FIFTY YEARS OF HYPERNUCLEAR PHYSICS

- Introduction
- Spectroscopy: the latest results
- Weak decays: the latest results
- Neutron-rich Hypernuclei
- Hypernuclear Physics in the next 50 years

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Introduction

Discovery 1953: Danysz and Pniewski: emulsion technique

1953→1970: visualizing techniques (emulsions, bubble chambers).
Identification of ~ 20 Hypernuclei, measurement of B_Λ , hints on the decay modes;

1963: discovery of the first ΛΛ Hypernucleus

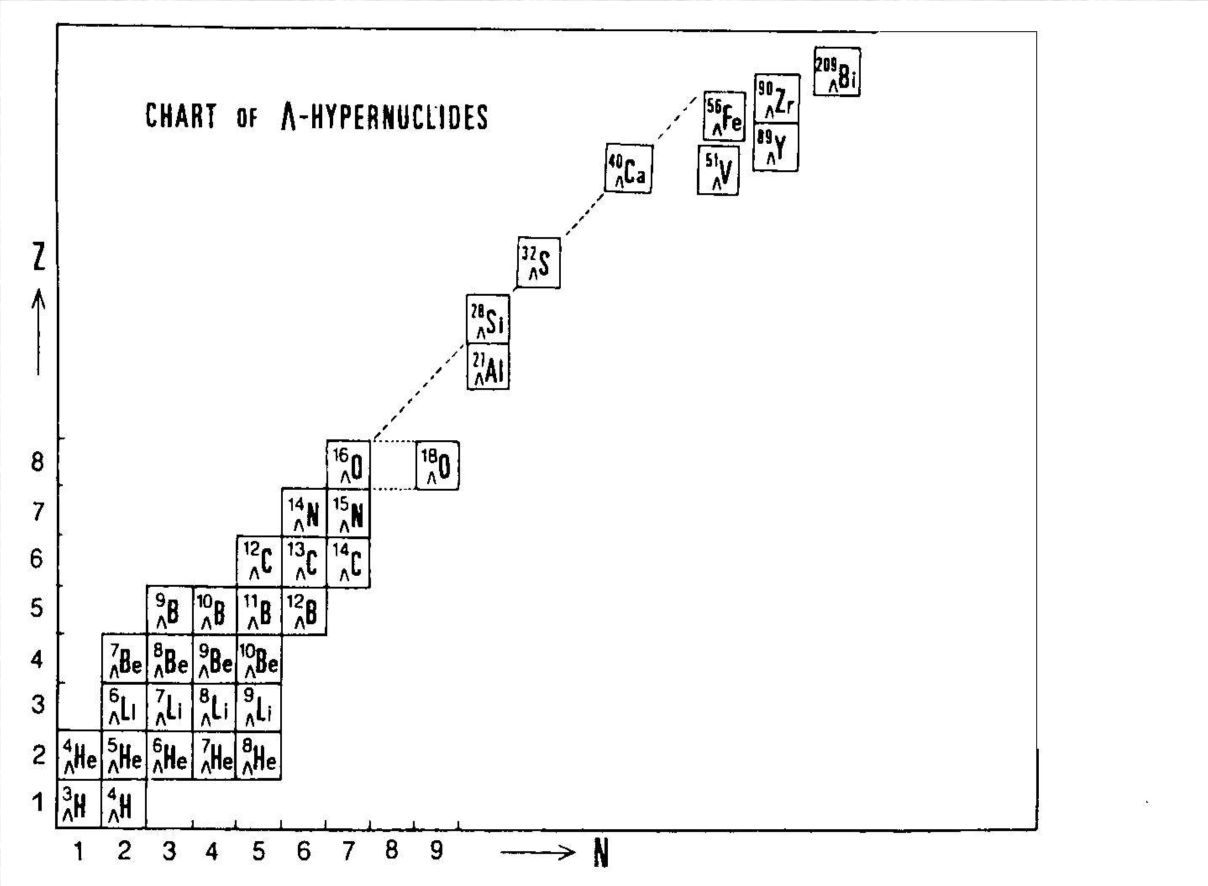
1970→now: Spectrometers at accelerators:

- CERN (up to 1980)
- BNL: (K^-, π^-) and (π^+, K^+) production methods
- KEK: (K^-, π^-) and (π^+, K^+) production methods

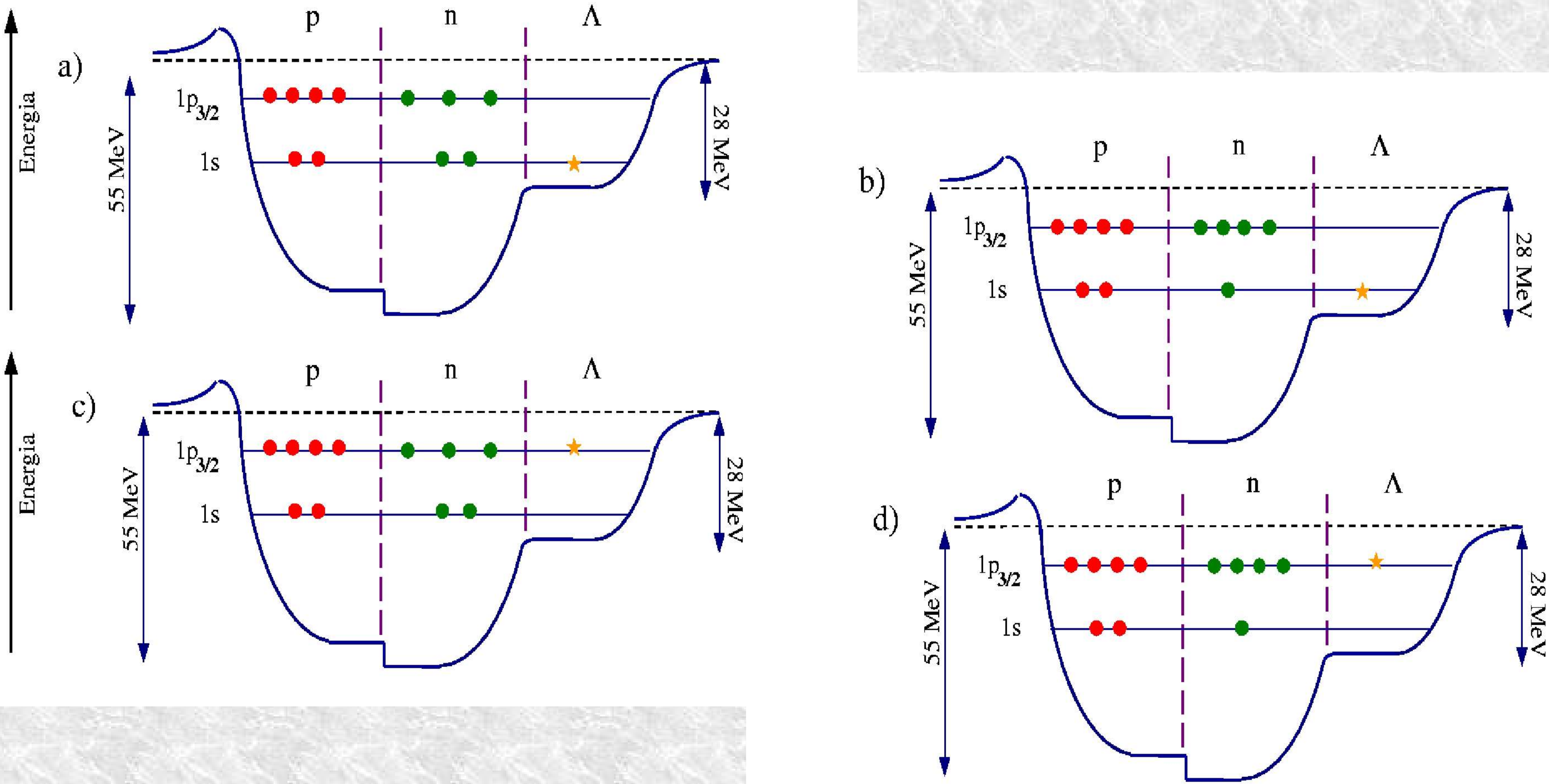
Very interesting results on spectroscopy and decay of Λ Hypernuclei
The rise and fall of Σ Hypernuclei

