Recent Charm Physics from BaBar

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On behalf of the BaBar Colloboration
International Conference on Particle Physics
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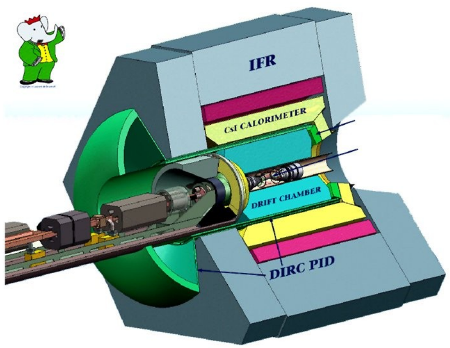
Recent Charm Physics Results from BaBar

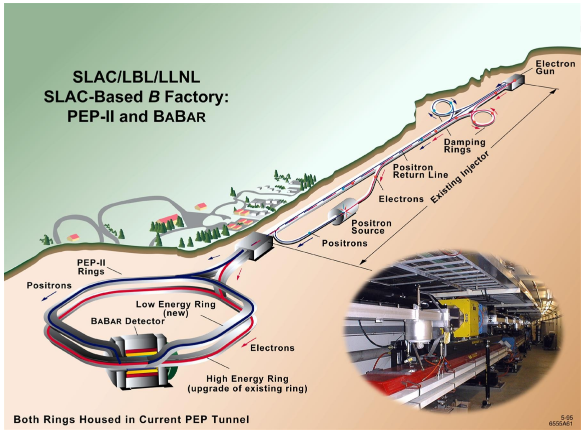
- The BaBar Experiment
- Dalitz plot & Partial Wave Analysis of $D_s^+ \to K^+ K^- \pi^+$
- Absolute Branching Fractions for D_s^- Leptonic Decays and the Decay Constant f_{D_s}
- Evidence of New Resonances decaying to $D\pi$ and $D^*\pi$ in inclusive e^+e^- collisions
- Precision Measurement of the Mass and Width of the $D_{s1}(2536)^+$
- Search for Rare and Forbidden Charm Decays
- Search for CP Violation in 2-Body and 4-Body Charm Decays

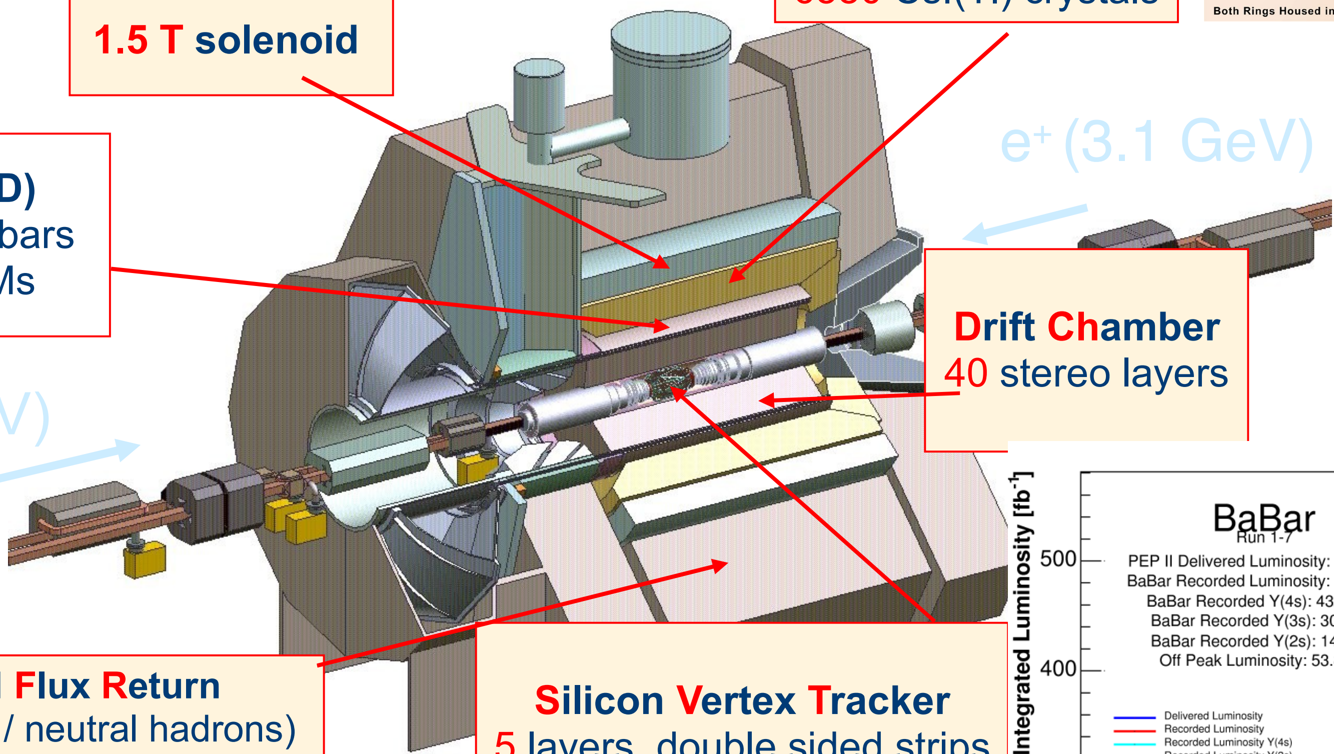


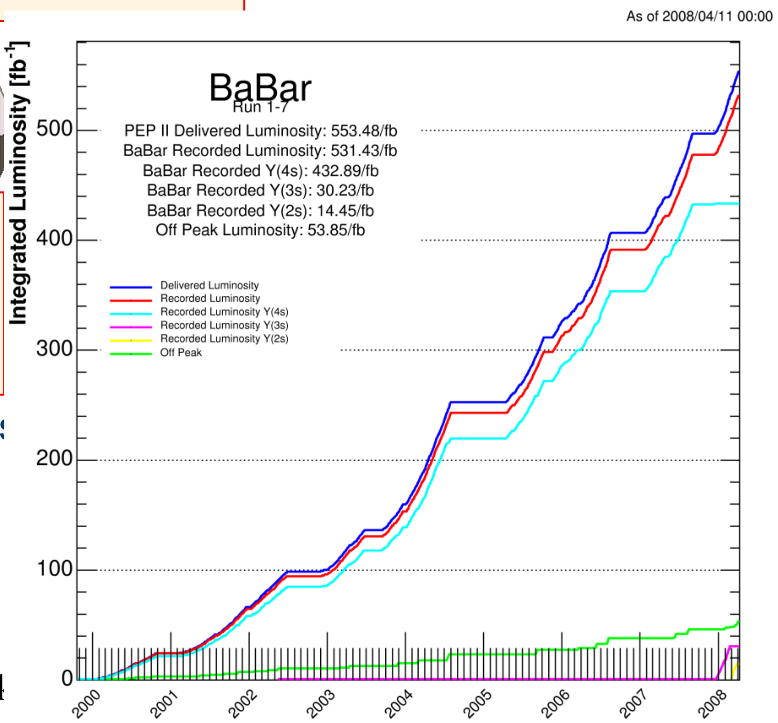
The BaBar Experiment

PEP-II and Stanford Linac

Delivers e^+e^- colliding beams at the collison point inside BaBar







SVT: 97% efficiency, 15 μm z hit resolution (inner layers, perp. tracks

SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$, $\sigma(z_0) = 65$ @ 1 GeV/c

DIRC: K-π separation 4.2 σ @ 3.0 GeV/c → 2.5 σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$

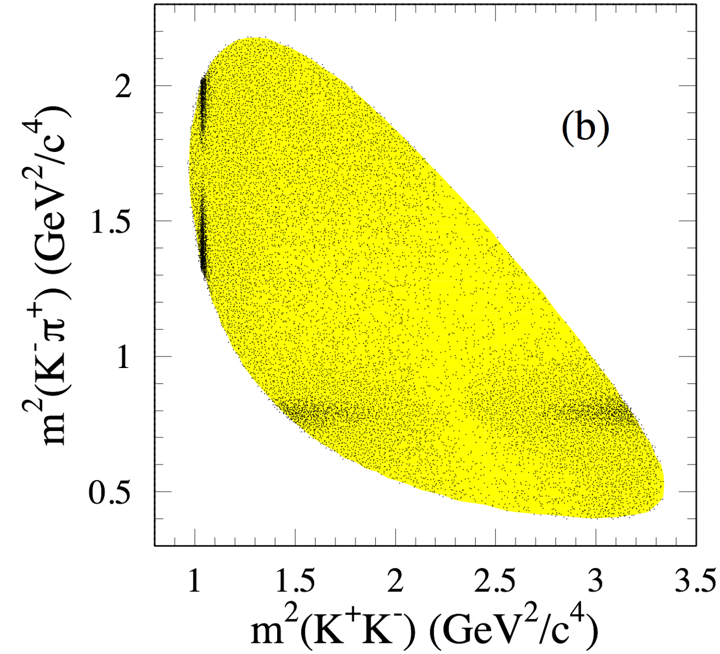
Partial Wave Analysis of D_s^+ to $K^+K^-\pi^+$

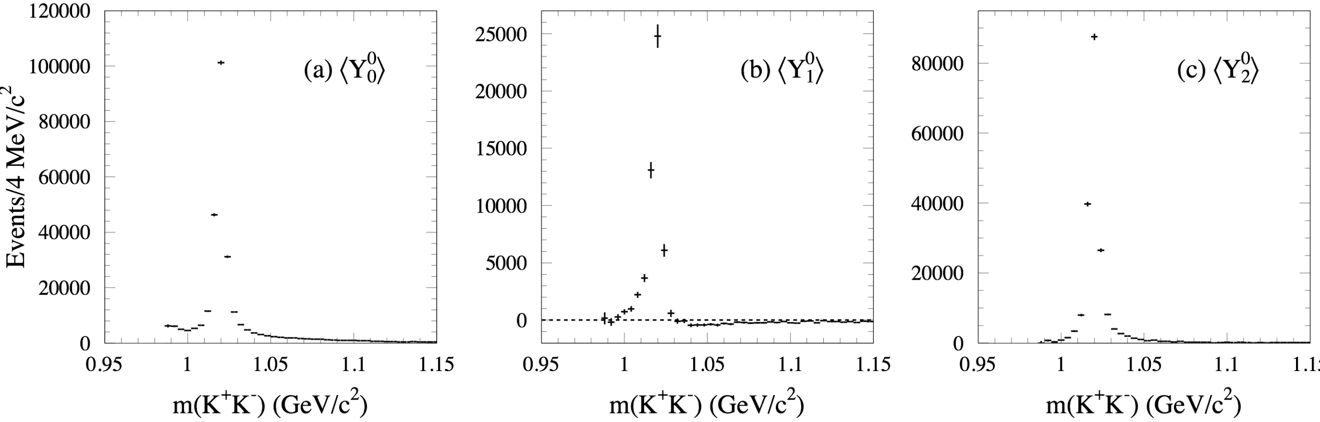
Estimating the S-wave contribution in D_s^+ to $\varphi\pi^+$

→**Analyze K^+K^- distributions weighted by spherical harmonics**

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

Phys. Rev. D 83 052001 (2011)



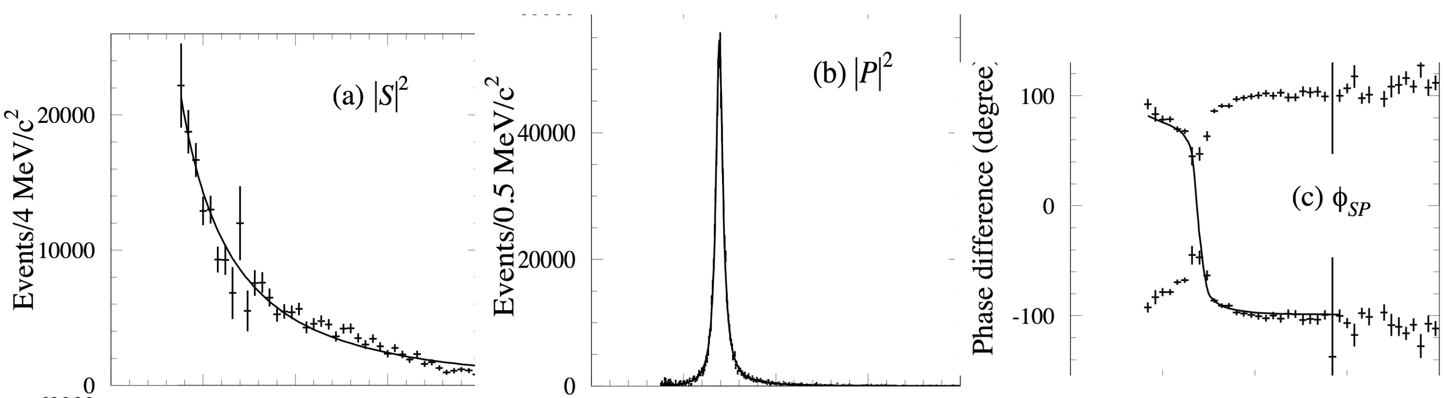


$$f_{S-wave} = \frac{\int |S|^2\,dDP}{\int (|S|^2+|P|^2)\,dDP} \qquad f_{P-wave} = \frac{\int |P|^2\,dDP}{\int (|S|^2+|P|^2)\,dDP}$$

$m_{K^+K^-}$ (MeV/c^2)	$f_{S-\text{wave}}$ (%)	$f_{P-\text{wave}}$ (%)	$\frac{N}{N_{\text{tot}}}$ (%)
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

Extracting the S-wave line-shape

→Simultaneous binned fit of $|S|^2$, $|P|^2$, and $\cos(\theta_S-\theta_P)$



$$A_{f_0(980)} = \frac{1}{m_0^2 - m^2 - i\,m_0\Gamma_0\rho_{KK}}$$
$$\rho_{KK} = p/m$$
$$m_0 = 0.922 \pm 0.003\ GeV/c^2$$
$$\Gamma_0 = 0.24 \pm 0.08\ GeV$$

