Nuclear Physics Program at KEK-PS

1977 **PS delivered the first extracted beam**

(Phase-1)

NUMATRON/BEVALAC

High-Energy Heavy-Ion Physics

Parasitic Experiments

K-Decay

Exotica Hunting

Baryonium, Dibaryon

Hadeon Spectroscopy

Low-momentum πμchannel

FANCY Spectrometer

Pion absorption

Hadron-nucleus reactions

1981 **TRISTAN**

(Phase-2)

Strangeness Physics

Nuclear Medium Effects

K-Decay

Hadron Spectroscopy

H Dibaryon Hunting

Hybrid Emulsion

Double Hypernuclei

YP Scattering

SCIFI

SCITIC

Hypernuclear Physics

(Σ hypernuclei)

ΛHypernuclei

New Exp.Hall

TROIDAL Spectrometr

SKSpectrometer

Hyperball

LS Effect
Deep Shell Structure
Lifetime
Weak Decay

K^-H Atom

Multifragmentation
Δproduction on Nuclei

D-Beam Acceleration

Subthreshold $\bar{p}$ Production

E325 Spectrometer

ω,ϱMass in Nuclei

Nuclear Physics Program at KEK-PS

1977 **PS First extracted beam**

(Phase-1)

Parasitic Nuclear Physics Experiments

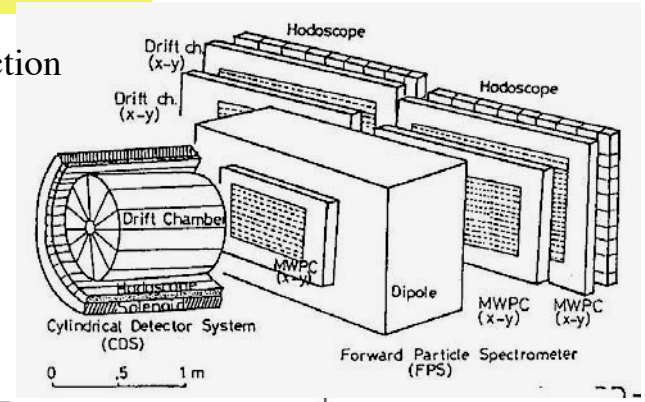
NUMATRON/BEVALAC

High-Energy Heavy-Ion Physics

Low-momentum πμchannel — pion absorption E65

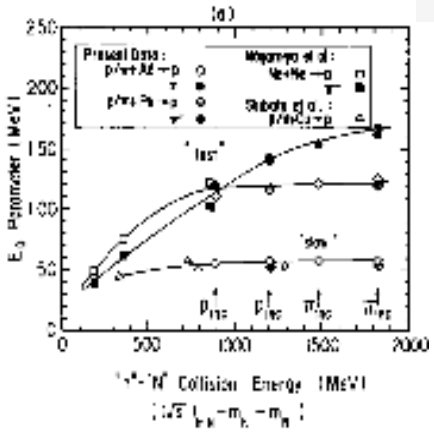
FANCY Spectrometer

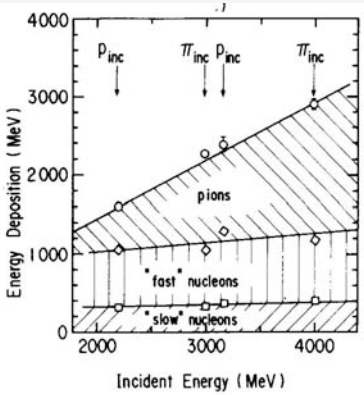
(h+A) reaction — E90,133



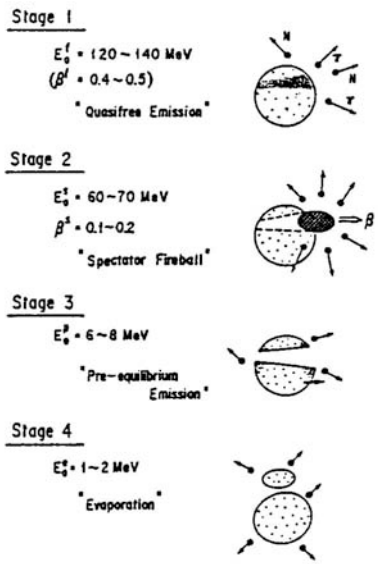
Δproduction in nuclei E173

Λproduction in nuclei E173





Stopping power and energy deposition in nuclei



Moving source model,

Nuclear Physics Program at KEK-PS

(Phase-2)

