Hypernuclear Physics Experiments at J-PARC

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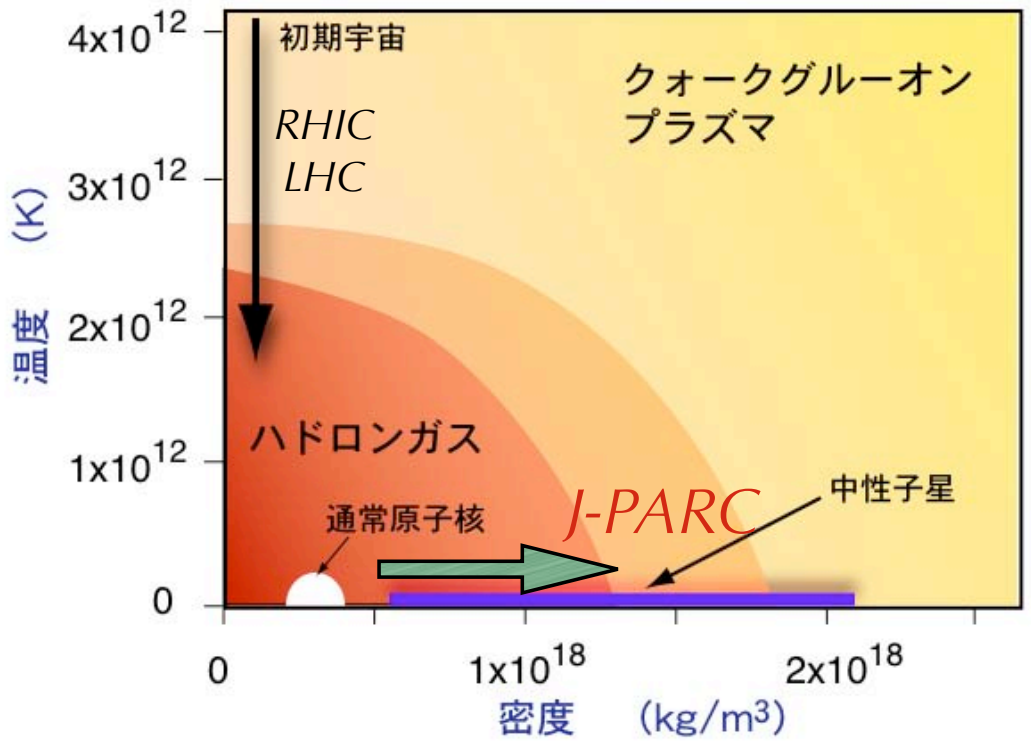
J-PARC Project Office

KEK

Nuclear Physics in the 21st Century

- Heavy-Ion Colliders : RHIC, LHC-Alice
  - *QGP at High Temperature*
- e^- and photon beams : JLab, SPring-8, etc.
  - *Structure of proton, Hadron spectroscopy, etc.*
- Hadron beams : J-PARC, DAFNE, GSI
  - *High-Density Hadronic Matter, Exotic Hadrons*
- Unstable Nuclear Beams : RIBF, GSI, ISOLs
  - *Isospin Limit, Nuclear Astrophysics*


4x10^12
3x10^12
2x10^12
1x10^12
0
温度 (K)
初期宇宙
RHIC
LHC
クォークグルーオン
プラズマ
ハドロンガス
通常原子核
J-PARC
中性子星
0
1x10^18
2x10^18
密度 (kg/m3)

LOIs in Strangeness Nuclear Physics

- L06: New Generation Spectroscopy of Hadron Many-Body Systems with Strageness S=-2 and -1 (K. Imai et al.)
- L07: Hyperon-Proton Scattering Experiments at the 50-GeV PS (M. Ieiri et al.)
- L08: High-Resolution Reaction Spectroscopy of S=-1 Hypernuclei (H. Noumi et al.)
- L09: Neutron-rich Λ hypernuclei by the double-charge exchange reaction (T. Fukuda et al.)
- L10: Study of Dense $\bar{K}$ Nuclear Systems (T. Nagae et al.)
- L21: Precise Measurement of the Nonmesonic Weak Decay of A=4,5 Λ Hypernuclei (S. Ajimura et al.)

Two LOIs selected as Day-1 Experiments

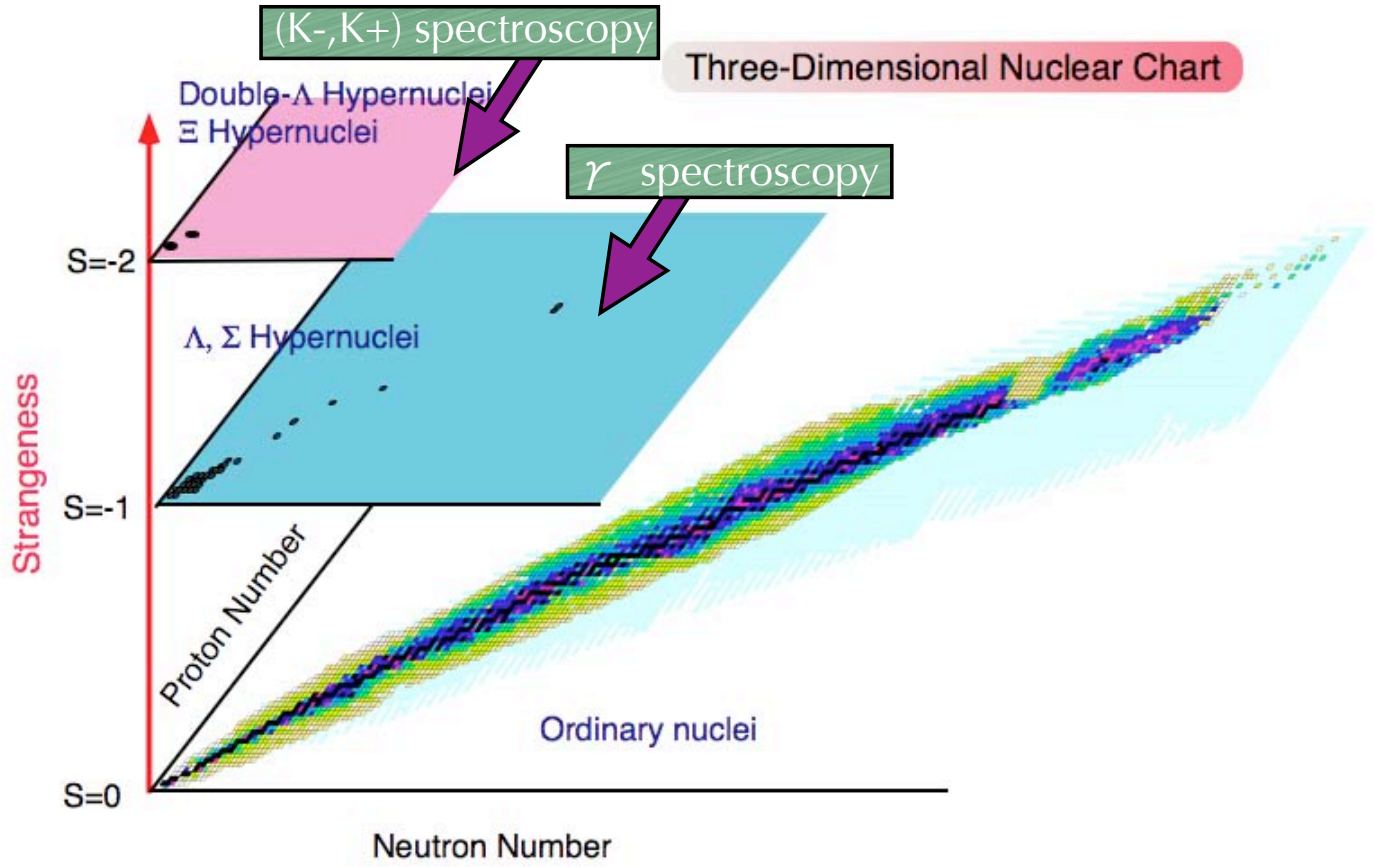
L06: New generation spectroscopy of hadron many-body systems with strangeness S=-2 and -1

