Rare and *CP* Correlated Charm Meson Decays

Results from CLEO-c
and
Opportunities for BES-III

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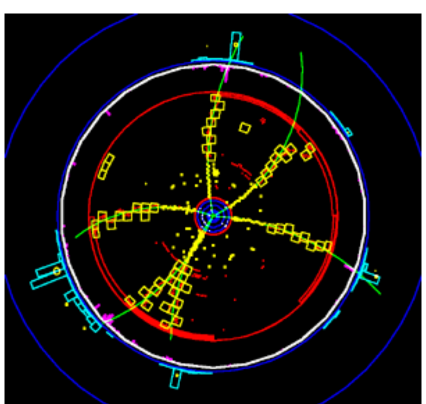


CLEO-c

Rensselaer

Rare Decays

Challenge to match physics goals against production rates and detection efficiencies. *Two examples*:

- Rare decay $D^0 \to K^- \pi^+ \pi^- e^+ \nu_e$

  The "Last remaining semileptonic decay" according to Heavy Quark Effective Theory

  See Phys Rev Lett 99(2007)191801

- Forbidden decays $D^+ \to h^\pm e^\mp e^+$

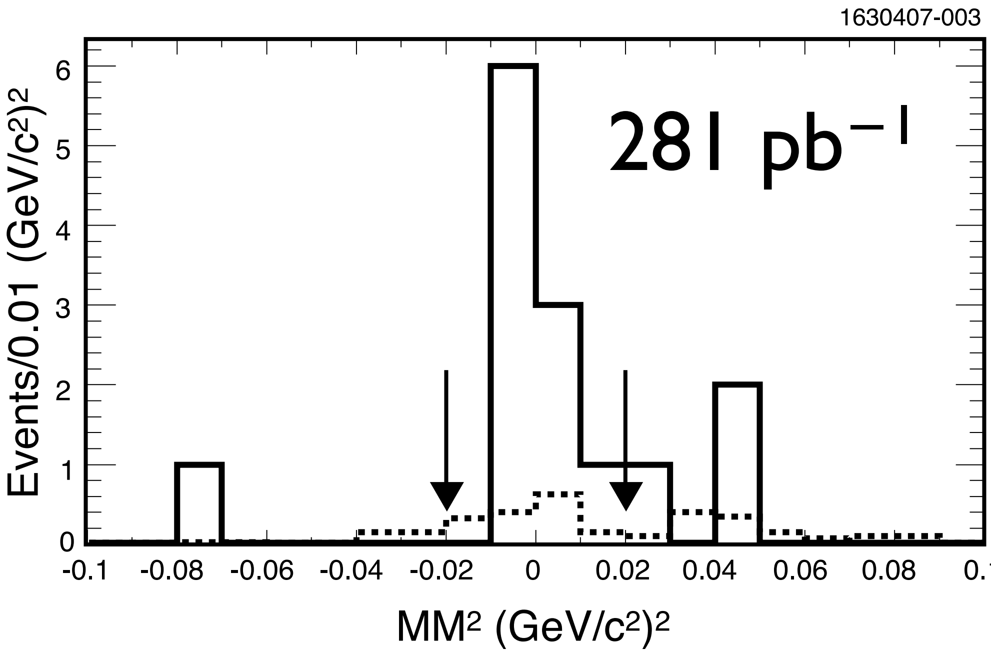
  Physics beyond the Standard Model

  See Phys Rev Lett 95(2005)221802

$D^0 \to K^- \pi^+ \pi^- e^+ \nu_e$

Heavy Quark Effective Theory (HQET) predicts that $D^0 \to K_1(1270) e \nu_e$ dominates decays to "excited" mesons

Clear signal, low background, but *not very many events*.



$$\mathcal{B}(D^0 \to K^- \pi^+ \pi^- e^+ \nu_e) = [2.8^{+1.4}_{-1.1}(\mathrm{stat}) \pm 0.3(\mathrm{syst})] \times 10^{-4}$$

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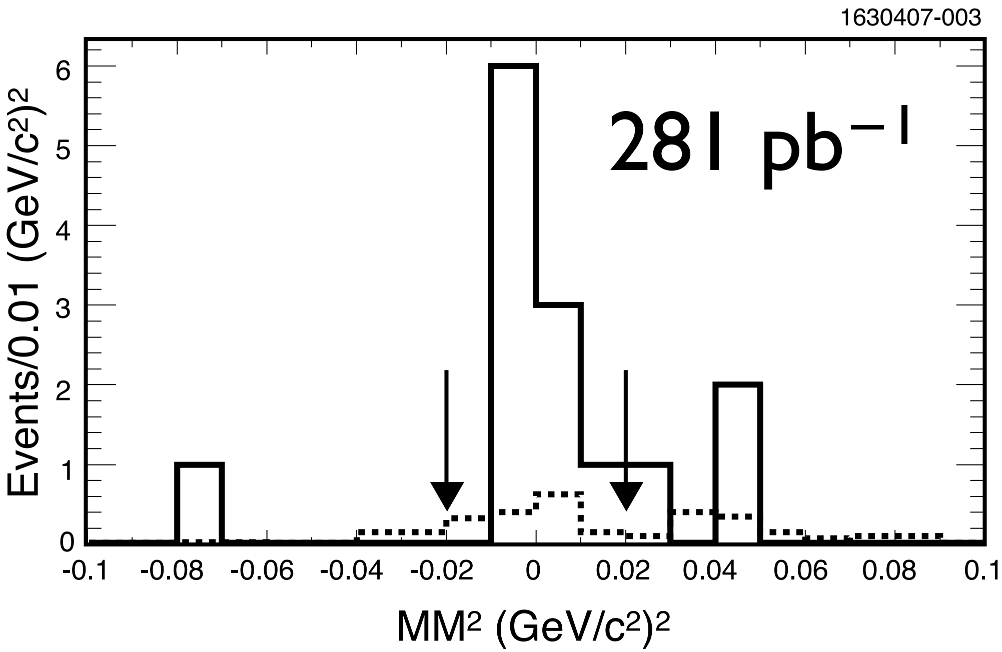
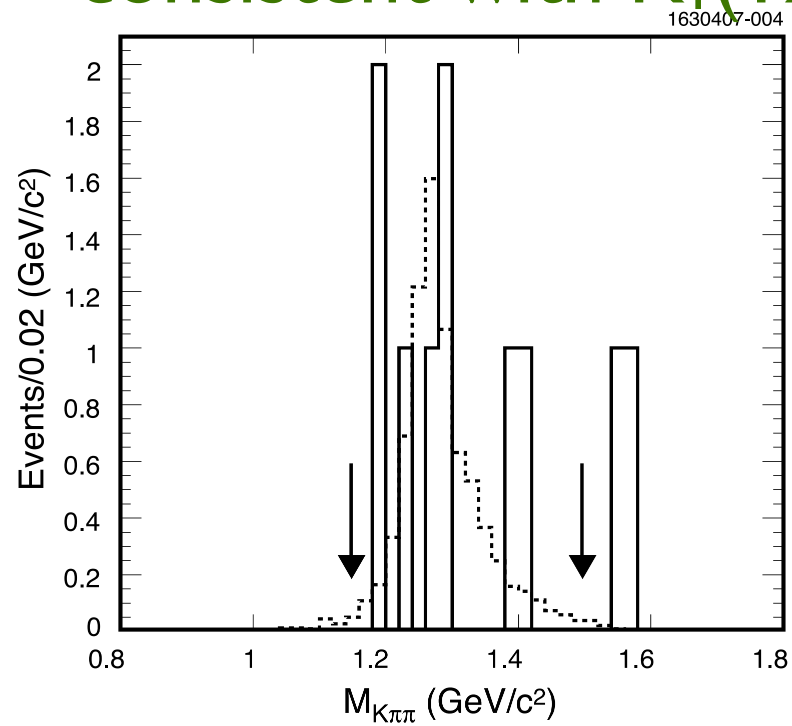


