HOT TOPICS IN CHARM PHYSICS

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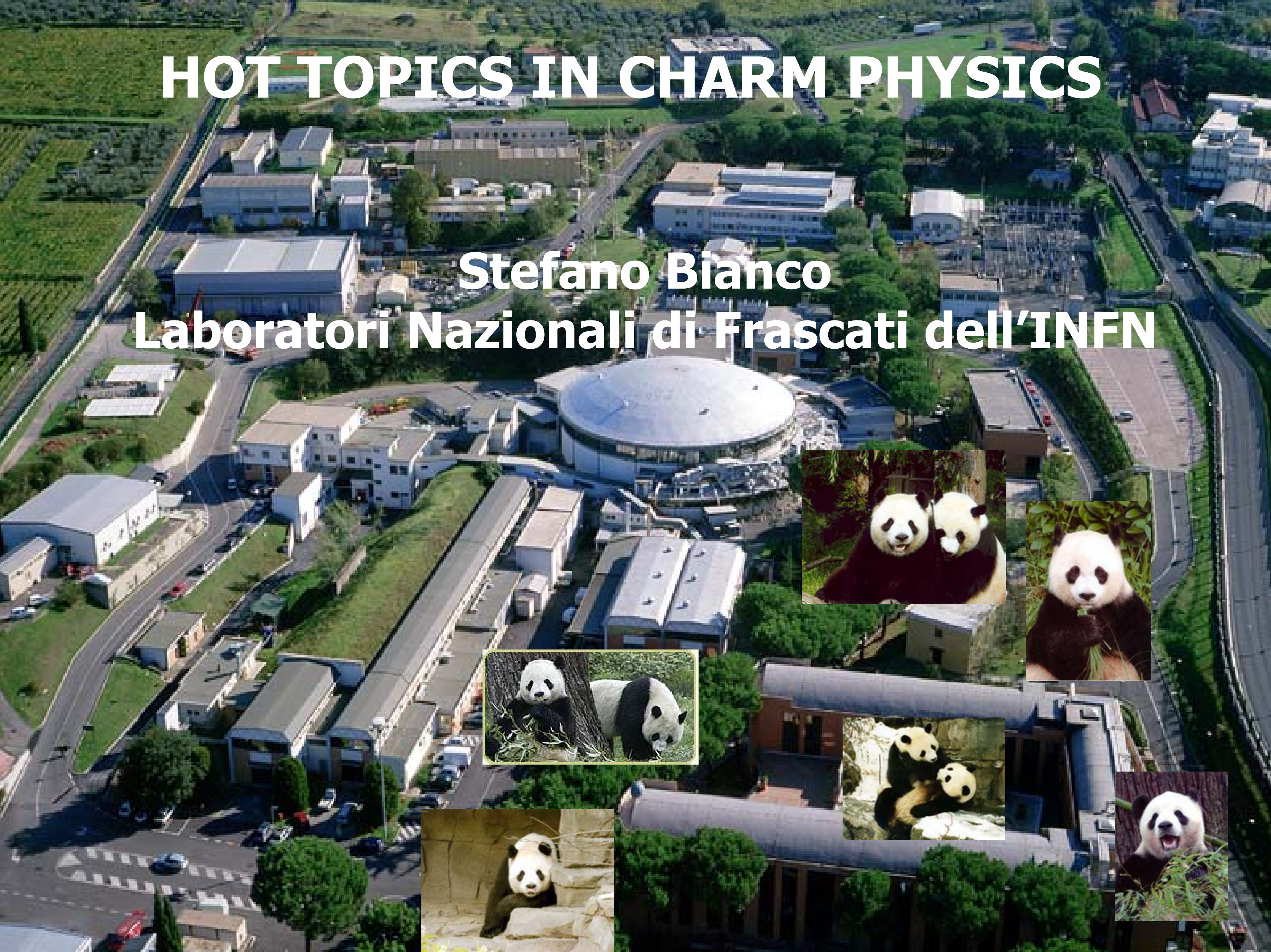

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- Charm quark and SM
- $D^0\bar{D}^0$ mixing
- CP violation
- Lifetimes
- Charm & Light Quarks:
  - in Semileptonic Decays
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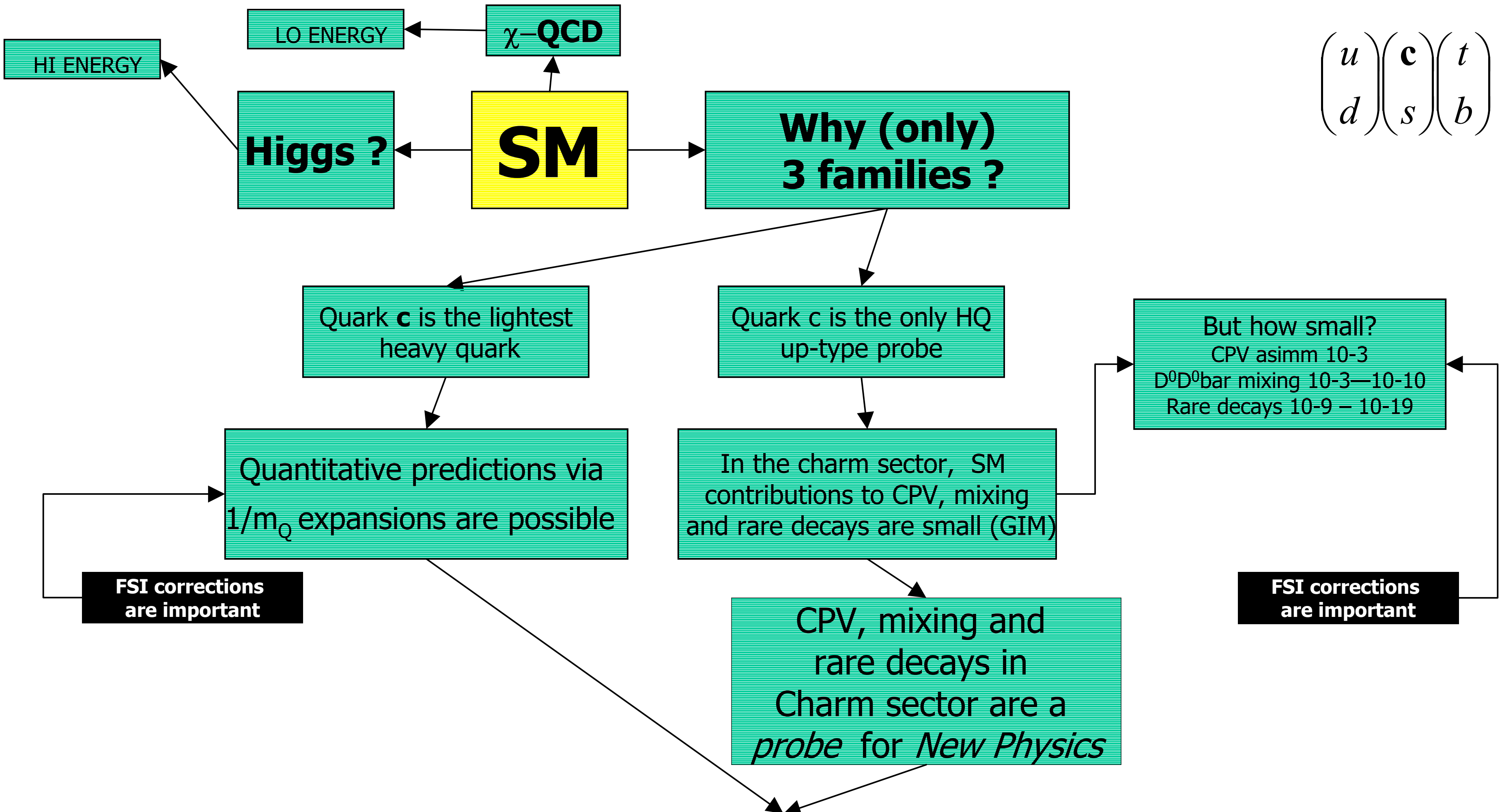
- Spectroscopy
- Outlook and Conclusions

Ref: SB, Fabbri, Benson, Bigi Riv.Nuovo Cim. 26,7-8, 2003 hep-ex/0309021

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} \mathbf{c} \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$



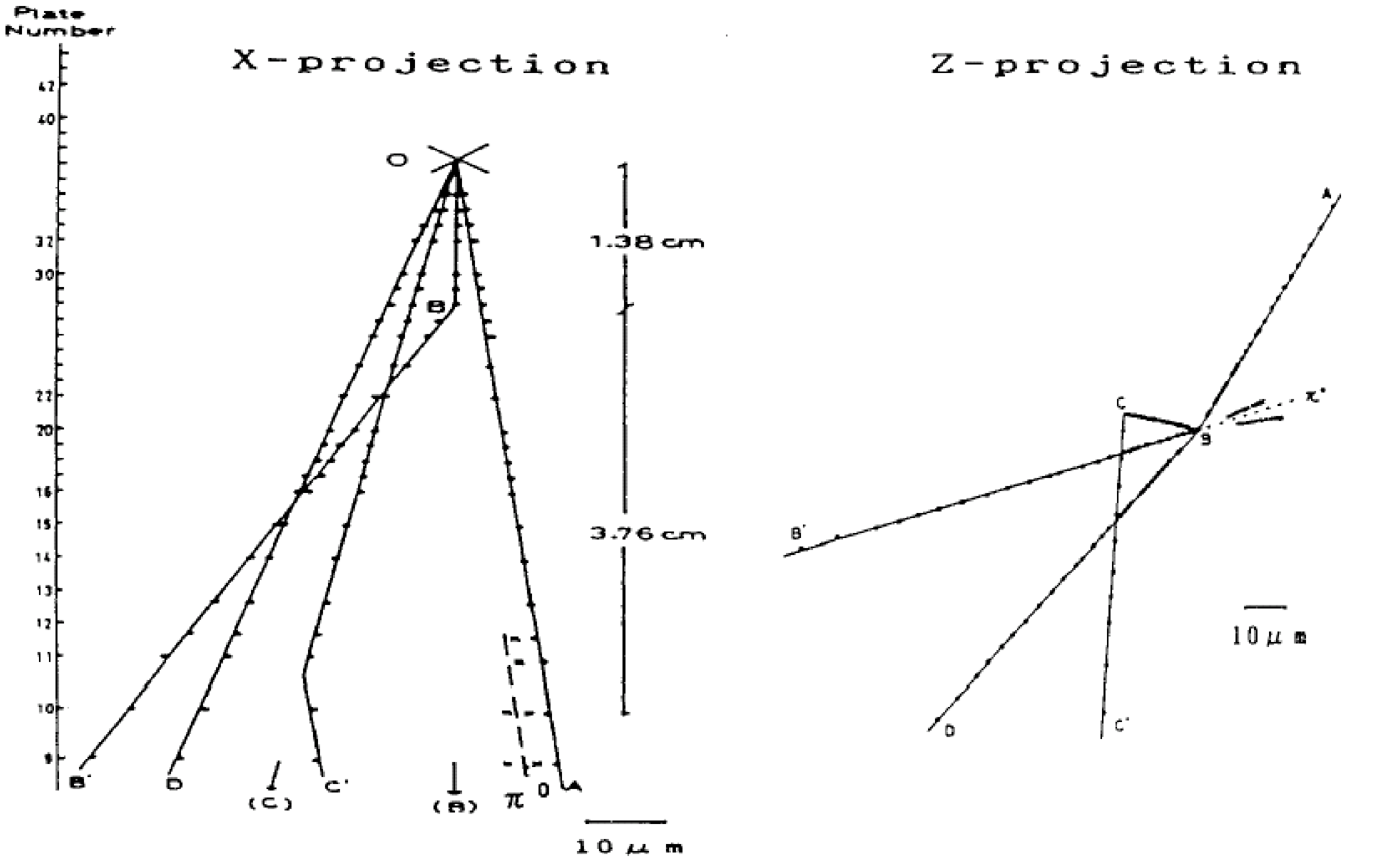
Studying the c-quark provides:

- ✓ **Engineering Database for b-physics**
- ✓ **Sensitivity and discovery potential for New Physics**

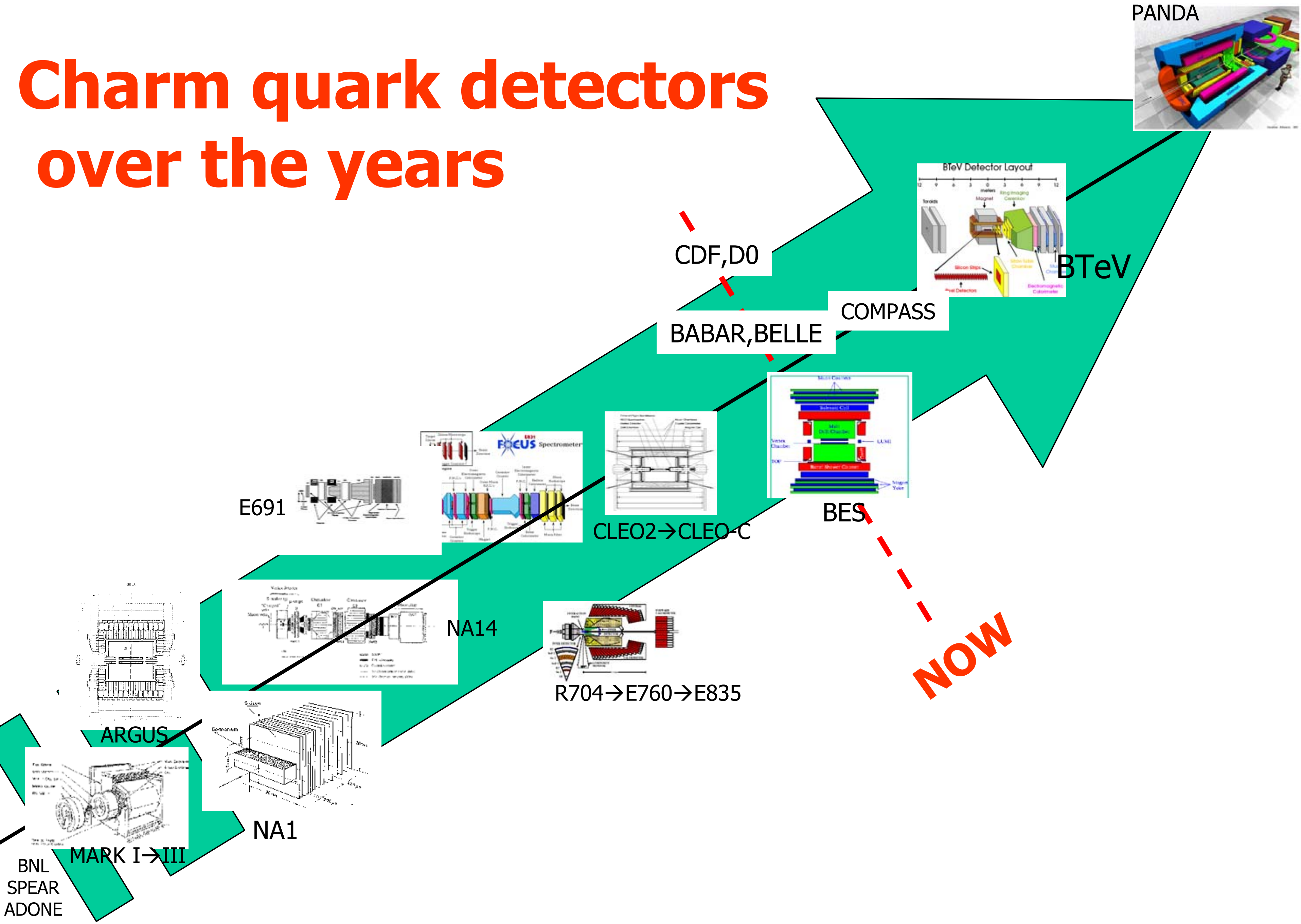
Charm discovery

K.Niu, E. Mikumo, Y. Maeda Prog. Theor. Phys. 46 (1971) 1644

$D^+ \rightarrow K^+ \pi^0$



Charm quark detectors over the years



$D^0\overline{D}^0$ MIXING

Formalism of P^0-$\bar{P}^0$ mixing

The time evolution of flavour eigenstates $P^0, \overline{P}^0$ is given by the Schrödinger equation

$$i\frac{\partial}{\partial t}\begin{pmatrix} P^0 \\ \overline{P}^0 \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix}\begin{pmatrix} P^0 \\ \overline{P}^0 \end{pmatrix}$$

$$H_{jk} \equiv m_{jk} - i\Gamma_{jk}/2$$

Processes which allow $P^0 \leftrightarrow \overline{P}^0$ mixing appear in $\boldsymbol{H_{12}}$ and $\boldsymbol{H_{21}}$.

If $H_{12} \neq 0, H_{21} \neq 0$ ⇒ $P^0, \overline{P}^0$ are not mass eigenstates. Mass eigenstates are (assuming CP conservation)

$$\left|P_{1,2}\right\rangle \equiv 1/\sqrt{2}\left(\left|P^0\right\rangle \pm \left|\overline{P}^0\right\rangle\right)$$

and mixing amplitude is

$$\left|\left\langle \overline{P}^0 \middle| P^0(t) \right\rangle\right|^2 \propto e^{-\Gamma_1 t}\left[1 + e^{\Delta\Gamma t} + 2e^{\frac{\Delta\Gamma t}{2}}\cos(\Delta m t)\right]$$

Mass and width differences are parametrized by

$$x \equiv \frac{\Delta m}{\overline{\Gamma}} \qquad y \equiv \frac{\Delta\Gamma}{2\overline{\Gamma}}$$

$|x| << 1 \qquad |y| << 1$

⇓

mixing can be described by the ratio r

$$r \equiv \frac{\Gamma(P^0 \to \overline{P}^0 \to \bar{f})}{\Gamma(P^0 \to f)} \cong \frac{x^2 + y^2}{2}$$

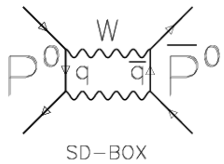
$|y|>0$ mixing is caused by the short-lived component disappearing rapidly, leaving behind the long-lived component, made of P^0 and $\overline{P}^0$

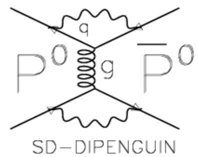
y splits lifetimes

$|x|>0$ mixing is caused by genuine $P^0 \leftrightarrow \overline{P}^0$ transitions ($\Delta f=2$)

x splits masses

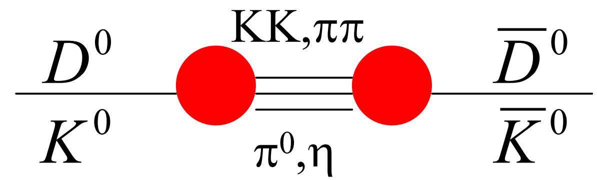
K^0, D^0, B^0 – Where's The Difference ?





SHORT DISTANCE

$$\frac{\left(m_q^2 - m_d^2\right)^2}{m_W^2 m_{s,c,b}^2}$$



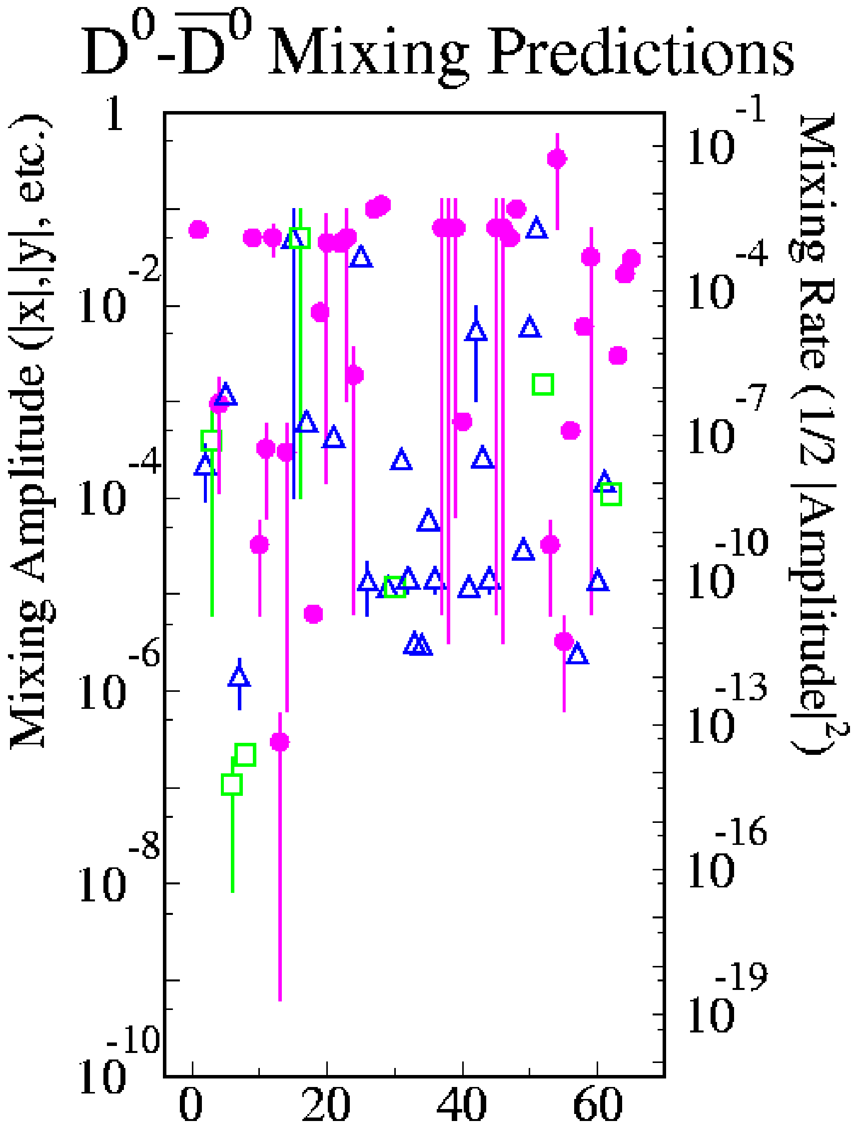
LONG DISTANCE

Also: OPE-based limits

I.Bigi, N.G.Uraltsev Nucl.Phys.B592(2001)92

	q	SD/LD	$x=\Delta m/\Gamma$	$y=\Delta\Gamma/(2\Gamma)$
$K^0(d\bar{s})$	c	SD~LD	0.48	100%
$D^0(c\bar{u})$	s	SD<<LD	?	<1%
$B_d^0(d\bar{b})$	t	SD>>LD	0.75	?
$B_s^0(s\bar{b})$	t	SD>>LD	>22	?

Theoretical "guidance"



From compilation of H.N.Nelson hep-ex/9908021

Triangles are SM x

Squares are SM y

Circles are NSM x

$$x, y\Big|_{SM} \leq 10^{-3}$$

"$\overline{D}^0 D^0$ mixing is a window on New Physics"

TECHNIQUES FOR STUDYING $D^0\overline{D}^0$ MIXING (I)

Measure y_{CP}, the y parameter for CP eigenstates

$$CP|K^+K^-\rangle = +|K^+K^-\rangle$$

Γ_2

$$CP|K_S\phi\rangle = -|K_S\phi\rangle$$

$$CP|K^-\pi^+\rangle = mixed$$

$(\Gamma_1+\Gamma_2)/2$

These Results

Also E791, BELLE

Measure r

$$r \equiv \frac{\Gamma(D^0 \to \overline{D}^0 \to \bar{f})}{\Gamma(D^0 \to f)} \cong \frac{x^2+y^2}{2}$$

HADRONIC DECAYS

$$f = |K^-\pi^+\rangle$$

E791, CLEO, ALEPH

SEMILEPTONIC DECAYS

$$f = |K^-\ell^+\nu_\ell\rangle$$

E791

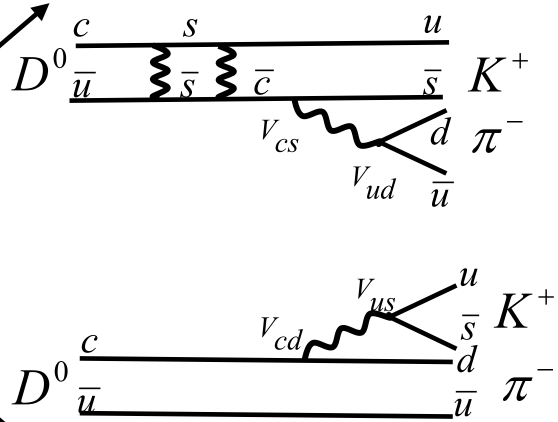
TECHNIQUES FOR STUDYING $D^0\overline{D}^0$ MIXING (II)

Measure r $\quad r \equiv \frac{\Gamma(D^0 \to \overline{D}^0 \to \bar{f})}{\Gamma(D^0 \to f)} \cong \frac{x^2+y^2}{2}$ via **HADRONIC DECAYS** $\quad f = |K^-\pi^+\rangle$

mixing

Cabibbo-Favoured Decay

$$D^0 \Rightarrow \overline{D}^0 \to K^+\pi^-$$



D* tags D⁰ flavour

$$D^{*+} \to \pi^+ D^0$$

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

Double Cabibbo-Suppressed Decay

Strong phase δ between CFD and DCSD mixes x and y

$$\begin{cases} y' \equiv y\cos\delta - x\sin\delta \\ x' \equiv x\cos\delta + y\sin\delta \end{cases}$$

$$r_{WS} \equiv \frac{\Gamma(D^0 \to \bar{f})}{\Gamma(D^0 \to f)} \propto e^{-t}\left\{ r_{DCS} + r'\frac{t^2}{2} + y'\sqrt{r_{DCS}}\,t \right\}$$

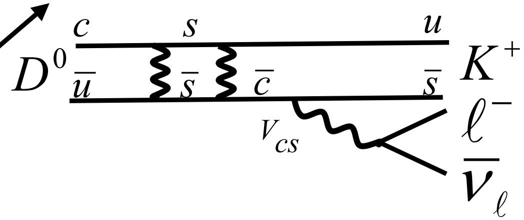
TECHNIQUES FOR STUDYING $D^0\overline{D}^0$ MIXING (III)

Measure r $\quad r \equiv \frac{\Gamma(D^0 \to \overline{D}^0 \to \bar{f})}{\Gamma(D^0 \to f)} \cong \frac{x^2 + y^2}{2}$ via **SEMILEPTONIC DECAYS** $f = \left| K^- \ell^+ \nu_\ell \right\rangle$

mixing

Cabibbo-Favoured Decay

$$D^0 \Rightarrow \overline{D}^0 \to K^+ \ell^- \overline{\nu}_\ell$$



D* tags D⁰ flavour

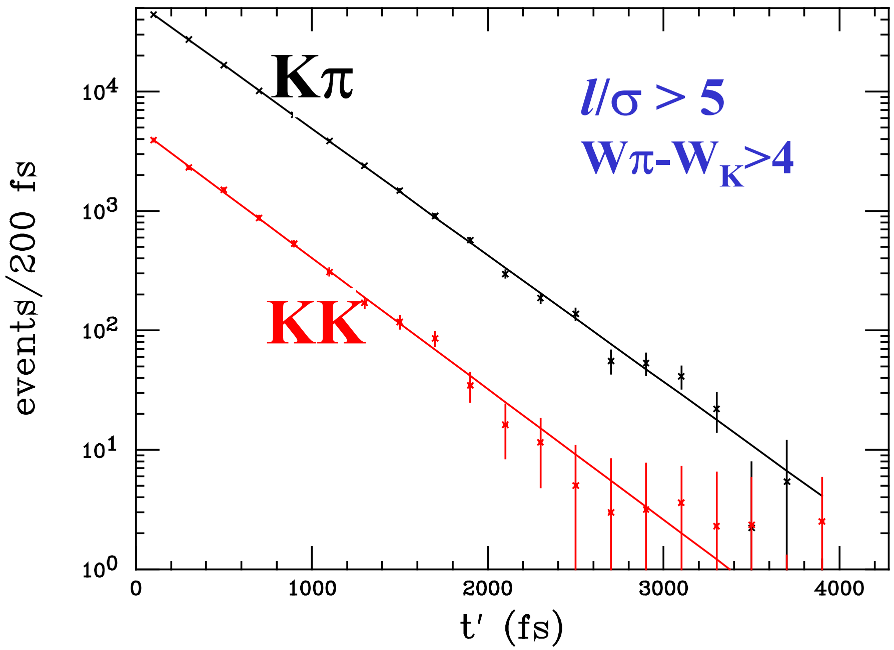
$$D^{*+} \to \pi^+ D^0$$

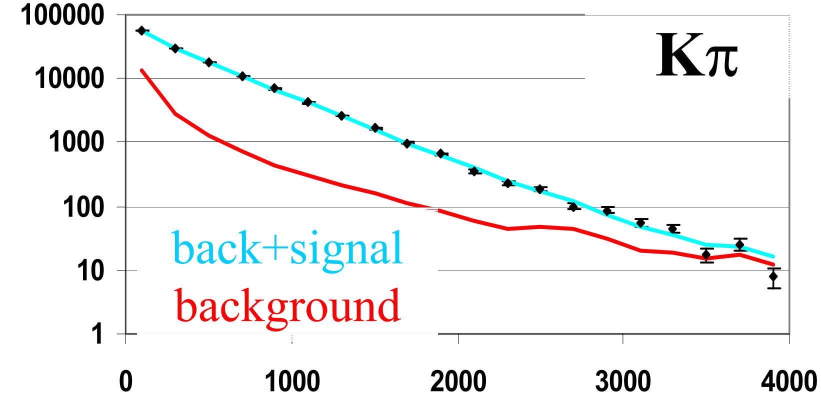
$$r_{WS} \equiv \frac{\Gamma(D^0 \to \bar{f})}{\Gamma(D^0 \to f)} = r$$

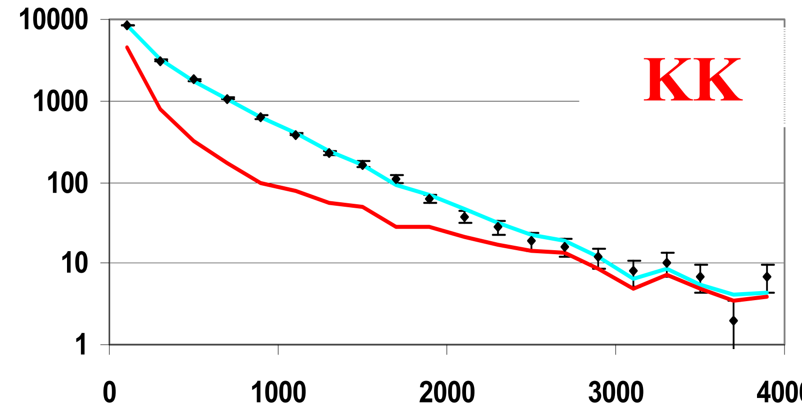
TECHNIQUES FOR STUDYING $D^0\bar{D}^0$ MIXING (Concl.)

