Dalitz Plot Analysis of the Decay $D^0 \rightarrow K^- K^+ \pi^0$

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On behalf of the BaBar Collaboration

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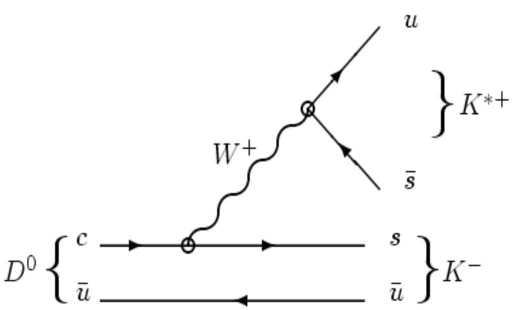
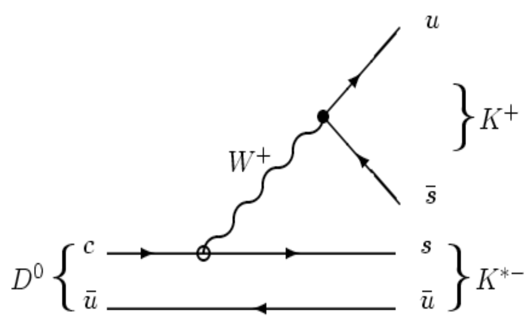
Amplitude Analysis of the Decay $D^0 \to K^- K^+ \pi^0$

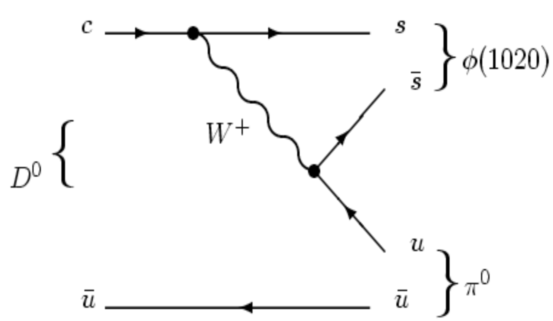
Interference between three types of singly Cabibbo-suppressed amplitudes



(I) Vector meson at W vertex



(II) Scalar at W vertex



(III) Color-suppressed

Motivation

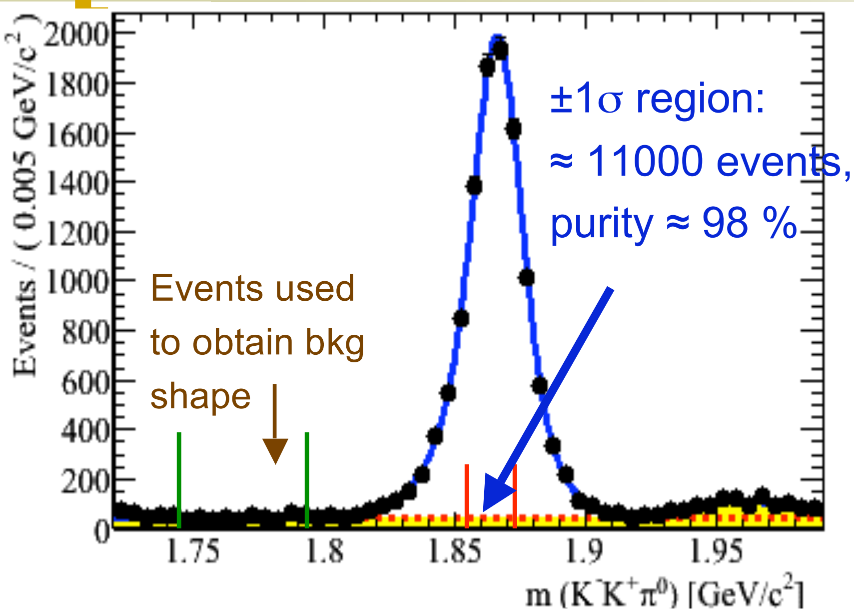
- Nature of $K\pi$ S-wave below 1.4 GeV.
- Is there a charged κ state ?
- Extract information useful for determination of the CKM phase γ from the decay $B^- \to D^0[\to K^- K^+ \pi^0]\, K^-$:

