フレーバー物理

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第一回A01班研究会@阪大H701

INTRODUCTION

歴史

1957: L. D. Landau

中性K中間子崩壊におけるCP保存

$K_S \to \pi\pi,\ K_L \to \pi\pi\pi$

1961: S. L. Glashow (ノーベル賞1979)

1964: J.W. Cronin,V. L. Fitch, ... (ノーベル賞1980)

中性K中間子崩壊におけるCPの破れ

$K_L \to \pi^+\pi^-$

1967: S.Weinberg (ノーベル賞1979)

1968: A. Salam (ノーベル賞1979)

1970: S.L.Glashow, J. Iliopoulos, L. Maiani

FCNCに基づくチャームクォークの予言

1971: G. 't Hooft (ノーベル賞1999)
ゲージ理論の繰り込み

1973: M. Kobayashi, T. Maskawa (ノーベル賞2008)
6クォーク模型

1974: S. Ting, B. Richter (ノーベル賞1976)
J/Ψの発見

1975: M. L. Perl (ノーベル賞1995)
タウの発見

1977: L. Lederman
ボトムの発見

1987: ARGUS

B^0–$\bar{B}^0$混合の発見

1989: CLEO

$b \to u$ 遷移の発見

1994: CDF, D0

トップの発見

2002: Belle, BaBar

B中間子崩壊におけるCPの破れの確立

Experiments

Energy frontier

CDF, D0 (Tevatron)

ATLAS, CMS (LHC)

Flavor dedicated

BELLE (KEKB), BaBar (PEP II), MEG

KTeV, KLOE, ISTRA+, NA48

CLEOc (CESRc), BESII (BEPC)

LHCb (LHC)

Super KEKB, Super B factory (Rome)

Super c-τ (Russia)

KOTO, TREK (JPARC), ...

Complementarity

目次

CKM ACHIEVMENT

CKM行列の構造

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

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij},\ s_{ij} = \sin\theta_{ij}$$

PDG parameterization

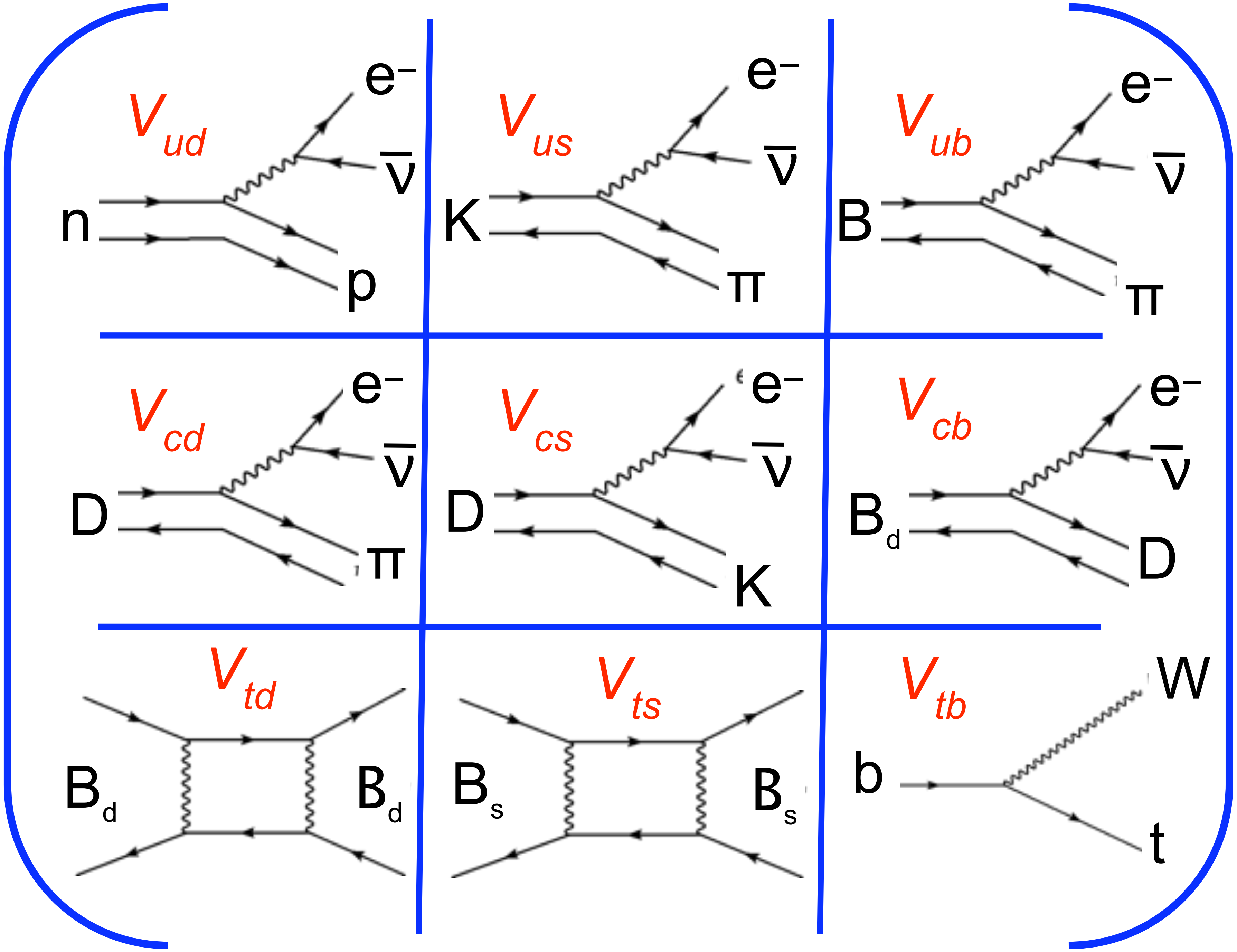
Wolfenstein parametrization

実験: $1 \gg |V_{us}| \gg |V_{cb}| \gg |V_{ub}|$

$$s_{12} = \lambda \simeq 0.22,\ s_{23} = \lambda^2 A,\ s_{13}e^{-i\delta_{13}} = \lambda^3 A(\rho - i\eta)$$