Hadronic invariant mass consistent with $K_1(1270)$



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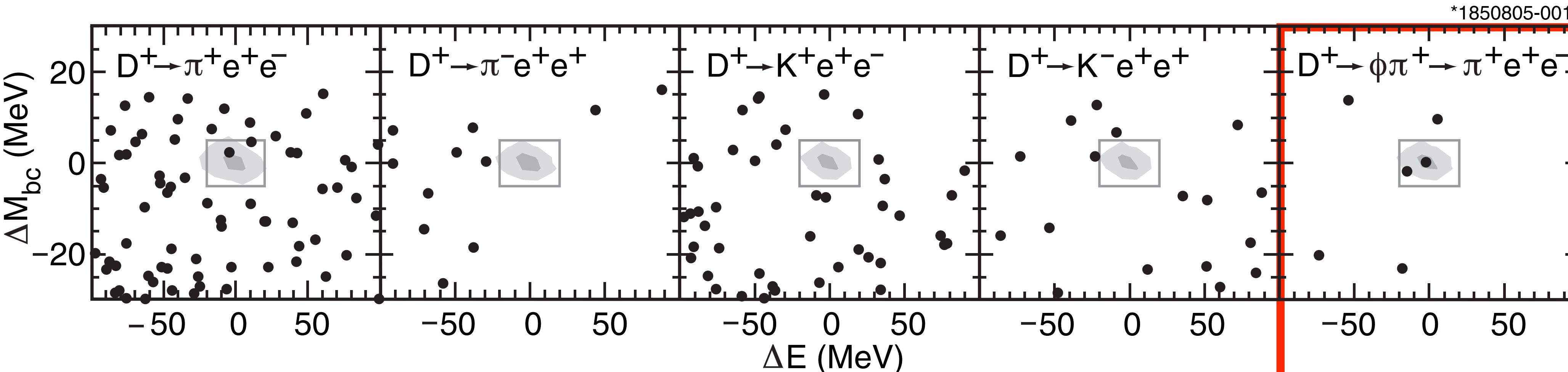
$$\mathcal{B}(D^0 \to K_1^-(1270)\ e^+ \nu_e) = [7.6^{+4.1}_{-3.0}\ (\mathrm{stat}) \pm 0.6\ (\mathrm{syst}) \pm 0.7] \times 10^{-4}$$

$D^+ \to h^\pm e^\mp e^+$

Well-known windows “beyond the Standard Model” from Flavor Changing Neutral Currents & Lepton Number Violation



281 pb^{-1}

$$\mathcal{B}(D^+ \to \pi^+ e^+ e^-) < 7.4 \times 10^{-6},$$
$$\mathcal{B}(D^+ \to \pi^- e^+ e^+) < 3.6 \times 10^{-6},$$
$$\mathcal{B}(D^+ \to K^+ e^+ e^-) < 6.2 \times 10^{-6},$$
$$\mathcal{B}(D^+ \to K^- e^+ e^+) < 4.5 \times 10^{-6}.$$

Allowed! Useful to calibrate and test analysis.

CP Correlations

Exploit unique properties of production mechanism

$$e^+e^- \longrightarrow \psi(3770) \longrightarrow \left(D^0\bar{D}^0\right)_{\ell=1}$$

Examples:

- Observation of *CP* Correlations
- Dalitz Plot structure of $D^0 \rightarrow K_S\pi^+\pi^-$

  Application to *CP* violation in $B \rightarrow DK$
- Charm mixing and *CP* violation

  Analyses in progress at CLEO-c

  Opportunities for BES III

The Essential Point

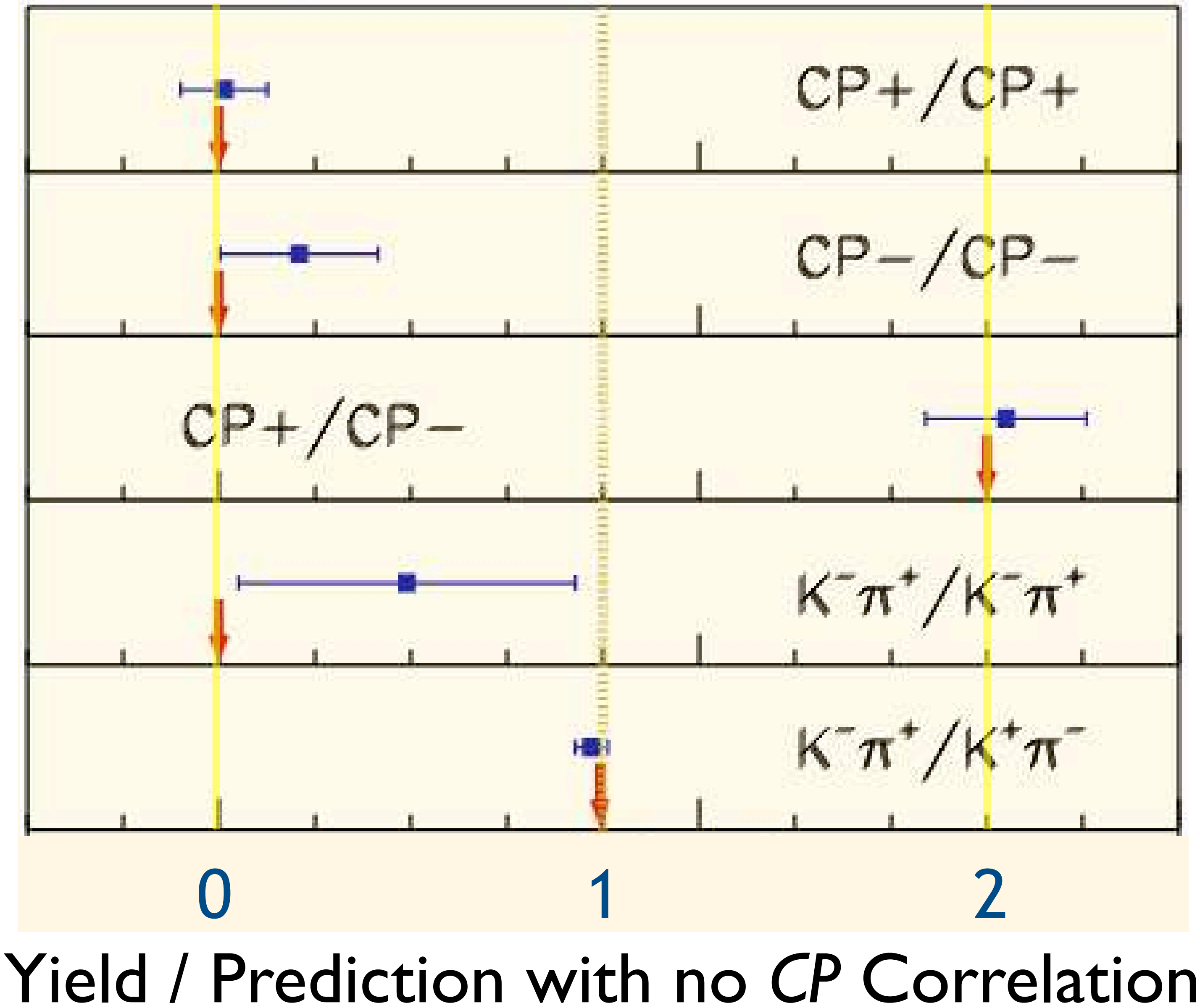
Interference of amplitudes comes "for free" when we integrate decay rate over all times.

