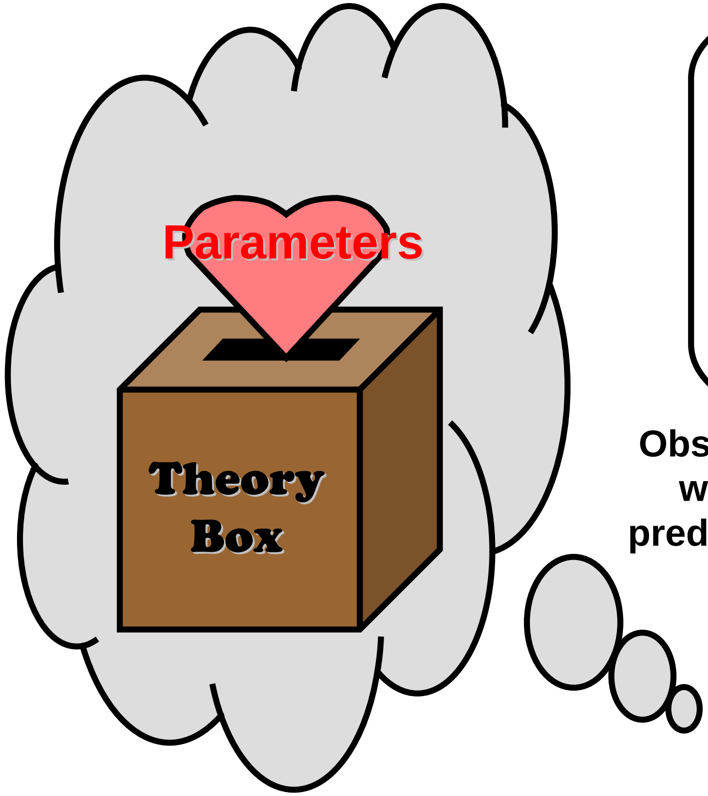
Charm Physics at BES and Impact on CKM elements

V. Niess, *on behalf of S. Descotes-Genon*

FCPPL 09 Workshop, Wuhan

FCPPL collaboration
Sébastien Descotes-Genon (LPT Orsay)
Jérôme Charles (CPT Marseille)
Haibo Li (IHEP Beijing)
Xian Wei Kang (IHEP Beijing)

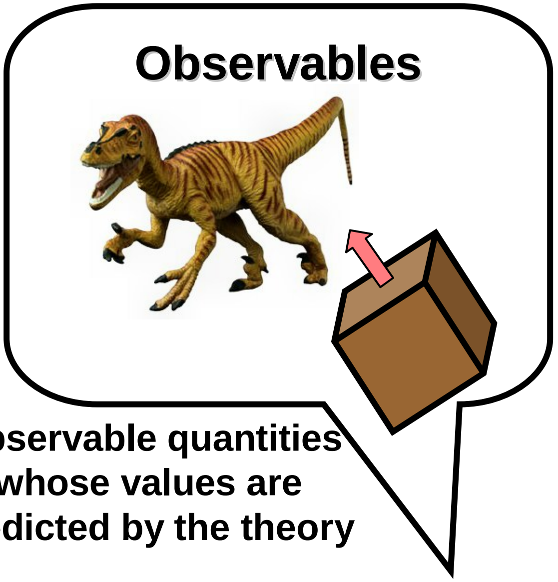
The Game



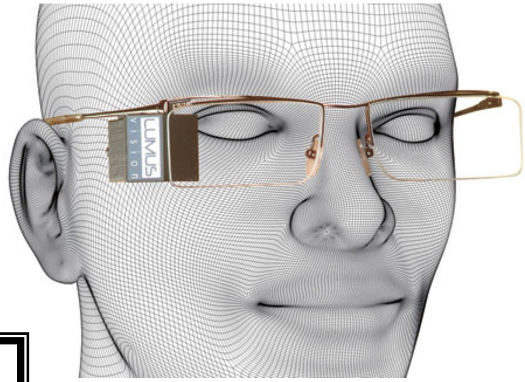
A descriptive theory

Goals

1) Quantify theory 'degrees of belief'
2) Estimate theory parameters

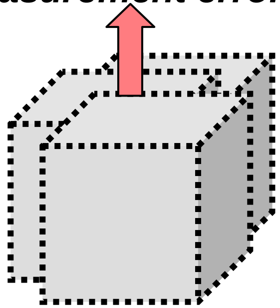


Observable quantities whose values are predicted by the theory



Observation

Observables smeared by measurement errors



Frequentism

2 types of measurement errors as regards to the repetition of the observation in *identical* conditions:

-**Systematics**: bias in the repetition of the measurements as regard to the observable value

-**Statistical**: fluctuations inherent to the measurement that can be described by a statistical distribution (mostly Gaussian, cf. central limit theorem)

