Multi-quark states in non-relativistic quark model with the feature of chiral symmetry breaking

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LEP2 Physics from theory side

- description of baryons from 3 to 5 quarks
- description of mesons from 2 to 4 quarks
- role of hidden color states (Van-der-Waals force)
- unification of chiral unitary model and quark model
- glueball and confinement
- Non-perturbative to perturbative QCD physics

Quantum chromo dynamics (QCD)

- QCD Lagrangian

$$L_{QCD} = \bar{\psi}(i\gamma_\mu \partial^\mu - ig\gamma_\mu \lambda^a A^{a\mu} - m_0)\psi - \frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu}$$

$$m_0 = (5 \sim 10) MeV << M_N$$

The chiral symmetry is fulfilled in the ud-sector

Baryon-Meson (Hadron Physics)

Chiral symmetry breaking → NJL model

Confinement → Long range confining potential

Nambu-Jona-Lasinio model

$$\mathcal{L} = \bar{\psi}(x)\left(i\gamma^{\mu}\partial_{\mu} - \mathbf{m_0}\right)\psi(x) - G_c \sum_{a=1}^{3} J_{\mu}^{a}(x)\, J_{a}^{\mu}(x)$$

$$J_{\mu}^{a} = \bar{\psi}\gamma_{\mu}t^{a}\psi$$

U.Vogl and W.Weise, PPNP 27(1991)195
A.Latti and W.Weise, hep-ph/0406159

Fierz transformation

$$\mathcal{L}_{NJL} = \bar{\psi}\left(i\gamma^{\mu}\partial_{\mu} - \mathbf{m_0}\right)\psi + \mathcal{L}_{q\bar{q}} + \mathcal{L}_{qq} + (\text{colour triplet terms})$$

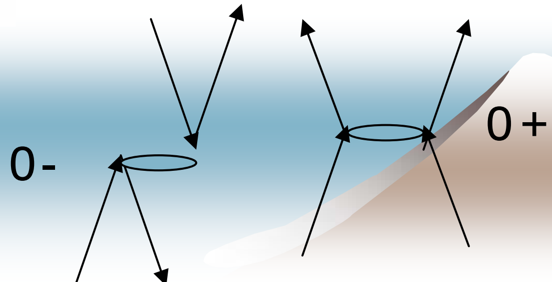
$$\mathcal{L}_{q\bar{q}} = \frac{G}{2}\left[\left(\bar{\psi}\psi\right)^2 + \left(\bar{\psi}i\gamma_5\vec{\tau}\psi\right)^2\right],$$

$$\mathcal{L}_{qq} = \frac{H}{2}\left(\bar{\psi}i\gamma_5\tau_2 t_2 C\bar{\psi}^T\right)\left(\psi^T C i\gamma_5\tau_2 t_2\psi\right)$$

$$G = H = \frac{3}{2}G_c$$

Pauli-Guersey Symmetry

$$m = m_0 - \langle\sigma\rangle = m_0 - G\langle\bar{\psi}\psi\rangle$$



Non-relativistic constituent quark model

- modeling for many body system

(simplest expression of the NJL model)

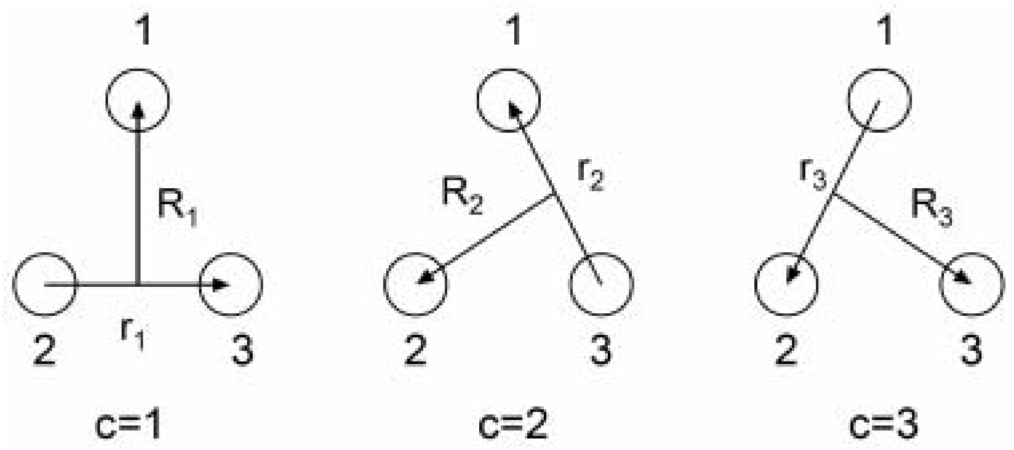
$$H = \sum_i \frac{\mathbf{p}_i^2}{2m_i} - T_G + V_C + V_S + V_0$$

$$V_C = \sum_{i<j} \frac{1}{2} K \left(\mathbf{x}_i - \mathbf{x}_j\right)^2$$

$$V_S = \sum_{i<j} \frac{C_{SS}}{m_i m_j} \exp\left[- \left(\mathbf{x}_i - \mathbf{x}_j\right)^2 / \beta^2 \right] \quad \text{(spin=0 pair)}$$

