NEW CHARM RESULTS FROM FOCUS

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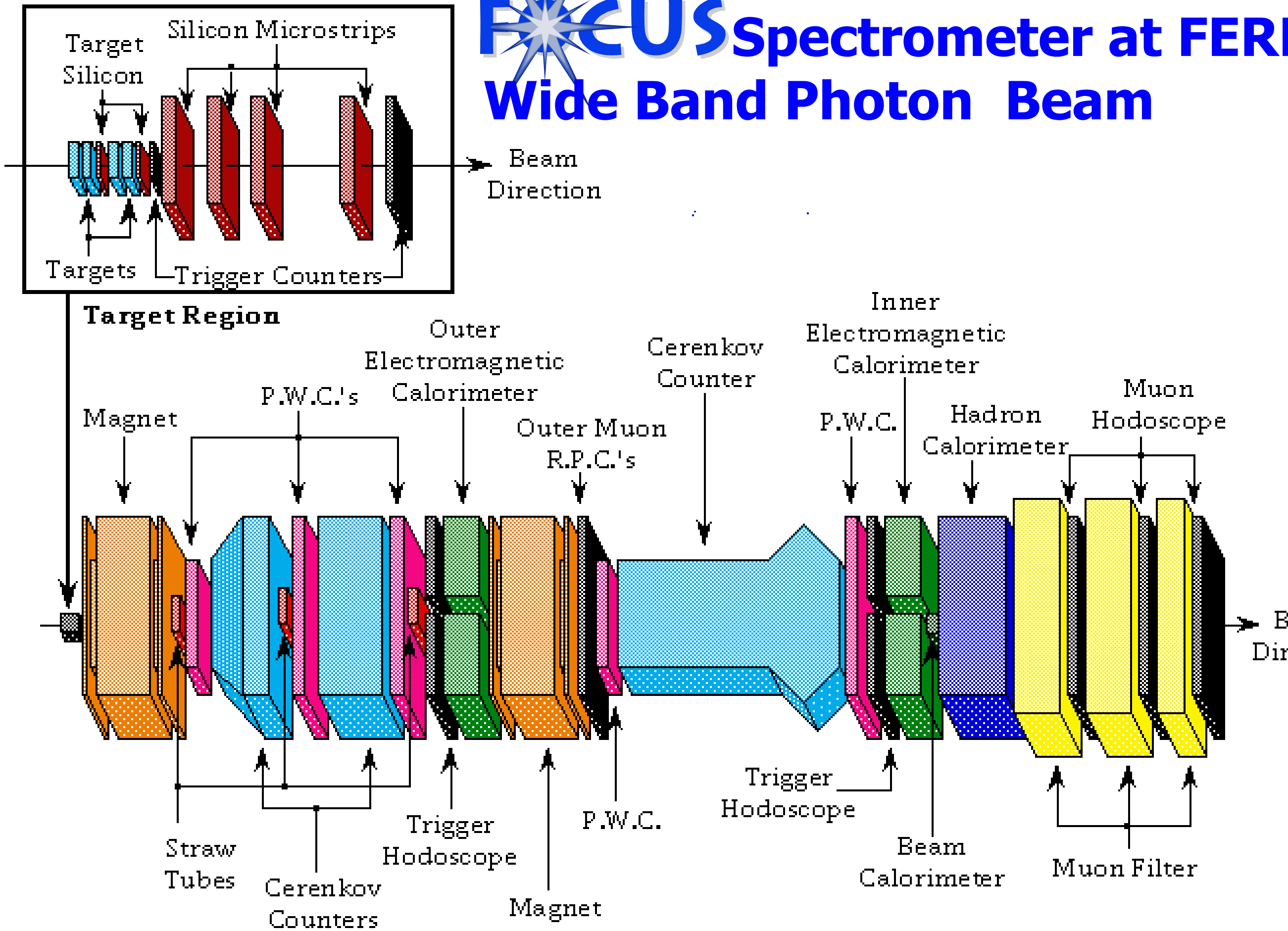
OVERVIEW

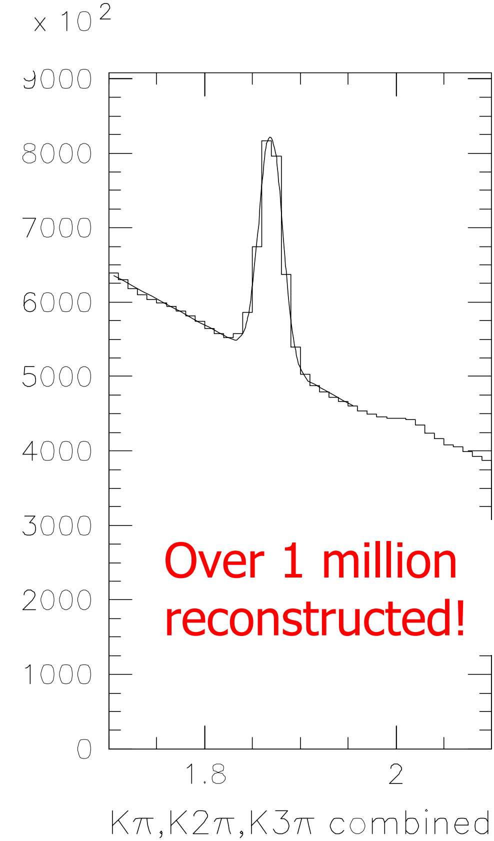
1. **Measurement of masses and widths of excited charm mesons, and evidence for broad states** **J.M.Link et al. (FOCUS Coll.) hep-ex/0312060 accepted by Phys.Lett.B**
2. **Measurement of $D_s^+ \to \phi\mu^+\nu$ formfactors** **J.M.Link et al. (FOCUS Coll.) hep-ex/0401001 accepted by Phys.Lett.B**
3. **K-matrix analysis of charm mesons Dalitz plots** **J.M.Link et al. (FOCUS Coll.) hep-ex/0312040 accepted by Phys.Lett.B**

Sorry, no time to report on these 2003-2004 results:

- Measurements of six body hadronic decays of the D0 charmed meson.
  By FOCUS Collaboration [hep-ex/0401019]
- Charm - anti-charm baryon production asymmetries in photon nucleon interactions.
  By FOCUS Collaboration Phys.Lett.B581:39-48,2004
- Study of hadronic five body decays of charmed mesons involving K0(S).
  By FOCUS Collaboration [hep-ex/0310051]
- Study of the decay mode D0 ---> K- K- K+ pi+.
  By FOCUS Collaboration
  Phys.Lett.B575:190-197,2003. [hep-ex/0308054]
- Search for rare and forbidden three body dimuon decays of the charmed mesons D+ and D(s)+.
  By FOCUS Collaboration
  Phys.Lett.B572:21-31,2003. [hep-ex/0306049]
- Measurements of Xi(c)+ branching ratios.
  By FOCUS Collaboration
  Phys.Lett.B571:139-147,2003. [hep-ex/0305038]
- Studies of correlations between D and anti-D mesons in high-energy photoproduction.
  By FOCUS Collaboration
  Phys.Lett.B566:51-60,2003. [hep-ex/0305018]
- Measurement of the Omega0(c) lifetime.
  By FOCUS Collaboration
  Phys.Lett.B561:41-48,2003. [hep-ex/0302033]

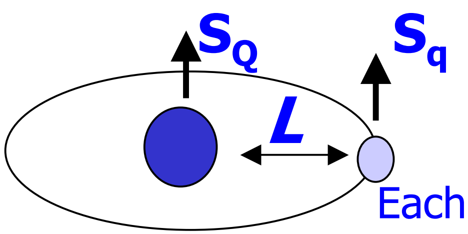
E831 FOCUS Spectrometer at FERMILAB
Wide Band Photon Beam





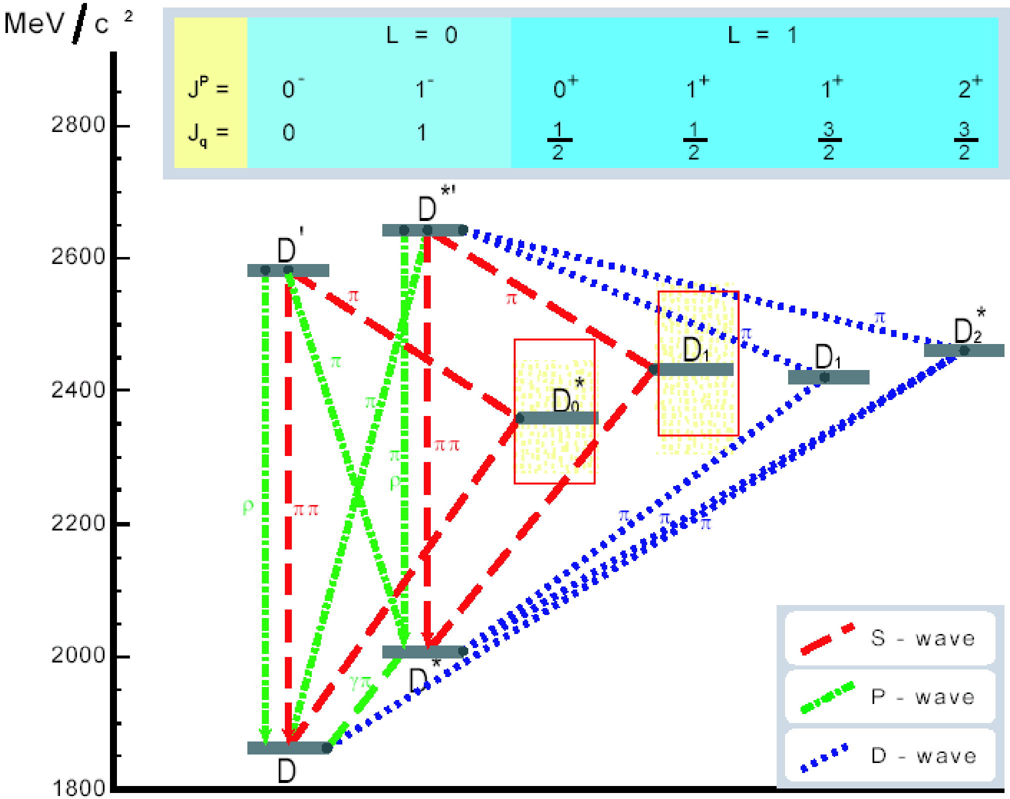
Successor to E687. Designed to study charm particles produced by ~200 GeV photons using a fixed target spectrometer with updated Vertexing, Cerenkov, EM Calorimeters, and Muon id capabilities. Member groups from USA, Italy, Brazil, Mexico, Korea. DATA COLLECTED IN 1996-1997

Charmed mesons spectroscopy chart (ante Spring 2003)



In the heavy-quark limit, the heavy-quark spin $\mathbf{S_Q}$ and the total angular momentum of the light-quark $\mathbf{j_q}=\mathbf{L}+\mathbf{S}$ are conserved

Each level is composed of a degenerate doublet of states with the same j_q and total angular momentum $J=j_q\pm ½$.
$j_q=½$ states are predicted to be broad (100-200MeV width).



