WG 2 – Theory Summary

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- τ decays & CP violation
- lepton flavour violation
- K decays & CP violation
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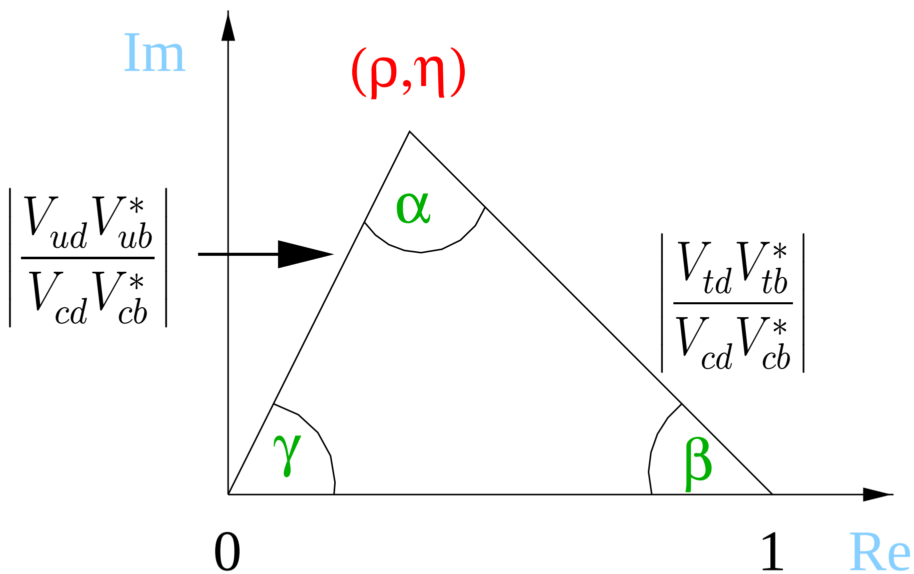

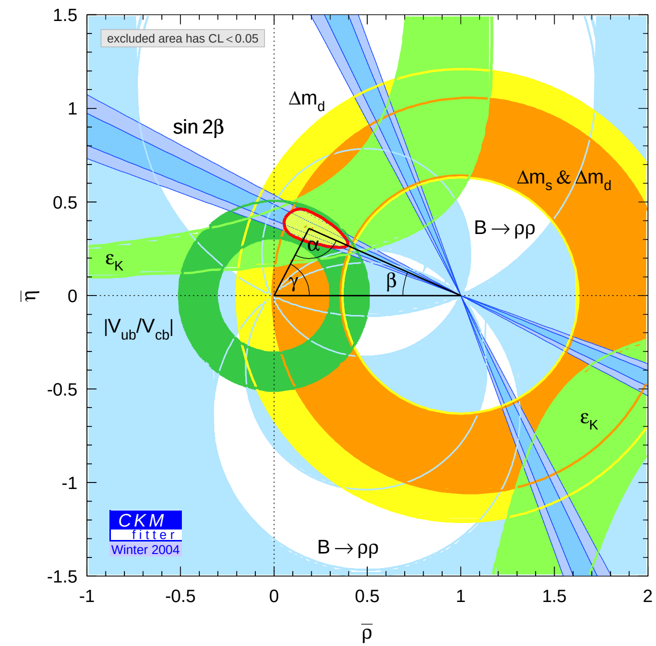

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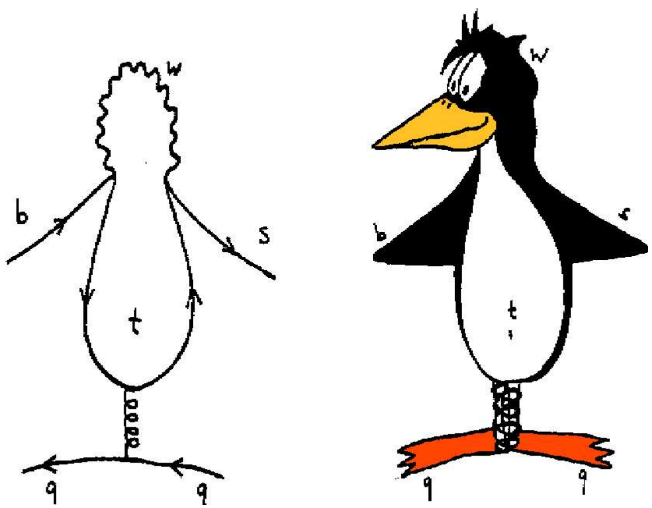
Exp. facilities:

- Tevatron: en route to B_s mixing
- BaBar (1999–2009) and Belle (1999–?): $\sim$500M B decays on tape
  LHCb: 2007+2 (?)
- K facilities at KEK, BNL;
  more planned at BNL (KOPIO), CERN (NA48/3), FNAL. . .