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

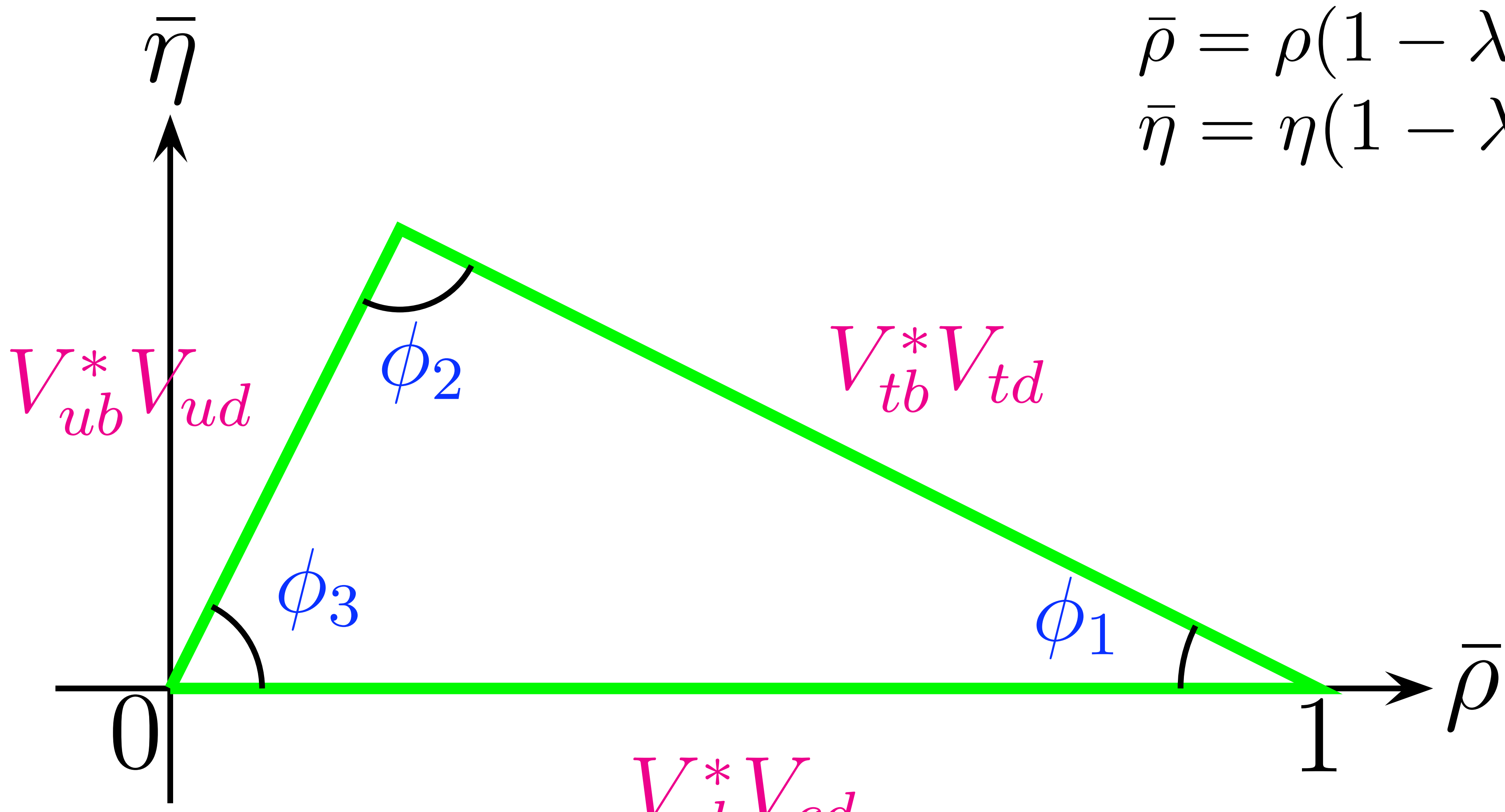
CKM Matrix Element Magnitudes

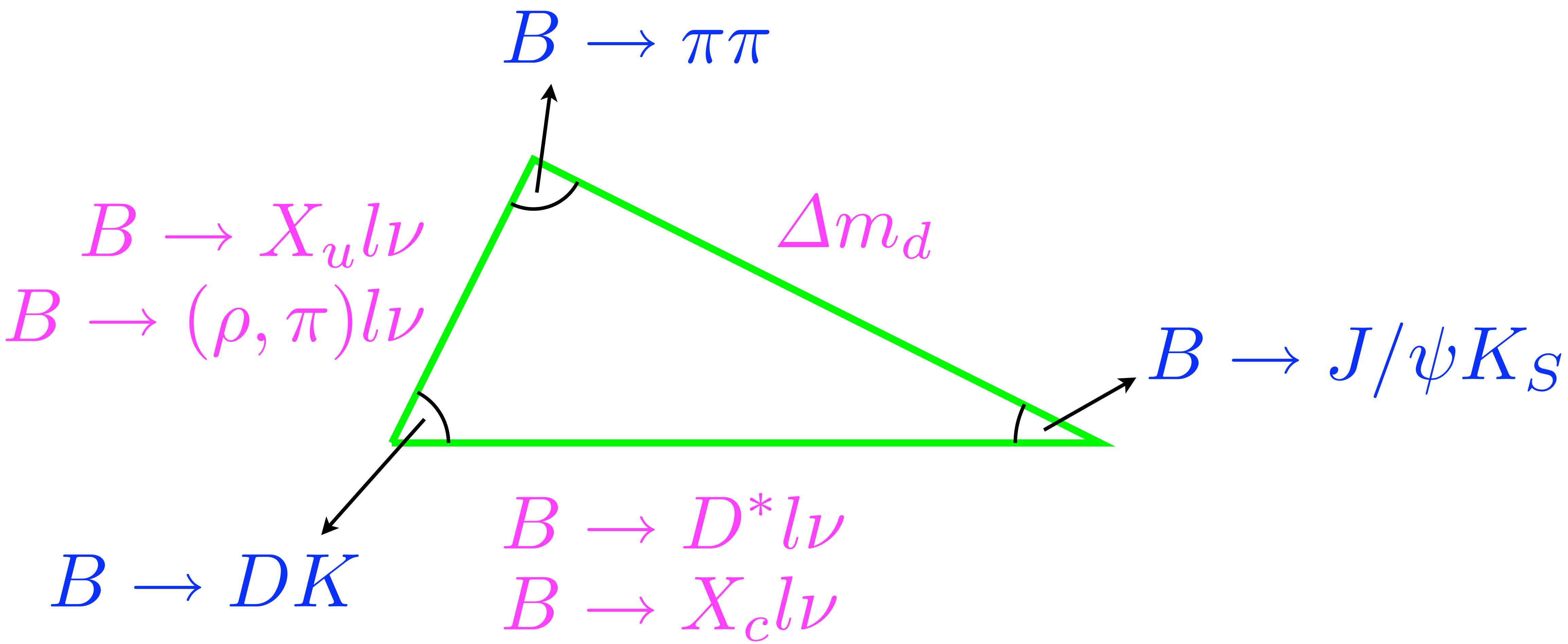


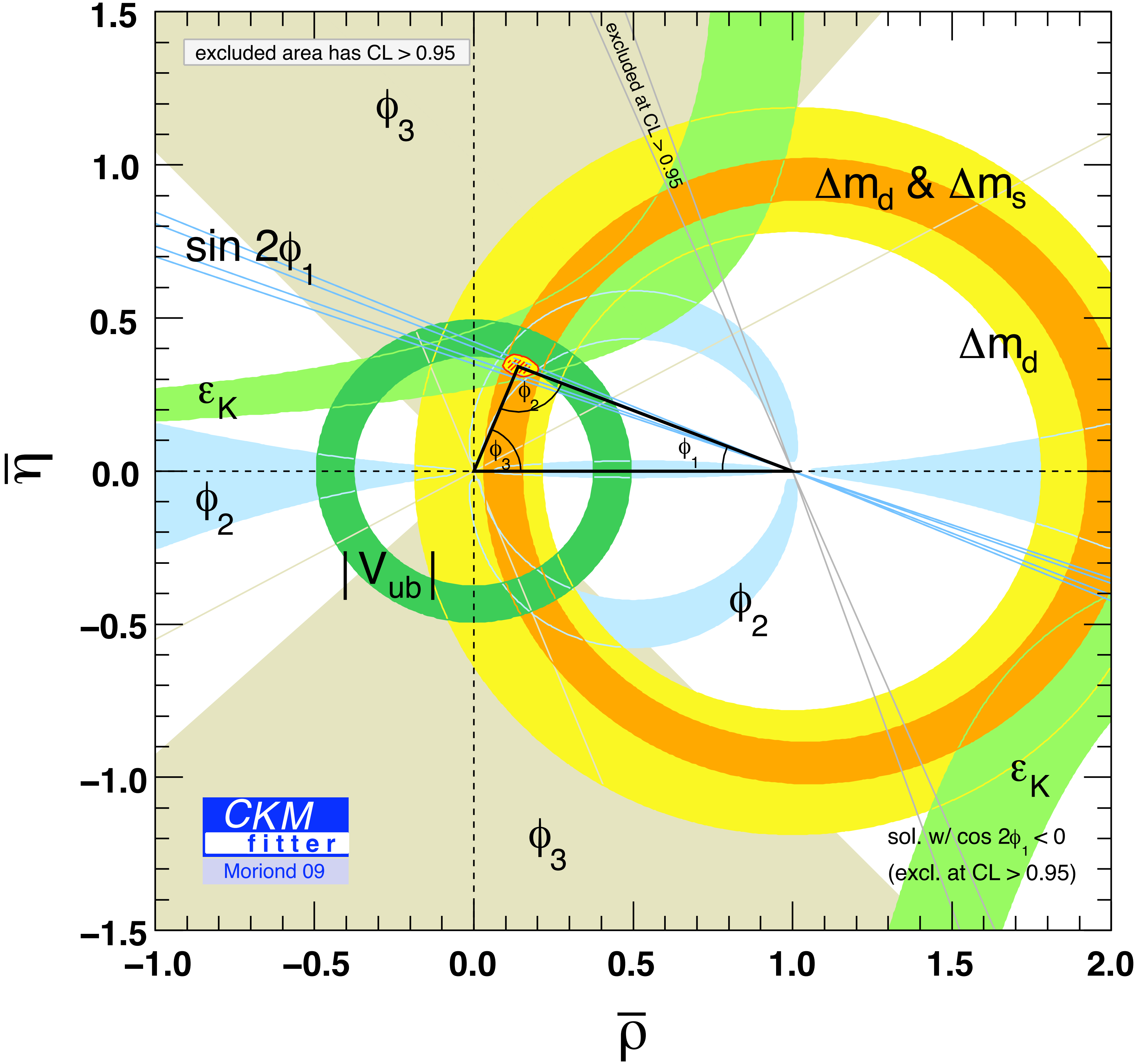
B中間子とUT

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

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




$B \to \pi\pi$
$B \to X_u l\nu$
$B \to (\rho, \pi) l\nu$
Δm_d
$B \to J/\psi K_S$
$B \to DK$
$B \to D^* l\nu$
$B \to X_c l\nu$



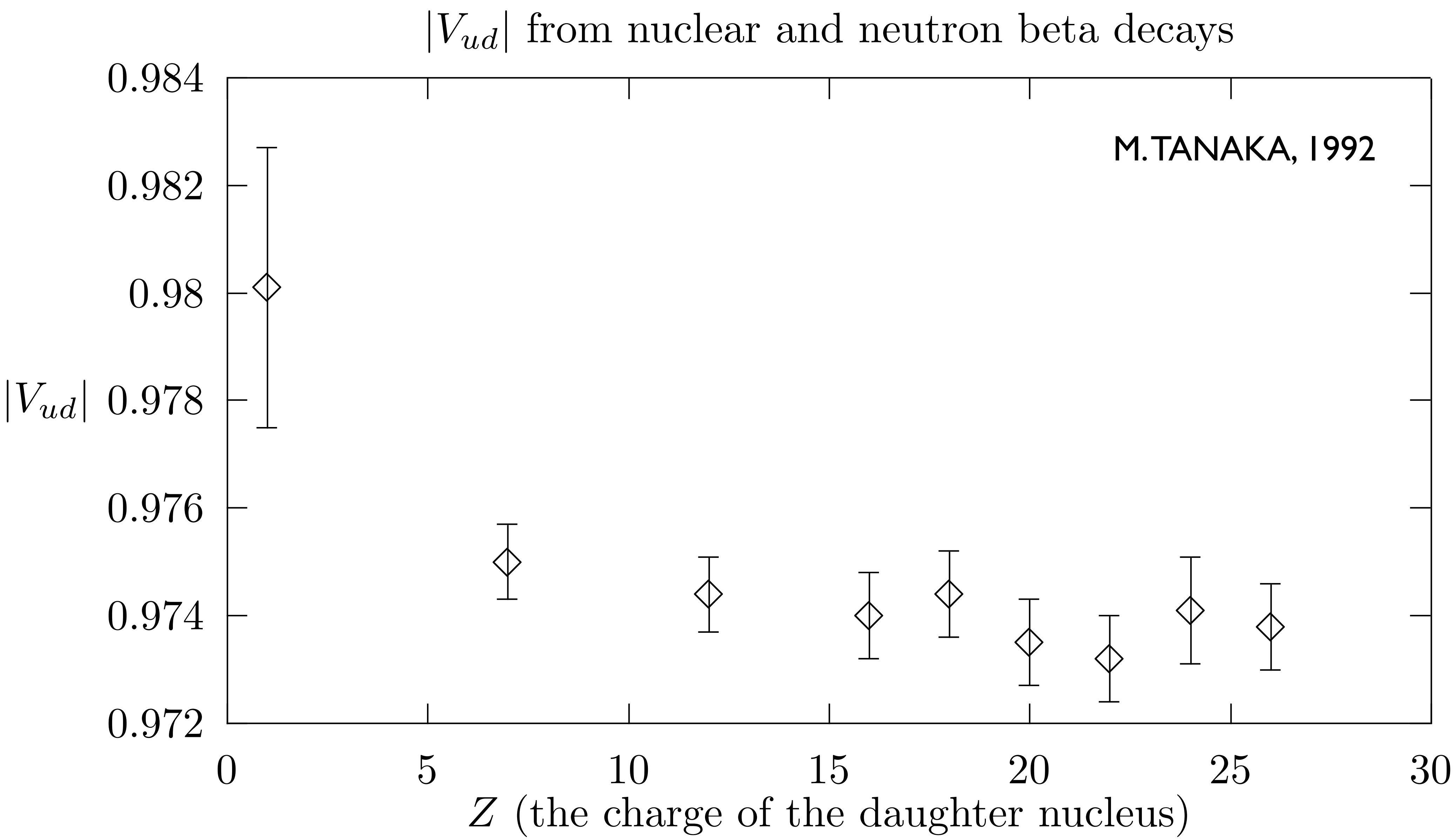
Moriond 2009

Good in ~10% accuracy

|Vud|

Superallowed ($0^+ \to 0^+$) nuclear β decays.

A sprious Z-dependence.



$$|V_{ud}|^2 = \frac{\pi^3 \ln 2}{ft G_\mu^2 m_e^5 (1+\delta)}$$

t : partial half-life

f : phase space statistical decay rate factor

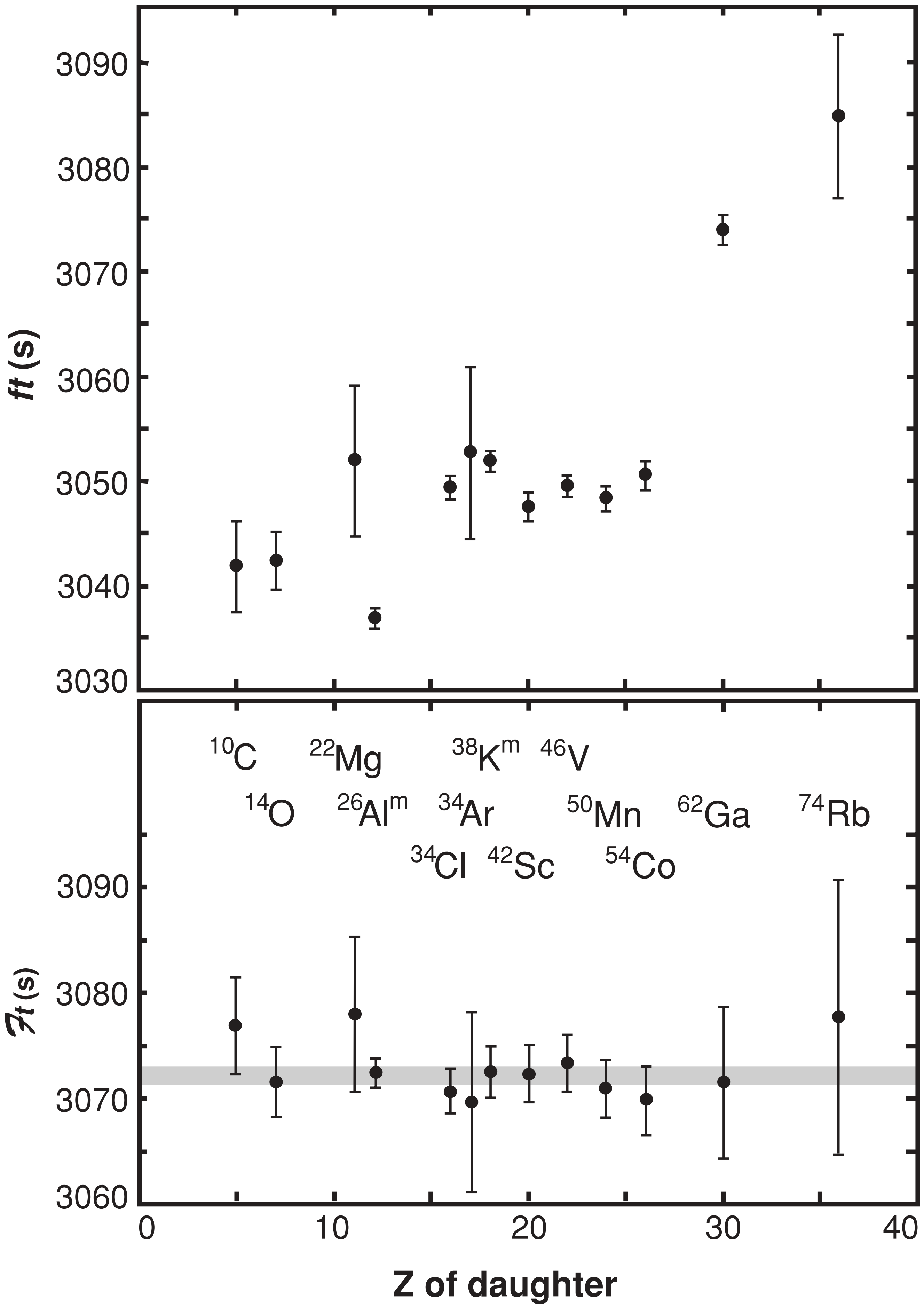
δ : radiative and other corrections

$$\delta = \delta_{\text{inner}} + \delta_{\text{outer}}$$

universal Z-dependent

$$Ft = ft(1 + \delta_{\text{outer}})$$

should be universal.



