Lattice Gauge Theory

Karl Jansen Hubert Simma Rainer Sommer

DESY

Review of Programme "Elementary Particle Physics", February 2009

Lattice & DESY, a long tradition

- 80's, Hamburg:
  Mathematical foundations
  Symanzik, Lüscher ...
  with University (Mack ...)

  founding of HLRZ (now NIC)
  for high performance computing

Lattice & DESY, a long tradition

- 80's, Hamburg:
  Mathematical foundations
  Symanzik, Lüscher ...
  with University (Mack ...)

  founding of HLRZ (now NIC)
  for high performance computing
- 90's, Hamburg: improvement,
  finite size scaling for QCD ...
  also **numerical**

  93' a small APE 100

ALPHA Collaboration

Lattice & DESY, a long tradition

- 80's, Hamburg:
  Mathematical foundations
  Symanzik, Lüscher ...
  with University (Mack ...)

  founding of HLRZ (now NIC)
  for high performance computing
- 90's, Hamburg: improvement,
  finite size scaling for QCD ...
  also **numerical**

  93' a small APE 100

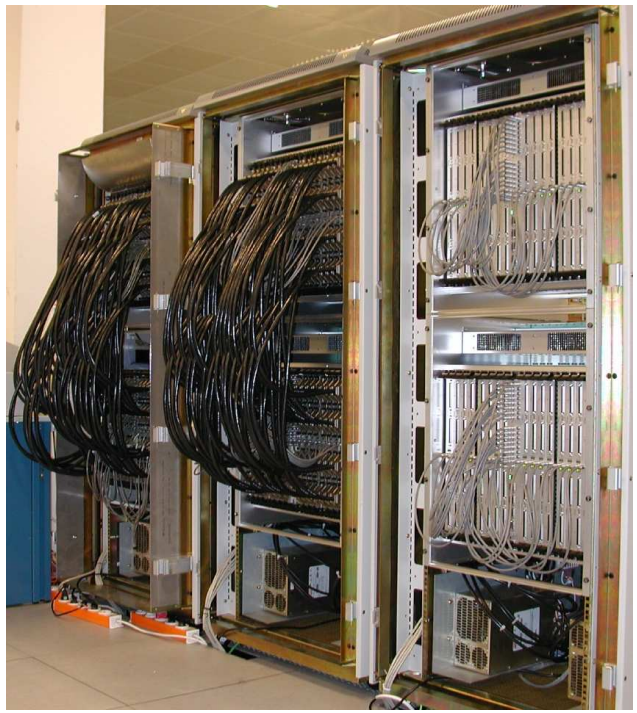
  ALPHA Collaboration
- Zeuthen:
  1994 significant APE installation

  NIC research group

European Twisted Mass Collaboration

ALPHA Collaboration

apeNEXT



Structure

- **John von Neumann Institute for Computing (NIC)**

  Joint Institute of **DESY, Forschungszentrum Jülich, GSI**

  Research groups

  - **DESY** (Zeuthen) particle physics group (lattice gauge theory)
  - **FZJ** many particle physics, statistical physics
  - **GSI** new group being installed: heavy ions (lattice gauge theory)

Structure

- The **DESY lattice gauge theory group** Jansen, Simma, Sommer
  - very close collaboration with Humboldt University Berlin
    Müller Preussker, Wolff
  - management of two European LGT Collaborations

ALPHA Collaboration

European Twisted Mass Collaboration

  - Additional Collaboration (+ funding) with
    Univ. Aachen and Karlsruhe: SFB-TR9
  - Marie Curie network: FlaviA net

NIC & Computational Ressources

- **FZ Jülich European supercomputer center**
  (top of the European pyramid)

  Since 2008: BlueGene/P $\sim$ 250 Tflop peak
  This year upgrade to **1Pflop** peak
  shared by many fields

NIC & Computational Ressources

- **FZ Jülich** **European supercomputer center**
  (top of the European pyramid)
  Since 2008: BlueGene/P $\sim$ 250 Tflop peak
  This year upgrade to **1Pflop** peak
  shared by many fields
- **DESY, Zeuthen**
  topical center now: apeNEXT
  2010-2014: PC-cluster, 540 k Euro investment
- **GSI**
  topical center foreseen

topical centers:

- smaller projects (e.g. PHD) not supported by national centers such as FZJ
- special hardware can be more efficient
- flexibility (no yearly applications)
- software development

Physics strengths and plans

Verification of QCD

in low energy, non-perturbative region

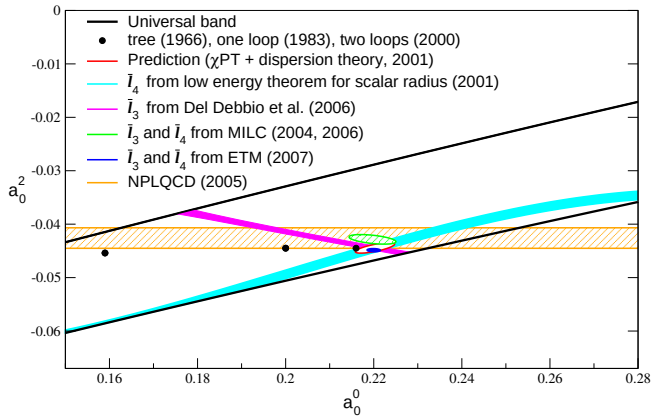
e.g. $\pi\pi \longrightarrow \pi\pi$ with unprecedented precision

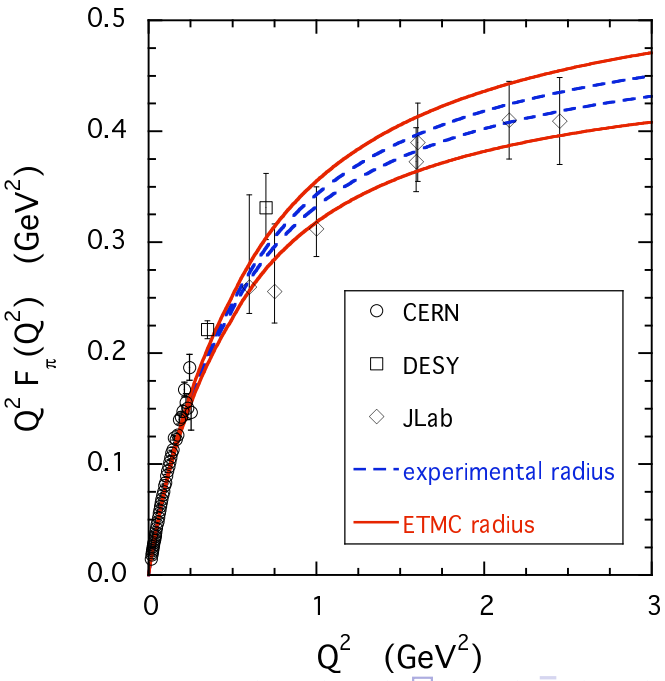
e.g. π formfactor

Unique: **twisted mass** fermion formulation: "automatic $O(a)$ improvement"

local field theory, no rooting ...

Future (has started): 2+1+1 simulations, broad range of physics applications





Physics strengths and plans

Fundamental parameters of QCD

experiments, hadrons

$$
\begin{aligned}
m_p &= 938.272\,\mathrm{MeV} \\
m_\pi &= 139.570\,\mathrm{MeV} \\
m_\mathrm{K} &= 493.7\,\mathrm{MeV} \\
m_\mathrm{D} &= 1896\,\mathrm{MeV} \\
m_\mathrm{B} &= 5279\,\mathrm{MeV}
\end{aligned}
$$

quarks, gluons

$$
\begin{aligned}
&\alpha(\mu) \\
&m_\mathrm{u}(\mu)\,,\ m_\mathrm{s}(\mu) \\
&m_\mathrm{c}(\mu)\,,\ m_\mathrm{b}(\mu)
\end{aligned}
$$