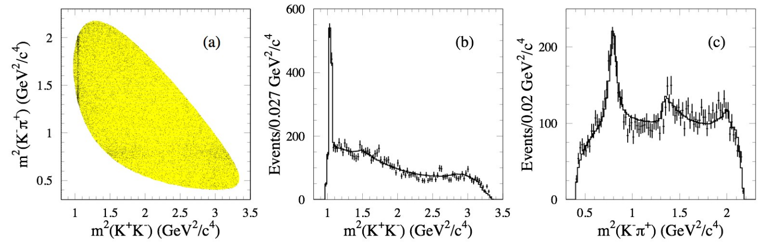
Dalitz plot Analysis of D_s^+ to $K^+K^-\pi^+$

Phys. Rev. D 83 052001 (2011)

Purity

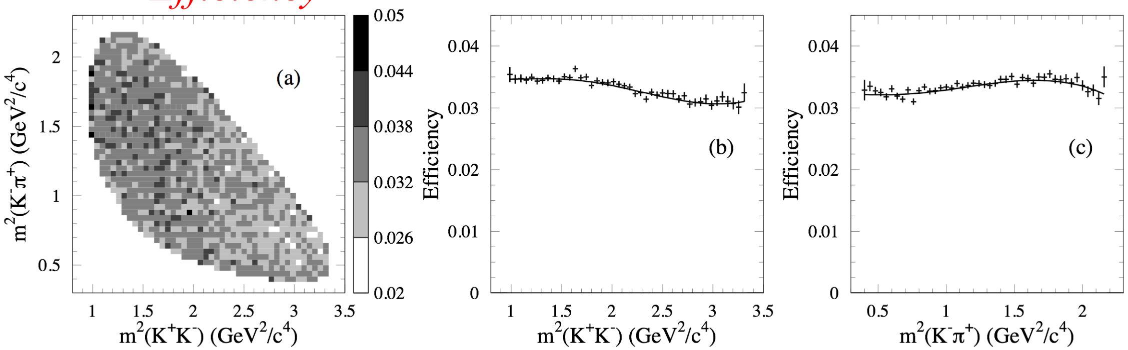
Dalitz Plot Model

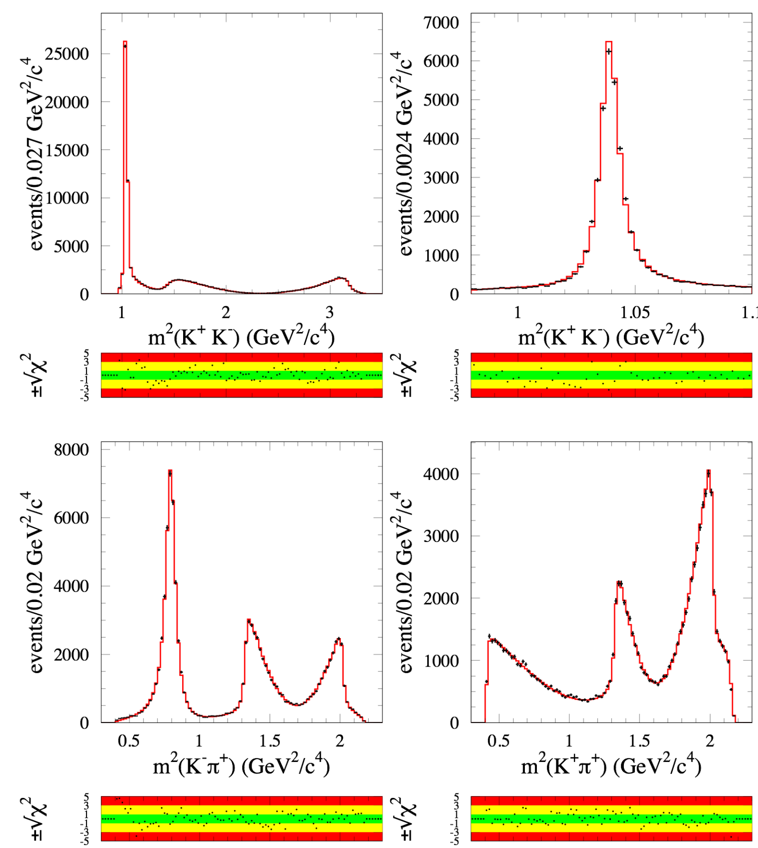
$$L=\prod_{Events}\left[x(M_{D_s})\,\eta(m_1^2,m_2^2)\frac{\sum_{i,j}c_i c_j^* A_i A_j^*}{\sum_{i,j}c_i c_j^* I_{A_i A_j^*}}+[1-x(M_{D_s})]\frac{\sum_i k_i^2 B_i B_i^*}{\sum_i k_i^2 I_{B_i B_i^*}}\right]$$



Efficiency

Background modeled from sideband data





Dalitz Plot Model

$f_0(1710)$, $\varphi(1020)$, $K^{*0}(1430)$: Rel. Breit Wigner

$f_0(980)$: Effective parameterization from PWA

$f_0(1370)$, $K^{*0}(892)$: Rel. Breit Wigner floated mass and widths

Results

χ^2/NDF = 1.2

m($f_0(1370)$) = 1.22 +/- 0.01 +/- 0.04 GeV/c^2

Γ($f_0(1370)$) = 0.21 +/- 0.02 +/- 0.03 GeV/c^2

m($K^{*0}(892)$) = 0.8956 +/- 0.0007 +/- 0.0003 GeV/c^2

Γ($K^{*0}(892)$) = 0.0451 +/- 0.0008 +/- 0.0004 GeV/c^2

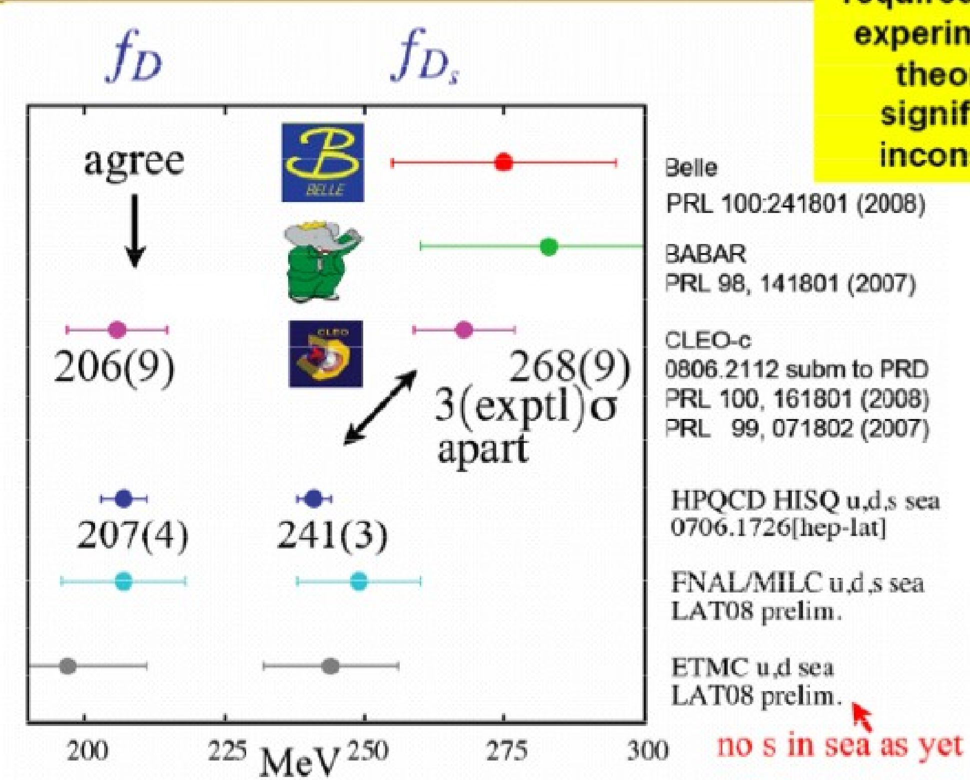
Absolute Branching Fractions for D_s^- Leptonic Decays and the Decay Constant f_{D_s}

Phys. Rev. D 82 091103(R) (2010)

- Leptonic decays of pseudoscalar mesons provide ideal environment to compare Lattice QCD results with experiment.
- Previous measurements from experiment and theory show a 3.8σ disagreement.
- More data, improved systematic uncertainties, and more robust analysis techniques needed.

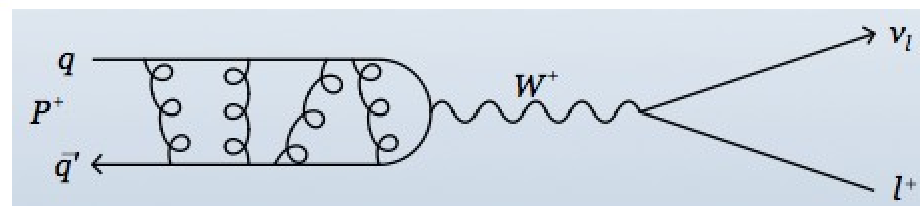
LQCD: f_{Ds} = 241 +/- 3 MeV (2008 prelim. No s in sea!)

From CKM08



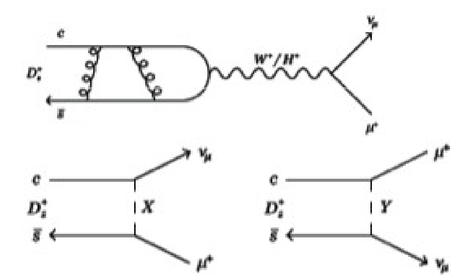
More data required to see if experiment and theory are significantly inconsistent

$$\Gamma(D_s^- \to l^- \bar{\nu}_l) = \frac{G_F^2 M_{D_s}^3}{8\pi} \left(\frac{m_l}{M_{D_s}}\right)^2 \left(1 - \frac{m_l^2}{M_{D_s}^2}\right)^2 |V_{cs}|^2 f_{D_s}^2$$



The 3.8σ disagreement could be a result of new physics. (Phys. Rev. Lett. 100: 241802,2008)

- Charged Higgs boson
- Leptoquarks



Absolute Branching Fractions for D_s^- Leptonic Decays and the Decay Constant f_{Ds}

Analysis Method - Inclusive sample of D_s decays

(1) Reconstruct Rest of Event (ROE) with:

Charmed Hadrons (D^0, D^+, D^*, Λ_c^+)

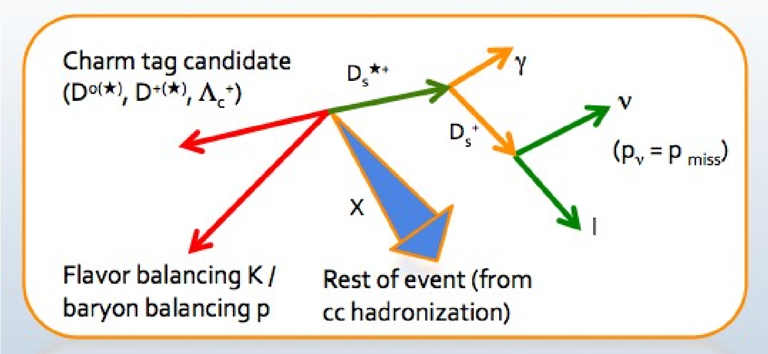
Flavor Balancing Kaon or Baryon Balancing proton

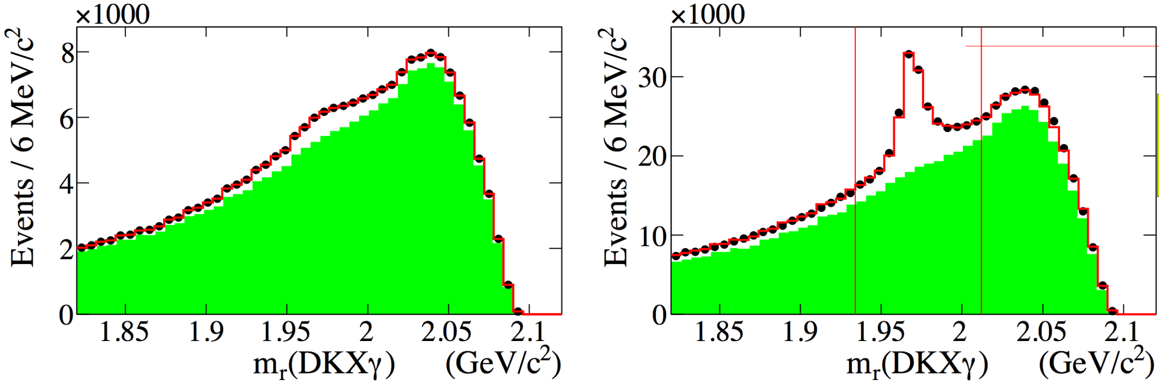
X (additional pions from fragmentation)

(2) Measure inclusive yield of D_s^- from fit of recoil mass

(3) Determine fraction of D_s^- leptonic decays

$$e^+ e^- \rightarrow c\,\bar{c} \rightarrow DKXD_s^{*-}\text{ , where } D_s^{*-} \rightarrow D_s^- \gamma$$



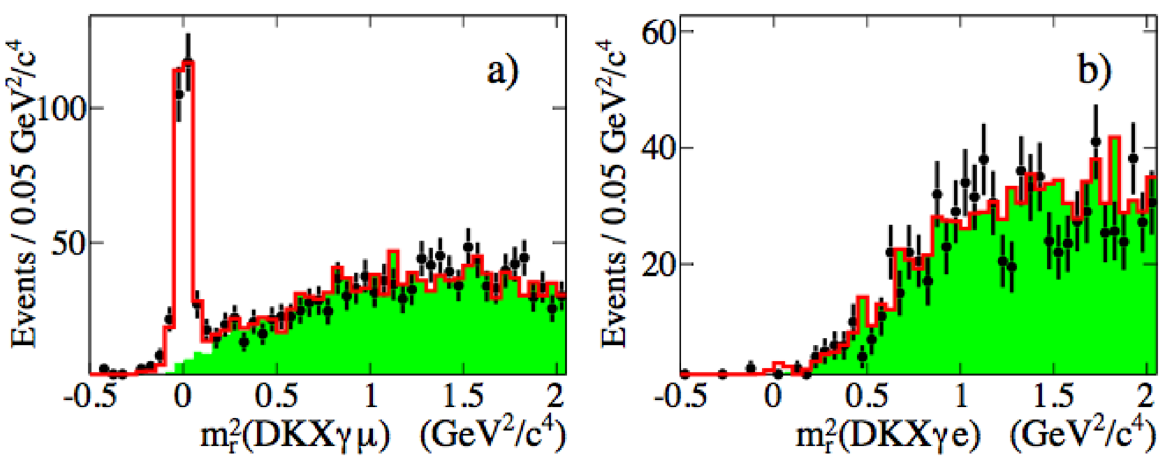


►Inclusive D_s decay region to select leptonic decays

1 additional charged track consistent with muon and E_{extra} < 1 GeV

Search for electron decay channel with similar criteria.

