Kaonic atom measurements at DAΦNE

Frascati (Italy)
May 14th – 18th, 2007

Florin Sirghi on behalf of DEAR/SIDDHARTA Collaboration
SIDDHARTA
Silicon Drift Detector for Hadronic Atom Research by Timing Applications

represents the natural development, from scientific and technical point of view, of the

DEAR
DAFNE Exotic Atom Research

along the line of research dedicated to exotic atoms at DAFNE
DEAR/SIDDHARTA Collaboration

LNF- INFN, Frascati, Italy
Politecnico, Milano, Italy

Stefan Meyer Institut, Vienna, Austria

IFIN–HH, Bucharest, Romania

Univ. Tokyo, Japan
RIKEN, Japan

Victoria University, Canada

PNSensor GmbH, Munich, Germany
Max-Planck-Institute for Extraterrestrial Physics, Garching, Germany

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
The scientific aim

the determination of the \textit{isospin dependent $\bar{K}N$ scattering lengths} through a

$\sim eV$ \textit{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}
Hydrogen atom

Hydrogen atom

Kaonic hydrogen

2p→1s (Kα)
X ray of interest
Kaonic cascade and the strong interaction

\[ \varepsilon = E_{2p-1s}(\text{meas.}) - E_{2p-1s}(\text{e.m.}) \]

\[ K_\alpha \sim 6.2 \text{ keV} = \Delta E_{2p\rightarrow 1s} \]

Strong Interaction causes:

- energy shift \( \varepsilon \) of the last energy levels form their purely electromagnetic values
- level width \( \Gamma \) finite lifetime of the state corresponding to an increase in the observed level width

Measurement of strong interaction shift and width of kaonic hydrogen and kaonic deuterium with an accuracy of a few eV
Results on Kaonic Hydrogen

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

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Experimental requirements

- **Kaon Beam at DAΦNE with unique performance**
  - Slow, nearly monochromatic kaons (E~16 MeV)
  - Kaon pair emitted back-to-back
  - Low hadronic background

- **Target System**
  - Cryogenic gas target, pure hydrogen gas
  - Thin windows, light-weight construction

- **X-ray Detector**
  - Large active area
  - Superior energy resolution
  - Background suppression capability

- **Calibration**
  - “online“ calbration – fluorescence lines
The choice of the detector

- A good X-ray detector, which preserves all good features of the CCD (no timing)
  - large active area
  - quantum efficiency
  - energy resolution
  - linearity and stability
  - performance in accelerator environment

- Trigger capability (fast shaping times – 1µs) for background rejection by using the kaon - X ray time correlation
Principle of the Semiconductor Drift Detector

The electrons are collected by the small anode, characterized by a low output capacitance.

Advantages: very high energy resolution at fast shaping times, due to the small anode capacitance, independent of the active area of the detector.
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
SDD readout side, cell center

- bond pads
  - 150μm x 150μm

- 7 internal contacts
  - source
  - drain
  - ring_1
  - inner guard ring
  - inner substrate
  - reset diode

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Special chip design for SIDDHARTA

- Chip size: 34 x 14 mm²
- SDDs required by the experiment: 72 chips
- Total area: 216 cm²
- Large sensitive area: 100 mm²
Using electron beam from BTF (beam test facility) at DAFNE, SDD tests are performed. BTF Electron beams = 500 MeV electrons with 50 Hz. High-energy gamma-rays/electrons are produced by 500-MeV electron beam and lead bricks.
SDD energy resolution

W49S06 cell3

FWHM=150 eV

W01S01 cell1

FWHM=140 eV

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
SDD linearity test

![Graph showing energy vs ADC channel with various Kα and Kβ lines within a 2eV linearity.]

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Background rejection

Counts/10ch/sec

no trigger (without coincidence)

trigger (with coincidence)

rejection factor $(4.6 \pm 0.5) \times 10^{-5}$
The SIDDHARTA Setup

- APD Cryo Cooler for target cell
- CryoTiger for SDD Cooling
- Turbo Molecular Pump
- LV and HV power supply
- Vacuum Chamber

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Cryogenic target cell

Working T 22 K
Working P 2.0 bar

Alu-grid

Side wall:
Kapton 50 µm

Kaon entrance

Window:
Kapton 50 µm
SDD arrangement

18 cm² SDD unit

2 array of 3cm² SDD

SDD electronics boards
CHIP card & transfer card

3.3V switch
Power supply

LV power
connector

HV voltage
filter

+6V voltage
regulator

-6V voltage
regulator

Bonding
area

Power supply
filter

CHIP card & transfer card

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
SIDDHARTA setup in DAΦNE

Beam pipe and trigger system

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Expected results for K⁻p

→ integrated luminosity ~ 400 pb⁻¹

Input:
\( \varepsilon_{1s} = 195 \text{ eV} \)
\( \Gamma_{1s} = 250 \text{ eV} \)
\( Y_{K\alpha} = 2.0 \% \)

\( \Delta \varepsilon_{1s} \sim \pm 2.0 \text{ eV} \)
\( \Delta \Gamma_{1s} \sim \pm 4.5 \text{ eV} \)

\( S/B = 6:1 \)
Expected results for K-\(d\)

→ integrated luminosity \(\sim 600\) pb\(^{-1}\)

Input:
\(\varepsilon_{1s} = 325\) eV
\(\Gamma_{1s} = 630\) eV
\(Y_{K\alpha} = 0.2\) %

\(\Delta\varepsilon_{1s} \sim \pm 15\) eV
\(\Delta\Gamma_{1s} \sim \pm 40\) eV

Florin Sirghi, LNF SPRING SCHOOL, Frascati 2007
Summary

• Tests of all subsystems done
  - characterization of large area SDDs under beam conditions
  - front-end electronics production
  - data acquisition production
  - construction of the experimental setup
  - slow-controls system

• The assembling at LNF in progress

• ready for installation at DAΦNE fall of 2007
SIDDHARTA future plans

**Kaonic helium** measurement towards the study of deeply bound nuclear kaonic state.

**Other light kaonic atoms** measurement (Li, Be...).

Investigate the possibility of the measurement of other types of hadronic *exotic atoms* (sigmonic atoms).

**Charged kaon mass** precision measurement.
DEAR results on the shift and width for kaonic hydrogen

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

Width: \( \Gamma_{1s} = 249 \pm 111 \) (stat.) \( \pm 30 \) (syst.) eV

represents the best measurement performed on Kaonic Hydrogen up to now
Motivation

• Exotic (kaonic) atoms – probes for strong interaction
  ➢ hadronic shift $\varepsilon_{1s}$ and width $\Gamma_{1s}$ directly observable
  ➢ experimental study of low energy QCD

• Kaonic hydrogen
  ➢ $K^-p$ simplest exotic atom with strangeness
  ➢ kaonic hydrogen „puzzle“ solved – but still: precision data missing
  ➢ kaonic deuterium never measured before

• Information on $\Lambda(1405)$ sub-threshold resonance
  ➢ important for research on deeply bound kaonic states

• Determination of the isospin dependent $K\bar{N}$ scattering lengths