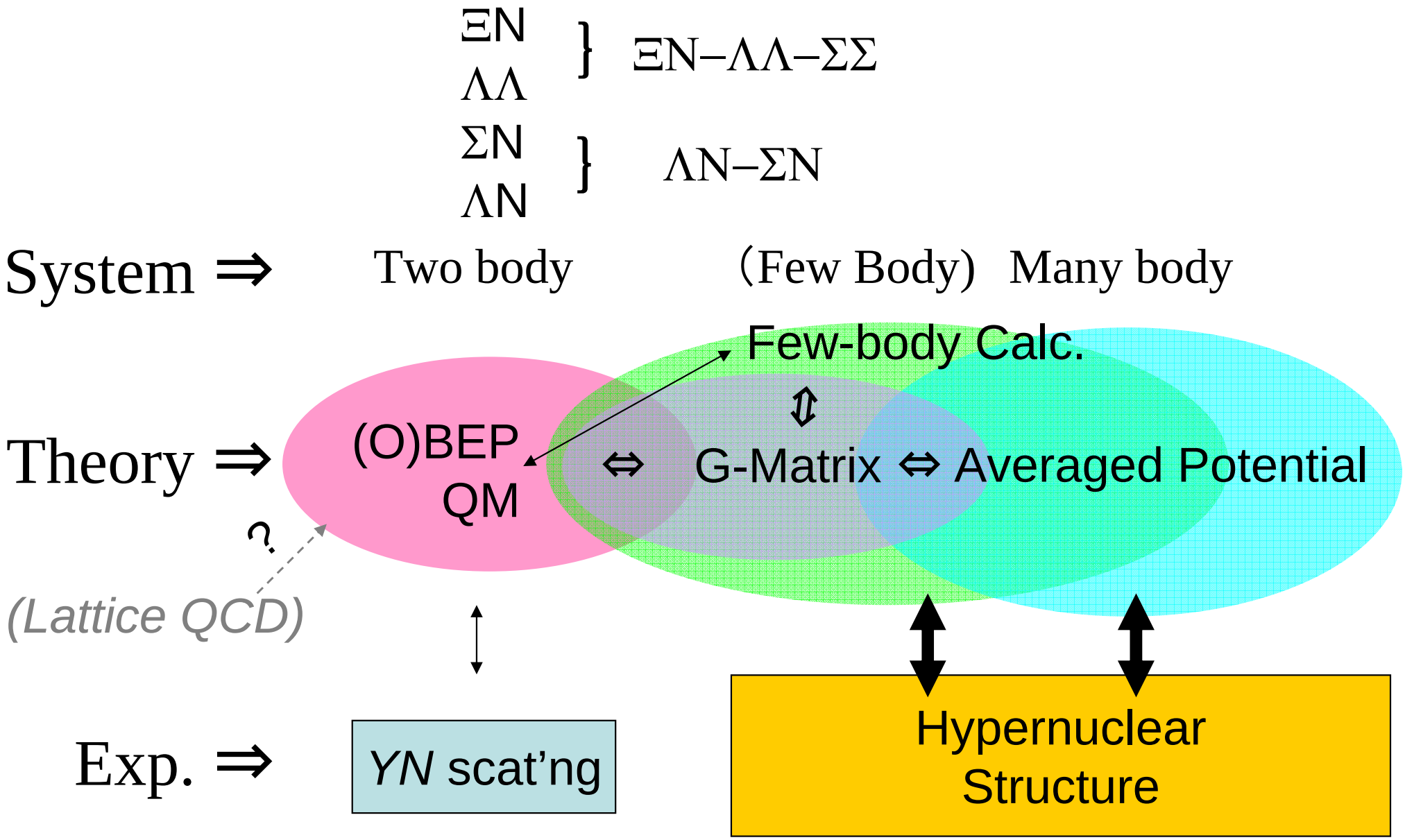
KEK-PS External Review, Jan 22-23, 2008
Seminar Hall, Bldg.4 KEK

E438: Study of Σ-Nucleus Potential by the (π^-, K^+) Reaction on Heavy Nuclei

Hiroyuki Noumi
RCNP, Osaka-U for E438

Precision Hypernuclear Spectroscopic Data
reveal *the Baryon-Baryon Interactions*
in collaboration with Precision Theoretical Calculations



YN, YY Potentials ⟷ Hypernuclear Structures

Spin-Spin, Spin-Orbit,
Tensor
Spin-Isospin dependence
Coupled Channels

Single-Particle Structure: $B_Y \rightarrow U_Y$
SS, LS splittings
Multi-body Effect (Many body force)

- *In Λ hypernuclear System, we have demonstrated that the frameworks work very well.*

- *We expect that it can be applicable to the Ξ (or $\Lambda\Lambda$) Hypernuclear System,*
  which will be examined in J-PARC

The Question to be asked for E438 was:

"Is the Σ-Nucleus Potential Attractive or Repulsive?"

Situation in Σ-Nucleus System

- Isospin dependent U_Σ in light systems
  - a bound state in A=4 at KEK (R.S. Hayano et al., PLB231(1989)355)
    at BNL (T. Nagae at al., PRL80(1998)1605)
  - systematics of $(K^-,\pi^\pm)$ in A=4,6,9 (S. Bart et al., RL83(1999)5238)

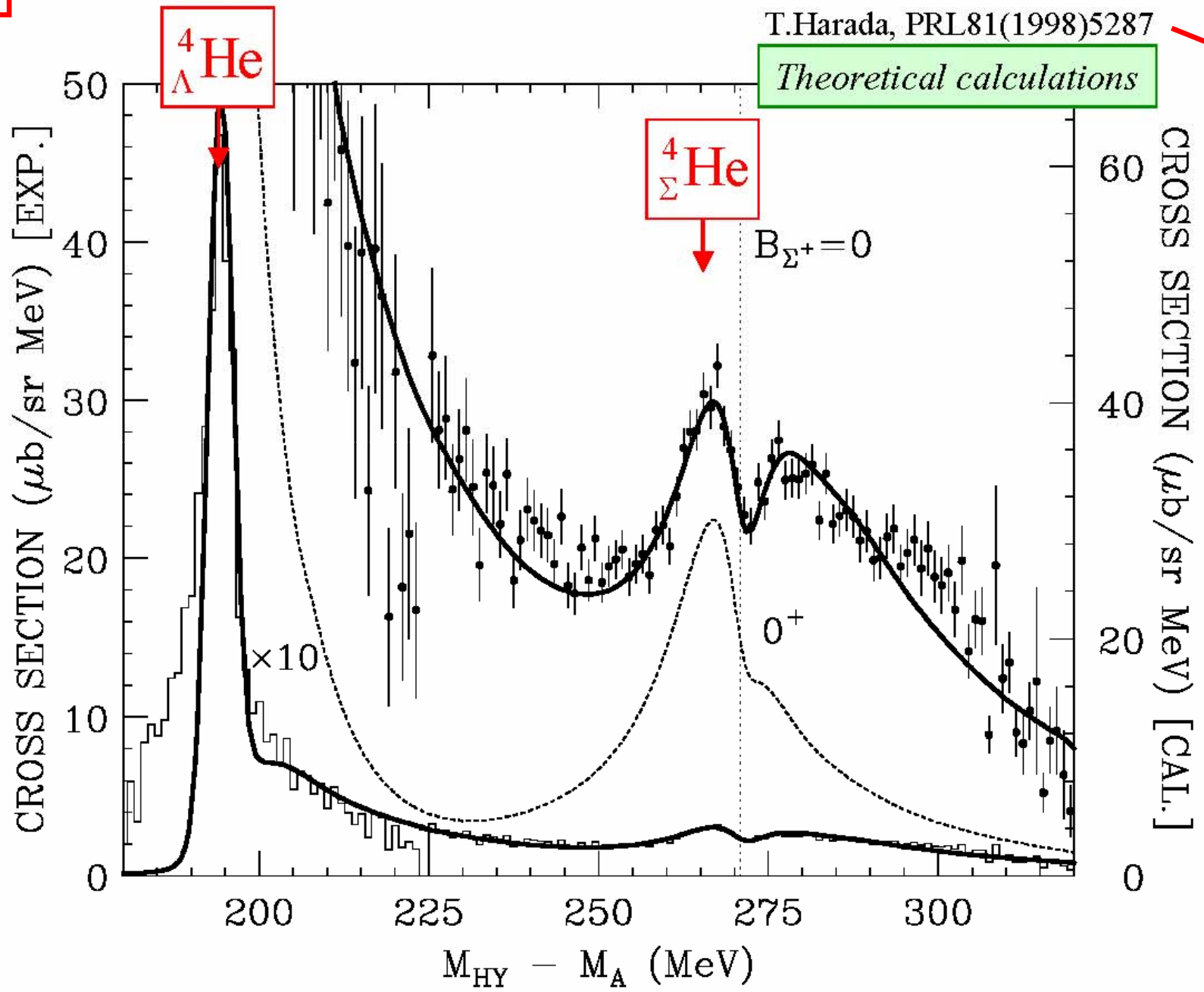
- Σ^-- atomic X ray data suggest that…
  - attractive/m. absorptive in tρ-potential
  - repulsive/s. absorptive in DD-potential
    (C.J. Batty, E. Friedman, and A. Gal, PTP117(1994)227)

- No other data is available…
  - Poor YN Scattering Data
  - $(K^-,\pi^\pm)$ spectra on $A \leqq 16$
    V_Σ(Re U_Σ)>-10 MeV from ^{12}C(stopped K^-,π^+)

by M. Iwasaki

$\Sigma^{+,0}$

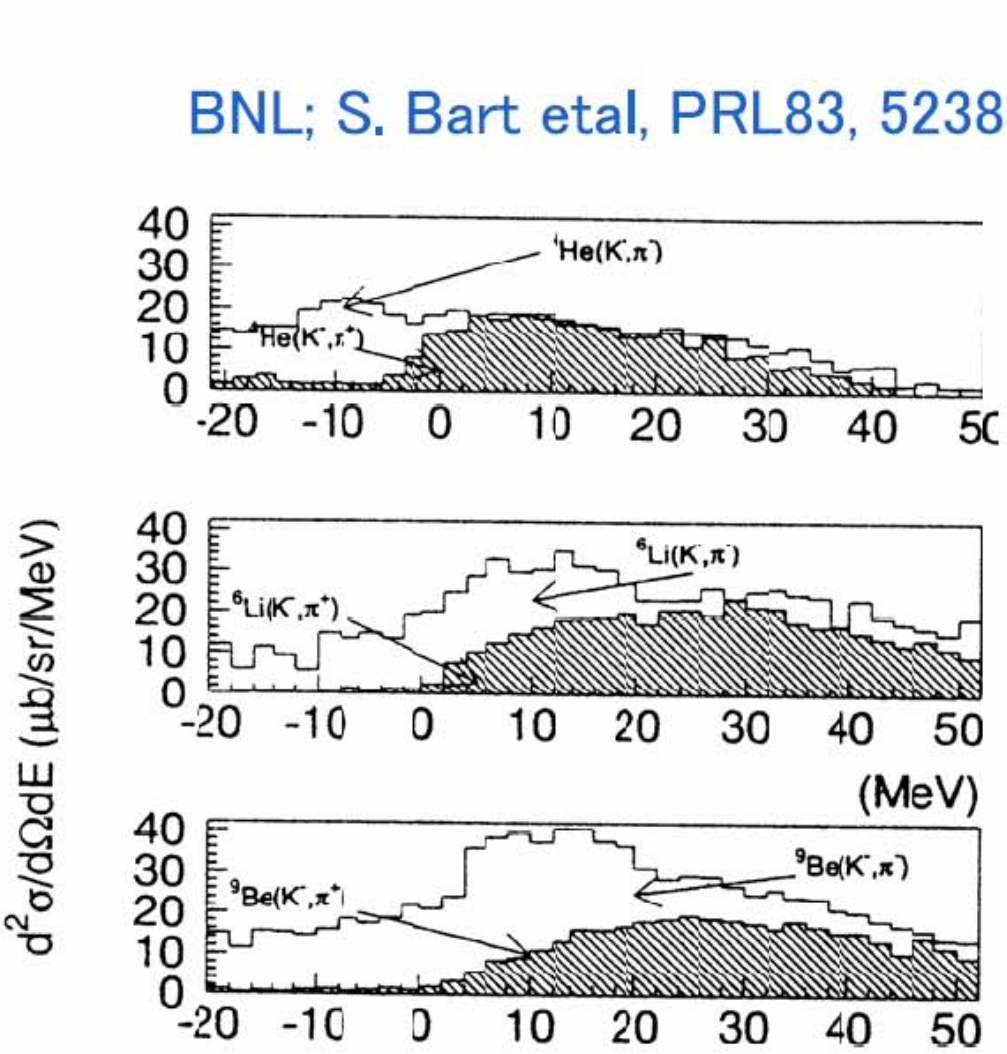
^{4}He(K$^-$,π^-) spectrum at 600 MeV/c (BNL)

