中重ハイパー核生成と構造研究の問題点

Advanced Reaction Spectroscopy in Medium-Mass Hypernuclear Production

T. MOTOBA （Osaka E-C Univ.)

特定領域研究会
Feb. 27-28, 2009
熱海

(1984)

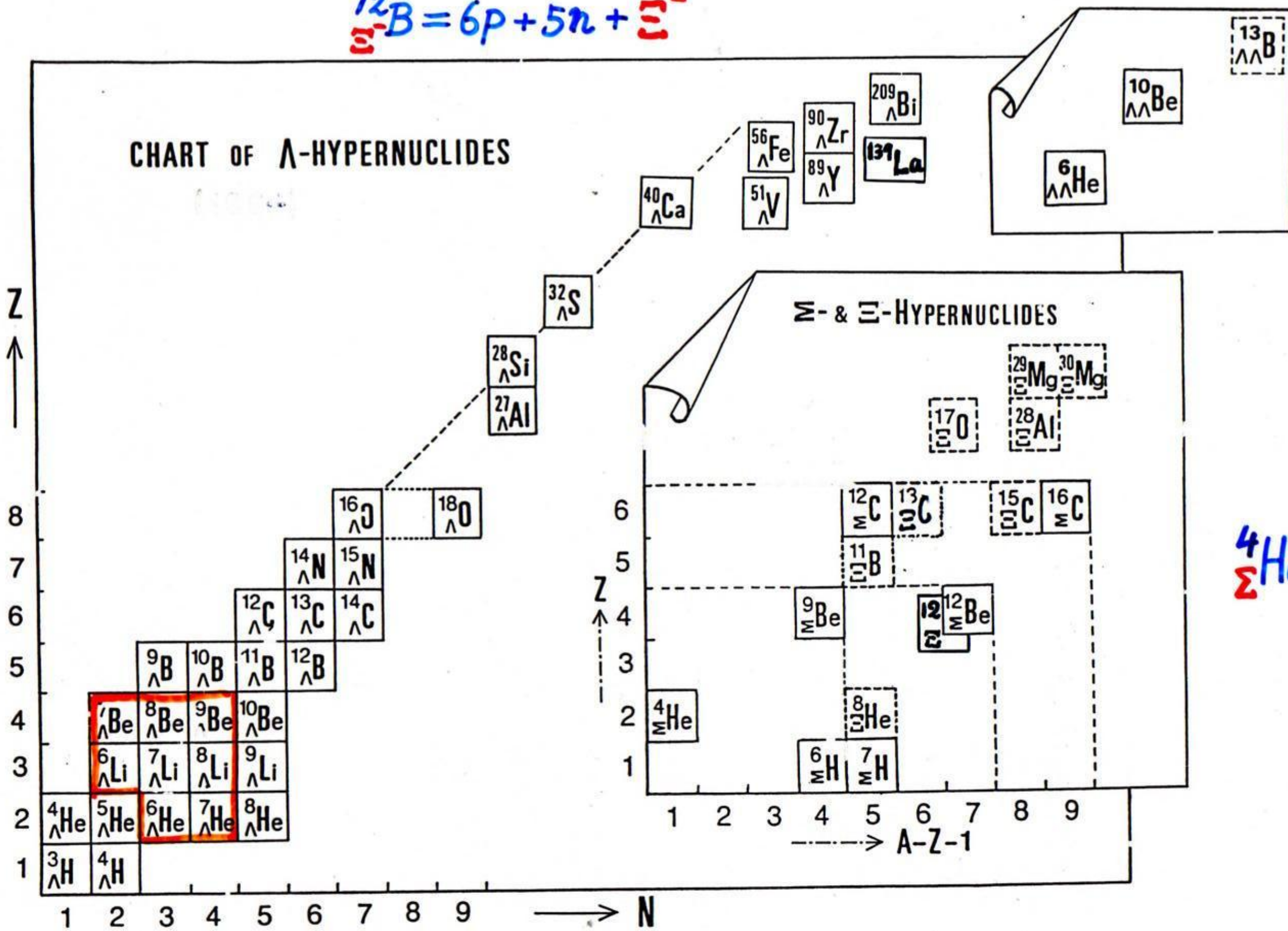
$^{6}Li = 3p + 3n$

$^{7}_{\Lambda}Li = 3p + 3n + \Lambda$

$^{11}C = 6p + 5n$

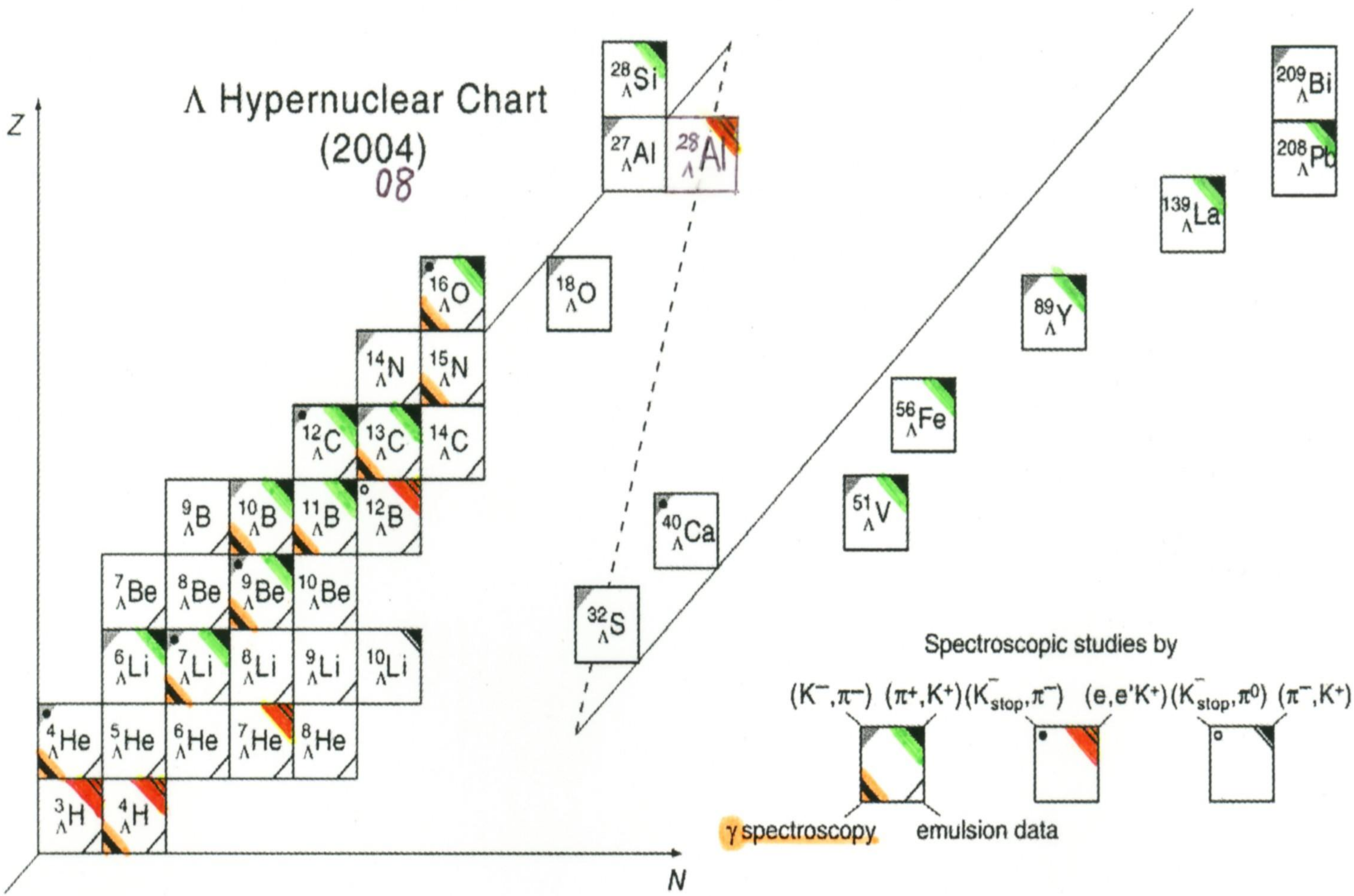
$^{12}_{\Lambda}C = 6p + 5n + \Lambda$

$^{12}_{\Xi^-}B = 6p + 5n + \Xi^-$



$^{4}_{\Sigma}He \begin{cases} 2p + n + \Sigma^0 & (^{3}He) \\ p + 2n + \Sigma^+ & (^{3}H) \end{cases}$

Fig. 1-1


Λ Hypernuclear Chart
(2004)
08
Z
N
Spectroscopic studies by
(K⁻,π⁻) (π+,K+) (K⁻stop,π⁻) (e,e'K+) (K⁻stop,π0) (π⁻,K+)
γ spectroscopy
emulsion data

最近+現に解析中のハイパー核実験における驚異的な進展:

- Hypernuclear γ-ray measurements

  $\Delta E \sim$ a few keV　　“超精密分光”

  軽いハイパー核

- **Reaction spectroscopy**においては

  最近におけるJlabでの(e,e’K$^+$)

  $\Delta E \sim$ 0.3 – 0.4 MeV (sub-MeV !)

(K^-, π^-)

(π^+, K^+)

played a great role of exciting high-spin series

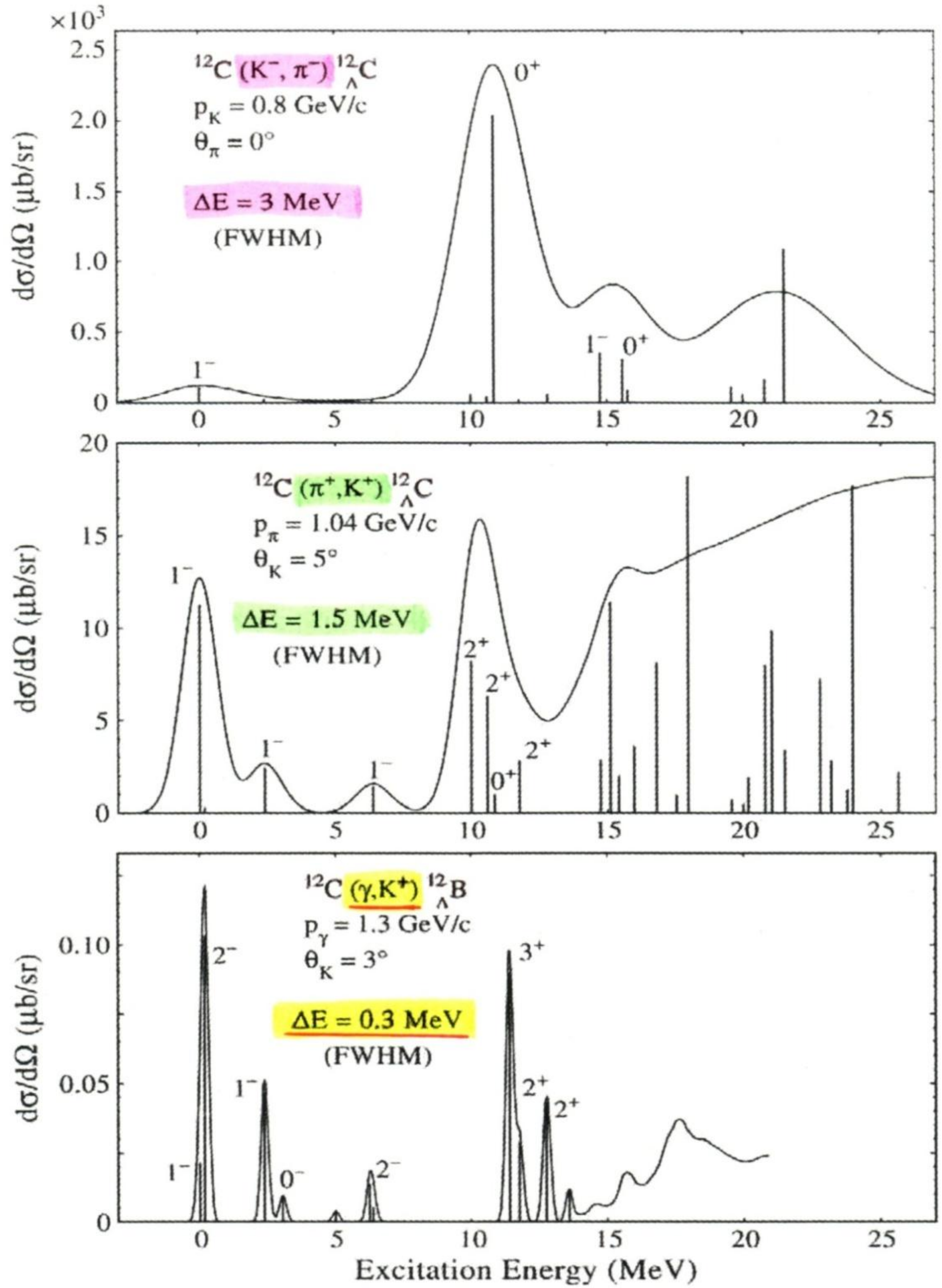
Γ = 1.5 MeV (best)

