CKM fits as of winter 2009 and sensitivity to New Physics

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http://ckmfitter.in2p3.fr/plots_Moriond09/

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The unitary CKM Matrix: mixing the 3 quark generations and CP violation

• Strong hierarchy in EW coupling of the 3 families:
diagonal $\approx 1$ & between $1 \leftrightarrow 2$: $\propto \lambda \approx 0.22$,
$2 \leftrightarrow 3$: $\propto \lambda^2$, and $1 \leftrightarrow 3$: $\propto \lambda^3$.

• KM mechanism: 3 generations $\Rightarrow$ 1 phase
as only source of CP violation in SM.

• Consider the Wolfenstein parameterization,
defined to hold to all orders in $\lambda$ and re-phasing invariant (EPJ C41, 1-131, 2005):

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

$$A^2 \lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

$$\bar{\rho} + i \bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

$\Rightarrow$ 4 parameters: $\lambda$, $\bar{\rho}$, and $\bar{\eta}$ to describe the CKM matrix, to extract from data the Unitary Triangle.

\[ V_{CKM} = \begin{pmatrix}
   d & e^- & \ell^-
   
   n & p & \bar{\nu}_e
   
   u & K & B
   
   D & \ell^- & \pi
   
   D & \ell^- & \pi
   
   B & \ell^- & D
   
   B^0 & \bar{B}^0
   
   B_s & \bar{B}_s
   
   t & W & b
\end{pmatrix} \]

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**Global SM CKM fit: the inputs**

CKM matrix within a frequentist framework ($\chi^2$ minimum) + uses all constraints on which we think we have a good theoretical control + Rfit treat. for theory errors (EPJ C41, 1-131, 2005)

→ data=weak ⊗ QCD ⇒ need for hadronic inputs (often LQCD: Our Own Average (OOA) of latest results)

### Phys.param. | Experim. observable | Theory method/ingredients
--- | --- | ---
$|V_{ud}|$ | Superallowed $\beta$ decays | *Towner & Hardy, PRC 77, 025501 (2008)*
$|V_{us}|$ | $K_{i3}$ (WA Flavianet) | $f_+^{K\pi}(0)=0.964(5)$ (most precise: RBC-UKQCD)
$|V_{cb}|$ | HFAG incl.+excl. $B \rightarrow X_c |V$ | 40.59(38)(58) $\times 10^{-3}$
$|V_{ub}|$ | HFAG incl.+excl. $B \rightarrow X_u |V$ | OOA (specif. uncer. budget): 3.87(9)(46) $\times 10^{-3}$
$\Delta m_d$ | last HFAG WA $B_d-\bar{B}_d$ mixing | OOA: $\frac{\hat{B}_{B_s}/\hat{B}_{B_d}}{\hat{B}_{B_s}} = 1.05(2)(5) + f_{B_s} + f_{B_d}$
$\Delta m_s$ | CDF $B_s-\bar{B}_s$ mixing | OOA: $\frac{\hat{B}_{B_s}/\hat{B}_{B_d}}{\hat{B}_{B_s}} = 1.23(3)(5) + f_{B_s} + f_{B_d}$
$B^+ \rightarrow \tau^+\nu$ | last 08 WA: BaBar/Belle | OOA: $f_{B_s}/f_{B_d} = 1.196(23)$ & $f_{B_s} = 228(3)(17)$
$|\varepsilon_K|$ | $K^0-\bar{K}^0$ (PDG08: KLOE, NA48,KTeV) | PDG param. (*Buchalla et al. ’96*) + OOA: $\hat{B}_K = 0.721(5)(40)$
$\beta/\phi_1$ | latest WA HFAG charmonium | -
$\alpha/\phi_2$ | latest WA $\pi\pi/\rho\pi/\rho\rho$ | isospin SU(2) (GL)
$\gamma/\phi_3$ | latest WA HFAG $B^- \rightarrow D^{(*)}K^{(*)}$ | GLW/ADS/GGSZ

Details:
http://ckmfitter.in2p3.fr/plots_Moriond09/
Global CKM fit: the Big $\{\bar{\rho}, \bar{\eta}\}$ Picture

- Overall consistency at 95% CL.
- KM mechanism is at work for CPV and dominant in B’s.
- Some tension in $B^+ \to \tau^+ \nu$ → the fit $\chi^2_{\text{min}}$ drops by 2.4 $\sigma$ when removing this input.
- and NP ? (see later)

\[
\begin{align*}
\bar{\rho} &= 0.139^{+0.025}_{-0.027} \\
\bar{\eta} &= 0.341^{+0.016}_{-0.015}
\end{align*}
\]

Details:
http://ckmfitter.in2p3.fr/plots_Moriond09/

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Global CKM fit: testing the paradigm

Assuming there is no NP in $\Delta I=3/2$ $b\to d$ EW penguin amp.
Use $\alpha$ with $\beta$ (charmonium) to produce a new $\gamma$ 'Tree'.

**Tension in between** $\sin(2\beta)$ (I) & $\text{BR}(B^+\to \tau^+\nu)$ (II) (through $|V_{ub}|$):
either removing I/II in the CKM global fit
the $\chi^2_{\text{min}}$ drops by 2.3/2.4 $\sigma$. reasons why:
- exp. fluctuations,
- LQCD,
- New Physics ... ?
\( \alpha \) from \( B \to \rho \rho, \rho \pi, \pi \pi \): new WA

\( \rho^+ \rho^0 \) has changed:

\( \alpha = (89.0^{+4.4}_{-4.2})^\circ \)
\{ \([+9.1^\circ -8.3^\circ]\) 95\% CL\}

CKM fit: \( (95.6^{+3.3}_{-8.8})^\circ \)

Summer'08 was: \( (88.2^{+6.1}_{-4.8})^\circ \)

\( \alpha \) is now a precise measurement @5\% !?
Note that \( \beta \) is @4.2\%
\[ \alpha \text{ from } b \rightarrow u \bar{u} d, \ B \rightarrow \rho \rho, \ \rho \pi, \ \pi \pi \]

\[ A(\bar{B}^0 \rightarrow h^+ h^-) = A_{+-} = V_{ub} V_{\bar{u}d}^* T + V_{tb} V_{\bar{t}d}^* P \]

Tree \( \propto \lambda^3 \)

\[ \bar{B}^0 \left\{ \begin{array}{c}
    b \\
    \bar{d}
\end{array} \right\} \rightarrow \left\{ \begin{array}{c}
    W^- \\
    u \\
    \bar{d}
\end{array} \right\} \rightarrow \left\{ \begin{array}{c}
    h^- \\
    h^+
\end{array} \right\} + \bar{B}^0 \left\{ \begin{array}{c}
    b \\
    \bar{d}
\end{array} \right\} \rightarrow \left\{ \begin{array}{c}
    g \\
    u \\
    \bar{d}
\end{array} \right\} \rightarrow \left\{ \begin{array}{c}
    h^- \\
    h^+
\end{array} \right\} \]

Penguin \( \propto \lambda^3 \)

\[ \sin 2\alpha \text{ from time dep. CP:} \]

\[ \Gamma(\bar{B}^0(t) \rightarrow h^+ h^-) \propto [1 + C_{hh} \cos \Delta m t - S_{hh} \sin \Delta m t] \]

\[ \sin 2\alpha_{\text{eff}} = \frac{S_{hh}}{(1 - C_{hh}^2)^{1/2}} \]

- Strong effective phases arise from \( P \): effective angle \( \alpha_{\text{eff}} \) measured (not \( \alpha \)!
  \[ \Delta \alpha = 2(\alpha_{\text{eff}} - \alpha) \]
- So far the \( \rho \rho \) dominates, \( R = P/T \):
  \[ R(\pi^+ \pi^-) > R(\rho^+ \pi^-) \sim R(\rho^- \pi^+) > R(\rho^+ \rho^-) \]
  smaller \( |\Delta \alpha| \) isospin bound
- 8 fold ambiguities (4 \( \Delta \alpha \), 2 \( \alpha_{\text{eff}} \))
- \( h^+ h^0 \): pure tree.

\[ \frac{1}{\sqrt{2}} |A_{+-}| = |A_{+0}| \]

Gronau London SU(2) isospin triangle:

\[ \begin{align*}
    A_{+-} + \sqrt{2} A_{00} &= \sqrt{2} A_{+0} \\
    A_{+-} + \sqrt{2} A_{00} &= \sqrt{2} A_{+0}
\end{align*} \]

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**Winter’ 09 BaBar** $\rho^+\rho^0$ update (0921.3522) $\text{BR}(f_L)$ ↑ by $\sim 2(1)\sigma$.

