Studies of D_s decays at BaBar

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On behalf of the BaBar Collaboration

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Outline

- Absolute Branching Fractions Measurement
  - $D_s^+ \to \ell^+\nu_\ell$ (ℓ = e, μ, τ)
  - Extraction of the Decay Constant f_{Ds}
  - $D_s^+ \to K^+ K^- \pi^+$

Preliminary

NEW

- Amplitude Analysis of D_s decay:
  - $D_s^+ \to K^+ K^- \pi^+$ Preliminary NEW
  - $D_s^+ \to \pi^+ \pi^- \pi^+$ Phys.Rev.D79:032003,2009

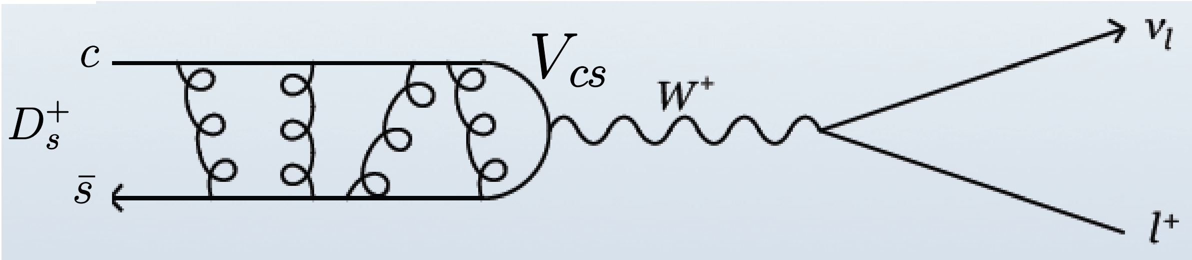
521 fb^{-1}

Preliminary

Absolute Branching Fractions Measurement

Motivation

The measurement of the leptonic decay relative branching fraction can be used to measure the decay constant f_{Ds}

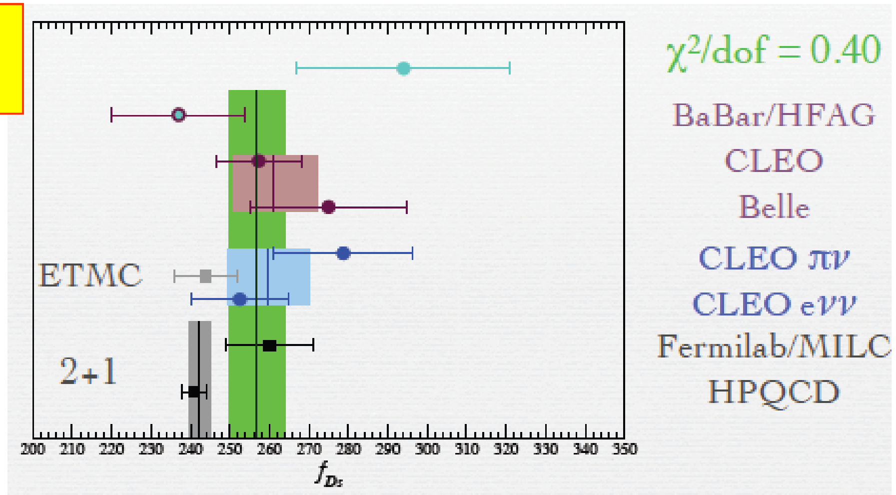


$$\Gamma = \frac{G_F^2 M_{D_s^+}^3}{8\pi} \left(\frac{m_\ell}{M_{D_s^+}} \right)^2 \left(1 - \frac{m_\ell^2}{M_{D_s^+}^2} \right)^2 |V_{cs}|^2 f_{D_s}^2$$

The global average(HFAG) and the recent unquenched lattice QCD expectations show some disagreement

- New physics could include:
  - Charged Higgs boson propagator.
  - Leptoquarks.
  - SUSY...

New preliminary results presented at FPCP2010
- **Fermilab/MILC(2010): f_{Ds} = 261.4 ± 9.2**
- **HPQCD(2010): f_{Ds} = 247 ± 2**