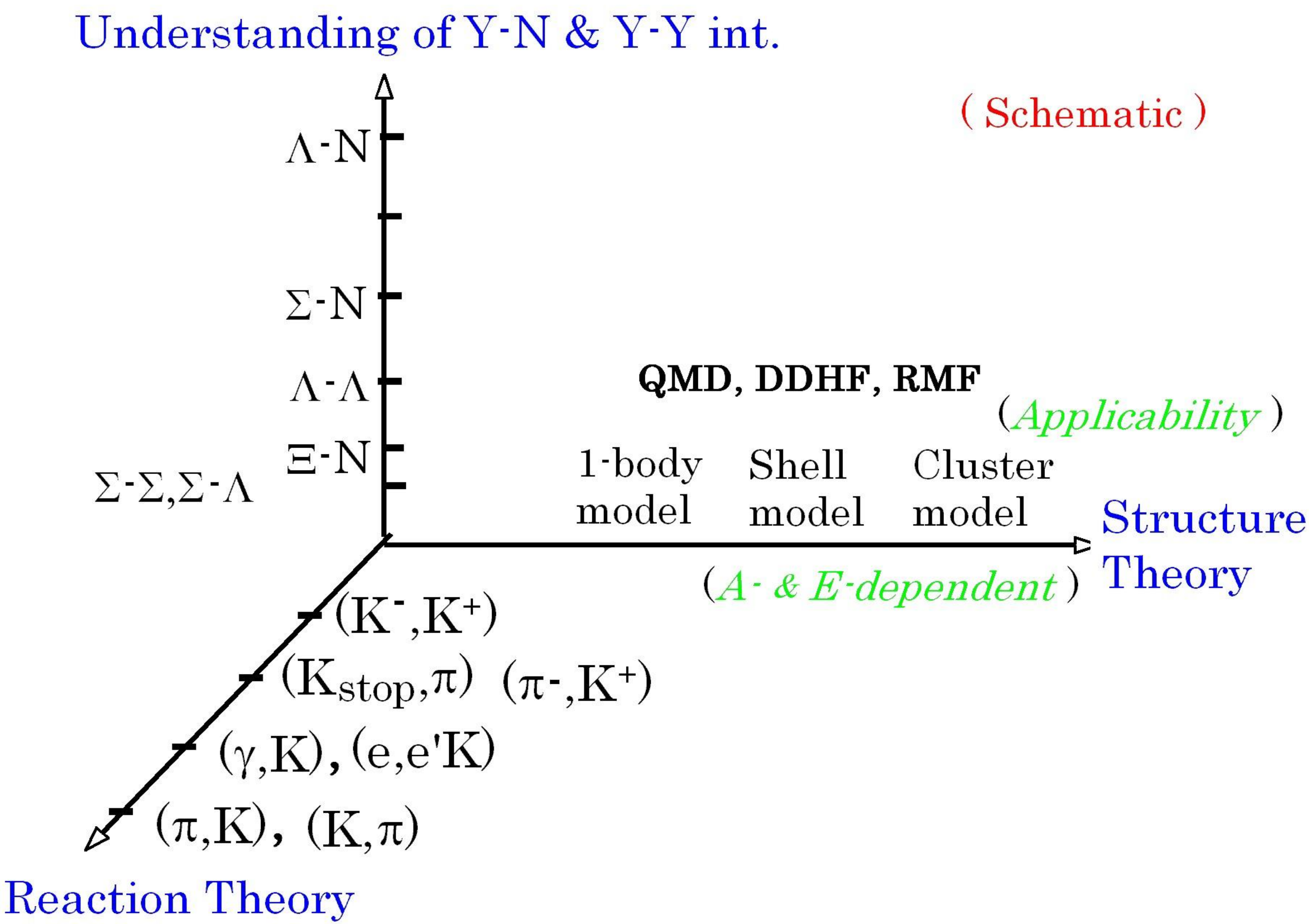
$(e,e'K^+)$, (γ, K^+)

Motoba. Sotona, Itonaga, Prog.Theor.Phys.S.117(1994)

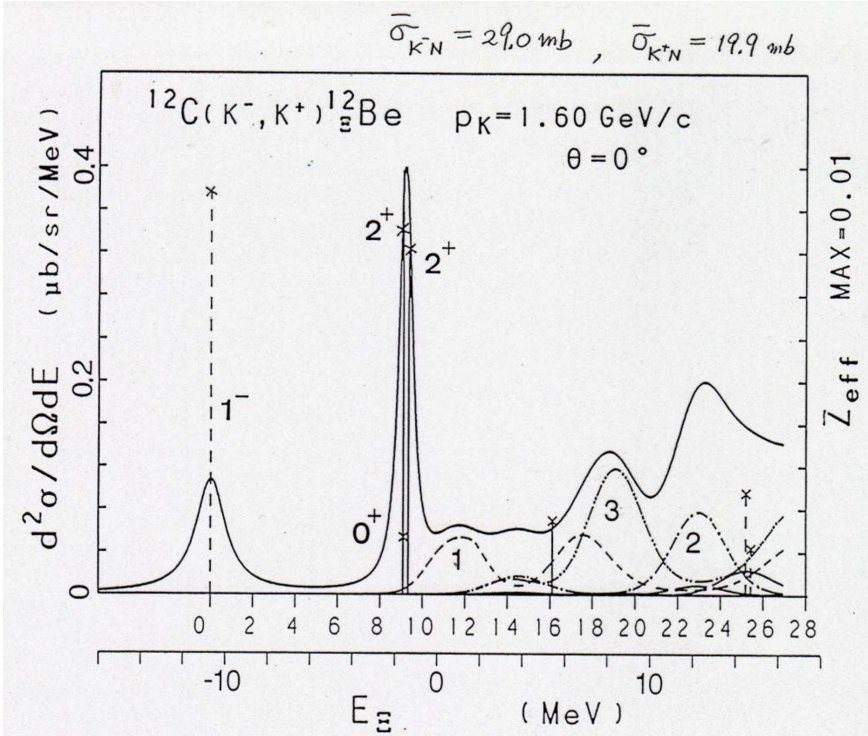
T.M. Mesons & Light Nuclei (2000) updated w/NSC97f.

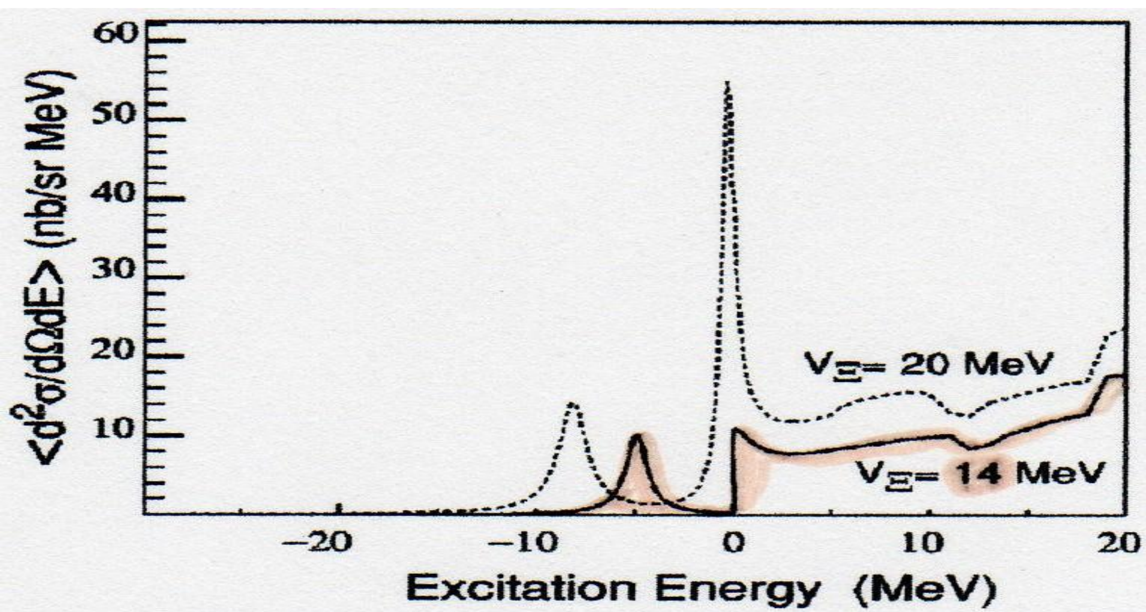
JLab proposal: Γ = 0.5 MeV





Understanding of Y-N & Y-Y int.
(Schematic)
Λ-N
Σ-N
Λ-Λ
Ξ-N
Σ-Σ,Σ-Λ
QMD, DDHF, RMF
(Applicability)
1-body model
Shell model
Cluster model
Structure Theory
(A- & E-dependent)
(K⁻,K⁺)
(K_stop,π)
(π⁻,K⁺)
(γ,K), (e,e'K)
(π,K), (K,π)
Reaction Theory





Kapur-Peierls Cal.
PTP,S.117 (1994)

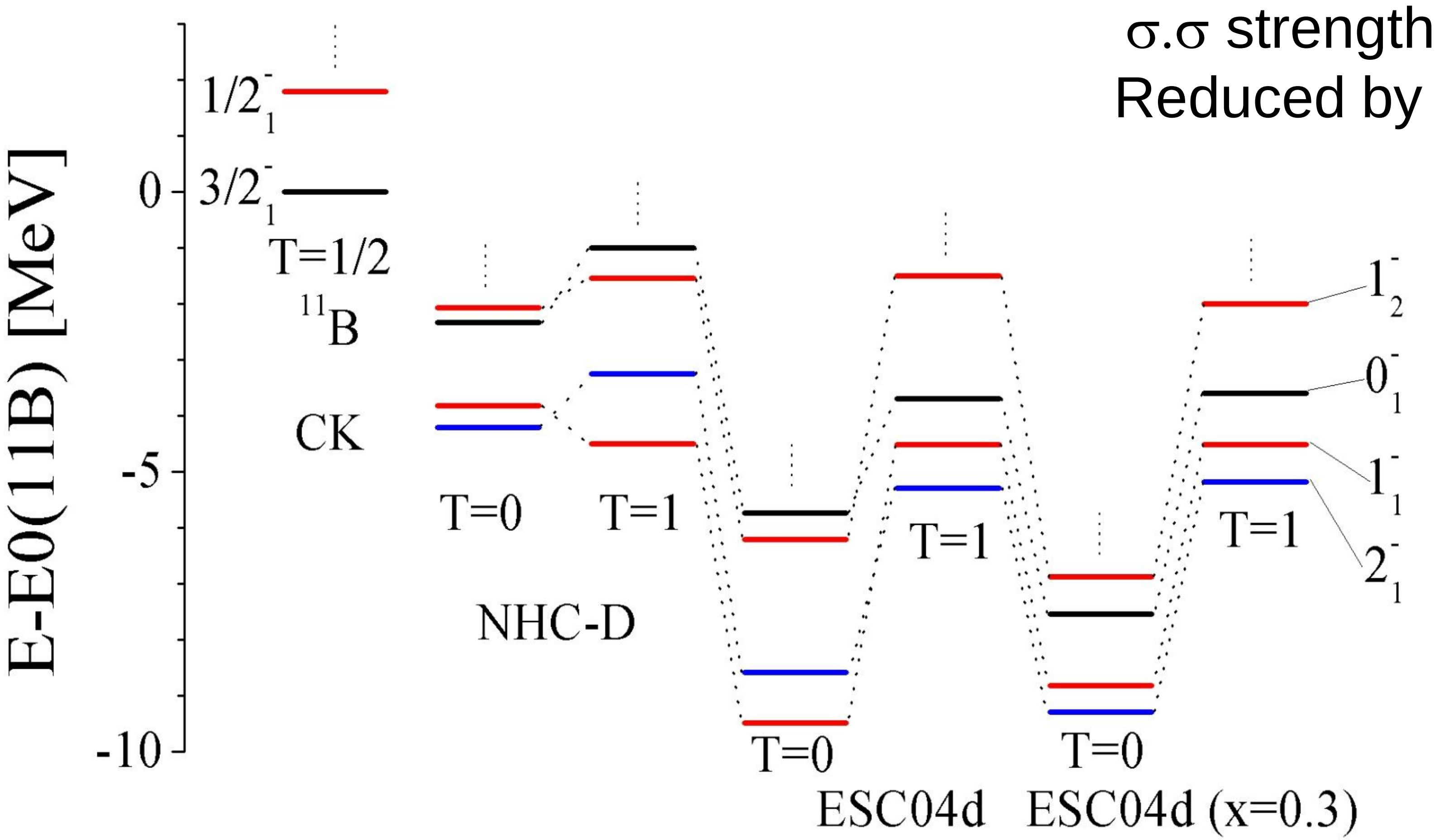
Depth of W-S potential

- V_0=**24** MeV (old emulsion case)

- V_0=**20** MeV

- V_0=**14** MeV

T=0 states are quite deep when ESC04 is employed, while not with ND.



