中間子交換模型による$K^{bar}N$相互作用

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Contents

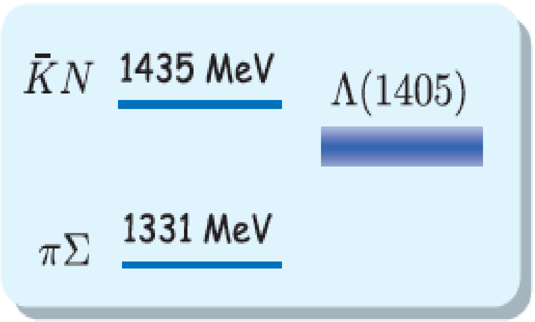
- ✗ *Properties of Λ(1405) state*
- ✗ *Meson exchange K^{bar} N potential*
- ✗ *Comparison with the chiral amplitudes*
- ✗ *Energy dependence of the potential*
- ✗ *Conclusion*

What is the Λ(1405)?

According to the PDG

Λ(1405) S_{01}

$I(J^P) = 0(\frac{1}{2}^-)$



Mass $m = 1406 \pm 4$ MeV
Full width $\Gamma = 50 \pm 2$ MeV
Below $\overline{K}N$ threshold

Λ(1405) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	157

W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) (URL: http://pdg.lbl.gov)

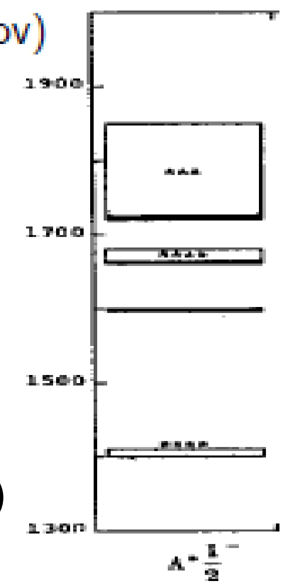
Most-established resonance with four-stars in PDG

The Λ(1405) can be observed directly only as a resonance bump in the $(\Sigma\pi)^0$ subsystem in final states of production experiments.

Theoretical interpretation ???

Quark model fails to reproduce splitting between Λ(1405) and Λ(1520)

3q state, meson-baryon system, two pole ?



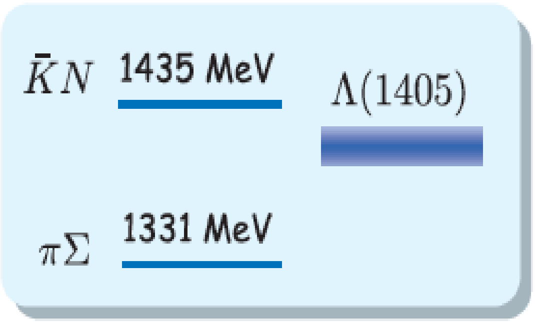
S.Capstick '89

What is the $\Lambda(1405)$?

According to the PDG

$\Lambda(1405)$ S_{01}

$I(J^P) = 0(\frac{1}{2}^-)$



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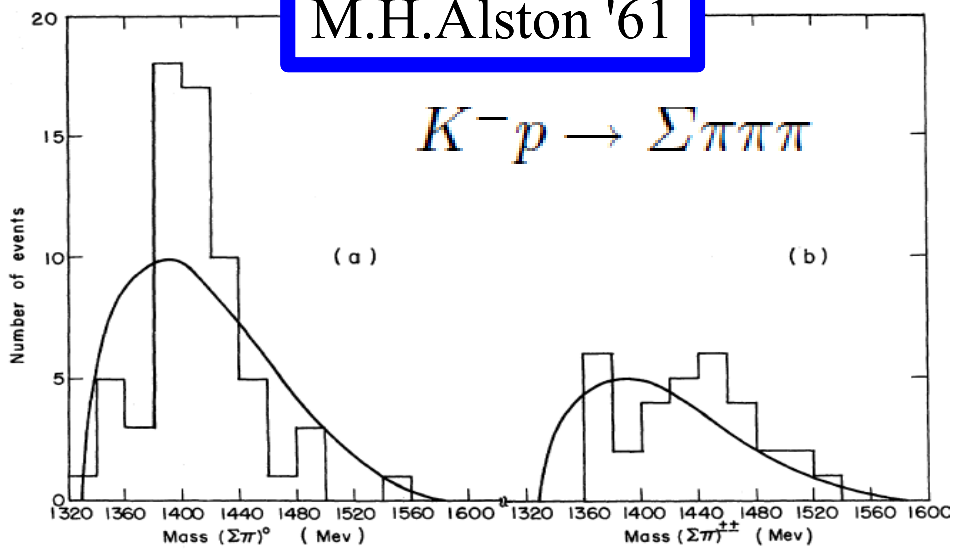
Most-established resonance with four-stars rating by PDG

The $\Lambda(1405)$ can be observed directly only as a resonance bump in the $(\Sigma\pi)^0$ subsystem in final states of production experiments.

Experimental view of Λ(1405)

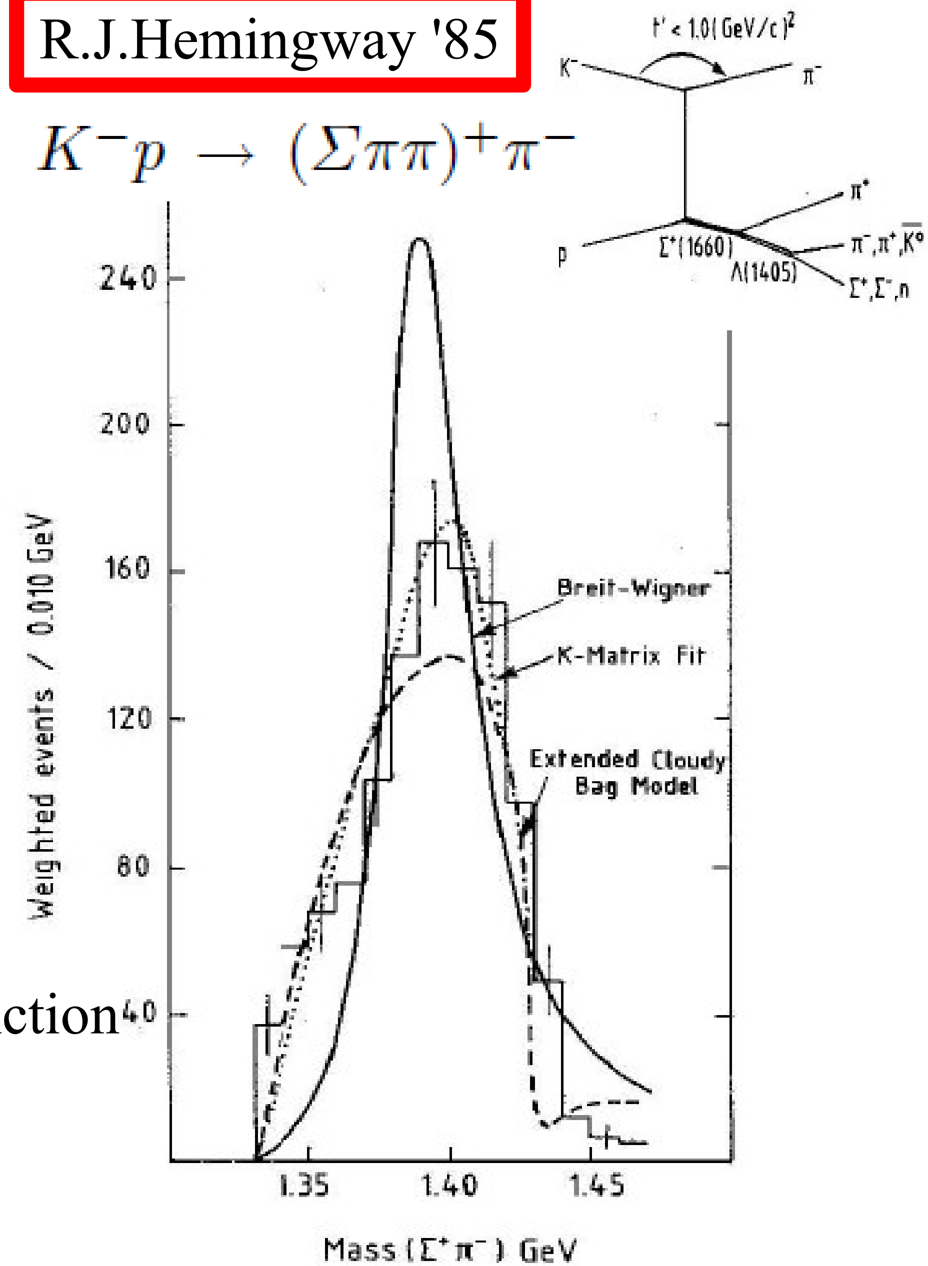
M.H.Alston '61

$$K^- p \to \Sigma\pi\pi\pi$$



R.J.Hemingway '85

$$K^- p \to (\Sigma\pi\pi)^+ \pi^-$$



D.W.Thomas '73

$$\pi^- p \to K^0 (\Sigma\pi)^0$$

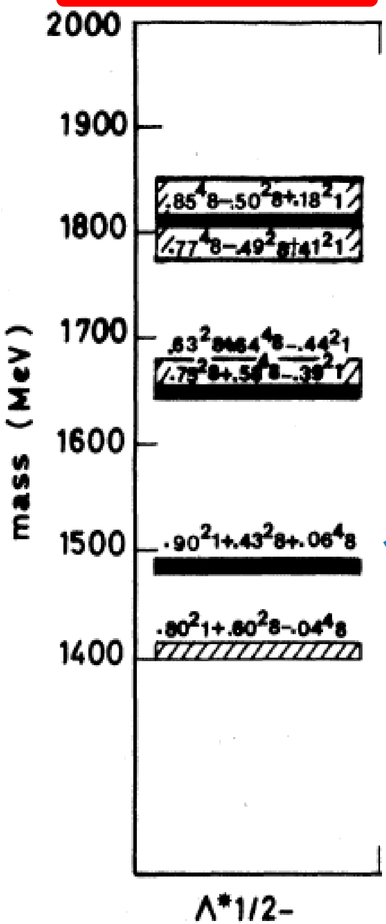
Asymmetric shape of the resonance bump
not well fitted by a Breit-Wigner resonance function

Direct evidence for $J^p=1/2^-$

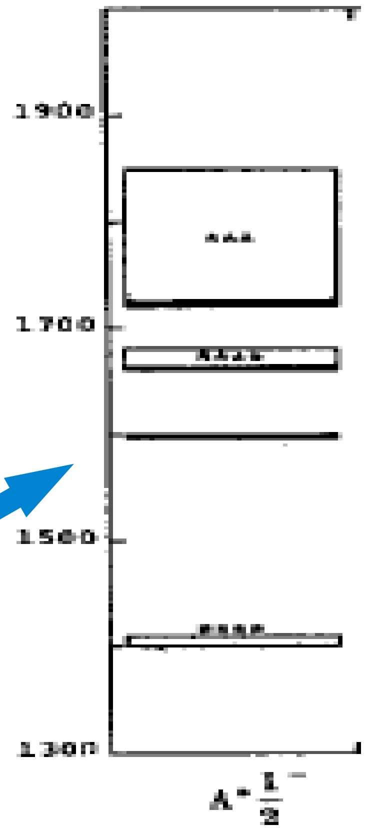
Theoretical interpretation of Λ(1405)

Three quark state

N.Isgur '78

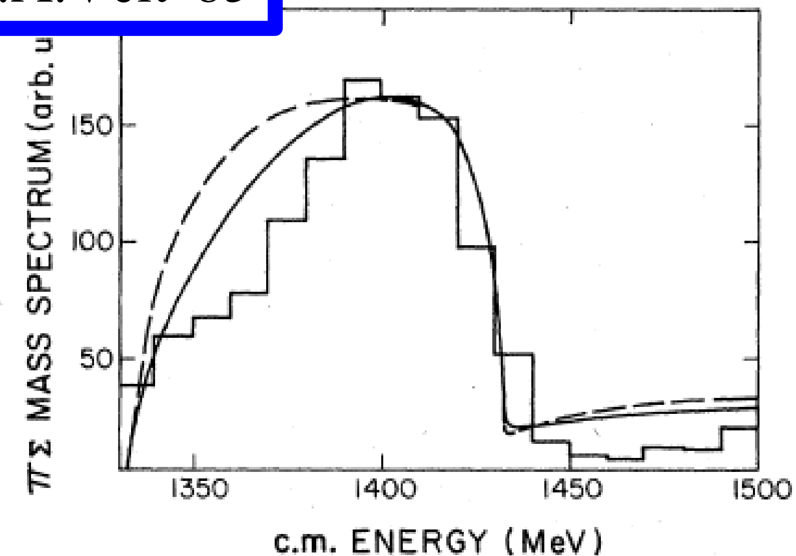


S.Capstick '89

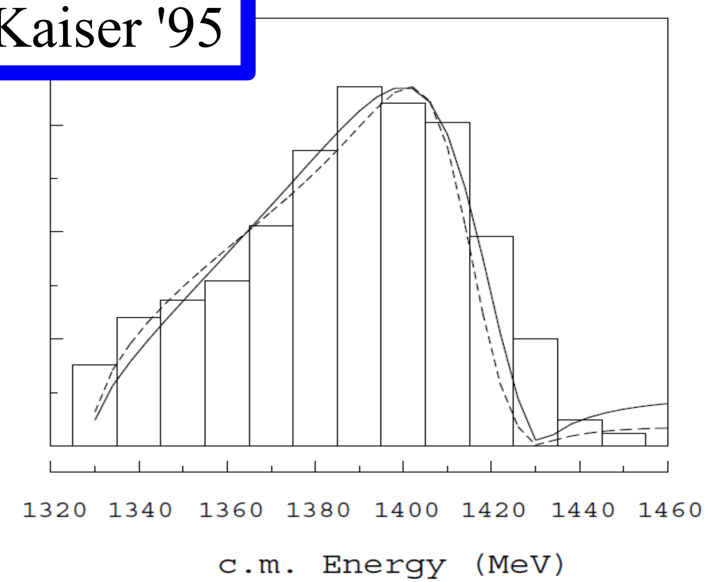


Meson + Baryon

E.A.Veit '85



N.Kaiser '95



Λ(1405) is dominated by the meson-baryon terms in the wavefunctions.

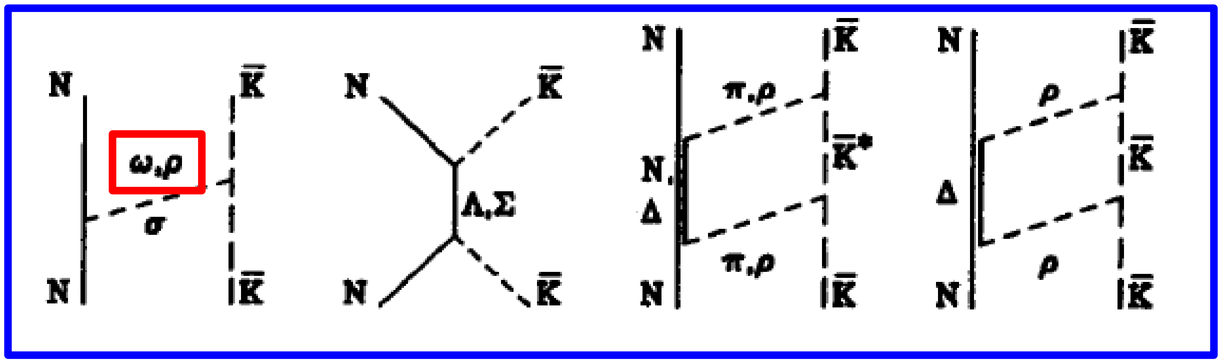
Juelich K^{bar} N interaction

The Juelich K^{bar} N interaction

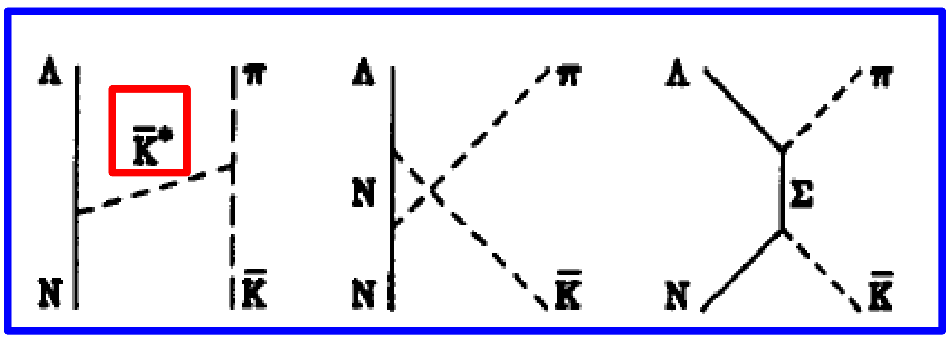
A.Muller-Groeling-NPA513(1990)557
(R.Buttgen-NPA506(1990)586)

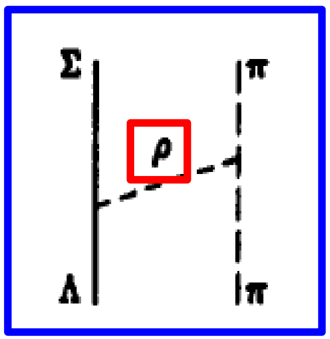
- Meson (hadron) exchange model
- $K^{bar}N$, $\pi\Sigma$, $\pi\Lambda$ channels are considered (Coupled channel approach)

