Studies of Charm Meson Decays at BaBar

Kalanand Mishra

University of Cincinnati

On behalf of the BaBar Collaboration

DPF 06, Honolulu, October 31, 2006

Outline

- Measurements of the ratio of branching fractions for the decays
  - $D^+ \to \pi^+\pi^0$, $K^+\pi^0$ — **Phys.Rev.D74:011107,2006**
  - $D^0 \to \pi^-\pi^+\pi^0$, $K^-K^+\pi^0$ — **hep-ex / 0608009, 2006, submitted to PRD**
- Amplitude (Dalitz plot) analysis of the decays
  - $D^0 \to K^-K^+\pi^0$ — **BaBar Preliminary**
  - $D_s^+ \to K^+K^-\pi^+$ — **BaBar Preliminary**

B.R. of the Decays $D^+ \to \pi^+\pi^0$, $K^+\pi^0$

- Use the decay $D^+ \to K^-\pi^+\pi^+$ as reference for normalization.
- Reconstruct the decay chain: [$D^{*+} \to D^+\pi^0_s$, $D^+ \to h^+\pi^0, K^-\pi^+\pi^+$, $\pi^0 \to \gamma\gamma$].
- Reject the events with D^+ NOT coming from D^{*+} decay (for cleaner signal).

Motivation

1. Measurement of the Cabibbo-suppressed branching ratio $D^+ \to \pi^+\pi^0$.
2. The first measurement of $D^+ \to K^+\pi^0$ branching ratio.

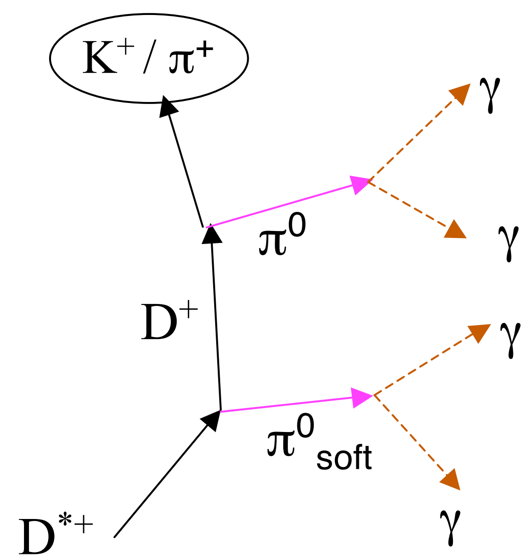
The description of charge conjugate decay is implied throughout this presentation unless explicitly stated otherwise.

Signal Reconstruction Efficiency

$\cdot D^{*+} \to D^+\pi^0_{soft}$, $D^+ \to \pi^+\pi^0$	7.8%
$\cdot D^{*+} \to D^+\pi^0_{soft}$, $D^+ \to K^+\pi^0$	5.9%
$\cdot D^{*+} \to D^+\pi^0_{soft}$, $D^+ \to K^-\pi^+\pi^+$	8.5%

Event Reconstruction

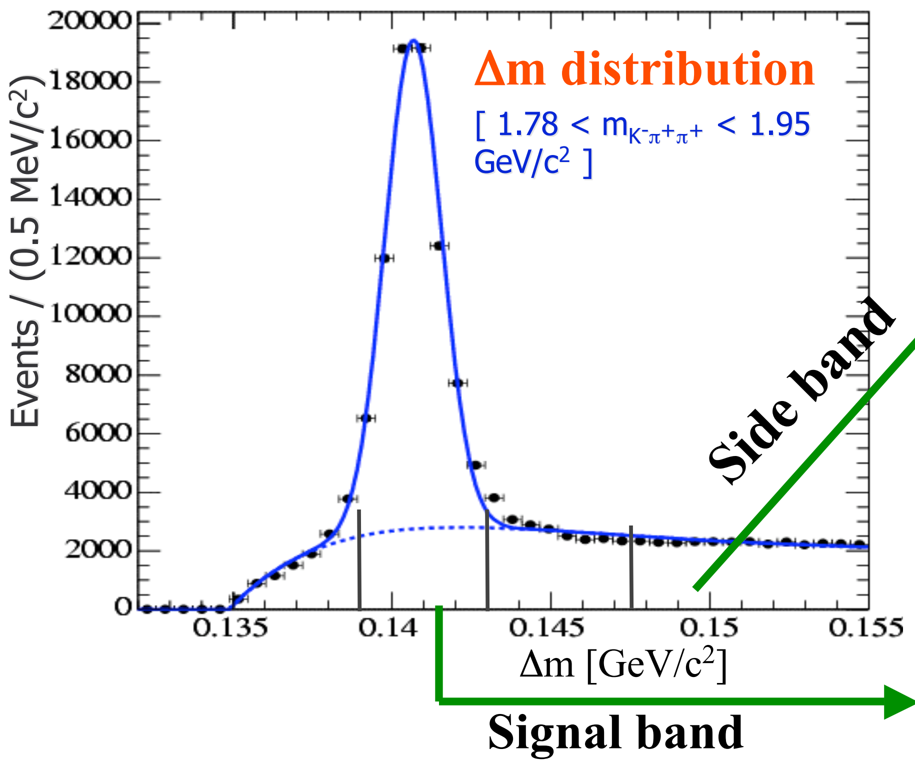
- $P_{CM}(D^*) > 2.9$ GeV/c
- $|m_{D^*} - m_{D^+}| < 155$ MeV/c^2

