Low energy kaon nuclei interaction studies at DAFNE: AMADEUS experiment

Oton Vázquez Doce
LNF-INFN
(on behalf of the AMADEUS collaboration)
Study of the hadronic interactions of $K^-$ in light nuclei at DAΦNE:

**AMADEUS experiment**
First dedicated full-acceptance study in Frascati laboratories

- Letter of Intend + Day-1 proposal:
  - Study of deeply bound kaonic nuclear states at DAΦNE2
  - Low energy kaon-nuclei Interaction studies

DAΦNE: e+e- collider in the Frascati National Laboratories
“Medium modification of Hadrons”
Prof. Chaden DJALALI, Monday plenary session

Mesons as probe of Chiral Symmetry restoration

Experiments roughly fall under two categories

1) Looking at the modification of the meson-nucleon interaction in medium:
   - pionic atoms (capture and nuclear reaction),
   - elastic pion-nucleus scattering at low energy
   - Double pion production in nuclei and the $\sigma$
   - Kaons in nuclei

2) Mass and width changes of light vector mesons $\rho$, $\omega$, and $\phi$:
   - in relativistic heavy ion collisions
   - in nuclei
study of the hadronic interactions of $K^-$ in light nuclei at DAΦNE:

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   - Kaons in nuclei

2) Mass and width changes of light vector mesons $\rho$, $\omega$, and $\phi$:
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   - in nuclei
Study of the hadronic interactions of K⁻ in light nuclei at DAΦNE:

Studying the properties of the KN potential in the nuclear medium

- **Intense theoretical debate** with several different approaches:
  - Variational calculations with phenomenological K⁻N potential
  - Chyral SU(3) dynamics by non-perturbative coupled channels
  - 3-body Faddeev calculations
  - etc

- **How deeply is a kaon bounded in a nucleus?**
- A strong attractive potential will allow the formation of deeply bound kaonic clusters, with exotic features that would allow to investigate:
  - spontaneous and explicit symmetry breaking of QCD
  - Kaon condensation in nuclear matter
  - etc
Study of the hadronic interactions of $K^-$ in light nuclei at DAΦNE:

Experimental data

**Experimental results from FINUDA**

- $K^-$ stopped in light nuclei
- Invariant mass spectroscopy

Next talk by A. Filippi

kaonic 3-baryon state: $ppnK^-

kaonic dibaryon state: $ppK^-$

![Graphs and data plots]

Physics case
Experimental data

Experimental results from **FINUDA**

K- stopped in light nuclei

Invariant mass spectroscopy

**Results from KEK:**

K- stopped in 4He

Invariant mass spectroscopy

**kaonic 3-baryon state:** ppnK-

**kaonic dibaryon state:** ppK-

E549/570 talk in the previous session by T. Suzuki
Study of the hadronic interactions of $K^-$ in light nuclei at DAΦNE:

Experimental data

Experimental results from FINUDA

$K^-$ stopped in light nuclei
Invariant mass spectroscopy

Results from KEK:

$K^-$ stopped in $^4$He
Invariant mass spectroscopy

DISTO

$p+p \rightarrow K^+ + X$

OBELIX

$p^4He$ annihilation

Physics case

kaonic 3-baryon state: $ppnK^-$
kaonic dibaryon state: $ppK^-$
Study of the hadronic interactions of K\(^-\) in light nuclei at DAΦNE:

International Workshop on Hadronic Atoms and Kaonic Nuclei solved puzzles, open problems and future challenges in theory and experiment
Trento, October 12 - 16, 2009

The AMADEUS experiment

Oton Vázquez Doce
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The AMADEUS experiment

Oton Vázquez Doce
**Planned experiments**

- *the future experiments in Japan* at J-PARC will produce kaonic nuclear states only with $K^-$-induced reactions in-flight ($E_{15}$; $E_{17}$)
- *alternative approaches followed* at GSI with FOPI using proton-nucleus collisions at beam energies close to the strangeness production threshold and with nucleus-nucleus collisions
- a dedicated facility – **AMADEUS at DAΦNE** will study antikaon-mediated bound nuclear systems with $K^-$-induced reactions at rest
**Experimental program**

- **DAFNE** produces charged Kaons of $P \sim 127$ MeV coming from $\Phi$ decay at rest
- $K^- \rightarrow 4\text{He}, 3\text{He}$ targets
- Full acceptancy $4\pi$ spectroscopy in all formation and decay channels

**AMADEUS phase-1**: start in 2011/2012 (after KLOE2), study di- and tri–baryon kaonic nuclei and low-energy kaon-nucleon/nuclei interactions

Requirements satisfied by...