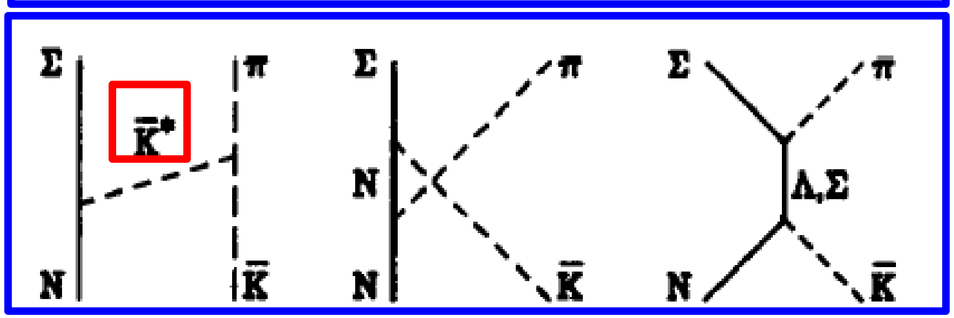
Diagrams

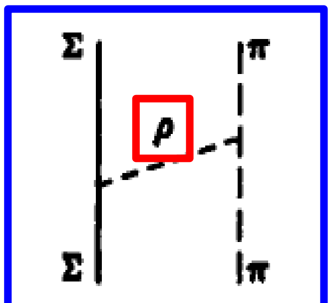


Potential is constructed
by small number of vertices









Main contribution comes from the vector meson exchange

The Juelich K^{bar} N interaction

Hamiltonians for meson-baryon couplings

Flavor SU(3) symmetry is assumed

Determined by baryon-baryon scattering

$$\mathcal{L}_{BBS} = g_{BBS}\bar{\psi}_B(x)\psi_B(x)\phi_S(x)\,,$$

$$\mathcal{L}_{BBP} = g_{BBP}\bar{\psi}_B(x)i\gamma^5\psi_B(x)\phi_P(x)\,,$$

$$\mathcal{L}_{BDP} = \frac{g_{BDP}}{m_P}(\bar{\psi}_{D\mu}(x)\psi_B(x) + \bar{\psi}_B(x)\psi_{D\mu}(x))\partial^\mu\phi_P(x)\,,$$

$$\mathcal{L}_{BDV} = \frac{g_{BDV}}{m_V}i(\bar{\psi}_{D\nu}(x)\gamma^5\gamma_\mu\psi_B(x) - \bar{\psi}_B(x)\gamma^5\gamma_\mu\psi_{D\nu}(x))(\partial^\mu\phi_V^\nu(x) - \partial^\nu\phi_V^\mu(x))\,,$$

$$\mathcal{L}_{BBV} = g_{BBV}\bar{\psi}_B(x)\gamma_\mu\psi_B(x)\phi_V^\mu(x) + \frac{f_{BBV}}{4m_N}\bar{\psi}_B(x)\sigma_{\mu\nu}\psi_B(x)(\partial^\mu\phi_V^\nu(x) - \partial^\nu\phi_V^\mu(x))\,,$$

Hamiltonians for meson-meson couplings

$$\mathcal{L}_{PPS} = g_{PPS}m_P\phi_P(x)\phi_P(x)\phi_S(x)\,,$$

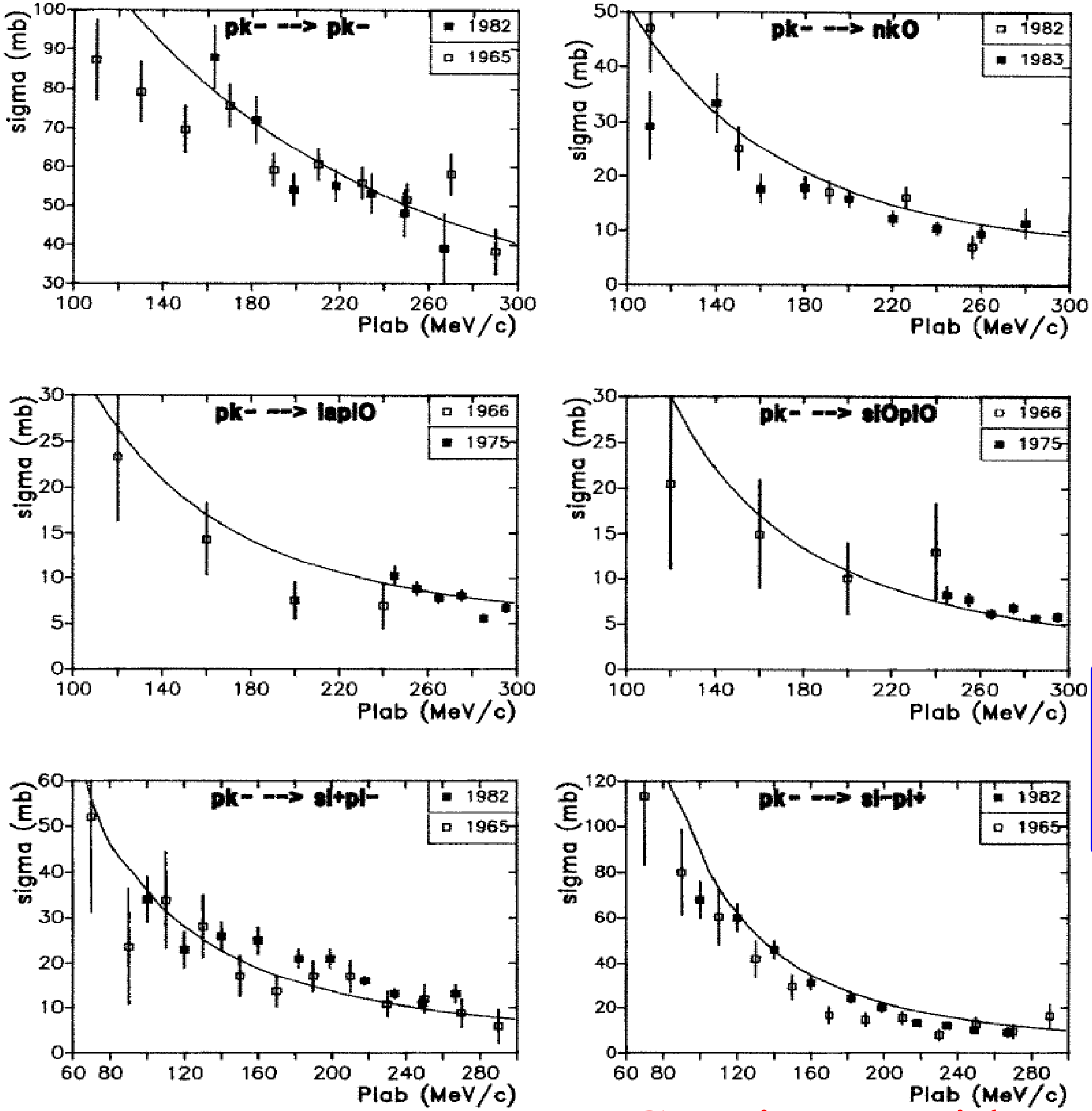
$$\mathcal{L}_{PPV} = g_{PPV}\phi_P(x)\partial_\mu\phi_P(x)\phi_V^\mu(x)\,,$$

$$\mathcal{L}_{VVP} = \frac{g_{VVP}}{m_V}i\varepsilon_{\mu\nu\tau\delta}\partial^\mu\phi_V^\nu(x)\partial^\tau\phi_V^\delta(x)\phi_P(x)\,.$$

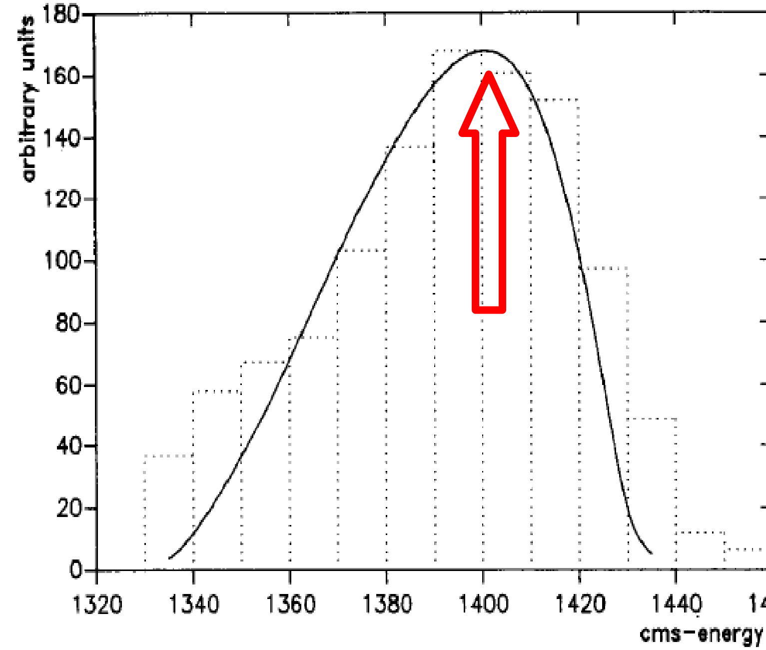
Parameters are determined by KN scattering

The Juelich K^{bar} N interaction

Cross sections



Invariant mass distribution



Peak around 1400MeV

Λ(1405) state can be seen
at proper position
without the pole graph in V.

It is predicted
as the quasi-bound state of K^{bar} N.

Consistent with experimental data

Phenomenological K^{bar} N potential

Y. Akaishi and T. Yamazaki, PRC52(2002)044005

Phenomenological AY potential

Ansatz The Λ(1405) resonance state is the I= 0 1*s* bound state of K^{bar} N

Regarding

1. 1*s* level shift of kaonic hydrogen atom
2. Martin's K^{bar} N scattering lengths
3. Binding energy and width of Λ(1405)

$$a_{K^-p} = (-0.78 \pm 0.15) + i\,(0.49 \pm 0.28)\ \text{fm},$$
$$a^{I=0} = (-1.70 \pm 0.07) + i\,(0.68 \pm 0.04)\ \text{fm},$$
$$a^{I=1} = (0.37 \pm 0.09) + i\,(0.60 \pm 0.07)\ \text{fm},$$

K^{bar} N-πΣ coupled channel with I=0

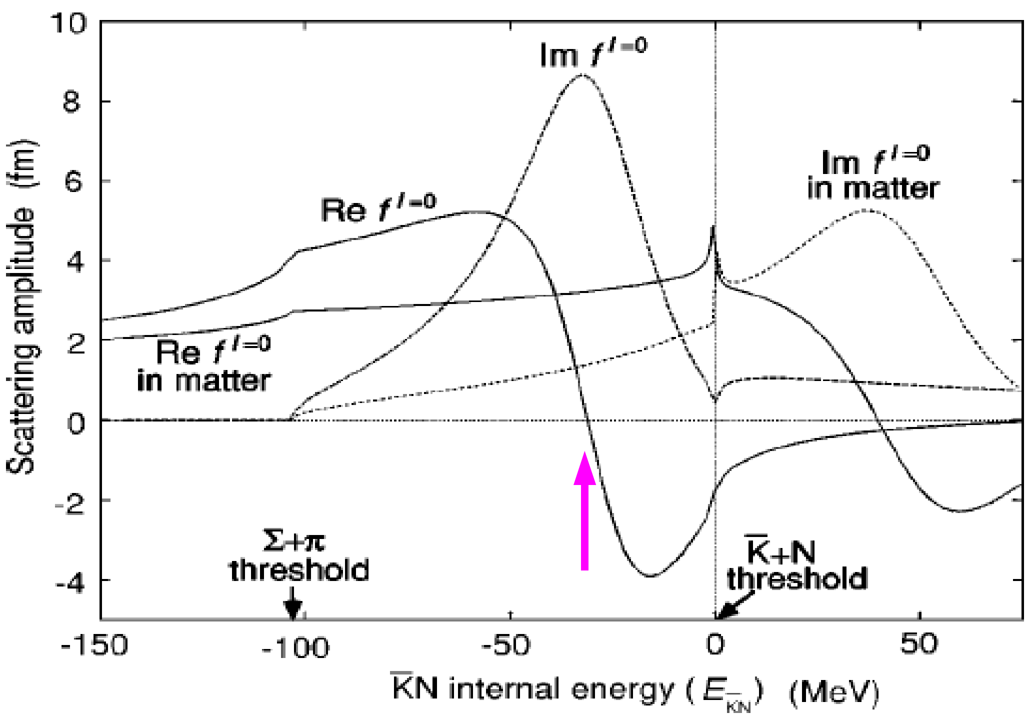
$$v_{ij}(r) = \begin{pmatrix} -436 & -412 \\ -412 & 0 \end{pmatrix} \exp[-(r/b)^2] \quad [\text{MeV}],$$

(rows and columns labelled K^{bar} N, πΣ)

$$b = 0.66\ \text{fm}$$

Equivalent single channel potential

$$v^{I=0}_{\bar{K}N}(r) = (-595 - i\,83)\exp[-(r/0.66)^2],$$



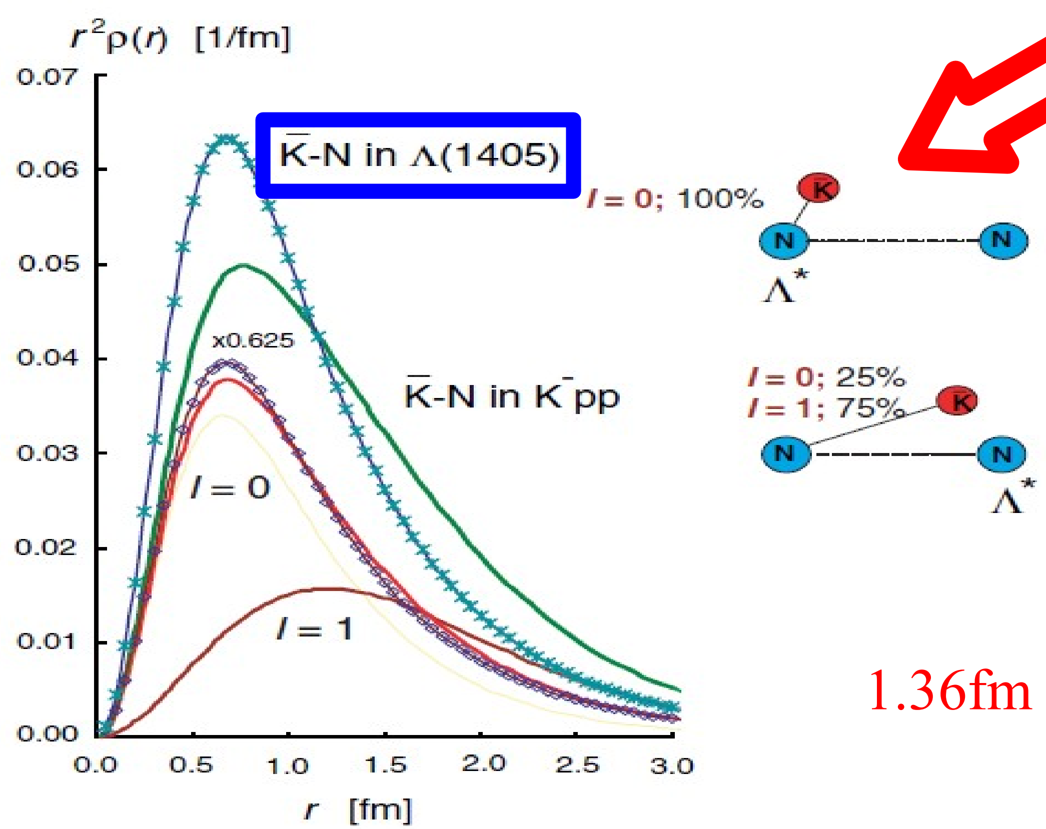
Various kaonic nuclear states with large binding energy and high density

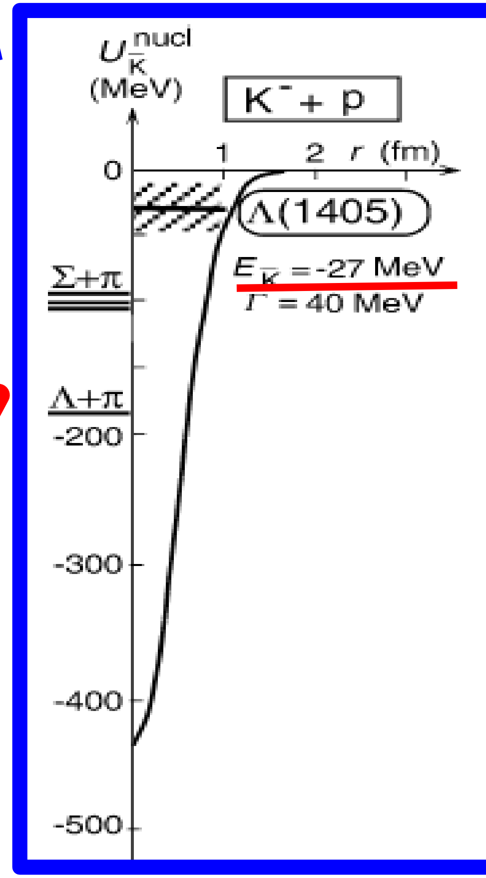
Y. Akaishi and T. Yamazaki, PRC52(2002)044005

Phenomenological AY potential

Points

- ✗ Λ(1405) ansatz (B.E = 27MeV)
- ✗ Energy independent potential
- ✗ Omission of the diagonal πΣ-channel interaction
- ✗ Compact object





1.36fm between K^{bar} and N (rms distance)

