Where do we go from here ?

--- Summary of HYP2003 ---

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HYP2003
October 13-19, 2003
Jefferson Lab. , Virginia, USA

50 years of Hypernuclear Physics

Opening talks : Davis & Dalitz

The 1st stage Emulsion Era --- Rich information

1953 Discovery of Λ hypernuclei
CERN PS, BNL AGS K- beam

Λ potential depth about 2/3

The 2nd stage Early Counter Experiments CERN & BNL

1973 Stopped (K-,π-) at CERN
1974- in-flight (K-,π-) at CERN PS and BNL AGS

very small ls splitting

The 3rd stage New reactions, New detectors
BNL AGS & KEK PS

1985- (π^+,K^+) started at AGS
1990- S=-2 searches at AGS and KEK
Emulsion-counter hybrid technique
1993- S=-1 Λ Spectroscopy, Weak decay,
SKS spectrometer
1998- γ ray spectroscopy (Hyperball)

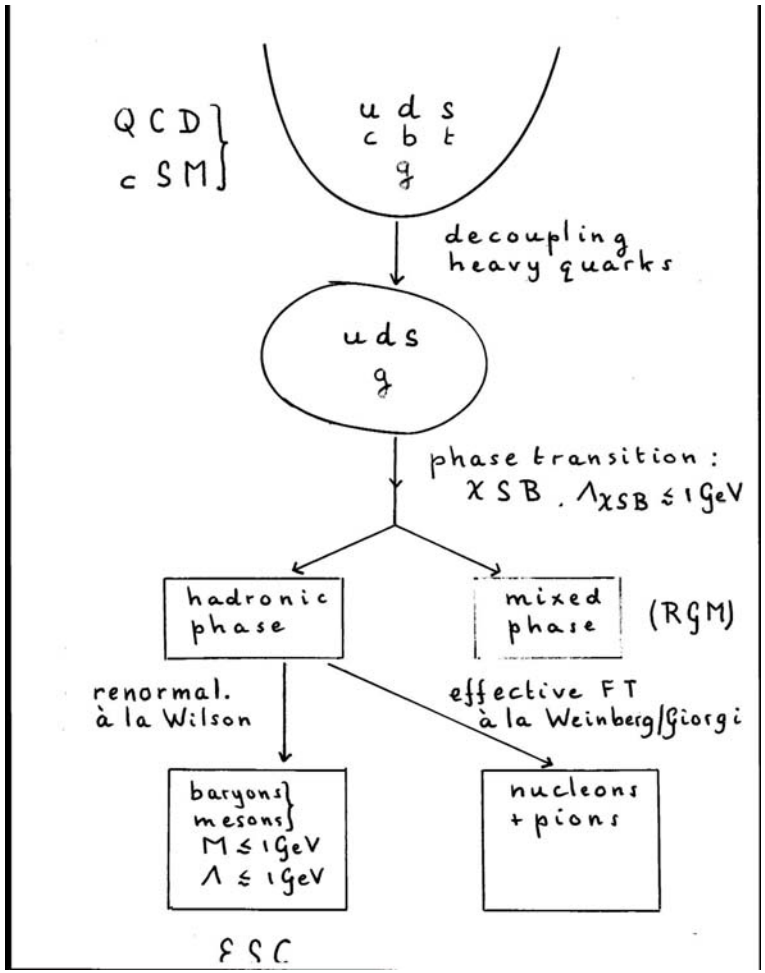
Transition to the 4th stage

HYP series

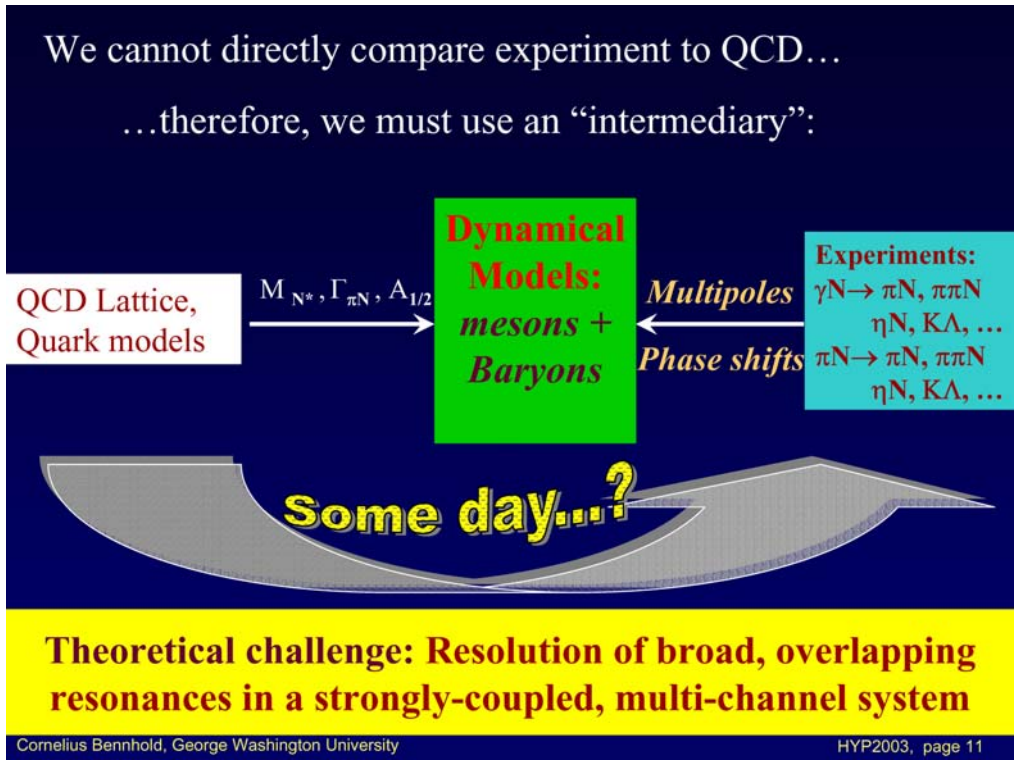
- 1982 Heidelberg, Germany,
- 1985 BNL, USA, September
- 1988 Padova, Italy, September
- 1991 Shimoda, Japan, December
- 1994 Vancouver, Canada, July
- 1997 BNL, USA, October
- 2000 Torino, Italy, October
- 2003 Jlab, USA, October
- 2006 Europe……..

Hypernuclear and strange particle physics

Rijken's view



Bennhold's view



Significance of hypernuclear investigation

- New structure of hadronic and/or quark many-body system with strangeness quantum number
  - Nuclear structure of deeply bound states
  - Baryon structure in nuclear medium
  - New form of nuclei, matter...
- Hyperon-nucleon interaction(B-B strong interaction)
  - On the basis of flavor SU(3)
  - Hyperon scattering experiment limitted
  - Spectroscopic information indispensable
- Weak interaction in nuclear medium
  - Nonmesonic decay -- B-B weak inter.action

Where are we now ?

--- Personal choice of Highlights --

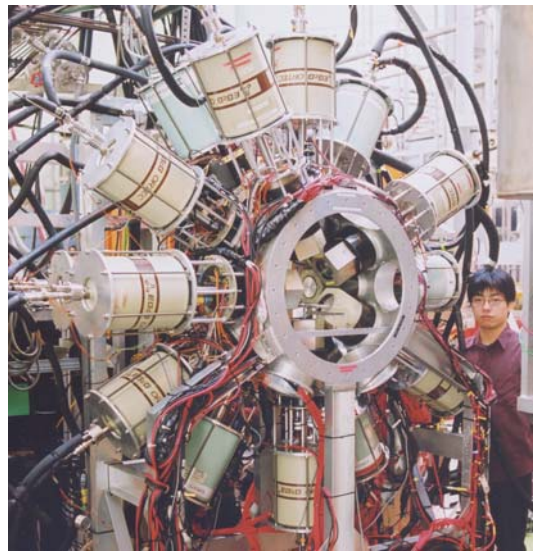
- Hypernuclear spectroscopy
  - Structure calculations
  - **γ-ray spectroscopy**
    - Spin-spin, spin-orbit, **tensor interaction**
    - First γ–γ coincidence data
  - New (e,e'K+) spectroscopy
- Multistrangeness
  - **Nagara event**
- **Γn/Γp puzzle** in nonmesonic weak decay
  - pn and np correlation measurement
  - Advanced theoretical calculation
- **Pentaquark**
  - Many Labs confirm the pentaquark peaks first observed at RCNP
- Electrophoto production of strangeness on nucleons and nuclei
  - Thorough data from Jlab, ELSA, GRAAL
- K- nucleus potential
  - Deep or shallow

Hypernuclear structure and spectroscopy

Spectroscopic data

Reaction spectroscopy(π,K),(K,π),(K-,K+)…
γ-ray spectroscopy with HYPERBALL

Tamura,…..



Structure calculation

Millener

Akaishi Motoba

Nogga Hiyama

Baryon-baryon interaction
Hyperon-nucleon interaction

Rijken

Phenomenological potential updated

Nijmegen ESC02, 03

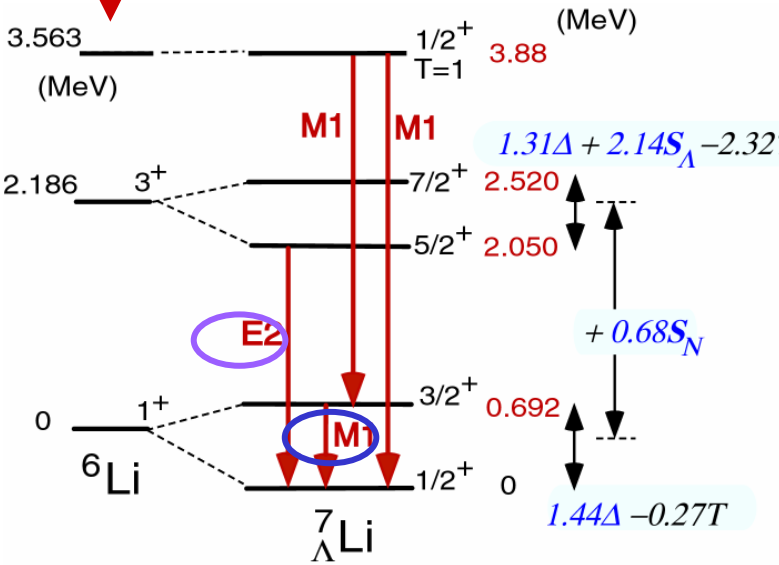
$$V_{\Lambda N}^{eff} = V_0(r) + V_\sigma(r)\,\vec{s}_\Lambda\vec{s}_N + V_\Lambda(r)\,\vec{l}_{\Lambda N}\vec{s}_\Lambda + V_N(r)\,\vec{l}_{\Lambda N}\vec{s}_N + V_T(r)\,S_{12}$$

Δ S_Λ S_N T

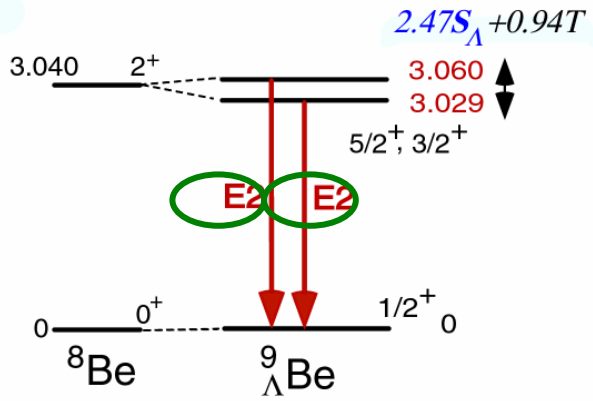
Millerner

p-shell : 4 radial integrals for p_N s_Λ w.f.