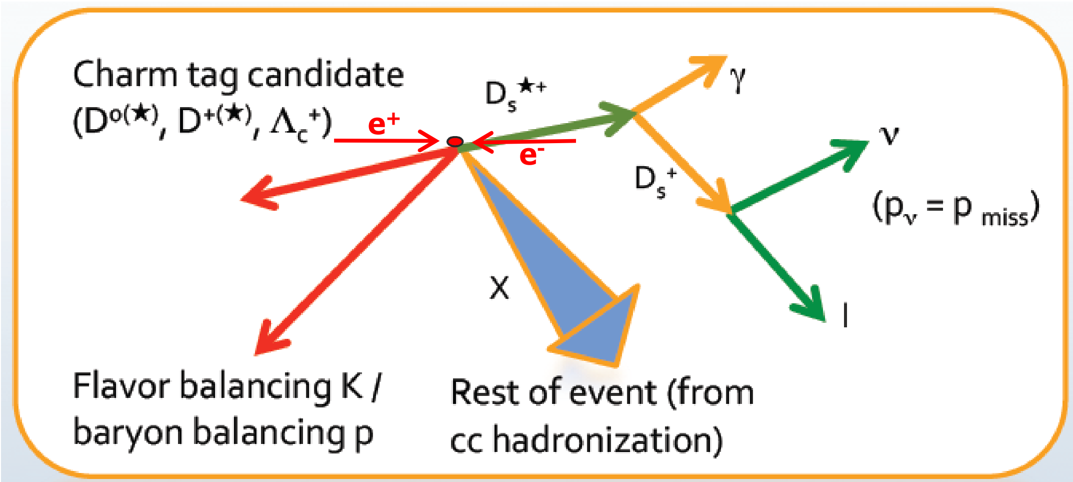


Analysis strategy

- **Inclusive D_s candidates**
  - **The signal consists of D_s^* candidates decaying to $D_s\,\gamma$**
  - **The D_s candidate is reconstructed from the four-momentum recoiling against the DKXγ ($D = D^{0(*)}$, $D^{+(*)}$, Λ_c^+; $K = K_s$, K^+,(p); $X = \pi^+$, π^0)**
- **Within this sample, the $D_s^+ \to \ell^+ \nu_\ell$ (ℓ = e, μ, τ) events are selected**
  - **One more track, identified as e/μ, is required**

Yields corrected by efficiency to obtain the branching fractions:

$$B(D_s^+ \to l\nu) = \frac{N(D_s^+ \to l\nu)}{N(D_s^+)\varepsilon_{l\nu}}$$



Fully Inclusive D_s Sample

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Most Relevant Selection criteria:

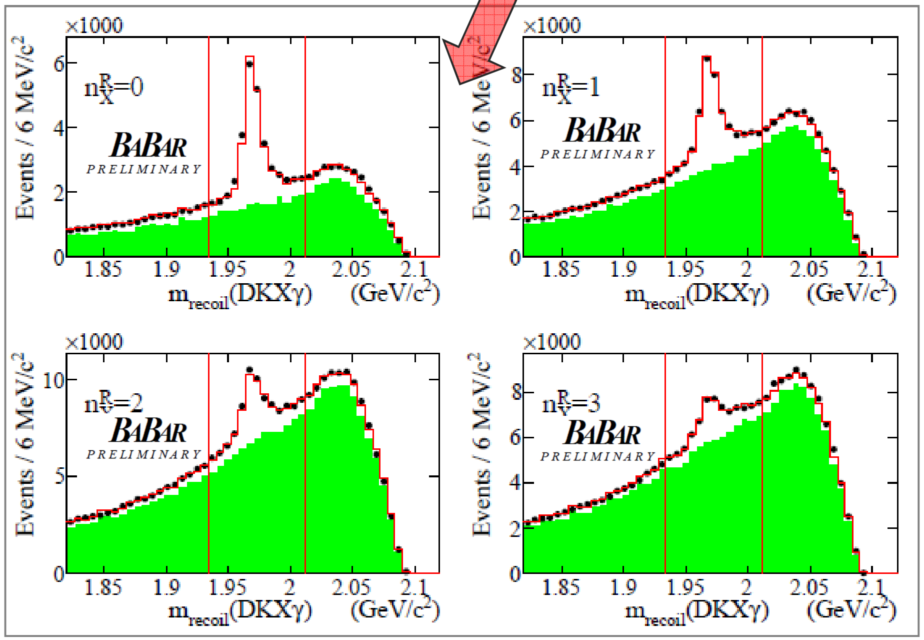
- $p^*(D_s) > 3.0$ GeV/c
- $m_{recoil}(DKX)$ within ~2.5σ of the D_s^* PDG mass value
- $E_\gamma > 120$ MeV + π^0 and η vetoes

N.B.

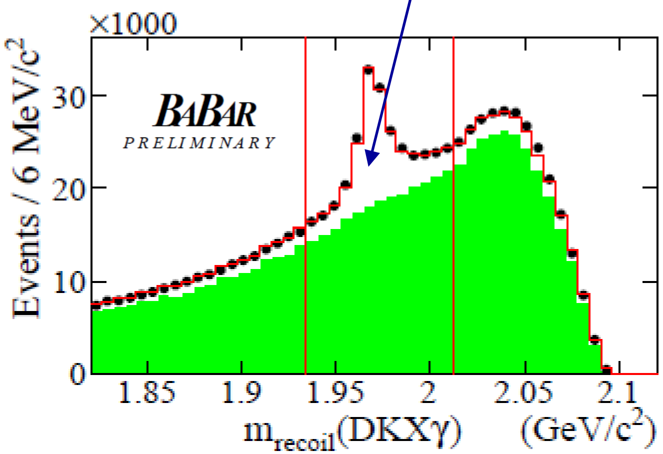
$m_{recoil}(DKX) \equiv m(D_s^*)$

$m_{recoil}(DKX\ \gamma) \equiv m(D_s)$

Result of 2D fit $m_{recoil}(DKX\ \gamma)$ vs. n^R_x (n^R_x = Number of reconstructed pions in X system)



