Status of the CKM Matrix & CP Violation in B-Decays

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Plan of Talk

- Introduction to Quark Flavour Mixing & the CKM Matrix
- Present Status of the First Two Rows of $V_{\rm CKM}$
- Status of the Third Row of $V_{\rm CKM}$
- Current Knowledge of the Phases α, β and γ
- CPV in Penguins ($b \longrightarrow s\bar{s}s$ and $b \longrightarrow s\bar{d}d$)
- Summary

Standard Model Lagrangian

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm GSW} + \mathcal{L}_{\rm QCD}$$

QCD [SU(3)]

$$\mathcal{L}_{\rm QCD} = -\frac{1}{4} F^{(a)}_{\mu\nu} F^{(a)\mu\nu} + i \sum_q \bar{\psi}^\alpha_q \gamma^\mu (D_\mu)_{\alpha\beta} \psi^\beta_q$$

with $F^{(a)}_{\mu\nu} = \partial_\mu A^{(a)}_\nu - \partial_\nu A^{(a)}_\mu - g_s f_{abc} A^{(b)}_\mu A^{(c)}_\nu; \quad a, b, c = 1, ..., 8$
and $(D_\mu)_{\alpha\beta} = \delta_{\alpha\beta}\partial_\mu + i g_s \sum_q \frac{1}{2} \lambda^{(a)}_{\alpha\beta} A^{(a)}_\mu$

Electroweak $[SU(2)_I \times U(1)_Y]$

$$\mathcal{L}_{\rm GSW} = \mathcal{L}_{\rm gauge}(W_i, B, \psi_j) + \mathcal{L}_{\rm Higgs}(\phi_k, W_i, B, \psi_j)$$

$$\mathcal{L}_{\rm gauge}(W_i, B, \psi_j) = -\frac{1}{4} F^i_{\mu\nu} F^{\mu\nu}_i - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} + \sum_{\psi_L} \overline{\psi_L} i D_\mu \gamma^\mu \psi_L + \sum_{\psi_R} \overline{\psi_R} i D_\mu \gamma^\mu \psi_R$$

$$\mathcal{L}_{\rm Higgs}(\phi_k, W_i, B, \psi_j) = \mathcal{L}_{\rm Higgs}({\rm gauge}) + \mathcal{L}_{\rm Higgs}({\rm fermions})$$

$$\mathcal{L}_{\rm Higgs}({\rm gauge}) = (D_\mu \Phi)^* (D^\mu \Phi) - V(\Phi)$$

$$D_\mu \Phi = ({\rm I}(\partial_\mu + i\frac{g_1}{2} B_\mu) + i g_2 \frac{\tau}{2} \cdot {\rm W}_\mu)\Phi; \; V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$

$$\mathcal{L}_{\rm Higgs}({\rm fermions}) = Y^{ij}_u \bar{Q}_{L,i} \tilde{\Phi} u_{R,j} + Y^{ij}_d \bar{Q}_{L,i} \Phi d_{R,j} + {\rm h.c.} + ...$$

- 3 Quark families: $Q_{L_j} = (u_L,\ d_L); (c_L,\ s_L); (t_L;\ b_L); \bar{u}_R,\ \bar{d}_R; \ldots$
- Flavour mixings in the SM reside in the Higgs-Yukawa sector of the theory
- Flavour symmetry broken by Yukawa interactions

$$Q_i Y_d^{ij} d_j \phi \longrightarrow Q_i M_d^{ij} d_j$$

$$Q_i Y_u^{ij} u_j \phi^c \longrightarrow Q_i M_u^{ij} u_j$$

$$M_d = \mathrm{diag}(m_d,\ m_s,\ m_b);\ \ M_u^\dagger = \mathrm{diag}(m_u,\ m_c,\ m_t) \times V_{\mathrm{CKM}}$$

- $\underline{V_{\mathrm{CKM}}}$ a (3×3) unitary matrix is the only source of Flavour Violation, as all gauge interactions (involving $\gamma,\ Z^0,\ g$) are Flavour diagonal
- All observed phenomena involving flavour changes in the hadrons are consistently described by the CKM framework; i.e., in terms of 10 fundamental parameters: 6 quark masses, 3 mixing angles and 1 phase
- Understanding the observed patterns of quark masses and mixings (as well as the lepton masses and neutrino mixings) requires an organizing principle which is certainly outside of the SM

The Cabibbo-Kobayashi-Maskawa Matrix

$$V_{\rm CKM} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

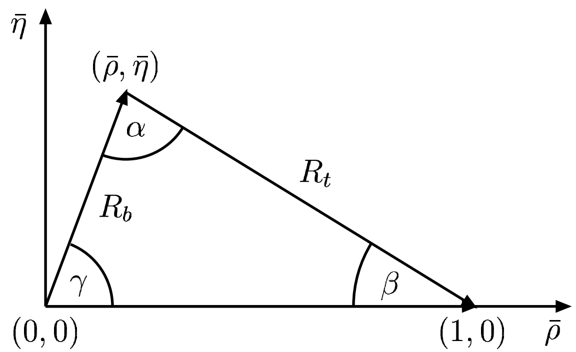
- Customary to use the handy Wolfenstein parametrization

$$V_{\rm CKM} \simeq \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda(1+iA^2\lambda^4\eta) & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2(1+i\lambda^2\eta) & 1 \end{pmatrix}$$

- Four parameters: $A, \ \lambda, \ \rho, \ \eta$
- Perturbatively improved version of this parametrization

$$\bar{\rho} = \rho(1-\lambda^2/2), \quad \bar{\eta} = \eta(1-\lambda^2/2)$$

- The CKM-Unitarity triangle $[\phi_1 = \beta; \ \ \phi_2 = \alpha; \ \ \phi_3 = \gamma]$



Phases and sides of the UT

$$\alpha \equiv \arg\left(-\frac{V_{tb}^* V_{td}}{V_{ub}^* V_{ud}}\right), \qquad \beta \equiv \arg\left(-\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right), \qquad \gamma \equiv \arg\left(-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right)$$

- β and γ have simple interpretation

$$V_{td} = |V_{td}| e^{-i\beta}, \qquad V_{ub} = |V_{ub}| e^{-i\gamma}$$

- α defined by the relation: $\alpha = \pi - \beta - \gamma$
- The Unitarity Triangle (UT) is defined by:

$$R_b \mathrm{e}^{i\gamma} + R_t \mathrm{e}^{-i\beta} = 1$$

$$R_b \equiv \frac{|V_{ub}^* V_{ud}|}{|V_{cb}^* V_{cd}|} = \sqrt{\bar{\rho}^2 + \bar{\eta}^2} = \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t \equiv \frac{|V_{tb}^* V_{td}|}{|V_{cb}^* V_{cd}|} = \sqrt{(1-\bar{\rho})^2 + \bar{\eta}^2} = \frac{1}{\lambda} \left|\frac{V_{td}}{V_{cb}}\right|$$

Summary of the First 2 Rows of $V_{\rm CKM}$

- $|V_{ud}| = 0.9739(3)$ [CKM 2005]
- $|V_{us}| = 0.2262(23)$ [CKM 2005]
  $|V_{us}| = 0.2269(13)$ [From unitarity]
- $|V_{ub}| = (4.38 \pm 0.19 \pm 0.27) \times 10^{-3}$ [HFAG 2005; inclusive]
  $|V_{ub}| = (3.76 \pm 0.16^{+0.87}_{-0.51}) \times 10^{-3}$ [HFAG 2005; exclusive using FNAL Lattice Calc.]

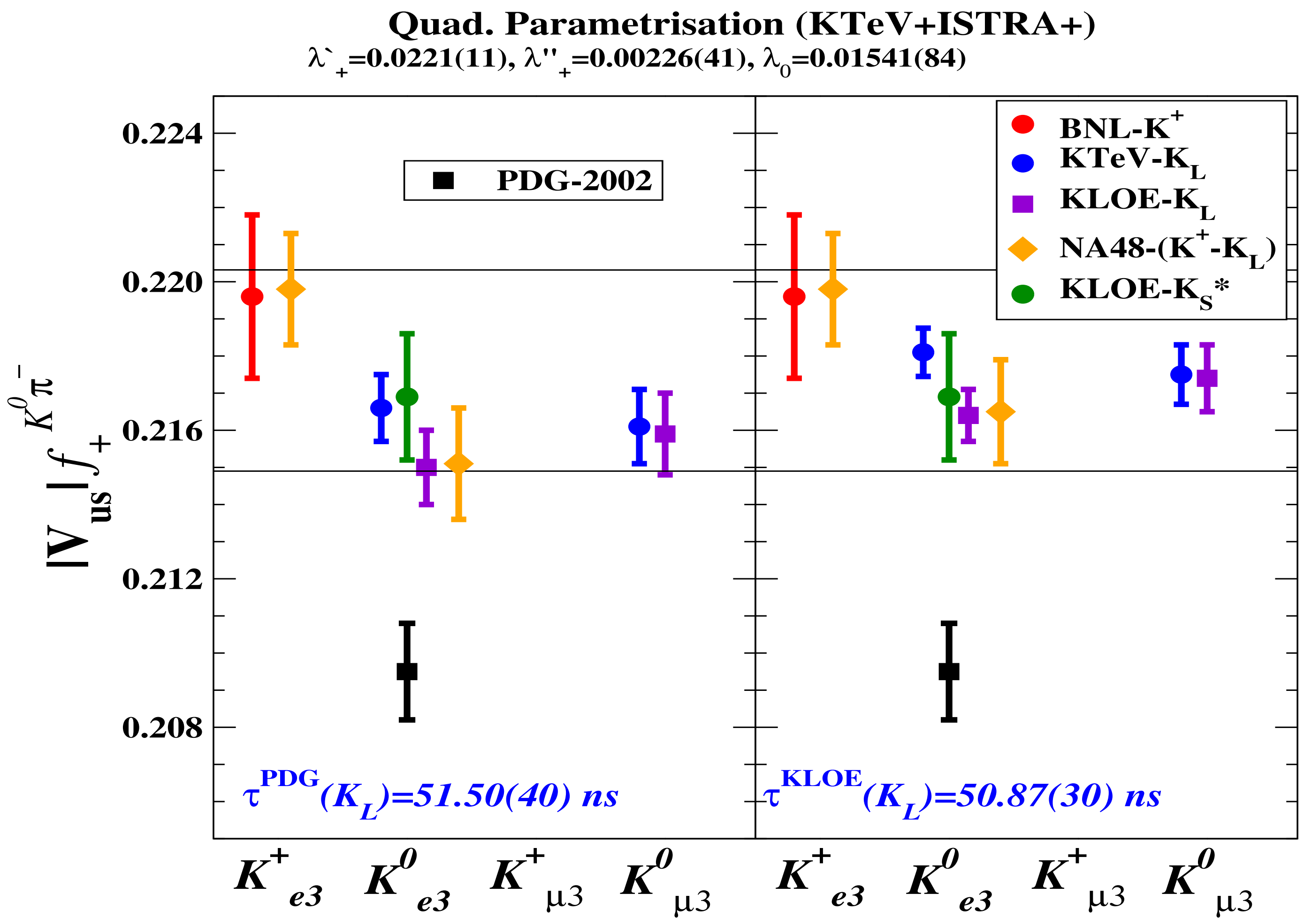
Unitarity of the Ist Row of $V_{\rm CKM}$

$$1 - (|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2) = 0.0004 \pm 0.0011 \quad [\mathrm{Schune, EPS, 2005}]$$

- $|V_{cd}| = 0.224(16)$ [PDG 2004]
- $|V_{cs}| = 0.97 \pm 0.09 \pm 0.07$ [PDG 2004]
- $|V_{cb}| = (41.58 \pm 0.45 \pm 0.58) \times 10^{-3}$ [Buchmüller-Flächer 2005; inclusive]
  $|V_{cb}| = (41.3 \pm 1.0 \pm 1.8) \times 10^{-3}$ [HFAG 2005; exclusive]

$|V_{us}| \times f_+^{K^0\pi}$ from K-semileptonics

[G. Lanfranchi (KLOE Collaboration); hep-ex/0505089]



$|V_{cb}|$ from Inclusive decays $B \to X_c \ell \nu_\ell$

- Theoretical Method

  Heavy Quark Mass Expansion and Operator Product Expansion (OPE)

  [Chay, Georgi, Grinstein; Voloshin, Shifman; Bigi et al.; Manohar, Wise; Blok et al.]

