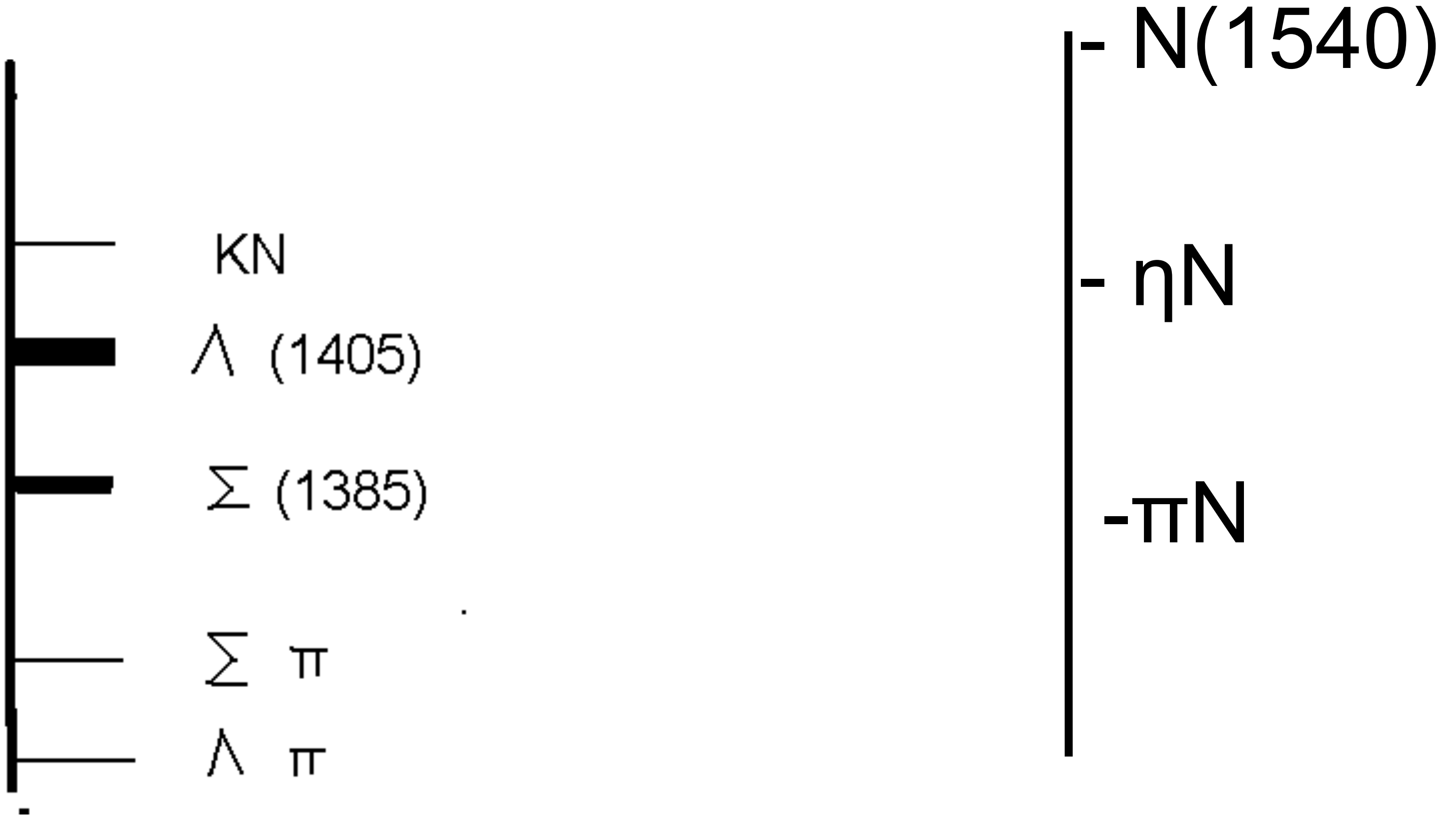
KAONIC-NUCLEI
vs
ETA-NUCLEI

Sławomir Wycech - Warsaw, IPJ

Level repulsion rule : KN , ηN



Normal prescription

1) Use scattering amplitude
   extrapolate below threshold

$$f\,(\eta N,\quad E = -\,E_{BINDING} - E_{RECOIL})$$

2) Correct for medium
2) Use optical potential

$$V = 2\pi/M \;\; f\,(\eta N)\;\; \rho(r)$$

add ηNN absorption

3) Solve for levels, widths

Difficulties of the average field description of kaons in nuclei

- KN, KNN correlations ,
  short ranged NN repulsion

- KN interactions are energy dependent,
  far off-energy-shell

The questions discussed here

CORRELATIONS

K-N   K-N-N

η-N   η-N-N

EXPLICIT DECAY CHANNELS

Σ π   πN

A variational method to find nuclear energies and widths