Hypernuclear Physics

Tracking Detector

Hybrid Emulsion

Double-hypernuclei

SCIFI

SCITIC

YP Scattering

Hypernuclear Spectroscopy

New Hall, New Beam-Lines
New Spectrometers

SKSpectrometer

TOROIDAL Spectrometer

Hyperball

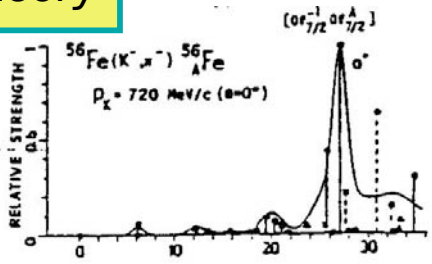
ΣHypernuclei E114

ΛHypernuclei E117/130/287

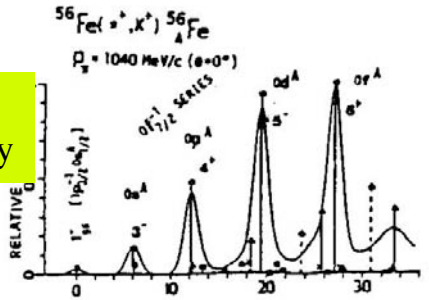
E140,/160

Nuclear Theory

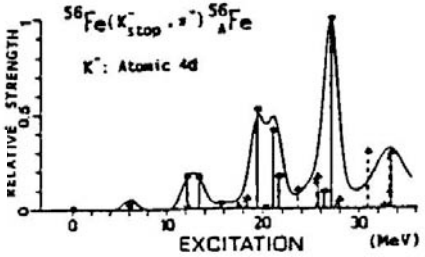
Recoilless



(π,K) spectroscopy

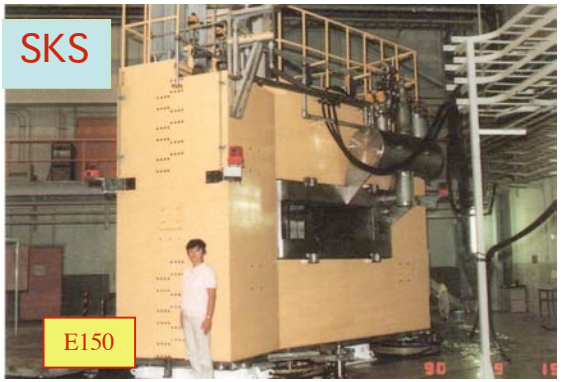


Stopped K

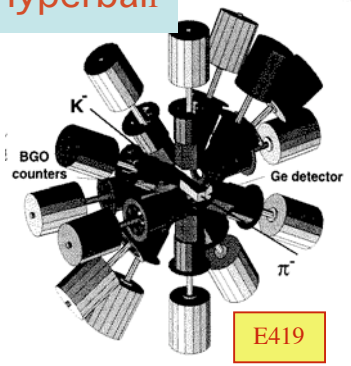


TOROIDAL

SKS

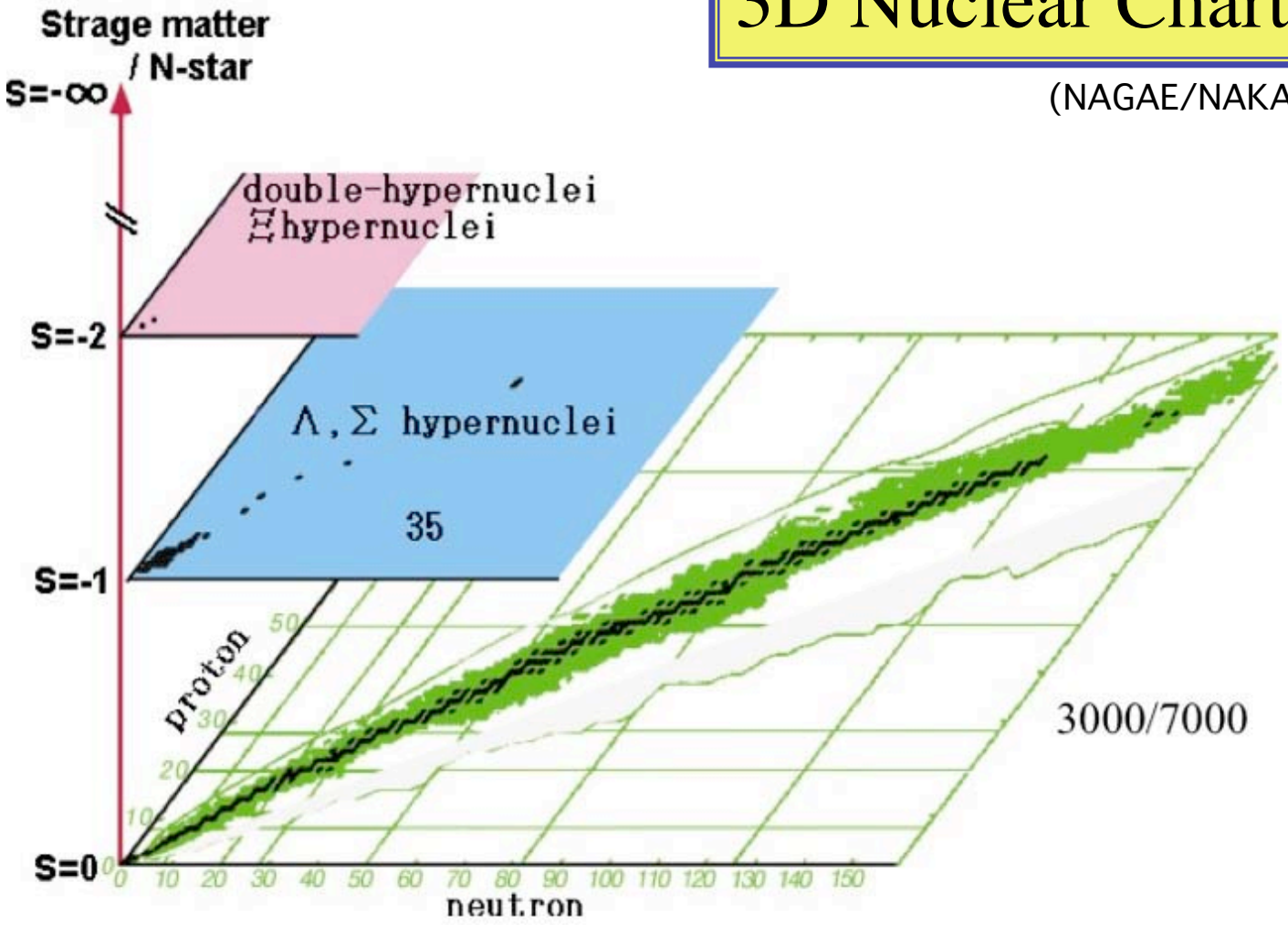


Hyperball

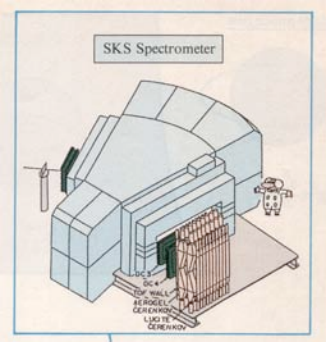


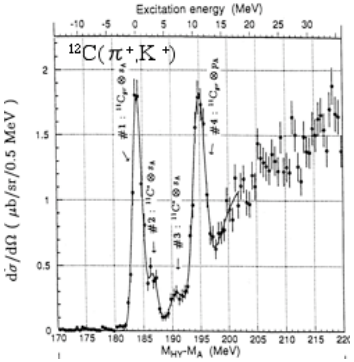
3D Nuclear Chart

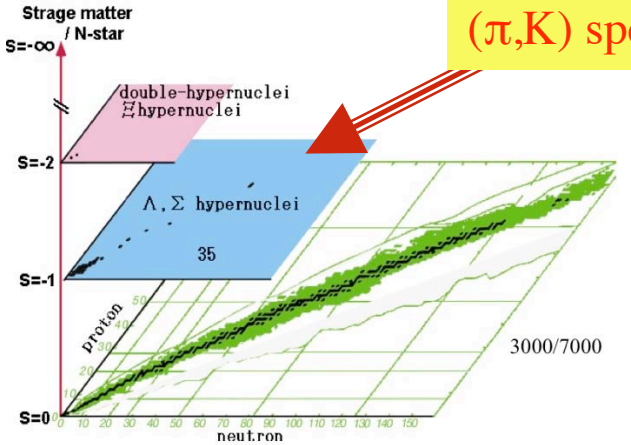
(NAGAE/NAKAI)



