D_s Dalitz Plot Analyses from the B Factories

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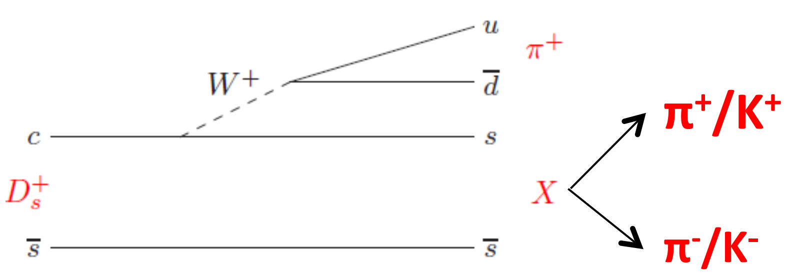
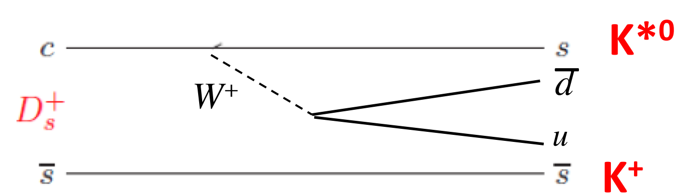
Overview

- Three-body D_s (and D) decays are dominated by resonant sub-structure
- Dalitz plot analysis with coherent amplitude sums necessary to explain observed structures
- Interference effects give extra information on:
  - Scalar mesons (through e.g. *S*-wave/*P*-wave interference)
  - K^+K^- *S*-wave
    - Important for e.g. $B_s \rightarrow \psi\phi$ ($\sin 2\beta_s$)
  - D^0 mixing (through Cabibbo-allowed/suppressed interference)
  - Measurement of γ/ϕ_3 in $B^+ \rightarrow D^{(*)}K^+$ ($D^0 \rightarrow K_s^0\pi^+\pi^-$)
- In this talk, $D_s^+ \rightarrow K^+ K^- \pi^+$ and $D_s^+ \rightarrow \pi^+ \pi^- \pi^+$ from BaBar





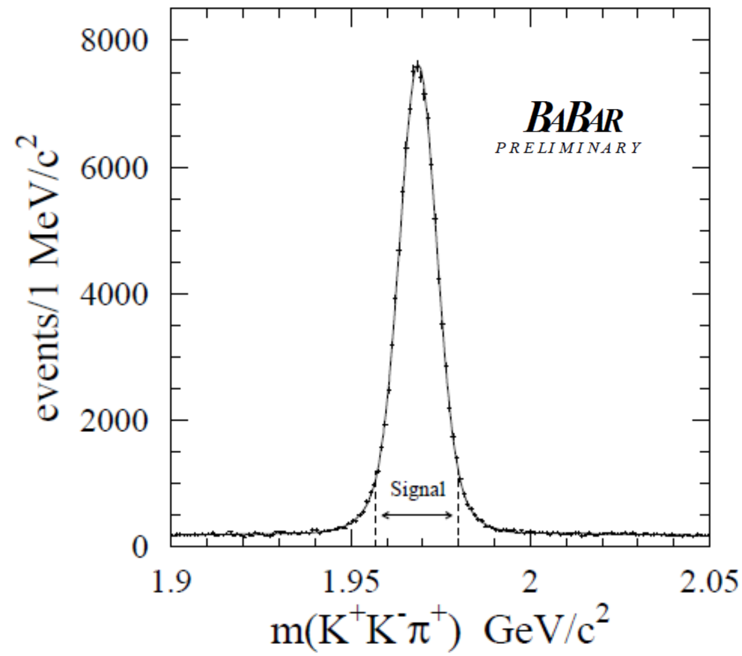
Scalar Mesons

- 46 years after quark model – the scalar meson nonet is still largely unknown
- Large widths, difficulty in isolation make assignments controversial
- Breit-Wigner description often not appropriate
- Situation may be complicated by the presence of 4-quark and/or glueball states
- Can use kinematics (i.e. angular distributions) to identify as scalar
- Need dynamics (i.e. couplings) to identify as
  - $\bar{q}q$ meson
  - 4-quark state (meson-meson)
  - glueball

	Quark Content	Estab-lished	ID'd
$K^*_0(1430)$	$\bar{s}d$	green	green
$f_0(980)$	$\bar{s}s$	green	red
$a_0(980)$	$\bar{u}u-\bar{d}d$	green	red
$f_0(600)/\sigma$	$\bar{u}u+\bar{d}d$	yellow	yellow
$K^*_0(800)/\kappa$	$\bar{s}d$	yellow	yellow
$a_0(1450)$	$\bar{u}u-\bar{d}d$	green	yellow
$f_0(1370)$ $f_0(1710)$	$\bar{s}s$	green	yellow

D Dalitz Plot Advantages

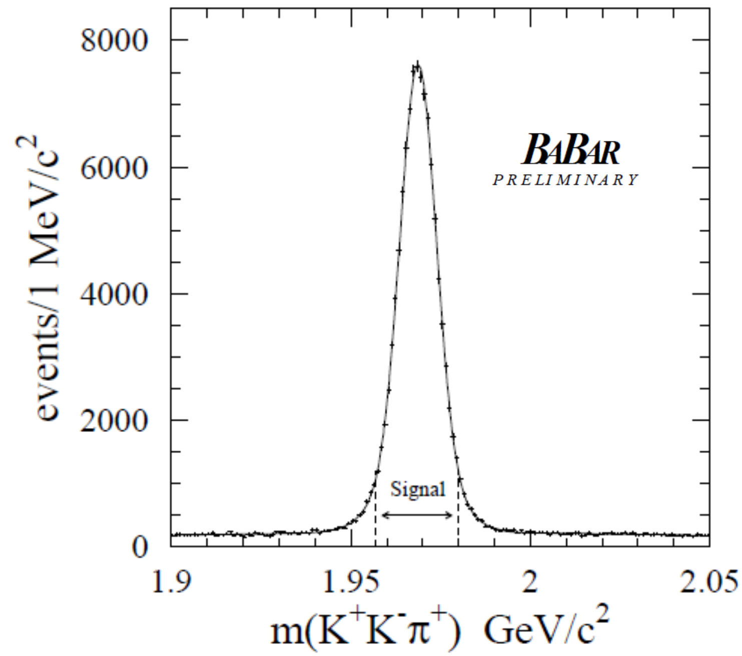
- Large coupling to scalar mesons
- Well-defined initial state ($J^P = 0^-$)
- Final state not constrained by isospin or parity symmetry
- Low background
- Large samples



$D_s^+ \rightarrow K^+ K^- \pi^+$ Dalitz Plot Analysis
BaBar Preliminary (384 fb^{-1})

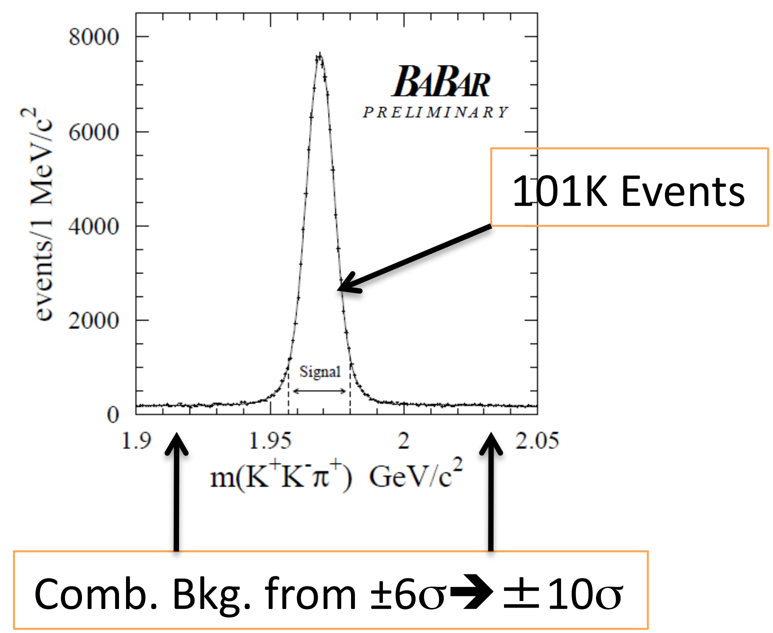
$D_s^+ \rightarrow K^+ K^- \pi^+$ Event Selection