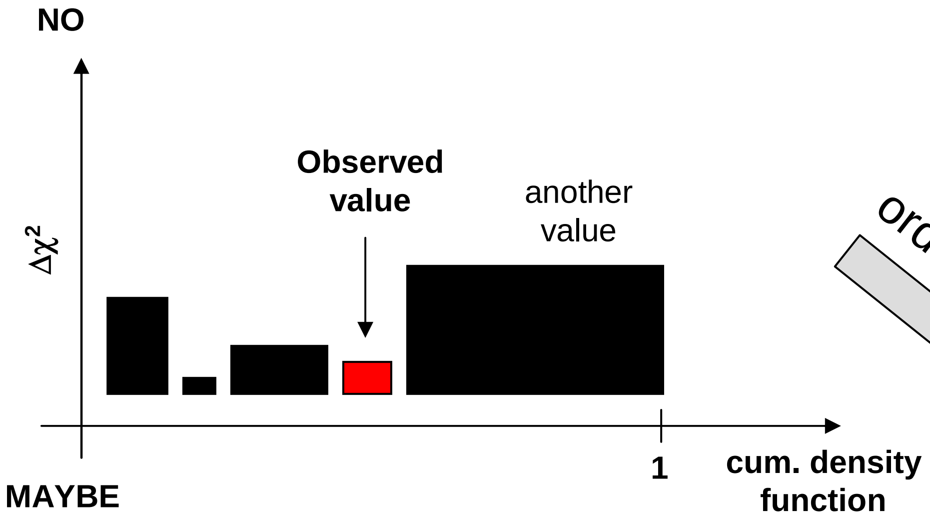
⇒ Use **Frequentist hypothesis test** statistical tools

The key ingredient: *a test statistic (typically,* χ^2 *type) as a decision rule for a hypothesis test of the chosen theory*

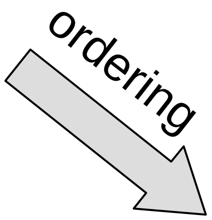
The tools: *p-value of the test, either by assuming an asymptotical* χ^2*(ndof) distribution or by Monte-Carlo*

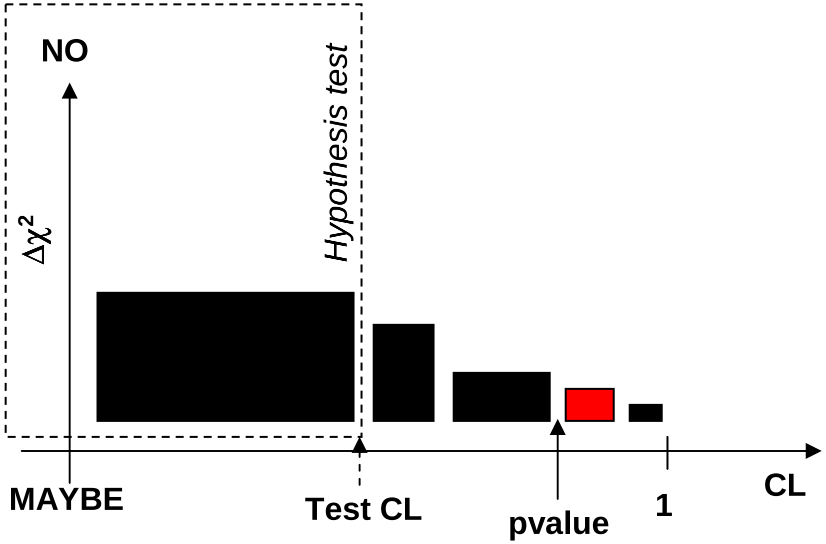
Illustrated Frequentism

Discrete illustration
Each of the 5 boxes is a possible value
for the observation



(small $\Delta\chi^2$ values are in favor of the theory /hypothesis)





Minimising χ^2 over *irrelevant* nuisance parameters (e.g. systematics) very time consuming.

Great improvement from Mathematica analytical pre-treatment of χ^2 gradient with respect to theory parameters.

Fastens computation time by 2 orders of magnitude!

Systematics & RFit

Systematics = *nuisance* parameters in a bounded range ±Δ

⇒ Range of width 2Δ of confident *enough* values for the systematics and minimise χ^2

Over this range, the resulting test significance is evenly flat.

Different from statistical modeling of systematics (e.g., uniform pdf)

Simple example:

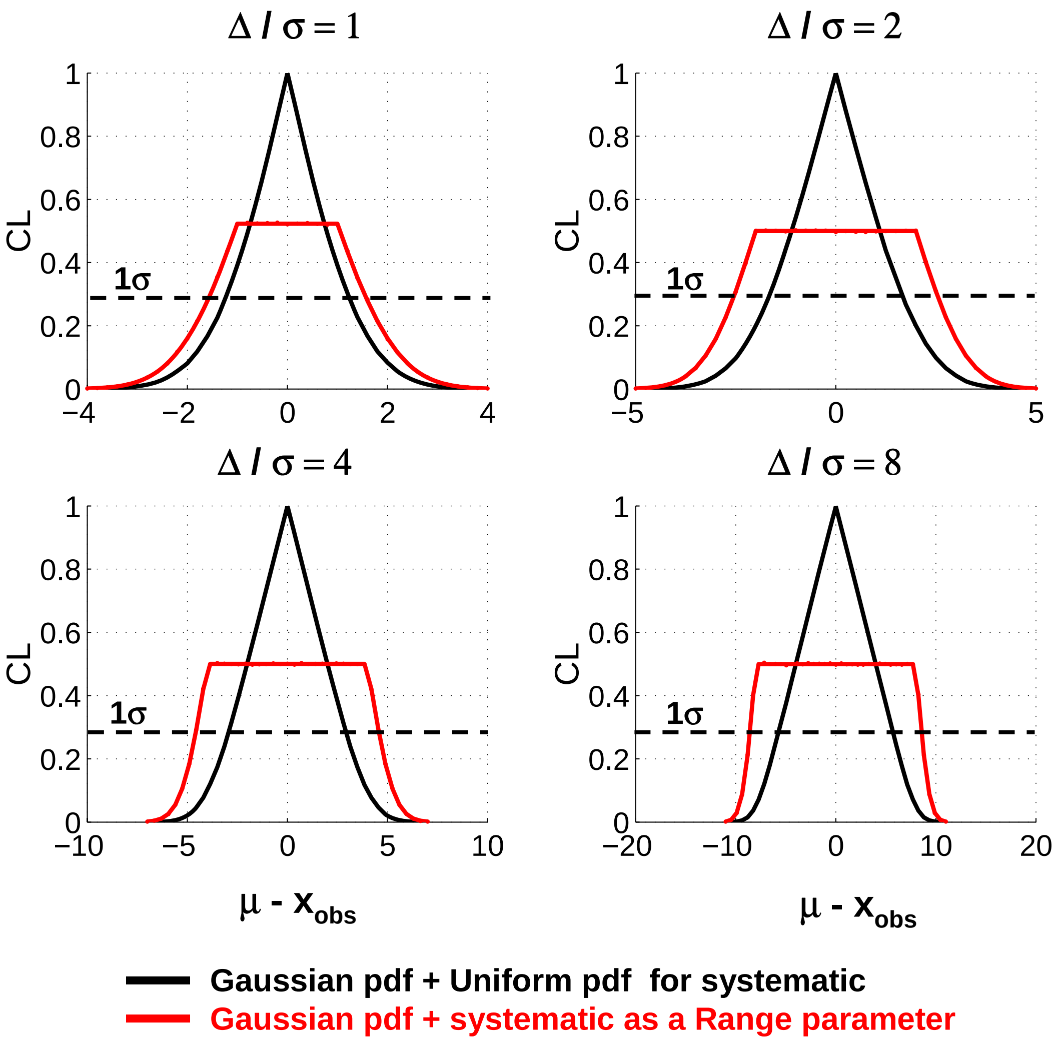
$$x = \mu + \sigma N[0,1] + \Delta_x$$

observation

parameter

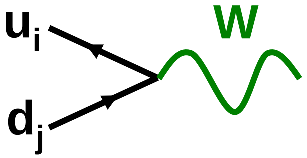
stat. error

systematics



Weak Interactions and the CKM Matrix

In the quark sector of the SM weak eigenstates ≠ mass eigenstates:



$$\frac{g}{\sqrt{2}}\bar{u}_{Li}V_{ij}\gamma^{\mu}d_{Lj}W_{\mu}+\text{h.c.}$$

Indirectly @ BES (HQET, lattice)

Directly @ BES

with the 3x3 unitary Cabbibo-Kobayashi-Maskawa matrix: $V_{CKM}=\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$

3 generations ⇒ parameterisation with 3 Euler angles θ_{ij} + 1 complex phase δ allowed (CP violation)

Hierarchy: transitions between generations are disfavoured ⇒ Wolfenstein parameterisation of V_{CKM}

$$V_{CKM}=\begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}+O(\lambda^4)$$

$$\begin{cases} \text{A}=0.8117\,[+0.0096-0.0236] \\ \lambda=\sin(\theta_{12})=0.2252\pm0.0008 \\ \bar{\rho}=0.145\,[+0.024-0.034] \\ \bar{\eta}=0.339\,[+0.019-0.015] \end{cases}$$

(1σ CL)

(from CKMfitter Summer 08)

CKM Unitarity Triangles

From V_{CKM} many unitarity relations, related to 4 Mesons (top excluded)
⇒ graphically represented as triangles in complex plan ($\vec{a}+\vec{b}=-\vec{c}$)

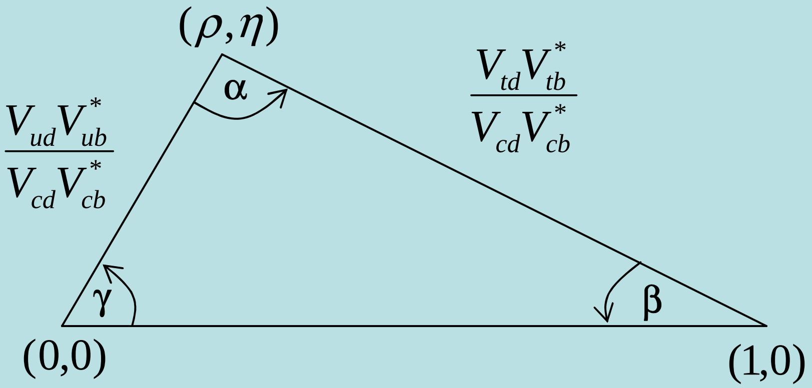
B_d $$\sum_{i\in\{u,c,t\}} V_{ib}^{*} V_{id} = 0 \quad (\lambda^3,\lambda^3,\lambda^3)$$