- Direct measurement of y_{CP} requires good lifetime resolution
- Measuring r_{ws} in hadronic decays requires
  - ✓ to disuntangle r_{DCS} from r;
  - ✓ and the knowledge of δ
- Measuring r_{ws} in semileptonic decays provides the r parameter, but it is experimentally more difficult

FOCUS y_{cp}: Time evolutions







- Background subtracted and f(t') corrected time evolution of **Kπ** and **KK** events in the final fit.

- Before background subtraction

$\tau(K\pi) = 409.2 \pm 1.3$ fs

$\tau(KK) = 395.7 \pm 5.5$ fs

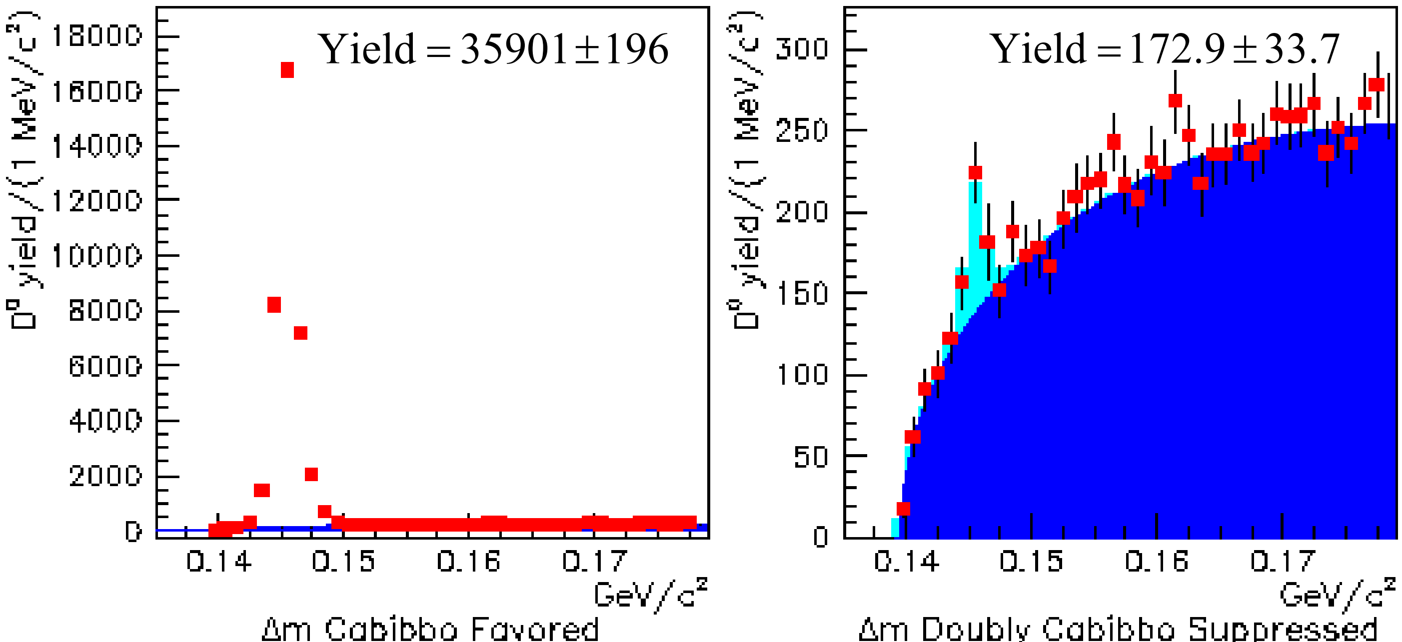
$$y_{CP} = 3.42 \pm 1.39 \pm 0.74\%$$

Measuring the DCS decay $D^{*+} \rightarrow \pi^+ (K^+\pi^-)$

Phys.Rev.Lett. 86 (2001) 2955-2958

Fit the Δm Distributions

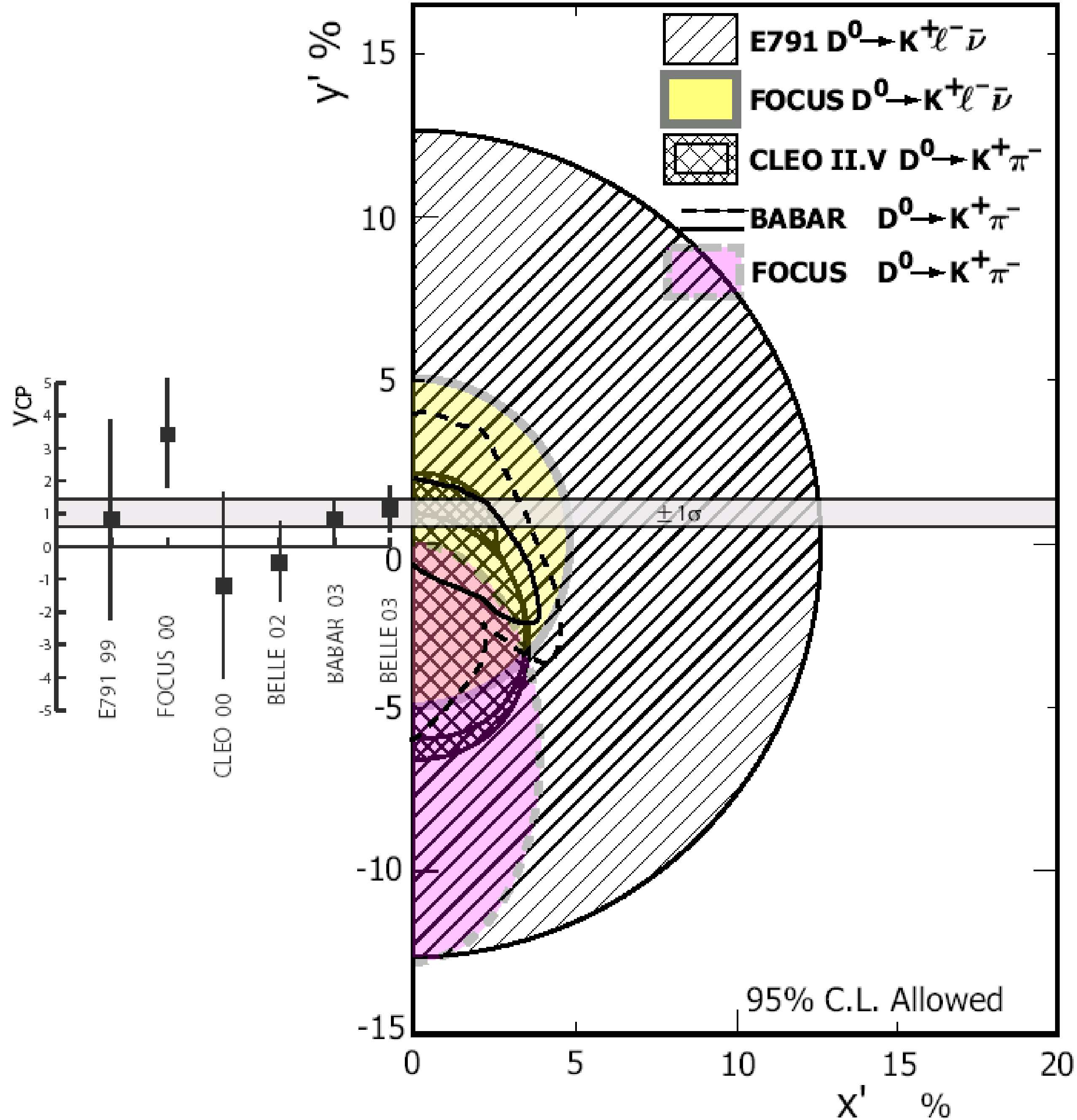
- Fitted D^0 yields are plotted in the appropriate Δm bins.
- Background is fit to: $f(m) = a(m - m_\pi)^{1/2} + b(m - m_\pi)^{3/2}$.
- DCS signal is fit directly to the CF histogram signal region.



CLEO: (0.332 ±0.064 ±0.040)%

r_{WS}= (0.404 ± 0.085 ± 0.025))%

STATUS OF $D^0\bar{D}^0$ MIXING AS OF SPRING 2004



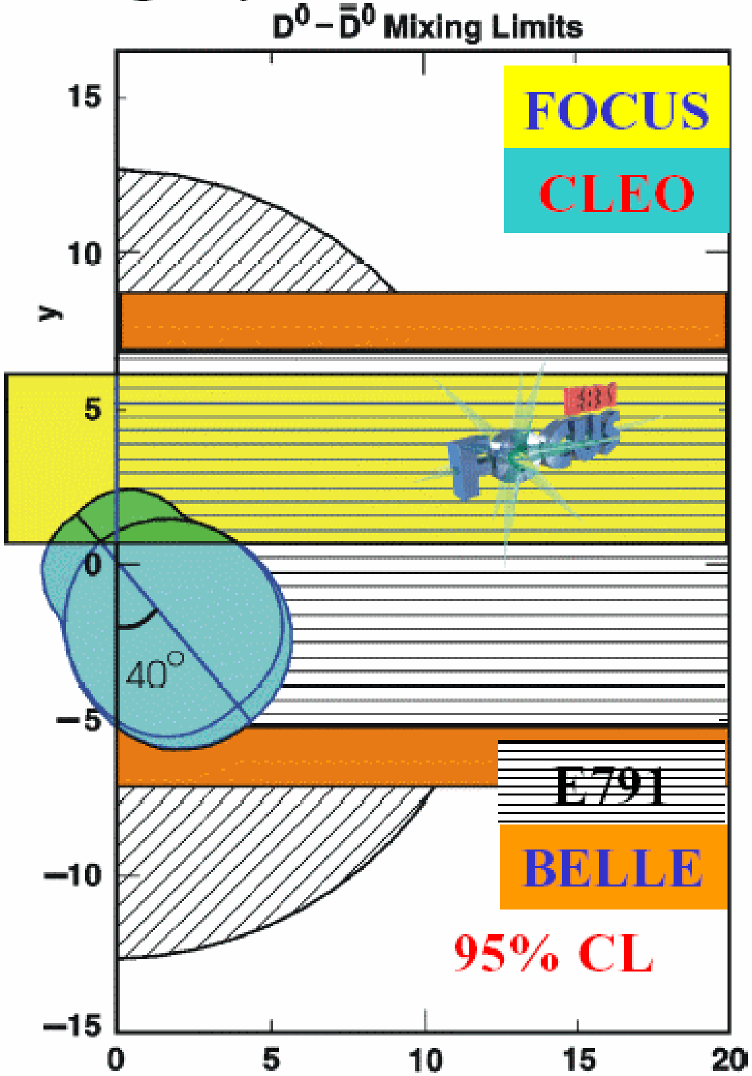
PHASE AMBIGUITY

Phase ambiguity

What if δ = 40°, the estimated maximum of the model of *Falk, Nir & Petrov (99)*? We see **some overlap...**

CLEO and FOCUS would be more consistent if δ > 90°...

Bergmann, Grossman et al (00).



CPV ASYMMETRIES

CP VIOLATING INTEGRATED ASYMMETRIES

For a two-amplitude decay

$$A_{tot} = g_1 M_1 e^{i\delta_1} + g_2 M_2 e^{i\delta_2}$$

CP conjugate

$$\overline{A}_{tot} = g_1^* M_1 e^{i\delta_1} + g_2^* M_2 e^{i\delta_2}$$

δ_i = strong phase

CP asymmetry:

$$a_{CP} = \frac{|A_{tot}|^2 - |\overline{A}_{tot}|^2}{|A_{tot}|^2 + |\overline{A}_{tot}|^2} = \frac{2\mathrm{Im}(g_2 g_1^*)\sin(\delta_1 - \delta_2) M_1 M_2}{|g_1|^2 M_1^2 + |g_2|^2 M_2^2 + 2\mathrm{Re}(g_2 g_1^*)\cos(\delta_1 - \delta_2) M_1 M_2}$$

2 different weak amplitudes — **strong phase-shift**

Search for CP violation via Dalitz plot analysis of Singly-Cabibbo-suppressed Decays

- Use full decay info, not only BR → must determine amplitude coefficients and phases

- Final state results from the interference of all intermediate states

- Differences between amplitude and/or phases patterns in a Dalitz analysis betw conjugate states (i.e., D^+ vs D^-), would be evidence of CP violation

(ref. I.Bigi,A.Sanda "*CP Violation*")

CP violation:Dalitz analysis

Dalitz plot = FULL OBSERVATION of the decay

COEFFICIENTS and **PHASES** for each amplitude

Measured phase: $\theta = \delta + \phi$

CP conserving: δ

CP violating: ϕ

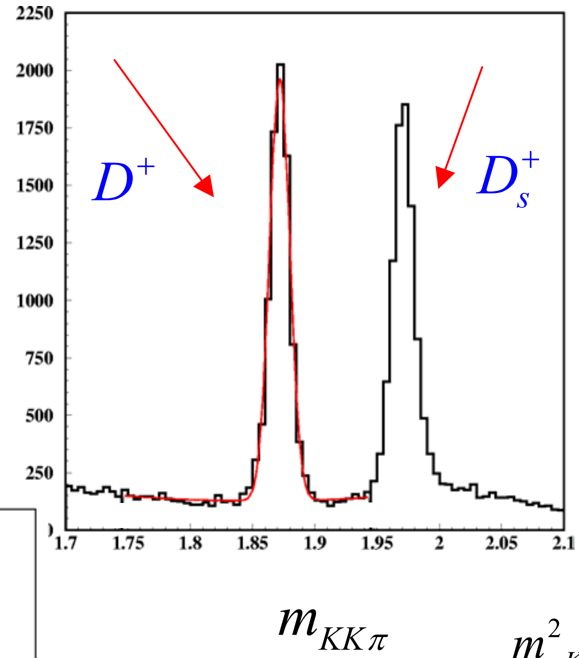
CP conjugate: $\bar{\delta} = \delta$ $\quad \bar{\phi} = -\phi$

$$\bar{\theta} = \delta - \phi$$

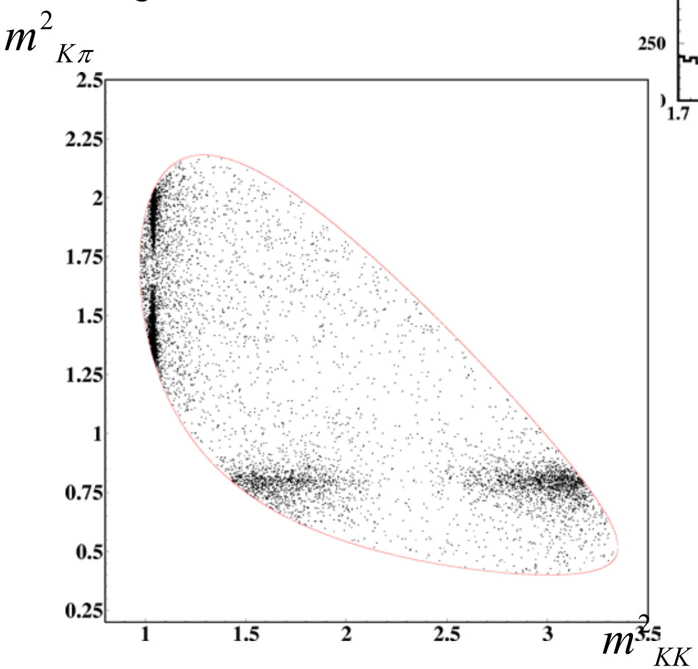
E831 → Measure of direct CP violation: asymmetrys in decay rates of $D^{\pm} \to K^{\pm} K \pi^{\pm\mp}$

$a_{CP} = 0.006 \pm 0.011 \pm 0.005$

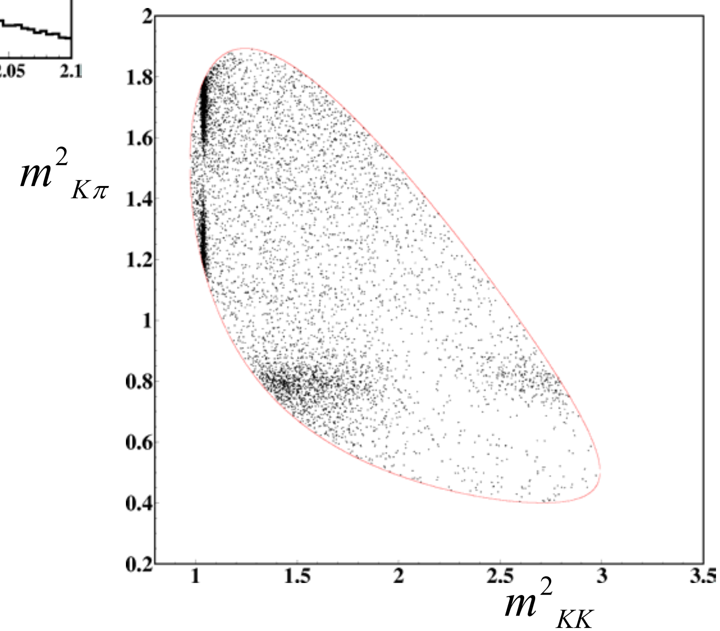
$D_s, D^+ \to KK\pi$



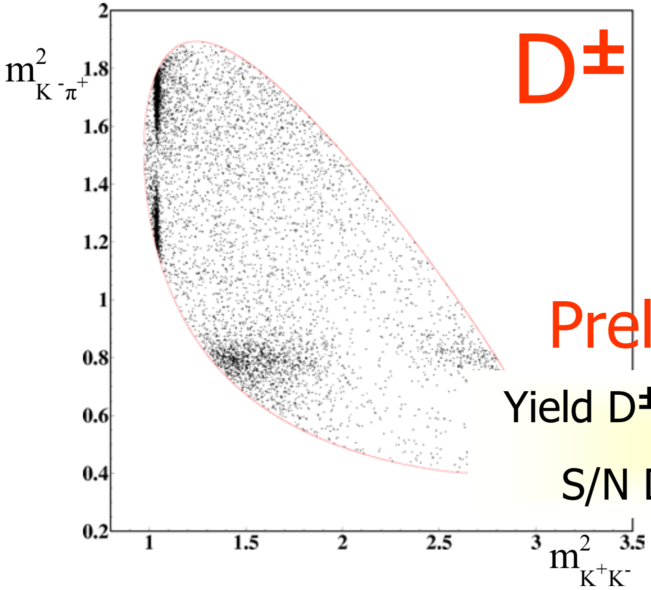
$D_s^+ \to K^+ K^- \pi^+$



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



$D^{\pm} \to KK\pi$



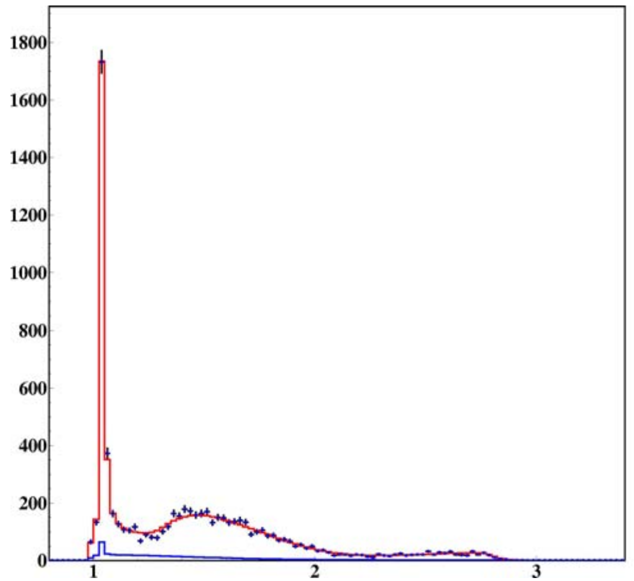
Preliminary

Yield $D^{\pm}$ = 7106 ±92

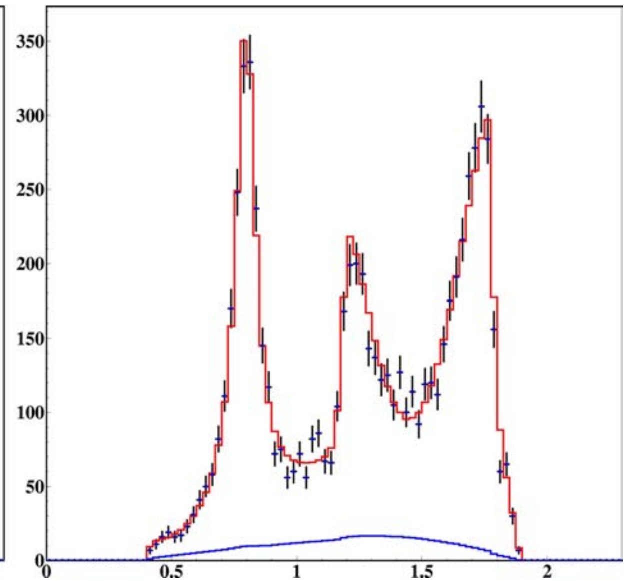
S/N $D^{\pm}$ = 8.62

Decay Fraction and phases

$K^*(892)$	= 20.7 ± 1.0	%	(0 fixed)
$\phi(1020)$	= 27.8 ± 0.7	%	(243.1 ±5.2)°
$K^*(1410)$	= 10.7 ± 1.9	%	(-47.4 ± 4.9) °
$K^*(1430)$	= 66.5 ± 6.0	%	(61.8 ± 3.8)°
$f_0(1370)$	= 7.0 ± 1.1	%	(60.0 ± 5.3) °
$a_0(980)$	= 27.0 ± 4.8	%	(145.6 ± 4.3)°
$f_2(1270)$	= 0.8 ± 0.2	%	(11.6 ± 7.0) °
$\phi(1680)$	= 1.6 ± 0.4	%	(-74.3 ± 7.5) °



$K^+ K^-$ projection

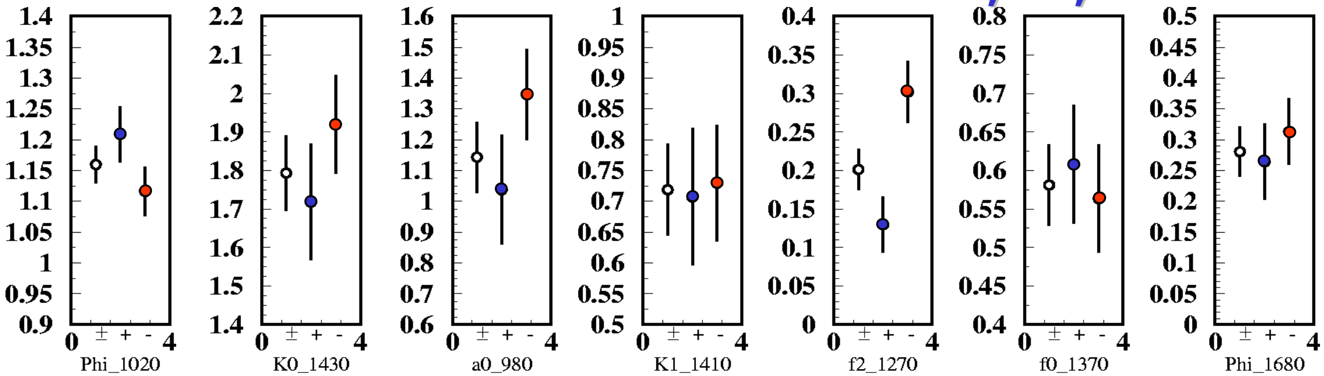


$K^- \pi^+$ projection

D$^+$/D$^-$ split sample analysis

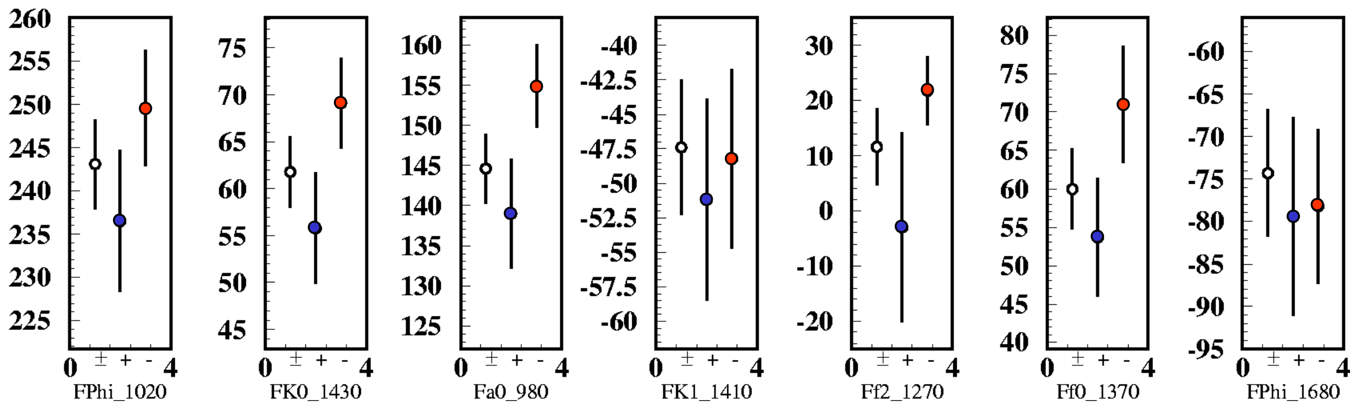
Preliminary!

Coefficients: D$^{\pm}$, D$^+$, D$^-$



Phases: D$^{\pm}$, D$^+$, D$^-$

No evidence of CPV



LIFETIMES

LIFETIMES

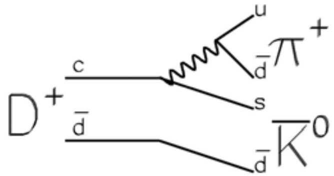
$$\tau(\Omega_c^0) \leq \tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Xi_c^+) < \tau(D^0) < \tau(D_s^+) < \tau(D^+)$$

- Measuring charm meson lifetimes is important to study contribution of W-Annih e W-eXchange diagrams
- Operator Product Expansion (OPE) Models

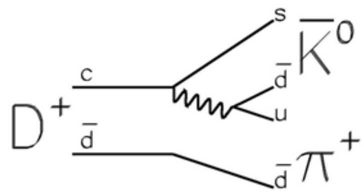
review: G.Bellini, I.Bigi, P.J.Dornan, Phys. Rept. 289, 1(1997)

$$\Gamma\left(H_Q \rightarrow f\right) = \frac{G_F^2 m_Q^5}{192\pi^3}\left|KM\right|^2\left[A_0 + \frac{A_2}{m_Q^2} + \frac{A_3}{m_Q^3} + \ldots\right]$$

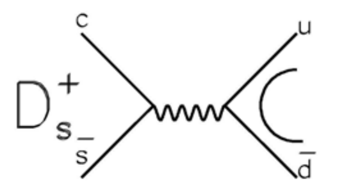
SPECTATOR (A_0) **SPIN-SPIN INTERCTN** (A_2/m_Q^2) **PI, WA, WX** (A_3/m_Q^3)



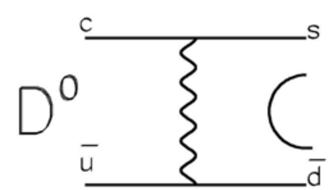
EXT. SPECTATOR



INT. SPECTATOR



ANNIHILATION (WA)

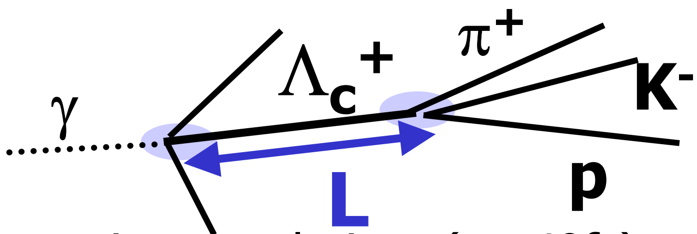


EXCHANGE (WX)

- Ratio $[\tau(D^0)/\tau(D_s^+)] < 1$ is sensitive to W-Annih
- In OPE models, W-Annih operator is the same appearing in B semilep decays.

Lifetime measurement technique

- Vertex algorithm is driven by charm candidates (cut on $L > N\,\sigma_L$)



- Proper time resolution: ($\sigma \sim$40fs)

– No resolution convolution systematics/error inflation

–Systematic test of the method validity for short lived decays

- The fit variable is the **reduced proper time** $t' = (L - N\,\sigma_L)/\beta\gamma c$, where N is the detachment cut

$\rightarrow$ minimize acceptance corrections

Binned likelihood method

The expected number of events in each t' bin is:

$$\mu_i = (N_s - B)\frac{f(t'_i)\,\exp(-t'_i/\tau)}{\Sigma_i\, f(t'_i)\, e^{-t'_i/\tau}} + B\frac{b_i}{\Sigma_i b_i}$$

- **Acceptance/efficiency/absorption f(t') correction by MC**
- **b_i: background from the i^{th} t' bin of sidebands distributions**

We maximize likelihood function:

$$\mathbf{L} = \left(\prod_i \frac{\mu_i^{-n_i} e^{-\mu_i}}{n_i!}\right) \times \left(\frac{(\alpha B)^{\Sigma_i b_i} e^{-\alpha B}}{(\Sigma_i b_i)!}\right)$$

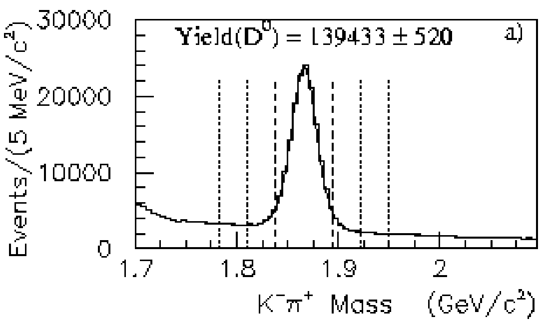
Fit Parameters are τ , **B**

B-tie term.