THIS PICTURE QUESTIONED BY BABAR AND CLEO DISCOVER OF Dsj.

For a recent review see
SB Fabbri Benson Bigi Hep-ex/0309021

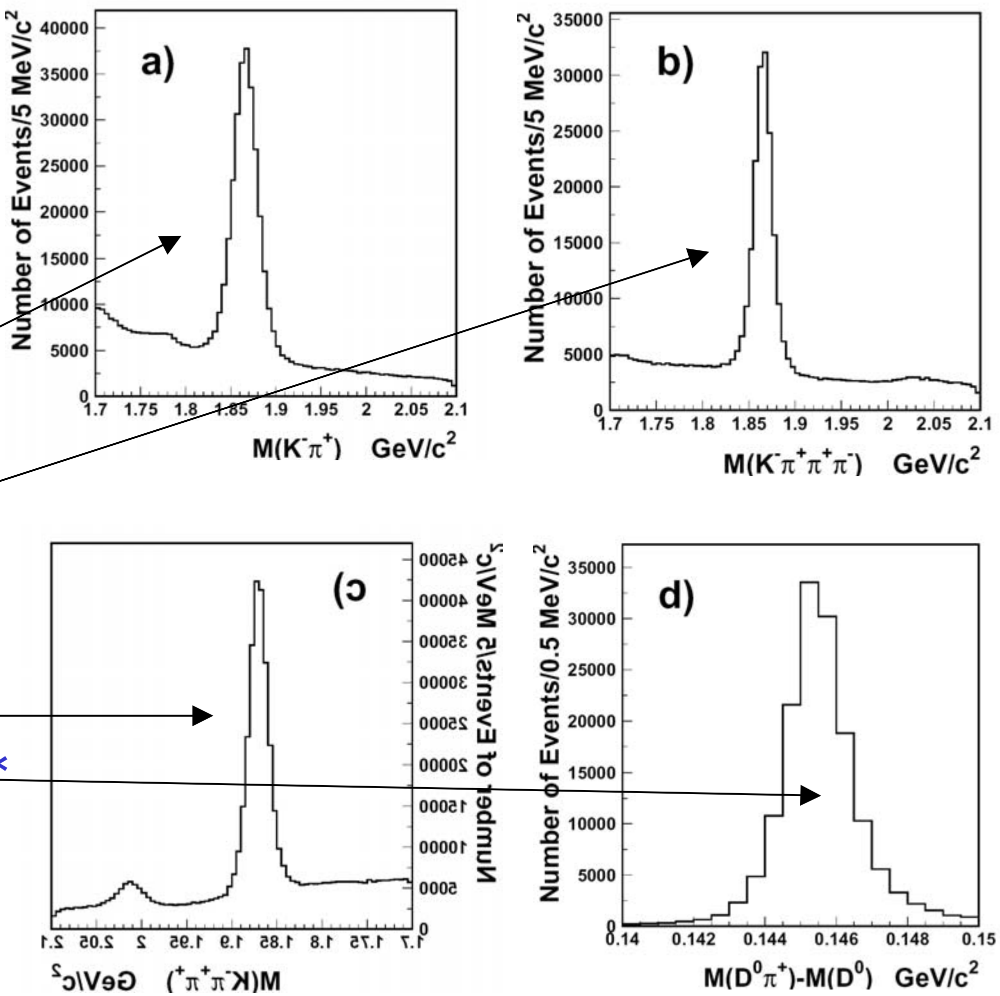
Measurement of masses and widths of excited charm mesons, and evidence for broad states

J.M.Link et al. (FOCUS Coll.) hep-ex/0312060 accepted by Phys.Lett.B

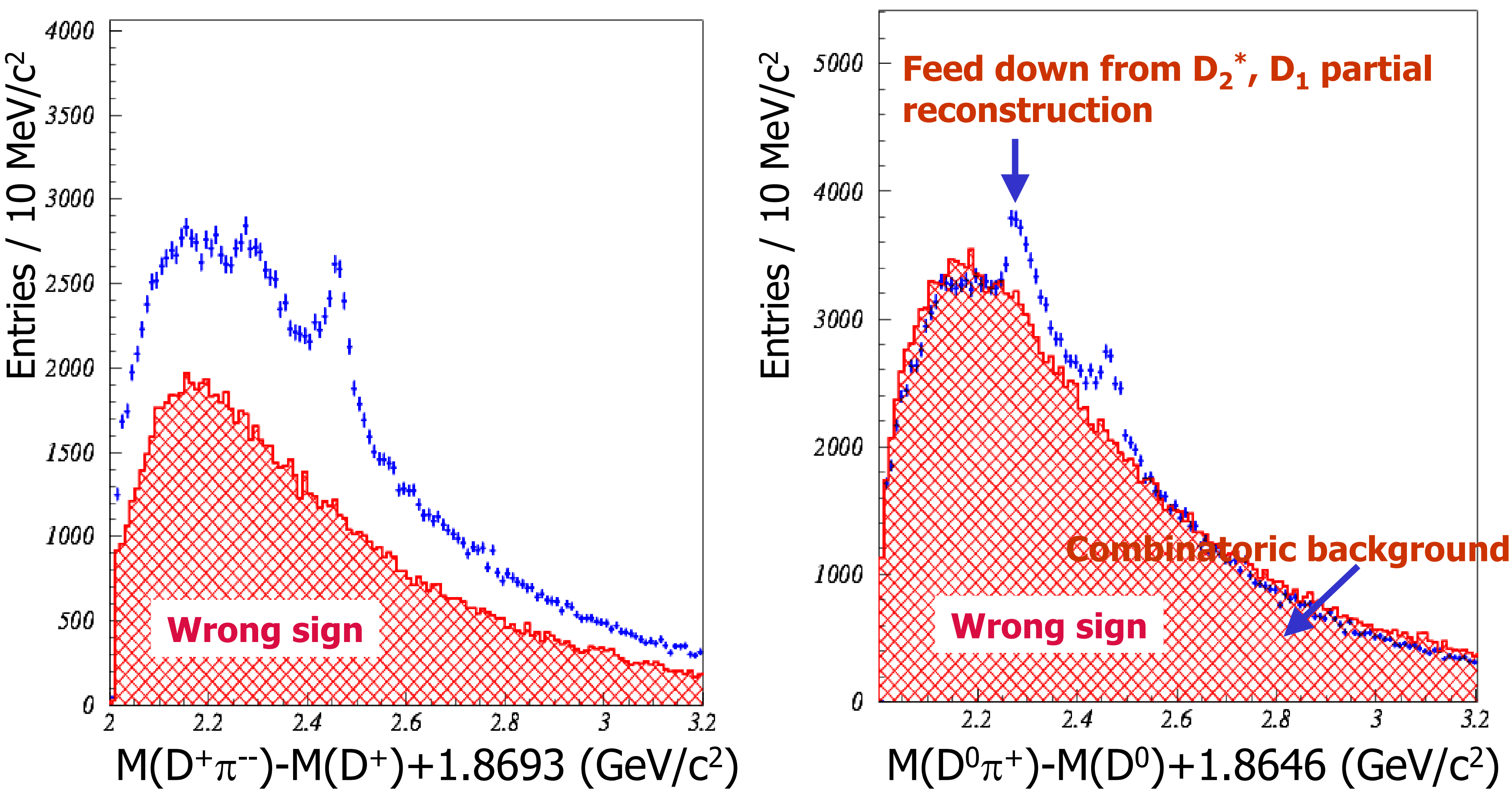
- Processes studied:
  1. $\gamma N \rightarrow D^0\pi^+ + X$, $D^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^+\pi^-$
  2. $\gamma N \rightarrow D^+\pi^- + X$, $D^+ \rightarrow K^-\pi^+\pi^+$
- Feeddowns:
  1. $D_1^+(j_q=3/2) \rightarrow D^{*0}\pi^+$, $D^{*0} \rightarrow D^0(\pi^0,\gamma)$
  2. $D_2^{*+} \rightarrow D^{*0}\pi^+$, $D^{*0} \rightarrow D^0(\pi^0,\gamma)$
  3. $D_1^+(j_q=1/2) \rightarrow D^{*0}\pi^+$, $D^{*0} \rightarrow D^0(\pi^0,\gamma)$

D and D* sample

- **Processes studied:**
  - $\gamma N \rightarrow D^0\pi^+ + X$,
    - $D^0 \rightarrow K\pi$
    - $D^0 \rightarrow K\pi\pi\pi$
  - $\gamma N \rightarrow D^+\pi^- + X$,
    - $D^+ \rightarrow K\pi\pi$
- **Remove $D\pi$ combinations from D^***



