Charmed Hadron Spectroscopy from FOCUS

XXXIXth Rencontres de Moriond: QCD and High Energy Hadronic Interactions

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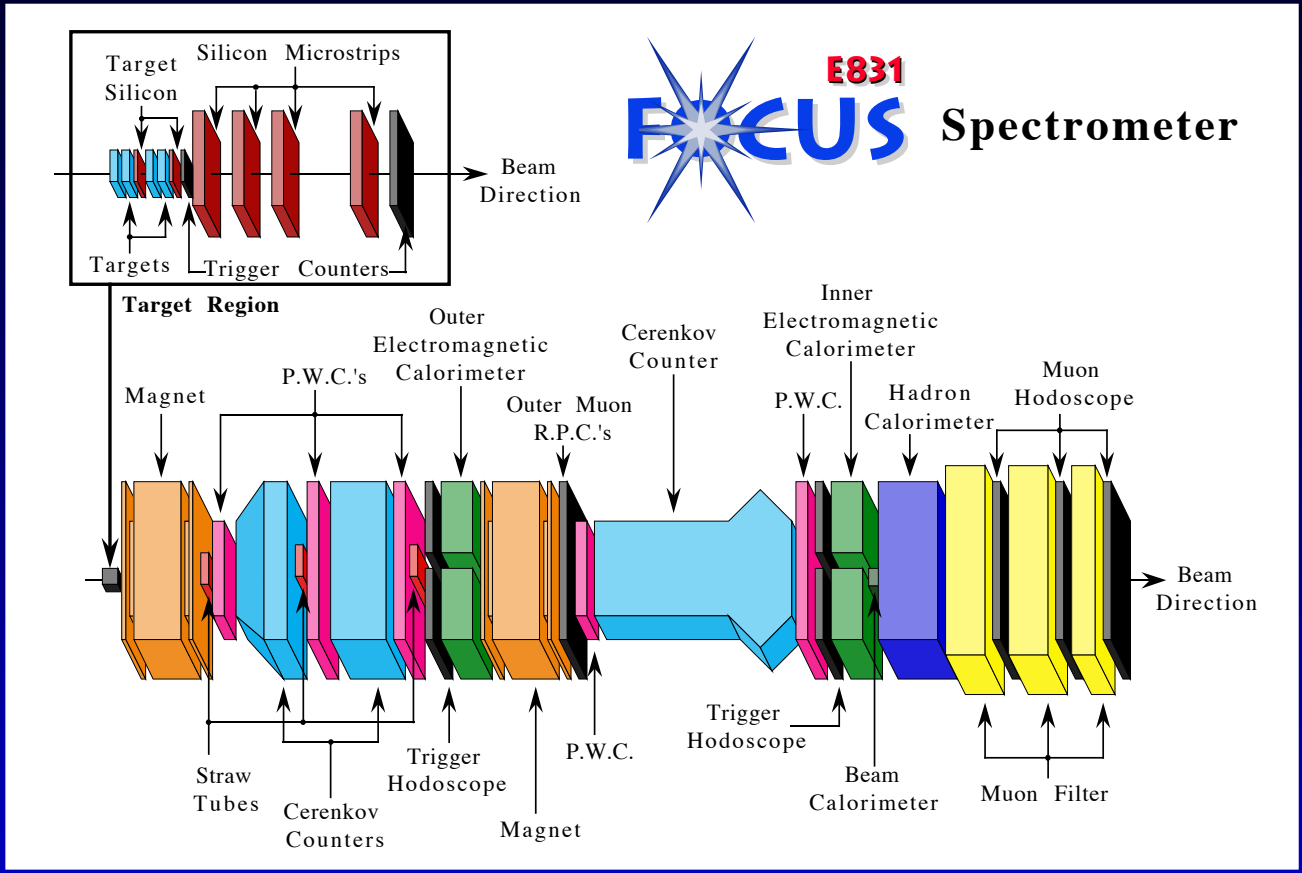
FOCUS Collaboration

Overview

- FOCUS Experiment
  - Photoproduction of charm
  - Fermilab, 1996–1997
- The $L = 1$ orbitally excited D states
- D_2^{*+}, $D_2^{*0} \to D\pi^{\pm}$ measurements plus evidence for D_0^* contributions
- $D_s^+(2317) \to D_s^+\pi^0$ observation
- Masses and widths for $L = 1$ $D_{sJ} \to DK$

FOCUS Spectrometer

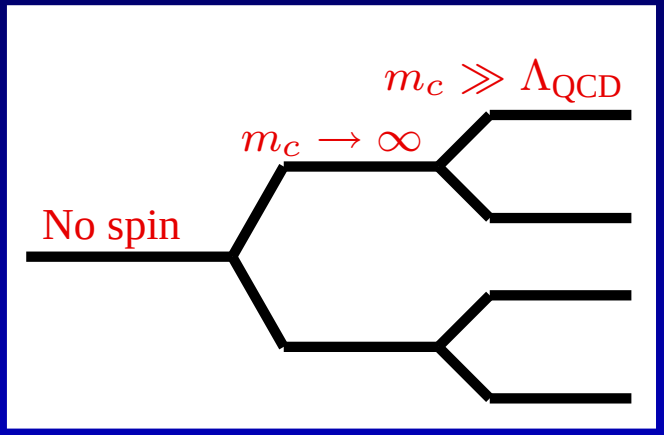


Highlights:

- Segmented target
- Silicon vertexing
- MWPC tracking
- Threshold Čerenkov
- EM/hadronic calorimeters
- Muon detectors

P-wave Charmed Mesons

- $L = 1$ between c and light quark (u, d)
- HQET: $j_{\text{light}} = s_{\text{light}} + L$, approximately good quantum number if $m_c \gg \Lambda_{\text{QCD}}$
- Idealized picture is doublet of doublets



j_{light}	J^P	Decays	$\Gamma(\text{MeV})$	Observed
$3/2$	2^+	$D^*\pi, D\pi$	≈ 20	$D_2^{*+}, D_2^{*0}, D_{s2}^{*+}$
$3/2$	1^+	$D^*\pi$	≈ 20	D_1^+, D_1^0, D_{s1}^+
$1/2$	1^+	$D^*\pi$	$\gtrsim 100$	Latest
$1/2$	0^+	$D\pi$	$\gtrsim 100$	Observations

