Recent BABAR results in Charmonium and Charm Spectroscopy

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Outline

- η_c and $\eta_c(2S)$ mass and total width from $\gamma\gamma$ production (hep-ex/0102030)
- Observation of a narrow state decaying to $D_s\,\pi^0$ (Phys. Rev. Lett. 90:242001)
  Preliminary observation a narrow state decaying to $D_s\,\pi^0\,\gamma$

η_c total width

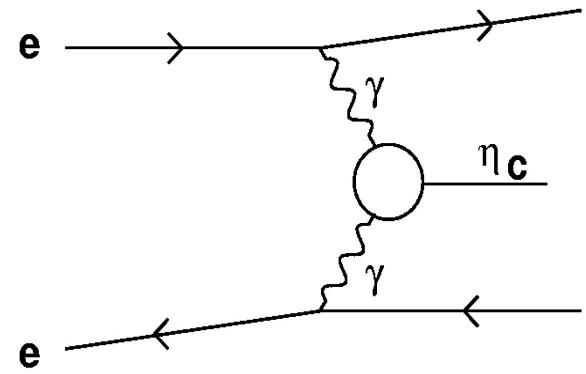
- Total width of η_c dominated by 2-gluon partial width: $\Gamma_{tot}(\eta_c) \approx \Gamma_{gg}(\eta_c)$
- Perturbative QCD calculations give $\frac{\Gamma_{tot}}{\Gamma_{\gamma\gamma}} \approx \frac{9\alpha_s^2}{8\alpha^2} \cdot \frac{1+4.8\alpha_s/\pi}{1-3.4\alpha_s/\pi}$

$\Rightarrow$ $\Gamma_{tot}(\eta_c)$ = (25.4 ± 6) MeV/c^2

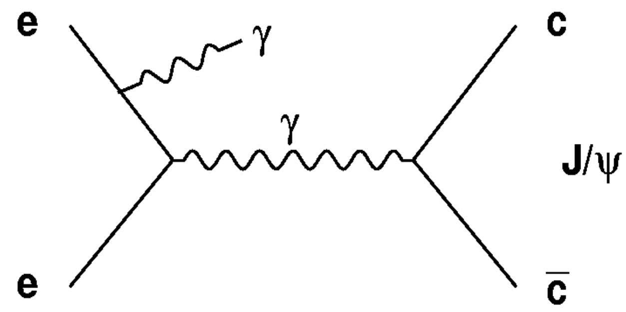
- Current measurements have large errors and are spread over a wide range of values:
  - PDG: ($16.0^{+3.6}_{-3.2}$) MeV/c^2;
  - BES: (17.0 ± 3.7 ± 7.4) MeV/c^2 (2003);
  - Belle: (27.0 ± 5.8 ± 1.4) MeV/c^2 (2003)

$\gamma\gamma$ production of η_c

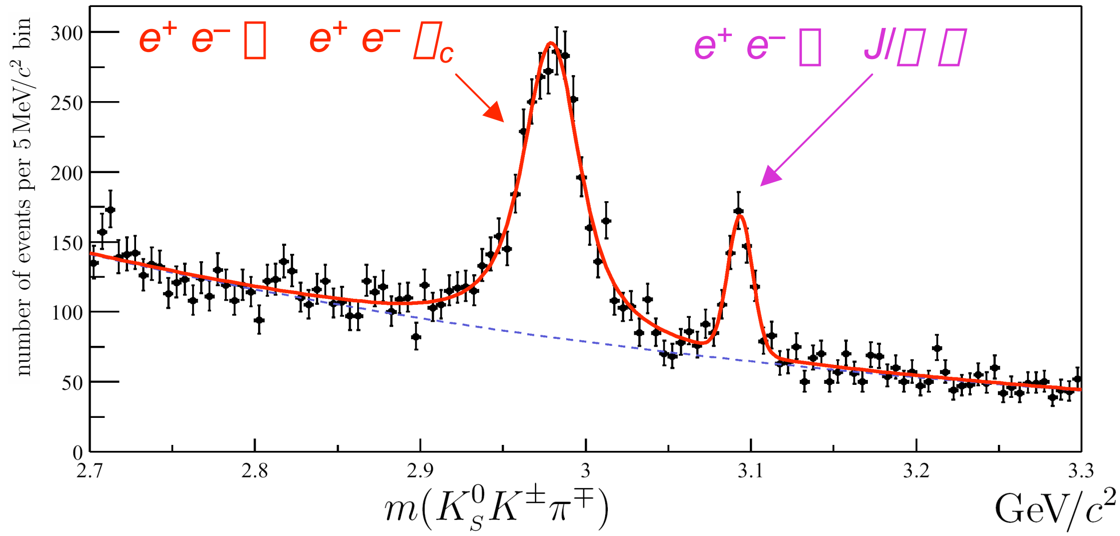
- η_c produced in
  $e^+ e^- \rightarrow e^+ e^- \gamma\gamma \rightarrow e^+ e^- \eta_c$
  and reconstructed in $\eta_c \rightarrow K_S K \pi$



- Analysis based on 88 fb^{-1} around $\Upsilon(4S)$
- 4-charged tracks events:
  - K_S reconstructed in $K_S \rightarrow \pi^+ \pi^-$;
  - $E_{tot} < 9$ GeV (suppress $e^+ e^- \rightarrow q \bar{q}$ events);
  - $E_{neutrals} < 0.5$ GeV
- J/ψ cannot be formed in $\gamma\gamma$ interactions, but can be produced in ISR events



η_c invariant mass spectrum



- Experimental resolution from J/ψ peak and MC
- Corrections and systematics from data-MC comparison for J/ψ mass and resolution, and from fit range
- Results:

$m(\eta_c)$ = (2983.3 ± 1.2 ± 1.8) MeV/c^2

$\Gamma_{tot}(\eta_c)$ = (33.3 ± 2.5 ± 0.8) MeV/c^2

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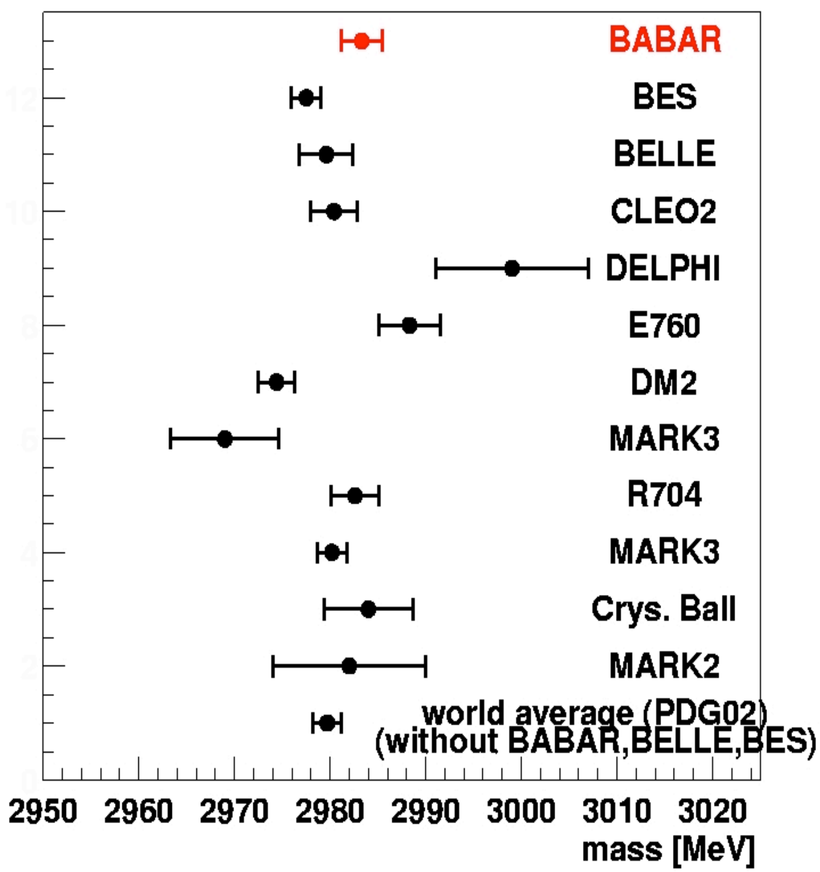
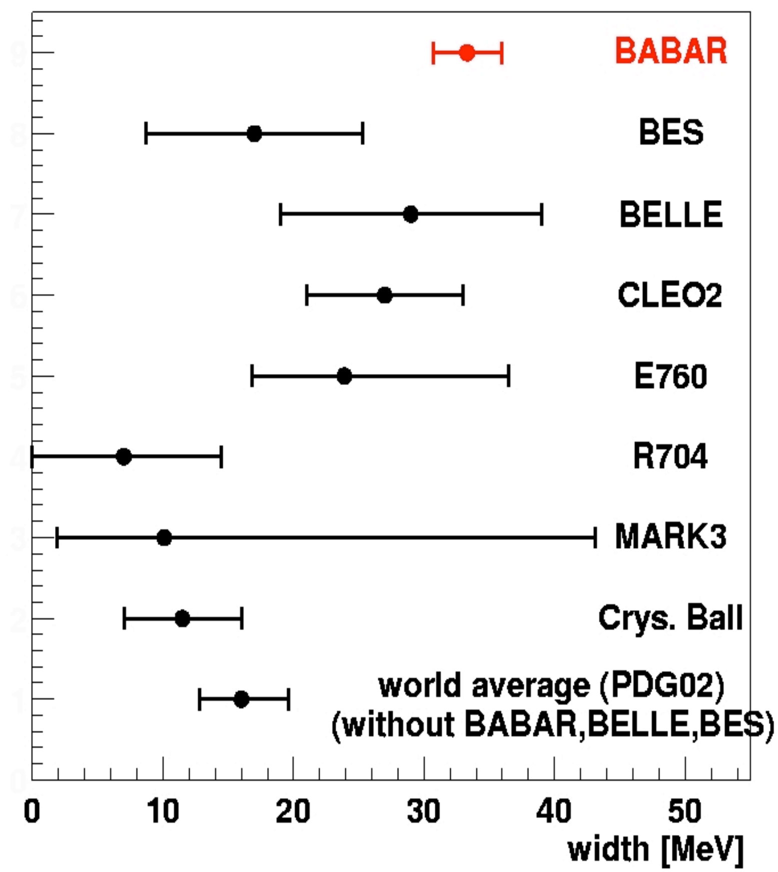
η_c mass and width

$m(\eta_c)$



$\Gamma(\eta_c)$



The $\eta_c(2S)$ state

- First radial excitation of the 0^{-+} state of charmonium: the heavy quark potential model predicts
$m(\psi(2S)) - m(\eta_c(2S)) \in (42, 103)$ MeV/c^2

- First claim for $\eta_c(2S)$: Crystall Ball (PRL 48:70, 1982)
$m(\eta_c(2S)) = (3595 \pm 5)$ MeV/c^2, $\Gamma(\eta_c(2S)) < 8$ MeV/c^2

- No other evidence until Belle result in $B \to \eta_c(2S) K$ decays (PRL 89:102001, 2002): $m(\eta_c(2S)) = (3654 \pm 6 \pm 8)$ MeV/c^2

- More recent evidence from
$e^+e^- \to J/\psi\, \eta_c(2S)$ (Belle) (PRL 89:142001, 2002),
$e^+ e^- \to e^+ e^- \eta_c(2S)$ (CLEO) (hep-ex/0306060)

$\eta_c(2S)$ mass and width

- Same analysis as for η_c, with slightly modified selection
- Look at higher part of $K_S K \pi$ spectrum: evidence for an $\eta_c(2S)$ peak
- Fit yields 86 ± 23 events under the peak
- Results:

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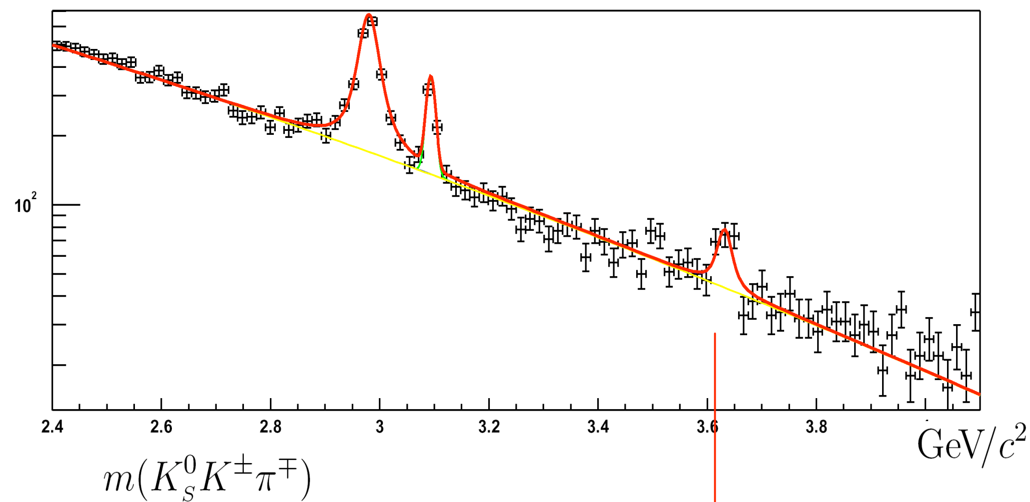
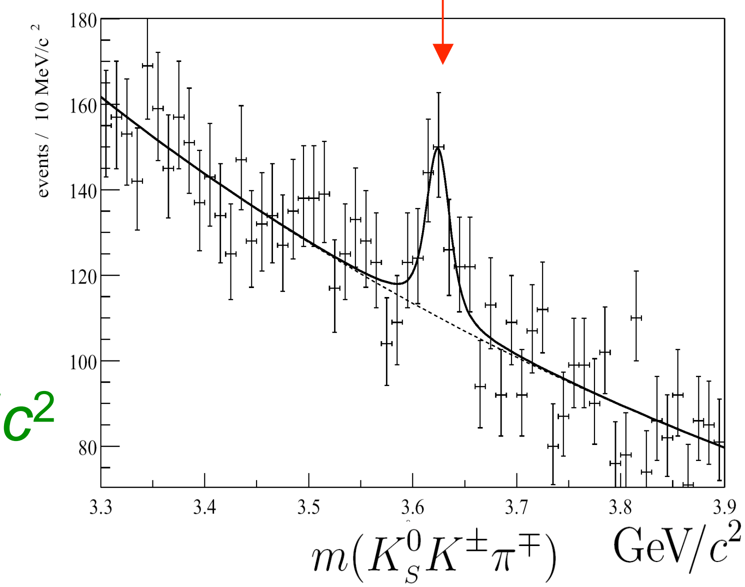
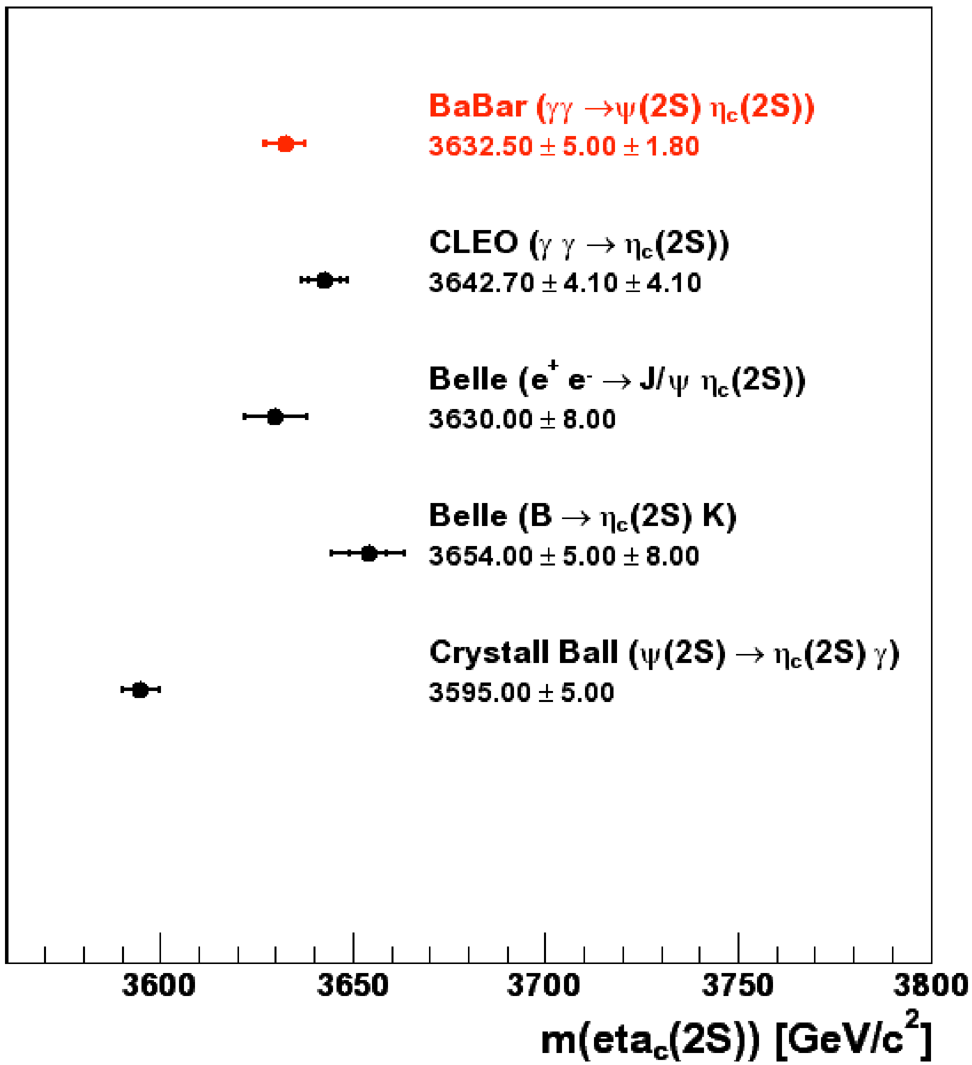
$m(\eta_c(2S)) = (3632.2 \pm 5.0 \pm 1.8)\ \mathrm{MeV}/c^2$