Why Flavour Physics?

- find/constrain new physics,
  e.g. in FCNC (flavour-changing neutral currents):



(penguin diagram)

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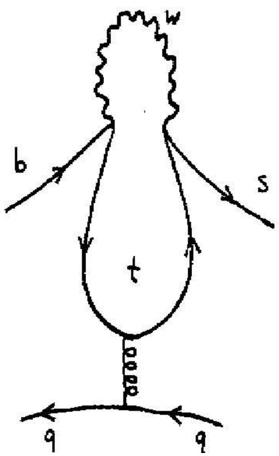
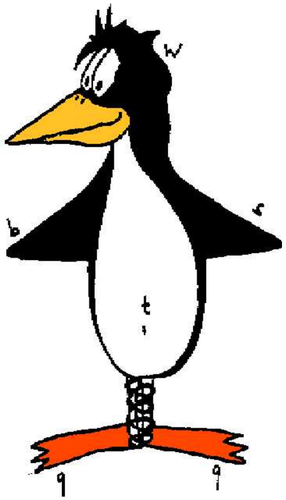




(penguin diagram)

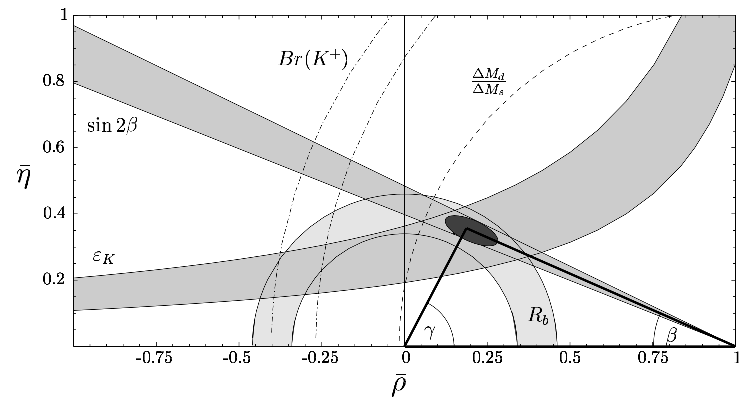
SM loop–suppressed, new physics contributions (SUSY?) possibly of same size as SM

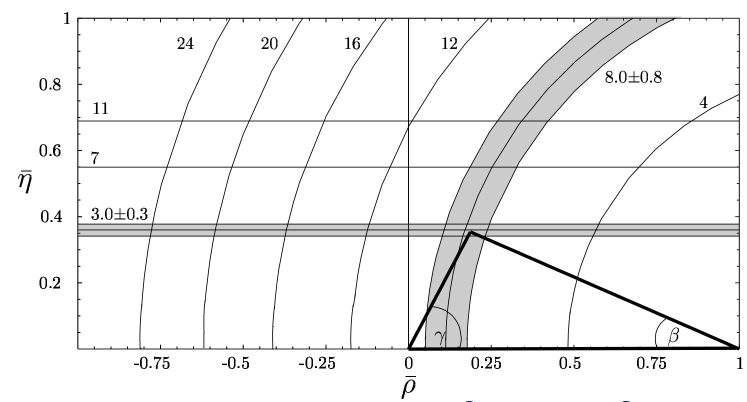
- complementary to LHC: mass scales from LHC,
  couplings from B physics
  or, if it will be built, a linear collider

M. Gorbahn: $K \to \pi\nu\bar{\nu}$

Future scenario for $K \to \pi\nu\nu$

- $K_L \to \pi^0 \nu\bar{\nu}$
  - Direct CP violating $\propto \mathrm{Im} V_{ts}^* V_{td} = \eta$
  - Only top $\to$ theory uncertainty $< 3\%$
- $K^+ \to \pi^+ \nu\bar{\nu}$
  - $\propto V_{ts}^* V_{td}$
  - Small theory uncertainty
- Experiment
  - Precision test of the Unitarity Triangle
  - And the Flavour Sector





Theory uncertainty for $K^+ \to \pi^+\nu\bar{\nu}$ larger than for $K^0 \to \pi^0\nu\bar{\nu}$ (charm quark contributions).
NNLO calculation underway (Gorbahn et al.).