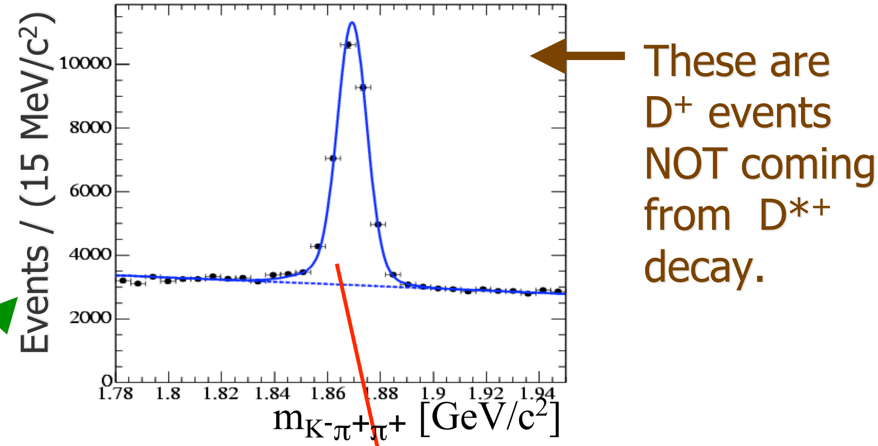


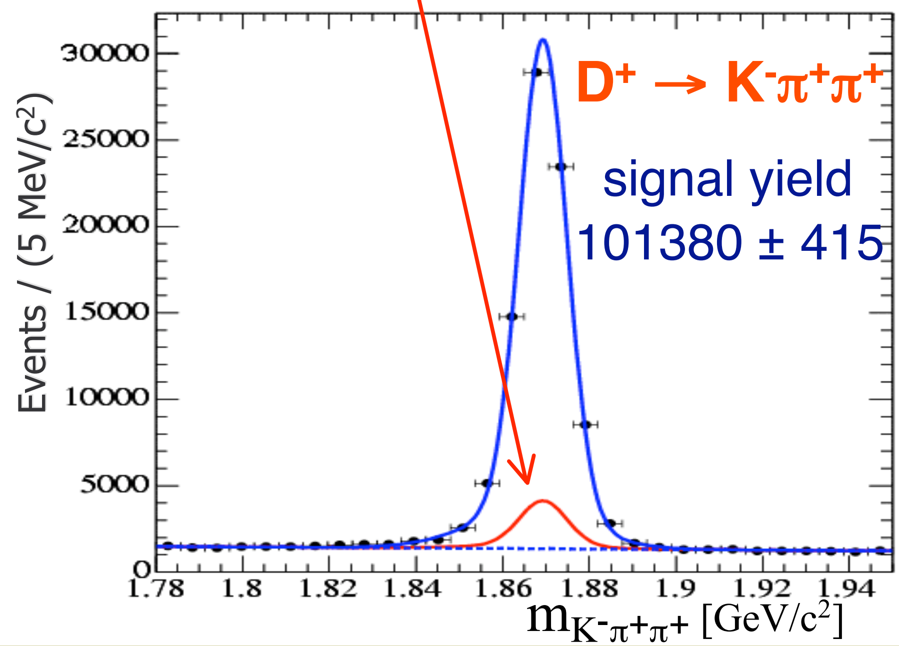
Data Sample = 124 fb^{-1}

Kalanand Mishra,
University of Cincinnati

Signal Yield

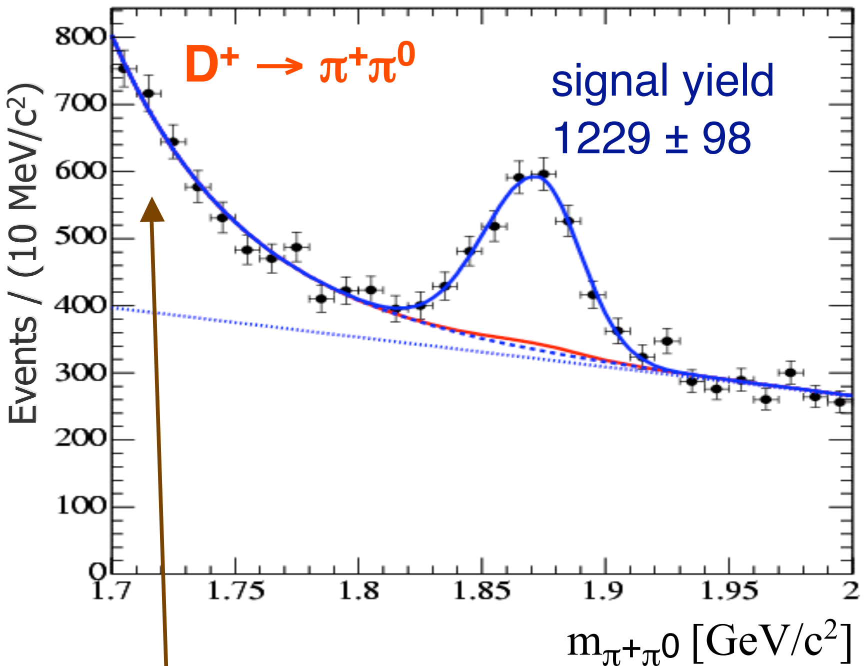


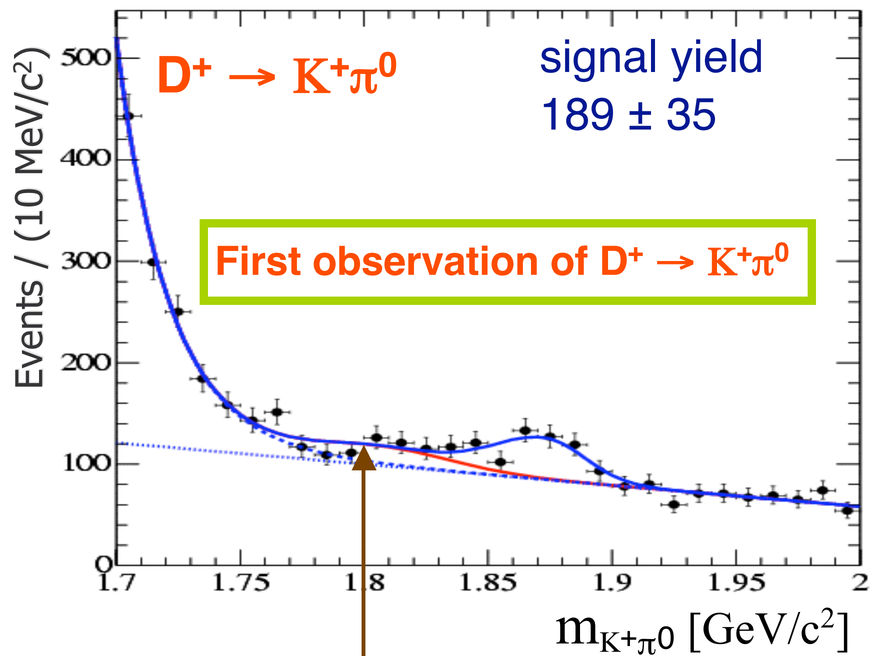




- Divide ΔM into 2σ signal band and $>5\sigma$ side band
- Fit D^+ mass distribution separately (with the same signal pdf)
- Subtract side band yield from signal band yield (adjusted by scale factor)

Signal Yield continued ....





Background from a missing π^0 in the event, parameterized by an exponential function.

Background from $D_s^+ \rightarrow K^+K_s$, $K_s \rightarrow \pi^0\pi^0$ events, when we miss one π^0.

- Signal events are modeled by bifurcated Gaussian functions.
- Combinatorial backgrounds are modeled by linear functions.

Results and Conclusion

$\mathcal{B}(D^+ \to \pi^+\pi^0) / \mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (1.33 \pm 0.11\ (stat) \pm 0.09\ (sys)) \times 10^{-2}$

$\mathcal{B}(D^+ \to K^+\pi^0) / \mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (2.68 \pm 0.50\ (stat) \pm 0.26\ (sys)) \times 10^{-3}$

using $\mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (9.4 \pm 0.3) \times 10^{-2}$,

Phys.Rev.D74:011107,2006

$\mathcal{B}(D^+ \to \pi^+\pi^0) = (1.25 \pm 0.10\ (stat) \pm 0.09\ (sys) \pm 0.04\ (ref)) \times 10^{-3}$

$\mathcal{B}(D^+ \to K^+\pi^0) = (2.52 \pm 0.47\ (stat) \pm 0.25\ (sys) \pm 0.08\ (ref)) \times 10^{-4}$

Excellent kaon ID has contributed significantly to the sensitivity of this measurement.

Comparison to the current PDG values :

- $D^+ \to \pi^+\pi^0$ world average (2006) $\mathcal{B}(D^+ \to \pi^+\pi^0) = (1.28 \pm 0.09) \times 10^{-3}$
- $D^+ \to K^+\pi^0$ world average (2006) $\mathcal{B}(D^+ \to K^+\pi^0) < 4.2 \times 10^{-4}$ at 90% CL

This is the first measurement of the doubly Cabibbo-suppressed decay $D^+ \to K^+\pi^0$ [The CLEO-c collaboration recently made a new measurement which is consistent with our result:
$\mathcal{B}(D^+ \to K^+\pi^0) = (2.25 \pm 0.36\ (stat) \pm 0.15\ (sys) \pm 0.07\ (ref)) \times 10^{-4}$]. hep-ex/0607075

Preliminary result

B.R. of the Decays $D^0 \to \pi^-\pi^+\pi^0$, $K^-K^+\pi^0$

Use the the Cabibbo-favored decay $D^0 \to K^-\pi^+\pi^0$ as reference for normalization.
Reconstruct the decay chain: [$D^{*+} \to D^0\pi_s^+$, $D^0 \to h^-h^+\pi^0$, $\pi^0 \to \gamma\gamma$] and c.c.

Motivation

1. Precision measurement of the branching ratios of 3-body Cabibbo-suppressed decays of D^0.
2. To investigate the anomaly in the BR of 2- & 3-body CS decays of D^0.

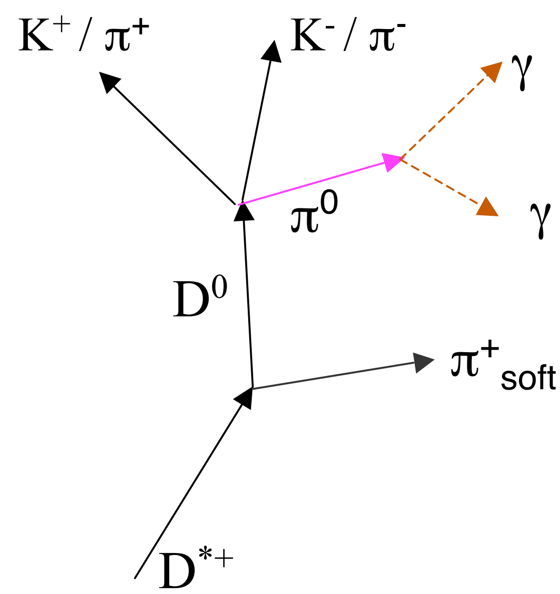
The charge of the π_{soft} determines the charm content of the D^0 meson (i.e., whether it is D^0 or $\overline{D^0}$).