$\psi(3770)$ has *CP*=+*1*, and then so does $\left(D^0\bar{D}^0\right)_{\ell=1}$

➥ Must have $CP(\bar{D}^0) = -CP(D^0)$ (assuming there is no *CP* violation)

Also: Flavor must be anti-correlated, but "wrong sign" flavor can enter through double Cabibbo suppression *and* charm mixing.

Observation of *CP* Correlations



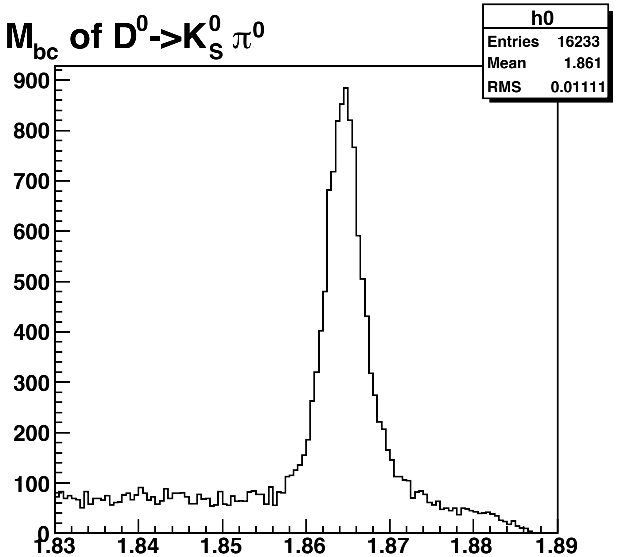
"Wrong" *CP* consistent with zero, but...

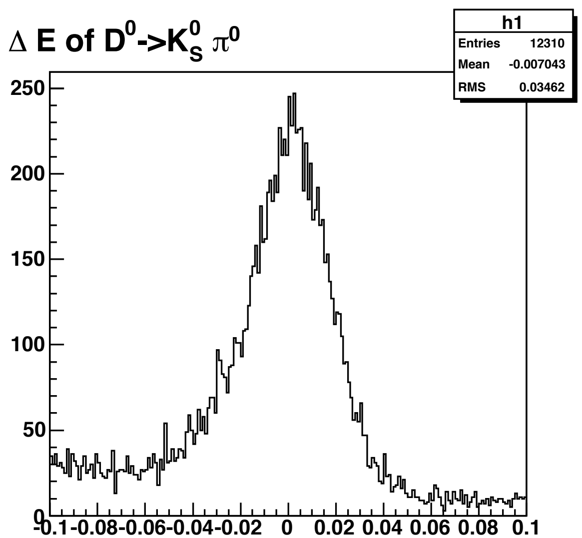
...it "doubles up" when it should!

Flavor appears unaffected, and is in fact small.

Exploit with "tag side" D^0

Example: CP odd





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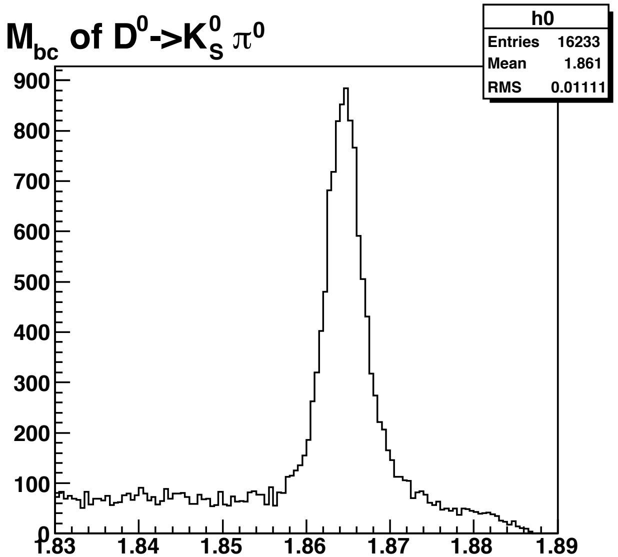
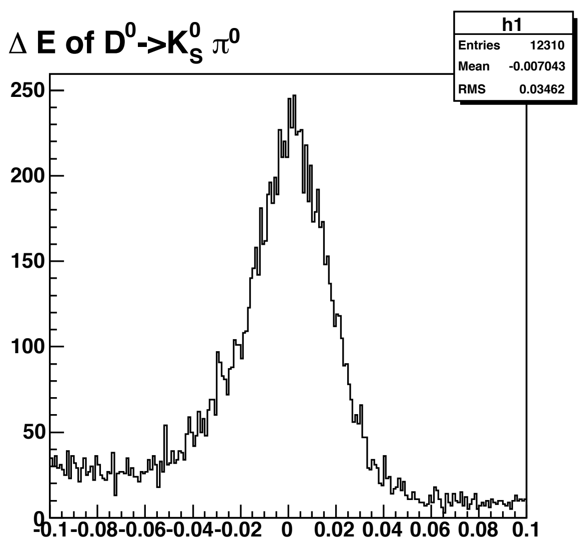
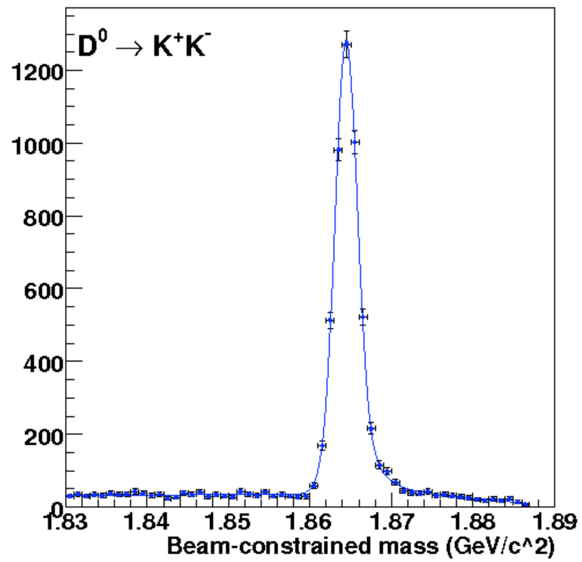




Example: CP even



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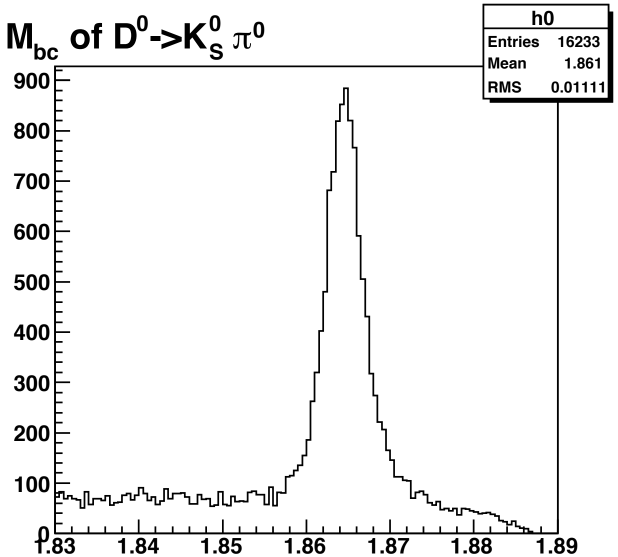

