Silicon Drift Detectors for high precision exotic atoms X-ray spectroscopy

Francesco Sgaramella
On behalf of SIDDHARTA-2 collaboration
Silicon Drift Detectors for Hadronic Atom Research by Timing Application

LNF-INFN, Frascati, Italy
SMI-ÖAW, Vienna, Austria
Politecnico di Milano, Italy
IFIN –HH, Bucharest, Romania
TUM, Munich, Germany
RIKEN, Japan
Univ. Tokyo, Japan
Victoria Univ., Canada
Univ. Zagreb, Croatia
Univ. Jagiellonian Krakow, Poland
ELPH, Tohoku University
To perform precision measurements at threshold of kaonic atoms X-ray transitions
  ➢ unique information about QCD in the non-perturbative regime in the strangeness sector

Started with the precision measurement of **shift** and **width** of **kaonic hydrogen** (SIDDHARTA)

**SIDDHARTA-2 AIM**

To perform the *first measurement ever of kaonic deuterium X-ray transition* to the ground state (1s-level) such as to determine its shift and width induced by the presence of the strong interaction.

The analysis of the combined measurements of kaonic deuterium and kaonic hydrogen will allow, the extraction of the **isospin-dependent antikaon-nucleon scattering length**.

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**DAΦNE Collider**

- $\Phi \to K^- K^+$ (49.1%)
- Monochromatic low-energy $K^-$
  
  ($\sim 127$ MeV/c ; $\Delta p/p = 0.1\%$)

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SIDDARATTA-2 experiment

8 keV signals

Monte Carlo simulation of SIDDHARTA-2 kaonic deuterium spectrum

He cooling line

SiDDHARTA-2 experimental apparatus
Large area Silicon Drift Detectors for X-ray spectroscopy

8 SDD units (0.64 cm$^2$) for a total active area of 5.12 cm$^2$
Large area Silicon Drift Detectors for X-ray spectroscopy

SDD schematic picture

SDD cross section

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Silicon Drift Detectors
arrays

SDDs array qualification
SDDs spectroscopic response

SIDDHARTA-2 ROI

Counts

Ti Kα
Fe Kα
Cu Kα
Sr Kα
Ti Kβ
Fe Kβ
Cu Kβ
Sr Kβ

ADC unit [a.u.]
SDDs spectroscopic response

Linearity

\[ \Delta E/E < 10^{-3} \]

Energy resolution

FWHM Fe Kα line

\[ 159.2 \pm 0.3 \text{ eV} \]

Stability

\[ \delta E < 10^{-3} \]

Timing resolution

DT Cu Kα line

\[ 461 \pm 9 \text{ ns} \]

\[ T \approx 140 \text{ K} \]
SDDs spectroscopic response – HV Scan

Linearity

\[ r = \sqrt{\frac{\sum_{i=1}^{4} (p_{i}^{\text{exp}} - p_{\text{label}})^2}{4}} \]

Energy resolution

\[ FWHM_{TOT}^2 = FWHM_{i}^2 + FWHM_{n}^2 + FWHM_{c,c}^2 \]

Kα Fe FWHM
SDDs spectroscopic response – HV Scan

HV = 140 V

$H_{\text{TAIL}} / H_{\text{GAUSS}} = 0.006 \pm 0.001$

HV = 180 V

$H_{\text{TAIL}} / H_{\text{GAUSS}} = 0.05 \pm 0.01$

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SDDs spectroscopic response – Temperature Scan

Drift Time Cu Kα line
400 ns at $T \approx 130$ K

$\Delta t_{Cu} = a \cdot \left( \frac{T}{T_0} \right)^n + c$

$\mu = mobility \approx T^{-n}$
SIDDHARTINO - installation
Evaluation of the machine background during the DAΦNE beams commissioning phase in preparation for the K-d run

Measurement of K-4He 3d->2p transition
SIDDHARTINO

SIDDHARTA-2 single BUS

SDDs arrays head-to-head
SDD energy response during DAΦNE BCP

SDDs and DAQ analog/digital chain characterization during the DAΦNE Beam Commissioning Phase

**heavy background conditions**
(high energy particle and radiation)

Multi-element target

**Ti-Fe-Cu-Br-Sr**

to include the

**SIDDHARTA-2 energy range**

Miliucci M. et al, Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy, MST 2020
SDD energy response during DAΦNE BCP

DAΦNE(BCP)
Beam Commissioning Phase
\( e^- e^+ \)

SDD Energy Spectrum

<table>
<thead>
<tr>
<th>Lines</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti Kα</td>
<td>3480329</td>
</tr>
<tr>
<td>Cu Kα</td>
<td>4328</td>
</tr>
<tr>
<td>Sr Kα</td>
<td>1164</td>
</tr>
</tbody>
</table>

![Graph showing energy spectrum and linearity](image)

Linearity

FWHM Fe Kα line

![Graph showing FWHM for different lines](image)
Sum of 18 calibrated units

- Linear response
  -> Residuals within ± 3 eV (4–15 keV range)
  -> $\Delta E/E < 10^{-3}$ (4–15 keV)

- FWHM Fe Ka line = 160.1 ± 0.5 eV (@ 140 K)
Linear energy response within $\pm 3$ eV (4–15 keV range) \( \Rightarrow \delta E/E < 10^{-3} \) eV.

Stable energy response within 1 eV.

Fe $K\alpha$ line energy resolution about 160 eV @ 140 K

Cu $K\alpha$ line timing resolution about 460 ns @ 140 K

Full optimization of the SDDs system spectroscopic response

SDDs analog/digital DAQ chain performances are preserved in the heavy background of the collider (published papers), to be used as key tools during the machine optimization phase;
SIDDHARTINO run – Kaonic Helium
SIDDHARTINO run – Kaonic Helium

Kaon Monitor

SDDs Drift Time

Kaons

MIPs
SIDDHARTINO run – Kaonic Helium

L = 26.156 pb^-1

- KHe4 (6.4 keV) (3->2)
- Ti
- KC (5.5 keV) (6->5)
- KC (8.8 keV) (7->5)
- KC (10.2 keV) (5->4)
- KTi (10.9 keV) (5->4)
- The **data analysis about the Kaonic helium4 spectrum** is still on going and will be followed by a publication.

- Installation of the full SDDs system and **start of the kaonic deuterium run** up to an estimated integrated luminosity of 800 pb-1
  - First run with SIDDHARTA-2 setup about 300 pb-1 – till end 2021
  - Second run with optimized shielding, veto system for other 500 pb-1 – 2022

- **Pioneering technology of 1mm thick SDDs**
  - to investigate other Kaonic atoms: Li – Be - B
Solid target system for light kaonic atoms

Li – Be - B

kaonic Lithium-6 3-->2 transition = 15.08 keV
kaonic Lithium-6 4-->3 transition = 5.28 keV
kaonic Lithium-7 3-->2 transition = 15.3 keV
kaonic Lithium-7 4-->3 transition = 5.34 keV

kaonic Beryllium-9 3-->2 transition = 27.56 keV
kaonic Beryllium-9 4-->3 transition = 9.64 keV
kaonic Beryllium-9 5-->4 transition = 4.46 keV
Solid target system for light kaonic atoms

Li – Be - B

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THANK YOU