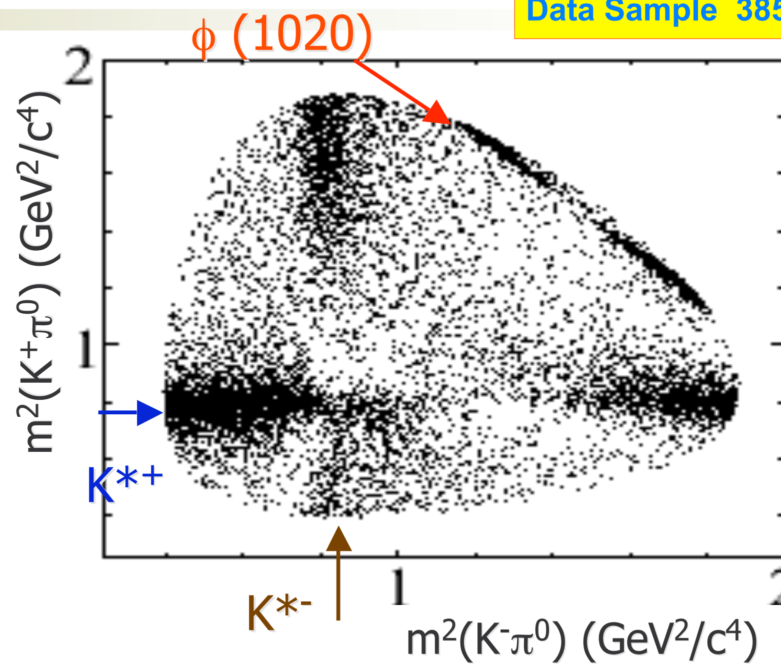
  strong phase difference & amplitude ratio for $\overline{D}^0$ and D^0 decays to $K^*(892)^+ K^-$.

- Nature of f_0/a_0 (980): KK S-wave.

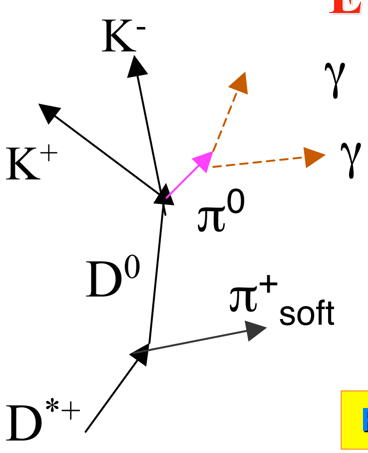
Dalitz Plot for $D^0 \rightarrow K^- K^+ \pi^0$

Data Sample 385 fb^{-1}





Event Selection



$P_{CM}(D^0) > 2.77$ GeV/c
$|m_{D^*} - m_{D^0} - 145.5|$
< 0.6 MeV/c^2

Phys. Rev. D74, 091102 (2006)

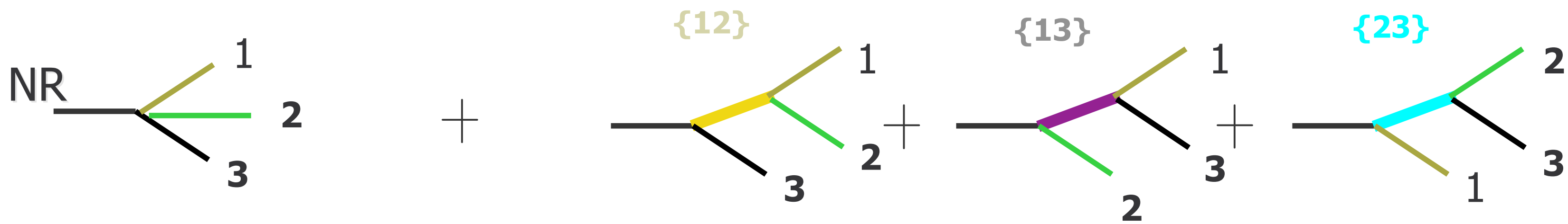
Define amplitude for the $D^0 \rightarrow K^- K^+ \pi^0$ decay as:

$$\mathcal{A}[D^0 \rightarrow K^- K^+ \pi^0] \equiv f(m^2_{K^+\pi^0}, m^2_{K^-\pi^0})$$
$$\bar{\mathcal{A}}[\bar{D}^0 \rightarrow K^+ K^- \pi^0] \equiv f(m^2_{K^-\pi^0}, m^2_{K^+\pi^0})$$

