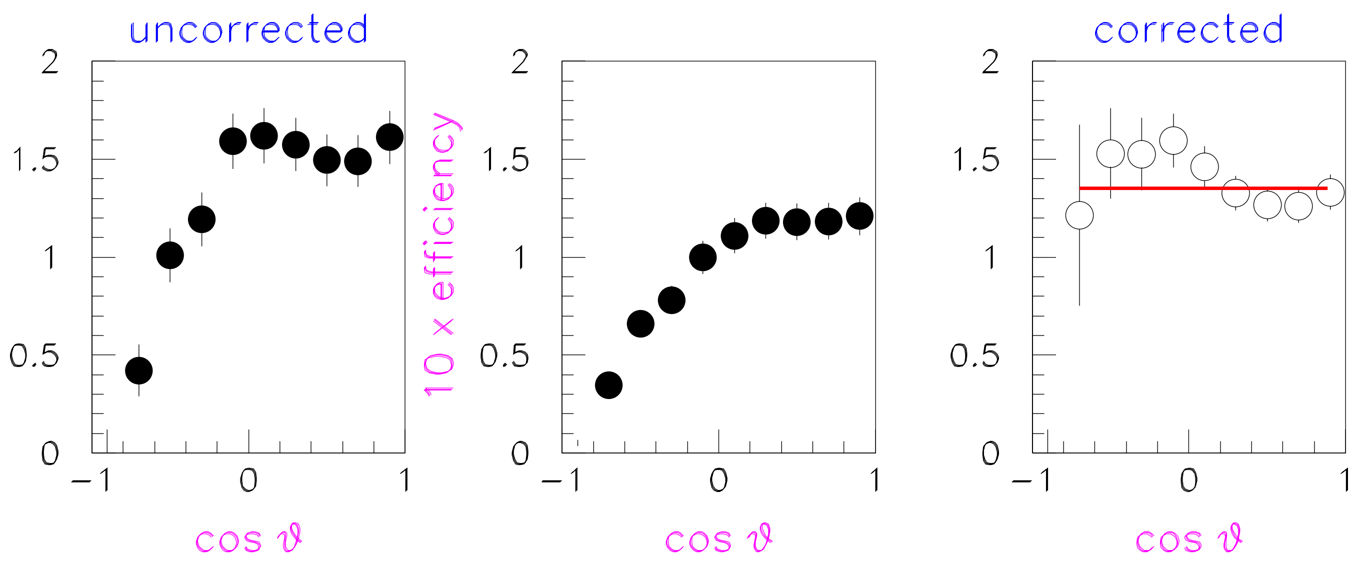
□ In the case of polarized production, the decay angular distribution can give information on the spin of the particle.

□ 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 $cos\theta$ 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:

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

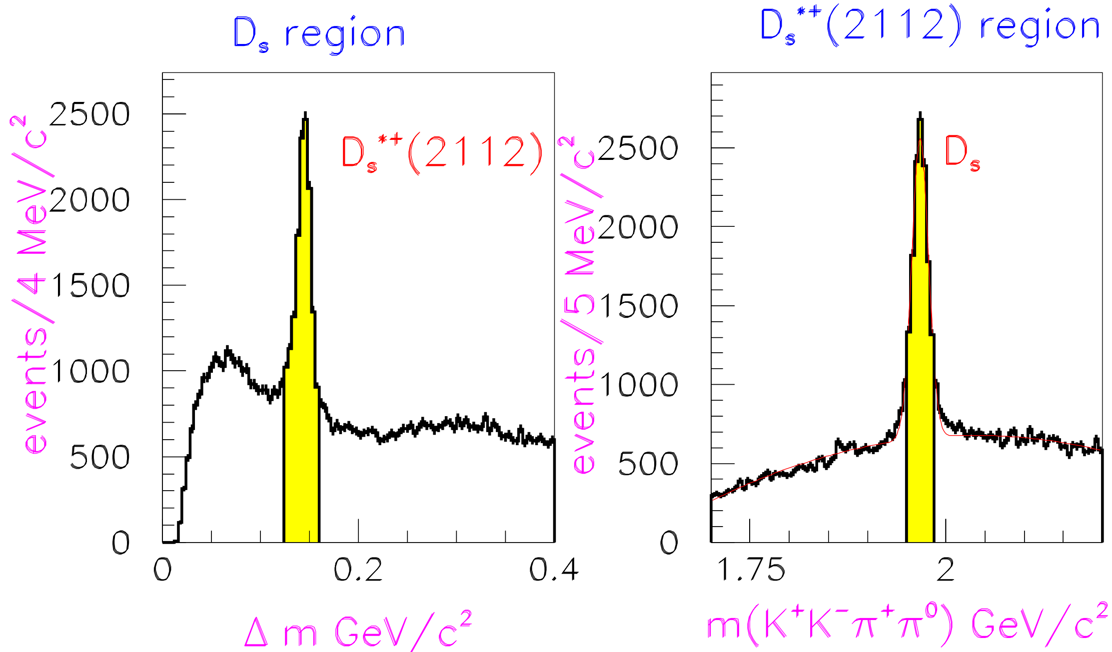
for the D_s^+ region, defined as:

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

- 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:

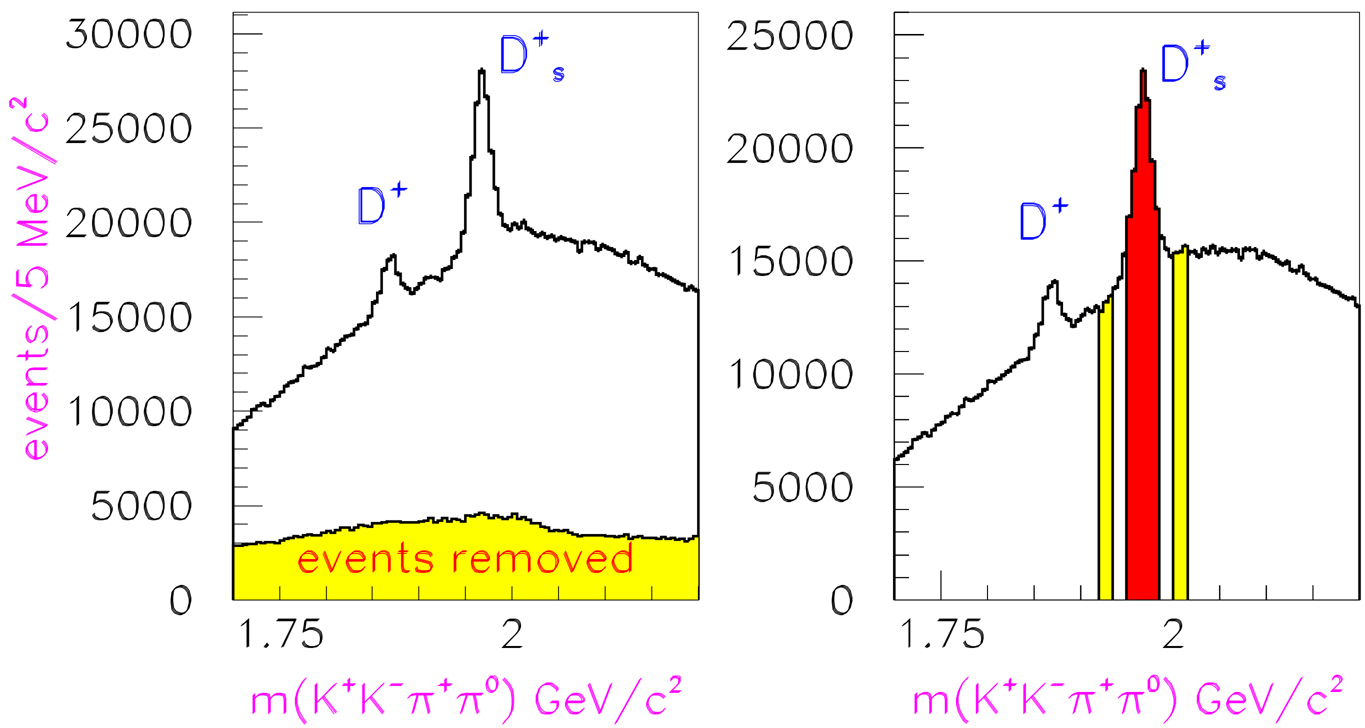
$$m_{D_s \to K^+K^-\pi^+} = 1967.20 \pm 0.03 \qquad MeV$$