Total



Results

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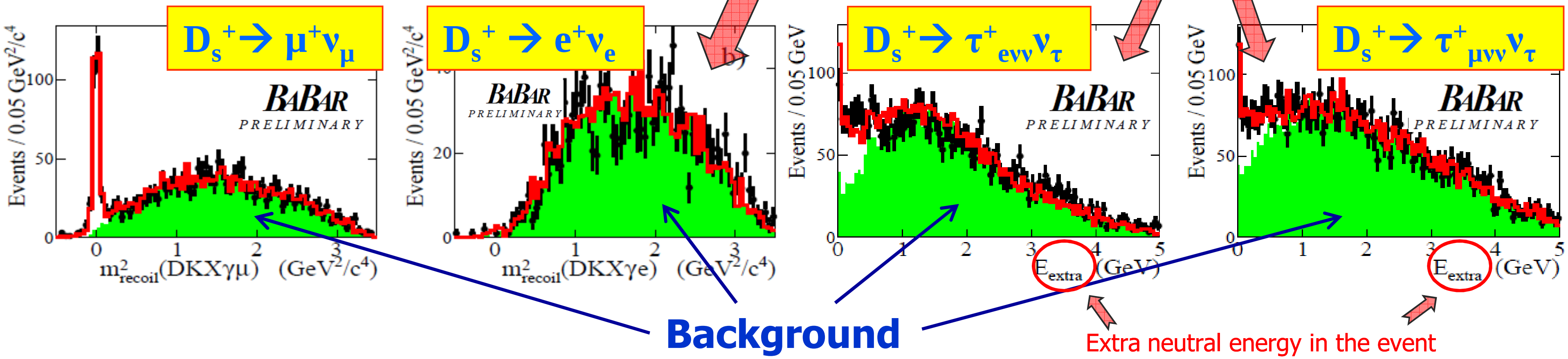
Helicity Suppressed

PHSP Suppressed



Decay	Signal Yield	$\mathcal{B}(D_s^+ \to \ell^+\nu_\ell)$	f_{D_s} (MeV)
$D_s^+ \to e^+\nu_e$	$6.1 \pm 2.2 \pm 5.2$	$< 2.3 \times 10^{-4}$ at 90% C.L.	
$D_s^+ \to \mu^+\nu_\mu$	275 ± 17	$(6.02 \pm 0.38 \pm 0.34) \times 10^{-3}$	$265.7 \pm 8.4 \pm 7.7$
$D_s^+ \to \tau^+_{e\nu\nu}\nu_\tau$	408 ± 42	$(5.07 \pm 0.52 \pm 0.68) \times 10^{-2}$	$247 \pm 13 \pm 17$
$D_s^+ \to \tau^+_{\mu\nu\nu}\nu_\tau$	340 ± 32	$(4.91 \pm 0.47 \pm 0.54) \times 10^{-2}$	$243 \pm 12 \pm 14$

Normalization mode of many D_s decays!

The hadronic $D_s^+ \to K^+K^-\pi^+$ used to cross-check the method

$$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.78 \pm 0.20(\text{stat}) \pm 0.30(\text{syst}))\%$$

$$f_{D_S} = (258.6 \pm 6.4(\text{stat}) \pm 7.5(\text{syst}))\ \text{MeV}$$

Very Competitive Measurements!

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Preliminary

$D_s^+ \rightarrow K^+K^-\pi^+$ & $D_s^+ \rightarrow \pi^+\pi^-\pi^+$ Dalitz Plot Analysis

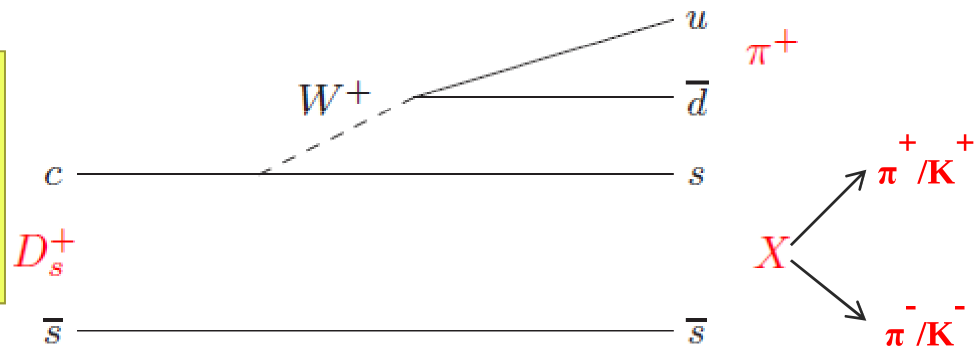
Motivation

Scalar meson candidates are too numerous to fit in a single $q\bar{q}$ nonet. Some of them may be multiquark, glueball, meson-meson bound state etc….

Charm meson decays are a powerful tool for investigating light quark spectroscopy:

- Large coupling to scalar mesons
- An initial state well defined $J^P = 0^-$
- Final spectrum not constrained by isospin and parity conservation

The $f_0(980)$ has still uncertain parameters and interpretations because is just sitting at the $K\bar{K}$ threshold and strongly coupled to the $K\bar{K}$ and $\pi\pi$ final states



PDG08

$I^G(J^{PC}) = 0^+(0^{++})$

See also the minireview on scalar mesons .

Mass m = 980 ± 10 MeV

Full width Γ = 40 to 100 MeV

$D_s^+ \to K^+K^-\pi^+$, and $D_s^+ \to \pi^+\pi^-\pi^+$ decays provide a way to study the coupling of $f_0(980)^\dagger$ to K^+K^- and $\pi^+\pi^-$ systems