SKS



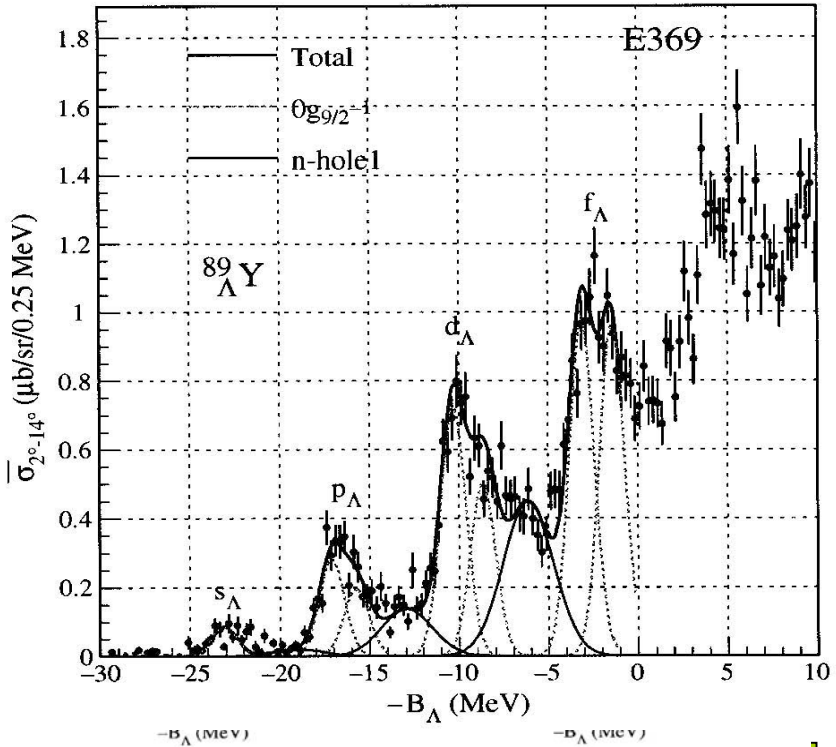




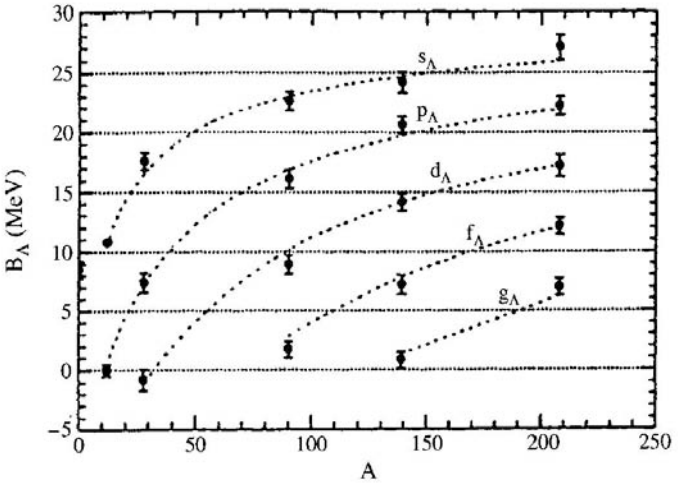
(π,K) spectroscopy

E140

E369

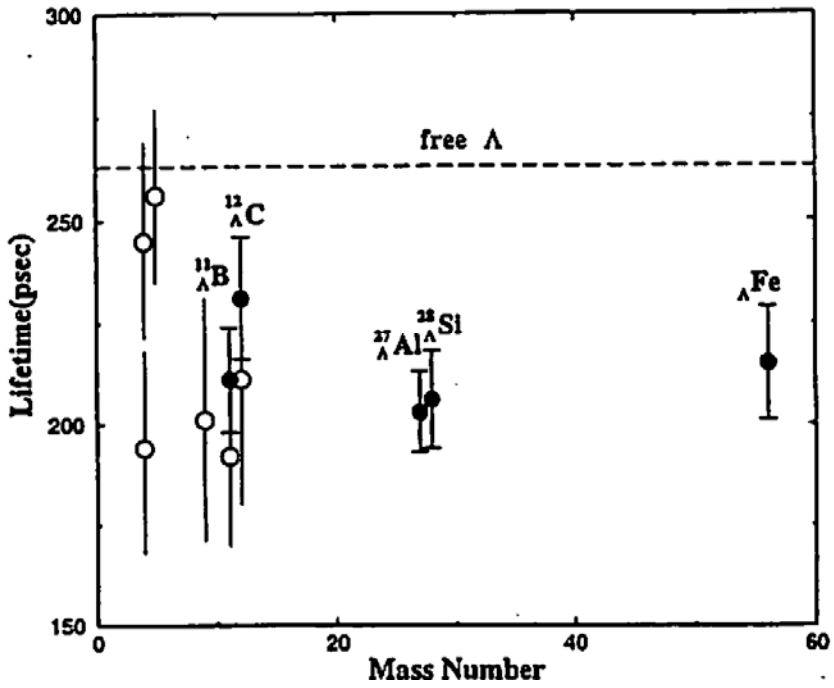


- Deep Shell Structure — E140/336
- Small LS-Effect in Λhypernuclei — E369
- Lifetimes of Λhypernuclei — E307
- Weak Decay of Λhypernuclei — E160/278, E462/508
- Repulsive Compohents in Σhypernuclear Potential — E438



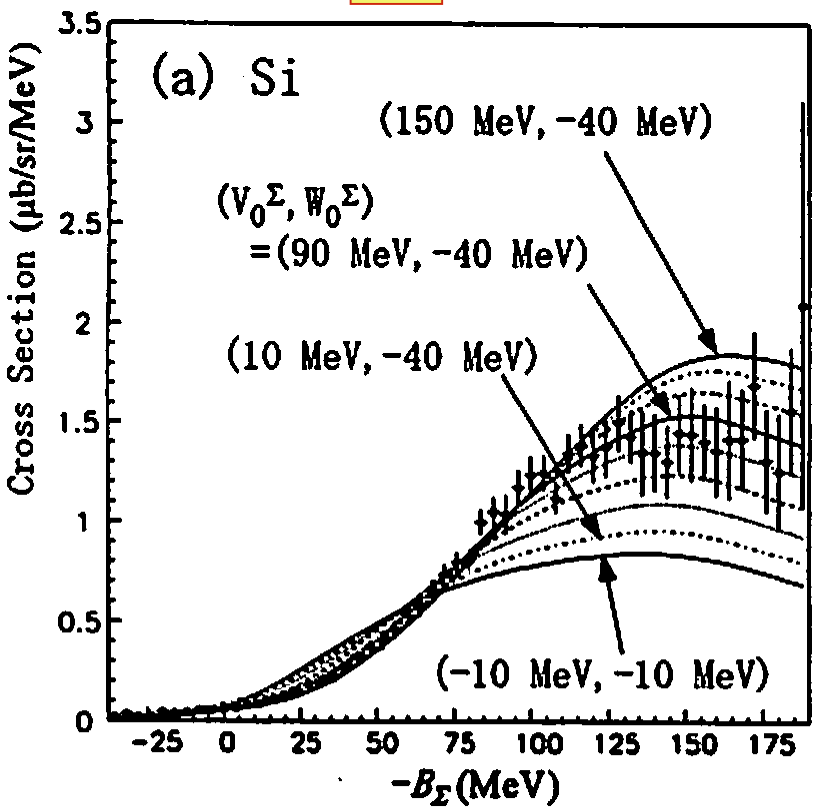
- Lifetimes of Λhypernuclei

E307



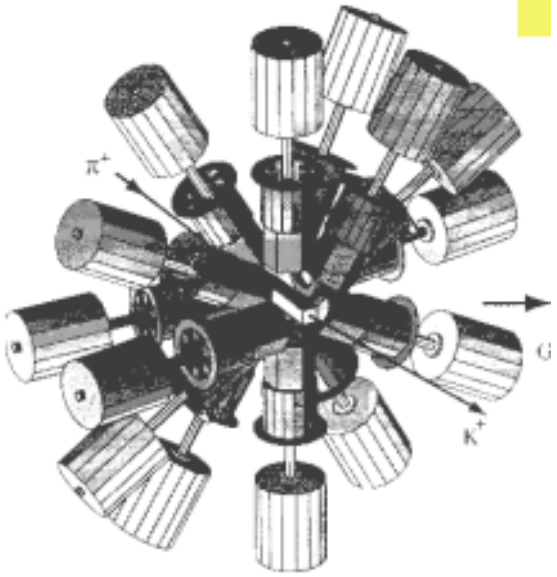
- Repulsive Compohents in Σhypernuclear Potential