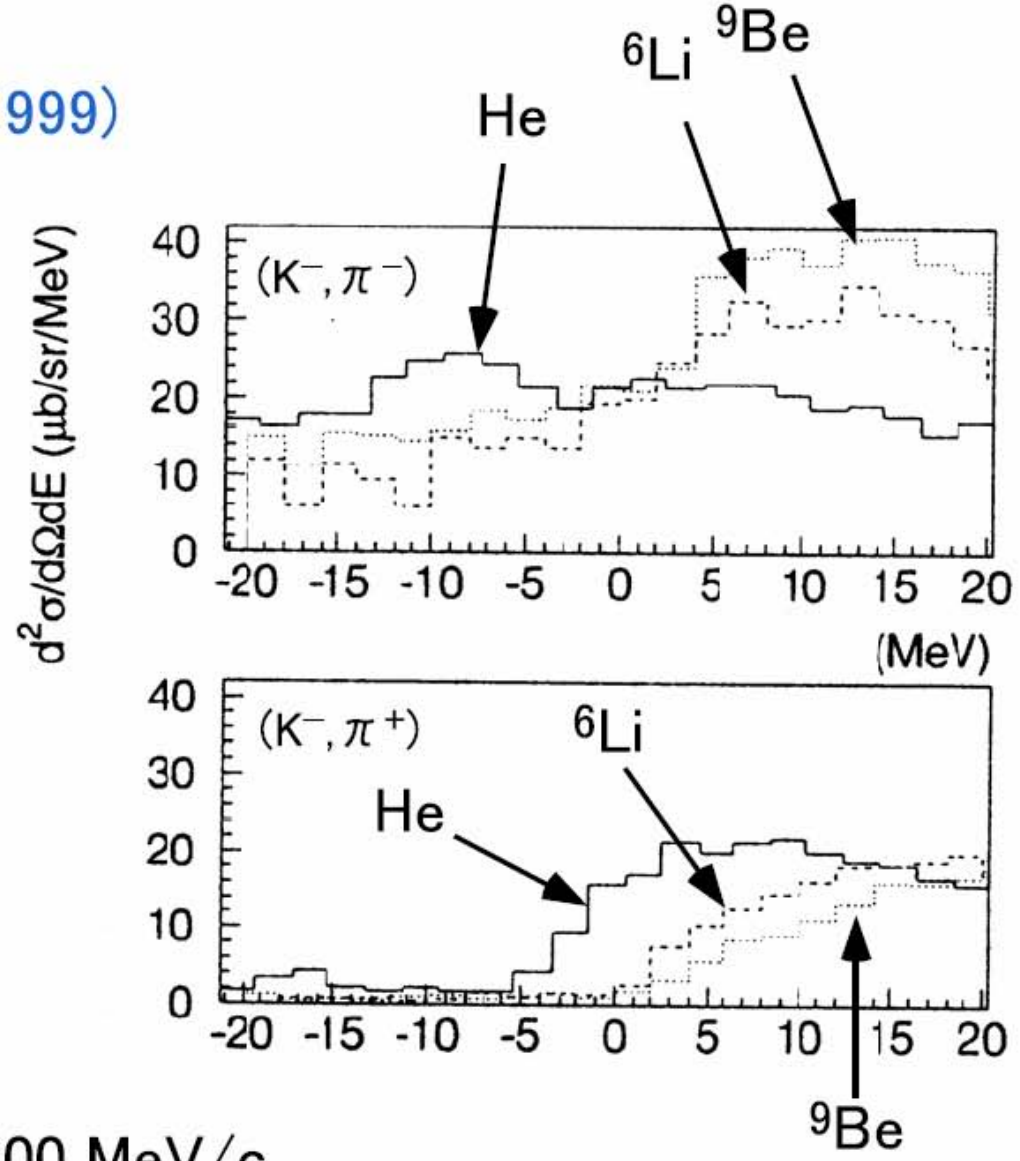


Histogram and closed cirles:T. Nagae et al., PRL80(`98)1605

Strong Isospin-Dependence of Σ-Nucleus Potential

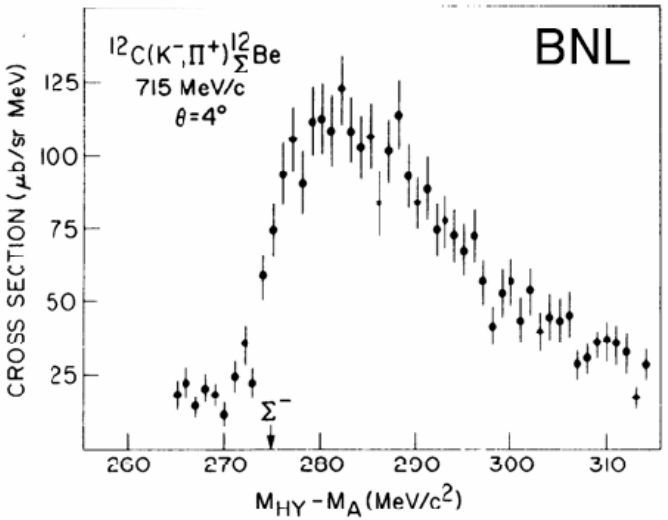
BNL; S. Bart etal, PRL83, 5238(1999)

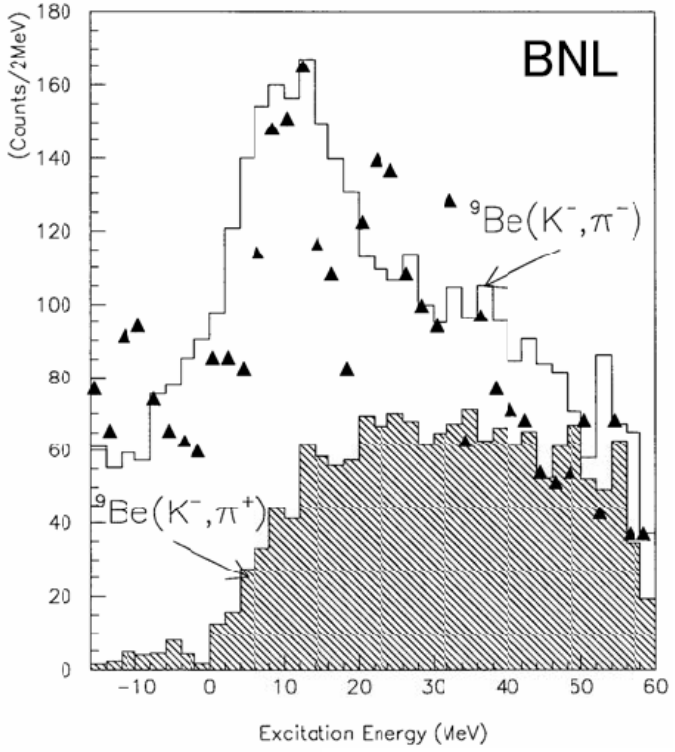


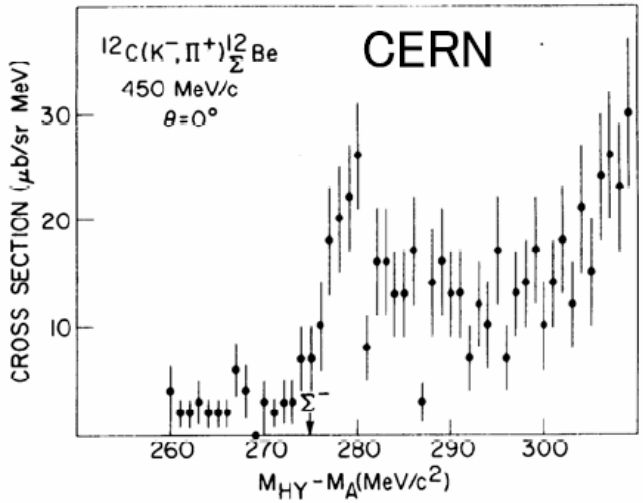


P_{K^-}=600 MeV/c

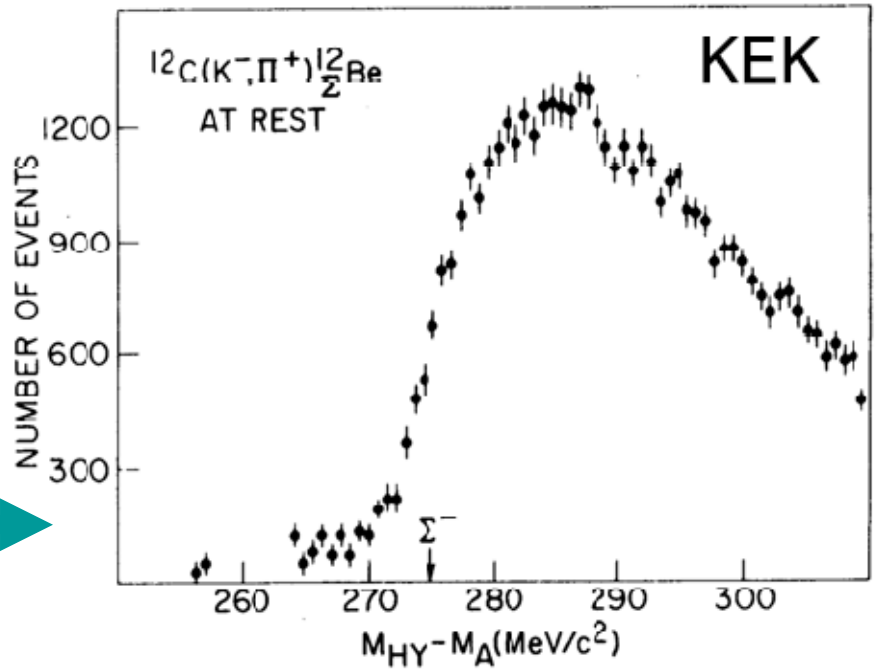
$(K^-, \pi^\pm)$ spectra A≦16 ; insufficient statistics, no BG free no peak







^{12}C(stopped K^-, π^+)