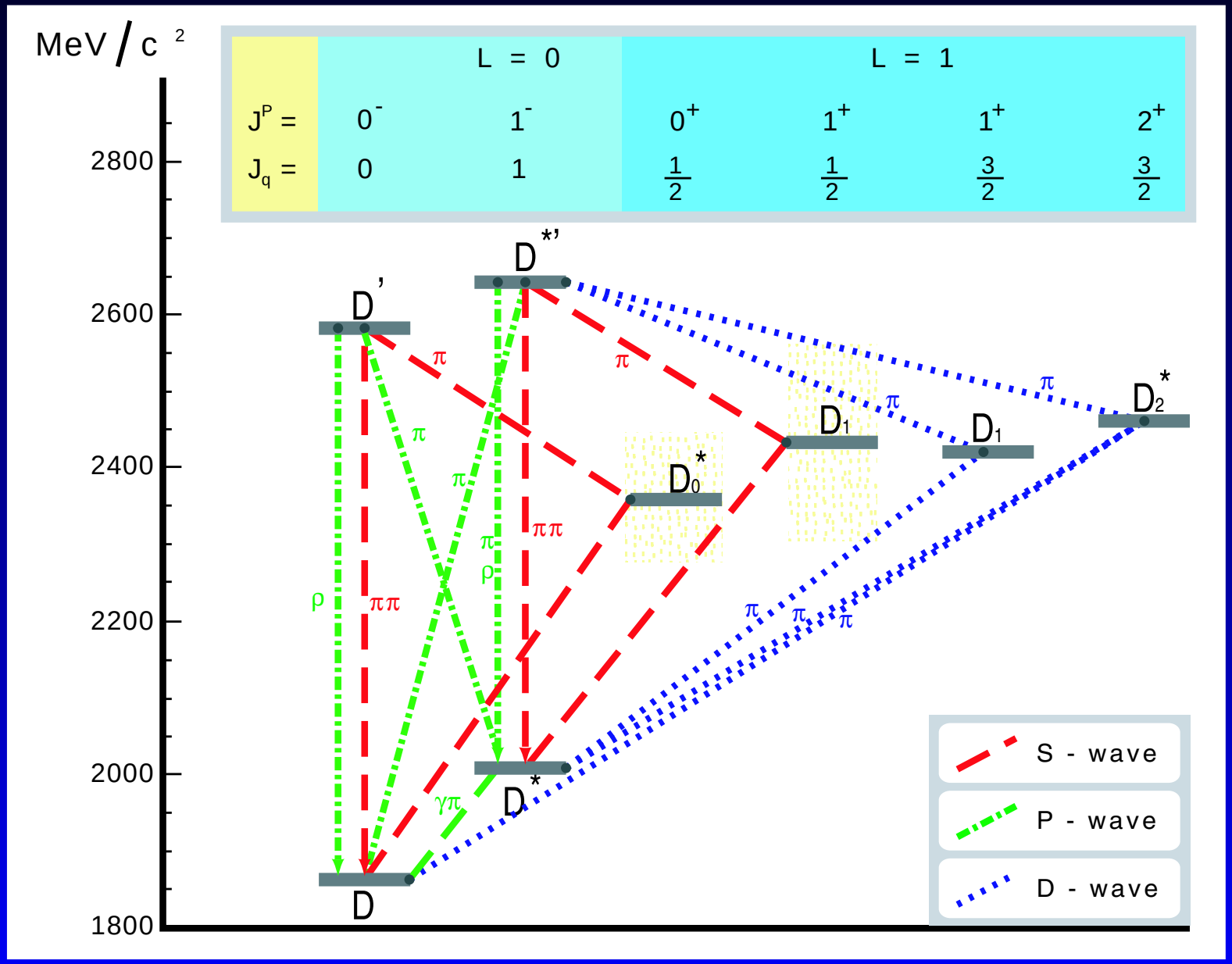
Heavy quark symmetry determines decay modes:

- $j_l = 3/2$ dominantly D-wave , $j_l = 1/2$ dominantly S-wave

Reminder: D and D^* form $j_{\text{light}} = 1/2$ doublet:

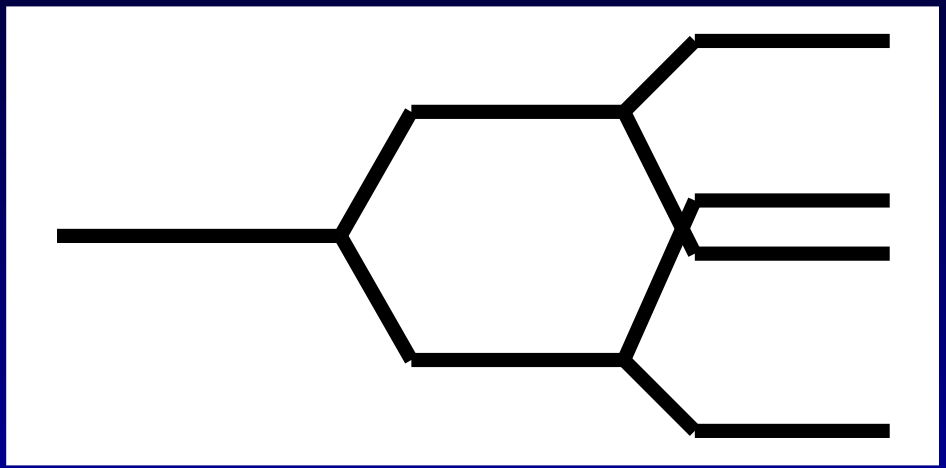
- D: $J^P = 0^-$, D^*: $J^P = 1^-$

$L = 1$ Charm Decays



What's overly simplified?

- Doublets may overlap (which 1^+ is more massive?)



- Is suppression of S-wave widths complete?
- D_{s1} right at threshold for D^*K
  - Very narrow, $\Gamma < 2.3\ \mathrm{MeV}/c^2$
  - Data suggests mostly S-wave
- Big surprise, new D_s states below DK threshold
  - How do they fit into this picture?