Hardy and Towner,
Phys. Rev. C79, 055502 (2009)

Z-dependence disappeared!

$$|V_{ud}| = 0.97425 \pm 0.00022$$

|Vus| $K \to \pi \ell \bar{\nu}$

V_{us} from K_{l3} decay rates

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{Kl}(\lambda) (1 + 2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

with $K = K^+, K^0$; $l = e, \mu$ and C_K^2 = 1/2 for K^+, 1 for K^0

Inputs from theory:

S_{EW} Universal short distance EW correction (1.0232)

$f_+^{K^0\pi^-}(0)$ Hadronic matrix element at zero momentum transfer (t=0)

$\Delta_K^{SU(2)}$ Form factor correction for SU(2) breaking

Δ_{Kl}^{EM} Long distance EM effects

Inputs from experiment:

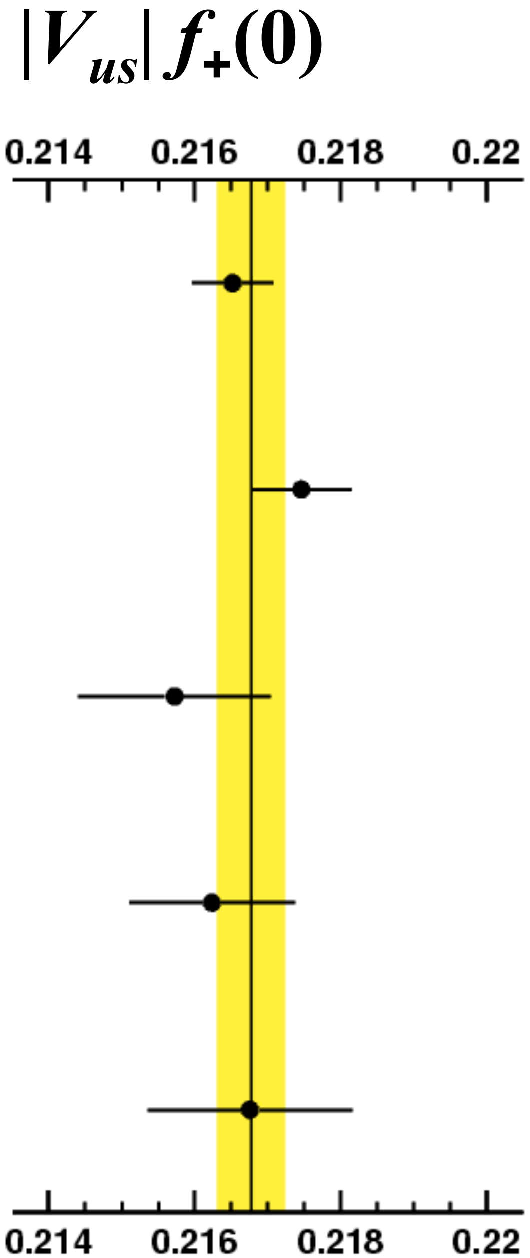
$\Gamma(K_{l3(\gamma)})$ **Branching ratios** with well determined treatment of radiative decays; **lifetimes**

$I_{Kl}(\lambda)$ Phase space integral: λs parameterize form factor dependence on t :

K_{e3} : only λ_+ (or λ_+' λ_+'')

$K_{\mu3}$: need λ_+ and λ_0

$|V_{us}|f_+(0)$ from K_{l3} data



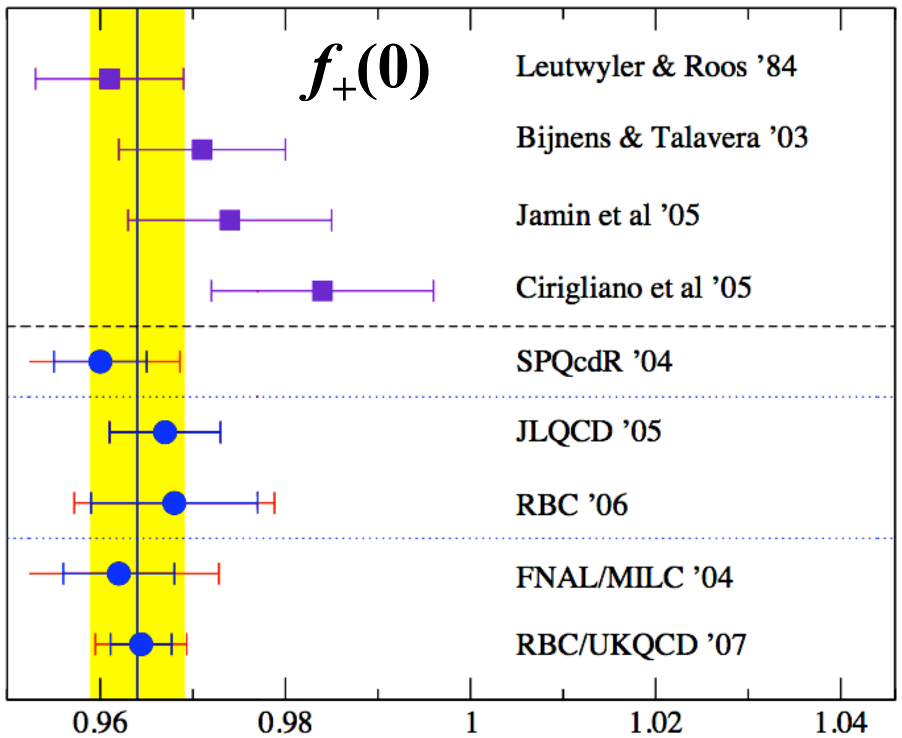
Approx. contrib. to % err from:

		% err	BR	τ	Δ	Int
$K_L e3$	**0.21652(56)**	**0.25**	0.11	**0.20**	0.11	0.10
$K_L \mu 3$	**0.21746(69)**	**0.32**	0.17	**0.19**	0.11	0.15
$K_S e3$	**0.21572(132)**	**0.61**	**0.60**	0.03	0.11	0.10
$K^{\pm} e3$	**0.21624(113)**	**0.52**	**0.31**	0.06	**0.41**	0.09
$K^{\pm} \mu 3$	**0.21676(141)**	**0.65**	**0.48**	0.06	**0.41**	0.15

Average: $|V_{us}|\, f_+(0)$ = 0.21660(47) **χ^2/ndf = 3.03/4 (55%)**

Evaluations of $f_+(0)$

Compilations: L. Lellouch, Lattice '08



Quark model
ChPT + QM
ChPT + disp
ChPT + $1/N_c$
$N_f = 0$
2 Wilson
2 DWF
2 Stag+Wilson
(2+1) DWF

Provisional coding (Lellouch), similar to FLAG scheme

ref.	publication	N_f, action, etc	mass extrap	$a \to 0$	finite volume
JLQCD '05	🔴	🟠	🔴	🔴	🔴
RBC '06	🟢	🟠	🔴	🔴	🔴
FNAL/MILC '04	🔴	🟠	🔴	🔴	🔴
RBC/UKQCD '08	🟢	🟢	🟠	🔴	🟠

Many evaluations available, analytic and lattice-based

ChPT results tend to give higher values for $f_+(0)$

Trend is to use lattice results, but which ones?

FlaviaNet Lattice Averaging Group (FLAG) has promised to make a recommendation

For now use:

$f_+(0) = 0.9644(49)$
RBC/UKQCD '07

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M.Palutan, KAON'09

$f_+(0)$ dominates the error.

V_{us} from K_{l3} data and CKM unitarity

K_{l3} average: $|V_{us}| f_+(0)$ = 0.21660(47)

was 0.2167 at Kaon'07

With $f_+(0)$ = **0.9644(49)** from lattice QCD:

K_{l3} average: $|V_{us}|$ = 0.2246(12)

Using $|V_{ud}|$ = **0.97424(22)** from average $0^+ \rightarrow 0^+$ β decays (Towner-Hardy '09)

$V_{ud}^2 + V_{us}^2 - 1$ = -0.0004(7)
Compatibility with unitarity -0.6σ

was 0031(15) in PDG04

$\sigma(V_{ud}^2)$~0.0004 $\sigma(V_{us}^2)$~0.0005

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

CKM matrix unitarity check

Inputs:

$\lvert V_{ud}\rvert = 0.97424 \pm 0.00022$	$\lvert V_{us}\rvert = 0.2252 \pm 0.0009$	$\lvert V_{ub}\rvert = (4.07 \pm 0.38)\times 10^{-3}$
$\lvert V_{cd}\rvert = 0.231 \pm 0.010$	$\lvert V_{cs}\rvert = 1.03 \pm 0.04$	$\lvert V_{cb}\rvert = (40.6 \pm 1.3)\times 10^{-3}$
$\lvert V_{td}\rvert = (8.1 \pm 0.6)\times 10^{-3}$	$\lvert V_{ts}\rvert = (38.7 \pm 2.3)\times 10^{-3}$	$\lvert V_{tb}\rvert = (1.00 \pm 0.10)\times 10^{-3}$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = -0.0004 \pm 0.0007 \quad (-0.6\sigma)$$
$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 - 1 = +0.11 \pm 0.08 \quad (+1.3\sigma)$$
$$|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 - 1 = +0.00 \pm 0.20 \quad (+0.0\sigma)$$
$$|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 - 1 = +0.003 \pm 0.005 \quad (+0.6\sigma)$$
$$|V_{us}|^2 + |V_{cs}|^2 + |V_{ts}|^2 - 1 = +0.11 \pm 0.08 \quad (+1.4\sigma)$$
$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 - 1 = +0.00 \pm 0.20 \quad (+0.0\sigma)$$

Magnitudes of CKM matrix elements fulfill unitarity well

From V_{cb} and V_{ts}

$$A\lambda^2 = (40.1 \pm 1.1)\times 10^{-3}$$

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Prospect

$$\delta|V_{ud}| \sim O(10^{-5})$$
$$\delta|V_{us}| \sim O(10^{-4})$$

→ ultimate test including Vub

TENSIONS, ANOMALIES and NEW PHYSICS

|Vus| from τ decays

Exclusive: $$\frac{\mathrm{BR}(\tau \to K\nu)}{\mathrm{BR}(\tau \to \pi\nu)}$$

$$|V_{us}| = 0.2255(23)$$ (BaBar, 2008)

Inclusive: $\tau \to \nu X_s$

$$|V_{us}| = 0.2159(30_{\mathrm{exp}})(5_{\mathrm{th}})$$

2σ or more difference from

K_{l3} average: $|V_{us}|$ = 0.2246(12)

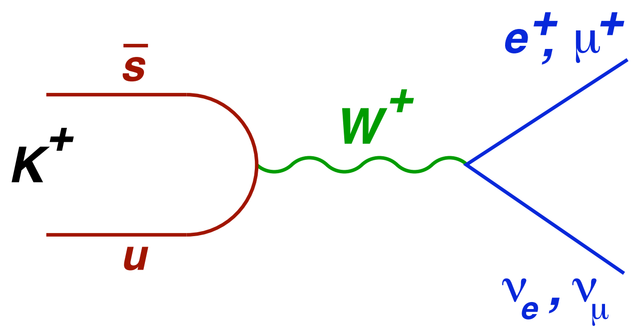
SUSY in $K_{\ell 2}$

Lepton Flavor Universality: $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$

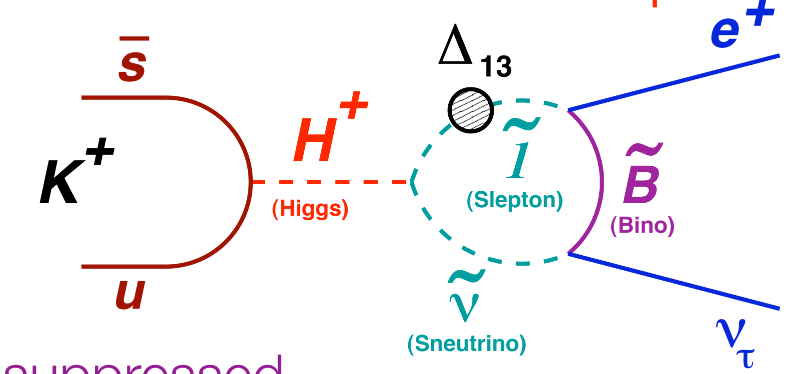
V-A couplings - helicity suppression

SM: $(2.477\pm0.001)\cdot 10^{-5}$

Cirigliano, Rosell, PRL99(2007)231801



SUSY
LFV loop



suppressed

$$R_K = \frac{\Sigma_i\ \Gamma(K\to e\nu_i)}{\Sigma_i\ \Gamma(K\to \mu\nu_i)} \simeq \frac{\Gamma_{SM}(K\to e\nu_e) + \Gamma(K\to e\nu_\tau)}{\Gamma_{SM}(K\to\mu\nu_\mu)}$$

experimentally the ν flavor is undetermined ...

effective e-τ coupling constant

$$\mathbf{R_K^{LFV}} \approx \mathbf{R_K^{SM}}\left[\mathbf{1} + \left(\frac{\mathbf{m_K^4}}{\mathbf{M^4_{H^\pm}}}\right)\left(\frac{\mathbf{m_\tau^2}}{\mathbf{M_e^2}}\right)|\mathbf{\Delta_{13}}|^{\mathbf{2}}\tan^{\mathbf{6}}\beta\right]$$

Deviations between $10^{-2} \sim 10^{-3}$
are studied in
Masiero, Paradisi, Petronzio, JHEP0811(2008)042

|Vcb|: exclusive vs inclusive

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

V_{cb} from B → $D^{(*)}$lν decays

$$\frac{d\Gamma}{dw}(\bar{B} \to D^{*} l \bar{\nu}) = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 \, m_{D^*}^3 (w-1)^{1/2} P(w)(F(w))^2$$

$$\frac{d\Gamma}{dw}(\bar{B} \to D l \bar{\nu}) = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 \, (m_B + m_D) m_D^3 (w-1)^{3/2} (G(w))^2$$