Charm Meson Lifetimes

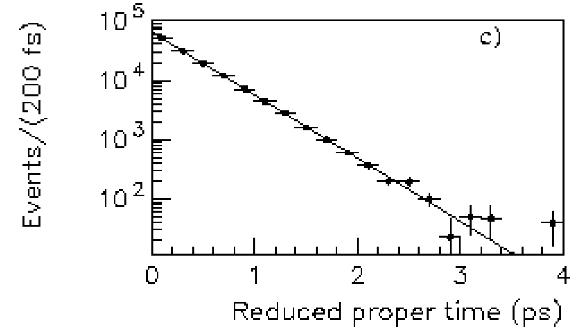
D^0, D^+ Signal

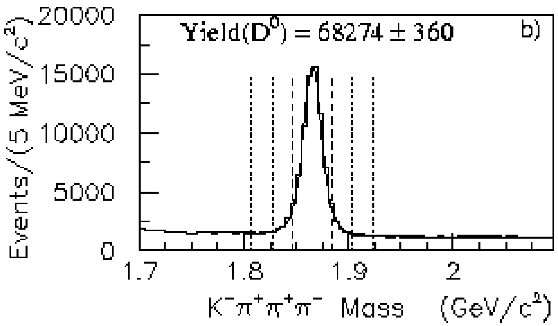
D^0, D^+ Lifetime fits



$D^0 \rightarrow K^- \pi^+$

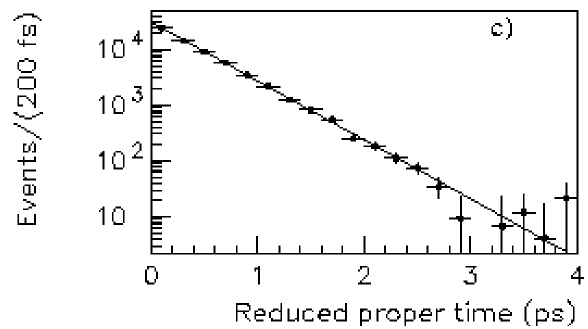
139433 ±520 evts

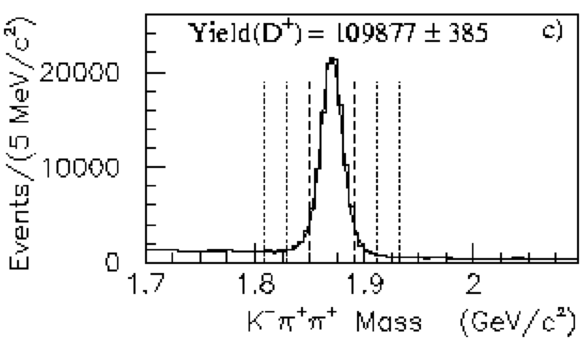




$D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$

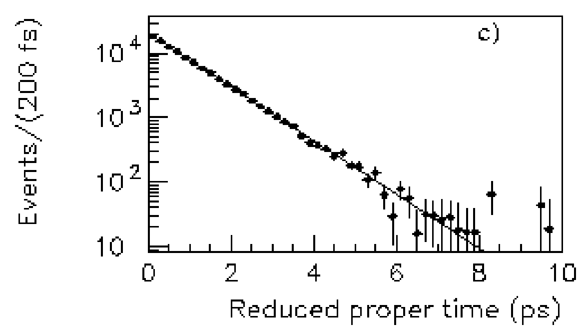
68274 ±360 evts





$D^+ \rightarrow K^- \pi^+ \pi^+$

109877 ±385 evts



Charm Baryon Lifetimes

- The hadronic partial width has contributions from mechanisms other than spectator quark decay (W exchange, destr. and constr. PI)

Qualitatively (neglecting mass difference and CS decays):

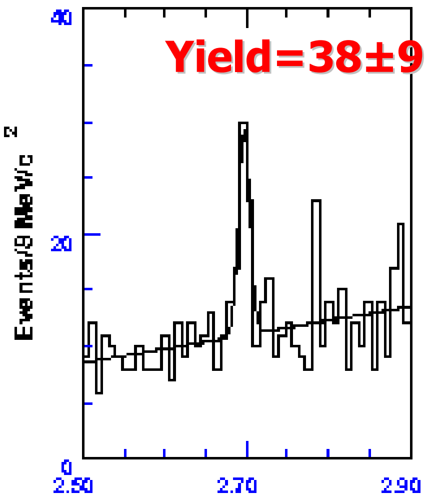
$$\Gamma(\Lambda_c^+) = \Gamma_{spec} + \Gamma_{exc} + \Gamma^-$$
$$\Gamma(\Xi_c^+) = \Gamma_{spec} + \Gamma^+ + \Gamma^-$$
$$\Gamma(\Xi_c^0) = \Gamma_{spec} + \Gamma_{exc} + \Gamma^+$$
$$\Gamma(\Omega_c^0) = \Gamma_{spec} + (10/3)\,\Gamma^+$$

Expected hierarchy:

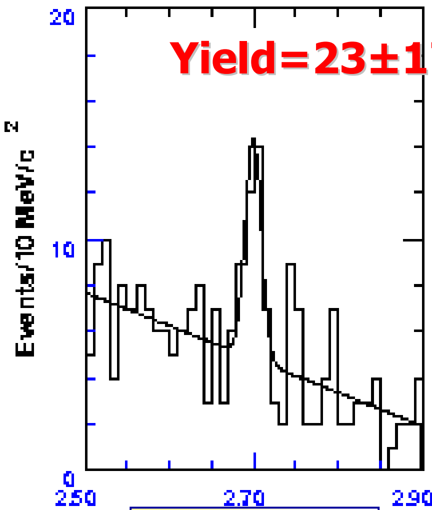
$$\Gamma(\Xi_c^+) < \Gamma(\Lambda_c^+) < \Gamma(\Xi_c^0) < \approx \Gamma(\Omega_c^0)$$

preliminary

Ω_c^0 samples



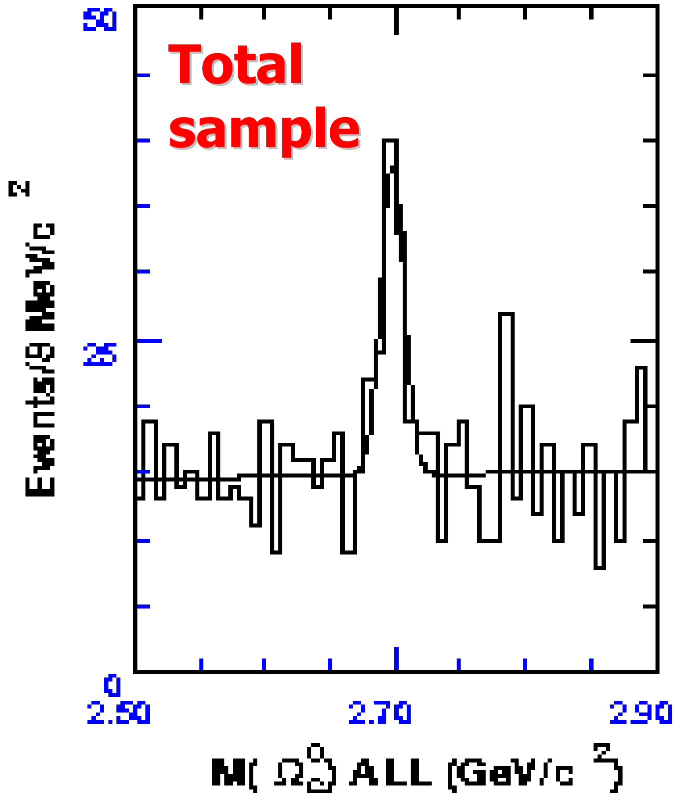
$M(\Xi^- K^- \pi^+ \pi^+)$



$M(\Omega^- \pi^+)$

Year	Expt.	Mass (MeV/c^2)	Mode(s)	Events
1985	WA62	2740.0 ± 20	$\Xi^- K^- \pi^+ \pi^+$	3
1992	ARGUS	$2719.0 \pm 7.0 \pm 2.5$	$\Omega^- \pi^- \pi^+ \pi^+$	11
1993	E687	$2705.9 \pm 3.3 \pm 2.0$	$\Omega^- \pi^+$	10
1994	E687	$2699.9 \pm 1.5 \pm 2.5$	$\Sigma^+ K^- K^- \pi^+$	42
2000	CLEO	$2694.6 \pm 2.6 \pm 1.9$	4 modes	40
2001	Belle	2697.3 ± 1.5	$\Omega^- \pi^+$	24

PDG 2002 = 2697.5 ± 2.6 MeV/c^2



Yield=64±14

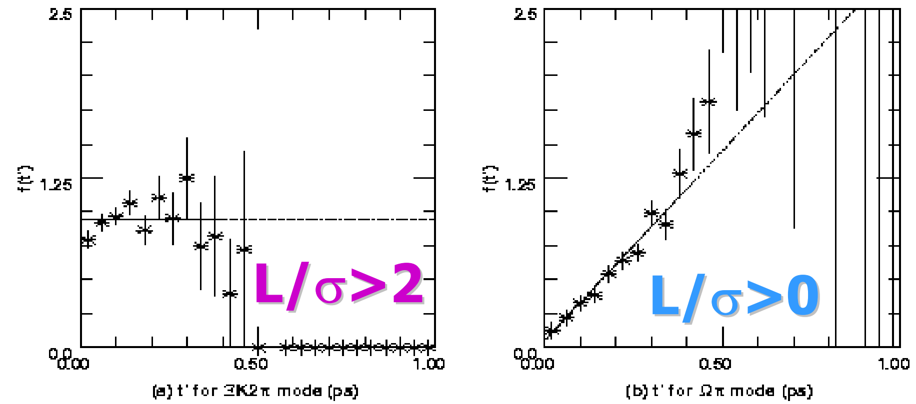
Mass=2697.5 ± 2.2 MeV/c^2

preliminary

Ω_c^0 lifetime measurement

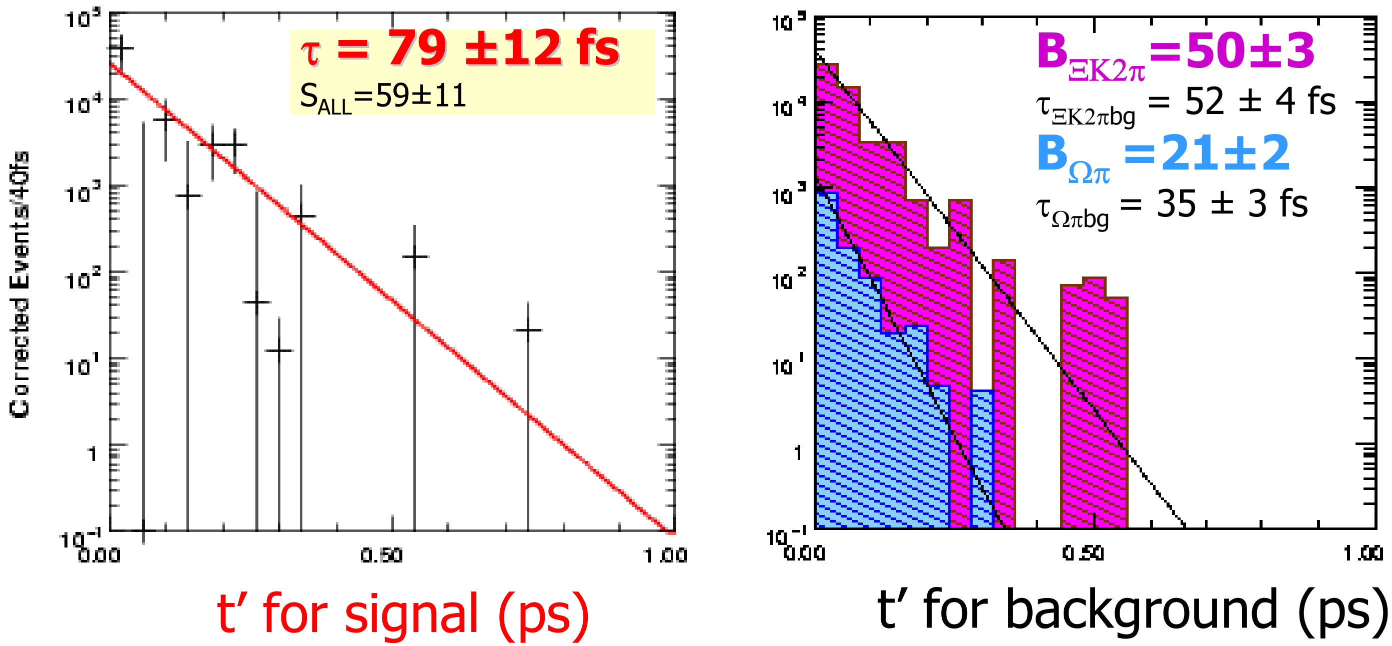
FOCUS E831

MC correction functions



$L(\Omega_c^0) = L(\Xi^- K^- \pi^+ \pi^+) \times L(\Omega^- \pi^+)$

- Large corrections because of loose detachement cut
- 3 fit parameters: τ , $B_{\Xi K2\pi}$, $B_{\Omega\pi}$

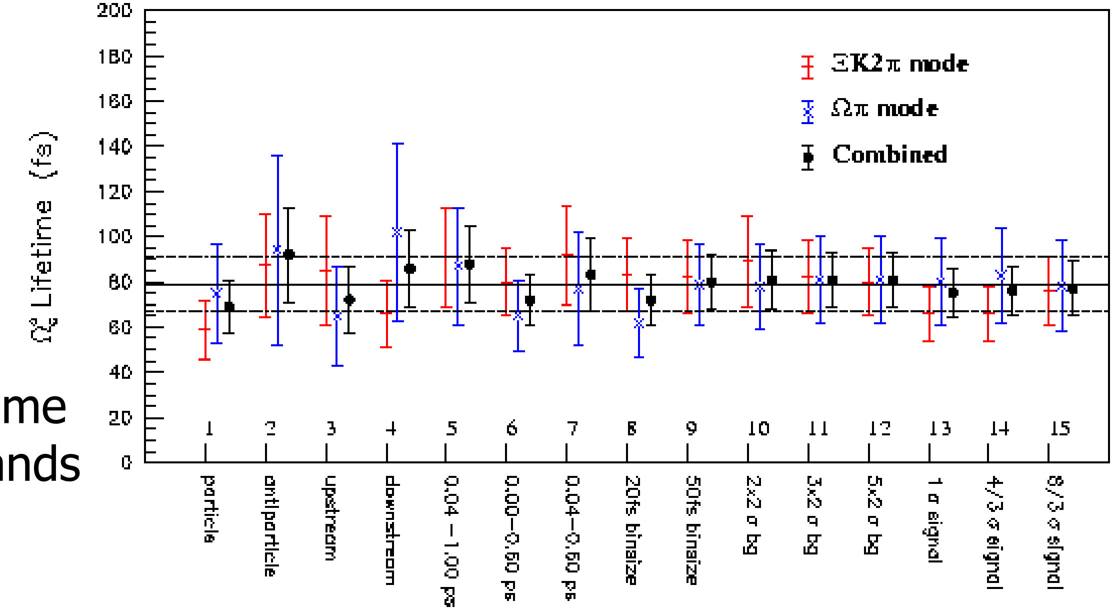


preliminary

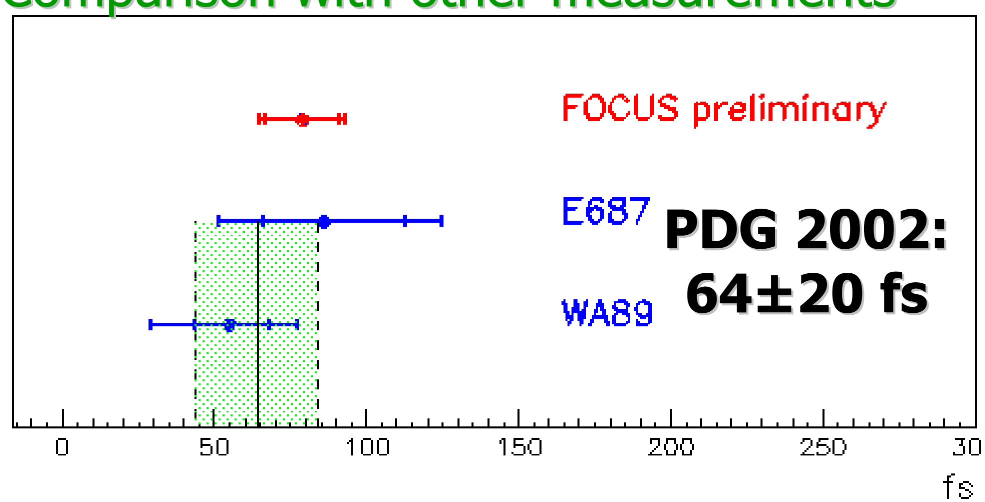
Ω_c^0 lifetime systematics and result

Systematics studies:

- No remarkable effects of production/absorption
- proper time resolution (bin size-fit range dependency)
- as for Ξ_c^0 , study effects due to resolution comparable to the lifetime
- Background studies: signal /sidebands region (location and widths)



Comparison with other measurements

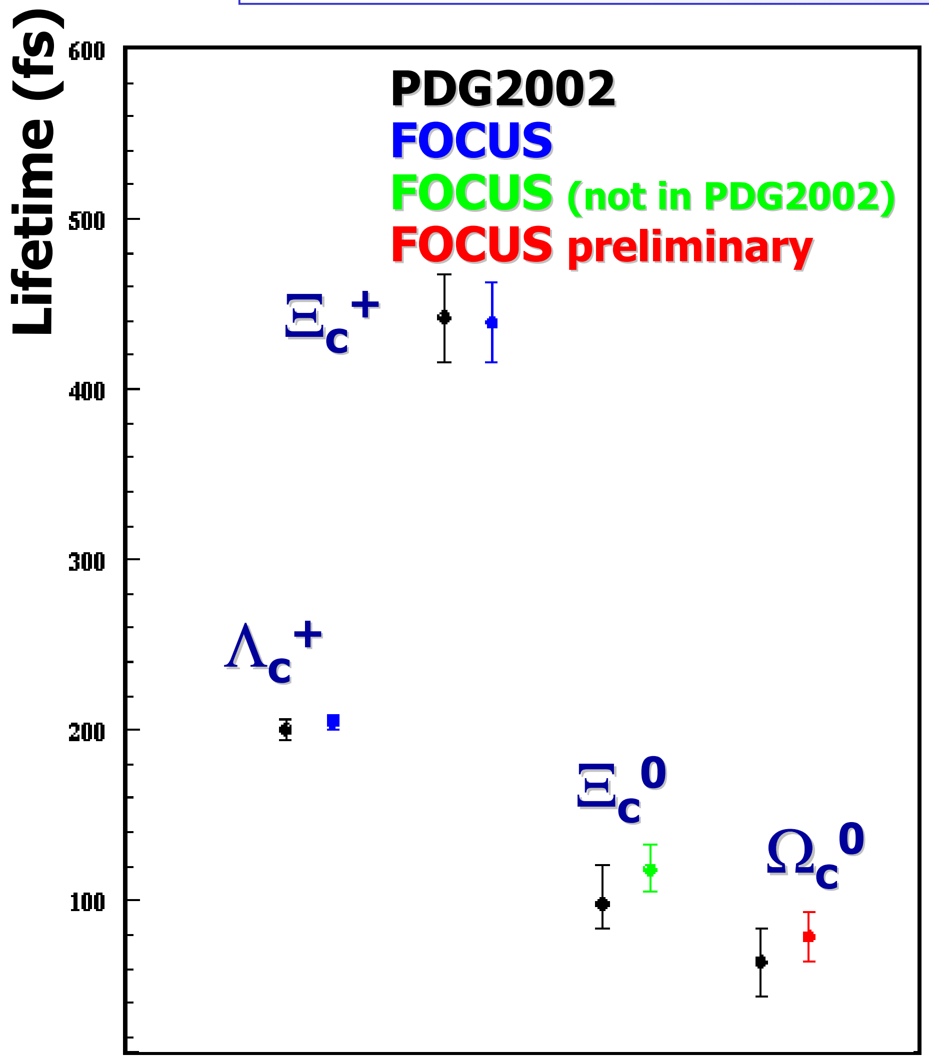


Preliminary FOCUS measurement:

$$\tau\left(\Omega_c^0\right) = 79 \pm 12(\text{stat}) \pm 9(\text{sys})\ \text{fs}$$

Accuracy improved by a factor of 2

Results for Charm Baryons Lifetimes



FOCUS significantly improved the accurancy of all charm baryons lifetimes.

From the FOCUS results:

$$\frac{\tau\left(\Xi_c^+\right)}{\tau\left(\Lambda_c^+\right)} = 2.15 \pm 0.13$$

(PDG 2002: 2.21 ± 0.15)

Theory predictions: 1.2-1.7

$$\frac{\tau\left(\Xi_c^0\right)}{\tau\left(\Omega_c^0\right)} = 1.5 \pm 0.3$$

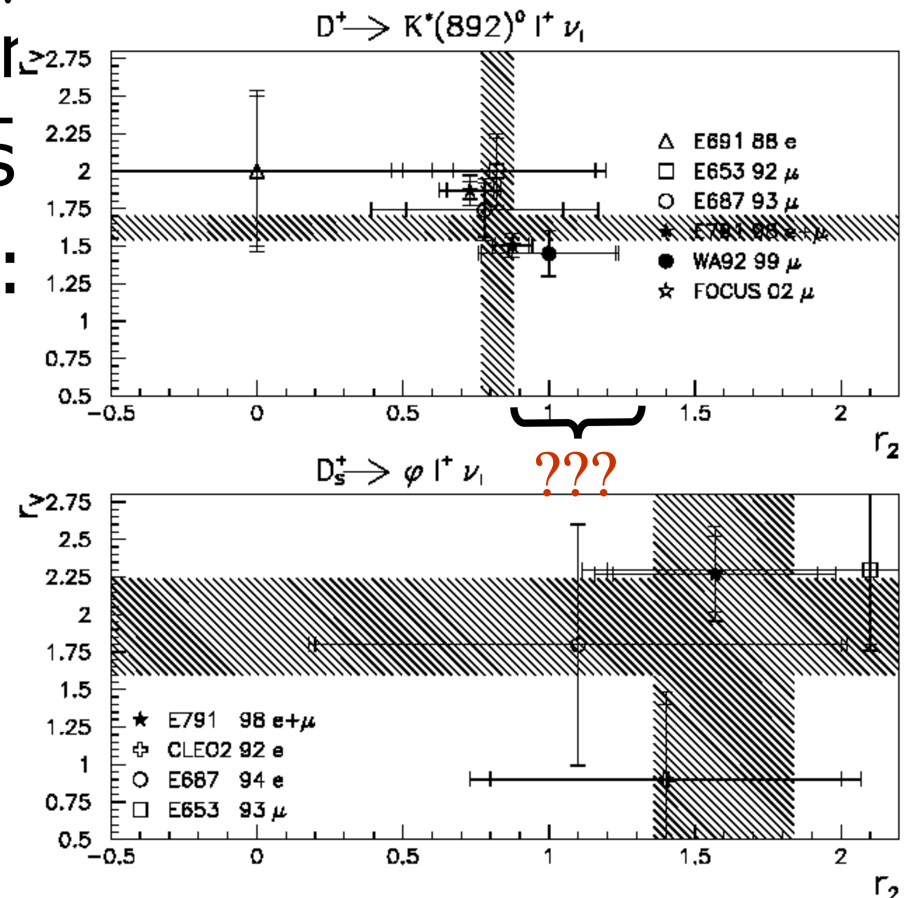
Theory predictions: >~ 1

SEMILEPTONIC AND NONLEPTONIC DECAYS

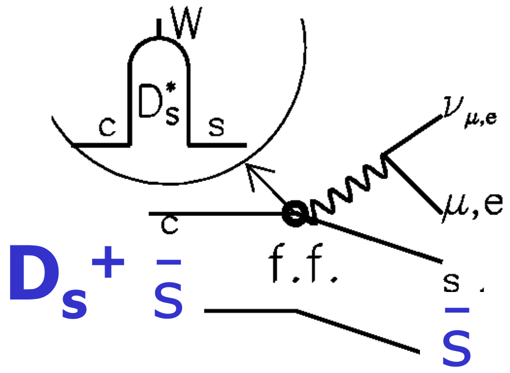
SKIP SEMILEP

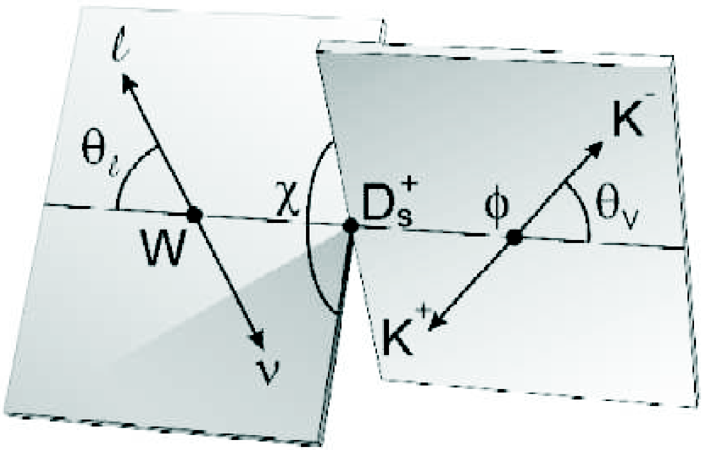
New measurements of the $D_s^+ \to \phi\mu^+\nu$ form factor ratios **J.M.Link et al. (FOCUS Coll.) hep-ex/0401001 accepted by Phys.Lett.B**

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



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





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

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

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

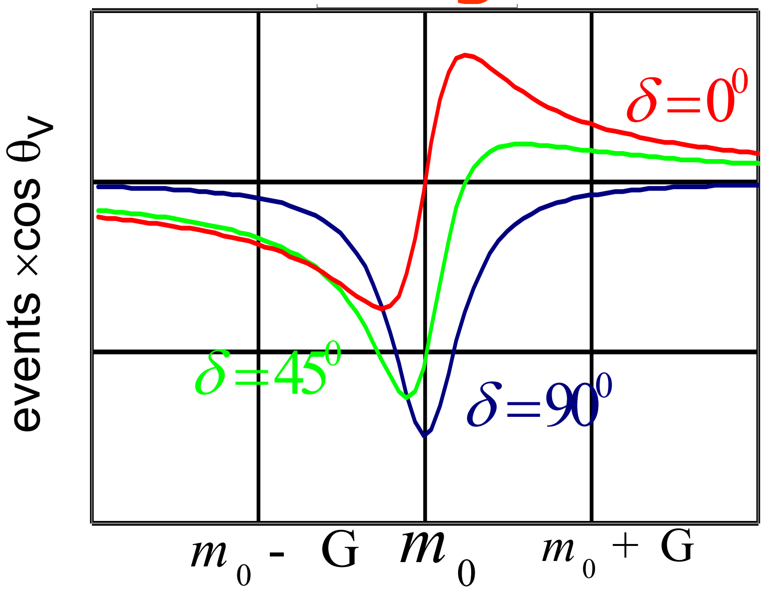
$$V(q^2) = \frac{V(0)}{1 - q^2/M^2{}_V}$$

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

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

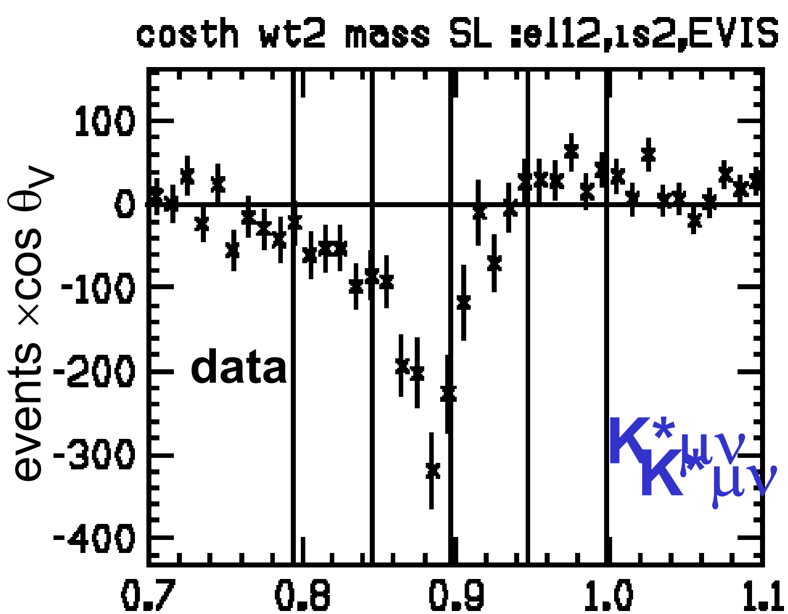
$$r_3 \equiv A_3(0)/A_1(0)$$

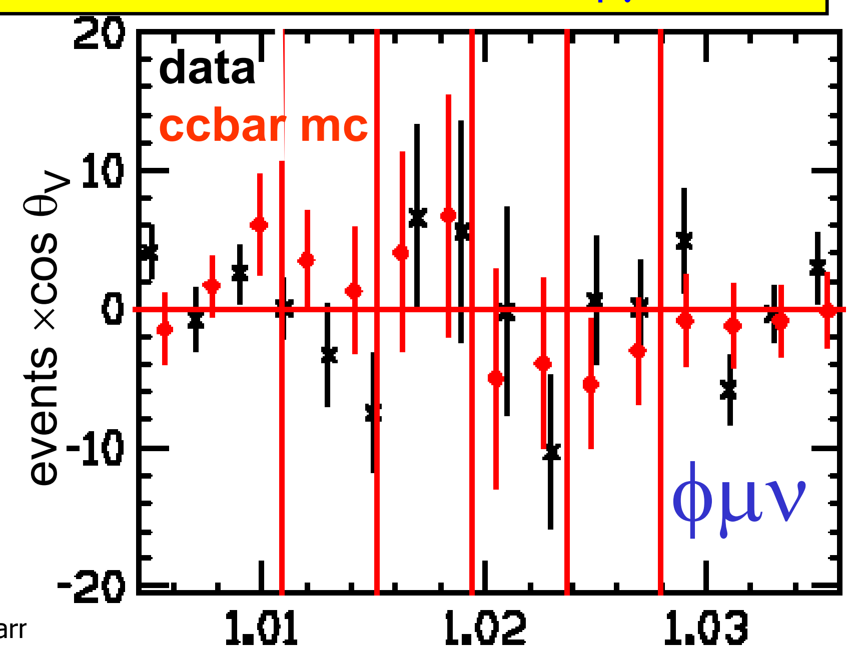
Searching for s-wave interference in $\phi\mu\nu$



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 Ds $\rightarrow \phi\mu\nu$

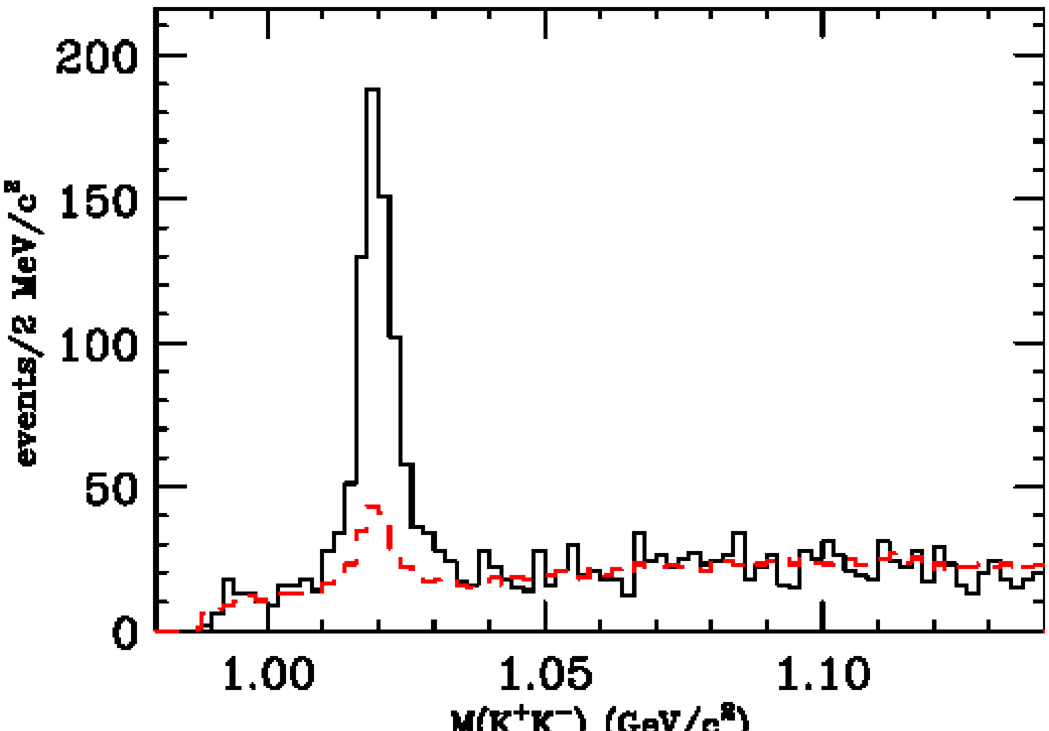




The m_{KK} distribution for $D_s^+ \rightarrow K^- K^+ \mu^+ \nu$ candidates

Data (solid) and $c\bar{c}$ background MonteCarlo (dashed).