B_s $$\sum_{i\in\{u,c,t\}} V_{ib}^{*} V_{is} = 0 \quad (\lambda^4,\lambda^2,\lambda^2)$$

K $$\sum_{i\in\{u,c,t\}} V_{is}^{*} V_{id} = 0 \quad (\lambda,\lambda,\lambda^5)$$

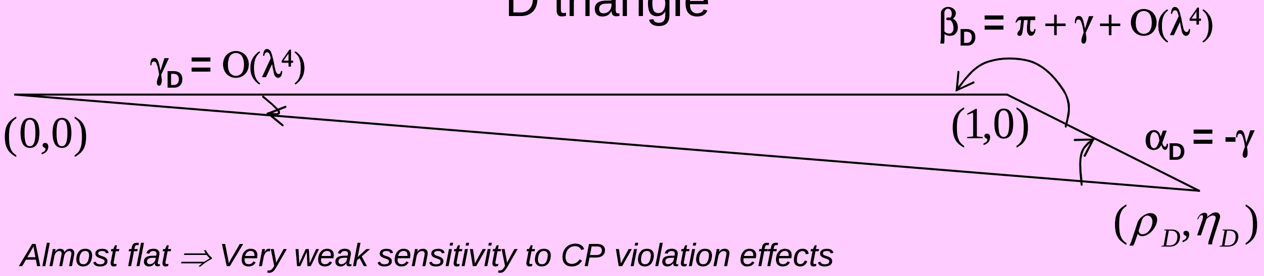
D $$\sum_{j\in\{d,s,b\}} V_{cj}^{*} V_{uj} = 0 \quad (\lambda,\lambda,\lambda^5)$$

B_d triangle



3 sides ~equivalent length ⇒ CP violation effects

D triangle



Almost flat ⇒ Very weak sensitivity to CP violation effects
Sensitive to γ angle only

Indirect Constraints on D-UT

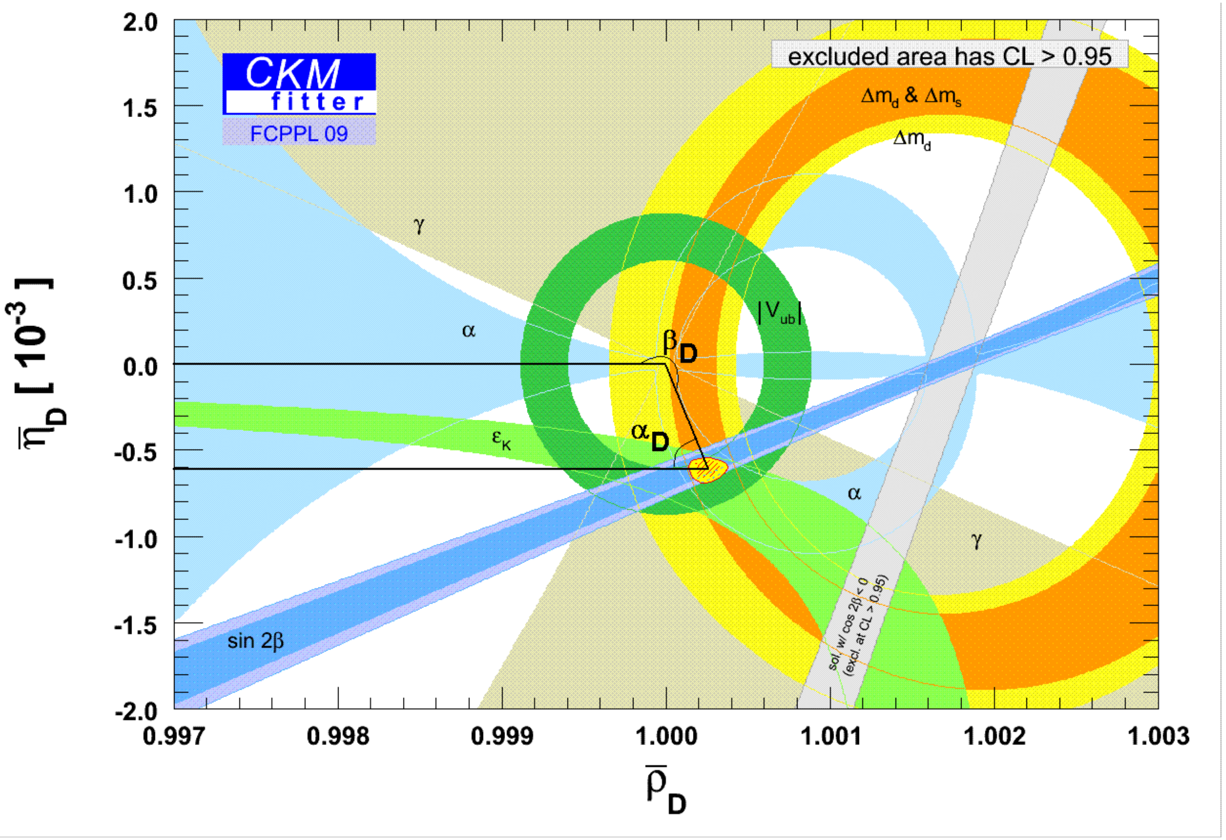
In the SM kaon and B processes constrain strongly D-UT through the CKM parameters:

- **$|V_{us}|$** constraints (in a first approximation) $\lambda \sim$ **$|V_{cd}|$**
- B→DK constraints γ and thus α_D and β_D

(1σ CL)

$$\begin{cases} |V_{cd}| = 0.22508 \pm 0.00082 \\ \alpha_D = -70^{o}\ [+29 - 27] \end{cases}$$

From the global fit (Summer 08)



Direct Constraints on V_{cd} and V_{cs}

Former direct determinations:

- $|V_{cd}|$: DIS of νs on nucleons (hard to improve) $\left|V_{cd}\right| = 0.2308 \pm 0.011$ (5%)
- $|V_{cs}|$: charm tagged W decays $\left|V_{cs}\right| = 0.97 \pm 0.09 \pm 0.07$ (12%)

For comparison $|V_{us}|$ from Kl3 is measured at 0.5% accuracy

New kid on the block:

Extract $|V_{cd}|$ and $|V_{cs}|$ from:

- Semileptonic decays of D and D_s mesons
- Lattice QCD (LQCD) for the strong interaction part (vector form factors f_+ dominant)

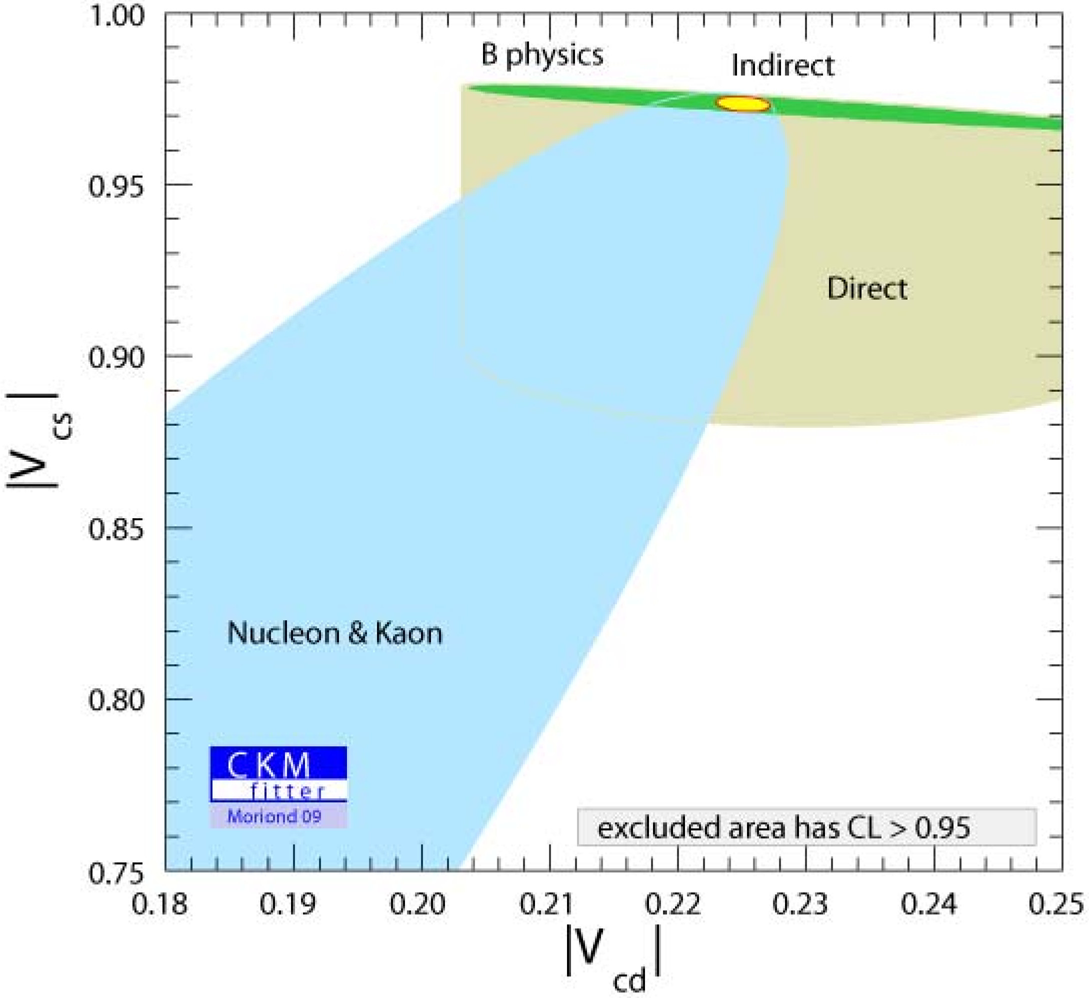
V_{cd} = 0.222 ± 0.008 (stat) ± 0.003 (syst) ± 0.023 (latt) (3.8% exp + 10% th)

V_{cs} = 1.018 ± 0.010 (stat) ± 0.008 (syst) ± 0.106 (latt) (1.3% exp + 10% th)

