KAON - FEW -NUCLEON STATES

variational calculations

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Experimental indications
KEK-Frascati-GSI

„Kpp" state

$E_{BINDING}$ ~ 100 MeV

Γ ~ 60-100 MeV

Interpretation not very certain

Calculations : $E_{BINDING}$ = 35- 105 MeV

Yamazaki-Akaishi, Dote –Weise, Hyodo-Weise, Schevchenko et al., Ikeda-Sato, Green- S.W.

THE INTEREST

Nuclear systems bound by nucleon excitations

N $\rightarrow$ Λ (1405) S-wave

N $\rightarrow$ Σ (1385) P-wave

High densities ρ ~ few times $\rho_{\text{nuclear matter}}$

Difficulties of the average field description

- Short ranged NN repulsion
  KN correlations

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

This model

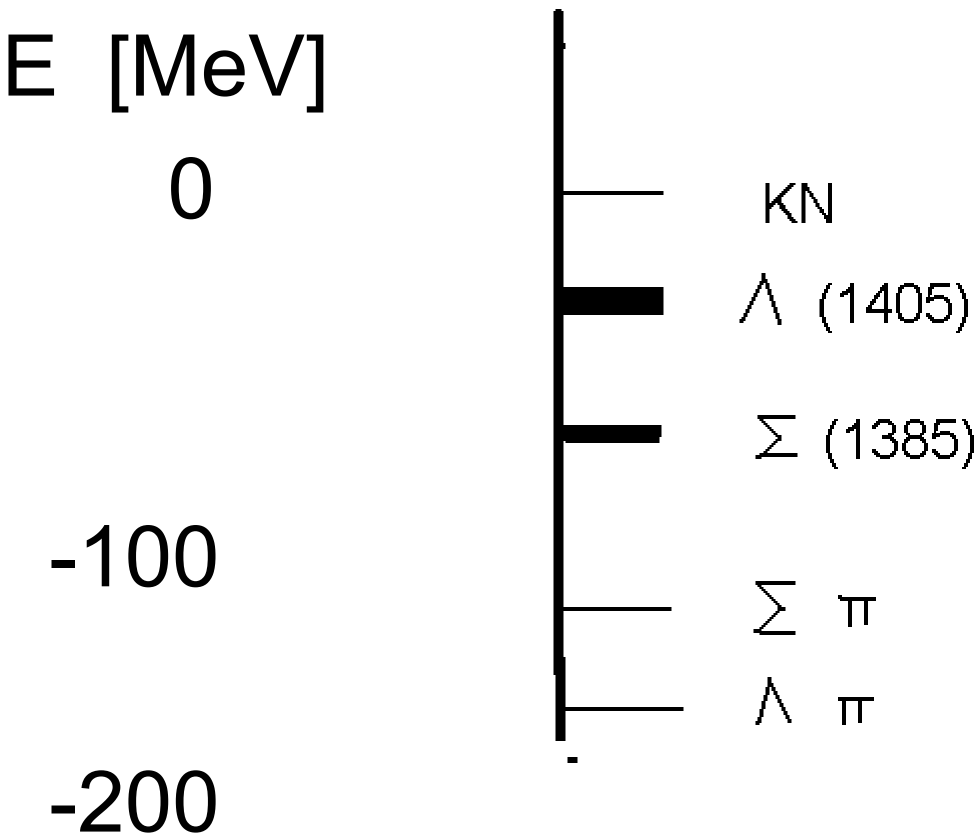
- Stress on K-N correlations
- Proper N-N interactions, repulsion

- Inclusion of

  S – wave Λ (1405)

  P wave Σ (1385)

States coupled to KN



blocked decays?