PDF for signal events = $|f|^2$

Isobar Model Formalism

three-body decay D→ABC decaying through an r=[AB] resonance



D decay three-body amplitude $\mathcal{A}_D(s_{12}, s_{13}) = a_0 e^{i\delta_0} + \sum_r a_r e^{i\delta r} \mathcal{A}_r(s_{12}, s_{13})$

→ NR term (direct 3 body decay)

a_0, δ_0, a_r, δ_r : Free parameters of fit

$$\mathcal{A}_r(s_{12}, s_{13}) = F_D^J F_r^J \times M_r^J \times BW_r^J$$

Relativistic Breit-Wigner

$$BW_r^J(s) = \begin{cases} \dfrac{1}{M_r^2 - s - iM_r\Gamma_r(\sqrt{s})} \\ \dfrac{1}{M_r^2 - s - i(\rho_1 g_1^2 + \rho_2 g_2^2)} \end{cases}$$

$f_0(980)$
$a_0(980)$

→ Angular distribution

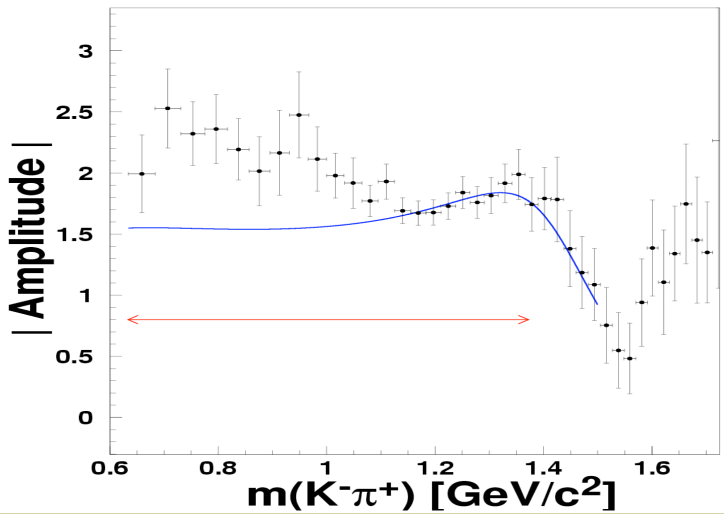
→ *D* and *r* Blatt-Weisskopf form factors

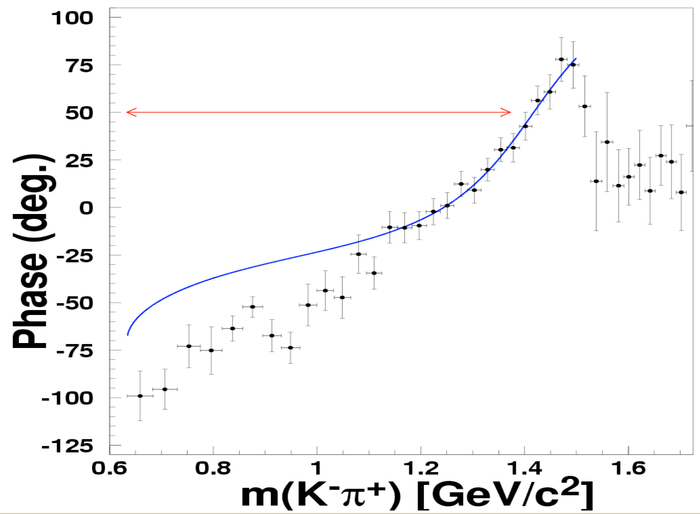
I=1/2 Kπ S-wave Parameterization

- Kπ S-wave in mass range 0.6–1.4 GeV/c^2 is not well-understood.
- A possible κ state ~ 800 MeV/c^2 has been conjectured, but this has only been reported in the neutral state.
- For the $K^+\pi^0$ and $K^-\pi^0$ S-wave amplitudes, we try three models:
  - Amplitude obtained from LASS $K^-\pi^+ \to K^-\pi^+$ scattering. Nucl. Phys. B296, 493 (1988);
  - $K^-\pi^+$ amplitude extracted from a model-independent partial-wave analysis of $D^+ \to K^-\pi^+\pi^+$ decay by the E791 collaboration. Phys. Rev. D73, 032004 (2006);
  - [coherent sum of κ(800) + uniform NR + $K^*_0(1430)$]. {No evidence in Kπ elastic scattering.}

Normalized to arbitrary scale for m(Kπ)>1.15 Gev/c^2 for easy comparison

- • E-791
- — LASS





Fit Results

For Kπ S-wave

- The LASS amplitude gives the best fit.
- E-791 fit worse at low mass.
- κ model yields

mass 870 ± 30 MeV/c^2
width 150 ± 20 MeV/c^2

significantly different from the values reported for κ^0.
- κ with E-791 parameters does not give a satisfactory fit.

