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Outline

Discovery potential of the strangeness nuclear physics
- recent experimental results
- unexpected effects

Need of sub-MeV resolution apparatuses
- $\gamma$-ray spectroscopy

Proposal for FINUDA spectrometer upgrade at DAΦNE/DAΦNE2
... not a last minute business!
Open questions

(low-energy) $YN$ interaction

- detailed knowledge of the hypernuclear fine structure
  → evaluation of the spin dependent terms of the $ΛN$ interaction
- measurement of angular distribution of $γ$-rays
  → determination of spin and parity of each observed level
Spin-dependent forces

The simple structure of light hypernuclear system can be described in the frame of the shell model.

\[ V_{\Lambda-N}(r) = V_0(r) + V_\sigma(r) \vec{S}_N \cdot \vec{S}_\Lambda + V_{\Lambda}(r) \vec{l}_{NA} \cdot \vec{S}_\Lambda + V_N(r) \vec{l}_{NA} \cdot \vec{S}_N + V_T(r)[3(\vec{\sigma}_N \cdot \vec{r})(\vec{\sigma}_\Lambda \cdot \vec{r} - \vec{\sigma}_N \cdot \vec{\sigma}_\Lambda)] \]

Each of the 4 terms (\(\Delta, S_\Lambda, S_N, T\)) correspond to a radial integral that can be phenomenologically determined from the low-lying level structure of \(p\)-shell hypernuclei.

The knowledge of these characteristics of the \(\Lambda N\) interaction allows to improve baryon-baryon interaction models and to discriminate between the ones based on meson exchange picture and those including quark-gluon degrees of freedom.
Where do we stand?

HYPERBALL

KEK E419: \((\pi^+, K^+)_{\Lambda Li}\)
BNL E930: \((K^-, \pi^-)_{\Lambda Li}\)
KEK E509: \((K^-, \pi^-)_{\Lambda Li}\)

\[
\begin{align*}
\Delta &= 0.43 \\
S_\Lambda &= -0.01 \\
S_N &= -0.40 \\
T &= 0.03
\end{align*}
\]


A lot of work remains to be done!
Which model description?


$^9\text{Be}(5/2^+ \rightarrow 3/2^+)$

- Experiment: $31 \pm 2$ keV
- OME: $80 - 200$ keV
- QM: $35 - 40$ keV

$^{13}\Lambda C(3/2^- \rightarrow 1/2^-)$

- Experiment: $152 \pm 36$ keV
- OME: $390 - 960$ keV
- QM: $150 - 200$ keV

BUT

quark based models have yet to provide
an extensive and satisfactory description of $YN$ interaction
Charge symmetry breaking

\[ I = 0 \]
\[ q = 0 \]

\[ \Lambda p = \Lambda n \]

if the charge symmetry holds exactly

\[ \Lambda n \]
\[ \Lambda p \]

Possible explanations:
- \( \Lambda \Sigma^0 \) mixing
- \( \Lambda N - \Sigma N \) coupling

Odd-state interaction

- **ND model**: attractive odd-state force
- **NSC97 model**: repulsive odd-state force

odd-states are usually particle unbound for light ($A < 50$) hypernuclei

→ best candidate hypernuclei $^{89}_{\Lambda}Y$ and $^{208}_{\Lambda}Pb$

Odd-states $\Lambda N(s\text{-}wave)$ interactions

Even-states $\Lambda N(p\text{-}wave)$ interactions

$s\text{-}wave$ vs. $p\text{-}wave$ = ?

Odd-states are usually particle unbound for light ($A < 50$) hypernuclei

$^{89}_{\Lambda}Y$ and $^{208}_{\Lambda}Pb$ are the best candidate hypernuclei.


In contrast with data on $^{13}_{\Lambda}C$!
Open questions

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- measurement of angular distribution of $\gamma$-rays → determination of spin and parity of each observed level

Impurity nuclear physics

- measurement of transition probability $B(E2)$ → information on the size and deformation of hypernuclei
- measurement of nucleus core shrinking → glue-like role of $\Lambda$
A hypernucleus can be considered the outcome of a genetic engineering manipulation applied to the nuclear physics domain.

The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure:

- changes of the size and of the shape
- changes of the cluster structure
- manifestation of new symmetries
- change of collective motions
- ...

