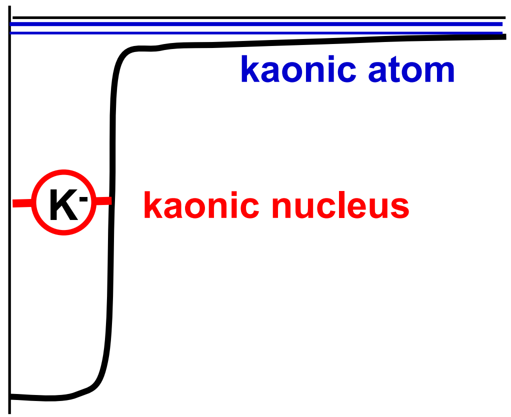
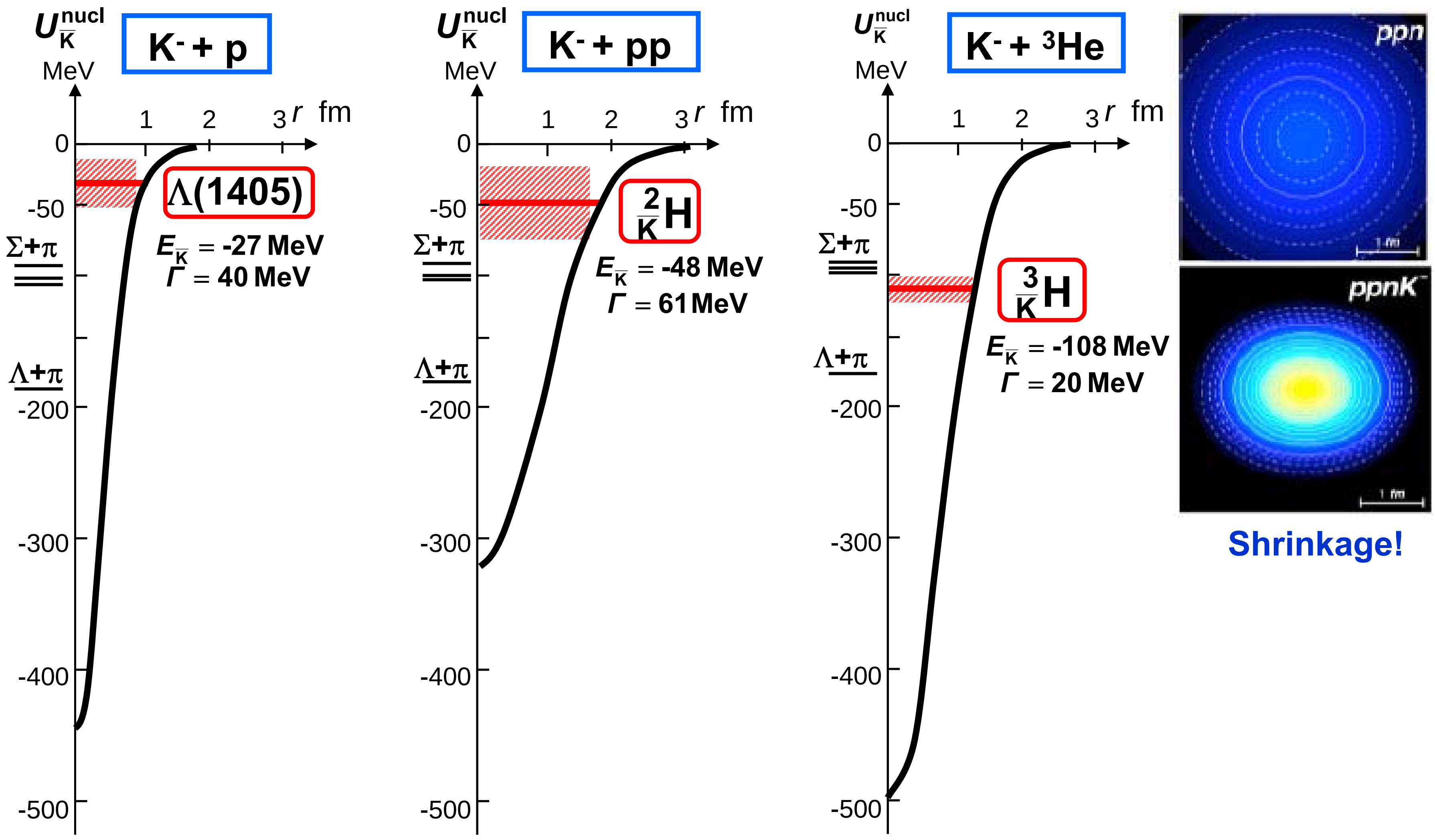
KEK meeting
August 3, 2006

Kaonic Nuclei

in reply to recent criticisms



Yoshinori AKAISHI and Toshimitsu YAMAZAKI



Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005

$\bar{K}N$ interaction

Akaishi-Yamazaki

$$V^T_{\bar{K}N}(r) = V^T_D \exp(-(r/0.66)^2)$$

$$V^T_{\bar{K}N,\pi\Sigma}(r) = V^T_{C_1} \exp(-(r/0.66)^2)$$

$$V^T_{\bar{K}N,\pi\Lambda}(r) = V^T_{C_2} \exp(-(r/0.66)^2)$$

fm

$$V^T_{\pi\Sigma}(r) = V^T_{\pi\Lambda} = 0$$

$V_D^{T=0}$ = -436 MeV

$V_{C_1}^{T=0}$ = -412 MeV

$V_{C_2}^{T=0}$ = none

$V_D^{T=1}$ = -62 MeV

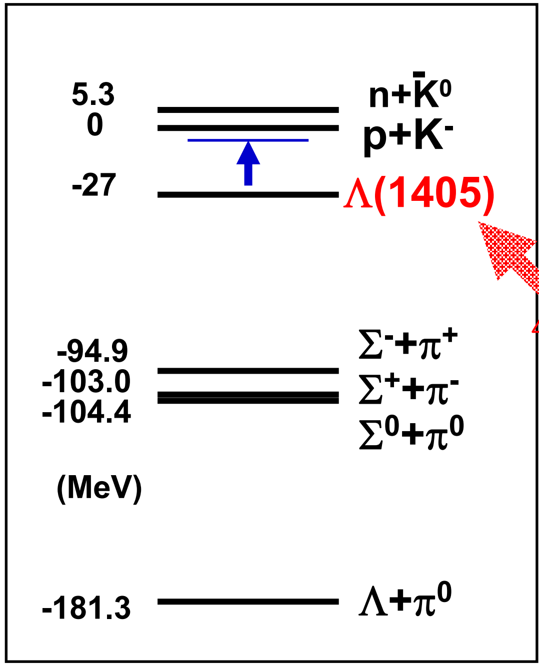
$V_{C_1}^{T=1}$ = -285 MeV

$V_{C_2}^{T=1}$ = -285 MeV

1

3

2



A critical analysis

by E. Oset and H. Toki,

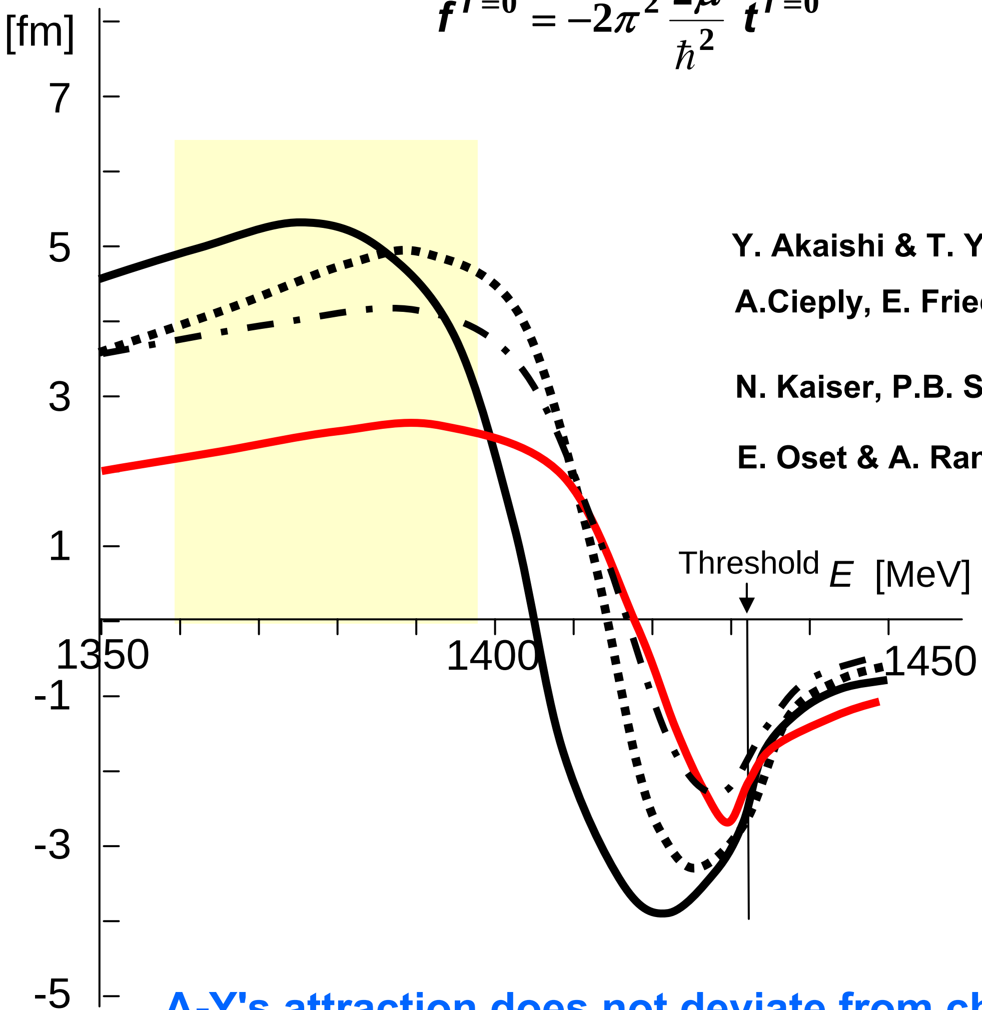
Phys. Rev. C 74 (2006) 015207

"The A-Y model set-up is unacceptably rough."

1

Forward K^{bar}N scattering amplitude

$$f^{T=0} = -2\pi^2 \frac{2\mu}{\hbar^2} t^{T=0}$$



Y. Akaishi & T. Yamazaki, P. R. C65 (2002) 044005

A.Cieply, E. Friedman, A. Gal & J. Mares, N. P. A696 (2001) 173

N. Kaiser, P.B. Siegel & W. Weise, N. P. A594 (1995) 325

E. Oset & A. Ramos, N. P. A635 (1998) 99

A-Y's attraction does not deviate from chiral-dynamics strength.

Chiral SU(3) dynamics

N. Kaiser, P.B. Siegel and W. Weise, Nucl. Phys. A 594 (1995) 325

$$\begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0+\frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0+\frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0+\frac{1}{\sqrt{6}}\Lambda^0 & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0+\frac{1}{\sqrt{6}}\Lambda^0 & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda^0 \end{pmatrix}$$

Lagrangian

$$L = L^{(1)} + L^{(2)} + \cdots$$

SU(3) meson field

$$L^{(1)}_{\rm int} = \frac{i}{8f^2}\,{\rm tr}\left(\overline{B}\left[[\phi,\partial_0\phi],B\right]\right), \qquad L^{(2)} = \cdots$$

SU(3) baryon field

Chiral perturbation expansion has a small radius of convergence for $K^{bar}N$.