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

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

Fixed nucleons

Brueckner

- separable KN interactions $v(u)v(u')\lambda$
- K amplitudes at each nucleon

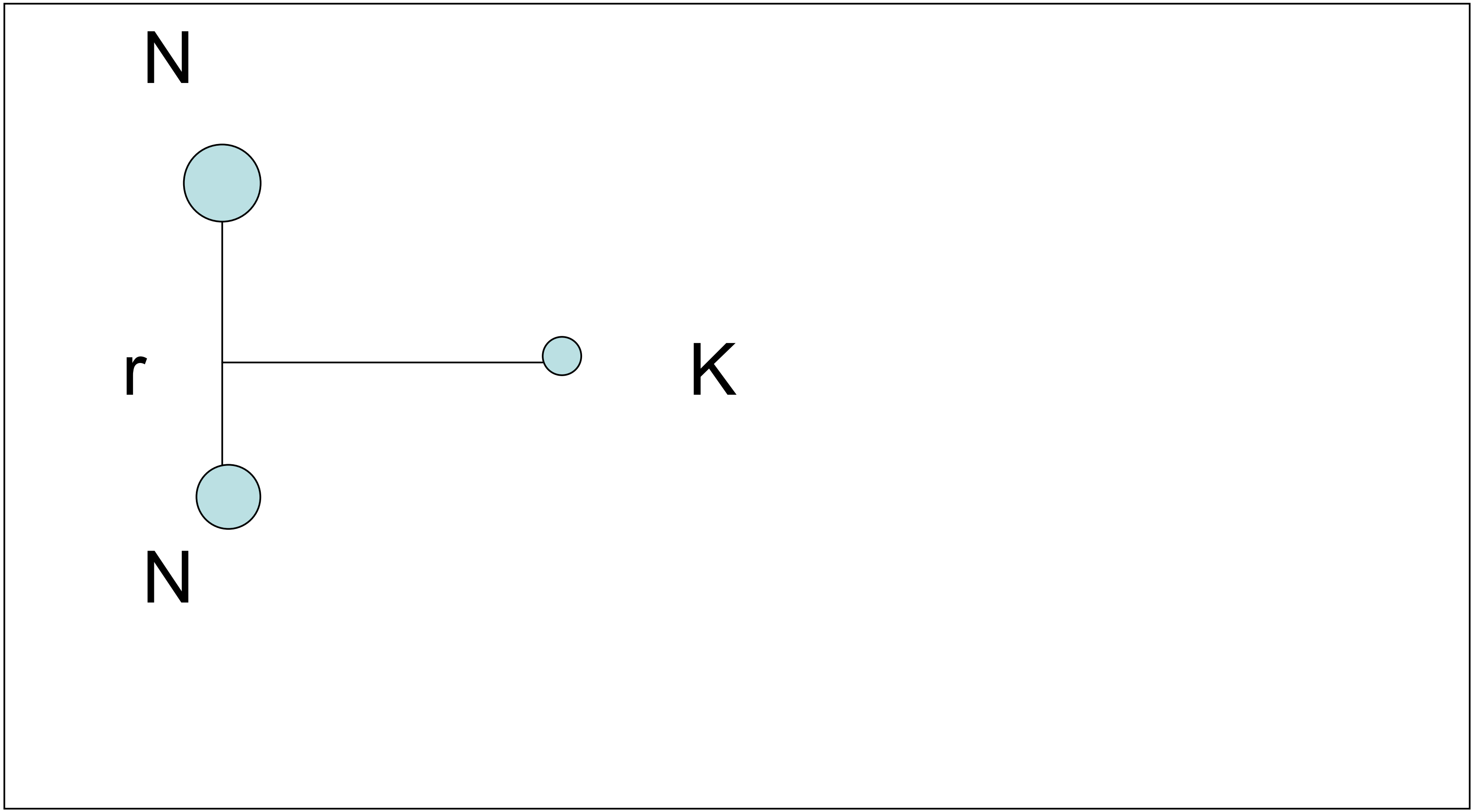
$$\varphi_i = \lambda \int du\, v(u) \quad \Phi_K(X_i - u , X_i)$$

- multiple scattering equation

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

- → eigenvalue k

KNN
S-wave interactions Λ(1405)