V_{cd} not competitive yet for CLEO-c : main improvement should come from lattice

with CLEO C results on D->pi e nu and D->K e nu (Shipsey, Aspen 08)
and with FNAL-MILC-HPQCD lattice values for f_+(0)

Direct vs Indirect measurements



Unitarity bound (inside a circle of radius unity)

<u>Constraints</u> :

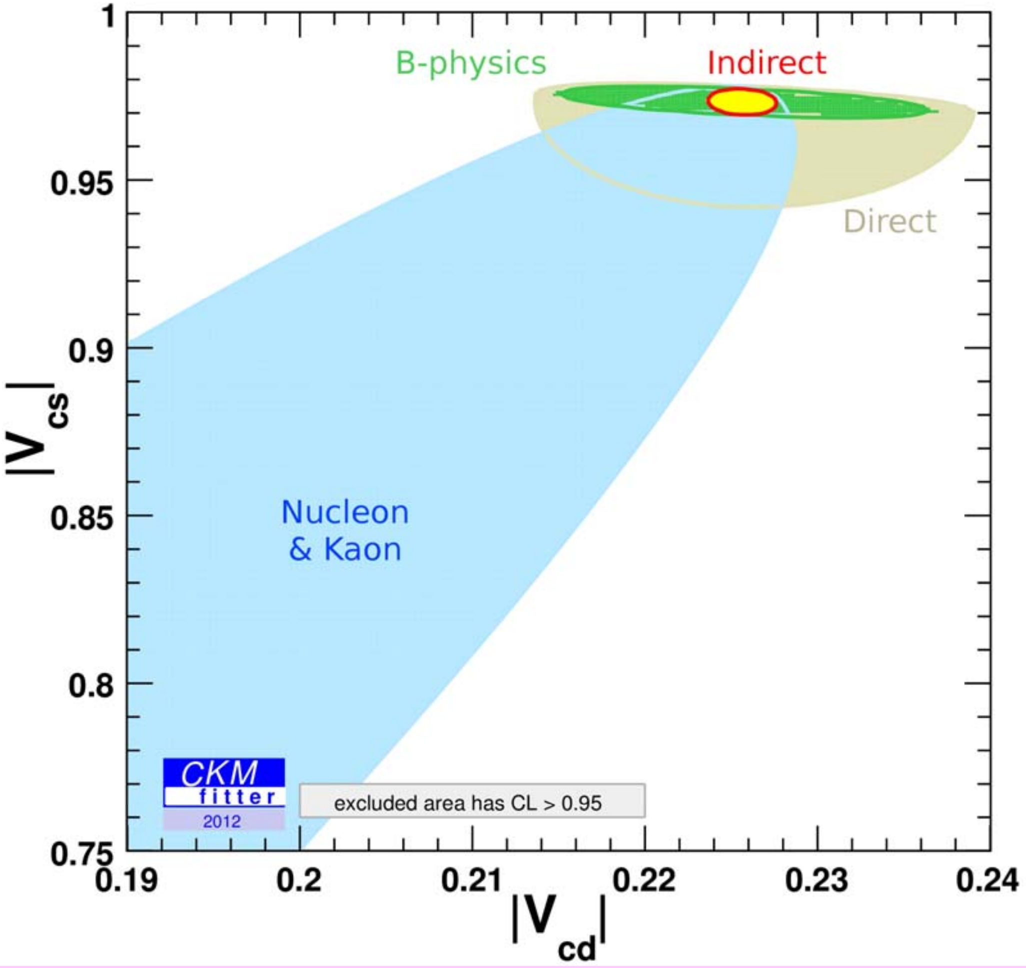
- Nucleon and kaon not very constraining
(V_{ud} and V_{us} identical to V_{cd} and V_{cs} only at first order in λ

- B physics rather constraining

- Indirect combination very powerful

CLEO-c competitive for V_{cs} (with a central value above unitarity bound), but not for V_{cd}… yet, mainly due to lattice

Direct vs Indirect measurements (2012)



Prospective estimates for BES 2012 from Physics at BESIII D. Asner et al, arXiv:0809.1869

(Chapter on the impact on BES & CKM from collaboration between CKMfitter group and BES)

For **BES 2012**, error on V_{cd} $f_+(0)$ and V_{cs} $f_+(0)$ below 1%, lattice error around 5%

- Competitive determination of V_{cd} and V_{cs}
- Potential to find defaults in unitarity, signs of New Physics

Direct Constraints on V_{cd} and V_{cs} (2)