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

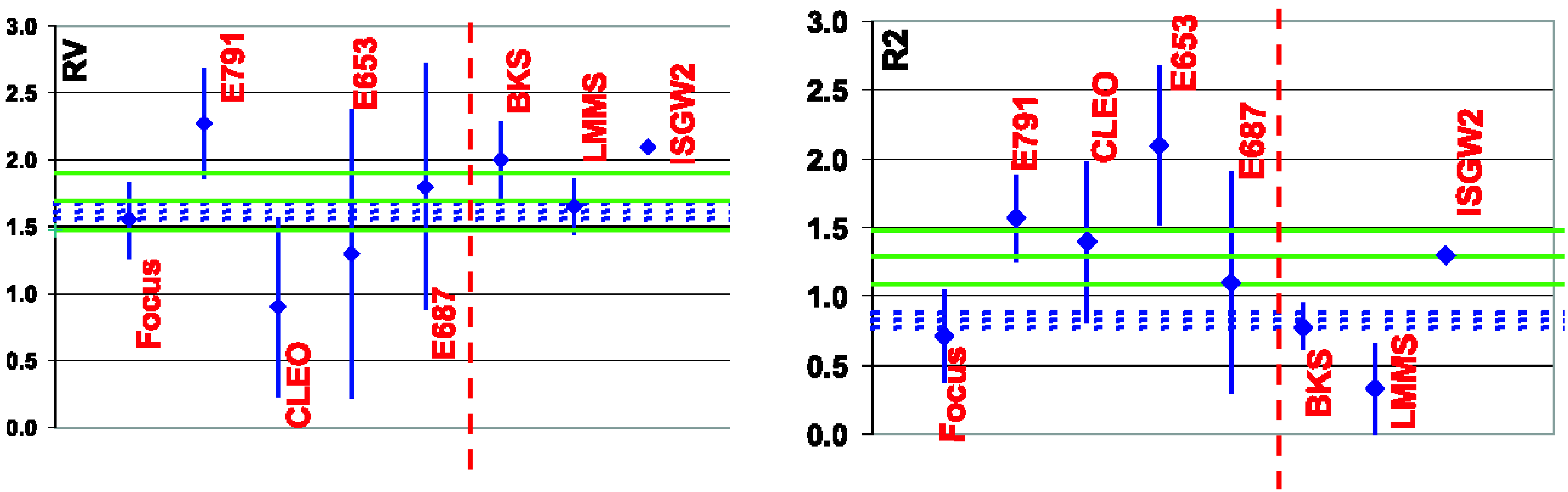


RESULTS

$r_v = 1.549 \pm 0.250 \pm 0.145$

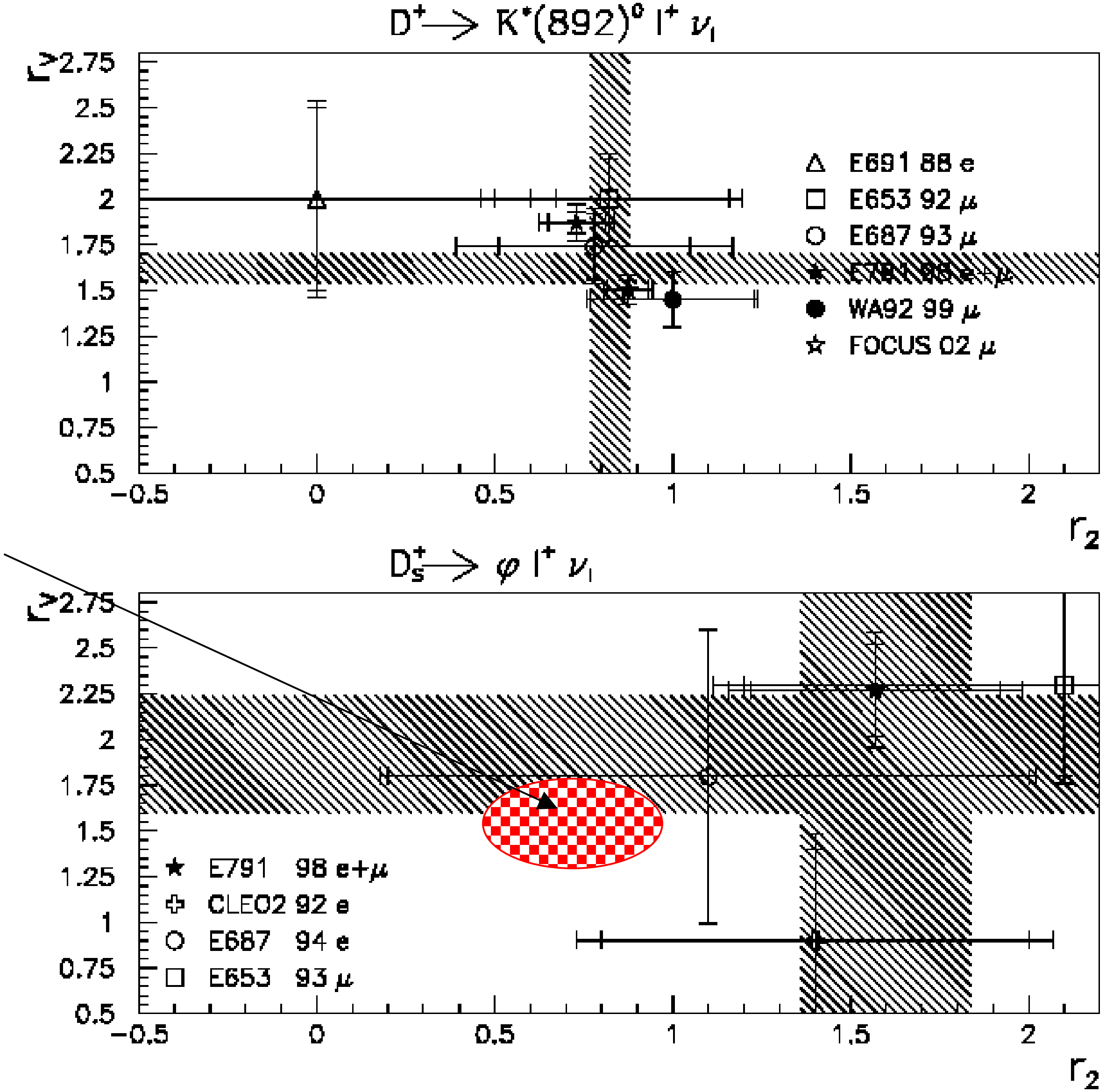
$r_2 = 0.713 \pm 0.202 \pm 0.266$

1. Most precise measurement to date
2. very consistent with $D^+ \rightarrow \overline{K}^{0*} \mu^+ \nu$
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. $D^+ \rightarrow \overline{K}^{0*} \mu^+ \nu$

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



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.

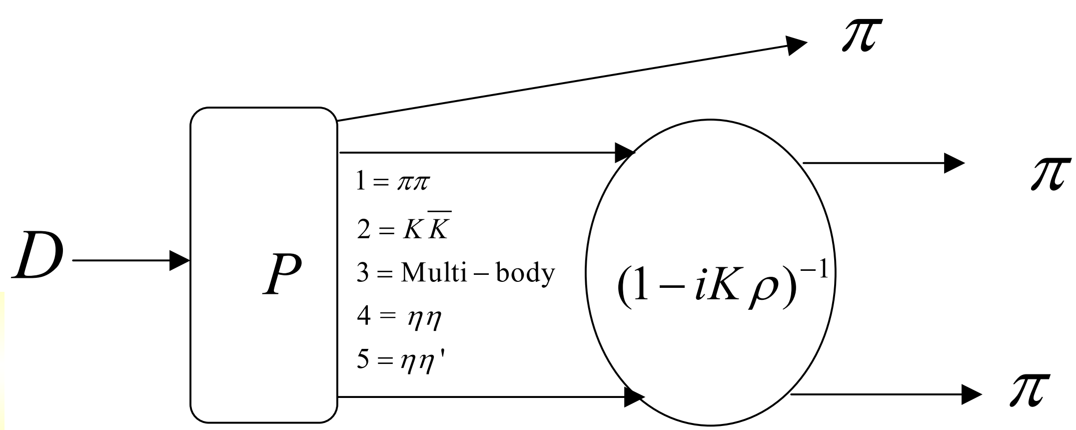
- Dalitz plots have been proved to be a powerful tool in three-body decays, investigating
  - Resonant substructure
  - Interference patterns
  - Final state interactions
  - Relationships to light-meson spectroscopy
- Traditionally, isobar formalism used
  - Decay amplitude is a sum of Breit-Wigner 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, K$\bar{K}$, 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"

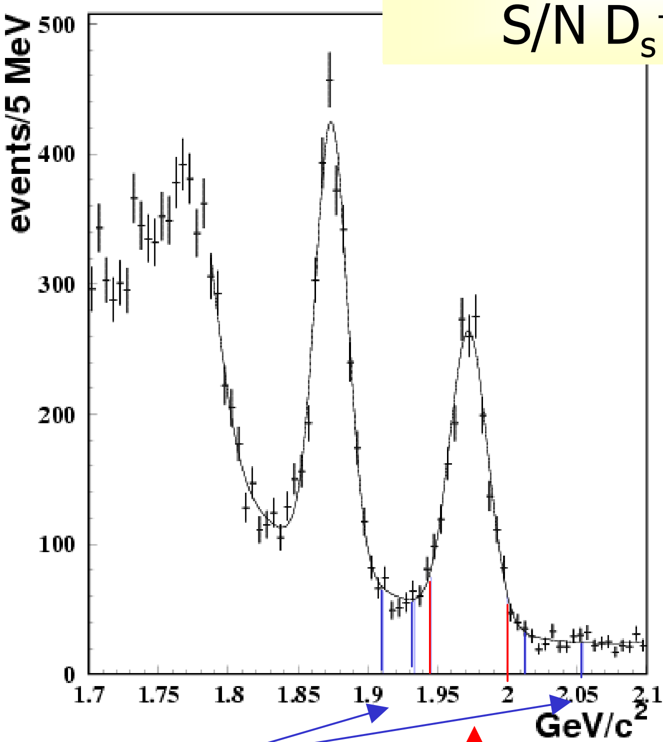
V.V Anisovich and A.V.Sarantsev Eur.Phys.J.A16 (2003) 229

- **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

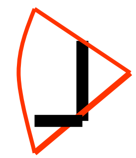
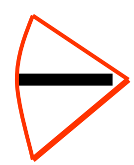
S/N D_s^+ = 3.41

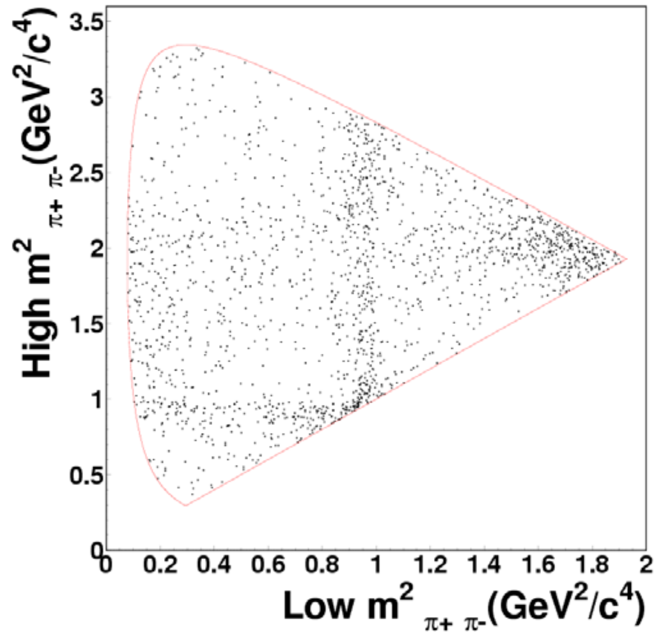


Sideband

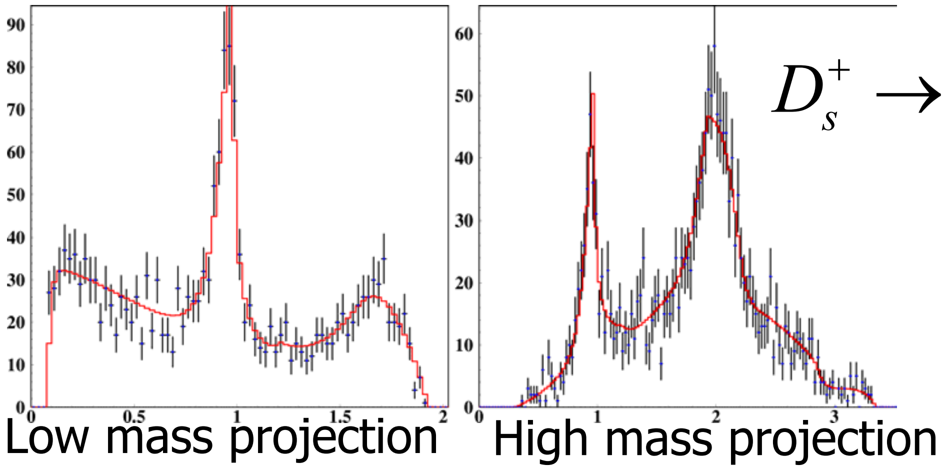
Signal

Observe:

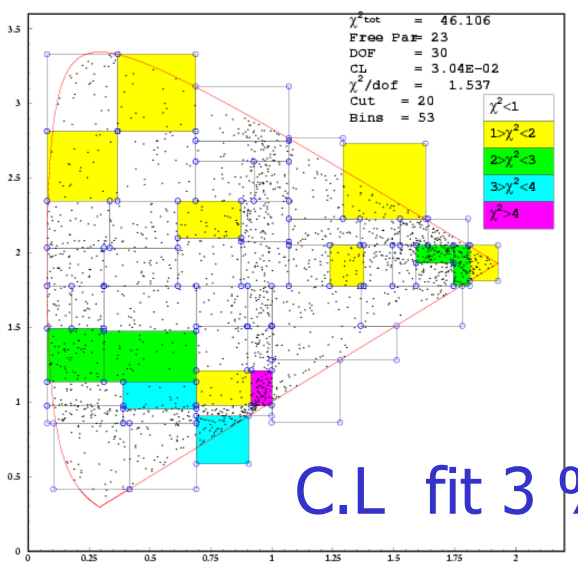
- $f_0(980)$ 
- $f_2(1270)$ 
- $f_0(1500)$ 



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

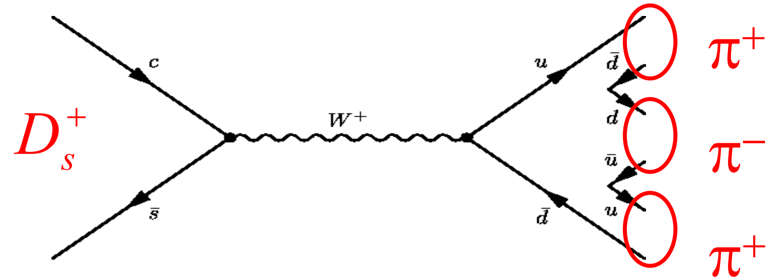


$$D_s^+ \to \pi^+\pi^-\pi^+$$

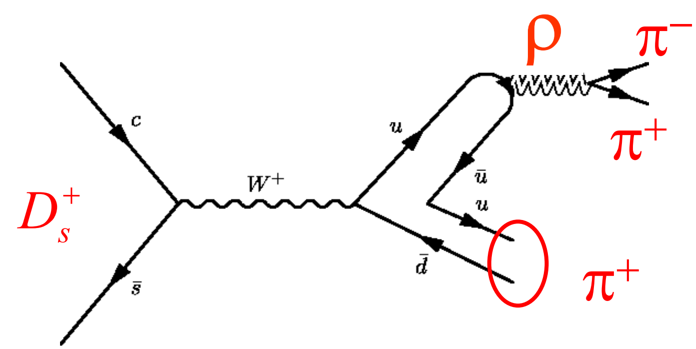


decay channel	fit fractions (%)	phase (deg)
$(S-wave)\pi^+$	$87.04 \pm 5.60 \pm 4.17 \pm 1.34$	$0(fixed)$
$f_2(1270)\pi^+$	$9.74 \pm 4.49 \pm 2.63 \pm 1.32$	$168.0 \pm 18.7 \pm 2.5 \pm 21.7$
$\rho^0(1450)\pi^+$	$6.56 \pm 3.43 \pm 3.31 \pm 2.90$	$234.9 \pm 19.5 \pm 13.3 \pm 24.9$

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



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

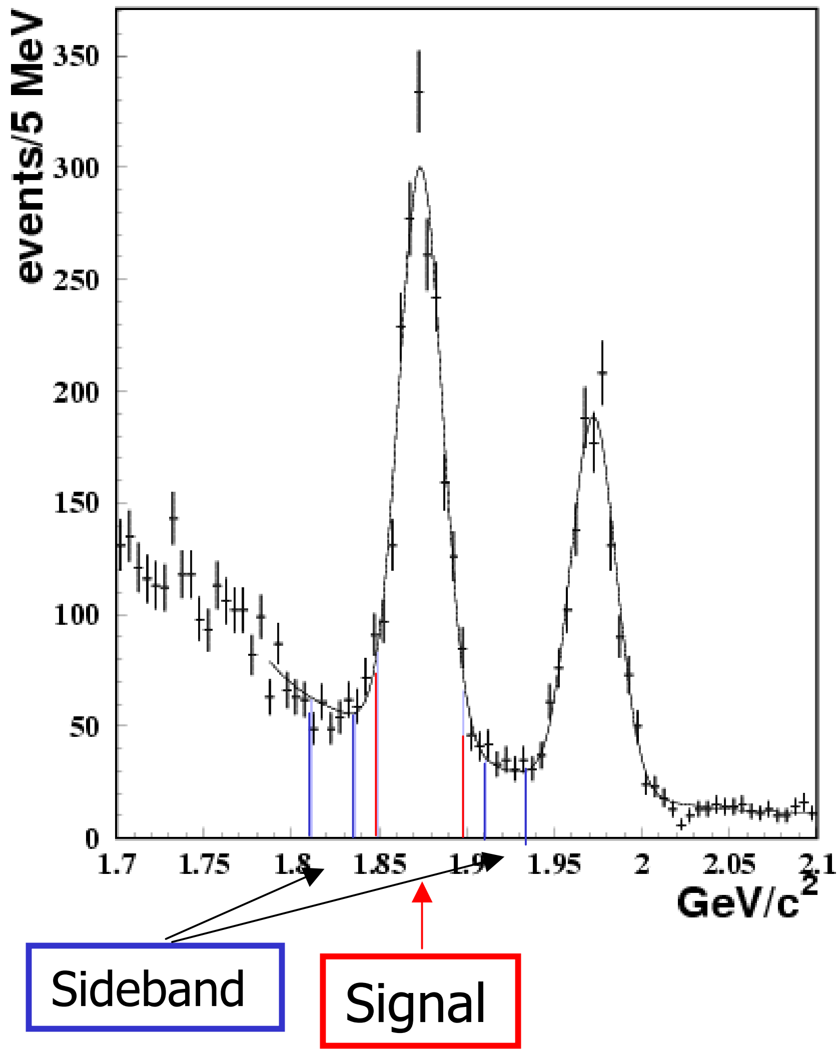


⬇

Marginal role of annihilation in charm hadronic decays

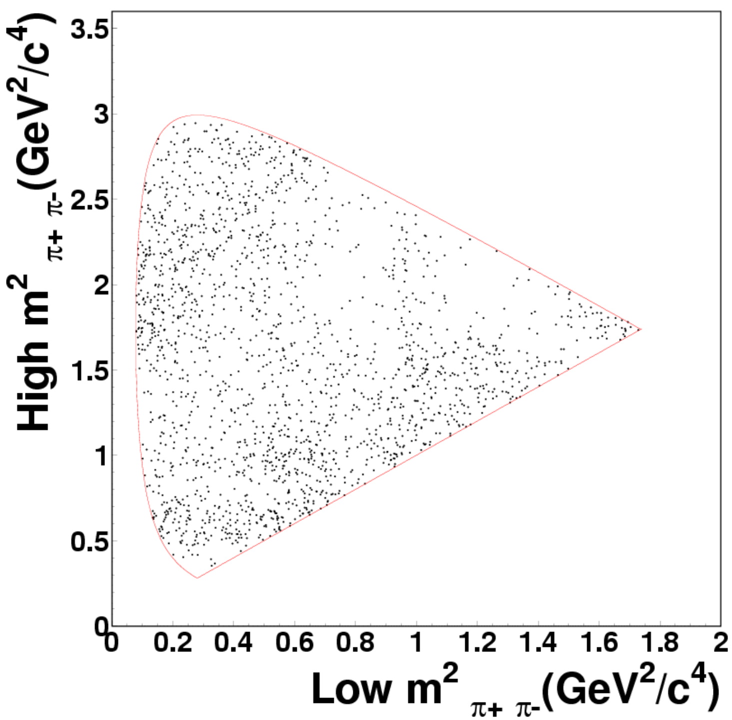
But need more data!

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

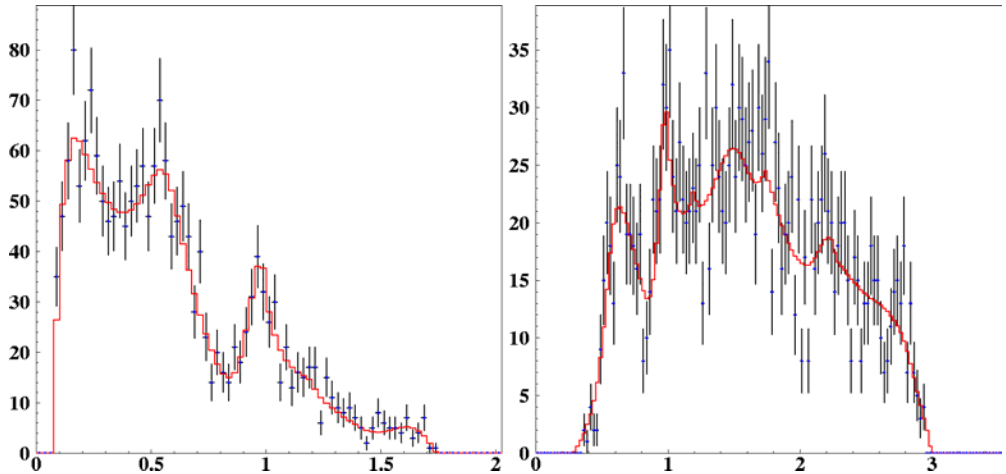


Yield D^+ = 1527 ±51

S/N D^+ = 3.64

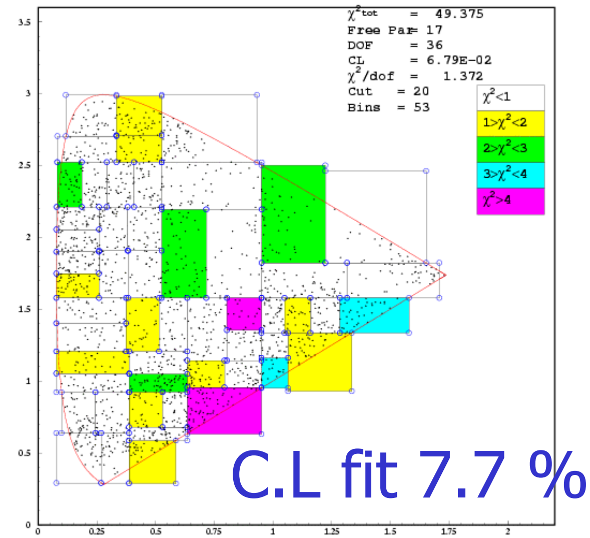


$D^+ \to \pi^+\pi^-\pi^+$ *K*-matrix fit results



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.