Spectroscopy: the latest results

$$B_\Lambda\,(g.s.) = M_{core} + M_\Lambda - M_{Hyp}$$

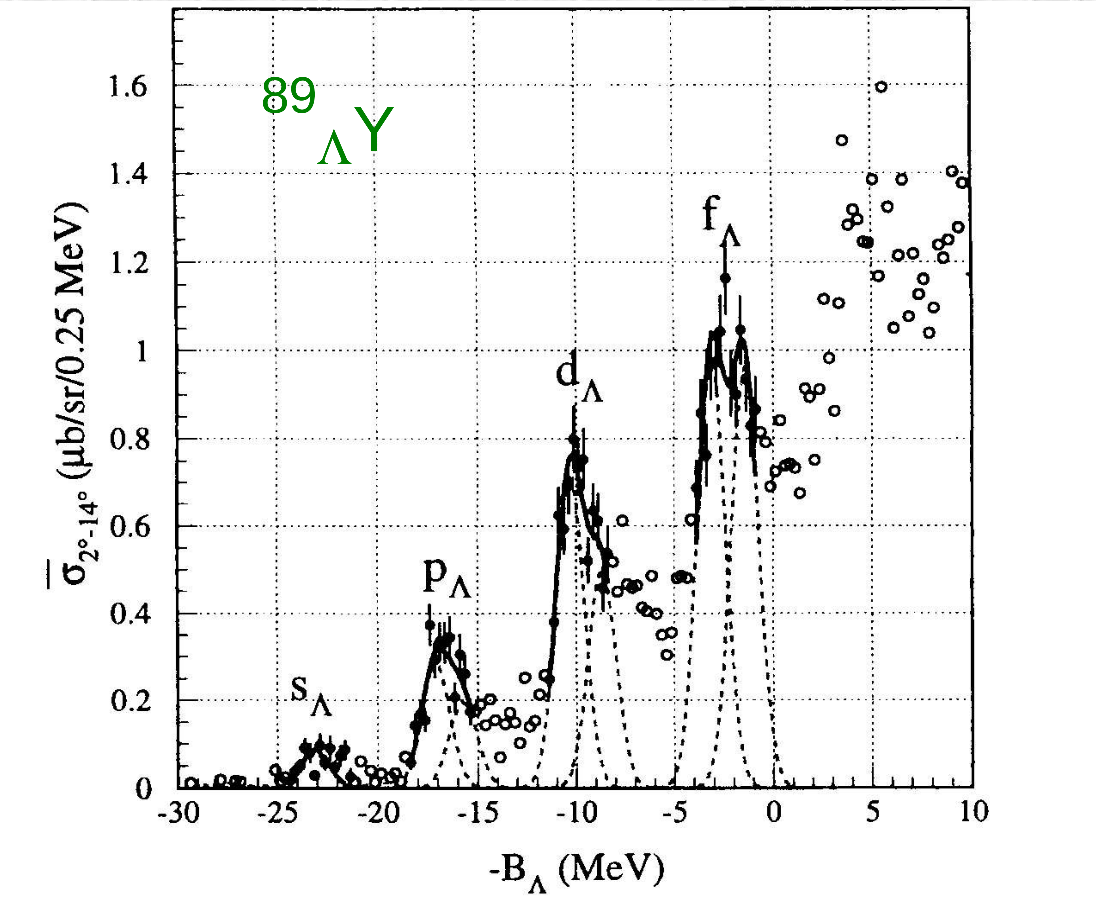


Many configurations of the 3 baryons may produce many excited states (more than in ordinary nuclei) but .... the Pauli principle may help to choose peculiar and simple configurations