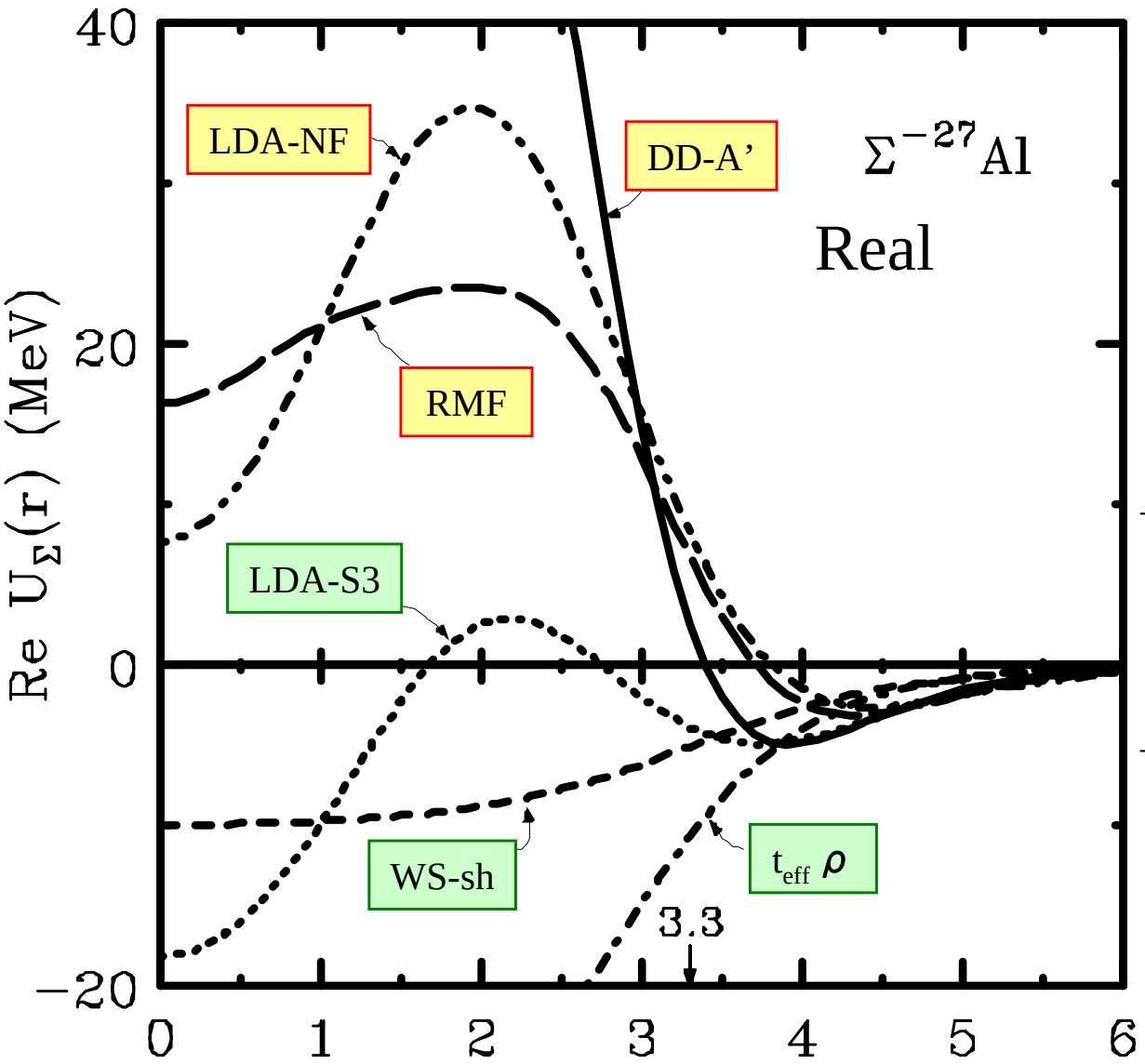
M. Iwasaki, Dr. Thesis, '87

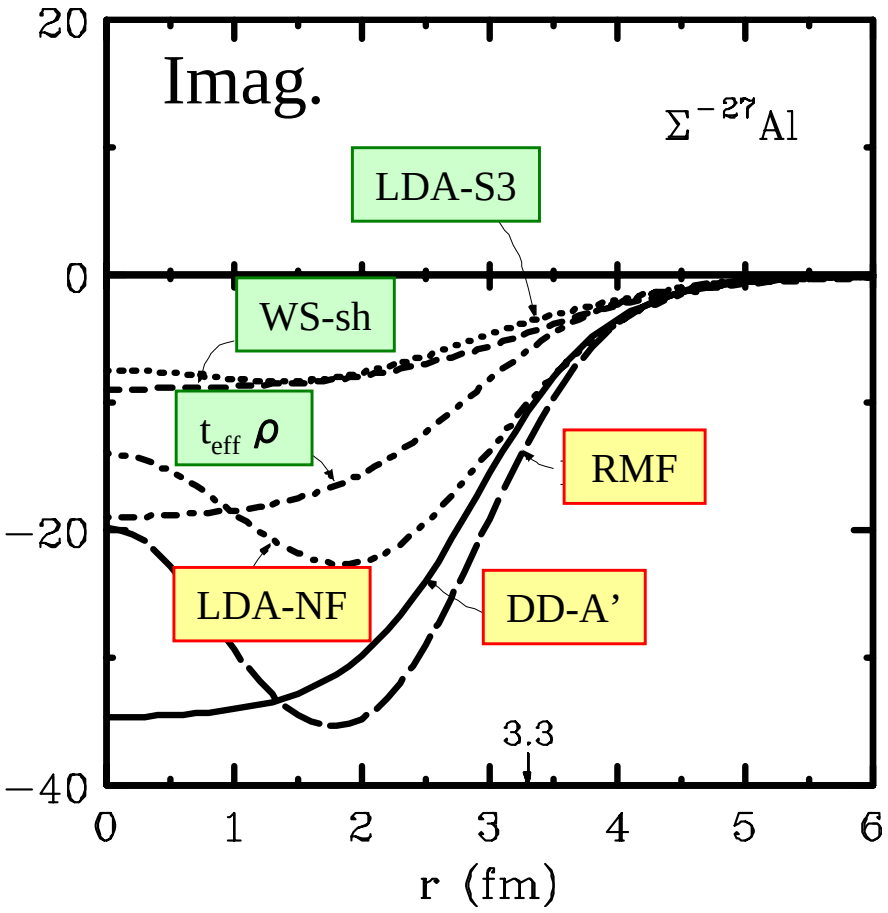
$V_\Sigma > -12$ MeV

$W_\Sigma < -7$ MeV if $-7 > V_\Sigma > -10$ MeV

undetermined if $V_\Sigma < 5$ MeV

Σ^--nucleus optical potentials in $^{27}Al+\Sigma^-$





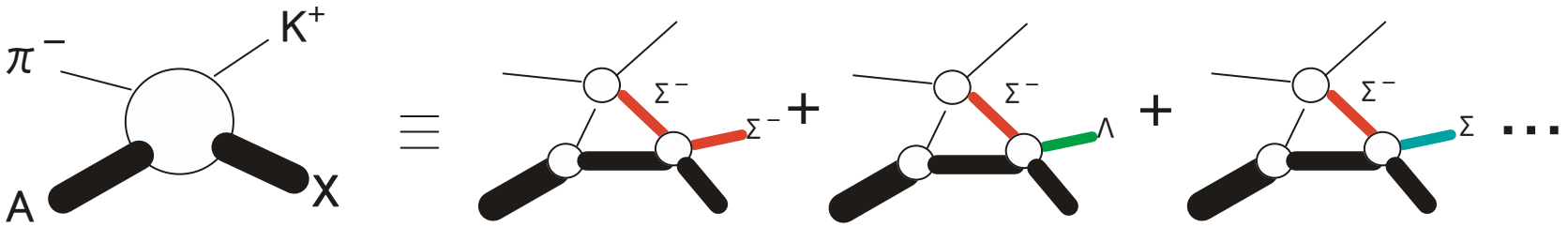
Compiled by
T. Harada (Osaka-EC)

	Real part	Imag. part		Real part	Imag. part
Type I	repulsive	strong (30-40MeV)	**Type II**	(weak) attractive	weak (< 10MeV)

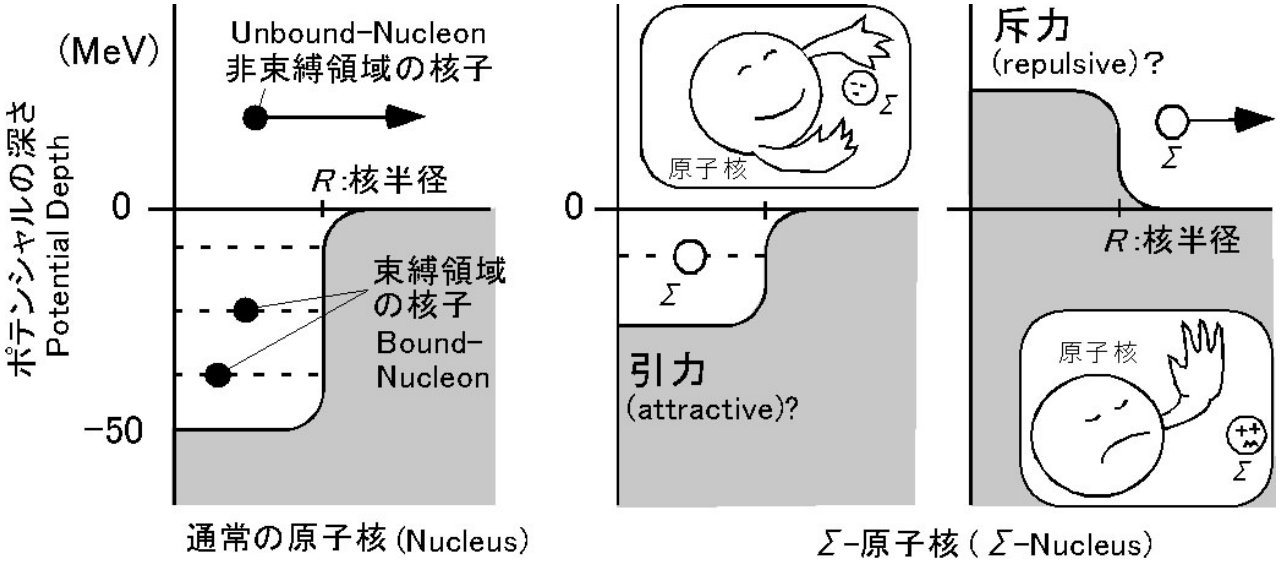
E438: Study of Σ-nucleus potential by the (π,K⁺) reaction on heavy nuclei

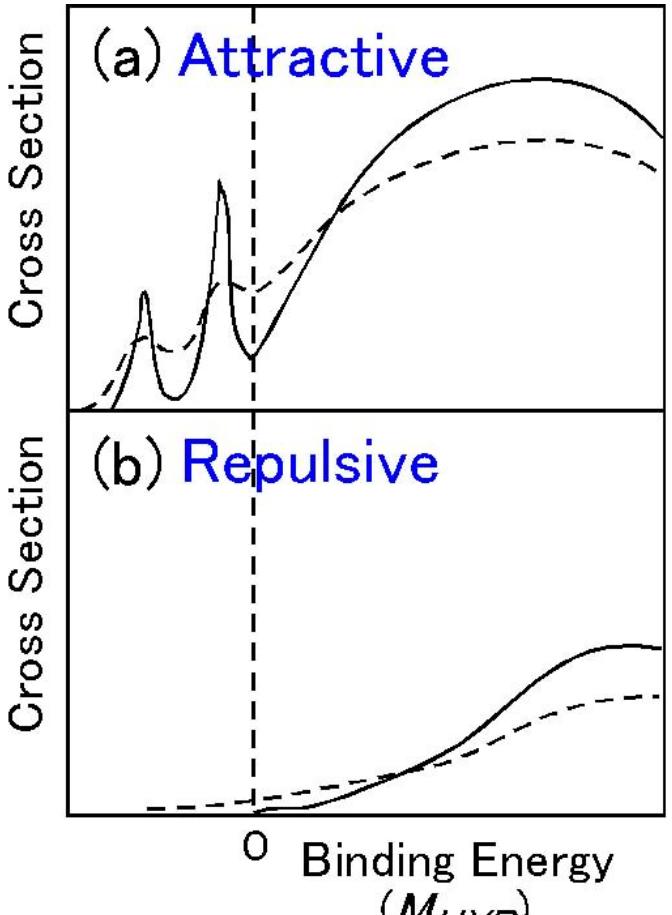
$U_\Sigma = V_\Sigma + i\,W_\Sigma$

No Σ-hypernuclear bound states, but ${}^{4}_{\Sigma}\mathrm{He}$



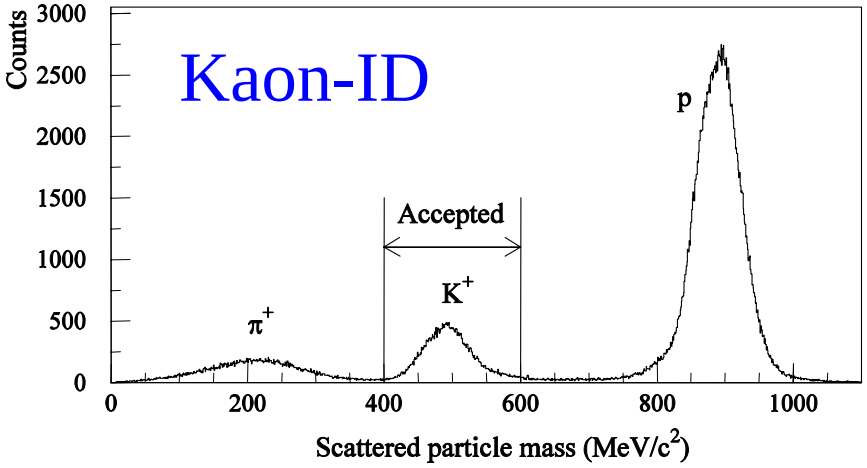
Inclusive spectrum tells the Σ potential…

