Charm Physics - Experimental

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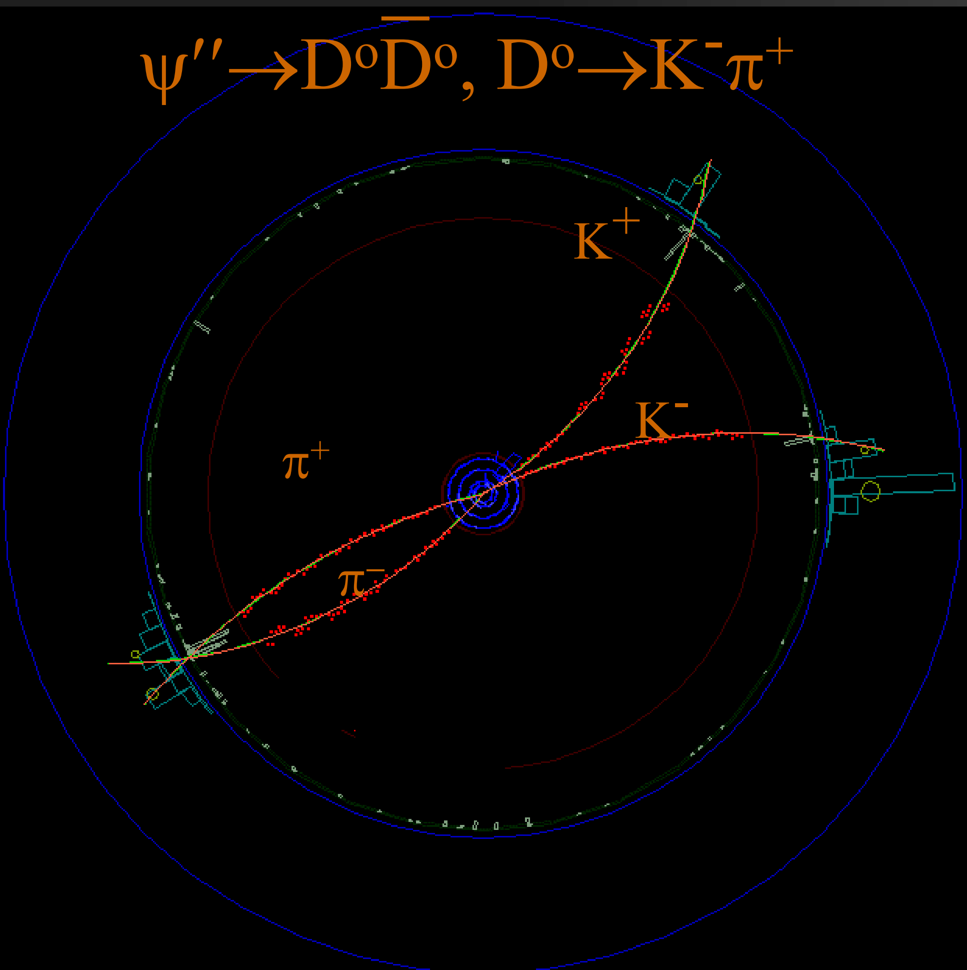
"I charm you, by my once-commended beauty"
Julius Cæsar, Act II, Scene I



Why Study Charm? – Overview

- Tests of Theoretical Models necessary to interpret critical CKM data, usually obtained from B decays
- CKM Matrix elements: Charm decays can be used to determine directly V_{cd} & V_{cs}, indirectly V_{ub} and contribute to V_{cb}
- Engineering measurements: e. g. absolute $\mathcal{B}$'s (& some inclusive ones, i.e. $D^{o,+} \rightarrow \phi X$)
- New Physics: May see in charm directly
  - SM CPV suppressed, perhaps also rare decays & mixing

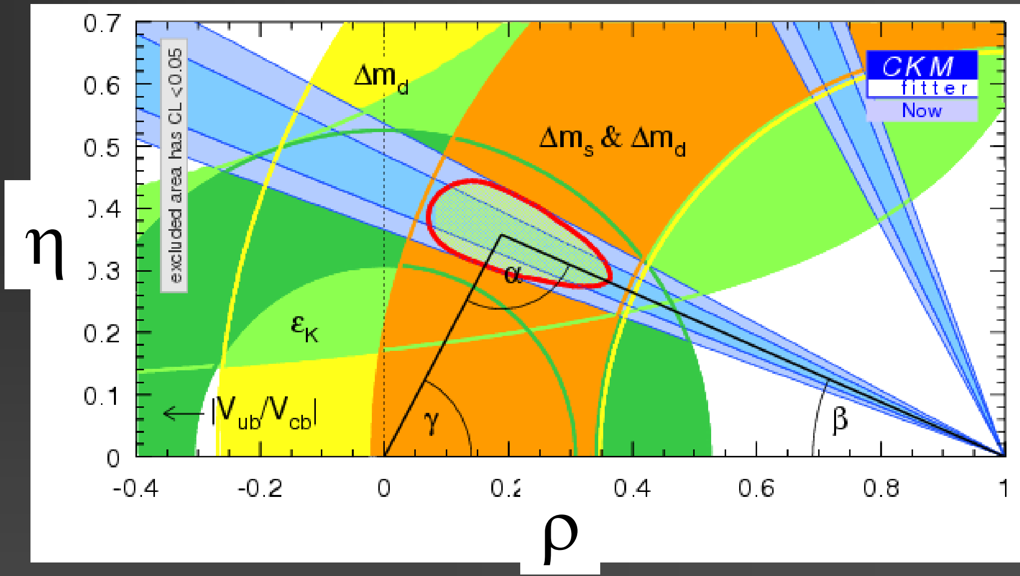
Use of Charm data to improve B measurements, etc..

Some examples:

Item: B_s mixing

- To relate constraints on CKM matrix in terms of say ρ & η need to use theoretical estimates of $f_{B_s}^2 B_{B_s} / f_{B_d}^2 B_{B_d}$
- CLEO-c's job: Measure f_{D_s}/f_{D^+} to check theoretical lattice calculations, best unquenched lattice.

Artists view of current constraints ±1σ bands, not precise

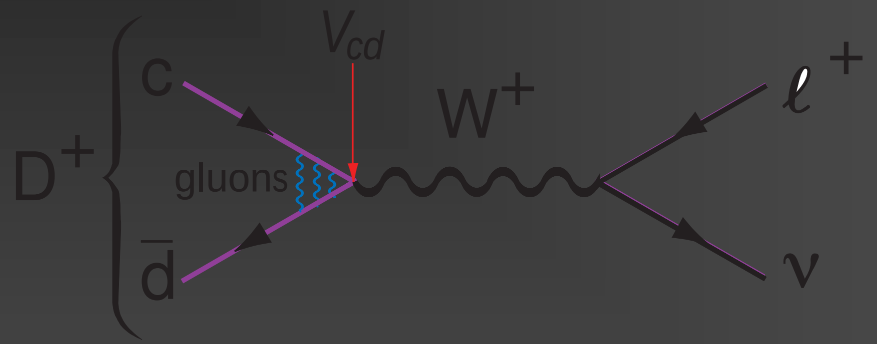


◆Idea is that (η,ρ) can be determined in several ways, differences will indicate new physics

Leptonic Decays: $D \to \ell^+\nu$

Introduction: Pseudoscalar decay constants: c and $\bar{q}$ can annihilate, probability is $\propto$ to wave function overlap

Example :



In general for all pseudoscalars:

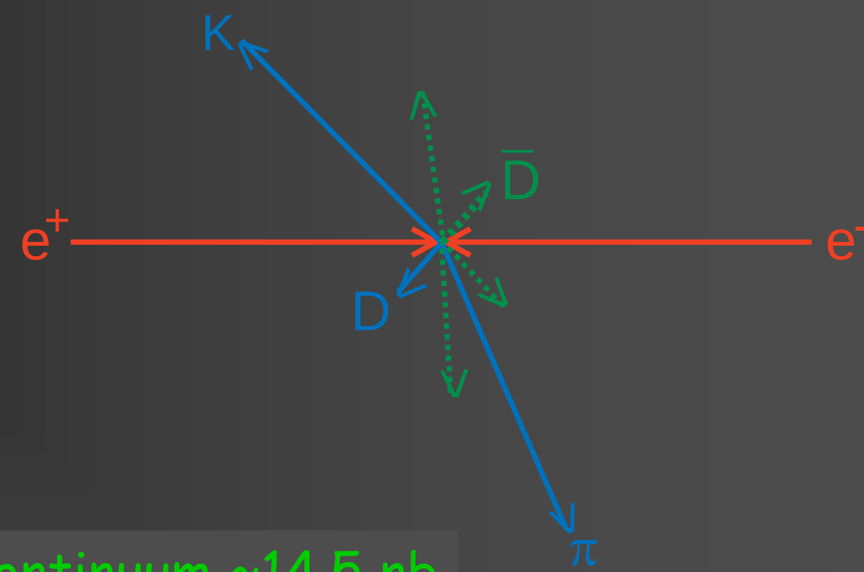
$$\Gamma(P^+ \to \ell^+\nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} is known

Experimental methods

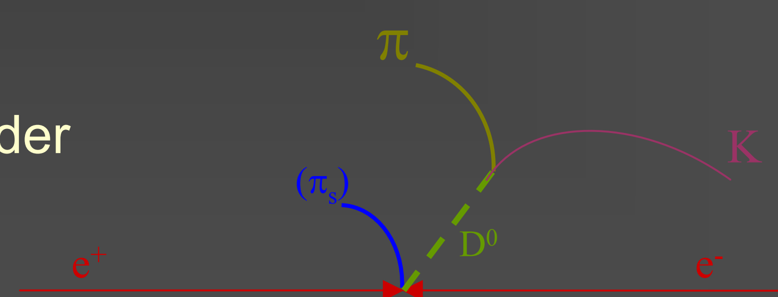
- $D\bar{D}$ production at threshold: used by Mark III, and more recently by CLEO-c and BES-II.
  - Unique event properties
    - ➢Only $D\bar{D}$ not $D\bar{D}x$ produced
  - Large cross sections:

$\sigma(D^o\bar{D}^o)$ = 3.72±0.09 nb
$\sigma(D^+D^-)$ = 2.82±0.09 nb
} World Ave



Continuum ~14.5 nb

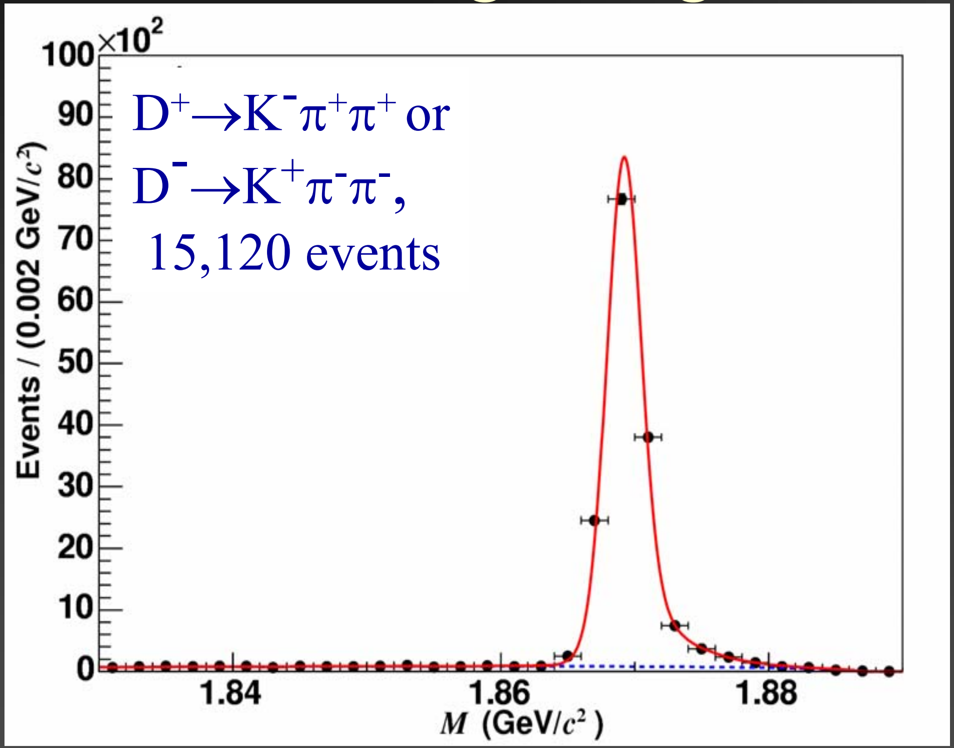
  - Ease of B measurements using "double tags"
  - $\mathcal{B}_A$ = # of A/# of D's



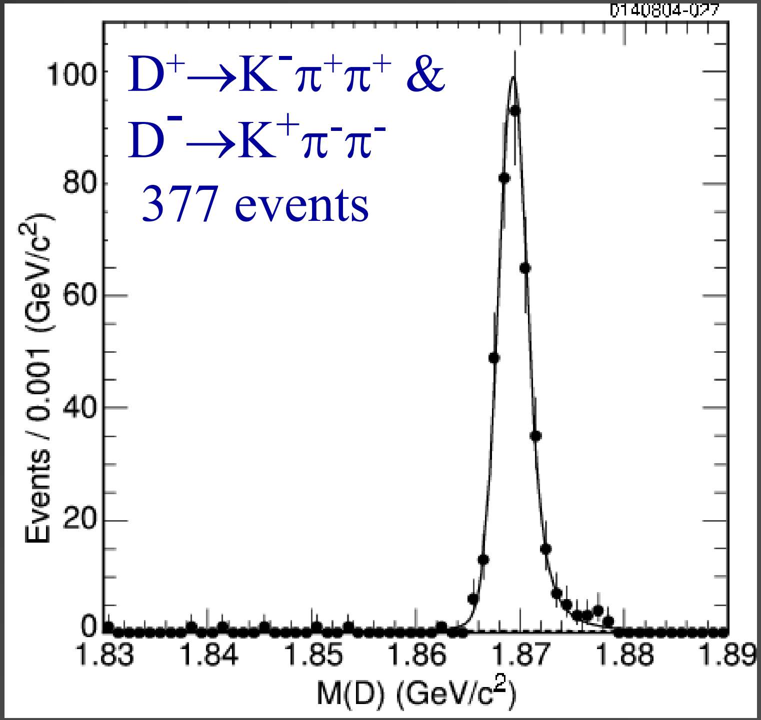
- B-factories (e^+e^-) + fixed target & collider experiments at hadron machines
  - D displaced vertex
  - $D^{*+} \rightarrow \pi^+ D^0$ tag

