



Observation in BaBar of a narrow  
resonance in the  $D_s^+ \pi^0$  system at  
2317 MeV

Roger Barlow

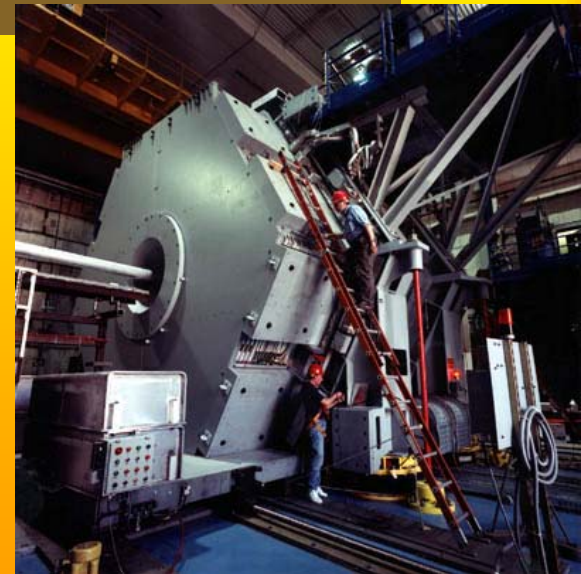
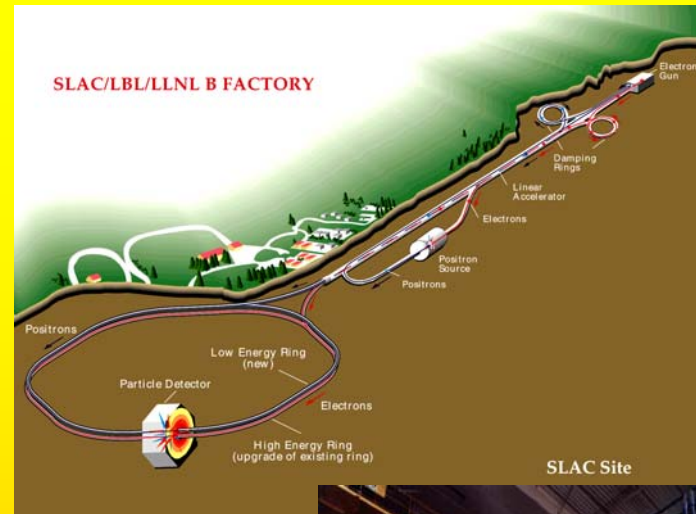
Manchester University

For the *BABAR* Collaboration

# Data



- 1999-2002
- $91 \text{ fb}^{-1}$
- On and off  $Y(4S)$
- Search for  $D_s^+$  and  $\pi^0$  :  
Require
  - $\geq 3$  tracks
  - $\geq 2$  photons over 100 MeV
  - FW moments  $H_2/H_0 < 0.9$



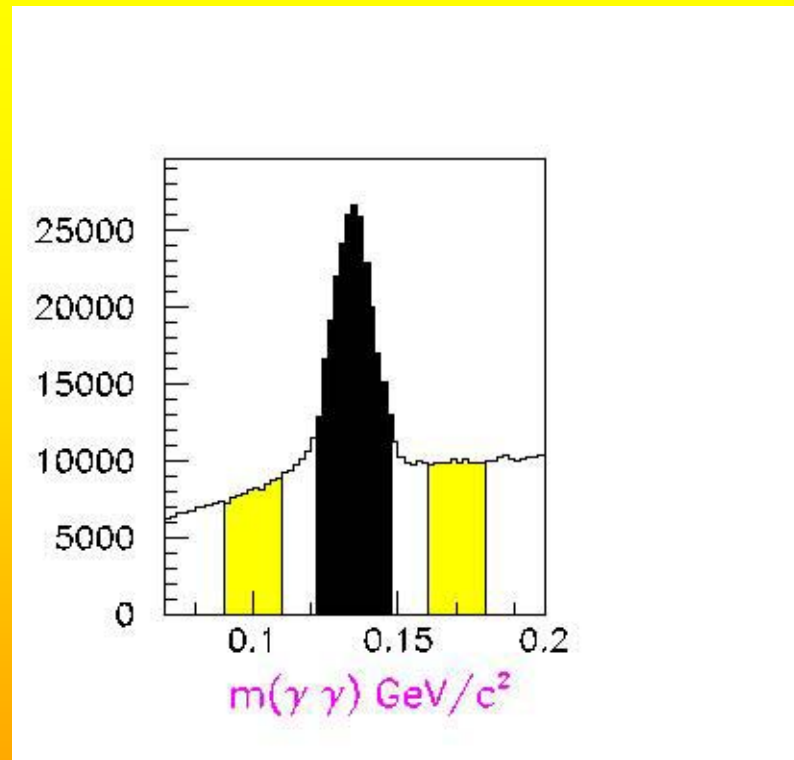


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## $\pi^0$ selection

- Both  $E_\gamma > 100$  MeV
- $\pi^0$  fit probability  $> 1\%$
- Neither  $\gamma$  shared with another  $\pi^0$  candidate

