Study of three-body decays of the η_c meson at the BABAR experiment

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Sat., Feb. 13th, 2016

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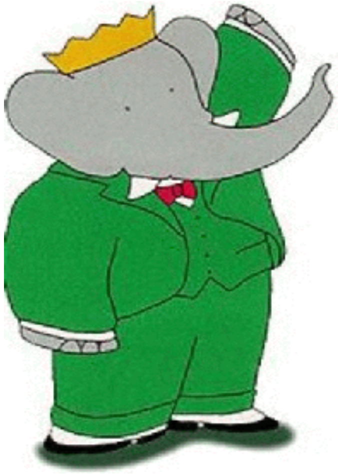


On behalf of the BaBar Collaboration

Theoretical Motivation

- Charmonium decays, η_c, are an excellent probe for light meson spectroscopy.

- Scalar mesons ($J^{PC}=0^{++}$) are still a puzzle.
  - Too many states: inconsistent with quark model
  - Large decay widths: overlap between resonance and background.

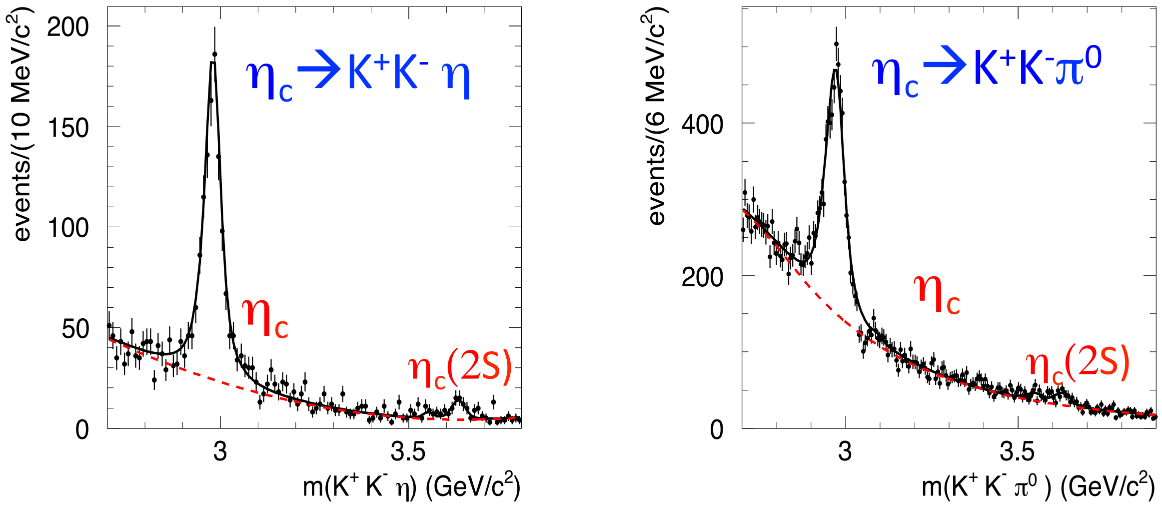
- Structure of I=1/2 Kπ S-wave is poorly known
  - Introduces large systematic uncertainties in analyses with 3 or 4-body decays of heavy flavour mesons

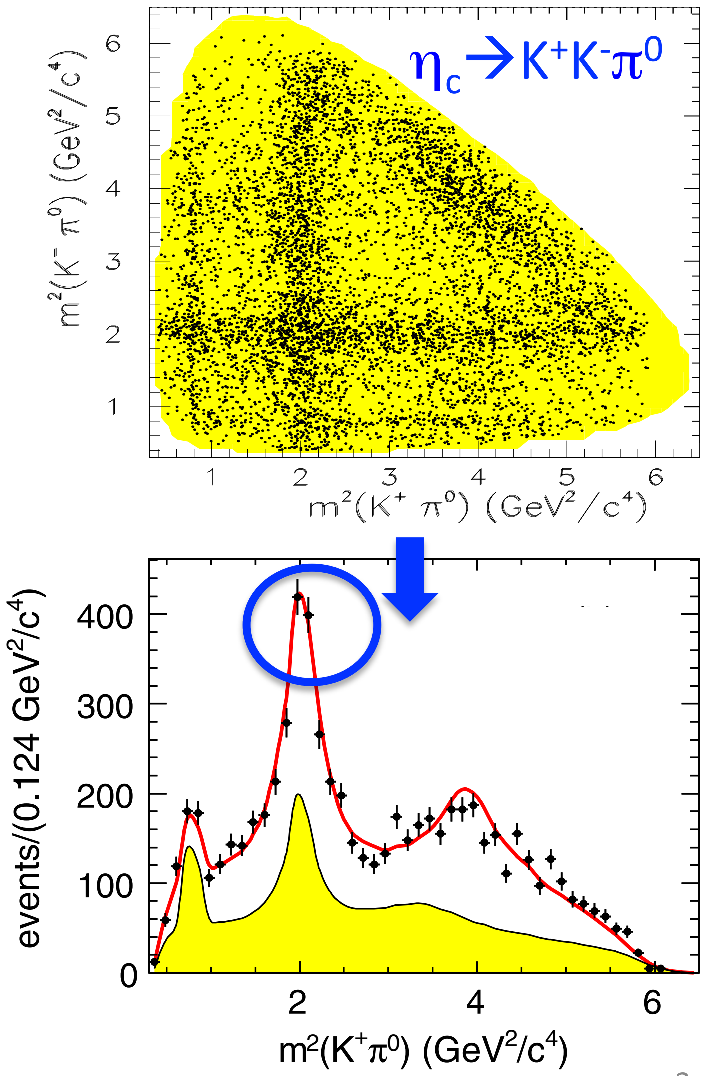
- Previous measurements of I=1/2 Kπ S-wave, limited to below D^+ mass and contamination from I=3/2
  - LASS experiment: Nucl. Phys. B **296**,493 (1988)
  - E791 experiment: Phys. Rev. D **73**, 032004 (2006)

Phys. Rev. D 89, 112004 (2014)

Dalitz plot analysis of η_c

BaBar performed first Dalitz plot analysis of $\eta_c \rightarrow K^+K^-\pi^0$ and $\eta_c \rightarrow K^+K^-\eta$.





First observation of K*(1430) as a Breit-Wigner peak:

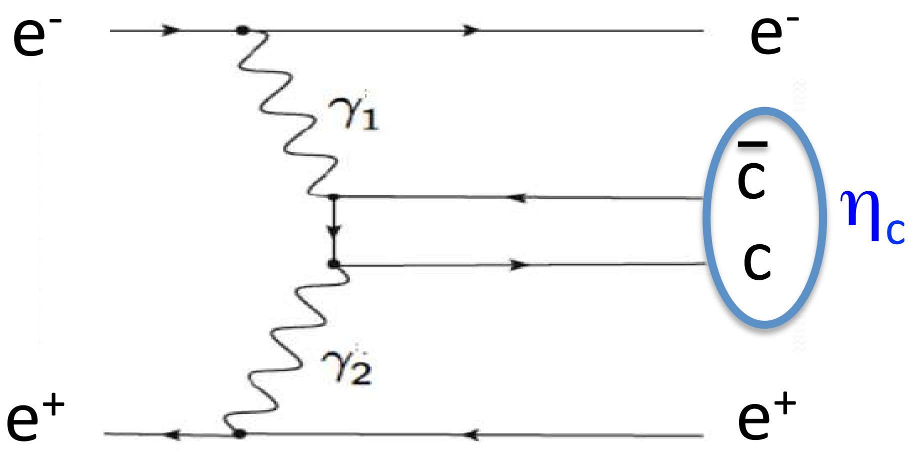
$$\frac{\mathcal{B}(K_0^*(1430)\to\eta K)}{\mathcal{B}(K_0^*(1430)\to\pi K)} = \mathcal{R}(\eta_c)\frac{f_{\eta K}}{f_{\pi K}} = 0.092\pm0.025^{+0.010}_{-0.025}$$

Dominance of scalar meson amplitudes:

$\eta_c \longrightarrow$ pseudoscalar + scalar

$\gamma\gamma \rightarrow K \bar{K} \pi$

- Two photon interactions are used to produce charmonium resonances.
- e+ e^- beam particles are scattered at small angles and undetected in the final state.