Pseudo-potential

$$v_{ij}(k',k) = \frac{C_{ij}}{f^2}\beta_i\beta_j g_i(k')g_j(k)$$

Meson decay constant

f =94.5 MeV

$$g_j(k) = \frac{1}{1+k^2/\alpha_j^2}, \qquad \beta_j = \sqrt{\frac{1}{2\omega_j}\frac{M_j}{E_j}}$$

Flux normalization

$$\alpha_{\overline{K}N} = 757.8\,\text{MeV}, \quad \alpha_{\pi\Lambda} = 300.0\,\text{MeV}, \quad \alpha_{\pi\Sigma} = 448.1\,\text{MeV}$$

"Oset-Ramos" chiral unitary model

E. Oset and A. Ramos, Nucl. Phys. A 635 (1998) 99

Weinberg-Tomozawa

$$-c_{ij}\frac{m_i+m_j}{4f^2}$$

$$c_{ij}^{I=0}=\begin{bmatrix} 3 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & 4 \end{bmatrix} \begin{matrix} \bar{K}N \\ \pi\Sigma \end{matrix}$$

10 channels

Virtually

$$\langle \vec{k}'|v_{ij}|\vec{k}\rangle = g(\vec{k}')V_{ij}^{WT}g(\vec{k})$$

$$g(\vec{k})=\begin{cases}1 & \text{for } k<\Lambda \\ 0 & \text{for } k>\Lambda\end{cases}$$

Λ = 630 MeV/c

$$\tilde{g}_\Lambda(r)\propto\frac{j_1(\Lambda r)}{\Lambda r}$$

$$\tilde{G}=\int_{q\le\Lambda}d\vec{q}\,\langle\vec{q}\,|\,G\,|\,\vec{q}\rangle$$

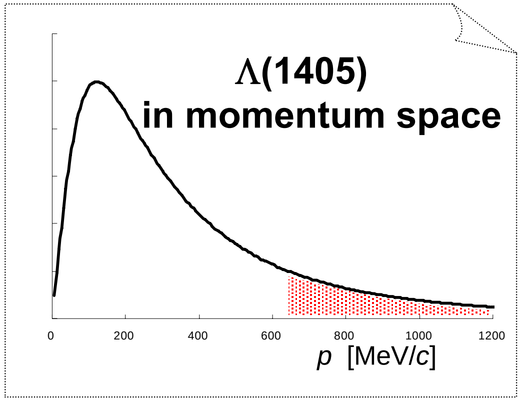
$$T=\frac{1}{1-V\tilde{G}}V$$

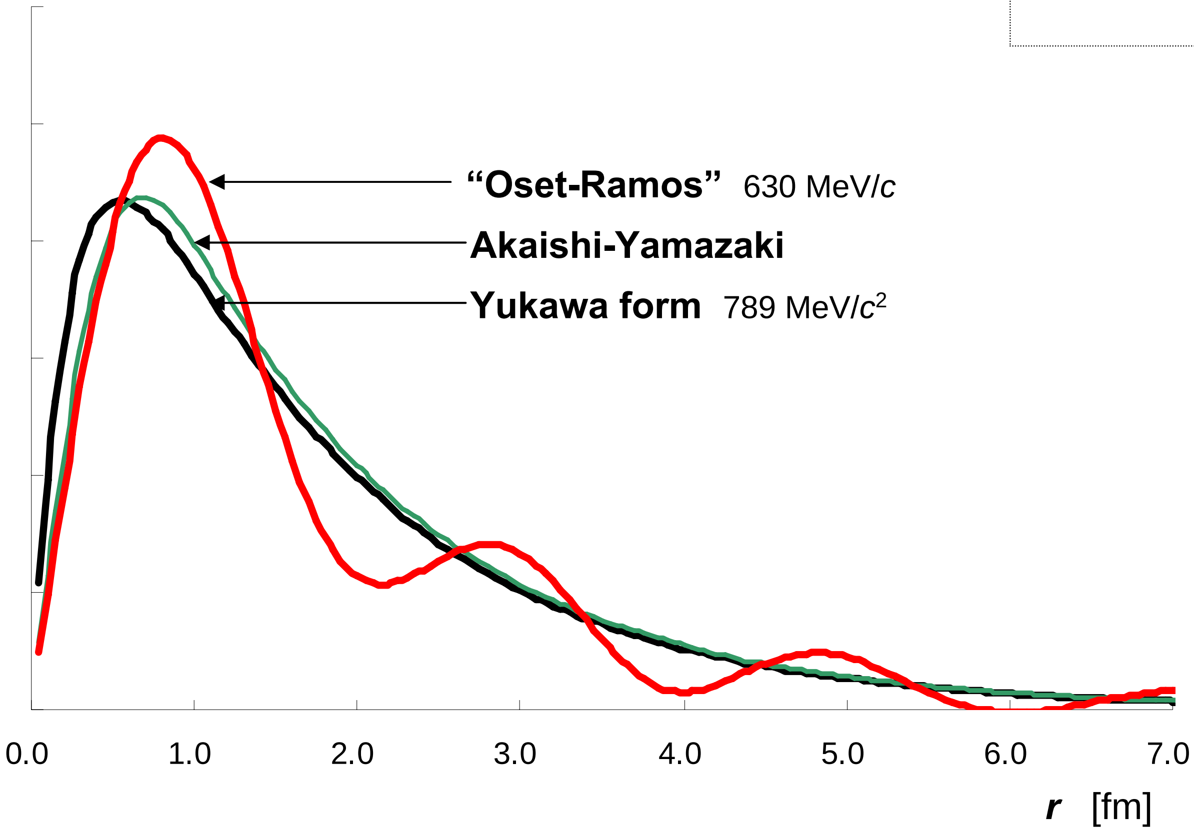
$$V=\{V_{ij}^{WT}\}$$

Unitarized

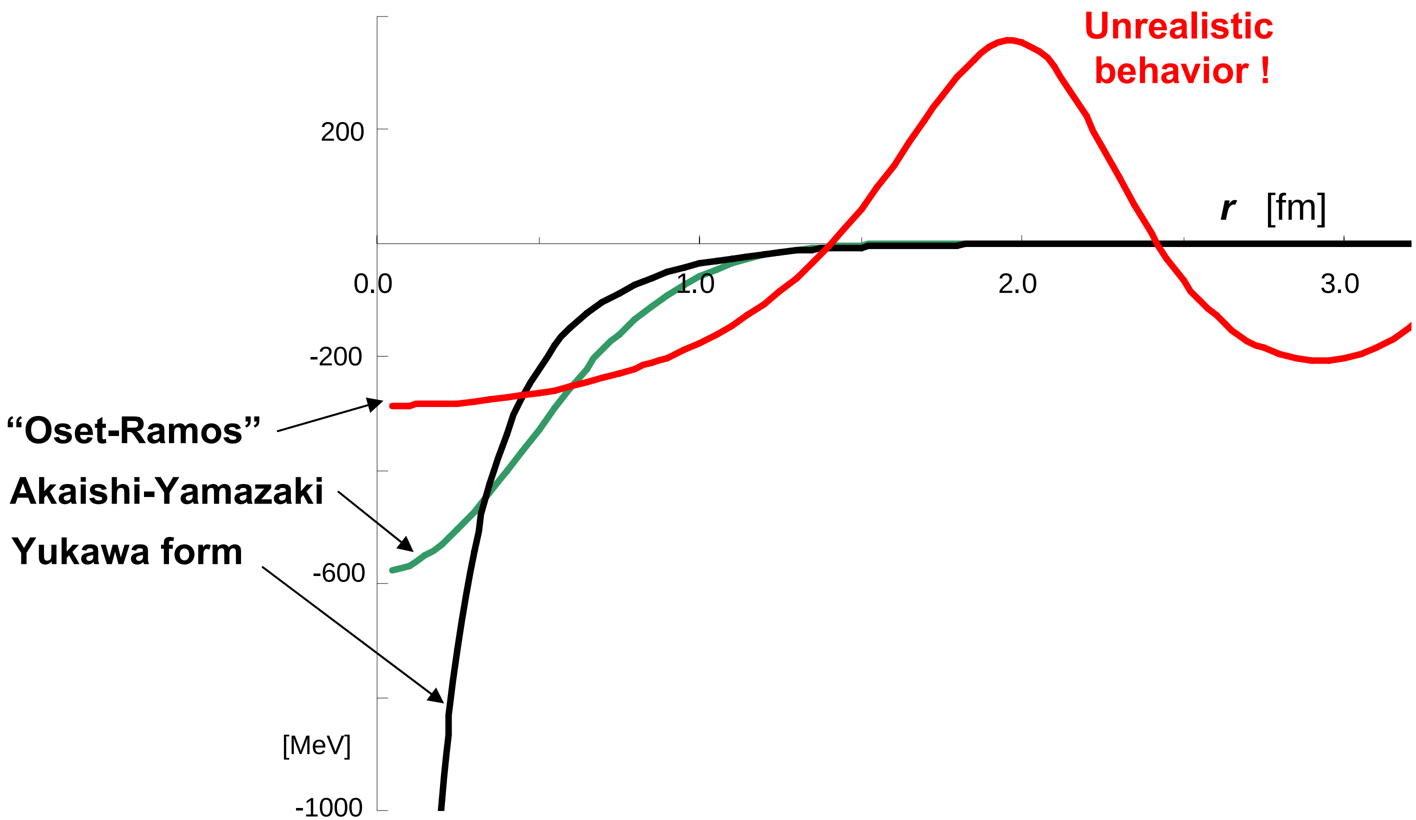
$1-V\tilde{G}=0$ ⇨ Resonance / bound states

Wave function of Λ(1405)



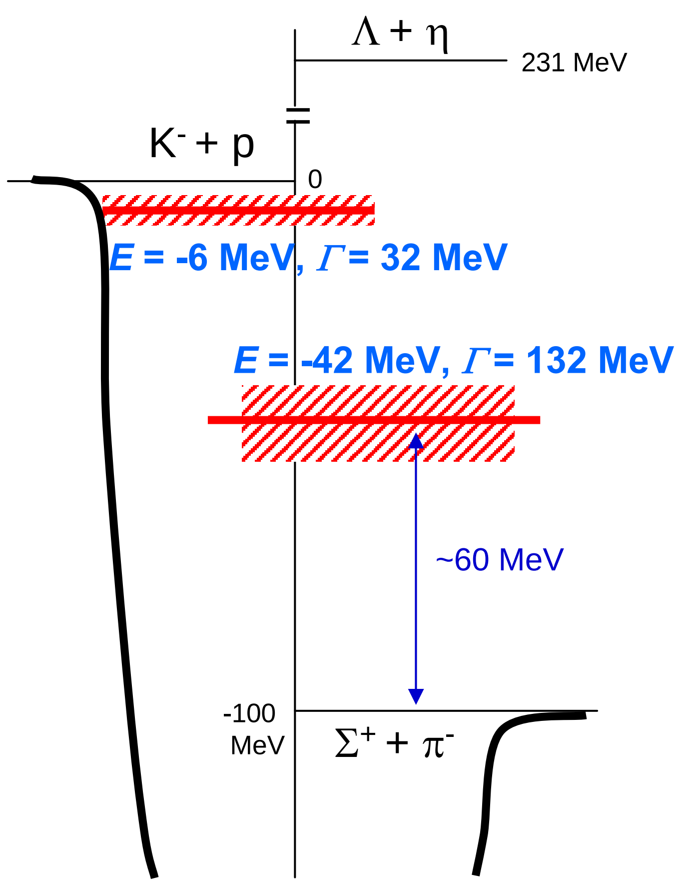


Equivalent local potential



2

Double pole structure of $\Lambda(1405)$

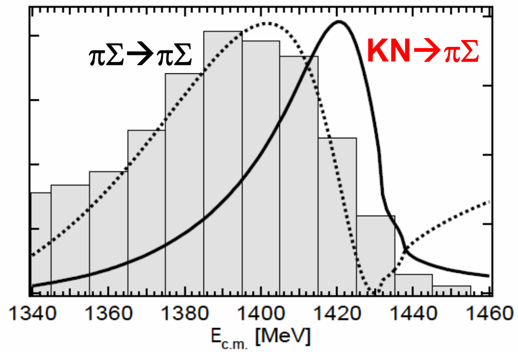


$\Lambda(1405)$ consists of two poles, one of which is not K^-p but $\Sigma\pi$ pole.