BES 2004 (Zhu, LaThuile 04)

2. σ and κ analyses

σ in $J/\psi \to \omega\pi^+\pi^-$

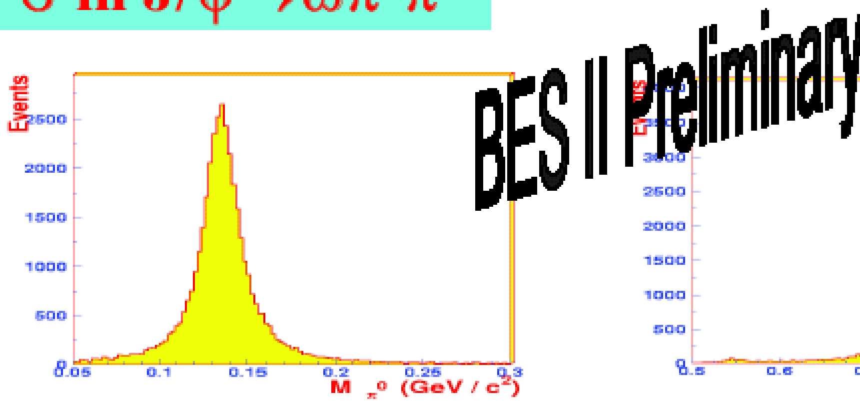


Figure 1: π^0 signal

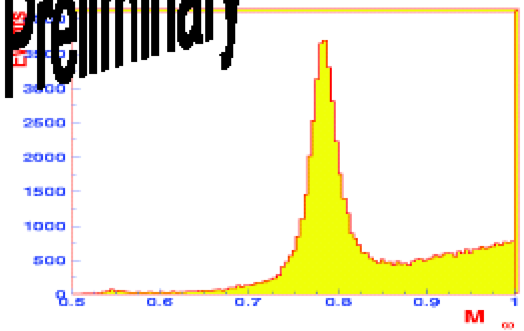


Figure 2: ω signal

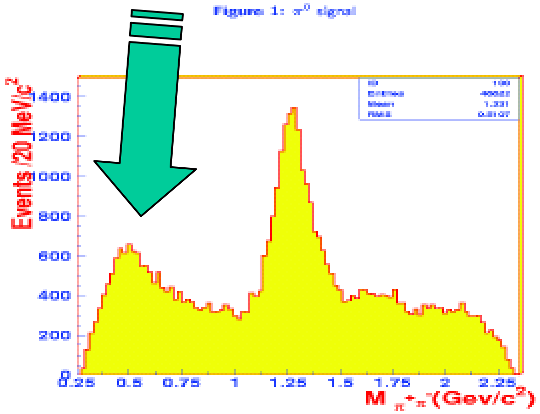
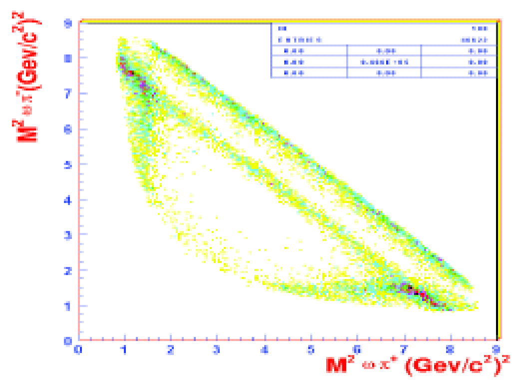


Figure 3: The invariant mass spectrum of $\pi^+\pi^-$



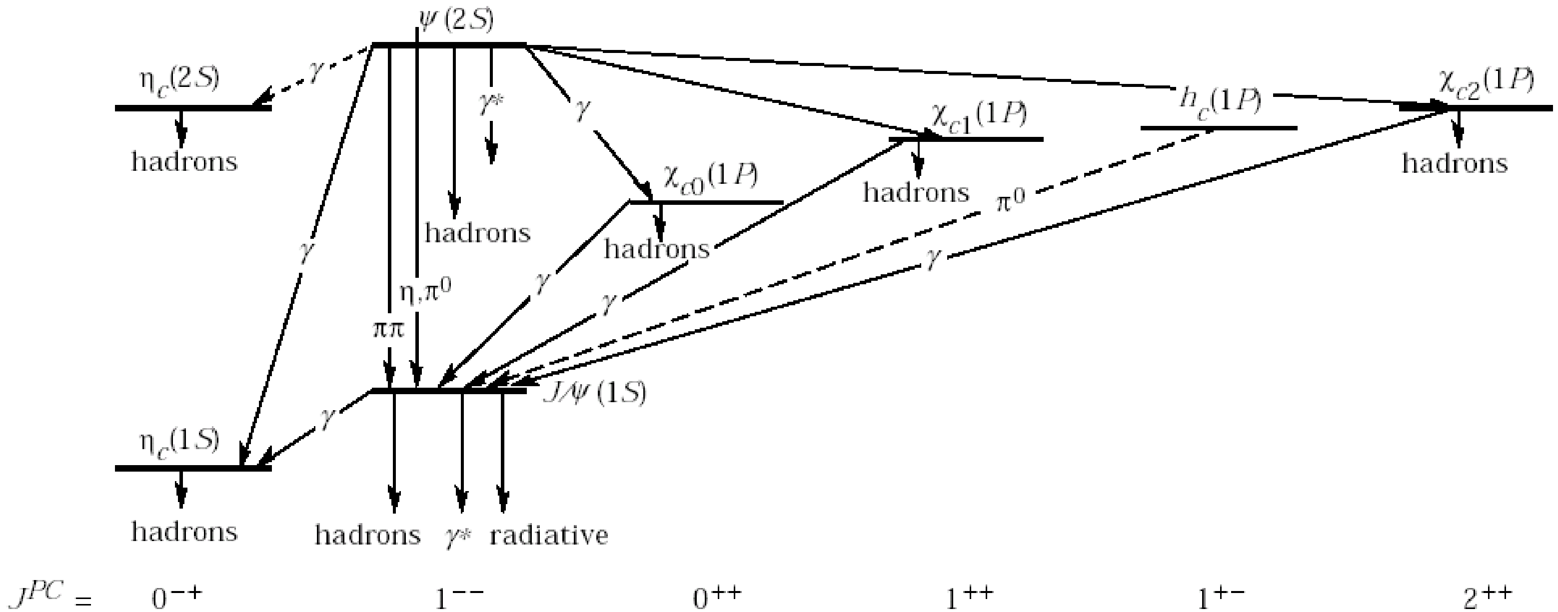
CONCLUSIONS (K-MATRIX)

- First DP analysis of D_s^+,$D^+ \rightarrow \pi^+\pi^+\pi^-$ charm decays using K-matrix formalism
  - Use information from light-quark scattering experiments (five virtual channels considered $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$, 4π). CONCLUSIONS:
    1. Non-resonant components are described by known two-body S-wave dynamics
    2. Negligible role of annihilation diagram in $D_s \rightarrow \pi^+\pi^+\pi^-$
  - Possible applications in $B \rightarrow \rho\pi$ (not discussed here)
  - DP analysis of D_s^+,$D^+ \rightarrow \pi^+\pi^+\pi^-$ charm decays using traditional isobar model is also in progress to compare to K-matrix model.

HOT PUZZLES IN SPECTROSCOPY

- Charmonium Spectroscopy
  CAVE:
  1. Lots of recent charmonium results from E835 (Patrignani's talk)
  2. Focussing on experimental data, for a theory review see Barabanov's talk
  3. No time to cover charmonium hadroproduction problem
  4. Ref.: excellent very recent reviews by V.Papadimitriou, C.Quigg LaThuile04
- L=1 Excited charm meson spectroscopy
- Exotica: doublecharm, c-5Q, etc etc

$c\bar{c}$ SPECTROSCOPY



Long-standing puzzle I

$\rho\pi$

- On general grounds one expects

$$Q_h \equiv \frac{BR(\psi' \to h)}{BR(J/\psi \to h)} \approx \frac{BR(\psi' \to e^+e^-)}{BR(J/\psi \to e^+e^-)} = (12.3 \pm 0.7)\%$$

- This is what we get for $p\bar{p}\pi^0$, $\pi^+\pi^-\omega$, etc but not for VP states such as

$Q_{\rho\pi}<0.23\%$, $Q_{K^{*+}K^-}<0.64\%$, $Q_{K^{*0}\bar{K}^0}=(1.7\pm0.6)\%$ (BES 2000)

More results shown at LaThuile 2004 (Zhu)

- Proposed explanations:
  - Vector gluonium mixed with J/ψ but not ψ' (Freund , Nambu 75)
  - Large intrinsic c component in ρ (Brodsky Karliner 97)
  - NRQCD, color octect (Chen, Braaten 98)

Long-standing puzzle II
$1P^1$

- aka h_c, was claimed by R704 @ISR (1986)
- Found by E760 @Tevatron (1993)
  Phys.Rev.Lett.69:2337-2340,1992

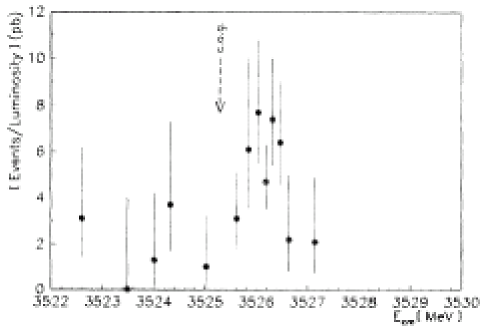


FIG. 2. Number of events per integrated luminosity vs center-of-mass energy; data are binned in 150-keV intervals in the average center-of-mass energy.

- Not confirmed by E835 (2002)

TO CHART

Long-standing puzzle III: η_c and $\eta_c(2S)$

- Conflicting results in the 80’s (DASP, Serpukhov, Mark II, Crystal B.)
- $\eta_c(2S)$ searched for by DELPHI and E835 and not confirmed
- Spotted by BELLE (2002) in B decays PRL 89 (2002) 102001-1 and in the recoil spectrum of $J/\psi\ c\bar{c}$

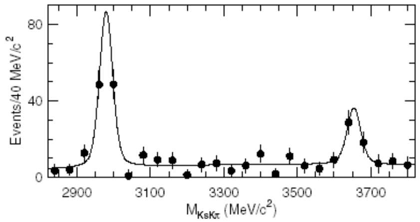


FIG. 3. The distribution of signal events from the simultaneous fits to M_{bc} and ΔE for each $K_S K\pi$ mass bin. The curve is the result of the fit described in the text.

TO CHART

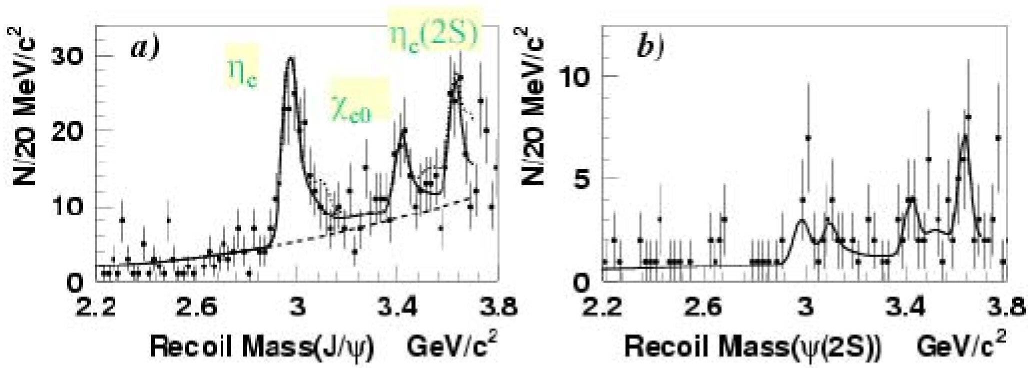
A somehow-newer puzzle
$J/\psi\ c\bar{c}$

Double $c\bar{c}$ production at BELLE

$e^+e^- \rightarrow J/\psi\ c\bar{c}$ $e^+e^- \rightarrow (c\bar{c})_{res}\ c\bar{c}$

PRL 89 (2002)142001
EPS-ID 562

101.8 fb $^{-1}$



$$\sigma(e^+e^- \rightarrow J/\psi\eta_c) = 46 \pm 6^{+7}_{-9}\ \text{fb}$$

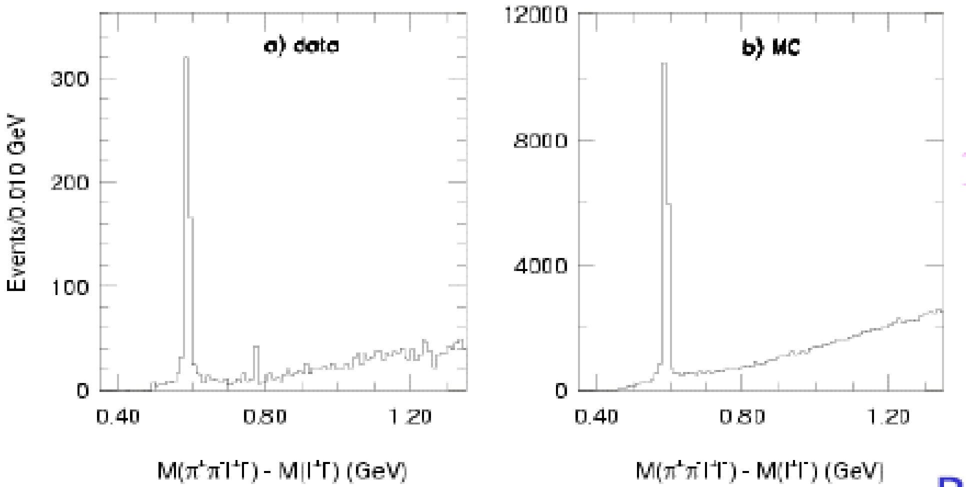
LO calculations: 2.31 ±1.09 fb

Vaia Papadimitriou (Fermilab) March 3, 2004

A brand-new puzzle
$X(3870) \rightarrow J/\psi\ \pi^+\pi^-$

- Discovered by BELLE in B decays
- Confirmed by CDF and D0 at the Tevatron in $p\bar{p}$ collisions
- A DD* bound state ?

Observation of X(3872) State at BELLE



PRL 91(2003)262001

140 fb^{-1}

152M $\Upsilon(4S) \to BB$ decays

$B^{\pm} \to K^{\pm} J/\psi \pi^+\pi^-$

$X \to J/\psi \pi^+\pi^-$

$R_{B\psi(2S)} = 6.3 \pm 1.4\%$

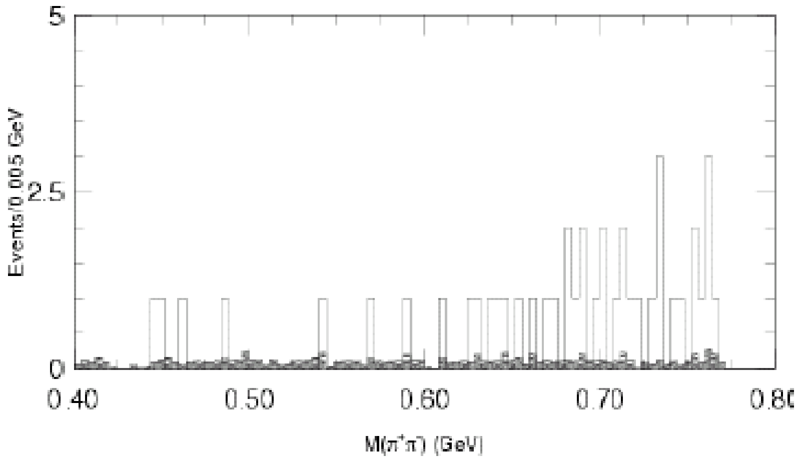
M = 3872.0 ± 0.6 (stat) ± 0.5 (syst) Me\

Width : 2.5 ± 0.5 MeV

489 ± 23 ψ(2S) events

35.7 ± 6.8 X events

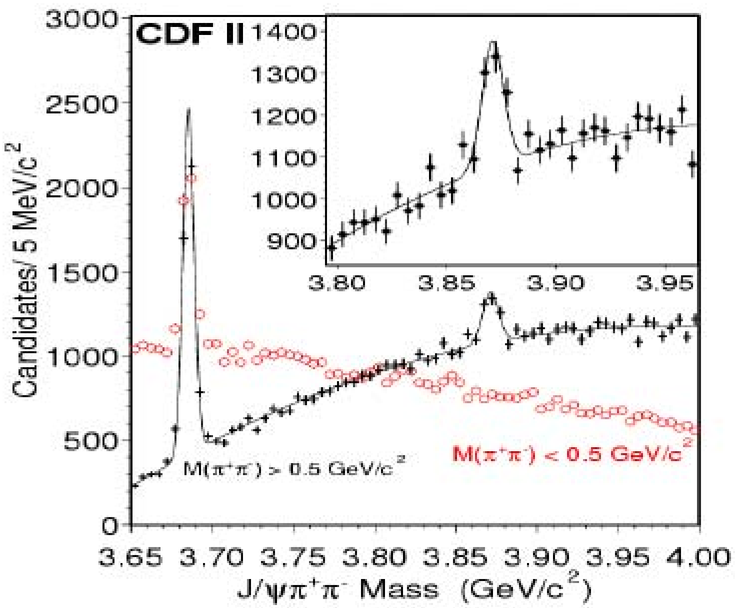
10.3 σ statistical significance



Vaia Papadimitriou (Fermilab)

hep-ex/0312021

Observation of X(3872) State at CDF



$X \to J/\psi\pi^+\pi^-$

$M_{\pi\pi} > 500$ MeV/c^2

3530 ± 100 ψ(2S) events

730 ± 90 X events

11.6 σ statistical significance

$M_{\psi(2S)}$ = 3685.65 ± 0.09 (stat) MeV/c^2

ψ(2S) Width : 3.44 ± 0.09 MeV/c^2

M_X = 3871.3 ± 0.7 (stat) ± 0.4 (syst) MeV/c^2

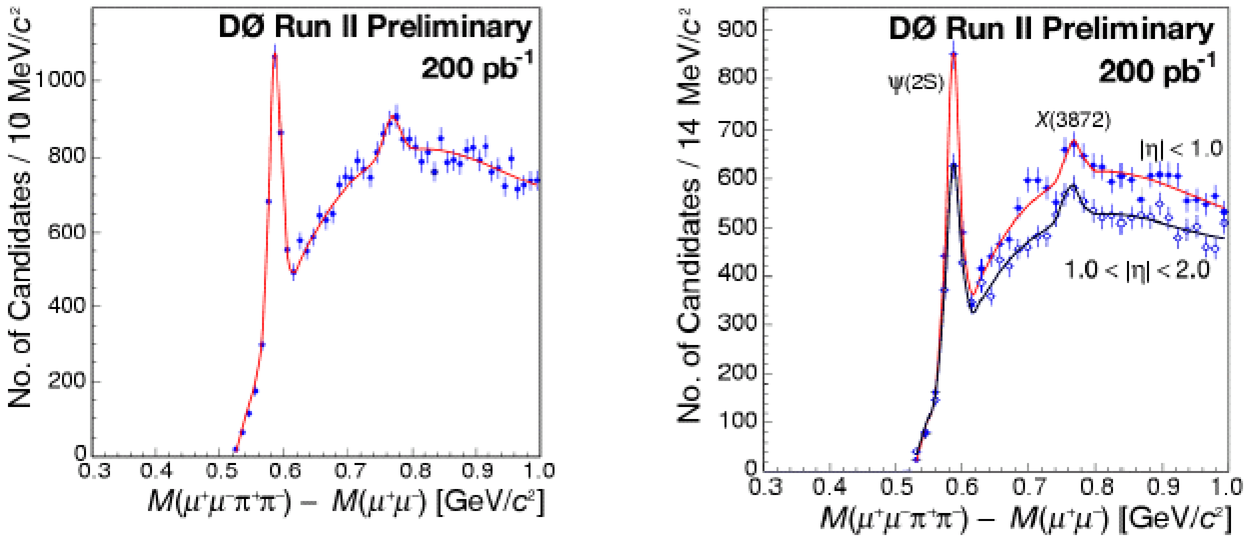
X Width : 4.9 ± 0.7 MeV /c^2

Vaia Papadimitriou (Fermilab) March 3, 2004

Observation of X(3872) State at D0   Moriond 2003

$M_{\pi\pi}$>520 MeV/c²

$X \rightarrow J/\psi\pi^+\pi^-$



ΔM = 768.4 ± 3.5 (stat) ± 3.9 (syst) MeV/c²

$\psi(2S)$ Width : 9.6 MeV/c²

X Width : 12.2 MeV /c²

1700 ± 109 $\psi(2S)$ events

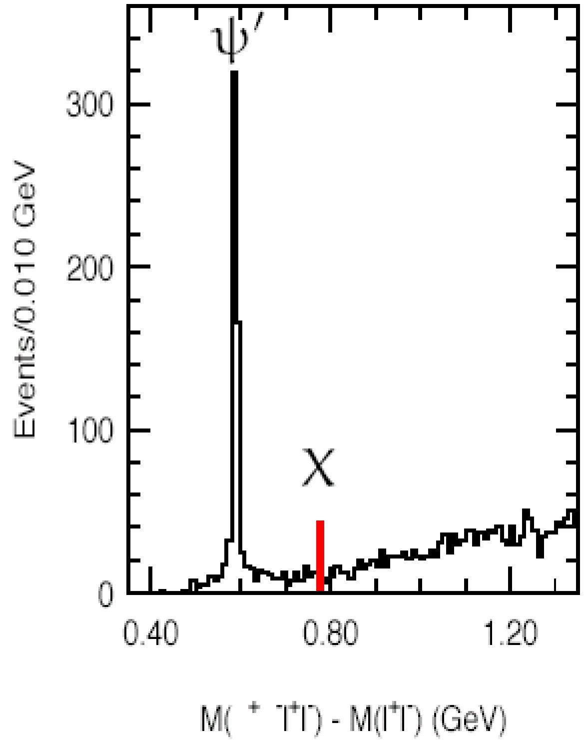
300 ± 61 X events

Vaia Papadimitriou (Fermilab)

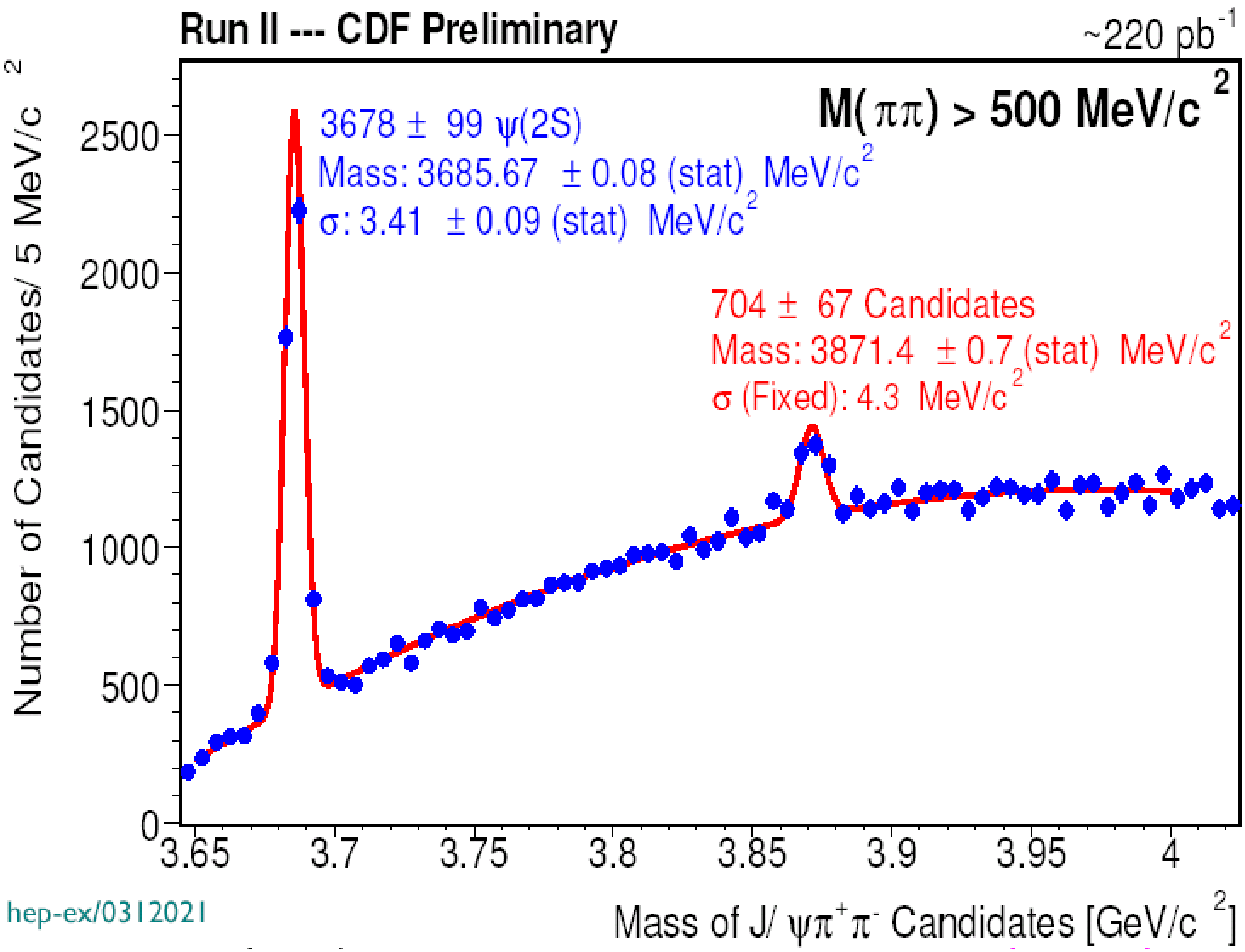
March 3, 2004

4.4 σ statistical significance

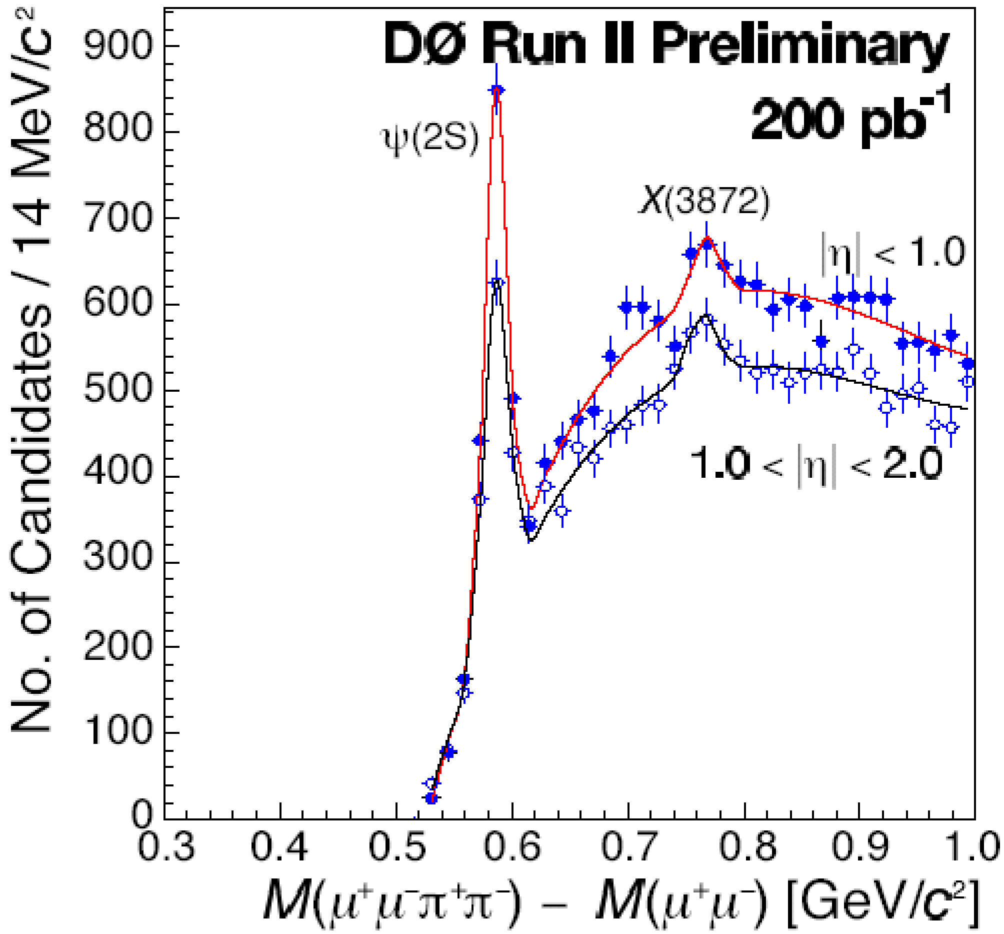
Belle $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$



Phys. Rev. Lett. 91, 262001 (2003)



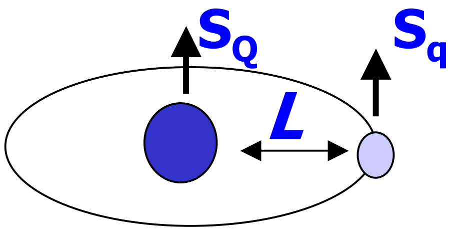
hep-ex/0312021



http://www-d0.fnal.gov/Run2Physics/ckm/Moriond_2003/X_conf_note_v9.ps

L=1 Excited Charmed Mesons

Charmed mesons spectroscopy chart (ante Spring 2003)

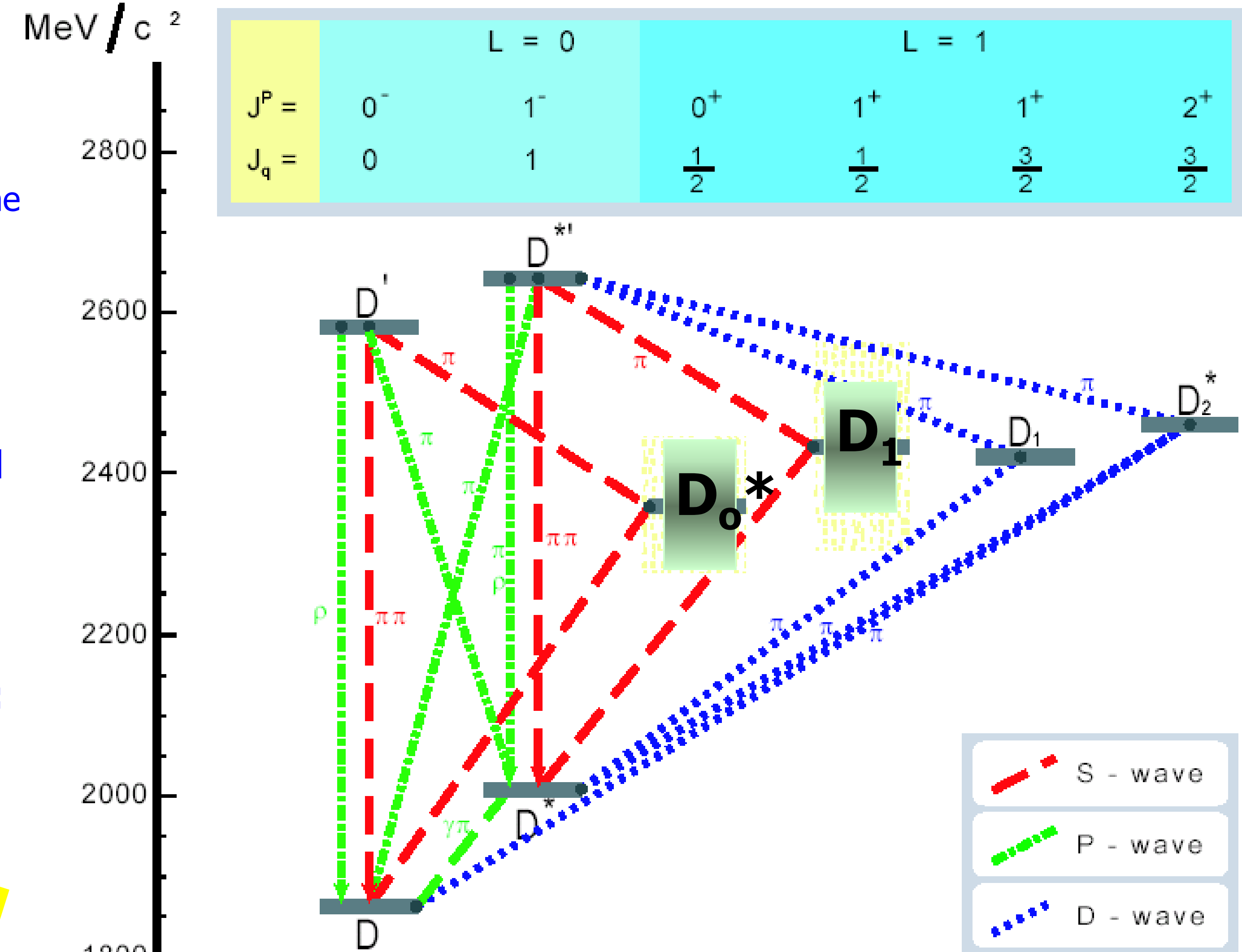


In the heavy-quark limit, the heavy-quark spin $\mathbf{S_Q}$ and the total angular momentum of the light-quark $\mathbf{j_q}$=**L**+**S** are conserved

PREDICTION #1: Each level is composed of a degenerate doublet of states with the same j_q and total angular momentum $J=j_q\pm\frac{1}{2}$.