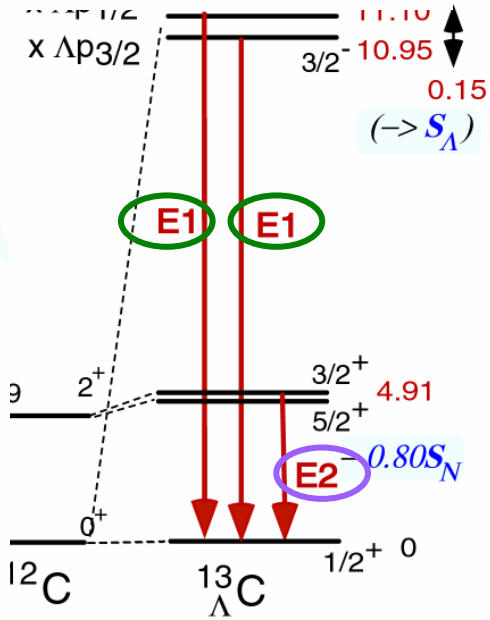
observed



KEK E419



BNL E930



BNL E929 (NaI)

-> Δ = 0.50 MeV
S_N= -0.4 MeV

-> $|S_\Lambda| < 0.03$ MeV
very small LS force

-> B(E2) = 3.6 ±0.5 ±0.5 e^2fm^4
Shrinkage of 19 ±4%

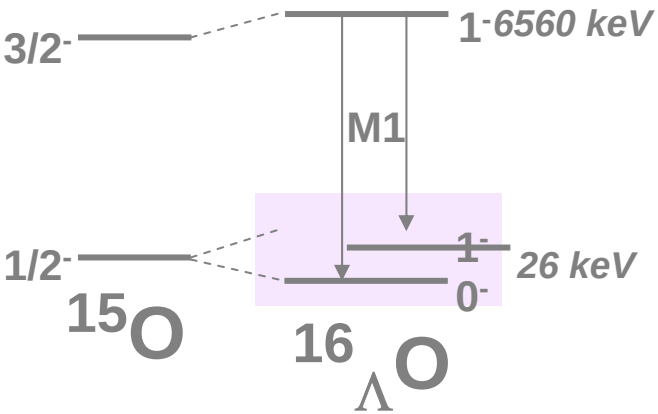
Tamura

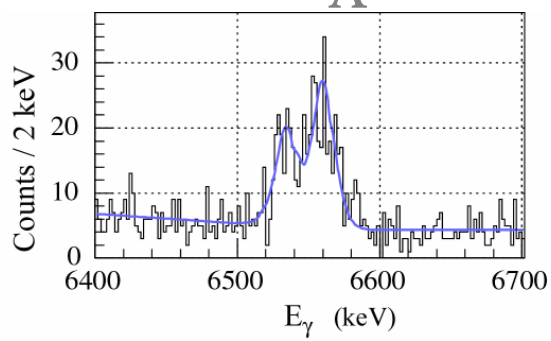
T: no experimental data in HYP2000

New results from γ-ray spectroscopy

(1) ΛN Tensor component

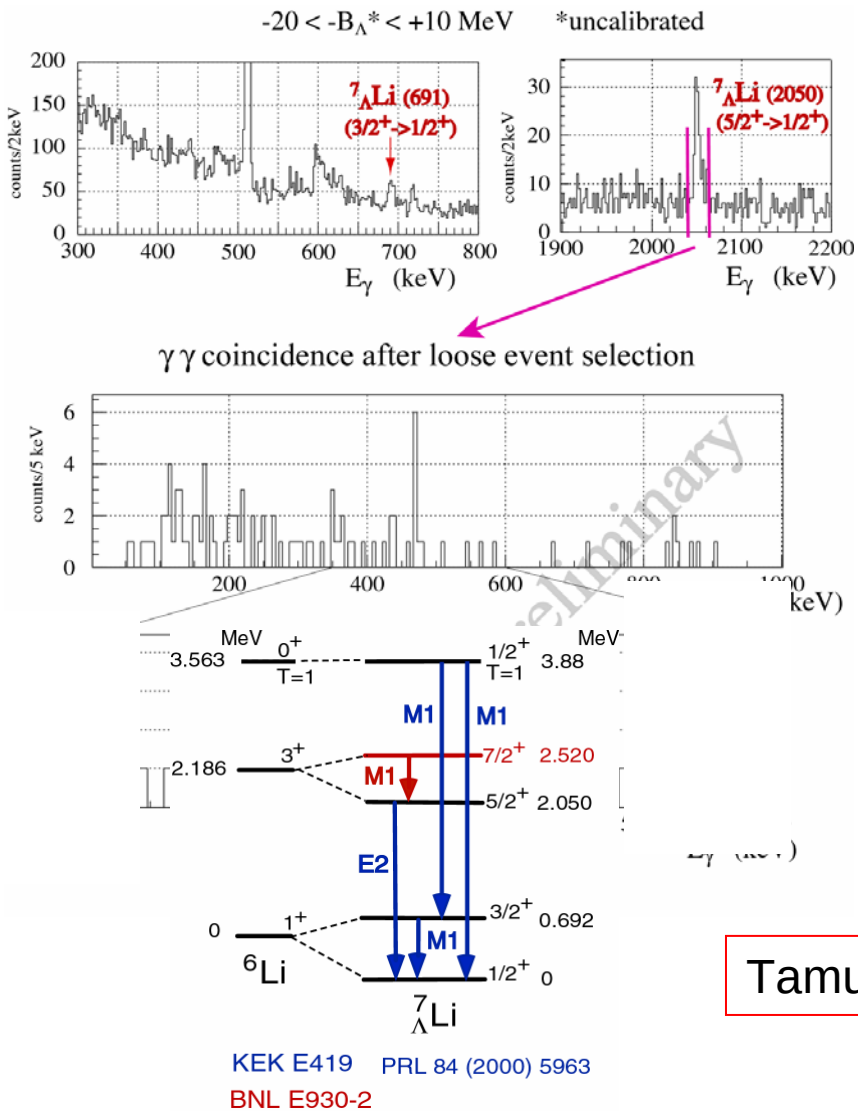
-> T ~ 30 keV (prelim.)





OBEP predictions agree with the experimental value.

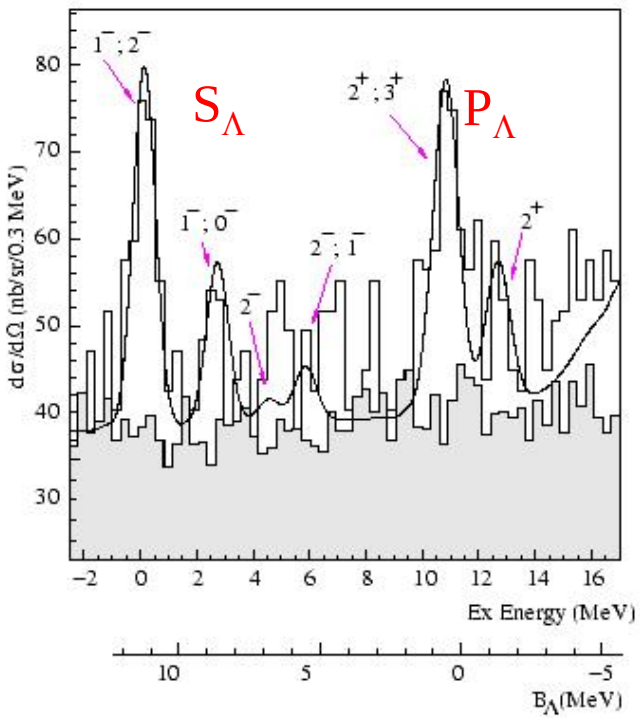
(2) First γ–γ coincidence



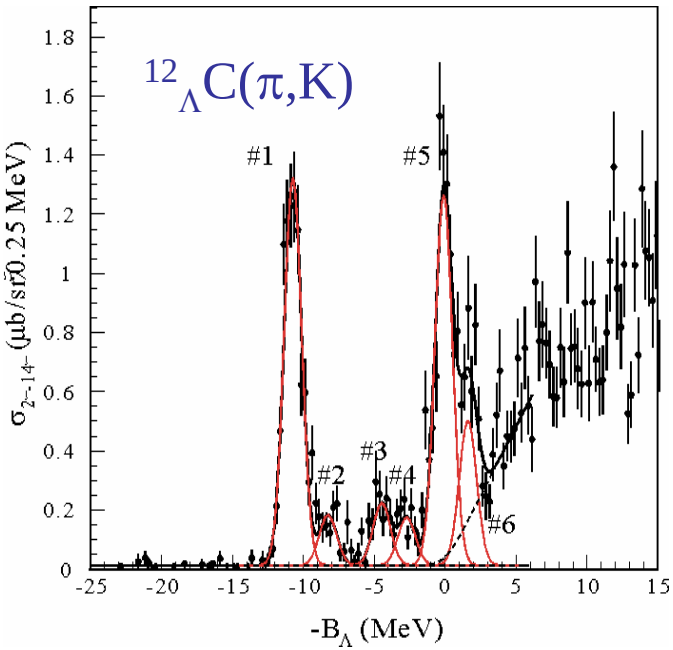
Tamura

The (e,e'K+) Hypernuclear spectroscopy

JLAB E89-009



KEKE369



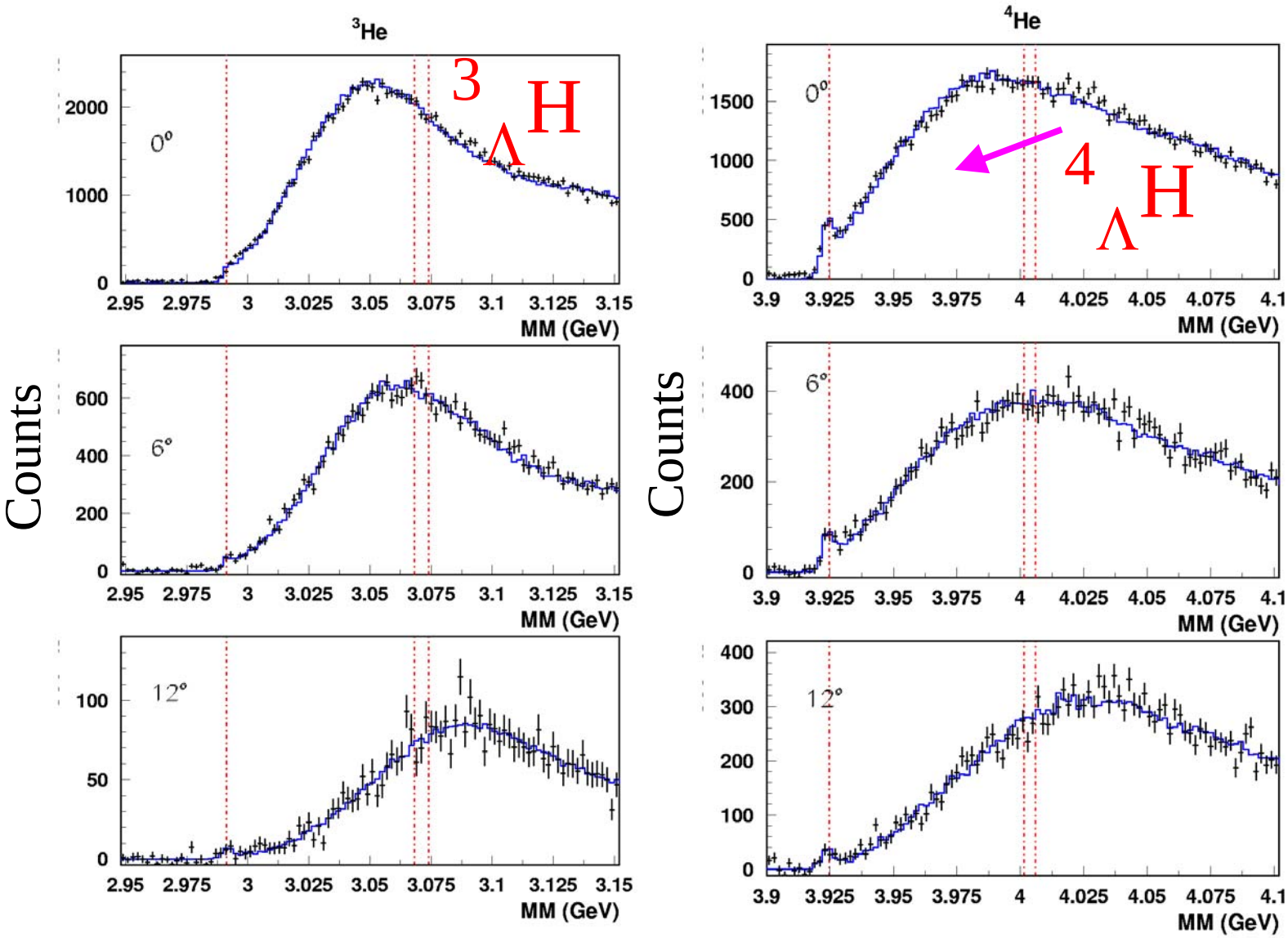
New hypernuclear spectroscopy →

FINUDA	Bressani,Zenoni
JLAB HALL A	Garibardi
JLAB HALL C(HKS)	Nakamura
MAMI C	Pochodzalla

^{3,4}He(e,e'K$^+$)

Markowitz

Reinhold



ΛΣ coherent coupling

The overbinding problem of $^{5}_{\Lambda}\mathrm{He}$

has been virtually solved.

Akaishi

ΛNN force

Repulsive/attractive : “D0 picture”

Attractive : “D2 picture”

Coherent Λ-Σ coupling is essential dynamics.

