BaBar's Discovery of the $D^*_{sJ}(2317)^+$ and Confirmation of the $D_{sJ}(2457)^+$

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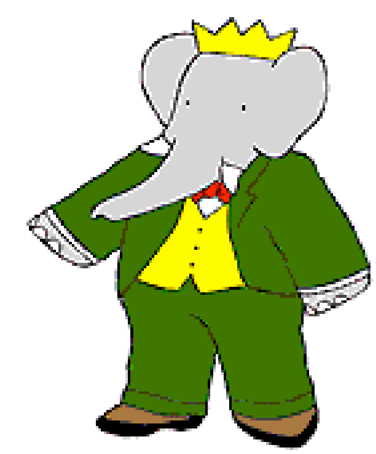
for the BaBar Collaboration

Joint Experimental-Theoretical Seminar
Fermi National Accelerator Laboratory
July 11, 2003

SCIPP

Outline:

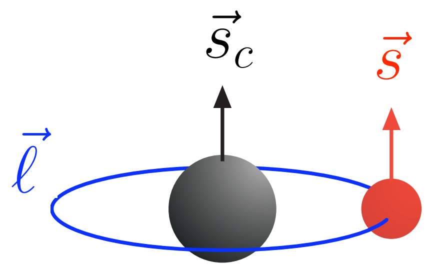
- Introduction
- $D^*_{sJ}(2317)^+$
- $D_{sJ}(2457)^+$
- Theoretical Implications
- Conclusion



Introduction

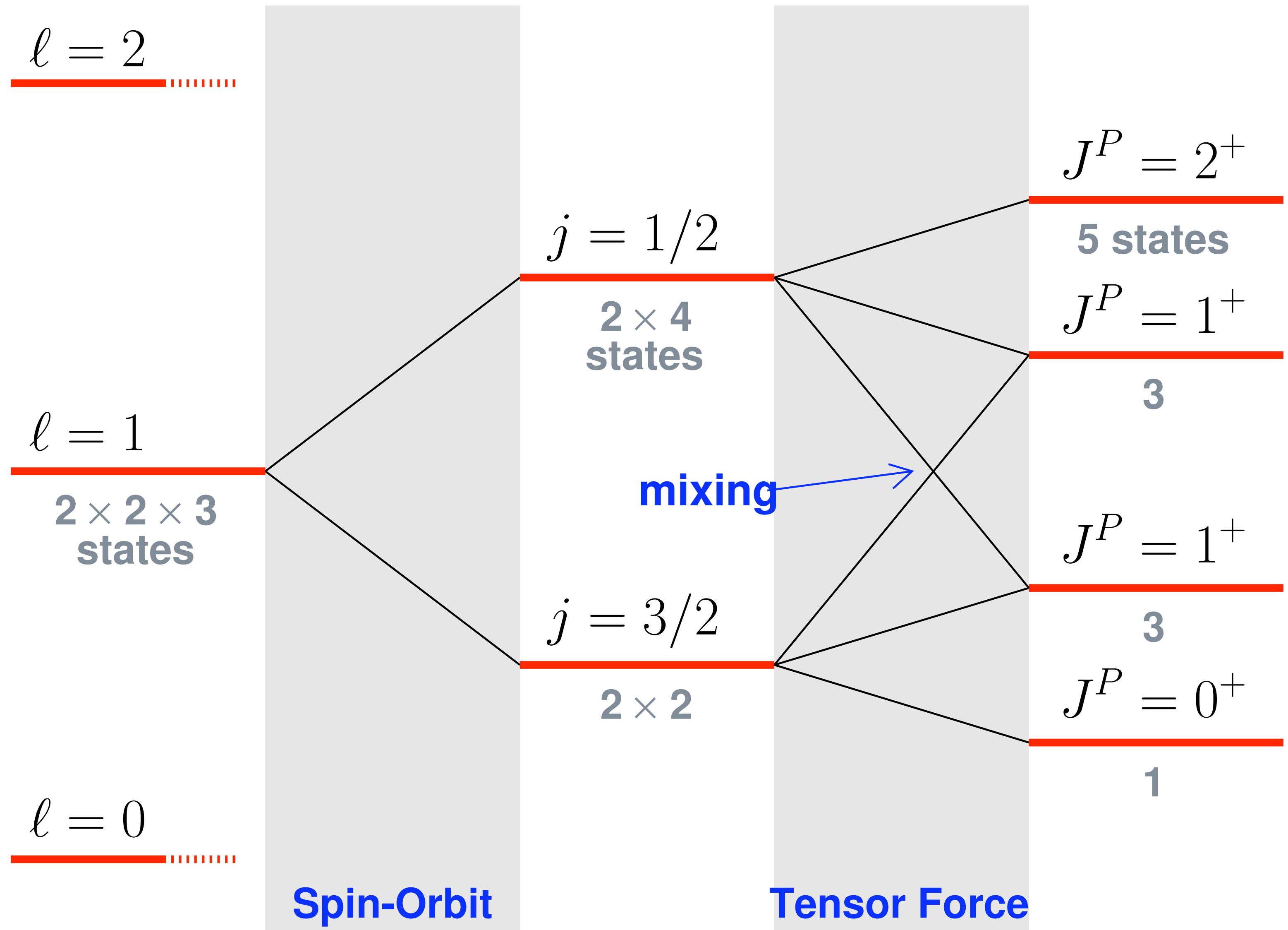
Heavy Meson Spectroscopy Theory

Potential model



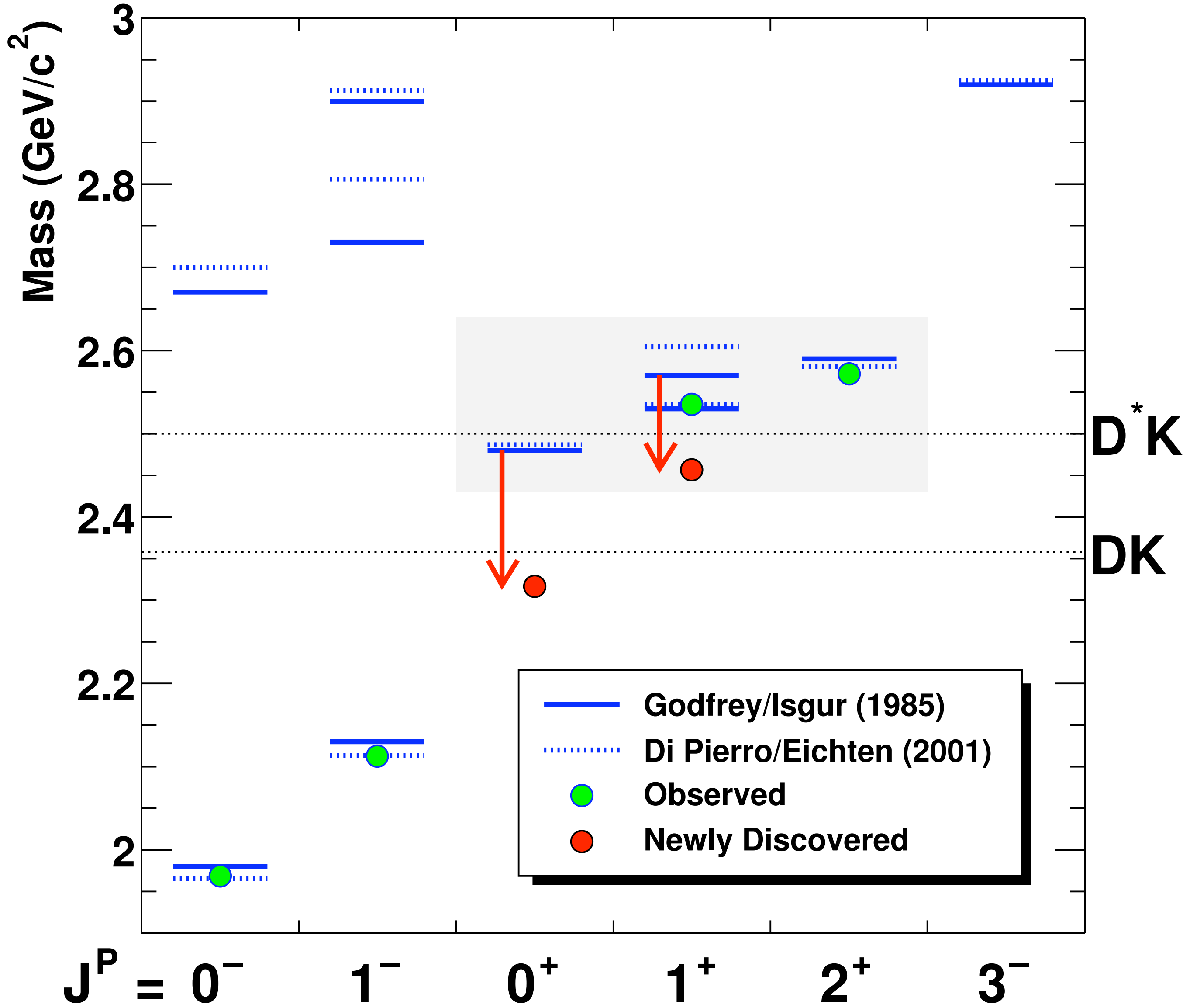
$$\vec{j} = \vec{\ell} + \vec{s}$$

$$\vec{J} = \vec{j} + \vec{s}_c$$



Then and Now

Status before and after $D_{sJ}^{*}(2317)^{+}$ and $D_{sJ}(2457)^{+}$



S. Godfrey and R. Kokoski, Phys.Rev. D43 (1991) 1679.
S. Godfrey and N. Isgur, Phys.Rev. D32 (1985) 189.
M. Di Pierro and E. Eichten, Phys.Rev. D64 (2001) 114004.

Introduction

The PEP-II Collider

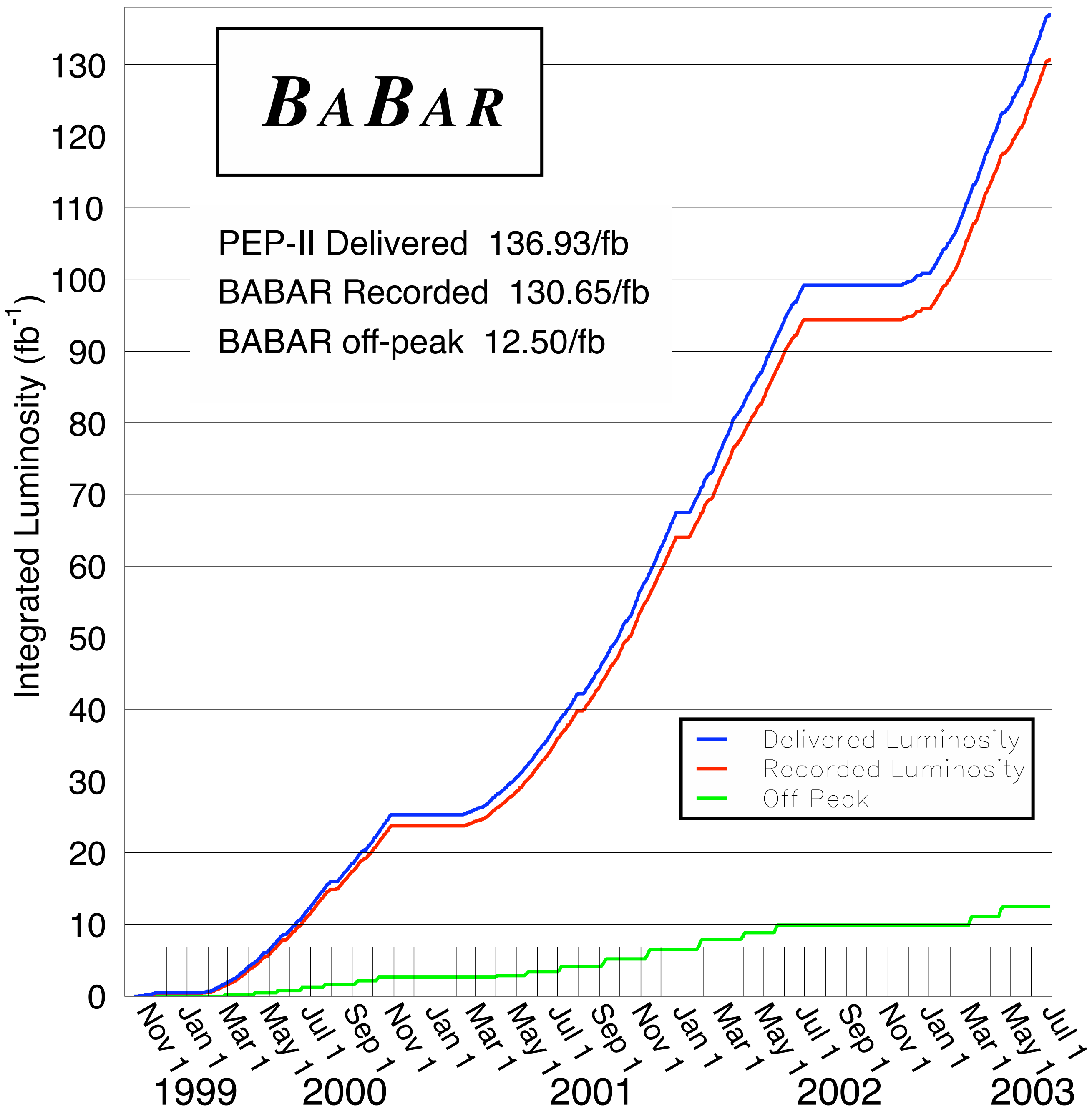
Record peak luminosity: 6.582×10^{33} cm^{-2} sec^{-1}

Other records:

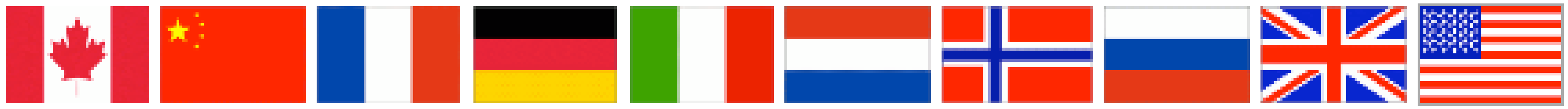
- ✦ Best shift: 138.4 pb^{-1}
- ✦ Best 24 hours: 395.1 pb^{-1}
- ✦ Best 7 days: 2115 fb^{-1}
- ✦ Best month: 7.395 fb^{-1}

Design values:

- ✦ Luminosity: 3×10^{33}
- ✦ Day: 135 pb^{-1}
- ✦ Month: 3.3 fb^{-1}

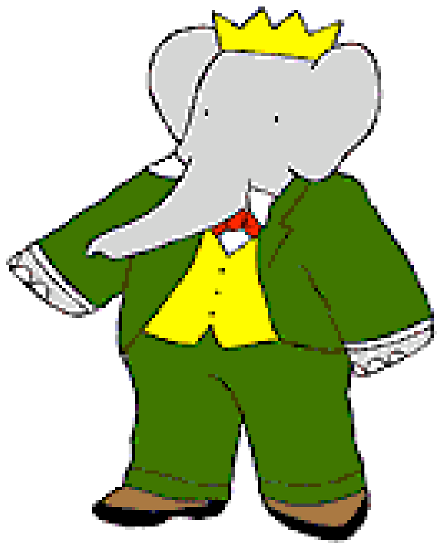


Introduction



The BaBar Collaboration

10 countries
77 Institutions
~580 Physicists



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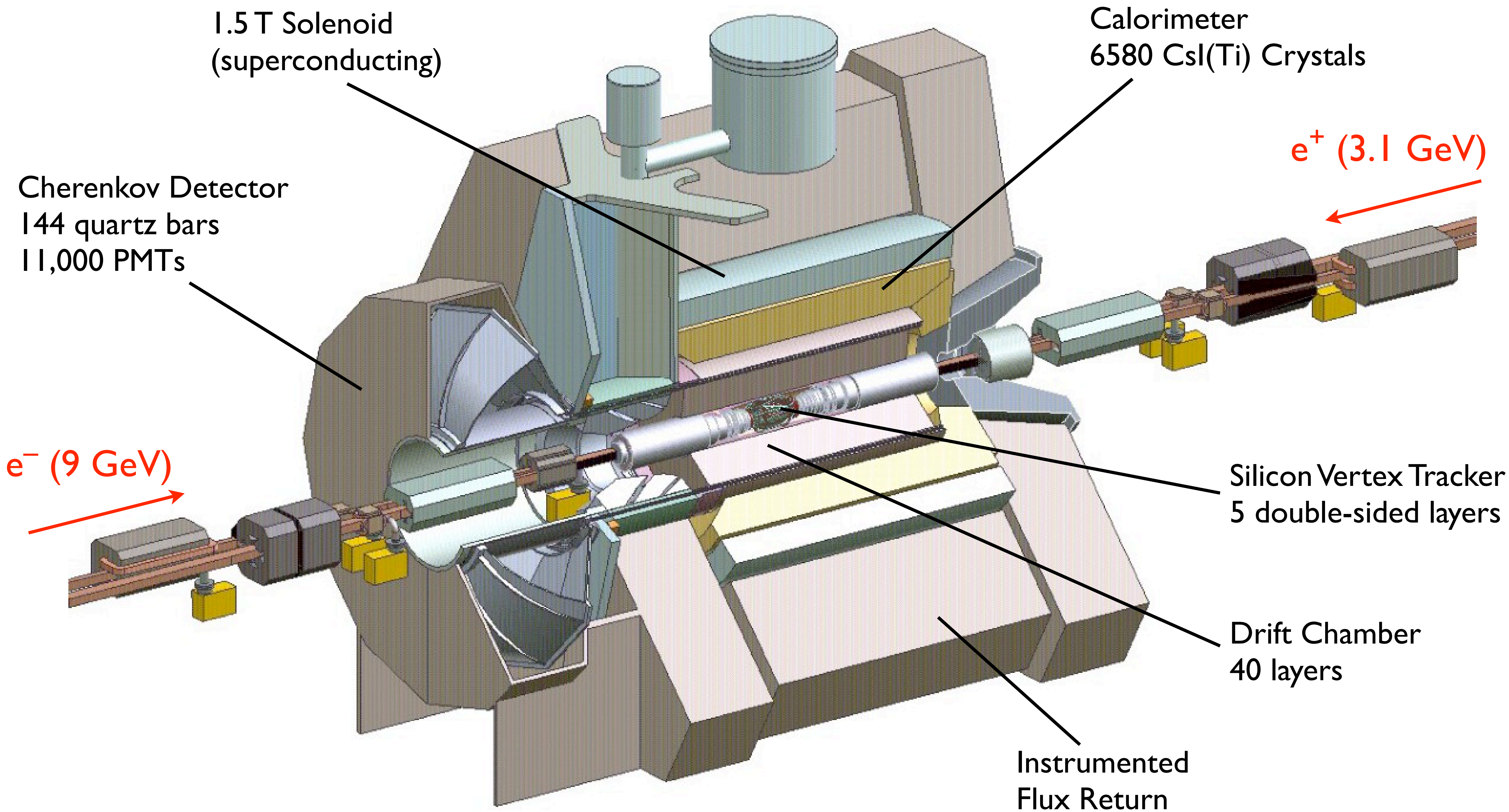
Introduction

The BaBar Detector

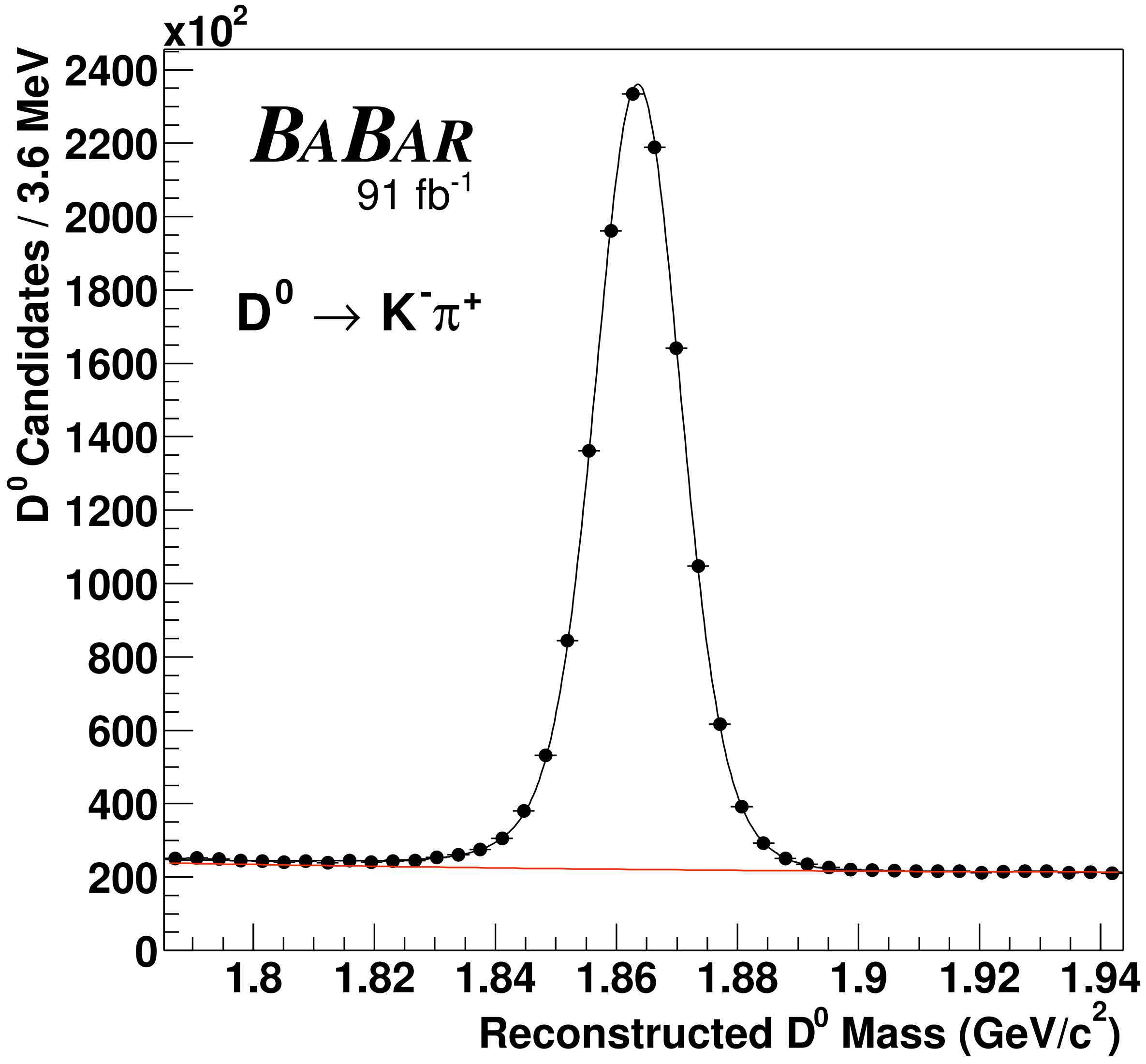


Introduction

Charm at B Factories

Charm cross section: $\sigma(e^+e^- \to c\bar{c}) \approx 1.3\ \mathrm{nb}$

- For 91 fb^{-1}, this corresponds to ~120 million charm pairs
- Or roughly 1.2 million $D^0 \to K^-\pi^+$ decays



Compare to these dedicated experiments:

- E791: 25,400 D* tagged
- Focus: 120,000 D* tagged

1. E791 Collaboration, Phys.Rev.Lett. 83 (1999) 32.
2. Focus Collaboration, Phys.Lett. B485 (2000) 62.

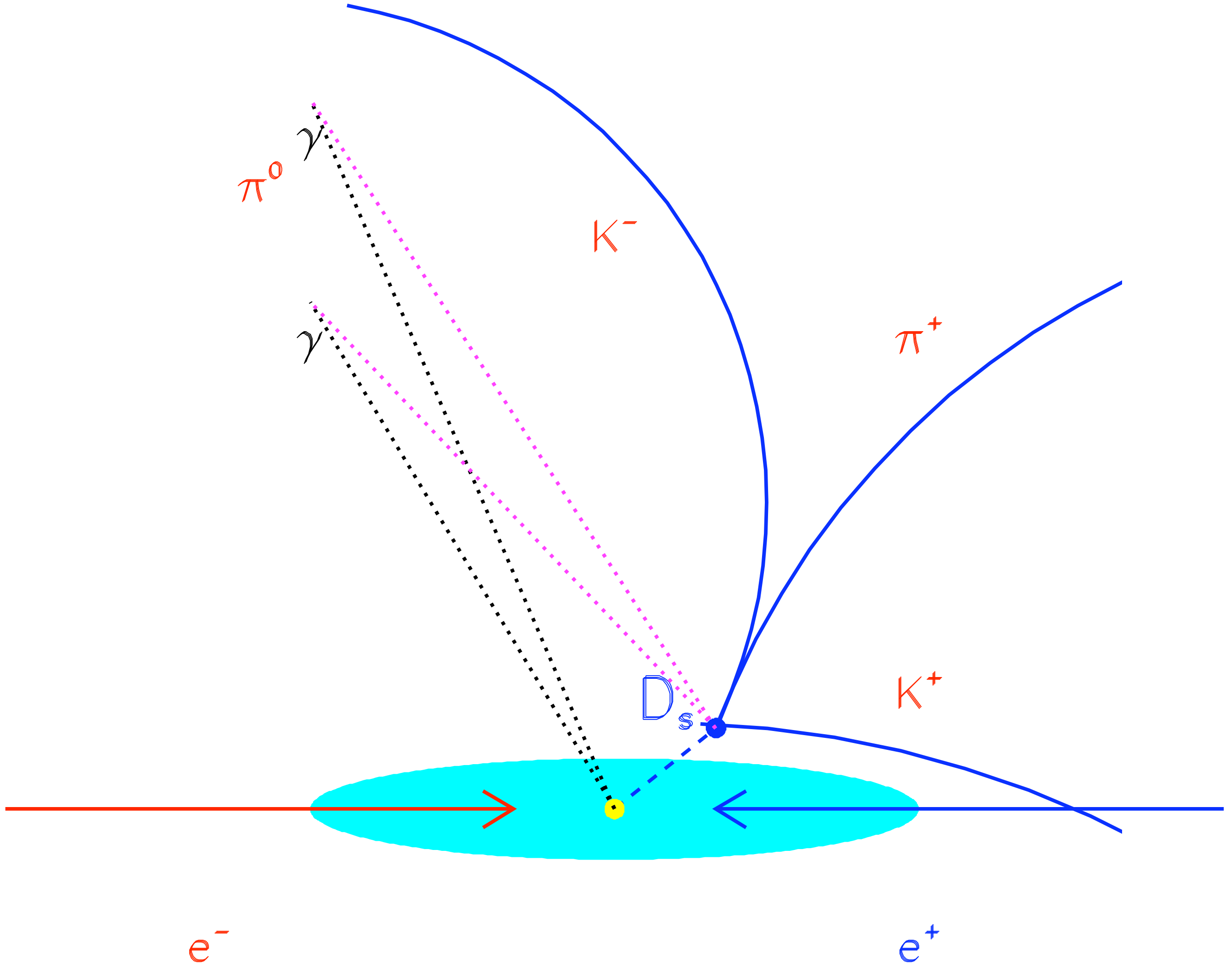
Event Selection

Goal is to identify the D_s decay

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

along with any number of π^0 and γ

- Kaon identification
- Vertex fit (χ^2 prob > 1%)
- Consistent with production at the interaction region
- $E_\gamma > 100$ MeV
- π^0 reconstructed at either vertex
- $p^*(K^+ K^- \pi^+ \pi^0) > 2.5$ GeV