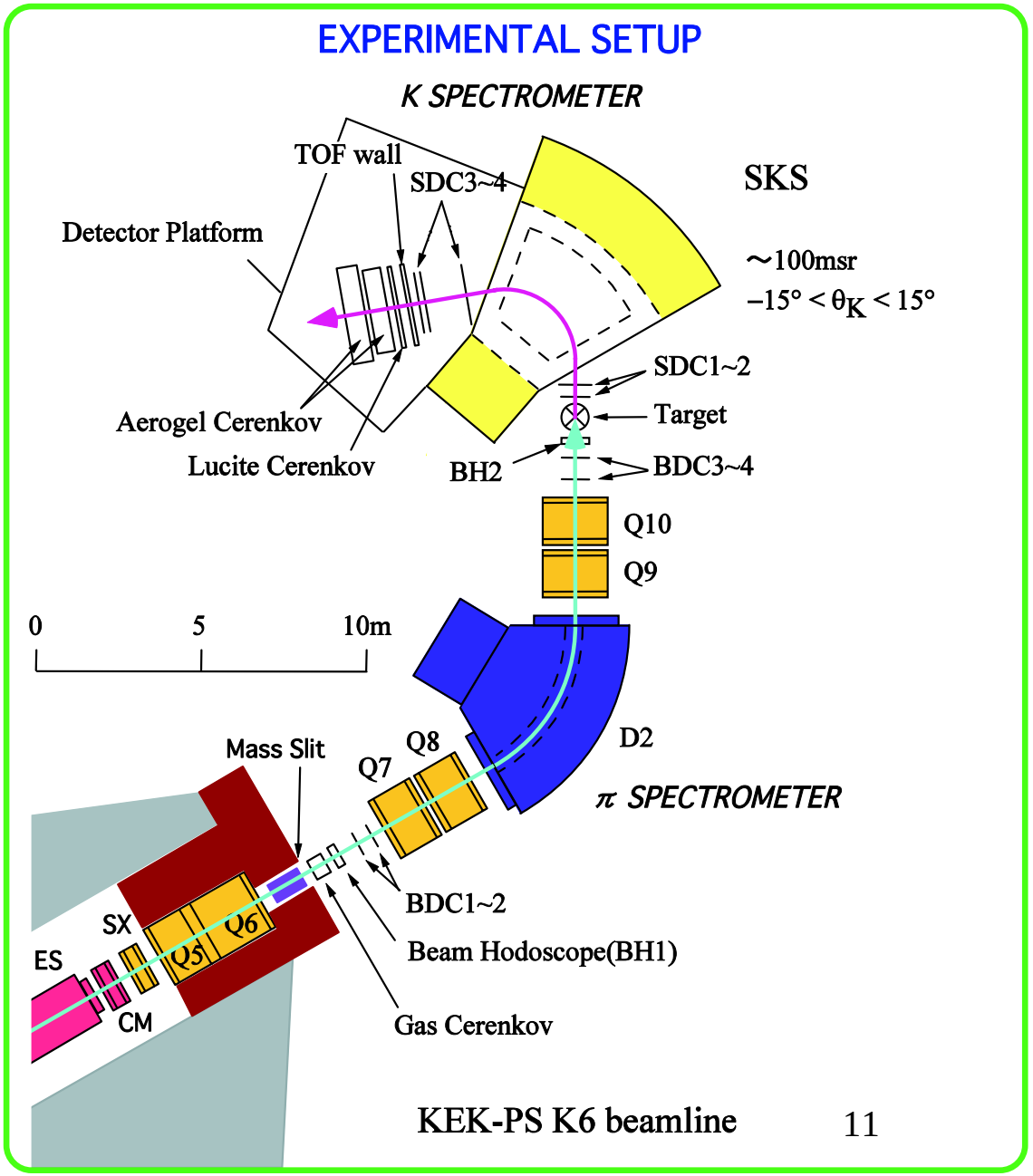




Inclusive (π^-,K^+) spectra at p_{beam}=1.2 GeV/c on CH_2, Si, Ni, In and Bi were measured at KEK-PS K6 with SKS in Oct. & Dec., 1999.

- Energy Resolutions
  3.3~5.2 MeV (depend on t_{TGT})
  maintain a sensitivity to W_Σ.
- Energy/Cross Section Scales
  calibrated by p(π^-,K^+)Σ^- .
- Large Solid Angle
  Wide Mom. Acceptance
  covered by SKS.
- Clear Event Selection (BG free)



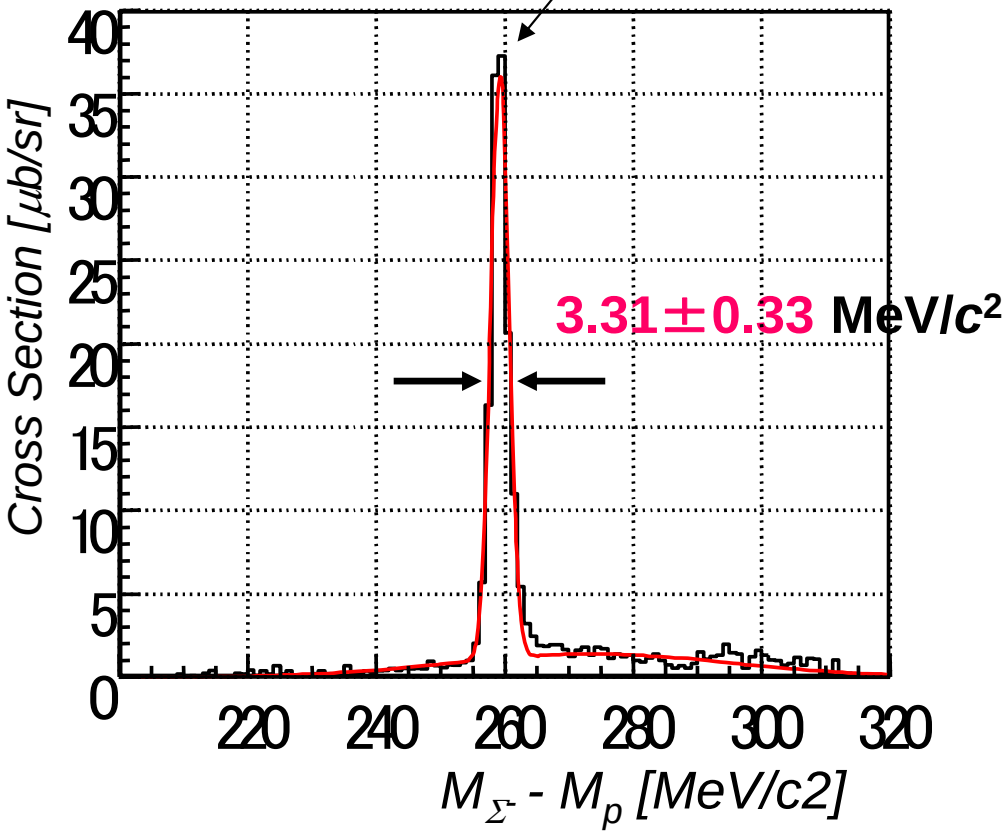


Energy Scale
Energy Resolution

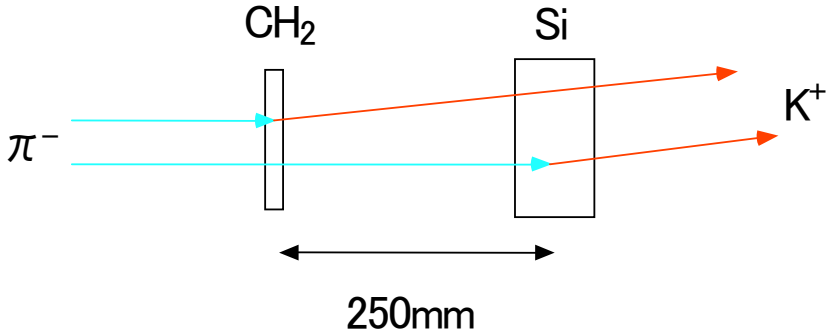
Elementary Peak

259.23±0.13 MeV/c^2

(c.f. 259.18±0.03, PDG)

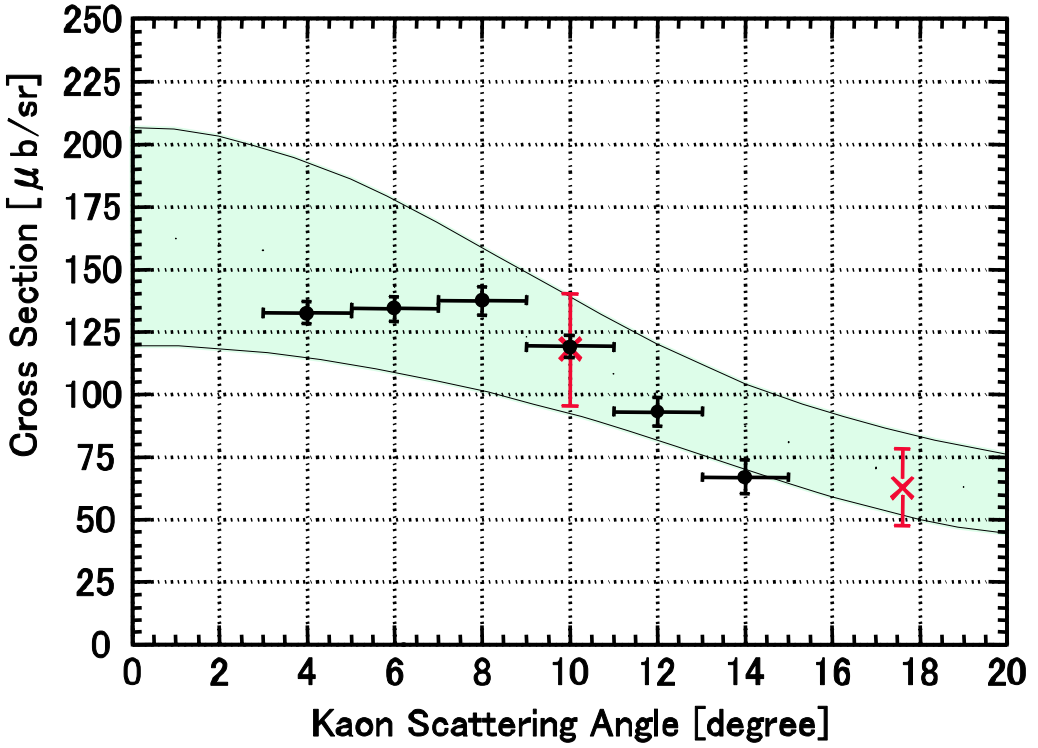


Target Setup and Z-Vertex Distribution



Cross Section Scale

Angular Dist. of the $p(\pi,K^+)\Sigma^-$ Reaction



Present Data

Previous Data @ 1.225 GeV/c

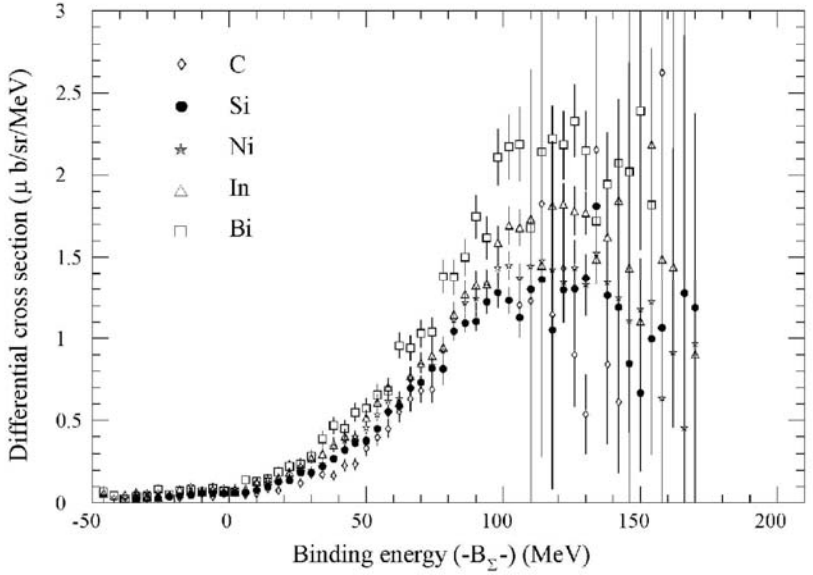
(Curves: Error Boundary from the Legendre Poly. Fitting)