### Dominates WA

\[
\text{BR}(\rho^+\rho^0)[10^{-6}]= 18.2 \pm 3.0 \rightarrow 24.0 \pm 1.9
\]

\[
f_L(\rho^+\rho^0)= 0.912(44) \rightarrow 0.950(15)
\]

- **Inputs**: $B^+, B^{0+}, B^{00}, C^+, S^+, C^{00}, S^{00}, f_L^{+-}, f_L^{0+}, f_L^{00}$

- **$B \rightarrow \rho\rho$ amps. & $\bar{B}$ amps has similar pictures**

- **Higher BR**: Both $B$ and $\bar{B}$ isospin triangles do not close (consistent within uncert.)
- **Mirror solutions are degenerated in a single peak.**
\( \alpha \) from \( B \to \rho \rho \\
\alpha = (89.9 \pm 5.4) ^\circ \\
\Delta \alpha = (1.4 \pm 3.7) ^\circ \\

\text{Summer'08 was:} \\
\alpha = (90.9^{+6.7}_{-14.9}) ^\circ \\
\Delta \alpha = (0.5^{+12.6}_{-5.5}) ^\circ \\

\rightarrow \text{How lucky are we? toy study:} \\
\text{Gaussian smearing of all inputs at best CKM fitted} \ \alpha \text{ by } 1\sigma \text{ half interval: } BR^+, BR^0+, BR^{00}, \\
C^+, S^+, C^{00}, S^{00}, f_L^+, f_L^0, f_L^{00} \\
\bullet \text{average toy error: } 7.5^\circ \text{ (observed 5.4^\circ)} \\
\bullet \text{long asymmetrical tail } (\rightarrow 20^\circ !) \text{ when triangle closes } \Rightarrow \text{pseudo mirror solution above the } 1\sigma \text{ CL(}\alpha\text{) threshold. Only } \sim 34\% \text{ of SU}(2) \text{ triangles close:} \\
|A_{+-}|/\sqrt{2} + |A_{00}| > |A_{+0}| \\
\bullet \text{same behavior when } 2\sigma \text{ half interval (less fluctuating).}
\[ \Delta \alpha = (1.4 \pm 3.7)° \]

Breaking isospin triangle in \( B \to \rho \rho \)

\[ \Rightarrow \text{Already sensitive to sources of SU(2) breaking (J. Zupan CKM’06)}: \]

- \( m_u \neq m_d \) & \( Q_u \neq Q_d \):
  \[ (m_u - m_d)/\Lambda_{QCD} \sim 1\% \]
- \( \Delta \alpha_{EWP} \sim 1.5° \)
- \( \Delta \) mass Eigen-States (EG) \( \neq \) isospin EG:
  \( (\rho - \omega) \) mixing \(< 2\% \)
- \( \Gamma_\rho \neq 0 \Rightarrow I=1 \) contribution possible:
  \[ 0(\Gamma^2_\rho/m^2_\rho) \sim 4\% \]
- \( \Delta I=5/2 \) operators no more negligible.
- ...

\[ \Rightarrow \text{Possible way out: K}^*\rho \text{\ SU(3) constraints} \]

\[ \Rightarrow \text{Break the triangle closure:} \]
\[ A^{+0} \to A^{+0} + \Delta A^{+0} \]

\[ \sqrt{2} \Delta A^{+0} = V_{ud}V_{ub}^* \Delta T^{+-} + V_{td}V_{tb}^* \Delta P^{+-} \]

\[ \Rightarrow \text{additional Amp. with } \Delta T^{i} \text{'s & } \Delta P^{i} \text{'s (arbitrary phases)} \]

- \( \text{tested } |\Delta A^{+0}|: 4, \ 10 \ & 15\% \)
- \( \text{small correction breaks } \text{SU}(2) \text{ at } 90° \)
  \( \text{but restore } \text{SU}(2) \text{ in the } \sim 0° \text{ vicinity} \)
- \( \text{need } \sim 15\% \text{ to restore } \text{SU}(2) \text{ at } \sim 90° \)
- \( \text{BTW small impact on } \pi \pi /\rho \rho /\rho \pi \text{ WA combo.} \)
$B \rightarrow (\rho, \omega) \gamma$ & $K^* \gamma$ exclusive $b \rightarrow D \gamma$ [$D = (d, s)$]

- access to $|V_{td} / V_{ts}|$ within SM, in ratios of excl. BRs: $R(d/s)\gamma$
- cross check of neutral $B_{d,s}$ mixing (penguins vs box)
- loop: sensitive to NP, in addition to accurate (N)NLO $B \rightarrow Xs \gamma$ (inclusive, Misiak et al. '06)
- available many recent ('08), more & more accurate excl. meas. $B \rightarrow V \gamma$ at B-factories.

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- But hadronic effects difficult to estimate:
  - early attempts: Ali, Lunghi, Parkhomenko ('02,'04,'06).
  - QCD Factorisation for LO in $1/m_b$ up to $O(\alpha_s)$ (Bosch and Buchalla ('02)).
  - use a more sophisticated analysis beyond QCDF: adding $1/m_b$-suppressed terms from light-cones sum rules (long dist. $\gamma$ emission & soft gluon): Ball, Jones, Zwicky ('06).

  - each exclusive decay described individually
  - isospin breaking (FF, strong phase)/CP asym. + weak annihilation (tree) can be large in $(\rho, \omega)(\gamma$ ...  
  - $u$ and $c$ internal loops (long and short distance) + other operators than magnetic operator $Q_7$ only
  - non trivial CKM matrix elements sensitivity

\[
\bar{\lambda} = \frac{G_F}{\sqrt{2}} \left( \lambda_D^D a_U^U(V) + \lambda_C^D a_C^C(V) \right) \langle V_\gamma | Q_7 | \bar{B} \rangle
\]

\[
\lambda_D^D = V_{UD}^* V_{Ub} \quad D = (d, s)
\]

\[
U = u, c, t
\]

\[
a_U^U(V) = a_U^{QCD}(V) + a_U^{ann}(V) + a_U^{soft}(V) + \ldots
\]

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$B \rightarrow (\rho, \omega) \gamma$ & $K^* \gamma$ impact on $(\bar{\rho}, \bar{\eta})$

- HFAG WA '08, all BFs updated ($\times 10^{-6}$):
  - $K^*-\gamma$: 45.7±1.9
  - $K^*0\gamma$: 44.0±1.5
  - $\rho^+\gamma$: $0.98^{+0.25}_{-0.24}$
  - $\rho^0\gamma$: $0.86^{+0.15}_{-0.14}$
  - $\omega\gamma$: $0.44^{+0.18}_{-0.16}$

- '08 ($\times 10^{-6}$):
  - $BF(B_s \rightarrow \phi \gamma) = 57 \pm 22$
  - $(\text{strange counter part } B \rightarrow K^*\gamma)$
  - $A_{CP}(B^- \rightarrow K^*\gamma) = -0.11 \pm 0.32 \pm 0.09$
    $(\gamma$ polar: NP? + check strong dynamic)

➔ Penguins constraint at 95% CL, as good as box B mixing and at 68% CL almost as good as $\Delta m_d$ alone,$\Delta m_d & \Delta m_s$, V. Tisserand, LAPP
No more trouble with $|V_{cs}|$

- Charm sector favorite place to test LQCD [$m_c \sim \Lambda_{QCD}$] for form fact. and decay constants (access $|V_{cs}|$)
- CLEO-c ’09 $D_s \rightarrow (\tau, \mu) \nu$ & $\tau[e^\nu, \pi \nu]$ annihilation: arXiv: 0901.1147 & 0901.1216 (fix $|V_{cs}| = |V_{ud}|$):
  
  $f_{D_s} = 259.5(6.6)(3.1)$ MeV
- Our LQD average:
  
  $f_{D_s} = 246.3(1.2)(5.3)$ MeV
  (mainly from full unquenched LQCD : HPQCD’07 & FNAL-MILC’07, but not only)