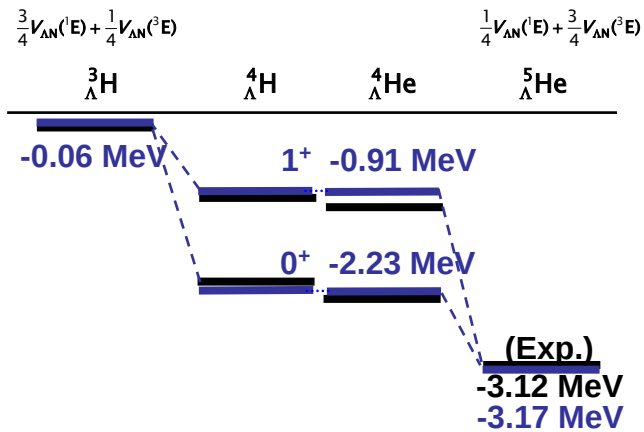
$$^{4}_{\Lambda}\mathrm{He}(0^{+}) - {}^{4}_{\Sigma}\mathrm{He}(0^{+})$$

Λ_{coh}(Λ-Σ^0 mixing) in dense neutron matter

Neutron-rich hypernuclei could provide additional evidences for coherent Λ-Σ coupling.

$$^{6}\mathrm{Li}(\pi^{-},K^{+})\,^{6}_{\Lambda}\mathrm{H}$$

The Overbinding Problem



H. Nemura: D2’+ Minnesota

Hypernuclear weak decay

Unique place to study baryon-baryon weak interaction

Neutron- to proton-induced nonmesonic weak decay

Γ_n/Γ_p puzzle

Experiments

Large Γ_n/Γ_p ratio > 1

- Precision measurements of proton & neutron singles spectra
  - Ambiguities from FSI & 1N/2N processes
- pn and nn correlation measurement
  - Select ΛN → NN process

Bhang

Outa

Theory

Small Γ_n/Γ_p ratio < 0.2

- Heavier meson exchange
- Direct quark exchange

Oka

Parreno

Garbarino

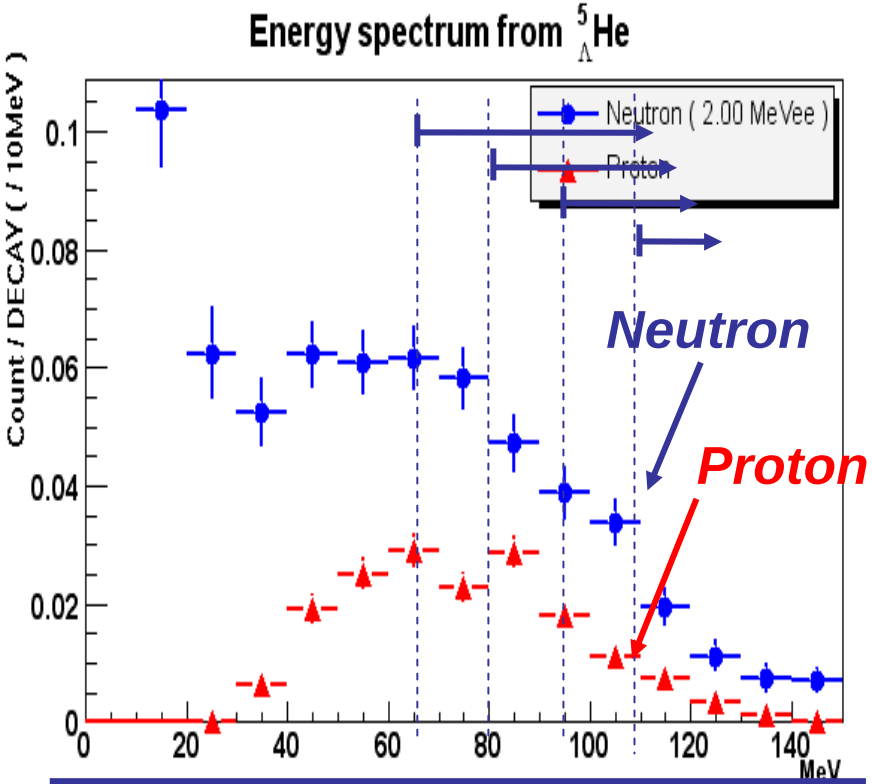
$\Gamma_n/\Gamma_p \sim 0.5$

Happy merging

But, asymmetry

- Experimental asymmetry parameters are small
- ΛNN process ?

Neutron and Proton Energy spectra from $^{5}_{\Lambda}$He



N_n / N_p (E>50MeV) ~ 2.35±0.14±0.30

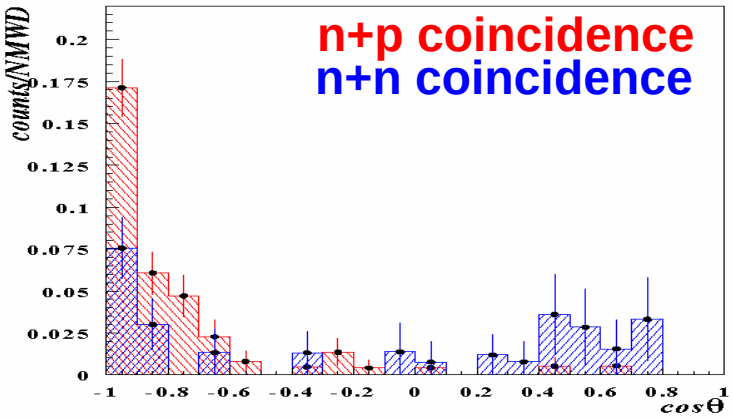
Naive estimation :

$N_n/N_p = 2\times\Gamma_n/\Gamma_p + 1$

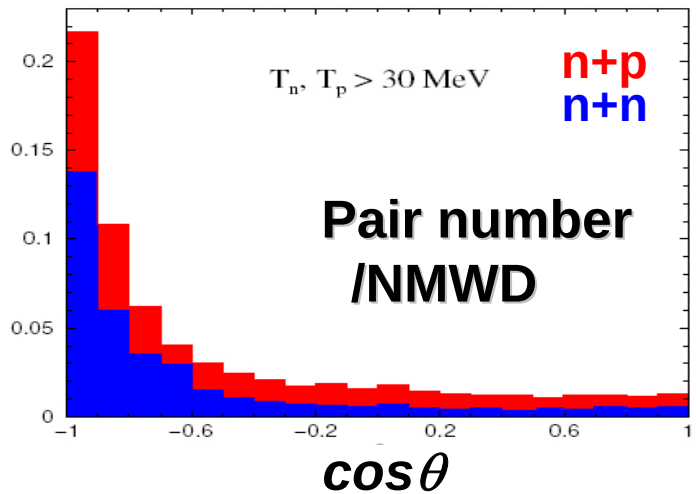
Γ_n / Γ_p ~ 0.6 ?

$^{5}_{\Lambda}$He (E462)

experimental data



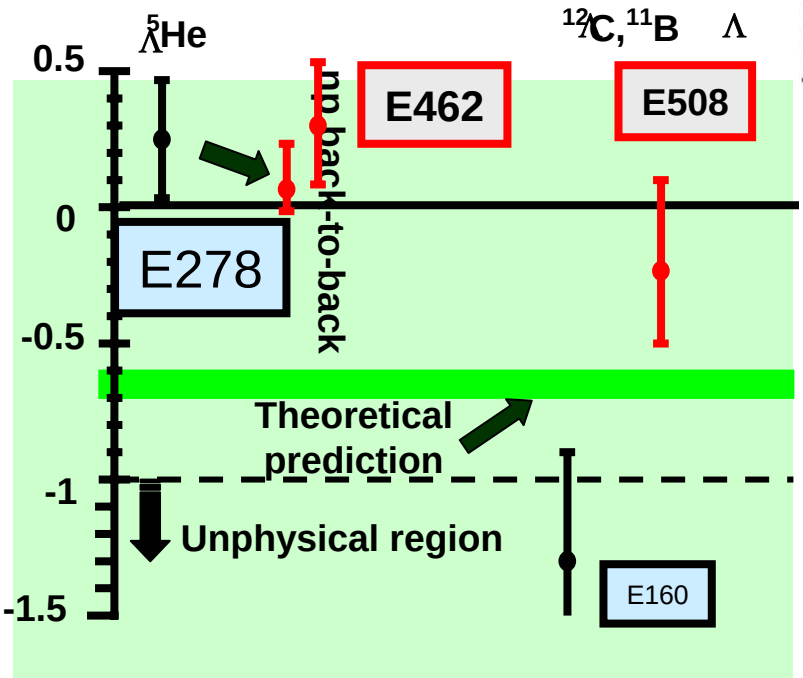
theoretical calc.

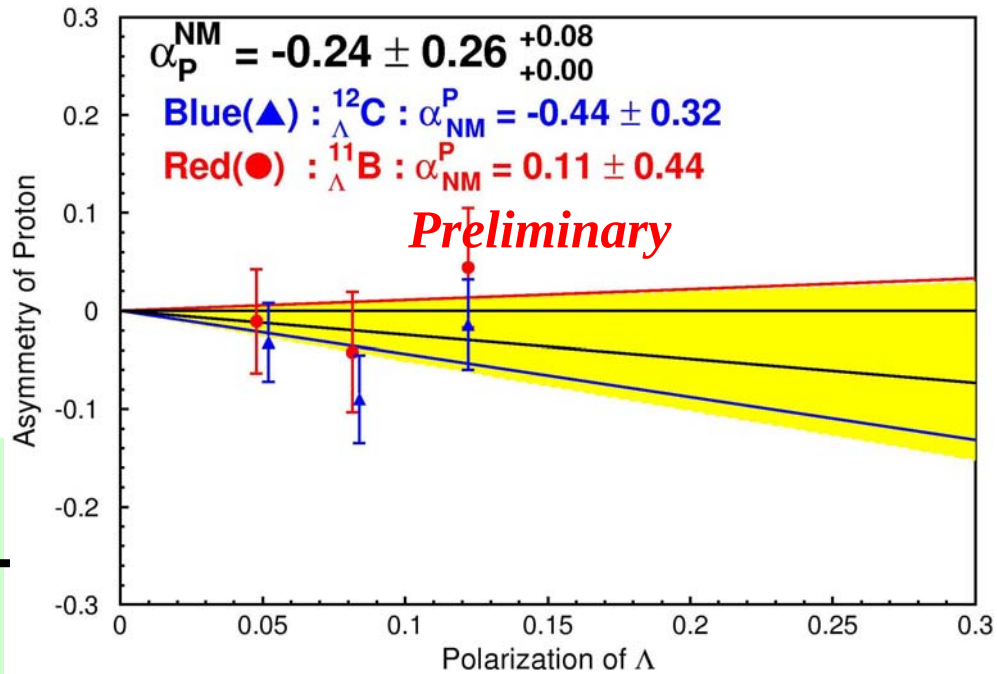


$^{5}_{\Lambda}$He (E462) : 0.44±0.11±0.03

Asymmetries

Bhang





$$\alpha^{NM} = -0.24 \pm 0.26\ ^{+0.08}_{+0.00}$$

Blue : $^{12}_{\Lambda}$C : $\alpha^{NM} = -0.44 \pm 0.32$

Red : $^{11}_{\Lambda}$B : $\alpha^{NM} = 0.11 \pm 0.44$

Issues that remain in hypernuclear weak decay

OKA

- Asymmetry
- ΔI =1/2 violation

  $\Gamma_{NM}({}^{4}_{\Lambda}\mathrm{H})$ is critical.

  π^+ decay is discriminative.
- Σ mixing $\quad \Lambda N \rightarrow \Sigma N \Rightarrow NN$

  Ξ mixing $\quad \Lambda\Lambda \rightarrow \Xi N, H \Rightarrow YN$

- $\Gamma_{YY} / \Gamma_{YN}$ ratio J = 0 amplitude

  Are they really small and negligible?

Multi-strange system and beyond

Gal

- S=-2
- Neutron star
- Strangeness in hot/dense matter
  Strangeness enhancement
- Strangelets/Exotics search

Nakazawa Pile Kahana

Bombaci

Koch

Long

Lu

Lampha and $B_{\Lambda\Lambda}$

Nakazawa

NAGARA event

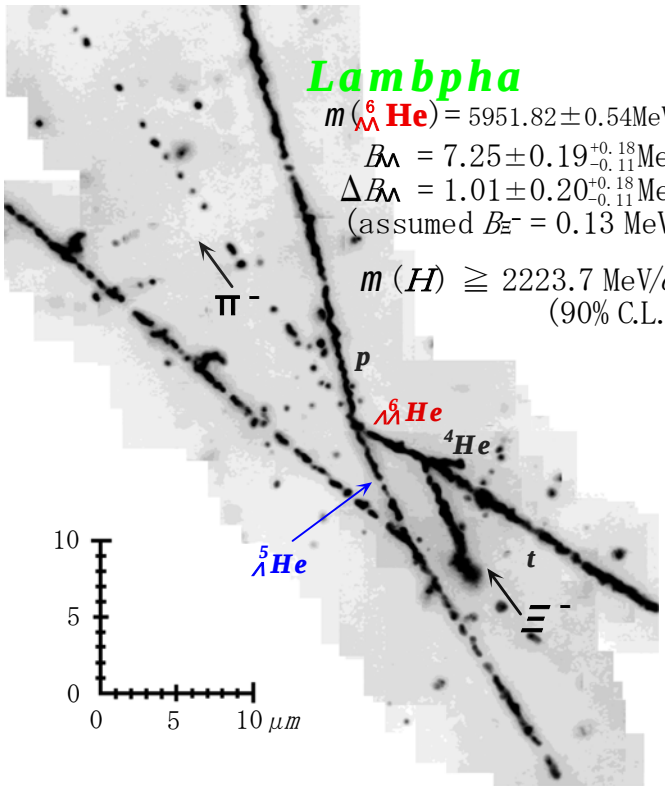
$^{6}_{\Lambda\Lambda}$He double-hypernucleus

Unique interpretation!!