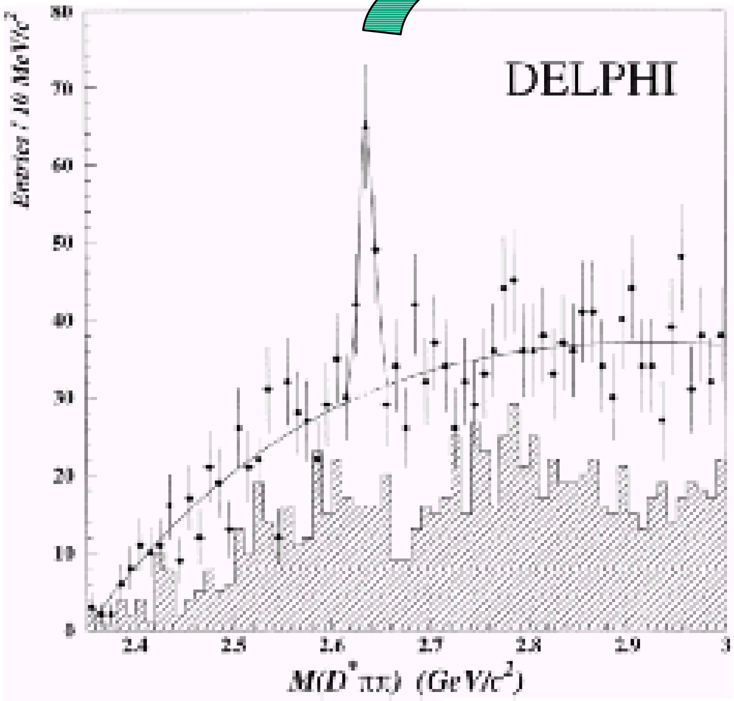
$j_q=\frac{1}{2}$ states are predicted to be broad (100-200MeV width). **PREDICTION #2:** FLAVOUR SYMMETRY

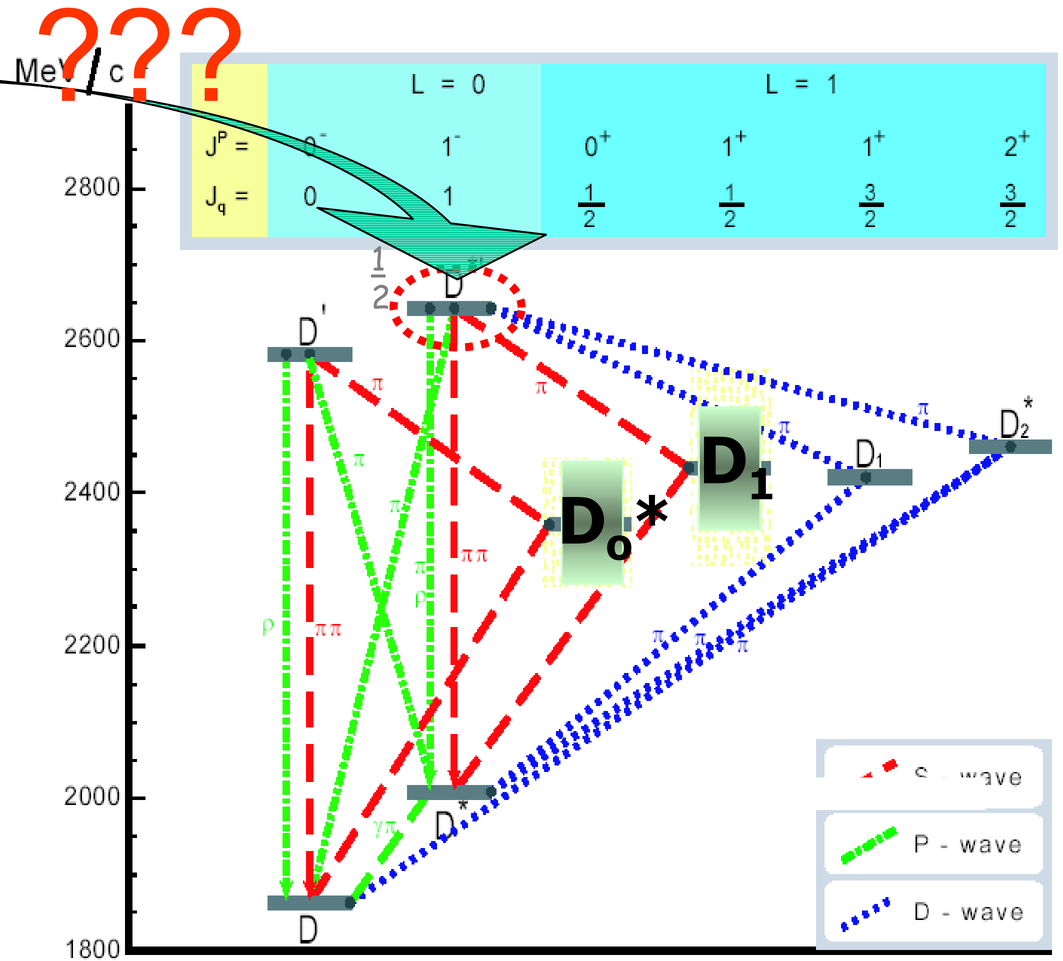
THIS PICTURE QUESTIONED BY BABAR AND CLEO DISCOVERY OF Dsj.



D*' ENIGMA

Observed by DELPHI (P.Abreu et al, PLB426, 231 (1998)) e not confirmed either by CLEO nor by OPAL.

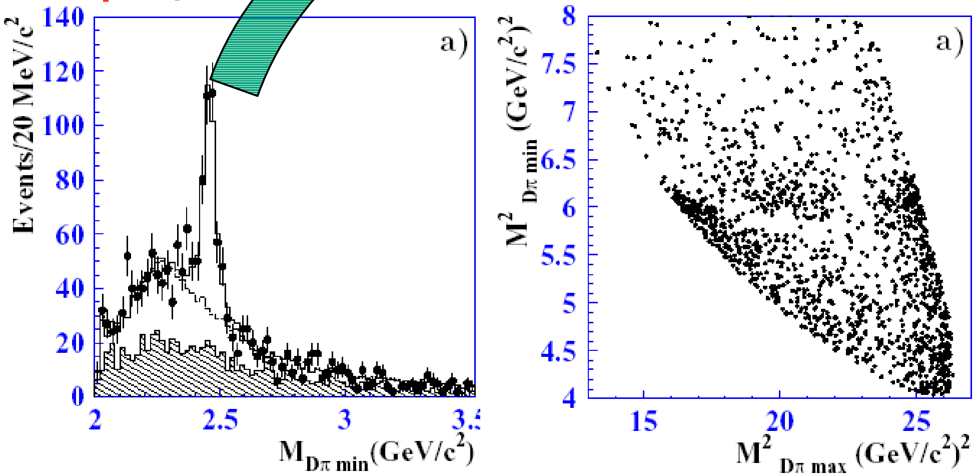


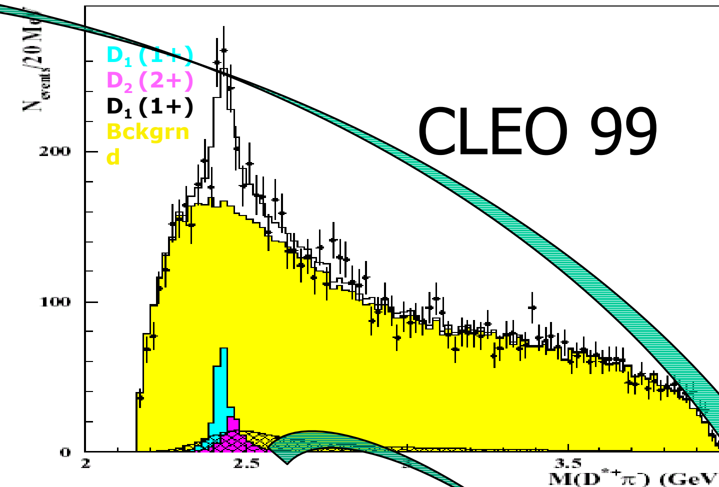


EVIDENCE OF BROAD STATES

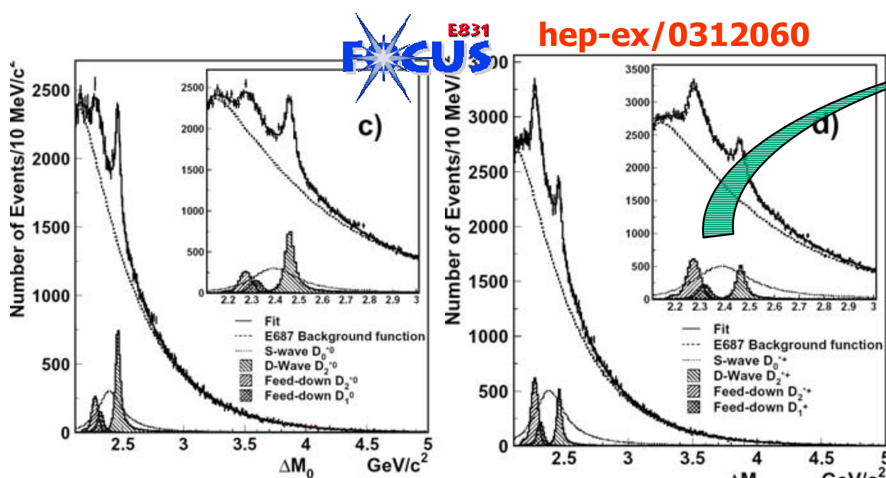
Observations by CLEO, BELLE, FOCUS

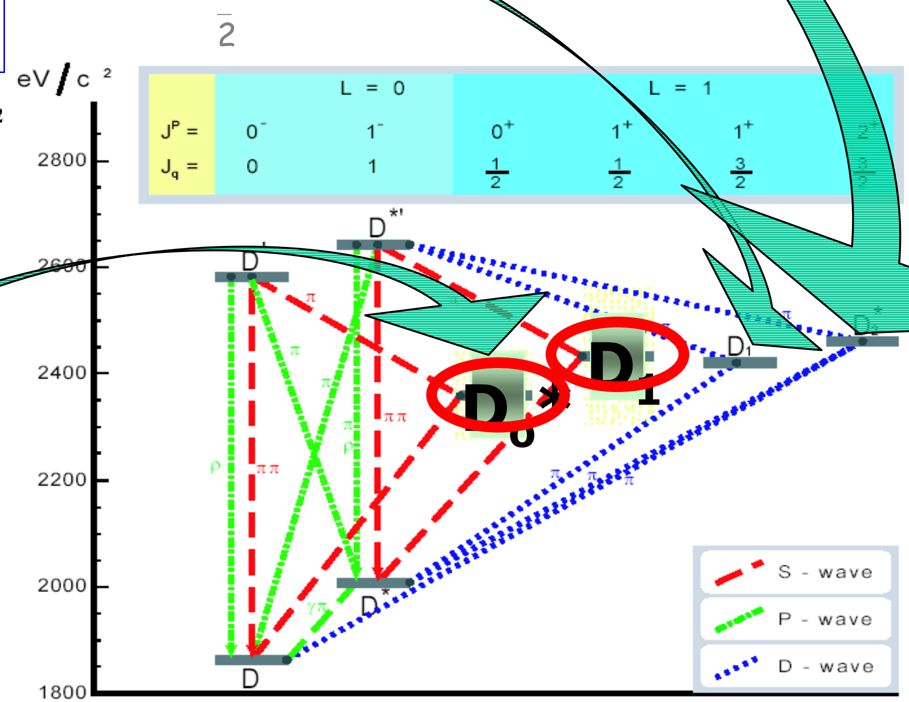
hep-ex/0307021





hep-ex/0312060

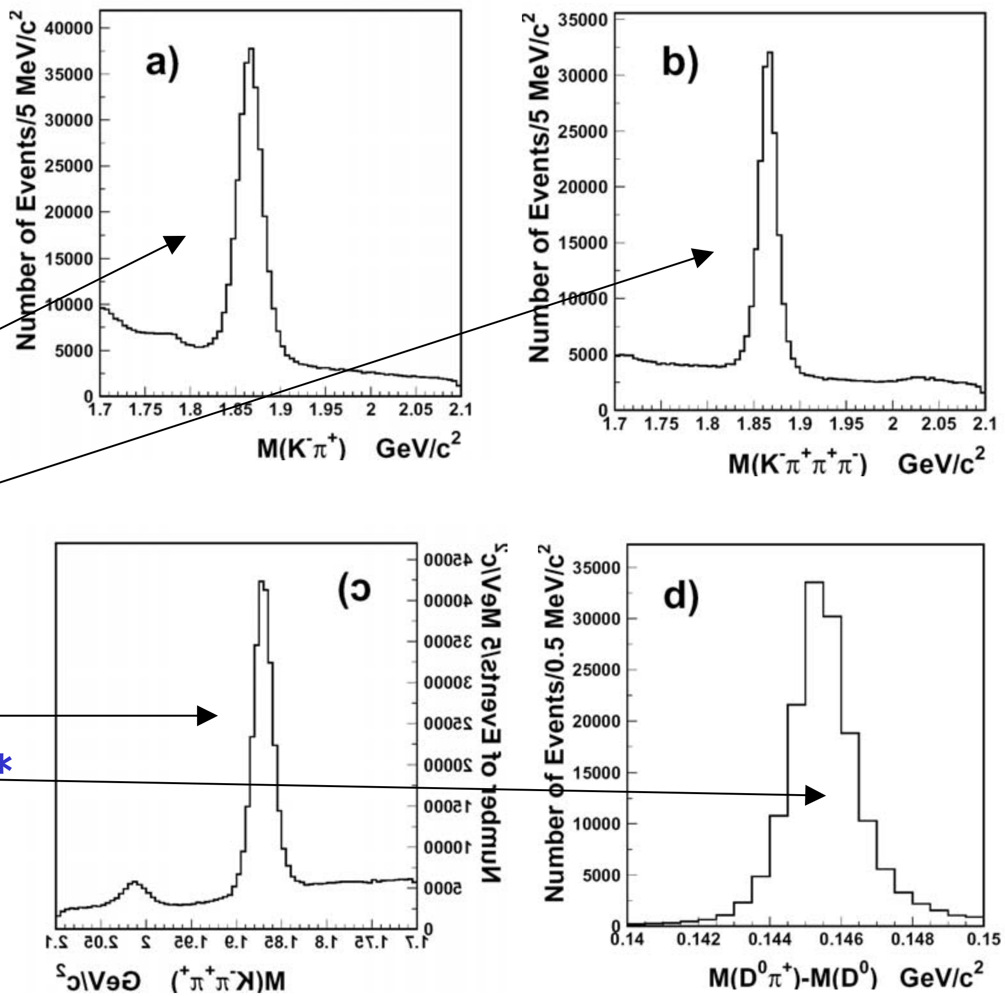




D and D* sample

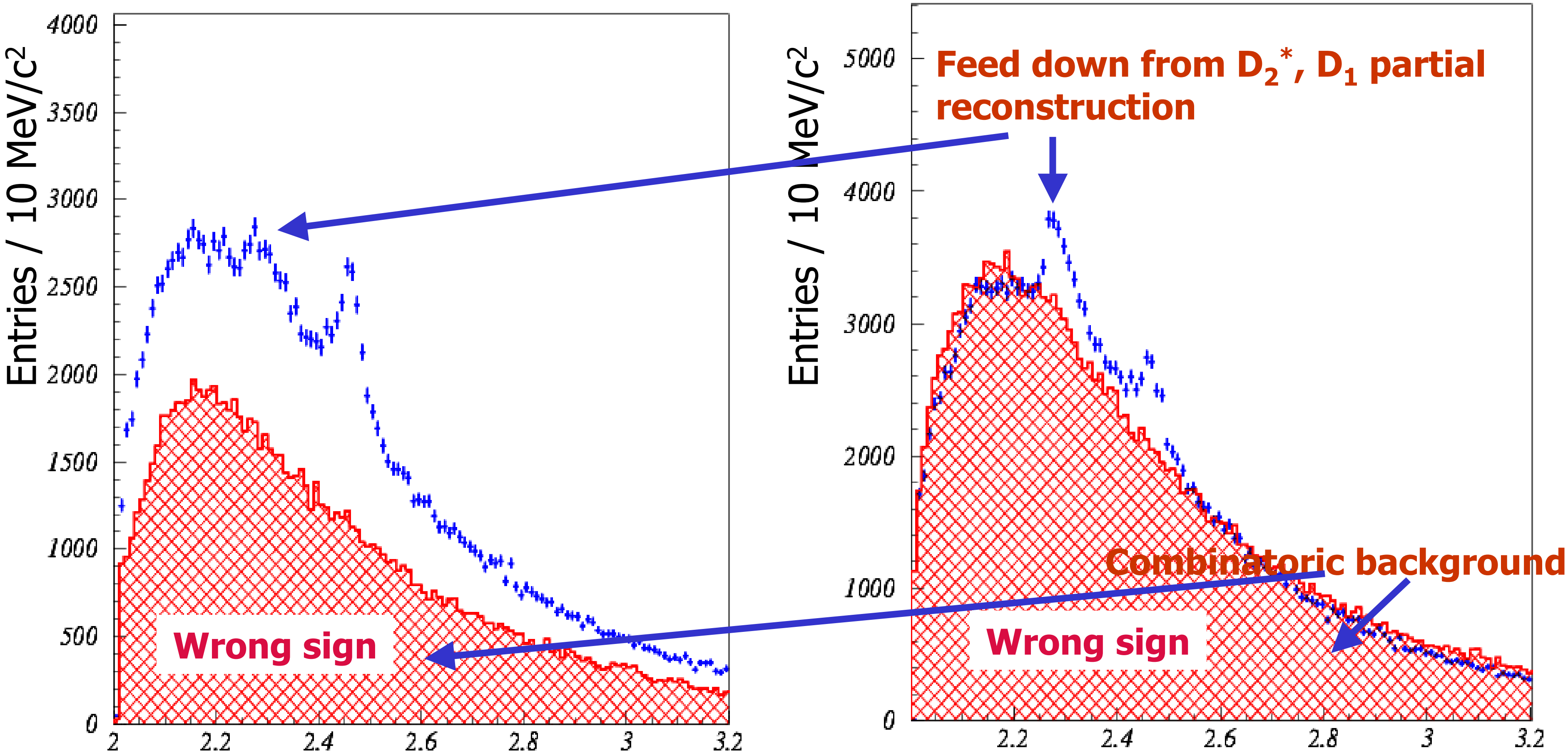
hep-ex/0312060

- **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

hep-ex/0312060



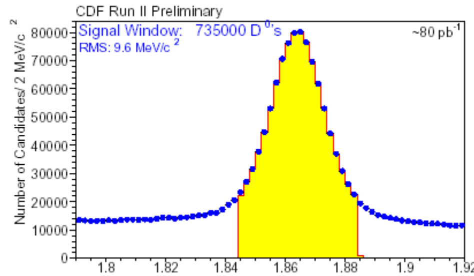
$M(D^+\pi^{--})$-$M(D^+)$+1.8693 (GeV/c²)

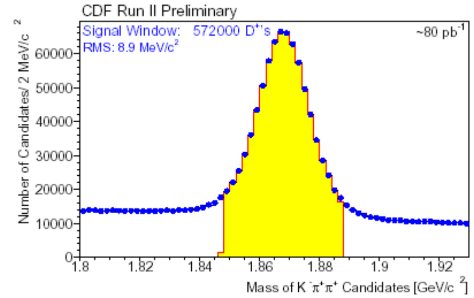
Shorthand: ΔM_0

$M(D^0\pi^+)$-$M(D^0)$+1.8646 (GeV/c²)

Shorthand: ΔM_+

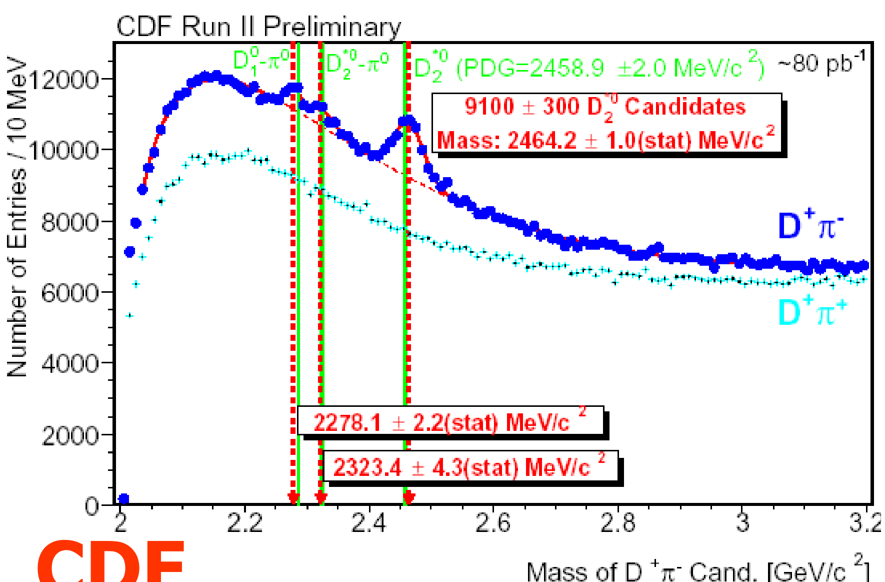
M.Shapiro, FPCP 2003 Paris

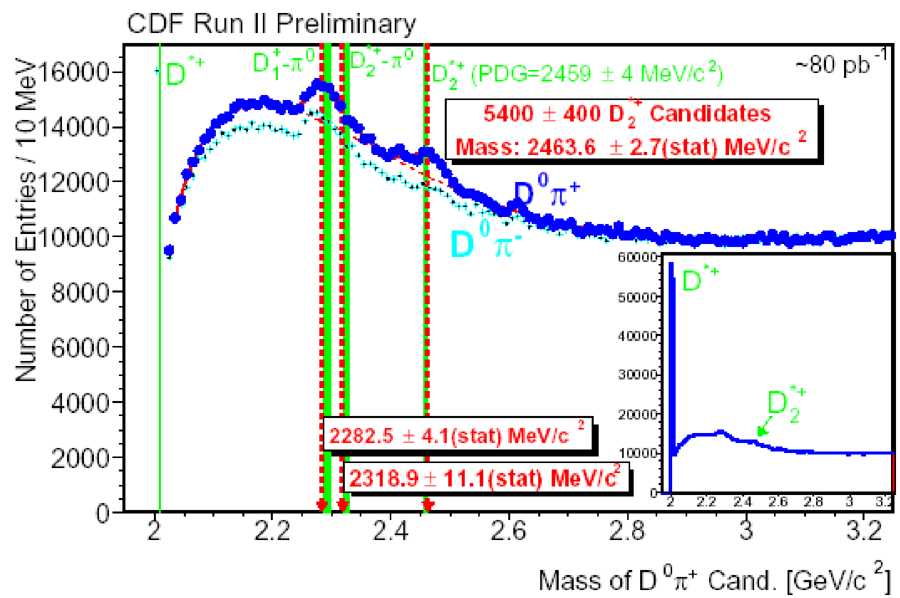




Benchmark I: $D_2^{*0} \to D^+\pi^-$

Benchmark II: $D_2^{*+} \to D^0\pi^+$





CDF

Greatly improved charm physics capabilities with impact parameter trigger using silicon vertex detector. Nonetheless, huge comb. bkgr at primary vertex. Hadroproduction not the best place to look for L=1 excited D mesons

PRE-SPRING 2003

The overall picture fairly well established, with a few puzzles remaining

j_q J^P L, n	1/2 0^+ 1, 1	1/2 1^+ 1, 1	3/2 1^+ 1, 1	3/2 2^+ 1, 1	1/2 0^- 0, 2	1/2 1^- 0, 2
Decay Mode	D_0^* $D\pi$	D_1 $D^*\pi$	$D_1(2420)$ $D^*\pi$	$D_2^*(2460)$ $D\pi, D^*\pi$	D'	$D^{*\prime}$ $D^*\pi\pi$
			Mass (MeV)			
PDG 0			2422 ± 2	2459 ± 2		
PDG ±			2427 ± 5	2459 ± 4		2637 ± 7
FOCUS 0	2407 ± 41			2464 ± 2		
FOCUS ±	2403 ± 38			2468 ± 2		
BELLE 0	2308 ± 36	2427 ± 36	2421 ± 2	2461 ± 4		
DELPHI ±		2470 ± 58				
CLEO 0		2461 ± 51				
Theory	2400	2490	2440	2500	2580	2640
			Width (MeV)			
PDG 0			19 ± 4	23 ± 5		
PDG ±			28 ± 8	25 ± 7		< 15
FOCUS 0	240 ± 77			39 ± 6		
FOCUS ±	283 ± 42			34 ± 8		
BELLE 0	276 ± 66	384 ± 114	24 ± 5	46 ± 8		
DELPHI ±		160 ± 77				
CLEO 0		290 ± 100				
Theory	> 170	> 250	20-40	20-40		40-200
Decay Mode	D_{s0}^*	D_{s1}	$D_{s1}(2536)$ D^*K	$D_{s2}^*(2573)$ DK	D_s'	$D_s^{*\prime}$
			Mass (MeV)			
PDG ±			2535.3 ± 0.6	2572.4 ± 1.5		
FOCUS ±			2535.1 ± 0.3	2567.3 ± 1.4		
Theory	2480	2570	2530	2590	2670	2730
			Width (MeV)			
PDG ±.			<2.3 90 % cl	15 ± 5		
FOCUS ±			1.6 ± 1.0	28 ± 5		
Theory			< 1	10 – 20		

$c\bar{u}$

$c\bar{s}$

D_{SJ} OBSERVATIONS BY BABAR CLEO BELLE

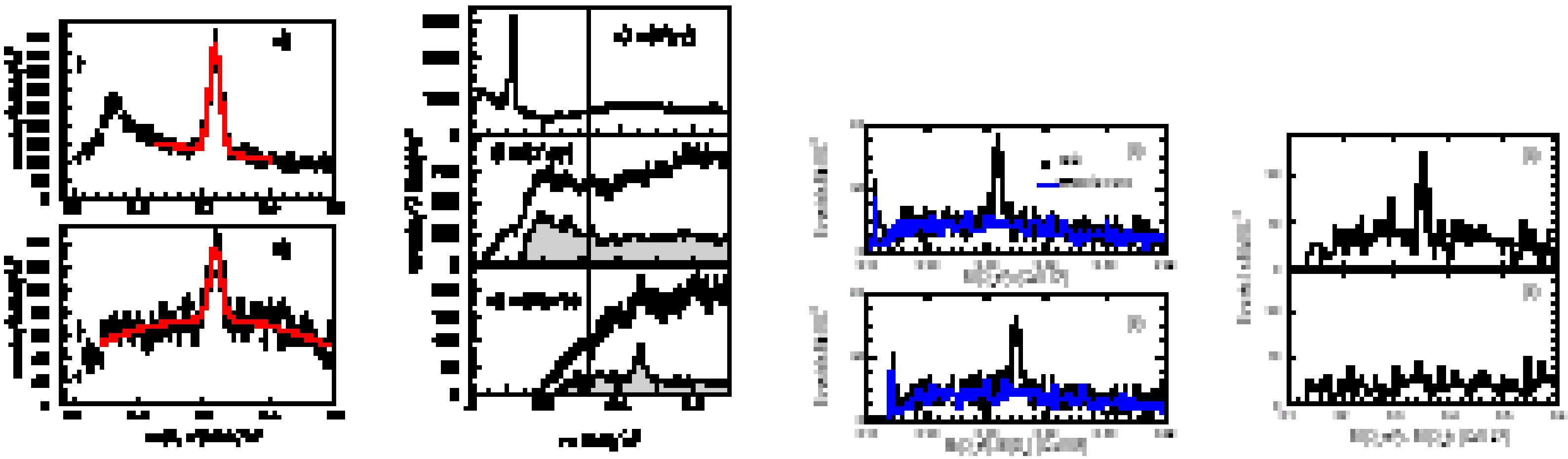


Fig. 16. – *New $D^*_{s0+}(2317)$ and $D^*_{s1+}(2463)$ states observed by BABAR (a,b) [209] and CLEO (c,d) [210].*