Peak and sidebands





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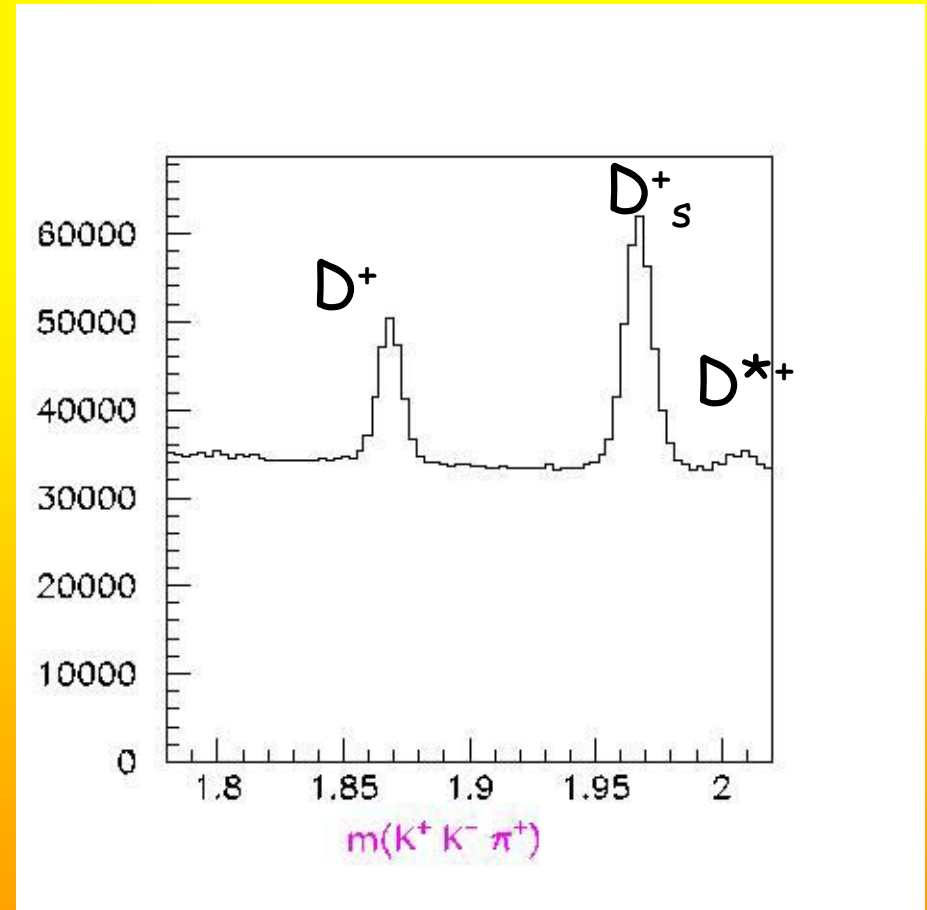
## $D_s^+$ selection(1)