$D^0\pi^+$ and $D^+\pi^-$ mass distributions



Shorthand: ΔM_0

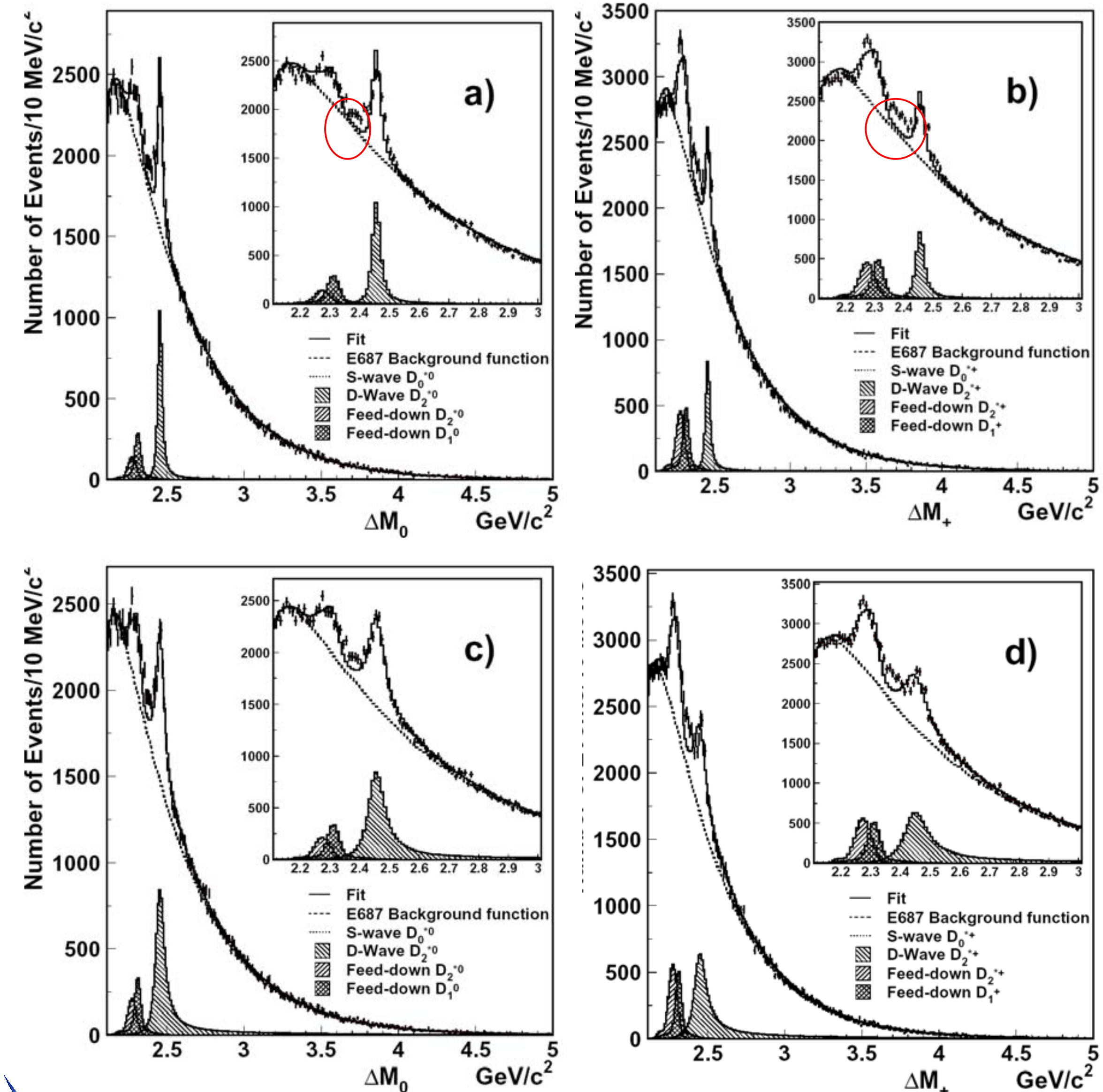
Shorthand: ΔM_+

Fitting $D^0\pi^+$ and $D^+\pi^-$ mass distributions

1. D-wave fixed to PDG D2* mass and width

2. D-wave free fit parameter

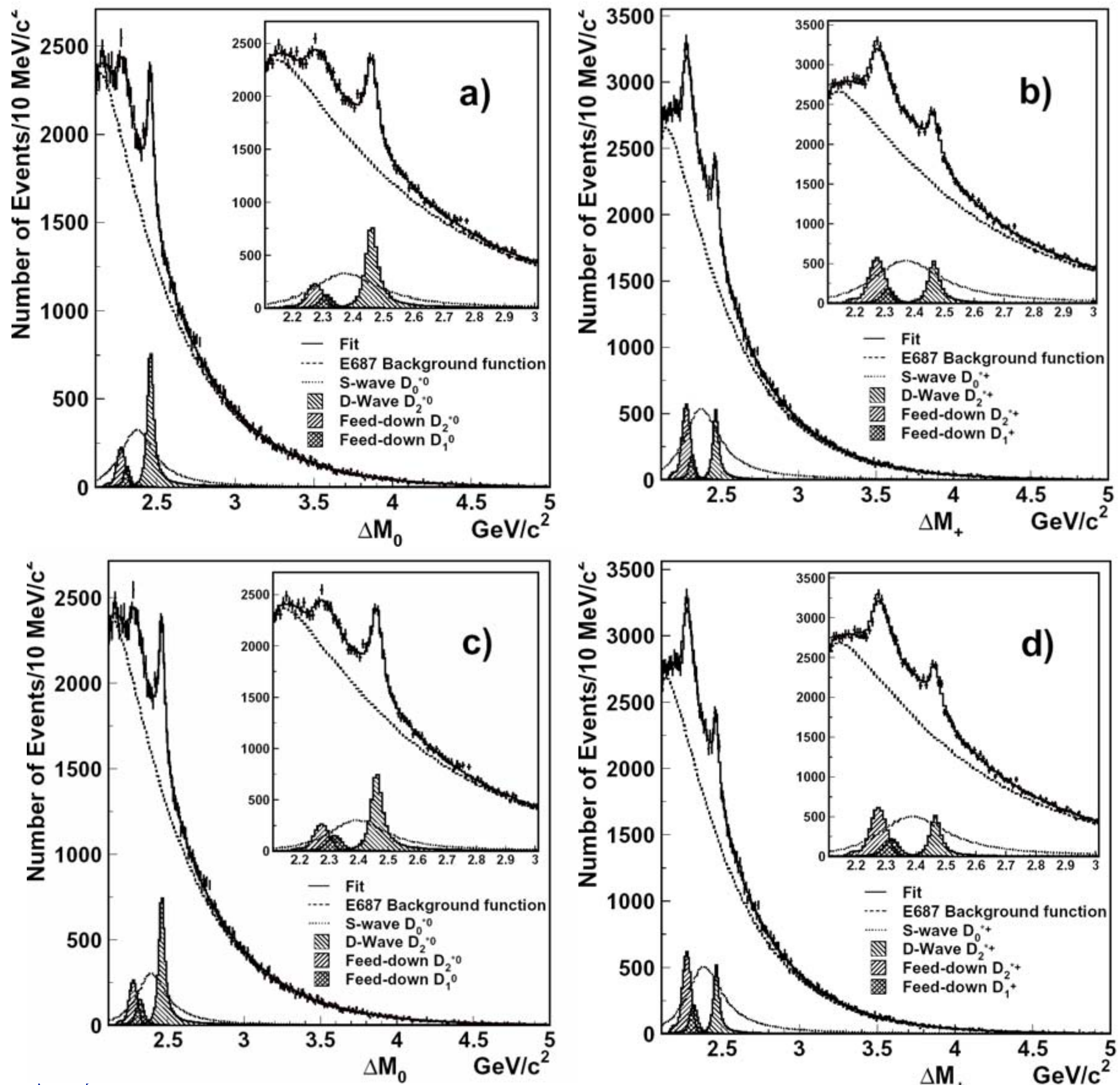
Bad fits, excess of events between D2* and the feeddowns



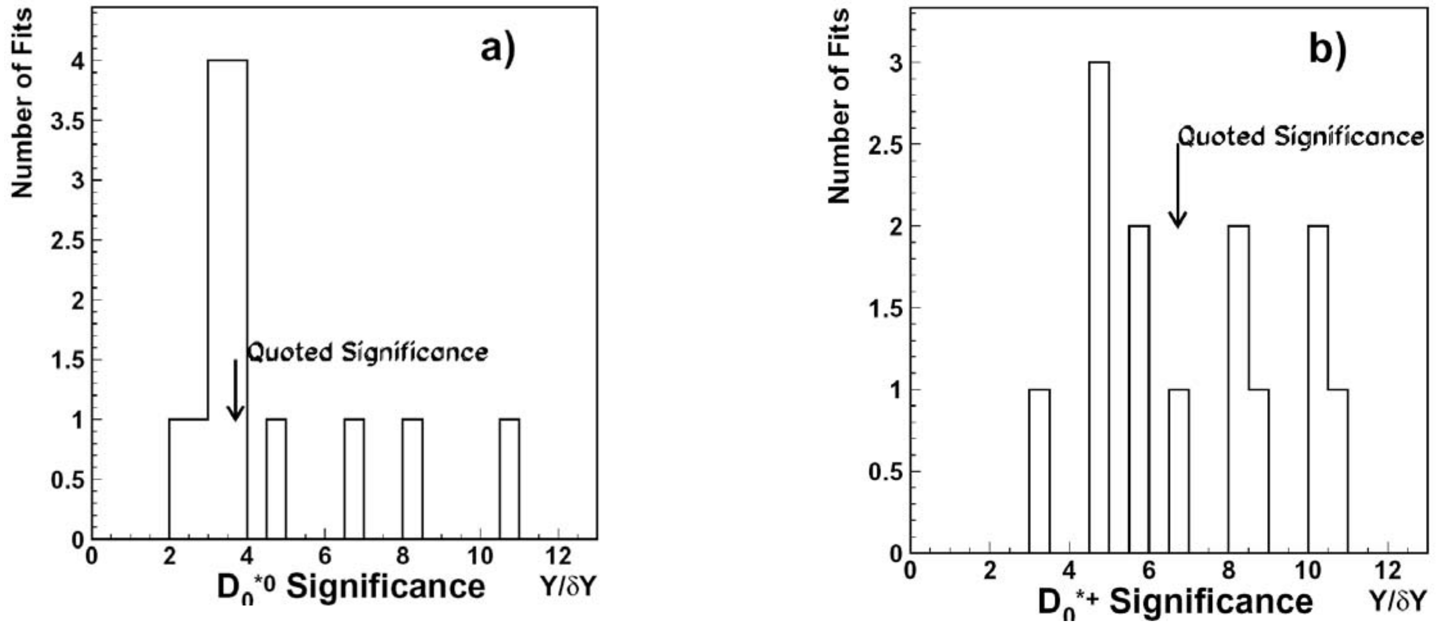
Fitting $D^0\pi^+$ and $D^+\pi^-$ mass distributions

3. Add S-wave
Fit cl=22% now

4. Recompute the feeddown lineshape using the D2* parameters measured in Step 3.
Fit cl=28% now



Significance of S-wave excess



The broad excess observed could be the broad state D_0^*, or the feeddown from a broad D_1 state

goto feedown list

RESULTS

	D_2^{*0}	D_2^{*+}	D_2^{*+}-D_2^{*0}	"$D^0_{1/2}$"	"$D^+_{1/2}$"
Yield	**5776±869±696**	**3474±670±656**		**9810 ± 2657**	**18754±2189**
Mass PDG03 BELLE03	**2464.5±1.1±1.9** 2458.9±2.0 2461.6± 3.9	**2467.6±1.5±0.76** 2459±4	**3.1±1.9±0.9** 0 ± 3.3	**2407±21±35** 2308± 36	**2403±14±35**
Width PDG03 BELLE03	**38.7±5.3±2.9** 23±5 45.6± 8.0	**34.1±6.5±4.2** 25^{+8}_{-7}		**240±55±59** 276±66	**283±24±34**

Errors on D_2^* masses and widths smaller than or equal to PDG03
Agreement with the recent BELLE result (hep-ex/0307021).