$D^+ \to K^-\pi^+\pi^+$ at the ψ'' (CLEO-c)

Single tags



Double



$$M_D^2 = \sum E_i^2 - \sum \vec{P}_i^2 = E_{beam}^2 - \sum \vec{P}_i^2$$

57 pb^{-1} of data at $\psi(3770)$, CLEO now has 281 pb^{-1}

Absolute $\mathcal{B}$ Results

$\mathcal{B}(D^+ \to K^- \pi^+ \pi^+)$

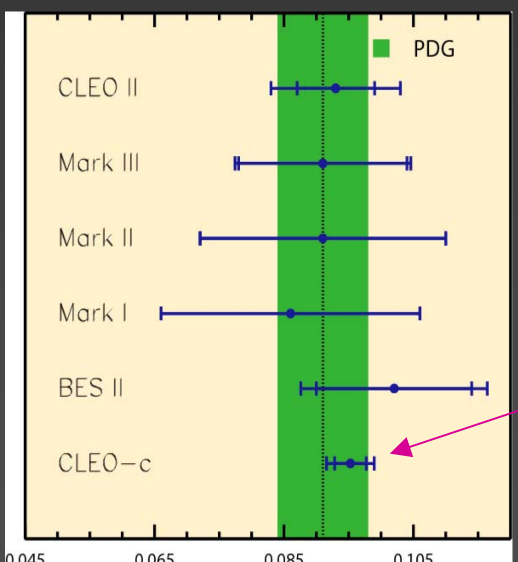
Three best measurements

$\mathcal{B}$ (%)	Error(%)	Source
9.3±0.6±0.8	10.8	CLEO II
9.1±1.3±0.4	14.9	MK III
9.52 ±0.25±0.27	3.9	CLEO-c

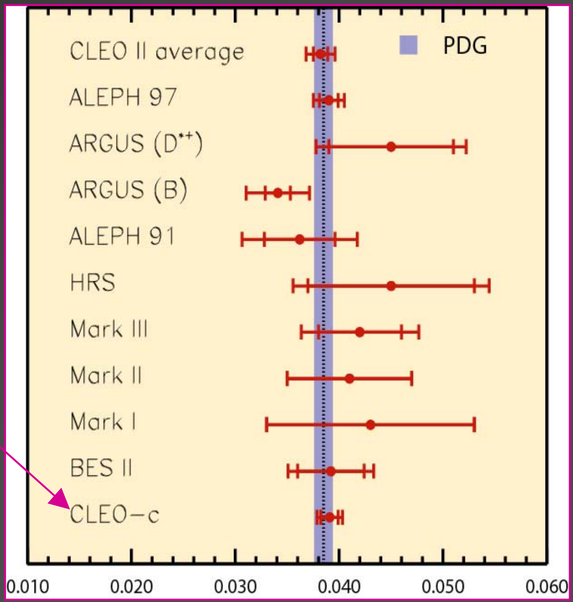
$\mathcal{B}(D^o \to K^- \pi^+)$

Three best measurements

$\mathcal{B}$ (%)	Error(%)	Source
3.82±0.07±0.12	3.6	CLEO II
3.90±0.09±0.12	3.8	ALEPH
3.91±0.08 ±0.09	3.1	CLEO-c



CLEO-c
(not in average)



Leptonics & Semileptonics at CLEO-c

- Ease of leptonic & semileptonic decays using double tags & MM^2 technique

$$MM^2 = (E_D - E_\ell - E_{hadrons})^2 - (\vec{p}_D - \vec{p}_\ell - \vec{p}_{hadrons})^2$$

We know $E_D = E_{beam}$, $\vec{p}_D = -\vec{p}_{\bar{D}}$

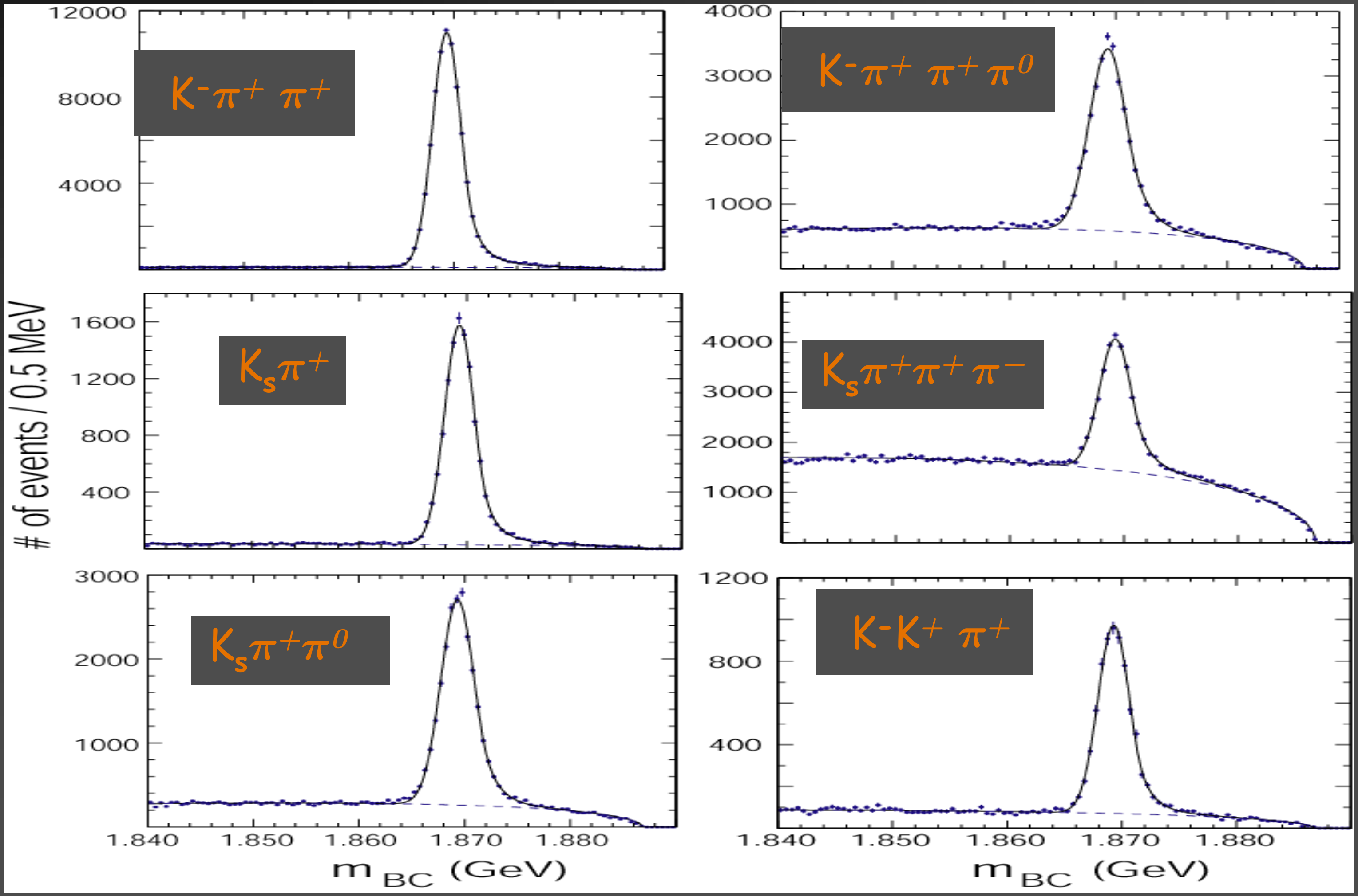
- Search for peak near $MM^2=0$
- Since resolution ~ $M^2_{\pi^o}$, reject extra particles with calorimeter & tracking
- Note that this method can be used to evaluate systematic errors on ε, simply by using double tags with one missing track
- Sometimes people use $U_{miss} = E_{miss} - |\vec{P}_{miss}|$

Technique for $D^+ \rightarrow \mu^+\nu$

- Fully reconstruct one $D^\pm$
- Seek events with only one additional charged track and no additional photons > 250 MeV to veto $D^+ \rightarrow \pi^+\pi^o$
- Charged track must deposit only minimum ionization in calorimeter
- Compute MM^{2}: If close to zero then almost certainly we have a $\mu^+\nu$ decay