$^\dagger a_0(980) \to K^+K^-$ may be contribute as well

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

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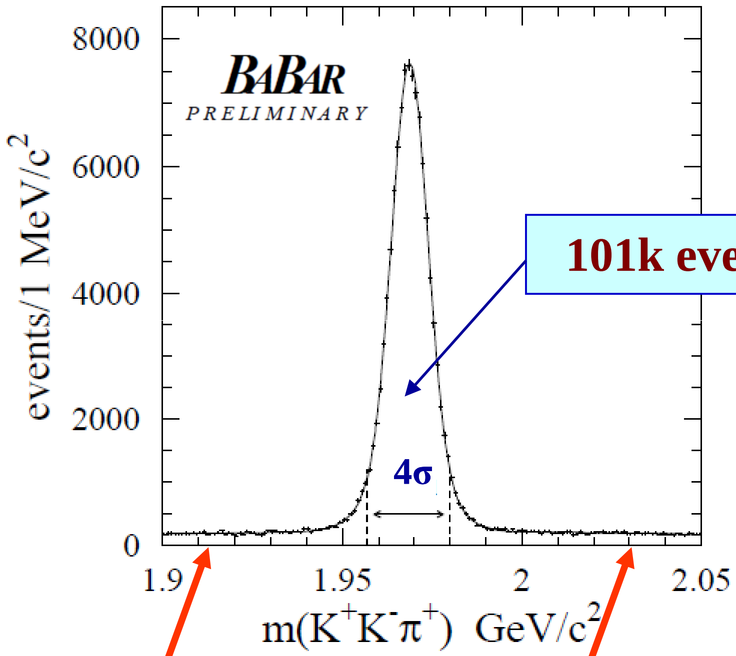
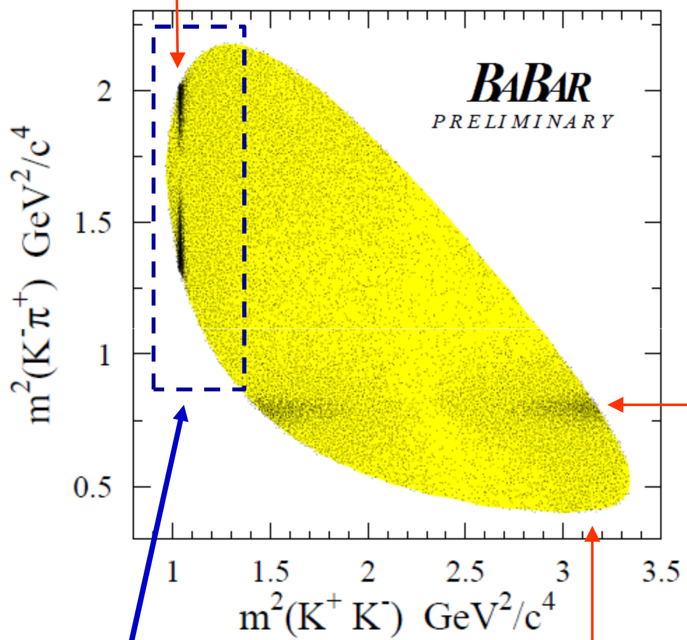
Inclusive D_s sample obtained with a likelihood selection using vertex separation and p*



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



- No *D*-wave in K^+K^-
- No $K^-\pi^+$ structure but a small $K^*_0(1430)$(~2%)

Partial Wave Analysis

Partial Wave Analysis at K^+K^- threshold

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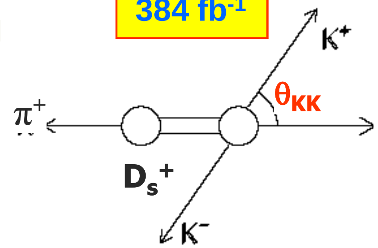
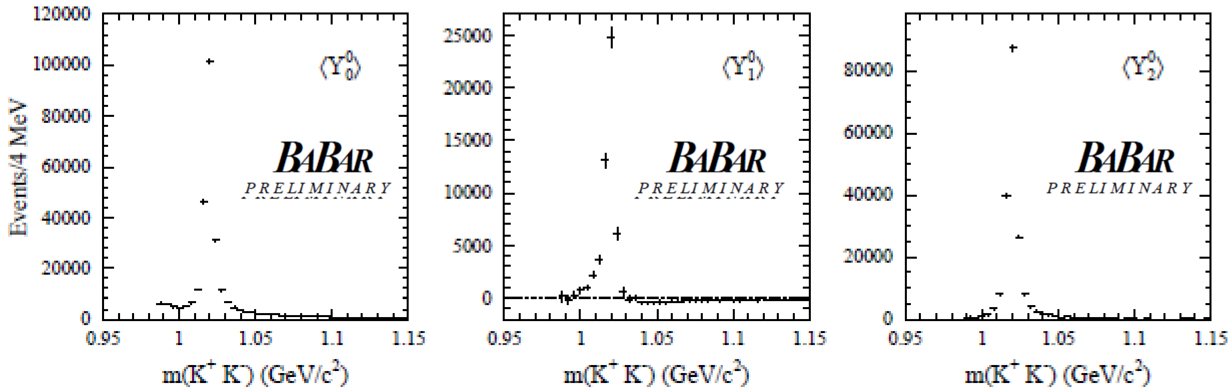
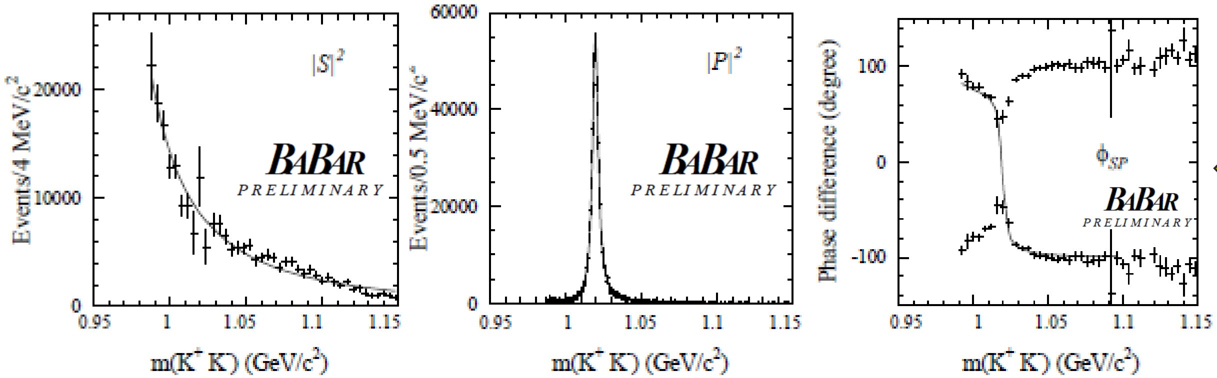