$\Gamma_{tot}(\eta_c(2S)) = (20 \pm 10 \pm 4)\ \mathrm{MeV}/c^2$



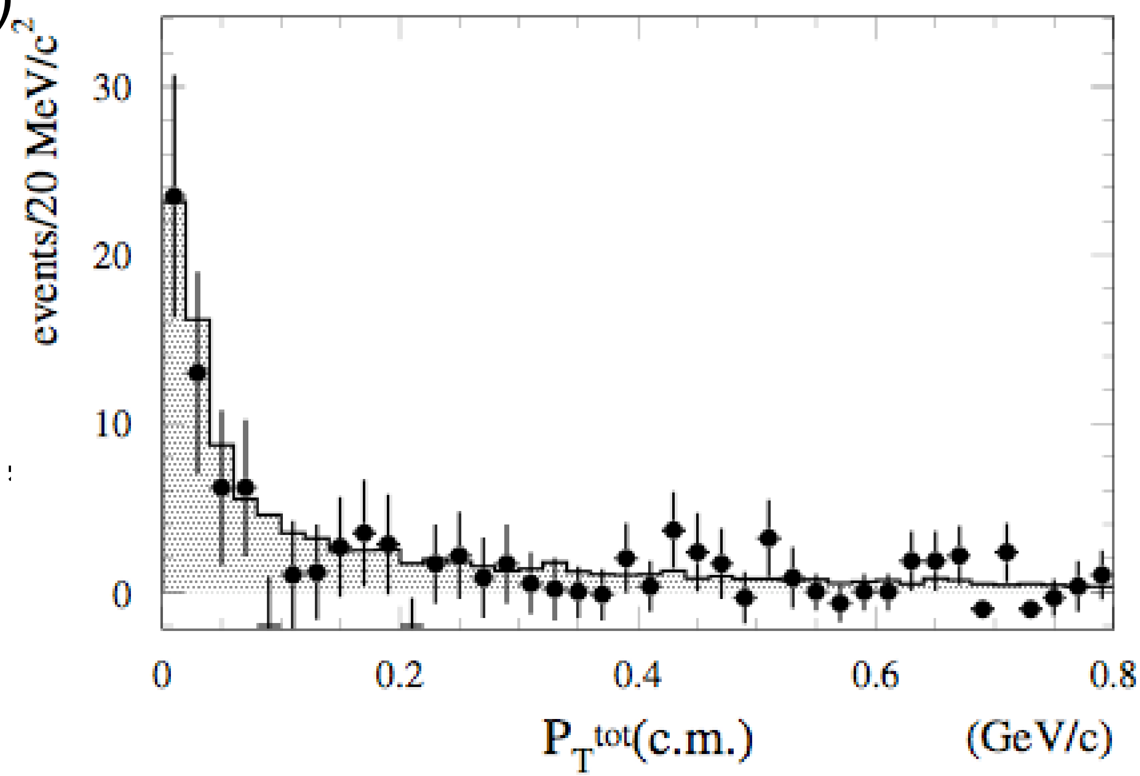


$\eta_c(2S)$ mass: all measurements



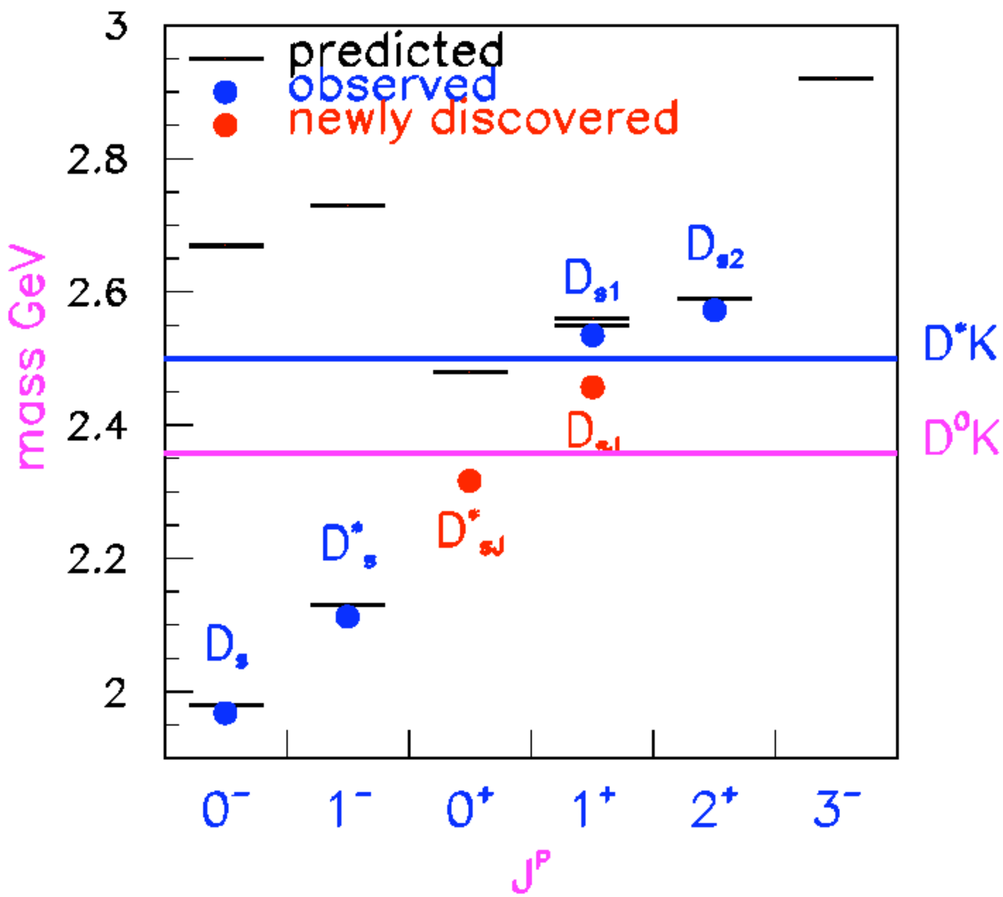
Quantum numbers

- $K_S K\pi$ final state excludes $J^P = 0^+$
- ISR production excluded by angular distribution of decay products (ISR decay products are detected in the backward region because of boost)
- Distribution of total transverse momentum peaks at 0 ⇒ quasi-real photons
- Formation in $\gamma\gamma$ fusion, with quasi-real photons ⇒ $J^P = 0^-, 2^\pm, 3^+, 4^\pm, \ldots$



D_s spectroscopy