- Kaon id from DIRC &  $dE/dx$  via Neural network
- Vertex fit  $P > 0.1\%$

Peaks from

- $D^+(1869)$
- $D_s^+(1970)$
- $D^{*+}(2010) \rightarrow D^0 \pi^+$





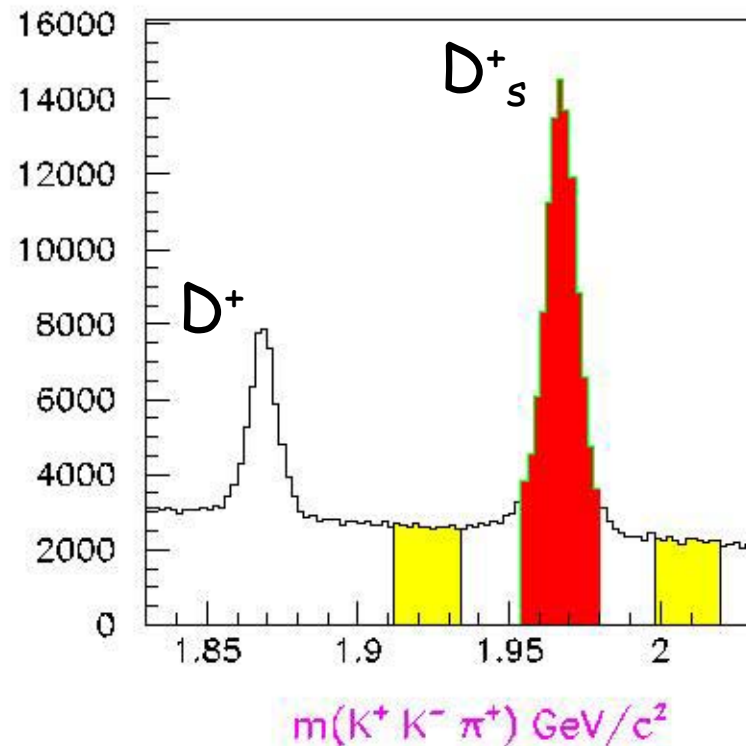
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## $D_s^+$ selection(2)

- $M(K^+K^-) < 1.84 \text{ GeV}$
- $M(K^+K^-) \approx M(\phi)$  or  
 $M(K\pi) \approx M(K^*)$
- $\phi$  or  $K^*$  decays with  
 $|\cos \theta_h| > 0.5$
- $p^*(K^+K^- \pi^+ \pi^0) > 2.5 \text{ GeV}$

Signal and sidebands  
shown

80K  $D_s^+$  in signal region





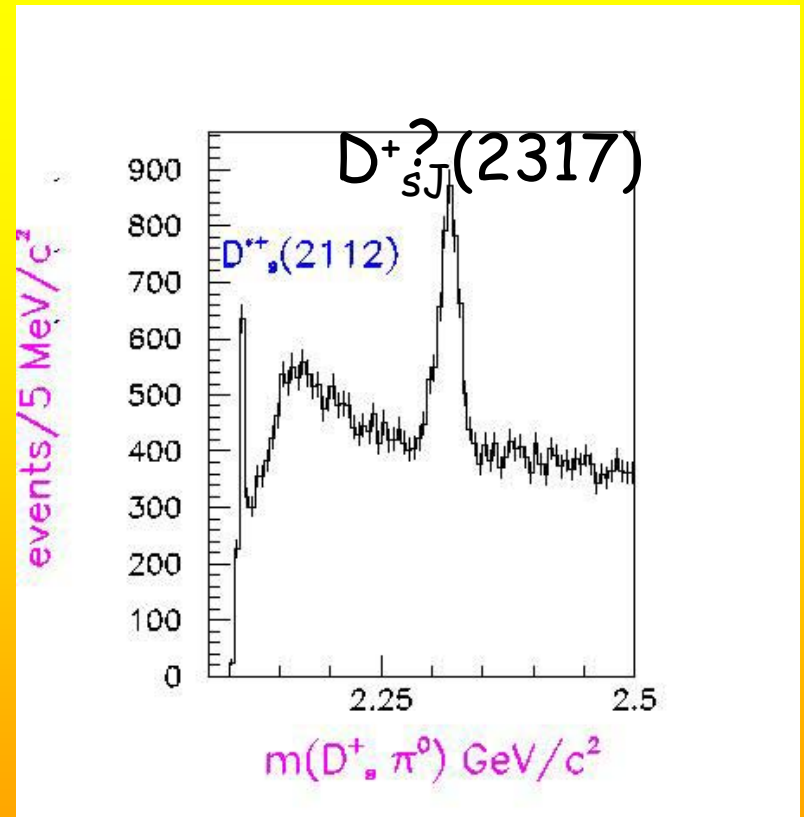
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## The signal