Events weighted by the spherical harmonic $Y^0_\ell(\cos\theta_{KK})(\ell=0,1,2)$



- **Background subtracted**
- **Efficiency corrected**
- **Phase space corrected**

$$
\begin{aligned}
\sqrt{4\pi}\,\langle Y^0_0\rangle &= \mathcal{S}^2+\mathcal{P}^2\\
\sqrt{4\pi}\,\langle Y^0_1\rangle &= 2\,|\mathcal{S}|\,|\mathcal{P}|\cos\phi_{\mathcal{SP}}\\
\sqrt{4\pi}\,\langle Y^0_2\rangle &= \frac{2}{\sqrt{5}}\mathcal{P}^2
\end{aligned}
$$



We extract a phenomenological description of the *S*-wave to be used in the DP analysis

Solid line is the result of a binned fit (Breit-Wigner for the *P*-wave and a "Breit-Wigner like" function for the *S*-wave)

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

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Reference Mode

Results of an unbinned maximum likelihood fit

Decay Mode	*BABAR*	E687	CLEO-c
$\overline{K}^*(892)^0K^+$	$47.9 \pm 0.2 \pm 0.5$	$47.8 \pm 4.6 \pm 4.0$	$47.4 \pm 1.5 \pm 0.4$
$\overline{K}_0^*(1430)K^+$	$2.4 \pm 0.3 \pm 1.$	$9.3 \pm 3.2 \pm 3.2$	$3.9 \pm 0.5 \pm 0.5$
$\phi(1020)\pi^+$	$41.4 \pm 0.2 \pm 0.5$	$39.6 \pm 3.3 \pm 4.7$	$42.2 \pm 1.6 \pm 0.3$
$f_0(980)\pi^+$	$16.4 \pm 0.3 \pm 2.0$	$11.0 \pm 3.5 \pm 2.6$	$28.2 \pm 1.9 \pm 1.8$
$f_0(1370)\pi^+$	$1.1 \pm 0.3 \pm 0.2$	—	$4.3 \pm 0.6 \pm 0.5$
$f_0(1710)\pi^+$	$1.1 \pm 0.1 \pm 0.1$	$3.4 \pm 2.3 \pm 3.5$	$3.4 \pm 0.5 \pm 0.3$
$\sum$ 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

- **$K^*(892)^0$ mass and width are floated parameters**
- **$f_0(980)$ parameterized by the effective parameterization extracted by the PWA**
- **χ^2 computed by an adaptive binning algorithm**

- **Decay dominated by vector intermediated resonances**
- **The total fit fraction closer to 1, due to $f_0(980)$ parameterization adopted**
- **$K^*(892)^0$ width is 5 MeV lower then PDG08(consistent with CLEO-c analysis)**
- **Contribution from $K^*_1(1410)$, $K_2(1430)$, κ(800), $f_0(1500)$, $f_2(1270)$, $f_2'(1525)$ consistent with zero**

Fit result projections

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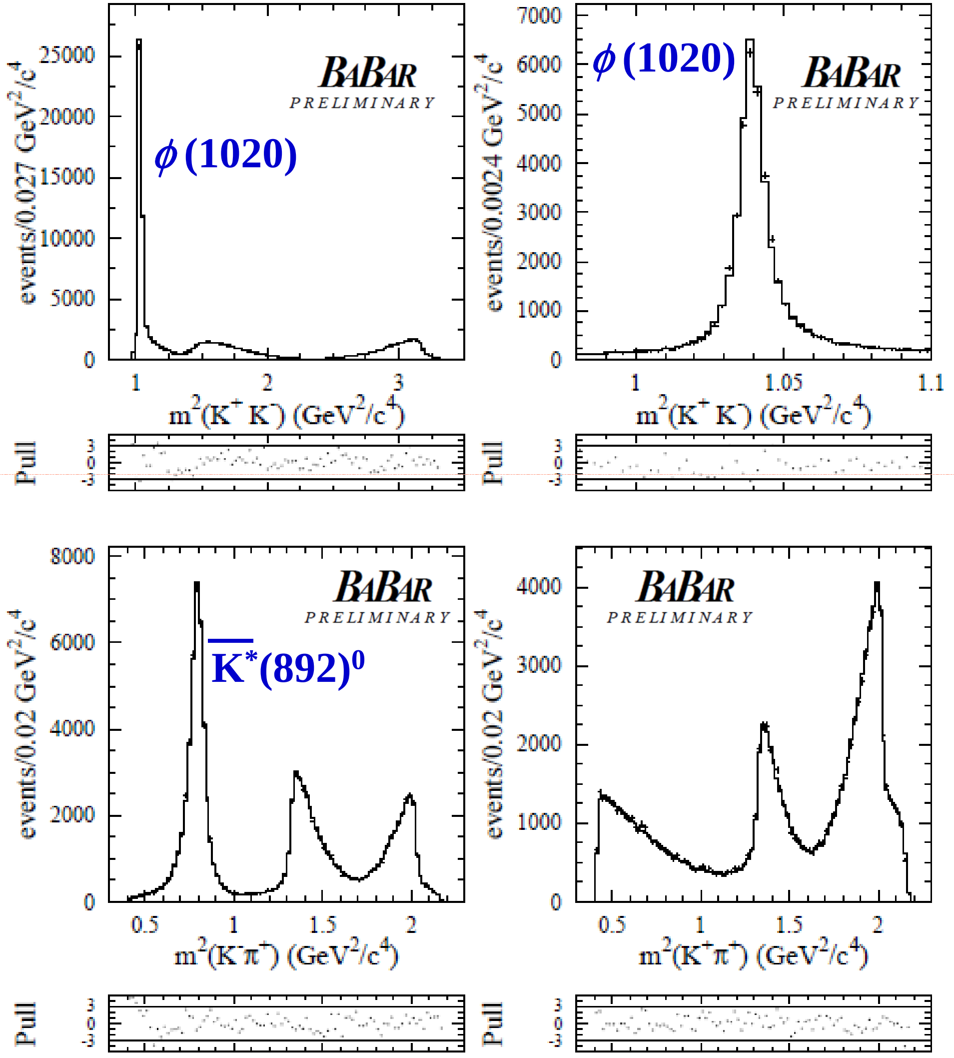
The data are well reproduced in all the projections