- Produced resonances can have $J^{PC}=0^{\pm+}, 2^{\pm+}, 3^{++}, 4^{\pm+}$, etc … with the exception that $K\bar{K}\pi$ cannot be in a $J^P=0^+$ state.
- The following two photon interactions are considered using an integrated luminosity of 519 fb^{-1}:

$\gamma\gamma \rightarrow K_s K^+\pi^-$, $K_s \rightarrow \pi^+\pi^-$ ← **first time**

$\gamma\gamma \rightarrow K^+K^-\pi^0$, $\pi^0 \rightarrow \gamma\gamma$

$\gamma\gamma \rightarrow K\bar{K}\pi$

$\gamma\gamma \rightarrow K_s K^+\pi^-$, $K_s \rightarrow \pi^+\pi^-$

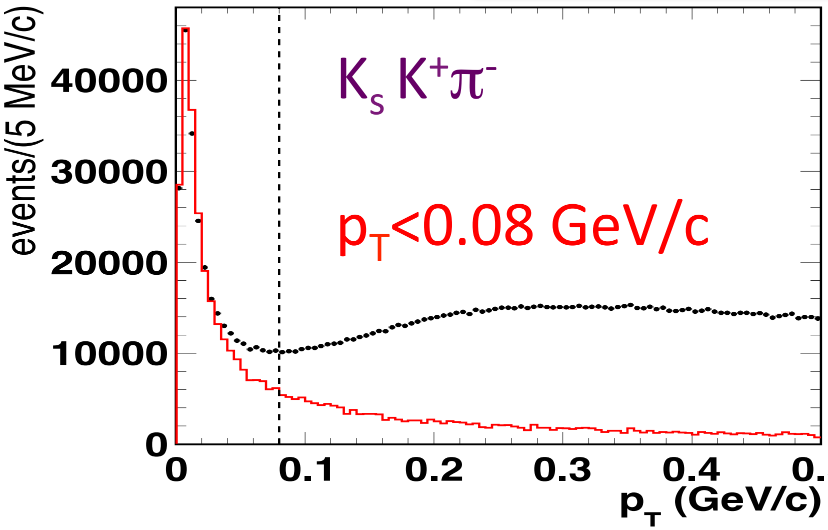
- Exactly 4 charged tracks with loose Kaon and Pion PID.
- Vertex fit of oppositely charged tracks to select K_s candidates.

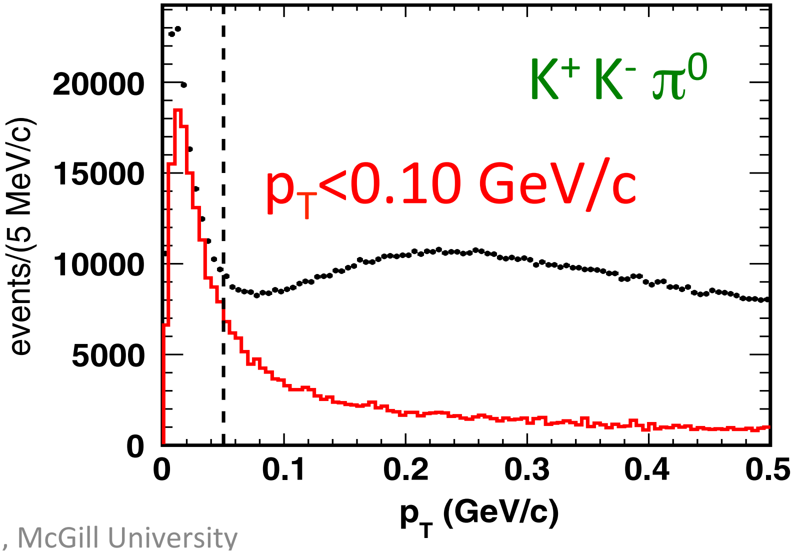
$\gamma\gamma \rightarrow K^+ K^- \pi^0$

- Exactly 2 charged tracks with loose Kaon PID.
- $\gamma\gamma$ pairs fit to a π^0 hypothesis, with E_γ>50 MeV.

Background from ISR events with $J^{PC}= 1^{--}$ resonance production suppressed:

$$M^2_{rec}=(p_{e+e} - p_{rec})^2 > 10\ \mathrm{GeV}^2/c^4$$

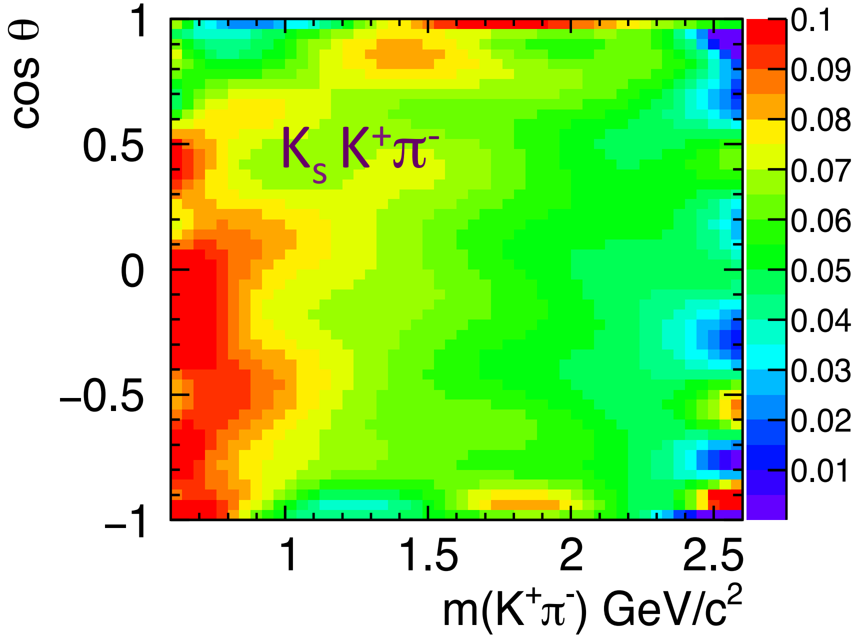


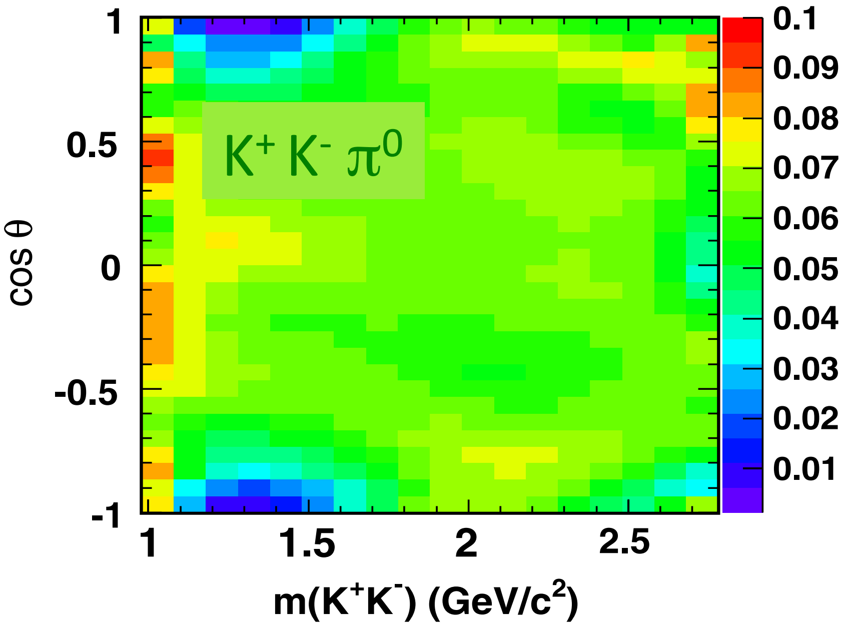


Signal Efficiency

- MC signal events in which the η_c decays uniformly in phase space.
- Restrict mass regions to η_c signal region.
- Efficiency: $N_{reconstructed}/N_{generated}$
- Express as a function of $m(K^+K^-)$ and $\cos\theta_{K^+}$
- $\cos\theta_{K^+}$: angle, in K^+K^- rest frame, between the direction of the K^+ and the boost from $K_sK^-\eta$ or $K^+K^-\pi^0$ rest frame.

$$\epsilon(\cos\theta) = \sum_{L=0}^{12} a_L(m) Y_L^0(\cos\theta)$$



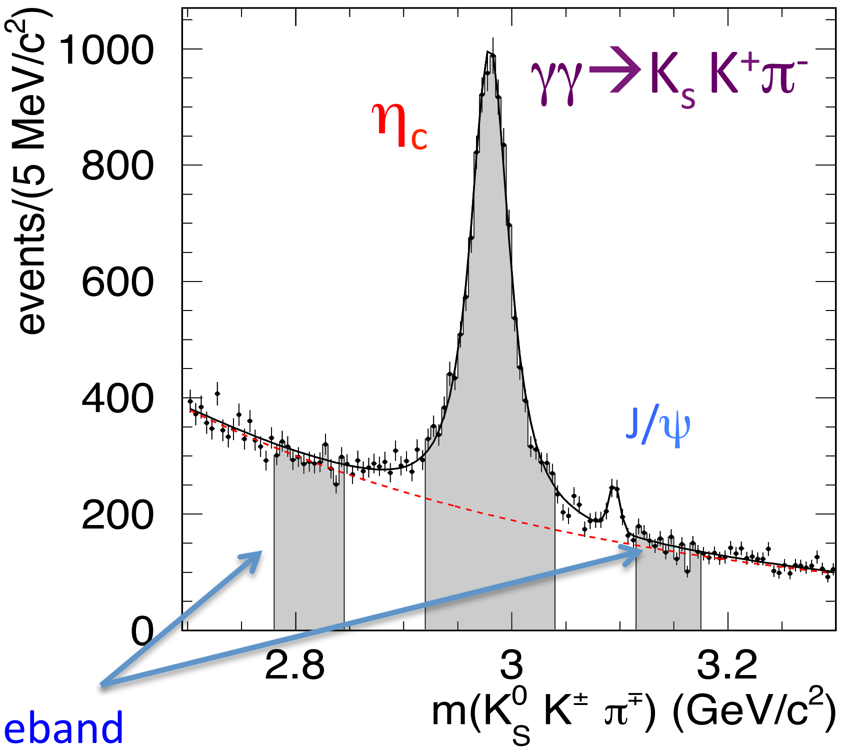


Efficiency loss due to low momentum kaons (<200 MeV/c)
K_s and $\pi^\pm$ (<100 MeV/c)