Large (unexpected)  
peak in  $D_s^+ \pi^0$  mass  
at 2.32 GeV

Named as  $D_{sJ}^{*+}(2317)^+$

Small spike from  $D_s^{*+}$  just on  
kinematic limit

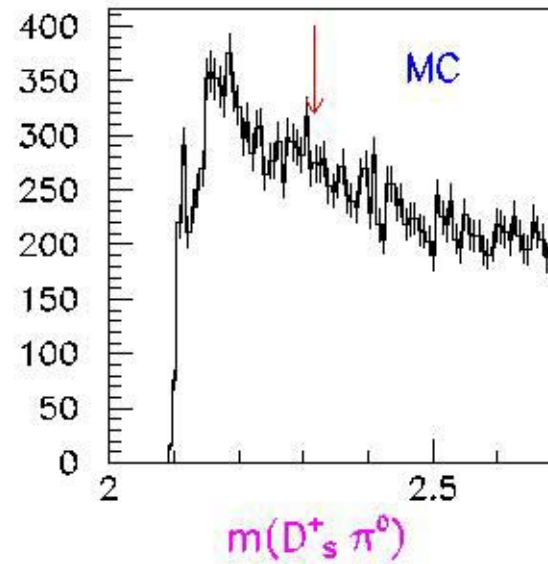
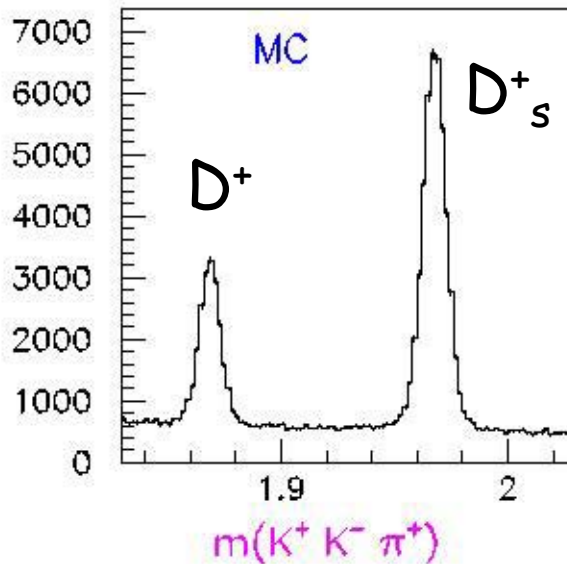