$\chi^2/\nu=1.24$

Relative Branching Ratios

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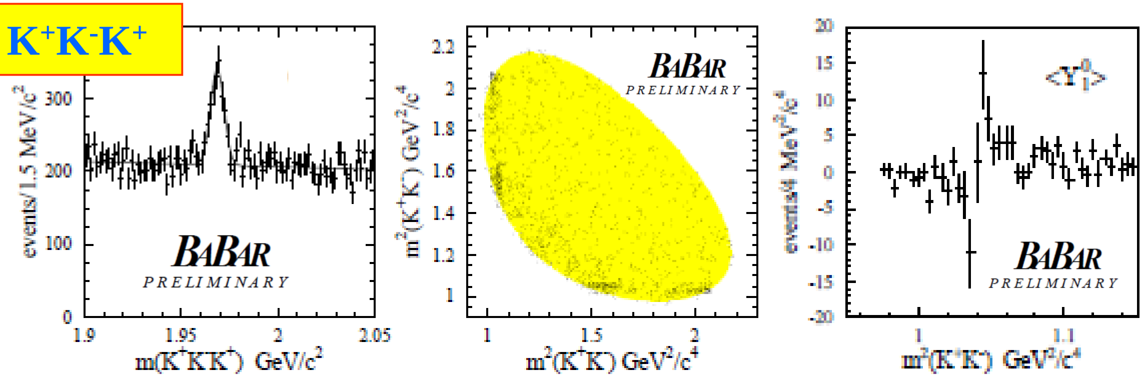
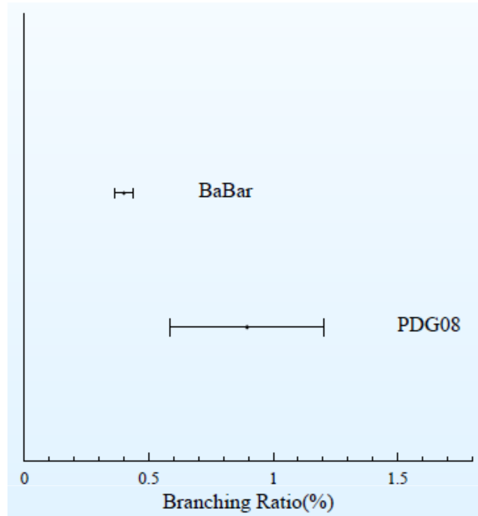
SCS

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

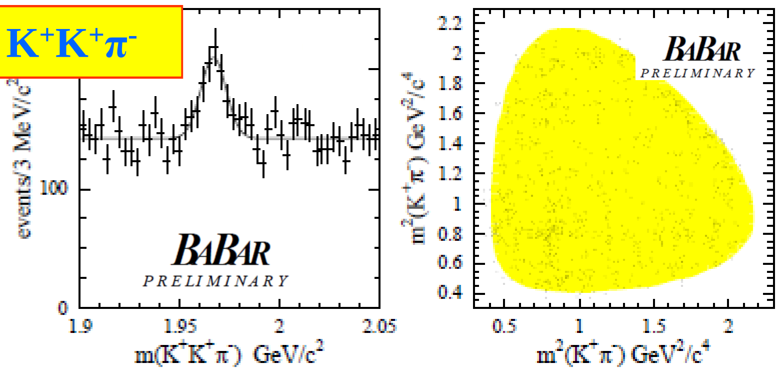


$$\frac{\mathcal{B}(D_s^+ \to K^+K^-K^+)}{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)} = (4.0 \pm 0.3_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}}) \times 10^{-3}$$