Mass Spectra

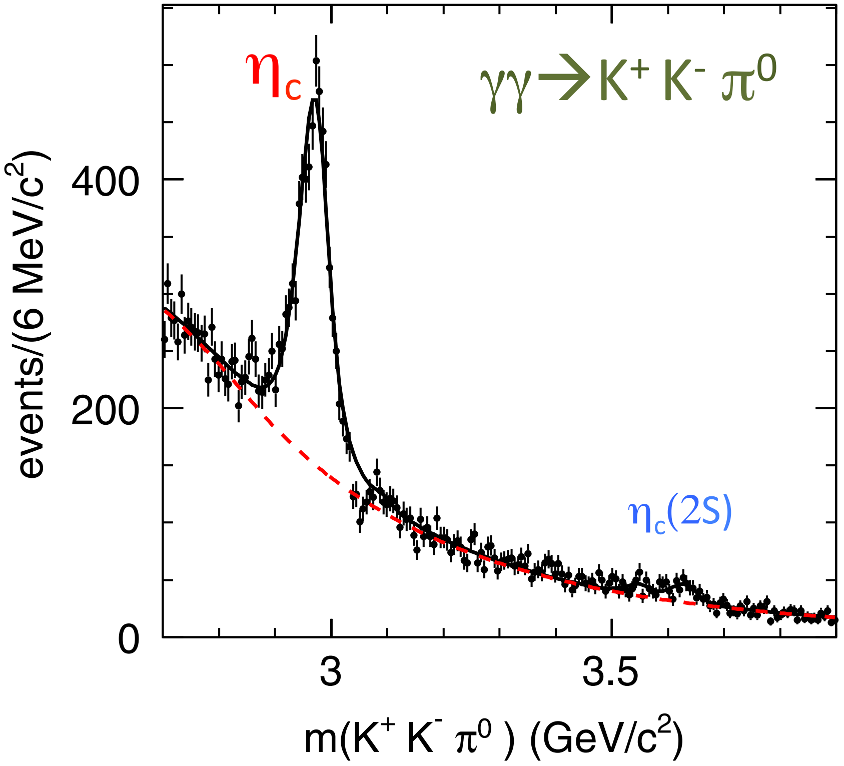
Clear η_c signal fit with a Breit-Wigner function convolved with the mass resolution function.

Background described with 2nd order polynomial.



sideband regions

12849 signal events with 64.3% purity

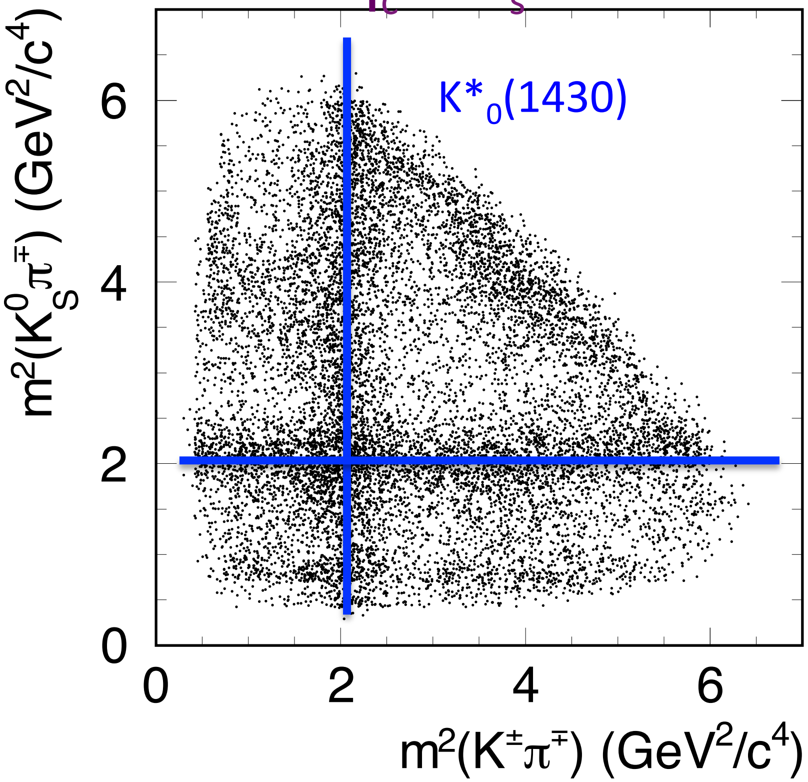


6710 signal events with 55.2% purity

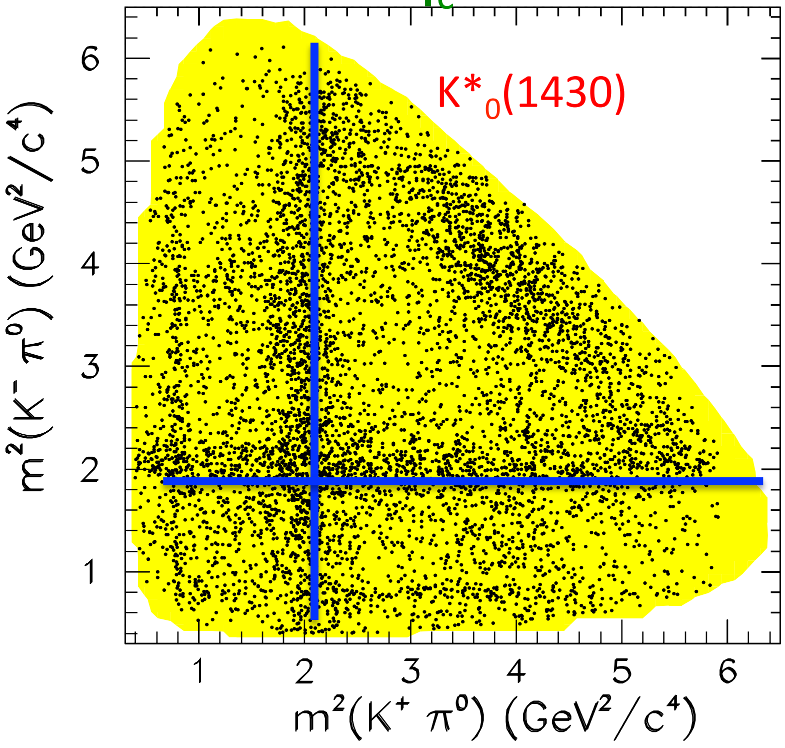
Dalitz Plot Analysis of $\eta_c \rightarrow K\bar{K}\pi$

- Unbinned maximum likelihood fit in the η_c mass region
- Full interference allowed among amplitudes.
- Fits performed using:
  - Isobar model: Phys. Lett. B **592**, 1 (2004)
  - Model Independent Partial Wave Analysis (MIPWA): Phys. Rev. D **73**, 032004 (2006)

$\eta_c \rightarrow K_s K^+ \pi^-$



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



Model Independent Partial Wave Analysis of $\eta_c \to K\overline{K}\pi$

Amplitude is written as a sum of partial waves with A_i and ϕ_i

$$A = |A_1 + c_2 A_2 e^{\phi 2} + c_3 A_3 e^{\phi 3} + \ldots|$$

- $\eta_c = 0^+ \longrightarrow$ Interference between (Kπ) K systems is constructive.
- Kπ amplitude is symmetrized

$\eta_c = K_s K^+ \pi^-$

$$A_{\mathcal{S}\text{-wave}} = \frac{1}{\sqrt{2}}\left(a_j^{K^+\pi^-} e^{i\phi_j^{K^+\pi^-}} + a_j^{\overline{K}^0\pi^-} e^{i\phi_j^{\overline{K}^0\pi^-}}\right)$$

where $a^{K^+\pi^-}(m) = a^{K^0_S\pi^-}(m)$ and $\phi^{K^+\pi^-}(m) = \phi^{K^0_S\pi^-}(m)$