Background Sources

- Combinatorial
- $K\pi\pi^0$ reflection in $\pi\pi\pi^0$ and $KK\pi^0$ modes

Event Reconstruction

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

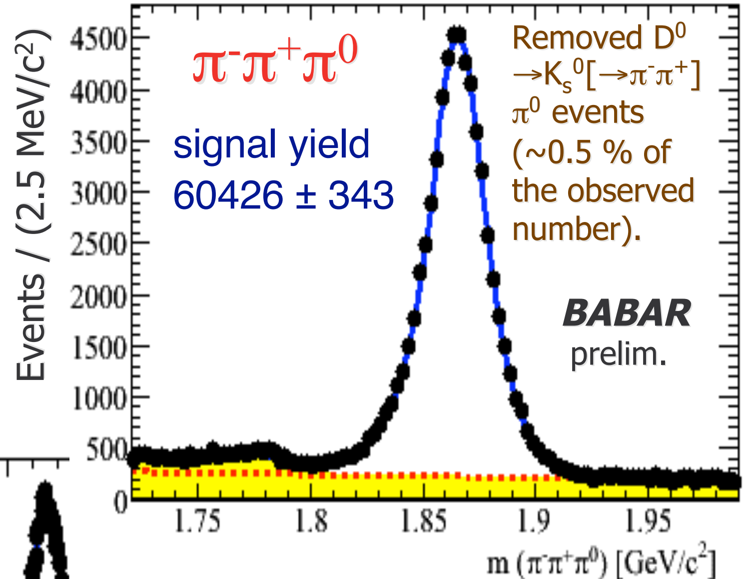


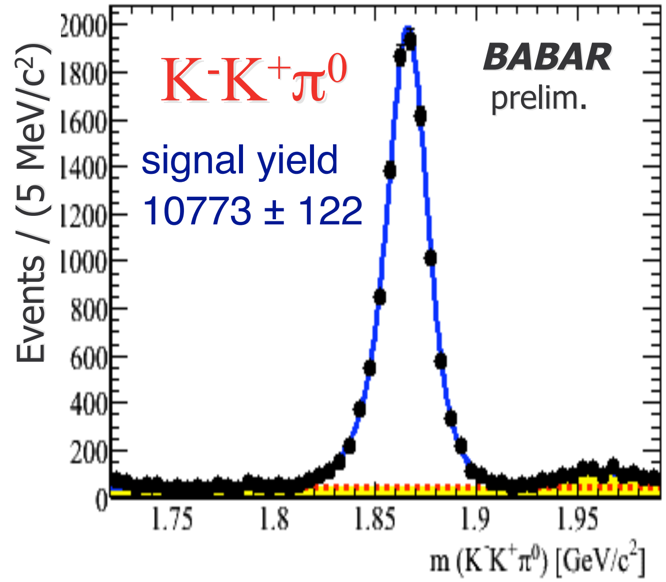
Data Sample = 232 fb^{-1}

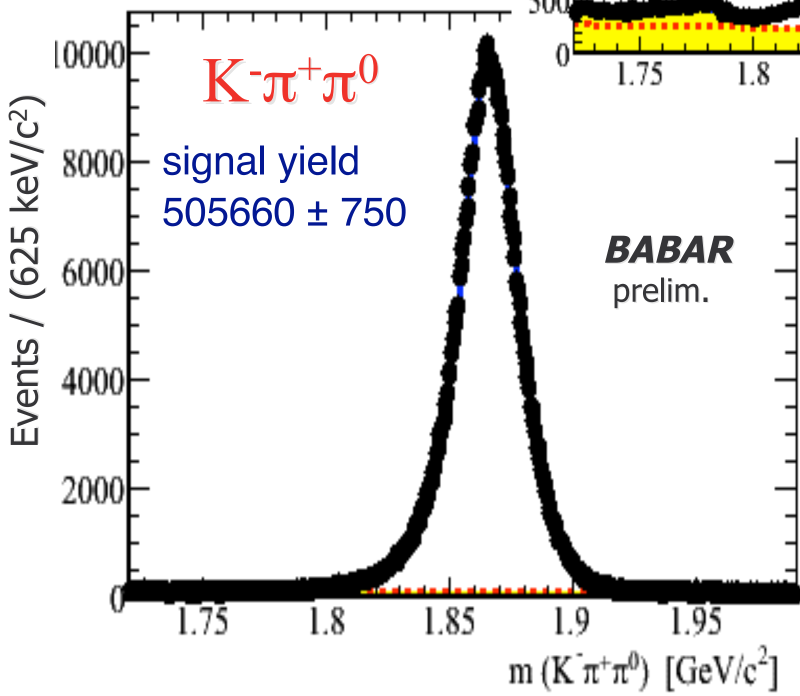
Kalanand Mishra,
University of Cincinnati

Fit for Signal Yield

Maximum Likelihood fit for signal yield

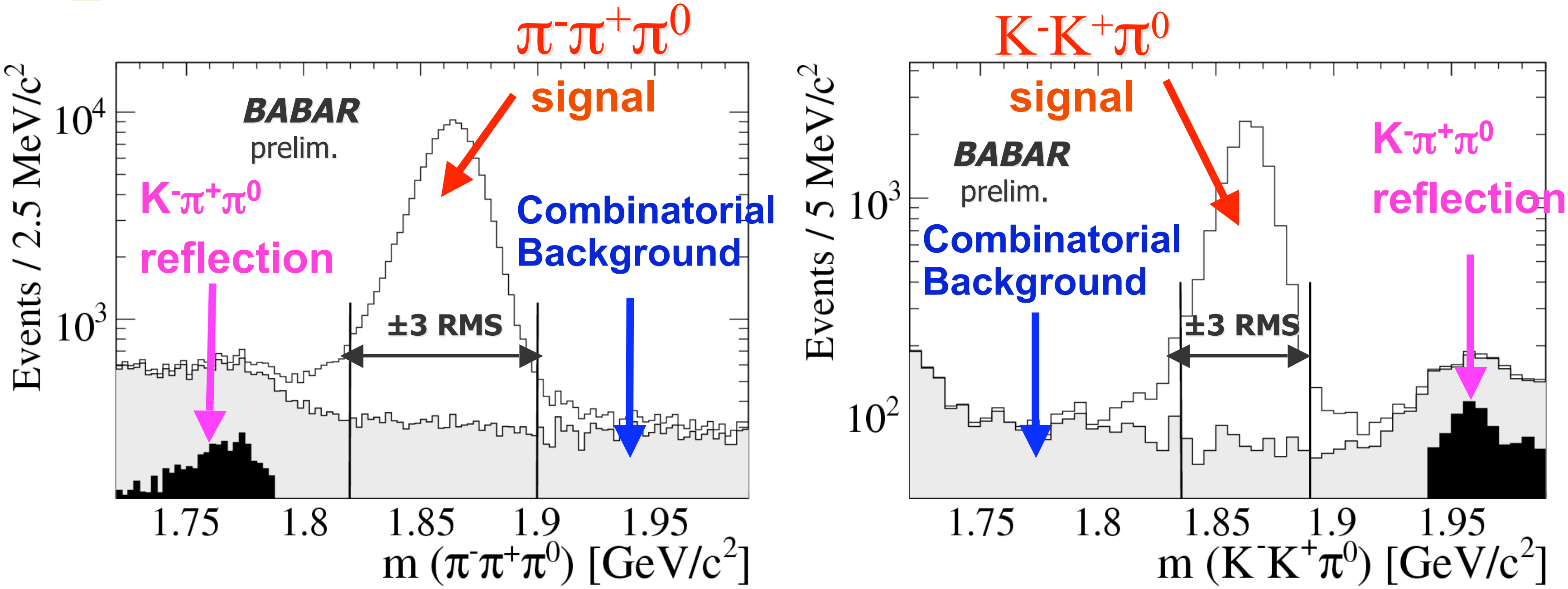






- Signal events are modeled by the sum of 3 Gaussian functions. The means and σ's of the Gaussians are allowed to vary.
- Combinatorial backgrounds are modeled by linear functions.
- The shape of $K^-\pi^+\pi^0$ reflection events in the sidebands of $\pi^-\pi^+\pi^0$ and $K^-K^+\pi^0$ is obtained from MC as described on the next slide.

Background Events in Monte Carlo



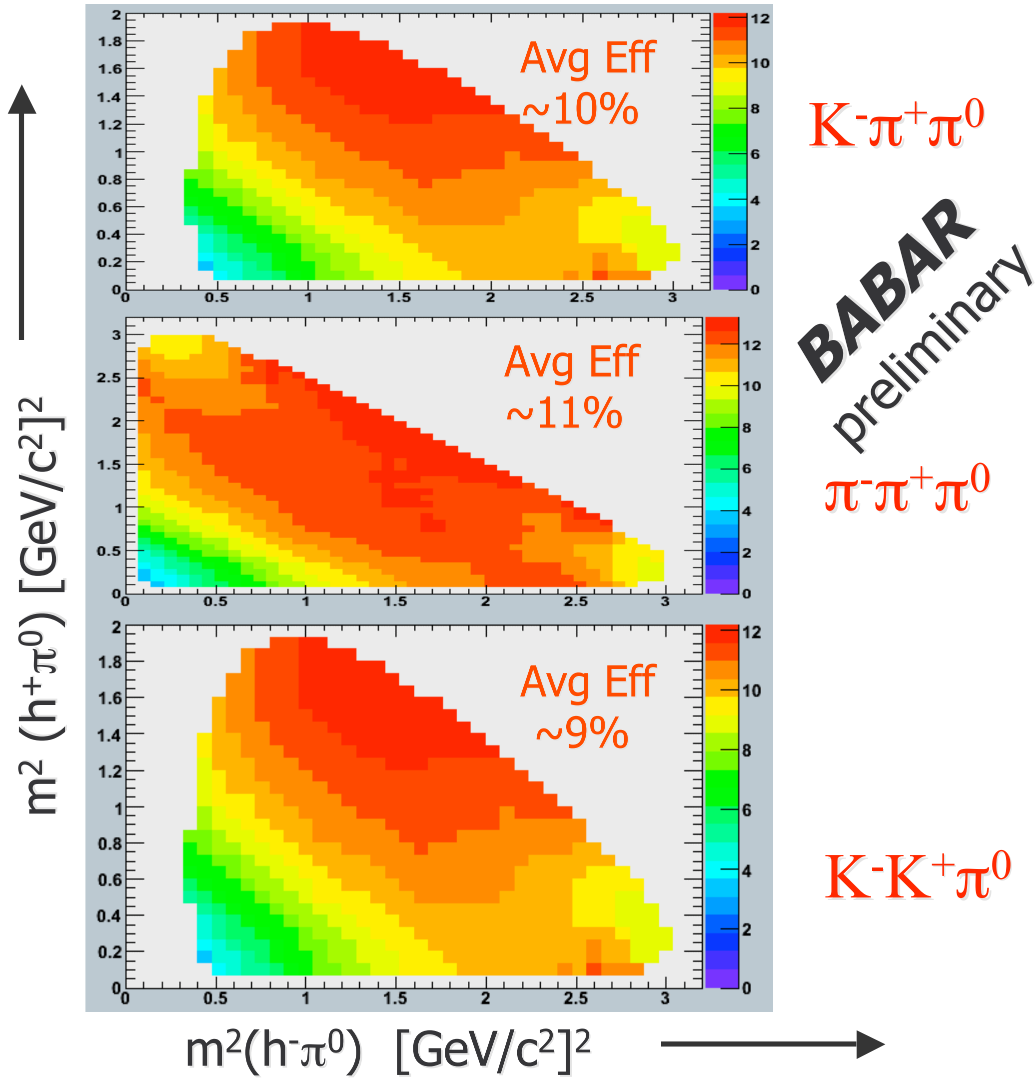
Note Log y-scale.

- Above: three-body invariant mass distributions of $D^0 \to \pi^-\pi^+\pi^0$ and $D^0 \to K^-K^+\pi^0$ events in generic $c\bar{c}$ Monte Carlo (MC).
- $K^- \pi^+\pi^0$ reflection events peak in the sidebands of $\pi^-\pi^+\pi^0$, $K^-K^+\pi^0$.
- We take the shape of the reflection from MC and obtain the number of reflection events by fitting their distribution in data.

