Relevance of LASS Results to B-Factory Analyses (?)

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For the LASS Collaboration: SLAC – Nagoya – Cincinnati – INS Tokyo
(Cal. Tech – Johns Hopkins – Carleton)

LASS → BaBar refugees :

David Leith, Blair Ratcliff, Dave Aston, Jaroslav Va'vra, WMD (SLAC),
Brian Meadows (Cincinnati)

Workshop on 3-Body Charmless B Decays

LPHNE, Paris Feb. 1-3, 2006

Outline

- Brief description of the LASS experiment
- Three-body charmless B decay :

  - The 3 bodies are pseudoscalar mesons (typically)
  - Isobar model used (i.e. quasi-two-body approach) in Dalitz Plot Analysis
  - Need to understand two-pseudoscalar-meson systems

  - LASS information on such systems may help

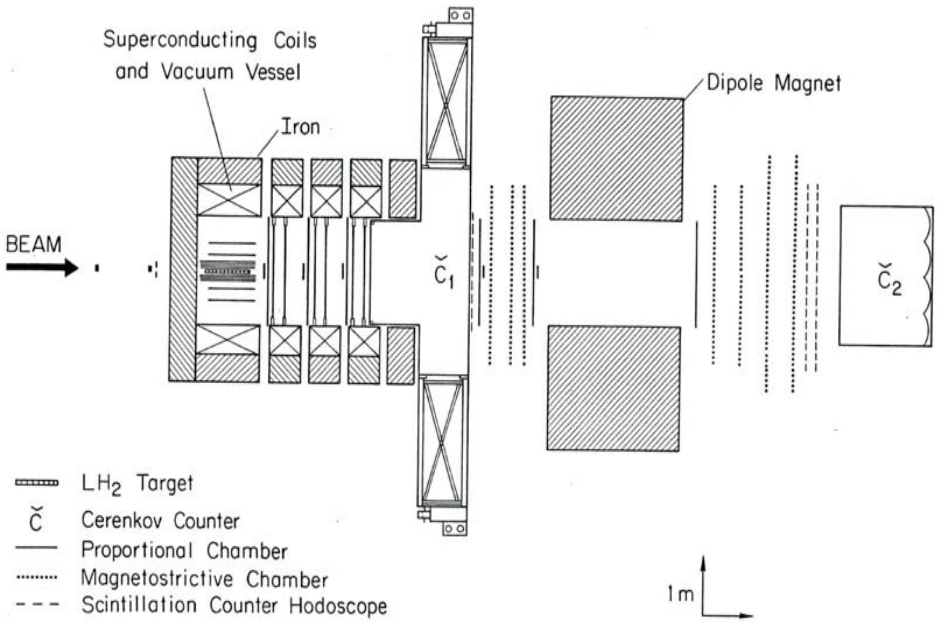
  - Consider $K\pi$ mainly; also $K\eta$, $K\bar{K}$ and $\pi\pi$ (P-wave) if have time

  - Comment on BaBar analyses in which such information has been, or might be, of use

- Summary

The Large Aperture Superconducting Solenoid Spectrometer

(SLAC-Report – 298, April 1986)



R.-f.-separated Kaon beam at 11 GeV/c

{5 -10 particles/pulse → ~10^7 hz. instantaneous rate on the forward PC's because of ~ 1 μsec. Accelerator duty cycle }

~110 million K^-, ~25 million K^+ triggers (6 mos. in 1981-82)

~ 40% processed on SLAC farm, ~ 60% at Nagoya

Reconstructed once; took ~ 1.2 years; finished Fall 1985

Innovations:

Solenoid (2.2 T) + Dipole (30 kG m)

~ 4π Acceptance and Trigger

Run in "Interaction Mode" ;

~ Electronic Bubble Chamber

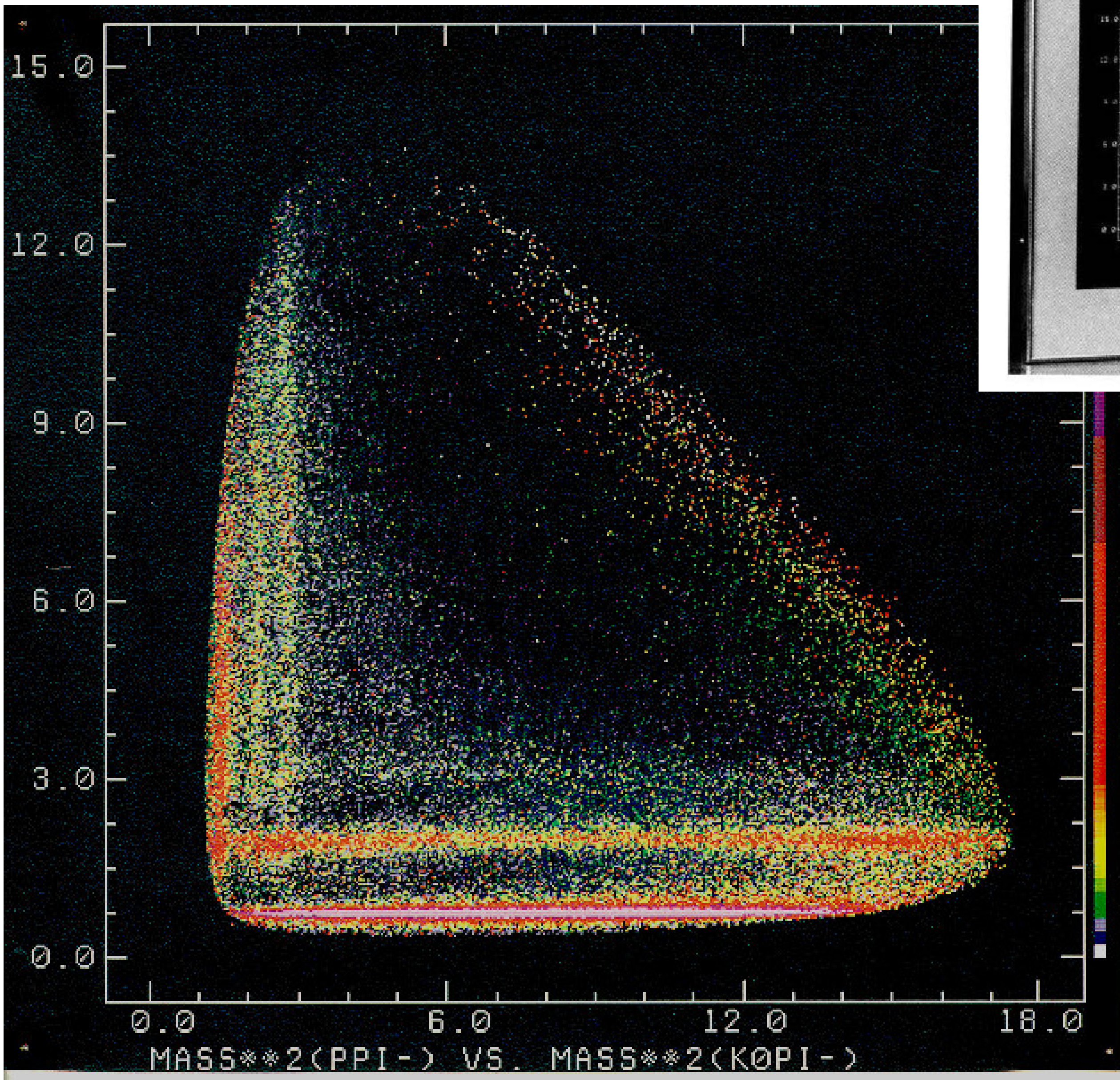
First use of microprocessor farm in HEP :

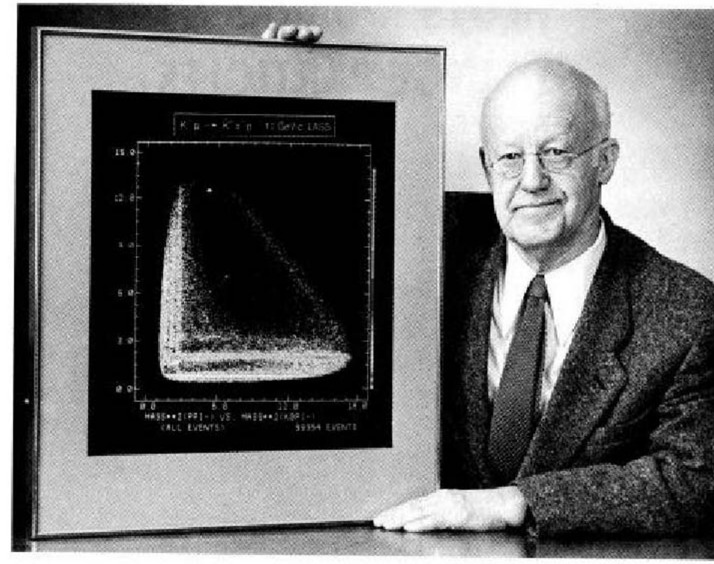
9 370 -168E processors built by Paul Kunz + 1 Tech.

2 3081E processors later for MC and kinematic fitting

Example of Data Quality

$K^- p \rightarrow K^0_S \pi^- p$ at 11 GeV/c : ~ 100 k evts





Presented to Prof. Dalitz on his retirement (1990)

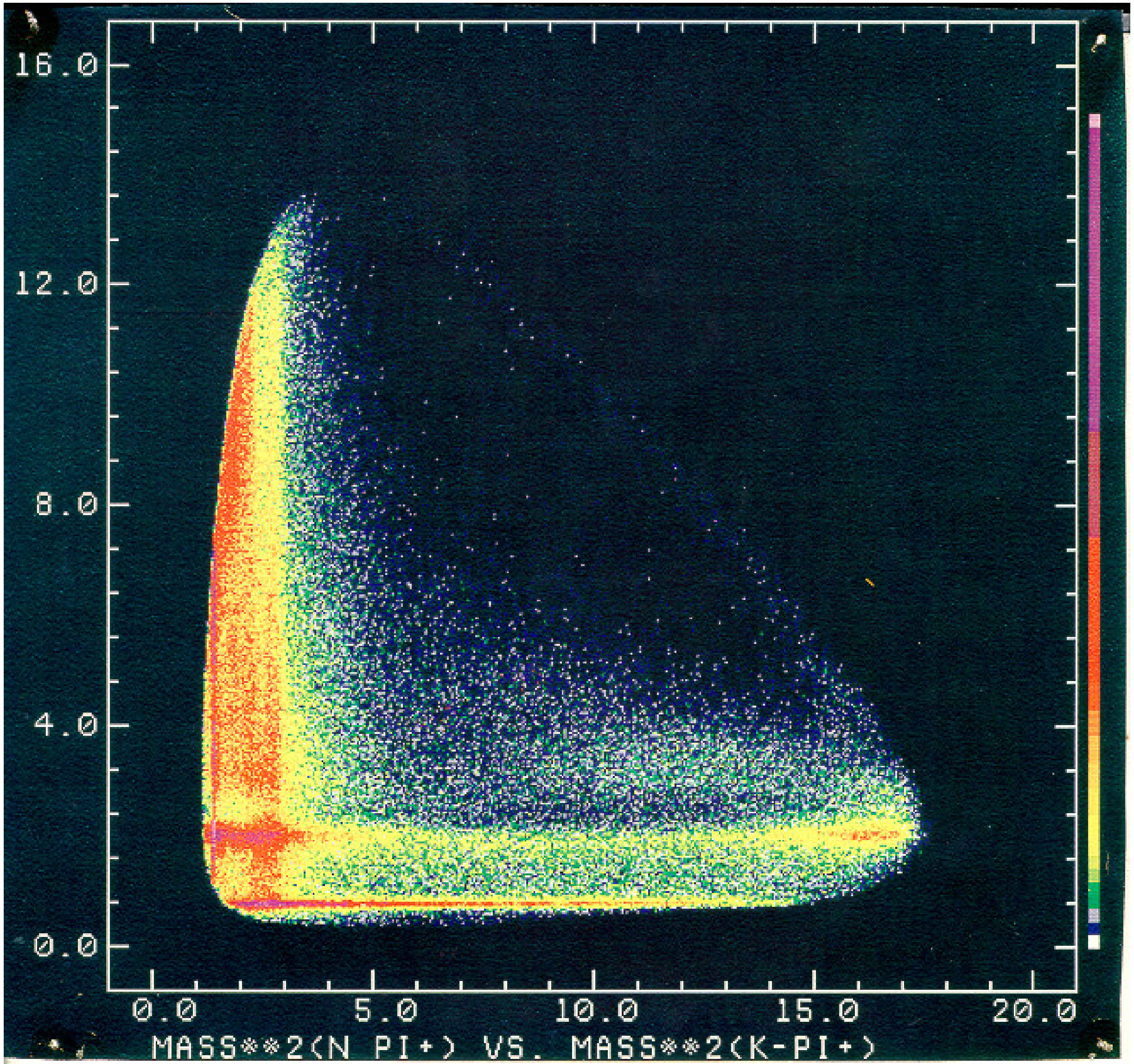
First use of coloured scatterplots in HEP

