WG II

nufact00

Dear Santa:
Heavy Flavour Physics at nuMC's -- Theoretical Desires

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Which info on HFlPh missing + interesting in 2010?

3 classes

- ○ (more precise) measurements of SM parameters
- ○ calibration of theoretical tools (control over hadronization)
- ○ probe for NP

(A) Measurements of SM Parameters

1) CKM Parameters

$$|V_{CKM}| = \begin{array}{cccc} d & s & b & \\ \left(\begin{matrix} 0.9742 - 0.9757 & 0.219 - 0.226 & 0.002 - 0.005 \\ 0.219 - 0.225 & 0.9734 - 0.9749 & 0.037 - 0.043 \\ 0.004 - 0.014 & 0.035 - 0.043 & 0.9990 - 0.9993 \end{matrix}\right) & & & \begin{matrix} u \\ c \\ t \end{matrix} \end{array}$$

with 3-family unitarity!

$$|V_{CKM}| = \begin{pmatrix} 0.9722 - 0.9748 & 0.216 - 0.223 & 0.002 - 0.005 & \cdots \\ 0.199 - 0.233 & 0.784 - 0.976 & 0.037 - 0.043 & \cdots \\ 0.0 - 0.09 & 0 - 0.55 & 0 - 0.9993 & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

without 3-family unitarity!

$|\Delta V_{cd}|_{PDG00} = 17\%$ $[3\%]$

$|\Delta V_{cs}|_{PDG00} = 20\%$ $[2\%]$

$|\Delta V_{ub}|$ " $= 40\%$

$|\Delta V_{cb}|$ " $= 8\%$

$$\begin{tikzcd}
\text{product. in DIS} \arrow[r, bend right] \arrow[dr] & V_{cs} & \text{SL decays} \arrow[l] \arrow[dl, bend left] \\
& V_{cd} &
\end{tikzcd}$$

future

$|\Delta V_{cd}|_{\text{pre}\,\nu\text{MC}} \sim 10\%$

$|\Delta V_{cs}|$ " $\sim 10\%$

$|\Delta V_{cb}|$ " $\simeq 4\%$

$|\Delta V_{ub}|$ " $\sim 10-15\%$ ← not guaranteed!

want to do better!

- ○ CKM fundamental quantities related to generation of mass
- ○ very different `textures' at GUT scales yield not so different CKM at EW scales
- ○ CP asymmetries in B decays:
  - ○ will be measured with few % accuracy
  - ○ are functions of |V(ub)|, |V(cb)|

challenge for nuMC

extract $\begin{pmatrix} |V_{cd}| \\ |V_{ub}| \\ |V_{cs}| \\ |V_{cb}| \end{pmatrix}$ with uncertainty $\begin{pmatrix} \mathcal{O}(1\%) \\ \mathcal{O}(1\%) \\ \mathcal{O}(\text{few}\,\%) \\ \mathcal{O}(\text{few}\,\%) \end{pmatrix}$

- ○ appears feasible experimentally
- ○ theoretical uncertainties?
  - actually measure ratios |V(cd)/V(ud)|

    uncertainties in PDF's drop out
  - threshold suppression

    lab for duality stud

    central challenge

    involves nonperturb. definit. of quark mass

    $\neq$ " " of " " in decays

    could use |V(cs)| and |V(cb)| as calibrators!

2) f_D

○ $D \to \mu\nu$ f_D

○ $D_s \to \mu\nu$ f_{D_s}

(B) Calibrating our Theoretical Tools

1) Inclusive charm decays

○ tool: OPE → $1/m_c$ expansion

quark-hadron duality

○ observables

○ lifetimes of Ω_c or exotic [ccq] baryons

○ absolute $\overset{\text{SL}}{\text{BR's}}$ $D_s / \Lambda_c^+ / \Xi_c^{+,0} / \Omega_c \to \ell\nu X$

○ multineutral final states

SU(3) & duality

2) Absolute charm BR's

$$\left.\begin{cases}\text{engineering input}\\ \text{experim. bottleneck}\end{cases}\right\}\ \text{to B studies}$$