Chiral effective theory

Chiral effective theory

D. Jido *et al* NPA725(2003)181
T. Hyodo-PRC77(2008)035204

Seagull (Tomozawa-Weinberg) term from chiral effective lagrangian

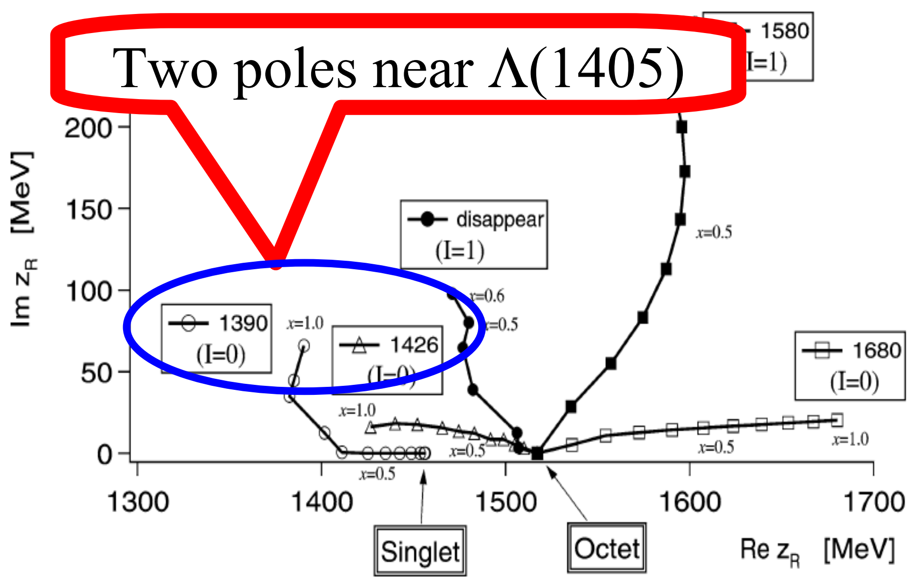
$$V_{ij}(\sqrt{s}) = -\frac{C_{ij}}{4f^2}(2\sqrt{s} - M_i - M_j)\sqrt{\frac{E_i + M_i}{2M_i}}\sqrt{\frac{E_j + M_j}{2M_j}},$$

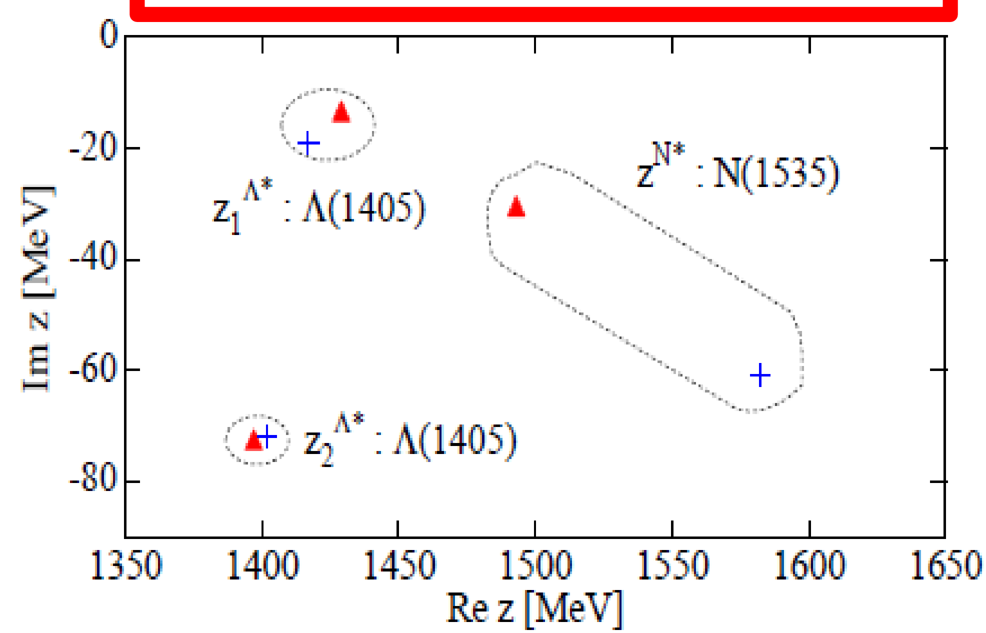
T-matrix is solved algebraically(on-shell treatment)

Choice of decay constant f and regularization mass in the loop function G

$$T = \frac{1}{1 - VG}V$$

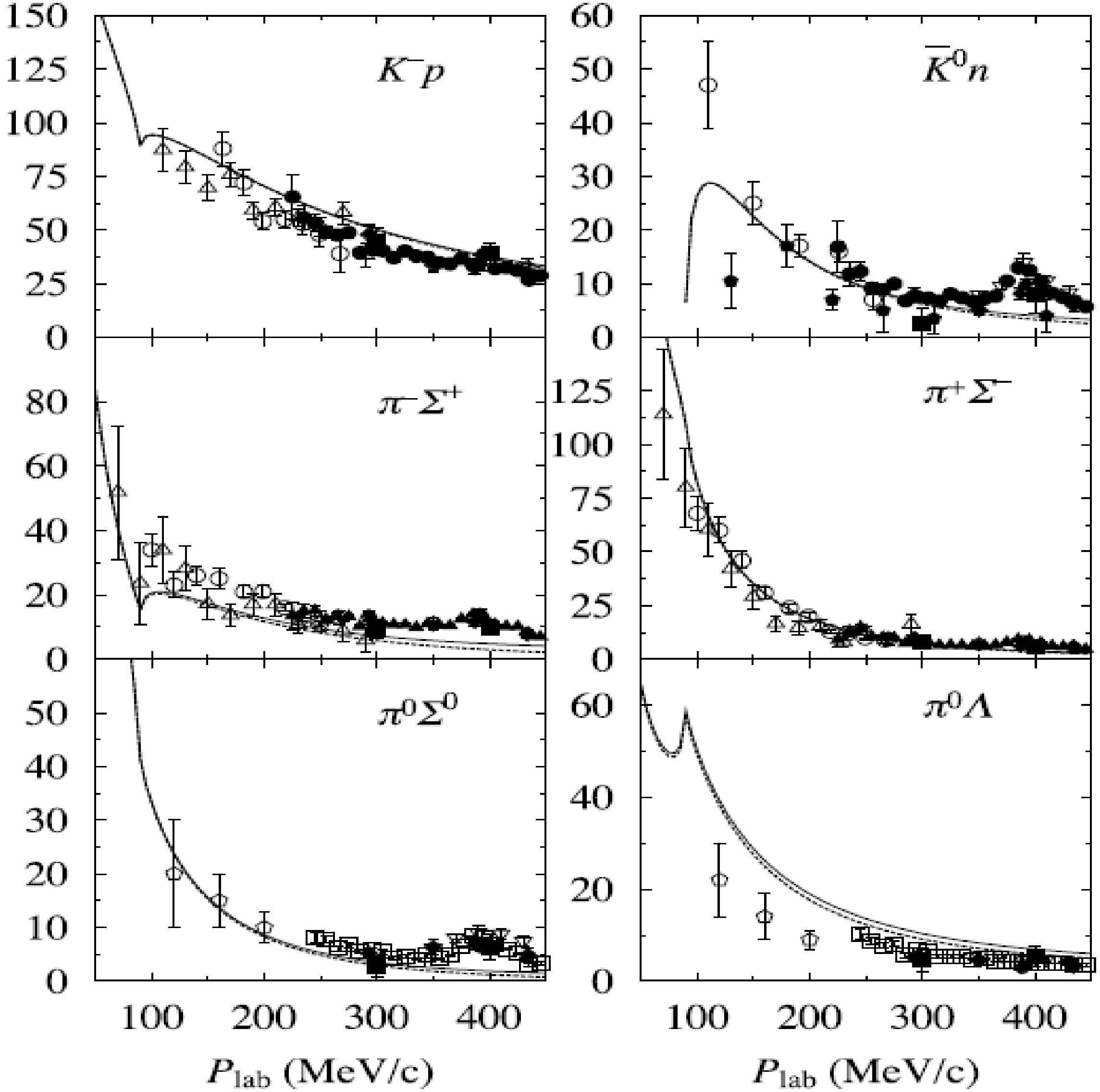
Evidence of meson-baryon state with natural subtraction constant



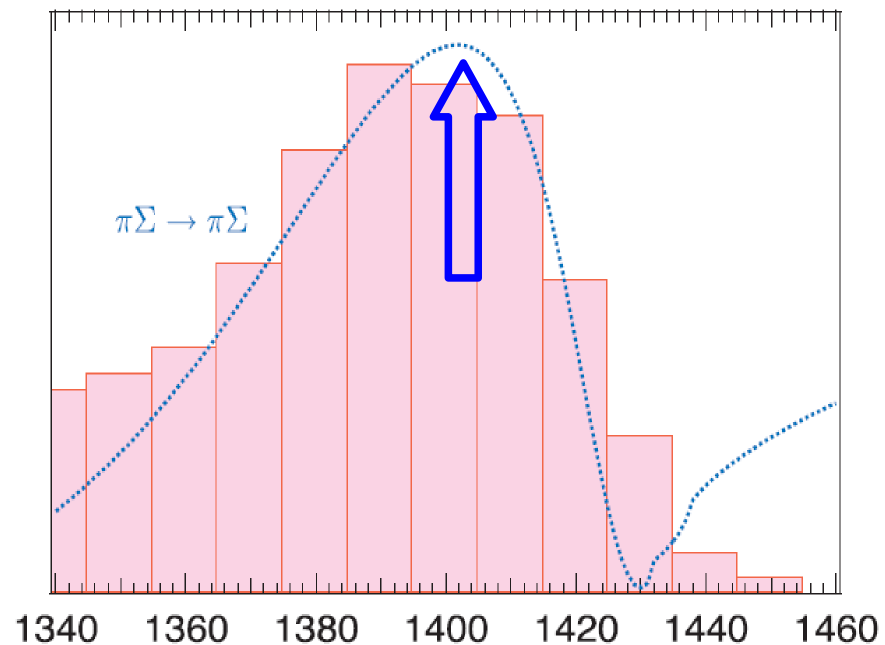


Chiral effective theory

Cross sections



Invariant mass distribution



Peak around 1400MeV

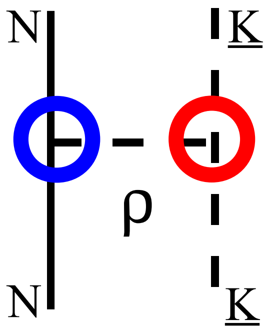
The resonance shape is generated as an interference of two poles

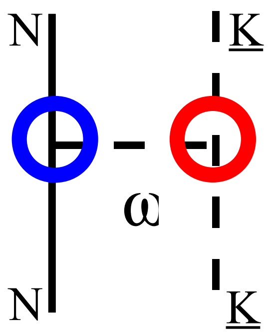
Consistent with experimental data

Roles of vector meson exchange potential

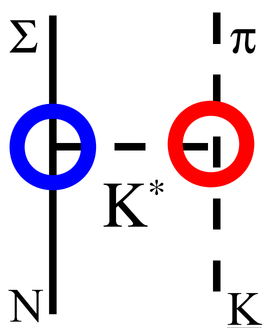
Vector meson exchange potentials

$\bar{K}$ N to $\bar{K}$ N

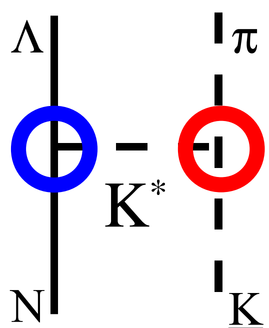




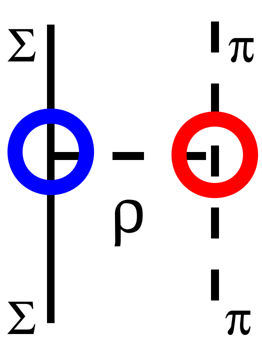
$\bar{K}$ N to πΣ



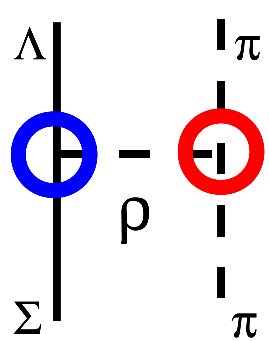
$\bar{K}$ N to πΛ



πΣ to πΣ



πΣ to πΛ



PPV couplings

Coupling constants of PPV vertex

$$L_{ppv} = g\, Tr\left[V^{\mu} [P, \partial_{\mu} P] \right]$$

Empirical V–>PP decay width and SU(3)

BBV couplings

Coupling constants of BBV vertex

$$L_{BBV} = \bar{B}\left[g\gamma^{\mu} + \frac{f}{2M} \sigma^{\nu\mu} q_{\nu} \right] V_{\mu} B$$

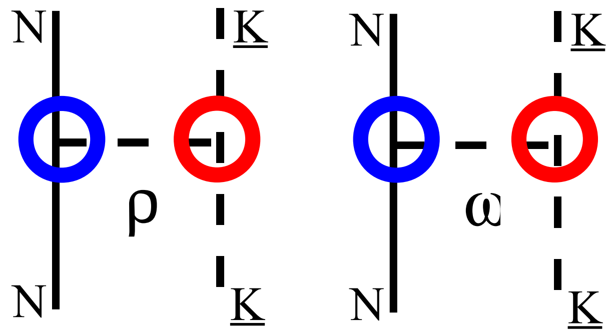
Vector coupling

Tensor coupling

The f/g are taken from the Bonn potential and SU(3).
The strength of g is determined by following way.

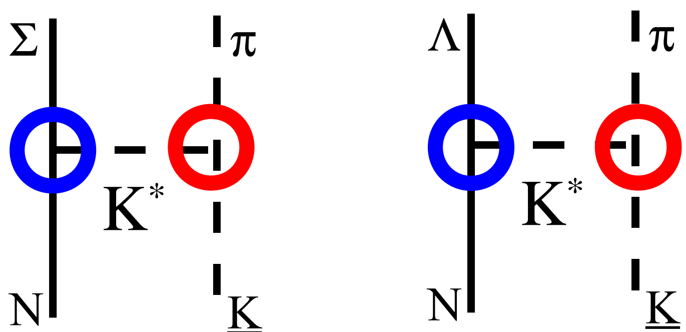
Vector meson exchange potentials

$\bar{K}$ N to $\bar{K}$ N



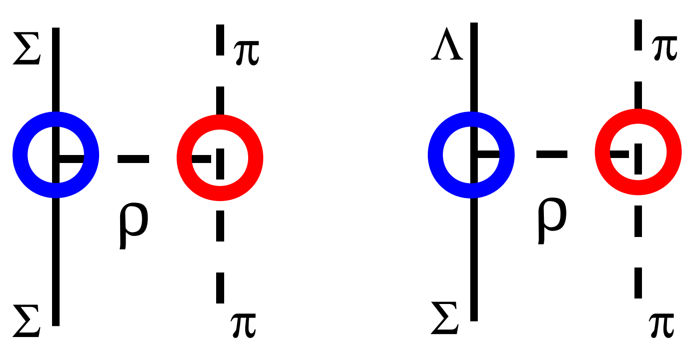
$\bar{K}$ N to πΣ

$\bar{K}$ N to πΛ



πΣ to πΣ

πΣ to πΛ



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Coupling constants of PPV vertex

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Empirical ρ–>ππ decay width and SU(3)

BBV couplings

Coupling constants of BBV vertex

$$L_{BBV} = \bar{B}[g\gamma^{\mu} + \frac{f}{2M}\sigma^{\nu\mu} q_{\nu}]V_{\mu} B$$

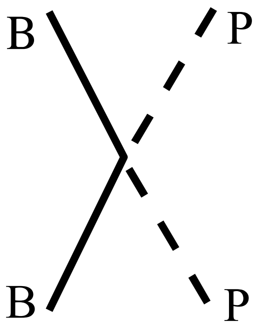
Vector coupling

Tensor coupling

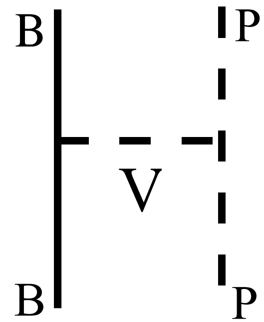
The f and g are taken from the Bonn potential

Comparison with the TW term

Tomozawa-Weinberg term | **Vector meson exchange**



q → 0



Vector dominance ansatz

$$\gamma_\mu * (p_f + p_i)^\mu$$

q → 0

$$\left(g\gamma_\mu + \frac{f}{2M}\sigma_{\mu\tau} q^\tau \right) * \left(g^{\mu\nu} + \frac{q^\mu q^\nu}{m^2} \right) * (p_f + p_i)_\nu$$

They would be the same contribution at q=0 limit

In the q=0 limit

$$E_B \simeq M_B, \quad \sqrt{s} = M_B + m_P, \quad t = 0$$

Tomozawa-Weinberg term

$$V^{th} = \frac{C}{f^2}$$

Vector meson exchange

$$V^{th} = \frac{g_1 g_2}{m^2}$$

Threshold behaviors

K.Kawarabayashi-PRL16(1966)255
Riazuddin-PRev147(1966)1071

		Vector meson	T-W	ratio
KN to KN	I=0	-0.839	-0.750	1.119
	I=1	-0.270	-0.250	1.081
KN to πΣ	I=0	0.264	0.306	0.862
	I=1	0.213	0.250	0.852
KN to πΛ	I=1	0.261	0.306	0.851
πΣ to πΣ	I=0	-1.153	-1.000	1.153
	I=1	-0.569	-0.500	1.138

Deviation from SU(3) value of $K^* \rightarrow K\pi$ decay constant

$$KSRF\ relation: m_V^2 = 2 f^2 g_V^2 \qquad \frac{g^2_{\pi K K^*}}{g^2_{K\bar{K}\rho}} = \frac{m^2_{K^*}}{m^2_\rho}$$