Equations for amplitudes

$$\varphi_1 = t\ G_S\ \varphi_2$$

$$\varphi_2 = t\ G_S\ \varphi_1$$

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

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

k(r) - complex eigenvalue

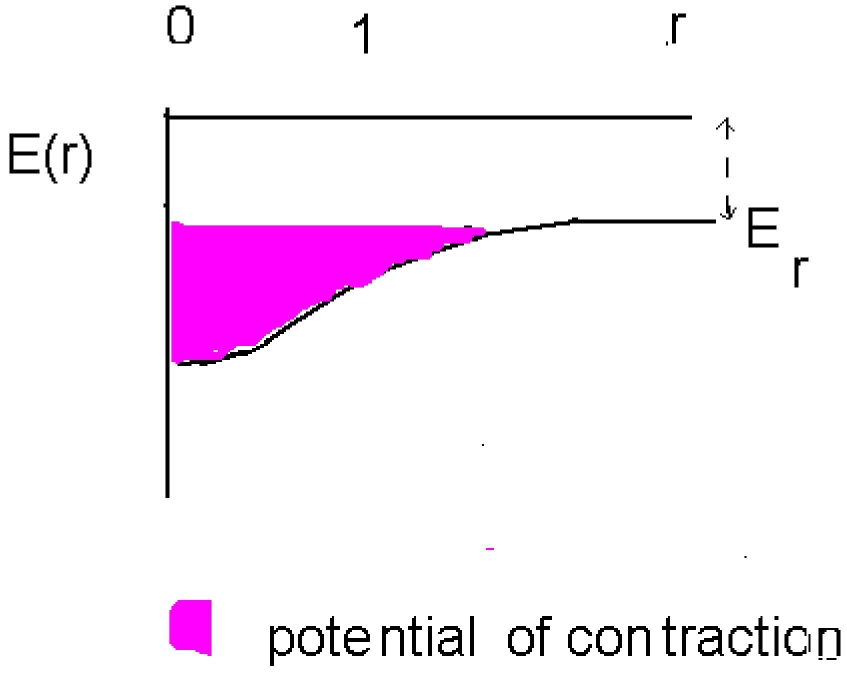
$E(r) - i\Gamma/2 = k(r)^2 / 2\,\mu_{KN}$

Asymptotic separation

KNN → N + Λ(1405)

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

Contraction due to Λ(1405)