(I think)

No printer; 35 mm slide of IBM 5080 monitor + off-site creation of transparencies and prints

$K^- \pi^+$ Elastic Scattering from $K^- p \rightarrow K^- \pi^+ n$ at 11 GeV/c

{ NPB 296 (1988) 493 ; Naoki Awaji, Ph.D Thesis, Nagoya (1986) }

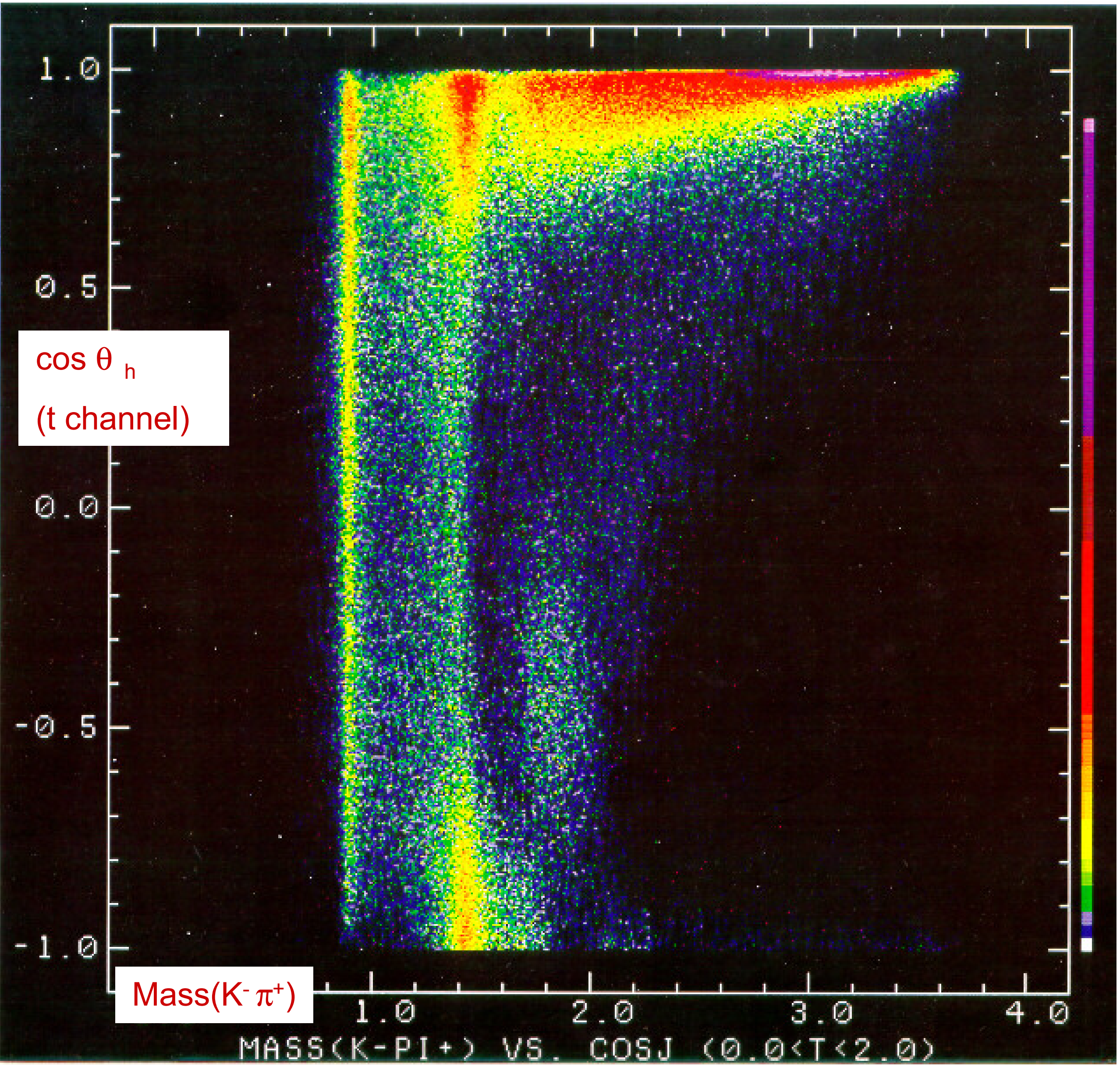


730 k

events

$K^- p \rightarrow K^- \pi^+ n$ at low p-to-n (momentum transfer)^2

(i.e. close to t-channel pion pole)



K π elastic scattering

K scattering on virtual π

(Chew and Low, 1959)

+ exchange dynamics

from [cos θ_h,ϕ]correlations

(Gottfried and Jackson, 1964)

+ Regge phenomenology

Culminated in model due to

Martin and Estabrooks

Used to obtain:

π π (CERN-Munich expt.)

K π (E75 , LASS)

scattering amplitudes

Focus on P and S waves

$K^- \pi^+$ Elastic Scattering: P- wave Amplitude

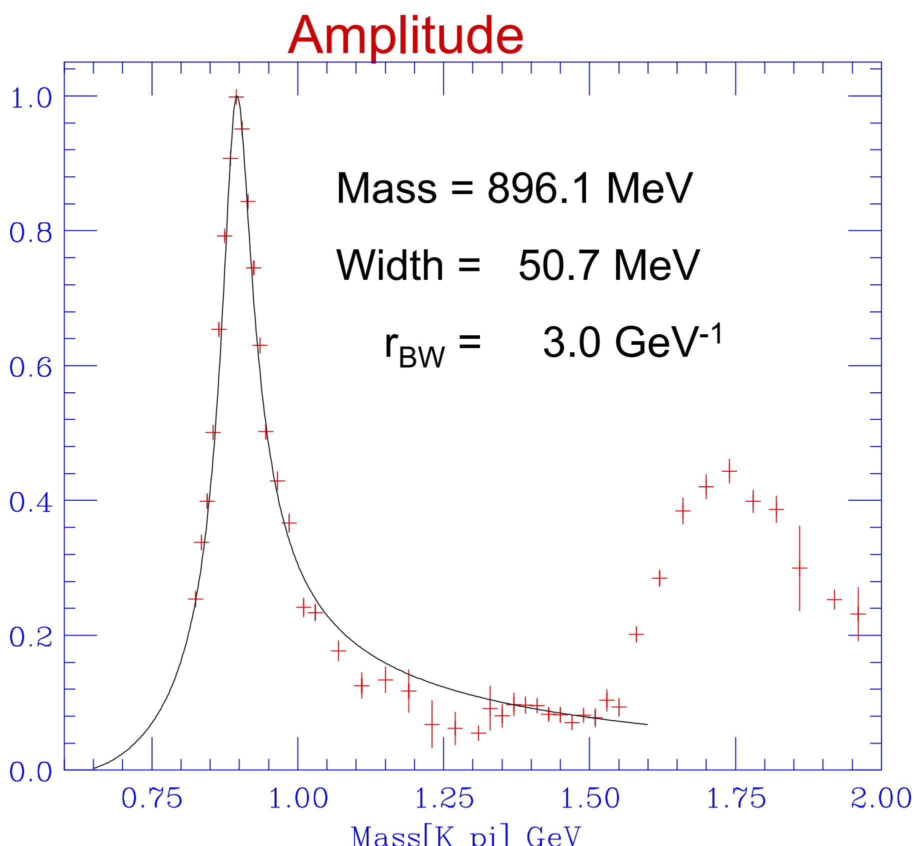
Consistent with elastic unitarity up to ~ 1.05 GeV; BW lineshape description

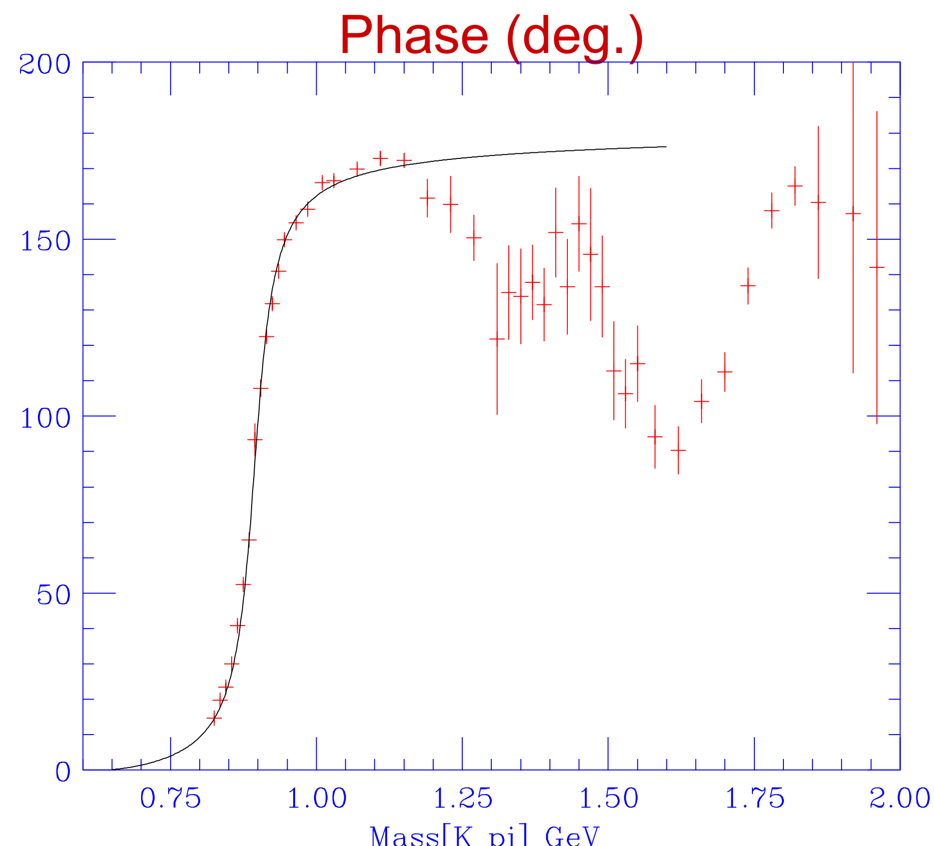
Clear deviation from BW amplitude and phase behaviour at higher mass

Radial excitation at ~ 1.4 GeV; highly inelastic; elasticity ~ 0.07 (hard to find)

Orbital excitation ($q\bar{q}$ $^3D_1$ ground state) at ~ 1.7 GeV, elasticity ~ 0.40

Note : "elasticity" means "branching fraction to K π"





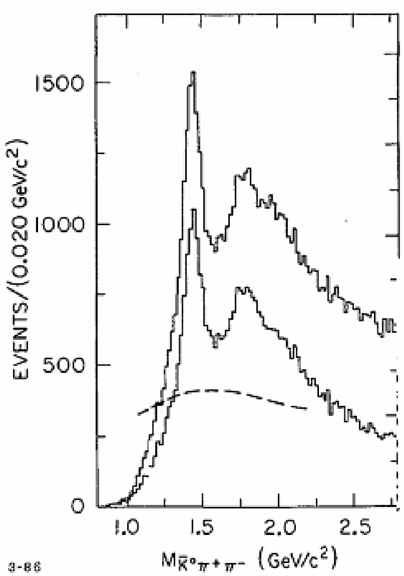
Additional Evidence for the $K_1^*(1410)$:

- in the data on $K^- p \to K^0_S \pi^- p$ shown earlier [also small]

{ SLAC-332, Fred Bird, Ph.D Thesis, Stanford (1988) }

- in the LASS data on $K^- p \to K^0_S \pi^+ \pi^- n$ [large ($K^*(892)\pi$) amplitude]