- Perform an OPE: m_b is much larger than any scale appearing in the matrix element
- Decay rate for $B \to X_c \ell \bar{\nu}_\ell$

$$\Gamma = \Gamma_0 + \frac{1}{m_b}\Gamma_1 + \frac{1}{m_b^2}\Gamma_2 + \frac{1}{m_b^3}\Gamma_3 + \cdots$$

- Γ_i are power series in $\alpha_s(m_b)$ $\to$ Perturbaton theory
- Γ_0 is the decay of a free quark ("Parton Model")
- Γ_1 vanishes due to Luke's theorem
- Γ_2 is expressed in terms of two non-perturbative parameters

  $2M_B\lambda_1 = \langle B(v)|\bar{Q}_v(iD)^2 Q_v|B(v)\rangle$

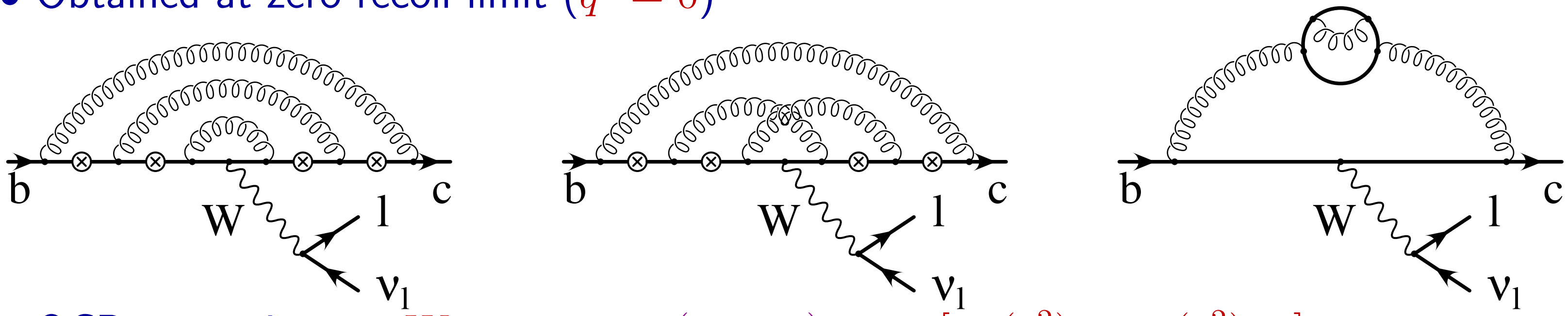
  $6M_B\lambda_2 = \langle B(v)|\bar{Q}_v\sigma_{\mu\nu}[iD^\mu, iD^\nu]Q_v|B(v)\rangle$

  λ_1: Kinetic energy, λ_2: Chromomagnetic moment (also called as μ_π^2 and μ_G^2)

- Γ_3 is currently under investigation; involves several new Non-perturbative parameters

Three-loop QCD corrections to $b \to c\ell\nu_\ell$ decays

- Obtained at zero recoil limit ($q^2 = 0$)



- QCD corrections to $W_{\bar{c}b}$ vertex: $\gamma_\mu(1-\gamma_5) \to \gamma_\mu[\eta_V(q^2) - \eta_A(q^2)\,\gamma_5]$

$$\eta_V(q^2=0) = 1$$

$$\eta_A(q^2=0) \equiv \eta_A = 1 + \frac{\alpha_s}{\pi} C_F \eta_A^{(1)} + \left(\frac{\alpha_s}{\pi}\right)^2 C_F \eta_A^{(2)} + \left(\frac{\alpha_s}{\pi}\right)^3 C_F \eta_A^{(3)} + \mathcal{O}(\alpha_s^4)$$

- $\eta_A^{(1)}$ and $\eta_A^{(2)}$ known since long ago [Shifman, Voloshin; Paschalis, Gounaris; Czarnecki]
- $\eta_A^{(3)}$ calculated recently [Archambault, Czarnecki]

$$\eta_A \simeq 1 - 0.667\frac{\alpha_s}{\pi} - 1.85\left(\frac{\alpha_s}{\pi}\right)^2 - 11.1\left(\frac{\alpha_s}{\pi}\right)^3 + \mathcal{O}(\alpha_s^4)$$

$$\simeq 1 - 0.0510 - 0.0108 - 0.00495 \simeq 0.933 \qquad (\text{for} \quad \alpha_s(\sqrt{m_b m_c}) = 0.24)$$

- Effect of $\eta_A^{(3)} \simeq -\frac{1}{2}\%$

$$C_F \eta_A^{(3)}(\text{BLM}) = \left(4 - \frac{33}{2}\right)^2 C_F T_R^2 \left(\frac{25}{324} - \frac{\pi^2}{27}\right) = -15.0$$

$$C_F \eta_A^{(3)}(\text{non-BLM}) = -11.1 + 15.0 = 3.9$$

- $\eta_A^{(3)}$ dominated by BLM correction

Moment analysis of $B \to X_c \ell \nu_\ell$ with lepton energy cut

Lepton-energy and hadron mass moments

[Gambino, Uraltsev; Benson et al.]

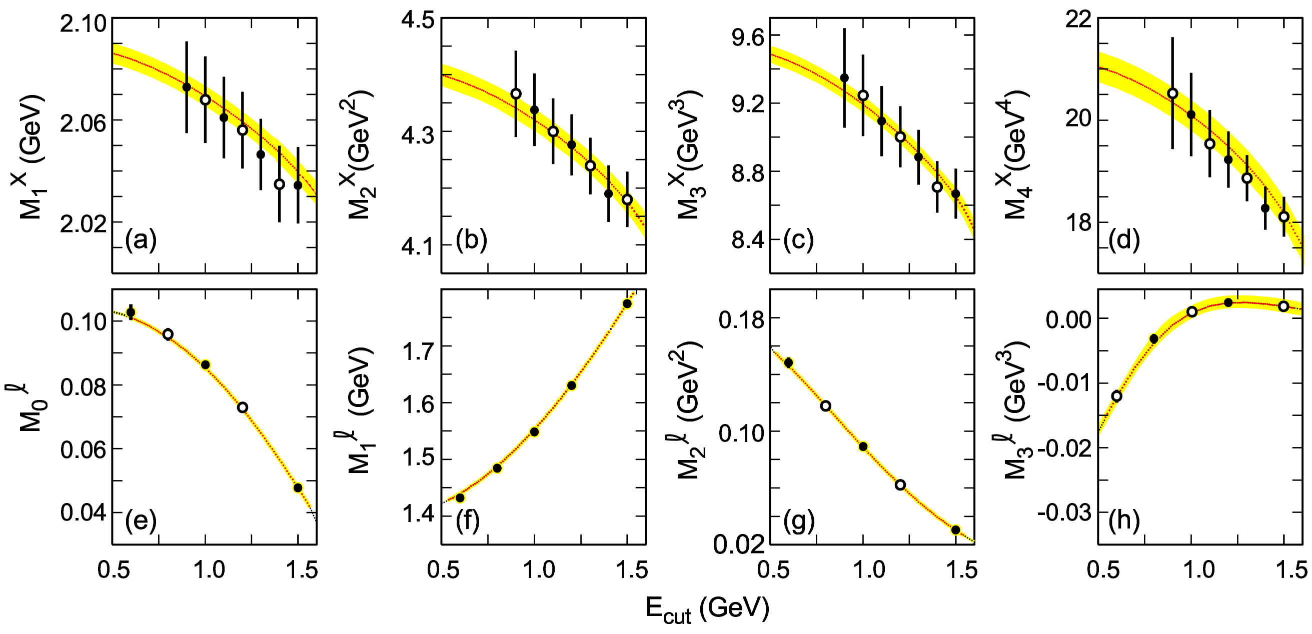
$$M_\ell^{(n)}(E_{\rm cut}) = \frac{\int_{E_{\rm cut}} E_\ell^n \frac{d\Gamma}{dE_\ell}\, dE_\ell}{\int_{E_{\rm cut}} \frac{d\Gamma}{dE_\ell}\, dE_\ell}, \quad \langle M_X^\nu \rangle = \left(\langle M_X^2 \rangle\right)^{\frac{\nu}{2}} \left[1 + \sum_{k=2}^{\infty} C_{\frac{\nu}{2}}^{k} \frac{\langle (M_X^2 - \langle M_X^2 \rangle)^k \rangle}{\langle M_X^2 \rangle^k}\right]$$

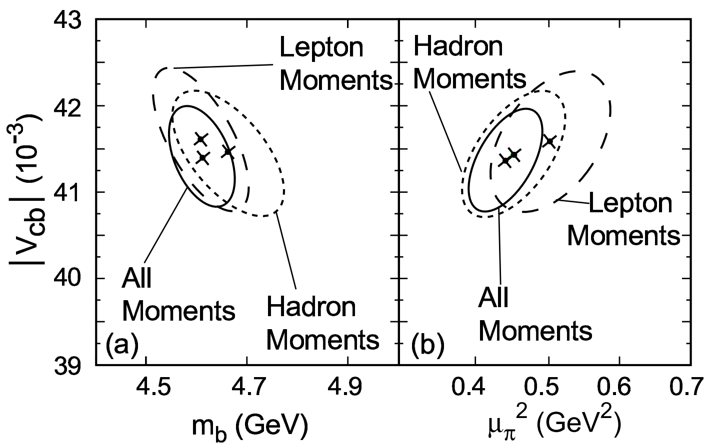
- Combined with the decay $B \to X_s \gamma$

$$\langle m_X^{2n} \rangle_{E_{\rm cut}} = \frac{\int_{E_{\rm cut}} (m_X^2)^n \frac{d\Gamma}{dm_X^2}\, dm_X^2}{\int_{E_{\rm cut}} \frac{d\Gamma}{dm_X^2}\, dm_X^2}, \qquad \langle E_\gamma^n \rangle_{E_{\rm cut}} = \frac{\int_{E_{\rm cut}} E_\gamma^n \frac{d\Gamma}{dE_\gamma}\, dE_\gamma}{\int_{E_{\rm cut}} \frac{d\Gamma}{dE_\gamma}\, dE_\gamma}$$

- Kinematic-mass scheme, $\mu \simeq 1$ GeV
- No Expansion in $1/m_c$
- Theory depends on $m_c(\mu), m_b(\mu),\ \underbrace{\mu_\pi^2(\mu), \mu_G^2,}_{\mathcal{O}(\Lambda_{\rm QCD}^2/m_b^2)}\ \underbrace{\rho_{\rm LS}^3(\mu), \rho_{\rm D}^3(\mu)}_{\mathcal{O}(\Lambda_{\rm QCD}^3/m_b^3)}$

BABAR hadronic-mass and lepton-energy moments analysis





$$|V_{cb}| = (41.4 \pm 0.4_{exp} \pm 0.4_{HQE} \pm 0.6_{th}) \times 10^{-3}$$

$$\mathcal{B}_{ce\nu} = (10.61 \pm 0.16_{exp} \pm 0.06_{HQE})$$

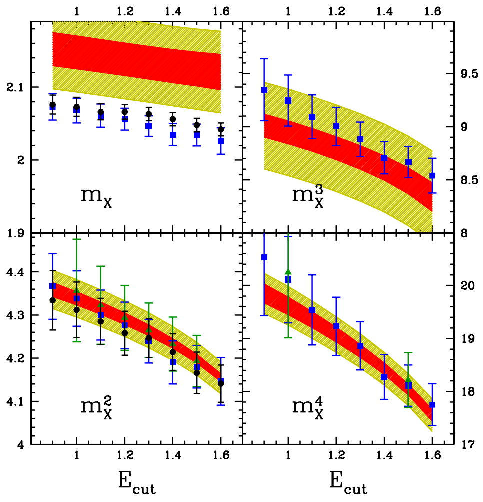
$$m_b\ (1\text{GeV}) = (4.61 \pm 0.05_{exp} \pm 0.04_{HQE} \pm 0.02_{th})\ \text{GeV}$$

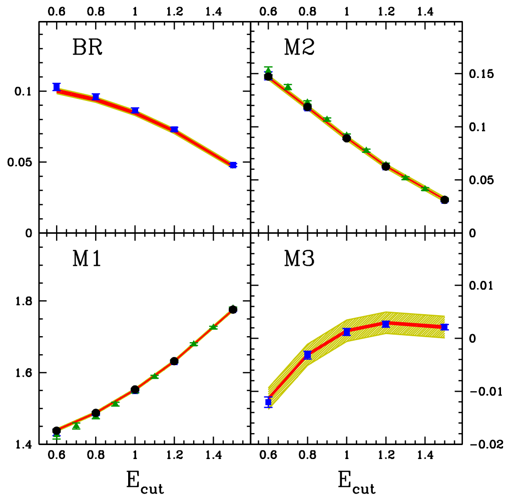
$$m_c\ (1\text{GeV}) = (1.18 \pm 0.07_{exp} \pm 0.06_{HQE} \pm 0.02_{th})\ \text{GeV}$$

Analysis of the moments by Bauer et al.

[Bauer, Ligeti, Luke, Manohar, Trott, hep/ph/0408002]

- Global fit of data from BABAR, BELLE, CDF, CLEO, DELPHI
- Theory precision: up to $\mathcal{O}(\alpha_s^2\beta_0)$, $\alpha_s\Lambda_{\rm QCD}/m_b$, $\Lambda_{\rm QCD}^3/m_b^3$
- Parameters: $m_b(\mu)$, $\underbrace{\lambda_1}_{\mathcal{O}(\Lambda_{\rm QCD}^2/m_b^2)}$, $\underbrace{\rho_1, \tau_1 - 3\tau_4, \tau_2 + \tau_4, \tau_3 + 3\tau_4}_{\mathcal{O}(\Lambda_{\rm QCD}^3/m_b^3)}$
- Scheme dependence: 1S, PS, $\overline{\rm MS}$, kinematic, pole
- Find: pole and $\overline{\rm MS}$ schemes significantly worse than others
- Analyse: $m_X^n \equiv \langle m_X^n \rangle$, $\langle E_\ell^n \rangle$, (n = 1,...4) $(B \to X_c \ell \nu_\ell)$; $\langle E_\gamma^n \rangle$ $(B \to X_s \gamma)$





$$|V_{cb}| = (41.4 \pm 0.6 \pm 0.1_{\tau_B}) \times 10^{-3},$$

$$m_b^{1S} = (4.68 \pm 0.03)\ \text{GeV},$$

$|V_{cb}|$ from $B \to (D, D^*)\,\ell\nu_\ell$ decays

$B \to D^*\ell\nu_\ell$ decays

$$\frac{d\Gamma}{d\omega} = \frac{G_F^2}{4\pi^3}\left(\omega^2-1\right)^{1/2} m_{D^*}^3\left(m_B - m_{D^*}\right)^2 \mathcal{G}(\omega)\,|V_{cb}|^2\,|\mathcal{F}(\omega)|^2$$

- $\mathcal{G}(\omega)$ phase space factor: $\mathcal{G}(1) = 1$, $\mathcal{F}(\omega) =$ Isgur–Wise function: $\mathcal{F}(1) = 1$;
- Leading $\Lambda_{\rm QCD}/m_b$ corrections absent Luke's theorem
- Theoretical issues: precise determination of the second order correction to $\mathcal{F}(\omega = 1)$, slope ρ^2 and curvature c

$$\mathcal{F}(\omega) = \mathcal{F}(1)\,\left[1 + \rho^2\,(\omega - 1) + c\,(\omega-1)^2 + ...\right]\,.$$

- Sum rules: $\rho^2 > \frac{3}{4}$ [Bjorken]; $c > 15/32$ [Uraltsev; Orsay group]

HFAG (Summer 2004 Update)