Phys. Rev. D 82 091103(R) (2010)



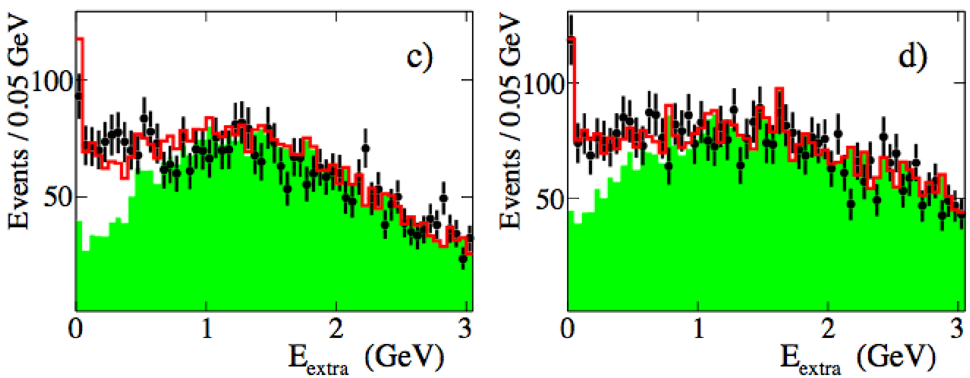
Absolute Branching Fractions for D_s^- Leptonic Decays and the Decay Constant f_{Ds}

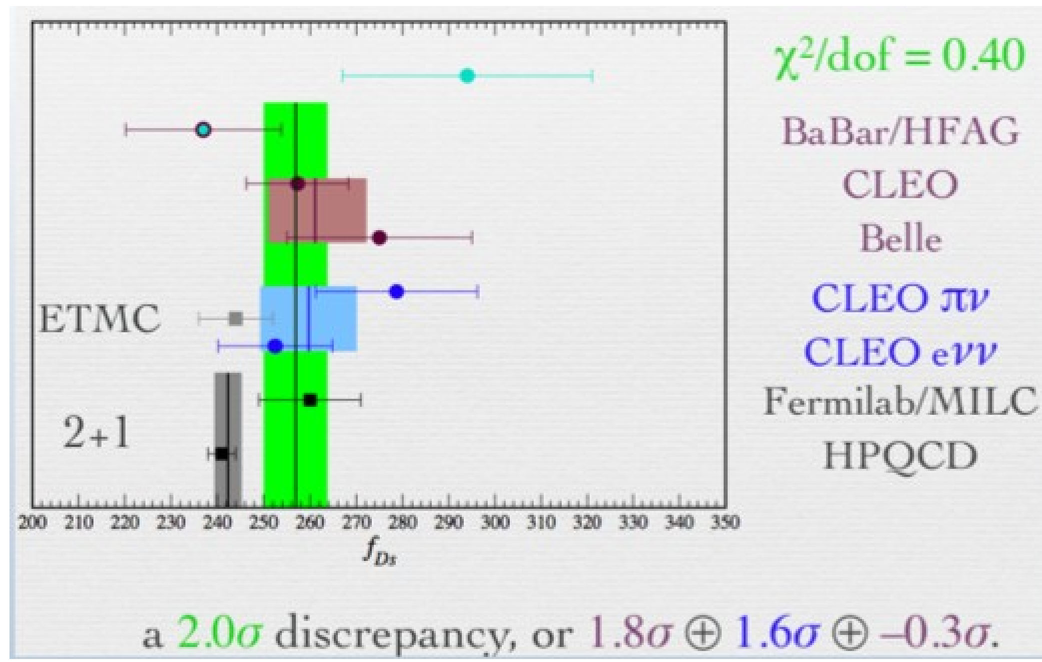
Phys. Rev. D 82 091103(R) (2010)

$$D_s^- \to \tau^- \bar{\nu}_\tau$$

Reconstruct tau decay channel with decays to electrons and muons. Since these events contain several neutrinos the extra energy in the event is used to extract the signal yield.

$\tau^- \to e^- \bar{\nu}_e \nu_\tau$ $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$





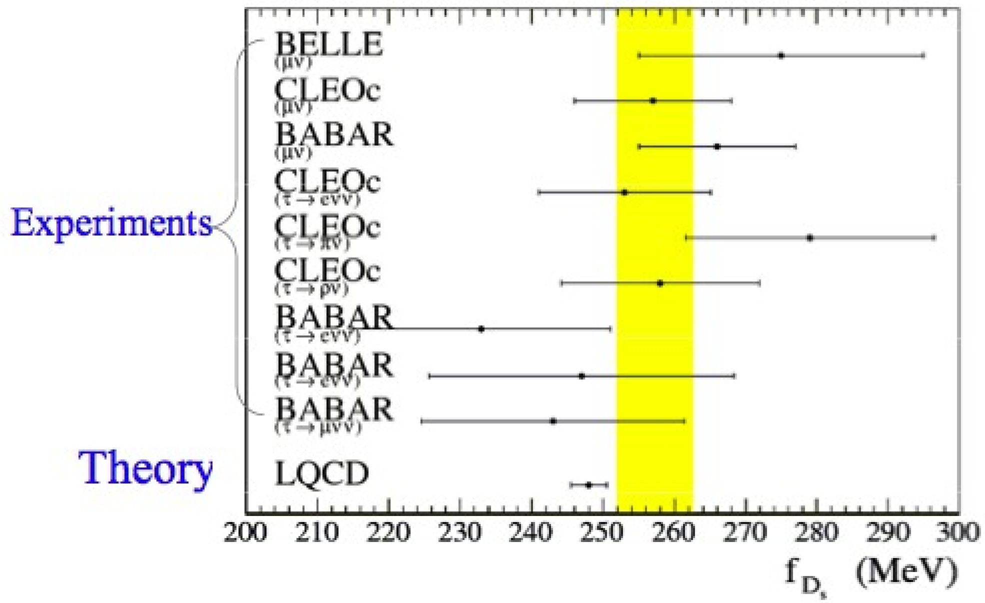
$$f_{D_s} = \frac{1}{G_F m_l \left(1 - \frac{m_l^2}{m_{D_s}^2}\right) |V_{cs}|^2} \sqrt{\frac{8\pi B(D_s \to l\nu)}{m_{D_s} \tau_{D_s}}}$$

Mode	$B(D_s \to l\nu)$	f_{Ds} (MeV)
$D_s \to \mu\nu$	$(6.02 \pm 0.38 \pm 0.34) \times 10^{-3}$	$265.7 \pm 8.4 \pm 7.7$
$D_s \to \tau\nu; \tau \to \mu\nu\nu$	$(4.91 \pm 0.47 \pm 0.54) \times 10^{-2}$	$247 \pm 13 \pm 17$
$D_s \to \tau\nu; \tau \to e\nu\nu$	$(5.07 \pm 0.52 \pm 0.68) \times 10^{-2}$	$243 \pm 12 \pm 14$
$D_s \to l\nu$ combined	-	$258.6 \pm 6.4 \pm 7.5$

f_{Ds} = 258.6 +/- 6.4 +/- 7.5 MeV (> 1.8σ LQCD)

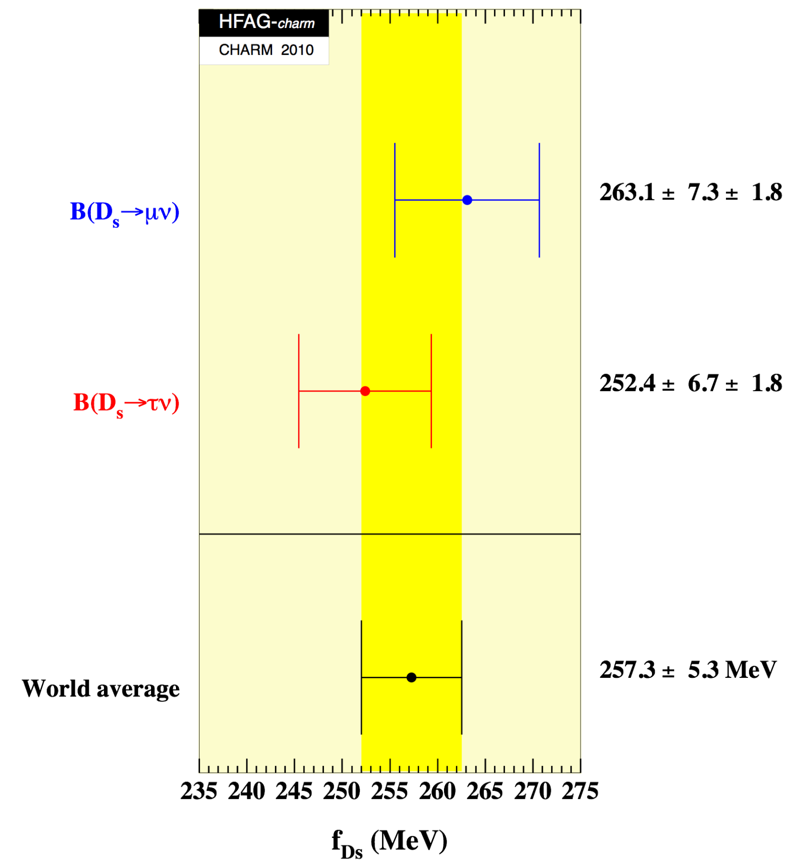
Summary of experiment and LQCD results for the Decay Constant f_{Ds}

Theory vs. Experiment (new LQCD calculation)



HFAG (2011) = 257.3 +- 5.3
LQCD (2010) = 248.0 +- 2.5

$\Delta = 1.6\,\sigma$



LQCD value changed with their new energy calibration scale. [PRD 82, 114504 (2010)]

Evidence of New Resonances decaying to Dπ and D*π in inclusive e+e- collisions

Phys. Rev. D 82 111101(R) (2010)

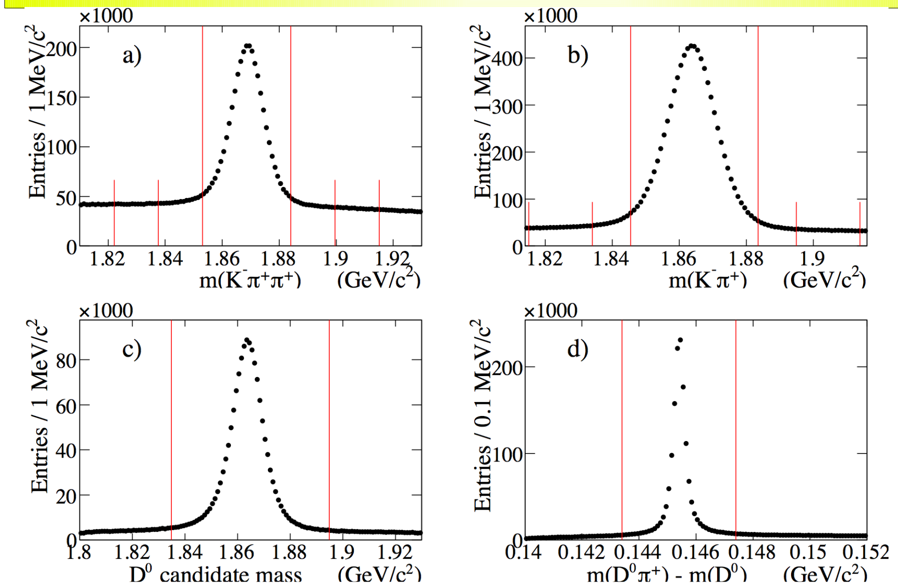
$$e^+ e^- \rightarrow c\bar{c} \rightarrow D^{(*)}\pi X$$

Spectrum of quark-antiquark states was predicted using a relativistic chromodynamic potential model.
The mass spectrum of charm mesons is comprised of several possible states:

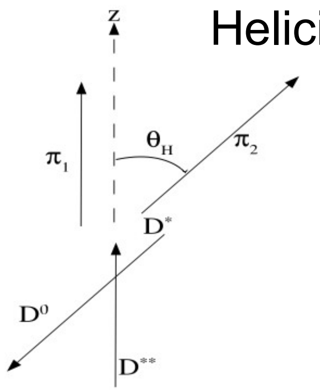
- Ground States (1S)
- Orbital excitations with angular momentum L=1,2 (1P,1D)
- First radial excitations (2S)