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

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

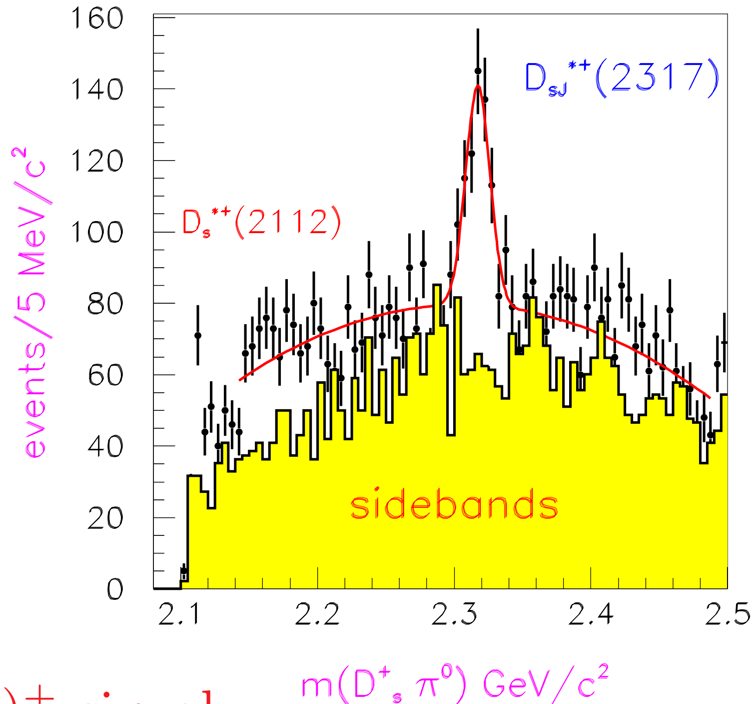
□ Combinatorial $K^+K^-\pi^+\pi^0$ effective mass.

□ 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.



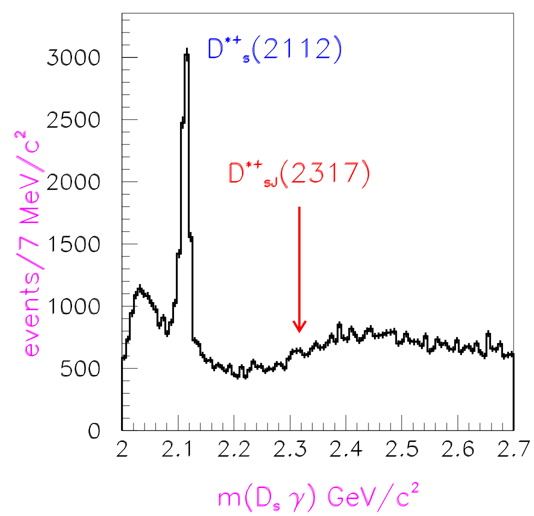
- There is a $D_s^*(2112)^+$ signal.
- No signals for the D_s^+ sideband regions.
- **There is a clear $D*_J(2317)^+$ signal with the following parameters:**

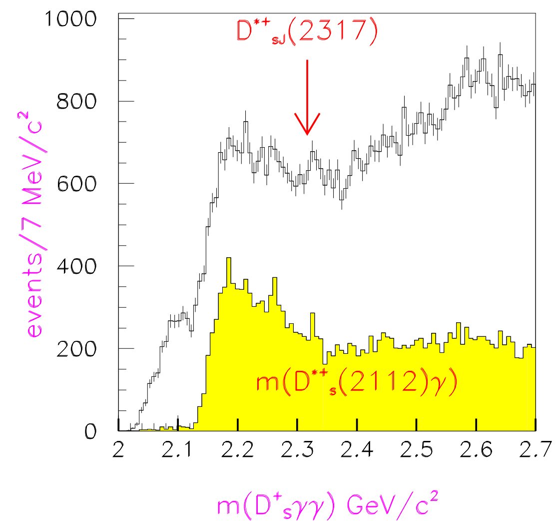
$$m = 2317.6 \pm 1.3 \quad MeV \qquad \sigma = 8.8 \pm 1.1 \quad MeV$$

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

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

- ☐ Require that a bachelor γ to be not part of any π^0 candidate.
- ☐ Require the particle combination under study have $p^* > 3.5$ GeV/c.

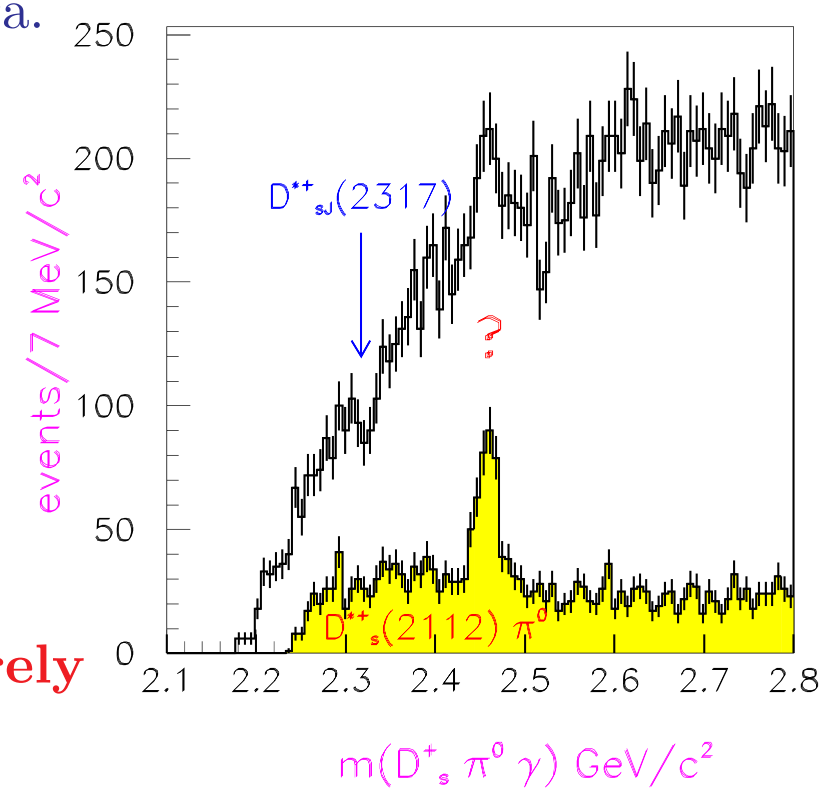




- ☐ At the present level of statistics.
  - No significant $D_{sJ}^*(2317)^+ \to D_s^+\gamma$ decay.
  - No significant $D_{sJ}^*(2317)^+ \to D_s^+\gamma\gamma$ decay.
  - No significant $D_{sJ}^*(2317)^+ \to D_s^*(2112)^+\gamma$ decay.

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

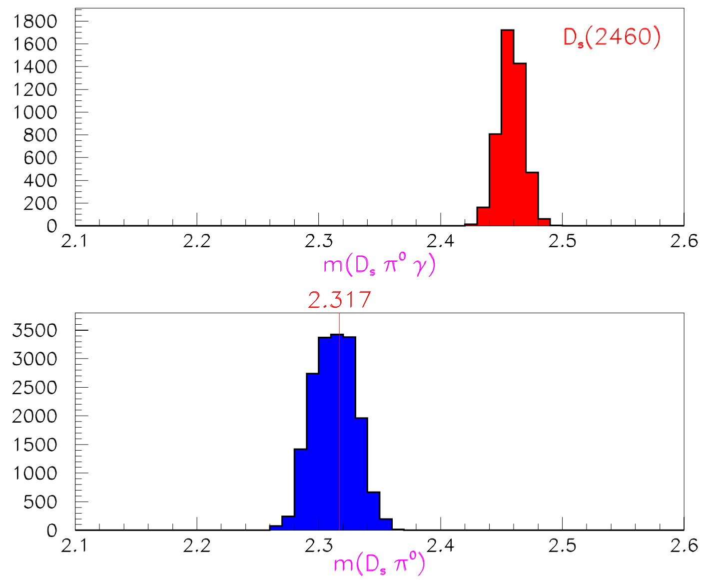
- Require $p^*_{D_s\pi^0\gamma} > 3.5$ GeV/c.
- Require the π^0 lab. momentum > 300 MeV/c.
- Neither γ from a π^0 can be part of any other π^0.
- The bachelor γ cannot belong to any π^0 candidate.
- $D_s^+\pi^0\gamma$ and $D_s^*(2112)^+\pi^0$ mass spectra.