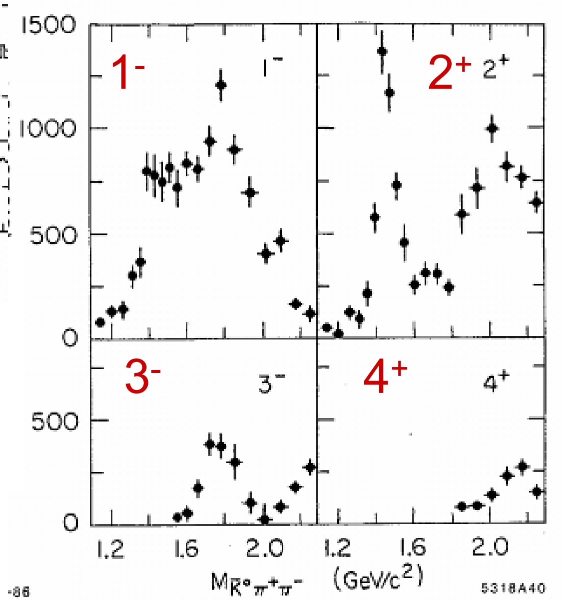
{ NP B292 (1987) 693; SLAC-299, Pekka Sinervo, Ph.D Thesis, Stanford (1986) }



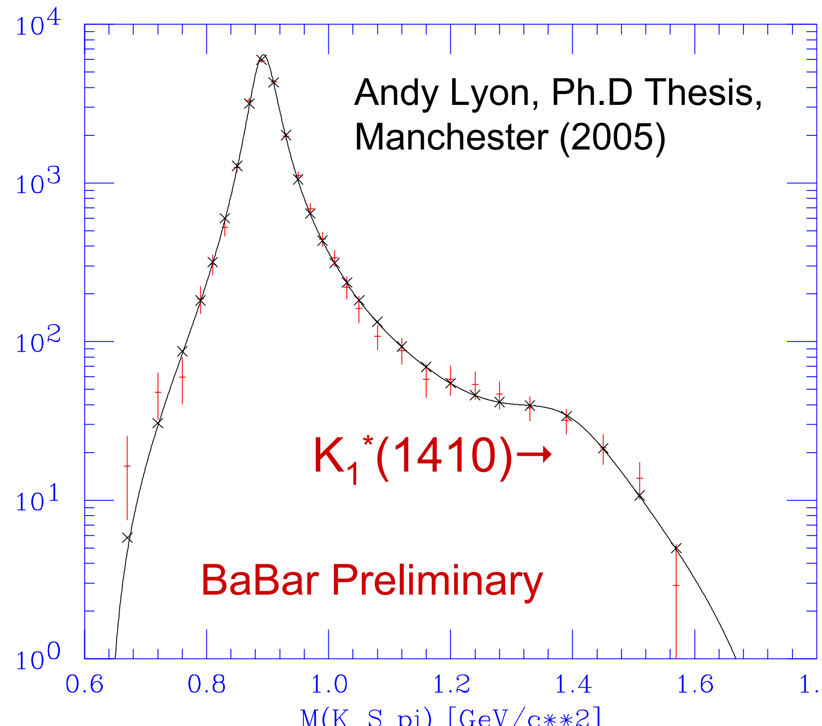
$M(K_S\, \pi^+ \pi^-)$

J^P Intensities from

3-body PWA



$\tau \to K_S\, \pi\, \nu$



$K^- \pi^+$ Elastic Scattering : I = ½ S-wave Amplitude

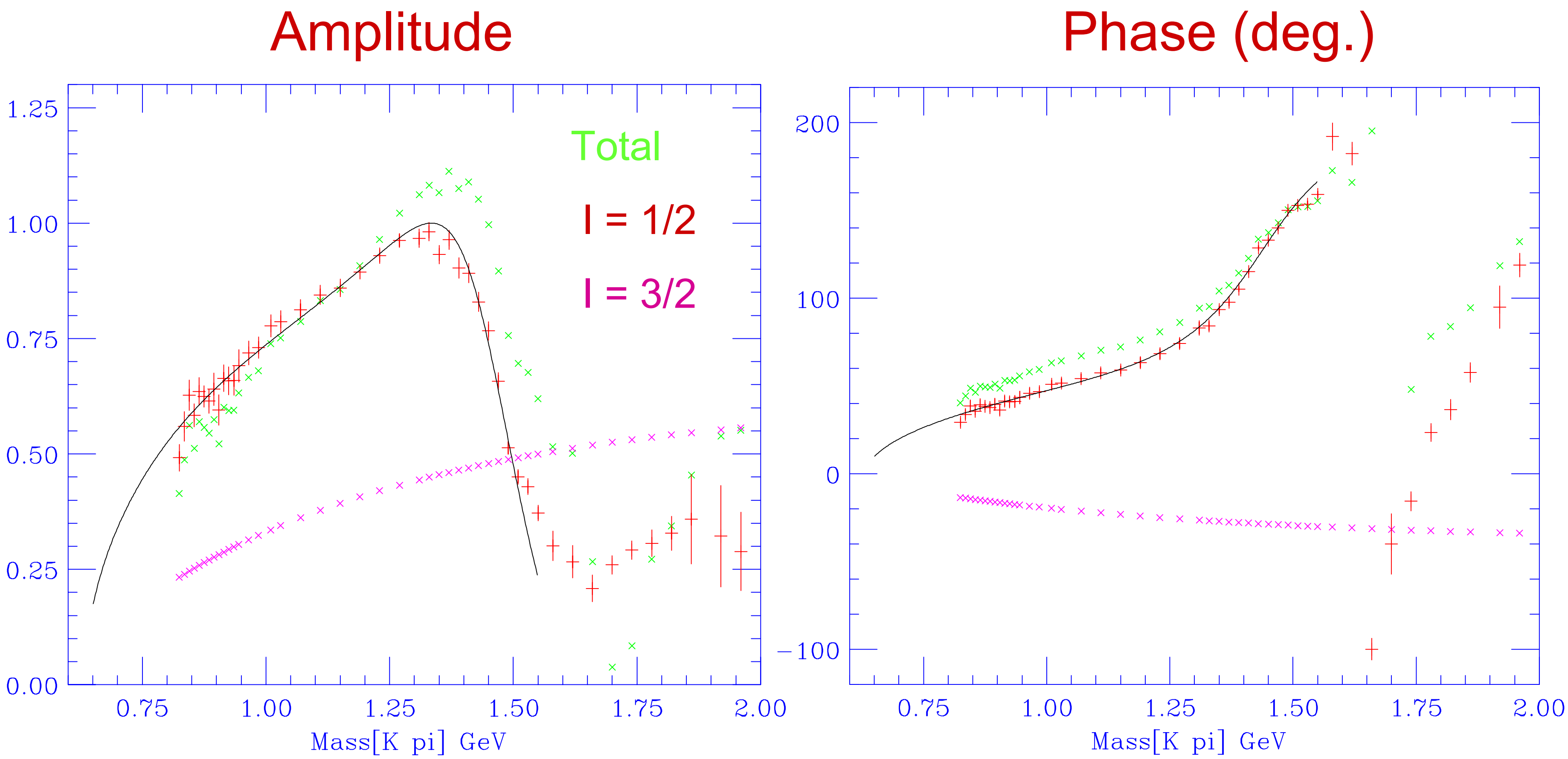
Subtract I = 3/2 Amplitude from Total S-wave {Total = | I = 1/2 > + 0.5 | I = 3/2 >}

Result consistent with elastic unitarity up to ~1.5 GeV/c^2

Fit with coherent superposition of Effective Range and Resonant amplitudes

(Resonance parameters : M ~ 1.435 GeV/c^2, Γ ~ 0.279 GeV)

Possible radial excitation in 1.9 - 2.0 GeV region, elasticity ~ 0.35



K π Amplitudes in BaBar Analyses [not meant to be comprehensive!]

F-wave (L=3) and higher L : not observed in any analysis so far

D-wave : observed in B $\rightarrow J/\psi K \pi$, but not analyzed

[S,P,D waves in Kπ yields 27 angular distribution functions !] ;

possibly in B $\rightarrow \gamma$ K π and charm meson DP analyses

P-wave : many analyses observe clear K*(892) signals ;

describe by relativistic BW lineshape, BUT in B meson

DP analyses this form is used usually over the entire plot

i.e. up to K π mass values of ~ 5 GeV although K π scattering

shows deviations from BW behaviour above ~ 1.1 GeV !!

may lead to high b.f.'s - should limit mass range (e.g.<~ 1.2 GeV)

and incorporate "tail" as systematic uncertainty (my opinion)

$K_1^*(1410)$ seen only in τ decay ; K_1^* at ~ 1.7 GeV not seen

$K\pi$ Amplitudes in BaBar Analyses (continued)

S-wave : seen in several analyses ; type of contribution varies with mass range and process:

(a) significant intensity contribution (i.e. $|S|^2$) in $K\pi$ mass range 1.1 – 1.6 GeV , e.g. for $B \to J/\psi K\pi$ and $B^+ \to K^+ \pi^- \pi^+$;

(b) S-P interference in vicinity of K*(892) ; leads to F-B asymmetry (AFB) in the distribution in $K\pi$ helicity angle cosine ($\cos\theta_K$) which varies significantly with mass because of the rapid BW phase motion of the resonant P-wave amplitude ;

such AFB behaviour, which "knows about" the K*(892), shows the presence of a coherent S-wave amplitude; the mass at which AFB passes through zero, and the sign change there, provide information on any overall S-P phase difference w.r.t. the LASS behaviour (e.g. for $B^+ \to K^+ \pi^- \pi^+$)

K π Amplitudes in BaBar Analyses (continued)

S-wave : (b) ctd. given sufficient data, the S-P phase difference can be measured in a model-independent way as a function of K π mass (e.g. for $B \rightarrow J/\psi K \pi$) ;

with a very large sample of high purity data, the S-P phase difference and the magnitude of the S-wave amplitude can be measured over a broad region of K π mass

(e.g. for $D^+ \rightarrow K^- \pi^+ \pi^+$; will show old results from E791 analysis by Brian Meadows [final results in hep-ex/0507099] ; Antimo Palano and Brian are performing a similar analysis using the much larger BaBar data set) ;

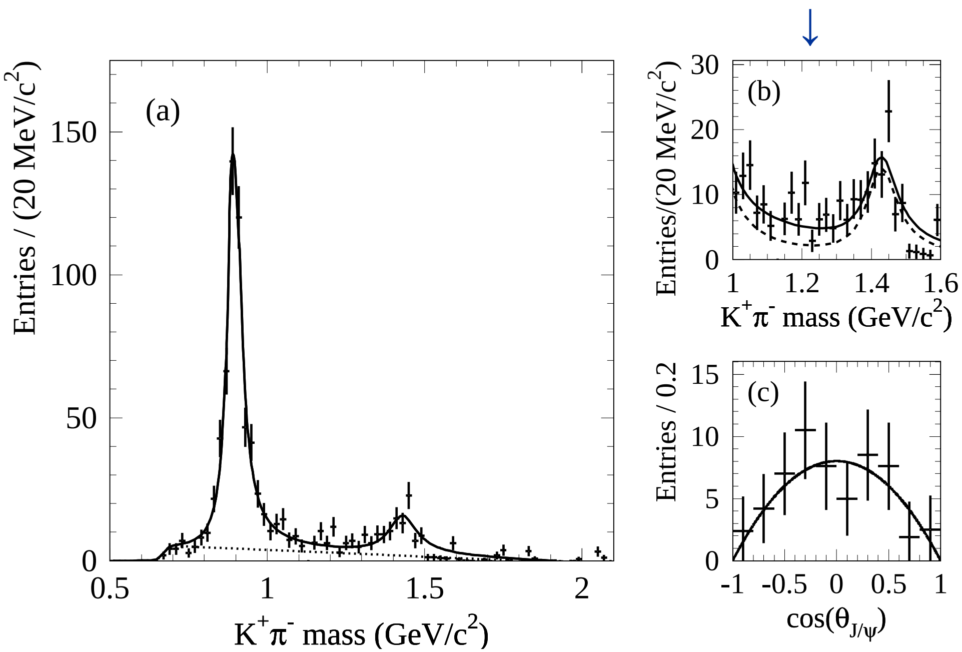
(c) there is a process in which the K π S-wave amplitude seems to be dominant viz. $\eta_c \rightarrow K^0_S K^+ \pi^-$, with the η_c produced in $2\gamma^*$ interactions ; the $K_0^*(1430)$ is seen clearly, and the radially-excited state seems present also ; Gautier H. de M. presented preliminary results at the Feb. 2005 CM ; I won't discuss here.