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## Check# 1 Monte Carlo

Reproduces  $D_s^+$  but no  $D_{sJ}^{*+}(2317)^+$



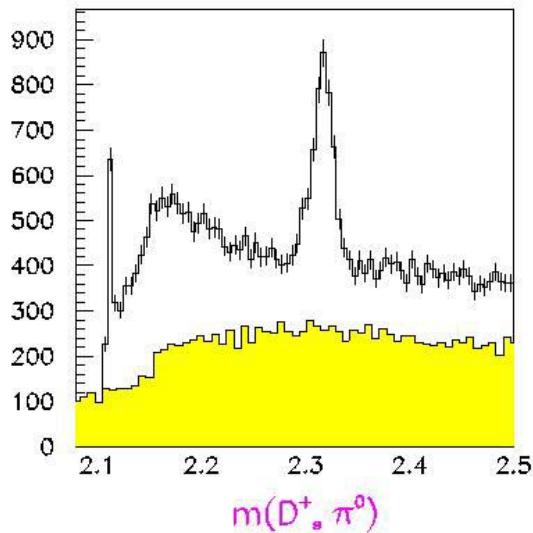


# BABAR

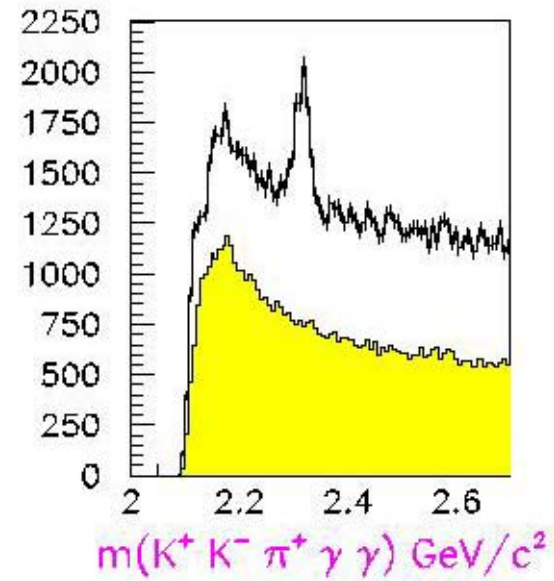
## Check# 2 Sidebands

$M(K^+K^- \pi^+ \pi^0)$  from sidebands in yellow

### $D_s^+$ sidebands



### $\pi^0$ sidebands



No signal present



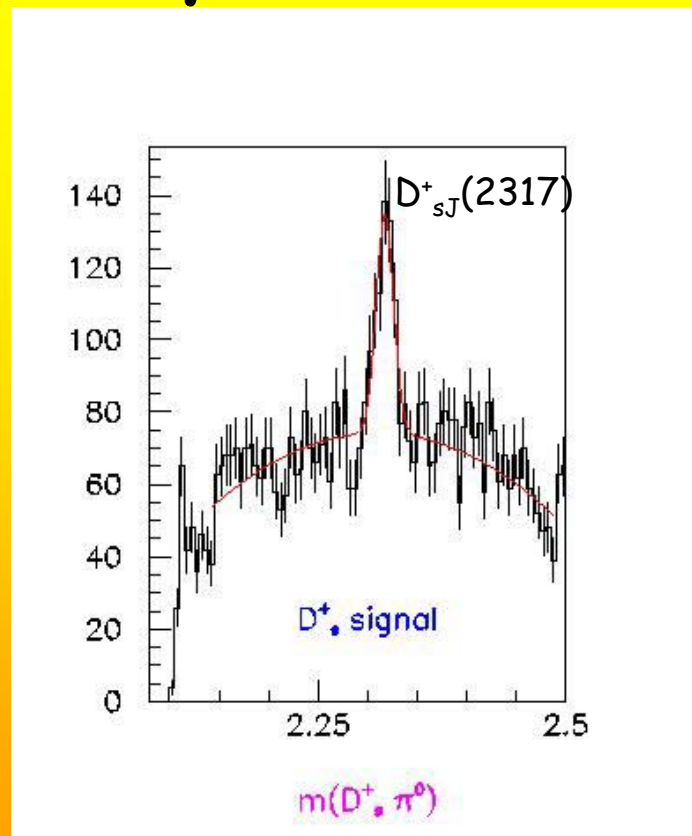


# Check# 3

## Different $D_s^+$ decays

Seen in both  $D_s^+ \rightarrow \phi\pi$   
and  $D_s^+ \rightarrow K^*K$

Also in  $D_s^+ \rightarrow K^+K^-\pi^+\pi^0$   
at the same mass





# Check# 4 Reflections

- Particle ID?
  - Take events: reassign K as  $\pi$ .
  - No sign of  $D^+$  or  $D^0$  or  $D^*$
- $D_s^{*+}(2112) \rightarrow D_s^+ \gamma + \text{extra } \gamma?$ 
  - No: Antiselecting  $M(D_s^+ \gamma \approx 2112)$   
enhances peak at 2317



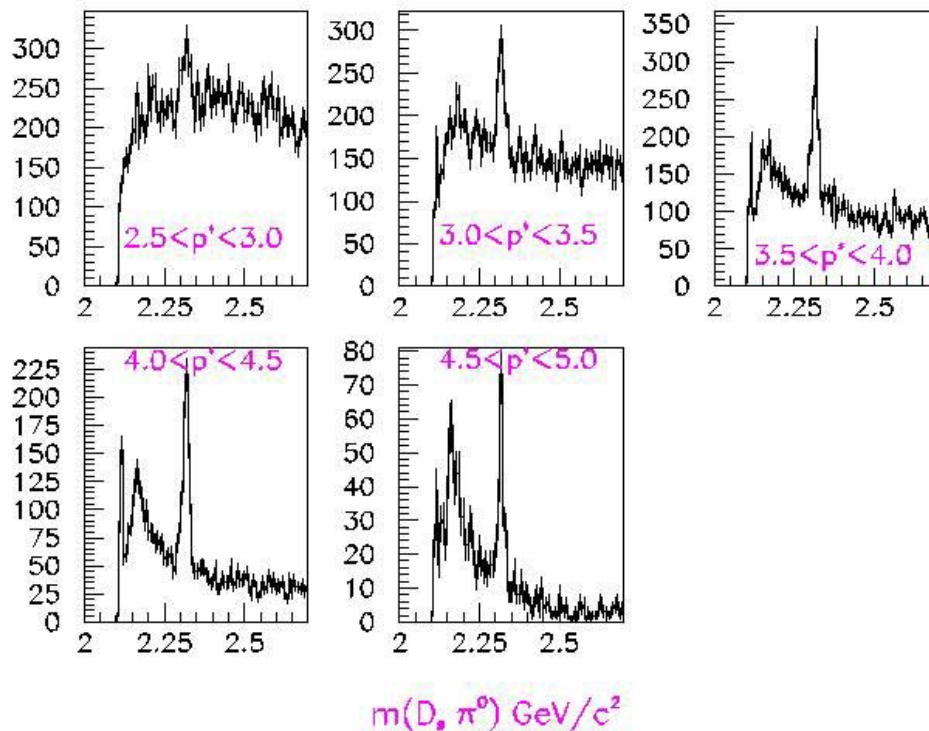
# Properties#1

## $p^*$ dependence

Signal enhanced at high  $p^*$

As expected from  $e^+e^- \rightarrow c \bar{c}$  production

(Momentum of  $D^{*+}_{sJ}(2317)$  in CMS)

