Nuclear and Hadron Physics in the Netherlands

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University of Groningen
In summary...

We are investigating subatomic matter at extremes.
Nuclear matter at extremes

Aim is to understand properties of nuclear matter at extreme isospin

Selected topics:
- Investigation of Nuclear Matter Distributions along Isotopic Chains
- Giant Monopole Resonance

Relevance for astrophysics:
- Systematic studies of isotopic chains → rp- and r-processes
- Nuclear compressibility → EOS of neutron stars
Electromagnetic counterparts of compact object mergers powered by the radioactive decay of r-process nuclei

B. D. Metzger,1*† G. Martínez-Pinedo,2 S. Darbha,3 E. Quataert,3 A. Arcones,2,4 D. Kasen,5† R. Thomas,6 P. Nugent,6 I. V. Panov7,8,9 and N. T. Zinner10
GW170817 observation of r-process?

August 17, 2017

- LIGO and Virgo observed a textbook signal of gravitational waves from a neutron star merger.
- 1.7 s later NASA’s Fermi gamma ray space telescope saw photons from the \( \gamma \)-ray burst.
- NASA’s swift telescope observed first a blue and ultraviolet object, which turned red to infrared in the following nights.
Our group is leading the development of new experimental techniques:

- Low momentum-transfer scattering of radioactive beams (EXL)

N. Kalantar-Nayestanaki
ex. EXL spokesperson
ex. NUSTAR spokesperson

C. Rigollet

M.N. Harakeh
Proof of the concept

First EXL experiment with the existing storage ring at GSI (ESR)
(EXL=EXotic nuclei studied with Light-ion induced reactions at storage rings)

First-ever scattering experiment with radioactive ions in a storage ring!
Proof of the concept

First EXL experiment with the existing storage ring at GSI (ESR)
(EXL=EXotic nuclei studied with Light-ion induced reactions at storage rings)

Elastic p-scattering off Ni isotopes

M. von Schmid et al., Submitted to Nature
Nuclear matter at extremes

Our group is leading the development of new experimental techniques:

- Chemical isobar-purification for radioactive beams (CISE)

J. Even
CISE Chemical Ion SEparation

Challenge: separation from isobars!

Octupole | Buncher | Transfer | Penning Traps | Detector
---|---|---|---|---
Ions from SHIP | CH₄Cd⁺ | CH₄Ag⁺ | | | Superconducting magnet | Diaphragm
Gas catcher | Sn⁺ In⁺ Cd⁺ | Sn⁺ In⁺ Cd⁺ | | | MCP detector (ToF)
| | | | | Measurement trap

CISE has been designed, under construction
In summary...

We are investigating subatomic matter at extremes.
Exotic hadron matter

Colour-neutral states allowed by QCD

- Pions, charmonium, etc
  - Mesons
- Protons, neutrons, etc
  - Baryons

- $Z_c$ and $Z_b$
  - Seen at BESIII and LHC-B

- Pentaquark
  - Seen at LHC-B

- $f_0(1500)$?
- $f_0(1500)$?
- XY states?

- Hybrid
- Glueball

Conventional matter

Exotic matter
Our key experiments

**PANDA@FAIR**
(FAIR, Darmstadt, Germany)
- High discovery potential for exotic states
- High-precision width measurement: \( \sim 100 \text{ keV} \)
- Cooled \( \bar{p} \) on fixed target
- Direct production of states with all possible quantum numbers

**BESIII@BEPCII**
(IHEP, Beijing, China)
- Systematic and precision studies of charmonia (state mass, transition rates); search for light hybrids, glueballs
- \( e^+ e^- \) collider
- Direct production of \( 1^- \) states
Conventional matter

\[ S = S_1 + S_2 \]
\[ J = L + S \]
\[ P = (-1)^{L+1} \]
\[ C = (-1)^{L+S} \]

Open charm threshold

established c\bar{c} states

[Diagram showing mass and JPC values]
Exotic matter at BESIII

Z_c states discovered by BESIII

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<th>MASS [GeV/c^2]</th>
<th>J/ψ(1^+S_1)</th>
<th>η_c(2^+S_1)</th>
<th>η_c(1^+P_1)</th>
<th>X_ψ(1^+P_1)</th>
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States can be directly populated in annihilation e^+e^-

Electrically-charged with hidden-charm:
- cannot be charmonium!
- Exotic (tetraquark?)

Y(4260)
π^±
Z_c^±(3900)
π^±
J/ψ
Other QCD exotic objects

$Z_c$ states discovered by BESIII

Lattice QCD predicts exotic matter (hybrids, glueballs) which have spin-symmetries forbidden for mesons

Can be unambiguously identified (no mixing with conventional states)

States can be directly populated in annihilation $e^+e^-$
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In proton-antiproton annihilation all possible conventional and high-spin states are directly formed!
Line-shape measurement with PANDA

Momentum spread of the cooled antiproton beams: $< 4 \cdot 10^{-5}$

Line shape measurement with CM energy resolution down to 50 keV
Line-shape scan of X(3872)

Klaus Goetzen et al.

PANDA will be able to provide crucial information on exotic matter

MC Simulations of the X(3872) scan (assumed \(\Gamma=100\) keV)

\[
\bar{p}p \rightarrow X(3872) \rightarrow J/\psi\pi^+\pi^-
\]
A glance to the future...

Add strangeness, a new dimension in the nuclear chart, hyprenuclear physics:

- NUSTAR – hypernuclei at extreme isospins
- PANDA – multiple strangeness