Antikaonic Matter At DAΦNE: Experiments with Unraveling Spectroscopy
Letter of Intent

Study of deeply bound kaonic nuclear states at DAΦNE 2

AMADEUS Collaboration

111 scientists from 33 Institutes of 13 Countries signed the Letter of Intent

March 2006
Phase Diagram of Hadronic Matter

Study of the Phase Diagram at High Densities and T=0 Using Deeply Bound Kaonic Nuclear Clusters

P. Kienle, IX International Conference on Hypernuclear and Strange Particle Physics, 10-14 October 2006
$\Lambda(1405)$ the Doorway to Antikaonic Nuclei

Strong Antikaon-Proton attraction below the $\Lambda(1405)$ resonance. Repulsion above it as shown experimentally by $\text{Re}\ a(K\cdot p)$. 

P. Kienle, IX International Conference on Hypernuclear and Strange Particle Physics, 10-14 October 2006
Decrease of $K^-$ Mass in a Nuclear Medium →
Strong Binding by Attractive $K^-N$ Force

Chiral SU(3) Dynamics


$m^*_K/m_K$ in nuclear matter

\[ \frac{m^*_K}{m_K} \text{ in nuclear matter} \]

Chiral symmetry

\[ T_{1/2} = 2 \frac{m_s}{2l^2} \]
\[ T_{3/2} = 3 \frac{m_s}{2l^2} \]
\[ 3a_s - a_\pi = 2(b_s + 3b_\pi) = 0 \]

\[ 2a_{1/2} + a_{3/2} = 2b_\pi = 0 \text{ [isoscalar]} \]

\[ 2\hat{u}U = -T^i \]

Tomozawa-Weinberg
Antikaon Production in Ni-Ni Collisions

P. Kienle, A. Gillitzer

Ed.: Stöcker, Gallmann, Hamilton, World Scientific


Indication of a decrease of the K⁻ mass of ~200 MeV in a nuclear medium with n/n₀ ~ 2
Prediction of Lightest Kaonic Nuclear Systems

Strong $K^-$ binding in a nuclear medium discussed by Wycech (1986) and p-wave contribution (EXA05)

Starting from:
- $K^-p$ atom
- $K^-N$ scattering
- $\Lambda(1405)$

Strong $K^- - p$ attraction (Weise: 1996) Nuclear shrinkage

Y. Akaishi and T. Yamazaki, PRC 65 (2002) 044005
T. Yamazaki and Y. Akaishi, PLB 535 (2002) 70

P. Kienle, IX International Conference on Hypernuclear and Strange Particle Physics, 10-14 October 2006
Summary of the Search for Deeply Bound Kaonic States

What do we know experimentally?

All experimental data are so far Missing Mass or Invariant Mass Spectra. No exclusive MM and IM data needed for proof.

P. Kienle, IX International Conference on Hypernuclear and Strange Particle Physics, 10-14 October 2006

\[ M_{\Lambda p} (\Lambda+p) \ (GeV) \]

Peak position: 2.13 ± 0.02 GeV

Reflection of other resonances?
Work in progress ...

Literature:
Strange Dibaryon \( H_2^+ \), \( M = 2.13 \) GeV, \( \Gamma = 17 \) MeV
C.Pegor et al. (Bonne-Saclay-Vanderbilt Collaboration), NPB 249 (1985) 172
Ap resonance in \( K/D \rightarrow \pi pA \) at rest,
\( M_P = 2.128 \) GeV, \( \Gamma_P = 7 \) MeV and \( M_T = 2.138 \) GeV, \( \Gamma_T = 9.1 \) MeV
Tai Ho Tan, SRL 33, 101 (1980)
AMADEUS STRATEGY

- **Confirm or reject** the existence of kaonic nuclear clusters by an **exclusive** measurement using $4\pi$-detection of all reaction and decay products for construction of missing mass and invariant mass spectra.

- **Use** $(K^-\text{-stopped},N)$ reaction with mono-energetic $K^-$ from $\Phi$ decay produced by DAΦNE.