E. Oset et al.

Chiral dynamics of two Λ(1405) states

D. Jido, J.A. Oller, E. Oset, A. Ramos & U.-G. Meissner,
Nucl. Phys. A 725 (2003) 181

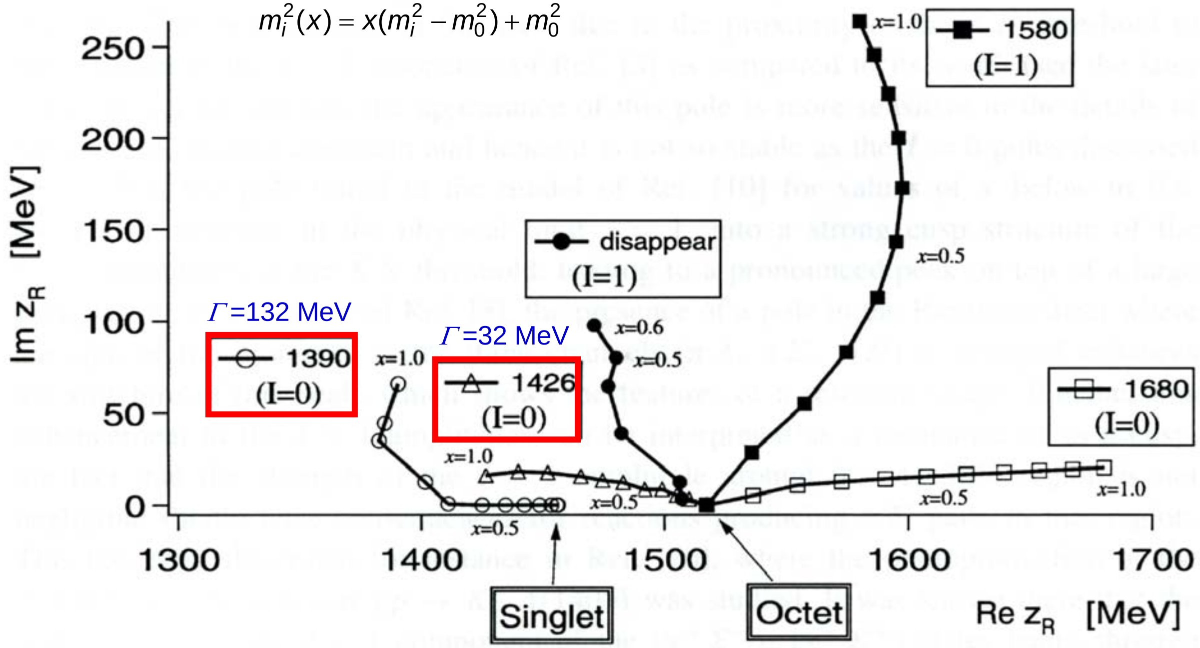


Experimental check !

$$8 \otimes 8 = 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus \overline{10} \oplus 27.$$

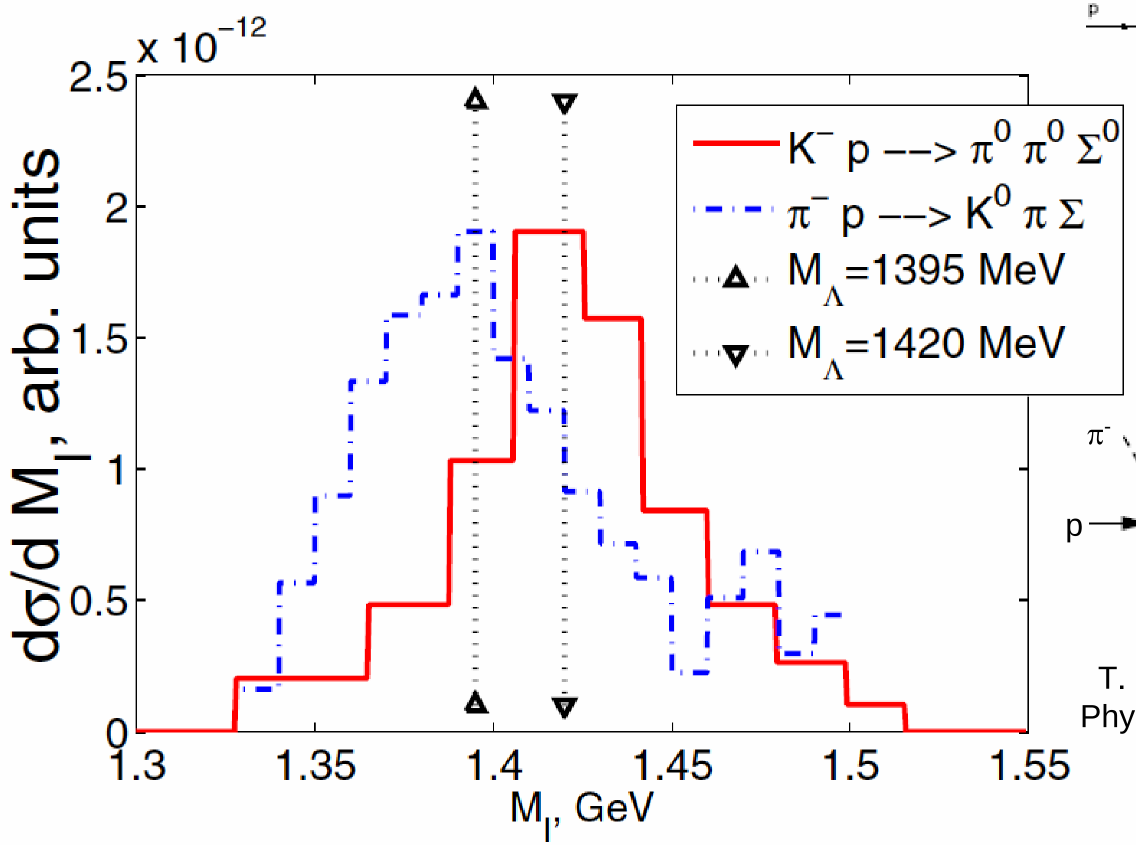
$$M_i(x) = x(M_i - M_0) + M_0$$

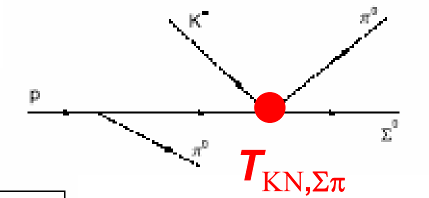
$$m_i^2(x) = x(m_i^2 - m_0^2) + m_0^2$$

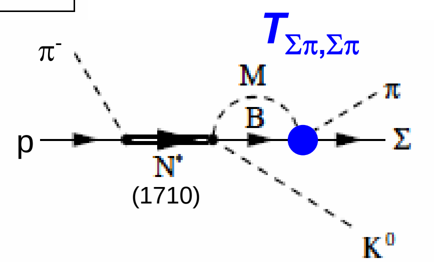


Evidence for two-pole structure of Λ(1405)

V.K. Magas, E. Oset and A. Ramos, Phys. Rev. Lett. 95 (2005) 052301







T. Hyodo, A. Hosaka et al., Phys. Rev. C68 (2003) 065203

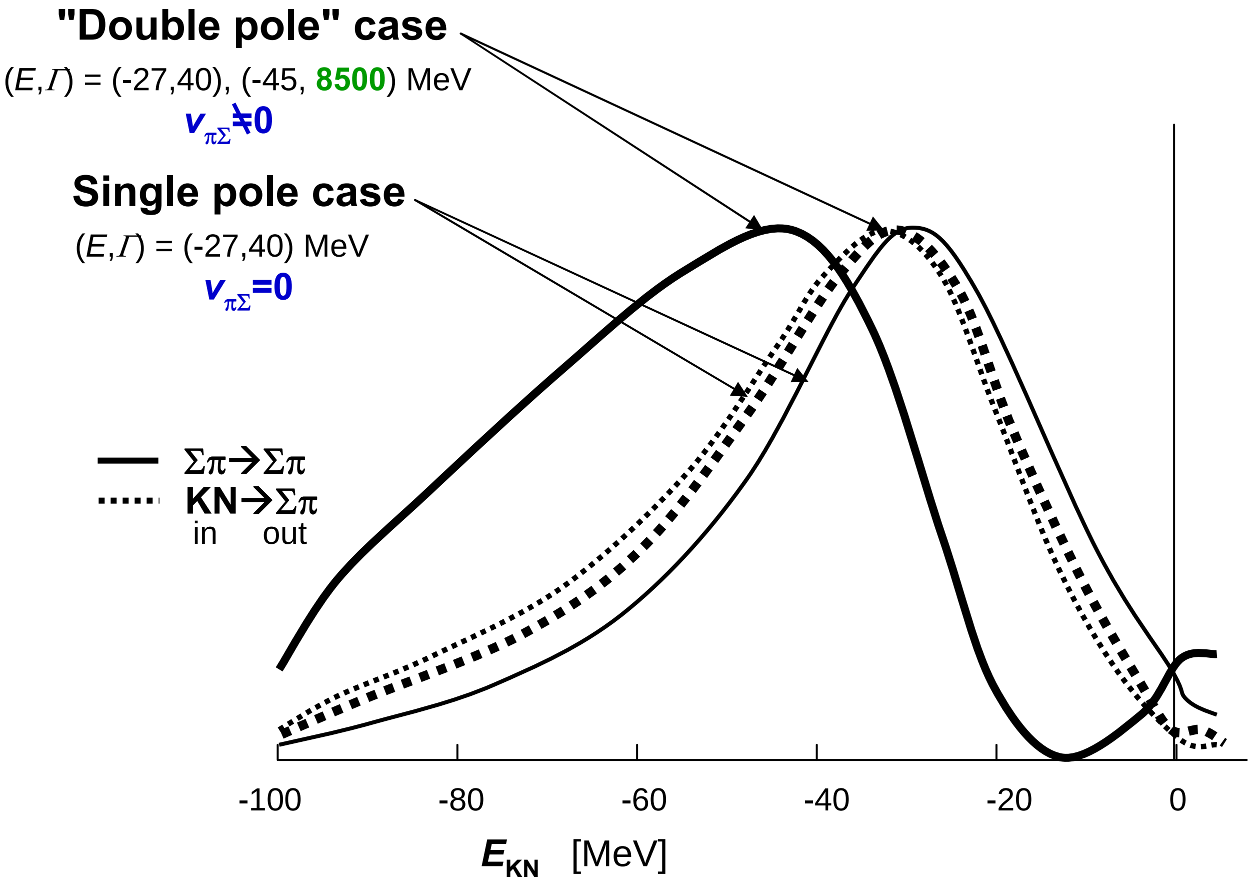
Event rate

Yukawa form: ***b*** **= 0.25** fm

Coupled channels

$$\begin{pmatrix}T_{11}\\T_{21}\end{pmatrix}_{\text{out,in}} = \begin{pmatrix} 1+\frac{s_{11}}{(1-ik_1b)^2}, & \frac{s_{12}}{(1-i\kappa_2 b)^2}\\ \frac{s_{21}}{(1-ik_1b)^2}, & 1+\frac{s_{22}}{(1-i\kappa_2 b)^2}\end{pmatrix}^{-1}\begin{pmatrix}V_{11}\\V_{21}\end{pmatrix}$$

$$s_{12} = \frac{1}{2B_1^{(0)}}V_{12}^{(0)}, \ldots$$



Resonance shape

The Jost function

$$\frac{1}{f_\ell(E)} = \frac{Ae^{-i\delta}}{E-\varepsilon_R} + \text{ terms regular at } \varepsilon_R \equiv E_R - i\frac{\Gamma}{2}$$

$$S_\ell(E) = \frac{f_\ell^*(E)}{f_\ell(E)} \approx e^{-2i\delta}\left\{1 - \frac{i\Gamma}{(E-E_R)+i\Gamma/2}\right\} = 1 + 2iT_\ell(E)$$