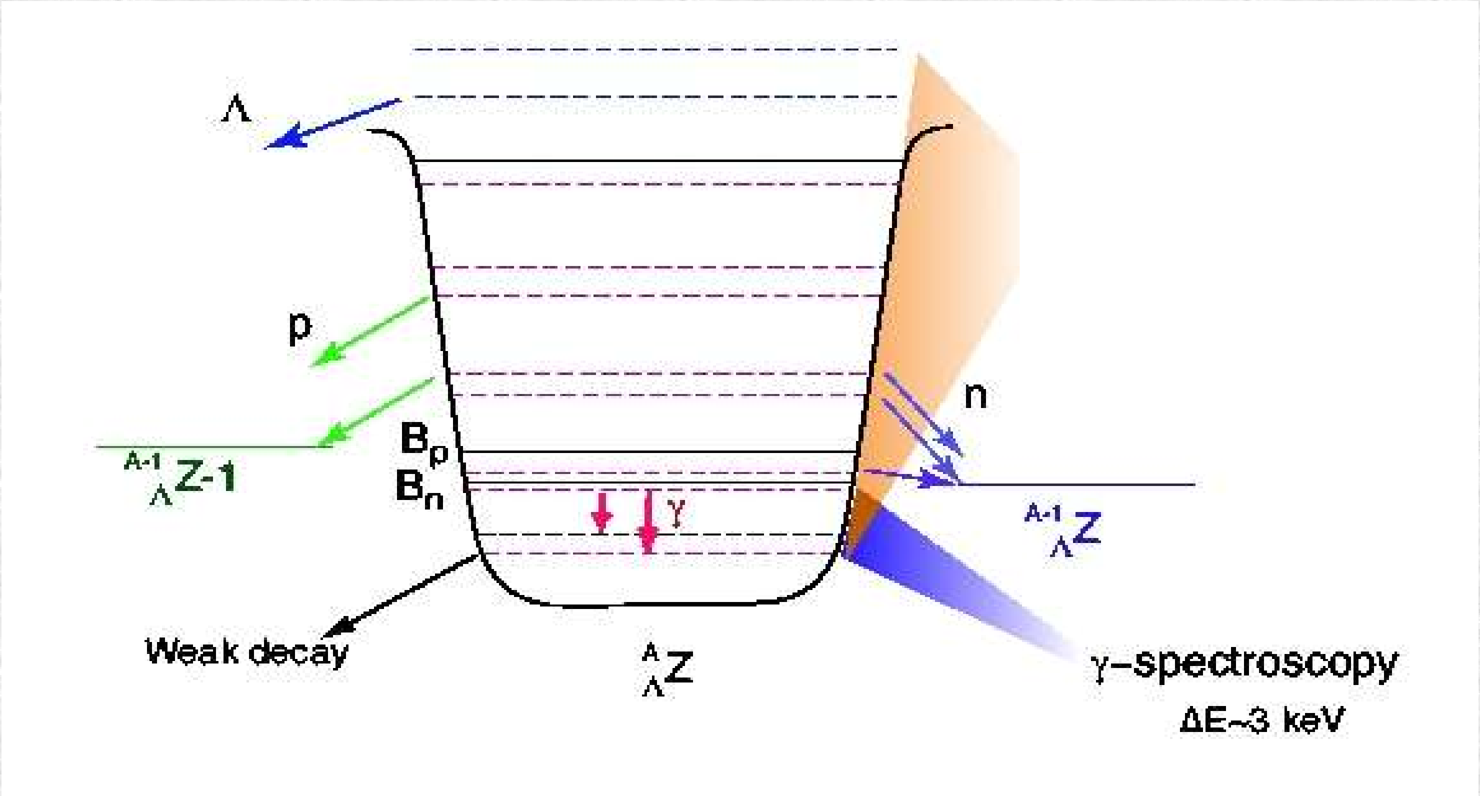


Most spectacular results:

all the single-particle states of Λ are visible at the same time!

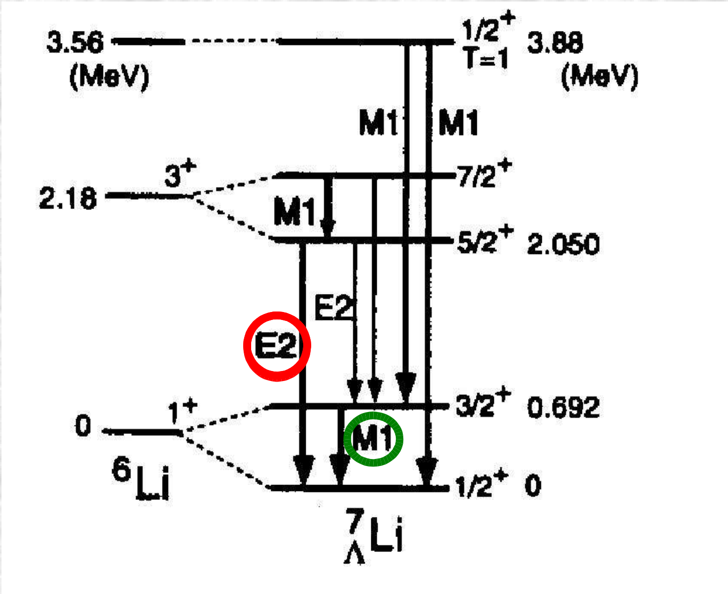


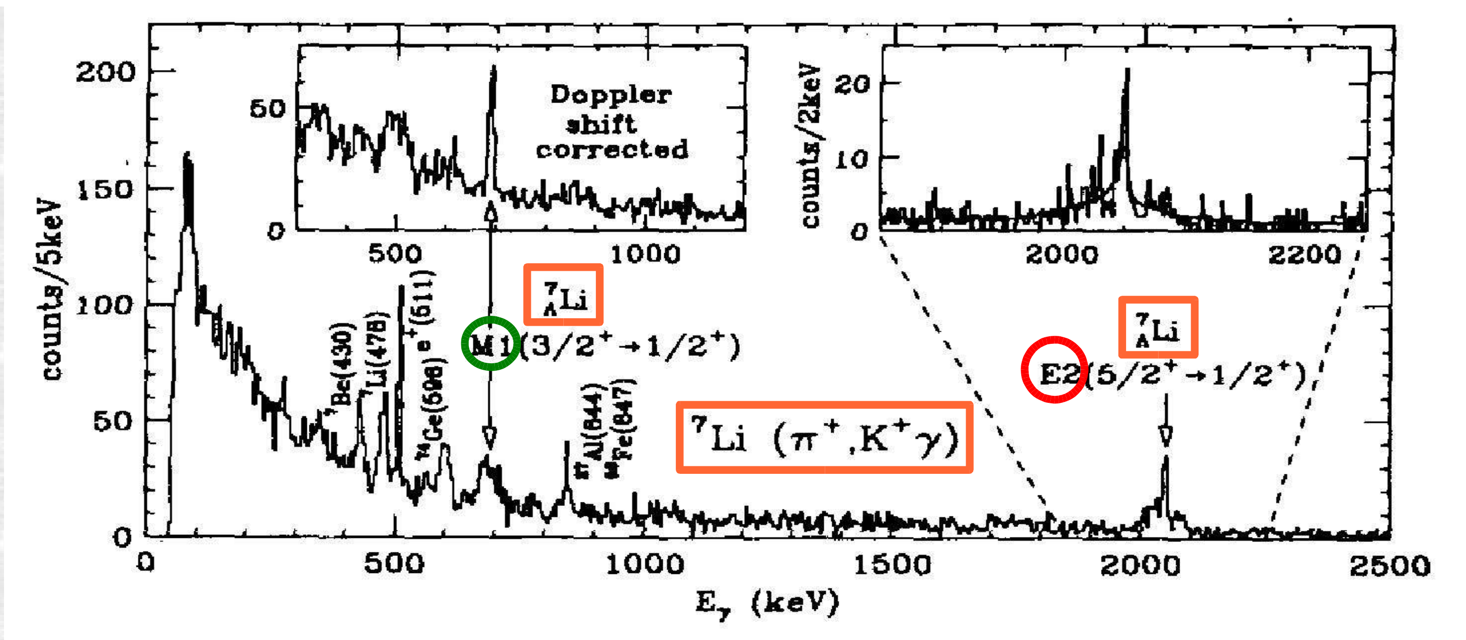
With the resolution of the magnetic spectrometers (present but also future) impossible to disentangle levels too close in energy (like those due to the coupling of the Λ in 1s to a core with $J \neq 0$). Only γ-spectroscopy is able to do the job.