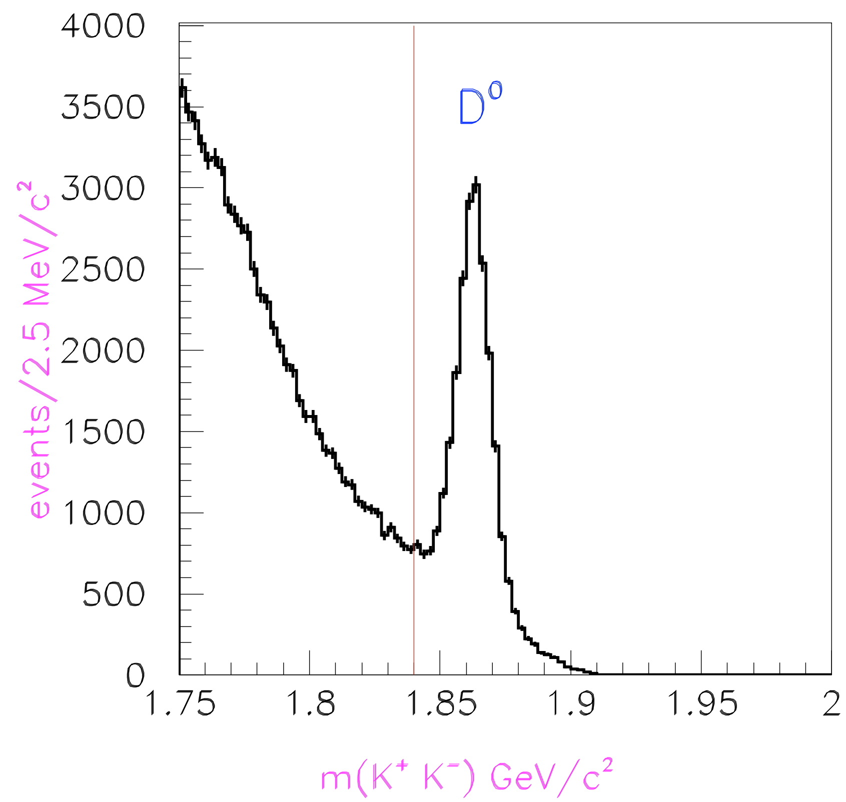
$K^+ K^- \pi^0$ Mass Spectrum

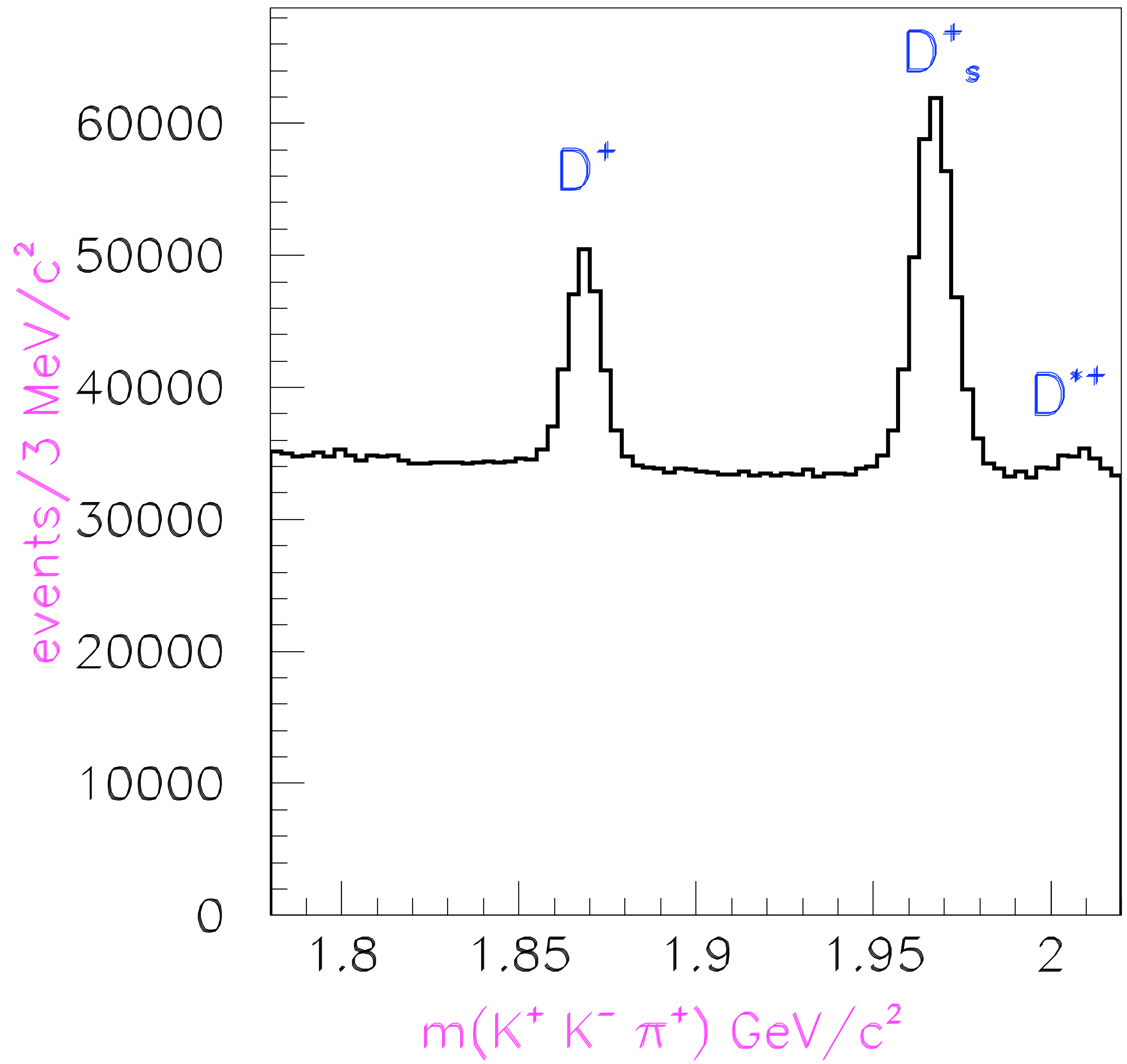
Clear D^+ and D_s^+ signals in 91 fb^{-1} of data