SYSTEMATICS STUDIES I

	D_2^{*0}		D_2^{*+}		$D_2^{*+}-D_2^{*0}$	"$D^0_{1/2}$"		"$D^+_{1/2}$"	
	Mass	Width	Mass	Width	Mass	Mass	Width	Mass	Width
$L/\sigma < 30$	0.160	1.231	0.134	0.960	0.294	0.926	15.73	0.050	2.871
Part/Antipart	1.67	0	0.53	0	0	0	0	0	31.4
PD < 70GeV/c	0.227	0.705	0.392	1.983	0.165	2.482	8.509	10.38	2.500
Different Fits	0.412	0.272	0.124	0.693	0.353	10.48	43.95	1.439	8.635
Fit Regions	0.376	0.536	0.174	0.991	0.315	1.571	12.80	1.209	6.657
Feed-down tests	0.633	2.373	0.262	3.289	0.443	32.71	31.91	32.45	6.137
Binning tests	0.442	0.576	0.113	0.770	0.550	6.584	6.652	6.380	0.894
Mass Scale	0.100	0	0.100	0	0.100	0.100	0	0.100	0
Total syst. error	1.94	2.89	0.76	4.2	0.91	35.1	59.0	34.7	34.0

SYSTEMATICS STUDIES II

- Background shapes:

1. $e^{(A+Bx)}(x-C)^{D}$ (E687)
2. $e^{(A+Bx)}$
3. $e^{(A+Bx+Cx^{2})}$
4. $e^{(A+Bx)}/(1+e^{(D-x)/E})$ (L3)

THIS RESULT AND THEORY PREDICTIONS

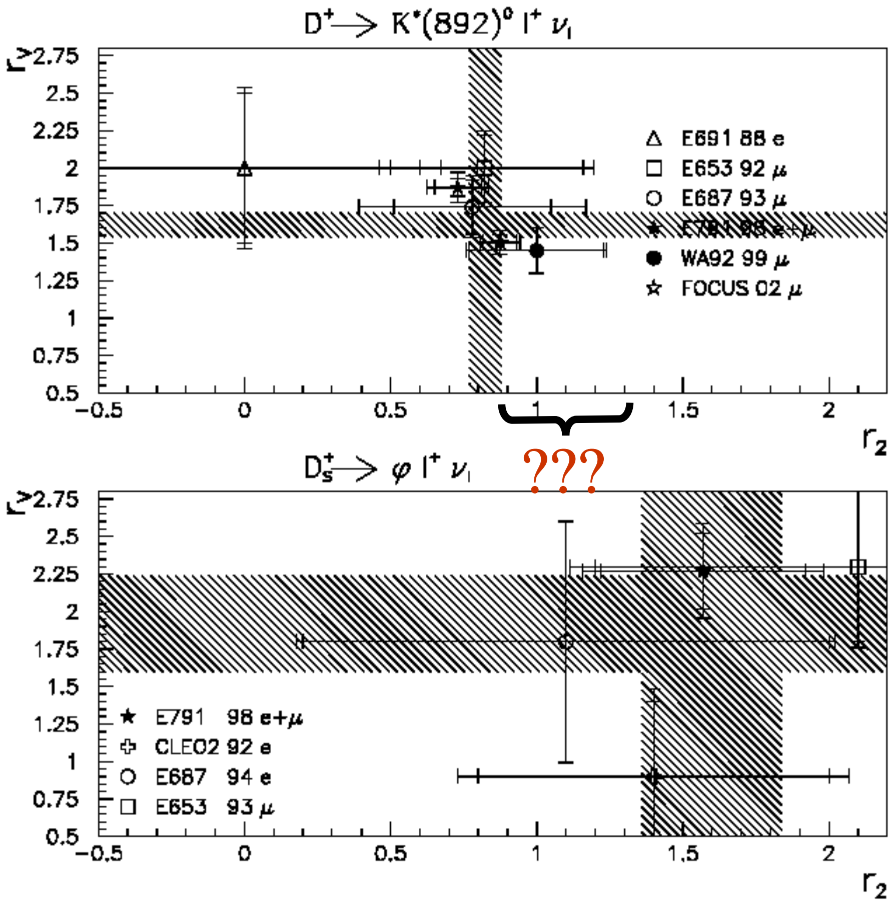
Predicted mass differences with respect to the D meson compared to this result

Reference	**D_2^*** $j_q = 3/2$ $^3P_2$	**D1** $j_q = 3/2$ $^3P_1$	**D1** $j_q = 1/2$ $^1P_1$	**D_0^*** $j_q = 1/2$ $^3P_0$
This paper	599 ± 2			538 ± 39
World Av.	593 ± 3	556 ± 4		
Kalashnikova et al. (2002)	579	562	603	564
Di Pierro et al. (2001)	592	549	622	509
Ebert et al. (1998)	584	539	626	563
Isgur (1998)	594	549	719	699
Godfrey and Kokoski (1991)	620	590	580	520
Godfrey and Isgur (1985)	620	610	560	520
Eichten et al. (1980)	645	637	498	489
Barbieri et al. (1976)	428	380	339	259
De Rujula et al. (1976)	494	464	384	374

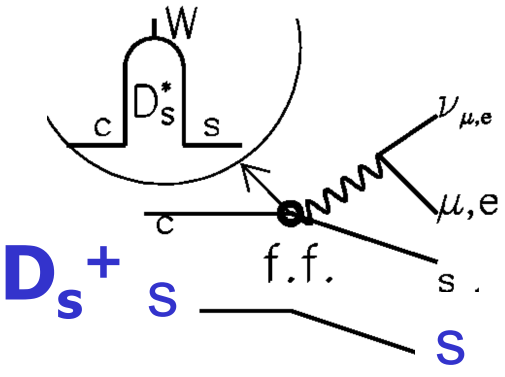
New measurements of the $D_s^+ \to \phi\mu^+\nu$ form factor ratios

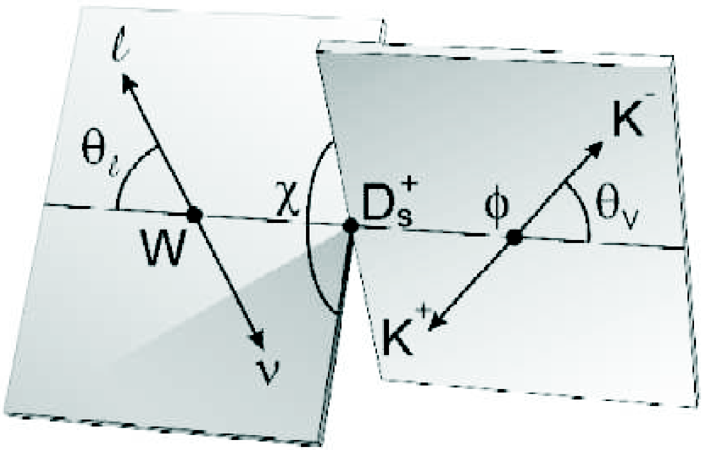
J.M.Link et al. (FOCUS Coll.) hep-ex/0401001 accepted by Phys.Lett.B

- A long-standing problem: the form factor ratios r_v and r_2 describing $D^+ \to K^{0*}\mu^+\nu$ should be close to $D_s^+ \to \phi\mu^+\nu$ since only difference is a spectator quark d replaced with a s
- Lattice gauge calculations: max diff= 10%
- Experiment:
  - r_v OK
  - r_2 inconsistent (3.3σ).



Form factor formalism for $D_s^+ \rightarrow \phi\mu^+\nu$





$$\frac{d^5\Gamma}{dm_{K\pi}dq^2 d\cos\theta_V d\cos\theta_\ell d\chi} \propto f(H_\pm, H_0, H_t)$$

$$H_{\pm,0,t}(q^2) = g\left[A_{1,2,3}(q^2), V(q^2))\right]$$

$$A_i(q^2) = \frac{A_i(0)}{1 - q^2/M^2{}_A}$$

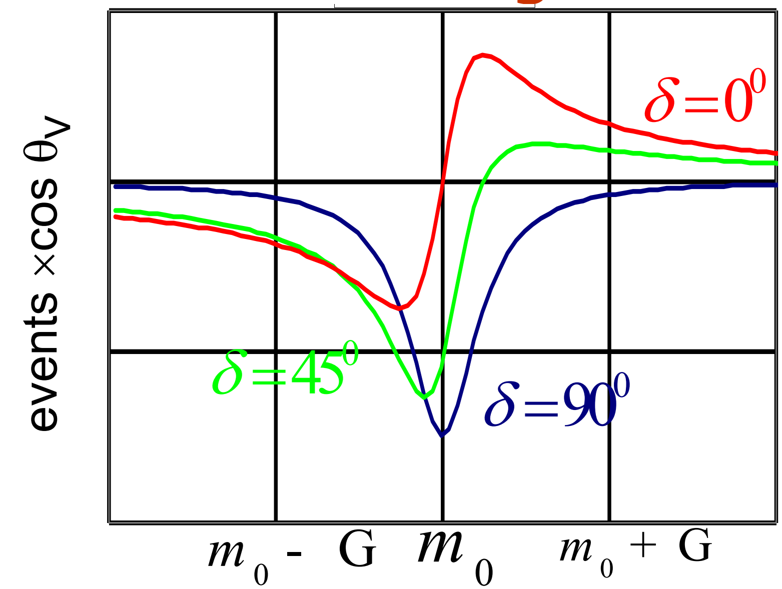
$$V(q^2) = \frac{V(0)}{1 - q^2/M^2{}_V}$$

$$r_v \equiv V(0)/A_1(0)$$

$$r_2 \equiv A_2(0)/A_1(0)$$

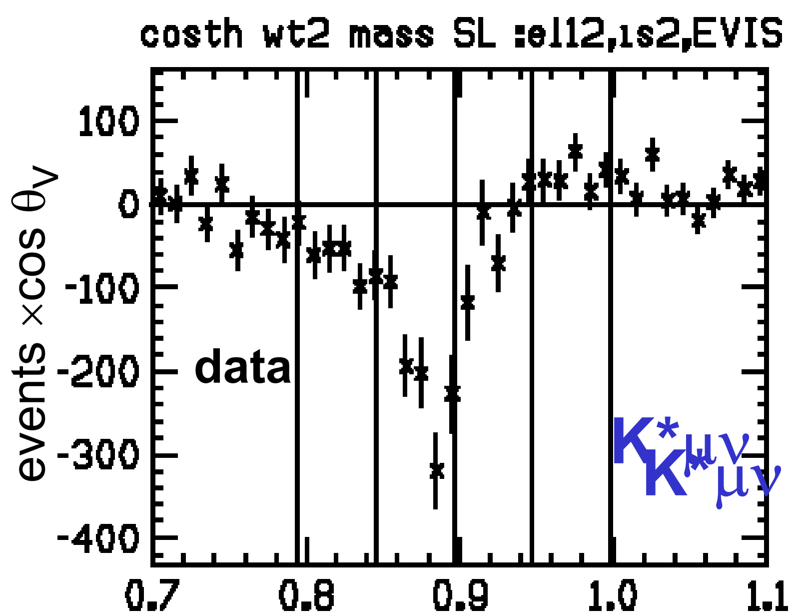
$$r_3 \equiv A_3(0)/A_1(0)$$

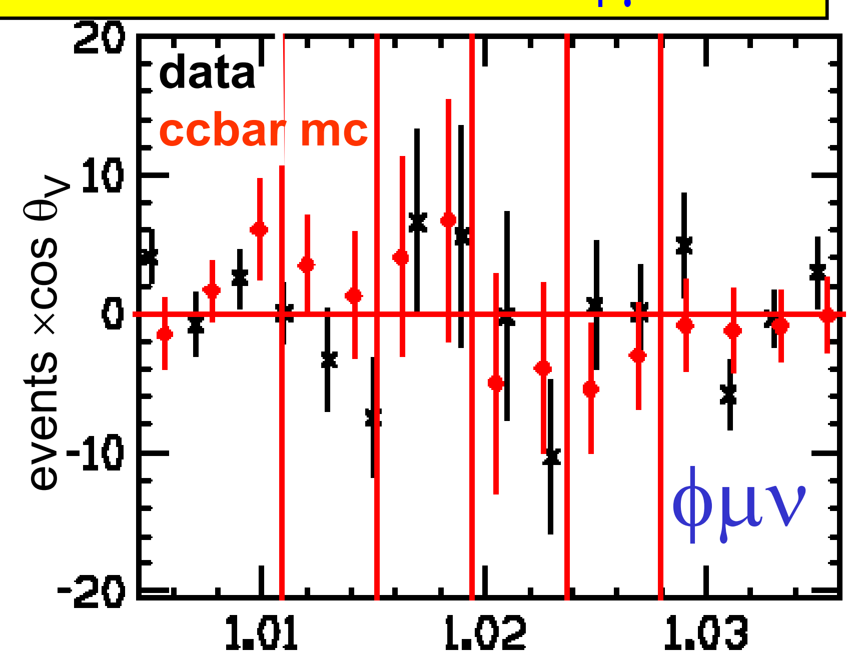
Searching for s-wave interference in $\phi\mu\nu$