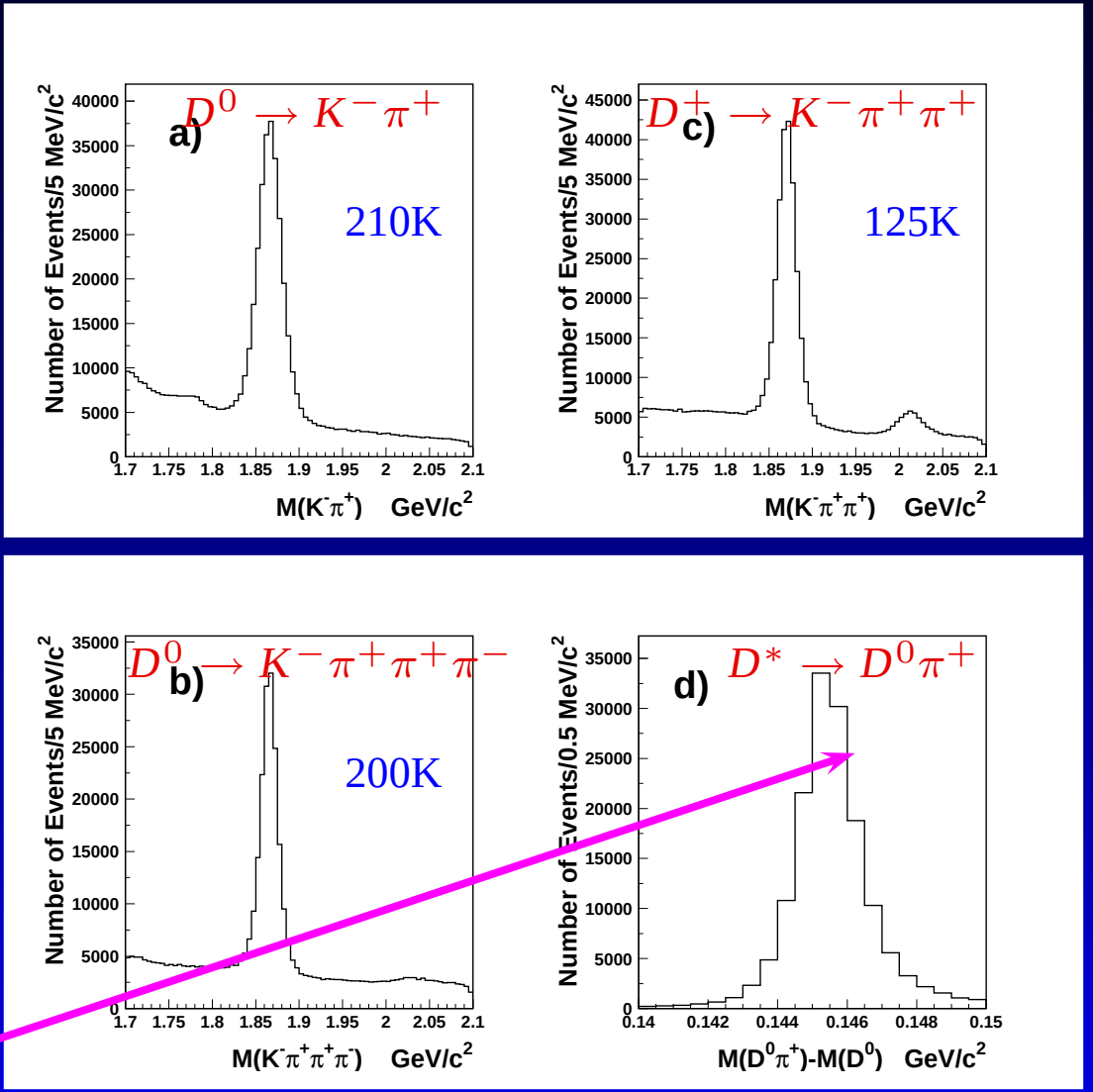
D Samples for D_2 Measurement

Photoproduction gives sizable yields with low multiplicity

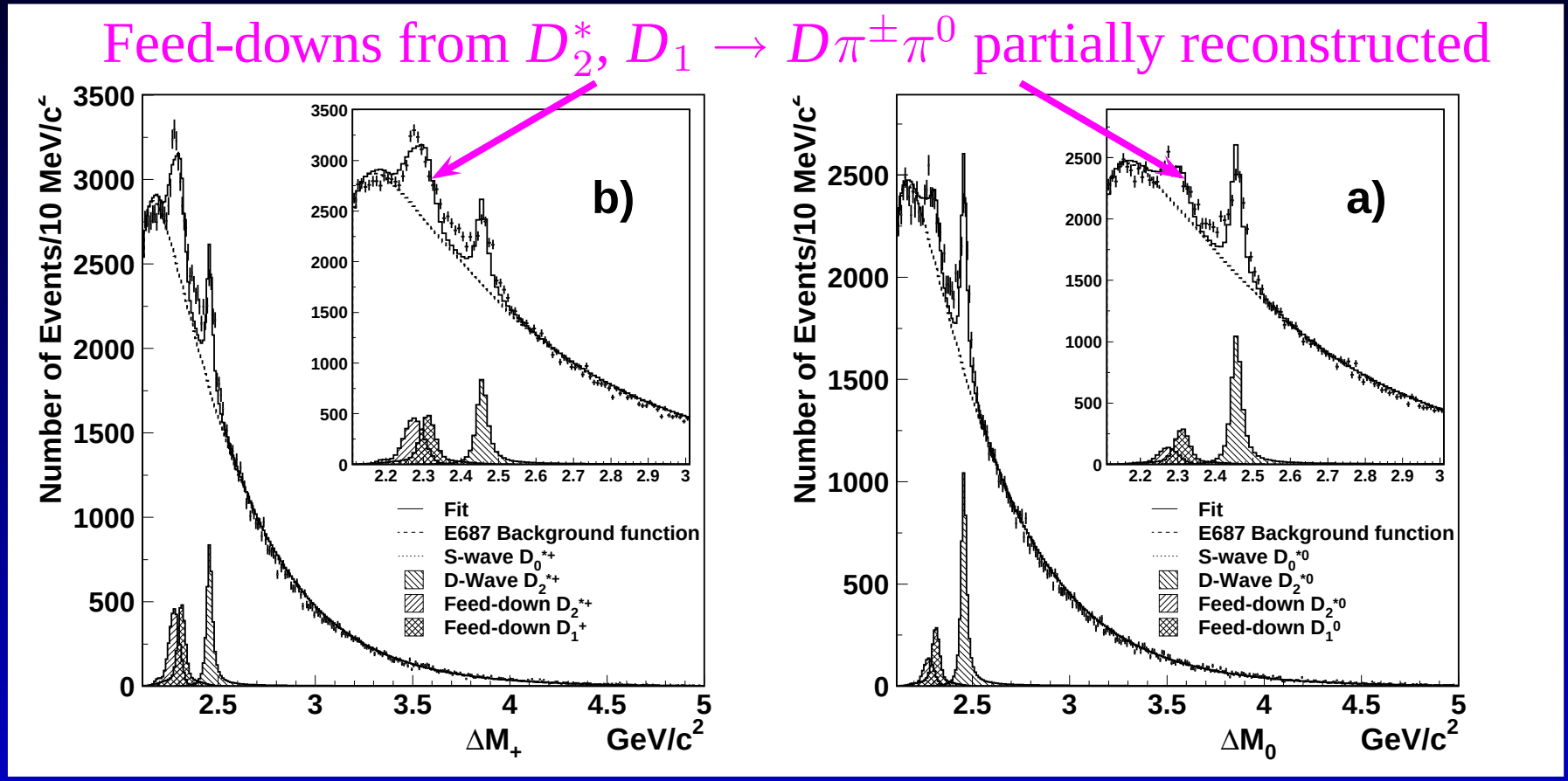
Processes studied:

- $\gamma N \to D^0 \pi^+ + X$
  - $D^0 \to K^- \pi^+$
  - $D^0 \to K \pi \pi \pi$
- $\gamma N \to D^+ \pi^- + X$
  - $D^+ \to K \pi \pi$

Remove any D^0 candidate with $D^* < 3\sigma$. (Cleans up $D^0 \pi^+$.)