First experiment on γ spectroscopy in co-incidence: Tamura et al. with Hyperball at KEK (E419).

Very interesting results with ^{7}Li.





Important Physics issues

1)

Spin-dependent forces

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

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

Each of the 5 terms (V, Δ, S_Λ, S_N, T) correspond to a radial integral that can be phenomelogically determined from the low-lying level structure of *p*-shell hypernuclei

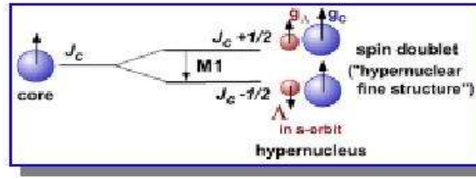
The knowledge of these characteristics of the ΛN interaction allows to improve baryon-baryon interaction models and to discriminate between the ones based on meson exchange picture and those including quark-gluon degree

2) Impurity Nuclear Physics → B(E2)

3)

Medium effect

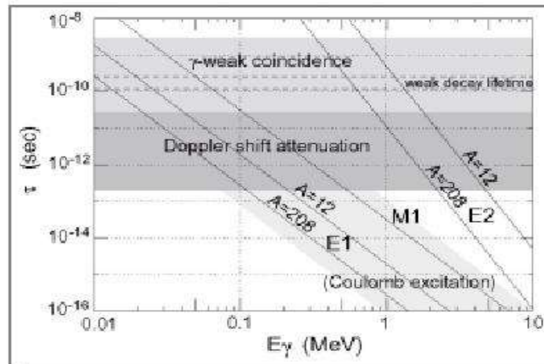
If the **mass** or the **size** of a hyperon is **modified** in a nucleus, its **magnetic moment** may be **changed**



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

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

- **Doppler-shift attenuation** method
- **γ-weak coincidence** method

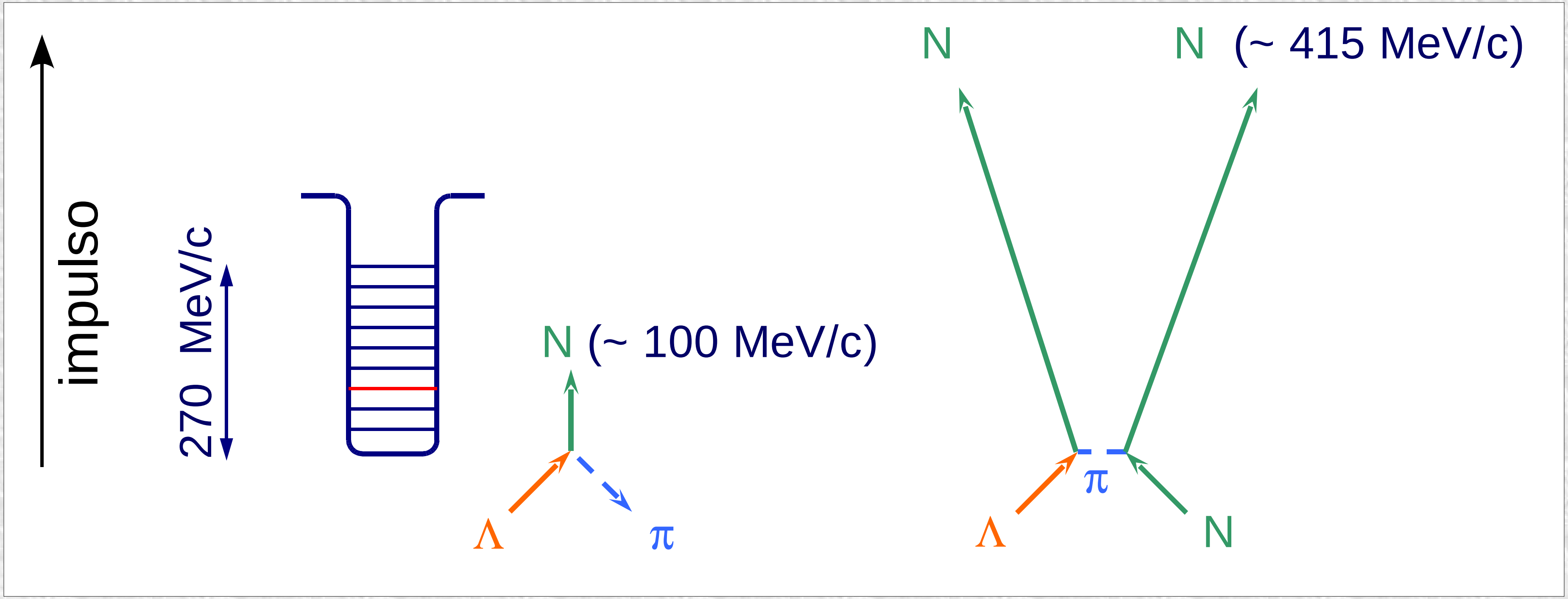


γ-spectroscopy with high-resolution Ge arrays will probably be one of the "battle horses" of the experiments at future machines (J-PARC, GSI)