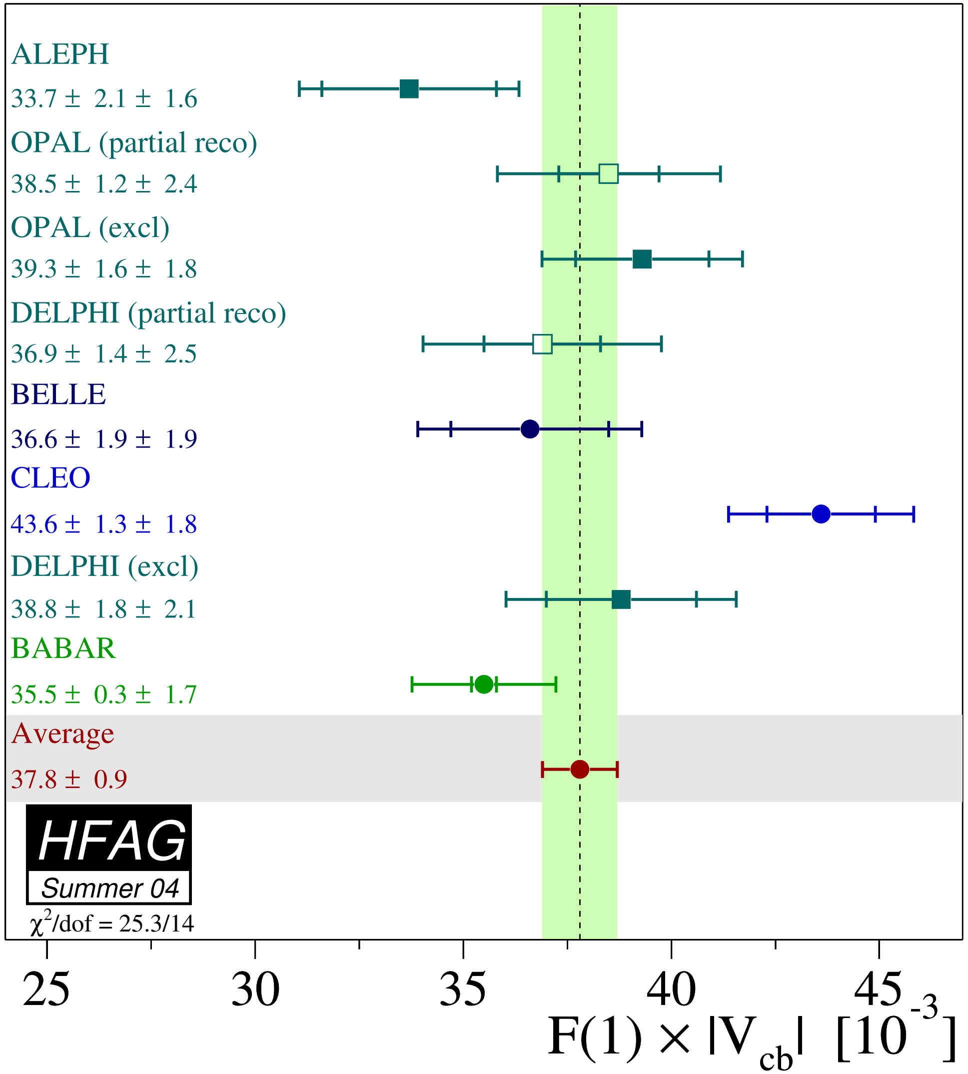
$$\mathcal{F}(1)|V_{cb}| = (37.8 \pm 0.8) \times 10^{-3}\,, \qquad \rho^2 = 1.54 \pm 0.14 \quad (\chi^2 = 25.3/14)$$

Current values of $\mathcal{F}(1)$

$$\begin{aligned}\mathcal{F}(1) \;&=\; 0.91 \pm 0.04 \quad \text{[BABAR book]}\\ &\;\; 0.919^{+0.030}_{-0.035} \quad \text{[Lattice QCD (Hashimoto et al.)]}\end{aligned}$$

With $\mathcal{F}(1) = 0.91 \pm 0.04$: $|V_{cb}|_{B\to D^*\ell\nu_\ell} = (41.6 \pm 0.9_{\rm exp} \pm 1.8_{\rm theo}) \times 10^{-3}$

$\mathcal{F}(1)|V_{cb}|$ (Summer 2004)



$|V_{ub}|$

From End-point spectra in $B \to X_u \ell \nu_\ell$ and $B \to X_s \gamma$

- To remove the background from $B \to X_c \ell \nu_\ell$, need to impose a large E_ℓ-cut

  Kinematics: $p_b^\mu = m_b v^\mu + k^\mu$; v^μ: 4-velocity of the b-quark, $k^\mu \sim O(\Lambda_{\rm QCD})$;
  $m_X^2 = (m_b v + k - q)^2 = (m_b v - q)^2 + 2E_X k_+ + ...,\quad k_+ = k_0 + k_3$
- Decay rate in the cut-region depends on the shape function $f(k_+)$
- Use of OPE to calculate inclusive spectra:

  Example: Photon Spectrum in $B \to X_s \gamma$ $\quad (x = \frac{2E_\gamma}{m_b})$

$$\frac{d\Gamma}{dx} = \frac{G_F^2 \alpha m_b^5}{32\pi^4} |V_{ts} V_{tb^*}|^2 |C_7|^2 \left(\delta(1-x) - \frac{\lambda_1 + 3\lambda_2}{2m_b^2} \delta'(1-x) + \frac{\lambda_1}{6m_b^2} \delta''(1-x) + \cdots \right)$$

- Leading terms can be resummed into a Shape function: [Neubert; Bigi et al.]

$$\frac{d\Gamma}{dx} = \frac{G_F^2 \alpha m_b^5}{32\pi^4} |V_{ts} V_{tb^*}|^2 |C_7|^2 f(1-x)$$

- $2M_B f(\omega) = \langle B | \bar{Q}_v \delta(\omega + n \cdot (iD)) Q_v | B \rangle$; n a light-like vector, $n.v = 1$, $n^2 = 0$
- E_ℓ - and M_{X_u} -spectra in $B \to X_u \ell \nu_\ell$ governed also by $f(x)$
- $f(x)$ can be measured in $B \to X_s \gamma$

Model independent determination of $|V_{ub}/(V_{ts}^* V_{tb})|$

$\longrightarrow$ Define Observables (E_c – energy cut)

$$\Gamma_u(E_c) = \int_{E_c}^{m_B/2} dE_\ell \frac{d\Gamma_u}{dE_\ell}, \qquad \Gamma_s(E_c) = \frac{2}{m_b}\int_{E_c}^{m_B/2} dE_\gamma (E_\gamma - E_c)\frac{d\Gamma_s}{dE_\gamma}$$

Including subleading Shape functions [Bauer, Luke, Mannel]

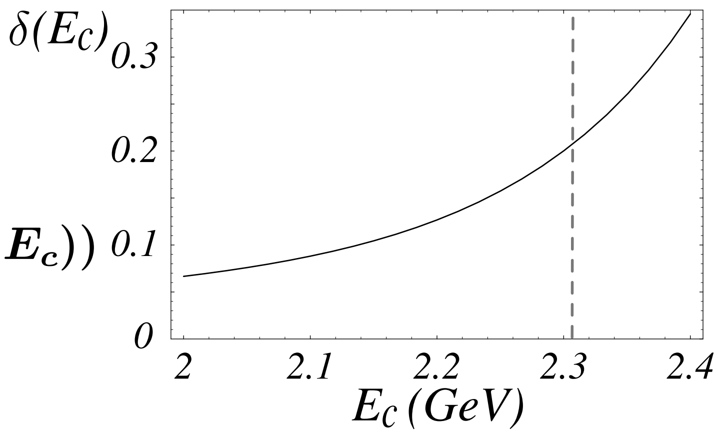
- $b \longrightarrow s\gamma$:

$$\frac{d\Gamma}{dE_\gamma} = \frac{\Gamma_0^s}{m_b}\left[(4E_\gamma - m_b)F(m_b - 2E_\gamma) + \frac{1}{m_b}[h_1(m_b - 2E_\gamma) + H_2(m_b - 2E_\gamma)]\right]$$

- $b \longrightarrow u\ell\bar{\nu}_\ell$

$$\frac{d\Gamma}{dE_\ell} = \frac{2\,\Gamma_0}{m_b}\int d\omega\,\theta(m_b - 2E_\ell - \omega)\left[F(\omega)\left(1 - \frac{\omega}{m_b}\right) - \frac{1}{m_b}h_1(\omega) + \frac{3}{m_b}H_2(\omega)\right]$$

- Ratio receives $1/m_b$ corrections



$$\left|\frac{V_{ub}}{V_{tb}V_{ts}^*}\right| = \left(\frac{3\alpha}{\pi}|C_7^{\rm eff}|^2\frac{\Gamma_u(E_c)}{\Gamma_s(E_c)}\right)^{\frac{1}{2}}(1 + \delta(E_c))$$

- $\delta(E_c)$ causes a shift of $\mathcal{O}(15\%)$ in $|V_{ub}|$

$|V_{ub}|$ from inclusive decays

Theoretical uncertainties [Bauer, Luke, Mannel; Leibovich, Ligeti, Wise; Neubert]

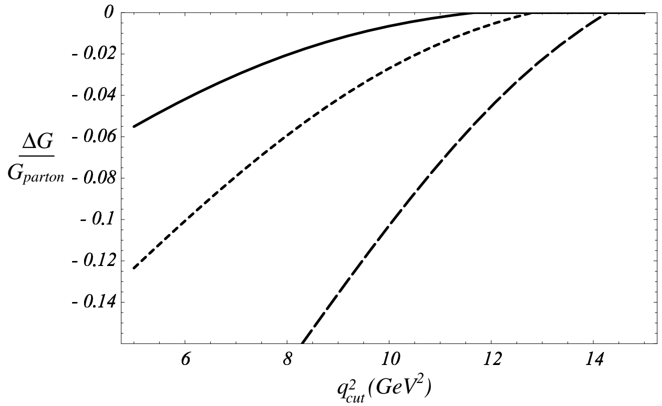
- Weak Annihilation (WA) contribution independent of $q^2_{\rm cut}$ and $m_{\rm cut}$; depends on the magnitude of Factorization violation

$$\frac{{\rm d}\Gamma_{WA}}{{\rm d}q^2} \sim (B_2 - B_1)\,\delta\,(q^2 - m_b^2)$$

$$\Gamma(q^2 < q^2_{\rm cut}, m_X < m_{\rm cut}) \equiv \frac{G_F^2 |V_{ub}|^2\,(4.7\,{\rm GeV})^5}{192\pi^3}\; G(q^2_{\rm cut}, m_{\rm cut})$$

- Effect of $O(\Lambda^3_{\rm QCD}/m_b^3)$ grows as q^2 is increased [Bauer, Luke, Mannel]

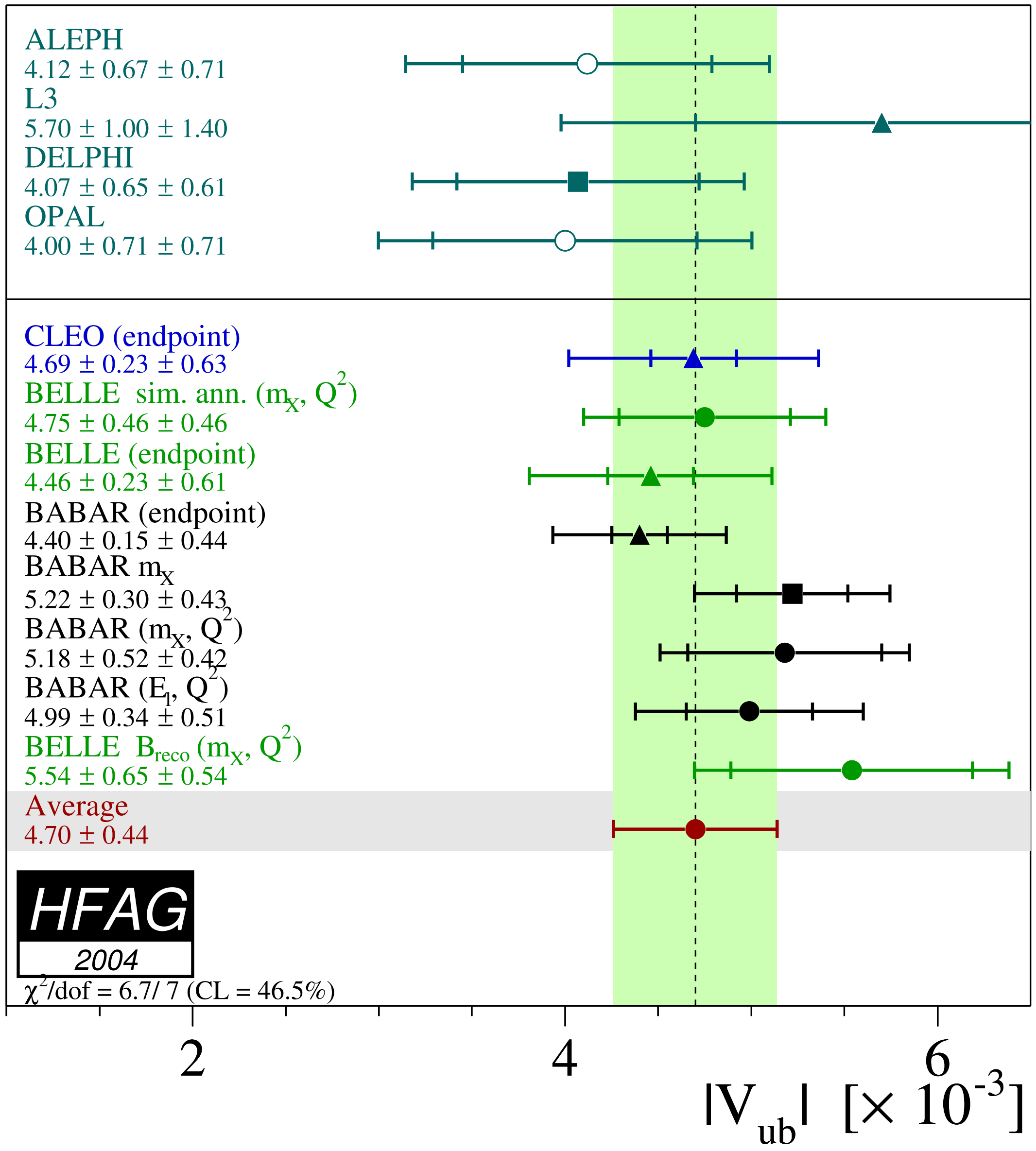
$\frac{\Delta G}{G}(q^2)_{\rm cut}$ for $m_{\rm cut} = 1.86$ GeV (top) to $m_{\rm cut} = 1.50$ GeV (bottom)



Experimental cuts

- $q^2 > (m_B - m_D)^2$: insensitive to $f(x)$; sensitive to m_b; WA corrections
- $m_X < m_D$: lots of rates; depends on $f(x)$
- $E_\ell > \frac{m_B^2 - m_D^2}{2m_B}$: simplest to measure; depends on shape functions