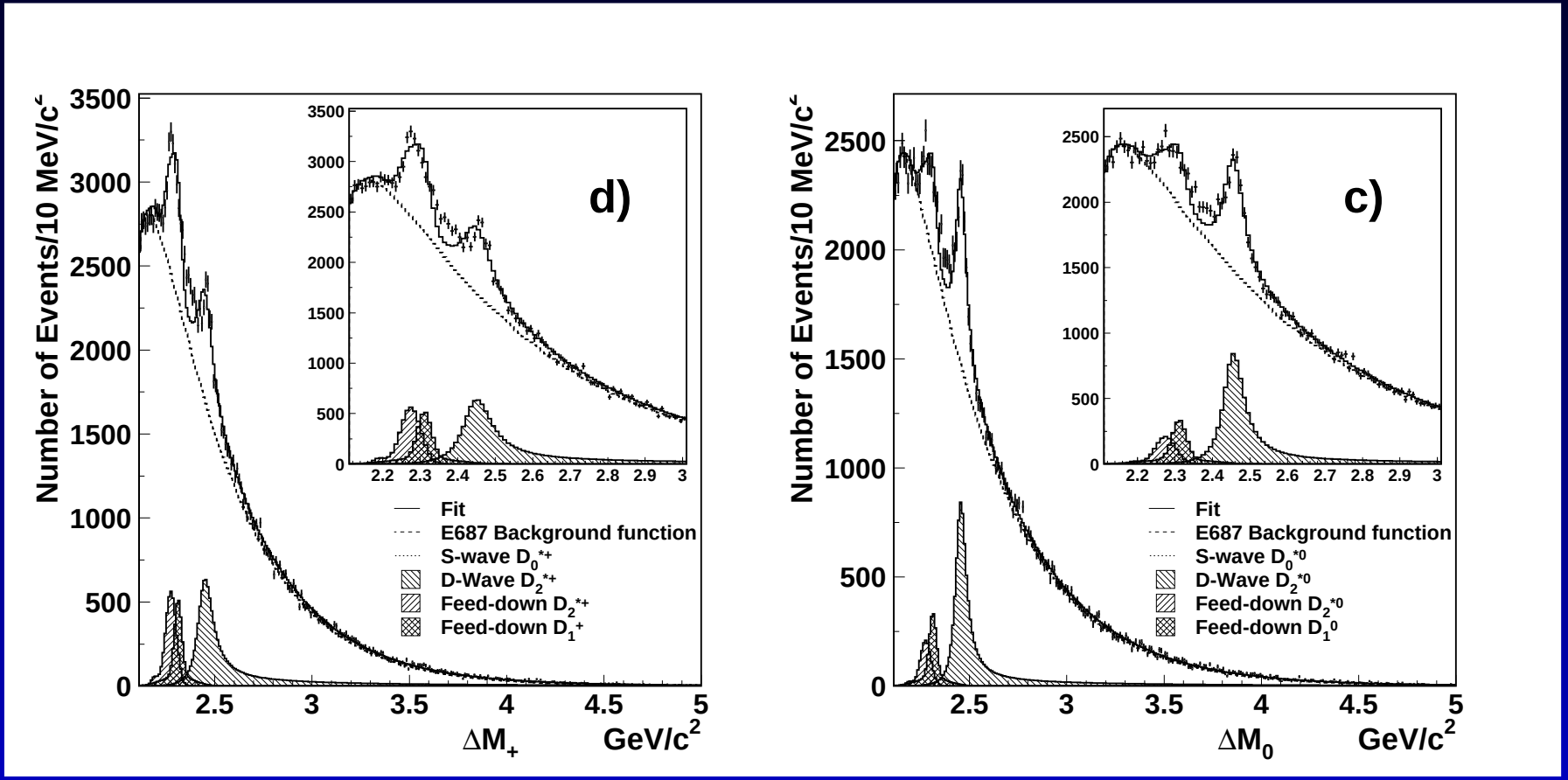
$D^0\pi^+$ and $D^+\pi^-$ Distributions



$D^+\pi^-$ (ΔM_0) and $D^0\pi^+$ (ΔM_+) distributions. D mass is subtracted and PDG mass added. All parameters fixed at PDG values, only normalizations float. Clearly not a good match.

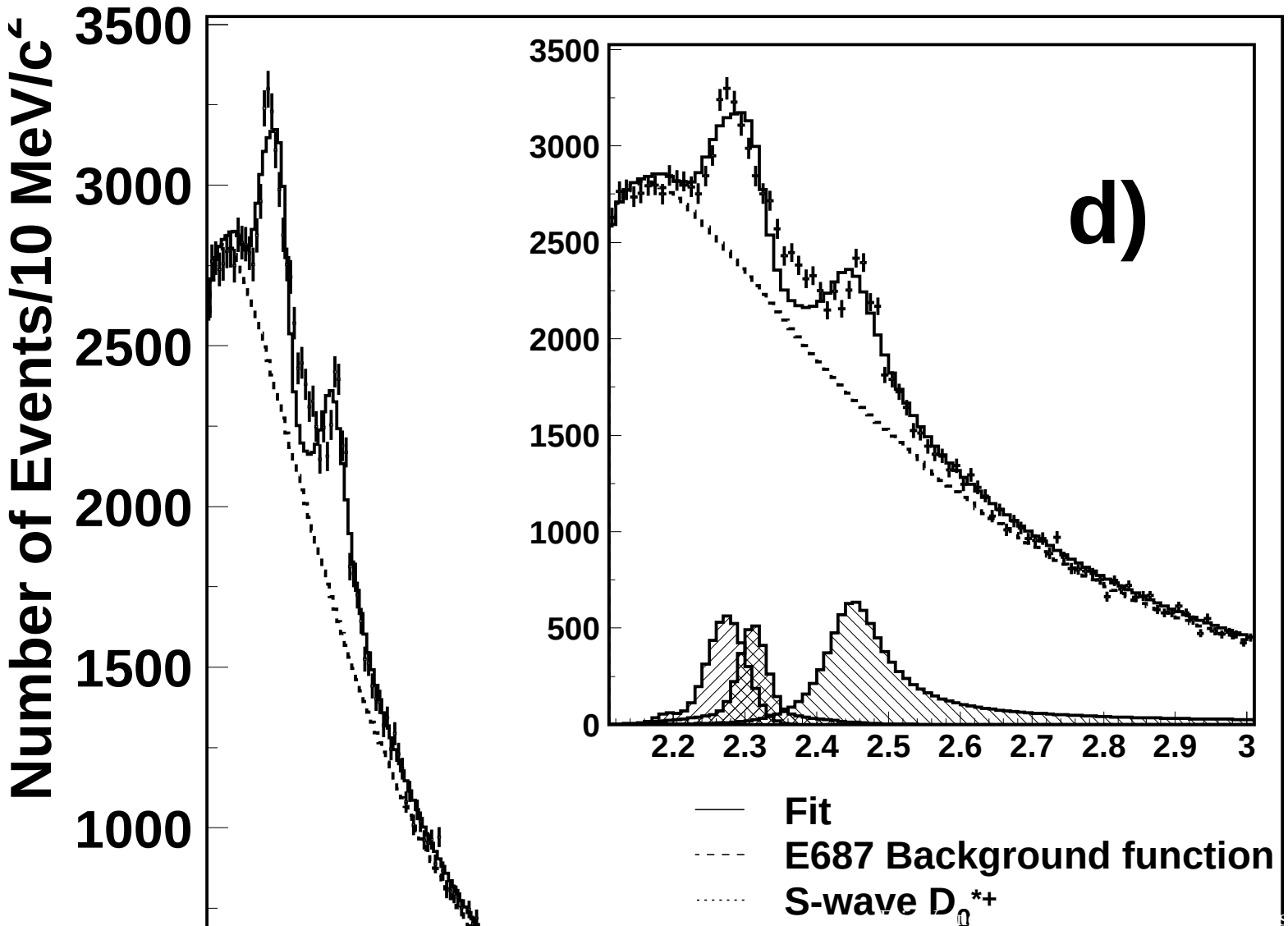
Exponential BG matches very well except in signal region.