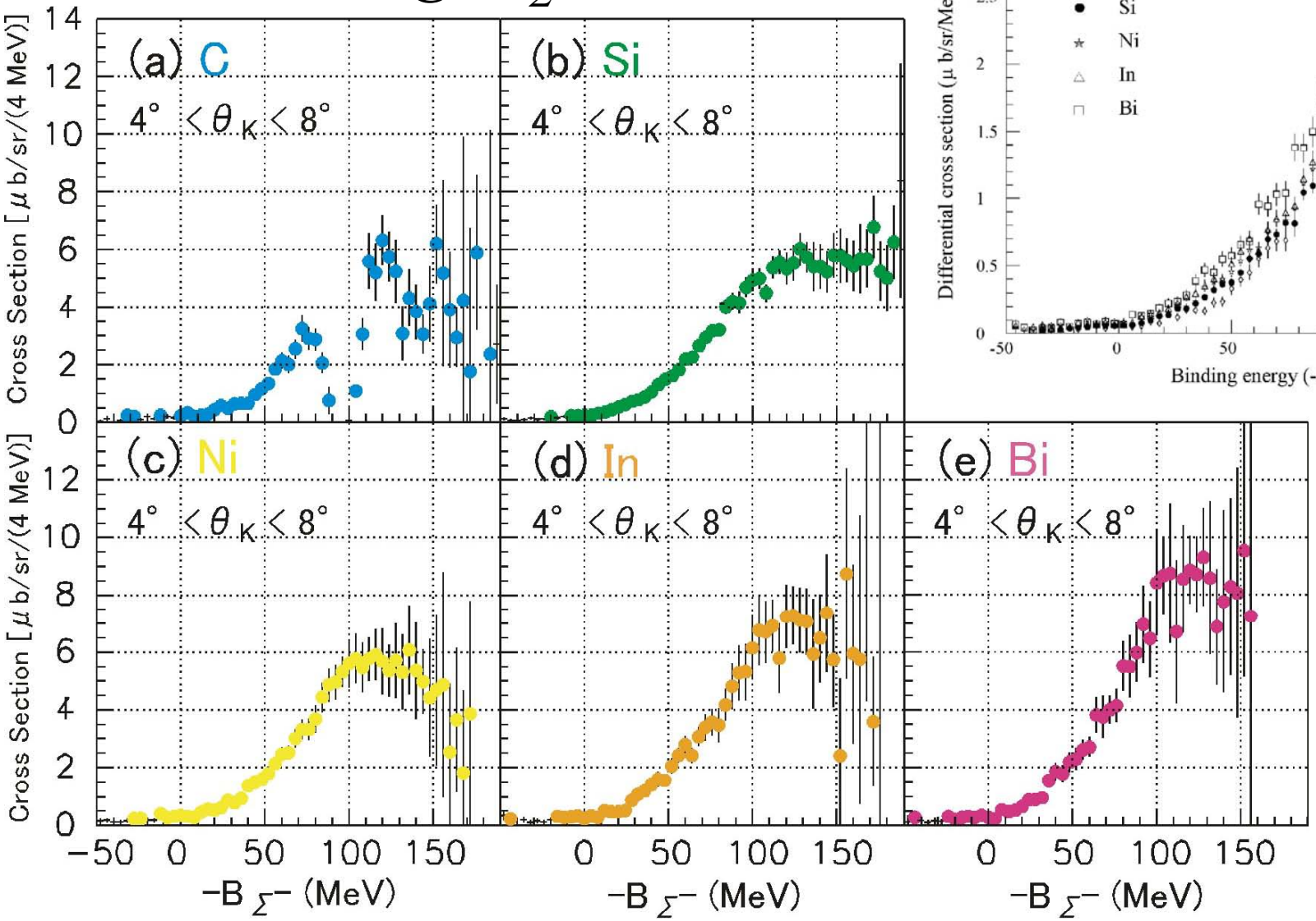
PR 183(1969)1142

Measured Inclusive (π,K^+) Spectra on C, Si, Ni, In, & Bi

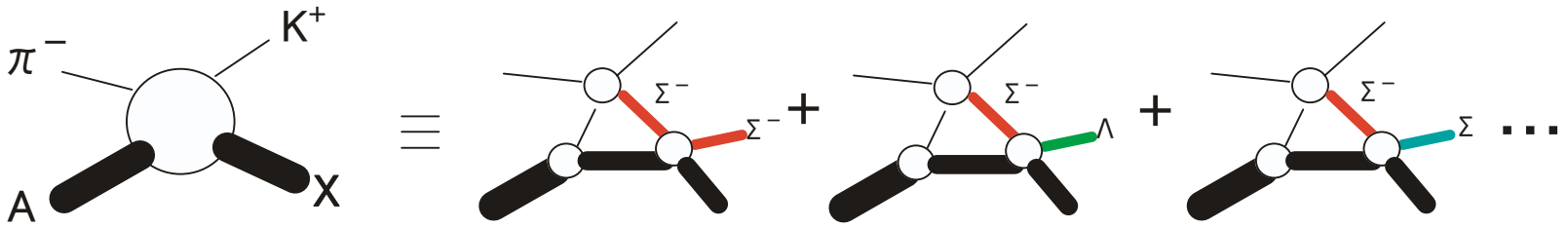
- Similar Shape
- No peak in $-B_\Sigma-$ <0 MeV
- Maximum @ $-B_\Sigma-$ >120 MeV

P. K. Saha, PhD thesis, KEK-Rep.2001-17
P. K. Saha, Phys. Rev. C70, 044613(2004)





Spectrum Analysis based on DWIA



Inclusive (π^-,K^+) Spectrum

$$d^2\sigma/d\Omega dE = \beta \cdot \overline{d\sigma/d\Omega}_{elem} \cdot S(E)$$

Strength Function:

$$S(E) = -1/\pi \; Im \sum_{\alpha\,\alpha'} \int dr dr' \, [f^{+}_{\alpha}(r') G_{\alpha\,\alpha'}(E;r',r) f_{\alpha'}(r)]$$

$$f_{\alpha}(r) = \chi^{(-)*}(R)\chi^{(+)}(R) \langle \alpha | \psi_N(r) | i \rangle, \; R=(M_c/M_{hy})r$$

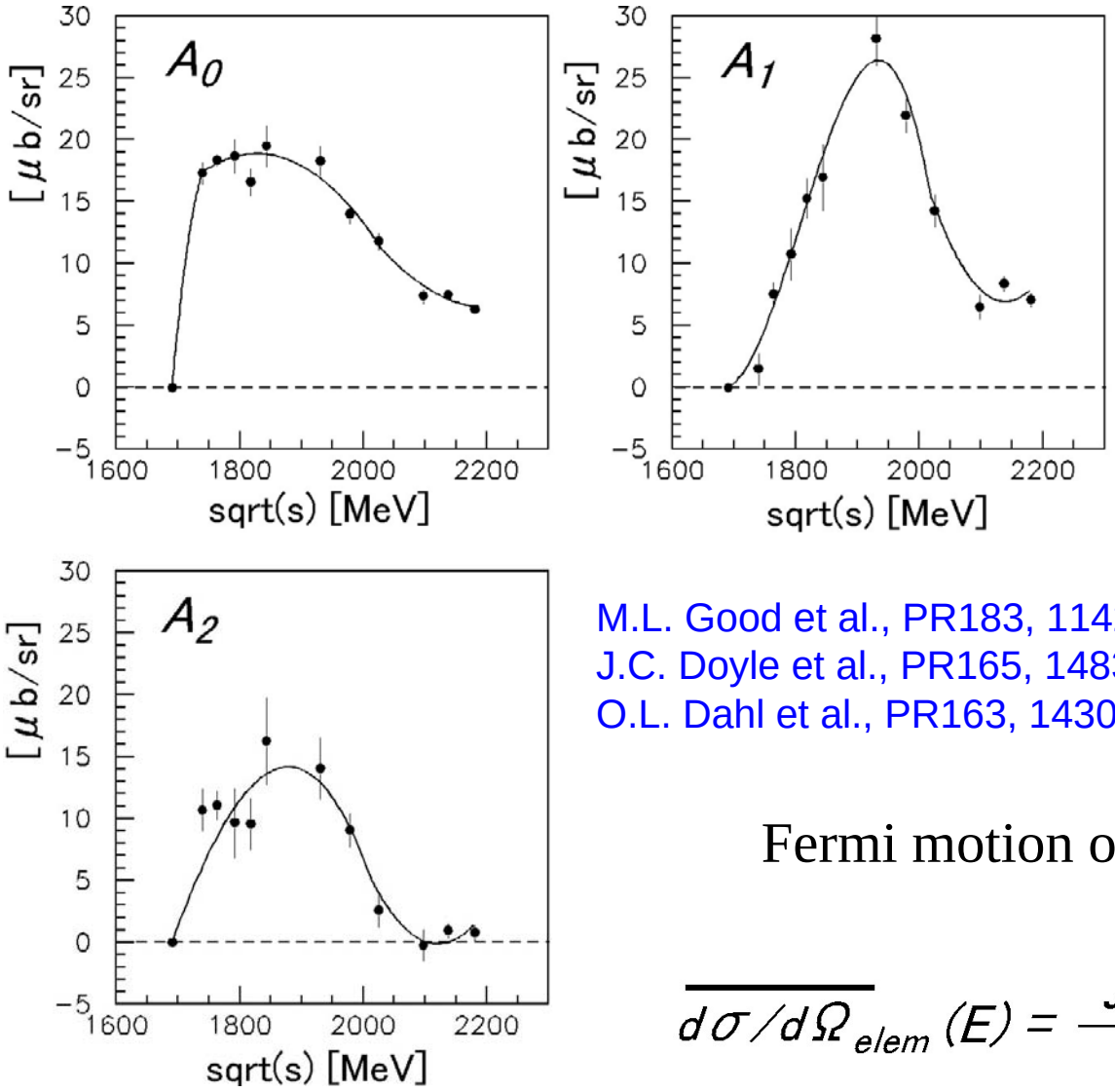
Green's Function:

$$G_{\alpha\,\alpha'}(E;r',r) = \langle \alpha | \psi_{\Sigma}(r) \frac{1}{E - H + i\eta} \psi^{+}_{\Sigma}(r') | \alpha' \rangle$$

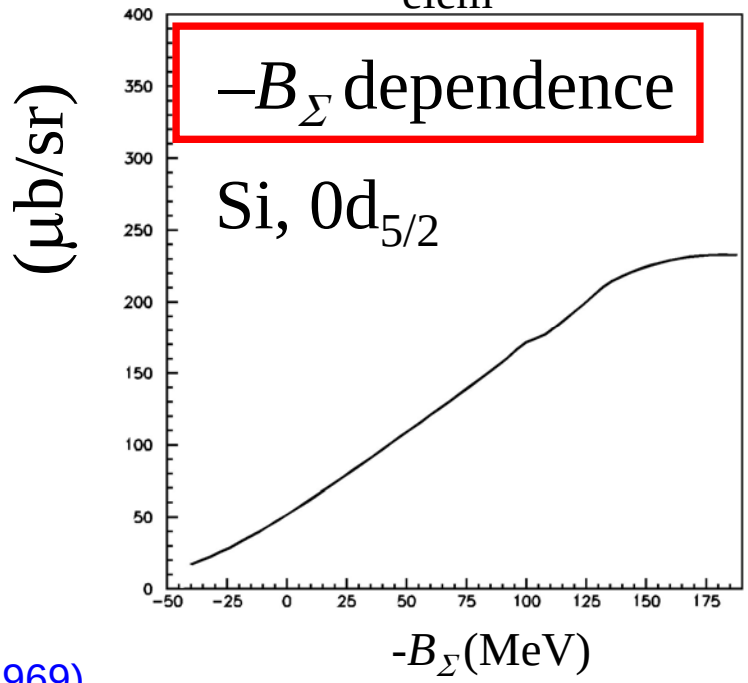
$$\rightarrow \quad \left(\frac{\hbar^2}{2\mu}\Delta + E - U_{\Sigma}\right) G(E;r',r) = -\delta(r'-r)$$

