Project B4: Field Theoretic Aspects of New Physics

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First SFB Colloquium
Hamburg, 26 October 2006

1. Mission
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1. Mission

- Rule: Mixing and instability of elementary particles concur in nature
- Status of field theory treatment:
  - Renormalization of CKM matrix for stable quarks satisfying UV finiteness, gauge independence, unitarity and flavour democracy
  - Renormalization of masses and wave functions of unstable particles without mixing satisfying gauge independence (pole scheme)
- Mission for SFB: Construct *pole scheme of mixing renormalization for unstable particles* that unifies both aspects in a physically consistent and mathematically rigorous way
- Methods: higher-order perturbation theory in R_ξ gauge, S-matrix theory, BRST symmetry, Nielsen identities, modern computer algebra
- Milestones:
  - $t \longrightarrow bl^+\nu_l$ in the SM as starting point: proper treatment of imaginary parts due CKM matrix and absortive parts

  - Incorporation of (Majorana) neutrinos: required by experimental evidence for flavour oscillations and finite masses in neutrino sector
  - Incorporation of bosons: mixing of unstable sfermions in MSSM scenarios
  - Generalization to all orders: proof on the basis of BRST symmetry exploiting Nielsen identities
  - Applications to new-physics scenarios: reliable predictions for most important production and decay processes of heavy neutrinos and sfermions at LHC and ILC
- Networking with other projects:
  - B3: neutrinos in the SM
  - B6: strong interactions and new physics at the LHC
  - B2: supersymmetry at the LHC
  - A3: high-energy limit of QCD
  - C3: leptogenesis

3. Status quo

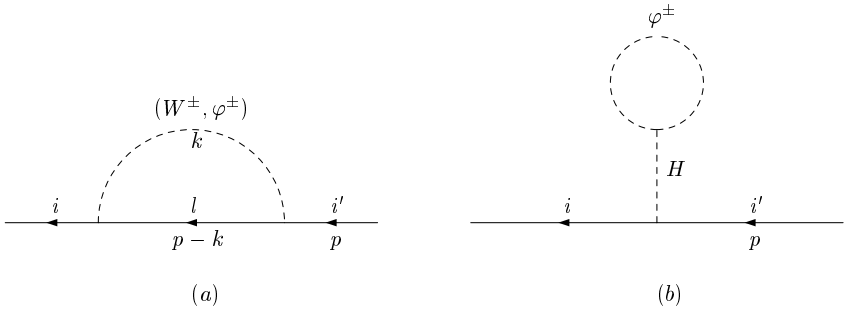
- People:
  - University: Simon Albino (since June 2006), Bernd Kniehl, Gustav Kramer
  - Guests: Alberto Sirlin (MPI Munich, August 2006)
  - SFB Positions: Malgorzata Awramik (from July 2006 through September 2007 lended out to Project B1; see her talk)
  - GK Positions: 1 PhD student searched for
- Papers:
  - B. A. Kniehl and A. Sirlin, "Simple approach to renormalize the Cabibbo-Kobayashi-Maskawa matrix," DESY 06-141, MPP-2006-108, NYU-TH/06/08/29, arXiv:hep-ph/0608306, to appear in Phys. Rev. Lett. (see below)
  - B. A. Kniehl and A. Sirlin, "Simple On-Shell Renormalization Framework for the Cabibbo-Kobayashi-Maskawa Matrix," submitted to Phys. Rev. D.

3. First physics results

- Goal: Find renormalization prescription for CKM matrix with properties:
  - on-shell scheme
  - UV finiteness
  - unitarity
  - gauge independence
  - absence of singularities for mass-degenerate quarks
  - no shift in V_{ud}
  - simplicity
- Literature: All starts from mass basis of quark fields.

  A. Denner and T. Sack, Nucl. Phys. **B347**, 203 (1990); B.A. Kniehl and A. Pilaftsis, *ibid.* **B474**, 286 (1996); P. Gambino, P.A. Grassi, and F. Madricardo, Phys. Lett. B **454**, 98 (1999); B.A. Kniehl, F. Madricardo, and M. Steinhauser, Phys. Rev. D **62**, 073010 (2000); A. Barroso, L. Brücher, and R. Santos, *ibid.* **62**, 096003 (2000); Y. Yamada, *ibid.* **64**, 036008 (2001); K.-P.O. Diener and B.A. Kniehl, Nucl. Phys. **B617**, 291 (2001); A. Pilaftsis, Phys. Rev. D **65**, 115013 (2002); D. Espriu, J. Manzano, and P. Talavera, *ibid.* **66**, 076002 (2002); Y. Zhou, Phys. Lett. B **577**, 67 (2003); J. Phys. G **30**, 491 (2004); Y. Liao, Phys. Rev. D **69**, 016001 (2004); A. Denner, E. Kraus, and M. Roth, *ibid.* **70**, 033002 (2004).

- Idea:



  - separate external-leg mixing corrections,

$$\Delta\mathcal{M}^{\rm leg}_{ii'} = \overline{u}_i(p)\Sigma_{ii'}(\not{p})\frac{1}{\not{p} - m_{i'}},$$

    into gauge-independent self-mass and gauge-dependent wave-function renormalization contributions
  - adjust non-diagonal mass counterterm matrices,

$$-\overline{\psi}_R\left(m - \delta m^{(-)}\right)\psi_L - \overline{\psi}_L\left(m - \delta m^{(+)}\right)\psi_R,$$

    to cancel all the divergent self-mass contributions, and also their finite parts subject

to constraints imposed by the hermiticity of the mass matrices,

$$\delta m^{(+)} = \delta m^{(-)\dagger}$$

– diagonalize complete mass matrix by biunitary transformation,

$$\begin{aligned} \psi_{L,R} &= U_{L,R}\hat{\psi}_{L,R}, \\ U_{L,R} &= 1 + ih_{L,R}, \\ i(h_{L,R})_{ii'} &= \frac{m_i \delta m^{(\mp)}_{ii'} + \delta m^{(\pm)}_{ii'} m_{i'}}{m_i^2 - m_{i'}^2} \qquad (i \neq i') \end{aligned}$$

– CKM counterterm matrix:

$$\delta V = i\left(h_L^U V - V h_L^D\right)$$