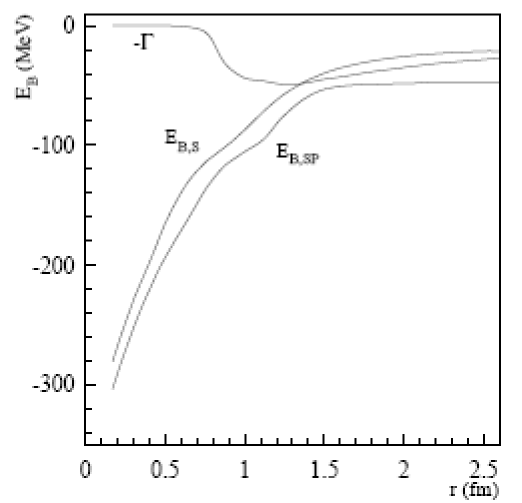


- K N N ⟶ Λ(1405) N

E(r)- E(∞)= 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

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

Typical solutions

AM- Alan Martin   KWW-Brian Martin

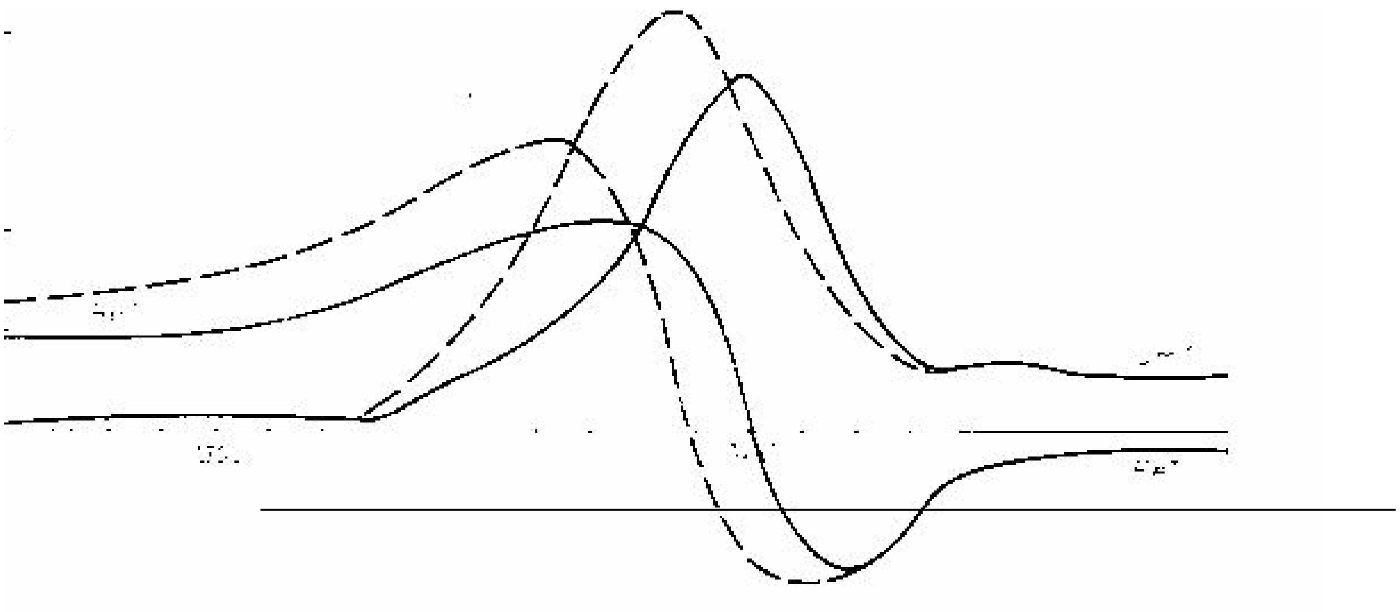
KN –single channel ,

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

Main uncertainty-position of Λ(1405)