Small background from

$$D^{*+} \to D^0 \pi^+ \\ \quad \hookrightarrow K^+ K^-$$

Require $m(K^+K^-) < 1.84$ GeV





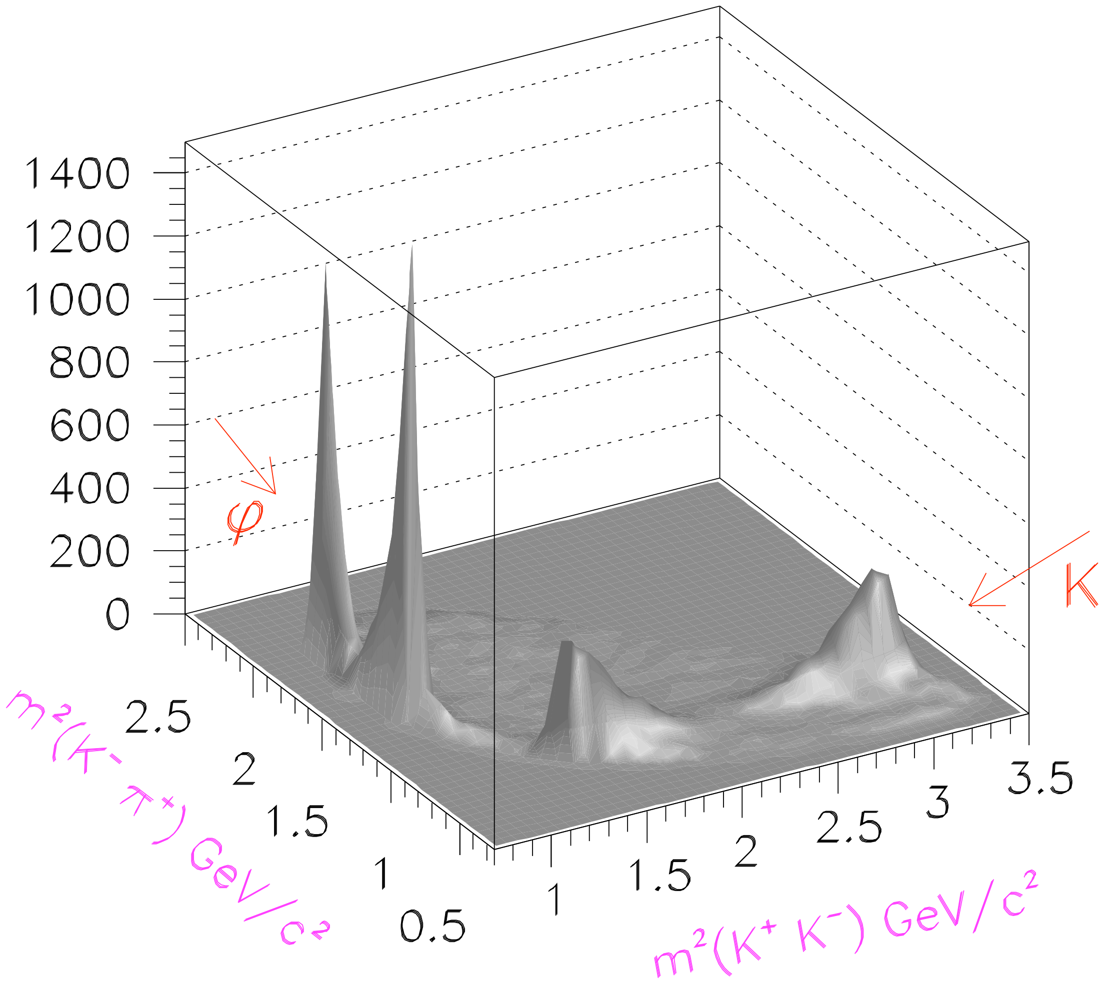
$D^{*}_{sJ}(2317)^{+}$

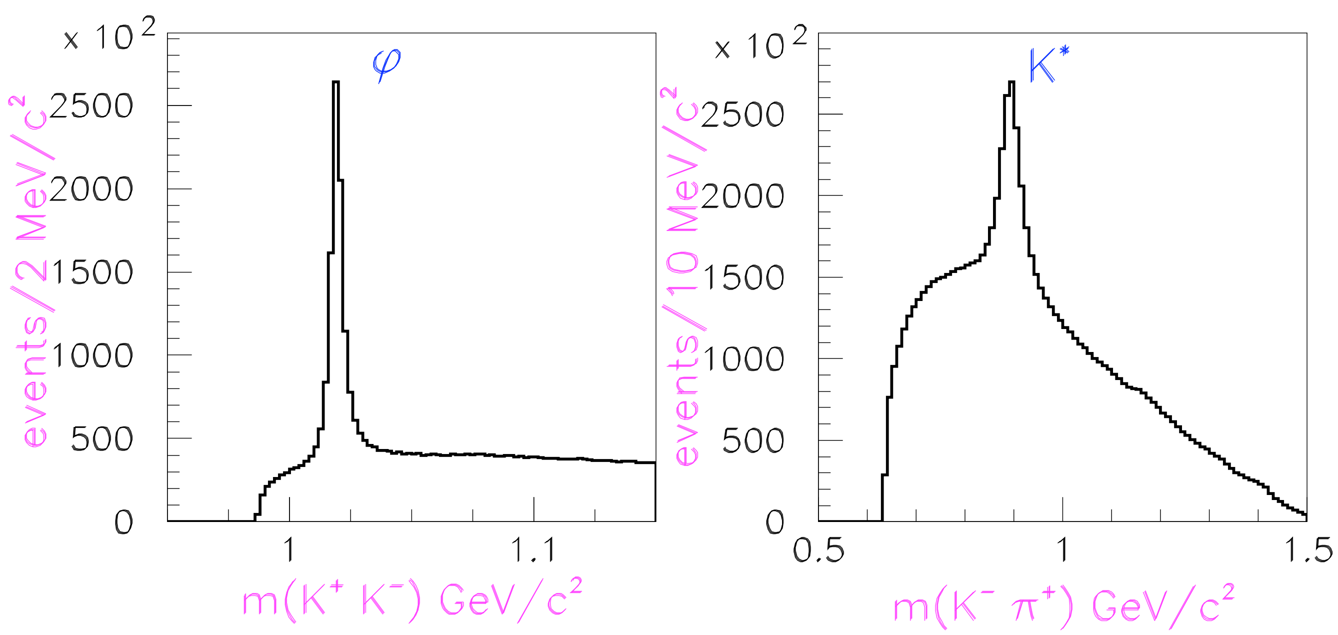
D_s Background Suppression

Select pseudo two-body decay modes

$$\left| m(K^+K^-) - m(\phi) \right| < 10 \text{ MeV}$$

$$\left| m(K^-\pi^+) - m(\overline{K}^{*0}) \right| < 50 \text{ MeV}$$



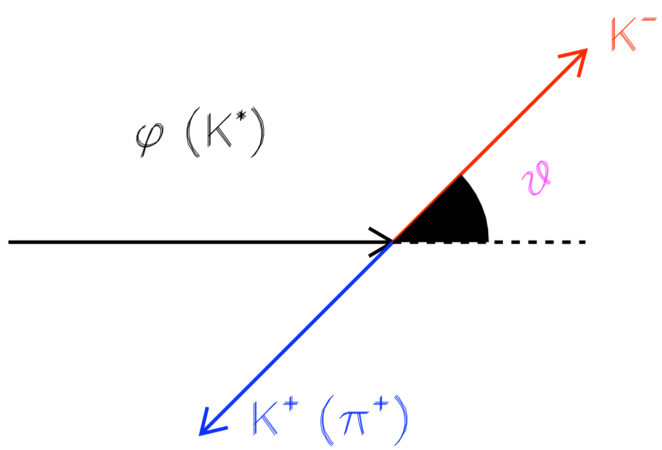


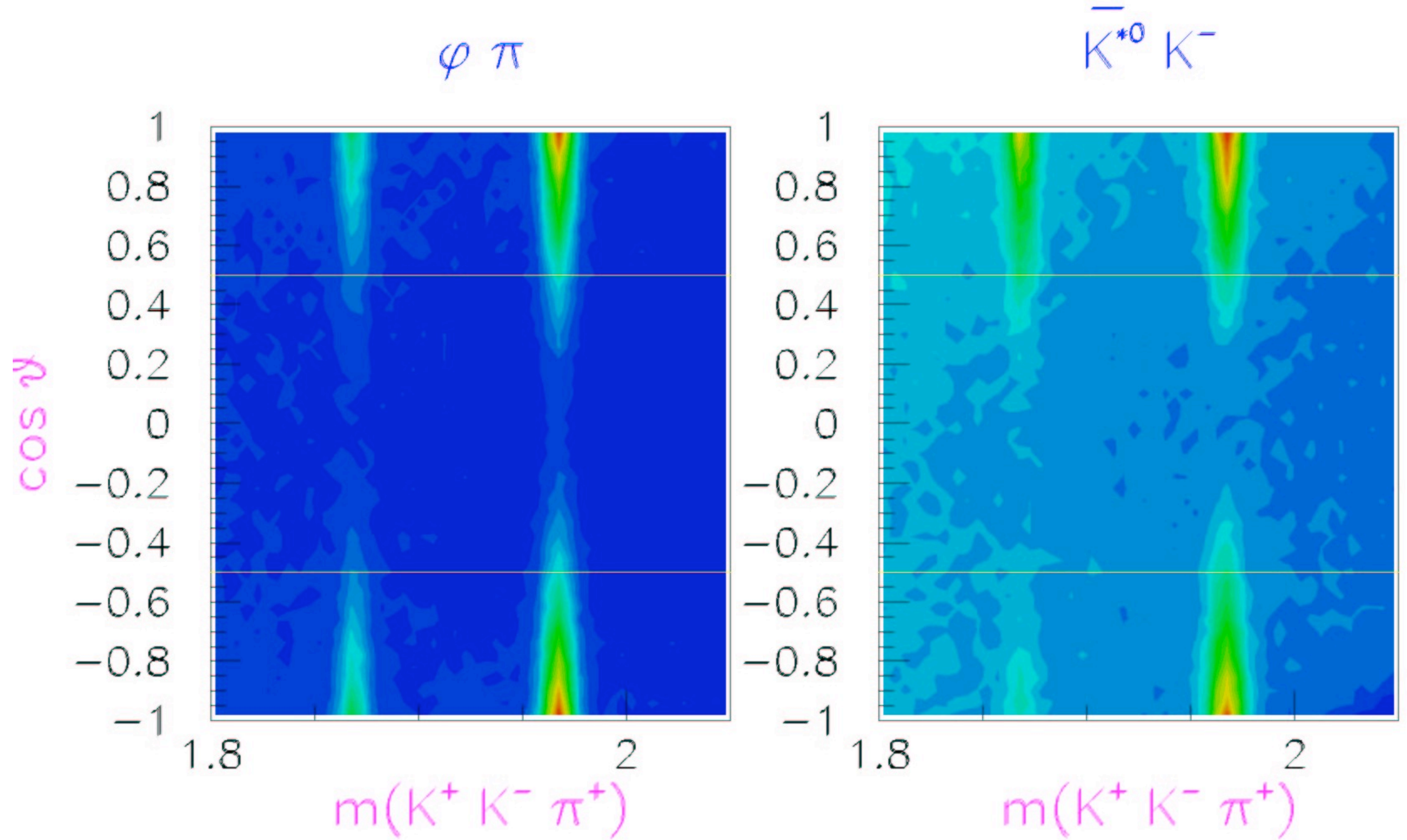
$D^*_{sJ}(2317)^+$

D_s Background Suppression

Helicity angle requirement

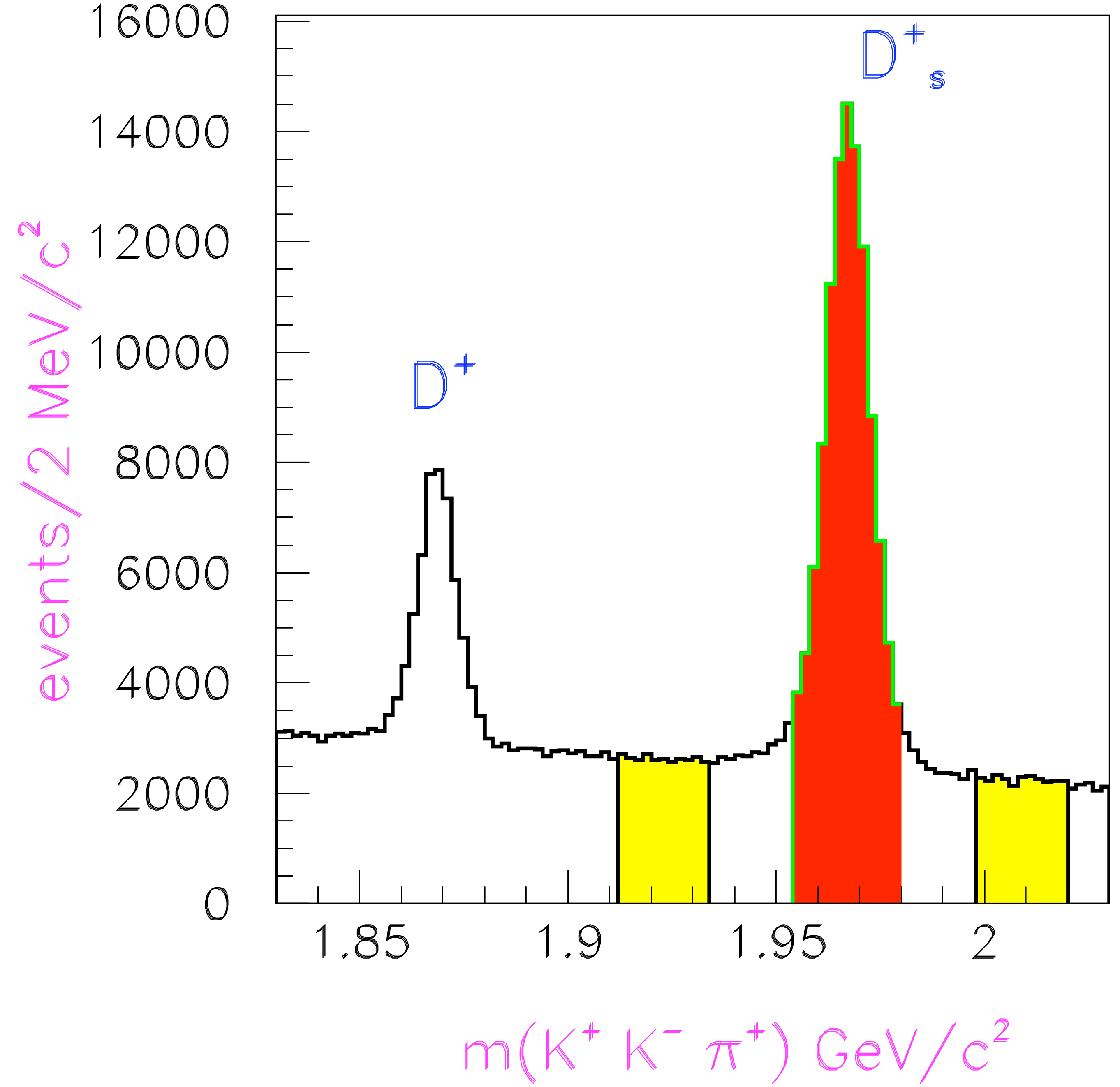
$$|\cos\vartheta| > 0.5$$





D_s Signal and Sidebands

Approximately 80,000 candidates above background

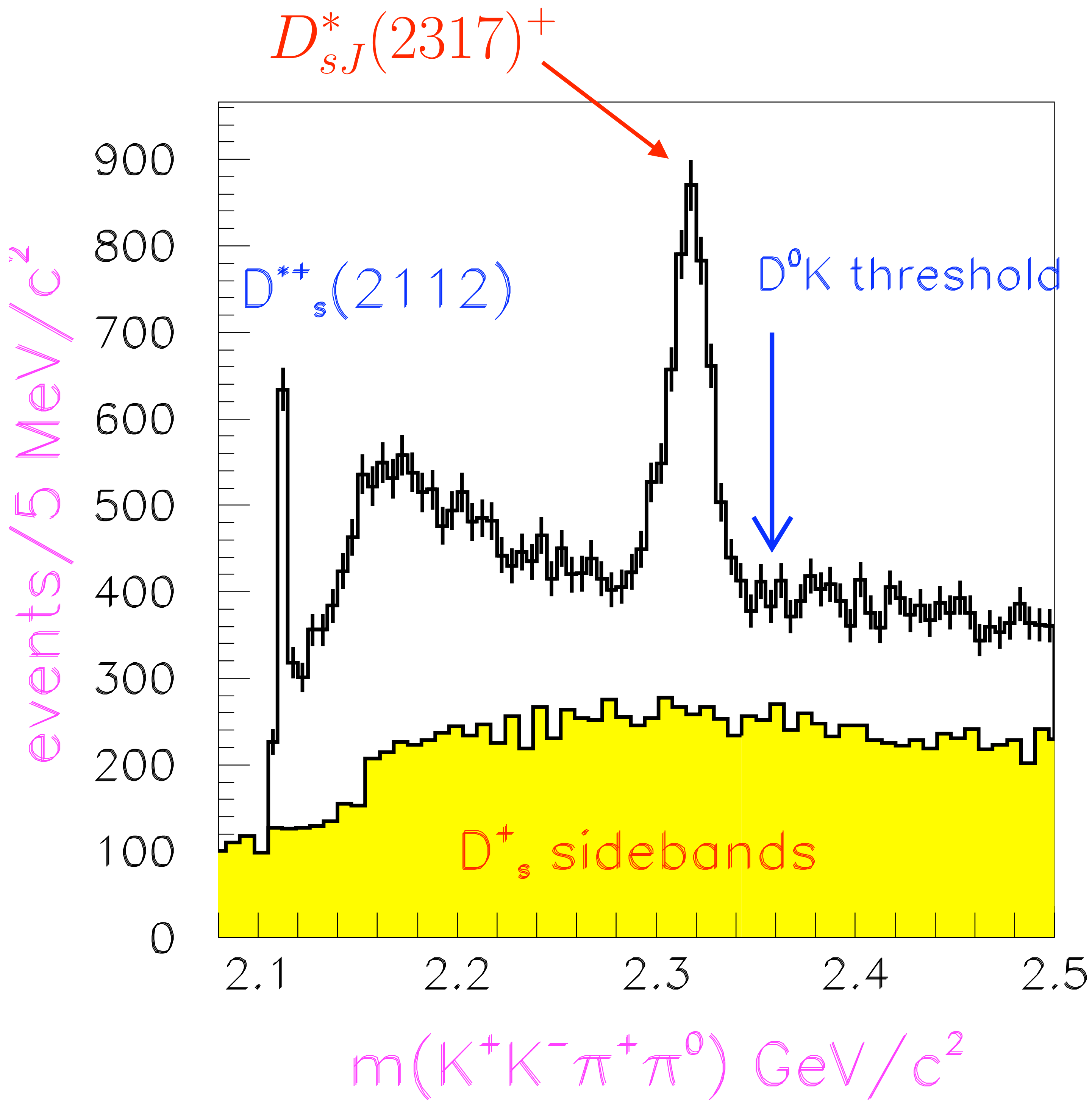


$D_{sJ}^{*}(2317)^{+}$

Adding a π^0

A bit of a surprise

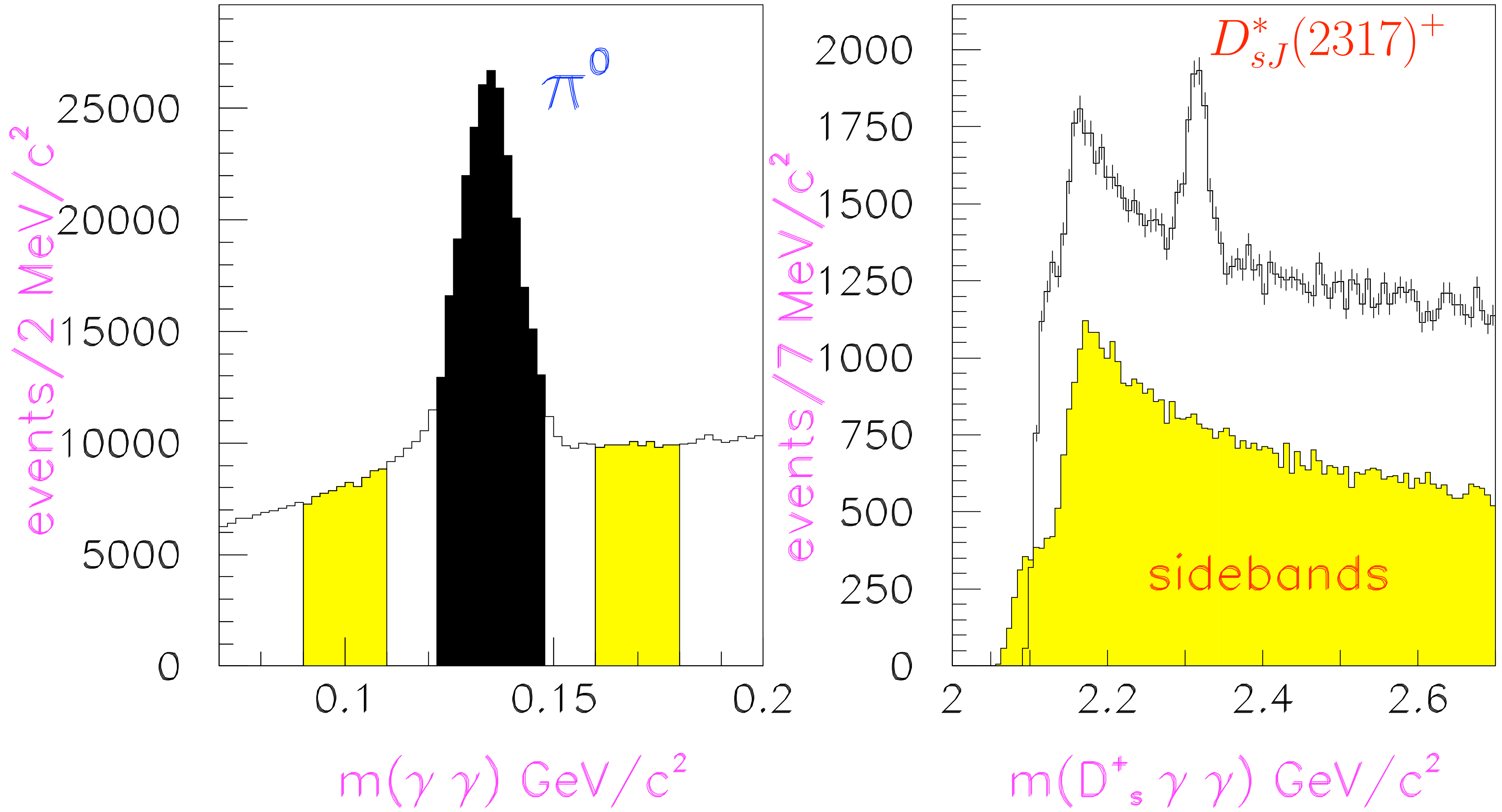
Peak clearly associated with D_s



Check π^0 Association

Relax π^0 vertex fit

Signal clearly associated with π^0



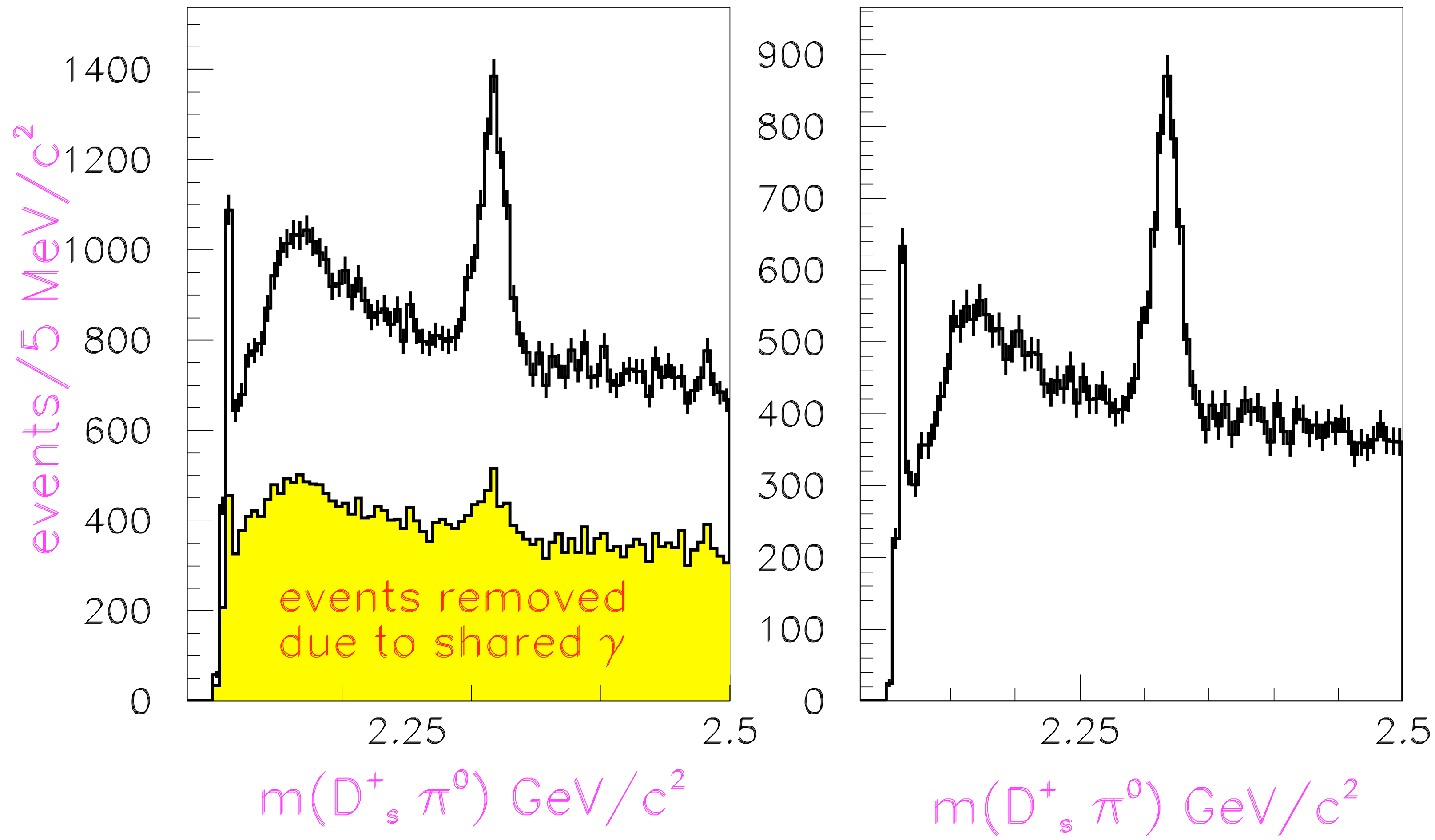
$D^*_{sJ}(2317)^+$

Additional Refinements

Constrain D_s energy

$$E_{D_s^+} = \sqrt{\vec{p}^{\,2} + m_{D_s^+}}$$

Remove any π^0 that shares a γ with any other π^0

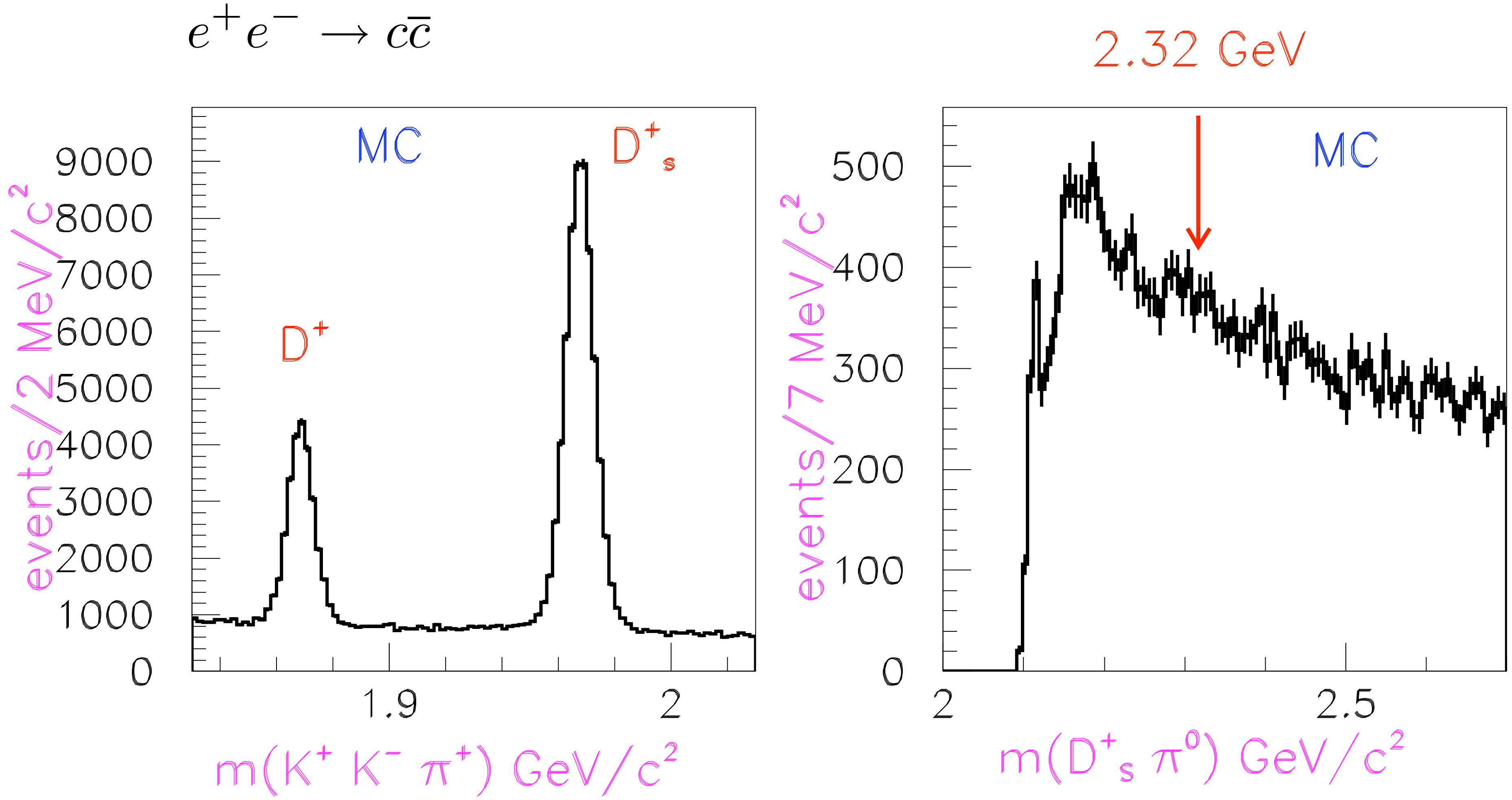


Monte Carlo Check

Monte Carlo includes all known (and expected) states

75 fb^{-1}

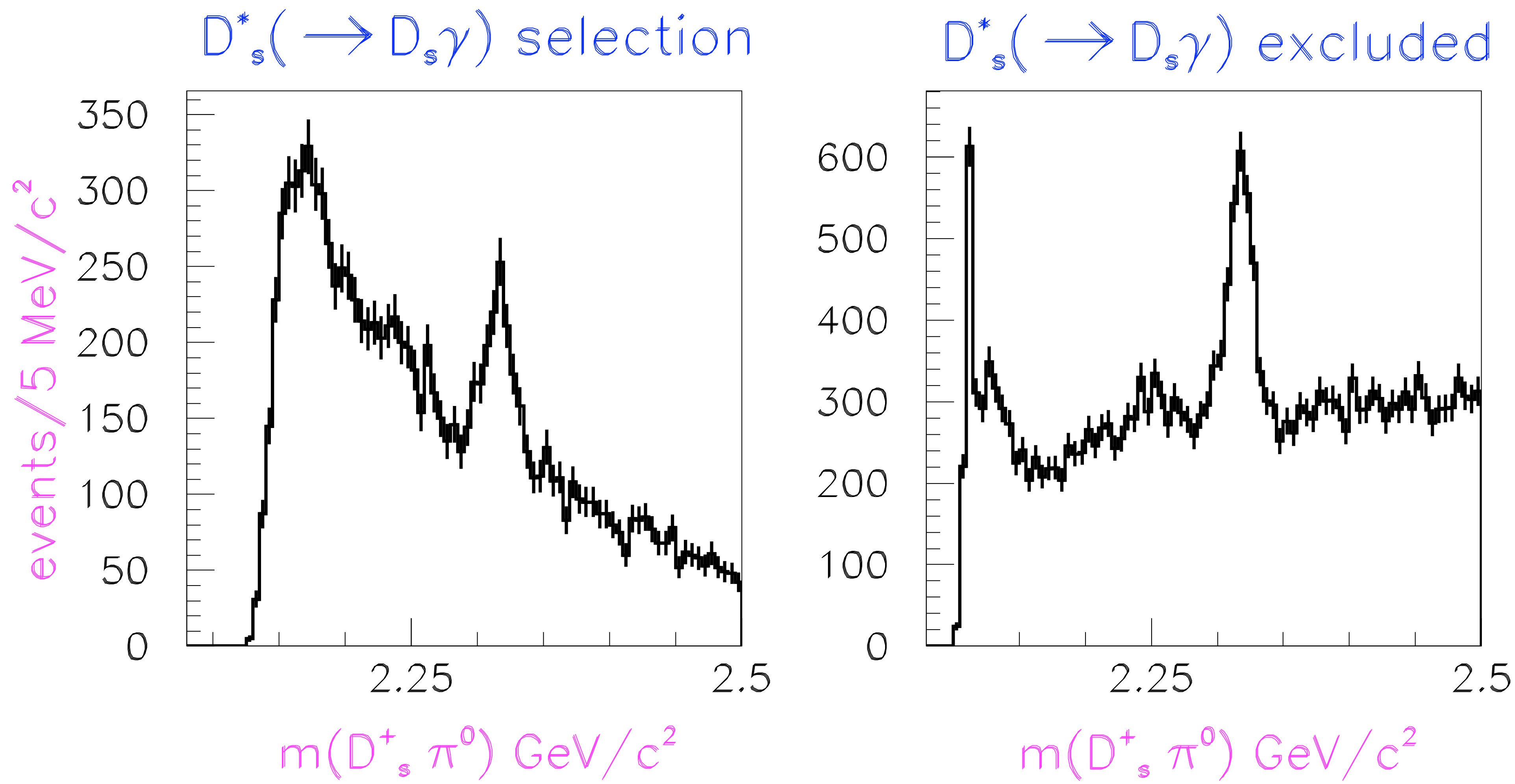
$e^+e^- \to c\bar{c}$



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

Example of Reflection

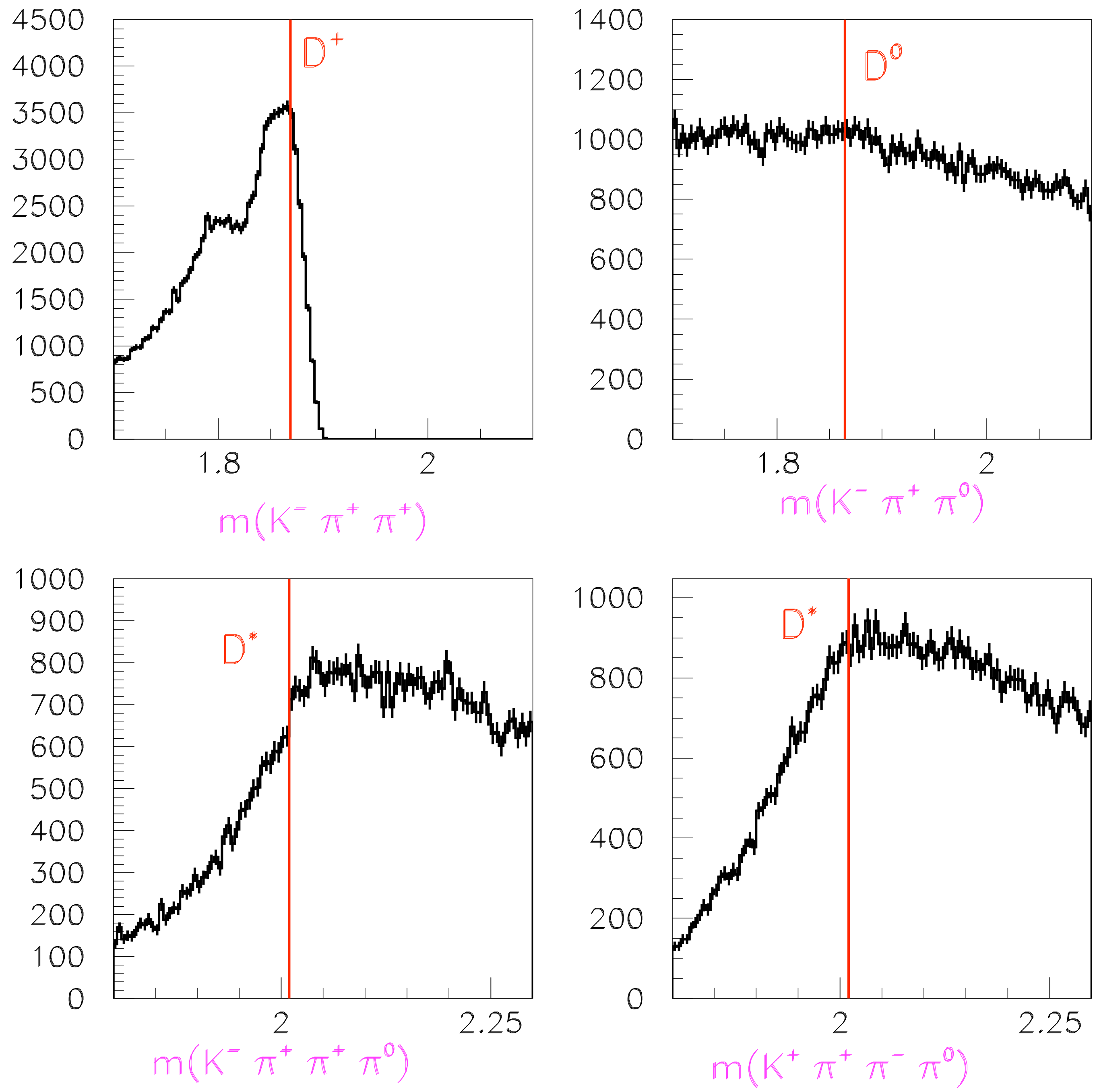
Remove or select $D_s^*(2112)^+ \rightarrow D_s^+\gamma$



Reflection Test

Check charged particle species assignment

(misidentification)



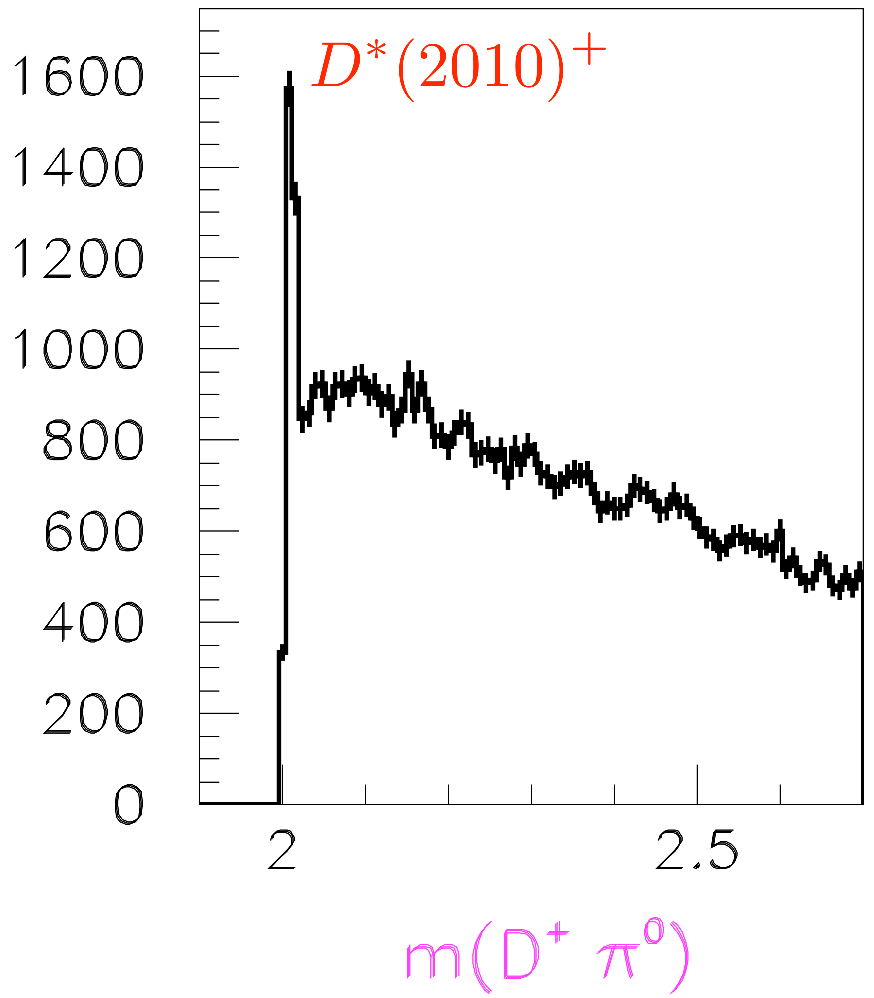
Another Reflection Test

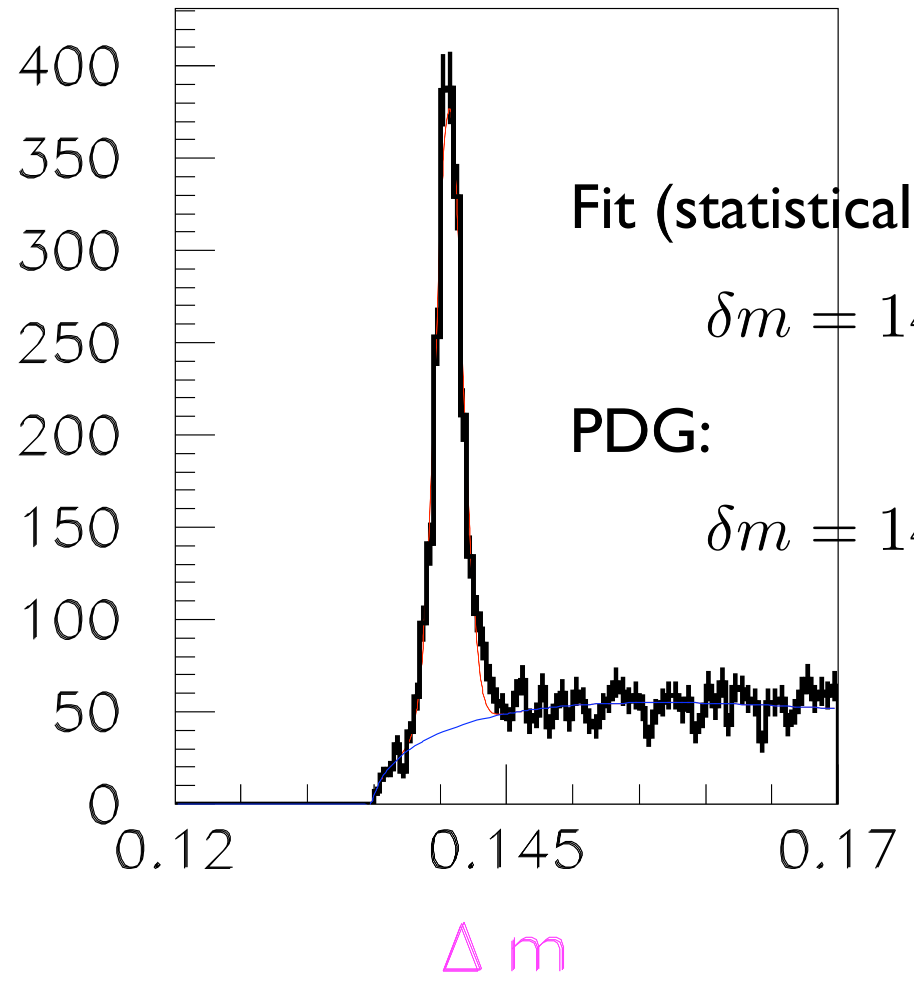
Select D^+

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

Observe:

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





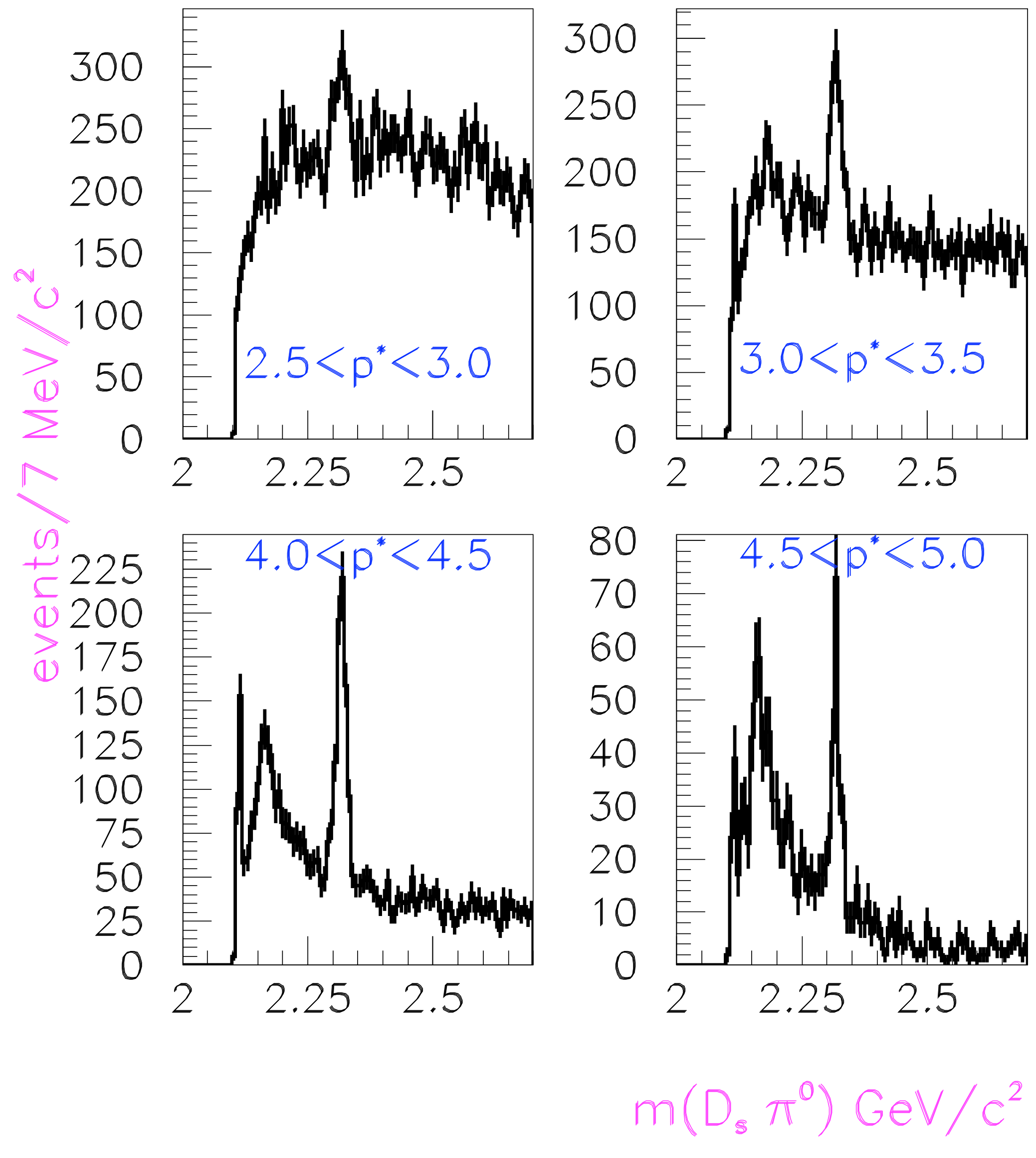
Fit (statistical error only):

$$\delta m = 140.67 \pm 0.05 \text{ MeV}$$

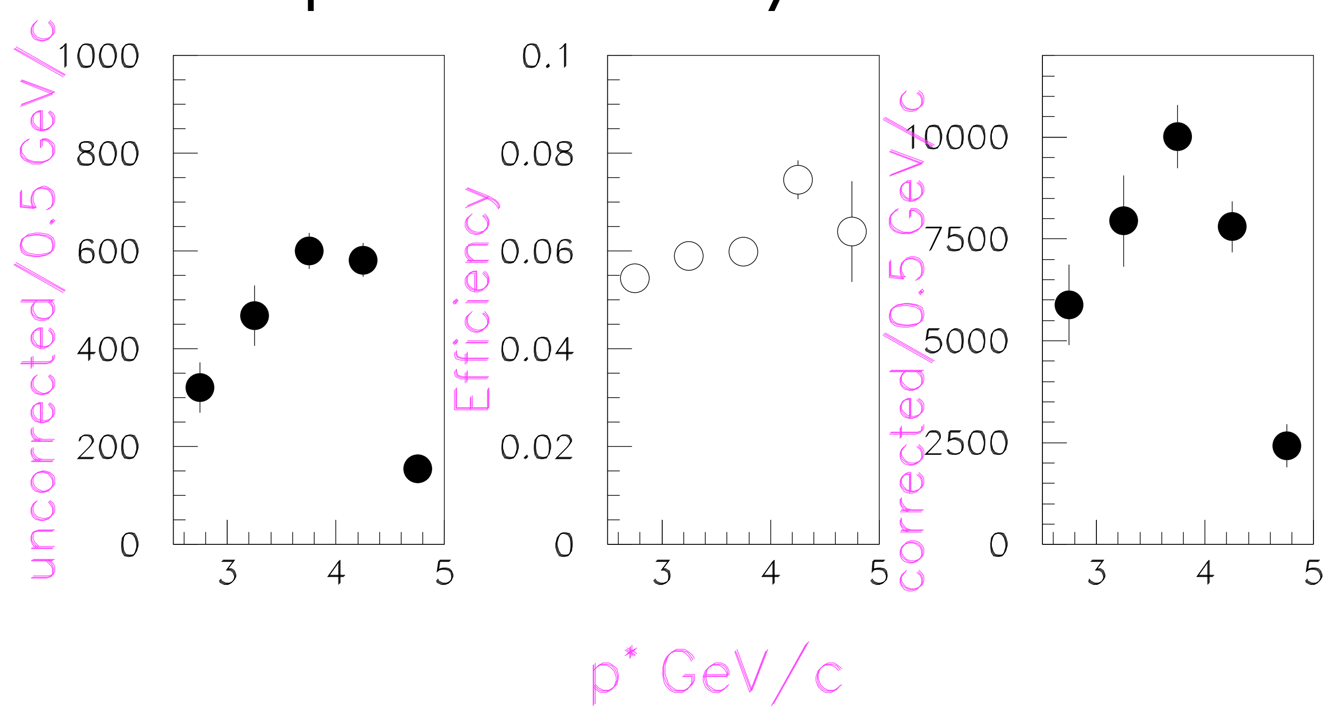
PDG:

$$\delta m = 140.64 \pm 0.10 \text{ MeV}$$

p* Dependence



Acceptance corrected yield



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

Fit to Mass

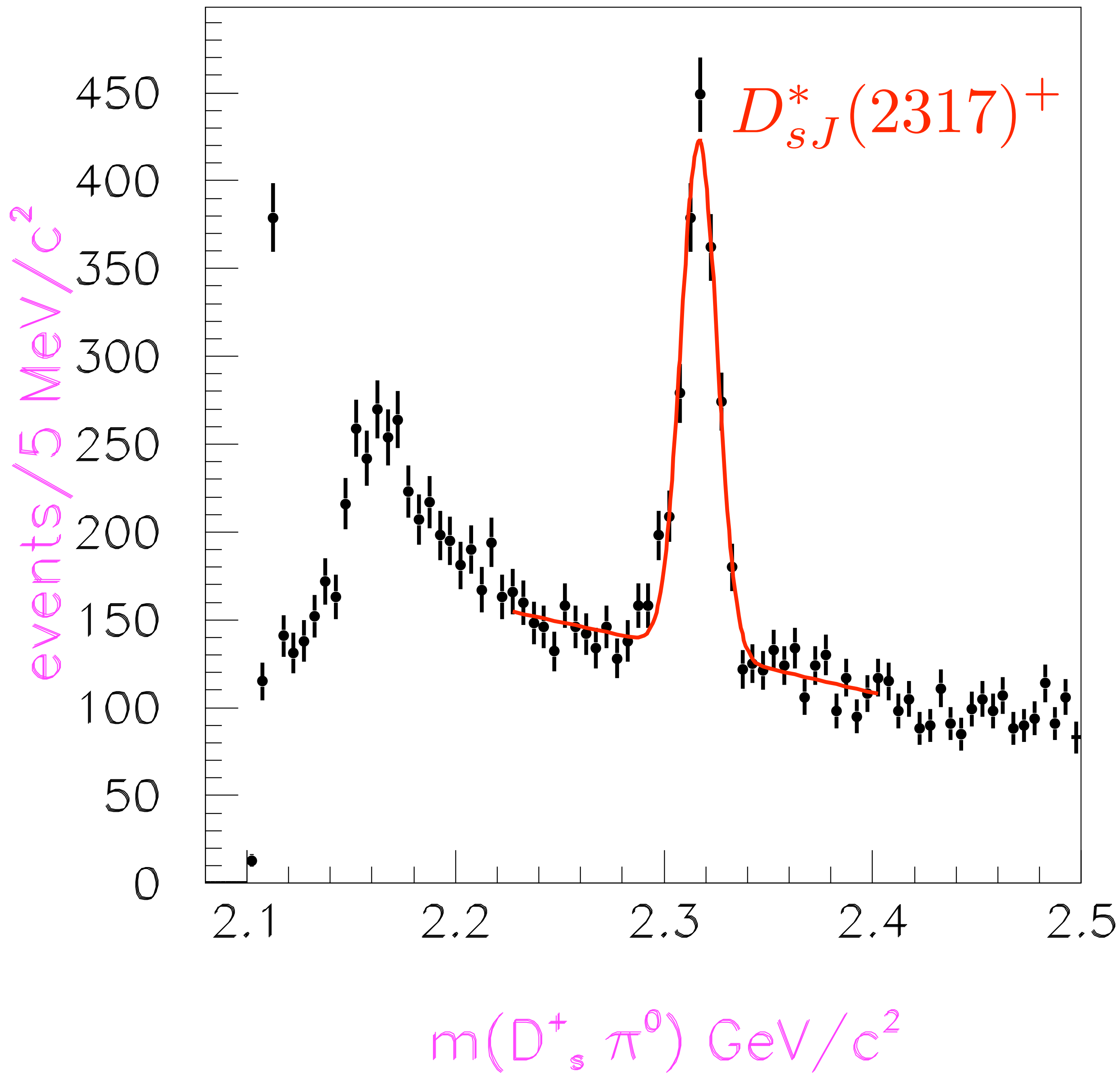
Signal Gaussian on top of a polynomial

$$m = 2316.8 \pm 0.4\,\mathrm{MeV}$$

$$\sigma = 8.6 \pm 0.4\,\mathrm{MeV}$$

(statistical errors only)

Conservative systematic uncertainty on mean ~3 MeV



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

Experimental Width

Comparison with GEANT4 Monte Carlo

- ✦ $p^* > 3$ GeV
- ✦ Generated (intrinsic) widths = 0
- ✦ Monte Carlo resolution a little optimistic

	Mass Resolution (MeV)		
Decay	Data	Monte Carlo	Ratio
$D^*_s(2112)^+ \rightarrow D^+_s \pi^0$	6.6 ± 0.1	5.7 ± 0.1	1.16
$D^*_{sJ}(2317)^+ \rightarrow D^+_s \pi^0$	9.0 ± 0.4	7.7 ± 0.2	1.17

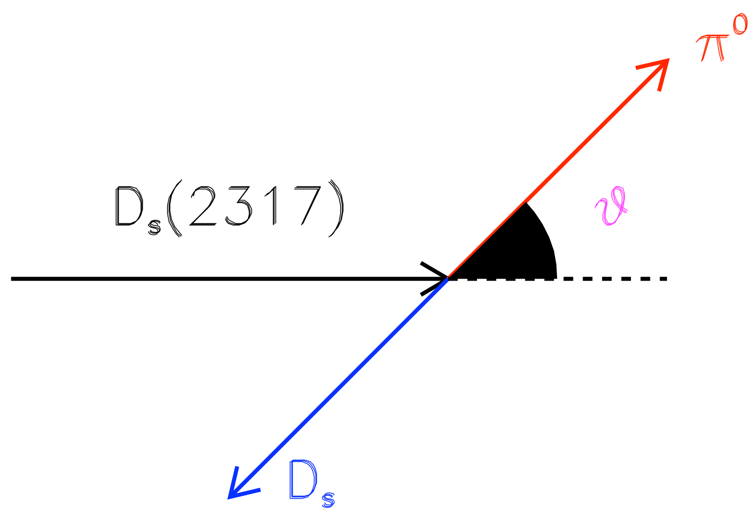
Conclusion: intrinsic width is small ($\Gamma < 10$ MeV) in data

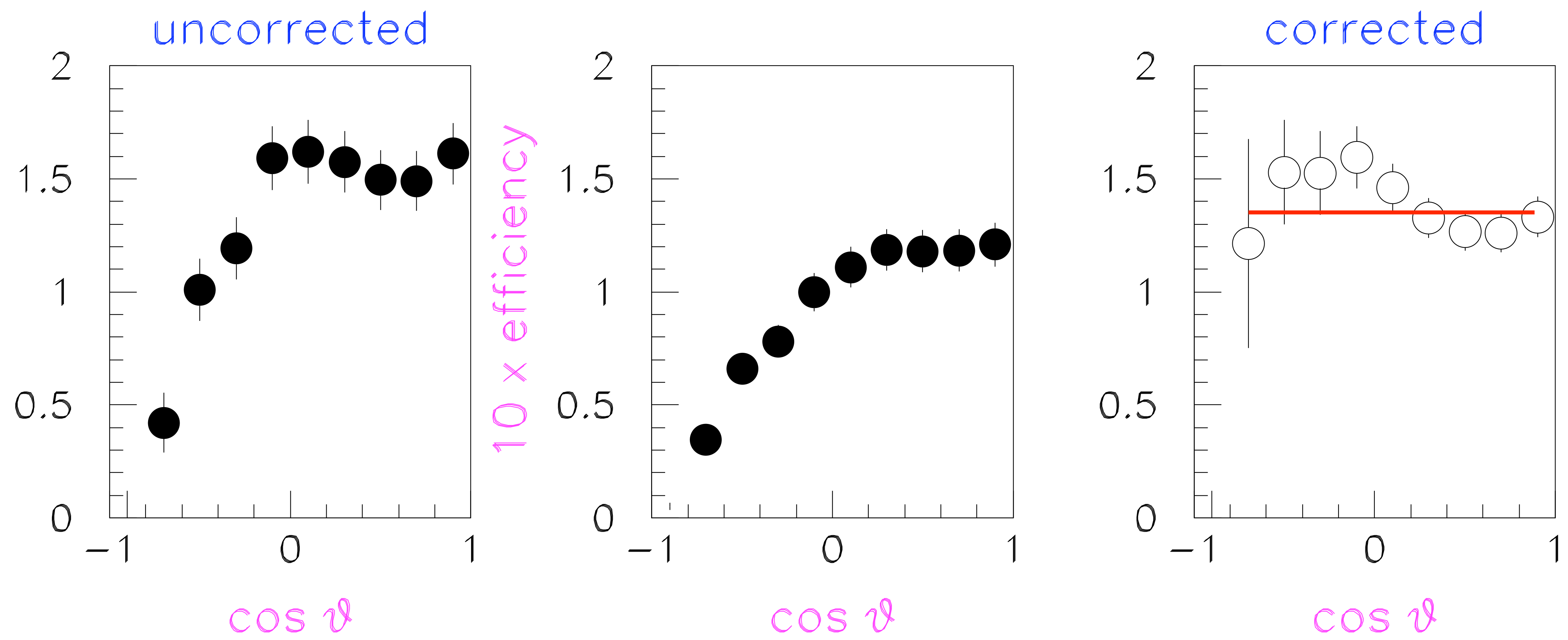
Decay Angle

Acceptance corrected with MC

Distribution is flat, consistent with either:

- ✦ Spin zero
- ✦ Unaligned production

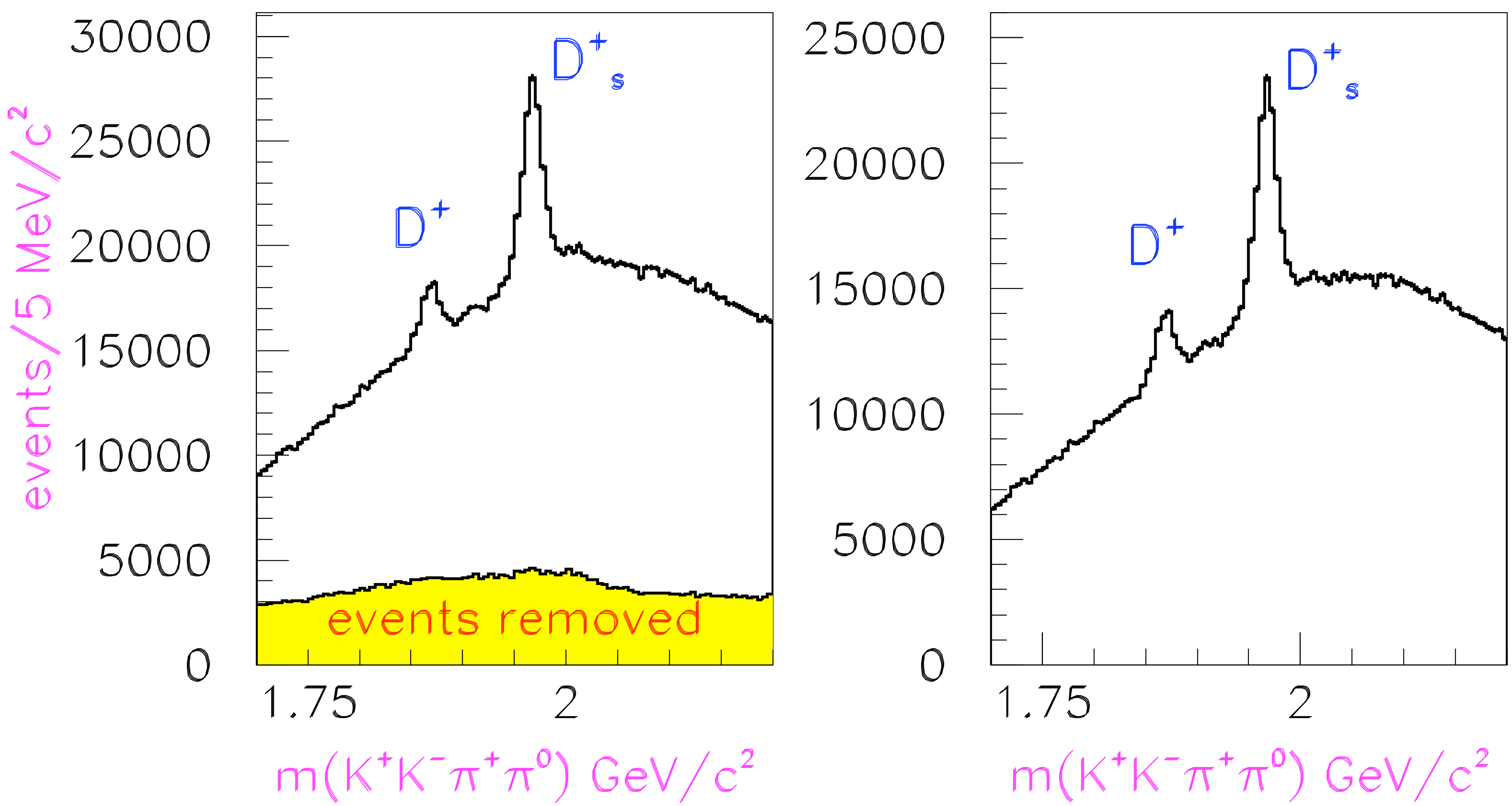




A Second D_s Mode

Add a π^0, select on various pseudo two-body decay modes (ϕ, K^*, ρ)

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



A Second D_s Mode: $m(D_s\,\pi)$

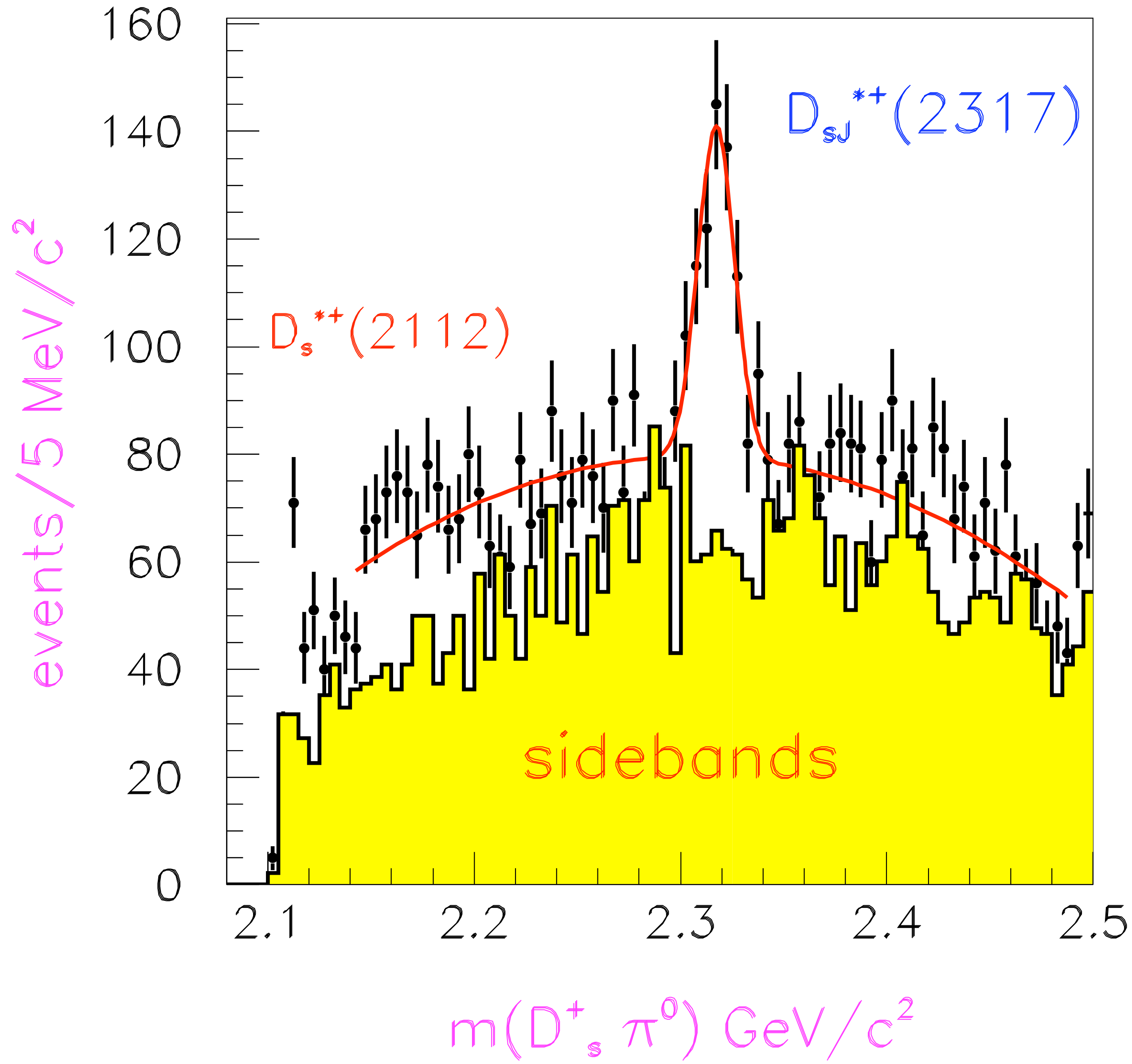
Requirements:

- ✦ p* > 3.5 GeV
- ✦ $p_{\pi^0} > 300$ MeV

Fit Results:

$$m = 2317.6 \pm 1.3 \text{ MeV}$$

$$\sigma = 8.8 \pm 1.1 \text{ MeV}$$



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

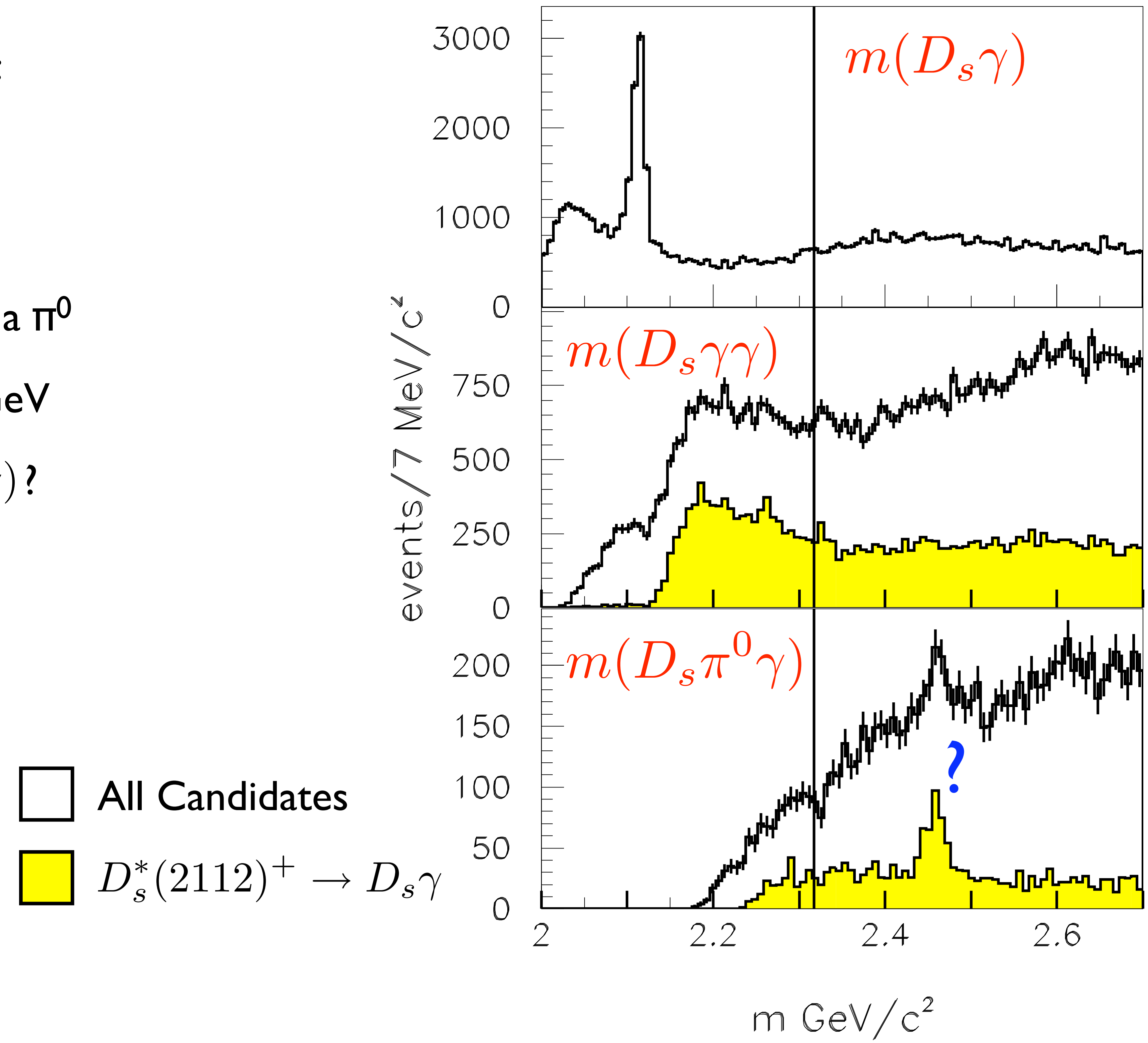
Other Decay Modes

Additional requirements:

- ✦ p* > 3.5 GeV
- ✦ $p_{\pi^0} > 300$ MeV
- ✦ No γ belonging to a π^0

No signal at m = 2.32 GeV

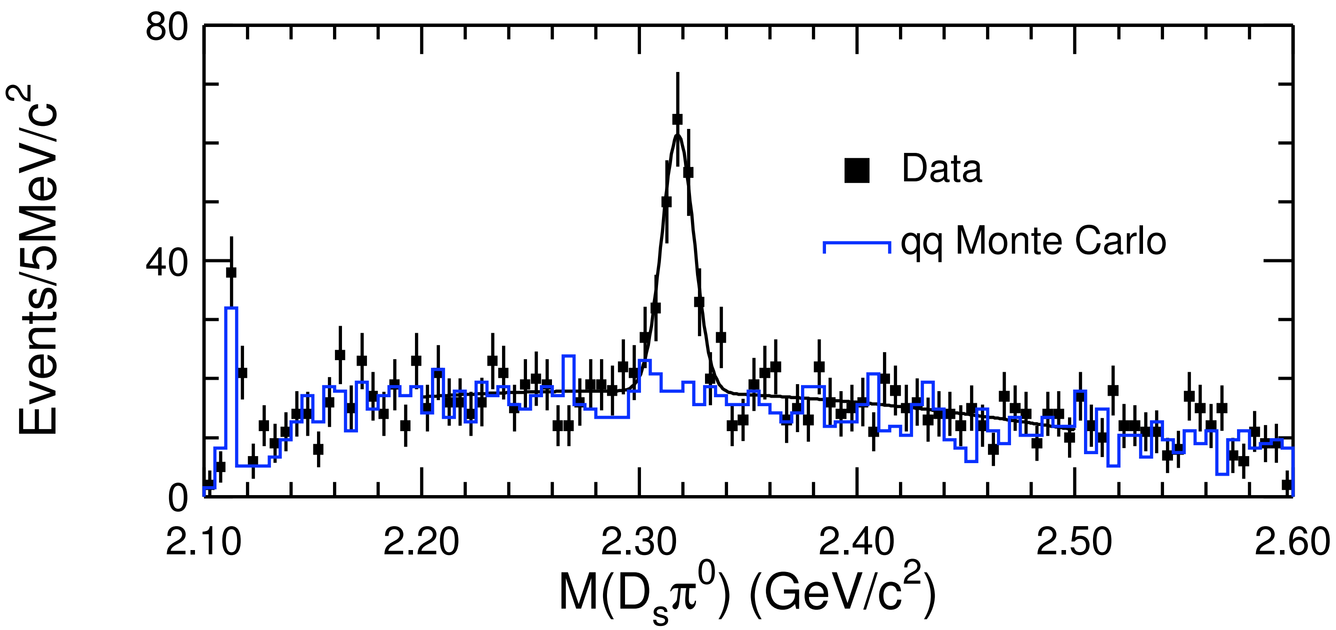
Small peak in $m(D_s\pi^0\gamma)$?



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

Confirmation from CLEO and BELLE

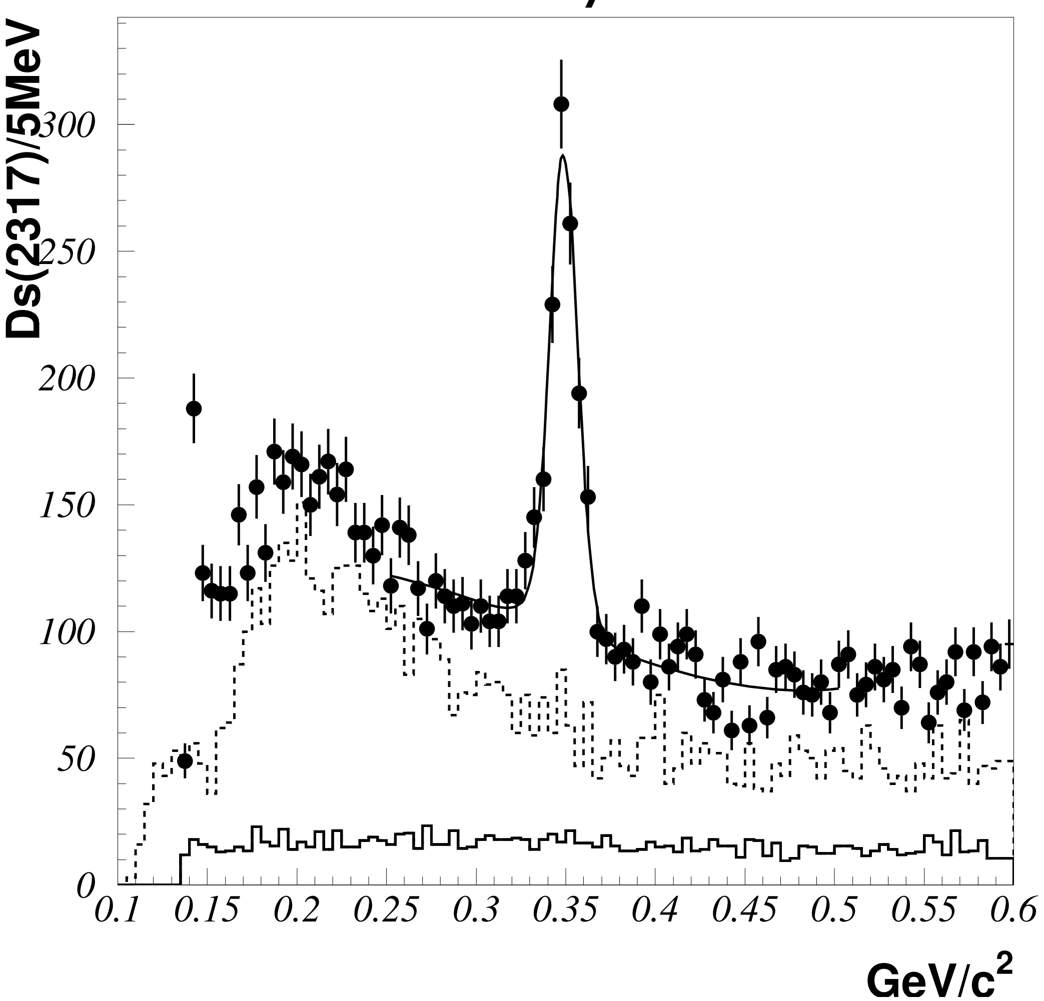
CLEO 13.5 fb^{-1}



$$\Delta m \equiv m(D_s^+) - m(D_s^+\pi^0)$$

$$\Delta m = 350.0 \pm 1.2\ (\text{stat}) \pm 1.0\ (\text{syst})\ \text{MeV}/c^2$$
$$N = 155 \pm 23$$

BELLE Preliminary 78 fb^{-1}



$$\Delta m = 348.4 \pm 0.4\ (\text{stat})\ \text{MeV}/c^2$$
$$N = 643 \pm 50$$

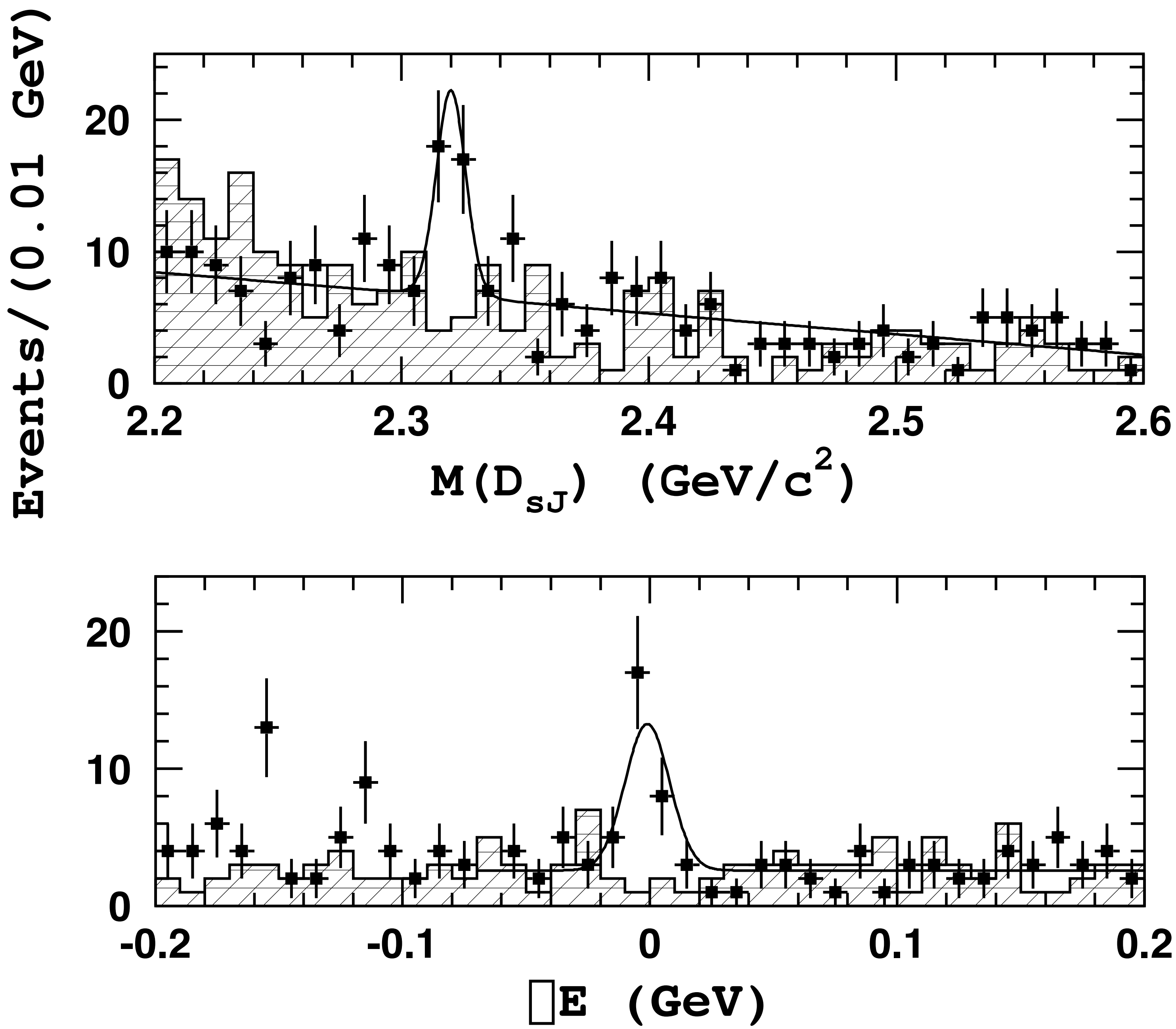
$D_{sJ}^{*}(2317)^{+}$

Confirmation from BELLE

From B decays

BELLE Preliminary, 124 million B-pairs

$B \rightarrow D D_{sJ}^{*}(2317)^{+}$



$m = 2319.8 \pm 2.1 \text{ MeV}/c^2$

$\mathcal{B}r = 8.5^{+2.1}_{-1.9} \text{ (stat)} \pm 2.6 \text{ (syst)}$

Brand new preliminary results from Belle, to be presented at EPS 2003

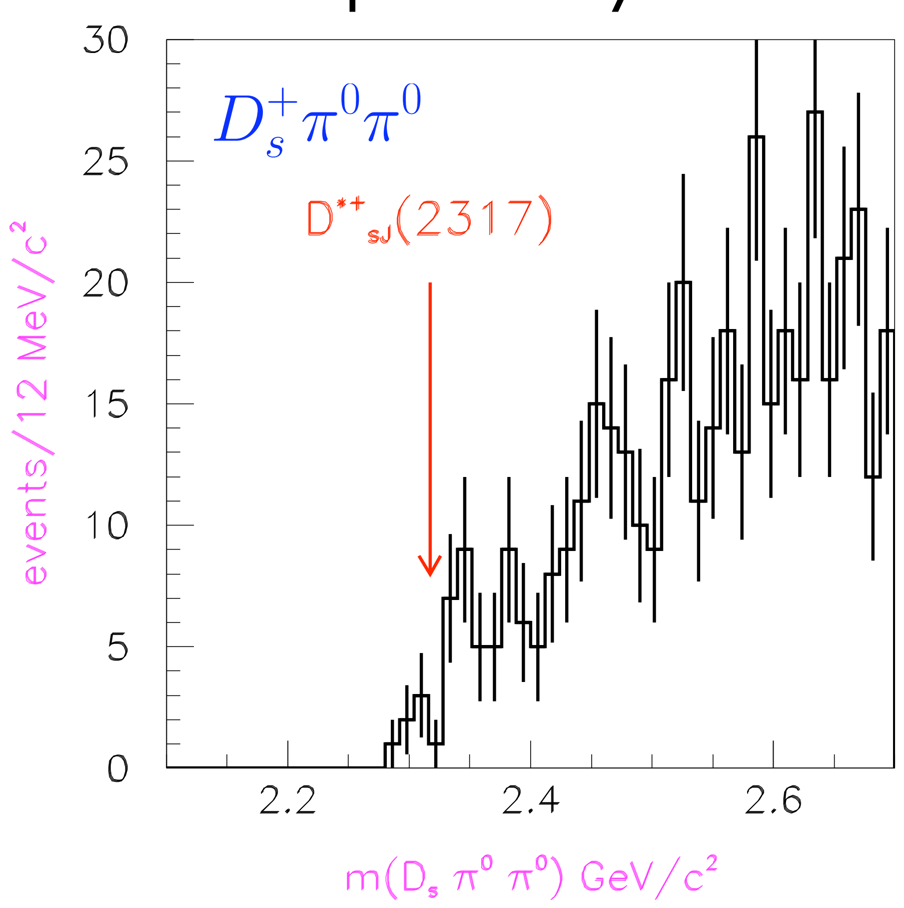
Courtesy of Yoshi Sakai

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

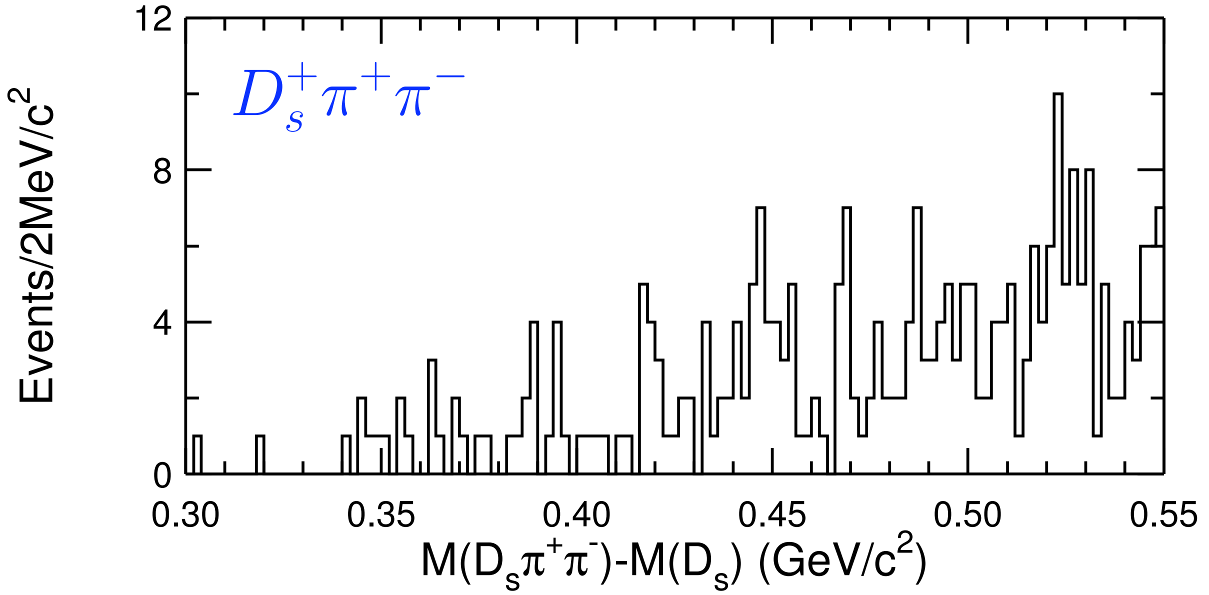
Search For $D_s\,\pi\,\pi$ Decay

No signals observed

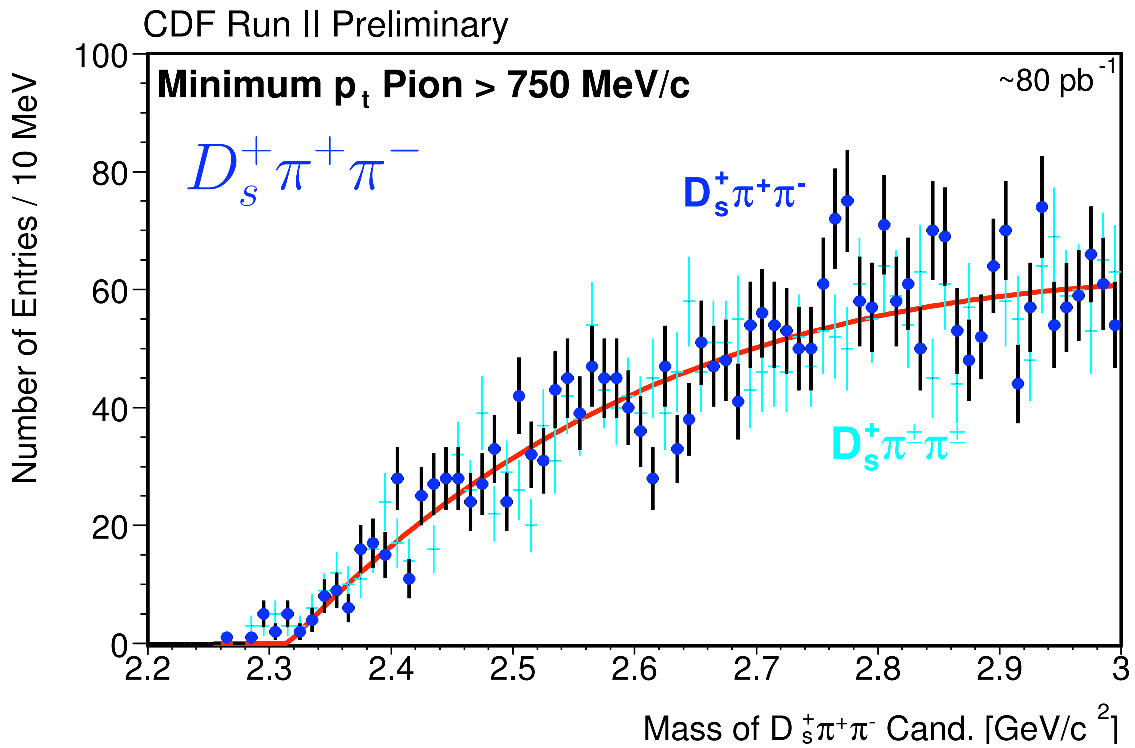
BaBar preliminary



CLEO



CDF II preliminary



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

Summary

A large (~2000 events), narrow signal has been discovered by BaBar in the inclusively produced $D_s\,\pi^0$ spectrum at a mass:[1]

$$m = 2316.8 \pm 0.4\,\mathrm{MeV}$$

- ✦ The measured width is consistent with detector resolution ($\Gamma < 10$ MeV).
- ✦ The decay violates isospin, but may occur strongly through η/π mixing (which explains the narrow width and rarity of radiative decay).
- ✦ Assuming parity conservation in decay, we must have:

  $$P = (-1)^J \qquad J^P = \{0^+, 1^-, 2^+, ...\}$$

  Given the low mass, the assignment $J^P = 0^+$ is most reasonable.
- ✦ Confirmed by CLEO in continuum[2] and by Belle in both continuum and in B decays.[3]
- ✦ Observed only in decay to $D_s\,\pi^0$.

1. BaBar, Phys.Rev.Lett. 90 (2003) 242001
2. CLEO, submitted to PRD, hep-ex/0305100
3. Belle, CIPANP 2003, FPCP 2003

$D_{sJ}(2457)^+$

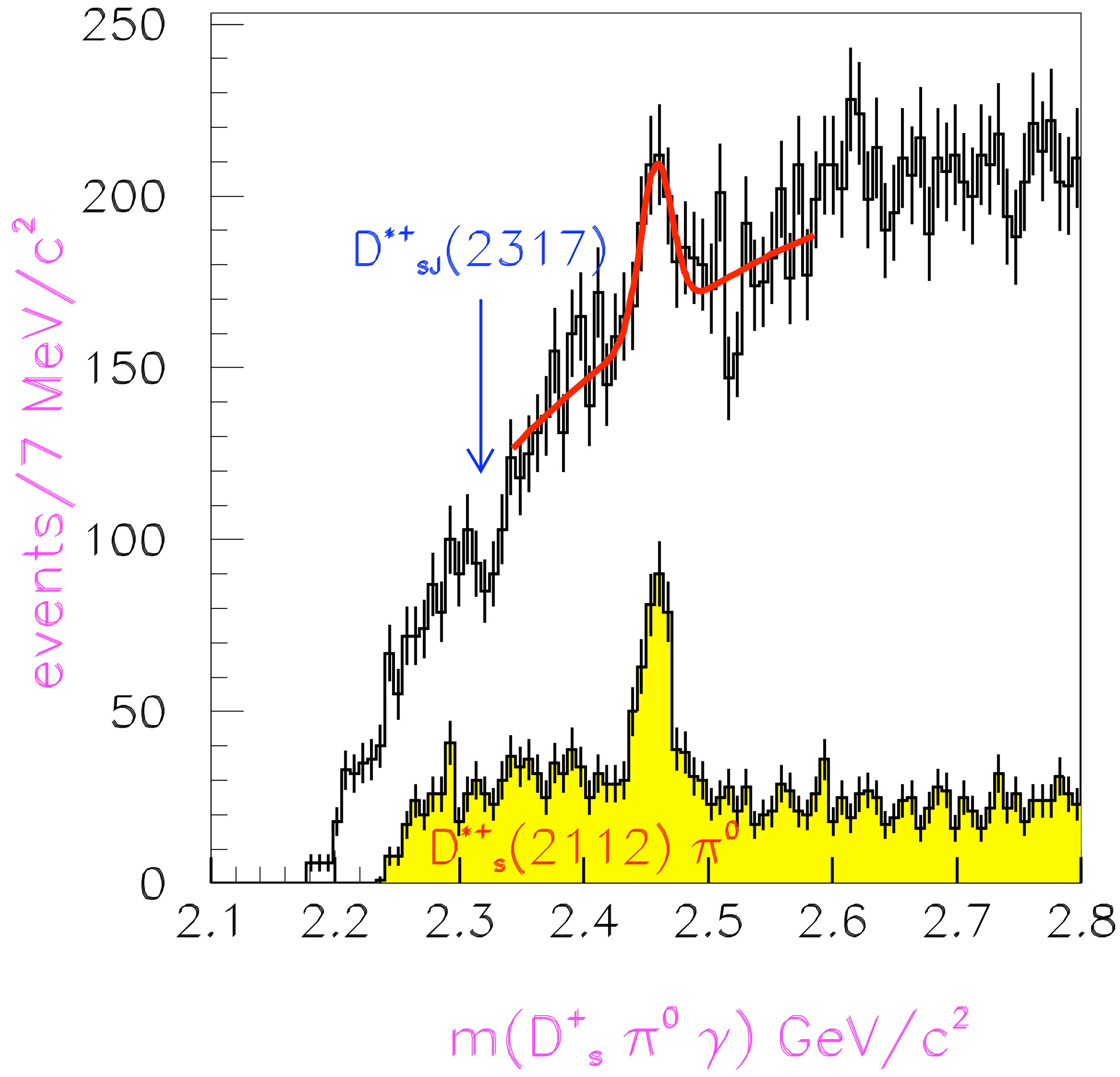
Bump or Reflection?