Fitting without D_0^* Broad States

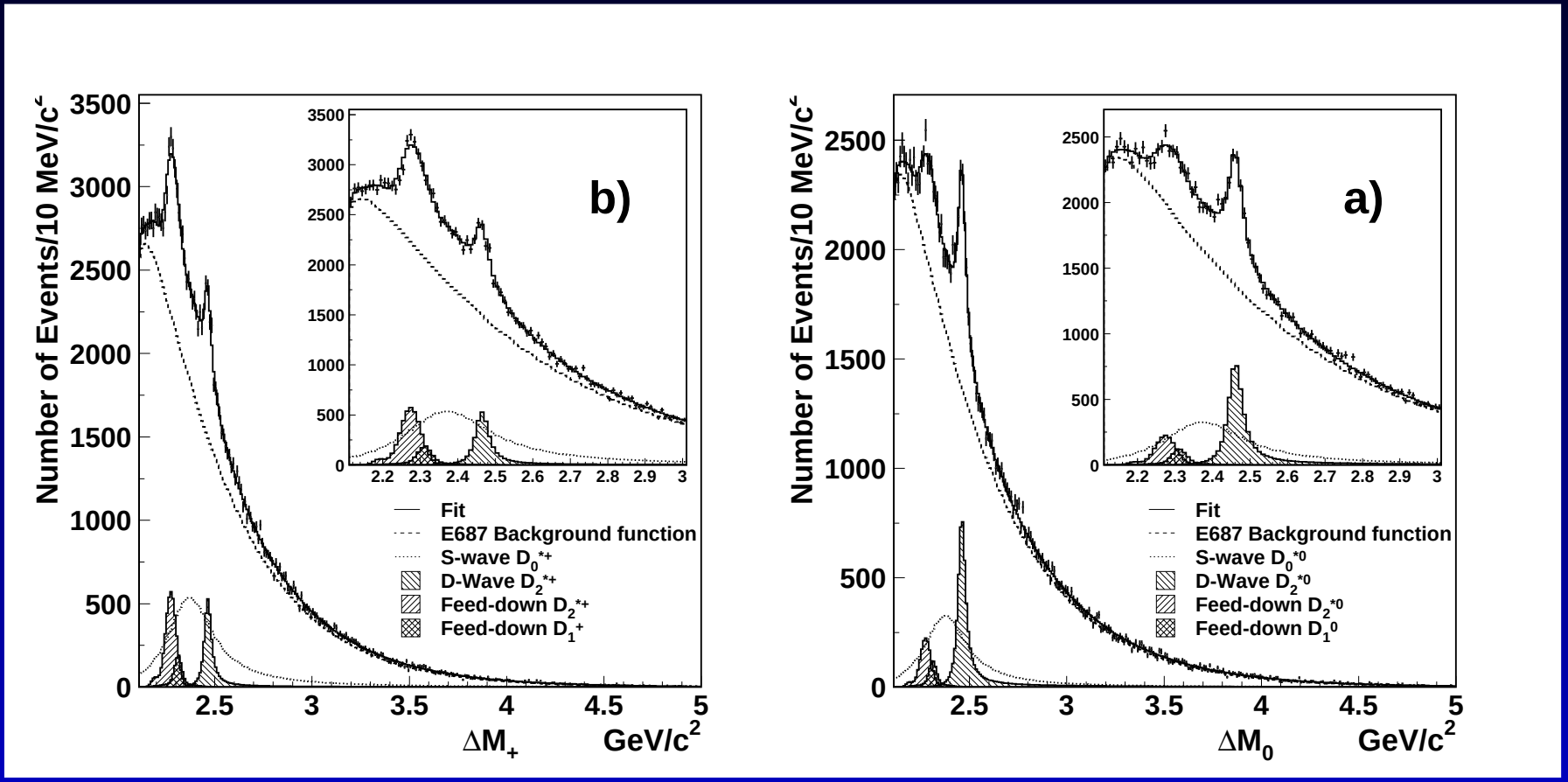


Perform a free fit just of D_2^* parameters. Feed-downs are calculated from PDG values. Still very poor agreement (χ^2/d.o.f ≈ 3) between D_2^* signal region and the feed-down region. D_2^* parameters are far from expected values.