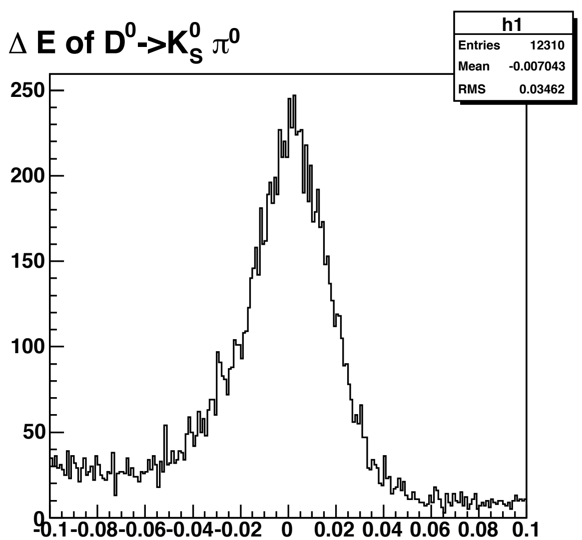

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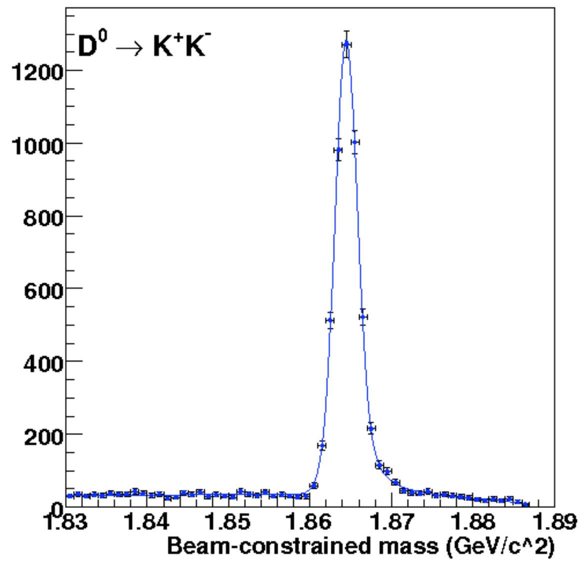
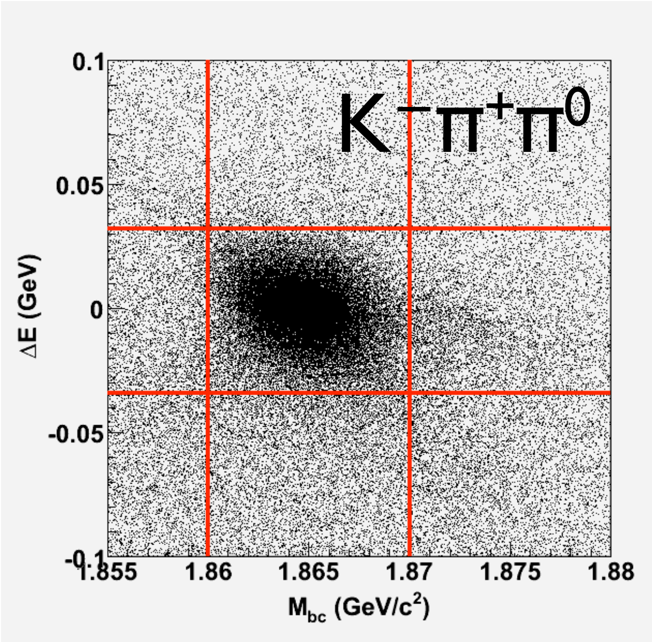


Example: Flavor



Exploit with “tag side” D^0

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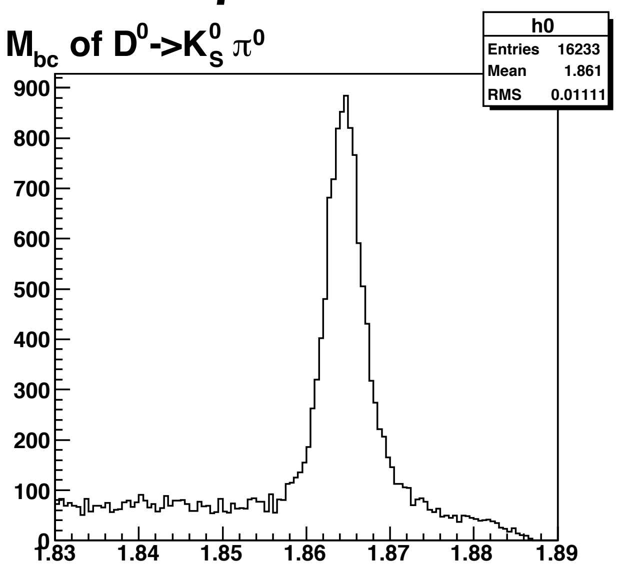

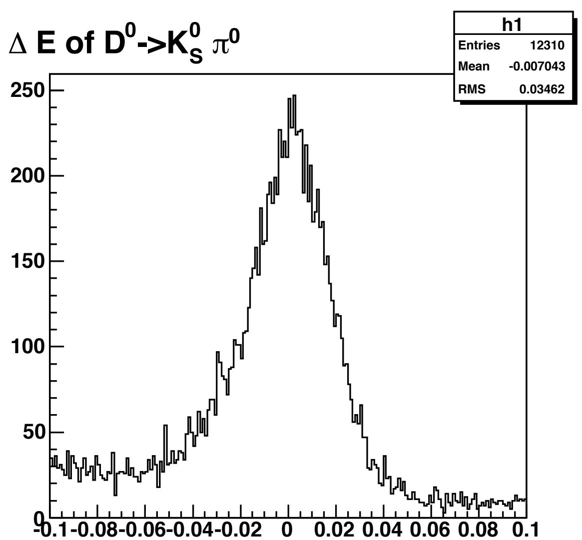

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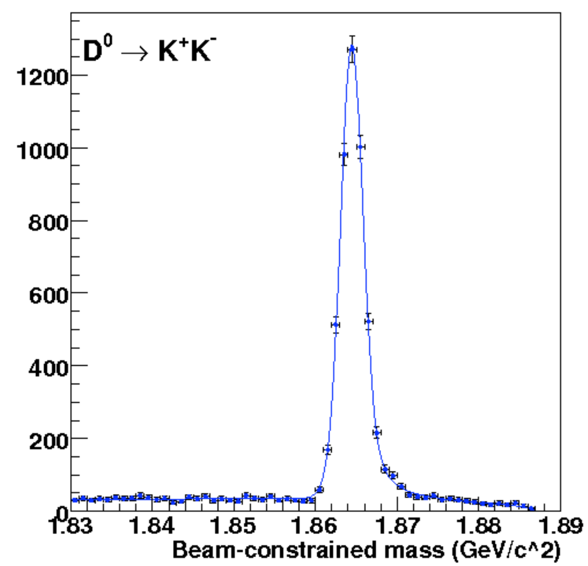

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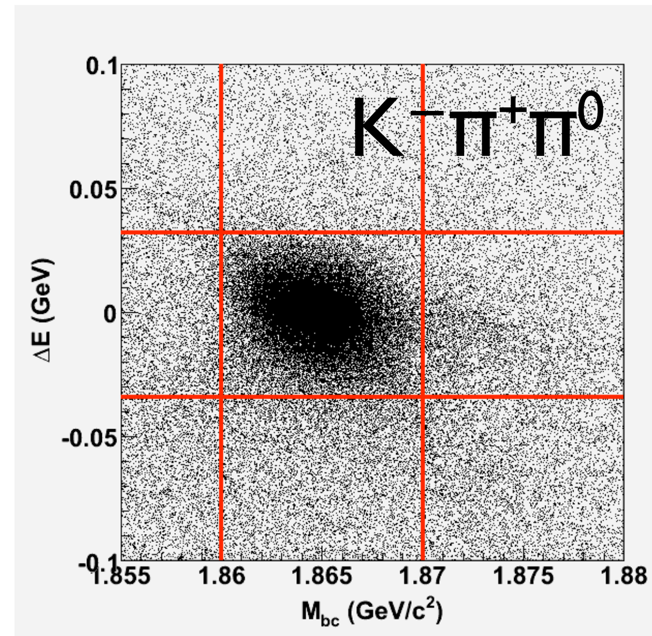