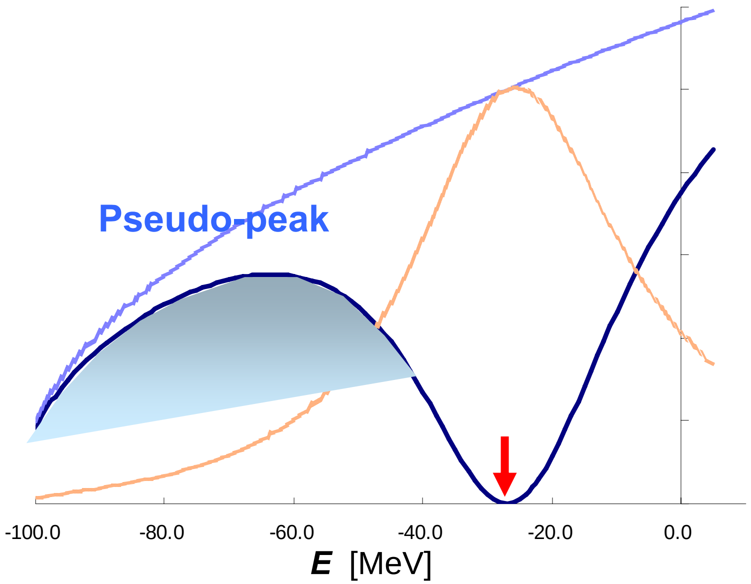
$$|T_\ell(E)|^2 = \left| e^{i\delta}\sin\delta + \frac{\Gamma/2}{(E-E_R)+i\Gamma/2}\right|^2$$

Interference!

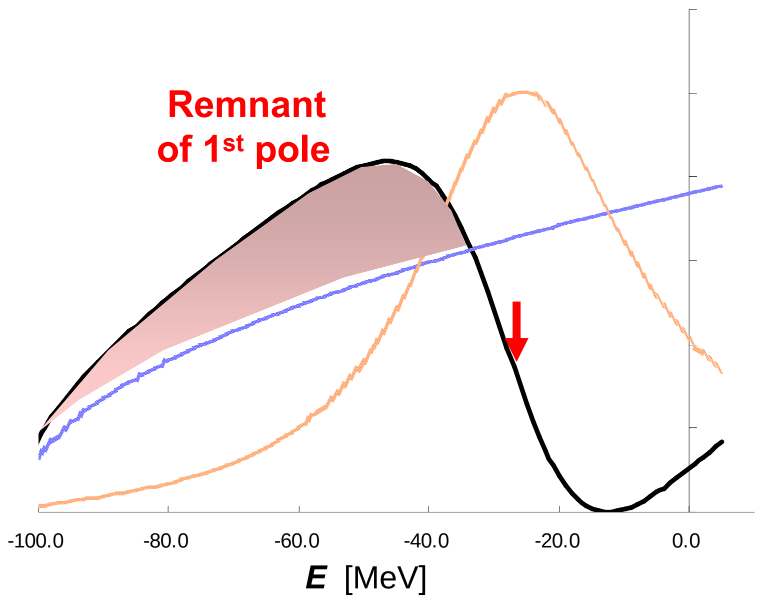
O. Morimatsu & K. Yazaki,
Nucl. Phys. A483 (1988) 493;
Prog. Part. Nucl. Phys. 33 (1994) 679

Interference effect

$\delta = -0.5\pi$

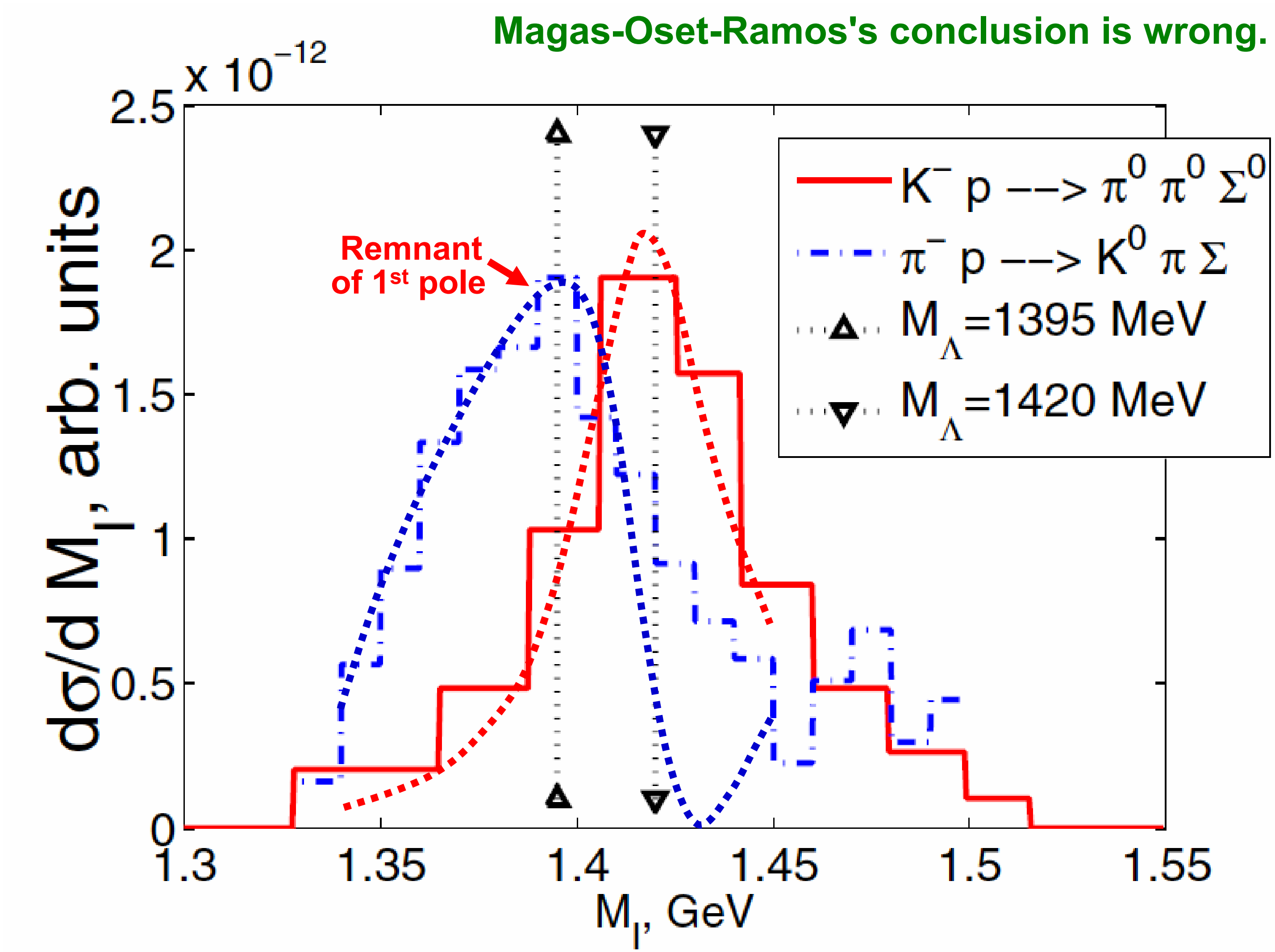


$\delta = -0.3\pi$



Inflection point

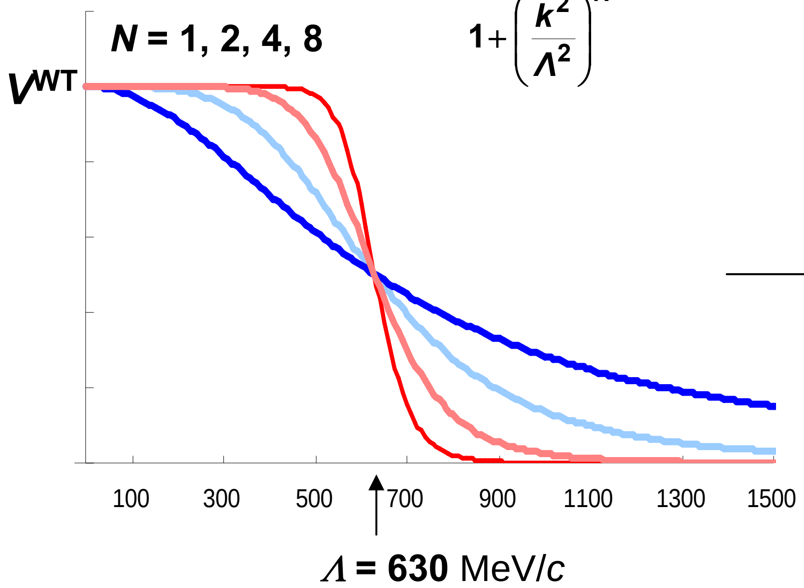
Not the evidence for double poles!