Use LASS amplitude for Kπ S-wave in the nominal fits.

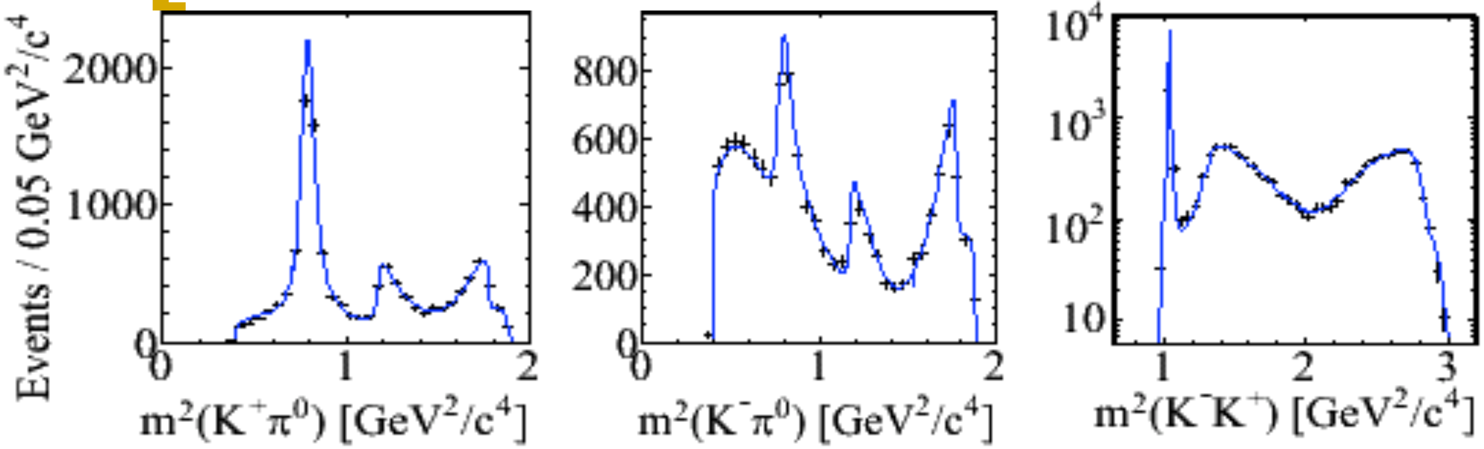
Use the fit model with E-791 Kπ S-wave for systematic uncertainty.

For K^-K^+ S-wave

- $f_0(980)$ and $a_0(980)$ virtually indistinguishable from each other.
- Both $f_0(980)$ and $a_0(980)$ give satisfactory fits.

Since they are so similar, we try each as a description of the KK S-wave amplitude.

Fit Results Continued ….



K^{*+} : 45 %
K^{*-} : 16 %
ϕ : 19 %
f_0/a_0: 7-10%

Ambiguity between a large $K^+\pi^0$ S-wave & $K^*(1410)$,$f_2'(1525)$.