in potential model



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

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

Extension to KNNN, KNNNN

Variational solutions : total S waves

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

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

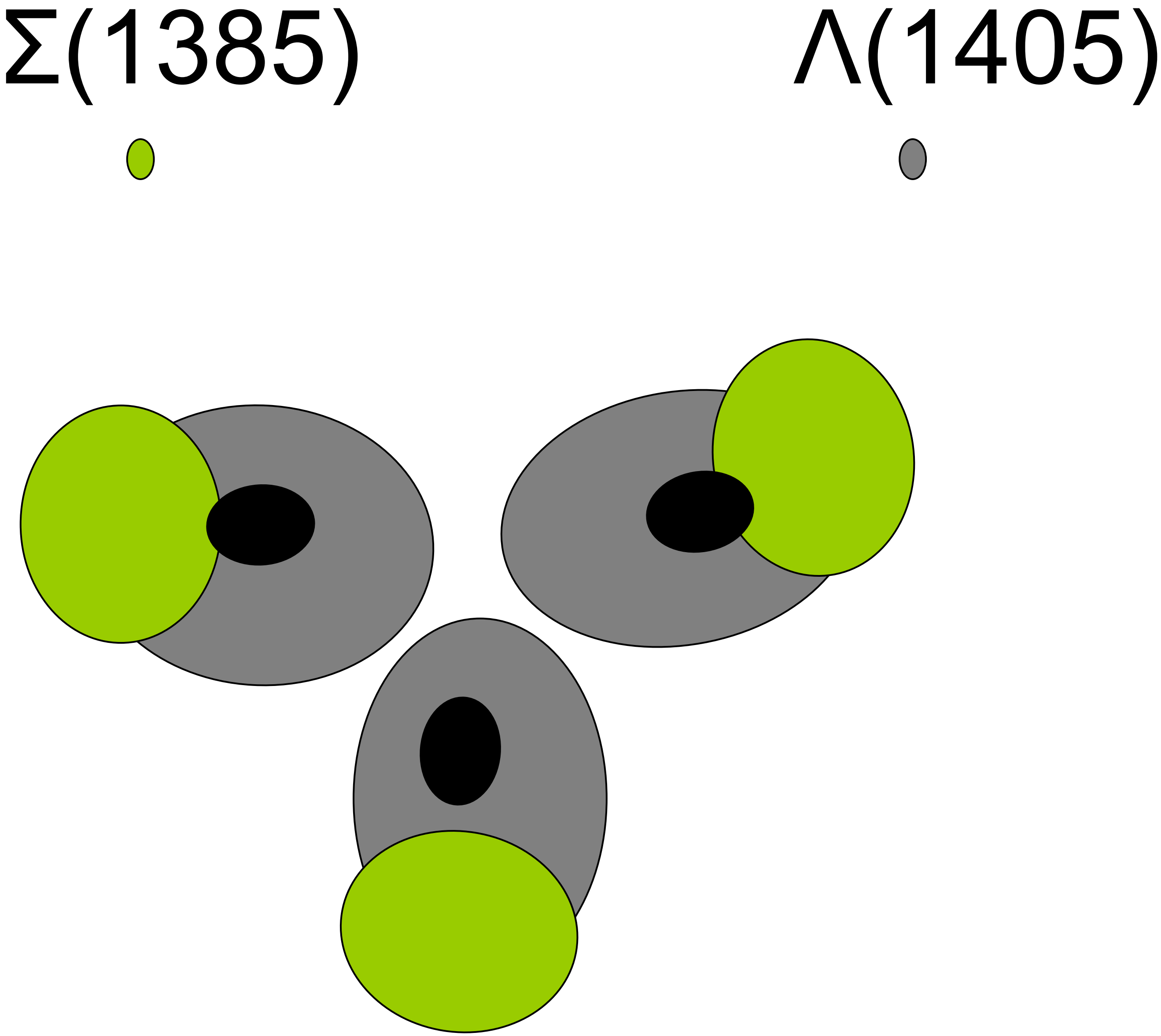
- KNNN S wave

	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

A simple physical picture emerges from this approach. The mesons are strongly correlated to slowly moving nucleons. The correlations are of the $\Lambda(1405)$ type at large densities, and of the $\Sigma(1385)$ type in the peripheries. Each K,N pair has a good chance to stay also in the Σ, π form. The structure is rather loose as sizable fractions of the binding energies are hidden in the short ranged correlations.


Σ(1385)
Λ(1405)

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

CONCLUSIONS

- Strong KN correlations
- Rather loose structure
- Sizable binding „within resonances”
- Uncertain Λ (1405)
- P wave spectrum

- Very deep binding in KNNNN
- Narrow States ? KNN→YN ?

Appendix

- P wave states

New branch of spectroscopy due to

KN - P wave Σ(1385)

K-(NN) odd L

$\Sigma(1385)$
energy dependent 2-channel width

$I = 1,\ J = 3/2$, $\Sigma(1385)$ dominates deep states

scattering amplitude $\quad f_\Sigma = 2\mathbf{p}\mathbf{p}'\frac{\gamma^2_{\Sigma KN}}{E_{KN} - E_\Sigma + i\Gamma_\Sigma/2}$

$\gamma^2_{\Sigma\pi\Lambda} = \Gamma_{\pi\Lambda}/(2p^3_{\pi\Lambda})$ $\quad$ from $\pi\Lambda$ final states

$$\gamma^2_{\Sigma KN}/\gamma^2_{\Sigma\pi\Lambda} = \ 2/3 : \mathrm{SU}(3)$$
$$= \ 0.51 \pm 0.18, \text{ from } K - D \text{ [Braun]}$$

K + fixed N N

P wave KN = Σ(1385)