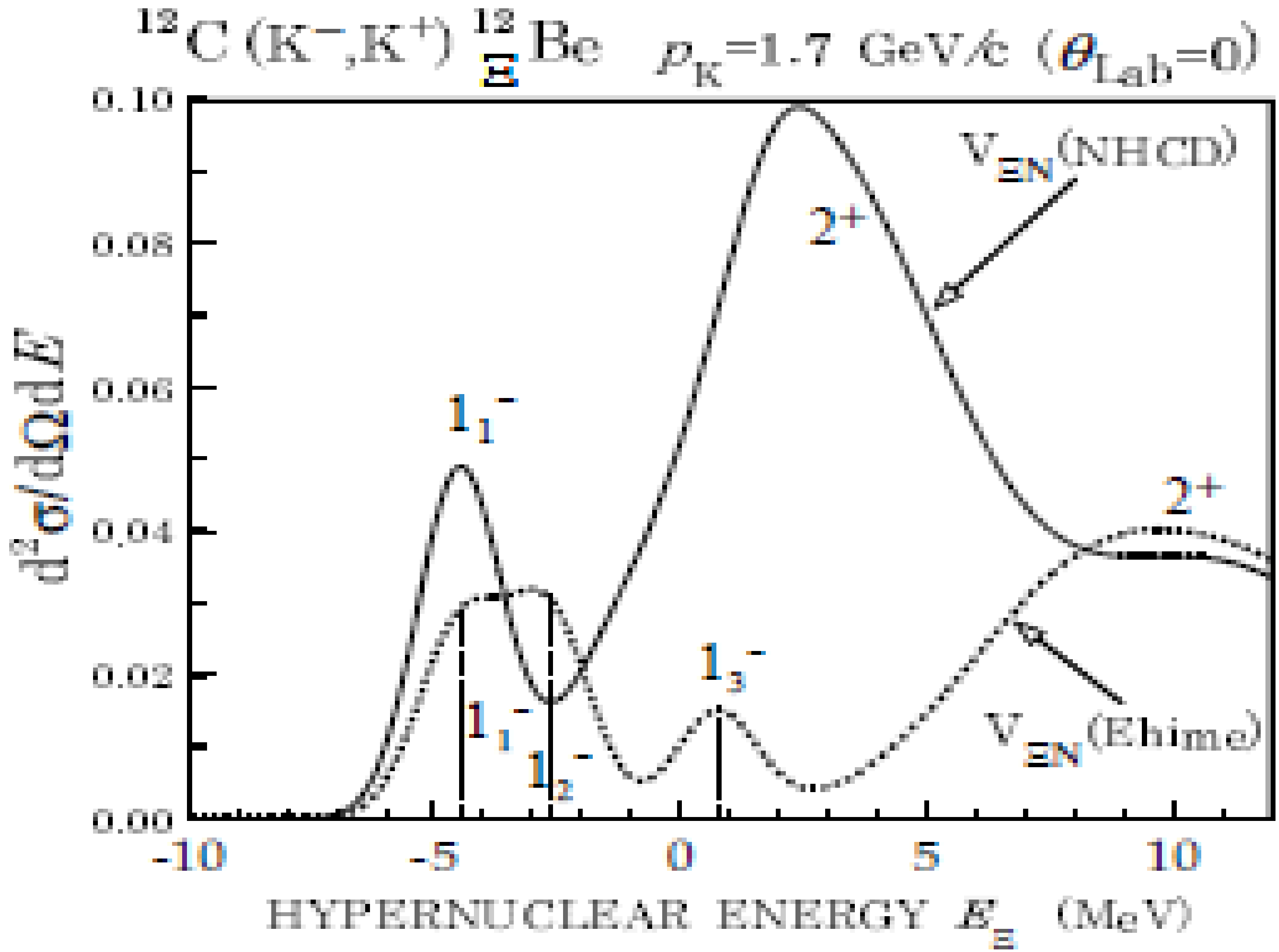
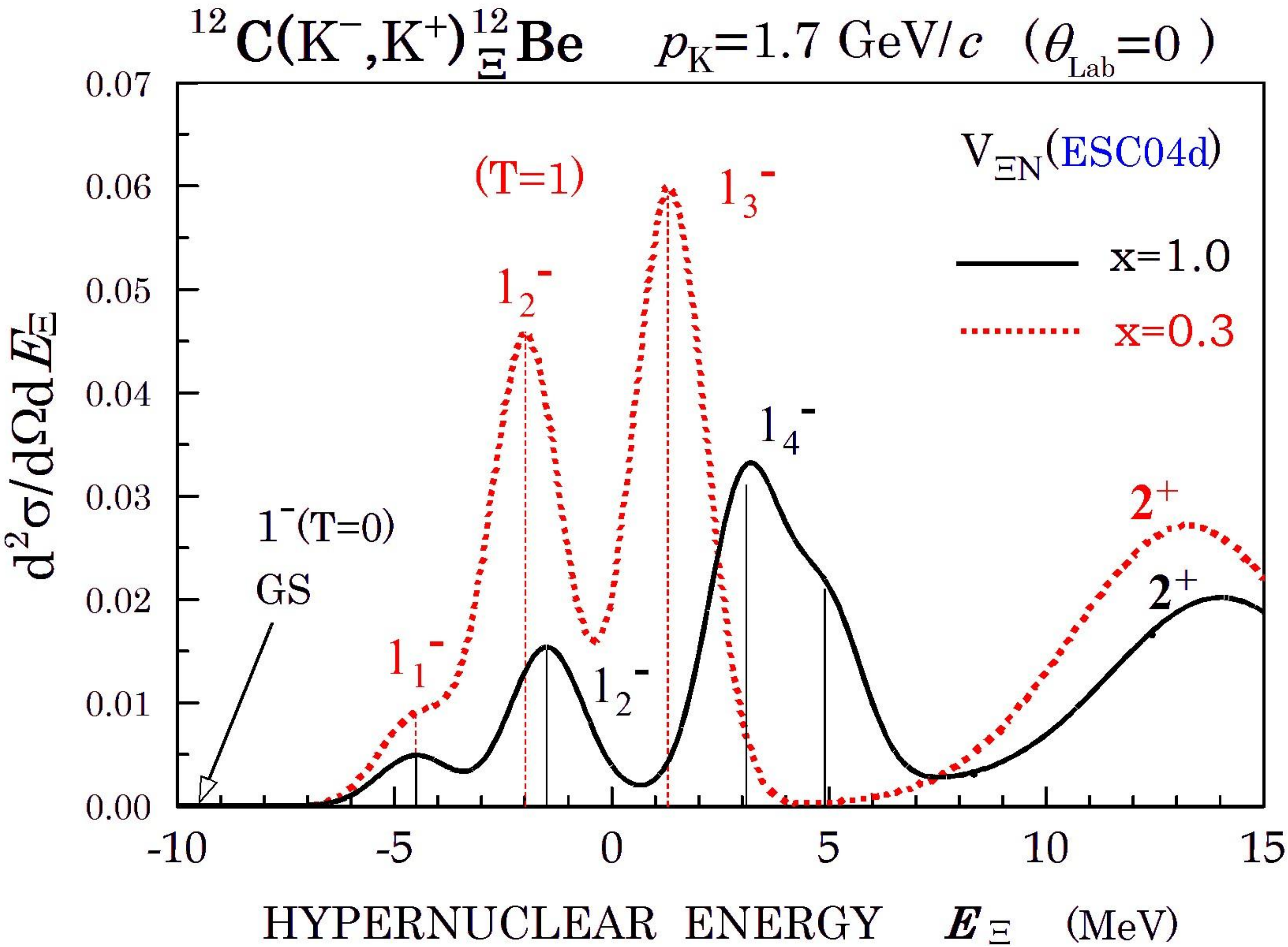


Fig. 3. DWIA spectra for NHC-D and Ehime.

ESC04d case



$^{12}C(K^-,K^+)^{12}_{\Xi}Be$ p_K=1.7 GeV/c (θ_{Lab}=0)
$V_{\Xi N}$(ESC04d)
x=1.0
x=0.3
(T=1)
1_3^-
1_2^-
1_4^-
1_1^-
1_2^-
2^+
2^+
1^-(T=0)
GS
$d^2\sigma/d\Omega dE_{\Xi}$
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-10
-5
0
5
10
15
HYPERNUCLEAR ENERGY E_{Ξ} (MeV)

Ξ-N interactions used in Shell Model

Comparison in the form of $V = -V_0 + \Delta(\sigma.\sigma)$

		V_0	Δ	Δ/V_0
NΞ(ESC04d)	T=0	4.98	-15.81	-3.18
	T=1	0.30	-2.96	-9.88
NΞ(NHC-D)	T=0	2.14	4.75	2.23
	T=1	1.55	0.79	0.51
NΛ(NSC97f)	T=1/2	1.05	0.04	0.04

$\sigma.\sigma$ interaction is quite strong and different for ESC and ND, so further improvements are required.

Reaction spectroscopyの

最近10年におけるの進展

現に解析中の興味あるもの

そして今後の数年の可能性＠J-PARC

- 最近におけるJlabでの(e,e'K$^+$)　reaction spectroscopyのpowerful & promising results

  $\Delta E \sim$ 0.3 – 0.4 MeV　(sub-MeV !)

- KEKでの（π^+,K$^+$）実験は やはり画期的

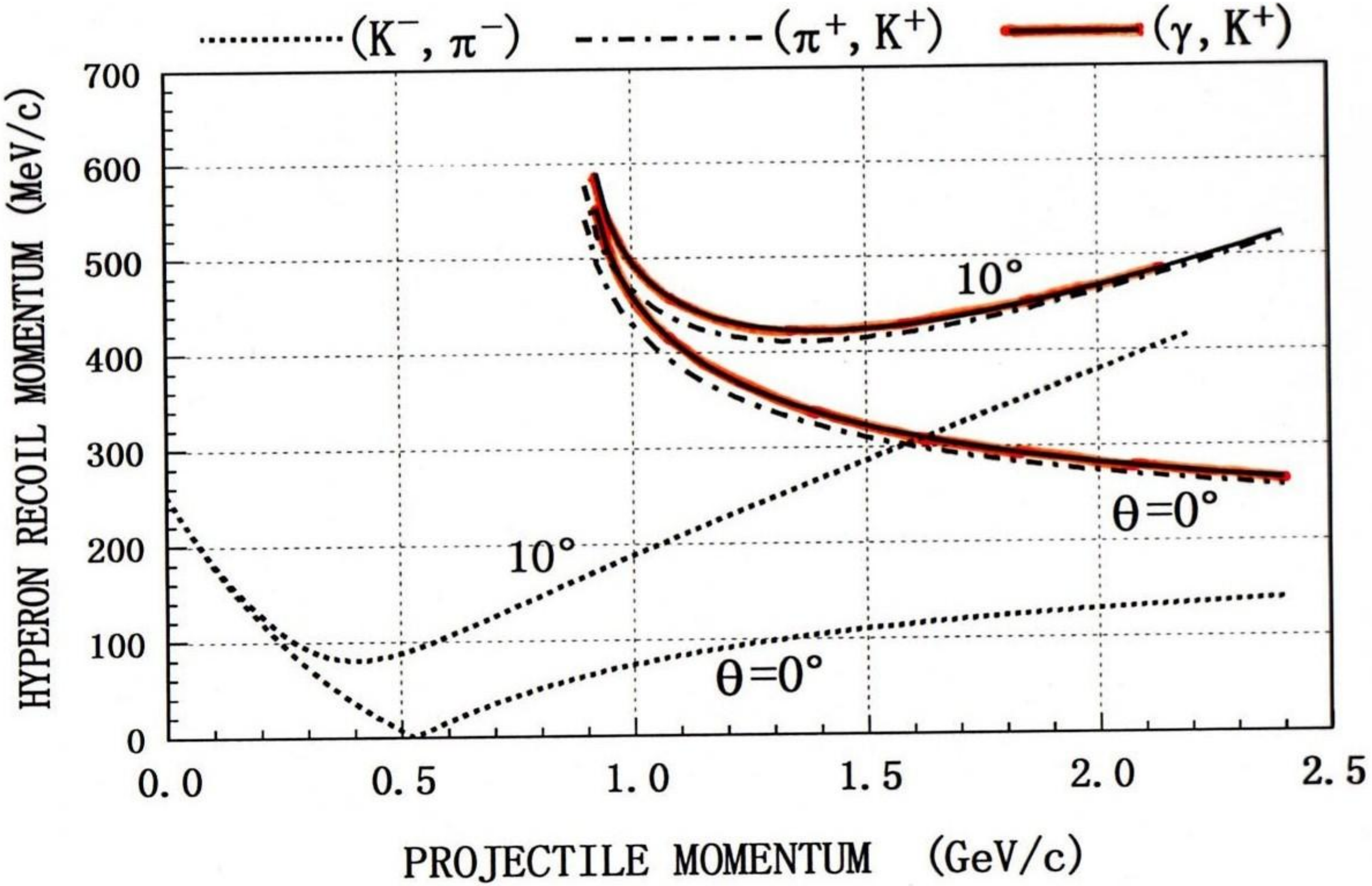
  ただし、　$\Delta E \sim$ 1.5 MeV

- High resolution（π^+,K$^+$）and（ K$^-$, π^-）

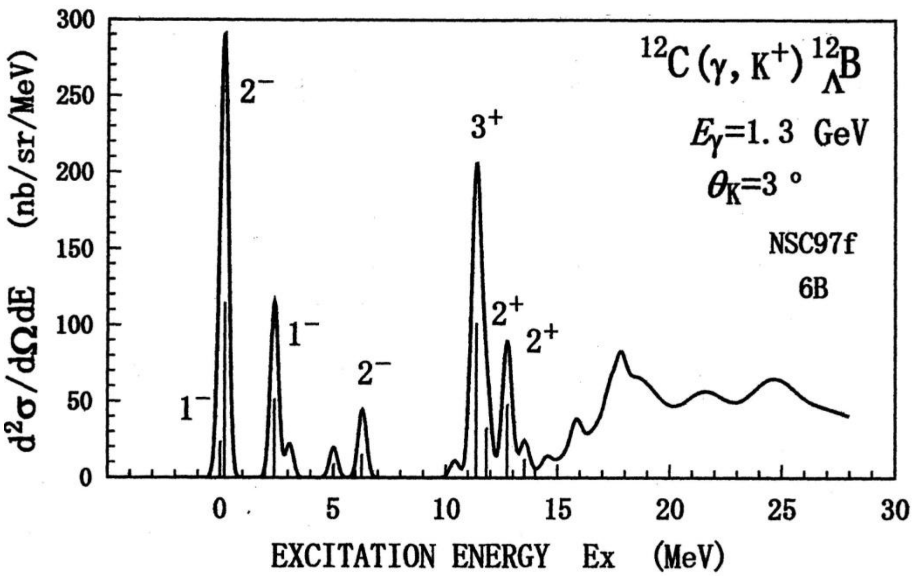
  (sub-MeV へ!)