Physics strengths and plans

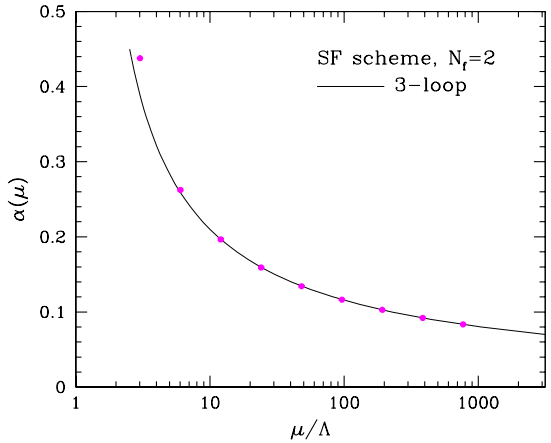
Fundamental parameters of QCD

experiments, hadrons

$$
\begin{aligned}
m_p &= 938.272\,\mathrm{MeV} \\
m_\pi &= 139.570\,\mathrm{MeV} \\
m_\mathrm{K} &= 493.7\,\mathrm{MeV} \\
m_\mathrm{D} &= 1896\,\mathrm{MeV} \\
m_\mathrm{B} &= 5279\,\mathrm{MeV}
\end{aligned}
$$

Non-perturbative theory

ALPHA Collaboration technology



quarks, gluons

$$\alpha(\mu)$$
$$m_\mathrm{u}(\mu)\,,\ m_\mathrm{s}(\mu)$$
$$m_\mathrm{c}(\mu)\,,\ m_\mathrm{b}(\mu)$$

high confidence
high precision
at high energy μ

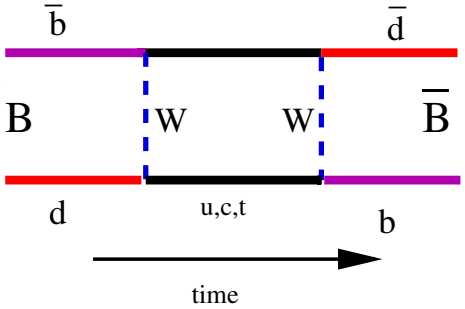
2010-2014: the real theory with strange and charm sea;
high, non-perturbative precision

Physics strengths and plans

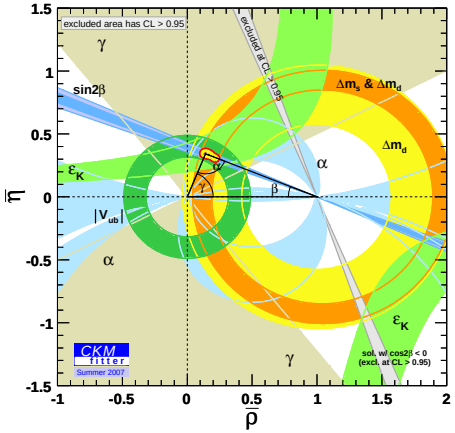
Non-perturbative QCD
"background"
for the high intensity frontier

e.g.

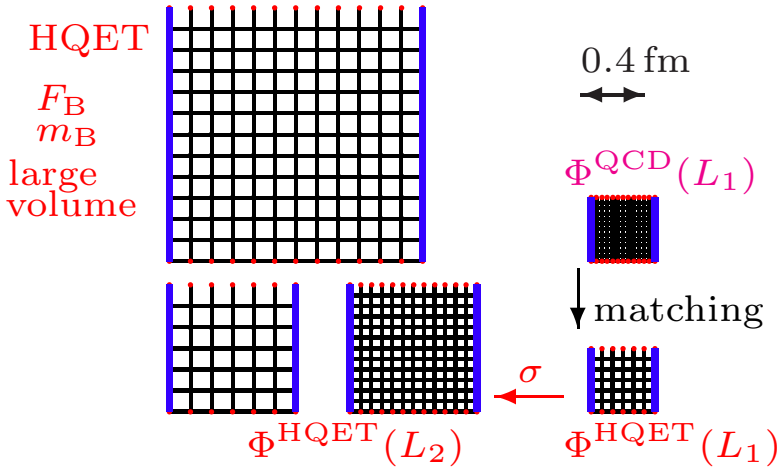
$$\Delta m_s = \underbrace{\frac{G_F m_W}{6\pi^2}\eta_2 S_0(x_t)}_{\text{known}} \underbrace{|V_{ts}V_{tb}^*|}_{\text{wanted}} \times \underbrace{F_{B_s}^2 B_{B_s}}_{\text{lattice, HQET}}$$



