Analysis of cascade production spectra in local optimal Fermi averaging *t*-matrix

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Ref. H. Maekawa, K. Tsubakihara, H. Matsumiya, A. Ohnishi, arXiv:0704.3929 [nucl-th], to be submitted PLB.

Cascade-Nucleus potential

Strong coupling dependence of cascade-Nucleus potential (c.f. Rijken's talk):

Nijmegen model D: V~-23 MeV

Nijmegen model F: V~ 28 MeV

ESC04d: V~-18MeV

→***Knowledge of the cascade-nucleus potential would give a valuable information for the YN interaction.***

In Phenomenological side

Old emulsion data → **Woods-Saxon type:** **Potential depth** **-24 < V< -20 (MeV)**

C. B. Dover and A. Gal, Annals of Phys, 146(1983)309.

Twin lambda emulsion data → **V~ -15 (MeV)**

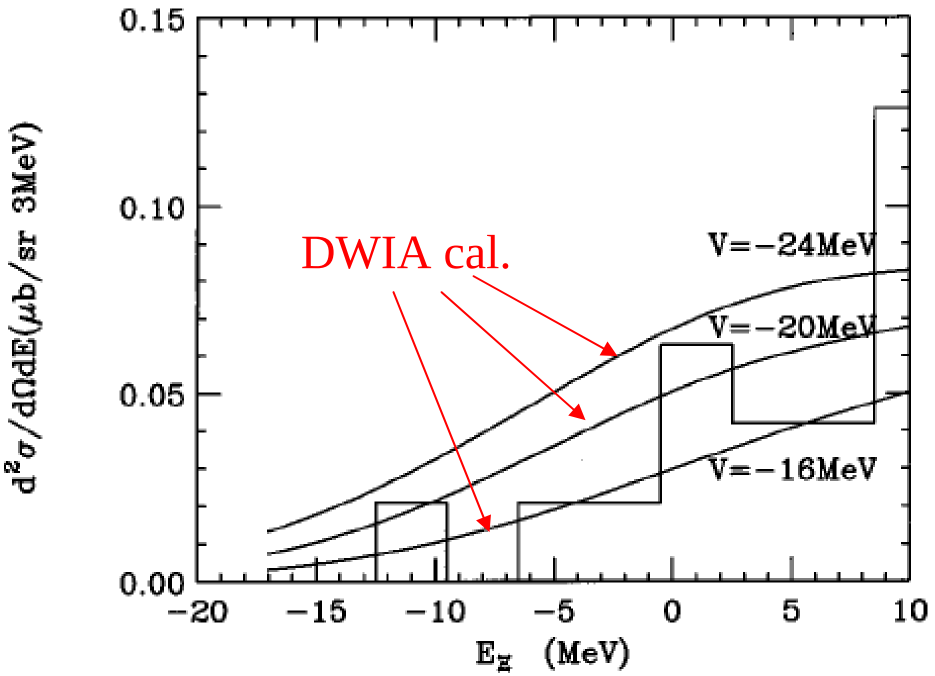
S. Aoki *et al.*, Phys. Lett. B **355** (1995) 45.

Production data → **V~ -16 (MeV)**

T. Fukuda et al., Phys. Rev. C58 (1998) 1306.

Ξ-production by (K^-, K^+) reaction in E224 at the KEK-PS

$^{12}C\ (K^-, K^+)$



T. Fukuda et al., Phys. Rev. C58 (1998) 1306.

DWIA calculation suggests that cascade-nucleus potential is about -16 MeV.

Shallow potential depth is suggested from their investigations.

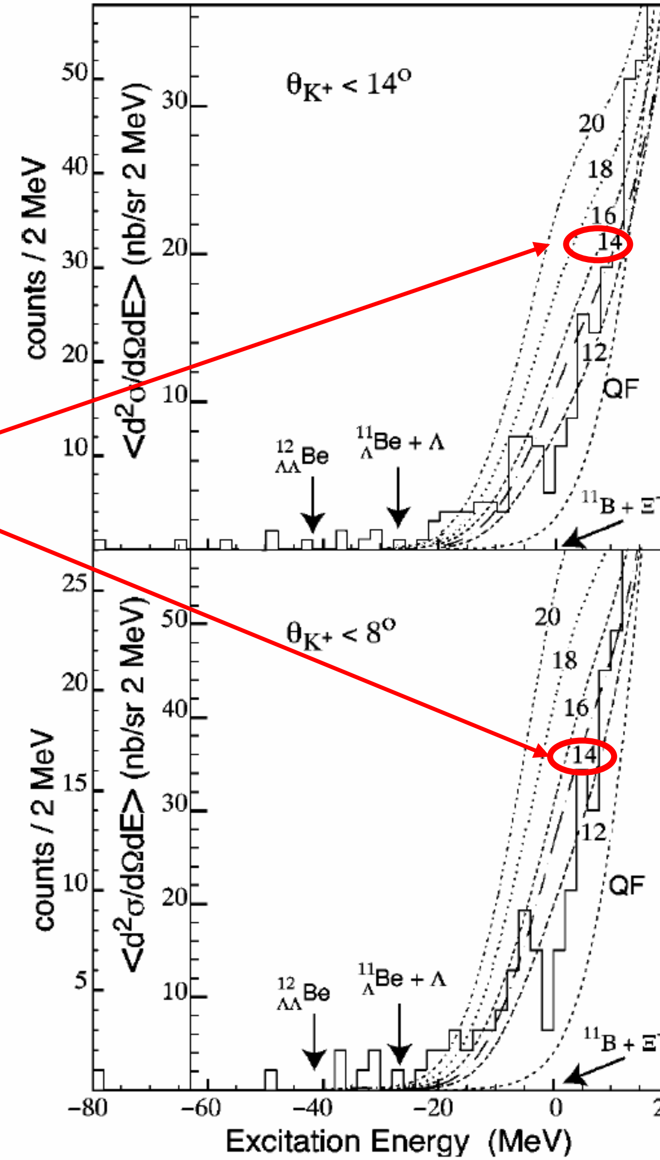
Ξ-production by (K⁻,K⁺) reaction in E885 at the AGS

$^{12}C(K^-,K^+)$

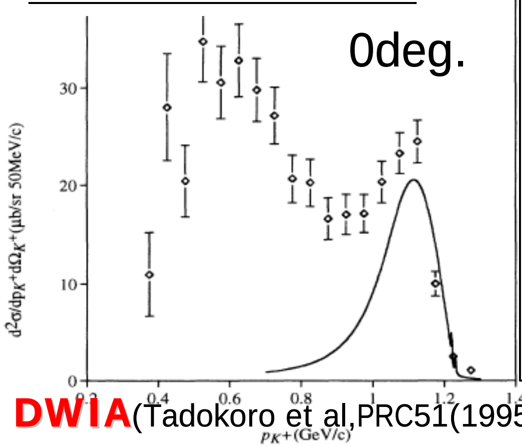
P_K=1.80GeV/c

P. Khaustov et al., Phys. Rev. C61 (2000) 054603-1.

Reasonable agreement between the experimental data and DWIA calculation is achieved by assuming a cascade-nucleus potential well depth of about **14 MeV** with the ential

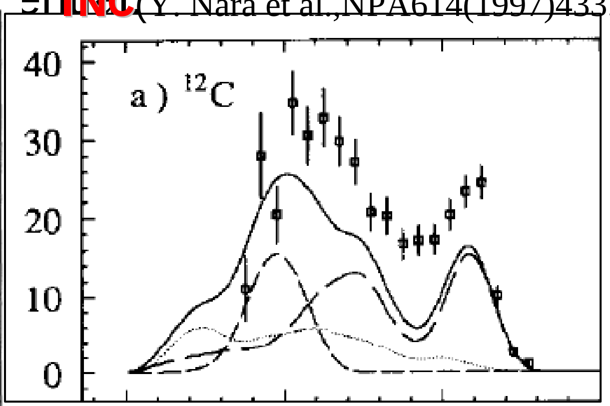


Theoretical curve:



DWIA(Tadokoro et al,PRC51(1995)2656.)

INC(Y. Nara et al.,NPA614(1997)433.)