- Standard BaBar tracking and particle ID
- 2σ cut on $\Delta m = m(K^+K^-\pi^+\gamma) - m(K^+K^-\pi^+)$
- Cut on likelihood ratio based on
  - $p^*(D_s)$
  - χ^2 probability difference due to D_s flight length
  - Signed decay distance



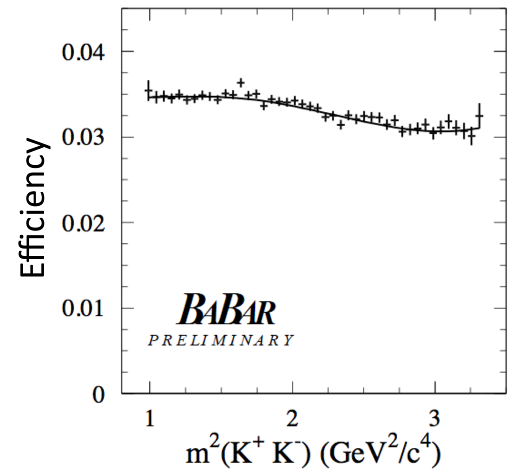
Background

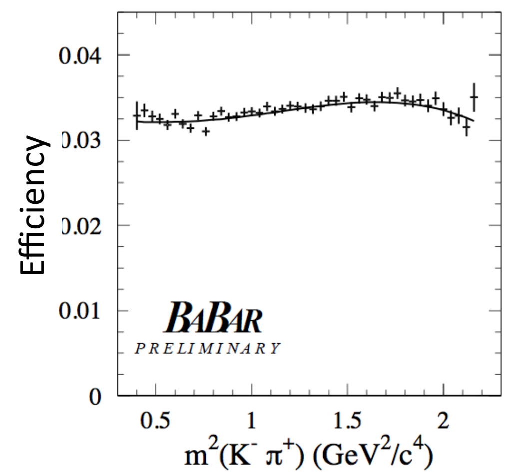
- Combinatorial background found from D_s^+ sidebands
- Background from $D^+ \rightarrow K^- \pi^+ \pi^+$ included in DP analysis
- Background from $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- \pi^+ \pi^0)$ removed via kinematics



Efficiency

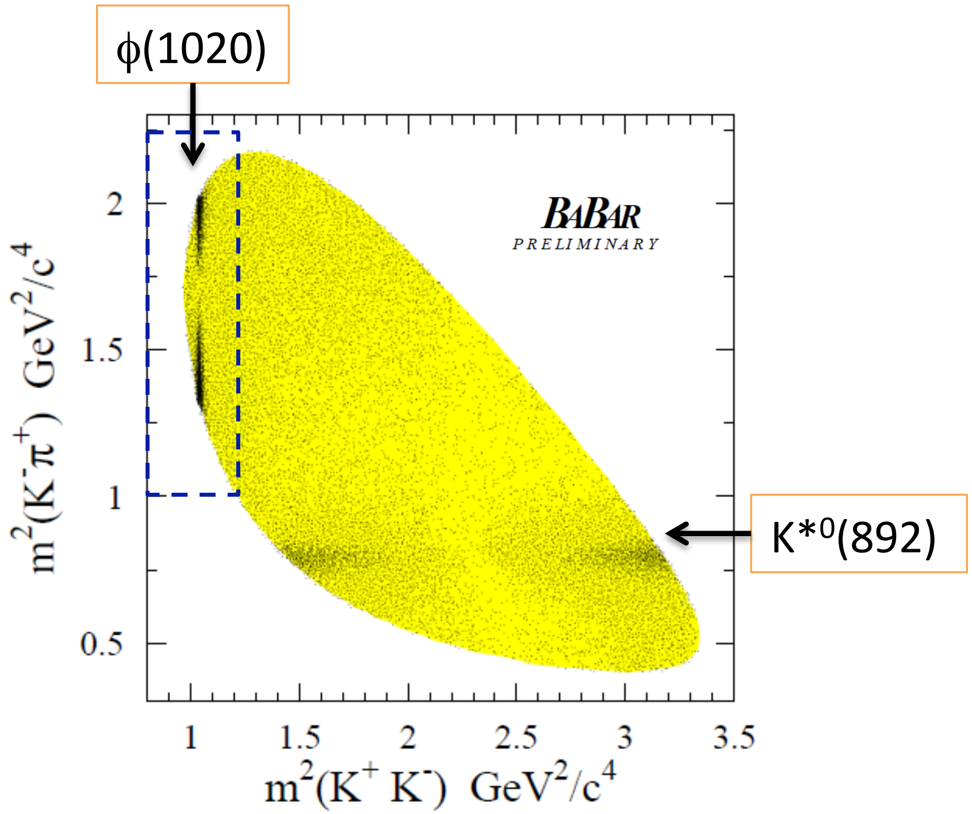
- Taken from flat-generated MC
- Fitted to 2-dimensional third order polynomial
- χ^2/dof = 1133/1140
- Projections onto $m(K^-\pi^+)$ and $m(K^+K^-)$ look good





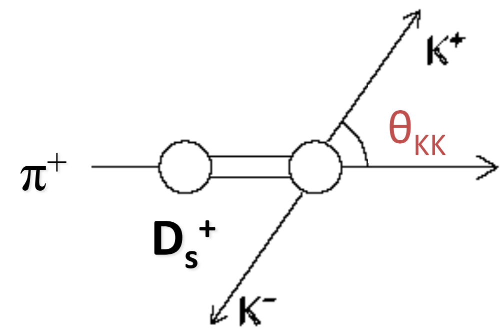
Dalitz Plot Gross Structures

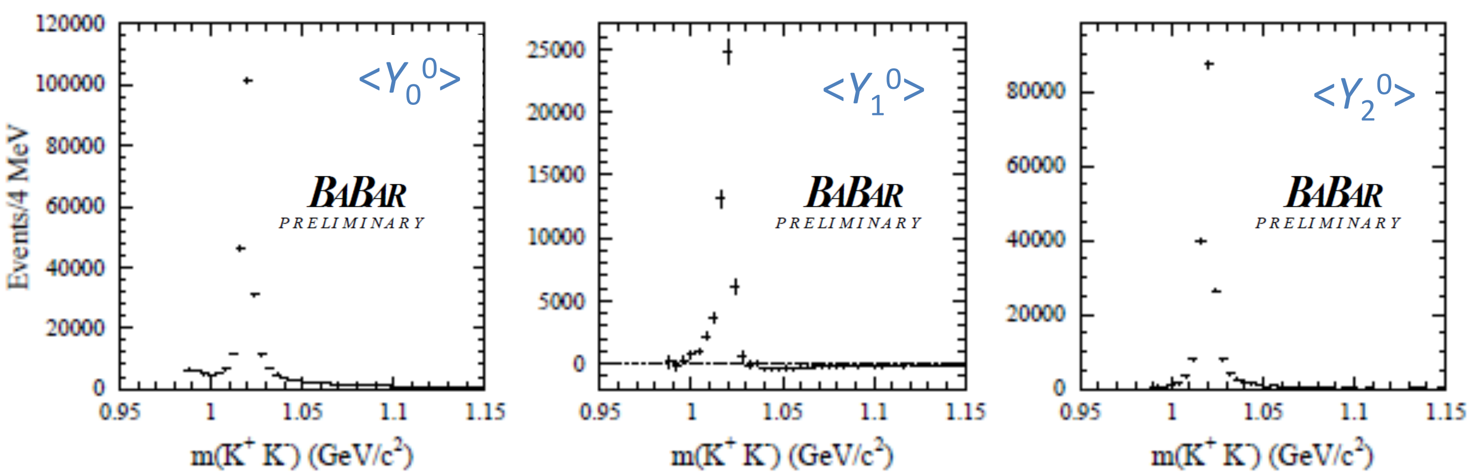
- $\phi(1020)$ and $K^*(892)$ clearly visible
- Before doing full DP, find K^+K^- *S*-wave in threshold region
  - No $K\pi$ structure in threshold region
  - No *D*-wave in KK
  - Model Independent Partial Wave analysis should work well