Evidence in BaBar Analyses for K π S-wave from Intensity

$B \rightarrow J/\psi K^+ \pi^-$

{ PRL 87 (2001) 241801; BAD 154 }

Too much between K*'s where $|S|^2$ maximal

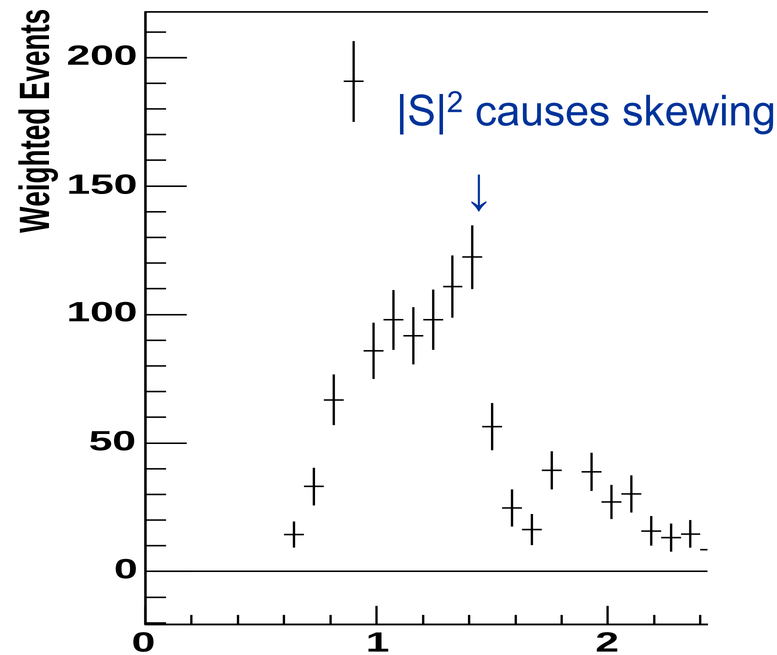


cos $\theta_{J/\psi}$distn. ~ $\sin^2 \theta_{J/\psi}$

for Kπ S-wave

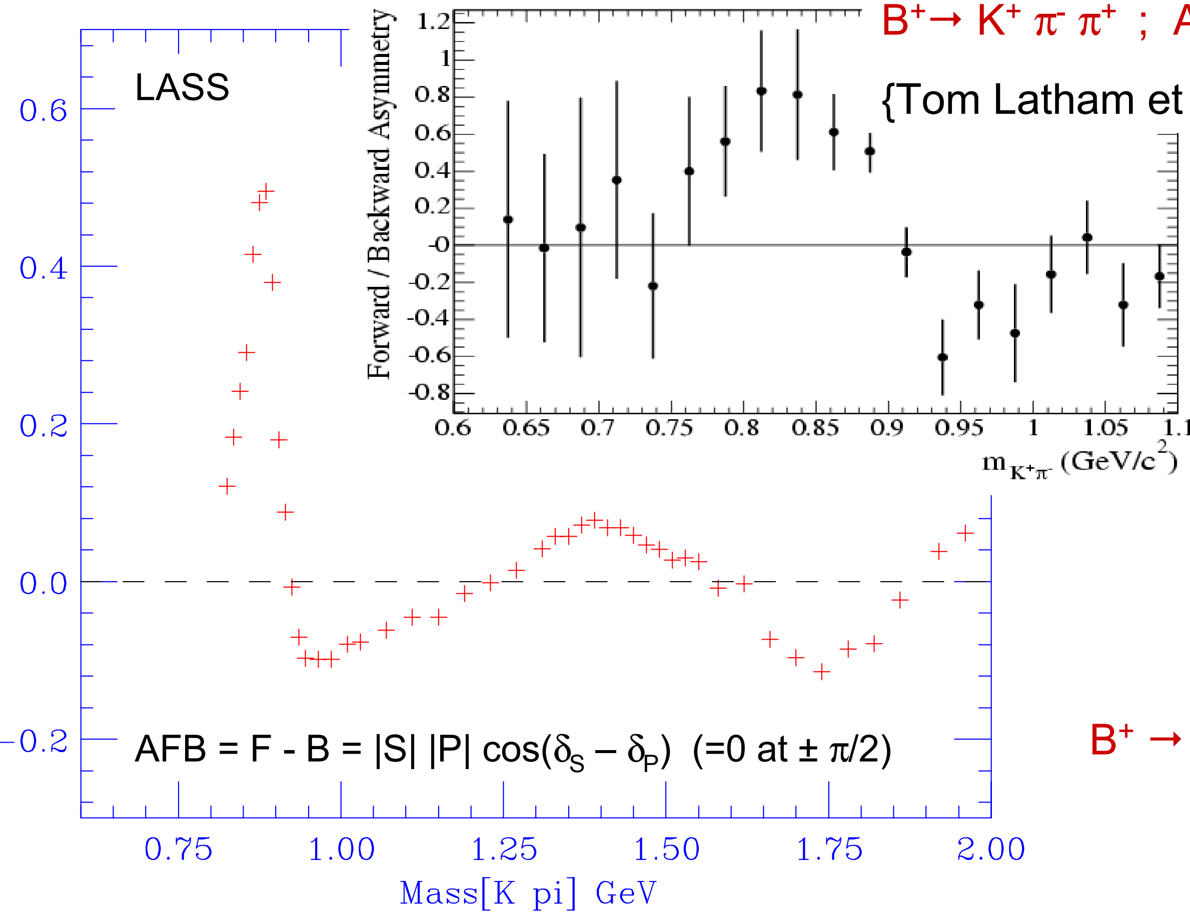
$B^+ \rightarrow K^+ \pi^- \pi^+$

{ PRD 72 (2005) 072003 ;   BAD 1181 }



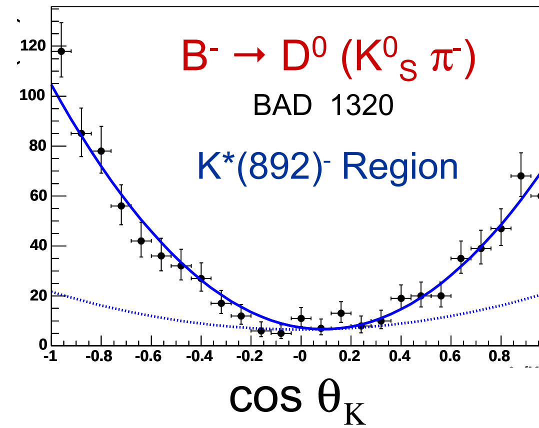
Mass ($K^+ \pi^-$) GeV/c^2

Evidence for K π S-wave from Mass Dependence of Forward-Backward Asymmetry



$B^+ \to K^+ \pi^- \pi^+$; AFB very similar to LASS

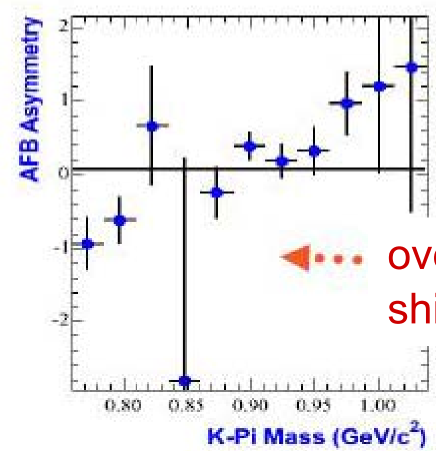
{Tom Latham et al., PRD 72 (2005) 072003; BAD1181}



$\cos\theta_K \sim [\vec{p}_K$ in $K\pi$ r.f.] . [$\vec{p}_{K\pi}$ in B r.f.]

Mass value and sign change at AFB=0 may indicate overall shift in $(\delta_S - \delta_P)$ w.r.t. LASS

$B^+ \to K^+ \pi^- \rho+$ {Georges Vasseur et al.}

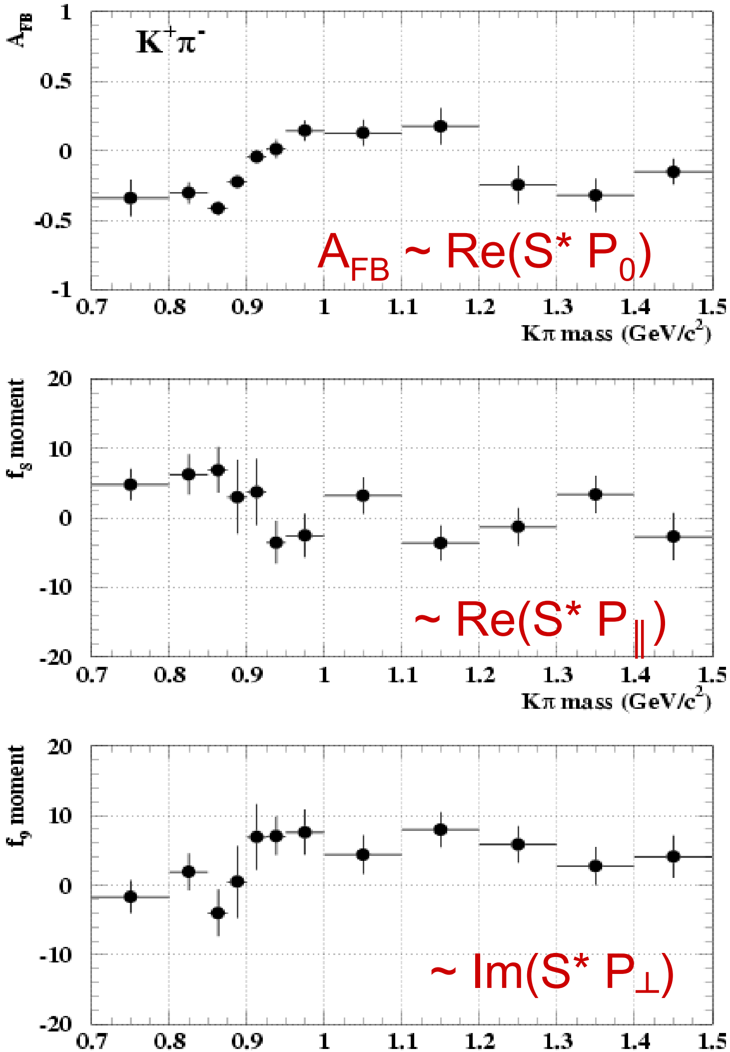


overall phase shift $\pm \pi$?

$B^0 \rightarrow J/\psi K^+ \pi^-$ (Marc Verderi et al.)