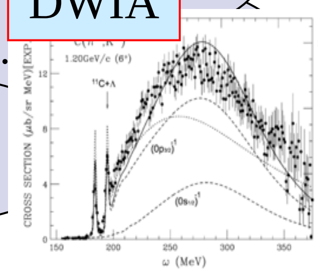


Purpose of our study

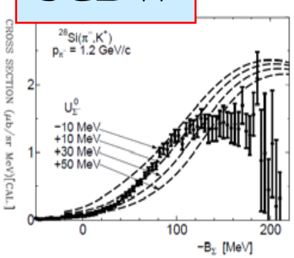
1. To describe the cascade production spectrum in both of Bound and Quasi-Free regions on the same footing using a Fermi averaging t-matrix with **on-shell condition** (Green’s function method).

T. Harada, Y. Hirabayashi, Nucl. Phys. A 744 (2004) 323.
M. Kohno, Y. Fujiwara, M. Kawai et al., Phys.Rev.C74:064613,2006.
S. Hashimoto, M. Kohho, K. Ogata, M. Kawai, nucl-th/0610126.
H. Maekawa, K. Tsubakihara, A. Ohnishi, nucl-th/0701066.

DWIA

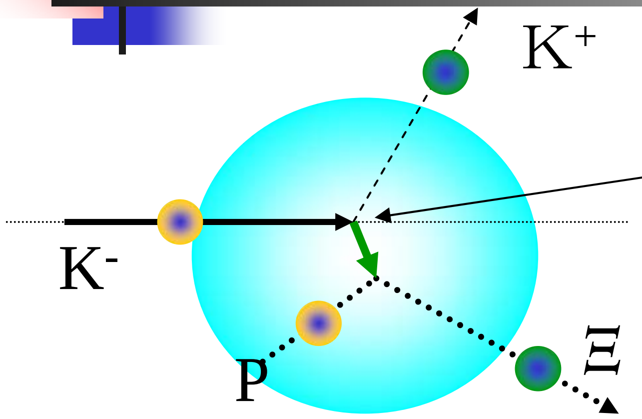


SCDW



2. To predict the cascade production spectra on several targets.

Fermi Averaging of *t*-matrix for elementary process



We include the potential effects at the cascade production points into the optimal Fermi average.

Energy conservation equation

$$E_{K^-}(r)+E_p(r)=E_{K^+}(r)+E_{\Xi^-}(r)$$

Local Energy of Hadrons

$$E_H(r)=\sqrt{\mathbf{p}_H^2+m_H^{*2}(r)}\approx m_H+\frac{\mathbf{p}_H^2}{2m_H}+V_H(r)$$

Effective mass of Hadrons

$$m_H^{*2}(r)=m_H^2+2m_H\boxed{V_H(r)}$$

"potential"

Local Optimal Fermi Averaging *t*-matrix (LOFAt)

$$\bar{t}(r,\omega,\mathbf{q})=\frac{\int d\mathbf{p}_N t(s,t)\rho(p_N)\delta^{(4)}(p_1+p_2(r)-p_3-p_4(r))}{\int d\mathbf{p}_N \rho(p_N)\delta^{(4)}(p_1+p_2(r)-p_3-p_4(r))}$$

Double differential cross section:

$$\frac{d^2\sigma}{dE_K d\Omega_K}=\frac{p_K E_K}{(2\pi)^2 v_{inc}}R(E)$$

Response function:

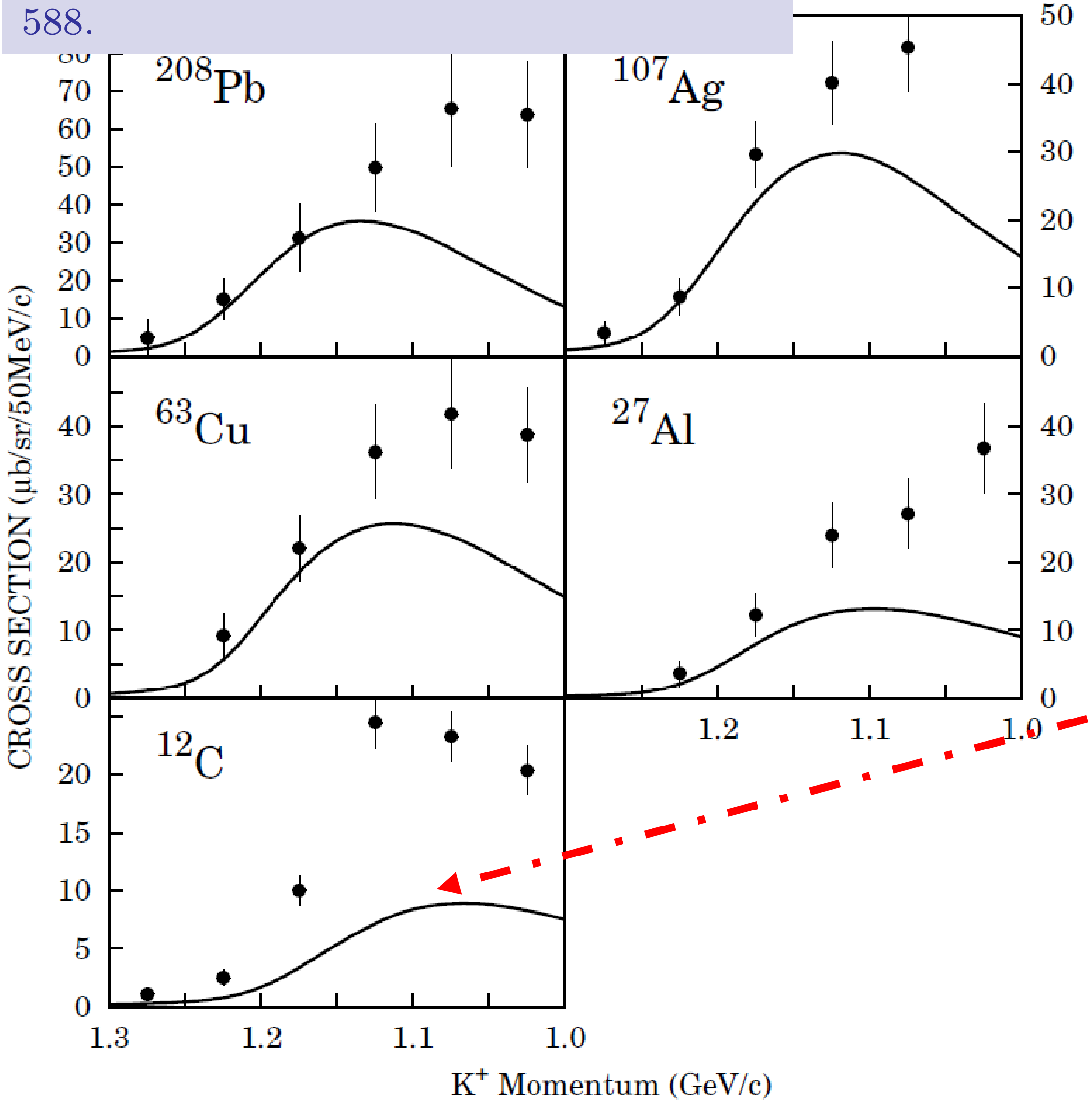
$$R(E)=-\frac{1}{\pi}\mathrm{Im}\int d\mathbf{r}d\mathbf{r}'\,f_\alpha^*(\mathbf{r})\bar{t}_\alpha^*(\mathbf{r})G_{\alpha\alpha'}(E;\mathbf{r}',\mathbf{r})\bar{t}_{\alpha'}(\mathbf{r})f_{\alpha'}(\mathbf{r})$$

Non-Factrization form

Cascade production Quasi-Free spectra on several targets

Exp. Data

T. Iijima *et al.*, Nucl. NPA **546** (1992), 588.



P_K=1.65(GeV/c)

Theory:

V=-14(MeV)

W=-1(MeV)

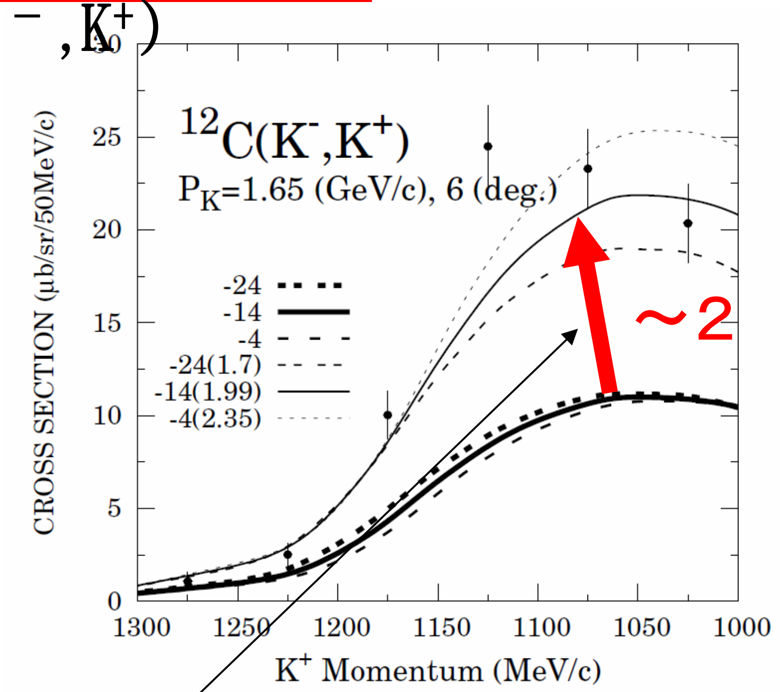
In many works, spectra on ^{12}C target are underestimated.