Expansion of problem region

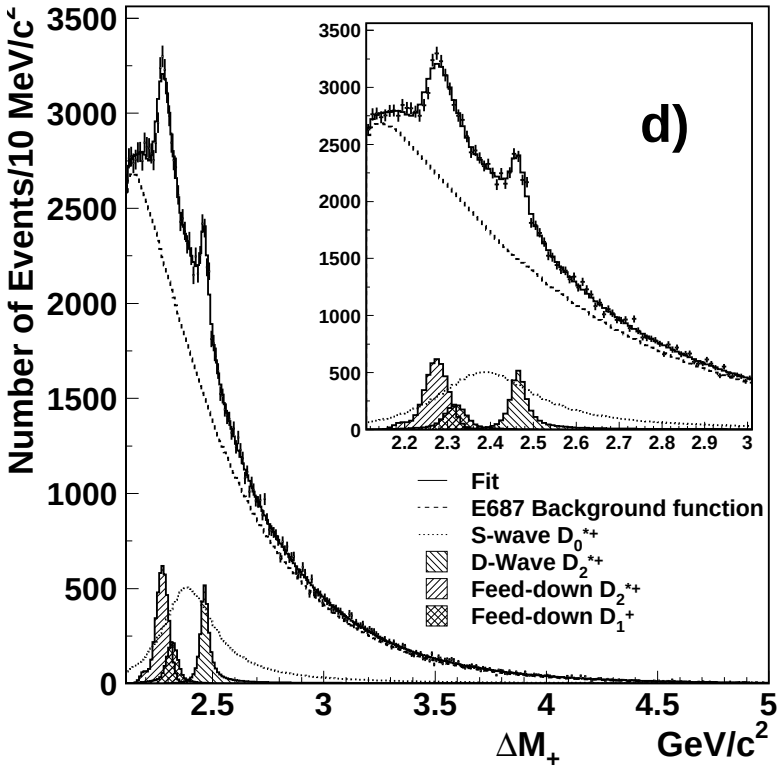


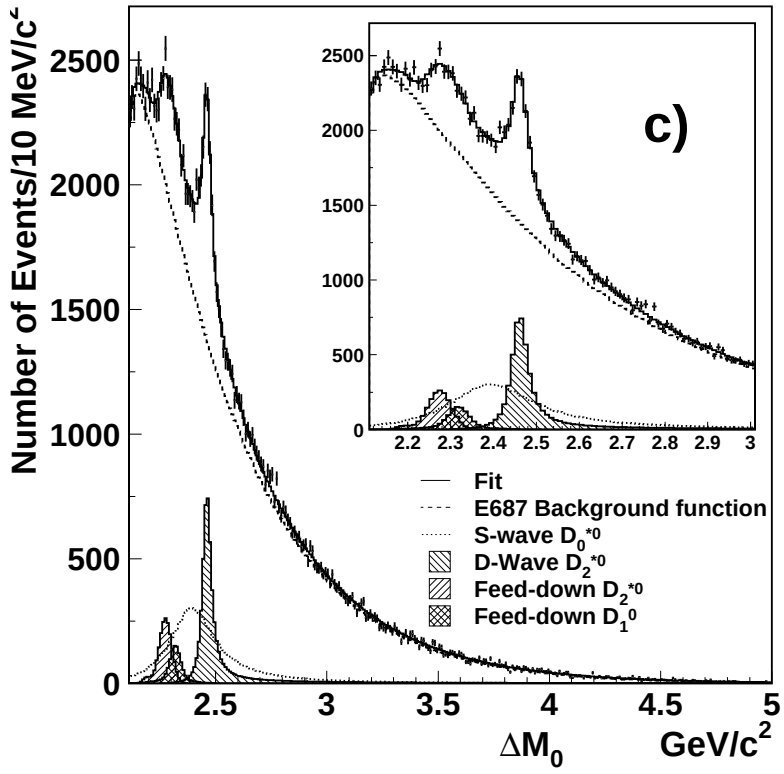
Adding D_0^* Broad States



Add S-wave contribution for D_0^* state ($j_\ell = \frac{1}{2}$). Fit is much improved, especially problem region before. CL = 22%. Also could be D_1^* ($j_\ell = \frac{1}{2}$) $\rightarrow D^*\pi$ with an unreconstructed π^0.

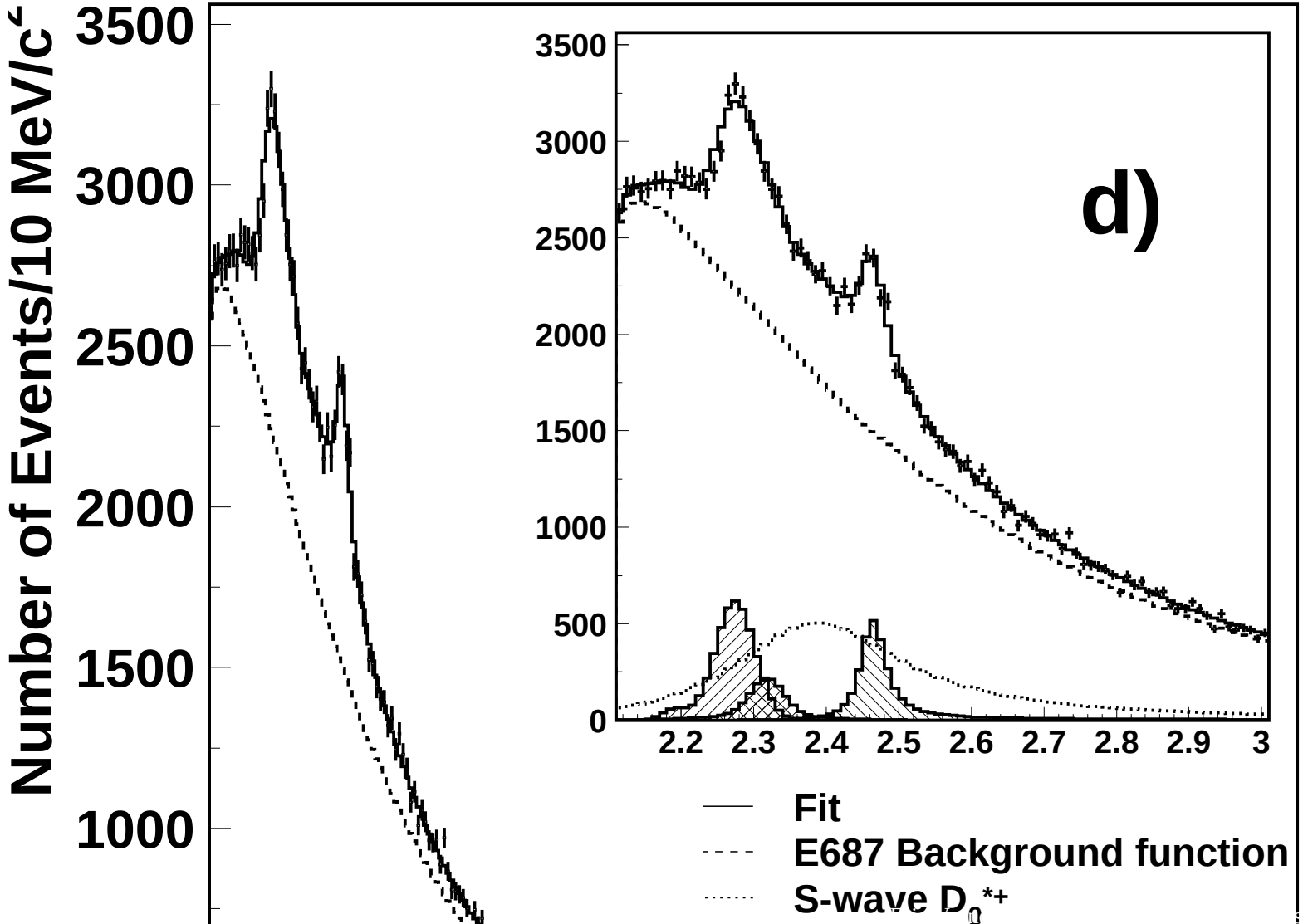
Final $D^0\pi^+$ and $D^+\pi^-$ fits





For consistency, we re-simulate the feed-down shapes with M, Γ found previously. CL of fit increases to 28%, central values basically unchanged.

Expansion of “problem” region



Systematic Checks

Signals are fit with relativistic Breit–Wigner $\oplus$ experimental resolution. BG is exponential + roll-over: $e^{a+bx}(x-c)^d$.