E.Hiyama, K.Suzuki, H.Toki and M.Kamimura, PTP 112 (2004) 99

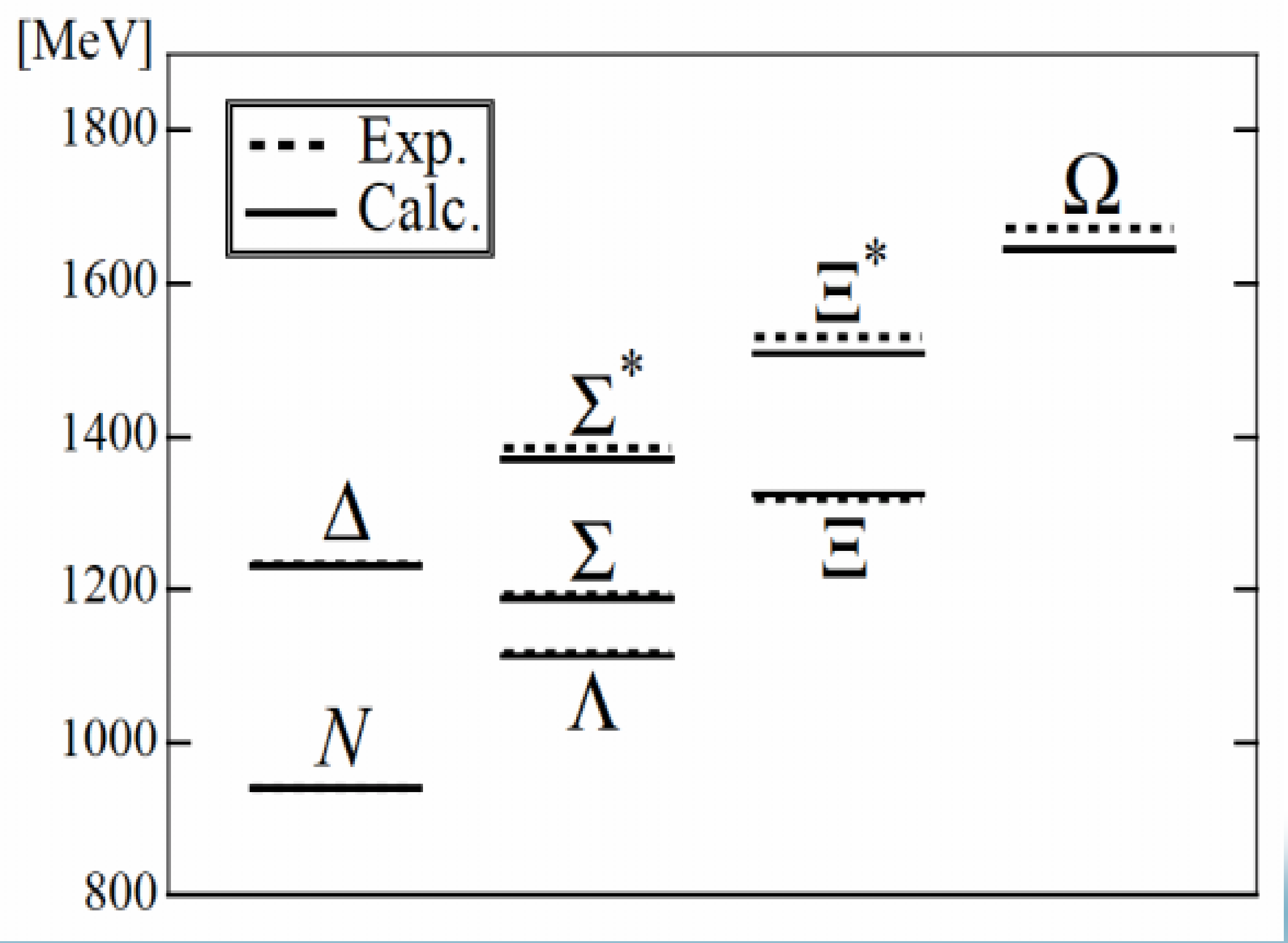
Baryon wave function



$$\Phi^{(c=k)}_{JMTT_z,\,\xi} = \left[\left[\left[\chi_{\frac{1}{2}}(i)\,\chi_{\frac{1}{2}}(j)\right]_s \chi_{\frac{1}{2}}(k)\right]_S \left[\phi_{nl}(\mathbf{r}_k)\,\psi_{NL}(\mathbf{R}_k)\right]_I\right]_{JM} \times \left[\left[\eta_\tau(i)\,\eta_\tau(j)\right]_t \eta_\tau(k)\right]_{TT_Z}, \qquad \xi \equiv \{s, S, n, l, N, L, I, t\}$$

Gaussian expansion quark rearrangement model (Hiyama-Kamimura)