- K.Imai,M.Nakamura, H.Funahashi, M.Yosoi
- T.Nagae, M.Ieiri, H.Noumi, H.Outa, M.Sekimoto, H.Takahashi, Y.Sato, A.Toyoda
- T.Fukuda, P.K.Saha
- K.Nakazawa
- K.Yamamoto, T.Yoshida
- O.Hashimoto, K.Maeda, H.Tamura, S.N.Nakamura, T.Takahashi, Y.Fujii,H.Kanda
- T.Kishimoto, A.Sakaguchi, S.Ajimura, Y.Shimizu, S.Minami, T.Itahashi, T.Hayakawa
- M.Iwasaki, K.Itahashi, K.Tanida, Y.Matsuda
  - Japan
- J.S.Song, I.G.Park, C.S.Yoon, S.H.Kim
- J.Y.Kim
- M.Y.Pac
- J.K.Ahn, I.K.Yoo
- H.Bhang, M.Youn
  - Korea
- S.Zhou, L.Zhu
  - China

- B.Bassalleck
- L.Tang
- P.Markowitz, B.Raue, J.Reinhold
- M.May, R.E.Chrien, A.Rusek, P.H.Pile
- S.Choi
- Ed.Hungerford
- G.Franklin, R.Schumacher, B.Quinn
  - USA
- T.R.Saitoh, A.Banu
  - Germany
- J.Arvieux
  - France
- P.Kienle, M.Cargnelli, J.Marton, J.Zmeskal
  - Austria
- S.Marcello, T.Bressani
- M.Agnello
- A.Feliciello
  - Italy
- P.Tlusty
  - Czech

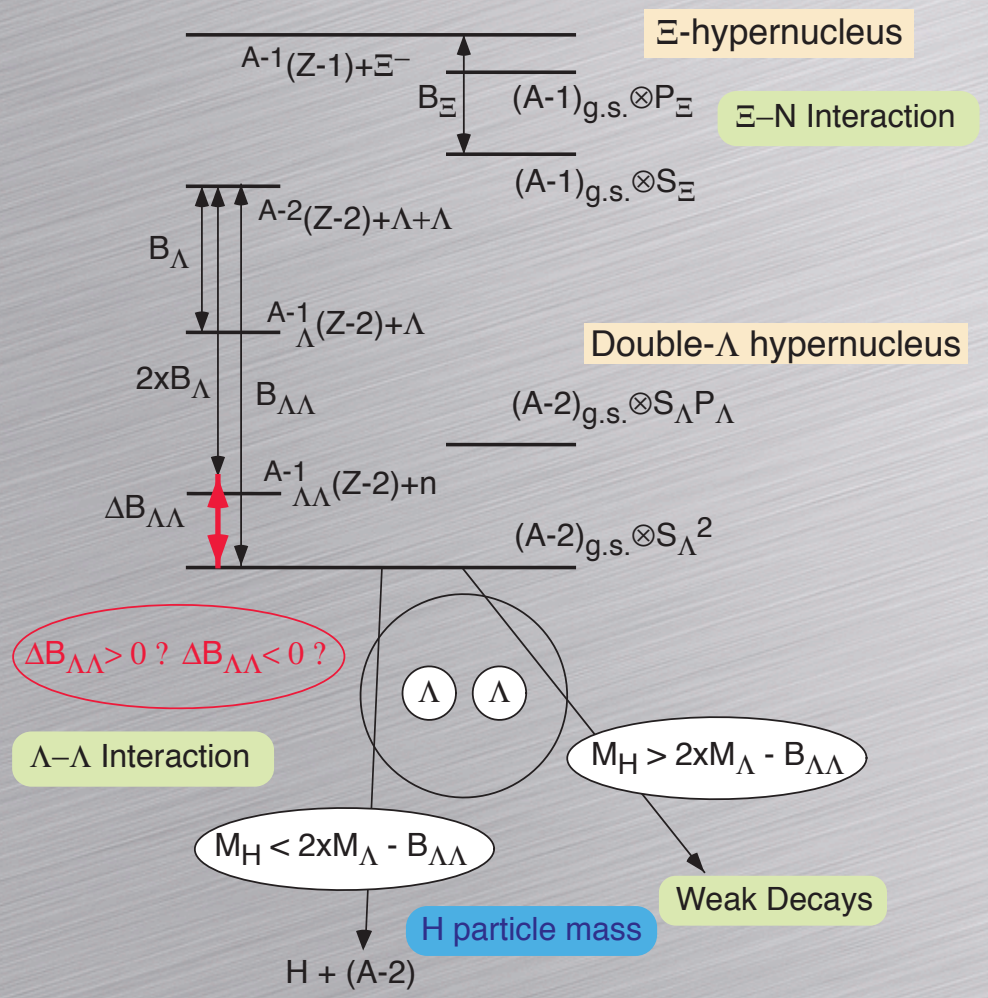
Strangeness Nuclear Physics

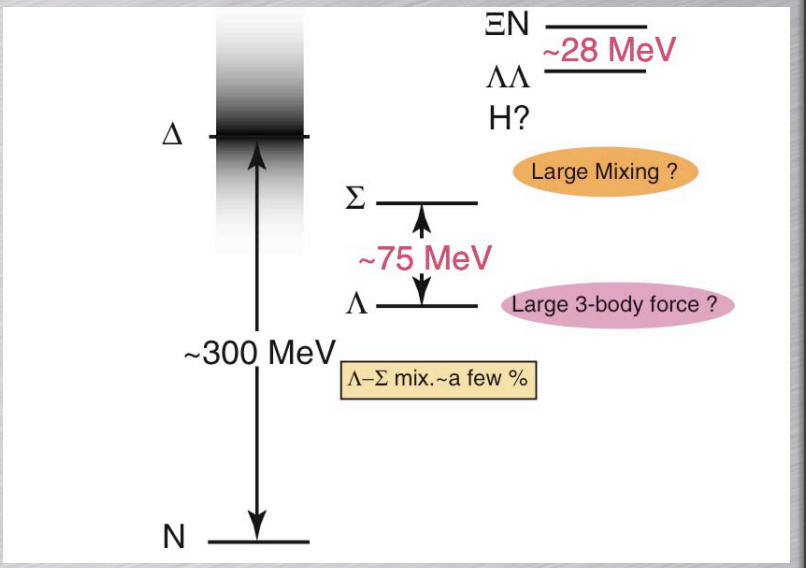
New Hadron Many-Body Systems with Strangeness



