Hyperfragments from Light p-shell Hypernuclei

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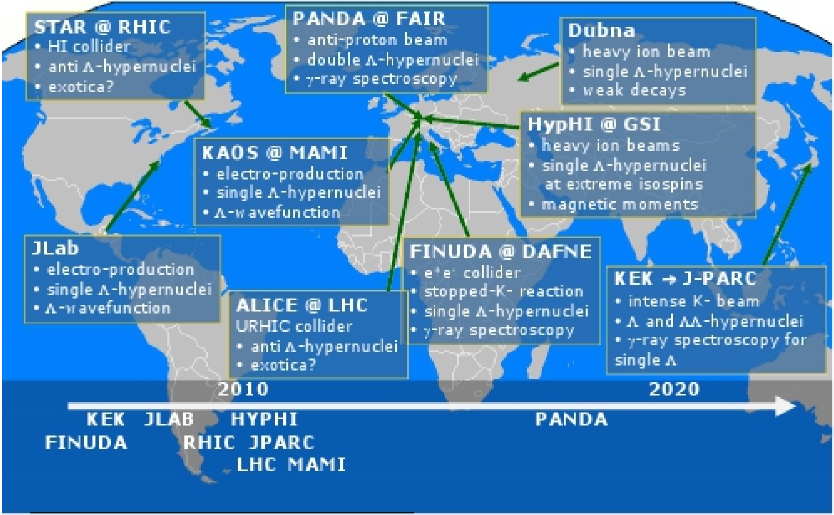
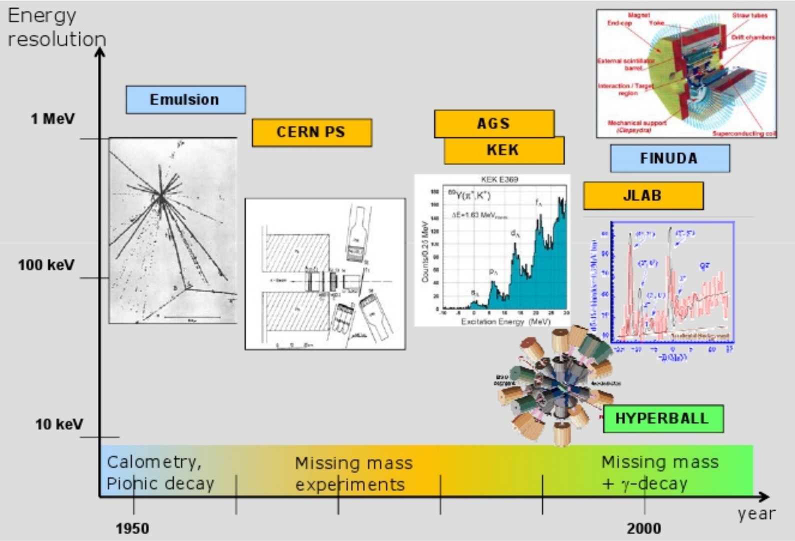
Outline

International Hypernuclear Network [1]



[1] Pochodzalla, Zakopane 2010

Past and Presence of Hypernuclei [2]



[2] Pochodzalla, NUFRA 2011

Hypernuclei in Dubna - past

Podgoretski's `JETP 17 ('63)` ingenious idea
to use the Strangeness Exchange Reaction $(K^-_{\mathrm{in-flight}}, \pi^-)$

Now hypernuclei are

part of intermediate energy nuclear physics

(interactions of μ, π, $K \dots$ with light nuclei)

Khorozov & Lukstins's `NP A 547 ('92)` unique
experiment: production of relativistic hypernuclei