Gaussian fit:

$$m = 2458 \pm 4 \text{ MeV}/c^2$$

$$\sigma = 13 \pm 6 \text{ MeV}/c^2$$

(preliminary, statistical error only)



All candidates

Fit to all candidates

$D_s^*(2112)^+ \rightarrow D_s\gamma$

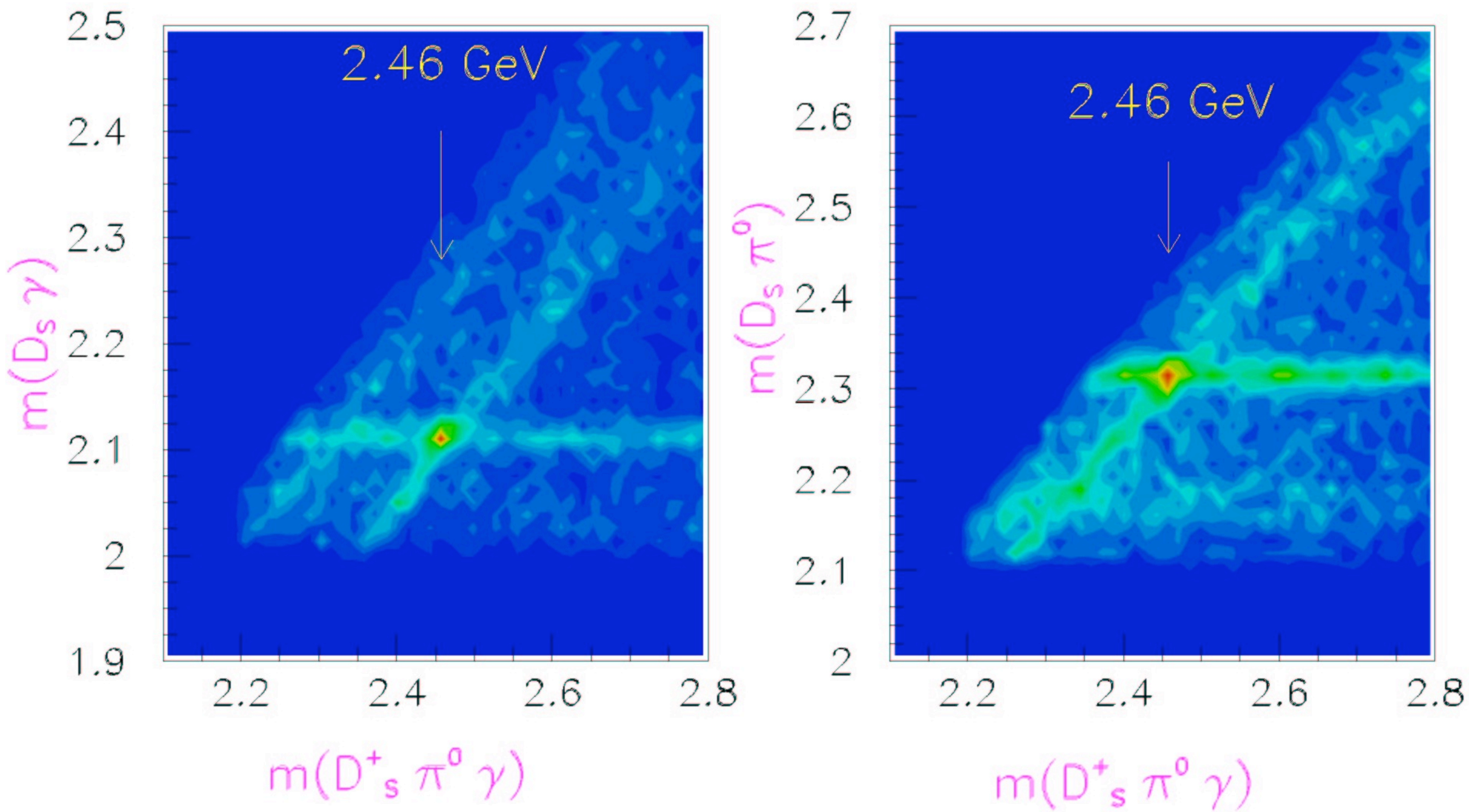
$D_{sJ}(2457)^+$

Kinematics of $D_s\,\pi^0\,\gamma$

Cross bands from two different decays:

$$D_s^*(2112)^+ \rightarrow D_s\gamma$$

$$D_{sJ}^*(2317)^+ \rightarrow D_s\pi^0$$

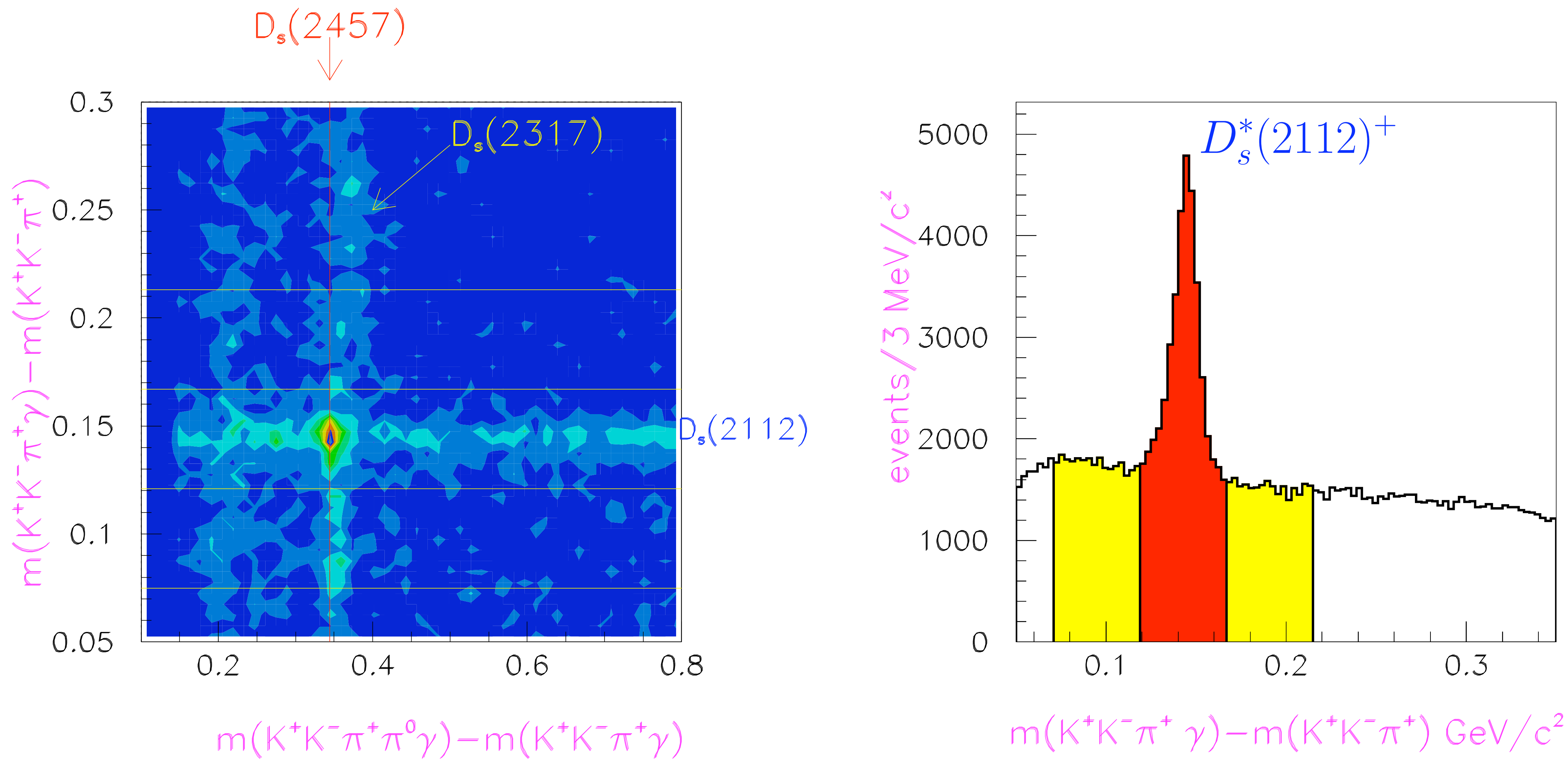


$D_{sJ}(2457)^+$

Delta Mass

Introduce mass differences:

$$\Delta m(D_s^+\gamma) \equiv (K^+K^-\pi^+\gamma) - m(K^+K^-\pi^+)$$
$$\Delta m(D_s^{+*}\pi^0) \equiv (K^+K^-\pi^+\gamma\,\pi^0) - m(K^+K^-\pi^+\gamma)$$



$D_{sJ}(2457)^+$

Sideband Subtraction

Fit results (preliminary, statistical errors only):

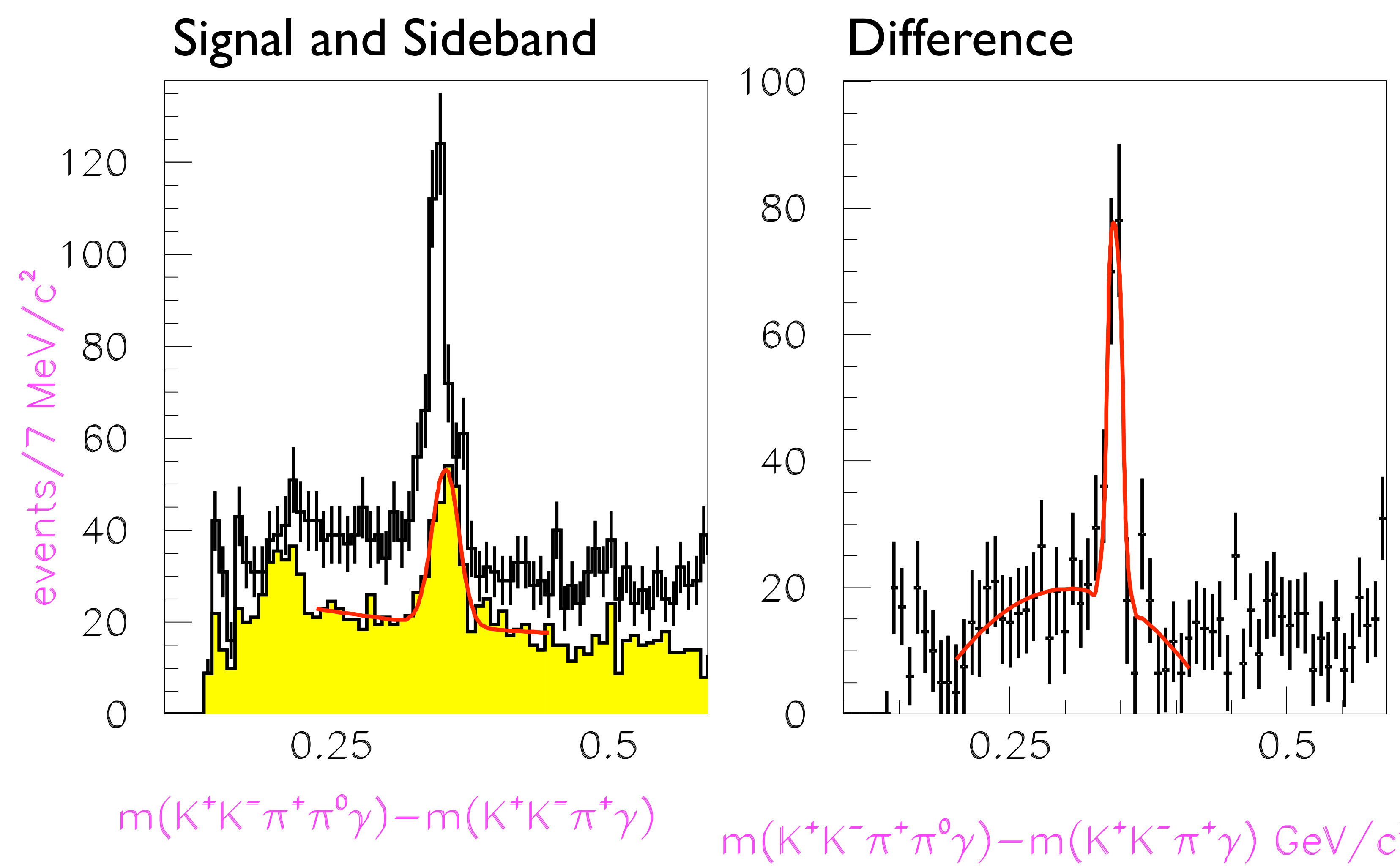
$$\Delta m(D_s^{+*}\pi^0) = 344.6 \pm 1.2 \text{ MeV}/c^2$$
$$\sigma = 5.5 \pm 1.4 \text{ MeV}/c^2$$
$$N = 140 \pm 22$$

Adding the PDG $D_s^*(2112)^+$ mass results in:

$$m = 2456.5 \pm 1.4 \text{ MeV}/c^2$$

The background peaks at:

$$\Delta m = 353.1 \pm 2.2 \text{ MeV}/c^2$$

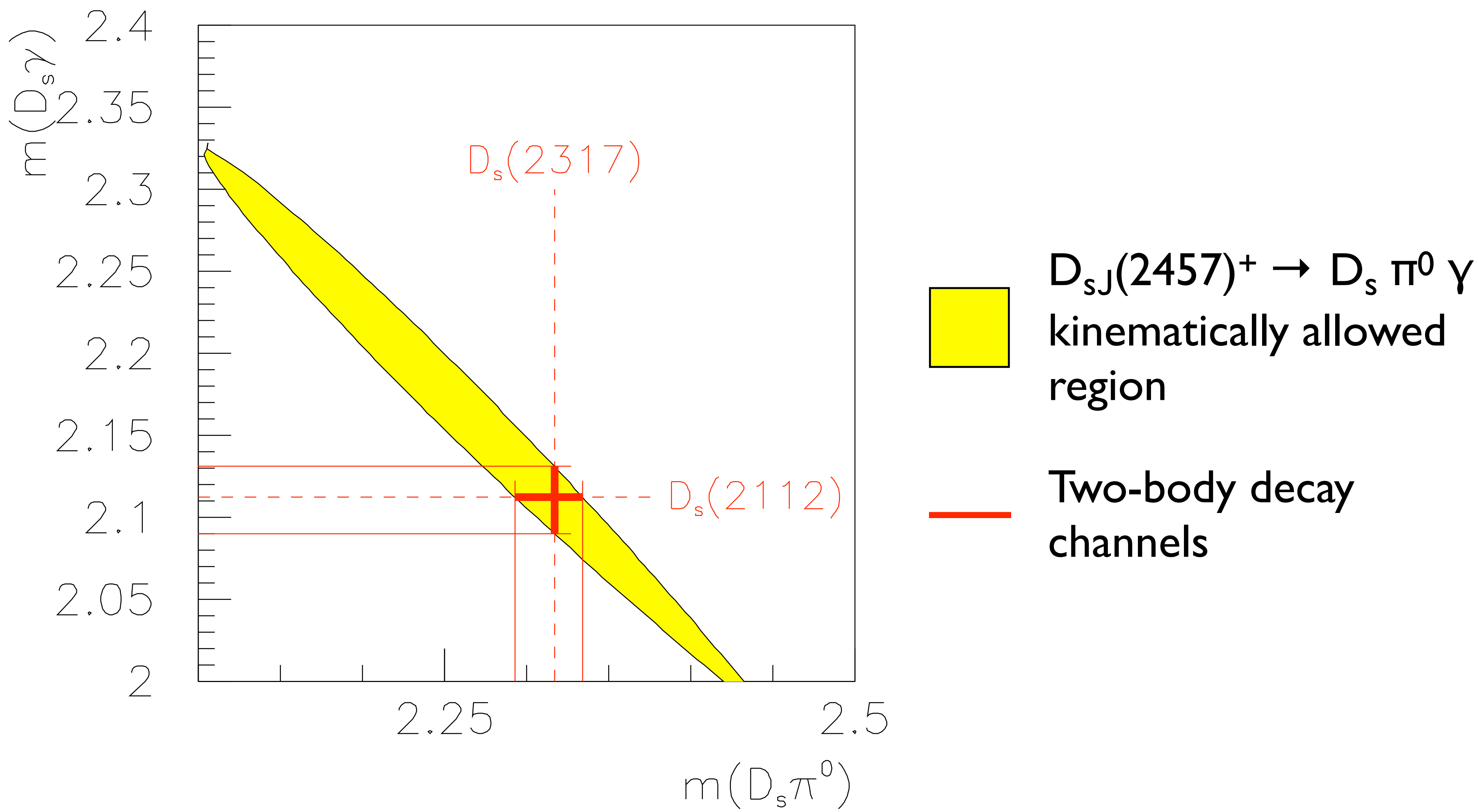


$D_{sJ}(2457)^+$

Two Possible Decay Modes

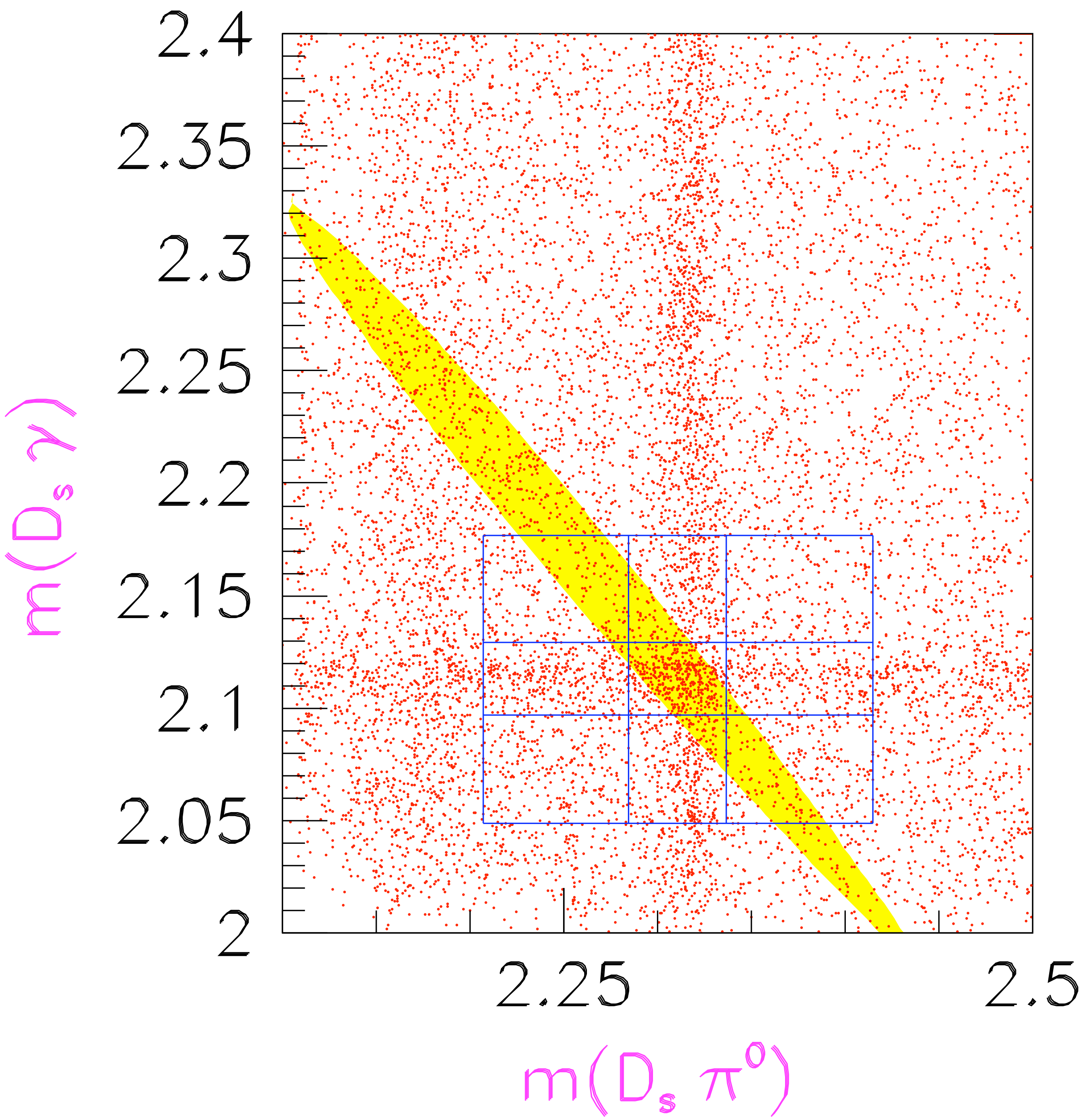
Difficult to distinguish due to a (not quite) kinematic accident

$$D_{sJ}(2457)^+ \rightarrow \begin{Bmatrix} D_s^*(2112)^+ \ \pi^0 \\ D_{sJ}^*(2317)^+\gamma \end{Bmatrix} \rightarrow D_s^+\pi^0\gamma$$



$D_{sJ}(2457)^+$

Nine Tiles



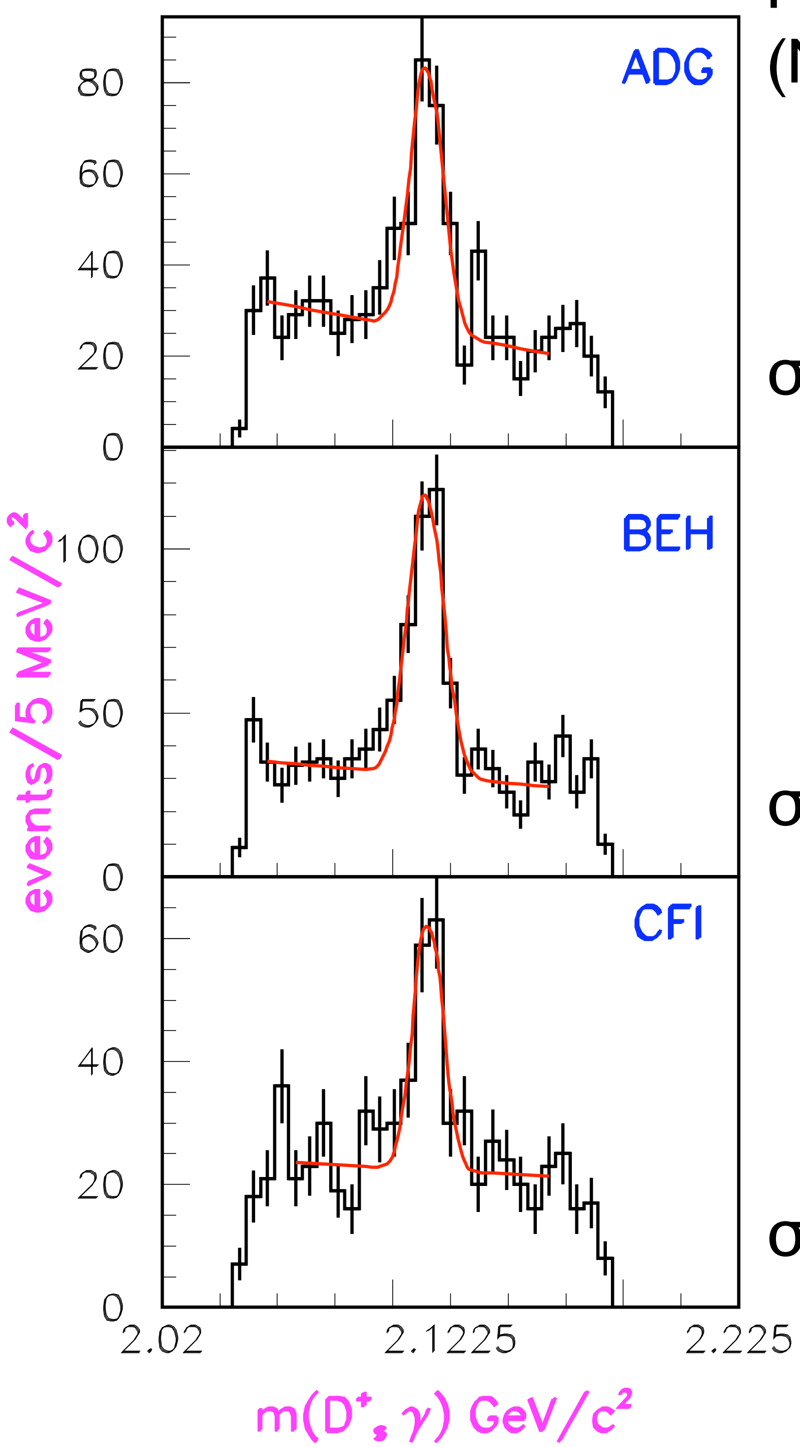
Number of events in each tile

A 239	B 304	C 202
D 345	E 472	F 261
G 281	H 344	I 236

Excess in E = 160 ± 25

(Assuming backgrounds distributed linearly in mass, statistical error only)