Y. Nara et al.,NPA614(1997)433.
M. Kohno, Y. Fujiwara, M. Kawai et al., Phys.Rev.C74(2006)064613.
S. Hashimoto, M. Kohho, K. Ogata, M. Kawai, nucl-th/0610126.
C. Gobbi, C. B. Dover, A. Gal, Phys. Rev. C 50(1994)1594.

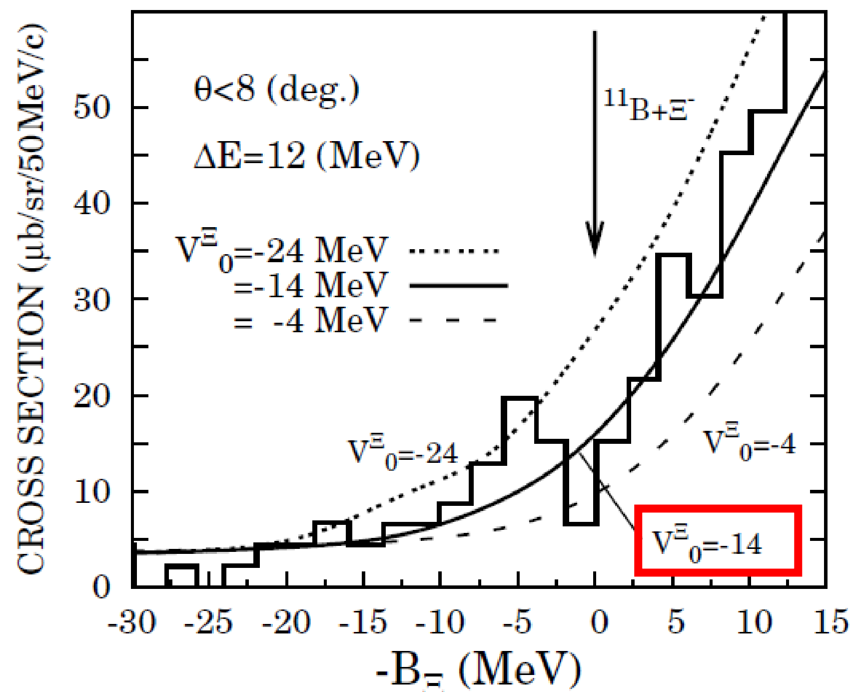
Possible origins: Recoil, t-matrix, ...
These does not change the spectrum shape.

Cascade production QF and BS spectra on ^{12}C

^{12}C (K^-, K^+)

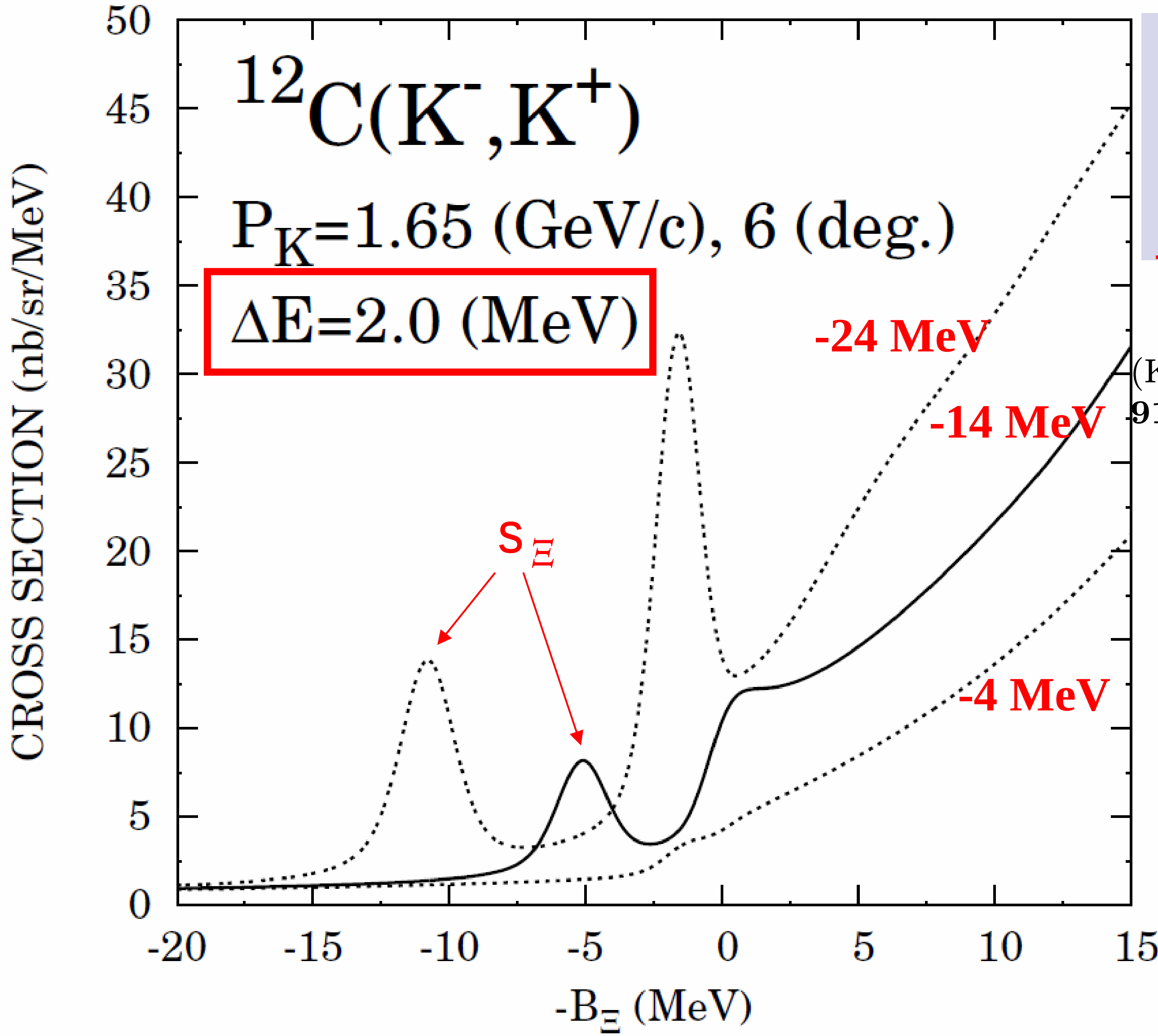


We decide the multiplicative factors in comparison with the QF data.



Calculated curve reproduces the low resolution data with cascade-nucleus potential of about **−14MeV**.