- combined CLEO-c + LQCD: $|V_{cs}| = 1.027 \pm 0.051$
- CKM fit: $|V_{cs}| = 0.97347 \pm 0.00019$

  - $|V_{cs}|$ situation improves : CLEO-C and LQCD have better agreement on $f_{D_s}$
  - $f_{D_s}$ ideal for lattice (cs quarks), better but still worse than $f_K$ & $f_K/f_\pi$ (light quarks).
  - note: $f_{D_s}$ from BaBar, Belle, & CLEO-c in pre-2009 meas. with $D_s \rightarrow \mu \nu$ is higher.
**a word on rare $K^+ \to \pi^+ \nu \bar{\nu}$**

- **Recent E949 update** (arXiv:0903.0030 with 5 events (& incl. E787)):
  \[ \text{BR} [10^{-10}] = 1.73^{+1.15}_{-1.05} \]

- **BR parameterization** as Brod & Gorbahn '08 (PRD 78, 034006):
  NLO QED-QCD & EW corr. to the charm quark contrib. \((\alpha_s(m_Z^2)=0.1176(20) \text{ & } m_c(\mu_c)=1.286(13)(40))\)

**Diagram:**

- CKM fit: \(\text{BR}[10^{-10}] = 0.730^{+0.081}_{-0.101}\)

- \(B(K^+ \to \pi^+ \nu \bar{\nu}) \propto \left[ (\sigma \eta)^2 + (\rho_0 - \bar{\rho})^2 \right] \)

- \(\Rightarrow\) wait for NA62: \(\mathcal{O}(100 \text{ events})!\)

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New Physics in $B_{q=d,s}$ mixing

Assume that:

- Tree-level processes are not affected by NP (SM4FC: $b \rightarrow q_i q_j q_k$ ($i \neq j \neq k$)) nor non-loop decays, e.g., $B^+ \rightarrow \tau^+ \nu$ (implies 2HDM model).
- NP only affects the short distance physics in $\Delta B=2$ transitions.
- Model independent parameterization:
  $$\Delta_q = |\Delta_q| e^{2i\Phi_{NP_q}}$$
  (use Cartesian coords.)

- $\Delta_q = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$
- SM $\Rightarrow \Delta_q = 1$
- MFV (Yukawa) $\Rightarrow \Phi_{NP_q} = 0$ and $\Delta_d = \Delta_s$

$\mathcal{H}_{\Delta B=2}$

$$\langle B_q \mid \mathcal{H}_{\Delta B=2}^{SM+NP} \mid \bar{B}_q \rangle \equiv \langle B_q \mid \mathcal{H}_{\Delta B=2}^{SM} \mid \bar{B}_q \rangle \times (\text{Re}(\Delta_q) + i \text{Im}(\Delta_q))$$

SM parameters are fixed by:

- $|V_{ub}|_{\text{SL+TV}}, |V_{cb}|, |V_{us}|, |V_{us}|, \gamma, \gamma(\alpha) = \pi - \beta - \alpha$

**Table:**

<table>
<thead>
<tr>
<th>parameter</th>
<th>prediction in the presence of NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscil. $\Delta m_q$</td>
<td>$</td>
</tr>
<tr>
<td>Phases $2\beta$</td>
<td>$2\beta^{SM} + \Phi_{NP_d}$</td>
</tr>
<tr>
<td>$2\beta_s$</td>
<td>$2\beta_s^{SM} - \Phi_{NP_s}$</td>
</tr>
<tr>
<td>$2\alpha$</td>
<td>$2(\pi - \beta^{SM} - \gamma) - \Phi_{NP_d}$</td>
</tr>
<tr>
<td>$\Phi_{12,q} = \text{Arg}[\frac{M_{12,q}}{\Gamma_{12,q}}]$</td>
<td>$\Phi_{12,q}^{SM} + \Phi_{NP_q}$</td>
</tr>
<tr>
<td>Asym SL $A_{SL}^q$</td>
<td>$\frac{\Gamma_{12,q}}{M_{12,q}^{SM}} \times \sin(\Phi_{12,q}^{SM} + \Phi_{NP_q})$</td>
</tr>
<tr>
<td>Lifetime diff. $\Delta \Gamma_q$</td>
<td>$2</td>
</tr>
</tbody>
</table>

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New Physics in $B_d$ mixing

**Warning**: 68% CL

**Inputs:**
- $\Delta m_s$
- $\Delta m_d$
- $\sin(2\beta)$
- $\alpha$
- $A_{SL}^d$, $A_{SL}^B$
- $\Delta\Gamma_d / \Gamma_d$
- $\Delta\Gamma_s$, $\phi_s$

+ SM params:
  - $|V_{ud}|$, $|V_{us}|$
  - $|V_{ub}|$, $|V_{cb}|$
  - $\gamma(\alpha)$, $B \rightarrow \tau \nu$

**Dominant constraints** from $\beta$ & $\Delta m_d$:
- both agrees with SM...*but...*
- $\Rightarrow$ tension from $BR(B \rightarrow \tau \nu)$
  - i.e.: $|V_{ub}| \Rightarrow \sin(2\beta)$

**Cartesian coordinates** give simple interpretation of constraints:
- angles: arcs
- $\Delta m$: ellipses
- $|\Delta d| < \text{or} \sim 1 \Rightarrow$ KM mechanism is dominant.

**Agreement with SM**:

<table>
<thead>
<tr>
<th>hypothesis</th>
<th>with $B^+ \rightarrow \tau^+ \nu$</th>
<th>with out</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta d = 1$ (Re=1,Im=0)</td>
<td>2.1 $\sigma$</td>
<td>0.6 $\sigma$</td>
</tr>
</tbody>
</table>

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New Physics in $B_s$ mixing

Inputs:
- $\Delta m_s$
- $\Delta m_d$
- $\sin(2\beta)$
- $\alpha$
- $A_{SL}$, $A_{SL}^d$
- $A_{SL}^B$
- $\Delta \Gamma_d / \Gamma_d$
- $\Delta \Gamma_s, \phi_s$

SM with $+$SM params:
- $|V_{ud}|, |V_{us}|$
- $|V_{ub}|, |V_{cb}|$
- $\gamma(\alpha), B_s \rightarrow \tau \nu$

Dominant constraints:
- $\Delta m_s$ agrees with SM.
- $(\phi_s = -2\beta_s, \Delta \Gamma_s)$ through time dependent angular analysis of $B_s \rightarrow J/\psi \phi$ by D$\emptyset$/CDF (HFAG'08 update) is $2.2\sigma$ away from SM.

Agreement with SM:

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</tr>
</thead>
<tbody>
<tr>
<td>$\Delta_s = 1$ (Re=1, Im=0)</td>
<td>1.9 $\sigma$</td>
<td>1.9 $\sigma$</td>
</tr>
</tbody>
</table>
MFV in $B_{q=d,s}$ mixing

**Inputs:**
- $\Delta m_s$
- $\Delta m_d$
- $\sin(2\beta)$
- $\delta$
- $A_{SL}^B, A_{SL}^d$
- $A_{SL}^{B_s}$
- $\Delta \Gamma_d / \Gamma_d$
- $\Delta \Gamma_s, \phi_s$
- +SM params: $|V_{ud}|, |V_{us}|, |V_{ub}|, |V_{cb}|, \gamma(\omega), B_{\tau \nu}$

**Additional constraints:**
- $\Phi^{NP}_{q=0}$ and $\Delta_d = \Delta_s = \Delta$

In MFV scenario the impact from $\sin(2\beta)$ (tension from $|V_{ub}|_{\tau^+,\nu}$) & TeVatron $\phi_s$ is washed out: no new NP phase!
• KM mechanism is at work and dominant for NP in quark b sector
  ⇒ still room for NP both in $B_d$ and $B_s$.

• overall good agreement in the global SM CKM fit:
  ▪ a step forward on $\alpha$ precision, but need to go beyond SU(2).
  ▪ but tension $\sin(2\beta) \Leftrightarrow |V_{ub}|$ with $B^+ \rightarrow \tau^+\nu$:
    - wait for new measurements by B-factories, whatever super-B factory ...
    - 2HDM models ?
    - LQCD, ... what else ?
  ▪ but tension in direct TeVatron $\beta_s$ measurement.
    ⇒ wait for more data & LHCb to enter the game.