<u>*Also*</u> semileptonic tags for “pure” flavor, as well as many other decay *CP* eigenstates

Dalitz Plot structure of $D^0 \to K_S \pi^+ \pi^-$

Interesting mode: Flavor and *CP* content depends on the position of the decay in phase space.

e.g. $(K^*)^- \pi^+$ is "charm" but $K_S \rho$ is "$CP = -1$"

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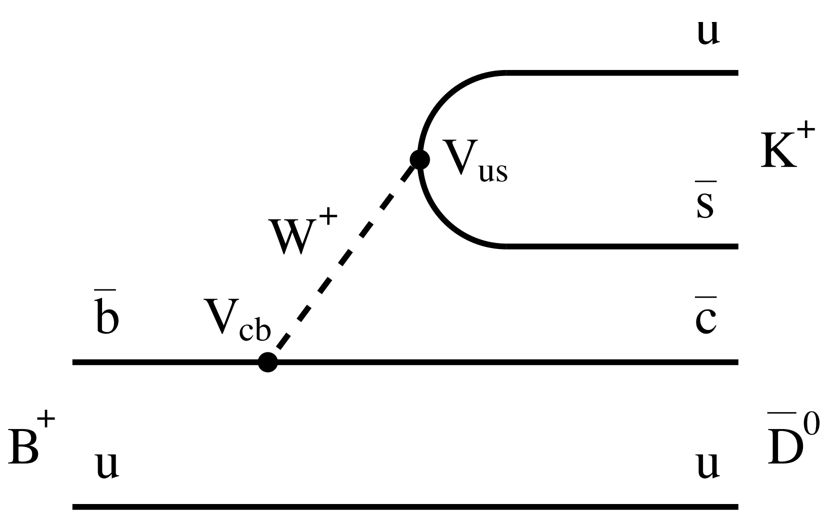
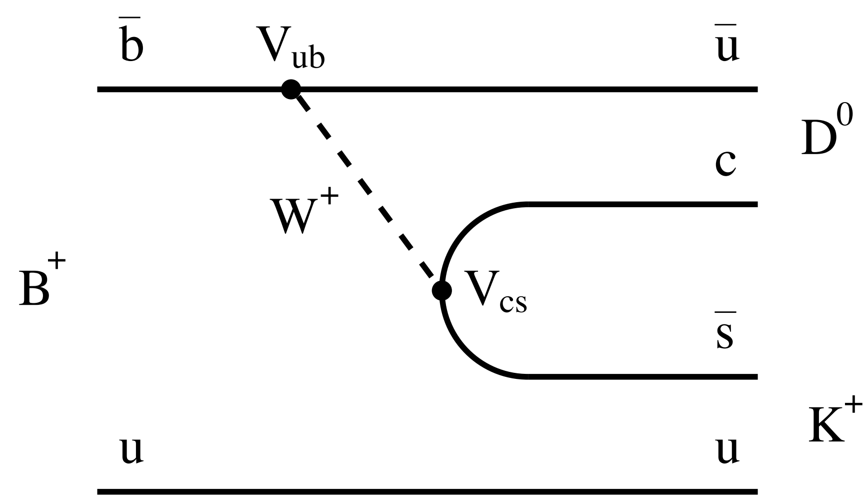
Useful "application": Determine γ/φ_3 from $B \to DK$