Hypernuclei in JINR - present

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NUCLEI
Experiment

Studying of Hypernuclei in Nuclotron Beams*

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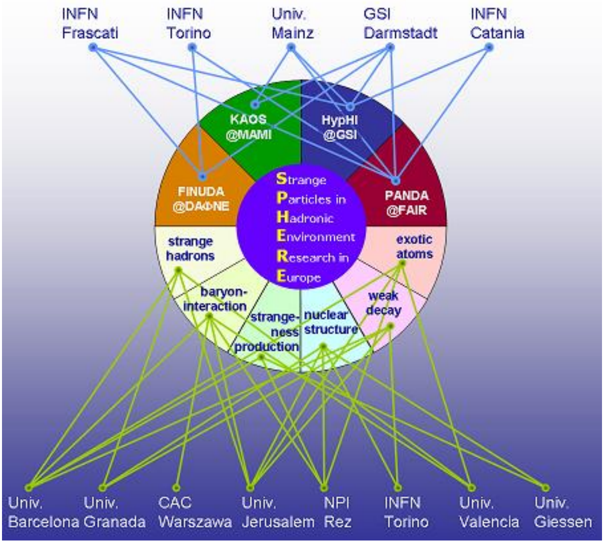
Abstract—A spectrometer is created to study relativistic hypernuclei produced in beams of accelerated nuclei from the Nuclotron facility (Dubna, JINR). Test runs have been carried out and the conclusion are drawn that the properties of the facility meet the requirements of the task of searching for unknown and studying poorly known neutron-rich hypernuclei.

PACS numbers: 21.80.+a, 29.30.Aj
DOI: 10.1134/S1063778808120119

Sphere Network



SPHERE Network

Hadron Physics$_2$ Study of Strongly Interacting Matter

SPHERE Network :

Strange **P**articles in **H**adronic **E**nvironment **R**esearch in **E**urope

coordinates studies of hypernuclei at

FINUDA@DAΦNE	(Frascati)
KAOS@MAMI	(Mainz)
HypHI@GSI	(Darmstadt)
$\bar{\mathrm{P}}$ANDA@FAIR	

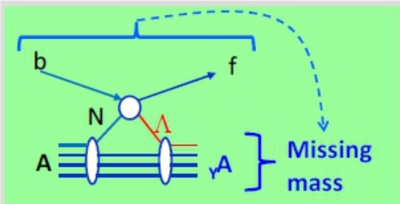
extended by including

J-PARC@Tokai and CEBAF@J-Lab

close cooperation with Network LEANNIS :

Low **E**nergy **A**ntikaon **N**ucleon and **N**uclei **I**nteraction **S**tudies