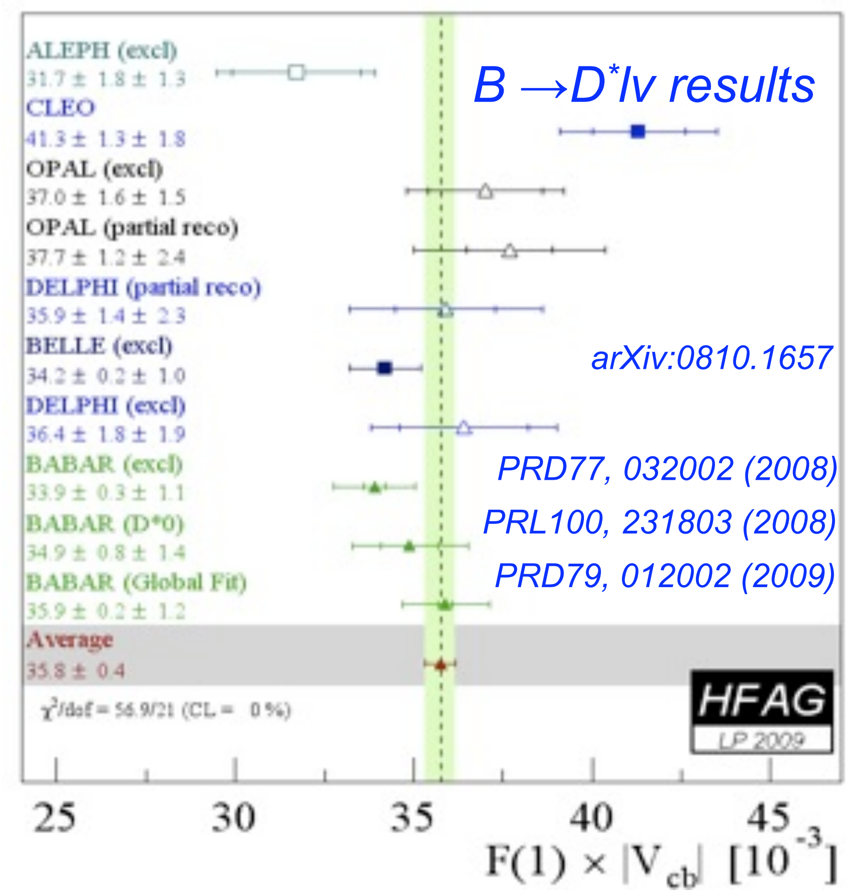
Experiments fit differential B → $D^{(*)}$lν decay rate for $|V_{cb}|F(1)$ and $|V_{cb}|G(1)$ using HQET-based form factor parameterizations

- B → $D^{(*)}$ form factor normalizations from lattice calculations

$$G(1) = 1.074 \pm 0.018 \pm 0.016 \quad \text{(FNAL/MILC (2005))}$$
$$F(1) = 0.921 \pm 0.013 \pm 0.020 \quad \text{(FNAL/MILC (2009))}$$

- Preliminary result from Belle with B- →D^{*0}lν (Dungel @ EPS'09, not yet included in average):

$$|V_{cb}| F(1) = (35.0 \pm 0.4 \pm 2.2) \times 10^{-3}$$



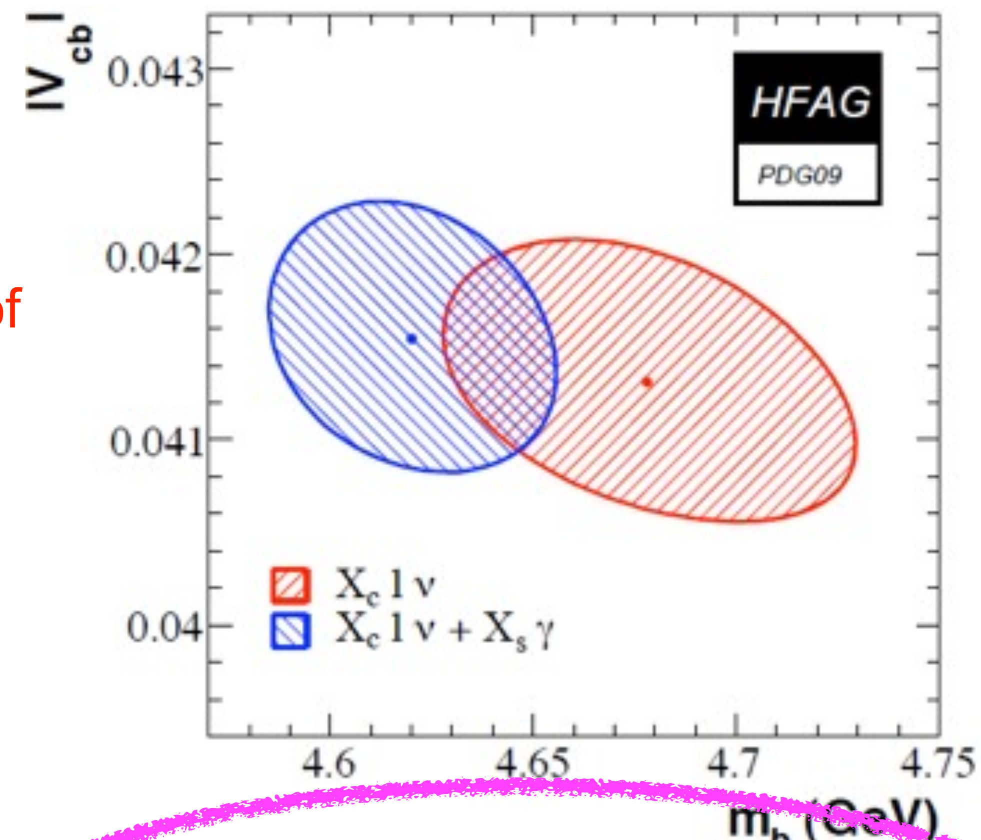
$$B \to D l \nu: \quad |V_{cb}| G(1) = (42.3 \pm 0.7 \pm 1.3) \times 10^{-3}$$
$$\Rightarrow \quad |V_{cb}| = (39.4 \pm 1.4(\text{exp}) \pm 0.9(\text{FF})) \times 10^{-3}$$

$$B \to D^{*} l \nu: \quad |V_{cb}| F(1) = (35.75 \pm 0.42) \times 10^{-3}$$
$$\Rightarrow \quad |V_{cb}| = (38.8 \pm 0.5(\text{exp}) \pm 1.0(\text{FF})) \times 10^{-3}$$

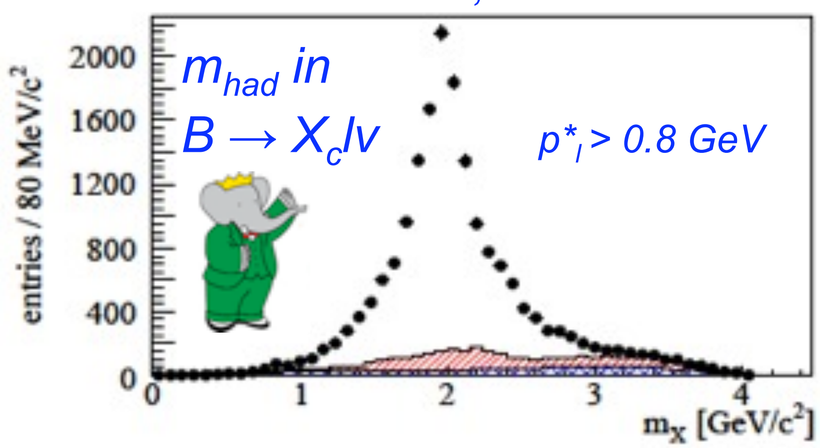
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

V_{cb} from inclusive $B \to X_c l\nu$ decays

- Inclusive rate $\Gamma(B \to X_c l\nu)$ can be described by expansion in powers of $1/m_b$ (HQET, OPE)
- Non-perturbative corrections up to $O(1/m_b^3)$ are determined from inclusive distributions in B decays (E_{lep} and m_{had} in $B \to X_c l\nu$ and E_γ in $B \to X_s\gamma$ decays)



BaBar, arXiv:0908.0415



HFAG, Winter 2009

$$|V_{cb}| = (41.67 \pm 0.44 \pm 0.58) \times 10^{-3}$$

(~2.3σ larger than V_{cb} from excl. decays)

My average (S = 2.3)

$$|V_{cb}| = (40.6 \pm 1.3) \times 10^{-3}$$

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2.3σ

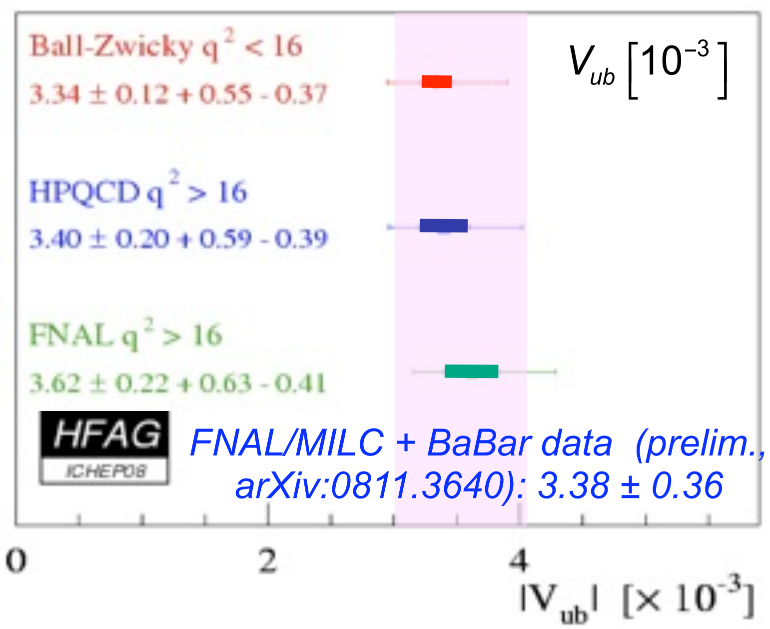
|Vub|: exclusive vs inclusive

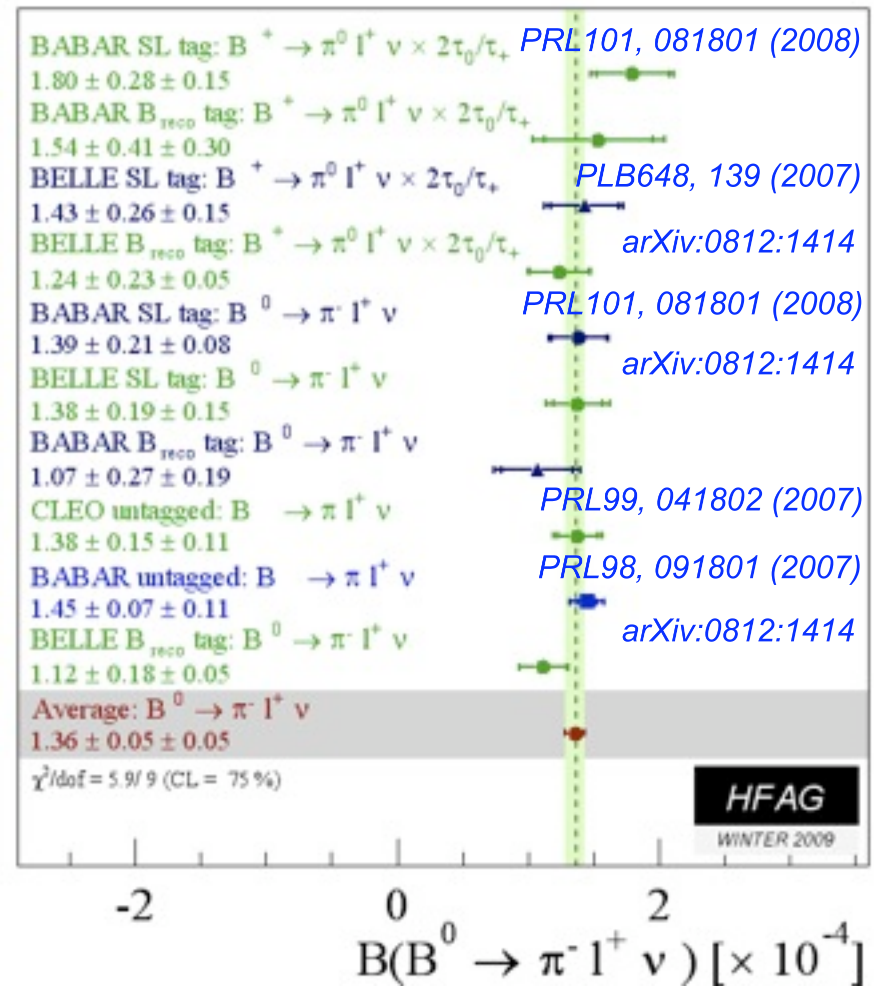
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

V_{ub} from B → π l ν decays

$$\frac{d\Gamma}{dq^2}(B \rightarrow \pi l \nu) = \frac{G_F^2}{24\pi^3} p_\pi^3 \, |V_{ub}|^2 |f_+(q^2)|^2$$

- Experiments determine $|V_{ub}||f_+(q^2)|$ from measured B → π l ν rate
  - $|f_+(q^2)|$ calculated from theory (LQCD (LCSR) at high (low) q^2)





$$BR(B^0 \to \pi^- l^+ \nu) = (1.36 \pm 0.05 \pm 0.05) \times 10^{-4}$$

$$|V_{ub}|_{\pi l \nu} = (3.5^{+0.6}_{-0.5}) \times 10^{-3}$$

Error dominated by $f_+(0)$ calculation

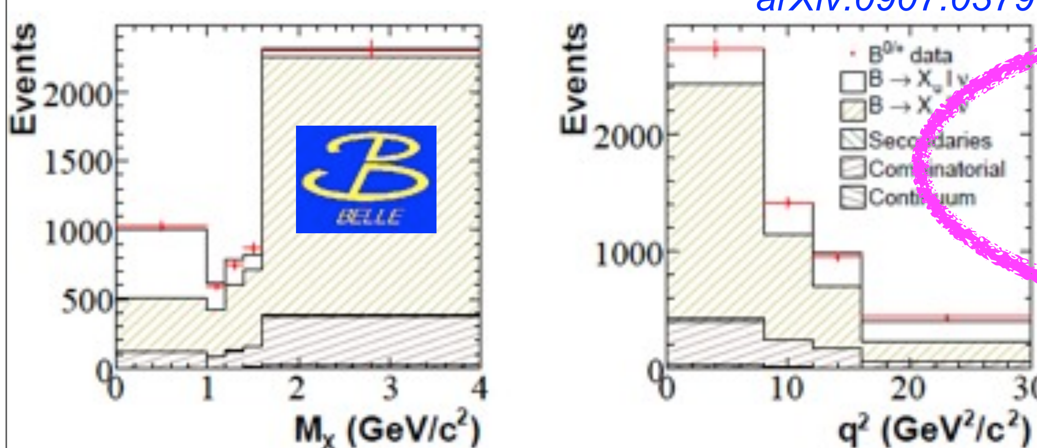
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