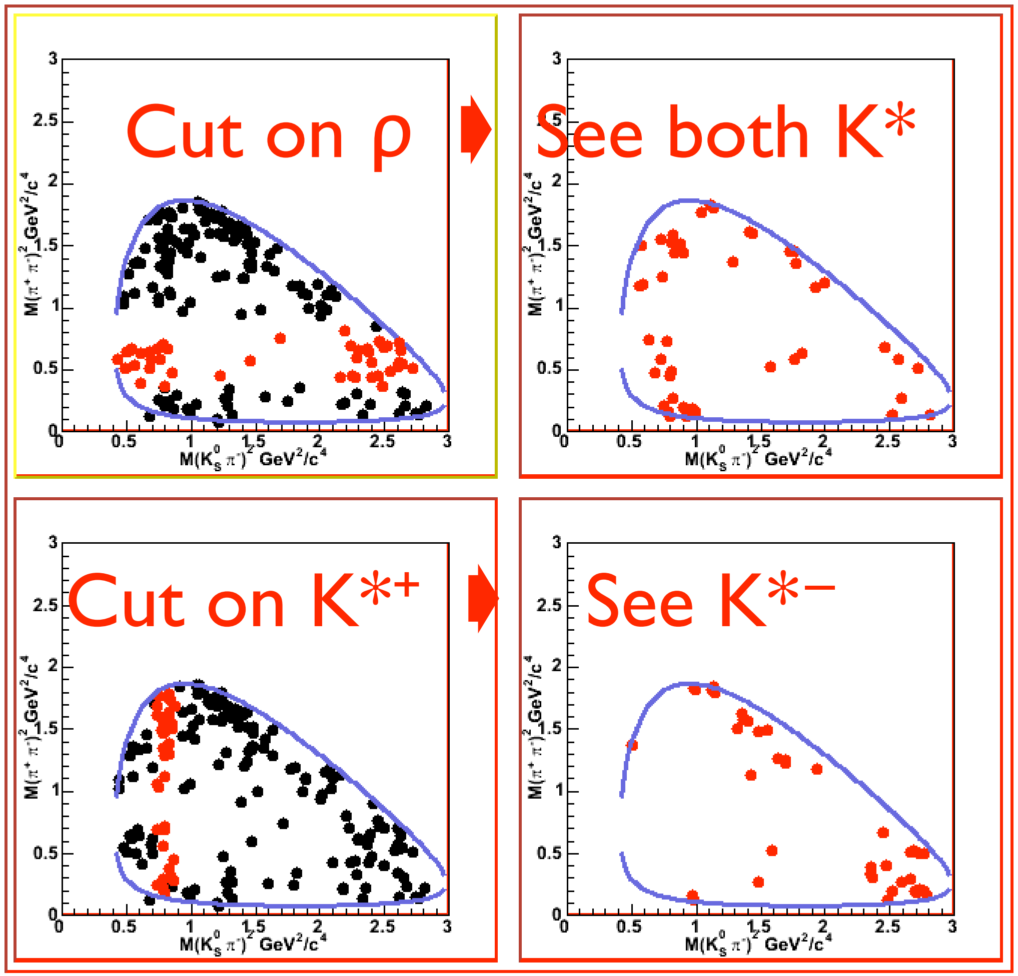




Example #1: Model Dependent Approach

$$e^+e^- \to \left(K_S\pi^+\pi^-\right)\left(K_S\pi^+\pi^-\right)$$

Two "large" branching ratios



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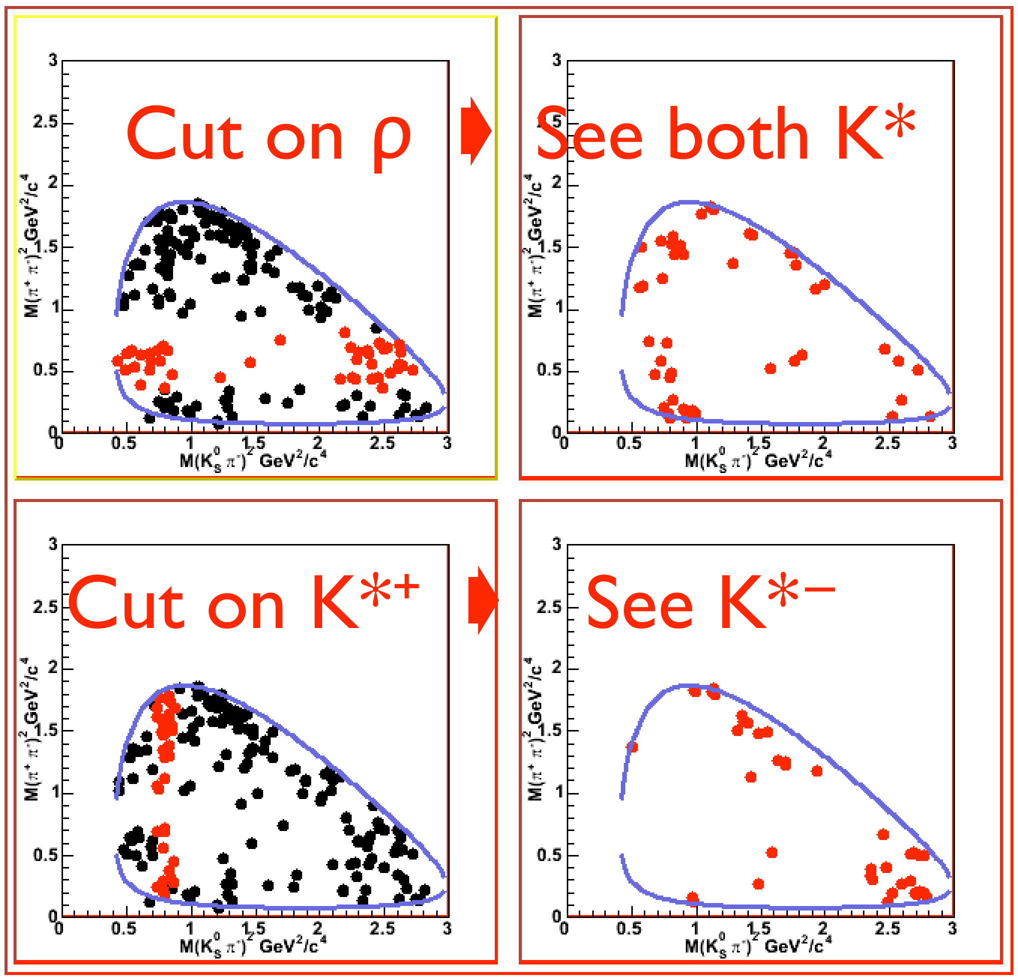
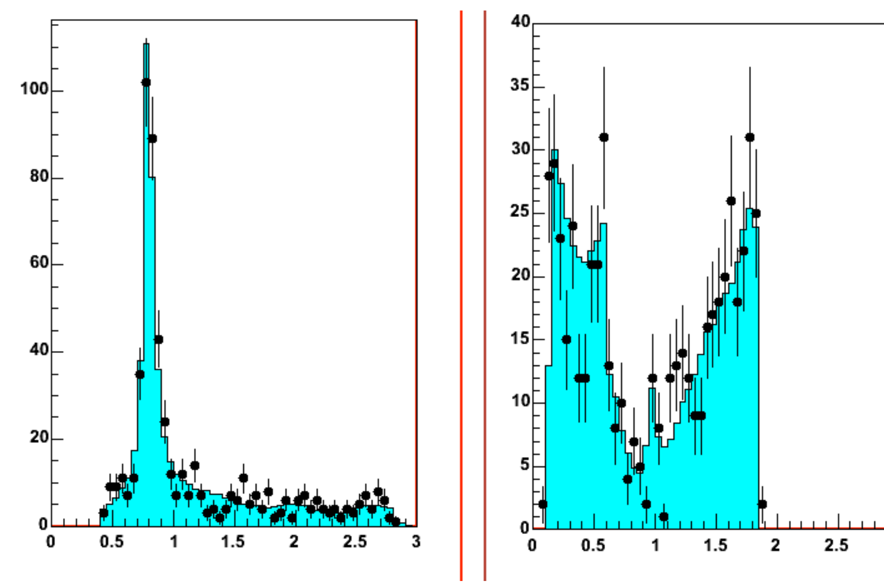


Fit to the "double Dalitz" plot with correlations.

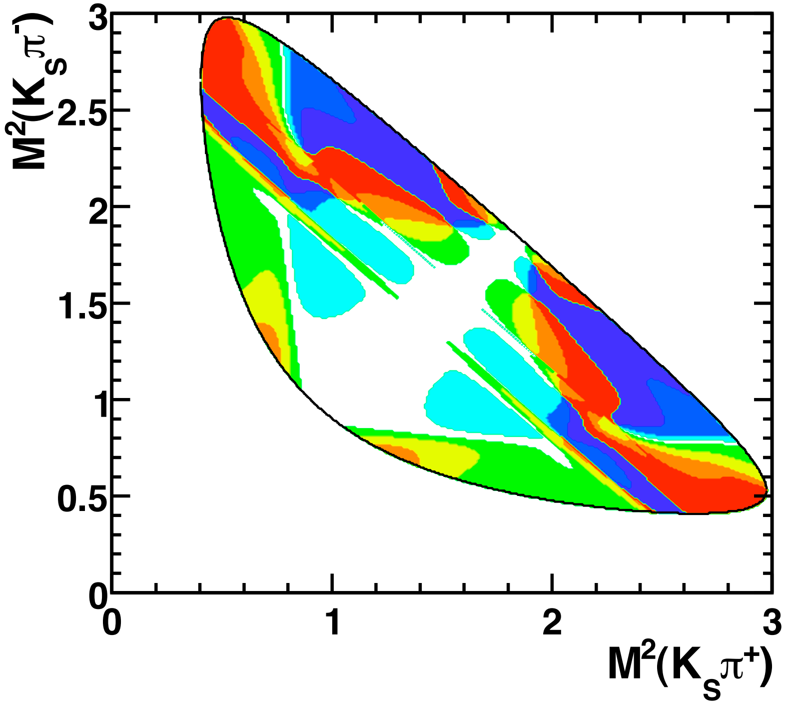


$M^2(K_S\pi^+)$ $M^2(\pi^+\pi^-)$

Analysis in progress.

Example #2: Model Independent Approach

See E. White, Q. He, et al, arXiv:0711.2285 (Charm 2007)



Symmetric binning by *phase*.

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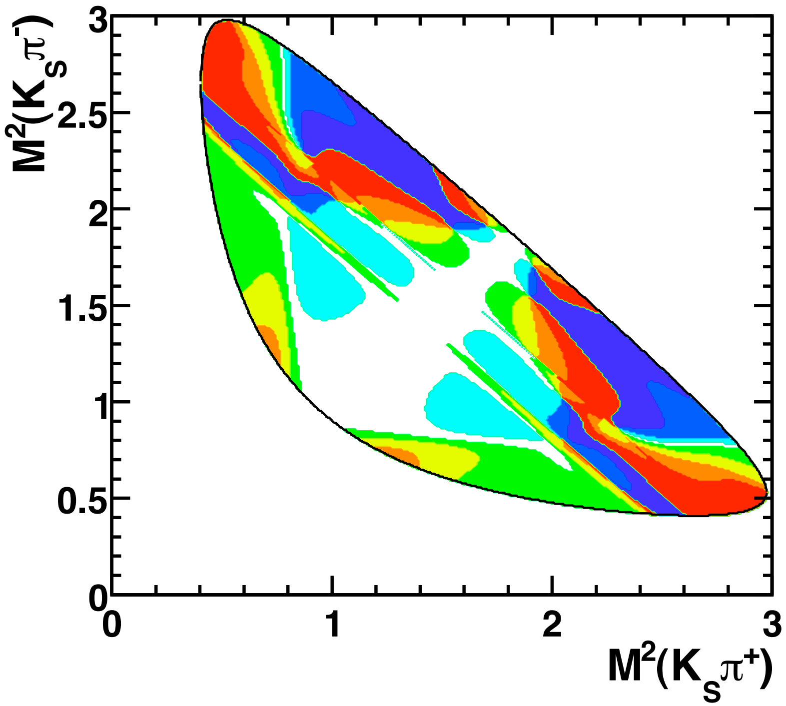

Symmetric binning by *phase*.