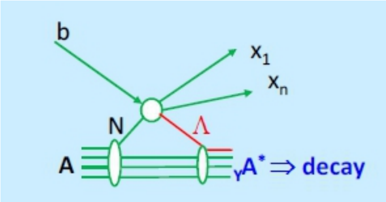
Two Classes Reactions



Direct production

Examples

- strangeness production
- strangeness exchange
- electroproduction



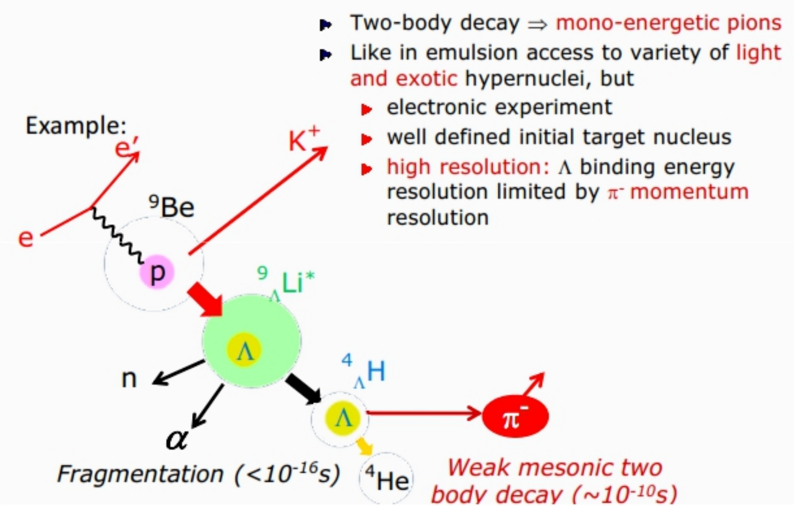
Decay spectroscopy

- π from weak decay
- Charged fragments

Examples

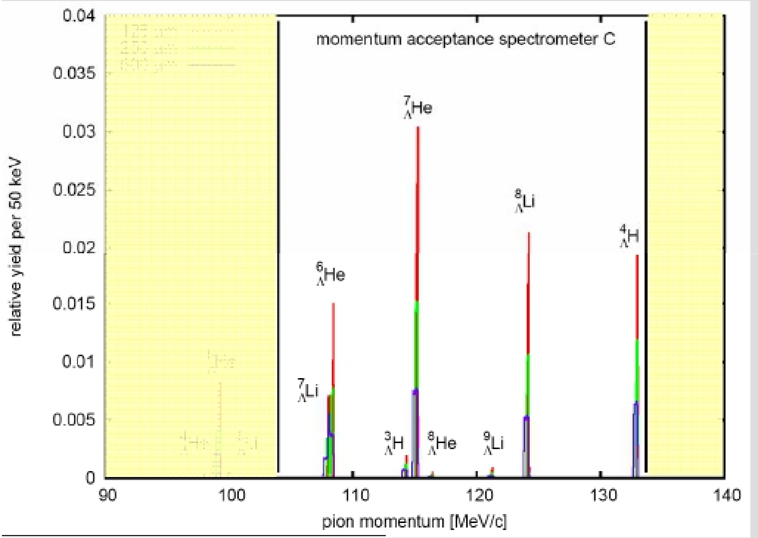
- nuclear emulsions
- heavy ion reactions
- continuum excitation in $(e, e' K^{+})$

Decay pion spectroscopy [3]



[3] Pochodzalla, NUFRA 2011

Expectations [4]



[4] Pochodzalla, NUFRA 2011

Chart of Light NUCLEI and HYPERNUCLEI

		${}^{7}_{\Lambda}$Be	${}^{8}_{\Lambda}$Be	${}^{9}_{\Lambda}$Be	${}^{10}_{\Lambda}$Be	${}^{11}_{\Lambda}$Be	${}^{12}_{\Lambda}$Be	${}^{13}_{\Lambda}$Be
		1370	^{7}Be	92	^{9}Be ⊙	^{10}Be	^{11}Be	^{12}Be
			${}^{7}_{\Lambda}$Li	${}^{8}_{\Lambda}$Li	${}^{9}_{\Lambda}$Li	${}^{10}_{\Lambda}$Li	${}^{11}_{\Lambda}$Li	${}^{12}_{\Lambda}$Li
		1690	^{6}Li ⊙	^{7}Li ⊙	^{8}Li	^{9}Li	25	^{11}Li
	${}^{4}_{\Lambda}$He	${}^{5}_{\Lambda}$He	${}^{6}_{\Lambda}$He	${}^{7}_{\Lambda}$He	${}^{8}_{\Lambda}$He	${}^{9}_{\Lambda}$He	${}^{10}_{\Lambda}$He	${}^{11}_{\Lambda}$He
	^{3}He ⊙	^{4}He ⊙	798	^{6}He	445	^{8}He	100	1069
	${}^{3}_{\Lambda}$H	${}^{4}_{\Lambda}$H		${}^{6}_{\Lambda}$H !		${}^{8}_{\Lambda}$H		
^{1}H ⊙	^{2}H ⊙	^{3}H	3190	1700	2700	840		

Discovery ${}^{6}_{\Lambda}$H

- Λ hyperon stabilizes nuclear cores, acting as a glue [*Dalitz & Levi Setti, Nouovo Cimento 30 (1963) 489*] ${}^{6}_{\Lambda}$He, ${}^{7}_{\Lambda}$Be, ${}^{8}_{\Lambda}$He, ${}^{9}_{\Lambda}$Be, ${}^{10}_{\Lambda}$Be observed in emulsion.
- The lightest unstable–core hypernucleus ${}^{6}_{\Lambda}$H was predicted by DLS, reinforced in estimates by **Majling** [*NPA 585 (1995) 211c*]

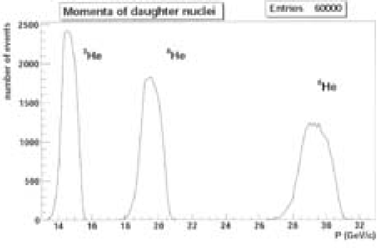
  with $\boxed{B_{\Lambda}^{Majling}({}^{6}_{\Lambda}\text{H}) = 4.2\ \text{MeV.}}$

  Akaishi (1999) predicted $\boxed{B_{\Lambda}^{Akaishi}({}^{6}_{\Lambda}\text{H}) = 5.8\ \text{MeV}}$ on the basis of a coherent $\Lambda N - \Sigma N$ mixing model originally practiced for ${}^{4}_{\Lambda}$H.