- **DAΦNE2**
- **KLOE**

\[ K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + n + (K^-pp) \quad \Lambda + p \]

\[ K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + (K^-ppn) \quad \Lambda + d \]

(detected particles)
Study the most fundamental antikaon deeply bound systems in **formation** and **decay** processes:

**kaonic dibaryon states:**
- $ppK^-$ and $pnK^-$
  produced in a $^3\text{He}$ gas target

**kaonic 3-baryon states:**
- $ppnK^-$ and $pnnK^-$
  produced in a $^4\text{He}$ gas target
Study the most fundamental antikaon deeply bound systems in formation and decay processes:

- Kaonic dibaryon states: \( ppK^- \) and \( pnK^- \) produced in a \(^3\)He gas target
- Kaonic 3-baryon states: \( ppnK^- \) and \( pnnK^- \) produced in a \(^4\)He gas target

Extended Program:

1. Low-energy charged kaon cross section on \( p, d, \text{He}-3 \) and \( \text{He}-4 \), for \( K^- \) momentum lower than 100 MeV/c (missing today)
2. The \( K^- \) nuclear interactions in Helium (poorly known – based on one paper from 1970...)
3. Properties of \( \Lambda \) and charged \( \Sigma \)'s for example decays in channels with a neutrino → astrophysics implications (cooling of compact stars)
4. Resonance states as \( \Lambda(1405) \) or the \( \Sigma(1385) \) could be understood with high statistics; their behaviour in nuclear medium can be studied too
Full acceptance and high precision measurements will be made by implementing the KLOE detector with an inner AMADEUS setup (50 cm. gap in KLOE DC around the beam pipe)

Setup for AMADEUS within KLOE
- Cryogenic target
- Inner tracker
- Kaon trigger
The AMADEUS experiment

Full acceptance and high precision measurements will be made by implementing the AMADEUS setup within the KLOE detector with an inner gap in KLOE DC (50 cm gap in KLOE DC around the beam pipe).

**Experimental setup**

- **KLOE Drift Chamber**
- **EMC**
- **KLOE**

\[
\begin{align*}
K^-_{\text{stopped}} + ^4\text{He} &\rightarrow p + (K^-pnn) \\
K^-_{\text{stopped}} + ^4\text{He} &\rightarrow n + (K^-ppn)
\end{align*}
\]
Full acceptance and high precision measurements will be made by implementing an inner AMADEUS setup (50 cm gap in KLOE DC around the beam pipe).

The AMADEUS experiment is shown in this diagram. It consists of a cryogenic target, an inner tracker, and a kaon trigger. The setup will allow for detailed measurements of kaon interactions with helium.

The experimental setup is as follows:

K\textsubscript{-} \text{stopped} + ^4\text{He} \rightarrow p + (K\text{-ppn})

K\textsubscript{-} \text{stopped} + ^4\text{He} \rightarrow n + (K\text{-ppn})

How an event will look like in AMADEUS:

Detail of the inner region of the DC.
The AMADEUS setup will be implemented in the 50 cm. gap in KLOE DC around the beam pipe:

- Modification of the beam pipe of KLOE-2 in order to allow access
- **Target** (A gaseous He target for a first phase of study)
- **Trigger** (1 or 2 layers of ScFi surrounding the interaction point)
- **Inner tracker** (eventually, a first tracking stage before the DC)
Interaction region + Target cell

Central region made of **CARBON FIBER**:
- Vacuum chamber
- External part of cryostate and target walls

**Aluminium** for the peripheral part
Target cell

SIDDHARTA experiment (shift on Kaonic Atoms lines due to strong interaction) has been running until past November in Dafne

working T 22 K working P 1.5 bar
Alu-grid
Side wall: Kapton 50 µm
Entrance window: Kapton 50 µm

• Stopping power optimization
• Monte Carlo simulations
**Target cell**

**SIDDHARTA experiment** (shift on Kaonic Atoms lines due to strong interaction) has been running until past November in Dafne.