Weak Decay: the latest results

The older (but still spectacular) evidence of Nuclear Medium Effects

The Pauli principle here acts in the opposite way

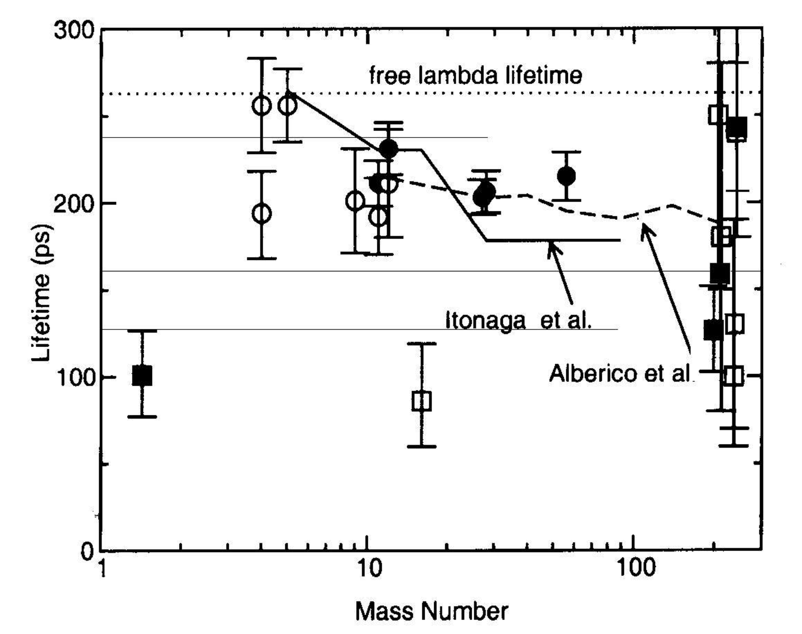


New category of weak reactions possible in a nucleus:

$\Lambda + p \rightarrow n + p$ proton stimulated decay

$\Lambda + n \rightarrow n + n$ neutron stimulated decay

Observables:



$\tau = \hbar/\Gamma$

$\Gamma = \Gamma_m + \Gamma_{nm}$

Mesonic decay: $\Gamma_m = \Gamma_{\pi^-} + \Gamma_{\pi^0}$

$\Lambda \rightarrow p + \pi^- + 41$ MeV (64%)

$\Lambda \rightarrow n + \pi^0 + 38$ MeV (36%)

Non Mesonic decay: $\Gamma_{nm} = \Gamma_p + \Gamma_n + \Gamma_{2N}$

$\Lambda + \mathbf{p} \rightarrow \mathbf{p} + \mathbf{n} + 176$ **MeV**

$\Lambda + \mathbf{n} \rightarrow \mathbf{n} + \mathbf{n} + 176$ **MeV**

$\Lambda + \mathbf{(N+N)} \rightarrow \mathbf{n} + \mathbf{N} + \mathbf{N}$

This sector of Hypernuclear Physics, quite important from the fundamental interactions point of view (only way to study the four-baryon strangeness non-conserving interaction, with access to both PC and ~~PC~~ terms) was quite forgotten up to ~ 10 years ago.

- Main reason: experimental hardness

- Theoretical interest: $\Delta I = 1/2$ is still valid?

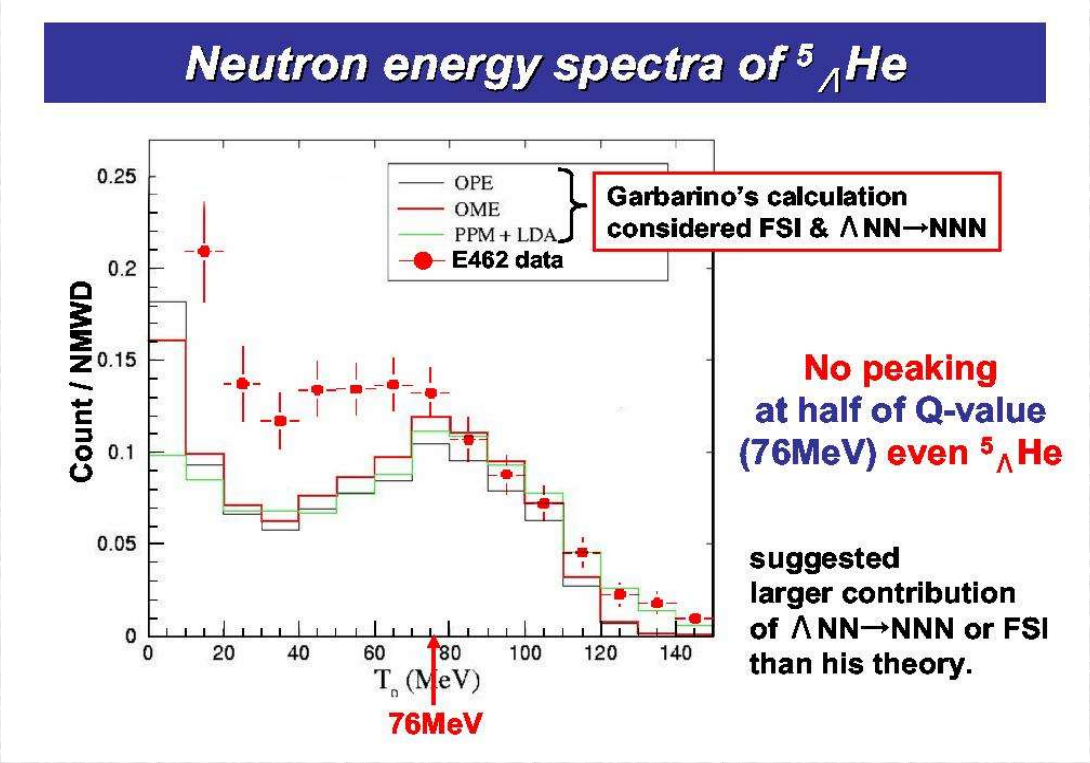
- Puzzle: $(\Gamma_n / \Gamma_p)_{theor.} \ll (\Gamma_n / \Gamma_p)_{exp.}$

  ~0.1 ~1-2

Toward a solution of the puzzle (both values agree to 0.4, with a ~30% error)

Better theoretical approach (not only OME models but also quark degrees of freedom)

Better experiments (both nucleons detected in coincidence with the Hypernucleus ground state). Angular correlations used to clean the results from FS interactions.



