Working Group 3 Summary: \( V_{td}, V_{ts}, \) and Friends

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Buchalla

Theoretically “Gold-Plated” relations of BFs to $\lambda_t = V_{td}V_{ts}^*$

$K^+ \rightarrow \pi^+\nu\nu$ rate $\sim |V_{td}V_{ts}^*|^2$

Theory error in $|V_{td}|$ extraction from BF $\sim 10\%$
mostly parametric errors from $m_c, V_{cb}$
Only 5% error from scale dependence

$K_L \rightarrow \pi^0\nu\nu$ rate $\sim (\text{Im } \lambda_t)^2 \sim \eta^2$

Theory error in $\eta$ extraction from BF $\sim 3\%$
**K+ → π⁺νν: Measurement Status**

Jaffe

**BNL E787/E949:**
Stop kaon, measure outgoing pion
Aggressively and redundantly veto huge backgrounds

\[
B(K^+ \to \pi^+\nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10}
\]
\[
\text{SM} = (0.77 \pm 0.11) \times 10^{-10}
\]

Blind analysis
3 candidate events in the signal box
Background probability = 0.001 (>$3\sigma$)

- **Suppression method**
  - Source
  - Kine
  - PID
  - Veto
  - Timing
  - K^+ → μ⁺ν(γ)
    - √
    - √
    - (√)
  - K^+ → π⁺π⁰
    - √
    - √
  - Scattered beam
    - √
    - √
  - CEX
    - √
    - √

Veto includes both γ and charged particle vetoing

No new data expected
15% precision improvement from final analysis
## Rare K Decays: Summary

### What do we know about $K_L^0 \rightarrow \pi^0 \ell^+ \ell^-$, $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ and $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$K^+ \rightarrow \pi^+ \nu \bar{\nu}$</th>
<th>$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$</th>
<th>$K_L^0 \rightarrow \pi^0 e^+ e^-$</th>
<th>$K_L^0 \rightarrow \pi^0 \mu^+ \mu^-$</th>
<th>$\mathcal{B}(\text{SM})$</th>
<th>$\mathcal{B}$(expt)</th>
<th>$\sigma_B/B$</th>
<th>UT</th>
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<tbody>
<tr>
<td>$7 \times 10^{-11}$</td>
<td>$3 \times 10^{-11}$</td>
<td>$4 \times 10^{-11}$</td>
<td>$1 \times 10^{-11}$</td>
<td>$&lt; 3.8 \times 10^{-10}$</td>
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<tr>
<td>$(1.47^{+1.30}_{-0.89}) \times 10^{-10}$</td>
<td>$&lt; 5.9 \times 10^{-7}$</td>
<td>$&lt; 2.8 \times 10^{-10}$</td>
<td>$10%$</td>
<td>$10%$</td>
<td>$\sigma_B/B$</td>
<td>$\mathcal{B}(\text{expt})$</td>
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<tr>
<td>$10%$</td>
<td>$&lt; 2%$</td>
<td>$10%$</td>
<td>$10%$</td>
<td>$10%$</td>
<td>$\sigma_B/B$</td>
<td>$\mathcal{B}(\text{expt})$</td>
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<td>$\text{Im}(\lambda_t)$</td>
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<td>$\text{Im}(\lambda_t)$</td>
<td>$\text{Im}(\lambda_t)$</td>
<td>$\sigma_B/B$</td>
<td>$\mathcal{B}(\text{expt})$</td>
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<td>E787/E949</td>
<td>E391a</td>
<td>NA48/5</td>
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<td>Expts</td>
<td>When</td>
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<td>1989-2002 (+?)</td>
<td>2002-</td>
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<tr>
<td>CKM2, NA48/3</td>
<td>KOPIO</td>
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<td></td>
<td>Expts</td>
<td>When</td>
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<td>2009?</td>
<td>2010-</td>
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$\lambda_t \equiv V_{ts}^* V_{td}$; All limits at 90% CL. * Assumes positive interference (next pages)
$K^0 - \bar{K}^0$ mixing induces indirect CP violation in $K \to \pi\pi$ which is governed by

$$|\epsilon_K| \simeq C e A^2 \lambda^6 \tilde{\eta} \left[ A^2 \lambda^4 (1 - \rho) \eta_2 S(x_t) + P(x_t, x_c, \cdots) \right] c_K(\mu) B_K(\mu)$$

$$c_K(\mu) \langle \bar{K}^0 | (\bar{s}d)_V - (\bar{d}s)_V - (\mu) | K^0 \rangle = \frac{8}{3} M_K^2 f_K^2 \hat{B}_K^{RGI}$$