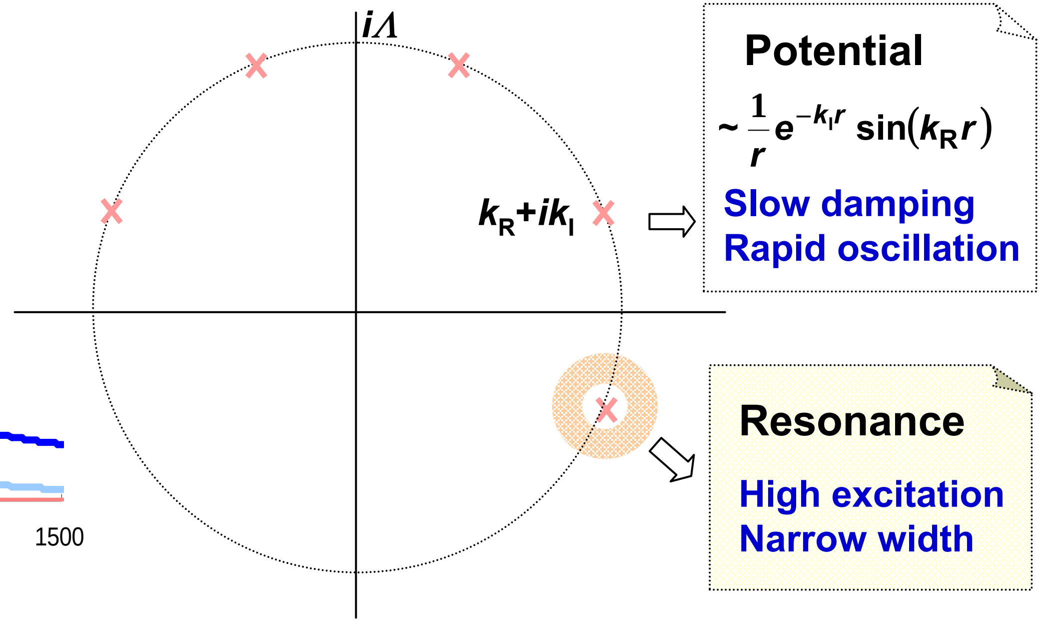


Step form factor & resonance width

M. Obu, M. Wada,

$$g(k) = \frac{1}{1 + \left(\frac{k^2}{\Lambda^2}\right)^N}$$





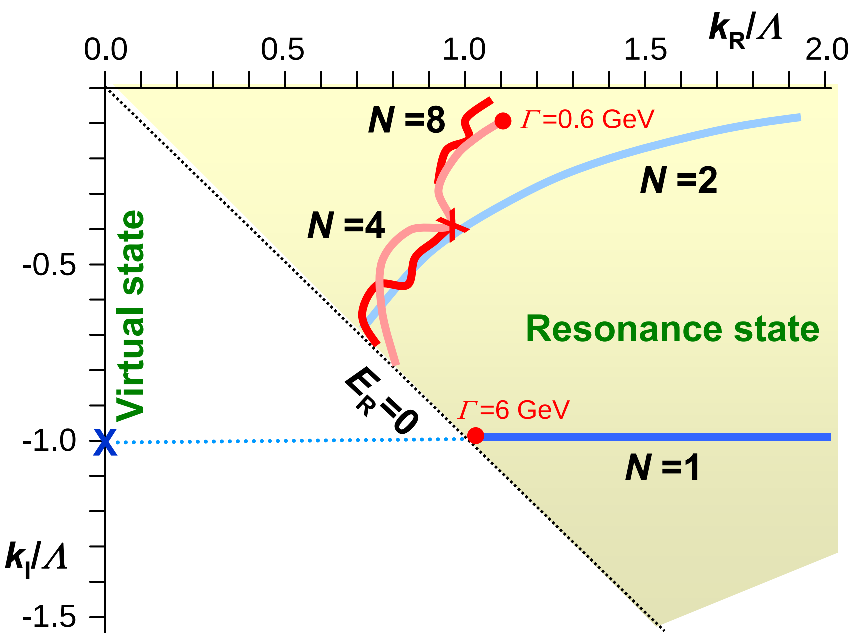
$$1 - V\tilde{G} = 1 + S\frac{2i}{\Lambda}\left\{A_G(\kappa) + \sum_{m=1}^{N} A_m(\kappa)\right\} = 0$$

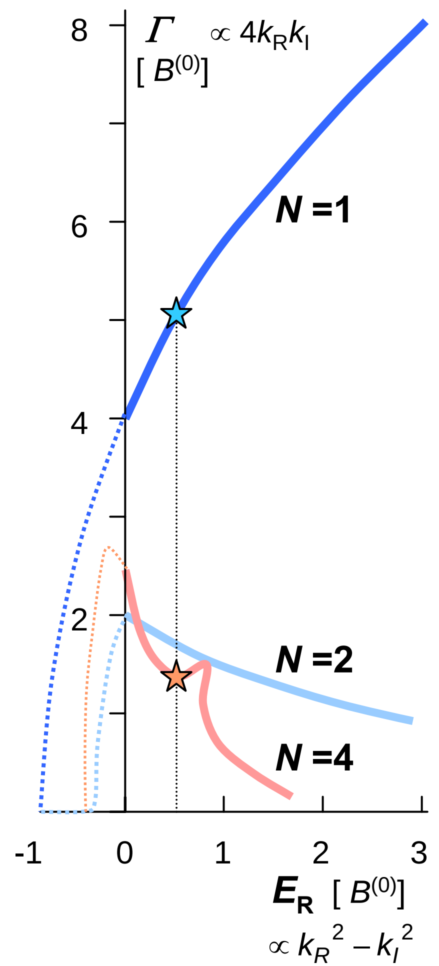
Residues

$$\tilde{G} = \frac{2\mu}{\hbar^2}\int d\vec{q}\,\frac{g^2(\kappa)}{\kappa^2 - q^2 + i\varepsilon} \xrightarrow{N\to\infty} 2\pi\frac{2\mu}{\hbar^2}\left\{-i\pi\kappa\theta(\Lambda-\kappa) - 2\Lambda + \kappa\log\frac{\kappa+\Lambda}{|\kappa-\Lambda|}\right\}$$

Possible position of resonance pole

"O-series"



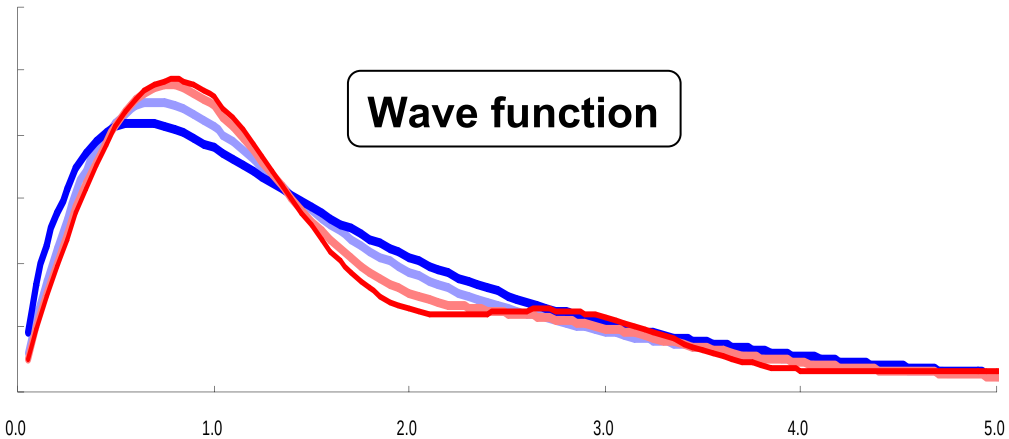


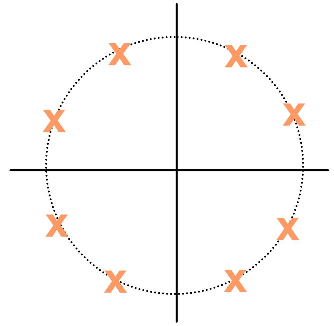
$$1+2is\left[z\left\{\frac{1}{1+z^{2N}}\right\}^2+4\sum_{m=1}^{N}\frac{z_0^{2m-1}}{z_0^{4m-2}-z^2}\frac{1}{\prod_{n\neq m}^{2N}\left(z_0^{2m-1}-z_0^{2n-1}\right)^2}\left\{1-\frac{z_0^{4m-2}}{z_0^{4m-2}-z^2}-\sum_{n\neq m}^{2N}\frac{z_0^{2m-1}}{z_0^{2m-1}-z_0^{2n-1}}\right\}\right]=0$$

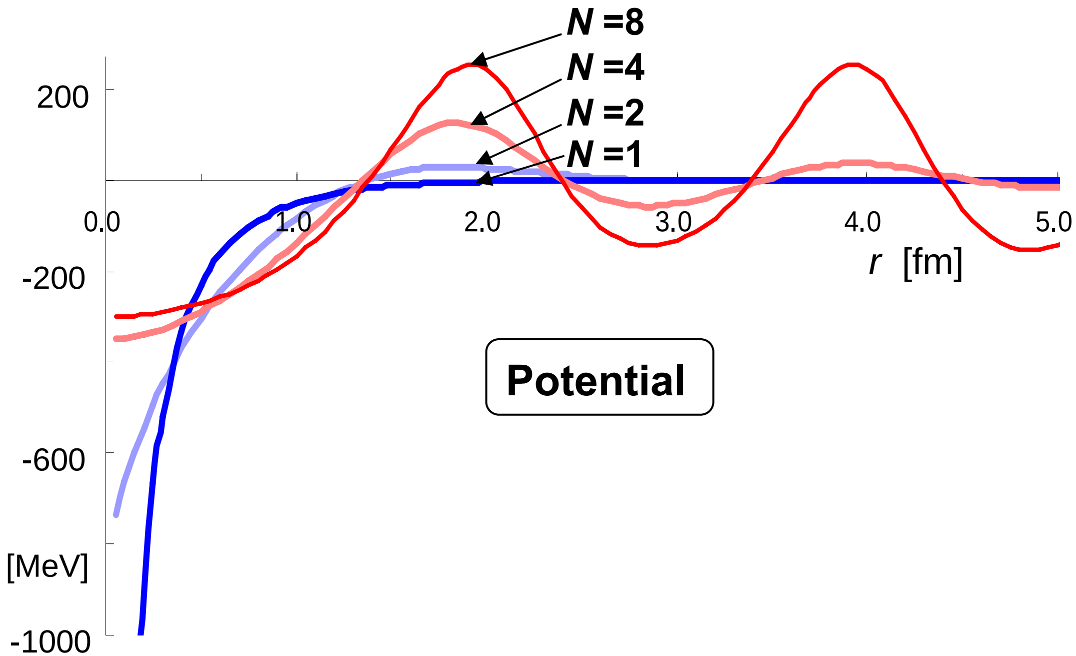
$$z_0=\exp\left(i\frac{\pi}{2N}\right),\qquad z=\left(k_R+ik_I\right)/\Lambda$$