{ PRD 71 (2005) 032005 ; BAD 752 }

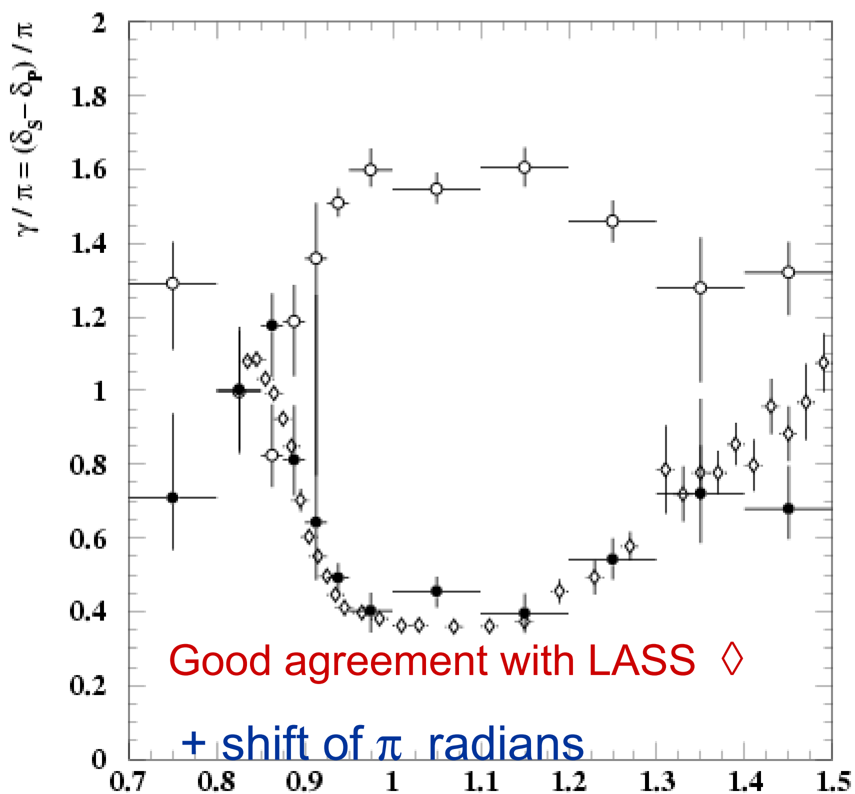
Clear evidence of K π S-P wave interference effects



$K^+ \pi^-$ Mass [GeV/c²]

Mass dependence of S-P phase defines sign of cos(2 β) { Wigner Causality, PR 98 (1955) 145 }

S – P phase in units of π



$K^+ \pi^-$ Mass [GeV/c²]

S-wave Amplitude using S-P interference in $D^+ \rightarrow K^- \pi^+ \pi^+$

{ E791 , Brian Meadows ; final results in hep-ex/0507099, submitted to PRD }

Comparison of LASS (I = 1/2) and E791 S-wave Amplitudes

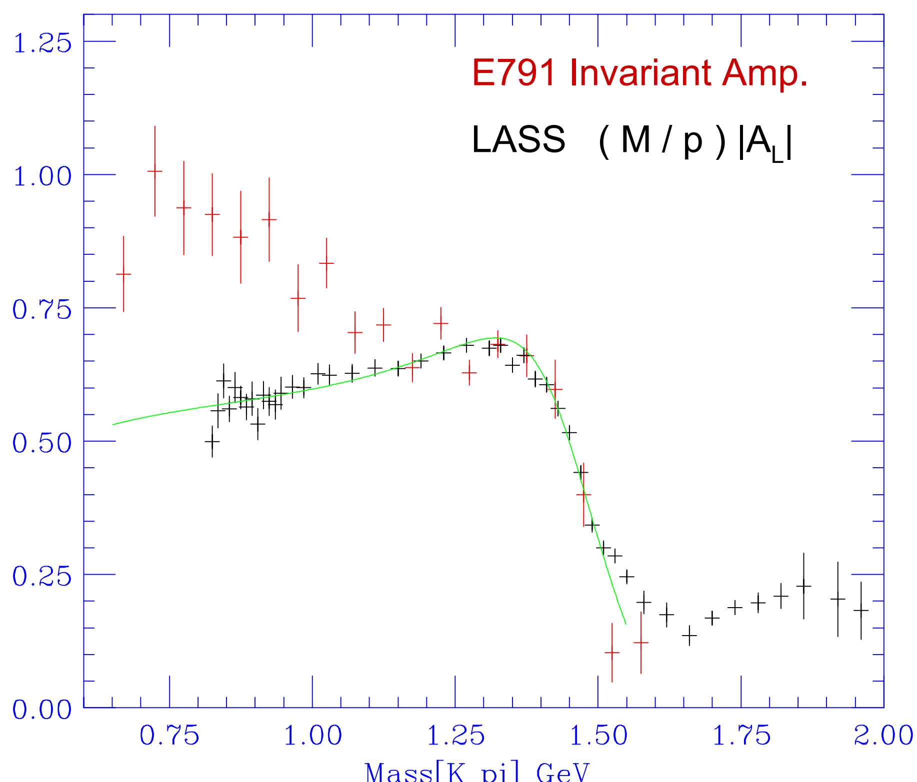
$$\sigma_L = (4\pi/p^2)\ (2L + 1)\ |A_L|^2 \qquad \text{(LASS)}$$

$$= (4\pi/M^2)\ (2L + 1)\ \{ (M/p)\ |A_L| \}^2$$

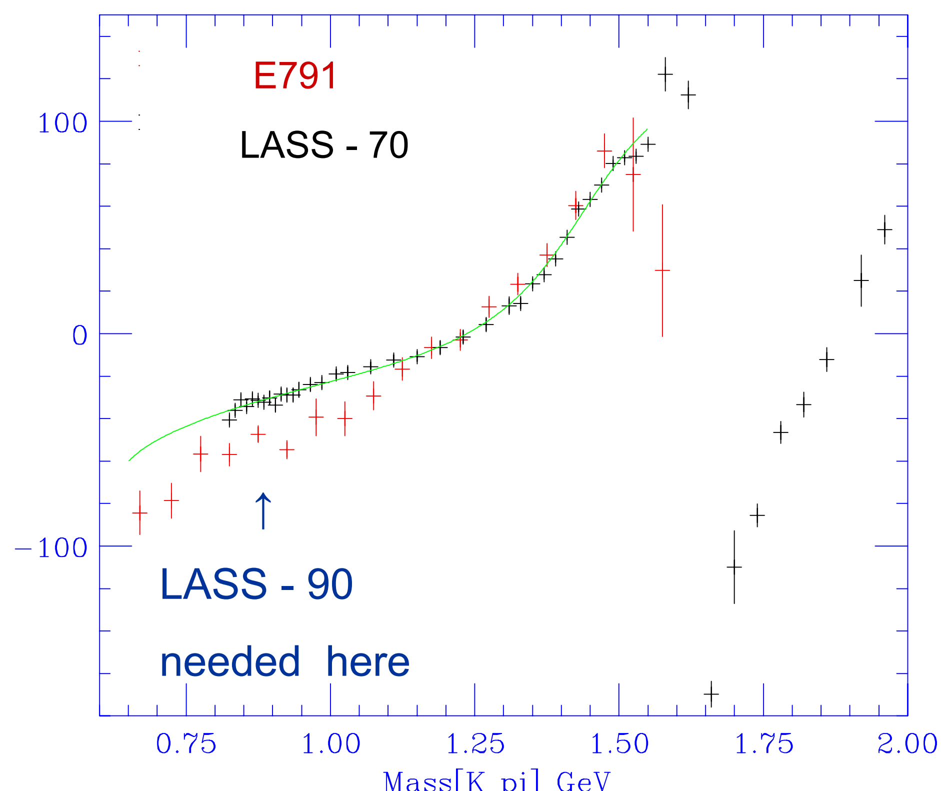
Invariant Amplitude

E791 : AFB = 0 at ~ 855 MeV →
-90 deg. phase shift w.r.t. LASS

Amplitude

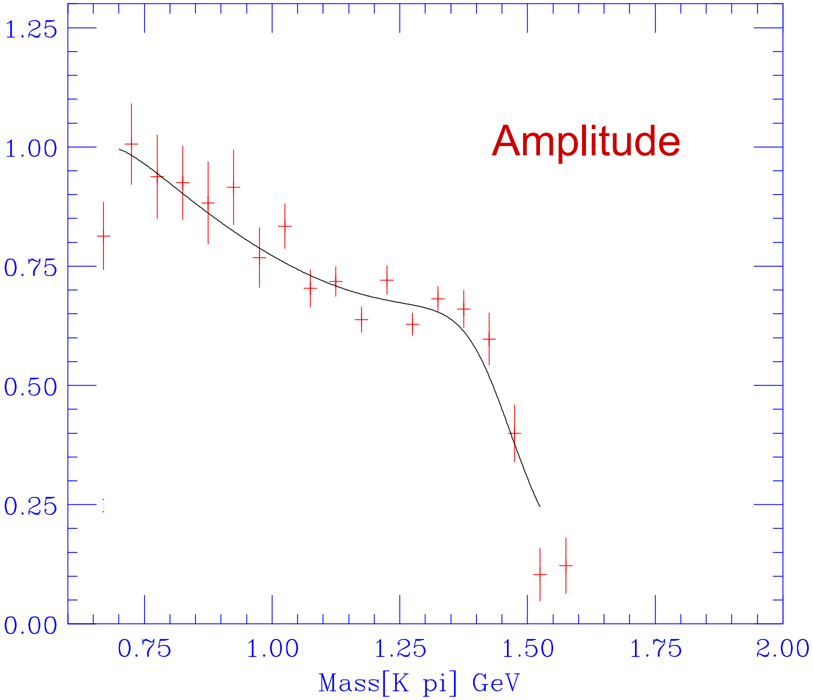


Phase (deg.)



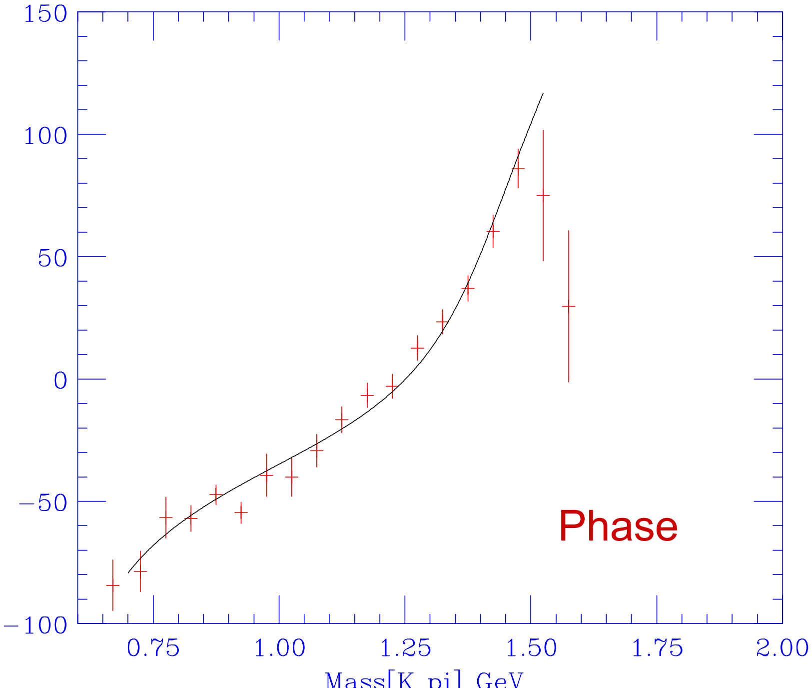
Generalize LASS fit to E791 data

{http://www.slac.stanford.edu/~wmd/kpi_swave/kpi_swave.note}

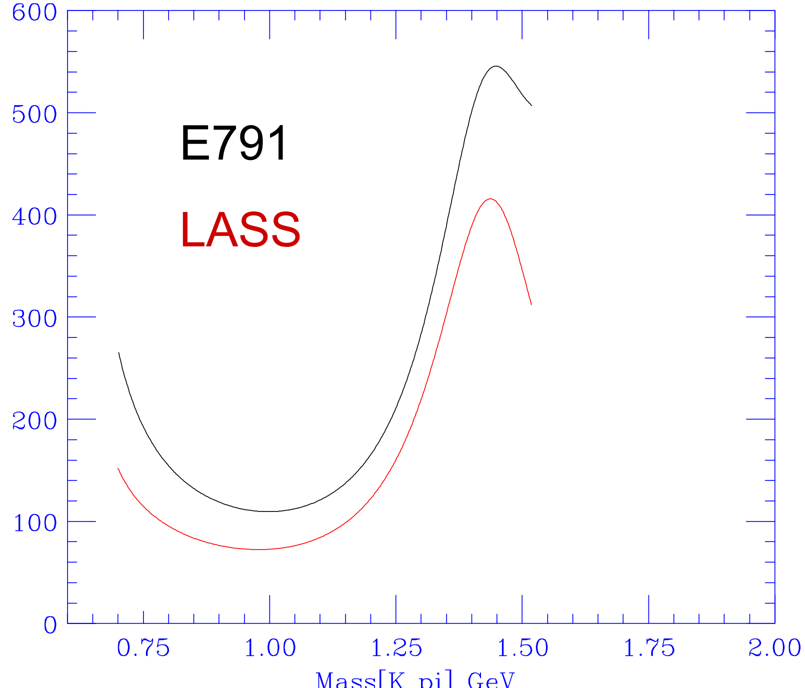


Resonance parameters agree well

	E791	LASS
Mass (MeV)	1428 +/- 16	1435 +/- 5
Width (MeV)	266 +/- 28	279 +/- 6



$d\phi_S$ / dm (deg./GeV)