$|V_{ub}|$ from inclusive $B \to X_u \ell \nu_\ell$ decays



$|V_{ub}|$ from exclusive decays $B \to \pi \ell \nu_\ell$

$$\langle \pi(p_\pi)|\bar{b}\gamma_\mu q|B(p_B)\rangle = \left((p_B+p_\pi)_\mu - \frac{m_B^2-m_\pi^2}{q^2}q_\mu\right) F_+(q^2) \; + \; \frac{m_B^2-m_\pi^2}{q^2} F_0(q^2)\, q_\mu \, ,$$

Techniques used to determine $F_+(q^2)$, $F_0(q^2)$

- Light-cone QCD sum rules [Colangelo, Khodjamirian]
- Lattice-QCD (Quenched) [APE, UKQCD, FNAL, JLQCD]
- Lattice-QCD (Unquenched) [HPQCD, FNAL]
- Lattice-QCD and phenomenological models [Becirevic, Kaidalov]

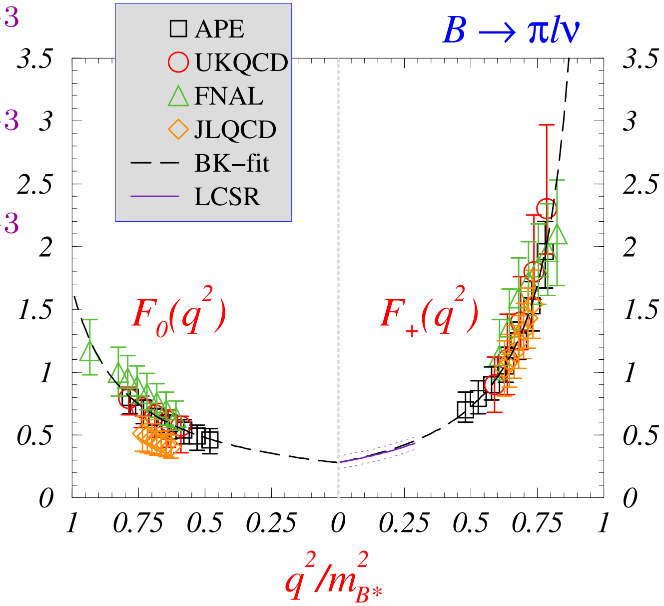
BELLE Analysis [Iijima, ICHEP'04]

[Becirevic]

$$|V_{ub}|_{\rm Quenched} = (3.90 \pm 0.71 \pm 0.23^{+0.62}_{-0.48}) \times 10^{-3}$$

$$|V_{ub}|_{\rm FNAL'04} = (3.87 \pm 0.70 \pm 0.22^{+0.85}_{-0.51}) \times 10^{-3}$$

$$|V_{ub}|_{\rm HPQCD} = (4.73 \pm 0.85 \pm 0.27^{+0.74}_{-0.50}) \times 10^{-3}$$



- Errors still large!
- $|V_{ub}|$ from BELLE's inclusive analysis

$$|V_{ub}|_{\rm BELLE} = (5.54 \pm 0.42 \pm 0.50 \pm 0.12 \pm 0.19 \pm 0.42 \pm 0.27) \times 10^{-3}$$

Status of the Third Row $V_{\rm CKM}$

$|V_{tb}|$

- From direct production and decays of the top quark (hep-ex/0505091)

$$R \equiv \frac{\mathcal{B}(t \to W + b)}{\mathcal{B}(t \to W + \sum_q q)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

$$R = 1.12^{+0.21}_{-0.19}\ (\mathrm{stat})^{+0.17}_{-0.13}(\mathrm{syst.})$$

- Assuming CKM unitarity & CDF Data $\Longrightarrow |V_{tb}| > 0.78$ (95% C.L.)

$|V_{td}|$

- From B_d^0 - $\overline{B_d^0}$ Mixing; $\Delta M_d = (0.505 \pm 0.005)$ ps^{-1} [HFAG 2005]
- SM (Box contribution with NLO QCD corrections) ($x_t = m_t^2/m_W^2$)

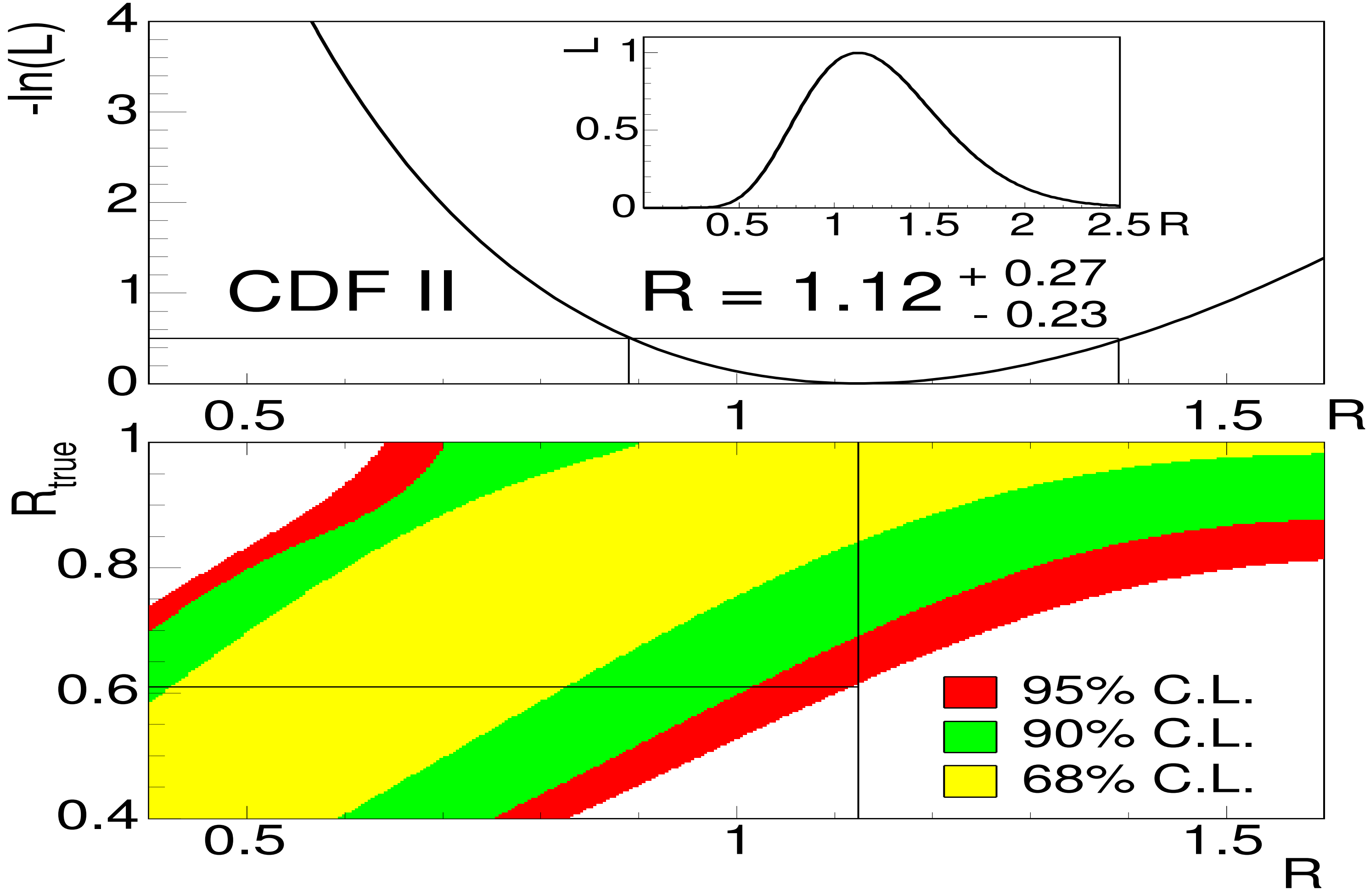
$$\Delta M_d = \frac{G_F^2}{6\pi^2}\hat{\eta}_B |V_{td}V_{tb}^*|^2 M_{B_d}(f_{B_d}^2 \hat{B}_{B_d}) M_W^2 S_0(x_t)$$

$$S_0(x) = x \cdot \left[\frac{1}{4} + \frac{9}{4}\frac{1}{(1-x)} - \frac{3}{2}\frac{1}{(1-x)^2} - \frac{3}{2}\frac{x^2 \ln x}{(1-x)^3}\right]$$

$$\langle \bar{B}_q^0 | (\bar{b}\gamma_\mu(1-\gamma_5)q)^2 | B_q^0 \rangle \equiv \frac{8}{3} f_{B_q}^2 B_{B_q} M_{B_q}^2$$

$-ln(L)$ vs. R from t-quark decays

[D. Acosta et al. (CDF Collaboration); hep-ex/0505091]



V_{td} and V_{ts} with Lattice-QCD

$|V_{td}|$

- Lattice-QCD [Updated H. Wittig, DPG, Berlin, '05]:
  $\sqrt{\hat{B}_{B_d}}F_{B_d} = 216 \pm 30^{+0}_{-21} \ \ \text{(chiral)}$ MeV

$$|V_{td}V_{tb}^*| = 8.5 \times 10^{-3}[\frac{210 \text{ MeV}}{\sqrt{\hat{B}_{B_d}}F_{B_d}}]\sqrt{\frac{2.40}{S_0(x_t)}}$$

  - Lattice-QCD & SM $\Longrightarrow$ $|V_{td}V_{tb}^*| = (8.5 \pm 1.0) \times 10^{-3}$

$|V_{ts}|$

- B_s^0 - $\overline{B_s^0}$ Mixing: $\Delta M_s > 14.5$ ps^{-1} (at 95% CL) [HFAG 2005]
- SM: $\Delta M_s = \frac{G_F^2}{6\pi^2}\hat{\eta}_B|V_{ts}V_{tb}^*|^2 M_{B_s}(f_{B_s}^2\hat{B}_{B_s})M_W^2 S_0(x_t)$
- Lattice-QCD: $\sqrt{\hat{B}_{B_s}}F_{B_s} = 249 \pm 34$ MeV
- The ratio $\Delta M_s/\Delta M_d$ has a smaller non-perturbative uncertainty

$$\frac{\Delta M_s}{\Delta M_d} = \xi\frac{M_{B_s}}{M_{B_d}}\frac{|V_{ts}|^2}{|V_{td}|^2}; \quad \xi = \sqrt{\frac{f_{B_s}^2\hat{B}_{B_s}}{f_{B_d}^2\hat{B}_{B_d}}}$$

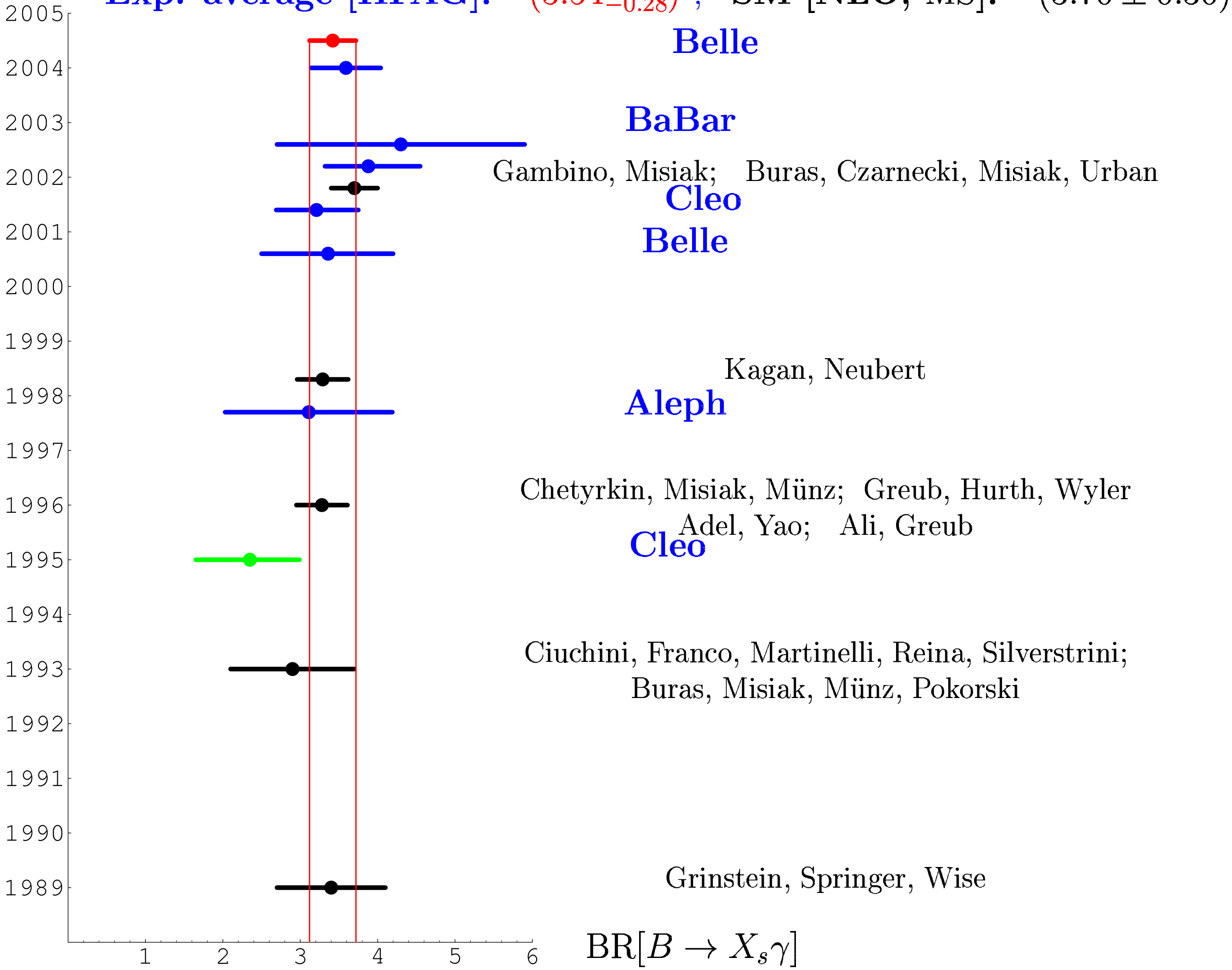
  - Lattice-QCD: $\xi = 1.15 \pm 0.05^{+0.12}_{-0.0}$ (Chiral extr.) $\Longrightarrow$ $|V_{ts}V_{tb}^*| > 0.033$

Evolution in time

$\mathrm{BR}[\bar{B} \to X_s \gamma]$ **(units: 10^{-4})**

Measurements & the SM calculations

Exp. average [HFAG]: $(3.54^{+0.30}_{-0.28})$; **SM [NLO; $\overline{\mathrm{MS}}$]:** (3.70 ± 0.30)