Studying the helicity distribution will determine J^P

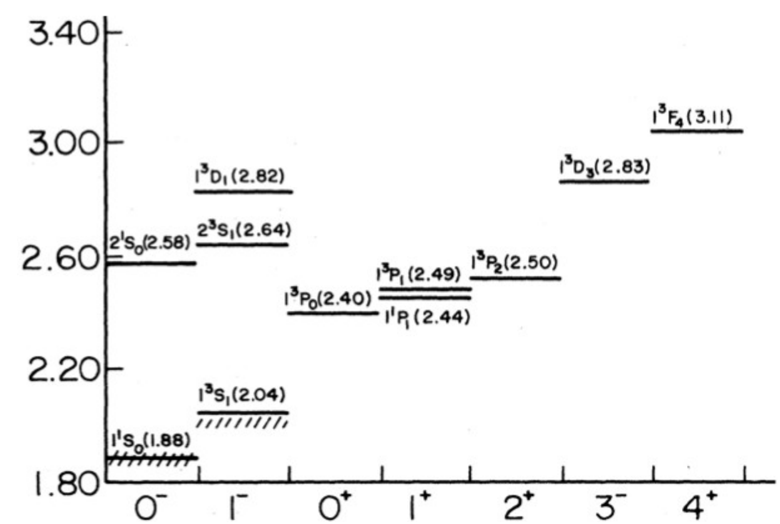
Search for new states in the inclusive production of 3 final states:
$D^+\pi^-$, $D^0\pi^+$ (veto D* decays), and $D^{*+}\pi^-$
Reconstruct D^+ to $K^-\pi^+\pi^+$, D^0 to $K^-\pi^+$, and D^0 to $K^-\pi^+\pi^-\pi^+$ (D^* to $D^0\pi_{slow}$)



Helicity Angle



State	Predicted Mass	J^P	$\cos\theta_H$ Distribution
$D_0^1(2S)$	2.58 GeV/c^2	0^-	$\propto \cos^2\theta_H$
$D_1^3(2S)$	2.64 GeV/c^2	1^-	$\propto \sin^2\theta_H$
$D_1^1(1P)$	2.44 GeV/c^2	1^+	$\propto 1 + h\cos^2\theta_H$
$D_0^3(1P)$	2.40 GeV/c^2	0^+	decay not allowed
$D_1^3(1P)$	2.49 GeV/c^2	1^+	$\propto 1 + h\cos^2\theta_H$
$D_2^3(1P)$	2.50 GeV/c^2	2^+	$\propto \sin^2\theta_H$
$D_2^1(1D)$	∼2.83 GeV/c^2	2^-	$\propto 1 + h\cos^2\theta_H$
$D_1^3(1D)$	2.82 GeV/c^2	1^-	$\propto \sin^2\theta_H$
$D_2^3(1D)$	∼2.83 GeV/c^2	2^-	$\propto 1 + h\cos^2\theta_H$
$D_3^3(1D)$	2.83 GeV/c^2	3^-	$\propto \sin^2\theta_H$



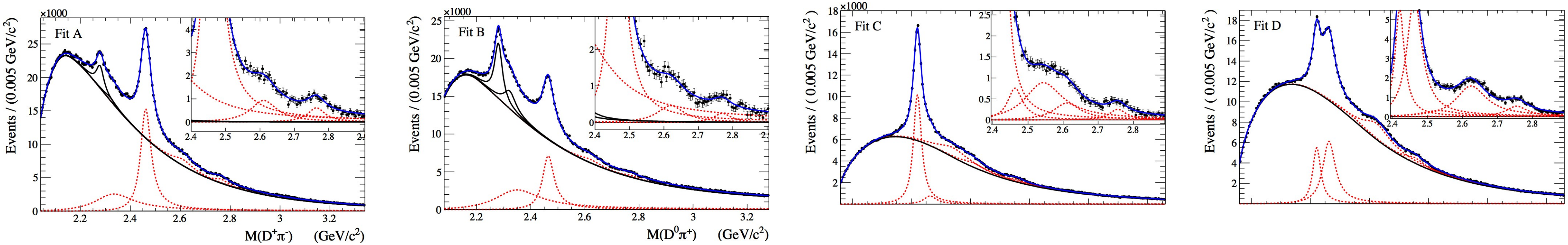
S. Godfrey and N. Isgur, Phys. Rev. D 32, 189 (1985)

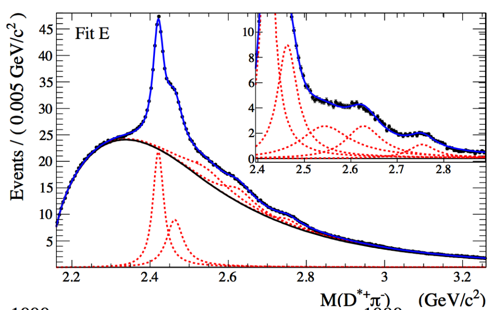
Evidence of New Resonances decaying to $D\pi$ and $D^*\pi$ in inclusive e^+e^- collisions

Combine charm candidates in signal with additional pion
Pion must come from primary vertex
Vertex fit required with $P(\chi^2) > 1\%$

Phys. Rev. D 82 111101(R) (2010)

Signal
Background
Total Fit



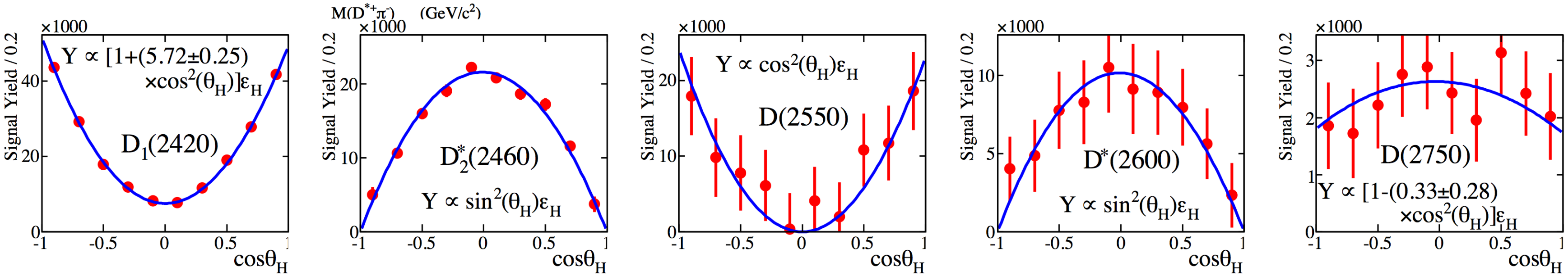


Determination of J^P and L

$D(2550)^0$ consistent with $D^1_0(2S)$

$D^*(2600)^0$ natural parity consistent with $D^3_1(2S)$

$D^*(2760)^0$ and $D(2750)^0$ candidates for L=2 states (4 states predicted in this region)



Evidence of new states

$D^+\pi^-$ (Fit A): $D^*(2600)^0$ (3.9σ) and $D^*(2760)^0$ (8.9σ)

$D^0\pi^+$ (Fit B): $D^*(2600)^+$ (2.8σ) and $D^*(2760)^+$ (3.5σ)

$D^{*+}\pi^-$ (Fit E): $D^*(2600)^0$ (7.3σ), $D(2750)^0$ (4.2σ), and $D(2550)^0$ (3.0σ)

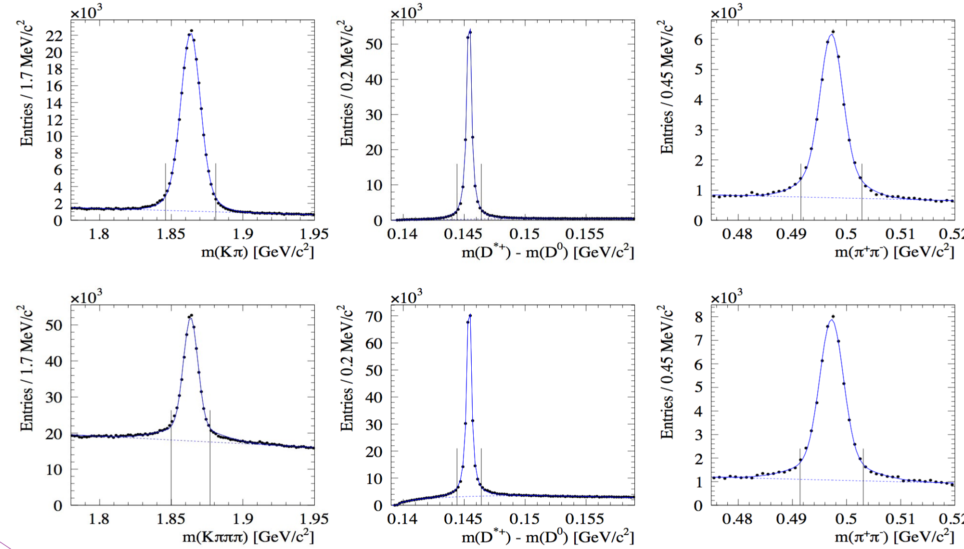
Precision Measurement of the Mass and Width of the $D_{s1}(2536)^+$

Phys. Rev. D 83 072003 (2011)

$$D_{s1}(2536)^+ \rightarrow D^{*+} K^0_S$$

D_{s1}^+ reconstructed via the decay $D^{*+}K_S$
K_s reconstructed via $\pi^+\pi^-$
D^{*+} reconstructed via $D^0\pi^+$
D^0 to $K^-\pi^+$, and D^0 to $K^-\pi^+\pi^-\pi^+$

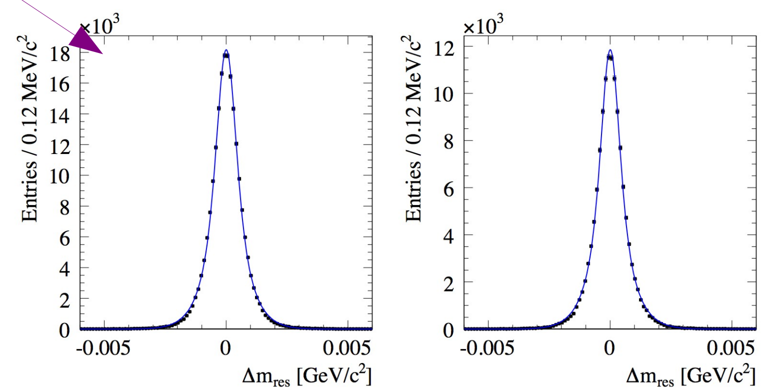
Masses and widths of D_s mesons not in agreement with HQET; such as $D_{s0}^*(2317)$ and $D_{s1}(2460)$.
Many possible theoretical explanations:
$D^{(*)}K$ molecules, chiral partners; tetraquarks, and LQCD

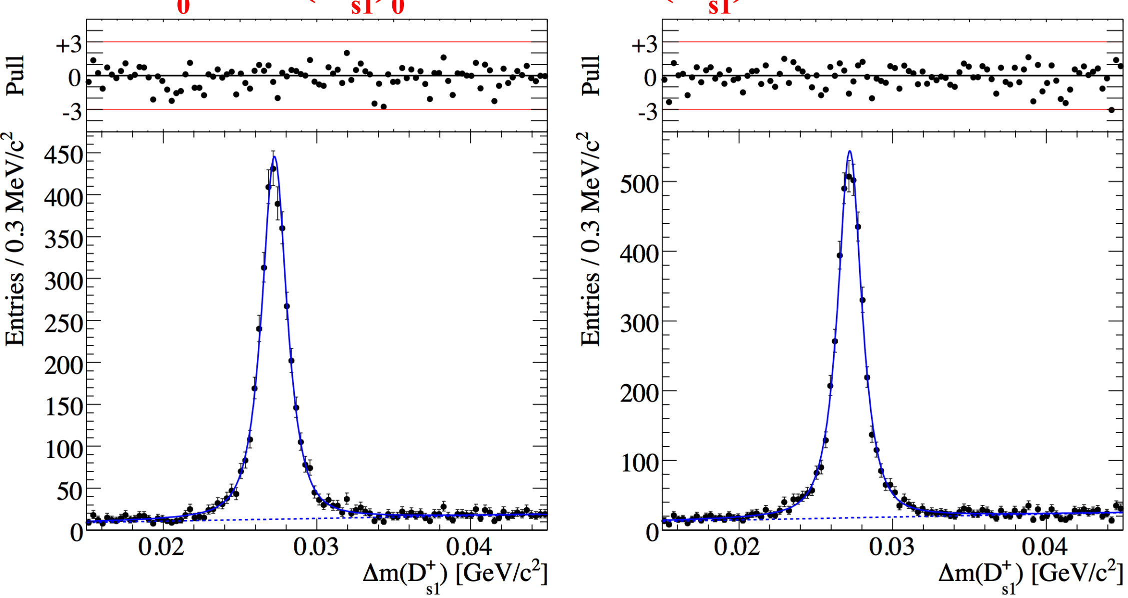


Relativistic Breit-Wigner convoluted with $p^*(D_{s1}^+)$-dependent resolution function

$$\left(\frac{p_{1,m}}{p_{1,m_0}}\right)^{2L+1}\left(\frac{m_0}{m}\right)\frac{mF_L(p_{1,m})^2}{(m_0^2-m^2)^2+\Gamma_m^2 m_0^2}$$

$m_0 = \Delta m(D_{s1})_0$ and $m = \Delta m(D_{s1})$





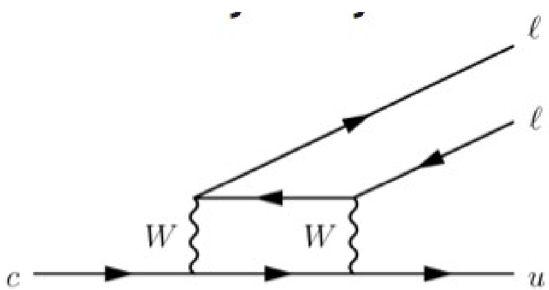
$$\Delta m(D_{s1}^+) = m(D_{s1}^+) - m(D^{*+}) - m(K_S^0)$$

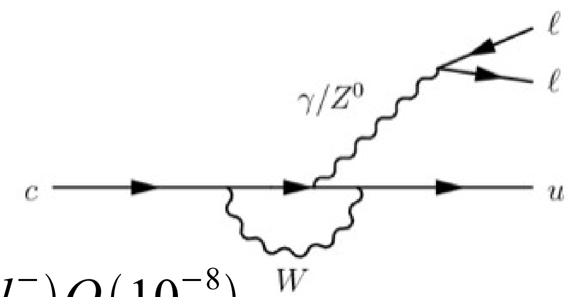
$\Gamma(D_{s1}^+) = 0.92$ +/- 0.03 +/- 0.04 MeV
$m(D_{s1}^+) = 2535.08$ +/- 0.01 +/- 0.15 MeV/c^2
Confirm $J^P = 1^+$

Search for Rare and Forbidden Charm Decays

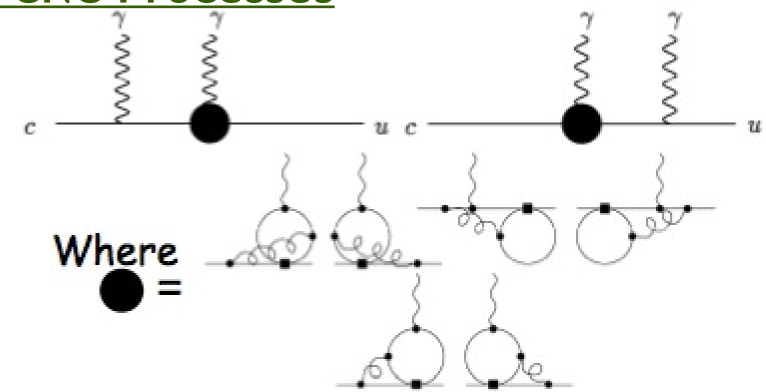
Flavor Changing Neutral Current (FCNC) processes occur in loop diagrams in the SM.
These decays are heavily GIM suppressed in the SM.