$\eta_c = K^+ K^- \pi^0$

$$A_{\mathcal{S}\text{-wave}} = \frac{1}{\sqrt{2}}\left(a_j^{K^+\pi^0} e^{i\phi_j^{K^+\pi^0}} + a_j^{K^-\pi^0} e^{i\phi_j^{K^-\pi^0}}\right)$$

where $a^{K^+\pi^0}(m) = a^{K^-\pi^0}(m)$ and $\phi^{K^+\pi^0}(m) = \phi^{K^-\pi^0}(m)$

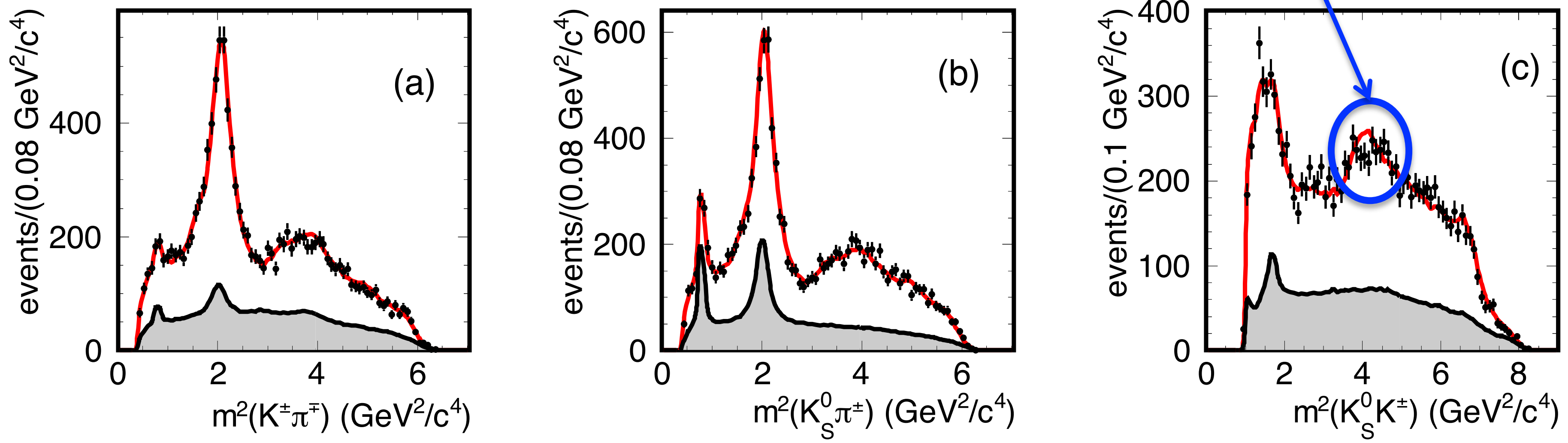
- Mass spectrum is divided into 30 equally spaced mass intervals 60 MeV wide.
- Each interval has 2 new free parameters, A_i and $\phi_{i.}$ with a total of 58
- Fix A=1 and $\phi = \pi/2$ in one arbitrary bin (bin 11 with mass=1.45 GeV/c^2)
- Other resonance contributions, A_2, A_3, etc…, are parameterized as Breit-Wigner amplitudes multiplied by their corresponding angular functions.
- Backgrounds are interpolated from sideband regions: K*(892) entirely background.

MIPWA of $\eta_c \rightarrow K_s K^+ \pi^-$

- Dominance of Kπ S-wave with contributions from $a_0\pi$ and K*(1430)K.
  - New resonance $a_0(1950)$ with 2.5σ significance.
    - Good description of the data!

	$\eta_c \to K^0_S K^\pm \pi^\mp$	
Amplitude	Fraction (%)	Phase (rad)
$(K\pi\ \mathcal{S}\text{-wave})\ \overline{K}$	$107.3 \pm 2.6 \pm 17.9$	fixed
$a_0(980)\pi$	$0.8 \pm 0.5 \pm 0.8$	$1.08 \pm 0.18 \pm 0.18$
$a_0(1450)\pi$	$0.7 \pm 0.2 \pm 1.4$	$2.63 \pm 0.13 \pm 0.17$
$a_0(1950)\pi$	$3.1 \pm 0.4 \pm 1.2$	$-1.04 \pm 0.08 \pm 0.77$
$a_2(1320)\pi$	$0.2 \pm 0.1 \pm 0.1$	$1.85 \pm 0.20 \pm 0.20$
$K_2^*(1430)\overline{K}$	$4.7 \pm 0.9 \pm 1.4$	$4.92 \pm 0.05 \pm 0.10$
Total	$116.8 \pm 2.8 \pm 18.1$	
$-2\log\mathcal{L}$	-4314.2	
χ^2/N_{cells}	$301/254 = 1.17$	