FOCUS published observation for a very strong s-wave interfering with p-wave in the $K\pi$ system for $D \rightarrow K^*\mu\nu$

NO evidence for s-wave interference in $D_s \rightarrow \phi\mu\nu$

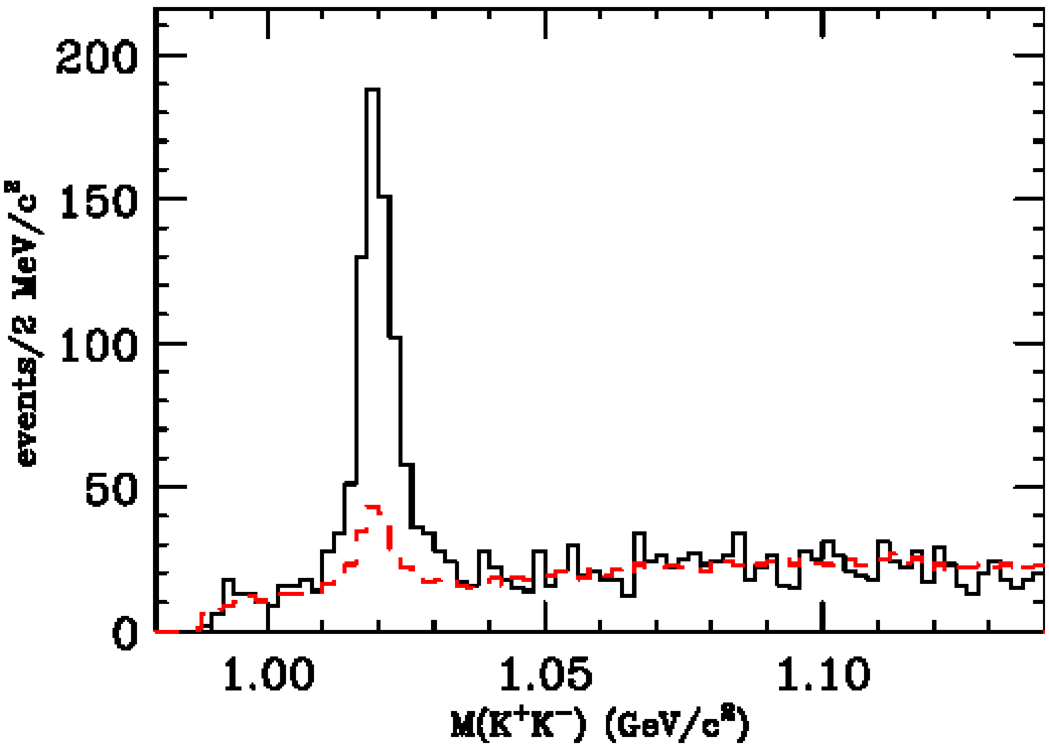




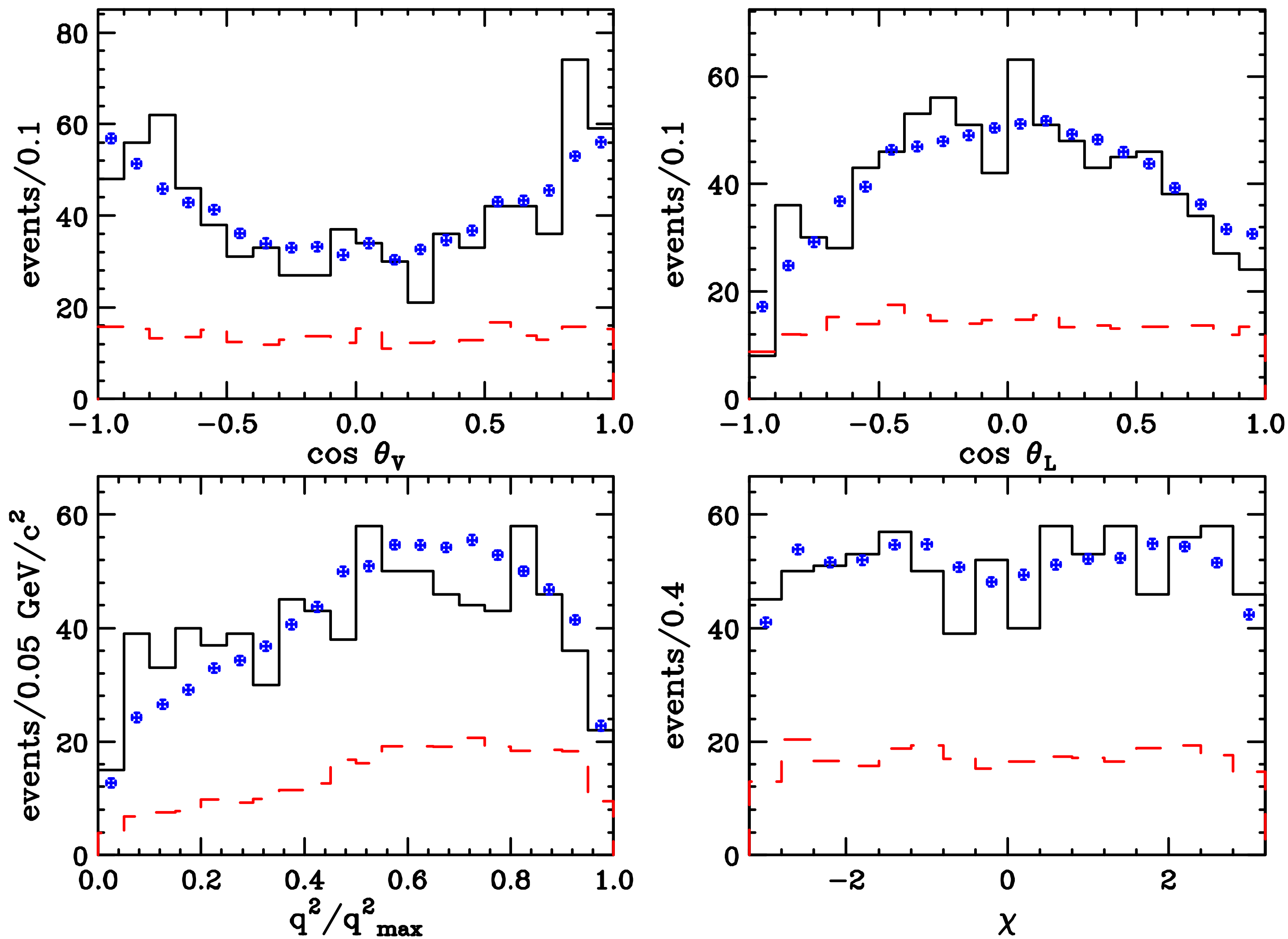
The m_{KK} distribution for $D_s^+ \rightarrow K^- K^+ \mu^+ \nu$ candidates

Data (solid) and cc background MonteCarlo (dashed).

Main background from $D^+ \rightarrow K^- K^+ \pi^+$ where a pion is misidentified as a muon



Comparing data and model



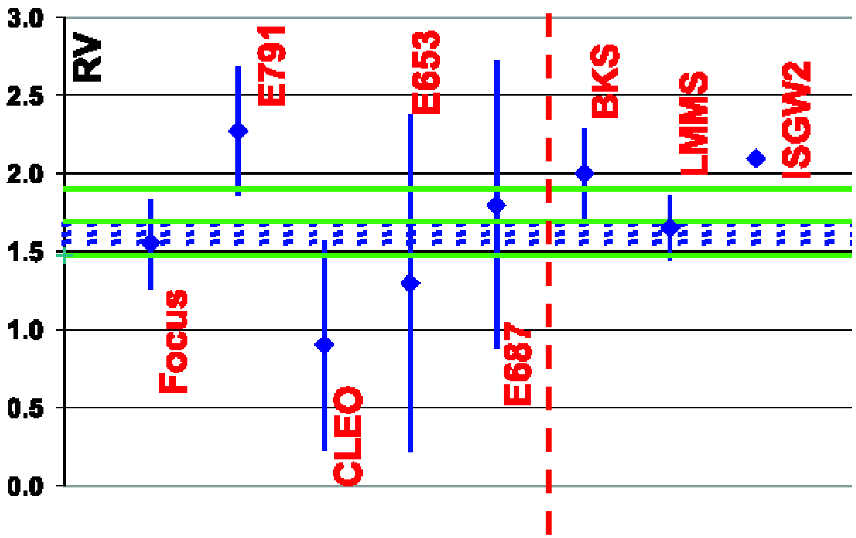
Histogram:data- dots:model-dashed histogram: cc Montecarlo

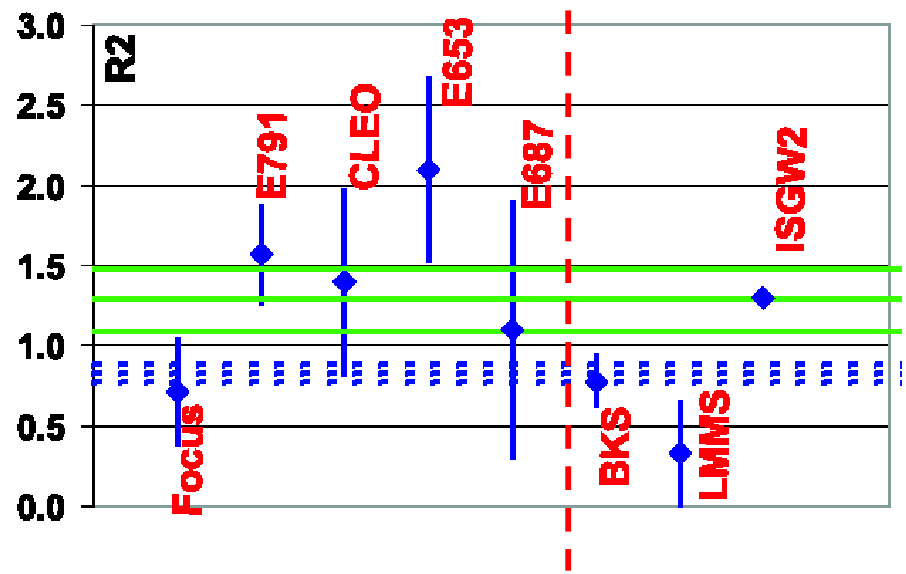
RESULTS

$r_v = 1.549 \pm 0.250 \pm 0.145$

$r_2 = 0.713 \pm 0.202 \pm 0.266$

1. Most precise measurement to date
2. very consistent with $D^+ \rightarrow K^{0*} \mu^+ \nu$
3. very consistent with expectation that the form factors for the two processes should be very similar