Constraints from current CKM fit

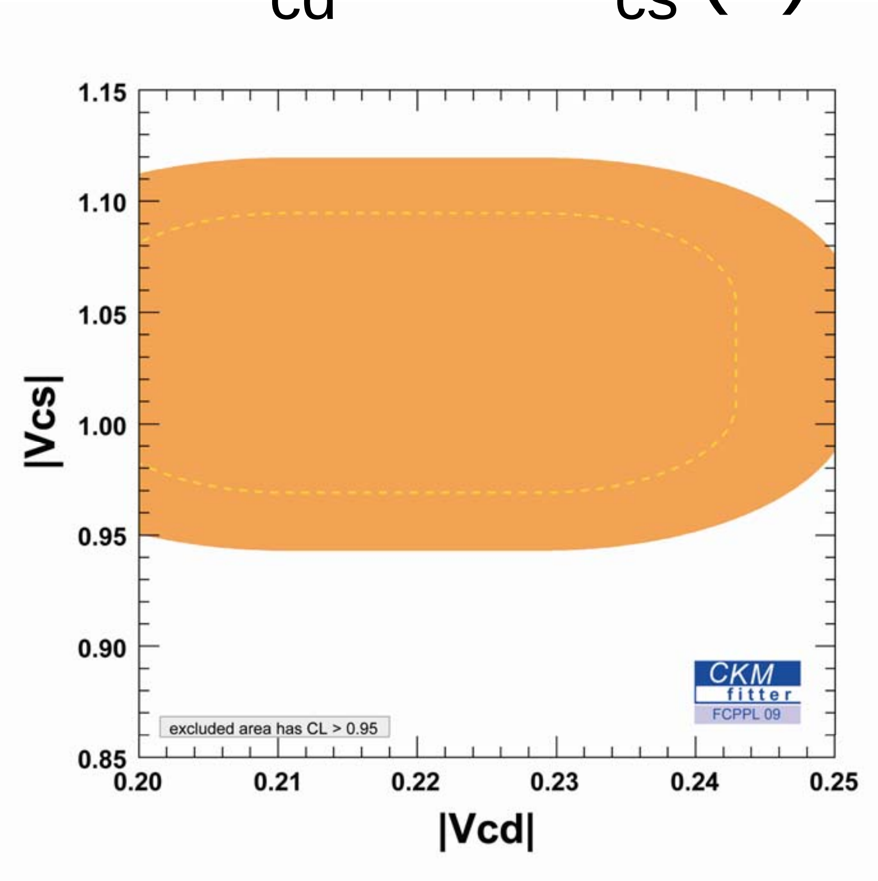
V_{cs} = 0.9735 + 0.0007 -0.0006
V_{cd} = 0.2251 + 0.0008 -0.0008

Another possibility

Extract $|V_{cd}|$ and $|V_{cs}|$ from
- leptonic decays of D and D_s mesons
- LQCD for decay constants $f_{D(s)}$

$$Br[D_s \to \ell\nu] = \frac{G_F^2 m_{D_s} m_\ell^2}{8\pi\hbar}\left(1-\frac{m_\ell^2}{m_{D_s}^2}\right)|V_{cs}|^2 f_{D_s}^2 \tau_{D_s}$$

- $|V_{cd}|$: from $D \to \mu\nu$
- $|V_{cs}|$: from $D_s \to \mu\nu$ and $D_s \to \tau\nu$



$$|V_{cd}| = 0.2248 \pm 0.0236 \qquad (10\%)$$
$$|V_{cs}| = 1.032 \pm 0.049 \qquad (5\%)$$

- *CLEO C (arXiv:0806.2112) for D $\to \mu\nu$,*
- *World Averaging CLEO, BaBar and Belle (arXiv:0901.1147 & 0901.1216) for $D_s \to l\nu$*
- *our own LQCD average (http://ckmfitter.in2p3.fr: mainly fully unquenched as HPQCD07, FNAL-MILC07, but also two-flavour simulations).*

The Story With D_s Decay Constant

But … discrepancy between experiment and theory for D_s to l ν branching ratios

CKM fitter

$$Br(D_s \to \mu\nu) = (5.17 \pm 0.28)\cdot 10^{-3}$$ **(5%)**

$$Br(D_s \to \tau\nu) = (5.05 \pm 0.27)\cdot 10^{-2}$$ **(5%)**

global CKMFit + our LQCD average

$$f_{D_s} = 246.3 \pm 1.2 \pm 5.3$$

Experiments

$$Br(D_s \to \mu\nu) = (5.65 \pm 0.48)\cdot 10^{-3}$$ **(8%)**

$$Br(D_s \to \tau\nu) = (5.62 \pm 0.44)\cdot 10^{-2}$$ **(8%)**

CLEO-C'09

$$Br(D_s \to \mu\nu) = (6.38 \pm 0.92)\cdot 10^{-3}$$ **(14%)**

Belle

$$Br(D_s \to \mu\nu) = (6.74 \pm 1.09)\cdot 10^{-3}$$ **(16%)**

BaBar

With recent LQCD updates the theoretical predictions for D and D_s purely leptonic branching ratios are more accurate than their direct measurements, and not in very good agreement

Little change expected from LQCD (f_{Ds} well controlled on the lattice)

More accurate measurements required!