Cascade production BS spectra on ^{12}C target



Woods-Saxon:

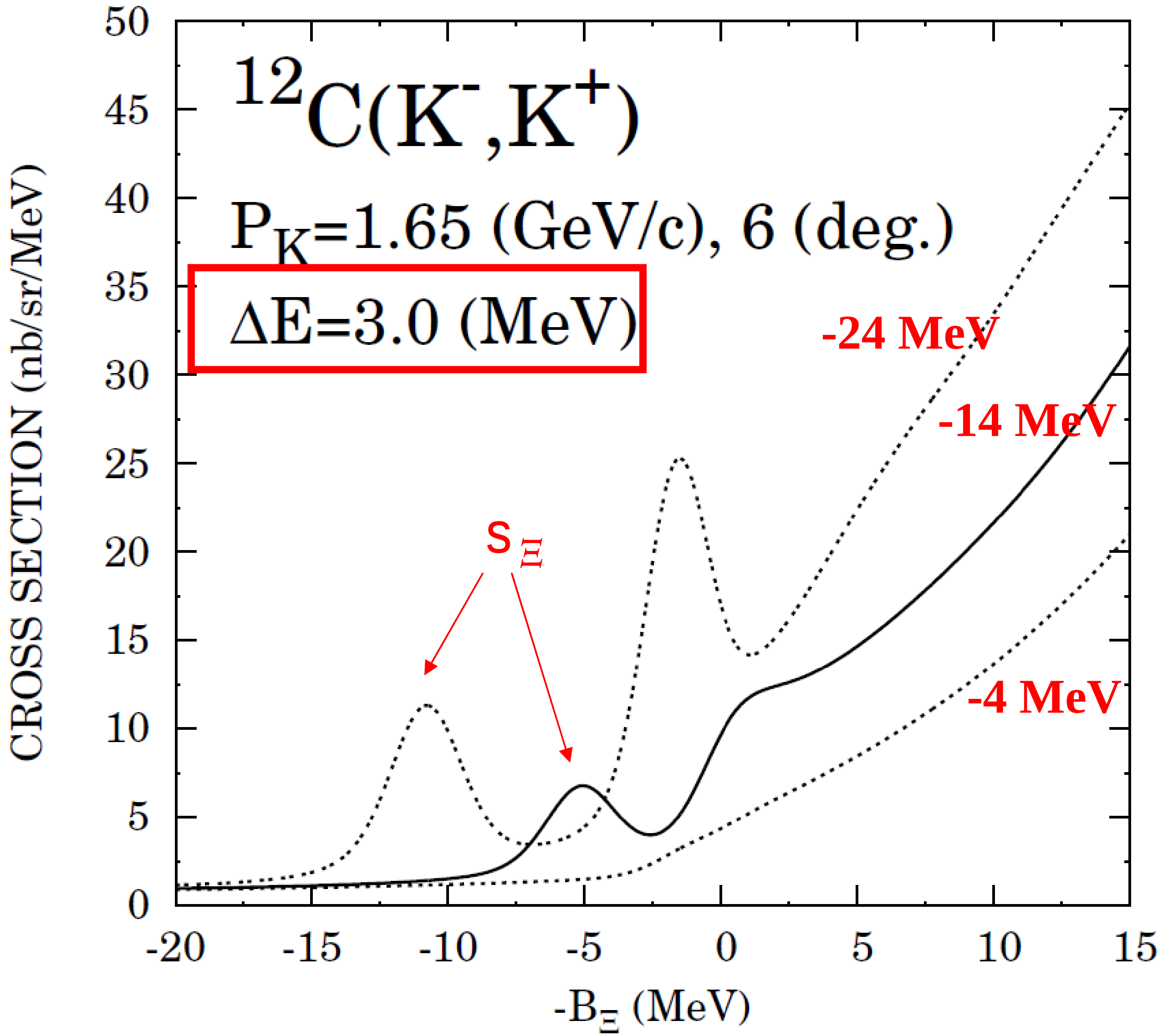
V=-4,-14,-24 MeV

W=-1 MeV

Estimated base on ND potential potential

(K. Ikeda, et al., PTP **91**(1994)747.)

Cascade production BS spectra on ^{12}C target



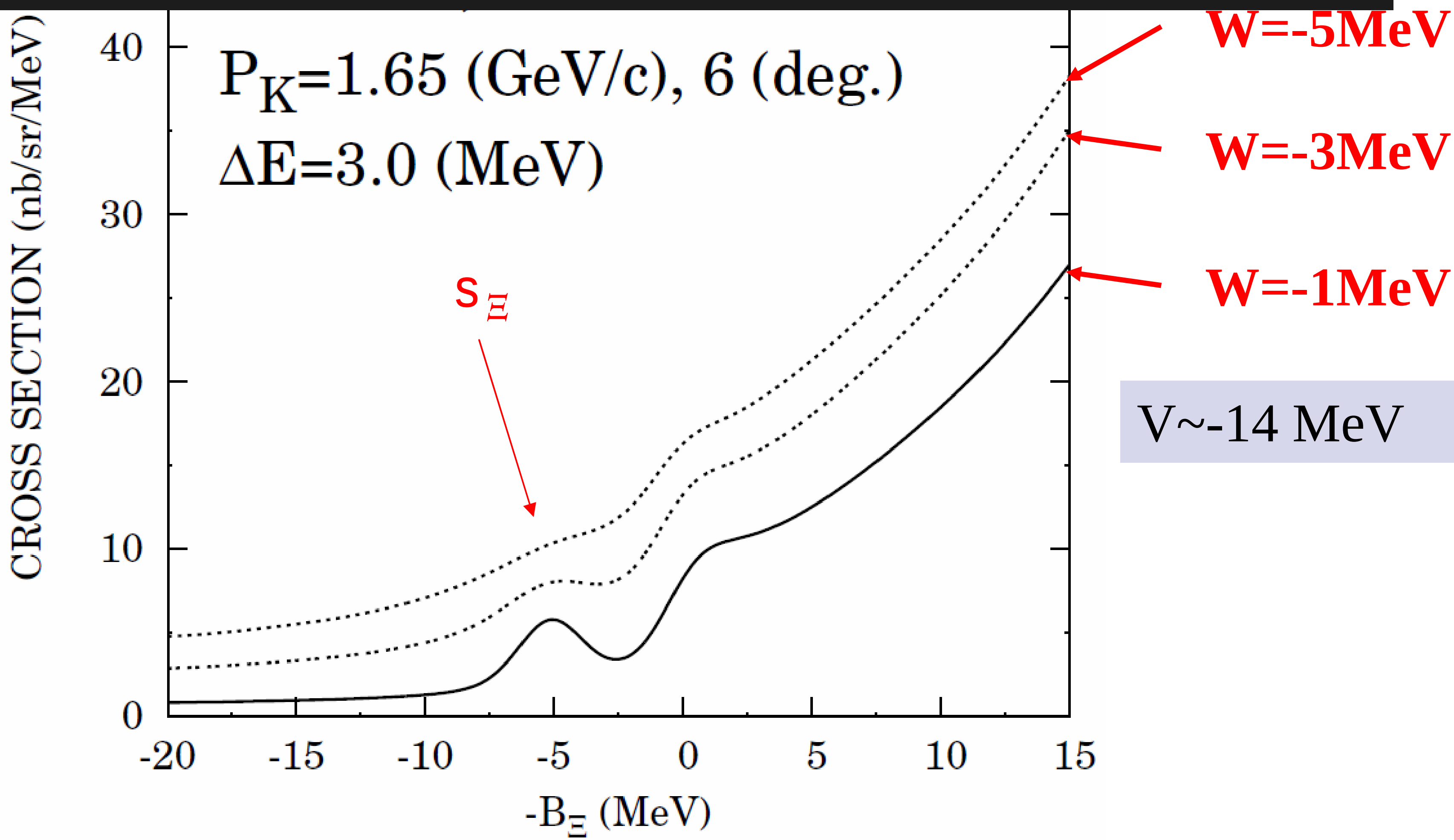
Woods-Saxon:

V=-4,-14,-24 MeV

W=-1 MeV

Cascade production BS spectra on ^{12}C target

When the conversion width is not very large (|W|<3MeV), we can identify the bound state peak.



