KAON09: Standard Model

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The Standard Model @ $E \sim M_K$

$$\mathcal{L}_{\mathrm{SM}} = \mathcal{L}_{\mathrm{QCD}}^{(u=d,s)} + \mathcal{L}_{\mathrm{QED}} + \mathcal{L}_{[m_u-m_d]} + \mathcal{L}_{nonren}$$

$\mathcal{L}_{\mathrm{QCD}}^{(u=d,s)} \equiv$ QCD with three flavours $\qquad m_u = m_d = \frac{m_u+m_d}{2} \equiv \hat{m}$

- dominant term
- only two parameters $(\hat{m}, m_s)$
- very rich phenomenology (spectrum, scattering, nuclear physics)
- $\Rightarrow$ ideal playground for a theorist!

The Standard Model @ $E \sim M_K$

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$\mathcal{L}_{\rm QED} + \mathcal{L}_{[m_u - m_d]}$ =isospin-breaking part

- small correction
- one more free parameter $(m_u - m_d)$
- mostly ignored by theorists
  $\Rightarrow$ until experiments become precise enough

The Standard Model @ $E \sim M_K$

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm QCD}^{(u=d,s)} + \mathcal{L}_{\rm QED} + \mathcal{L}_{[m_u-m_d]} + \mathcal{L}_{nonren}$$

$$\mathcal{L}_{nonren} = \sum_{d=5}^{\infty} \frac{1}{M_W^{d-4}} \sum_i c_i^{(d)} \mathcal{O}_i^{(d)}$$

Examples:

$$\mathcal{O}_{a_\mu}^{(5)} = \bar{\mu}\sigma_{\mu\nu}F^{\mu\nu}\mu$$
$$\mathcal{O}_{K_{\ell n}}^{(6)} = \bar{u}_L\gamma^\mu s_L \bar{e}_L\,\gamma_\mu \nu_L$$

- tiny nonrenormalizable corrections
- breaks several symmetries (*P*, *CP*, flavour)
- makes kaons most interesting
  through them we glimpse into the physics at the electroweak scale

QCD @ low energy

Problem: calculate the path integral of QCD nonperturbatively

Approaches:

- lattice (brute force, first principles)
- chiral perturbation theory (symmetry)
- dispersion relations (causality≡analyticity, unitarity)

Topics @ this conference:

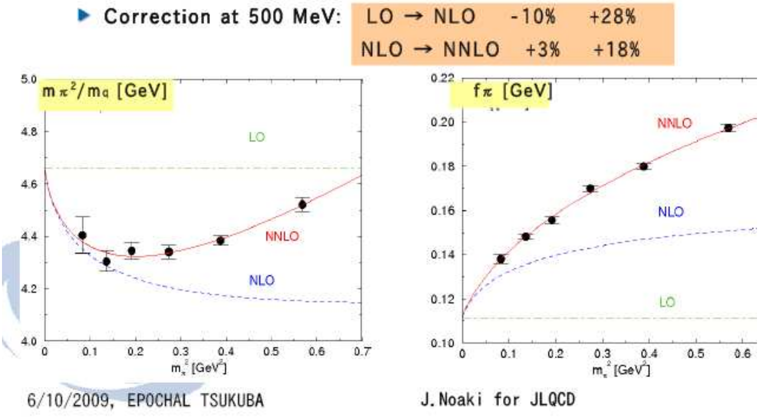
- determination of LECs
- convergence of $SU(3)$ χPT
  (role of the strange quark?)
- $\pi\pi$ scattering lengths

Convergence of [$SU(3)$] χPT

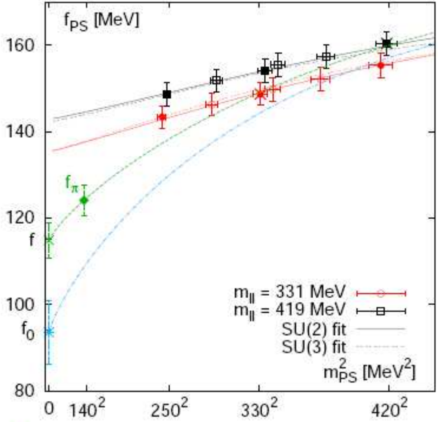
Lattice talks by: Boyle, Christ, Izubuchi, Mescia, Noaki

Observed quark mass dependence described by χPT?