Determination of V_{ts} from BR $(\bar{B} \to X_s\gamma)$

- Unitarity of the CKM Matrix

$$\sum_{u,c,t} \lambda_i = 0, \quad \text{with} \quad \lambda_i = V_{ib}V_{is}^*$$

- $\lambda_u = V_{ub}V_{us}^* \simeq A\lambda^4(\bar{\rho} - i\bar{\eta}) \simeq O(10^{-2})$
- $\lambda_t = -\lambda_c = -A\lambda^2 + ... = -(41.0 \pm 2.1) \times 10^{-3}$
- Without invoking the CKM unitarity, NLO SM-calculations in the $\overline{\text{MS}}$ scheme and current data $\mathcal{B}(B \to X_s\gamma) = (3.39^{+0.30}_{-0.27}) \times 10^{-4}$ imply the constraint [Misiak, AA]

$$|1.69\lambda_u + 1.60\lambda_c + 0.60\lambda_t| = (0.92 \pm 0.07)|V_{cb}|$$

$$\Longrightarrow \lambda_t = V_{tb}V_{ts}^* = -(46.0 \pm 8.0) \times 10^{-3}$$

- In future, NNLO calculations will lead to a determination of BR$(\bar{B} \to X_s\gamma)$ to an accuracy of 5%
- With improved data, this will determine V_{ts} to an accuracy of about 10%

D. Mohapatra (BELLE)[EPS 2005]

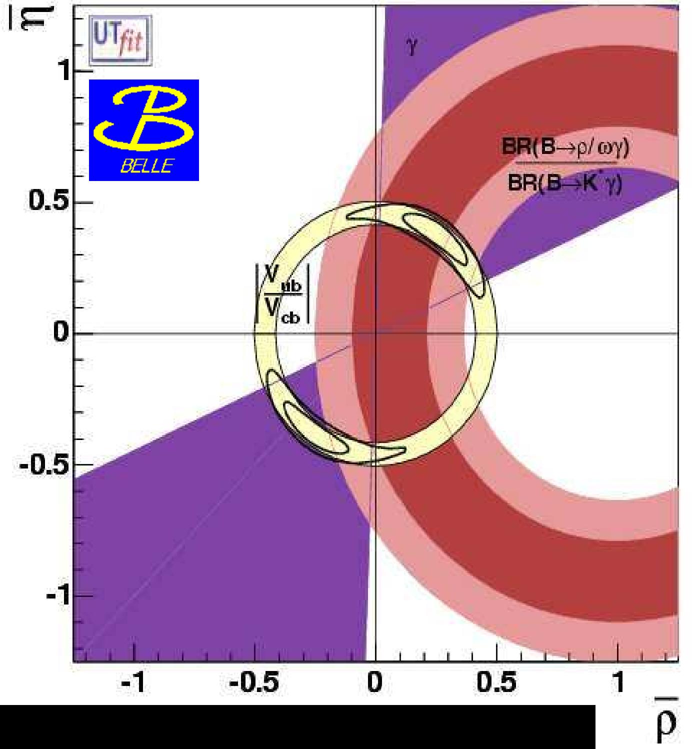
Extraction of $|V_{td}/V_{ts}|$

$$\frac{B(\overline{B}\to(\rho,\omega)\gamma)}{B(B\to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1-M_\rho^2/M_B^2}{1-M_{K^*}^2/M_B^2}\right)\zeta^2[1+\Delta R]$$

Form factor ratio $\zeta = 0.85 \pm 0.10$

SU(3)-breaking effect $\Delta R = 0.1 \pm 0.1$

$$\frac{B(B\to(\rho,\omega)\gamma)}{B(B\to K^*\gamma)} = 0.032 \pm 0.008^{+0.003}_{-0.002}$$



$$0.143 < \left|\frac{V_{td}}{V_{ts}}\right| < 0.260$$

(95 % C.L. interval)

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.200^{+0.026}_{-0.025}(\text{expt.})^{+0.038}_{-0.029}(\text{theo.})$$

17

Introduction to CP Violation in B Decays & Mixings -1

- CKM Violation in the SM is due to the phase η in the CKM matrix
- All CP violations in the SM are due to the interference of two *different* amplitudes

Three Classes of CP Violation in B Decays

1. Direct CP Violation: e.g., in $B^\pm \to K_s \pi^\pm$ decays

$$\mathcal{A}_{\rm CP} = \frac{2|A_1||A_2| \sin(\delta_1 - \delta_2) \sin(\phi_1 - \phi_2)}{|A_1|^2 + 2|A_1||A_2| \cos(\delta_1 - \delta_2) \cos(\phi_1 - \phi_2) + |A_2|^2}$$

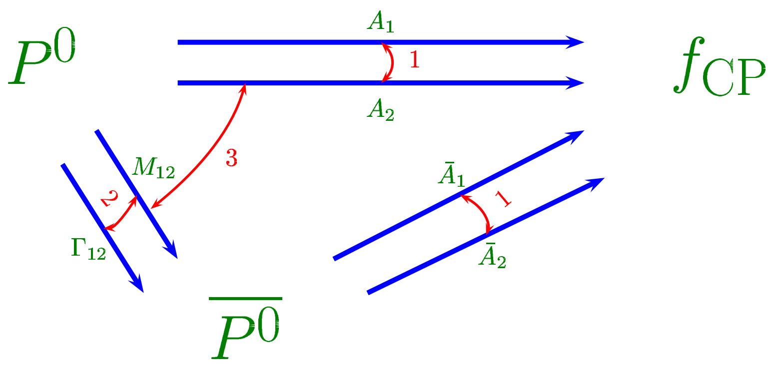
   - Requires Strong phase difference $(\delta_1 - \delta_2) \neq 0$ & Weak phase difference $(\phi_1 - \phi_2) \neq 0$; Difficult to calculate

2. Indirect CP Violation:

$$\mathcal{A}_{\rm SL} = \frac{\Gamma(\overline{B^0} \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\overline{B^0} \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)}$$

   - Involves the relative phase in the absorptive & dispersive parts of the B^0 - $\overline{B^0}$ Mixing Amplitude: $\mathcal{A}_{\rm SL} = {\rm Im}(\frac{\Gamma_{12}}{M_{12}})$
   - Writing $(\frac{\Gamma_{12}}{M_{12}})_q = r_q e^{i\zeta_q}$: $\mathcal{A}_{\rm SL}(B_d) = r_d \sin\zeta_d$
   - SM (NLO): $\mathcal{A}_{\rm SL}(B_d) = -(5.5 \pm 1.3)(10^{-4})$ [Beneke et al.; Ciuchini et al.]
   - Present Experimental Constraint: $\mathcal{A}_{\rm SL}(B_d) = (-0.05 \pm 0.71) \times 10^{-2}$

CP violation in neutral meson decay into a CP eigenstate



1. In decay: $\bar{A}/A \neq 1$ $\left(\frac{\bar{A}}{A} = \frac{\bar{A}_1+\bar{A}_2}{A_1+A_2}\right)$
   (For example, A_1 is a Tree amplitude & A_2 is Penguin)
2. In mixing: $|q/p| \neq 1$ $\left(\frac{q}{p} = \frac{2M_{12}^* - i\Gamma_{12}^*}{\Delta m - (i/2)\Delta\Gamma}\right)$
3. In interference: $\mathcal{I}m\lambda \neq 1$ $\left(\lambda = \frac{q}{p}\frac{\bar{A}}{A}\right)$

- The case theorists love!
  - Decay dominated by a single CPV phase: $|\frac{\bar{A}}{A}| = 1$;
  - CPV in mixing negligible $|\frac{q}{p}| = 1$;
  - The remaining eefect is: $S_f \sim \sin[\arg(M_{12}) - 2\arg(A)] = 1$

Interplay of Mixing & Decays of B^0 and $\overline{B^0}$ to CP Eigenstate

- Involving tree-dominated B-decays ($b \to c\bar{c}s$), such as $B^0/\overline{B^0} \to J/\psi K_s;\ J/\psi K_L$

$$\mathcal{A}_f(t) = \frac{\Gamma(\overline{B^0}(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B^0}(t) \to f) + \Gamma(B^0(t) \to f)}$$

$$= C_f \cos(\Delta M_B t) + S_f \sin(\Delta M_B t)$$

$$C_f = \frac{(|\lambda_f|^2) - 1}{(|\lambda_f|^2 + 1)}; \qquad S_f = \frac{2\ \mathrm{Im}\lambda_f}{(|\lambda_f|^2 + 1)}$$

- Definitions:

$$\lambda_f \equiv (q/p)\ \rho(f); \qquad \rho(f) = \frac{\bar{A}(f)}{A(f)}$$

$$A(f) = \langle f|H|B^0\rangle; \quad \bar{A}(f) = \langle f|H|\overline{B^0}\rangle$$

$$q/p = \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} = \mathrm{e}^{-2i\phi_{\mathrm{mixing}}} = \mathrm{e}^{-2i\beta}$$

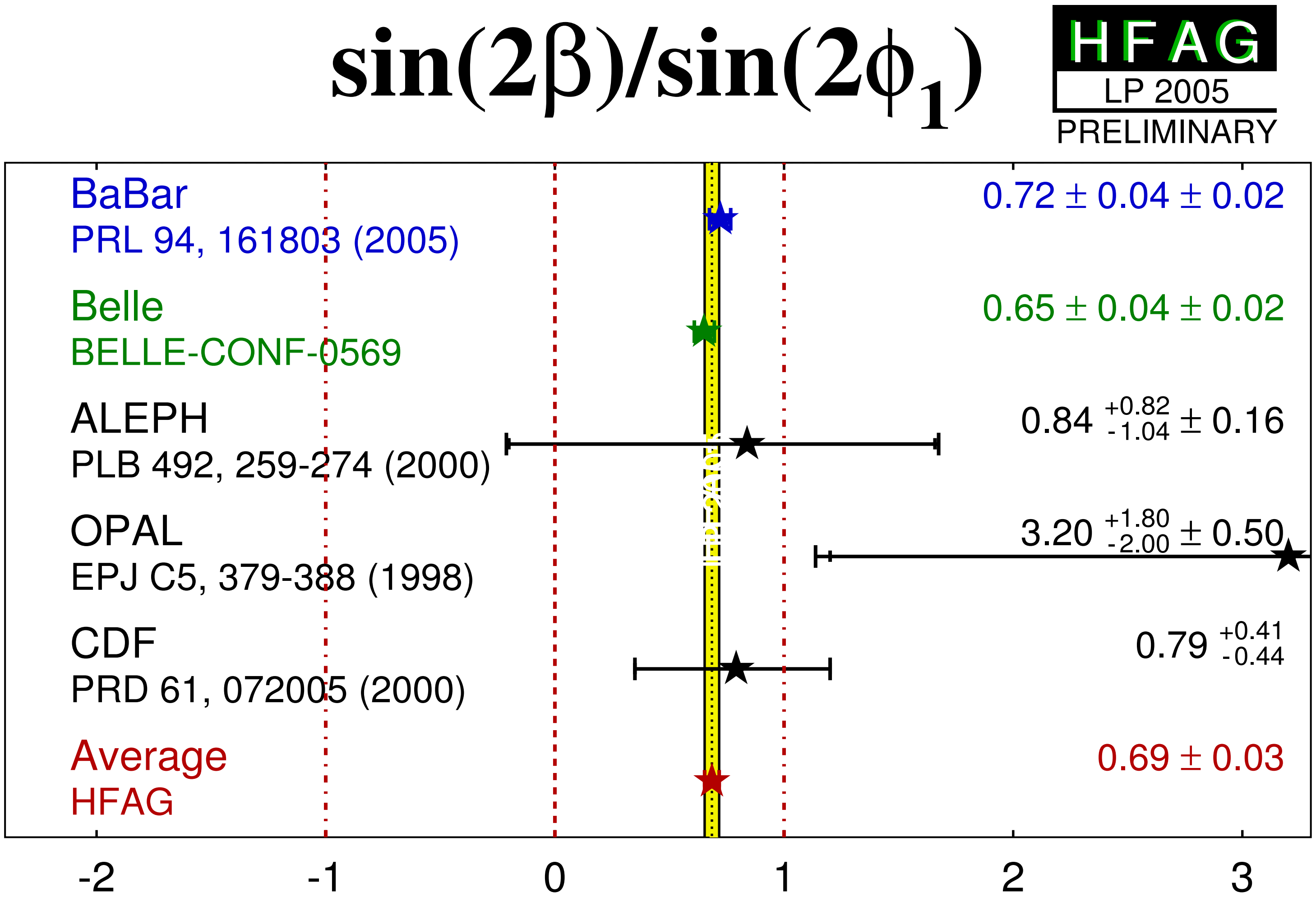
- If only a Single Amplitude dominant, then one can write:

$$\rho(f) = \eta_f \mathrm{e}^{-2i\phi_{\mathrm{decay}}}$$

where $\eta_f = \pm 1$ is the intrinsic CP-Parity of the state $f \Rightarrow |\rho(f)| = 1$

$$\mathcal{A}_f(t) = S_f \sin(\Delta M_B t);\ S_f = -\eta_f \sin 2(\phi_{\mathrm{mixing}} + \phi_{\mathrm{decay}});\ C_f = 0$$

Current World Average [EPS 2005]



Current World Average [EPS 2005]

Determination of β/φ1

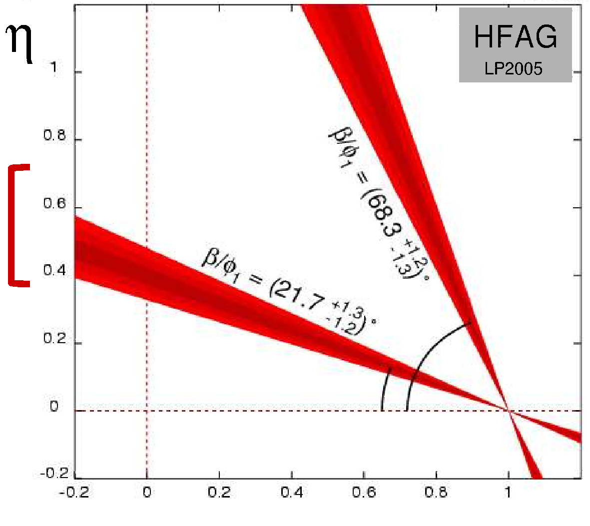
Experiment	BaBar (227 x 10⁶ BB)	Belle (386 x 10⁶ BB)
sin2β from (cc) K_S	$0.75 \pm 0.04_{stat}$	$0.668 \pm 0.047_{stat}$
(cc) K_L	$0.57 \pm 0.09_{stat}$	$0.619 \pm 0.069_{stat}$
All charmonium	$0.722 \pm 0.040_{stat} \pm 0.023_{syst}$	$0.652 \pm 0.039_{stat} \pm 0.020_{syst}$