- Works for K – few –nucleons

An intuitive extensions to η

Two steps

1) K bound to N…N fixed nucleons

→ correlated wave function $\Phi_K(X , X_i)$

$= \Sigma_i \ \psi_i(X - X_i)$

→ complex binding energy $E(X_i)$

→ contracting potential $E(X_i) – E (\infty)$

2) Variational wave for KN…N

$F = \Phi_K(X , X_i) \Theta_{N…N}(X_i)$

Nucleons Fixed at X_i

Brueckner, Foldy, Walecka

- multiple scattering equation for meson

$$\Phi = G_o \quad \Sigma_i \; V_i \quad \Phi \quad + \Phi_o$$

no incident wave $\Phi_o = 0$

separable $V = v(u)v(u')\lambda$

- K amplitudes at each nucleon

$$\varphi_i = \lambda \int du \; v(u) \quad \Phi_K (X_i - u , X_i)$$

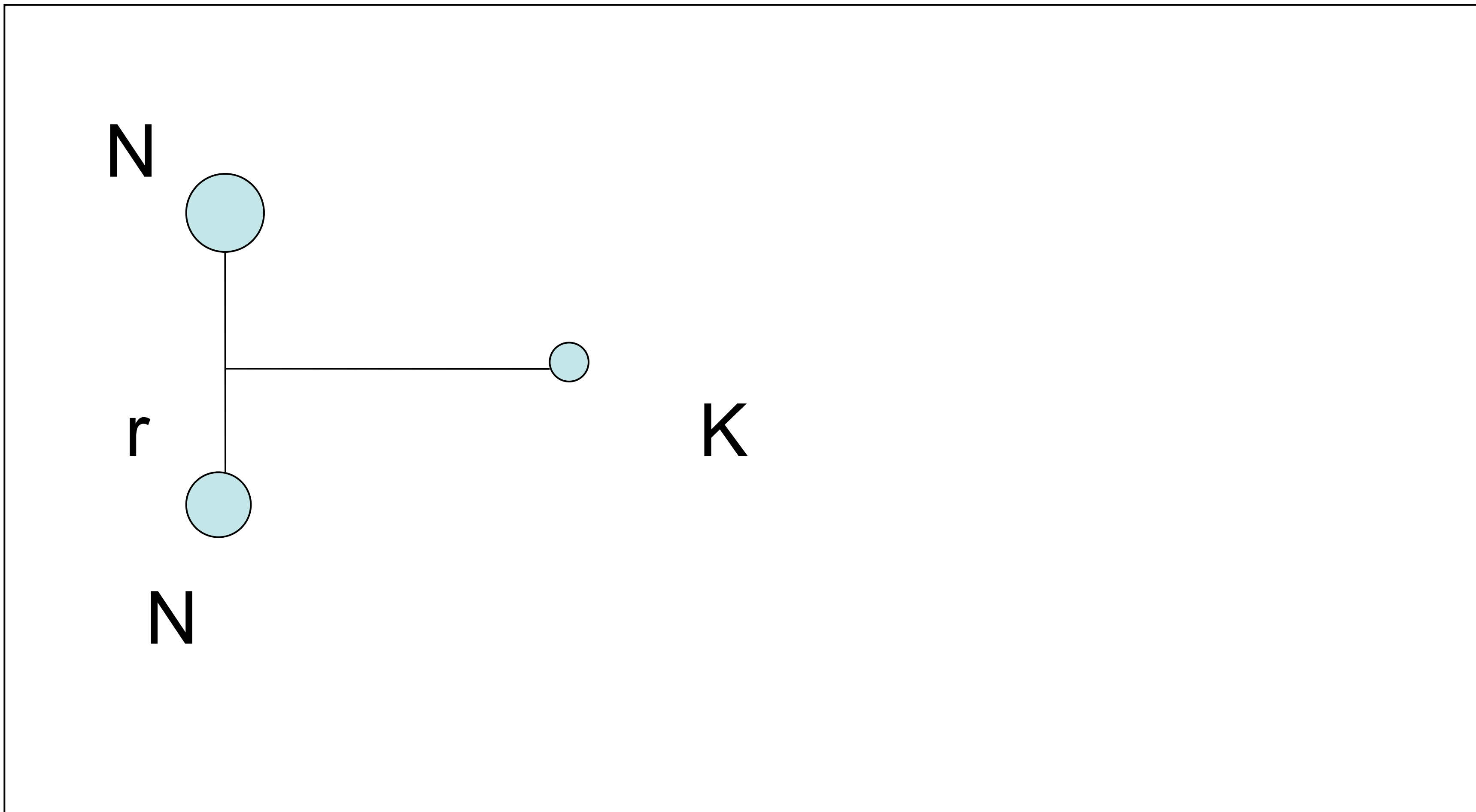
- multiple scattering → eigenvalue equation