6. For CKMology, assume no NP in this FCNC process and CKM unitarity
6. many quenched calculations of $B_K$ with different fermion discretizations agree in continuum limit
6. newer calculations performed with “chirally-improved” fermions give value of $B_K$ slightly lower than reference JLQCD ’97 result
6. $\star$ 2 new $N_f = 2$ calculations (C−) (UKQCD ’04, RBC ’05) suggest mild decrease of $B_K$ with $m_{\text{sea}}$
**Recent quenched** \( B_K^{NDR}(2 \text{ GeV}) \)

\[ N_f = 2 \text{ and quenched vs lattice spacing} \]

![Graph showing quenched vs lattice spacing](image)

(Dawson, WG 3)

**Summary** (Dawson, WG3)

\[ \hat{B}_K^{RG} = 0.79(4)(9) \quad [0.86(6)(14) – ICHEP ’02] \]

- central value is average of recent quenched results
- \( N_f = 2 \) used to estimate quenching uncertainty
- \( \delta B_K = 12\% \) of which 10% is (educated) guess of quenching uncertainty
- situation will be clarified by \( N_f = 2 + 1 \) calculations underway
- Non lattice estimates in certain limits of QCD: Peris et al ’00, Bijnens et al ’95 & ’05, ...
$B_{(d,s)}^0 - \bar{B}_{(d,s)}^0$ oscillations in SM

\[
\Delta M_q \simeq \frac{G_F^2}{8\pi^2} M_W^2 |V_{tb}V_{tb}^*|^2 \eta_B S_0(x_t)c_B(\mu) \frac{|\langle \bar{B}_q |(\bar{b}q)V_A(\bar{b}q)\bar{V}_A(\mu)|B_q \rangle|}{2M_{B_d}}
\]

\[
c_B(\mu)\langle \bar{B}_q^0 |(\bar{b}q)V_A(\bar{b}q)\bar{V}_A(\mu)|B_q^0 \rangle = \frac{8}{3} M_{B_q}^2 f_{B_q}^2 \hat{B}_{B_q}
\]

- CKMology assumes no NP in these FCNC processes and CKM unitarity
- In $\Delta M_d/\Delta M_s$, short distance coefficients and many lattice uncertainties cancel
- $f_{B_q}$ and $B_{B_q}$ on lattice separately, because systematics very different
- methods similar as those for $f_{D_{d,s}} \rightarrow$ important rôle of CLEO-c
Extrapolation in light $u$ valence and $u, d$ sea quark necessary for $f_B$ and $B_B$

2002: inclusion large chiral log term could lower value of $f_B$ obtained from extrapolating lattice results obtained w/ $m_u = m_d \gtrsim m_s^{\text{phys}}/2$ (Kronfeld et al)

- by $O(20\%)$ (Yamada; Kronfeld et al)
- by $O(10\%)$ (Lellouch; Becirevic)

★ New results on subset of $N_f = 2+1$, MILC gauge configurations (C on Bernard scale): Wingate et al ’04 and Gray et al ’04 (preliminary)
→ some evidence for log
→ $O(10\%)$ effect
→ will be checked with full $\chi$PT fit

$f_{B_s} \sqrt{M_{B_s}} / f_B \sqrt{M_B}$ from Kronfeld WG3

Not an issue for $B_B$, $B_{B_s}$ and $f_{B_s}$
Lattice summary:

<table>
<thead>
<tr>
<th>Qty</th>
<th>Lellouch</th>
<th>Hashimoto</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICHEP 2002</td>
<td>ICHEP 2004</td>
</tr>
<tr>
<td>$f_B \hat{B}_B^{1/2}$</td>
<td>235(33)(±0.24)</td>
<td>214(38)</td>
</tr>
<tr>
<td>$f_{B_s} \hat{B}_{B_s}^{1/2}$</td>
<td>276(38)</td>
<td>262(35)</td>
</tr>
<tr>
<td>$\xi$</td>
<td>1.18(4)(±0.12)</td>
<td>1.23(6)</td>
</tr>
</tbody>
</table>

(QCD sum-rules results:

$f_B = 210(19)$ MeV,

$f_{B_s} = 244(21)$ MeV (Jamin et al '02)

$\hat{B}_B = 1.60(3)$ (Körner et al '03)

(Decay constants in MeV)

6 Evidence for chiral logs in $f_{B_s} \rightarrow$ central value shifts to middle of asymmetric error range

6 Summary numbers are $C^-$ results

6 * Expect $C^+ - B^-$ results in coming year or so ($N_f = 2 + 1$ staggered at more than 1 lattice spacing)

   $\rightarrow$ most of chiral extrapolation error will be statistical

6 Also need non-staggered $N_f = 2 + 1$ results to check assumptions and methods used

6 $\delta_{th}|V_{td}| \simeq 20\%$ from $\Delta M_d$

6 $\delta_{th}|V_{td}/V_{ts}| \simeq 5\%$ from $\Delta M_d/\Delta M_s$
**$B_s$ Mixing Measurements**

CKM fits expect $\Delta m_s \approx 14$-24 ps$^{-1}$

World average
“Amplitude scan”
$\Delta m_s > 14.5$ ps$^{-1}$

- naïve picture:
  fit time-dependant asymmetry:

\[ A_{\text{mix}}(t) = \frac{N_{\text{unmix}}(t) - N_{\text{mix}}(t)}{N_{\text{unmix}}(t) + N_{\text{mix}}(t)} = D \cdot \cos(\Delta m t) \]

- in reality, perform amplitude scan using likelihood fit (discussed in more detail later)

\[ \text{Signif} = \sqrt{\frac{N e D^2}{2}} e^{\frac{(\Delta m_s \sigma_t)^2}{2}} \frac{S}{S + B} \]
DØ $B_s$ Mixing in Semileptonics

- $B_s \rightarrow D_s \mu X$ (460 pb$^{-1}$)
  - $D_s \rightarrow \phi\pi$
  - Enhanced opposite side $\mu$ tag
  - 7037 events (376 tags)
  - $\varepsilon D^2 = (1.17 \pm 0.04)\%$

**Abbott**

Limit: $\Delta m_s > 5.0 \text{ps}^{-1}$ @95% CL
Sensitivity: 4.6 ps$^{-1}$

DØ Run II Preliminary
CDF $B_s$ Mixing in Semileptonics

- $B_s \rightarrow D_s + \text{lepton (e/\mu)}$
  - $D_s \rightarrow \phi\pi, K^*K, \pi\pi\pi$
  - 4355 events
  - Trigger: 4GeV $e/\mu + $ track
  - Opposite side flavor tags $e, \mu, \text{jetcharge}\epsilon D^2 = (1.43 \pm 0.09)\%$

**Limit:** $\Delta m_s > 7.7\text{ps}^{-1}$ @95% CL

**Sensitivity:** $7.3 \text{ ps}^{-1}$

For both CDF+D0, semileptonic decays rapidly lose ct resolution at realistic $\Delta m_s$
CDF Hadronic B decays

Improvements: Hadronic

- assuming 4x effective statistics lowers the sensitivity curve
- 20% improvement in ct resolution further flattens sensitivity curve in the region of interest

more statistics
better ct resolution
**$B_s$ Mixing, Roadmap to Improvement**

- More integrated luminosity
- Better flavor tagging (same-side K tag)
- Improve proper time resolution (event-by-event vertexing)
- Hadronic decays matter more for larger $\Delta m_s$
- D0 tracking upgrade (add small radius silicon this summer)
- DAQ/trigger/offline upgrades
- Peril: can present trigger efficiency be maintained at high instantaneous luminosity?