$K^{-}p$ bound state

"O-series" $g(k) = \dfrac{1}{1+\left(\dfrac{k^2}{\Lambda^2}\right)^N}$



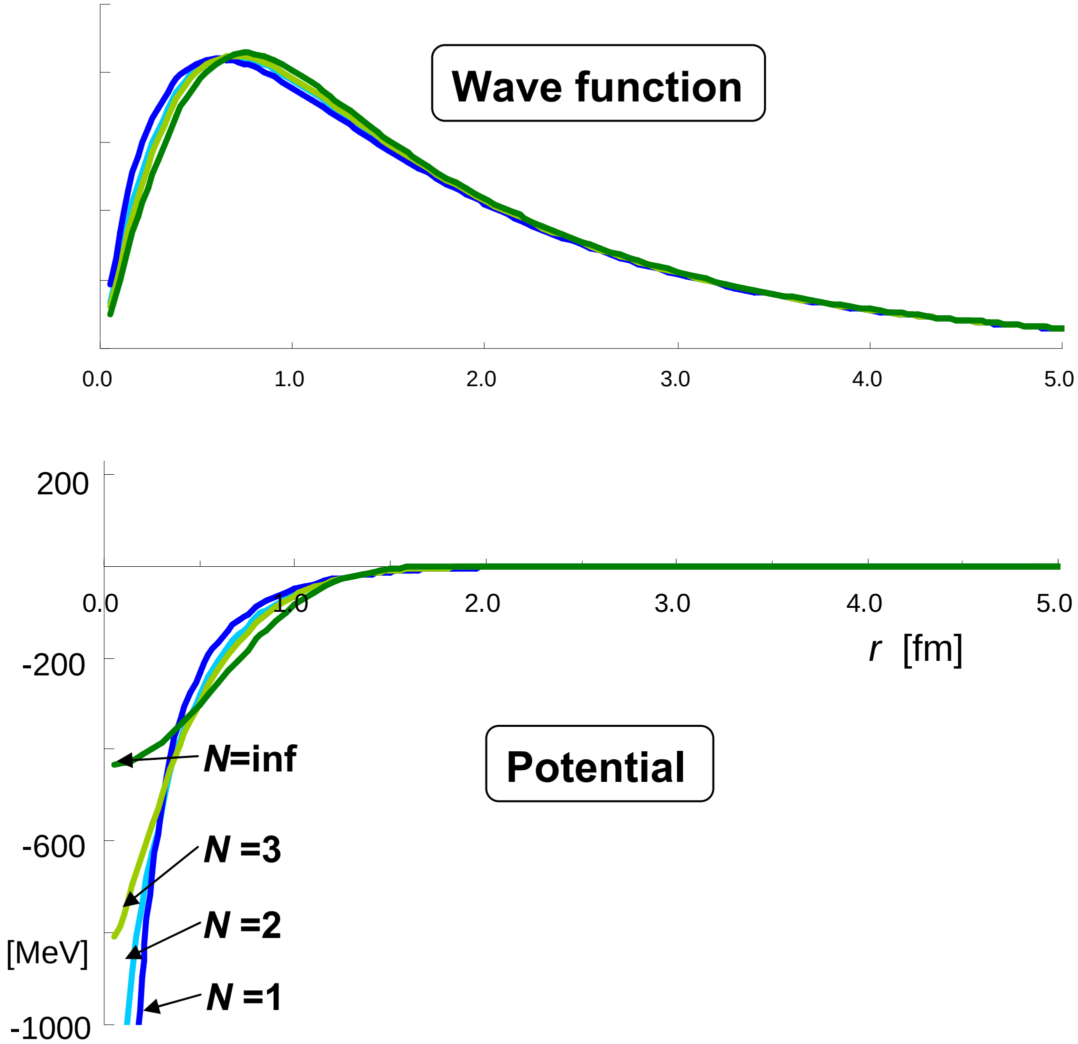


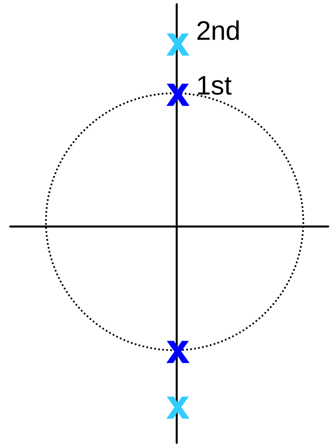


$K^{-}p$ bound state

"W-series"

$$g(k) = \frac{1}{\left(1 + \frac{k^2}{N\Lambda^2}\right)^N}$$





$K_{N-3/2}$ family

M. Wada

<u>Remarks by Oset-Toki</u>

irrelevant

The Akaishi-Yamazaki model set-up, after dropping several important processes and channels, leads unavoidably to **<u>an unrealistic deep potential</u>**.

a realistic potential for decaying state.

The *a posteriori* corrections of the theory to match the experimental findings and increase the binding energy by a factor of two **<u>only added more uncertainties</u>** to **the already unacceptably rough approach**.

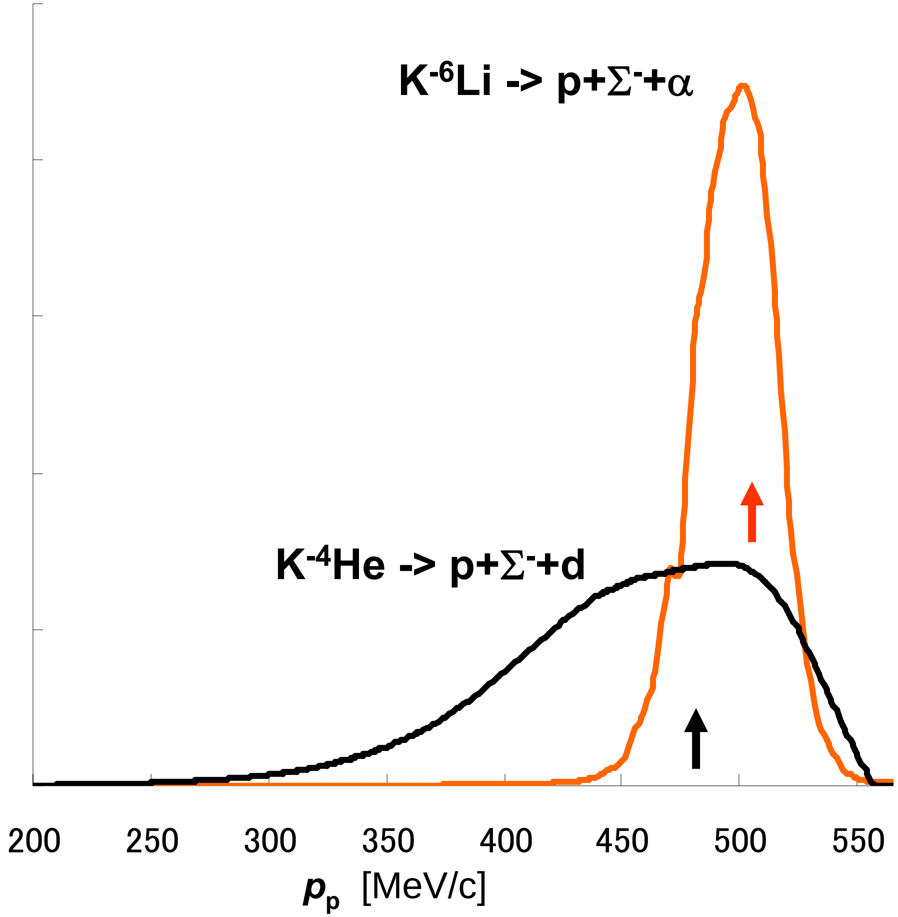
pointed out key issues to be investigated.

These criticisms are not the cases!

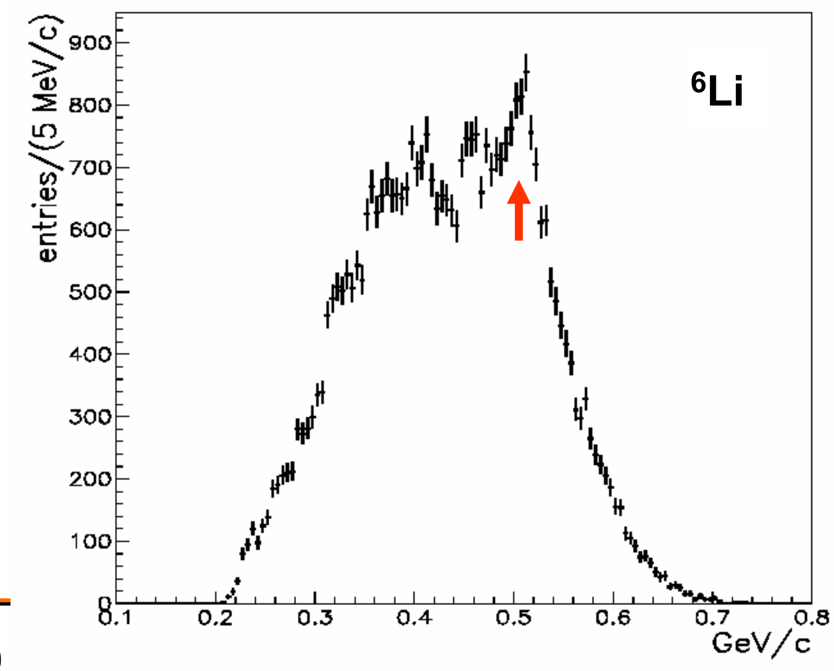
"Double-pole structure" of Λ(1405) could be a kind of artifact!

Application of O-R's chiral unitary model should be carefully checked.

Proton spectra from K^- captures at rest

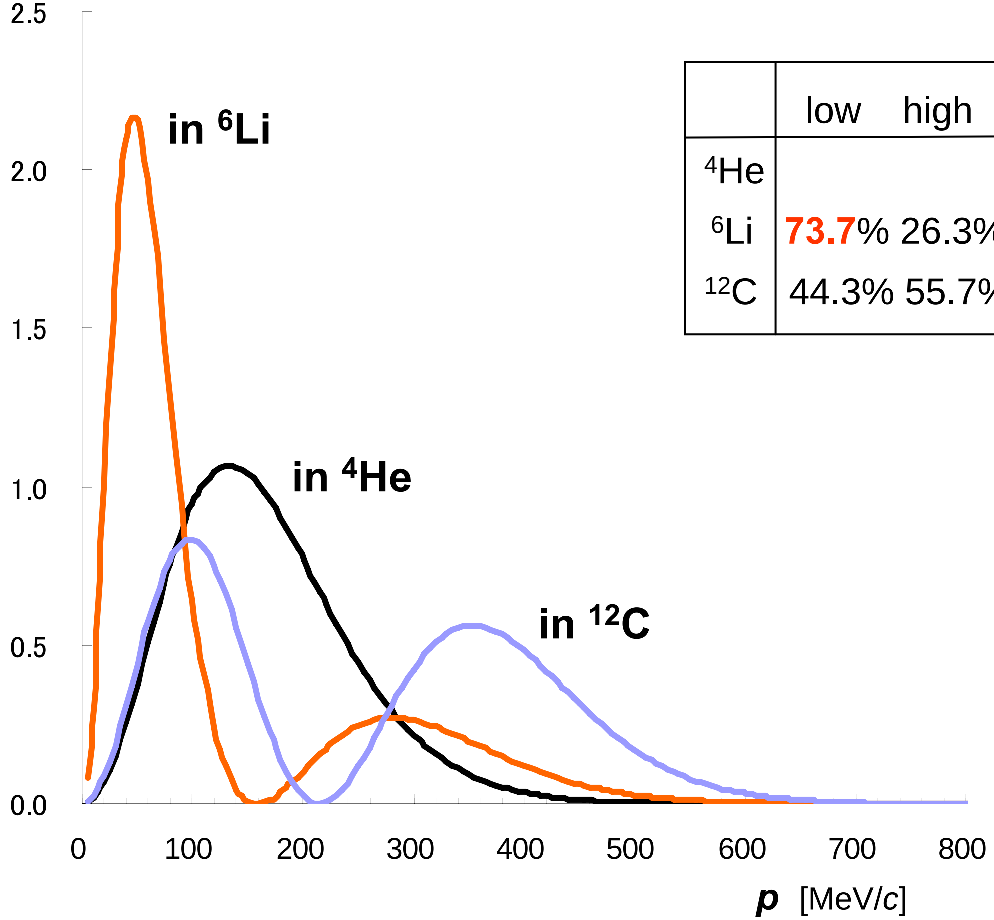


FINUDA
M. Agnello et al., nucl-ex/0606021



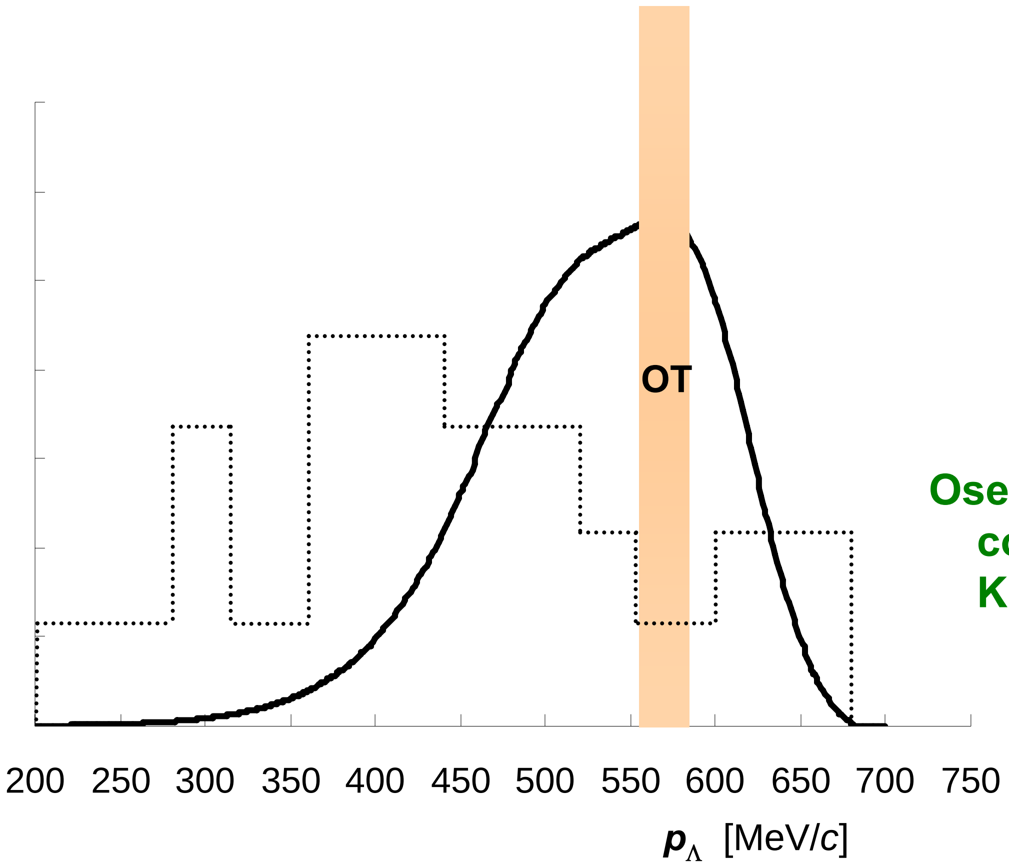
OT
508 MeV/c for ^6Li
482 MeV/c for ^4He