HFAG Average : 0.685 ± 0.032 ~5% precision

Constraint from sides only: 0.720±0.024 (CKMFitter) → **Coherent description of CPV within the SM**
SM is the dominant source of CPV

Preferred solution:

Use of the $B^0 \to J/\psi K^*(\to K_s\pi^0)$ (VV decay) information on cos(2β) (after strong phase ambiguity resolution) BABAR PRD 71, 032005 (2005): cos (2β)>0 at 86%CL



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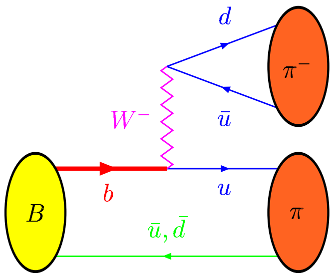
$B \to \pi\pi$ *Topologies*

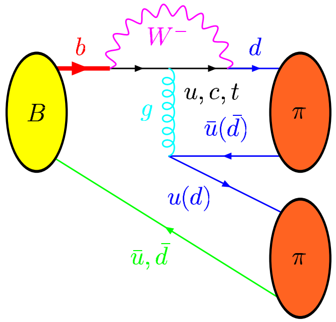
Dominant topologies contributed within the Standard Model

Tree ($\mathcal{T}$)



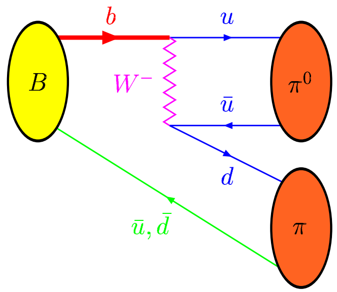
$B^- \to \pi^- \pi^0$
$\bar{B}^0 \to \pi^+ \pi^-$

Penguin ($\mathcal{P}$)



$\bar{B}^0 \to \pi^+ \pi^-$
$\bar{B}^0 \to \pi^0 \pi^0$

Color-suppressed ($\mathcal{C}$)



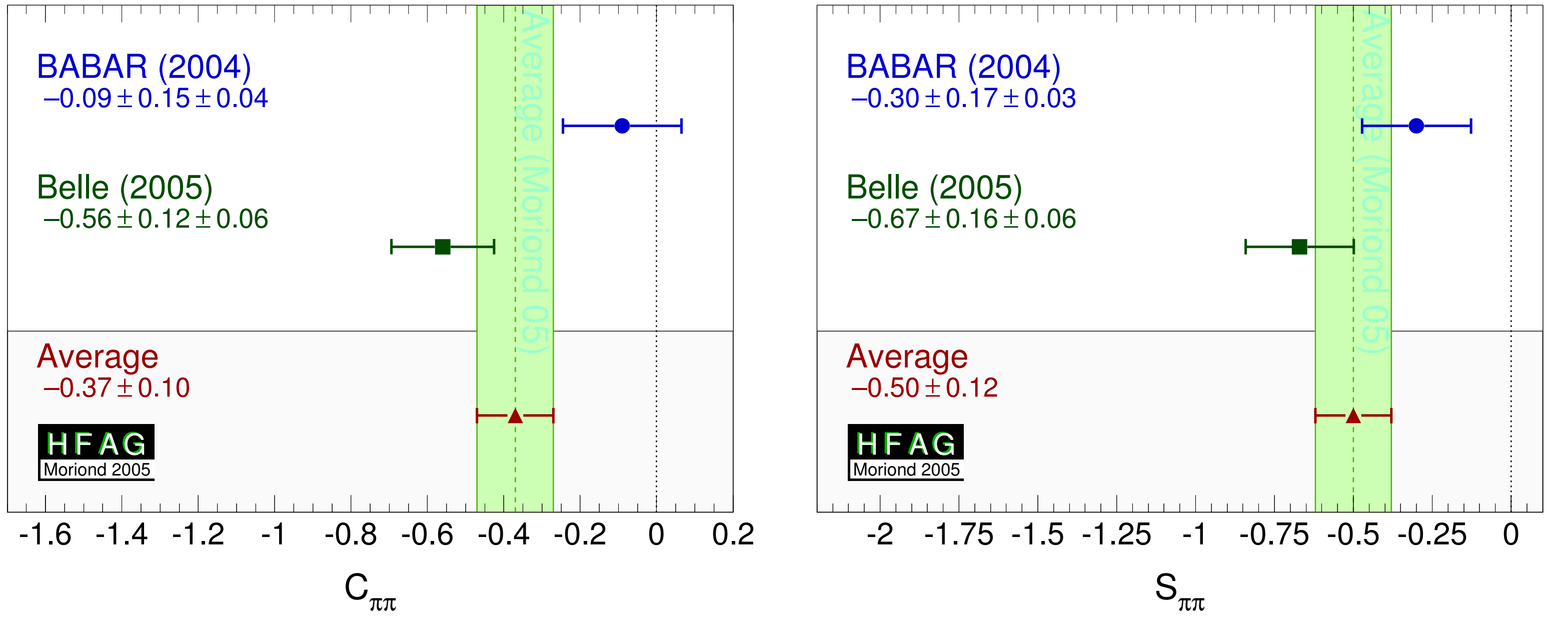
$B^- \to \pi^- \pi^0$
$\bar{B}^0 \to \pi^0 \pi^0$

Subdominant topologies:

- exchange ($\mathcal{E}$) $\Longrightarrow$ $\bar{B}^0 \to \pi^+ \pi^-,\ \pi^0 \pi^0$
- annihilation ($\mathcal{A}$) $\Longrightarrow$ $B^- \to \pi^- \pi^0$
- penguin-annihilation ($\mathcal{PA}$) $\Longrightarrow$ $\bar{B}^0 \to \pi^+ \pi^-,\ \pi^0 \pi^0$
- electroweak-penguin ($\mathcal{P}_{\rm EW}$) $\Longrightarrow$ $B^- \to \pi^- \pi^0,\ \bar{B}^0 \to \pi^0 \pi^0$
- color-suppressed electroweak-penguin ($\mathcal{P}_{\rm EW}^C$) $\Longrightarrow$ $\bar{B}^0 \to \pi^+ \pi^-,\ \pi^0 \pi^0$

Time-dependent CP-asymmetry in $B^0/\overline{B^0} \to \pi^+\pi^-$

$$a_{\pi\pi}^{+-}(t) \equiv \frac{\Gamma[\bar{B}^0(t) \to \pi^+\pi^-] - \Gamma[B^0(t) \to \pi^+\pi^-]}{\Gamma[\bar{B}^0(t) \to \pi^+\pi^-] + \Gamma[B^0(t) \to \pi^+\pi^-]}$$
$$= S_{\pi\pi}^{+-}(t)\sin(\Delta M_B t) - C_{\pi\pi}^{+-}(t)\cos(\Delta M_B t)$$



- BELLE and BABAR are in better agreement now (2.3σ)

$C_{\pi\pi} - S_{\pi\pi}$ Data vs. QCDF & PQCD

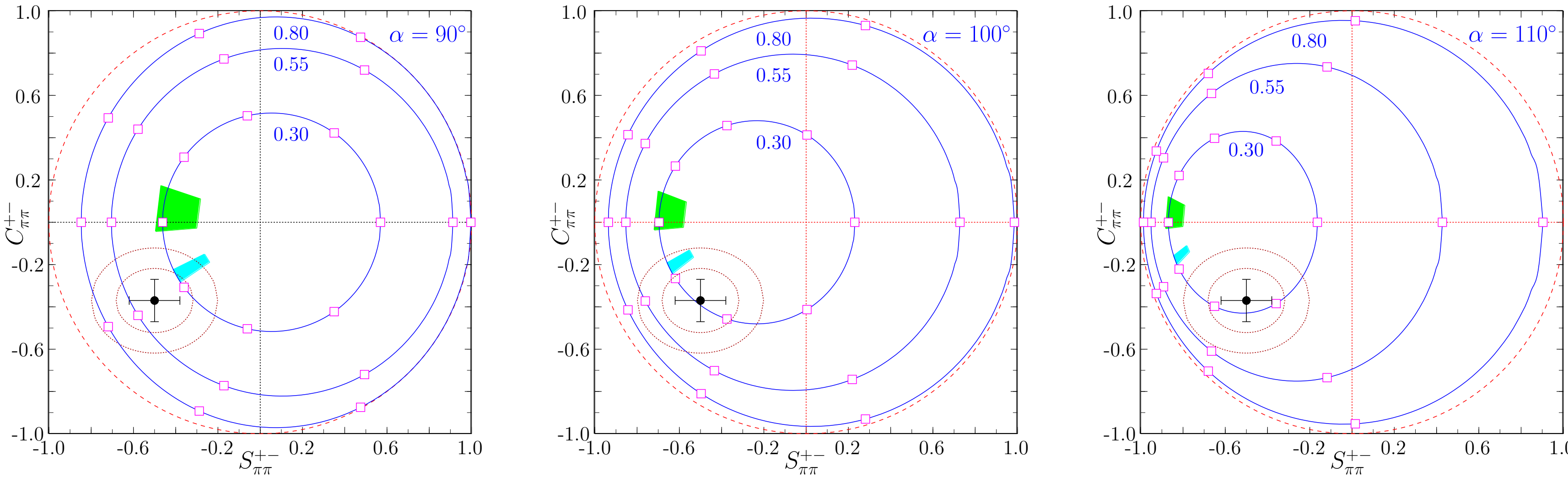
- Isospin-based analysis of data (68% C.L.)

[Lunghi, Parkhomenko, AA; Parkhomenko '05]

$$|P/T| = 0.48^{+0.09}_{-0.08} \qquad \delta = (-38^{+9.3}_{-9.0})^\circ$$

- Similar analyses by Buras et al.; Bauer et al.; Gronau et al.; ...
- Theoretical predictions based on Factorization

$$|P/T| = 0.29 \pm 0.09 \qquad \delta = (9 \pm 15)^\circ \qquad \text{QCDF}$$
$$|P/T| = 0.23^{+0.07}_{-0.05} \qquad \delta = (-37 \pm 5)^\circ \qquad \text{PQCD}$$



- Data supports large penguin contribution and strong phase difference

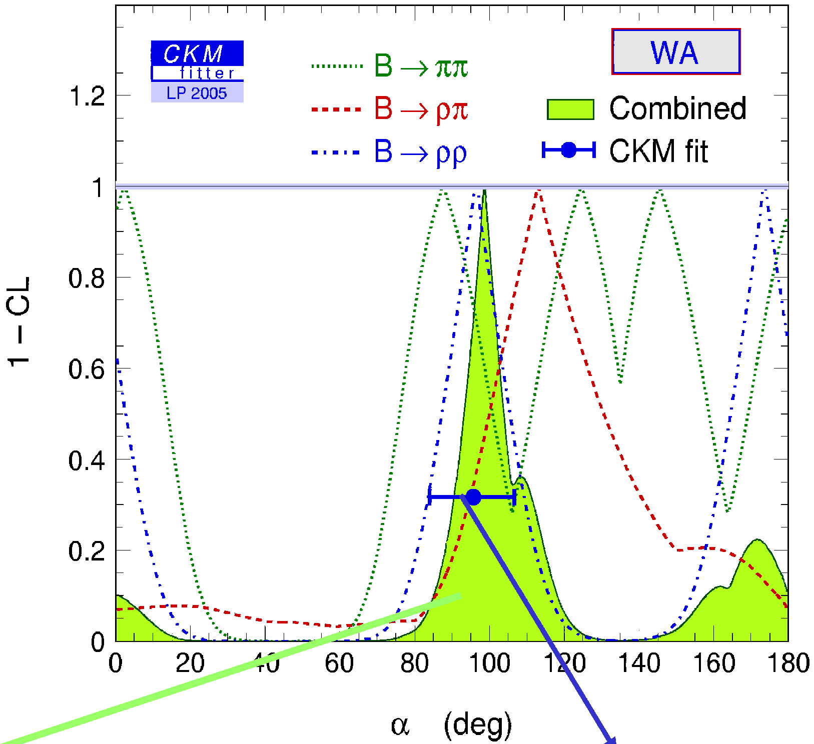
Overall constraint on α

Additional constraints on α from time dependent CP violation analysis of B→ρπ

ππ determination very weak

ρρ best individual measurement

Mirror solution are disfavored by ρπ



$\alpha = (99^{+12}_{-9})°$

Same precision as global CKM fit :

$\alpha_{CKM} = (94.9^{+9.6}_{-13.3})°$

39

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Current World Average of γ [EPS 2005]

Overall information on r_B and ϕ_3/γ from GLW, ADS, Dalitz

r_{DK} = 0.081 ± 0.029 [0.021,0.138] @95% CL

r_{D^*K} = 0.088 ± 0.042 [0.010,0.170] @95% CL

r_{DK^*} = 0.15 ± 0.09 [0.01,0.31] @95% CL

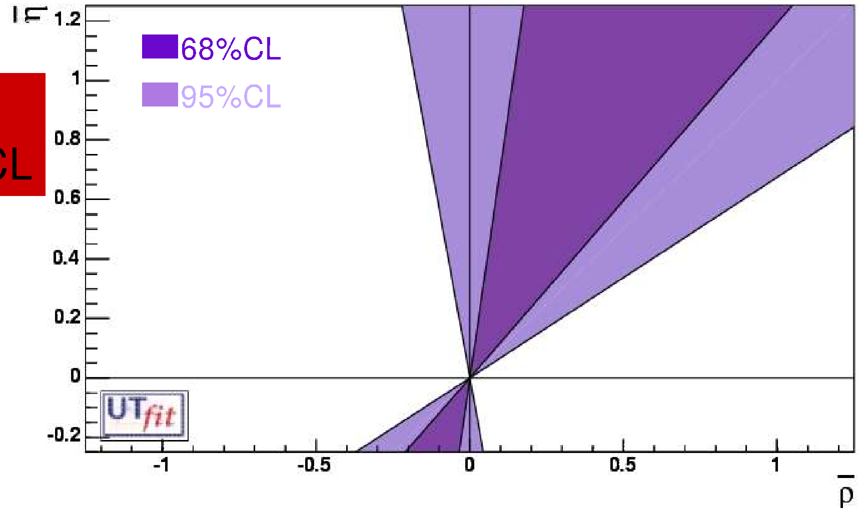
UTFit

⇒ r_B is small

⇒ γ is not easy to measure….