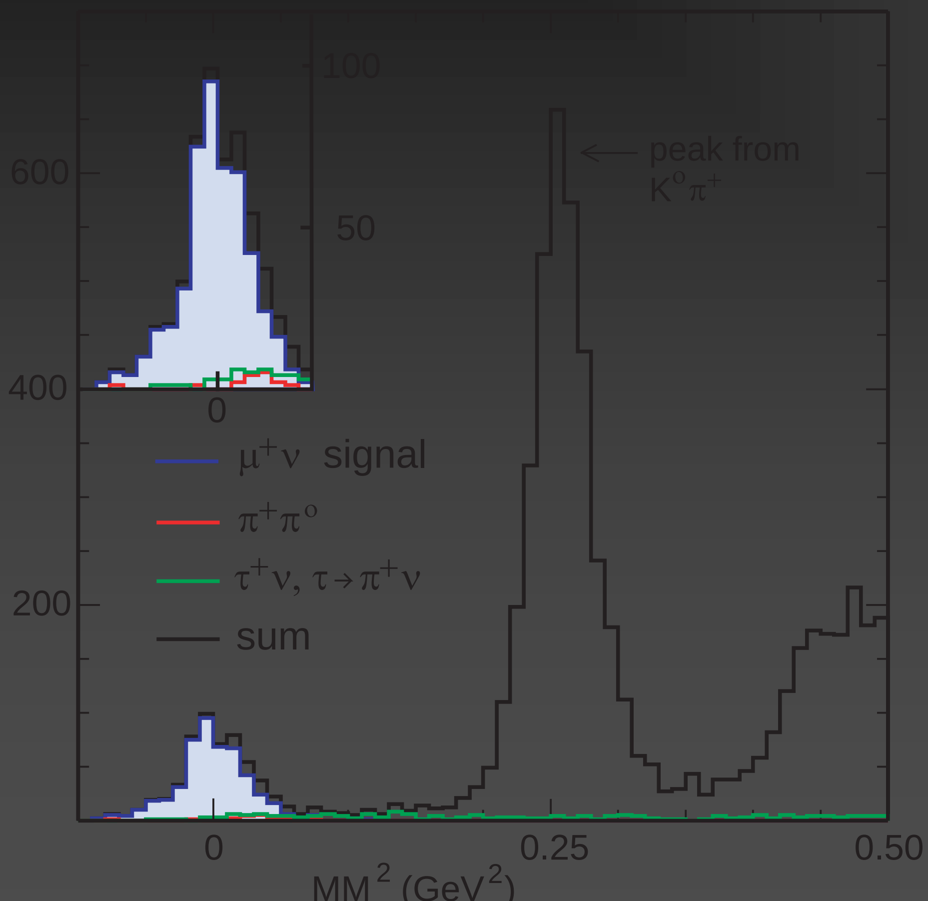
Single Tag Sample

- From 281 pb^{-1}

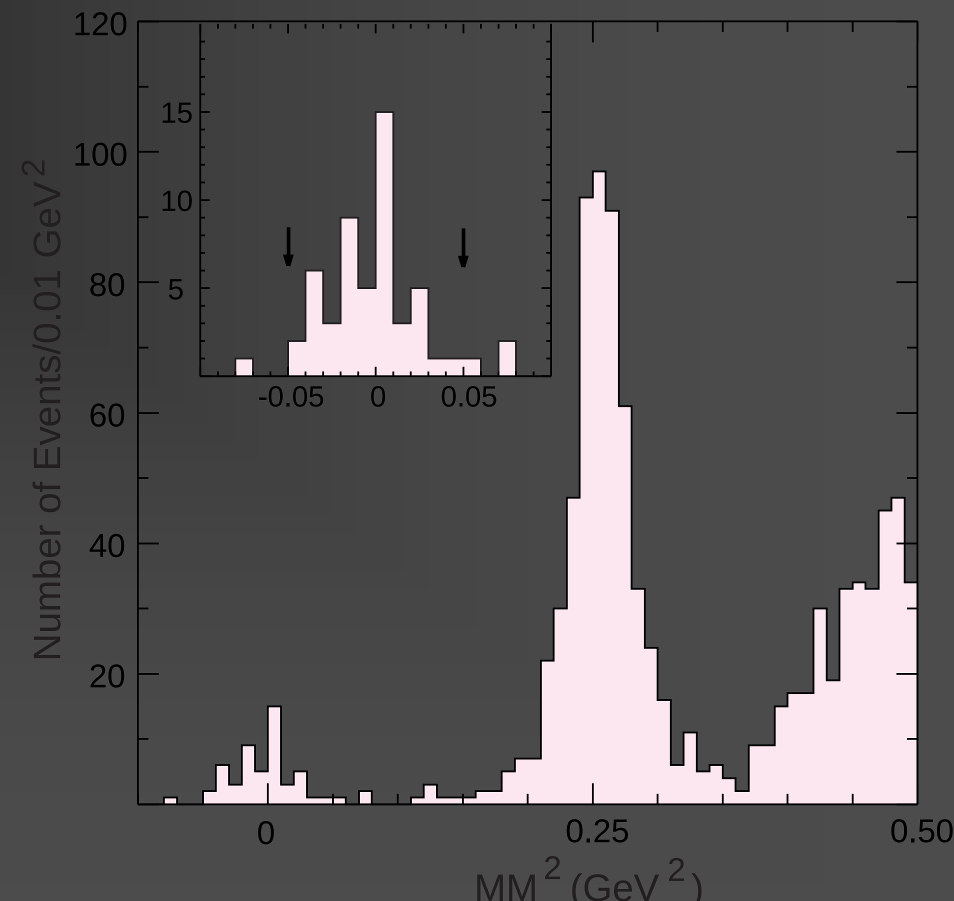


Measurement of f_{D^+}

MC Expectations from 1.7 fb^{-1}, 6X this sample



Data have 50 signal events in 281 pb^{-1}



Deriving a Value for f_{D^+}

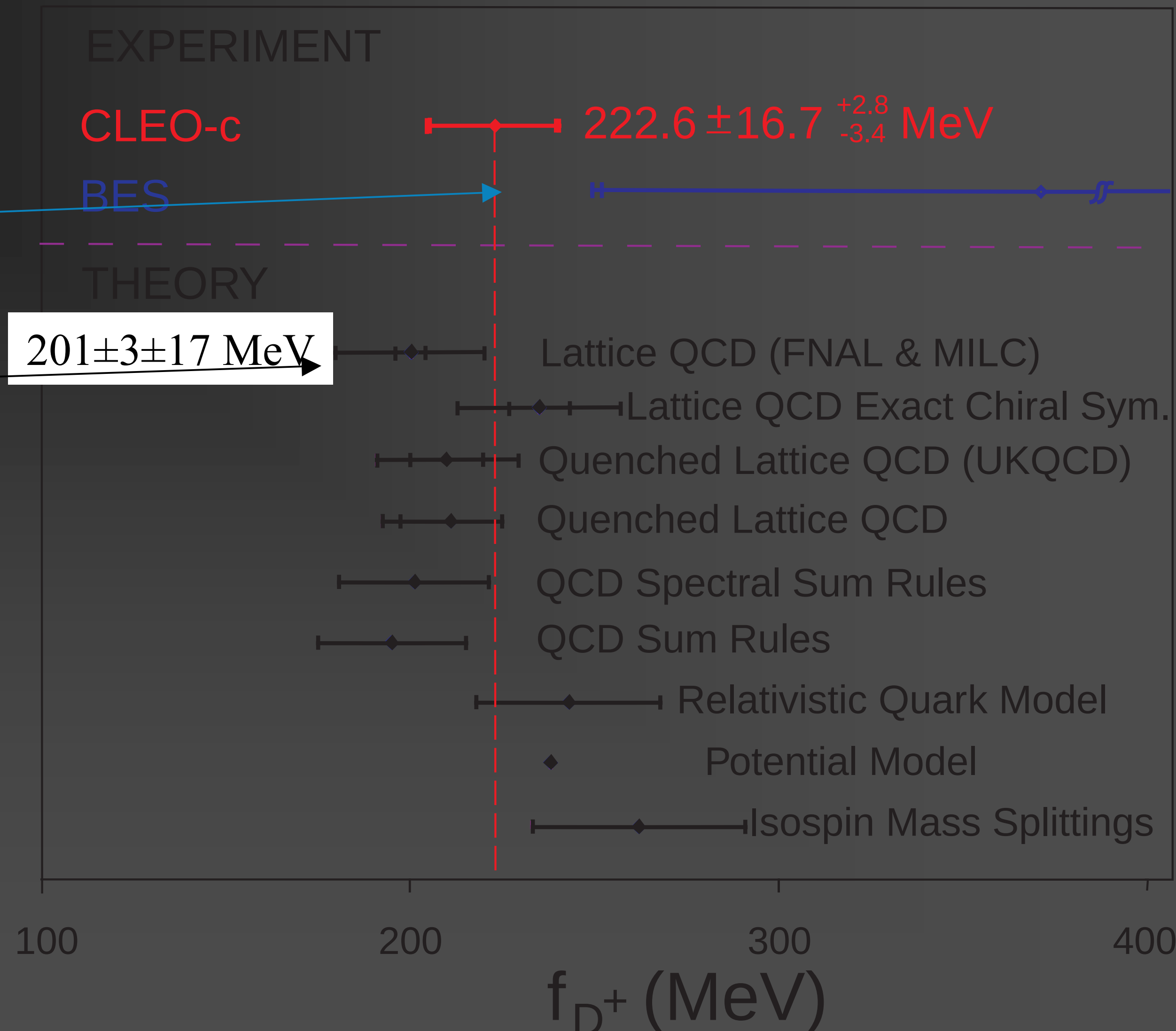
Backgrounds		
Mode	$\mathcal{B}$(%)	# Events
$\pi^+\pi^0$	0.13±0.02	1.40±0.18±0.22
$K^0\pi^+$	2.77±0.18	0.33±0.19±0.02
$\tau^+\nu$ ($\tau \rightarrow \pi^+\nu$)	2.65*$\mathcal{B}(D^+ \rightarrow \mu^+\nu)$	1.08 ±0.15±0.02
Other D^+, D^o	0	<0.4, <0.4 @ 90% cl
+ Continuum	0	<1.2 @ 90% c.l.
Total		$2.81 \pm 0.30^{+0.84}_{-0.27}$

- Tags are 158,354 events
- $\mathcal{B}(D^+ \rightarrow \mu^+\nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$
- $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV
- $\mathcal{B}(D^+ \rightarrow e^+\nu) < 2.4 \times 10^{-5}$ @ 90% c.l.

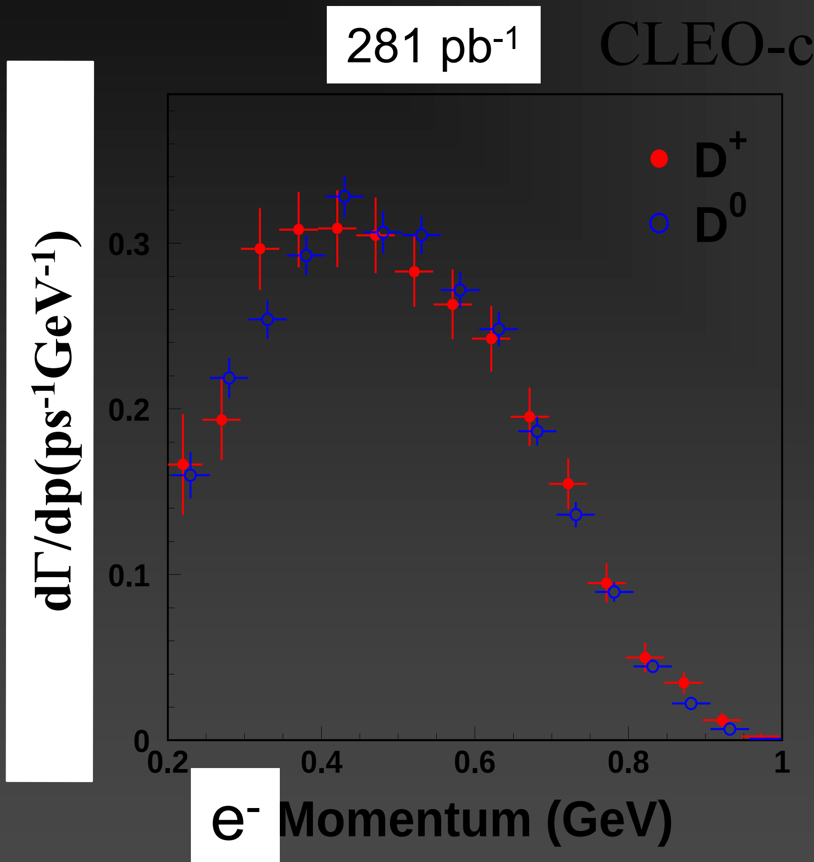
Efficiencies: μ^+ detection (69.4%); extra shower (96.1%); correction for easier tag reconstruction in $\mu^+\nu$ events (1.5%)

Comparison to Theory

- BES measurement based on 2.67±1.74 events
- Current Lattice measurement (unquenched light flavors) is consistent
- But systematic errors on theory & statistical errors on data are still large



Inclusive semileptonic branching fractions



preliminary

Lab momentum spectrum – no FSR correction

- Tagged sample: only "golden modes" $D^0 \to K^- \pi^+$ and $D^+ \to K^- \pi^+ \pi^+$
- Identify *e*, π, K right-sign and wrong-sign samples, use unfolding matrix→true *e* population.
- Correction for p_e- cut

$$B(D^+ \to Xe\nu) = (16.19 \pm 0.20 \pm 0.36)\%$$

$$\sum B(D^+ \to Xe\nu)_{excl} = (15.1 \pm 0.50 \pm 0.5)\%$$

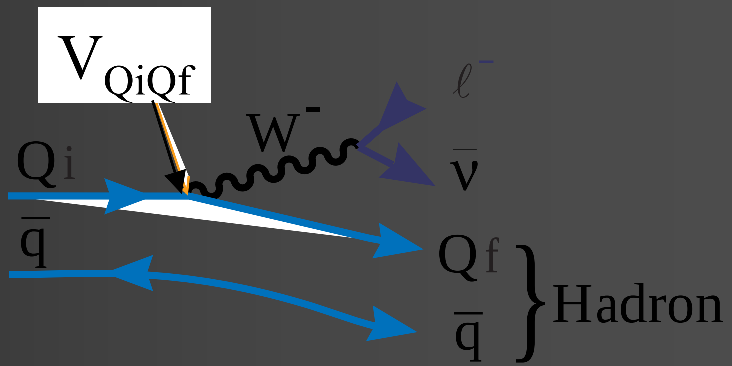
$$B(D^0 \to Xe\nu) = (6.45 \pm 0.17 \pm 0.15)\%$$

$$\sum B(D^0 \to Xe\nu)_{excl} = (6.1 \pm 0.2 \pm 0.2)\%$$

$$\frac{\Gamma(D^+ \to Xe^+\nu)}{\Gamma(D^o \to Xe^+\nu)} = 1.01 \pm 0.03 \pm 0.03$$

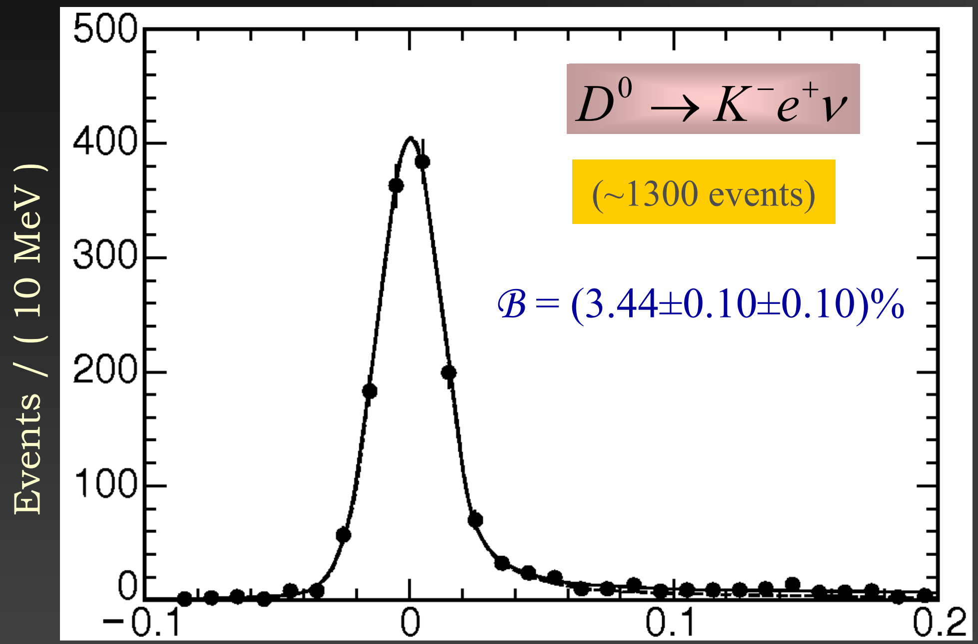
Exclusive Semileptonic Decays

- Best way to determine magnitudes of CKM elements, in principle is to use semileptonic decays. Decay rate $\alpha |V_{QiQf}|^2$

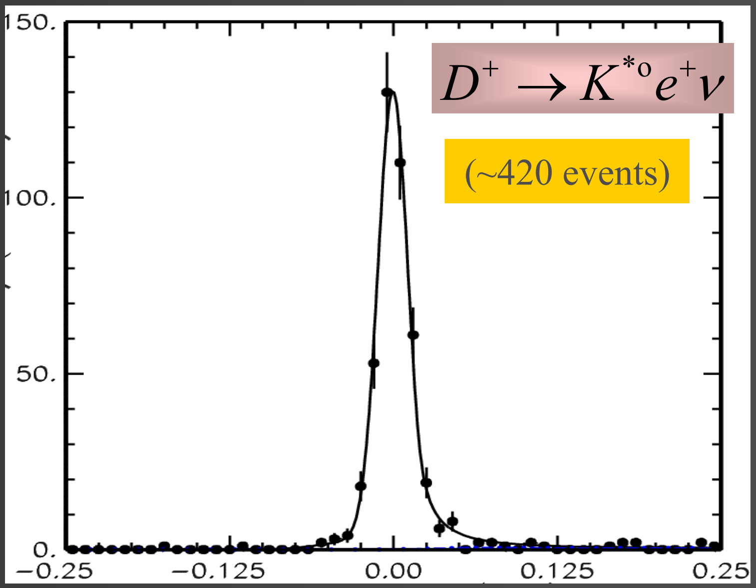


- This is how V_{us} (λ) and V_{cb} (A) have been determined
- Kinematics: $q^2 = \left(p_D^\mu - p_{hadron}^\mu\right)^2 = m_D^2 + m_P^2 - 2E_P m_D$
- Matrix element in terms of form-factors (for D→Pseudoscalar $\ell^+ \nu$
- $\left\langle P(P_P)\middle|J_\mu\middle|D(P_D)\right\rangle = f_+(q^2)(P_D + P_P)_\mu + f_-(q^2)(P_D - P_P)_\mu$
- For $\ell = e$, contribution of $f_-(q^2) \rightarrow 0$