Deuteron momentum distribution in nuclei



	low	high	rms mom.	*E*(d-core)
^{4}He			184 MeV/*c*	**-23.8** MeV
^{6}Li	**73.7**%	26.3%	177 MeV/*c*	**-1.48** MeV
^{12}C	44.3%	55.7%	303 MeV/*c*	-25.2 MeV

Lambda spectra from $K^{-4}He \rightarrow \Lambda + n + d$



Oset-Toki's process contradicts with Katz et al.'s data.

P.A. Katz, K. Bunnell, M. Derrick, T. Fields, L.G. Hyman & G. Keyes, Phys. Rev. D 1 (1970) 1267

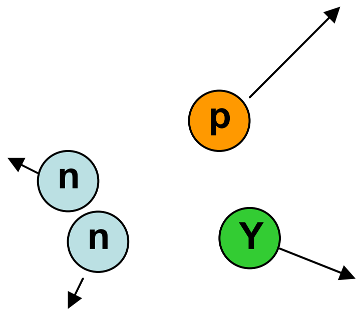
K^- absorption on pp

$$\frac{d^3\Gamma}{dp_p dp_Y dx} = \text{const} \cdot p_p^2 p_Y^2 \ p_{(pY)}^2 \exp\left(-\frac{1}{4a}(p_{(pY)}/\hbar)^2\right) p_{nn} \exp\left(-\frac{2}{a}(p_{nn}/\hbar)^2\right)$$

$$\hbar\omega = \frac{\hbar^2}{M_N} a$$

$$p_{(pY)}^2 = \left\{\frac{(2M_n + M_Y + M_p)M_\alpha}{2M_n(M_\alpha + m_K)}\right\}^2 \left(p_p^2 + p_Y^2 + 2p_p p_Y x\right), \quad x = \cos\theta_{pY}$$

$$\frac{p_{nn}^2}{M_n} = M_p c^2 + m_K c^2 - M_Y c^2 - BE_\alpha - \frac{1}{2\mu_{(pY)(nn)}}(p_p^2 + p_Y^2 + 2p_p p_Y x)$$
$$- \frac{1}{2\mu_{pY}} \frac{M_Y^2 p_p^2 + M_p^2 p_Y^2 - 2M_p p_p M_Y p_Y x}{(M_p + M_Y)^2}$$

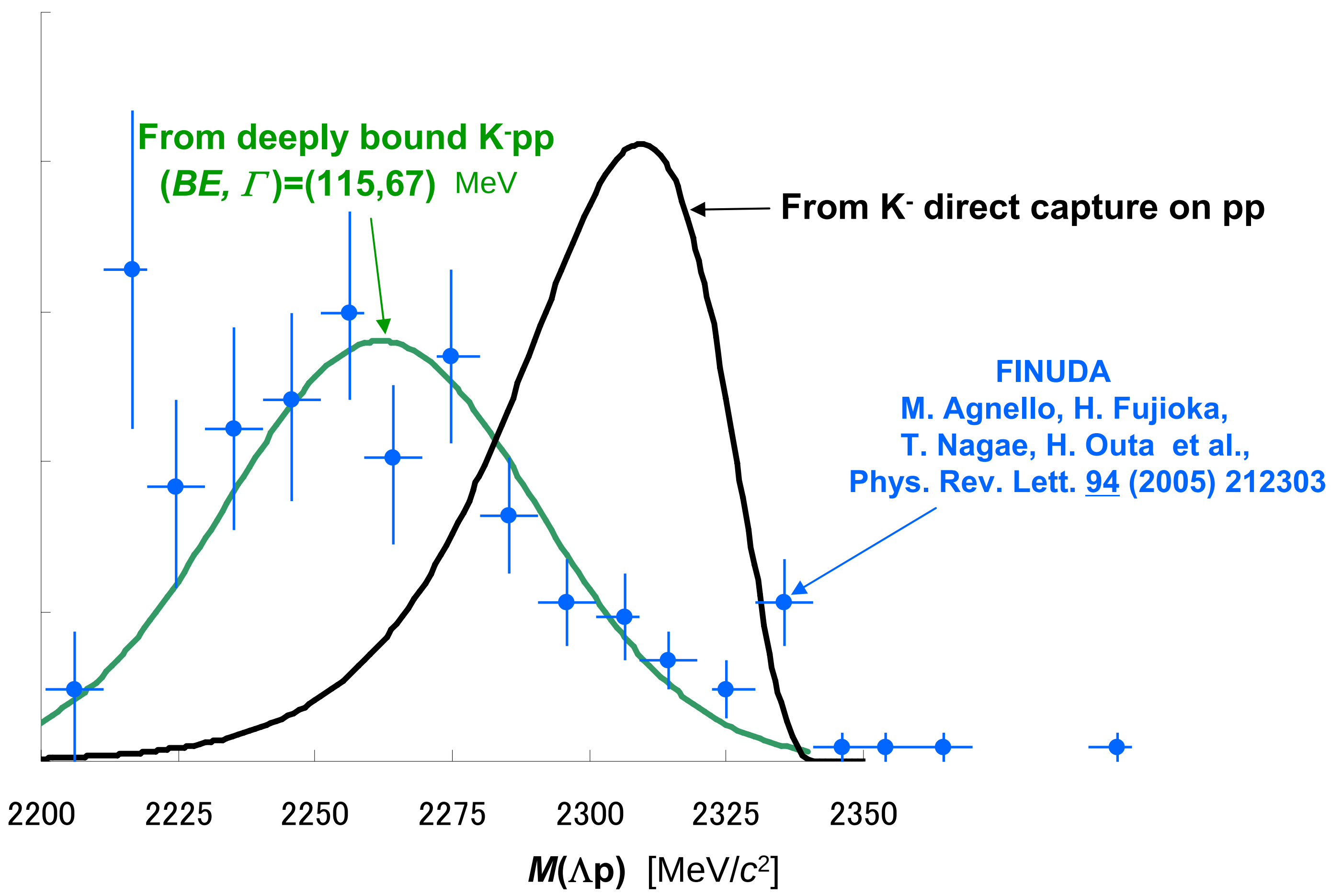


$$M_n \to \infty$$

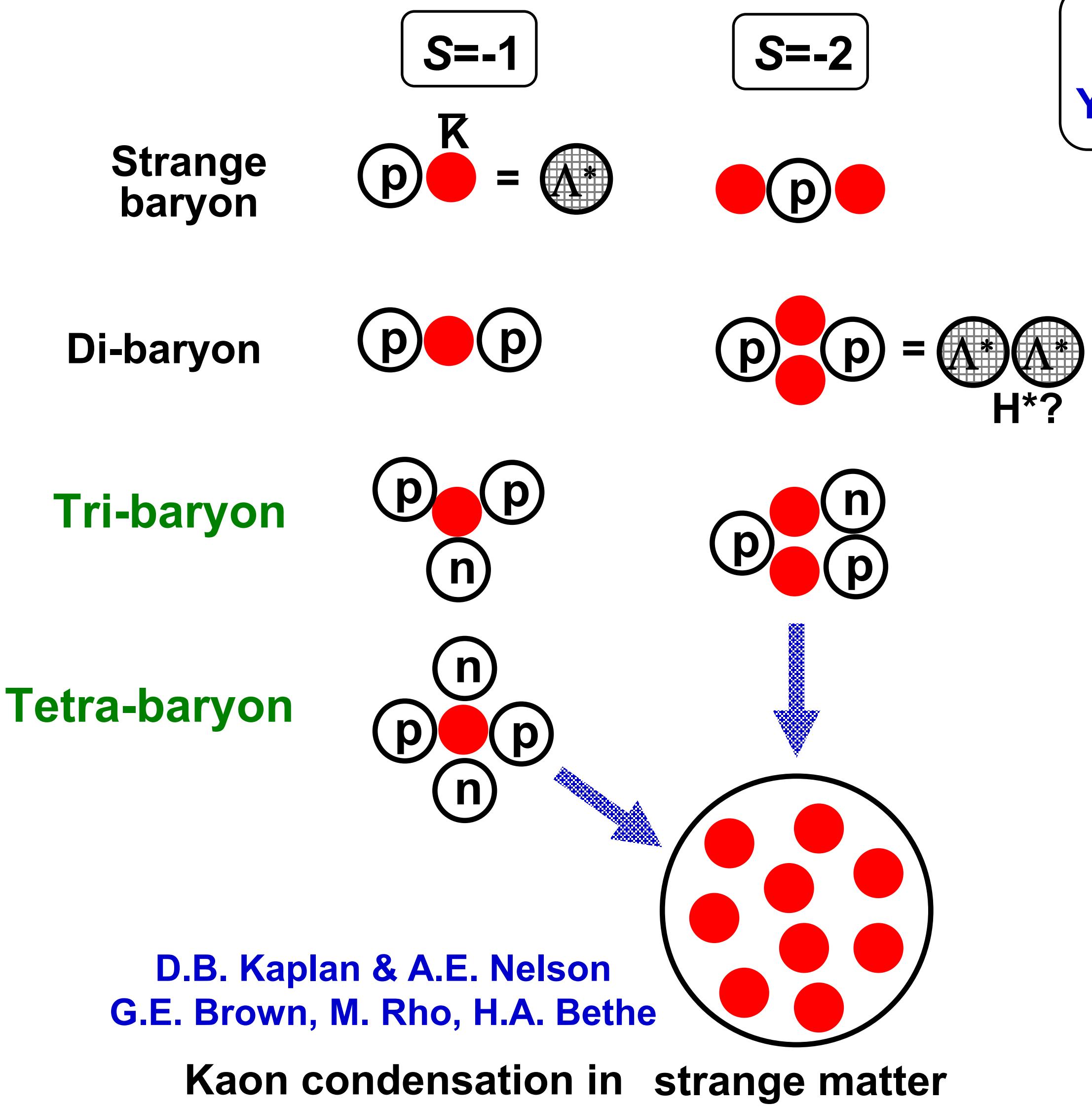
$p_{(pY)}^2 = (\vec{p}_p + \vec{p}_Y)^2$: (pY) c.m. momentum