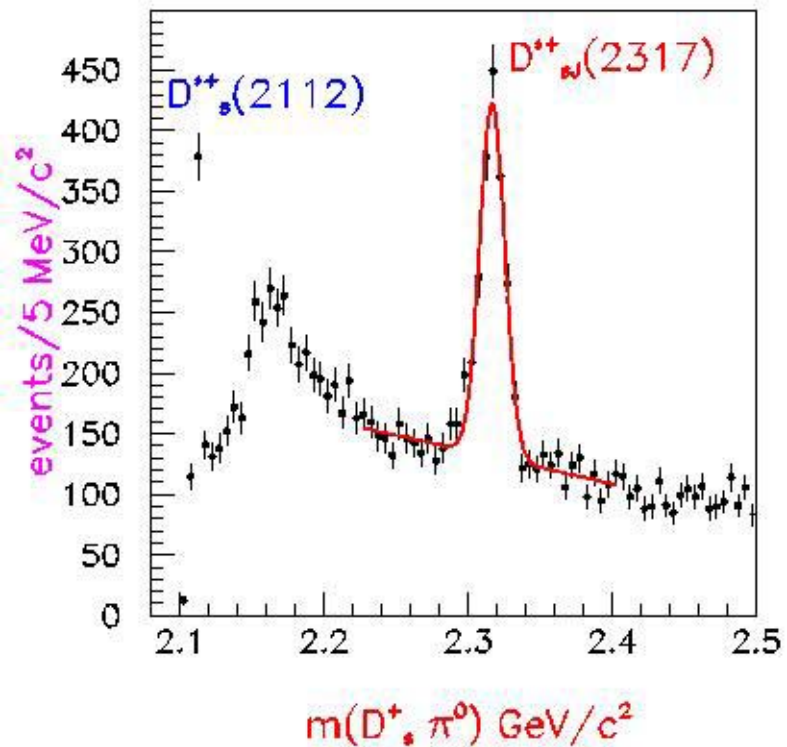




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## Properties#2 Mass

- Take  $p^* > 3.5 \text{ GeV}$
- Gaussian + polynomial
- Peak at  $2316.8 \pm 0.4 \text{ MeV}$
- $1267 \pm 53$  signal events
- Systematic uncertainty below  $3 \text{ MeV}$



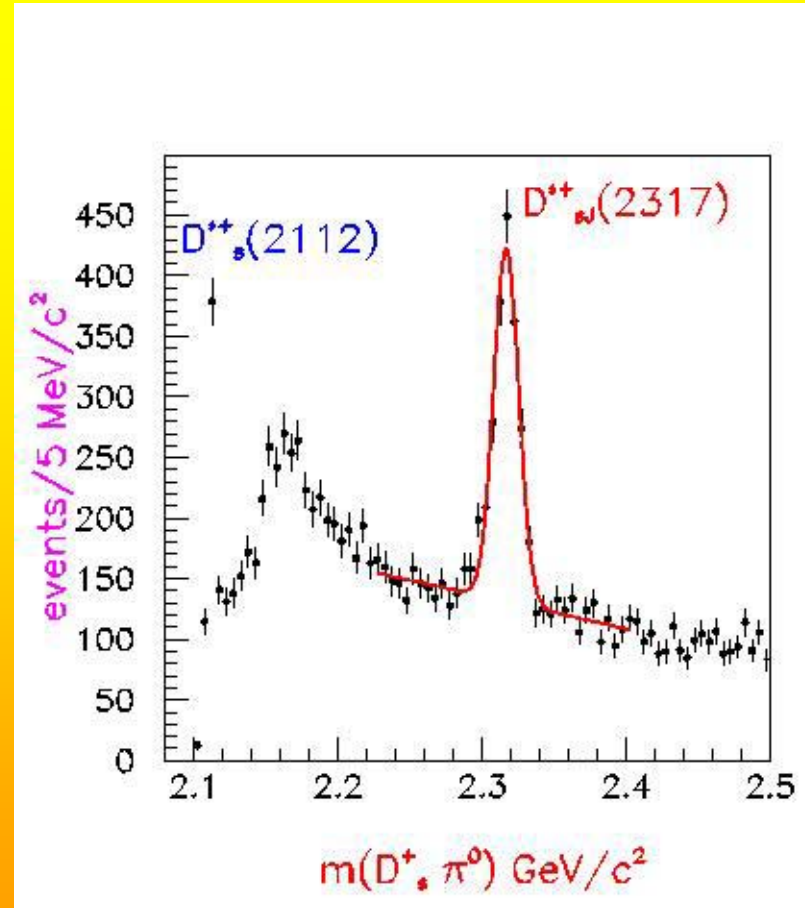


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## Properties#3 Width

- Single Gaussian
- Standard Deviation  
 $8.6 \pm 0.4 \text{ MeV}$
- MC (revised) predicts  
 $7.5 \pm 0.3 \text{ MeV}$
- Measurement of  
 $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0$  gives  $6.7 \pm 0.1 \text{ MeV}$
- Observed width  
compatible with our mass  
resolution