S=-2 World

Energy Spectrum of S=-2 systems





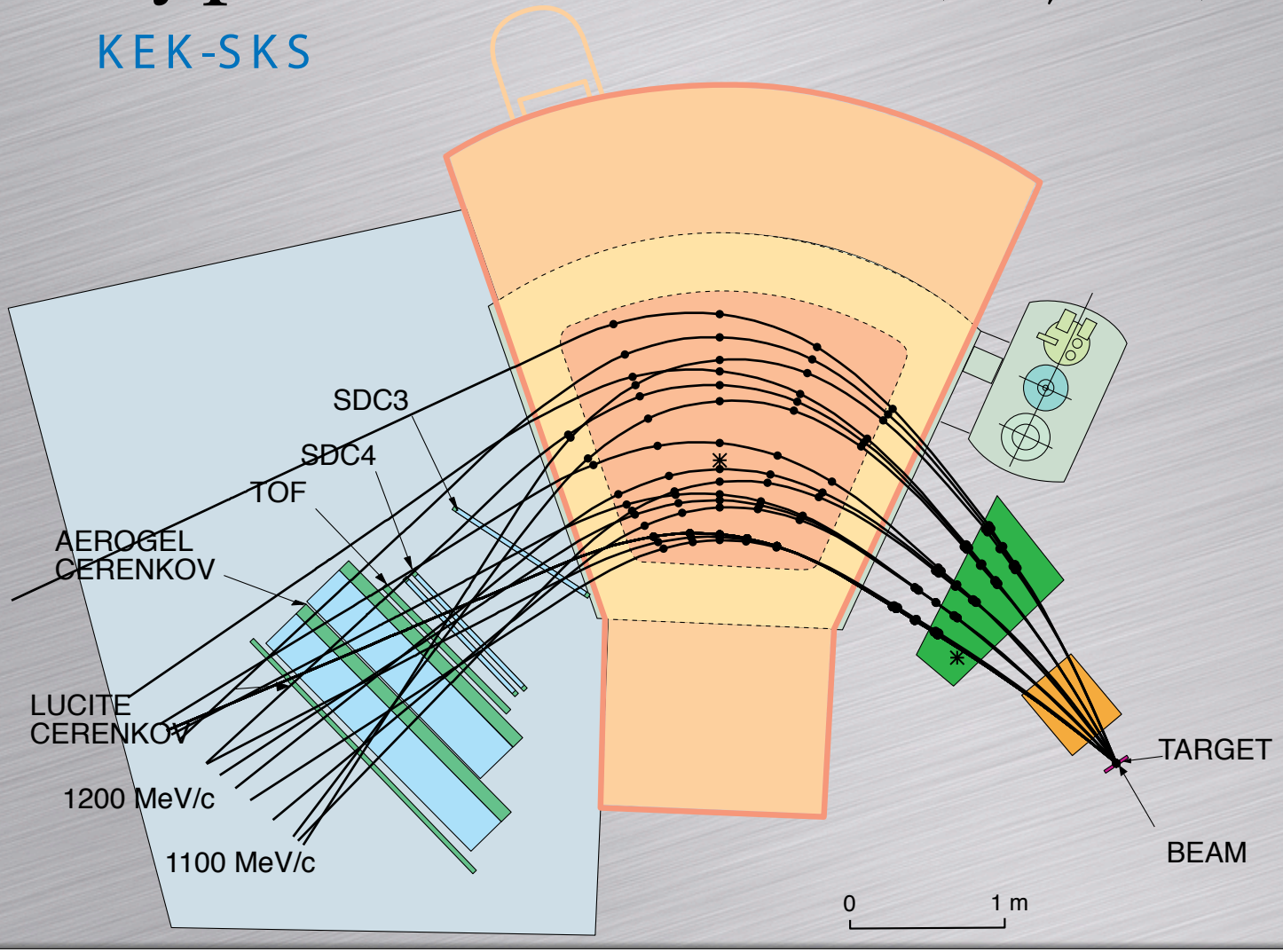
Information on S=-2

- Double Λ hypernuclei
  - Two old emulsion events(1963,1966)
  - One recent event in KEK E176(1991)
  - Nagara event in KEK E373(2001)
    - Binding energy of ${}^{6}_{\Lambda\Lambda}\mathrm{He}$
    - $m_H > 2223.7$ MeV/c^2
- Ξ hypernuclei ?

Very limited spectroscopic information

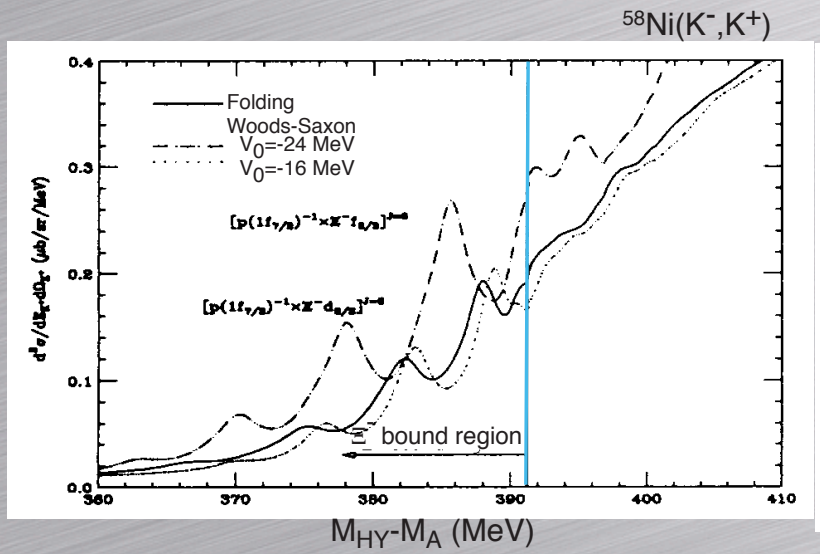
ΞHypernuclei with (K⁻,K⁺)

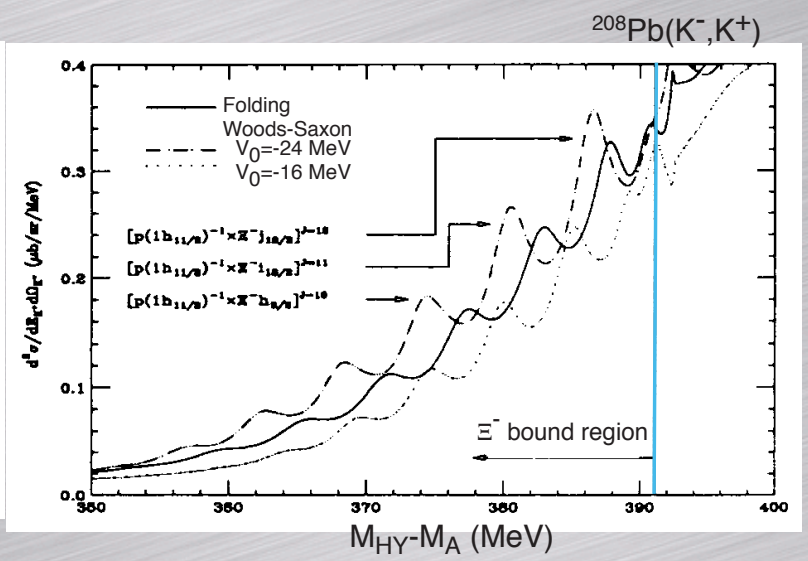
KEK-SKS



(K^-,K^+) Spectroscopy

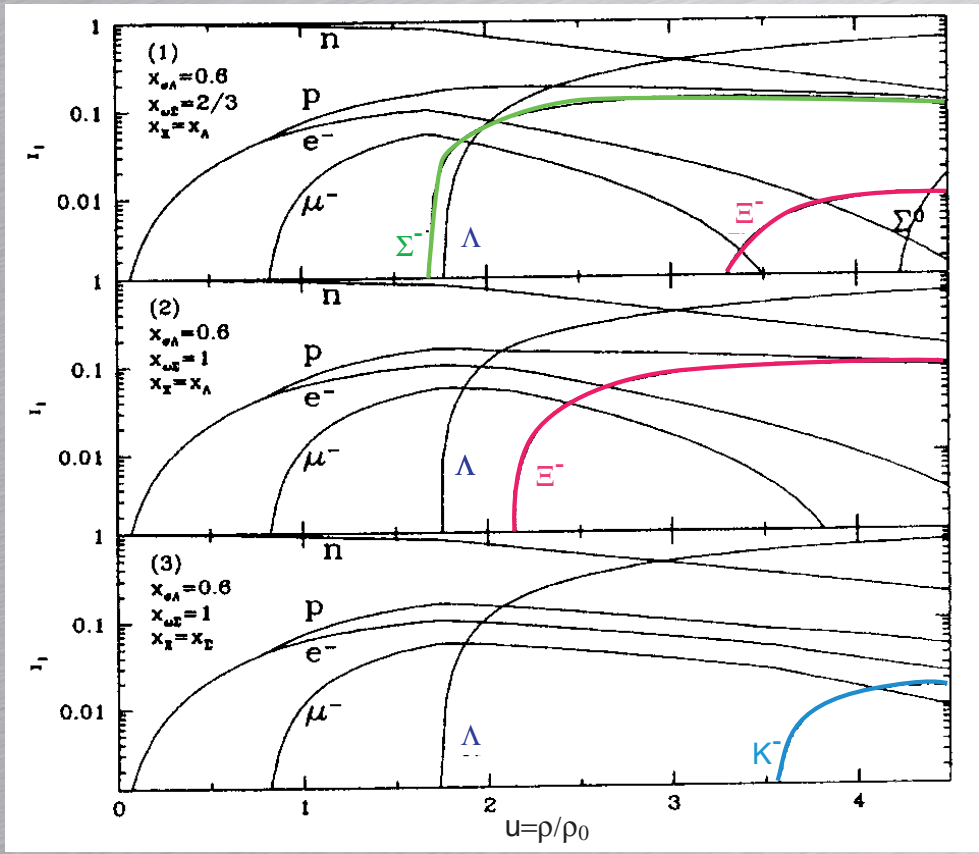
- 2 MeV_{FWHM} resolution
- ~6 events/day/MeV for 50 msr, 2g/cm^2-thick Pb ⟶ ~20 days





Ξ hypernuclei potential ?