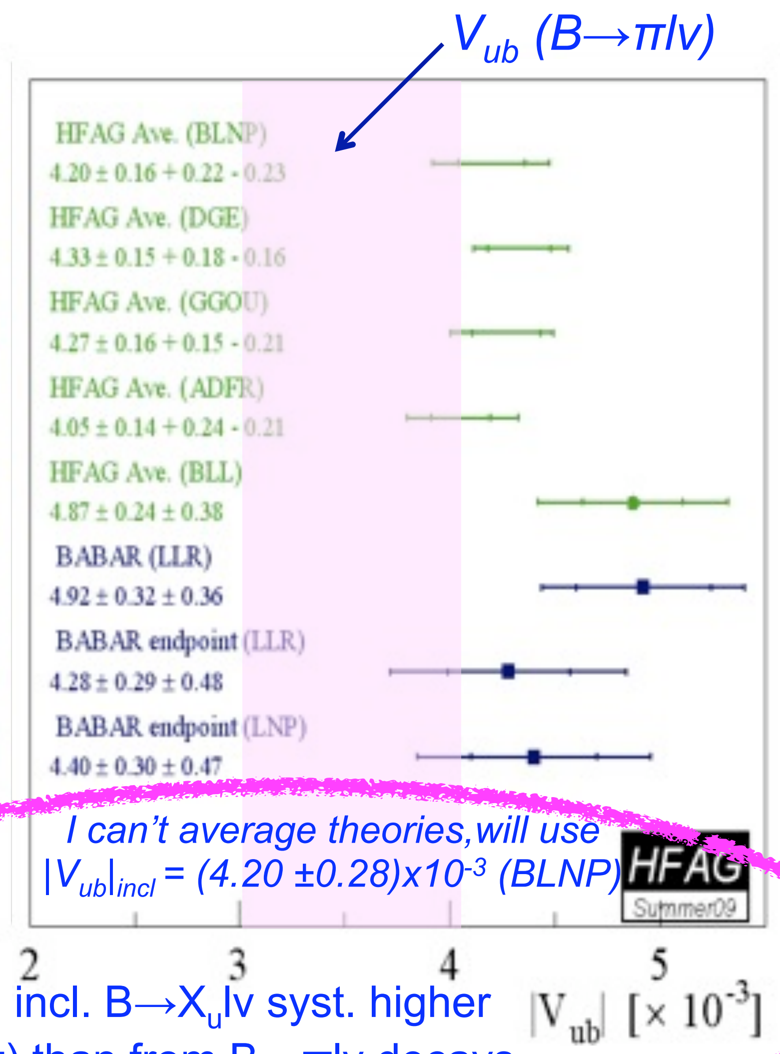
V_{ub} from incl. $B \to X_u l \nu$ decays

$$\Gamma(B \to X_u l\nu) = \frac{G_F^2}{192\pi^3} |V_{ub}|^2 \, m_b^5 (1 + \text{had. corr.})$$

- Challenges
  - m_b^5-dependence of $\Gamma(B \to X_u l\nu)$
  - $b \to c$ background: $\Gamma(B \to X_c l\nu) / \Gamma(B \to X_u l\nu) \sim 50$
- Select $B \to X_u l\nu$ enhanced region in PS
  - use shape function from $B \to X_s \gamma$ E_γ-spectrum and theory to extrapolate rate to full PS
- New Belle multivariate analysis
  - Reconstruct other B in hadronic mode
  - Covers about 90% of $B \to X_u l\nu$ PS

arXiv:0907.0379





I can't average theories, will use $|V_{ub}|_{incl}$ = (4.20 ±0.28)x10^{-3} (BLNP)

V_{ub} from incl. $B \to X_u l\nu$ syst. higher (~1-2σ) than from $B \to \pi l\nu$ decays

My average

$$|V_{ub}| = (4.07 \pm 0.38) \times 10^{-3}$$

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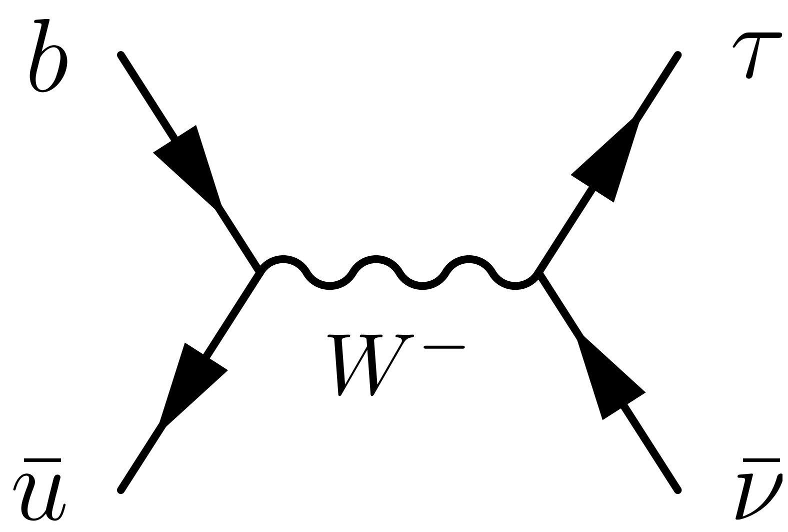
1~2σ

|Vub| and B → τν



$$\Gamma = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

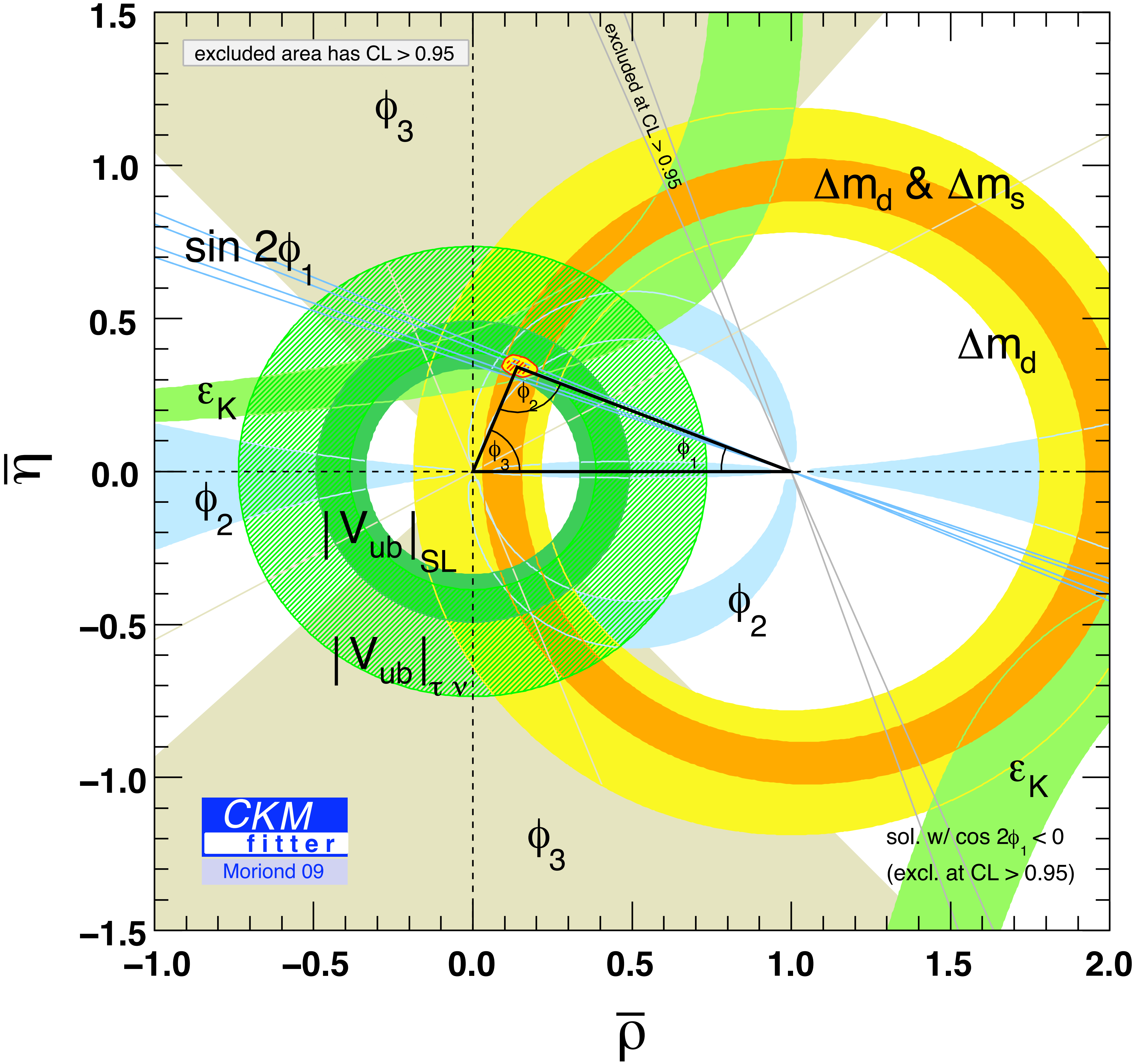
$f_B = 190 \pm 13\ MeV$ HPQCD, 0902.1815v2

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29)\times 10^{-3}$ HFAG ICHEP08

⇒ $Br_{SM}(\tau\nu) = (1.20 \pm 0.25)\times 10^{-4}$

Exp. (Belle, BaBar)

$Br(\tau\nu) = [1.73 \pm 0.35]\times 10^{-4}$ T.Iijima, LP2009



tension

$\sin 2\phi_1$

ε_K

$|V_{ub}|$

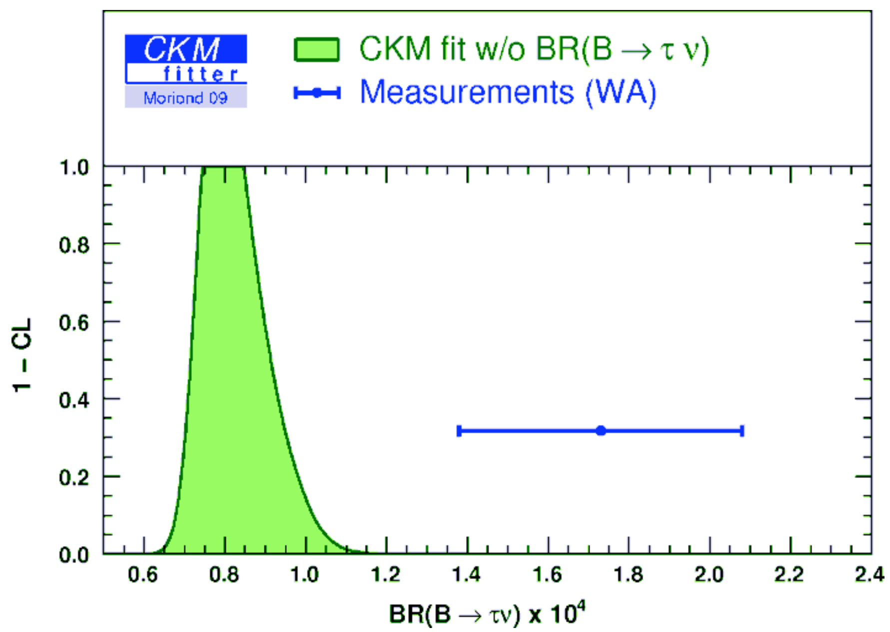
Comparison to CKM fit

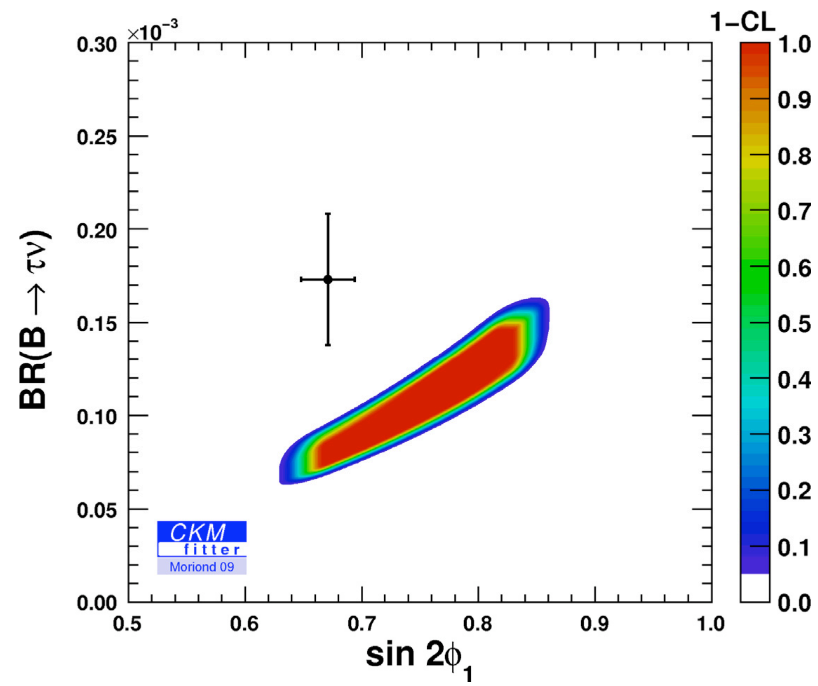
Naïve world average

$$Br(\tau\nu) = [1.73 \pm 0.35] \times 10^{-4}$$

$$Br(\tau\nu)_{CKM\ fit} = \left[0.786\ ^{+0.179}_{-0.083}\right] \times 10^{-4}$$

Output of a CKM fit without including B→τν in the fit (CKM fitter, ICHEP08)





The measured Br is 2.4 σ higher than the value predicted by the CKM fit.