**AMADEUS:**

Low-mass cryogenic gas target cell:
- Working T = 22 K
- Working P = 1.5 bar
- Alu-grid
- Side wall: Kapton 50 µm
- Entrance window: Kapton 50 µm

- Stopping power optimization
- Monte Carlo simulations
**Target cell**

- Stopping power optimization
- Monte Carlo simulations

**Low-mass cryogenic gas target cell:**

- $T = 10$ K
- $P = 1.0$ bar
- $R_{in} = 5$ cm
- $R_{out} = 15$ cm
- $L = 20$ cm

**SIDDHARTA experiment** (shift on Kaonic Atoms lines due to strong interaction) has been running until past November in Dafne

**SIDDHARTA Monte Carlo**

**AMADEUS Monte Carlo**

**Experimental setup**
**Trigger system**

- **Cylindrical layer of scintillating fibers** surrounding the beam pipe to **trigger $K^+ K^-$ in opposite directions**
- Single or double layer
  
  In this case possibility of perform tracking as well: X-Y measurement with high granularity layers

- **Readout to be done by MPPC** (*Multi Pixel Photon Counter*)
The AMADEUS experiment

**Trigger system**

- Ideal for ScFi coupling and high granularity detector
- Time resolution below 1 ns
- Insensitive to strong magnetic fields
- High gain (>10^6) and quantum efficiency

**Electronics: New CAMAC modules providing:**

Variable $V_{\text{bias}}$ for 5 channels with a stability for nominal voltages below 10 mV

**MPPC Hamamatsu S10362-11-050U,** effective area 1mm^2, 400 pixels, working biases ~ 70 V.

**New mechanical support** for 5 ScFi read from both sides

**10 SiPM + readout card**

**Instrumented fibers:** Saint Gobain BCF-10 single cladding:

- Emission peak 432 nm
- Decay time 2.7 ns
- $1/e$ 2.2 m
- 80000 ph./MeV
Trigger system

tests installation at DAΦNE

SIDHARTA setup

DAΦNE beam pipe

Our test setup
**Experimental setup**

**Trigger system tests at DAΦNE**

- **Kaon Monitor TDC (upper/lower coincidence)**
  - TDC working in Common Start (RF/2)
  - Single peak resolution ~ 100 ps
  - MIP/K separation ~ 1 ns

- **MPPC tdc spectra**
  - TDC working in Common Stop (RF/2)

- Achieved best single peak resolution below 200 ps
**Trigger system** tests at DAΦNE

Time correlation between MPPC and KM

Black: MPPC total ADC spectrum
Green: MPPC ADC when Kaons in KM

ADC in SiPM

Dark noise

MIPS + KAONS

KAONS
Before AMADEUS...

...analysis of KLOE data from 2004/2005:

- Test the behaviour of the KLOE spectrometer for hadronic physics purposes
- Possibility to study the phenomenon with an active target
Hadronic interactions of $K^-$ inside the KLOE Drift Chamber

- The Drift Chambers of KLOE contain mainly $^4\text{He}$ (90% helium, 10% isobutane mixture)

- From analysis of KLOE data and Monte Carlo: 0.1% of $K^-$ from daΦne should stop in the DC volume

- This would lead to hundreds of possible kaonic clusters produced in the 2 fb$^{-1}$ of KLOE data.

\[
K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + n + (K^-pp) \\
\downarrow \Lambda + p
\]

\[
K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + (K^-ppn) \\
\downarrow \Lambda + d
\]
Lambda invariant mass

\[ M_{\text{inv}} = 1115,723 \pm 0.003 \text{ stat (MeV/c}^2) \]

- Dedicated event selection to avoid Eloss in the DC wall
- Best \( \chi^2 \) tracks and vertices

KLOE:

\[ M_{\text{inv}} = 1115,723 \pm 0.003 \text{ stat (MeV/c}^2) \]

PDG:

\[ M_\Lambda = 1115,683 \pm 0.006 \text{ stat} \pm 0.006 \text{ syst (MeV/c}^2) \]

- Sistematics dependent of momentum calibration
- Evaluated by 2-body decay of \( K^\pm \):
  \[ K^\pm \rightarrow \mu^\pm \nu \]
  \[ K^\pm \rightarrow \pi^\pm \pi^0 \]
Lambda-d

\[ \Lambda - d \]

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

Lambda momentum vs. Minv

deuteron momentum vs. Minv

\[ M_{\text{inv}} \Lambda d (\text{MeV}/c^2) \]

\[ M_{d} + M_p + M_{\pi^-} \]