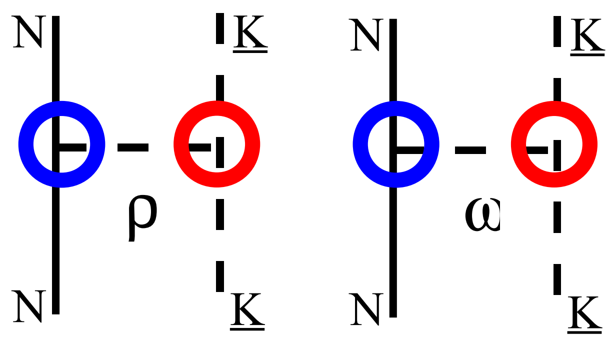
Effect of form-factor ?

$$F(q^2) = \frac{\Lambda^2 - m^2}{\Lambda^2 + q^2} \Rightarrow F(q^2) = \frac{\Lambda^2}{\Lambda^2 + q^2} \qquad F(q^2) = \exp\left(\frac{-q^2}{\Lambda^2}\right)$$

$$F_\rho(0) = \frac{1.5^2 - 0.78^2}{1.5^2} = 0.73$$

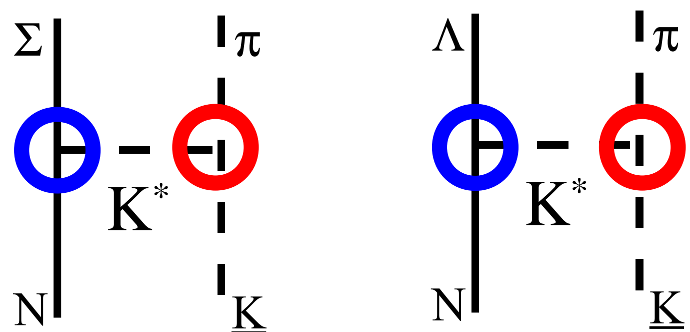
Vector meson exchange potentials

$\bar{K}$ N to $\bar{K}$ N (printed as K^{bar} N to K^{bar} N)



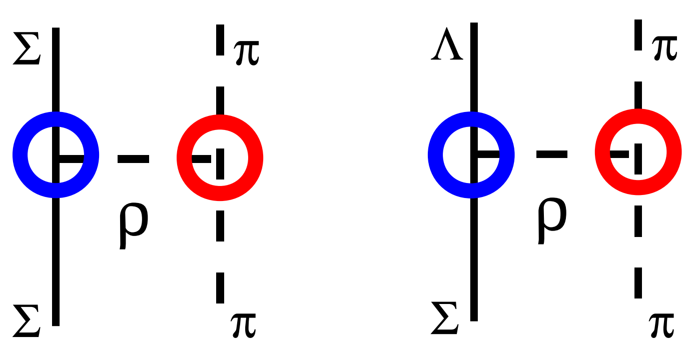
K^{bar} N to πΣ

K^{bar} N to πΛ



πΣ to πΣ

πΣ to πΛ



PPV couplings

Cutoff parameters

Λ_{NS} : P^{bar} P V_{NS} coupling vertices

Λ_{S} : K^{bar} π V_{S} coupling vertex

BBV couplings

Cutoff parameters

Λ_{NS} : BB V_{NS} coupling vertices

Λ_{S} : NY V_{S} coupling vertices

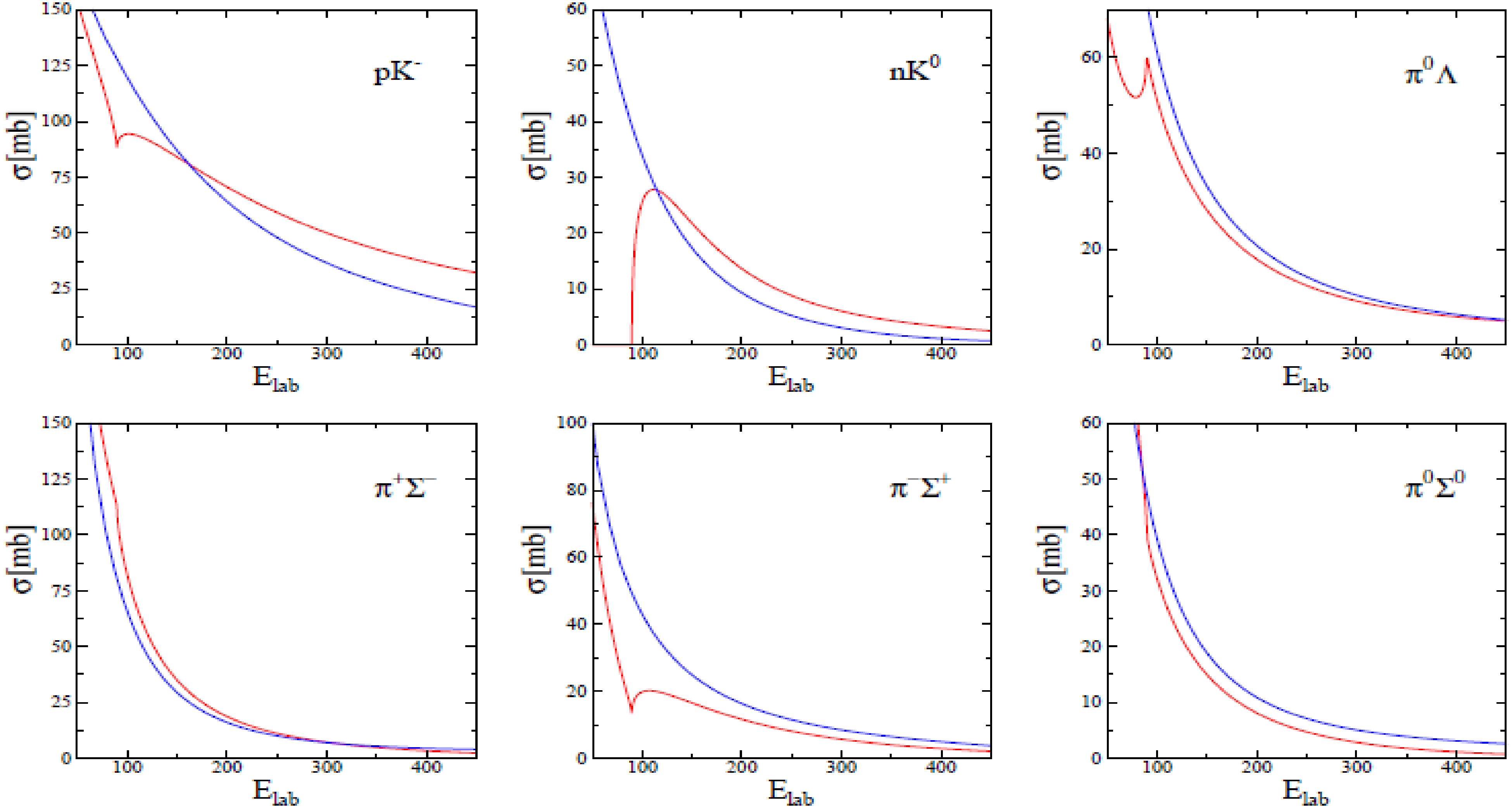
Monopole or Gaussian form factors are employed

$$F(q^2) = \frac{\Lambda^2}{\Lambda^2 + q^2}$$

$$F(q^2) = \exp\left(\frac{-q^2}{\Lambda^2}\right)$$

Results of the vector meson exchange

Scattering cross sections compared with chiral unitary calculations

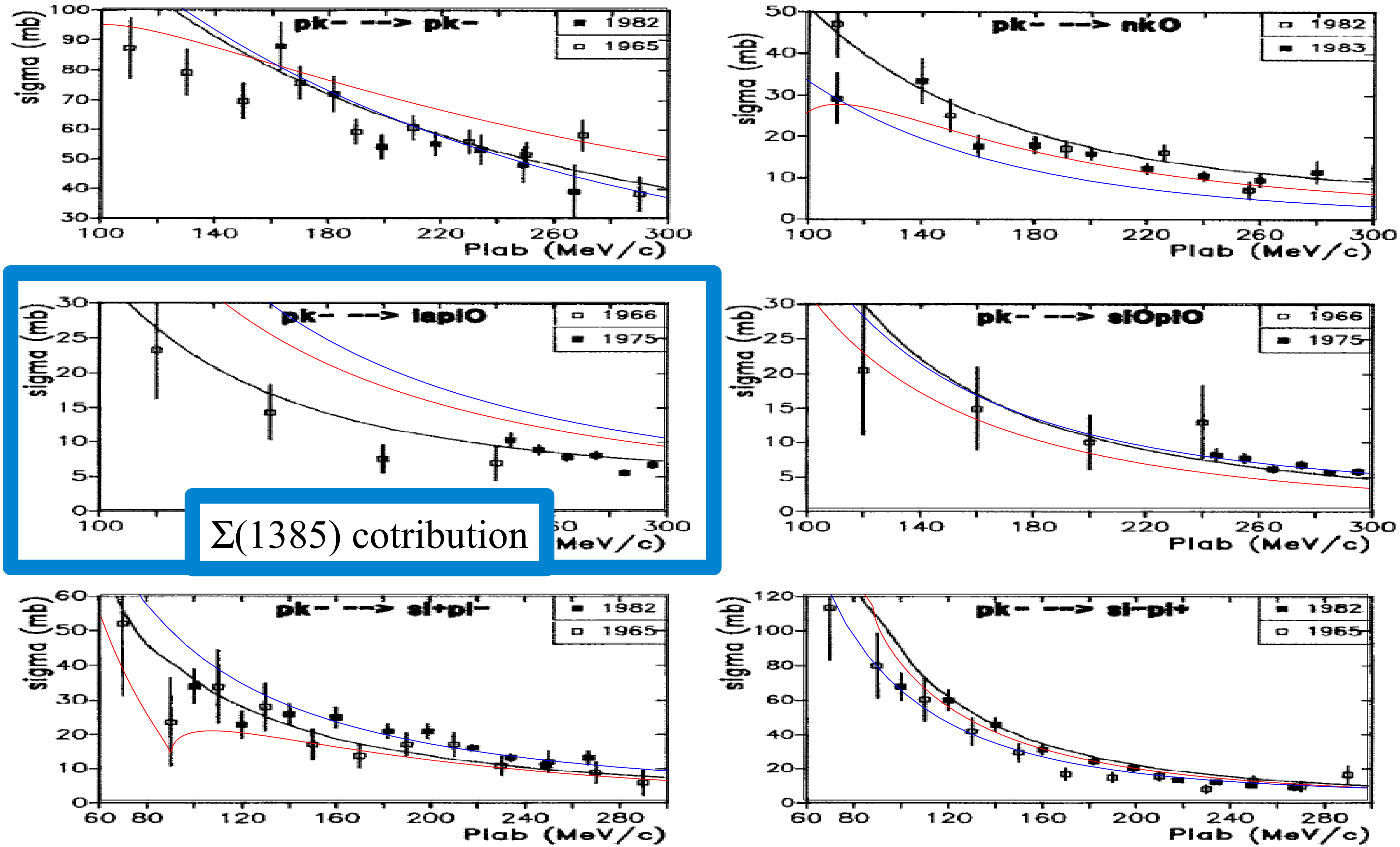


These results are obtained by changing the cutoffs for each vertex

The vector meson plays a crucial role in the K^{bar} N system

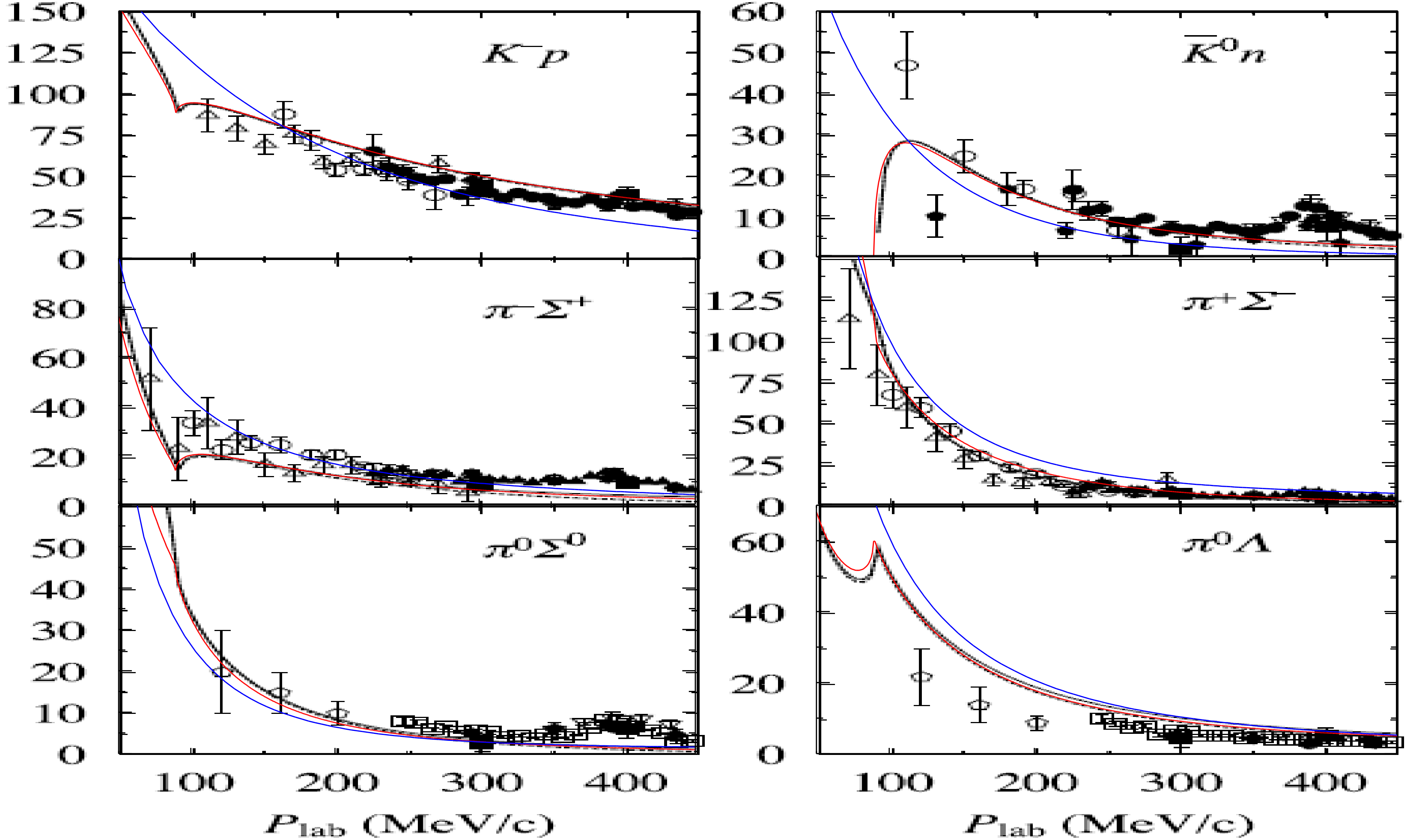
Comparison with the Julich K^{bar} N interaction

Cross sections



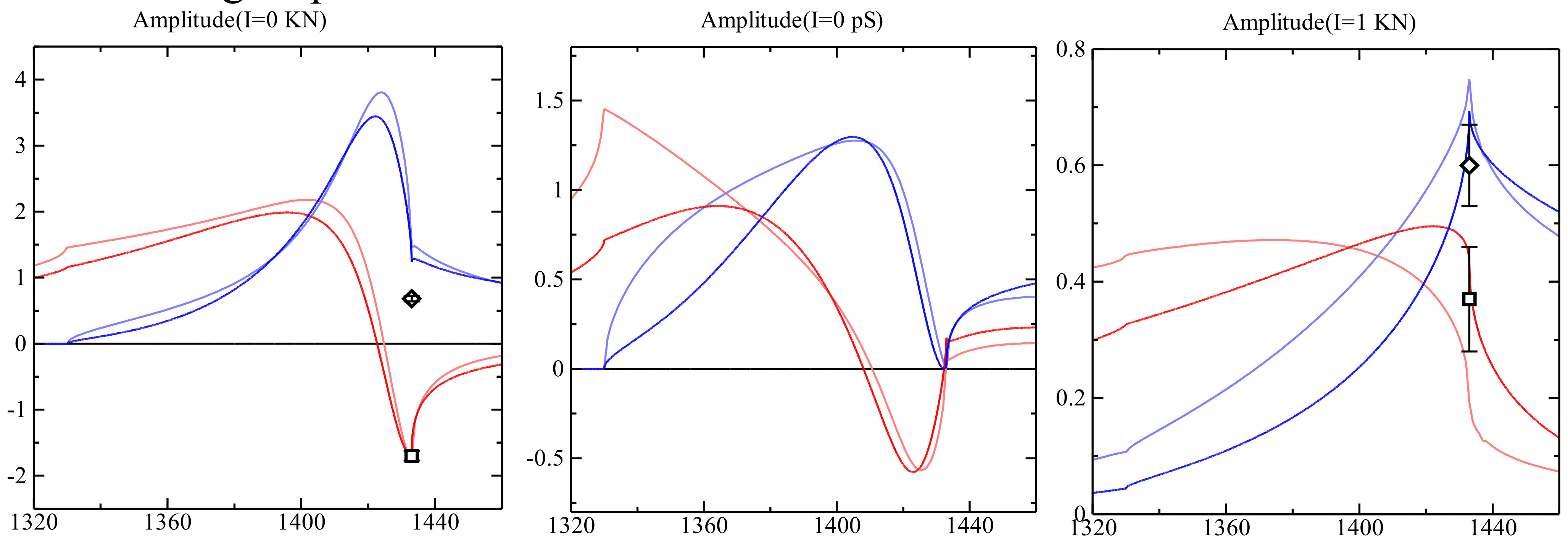
Comparison with the chiral effective theory

Cross sections



Results of the vector meson exchange

Scattering amplitudes



- ✗ The KSRF corrected coupling constants are used in calculation
- ✗ Cutoff parameters are : Λ_{NS}=1.5GeV, Λ_{S}=2.2GeV