Convergence of [$SU(3)$] χPT



Convergence of $[SU(3)]$ χPT



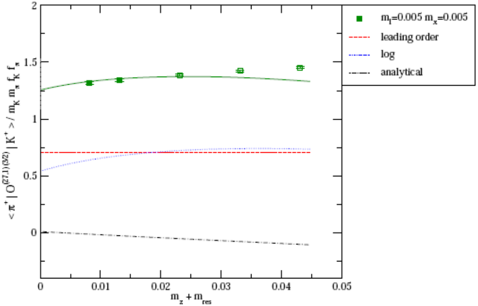
- Partially quenched & simultaneous fit with pion mass

talk by P. Boyle

Convergence of $[SU(3)]$ χPT

Relative size of LO and NLO terms

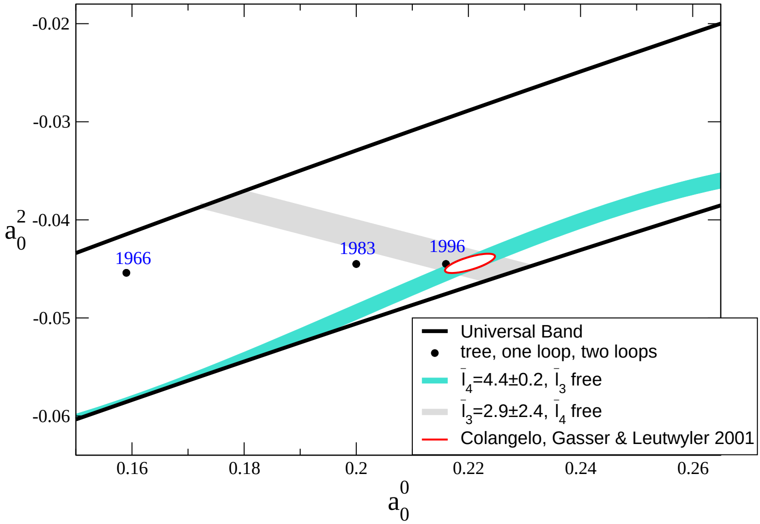
- LO and NLO log terms are the same size.
- Consistent results if we divide by $m_K m_\pi (f_K f_\pi)^2$
- Double the difference between two fits to estimate systematic error.



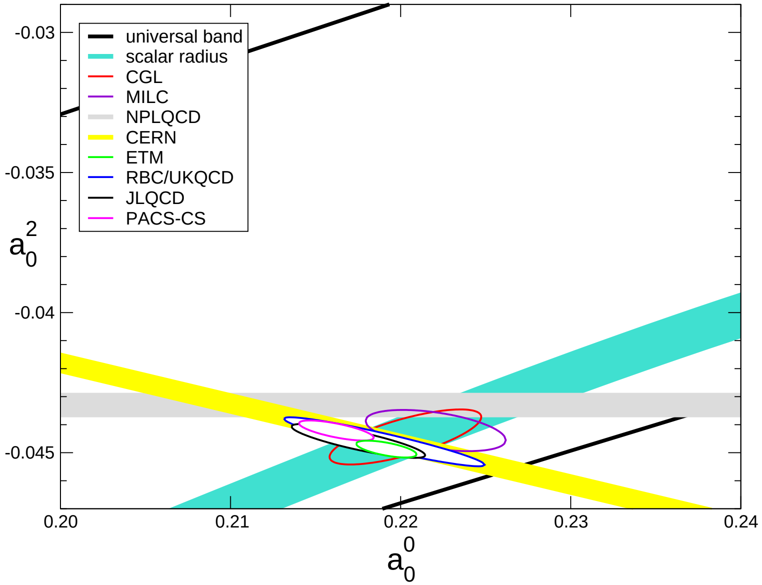
Convergence of [$SU(3)$] χPT

- NLO $SU(3)$ χPT works as expected in phenomenology
- NNLO analyses show that fits may be delicate
  (many-parameter fits may end up in a region where the χPT series looks not convergent)
- m_s is not small
- lattice may teach us something new about the role of the strange quark in QCD
- need to wait for lattice data at lower m_s