- **Use** the high performance **KLOE** detector implemented with a cryogenic gas target and a stopped $K^-$ trigger system.
Realization of the AMADEUS Project

- Determination of the neutron detection efficiency of the KLOE electromagnetic calorimeter
- Implementation of a cryogenic gas target and a $K^-$ stop position detection system
- Analysis of the data from $K^-$ stopped in the $^4$He gas of the KLOE drift chamber
Reaction Channels (simplified)


Measure all outgoing particles to obtain the total cms energy = invariant mass of the object.
Possible setup for AMADEUS within KLOE:

- Cryogenic target
- Inner tracker
- Kaon trigger
Signature for ppnK\(^{-}\) Decay

\[ ^4\text{He} + K^- \rightarrow \text{ppnK}^- + \text{n} \]

decay:

\[ \Lambda^0 + \]

\[ p + n \]

\[ p + \pi^- \]
Event Display for ppnK⁻ Decay

\[ \text{ppnK}^{-} \rightarrow \Sigma^{0} + n + p \]
\[ \rightarrow \gamma + \Lambda \]
\[ \rightarrow \pi^{-} + p \]
Determination of the KLOE Calorimeter Efficiency for Neutrons

- **MonteCarlo simulations**
  - AMADEUS MonteCarlo GEANT simulation (and FLUKA MonteCarlo from KLOE)

- **Measurement with a neutron beam**
  - KLOE+AMADEUS experimental test of a prototype of the KLOE calorimeter on the neutron beam of TSL (Uppsala): KLONE proposal
Neutron detection efficiency

Threshold at 1 MeV
Threshold at 3 MeV
AMADEUS Setup
second version

- Vacuum chamber
- Half-toroidal cryogenic target cell
- Kaon trigger made of 2+3 scintillating fibers layers, inside a vacuum chamber
- Two TPC sections with triple GEM and x-y readout on both sides
- Thin-walled beam pipe
MonteCarlo Simulations for AMADEUS with Optimized Degrader and Cryo-target

\[ R = L \sigma b = 1500 \text{ s}^{-1} \]

production rate for charged kaon pairs

produced \( K^\pm \) per month: \( 31 \times 10^8 \) (80% duty cycle assumed)

40% are stopped in the cryogenic He gas target (15% liq. He density, \(~ 5 \text{ cm thick}\) \( \rightarrow 12.5 \times 10^8 \) \( K^- \) \(^4\text{He} \) atoms per month

for \( 10^{-3} \) cluster formation yield: \( 12.5 \times 10^5 \) kaonic clusters formed in one month

* Efficiency of tracking & identification \( K^\pm \) & detection of decay products \( \rightarrow \)

\(~10^5\) events per month (\(~1000 \text{ pb}^{-1}\)
Start Program of AMADEUS

• Reactions used:
  \[ ^3\text{He}(K^{-}\text{stopped},n)ppK^- \]
  \[ ^4\text{He}(K^{-}\text{stopped},n/p)ppnK^-/pnnK^- \]

• Complete determination of all reaction and decay channels by detection of all charged particles, neutrons, and \( \gamma \)-rays

• Deduce from such exclusive data:
  Binding energies, total and partial widths, angular momenta, isospins, sizes, densities, etc
Pre-experiment: Proposal to KLOE

Preliminary Monte Carlo simulations shows that with 2 \(fb^{-1}\) one might have

> 1500 \(K^{-}\)-stopped events in Helium of KLOE Drift Chamber, of the type:

\[
K^{-} + ^{4}He \rightarrow p + (K^{-}pnn)
\]

\[
p \sim 550 \text{ MeV/c}
\]

and > 500 events of the type

\[
K^{-} + ^{4}He \rightarrow n + (K^{-}ppn)
\]

\[
n \sim 510 \text{ MeV/c (assuming } \varepsilon_n \sim 30\%\)
\]

AMADEUS group \(\rightarrow\) willing to help KLOE in data analysis
Detection of Reactions in $^4\text{He}$ of Drift Chamber

The drift chamber is filled with He + isobutane at atmospheric pressure; He as active volume
Kaon production rate:
\[ \sim 150 \text{K}^- \text{s}^{-1} \text{ (for } L \sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}) \]

Integrated luminosity

\[ \mathcal{L} = 2 \text{ fb}^{-1} \]

Production cross section

\[ \sigma = 3 \times 10^{39} \text{ cm}^{-2} \]

Branching ratio for \( K^+ \)

\[ b = 2.9 \times 10^9 \]

\[ \sim 0.3\% \text{ stopped in the gas of the chamber} \]

\[ \rightarrow 3 \times 10^{-3} \times 2.9 \times 10^9 = 8.8 \times 10^6 \text{ K}^- \text{ }^4\text{He atoms} \]

For a cluster yield of \( 10^{-3} \) we have \( \sim 8800 \) clusters

With efficiency of tracking & identification of \( K^{+/0} \) & detection of decay products 1000-2000 reconstructed clusters
Conclusion and Summary

The **AMADEUS** project plans to use a dedicated $4\pi$-detector capable of detecting **all** charged and neutral particles emitted in the formation and decay of kaonic nuclear clusters for a **definitive clarification** of their debated existence.

For the realisation of the **AMADEUS** set up a cryogenic target, a kaon trigger and an inner tracker must be implemented in the **KLOE** detector.