Studied a large number of similar backgrounds (wrong sign, D sidebands, simulations). All are consistent with single exponential beyond 2250 MeV/c^2.

Studied alternative BG parameterizations too. S-wave contribution is needed for an acceptable fit. Many other systematic studies on fitting method and significance of S-wave.

In addition, circumstantial evidence that S-wave contribution is *not* dominated by feed-down from $D_1(j_\ell = \frac{1}{2})$

- Ratios of D_0^*/D_2^* for both charges make sense (Feed-down should be larger for $D^0\pi^+$ since $D^{*0} \not\to D^+$)
- Fit parameters of two broad states are consistent

$D^{0/+}\pi^{\pm}$ Results

	D_2^{*0}	D_2^{*+}	$D_2^{*+} - D_2^{*0}$
Yield	$5776 \pm 869 \pm 696$	$3474 \pm 670 \pm 656$	—
Mass	$2464.5 \pm 1.1 \pm 1.9$	$2467.6 \pm 1.5 \pm 0.8$	$3.1 \pm 1.9 \pm 0.9$
PDG03	2458.9 ± 2.0	2459 ± 4	0.0 ± 3.3
Belle03	2461.6 ± 3.9		
Width	$38.7 \pm 5.3 \pm 2.9$	$34.1 \pm 6.5 \pm 4.2$	
PDG03	23 ± 5	25^{+8}_{-7}	
Belle03	45.6 ± 8.0		

	"$D_0^{*0}(j_\ell = \frac{1}{2})$"	"$D_0^{*+}(j_\ell = \frac{1}{2})$"
Yield	9810 ± 2657	18754 ± 2189
Mass	$2407 \pm 21 \pm 35$	$2403 \pm 14 \pm 35$
Belle03	2308 ± 36	
Width	$240 \pm 55 \pm 59$	$283 \pm 24 \pm 34$
Belle03	276 ± 66	

Errors on D_2^* masses and widths smaller than or same as PDG03 and agree with recent Belle report (hep-ex/0307021).

Excited D_s Mesons

Until spring 2003, this pattern was expected to be repeated in the D_s sector. Two relatively narrow $j_{\text{light}} = 3/2$ states had been observed and broad $j_{\text{light}} = 1/2$ were expected to be there too.

Instead, two new, very narrow states have been observed by the B factories decaying to $D_s^+\pi^0$.

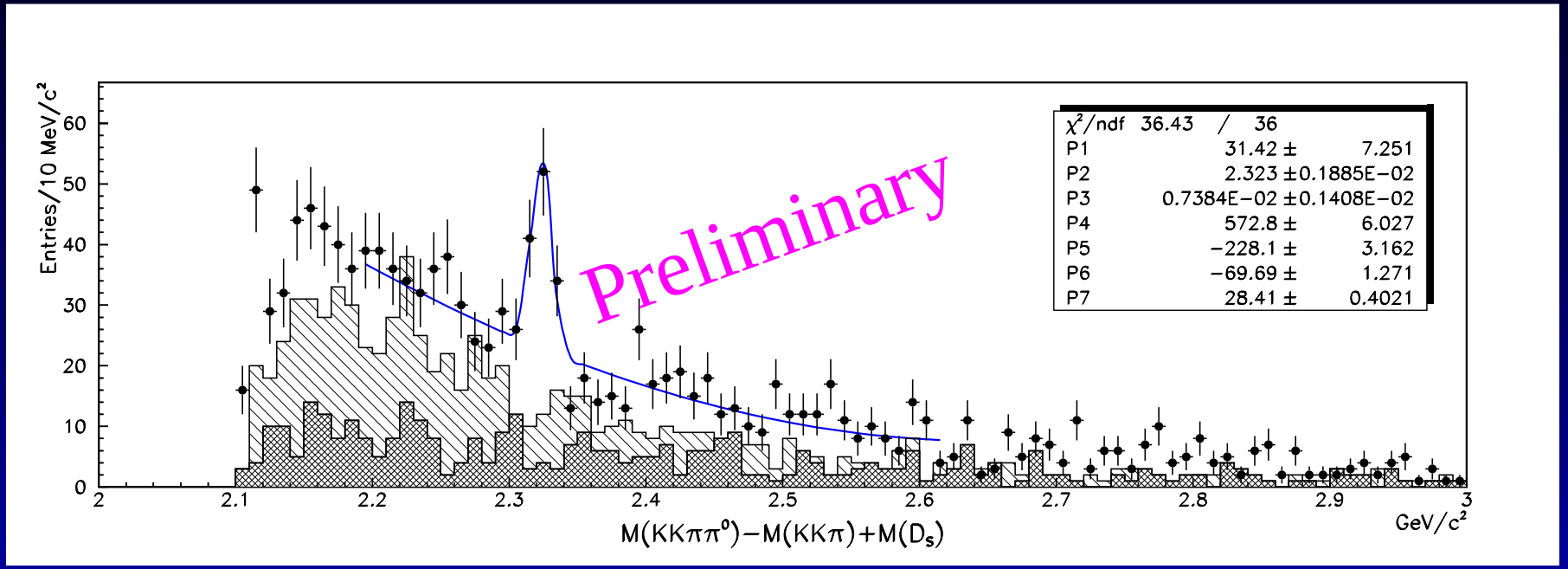
The first, dubbed $D_{sJ}^*(2317)$, was discovered by BABAR and later confirmed by CLEO and Belle.

The second, $D_{sJ}^*(2463)$, was discovered by CLEO and confirmed by BABAR and Belle.