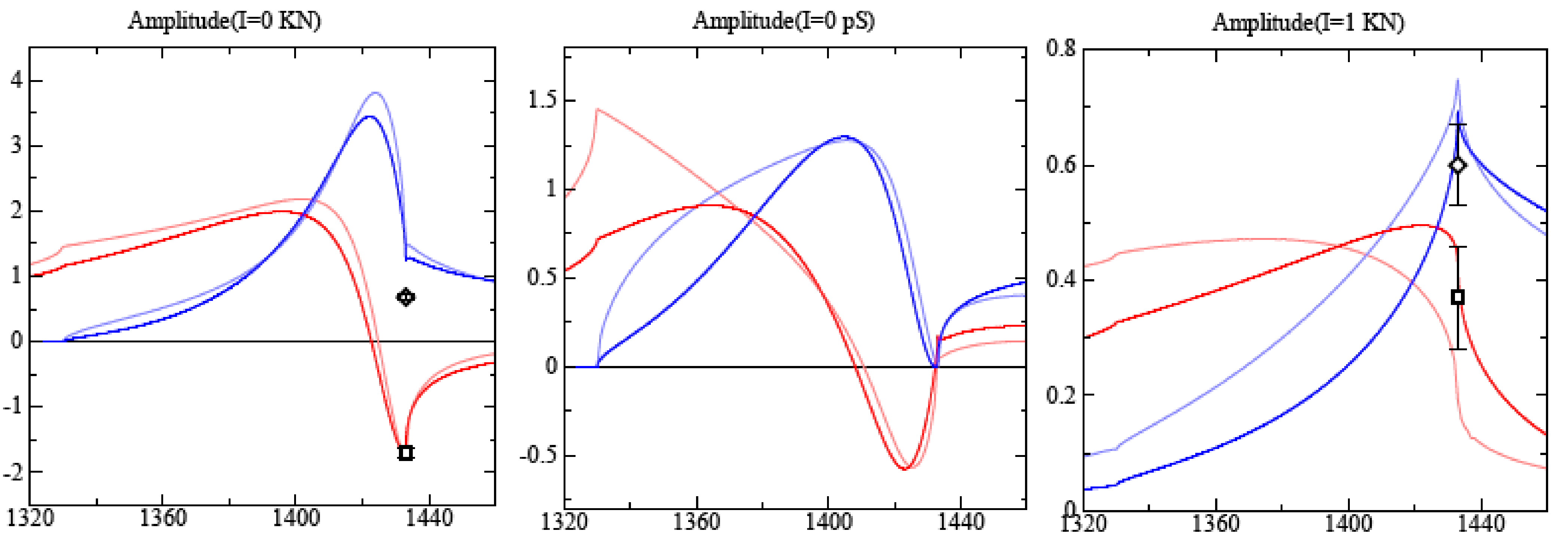
This model is similar to the chiral unitary model

$$a^{I=0}_{\bar{K}N} = -1.746 + i1.467\text{fm}$$
$$a^{I=1}_{\bar{K}N} = 0.193 + i0.748\text{fm},$$

$$a^{I=0} = (-1.70 \pm 0.07) + i\,(0.68 \pm 0.04)\ \text{fm},$$
$$a^{I=1} = (0.37 \pm 0.09) + i(0.60 \pm 0.07)\ \text{fm},$$

Results of the vector meson exchange

Scattering amplitudes



- The KSRF corrected coupling constants are used in calculation
- Cutoff parameters are Λ_{NS}=1.5GeV and Λ_{S}=2.2GeV.

This model is similar to the chiral unitary model

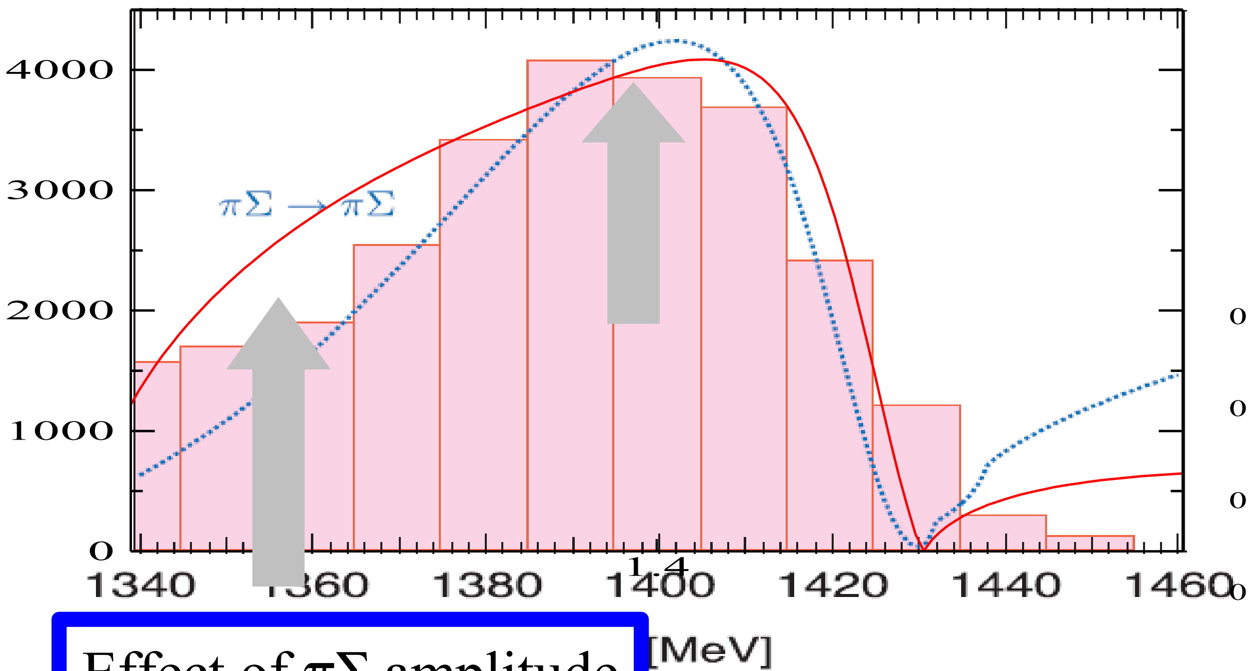
Scattering lengths are reproduced fairly well

$$a^{I=0}_{\bar{K}N} = -1.746 + i1.467\text{fm}$$
$$a^{I=1}_{\bar{K}N} = \quad 0.193 + i0.748\text{fm},$$

⇔

$$a^{I=0} = (-1.70 \pm 0.07) + i\,(0.68 \pm 0.04)\ \text{fm},$$
$$a^{I=1} = (0.37 \pm 0.09) + i(0.60 \pm 0.07)\ \text{fm},$$

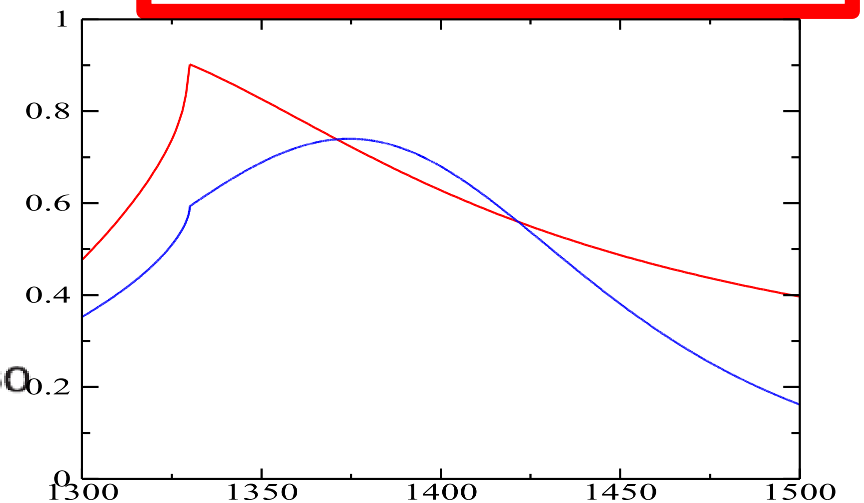
Invariant mass plot



Effect of πΣ amplitude

πΣ scattering amplitude

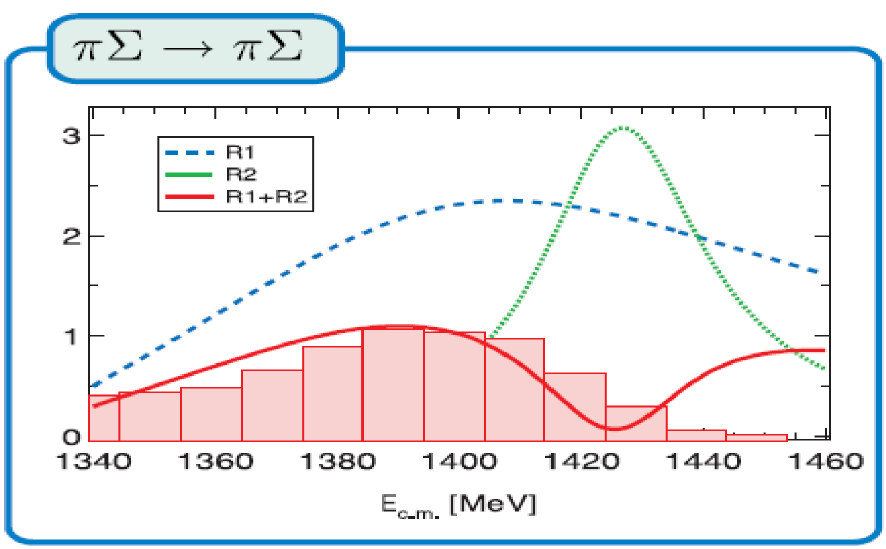
No peak is seen in amplitude by meson exchange model



Pole in T-matrix

$$z = 1388 - 96\,i\ MeV$$

T. Hyodo-PRC77(2008)035204



D.Jido[特定領域研究会2006]

Energy dependent potential creates the πΣ resonance pole?

Energy dependence of K^{bar} N potential

General form of vector meson exchange potential

The t-matrix for the meson-baryon scattering

$$T_{fi} = \frac{1}{2\sqrt{\omega'\omega}}\sqrt{\frac{M'}{E'}\frac{M}{E}}\bar{u}_{s'}(p')\left[A(s,t,u) + \frac{\not{q}' + \not{q}}{2}B(s,t,u)\right]u_s(p)$$

$$T_{fi} = \chi^{\dagger}_{s'}\left[F + \hat{\mathrm{p}}'\cdot\hat{\mathrm{p}}G + i\boldsymbol{\sigma}\cdot(\hat{\mathrm{p}}'\times\cdot\hat{\mathrm{p}})G\right]\chi_s$$

Central potential (spin independent)

L-S potential (spin dependent)

$$F = \sqrt{\frac{E'+M'}{4\omega' E'}}\sqrt{\frac{E+M}{4\omega E}}\left[A(s,t,u) + \frac{2\sqrt{s} - M' - M}{2}B(s,t,u)\right]$$

$$G = \sqrt{\frac{E'-M'}{4\omega' E'}}\sqrt{\frac{E-M}{4\omega E}}\left[-A(s,t,u) + \frac{2\sqrt{s} + M' + M}{2}B(s,t,u)\right]$$

The functions, A and B, for the vector meson exchange are

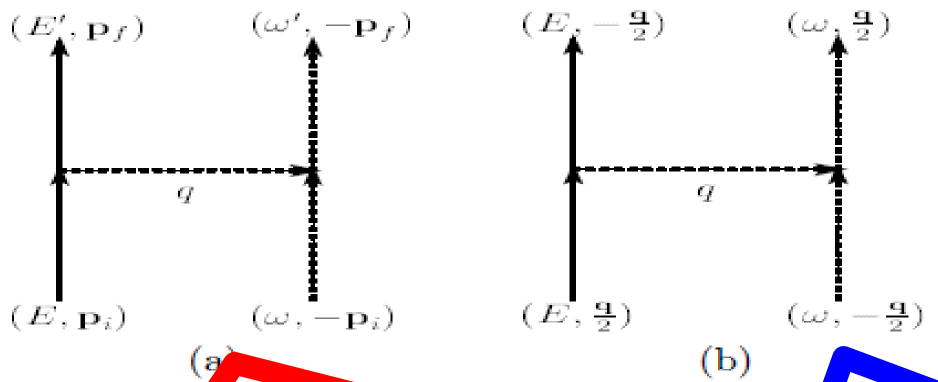
$$A(s,t,u) = \frac{g_V}{t - m_V^2}\frac{f_V}{2\mathcal{M}}(s-u)$$

$$B(s,t,u) = -\frac{2g'_V}{t - m_V^2}\left(g_V + \frac{M'+M}{2\mathcal{M}}f_V\right)$$

Form of vector meson exchange potential

Options of momentum configurations

$$\mathbf{k} = \frac{\mathbf{p}_f + \mathbf{p}_i}{2}$$
$$\mathbf{q} = \mathbf{p}_f - \mathbf{p}_i.$$



$$\mathbf{k} = \mathbf{0}$$
$$\mathbf{q} = \mathbf{p}_f - \mathbf{p}_i.$$

$$A = -\frac{2g'_V f_V}{\mathbf{q}^2 + m_V^2}\left(\bar{\omega} + \frac{\bar{\omega}}{8\bar{M}^2}\left(\mathbf{k}^2 + \frac{\mathbf{q}^2}{4}\right) + \frac{\mathbf{k}^2}{\bar{M}}\right)$$
$$B = \frac{2g'_V}{\mathbf{q}^2 + m_V^2}\left(g_V + \frac{\bar{M}}{\mathcal{M}} f_V\right)$$

$$A = -\frac{g'_V f_V}{\bar{M}}\frac{2\bar{E}\bar{\omega}}{\mathbf{q}^2 + m_V^2},$$
$$B = \frac{2g'_V(g_V + f_V)}{\mathbf{q}^2 + m_V^2}$$

Nonlocal (and energy dependent potential)

Local potential

$$V_c^V(\mathbf{q}, \mathbf{k}) = \frac{g'_V}{\mathbf{q}^2 + m_V^2}\left[g_V + \frac{g_V}{\bar{\omega}\bar{M}}\mathbf{k}^2 - \frac{g_V + 2f_V}{8\bar{M}^2}\mathbf{q}^2\right].$$

$$V_c^V(\mathbf{q}, \mathbf{0}) = \frac{\bar{M}}{\bar{E}}\frac{g'_V}{\mathbf{q}^2 + m_V^2}\left(g_V - \frac{\mathbf{q}^2}{4\bar{M}^2} f_V\right).$$

Same potential at the case of k=0

Further transformation

Nonlocal and energy dependent potential

$$V_c^V(\mathbf{q},\mathbf{k}) = \frac{g'_V}{\mathbf{q}^2 + m_V^2}\left[g_V + \frac{g_V}{\bar{\omega}\bar{M}}\mathbf{k}^2 - \frac{g_V + 2f_V}{8\bar{M}^2}\mathbf{q}^2\right].$$

This term gives rise to the energy dependence and the nonlocality of the potential.

Technique for minimizing the nonlocality of the potential

$$\mathbf{k}^2 = \frac{\mathbf{p}_f^2 + \mathbf{p}_i^2}{2} - \frac{\mathbf{q}^2}{4}$$

Momentum dependent interaction

Additional local potential

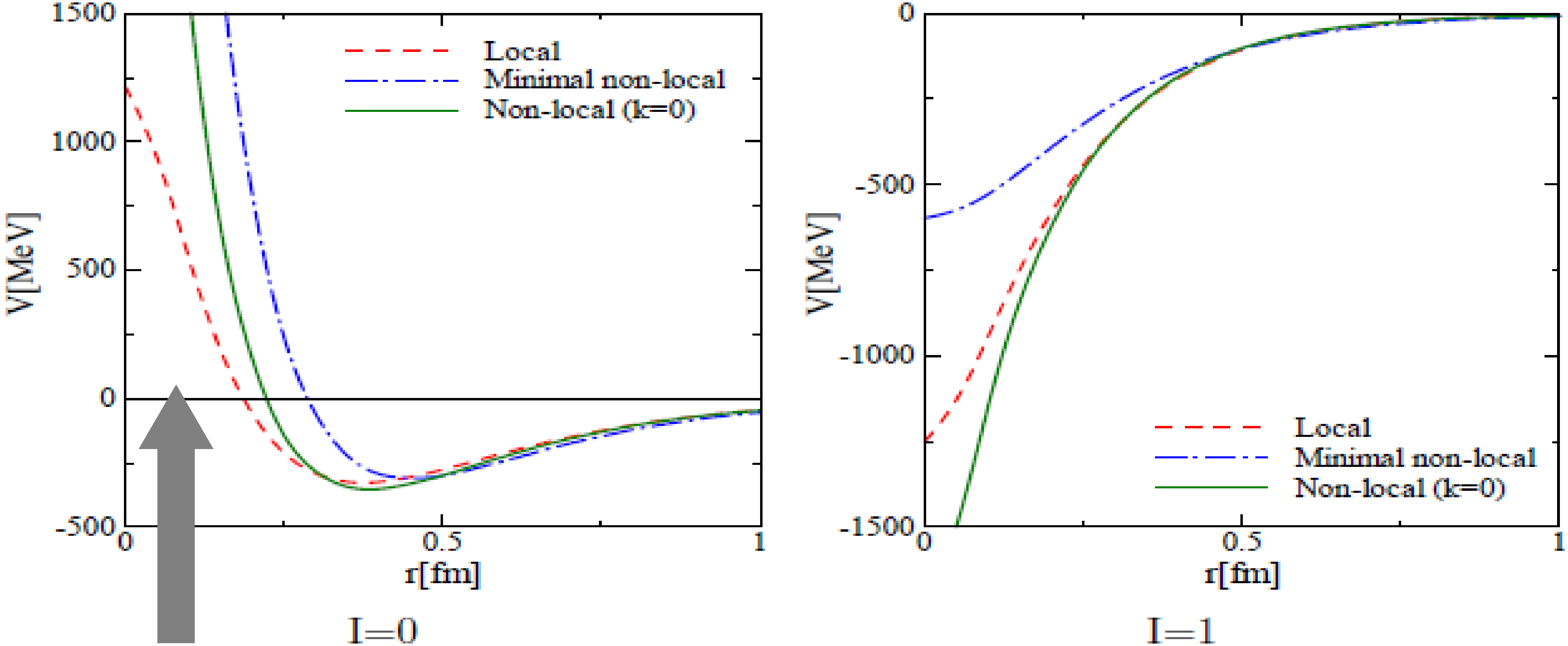
Modified local potential

$$\tilde{V}_c^V(\mathbf{q}) = \frac{g'_V g_V}{\mathbf{q}^2 + m_V^2}\left[1 - \left(1 + 2\frac{f_V}{g_V} + 2\frac{\bar{M}}{\bar{\omega}}\right)\frac{\mathbf{q}^2}{8\bar{M}^2}\right].$$