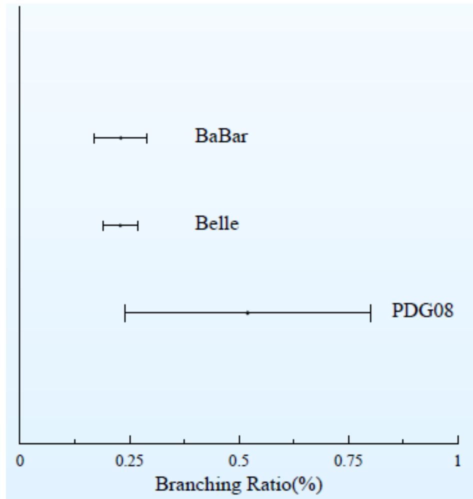


DCS

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



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



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

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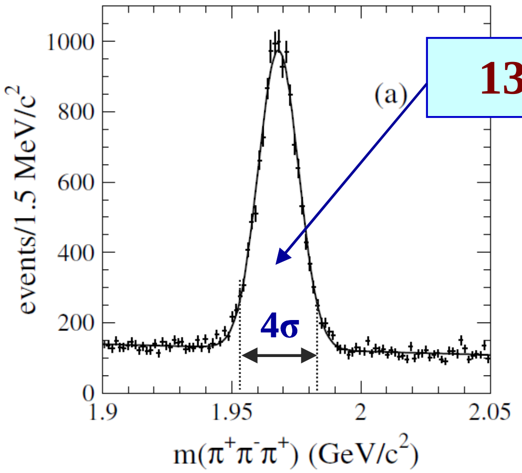
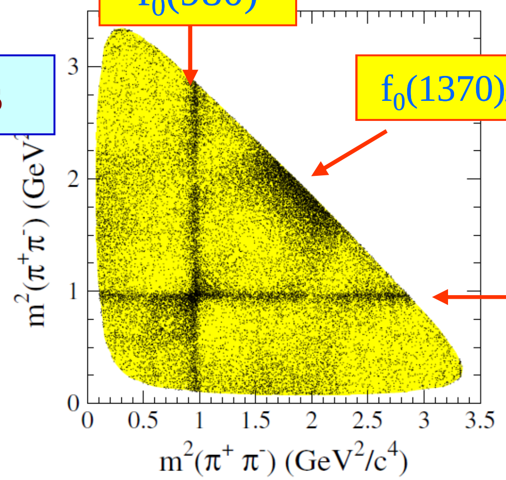
Phys.Rev.D79:032003,2009





$\chi^2/\nu=437/(422-64)=1.2$

Results of an unbinned maximum likelihood fit

Reference Mode

		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	$19.7 \pm 3.3 \pm 0.6$	$9.74 \pm 4.49 \pm 2.63$
$\rho(770)\pi^+$	$1.8 \pm 0.5 \pm 1.0$	—	$5.8 \pm 2.3 \pm 3.7$	—
$\rho(1450)\pi^+$	$2.3 \pm 0.8 \pm 1.7$	—	$4.4 \pm 2.1 \pm 0.2$	$6.56 \pm 3.43 \pm 3.37$
$\mathcal{S}$-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	$119.3 \pm 21.1 \pm 12.8$	$103.34 \pm 13.52 \pm 10.17$

Model Independent Partial Wave Analysis

Sum of BW's

K-matrix Formalism

- ***S*-wave is the main contribution**
- **Large $f_2(1270)$ contribution**
- **Small ρ's fit fractions**

$\pi^+\pi^-$ *S*-wave

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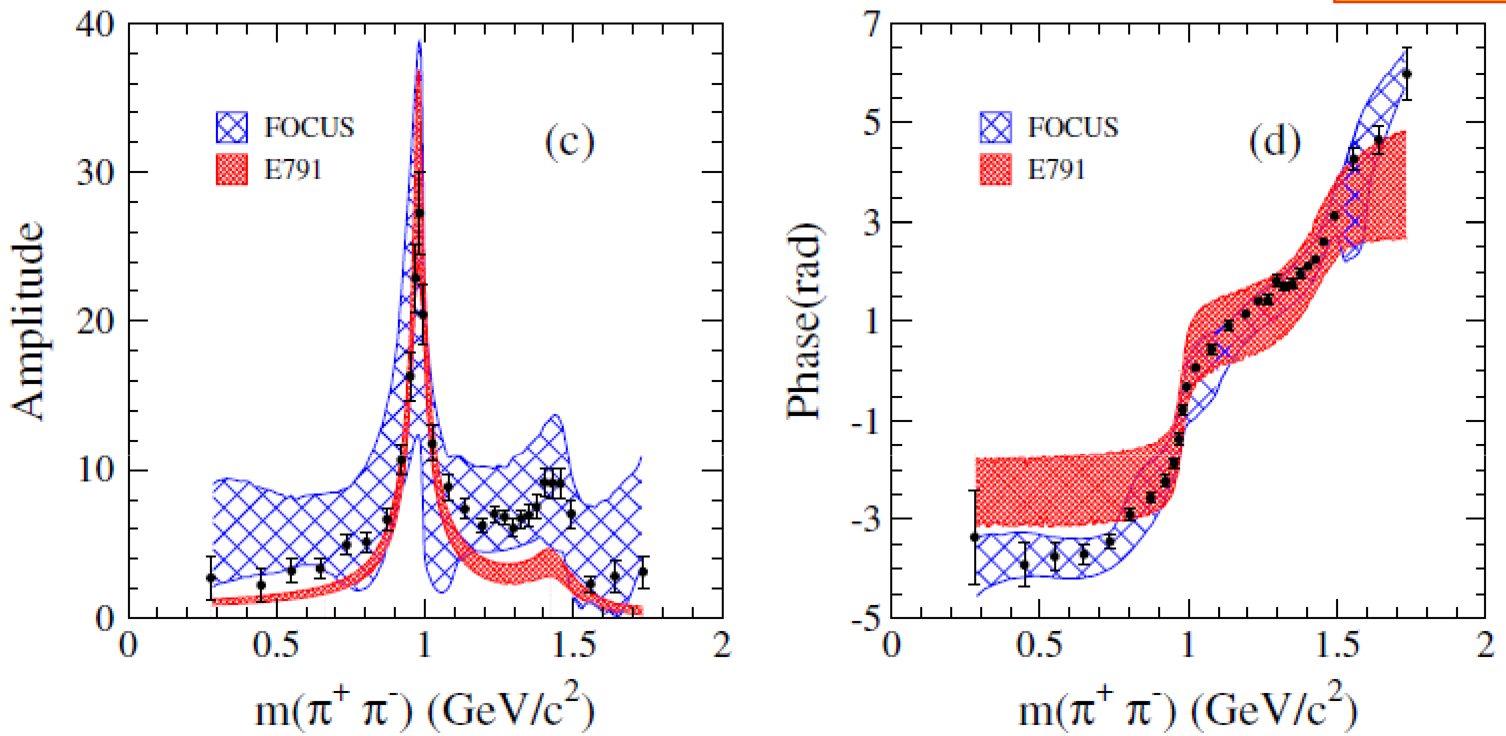
Phys.Rev.D79:032003,2009