Cabibbo Favored Semileptonic Decays



$U = E_{miss} - |P_{miss}|$ (GeV)

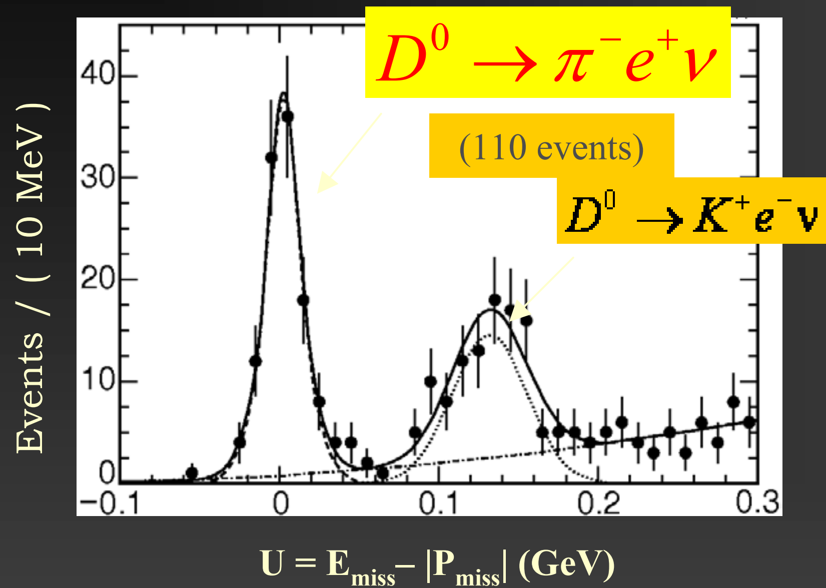


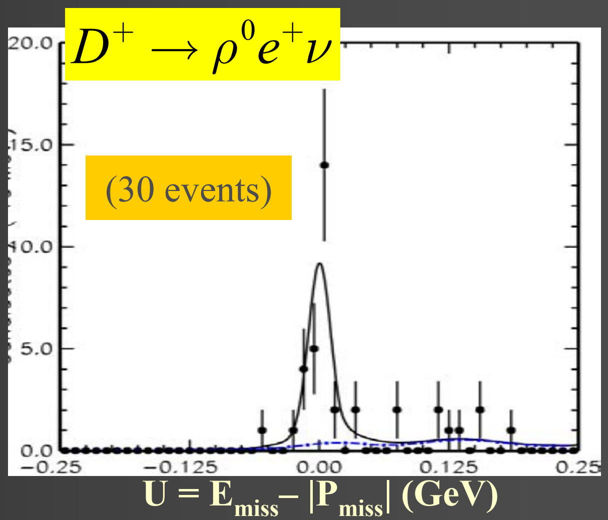
$U = E_{miss} - |P_{miss}|$ (GeV)

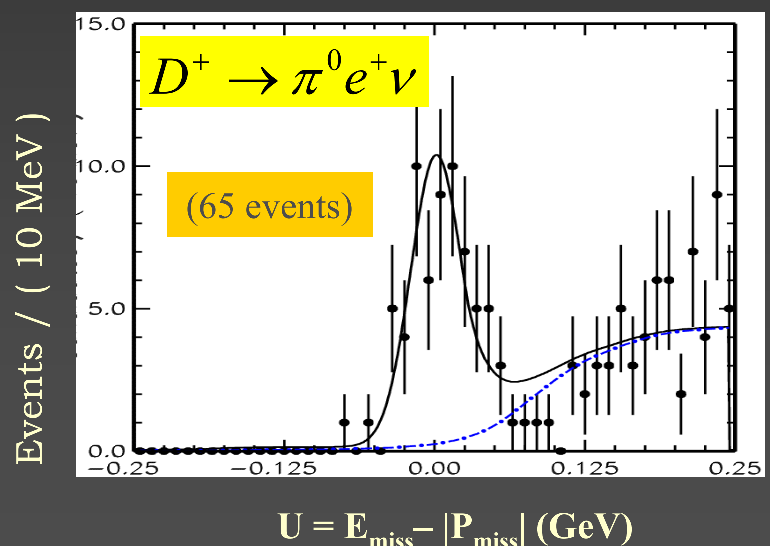
$\mathcal{B} = (5.70\pm0.28\pm0.25)\%$

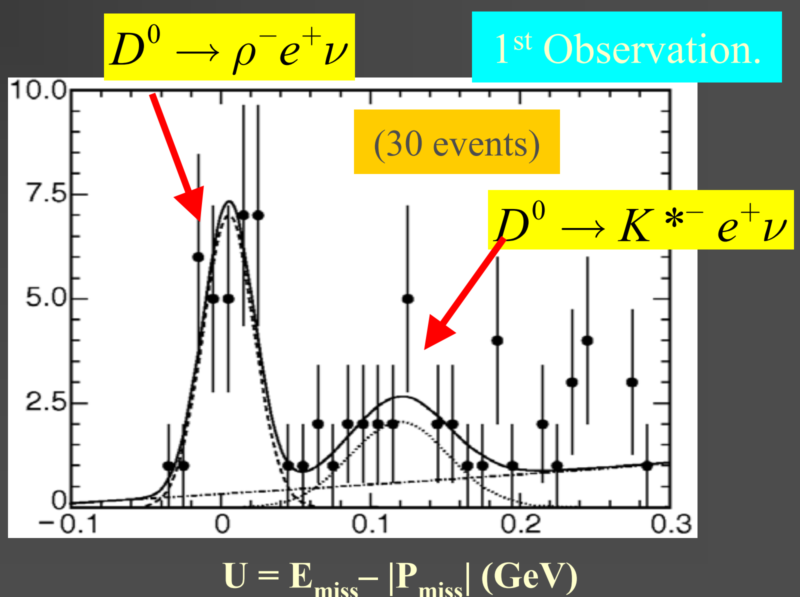
These are the dominant modes, so backgrounds are almost non-existent

Cabibbo Suppressed Semileptonic Decays





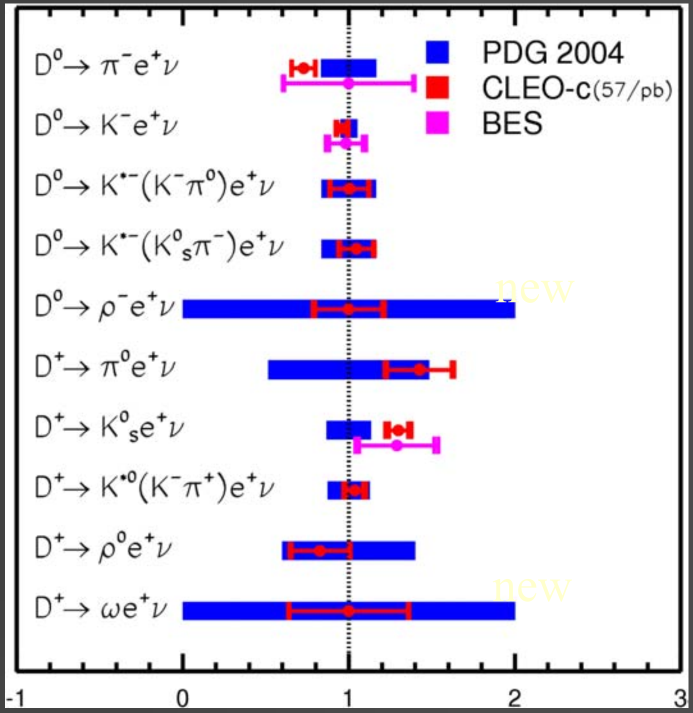




Summary of Semileptonic Branching Ratio Results

	Decay Mode	$\mathcal{B}$ (%) (CLEO-c/(57/pb))	$\mathcal{B}$ (%) (PDG-04)
1.	$D^0 \to \pi^- e^+ \nu$	$0.26 \pm 0.03 \pm 0.01$	0.36 ± 0.06
2.	$D^0 \to K^- e^+ \nu$	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
3.	$D^0 \to K^{*-}(K^-\pi^0) e^+ \nu$	$2.16 \pm 0.24 \pm 0.11$	2.15 ± 0.35
4.	$D^0 \to K^{*-}(K^0_S\pi^-) e^+ \nu$	$2.25 \pm 0.21 \pm 0.11$	2.15 ± 0.35
5.	$D^0 \to \rho^- e^+ \nu$	$0.19 \pm 0.04 \pm 0.02$	—
6.	$D^+ \to \pi^0 e^+ \nu$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
7.	$D^+ \to \bar{K}^0 e^+ \nu$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
8.	$D^+ \to \bar{K}^{*0}(K^-\pi^+) e^+ \nu$	$5.70 \pm 0.28 \pm 0.25$	5.5 ± 0.7
9.	$D^+ \to \rho^0(\pi^+\pi^-) e^+ \nu$	$0.21 \pm 0.04 \pm 0.02$	0.25 ± 0.10
10.	$D^+ \to \omega(\pi^+\pi^-\pi^0) e^+ \nu$	$0.17 \pm 0.06 \pm 0.01$	—

Ratio to PDG



- Using unquenched lattice (hep-ph/0408306) find
- $V_{cs} = 0.956 \pm 0.036 \pm 0.093 \pm 0.017$
- $V_{cd} = 0.213 \pm 0.008 \pm 0.020 \pm 0.008$

stat lat   sys lat   exp CLEO

V_{cs} (LEP) = 0.976 ± 0.014
$V_{cd}(\nu N)$ = 0.224 ± 0.012
Currently this checks
Lattice calculations

Combining Semileptonics & Leptonics

- Decay rate:

$$\frac{d\Gamma\left(D \to Pe\nu\right)}{dq^2} = \frac{\left|V_{cq}\right|^2 P_P^3}{24\pi^3}\left|f_+(q^2)\right|^2$$

- Test of models in D decays: predictions of shapes of form factors (for D→Vector $\ell^+\nu$ there are 3 form-factors)
- Note that the ratio below depends only on QCD:

$$\frac{1}{\Gamma\left(D^+ \to \ell\,\nu\right)} \frac{d\Gamma\left(D^+ \to \pi e \nu\right)}{dq^2} \;\alpha\; \frac{P_\pi^3\left|f_+(q^2)\right|^2}{f_{D^+}^2}$$

Lattice comparison: f_D and semileptonic ff

- We can use a quantity independent of V_{cd} to do a CKM independent lattice check:

$$R_{\ell sl} \equiv \sqrt{\frac{\Gamma(D^+ \to \mu \upsilon)}{\Gamma(D^+ \to \pi \ell \upsilon)}} \propto \frac{f_D}{f_+^{\pi}(0)}$$

- I obtain:

$$R_{\ell sl}^{th} = 0.22 \pm 0.02$$

$$R_{\ell sl}^{\exp} = 0.25 \pm 0.02$$

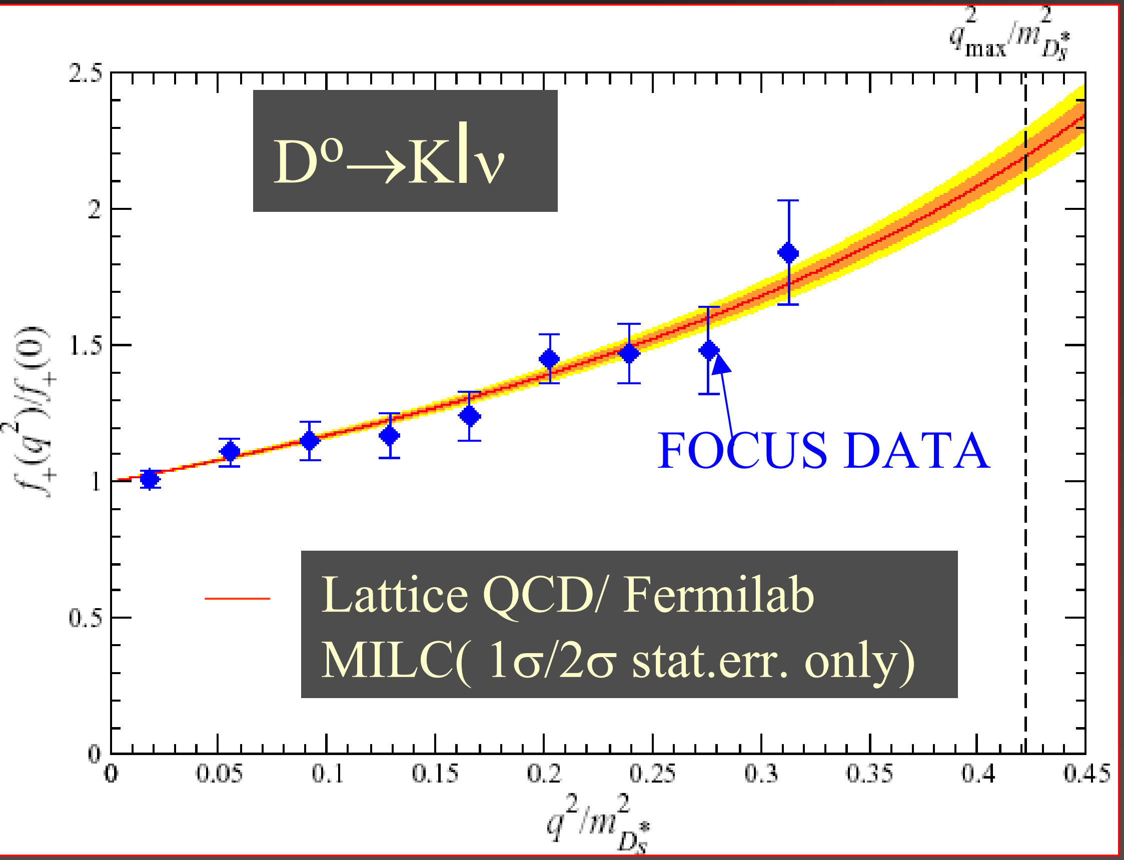
- Theory and data consistent at ~30% C.L.