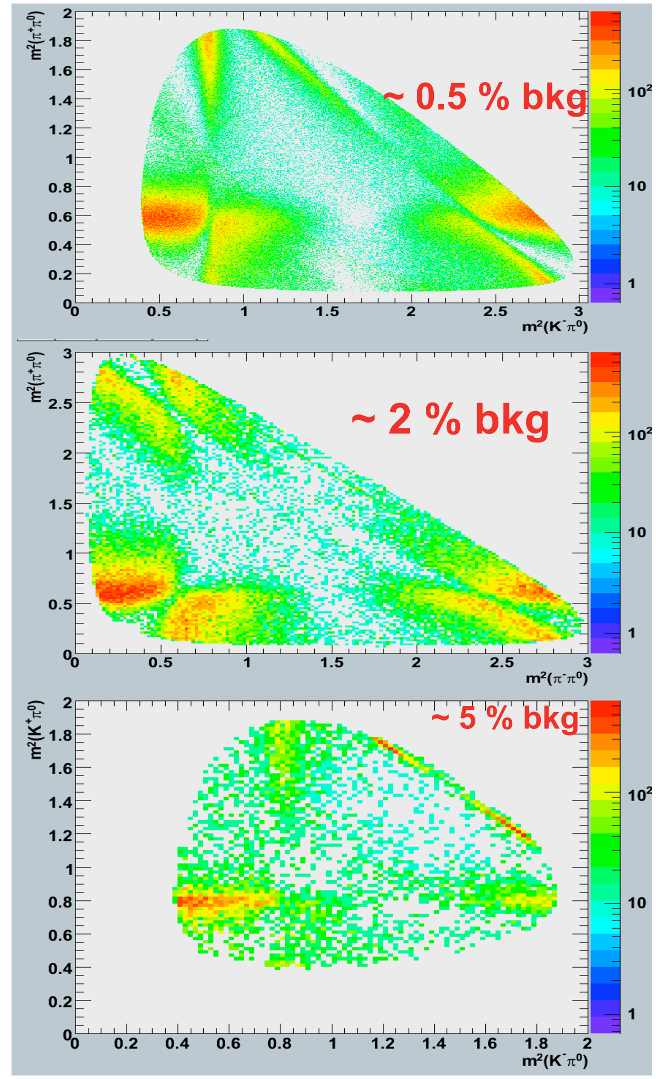
Kalanand Mishra,
University of Cincinnati

Reconstruction Efficiency

Reco. Efficiency (%) from Monte Carlo



Dalitz plot of events in data



Kalanand Mishra,
University of Cincinnati

Results and Conclusion

D^0 decay mode	Our Results(%)	PDG-2006 (%)
$B(\pi^-\pi^+\pi^0)/B(K^-\pi^+\pi^0)$	$10.59 \pm 0.06 \pm 0.13$	8.40 ± 3.11
$B(K^-K^+\pi^0)/B(K^-\pi^+\pi^0)$	$2.37 \pm 0.03 \pm 0.04$	0.95 ± 0.26

The decay rate for each mode

$$\Gamma = \langle |M|^2 \rangle \cdot \Phi$$

where

M = decay matrix element

Φ = phase space factor

= For 3-body decays: area of the Dalitz plot
For 2-body decays: momentum of either daughter in D^0 rest frame.

> 5σ difference with PDG value. Excellent PID performance has greatly improved the the sensitivity of this measurement.

Using 2-body B.R. values from PDG:

$|M|^2(\pi^-\pi^+)/|M|^2(K^-\pi^+) = 0.034 \pm 0.001$

$|M|^2(K^-K^+)/|M|^2(K^-\pi^+) = 0.111 \pm 0.002$

$|M|^2(K^-K^+)/|M|^2(\pi^-\pi^+) = 3.53 \pm 0.12$

Very different from naïve expectations (see the orange box below).

Using branching ratio values from above table:

$|M|^2(\pi^-\pi^+\pi^0)/|M|^2(K^-\pi^+\pi^0) = 0.0668 \pm 0.0004 \pm 0.0008$

$|M|^2(K^-K^+\pi^0)/|M|^2(K^-\pi^+\pi^0) = 0.0453 \pm 0.0006 \pm 0.0008$

$|M|^2(K^-K^+\pi^0)/|M|^2(\pi^-\pi^+\pi^0) = 0.678 \pm 0.014 \pm 0.021$

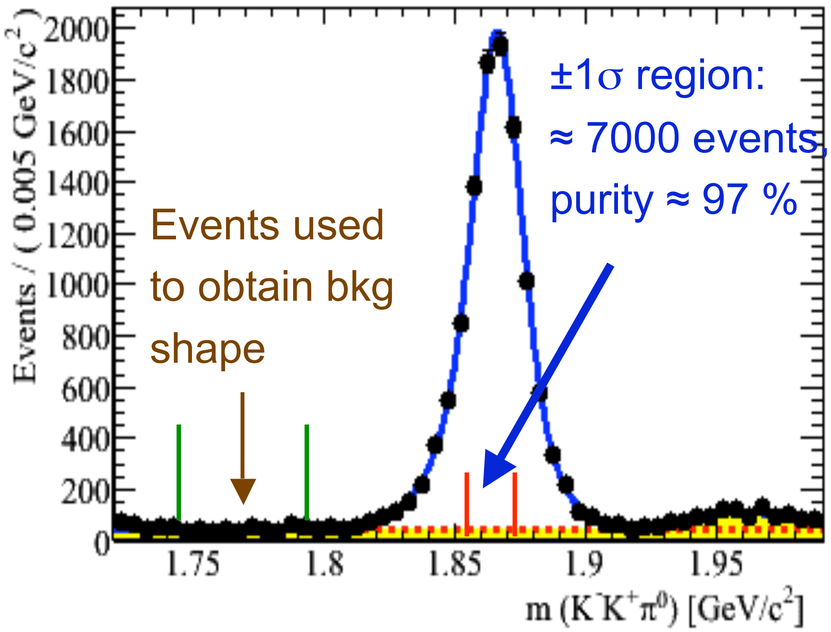
(Naïve expectation = 1.0)

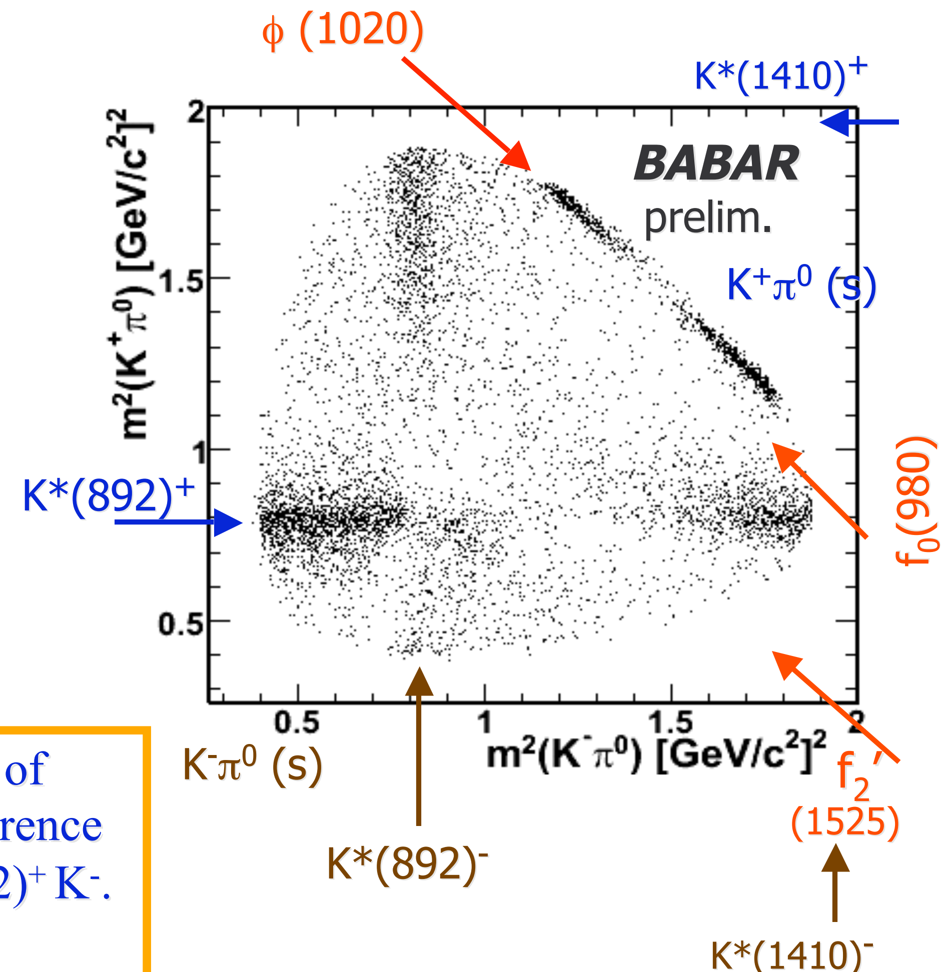
Roughly consistent with naïve expectations, i.e., $\sin^2\theta_c = 0.05$

hep-ex / 0608009, 2006, submitted to PRD

Amplitude Analysis of D and D_s decays

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





Motivation

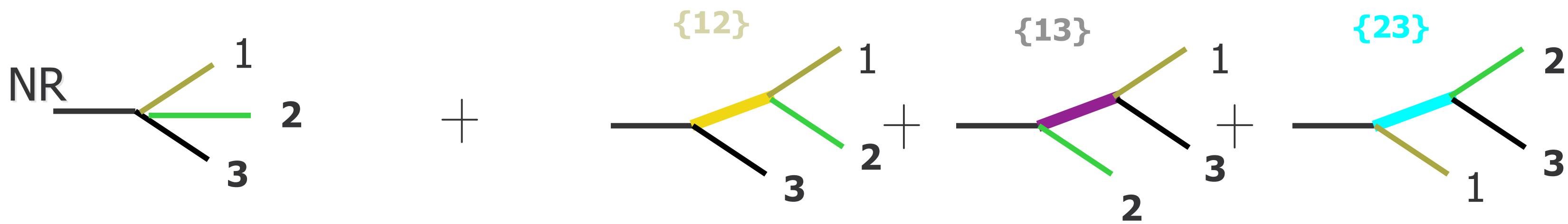
- Extract information useful for determination of angle γ of the CKM matrix: strong phase difference & relative phase for $D^0 \to K^*(892)^- K^+$, $K^*(892)^+ K^-$.
- Is there a charged κ state ?
- Nature of $K\pi$ S-wave below 1.4 GeV/c^2 ?