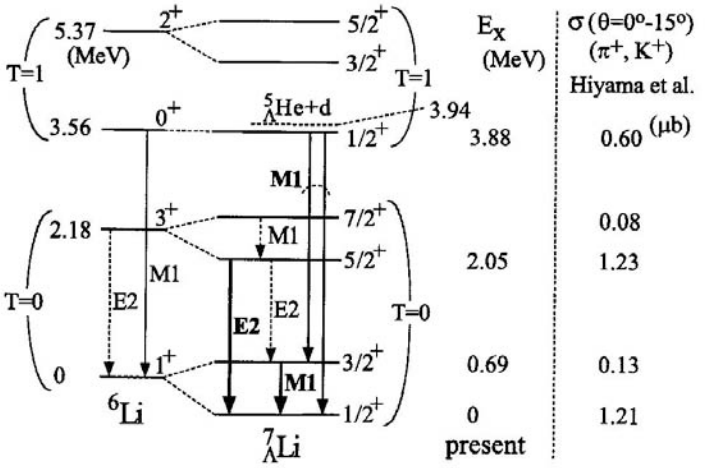
E438



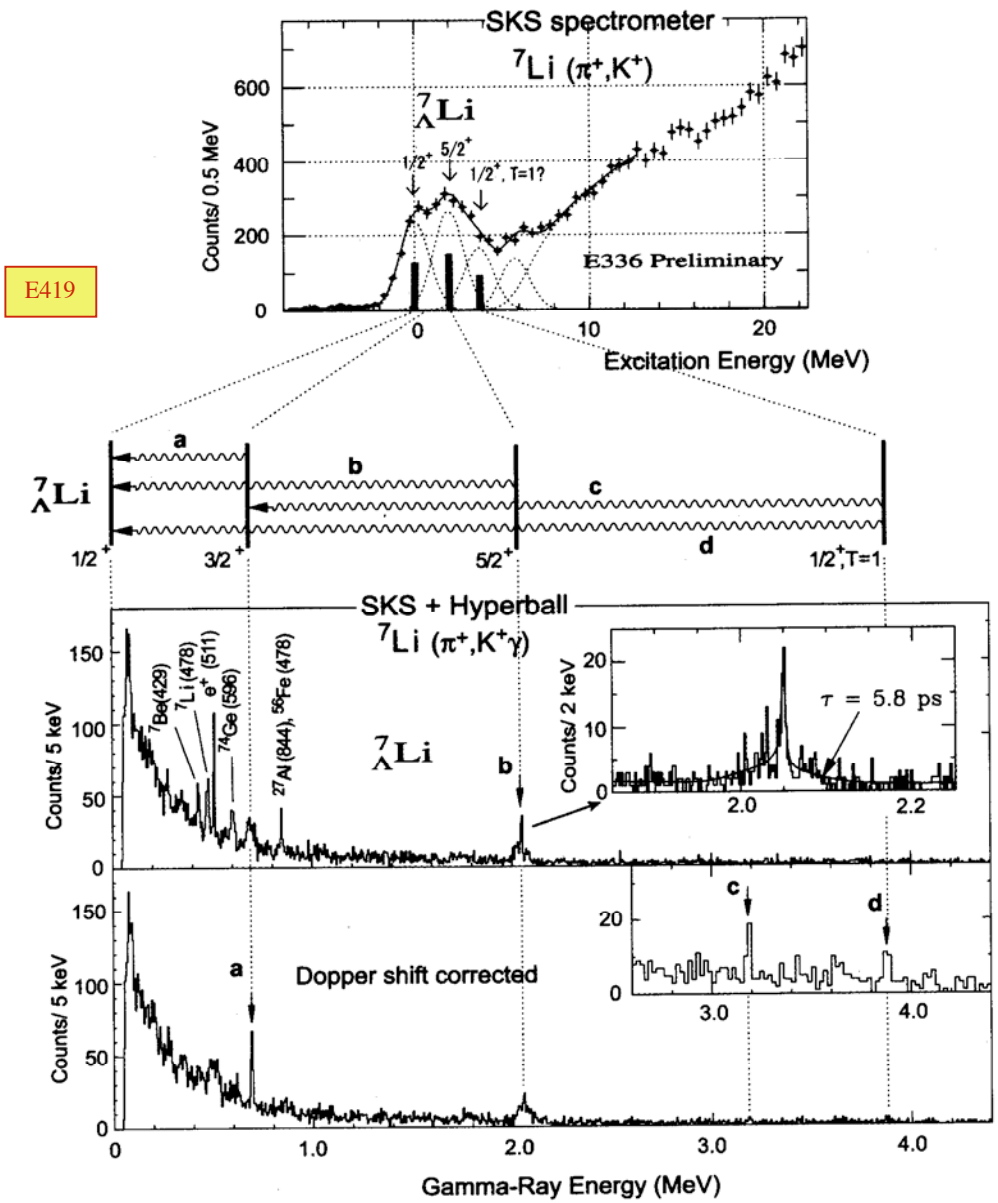
Hyperball

Ultra-high Resolution Spectroscopy
- Nuclear Structure Specific to s=-1
- Deduction of Elementary YN-interaction





E419



Determination of Spin Dependent Interactions

$$V_{\Lambda N}(r) = V_0(r)$$

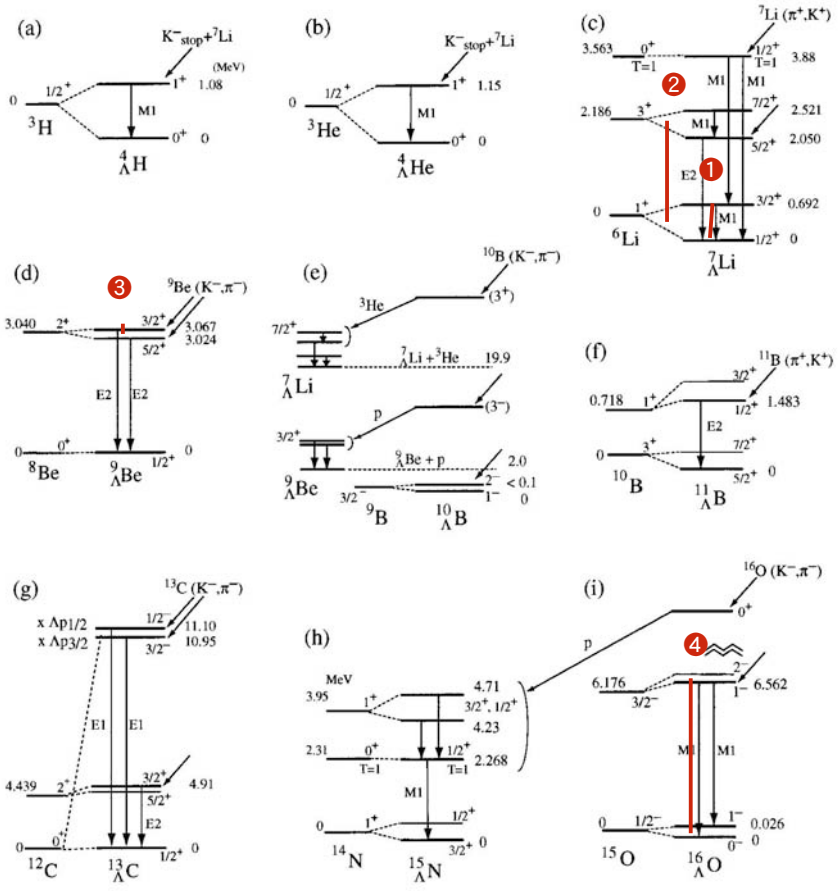
$$+ V_\sigma s_N s_\Lambda \qquad \text{spin-spin} : \Delta$$

$$+ V_\Lambda \ell_{Na} s_\Lambda \qquad \ell\, s_\Lambda : S_\Lambda$$

$$+ V_N \ell_{NA} s_N \qquad \ell\, s_N : S_N$$

$$+ V_T[3(s_N r)/(s_\Lambda r)/r^2 - s_N s_\Lambda] \qquad \text{Tensor} : T$$

E287/419/509/518

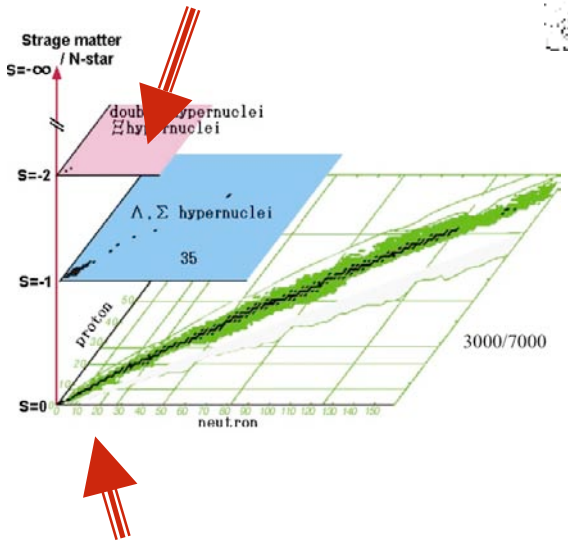


	Hypernuclear levels		Shell model calculation by Millener	$\Lambda\Sigma$ (MeV)	Exp. (MeV)
❶	${}^{7}_{\Lambda}$Li	$E(3/2^+) - E(1/2^+)$	$1.444\Delta + 0.054S_\Lambda + 0.016S_N - 0.271T$	+0.071	0.692
❷	${}^{7}_{\Lambda}$Li	$\overline{E(7/2^+, 5/2^+)}$	$-0.05\Delta + 0.07S_\Lambda + 0.70S_N - 0.08T$		1.858
		$-\overline{E(3/2^+, 1/2^+)}^{a}$	$+\Delta E_{core}{}^{b}$		
❸	${}^{9}_{\Lambda}$Be	$E(3/2^+) - E(5/2^+)$	$-0.037\Delta - 2.464S_\Lambda + 0.003S_N + 0.994T$	−0.008	0.043
❹	${}^{16}_{\Lambda}$O	$E(1^-) - E(0^-)$	$-0.382\Delta + 1.378S_\Lambda - 0.004S_N + 7.850T$	−0.014[c]	0.026