Tag Mode	$K_S\pi^+\pi^-$	$K_L\pi^+\pi^-$
K^+K^-	61	194
$\pi^+\pi^-$	33	90
$K_S\pi^0$	108	263
$K_S\eta$	29	21
$K_L\pi^0$	190	-

Events for 398 pb^{-1}

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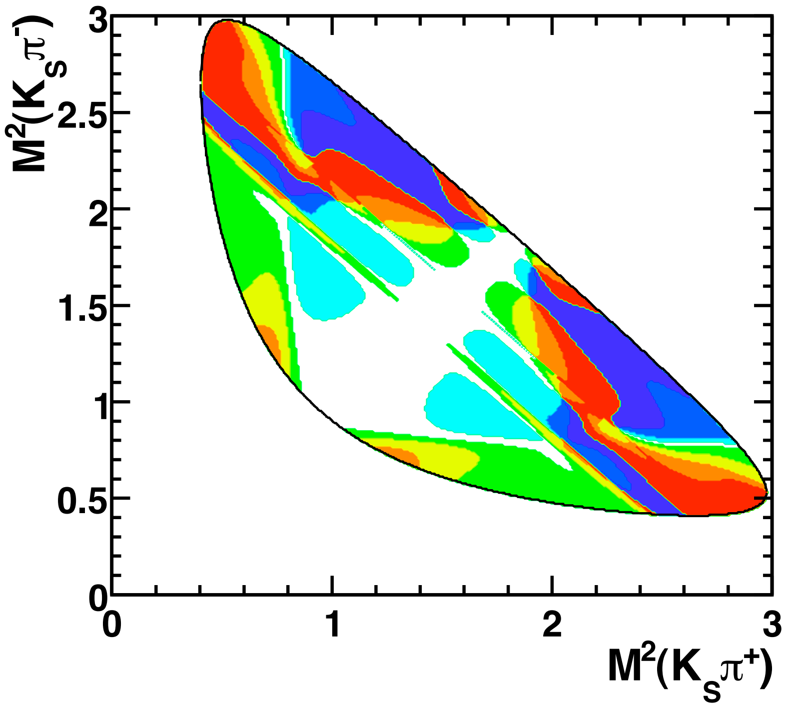

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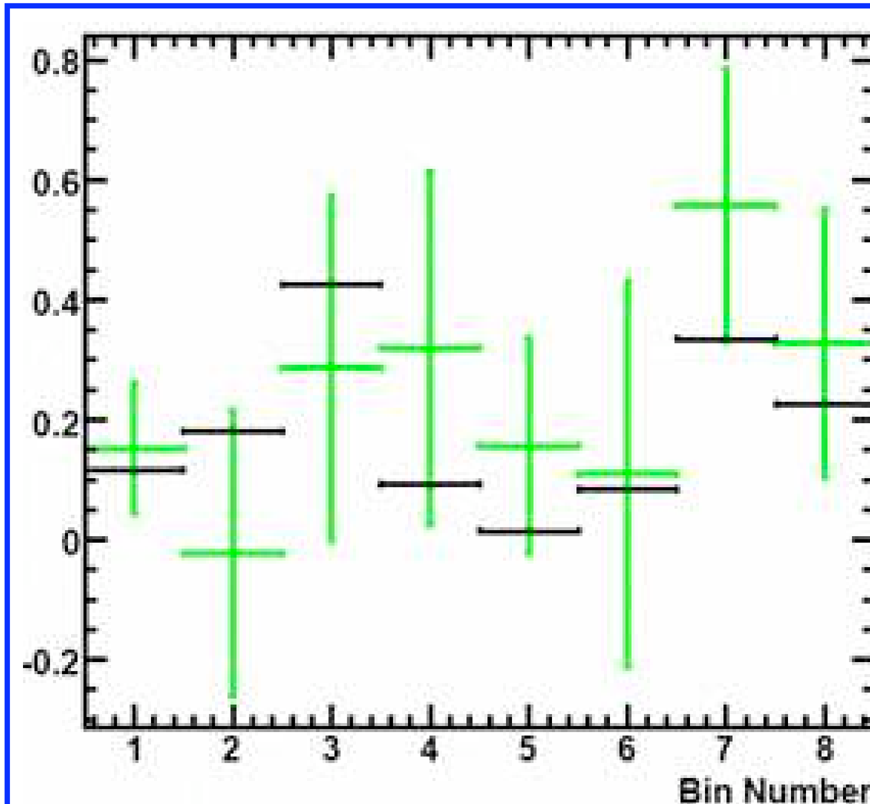

Difference in c_i for $K_L\pi^+\pi^-$ and $K_S\pi^+\pi^-$ for model and data.

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Charm Mixing and *CP* violation

$$x = \frac{\Delta M}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma}$$

Standard mixing parameters

$$\frac{\langle K^-\pi^+|\bar{D}^0\rangle}{\langle K^-\pi^+|D^0\rangle} = -re^{-i\delta}$$

"Strong phase"

First measurement from CLEO-c

$$\begin{aligned} x' &= x\cos\delta + y\sin\delta \\ y' &= -x\sin\delta + y\cos\delta \end{aligned}$$

Formalism

See: Asner & Sun, Phys.Rev. D73(2006)034024
(Recently updated on arXiv as hep/ph:0507238v3)

$$\Gamma^{C-}(j,k) = Q_M \left|A^{(-)}(j,k)\right|^2 + R_M \left|B^{(-)}(j,k)\right|^2$$
$$\Gamma^{C+}(j,k) = Q'_M \left|A^{(+)}(j,k)\right|^2 + R'_M \left|B^{(+)}(j,k)\right|^2 + C^{(+)}(j,k),$$