• progresses on constraints from exp. vs LQCD ($f_{D_s}$), $b \rightarrow V\gamma$, and rare K decays.
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$B^+ \rightarrow \tau^+ \nu$

- helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Sensitive to tree-level charged Higgs replacing the $W$ propagator.

$$\text{BR}(B^+ \rightarrow \tau^+ \nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_{\tau}^2 \left(1 - \frac{m_{\tau}^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

$\text{BR}[10^{-4}] = 1.80 \pm 0.63$

- $1.80 \pm 1.00$ (had)
- $1.80 \pm 0.81$ (semi-lept)

$\text{BR}[10^{-4}] = 1.70 \pm 0.42$

- $1.70 \pm 0.10$ (had)
- $1.65 \pm 0.52$ (semi-lept)

Measurement are consistent & WA:

$\text{BF}[10^{-4}] = 1.73 \pm 0.35$

$\text{BF}[10^{-4}] = 0.796 \pm 0.154 - 0.093$

Inputs:

$|V_{ub}|$

$\Delta m_d$

$\Delta m_s$

$|\epsilon_K|$

$sin2\beta$

$\alpha$

$\gamma$

$f_{Bd}$ from our own LQCD average:

$f_{Bs}/f_{Bd} = 1.196(8)(23)$ & $f_{Bs} = 228(3)(17)$

Measurements (WA):

$|V_{ub}|$

$\Delta m_d$

$\Delta m_s$

$|\epsilon_K|$

$sin2\beta$

$\alpha$

$\gamma$

deviation : $2.4\sigma$

Measurement from global CKM fit:

$\text{BF}[10^{-4}] = 0.796 ^{+0.154} _{-0.093}$

new CLEO-C '09 $D_s^+ \rightarrow \tau^+ \nu$ (~fine)
Powerful together with $\Delta m_d$ : removes $f_B$ (Lattice QCD) dependence (left with $B_d$ errors anyway). If error of $f_{Bd}$ small : 2 circles that intersect at $\sim 90^\circ$

\[
\frac{BR(B^+ \rightarrow \tau^+ \nu)}{\Delta m_d} = \frac{3\pi}{4} \frac{m_{\tau}^2 m_{B^+}^2}{m_{w}^2 S(x_t)} \left(1 - \frac{m_{\tau}^2}{m_{B}^2}\right)^2 \frac{\sin^2(\beta)}{\sin^2(\gamma)} |V_{ud}|^2 B_{Bd}
\]

**Theory free prediction for $B_{Bd}$**

Inputs:
- $\Delta m_d$
- $B \rightarrow \tau \nu$
- $\gamma(-\pi-\beta-\alpha)$
- $\sin 2\beta$
- $|V_{ud}|$

Constraint from $B^+ \rightarrow \tau^+ \nu$ and $\Delta m_d$

**The tension is not driven by**

$V_{ub}$ (SL) nor $f_{Bd}$ (nor $\varepsilon_K$)
$B^+ \to \tau^+ \nu$ & charged Higgs

$$\text{BR}(B^+ \to \tau^+ \nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- Helicity-suppressed annihilation decay sensitive to $f_\theta^2 |V_{ub}|$
- Powerful together with $\Delta m_d$: removes $f_\theta$ dependence
- Sensitive to charged Higgs replacing the $W$ propagator

e.g: 2HDM type II

$$\text{BR}(B^+ \to \tau^+ \nu) = \text{BR}^{SM} \times \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right)^2$$

Disfavoured region
$\text{BR}/\text{BR}^{SM} < 1$

O. Deschamps ICHEP’08
New Physics in $B_d$ & $B_s$ mixing without $B^+ \rightarrow \tau^+ \nu$

Removing $B^+ \rightarrow \tau^+ \nu$ impacts $\Delta m_d$ precision $\Rightarrow$ one less constraint
for the decay constant $f_{B_d}$ (only LQCD: more SM like) and
relaxes the $\sin(2\beta) \leftrightarrow |V_{ub}|$ tension but no impact on TeVatron $\phi_s$
**MFV in** $B_{d,s}$ mixing without $B^+\rightarrow \tau^+\nu$  

**additional constraints:**  
$\Phi_{NP}^q = 0$ and $\Delta_d = \Delta_s = \Delta$

**Inputs:**
- $\Delta m_s$
- $\Delta m_d$
- $\sin(2\beta)$
- $\alpha$
- $A_{sL}, A_{dL}^{B_d}$
- $A_{sL}^{B_s}$
- $\Delta \Gamma_d / \Gamma_d$
- $\Delta \Gamma_s, \phi_s$
+ SM params: 
  - $|V_{ud}|, |V_{us}|$
  - $|V_{ub}|, |V_{cb}|$
  - $\gamma(\alpha), B\rightarrow \tau \nu$

Removing $B^+\rightarrow \tau^+\nu$ impacts $\Delta m_d$ precision $\Rightarrow$ one less constraint for the decay constant $f_{Bd}$ (only LQCD: more SM like)
Only input from indirect CP violation in mixing and in $K^0$-$\bar{K}^0$ interference w. and w.o. mixing

- dominated by badly controlled long distances contributions but accountable corresponding systematic.
- Note : $\epsilon'$ direct CPV has much larger hadronic uncertainties (gluonic penguins): excluded.

$$|\epsilon_K| = C_\epsilon \hat{B}_K \lambda^2 \eta^2 |V_{cb}|^2 \left[ |V_{cb}|^2 (1 - \bar{\rho}) \eta_{tt} S_0(x_t) + \eta_{ct} S_0(x_c, x_t) - \eta_{cc} S_0(x_c) \right]$$

$$C_\epsilon = \frac{G_F^2 f_K^2 m_K m_W^2}{6 \sqrt{2} \pi^2 \Delta m_K}$$

Where $S_0$ is an Inami-Lim loop function, $x_q=m^2_q/m^2_W$, and $\eta_{ij}$ are perturbative QCD corrections.

- The constraint from in the ($\bar{\rho}, \eta$) plane is bounded by approximate hyperbolas.
- The dominant uncertainties are due to the bag parameter, for which we use $\hat{B}_K=0.721(5)(40)$ from LQCD, and the parametric uncertainty approximately proportional to $\sigma(|V_{cb}|^4)$~8%, comparable in size.

$$|\epsilon_K|_{\text{PDG08,exp}} = 2.229(12) \times 10^{-3} \text{ and } |\epsilon_K|_{\text{CKMfit}} = (2.06^{+0.47}_{-0.53}) \times 10^{-3}$$

$\epsilon_K = e^{i\phi_{\epsilon}} \sin \phi_{\epsilon} \left( \frac{\text{Im}(M_{12}^K)}{\Delta M_K} + \xi \right)$

$\phi_{\epsilon} = (43.51 \pm 0.05)^\circ \quad \kappa_{\epsilon} = \sqrt{2} \sin \phi_{\epsilon} \bar{\kappa}_{\epsilon}$

- Recent work by Buras & Guadagnoli (+Soni & Lunghi) suggest an additional effective suppression multiplicative factor $\kappa_{\epsilon}=0.92(2)$, not clear yet how we understand this parameter $\dot{\kappa}_{\epsilon}$ in arXiv 0805.3887: “our very rough estimate at the end of the paper show that $\tilde{\kappa}_{\epsilon}<0.96$, with 0.94(2) being a plausible figure”.