Lattice comparison – the shape of $f_+(q^2)$

- Modern parameterization of the form factors proposed by Becirevic & Kaidalov (BK):

$$f_+(x) = f_+(0)\left(\frac{1}{(1-q^2/m^2_{D_s^*})}\frac{1}{(1-\alpha q^2/m^2_{D_s^*})}\right)$$

Representing contributions beyond the lowest lying resonances (D*)

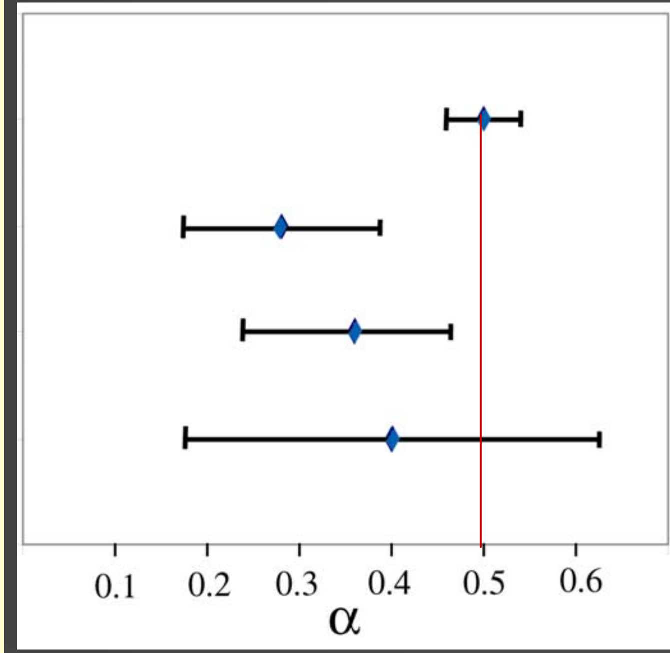


Another model by Fajfer and Kamenik shows that including the next radial excitation in ff gives good fits to measured branching fractions.

Fajfer et al. hep-ph/0506051 and 0412140

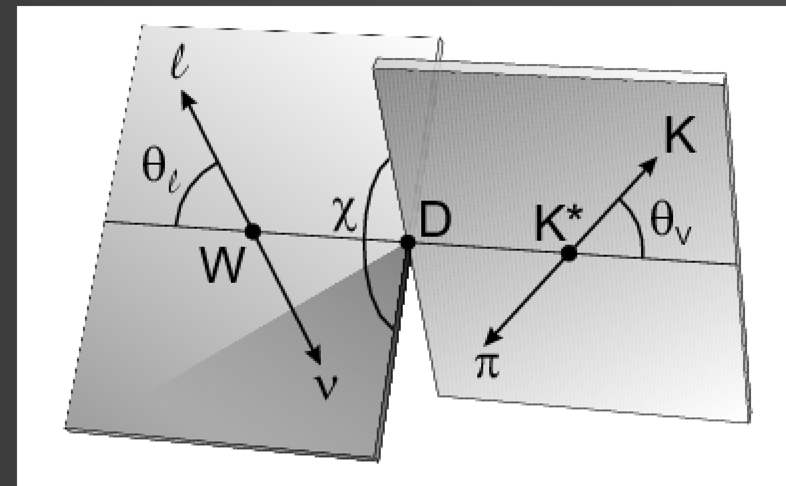
Form Factor shapes

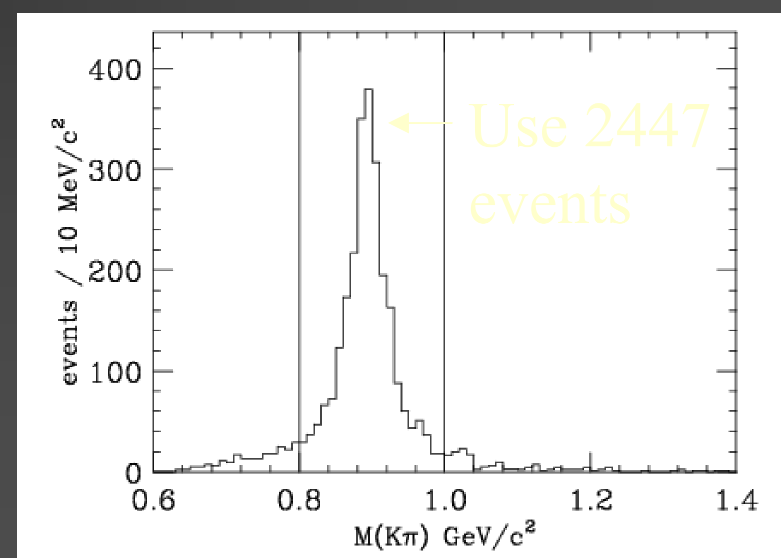
$\alpha(D^o \to K \ell \nu)$	
Lattice (Fermilab-MILC hep-ph/0408306)	0.50±0.04(stat)
FOCUS	0.28 ±0.08 ±0.07
CLEO III	$0.36 \pm 0.10 ^{+0.03}_{-0.07}$
Belle	0.40 ±0.12 ±0.19
$\alpha(D^o \to \pi \ell \nu)$	
Lattice (Fermilab-MILC hep-ph/0408306)	0.44 ±0.04(stat)
CLEO III	$0.37 ^{+0.20}_{-0.31} \pm 0.15$
Belle	0.03 ±0.27±0.13



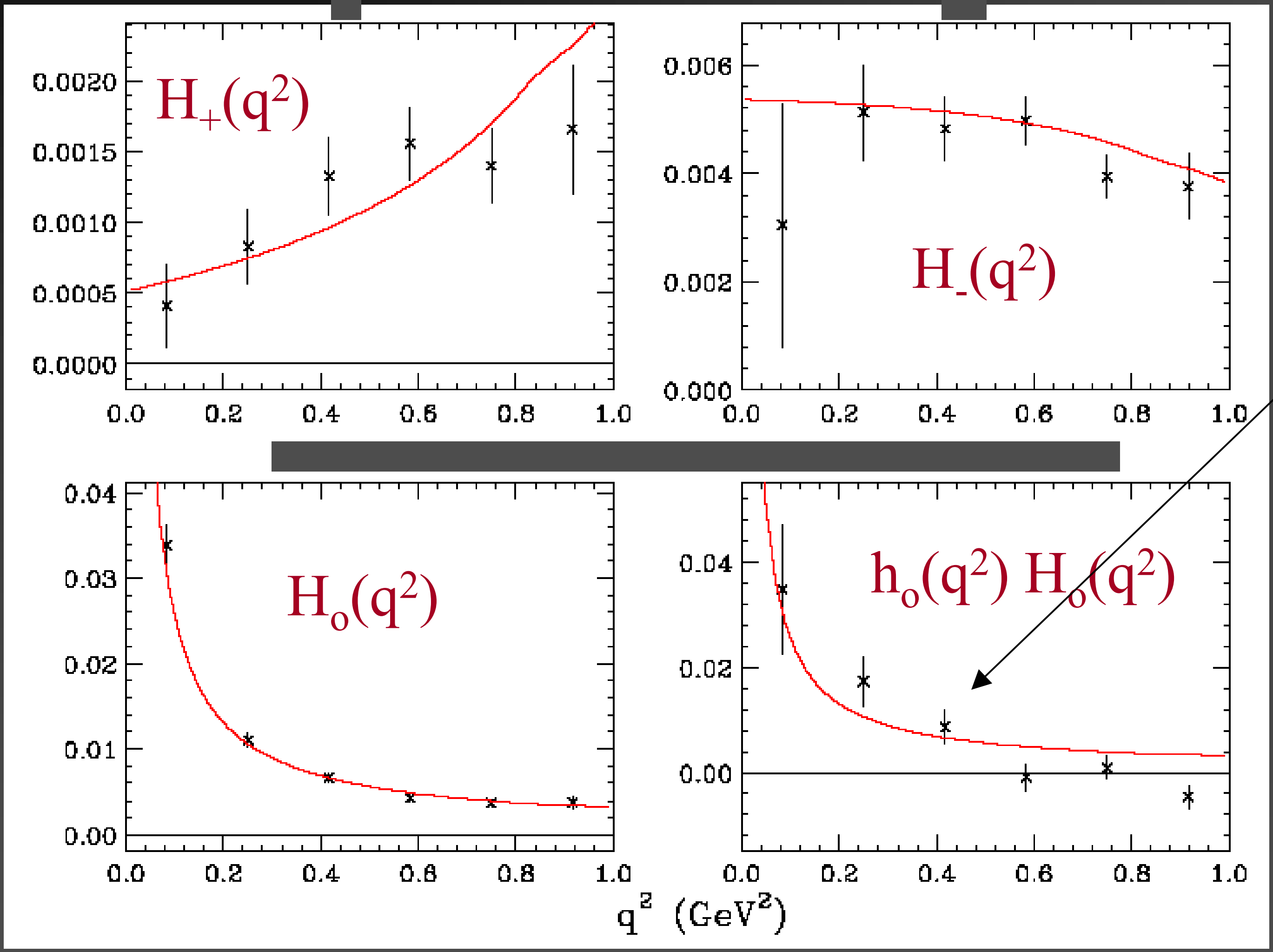
$D^+ \to K^- \pi^+ e^+ \nu$ Form Factors

- $K^- \pi^+$ mostly K^* with some s-wave (1st seen by FOCUS)
- For $D \to V e^+ \nu$, use 3 helicity amplitudes $H_o(q^2)$, $H_+(q^2)$, & $H_-(q^2)$
- Add $h_o(q^2) \cdot H_o(q^2)$ to account for s-wave term
- Use 281 pb^{-1}





Form Factor Results



- Significant s-wave amplitude confirmed
- Parameter-ization not great
- No evidence for d or f wave

$|V_{ub}|$

- This important part of b physics is and will continue to be dominated by theoretical errors in the LHC era
- New methods can lead to more precise results
- Theory
  - Heavy Quark Symmetry predicts that form-factor for a V_{ub} decay, say $B\to\pi\ell\nu$ is the same as for $D\to\pi\ell\nu$ at the same invariant 4 velocity, modulo corrections
  - Double Ratios:

$$f_+^{(B\to K)} / f_+^{(D\to K)} = \sqrt{m_b / m_c}$$

$$f_+^{(B\to \pi)} / f_+^{(D\to \pi)} = \sqrt{m_b / m_c}$$

Grinstein, [hep-ph/9308226]

V_{ub} Theory

- Thus
$$\frac{f_+^{(B\to K)} / f_+^{(B\to\pi)}}{f_+^{(D\to K)} / f_+^{(D\to\pi)}} = 1$$

- Specifically for Vector modes:

$$\frac{d\Gamma(\bar{B}\to\rho e\nu)/dq^2}{d\Gamma(\bar{B}\to K^*\ell^+\ell^-)/dq^2} = \frac{|V_{ub}|^2}{|V_{tb}V_{ts}^*|^2}\cdot\frac{8\pi^2}{\alpha^2}\cdot\frac{1}{|C_9^{\mathrm{eff}}(1+\delta(q^2))|^2+|C_{10}|^2}\frac{\sum_\lambda |H_\lambda^{B\to\rho}(q^2)|^2}{\sum_\lambda |H_\lambda^{B\to K^*}(q^2)|^2}$$

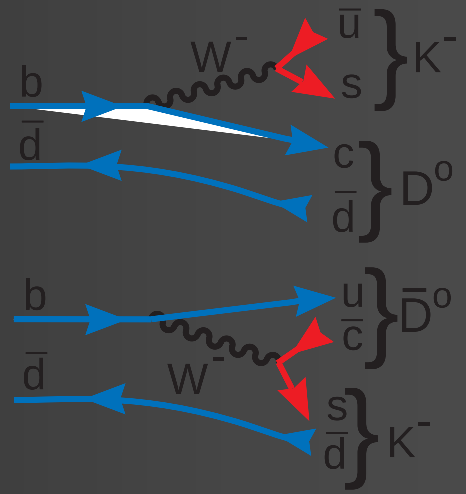
the $H_\lambda^{(V)}(q^2)$ amplitudes for rare $B\to V\ell^+\ell^-$ decays are related at leading order in Λ/m_b to those for semileptonic decay $B\to Ve\bar{\nu}$ with a common proportionality factor

$$H_\lambda^{(V)}(q^2) = C_9^{\mathrm{eff}}(1+\delta(q^2)+O(\Lambda/m_b))H_\lambda(q^2)\,. \qquad (91)$$

See Grinstein & Pirjol [hep-ph/0404250]

$B^{\pm}\to D^{o}K^{\pm}$ decays, $D^{o}\to K_{s}\pi^{+}\pi^{-}$

- Use Daltiz plot analysis to find γ see A. Giri et al., [hep-ph/0303187]
- For the B^{-} decay:



$A(B^{-}\to D^{o}K^{-})\equiv A_{B}$

$A(B^{-}\to \overline{D}^{o}K^{-})\equiv A_{B}r_{B}e^{i(\delta_{B}-\gamma)}$

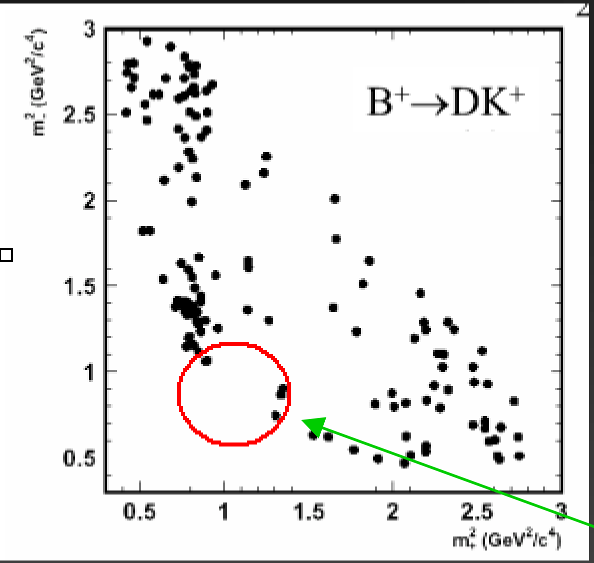
- For the D^{o} decay:

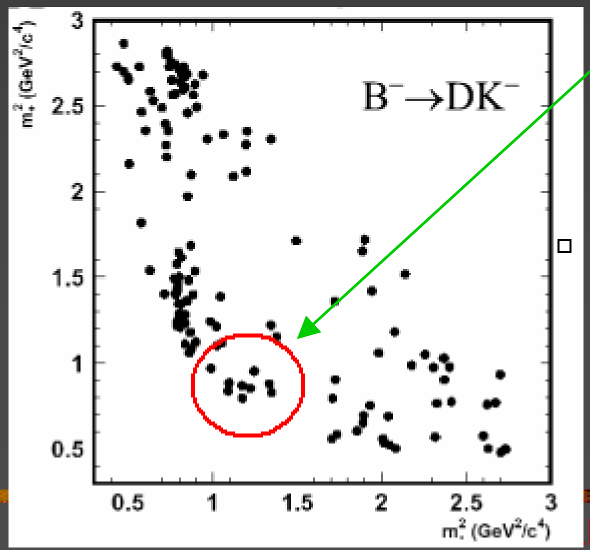
$A_{D}(s_{12},s_{13})\equiv A_{12,13}e^{i\delta_{12,13}}\equiv A(D^{o}\to K_{S}(p_{1})\pi^{-}(p_{2})\pi^{+}(p_{3}))$
$=\overline{A}(D^{o}\to K_{S}(p_{1})\pi^{+}(p_{2})\pi^{-}(p_{3}))$,

where $s_{ij}=(p_{i}+p_{j})^{2}$ (the mass)

- Similar relations for B^{+}

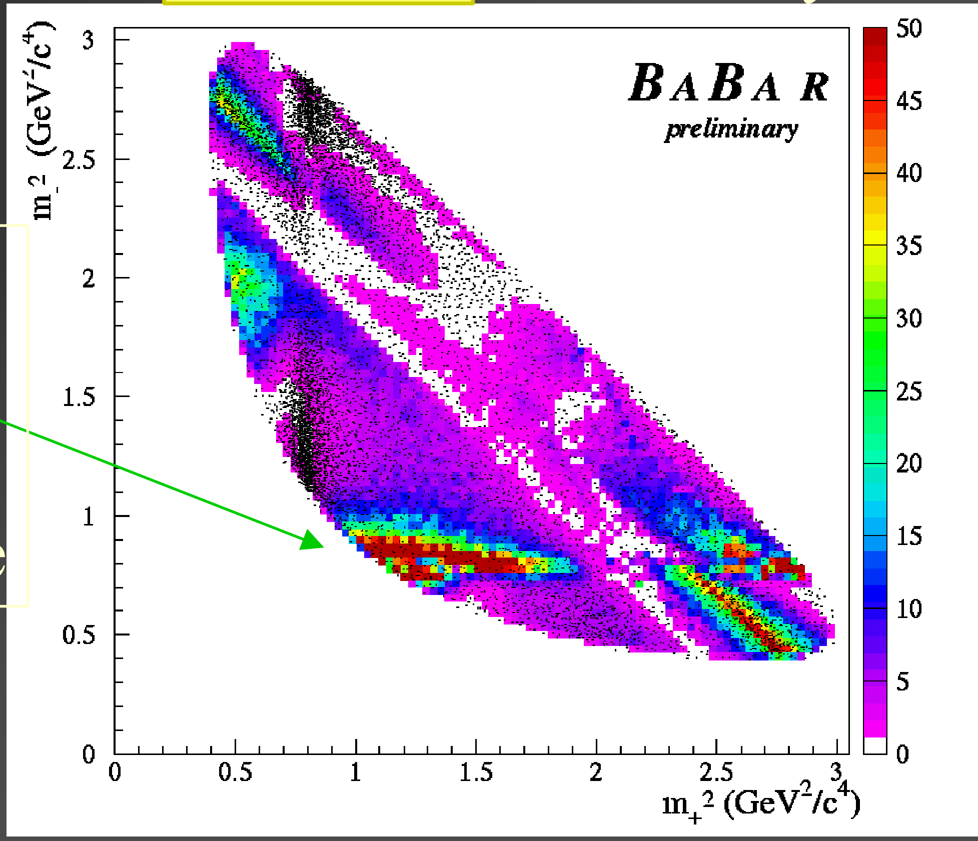
Dalitz Plot Sensitivity





Belle
Sees
Clear
difference

$d^2 \ln L/d^2\gamma$ sensitivity



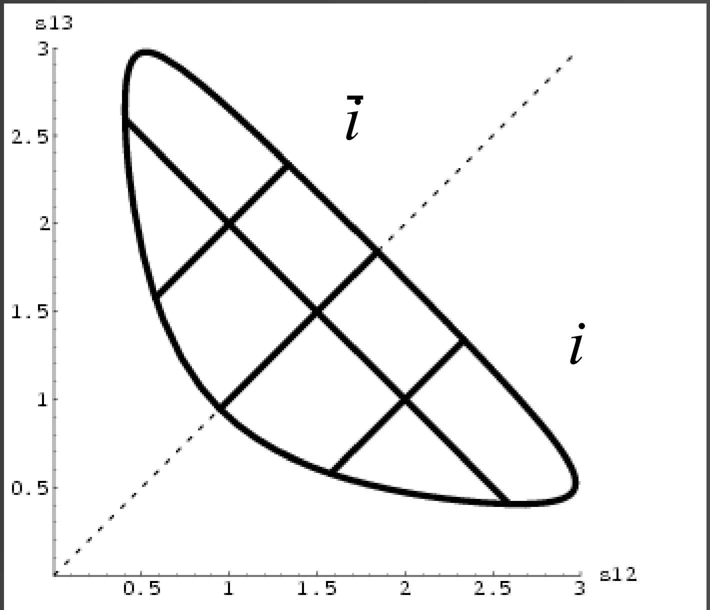
$D^o \rightarrow K_s\pi^+\pi^-$ Dalitz Analysis

- Partition Dalitz plot

$$c_i \equiv \int_i dp\; A_{12,13}\, A_{13,12} \cos(\delta_{12,13} - \delta_{13,12}),$$

$$s_i \equiv \int_i dp\; A_{12,13}\, A_{13,12} \sin(\delta_{12,13} - \delta_{13,12}),$$

$$T_i \equiv \int_i dp\; A^2_{12,13},$$



- For the k bins, each denoted by *i*, form 4k equations: with variables c_i, s_i, r_B, δ_B, γ

CLEO-c Can Measure c_i

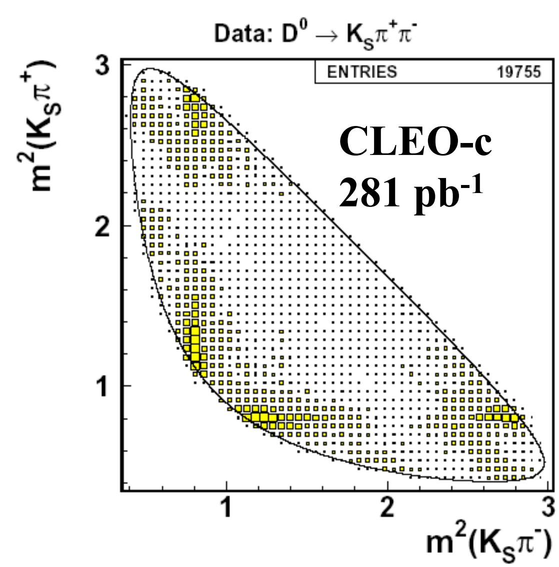
$$A(D^0_\pm \to K_S(p_1)\pi^-(p_2)\pi^+(p_3)) = \frac{1}{\sqrt{2}}\left(A_D(s_{12}, s_{13}) \pm A_D(s_{13}, s_{12})\right), \quad (14)$$

$$d\Gamma(D^0_\pm \to K_S(p_1)\pi^-(p_2)\pi^+(p_3)) = \frac{1}{2}\left(A^2_{12,13} + A^2_{13,12}\right) \pm A_{12,13}A_{13,12}\cos(\delta_{12,13} - \delta_{13,12})dp.$$

where we defined $D^0_\pm \equiv (D^0 \pm \overline{D}^0)/\sqrt{2}$. With these relations, one readily obtains

$$c_i = \frac{1}{2}\left[\int_i d\Gamma(D^0_+ \to K_S(p_1)\pi^-(p_2)\pi^+(p_3)) - \int_i d\Gamma(D^0_- \to K_S(p_1)\pi^-(p_2)\pi^+(p_3))\right]. \quad (15)$$

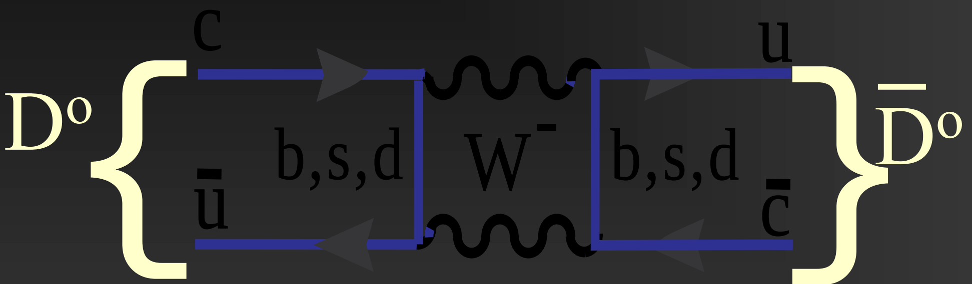
- Measure Dalitz plot opposite a CP eigenstate tag such as K^+K^- or $K_s\phi$.
- Supplies k of 2k+3 unknowns
- Accuracy will depend on statistics
- Other δ's will also be measured, such as $K^-\pi^+$ and $K^{*\pm}K^\pm$



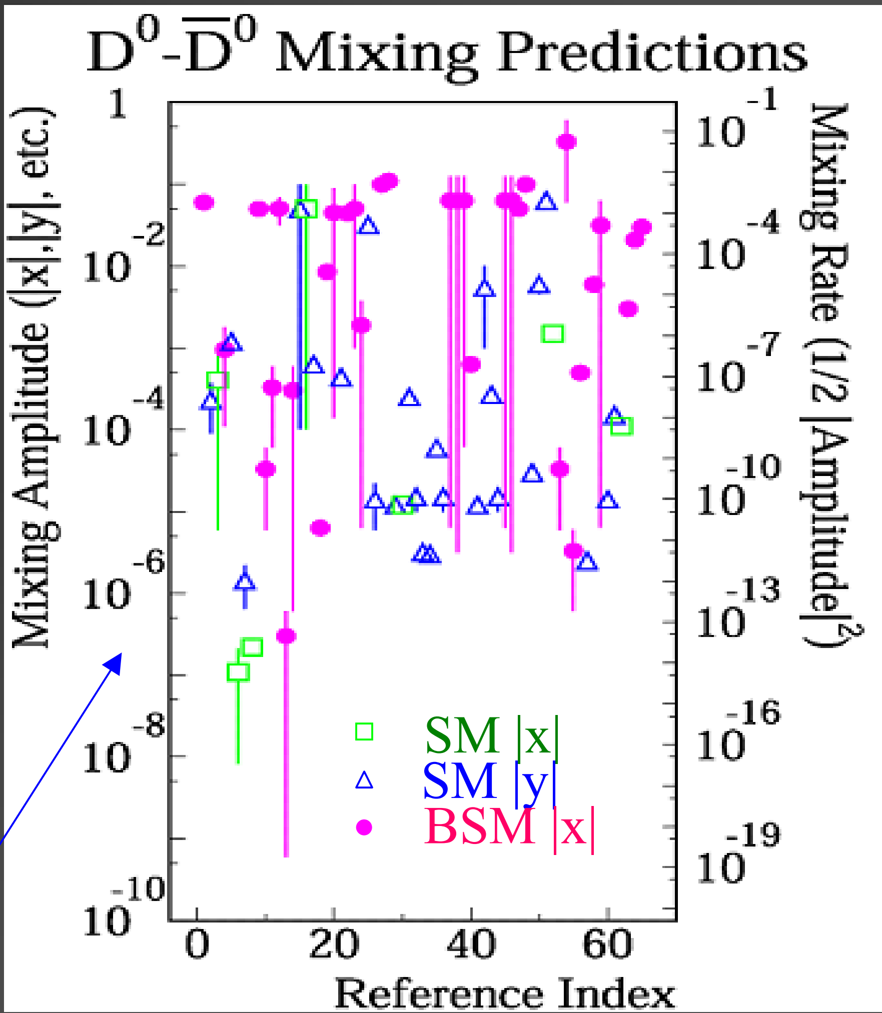
Searches for New Physics in Charm Decays