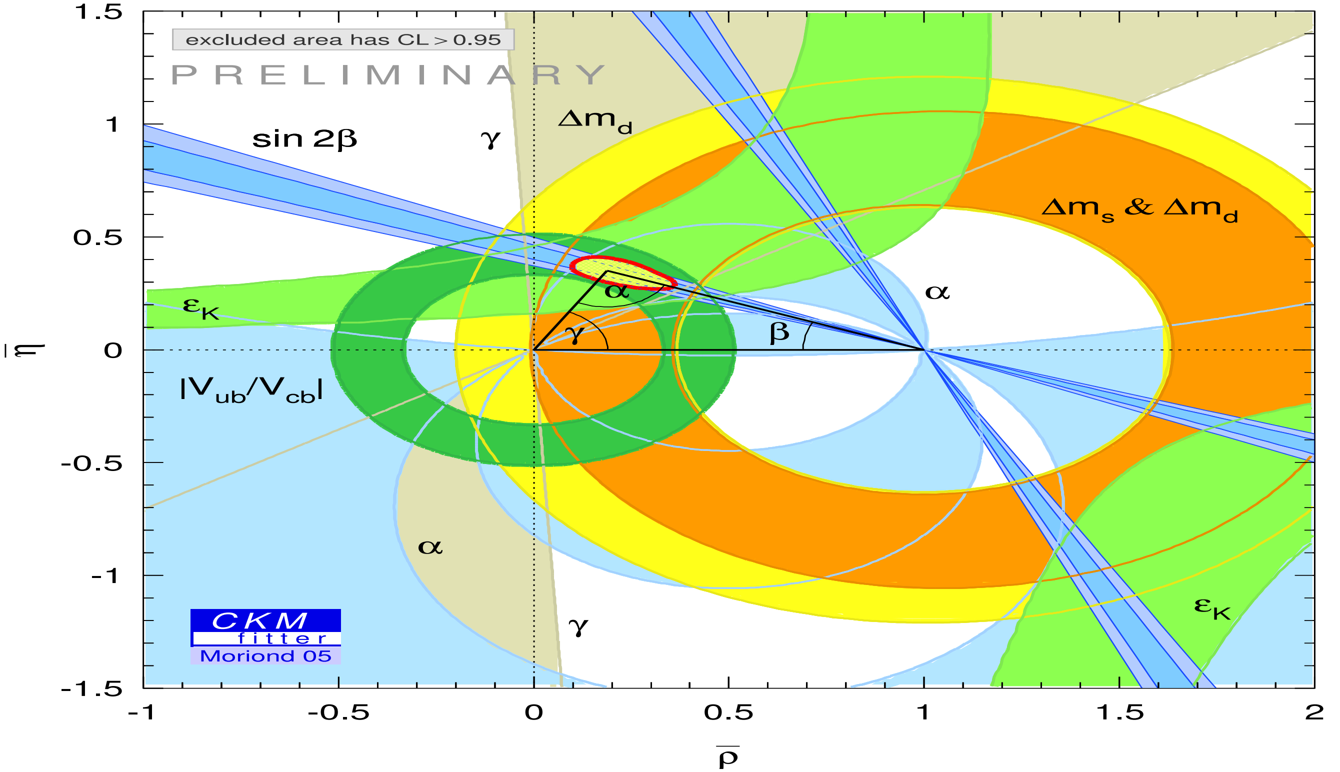
$\gamma = 66 \pm 17$ [32,102] at 95% CL

$\gamma = -114 \pm 17$ [-148,-78] at 95% CL



HEP-EPS 2(

SM confronts measurements of $\sin 2\beta, \quad \alpha, \quad \gamma$



- $\sin 2\beta = 0.685 \pm 0.032 (\beta = [21.7 \pm 1.3]^\circ)$
- $\alpha = [99^{+12}_{-9}]^\circ$
- $\gamma = [66 \pm 17]^\circ$
- Direct and indirect measurements of angles agree very well
- Unconstrained sum of angles $= (187 \pm 21)^\circ$, consistent with unitarity sum within errors

Flavour Mixing in the MSSM

- Flavour mixings in the MSSM reside in the Superpotential $W_{\rm MSSM}$ and in the soft supersymmetry-breaking Lagrangian $\mathcal{L}_{\rm soft}$
- Assume R-parity: $R = (-1)^{3(B-L)+2S}$; where $B(L)$ is Baryon (Lepton) quantum number and S is the spin: SM particles are R-even, supersymmetric particles are R-odd
- $W_{\rm MSSM}$

$$W_{\rm MSSM} = \epsilon_{\alpha\beta}[-\hat{H}_u^\alpha \hat{Q}_i^\beta Y_u^{ij} \hat{U}_j^c + \hat{H}_d^\alpha \hat{Q}_i^\beta Y_d^{ij} \hat{D}_j^c + \hat{H}_d^\alpha \hat{L}_i^\beta Y_e^{ij} \hat{E}_j^c - \mu \hat{H}_d^\alpha \hat{H}_u^\beta]$$

$$\epsilon_{\alpha\beta} = -\epsilon_{\beta\alpha}; \quad \epsilon_{12} = 1$$

- $\mathcal{L}_{\rm soft}$

$$\mathcal{L}_{\rm soft} = \frac{1}{2}[M_3 \tilde{g}\tilde{g} + M_2 \tilde{W}^\alpha \tilde{W}^\alpha + M_1 \tilde{B}\tilde{B} + h.c.]$$

$$+\epsilon_{\alpha\beta}[-b H_d^\alpha H_u^\beta - H_u^\alpha \tilde{Q}_i^\beta \tilde{A}_{u_{ij}} \tilde{U}_j^c + H_d^\alpha \tilde{Q}_i^\beta \tilde{A}_{d_{ij}} \tilde{D}_j^c + H_d^\alpha \tilde{L}_i^\beta \tilde{A}_{e_{ij}} \tilde{E}_j^c + h.c.]$$

$$+m_{H_d}^2 |H_d|^2 + m_{H_u}^2 |H_u|^2 + \tilde{Q}_i^\alpha m_{Q_{ij}}^2 \tilde{Q}_j^{\alpha *}$$

$$+\tilde{L}_i^\alpha m_{L_{ij}}^2 \tilde{L}_j^{\alpha *} + \tilde{U}_i^{c*} m_{U_{ij}}^2 \tilde{U}_j^c + \tilde{D}_i^{c*} m_{D_{ij}}^2 \tilde{D}_j^c + \tilde{E}_i^{c*} m_{E_{ij}}^2 \tilde{E}_j^c$$

- MSSM contains 124 parameters residing in the Superpotential $W_{\rm MSSM}$ (Yukawa couplings) and Soft-SUSY-breaking $\mathcal{L}_{\rm soft}$ (Scalar) terms
- Various realizations of the MSSM differ from each other in the details of $\mathcal{L}_{\rm soft}$

SUGRA and mSUGRA models

- CKM matrix is the only source of Flavour transitions
- In SUGRA models, this is achieved by assuming that the SUSY-breaking parameters have a simple structure at the GUT scale (m_X)

$$(m_Q^2)^i_j = (m_E^2)^i_j = (m_D^2)^i_j = (m_U^2)^i_j = (m_L^2)^i_j = M_0^2 \delta^i_j$$

$$m^2_{H_d} = m^2_{H_u} = \Delta_0^2$$

$$M_1 = M_2 = M_3 = M_{1/2}$$

$$A_{d_{ij}} = A_0 (Y_d)_{ij}; \quad Au_{ij} = A_0 (Y_u)_{ij}; \quad Ae_{ij} = A_0 (Y_e)_{ij}$$

- In MSUGRA model, in addition $\Delta_0^2 = M_0^2$
- RG running ($m_X \to m_W$) induces flavour non-diagonal terms, but they are small
- This reduces the number of parameters enormously, leaving the parameters: M_0, $M_{1/2}$, $|A_0|$, $\tan\beta$, ϕ_μ, ϕ_A, where the phases are constrained by the EDMs
- Minimal flavour violation (MFV) models are highly predictive, and hence highly constrained

General Flavour Violating SUSY & The MIA Technique

- In a general SUSY Model, many more sources of Flavour Violation
- A technique to carry out an analysis in a general SUSY framework is the Mass Insertion Approximation (MIA) [Hall, Kostelecky, Raby 1986]
- In the MIA approach, one choses a basis in which the couplings of $\tilde{f}_i \tilde{g} f_j$ are flavour-diagonal ($\propto \delta_{ij}$); FC take place on the sfermion propagators by mass insertions: Δ^u_{ij}, Δ^d_{ij} etc.

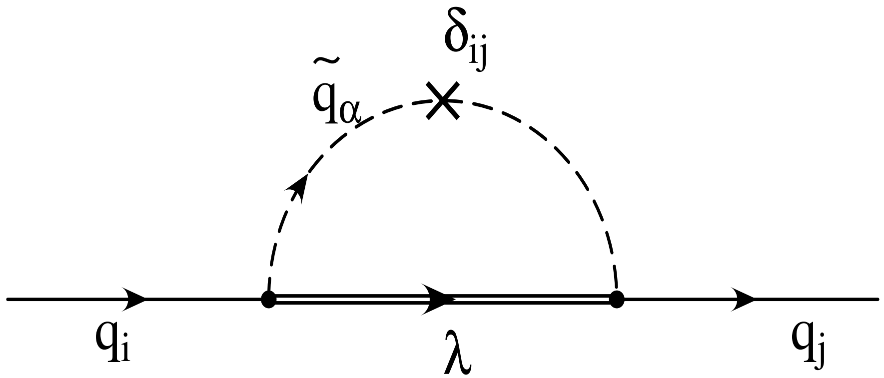
$$(m_0^2)_i \delta_{ij} + \Delta_{ij}$$

- Need not know the full diagonalization of the sfermion ($\tilde{f}$) mass matrices; sufficient to compute the ratios ($\langle m_0^2 \rangle$ is an average sfermion mass squared):

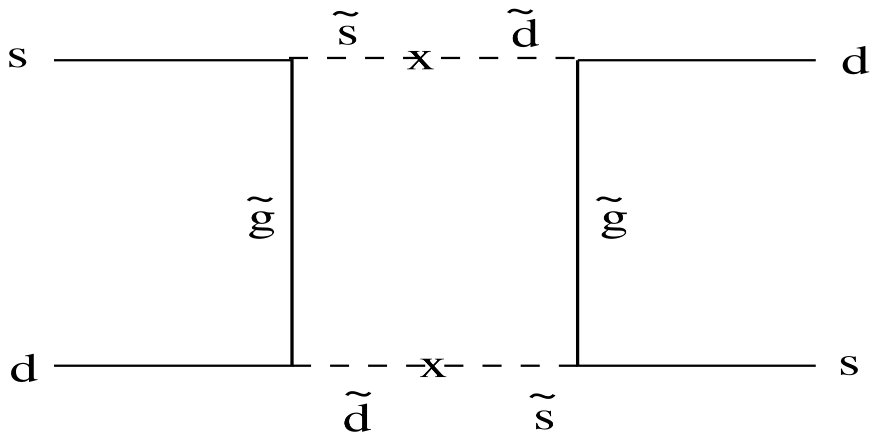
$$\delta_{ij} = \frac{\Delta_{ij}}{\langle m_0^2 \rangle}$$

- All FC effects can be parametrized in terms of a limited number of complex MIA parameters: $(\delta^u_{ij})_{AB}$ & $(\delta^u_{ij})_{AB}$, $(A, B = L, R)$
- Typically, one expects $(\delta^f_{ij})_{AB} \leq 1$
- Analysis for FV processes can then be carried out in terms of the SUSY-MFV contributions and the MIA parameters [Masiero et al.,...]

Typical Mass Insertion Diagrams



A SUSY contribution for K^0 - $\overline{K^0}$ Mixing

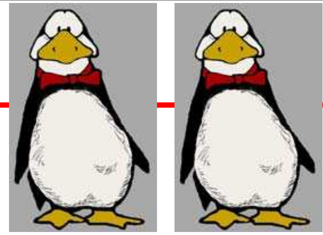


- For B_d^0 - $\overline{B_d^0}$ Mixings: $s \longrightarrow b$; $\tilde{s} \longrightarrow \tilde{b}$
- For B_s^0 - $\overline{B_s^0}$ Mixings: $d \longrightarrow b$; $\tilde{d} \longrightarrow \tilde{b}$

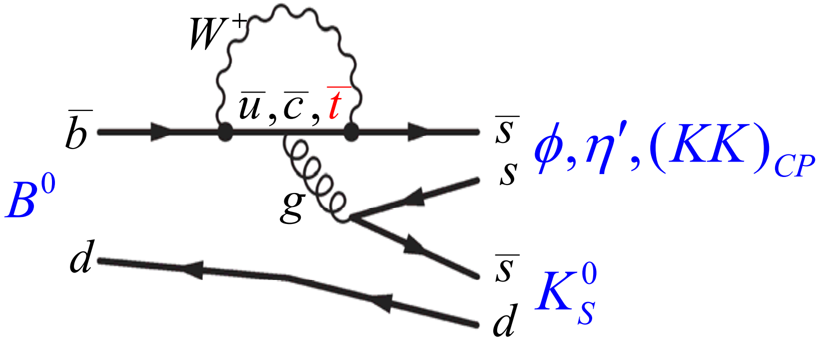
A list of flavour-violating observables

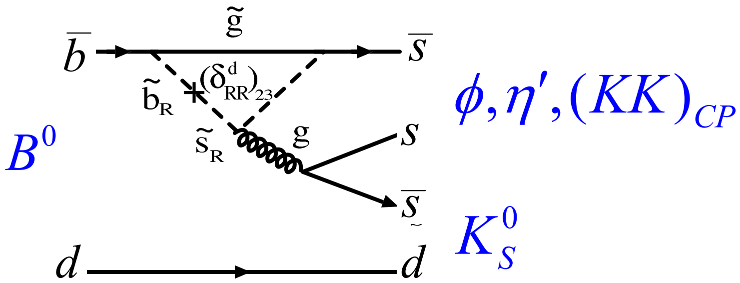
Observable	SM Prediction	MSSM-MIA (AB=LL, LR, RL, RR)
Δm_K	$\sim (V_{cs}^* V_{cd})^2$	$(\delta_{AB})_{12}$
ϵ	$\sim \text{Im}(V_{ts}^* V_{td}) \text{Re}(V_{cs}^* V_{cd})$	$(\delta_{AB})_{12}$
$\epsilon^{'}/\epsilon$	$\sim \text{Im}(V_{ts}^* V_{td})$	$(\delta_{AB})_{12}$
$b \to s\gamma$	$\sim V_{tb} V_{ts}^*$	$(\delta_{AB})_{23}$
$A_{CP}(b \to \ s\gamma)$	$\sim \alpha_s(m_b) \frac{V_{ub}}{V_{cb}} \frac{m_c^2}{m_b^2}$	$(\delta_{AB})_{23}$
Δm_{B_d}	$\sim (V_{td}^* V_{tb})^2$	$(\delta_{AB})_{13}$
Δm_{B_s}	$\sim (V_{ts}^* V_{tb})^2$	$(\delta_{AB})_{23}$
$A_{CP}(B \to \ \psi K_S)$	$= \sin 2\beta$	$(\delta_{AB})_{13}$
$A_{CP}(B \to \ \phi K_S)$	$= \sin 2\beta$	$(\delta_{AB})_{23}$

Feynman Diagrams for $\sin 2\beta$ from Penguins

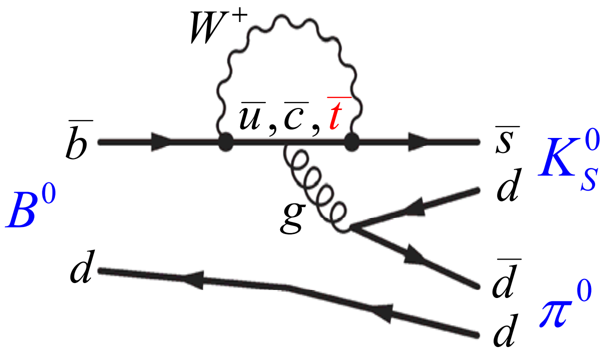
$\sin 2\beta$ and...  and.... 