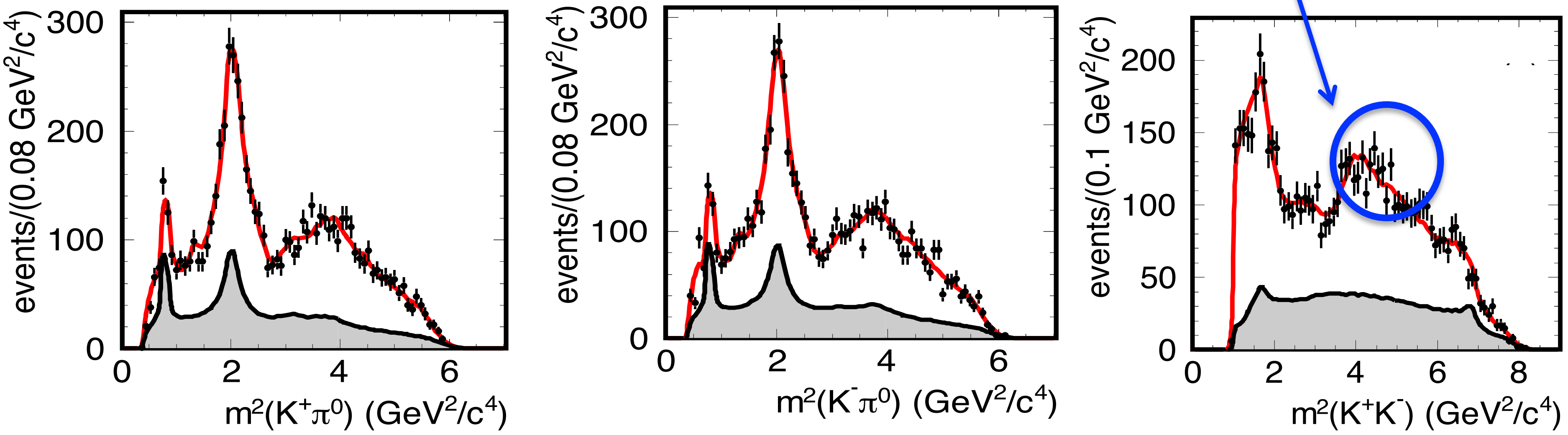
→ Interference effects



MIPWA of $\eta_c \to K^+ K^- \pi^0$

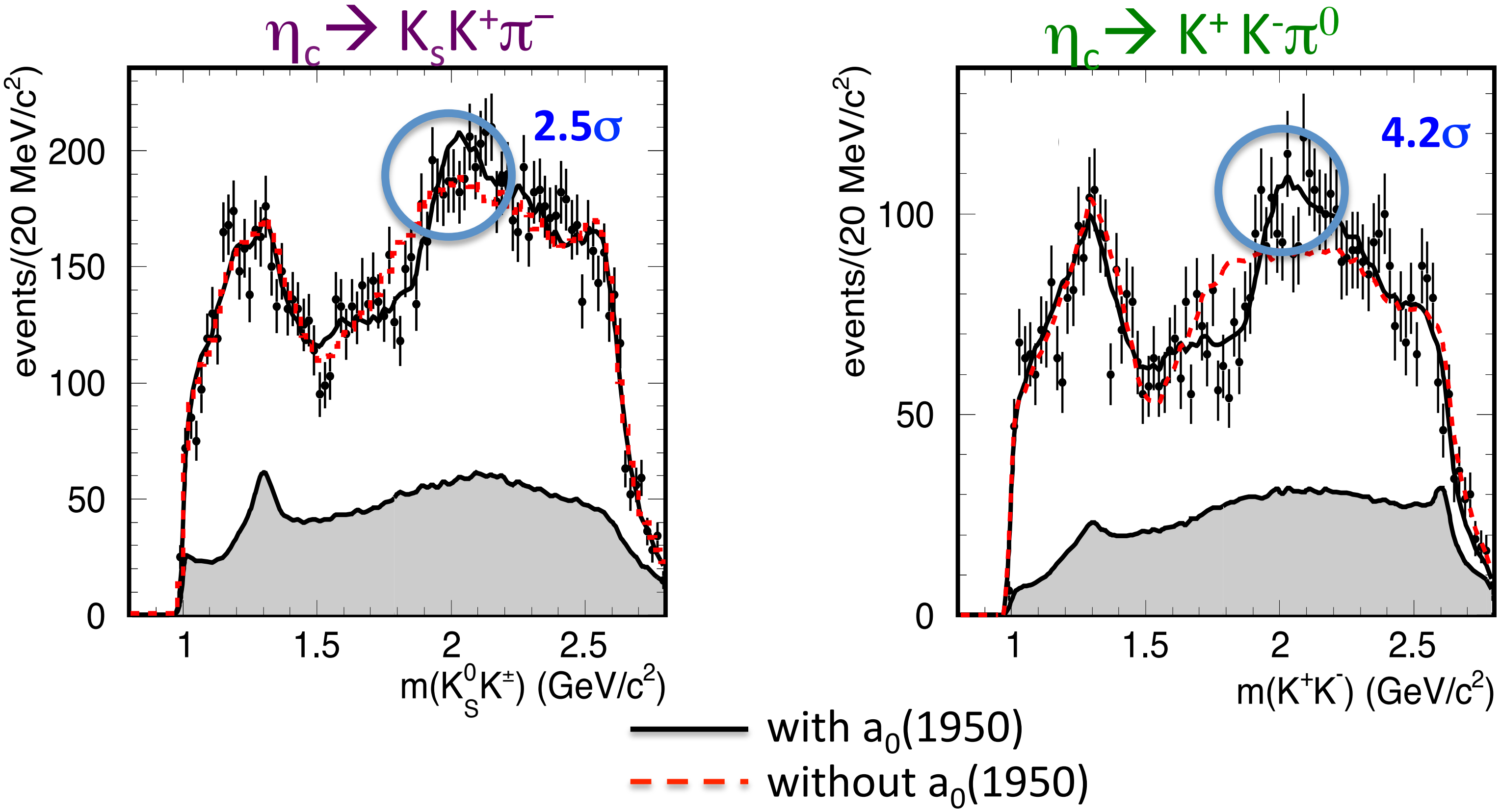
- Dominance of Kπ S-wave with contributions from $a_0\pi$ and K*(1430)K.
  - New resonance $a_0(1950)$ with **4.2σ** significance
    - Good description of the data!

	$\eta_c \to K^+ K^- \pi^0$	
Amplitude	Fraction (%)	Phase (rad)
$(K\pi\ \mathcal{S}\text{-wave})\ \overline{K}$	$125.5 \pm 2.4 \pm 4.2$	fixed
$a_0(980)\pi$	$0.0 \pm 0.1 \pm 1.7$	-
$a_0(1450)\pi$	$1.2 \pm 0.4 \pm 0.7$	$2.90 \pm 0.12 \pm 0.25$
$a_0(1950)\pi$	$4.4 \pm 0.8 \pm 0.8$	$-1.45 \pm 0.08 \pm 0.27$
$a_2(1320)\pi$	$0.6 \pm 0.2 \pm 0.3$	$1.75 \pm 0.23 \pm 0.42$
$K_2^*(1430)\overline{K}$	$3.0 \pm 0.8 \pm 4.4$	$5.07 \pm 0.09 \pm 0.30$
Total	$134.8 \pm 2.7 \pm 6.4$ → Interference effects	
$-\ 2\log\mathcal{L}$	-2339	
χ^2/N_{cells}	$283.2/233 = 1.22$	



a_0(1950) resonance

MIPWA fit improved with the a_0(1950) resonance in both η_c channels.



Final state	Mass (MeV/c^2)	Width (MeV)
$\eta_c \rightarrow K^0_S K^\pm \pi^\mp$	$1949 \pm 32 \pm 76$	$265 \pm 36 \pm 110$
$\eta_c \rightarrow K^+ K^- \pi^0$	$1927 \pm 15 \pm 23$	$274 \pm 28 \pm 30$
Weighted mean	$1931 \pm 14 \pm 22$	$271 \pm 22 \pm 29$

large systematics

Isobar Model of $\eta_c \rightarrow K_s K^+ \pi^-$

- Resonances are modeled as Breit-Wigner multiplied by their angular functions.
- $K\pi$ S-wave is parametrized as a superposition of interfering $K^*_0(1430)$, $K^*_0(1950)$, and non-resonant amplitude (NR).

Amplitude	Fraction %	Phase (rad)
$K_0^*(1430)\overline{K}$	40.8 ± 2.2	$0.$
$K_0^*(1950)\overline{K}$	14.8 ± 1.7	-1.00 ± 0.07
NR	18.0 ± 2.5	1.94 ± 0.09
$a_0(980)\pi$	10.5 ± 1.2	0.94 ± 0.12
$a_0(1450)\pi$	1.7 ± 0.5	2.94 ± 0.13
$a_0(1950)\pi$	0.7 ± 0.2	-1.76 ± 0.24
$a_2(1320)\pi$	0.2 ± 0.2	-0.53 ± 0.42
$K_2^*(1430)\overline{K}$	2.3 ± 0.7	-1.55 ± 0.11
Total	88.8 ± 4.3	
$-2 \log \mathcal{L}$	-4290.7	
χ^2/N_{cells}	$467/256=1.82$	

$K\pi$ S-wave

Interference effects

Poor description of data!

Compare with **1.17** with MIWPA fit.

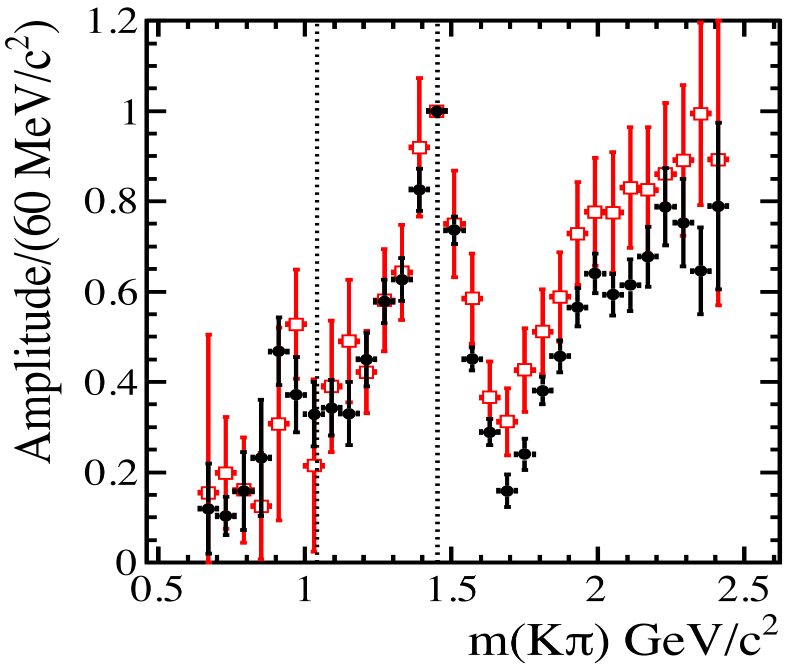
Similar result for $K^+K^-\pi^0$

I=1/2 Kπ S-wave Amplitude

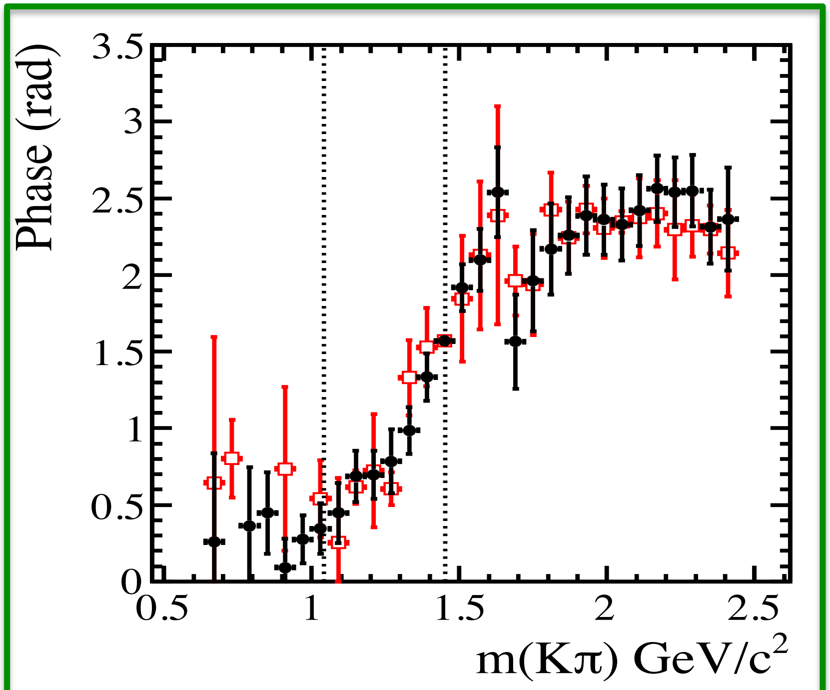
- Amplitude extending up to a mass of 2.5 GeV/c^2.
- Due to isospin conservation, no contribution from I=3/2.