$$\varphi_i = \Sigma_{i \neq j} \; t_i \, G_{i,j} (k) \quad \varphi_j$$

- → eigenvalue k

KNN

S-wave interactions Λ(1405)
P-wave interactions Σ(1385)



Equations for amplitudes

$\varphi_1 = t\ G_S\ \varphi_2$

$\varphi_2 = t\ G_S\ \varphi_1$

$G_S \sim \langle v|\ \exp(-k_I\ r + i\ k_R\ r)|v\rangle\ /r$

$\varphi_1 = \varphi_2$ symmetric = total S wave

$k(r)$ - complex eigenvalue

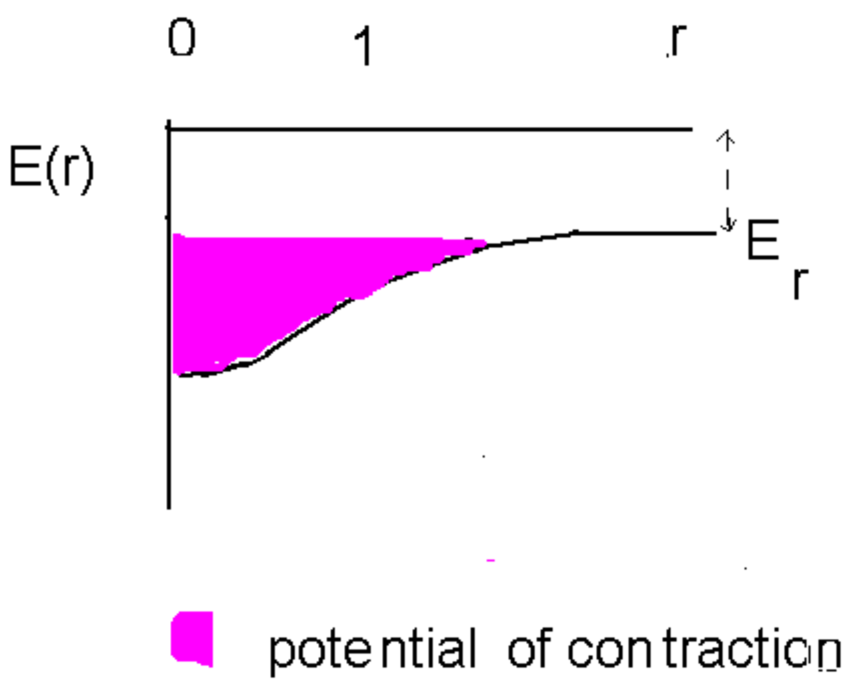
$E(r) - i\Gamma/2 = k(r)^2 / 2\mu_{KN}$

Asymptotic separation

KNN → N + Λ(1405)

$k(\infty)^2 / 2\mu_{KN}$ = binding of Λ(1405)

Contraction due to Λ(1405)