${}^{6}_{\Lambda}H$ @BALDIN ISHEPP Contributions

2004, 2006:

- **Nuclotron**:measuring the cross sections for elmg dissociation of weakly couple ${}^{3}_{\Lambda}H$ and ${}^{6}_{\Lambda}He$ in order to accurately determine their binding energies.



- **Neutron rich HNi** - with neutron halo.
- Identification of exotic hypernuclei ${}^{6}_{\Lambda}H$ and ${}^{8}_{\Lambda}H$.

In all these contributions original Dubna's experimental technique – registration hypernuclei by their decay – was pointed out.

FINUDA' s Experiment

- Finuda @ DAΦNE, Frascati, collected data on ^{6}Li(K^-_{stop}, π^+) in 2003 – 2007 with total integrated luminosity 1156 pb^{-1} $\Rightarrow$ 3 candidate events of $^6_\Lambda$H.
- FINUDA's inovation:
  consider production & decay in coincidence

$$K^-_{stop} + ^6\mathrm{Li} \rightarrow ^6_\Lambda\mathrm{H} + \pi^+ (\sim 250 < p_{\pi^+} < 255 MeV/c)$$
$$\rightarrow ^6\mathrm{He} + \pi^- (\sim 130 < p_{\pi^-} < 137 MeV/c)$$

Results in

$$\boxed{\mathrm{B}_\Lambda(^6_\Lambda\mathrm{H}) = 4.0 \pm 1.1 \text{ MeV};}$$

Majling: 4.2 MeV, Akaishi: 5.8 Mev

Akaishi's substantial $\Lambda - \Sigma$ coupling appears unnecessary.

[*Finuda collaboration & Gal, PRL 108,042501 (2012); NPA 881 (2012) 269*]

In FINUDA experiment lifetime of $^{6}_{\Lambda}$H was **not** (and could not be) measured.

In experiment on Nuclotron it **is** possible.

Proposal

Study of light hypernuclei by pionic decay at JLab

Liguang Tang, A. Margaryan, S.N. Nakamura, J. Reinhold
spokespersons

We propose to use high precision monochromatic π^-'s from the unique two-body mesonic weak decay of HNi

to investigate light Λ-HNi with variety of (Z,A) combination

through **identification of hyperfragments**

from **strongly produced** **hypernuclearar continuum**

(quasi free production) in $(e, e'K^+)$ electro-production.

Approach

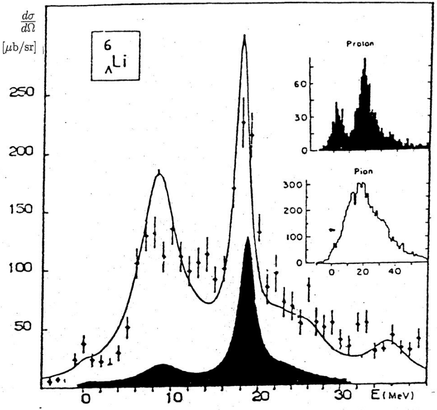
1. We based on primary (missing mass) reaction in which from known and stable target nucleus hypernucleus is produced.
2. This gives us (already known) hypernuclei spectrum.
3. This spectrum could be deciphered: its peaks could be interpreted in terms of strange analoguos sates (SAS).