BaBar Preliminary

Kalanand Mishra,
University of Cincinnati

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

$$BW_r^J(s) = \begin{cases} \dfrac{1}{M_r^2 - s - iM_r\Gamma_r(\sqrt{s})} \\ \dfrac{1}{M_r^2 - s - i(\rho_1 g_1^2 + \rho_2 g_2^2)} & f_0(980) \end{cases}$$

Angular distribution

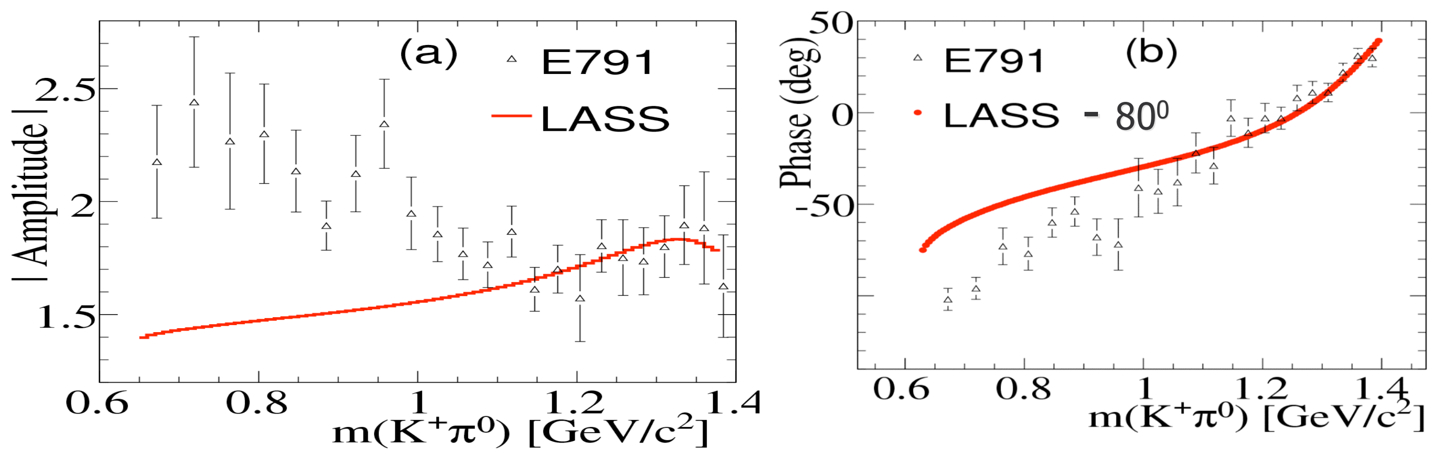
D and *r* Blatt-Weisskopf form factors

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 $K^-\pi^+ \rightarrow K^-\pi^+$ scattering.

    Nucl. Phys. B296, 493 (1988); W. Dunwoodie, web notes.
  - $K^-\pi^+$ amplitude extracted from a model-independent partial-wave analysis of $D^+ \rightarrow K^-\pi^+\pi^+$ 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. }

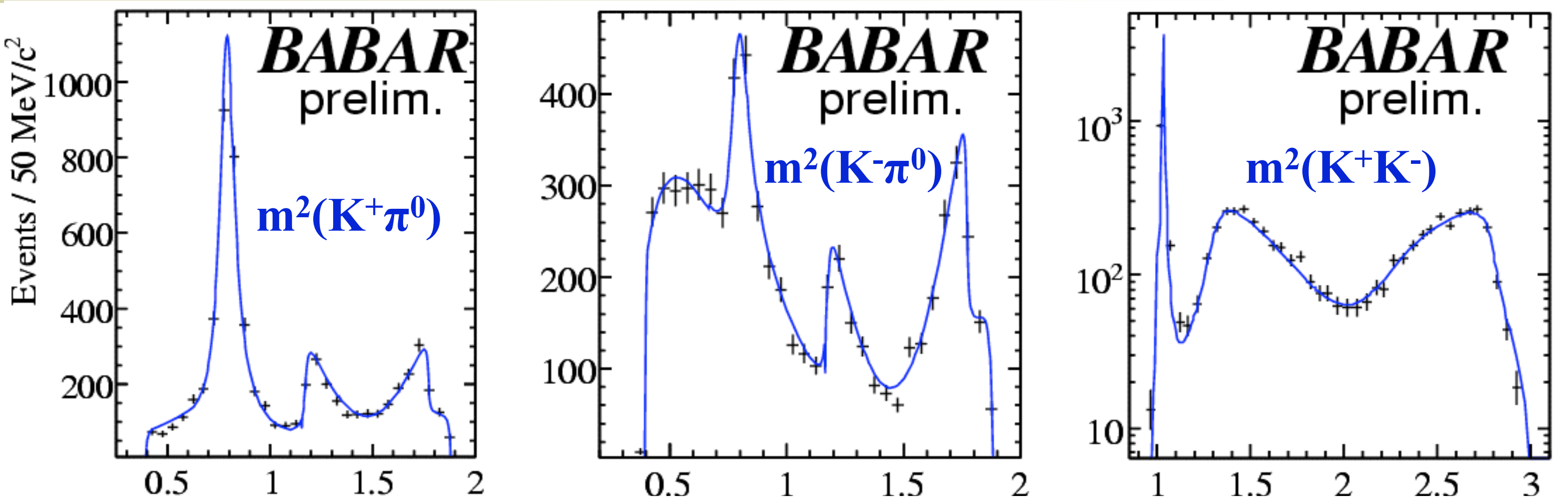
Normalized to arbitrary scale for m(Kπ)>1.1 Gev/c^2 for easy comparison.



Fit Results

LASS parameterization for Kπ S-wave

Use the fit model with Kπ S-wave from E791 for model systematic uncertainty
.



Component	Amplitude, a_r	Phase, ϕ_r (°)	Fraction (%)
$K^{*+}(892)$	1.0 (fixed)	0.0 (fixed)	41.6±0.8±0.6
$K^{*+}(1410)$	0.99±0.15±0.17	92.4±12.2±19.5	0.7±0.2±0.2
$[K^+\pi^0](S)$	3.85±0.12±0.71	85.2±3.5±13.2	8.1±0.6±1.3
$\phi(1020)$	0.72±0.01±0.03	-15.0±4.8±1.6	19.0±0.7±0.7
$f_0(980)$	0.60±0.08±0.08	97.7±6.0±7.9	3.0±0.8±0.7
$f_2'(1525)$	0.85±0.15±0.08	-41.8±6.7±5.9	0.6±0.2±0.1
$K^{*-}(892)$	0.64±0.01±0.01	-37.9±2.2±4.2	16.8±0.8±0.2
$K^{*-}(1410)$	2.93±0.20±0.34	177.3±3.0±19.4	5.1±0.8±1.3
$[K^-\pi^0](S)$	3.05±0.24±0.17	156.9±3.7±6.0	6.2±0.9±0.4

For Kπ S-wave

- The best fit is LASS parameterization.
- E791 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 previously for κ^0.

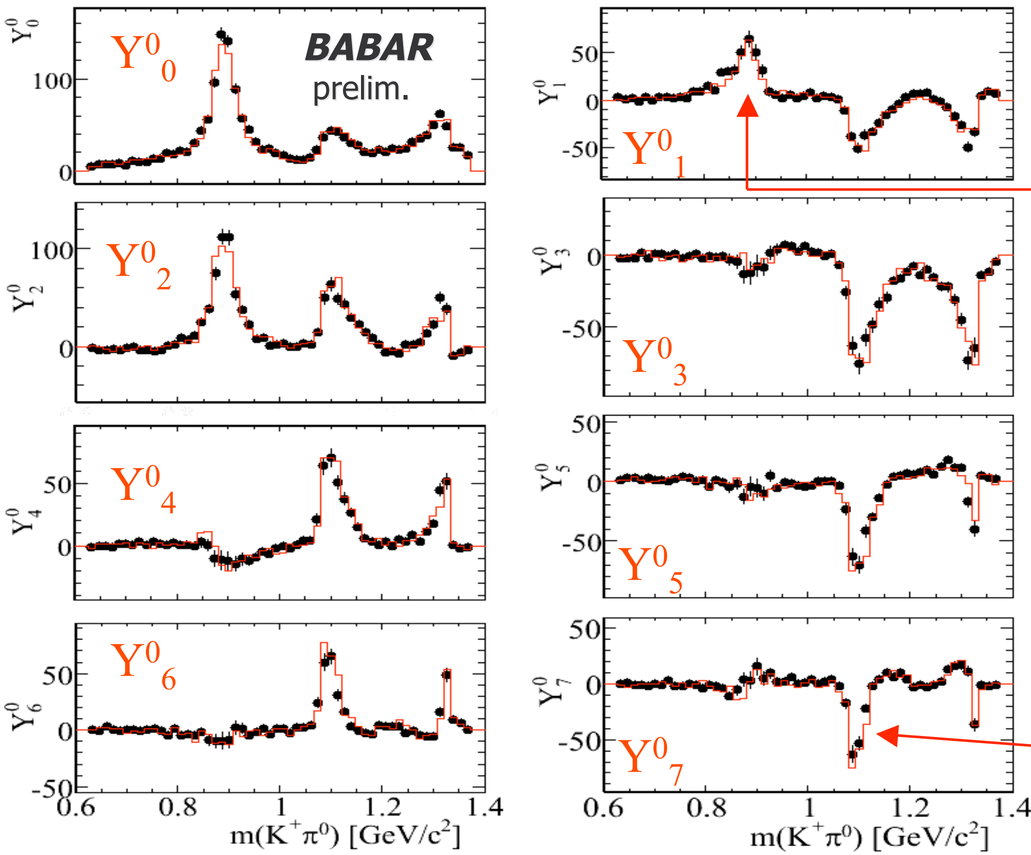
These results are preliminary. We are investigating the Kπ S-wave at lower mass, and contribution of K*(1410).