- BTW when plugging $\sin2\beta$ WA + other relevant inputs, they quote (error treatment/budget ??):

$$|\epsilon_K|_{\text{SM}} = 1.78(25) \times 10^{-3} \text{ ie: deviation } \Rightarrow \text{ NP ?!}$$

V. Tisserand, LAPP
**$|V_{cb}|$: already precision measurement: 1.7%!**

$|V_{cb}|_{\text{incl.}}[10^{-3}]=41.67(44)(58)$

**Note:** $|V_{cb}|_{\text{excl.}}[10^{-3}]=38.20(78)(83)$

(dominated by Form Factor $F(t)=0.921(13)(20)$)

**$|V_{ub}|$: room for questions!**

Very difficult as phase space cuts applied to suppress $b \rightarrow c\nu$ bkgd ($\sim 50$) complicate the theory for inclus. 
Meas.: lower scales (non perturb. function), renorm. shape functions, structure of sub-leading terms complicated. 
Use the B-beam technique & several kinematic variables: 
$E_{\nu}, m_{X}, q^{2}, ...$

- $|V_{cb}| (\rightarrow A)$ is important in the kaon system ($\varepsilon_{K}, \text{BR}(K \rightarrow \pi \nu \nu), ...$)
- $|V_{ub}| (\rightarrow \bar{p}^{2} + \bar{p}^{2})$ is crucial for the SM prediction of $\sin(2\beta)$

- SF params. from $b \rightarrow c\nu$, OPE from BLNP
- BR precision $\sim 8\%$, $|V_{ub}|$ excl. $\sim 14\%$: FF theory dom. ($B \rightarrow \pi \nu \nu$ important also for $\pi\pi, K\pi$ decays ...)
- adapted from HFAG summer 08:
  - $|V_{ub}|_{\text{incl.}}[10^{-3}]=4.38(16)(57)$ our syst. estimate
  - $|V_{ub}|_{\text{excl.}}[10^{-3}]=3.46(11)(46)$
\[ \Delta m_s = 17.77(10)(7) \text{ ps}^{-1} \]

\[ \Delta m_s = 0.507(5) \text{ ps}^{-1} \]

\( \Rightarrow \) a 5.4 \( \sigma \) measurement

HFAG: \( \Delta m_d = 0.507(5) \text{ ps}^{-1} \)

\( \Rightarrow \) uncertainty \( \sigma(\Delta m_s) = 0.7\% \) already smaller than \( \sigma(\Delta m_d) \approx 1\% \)

\[ \Delta m_s = \frac{G_F^2}{6 \pi^2} m_B m_W^2 \eta_B S_0(x_1) f_{B_s}^2 B_s \left| V_{ts} V_{tb}^* \right|^2 \]

\( \xi = \frac{f_{B_s} \sqrt{B_s}}{f_{B_d} \sqrt{B_d}} \)

the SU(3) breaking corrections (largest uncertainty)

Measurement of \( \Delta m_s \) reduces the uncertainties on \( f_{B_d}^2 B_d \) since \( \xi \) is better known from LQCD

\( \Rightarrow \) Leads to improvement of the constraint from \( \Delta m_d \) measurement on \( |V_{td} V_{tb}^*|^2 \)

\[ \Delta m_d = \frac{G_F^2}{6 \pi^2} m_{B_d} m_W^2 \eta_B S_0(x_1) f_{B_d}^2 B_d \left| V_{td} V_{tb}^* \right|^2 \propto A^2 \lambda^6 \left[ (1 - \rho)^2 + \eta^2 \right] \]
The one associated with $B_d$ meson

$$v_{ud}v_{ub}^* \overline{v}_{cb}v_{cb}^* + 1 + {v}_{td}v_{tb}^* \overline{v}_{cd}v_{cb}^* = 0$$

$O(1) + O(1) + O(1)$

$$\bar{\rho} = \frac{v_{td}v_{tb}^*}{v_{ud}v_{ub}^*}$$

$$\gamma = \arg \left(-\frac{v_{ud}v_{ub}^*}{v_{cd}v_{cb}^*}\right)$$

$$\beta = \arg \left(-\frac{v_{cd}v_{cb}^*}{v_{td}v_{tb}^*}\right)$$

One single minimum

V. Tissierand, LAPP
Global CKM fit: testing the paradigm

**CP-conserving observables**

- Inputs:
  - $|V_{ub}|$
  - $B \rightarrow \tau\nu$
  - $\Delta m_d$
  - $\Delta m_s$

**CP-violating observables**

- Inputs:
  - $|\epsilon_K|$
  - $\sin 2\beta$
  - $\alpha$
  - $\gamma$

**Angles (small theor. uncertainties)**

- Inputs:
  - $\sin 2\beta$
  - $\alpha$
  - $\gamma$

**No angles (large theo. uncertainties)**

- Inputs:
  - $|\epsilon_K|$
  - $|V_{ub}|$
  - $B \rightarrow \tau\nu$
  - $\Delta m_d$
  - $\Delta m_s$
### Global CKM fit: other numerical results, a selection

<table>
<thead>
<tr>
<th>Physics param./Observable</th>
<th>Central ± 1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.8116 [+0.0096 -0.0241]</td>
</tr>
<tr>
<td>λ</td>
<td>0.22521 [+0.00082 -0.00082]</td>
</tr>
<tr>
<td>J [10⁻⁵]</td>
<td>2.92 [+0.15 -0.15]</td>
</tr>
<tr>
<td>α (deg) (meas. not in the fit)</td>
<td>95.6 [+3.8 -8.8]</td>
</tr>
<tr>
<td>β (deg) (meas. not in the fit)</td>
<td>21.66 [+0.95 -0.87]</td>
</tr>
<tr>
<td>γ (deg) (meas. not in the fit)</td>
<td>67.8 [+4.2 -3.9]</td>
</tr>
<tr>
<td>βₜ(deg) (meas. not in the fit)</td>
<td>1.035 [+0.049 -0.046]</td>
</tr>
<tr>
<td>Δmₜ [ps⁻¹] (meas. not in the fit)</td>
<td>17.6 [+1.7 -1.8]</td>
</tr>
<tr>
<td></td>
<td>Vₜₜ</td>
</tr>
<tr>
<td>BR(B→τν) [10⁻⁴] (meas. not in the fit)</td>
<td>0.796 [+0.154 -0.093]</td>
</tr>
<tr>
<td>BR(B→μ⁺μ⁻) [10⁻⁷]</td>
<td>10.8 [+0.4 -0.9]</td>
</tr>
<tr>
<td>BR(Bₛ→μ⁺μ⁻) [10⁻⁹]</td>
<td>3.29 [+0.09 -0.27]</td>
</tr>
</tbody>
</table>

LQCD own average: the most of hadronic inputs

- Z. Ligeti at USLQCD Dec’07 on lack of LQCD averages: “If experts cannot agree, it’s unlikely the rest of the community would believe a claim of new physics”.

- Many collaborations with different methods of simulations, results, and estimations of errors.

- Use only unquenched results with 2 or 2+1 dynamical fermions (sea quarks), also include staggered fermions (even if: still QCD?)

  - Papers & proceedings: RBC, UKQCD, HPQCD, JLQCD, CP-PACS, FNAL Lattice, MILC, ETMC, NPLQCD...

- Our Own Average this time:
  1) Standard $\chi^2$ fit with only the statistical errors
  2) Theoretical uncertainty of the combination = the one of the most precise method

  - Conservative approach:
    1. The present state of art cannot allow us to reach a better theoretical accuracy than the best of all estimates
    2. This best estimate should not be penalized by less precise methods (opposed to combined syst = dispersion of central values).

Sources of uncertainties

- Euclidean, finite, discrete box $\langle Q \rangle = \int [dA] \hat{Q}[A] (\det S_{\phi}[A])^{N_f} \exp(-S_{YM}[A])$

  - Observable = Statistical average over gauge configurations weighted according to gauge and fermion actions

  - **Statistical**
    1. Size of the ensemble of gauge configurations
    2. Part of errors listed below (when scaling with size of gauge config)

  - **Systematics**
    1. Fermion action: $N_f = 2$, staggered fermions
    2. Continuum limit/discretisation error $a \rightarrow 0$
    3. Finite volume effects $L \rightarrow \infty$
    4. Quark mass extrapolation (chiral limit and heavy quark limit)

V. Tisserand, LAPP
completely general isospin decomposition

\[ A_{+-} = \langle \pi^+\pi^- | H | B^0 \rangle = -A_{1/2} + \frac{1}{\sqrt{2}} A_{3/2} - \frac{1}{\sqrt{2}} A_{5/2} \]
\[ A_{00} = \langle \pi^0\pi^0 | H | B^0 \rangle = \frac{1}{\sqrt{2}} A_{1/2} + A_{3/2} - A_{5/2} \]
\[ A_{+0} = \langle \pi^+\pi^0 | H | B^+ \rangle = \frac{3}{2} A_{3/2} + A_{5/2} \]

neglecting \( A_{5/2} \approx \alpha A_{1/2} \) (i.e. \( \approx 1\% \) correction)

\[ A_{+-} + \sqrt{2} A_{00} = \sqrt{2} A_{+0} \]
\[ \bar{A}_{+-} + \sqrt{2} \bar{A}_{00} = \sqrt{2} \bar{A}_{+0} \]

neglecting EWP \( \Rightarrow A_{+0} \) only tree contribs.