Short Distance Contributions to FCNC Processes





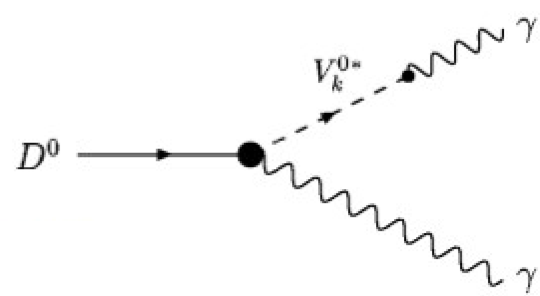
$$BF(c \to u\, l^+ l^-)\, O(10^{-8})$$



$$BF(D^0 \to \gamma\gamma)^{SD}(HQET) \simeq 3 \times 10^{-11}$$

New physics introduce new particles into loop increasing rates from 10^{-6} to 10^{-5}.
Also look for exotic decays, Lepton Flavor Violating (LFV) and Lepton Number Violating (LNV).
Recent FCNC, LNV, and LFV measurements starting to confine the allowed parameters space of R-parity violating super-symmetric models.

Long Distance Contributions to FCNC Processes



$$BF(D^0 \to \gamma\gamma)^{VMD} \simeq (3.5^{+4.0}_{-2.6}) \times 10^{-8}$$

(Vector Meson Dominance)
Burdman et al. hep-ph/0112235v2 1 March 2002
Possible 10^2 enhancement from new physics (MSSM gluino exchange)
S. Prelovsek and D. Wyler, hep-ph/0012116v1 11 Dec 2000

Search for Rare and Forbidden Semileptonic Charm Decays

$$X_c^+ \to h^\pm l^\mp l^\pm \,(X_c^+ = D^+, D_s^+, \Lambda_c^+)$$

***BABAR* preliminary**

Search for FCNC processes, LFV decays, LNV violating decays

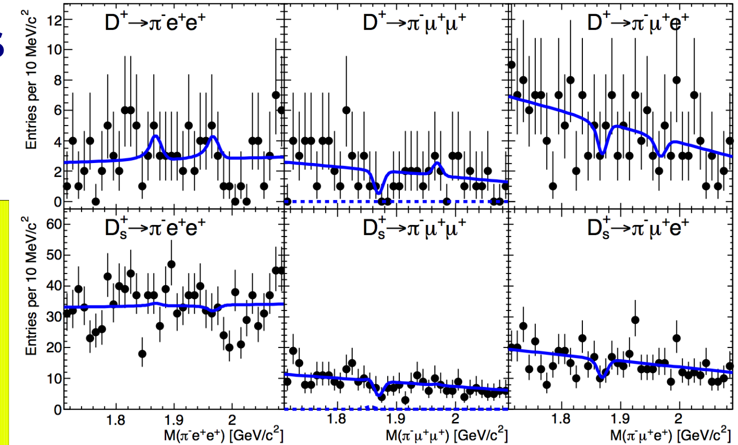
Hadrons are either kaons or pions (protons)

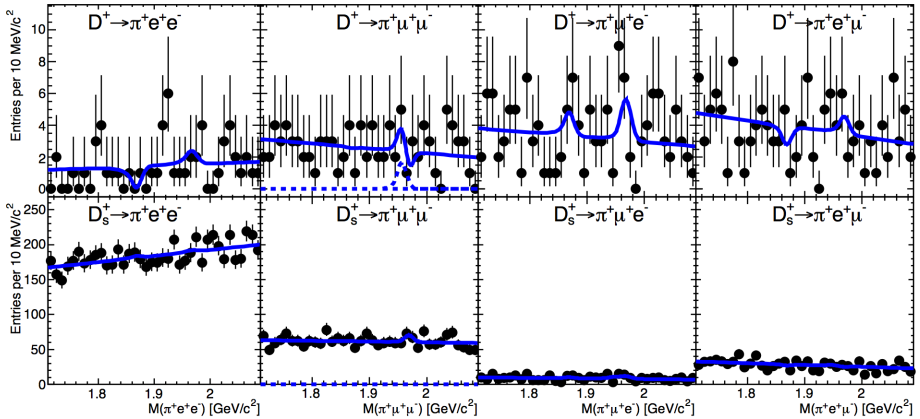
Leptons are either muons or electrons

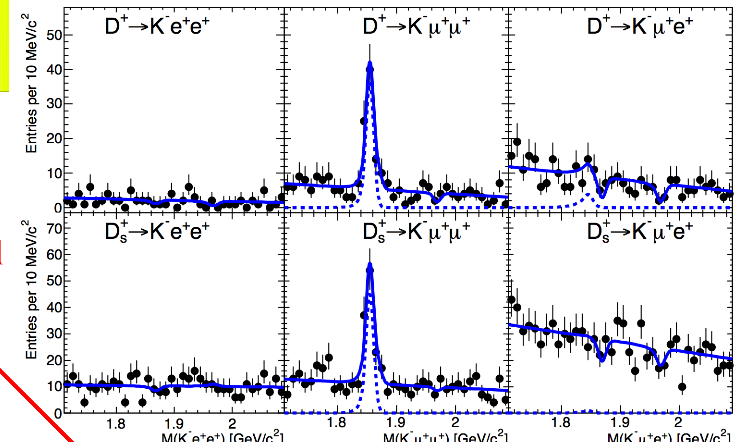
Total of 35 decay modes analyzed

Branching fractions normalized to D^+ and D_s^+ to $\varphi\pi^+$ or Λ_c to $pK\pi$

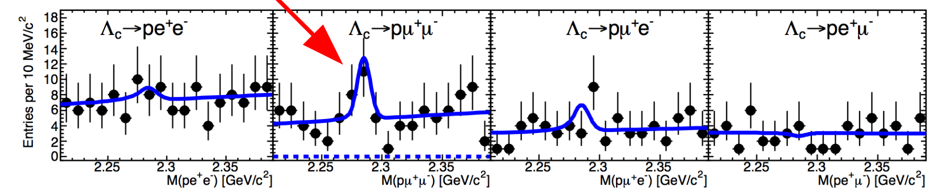
No observation of new signal, improvement over previous results

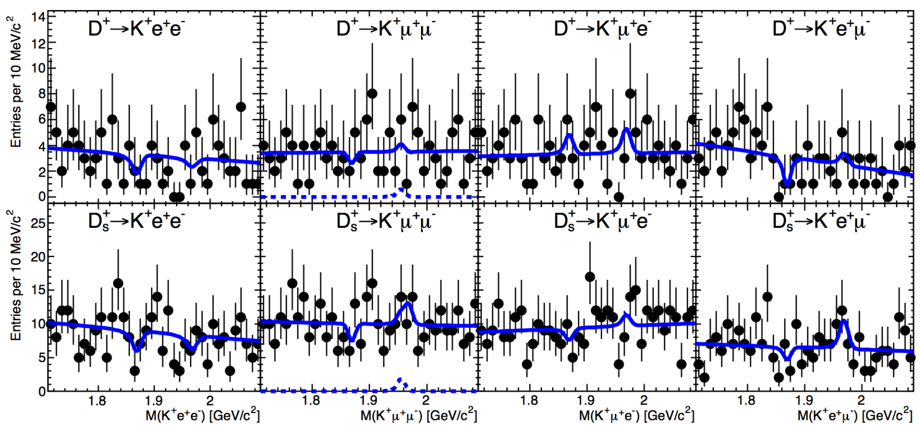


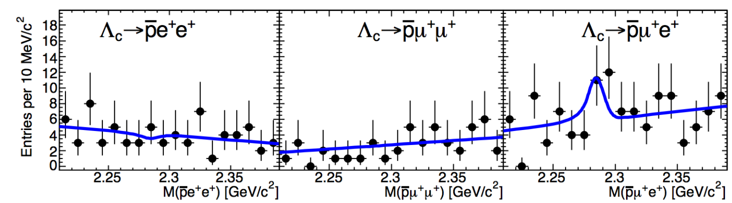




Most significant signal 2.6σ (stat. only)







Limits on branching fractions between 1 x10^{-6} and 44 x 10^{-6}

Search for the Decay D^0 to $\gamma\gamma$ (previously presented at FPCP 2011)

Search for forbidden FCNC decay

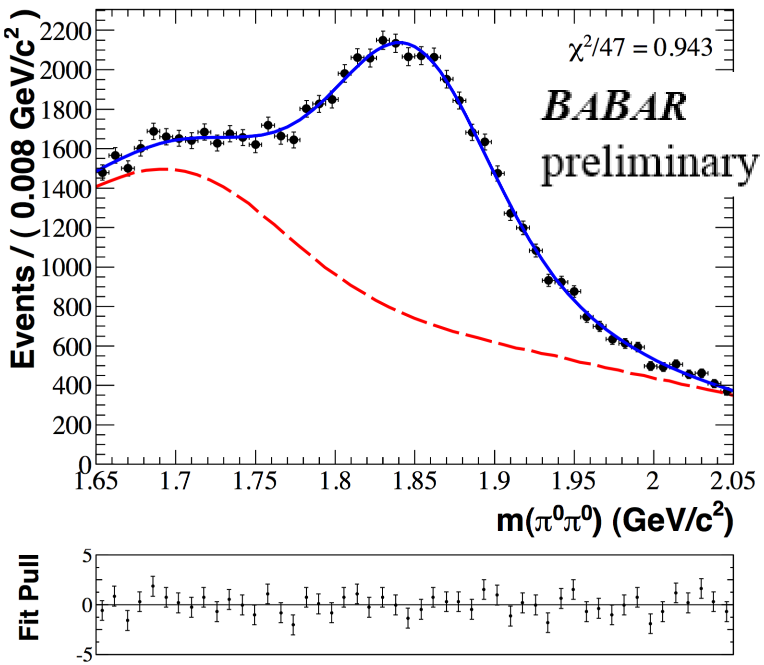
Dominant background from D^0 to $\pi^0\pi^0$

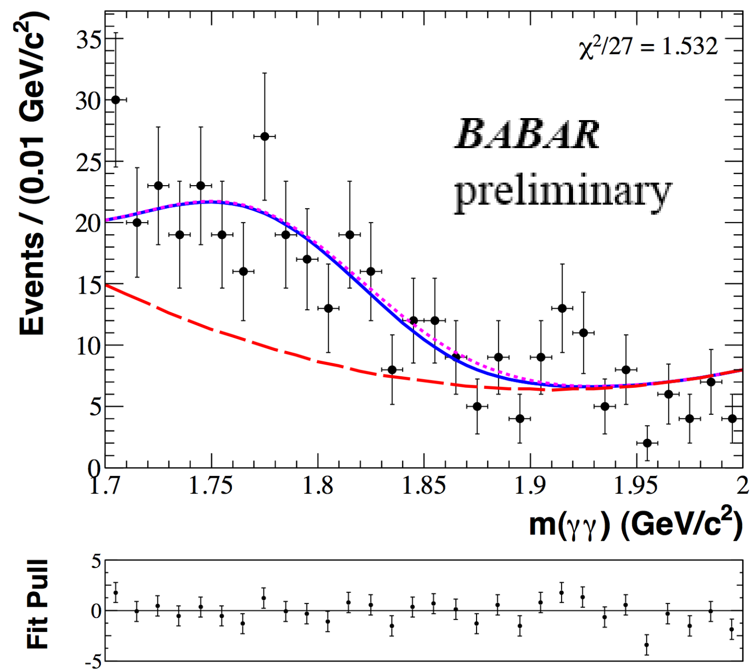
Branching fraction measurements for $\gamma\gamma$ and $\pi^0\pi^0$ modes normalized to D^0 to $K_s\pi^0$

D^0 decays from D^* used to suppress backgrounds along with pion veto (95% rejection 66% signal efficiency)

$$B(D^0\rightarrow\pi^0\pi^0)=\frac{\frac{1}{\epsilon_{\pi^0\pi^0}}N(D^0\rightarrow\pi^0\pi^0)}{\frac{1}{\epsilon_{K_S^0\pi^0}}N(D^0\rightarrow K_S^0\pi^0)}\times B(D^0\rightarrow K_S^0\pi^0)$$

$$B(D^0\rightarrow\gamma\gamma)=\frac{\frac{1}{\epsilon_{\gamma\gamma}}N(D^0\rightarrow\gamma\gamma)}{\frac{1}{\epsilon_{K_S^0\pi^0}}N(D^0\rightarrow K_S^0\pi^0)}\times B(D^0\rightarrow K_S^0\pi^0)$$