$\Xi^- + {}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$

${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$

H.Takahashi et al.,
P. R. L. 87, 212502(20



Lambpha

$m(^{6}_{\Lambda\Lambda}He) = 5951.82 \pm 0.54$MeV

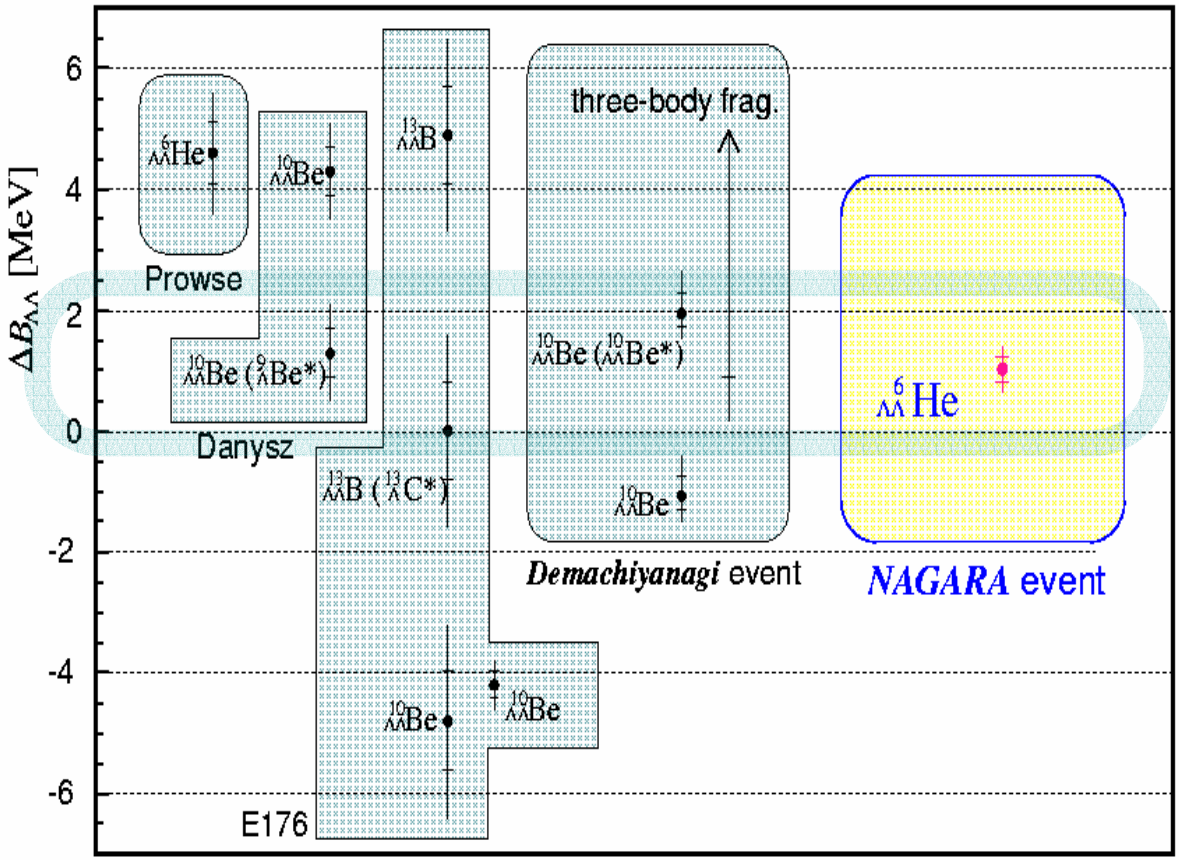
$B_{\Lambda\Lambda} = 7.25 \pm 0.19^{+0.18}_{-0.11}$MeV

$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}$MeV

(assumed $B_{\Xi^-} = 0.13$ MeV)

$m(H) \geqq 2223.7$ MeV/c^2

(90% C.L.)

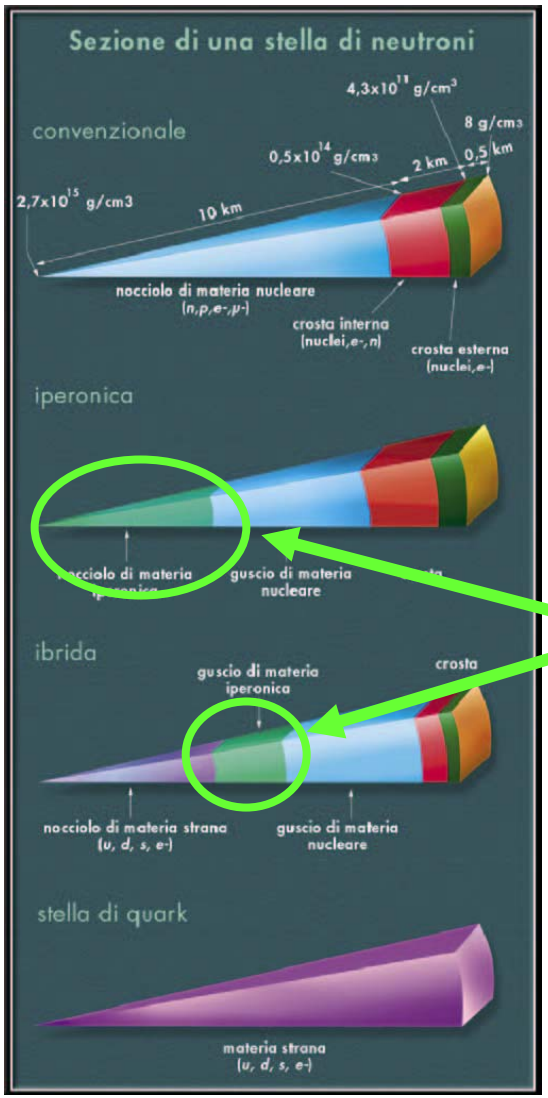


ΛΛ interaction is attractive but weak

$^{4}_{\Lambda\Lambda}H$ Need confirmation

Compact stars

Bombaci



Biggest nuclear system with strangeness

$M_{max} < 1.44\ M_{solar}$

Conventional neutron star

Hadronic star

Hyperon star

HYPERON

Hybrid star

Strange star

EOS with strangeness degree of freedom

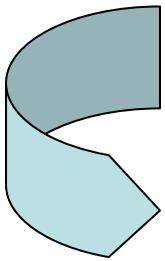
Hyperons make compact stars softer
Need extra pressure

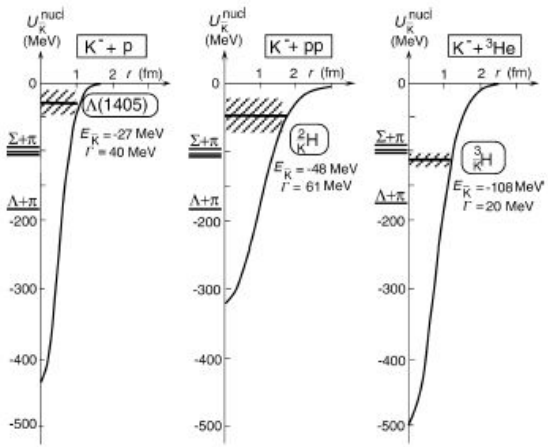
Stringent constraint
YN, YY, YNN interaction
KN interaction
$\Lambda\Sigma$ mixing

K-Nucleus Interaction

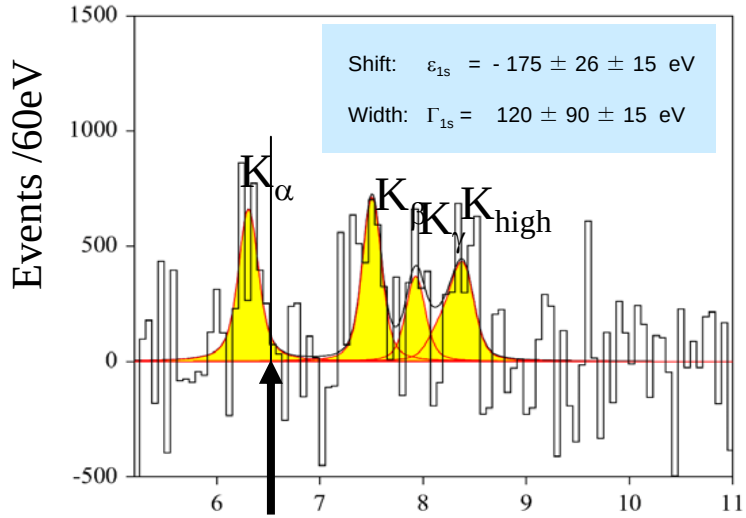
KN Interaction strongly attractive in I = 0 channel
(From Kaonic X ray data)

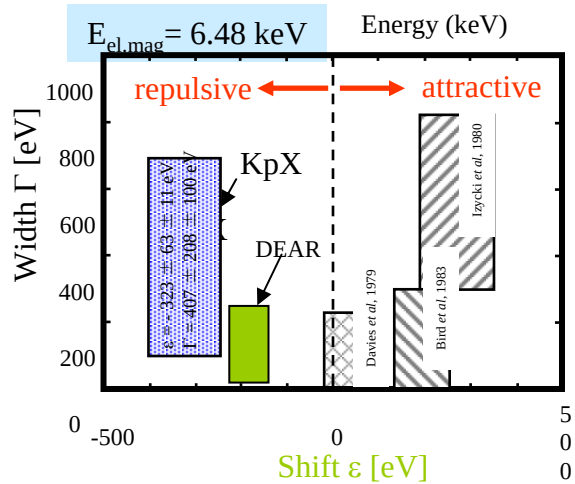
- Shallow ~ −80~40 MeV
  Gal,Ramos,Oset,……...
- Deep ~ −200 MeV
  Akaishi, Yamazaki.





DEAR DATA Zmeskal





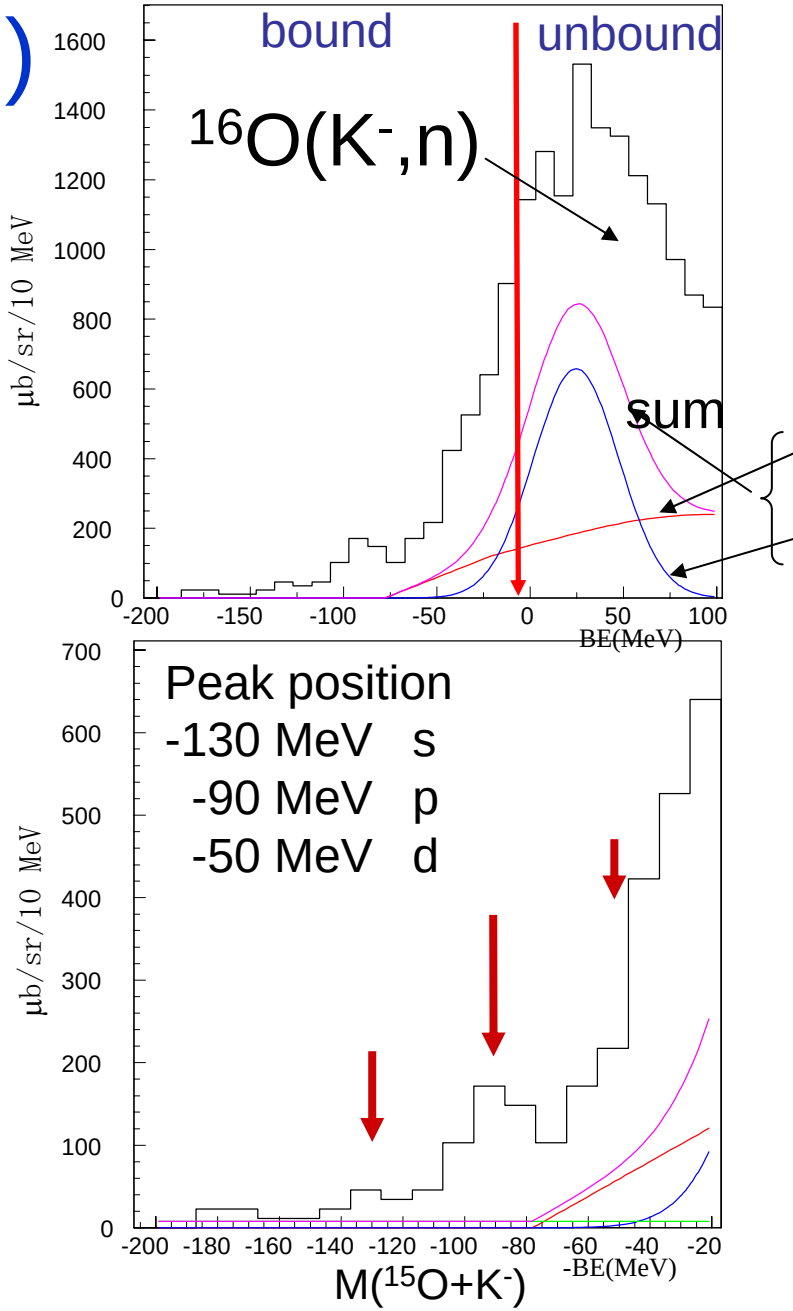
Deeply bound K-Nucleus states ?
High-density nuclear matter ?
Kaon condensation in neutron stars ?