- No significant signal in the 2.32 GeV region.
- **Structure at $\approx$ 2.46 GeV which seems to be associated almost entirely with the $D_s^*(2112)^+$ region.**

Could the $D^*_{sJ}(2317)^+$ signal be due to the decay of a narrow state at 2.46 GeV?

□ 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:

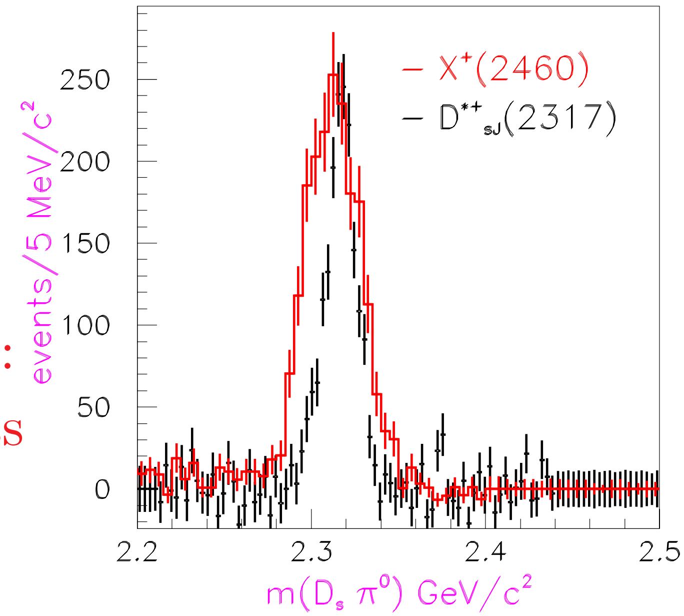
- The $D^*_{sJ}(2317)^+$ lineshape.
- Comparison of the $D^*_{sJ}(2317)^+/X(2460)^+$ relative rates for data and $X(2460)^+$ Monte Carlo simulation.

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

□ Use of Monte Carlo simulation of:

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

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



□ The reflection is wider (15 MeV) and shifted: the shift can be removed by increasing the mass of the $X(2460)^+$ but the width cannot be reduced to $\approx$ 9 MeV.

□ **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 $X(2460)^+ \rightarrow D^*_s(2112)^+\pi^0$ with no D^{*+}_{sJ} generated.

□ For $p^* > 3.0$ GeV/c:

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

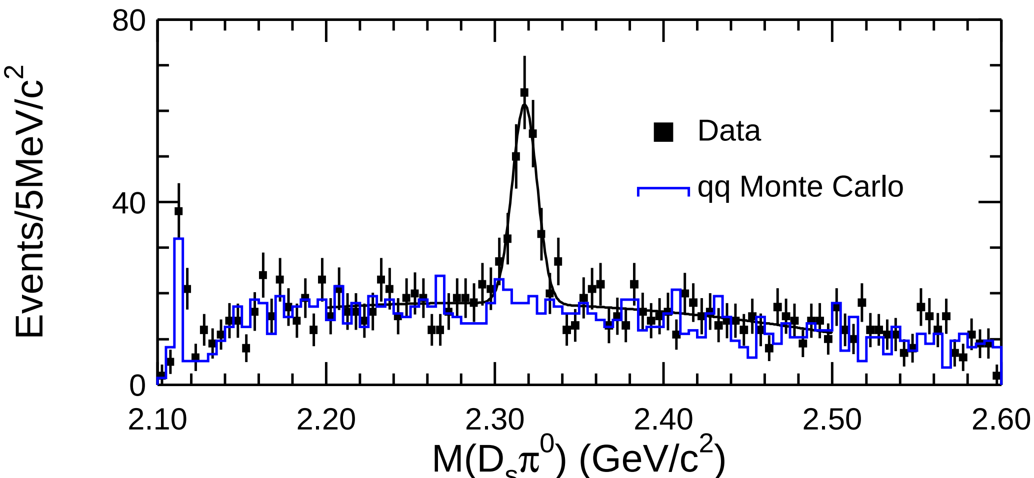
where "$D^*_{sJ}(2317)^+$" stands for $X(2460)^+$ reflection.

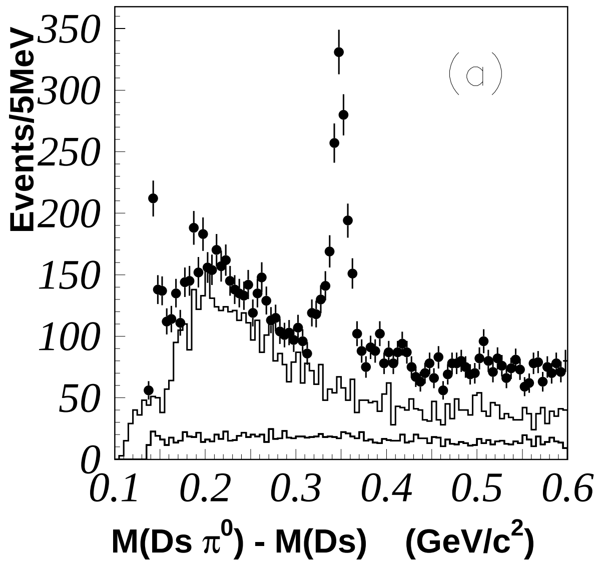
□ *In the data we find ≈ 5 times more $D^*_{sJ}(2317)^+$ events than expected from a Monte Carlo simulation with only $X(2460)^+$ production.*

□ **Conclusion: the relative rates disagree with the hypothesis that the $D^*_{sJ}(2317)^+$ signal is due entirely to production of a state at $\approx$ 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** 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/c^2, N=155 $\pm$ 23

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

$\Delta m = 348.7 \pm 0.5\,(\text{stat})$ MeV/c^2, $N = 761 \pm 44$

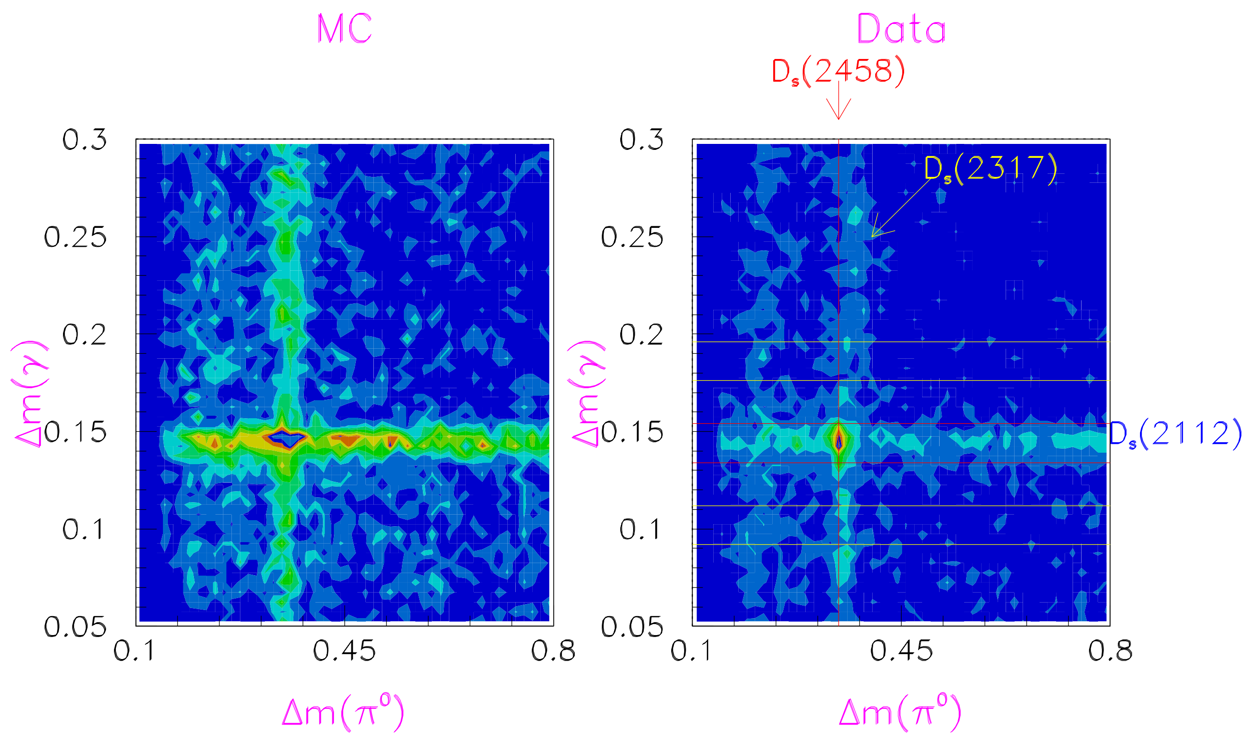
□ In good agreement with BaBar (91.5 fb^{-1}):