Nine Tile Fits

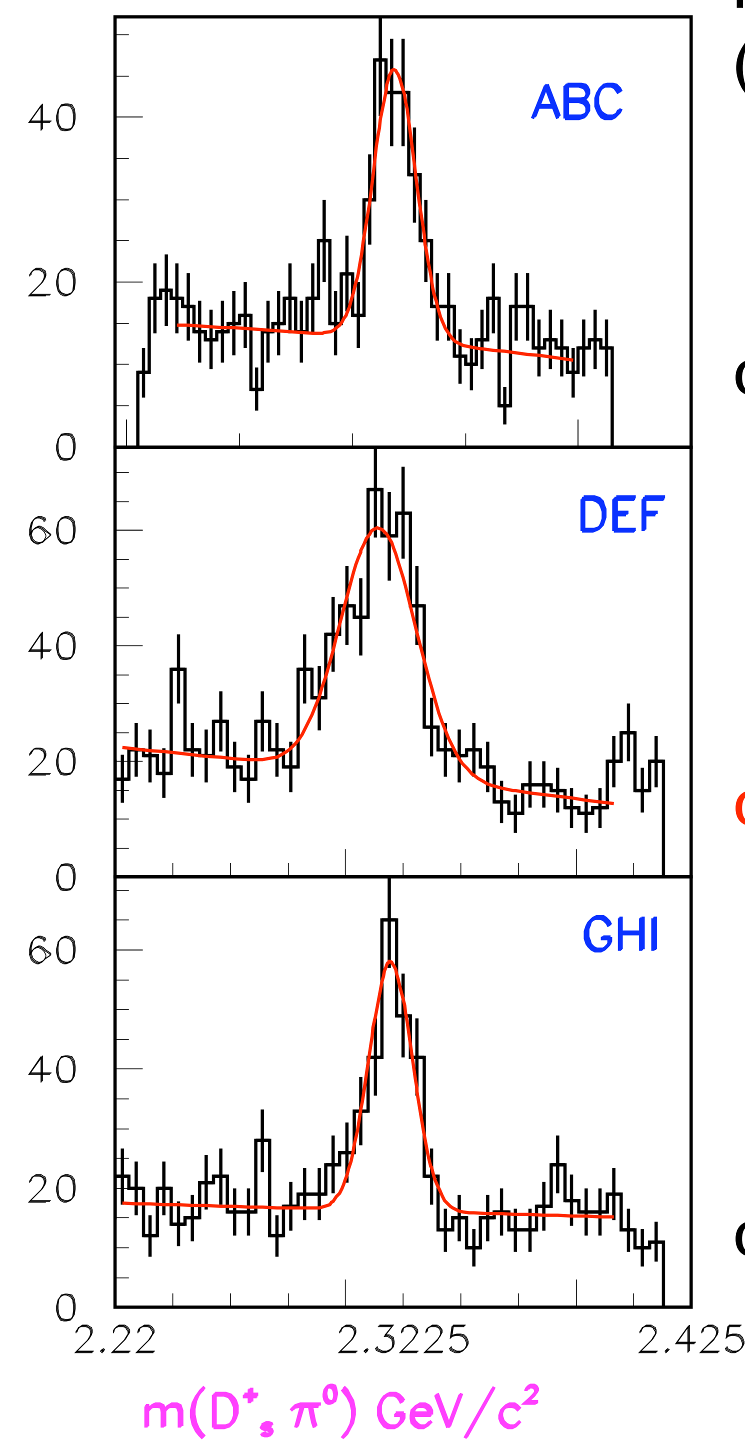


Mean and width (MeV)

= 2114.0 ± 0.8
σ = 5.7 ± 0.8

= 2113.8 ± 0.6
σ = 6.2 ± 0.6

= 2114.6 ± 3.6
σ = 5.1 ± 1.5



Mean and width (MeV)

= 2318.7 ± 1.2
σ = 9.5 ± 1.3

= 2313.7 ± 1.3
σ = 13.5 ± 1.3

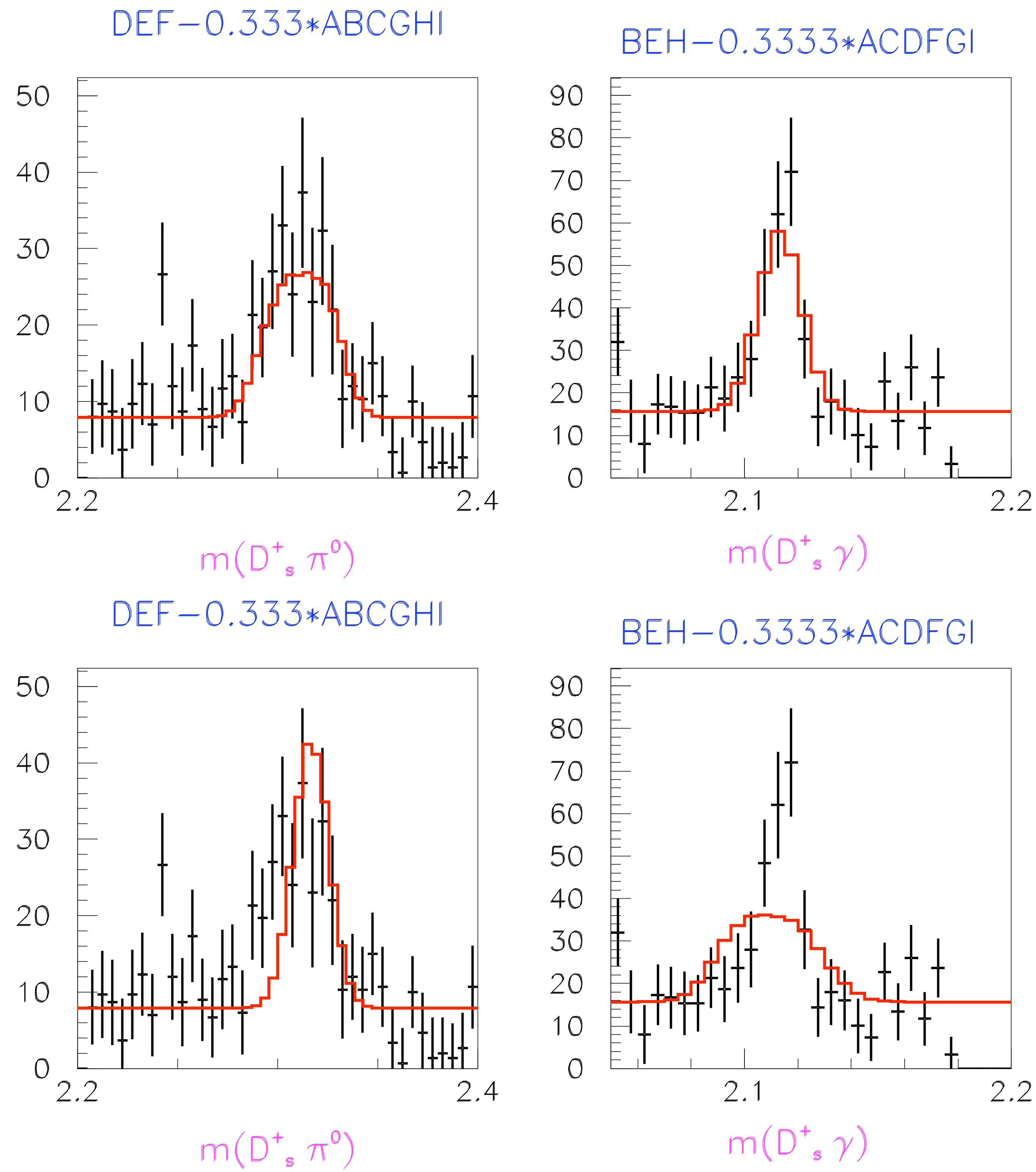
= 2318.7 ± 1.4
σ = 7.8 ± 0.9

$D_{sJ}(2457)^+$

Nine Tile Sideband Subtraction

$$D_{sJ}(2457)^+ \rightarrow D_s^*(2112)^+\pi^0$$

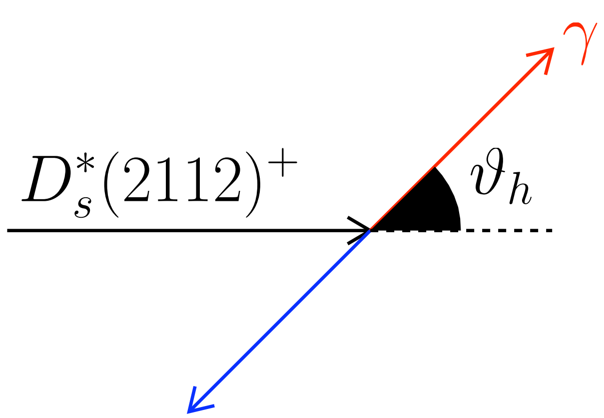
$$D_{sJ}(2457)^+ \rightarrow D_{sJ}^*(2317)^+\gamma$$

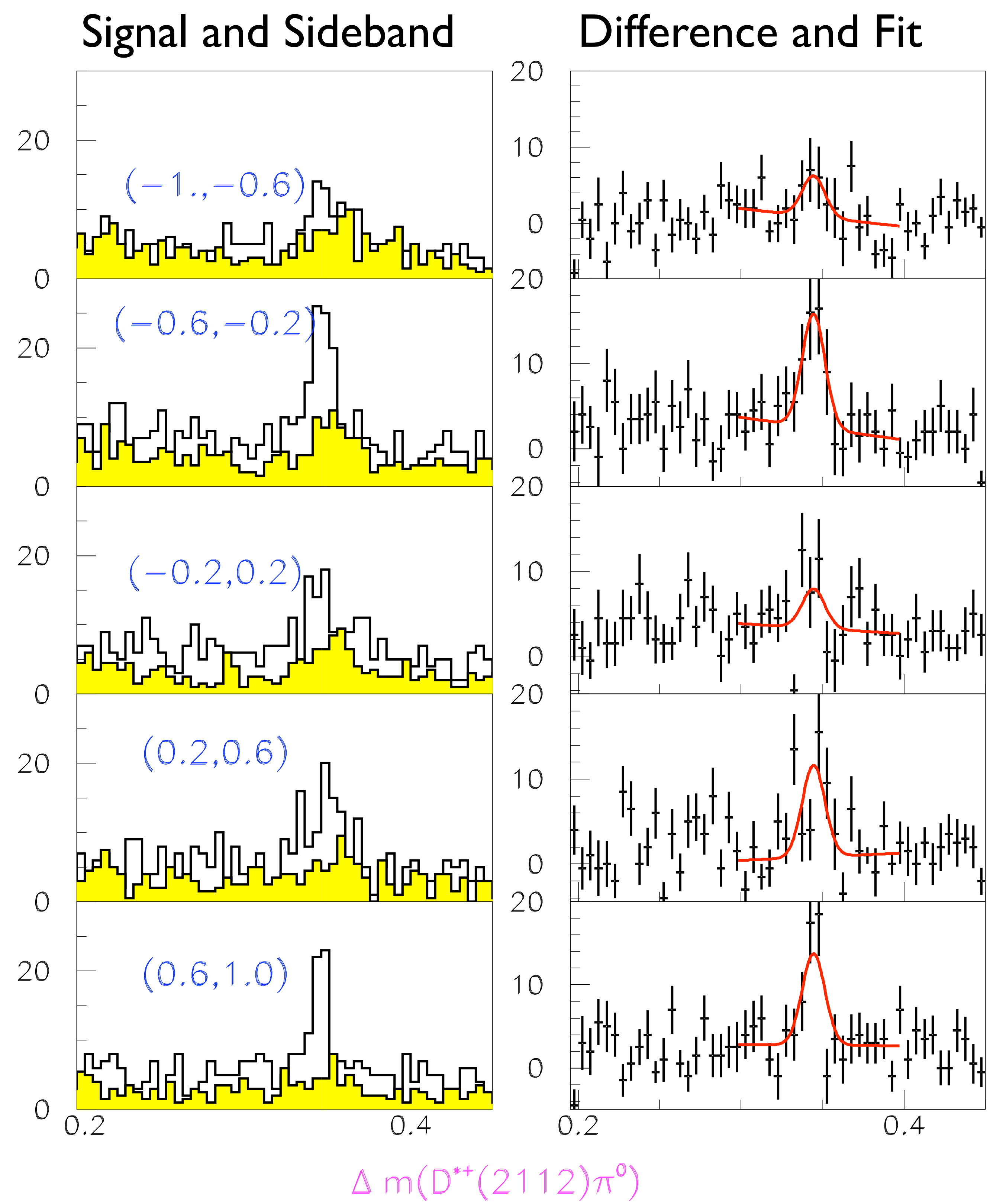


Helicity Angle Study

Assume $D_s^*(2112)^+ \pi^0$ decay

Divide data into ϑ_h bins

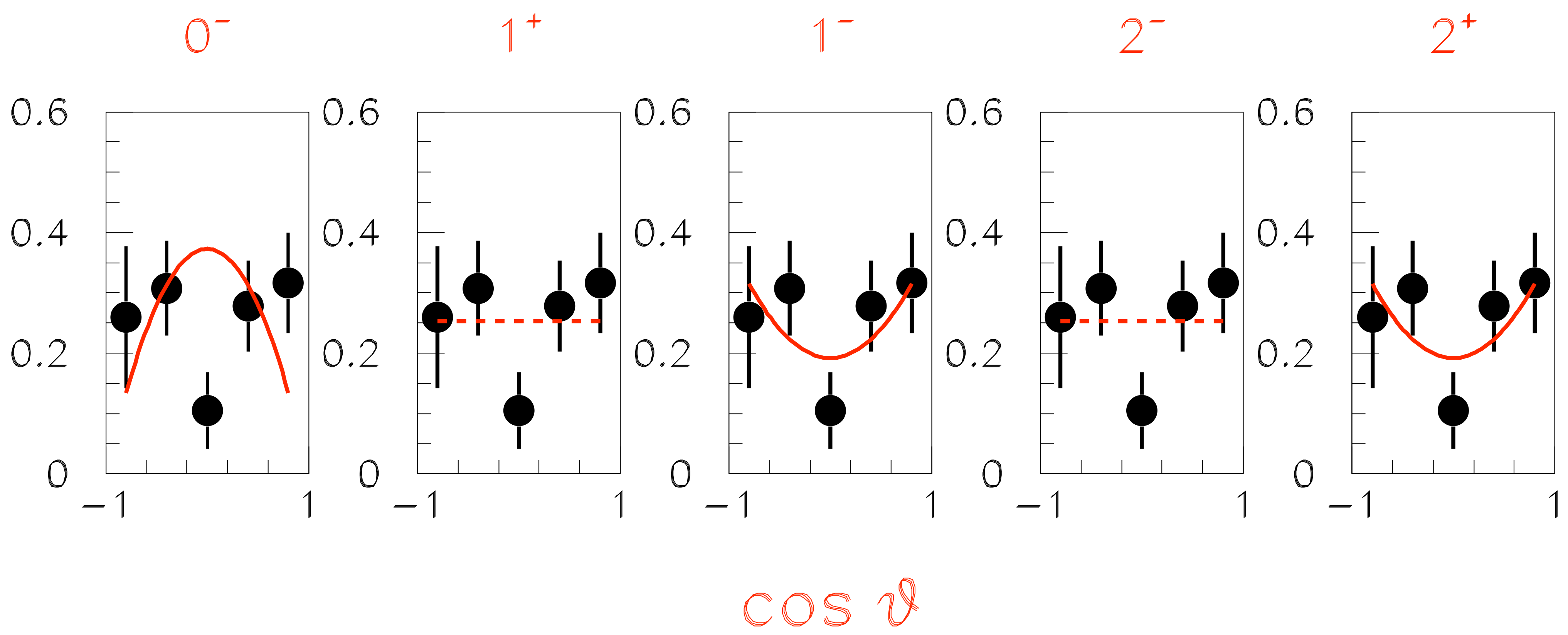




$D_{sJ}(2457)^+$

Helicity Study

Comparison to various spin-parity hypotheses (assuming parity conservation)

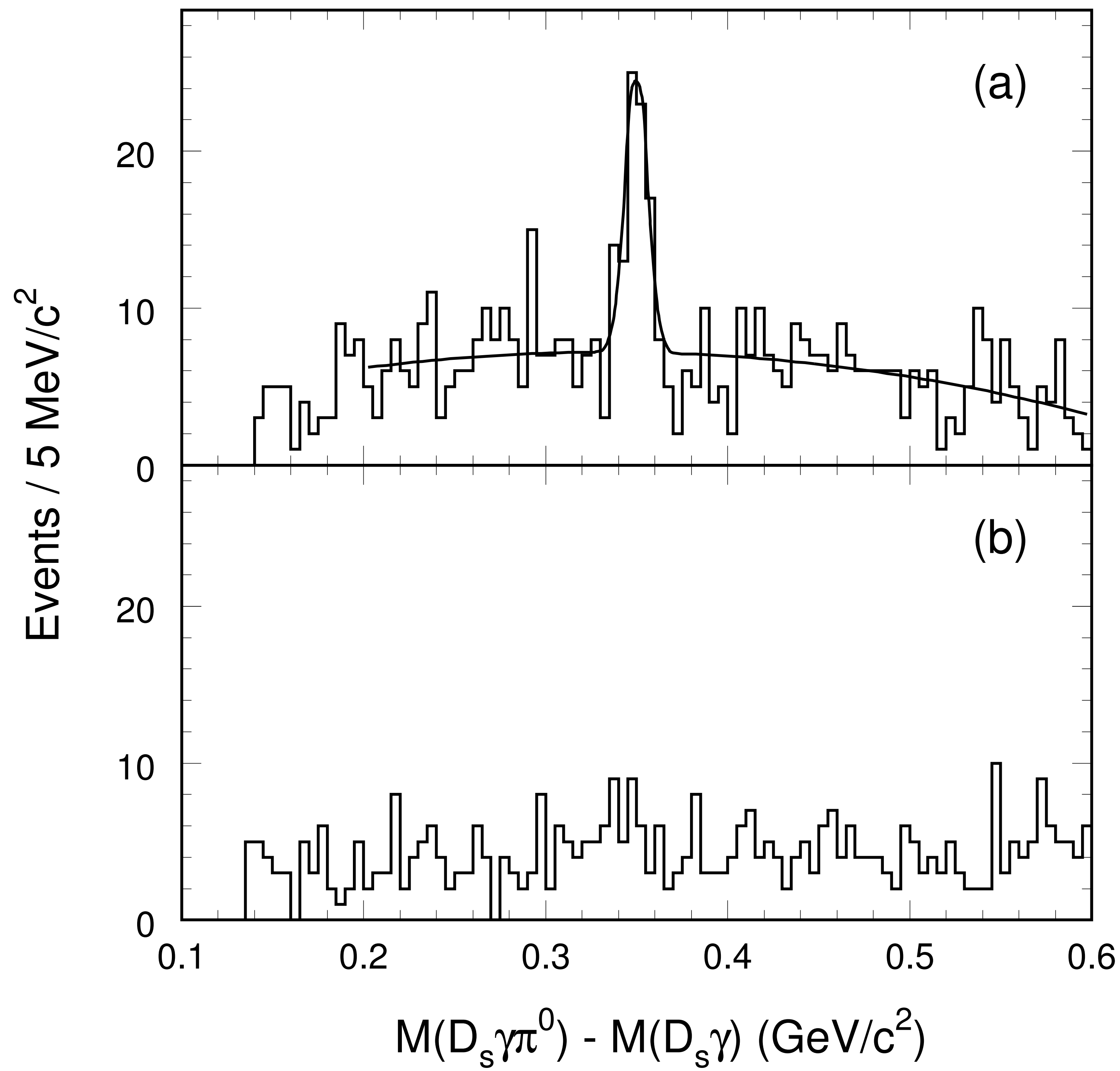


- ✦ $J^P = 1^+$ and 2^- distributions depend on production helicity
- ✦ Data is least consistent with 0^-

$D_{sJ}(2457)^+$

Observation from CLEO

Submitted to PRD (hep-ex/0305100)



Corrected fit results:

$$\Delta m = 351.2 \pm 1.7\ (\mathrm{stat}) \pm 1.0\ (\mathrm{syst})\ \mathrm{MeV}/c^2$$

$$N = 41 \pm 12$$

Little peaking background

$D_{sJ}(2457)^+$

Confirmation From Belle

Preliminary 78 fb^{-1}

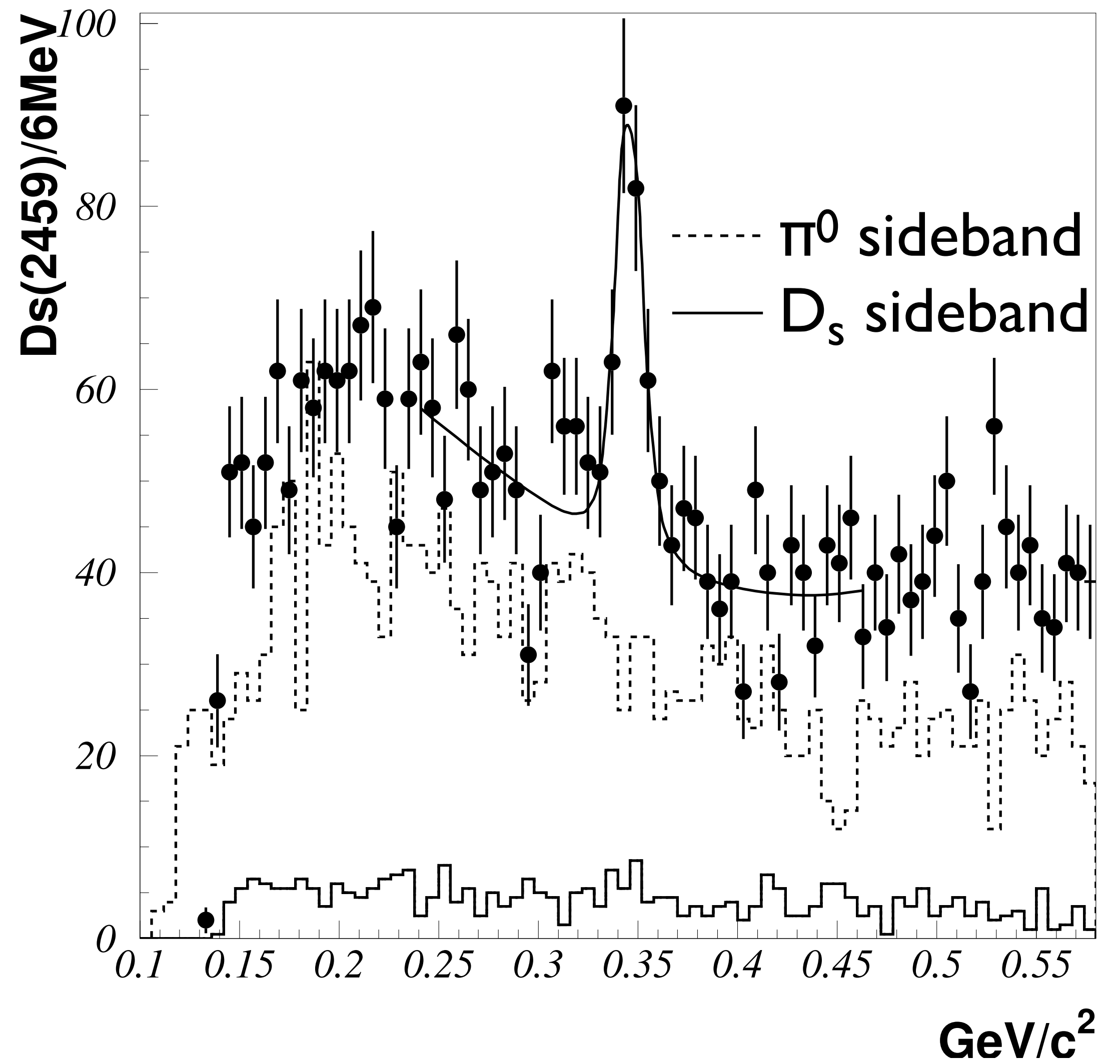
- $D_s \rightarrow \varphi \pi^+$ mode only

Fit results:

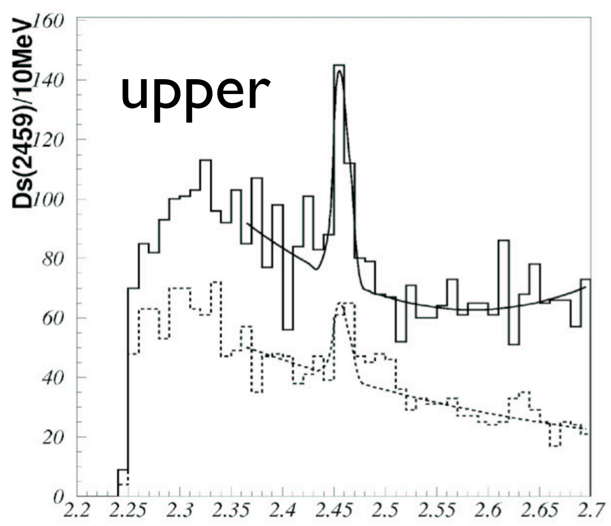
$$m = 2457.8 \pm 1.4 \text{ MeV}/c^2$$

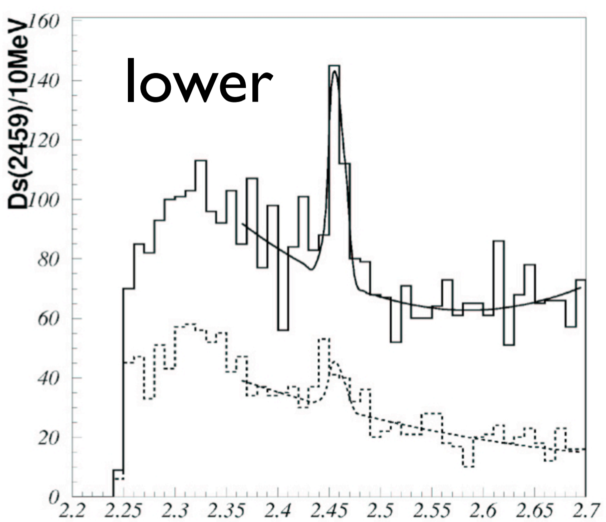
$$N = 79 \pm 14$$

Qualitative agreement with BaBar



$D_s^*(2112)^+$ sidebands





$D_{sJ}(2457)^+$

Confirmation From Belle

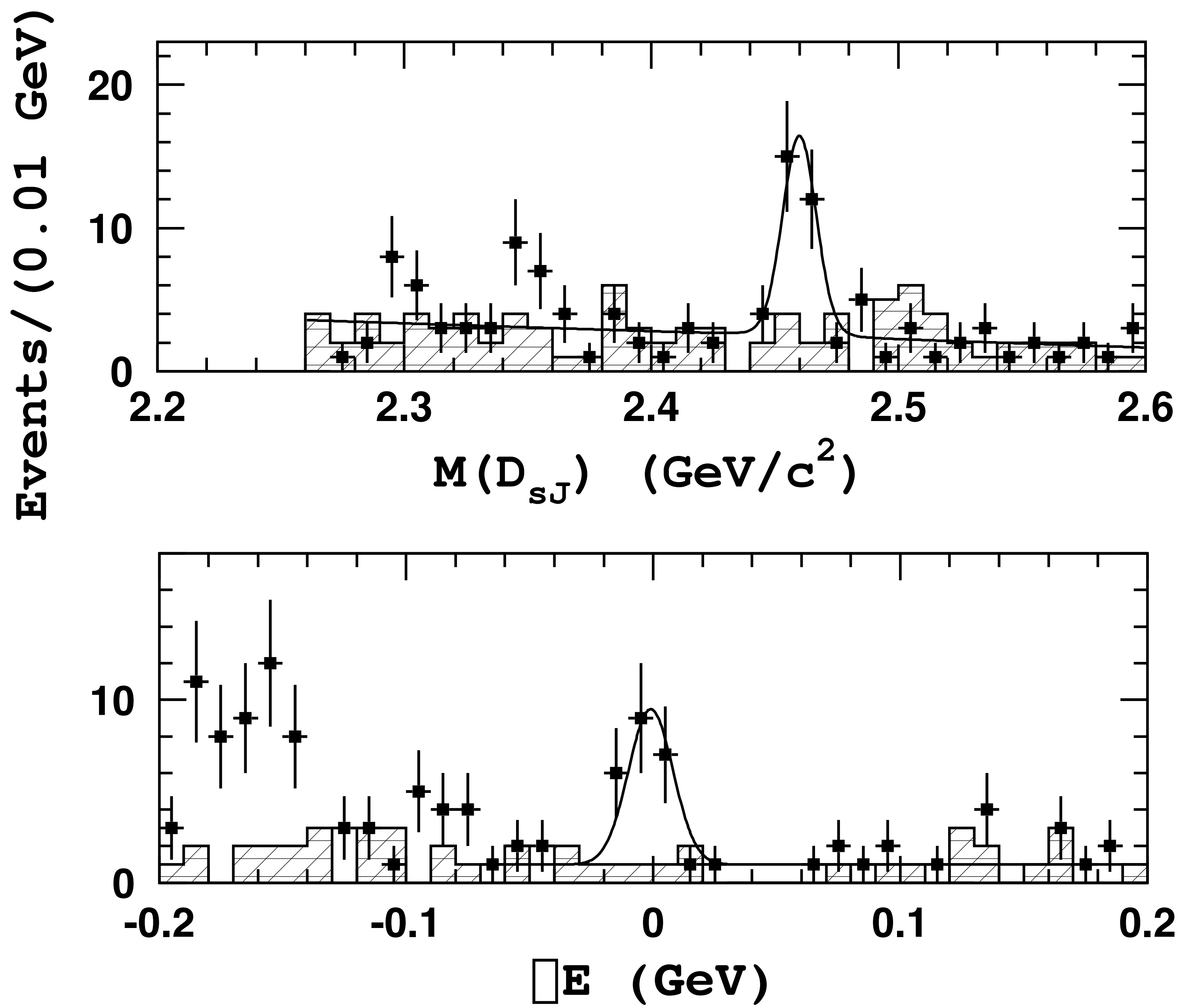
From B decays

$$m = 2459.2 \pm 1.6 \text{ MeV}/c^2$$

$$\mathcal{B}r = 17.8^{+4.5}_{-3.9}\,(\text{stat}) \pm 5.3\,(\text{syst})$$

BELLE Preliminary, 124 million B-pairs

$B \to D D_{sJ}(2457)^+$

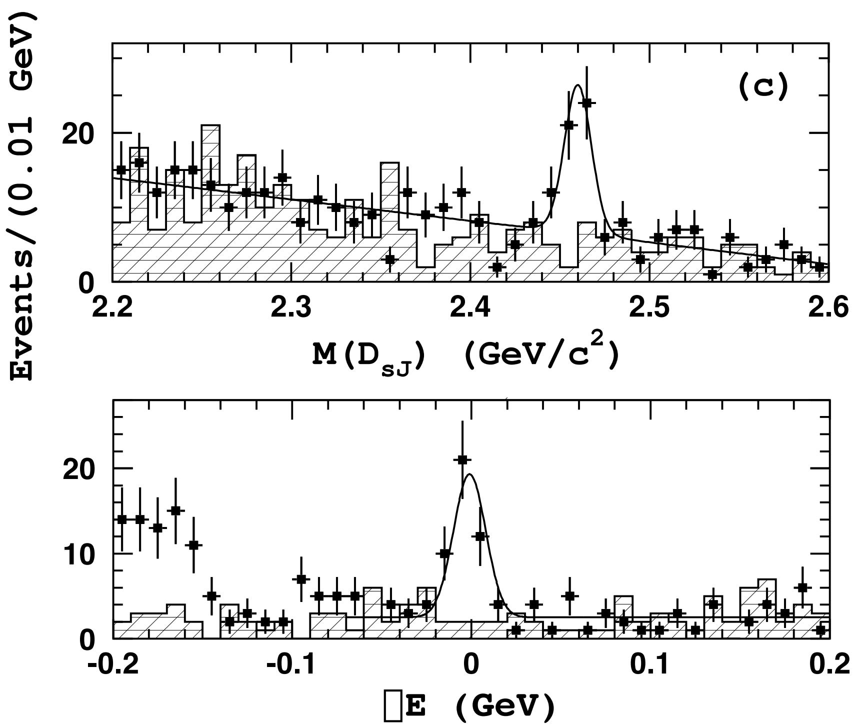


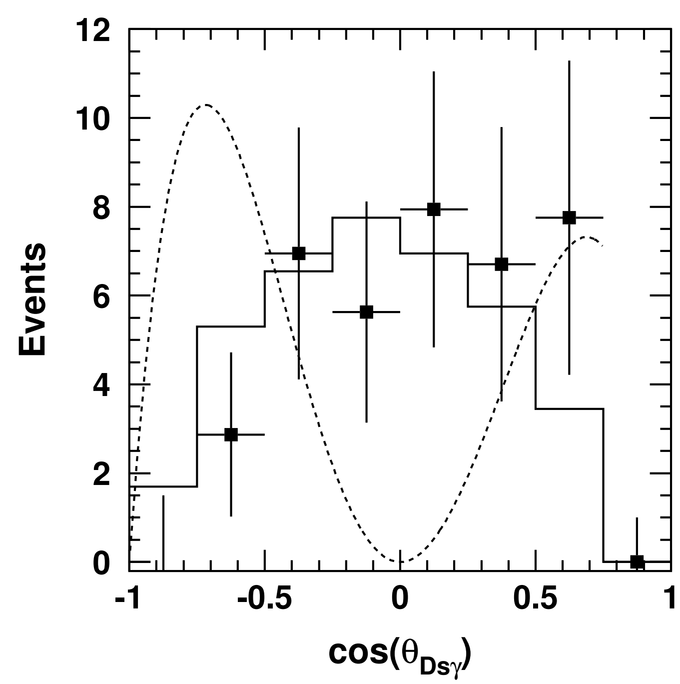
$D_{sJ}(2457)^+$

New Decay Mode From Belle

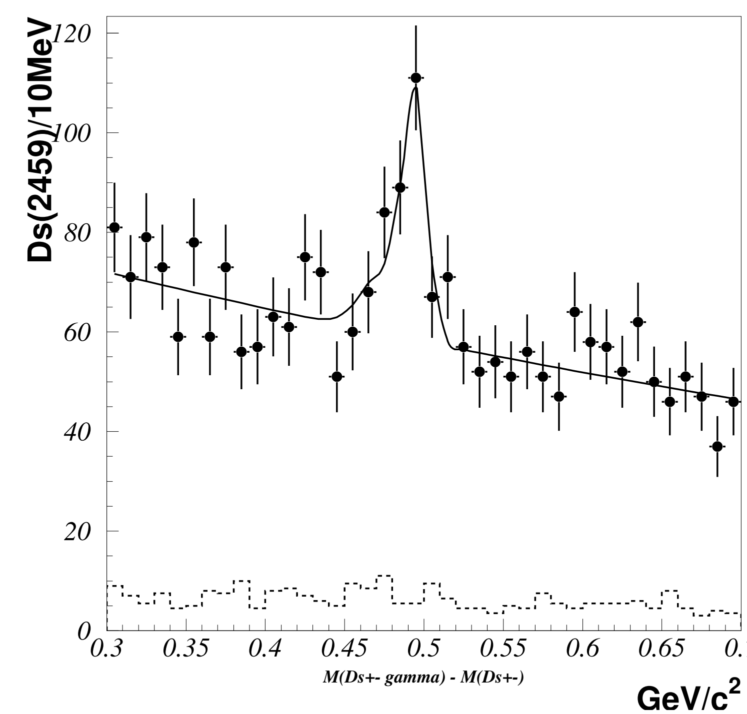
Evidence for $D_{sJ}(2457)^+ \rightarrow D_s\,\gamma$ from both B decays and continuum (preliminary)

$B \rightarrow D D_{sJ}(2457)^+$





$c\bar{c} \rightarrow X D_{sJ}(2457)^+$



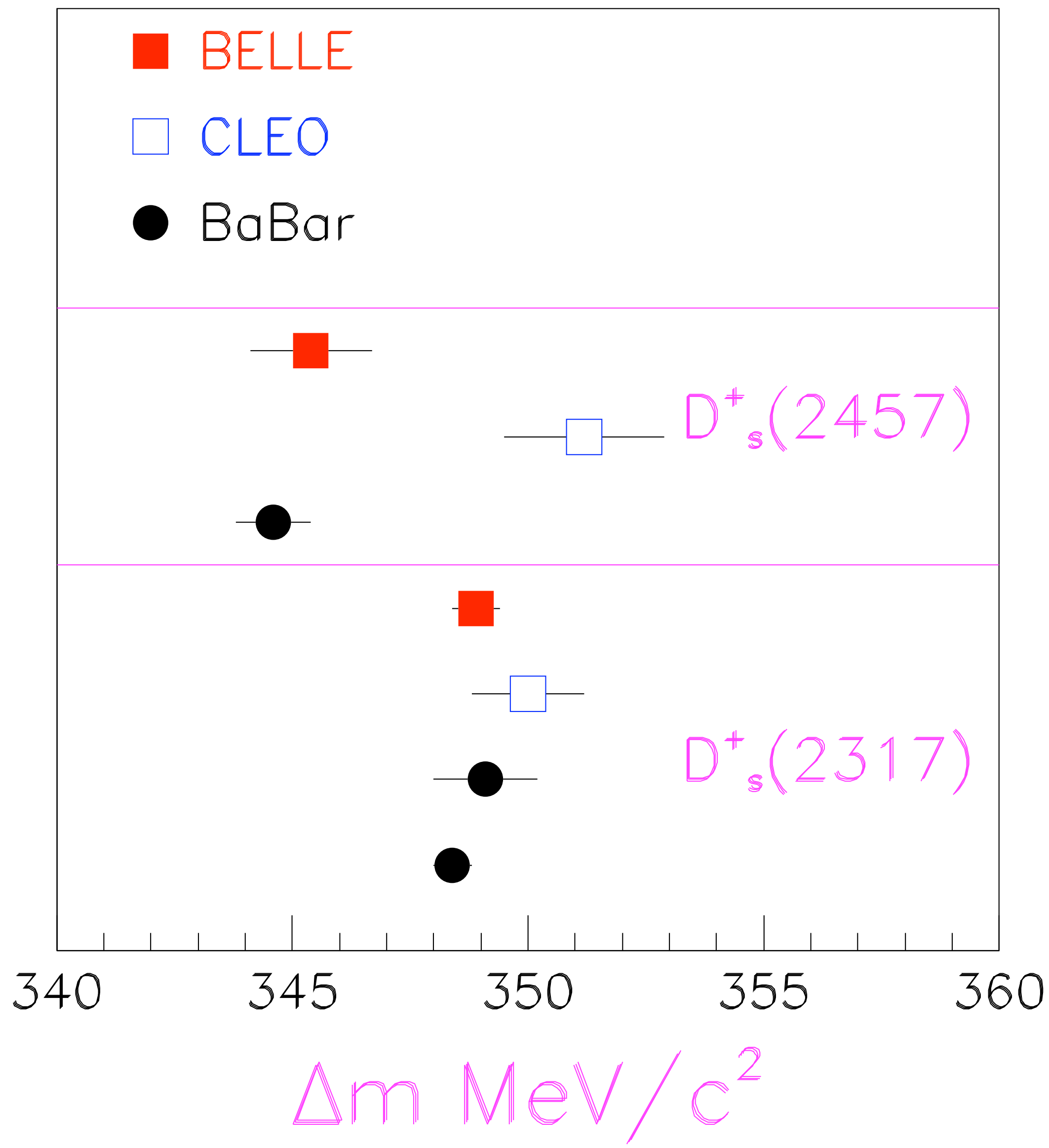
$N = 128 \pm 20$

$$\frac{\mathcal{B}r[D_{sJ}(2457)^+ \rightarrow D_s^+\gamma]}{\mathcal{B}r[D_{sJ}(2457)^+ \rightarrow D_s^*(2112)^+\pi^0]} = 0.38 \pm 0.11\,(\mathrm{stat}) \pm 0.04\,(\mathrm{syst})$$

Consistent with either J = 1⁺ or 1⁻

$D_{sJ}(2457)^+$

Comparison of Experiments



$D_{sJ}(2457)^+$

Experimental Summary

First evidence for structure in $D_s\,\pi^0\,\gamma$ mass spectrum apparent in BaBar data.[1]

- "However, the complexity of the overlapping kinematics … requires more detailed study … to arrive at a definitive conclusion."

Observation of $D_{sJ}(2457)^+$ ("$D_{sJ}(2463)^+$") reported by CLEO.[2]

Confirmed by Belle, including $D_s\gamma$ decay mode.[3]

Preliminary BaBar analysis:[4]

$$m = 2456.5 \pm 1.4\ \mathrm{MeV}/c^2 \qquad \sigma = 5.5 \pm 1.4\ \mathrm{MeV}/c^2$$

- Width is consistent with resolution
- Some disagreement with CLEO to be understood

A spin analysis is consistent with $J^P = 1^+$.

The Belle observation of the $D_s\gamma$ decay mode rule out all J besides J=1.

1. BaBar, Phys.Rev.Lett. 90 (2003) 242001
2. CLEO, submitted to PRD, hep-ex/0305100
3. Belle, CIPANP 2003, FPCP 2003
4. BaBar, PIC 2003

Theoretical Implications

Possible Explanations

Lots of theoretical activity (24 preprints so far)

Possible explanations:

- The $D^{*}_{sJ}(2317)^{+}$ and $D_{sJ}(2457)^{+}$ are the missing L=1 D_s mesons and that the models need adjustment
- Either the $D^{*}_{sJ}(2317)^{+}$ or $D_{sJ}(2457)^{+}$ is something else entirely (four-quark state)

Theoretical Implications

Pre-Prints

Spin-Orbit and Tensor Forces in Heavy-quark Light-quark Mesons: Implications of the New Ds state at 2.32 GeV	R.N. Cahn, J.D. Jackson	hep-ph/0305012	May 1
Implications of a DK Molecule at 2.32 GeV	T. Barnes, F.E. Close, H.J. Lipkin	hep-ph/0305025	May 2
Observed D_s(2317) and tentative D(2030) as the charmed cousins of the light scalar nonet	E.v. Beveren, G. Rupp	hep-ph/0305035	May 5
B Decays as Spectroscope for Charmed Four-quark States	H-Y. Cheng, W-S. Hou	hep-ph/0305038	May 5
Chiral Multiplets of Heavy-Light Mesons	W.A. Bardeen, E.J. Eichten, C.T. Hill	hep-ph/0305049	May 5
Description of the \$D^*_s(2320)\$ resonance as the \$D\pi\$ atom	A.P. Szczepaniak	hep-ph/0305060	May 6
Hybrid configuration content of heavy S-wave mesons	T. Burch, D. Toussaint	hep-lat/0305008	May 8
Using Radiative Transitions to Test the 1^3P_0(c\bar{s}) Nature of the D_{sJ}^*(2317)^+ State	S. Godfrey	hep-ph/0305122	May 12
Understanding \$D_{sJ}(2317)\$	P. Colangelo, F. De Fazio	hep-ph/0305140	May 13
The DsJ(2317): what can the Lattice say? The DsJ(2317): what can the Lattice say?	G.S. Bali	hep-ph/0305209	May 19
BABAR resonance as a new window of hadron physics	K. Terasaki	hep-ph/0305213	May 20
Continuum bound states K-long, D_{1}(2420), D_{s1}(2536) and their partners K-short, D_{1}(2400), D*_{sJ}(2463)	E. v.Beveren, G. Rupp	hep-ph/0306051	June 5
Explaining the Ds(2317)	E. v.Beveren, G. Rupp	hep-ph/0306155	June 17
QCD Inequalities and the \$D_s(2320)\$	S. Nussinov	hep-ph/0306187	June 20
New Predictions for Multiquark Hadron Masses	H. Lipkin	hep-ph/0306204	June 22
Charmed and Charmed-Strange Mesons in Kaluza-Klein Picture	A.A. Arkhipov	hep-ph/0306237	June 24
Understanding the \$D^+_{sJ}(2317)\$ and \$D^+_{sJ}(2460)\$ with Sum Rules in HQET	Y-B. Dai, C-S. Huang, C. Liu, S-L. Zhu	hep-ph/0306274	June 27
The spectrum of D_s mesons from lattice QCD	A. Dougall, R.D. Kenway, C.M. Maynard, C. McNeile	hep-lat/0307001	July 1
Comment on the new \$D_s^{(*)+} \pi^0\$ resonances	T.E. Browder, S. Pakvasa, A.A. Petrov	hep-ph/0307054	July 4
On the mass of the Ds(0+,1+) system	A. Deandrea, G. Nardulli, A.D. Polosa	hep-ph/0307069	July 4
Search of \$D^{*}_{sJ}\$ mesons in \$B\$ meson decays	C-H. Chen, H-n Li	hep-ph/0307075	July 5
The masses of \$D_{sj}^\ast\$(2317) and \$D_{sj}^\ast\$(2463) in the MIT bag model	M. Sadzikowski	hep-ph/0307084	July 7
Chiral Doubling of Heavy-Light Hadrons: BaBar 2317 MeV and CLEO 2463 MeV Discoveries	M.A. Nowak, M. Rho, I. Zahed	hep-ph/0307102	July 8
Understanding the nature of \$D_s(2317)\$ and \$D_s^*(2460)\$ through nonleptonic B Decays	A. Datta, P.J. O'donnell	hep-ph/0307106	July 8

Theoretical Implications

Modifying the Potential Model

R. Cahn and J.D. Jackson[1]

Before observation of $D_{sJ}(2457)^+$

- ✦ Generic potential model
- ✦ Sol. B = preferred fit
- ✦ Sol. A = alternate fit
- ✦ Fit does not include non-charm mesons

	Exp.	Theory		
	Ref. [a,b,c]	Sol. A	Sol. B	Ref. [d]
D mesons				
$M(2^+)$(GeV)	2.459	[2.459]	[2.459]	2.460
$M(1^+)$(GeV)	2.400	2.400	2.385	2.490
$M(1^+)$(GeV)	2.422	[2.422]	[2.422]	2.417
$M(0^+)$(GeV)	2.290	[2.290]	[2.290]	2.377
λ (MeV)		39	54	−11
τ (MeV)		11	9	11
D_s mesons				
$M(2^+)$(GeV)	2.572	[2.572]	[2.572]	2.581
$M(1^+)$(GeV)		2.480	2.408	2.605
$M(1^+)$(GeV)	2.536	[2.536]	[2.536]	2.535
$M(0^+)$(GeV)	2.317	[2.317]	[2.317]	2.487
λ (MeV)		43	115	−7
τ (MeV)		20	9	11

a. Particle Data Group

b. This analysis

c. ICHEP 2002, BELLE-CONF-0235

d. M. DiPierro and E. Eichten *Phys. Rev.* **D64**, 114004 (2001)

1. hep-ex/0305012

Theoretical Implications

More on Meson Interpretation

Lattice calculations:

- May[1] or may not[2] have trouble coping with low mass D_s scalar

Chiral symmetry models:[3]

- Correctly predicts approximately equal $D^*_{sJ}(2317)^+/D_{sJ}(2457)^+$ and $D^+_s/D^*_s(2112)^+$ mass splittings
- Correctly predicted $D_{sJ}(2457)^+$ radiative decay along with branching fraction

Heavy-quark effective theory (HQET):[4]

- Roughly consistent with measured $D^*_{sJ}(2317)^+$ and $D_{sJ}(2457)^+$ masses

Unitarised meson model:[5]

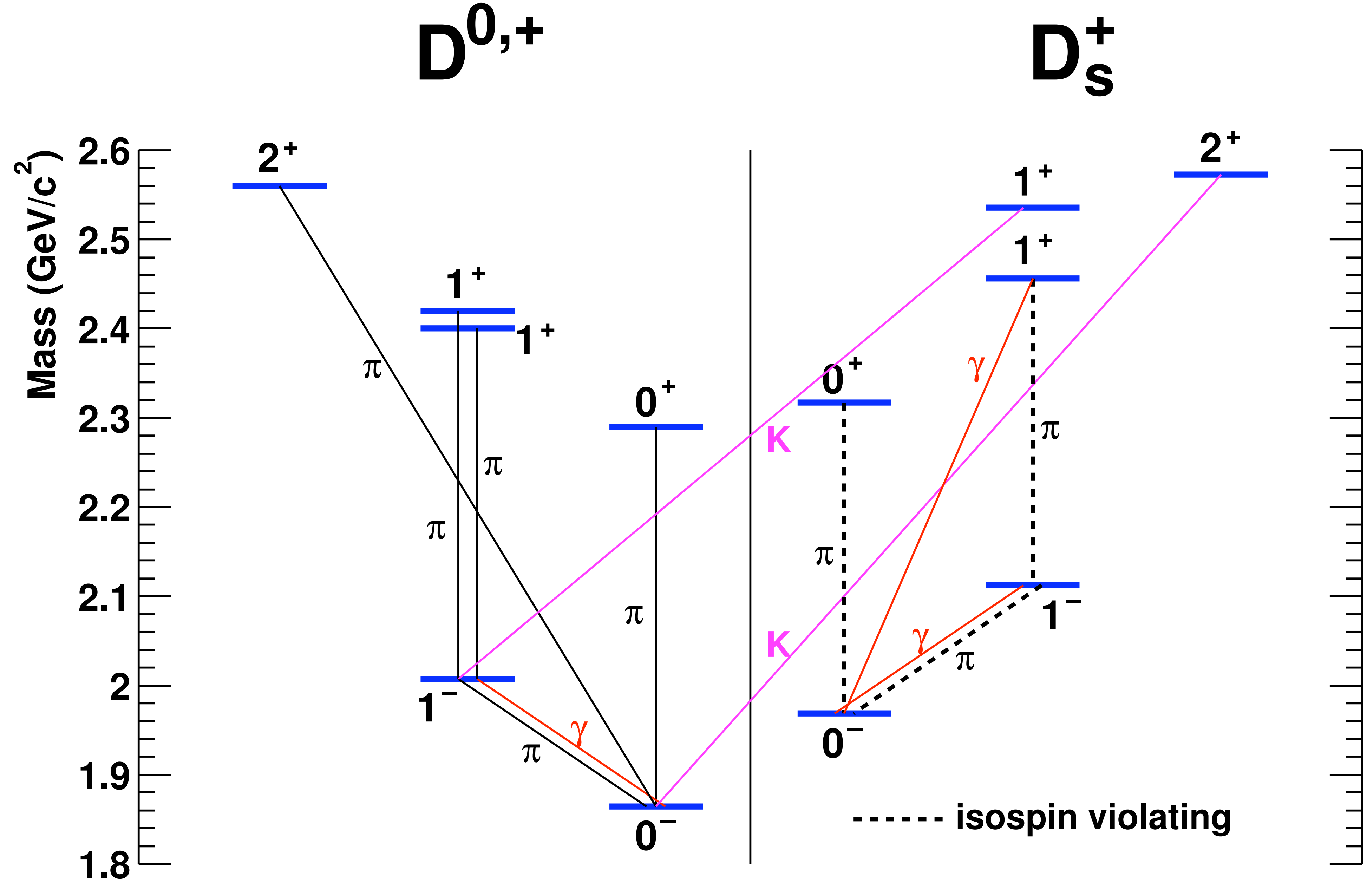
- D-K coupling explains $D^*_{sJ}(2317)^+$ and $D_{sJ}(2457)^+$

1. G.S. Bali, hep-ph/0305209
2. A. Dougall, R.D. Kenway, C.M. Maynard, C. McNeile, hep-lat/0307001.
3. W.A. Bardeen, E.J. Eichten, C.T. Hill, hep-ph./0305049l
4. Y-B. Dai, C-S. Huang, C. Liu, S-L. Zhu, hep-ph/0306274.
5. E. v.Beveren, G. Rupp, hep-ph/0305035.

Theoretical Implications

Charm Mesons

Observed states and transitions



Theoretical Implications

Four-Quark States

In 1981 Lipkin and Isgur predicted a D-K molecule of mass ~2360 MeV[1]

If the $D^*_{sJ}(2317)^+$ is a molecule, then:[2]

- ✦ The ordinary D_s meson have not yet been found
- ✦ Expect a large variety of new states of isospin 0 and 1

Perhaps the $D^*_{sJ}(2317)^+$ and $D_{sJ}(2457)^+$ are mixtures of ordinary mesons and four-quark states[3]

1. H. Lipkin and N. Isgur, Phys.Lett. B99 (1981) 151.
2. T. Barnes, F. Close, H. Lipkin, hep-ph/0305025,
   H-Y. Cheng and W-S. Hou, hep-ph/0305038,
   A.P. Szczepaniak, hep-ph/0305060,
   K. Terasaki, hep-ph/0305213,
   H. Lipkin, hep-ph/0306204.
   S. Nussinov, hep-ph/0306187.
3. T. Browder, S. Pakvasa, A. Petrov, hep-ph/0307054.

Conclusion

Conclusions

You can find unexpected things if you are clever enough to look

We expect to include many more details of the $D^*_{sJ}(2317)^+$ and $D_{sJ}(2457)^+$ in a future, detailed publication

We have witnessed a revitalization of heavy-light meson spectroscopy theory and experiment:

- We will work with Belle, CLEO, and CDF II (and D0 II?) to understand these new states and to resolve any experimental differences
- We are also looking forward to more theoretical explanations and are prepared to test them