- Λ, Σ^-, Ξ^-, K^- in Neutron Star Core ?
  - Chemical Potential: $\mu_B = m_B + \frac{k_F^{\,2}}{2m_B} + U(k_F)$



U_Σ<0, U_Ξ<0

U_Σ>0, U_Ξ<0

U_Σ>0, U_Ξ>0

High-presicion γ spectroscopy of hypernuclei

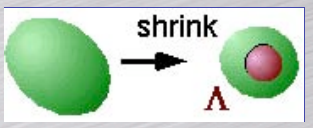
ΔE ~ a few keV (FWHM) by Hyperball
<< ~ 1 MeV by reactions

Precise Structure of Λ Hypernuclei

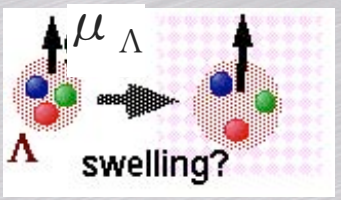
↓

- **YN, YY Interactions**
  ΛN : spin-dependent forces, ΛN-ΣN / ΛNN forces,
  charge symmetry breaking, p-wave interaction
  ΞN, $\Lambda\Lambda$ interactions

- **Impurity effects**
  B(E2) -> shrinking effect
  Change of cluster structure/shell structure

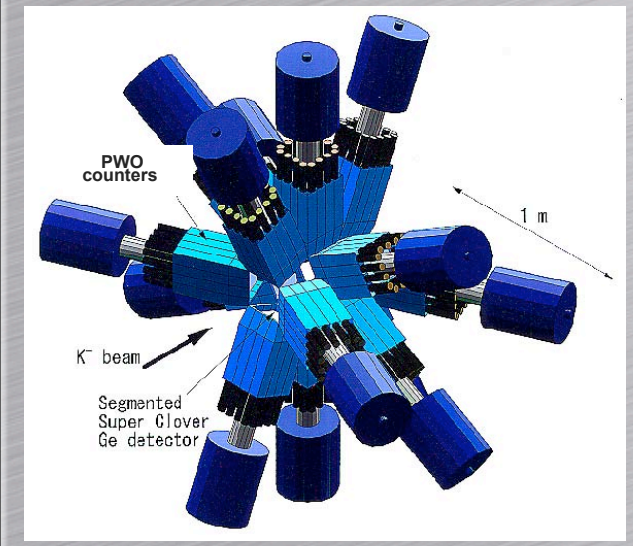


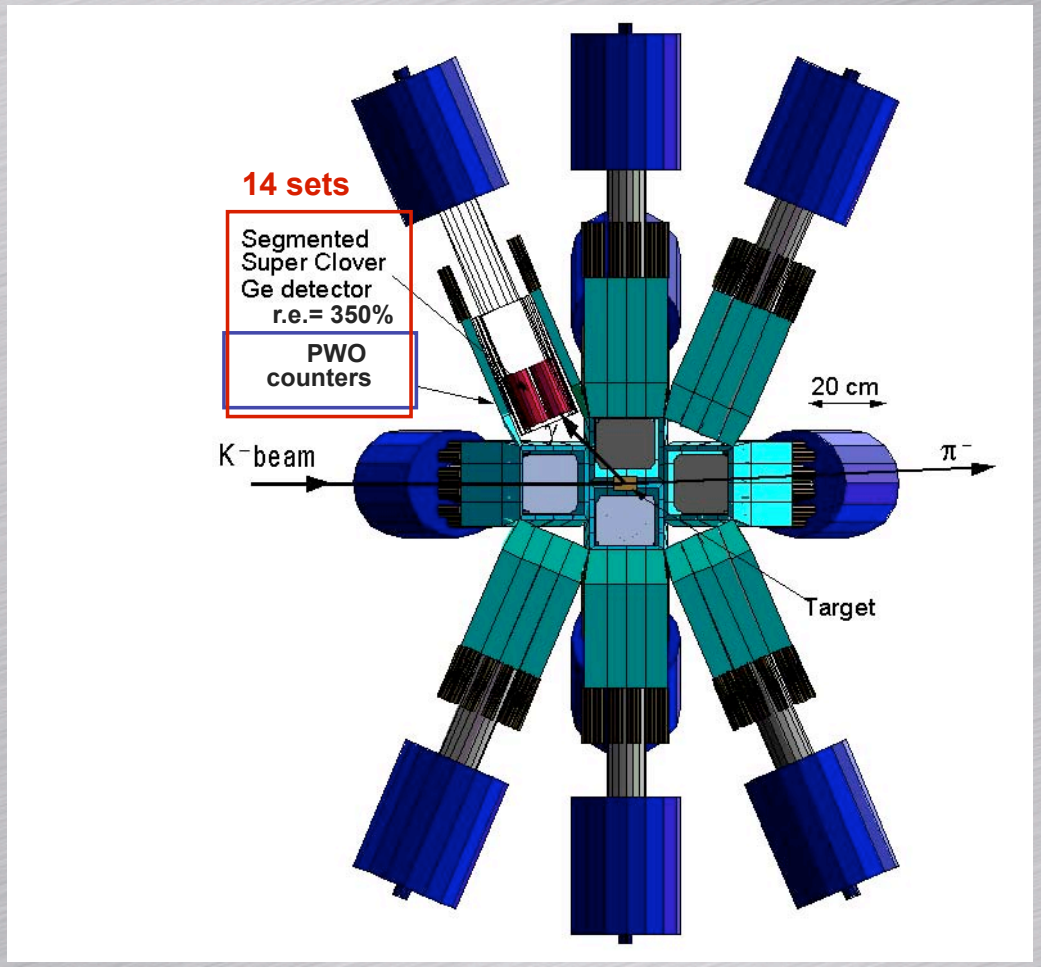
- **Nuclear medium effects**
  B(M1) -> m_Λ inside a nucleus



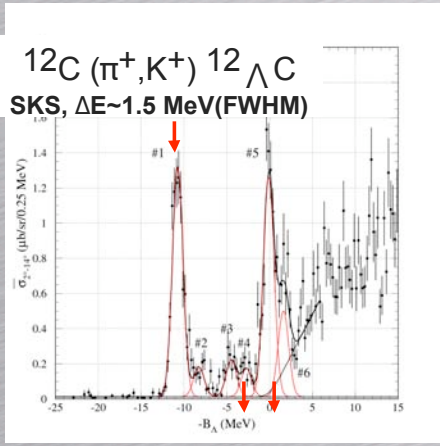
Hyperball-3

- effic. **> 10% at 1 MeV**
  (x4 of Hyperball)
- **Rate limit**
  ~2x10^7 particles /s (x5)
- **Yield: x20 for single γ**
  x80 for γ γ