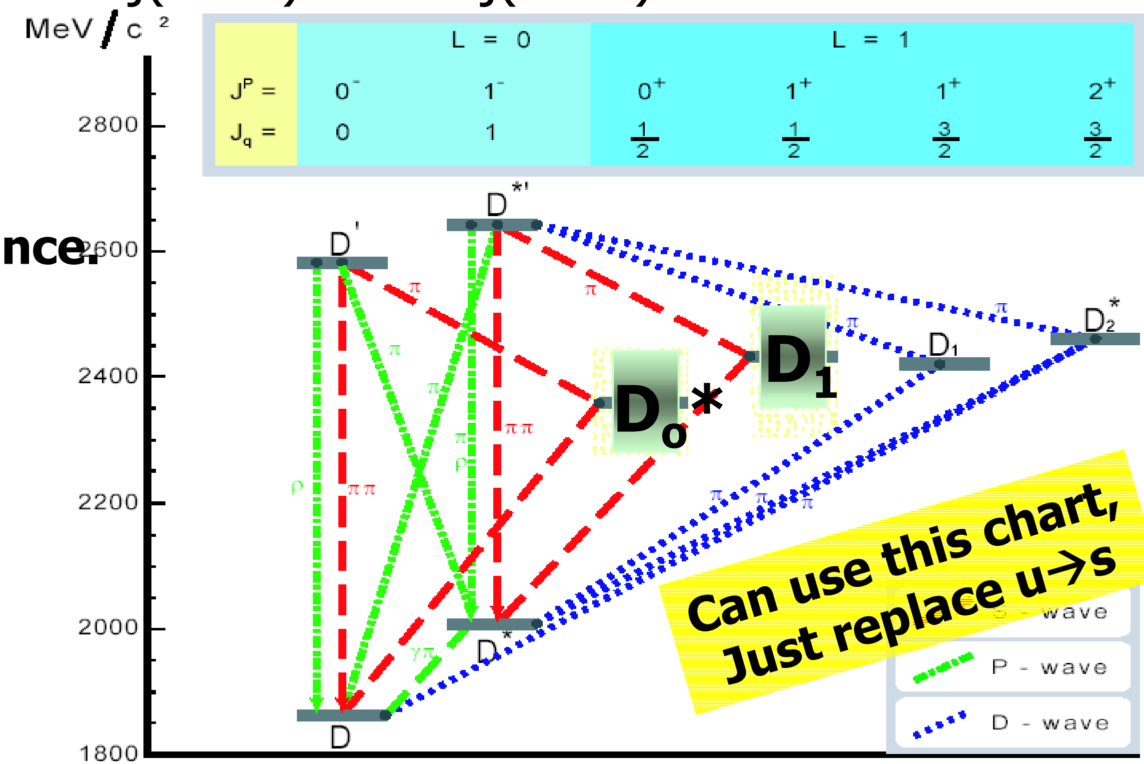
- BABAR finds prominent narrow resonance Dsj(2317)→$Ds^+ \pi^0$
- CLEO finds prominent narrow resonance Dsj(2463)→$Ds^{*+} \pi^0$
- BELLE finds evidence for Dsj(2463)→$Ds^+\gamma$ and determines JP=1+ for Dsj(2463)

TO CHART

D_{SJ} OBSERVATIONS BY BABAR CLEO BELLE

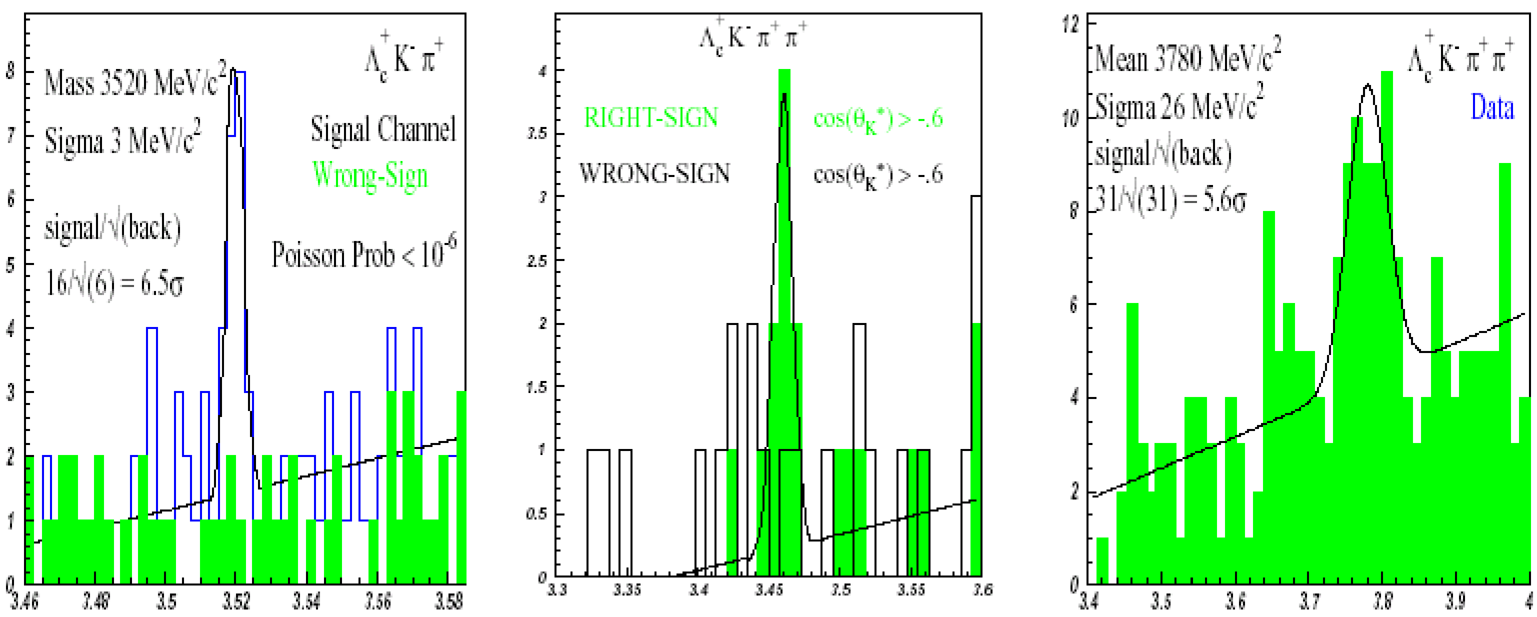
1. It seems natural to interpret Dsj(2317) and Dsj(2463) as 0^+ and 1^+ states, respectively;
2. They are narrow because below the DK threshold, and therefore isospin-violating;
3. Much lower mass than the 1^+ (2535) and 2^+ (2572) "narrow" partners;
4. Where are the corresponding $c\bar{u}$ states (if flavour symmetry applies) ???
   They should be lighter than Dsj(2317) and Dsj(2463).

Bardeen Eichten Hill
hep-ph/0305049 :
Combine HQS and chiral invariance.
Form doublets (Ds,D*s) with
(D_{s0+},D_{s1+})



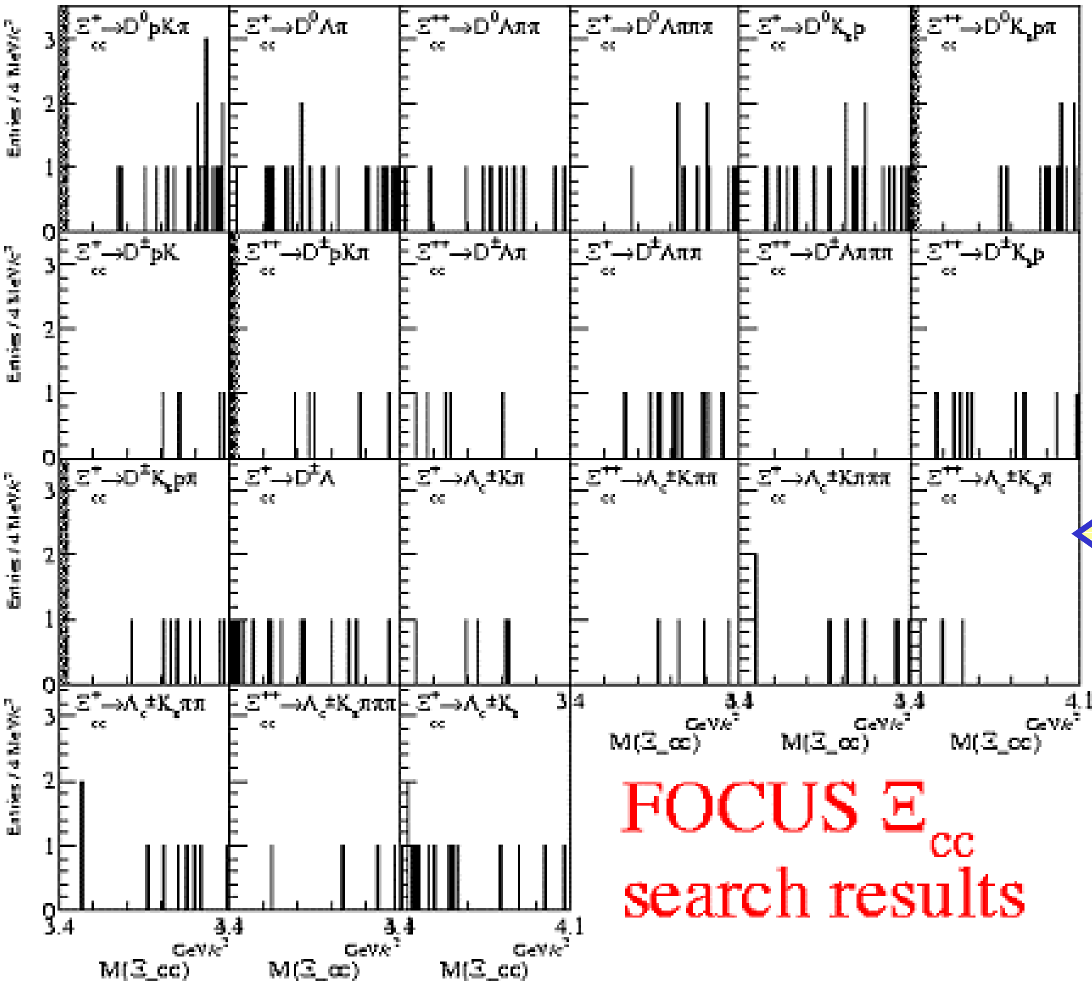
THE SELEX DOUBLECHARM BARYONS RIDDLE

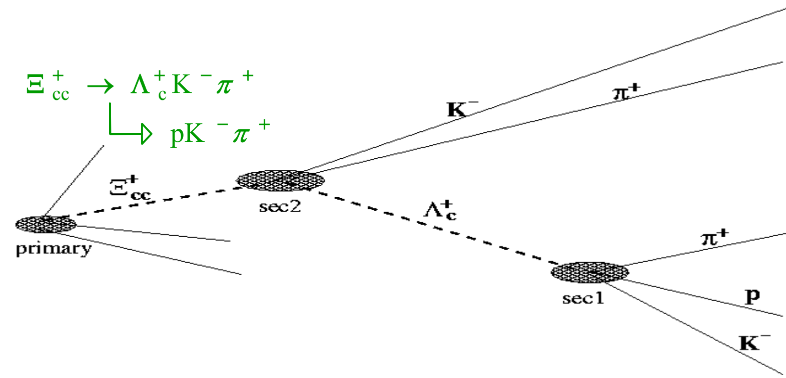
ccd^+ ccu^{++} ccu^{*++}



An extensive search was conducted in 2000 using:

~20,000 $\Lambda^{+}_{c} \to pK\pi$ + ~1.2 million $D^{+,0}$ ($K\pi$, $K2\pi$, $K3\pi$)



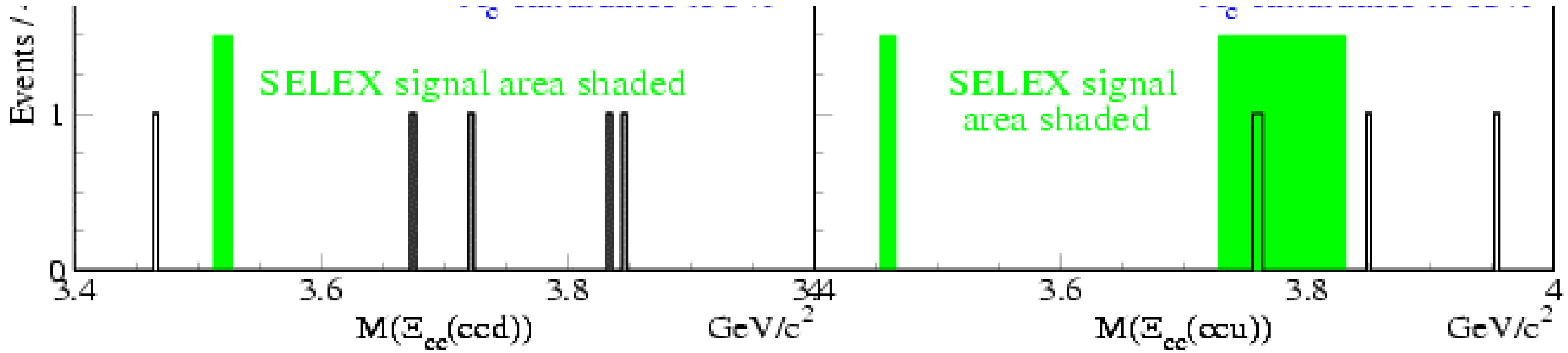


14 $\Xi_{cc}(D^{0,\pm}X)$ and 7 $\Xi_{cc}(\Lambda^{+}_{c}X)$ decay modes searched

FOCUS Ξ_{cc} search results

No evidence of Ξ_{cc}

FOCUS data for SELEX decay modes



Decay Mode	$\Xi_{cc}^{+} \rightarrow \Lambda_c^+ K^- \pi^+$		$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$	
Experiment	FOCUS	SELEX	FOCUS	SELEX
Ξ_{cc} Events	< 2.21 @ 90%	15.8	< 2.21 @ 90%	8
Reconstructed Λ_c	$19,444 \pm 262$	1650	$19,444 \pm 262$	1650
Efficiency Relative to Λ_c	5%	10%	13%	5%
Ξ_{cc}/Λ_c^+	<0.23% @ 90%	9.6%	<0.09% @ 90%	9.7%
$\frac{\text{SELEX}}{\text{FOCUS}}$ Relative $\frac{\Xi_{cc}}{\Lambda_c}$ Prod	> 42 @ 90%		> 111 @ 90%	

FOCUS efficiencies assume Ξ_{cc}^{+} (Ξ_{cc}^{++}) lifetime of 0.2 ps (1.0 ps), a mass of 3.6 GeV/c^2, and production characteristics of a 3.6 GeV/c^2 Ξ_c particle in Pythia

TERRA INCOGNITA

Charmonium Hybrids

well-suited for a hadron collider

Charm Supernuclei

need very ambitious vertex detector

<u>BREAKING NEWS</u>

H1 EVIDENCE FOR A CHARM 5Q hep-ex/0403017

M=3099 ± 3 (stat.) ± 5 (syst.) MeV

uudd$\bar{c}$ candidate

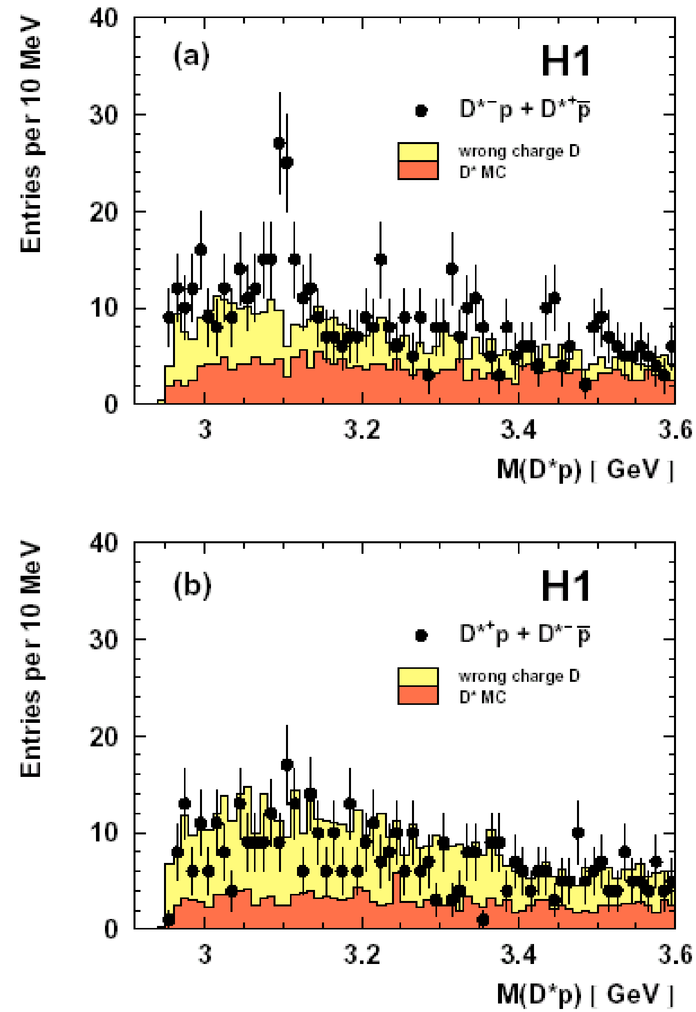
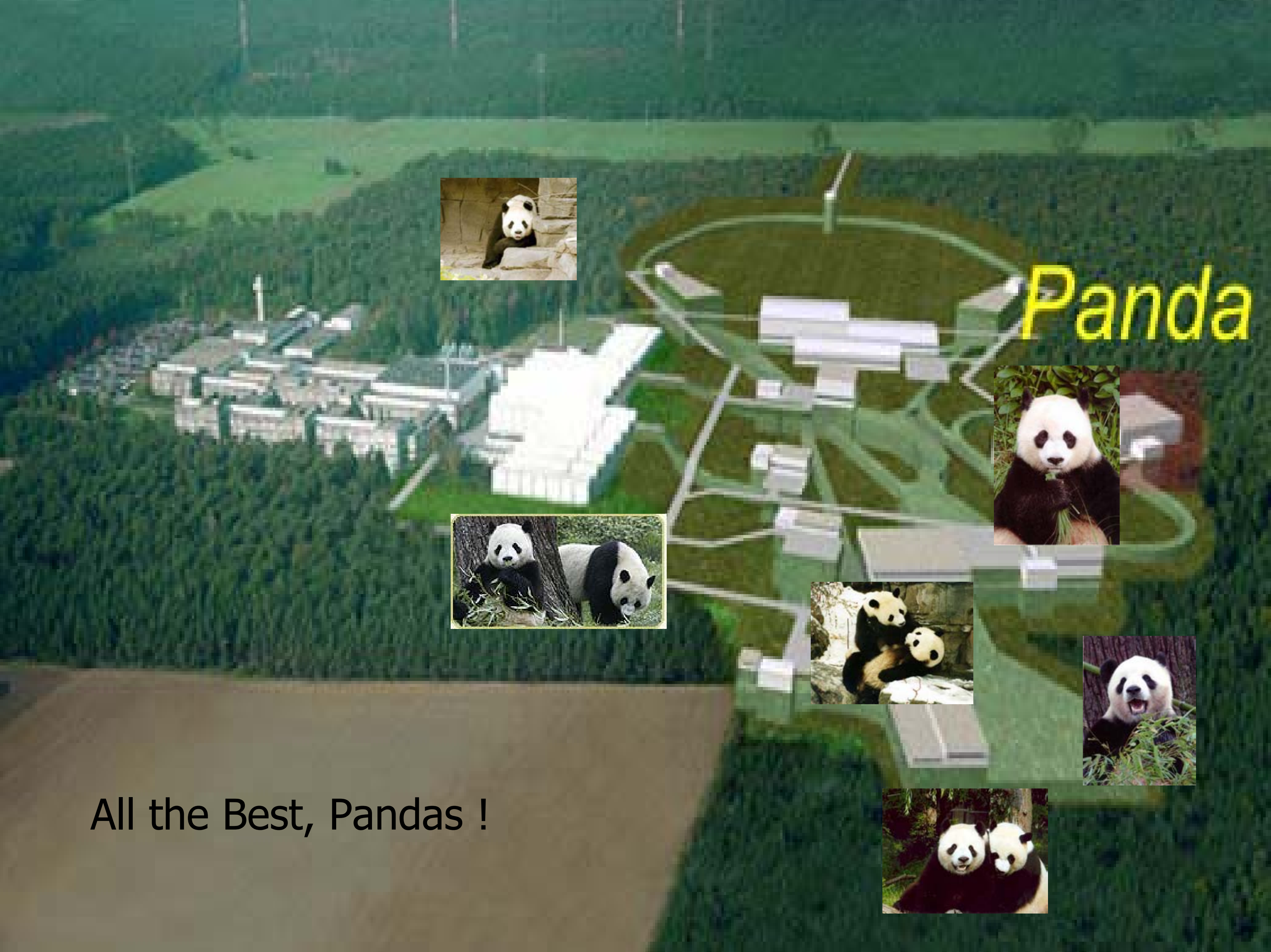


Figure 2: Distributions in $M(D^*p)$ for (a) opposite-charge and (b) same-charge D^*p combinations. The data are compared with a two-component background model in which "wrong charge D" $K^{\pm}\pi^{\pm}$ combinations are used to describe non-charm related background and the "D^* MC" simulation describes background involving real D^* mesons.

9

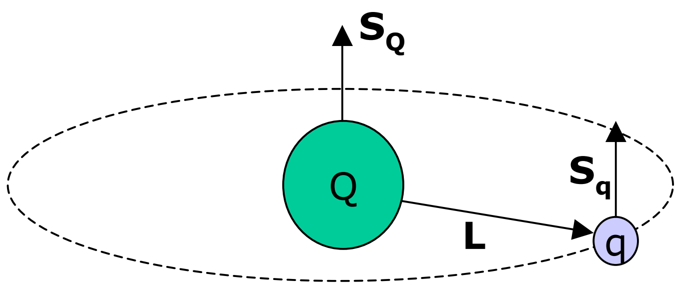
OUTLOOK AND CONCLUSIONS

- Lots of new charm quark physics results from B-factories, BES, CLEO-c, FOCUS, CDF, D0, H1, ZEUS …
- Future charm experiments: COMPASS, BTEV, PANDA, SuperB-factories,…
- Golden physics items:
  - New Physics in CP Violation asymmetries (or rare decays, not discussed here)
- Silver physics items:
  - Leptonic and semileptonic decays (decay constants, formfactors, etc)
  - Solving the puzzles in spectroscopy
- Due to its unique production mechanism, PANDA will have leading role in
  - $c\bar{c}$ spectroscopy;
  - Charm quark in nuclear matter, charm hybrids;
  - and perhaps CPV, but watch the competition by 2013 !


Panda
All the Best, Pandas !

-------QUESTION SLIDES-----

Models...HQS/HQET



"The hydrogen atom of QCD"

In the heavy-quark limit ($m_Q >> \Lambda_{QCD}$) the heavy quark spin $\mathbf{S_Q}$, the total angular momentum of the light quark $\mathbf{j_q = L + S_q}$ and the total angular momentum of the system $\mathbf{J = j_q + S_Q}$ are conserved

As m_Q increases the system properties are increasingly dominated by light quark dynamics.

If m_Q and $m_q >> \Lambda_{QDC}$ the system is described by a non-rel. Schrödinger equation with a generic two-body potential $V = V_c + V_{ss} + V_{so}$

With

V_c = central potential + linear confining term
V_{ss} = spin-spin potential + color hyperfine interaction ($1/m_Q m_q$)
V_{so} = spin-orbit potential + color magnetic term ($1/m_Q, 1/m_q, 1/m_Q m_q$)

If $m_Q \to \infty$ the meson spectrum consists of degenerated spin doublets with:

$$J^P = (s_{light} \pm \frac{1}{2})^P$$

In heavy-light system states with J =1 can mix.

Topical issue:
- Can HQS work with c-quark?

Flashing on lattice QCD

Reminder:
- Calculation are performed in discrete space-time lattice: lattice spacing << $1/M_{quark}$;
  - High computational requirements

- In the case of one heavy quark the dynamics can by written in powers of $1/M_{quark}$;

- HQET help to reduce computational requirements (NRQDC);

- NRQCD works well for bottom meson;

Topical issues:

o Is the charm mass heavy enough for NRQDC?

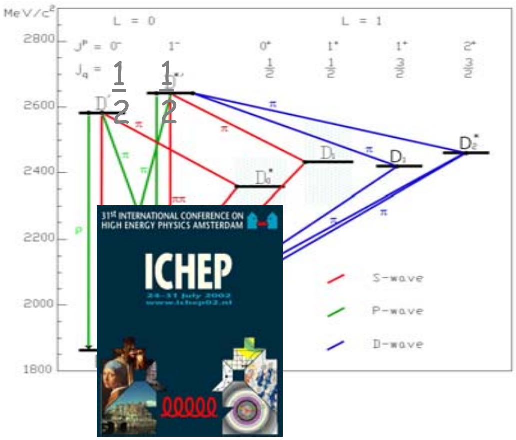
o Again mass splittings between P-wave mesons?

Synopsis of running and planned experiments

Ref: D.Pedrini LEPTRE, Roma 2001

Exp.	Beam	Lum.	Int. L (10**7 sec)	Cross Sec. cc	Cross Sec. bb	#evts cc prod.	#evts bb prod.	# evt cc ric. stima	Physics start date
BABAR	e+e- Y(4s) asym.	3 x 10**33 cm-2s-1	30 fb-1		1.2 nb		3.6 x 10**7	3.6 x 10**6	1999
BELLE	e+e- Y(4s) asym.	3 x 10**33 cm-2 s-1	30 fb-1		1.2 nb		3.6 x 10**7	3.6 x 10**6	1999
COMPASS	FT π-Cu	~ 1 x 10**32 cm-2 s-1	1 fb-1	~ 10 μb		10**9		~ 5 x 10**6	2001
CESR/ CLEO-C	e+e- 3-5 Gev	2 x 10**32 cm-2 s-1	2 fb-1	~ 10 nb		2 x 10**7		2 x 10**6	2003
BTeV	ppbar 2TeV	2 x 10**32 cm-2 s-1	2 fb-1	> 500 μb	100 μb	10**12	2 x 10*11	10**9	>2005
LHC-b	pp 14 TeV	2 x 10**32 cm-2 s-1	2 fb-1	> 500 μb	500 μb	> 10**12	10**12		>2005

clipboard



MeV/c²
L = 0
L = 1
S-wave
P-wave
D-wave
31st INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS AMSTERDAM
ICHEP

FLAVOR PHYSICS
& CP VIOLATION
(FPCP)
May 16-18, 2002
University of Pennsylvania
Philadelphia, PA, U.S.A.

VANDERBILT UNIVERSITY
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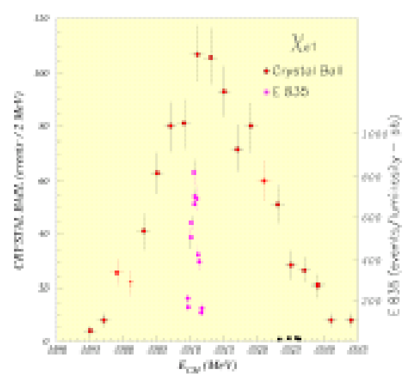
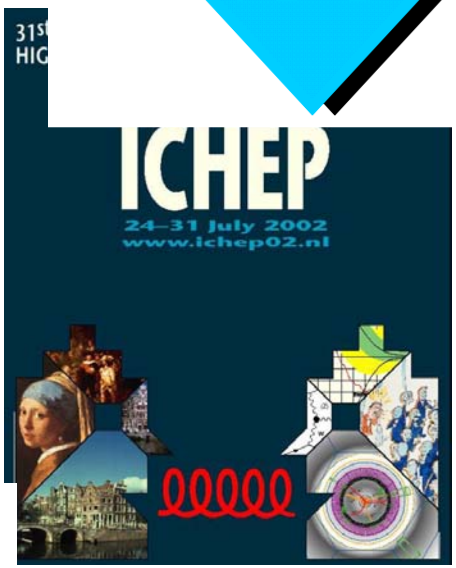
NEXT PHOTO
PREVIOUS PHOTO
VANDERBILT HOME

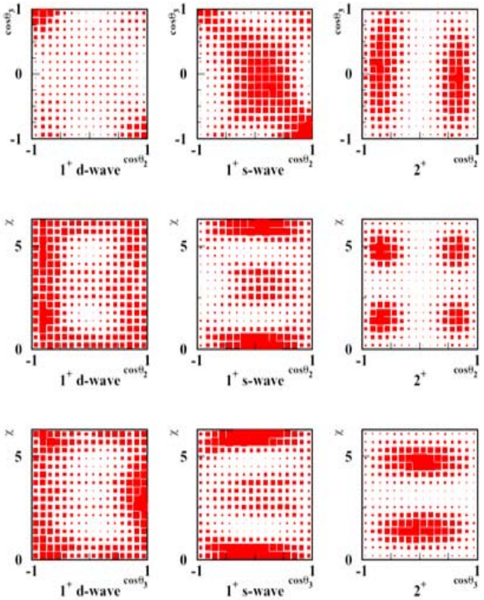


Crystal Ball
E 835



ICHEP
24–31 July 2002
www.ichep02.nl

D_1 Cleo L. Rodriguez. HQF98



Full partial wave analysis of the following decays:

$B^- \to D_j^0 \pi^-$

$D_j^0 \to D^{*+} \pi^-$

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

Data sample ~ 3.1 Million $B\bar{B}$ pairs

D_j is complete: is possible to distinguish the three L =1 states by angular distribution of final state.