Kalanand Mishra,
University of Cincinnati

Analysis of Angular Moments

Excellent agreement between data & model.

Each event was weighted by the spherical harmonic $Y^0_L(\cos\theta_H)$ (L=0,1,2,…..).



For S- and P- waves in absence of cross-feeds from other channels (also, assuming negligible contributions from D- and higher waves):

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

- Significantly large interference between S and P waves.

Higher moments above 1 GeV are coming from cross channels.

Kalanand Mishra,
University of Cincinnati

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

δ_D = -37.9° ± 2.2° (stat) ± 0.7° (exp sys) ± 4.2° (model sys)
r_D = 0.64 ± 0.01 (stat) ± 0.01 (exp sys) ± 0.01 (model sys).

These results are preliminary.

These measurements are consistent with the previous measurement by CLEO:

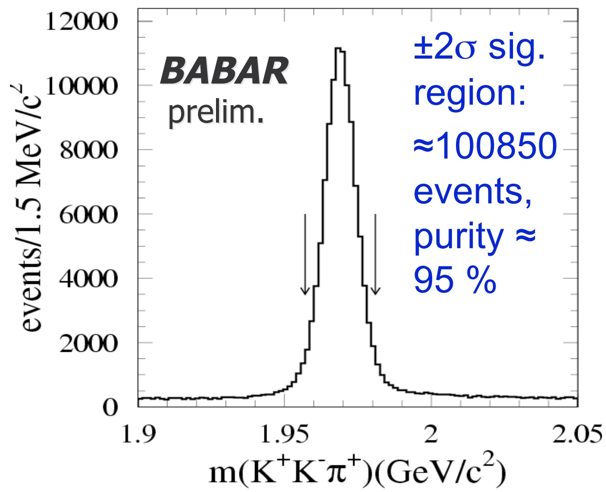
δ_D = -28° ± 8° (stat) ± 2.9° (exp sys) ± 10.6° (model sys)
r_D = 0.52 ± 0.05 (stat) ± 0.02 (exp sys) ± 0.04 (model sys).

hep-ex/ 0606045

BaBar Preliminary

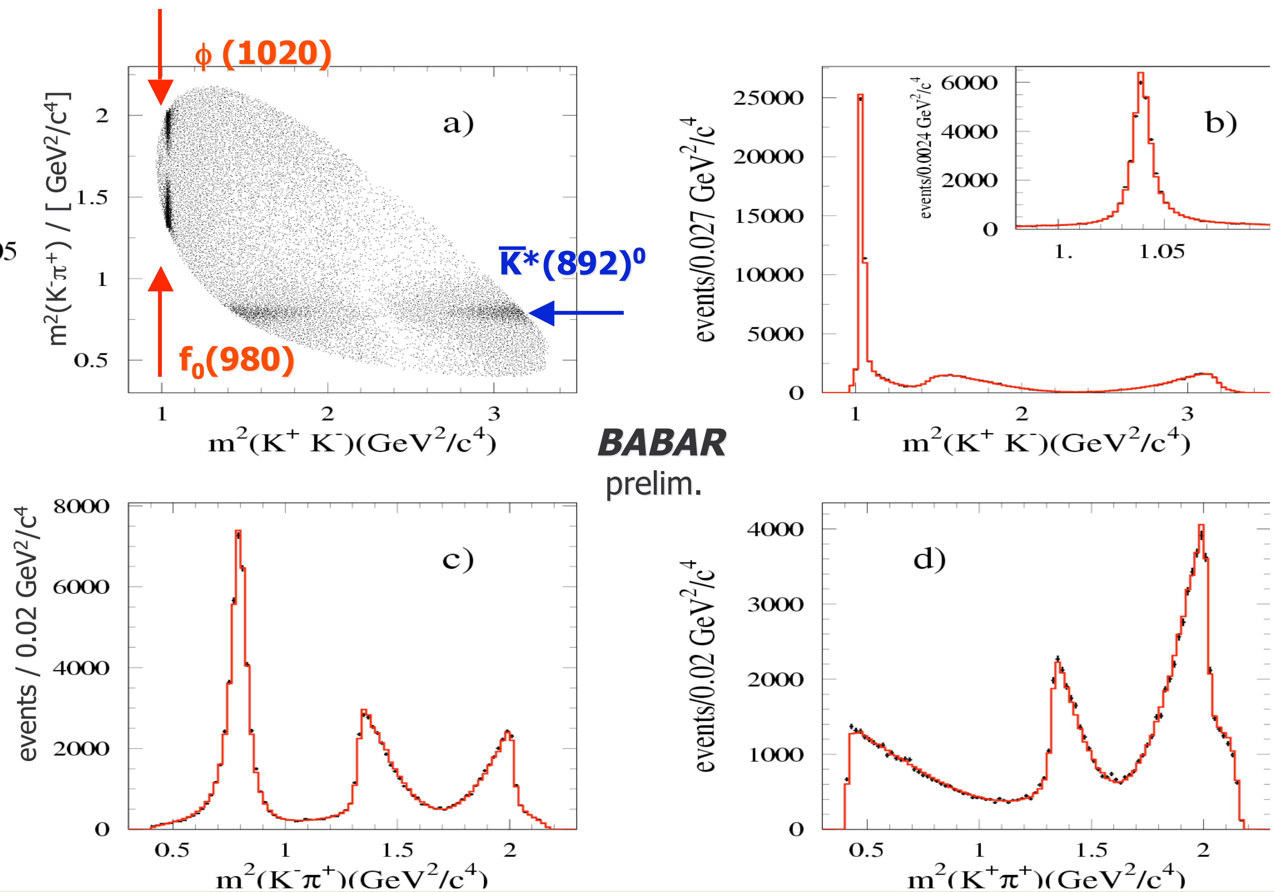
Amplitude Analysis of $D_s^+ \to K^+ K^- \pi^+$ Decay

Data Sample = 240 fb^{-1}



Motivation

Precise measurement of the branching fractions of $D_s^+ \to \phi\pi^+$ and $D_s^+ \to \overline{K}^*(892)^0 K^+$.



- Clean signal obtained with a likelihood selection using vertex separation and p*.
- Average reconstruction efficiency ~30 %.

BaBar Preliminary

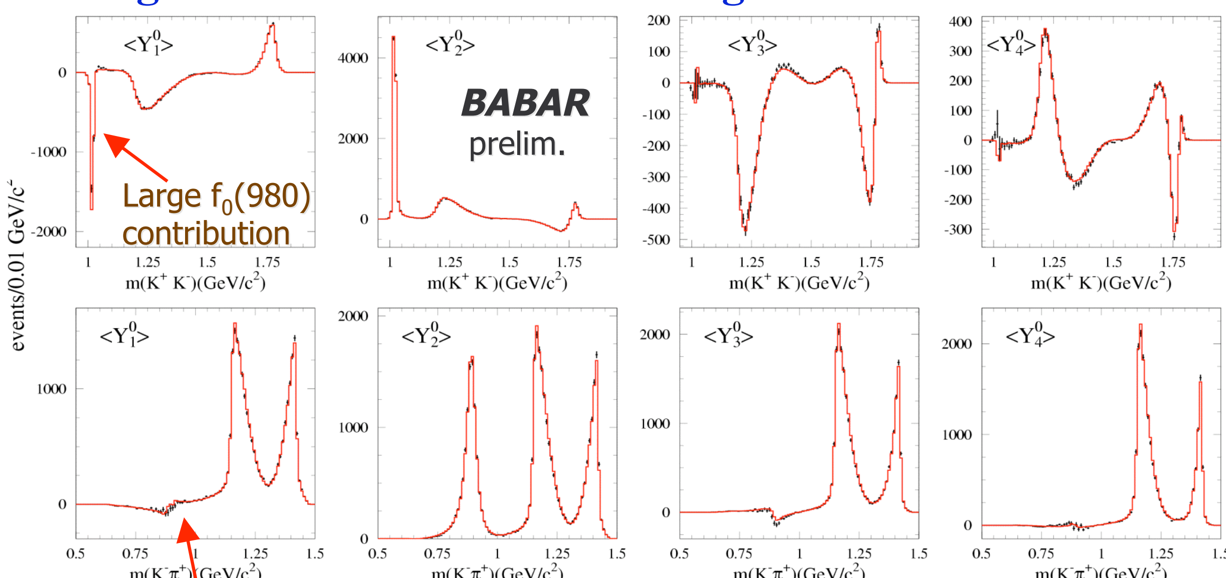
Kalanand Mishra,
University of Cincinnati

Fit Results

Decay Mode	Decay fraction(%)	Amplitude	Phase(radians)
$\bar{K}^*(892)^0K^+$	$48.7\pm 0.2\ \pm 1.6$	$1.(Fixed)$	$0.(Fixed)$
$\phi(1020)\pi^+$	$37.9\pm 0.2\ \pm 1.8$	$1.081\pm 0.006\pm 0.049$	$2.56\pm 0.02\pm 0.38$
$f_0(980)\pi^+$	$35\pm\ 1\ \pm 14$	$4.6\pm\ 0.1\ \pm 1.6$	$-1.04\pm 0.04\pm 0.48$
$\bar{K}_0^*(1430)^0K^+$	$2.0\pm 0.2\ \pm 3.3$	$1.07\pm\ 0.06\ \pm 0.73$	$-1.37\pm 0.05\pm 0.81$
$f_0(1710)\pi^+$	$2.0\pm 0.1\ \pm 1.0$	$0.83\pm\ 0.02\ \pm 0.18$	$-2.11\pm 0.05\pm 0.42$
$f_0(1370)\pi^+$	$6.3\pm 0.6\ \pm 4.8$	$1.74\pm\ 0.09\ \pm 1.05$	$-2.6\pm\ 0.1\ \pm 1.1$
$\bar{K}_2^*(1430)^0K^+$	$0.17\pm 0.05\pm 0.3$	$0.43\pm\ 0.05\ \pm 0.34$	$-2.5\pm\ 0.1\ \pm 0.3$
$f_2(1270)\pi^+$	$0.18\pm 0.03\pm 0.4$	$0.40\pm\ 0.04\ \pm 0.35$	$0.3\pm\ 0.2\ \pm 0.5$
Sum	$132\pm\ 1.2\ \pm 15.6$		
χ^2/NDF	1.5		

Large systematic uncertainty in $f_0(980)$ amplitude and phase because several different parameterizations were tried.