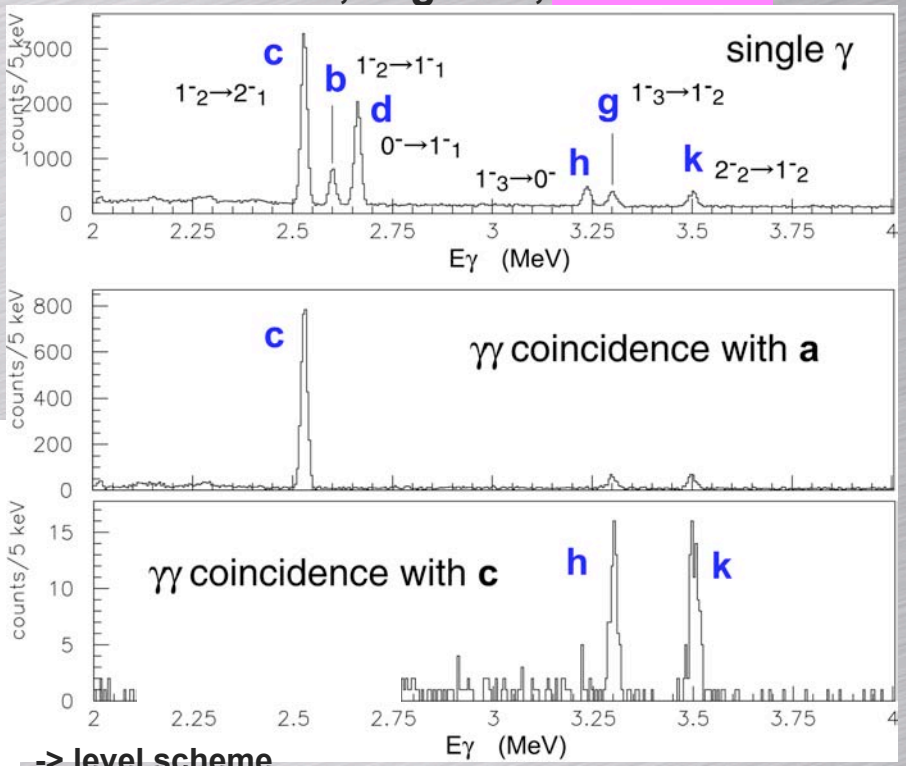


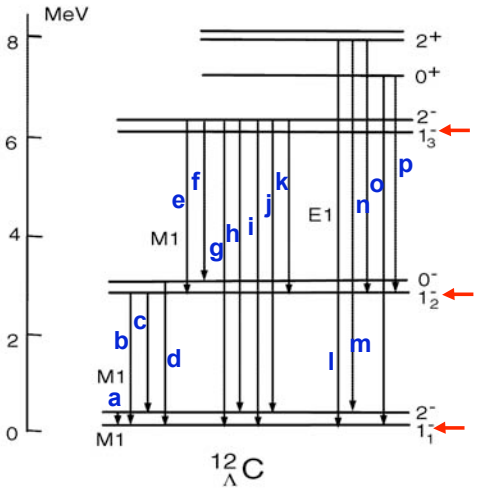


(1-b) Light hypernuclei--$^{12}_{\Lambda}$C case



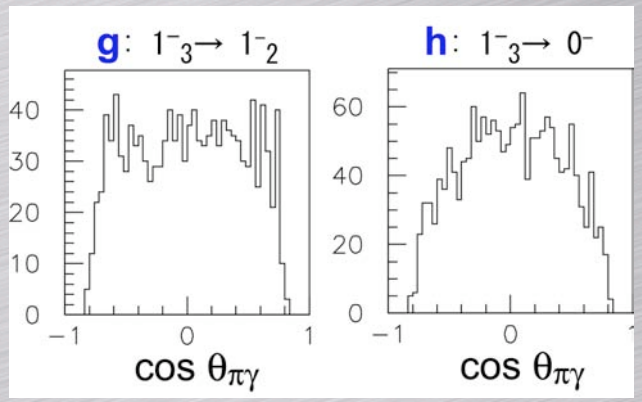
Simulation: K1.1, 10g/cm^2, 120 hours





-> level scheme

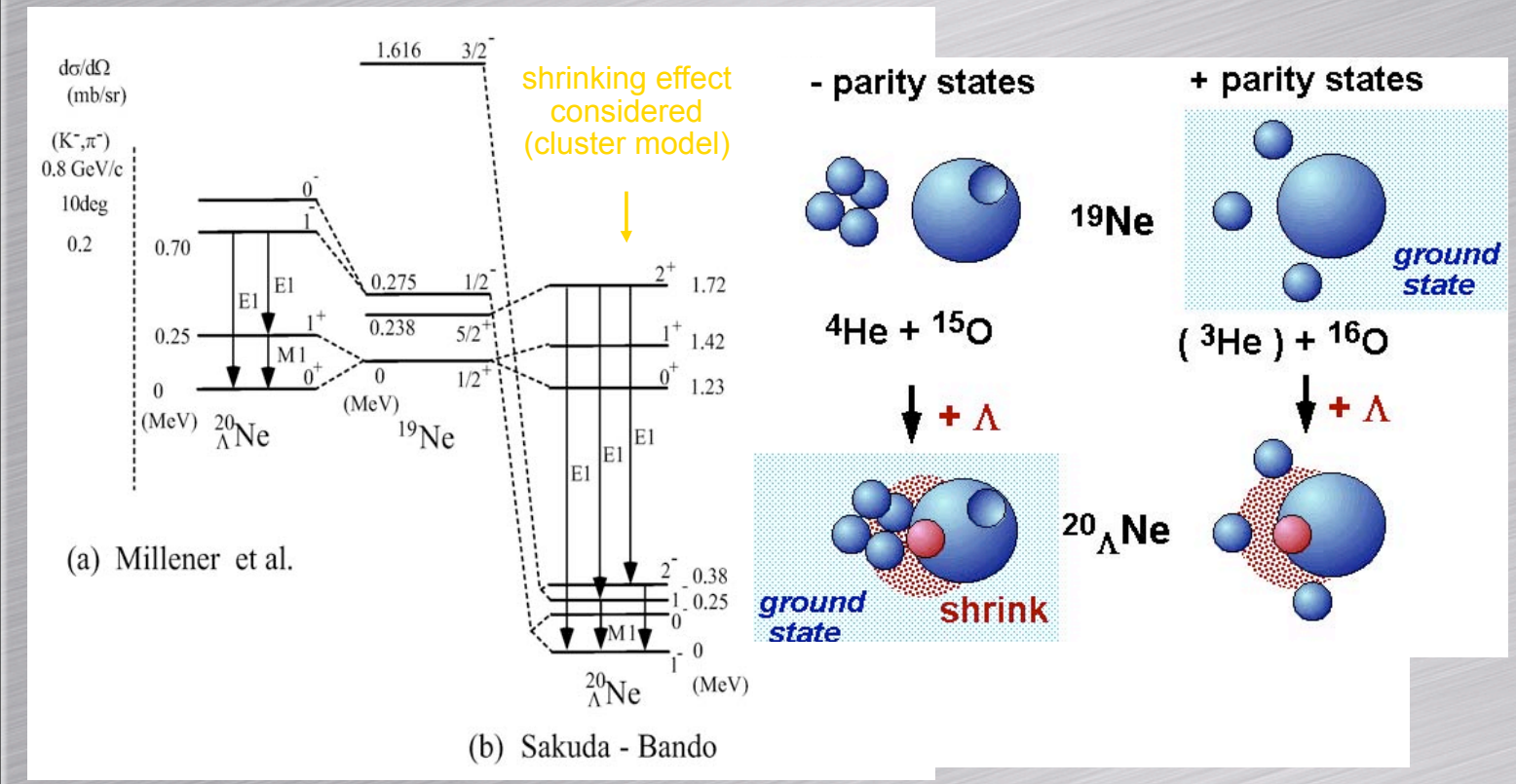
Angular corr.
-> spin assign



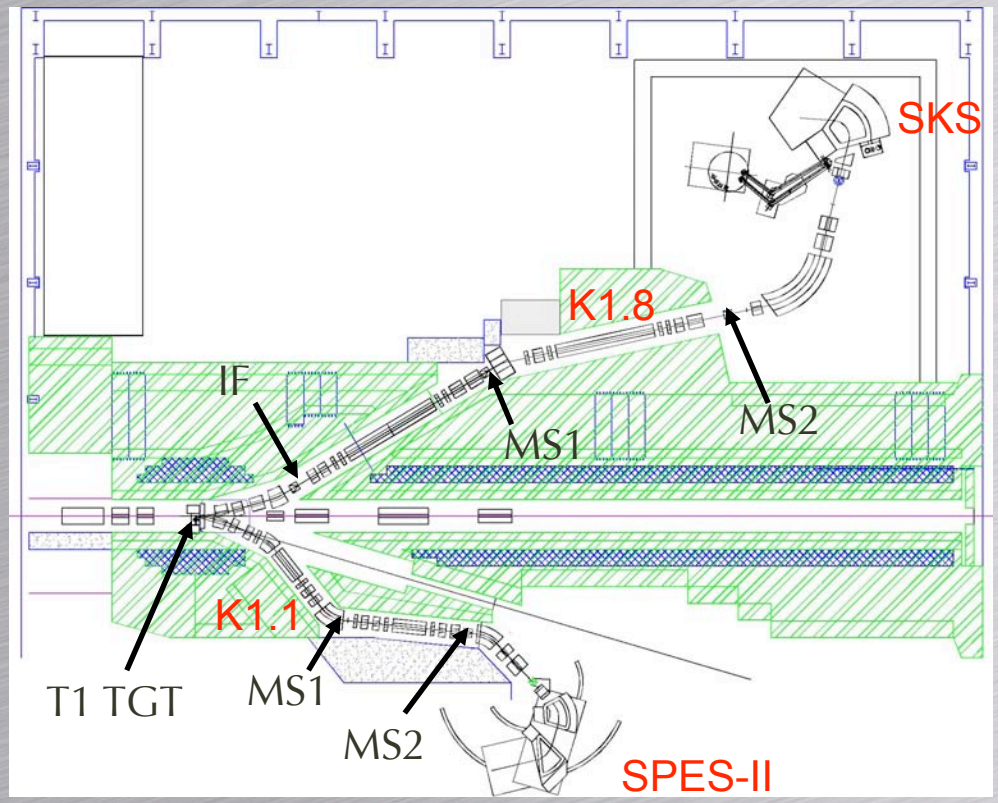
(1-b) Light hypernuclei

Impurity effect

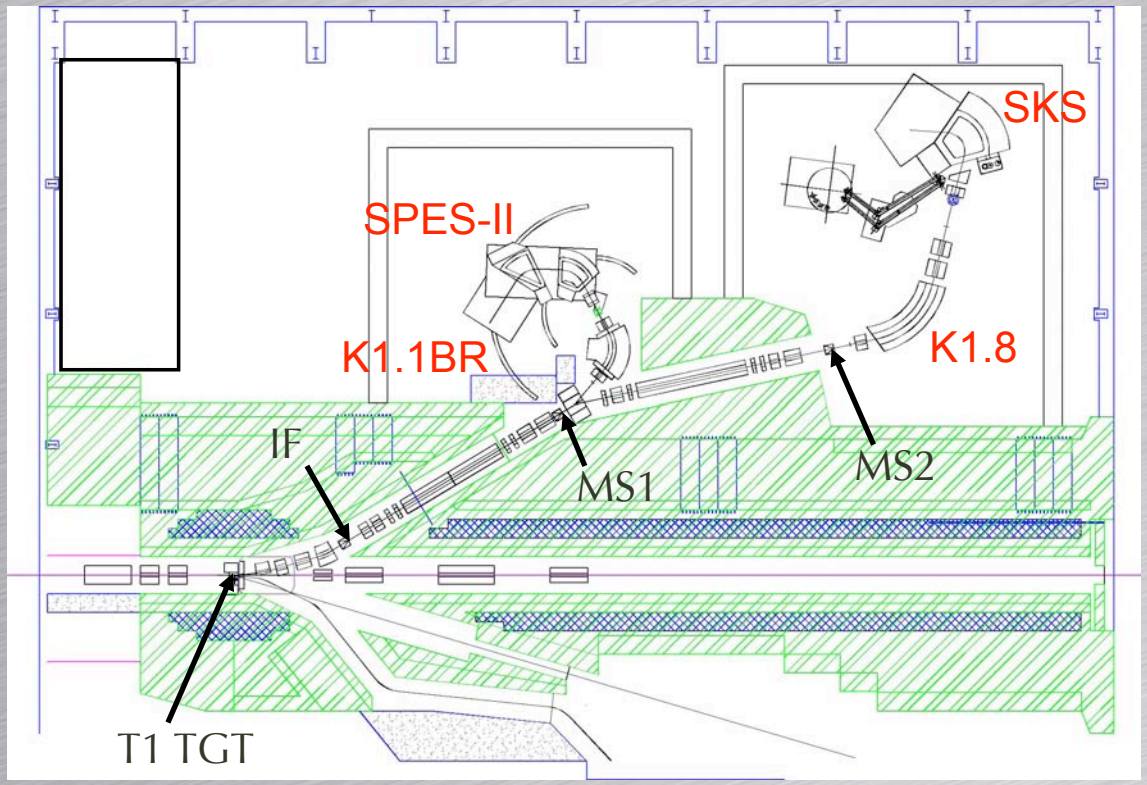
example of $^{20}_{\Lambda}$Ne : change of cluster structure