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**Abbott**

**D0 projections**
Friends of $B_s$ mixing: leptonic D decays

$$\Gamma(D^+ \rightarrow l^+ \nu) = \frac{G_F^2}{8\pi} \int f_D^2 \frac{m_l^2}{M_{D^+}} \left(1 - \frac{m_l^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

Extract $f(D^+)$ from $D^+ \rightarrow \mu \nu$ decay rate

30k fully reconstructed $\psi'' \rightarrow D^+D^-$ events
8 signal events with missing mass = 0

Can improve to 3% precision for $f(D^+)$

$f(D_{s^+})$ 2% precision expected from $\psi(3770) \rightarrow D_{s^+} D_{s^-}$ running ($\tau \nu$ and $\mu \nu$)

BF($D^+ \rightarrow \mu \nu$) = $3.5 \pm 1.4 \pm 0.6 \times 10^{-4}$

$f(D^+)$ = $202 \pm 41 \pm 17$ MeV

LAT = $225 \pm 13 \pm 21$ MeV

D decay constants and their ratios check or bound errors of lattice estimates of B decay constants
Friends of $B_s$ Mixing: $B$ mixing and lifetime

Further improvement in $B^0$, $B^+$ lifetime and $B^0$ mixing from $B$ factories

Asymmetry vs. $|\Delta t|$

$< 1\%$ $B$ factory precision on lifetime and mixing

Mixing and lifetimes from $B$ factories could ultimately improve by another $2x$

$\Delta m_d = (0.514 \pm 0.005) \text{ ps}^{-1}$

$\tau_{B^0} = (1.532 \pm 0.011) \text{ ps}$
$b$-hadron lifetime ratios and width differences: theory

Review by Tarantino in WG 3

$$\Gamma_{H_q} \sim \text{Im} \langle H_q | T | H_q \rangle \quad \Delta \Gamma_q \sim \text{Im} \langle \bar{B}_q | T | B_q \rangle$$

$$T = i \int d^4 x \ T \{ H_{\Delta B=1}^{\Delta B=1}(x) H_{\Delta B=1}^{\Delta B=1}(0) \}$$

$m_b \gg \lambda_{QCD}$ allows short distance expansion in $\alpha_s(m_b)$ and $1/m_b$

Lifetime ratios and width differences differ from 1 and 0 at order $1/m_b^3$, when spectator effects appear

**Lifetime ratios**

- $O(\alpha_s)$ (Beneke et al, Franco et al ’02)
- $\ast O(1/m_b^4)$ estimated (Gabbiani et al ’04)
- $O(\alpha_s)$ penguins neglected

**Width differences**

- $O(\alpha_s)$ (Beneke et al, Ciuchini et al ’03)
- $O(1/m_b^4)$ estimated (Beneke et al ’96)
- $\ast O(1/m_b^5)$ in progress (Lenz et al)
Lifetime ratios

- \( O(1/m_b^3), \Delta B=0 \) matrix elements computed in quenched approximation for mesons (Di Pierro et al '98, APE '01) and baryons (Di Pierro et al '99)
- for mesons also with sum rules (Baek et al '98)
- agreement less good for color suppressed matrix elements
- NLO corrections can be large, as are \( O(1/m_b^4) \) for \( \tau(\Lambda_b)/\tau(B_d) \)
- \( O(30-40\%) \) uncertainties in deviation from 1
- effect of neglected penguins on \( \tau(\Lambda_b)/\tau(B_d) \)?