K^+K^- Partial Wave Analysis

- Background subtract, efficiency and phase-space correct
- Weight *cos*θ_{KK} distribution by spherical harmonics to get coefficients $<Y_k^0>$

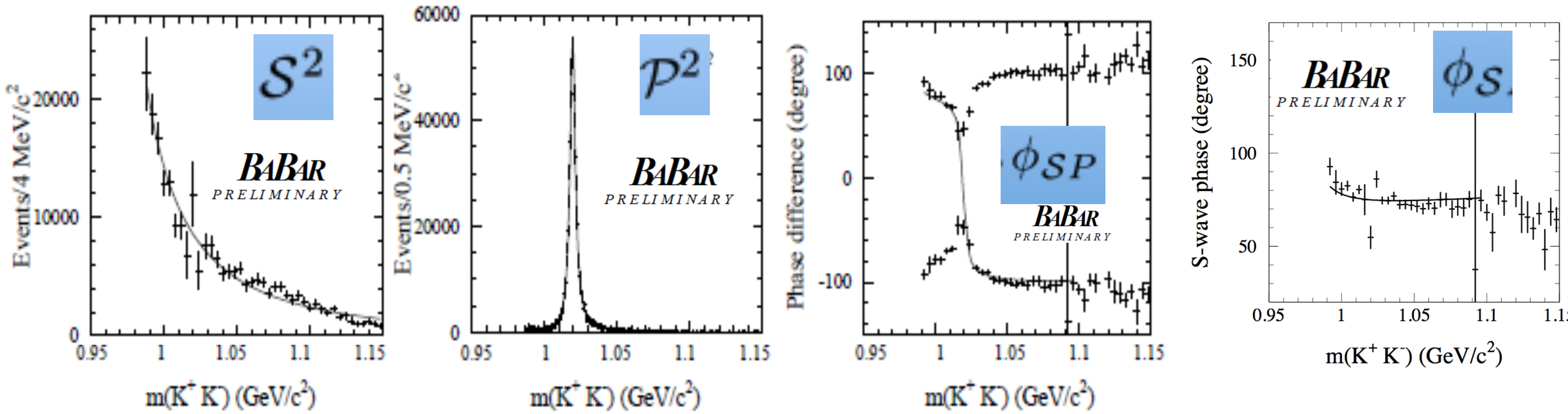




K^+K^- *S*-Wave

- Use $\langle Y_k^0 \rangle$ coefficients to extract *S* and *P* amplitudes and relative phase ϕ_{SP} as a function of $m(K^+K^-)$
- Use BW for *P*-wave and "BW-like" for the *S*-wave
- Phase motion coming from *P*-wave, *S*-wave slowly changing

$$\sqrt{4\pi}\,\langle Y_0^0 \rangle = \mathcal{S}^2 + \mathcal{P}^2$$
$$\sqrt{4\pi}\,\langle Y_1^0 \rangle = 2\,|\mathcal{S}|\,|\mathcal{P}|\cos\phi_{\mathcal{SP}}$$
$$\sqrt{4\pi}\,\langle Y_2^0 \rangle = \frac{2}{\sqrt{5}}\mathcal{P}^2$$



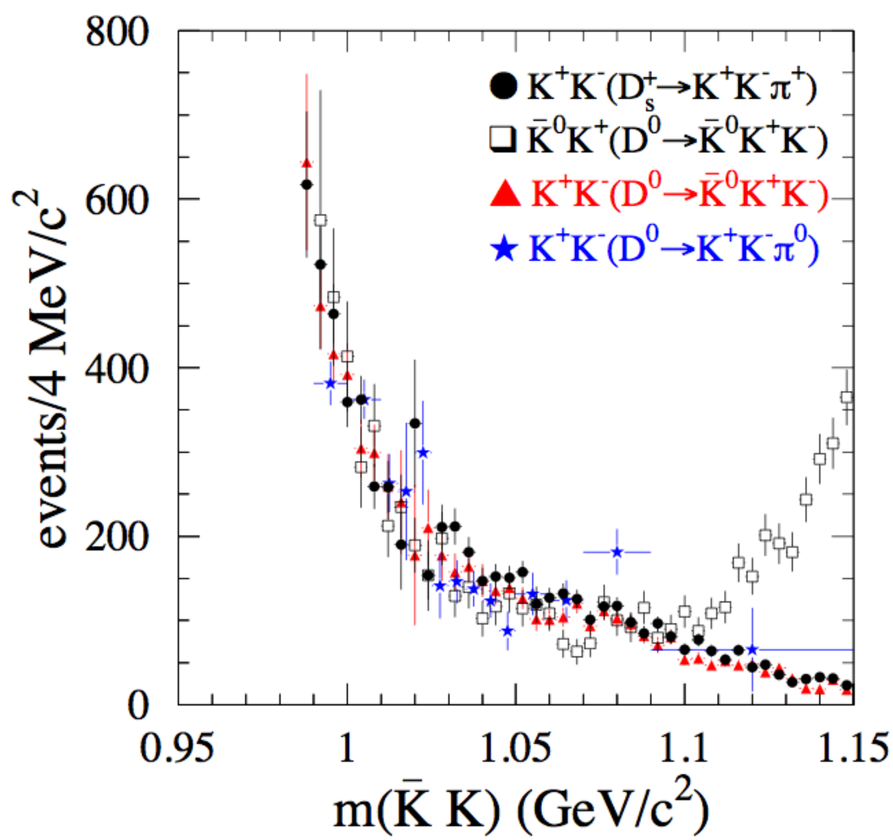
P-wave/*S*-wave Ratio in $\phi(1020)$ Region

- $D_s^+ \rightarrow \phi\pi^+$ often used as normalization mode
- Presence of *S*-wave must be taken into account
- As a service, calculate *S*- and *P*-wave contributions and relative overall rate for different cuts on $m(K^+K^-)$

$m_{K^+K^-}$ (MeV/c^2)	f_{S-wave}(%)	$f_{\mathcal{P}-wave}$(%)	Rel.Ov.Rate(%)
1019.456 ± 5	3.5 ± 1.0	96.5 ± 1.0	29.4 ± 0.2
1019.456 ± 10	5.6 ± 0.9	94.4 ± 0.9	35.1 ± 0.2
1019.456 ± 15	7.9 ± 0.9	92.1 ± 0.9	37.8 ± 0.2