$\Delta m = 348.4 \pm 0.4\,(\text{stat})$ MeV/c^2, $N = 1948 \pm 104$.

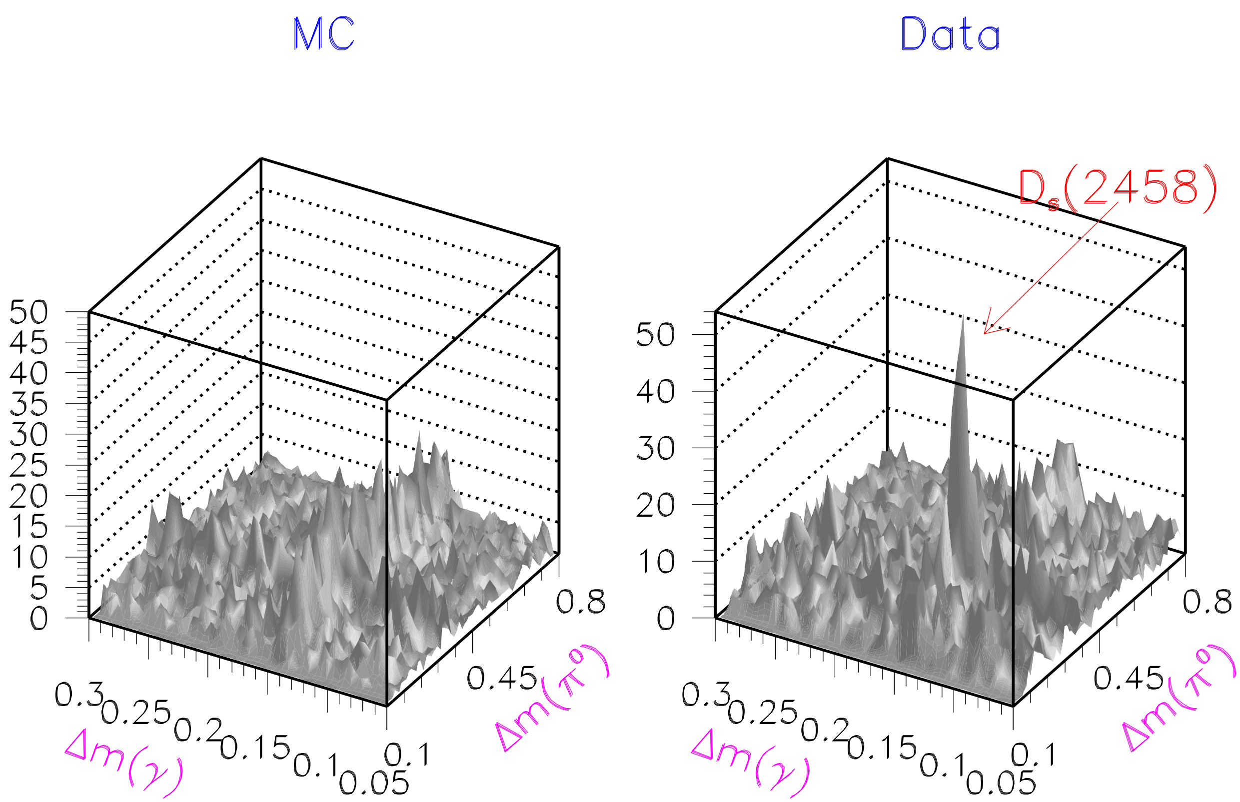
Both CLEO and BELLE use only the $D_s^+ \to \phi\pi^+$ decay mode.

The 2.46 GeV/c^2 region of $m(D_s^+\pi^0\gamma)$: a new particle or an artifact of kinematics?

☐ 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/c^2.



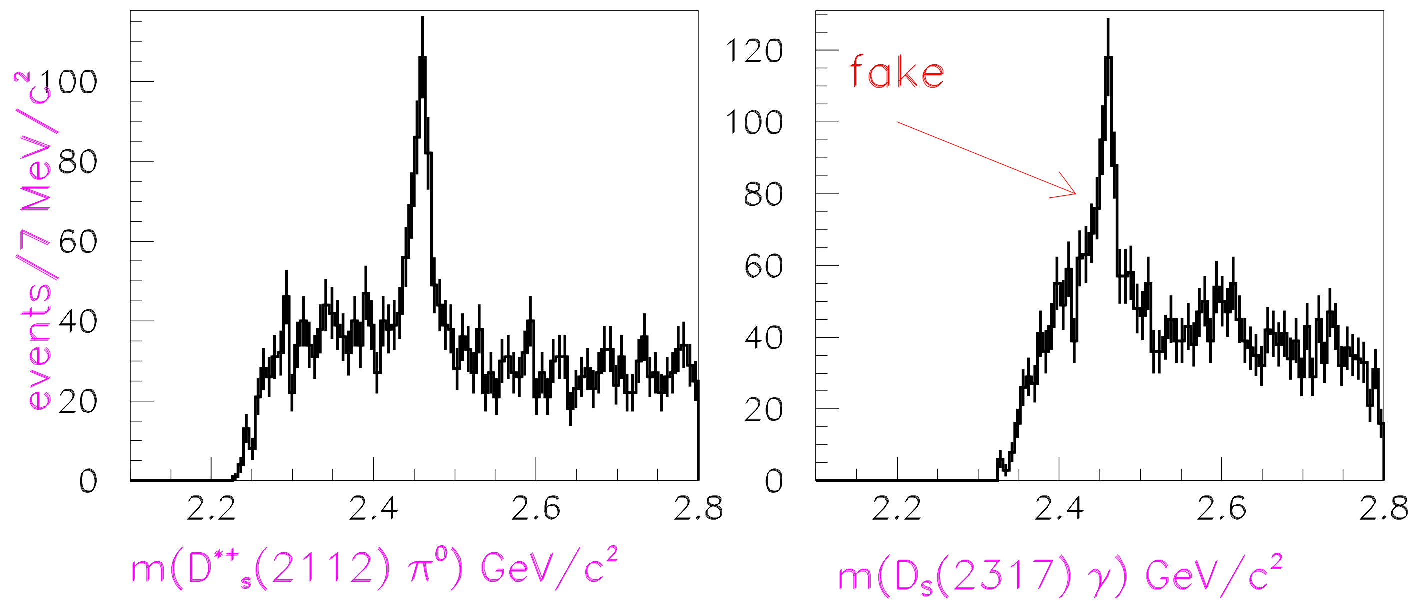
The same as Lego plot.



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

Mass distributions.