Fermi-averaging of the Elementary Cross Section

$d\sigma/d\Omega_{\Sigma}$-(s,t) = $\sum_n A_n P_n(\cos\theta_{K^+})$ in CM

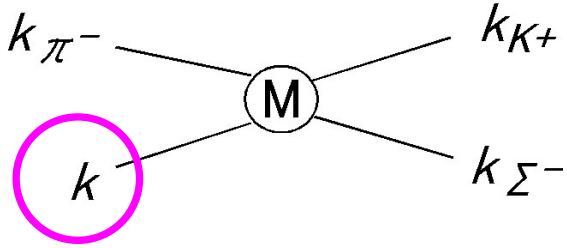


$\overline{d\sigma/d\Omega}_{elem}$ in Lab



M.L. Good et al., PR183, 1142(1969)
J.C. Doyle et al., PR165, 1483(1968)
O.L. Dahl et al., PR163, 1430(1967)

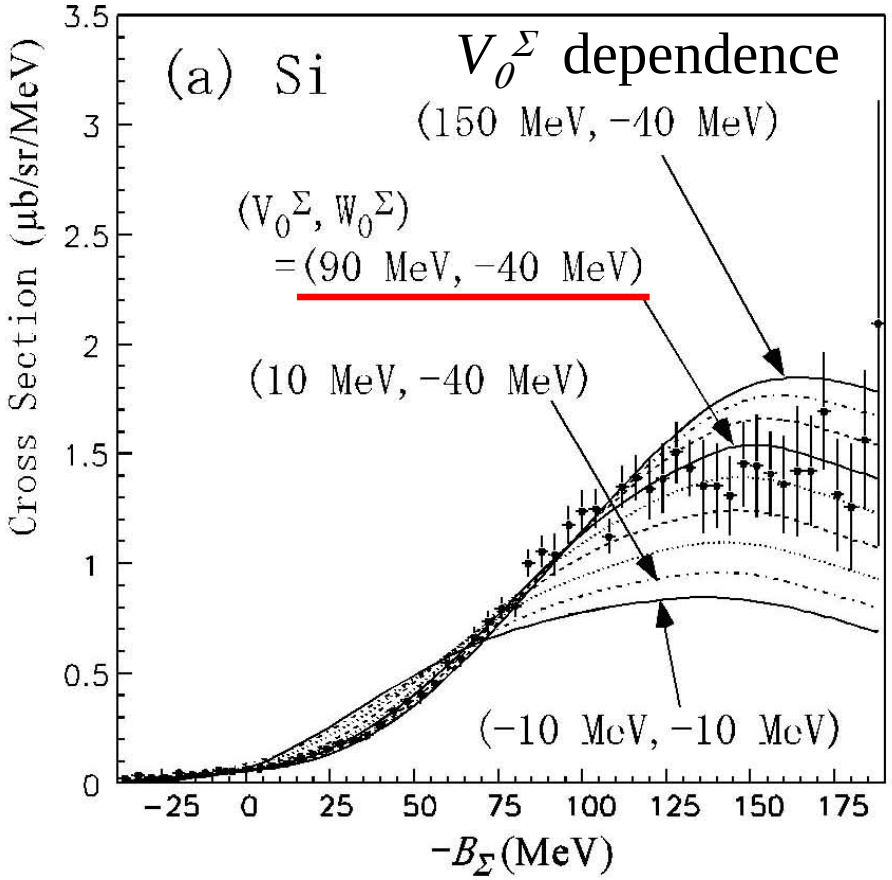
Fermi motion of a proton →

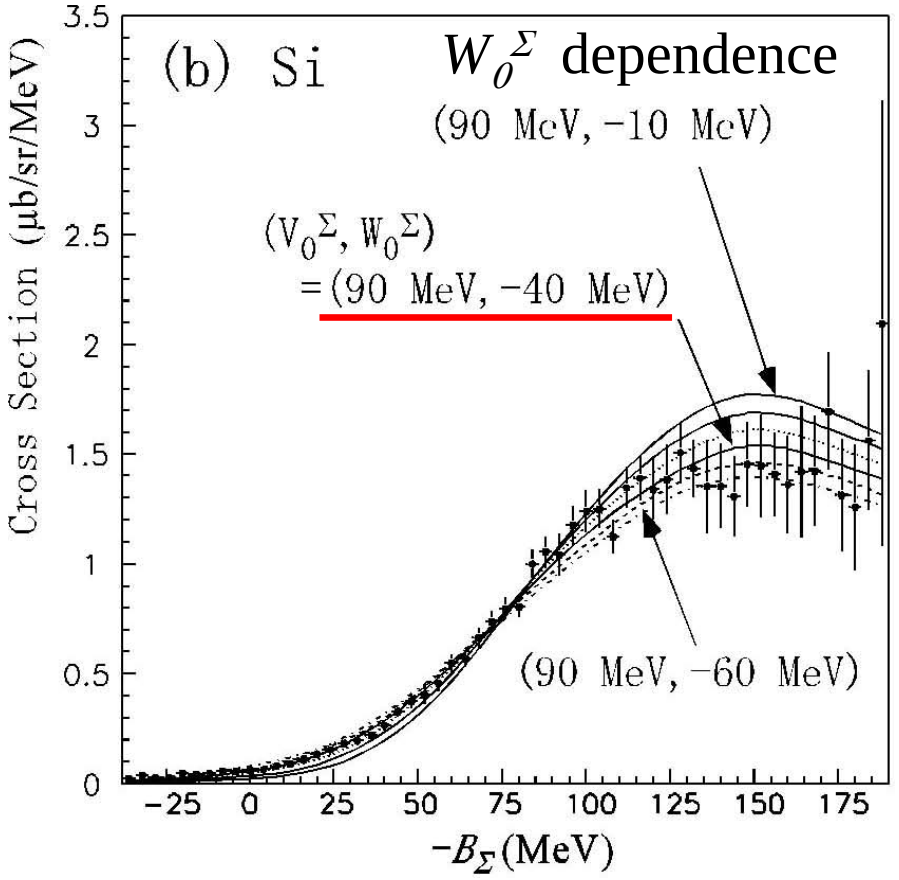


$$\overline{d\sigma/d\Omega}_{elem}(E) = \frac{\int \rho(\mathbf{k})[d\sigma/d\Omega(s,t)]\delta(\mathbf{k}-\mathbf{P})d\mathbf{k}}{\int \rho(\mathbf{k})\delta(\mathbf{k}-\mathbf{P})d\mathbf{k}}$$

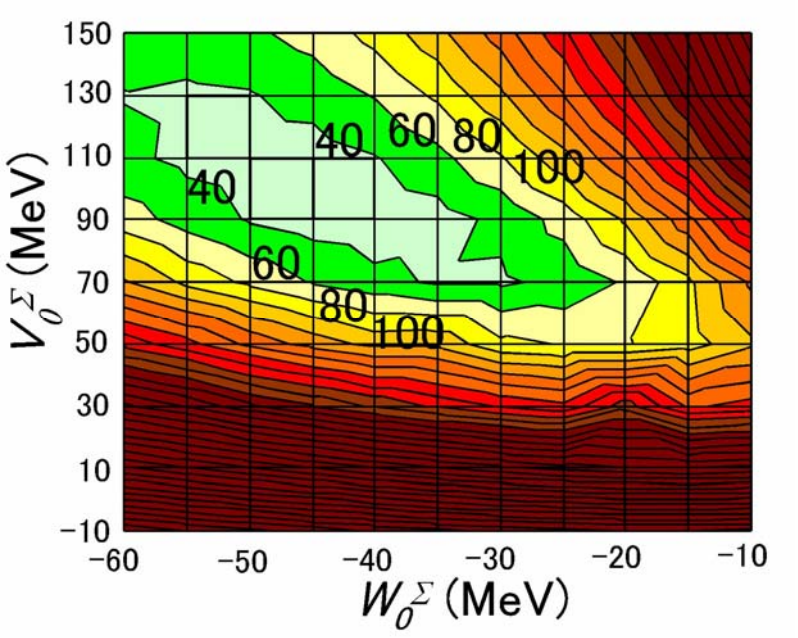
$$P = k_{K+} + k_{\Sigma^-} - k_{\pi^-}$$

Compared with DWIA Cal. - Fitting Results -





χ^2 dist. (dof=56)