Kaonic bound states ? (1)

(1) ^{16}O(K-,n)X

Kishimoto

- BNL AGS E930 parasite
- Strength extended to –120 MeV
- Potential depth ~ 170 MeV



Kaonic bound states ? (2)

(2) ^{4}He(K-stopped,n)X Suzuki

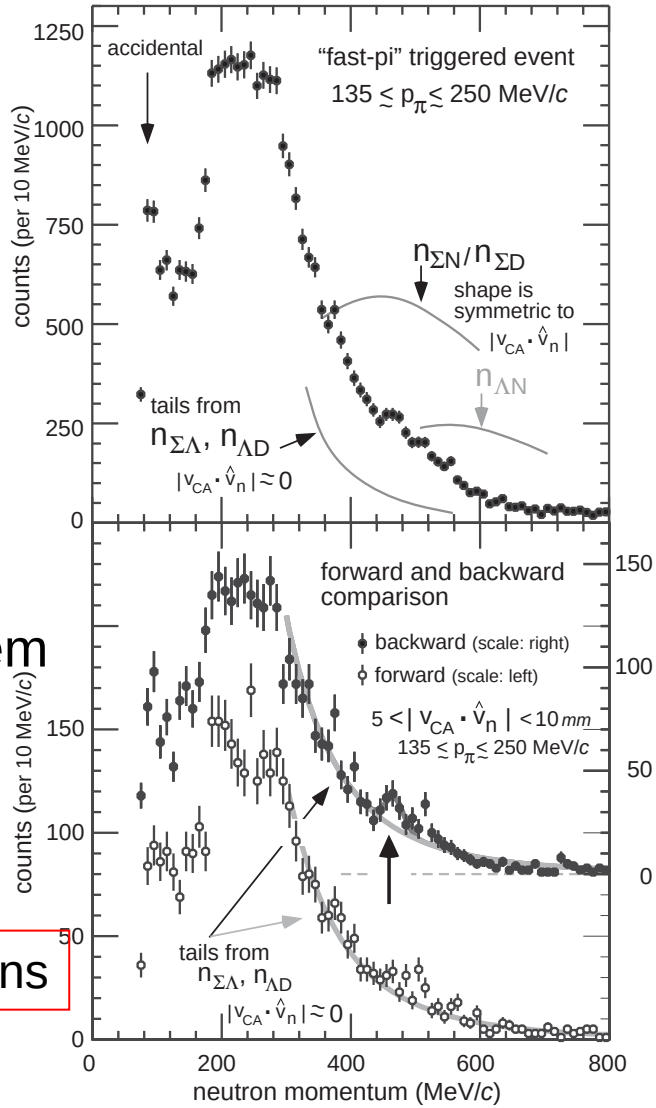
-- KEK PS E471

-- Evidence for strongly bound system

-- B_{Kpnn} = 173 MeV, Γ_{Kppn} < 25 MeV

Need careful examination of data

Expected to arouse further heated discussions



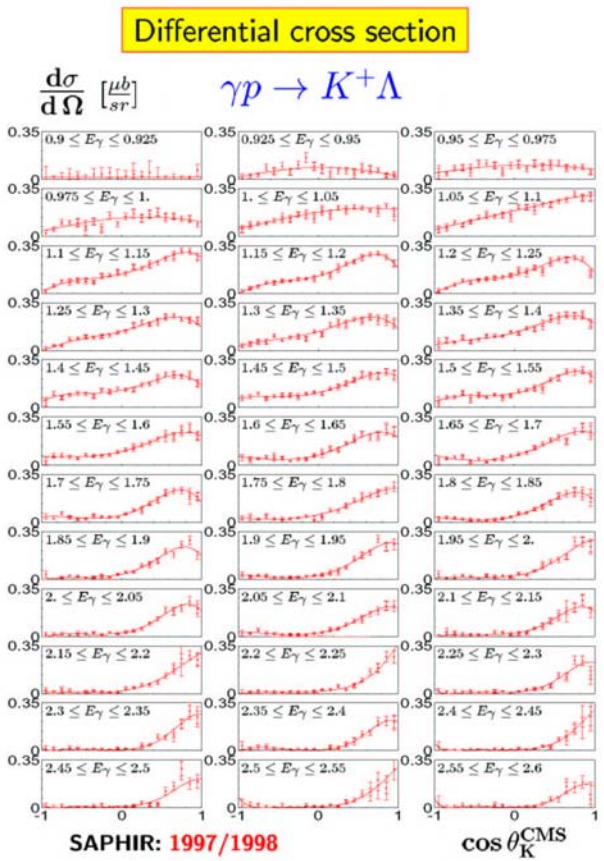
Electromagnetic production of strangeness

Missing resonances

Stronger coupling to the strangeness sector ?

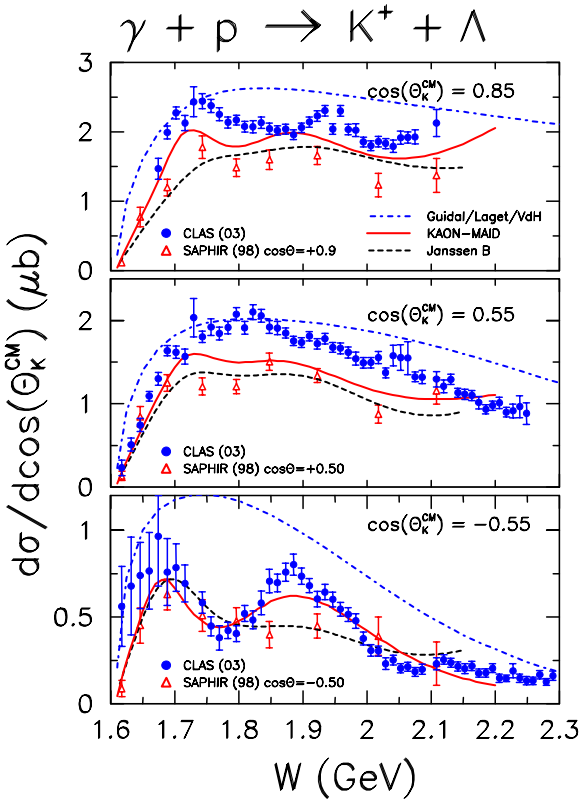
Bennhold			
Carman	Markowitz	Reinhold	Jlab
Sumihama			Spring8
Glander			Saphir
Manley			Crystal ball
Price	$\gamma p \rightarrow K^+K^+\Xi^-$		

Strangeness photoproduction



SAPHIR

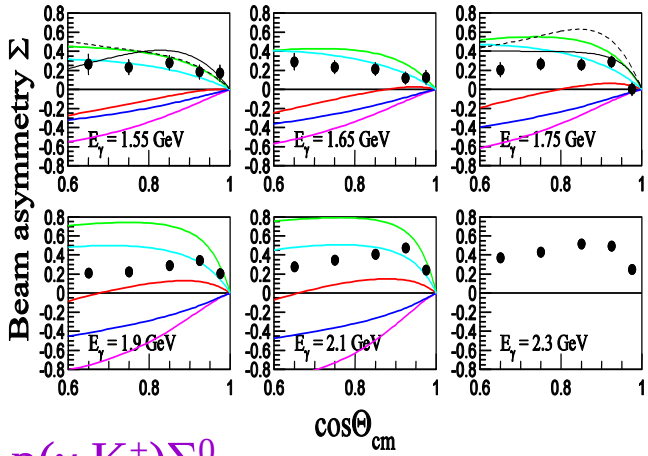
Glander



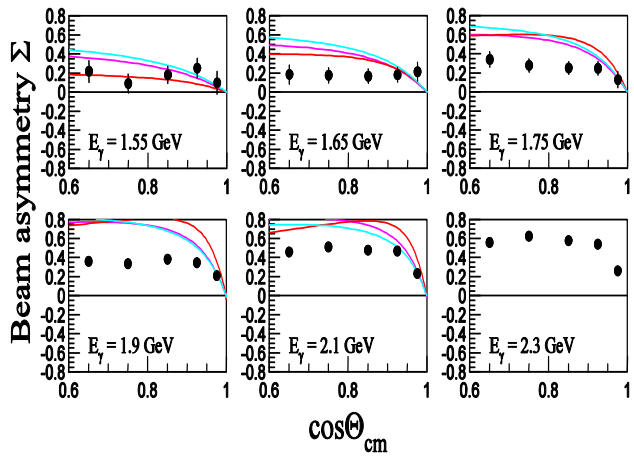
CLAS

Carman

$p(\gamma,K^+)\Lambda$



$p(\gamma,K^+)\Sigma^0$



Spring8 LEPS

Sumihama

Pentaquark

Imai

1. RCNP 1.54 $\pm$ 0.01 GeV width < 25 MeV
   $\gamma + n(^{12}C) \rightarrow K^+ + K^- + n$ at forward angles

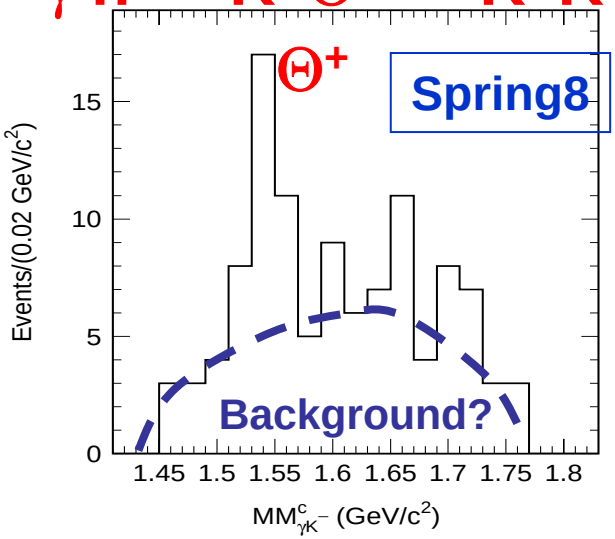
2. ITEP K^+Xe scattering
   K^0p invariant mass in the charge exchange $K^+n \rightarrow K^0p$ reaction

3. Jlab CLAS 1.548 MeV
   1. $\gamma + d \rightarrow p+K^++K^-+(n)$
   2. $\gamma + p \rightarrow \pi^+ + K^- + K^+ +(n)$
4. Saphir/ELSA 1540 MeV, <25 MeV
   $\gamma + p \rightarrow \pi^+ + K^- + K^- + n$

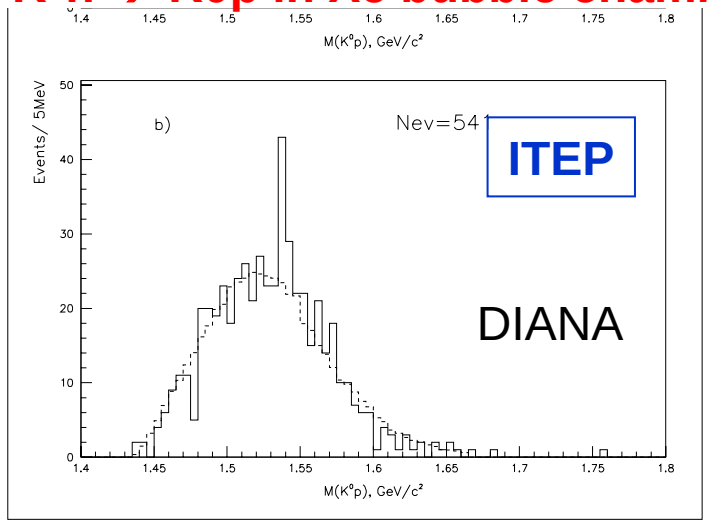
5. Neutrino scattering 1533 MeV, <20 MeV

Pentaquark in various channels

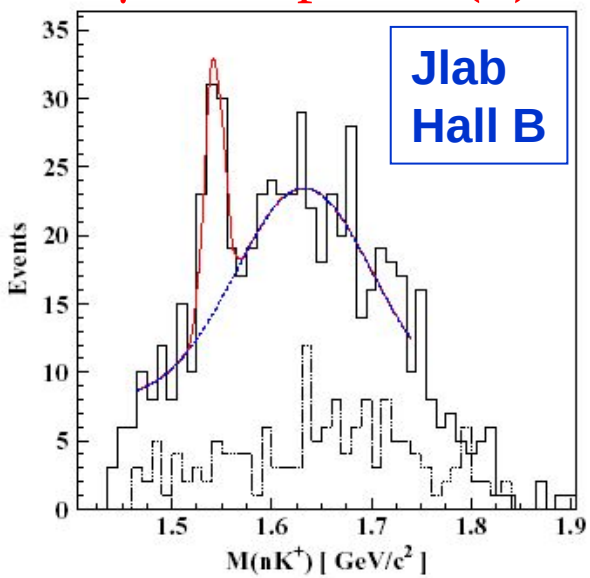
$\gamma\, n \rightarrow K^- \Theta^+ \rightarrow K^- K^+ n$



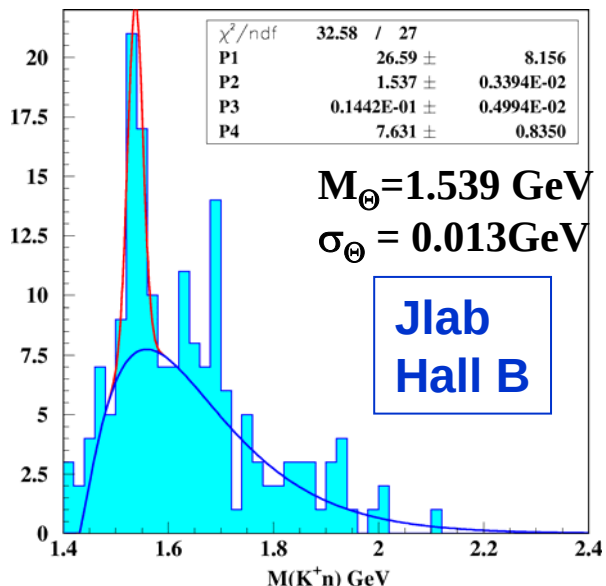
$K^+n \rightarrow K0p$ in Xe bubble chamber