For 1*p*-shell hypernuclei SAS do belong to the $1\hbar\omega$ excitation band. The latter may be split into THREE groups, the single-particle energies differ significantly.

					decay :
$1\hbar\omega_{(\Lambda)}$	$(\varepsilon_{p_\Lambda})$	$p^{-1}p_\Lambda$			Λ
$1\hbar\omega_N$	(ε_d)		$p^{-1}d\ s_\Lambda$		N
$1\hbar\omega_N$	$(\varepsilon_{s^{-1}})$			$s^{-1}p\ s_\Lambda$	$^3\mathrm{H},\ ^4_\Lambda\mathrm{H}$

Example: $^{6}_{\Lambda}$Li

deciphering: $p^{-1}s_\Lambda$ $p^{-1}p_\Lambda$ $s^{-1}s_\Lambda$



The (K^-,π^-) spectrum of the $^{6}_{\Lambda}$Li production.

Approach - continued

After deciphering the spectrum
4. we write Young tableaux for stange analogue states.
5. So, we obtain wave function (in LS coupling) of primary hypernucleus (in terms of SAS).
6. For wave function we compute fractional parentage coefficients (FPC).
7. In shell model we calculate the probability of different fragments emission.

TISM FPC

The key ingredients in the shell model are coefficients of fractional parentage (FPC) - coefficients in decomposition of anti-symmetrized w.f.

For TISM we have :

$$\Phi_k^{(A)}\ [f](\lambda\mu) = \sum_{f_1,f_2} \sum_{k_1,k_2,\nu} \sqrt{\frac{nf_1 \cdot nf_2}{nf}}\ \Phi_{k_1}^{(A_1)}\ [f_1](\lambda\mu)_1\ \Phi_{k_2}^{(A_2)}\ [f_2](\lambda\mu)_2\ \varphi_\nu\ (R_1 - R_2)$$

W.f. for "usual" clusters (d, t, α) are $|s^k >\equiv \Phi_0^{(k)}[k]$

For heavy Hydrogen isotopes we take:

$$|s^3\ p : [31] > \ \equiv\ \Phi_1^{(4)}[31] \quad (^4\mathrm{H})$$

$$|s^3\ p^2 : [32] > \ \equiv\ \Phi_2^{(5)}[32] \quad (^5\mathrm{H}).$$

$^{6}_{\Lambda}$Li - discussion

In Phys. Lett. B **92** 256 (1980)
we have discussed hypernucleus $^{6}_{\Lambda}$Li in terms of an

extended supermultiplet scheme

which combines the 1*s* and 1*p* orbitals, and classifies the nuclear and Λ- hypernuclear states by Young tableaux [*f*].

The lower state has symmetry [41] for its nuclear core, so its break-up to $^{5}_{\Lambda}\mathrm{He}+p$ or to $^{5}\mathrm{Li}+\Lambda$ is ALLOWED both energetically and by supermultiplet symmetry.

The upper state has symmetry [32] for its nuclear core so that its decay to $^{5}\mathrm{Li}+\Lambda$ or $^{5}_{\Lambda}\mathrm{He}+p$, is FORBIDDEN by the selection rules for the supermultiplet symmetry.

ALLOWED : $^{4}_{\Lambda}\mathrm{H}+2p$, $^{4}_{\Lambda}\mathrm{He}+d$, $^{3}_{\Lambda}\mathrm{H}+t$

SAS

		n_f	g_I	
^{6}Li :	$\|s^4p^2[42](20)>$	$\frac{4}{9}$	$\frac{9}{10}$	$\Phi_1[41] \otimes p_\Lambda$
			$\frac{1}{10}$	$\Phi_2[41] \otimes s_\Lambda$
		$\frac{5}{9}$	1	$\Phi_2[32] \otimes s_\Lambda$
^{7}Li :	$\|s^4p^3[43](30)>$	$\frac{9}{14}$	$\frac{7}{9}$	$\Phi_2[42] \otimes p_\Lambda$
			$\frac{2}{9}$	$\Phi_3[42] \otimes s_\Lambda$
		$\frac{5}{14}$	1	$\Phi_3[33] \otimes s_\Lambda$
^{9}Be :	$\|s^4p^5[441](31)>$	$\frac{1}{6}$	$\frac{15}{16}$	$\Phi_4[44] \otimes p_\Lambda$
			$\frac{1}{16}$	$\Phi_5[44] \otimes s_\Lambda$
		$\frac{5}{6}$	$\frac{9}{16}$	$\Phi_4[431] \otimes p_\Lambda$
			$\frac{7}{16}$	$\Phi_5[431] \otimes s_\Lambda$