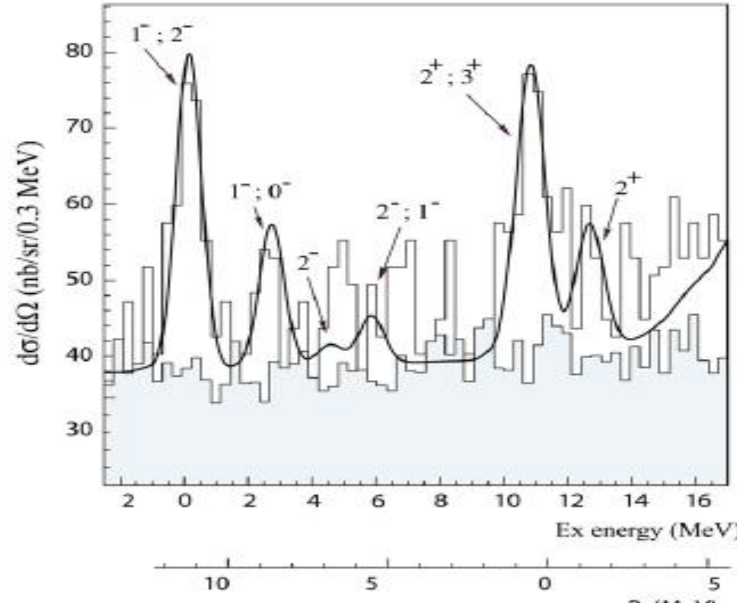
Comparison of the recoil momentum

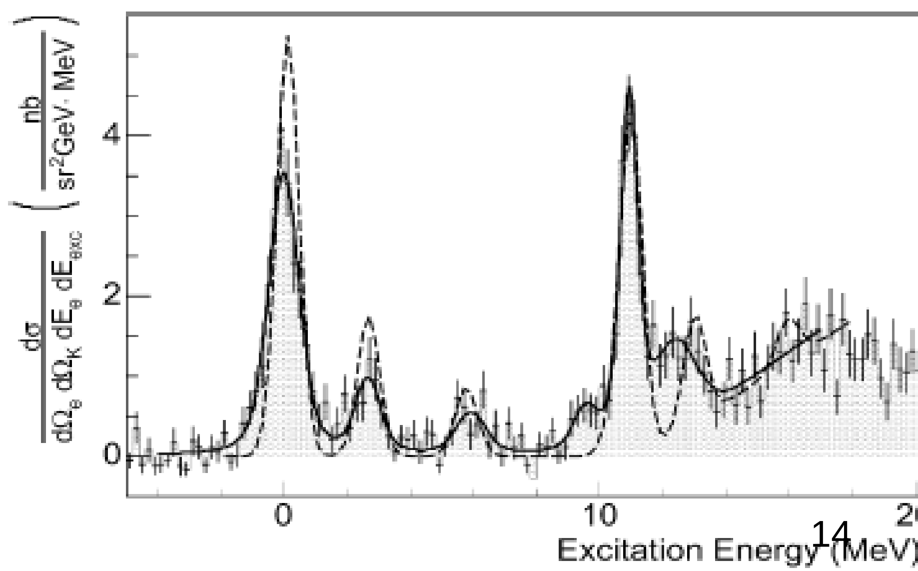
q_Λ=350-420 MeV/c at Eγ=1.3 GeV



Theor. prediction vs. (e,e'K$^+$) experiments







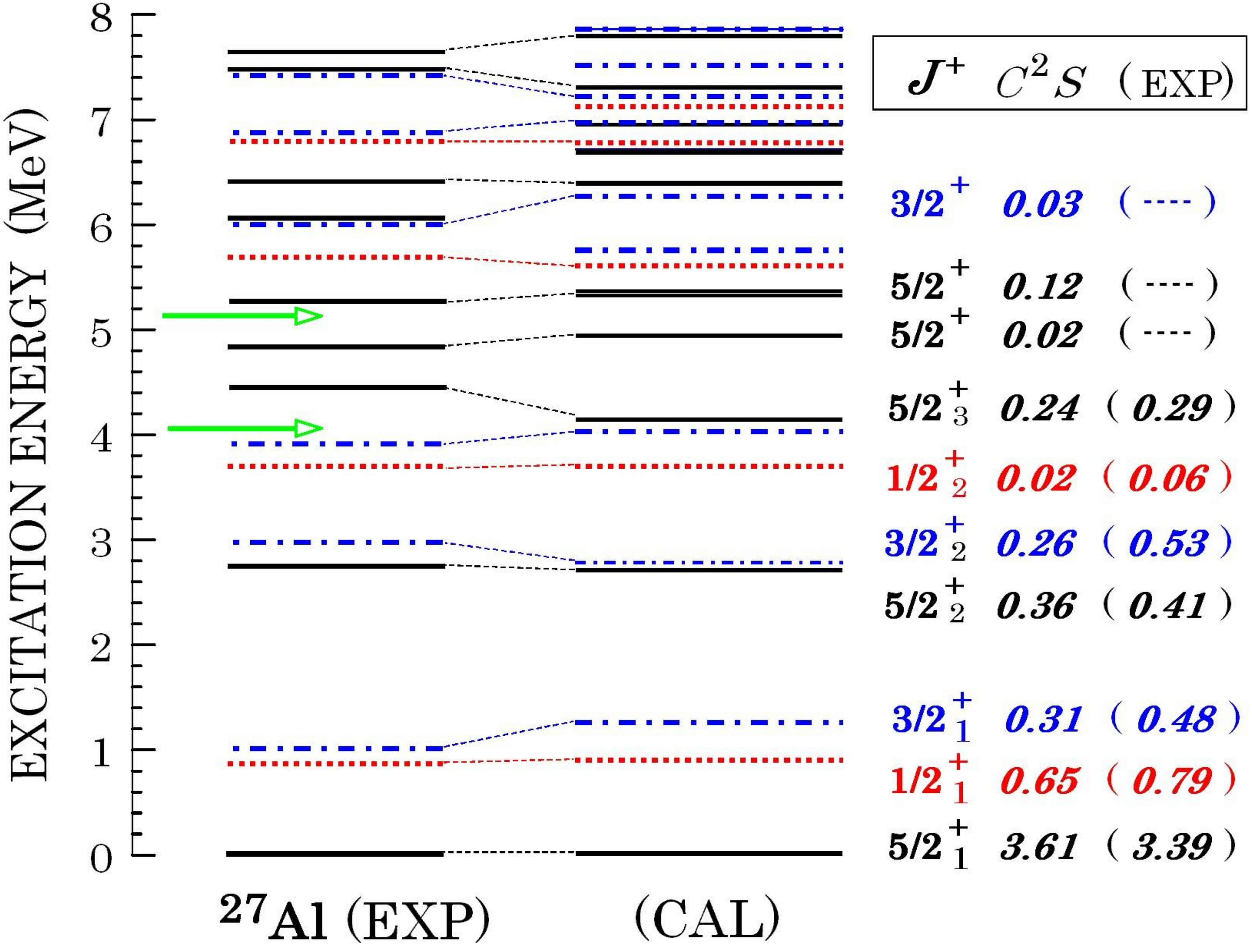
Motoba. Sotona, Itonaga,
Prog.Theor.Phys.S.117 (1994)
T.M. *Mesons & Light Nuclei* (2000)
updated w/NSC97f.

---→

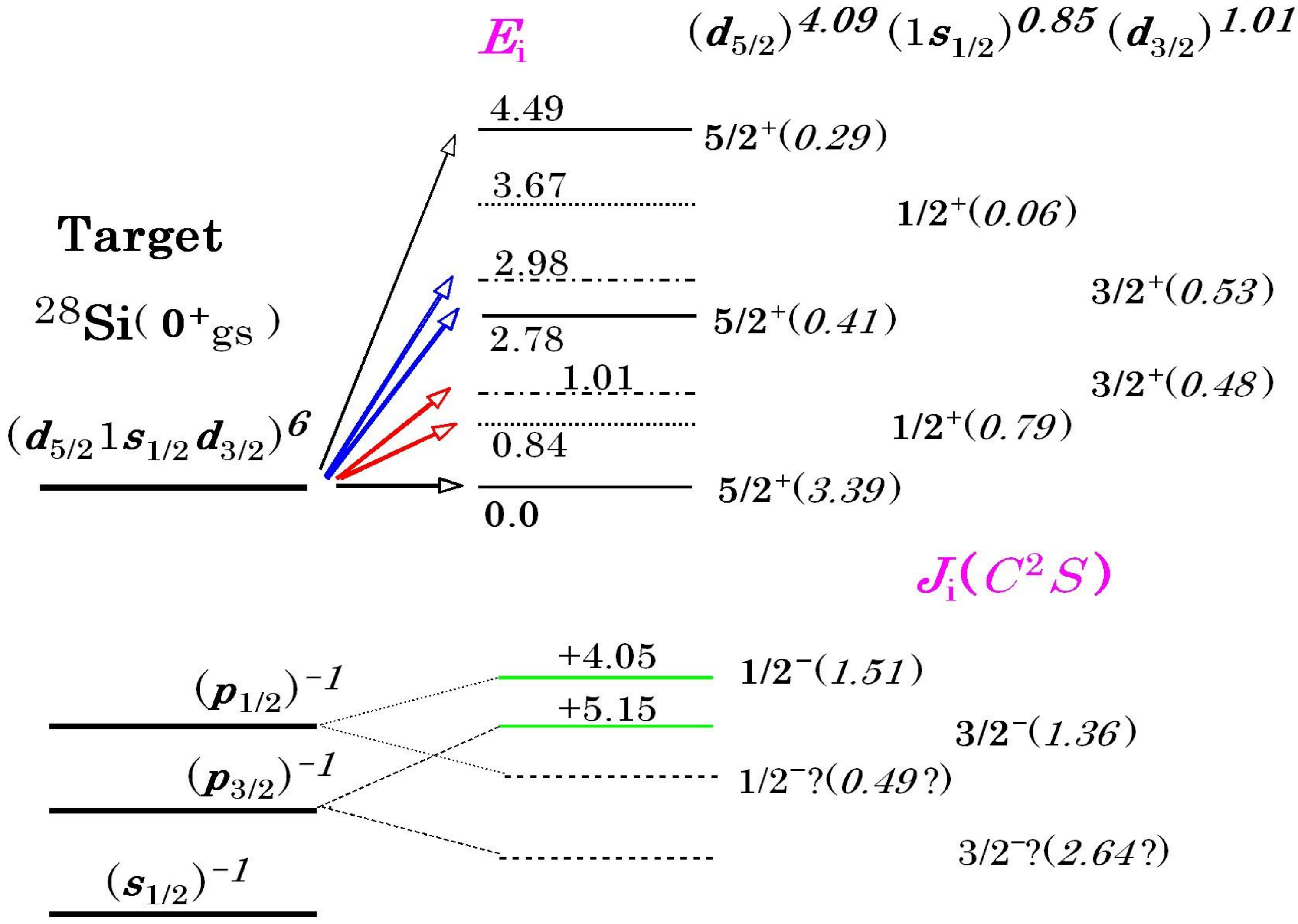
Hall C (up) T. Miyoshi et al.
*P.R.L.*90 (2003) 232502. **Γ=0.75keV**

Hall A (bottom), J.J. LeRose et al.
N.P. A804 (2008) 116. **Γ=0.67keV**

$(sd)^n$ Shell Model from K. Ogawa

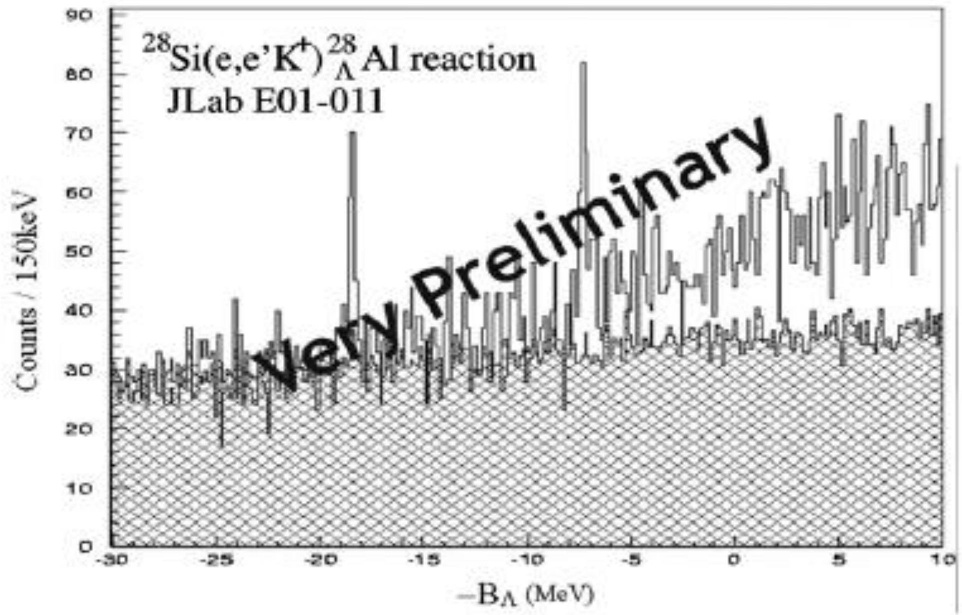


proton-state **fragmentations** are taken into account *to be realistic*

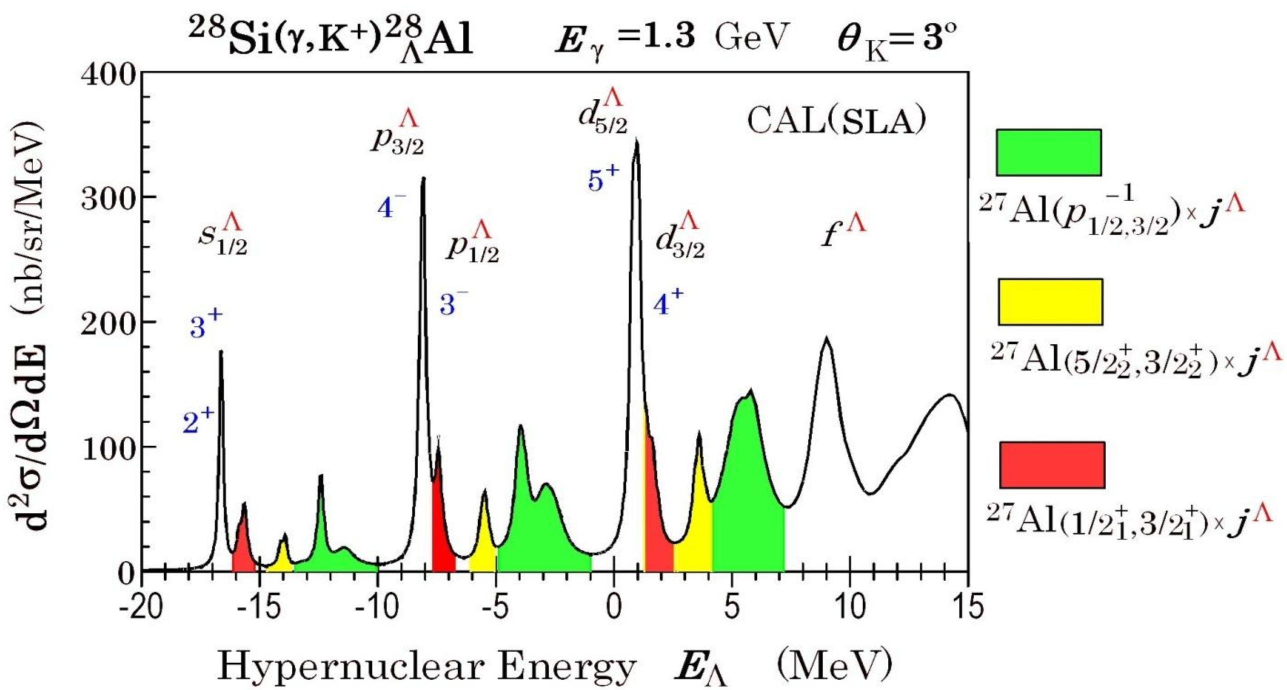


Comparison with new exp. data JLab Hall C

Hashimoto et al.,
Nucl. Phys. A804 (2008)