$\gamma D \rightarrow pK^-K^+(n)$

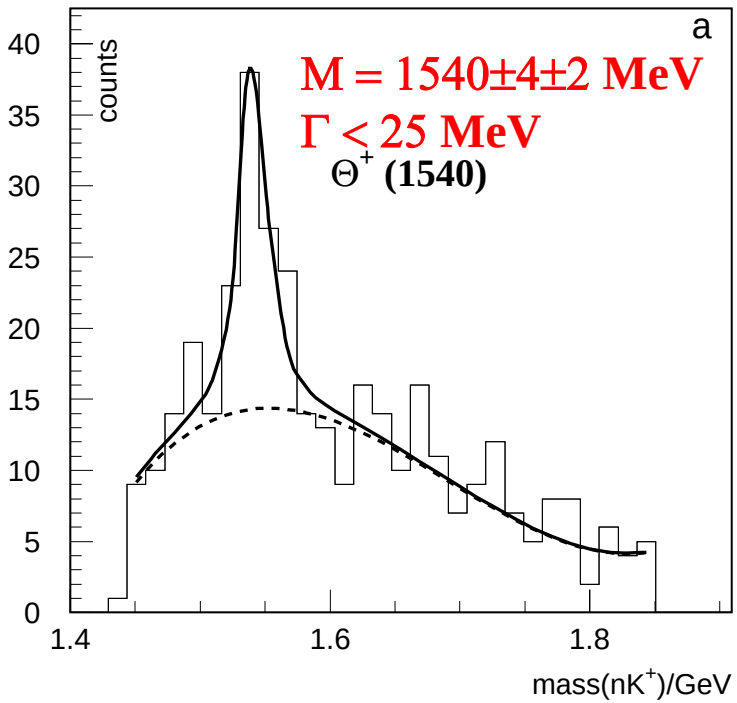


$\gamma p \rightarrow \pi^+K^-K^+(n)$



More data on pentaquark

$\gamma + p \rightarrow p+ + K- + K- + n$

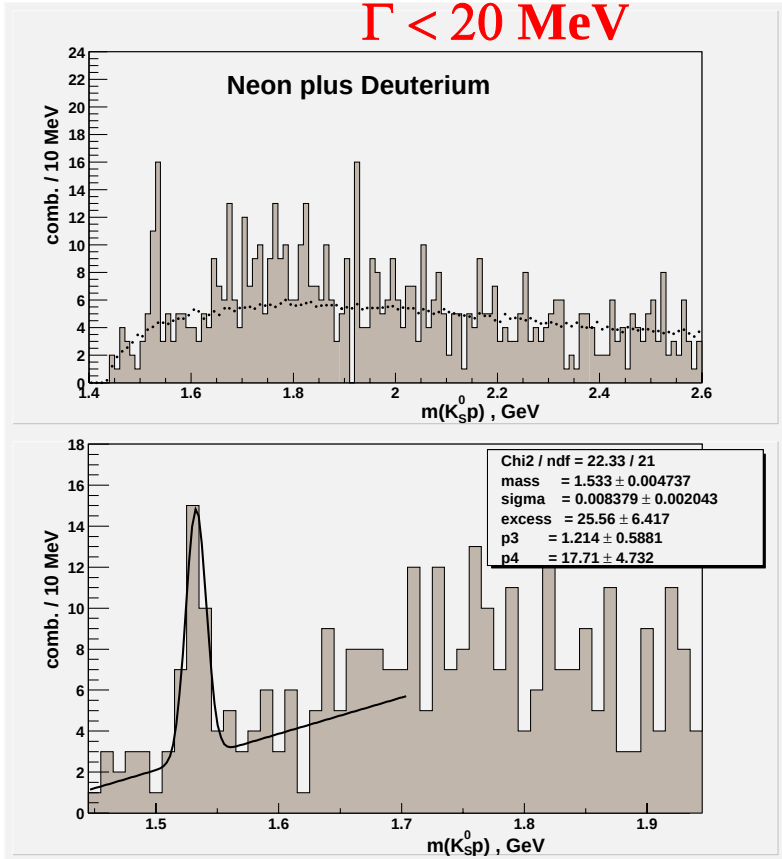


SAPHIR/ELSA

hep-ex/0307083

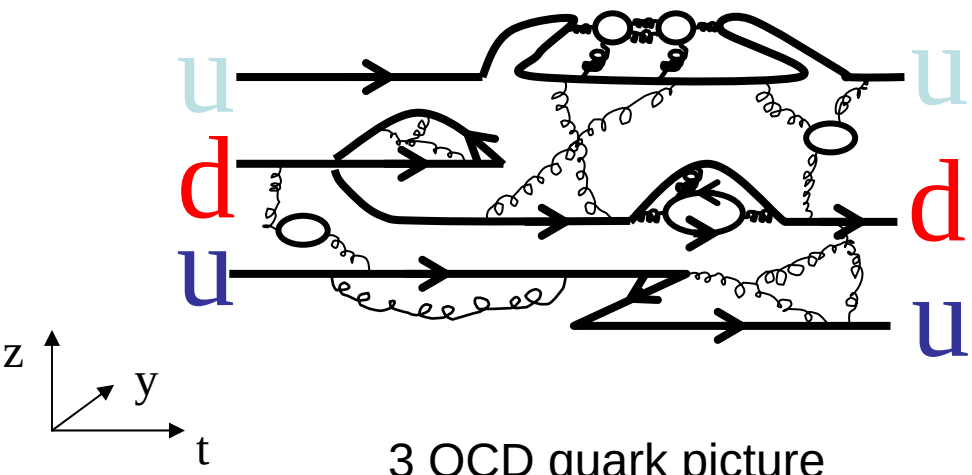
M = 1533± 5 MeV

Γ < 20 MeV



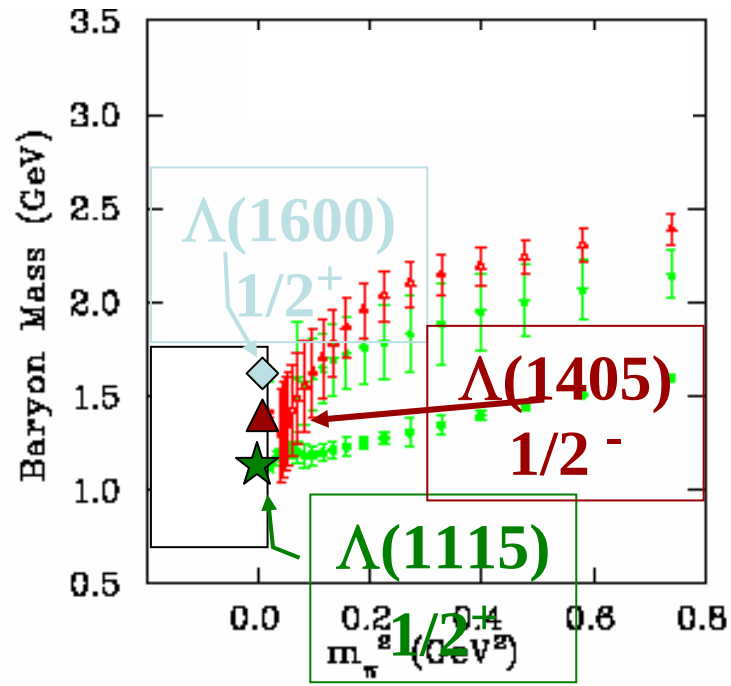
Neutrino scattering

Lattice QCD



3 QCD quark picture

Lee



3 QCD quark framework reproduce Roper and Λ(1405)

Pentaquark --- positive parity around 1.5 GeV not reproduced

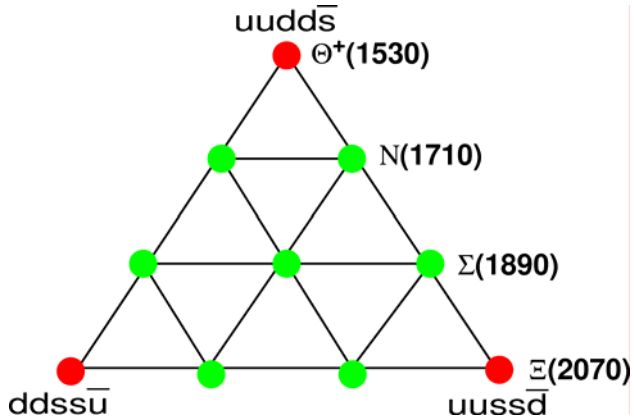
What drives physics behind ?

Θ^+, Pentaquark

Chiral soliton model predictin : D. Diakonov, M. Petrov, M. Polyakov

uudds : lightest member of antidecuplet baryons ?

1. Spin parity assignment
   Phase shift analysis
   → Oset K+p → p+K+n
2. Measure the width, narrow
   Difficult to explain by theories
3. Other members of antidecuplet
   Ξ^{--}, Ξ^+



Pentaquark workshop
November at Jlab

Search : $\gamma + p \rightarrow K^+ + K^+ + \pi^+ + \Xi^{--}$ Price

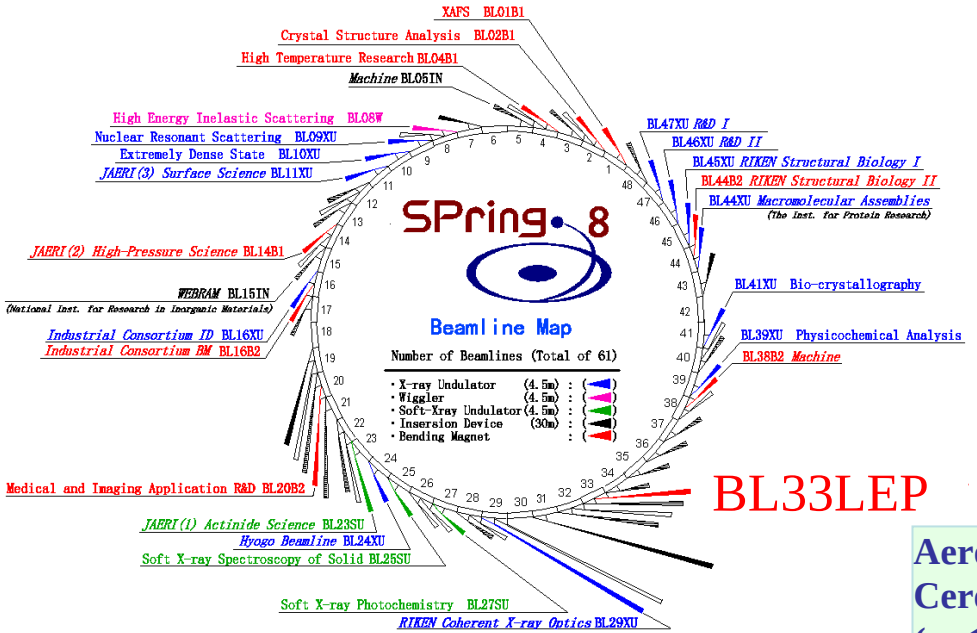
→ Birth of exotic hadron spectroscopy Imai

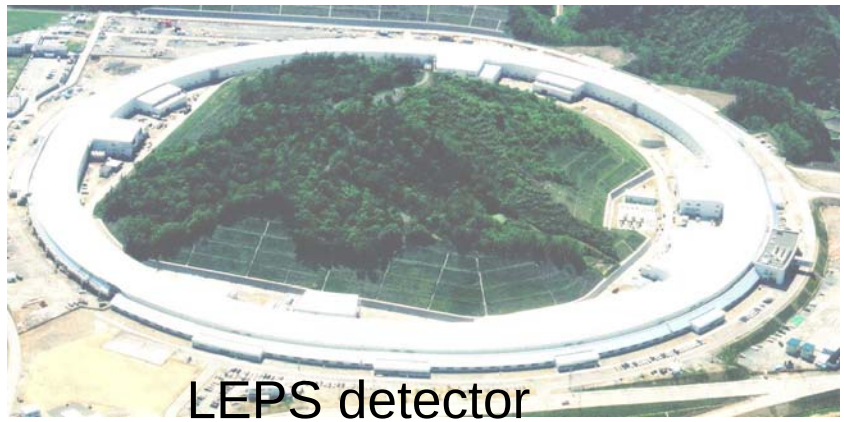
Experimental opportunities for hypernuclear and strange particle physics(1)

Electromagnetic beam

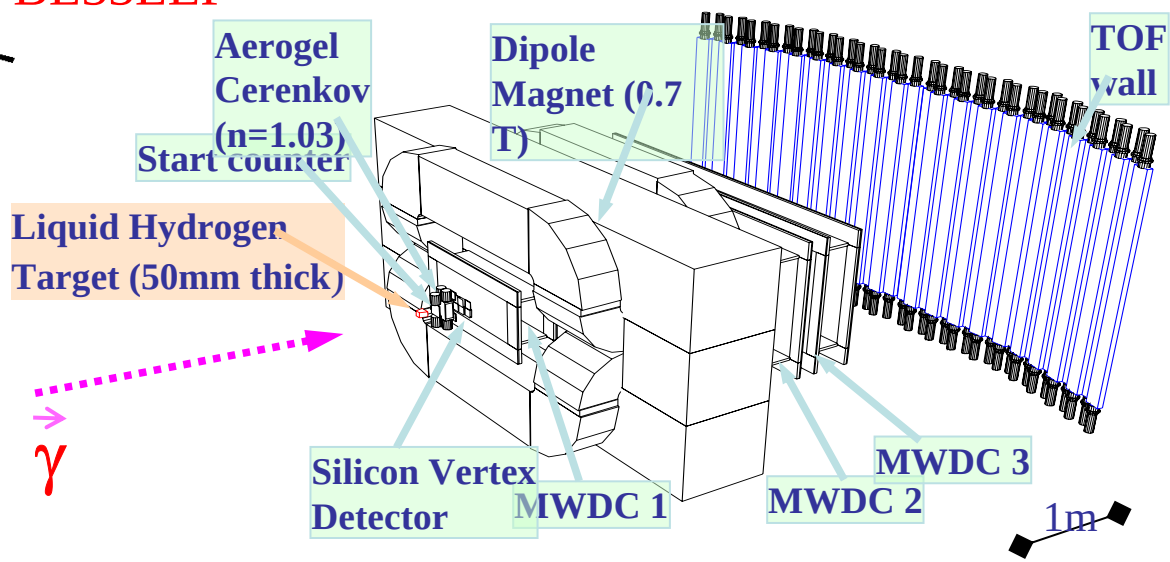
• Spring8 *	8 GeV
• GRAAL*	6 GeV
• ELSA	3.5 GeV
• LNS, Tohoku	1.2 GeV
• Jlab HALL A,B,C	6 GeV →
• DAΦNE & DAΦNEII	0.51+0.51 GeV
	→ 1.05+1.05 GeV
• MAMIC	1.5 GeV