V~-14 MeV

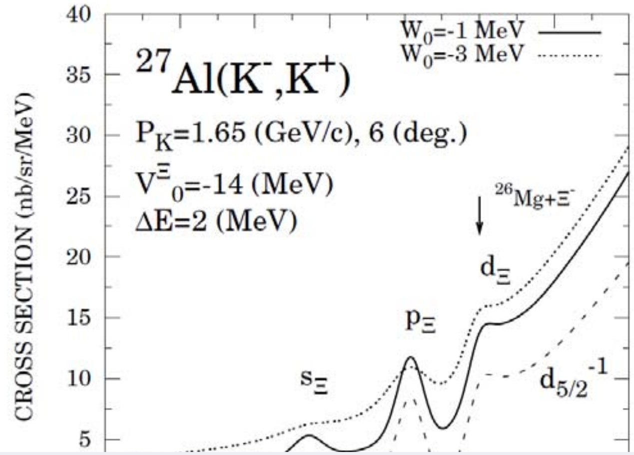
Cascade production BS spectra on several targets

High resolution case

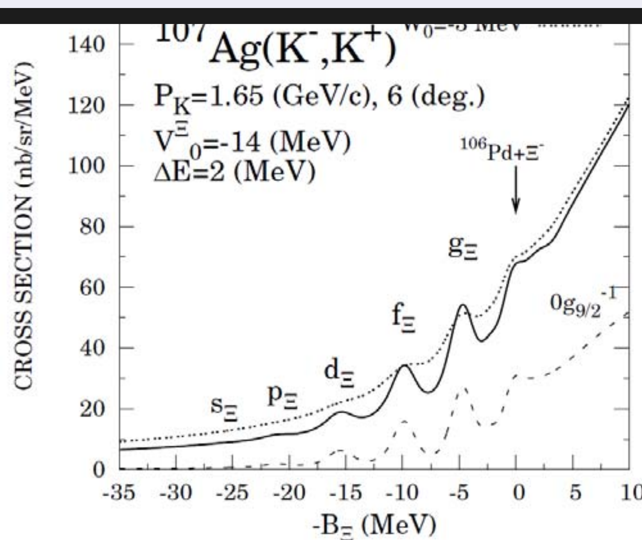
FWHM=2 (MeV)

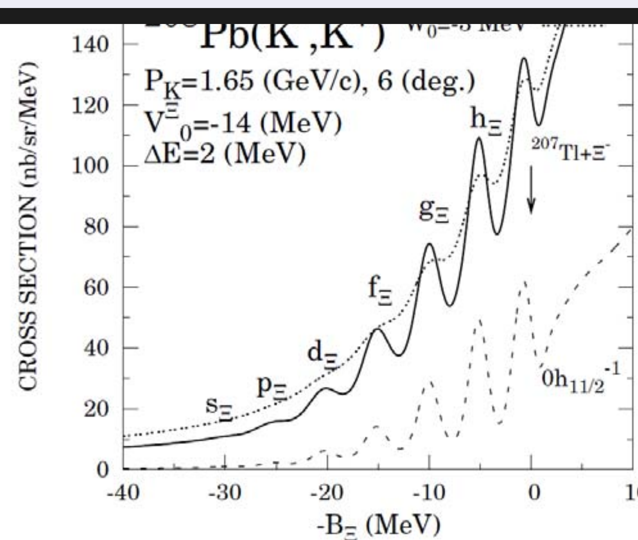
Potential: Woods-Saxon type

U=(V+iW)f(r)



For small width (|W|<3MeV), we can identify the stretched state peak just below the threshold.





Summary and Conclusion

- We have investigated the cascade-nucleus potential through the cascade hypernuclear production spectra by (K^-,K^+) reaction
  in both of the bound and continuum regions
  in the Green's function method of the distorted wave impulse approximation with the local optimal Fermi averaging *t*-matrix.

- The calculated Quasi-Free spectra are in good agreement with the experimental data for heavy targets. After fixing the absolute value in QF region, low resolution bound spectrum data on ^{12}C are well described
  with cascade-nucleus potential **U_{Ξ}~-14MeV**

- The cascade bound state peak structure can be found in the (K^-,K^+) spectra on light target such as ^{12}C, as far as
  the imaginary part is **not very large (|W|<3 MeV)**
  and
  the experimental resolution is improved (**ΔE = 2～3 MeV**),
  as expected in the J-PARC experiment.

Model: Green function method by Morimatsu and Yazaki

Ref) O.Morimatsu and K.Yazaki, Nucl. Phys. A483(1988)493.
S.Tadokoro,Y.Akaishi,H.Kobayashi. Phys.Rev.C51(1995)2656.
M.T.Lopez-Arias, Nucl. Phys. A582(1995)440.

Double differential cross section

$$\frac{d^2\sigma}{dE_K d\Omega_K} = \underline{\beta} \left\langle \left(\frac{d\sigma}{d\Omega} \right)^{(ele)}_{\pi+n\to K+Y} \right\rangle_{Average} S(E)$$

Kinematical factor

$$\beta = \left\{ 1 + \frac{E_K}{E_Y} \left(\frac{p_K - p_\pi \cos\theta}{p_K} \right) \right\} \frac{E_K^M p_K^M}{E_K p_K}$$

Strength function

Fermi averaged Elementary cross section

Strength function

$$S(E) = -\frac{1}{\pi} \mathrm{Im} \int d\mathbf{r} d\mathbf{r}' f_\alpha^*(\mathbf{r}) G_{\alpha\alpha'}(E;\mathbf{r}',\mathbf{r}) f_{\alpha'}(\mathbf{r})$$

$$f_\alpha(\mathbf{r}) = \chi_K^{(-)*}(\mathbf{r}) \chi_\pi^{(+)}(\mathbf{r}) \langle \alpha | \psi_N(\mathbf{r}) | i \rangle$$

Include the hyperon potential in Green function

Meson distorted waves

$$\chi_K^{(+)*}(\mathbf{r}) \chi_\pi^{(-)}(\mathbf{r}) = e^{i\mathbf{q}\mathbf{r}} \Gamma(\mathbf{r})$$

$$G = \frac{1}{E - T_Y - U_Y - H_{Core} + i\varepsilon}$$

"Green function"

Distortion factor

$$\Gamma(\mathbf{r}) = \exp\left[-\bar{\sigma}_{\pi N} \int_{-\infty}^{z} \rho(z') dz' - \bar{\sigma}_{KN} \int_{z}^{\infty} \rho(z') dz' \right]$$

Meson distorted waves in eikonal approximation

（π，K） reaction at 1.20 GeV/c

$$\chi_K^{(+)*}(\mathbf{r})\chi_\pi^{(-)}(\mathbf{r}) = e^{i\mathbf{qr}}\Gamma(\mathbf{r})$$

Distortion factor $\Gamma(r) = \exp\left[-\bar{\sigma}_{\pi N}\int_{-\infty}^{z}\rho(z')dz' - \bar{\sigma}_{KN}\int_{z}^{\infty}\rho(z')dz'\right]$

～35.2mb ～16.3mb

Eikonal phase for Kaon

$$\longrightarrow \quad \Gamma(r) = \exp\left[-\bar{\sigma}_{\pi N}\int_{-\infty}^{z}\rho(z')dz' - \bar{\sigma}_{KN}\int_{z}^{\infty}\rho(z')dz' + i\chi_{K^+}(b)\right]$$

$$\chi_{K^+}(b) = -\frac{1}{\hbar v}\int_{-\infty}^{\infty}dz'U(z')$$

Kaon optical potential(real)