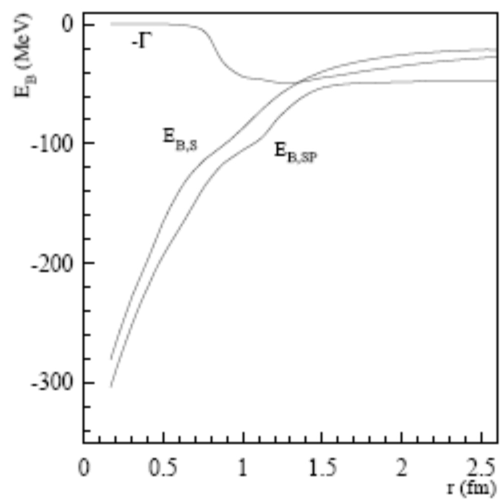


- K N N ⟶ Λ(1405) N

$E(r) - E(\infty)$ = contracting potential

KN parameters, A.Martin , Σ- W.Cameron, O.Brown

- E_{BS} Λ(1405)
- E_{BSP} Λ(1405)+ Σ(1385)



- KNN total S-wave
- NN even L

Typical solutions

AM- Alan Martin KWW-Brian Martin

KN –single channel ,

KN,Σπ- two channel –collision broadening

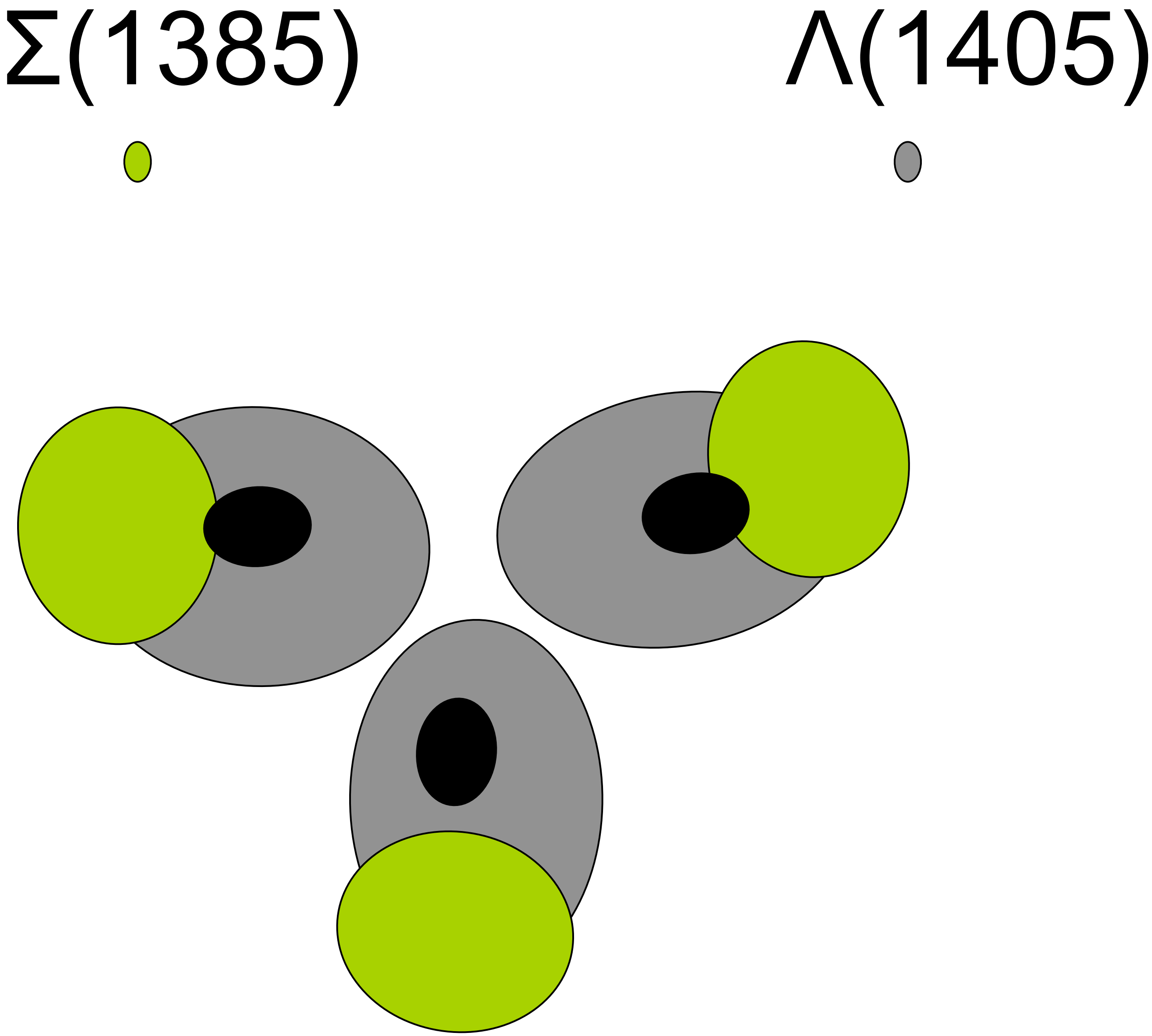
solution	AM[19]			KWW[11]		
	E_B	Γ	R_{rms}	E_B	Γ	R_{rms}
$KN;\quad S$	27	36	3.1	35.5	37	2.4
$KN,\Sigma\pi;\ S$	37	42	2.5	43.1	47	2.1
$KN;\quad S,P$	49	36	3.7	49.7	36	3.3
$KN,\Sigma\pi;\ S,P$	52	37	2.9	56.5	39	2.3