S=-2 System

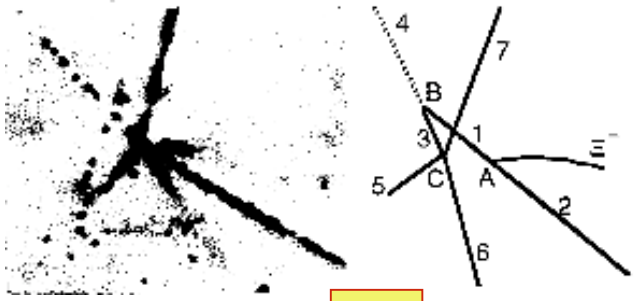
Search for the H-dibaryon

Double Hypernuclei



Hyperon-Nucleon Scattering

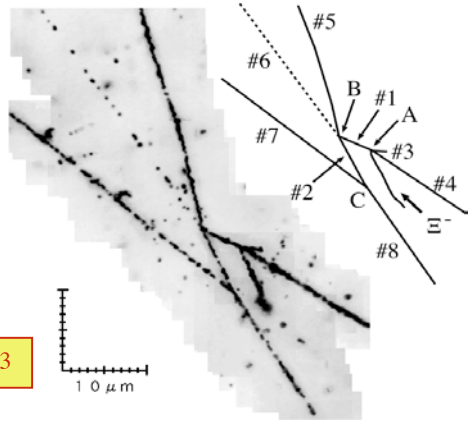
Hybrid Emulsion



E176

$\Xi^- + {}^{12}C \rightarrow {}_{\Lambda\Lambda}{}^{10}Be + {}^{3}H$, or
$\Xi^- + {}^{14}N \rightarrow {}_{\Lambda\Lambda}{}^{13}B + {}^{1}H + n$

Hybrid Emulsion + SCIFI



E373

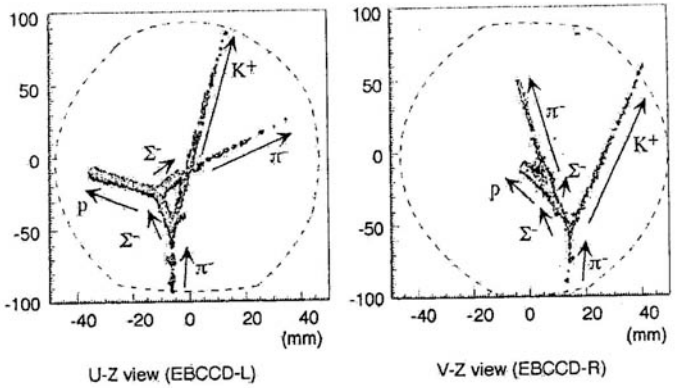
NAGARA event

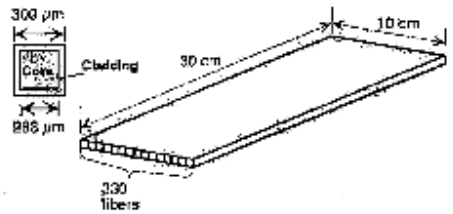
$\Xi^- + {}^{12}C \rightarrow {}_{\Lambda\Lambda}{}^{6}He + {}^{4}He + {}^{3}H$

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

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

SCIFI



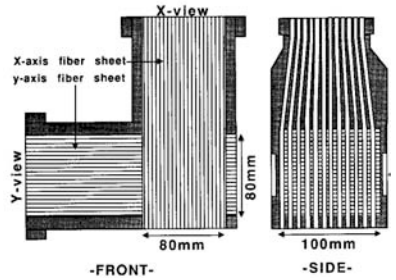


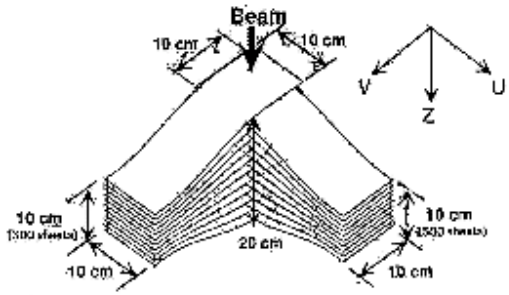
SCIFI : E224/251/289/522

Scintillation Fiber Detector

SCITIC : E452

Scintillation Track Imaging Camera





The first hypernuclear experiment at KEK-PS

Hunting for Σ Hypernuclei

Heidelberg-Saclay collaboration at CERN

Very small LS effect in **Λ Hypernuclei**

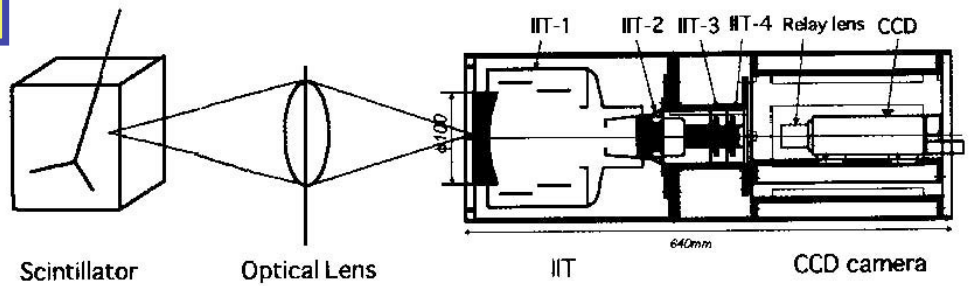
Theoretical interpretations by Povh-Pirner and Oka-Yazaki

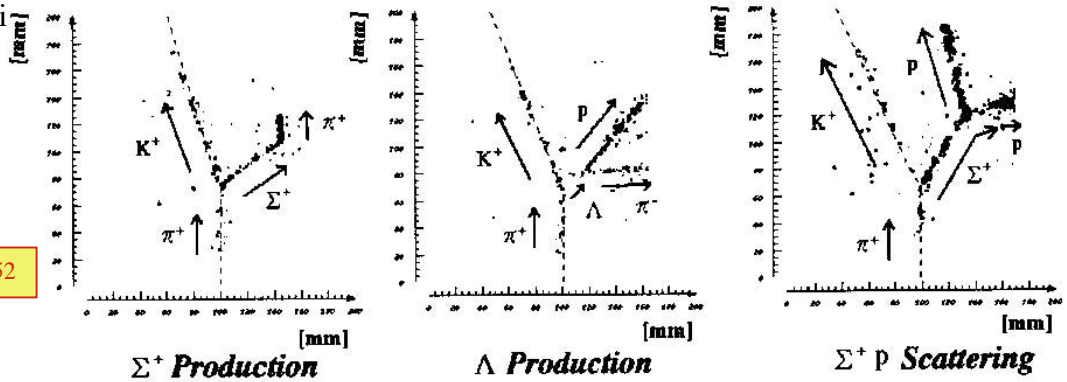
Predicted a large LS effect in **Σ Hypernuclei**