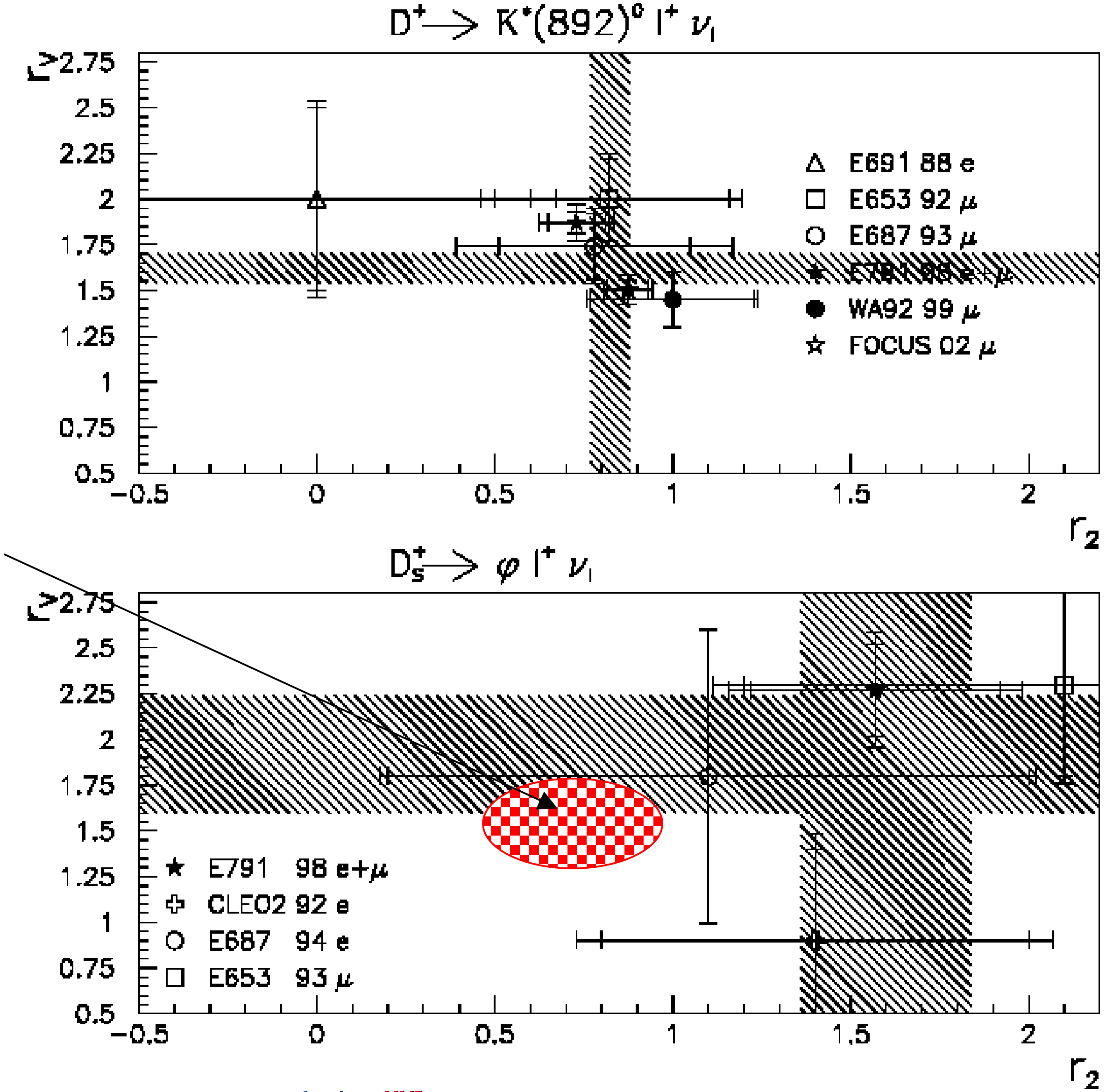




Solid green: world av. $D_s^+ \rightarrow \phi \mu^+ \nu$ Dashed blue: world av. $D^+ \rightarrow K^{0*} \mu^+ \nu$

Form Factors $D^+ \rightarrow K^{0*}\mu^+\nu$ and $D_s^+ \rightarrow \phi\mu^+\nu$

THIS RESULT



DP analysis of D_s^+ and D^+ decay to $\pi+\pi-\pi+$ using the K-matrix formalism

J.M.Link et al. (FOCUS Coll.) hep-ex/0312040 accepted by Phys.Lett.B

see also : S.Malvezzi Workshop on B physics, Rome Italy January 15, 2004.

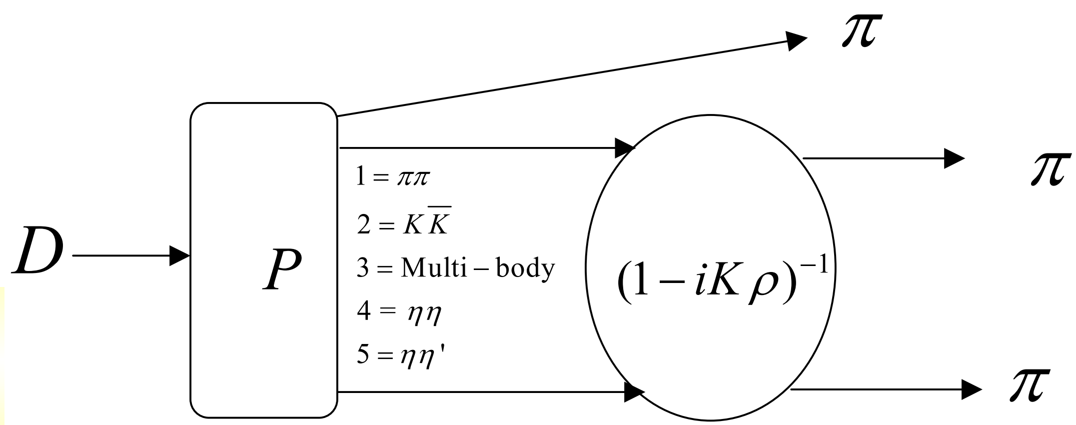
- Dalitz plots have been proved to be a powerful tool in three-body decays, investigating
  - Resonant substructure
  - Interference patterns
  - Final state interactions
  - Relationships to light-meson spectroscopy
- Traditionally, isobar formalism used
  - Decay amplitude is a sum of Breit-Wigner propagators
  - Breit-Wigner amplitudes for a resonance which is broad and overlaps with other resonances can be connected to the pole positions only through models of analytic continuation

K-matrix picture

- The amplitude is written as a sum

$$A(D) = a_0 e^{i\delta_0} + F_1 + \sum_i a_i e^{i\delta_i} BW$$

- The amplitude F takes care of S-wave component by integrating over the scattering amplitudes of the five virtual states ππ, KK, ηη, ηη′, 4π



$$F = (I - iK \cdot \rho)^{-1} P$$

describes coupling of resonances to D

known from scattering data

To describe the scattering a global fit to all available data was performed

"K-matrix analysis of the 00++-wave in the mass region below 1900 MeV"

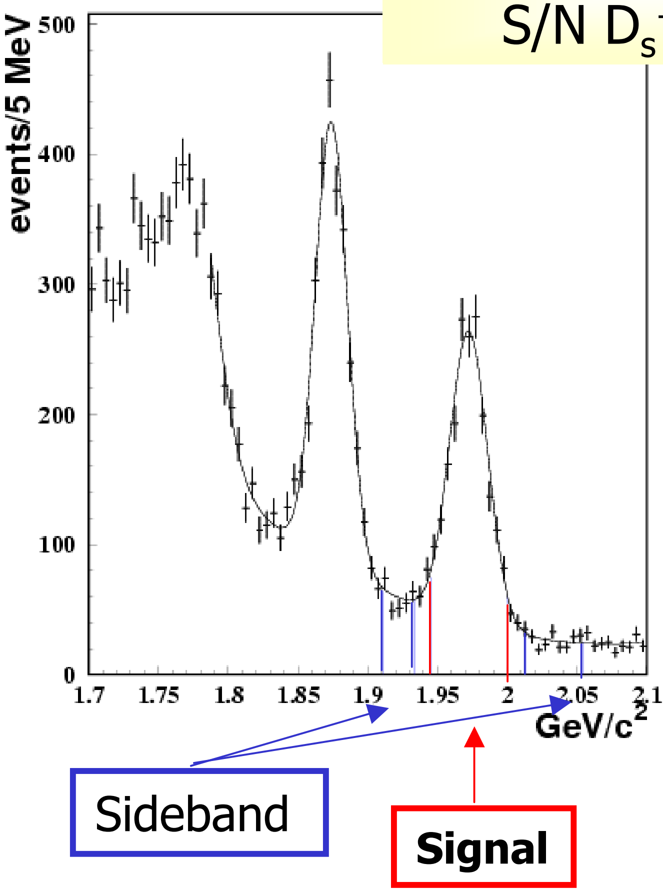
V.V Anisovich and A.V.Sarantsev Eur.Phys.J.A16 (2003) 229

* **GAMS**	$\pi p \to \pi^0\pi^0 n, \eta\eta n, \eta\eta' n$, $\|t\| < 0.2$ (GeV/c²)	
* **GAMS**	$\pi p \to \pi^0\pi^0 n$, $0.30 < \|t\| < 1.0$ (GeV/c²)	
* **BNL**	$\pi p^- \to K\bar{K}n$	
* **CERN-Munich**	$\pi^+\pi^- \to \pi^+\pi^-$	
* **Crystal Barrel**	$p\bar{p} \to \pi^0\pi^0\pi^0, \pi^0\pi^0\eta, \pi^0\eta\eta$	At rest, from liquid H_2
* **Crystal Barrel**	$p\bar{p} \to \pi^0\pi^0\pi^0, \pi^0\pi^0\eta$	At rest, from gaseous H_2
* **Crystal Barrel**	$p\bar{p} \to \pi^+\pi^-\pi^0, K^+K^-\pi^0, K_sK_s\pi^0, K^+K_s\pi^-$	At rest, from liquid H_2
* **Crystal Barrel**	$n\bar{p} \to \pi^0\pi^0\pi^-, \pi^-\pi^-\pi^+, K_sK^-\pi^0, K_sK_s\pi^-$	At rest, from liquid D_2
* **E852**	$\pi^- p \to \pi^0\pi^0 n$, $0 < \|t\| < 1.5$ (GeV/c²)	

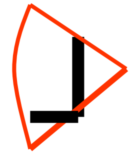
FOCUS $D_s^+ \to \pi^+\pi^+\pi^-$ analysis