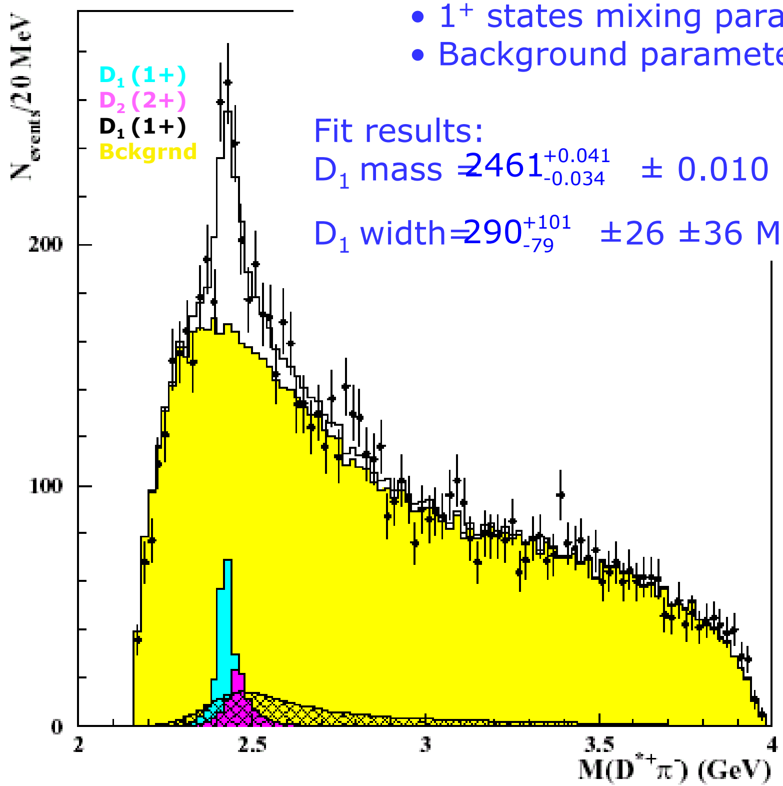
Fit function includes:

- Angular distribution term
- Narrow states fixed at PDG values)
- Strong phase shift
- 1^+ states mixing parameter
- Background parameterization

Fit results:

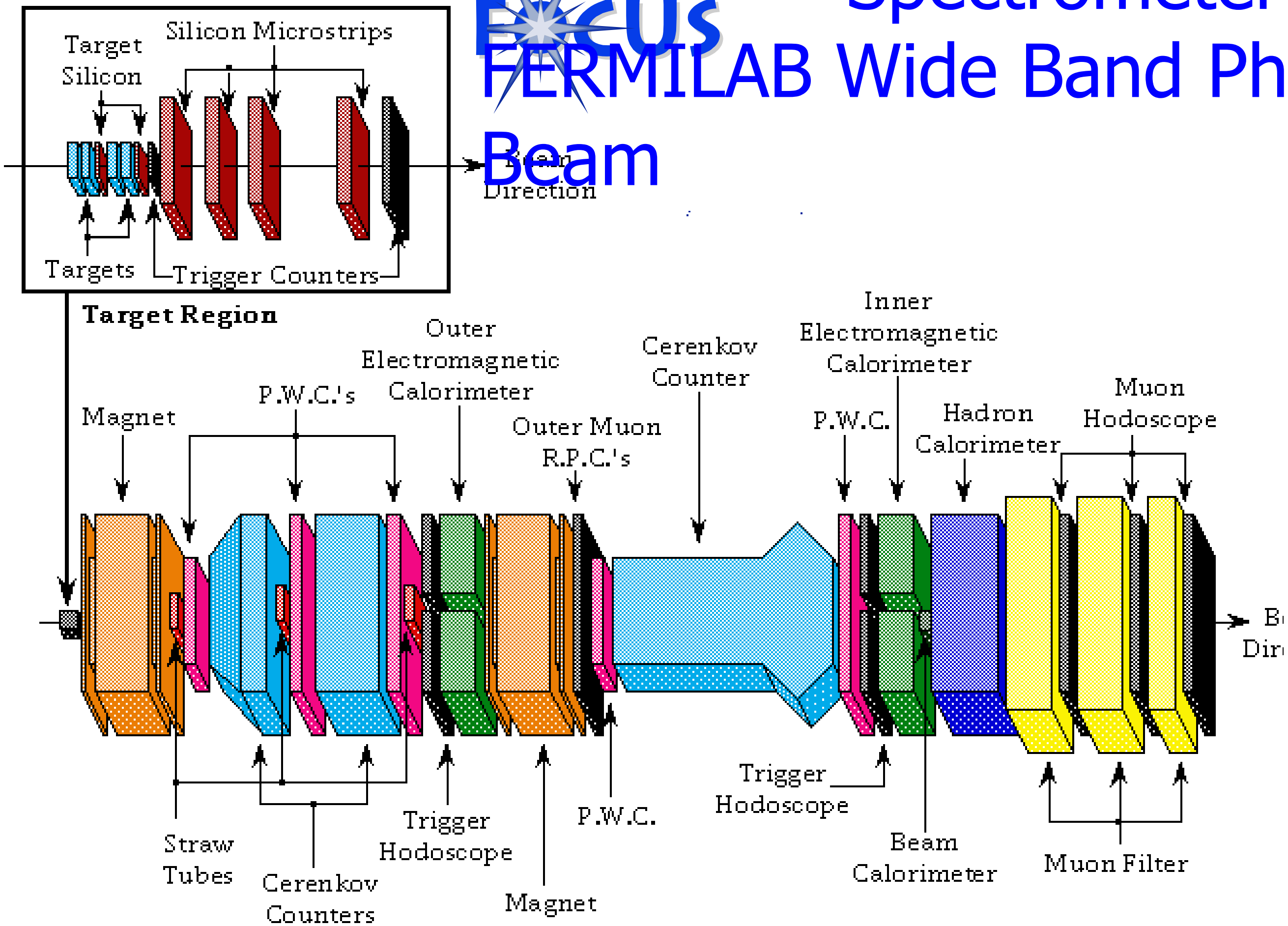
D_1 mass = $2461^{+0.041}_{-0.034}$ ± 0.010 ±0.032 MeV/c^2

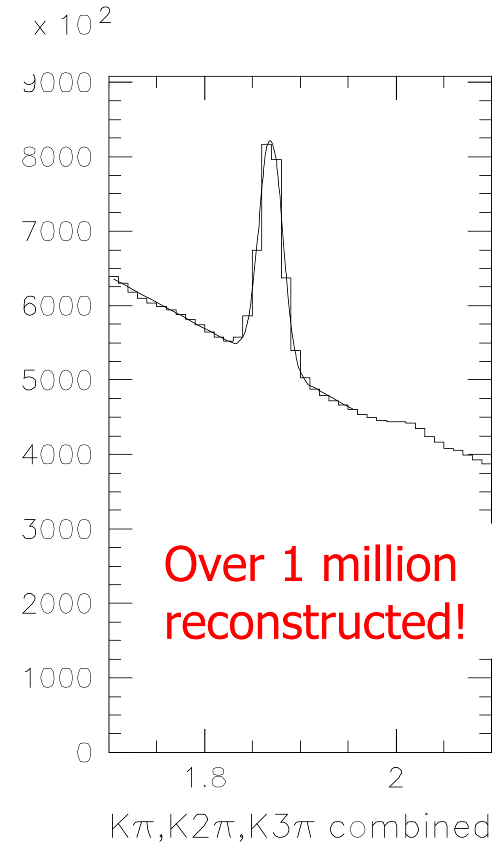
D_1 width= 290^{+101}_{-79} ±26 ±36 MeV/c^2



Good D_1 narrow signal also seen in Focus

E831 FOCUS Spectrometer at FERMILAB Wide Band Photon Beam



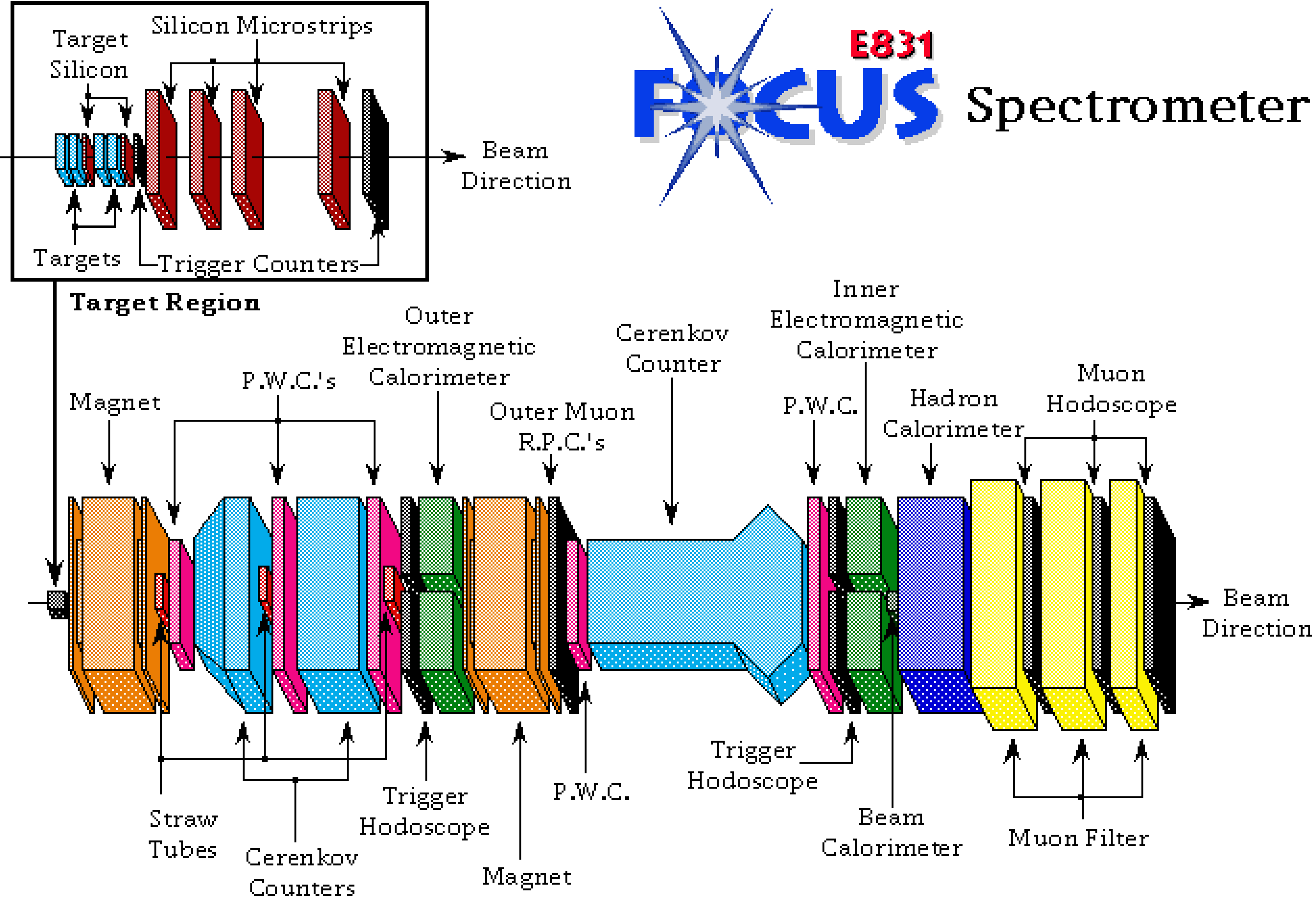


Successor to E687. Designed to study charm particles produced by ~200 GeV photons using a fixed target spectrometer with updated Vertexing, Cerenkov, EM Calorimeters, and Muon id capabilities. Member groups from USA, Italy, Brazil, Mexico, Korea. <u>DATA COLLECTED IN 1996-1997</u>

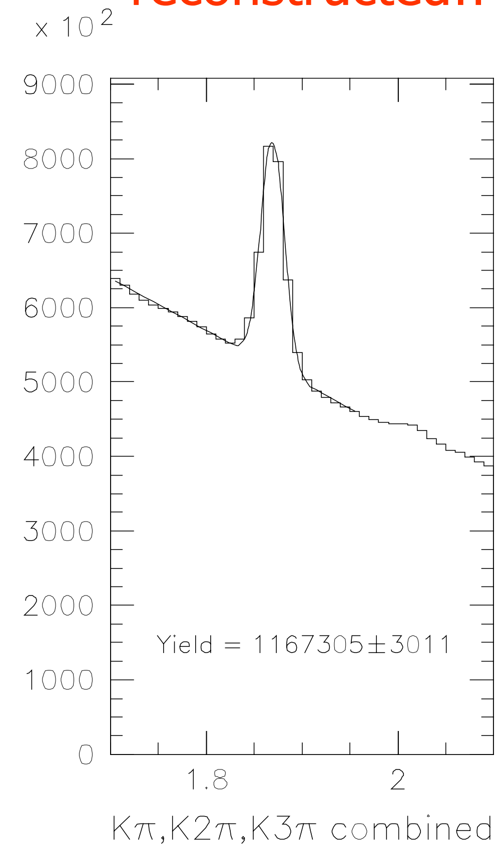
Bibliography

- ICHEP02 Amsterdam
  - S.Malvezzi *Mesons*
  - C.Riccardi *Baryons*
  - E.Gottschalk *Production Dynamics*
- FPCP02
  - J.Wiss *Semileptonics*
- HQL2k2 Vietri
  - L.Benussi *Spectroscopy*
- FCP01
  - R.Kutschke *Spectroscopy*
- LEPTRE00 Roma
  - D.Pedrini
- CICERONE

E831 FOCUS Spectrometer



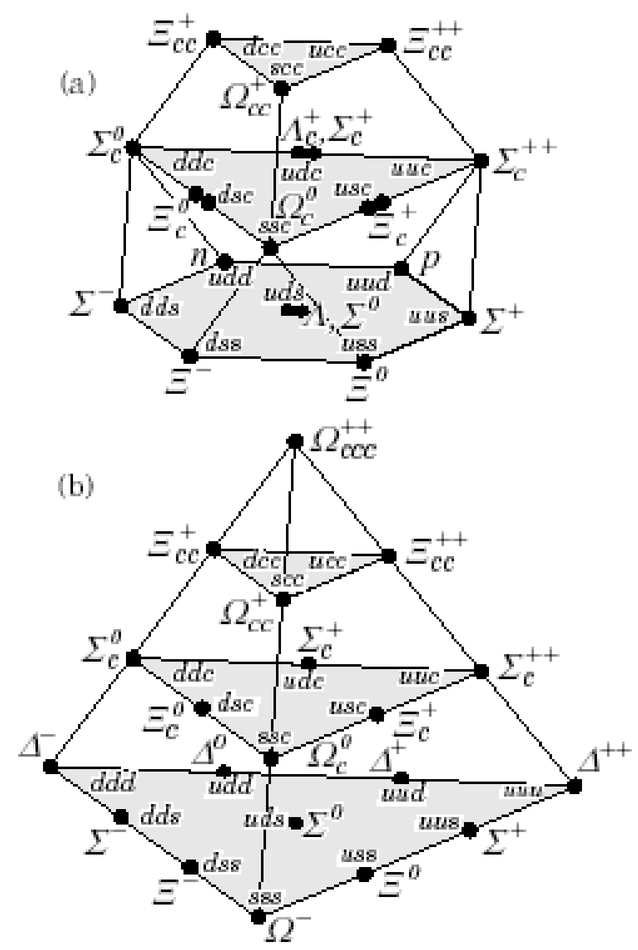
Over 1 million reconstructed!!



Successor to E687. Designed to study charm particles produced by ~200 GeV photons using a fixed target spectrometer with upgraded **Vertexing**, **Cerenkov**, **E+M Calorimetry**, and **Muon id** capabilities. Includes groups from USA, Italy, Brazil, Mexico, Korea

1 million charm particles reconstructed into $D \to K\pi$, $K2\pi$, $K3\pi$

Baryon multiplets



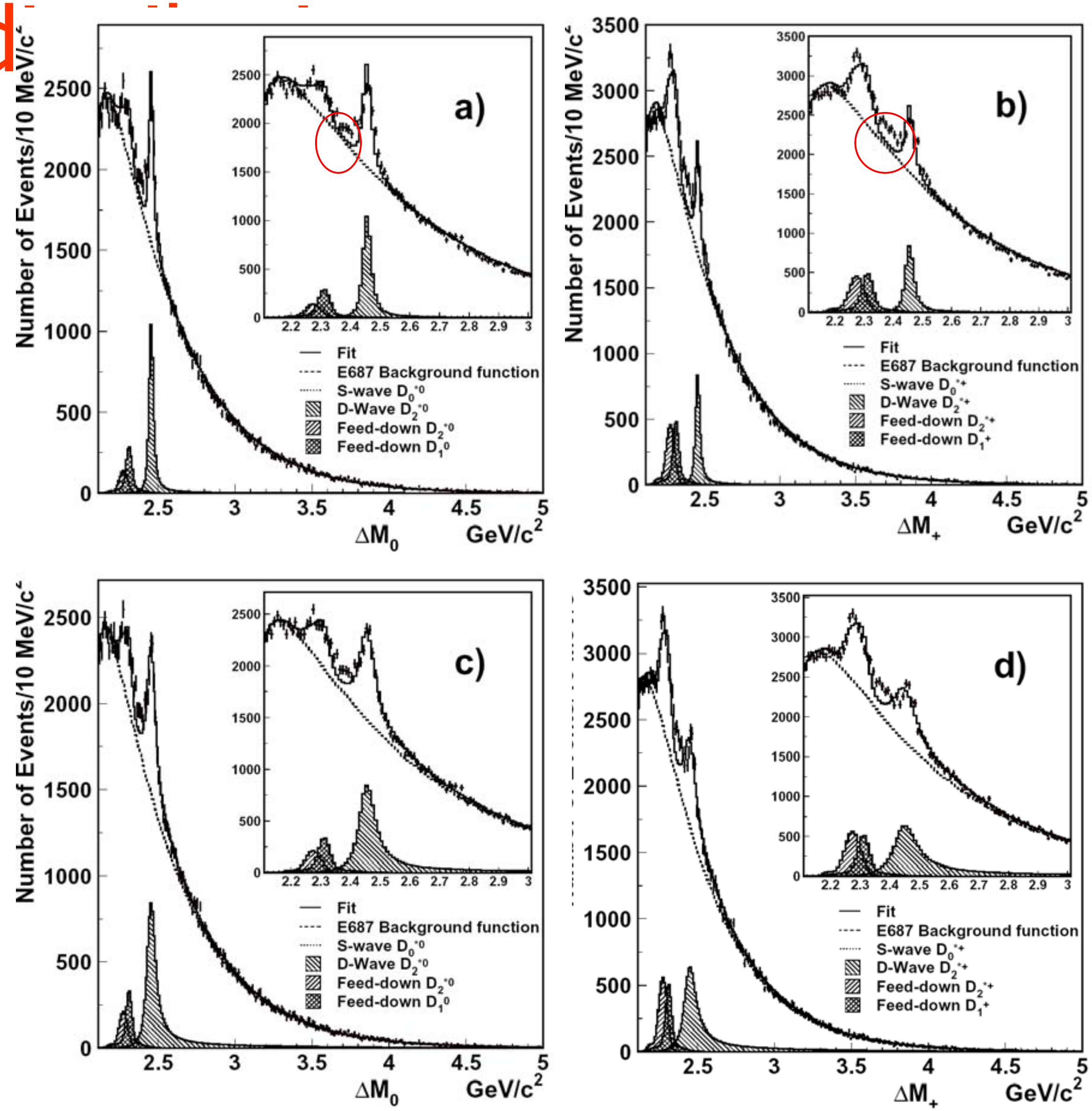
SU(4) Baryon Multiplets

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 $\pi\pi$, $K\overline{K}$, $\eta\eta$, $\eta\eta'$, 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.

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

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

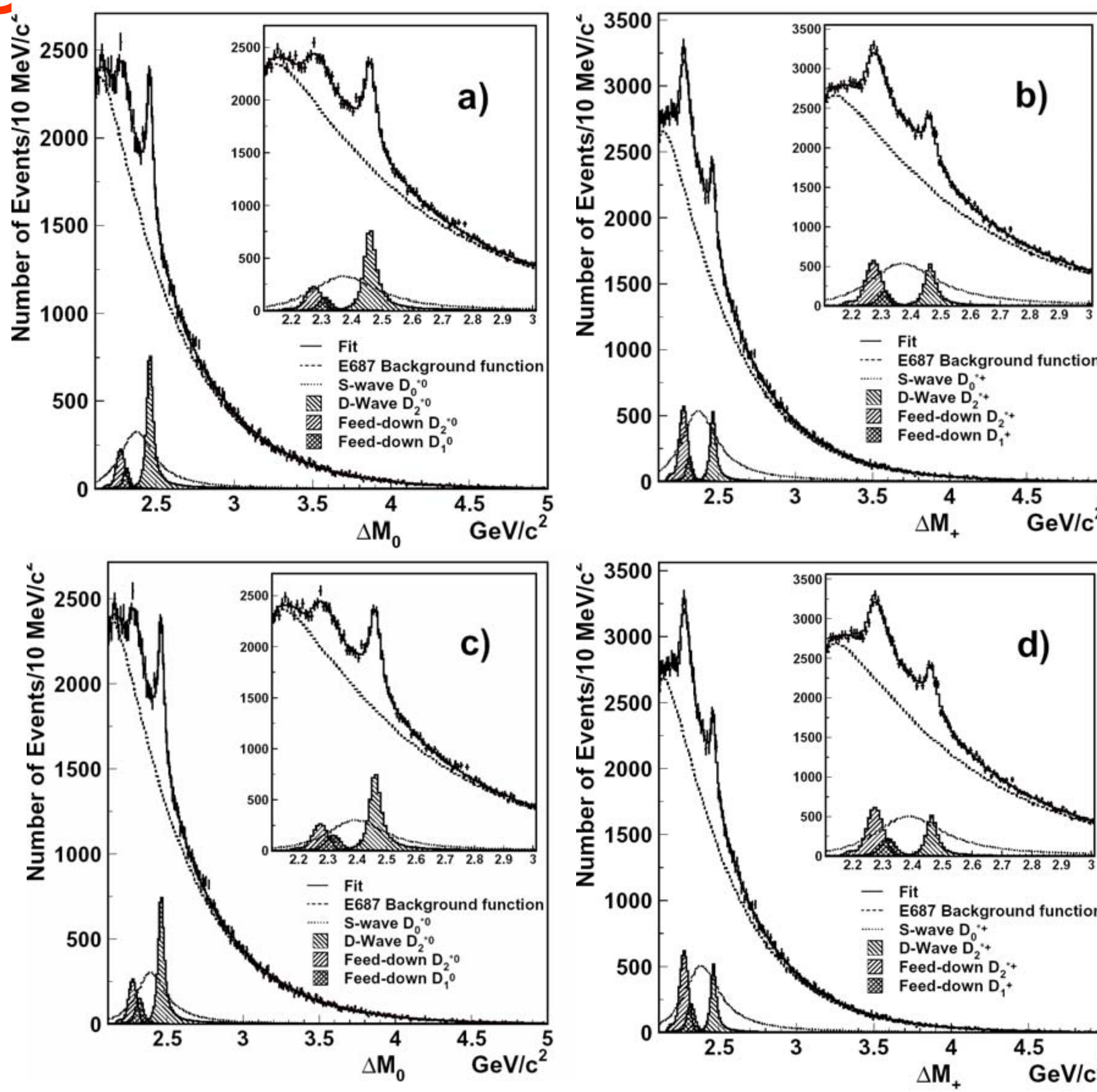


2. D-wave free fit parameter

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

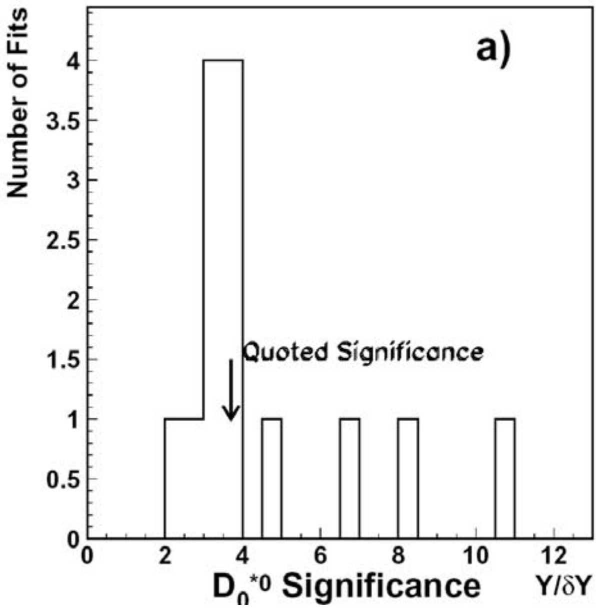
Fitting $D^0\pi^+$ and $D^+\pi^-$ mass

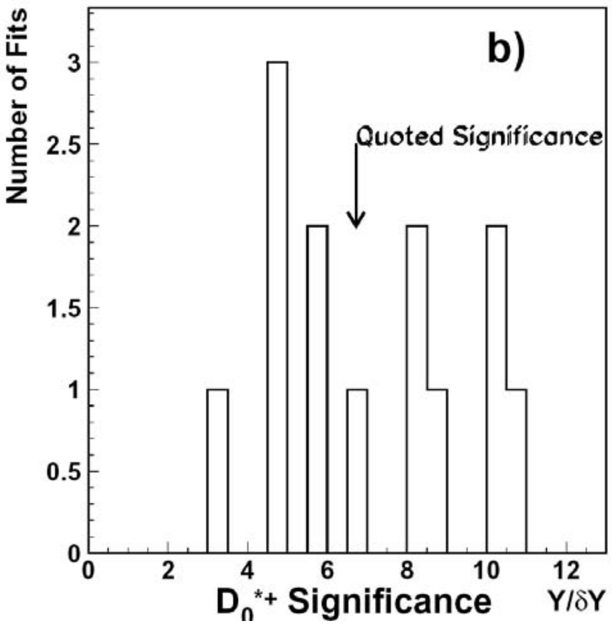
3. Add S-wave
Fit cl=22% now



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/σ< 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:

$e^{(A+Bx)}(x-C)^D$

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

THIS RESULT AND THEORY PREDICTIONS

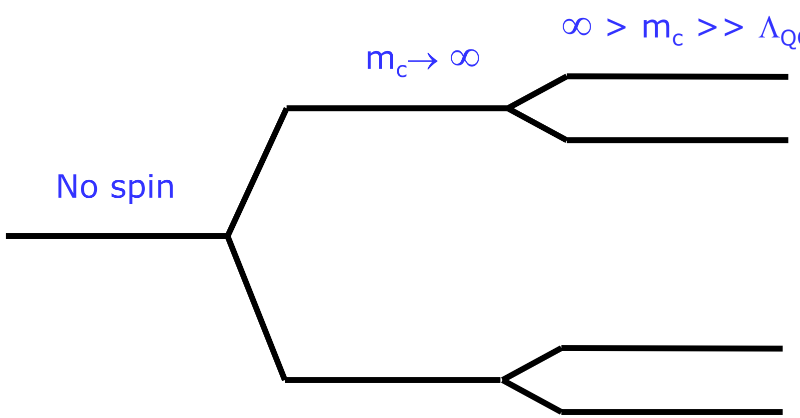
Predicted mass differences with respect to the D meson compared to this result

Reference	**D_2*** *jq* = 3/2 $_3P2$	**D1** *jq* = 3/2 3*P*1	**D1** *jq* = 1/2 1*P*1	**D_0*** *jq* = 1/2 3*P*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

TO CHART

Levels Splitting (I)

- L = 1 between c and light quark (u,d,s)
- $j_{light} = S_{light} + L$: is approximately good Q number if $m_c >> \Lambda_{QCD}$
- Idealized picture is a "doublet of doublet"



J_q	J^P	Decays	Γ (MeV/c²)	Observed	Decay
3/2	2^+	$D^*\pi$, $D\pi$	≈ 20	$D_2^{*+}, D_2^{*0}, D_{s2}^*$	$1^+_{3/2}$ D-wave
3/2	1^+	$D^*\pi$	≈ 20	D_1^+, D_2^0, D_{s1}	
1/2	1^+	$D^*\pi$	≥ 100	**New results**	$1^+_{1/2}$ S-wave
1/2	0^+	$D\pi$	≥ 100		

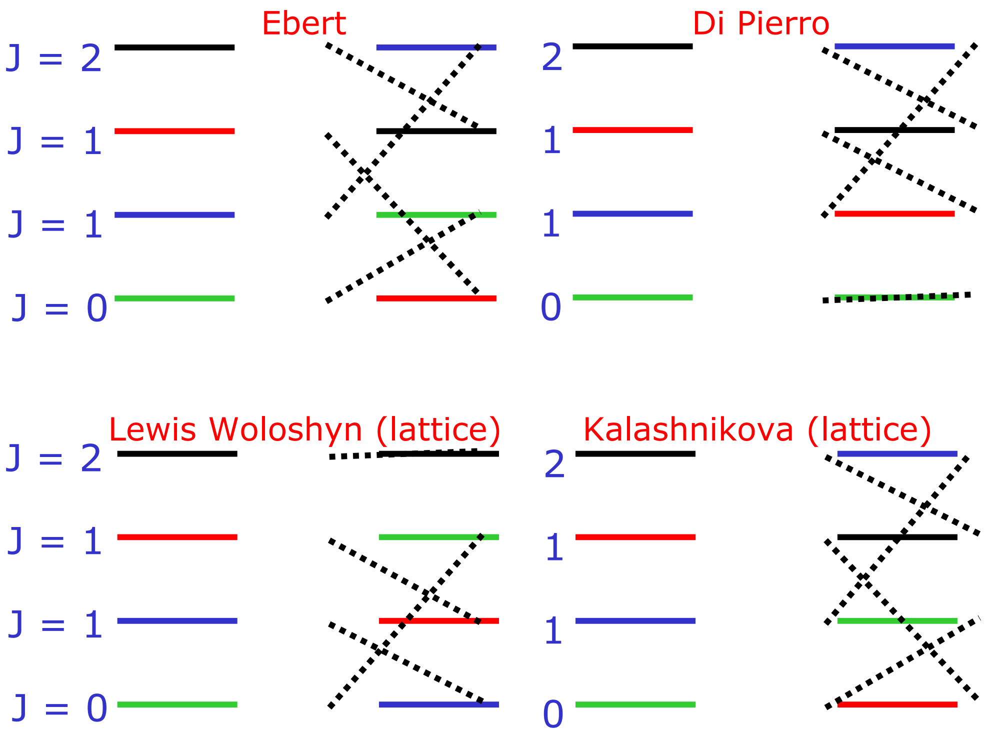
Levels Splitting (II)

Doublets of doublets…But what happen in real life?

…m_Q is not infinite: working with the real mass causes the P-wave states to overlap. But:

- The L= 1 states pattern is not univocally described by models.

- The choice of potential is crucial.



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. $D_1^+(j_q=1/2) \rightarrow D^{*0}\pi^+$, $D^{*0} \rightarrow D^0(\pi^0,\gamma)$