Extension to KNNN, KNNNN

Variational solutions : total S waves

$$F = \Phi_K(X , X_i)_{\text{FIXED-NUCLEONS}} \cdot$$

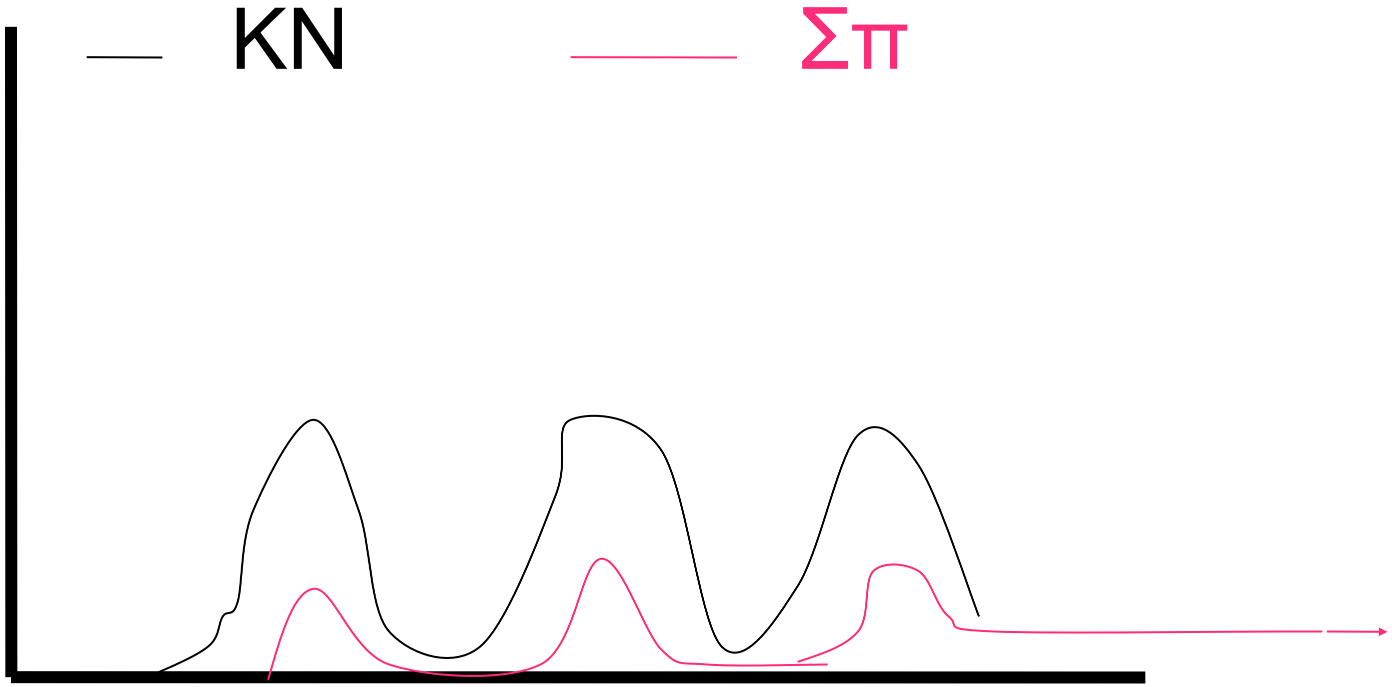
$$\Pi_{\text{NN pairs}} [(1\text{-}\exp(-r^2 \gamma^2)) (1\text{-}\exp(-r\lambda))/r]$$