Major peaks:
as redicted

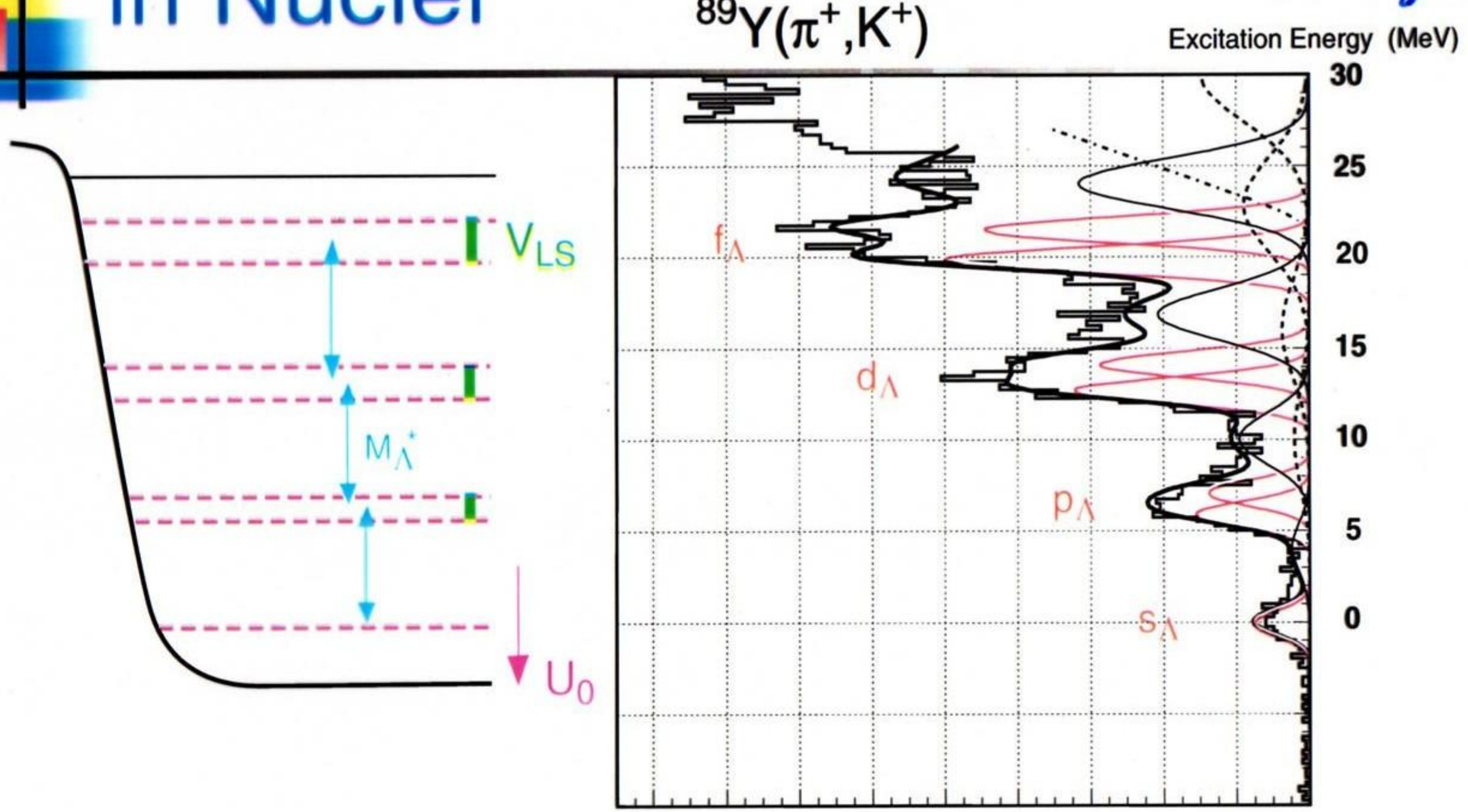


Satellite peaks ?

Wait for the final report.

Single-Particle Motion of a Λ in Nuclei

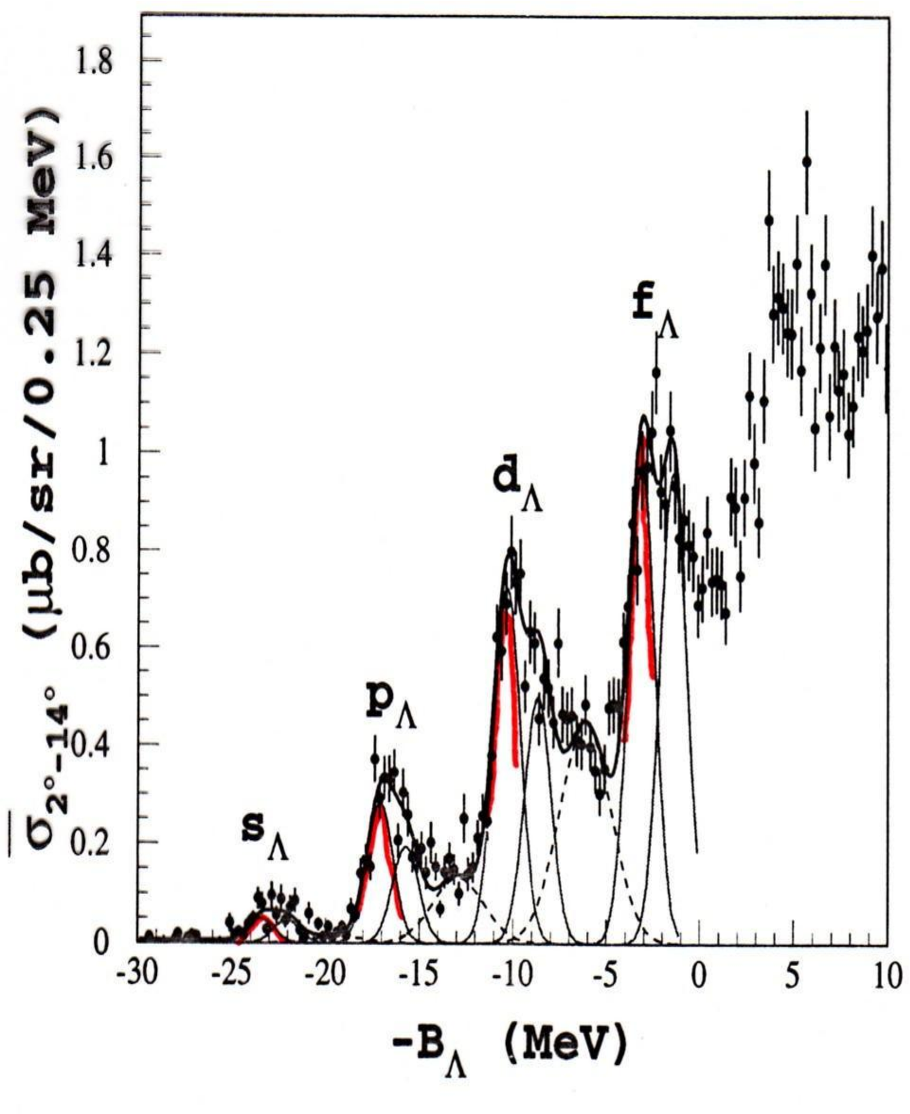
KEK E369 (*T. Nagae*)

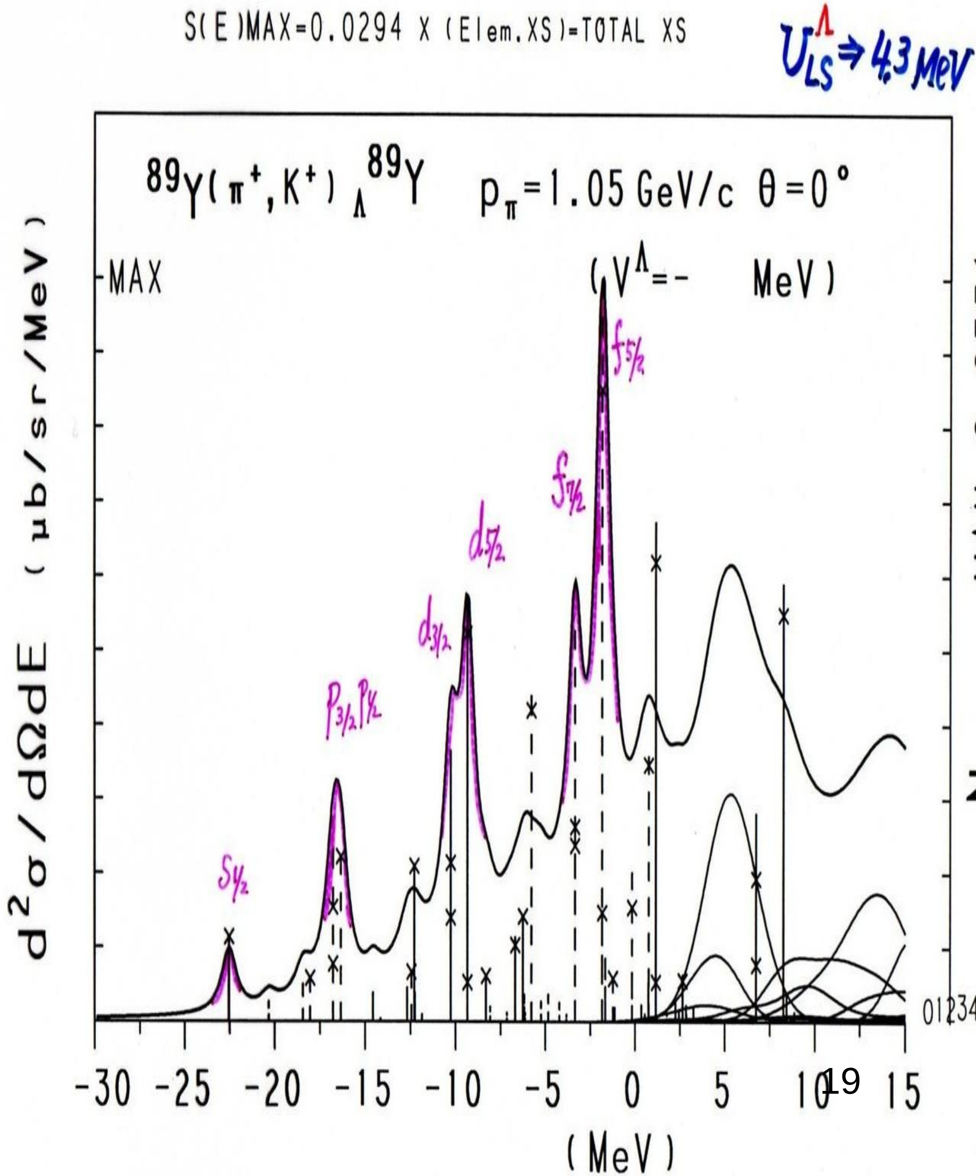


EXP: H. Hotchi et al. P.R.C 64, 044302 (2001)

EXP vs. DWIA CAL(WS, V_{LS}=4.3MeV)

Motoba-Bando-Wuensch-Zofka, PRC 38 (1988)





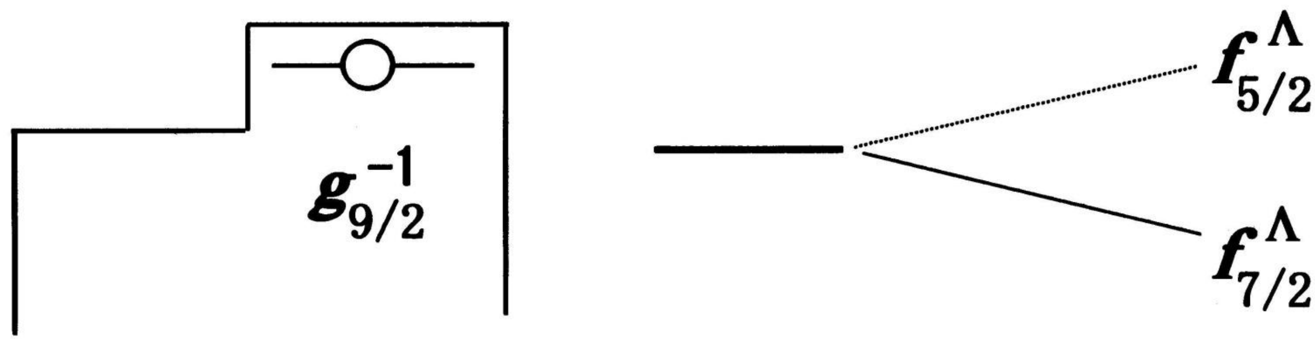
Λ spin-orbit splitting deduced from DWIA analysis of the $^{89}Y(\pi^+,K^+)\,{}_{\Lambda}^{89}Y$ reaction

T. Motoba (Osaka E-C U.)
D.J. Millener (Brookhaven N.L.)
D. Lanskoy (Moscow State U.)
Y. Yamamoto (Tsuru U.)

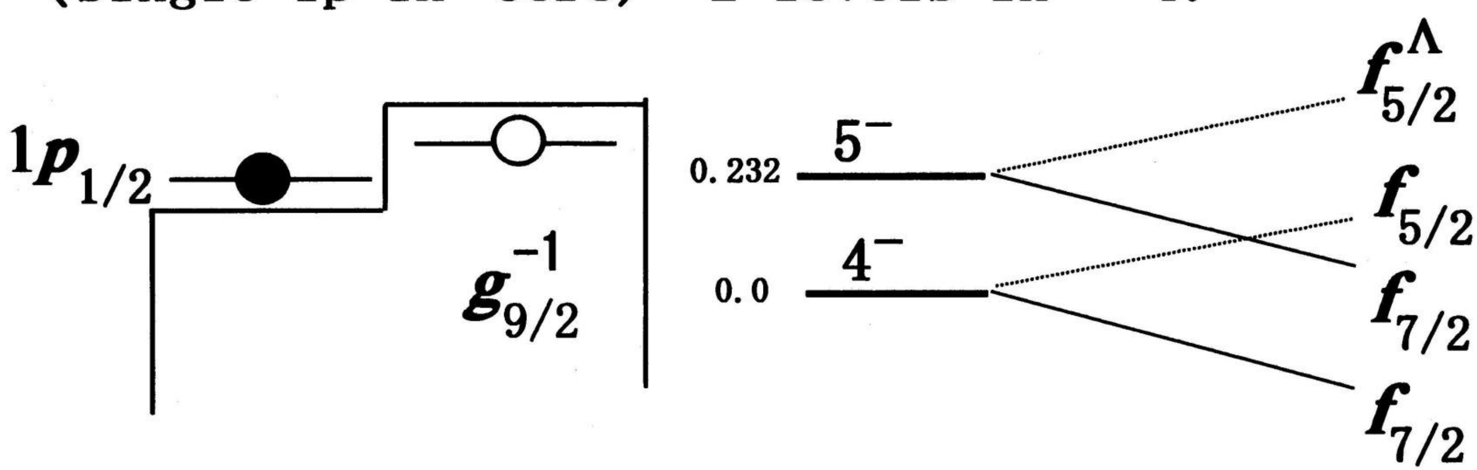
Nucl. Phys. A804 (2008)

Models for Stucture of $^{89}{}_{\Lambda}Y$:

(1) The simplest model with 1-hole core
(assume a ^{90}Zr target)