\[ e^{i\gamma} A_{+0} = e^{-i\gamma} \bar{A}_{+0} \quad \Rightarrow \quad |A_{+0}| = |\bar{A}_{+0}| \]
$\alpha$ from $b \rightarrow u\bar{u}d$, $B \rightarrow \pi\pi$

Same as for summer'08

$\Delta \alpha = (20.0\pm10.3)^\circ$

$\chi^2(0) \sim 140$
• Inputs:
  - $B^{++}$
  - $B^{0+}$
  - $B^{00}$
  - $C^+$
  - $S^{-}$
  - $C^{00}$

  - One among the 2 triangles does not close
    $\rightarrow$ 4-fold solution for alpha
• Much like $B \to \pi\pi$

• **Disadvantages:**
  - Wide $\rho$ resonances
  - V-V decay: different polarization states ($L=0,1,2$)
    ⇒ Longitudinal: CP-even
    ⇒ Transverse: Mixed CP states

• **Advantages:**
  - $BF(\rho^+\rho^-) \sim 5$ times larger than for $\pi^+\pi^-$
  - Penguin pollution smaller than in $\pi\pi$
  - $\rho$ 99% longitudinally polarized
  - Possible to measure $S(\rho^0\rho^0)$
    ⇒ raise degeneracy in ambiguities

A. Perez Lake Louise '09

\[\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4} \left[ f_L \cos^2\theta_1 \cos^2\theta_2 \right] + \frac{1}{4} (1 - f_L) \sin^2\theta_1 \sin^2\theta_2,\]
\[ \alpha \text{ from } b \to u\bar{u}d, \ B \to \rho \rho \]

**Winter' 09 update :** \( B \to \rho^+\rho^0 \) from BaBar (arXiv:0921.3522 wrt PRL 97, 261801 (06))

Both BR and \( f_L \) increase wrt summer '08 by \(-2\sigma\) and \(-1\sigma\), respectively

\[
\begin{align*}
B^+ &= 16.8 (3.2) \times 10^{-6} \Rightarrow 23.7 (2.0) \times 10^{-6} \text{ (BaBar)} \\
\rho^0_L &= 0.905 (47) \Rightarrow 0.950 (16) \text{ (BaBar)} \\
B^+ &= 18.2 (3.0) \times 10^{-6} \Rightarrow 24.0 (1.9) \times 10^{-6} \text{ (WA)} \\
\rho^0_L &= 0.912 (44) \Rightarrow 0.950 (15) \text{ (WA)}
\end{align*}
\]
\[ \alpha = (89.9 \pm 5.4)^\circ \]
\[ \Delta \alpha = (1.4 \pm 3.7)^\circ \]

Summer'08 was:
\[ \alpha = (90.9^{+6.7}_{-14.9})^\circ \]
\[ \Delta \alpha = (0.5^{+12.6}_{-5.5})^\circ \]
How lucky are we? toy study:
Gaussian smear of all inputs around best CKM fitted values: $BR^+, BR^0, BR^{00}, C^+, S^+$, $C^0, S^0, f_{L}^{+-}, f_{L}^{-0}, f_{L}^{00}$

$\alpha = (89.9 \pm 5.4)^\circ$
$\Delta \alpha = (1.4 \pm 3.7)^\circ$

Summer'08 was:
$\alpha = (90.9^{+6.7}_{-14.9})^\circ$
$\Delta \alpha = (0.5^{+12.6}_{-5.5})^\circ$

$\sim 50\%$ of closing triangles
Isospin breaking

**SOURCES**

- the standard methods for obtaining $\alpha$ from $B \to \pi\pi, \rho\rho, \rho\pi$ use isospin
- theory error on $\alpha$ due to isospin breaking
  - $d$ and $u$ charges different
  - $m_u \neq m_d$
- extends the basis of operators to EWP $Q_7,\ldots,10$
- mass eigenstates do not coincide with isospin eigenstates: $\pi - \eta - \eta'$ and $\rho - \omega$ mixing
- reduced matrix elements only appr. related by Clebsch Gordan coeff.
- may induce $\Delta I = 5/2$ operators not present in $H_W$

**SIZES**

- not all isospin breaking effects can be calculated/constrained at present
- the ones that can be are of expected size
  \[ \sim (m_u - m_d)/\Lambda_{QCD} \sim \alpha_0 \sim 1\% \]
- EWP effect known model indep. (negl. $Q_{7,8}$)
  \[ \Delta \alpha_{EWP} = (1.5 \pm 0.3 \pm 0.3)^\circ \]
  the same for $\pi\pi, \rho\rho, \rho\pi$
- for $\pi^0 - \eta - \eta'$ mixing
  \[ |\Delta \alpha_{\pi\pi-\eta-\eta'}| < 1.6^\circ \]

Gronau, London (1990)
Snyder, Quinn (1993)
since $\Gamma_\rho \neq 0 \Rightarrow I = 1$ contributions possible

$O(\Gamma_\rho^2/m_\rho^2)$ effect

possible to constrain experimentally

isospin breaking

EWP same as for $B \rightarrow \pi\pi$

$\rho - \omega$ mixing, integrated effect $< 2\%$

other: $g_I \equiv g(\rho_I \rightarrow \pi^+\pi^-) \neq g_c \equiv g(\rho^+ \rightarrow \pi^+\pi_3)$

[PDG: $g_c/g_I - 1 = (0.5 \pm 1.0)\%$]
Breaking isospin triangle in $B \rightarrow \rho \rho$ WA all channels

- Already sensitive to sources of SU(2) breaking (J. Zupan CKM'06):
  - $m_u \neq m_d$ & $Q_u \neq Q_d$:
    $$(m_u - m_d) / \Lambda_{QCD} \sim 1\%$$
  - extend the basis of EW penguins: $Q_{7,10}$
    $\Delta_{\alpha EWP} \sim 1.5^\circ$
  - mass Eigen-States (EG) $\neq$ isospin EG:
    $(\rho - \omega)$ mixing $< 2\%$
  - $\Gamma_{\rho} \neq 0$ $\Rightarrow$ $I=1$ contribution possible:
    $O(\Gamma_{\rho}^2 / m_{\rho}^2) \sim 4\%$
  - $\Delta I=5/2$ operators no more negligible.
  - ...
- Possible way out: $K^*\rho$ SU(3) constraints

Break the triangle closure:

$$A^{+0} \rightarrow A^{+0} + \Delta A^{+0}$$

$$\sqrt{2} \Delta A^{+0} = V_{ud}V_{ub}^* \Delta T^{++} + V_{td}V_{tb}^* \Delta P^{++}$$

addit. $\Delta T$’s & $\Delta P$’s (arbitrary phases)

- tested $|\Delta A^{+0}|$: 4, 10 & 15%
- small impact on $\pi\pi/\rho\rho/\rho\pi$ WA combo.
  $\Rightarrow$ only visible @95% CL
\[ \alpha \text{ from } b \rightarrow u \bar{u} d, \ B \rightarrow \rho \pi \]

**Dominant mode** \[ \rho^+ \pi^- \] is **not** a CP eigenstate

**Amplitude interference in Dalitz plot**

- Simultaneous fit of \( \alpha \) and strong phases
- Measure 26 (27) bilinear Form Factor coefficients
- Correlated \( \chi^2 \) fit to determine physics quantities

\[ t = 0 \]

Snyder-Quinn, PRD 48, 2139 (1993)

\[ q/p \sim e^{-2i\beta} \]

S. Aleksan et al, NP B361, 141 (1991)

**Same as for Moriond’07**
$B \rightarrow (\rho, \omega)\gamma$ & $B \rightarrow K^*\gamma$ exclusive \(b \rightarrow D\gamma\) where \(D=(d,s)\)

\(b \rightarrow d, s\gamma\): loop processes, give access to \(|V_{t(d,s)}|\), complement \(\Delta m_{d,s}\)