Shape of vector meson exchange potential

Potential shape in K^{bar} N I=0 and I=1 channels

Bound state (1~2MeV)   No bound state

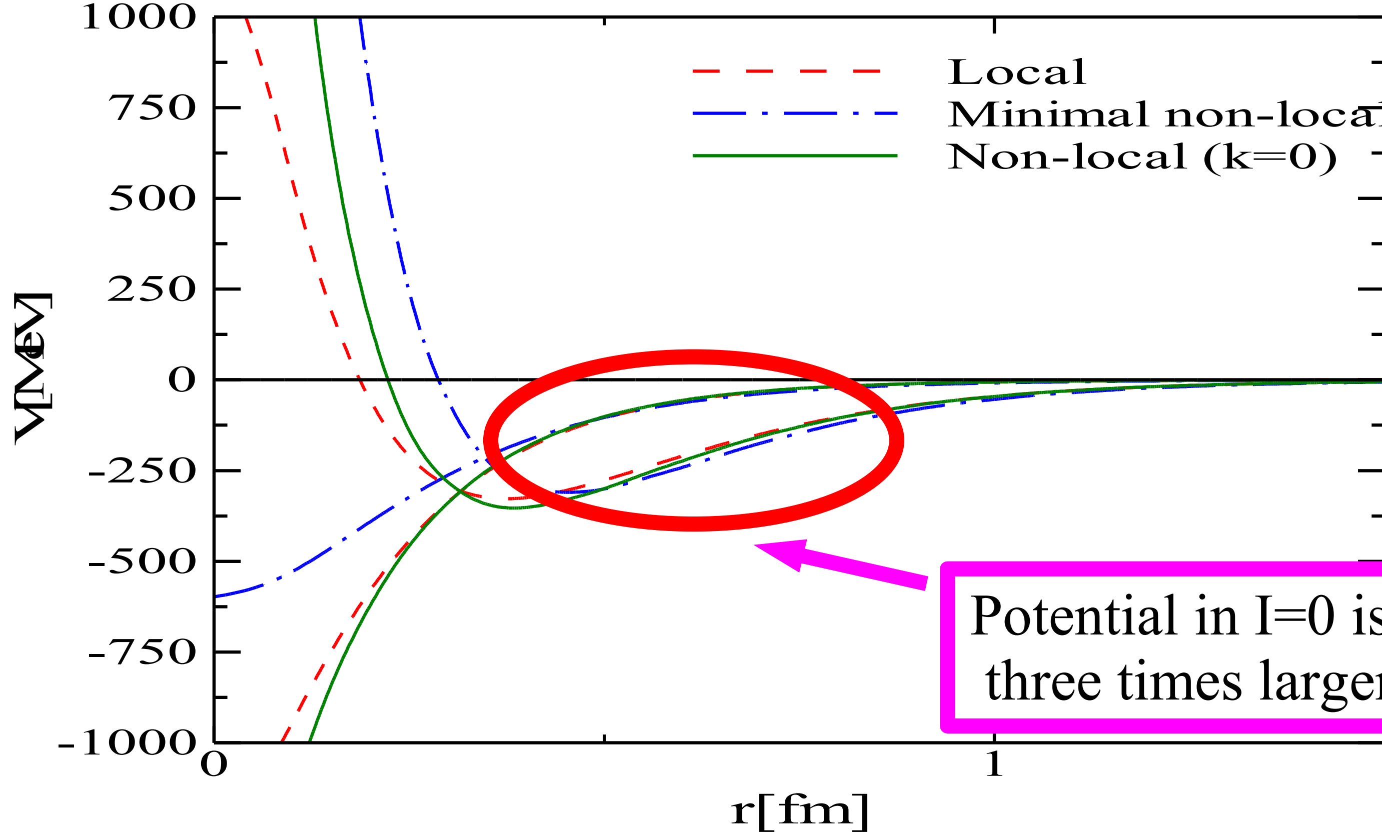


Short range repulsion is generated by tensor coupling part

Energy dependence is small in diagonal channel

Shape of vector meson exchange potential

Potential shape in K^{bar} N I=0 and I=1 channels



Potential in I=0 is three times larger than one in I=1

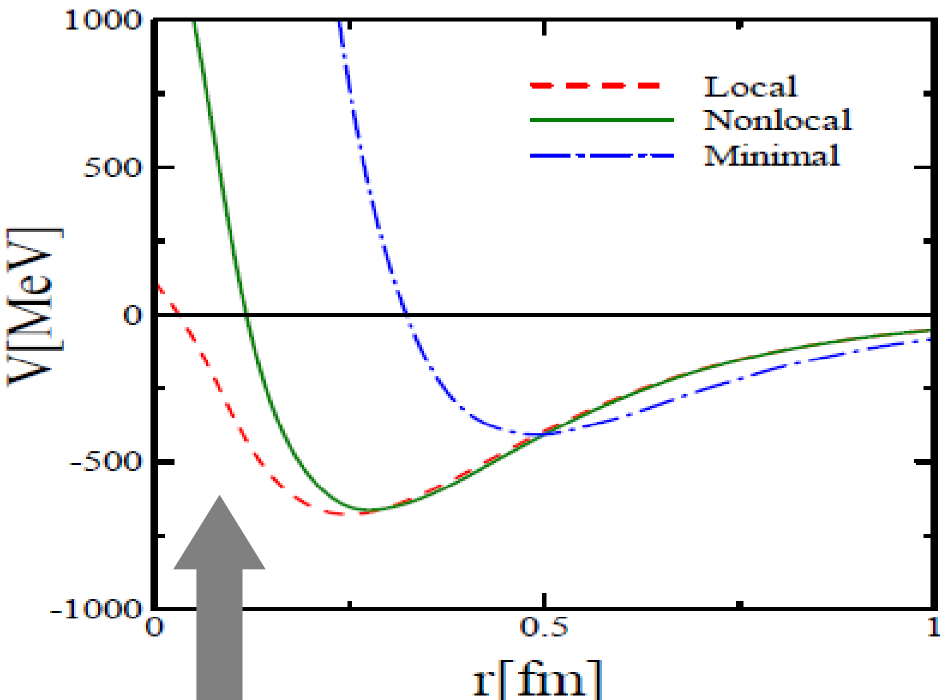
Medium range attraction is important to seek the bound state

The zero range attraction is not so important for I=1 channel

Shape of vector meson exchange potential

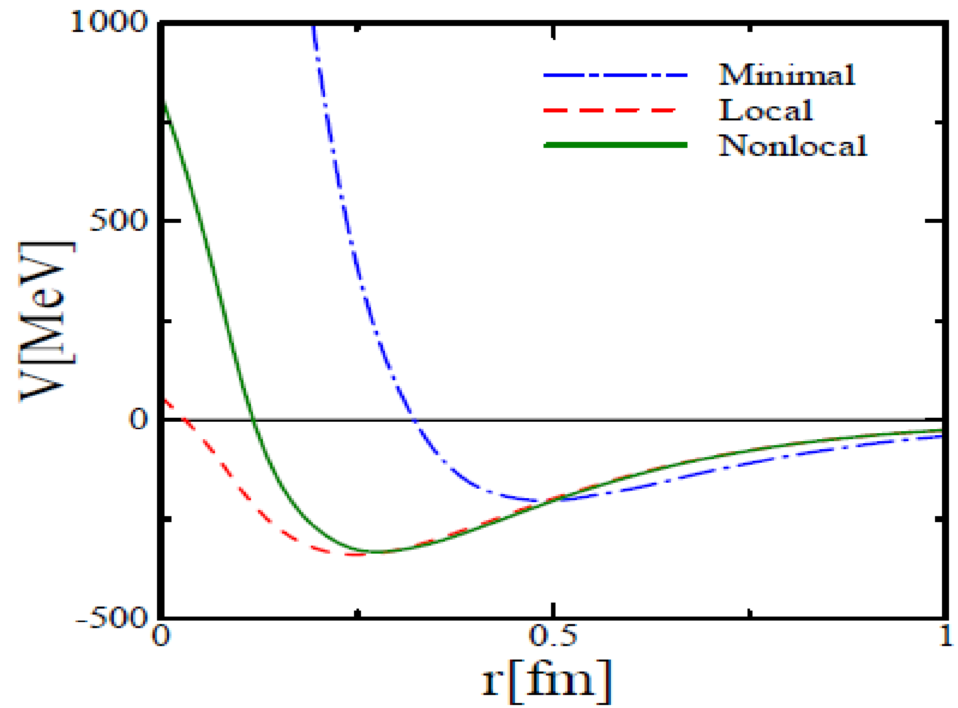
Potential shape in πΣ I=0 and I=1 channels

No bound state



I=0

No bound state



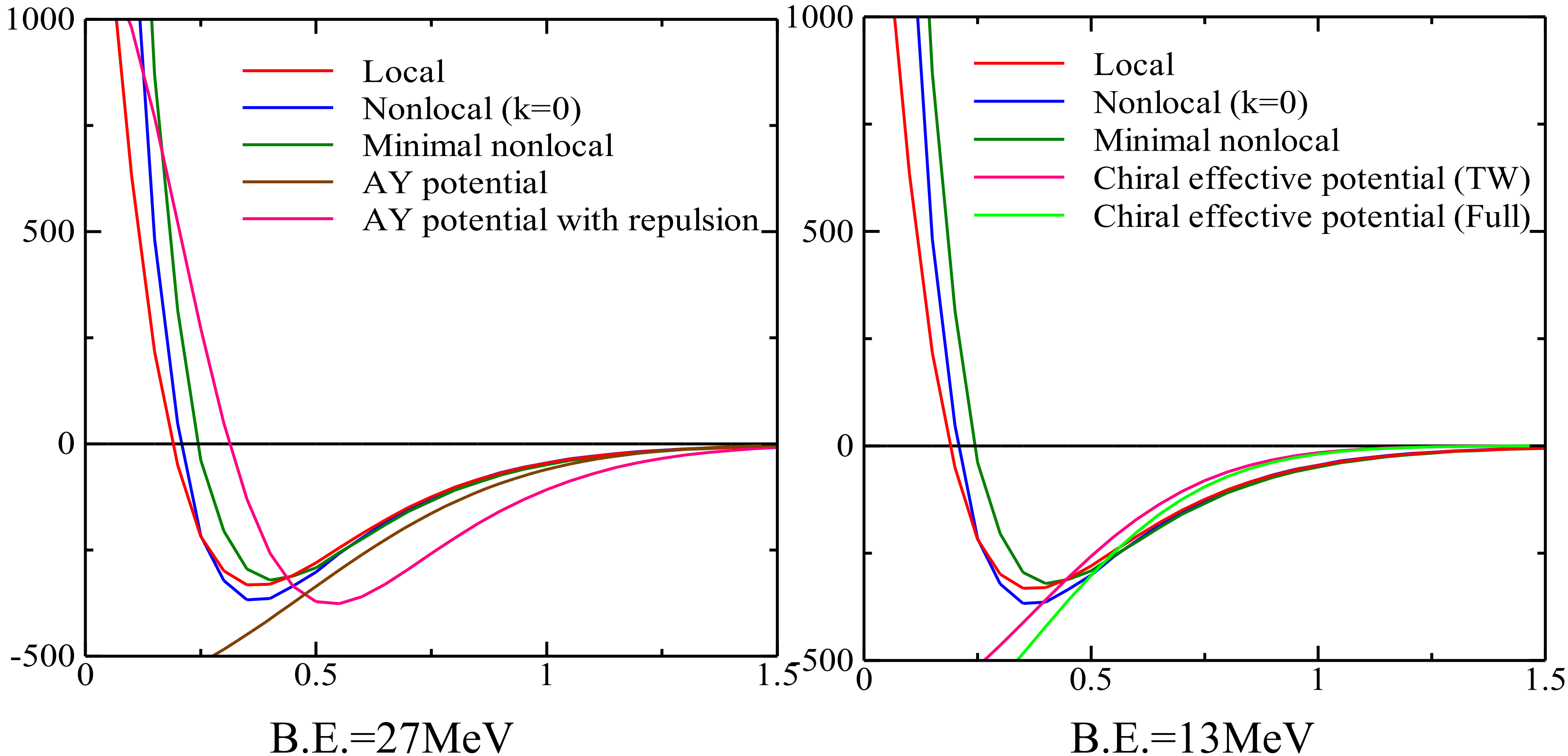
I=1

Short range repulsion is generated by tensor coupling part

Energy dependence would be large in πΣ channel

Shape of vector meson exchange potential

Potential shape in K^{bar} N (I=0) channel



Binding energy is sensitive to the strength of medium range attraction

Potential range could be important than the energy dependence

⇒ Is the vector dominance ansatz proper?

Conclusions

- ✔ I have investigated the K^{bar} N system by a vector meson exchange process assuming the vector dominance ansatz.
- ✔ I have constructed the meson exchange potential consistent with the Tomozawa-Weinberg term.
  - ➔ Vector meson exchange generates a strong attraction in the I=0 K^{bar} N channel.
  - ➔ The vector meson exchange potential plays an important role to generate a Λ(1405) resonance bump.
    - ¿ Energy dependence of this potential is not so large.
    - ¿ The πΣ resonance pole is not necessary.
- ✔ This model has ambiguities as follows.
  - ¿ Tensor couplings for the meson-baryon vertices.
  - ¿ Cutoff parameters dependence for the vertices.
  - ¿ Strengths of scalar meson exchange contributions.

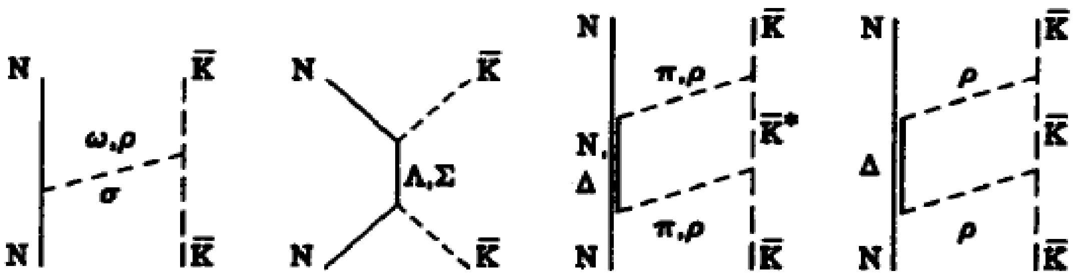
Scalar K^{bar} N potential

The Julich K N and K^{bar} N interactions

Model

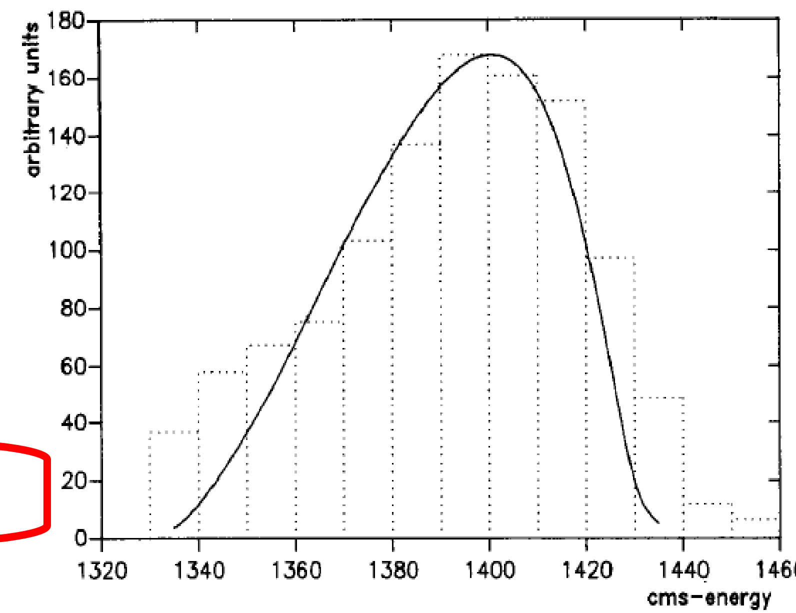
R. Buttgen NPA506(1990)586
A. Muller-Groeling NPA513(1990)557

- The V is constructed by relatively lower-order diagrams.
- The scalar coupling is adjusted by the empirical data.
- Phenomenological short-ranged repulsion (σ_0) is needed mixture of positive and negative G-parity parts
- This interaction model predicts the Λ(1405) to be a quasibound KN state without an additional pole graph around 1.4 GeV.