Final Results (about a factor 10 improvement over previous results)

$$B(D^0\rightarrow\pi^0\pi^0)=(8.4\pm0.1\pm0.4\pm0.3)\times10^{-4}$$

$$B(D^0\rightarrow\gamma\gamma)<2.4\times10^{-6}$$

Search for CP Violation in Charm Decays

- Search for Direct CP Violation from the interference of Cabibbo-Suppressed (CS) and Doubly CS (DCS) Decays.
- Search for Direct CP Violation from tree-level and penguin-level transitions in Singly CS (SCS) Decays.
- Assuming CPT invariance, search for T-Violation in 4-body Charm Decays.
- In the SM, CP violating asymmetries are expected at the rate of 10^{-3}.
- New physics may enhance these rates to 10^{-2}.

$$A_{CP}(D^+ \to K^0_S \pi^+)$$
$$(-0.6 \pm 1.0 \pm 0.3) \times 10^{-2} (CLEO-c)$$
$$(-0.71 \pm 0.19 \pm 0.20) \times 10^{-2} (Belle)$$

$$A_T(D^0 \to K^- K^+ \pi^- \pi^+) = 0.010 \pm 0.057 \pm 0.037 (FOCUS)$$
$$A_T(D^+ \to K^0_S K^+ \pi^- \pi^+) = 0.023 \pm 0.062 \pm 0.022 (FOCUS)$$
$$A_T(D_s^+ \to K^0_S K^+ \pi^- \pi^+) = -0.036 \pm 0.067 \pm 0.023 (FOCUS)$$

Previous BaBar Measurements

$$A_{CP}(D^+ \to K^+ K^- \pi^+) = (1.4 \pm 1.0 \pm 0.8) \times 10^{-2}$$ 76 fb^{-1} of data measures integrated asymmetry
$$A_{CP}(D^0 \to K^+ K^-) = (0.00 \pm 0.34 \pm 0.13) \times 10^{-2}$$
$$A_{CP}(D^0 \to \pi^+ \pi^-) = (-0.24 \pm 0.52 \pm 0.22) \times 10^{-2}$$
$$A_{CP}(D^0 \to K^+ K^- \pi^0) = (1.00 \pm 1.67 \pm 0.25) \times 10^{-2}$$
$$A_{CP}(D^0 \to \pi^+ \pi^- \pi^0) = (-0.31 \pm 0.41 \pm 0.17) \times 10^{-2}$$

In progress is an update of D^+ to $K^+K^-\pi^+$ with 467 fb^{-1}.
SM prediction not affected by neutral kaon mixing effects.
Babar can achieve 0.2% to 0.3% precision on integrated asymmetry.
In addition, we can probe individual resonances as well as regions of the Dalitz plot.

Search for CP Violation in the Decay D^+ to $K_S\pi^+$

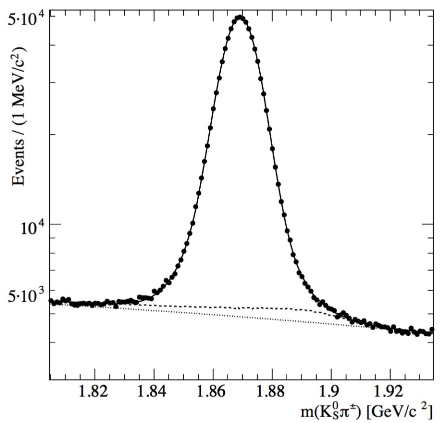
Phys. Rev. D 83, 071103 (R) (2011)

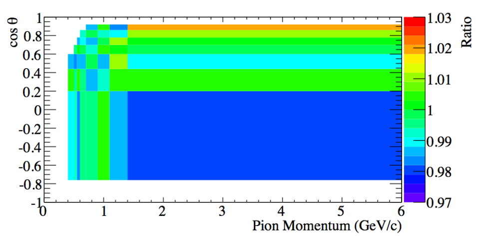
Expected time-integrated CP violating asymmetry for K^0 mixing (-0.332 +/- 0.006)%.
Direct CP violation from interference of CF and DCS decays negligible in SM.
Deviation from K^0 mixing at the level of 1% indicates new physics!
Electroweak interference in charm production (γ-Z^0) –
Measure CP asymmetry and Forward-Backward (FB) asymmetry as function of production angle.
Corrections applied to D^- yields to account for detector charged-track efficiency asymmetry.

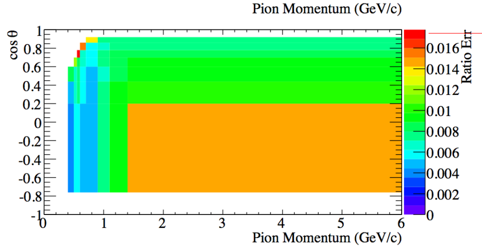
$$A = \frac{N_{D^+} - N_{D^-}}{N_{D^+} + N_{D^-}}$$

$$A_{FB}(|\cos\theta_D^*|) = \frac{A(+|\cos\theta_D^*|) - A(-|\cos\theta_D^*|)}{2}$$

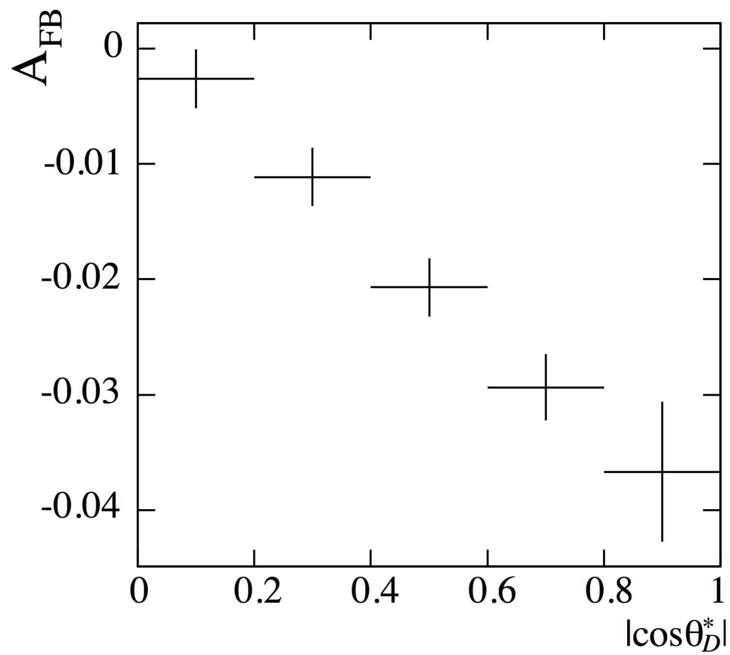
$$A_{CP}(|\cos\theta_D^*|) = \frac{A(+|\cos\theta_D^*|) + A(-|\cos\theta_D^*|)}{2}$$

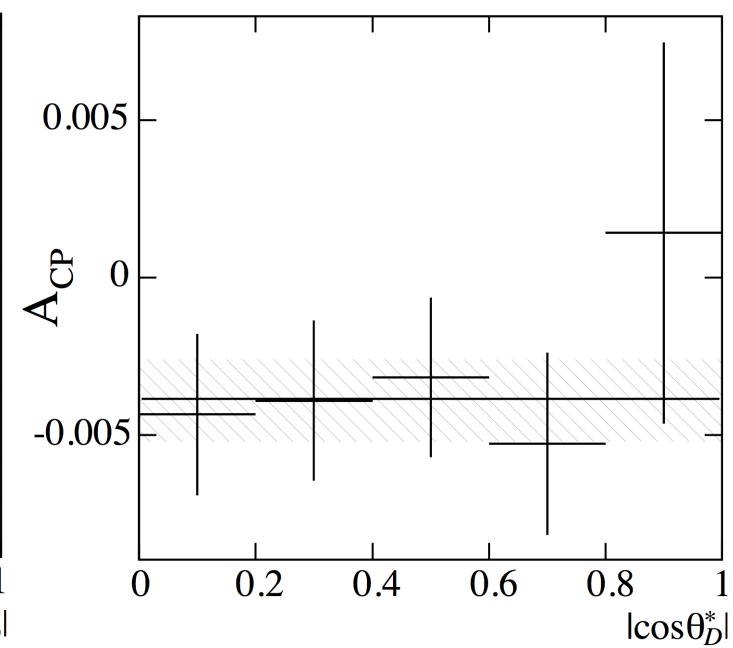






Ratio of charged-track reconstruction efficiencies





A_{CP} = (-0.44 +/- 0.13 +/- 0.10)%

Search for CP Violation using T-Odd Correlations in 4-body Charm Decays

$$e^+e^- \rightarrow XD^+_{(s)};\ D^+_{(s)} \rightarrow K^+K^0_S\pi^+\pi^-;\ K^0_S \rightarrow \pi^+\pi^-$$

arXiv:1105.4410 [hep-ex]

Kinematic triple product (C_T) is odd under time reversal.

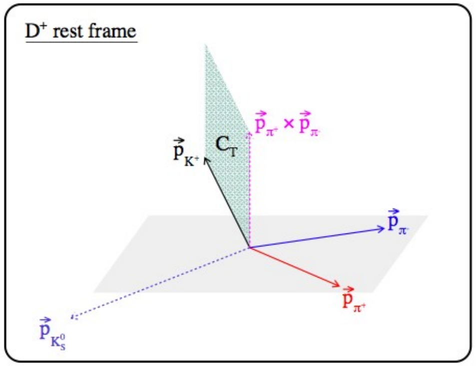
Assuming CPT invariance, T-violation implies CP-violation.

Mass fits performed in bins of C_T.

T-violating asymmetry $\frac{1}{2}(A_T - \bar{A}_T)$

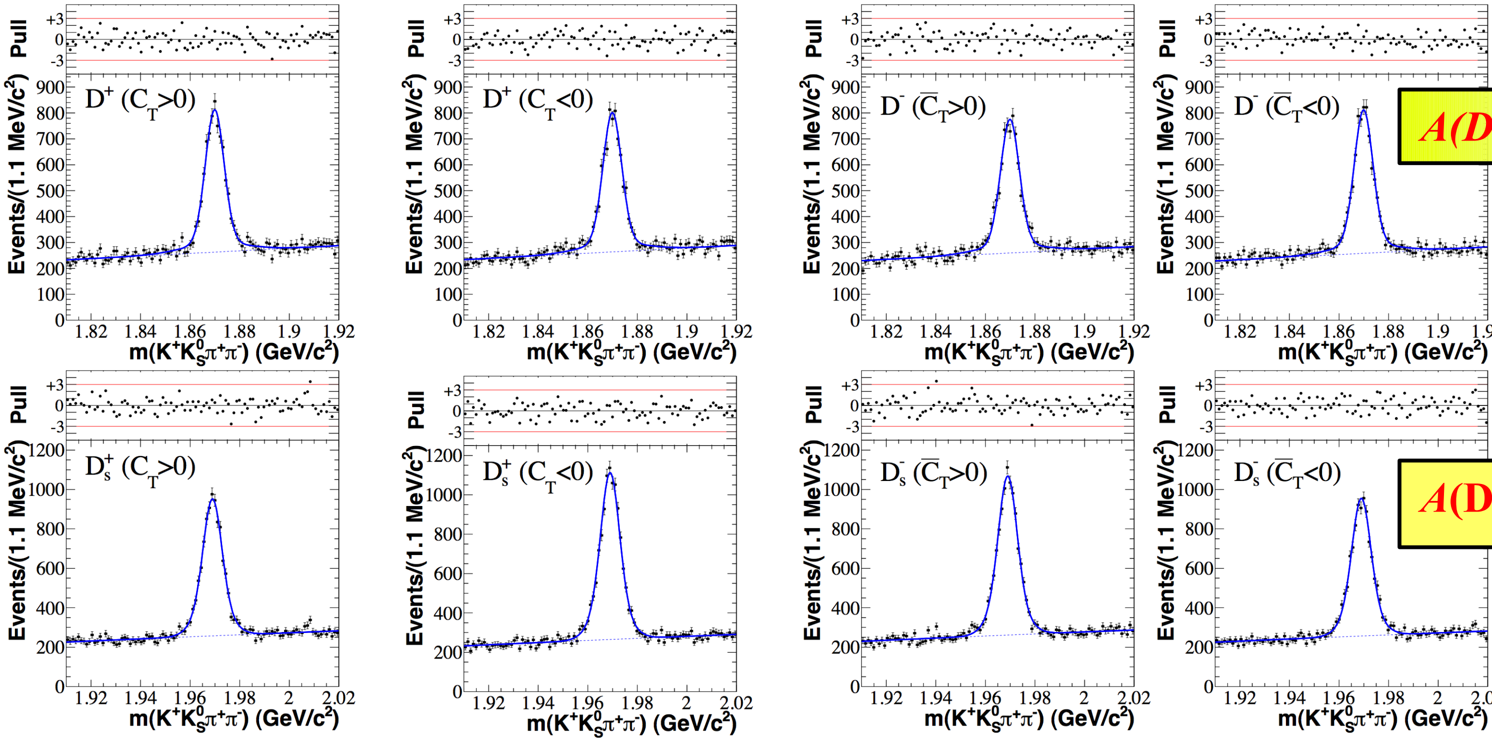
$$C_T \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$$

$$\bar{C}_T \equiv \vec{p}_{K^-} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\pi^+})$$



$$A_T \equiv \frac{\Gamma(C_T>0)-\Gamma(C_T<0)}{\Gamma(C_T>0)+\Gamma(C_T<0)}$$

$$\bar{A}_T \equiv \frac{\Gamma(-\bar{C}_T>0)-\Gamma(-\bar{C}_T<0)}{\Gamma(-\bar{C}_T>0)+\Gamma(-\bar{C}_T<0)}$$



$A(D^+) = (-12.0 +/- 10.0 +/- 4.6) \times 10^{-3}$

$A(D_s^+) = (-13.6 +/- 7.7 +/- 3.4) \times 10^{-3}$

Phys. Rev. D 81 111103 (R) (2010) D^0 decay mode: $A(D^0) = (1.0 +/- 5.1 +/- 4.4)$ X 10^{-3}