Partial wave decomposition for DW product

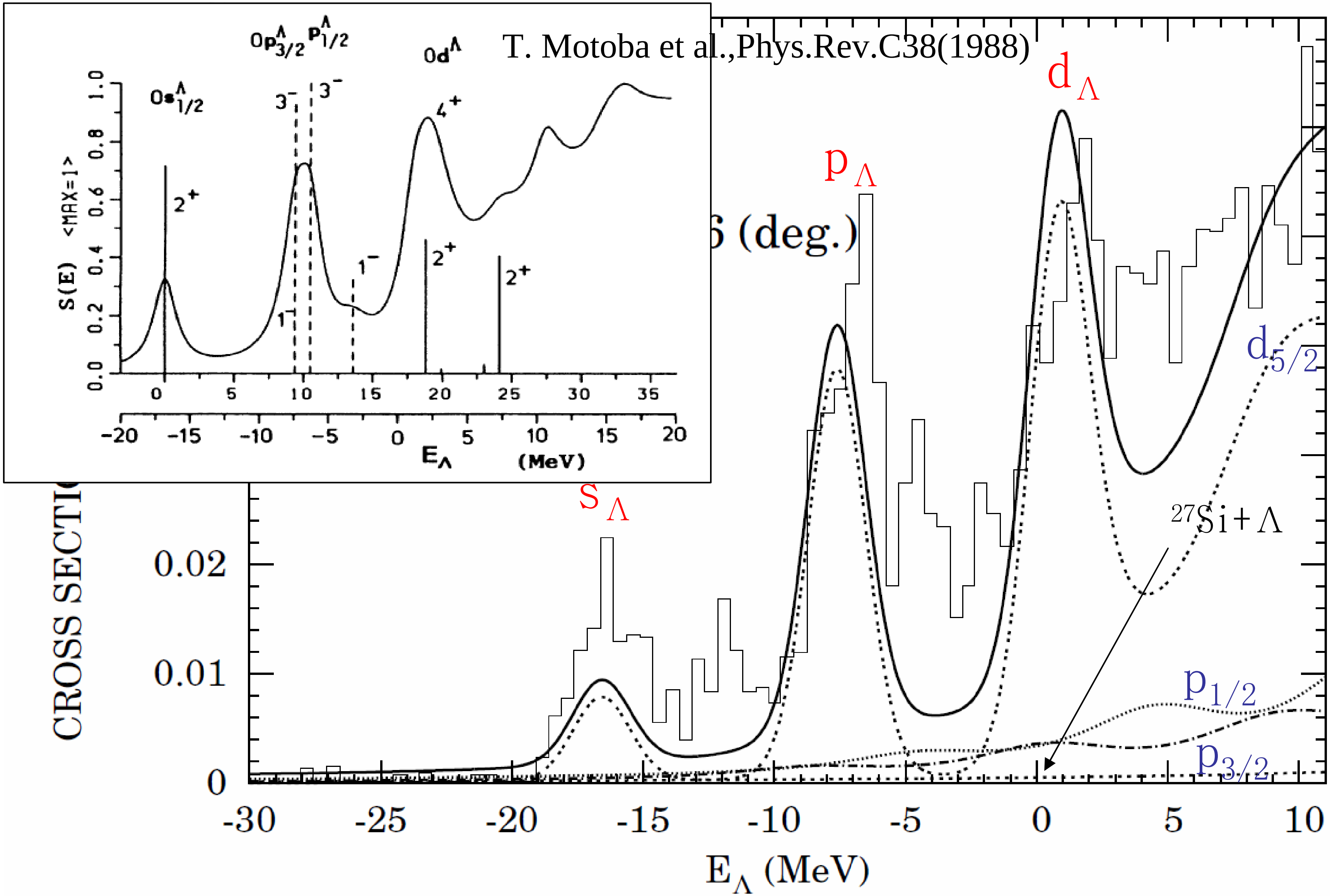
$$\chi_K^{(+)*}(\mathbf{r})\chi_\pi^{(-)}(\mathbf{r}) = \sum_{LM} 4\pi i^L \tilde{j}_L(qr) Y_{LM}^*(\hat{k}) Y_{LM}(\hat{r})$$

$$\tilde{j}_L(qr) = i^{-L}(2L+1)^{-1}\sum_{ll'}(2l+1)^l\sqrt{(2l'+1)/4\pi}\,(l0l'0|L0)^2 j_l(qr)\Gamma_{l'}(r)$$