Layout Option - K1.8 and K1.1



Layout Option - K1.8+K1.1BR

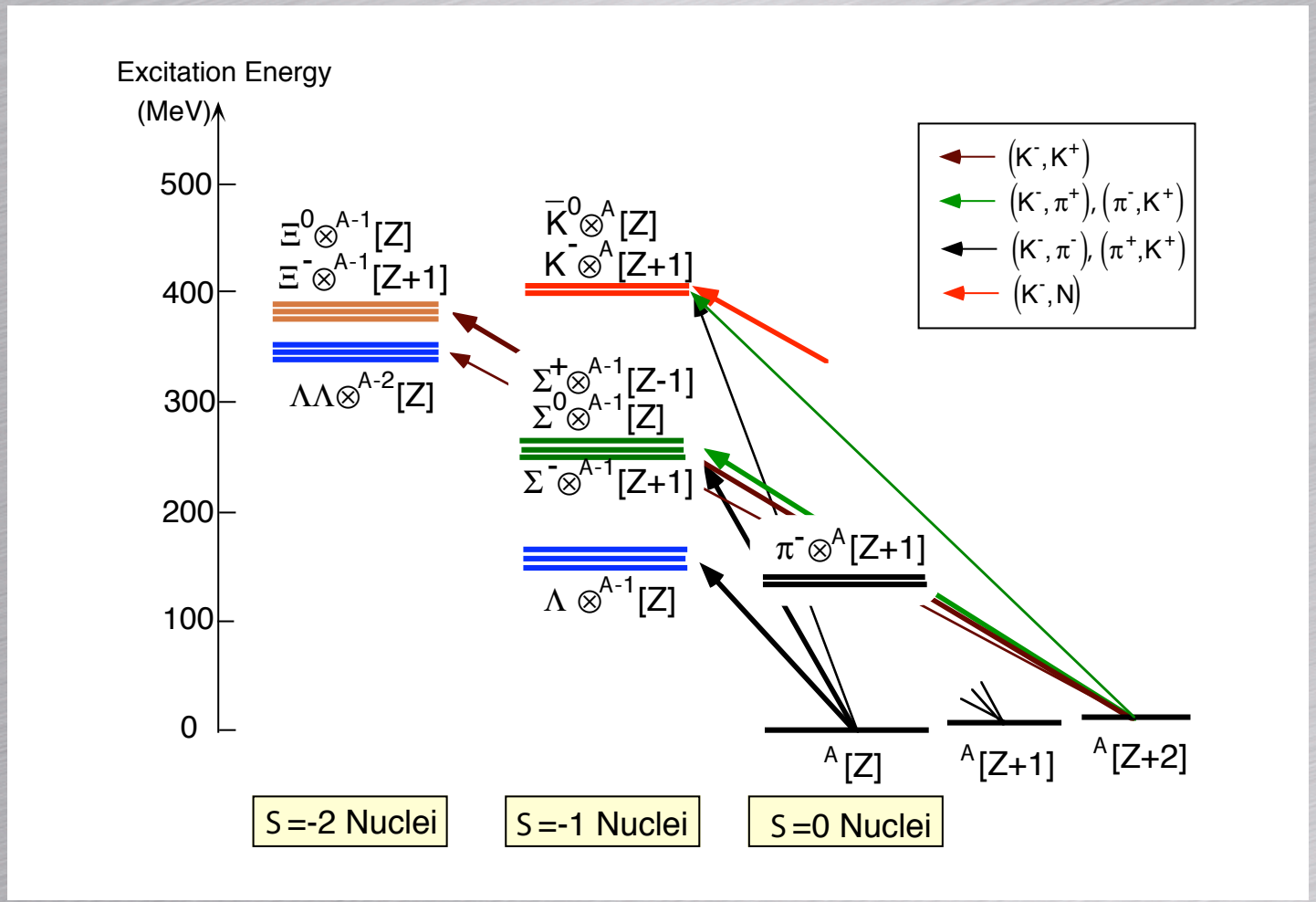


Beam Line Specification

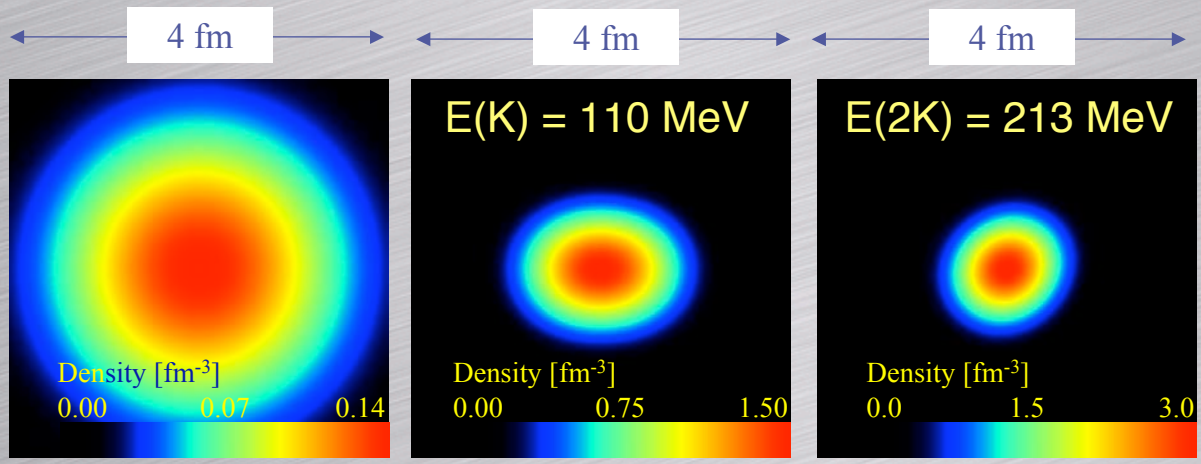
by H. Noumi

	K1.8	K1.1	K1.1BR
Length (m)	46.4	24	26.9
Acceptance (msr.%)	2.7	16.5	4.9
Intensity (ppp)			
1.8 GeV/c	1.0E+07		
1.1 GeV/c	4.9E+05	4.1E+07	1.0E+07
Electro-static Separator	6m-7.5MV/m ×2	2m-7.5MV/m ×2	6m-5MV/m ×1
Separation/Size(rms)	10.8	4.2	6.5
Beam Mom.Resol.(%)	0.07	-	0.05