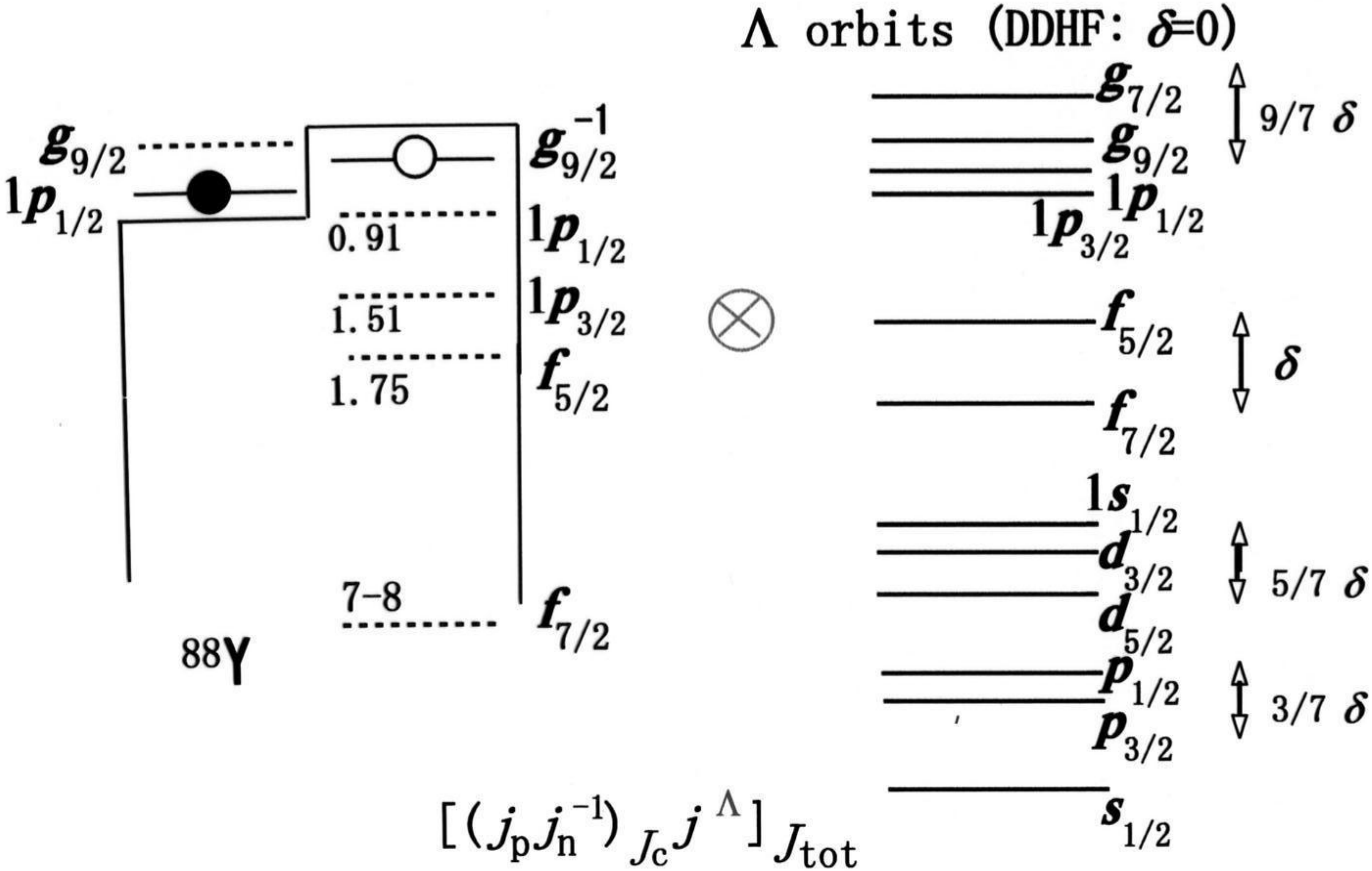


(2) Role of an odd proton introduced
(single 1p-1h core): 2 levels in ^{88}Y.



Models for Stucture of $^{89}{}_{\Lambda}Y$:

(3) Many [1p-1h] $_{J_c}$ multiplets of the ^{88}Y core excitation due to V_{NN}.



<%%%%%%%%%%%%% Lambda Coupling to the 88Y Core %%%%%%%%%%%%%%%%%%%%%%%%%>

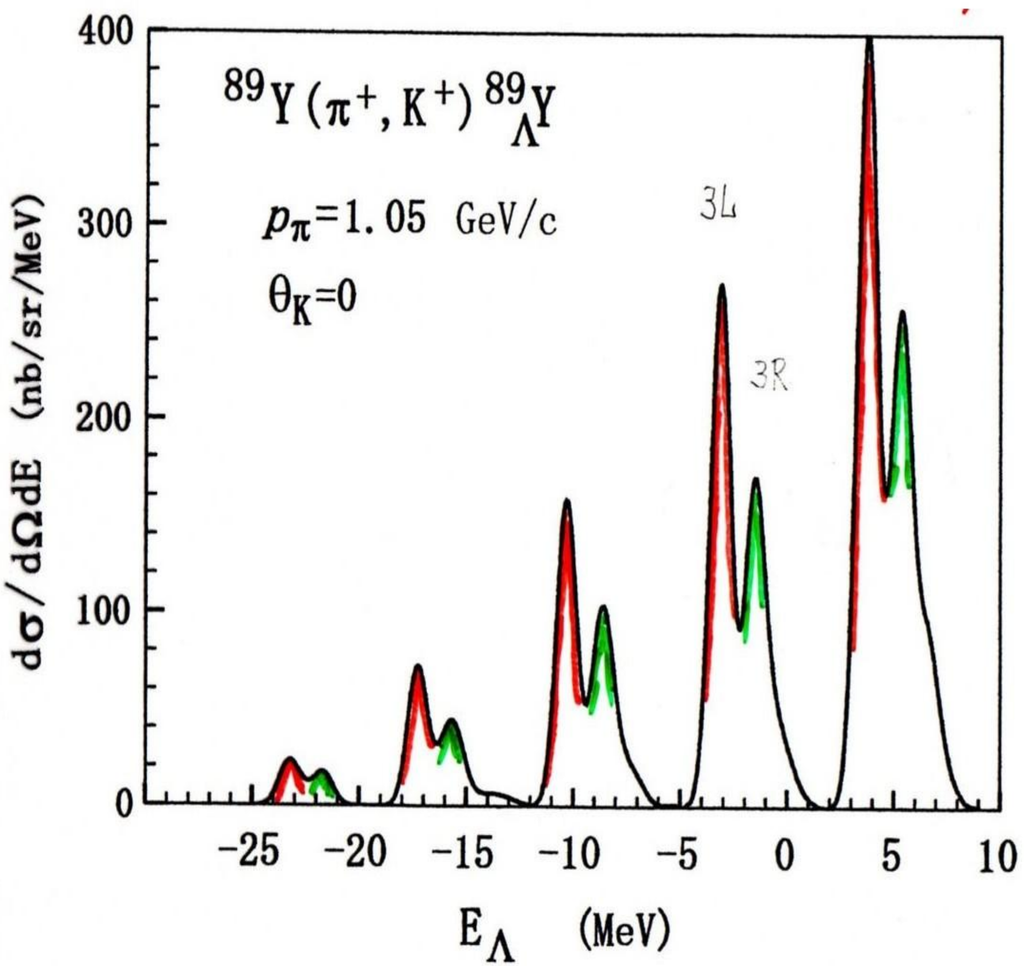
```
    2.2105++++++++ 1,2,3+
       2.1218-------(4,5,6-)
    2.0552++++++++ 1,2,3+
    1.9503++++++++ 1,2,3+
    1.8320-------(GH2,3,4-)
    1.7610-------(GH3,4,5-)   H:[g9*-f5*]_Jc=2,..,7-{2.7}xY(fp)
                                                   2J=21+,19+,17+,...
    1.7027 +++++++ F(3,4+)
                              G:[g9*-p3*]_Jc=3,..,6-{2.0}xY(fp)
                                                   2J=19+,17+,13+,...
    1.5959---------G(2,3,4-)
    1.5754 +++++++ F2+(1+)    F:[p1-f5*]_Jc=2,3+{1.8}xY(fp)
                                              2J=13-,11-,9-,7-,5-,...
1.4772 ++++++++++ C9+
    1.4754---------G(2,3,4-)


1.2840 ++++++++++ C3+(4,5+)
1.275  ++++++++++ C1+(2+)D
    1.2340---------- E4-      E:[g9*-p1*]_Jc=4,5-{1.5}xY(fp) 2J=17+,15+,13+,

1.221  ++++++++++ C0+(1+)D
    1.1291----------E3,4,5-   D:[p1-p3*]_Jc=1,2+{1.1}xY(fp)
    1.0882---------- E5-                           2J=11-,9-,7-,5-,...
0.9848 ++++++++++ C4+
0.8432 ++++++++++ C5+         C:[g9*-g9]_Jc=0,.,9+{0.9}xY(fp)
    0.7664++++++++++++ B0+                     2J=25-,23-,21-,19-,...
0.7152 ++++++++++ C6+
0.7125 ++++++++++ C7+
0.7073 ++++++++++ C2+(1+)
0.6746 ++++++++++ C8+
                              B:[p1-p1*]_Jc=0,1+{0.6}xY(fp)
                                                    2J=9-,7-,5-,...
    0.3929++++++++++++ B1+


0.2319 ------------- A5-
                              A:[p1-g9]_Jc=4,5-{0.0}xY(fp)
                                             2J=17+,15+,13+,11+,9+,...
  0.0  ------------- A4-

        88Y(39,49)
                                            88Y x Lambda
```

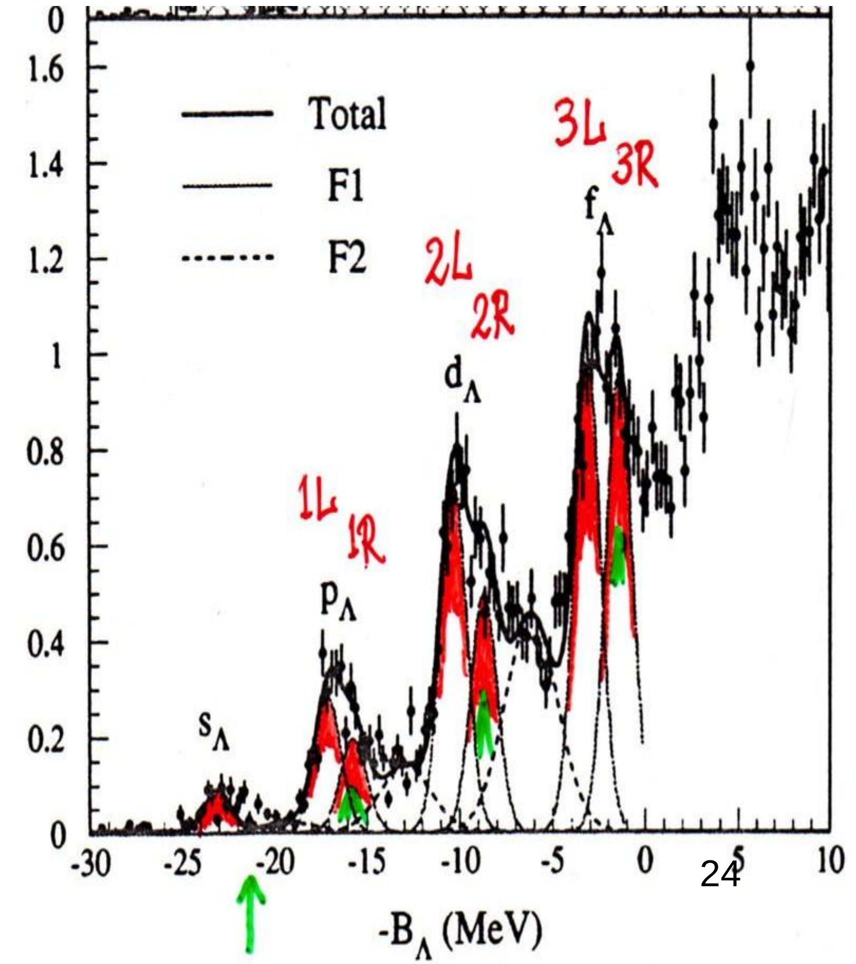
%%%

Low-lying states in ^{88}Y core ~[1p-1h]

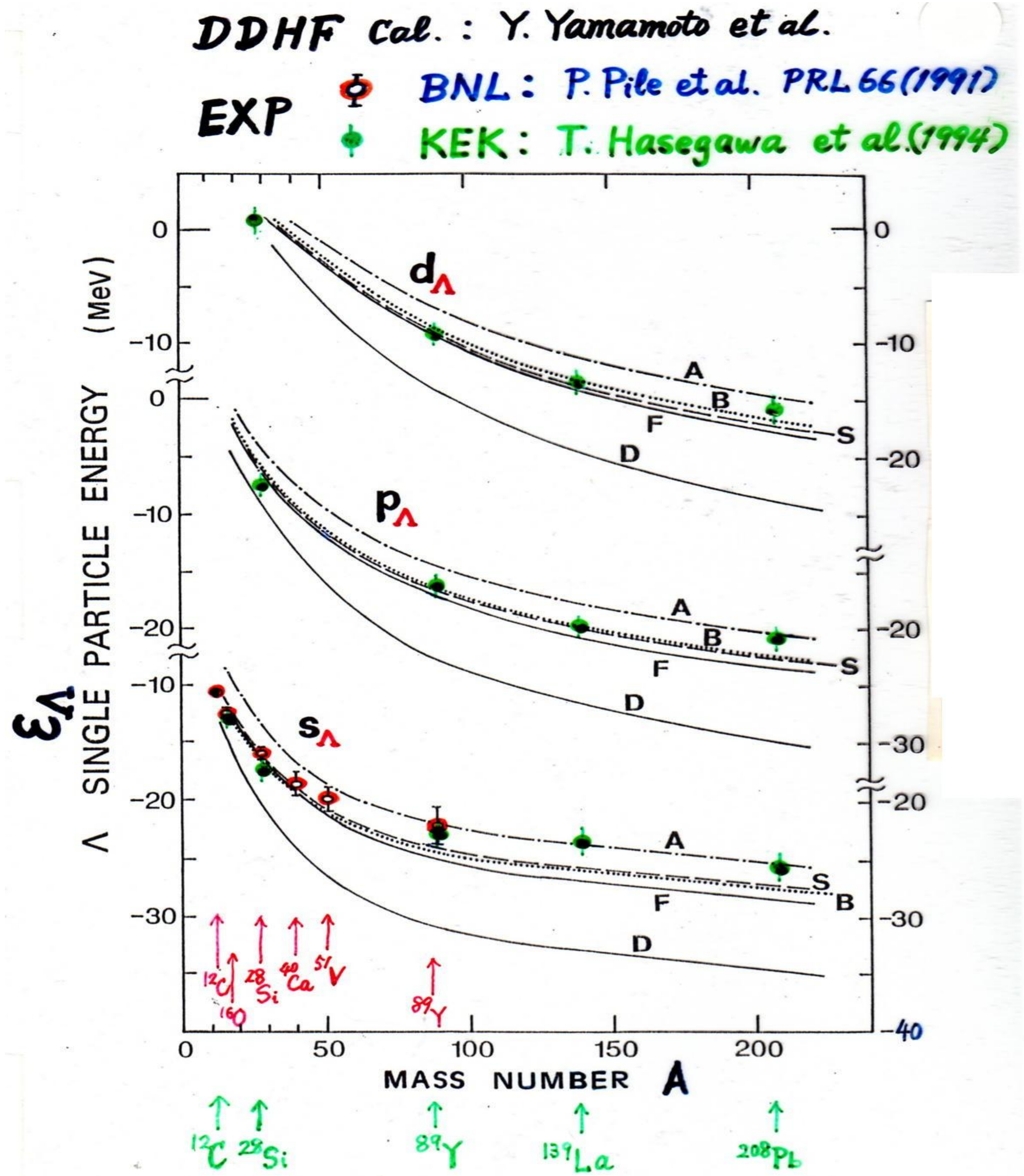
CONCLUSION

(1)Reproduce cross section ratios among a series of pronounced peaks and sub-peaks.