K^+K^- *S*-wave Comparison

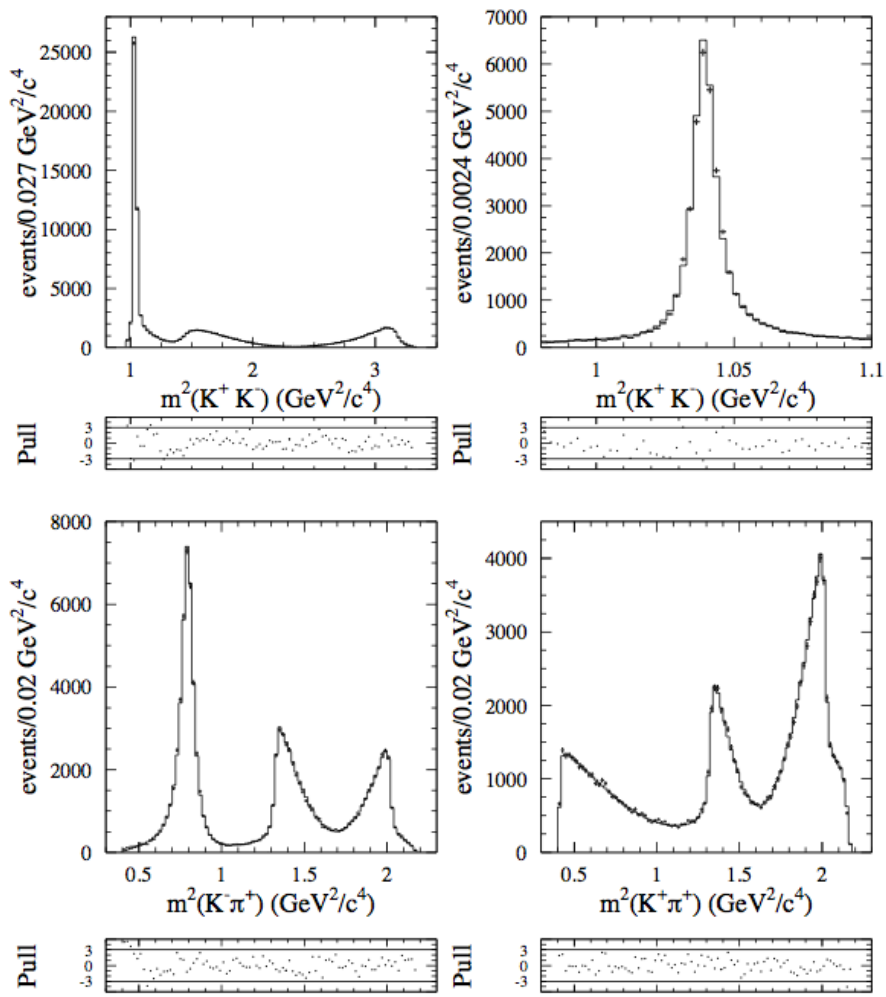
- K^+K^- *S*-wave shape consistent with other charm analyses
- For $\bar{K}^0K^+$ mode would expect a_0 to dominate
- For D_s, expect f_0
- Shape similarity evidence that they are both 4-quark states



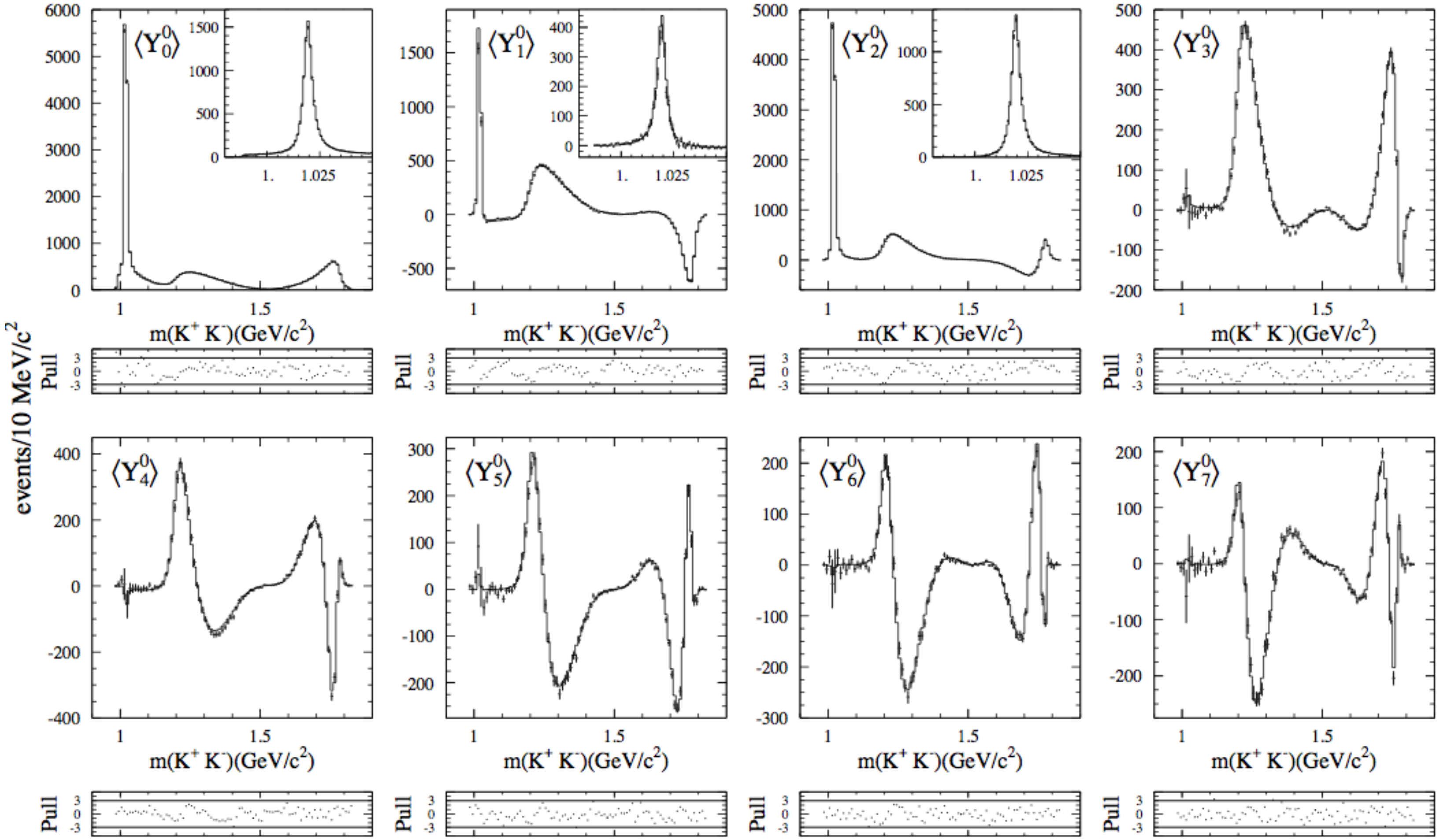
Dalitz Plot Details

- With *S*-wave empirical parameterization in hand to describe $f_0(980)$, move on to full Dalitz Plot fit
- *P*- and *D*-waves modeled with sum of resonances
- Unbinned maximum likelihood fit with complex amplitudes floating
- K*(892) mass and width are floated parameters
- χ^2 computed by adaptive binning algorithm