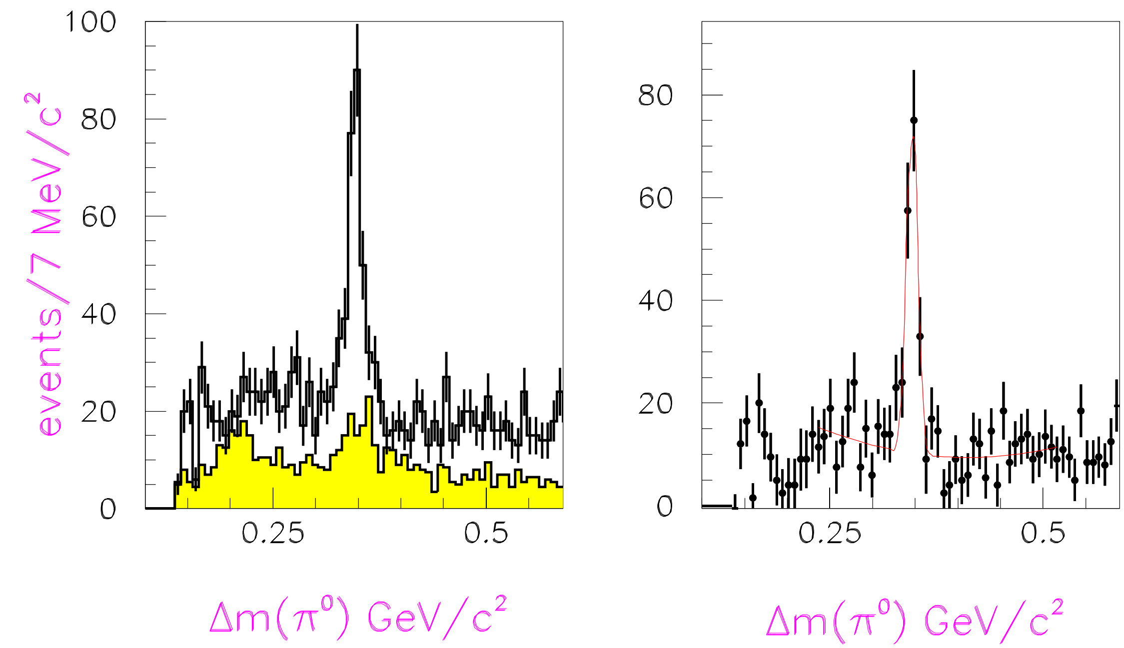
□ Data: $D_s^*(2112)^+\pi^0$ and $D_{sJ}^*(2317)^+\gamma$ mass distributions.



□ Structures at ≈ 2.46 GeV/c^2 in both $D_s^*(2112)^+\pi^0$ and $D_{sJ}^*(2317)^+\gamma$. 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).

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:

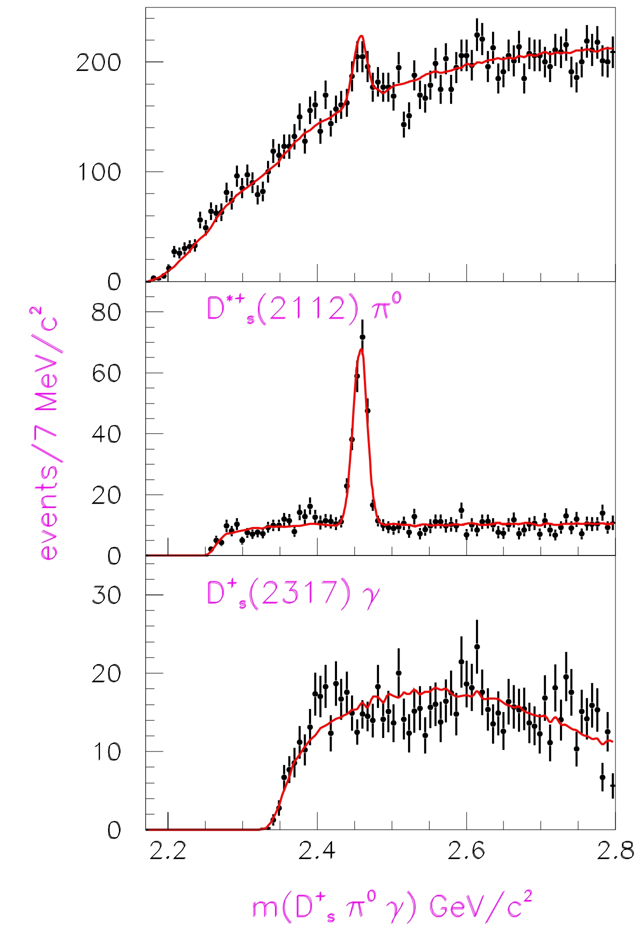
$$L = x_1 P_1 + x_2 P_2 + ... + (1 - x_1 - x_2 - ...)$$

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:

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

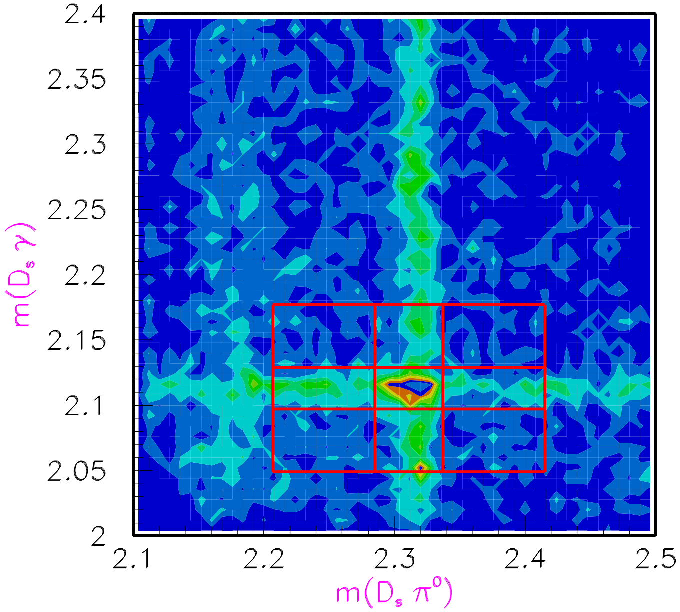
$$N(D_{sJ}(2458)^+ \to D^*_{sJ}(2317)^+\gamma) = 0 \pm 22$$

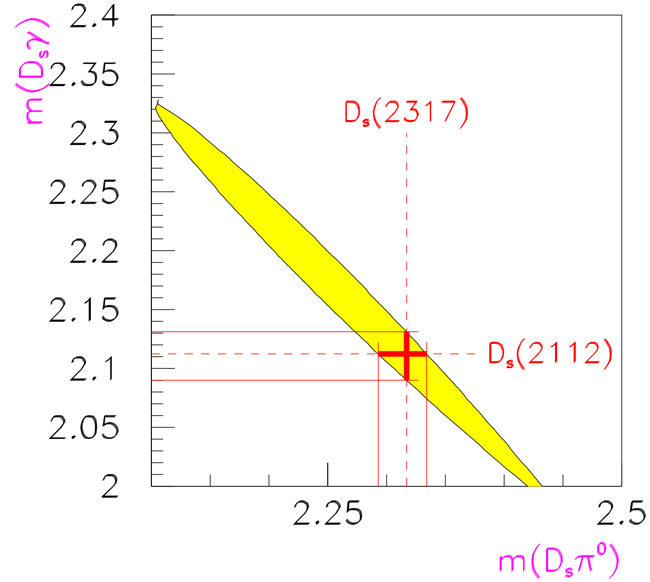
☐ Correcting for efficiency we derive the following upper limit:

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

The method of the 9 tiles.

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



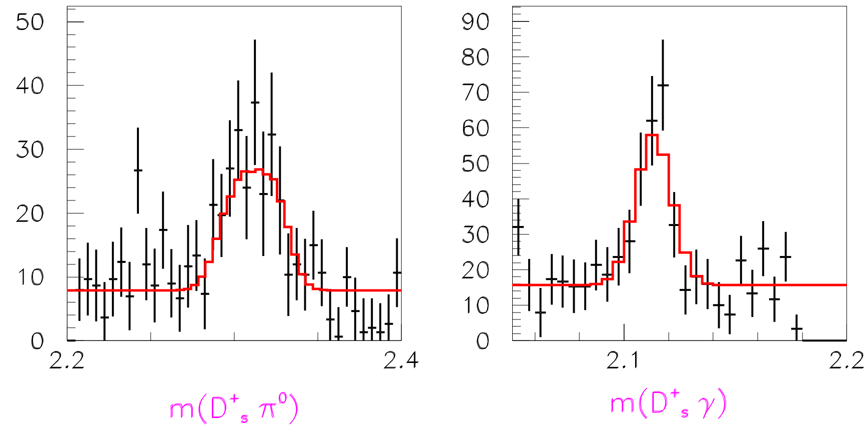


□ Subtracting the adjacent tiles it is possible to extract the $D_s^+\gamma$ and $D_s^+\pi^0$ projections.