DECAYS of ${}^{7}_{\Lambda}$He SAS configurations

$\frac{7}{14}$ $\Phi^{(6)}_{2}[42](20)\ \varphi^{\Lambda}_{1} : (30)$

$\frac{2}{14}$ $\Phi^{(6)}_{3}[42](30)\ \varphi^{\Lambda}_{0}$

$\frac{5}{14}$ $\Phi^{(6)}_{3}[33](30)\ \varphi^{\Lambda}_{0}$

$E_{\rm th}$	channel			$[f_i][f_k]$	$\Phi^{(6)}_{N}[42]$	$\Phi^{(6)}_{3}[33]$
2.8	${}^{6}_{\Lambda}$He	+	n	[41][1]	$\surd$	–
3.1	${}^{5}_{\Lambda}$He	+	$2n$	[4][1][1]	$\surd$	–
5.23	Λ	+	^{6}He	[42]	$\surd$	–
15.5	${}^{4}_{\Lambda}$H	+	t	[3][3]	$\surd$	$\surd$
21.1	${}^{4}_{\Lambda}$He	+	$3n$	[3][1][1][1]	$\surd$	$\surd$
(22.1)	${}^{5}_{\Lambda}$H	+	d	[31][2]	$\surd$	$\surd$
23.7	${}^{3}_{\Lambda}$H	+	tn	[2][3][1]	$\surd$	$\surd$
23.8	${}^{6}_{\Lambda}$H	+	p	[32][1]	$\surd$	$\surd$

HYPERFRAGMENTS from $^{9}_{\Lambda}\mathrm{Li}$

E_{thr}	decay			$[f_1][f_2]$	$T_1\ T_2$	
3.7	$^{8}_{\Lambda}\mathrm{Li}$	+	n	[43][1]	$\frac{1}{2}\ \frac{1}{2}$	**
8.5	Λ	+	$^{8}\mathrm{Li}$	[431]	0 1	
9.7	$^{6}_{\Lambda}\mathrm{He}$	+	t	[3][41]	$\frac{1}{2}\ \frac{1}{2}$	*
			$\downarrow$			
9.9	$^{5}_{\Lambda}\mathrm{He}$	+	tn	[3][1][4]	$0\ \frac{1}{2}\ \frac{1}{2}$	*
11.8	$^{4}_{\Lambda}\mathrm{H}$	+	$^{5}\mathrm{He}$	[41][3]	$\frac{1}{2}\ \frac{1}{2}$	*
12.2	$^{7}_{\Lambda}\mathrm{Li}$	+	$2n$	[1][1][42]	1 0	
13.0	$^{7}_{\Lambda}\mathrm{He}$	+	d	[42][2]	1 0	
13.8	$^{8}_{\Lambda}\mathrm{He}$	+	p	[421][1]	$\frac{3}{2}\ \frac{1}{2}$	
18.2	$^{3}_{\Lambda}\mathrm{H}$	+	$^{6}\mathrm{He}$	[2][42]	0 1	
31.5	$^{4}_{\Lambda}\mathrm{He}$	+	tnn	[3][3][1][1]	$\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}$	
38.5	$^{6}_{\Lambda}\mathrm{H}$	+	$^{3}\mathrm{He}$	[32][3]	$\frac{3}{2}\ \frac{1}{2}$	

Summary

We present one approach to build model for identification hyperfragments based on

shell model, w.f. for LS coupling and SAS.

Model selection affects the complexity of calculation.

Complexity of caclulation may be resolved by

numerical methods

or (our case)

constraint satisfaction method.

In our case we use our knowledge to simplify the calculations and reduce "unimportant" states.

So, we try to remain in algebraic solving

– KNOWLEDGE BASED REDUCED –

problem.

For light (H)Nuclei it is possible.

THANK YOU!