D^o-$\bar{D}^o$ Mixing

- Mixing could proceed via



- **the presence of d-type quarks in the loop makes the SM expectations for D^o- D^o mixing small** compared with systems involving u-type quarks in the box diagram because these loops include 1 dominant super-heavy quark **(t)**: K^o (50%), B^o (20%) & B_s (50%)
- New physics in loops implies $x \equiv \Delta M/\Gamma >> y \equiv \Delta\Gamma/2\Gamma$; but long range effects complicate predictions



From H. Nelson

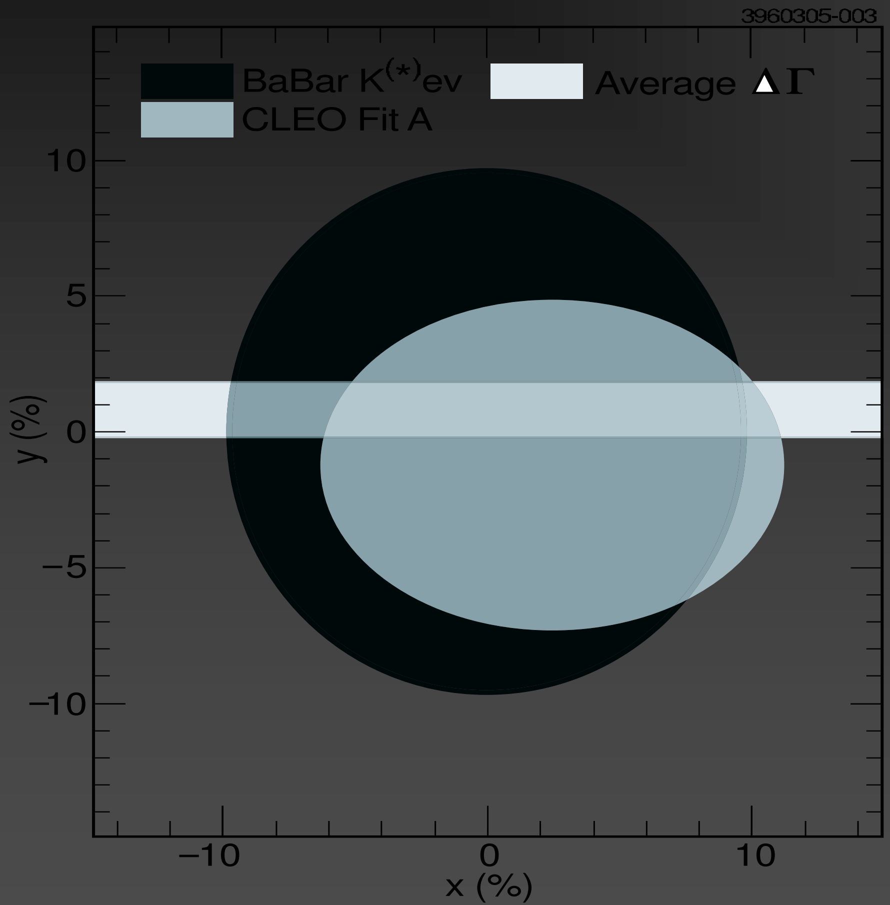
D^o- $\bar{D}^o$ mixing: the data

- The study of D^o wrong-sign $K\pi$ yields has been a key step in our experimental study of $D^o \bar{D}^o$ mixing.
- Caveats:
  - Complicated by interference between DCSD & mixing [strong phase $\delta \Rightarrow$ data constrain only x' & y']
  - Complicated by CP violation

Experiment	x'^2 (95 % C.L.) ($\times 10^{-3}$)	y'(95% C.L.) ($\times 10^{-3}$)
Belle (2004)	0.81	$-8.2<y'<16$
BaBar (2003)	2.2	$-56<y'<39$
FOCUS (2001)	1.52	$-124<y'<-5$
CLEO (2000)	0.82	$-58<y'<10$

Most general fit

$D^o \bar{D}^o$ mixing: the data II



- D^o semileptonic decays: $R_{ws} = ½(x^2+y^2)$ [no strong phase δ]

Experiment	R_M(95% CL)	$\sqrt{x^2+y^2}$
BaBar 04	0.0046	0.1
Belle 05	0.0016	0.056

- Dalitz plot analysis of $D^0 \rightarrow K_s^0 \pi^+\pi^-$ (CLEO II.V) comparable sensitivity

CP/T Violation

- Unexpectedly large CP violation asymmetries may be a better signature for new physics (0.01-0.001)
- CP violation can be studied in a variety of ways:
  - Direct CP violation
  - CP violation in mixing
  - T violation in 4-body decays of D^0/D^+ (assuming CPT) and studying triple product correlations
  - Exploiting quantum coherence of $D\overline{D}$ produced in $\psi(3770)$ decays

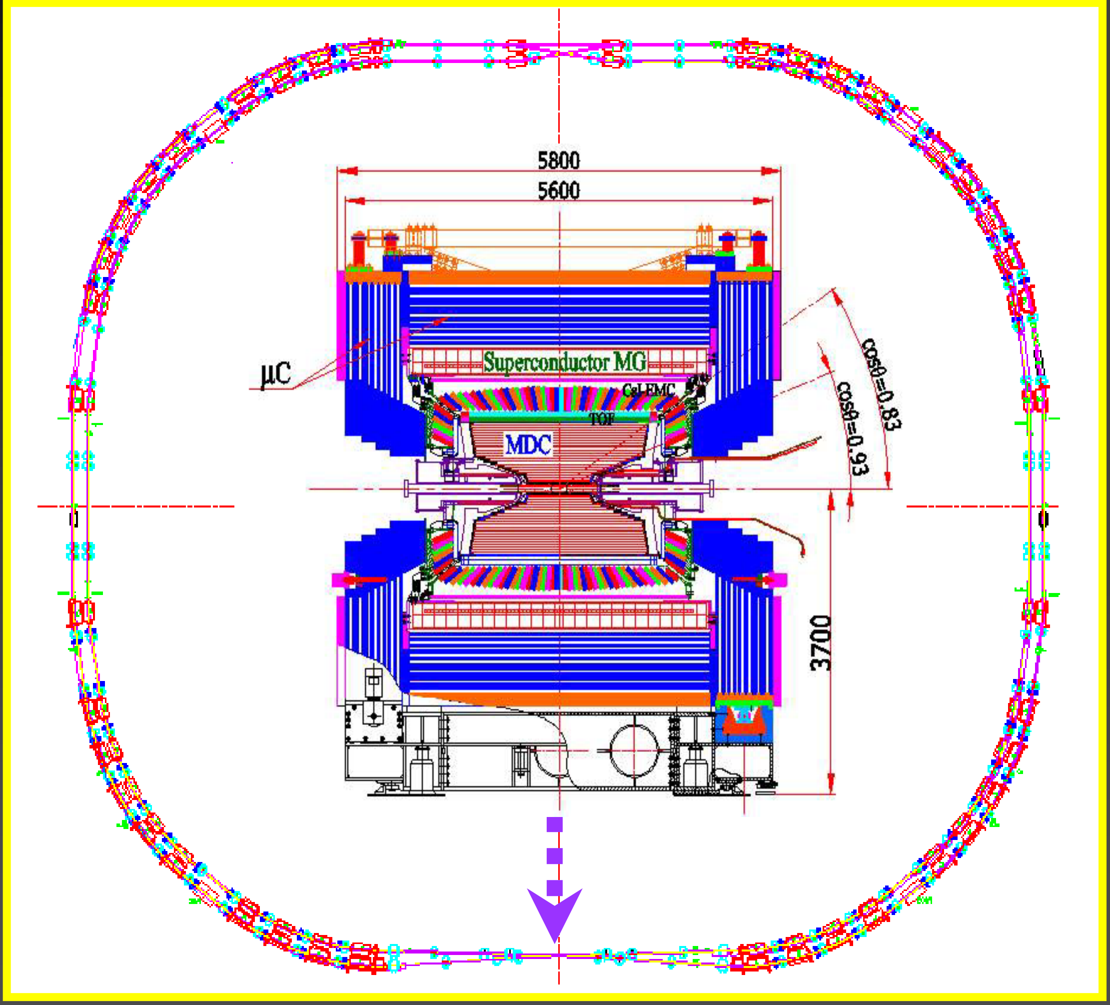
CP/T Violation: some recent data

Experiment	Decay mode	A_{CP} (%)	Notes
BaBar	$D^+ \to K^- K^+ \pi^+$	1.4±1.0 ±0.8	
BaBar	$D^+ \to \phi^+ \pi^+$	0.2±1.5±0.6	Res. Substr. Of $D^+ \to K^- K^+ \pi^+$
BaBar	$D^+ \to K^{*0} K^+$	0.9±1.7±0.7	
CLEO II.V	$D^0 \to \pi^+ \pi^- \pi^0$	$1^{+9}_{-7} \pm 8$	Dalitz plot analysis
CDF	$D^0 \to K^+ K^-$	2.0 ±1.2 ± 0.6	Direct CPV
CDF	$D^0 \to \pi^+ \pi^-$	1.0 ±1.3 ± 0.6	Direct CPV
FOCUS	$D^0 \to K^+ K^- \pi^+ \pi^-$	1.0 ±5.7±3.7	T violation through triple product correlations
FOCUS	$D^+ \to K^o K^+ \pi^+ \pi^-$	2.3 ±6.2±2.2	
FOCUS	$D_S \to K^o K^+ \pi^+$	-3.6 ±6.7±2.3	

Future

- Immediate: Take data on D_s
- CLEO runs until sometime in 2008. Most of the running is now planned to be on ψ'' & $\psi(4160)$ for D_s, with some on ψ'
  - Errors will depend on how much data CLEO-c gets on charm
- Beijing has started building a two-ring machine for this physics with much more projected luminosity

BEPCII/BESIII Project



Design

- Two ring machine
- 93 bunches each
- Luminosity

  10^{33} cm^{-2} s^{-1} @1.89GeV

  6×10^{32} cm^{-2} s^{-1} @1.55GeV

  6×10^{32} cm^{-2} s^{-1} @ 2.1GeV
- New BESIII

Status and Schedule

- Most contracts signed
- Linac installed 2004
- Ring installed 2005
- BESIII in place 2006
- Commissioning

  BEPCII/BESIII

  beginning of 2007

Backup Slides

Exclusive branching fractions

Decay Mode	B(%) (CLEO-c)	B(%) (BES-II)	B(%) (Artuso's avg including others)
$D^o \to K^- e^+ \nu_e$	3.44±0.10±0.10	3.82±0.40±0.27	3.54±0.11
$D^o \to \pi^- e^+ \nu_e$	0.262±0.025±0.008	0.33±0.13±0.03	0.285±0.018
$D^o \to K^{*-} e^+ \nu_e$	2.16±0.15±0.08		2.14±0.16
$D^o \to \rho^- e^+ \nu_e$	0.194±0.039±0.013		
$D^+ \to \underline{K}^o e^+ \nu_e$	8.71 ±0.38±0.37		8.31±0.44
$D^+ \to \pi^o e^+ \nu_e$	0.44±0.06±0.03		0.43±0.06
$D^+ \to \underline{K}^{*o} e^+ \nu_e$	5.56±0.27±0.23		5.61±0.32
$D^+ \to \rho^o e^+ \nu_e$	0.21±0.04±0.01		0.22±0.04
$D^+ \to \omega^o e^+ \nu_e$	$0.16^{+0.07}_{-0.01}\pm 0.01$		

Measurements of γ in $B^{\pm}$ decays

- D^o Dalitz plot analyses to improve the measurement of γ using $B^{\pm}\rightarrow D^o K^{\pm}$ decays, for example $D^o \rightarrow K_s \pi^+ \pi^-$
- Measurement of relative strong decay phase used in ADS method using $B^{\pm}\rightarrow D^o K^{\pm}$ decays, where, for example, the interference between $D^o \rightarrow K^+ \pi^-$ and DCSD decays is used
- Measurement of relative strong decay phase used in $B^{\pm}\rightarrow D^o K^{\pm}$ decays, where $D^o \rightarrow K^{*\pm} K^{\mp}$ is used
- Important to measure γ this way and $B_s \rightarrow D_s K^{\pm}$, because one uses B_s mixing and the other is mostly tree level so if different would point directly to new physics source

Other Items Useful for B decays

- Measurement of semileptonic decay form-factors that will allow use of exclusive B decays to measure V_{ub} with good precision via “double ratios”
- Much improved absolute branching ratios
- Measurement of strong phase used in $\overline{D}^o$-D^o mixing
- Measurement of inclusive decay rates

Are Babar & Belle compatible?

Babar

DK :

$$r_B = 0.118 \pm 0.079 \pm 0.034\ {}^{+0.036}_{-0.034}$$

$$\delta_B = (104 \pm 45\ {}^{+17}_{-21}\ {}^{+16}_{-24})^\circ$$

$$D^*K:\ r_B^* = 0.169 \pm 0.096\ {}^{+0.030}_{-0.028}\ {}^{+0.029}_{-0.026}$$

$$\delta_B^* = (296 \pm 41\ {}^{+14}_{-12} \pm 15)^\circ$$

$$\gamma = (70 \pm 31_{\text{stat.}}\ {}^{+12}_{-10}\,{}_{\text{syst.}}\ {}^{+14}_{-11}\,{}_{\text{Dalitz}})^\circ$$

Belle

$$r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$$

$$\delta_B = (157 \pm 19 \pm 11 \pm 21)^\circ$$

$$r_B^* = 0.12\ {}^{+0.16}_{-0.11} \pm 0.02 \pm 0.04$$

$$\delta_B^* = (321 \pm 57 \pm 11 \pm 21)^\circ$$

$$\gamma = (68\ {}^{+14}_{-15}\,{}_{\text{stat.}} \pm 13_{\text{syst.}} \pm 11_{\text{Dalitz}})^\circ$$

- Different r_B values generate very different errors. If r_B is fixed are results for γ compatible?