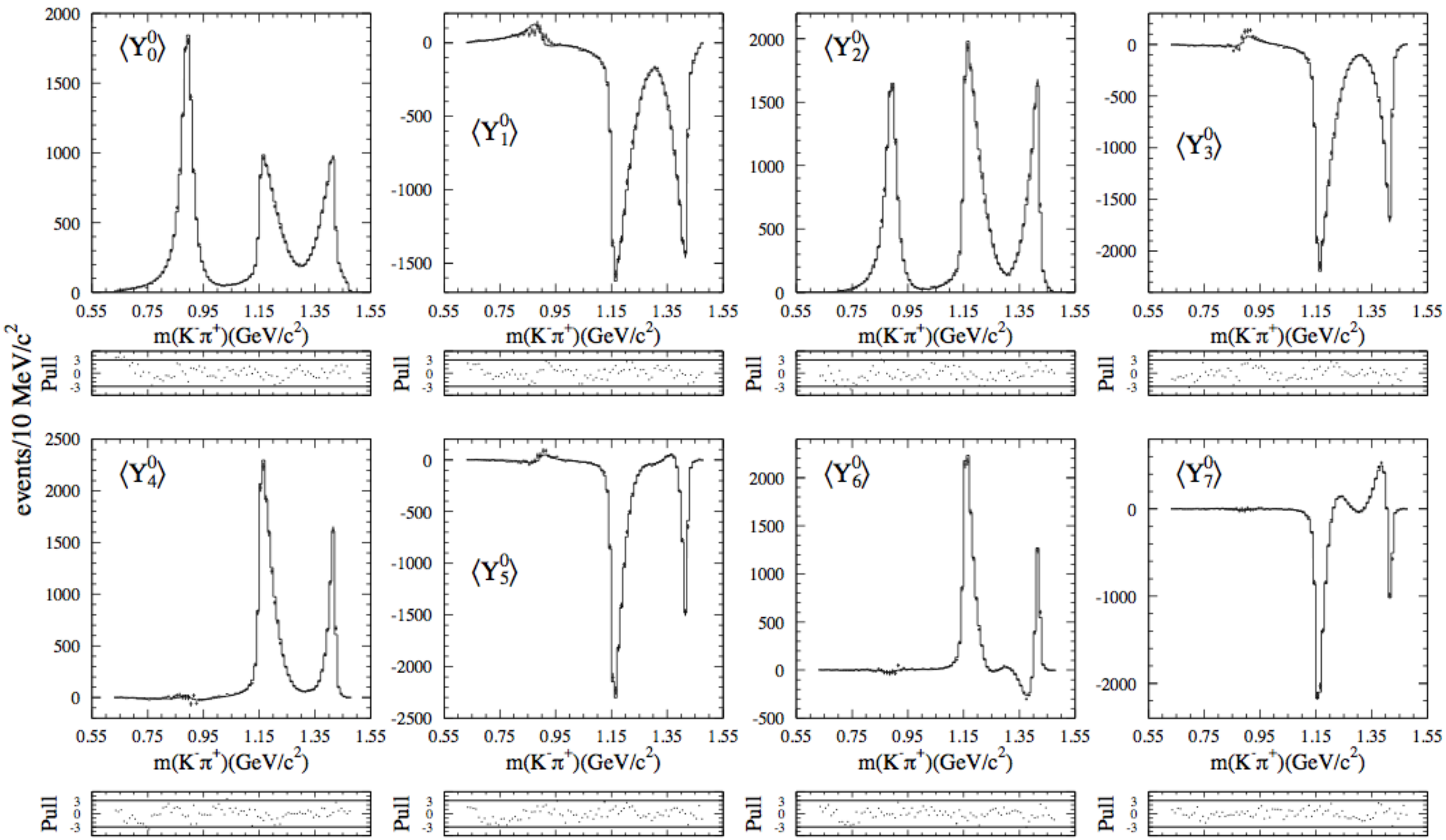
Dalitz Plot Projections



Dalitz Plot m(K^+K^-)Moments



Dalitz Plot $m(K^-\pi^+)$ Moments



Dalitz Plot Results

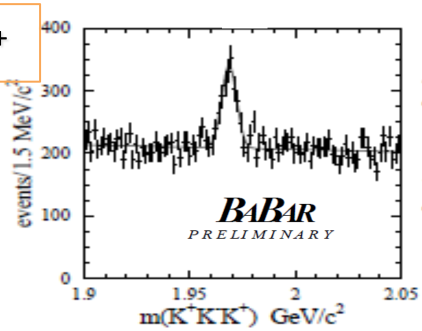
Decay Mode	*BABAR*	E687	CLEO-c
$\overline{K}^*(892)^0 K^+$	$47.9 \pm 0.2 \pm 0.5$	$47.8 \pm 4.6 \pm 4.0$	$47.4 \pm 1.5 \pm 0.4$
$\overline{K}^*_0(1430) K^+$	$2.4 \pm 0.3 \pm 1.$	$9.3 \pm 3.2 \pm 3.2$	$3.9 \pm 0.5 \pm 0.5$
$\phi(1020)\pi^+$	$41.4 \pm 0.2 \pm 0.5$	$39.6 \pm 3.3 \pm 4.7$	$42.2 \pm 1.6 \pm 0.3$
$f_0(980)\pi^+$	$16.4 \pm 0.3 \pm 2.0$	$11.0 \pm 3.5 \pm 2.6$	$28.2 \pm 1.9 \pm 1.8$
$f_0(1370)\pi^+$	$1.1 \pm 0.3 \pm 0.2$	—	$4.3 \pm 0.6 \pm 0.5$
$f_0(1710)\pi^+$	$1.1 \pm 0.1 \pm 0.1$	$3.4 \pm 2.3 \pm 3.5$	$3.4 \pm 0.5 \pm 0.3$
$\sum$ FF (%)	$110.2 \pm 0.3 \pm 2.$	111.1	$129.5 \pm 4.4 \pm 2.0$
# events on DP	101445		14400
# Signal events	96382	701 ± 36	12226 ± 123
Goodness(χ^2/ν)	2843/(2305-14)=1.2	50.2/33=1.5	178/117=1.5

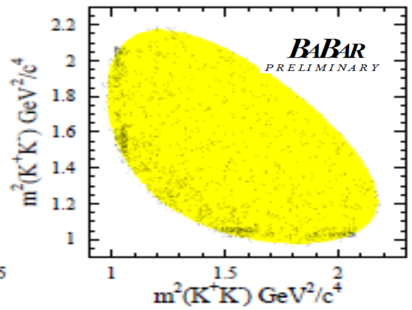
- Decay dominated by vector resonances
- K*0(892) width is 5 MeV lower than PDG '08 (consistent with CLEO-c)
- Contribution from K*(1410), $K^*_2(1430)$, κ(800), $f_0(1500)$, $f_2(1270)$, $f_2'(1525)$, non-resonant, each consistent with zero

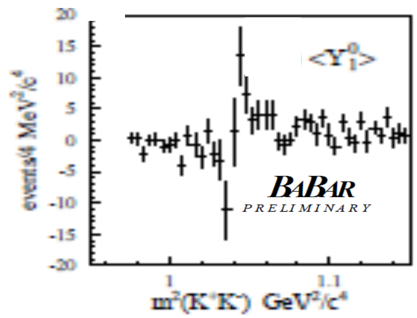
Cabibbo Suppressed Modes

$D_s^+ \rightarrow K^+ K^- K^+$

SCS



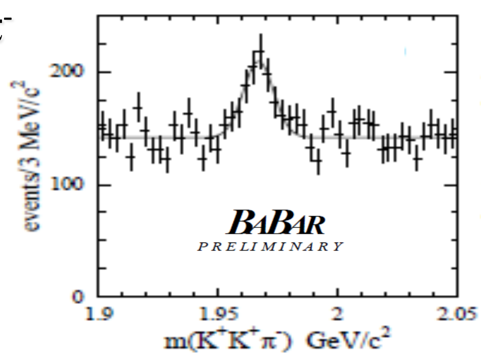


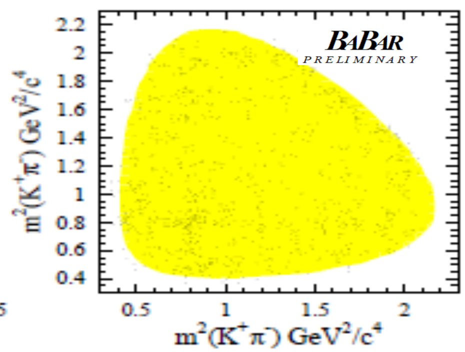


$$\frac{\mathcal{B}(D_s^+ \to K^+K^-K^+)}{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)} = (4.0 \pm 0.3_{\rm stat} \pm 0.2_{\rm syst}) \times 10^{-3}$$