$\eta_c \rightarrow K_s K^+ \pi^-$

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



- Clear peak about $K^*_0(1430)$ resonance
- Broad structure likely due to $K^*_0(1950.)$



- Phase varies by about π about $K^*_0(1430)$ resonance.
- Drop at 1.7 GeV/c^2 due to interference with $K^*_0(1950)$

I=1/2 Kπ S-wave Amplitude

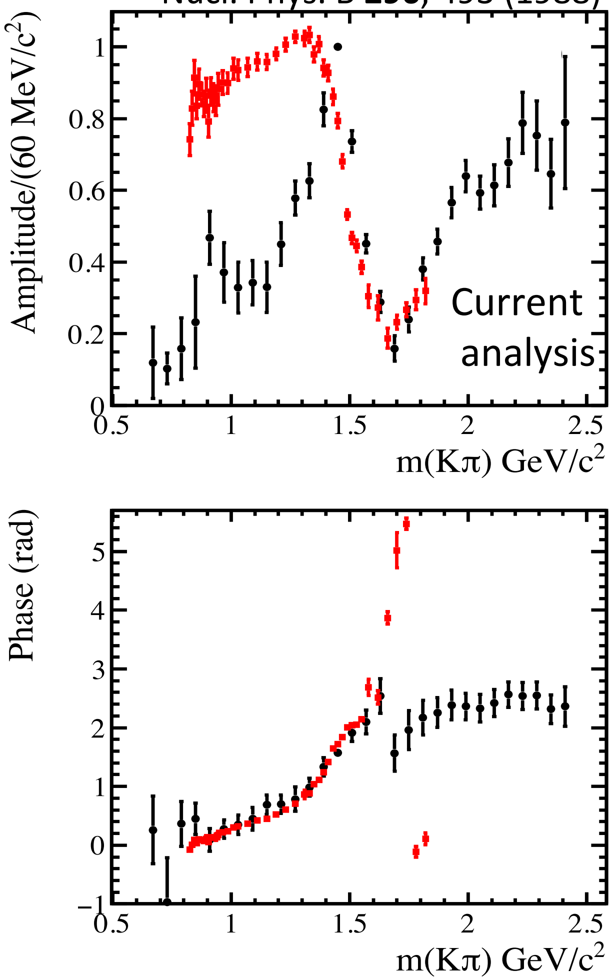
Difficulty separating I=1/2 and I=3/2 contributions in LASS and E791 experiments.

LASS measurement has two-fold ambiguity above 1.82 GeV/c^2.

E791 measurements are limited to below 1.6 GeV/c^2

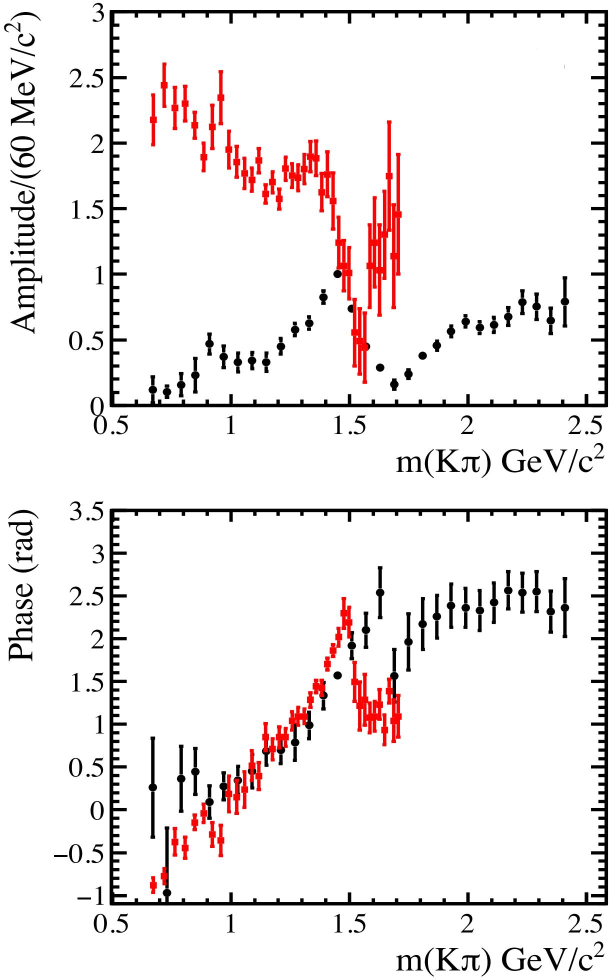
LASS: $K^-p^- \longrightarrow K^+\pi^+n$

Nucl. Phys. B **296**, 493 (1988)



E791: $D^- \longrightarrow K^+\pi^+\pi^-$

Phys. Rev. D **73**, 032004 (2006)



Striking difference in the mass dependence of amplitudes!

Phase behaviour is similar as expected by Watson's theorem!

Conclusion

- Dalitz plot analysis of $\eta_c \rightarrow K\bar{K}\pi$ using MIPWA and isobar model.
  - **Improved** description with MIPWA.
  - $a_0(1950)$ resonance with m= 1931±14±22 MeV/c^2 and Γ=271±22±29 MeV with significance of **2.5σ** and **4.2σ**.

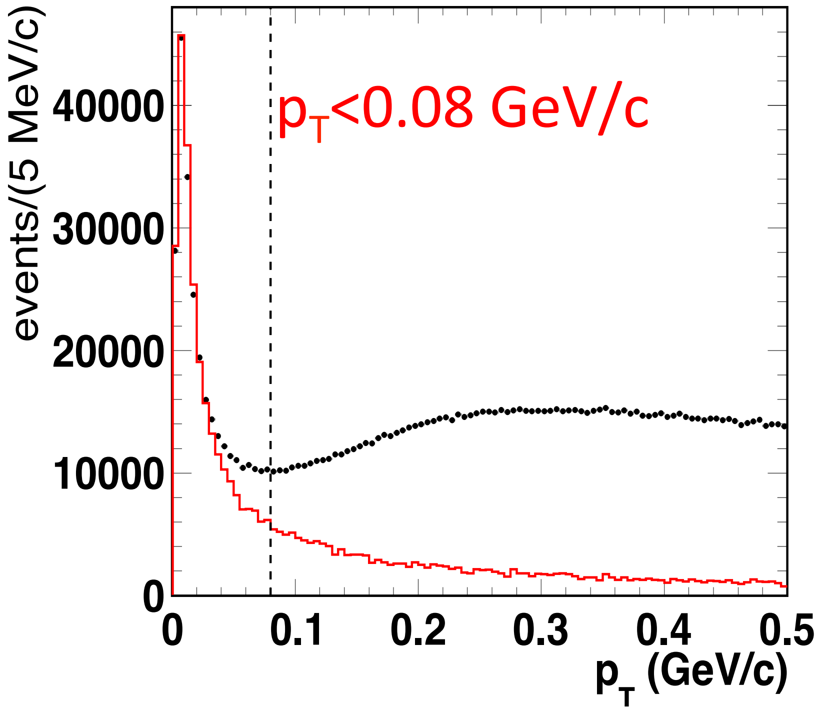
- Extraction of I=1/2 $K\pi$ S-wave using MIPWA
  - Amplitudes show **distinct differences** with previous measurements by E791 and LASS.

BACK UP SLIDES

$\gamma\gamma \rightarrow K_s K^+\pi^-$, $K_s \rightarrow \pi^+\pi^-$

- Consider only events with 4 charged tracks and no more than 5 photon candidates with energy >100 MeV.
- Vertex fit of oppositely charged tracks to select Ks candidates.
  - No PID on daughter π, decay length >0.2 cm.
  - Mass +/-2σ from Gaussian-fitted $\pi^+\pi^-$ mass spectrum with m=497.24 MeV/c^2, σ=2.9 MeV/c^2.
- Loose Kaon and Pion PID for remaining two tracks.
- Background from ISR events with $J^{PC}= 1^{--}$ resonance production suppressed:

$M^2_{rec}=(p_{e+e-}-p_{rec})^2 > 10$ GeV/c^2



Selection optimized as a function of p_T.