Baryon mass spectrum



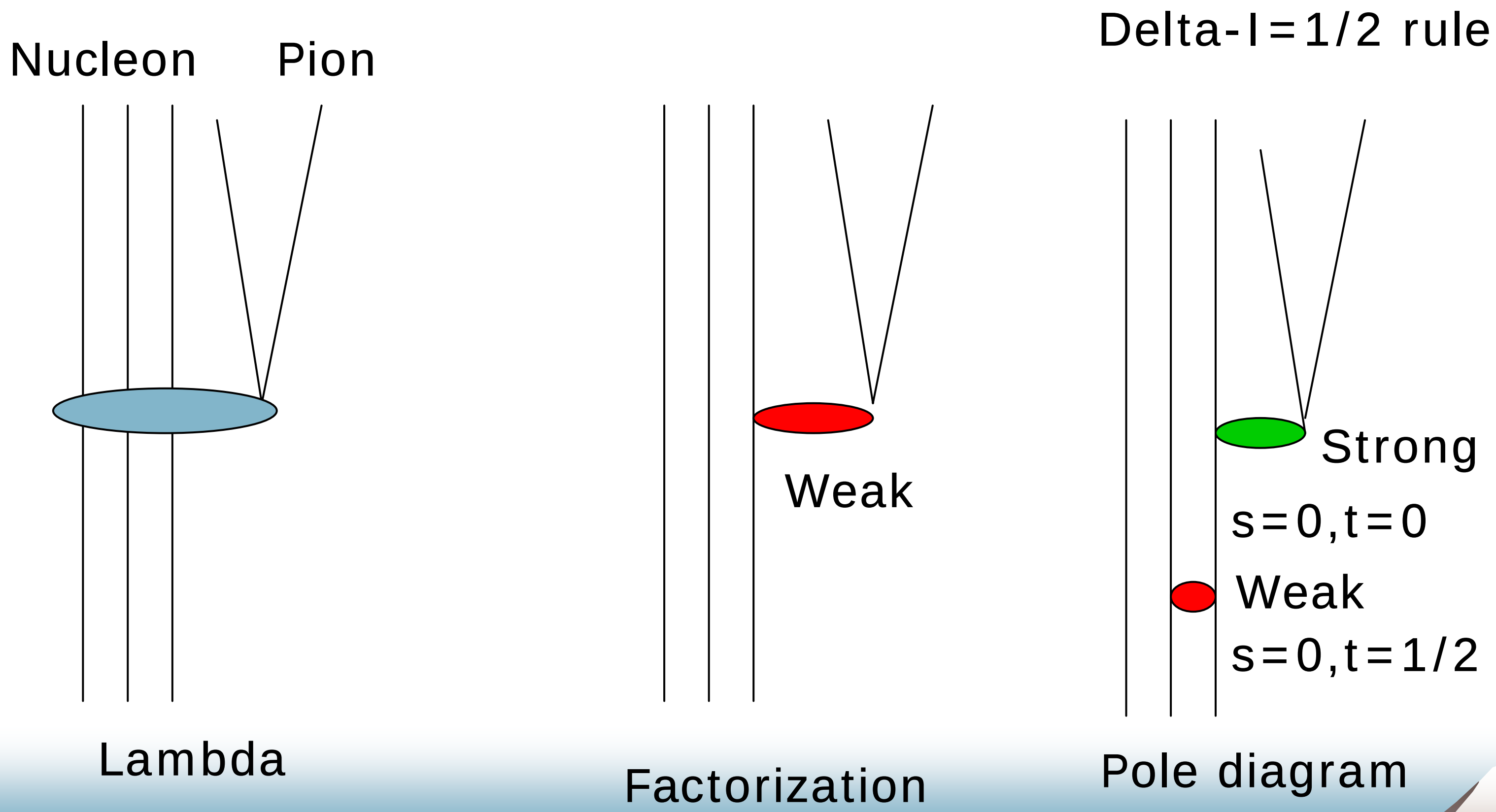
m(u)=330MeV

m(s)=500MeV

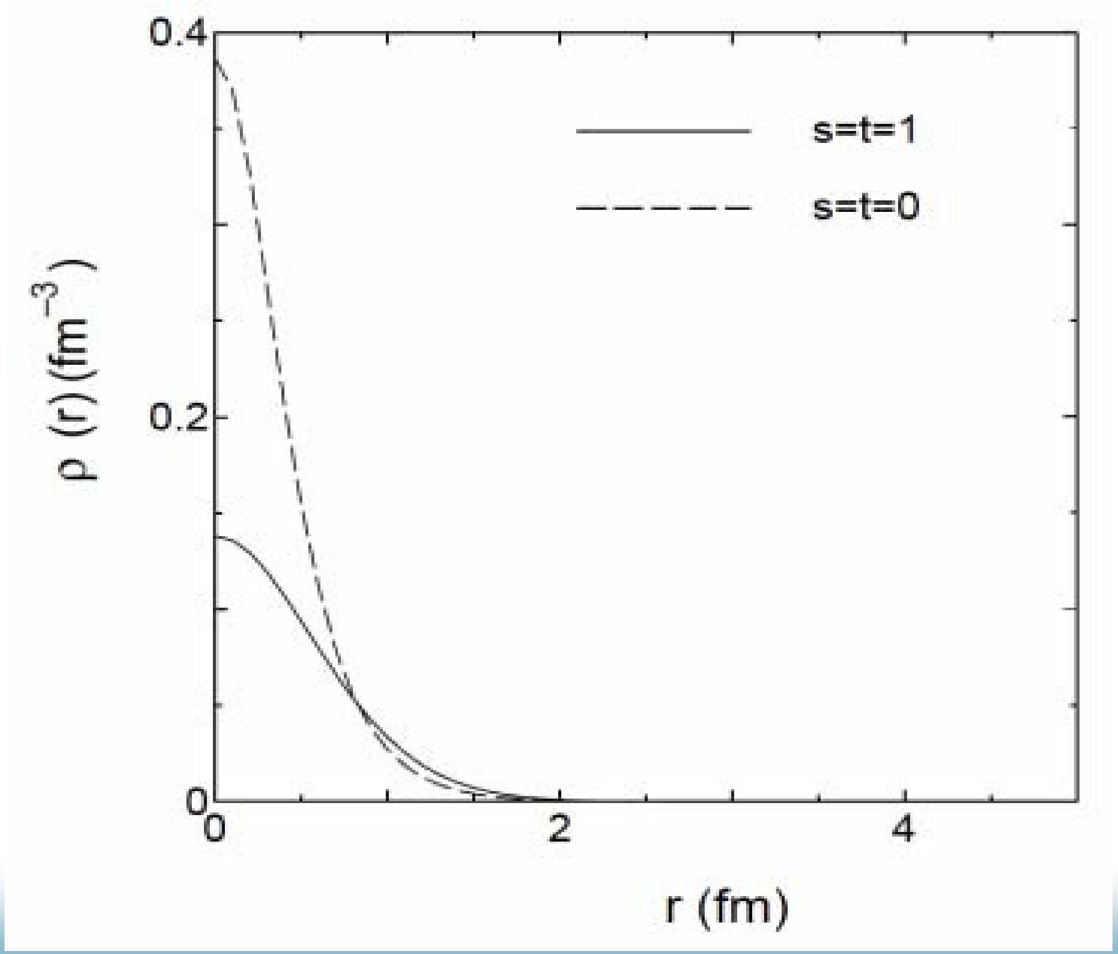
Pion M~200MeV

Kaon M~500MeV

Non-leptonic weak decay



Relative wave function



Non-leptonic weak decay

Table III. P-wave non-leptonic weak transition amplitude (in 10^{-7} unit). In the second and forth columns, values in brackets show the results without V_s.Empirical values are taken from ref. 1).