Λ s.p.e. vs. DDHF

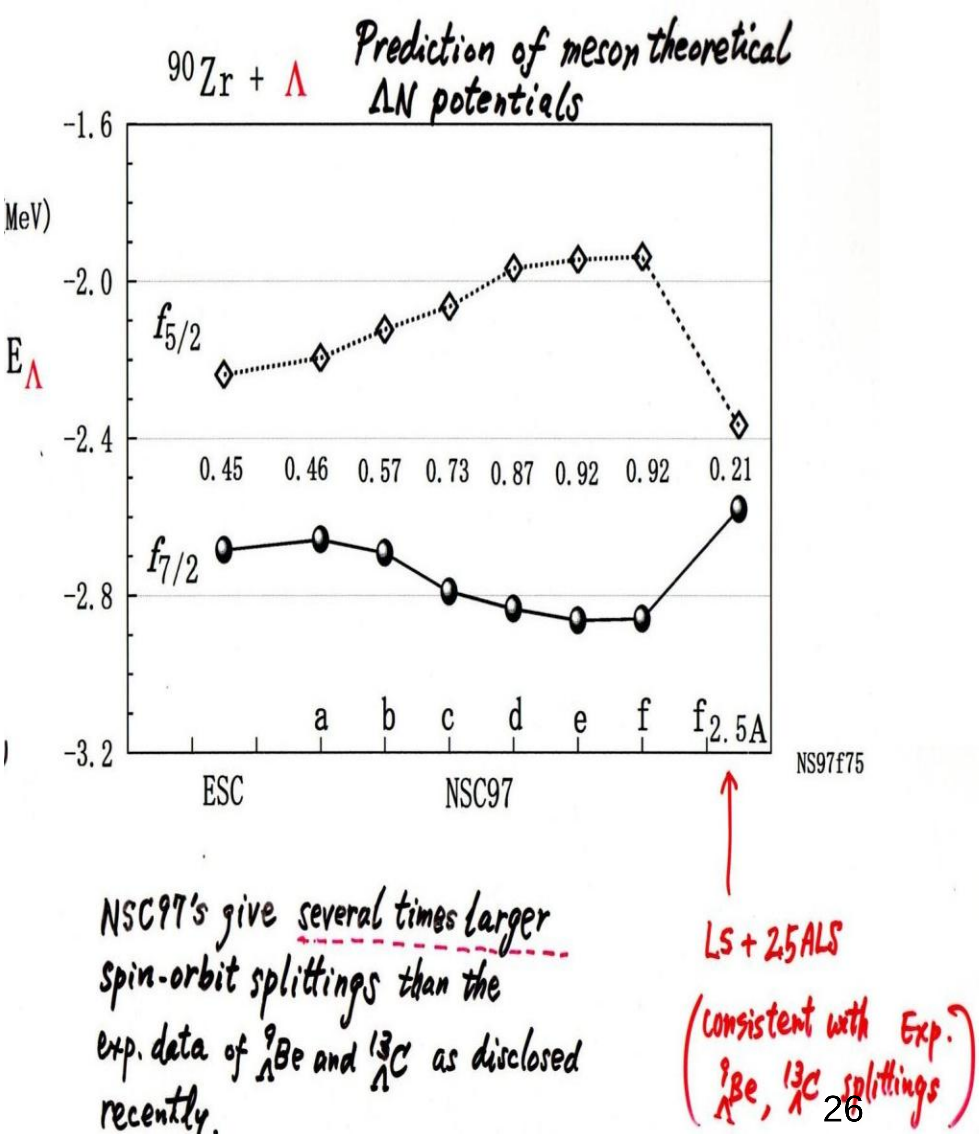

DDHF Cal. : Y. Yamamoto et al.
EXP
BNL : P. Pile et al. PRL 66 (1991)
KEK : T. Hasegawa et al. (1994)
ε_Λ
Λ SINGLE PARTICLE ENERGY (MeV)
MASS NUMBER A
d_Λ
p_Λ
s_Λ
A
B
F
D
S
12C
16O
28Si
40Ca
51V
89Y
139La
208Pb

CONCLUSION

(2) Observed energy spacing between

doublet like sub-peaks (3L-3R) are reproduced with δ(***f***)=0.20 MeV, which leads to δ(***d***)=0.15 MeV and δ(***p***)=0.09 MeV.

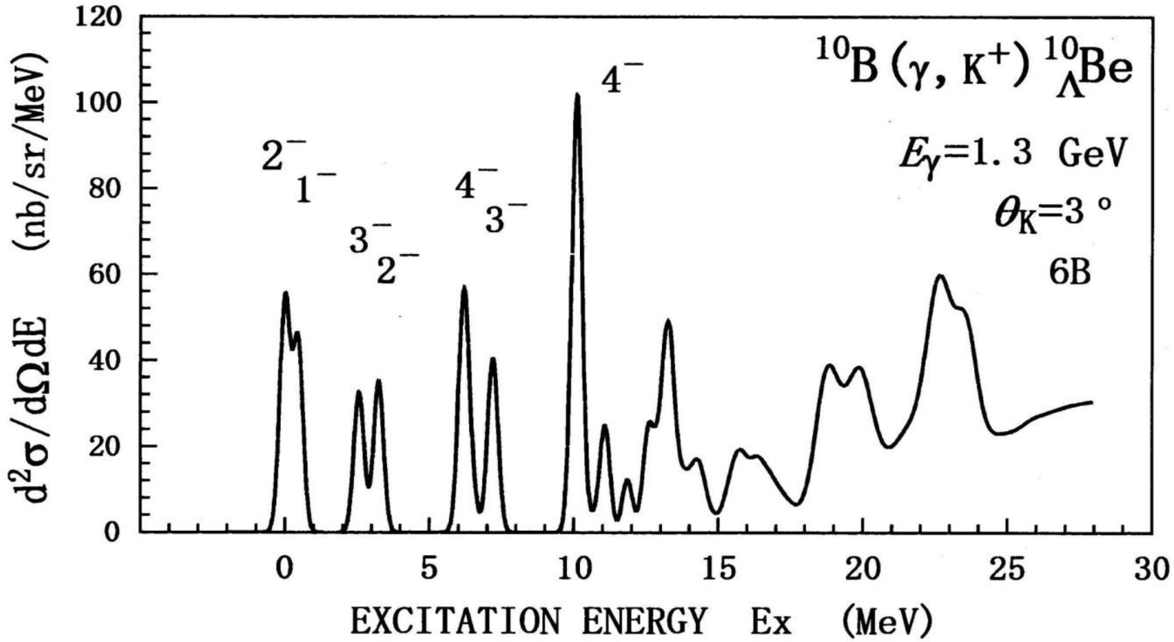
(cf. Λ13C:δ(***p***)=0.152+-0.07 MeV)



^{10}B target:

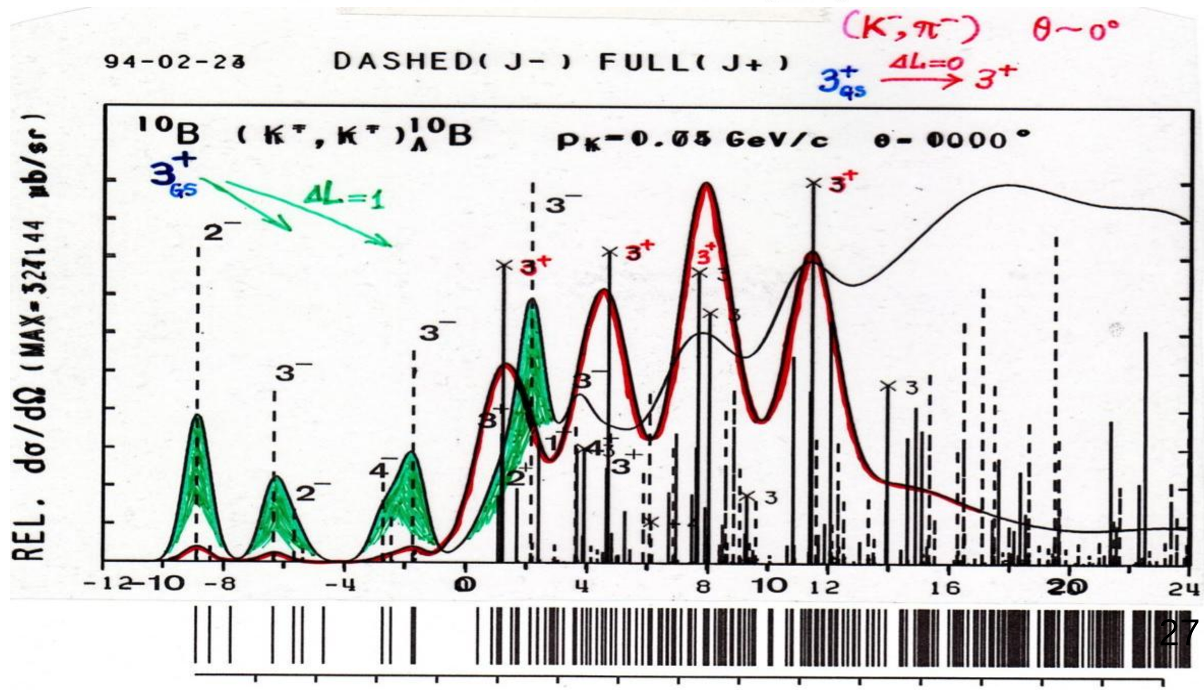
Prediction

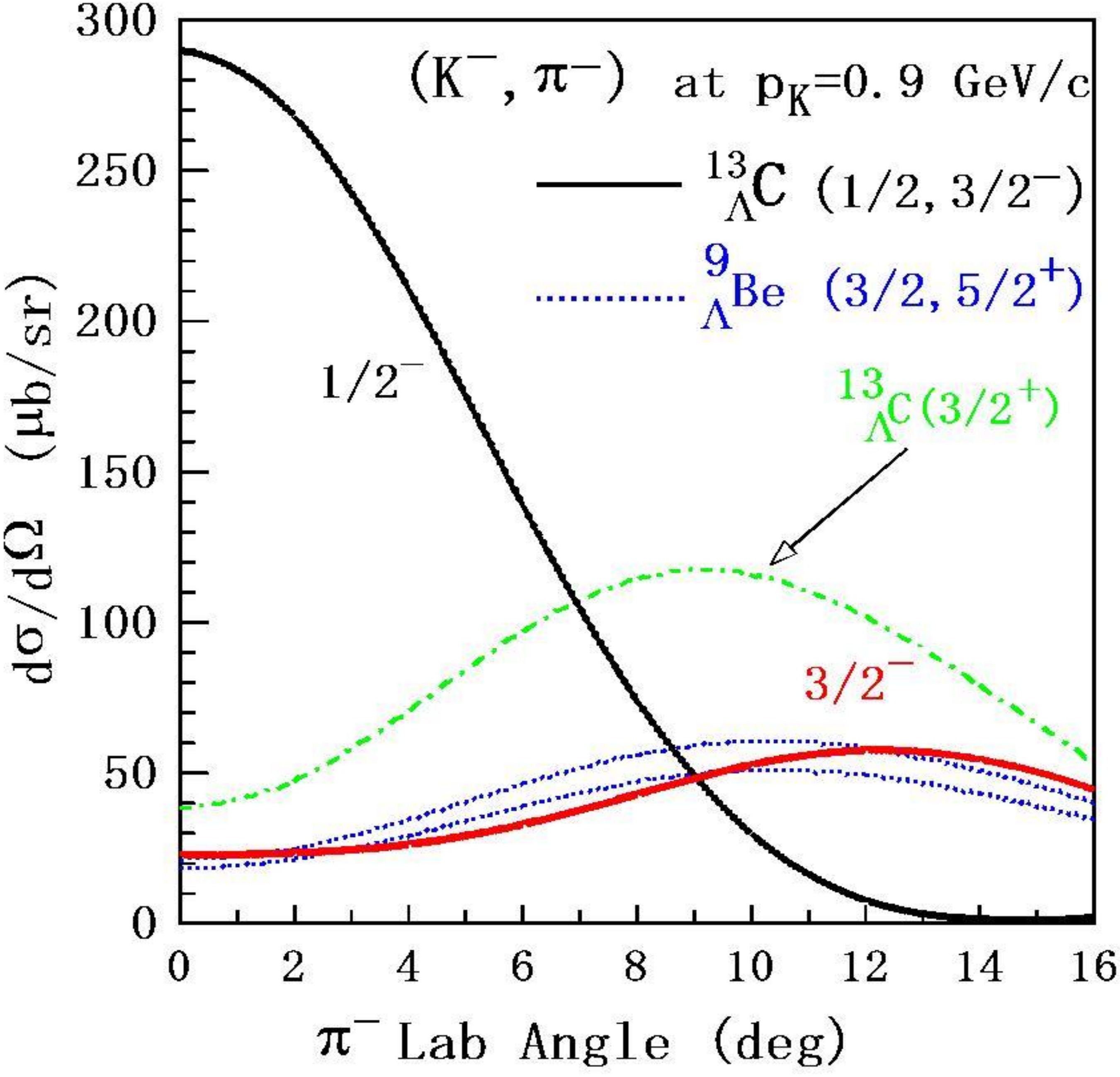
Motoba-Sotona-Itonaga, P.T.P. Suppl.117 (1994)