F. Mescia: B Mixing and Lifetimes

Theoretical inputs for

- mass differences Δm_d, Δm_s
  - needed for unitarity triangle determination & bounds on/evidence for new physics
- width differences $\Delta\Gamma_d$, $\Delta\Gamma_s$
  - input for time-dependent CP-asymmetries in B_s decays & bounds on/evidence for new physics

Method of choice: lattice calculations

Main problems:

- simulation of heavy quarks $m_b \gg 1$ GeV
- simulation of light quarks $m_d \ll 1$ GeV
- inclusion of sea quarks (unquenched calculations)

F. Mescia: B Mixing and Lifetimes

Summarizing from Lattice QCD

Observable	$\|\varepsilon\|$	ΔM_{B_s}	$\frac{\Delta M_{B_s}}{\Delta M_{B_d}}$	$B \to (\begin{smallmatrix}\pi \\ \rho\end{smallmatrix}) l\nu$	$B \to (\begin{smallmatrix}D \\ D^*\end{smallmatrix}) l\nu$
CKM	$\mathrm{Im}[V_{td}]$	$\|V_{ts}\|^2$	$\|V_{ts}\|^2/\|V_{td}\|^2$	$\|V_{ub}\|^2$	$\|V_{cb}\|^2$
Matr. Elem.	$\hat{B}_K$	$f_{B_s}^2 \hat{B}_{B_s}$	$\frac{f_{B_s}^2 \hat{B}_{B_s}}{f_{B_d}^2 \hat{B}_{B_d}}$	$\|\langle \begin{smallmatrix}\pi \\ \rho\end{smallmatrix} \| J_L^{ub} \| B\rangle\|^2$	$\|\langle \begin{smallmatrix}D \\ D^*\end{smallmatrix} \| J_L^{cb} \| B\rangle\|^2$
Err. in Quen.	7%	10%	6%	30%	8%
(Error	15%	25%	10%	-	3%
Proj. error	5%	10%	5%	20%	6%

At present

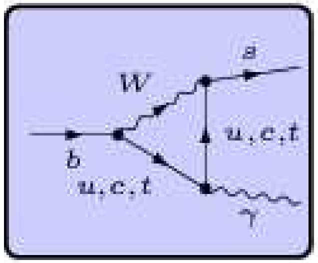
- If we are able to run full QCD simulations with machines $\mathcal{O}(1-10)$ Tflops

$$L = 2.0 - 2.5\,\mathrm{fm} \qquad \frac{m_\pi}{m_\rho} = 0.25 - 0.5 \qquad a = 0.05 - 0.10\,\mathrm{fm}$$

- **Expected results in coming year and so:**

Staggered, TmQCD … fermions… at more lattice spacings (continuum limit) and smaller masses.

M. Gorbahn: Inclusive Rare B Decays: $b \to s\gamma$



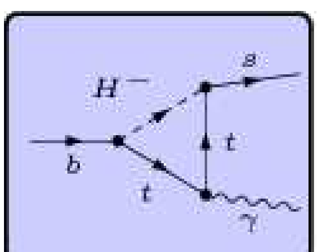
$$
\begin{array}{lll}
\text{top loop} & \propto V_{tb}V_{ts}^* = \mathcal{O}(\lambda^2) & \to -100\% \\
\text{charm loop} & \propto V_{cb}V_{cs}^* \approx -V_{tb}V_{ts}^* & \to +200\% \\
\text{up loop} & \propto V_{ub}V_{us}^* = \mathcal{O}(\lambda^4) & \to 0
\end{array}
$$

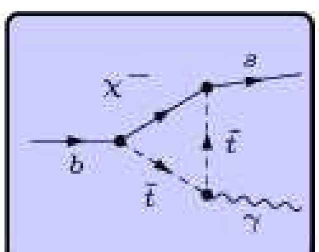
including LO QCD

In the SM forbidden at tree level & CKM suppressed

Precision test of the flavour sector

Enhanced sensitivity to new physics





- Charged Higgs contribution enhance $b \to s\gamma$
- Different new physics contributions have to cancel

NLO analysis available (Gambino/Misiak '01), NNLO underway (Gorbahn et al.)

M. Gorbahn: Inclusive Rare B Decays: $b \longrightarrow s\gamma$

Error Anatomy of $\mathrm{BR}(\bar{B} \to X_s\gamma)$

- Following the analysis of Gambino Misiak

$$
\begin{aligned}
\mathrm{BR}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6\mathrm{GeV}} = 3.61 \times 10^{-4} \times \\
(1 \pm 0.06_{m_c/m_b} \pm 0.04_{\mathrm{otherNNLO}} \\
\pm 0.01_{(\mathrm{pert\,C})} \pm 0.02_{\lambda_1} \pm 0.02_{\Delta} \\
\pm 0.02_{\alpha_s(M_Z)} \pm 0.02_{\mathrm{BR(semilept)_{exp}}} \pm 0.01_{m_t}) \\
= (3.61 \pm 0.30) \times 10^{-4}
\end{aligned}
$$