Study of hypernucleus level schemes and \( B(E2) \)

Doppler-shift attenuation method
The $\Lambda$ glue-like role


$B(E2; ^7\Lambda Li : 5/2^+ \rightarrow 1/2^+) = \frac{3.6 \pm 0.5^{+0.5}_{-0.4} e^2 fm^4}{10.9 \pm 0.9 e^2 fm^4} \approx \frac{1}{3}$

$B(E2) \propto r^4 \Rightarrow$ shrinkage of $^6Li$ core by $\sim 20\%$
(low-energy) $YN$ interaction
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Impurity nuclear physics
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Properties of hyperons in nuclear matter (medium effect)
- measurement of transition probability $B(M1)$
  → $g$-factor value for $\Lambda$ in nuclear matter
Medium effect

If the mass or the size of a hyperon is modified in a nucleus, its magnetic moment may be changed.

\[ B(M1) \propto \left| \left\langle \phi_{lo} \mu^z \phi_{up} \right\rangle \right|^2 = \left| \left\langle \phi_{lo} g_N J_N^z + g_\Lambda J_\Lambda^z \phi_{up} \right\rangle \right|^2 \]
\[ \propto (g_N - g_\Lambda)^2 \]

B(M1) can be derived from excited states lifetimes.

- Doppler-shift attenuation method
- \( \gamma \)-weak coincidence method
One step beyond

$^7\text{Li}(K^-_{\text{stop}},\pi^-)^{\Lambda}\text{Li}$

The FINUDA spectrometer @ DAΦNE

$\Delta E \sim 1.9$ MeV FWHM

$\Delta E \sim 2$ keV FWHM

Is the integration possible?

Hyperball

FINUDA
Experimental challenges

Do HPGe crystals work in (strong) magnetic field?
The EUROBALL cluster

The FINUDA spectrometer

Geometrical acceptance reduced to 72%
Geometrical acceptance reduced to 82%
Spectroscopy of light hypernuclei

\[ K_{\text{stop}}^- + {}^A Z \rightarrow {}_\Lambda^A Z + \pi^- \]

Survey of hypernuclei with \( A < 30 \):

\[ _\Lambda^7 Li, \ _\Lambda^9 Be, \ _\Lambda^{10} B, \ _\Lambda^{11} B, \ _\Lambda^{12} C, \ _\Lambda^{13} C, \ _\Lambda^{23} Na, \ _\Lambda^{27} Al, \ _\Lambda^{28} Si \]

\[ {}^{12}C(K_{\text{stop}}^- , \pi^-){}^{12}C \]

Expected rates

with 500 pb\(^{-1}\) FINUDA can observe \(~ 2.5 \times 10^4\) ev from \(^{12}\text{C}\) g.s.

- spectrometer acceptance: 82%
- Ge array acceptance: \(~ 12\%\)
- \(\varepsilon_{\text{Ge}}\): \(~ 10\%\)

\(~ 1500\) \(\gamma\) transitions

J-PARC MC data

8 targets
Quality vs. quantity

KEK, JPARC

- High energy \( K^- \) beam
- \( K^- \) stopping efficiency 10\%-20%
- Massive targets
- \( \gamma \gamma \) coincidence mandatory

DA\( \Phi \)NE

- Very low energy \( K^- \) beam
- \( K^- \) stopping efficiency 90%
- Thin targets
- Independent \( \gamma \) measurement

Excited level “fine” splitting

\( \gamma_1 \) \( \gamma_2 \) \( \gamma_3 \) \( \gamma_4 \) \( \gamma_5 \) \( \gamma_6 \)

Ground state “fine” splitting

\( B_\Lambda \)

\( \sim 10 \text{ MeV} \)

\( \sim 5 \text{ MeV} \)

Once more the DA\( \Phi \)NE \( K^- \) characteristics make our setup competitive.
Quality vs. quantity
Strategy

Total synergy with the I3HP JRA6 project
- study of HPGe crystal performance in strong magnetic field

Close collaboration with TORTOLISO experiment, approved by INFN CSN V
- Cagliari-Torino Collaboration
- production of LYSO crystals by an Italian firm

Contacts with INFN Groups, with solid experience on HPGe
- exploitation of previous INFN investment
Interested community

HyperGamma
Costs

- 12 + 3 HPGe detectors 450 k€
- 4 + 1 electric cooling systems 50 k€
- front-end electronics 50 k€
- DAQ system upgrade 50 k€
Time schedule

- 2006: Letter of Intent
- 2008: completion of FINUDA physics program
- 2009: FINUDA upgrade
- 2010: pilot run at DAΦNE1 (500 pb⁻¹)
- 201X: DAΦNE upgrade
- 201X: 1ˢᵗ data taking period (1 fb⁻¹)
- 201X: 2ⁿᵈ data taking period (1 fb⁻¹)
strangeness nuclear physics still has a great discovery potential

explorative run on $\gamma$-ray spectroscopy is feasible with:

- present DAΦNE machine
- minor investment on FINUDA apparatus

DAΦNE luminosity upgrade will allow to our community to maintain a main role in the field

- the FINUDA upgrade could represent the opportunity to install a liquid $^4$He target for studying $K$ deeply bound states