Width differences

- \( O(1/m_b^3), \Delta B=2 \) matrix elements computed in quenched approximation (Gimenez et al '00, Hi-KEK '00, APE '01-'02) and with \( N_f = 2 \) (JLQCD '01-'03)
- results are consistent
- NLO corrections of order \( -35\% \)
- estimated \( 1/m_b^4 \) corrections further reduce LO result
- \( O(30-40\%) \) uncertainties in deviation from 0
Abbott

\[ \frac{\Delta \Gamma_s}{\Gamma_s} : \text{new D0 measurement consistent with predictions} \]

- New DØ result
  \[ \frac{\Delta \Gamma_s}{\Gamma_s} = 0.21 \pm 0.33 - 0.45 \text{(stat.+syst.)} \]
- Constrain \( \tau_{\text{Bs}} = 1.39 \text{ ps} \)
  \[ \frac{\Delta \Gamma_s}{\Gamma_s} = 0.23 + 0.16 - 0.17 \text{(stat.+syst.)} \]

Tarantino

HFAG measurements

\[ \frac{\tau(B^+)}{\tau(B_d)} = 1.081 \pm 0.015, \quad \frac{\tau(B_s)}{\tau(B_d)} = 0.939 \pm 0.044, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.803 \pm 0.047 \]

Recent predictions and measurements exhibit no serious “lifetime puzzle”
Radiative Penguin

Nishida

Radiative B decays: penguin diagram

\[ b \rightarrow s \gamma \] process has been studied.
Branching fraction.
Charge and isospin asymmetry.
Mixing induced CP asymmetry.

But, \( b \rightarrow d \gamma \) is not observed yet.

- Suppressed by \( |V_{td} / V_{ts}|^2 \) in SM.
- Search for \( B \rightarrow \rho \gamma, \omega \gamma \) has been done.

\[ \frac{V_{td}}{V_{ts}} \approx 0.04 \]
Search for $B \rightarrow \rho \gamma$, $B \rightarrow \omega \gamma$

Search for $B^+ \rightarrow \rho^+ \gamma$, $B^0 \rightarrow \rho^0 \gamma$, $B^0 \rightarrow \omega \gamma$

Isospin relation

$\mathcal{B}(B \rightarrow (\rho, \omega) \gamma) \equiv \mathcal{B}(B^+ \rightarrow \rho^+ \gamma)$

$= 2(\tau_{B^+}/\tau_{B^0}) \mathcal{B}(B^0 \rightarrow \rho^0 \gamma)$

$= 2(\tau_{B^+}/\tau_{B^0}) \mathcal{B}(B^0 \rightarrow \omega \gamma)$

Analysis

- Severe continuum background.
- $b \rightarrow s \gamma$ (esp. $B \rightarrow K^* \gamma$) background.
- Non-negligible $BB$ background.

Simultaneous fit to 3 modes ($+B \rightarrow K^* \gamma$)

SM prediction: $\mathcal{B}(B \rightarrow (\rho, \omega) \gamma) = (0.9-1.8) \times 10^{-6}$
\( b \rightarrow d \gamma \) Branching Fractions: Exclusive

\[ \bar{B}[B \rightarrow (\rho, \omega) \gamma] = \frac{1}{2} \left\{ \mathcal{B}(B^+ \rightarrow \rho^+ \gamma) + \frac{\tau_{B^+}}{\tau_{B^0}} \left[ \mathcal{B}(B^0_d \rightarrow \rho^0 \gamma) + \mathcal{B}(B^0_d \rightarrow \omega \gamma) \right] \right\} \]

Central value 90\% C.L. upper limit

Combined significance Belle+BaBar = 2.6 \sigma

5\sigma observation in 1-2 years
\[ |V_{td}/V_{ts}| \quad \text{from} \quad \mathcal{B}(B \to \rho \gamma)/\mathcal{B}(B \to K^* \gamma) \quad \text{(talk by S. Bosch)} \]

Bosch

The \( \rho^0/K^*0 \) modes are theoretically the cleanest.

The ratio of their CP-averaged branching fractions reads

\[ R_0 \equiv \frac{\mathcal{B}(B^0 \to \rho^0 \gamma) + \mathcal{B}(\bar{B}^0 \to \rho^0 \gamma)}{\mathcal{B}(B^0 \to K^*0 \gamma) + \mathcal{B}(\bar{B} \to K^*0 \gamma)} = \frac{K}{2\xi^2} \left| \frac{V_{td}}{V_{ts}} \right|^2 (1 + \Delta), \]

where

\( K = 1.023 \) — kinematic factor.

