The **AMADEUS** experiment

**study of the kaonic clusters at daΦne**

Oton Vázquez Doce (LNF-INFN)

on behalf of the AMADEUS Collaboration

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ANTIKAONIC

MATTER

AT

DAΦNE: AN

EXPERIMENT

WITH UNRAVELING

SPECTROSCOPY
Letter of Intent

Study of deeply bound kaonic nuclear states at DAΦNE2

AMADEUS Collaboration

111 scientists from 33 Institutes of 13 Countries signed the LOI

March 2006
A hadron physics important and unresolved topic:

*How the hadronic masses and interactions change in nuclear medium*

Approach by means of the predicted

**Deeply bound kaonic nuclear states**

firstly suggested by S. Wycech


Might offer the **ideal condition** to study how the **low-energy QCD** spontaneous and splicit Chiral-simmetry breaking changes in the **nuclear enviroment**.
Y. Akaishi and T. Yamazaki “Nuclear bound states in light nuclei” 

• Prediction based on the interpretation of the s-wave, isospin $I=0$ $\Lambda(1405)$ resonance as a $K\cdot p$ bound state
• Creation of a $KN$ potential as to simultaneously reproduce data from $KN$ scattering lengths and binding energy and width of kaonic hydrogen

**Strong attractive $I=0$ $KN$ interaction** favors discrete nuclear states *bound 100-200 MeV* and $\Gamma\approx20-30$ MeV.

**Shrinkage effect** of a K on core nuclei forming unusual dense nuclear medium (5-10 times nuclear density)
Kaonic Clusters contribution to fundamental physics

- Modification of the **Kaon mass** and of the **KN interaction in the nuclear medium** (symmetry breaking of QCD)

- Transition from the **hadronic phase** to a **quark-gluon phase** (changes of vacuum properties of QCD and quark condensate)

- Partial **restoration of Chiral symmetry** in nuclear medium

- Behaviour of strange particles and **kaon condensation** in dense nuclear matter (astrophysics: dynamics of supernovae, neutron stars, black holes)

- **Nuclear dynamics** under extreme conditions
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Experimental search for Kaonic Clusters

**E471 @ KEK**

He\(^4\)(K\(^-\)\(_{\text{stopped}}, n\))Kppn  neutron missing mass  
S\(^+(3140)\)  \(\Gamma \leq 23\) MeV  \(B = -194\) MeV

**FINUDA @ DAΦNE**

K\(^-\)pp on \(^6\)Li, \(^7\)Li, \(^9\)Be  
\(B = -115\) MeV  \(\Gamma = 67\) MeV

**E930 @ BNL-AGS**  in-flight (K\(^-\),n) reactions in water

**FOPI @ GSI**  Ni-Ni collisions  
\(M_{\Lambda d} = 3170\) MeV  \(B = -149\) MeV  \(\Gamma \approx 100\) MeV

**OBELIX** old data analysis

(K\(^-\)\(_{\text{stopped}}, \text{Li}\)) -> K\(^-\)pp  \(B = 170\) MeV/c  \(\Gamma \leq 25\)  
(K\(^-\)\(_{\text{stopped}}, \text{\(^4\)He}\)) -> K\(^-\)ppn  \(B = -121\) MeV/c  \(\Gamma \leq 60\)
Future experiments

- **FOPI @ GSI-SIS:** Al-Al, p-d
- **E15 @ J-PARC:** K\(^-\) induced reactions in flight \((K^-,N)(K^-,\pi^-)\)
- **FAIR @ GSI**

New data from:

- **FINUDA @ DAFNE**
- **E570 @ KEK**

... and AMADEUS!

“a global strategy to attack the major open problems of low-energy QCD”
**Theoretical debate**

- Alternative interpretations of the present data: double nucleon absorption followed by FSI of the produced particles with daughter nucleus

- Theoretical development of $\bar{K}N$ interaction in free space in the framework of SU(3) Chiral unitary model, and modification due to many-body effects in nuclear medium

- Nature of the $\Lambda(1405)$ resonance

- Bound kaon approach in the Skyrme model also predicts Kaonic Clusters

- Interpretations with not-so-strongly attractive $\bar{K}N$ potentials

- Nucleon-Nucleon repulsion

- Deeply bound states only in heavy nucleus

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*Theoreticians demand new complete experimental results!*
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AMADEUS aims to **confirm or deny** the existence of such an exotic states by performing a good measurement in a high performance detector on a suitable accelerator using

**In-medium full hadron spectroscopy**

A complete determination of all **formation and decay channel** measuring, binding energies, widths, angular momenta, isospin, sizes, densities...