Σ(1385)
Λ(1405)

solution	AM[19]			KWW[11]		
	E_B	Γ	R_{rms}	E_B	Γ	R_{rms}
KN; S	27	36	3.1	35.5	37	2.4
$KN, \Sigma\pi$; S	37	42	2.5	43.1	47	2.1
KN; S, P	49	36	3.7	49.7	36	3.3
$KN, \Sigma\pi$; S, P	52	37	2.9	56.5	39	2.3

Explicit decay channel



Two channels

Two amplitudes at each nucleon

$$\chi_i = \begin{vmatrix} \varphi_i\,(KN) \\ \varphi_i\,(\pi\Sigma) \end{vmatrix}$$

- multiple scattering equation

  $\chi_i = \Sigma_{i \neq j} \; T \; G_{i,j}\,(k)\,\chi_j$
- → eigenvalue k

Induced shift , induced width

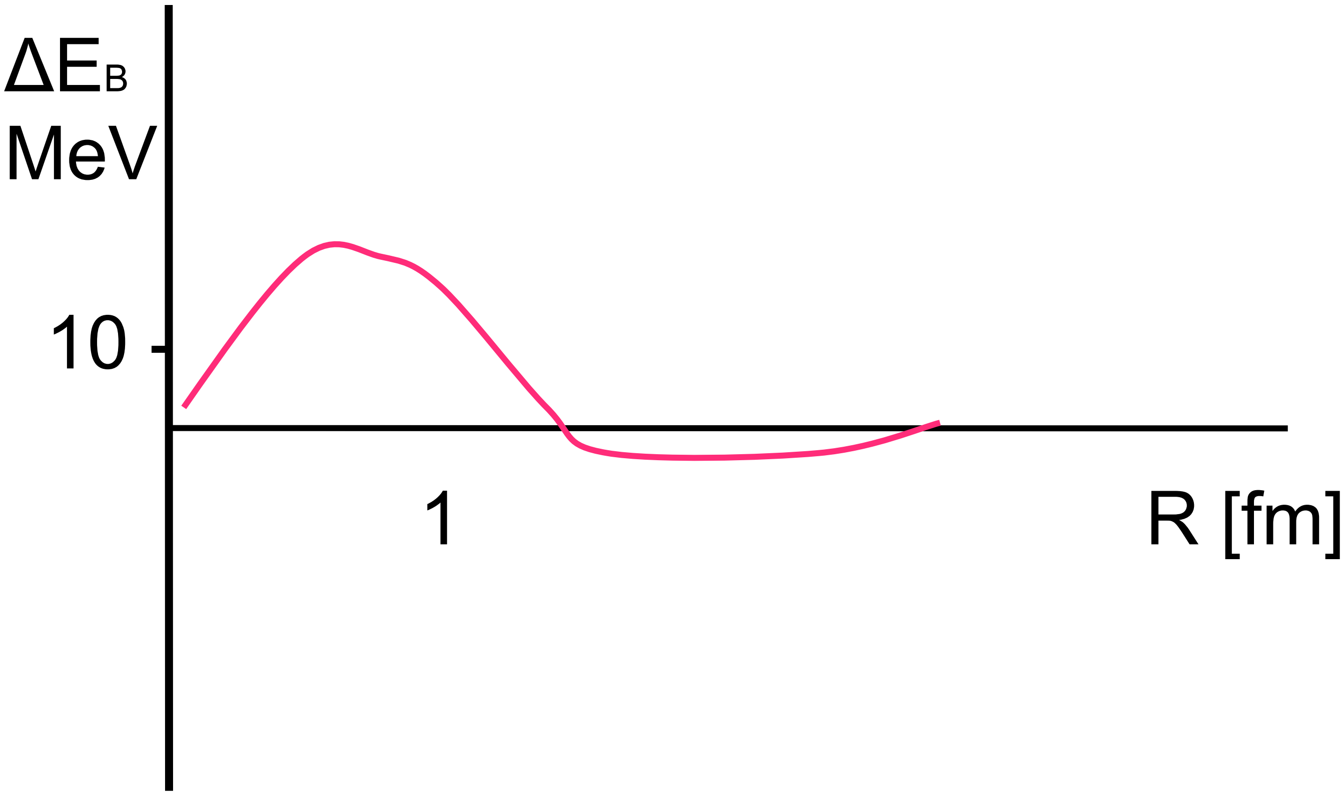
Two nucleons at distance r, zero range force