L10: Study of Dense Kbar-Nuclear Systems



Formation of High Density State



ppn

total B.E. = 6.0 MeV
central density = 0.14 fm^{-3}
R_{rms} = 1.59 fm

ppnK$^-$

total B.E. = 118 MeV
central density = 1.50 fm^{-3}
R_{rms} = 0.72 fm

ppnK$^-$K$^-$

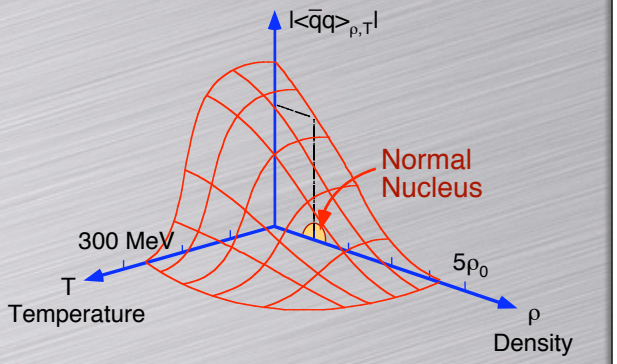
total B.E. = 221 MeV
central density = 3.01 fm^{-3}
R_{rms} = 0.69 fm

$\rho > \rho_0 \times 10$!!

Dote et al.

Physics Impacts

- Formation of Cold(T=0) and Dense($\rho > 5\ \rho_0$) nuclear matter
  - **Quark-gluon plasma, color superconductivity**
- Chiral symmetry restoration
  - **In-medium $\bar{K}N$ interactions**
- Kaon condensation
  - **Neutron star, strange star**



T. Hatsuda and T. Kunihiro, Phys. Rev. Lett. **55** (1985) 158.
W. Weise, Nucl. Phys. **A443** (1993) 59c.

How to produce ?

- Single Kaon bound state
  - **(K^-,π^-) reaction: BNL P967** *Nagae*
  - **(K^-,N) reaction** *Kishimoto E548*
  - **(Stopped K^-,n) reaction: KEK E471** *Iwasaki E549*
- Double Kaon bound state
  - **(K^-,K^+) reaction**

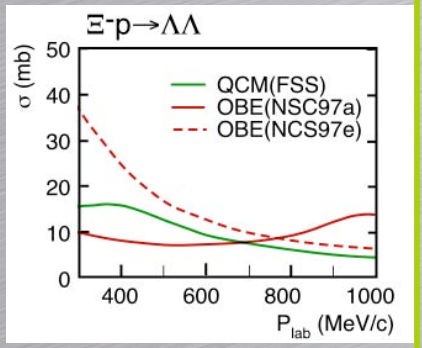
L07: Hyperon-Proton Scattering Experiments

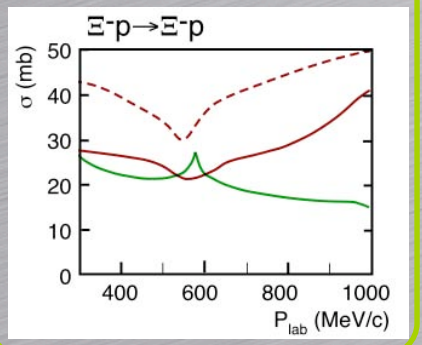
Toward a Modern picture of "Nuclear Force"
Baryon-Baryon Interaction in $SU(3)_F$

meson or quark ?

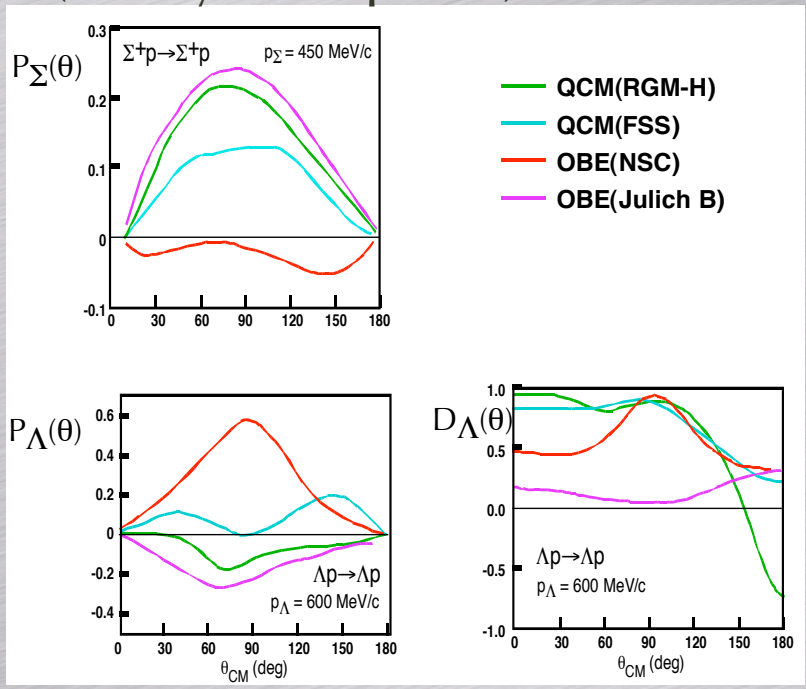
M. Ieiri (KEK)
K. Imai (Kyoto U.)
B. Bassalleck (U.ofNM)
P. Tlusty (NPI)

S=-2
$\Xi^- p \to \Lambda\Lambda$, $\Xi^- p \to \Xi^- p$



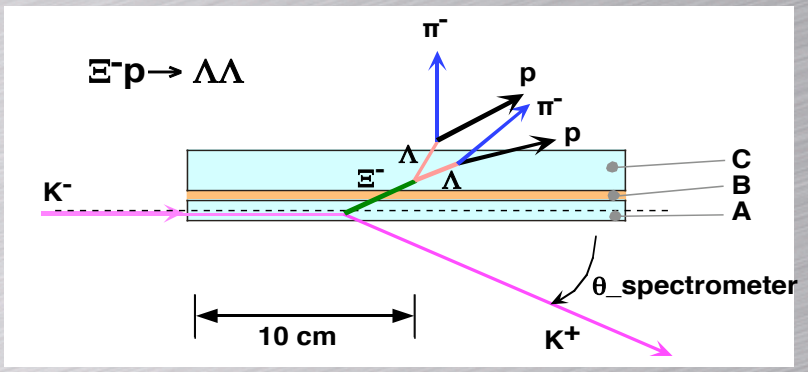


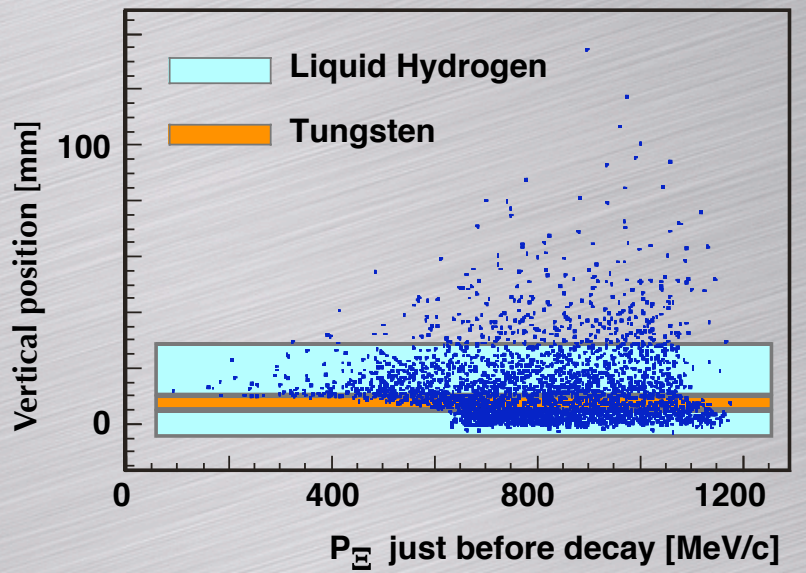
Polarization observables
(≈ Anti-symmetric spin-orbit)



Estimated Yields

- Target 5 cm wide × 20 cm long
  - A: production 1 cm
    Liq. Hydrogen
  - B: degrader 0.5 cm
    Tungsten
  - C: scattering 2 cm
    Liq. Hydrogen
- K^+ spectrometer
  - θ_spectrometer ~ 25° at center
- K^- beam (assumption @ LOI)
  - Intensity 10^7 K^-/sec
  - Momentum 1.7 GeV/c
  - Size σ_horizontal 15 mm
    σ_vertical 1 mm





