The SIDDHARTA experiment at DAFNE and future perspectives

Catalina Curceanu (Petrascu)
LNF – INFN, Frascati
On behalf of SIDDHARTA Collaboration

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SIDDHARTA Collaboration:

LNF- INFN, Frascati, Italy
IMEP- ÖAW, Vienna, Austria
IFIN – HH, Bucharest, Romania
Politecnico, Milano, Italy
MPE, Garching, Germany
PNSensors, Munich, Germany
RIKEN, Japan
Victoria Univ., Canada

Silicon Drift Detector for Hadronic Atom Research by Timing Applications
The scientific aim

the determination of the \textit{isospin dependent} \textit{\kappaN scattering lengths} through a

\( \sim eV \) measurement of the shift

and \textit{of the width}

of the \( K_\alpha \) line of \textit{kaonic hydrogen}

and

the \textit{first (similar) measurement} of \textit{kaonic deuterium}
Kaonic cascade and the strong interaction

K_α \sim 6.3 \text{ keV} = \Delta E_{2p \rightarrow 1s}
Antikaon-nucleon scattering lengths

Once the shift and width of the 1s level for kaonic hydrogen and deuterium are measured, with the Deser formulae (neglecting isospin breaking corrections):

\[ \varepsilon + i \frac{\Gamma}{2} = 412 \ a_{K-p} \ eV \ fm^{-1} \]
\[ \varepsilon + i \frac{\Gamma}{2} = 602 \ a_{K-d} \ eV \ fm^{-1} \]

one can obtain the isospin dependent antikaon-nucleon scattering lengths

\[ a_{K-p} = \frac{(a_0 + a_1)}{2} \]
\[ a_{K-n} = a_1 \]
Measuring the KN scattering lengths with the precision of a few percent will drastically change the present status of low-energy KN phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

1. Breakthrough in the low-energy KN phenomenology;
2. Threshold amplitude in QCD
3. Determination of the KN sigma terms, which give the degree of chiral symmetry breaking;
4. Determination of the strangeness content of the nucleon from the KN sigma terms
5. Information on Λ(1405)
DEAR (DAΦNE Exotic Atom Research) 2002

Cryogenic setup

APD Cryo Cooler
Varian Turbo Molecular Pump
CryoTiger, CCD Cooling
CCD Electronics
Vacuum Chamber
Cooling Lines
CCD Pre-Amplifier Boards
Hydrogen Target Cell
CCD55-Chip (total of 16 chips)

Kaons from DAΦNE
DAΦNE
DEAR on DAΦNE (2002)
October – December 2002 DAQ set of “good quality” data

Collected data:

- Kaonic Nitrogen:
  6 – 28 October (about 17 pb$^{-1}$ – 10 pb$^{-1}$ in stable conditions);

- Kaonic Hydrogen:
  30 October – 16 December: about 60 pb$^{-1}$

- Background data (no collisions) for KH:
  16 – 23 December
Resulting K-\(\alpha\) Spectrum
(all background fit-components subtracted)

\[ E_{el.mag} = 6.48 \text{ keV} \]
DEAR Results on the Shift and Width

2 independent analyses starting from the raw data giving consistent results


Shift: $\varepsilon_{1s} = -193 \pm 37 \text{ (stat.)} \pm 6 \text{ (syst.) eV}$

Width: $\Gamma_{1s} = 249 \pm 111 \text{ (stat.)} \pm 30 \text{ (syst.) eV}$
DEAR Results on kaonic hydrogen

- Γ₁s [eV]
- ε₁s [eV]

KpX (KEK)
M. Iwasaki et al, 1997

ε₁s = -323 ± 63 ± 11 eV
Γ₁s = 407 ± 208 ± 100 eV

DEAR

Repulsive-type
attractive

Davies et al, 1979
Izycki et al, 1980
Bird et al, 1983
Many interesting discussion in the dedicated Workshop:

“Exotic hadronic atoms, deeply bound nuclear states and antihydrogen: present results and future”

held at ECT* (Trento), on June 19-24, 2006

Organizers: Catalina Curceanu (Petrascu) – LNF – INFN, Frascati (Italy) coordinator
Eberhard Widmann, Stefan Meyer Institut für subatomare Physik - Austrian Academy of Sciences, Vienna (Austria)
Akaki Rusetsky, Univ. Bonn, Germany

Akaki Rusetsky, Univ. Bonn, Germany
W. Weise – at *Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges,*
ECT* Trento, 19-24 June 2006


J. Mares, E. Friedman and A. Gal, Nucl. Phys. A770 (2006);

\[ \sqrt{s} = \omega + M_N \]

(N. Borasoy, R. Nissler et al.)
W. Weise – at *Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges*,