KEK E462/508

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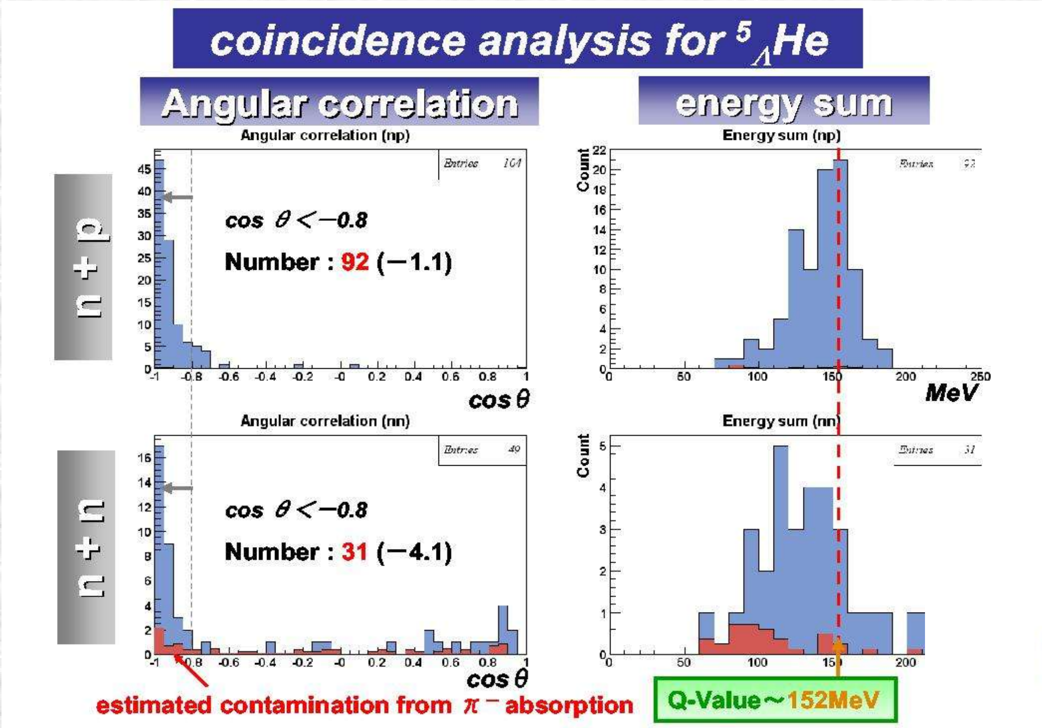
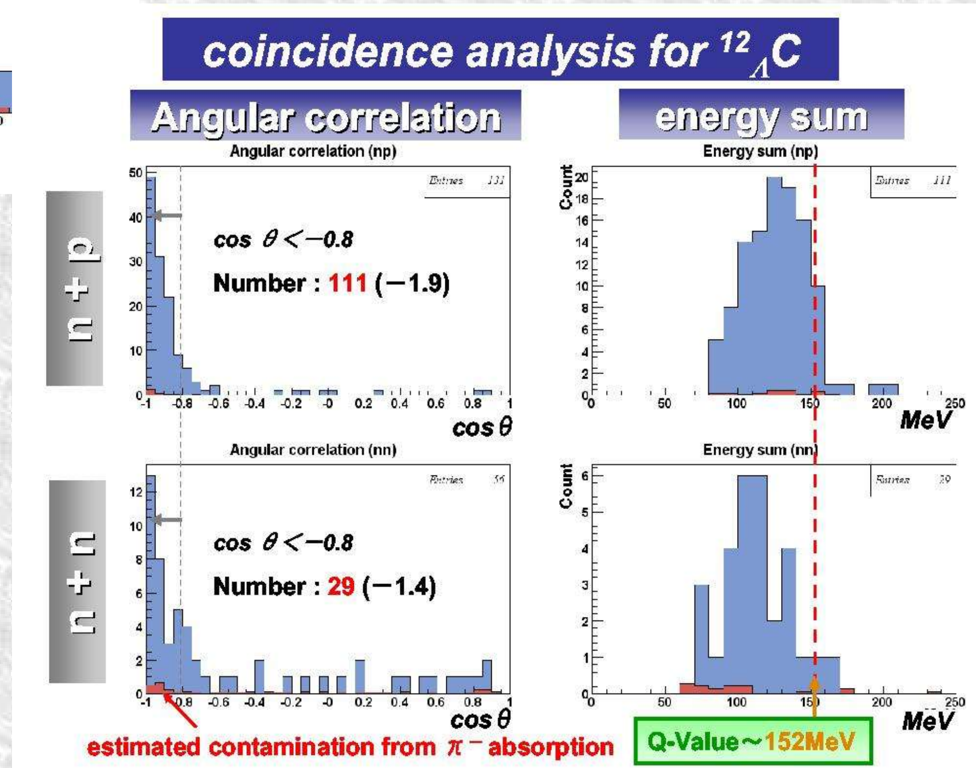


$^{5}{}_{\Lambda}$He

$^{12}{}_{\Lambda}$C



Γ_{2N} (could amount up to ~ 15%of Γ_{nm}) not measured

Complete experiments on Hypernuclear Weak Decay just started.

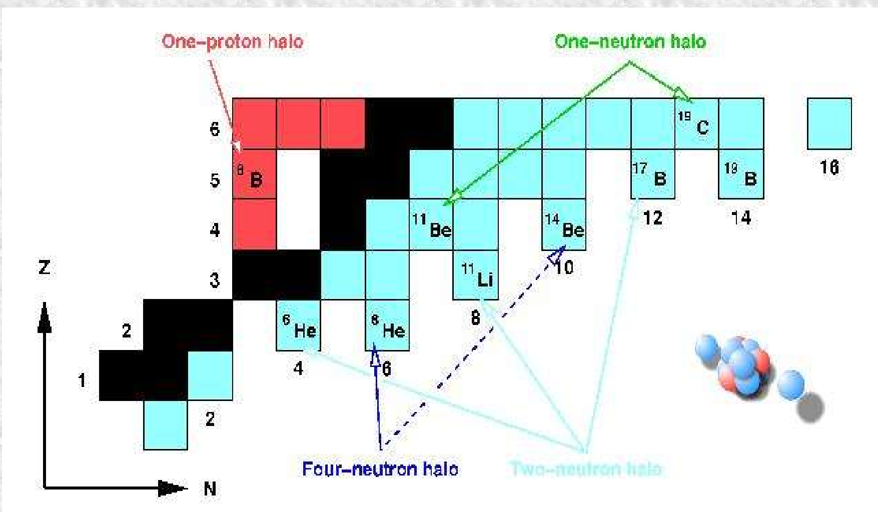
More precise and systematic data urgently needed to answer important questions ($\Delta I = ½$. OME/quark ....)

FINUDA (see Piano's talk) will try to do this job soon.

Neutron-rich Hypernuclei and $\Lambda\Lambda$ Hypernuclei

The existence of neutron-rich Hypernuclei, with N/Z ratios ~2 times larger than that observed for ordinary nuclei was anticipated by Majling.

Extra binding energy of the Λ (again the Pauli principle!) allows to bind more neutrons to the protons of the nucleus.