		$\Xi^-p \rightarrow \Xi^-p$	$\Xi^-p \rightarrow \Lambda\Lambda$
• reaction rate	[s^{-1}]	0.009	0.0043
• 100 days		78000	37000
• Detectable number		2300	550

L08:

High-resolution Reaction Spectroscopy of S=-1 Hypernuclei

Y. Fujii, T. Fukuda, O. Hashimoto, H. Noumi, P.K. Saha, and T. Takahashi

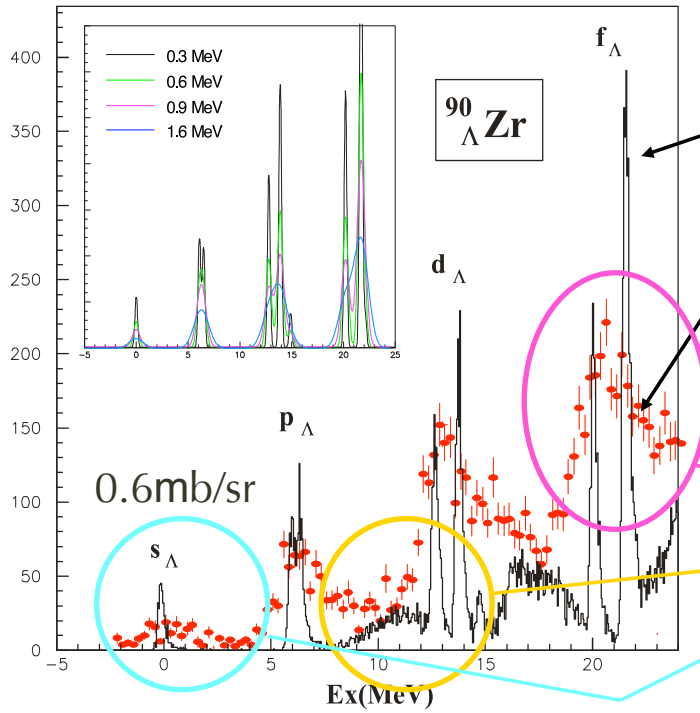
L09:

Neutron-Rich Λ Hypernuclei by the Double-Charge Exchange Reaction

T. Fukuda, H. Noumi, and P.K. Saha

Superfine Structure of Λ hypernuclei

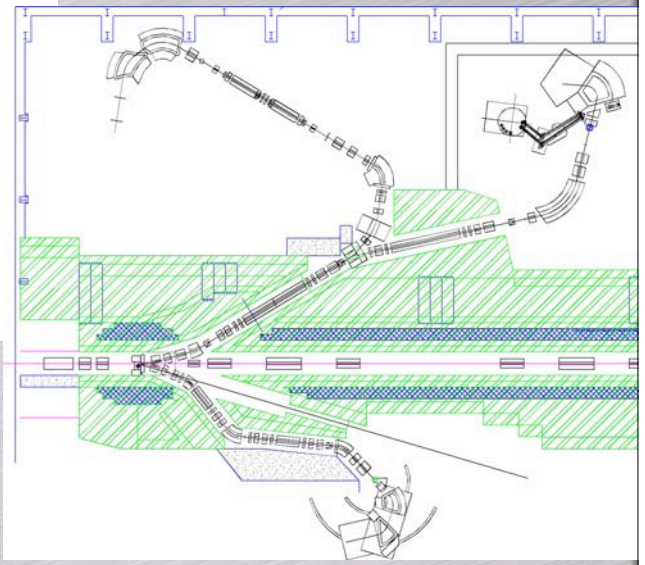
- *World of ΔE=0.2 MeV*



Simulation

E369 Data ($^{89}_{\Lambda}$Y)

Further decomposition of the states



L21: Weak decay measurement of light hypernuclei at J-PARC

Shuhei Ajimura, Osaka University

Nonmesonic decay of A=4, 5 hypernuclei

Allowed initial states for A=4, 5 hypernuclei

hypernucleus	$\Lambda n \rightarrow nn$	$\Lambda p \rightarrow np$
${}^{4}_{\Lambda}\mathrm{H}$	${}^{1}S_0, {}^{3}S_1$	${}^{1}S_0$
${}^{4}_{\Lambda}\mathrm{He}$	${}^{1}S_0$	${}^{1}S_0, {}^{3}S_1$
${}^{5}_{\Lambda}\mathrm{He}$	${}^{1}S_0, {}^{3}S_1$	${}^{1}S_0, {}^{3}S_1$

- $\Gamma_p({}^{4}_{\Lambda}\mathrm{H})$, $\Gamma_n({}^{4}_{\Lambda}\mathrm{He})$

$\Rightarrow$ we can measure ${}^{1}S_0$ amplitudes directly.

- If $\Delta I=1/2$ rule holds, $\Gamma_n({}^{4}_{\Lambda}\mathrm{He})/\Gamma_p({}^{4}_{\Lambda}\mathrm{H})=2$.

$\Rightarrow$ we can check the validity of the $\Delta I=1/2$ rule in B-B weak interaction.

Existing experimental results

$\Gamma_n({}^{4}_{\Lambda}\mathrm{He})/\Gamma_\Lambda = 0.01^{+0.04}_{-0.01}$ (KEK), 0.04 ± 0.02(BNL) NP A639(1998)261c

$\Gamma_p({}^{4}_{\Lambda}\mathrm{He})/\Gamma_\Lambda = 0.16\pm0.02$(KEK), 0.16 ± 0.02(BNL) NP A639(1998)251c

Detectors

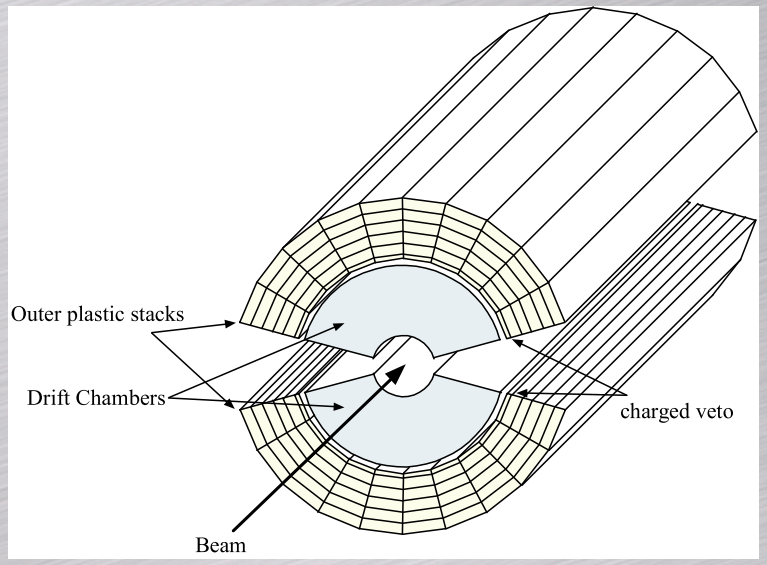
- Decay Counter System

  ΔE – E

  ΔE – TOF

  - thin plastic counter surrounding target(ΔE)
  - outer plastic stack(E)
  - tracking by DC
  - neutrons by TOF

- π0 Spectrometer: ΔE=2 MeV



Estimated Yields

	$^{4}_{\Lambda}$H	$^{4}_{\Lambda}$He	$^{5}_{\Lambda}$He
beam intensity	5×10^{6} K^-/3.4 sec	5×10^{6} K^-	1×10^{7} π^+
target thickness	0.125 g/cm^2	1.25	4
cross section	0.2 mb/sr	0.5	0.005
spectrometer acceptance	0.10 sr	0.05	0.03
spectrometer efficiency	0.8	0.5	0.5×0.5
decay counter acceptance	0.5	0.5	0.5
efficiency for decay p	0.8	0.8	0.8
efficiency for decay n	0.2	0.2	0.2
branching ratio (Ln→nn)	0.1	0.01	-
branching ratio (Lp→np)	0.01	0.1	0.2
nn events/200 shifts	10000	5500	-
np events/200 shifts	4000	220000	4000
expected error level	1.6%	1.5%	4%

Summary

- Strangeness Nuclear Physics Program
  - *Many interesting subjects are waiting for J-PARC*
  - Two LOIs (L06, L10) as Day-1 Experiments
  - At least, two K^- beam lines, K1.8 and K1.1BR, should be available at Day-1.
    - *most of the proposed experiments can be done with these beams.*
  - We will prepare new detectors, SKS', SPES-II, Hyperball-3, new CDS, etc.
- We are ready for Full proposals.