$\psi_1 = t\, G_P\, \psi_2$

$\psi_2 = t\, G_P\, \psi_1$

ψ – vector , $\mathbf{G}_P$ – tensor

$G_P \sim \Delta \quad \exp(-k_I\, \mathbf{I}\, r + i\, k_R\, r) \;/\; r$

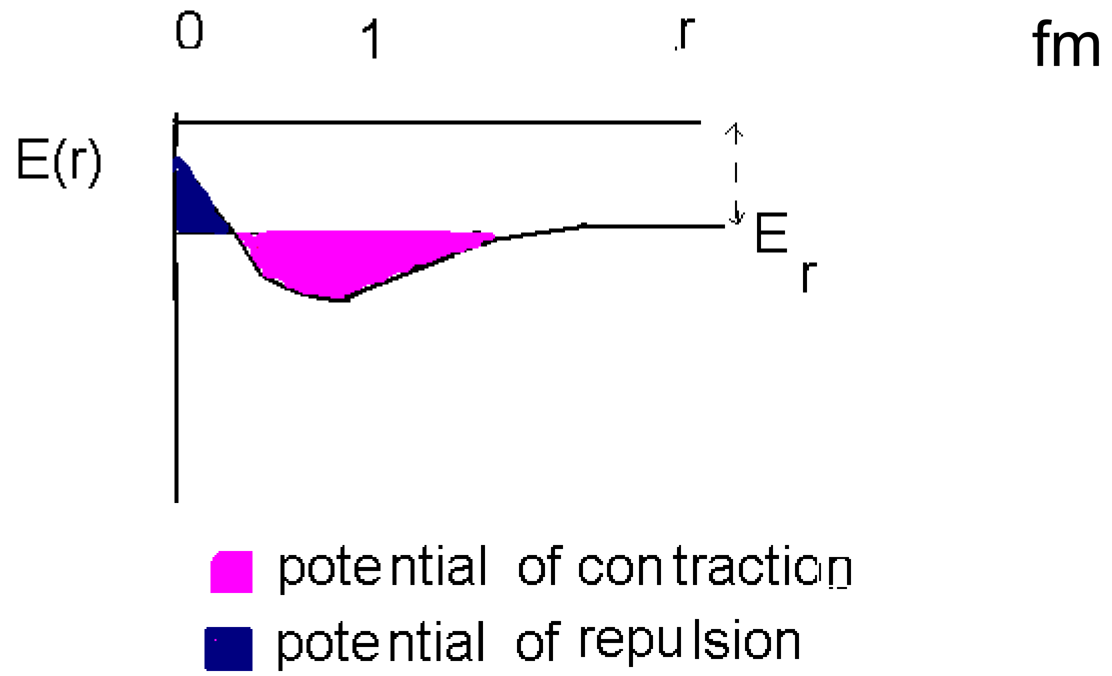
$\sim (k_I)^2 \quad \exp(-k_I\, \mathbf{I}\, r + i\, k_R\, r) \;/\; r \;-\; 4\pi\, \delta(\mathbf{r})$

attraction repulsion

$\psi_2 = \psi_1$

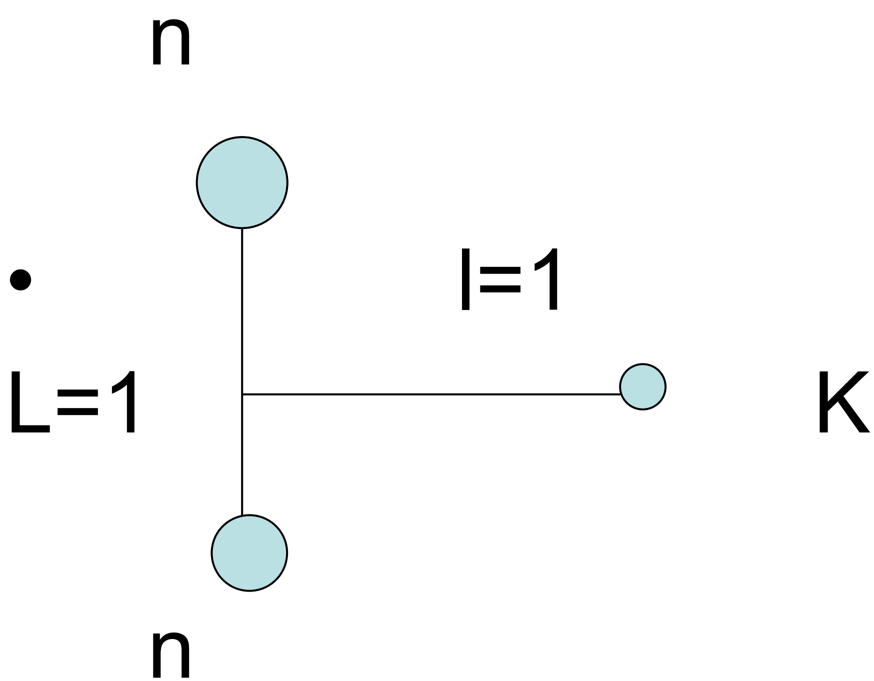
K - (NN) : P wave

Contraction due to Σ(1385)