B $^{4}_{\Lambda}$He 2.39 Λ	$^{5}_{\Lambda}$He 3.12 Λ	◊ $^{6}_{\Lambda}$He 4.18 n 0.17 xxx	◊ $^{7}_{\Lambda}$He 5.23 n 2.92 halo	$^{8}_{\Lambda}$He 7.16 n 1.49 xxx	♠ $^{9}_{\Lambda}$He (8.5) n 3.9 halo
$^{3}_{\Lambda}$H 0.13 Λ	◊ $^{4}_{\Lambda}$H 2.04 Λ	$^{5}_{\Lambda}$H (3.1) n -1.8 xxx	♠ $^{6}_{\Lambda}$H (4.2) 2n -5 xxx	♠ $^{7}_{\Lambda}$H (5.2) 3n 0.4 xxx	

Difficulty in observing them: two-step reactions in the same nucleus

$$K^- + {}^7Li \rightarrow {}^7_\Lambda H + \pi^-$$

$$\hookrightarrow K^- + p \rightarrow \Lambda + \pi^0$$

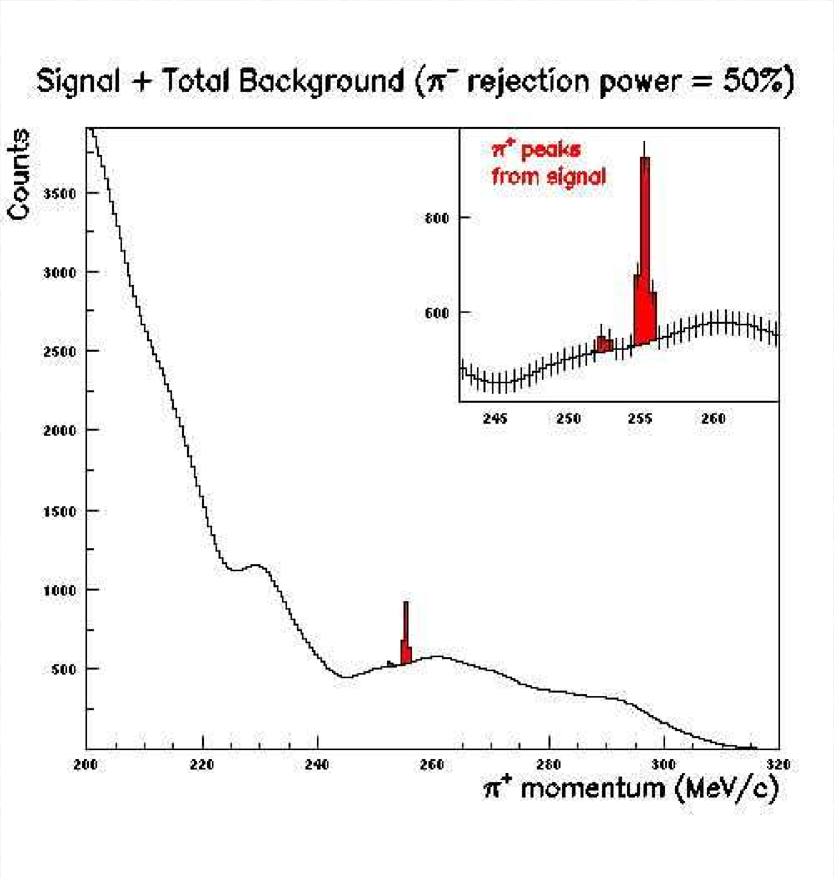
$$\hookrightarrow \pi^0 + p \rightarrow n + \pi^+$$

} in the same nucleus

B.R. (or $d\sigma / d\Omega$) lower by 2-3 orders of magnitude with respect to those for the production of ordinary Hypernuclei

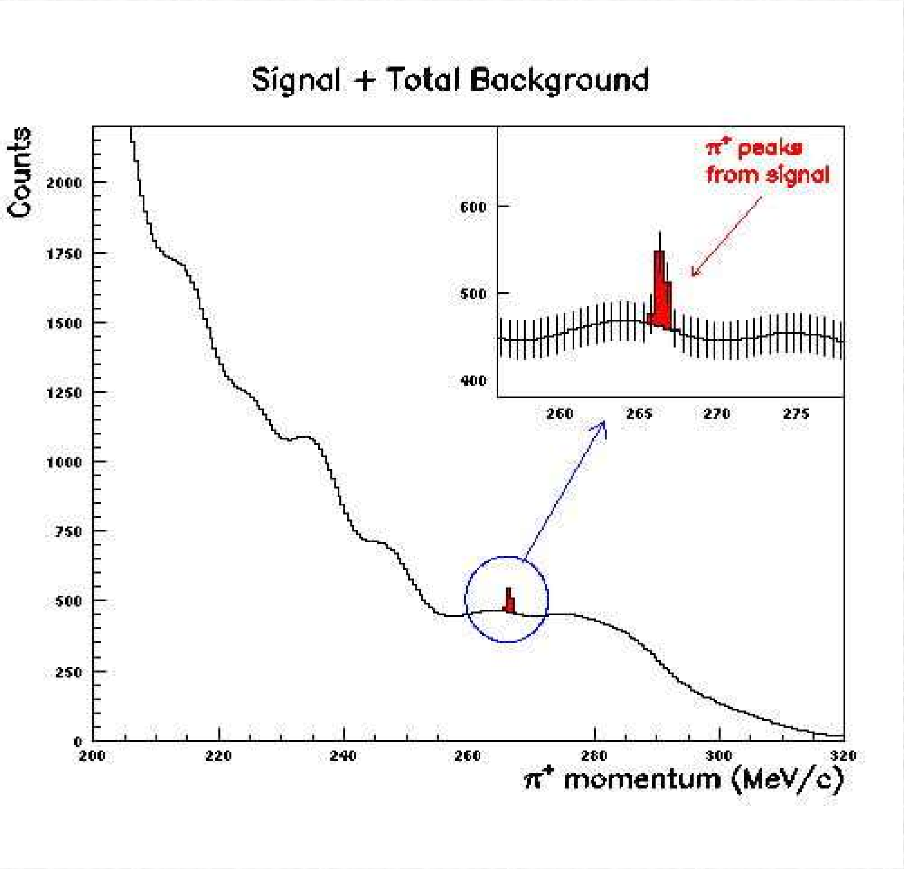
Efforts up to now unsuccessfull.

FINUDA is attempting now such a search in the present run (not dedicated)



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

$^{12}_{\Lambda}Be$



First $\Lambda\Lambda$ Hypernucleus was discovered 40 years ago with emulsion techniques. A second one year later.

From 1980 to ~ 2000 several unsuccessful attempts to observe $\Lambda\Lambda$ Hypernuclei with spectrometers (H-particle, ...)

Recently, three more candidates recorded.

Great interest for these objects (only way to measure the Λ–Λ interaction).