Early days: focus on magnetic op. \(Q_7 = (e/8\pi^2)m_b \tilde{D}\sigma^{\mu\nu}(1 + \gamma_5)F_{\mu\nu}b\) and assume short-distance dominance

\[
R_{\rho/\omega} = \frac{\overline{B}(\rho^\pm\gamma) + \frac{\tau_B^+}{\tau_{B^0}} [\overline{B}(\rho^0\gamma) + \overline{B}(\omega\gamma)]}{\overline{B}(K^{*\pm\gamma}) + \frac{\tau_{K^{*\pm\gamma}}}{\tau_{B^0}} [\overline{B}(K^{*\pm\gamma}) + \overline{B}(K^{*0\gamma})]}
\]

\[
= \left| \frac{V_{td}}{V_{ts}} \right|^2 \left( \frac{1 - m_D^2/m_B^2}{1 - m_{K^*}^2/m_B^2} \right)^3 \frac{1}{\xi^2} [1 + \Delta R]
\]

- \(\xi\) ratio of form factors
- \(\Delta R\) estimated as \(\Delta R = 0.1 \pm 0.1\)

Ali, Lunghi, Parkhomenko 02,04,06

Many open questions: dependence of \(\Delta R\) on CKM matrix? isospin breaking? weak annihilation (tree for \((\rho, \omega)\gamma\)?)

S. Descotes-Genon MEW’08

V. Tisserand, LAPP
Recently, big steps in lattice simulations: 3 dynamical quarks (unquenched) with light masses and (very) small errors

$\rightarrow$ Essential role in reducing the theoretical QCD uncertainties

- $|V_{ud}|$: improved analysis of nuclear $\beta$ decays [in fit]
- $|V_{us}|$: $K \rightarrow \pi \ell \nu +$ (dom wall) $f_+(0) = 0.964(5)$ [in fit] (UKQCD+RBC)
- $|V_{us}/V_{ud}|$:
  $K \rightarrow \ell \nu/\pi \rightarrow \ell \nu +$
  (staggered) $f_K/f_\pi = 1.189(7)$ [not in fit] (HPQCD+UKQCD)

Remarkable: $f_K/f_\pi$ very difficult to control on the lattice [light quarks]
• Charm sector favorite place to test LQCD \([m_c \sim \Lambda_{\text{QCD}}]\) for form fact. and decay constants (access \(|V_{c(d,s)}|\))

- **K and nucleon:** \(V_{ud} \sim V_{cs} (V_{cd} \sim V_{us})\) only at first non trivial order in \(\lambda\).
- **Unitarity:** \(|V_{cd}|^2 + |V_{cs}|^2 \leq 1\)

• **Direct (new):** I. Shipsey Aspen’09
  - \(|V_{cd}|\) from DIS \(\nu N\) scattering (still most precise meas. !)
  - \(|V_{cs}| = 1.018(10)_{\text{stat}}(8)_{\text{syst}}(106)_{\text{theo}}\) (above 1!) from LQCD + CLEO-c \(D \rightarrow K \nu SL\)
  - absolute BRs ((un-)tagged 280/pb \((\times 3 \text{ under study + future BES-III game field})\)).
No more trouble with $|V_{cs}|$

CLEO-c + LQCD (LPQCD)
$|V_{cs}|$ from the global fit

CLEO-c + LQCD (FNAL-MILC)
$|V_{cs}|$ from the global fit

$f^{\text{Lat}}_{D_s} = 241.0(1.4)(5.3) \text{ MeV}$

$|V_{cs}| = 1.050 \pm 0.053$

$f^{\text{Lat}}_{D_s} = 254.3(8)(11) \text{ MeV}$

$|V_{cs}| = 0.995 \pm 0.081$

We measure $B(D_s^+ \rightarrow \ell \nu_{\ell})$ and extract $f_{D_s^+}$

$$B(D_s^+ \rightarrow \ell^+ \nu_{\ell}) = \frac{\tau_{D_s}}{8\pi} f_{D_s^+}^2 |V_{cs}|^2 G_F^2 M_{D_s^+} \left( 1 - \frac{m_{\ell}^2}{M_{D_s^+}^2} \right)^2 m_{\ell}^2$$

J.Hunt
Lake Louise'09
Charm sector favorite place to test LQCD [$m_c \sim \Lambda_{QCD}$] for form fact. & decay constants (|V_{cs}| through $f_{D_s}$).

$\chi^2$/dof = 0.67

- BaBar
- CLEO
- Belle
- CLEO $\pi\nu$
- CLEO $e\nu\nu$
- Fermilab/MILC
- HPQCD

A 3.8σ discrepancy, or 2.7σ $\oplus$ 2.9σ.

A. Kronfeld Aspen'09
**f_{D_s} Puzzle: Jan 2009?**

**Charm sector** favorite place to test **LQCD** \([m_c \sim \Lambda_{QCD}]\) for form fact. & decay constants (|V_{cs}| through \(f_{D_s}\))

CLEO-C Ds to \((\tau, \mu)\nu: \text{arXiv:hep/ex 0901.1147 and 0901.1216}: f_{D_s} = (259.5 \pm 6.6 \pm 3.1)\) MeV

\[\chi^2/\text{dof} = 0.73\]

BaBar
CLEO
Belle
CLEO \(\pi\nu\)
CLEO \(e\nu\nu\)
Fermilab/MILC
HPQCD

a 3.0\(\sigma\) discrepancy, or 2.5\(\sigma\) \(\pm\) 1.9\(\sigma\).

A. Kronfeld Aspen'09
**a word on rare $K^+ \rightarrow \pi^+ \nu \bar{\nu}$**

**BR parameterization** as Brod & Gorbahn ’08 (PRD 78, 034006), NLO QED-QCD & EW corr. to the charm quark contrib. ($\alpha_s(m_Z^2) = 0.1176(20)$ & $m_c(\mu_c) = 1.286(13)(40)$):

$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu}(\gamma)) = \kappa_+ (1 + \Delta_{\text{EM}}) \left[ \left( \frac{\text{Im} \lambda_t}{\lambda_5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_c}{\lambda} (P_c(X) + \delta P_{c,u}) + \frac{\text{Re} \lambda_t}{\lambda_5} X(x_t) \right)^2 \right]$$

$$P_c(X) = \frac{1}{\lambda_4^4} \left( \frac{2}{3} X^e(x_c) + \frac{1}{3} X^\tau(x_c) \right)$$

$\delta P_{c,u} = 0.04 \pm 0.02$  : long distance corr. LQCD

$K_s$: higher order EW corr.

$\Delta_{\text{EM}}$: long dist. QED corr

$\lambda_i$: $V^*_i V_{id}$

$X(x_i)$: Inami Lim loop function

$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \propto [(\sigma \eta)^2 + (\rho_0 - \bar{\rho})^2]$$
Global CKM fit: the $B_s$ mesons ($\bar{\rho}_s, \bar{\eta}_s$) plane

(Squashed) $B_s$ unitarity triangle

$$\frac{V_{us} V_{ub}^*}{V_{cs} V_{cb}^*} + 1 + \frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} = 0$$

$O(\chi^2) + O(1) + O(1)$

$CP$-violation for $B_s$ meson

$$\bar{\rho}_s + i \bar{\eta}_s = -\frac{V_{us} V_{ub}^*}{V_{cs} V_{cb}^*}$$

$$\beta_s = -\arg\left[-\frac{V_{cs}}{V_{ts}} \frac{V_{cb}^*}{V_{tb}^*}\right]$$

$$\beta_s = (1.035^{+0.049}_{-0.046})^\circ$$

(from global CKM fit MEW '09)

V. Tisserand, LAPP

CDF+DØ HFAG'08: $\beta_s = (22.3^{+10.3}_{-8.0})^\circ$
New Physics in $B_s$ mixing

- Direct constraint on NP phase in $B_s$ mixing
  - The CDF/Do measurement of $(-2\beta_s, \Delta\Gamma_s)$ from the time-dependent angular analysis of the $B_s \rightarrow J/\psi \phi$ provides a direct constraint on $\Phi_{NP}^s$.
  - Using the HFAG combination of CDF and Do likelihood:
    $(-2\beta_s, \Delta\Gamma_s) / (\pi + 2\beta_s, -\Delta\Gamma_s) = (-44^{+17}_{-21} \degree, 0.154^{+0.054}_{-0.070} \text{ps}^{-1})$

- Other constraints
  - $\Delta m_s$: consistent with SM expectation
  - $A_{sL}(B_s)$: large error wrt SM prediction
  - $\tau_{FS}^+$: weak constraint on $\Delta\Gamma_s$
  - NP relation $\Delta\Gamma_s \approx \Delta\Gamma_s^{SM} \cos(\Phi_{NP}^s)$
    - $\Delta\Gamma_s^{SM} = (0.090^{+0.019}_{-0.022}) \text{ps}$ [Lenz,Nierste]
    - tends to push the NP phase $\Phi_{NP}^s$ towards SM.