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

DCS



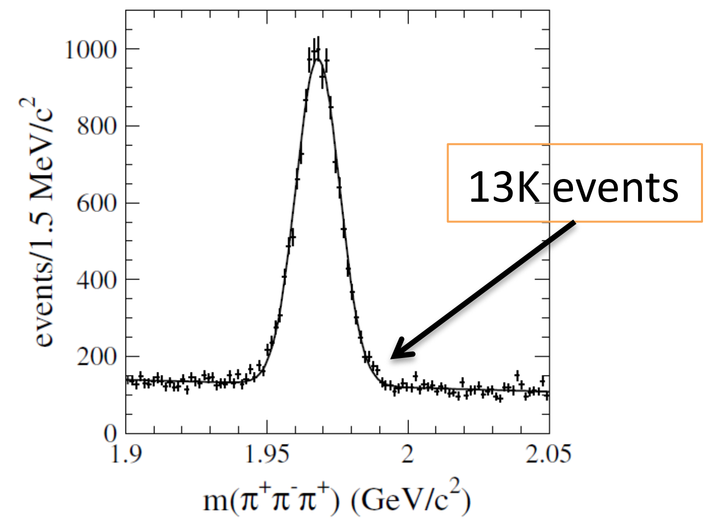


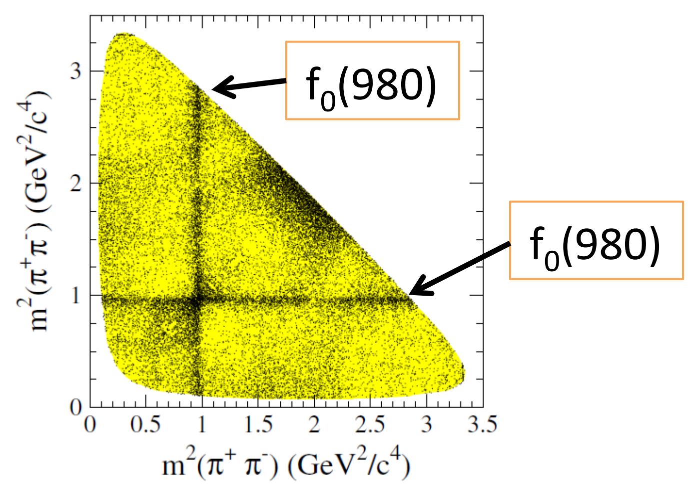
$$\frac{\mathcal{B}(D_s^+ \to K^+K^+\pi^-)}{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)} = (2.3 \pm 0.3_{\rm stat} \pm 0.2_{\rm syst}) \times 10^{-3}$$

$D_s^+ \rightarrow \pi^+ \pi^- \pi^+$ Dalitz Plot Analysis
Phys. Rev. D79:032003,2009.(384 fb^{-1})

Dalitz Plot Preliminaries

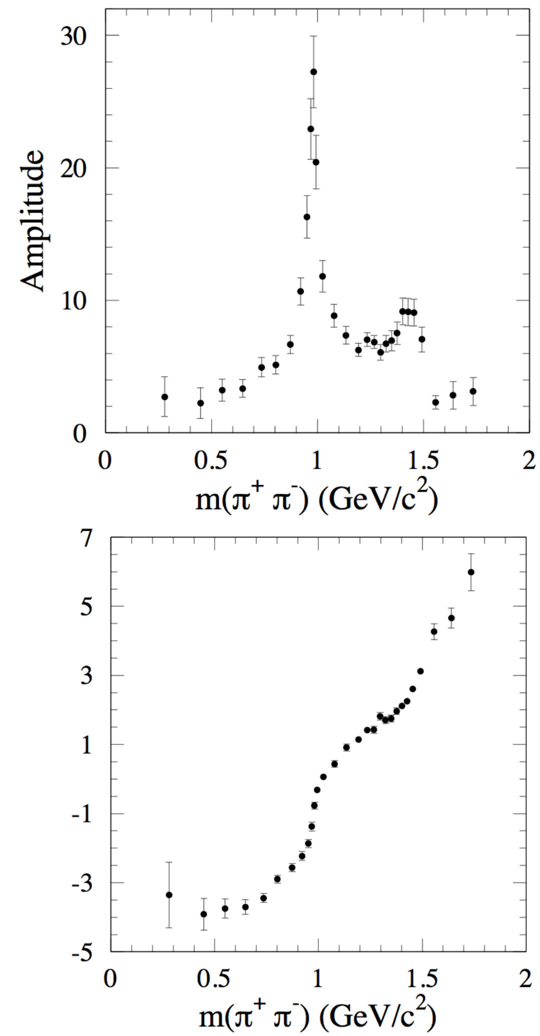
- Similar to $D_s^+ \to K^+ K^- \pi^+$
- 2σ cut on $\Delta m = m(K^+K^-\pi^+\gamma) - m(K^+K^-\pi^+)$
- Cut on likelihood ratio based on
  - p*(Ds)
  - χ^2 probability difference due to Ds flight length
  - Signed decay distance
- Symmetrized Dalitz plot
- Efficiency and backgrounds modeled similarly