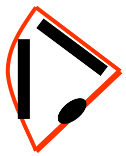
Yield D_s^+ = 1475 ±50

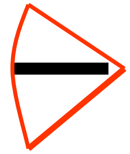
S/N D_s^+ = 3.41

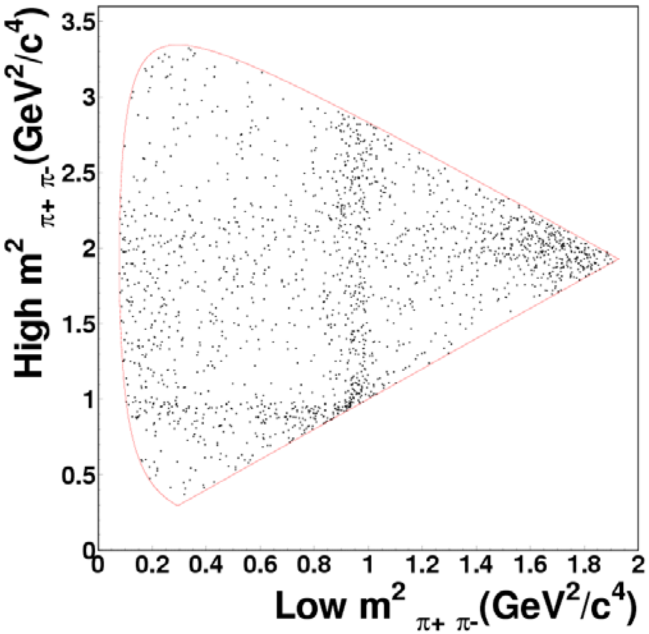


Observe:

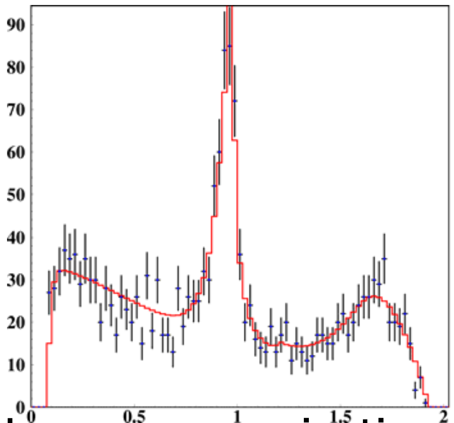
•$f_0(980)$ 

•$f_2(1270)$ 

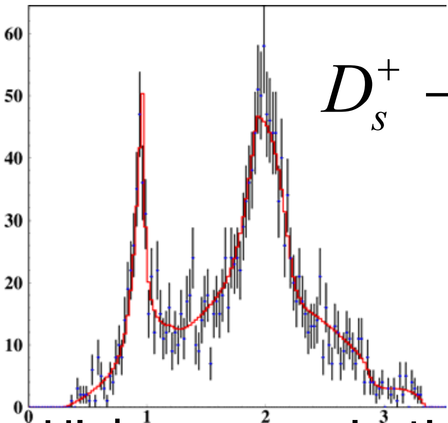
•$f_0(1500)$ 



First fits to charm Dalitz plots in the *K*-matrix approach

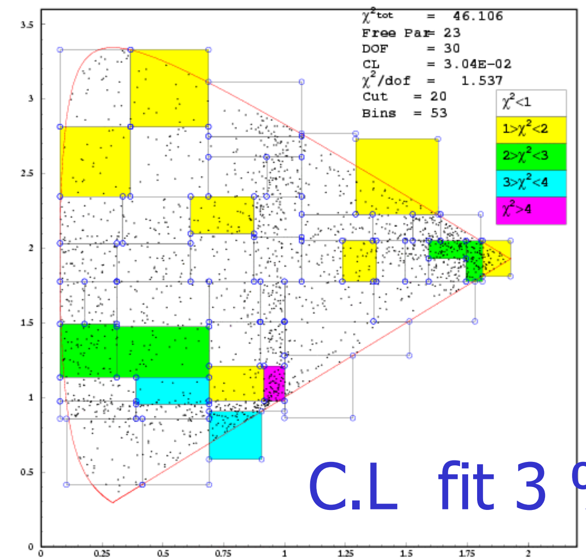


Low mass projection



High mass projection

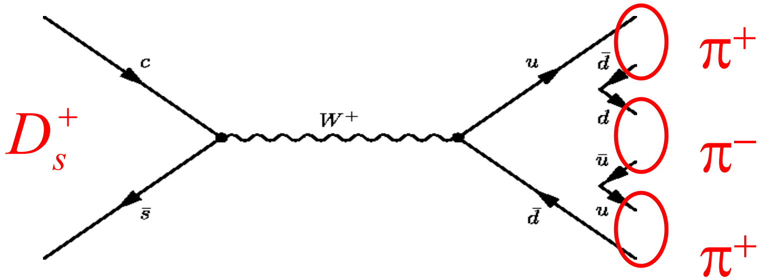
$$D_s^+ \to \pi^+\pi^-\pi^+$$



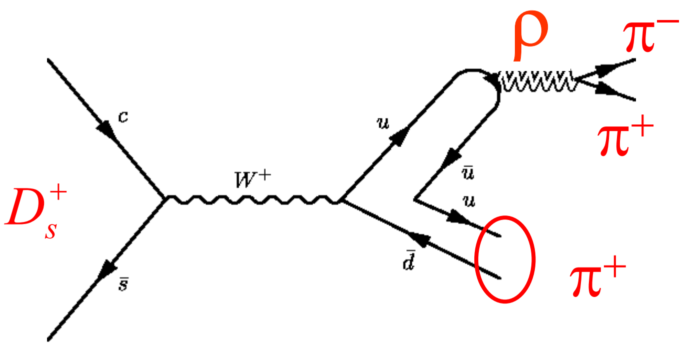
C.L fit 3 %

decay channel	fit fractions (%)	phase (deg)
$(S-wave)\pi^+$	$87.04 \pm 5.60 \pm 4.17 \pm 1.34$	$0(fixed)$
$f_2(1270)\pi^+$	$9.74 \pm 4.49 \pm 2.63 \pm 1.32$	$168.0 \pm 18.7 \pm 2.5 \pm 21.7$
$\rho^0(1450)\pi^+$	$6.56 \pm 3.43 \pm 3.31 \pm 2.90$	$234.9 \pm 19.5 \pm 13.3 \pm 24.9$

•**No significant direct three-body-decay component**



•**No significant $\rho(770)\ \pi$ contribution**



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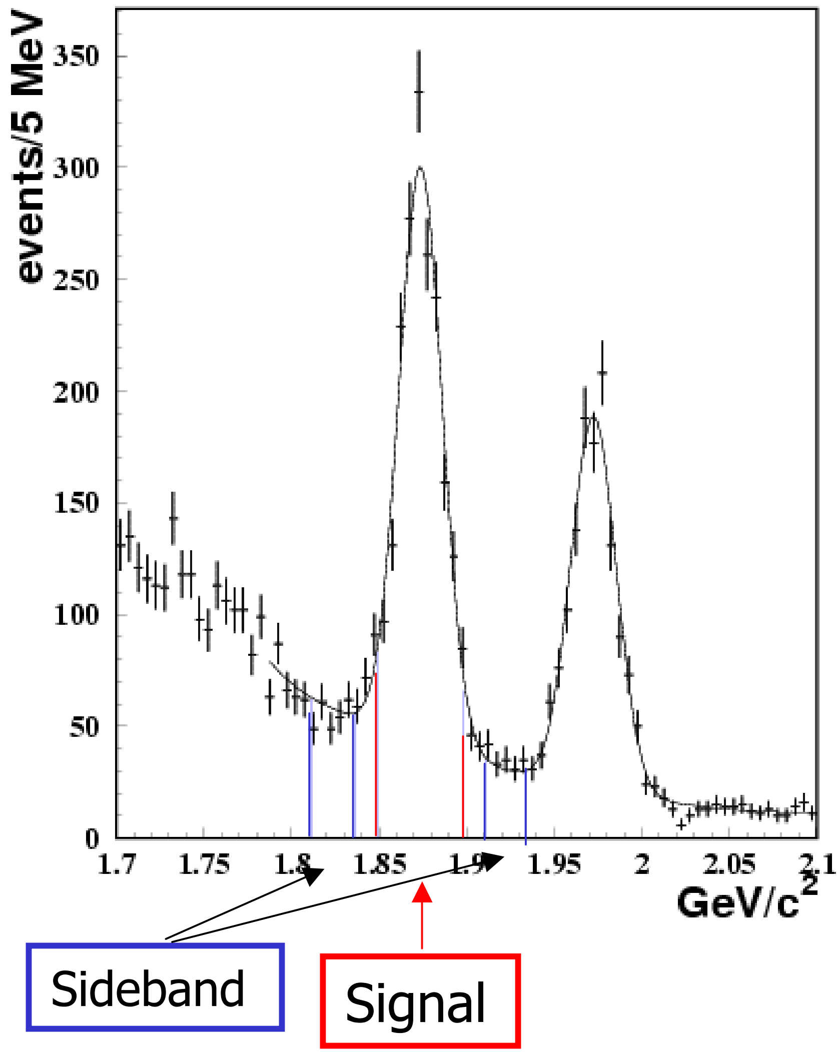
Marginal role of annihilation in charm hadronic decays

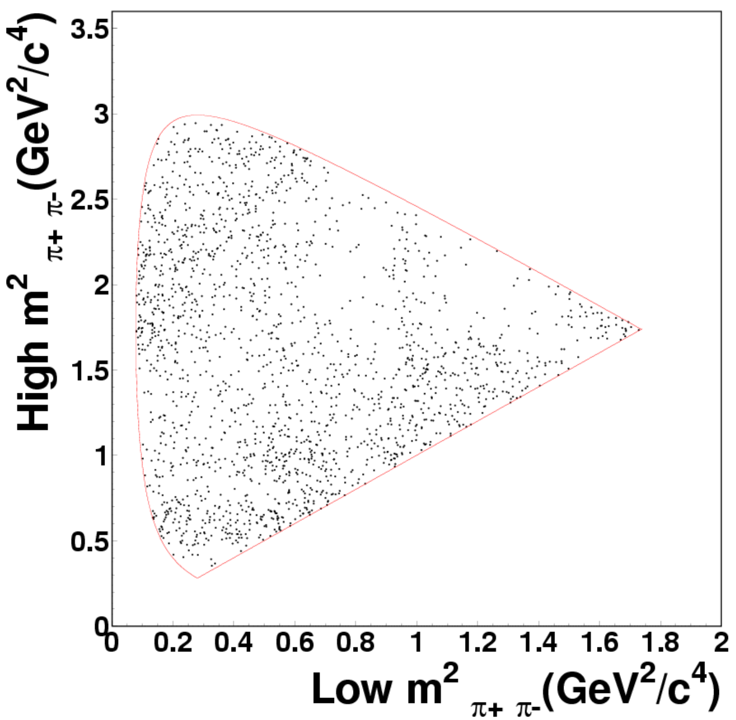
But need more data!