W.S. Potential Params

	U_Σ	U_{Si}
z(fm)	0.67	0.537
c(fm)	3.3	3.82
V0(MeV)		-54.5

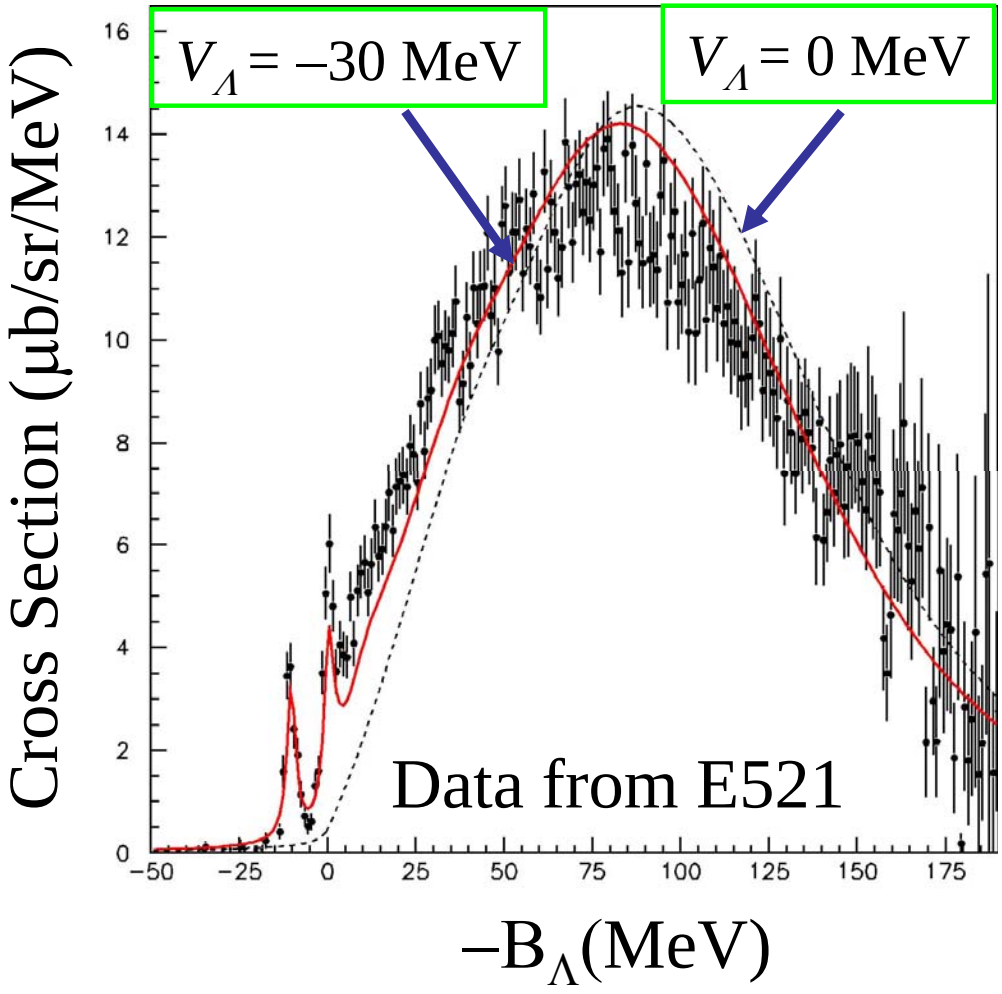
DWIA application to…

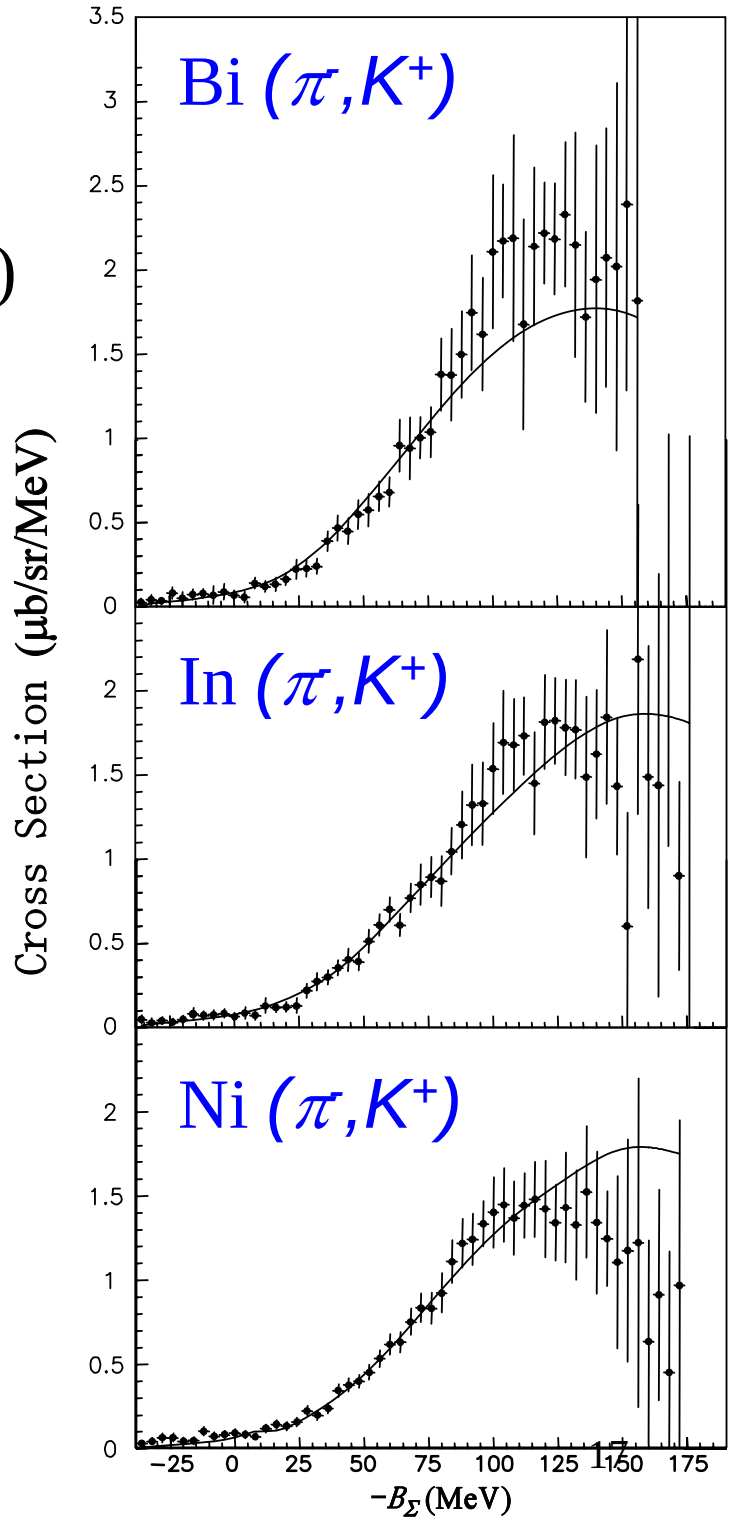
Ni, In, Bi(π,K^+)

w/ (V_0^Σ, W_0^Σ) = (90 MeV, -40 MeV)

^{12}C (π^+,K^+) at $\theta_K = 6^o \pm 2^o$

p_π=1.2 GeV/c





Concluding Remarks of E438

1. Inclusive (π^-,K^+) spectra on CH_2, Si, Ni, In, & Bi were measured with a good resolution (3~5 MeV in FWHM).
   1.1 The measured spectra show a similar shape.
   1.2 No peak structure in the bound region
   1.3 The maximum at $-B_{\Sigma^-}$ >120 MeV

2. The measured spectra on Si, Ni, In, & Bi were compared to calculated ones within the framework of the DWIA.
   2.1 A repulsive Σ^--nucleus potential with a non-zero size of the imaginary part was required to reproduce the measured (π^-,K^+) spectra in shape.
   2.2 This framework was successfully applied to reproduce the (π^+,K^+) spectrum on C.
   Fermi-averaging of the elementary reaction on mass-shell condition is required. → Optimal Fermi Averaging

E438

VOLUME 89, NUMBER 7 PHYSICAL REVIEW LETTERS 12 AUGUST 2002

Sigma-Nucleus Potential in $A = 28$

H. Noumi,[1] P. K. Saha,[1,*] D. Abe,[2] S. Ajimura,[3] K. Aoki,[1] H. C. Bhang,[4] T. Endo,[2] Y. Fujii,[2] T. Fukuda,[1,*] H. C. Guo,[5] K. Imai,[7] O. Hashimoto,[2] H. Hotchi,[6,†] E. H. Kim,[4] J. H. Kim,[4] T. Kishimoto,[3] A. Krutenkova,[8] K. Maeda,[2] T. Nagae,[1] M. Nakamura,[6] H. Outa,[1] M. Sekimoto,[1] T. Saito,[2,‡] A. Sakaguchi,[3] Y. Sato,[1,2] R. Sawafta,[9] Y. Shimizu,[3,*] T. Takahashi,[2] L. Tang,[10] H. Tamura,[2] K. Tanida,[6] T. Watanabe,[2] H. H. Xia,[5] S. H. Zhou,[5] L. H. Zhu,[7] and X. F. Zhu[5]

[1]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[2]*Department of Physics, Tohoku University, Sendai 980-8578, Japan*
[3]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[4]*Department of Physics, Seoul National University, Seoul 151-742, Korea*
[5]*Department of Nuclear Physics, CIAE, P.O. Box 275(80), Beijing 102413, China*
[6]*Graduate School of Science, University of Tokyo, Tokyo 113-003, Japan*
[7]*Department of Physics, Kyoto University, Sakyo, Kyoto 606-8502, Japan*
[8]*Institute of Theoretical and Experimental Physics, Moscow 117218, Russia*
[9]*Physics Department, North Carolina A&T State University, Greensboro, North Carolina 27411*
[10]*Department of Physics, Hampton University, Hampton, Virginia 23668*

(Received 16 December 2001; published 30 July 2002)

We have studied the (π^-, K^+) reaction on a silicon target to investigate the sigma-nucleus potential. The inclusive spectrum was measured at a beam momentum of 1.2 GeV/c with an energy resolution of 3.3 MeV (FWHM) by employing the superconducting kaon spectrometer system. The spectrum was compared with theoretical calculations within the framework of the distorted-wave impulse approximation, which demonstrates that a strongly repulsive sigma-nucleus potential with a nonzero size of the imaginary part reproduces the observed spectrum.

DOI: 10.1103/PhysRevLett.89.072301 PACS numbers: 21.80.+a, 13.75.Ev, 25.80.Hp, 25.80.Nv

The sigma(Σ)-nucleus potential describe
of a Σ hyperon in the nuclear medium.
Σ-nucleus potential is still unclear becaus

Papers: published in PRL89(2002)072301
PRC70(2004)044613

Recent Theoretical Analysis

(π^-,K^+) reaction at 1.2GeV/c

^{28}Si Σ^-

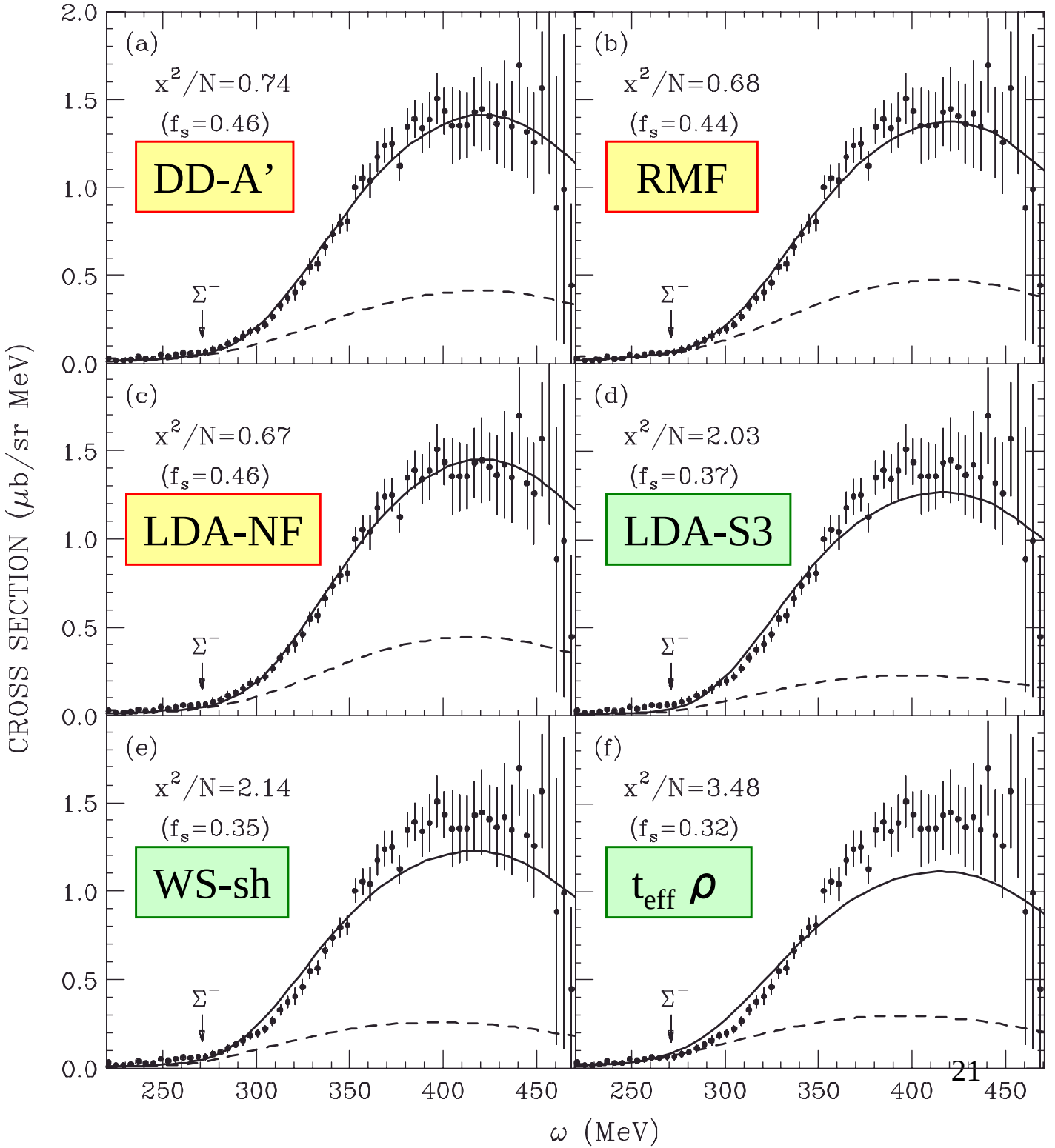
by T. Harada (Osaka-EC)