	χ^2 Prob = 62 % Model-I			χ^2 Prob = 48 % Model-II		
State	Amplitude, a_r	Phase, ϕ_r (°)	Fraction, f_r (%)	Amplitude, a_r	Phase, ϕ_r (°)	Fraction, f_r (%)
$K^*(892)^+$	1.0 (fixed)	0.0 (fixed)	45.2±0.8±0.6	1.0 (fixed)	0.0 (fixed)	44.4±0.8±0.6
$K^*(1410)^+$	2.29±0.37±0.20	86.7±12.0±9.6	3.7±1.1±1.1			
$K^+\pi^0(S)$	1.76±0.36±0.18	-179.8±21.3±12.3	16.3±3.4±2.1	3.66±0.11±0.09	-148.0±2.0±2.8	71.1±3.7±1.9
$\phi(1020)$	0.69±0.01±0.02	-20.7±13.6±9.3	19.3±0.6±0.4	0.70±0.01±0.02	18.0±3.7±3.6	19.4±0.6±0.5
$f_0(980)$	0.51±0.07±0.04	-177.5±13.7±8.6	6.7±1.4±1.2	0.64±0.04±0.03	-60.8±2.5±3.0	10.5±1.1±1.2
[$a_0(980)^0$]	[0.48±0.08±0.04]	[-154.0±14.1±8.6]	[6.0±1.8±1.2]	[0.68±0.06±0.03]	[-38.5±4.3±3.0]	[11.0±1.5±1.2]
$f_2'(1525)$	1.11±0.38±0.28	-18.7±19.3±13.6	0.08±0.04±0.05			
$K^*(892)^-$	0.601±0.011±0.011	-37.0±1.9±2.2	16.0±0.8±0.6	0.597±0.013±0.009	-34.1±1.9±2.2	15.9±0.7±0.6
$K^*(1410)^-$	2.63±0.51±0.47	-172.0±6.6±6.2	4.8±1.8±1.2			
$K^-\pi^0(S)$	0.70±0.27±0.24	133.2±22.5±25.2	2.7±1.4±0.8	0.85±0.09±0.11	108.4±7.8±8.9	3.9±0.9±1.0

Strong Phase Difference & Amplitude Ratio

- The strong phase difference δ_D and relative amplitude r_D between the decays $D^0 \rightarrow K^{*-}K^+$ and $D^0 \rightarrow K^{*+}K^-$ are defined, neglecting direct CP violation in D^0 decays, by the equation:

$$r_D\, e^{i\delta_D} = [a_{K^{*-}K^+} / a_{K^{*+}K^-}]\ \exp[\, i(\delta_{K^{*-}K^+} - \delta_{K^{*-}K^+})\,]$$

- We find

$\delta_D = -35.5^o \pm 1.9^o$ (stat) $\pm 2.2^o$ (syst)
$r_D = 0.599 \pm 0.013$ (stat) ± 0.011 (syst).

To be submitted to Phys. Rev. D (RC)

These measurements are consistent with the previous measurement by CLEO:

$\delta_D = -28^o \pm 8^o$ (stat) $\pm 2.9^o$ (exp sys) $\pm 10.6^o$ (model sys)
$r_D = 0.52 \pm 0.05$ (stat) ± 0.02 (exp sys) ± 0.04 (model sys).

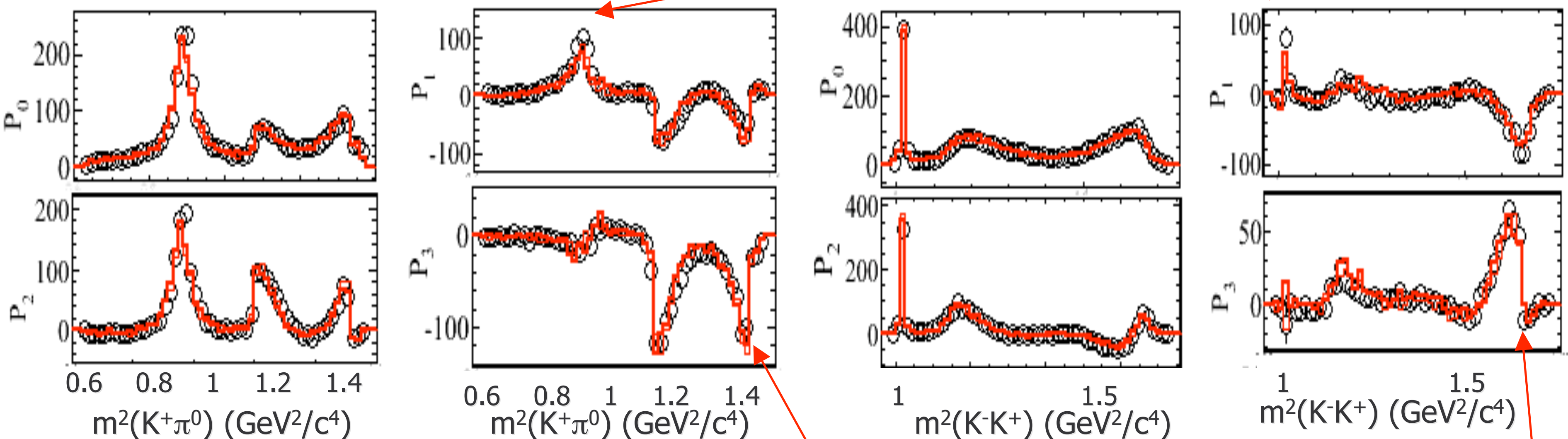
Phys. Rev. D74, 031108 (2006)

Analysis of Angular Moments

Each event is weighted by the spherical harmonic functions $Y_l^0(\cos\theta_H) = \sqrt{\frac{2l+1}{4\pi}} P_l(\cos\theta_H)$ (l=0,1,2,.....).