$$A^{(\pm)}(j,k) \equiv \langle j|D^0\rangle\langle k|\overline{D}^0\rangle \pm \langle j|\overline{D}^0\rangle\langle k|D^0\rangle$$
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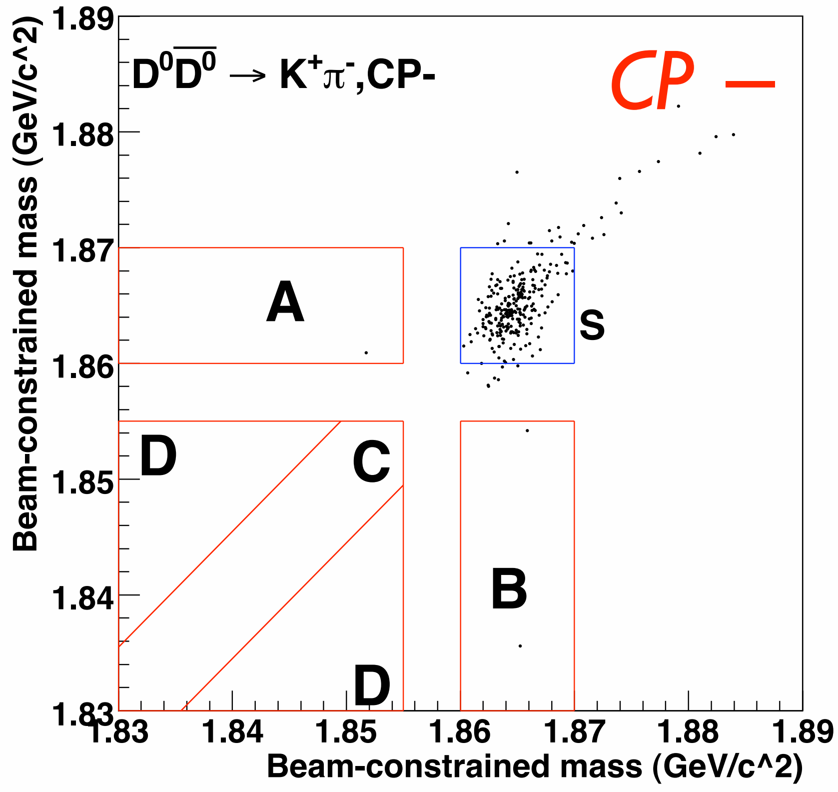
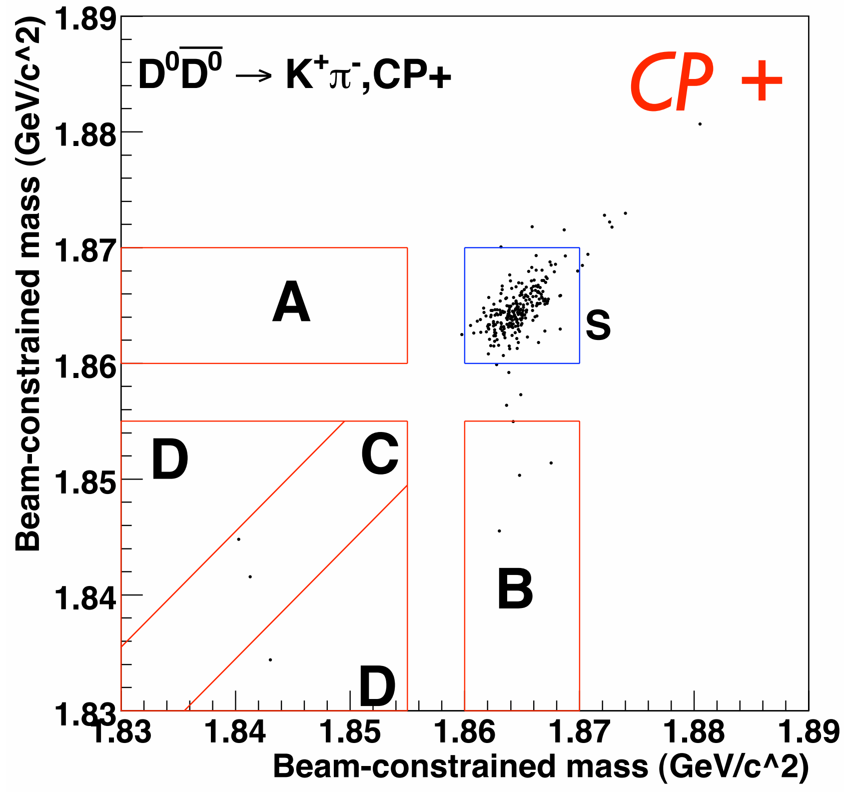
CP Violation

Preliminary Results

See W. Sun, Charm 2007





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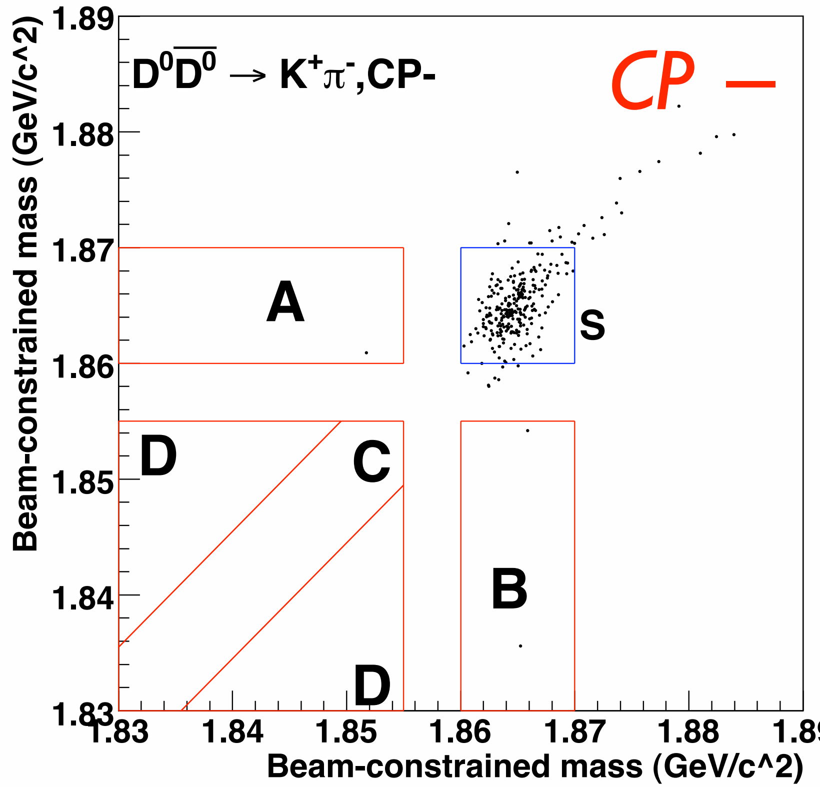

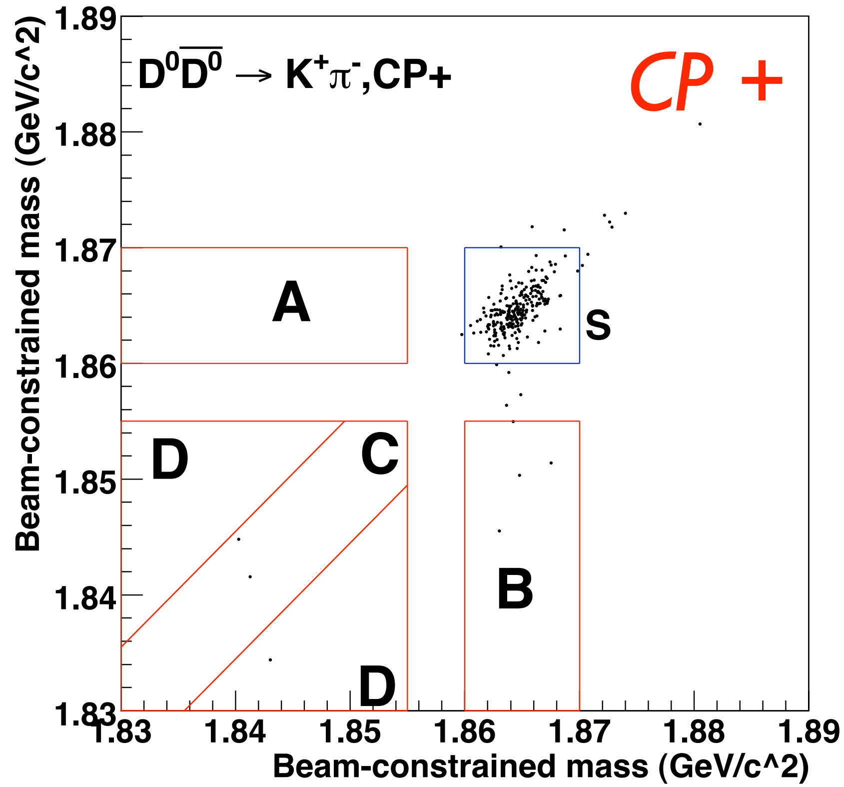

Quantity	Standard Fit	Extended Fit
N (10^6)	1.046±0.019±0.013	1.044±0.019±0.012
cos δ	1.03±0.19±0.08	0.93±0.32±0.04

Conclusions and Outlook

Many more results are yet to come from CLEO-c. Stay tuned.

The opportunities for BES-III are tremendous. Unique windows on charm mixing and possible physics beyond the Standard Model.

Thank you!