Measured (or Observed) K π S-wave Compared to LASS Amplitude

Decay Process	$\delta_S - \delta_P$ Meas. – LASS (deg.)	| Amplitude | m(K π) < 1 GeV	| Amplitude | m(K π) > 1 GeV
$B^+ \to K^+ \pi^- \pi^+$	~ 0	Unknown ; (M/p) | A_{LASS} | used in fit	Similar to LASS
$B^0 \to J/\psi K^+ \pi^-$	~ + 180	Poorly defined ; to be updated soon by Marc Verderi	Similar to LASS
$B^+ \to K^+ \pi^- \rho^+$	~ ± 180	Unknown	Unknown
$D^+ \to K^- \pi^+ \pi^+$	~ - 90	Very different ; significant rise toward threshold	Similar to LASS get ~ same $K_0^*(1430)$ mass and width

Crude "Explanation"

The Decay Processes are of type : Parent [P] → bachelor [b] + (K π) system

Write amplitude schematically as : $< (K\pi)_L \mid P\,\bar{b} >$ L = angular momentum

Introduce a complete set of intermediate states for each L :

for L = 0, only 1 state up to ~ 1.5 GeV

for L = 1, only 1 state up to ~ 1.1 GeV

so that , up to ~ 1 GeV :

S-wave amplitude = $< (K\pi)_0 \mid (K\pi)_0 >$ $< (K\pi)_0 \mid P\,\bar{b} >$

P-wave amplitude = $< (K\pi)_1 \mid (K\pi)_1 >$ $< (K\pi)_1 \mid P\,\bar{b} >$

same as K π scattering

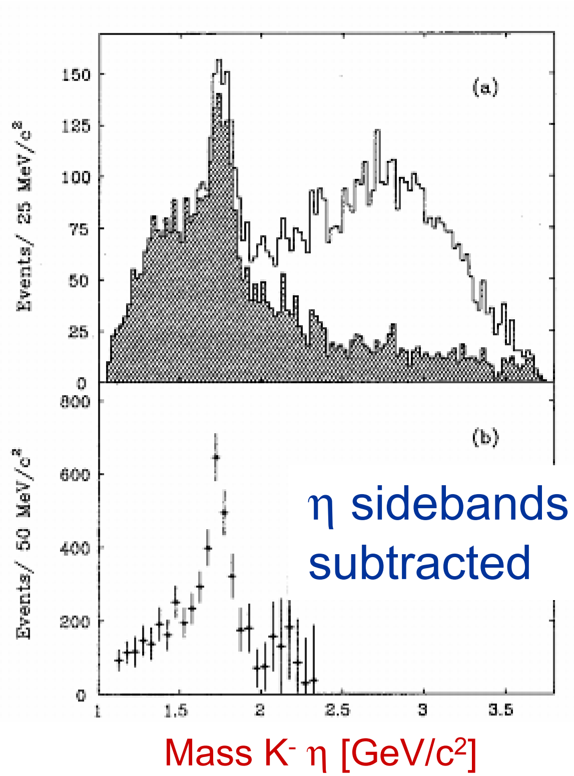
Form Factors – in general, Amp. and phase depend on M(K π); empirically (to date) S-P phase diff. ~ constant.

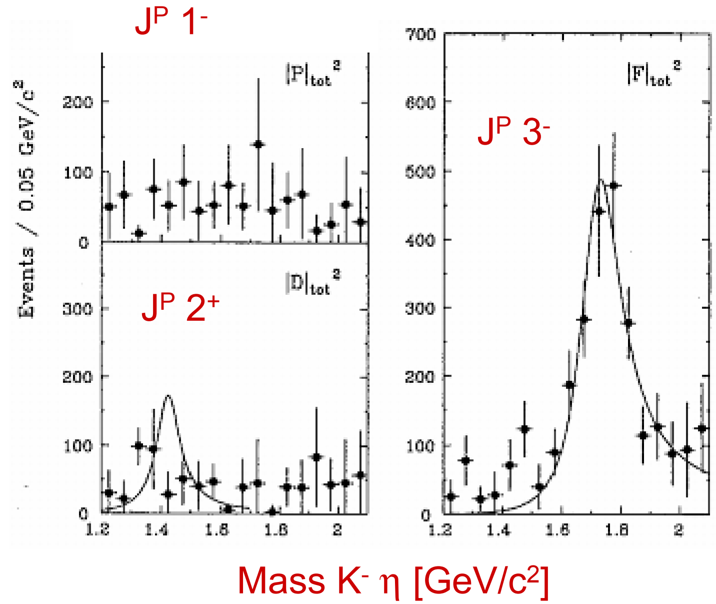
Above 1 GeV, more complicated since >1 intermediate state

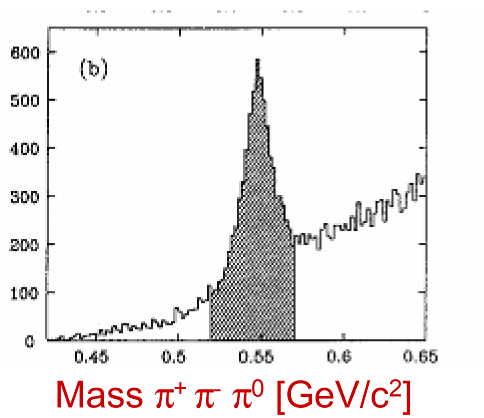
In $D^+ \rightarrow K^- \pi^+ \pi^+$, $|Amp|_S$ has strong M(K π) dependence at low mass

The K η System in $K^- p \rightarrow K^- \eta p$ at 11 GeV/c

{ Phys.Lett.B 201 (1988) 169 ; Hisaki Hayashii, Ph.D Thesis, Nagoya (1988) }







Odd spin : large $J^P = 3^-$ intensity [$K_3^*(1780)$]

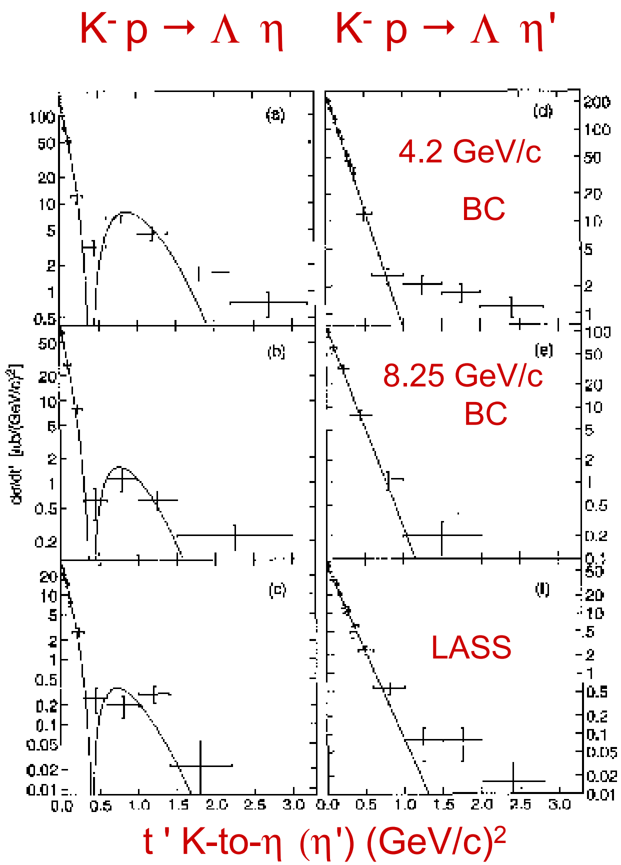
no structure in $J^P = 1^-$

Even spin : no structure in $J^P = 2^+$

no evidence of coupling in $J^P = 0^+$ either

[K π S-wave remains ~ elastic well beyond K η threshold]

Additional Evidence for Weak Coupling of K η to Even Angular Momentum States



SLAC-421; Paul Rensing, Ph.D Thesis, Stanford(1993)

SLAC-369 ; Tim Bienz, Ph.D Thesis, Stanford(1990)

Low momentum transfer η and η' production is described in terms of t-channel exchange of K_1^* and K_2^* degenerate Regge trajectories.

The η' cross section decreases monotonically.

The η cross section has a dip at ~ 0.5 $(GeV/c)^2$ (the location of the K_1^* Wrong-Signature Zero) due to weak coupling to the K_2^* trajectory

(i.e. to Even K η angular momentum).

Why the Absence of Even Angular Momentum Coupling for K η?

SU_3 with nonet symmetry defines the singlet to octet coupling strengths

For a K* of spin L , the Branching Ratio $R_L = \Gamma(K_L^* \to K\eta) / \Gamma(K_L^* \to K\pi)$

is then predicted as follows:

Even L $\quad R_L = 1/9 \, (\cos\theta_p + 2\sqrt{2} \sin\theta_p)^2 \, [q_{K\eta} / q_{K\pi}]^{(2L+1)}$

Odd L $\quad R_L = (\cos\theta_p)^2 \, [q_{K\eta} / q_{K\pi}]^{(2L+1)}$

θ_p is the pseudoscalar meson mixing angle , and is ~ - 20 deg.

{F.Gilman and R.Kauffman, PRD 36 (1987) 2761} ; if θ_p = - 19.5 deg. , then

$\tan\theta_p = - (1 / 2\sqrt{2})$ and $R_L = 0$ for all Even values of L

The LASS measurements of R_2 and R_3, and the predictions, are :

BR	LASS	Prediction θ_p = -19.5 deg.
R_2	< 0.009 (95% cl)	0.0
R_3	0.41 ± 0.06	0.37

Very good agreement

Implications for the K η System in BaBar Analyses

B decay to K η and K η'

In each case, the final state is in an orbital S-wave.

The LASS analyses indicate that the K η system couples only weakly, or not at all, in this configuration for M(K η) < 2 GeV/c^2 . If this should remain true at ~ 5 GeV/c^2 , the decay B → K η should be suppressed, as is observed.

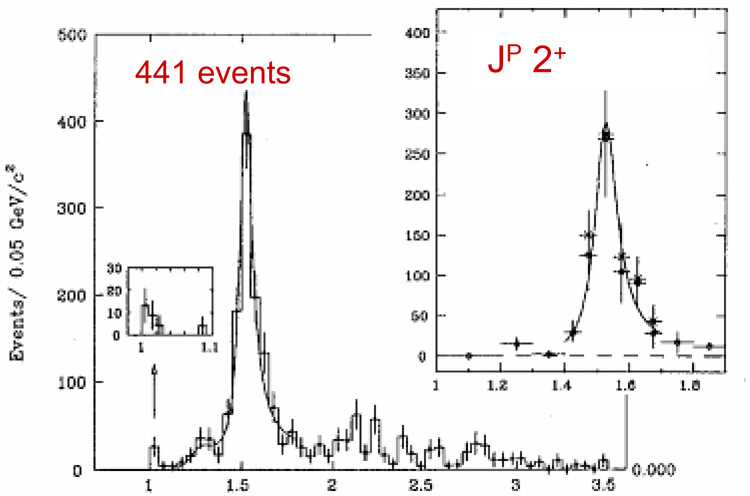
There would be no such suppression for K η', and the K η' BF would equal that for K π ; in fact it is ~ twice as large, but it is certainly not suppressed.

B (and D) decay Dalitz Plot analyses of (K η X) final states

The first significant resonant structure in the K η system occurs in the L=3 amplitude. I know of no observed excitation of any L=3 sub-system in any B (or D) decay. It follows that in the DP analysis of a final state K η X , the possibility of isobar structure in the K η system can be safely ignored; any apparent structure in the K η system is probably the result of reflection.