Decay	Pole	others	Total	Exp.
$\Sigma^+ \to p\pi^0$	23.23(13.45)	2.05	25.28(15.50)	26.6
$\Sigma^+ \to n\pi^+$	40.9(8.21)	0.00	40.9(8.21)	42.2
$\Lambda \to n\pi^0$	−5.29(−3.54)	−5.02	−10.31(−8.56)	−15.8

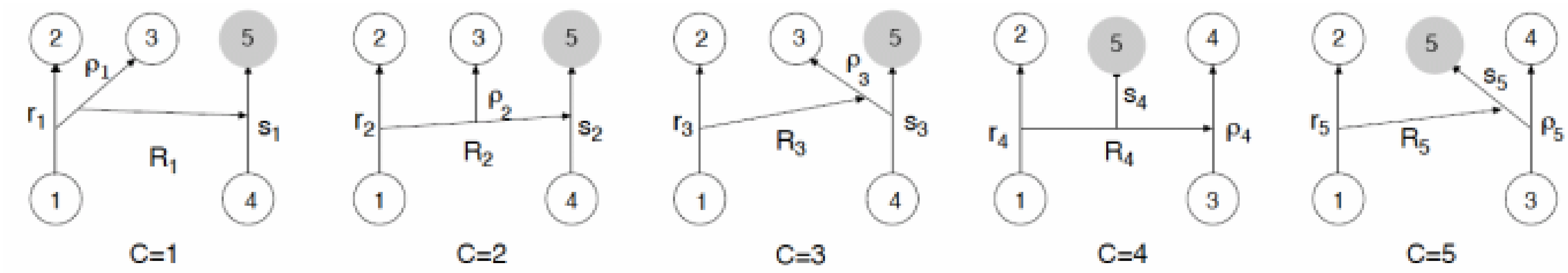
B.Stech and Q.P. Xu, Z.Physik C49 (1991) 491
K. Suzuki and H. Toki, Mod. Phys. Lett. A9 (1994) 1059