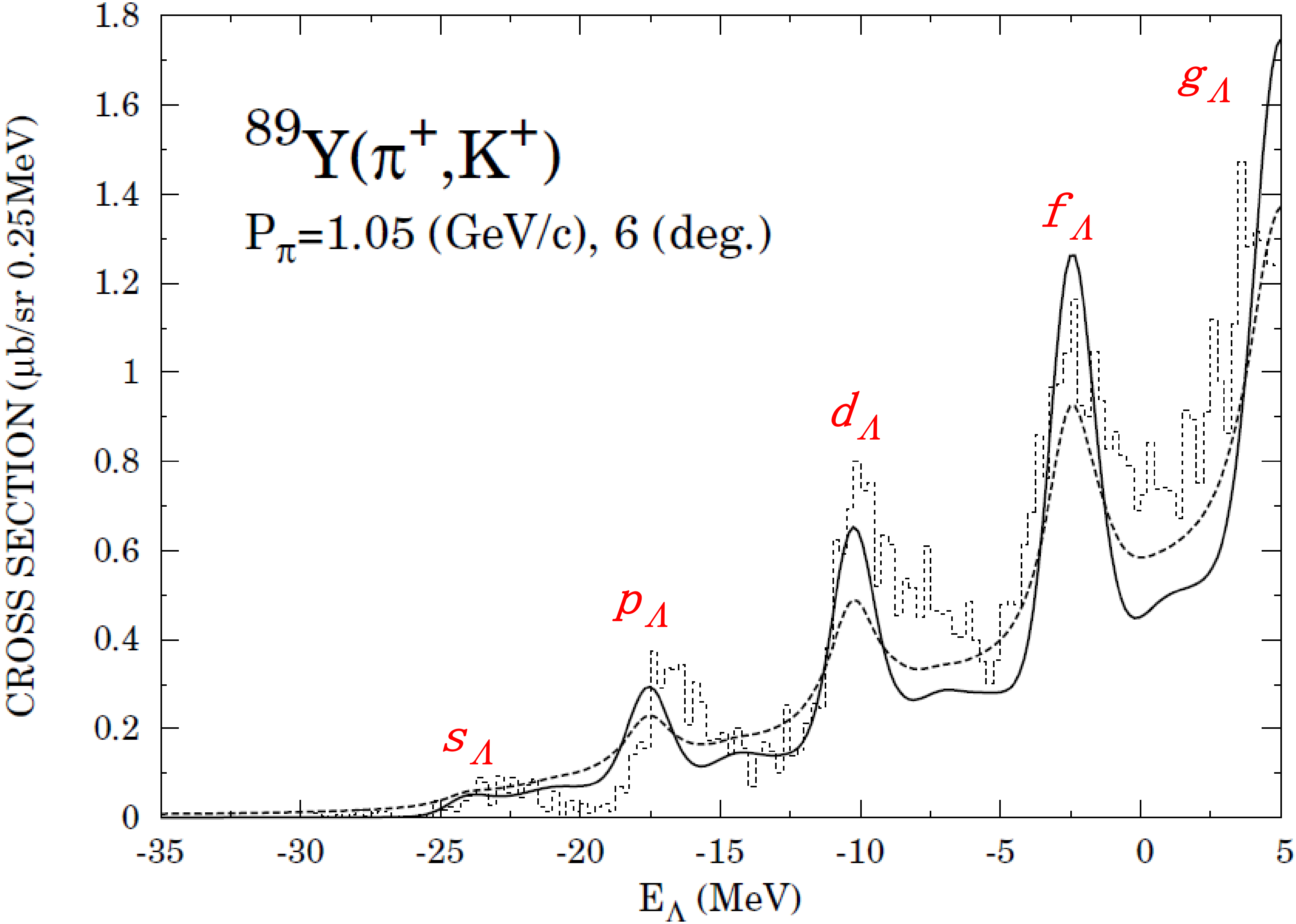
Distorted Bessel function

Distortion factor

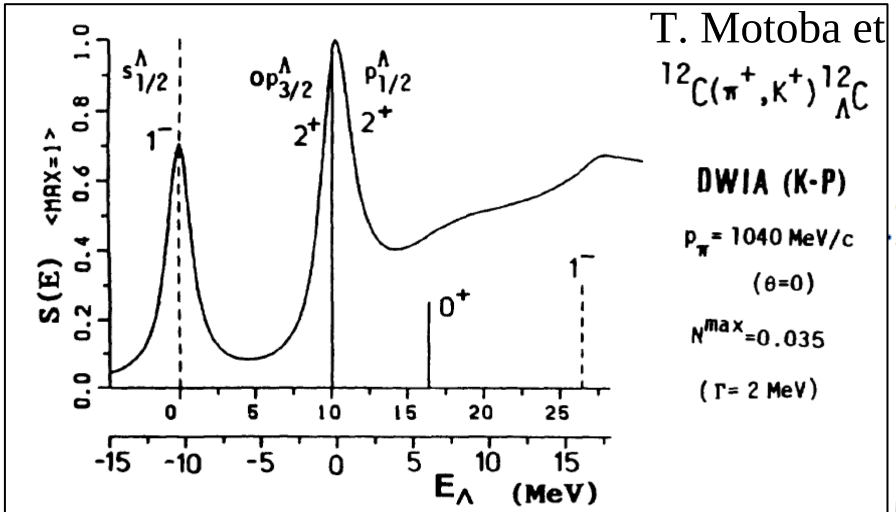
Λ production spectra on ^{28}Si



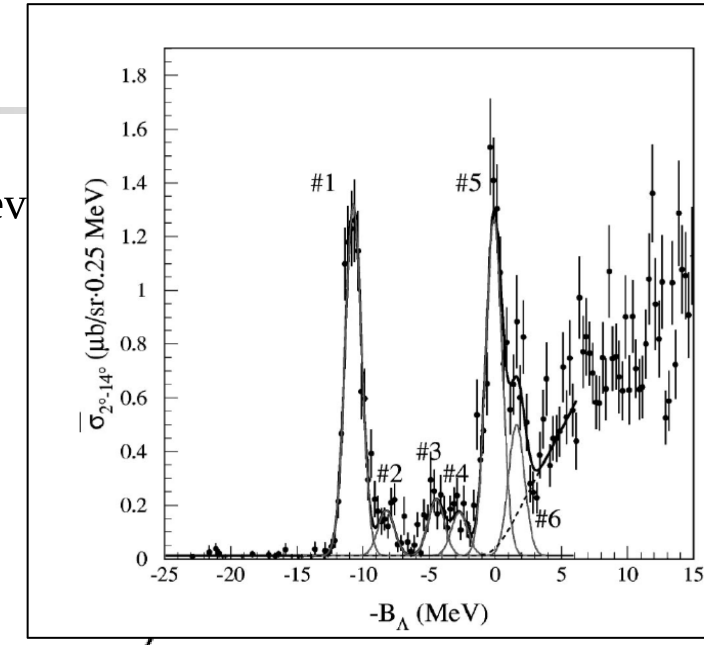
Λ production spectra on ^{89}Y



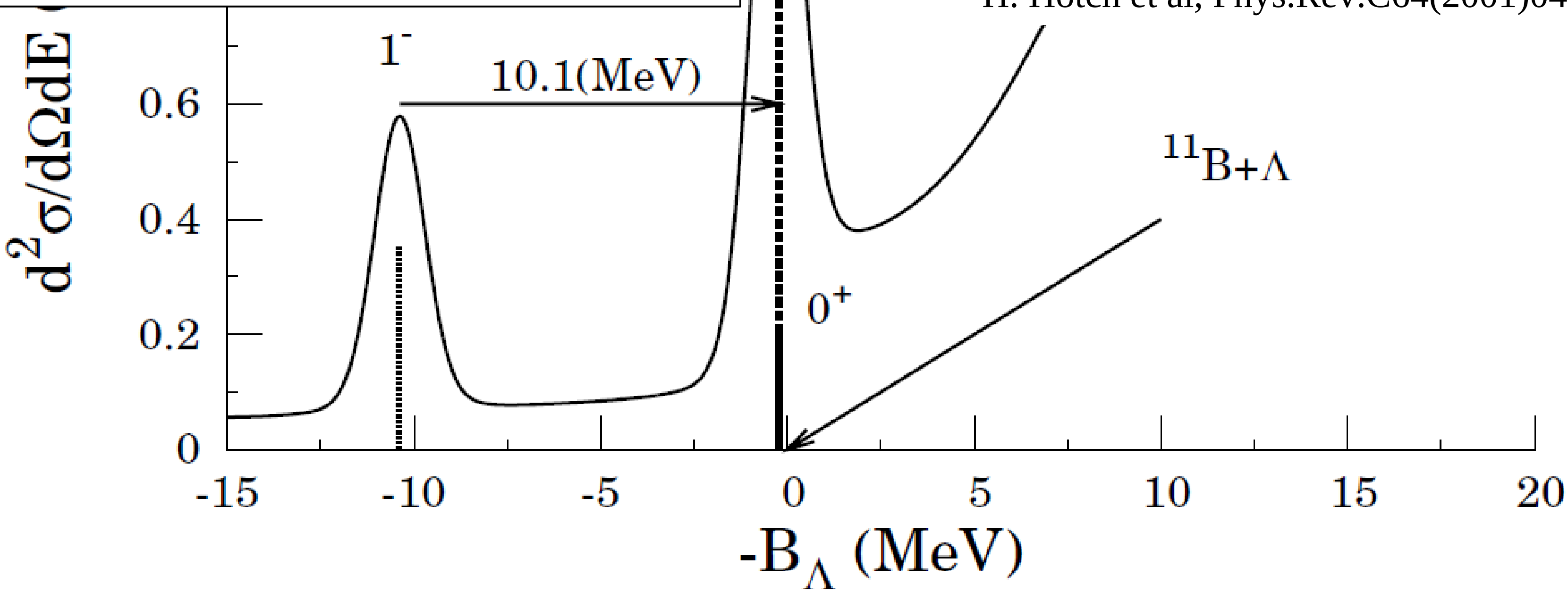
Λ production spectra on ^{12}C



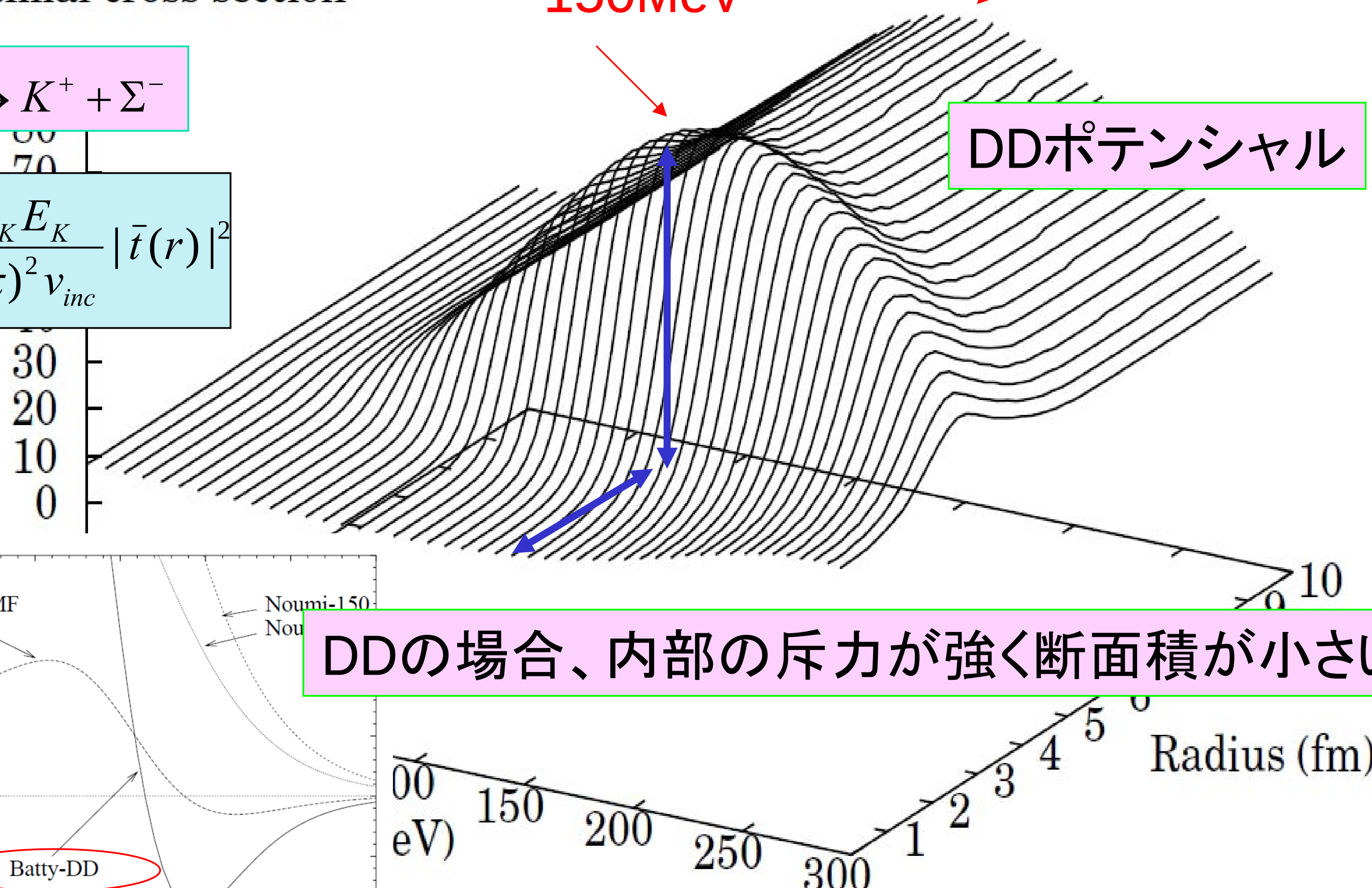
T. Motoba et al.,Phys.Rev



H. Hotch et al, Phys.Rev.C64(2001)044302

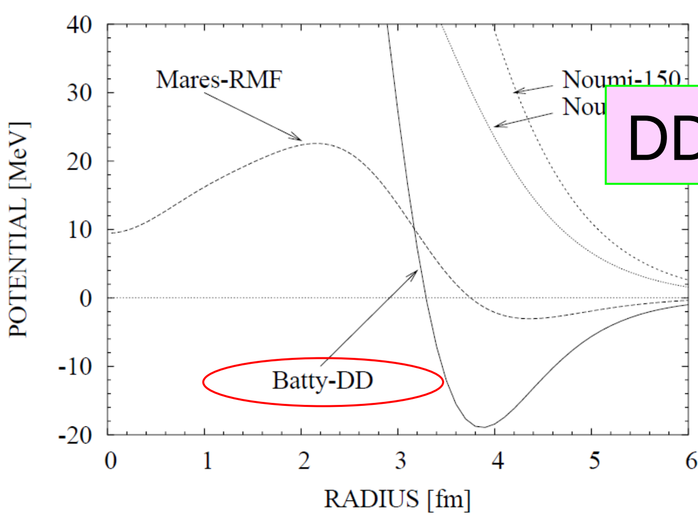


局所最適フェルミ平均した素過程断面積(t行列)



$$\pi^- + p \rightarrow K^+ + \Sigma^-$$

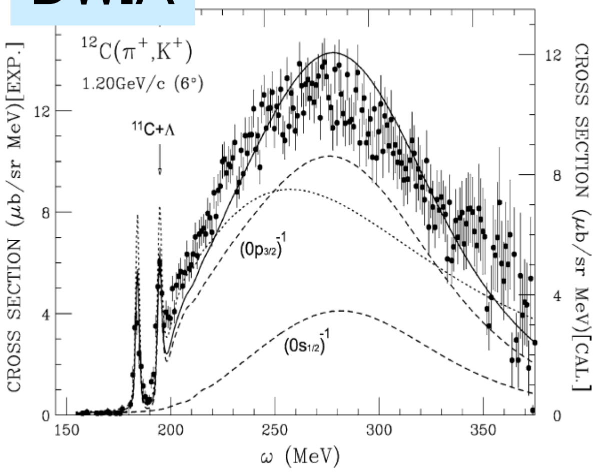
$$\frac{d\sigma}{d\Omega}(r) = \frac{p_K E_K}{(2\pi)^2 v_{inc}} |\bar{t}(r)|^2$$



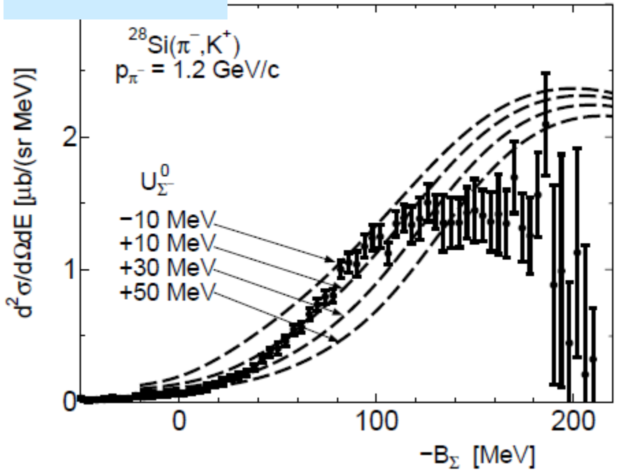
DDの場合、内部の斥力が強く断面積が小さい

Fermi averaging with the on-shell condition

DWIA



SCDW



Several authors pointed out.

In order to describe the Quasi-Free spectrum,

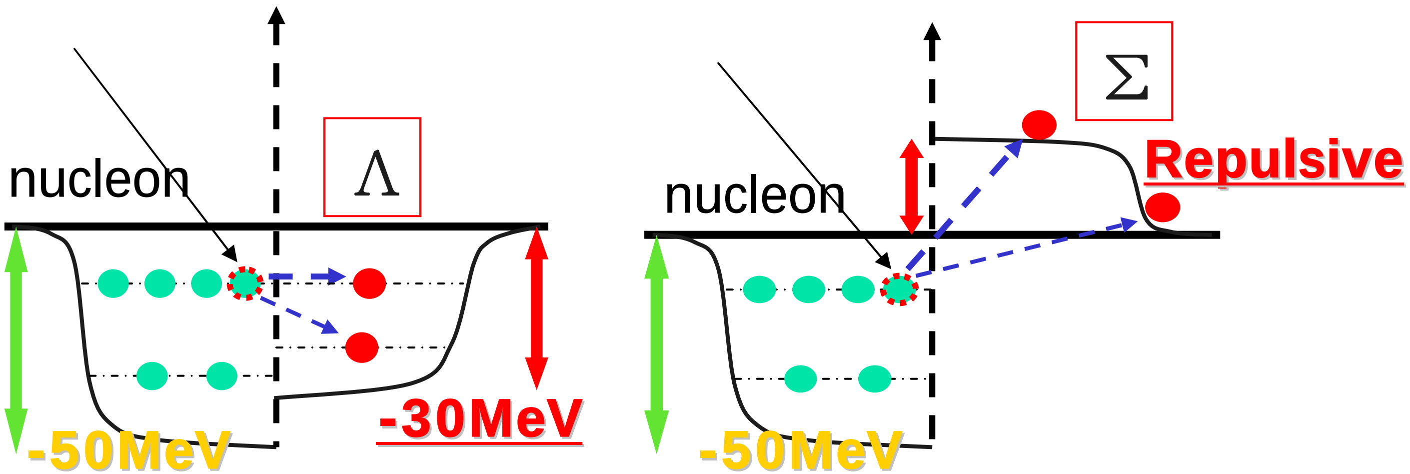
On-shell condition is very important under the averaging t-matrix of elementary process.

T. Harada, Y. Hirabayashi, Nucl. Phys. A 744 (2004) 323.