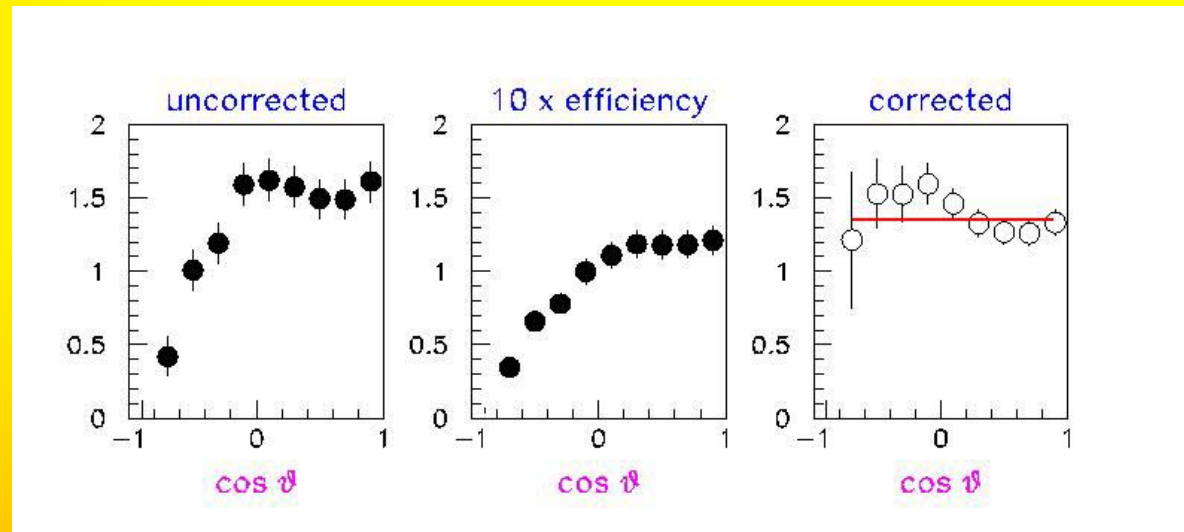
$$\Gamma \leq 10 \text{ MeV}$$





# Properties#4 Angular Distribution

- Plot helicity angle of  $\pi^0$  in  $D^{*+}_{S_J}(2317)$  frame
- Correct for efficiency



Consistent with being flat:

Suggests  $J=0$ . (Or unpolarised  
and  $J=\text{anything}$ )