Process	Exch. part
$N\bar{K} \rightarrow N\bar{K}$	σ
	σ_0
	ω
	ρ
	Λ
	Σ

Repulsive scalar potential



Λ(1405) mass spectrum

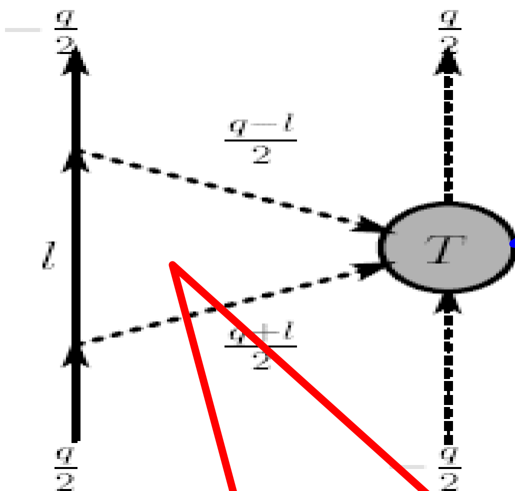
The roles of the scalar potential ?

Scalar K^{bar} N potential by correlated two meson

What is the repulsive interaction in the scalar channel ?

Method

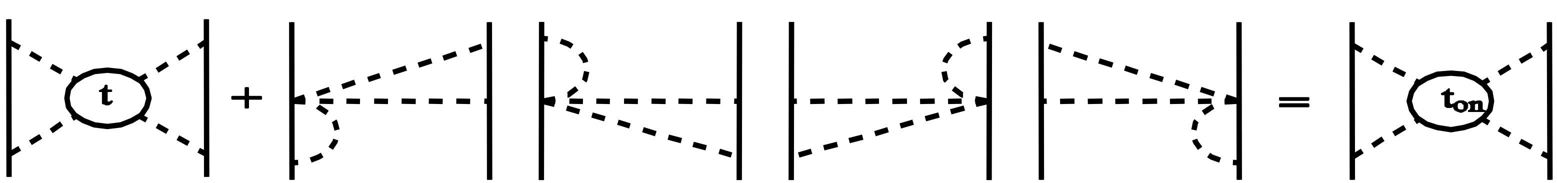
Breit frame kinematics for two-meson exchange process



- T-matrix of meson-meson scattering calculated by the chiral unitary method.
- It reproduces the meson-meson phase shift up to 1.2GeV quite well.

- Triangle scalar loop contribution

Cancellation mechanism for off-shell part of meson-meson amplitude



•(E Oset, H Toki, M Mizobe, and T T Takahashi PTP103 (2000) 351).

Triangle scalar loop contribution

Meson-baryon (Octet) interaction

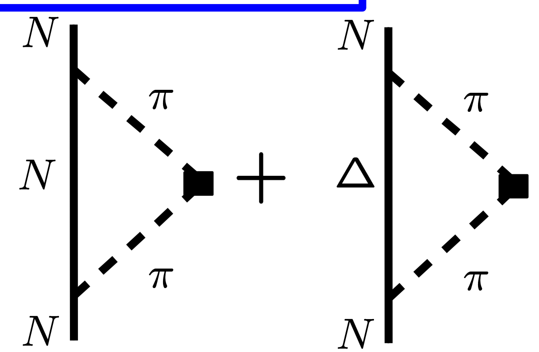
$$\mathcal{L}^B = \frac{D+F}{\sqrt{2}f_\pi}\langle \bar{B}\gamma_5\gamma^\mu\partial_\mu\Phi B\rangle + \frac{D-F}{\sqrt{2}f_\pi}\langle \bar{B}\gamma_5\gamma^\mu B\partial_\mu\Phi\rangle$$

Meson-baryon (Decuplet) interaction

$$\mathcal{L} = \frac{\sqrt{2}}{f_\pi}\mathcal{C}\sum_{a,b,c,d,e}^{1\sim3}\epsilon^{abc}\left(-(\bar{T}_{ade}\Phi^d_b B^e_c)\vec{S}\cdot\vec{q} + (\bar{B}^c_e\Phi^b_d T_{ade})\vec{S}^\dagger\cdot\vec{q}\right)$$

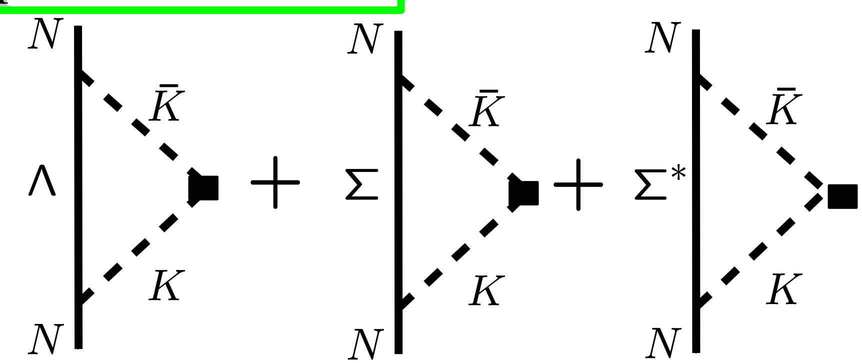
Pion loop contributions

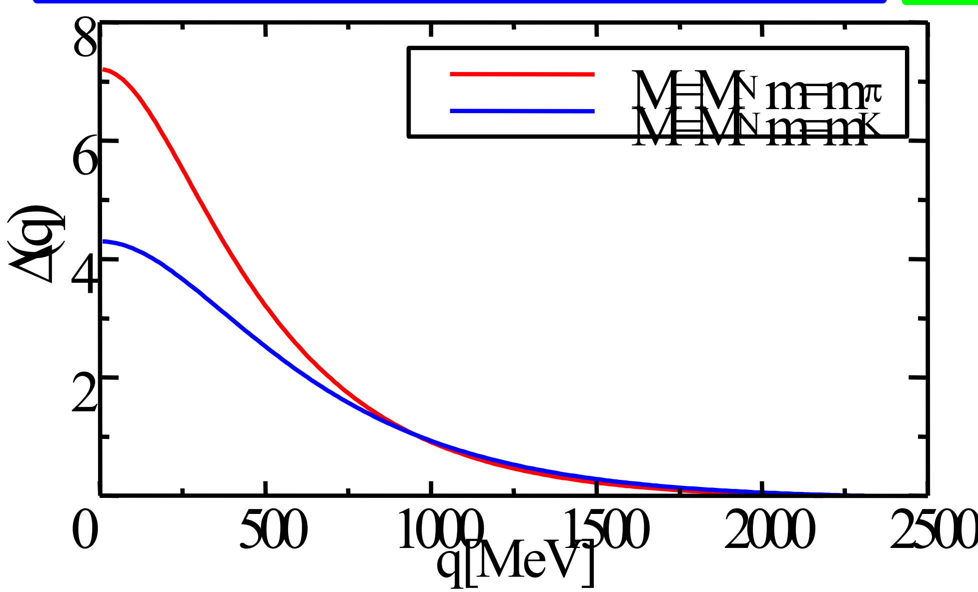
$\Delta^\pi_{B'N} =$



Kaon loop contributions

$\Delta^K_{B'N} =$





$$\Delta^M_{B'B}(q) = \int \frac{d^3p}{(2\pi)^3}\frac{M'}{E}\frac{(\vec{p}+\vec{q})\cdot\vec{p}}{2\omega\omega'(\omega+\omega')}\frac{\omega+\omega'+E-M}{(\omega+E-M)(\omega'+E-M)}$$

$$E = \sqrt{\vec{p}^2 + M'^2}$$

$$\omega = \sqrt{m_1^2 + \vec{p}^2}$$

$$\omega' = \sqrt{m_2^2 + (\vec{p}+\vec{q})^2}$$

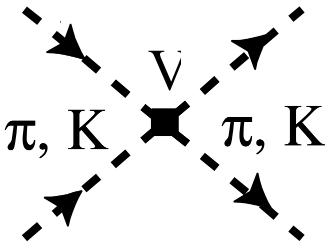
The contribution of the heavy meson loop is suppressed in the small momentum region.

Unitarized two meson amplitude

Chiral Lagrangean for meson-meson interaction

$$\mathcal{L}_2 = \frac{1}{6f_\pi^2}\langle \Phi\partial_\mu\Phi\Phi\partial_\mu\Phi - \Phi\Phi\partial_\mu\Phi\partial_\mu\Phi\rangle + \frac{1}{12f_\pi^2}\langle M\Phi^4\rangle$$

Tree level amplitudes of meson-meson scattering



$$t^{(I=0)}_{K\overline{K}\to K\overline{K}}(q^2) = -\frac{3q^2}{4f_\pi^2}, \qquad t^{(I=0)}_{\pi\pi\to K\overline{K}}(q^2) = -\frac{\sqrt{3}q^2}{4f_\pi^2}$$

Unitarization procedure

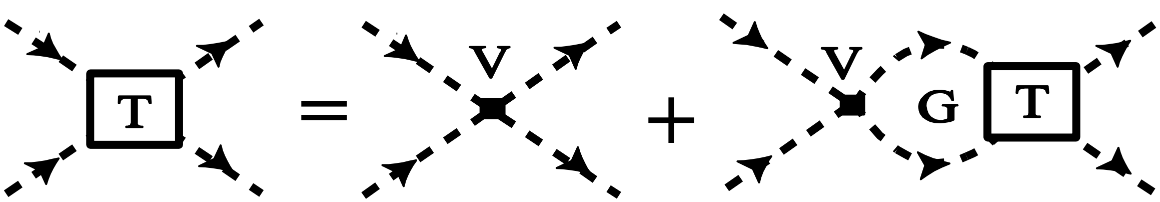
J A Oller and E Oset, Nucl Phys A620 (1997) 438
J A Oller E Oset and J R Pelaez Phys Rev D59 (1999) 074001

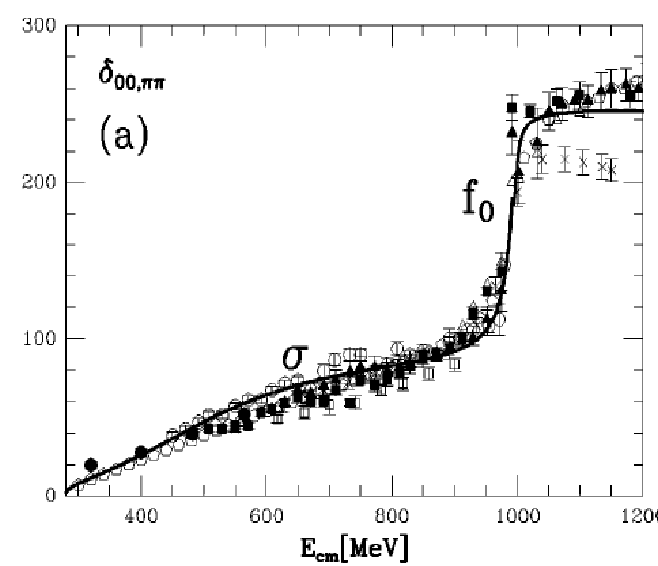
$$T = V + VGT = \frac{1}{1-VG}V$$

The G is the meson-meson loop function

$$G(s) = \int_0^{q_{\max}} \frac{q^2dq}{(2\pi)^2}\frac{\omega_1+\omega_2}{\omega_1\omega_2[s-(\omega_1+\omega_2)^2+i\epsilon]}$$

$q_{\max} = 1.0\text{GeV}$





π–π phase shift

(The off-shell part of interaction is renormalized to the physical values.)

Scalar K^{bar} N potential

Correlated two-meson potential

Unitarized amplitudes

$$V_{BM}^{Cor}(q) = \frac{1}{2\sqrt{\omega_I \omega_F}} \sqrt{\frac{M_I}{E_I}\frac{M_F}{E_F}} \left[\sqrt{3}\tilde{\Delta}_N^{\pi\pi} T_{\pi\pi\to K\overline{K}}^{(I=0)} + \tilde{\Delta}_N^{K\overline{K}} T_{K\overline{K}\to K\overline{K}}^{(I=0)}\right]$$

Scalar loop contributions

Pionic loop contributions

$$\tilde{\Delta}_N^{\pi\pi} = \left(\frac{D+F}{2f_\pi}\right)^2 V_{NN}^{\pi\pi}(q) + \frac{4}{9}\left(\frac{f_{\pi N\Delta}^*}{m_\pi}\right)^2 V_{\Delta N}^{\pi\pi}(q)$$

$$\tilde{\Delta}_N^{K\overline{K}} = \frac{3}{2}\left(\frac{D-F}{2\sqrt{3}f_\pi}\right)^2 V_{\Sigma N}^{K\overline{K}}(q) + \frac{1}{2}\left(\frac{D+3F}{2\sqrt{3}f_\pi}\right)^2 V_{\Lambda N}^{K\overline{K}}(q) + \frac{2}{3}\left(\frac{f_{\pi N\Delta}^*}{\sqrt{6}m_\pi}\right)^2 V_{\Sigma^* N}^{(K\overline{K})}(q).$$

Kaonic loop contributions

Conventional s exchange potential

$$V^\sigma(q) = -\frac{m_K}{\omega_I}\frac{g_S g_S'}{\mathbf{q}^2 + m_\sigma} F_1(\mathbf{q}^2) F_2(\mathbf{q}^2)$$

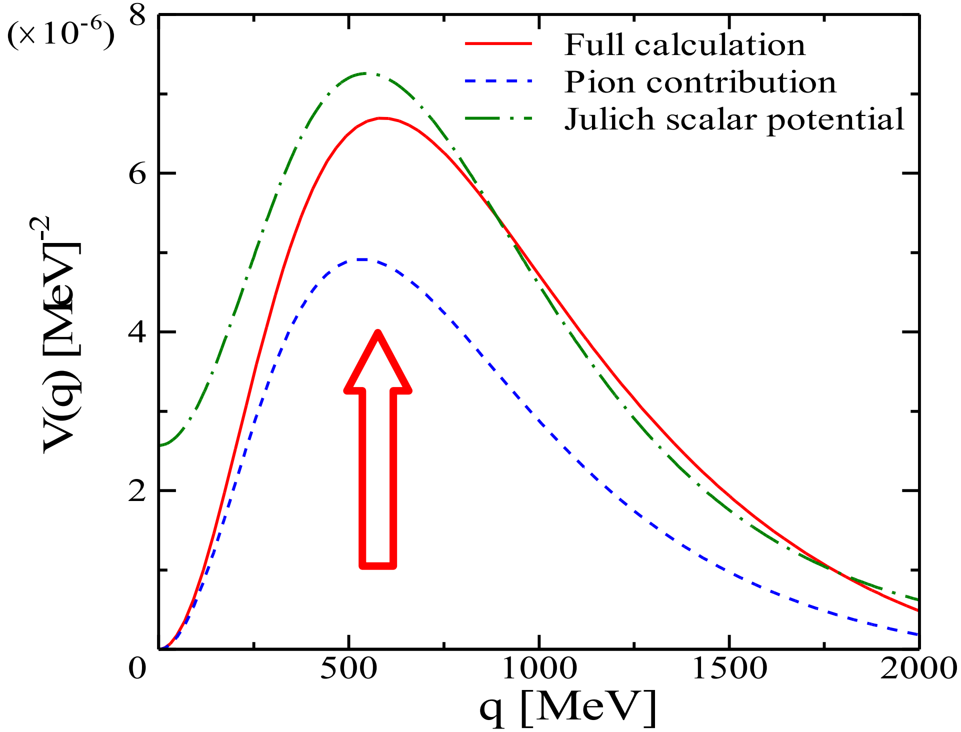
	σ	σ_0
m_i[MeV]	600	1200
$g_S g_S'$	11.310	87.964
Λ_1[MeV]	1400	2000
Λ_2[MeV]	1700	2000

Positive *G*-parity part is extracted

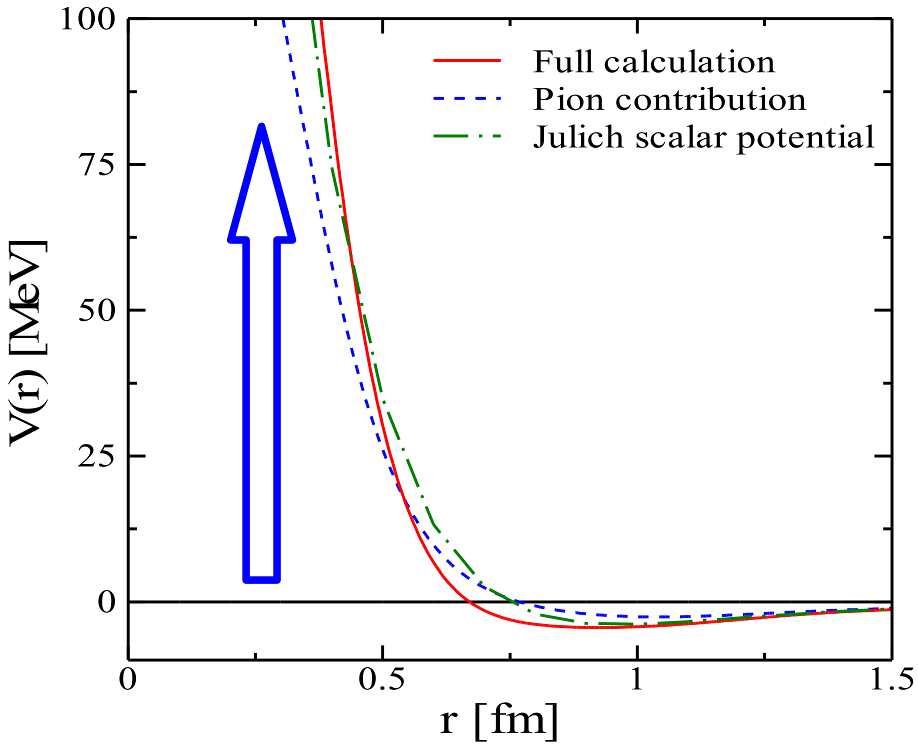
The σ_0 state is composed of a mixture of about 60% positive and 40% negative *G*-parity state.