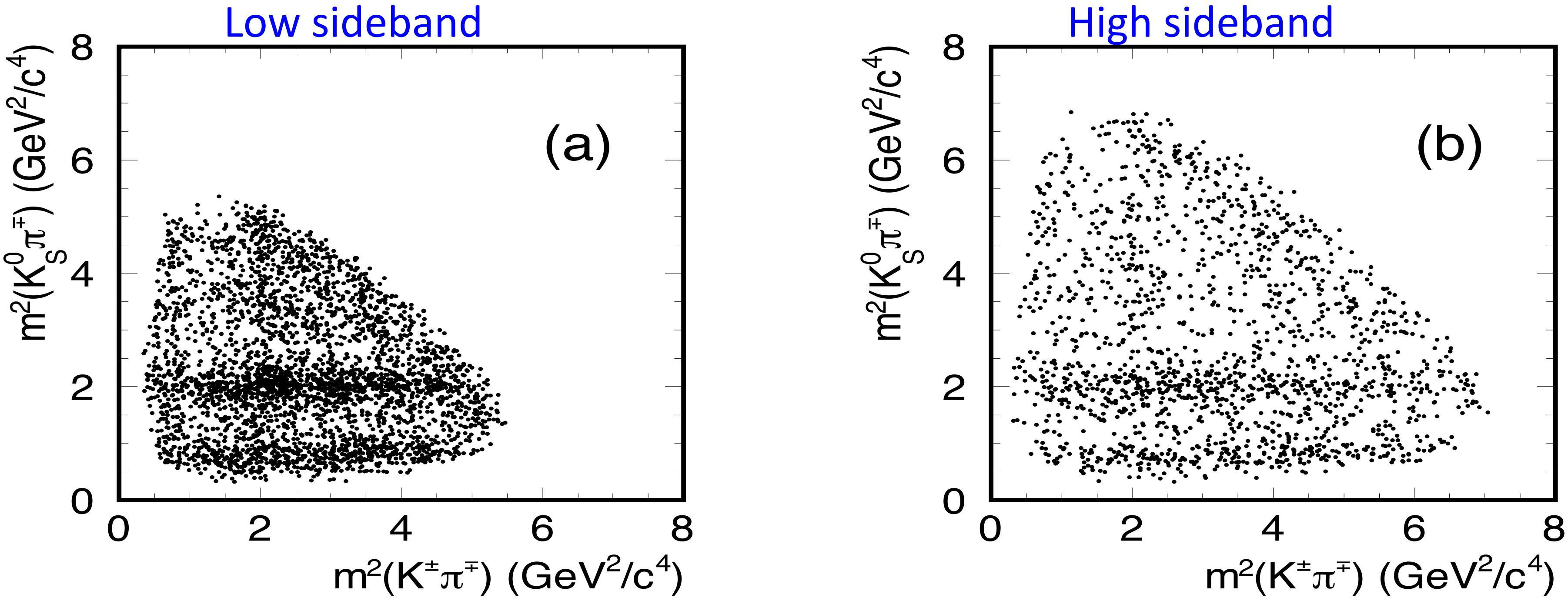
Maximize P•S:

$P=N_s/(N_s+N_b)$

$S=N_s/ \sqrt{(N_s+N_b)}$

η_c sideband regions

- Uniformly distributed resonant structures in multi-channel likelihood.
- Weaker in $K^+\pi^-$ than in $K^0_s\pi^-$ due to interference between I=0 and I=1 configurations.



- Backgrounds from $a_0(980)$, $a_0(1450)$, $a_2(1320)$, $K^*(892)$, $K^*_0(1430)$, $K^*_2(1430)$.
- Spin-1 resonance contributions are entirely from background.

MIPWA of $\eta_c \rightarrow K K \pi$

Systematic uncertainties:

1. Fit bias.
    - Generate signal MC starting from fit.
2. Replace $K\pi$ S-wave representation with cubic spline
3. Remove low significance contributions
4. Vary signal purity
5. Account for efficiency variation as a function of η_c mass.

		$\eta_c \rightarrow K^0_S K^\pm \pi^\mp$		$\eta_c \rightarrow K^+ K^- \pi^0$	
N	$K\pi$ mass	Amplitude	Phase (rad)	Amplitude	Phase (rad)
1	0.67	$0.119 \pm 0.100 \pm 0.215$	$0.259 \pm 0.577 \pm 1.290$	$0.154 \pm 0.350 \pm 0.337$	$3.786 \pm 1.199 \pm 0.857$
2	0.73	$0.103 \pm 0.043 \pm 0.113$	$-0.969 \pm 0.757 \pm 1.600$	$0.198 \pm 0.124 \pm 0.216$	$3.944 \pm 0.321 \pm 0.448$
3	0.79	$0.158 \pm 0.086 \pm 0.180$	$0.363 \pm 0.381 \pm 1.500$	$0.161 \pm 0.116 \pm 0.098$	$1.634 \pm 0.584 \pm 0.448$
4	0.85	$0.232 \pm 0.128 \pm 0.214$	$0.448 \pm 0.266 \pm 1.500$	$0.125 \pm 0.118 \pm 0.031$	$3.094 \pm 0.725 \pm 0.448$
5	0.91	$0.468 \pm 0.075 \pm 0.194$	$0.091 \pm 0.191 \pm 0.237$	$0.307 \pm 0.213 \pm 0.162$	$0.735 \pm 0.326 \pm 0.255$
6	0.97	$0.371 \pm 0.083 \pm 0.129$	$0.276 \pm 0.156 \pm 0.190$	$0.528 \pm 0.121 \pm 0.055$	$-0.083 \pm 0.178 \pm 0.303$
7	1.03	$0.329 \pm 0.071 \pm 0.102$	$0.345 \pm 0.164 \pm 0.273$	$0.215 \pm 0.191 \pm 0.053$	$0.541 \pm 0.320 \pm 0.638$
8	1.09	$0.343 \pm 0.062 \pm 0.062$	$0.449 \pm 0.196 \pm 0.213$	$0.390 \pm 0.146 \pm 0.046$	$0.254 \pm 0.167 \pm 0.144$
9	1.15	$0.330 \pm 0.070 \pm 0.081$	$0.687 \pm 0.167 \pm 0.221$	$0.490 \pm 0.135 \pm 0.089$	$0.618 \pm 0.155 \pm 0.099$
10	1.21	$0.450 \pm 0.059 \pm 0.042$	$0.696 \pm 0.156 \pm 0.226$	$0.422 \pm 0.092 \pm 0.102$	$0.723 \pm 0.242 \pm 0.267$
11	1.27	$0.578 \pm 0.048 \pm 0.112$	$0.785 \pm 0.208 \pm 0.358$	$0.581 \pm 0.113 \pm 0.084$	$0.605 \pm 0.186 \pm 0.166$
12	1.33	$0.627 \pm 0.047 \pm 0.053$	$0.986 \pm 0.153 \pm 0.166$	$0.643 \pm 0.106 \pm 0.039$	$1.330 \pm 0.264 \pm 0.130$
13	1.39	$0.826 \pm 0.047 \pm 0.105$	$1.334 \pm 0.155 \pm 0.288$	$0.920 \pm 0.153 \pm 0.056$	$1.528 \pm 0.161 \pm 0.160$
14	1.45	1.000	1.570	1.000	1.570
15	1.51	$0.736 \pm 0.031 \pm 0.059$	$1.918 \pm 0.153 \pm 0.132$	$0.750 \pm 0.118 \pm 0.076$	$1.844 \pm 0.149 \pm 0.048$
16	1.57	$0.451 \pm 0.025 \pm 0.053$	$2.098 \pm 0.202 \pm 0.277$	$0.585 \pm 0.099 \pm 0.047$	$2.128 \pm 0.182 \pm 0.110$
17	1.63	$0.289 \pm 0.029 \pm 0.065$	$2.539 \pm 0.292 \pm 0.180$	$0.366 \pm 0.079 \pm 0.052$	$2.389 \pm 0.230 \pm 0.213$
18	1.69	$0.159 \pm 0.036 \pm 0.089$	$1.566 \pm 0.308 \pm 0.619$	$0.312 \pm 0.074 \pm 0.043$	$1.962 \pm 0.195 \pm 0.150$
19	1.75	$0.240 \pm 0.034 \pm 0.067$	$1.962 \pm 0.331 \pm 0.655$	$0.427 \pm 0.093 \pm 0.063$	$1.939 \pm 0.150 \pm 0.182$
20	1.81	$0.381 \pm 0.031 \pm 0.059$	$2.170 \pm 0.297 \pm 0.251$	$0.511 \pm 0.094 \pm 0.063$	$2.426 \pm 0.156 \pm 0.277$
21	1.87	$0.457 \pm 0.035 \pm 0.085$	$2.258 \pm 0.251 \pm 0.284$	$0.588 \pm 0.098 \pm 0.080$	$2.242 \pm 0.084 \pm 0.210$
22	1.93	$0.565 \pm 0.042 \pm 0.067$	$2.386 \pm 0.255 \pm 0.207$	$0.729 \pm 0.114 \pm 0.095$	$2.427 \pm 0.098 \pm 0.254$
23	1.99	$0.640 \pm 0.044 \pm 0.055$	$2.361 \pm 0.228 \pm 0.092$	$0.777 \pm 0.119 \pm 0.075$	$2.306 \pm 0.102 \pm 0.325$
24	2.05	$0.593 \pm 0.046 \pm 0.065$	$2.329 \pm 0.235 \pm 0.268$	$0.775 \pm 0.134 \pm 0.075$	$2.347 \pm 0.107 \pm 0.299$
25	2.11	$0.614 \pm 0.057 \pm 0.083$	$2.421 \pm 0.230 \pm 0.169$	$0.830 \pm 0.134 \pm 0.078$	$2.374 \pm 0.105 \pm 0.199$
26	2.17	$0.677 \pm 0.067 \pm 0.117$	$2.563 \pm 0.218 \pm 0.137$	$0.825 \pm 0.140 \pm 0.070$	$2.401 \pm 0.127 \pm 0.189$
27	2.23	$0.788 \pm 0.085 \pm 0.104$	$2.539 \pm 0.228 \pm 0.241$	$0.860 \pm 0.158 \pm 0.123$	$2.296 \pm 0.131 \pm 0.297$
28	2.29	$0.753 \pm 0.097 \pm 0.125$	$2.550 \pm 0.234 \pm 0.168$	$0.891 \pm 0.167 \pm 0.133$	$2.320 \pm 0.131 \pm 0.273$
29	2.35	$0.646 \pm 0.096 \pm 0.118$	$2.315 \pm 0.241 \pm 0.321$	$0.994 \pm 0.202 \pm 0.076$	$2.297 \pm 0.153 \pm 0.197$
30	2.41	$0.789 \pm 0.184 \pm 0.187$	$2.364 \pm 0.336 \pm 0.199$	$0.892 \pm 0.322 \pm 0.098$	$2.143 \pm 0.292 \pm 0.393$