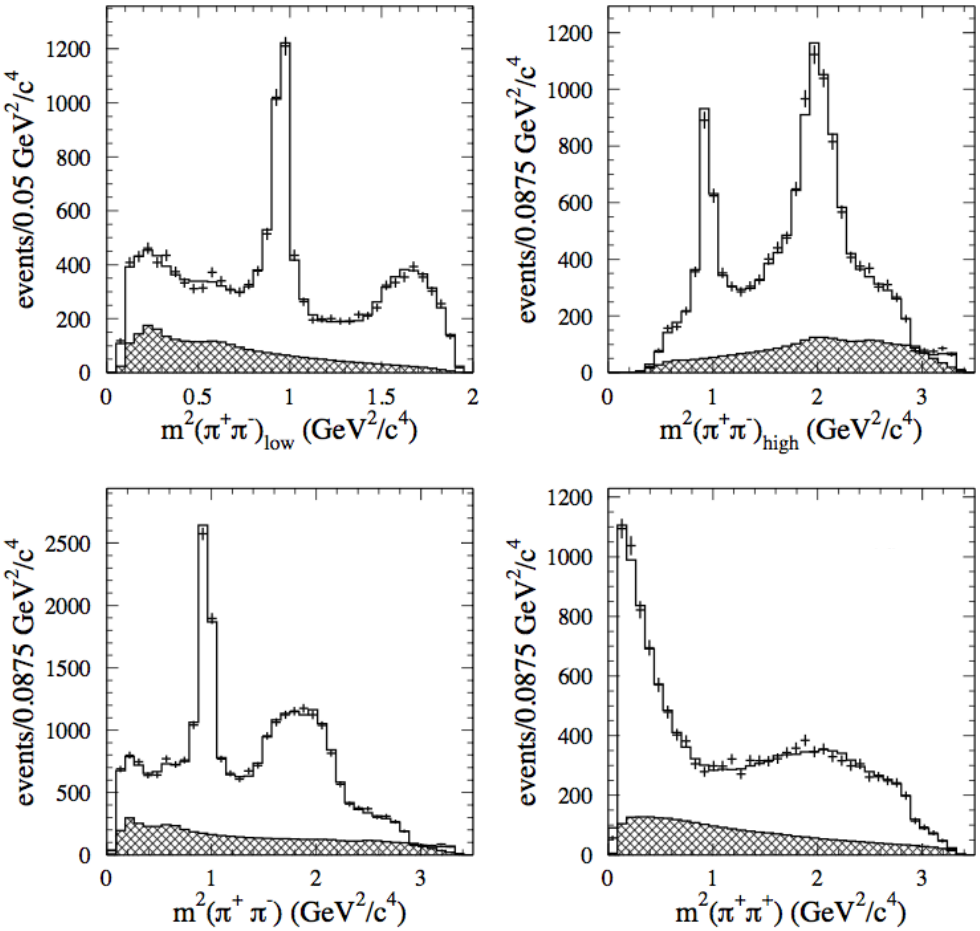


S-wave Modeling

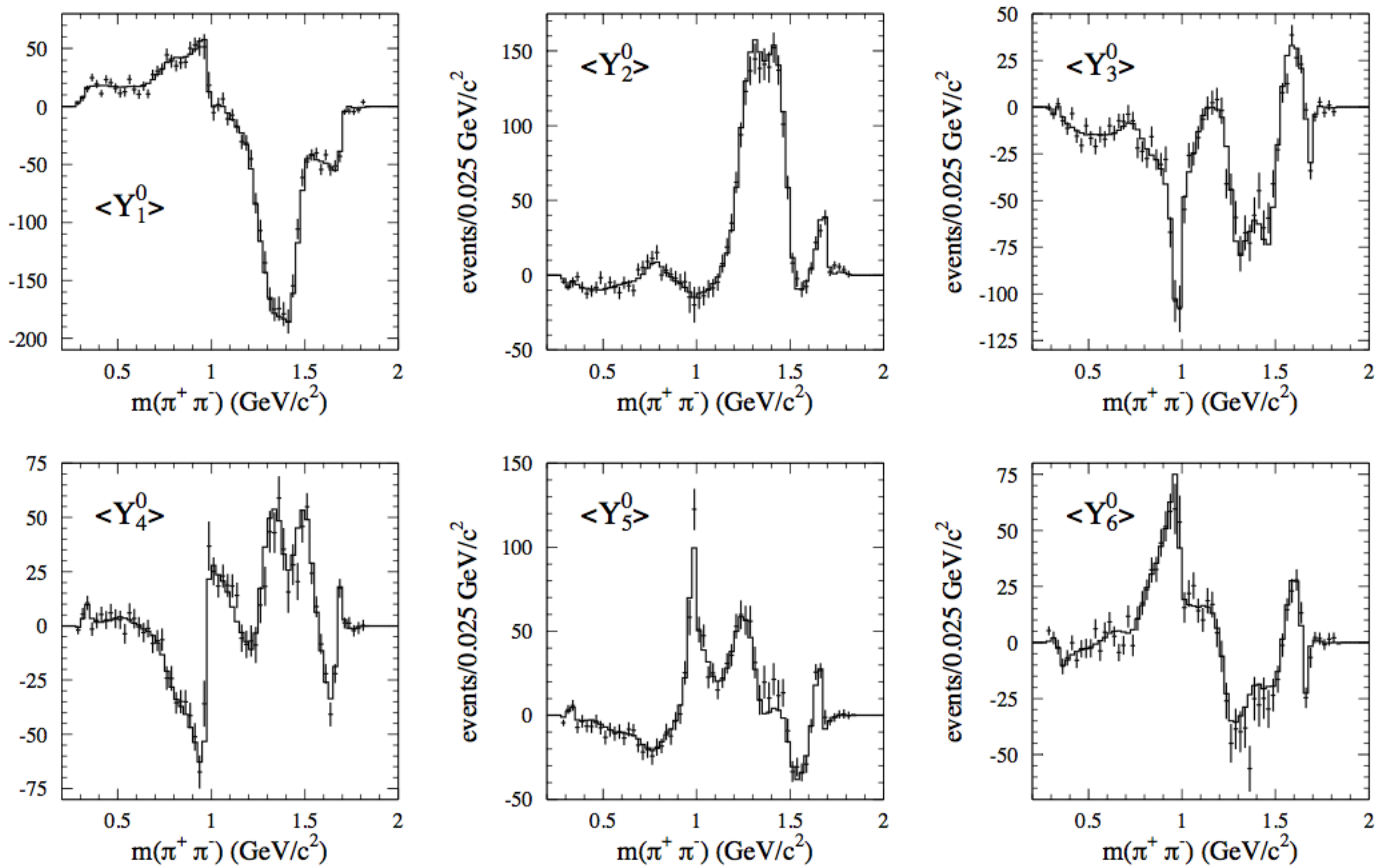
- ππ *S*-wave cannot be modeled as sum of resonances
- Instead use MIPWA, as introduced by E791
- Split the mass range into 29 slices with free complex amplitudes at each boundary
- Interpolate within slice



Dalitz Plot Projections



Dalitz Plot m($\pi^-\pi^+$)Moments



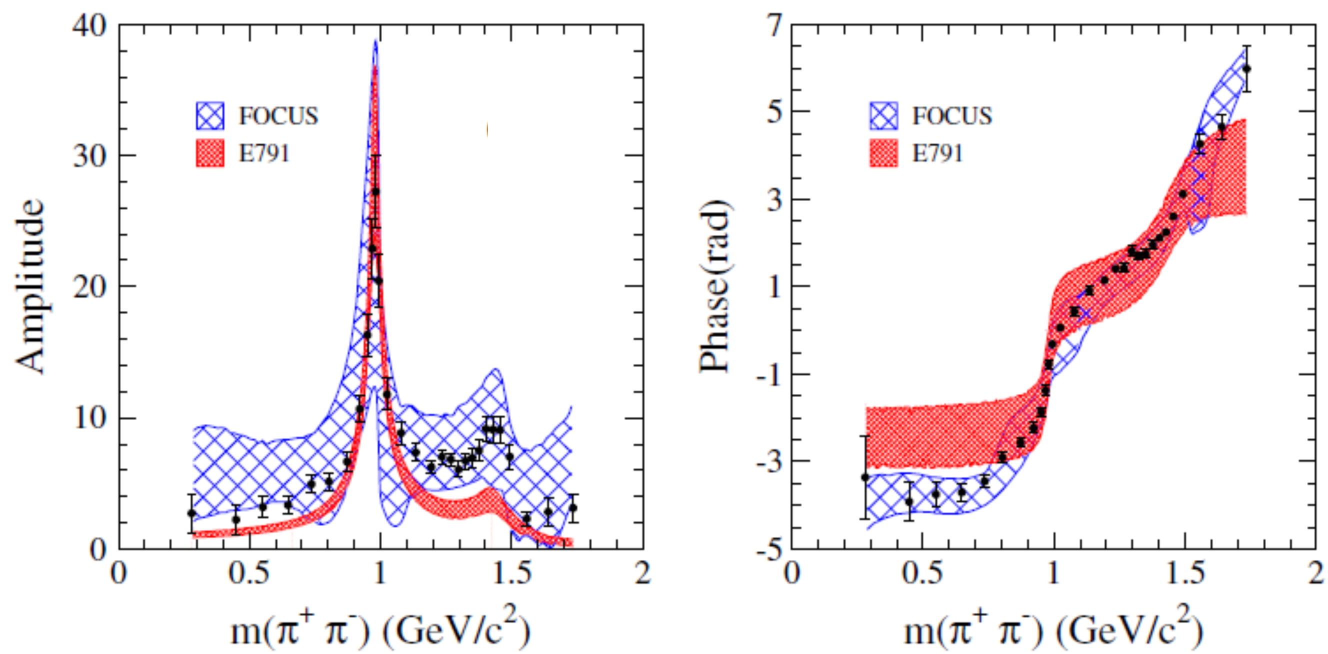
Dalitz Plot Results

- χ^2/DOF = 437/(422-64)
- Interesting to compare different *S*-wave modeling from E791 (sum of BW's) and FOCUS (K Matrix formalism)
- Large *S*-wave component
- Significant $f_2(1270)$