Results

K^{bar} N potential in momentum space



K^{bar} N potential in configuration space



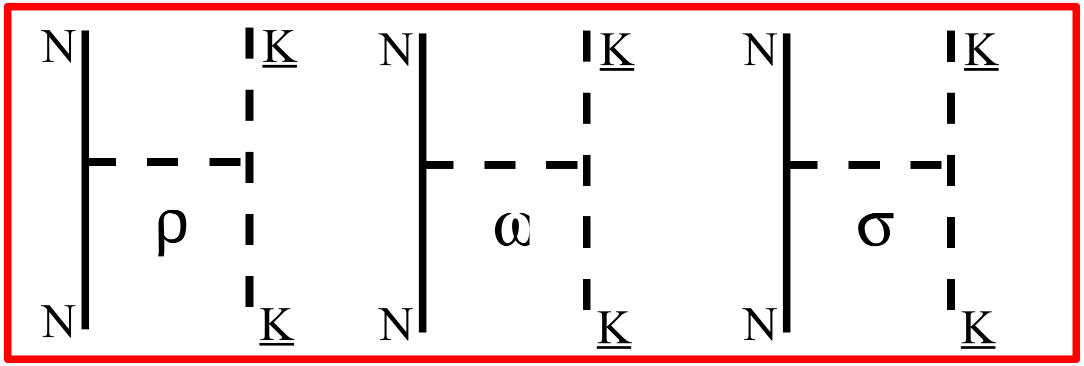
- ✗ A peak structure has been found around 700 MeV in all potential model.
- ✗ The kaonic-loop contribution can not be neglected to seek the accurate K^{bar} N potential
- ✗ The total potential is consistent with the Julich scalar potential without a region of small momentum transfer.
- ✗ The scalar potential has moderate attraction at the long range and strong repulsion at the short range region for both the pionic and full potential.

Summaries and conclusions

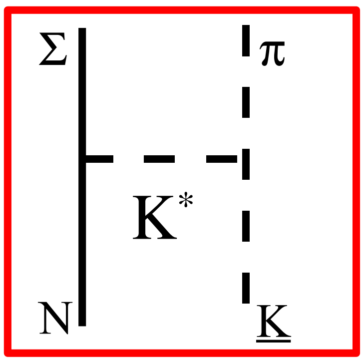
- The dynamical two-meson exchange potential between a kaon and a nucleon has been calculated by means of chiral unitary method.
- This potential should have a positive G-parity due to the intermediate two-pion state in the unitarized chiral two-meson amplitude.
- The kaonic loop contribution is not negligible especially at high momentum transfer or in the short range region.
- The full calculation result of the potential has a similar q behavior to the Julich scalar potential except for its strength at the threshold.
- This potential has a similar short-ranged repulsion which is assigned to the σ_0 exchange contribution by the Julich group.
- This is a candidate of the short-ranged repulsion which was needed to reproduce the empirical KN scattering data at high energy.

Phenomenological K^{bar} N potential (I=0)

K^{bar} N to K^{bar} N transition

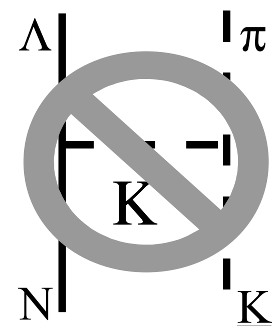


K^{bar} N to πΣ transition



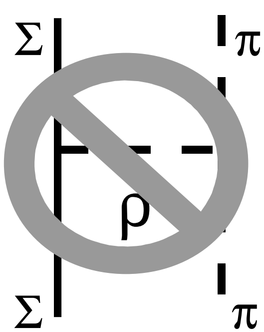
× 2

K^{bar} N to πΛ transition

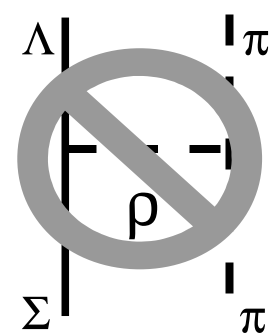


I=1 state

πΣ to πΣ transition

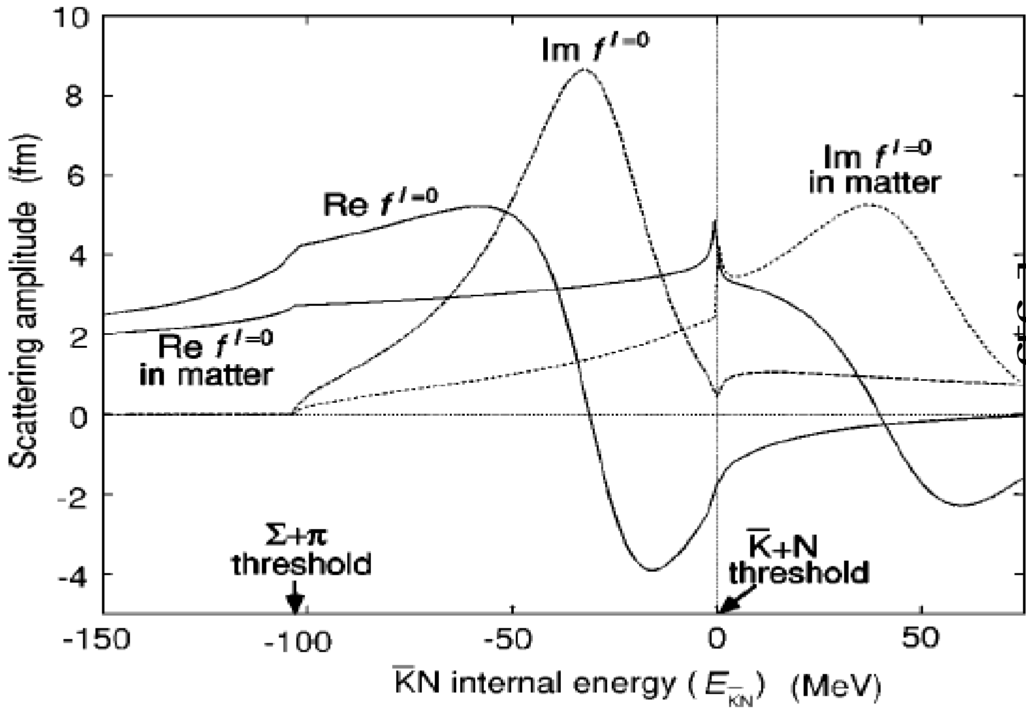


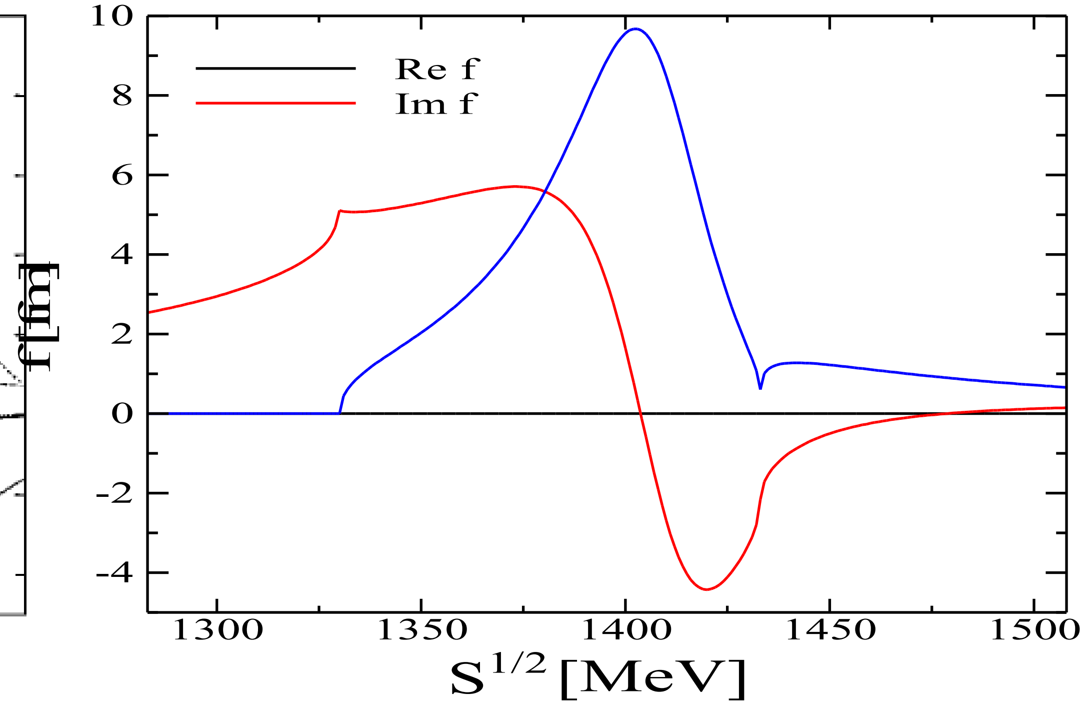
πΣ to πΛ transition



Reproduction of AY scattering amplitude

K^{bar} N scattering amplitude in I=0 channel





Binding energy = -30 MeV
Scattering length = -1.7 + i 0.7 fm

Binding energy = -28 MeV
Scattering length = -2.0 + i 0.7 fm

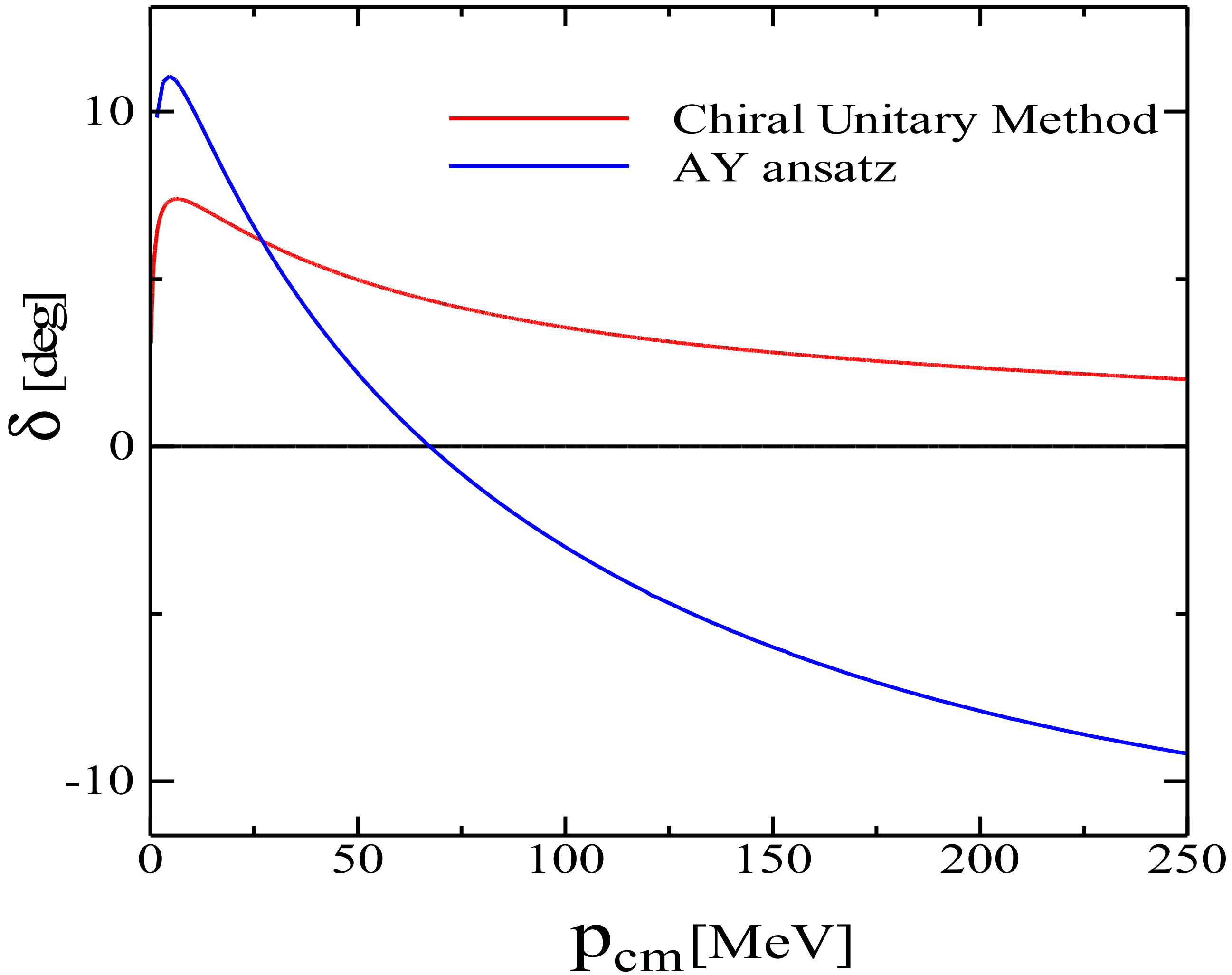
Similar K^{bar} N scattering amplitude is reproduced by meson exchange model

Summary

	Phenomenological pot.	Chiral theory	*Hadron exchange*
Local or non-local	*Local*	*Local*	*Non local*
Energy dependence	*Off*	*On*	*On*
Scattering length (threshold bahavior)	*OK*	*OK*	*OK*
Total cross section	*NO*	*OK*	*OK*
Mass spectrum	*OK(?)*	*OK*	*OK*
B.E. of Λ*	-27MeV	-15MeV	?

Phase shift of K^{bar} N scattering

$$\delta_0 = \frac{1}{2i} \ln(1 + 2iqf(q))$$

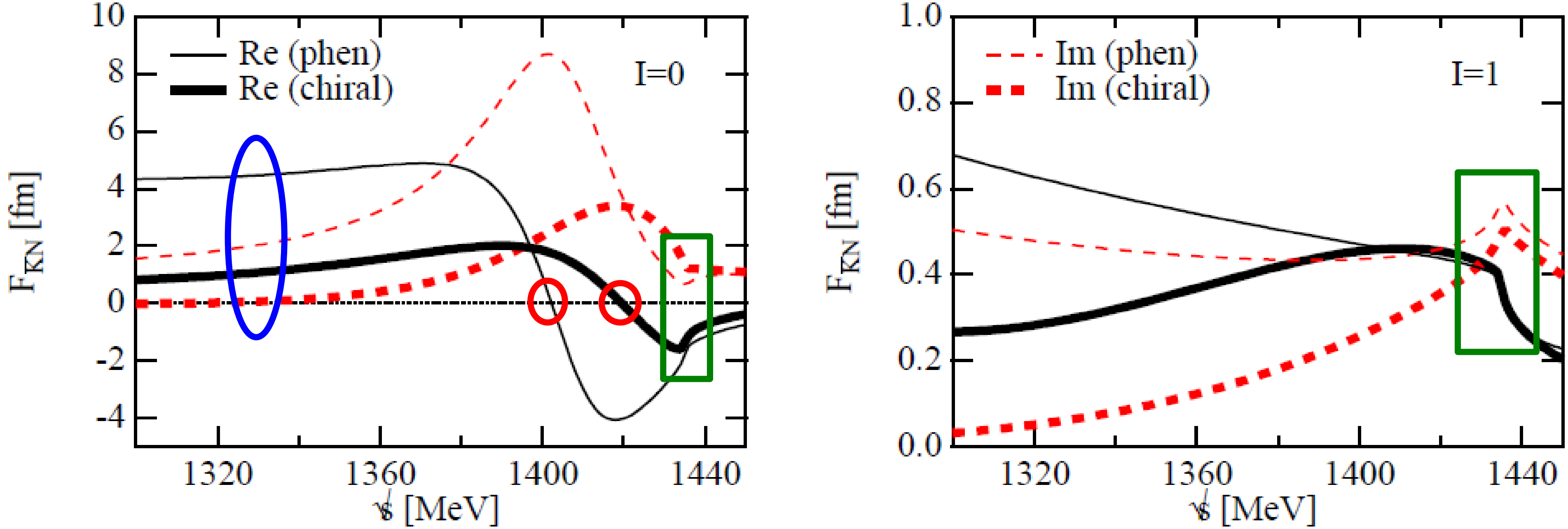


Chiral effective theory

Construction of single channel potential

Comparison

Scattering amplitudes of chiral effective theory and phenomenological model



-Energy dependence

Imaginary part of I=0 scattering amplitude

-Position of Λ(1405)

Around 1400MeV or 1420MeV ?

-At the threshold, both models agree with the empirical data.

Summary

	Phenomenological pot.	Chiral theory
Local or non-local	*Local*	*Local*
Energy dependence	*Off*	*On*
Scattering length	*OK*	*OK*
Total cross section	*NO*	*OK*
Mass spectrum	*OK(?)*	*OK*
B.E. of Λ*	-27MeV	-15MeV

Check the validity of two pole prediction for Λ(1405)!!

Questions of K^{bar} N potential

-Coupled channel or single channel projection

$\Sigma\pi$ channel effect to the K^{bar} N channel

Validity of complex potential

-Importance of energy dependence

Small energy dependence ?

-Local or non-local potential?

Resonance and non-locality

-Strength of scalar repulsion

-Interpretation of $\Lambda(1405)$

Binding energy of the kaon ???
Single pole or two pole ???

Few body calc. in our group ⇨ Coupled channel : possible
Energy dependent potential : possible
Non-local potential : possible

Realistic potential

Summaries and conclusions

- I have calculated the correlated two-meson exchange potential for K^{bar} N system.
- In my estimation the correlated two meson potential generates a strong repulsion at the short range region.
- This is a candidate of the short-ranged repulsion which was needed to reproduce the empirical KN scattering data at high energy.

Future plans

- Other contributions to the scalar channel
- What about the negative G-parity part ?
- Construction of the K^{bar} N potential by the hadron exchange picture

Cutoff dependence of meson exchange potential