repulsive

attractive

DWIA analysis with the optimal Fermi-averaging

T.Harada, Y.Hirabayashi, NPA759 (2005) 143



Comparison with resent studies

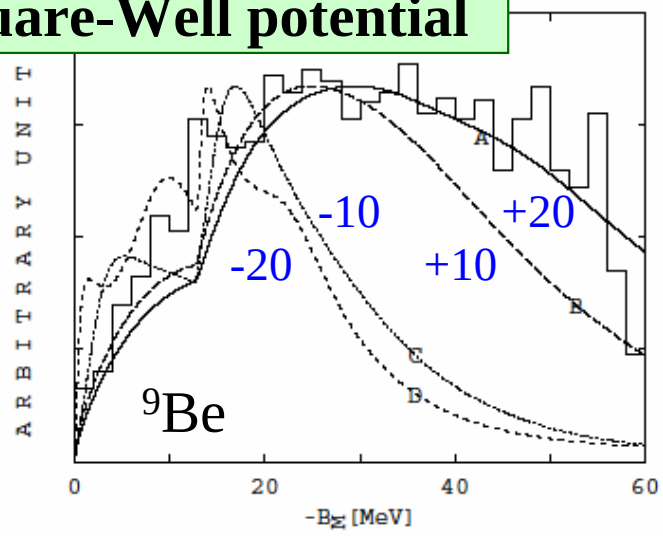
Compiled by T. Harada

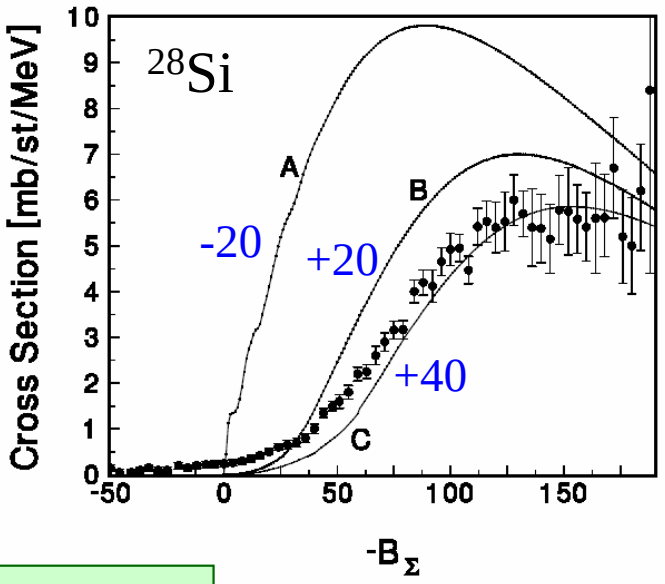
PWIA Analysis with the Square-Well potential

J. Dabrowski, PRC60 (1999) 025205.

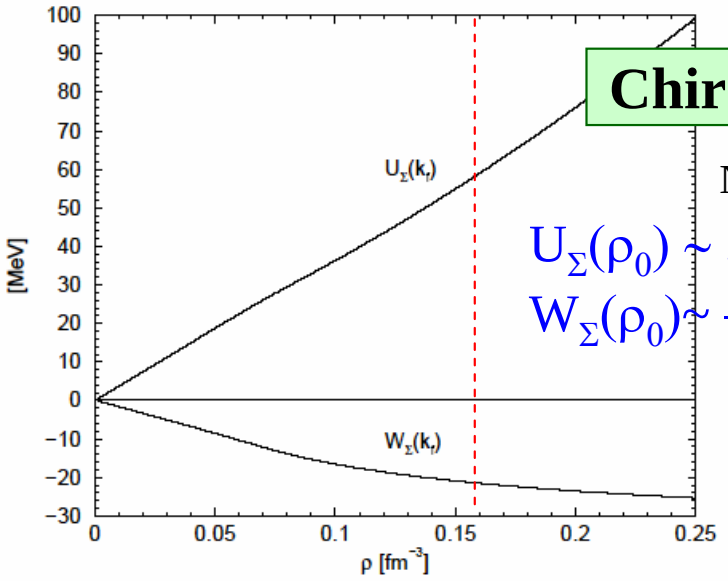
J. Dabrowski, J. Rozynek, Acta. Phys. Pol. B35 (2004) 2303.

"The Σ s.p. potential is repulsive inside nucleus. Only NHC-F is acceptable."





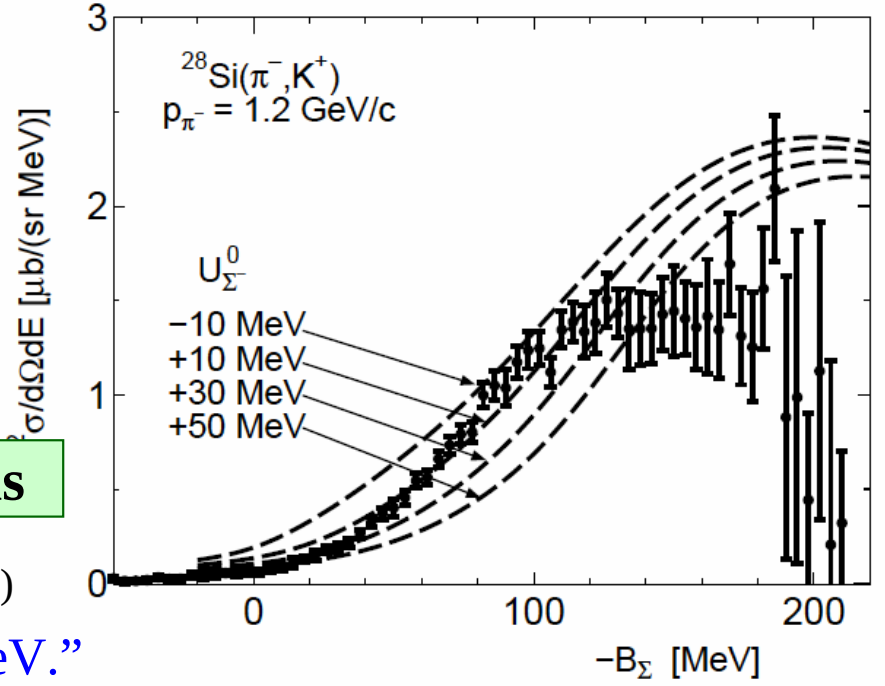
Chiral dynamics in the nuclear medium



N. Kaiser, PRC71 (2005) 068201

$U_\Sigma(\rho_0) \sim 59$MeV : repulsive

$W_\Sigma(\rho_0) \sim -21$MeV



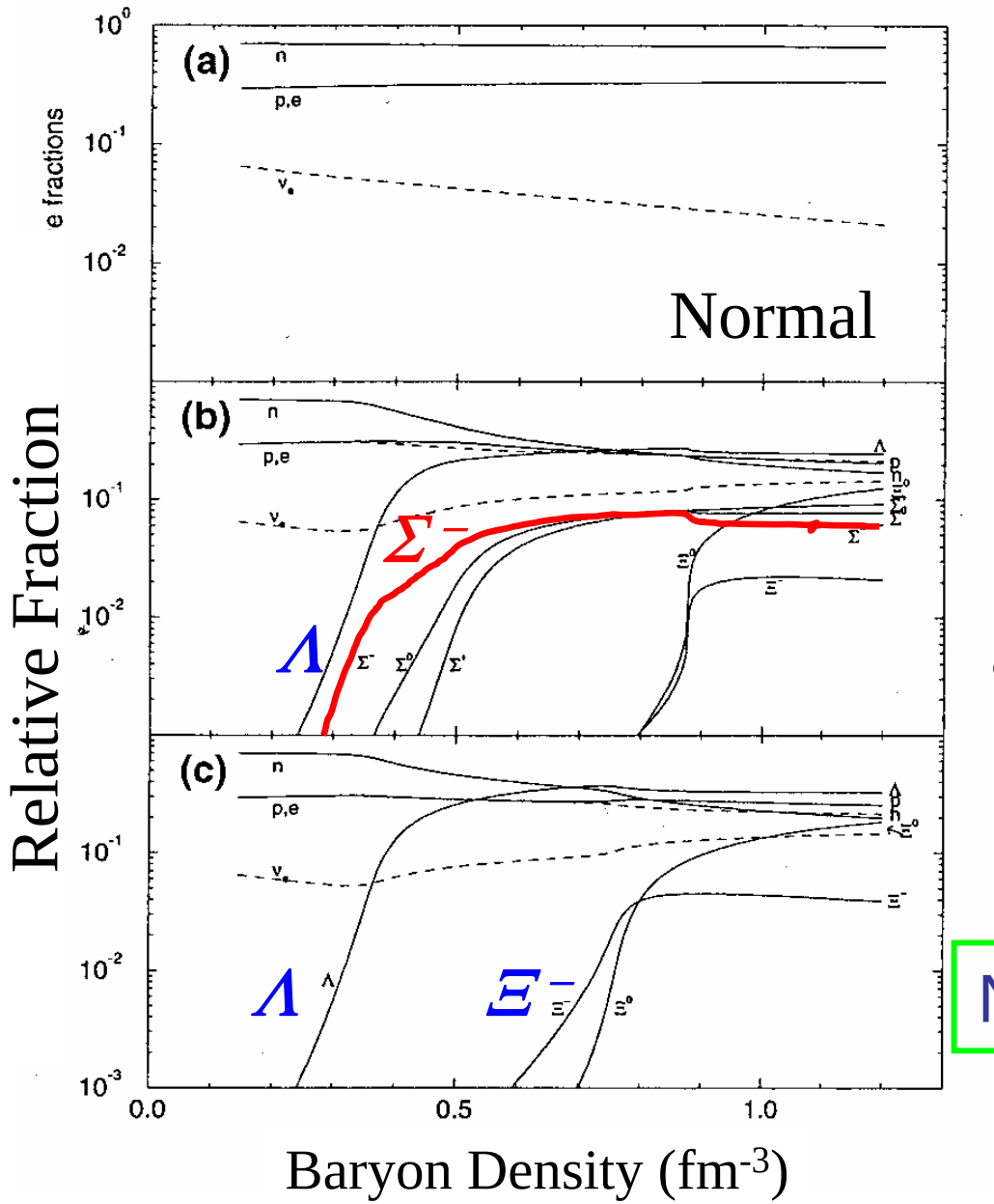
Semi-Classical Distorted Wave Model Analysis

M. Kohno, Y. Fujiwara, et al., nucl-th/0611080 (2006)

"The repulsive Σ potential is not so strong as ~100MeV."

Impact of the repulsive Σ-Nucleus Potential on Hyperon Constituent in Neutron Star Cores

S. Balberg and A. Gal, NPA625(1997)435

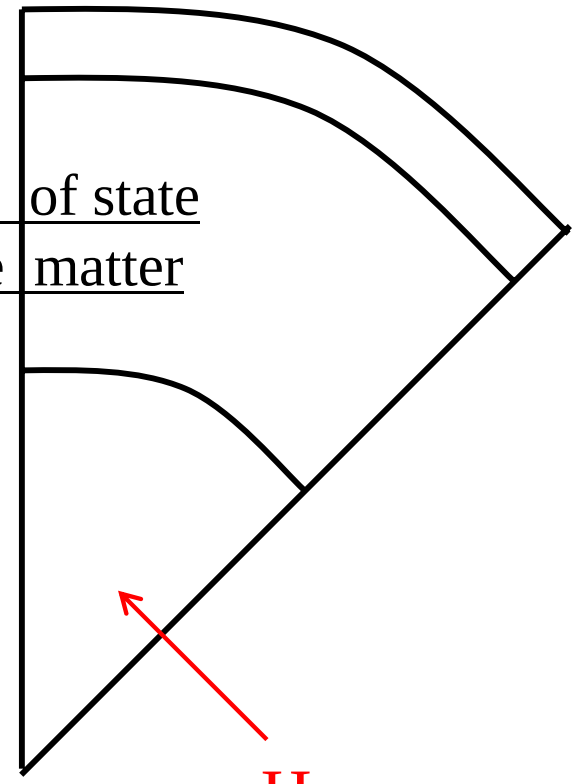


$V_\Lambda \sim V_\Sigma$: attractive

V_Σ : repulsive

No Sigma Appears

Equation of state for dense matter



Hyperon mixing in NS core

Prospects of Σ Hypernuclear Studies

- *More precision measurement of the (π,K^+) spectrum over a wide range from the Λ-bound up to Σ-unbound states*

  The Λ region would be sensitive to the ΛN-ΣN coupled channel: conversion width

  → E10 for J-PARC

- *High resolution Spectroscopy of the low-lying Σ^--atomic state via the (K^-,π^+) reaction near the recoilless momentum*

  Large Shift of 1s state

- *Study of Σ-N interaction using light Σ-nuclear systems*

  → H. Tamura's, LoI for J-PARC

- *Σ-N and/or Σ-Nucleus Scattering Experiment*

  → K. Miwa's, LoI for J-PARC