		E687	E791	FOCUS
No. Events	13k	0.1k	0.6k	1.5k
Decay Mode	Fraction(%)	Fraction(%)	Fraction(%)	Fraction(%)
$f_2(1270)\pi^+$	$10.1 \pm 1.5 \pm 1.1$	14.7 ± 5.3	$19.7 \pm 3.3 \pm 0.6$	$9.74 \pm 4.49 \pm 2.63$
$\rho(770)\pi^+$	$1.8 \pm 0.5 \pm 1.0$	—	$5.8 \pm 2.3 \pm 3.7$	—
$\rho(1450)\pi^+$	$2.3 \pm 0.8 \pm 1.7$	—	$4.4 \pm 2.1 \pm 0.2$	$6.56 \pm 3.43 \pm 3.37$
S-wave	$83.0 \pm 0.9 \pm 1.9$	"118.9 ± 14.5"	"$89.4 \pm 13.4 \pm 8.3$"	$87.04 \pm 5.60 \pm 4.17$
TOT.	$97.2 \pm 3.7 \pm 3.8$	133.6 ± 19.8	$119.3 \pm 21.1 \pm 12.8$	$103.34 \pm 13.52 \pm 10.17$

S-wave Comparison

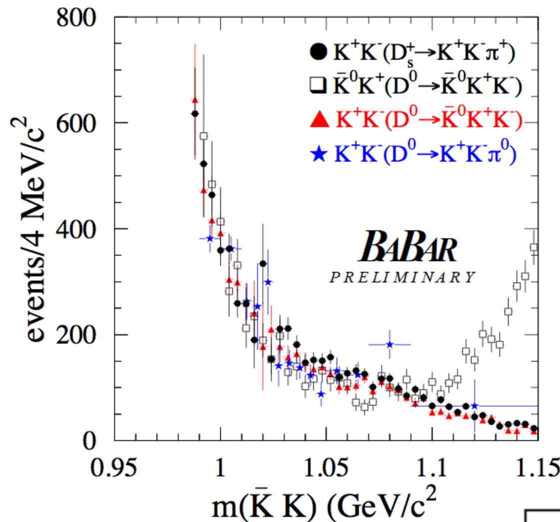
- As expected for $f_0(980)$
- Activity at $f_0(1370)$ and $f_0(1520)$
- Small in $f_0(600)$ region

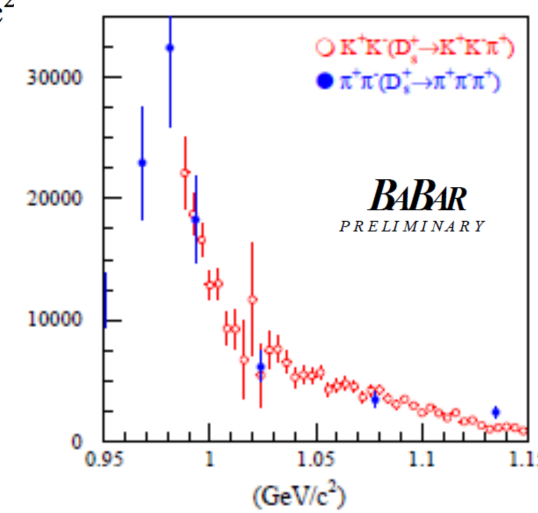


Conclusions

- Dalitz plot analyses yield information on structure of scalar mesons
- Striking agreement in KK *S*-wave between f_0 and a_0 modes.
- Agreement between K^+K^- and $\pi^+\pi^-$ *S*-waves
- Could they be 4-quark modes*?

***L. Maiani, A. D. Polosa, and V. Riquer, Phys. Lett.B651, 129 (2007)**



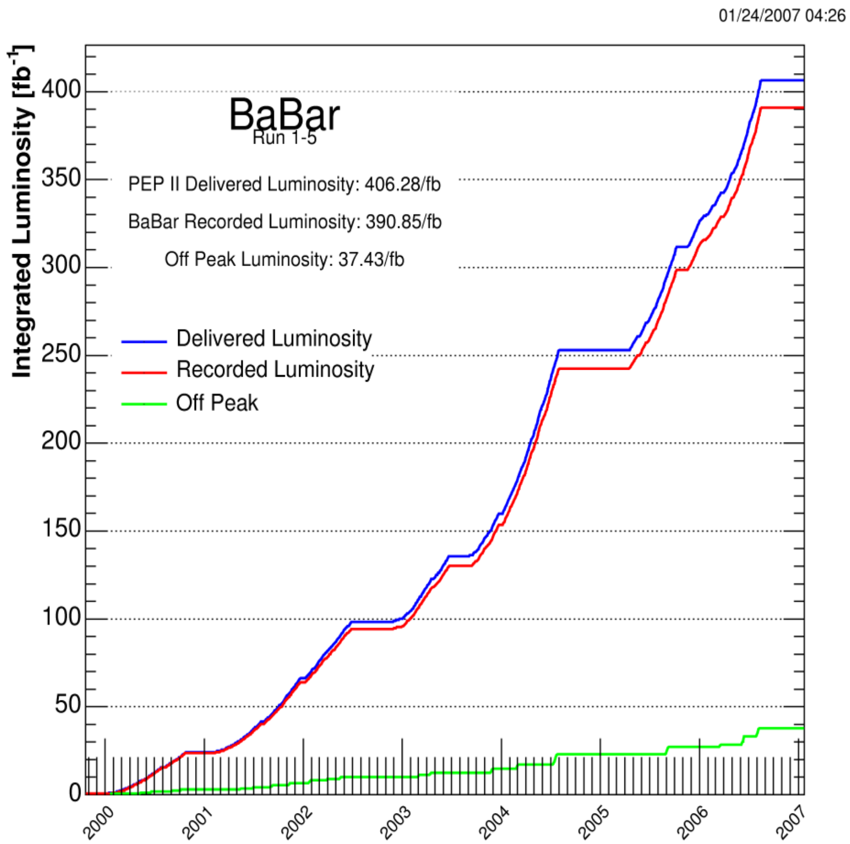


Backup Slides

PEP-II

- Asymmetric storage rings operating near $\Upsilon(4s)$ resonance
- Peak luminosity 1.21×10^{34} cm^2/s =12 nb^{-1}/s = 1 fb^{-1}/day
- Produces B's in flight with <|Δz|> = 250 μm
- Finished data-taking April '08

Process	effective σ (nb)
e+e-→bb	1.1
e+e- →cc	1.3
e+e- →qq (q=u,d,s)	~2.1
e+e- →$\tau^+\tau^-$	0.9



Total Luminosity Recorded=530.82 fb^{-1}

BaBar

- 5-layer Silicon Vertex Detector
- 40-layer Drift Chamber for p_t and dE/dx
- Fused Silica Cherenkov Detector for charged particle PID
- CsI (Tl) calorimeter for neutral reconstruction
- Instrumented flux return for muon and K_L ID