⇒BESIII could achieve 0.7% accuracy on D_s leptonic branching ratios

CP violation in Psi → 2D → 4V

CP violation in D decays:

- Challenging in Standard Model but clean probe of new Physics
- BEPC will provide intricate $D\bar{D}$ pairs
- If CP studied at BESIII à la BaBar/Belle, price for flavour tagging

Alternative proposal: **Psi → 2D → 4V**

Haibo Li (IHEP)
Jérôme Charles (CPT Marseille)
Sébastien Descotes-Genon (LPT Orsay)

- $D\bar{D}$ produced in definite quantum state (L=1)

$$e^+e^- \rightarrow \Psi \rightarrow D^0\bar{D}^0 \rightarrow f_a f_b$$

- Observation of final states are CP eigenstates with same CP parity

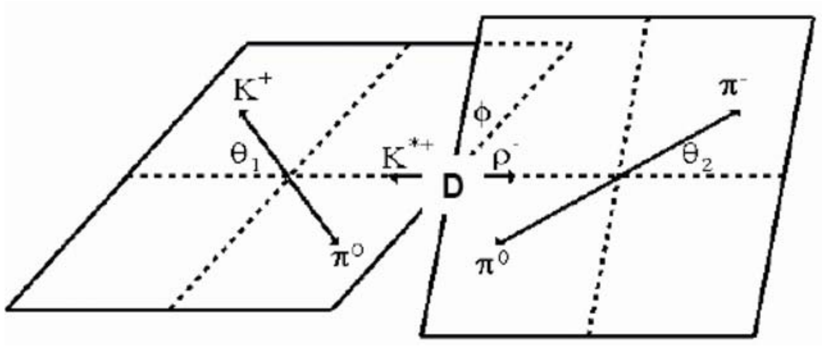
$$CP|\Psi\rangle = |\Psi\rangle \qquad CP|f_a f_b\rangle = \eta_a\eta_b(-1)^\ell|f_a f_b\rangle = -|f_a f_b\rangle$$

… means observation of CP violation !

- D→2V high branching ratio (a few % for K*ρ)

Ikaros I.Y. Bigi, UND-HEP-89-BIG01, Jul 1989

CP violation in Psi → 2D → 4V (2)



$$
\begin{aligned}
d\Gamma \;=\; & dLIPS \times \frac{81}{2(4\pi)^6}|H^{\Psi V_1 V_2 V_3 V_4}|^2 \qquad (\\
& \Bigg|\Bigg[\cos\theta_{V_1}\cos\theta_{V_2}A_0^{D_1\to V_1V_2} - \frac{1}{\sqrt{2}}\sin\theta_{V_1}\sin\theta_{V_2}\cos\Phi A_{\|}^{D_1\to V_1V_2} \\
& \quad -\frac{i}{\sqrt{2}}\sin\theta_{V_1}\sin\theta_{V_2}\sin\Phi A_{\perp}^{D_1\to V_1V_2}\Bigg] \\
& \times\Bigg[\cos\theta_{V_3}\cos\theta_{V_4}A_0^{D_2\to V_3V_4} - \frac{1}{\sqrt{2}}\sin\theta_{V_3}\sin\theta_{V_4}\cos\Psi A_{\|}^{D_2\to V_3V_4} \\
& \quad -\frac{i}{\sqrt{2}}\sin\theta_{V_3}\sin\theta_{V_4}\sin\Psi A_{\perp}^{D_2\to V_3V_4}\Bigg] \\
& -\Bigg[\cos\theta_{V_1}\cos\theta_{V_2}A_0^{D_2\to V_1V_2} - \frac{1}{\sqrt{2}}\sin\theta_{V_1}\sin\theta_{V_2}\cos\Phi A_{\|}^{D_2\to V_1V_2} \\
& \quad -\frac{i}{\sqrt{2}}\sin\theta_{V_1}\sin\theta_{V_2}\sin\Phi A_{\perp}^{D_2\to V_1V_2}\Bigg] \\
& \times\Bigg[\cos\theta_{V_3}\cos\theta_{V_4}A_0^{D_1\to V_3V_4} - \frac{1}{\sqrt{2}}\sin\theta_{V_3}\sin\theta_{V_4}\cos\Psi A_{\|}^{D_1\to V_3V_4} \\
& \quad -\frac{i}{\sqrt{2}}\sin\theta_{V_3}\sin\theta_{V_4}\sin\Psi A_{\perp}^{D_1\to V_3V_4}\Bigg]\Bigg|^2
\end{aligned}
$$

- Angular analysis for each D
- Quantum correlation of the pair

⇒CP-violating observables from differential BR, related to particular combination of helicities or partial waves
(eg: S wave + S wave, P wave + P wave)

$$
\begin{gathered}
\rho^0\rho^0 \\
\bar{K}^{*0}\rho^0 \longrightarrow (K_S\pi_0)(\pi^+\pi^-) \\
\rho^0\phi \\
\bar{K}^{*0}\omega \longrightarrow (K_S\pi^0)(\pi^+\pi^-\pi^0)
\end{gathered}
$$

Most promising modes,
but need dedicated study of efficiency at BES
(work in progress)

Conclusion and Outlook

- Charm physics provides interesting cross-checks of the KM mechanism of CP violation tested in B and K physics

- Two obvious places :
  - Semi leptonic decays : good agreement,
    but V_{cd} not competitive yet (room for improvement)
  - Leptonic decays : situation quite unclear for D_s decays
    disagreement between experiments

- CP violation small in the SM, therefore a good place to search for new physics
  - either in a similar way to Babar and Belle
  - or through quantum correlations in D pairs

Many issues where high statistics needed
BES can help solve them
and test consistency of KM mechanism with charm