Events in the DC volume

Sharp cut due to EMC requirement (mass by TOF)

Analysis of KLOE data

Hadronic interactions of K- inside the KLOE Drift Chamber
Production rate for $K^\pm$ pairs

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

Production rate for $K^\pm$ pairs

- Peak luminosity: $L = 10^{33} \text{cm}^{-2}\text{s}^{-1}$
- Production cross section: $\sigma = 3 \times 10^{-30} \text{cm}^2$
- Branching ratio for $K$: $b = 0.49$

- 40% $K^-$ stopped in He target $\rightarrow$ 12.5 $10^8$ He-$K^-$ atoms/month
- $10^{-3}$ cluster formation yield $\rightarrow$ 12.5 $10^5$ kaonic clusters/month
- Identification & tracking efficiencies $\rightarrow$ 10$^5$ events/month ($\sim 1000 \text{ pb}^{-1}$)

The AMADEUS experiment

Oton Vázquez Doce
The AMADEUS experiment

Conclusions

Minutes from last LNF Scientific Committee (November 2009):

In the field of deeply bound kaonic nuclear (DBKN) states, the AMADEUS experiment offers unique potential in comparison to existing experiments like FINUDA, DISTO and OBELIX:

1. AMADEUS allows full reconstruction of the formation and decay of the DBKN state;
2. AMADEUS allows to investigate the DBKN is a clean environment because the lightest nuclei are used as target material and because the K^- is virtually at rest during the formation process; and
3. the required acceptance corrections for the AMADEUS measurements are small.

Even though the main justification for the AMADEUS experiment is to clarify the DBKN state issue, AMADEUS offers interesting measurements of properties of Λ and Σ baryons as shown by the promising results already obtained from a study of existing KLOE drift chamber data as well as measurements of kaon-nucleus cross section measurements for various nuclei.
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In the field of deeply bound kaonic nuclear (DBKN) states, the AMADEUS experiment offers unique potential in comparison to existing experiments like FINUDA, DISTO and OBELIX:
1. AMADEUS allows full reconstruction of the formation and the decay of the DBKN state;
2. AMADEUS allows to investigate the DBKN is a clean environment because the lightest nuclei are used as target material and because the K\(^-\) is virtually at rest during the formation process; and
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Thank you
• spare
Trigger system tests: installation at DAΦNE

Installation of AMADEUS trigger test setup in DAΦNE 2009
Montecarlo simulations: what are we expecting?

Geant3 simulation of situation in daphne for AMADEUS and test setups (tunned with 90Sr source results)

Setup consists in 2 layers of 70 cm scintillating fibers BCF-10 multicladding. Beam Pipe is an alluminium tube with radius \( r = 2.95 \text{ cm} \) and 300 \( \mu \text{m} \) thickness.
$K^-\text{stopped} + ^4\text{He} \rightarrow n + (K^-\text{ppn})$

Lambda-d

Events in the DC volume

Momentum of lambda and deuteron:

$M_{\text{inv}} \Lambda d \text{ (MeV/c}^2\text{)}$

$P_{\Lambda} \text{ (MeV/c)}$

$P_d \text{ (MeV/c)}$

$\cos \theta (\Lambda d)$

$M_d + M_p + M_{\pi^-} - M_d + M_p + M_K$
$K^-_{\text{stopped}} + ^4\text{He} \rightarrow n + (K^-\text{ppn})$

$\Lambda + d$

**FINUDA**
K- stopped in light nuclei

**KEK**
K- stopped in 4He

$M_{\text{inv} \Lambda d} (\text{MeV}/c^2)$

$\cos \theta (\Lambda d)$

$M_d + M_p + M_{\pi^-}$

K-He interactions in KLOE

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Selection of triton

Mass by time of flight (MeV/c^2)
Lambda-triton

\[ \cos \theta (\Lambda t) \]

\[ M_\Lambda (\text{MeV}/c^2) \]

\[ P_\Lambda (\text{MeV}/c) \]

\[ M_\text{t} (\text{MeV}/c^2) \]

\[ P_\text{t} (\text{MeV}/c) \]

Lambda-triton interactions in KLOE

Oton Vázquez Doce
Lambda-triton

\[ \text{triton} \]

\[ M_{\Lambda t} (\text{MeV/c}^2) \]

\[ P_t (\text{MeV/c}) \]

\[ M_{\text{inv} \Lambda t} (\text{MeV/c}^2) \]

\[ \rho > 40\text{cm DC volume} \]

\[ \rho < 40\text{ cm DC inner wall} \]