$D^+ \to \pi^+ \pi^+ \pi^-$ analysis

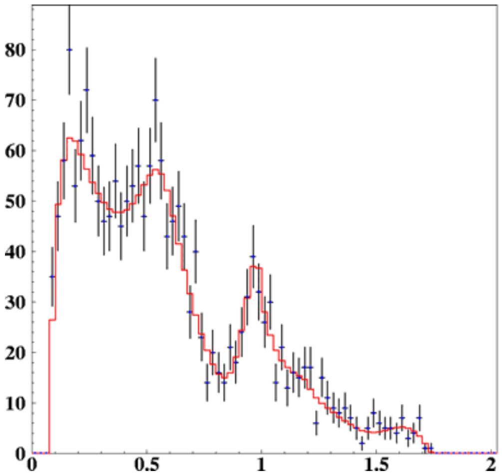


Yield D^+ = 1527 ±51

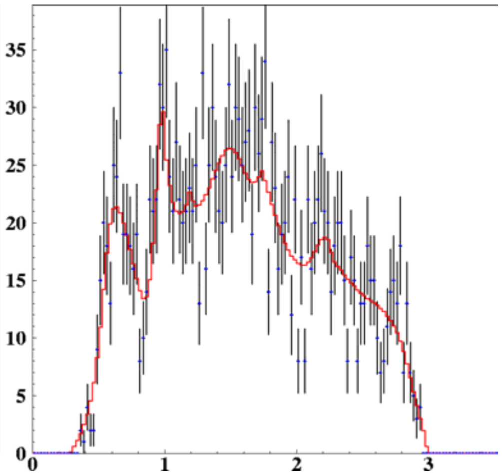
S/N D^+ = 3.64



$D^+ \to \pi^+\pi^-\pi^+$ *K*-matrix fit results

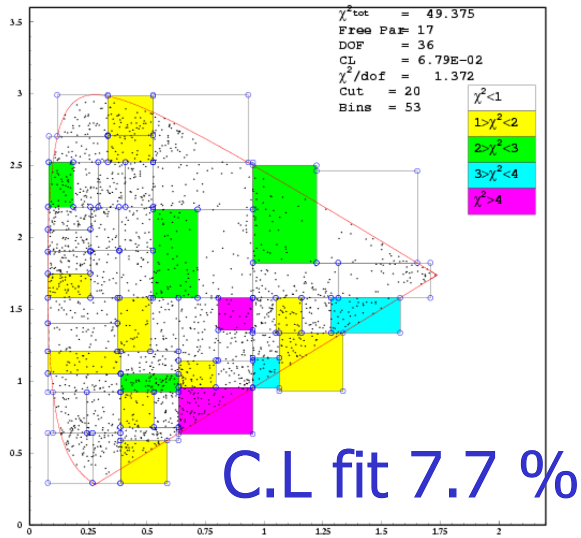


Low mass projection



High mass projection

m^2_{high}



m^2_{low}

decay channel	fit fractions (%)	phase (deg)
$(S-wave)\pi^+$	$56.00 \pm 3.24 \pm 2.08 \pm 0.50$	$0(fixed)$
$f_2(1270)\pi^+$	$11.74 \pm 1.90 \pm 0.23 \pm 0.18$	$-47.5 \pm 18.7 \pm 11.7 \pm 5.3$
$\rho^0(770)\pi^+$	$30.82 \pm 3.14 \pm 2.29 \pm 0.17$	$-139.4 \pm 16.5 \pm 9.9 \pm 5.0$

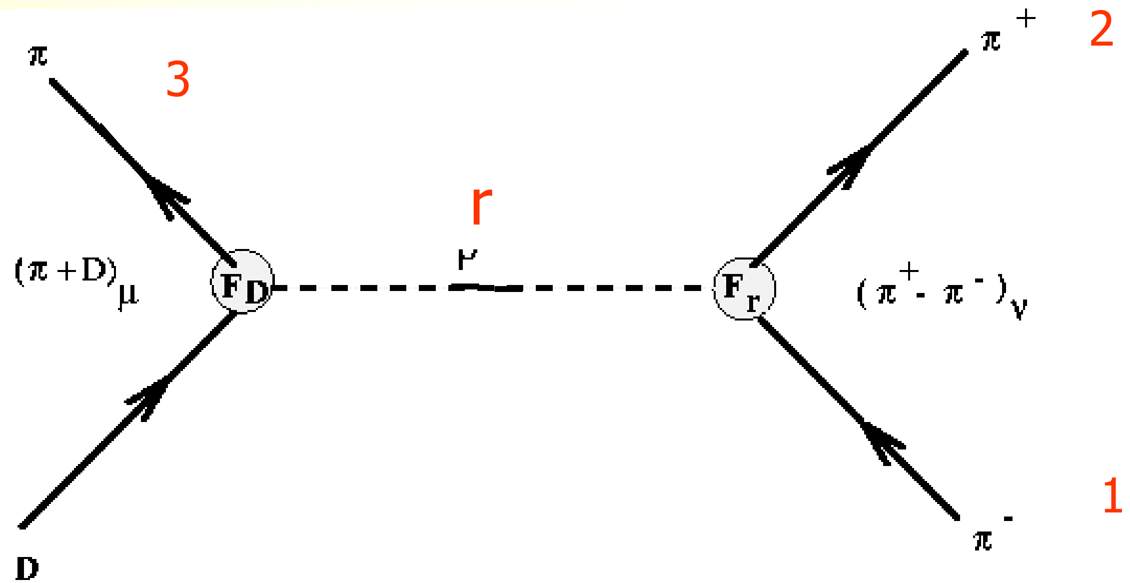
No new resonance required not present in the scattering.

SUMMARY AND CONCLUSIONS

- New precise measurements of mass and widths of $D2^{*+}$ and $D2^{*0}$, with errors better than or equal to PDG03
- Evidence for broad states in $D^+\pi^-$ and $D^0\pi^+$ final states
- Puzzle of $D_s^+ \to \phi\mu^+\nu$ form factors discrepancy solved with new precise measurement
- First DP analysis of $D_s^+, D^+ \to \pi^+\pi^+\pi^-$ charm decays using K-matrix formalism
  - Use information from light-quark scattering experiments (five virtual channels considered $\pi\pi$, KK, $\eta\eta$, $\eta\eta'$, 4π). CONCLUSIONS:
    1. Non-resonant components are described by known two-body S-wave dynamics
    2. Negligible role of annihilation diagram in $Ds \to \pi^+\pi^+\pi^-$
  - Possible applications in $B \to \rho\pi$ (not discussed here)
  - DP analysis of $D_s^+, D^+ \to \pi^+\pi^+\pi^-$ charm decays using traditional isobar model is also in progress to compare to K-matrix model.

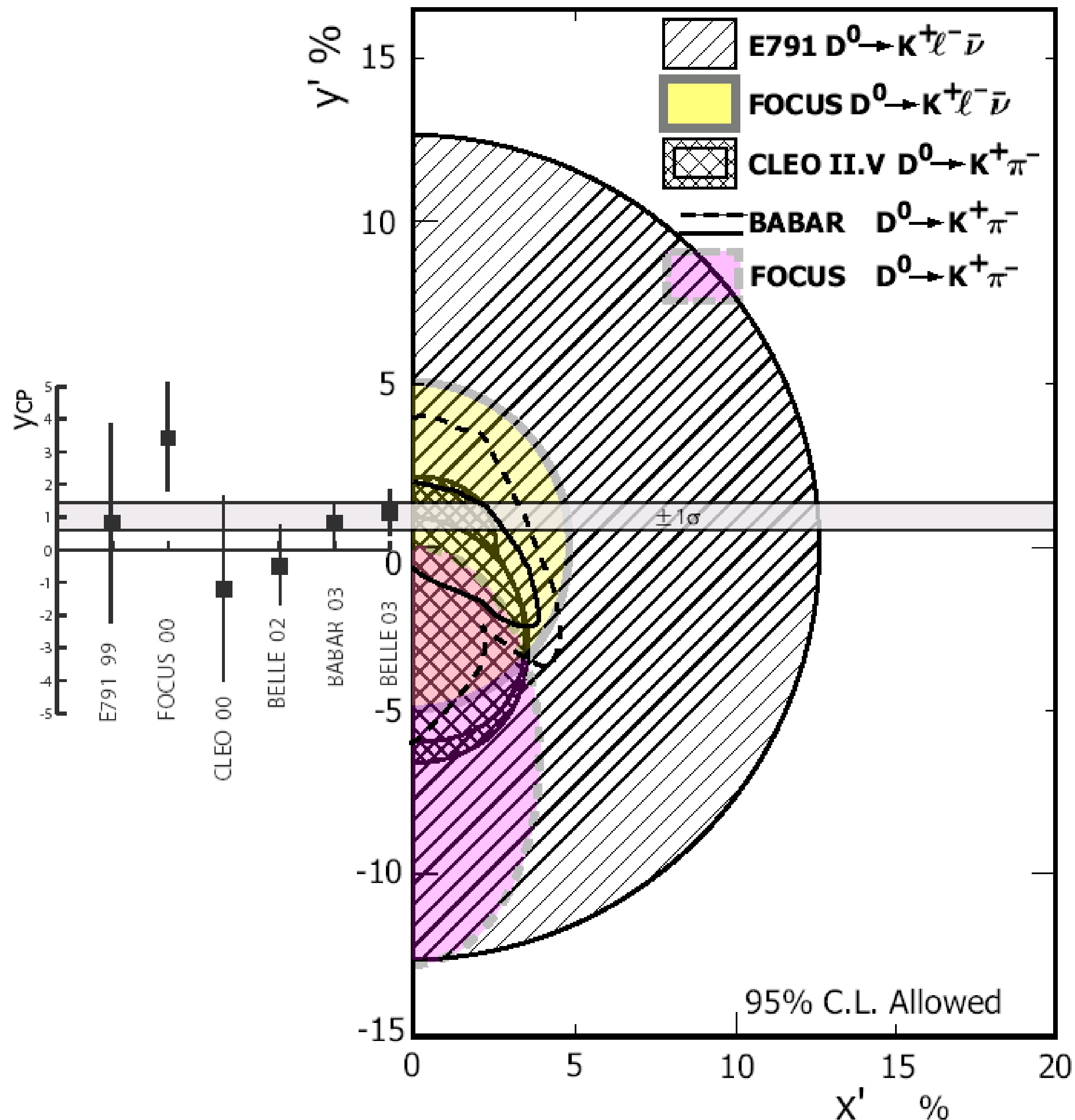
How can we formulate the problem?

$D \rightarrow r\ 3$
$\quad \hookrightarrow 1\ 2$



The problem is to write the propagator for the resonance r

For a well-defined wave with specific isospin and spin *(IJ)* characterized by narrow and well-isolated resonances, we know how.



E791 $D^0 \to K^+\ell^-\bar{\nu}$
FOCUS $D^0 \to K^+\ell^-\bar{\nu}$
CLEO II.V $D^0 \to K^+\pi^-$
BABAR $D^0 \to K^+\pi^-$
FOCUS $D^0 \to K^+\pi^-$
y' %
x' %
95% C.L. Allowed
±1σ
y_{CP}
E791 99
FOCUS 00
CLEO 00
BELLE 02
BABAR 03
BELLE 03