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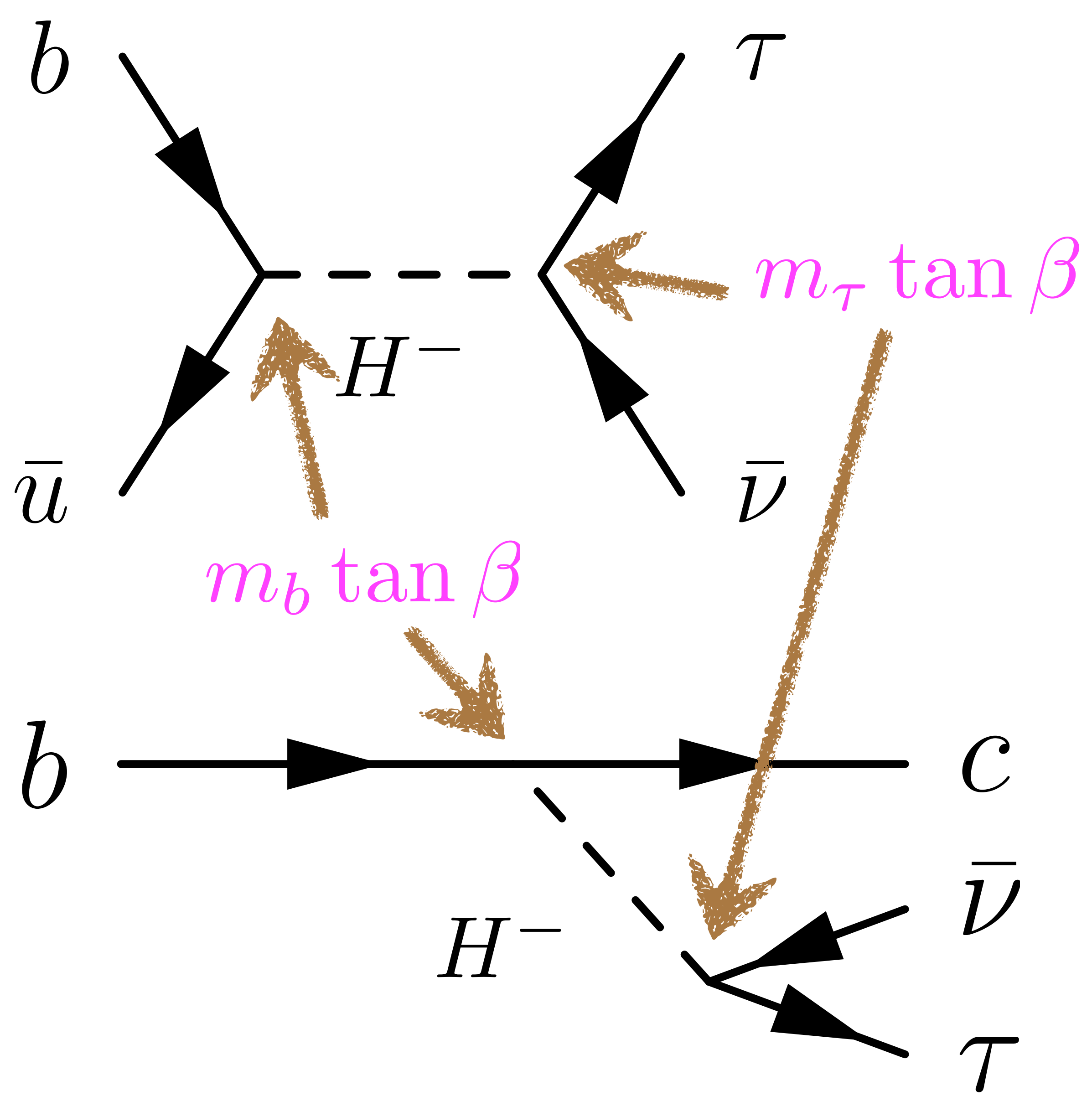
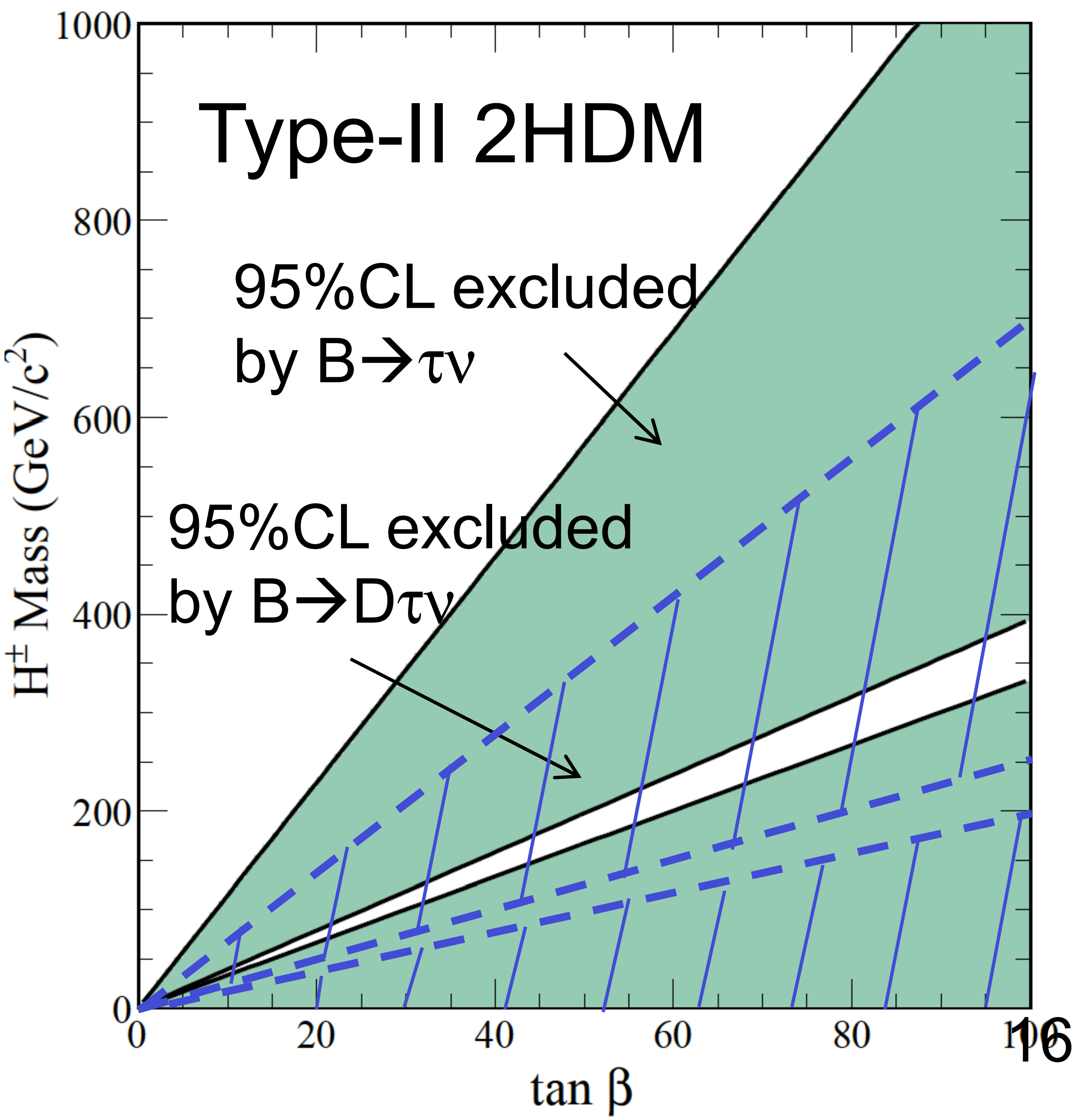
2.4σ

T.Iijima, LP2009

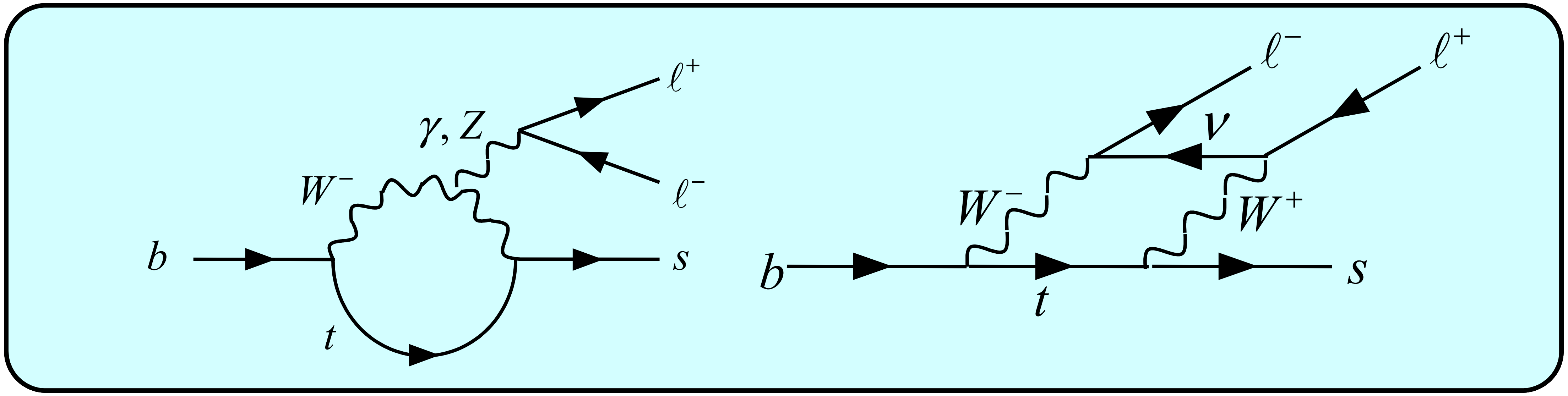
Charged Higgs in B → τν and B → Dτν

Type-II 2HDM (SUSY)





$b \to s\ell\bar{\ell}$

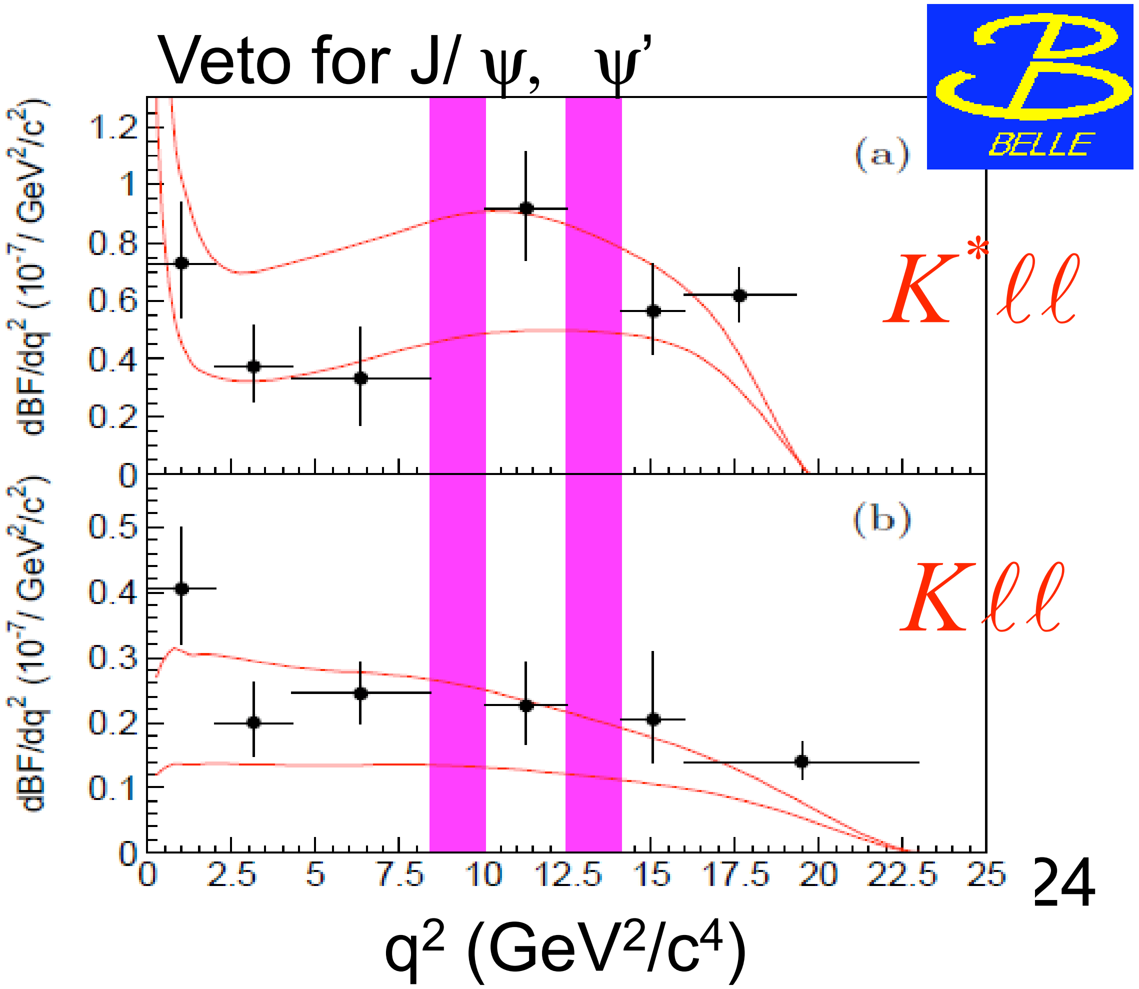


HFAG Average (2009 Winter)

$$Br(B \to K^* \ell\ell) = (10.0 \pm 1.1) \times 10^{-7}$$

$$Br(B \to K\ell\ell) = (4.3 \pm 0.4) \times 10^{-7}$$

q^2-dependence



Forward-Backward asymmetry in $B \to K^* \ell\bar{\ell}$

$$H_{\rm eff} = \frac{4G_F}{\sqrt{2}} \sum_{i=1}^{10} C_i(Q) O_i(Q)$$

$$O_7 = \frac{e}{16\pi^2} m_b (\bar{s}_{L\alpha}\sigma_{\mu\nu} b_{R\alpha}) F^{\mu\nu},$$