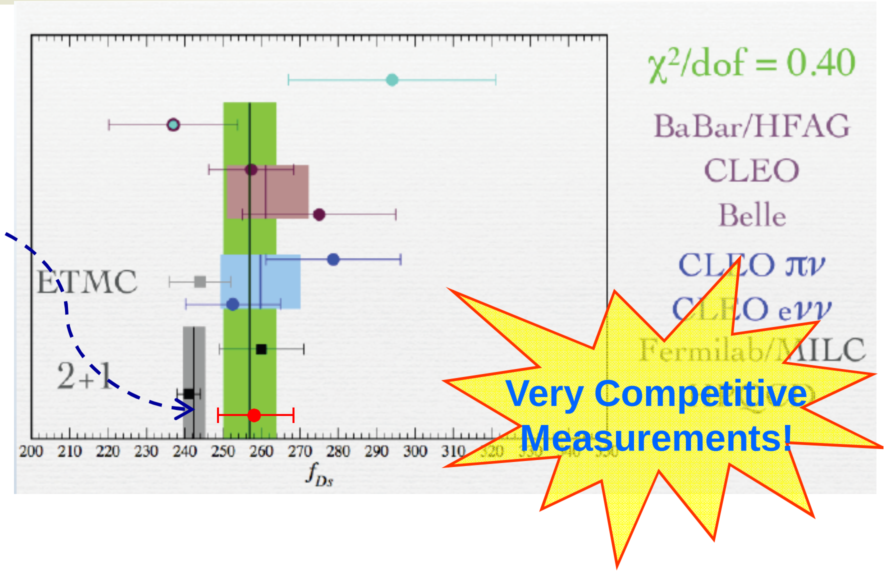


- **The *S*-wave shows in both amplitude and phase the expected behavior for the $f_0(980)$**
- **Activity in the region $f_0(1370)$ and $f_0(1500)$ resonances**
- **The *S*-wave is small in the $f_0(600)$ region**

Summary

Extraction of the Decay Constant f_{D_s}

$$f_{D_S} = (258.6 \pm 6.4(\text{stat}) \pm 7.5(\text{syst}))\,\text{MeV}$$

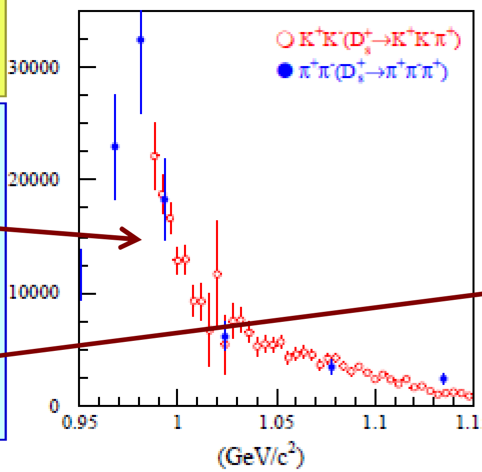


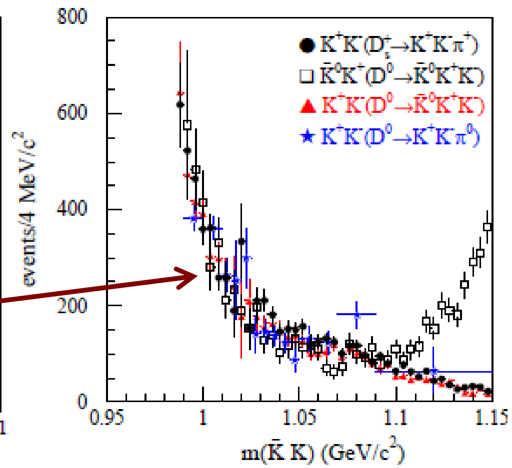
$D_s^+ \to K^+K^-\pi^+$ & $D_s^+ \to \pi^+\pi^-\pi^+$ Dalitz Plot Analysis

K^+K^- and $\pi^+\pi^-$ *S*-waves extracted by a <u>Model Independent</u> way. Opportunity to obtain new information about $f_0(980)$!

Remarks:

- **Agreement between K^+K^- *S*-wave and $\pi^+\pi^-$ *S*-waves despite the interferences with the other scalar mesons (especially in the $\pi^+\pi^-$ system)**
- **Agreement between the $K\bar{K}$ *S*-waves extracted by D^0 and D_s decays. Are $f_0(980)$ and $a_0(980)$ 4-quark states?***





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