$T_{\alpha\beta} = \gamma_\alpha \gamma_\beta / (E- E + i \Gamma/2)$

$\Delta E = - (\gamma_\pi)^2 \cos(q_\pi r) / r$

$\Delta\Gamma = (\gamma_\pi)^2 \sin(q_\pi r) / (q_\pi r)$

Extra binding of KNN MeV due to multiple scattering in decay channel



E_{KN} below above $\pi\Sigma$ threshold

KNN , T =1/2 „deep state”

E_B ~ 80 MeV : Γ ~ 70 MeV

Effects of explicit decay channel

ΔΓ : 10 -30 MeV

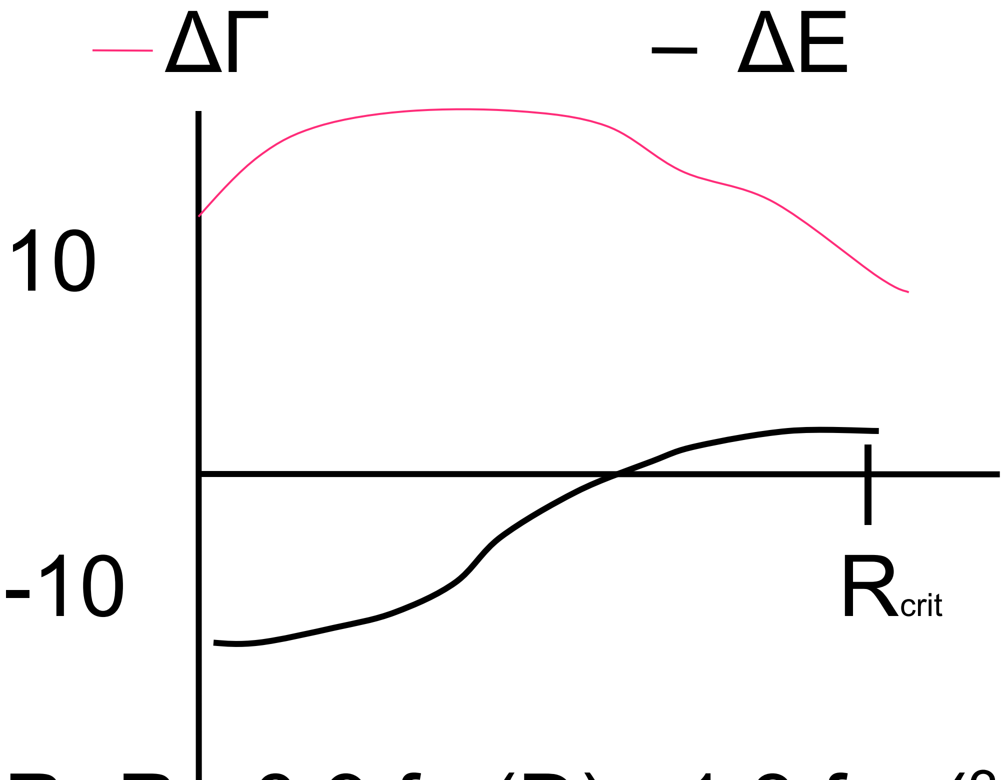
ΔE : 10 -20 MeV

Similar results with Faddeev method

Schevchenko, Gal, Mares, Revai

Expectations for η +few nucleons ?

Decay channel in η- nuclei



R_{crit} R~ 0.9 fm(D), 1.3 fm (^{3}He), 1.5 fm (^{4}He)

Applicability of this method

Is limited to central part of nuclei

BUT

multiple scattering in other channels enhances widths , probably adds attraction

This is not $\rho(r)^2$ effect

This is a boundary condition and interaction in decay channels

(textbook effect in many channel systems)

Summary

Two channel description

ηN

πN

of η -nuclear states is

recommended , if someone finds

a method to do it.