SPring-8(Super Photon ring-8 GeV)





BL33LEP



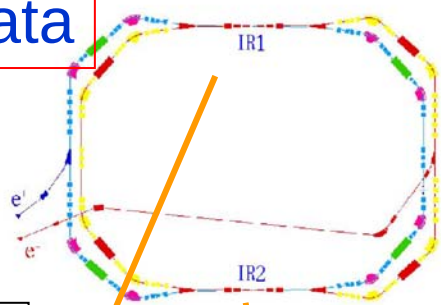
FINUDA Detector
for Hypernuclear Physics

$e^+ e^- \rightarrow \phi \rightarrow K^+ K^-$

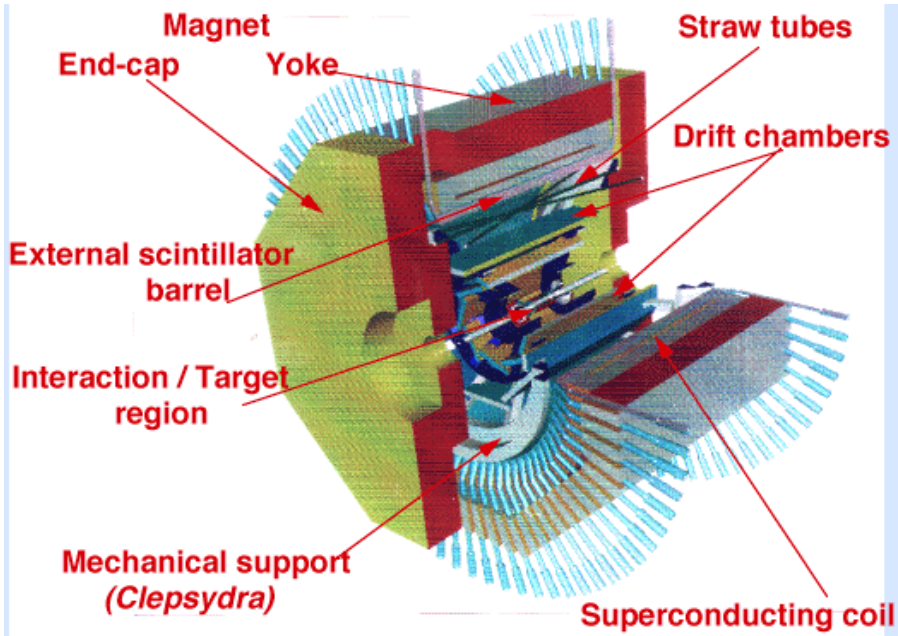
16 MeV

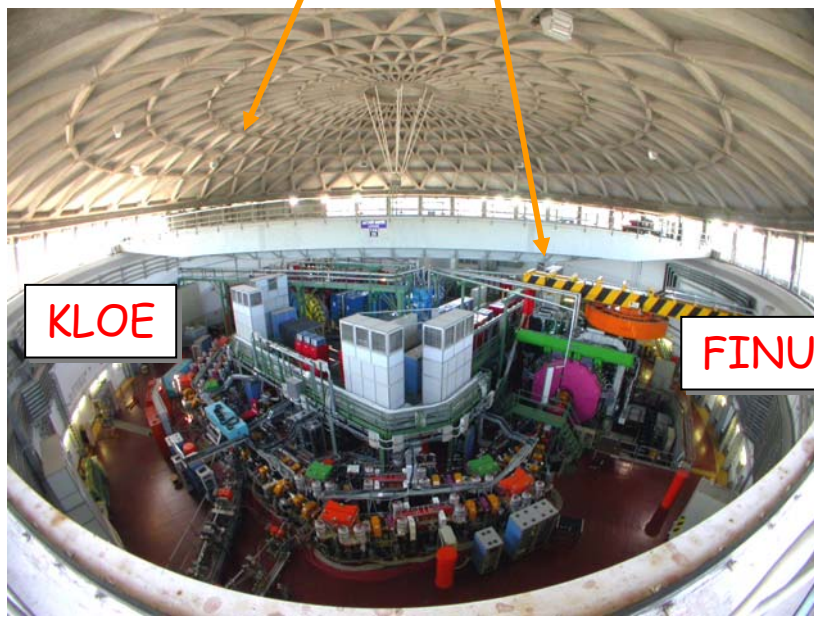
$K^-_{stop}\ {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z\ \pi^-$

About to take data



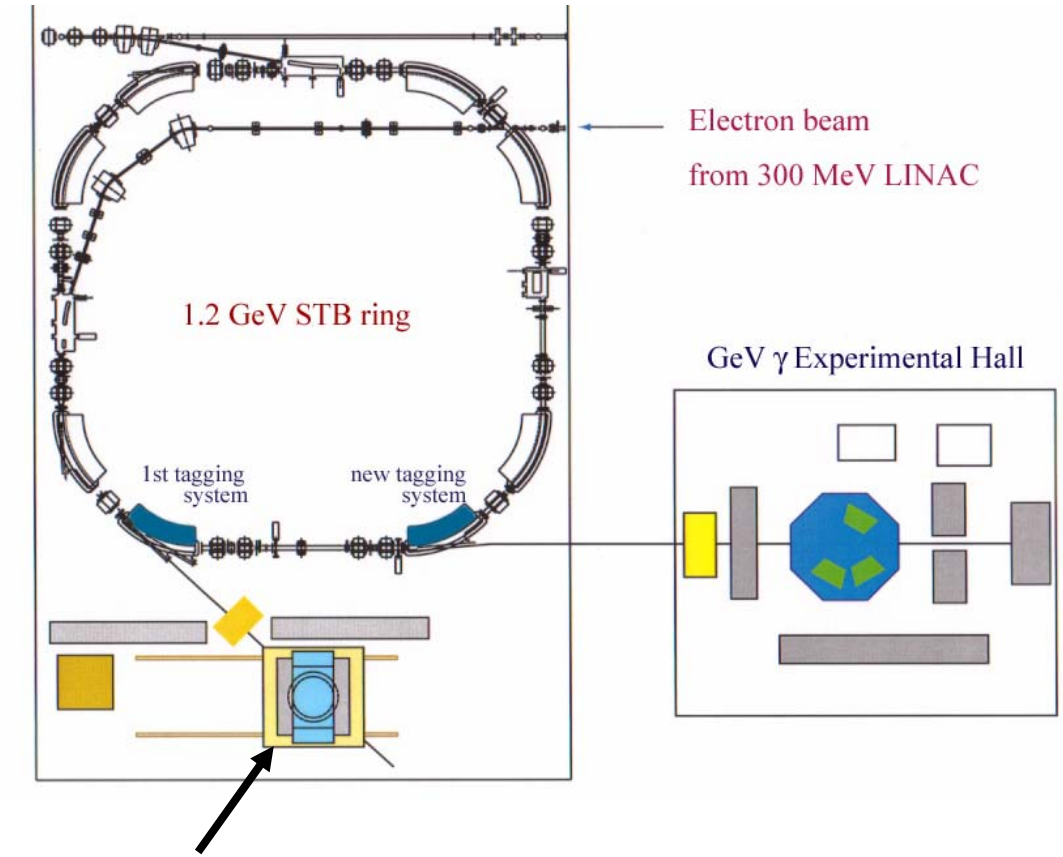
Main Rings





Internal tagger and NKS at LNS, Tohoku

1.2 GeV



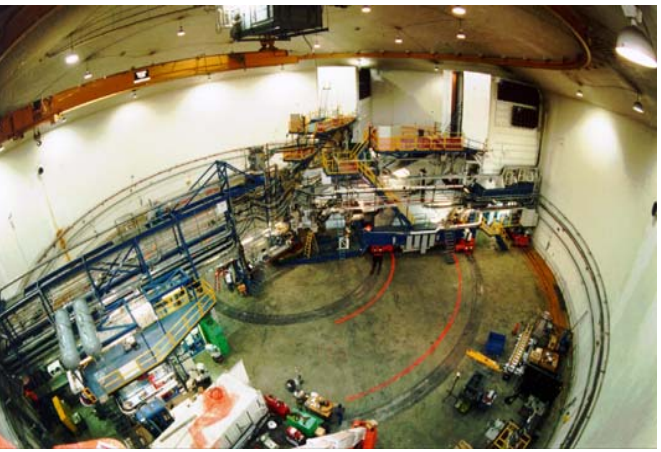
Neutral Kaon Spectrometer (NKS)

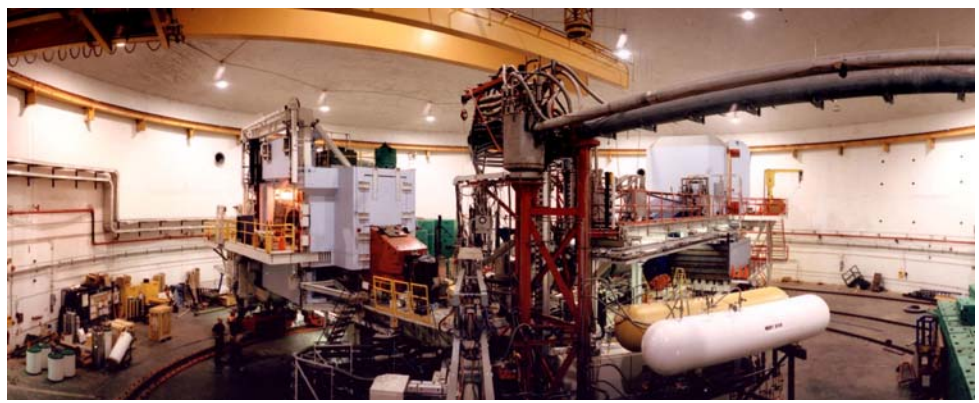
Jefferson Lab

HALL A

HALL B

HALL C

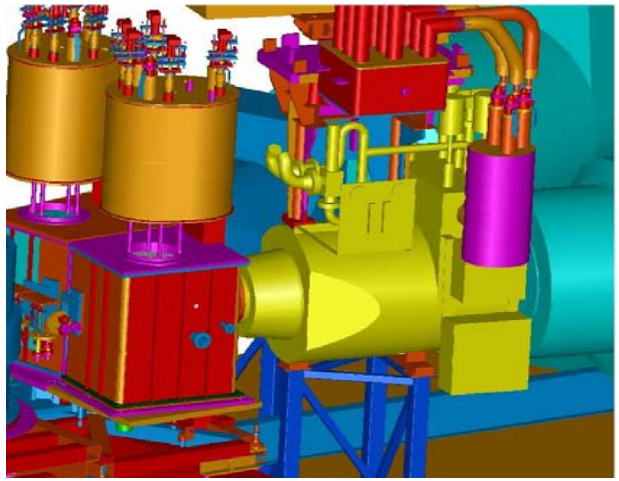


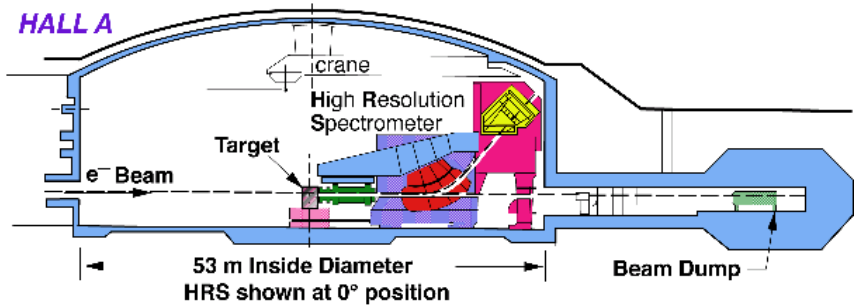


Two hypernuclear spectrometer system at Jlab

HALL A

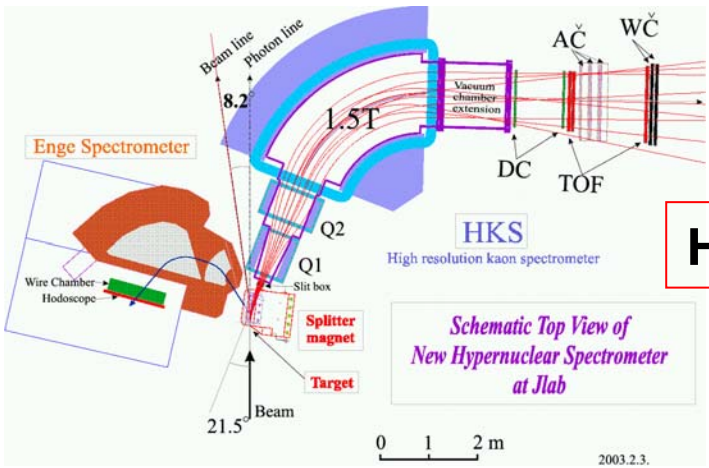
P-shell hypernuclei





HALL C

P-shell and beyond



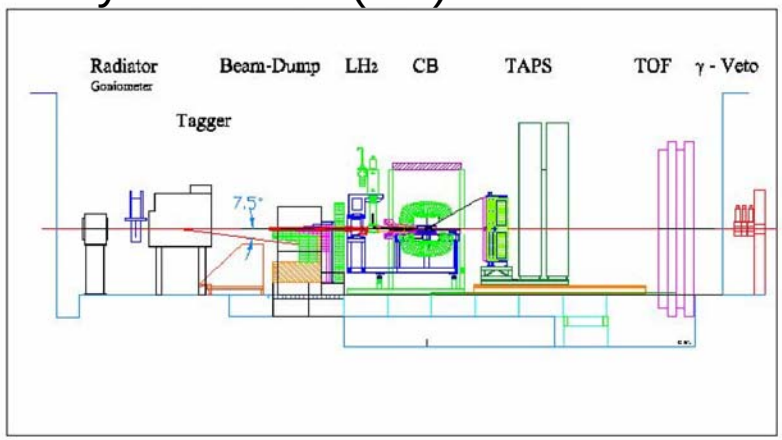
HKS

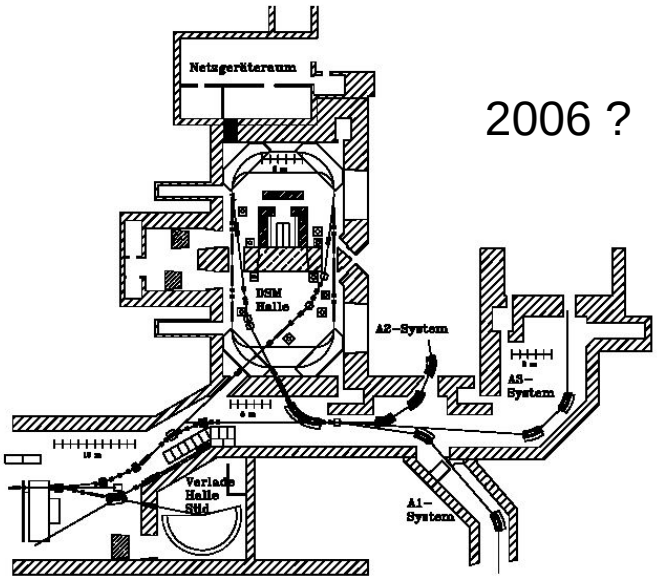
HKS magnets shipped to Jlab from Kobe, Japan