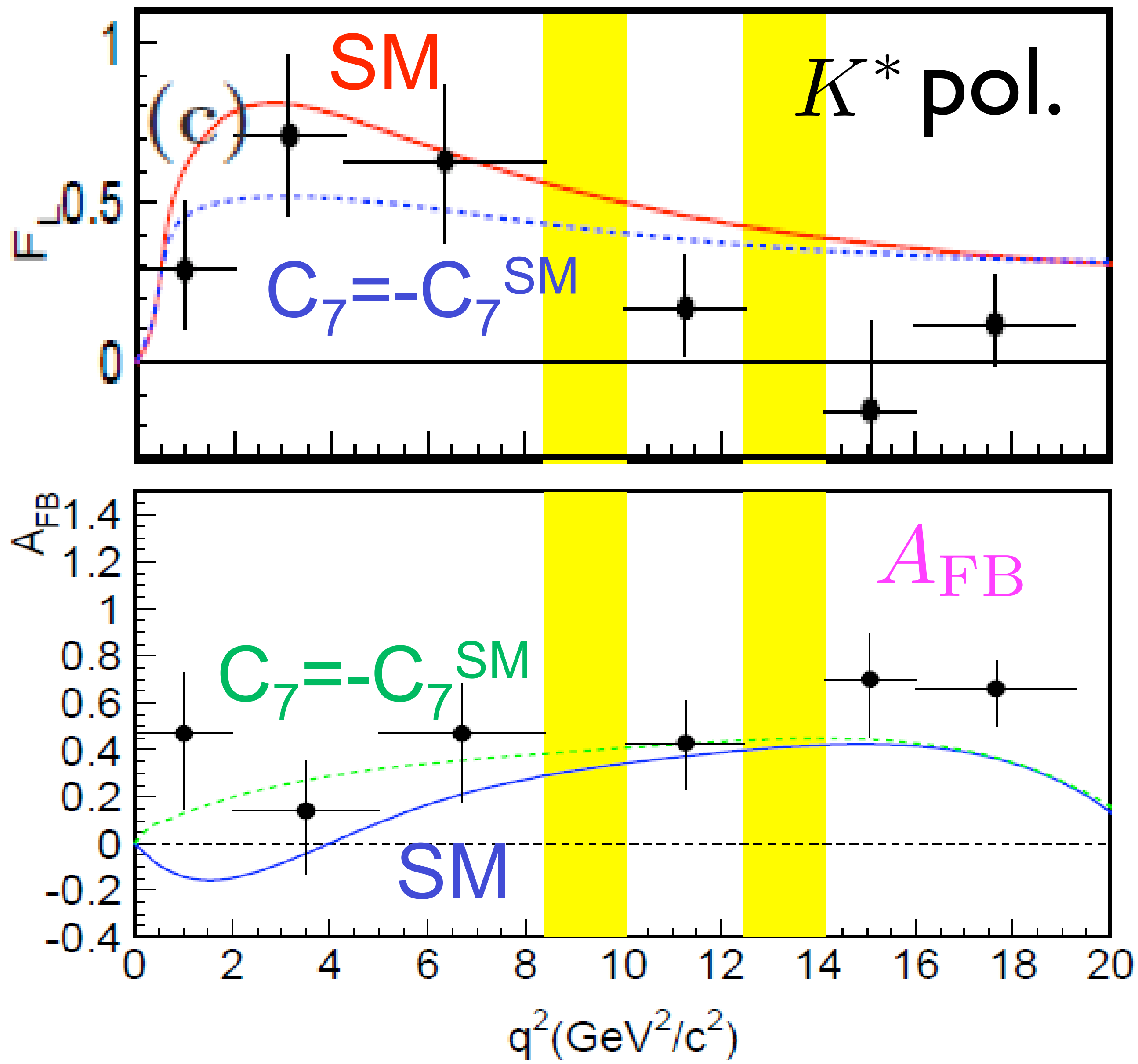
$$O_9 = \frac{e^2}{16\pi^2} (\bar{s}_{L\alpha}\gamma_\mu b_{L\alpha})(\bar{l}\gamma^\mu l),$$

$$O_{10} = \frac{e^2}{16\pi^2} (\bar{s}_{L\alpha}\gamma_\mu b_{L\alpha})(\bar{l}\gamma^\mu \gamma_5 l).$$

$$\mathrm{BR}(b \to s\gamma) \propto |C_7|^2$$

657 M BB,

submitted to PRL, arXiv: 0904.0770



Direct CPV in $B \to K\pi$

$$A_{CP}(K^\pm\pi^\mp) \equiv \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

$$A_{CP}(K^\pm\pi^0) \equiv \frac{\Gamma(B^- \to K^-\pi^0) - \Gamma(B^+ \to K^+\pi^0)}{\Gamma(B^- \to K^-\pi^0) + \Gamma(B^+ \to K^+\pi^0)}$$

Belle: $A_{CP}(K^\pm\pi^\mp) = -0.094 \pm 0.018 \pm 0.08$

$A_{CP}(K^\pm\pi^0) = 0.007 \pm 0.03 \pm 0.01$

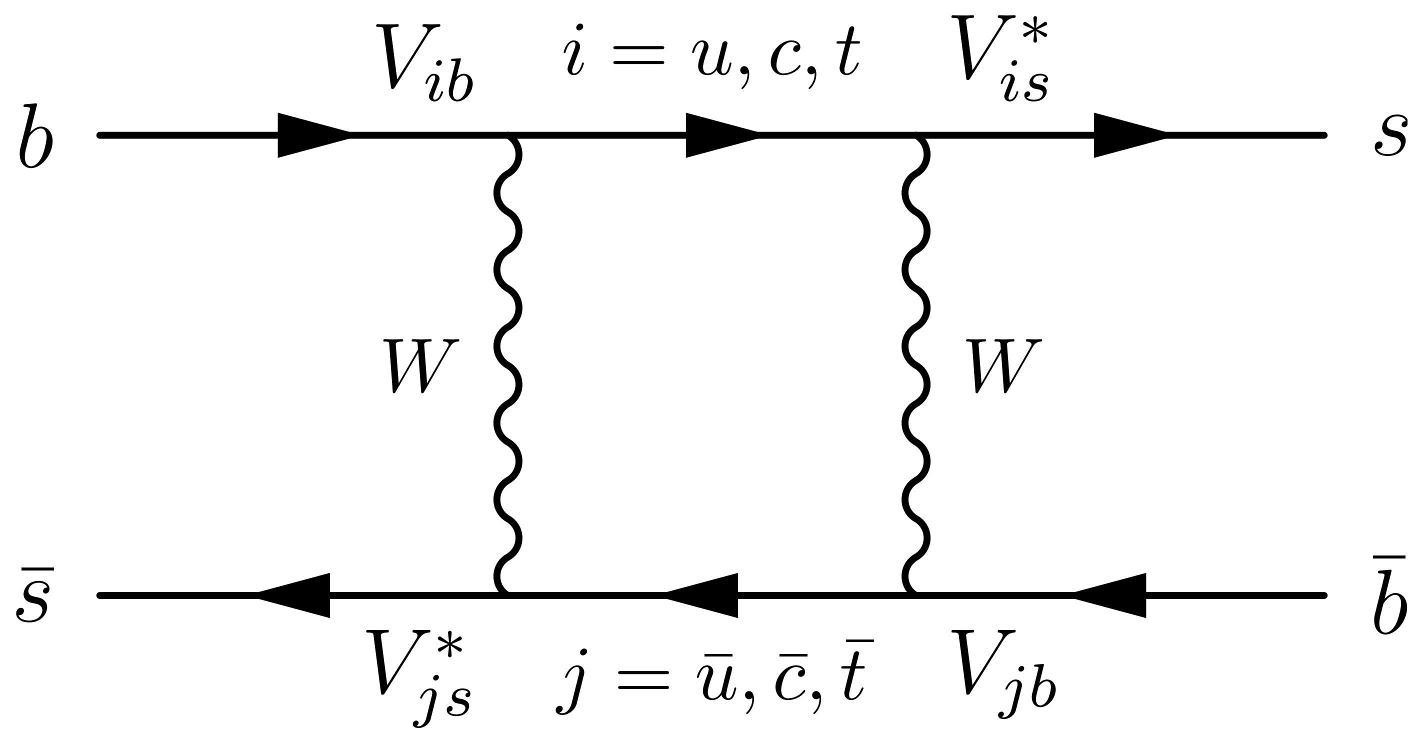
Kπ puzzle: $\Delta A_{CP} \equiv A_{CP}(K^\pm\pi^0) - A_{CP}(K^\pm\pi^\mp)$

$= 0.164 \pm 0.037$ 4.4σ

Naive isospin sym. ⟶ $\Delta A_{CP} \simeq 0$

QCD?

CPV in Bs mixing



$$\sim M_{12} - \frac{i}{2}\Gamma_{12}$$

$$|M_{12}| \gg |\Gamma_{12}| : \ \Delta m \simeq 2|M_{12}|, \ \Delta\Gamma \simeq 2|\Gamma_{12}| \cos\phi_s$$

$$\phi_s \equiv \arg(-M_{12}\Gamma_{12}^*)$$

CDF $\Delta m_s = 17.77 \pm 0.12\,\mathrm{ps}^{-1}$

In the SM, $\phi_s \sim O(\lambda^2) \sim O(10^{-2})$

CPV in $B_s \to J/\psi\,\phi$

$$J/\psi \to \mu^+\mu^-,\ \phi \to K^+K^-$$

$$\frac{d^4\Gamma}{dtd\cos\theta d\varphi d\cos\psi} \propto 2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)|A_0(t)|^2 + \sin^2\psi(1-\sin^2\theta\sin^2\varphi)|A_\parallel(t)|^2 + \sin^2\psi\sin^2\theta|A_\perp(t)|^2$$
$$+ (1/\sqrt{2})\sin2\psi\sin^2\theta\sin2\varphi\mathrm{Re}(A_0^*(t)A_\parallel(t)) + (1/\sqrt{2})\sin2\psi\sin2\theta\cos\varphi\mathrm{Im}(A_0^*(t)A_\perp(t))$$
$$-\sin^2\psi\sin2\theta\sin\varphi\mathrm{Im}(A_\parallel^*(t)A_\perp(t)).$$

$$|A_{0,\parallel}(t)|^2 = |A_{0,\parallel}(0)|^2[\mathcal{T}_+ \pm e^{-\bar{\Gamma}'t}\sin\phi_s\sin(\Delta M_s t)], \qquad |A_\perp(t)|^2 = |A_\perp(0)|^2[\mathcal{T}_- \mp e^{-\bar{\Gamma}'t}\sin\phi_s\sin(\Delta M_s t)],$$