Angular moments : Excellent agreement with data



- Decay is dominated by $D_s^+\rightarrow K^{*0}K^+$, $\phi\pi^+$, and $f_0(980)\pi^+$
- $f_0(980)$ contribution is large but has large systematic error as well.
- Higher mass f_0's and D-wave resonances have small contributions.

Very small interference between S-wave ($\kappa(800)$?) and P-wave ($K^*(892)$) => no $\kappa(800)$ contribution found.

Branching Ratios

- The decay $D_s^+ \to \phi\pi^+$ is frequently used as the D_s^+ reference decay mode for measurement of branching ratios.
- The previous analysis (E687) of this Dalitz plot was performed with ~ 700 events (vs. 10^5 events in our case).
- Using Dalitz plot results, we make a precise measurement of the branching ratios of the decays $D_s^+ \to \phi\pi^+$ and $D_s^+ \to \bar{K}^*(892)^0 K^+$ integrated over the whole phase space.

$B(D_s^+ \to \phi\pi^+) / B(D_s^+ \to K^+K^-\pi^+) = 0.379 \pm 0.002\ (stat) \pm 0.018\ (sys)$

$B(D_s^+ \to \bar{K}^*(892)^0 K^+) / B(D_s^+ \to K^+K^-\pi^+) = 0.487 \pm 0.002\ (stat) \pm 0.016\ (sys)$

where $\phi \to K^+K^-$ and $\bar{K}^*(892)^0 \to K^-\pi^+$.

These results are preliminary.

BaBar Preliminary

Kalanand Mishra,
University of Cincinnati

Summary

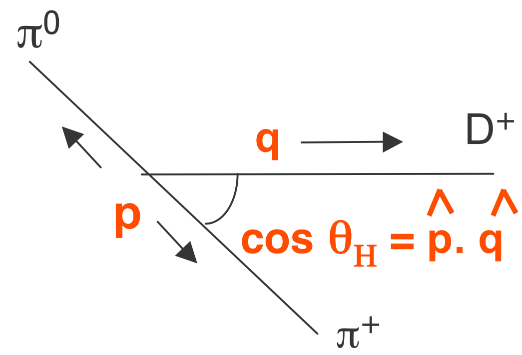
- Precise measurements of singly Cabibbo-suppressed branching ratios: $D^+ \to \pi^+\pi^0$ and $D^0 \to \pi^-\pi^+\pi^0$, $K^-K^+\pi^0$.
- First measurement of doubly Cabibbo-suppressed branching ratio : $D^+ \to K^+\pi^0$.
- Amplitude analysis of $D^0 \to K^-K^+\pi^0$: measure δ_D & r_D for the charge-conjugate dominant decays.
- Amplitude analysis $D_s^+ \to K^+K^-\pi^+$: measure precise branching ratios of $D_s^+ \to \phi\pi^+$ and $D_s^+ \to \bar{K}^{*0}(892)K^+$ with $\phi \to K^+K^-$ and $\bar{K}^*(892)^0 \to K^-\pi^+$.

Back up slides

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

Event Reconstruction

- **π^0 reconstruction: have two of them, one from D^{*+}, other from D^+ :**
  - π^0 from D^{*+} is soft , $150 < p_{\pi^0} < 450$ MeV/c
  - π^0 from D^+ has higher mom., $p_{\pi^0} > 200$ MeV/c
- **$D^+ \to h^+\pi^0$ reconstruction: $1.7 < m(h^+\pi^0) < 2.0$ GeV/c^2, $-0.9 < \cos\theta_h < 0.8$ (0.7 in case of $K^+\pi^0$).**
- **K^-, π^+ and π^+ tracks are fit to a vertex to reconstruct D^+ candidate for reference mode.**
- **$P_{CM}(D^*) > 2.9$ GeV/c, $|m_{D^*} - m_{D^+}| < 155$ MeV/c^2**
- **In case of multiple candidates in an event, select the one with higher D^* momentum.**



Helicity angle for $\pi^+\pi^0$ mode

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

$D^0 \to h^-h^+\pi^0$ Reconstruction

- h^- and h^+ tracks are fit to a vertex
- Mass of π^0 candidate is constrained to m_{π^0} at h^-h^+ vertex
- $P_{CM}(D^0) > 2.77$ GeV/c

Background Sources

- Charged track combinatoric
- Mis-reconstructed π^0
- Real D^0, fake π_s
- $K\pi\pi^0$ reflection in $\pi\pi\pi^0$ and $KK\pi^0$ modes

D* Reconstruction

- D^{*+} candidate is made by fitting the D^0 and the π_s^+ to a vertex constrained in x and y to the measured beam-spot for the run.
- $|m_{D^*} - m_{D^0} - 145.5| < 0.6$ MeV/c^2
- Vertex χ^2 probability > 0.01
- Choose a single best candidate with smallest χ^2 for the whole decay chain (multiplicity = 1.03).

$K^-K^+\pi^0$ branching ratio: CLEO result

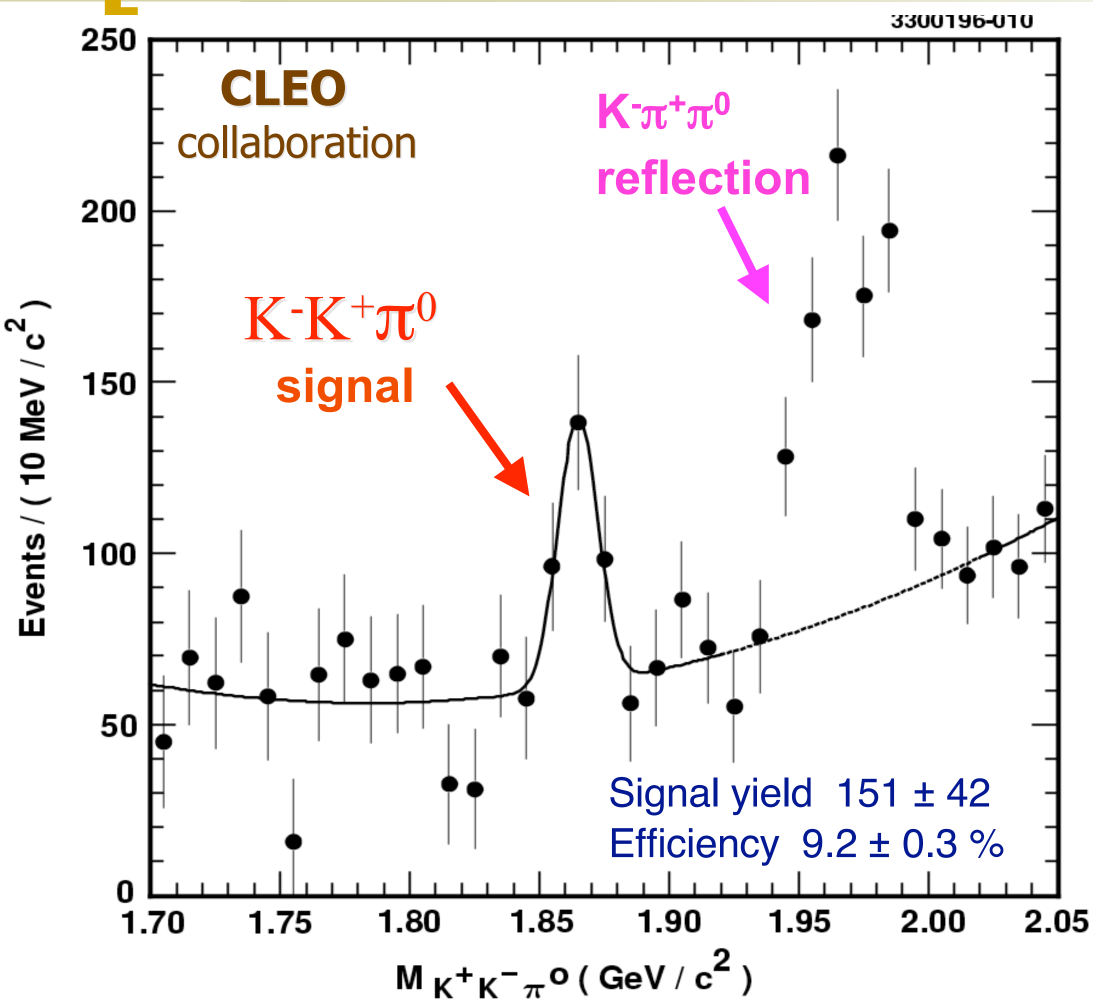


FIG. 10. The invariant mass distribution of $K^+K^-\pi^0$ after doing the normalized mass difference sideband subtraction. In fitting, we exclude the region between 1.92 and 2.02 GeV/c^2 due to an excess of misidentified $D^0 \to K^-\pi^+\pi^0$ events which survive the veto.

Phys. Rev. D54, 4211 (1996)
$B(D^0 \to KK\pi^0)/ B(D^0 \to KK\pi^0)$ =
0.95 ± 0.26 %

- High pion-to-kaon misidentification rate ⇒ contamination from $D^0 \to K^-\pi^+\pi^0$ events very high.
- Had to apply various vetoes and the corresponding efficiency corrections.
- Combinatorial background not fully understood.