3) $B_d \to \pi^0 \pi^0$

unfolding Penguins

4) D^0 - D^0 oscillations

$\Delta \Gamma_D$ vs. ΔM_D

see below

(C) Probe for New Physics

(1) $D \to \mu\nu$ vs. $D \to \tau\nu$

$$\begin{tikzcd}
D \to \mu\nu \arrow[d, leftrightarrow, bend right, "SU(3)"'] & D \to \tau\nu \arrow[d, leftrightarrow, bend left, "SU(3)"] \\
D_s \to \mu\nu \arrow[r, leftrightarrow, bend right, "\text{pseudoscalar exchange}"'] & D_s \to \tau\nu
\end{tikzcd}$$

2) D^0 - D^0 oscillations

- **basic quantities**

$$x_D = \frac{\Delta M_D}{\Gamma_D} \qquad\qquad y_D = \frac{\Delta \Gamma_D}{2\Gamma_D}$$

x_D ↑ sensitive to NP

y_D ↑ hardly sensitive to NP

- **flavour tag**

initial state

- $D^{+*} \longrightarrow D^0 \pi^{\oplus}$
- $D^{\oplus} \bar{D}^0$, $D^{\ominus} D^0$
- $\nu N \longrightarrow \mu^{\ominus} D X$

  $\bar{\nu} N \longrightarrow \mu^{\oplus} \bar{D} X$

νMC $\Delta C = -\Delta Q_\ell$ rul

final state

$D^0 \longrightarrow K^{\ominus} X$ SM backgrd: DCSD

$D^0 \longrightarrow \ell^{\oplus} X$ " " none - but check

- experim. landscape

$$r_D = \frac{\Gamma(D^0 \to \ell^- X)}{\Gamma(D^0 \to \ell^+ X)} \simeq \frac{1}{2}(x_D^2 + y_D^2)$$

$$D^0 \to K^+\pi^- \quad \text{vs.} \quad D^0 \to K^-\pi^+$$

$$y_D' = y_D \cos\delta_{K\pi} - x_D \sin\delta_{K\pi}$$

$r_D \leq 5 \times 10^{-4}$	95% C.L.	CLEO
$-0.04 \leq y_D \leq 0.06$	90% C.L.	E791
$-0.058 \leq y_D' \leq 0.01$	95% C.L.	CLEO
$y_D = 0.0342 \pm 0.0139 \pm 0.0074$		FOCUS

- theoret. landscape

folklore

$y_D, x_D \sim 10^{-4} - 10^{-3}$ dominated by LDD

my (& Uraltsev's) opinion

$y_D, x_D \sim \mathcal{O}(10^{-3})$ can be obtained from OPE

<u>if</u> FOCUS has seen signal for $\Delta\Gamma_D$

→ ΔM_D 'just around corner'

→ bad news for NP hunters

NP $\neq$ big game $\hat{=}$ "if encounter it, can't miss it!"

future

CLEO, BELLE, BABAR, (FOCUS)

r_D down to few $\times 10^{-4}$

not just game of statistics!

$$\Gamma(D^0(t) \to \ell^- X) \propto e^{-\Gamma_D t} \cdot \left[\left(\frac{x_D}{2}\right)^2 \left(\frac{t}{\tau_D}\right)^2 + y_D \frac{t}{\tau_D} \mathrm{Re} \frac{p}{q} \hat{\rho}_{wrong} + \left(1 - y_D \frac{t}{\tau_D}\right) |\hat{\rho}_{wrong}|^2 \right]$$

$$\hat{\rho}_{wrong} = \frac{T(D^0 \to \ell^- X)}{T(D^0 \to \ell^+ X)} \quad [\equiv 0 \text{ in SM}]$$

might still be open issue in 2010
" " systematics limited in 2010

→ νMC might play decisive role!