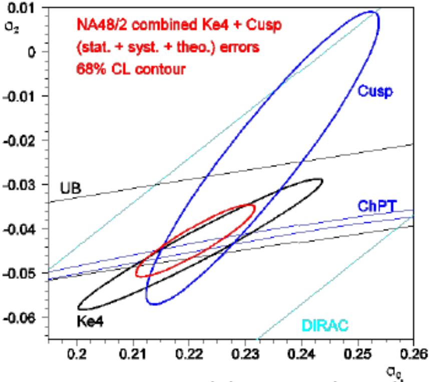
$\pi\pi$ scattering lengths



$\pi\pi$ scattering lengths



$\pi\pi$ scattering lengths



stat syst theo

a_0 = 0.2210 ± 0.0047 ± 0.0015 ± 0.0049

a_2 = -0.0429 ± 0.0044 ± 0.0016 ± 0.0030

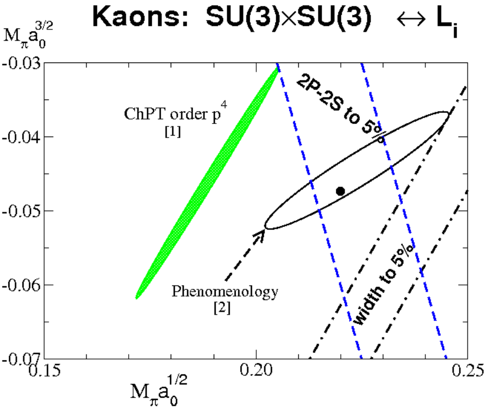
Correlation 0.912

Total errors Δa_0: ± 0.0070 (3% rel. precision)

Δa_2: ± 0.0055 (13% rel. precision)

Figure by B. Bloch-Devaux, talks also by D. Madighozin and E. Blucher

πK scattering lengths?



[1] Bernard, Kaiser and Meißner '91; Roessl '99; Kubis and Meißner '01; [2] Büttiker, Descotes-Genon, Moussallam '03; ● Bijnens, Dhonte and Talavera '04, ChPT 2 loops.

Figure courtesy of J. Gasser

πK scattering lengths?

Evidence for πK-atoms with DIRAC

B. Adeva[o], L. Afanasyev[ℓ], Y. Allkofer[r,*], C. Amsler[r,*],
A. Anania[f], A. Benelli[r], V. Brekhovskikh[n],

et al.

Abstract

We present evidence for the first observation of electromagnetically bound $\pi^\pm K^\mp$-pairs (πK-atoms) with the DIRAC experiment at the CERN-PS. The πK-atoms are produced by the 24 GeV/c proton beam in a thin Pt-target and the $\pi^\pm$ and $K^\mp$-mesons from the atom dissociation are analyzed in a two-arm magnetic spectrometer. The observed enhancement at low relative momentum corresponds to the production of 173 ± 54 πK-atoms. The mean life of πK-atoms is related to the s-wave πK-scattering lengths, the measurement of which is the goal of the experiment. From these first data we derive a lower limit for the mean life of 0.8 fs at 90% confidence level.

Key words: DIRAC experiment, exotic atoms, scattering length, πK-scattering, chiral perturbation
PACS: 36.10.-k, 32.70.Cs, 25.80.Nv, 29.30.Aj

On the measurement of the $\pi\pi$ scattering lengths

- measurement done in three different ways
  1. $\pi^+\pi^-$ lifetime — DIRAC
  2. cusp in $K \to 3\pi$ — NA48 (cf. also first results by KTeV)
  3. K_{e4} decays — Geneva-Saclay, E865, NA48
- for the first two: measurement at all possible thanks to isospin breaking
- for the third: isospin breaking corrections necessary to properly interpret the result — cf. talk by B. Bloch-Devaux

Isospin breaking effects

At the present level of experimental precision, isospin breaking effects have to be understood in detail:

$\Rightarrow$ lattice for QCD+QED and with $m_u \neq m_d$ talk by T. Izubuchi

- very interesting exploratory study
- new theoretical issues (finite volume effects)
- long term goal (light-by-light) worth the efforts

Isospin breaking effects

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$\Rightarrow$ lattice for QCD+QED and with $m_u \neq m_d$ talk by T. Izubuchi