Input

- V(N,N) Argonne V18

R.B.Wiringa

V(KN) : 5-channel K matrix for S wave,

A.Martin , B.Martin –M.Sakitt

2-channel Σ(1385) for P wave

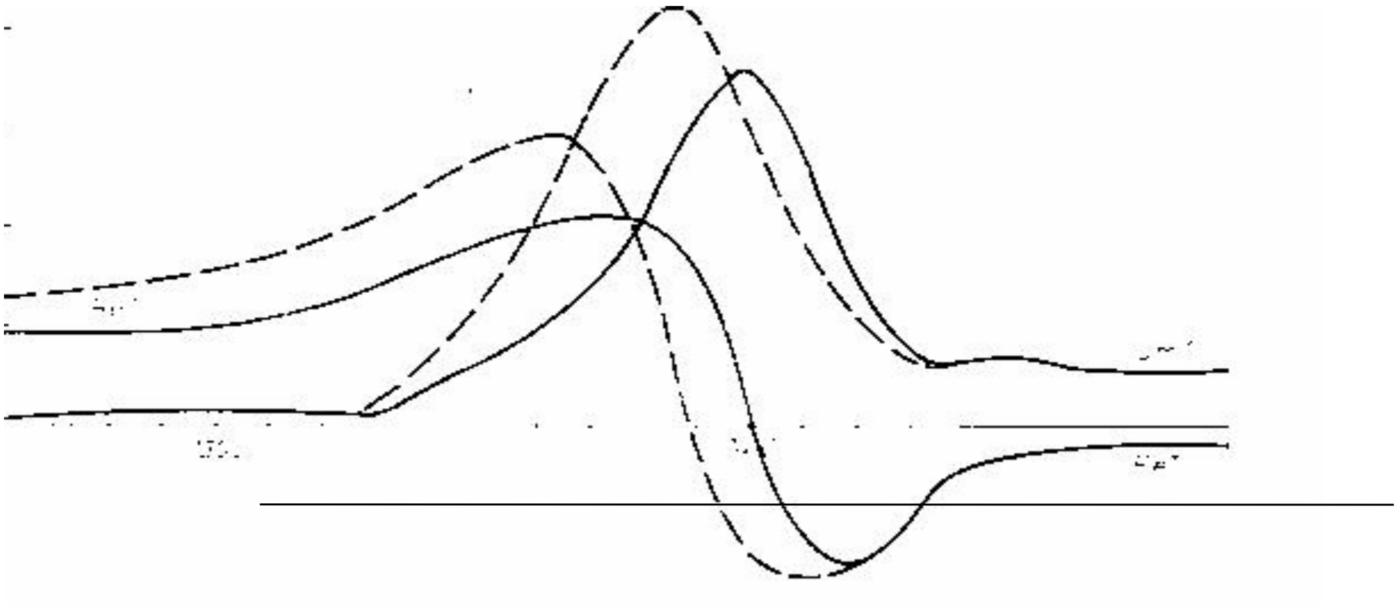
O.Brown, W.Cameron

Strong dependence on Λ resonance position at 1405

solution KWW*			
	E_B	Γ	R_{rms}
$KN;\ \ S$	50	51	2.05
$KN,\Sigma\pi;\ S$	71	85	1.81
$KN;\ \ S,P$	65	43	2.09
$KN,\Sigma\pi;\ S,P$	78	60	1.88

Main uncertainty-position of Λ(1405)

in potential model



Other –chiral models. Low Λ(1405) mass , second pole due to Σπ, [Munich, Valencia]

- KNNN S wave

	E_B	Γ	E_B	Γ
S	103	29	142	25
$S+P$	119	23	153	21

- KNNNN S wave

	E_B	Γ	E_B	Γ
S	121	25	170	10
$S+P$	136	20	172	10

New branch, states bound by Σ(1385)

- KNN J(NN)=2, L(NN) =1

	I_{NNK}	I_{NN}	$E_B[MeV]$	$\Gamma[MeV]$	$R_{rms}[fm]$
K^-nn	$3/2$	1	48.5	36	4.9