Detection of:  
- charged and neutral particles  
- up to about 800 MeV/c  
- high efficiency and resolution  
- **in 4\pi geometry**  **(full acceptance)**
Requirements satisfied by...

DAΦNE2

KLOE
Setup performance requirements

Formation processes

\[
K^-_{\text{stopped}} + ^4\text{He} \rightarrow p + (K^-\text{pnn}) \\
K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + (K^-\text{ppn})
\]

Exotic states produced with \((K^-, N)\) reactions will be observed by the energy distribution of the **ejected protons and neutrons** via the **missing mass spectra** of the \((K^-, p)\) and \((K^-, n)\) reactions.

⇒ **The setup should be capable to measure:**
- Position of \(K^-\) stop: primary vertex and \(K^+\) tracking (trigger)
- Outgoing **neutrons** and **protons** 400 - 600 MeV/c

⇒ KLOE has an experimentally proved capability for neutron detection (KLOnE)
Decay processes

→ all decay products have to be identified, including hyperons decay products
→ 4-momenta of charged and neutral particles must be determined

- protons 200 - 500 MeV
- pions 50 - 200 MeV
- neutrons 200 - 500 MeV
- deuterons...
AMADEUS setup within KLOE

Possible setup for AMADEUS within KLOE:
- Cryogenic target
- Inner tracker
- Kaon trigger
Without AMADEUS setup

\[ \Phi \]

- How?
WITH AMADEUS setup
Example of Strange tribaryon formation and decay detection

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

\[ \Lambda + p + n \rightarrow p + \pi^- \]
AMADEUS inner region setup

- Gaseous or thin solid **target**

Draft design of a **toroidal cryogenic cell target**:
- 2 bar
- 10 K
- 150 NTP density
- 75µm Kapton, with aluminum grid reinforcement
- 30-40% of K⁻ stopped

- **tracking/vertex detector** (a **Multilayer cylindrical GEM** or a **Time Projection Chamber (TPC)** with **GEM-readout**) surrounding the half toroidal cryogenic target cell with the kaon trigger configuration.
AMADEUS Phase-1 -> Integrated luminosity request $3.5 - 4 \text{ fb}^{-1}$ in order to study the tribaryon DBKNS, dibaryon DBKNS and low-energy kaon-nuclear dedicated measurements.

**LNF test of SiPM (Hamamatsu)**

SiPM = Silicon Photomultipliers (array of APDs)

Characterization of SiPM detectors reading light from thin scintillating fibers

![Graph showing # of photoelectrons](image)
LNF test of SiPM (Hamamatsu)

- Stabilized Power Supply realization
- Preamplifier design
- Test setup design and realization (mechanics, cooling, electronics...)

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Additional tracking device?

- two TPC sections with triple GEM and x-y readout on both sides
- vacuum chamber
- half-toroidal cryogenic target cell
- kaon trigger made of 2+3 scintillating fibers layers
From preliminary Monte Carlo simulation

\[ \Phi \text{ production cross section} \]

peak luminosity \( L \)

branching ratio for \( K^\pm \)

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

production rate for \( K^\pm \) pairs

40% \( K^- \) stopped in He target \( \rightarrow \) 12.5 \( \times \) 10^8 ^4\text{He}-K^- atoms/month

10^{-3} \text{ cluster formation yield} \rightarrow 12.5 \times 10^5 \text{ kaonic clusters/month}

Identification & tracking efficiencies \( \rightarrow \) 10^5 events/month (\( \sim \) 1000 pb^{-1})
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The AMADEUS experiment

Oton Vázquez Doce
Further requests (other targets) depend on the results of these first measurements

From AMADEUS LOI:

“In conclusion, an initial programme based on the study of the $^3\text{He}$ and the $^4\text{He}$ targets, to investigate dibaryonic and tribaryonic states, would require an integrated luminosity from 2 to 6 fb$^{-1}$, according to depth of the investigation”
From AMADEUS LOI:

“In conclusion, an initial programme based on the study of the $^3\text{He}$ and the $^4\text{He}$ targets, to investigate dibaryonic and tribaryonic states, would require an integrated luminosity from 2 to 6 fb$^{-1}$, according to depth of the investigation”

Further requests (other targets) depend on the results of these first measurements

Possible at DAΦNE with luminosity upgrade (before J-PARC, FOPI, FAIR)

• Full hadron spectroscopy with 4$\pi$ geometry
• Target+trigger+tracking devices in existing KLOE setup