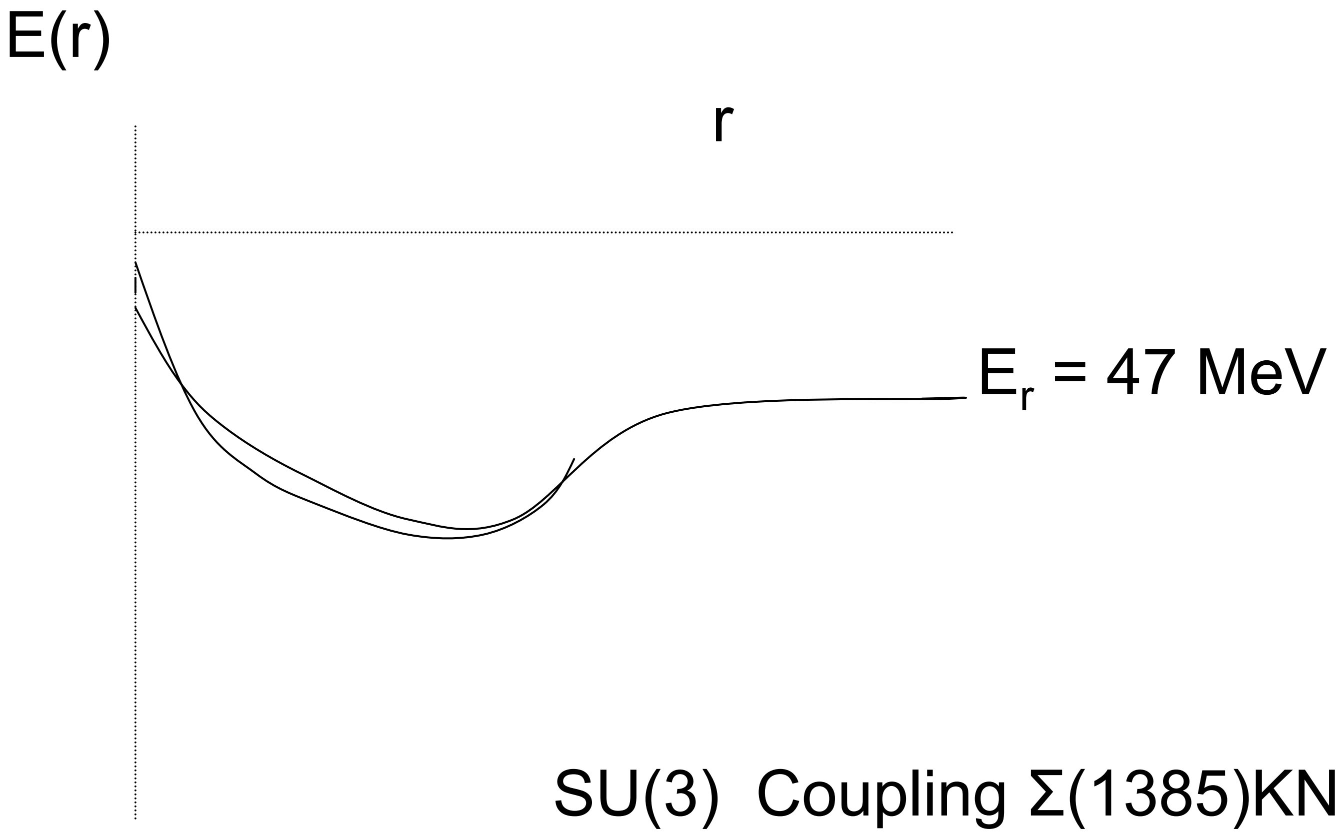


- Asymptotics KNN ⟶ Σ(1385) N

Can one bind K^-nn ?



Two semi-certain parameters



SU(3) Coupling Σ(1385)KN

range κ =4.5/fm

Additional strength from NN

- T =1, L=1, S=1, J=2

- scattering phase is attractive
- one pion exchange is attractive
- AV18 – potential used

- Binding 47 +1.5 MeV
- Radius m.s. 5 fm