$\frac{p_{nn}^2}{M_n} \to 0$: Energy conservation relation

(Λp) partial invariant mass from K^{-} $^{4}He \rightarrow \Lambda$+p+n+n



Few-body $\bar{K}N$ systems



DAΦNE1999

Y. Akaishi & T. Yamazaki

FINUDA@DAΦNE
FOPI@GSI
AMADEUS@DAΦNE
J-PARC

@high densities

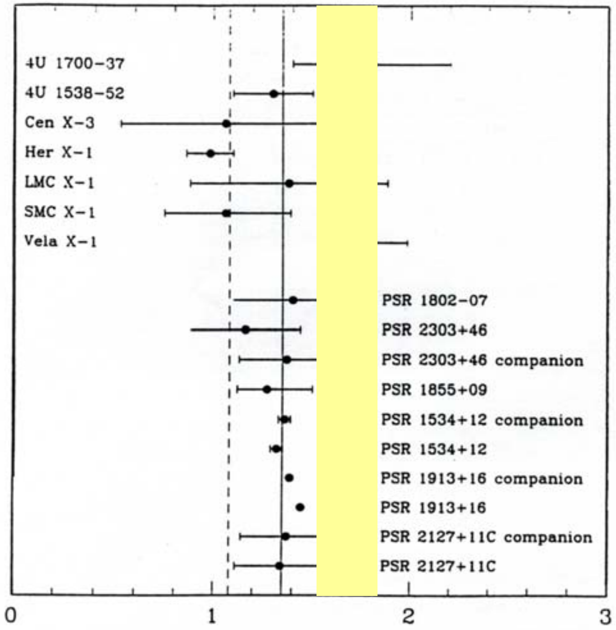
$e^- + p + n \longrightarrow \nu + n + n$ "Neutron star"

$\sim 3\rho_0$

$\nu + K^- + p + n$

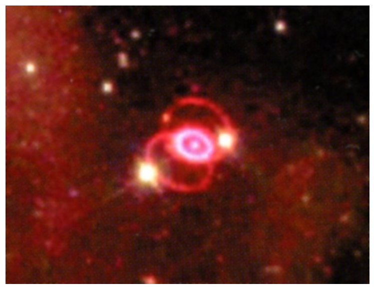
Strong attraction

"Nucleon star"
with kaon condensation



"Low-mass black hole"
$1.5 \sim 1.8\ M_\odot$

SN1987A ?

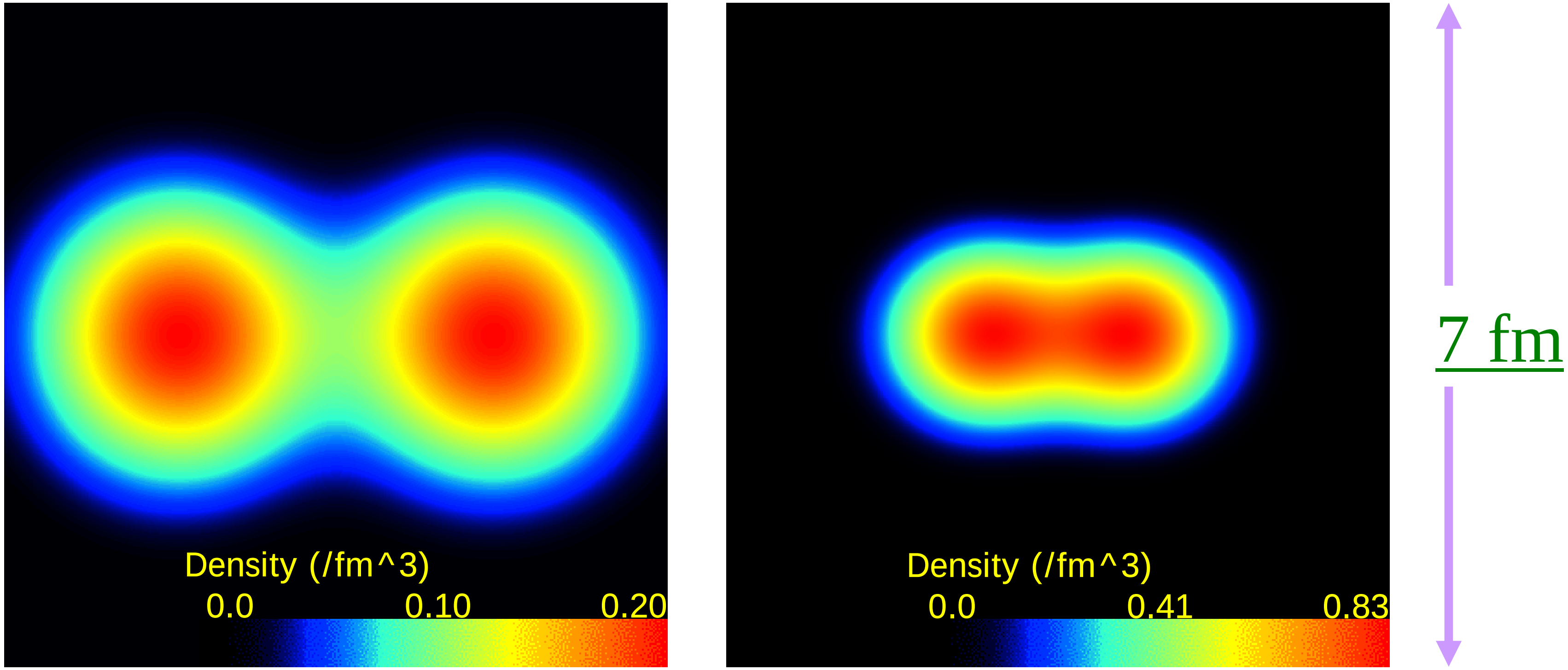


G.E. Brown, Nucl. Phys. A<u>574</u> (1994) 217c.

G.E. Brown & H.A. Bethe, Astrophys. J. <u>423</u> (1994) 659.

G.E. Brown & M. Rho, Phys. Rev. Lett. <u>66</u> (1991) 2720,
"BR scaling"
C.H. Lee, G.E. Brown, D.P. Min & M. Rho, Nucl. Phys. A<u>585</u> (1995) 401

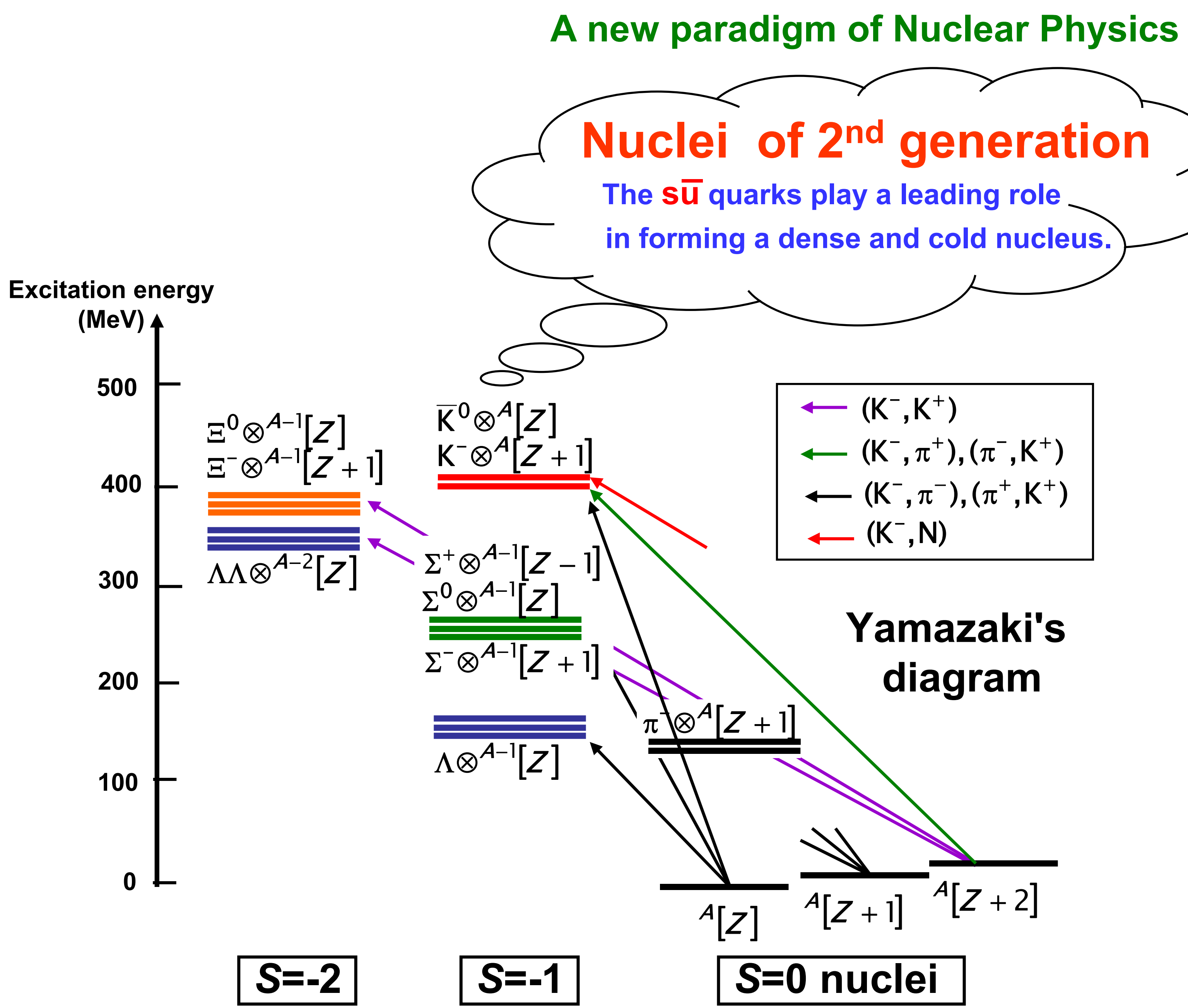
^{8}Be $\qquad$ $^{8}BeK^{-}$



Dense & Cold

AntisymmetrizedMolecularDynamics calculation

A. Dote, H. Horiuchi, Y. Akaishi & T. Yamazaki, Phys. Lett. B590 (2004) 51.



A new paradigm of Nuclear Physics
Nuclei of 2nd generation
The sū quarks play a leading role
in forming a dense and cold nucleus.
Excitation energy
(MeV)
500
400
300
200
100
0
$\Xi^0 \otimes {}^{A-1}[Z]$
$\Xi^- \otimes {}^{A-1}[Z+1]$
$\Lambda\Lambda \otimes {}^{A-2}[Z]$
$\bar{K}^0 \otimes {}^{A}[Z]$
$K^- \otimes {}^{A}[Z+1]$
$\Sigma^+ \otimes {}^{A-1}[Z-1]$
$\Sigma^0 \otimes {}^{A-1}[Z]$
$\Sigma^- \otimes {}^{A-1}[Z+1]$
$\Lambda \otimes {}^{A-1}[Z]$
$\pi^- \otimes {}^{A}[Z+1]$
${}^{A}[Z]$
${}^{A}[Z+1]$
${}^{A}[Z+2]$
(K^-, K^+)
$(K^-, \pi^+), (\pi^-, K^+)$
$(K^-, \pi^-), (\pi^+, K^+)$
(K^-, N)
Yamazaki's diagram
S=-2
S=-1
S=0 nuclei

Acknowledgements:

S. Shinmura, M. Wada, M. Obu
A. Dote, O. Morimatsu

Thank you very much!