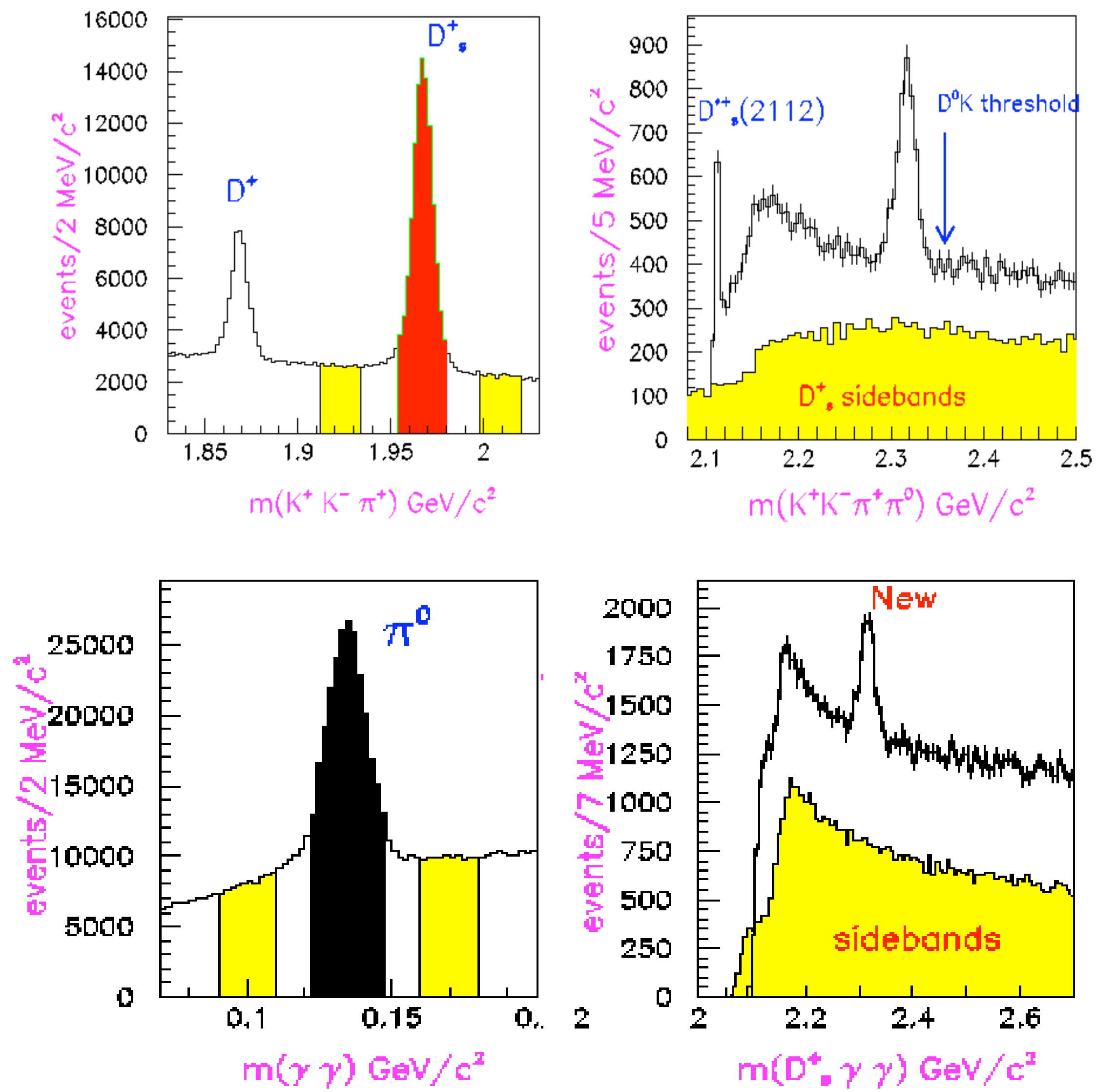
- The D_s spectrum has still empty slots



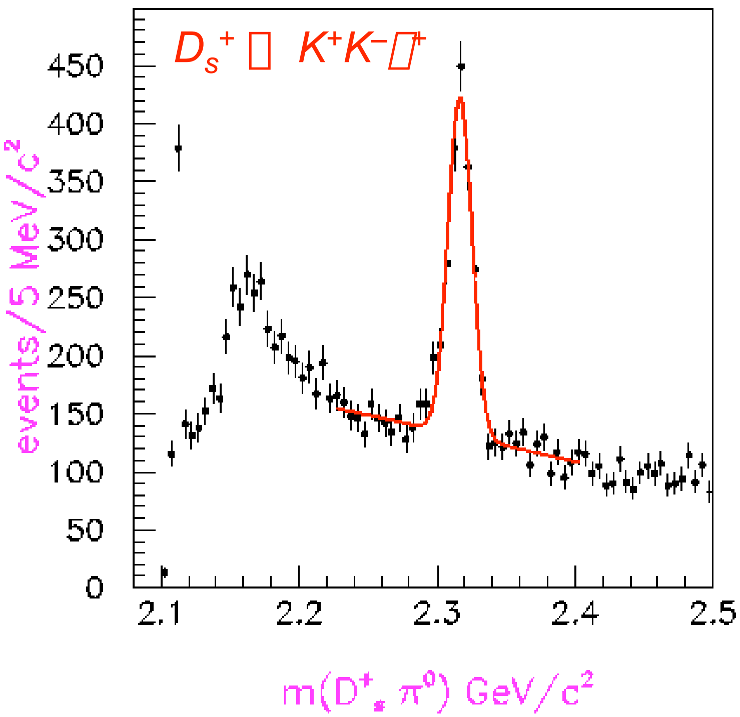
- Potential model predictions:
  - agree very well with previously known states;
  - expect missing states to lie above $D^{(*)}$ K threshold large width;
  - in particular,give $J^P = 0^+$ at 2.48 GeV/c^2 and $J^P = 1^+$ at 2.55, 2.56 GeV/c^2

Evidence for $D_{sJ}^{*}(2317)^{+}$

- D_s^+ reconstructed in ϕK^+, $K^{*0} K^+$ modes
- $D_s^+ \pi^0$ mass spectrum reveals a large signal with narrow width
- No signal observed in D_s^+ and π^0 mass sidebands
- Decay mode is isospin-violating