A new cross-check done by the CLEO collaboration shows $B(D^0 \to KK\pi^0)/ B(D^0 \to K\pi\pi^0)$ = 2.21 ± 0.14 (stat) %, which is consistent with our measurement.

Phys. Rev. D74, 031108 (2006)

LASS Kπ S-wave Parameterization

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

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

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

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

Phase space factor

a = scat. length, r = eff. range, m_R = mass of $K^*_0(1430)$, Γ_R = width

p = momentum of either daughter in the Kπ rest frame.

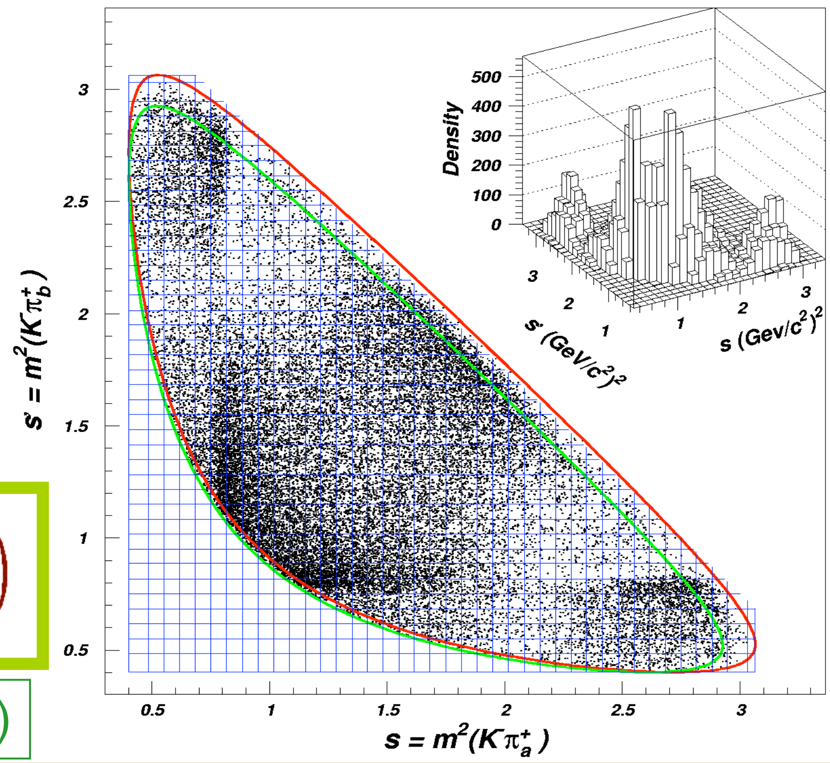
For Kπ scattering, S-wave is elastic up to Kη' threshold (1.45 GeV).

$K\pi$ 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
- 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.

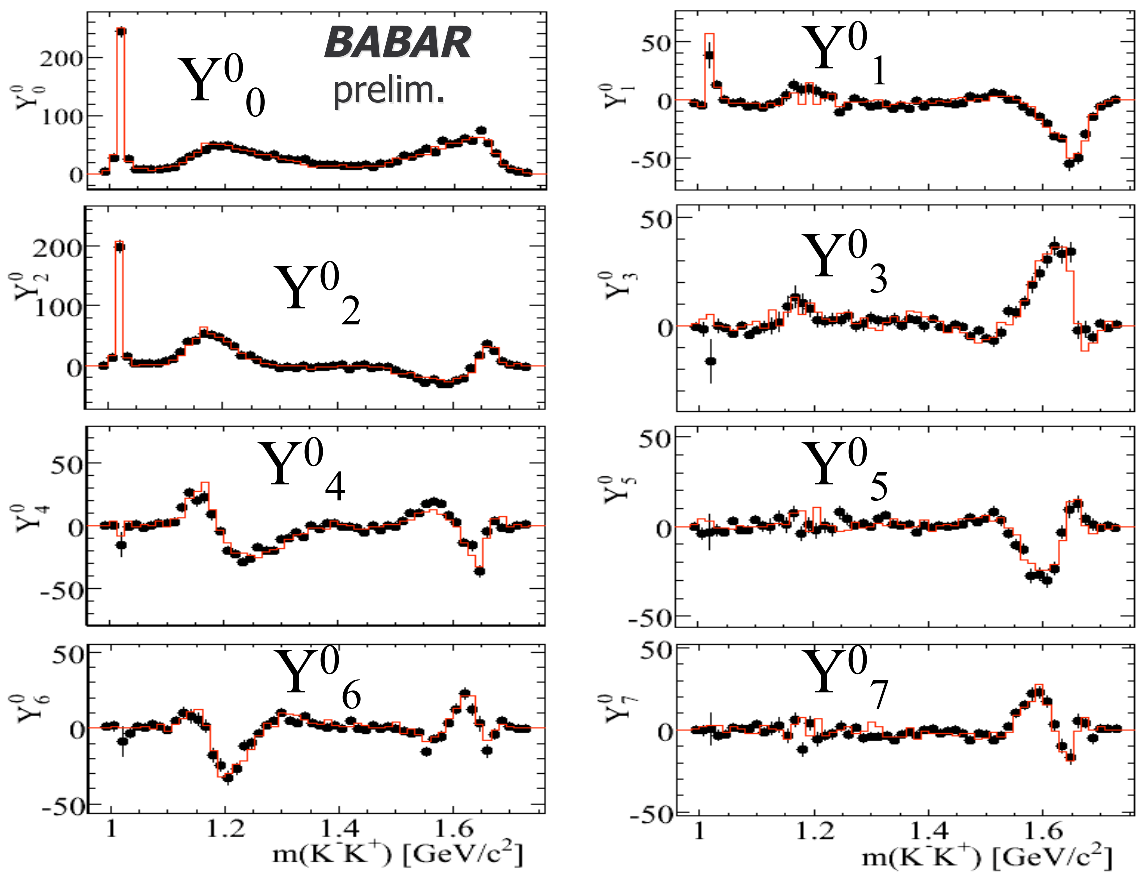
$$\mathcal{S} = \mathrm{Interp}\left(c_k e^{i\gamma_k}\right) \times F_0^D(q,r_D)F_0^R(p,r_R)$$

S ("partial wave")

Moments Analysis in K$^-$K$^+$ channel

Excellent agreement between data & model.

Each event was weighted by the spherical harmonic $Y^0_L(\cos\theta_H)$ (L=0,1,2).



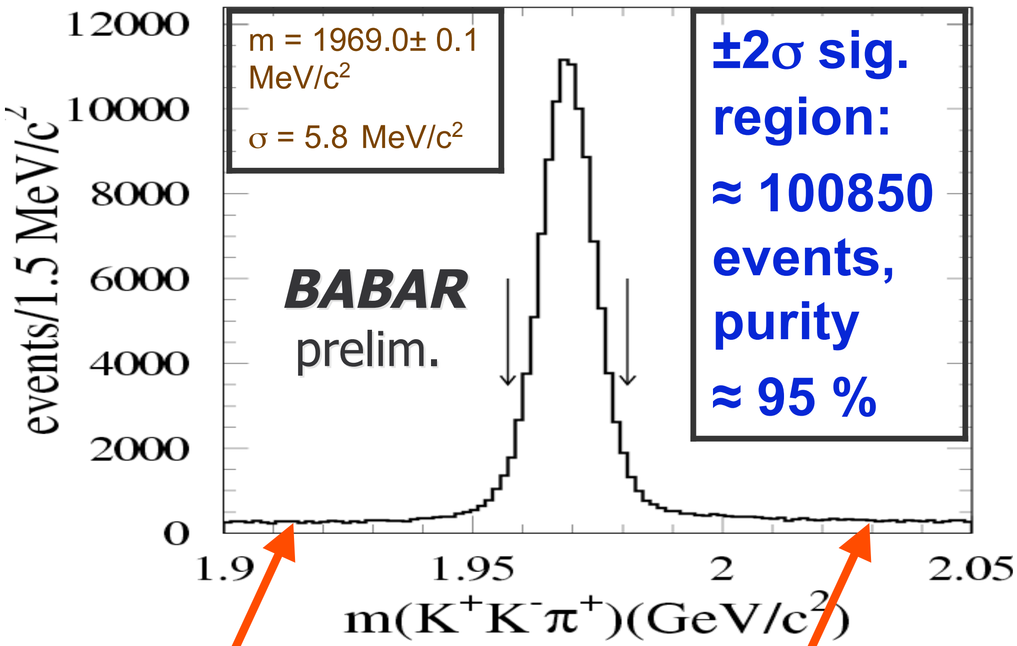
For S- and P- waves in absence of cross-feeds from other channels:

$$\begin{cases} \sqrt{4\pi}\langle Y^0_0\rangle = S^2 + P^2 \\ \sqrt{4\pi}\langle Y^0_1\rangle = 2|S||P|\cos\phi_{SP} \\ \sqrt{4\pi}\langle Y^0_2\rangle = \dfrac{2}{\sqrt{5}}P^2 \end{cases}$$

- **With cross-feeds or in the presence of D-waves, higher moments $\neq$ 0 .**
- **Wrong fit models tend to give rise to higher moments in the ϕ region, creating disagreement with data.**

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

Data Sample = 240 fb^{-1}



Events used to obtain Bkg shape: (-10σ, -6σ) and (6σ, 10σ).

- Signal events reconstructed from two kaon and a pion charged tracks fitted to a common vertex, with χ^2>0.1 %.
- Background from $D^{*+} \to D^0[K^+K^-]\,\pi^+$ removed by requiring $m(K^+K^-)$<1.85 GeV/c^2.
- Removed $K^-\pi^+_{mis}\pi^+$ reflection by requiring $m(K^-\pi^+_{mis}\pi^+) - m(K^-\pi^+_{mis})$ > 0.15 GeV/c^2.
- Average event reconstruction efficiency ~ 30 %.

Kalanand Mishra,
University of Cincinnati