$\Rightarrow$ χPT for QCD+QED and with $m_u \neq m_d$

- $K_{\ell 2}$ and $K_{\ell 3}$ decays th: E. Passemar
  exp: E. Goudzovski, M. Palutan, B. Sciascia
- for rare decays th: C. Smith
- study of radiative decays exp: V. Duk, M. Moulson, R. Wanke

The very sensitive tests of lepton universality, or of CKM unitarity, or the SM test in $K \to \pi\bar{\nu}\nu$ need a thorough control of isospin breaking corrections

Experimental study of non-renormalizable interactions

In contrast to new-physics searches, in the SM one can explicitly

- integrate out the heavy degrees of freedom in the SM

  talk by C.S. Lim

- run the effective Hamiltonian down to lower scales

  talk by M. Gorbahn

- obtain the Wilson coefficients of the non-renormalizable operators at low-energy as functions of
  - the CKM matrix elements
  - the masses of the heavy degrees of freedom
  - the gauge couplings

cf. reviews by A. Buras

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to obtain predictions $\Rightarrow$ evaluate the hadronic matrix elements

Semileptonic decays

If leptons are involved, the hadronic matrix elements can be evaluated with good accuracy talks by P. Boyle, F. Mescia, E. Passemar, C. Smith

Lepton universality test: talks by E. Goudzovski, B. Sciascia

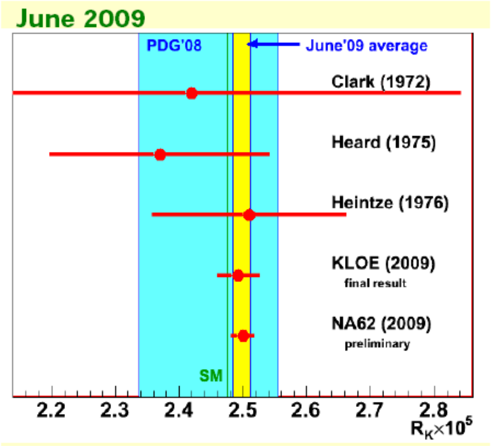
$$R_K = (2.498 \pm 0.014) \cdot 10^{-5} (\text{WA})$$
$$R_K = (2.477 \pm 0.001) \cdot 10^{-5} (\text{SM})$$

Cirigliano, Rosell 07

CKM unitarity talk by M. Palutan

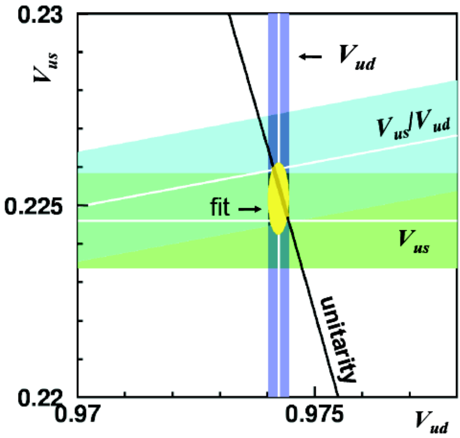
$$|V_{ud}|^2 + |V_{us}|^2 - 1 = -0.0004(7)$$

Semileptonic decays



talk by E. Goudzovski

Semileptonic decays



talk by M. Palutan

Nonleptonic decays

If only light quarks are involved, the hadronic matrix element evaluation becomes very hard: talk by N. Christ

- $K \to \pi\pi$ a major RBC/UKQCD project:
  $L = 4.5$ fm, $1/a = 1.4$ GeV, $M_\pi = 240, 180$ MeV
- "Expect 20% result for $\Delta I = 1/2$ rule and ϵ'/ϵ in ~ 3 years!"
- First lattice calculation of the $\pi\pi$ a_0^0 as a by-product?

Until then, the beautiful results of NA48 and KTeV:

by E. Blucher and M. Pepe

$$\mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right) = (16.8 \pm 1.4) \cdot 10^{-4} \qquad \text{(WA)}$$

and measurements of K lifetimes and $K \to 3\pi$ BR's talk by S. Bocchetta

do not provide a test of the SM

Photon and Z penguins...