No **Σ Hypernuclei** Except for ${}^{4}_{\Sigma}\mathrm{He}$

E452

Asymmetry measurements in **YP Scattering**





E117

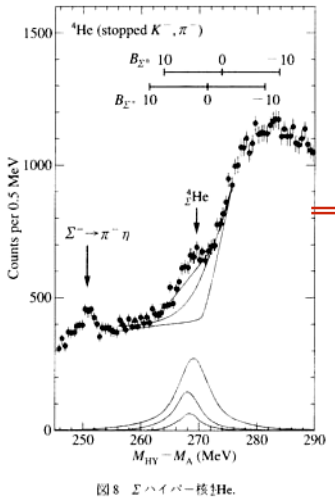
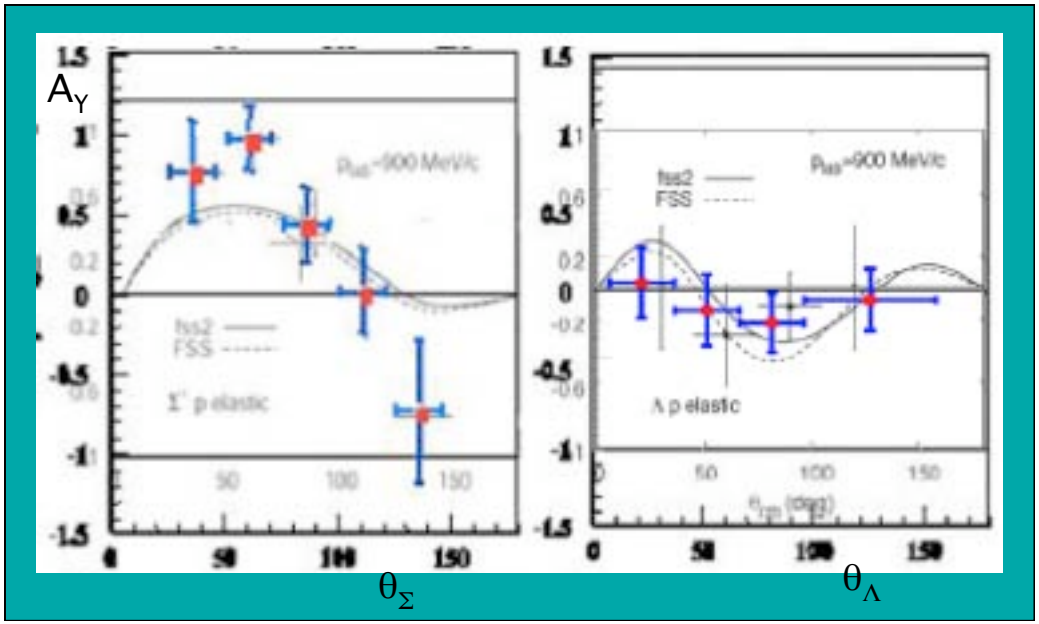


図8 Σハイパー核 ${}^{4}_{\Sigma}\mathrm{He}$.

GSI, Saclay,
TRIUMF, CERN,

- Coul.-Assisted Hypernuclei
- Deeply Bound Pionic Atom
- Antiprotonic Atomucle
- KN Atomucle
- - - - - - - - -



Barrier-free Physics for J-PARC

Elementary Particles, Nuclei, Atoms, Molecules

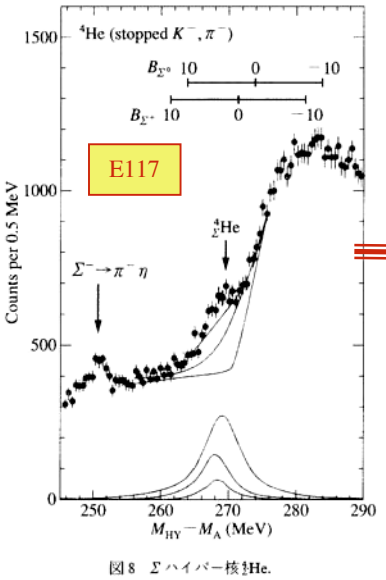


図 8　Σ ハイパー核 $^4_\Sigma$He.

GSI, Saclay, TRIUMF, CERN

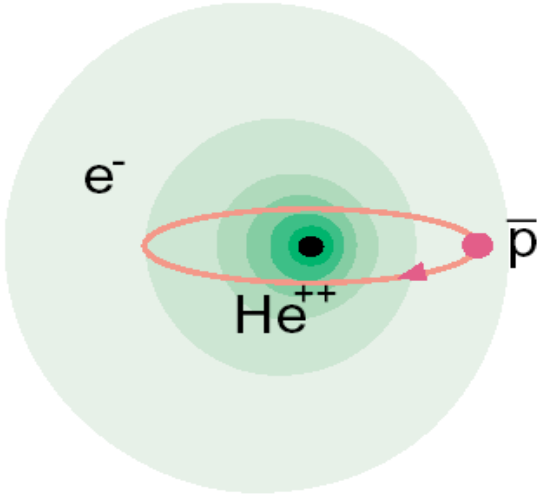
Coul.-Assisted Hypernuclei

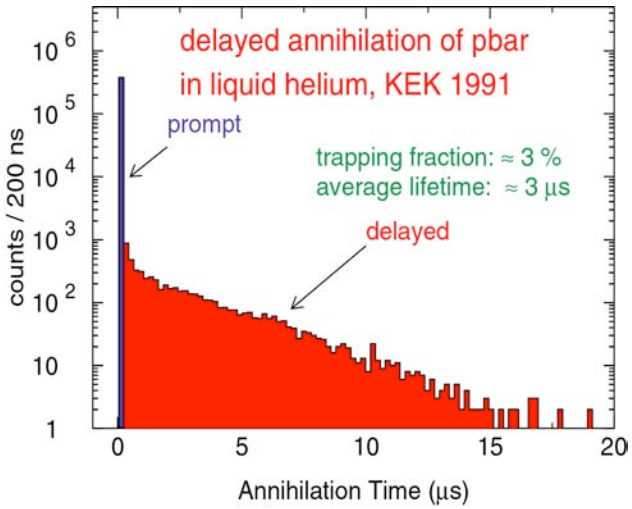
Deeply Bound Pionic Atom

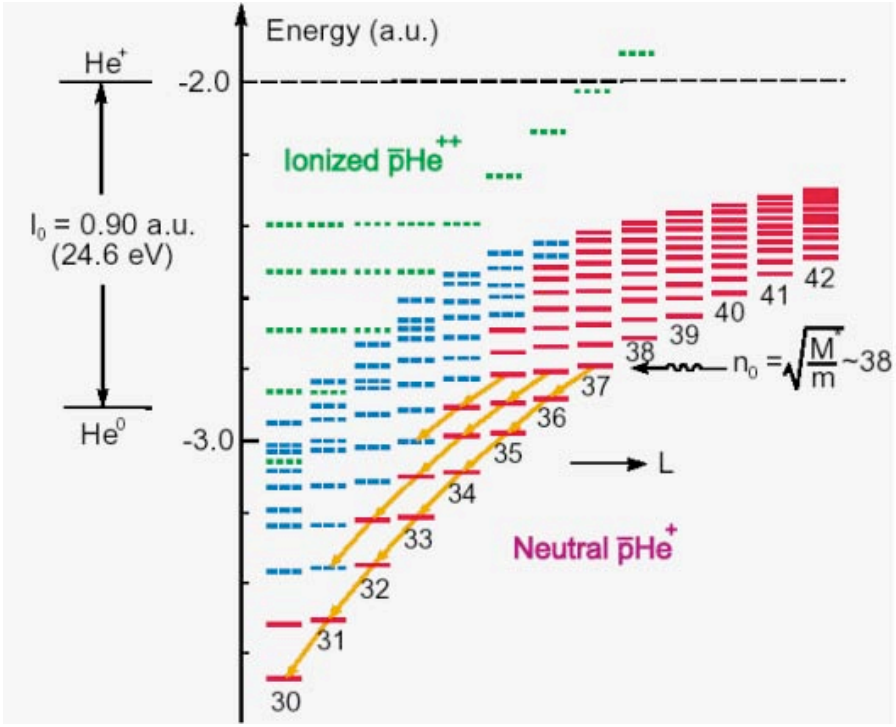
Antiprotonic Atomucle

KN Atomucle

- - - - - - - - -







Barrier-free Physics for J-PARC

Elementary Particles, Nuclei, Atoms, Molecules

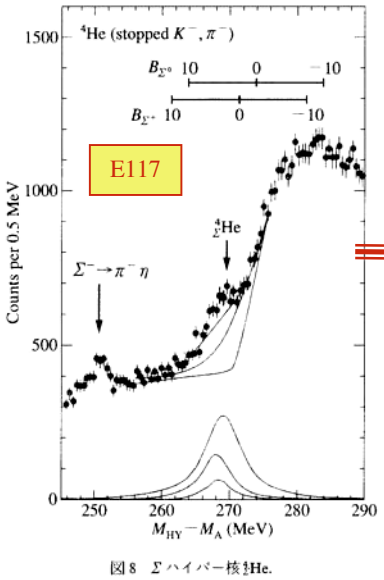


図 8　Σ ハイパー核 $^4_\Sigma$He.