- Total 8% error dominated by charm mass
- This will be improved by going to NNLO

Comparing Theory and Experiment

- Integrating over low-q^2 region:

$$\mathrm{BR}_{1<q^2/\mathrm{GeV}^2<6} = (1.57 \pm 0.11|_{m_t} \pm 0.07|_{m_b} \pm 0.07|_{\mu} \pm 0.05|_{c\bar{c}} \pm 0.05|_{C}) \times 10^{-6}$$

- Integrating over high-q^2 region:

$$\mathrm{BR}_{14.4<q^2/\mathrm{GeV}^2} = (4.02 \pm 0.71|_{m_b} \pm 0.24|_{m_t} \pm 0.13|_{\mu} \pm 0.13|_{c\bar{c}} \pm 0.12|_{C}) \times 10^{-7}$$

- Integrating the non-resonant differential rate

$$\mathrm{BR}_{SM} = (4.58 \pm 0.18 \pm 0.66) \times 10^{-6}$$

- Agrees with experiments

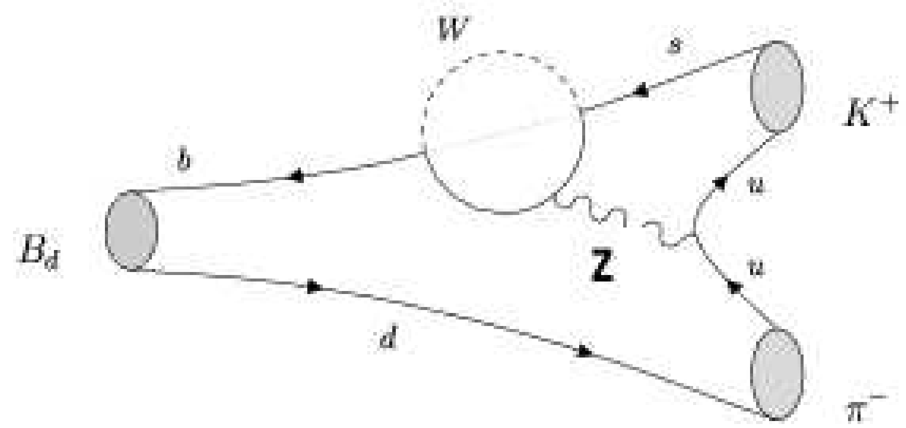
$$\mathrm{BR}_{BaBar} = 5.6 \pm 1.5 \pm 0.6 \pm 1.1 \times 10^{-6} \qquad \mathrm{BR}_{Belle} = 4.11 \pm 0.83^{+0.85}_{-0.81} \times 10^{-6}$$
$$\mathrm{BR}^{<6\mathrm{GeV}}_{BaBar} = 1.8 \pm 0.7 \pm 0.5 \times 10^{-6} \qquad \mathrm{BR}^{<6\mathrm{GeV}}_{Belle} = 1.493 \pm 0.503^{+0.382}_{-0.283} \times 10^{-6}$$

Theory improvement (NNLO) underway!

F. Schwab: $B \to \pi\pi$, $B \to K\pi$

- measurements in $B \to \pi\pi$: 3 BRs, 4 CP asymmetries
- measurements in $B \to K\pi$: 4 BRs, 5 CP asymmetries
- theory: QCD factorisation (Beneke et al.) unable to describe data (more than 4σ for some BRs)
- alternative: SU(3) symmetry (Buras/Fleischer et al.): extract hadronic parameters from $B \to \pi\pi$, plug into $B \to K\pi$: discrepancies attributed to

  enhanced electroweak penguins:



- induces **large effects in $K \to \pi\nu\bar{\nu}$**

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- theory predictions based on
  - expansion in α_s
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- theoretical accuracy $\sim$ 2% limited by higher order perturbation theory & terms suppressed by $1/m_b^4$ and higher

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Extracting CKM parameters with accuracy seemingly unrealistic less than 10 years ago --
with detailed & defensible error budgets from theorists!

- δV(cb) ~ 2 % now, ~ 1 % soon
- δV(ub) ~ 5 % conceivable

without new theoretical breakthrough

Progress based on two key elements:

- robust theory subjected to the challenges of
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  - precision, i.e. small defensible uncertainties

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Shape functions? (Neubert et al.)
But $O(1/m_b)$ unknown!
Intrinsic theory error $\sim$ 20%?

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- conclusion for unitarity triangle determination:
  - all sides and angles accessible with <10% th. uncertainty:
    - need more data for γ from $B \to DK$
    - $|V_{ts}V_{td}^*|$, Im $V_{ts}V_{td}^*$ from $K \to \pi\nu\bar{\nu}$
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