Summary of Recent Charm Results from Babar

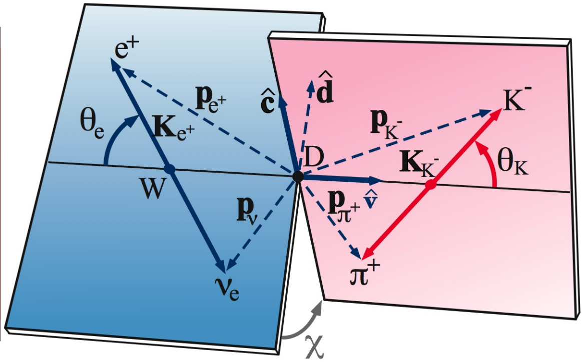
- Partial wave analysis of D_s^+ to $K^+K^-\pi^+$ provides an accurate description of the S-wave in the vicinity of the $\varphi(1020)$ resonance.
  - Effective parameterization of $f_0(980)$: m = 0.922 +- 0.003 GeV/c^2 and Γ = 0.24 +- 0.08 GeV
- Leptonic decay constant of the D_s finds agreement with theory.
  - f_{Ds} = 258.6 +/- 6.4 +/- 7.5 MeV (> 1.8σ LQCD)
- Evidence of several new charm resonances decaying to $D^{(*)}\pi$.
  - $D^*(2600)$, D(2750), $D^*(2760)$, and D(2550)
- Precise measurement of the mass and width of the D_{s1}^+
  - $\Gamma(D_{s1}^+)$ = 0.92 +/- 0.03 +/- 0.04 MeV and $m(D_{s1}^+)$ = 2535.08 +/- 0.01 +/- 0.15 MeV/c^2
- Searches for rare or forbidden decays improves upon existing upper limits of branching fractions. No new signals are observed.
- Searches for CP violation provide most precise measurements.
  - $A_{CP}(D^+ \text{ to } K_S^0\pi^+)$ = (-0.44 +/- 0.13 +/- 0.10)%
  - $A_T(D^+)$ = (-12.0 +/- 10.0 +/- 4.6) x 10^{-3}
  - $A_T(D_s^+)$ = (-13.6 +/- 7.7 +/- 3.4) x 10^{-3}

References

- P. del Amo Sanchez (BaBar Collaboration), "Dalitz Plot Analysis of D_s^+ to $K^+K^-\pi^+$", Phys. Rev. D 83 052001 (2011).
- P. del Amo Sanchez (BaBar Collaboration), "Measurement of the Absolute Branching Fractions for D_s^- to $l^-\nu_l$ and Extraction of the Decay Constant f_{Ds}", Phys. Rev. D 82 091103(R) (2010).
- P. del Amo Sanchez (BaBar Collaboration), "Analysis of the D^+ to $K^-\pi^+e^+\nu_e$ Decay Channel", Phys. Rev. D 83, 072001 (2011).
- P. del Amo Sanchez (BaBar Collaboration), "Observation of New Resonances Decaying to $D\pi$ and $D^*\pi$ in Inclusive e^+e^- Collisions", Phys. Rev. D 82 111101(R) (2010).
- P. del Amo Sanchez (BaBar Collaboration), "Measurement of the Mass and Width of the $D^*_{s1}(2536)^+$ Meson", Phys. Rev. D 83 072003 (2011).
- P. del Amo Sanchez (BaBar Collaboration), "Search for CP Violation in the Decay D^+ to $K_S^0\pi^+$", Phys. Rev. D 83, 071103 (R) (2011).
- P. del Amo Sanchez (BaBar Collaboration), "Search for CP Violation using T-Odd Correlations in D^0 to $K^+K^-\pi^+\pi^-$", Phys. Rev. D 81 111103 (R) (2010).
- P. del Amo Sanchez (BaBar Collaboration), "Search for CP Violation using T-Odd Correlations in D^+ to $K^+K_S^0\pi^+\pi^-$ and D_s^+ to $K^+K_S^0\pi^+\pi^-$ decays". arXiv:1105.4410[hep-ex]

Backup Slides

Analysis of the D^+ to $K^-\pi^+e^+\nu_e$ Decay Channel



Analyze the Kπ in Charm decays without accompanying hadrons.
Measurement of the Kπ S-wave phase variation (test Watson's Theorem).
Measurement of the K^{*0}(892) P-wave resonance parameters.
Determination of semileptonic decay form factors.
5-dimensional angular analysis in $m_{K\pi}$, $q^2 = m^2_{e\nu}$, $\cos\theta_e$, $\cos\theta_K$, and χ.

Decay Rate Formalism

$$d^5\Gamma = \frac{G_F^2 \|V_{cs}\|^2}{(4\pi)^6 m_D^3} X\, B\, I(m^2, q^2, \theta_K, \theta_e, X)\, dm^2\, dq^2\, d\cos(\theta_k)\, d\cos(\theta_e)\, dX$$

$$\begin{aligned}
\mathcal{I} = \;& \mathcal{I}_1 + \mathcal{I}_2 \cos 2\theta_e + \mathcal{I}_3 \sin^2\theta_e \cos 2\chi \\
& + \mathcal{I}_4 \sin 2\theta_e \cos\chi + \mathcal{I}_5 \sin\theta_e \cos\chi \\
& + \mathcal{I}_6 \cos\theta_e + \mathcal{I}_7 \sin\theta_e \sin\chi \\
& + \mathcal{I}_8 \sin 2\theta_e \sin\chi + \mathcal{I}_9 \sin^2\theta_e \sin 2\chi
\end{aligned}$$

$$\begin{aligned}
\mathcal{I}_1 &= \frac{1}{4}\left\{|\mathcal{F}_1|^2 + \frac{3}{2}\sin^2\theta_K \left(|\mathcal{F}_2|^2 + |\mathcal{F}_3|^2\right)\right\} \\
\mathcal{I}_2 &= -\frac{1}{4}\left\{|\mathcal{F}_1|^2 - \frac{1}{2}\sin^2\theta_K \left(|\mathcal{F}_2|^2 + |\mathcal{F}_3|^2\right)\right\} \\
\mathcal{I}_3 &= -\frac{1}{4}\left\{|\mathcal{F}_2|^2 - |\mathcal{F}_3|^2\right\}\sin^2\theta_K \\
\mathcal{I}_4 &= \frac{1}{2}\mathrm{Re}\left(\mathcal{F}_1^*\mathcal{F}_2\right)\sin\theta_K \\
\mathcal{I}_5 &= \mathrm{Re}\left(\mathcal{F}_1^*\mathcal{F}_3\right)\sin\theta_K \\
\mathcal{I}_6 &= \mathrm{Re}\left(\mathcal{F}_2^*\mathcal{F}_3\right)\sin^2\theta_K \\
\mathcal{I}_7 &= \mathrm{Im}\left(\mathcal{F}_1\mathcal{F}_2^*\right)\sin\theta_K \\
\mathcal{I}_8 &= \frac{1}{2}\mathrm{Im}\left(\mathcal{F}_1\mathcal{F}_3^*\right)\sin\theta_K \\
\mathcal{I}_9 &= -\frac{1}{2}\mathrm{Im}\left(\mathcal{F}_2\mathcal{F}_3^*\right)\sin^2\theta_K
\end{aligned}$$

Expansion of form factors into partial waves (S,P,D)

$$\begin{aligned}
\mathcal{F}_1 &= \mathcal{F}_{10} + \mathcal{F}_{11}\cos\theta_K + \mathcal{F}_{12}\frac{3\cos^2\theta_K - 1}{2}; \\
\mathcal{F}_2 &= \frac{1}{\sqrt{2}}\mathcal{F}_{21} + \sqrt{\frac{3}{2}}\mathcal{F}_{22}\cos\theta_K; \\
\mathcal{F}_3 &= \frac{1}{\sqrt{2}}\mathcal{F}_{31} + \sqrt{\frac{3}{2}}\mathcal{F}_{32}\cos\theta_K.
\end{aligned}$$

$$V(q^2) = \frac{V(0)}{1 - \frac{q^2}{m_V^2}} \qquad A_1(q^2) = \frac{A_1(0)}{1 - \frac{q^2}{m_A^2}} \qquad A_2(q^2) = \frac{A_2(0)}{1 - \frac{q^2}{m_A^2}}$$

S-wave Model

$$\mathcal{F}_{10} = p_{K\pi} m_D \frac{1}{1 - \frac{q^2}{m_A^2}} \mathcal{A}_S(m).$$

P-Wave Model

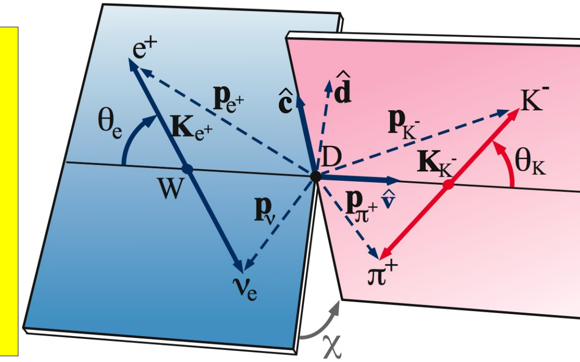
$$\begin{aligned}
\mathcal{F}_{11} &= (BW + r_{P'} e^{i\delta_{P'}} BW') 2\sqrt{2} q H_0 \\
\mathcal{F}_{21} &= (BW + r_{P'} e^{i\delta_{P'}} BW') 2q (H_+ + H_-) \\
\mathcal{F}_{31} &= (BW + r_{P'} e^{i\delta_{P'}} BW') 2q (H_+ - H_-)
\end{aligned}$$

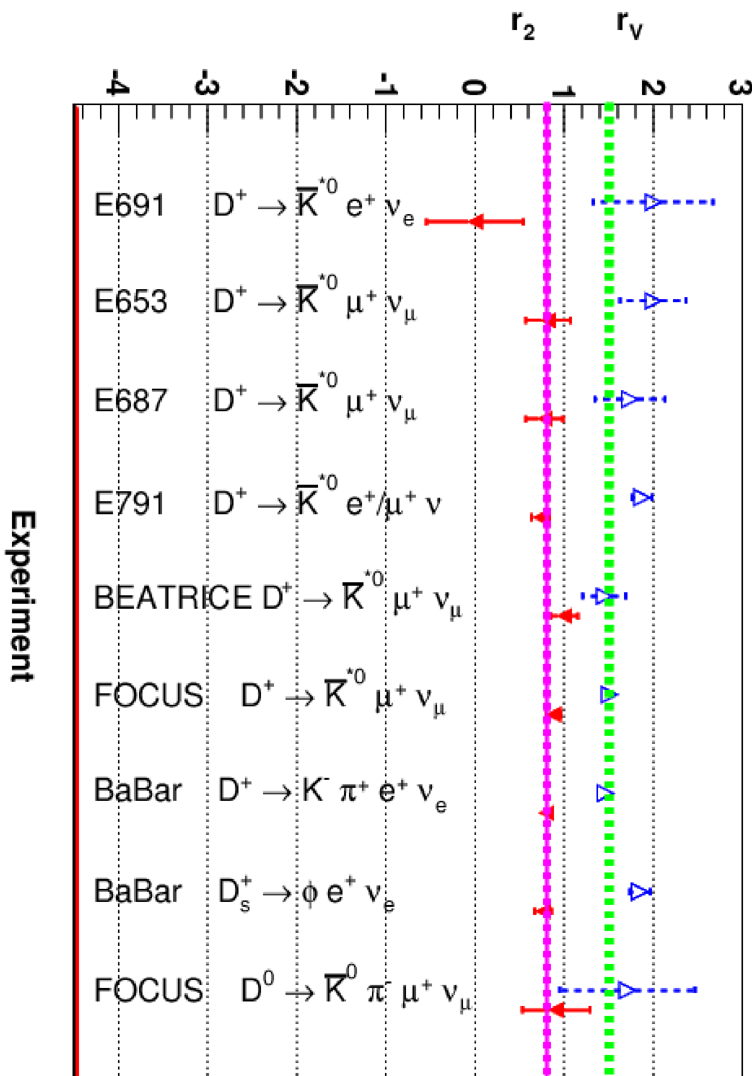
$$\mathcal{A}_{K^*(892)} = \frac{m_{K^*(892)}\Gamma^0_{K^*(892)} F_1(m)}{m^2_{K^*(892)} - m^2 - i m_{K^*(892)}\Gamma_{K^*(892)}(m)}.$$

Analysis of the D^+ to $K^-\pi^+e^+\nu_e$ Decay Channel

Phys. Rev. D 83, 072001 (2011)

Analyze the Kπ in Charm decays without accompanying hadrons.
Measurement of the Kπ S-wave phase variation (test Watson's Theorem).
Measurement of the $K^{*0}(892)$ P-wave resonance parameters.
Determination of semileptonic decay form factors (r_2, r_v).
5-dimensional angular analysis in $m_{K\pi}$, $q^2 = m^2_{e\nu}$, $\cos\theta_e$, $\cos\theta_K$, and χ.