GSI, Saclay, TRIUMF, CERN

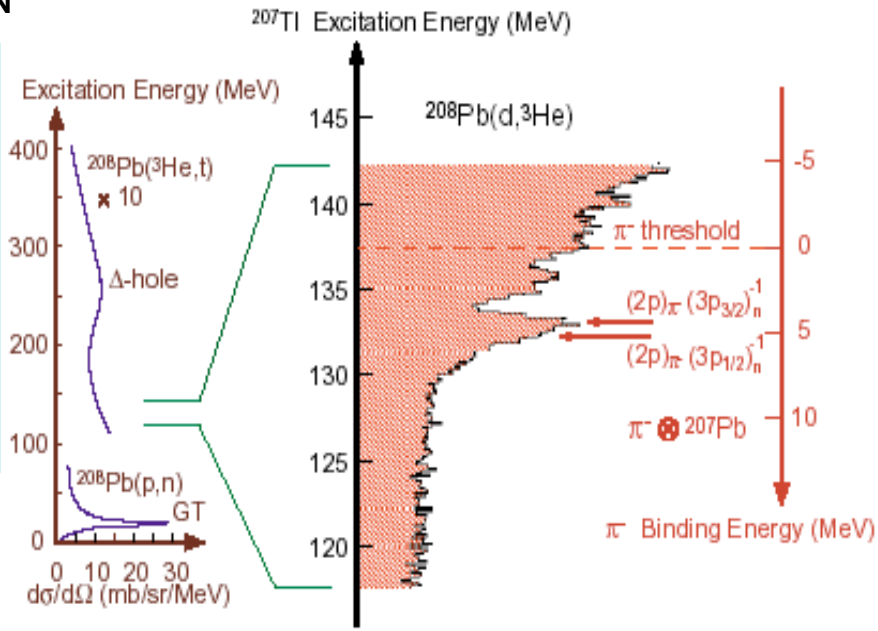
Coul.-Assisted Hypernuclei

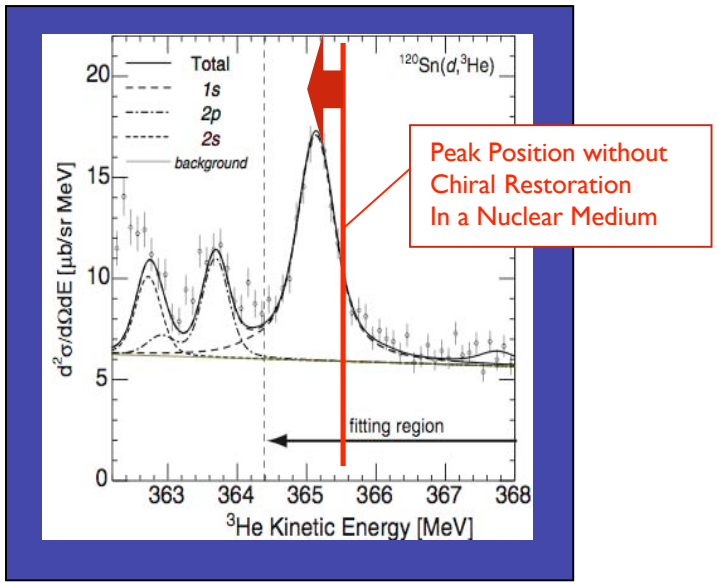
Deeply Bound Pionic Atom

Antiprotonic Atomucle

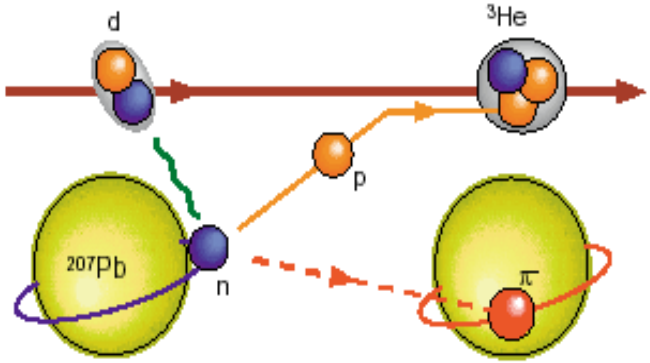
KN Atomucle

- - - - - - - - -

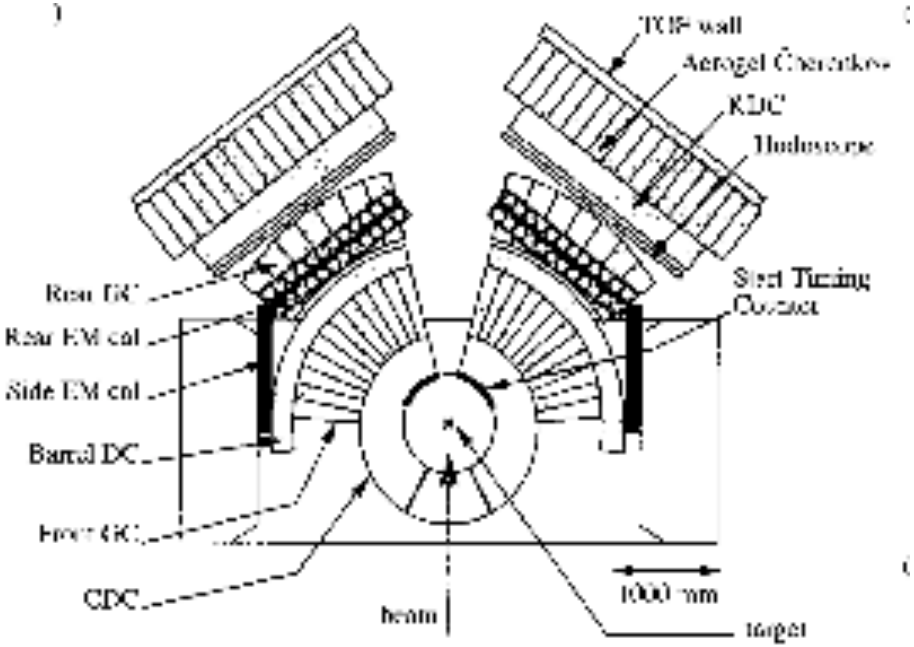


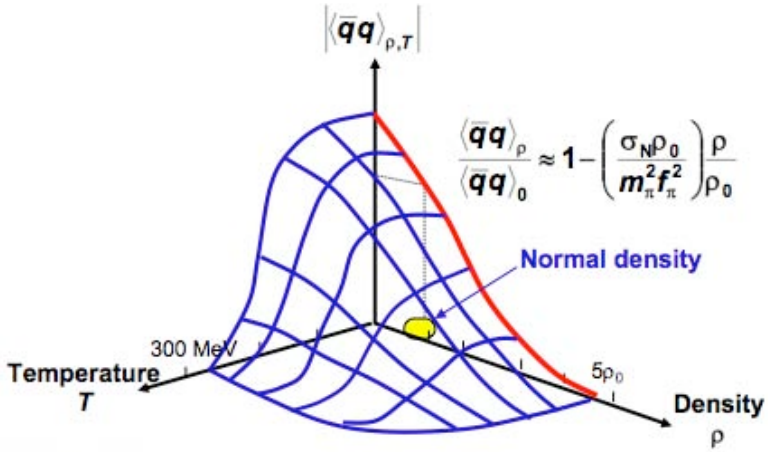


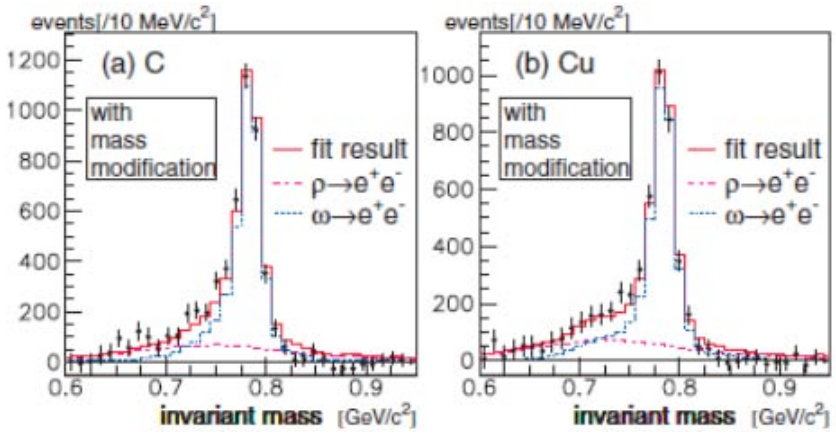
Peak Position without
Chiral Restoration
In a Nuclear Medium