The $K^0_S K^0_S$ System in $K^- p \rightarrow K^0_S K^0_S \Lambda$ at 11 GeV/c

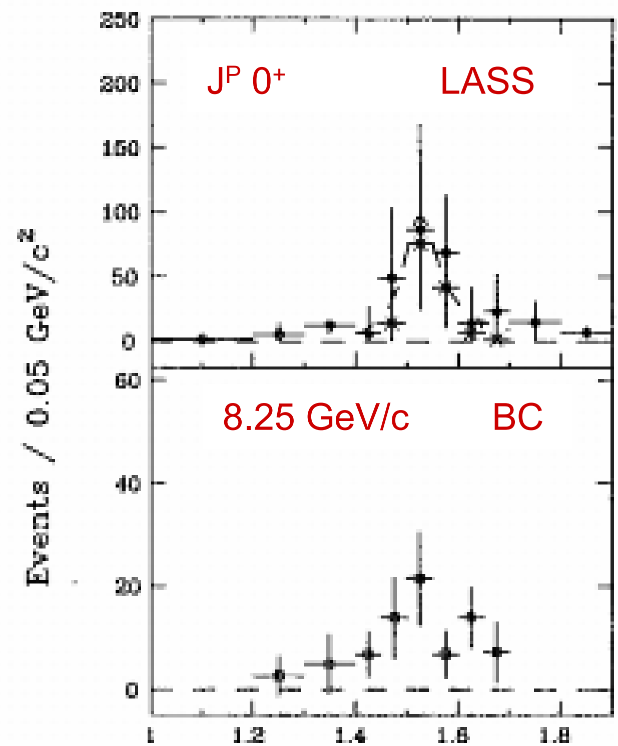
{ NPB 301 (1988) 525 ; Keisuke Fujii, Ph.D Thesis, Nagoya (1986) }



Mass ($K^0_S K^0_S$) [GeV/c²]

f_2' (1525) dominates

i.e. producing mainly $s\bar{s}$ meson states



Mass K Kbar [GeV/c²]

Weak evidence for a mainly-$s\bar{s}$ S-wave state approx. degenerate with the f_2' (1525)

$K^- p \rightarrow K^- K^+ \Lambda$

{ Baubillier et al., ZPC 17 (1983) 309 }

Evidence for this Possible S-wave s-$\bar{s}$ state from BaBar Analyses

In $B^0 \to K^0_S \pi^+ \pi^-$:

clear $f_0(980)$ peak indicates $(\pi^+ \pi^-)$ couples to s $\bar{s}$; small enhancement in $(\pi^+ \pi^-)$ mass near 1.5 GeV/c^2

In $B^0 \to K^0_S K^+ K^-$:

strong $\phi(1020)$ peak in $(K^+ K^-)$, other P-wave contributions weak [small < $P_2(\cos \theta_h)$ >] ;

clear enhancement in $(K^+ K^-)$ mass at ~ 1.5 GeV/c^2 ; larger than in $(\pi^+ \pi^-)$; no evidence of D-wave

i.e. no f_2 ' (1525) to mask the 1.5 GeV/c^2 region ;

In $B^+ \to K^+ K^+ K^-$:

similar structure, 2 entries/event ; may get phase info. from overlap region ;

Possible Interpretation :

mainly s $\bar{s}$ isoscalar meson, the f_0'(1500) say ; NOT the PDG's $f_0(1500)$, since the $(\pi^+ \pi^-)$ / $(K^+ K^-)$ rate ratio is too small ;

Corollary:

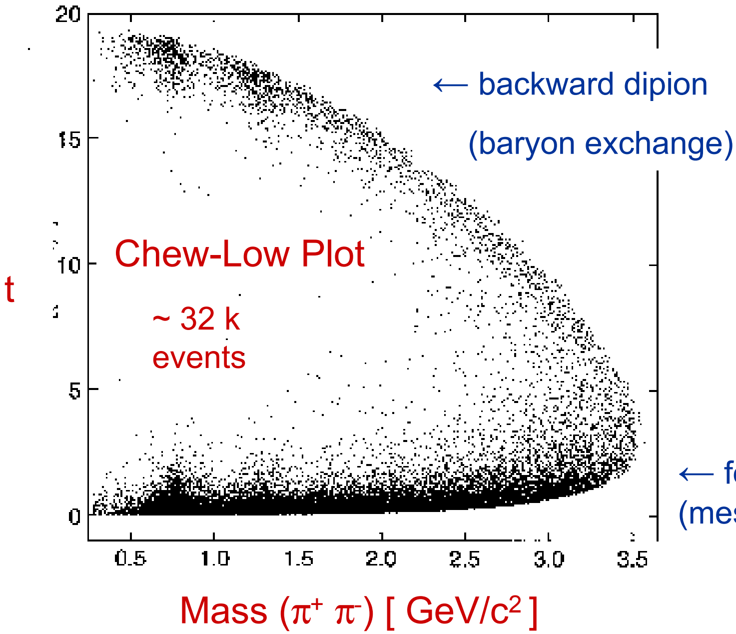
if the $f_0(1370)$ is the mainly non-s $\bar{s}$ isoscalar , and the $f_0(1710)$ is the lightest scalar glueball (mainly) {since seen clearly in J/ψ radiative decays},

what then is the $f_0(1500)$? { discovered in p $\bar{p}$ annihilation at rest [Crystal Barrel] }

Interesting spectroscopy issue in these BaBar analyses; need for much more data in order to extract amplitude structure and phase motion

The π π P-wave Amplitude in $K^- p \rightarrow \pi^+ \pi^- \Lambda$ at 11 GeV/c

{ SLAC - 421; Paul Rensing, Ph.D Thesis, Stanford (1993) }



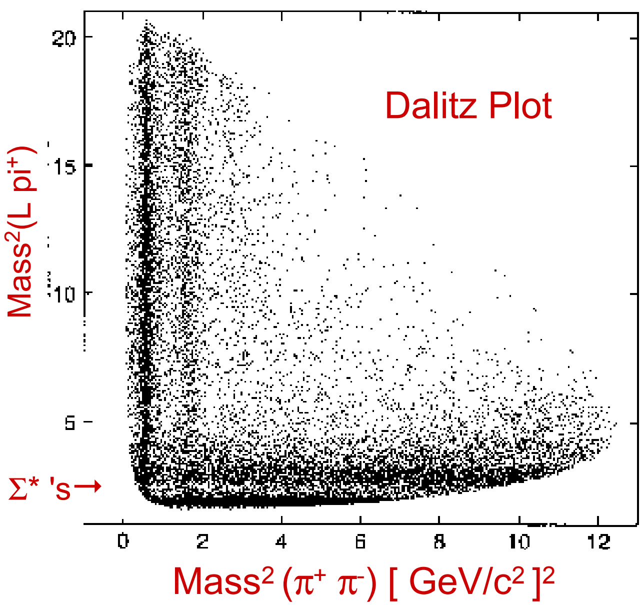
($\pi^+ \pi^-$) system produced with similar mass structure

forward and backward w.r.t. K^- beam in c.m.

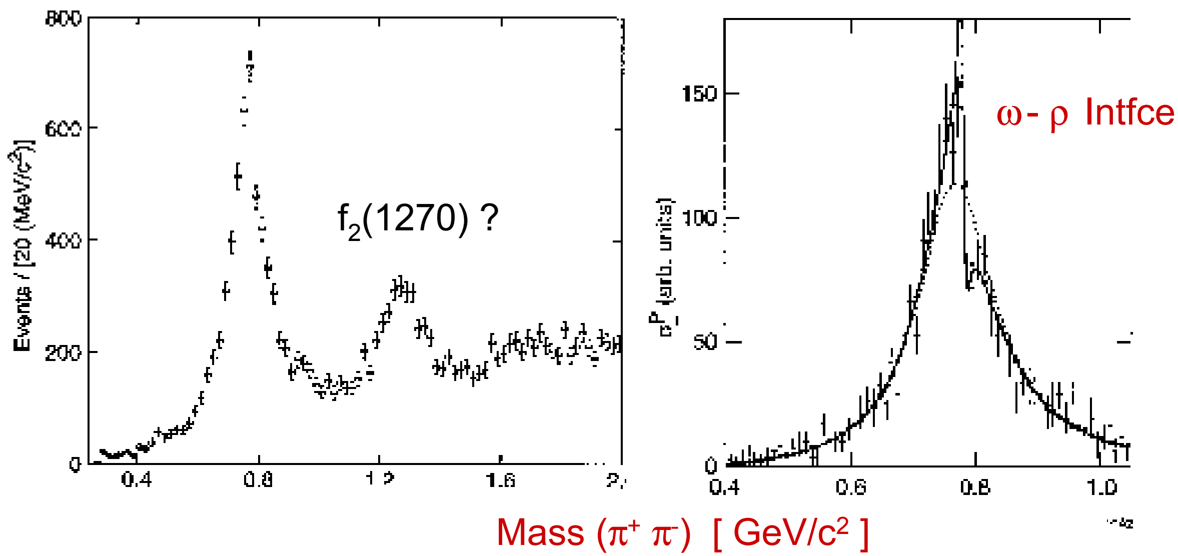
Strong ρ^0 production, and clear ω- ρ interference.

Apparent $f_2(1270)$ signal also.

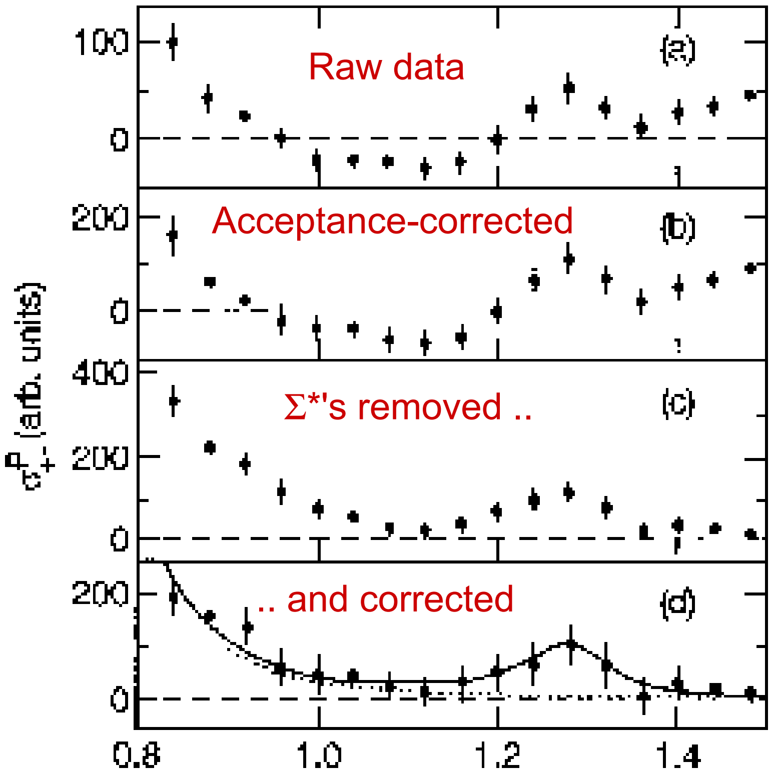
Large production of $\Sigma^*(1385)^+$ and higher mass Σ^{*+} states



Forward Dipion Production



The Forward-produced π π P-wave Intensity near 1.3 GeV/c^2



Mass ($\pi^+ \pi^-$) [GeV/c^2]

The quantity plotted in the above figure is :

$$\sigma_{+-}^{P} = \sqrt{5}/2 < \mathrm{Re}(Y_4^2) > - \sqrt{10}/3 < \mathrm{Re}(Y_2^2) >$$

$$= |P_+|^2 - |P_-|^2$$

i.e. any D-wave contributions are cancelled, and only P-wave remains

The plots of σ_{+-}^{P} all show a peak at ~ 1.3 GeV/c^2;

the full amplitude analysis yields the solid curve shown,

and has Breit-Wigner parameter values for this ρ' (1300)

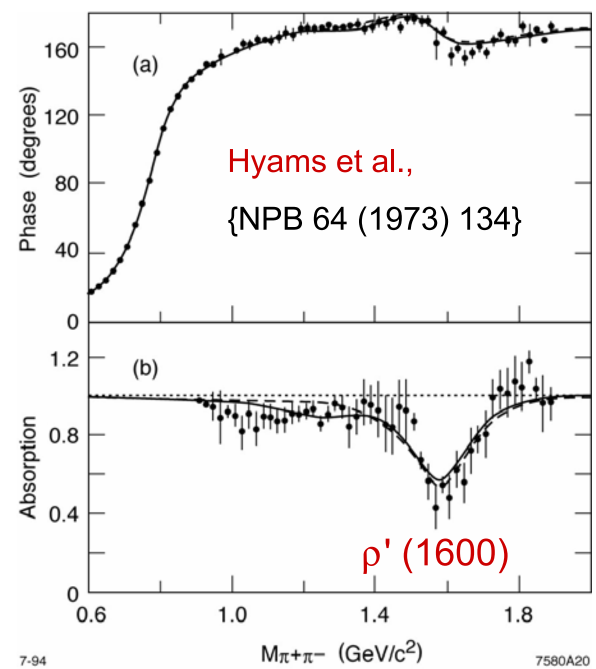
M = 1290 ± 30 MeV/c^2 , Γ = 120 ± 60 MeV/c^2

The elasticity is ~ 5% , very similar to that of the $K_1^*(1410)$ but we have been unable to find any decay mode analogous to K*(892) π for the latter which contributes significantly to the inelastic width.