...offer an interesting situation in which short and long distance give competing contributions

using χPT and dispersion relations $\Rightarrow$ long-distance physics

talk by C. Smith

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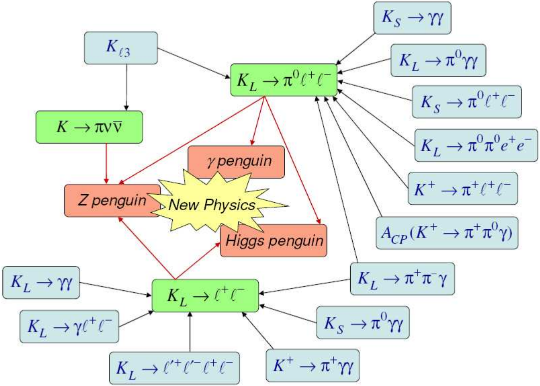
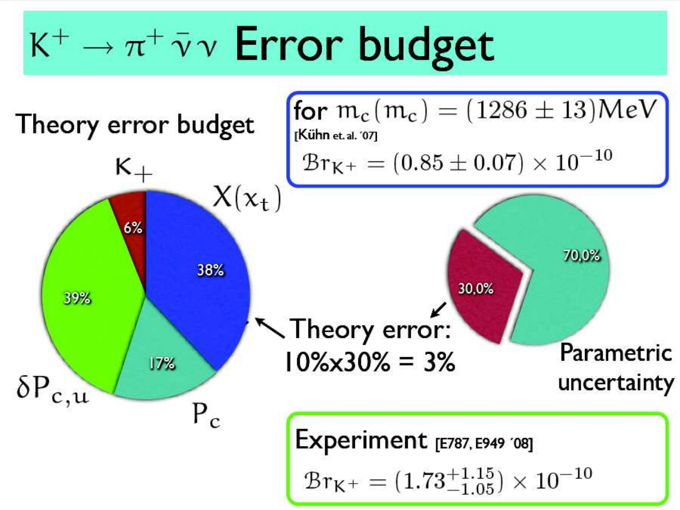
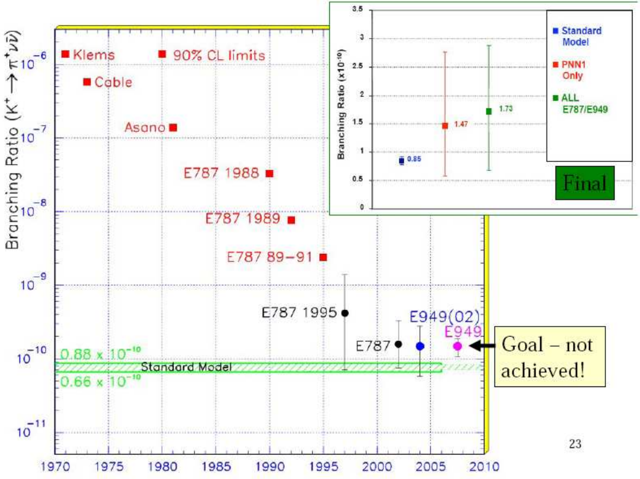


Photon and Z penguins...



talk by M. Gorbahn

Photon and Z penguins...



talk by D. Bryman

Outlook

In a few years from now...

talks by D. Bryman, H. Morii, H. Nanjo and G. Ruggiero

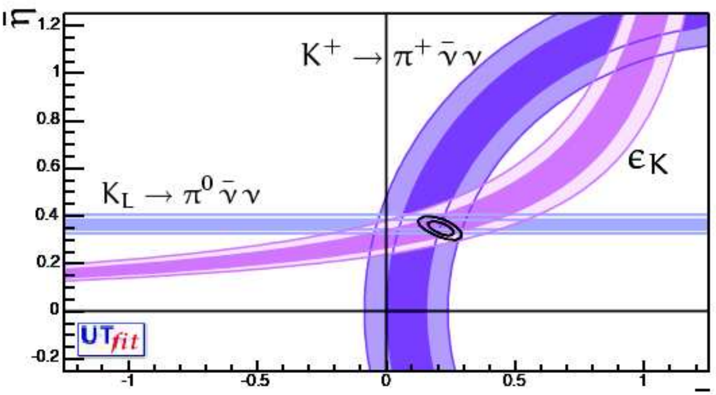


Fig. from the talk by M. Gorbahn