Magnetic moments

Table IV. Baryon magnetic moments

	with V_s	without V_s	Exp.
μ_p	2.78	2.84	2.792847
μ_n	-1.83	-1.90	-1.913042
μ_Λ	-0.602	-0.613	-0.613 ± 0.004
μ_{Σ^+}	2.69	2.73	2.458 ± 0.010
μ_{Σ^-}	-1.05	-1.06	-1.160 ± 0.025
μ_{Σ^0}	0.817	0.836	$-$
μ_{Ξ^0}	-1.410	-1.449	-1.250 ± 0.014
μ_{Ξ^-}	-0.507	-0.502	-0.6507 ± 0.0025
μ_ω	-1.84	-1.84	-2.02 ± 0.05

Pentaquark wave function



$$\xi_1^{(1)} = \left[(123)_1(45)_1\right]_1, \quad \xi_1^{(2)} = \left[[(12)_{\bar{3}}(45)_1]_{\bar{3}}3\right]_1$$

$$\xi_1^{(3)} = \left[(12)_{\bar{3}}[(45)_1 3]_3\right]_1, \; \xi_1^{(4)} = \left[[(12)_{\bar{3}}(34)_{\bar{3}}]_3 5\right]_1$$

$$\xi_1^{(5)} = \left[(12)_{\bar{3}}[(34)_{\bar{3}}5]_3\right]_1$$

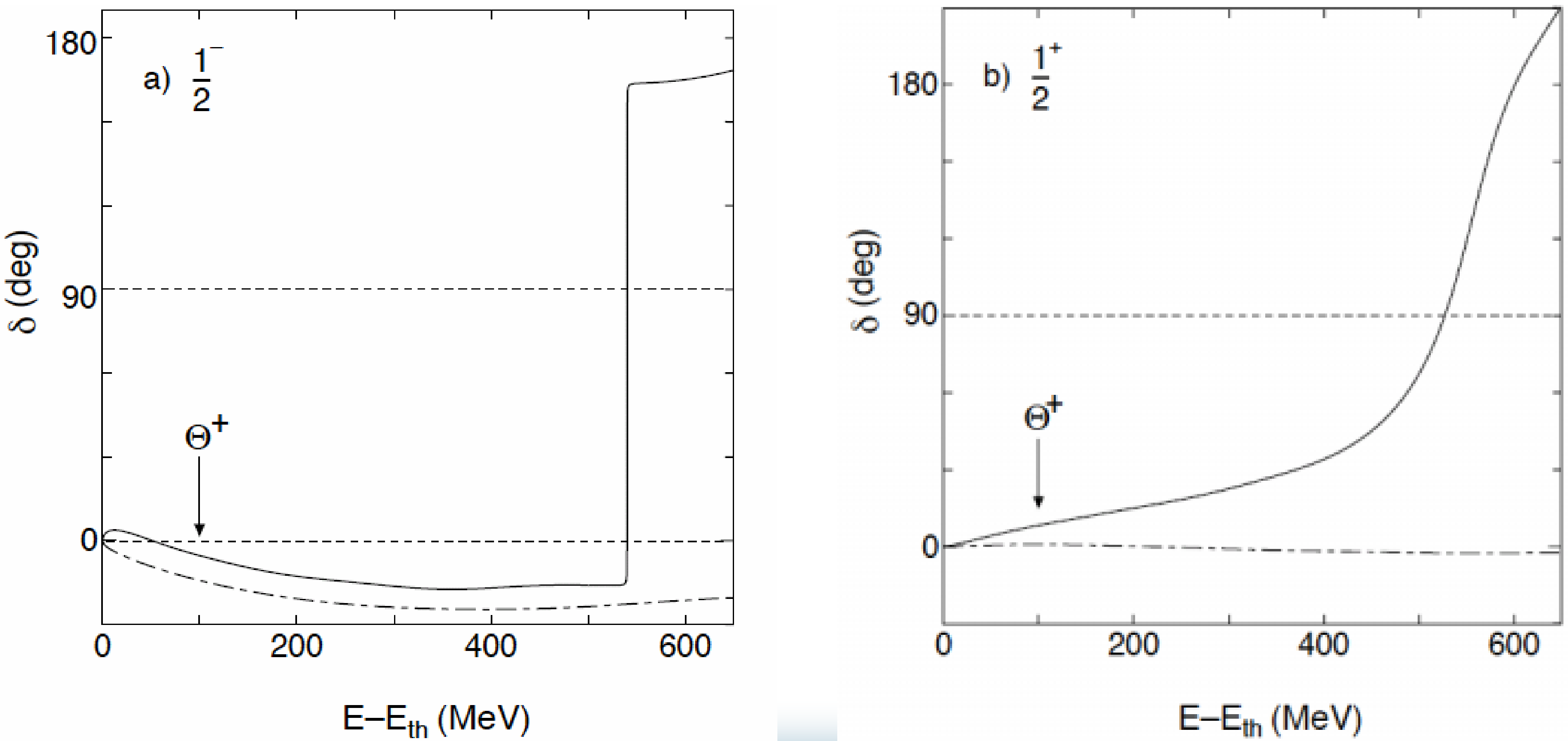
Many body Schroedinger equation

$$(H - E)\,\Psi_{J^\pi M} = 0$$

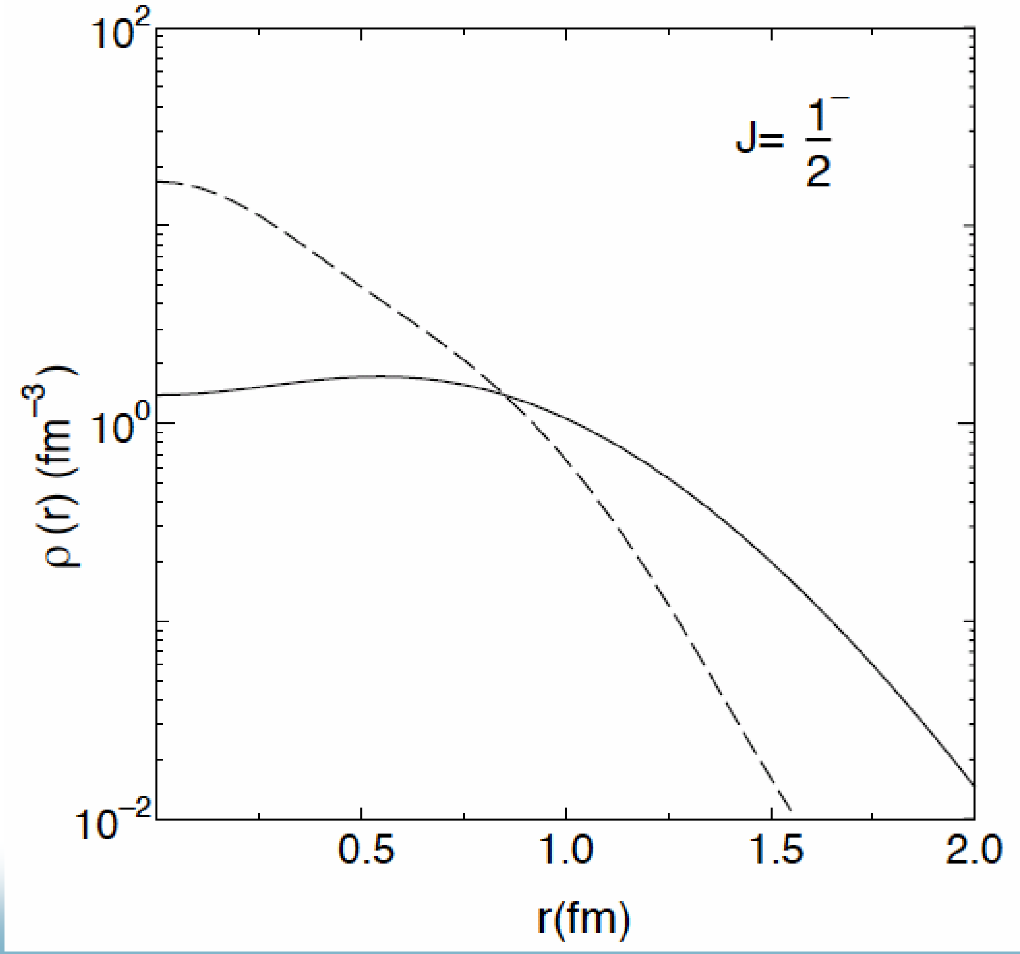
$$\widehat{\Phi}_{J^\pi M}(E_\nu) = \sum_{c,\alpha} A^{(c)}_{J,\alpha}(E_\nu)\;\Phi^{(c)}_{J^\pi M,\alpha}(\mathbf{r}_c, \boldsymbol{\rho}_c, \mathbf{s}_c, \mathbf{R}_c)$$

$$\Phi^{(c)}_{J^\pi M,\alpha} = \mathcal{A}_{1234}\left\{\xi^{(c)}_{1}(1234,5)\,\eta^{(c)}_{0(t)}(1234,5)\right.$$
$$\left.\times\left[\chi^{(c)}_{S(s\bar{s}\sigma)}(1234,5)\,\psi^{(c)}_{L\{n\}}(\mathbf{r}_c, \boldsymbol{\rho}_c, \mathbf{s}_c, \mathbf{R}_c)\right]_{J^\pi M}\right\}$$