- Two primary sources of **imaginary parts**:
  - Reactions on a **single** nucleon:
    - \( \bar{K} \rightarrow \pi \quad \text{N} \rightarrow \text{Y} \)
    - can be handled in coupled-channels approach
  - Absorption on **two** nucleons:
    - \( \bar{K} \rightarrow \text{N} \quad \text{N} \rightarrow \text{Y} \)
    - must be accurately constrained by \( K^- d \rightarrow YN \)
    - ... a case for SIDDHARTA
The obtained DEAR result:
represents indeed the **best measurement performed on**
**Kaonic Hydrogen up to now**

**BUT**

what we are aiming for is =>
SIDDHARTA’s aim

# few eV precision measurement of kaonic hydrogen 1s level shift;

# first measurement of kaonic deuterium

in order to determine the isospin dependent antikaon nucleon scattering lengths at percent level precision
Use instead of the CCD detectors of DEAR new X-ray triggerable device

*Choice of the detector based on criteria:*

- preserve good features of CCDs (efficiency, resolution);
- offer a timing ~ 1 μs – trigger

⇒Large Area Silicon Drift Detector (JRA10 – HadronPhysics, FP6)
Spectroscopic resolution and timing: detector comparison

SDD PIN Si(Li) 150 K 5.9 keV line

PIN Tsh=20us

Si(Li) Tsh=20us

SDD Tsh=1us
The Silicon Drift Detector with on-chip JFET

JFET integrated on the detector
- capacitive ‘matching’: $C_{\text{gate}} = C_{\text{detector}}$
- minimization of the parasitic capacitances
- reduction of the microphonic noise
- simple solution for the connection detector-electronics in monolithic arrays of several units
Background reduction with triggered acquisition
by Monte Carlo
starting from DEAR results (S/B = 1/70):

\[ S/B = 4/1 \]
SDD layout – readout side

- Chip size: 34 x 14 mm²
- Sensitive area: 3 x 100 mm²
- Integrated temperature sensors
The final SDD module
SDD-subunit

2 array of 3 cm² SDD

18 cm² SDD unit
SDD-subunit
PIXE of Al and Al$_2$O$_3$
Spectroscopy test

- SIDDHARTA SDDs  •  $T = -60 \, ^\circ\text{C}$, $\tau = 1 \, \mu\text{sec}$
The SIDDHARTA Setup
The Cryogenic Target Cell

APD 2-stage cryo cooler with 8 watt @ 20K

Cryogenic target cell
75 µm Kapton within a pure aluminum grid
$P_{\text{max}} \sim 5 \text{ bar}$
The Cryogenic Target Cell
Target Cell and SDD-subunit
The VLSI readout electronics
(New) SDD Charge Preamp configuration

- **detector chip**
- **leakage current**
- **gate current**
- **Cgd**
- **Rd**
- **Vg**
- **Cd**
- **Cf**
- **Vss**
- **Vdet**
- **Vs**
- **Iref**
- **Low frequency loop**
- **transimpedance amplifier**

* World first application*
Spectroscopic Measurements

Fe$^{55}$ source

- 8 channels ASIC
- Peaking time 3μs

Counts vs. E [keV]

144 eV
The Kaon trigger
Study for PMs supporting
The tdc's and adc's information of PMs and the output of SIDDHARDA SDDs must be recorded simultaneously for any trigger in order to allow selection of “true” kaon or background (mip) events.
The setup on DAFNE
The SIDDHARTA setup in DAΦNE
Monte Carlo simulations
SIDDHARTA Kaonic hydrogen simulated spectrum

S/B = 5/1

Precision on shift ~1 eV

~300 pb$^{-1}$

Counts/30 eV

X-ray energy (keV)
SIDDHARTA Kaonic deuterium simulated spectrum

Precision on shift < 10 eV

S/B = 1/4

500 pb⁻¹
Results on Kaonic Hydrogen

A strong motivation for the community working on the low-energy kaon-nucleon interactions
2006:

- Assembly of the SDD large area detectors in the setup;

- Assembly of the final setup so that

second half 2007:

install on DAFNE and start DAQ
SIDDHARTA future plans

1) ~ eV level precision measurement of kaonic hydrogen;

2) first measurement of kaonic deuterium

3) Kaonic helium measurement (“kaonic helium puzzle” and implications on deeply bound kaonic nuclear states);

4) Kaon mass precision measurement at the level of 10 keV

5) Other light kaonic atoms measurement (Li, Be…);

6) Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)
From kaonic atoms to kaonic-nuclei
Continuity and innovation

Kaonic Hydrogen and deuterium

KN low-energy scattering

Λ(1405)

Deeply Bound Kaonic Nuclear States

An unique opportunity

ONLY AT DAFNE2
Spare
Meson-nucleon sigma terms

- Sigma terms are directly connected with the symmetry breaking part of the strong interaction Hamiltonian.

- Sigma terms measure the nucleon mass shift away from the chiral limit \( (m_q=0) \), therefore parameterizing the explicit breaking of chiral symmetry in QCD due to the non-zero quark masses.
The impact of the SIDDHARTA results

Presently only estimates exists of KN sigma terms.

A measurement of KN scattering lengths at the percent level would enable the determination of the KN sigma terms with a precision of about 20% or less.
The DAQ