Flavour physics

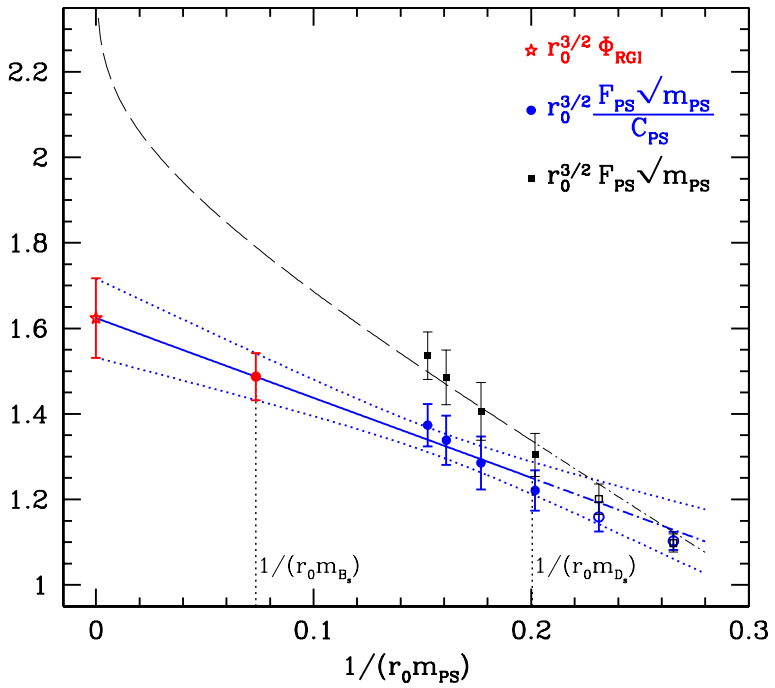


Non-perturbative HQET strategy



Physics strengths and plans

Full control of HQET needed
Example: F_{B_s} $\longrightarrow$



in SFB-TR/9:

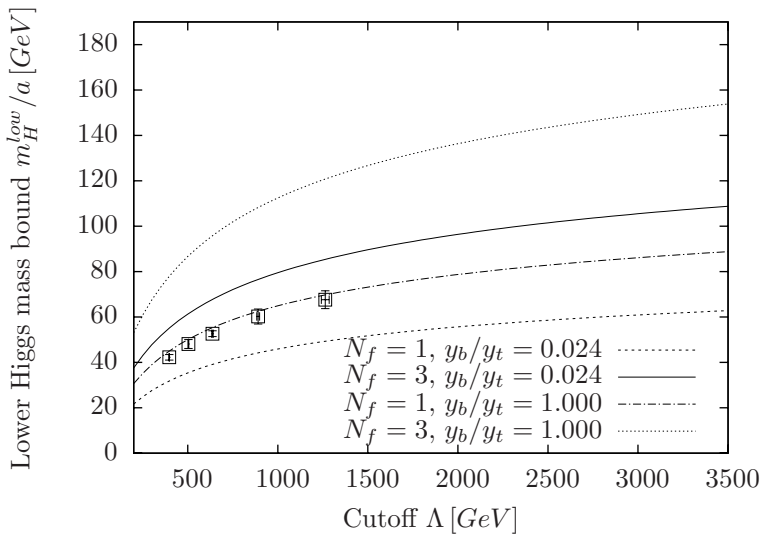
- 3-loop anomalous dimension: Karlsruhe
- NP renormalization and matrix element in HQET: DESY

Future: precision in the full theory; B-parameters, $B \longrightarrow \pi l \nu$

Physics strengths and plans

Higgs mass bounds in a **chirally invariant** Higgs-Yukawa model

Upper and lower bounds



- non-degenerate top and bottom quark mass with physical ratio $m_{\mathrm{bottom}}/m_{\mathrm{top}}$
- comparison to 1-loop lattice perturbation theory
- allowed maximal Higgs boson mass interval

$$80\mathrm{GeV} \lesssim M_{\mathrm{Higgs}} \lesssim 700\mathrm{GeV}$$

Lattice at DESY

Maintain strong support for NIC research group and topical center

- Development of advanced methods – algorithms and field theory apply to $\Longrightarrow$ **dynamical EW symmetry breaking** (if found at LHC)
- Control over systematic errors, Connection to phenomenology
- Management of European collaborations
  conferences and education for German and other students

Lattice practices 2006

Lattice practices 2008