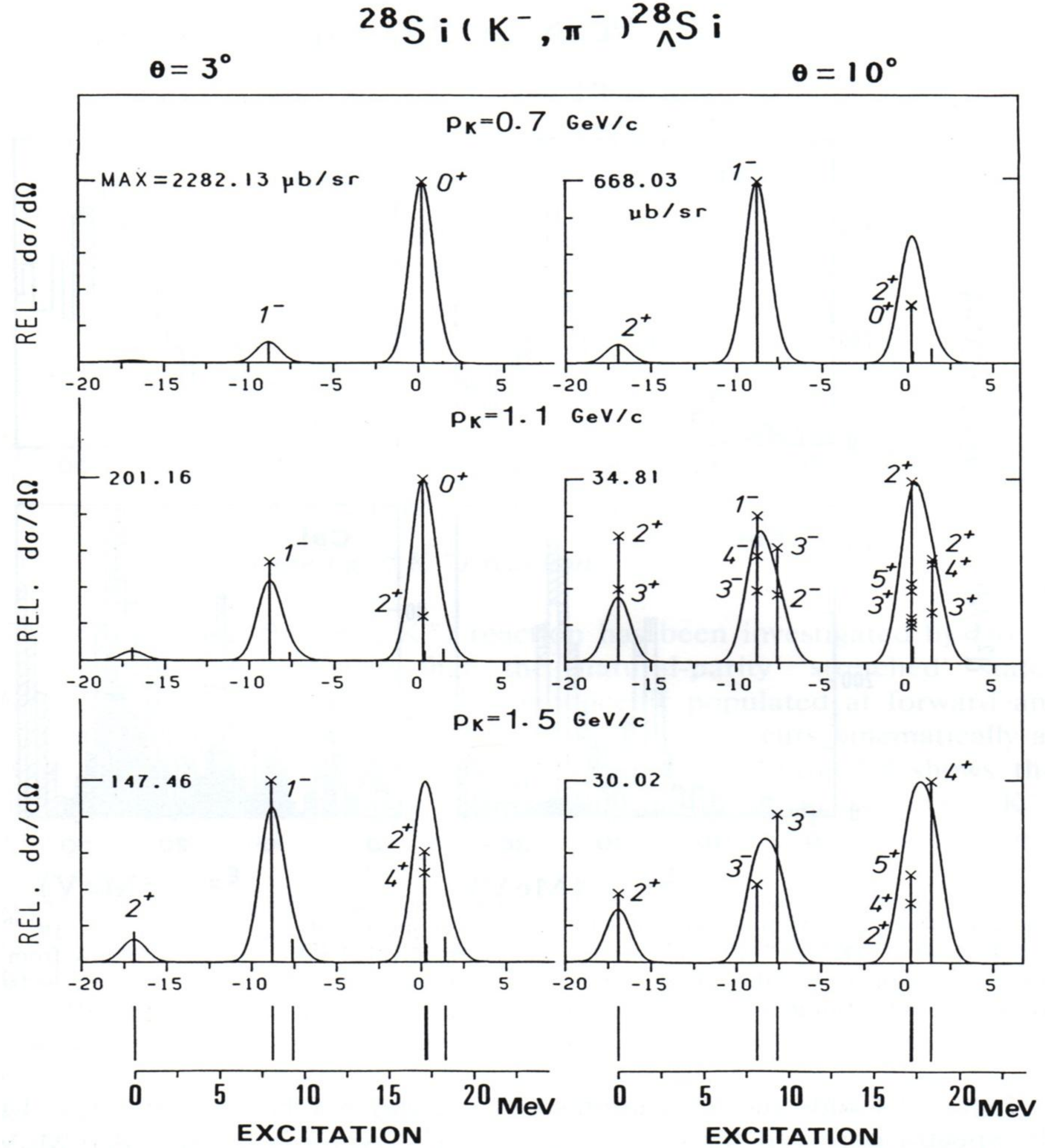
compared with

Theoretical results for
(K-,π-)
(π+,K+)





(K⁻, π⁻) at p_K=0.9 GeV/c
13 Λ C (1/2, 3/2⁻)
9 Λ Be (3/2, 5/2⁺)
13 Λ C (3/2⁺)
1/2⁻
3/2⁻
dσ/dΩ (μb/sr)
π⁻ Lab Angle (deg)
0
50
100
150
200
250
300
0
2
4
6
8
10
12
14
16



$^{28}Si(K^-,\pi^-)^{28}_{\Lambda}Si$
θ= 3°
θ = 10°
pK=0.7 GeV/c
pK=1.1 GeV/c
pK=1.5 GeV/c
MAX=2282.13 μb/sr
668.03 μb/sr
201.16
34.81
147.46
30.02
REL. dσ/dΩ
EXCITATION
MeV

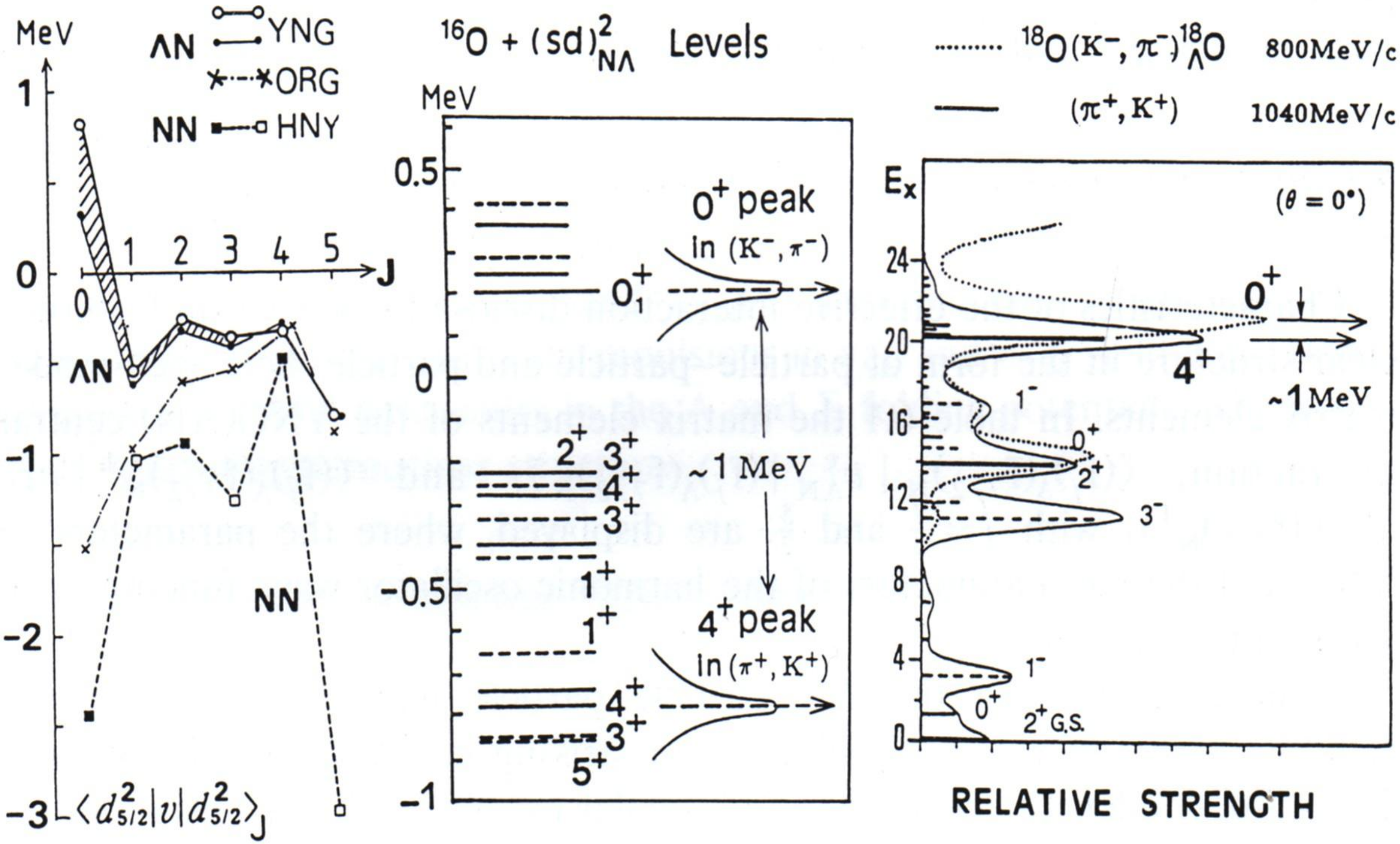
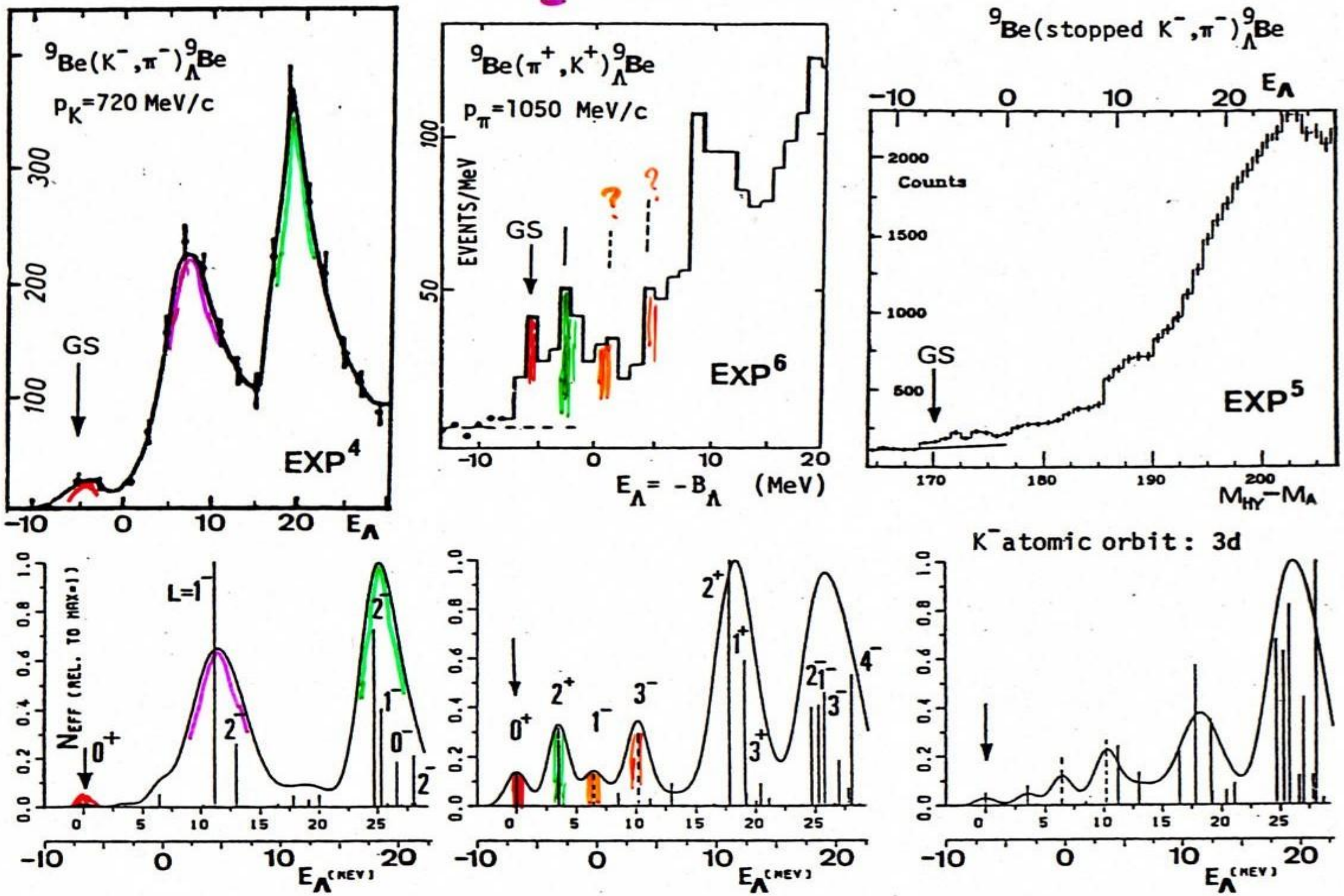


Fig. 6.3. Left: Comparison of two versions of YNG(ΛN) interactions, one-range Gaussian ΛN interaction (see eq. (8.24) [115]) and HNY NN interaction in the form of the shell-model matrix elements. Center: Predicted energy levels from the diagonalization in the $(sd)^2_{\Lambda N}$ shell model space. The selectively populated peaks in the (K^-, π^-) and (π^+, K^+) reactions are indicated. Right: The calculated whole spectra are shown.

P. Pile et al. P.R.L. (1991)

$q \simeq 350$ MeV/c



CAL: T. Motoba, H. Bandō, K. Ikeda: PTP (1983)

T. Yamada et al., P.R. C38 (1988)

中重ハイパー核:何が面白いか？

- Λ s.p.e. over wide periodic table

  広い範囲で本当に理論記述可能か

  DDHF, Rel.DDHF work?, Y identity: μ, mass

- Dynamical coupling of Y w/rot. & vib. L^{9}Be

・ Unique role of Y when coupled with shell & cluster states

  (軽い系のクラスター構造:本質的) ^{9}Be(e,e'K+)

・valuable experience to predict sd-shell

  三-hyernuclei（軽い典型例からsd殻へ）

Reaction spectroscopyの

最近10年におけるの進展

現に解析中の興味あるもの

そして今後の数年の可能性@J-PARC

- 最近におけるJlabでの(e,e'K^+) reaction spectroscopyのpowerful & promising results

  $\Delta E \sim$ 0.3 – 0.4 MeV (sub-MeV !)

- KEKでの(π^+,K^+)実験は やはり画期的

  ただし、 $\Delta E \sim$ 1.5 MeV

- High resolution (π^+,K^+) and (K^-, π^-) [+γ]

  (sub-MeV へ!)