M. Kohno, Y. Fujiwara, M. Kawai et al.,Phys.Rev.C74:064613,2006.
S. Hashimoto, M. Kohho, K. Ogata, M. Kawai, nucl-th/0610126.
H. Maekawa, K. Tsubakihara, A. Ohnishi, nucl-th/0701066.

DWIA+最適Fermi平均(自由空間での平均)

→QFの記述に重要

→素過程におけるポテンシャル効果は？



研究目的

・最適Fermi平均にポテンシャル効果を取り入れ、
Fermi平均の取り扱いによる核内での
素過程のエネルギー依存性の変化について議論する

・反応データとの比較からのポテンシャル情報を引き出す

Cascade-Nucleus interaction

A different sign of cascade-Nucleus potential:

Nijmegen model D: V~-23 MeV

Nijmegen model F: V~ 28 MeV

→***Knowledge of the cascade-nucleus potential would give a valuable information for the YN interaction models.***

Old emulsion data analysis

$^{8}_{\Xi}$He: $B_\Xi = 5.9 \pm 1.2$ MeV,

$^{11}_{\Xi}$B: $B_\Xi = 9.2 \pm 2.2$ MeV,

$^{13}_{\Xi}$C: $B_\Xi = 18.1 \pm 3.2$ MeV,

$^{15}_{\Xi}$C: $B_\Xi = 16.0 \pm 4.7$ MeV,

$^{17}_{\Xi}$O: $B_\Xi = 16.0 \pm 5.5$ MeV,

$^{28}_{\Xi}$Al: $B_\Xi = 23.2 \pm 6.8$ MeV,

$^{29,30}_{\Xi}$Mg: $B_\Xi = 2.4 \pm 6.3$ MeV.

→

Woods-Saxon type:

Potential depth

-24 < V< -20 (MeV)

C. B. Dover and A. Gal, Annals of Phys, 146(1983)309.