K-He interactions in KLOE

Oton Vázquez Doce
\( \Lambda(1405)/\Lambda(1420) \) search
- Strongly related with the deeply bound kaonic states prediction
- Lack of experimental data

**Kinematic fit:**
- \( \chi^2 \) computing:
  - momentum of proton and pion
  - Covariance matrix elements for every track
  - time and positions and resolutions for photons
- Allows to reject background selecting the right combination of photons
- Constraints: \( \Delta t \) for the arrival time of photons
- No mass assumption -> unbiased mass spectras

\( (\Sigma \pi) \)^0

K-He interactions in KLOE

Oton Vázquez Doce
$(\Sigma\pi)^{0}$

$\Lambda(1405)/\Lambda(1420)$ search
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- Constraints: $\Delta t$ for the arrival time of photons
- No mass assumption -> unbiased mass spectrum
$M_{\text{inv}} \Lambda\gamma$ (MeV/c$^2$)

$M_{\text{inv}} \gamma\gamma$ (MeV/c$^2$)

$(\Sigma\pi)^0$

K-He interactions in KLOE

Oton Vázquez Doce
$(\Sigma \pi)^0$

Events in the DC volume

DC wall

$M_{\text{inv}} \Sigma^0 \pi^0 \text{ (MeV}/c^2)$

K$^-$He interactions in KLOE

Oton Vázquez Doce
Full reconstruction of the events

KEK (invariant mass)

FOPI (missing mass)

AMADEUS, Full event reconstruction:

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

\[ \Lambda + d \]

\[ \Lambda^*, \Sigma^* \rightarrow \text{neutral/charged channels} \]

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

Stressed this morning during the open session!!!
“Pureness” of the production mechanism

FINUDA
- FSI interaction ?
- Reconstruction of spectators ?
- Addition of data from different nuclei
- $^6\text{Li}=^4\text{He}+d$ ?

AMADEUS, $K^-$ at rest in light nuclei (simplest case)

**kaonic dibaryon states:**
- $ppK^-$ and $pnK^-$
  produced in a $^3\text{He}$ gas target

**kaonic 3-baryon states:**
- $ppnK^-$ and $pnnK^-$
  produced in a $^4\text{He}$ gas target

DISTO
- Momentum transfer?
Acceptancy

\[ \Lambda p \text{ invariant mass in } \Lambda p\] analysis of K^-He KLOE data

AMADEUS, full acceptancy
KLOE: 98% of 4\pi
Study the most fundamental antikaon deeply bound systems in formation and decay processes:

**Low-energy charged kaon cross section on p, d, He-3 and He-4, for K\(^-\) momentum lower than 100 MeV/c (missing today)**

**The K\(^-\) nuclear interactions in Helium (poorly known – based on one paper from 1970...)**

**Properties of Λ and charged Σ\(\prime\)s for example decays in channels with a neutrino → astrophysics implications (cooling of compact stars)**

**Resonance states as Λ(1405) or the Σ(1385) could be understood with high statistics; their behaviour in nuclear medium can be studied too**

**kaonic dibaryon states:**
- ppK\(^-\) and pnK\(^-\)
  - produced in a \(^3\)He gas target

**kaonic 3-baryon states:**
- ppnK\(^-\) and pnnK\(^-\)
  - produced in a \(^4\)He gas target

**EXTENDED PROGRAM:**
- Experimental program

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**The AMADEUS experiment**
Reactions of Stopping $K^-$ in Helium*

P. A. Katz†

K$^-$ (2N) is an old story...