Both expected to run in 2004

ELSA and MAMIC

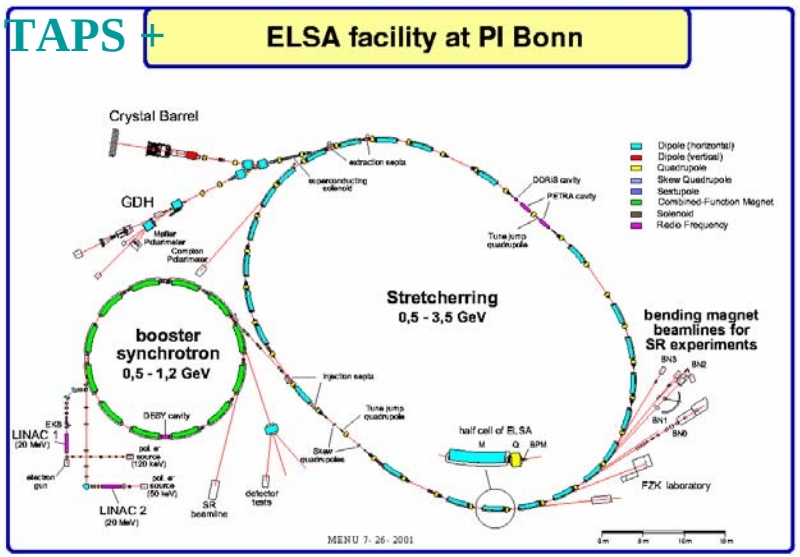
Crystal Barrel (CB) and TAPS

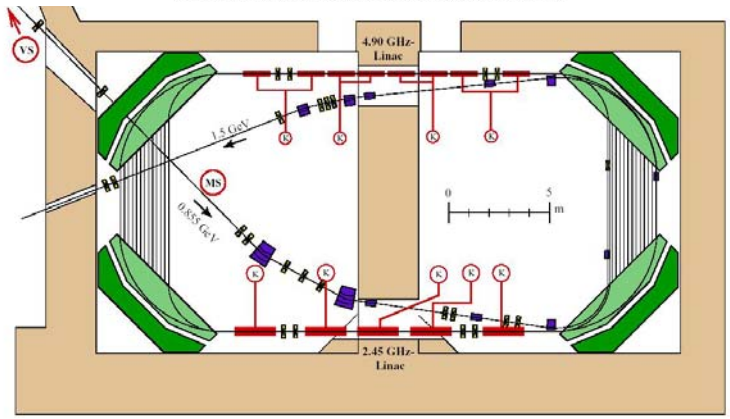




2006 ?

Abb. 1.22: Grundriss der neuen Strahlführung und des HDSM





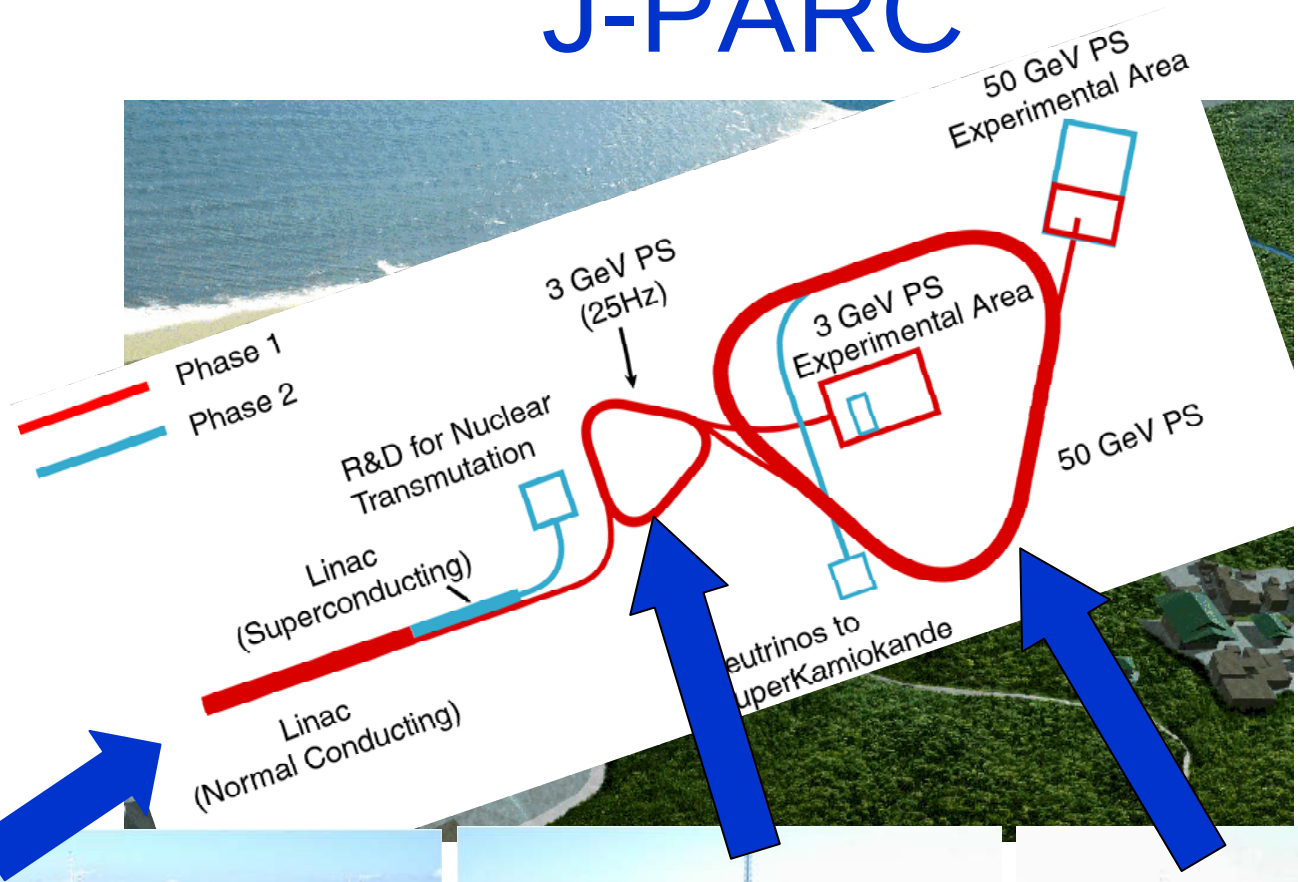
Hypernuclear program

Experimental opportunities for hypernuclear and strange particle physics(2)

Hadron beam facilities

• BNL AGS	30 GeV
• KEK PS	12 GeV
• COSY	3.3 GeV
• J-PARC PS	50 GeV
under construction	-- 2008
K1.8 & K.1.1	
• GSI PANDA	-- ?

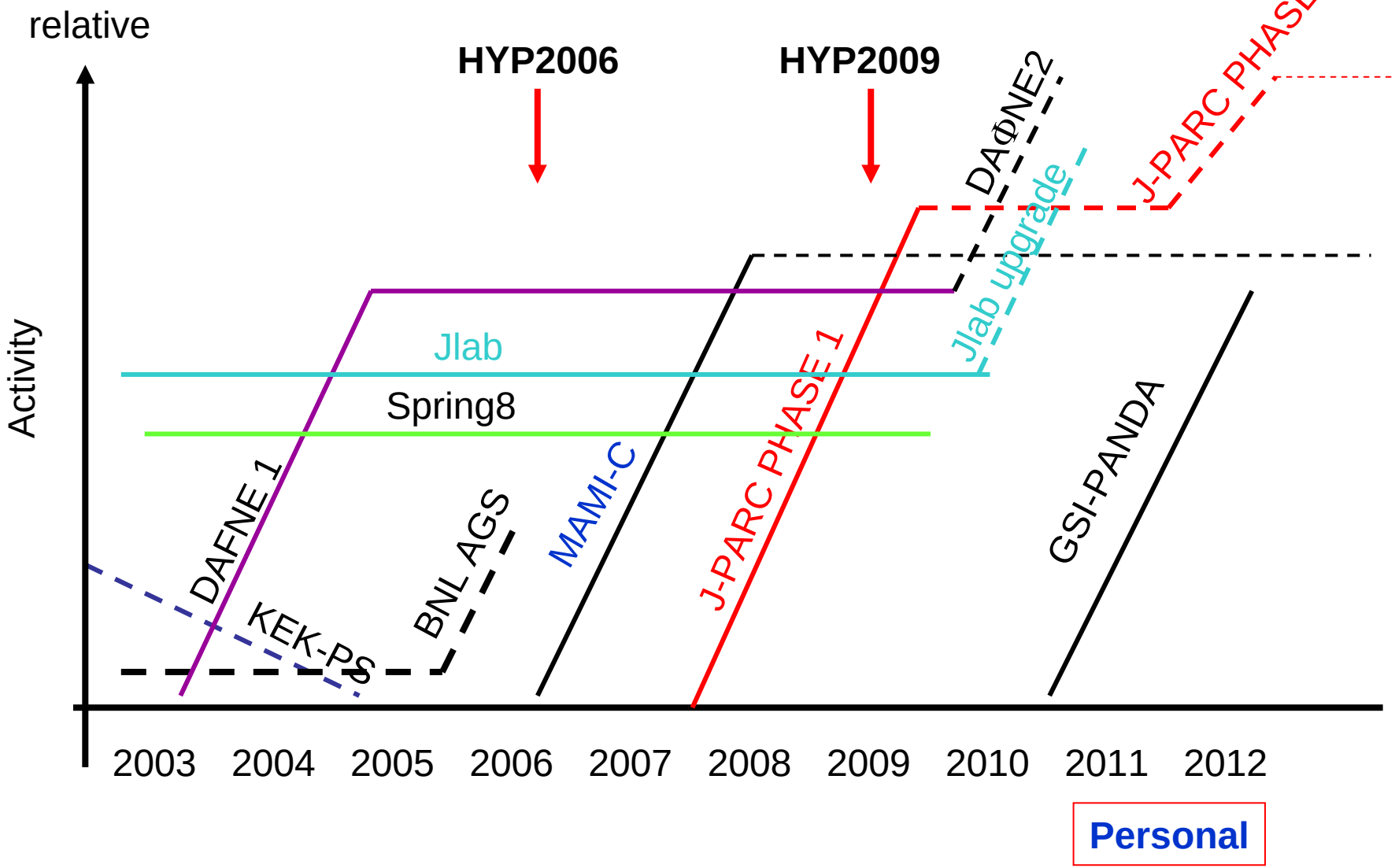
J-PARC



First beam : 2008

PANDA at GSI

Expected Timeline of some accelerator facilities for strangeness physics



Personal

4^{th} stage of hypernuclear physics

- Hypernuclear spectroscopy
  - Reaction spectroscopy for S= -1 & S= -2
    - High-resolution(a few 100 keV) for S=-1
    - Good resolution for S=-2
  - γ–ray spectroscopy
    - Even γ–γ coincidence for S=-1 & S=-2
    - Radiation hard detector
- Double Λ hypernuclei
- Hyperon scattering
- Weak decay for S=-2
- Magnetic moments --- static and transition ---

by hadronic and electron beams

Stronger LINK

- Between the hadronic picture and the QCD picture
  - Community have been struggling for
- Between “Interaction” and “Structure”
  - We have been successful in hypernuclear physics
- Between Experimentalists and Theorists
  - Further extend good tradition
- Between Hadronic and Electromagnetic “realms”
  - Even more necessary
- To the next generation with full of new ideas and enthusiasm
  - Important to the future of the field

Thanks

- Thanks to the organizers
  -- Cornelius, Liguang and John ---
- Thanks to Secretarial supports
  by Jlab staffs and Students,
  particularly by Cynthia.
- Thanks to all the speakers

Hope the sprit of HYP series of conference transferred to Europe with a key word of "strangeness" and we all get together in MAINZ in 2006

Jefferson Lab
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

universität mainz