Excellent agreement between data & models.

Large interference between S and P waves.



Higher moments above 1.1 GeV are coming from cross channels.

$$
\begin{cases}
\sqrt{4\pi}\left\langle Y_0^0\right\rangle = S^2 + P^2 \\
\sqrt{4\pi}\left\langle Y_1^0\right\rangle = 2|S||P|\cos\phi_{SP} \\
\sqrt{4\pi}\left\langle Y_2^0\right\rangle = \frac{2}{\sqrt{5}} P^2
\end{cases}
$$

For S- and P- waves only, in the absence of cross-feeds from other channels, the amplitudes and the relative phase are given by:

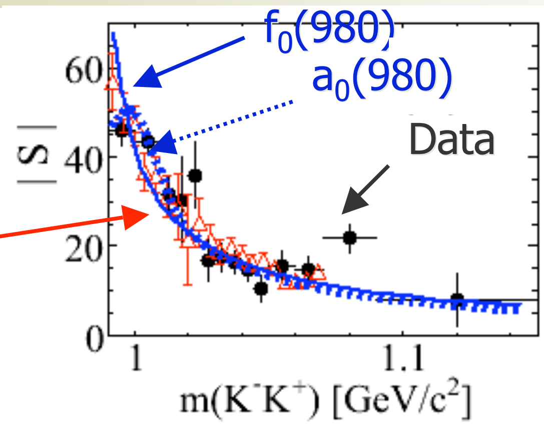
We solve these equations for the K^-K^+ system in a limited mass range (where the above conditions are satisfied) to extract |S|, |P|, and cos ϕ_{SP}.

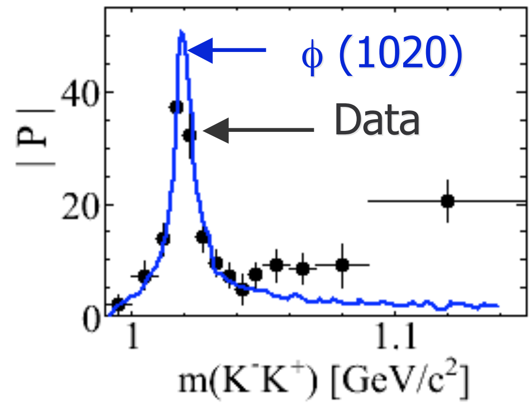
Moments Analysis in K^-K^+ channel

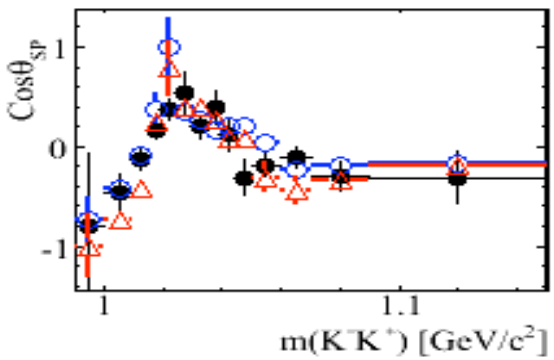
Solve the equations on the previous slide to extract |S|, |P|, and cos θ_{SP}.

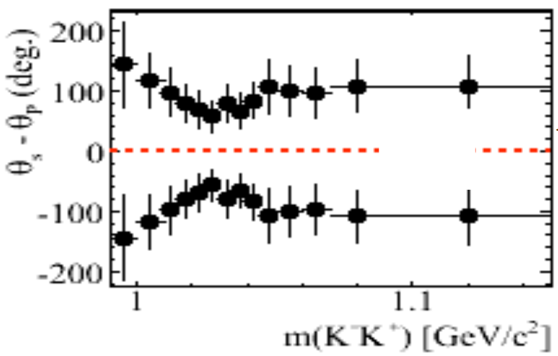
KK S-wave amplitude, extracted in a model independent analysis of the decay $D^0 \to K^-K^+\bar{K}^0$.