Phase shift for ½- and ½+ states

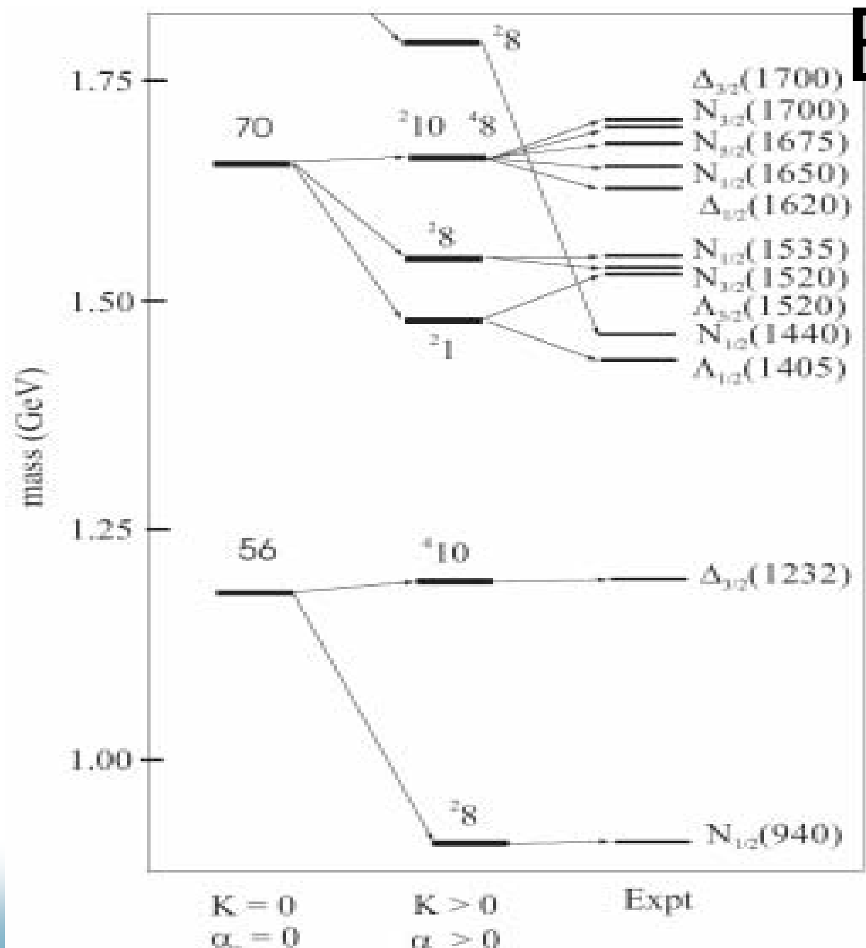


Wave function

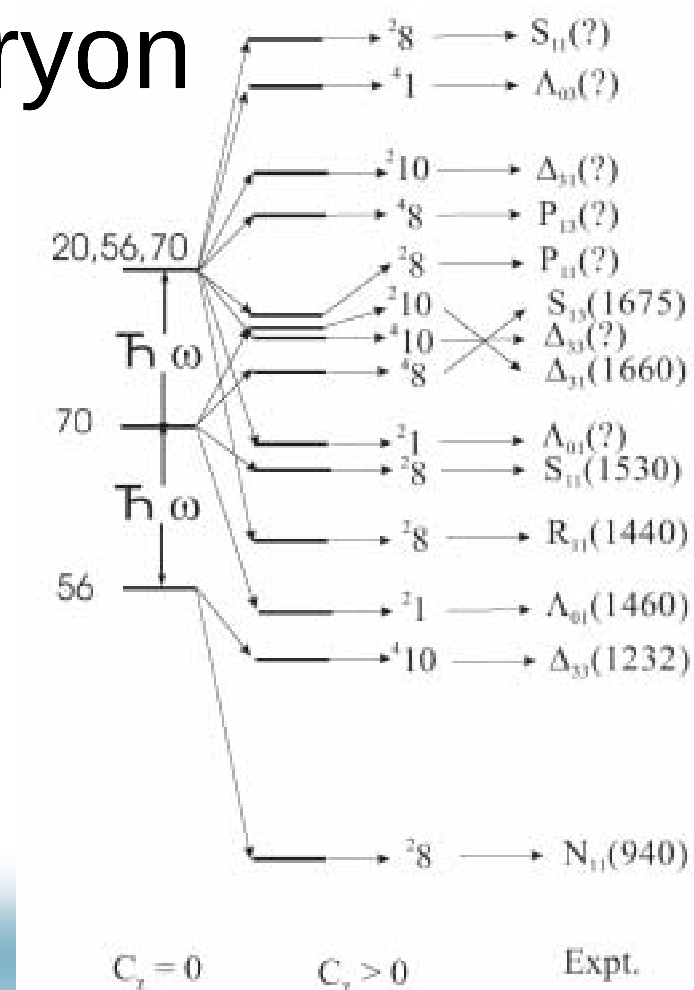


Instanton induced interaction vs Glozman-Riska interaction

Baryon

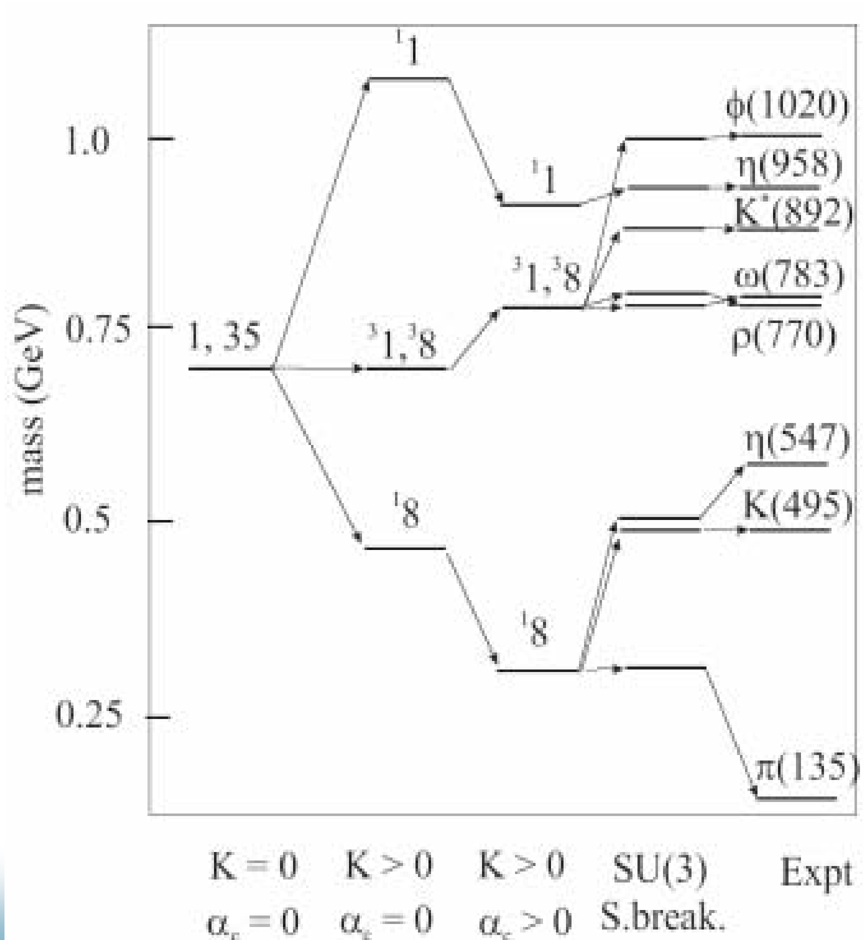


Instanton inteaction

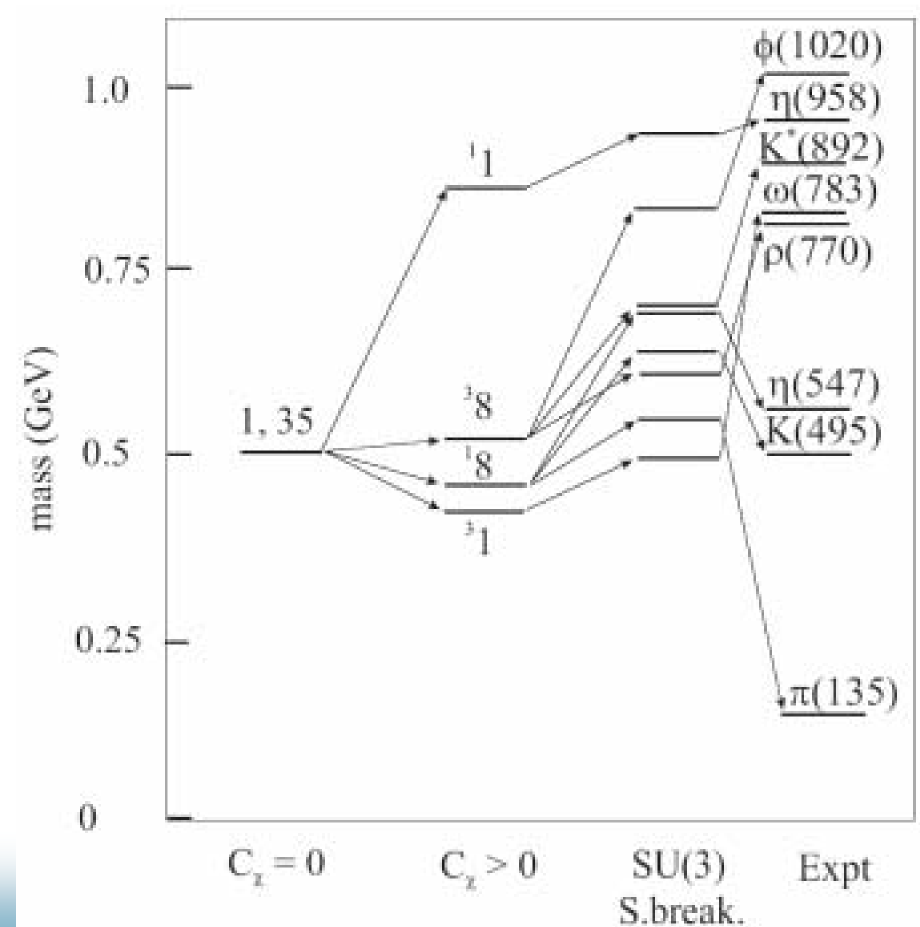


GR interaction

Meson spectrum



Instanton inteaction



GR interaction

V.Dmitrasinovic and H.Toki Annals Physics (2005)

Conclusion and swetting

- non-relativistic model is not bad (want to calculate many states)
- want to verify vanishing Van-der-Waals force
- multi confinement force
- charm against strange hadrons
- from form factor to structure function
- quark nucleus (A=1~1000)