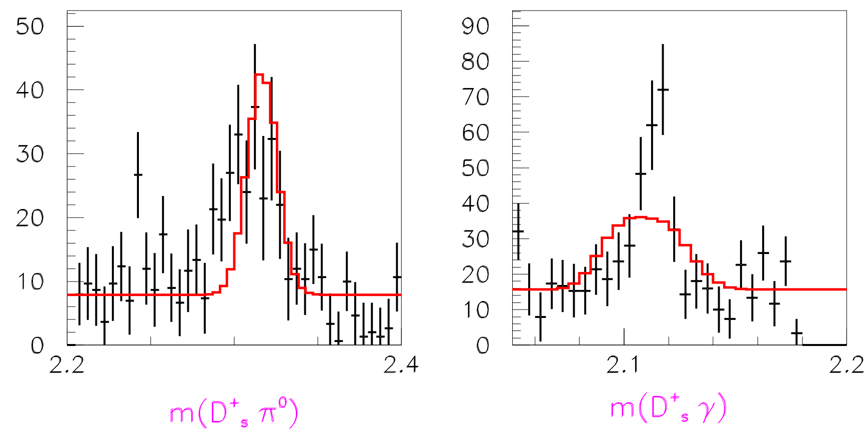
$D_{sJ}(2458)^+$ projections.

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

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



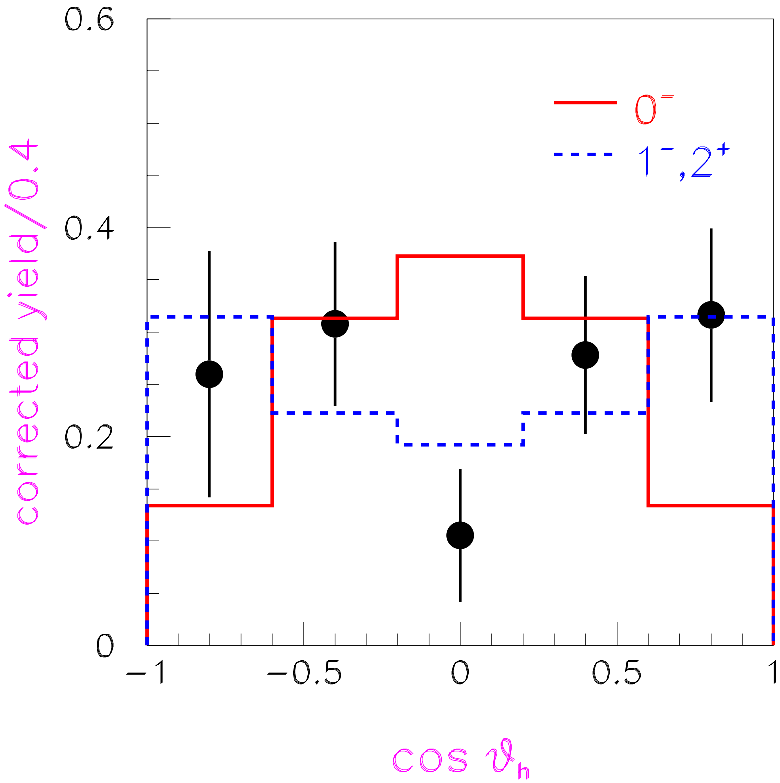
$$D_{sJ}(2458)^+ \rightarrow D_{sJ}^*(2317)^+\gamma$$



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

Angular analysis.

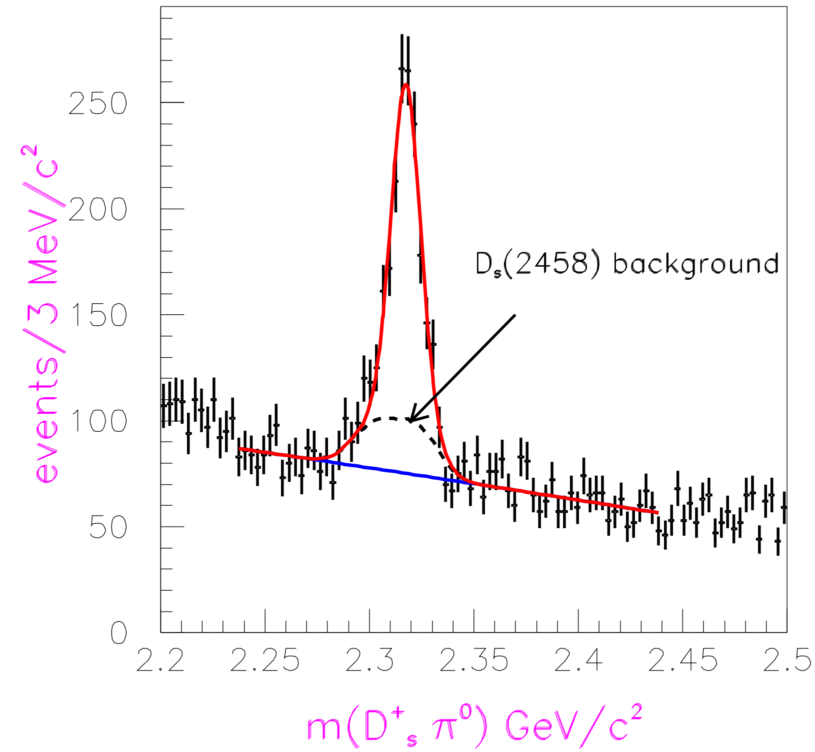
□ Distribution of the helicity angle θ of the γ with respect to the $D_s^*(2112)^+$ direction in the $D_{sJ}(2458)^+$ rest frame.



□ **Inconsistent with $J^P = 0^-$.**

New determination of the $D^*_{sJ}(2317)^+$ parameters.

□ Knowing the $D_{sJ}(2458)^+$ parameters, and assuming decay only to $D_s^*(2112)^+\pi^0$, the reflection near the $D^*_{sJ}(2317)^+$ can be estimated by Monte Carlo simulation.

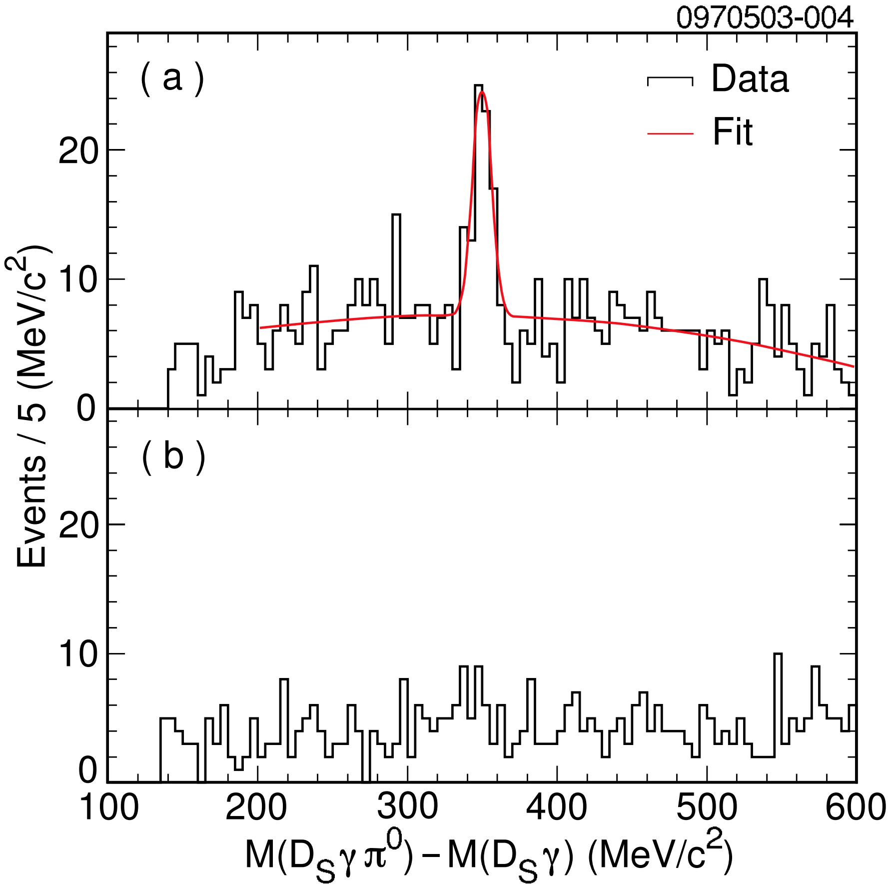


□ Taking this into account, the fitted values of the $D^*_{sJ}(2317)^+$ become:

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

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

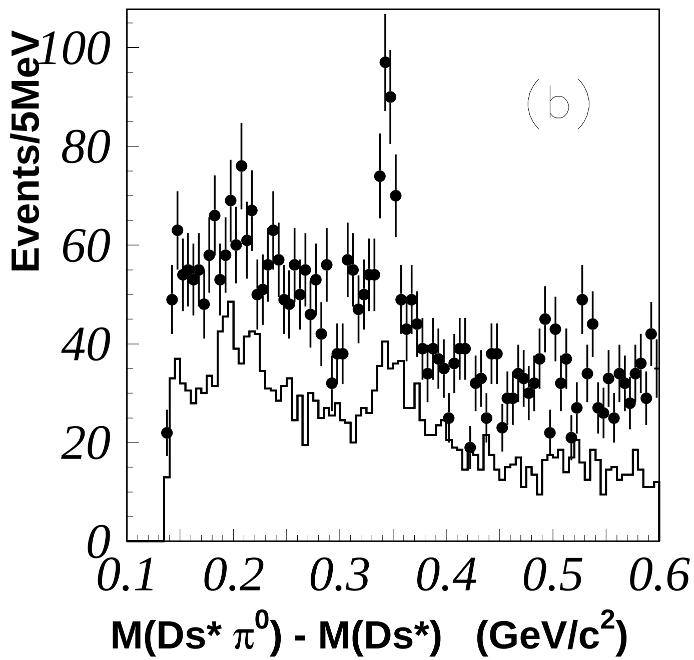
CLEO 13.5 fb^{-1}



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

$N = 41 \pm 12$

BELLE 86.9 fb^{-1}



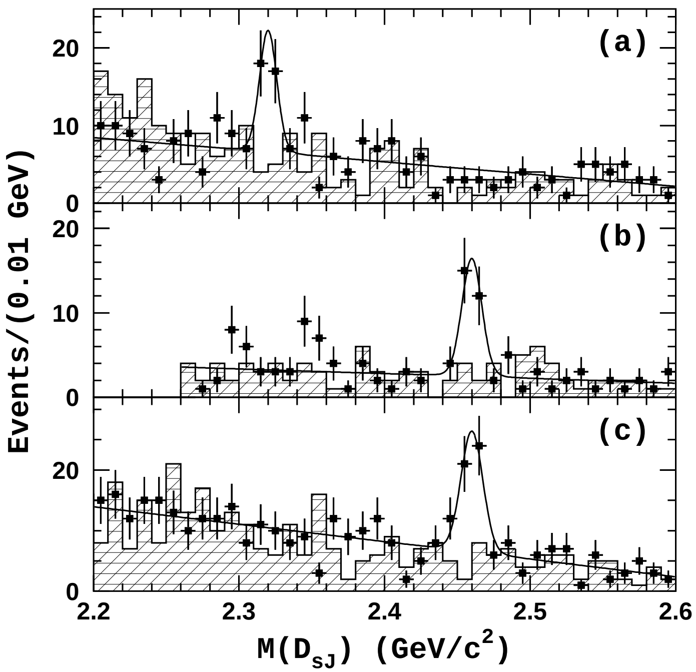
$\Delta m = 345.4 \pm 1.3 \ \text{MeV}/c^2$

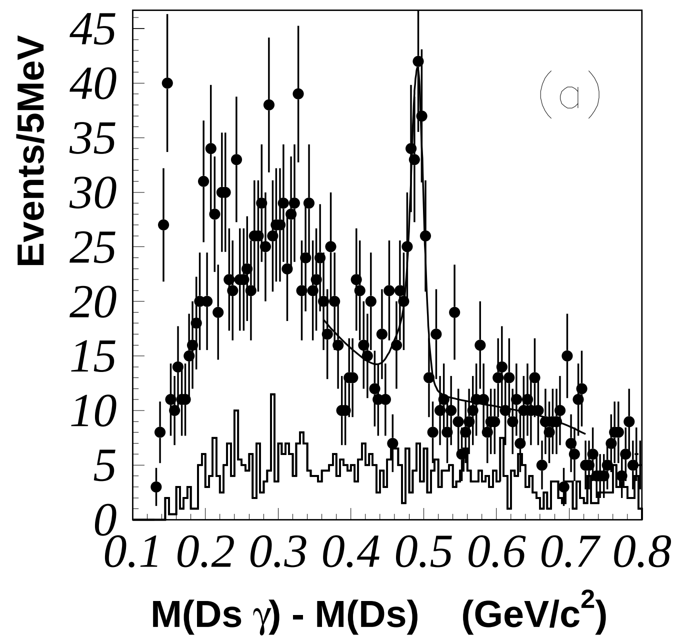
$N = 126 \pm 25$

Further results from BELLE.

□ Evidence for:

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



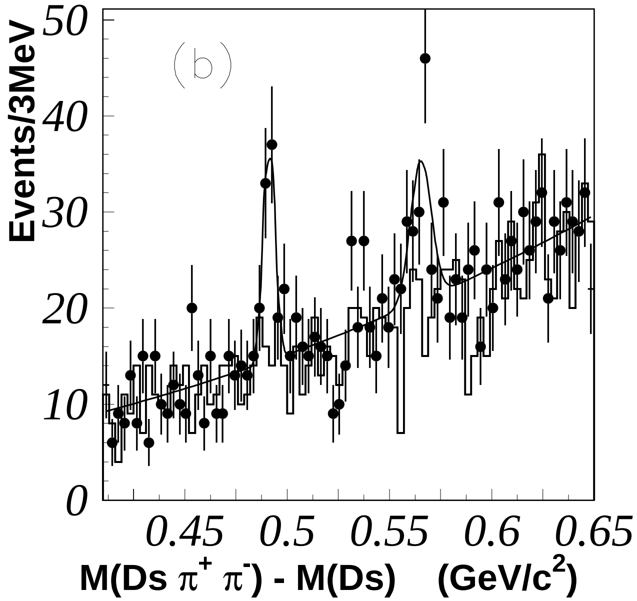


□ Evidence for $D_{sJ}(2458)^{+} \to D_{s}^{+}\gamma$: $J = 0$ excluded.

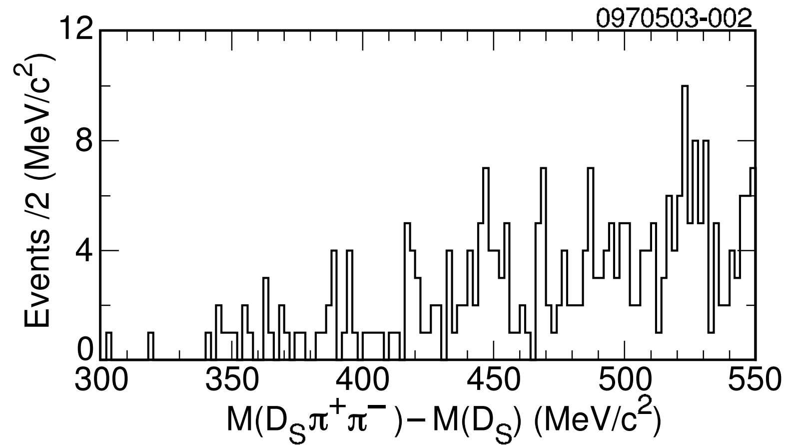
□ Spin Analysis in B decays: $J = 1$ favoured.