Phys. Rev. D72, 052008 (2005)



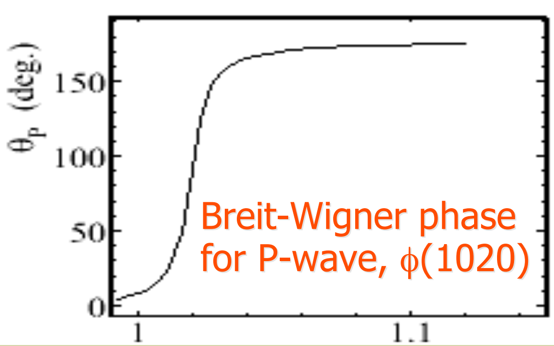


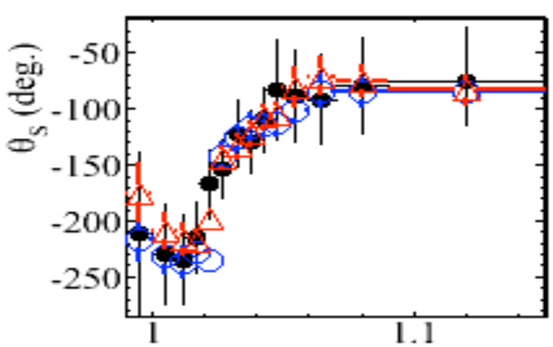




Two solutions for $\theta_{SP} \Rightarrow$ the upper one is the physical.

Because of the interference from the crossing $K\pi$ channels, the model independent partial-wave analysis performed here is valid only up to about 1.02 - 1.03 GeV/c².





- • Data
- O Model-I
- Δ Model-II

Summary

- Determine resonant structure of the singly Cabibbo-suppressed decay: $D^0 \rightarrow K^- K^+ \pi^0$ and measure δ_D & r_D $\Rightarrow$ useful for measurements of γ and D^0 mixing.
- $D^0 \rightarrow K^*(892)^+ K^-$ dominates over $D^0 \rightarrow K^*(892)^- K^+$ $\Rightarrow$ at tree-level, D^0 coupling to K^{*-} is suppressed w.r.t. K^- coupling.

- $K\pi$ S-wave amplitudes are consistent with LASS results.
- No evidence for charged, scalar $\kappa(800)$ states.
- $K^- K^+$ S-wave amplitude is consistent with $f_0/a_0(980)$.
- No evidence for higher f_0 states.

- Perform a model-independent partial-wave analysis of the spherical harmonic moments of the $\cos\theta_H$ in the K^+K^- system in a limited mass range around 1 GeV/c^2.

Back up slides

LASS $K\pi$ S-wave Parameterization

$K\pi$ S-wave amplitude is described by the coherent sum of an effective range term and the $K^*_0(1430)$ resonance:

$$S(s) = (\sqrt{s}/p) . \sin\Delta . e^{i\Delta}$$

Phase space factor

$$\Delta = \cot^{-1}[1/ap + rp/2] + \cot^{-1}[(m^2_R - s)/(m_R \Gamma_R)]$$

Effective Range (NR) term **$K^*_0(1430)$ resonance term**

a = scat. length, r = eff. range, m_R = mass of $K^*_0(1430)$, Γ_R= width
p = momentum of either daughter in the $K\pi$ rest frame.

For $K\pi$ scattering, S-wave is elastic up to $K\eta'$ threshold (1.45 GeV).

$K\pi$ S-wave from $D^0 \to K^-\pi^+\pi^+$ DP

[E791 Collaboration, slide from Brian Meadow's Moriond 2005 talk]

- Divide $m^2(K^-\pi^+)$ into slices

Phys. Rev. D73, 032004 (2006); hep-ex/0507099

- Find s–wave amplitude in each slice (two parameters)
  - Use remainder of Dalitz plot as an interferometer

$$\frac{d^2\Gamma}{ds_{12}ds_{13}} \propto |\mathcal{S} + (\mathcal{P} + \mathcal{D})|^2$$

- For s-wave:

- Interpolate between (c_k, γ_k).

- Model P and D waves.

$$\mathcal{S} = \mathrm{Interp}\left(c_k e^{i\gamma_k}\right) \times F_0^D(q, r_D) F_0^R(p, r_R)$$

S ("partial wave")