$D_{sJ}^{*}(2317)^{+}$ mass fit

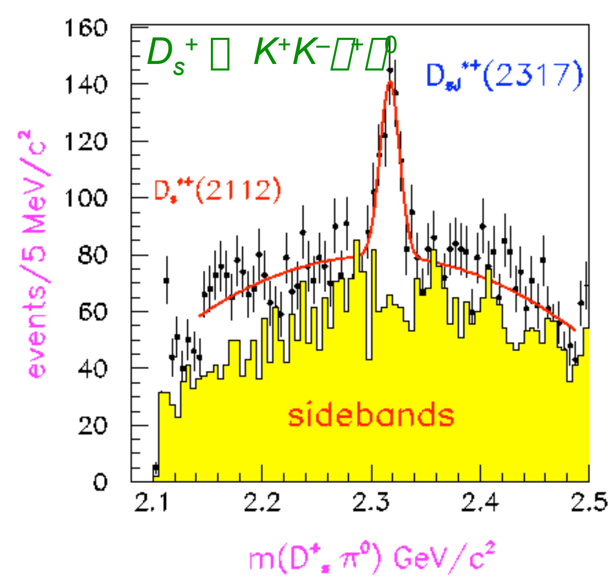


- Select continuum events: require $D_s^+\pi^0$ c.m. momentum $p^* > 3.5$ GeV/c
- Fit to Gaussian:

$\Delta m = (348.4 \pm 0.4 \pm 3.0)$ MeV/c^2

$\Rightarrow \; m = (2316.8 \pm 0.4 \pm 3.0)$ MeV/c^2,

$\sigma = (8.6 \pm 0.4)$ MeV/c^2



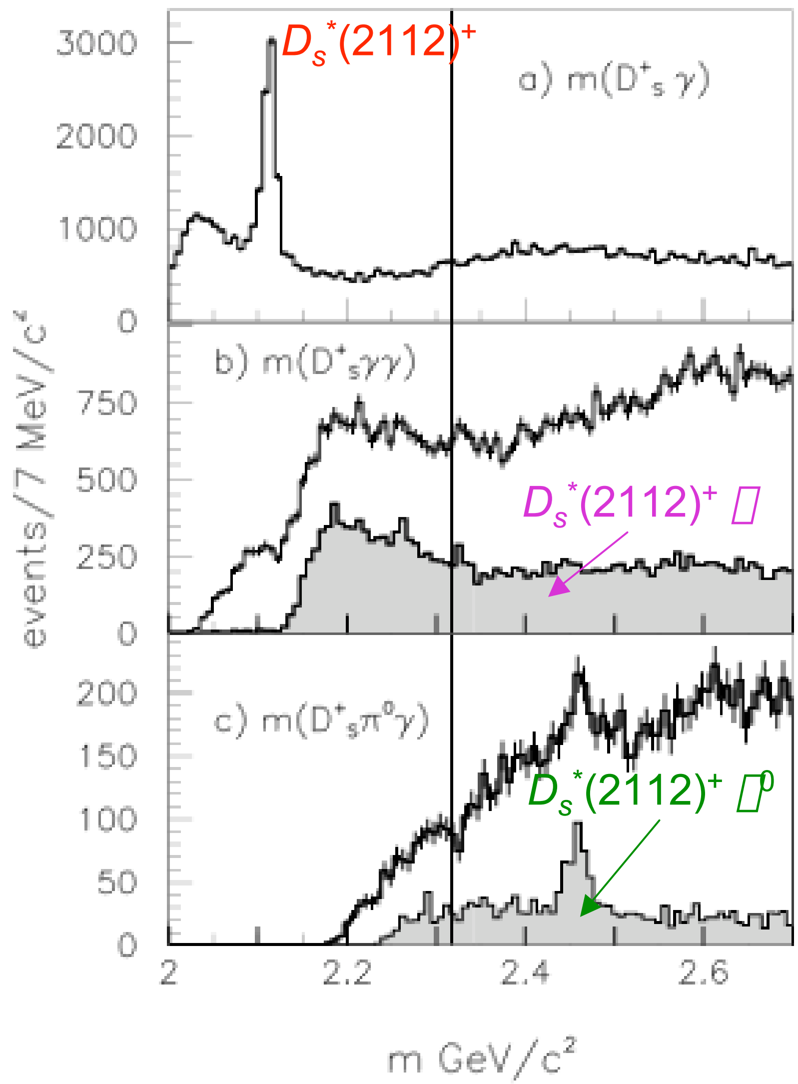
- Repeat mass spectrum with D_s^+ reconstructed in $K^+K^-\pi^+\pi^0$: fit yields

$m = (2317.6 \pm 1.3)$ MeV/c^2,

$\sigma = (8.8 \pm 1.1)$ MeV/c^2

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

- Look at D_s^+□, D_s^+□□, D_s^+□^{0}□ spectra by requiring □not to belong to any reconstructed □^{0}
- In all cases require $p^* > 3.5$ MeV/c
- Also look at D_s^+□reconstructing a $D_s^*(2112)^+$
- No further evidence of $D_{sJ}^*(2317)^+$ but…
- A structure is seen around 2460 GeV/c^2 (CLEO, hep-ex/0305100)

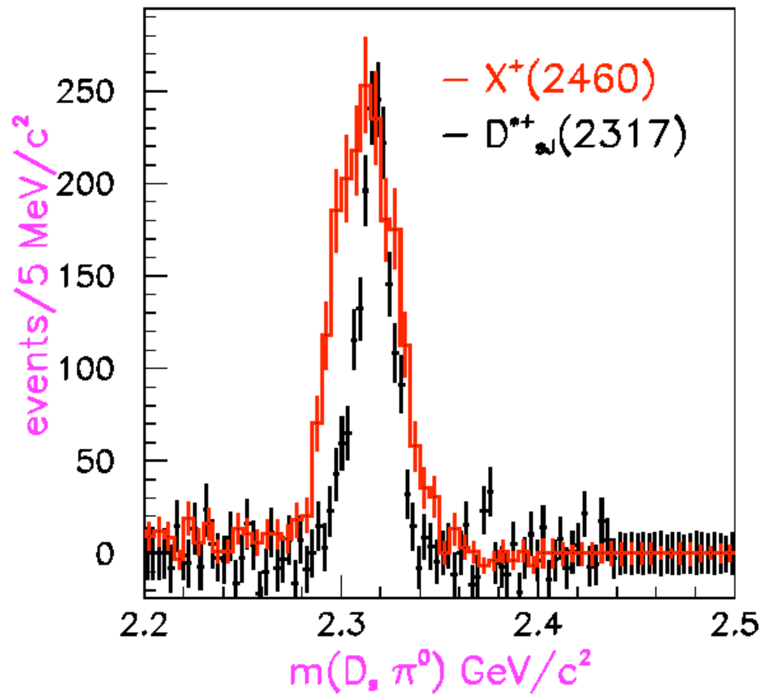


Feed-down from state at 2460 MeV/c^2?