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

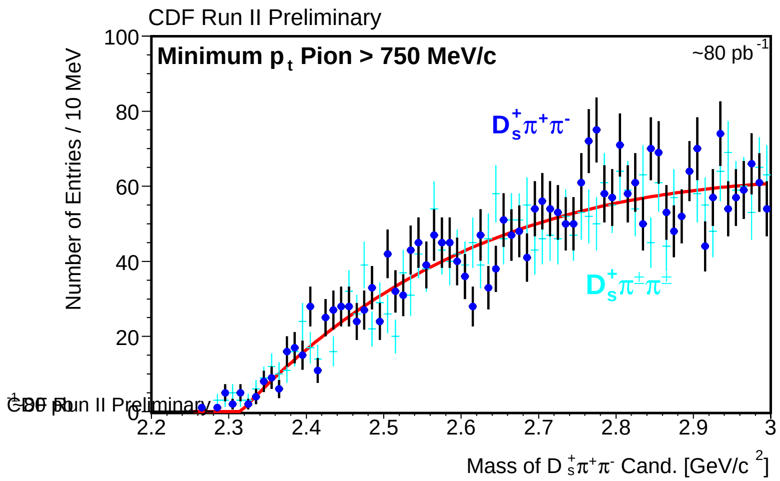
BELLE $D_s^+\pi^+\pi^-$



CLEO $D_s^+\pi^+\pi^-$



CDF II $D_s^+\pi^+\pi^-$



□ $D_{sJ}(2458)^+ \to D_s^+\pi^+\pi^-$ from BELLE.

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

□ A large (≈ 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:

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

□ 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 $D_s^+\gamma$, $D_s^+\gamma\gamma$, $D_s^*(2112)^+\gamma$, $D_s^+\pi^0\pi^0$, $D_s^+\pi^+\pi^-$ 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 in continuum and by BELLE in both continuum and B decays.

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

□ BaBar has first shown evidence of structure in the $D_s^+\pi^0\gamma$ mass distribution at ≈ 2.46 GeV/c^2. "However, the complexity of the overlapping kinematics of the $D_s^*(2112)^+ \to D_s^+\gamma$ and $D_{sJ}^*(2317)^+ \to D_s^+\pi^0$ requires more detailed study ... in order to arrive at a definitive conclusion." Phys.Rev.Lett. 90 (2003) 242001

□ CLEO experiment observes $D_s^+(2463)$ state.

□ Confirmed by Belle in continuum and B decays, including $D_s^+\gamma$ and $D_s^+\pi^+\pi^-$decay modes.

□ BaBar experiment reports the observation of a state at 2.458 GeV/c^2 decaying to $D_s^*(2112)^+\pi^0$. The parameters of this state are the following:

$$\Delta m = 346.2 \pm 0.9 \quad MeV/c^2$$

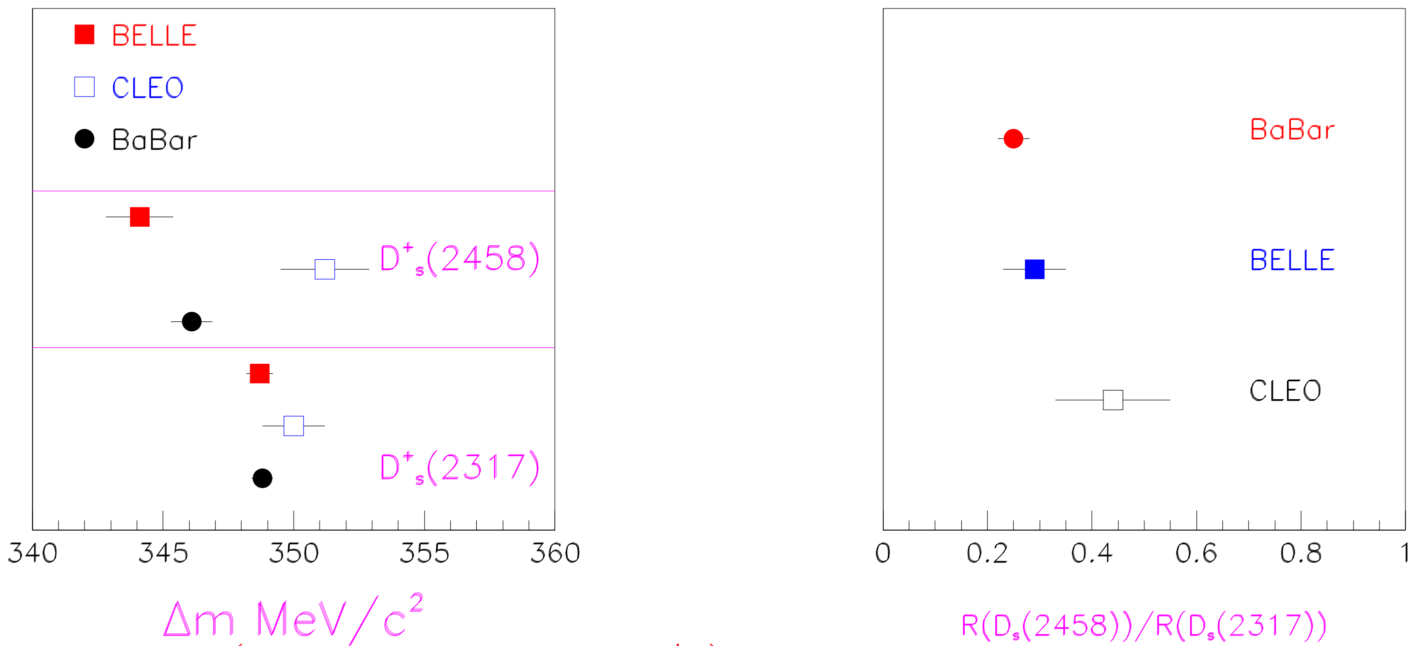
$$m(D_{sJ}(2458)^+) = 2458.0 \pm 1.0(stat.) \pm 1.0(syst.)\ \text{GeV}/c^2$$

□ The width is consistent with experimental resolution.

□ The spin analyses favours $J = 1$.

Experimental Summary.

□ Comparison of Δm and rates from BELLE, CLEO, and BaBar:



□ BaBar measures (for $p^* > 3.5$ GeV/c):

$$R = \frac{\sigma(D_{sJ}(2458)^+)\mathcal{B}(D_{sJ}(2458)^+ \to D_s^*(2112)^+\pi^0}{\sigma(D_{sJ}^*(2317)^+)\mathcal{B}(D_{sJ}^*(2317)^+ \to D_s^+\pi^0)} = 0.25 \pm 0.03(stat) \pm 0.03(syst)$$

□ Some disagreement with CLEO results.

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.

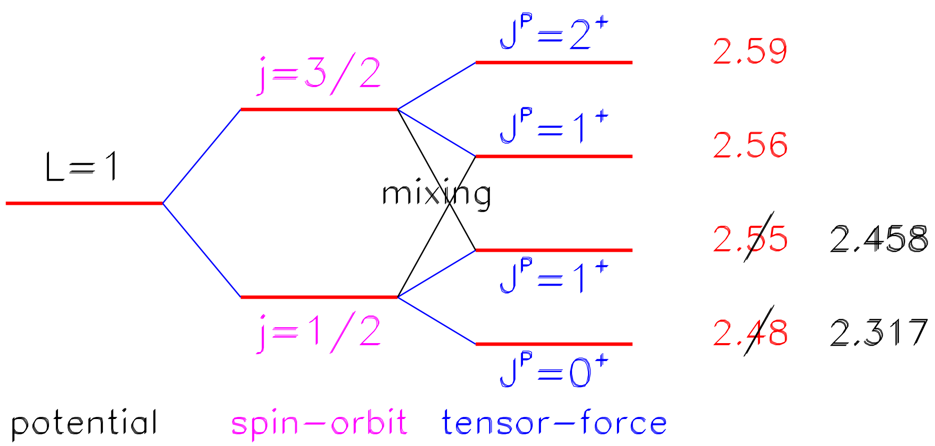
□ If the isospin of these states is I=0, since the $D_s^+\pi^0$ and $D_s^{*+}\pi^0$ systems have isospin I=1, these decays violate isospin conservation. This would explain the small widths.

□ 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.

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 di-pion emission.

□ Find still more states.

Conclusions and Outlook.

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

□ This, and related discoveries, will have a large impact on the theory of charmed and beauty meson spectroscopy.

□ Lots of activity, both experimental and theoretical.

□ **More than 40 papers, written to date, aiming at interpreting these experimental results.**