\( \xi \) — ratio of heavy-to-light formfactors (\( \xi \to 1 \text{ when } m_d \to m_s \)).

"SU(3) limit"

\( \Delta \) — subleading contributions:

(i) weak annihilation (suppression by \( C_1 + \frac{1}{3}C_2 \approx -0.2 \) and \( \Lambda/m_b \))

(ii) (penguin)\(_c\)–(penguin)\(_u\) (suppression by \( m_c^2/m_b^2 \approx 0.1 \))

\( \Delta \) depends on the CKM parameters. In the domain of interest for the SM (\( 0.3 < \sqrt{\rho^2 + \eta^2} < 0.5, \quad \frac{\pi}{4} < \gamma < \frac{\pi}{2} \)), the CKM factor in \( \Delta \) becomes a suppression factor \( \sim 0.2 \). Consequently, \( |\Delta| < 0.04 \Rightarrow \) Uncertainties in \( \Delta \) have little effect on the determination of \( |V_{td}/V_{ts}| \).

What is the value of \( \xi \)?

23
\[ B(B \to \rho\gamma)/B(B \to K^*\gamma) \]

- Ratio \( R_0 \) of neutral branching fractions \( \sim \xi = F_{K^*}/F_\rho \)
- \( R_0 \) theoretically clean
- \( R_t = 0.82 \frac{\xi}{1.3} \sqrt{\frac{R_0}{0.01}} \) within \( \pm 3\% \)

\( \xi_{\text{LCSR}} = 1.25 \pm 0.20 \) 
\( \xi_{\text{LQCD}} = 1.1 \pm 0.1 \)

\( \xi = 1.2 \pm 0.1 \) 

vary \( \xi \)

Inclusive ratio \( b \to d\gamma/b \to s\gamma \)
better theory errors for \( V_{td}/V_{ts} \), but might need SuperB factory
Other Penguin Decays

Hollar, Feldmann

\[ B \rightarrow K^{(*)}ll, \ s \ ll \ \text{branching fractions measured by B factories and theory error already dominant} \]

More will be learned from distributions and asymmetries

\[ B \rightarrow \pi \ ll \ \text{has possibility for observation at B factories (not background limited)} \]

\[ \rho ll \ \text{much harder} \]
Challenges

A list of future challenges to the Workshop participants.
Challenges

To the Tevatron: Now that you have a good shovel, break substantial new ground with it for $\Delta m_s$ constraints.

Upgrades, better tagging, better vertexing, more luminosity, better DAQ, Whatever it takes! The flavor physics community is cheering you on!
To the Lattice community: Raise the “letter grade” above “C” level for $f_B, B_B$ et al., so that the impact of future Tevatron results is maximized.

$$f_{B_s} = 260 \pm 7 \pm 28 \text{ MeV} \quad \text{[HPQCD]}$$

$$\hat{B}_{B_s} = 1.31 \pm 0.10 \quad \text{[JLQCD; Lattice2003]}$$

$$\xi_B = 1.022 \pm 0.018 \quad \text{[JLQCD; Lattice2003]}$$

$$\xi = 1.25 \pm 0.10 \quad \text{[Lattice2003]}$$

Andreas Kronfeld

My grade in Claude’s scheme

To CLEO-c et al.: Continue to keep the lattice community honest!
Challenges

To the B factories: Measure a clear signal for $B \to \rho \gamma$ or drive lower limit off the (CKM) map!
To the heavy quark theory community: Improve and/or realistically bound the impact of penguins on $V_{td}/V_{ts}$ et al. The measurements are there and ready to be exploited now!
To the Kaon physics community: Keep your future projects alive (and Andrzej out of retirement). The small theory errors mean these may ultimately be the best attainable CKM constraints on $V_{td}$ and $\eta$. 