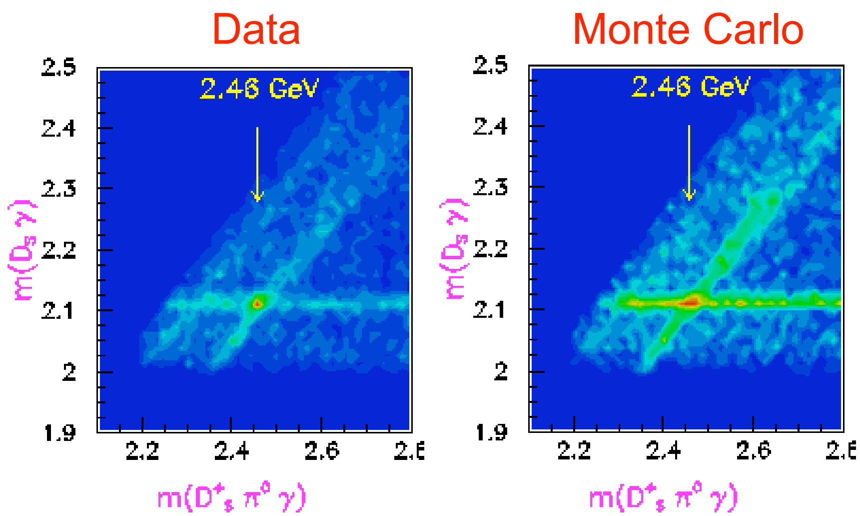
- A narrow state at 2460 MeV/c^2 decaying to $D_s^*(2112)^+ \pi^0$ could produce a peak in the $m(D_s^+\pi^0)$ distribution around 2320 MeV/c^2 (because (2460 MeV/c^2) – $m(D_s^*(2112)^+)$ ≈ (2320 MeV/c^2) – $m(D_s^+)$ ≈ 350 MeV/c^2)

- Monte Carlo simulation shows that the resulting line shape from $D_{sJ}(2460)^+$ feed-down does not agree with that observed on data

- Moreover, if the signal at 2460 MeV/c^2 were due to a state entirely decaying to $D_s^*(2112)^+ \pi^0$ ⇒ only expect ~1/5 of the observed signal at 2317 MeV/c^2

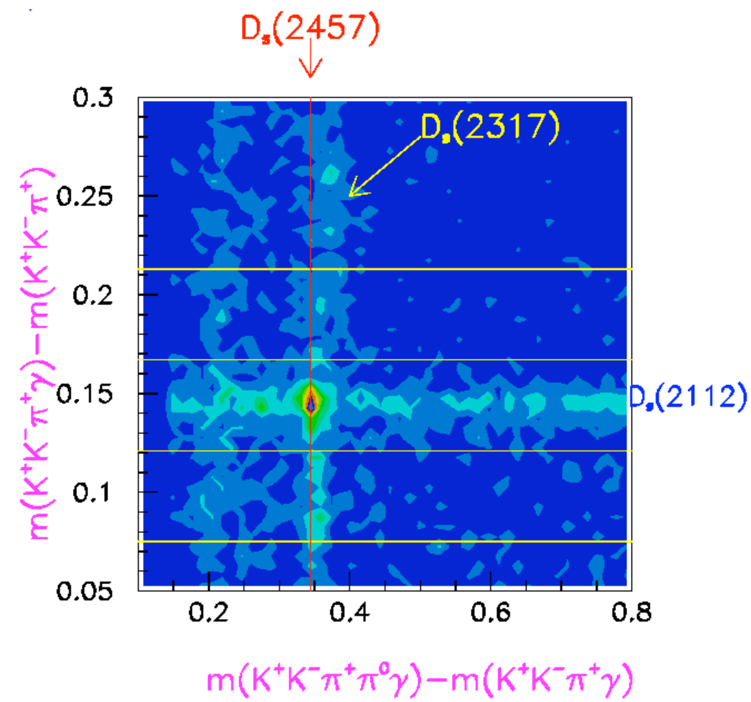


$D_{sJ}(2460)^+$: new state or kinematic artifact?



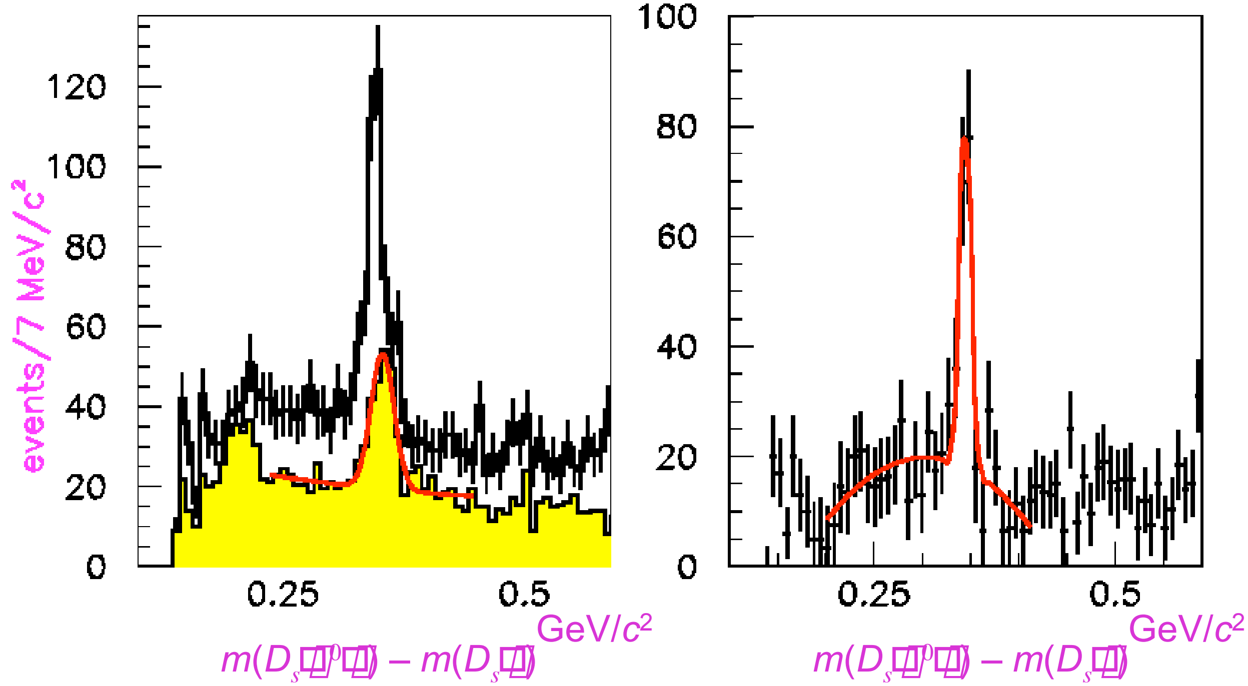
- Because of a kinematic coincidence, $D_s^*(2112)^+ \to D_s^+\gamma$ and $D_{sJ}^*(2317)^+ \to D_s^+\pi^0$ bands in invariant mass diagram cross at $m(D_s^+\pi^0\gamma) \approx 2460$ MeV/c^2

- In order to extract signal from peaking background, use mass differences distributions:
$(m(D_s^+\gamma) - m(D_s^+))$ vs.
$(m(D_s^+\pi^0\gamma) - m(D_s^+\gamma))$



$D_{sJ}(2460)^+$ signal fit

- Subtract background from scatter plot sidebands and fit to a Gaussian



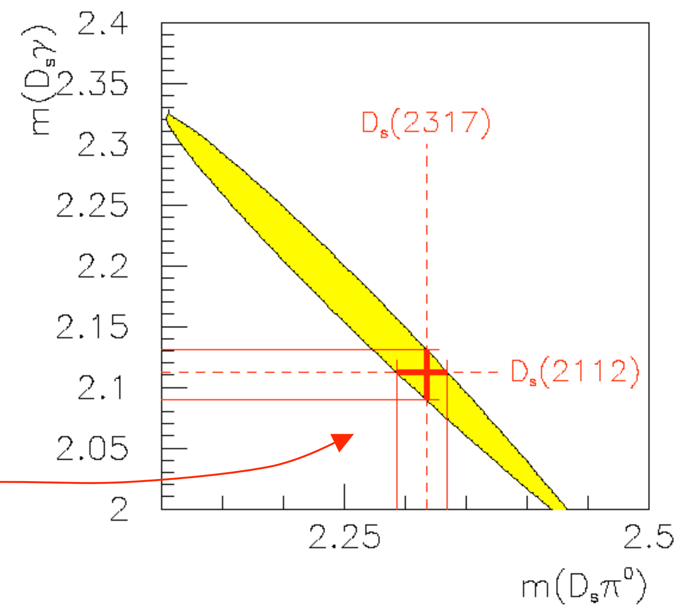
$\Delta m = (344.6 \pm 1.2 \pm 3.0)\ \mathrm{MeV}/c^2$