$D_{sJ}^*(2317)$ also seen by FOCUS

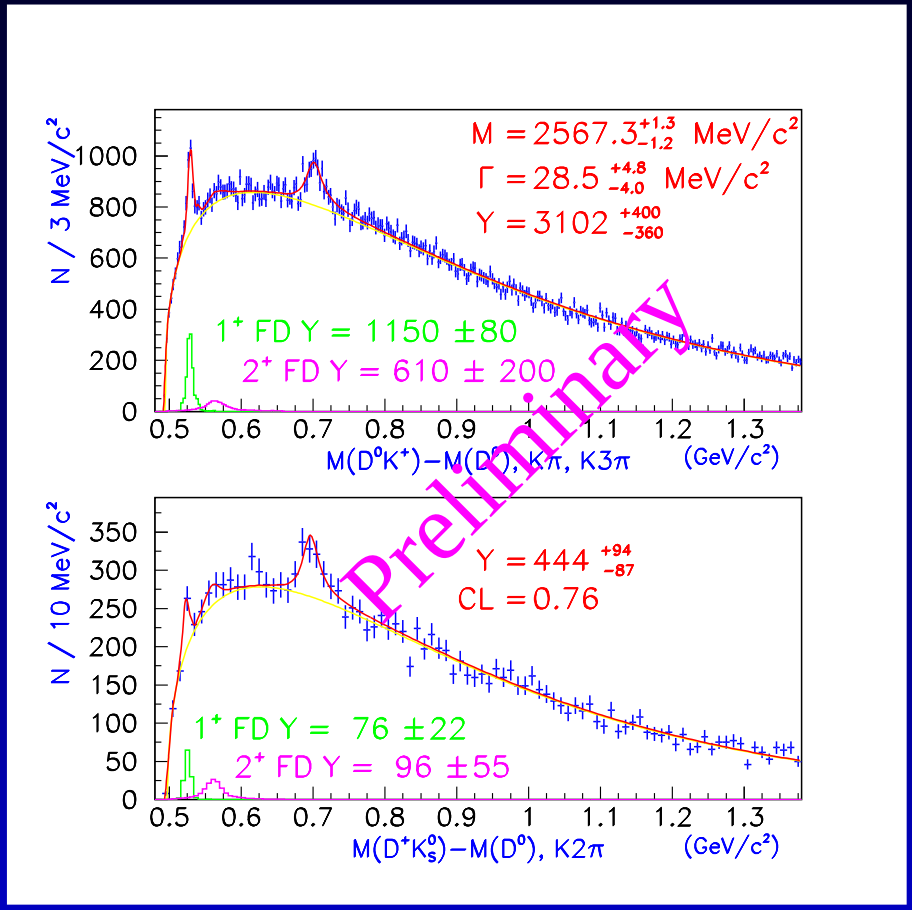
For $j_\ell = 3/2$ states, analysis is very similar to D sector; replace π with K^+/K_S^0.

$D_s^+(2317)$ Observation



- Reconstructed in $D_s^+(\to K^-K^+\pi^+)\pi^0$ (58 events, inner EM Cal only)
- Correction to π^0 energy based on $D_s^* \to D_s^+\pi^0$ and $D^0 \to K^-\pi^+\pi^0$.
- Mass (using PDG D_s^+ value) found to be $2323 \pm 2\ \mathrm{MeV}/c^2$. BABAR/Belle/CLEO avg. ~ 2317

$D_{sJ}^+(2573) \to D^0K^+$ and $D^+K_S^0$



Simultaneous fit to D^0K^+ and $D^+K_S^0$. Terms:

- D_{s2}^* signal: D-wave Rel. BW
- Smooth BG shape
- D_{s1}& D_{s2}^* feed-down shapes

Common M and Γ, stat. only.

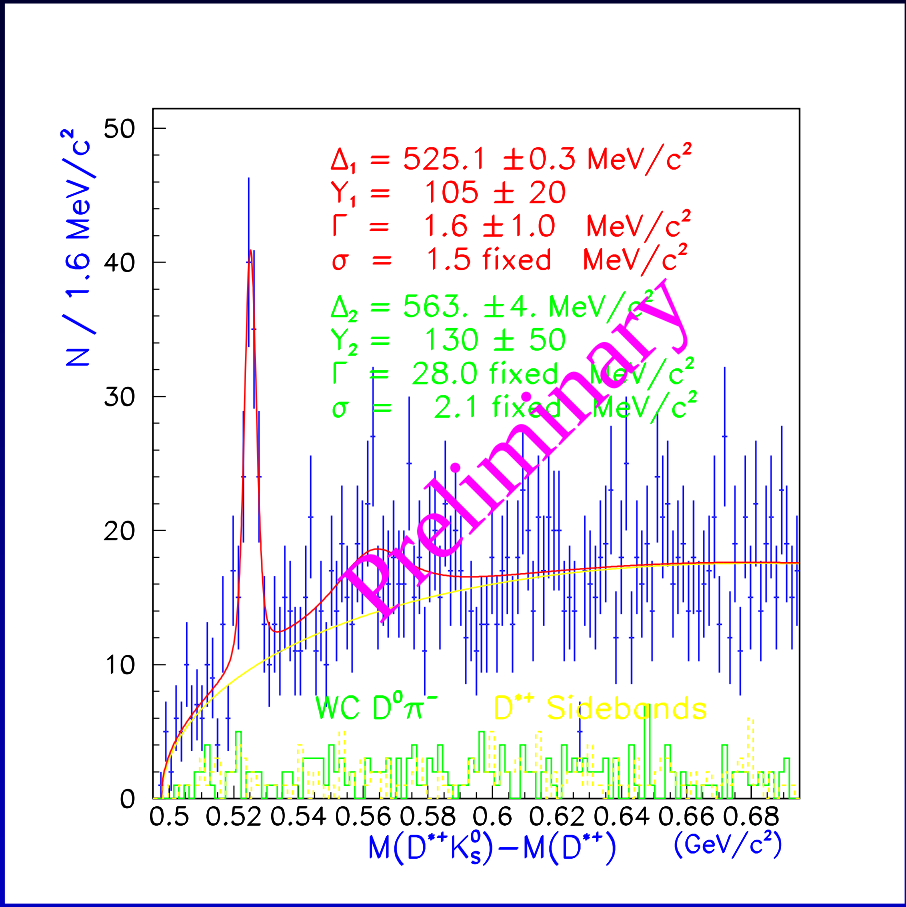
- $M = 2567.3^{+1.3}_{-1.2}$ MeV/c^2
- $\Gamma = 28.5^{+4.8}_{-4.0}$ MeV/c^2

PDG values are:

- $M = 2572.4 \pm 1.5$ MeV/c^2
- $\Gamma = 15 \pm 5$ MeV/c^2

First observation of $D^+K_S^0$ decay mode.
Comparable errors to PDG averages

$D_{s1}^+(2536) \longrightarrow \boldsymbol{D^{*+}K_S^0}$



Terms in fit:

- D_{s1} signal: Non-rel. BW convoluted with Gaussian
- Smooth background shape
- D_{s2}^* signal: D-wave Rel. BW

Measure $M(D_s^+K_S^0) - M(D_s^+)$

- $\Delta M = 525.1 \pm 0.3\ \mathrm{MeV}/c^2$
- $\Gamma = 1.6 \pm 1.0\ \mathrm{MeV}/c^2$

Statistical errors only. PDG values:

- $\Delta M = 525.35 \pm 0.34\ \mathrm{MeV}/c^2$
- $\Gamma < 2.3\ \mathrm{MeV}/c^2$ @ 90% CL

Very near threshold $\longrightarrow$ narrow ($\ll 20\ \mathrm{MeV}/c^2$) width

$D_{s2} \longrightarrow D^{*+}K_S^0$ is not significant, but interesting.

Conclusions

- New precise measurements of D_2^{*+} and D_2^{*0} masses and widths. Errors comparable to PDG averages. Published as PLB 586 (2004) 11–20.
- Same paper presents evidence for broad (D_0^{*0}) states in $D^+\pi^-$ and $D^0\pi^+$ final states (first evidence in $D^0\pi^+$).
- Combined paper on excited D_s states in preparation.
- $D^*\pi^\pm$ under study for other $L = 1$ states.
- Renewed interest in sector due to “strange” charmed mesons