Effect of systematic uncertainties is an average of 16 %.

BaBar Experiment:

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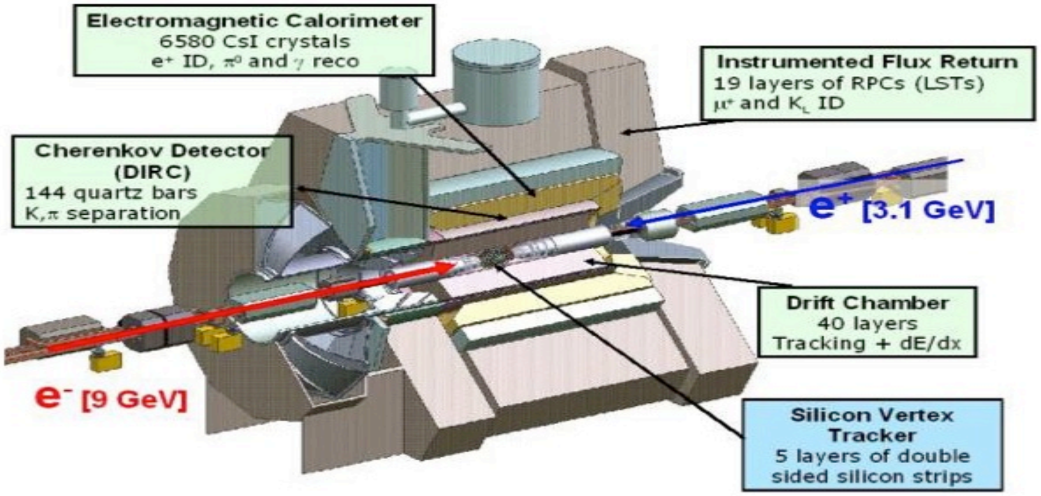
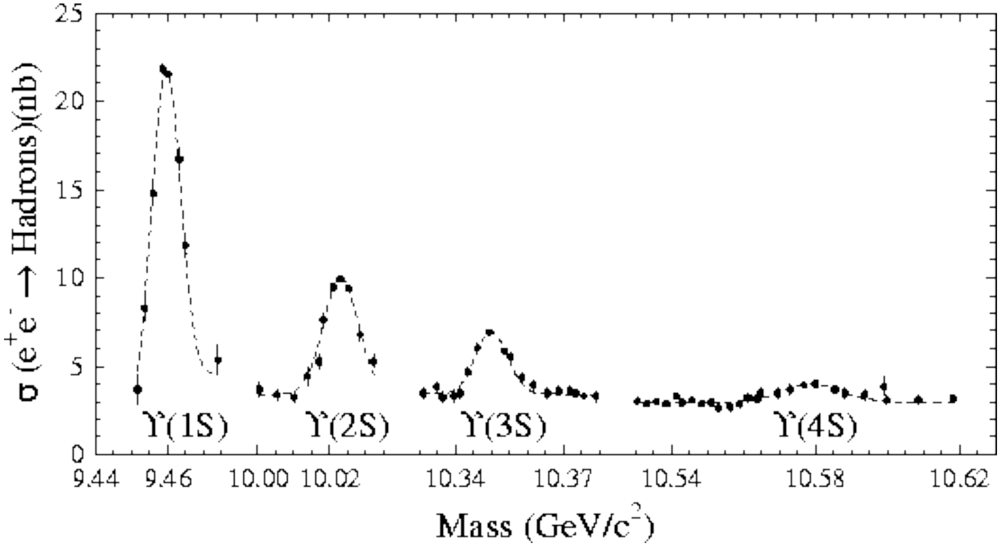
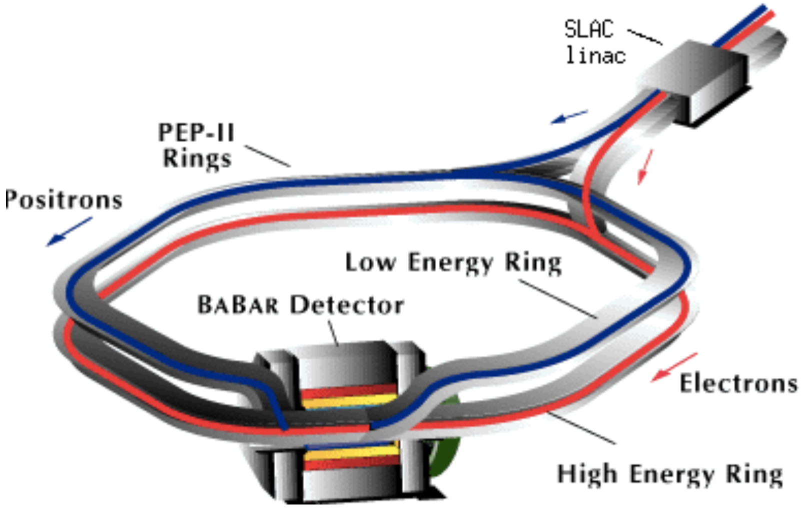
- Located at SLAC National Accelerator Laboratory
- Asymmetric e+e- collisions at CM energy of 10.58 GeV .
- Data collection 1999 to 2008.







Resonance Parameterization

- Each amplitude is parameterized as the product of a complex Breit-Wigner and a real angular term T:

$$A(x, y) = BW(m) \times T(\Omega).$$

- Relativistic BW is written as: D→rc, r→ab

$$BW(M_{AB}) = \frac{F_r F_D}{M_r^2 - M_{AB}^2 - i\Gamma_{AB} M_r} \qquad \Gamma_{AB} = \Gamma_r \left(\frac{p_{AB}}{p_r}\right)^{2J+1} \left(\frac{M_r}{M_{AB}}\right) F_r^2$$

  - F_r and F_D are form factors
- $f_0(980)$ amplitude parameterized as:

$$\rho_{KK} = 2p/m$$

$$A_{f_0(980)} = \frac{1}{m_0^2 - m^2 - i m_0 \Gamma_0 \rho_{KK}},$$

$$m_0 = (0.922 \pm 0.003_{\text{stat}})\ \text{GeV}/c^2,$$

$$\Gamma_0 = (0.24 \pm 0.08_{\text{stat}})\ \text{GeV}.$$

  - Coupled channed BW (Flatte) formalisim does not take into account coupling to tjheππ channel:

- $a_0(980)$ amplitude parameterized using Flatte formalism, because of its coupling to KK and πη:

$$F_0 = \beta_0' \frac{\begin{pmatrix} g_1 \\ g_2 \end{pmatrix}}{m_0^2 - m^2 - i(\rho_1 g_1^2 + \rho_2 g_2^2)}.$$

Model Independent Partial Wave Analysis

- $k\pi$ S-wave is taken as reference amplitude,

$$A=|A_1 + c_2A_2e^{\phi 2}+ c_3A_3e^{\phi 3}+\ldots|$$

- Other resonance contributions, A_2, A_3, etc…, are parametrized as Breit-Wigner amplitudes multiplied by their corresponding angular functions.

- Mass spectrum is divided into 30 equally spaced mass intervals 60 MeV wide.

- In each interval, 2 new free parameters are added: A_i and ϕ_i

Outline

- Theoretical Motivation
- $\gamma\gamma \rightarrow K_s K^+\pi^-$ and $\gamma\gamma \rightarrow K^+K^-\pi^0$
  - – PHYSICAL REVIEW D **89**, 112004 (2014)
- Model Independent Partial Wave Analysis
- $K\pi$ S-wave amplitude