$m = (2457.0 \pm 1.4 \pm 3.0)\ \mathrm{MeV}/c^2$

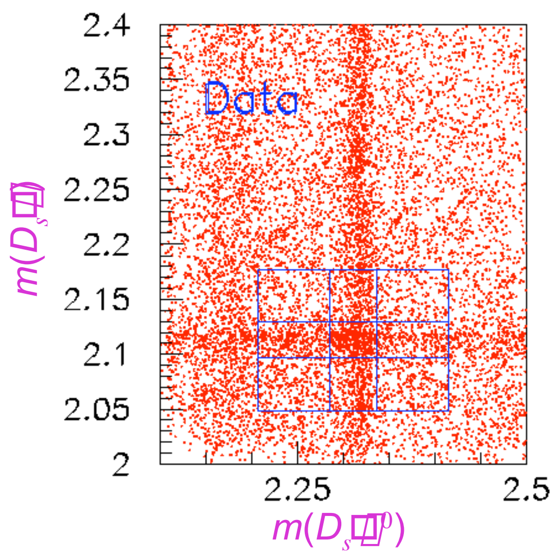
PRELIMINARY

$D_{sJ}(2460)^+$: which decay mode?

- The observed $D_{sJ}(2460)^+ \to D_s^+ \pi^0 \gamma$ decay can proceed via
  $D_{sJ}(2460)^+ \to D_s^*(2112)^+ \pi^0$ or
  $D_{sJ}(2460)^+ \to D_{sJ}^*(2317)^+ \gamma$



- A "standard" Dalitz analysis does not help in this case

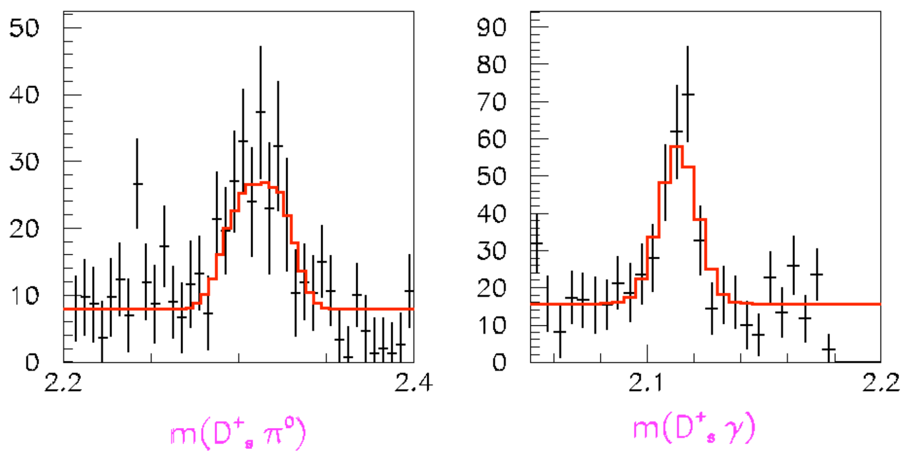


- 9 regions are defined in the $m(D_s^+\pi^0)$ - $m(D_s^+\gamma)$ plane in order to perform a background subtraction in the two projections

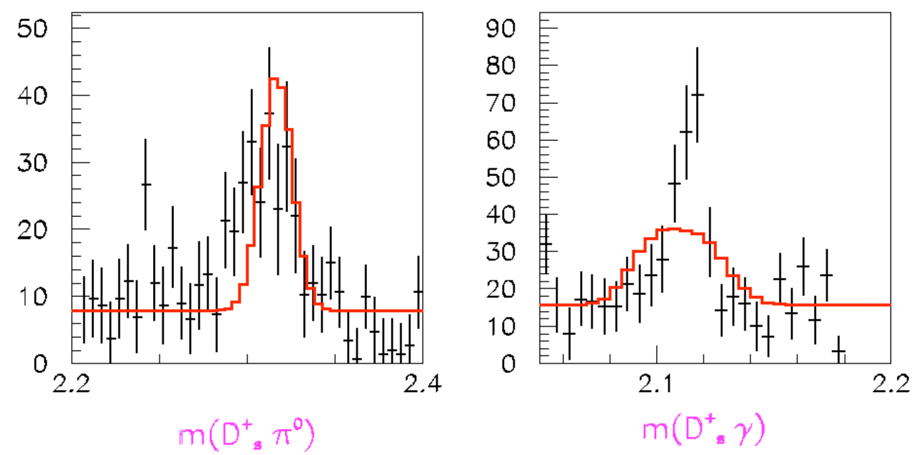
$D_{sJ}(2460)^{+}$: which decay mode? (cont'd)

- After background subtraction, a given decay produces a narrow (wide) peak in the "right" ("wrong") projection

$D_{sJ}(2460)^{+} \to D_{s}^{*+}(2112)\pi^{0}$ MC



$D_{sJ}(2460)^{+} \to D_{sJ}^{*}(2317)^{+}\gamma$ MC



- Comparison to Monte Carlo strongly favours $D_{sJ}(2460)^{+} \to D_{s}^{*}(2112)^{+}\pi^{0}$

Summary

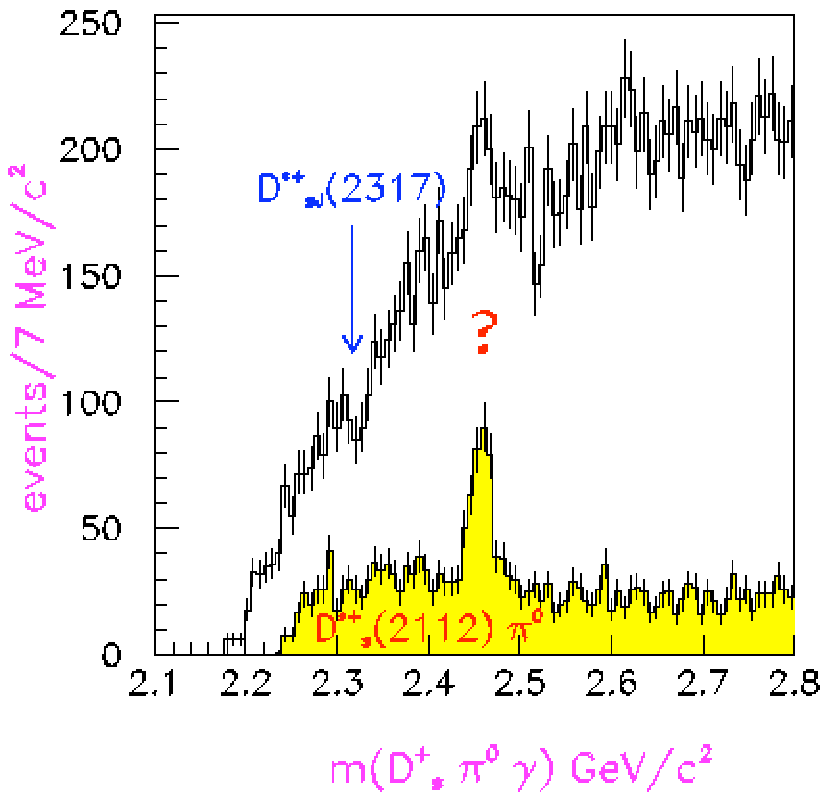
- Study of η_c and $\eta_c(2S)$ in $\gamma\gamma$ production:
  - Precision measurement of η_c resonance parameters:
    $m(\eta_c) = (2983.3 \pm 1.2 \pm 1.8)$ MeV/c^2
    $\Gamma_{tot}(\eta_c) = (33.8 \pm 2.6 \pm 0.6)$ MeV/c^2
  - Observation of an $\eta_c(2S)$ candidate with resonance parameters:
    $m(\eta_c(2S)) = (3632.5 \pm 3.5 \pm 1.8)$ MeV/c^2
    $\Gamma_{tot}(\eta_c(2S)) = (18.5 \pm 8.4 \pm 2.0)$ MeV/c^2
    and quantum numbers compatible with $\eta_c(2S)$