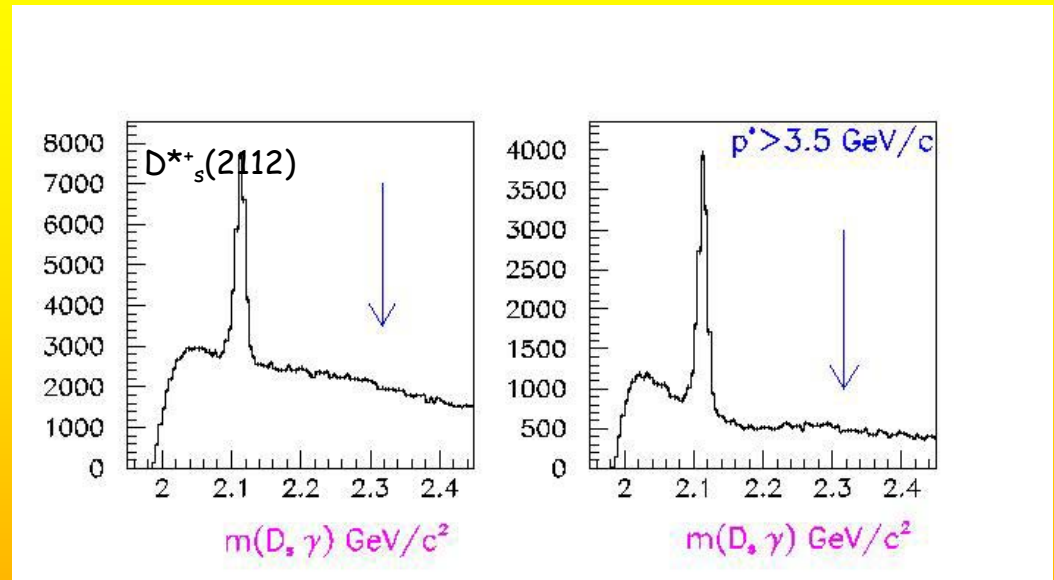


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## Properties#5 Other modes

Not seen in

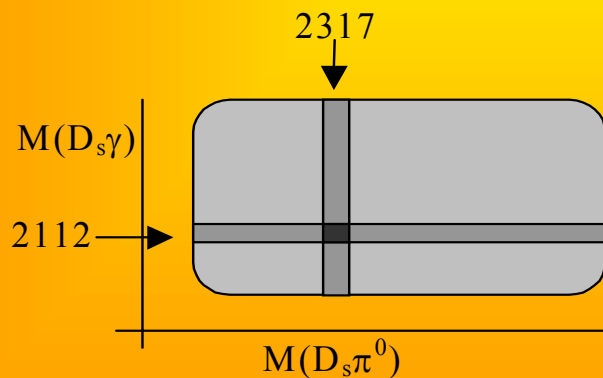
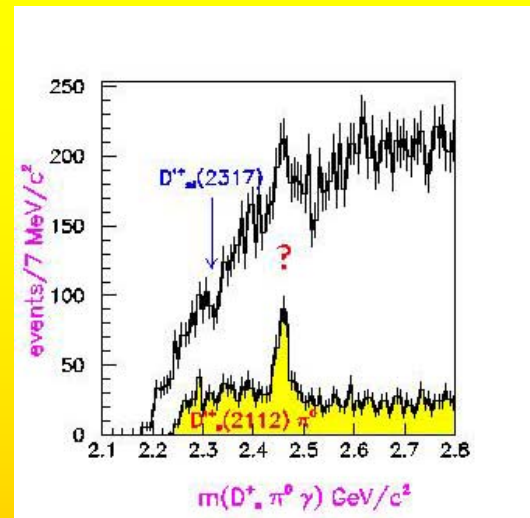
- $D_s^+ \gamma$
- $D_s^{*+} (2112) \gamma$
- $D_s^+ \gamma \gamma$
- $D_s^+ \pi^0 \gamma$
- $D_s^+ \pi^0 \pi^0$





# Comment on $D_s^+ \pi^0 \gamma$

- No peak at 2317
- But new peak appears at 2460
- Enhanced when  $M(D_s^+ \gamma) \approx 2112 = M(D_s^{*+})$



Care needed!

Peaks at  $D_s \pi^0$  (2317) and  $D_s \gamma$  (2112) combine to give reflection with  $M(D_s \pi^0 \gamma) \approx 2460$





# Interpretation

A  $c\bar{s}$  state:  $D_s^*$

Below threshold for  $DK$ ,  $D_s^*K$

$D_s\pi$  decay violates isospin, hence narrow

Parity conservation  $\Rightarrow J^P=0^+, 1^-, 2^+, \dots$

$0^+$  plausible from  $\cos\theta$  distribution

$L=1$  radial excitation.

But other  $L=1$  states ( $1^+$  and  $2^+$ ) are at 2536, 2573

$Q\bar{q}$  potential models predict  $0^+$  at  $M=2480$

$2317 \ll 2480$

Either re-think theory or include hybrid



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## Confirmation

Confirmed by CLEO and BELLE  
Mass and width and decay modes  
consistent.

CLEO also claim  $D^{*+}_s(2463)$  in  
 $D^{*+}_s(2112) \pi^0$



# The Peak in $D_s^{*+} \pi^0$

## BaBar

- There is a peak at 2.46 GeV
- Some of it is a reflection of the 2317. How much is still under study. Great care is required.
- Even if this peak is a resonance, it cannot account for all the 2317 signal

## CLEO

- There is a peak at 2.463 GeV
- Some, but not all of it, is a reflection of the 2317
- Some of the 2317 is a reflection of the 2463

*If it exists, careful extraction of yields, masses and widths is needed. Work in progress...*



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## Conclusions

- BaBar has observed an unexpected narrow resonance: the  $D_{sJ}^{*+}(2317)$
- Decays to  $D_s^+ \pi^0$
- Spin-parity compatible with  $0^+$
- Confirmed by CLEO and BELLE