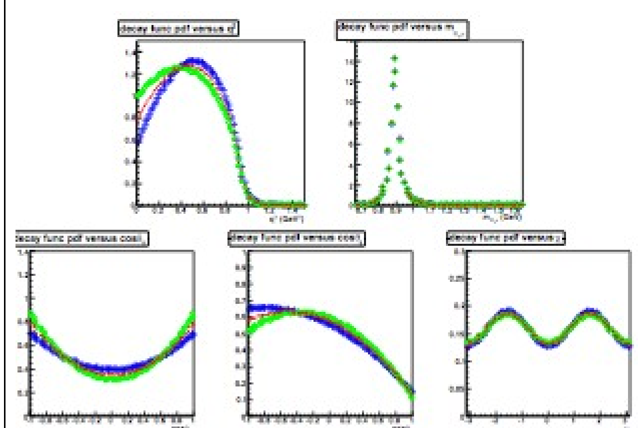




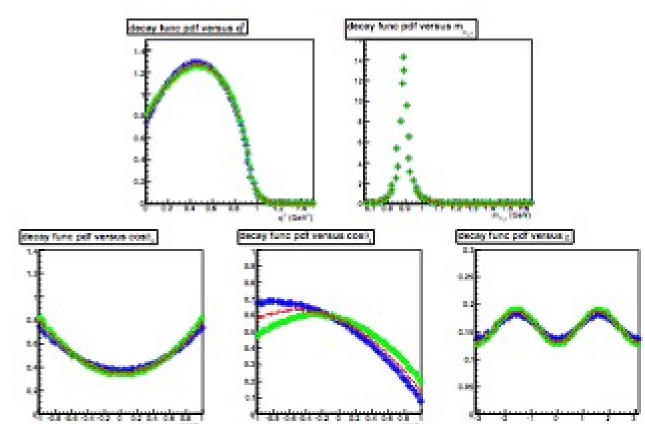
Decay Rate

$$d^5\Gamma = \frac{G_F^2\|V_{cs}\|^2}{(4\pi)^6 m_D^3} X\, B\, I(m^2, q^2, \theta_K, \theta_e, X)\, dm^2\, dq^2\, d\cos(\theta_k)\, d\cos(\theta_e)\, dX$$

Decay Rate vs. r_2



Decay Rate vs. r_v

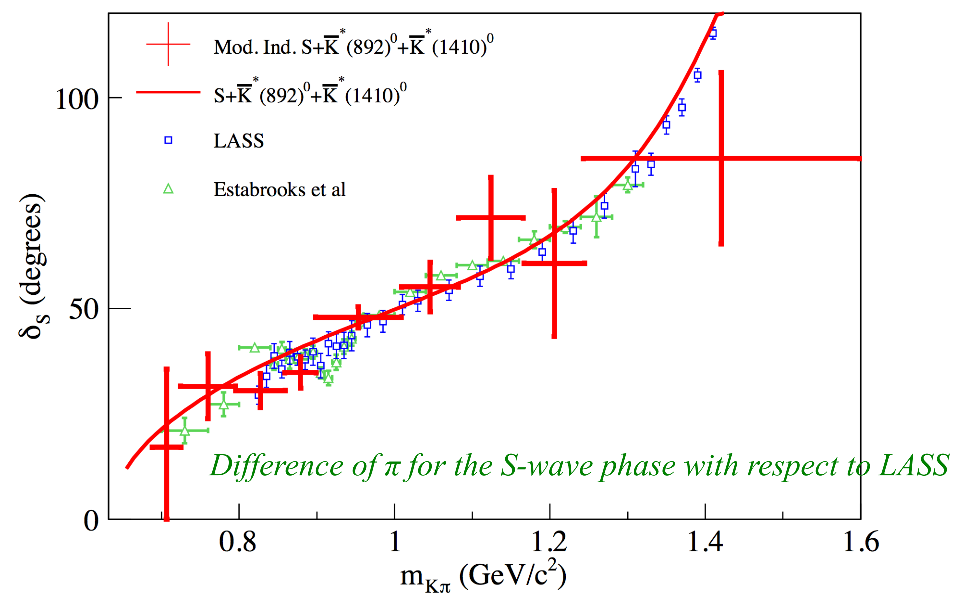


Analysis of the D^+ to $K^-\pi^+e^+\nu_e$ Decay Channel - Results

Phys. Rev. D 83, 072001 (2011)

$$r_v = \frac{V(0)}{A_1(0)} \qquad r_2 = \frac{A_2(0)}{A_1(0)}$$

variable	$S+\overline{K}^*(892)^0$	$S+\overline{K}^*(892)^0$ $\overline{K}^*(1410)^0$	$S+\overline{K}^*(892)^0$ $\overline{K}^*(1410)^0+D$
$m_{K^*(892)}(\mathrm{MeV}/c^2)$	894.77 ± 0.08	895.43 ± 0.21	895.27 ± 0.15
$\Gamma^0_{K^*(892)}(\mathrm{MeV}/c^2)$	45.78 ± 0.23	46.48 ± 0.31	46.38 ± 0.26
$r_{BW}(\mathrm{GeV}/c)^{-1}$	3.71 ± 0.22	2.13 ± 0.48	2.31 ± 0.20
$m_A(\mathrm{GeV}/c^2)$	2.65 ± 0.10	2.63 ± 0.10	2.58 ± 0.09
r_V	1.458 ± 0.016	1.463 ± 0.017	1.471 ± 0.016
r_2	0.804 ± 0.020	0.801 ± 0.020	0.786 ± 0.020
$r_S(\mathrm{GeV})^{-1}$	-0.470 ± 0.032	-0.497 ± 0.029	-0.548 ± 0.027
$r_S^{(1)}$	0.17 ± 0.08	0.14 ± 0.06	0.03 ± 0.06
$a^{1/2}_{S,BG}(\mathrm{GeV}/c)^{-1}$	1.82 ± 0.14	2.18 ± 0.14	2.10 ± 0.10
$b^{1/2}_{S,BG}(\mathrm{GeV}/c)^{-1}$	-1.66 ± 0.65	1.76 fixed	1.76 fixed
$r_{K^*(1410)^0}$		0.074 ± 0.016	0.052 ± 0.013
$\delta_{K^*(1410)^0}$(degree)		8.3 ± 13.0	0 fixed
$r_D(\mathrm{GeV})^{-4}$			0.78 ± 0.18
δ_D(degree)			0 fixed
N_{sig}	243850 ± 699	243219 ± 713	243521 ± 688
N_{bkg}	107370 ± 593	108001 ± 613	107699 ± 583
Fit probability	4.6%	6.4%	8.8%



Form Factors

$$r_v = \frac{V(0)}{A_1(0)} = 1.463 \pm 0.017 \pm 0.032$$

$$r_2 = \frac{A_2(0)}{A_1(0)} = 0.801 \pm 0.020 \pm 0.020$$

$$m_A = 2.63 \pm 0.10 \pm 0.13\, GeV/c^2$$

K^{*0}(892) Resonance

$$m(\overline{K}^{*0}(892)) = 895.4 \pm 0.2 \pm 0.2\, MeV/c^2$$

$$\Gamma(\overline{K}^{*0}(892)) = 46.5 \pm 0.3 \pm 0.2\, MeV/c^2$$

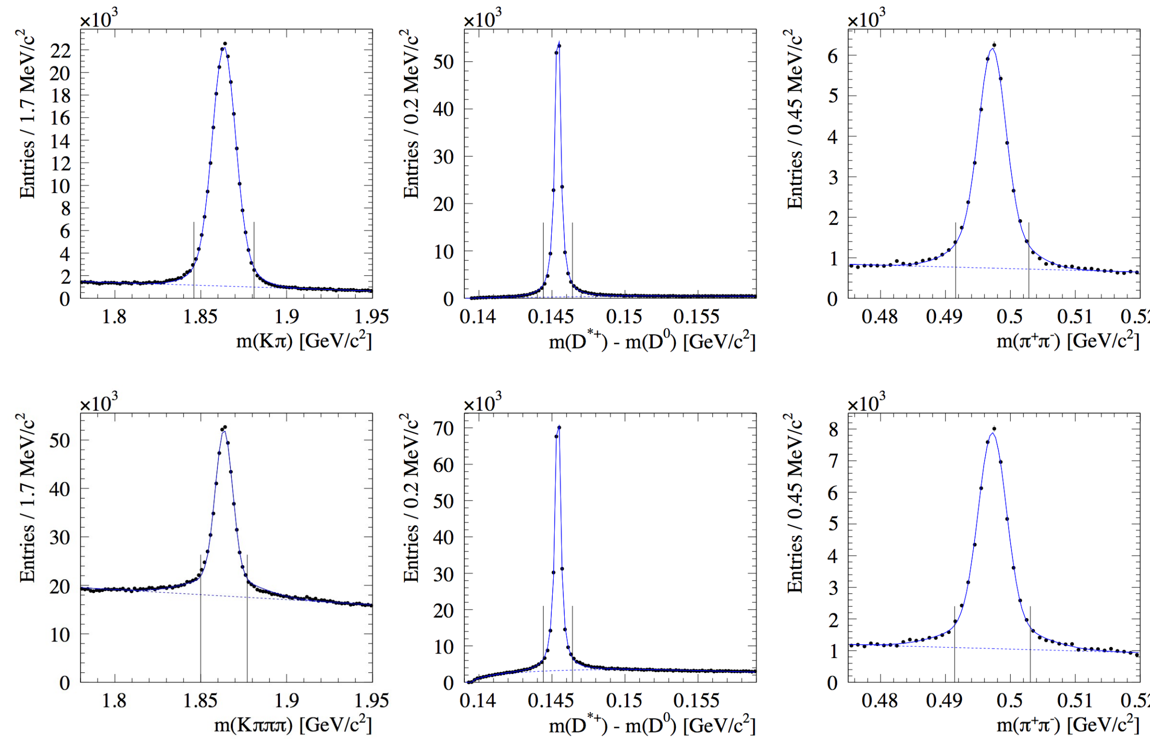
$$r_{BW} = 2.1 \pm 0.5 \pm 0.5\,(GeV/c)^{-1}$$

Precision Measurement of the Mass and Width of the $D_{s1}(2536)^+$

Phys. Rev. D 83 072003 (2011)

$$D_{s1}(2536)^+ \rightarrow D^{*+} K^0_S$$

$D_{s1}^{\ +}$ reconstructed via the decay $D^{*+}K_S$
K_s reconstructed via $\pi^+\pi^-$
D^{*+} reconstructed via $D^0\pi^+$
D^0 to $K^-\pi^+$, and D^0 to $K^-\pi^+\pi^-\pi^+$



Relativistic Breit-Wigner convoluted with $p^*(D_{s1}^{\ +})$-dependent resolution function

$$\left(\frac{p_{1,m}}{p_{1,m_0}}\right)^{2L+1}\left(\frac{m_0}{m}\right)\frac{mF_L(p_{1,m})^2}{(m_0^2-m^2)^2+\Gamma_m^2 m_0^2}$$

$$F_0(p_{1,m})=1,$$

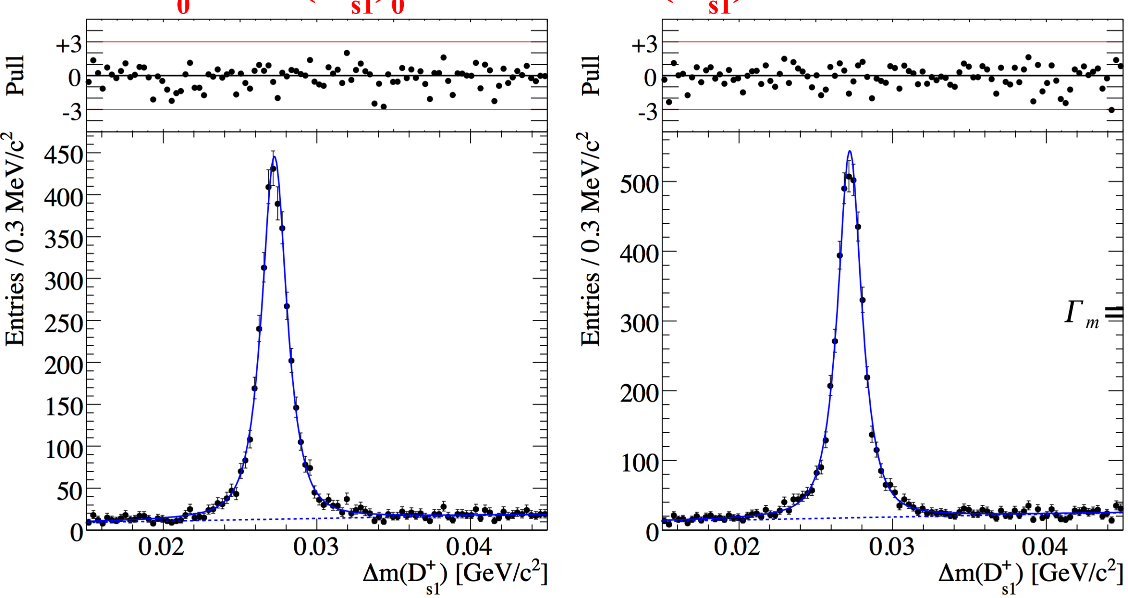
$$F_1(p_{1,m})=\frac{\sqrt{1+(Rp_{1,m_0})^2}}{\sqrt{1+(Rp_{1,m})^2}},$$

$$F_2(p_{1,m})=\frac{\sqrt{9+3(Rp_{1,m_0})^2+(Rp_{1,m_0})^4}}{\sqrt{9+3(Rp_{1,m})^2+(Rp_{1,m})^4}},$$

$$\Gamma_m=\Gamma(D^+_{s1})\left(B_1\left(\frac{p_{1,m}}{p_{1,m_0}}\right)^{2L+1}\left(\frac{m_0}{m}\right)F_L(p_{1,m})^2+B_2\left(\frac{p_{2,m}}{p_{2,m_0}}\right)^{2L+1}\left(\frac{m_0}{m}\right)F_L(p_{2,m})^2\right),$$

$$B_1(D^+_{s1}\rightarrow D^{*+}K^0),\ B_2(D^+_{s1}\rightarrow D^{*0}K^+)$$

$m_0 = \Delta m(D_{s1})_0$ and $m = \Delta m(D_{s1})$



$$\Delta m(D^+_{s1})=m(D^+_{s1})-m(D^{*+})-m(K^0_S)$$

$\Gamma(D_{s1}^{\ +})$ = 0.92 +/- 0.03 +/- 0.04 MeV
$m(D_{s1}^{\ +})$ = 2535.08 +/- 0.01 +/- 0.15 MeV/c^2
Confirm $J^P = 1^+$

A simulated signal event in the BaBar detector

$$c\, c \rightarrow D^0\, K^-\, X\, D_s^{*+}$$

$D^0 \rightarrow K^+\pi^-\pi^0$, $X \rightarrow \pi^+\pi^-\pi^0$, $D_s^{*+} \rightarrow (\mu^+\nu_\mu)\gamma$