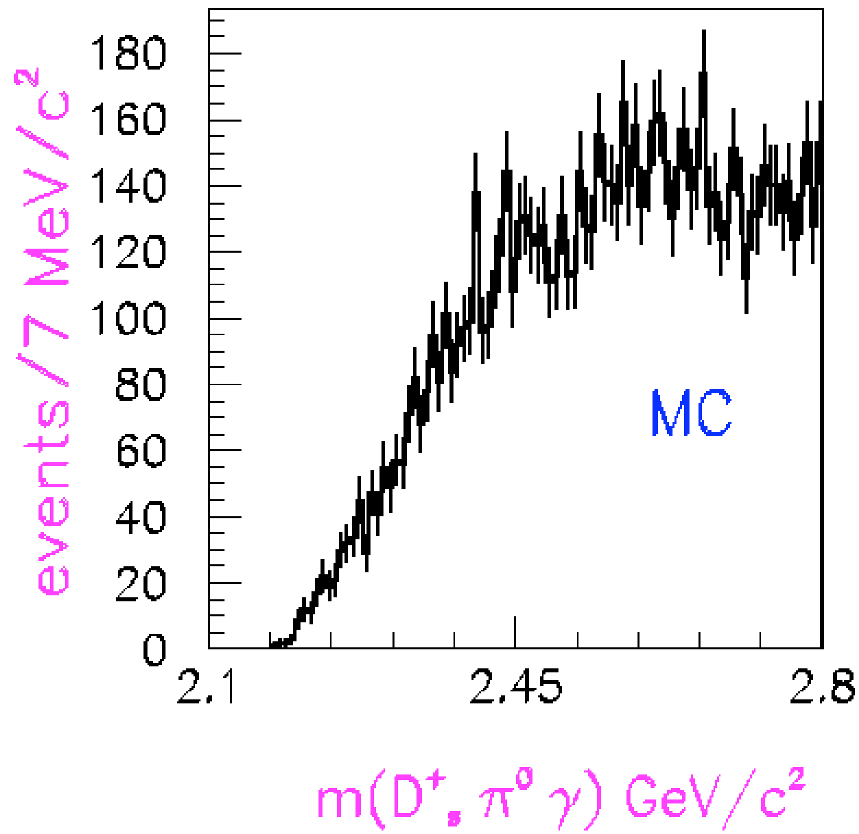
Summary (cont'd)

- Observation of two narrow states in the D_s spectrum, in isospin-violating decays:
  - $D_{sJ}^*(2317)^+ \rightarrow D_s^+ \pi^0$:
    $m = (2316.8 \pm 0.4 \pm 3.0)$ MeV/c^2
  - $D_{sJ}(2460)^+ \rightarrow D_s^+ \pi^0 \gamma$:
    $m = (2457.0 \pm 1.4 \pm 3.0)$ MeV/c^2
    $D_{sJ}(2460)^+ \rightarrow D_s^*(2112)^+ \pi^0$ decay strongly favoured
  - Measured mass below D^0K^+, $D^{*0}K^+$ threshold, respectively, contrary to theoretical predictions
  - Quantum numbers consistent with $J^P = 0^+$, 1^+ respectively (not discussed here: see F. Porter's talk in Heavy Flavors session)

Additional plots

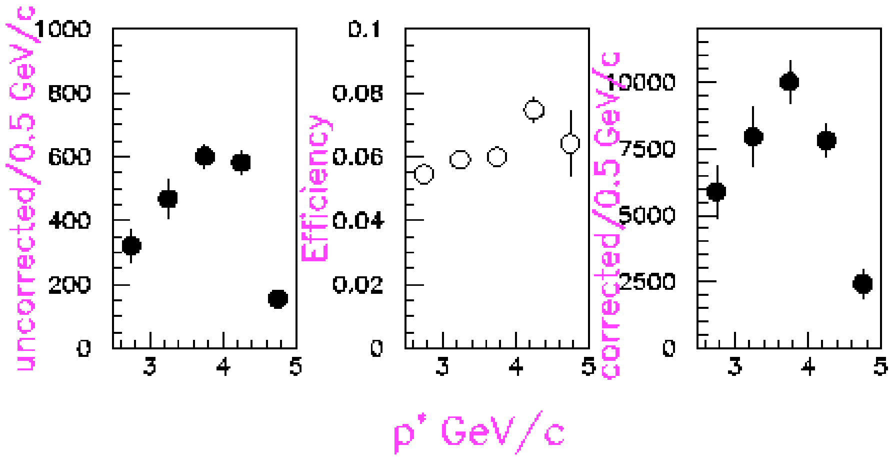
$m(D_s^+\pi^0\gamma)$ spectrum



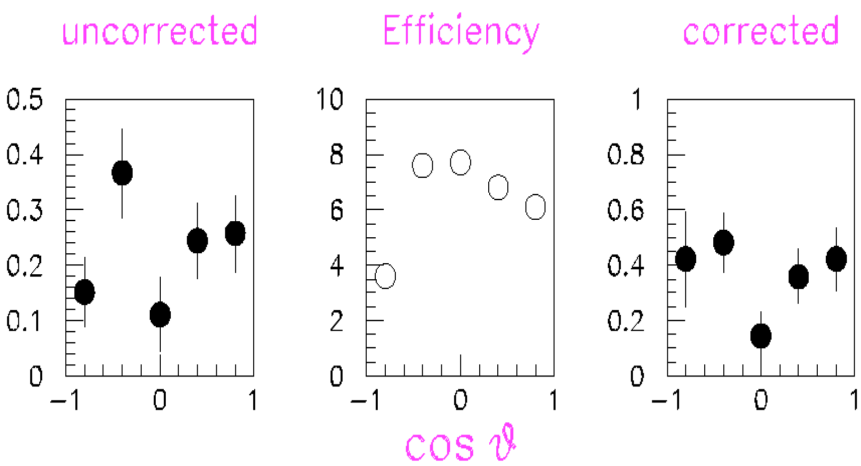


Helicity angles

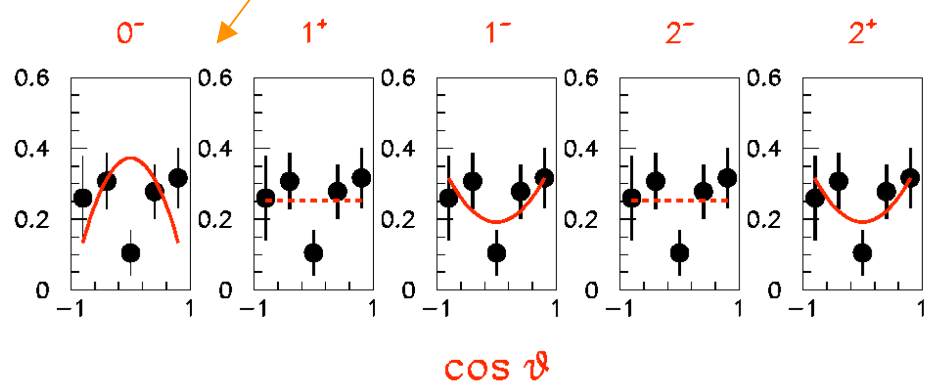
$D_{sJ}^{*}(2317)^{+}$



$D_{sJ}(2460)^{+}$



Inconsistent with $J^P = 0^-$



Comparison of m measurements