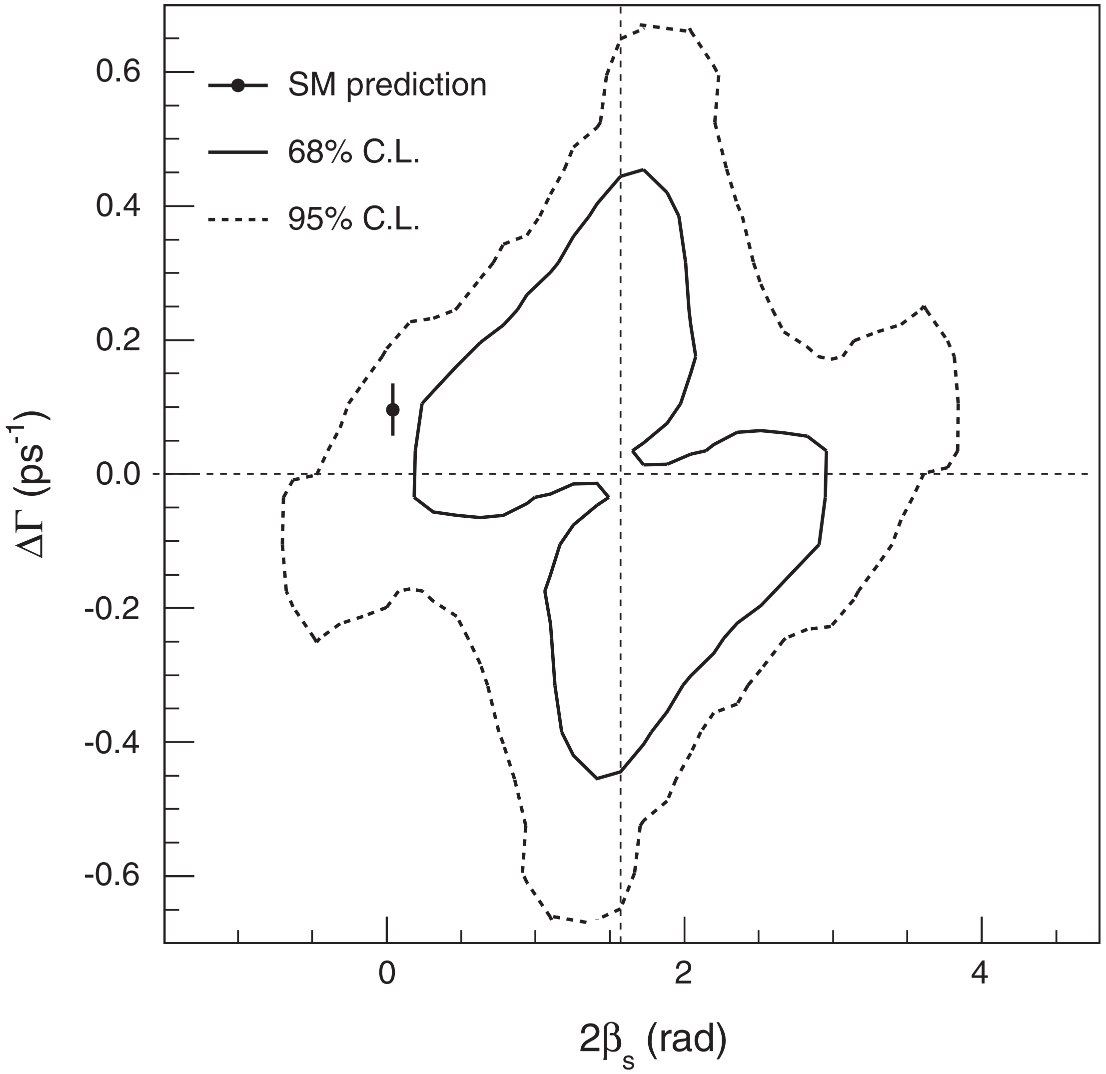
$$\mathrm{Re}\,(A_0^*(t)A_\parallel(t)) = |A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1)\times[\mathcal{T}_+ \pm e^{-\bar{\Gamma}'t}\sin\phi_s\sin(\Delta M_s t)],$$

$$\mathrm{Im}(A_0^*(t)A_\perp(t)) = |A_0(0)||A_\perp(0)|| \times [e^{-\bar{\Gamma}t}(\pm\sin\delta_2\cos(\Delta M_s t) \mp \cos\delta_2\sin(\Delta M_s t)\cos\phi_s)$$
$$-(1/2)(e^{-\Gamma_H t} - e^{-\Gamma_L t})\sin\phi_s\cos\delta_2],$$

$$\mathrm{Im}(A_\parallel^*(t)A_\perp(t)) = |A_\parallel(0)||A_\perp(0)| \times [e^{-\bar{\Gamma}t}(\pm\sin\delta_1\cos(\Delta M_s t) \mp \cos\delta_1\sin(\Delta M_s t)\cos\phi_s)$$
$$-(1/2)(e^{-\Gamma_H t} - e^{-\Gamma_L t})\sin\phi_s\cos\delta_1],$$

$$\mathcal{T}_\pm = (1/2)[(1\pm\cos\phi_s)e^{-\Gamma_L t} + (1\mp\cos\phi_s)e^{-\Gamma_H t}]$$

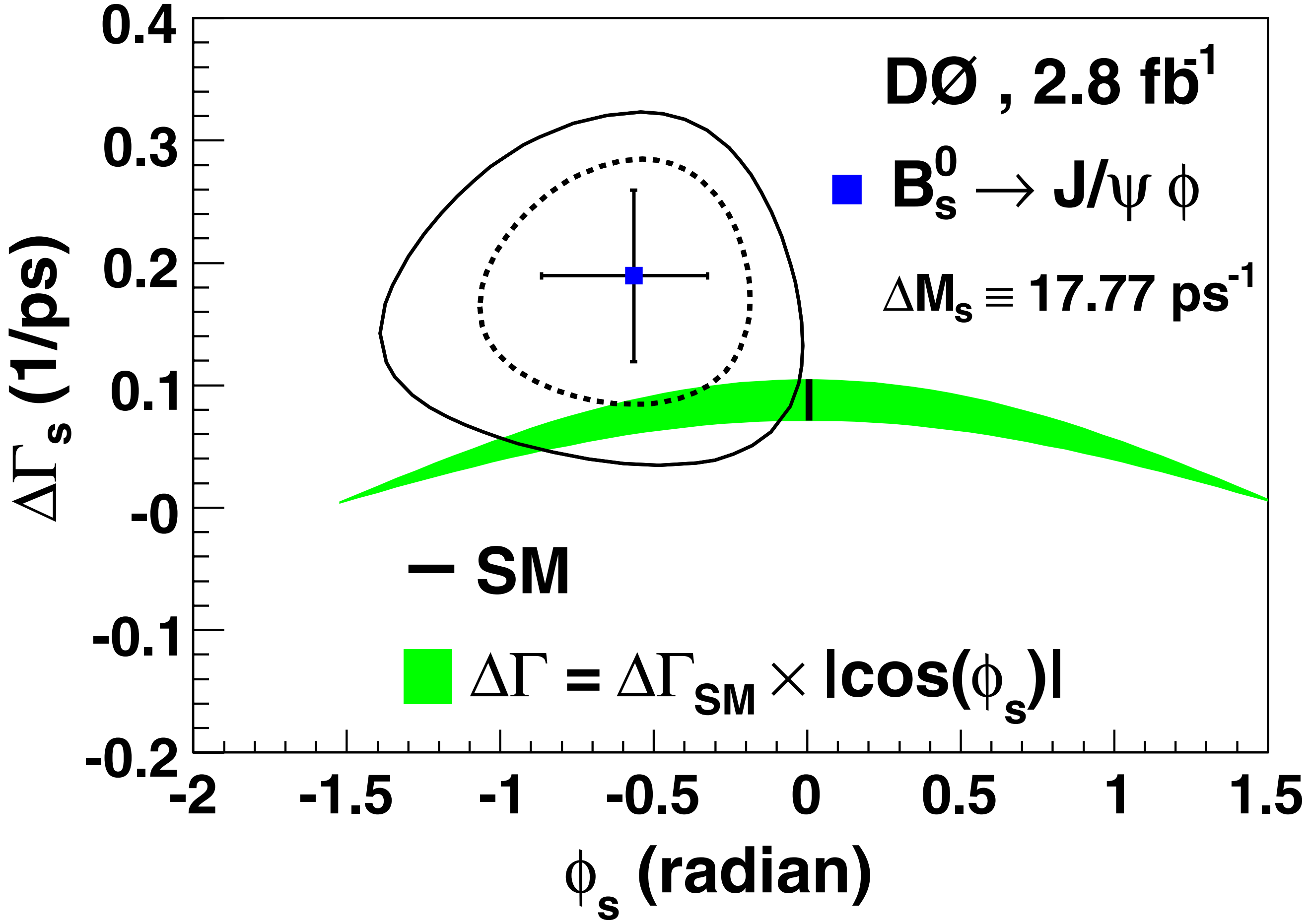
CDF



SM prediction
68% C.L.
95% C.L.
ΔΓ (ps-1)
2βs (rad)

$$= -\phi_s$$

D0



DØ , 2.8 fb-1
B0s → J/ψ φ
ΔMs ≡ 17.77 ps-1
SM
ΔΓ = ΔΓSM × |cos(φs)|
ΔΓs (1/ps)
φs (radian)

New Physics Parameterization

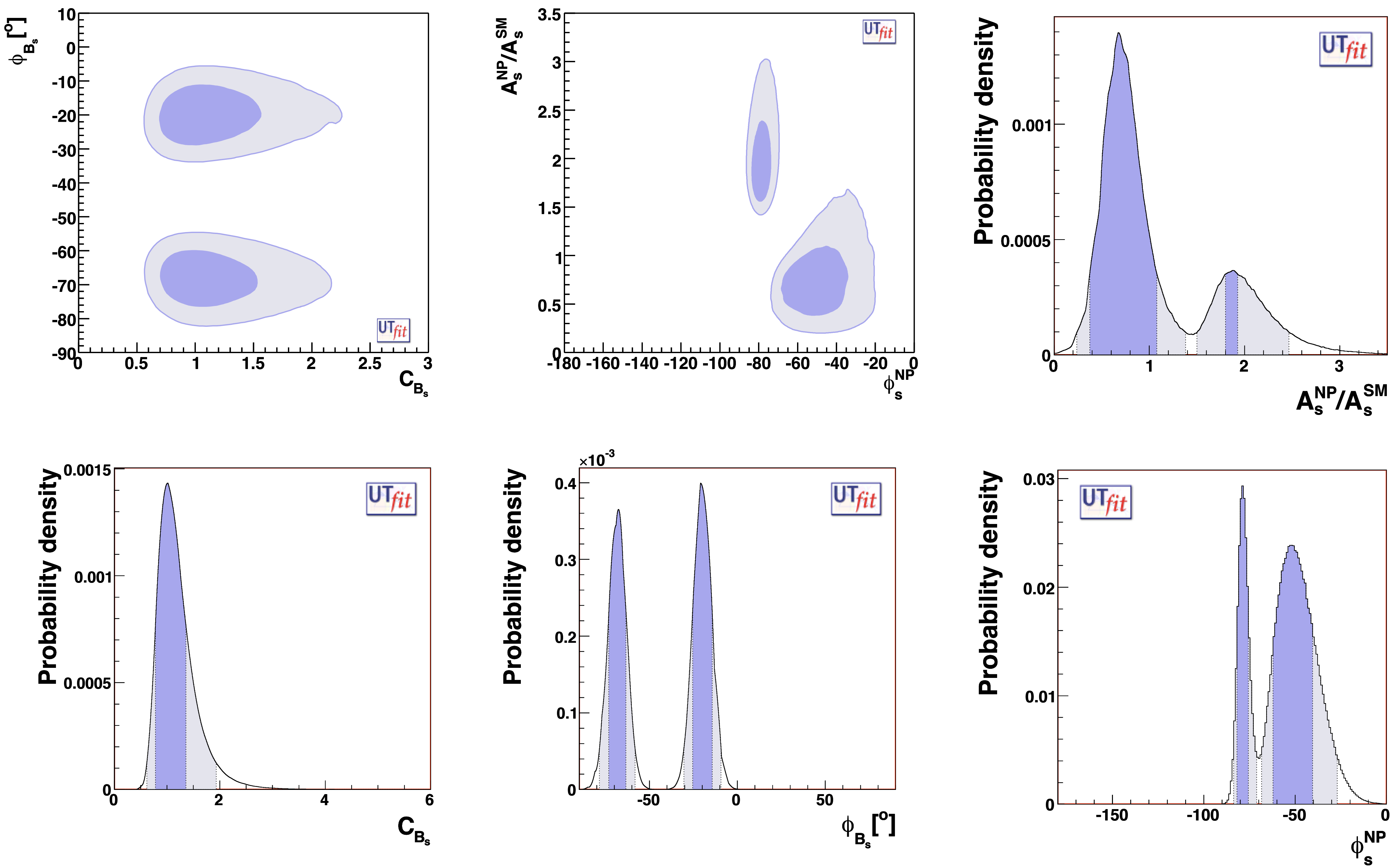
UTfit, arXiv:0803.0659v1 [hep-ph], Mar. 2008

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP}-\beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}} = \frac{M_{12}^{\rm SM} + M_{12}^{\rm NP}}{M_{12}^{\rm SM}}$$

$$= \frac{\langle B_s | H_{\rm eff}^{\rm full} | \bar{B}_s \rangle}{\langle B_s | H_{\rm eff}^{\rm SM} | \bar{B}_s \rangle}\,,$$

$$\phi_s = 2\phi_{B_s} - 2\beta_s$$

$$\beta_s = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \sim O(\lambda^2)$$



3.7σ: Non-MFV NP?

SUMMARY

- CKM scheme seems OK at ~10% accuracy.
- A few % new physics might be there.
- Several inconsistencies exit.

  NP? QCD? Exp.?

  Need more statistics, lattice calculations, phenomenological ideas, etc.
- Interplay between LHC and flavor factories.

  Super KEKB, JPARC K experiments,

  LFV searches, EDM, neutrinos, etc.