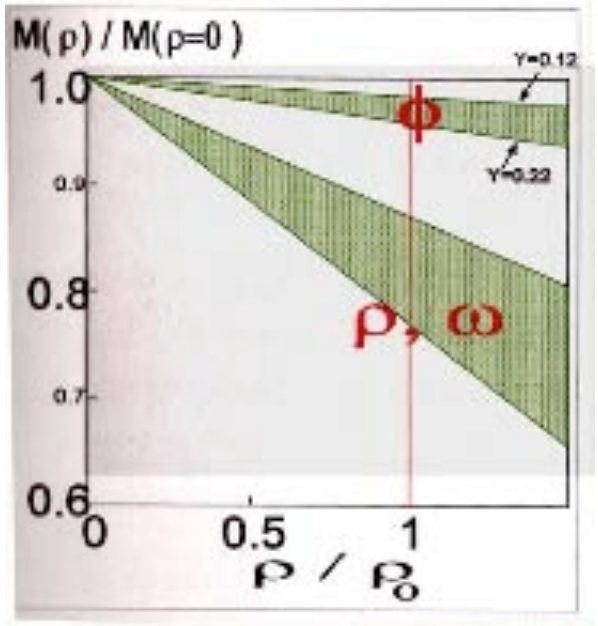
Mass change ofϱ, ω mesons in nuclei







E325



$\bar{K}$-N interaction

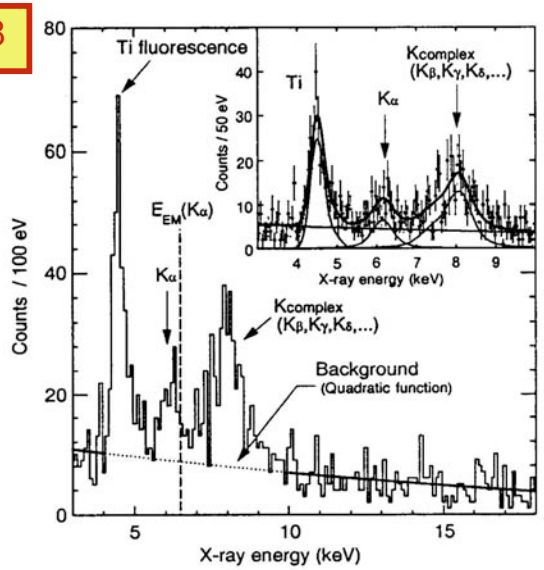
Yamazaki & Akaishi : Proc. of the Japanese Academy, Ser.B, Vol.83, p.144 (2007)

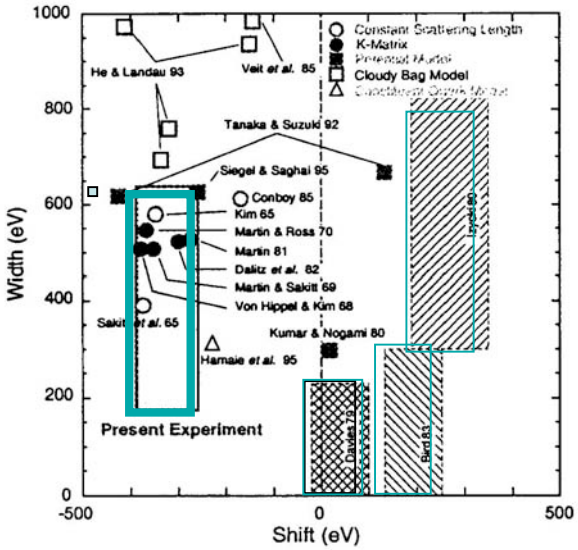
Strong attractive force with I=0

"Superstrong Nuclear force"

Kaonic Hydrogen X-Ray

E228

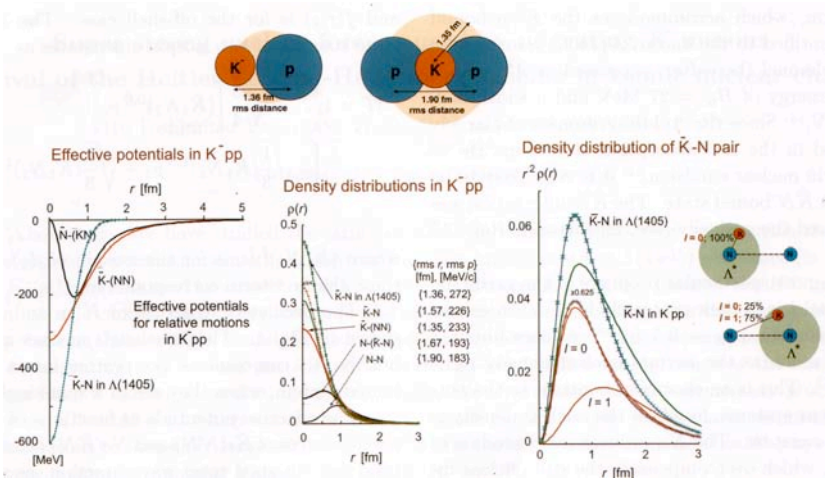


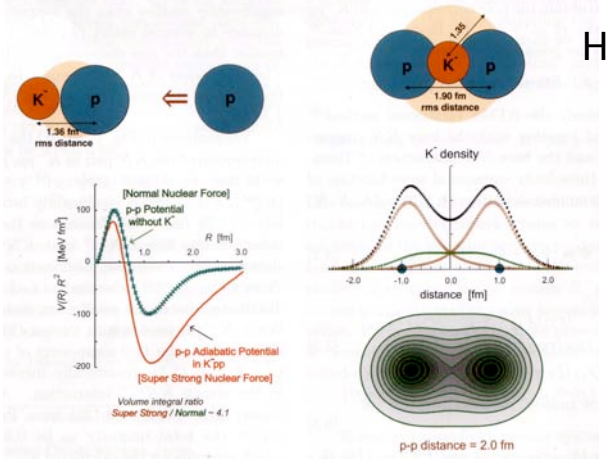


K^-p bound states

$\Lambda(1405)$: The lowest K^-p state

Search for K^-pp states





High-density nuclear matter

$\varrho \sim 3\,\varrho_0$

From KEK-PS to J-PARC
素粒子原子・原子核・物質創生の
プレーグラウンド

山崎敏光　２００６．５．１９

エキゾティックな物質

通常世界に存在しない、常識に反し準安定

＊　ハイパー原子核
＊　反陽子のつくるアトモレキュール：反物質
＊　パイ中間子などを含む原子核
＊　K中間子の創る高密度核クラスター

螺旋階段　―　試行錯誤、失敗と成功、セレンディピティの連鎖
予想を裏切る、しかし、予想しなかった結果！

KEK-PS　新しい方法、視点、の開発（発見的手法）世界に発信
J-PARC　求心、世界、とくにアジア地域から

From KEK-PS to J-PARC

Playground for
Production of Particle-Atom, Nuclei and Matter

Toshimitsu Yamazaki 2006. 5. 19

Exotic Matter

Abnormal, Quasi-stable !

* Hypernuclei
* Atomolecule made of anti-proton : Anti-matter
* Nuclei involving π mesons
* High density nuclear clusters made of Kmesons

Spiral Steps - Try and Errors Failure and Success Chain of Serendipity

KEK-PS Developments of New Methods, New Scopes → Dispatch to the world
J-PARC World-wide centripetal force, especially from Asia

Bogdan Povh ;

Stop doing the dirty physics like high-energy heavy-ion reactions,
but let us start the clear physics like hypernuclear spectroscopy.

Bill Willis ;

No, it's not a question of dirty or clean,
more important is whether you want to choose Big or Small.

J-PARC Programs should not be
Simple Extension and/or Expansion of
the KEK-PS Programs !!