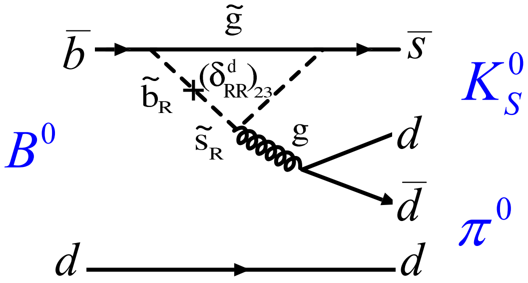
In SM interference between B mixing, K mixing and Penguin $b \to s\bar{s}s$ or $b \to s\bar{d}d$ gives the same $e^{-2i\beta}$ as in tree process $b \to c\bar{c}s$. However loops can also be sensitive to New Physics!





New phases from SUSY?





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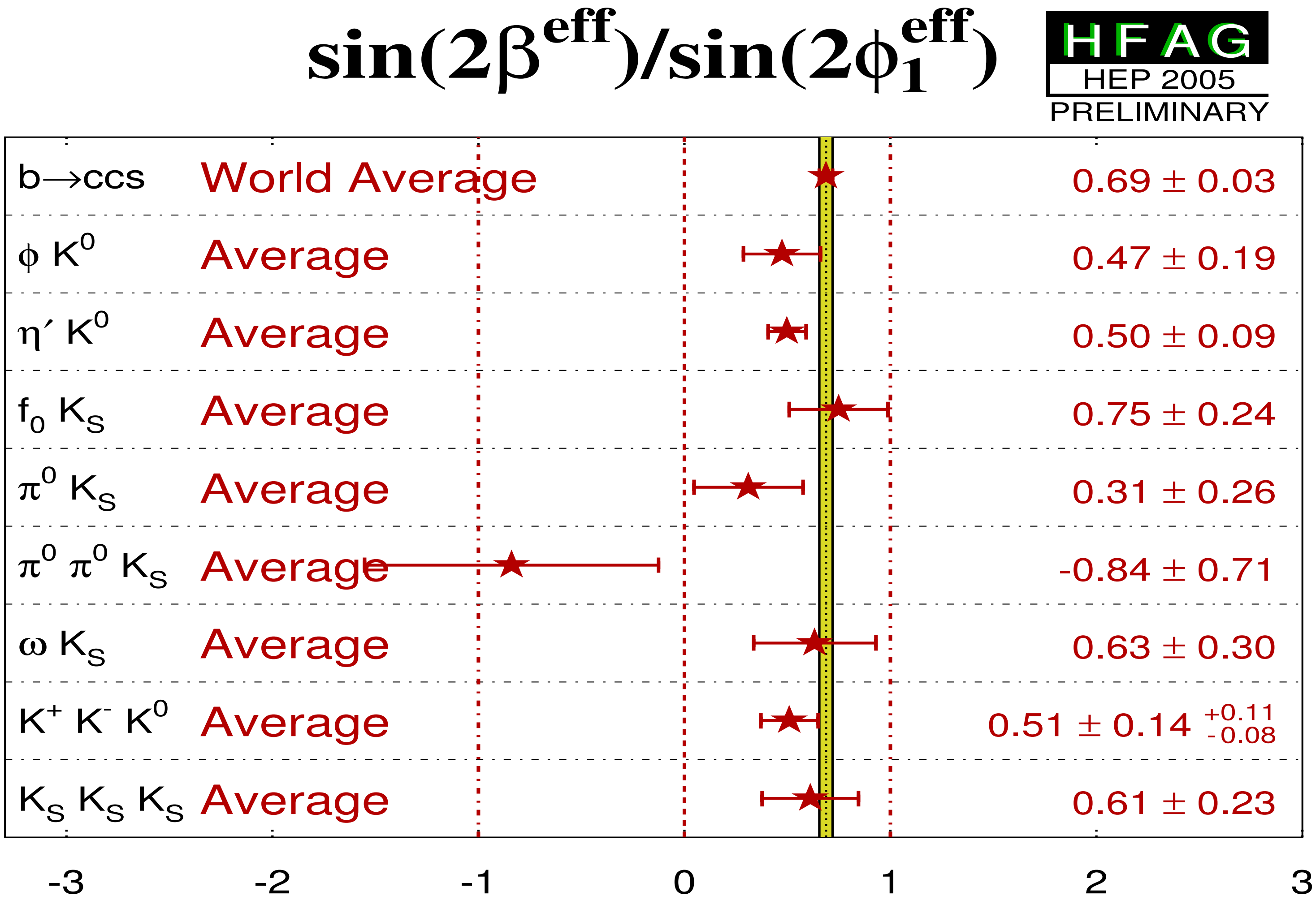
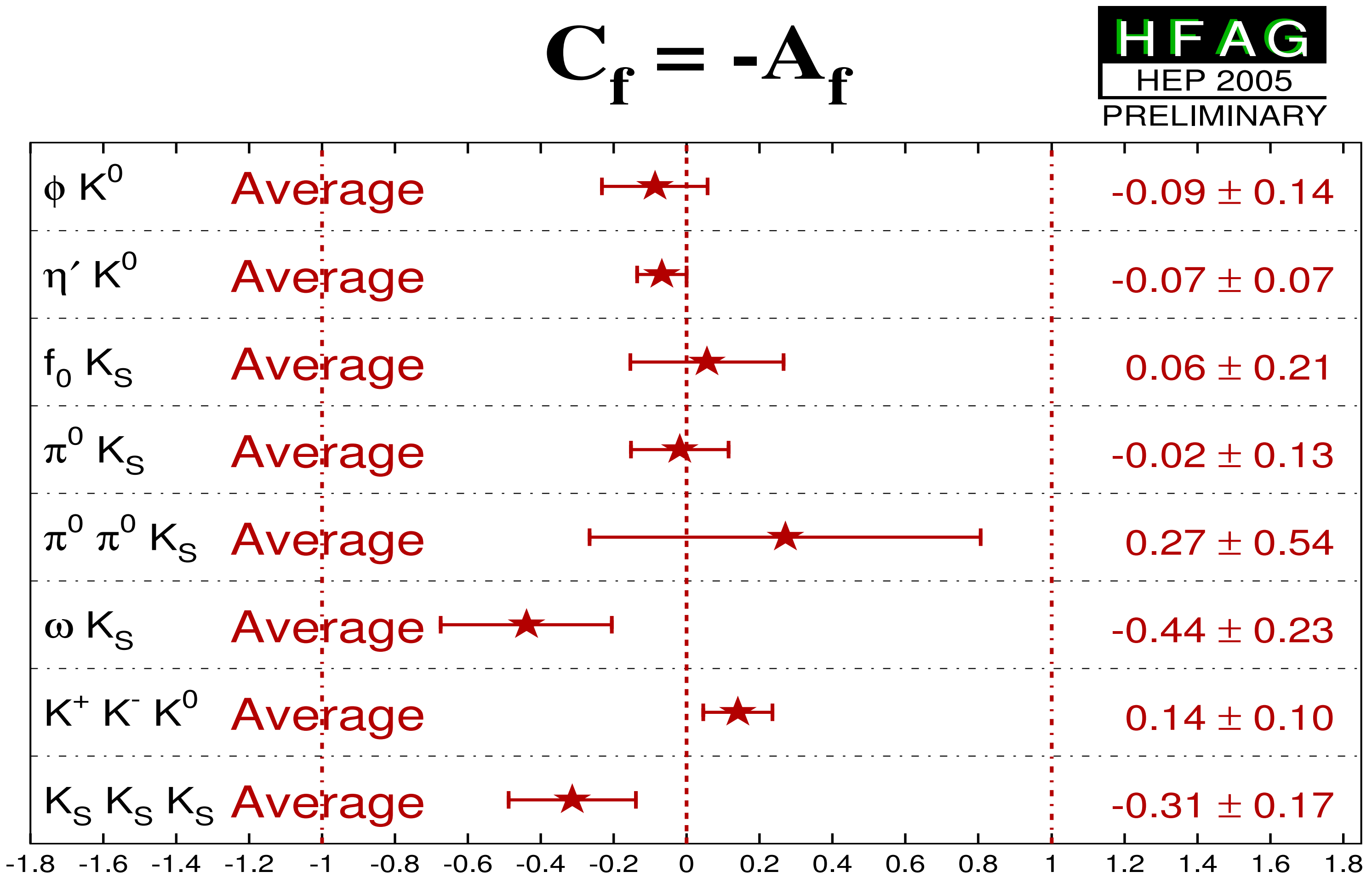
Marcello A. Giorgi

25

$S_{b\to q\bar{q}s}$ and $C_{b\to q\bar{q}s}$ [HFAG 2005; hep-ex/0505100]



$S_{b\to q\bar{q}s}$ and $C_{b\to q\bar{q}s}$ [HFAG 2005; hep-ex/0505100]



Summary

- Thanks to dedicated experiments and progress in theoretical techniques (χPT, Lattice-QCD, QCD Sum Rules, Heavy quark expansion) $V_{\rm CKM}$ now well measured
- Precision on V_{ij} ranges from $\delta|V_{ud}|/|V_{ud}| = 5 \times 10^{-4}$ (best measurement) to $\delta|V_{tb}|/|V_{tb}| = 0.2$ (current CDF measurement), which will be vastly improved at the LHC and ILC
- $|V_{cb}|$ determined precisely: $\frac{\delta|V_{cb}|}{|V_{cb}|} \sim 2\%$; close on the heels of $\frac{\delta|V_{us}|}{|V_{us}|}$!
- Current precision on $|V_{ub}|$ about 14%; many theoretical proposals to improve our knowledge of $|V_{ub}|$; require lot more data; forthcoming from B factories
- Radiative rare B-decays in agreement with the SM rates; determine $|V_{ts}|$ and $|V_{td}|$); Current precision on $|V_{td}|$ from B^0 - $\overline{B^0}$ mixing is about 10%
- A non-trivial test of the CKM paradigm for CP violation in the K- and B-meson sectors has been carried out at the current B-factories by overconstraining the CKM unitarity triangle
- B-factories have measured all three inner angles of the UT triangle: $\alpha = (99^{+12}_{-9})^\circ$; $\beta = (21.7 \pm 1.3)^\circ$; $\gamma = (66 \pm 17)^\circ$
- Largest current discrepancy from SM is in CPV $b \to s\bar{s}s$ penguins; $3\ \sigma$ effect
- We look forward to new data from the ongoing and planned experiments at CERN, Fermilab, Frascati, BNL, KEK, and ILC

Superfield Classification in the MSSM

- Superfields classified according to their $SU(3)_C \otimes SU(2)_I \otimes U(1)_Y$ Quantum Numbers; $i = 1, 2, 3$ a generation index
- Chiral Superfields for Quarks $(\hat{Q}_i, \hat{U}_i^c, \hat{D}_i^c)$

$$\hat{Q}_i(3, 2, 1/6); \quad \hat{U}_i^c(\bar{3}, 1, -2/3); \quad \hat{D}_i^c(\bar{3}, 1, 1/3)$$

$$\hat{Q}_i = (\tilde{Q}_{L_i}, Q_{L_i}); \quad \hat{U}_i^c = (\tilde{U}_{L_i}^c, U_{L_i}^c); \quad \hat{D}_i^c = (\tilde{D}_{L_i}^c, D_{L_i}^c)$$

- Chiral Superfields for Leptons $(\hat{L}_i, \hat{E}_i^c)$

$$\hat{L}_i(1, 2, -1/2); \quad \hat{E}_i^c(1, 1, 1)$$

$$\hat{L}_i = (\tilde{E}_{L_i}, E_{L_i}); \quad \hat{E}_i^c = (\tilde{E}_{L_i}^c, E_{L_i}^c)$$

- Chiral Superfields for Two Higgs Doublets (also denoted as $\hat{H}_1$ & $\hat{H}_2$)

$$\hat{H}_u(1, 2, -1/2); \quad \hat{H}_d(1, 2, 1/2)$$

$$\hat{H}_u = (H_u, \tilde{H}_u); \quad \hat{H}_d = (H_d, \tilde{H}_d)$$

- Vector Superfields $(\hat{G}, \hat{W}, \hat{B})$ (α is an SU(2) index)

$$\hat{G}(8, 1, 1); \quad \hat{W}^\alpha(1, 3, 1); \quad \hat{B}(1, 1, 1)$$

$$\hat{G} = (g, \tilde{g}); \quad \hat{W} = (W^\alpha, \tilde{W}^\alpha); \quad \hat{B} = (B, \tilde{B})$$