(3) $\cancel{CP}$

- $$\Gamma(D^0(t) \longrightarrow K^+\pi^-) \propto e^{-\Gamma_D t}\, tg^4\theta_c\, |\hat{\rho}_{K\pi}|^2 \times$$

$$\left[1 - \tfrac{1}{2}\Delta\Gamma_D t + \frac{(\Delta m_D t)^2}{4\, tg^4\theta_c\, |\hat{\rho}_{K\pi}|^2} + \frac{\Delta\Gamma_D t}{2\, tg^2\theta_c\, |\hat{\rho}_{K\pi}|}\, \mathrm{Re}\, \frac{p}{q}\frac{\hat{\rho}_{K\pi}}{|\hat{\rho}_{K\pi}|} - \frac{\Delta m_D t}{tg^2\theta_c\, |\hat{\rho}_{K\pi}|}\, \mathrm{Im}\, \frac{p}{q}\frac{\hat{\rho}_{K\pi}}{|\hat{\rho}_{K\pi}|}\right]$$

$$tg^2\theta_c\, \hat{\rho}_{K\pi} \equiv \frac{T(D^0 \to K^+\pi^-)}{T(D^0 \to K^-\pi^+)}$$

CP asym.

$$\Gamma(\bar{D}^0(t) \longrightarrow K^-\pi^+) \propto e^{-\Gamma_D t}\, tg^4\theta_c\, |\hat{\rho}_{K\pi}|^2 \times$$

$$\left[\quad \left\{ \hat{\bar{\rho}}_{K\pi} \longrightarrow \hat{\rho}_{K\pi} \right\} \qquad + \frac{\Delta m_D t}{tg^2\theta_c\, |\hat{\bar{\rho}}_{K\pi}|}\, \mathrm{Im}\, \frac{p}{q}\frac{\hat{\bar{\rho}}_{K\pi}}{|\hat{\bar{\rho}}_{K\pi}|}\right]$$

observable CP asymm. $\propto \dfrac{x_D}{tg^2\theta_c}$

e.g.:

if

$$x_D = 10^{-2} \begin{cases} r_D \simeq \frac{1}{2}(x_D^2 + y_D^2) \sim 10^{-4} \\ \dfrac{x_D}{tg^2\theta_c} \sim 0.2 \;! \end{cases}$$

i.e.: could be CP asymm. as large as 10%
without $D^0 - \bar{D}^0$ oscill. exceeding $r_D = 10^{-4}$!

will be searched for at beauty factories

superior systematics at νMC ?

- direct $\not{CP}$

within KM only in Cabibbo suppr. modes
"typical" expectations $\lesssim O(10^{-3})$

exotic exception: $D^+ \to K_S \pi^+$ vs. $D^- \to K_S \pi^-$

2 classes of effects

- partial width differences

$$\Gamma(D \to f) \neq \Gamma(\bar{D} \to \bar{f})$$

- asymm. in final state distributions: Dalitz plots etc.

highly desirable to analyze multi-neutral final states
ⓘ more places to search / self-consistency checks
ⓘⓘ great benefit for proper interpretation
¿ is it KM or is it NP ?

superior ~~statistics~~ systematics at νMC ?

special case of direct $\not{CP}$
T odd correlation in

$$\nu N \to \Lambda_c X$$
$$\hookrightarrow \ell^+ \nu \Lambda$$

$$C_{T\,odd} \equiv \langle \vec{\sigma}_\Lambda \cdot (\vec{p}_\Lambda \times \vec{p}_\ell) \rangle \overset{?}{\neq} 0 \qquad \text{no FSI!}$$

similar to $P_\perp$ in $K^+ \to \mu^+ \nu \pi^0$

FABULA DOCET

- many important questions in charm & beauty decays (mainly - but not only - quantitative ones) will still await a definitive answer in 2010.

- the urgency of some of them might actually be enhanced by then

$$\Delta \not{C}\not{P}(B)\Big|_{exp} \sim 2\% \longleftrightarrow \Delta \not{C}\not{P}(B)\Big|_{KM} \text{ ?}$$

$$\not{C}\not{P}(D) \sim \mathcal{O}(10^{-3}) \longleftrightarrow NP \text{ ?}$$

$$x_D, y_D \sim 0.01 \longleftrightarrow NP \text{ ?}$$

- νMC might represent a powerful answer to these challenges due to novel and superior (?) systematics
  - better extraction of $|V(cd)|, |V(ub)|, \ldots$
  - better calibration of theoret. tools
    f_D, f_{D_s}; multi-neutral final states
  - searches for NP
    $D^0 - \bar{D}^0$ oscill.

    $\not{C}\not{P}$