THEORETICAL NUCLEAR and PARTICLE PHYSICS

Theory Groups at work:

- Andrzej Buras
- Michael Ratz
- Peter Ring
- Norbert Kaiser
- Wolfram Weise

... plus two additional permanent positions

- Fundamental Interactions
- New Physics beyond the Standard Model
- QCD: Phases and Structures
- Nuclear Many-Body Systems
Theory Group T31

- Fundamental Interactions
  ... from “Femto” to “Atto” Physics

- Signals of New Physics
  beyond the Standard Model

- Weak Decays of K and B Mesons:
  - CP Violation
  - QCD Corrections

- Supersymmetry
- Extra Dimensions

\[ \text{Supersymmetric "shadow" particles} \]

\[ \begin{align*}
  \frac{\Delta M_s}{\Delta M_d} & = \text{Gates-Nelson Bound} \\
  \sin 2\beta & = 0.83 \\
  \rho & = 0.79 \\
  \eta & = 0.74 \\
  \psi_{KS} & = 0.69
\end{align*} \]

\[ \begin{align*}
  \epsilon_K & = 0.83 \\
  R_b & = 0.79
\end{align*} \]
Theoretical Nuclear Physics

broad range of Nuclear Structure investigations from ...

- Rare Isotopes
- New Heavy Elements
- New Collective Excitations ...

Covariant Density Functional Theory

Experimental indications of the soft dipole mode
... to:

- Halo Nuclei
- Nuclear Astro Physics

**r-process**
Hadrons
Nuclei
Matter under Extreme Conditions

... exploring the PHASES and STRUCTURES of QCD
Low-Energy QCD

- Spontaneous Symmetry Breaking and Effective Field Theory
- Chiral Perturbation Theory and Lattice QCD
- Mass and Spin Structure of the Nucleon

\[ u + u + d = \text{proton} \]

\[ m_u \approx 3 \text{ MeV} \quad m_d \approx 6 \text{ MeV} \]

mass: \( 3 + 3 + 6 \neq 938 \)!

M. Procura et al.

\[
\begin{align*}
\text{nucleon mass} & \quad [\text{GeV}] \\
\text{chiral theory} & \\
\text{lattice QCD} & \\
\text{physical point} & \\
\end{align*}
\]

\[
\begin{align*}
\text{quark mass} & \quad [\text{MeV}] \\
0 & \quad 25 \quad 50 \quad 75 \quad 100 \quad 150 \\
0.8 & \quad 1.0 \quad 1.2 \quad 1.4 \quad 1.6 \quad 1.8 \\
\end{align*}
\]
QCD Thermodynamics and Hadrons in Dense and Hot Matter

energy density, entropy density, pressure

phase diagram

... from QCD
via
CHIRAL EFFECTIVE FIELD THEORY ...

... to the NUCLEAR CHART?
---

**Nuclear Density Functional constrained by Low-Energy QCD**

- Strategy:
  - Calculate physics at [long and intermediate] distances using nuclear [chiral effective field theory]
  - Fix [short] distance constants (contact interactions) e.g. in Pb region
  - Predict [systematics] for all other nuclei

---

**Strategies**

- Fix short distance constants (contact interactions) e.g. in Pb region
- Predict systematics for all other nuclei

---

**Graphs**

- **\( \delta \frac{E}{A} \) (%):**
  - Various elements from 16O to 210Po
  - Data points showing deviations between calculated and measured binding energies per nucleon

- **\( \delta \langle r^2 \rangle^{1/2} \) (%):**
  - Various elements from 16O to 210Po
  - Data points showing deviations between calculated and measured charge radii

---

**References**


---

*Technische Universität München*
Nuclear Density Functional constrained by Low-Energy QCD

deviations (in %) between calculated and measured binding energies

Ground state deformations


Systematics through isotopic chains governed by isospin dependent forces from chiral pion dynamics

Technische Universität München
• Hydrodynamics Simulations of Core Collapse Supernovae

Th. Janka et al. (2006)
THEORETICAL NUCLEAR and PARTICLE PHYSICS

Theory Groups at work:

Andrzej Buras
Michael Ratz
Wolfram Weise
Peter Ring
Norbert Kaiser

Permanent Faculty (Professors): 5
Postdocs: 10
PhD & Dipl. Students: 22
Visiting Scientists: ~10

“UNIVERSE” Cluster

MLL