Clean analysis: all theoretical uncertainties are in the DG$^{SM}$ prediction but...
... it cannot tell much more on $\Phi_{NP}^s$ than the direct TeVatron measurement.
Back to the \((\phi_s, \Delta \Gamma_s)\) plane

here \(\tau_s^{FS} = \frac{1 + (\tau_s \Delta \Gamma_s)^2}{1 - (\tau_s \Delta \Gamma_s)^2}\) can be viewed as an independent measurement of \(\Delta \Gamma_s^s\) using all \((\phi_s, \Delta \Gamma_s)\) inputs,

\(\phi_s = -2 \beta_s\) is excluded at 2.4\(\sigma\), while the 2D hypothesis \(\phi_s = -2 \beta_s\), \(\Delta \Gamma_s = \Delta \Gamma_s^{SM}\) is excluded at only 1.9\(\sigma\) (wrt to 1.4\(\sigma\) from FC treatment by CDF)

the combined region is tangent to the SM one, simply because the phase is vanishingly small there and thus \(\cos 2\phi_s \sim 1 + \mathcal{O}(\phi_s^2)\)

very transparent analysis: all theoretical uncertainties are contained in the SM prediction \(\Delta \Gamma_s^{SM} = 0.090^{+0.017}_{-0.022}\) ps (red line)
\[ \gamma \text{ from interference in charged } B^- \rightarrow \bar{D}^{(*)0}K^{(*)-} \text{ decays} \]

\[ \text{Cabibbo-"favored" } \]

\[ \gamma \sim \bar{V}_{ub} \]

\[ V_{ub} \]

\[ \text{D}^- \rightarrow \bar{D}^{(*)0}K^{(*)-} \]

\[ A_{cb}(D^{(*)0}K^{(*)-}) \propto \lambda^3 \]

\[ A_{ub}(\bar{D}^{(*)0}K^{(*)-}) \propto \lambda^3 \sqrt{\eta^2 + \bar{\rho}^2} \text{ e } i(\delta_{B^-}) \]

\[ \text{relative strong & weak phases} \]

\[ \Rightarrow \text{Measurement of } \gamma \text{ using direct CP violation (interference } [b \leftrightarrow c \leftrightarrow b \rightarrow u] ) : \]

\[ \Rightarrow 3 \text{ various } B^- \rightarrow \bar{D}^{(*)0}K^{(*)-} \text{ charged decays (no time dependence): } DK, D*K, \text{ and } DK*. \]

\[ \Rightarrow \text{Size of CPV is limited by the size of } |A_{ub}/A_{cb}| \text{ amplitudes ratio: } 3 \text{ r}^{(*)}_{(i)B} \text{ nuisance parameters (~5-30% ?).} \]

\[ \Rightarrow \text{3 methods that need a lot of B mesons:} \]

\[ \text{GLW: } \bar{D} = \text{CP-eigenstate: many modes, but small asymmetry.} \]

\[ \text{ADS: } \bar{D} = \text{DCS: large asymmetry, but very few events.} \]

\[ \text{GGSZ: } \bar{D} = \text{Dalitz: better than a mixture of ADS+GLW } \Rightarrow \text{large asymmetry in some regions, but strong phases varying other the Dalitz plane.} \]
\( \gamma \) from interference in charged \( B^- \rightarrow \bar{D}^{(*)+}K^{(*)-} \) decays

\[ \gamma = (70.9^{+27}_{-29})^\circ \{ [+44^\circ-41^\circ] 95\% \text{ CL} \} \]

CKM fit MEW’09: \( (67.8^{+4.2}_{-3.9})^\circ \)

\( \Rightarrow \) Only recent meas. is ADS/GLW BaBar DK* at CKM’08
**r_B and strong phase δ_B from GLW+ADS+GGSZ WA global fit**

\[ r_B(DK) = (0.087^{+0.022}_{-0.028}) \]

\[ r_B(D^*K) = (0.101^{+0.034}_{-0.040}) \]

\[ r_B(DK^*) = (0.161^{+0.079}_{-0.084}) \]

\[ \delta_B(DK) = (110^{+22}_{-27})^\circ \]

\[ \delta_B(D^*K) = (-42^{+26}_{-32})^\circ \]

\[ \delta_B(DK^*) = (47^{+103}_{-28})^\circ \]
Combination may not lead to naïve expectation. The $r_B$ nuisance parameter (([b→u]/[b→c] transition size), even when large (∼30%) , interferes in the CKM angle $\gamma$ extract:

- This is not a naïve GLW+ADS average (multi-dim.)
- The accuracy may degrade in combo.
\[ \gamma \] from direct CPV in charged \( B \rightarrow \bar{D}_0 K^* \) decays

\[
\begin{align*}
R_{CP^+} &= 1 + r_B^2 \pm 2 r_B \cos(\delta_B) \cos(\gamma) \\
A_{CP^\pm} &= \frac{\pm 2 r_B \sin(\delta_B) \sin(\gamma)}{R_{CP^\pm}}
\end{align*}
\]

marginal sensitivity to \( r_B^2 \ll 1 \)

8 fold-ambiguities on \( \gamma \)

\[
\begin{align*}
R_{ADS} &= r_B^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos(\gamma) \\
A_{ADS} &= 2 r_B r_D \sin(\delta_B + \delta_D) \sin(\gamma)
\end{align*}
\]

good sensitivity to \( r_B^2 > r_D^2 \)

\[ \gamma = (34^{+28}_{-30})^\circ \text{ or } (146^{+30}_{-29})^\circ \]
Combining methods on $\gamma$ not always leads to what one naïvely expects (nuisance params)

Not only $\gamma$ in 3 methods, also hadronic quantities (strong phases . . . )

- **GLW** ($DK, D^*K, DK^*$)
  \[ R_{CP\pm} = 1 \pm 2r_B \cos \delta_B \cos \gamma + r_R^2 \]
  \[ A_{CP+} = \pm 2r_B \sin \delta_B \sin \gamma / R_{CP\pm} \]

- **ADS** ($DK, D^*K, DK^*$ for $K_\pi, K_\pi \pi^0 . . .$)
  \[ R_{ADS} = r_B^2 + r_D^2 \]
  \[ + 2r_B r_D \cos(\delta_B + \delta_D) \cos \gamma \]

- **GGSZ** ($DK, D^*K, DK^*$)
  \[ x_\pm = r_B \cos(\delta_B \pm \gamma) \]
  \[ y_\pm = r_B \sin(\delta_B \pm \gamma) \]

Combining results may not yield the naive average and may not improve the accuracy . . . at least sometimes ($DK^*$)

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Combining methods on $\gamma$: statistical treatment matters!

Determination of $\gamma$ (central value and intervals) from different measurements, independently of other parameters

$1-CL$ \hspace{2cm} $\gamma$ (degree)

$\gamma$ parameter of interest, $\mu$ (= $r_B$, $\delta_B$) nuisance parameters

$\Delta \chi^2(\hat{\gamma}) = \chi^2(\hat{\gamma}, \hat{\mu}) - \chi^2(\gamma_{best}, \mu_{best})$

$N_{\gamma}$ minimisations

get the CL:

○ if the sampling PDF of $\Delta \chi^2$ is a $\chi^2$ law
⇒ cumulative distribution function (prob)
  (true asymptotically)

if not: the sampling PDF depends, in general, on the nuisance parameters

what to do with the nuisance parameters?

→ plug-in principle ($\hat{\mu}$ method): nuisance parameters are fixed to $\hat{\mu}$ values
→ supremum method: least favored values of the nuisance parameters
  (sure to never undercover)

So far CKMfitter conservative baseline method