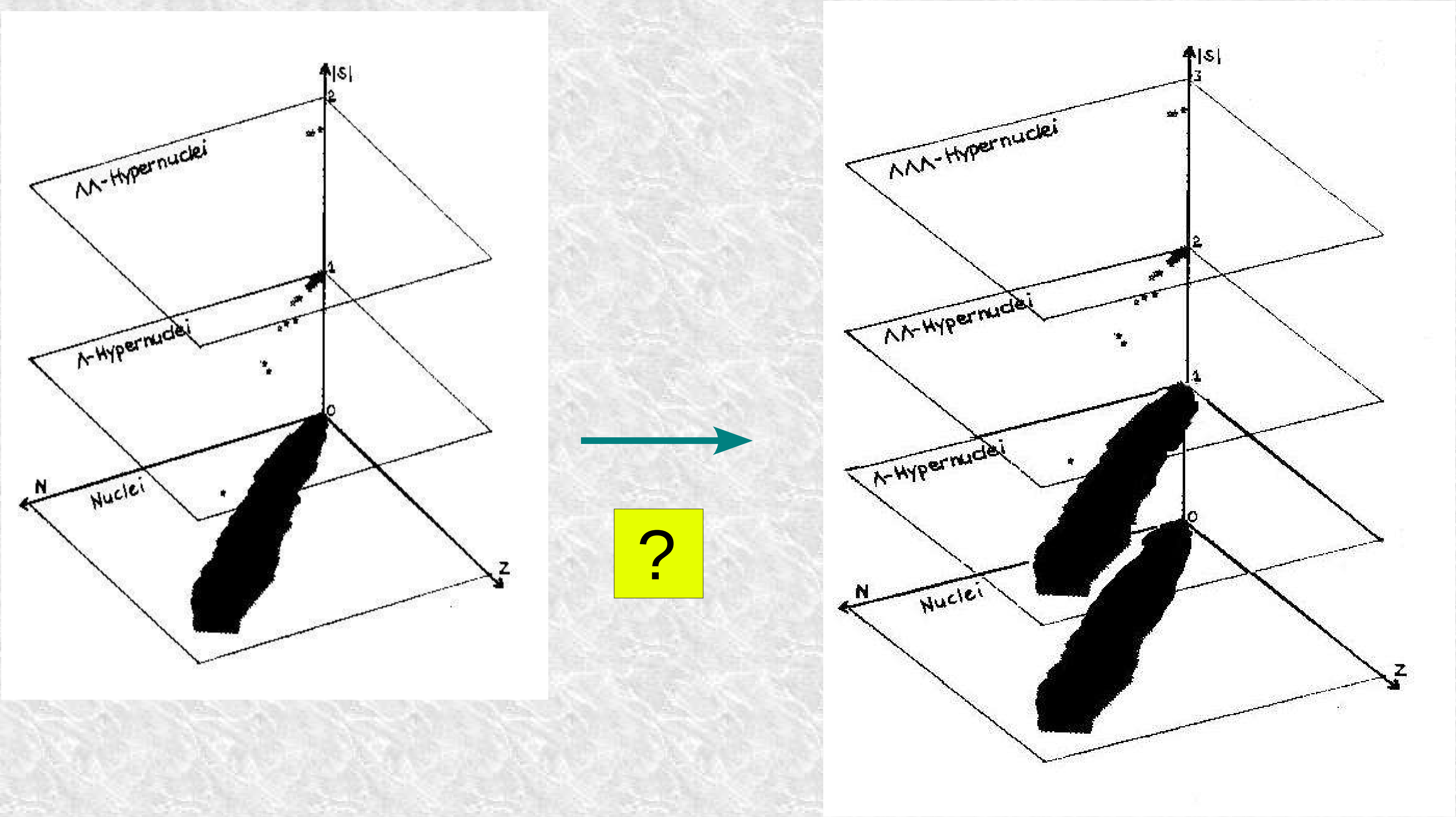
Hypernuclear Physics in the next 50 years

Facilities: DAΦNE (up to ~ 2010 ?)
TJNAF (up to ~ 2010 ?)
J-PARC (from 2008)
GSI (from 2012)

Powerful third generation detectors under construction

Hope:

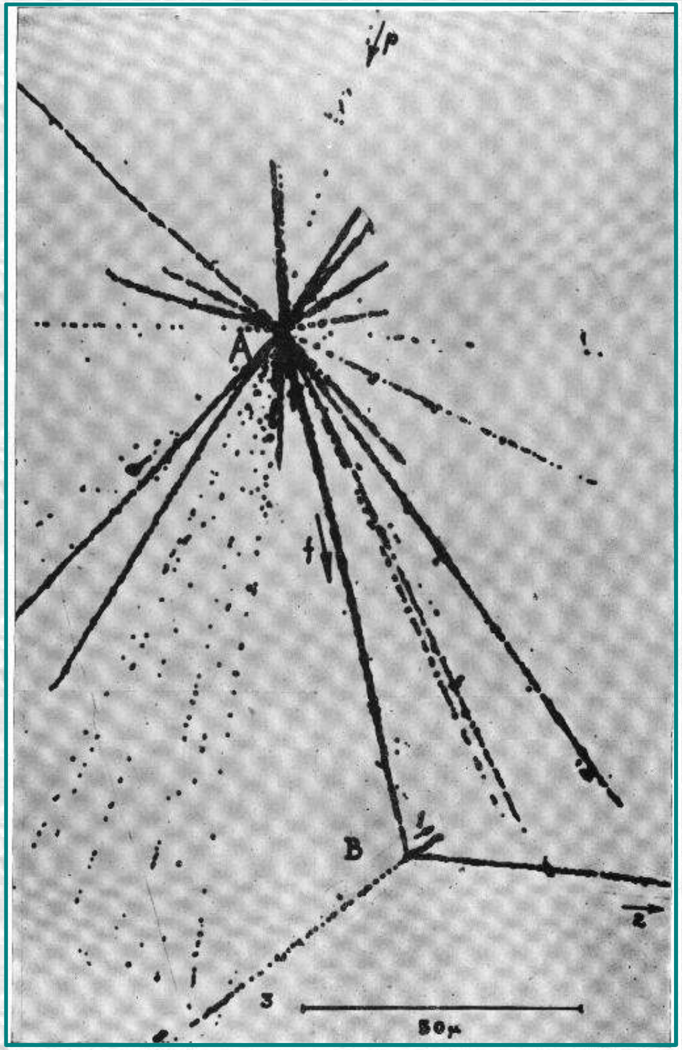
- Scale by one step the S-axis on the three dimensional chart of nuclear systems: S = - 3 systems?



- Fill other three-dimensional plots (C, B axis?)

LOGOS

First 50 years



Second 50 years