$K^-$ absorption at rest in Helium:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Events/Stopping $K^-$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^-$He$^+$ → 2$^+$e$^+$He</td>
<td>9.5±2.3</td>
</tr>
<tr>
<td>$→ 2^+e^+e^0$</td>
<td>1.9±0.7</td>
</tr>
<tr>
<td>$→ 2^+e^+e^0$</td>
<td>1.6±0.6</td>
</tr>
<tr>
<td>$→ 2^+e^+e^0$</td>
<td>3.2±1.0</td>
</tr>
<tr>
<td>$→ 2^+e^+e^0$</td>
<td>1.0±0.4</td>
</tr>
<tr>
<td><strong>Total 2$^+$</strong></td>
<td>(37.0±2.7)%</td>
</tr>
<tr>
<td>$K^-$He$^+$ → 2$^-$e$^-$$^0$He</td>
<td>4.2±1.3</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.6±0.6</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.4±0.5</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.0±0.5</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.0±0.5</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.0±0.4</td>
</tr>
<tr>
<td>$→ 2^-e^-e^0$</td>
<td>1.6±0.6</td>
</tr>
<tr>
<td><strong>Total 2$^-$</strong></td>
<td>(33.8±1.8)%</td>
</tr>
<tr>
<td>$K^-$He$^+$ → $^3$$^2$He$^+$</td>
<td>11.3±2.7</td>
</tr>
<tr>
<td>$→ \Lambda \Lambda$</td>
<td>10.9±2.6</td>
</tr>
<tr>
<td>$→ \Lambda \Lambda$</td>
<td>9.8±2.4</td>
</tr>
<tr>
<td>$→ \Lambda \Lambda$</td>
<td>9.9±2.6</td>
</tr>
<tr>
<td>$→ \Lambda \Lambda$</td>
<td>1.4±0.3</td>
</tr>
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<td>1.4±0.3</td>
</tr>
<tr>
<td>$→ \Lambda \Lambda$</td>
<td>1.4±0.3</td>
</tr>
<tr>
<td><strong>Total 2$^+$</strong></td>
<td>(69.2±6.6)%</td>
</tr>
</tbody>
</table>

**No-mesonic $\Lambda (\Sigma^0)$ 11.7%**
**No-mesonic $\Sigma^+$ only 1.0%**
**No-mesonic $\Sigma^-$ 3.6%**

A-dependence:
no-mesonic production increasing with A
Reactions of Stopping $K^-$ in Helium*

P. A. Katz†

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FINUDA DATA: $K^-_{stop}^6\text{Li} \rightarrow \Lambda + X$

Katz et al.; $K^-_{stop}^4\text{He} \rightarrow \Lambda X$

No Data

---

**Table V. Comparative data on the frequency of emission of various particles.**

<table>
<thead>
<tr>
<th>Particle</th>
<th>Hydrogen</th>
<th>Deuterium</th>
<th>Helium (this experiment)</th>
<th>Helium (H-bubble chamber collaboration)</th>
<th>Nuclear emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^- - [K^-]^{-}$</td>
<td>0.64</td>
<td>0.67</td>
<td>0.55 ± 0.05</td>
<td>0.55</td>
<td>0.45</td>
</tr>
<tr>
<td>$K^- - [K^-]^{0}$</td>
<td>0.64</td>
<td>0.67</td>
<td>0.49 ± 0.01</td>
<td>0.55</td>
<td>3.9</td>
</tr>
<tr>
<td>$K^- - [K^-]^{+}$</td>
<td>0.64</td>
<td>0.67</td>
<td>0.34 ± 0.03</td>
<td>0.27</td>
<td>0.19</td>
</tr>
<tr>
<td>$K^- - [K^-]^{0+}$</td>
<td>0.64</td>
<td>0.67</td>
<td>1.2 ± 0.2</td>
<td>1.16</td>
<td>1.05</td>
</tr>
<tr>
<td>$K^- - [K^-]^{0+}$</td>
<td>0.64</td>
<td>0.67</td>
<td>1.5 ± 0.5</td>
<td>1.82</td>
<td>1.52</td>
</tr>
<tr>
<td>No-mesonic (i.e., no plastic) capture</td>
<td>...</td>
<td>0.01</td>
<td>0.17 ± 0.09</td>
<td>0.25</td>
<td>0.15 ± 0.30</td>
</tr>
</tbody>
</table>

---

A-dependence:
no-mesonic production increasing with $A$
Reactions of Stopping $K^-$ in Helium*

P. A. Katz†

FINUDA DATA: $K^-_{stop}^6\text{Li} \rightarrow \Lambda \chi$

$\bar{K}N \rightarrow \pi \Sigma, \pi \Lambda (70\%, 10\%), \bar{K}NN \rightarrow \Sigma N (20\%) \propto \rho^2$

Katz et al.: $K^-_{stop}^4\text{He} \rightarrow \Lambda \chi$

No-mesonic $\Lambda (\Sigma^0) 11.7\%$
No-mesonic $\Sigma^+ 1.0\%$
No-mesonic $\Sigma^- 3.6\%$

A-dependence:
no-mesonic production increasing with $A$

* Reference 2.