DK :*

$$r_B(K^*) = 0.25\ {}^{+0.17}_{-0.18} \pm 0.09 \pm 0.04 \pm 0.08$$

$$\delta_B(K^*) = (353 \pm 35 \pm 8 \pm 21 \pm 49)^\circ$$

$$\gamma = (112 \pm 35 \pm 9 \pm 11 \pm 8)^\circ$$

Measuring δ at CLEO-c

- For C=-1 $D^o\overline{D}^o$ states such as the ψ''

$$\Gamma^{(-)}(K^-\pi^+, S_\zeta) = A^2 A_{S_\zeta}^2 |1 + \zeta r e^{-i\delta}|^2 (1 + y^2)$$
$$\approx A^2 A_{S_\zeta}^2 (1 + 2\zeta r \cos\delta) \quad .$$

- Thus by using both ζ=-1 & ζ=+1 & the fact that r has been measured, cosδ can be determined
- For C=+1 $D^o\overline{D}^o$ states

$$\Gamma^{(+)}(K^-\pi^+, S_\zeta) = A^2 A_{S_\zeta}^2 |1 - \zeta r e^{-i\delta}|^2 (1 - 2\zeta y + 3y^2)$$
$$\approx A^2 A_{S_\zeta}^2 (1 - 2\zeta r \cos\delta)(1 - 2\zeta y) \quad .$$

- Here y and cosδ are coupled

See Gronau, Grossman & Rosner hep-ph/0103110]

ADS Method for Measuring γ

- ADS: Atwood, Duniez & Soni Phys. Rev. Lett. 78, 3257 (1997)
- This is based on an older method of Gronau, London & Wyler that is more difficult to apply Phys. Lett. B253, 483 (1991); Phys. Lett. B265, 172 (1991); Gronau, Phys. Lett. B557, 198 (2003)
- Consider $B^- \to D^o K^-$ & $B^- \to \overline{D}^o K^-$ where the D^o again goes to states f_i common to both D^o & $\overline{D}^o$. These can be states like $K^-\pi^+$ which interfere due to DCSD or even CP eigenstates, but they can't all be CP eigenstates or we are back in the realm of GLW

Measuring δ at CLEO-c

- For C=-1 $D^o\overline{D}^o$ states such as the ψ''

$$\Gamma^{(-)}(K^-\pi^+, S_\zeta) = A^2 A^2_{S_\zeta} |1+\zeta r e^{-i\delta}|^2 (1+y^2)$$
$$\approx A^2 A^2_{S_\zeta} (1 + 2\zeta r\cos\delta) \quad .$$

- Thus by using both ζ=-1 & ζ=+1 & the fact that r has been measured, cosδ can be determined
- For C=+1 $D^o\overline{D}^o$ states

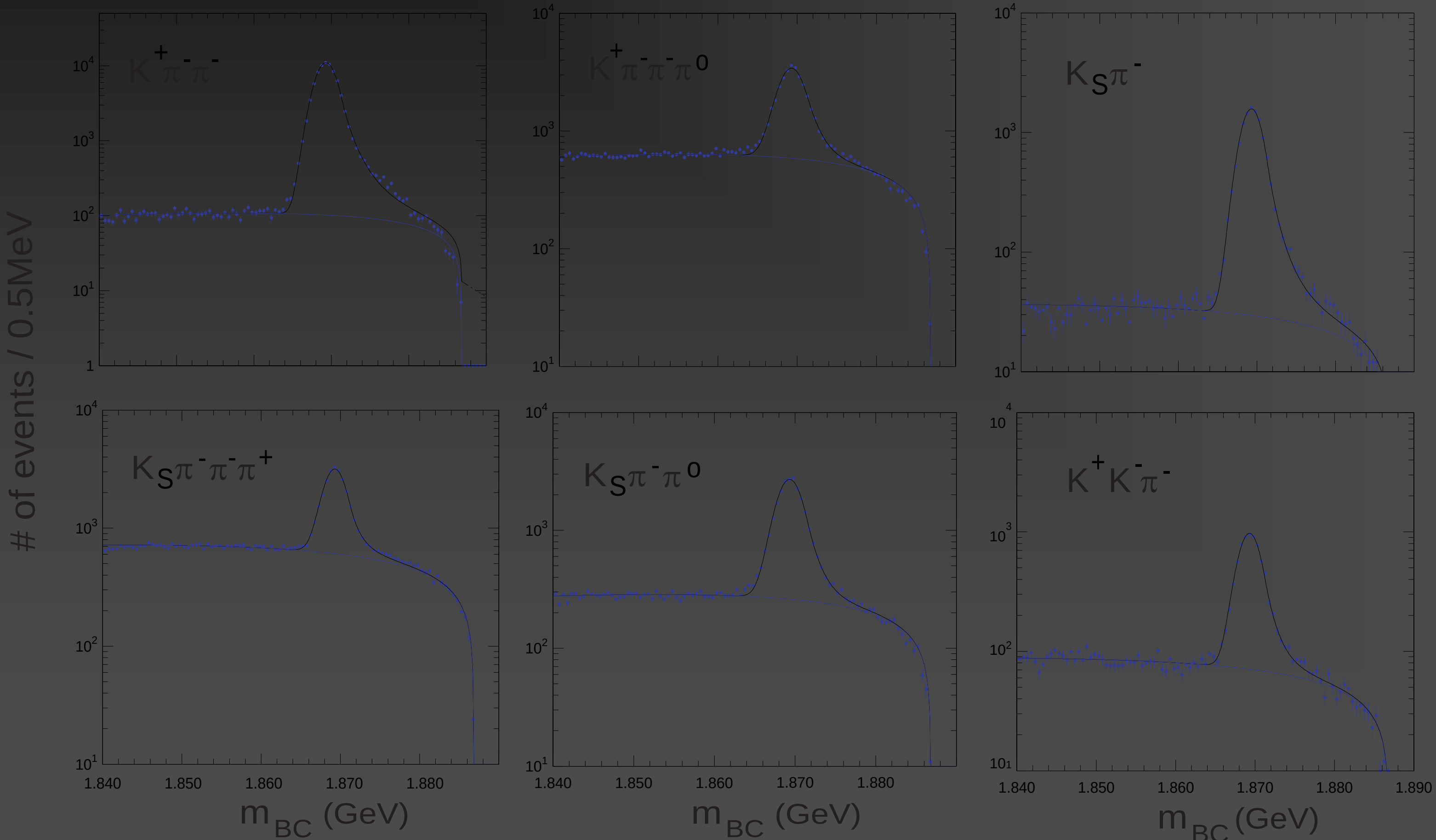
$$\Gamma^{(+)}(K^-\pi^+, S_\zeta) = A^2 A^2_{S_\zeta} |1-\zeta r e^{-i\delta}|^2 (1-2\zeta y+3y^2)$$
$$\approx A^2 A^2_{S_\zeta} (1 - 2\zeta r\cos\delta)(1-2\zeta y) \quad .$$

- Here y and cosδ are coupled

See Gronau, Grossman & Rosner hep-ph/0103110]

Problem: how many events?

- Fits to Asymmetric signal function (Crystal Ball shape) plus smooth background shape (ARGUS function) – error in tags ±0.3%



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What about f_{D_s}?

Model	f_{D^+} (MeV)	$f_{D_s^+}/f_{D^+}$
Lattice (n_f=2+1) [13]	$201 \pm 3 \pm 17$	$1.24 \pm 0.01 \pm 0.07$
Lattice (n_f=2) (CP-PACS) [14]	$202 \pm 12^{+20}_{-25}$	1.18±0.09±xx
Quenched Lattice (Taiwan) [15]	$235 \pm 8 \pm 14$	$1.13 \pm 0.03 \pm 0.05$
Quenched Lattice (UKQCD) [16]	$210 \pm 10^{+17}_{-16}$	$1.13 \pm 0.02^{+0.04}_{-0.02}$
Quenched Lattice [17]	$211 \pm 14^{+0}_{-12}$	1.10 ± 0.02
QCD Spectral Sum Rules [18]	203 ± 20	1.15 ± 0.04
QCD Sum Rules [19]	195 ± 20	
Relativistic Quark Model [20]	243 ± 25	1.10
Potential Model [21]	238	1.01
Isospin Mass Splittings [22]	262 ± 29	

- CLEO-c will start scan to determine best place to run for D_s now; will also measure $\mathcal{B}(D_s \rightarrow \phi\pi^+)$
- Old determinations of f_{D_s} are too poor to use

Systematic Errors

Source of Error	%
Finding the μ^+ track	0.7
Minimum ionization of μ^+ in EM cal	1.0
Particle identification of μ^+	1.0
MM^2 width	1.0
Extra showers in event > 250 MeV	0.5
Number of single tag D^+	0.6
Monte Carlo statistics	0.4
Background	+ 0.6, -1.7
Total	**+2.1, -2.5**

ADS: more details

- a is the dominant mode, while b is suppressed:

$$a = \mathcal{B}(B^- \to K^- D^0) \tag{6.117}$$

$$b = \mathcal{B}(B^- \to K^- \bar{D}^0) \tag{6.118}$$

$$c(f_1) = \mathcal{B}(D^0 \to f_1), \qquad c(f_2) = \mathcal{B}(D^0 \to f_2) \tag{6.119}$$

$$c(\bar{f}_1) = \mathcal{B}(D^0 \to \bar{f}_1), \qquad c(\bar{f}_2) = \mathcal{B}(D^0 \to \bar{f}_2) \tag{6.120}$$

$$d(f_1) = \mathcal{B}(B^- \to K^- f_1), \qquad d(f_2) = \mathcal{B}(B^- \to K^- f_2) \tag{6.121}$$

$$\bar{d}(f_1) = \mathcal{B}(B^+ \to K^+ f_1), \qquad \bar{d}(f_2) = \mathcal{B}(B^+ \to K^+ f_2) \tag{6.122}$$

Assume that we can measure the quantities a, $c(f_1)$, $c(f_2)$, $c(\bar{f}_1)$, $c(\bar{f}_2)$, $d(f_1)$, $d(f_2)$, $\bar{d}(f_1)$ and $\bar{d}(f_2)$ but not b.

ADS: more details II

We can express $d(f_1)$ in terms of a, b, $c(f_1)$, $c(\bar{f}_1)$, the strong phase ξ_1 and the weak phase γ.

$$d(f_1) = a \times c(f_1) + b \times c(\bar{f}_1) + 2\sqrt{a \times b \times c(f_1) \times c(\bar{f}_1)}\cos(\xi_1 + \gamma) \quad (6.123)$$

$$\bar{d}(f_1) = a \times c(f_1) + b \times c(\bar{f}_1) + 2\sqrt{a \times b \times c(f_1) \times c(\bar{f}_1)}\cos(\xi_1 - \gamma) \quad (6.124)$$

$$d(f_2) = a \times c(f_2) + b \times c(\bar{f}_2) + 2\sqrt{a \times b \times c(f_2) \times c(\bar{f}_2)}\cos(\xi_2 + \gamma) \quad (6.125)$$

$$\bar{d}(f_2) = a \times c(f_2) + b \times c(\bar{f}_2) + 2\sqrt{a \times b \times c(f_2) \times c(\bar{f}_2)}\cos(\xi_2 - \gamma) \quad (6.126)$$

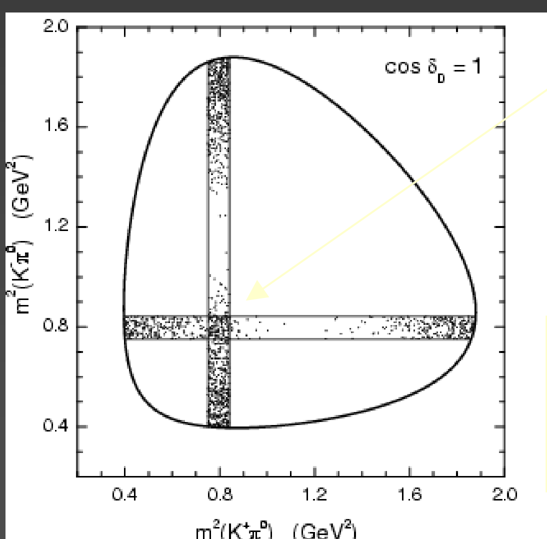
These four equations contain the four unknowns ξ_1, ξ_2, b and γ which can be determined up to discrete ambiguities. Adding additional decay modes will reduce the ambiguities. The strong phases ξ_i are related to the D decay phase shifts δ_i by the relation :

$$\xi_1 - \xi_2 = \delta_1 - \delta_2. \quad (6.127)$$

- $\zeta_1 - \zeta_2 \equiv$ can be measured at CLEO-c, by choosing f_2 as a CP eigenstate
- More modes can be added

$B^{\pm} \rightarrow D^{o}K^{\pm}$ decays, where $D^{o} \rightarrow K^{*\pm}K^{\pm}$

- Grossman, Ligeti & Soffer [hep-ph/0210433]
- The $K^{*\pm}K^{\mp}$ is only singly Cabibbo suppressed
- Rosner & Suprun show how to measure the relative phase between $K^{*+}K^{-}$ & $K^{*-}K^{+}$ [hep-ph/0303117] using the $K^{+}K^{-}\pi^{o}$ Dalitz plot



Constructive interference gives 113 in overlap region, while destructive gives 4 events, both out of 1500

Can measure δ in $KK\pi$ & use $K_{s}\pi K$