The P-wave amplitude in π π scattering shows some small phase and inelasticity activity near 1.3 GeV/c^2, but most of the P-wave action is due to the ρ'(1600)

[next slide]

P-wave in π π scattering



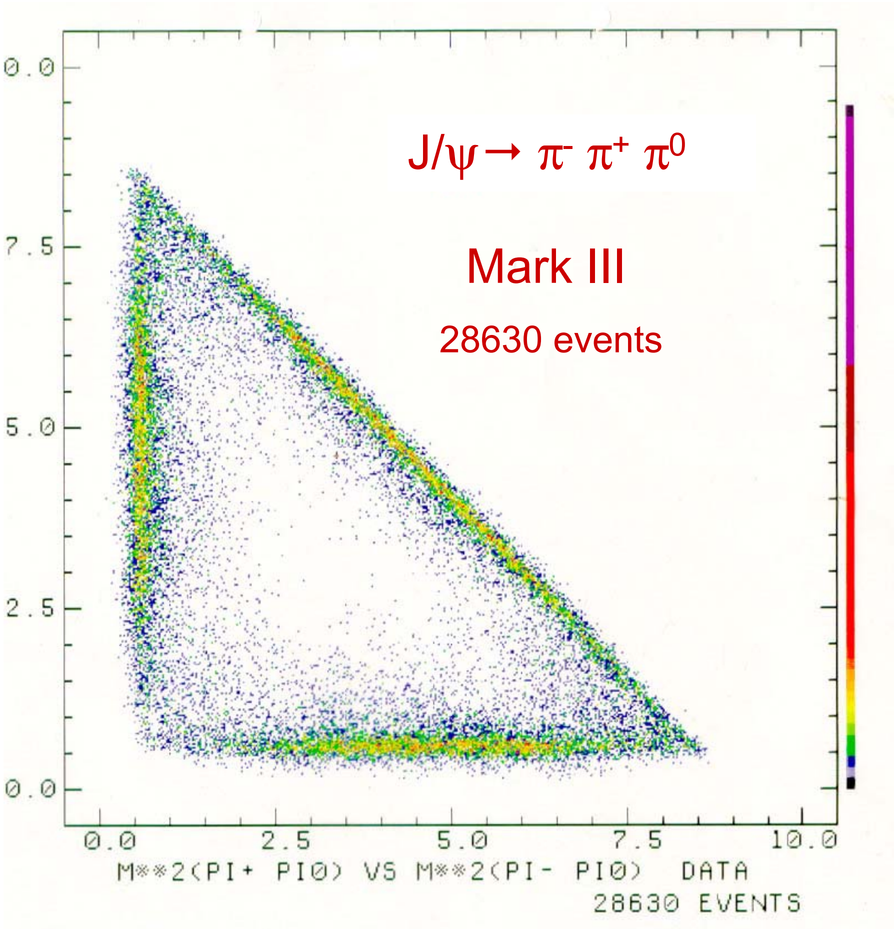
The $\pi\,\pi$ P-wave Amplitude in $J/\psi \rightarrow \pi^- \pi^+ \pi^0$ [Mark III]

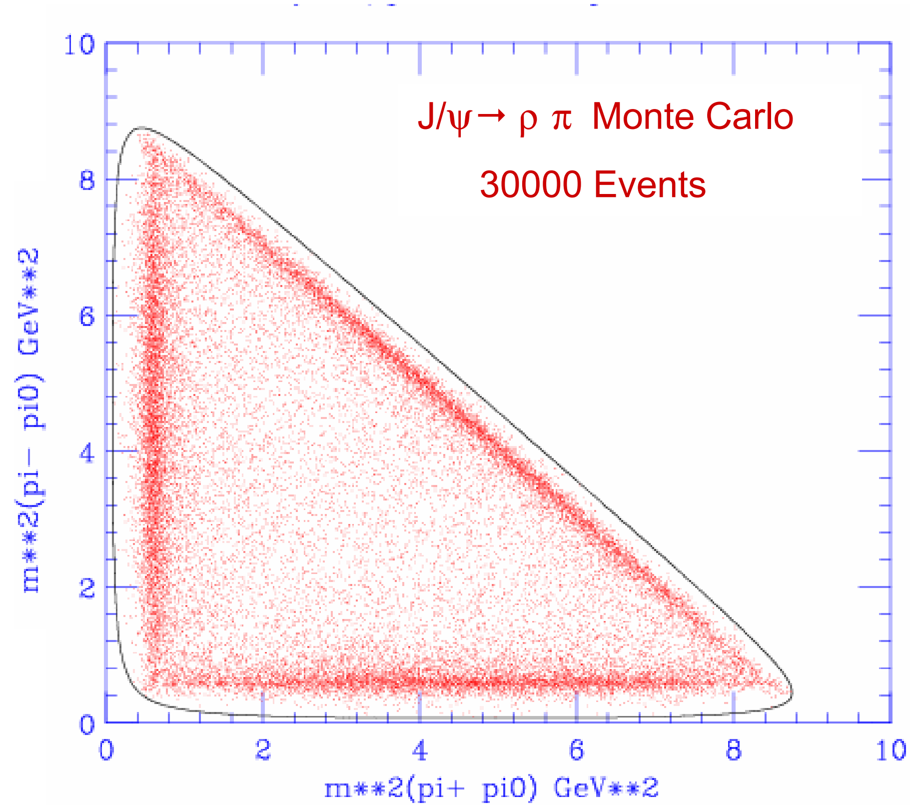
{ L.-P. Chen and W. Dunwoodie, SLAC-PUB-5674 (1991) }

Each $(\pi\,\pi)$ pair in an internal P-wave state, and in an orbital P-wave w.r.t. the bachelor π to get J/ψ spin and parity; ang. mom. cons. → helicity ±1 i.e. $\sin^2\theta_h$ distribution in each ρ band ;

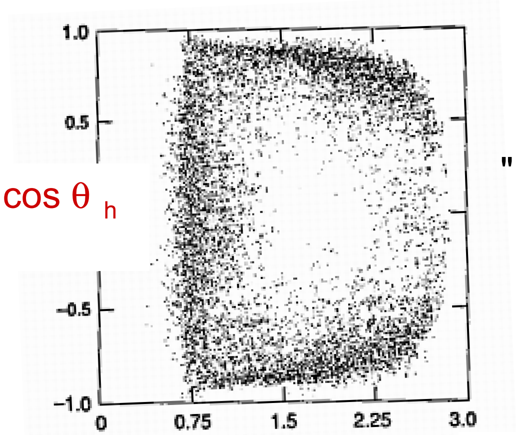
depopulation observed in centre of Dalitz Plot

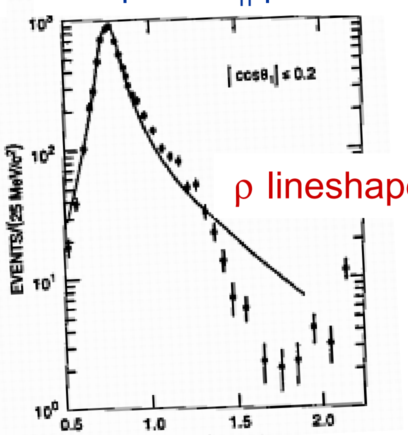
For $J/\psi \rightarrow \rho\,\pi$, the relative phase of the three dipion amplitude contributions is fixed by Bose Symmetry ; there is no destructive interference in the centre of theDalitz Plot ; the "hole" is due to some additional effect

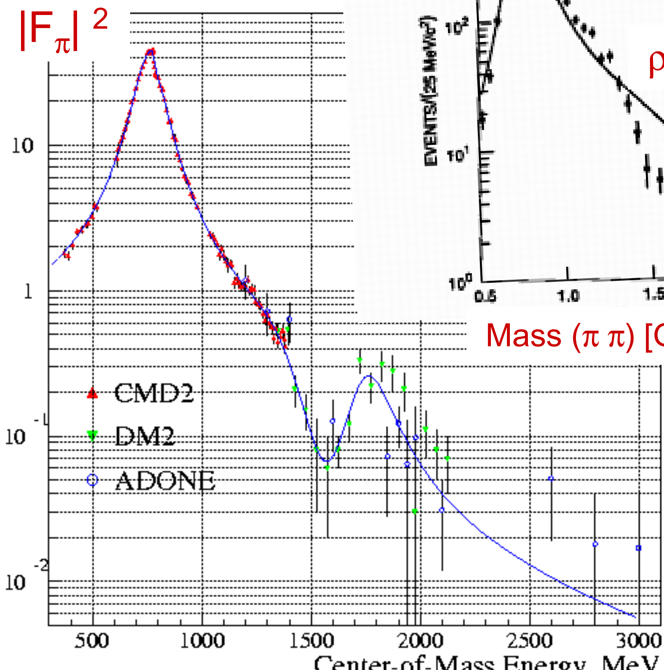




The π π P-wave Amplitude in J/ψ→ π⁻ π⁺ π⁰ [Mark III]







The π π mass distribution for the sum of the regions $|\cos\theta_h| < 0.2$ bears a strong resemblance to the π Form Factor ; suggests destructive interference due to a P-wave excited state.

A corresponding BW amplitude with the same strength, mass, width and relative phase was included in each π π amplitude and a fit made to the DP.

The overlap of the 3 dipion amplitudes enables the extraction of the ρ - ρ ' relative phase ; this is not possible in fits to the pion Form Factor , where a phase value must be assumed.

The fit yields :

$M = 1600 \pm 28$ MeV/c², $\Gamma = 383 \pm 25$ MeV

phase = - 120 ± 8 deg. , elasticity ~ 0.25

In a review of π π scattering data, Martin and Pennington { Ann.Phys. 114 (1978) 1 } conclude that the preferred P-wave solution has M ~ 1575 MeV/c², Γ ~ 340 MeV , elasticity ~ 0.15 - 0.30 , in agreement with the J/ψ results.

The $\pi\pi$ P-wave Amplitude in BaBar Analyses

PDG 2004 lists the $\rho(1450)$ with $M = 1465 \pm 25$ MeV/c^2, $\Gamma = 400 \pm 60$ MeV, and elasticity "seen" This is presumably meant to be the state discussed above, and although the width seems about right, the mass value is heavily influenced by the phase assumed in fits to the pion Form Factor.

The ρ ' (1300) was included in the J/ψ fits, but the corresponding amplitude strength was found consistent with zero. Also, to date, no evidence for this state has been seen in BaBar ISR analyses, and so it remains something of a mystery. The structural similarity between the vector meson states in the Strange and Isovector Sectors when this state is included is nevertheless very intriguing.

The message from the above for BaBar analyses which involve the $\pi\pi$ P-wave amplitude at mass values above 1 GeV/c^2 would seem to be to proceed with caution, and to have some reservations about the information in the PDG book!

Summary

$K\pi$: P-wave : Inelastic above ~ 1.1 GeV/c^2; exercise care in using BW amplitude at higher mass

S-wave : Inelastic above ~ 1.5 GeV/c^2; characteristic asymmetric intensity distribution centred at ~ 1.3 GeV/c^2; check mass dependence of AFB in order to learn about overall phase relative to P-wave; try to measure mass dependence of amplitude strength and phase if statistics and background permit

$K\eta$: Even L : Only weakly coupled

Odd L : First significant coupling seems to be to F-wave (L=3)

Net effect is to simplify relevant DP analyses, since $K\eta$ isobars seem not to be relevant

$K\bar{K}$: Amplitudes with $L \geq 2$ seem to be small in B decay DP analyses

Intriguing S-wave state may exist at ~ 1.5 GeV/c^2

$\pi\pi$: P-wave : The status of the excited states is not well defined; results based on measurements incorporating phase information are probably more reliable

(?) : The status of the (?) on slide 1 is up to you