PS-Meson － octet-baryon couplings constants from two-flavor lattice QCD

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Introduction

Nuclear and Hadron system

Governed by QCD

$$\mathcal{L}_{\mathrm{QCD}} = -\frac{1}{2}\mathrm{tr}F_{\mu\nu}F^{\mu\nu} + \sum_f \bar{\psi}(i\gamma^\mu D_\mu - m_f)\psi$$

The symmetry in QCD plays an important role also in hadron physics.

Global symmetry in 3-flavor QCD $SU(3)_L \times SU(3)_R$

By spontaneous symmetry breaking $SU(3)_V$

Massless NG bosons appear $\frac{SU(3)_L \times SU(3)_R}{SU(3)_V}$

Hadronic interactions

$$B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ -\Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix} \quad M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & K^0 \\ K^- & \overline{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix}$$

Baryon fields　　　　　　　　Meson fields

In terms of QCD's symmetry,
effective interactions can be constructed

(Eg.)　$\mathrm{tr}[[\overline{B}, B]M] \quad \mathrm{tr}[\{\overline{B}, B\}M] \quad , \ldots$

besides overall coefficiens, which are determined by QCD dynamics.

Lattice QCD calculations are helpful

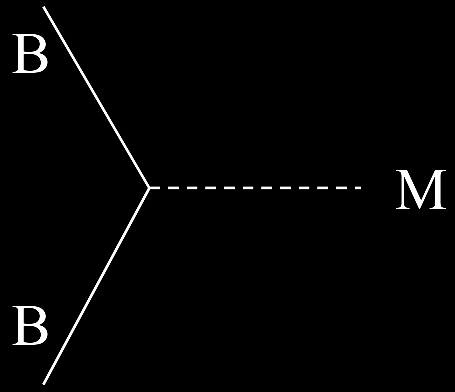
Hadronic interactions

We will focus on

Meson-baryon couplings

pseudoscalar

octet baryon



baryons → building blocks of our world

mesons → baryon-baryon interactions

One of the most fundamental quantities in hadron physics

Mesons → 8 rep. (Octet)

Baryons → 8 rep. (Octet)

8 x 8 x 8 = 1

Two independent combinations

$$\mathcal{L}_{\mathrm{BBM}} = F\ \mathrm{tr}[[\overline{B}, B]M] + D\ \mathrm{tr}[\{\overline{B}, B\}M]$$

F and D remains undetermined

Hadronic interactions

$$\mathcal{L}_{\mathrm{BBM}} = F\ \mathrm{tr}[[\overline{B}, B]M] + D\ \mathrm{tr}[\{\overline{B}, B\}M]$$

F and D cannot be determined
→ Two unknown parameters

SU(3) relations

$$g_{NN\pi} = g$$

$$g_{\Sigma\Sigma\pi} = 2g\alpha,\ \ g_{\Lambda\Sigma\pi} = \frac{2}{\sqrt{3}}g(1-\alpha),\ \ g_{\Xi\Xi\pi} = g(2\alpha - 1)$$

$$g_{\Sigma NK} = g(1-2\alpha),\ \ g_{\Lambda NK} = -\frac{1}{\sqrt{3}}g(1+2\alpha)$$

$$g_{NN\eta_8} = \frac{1}{\sqrt{3}}g(4\alpha - 1),\ \ g_{\Sigma\Sigma\eta_8} = \frac{2}{\sqrt{3}}g(1-\alpha)$$

$$g_{\Lambda\Lambda\eta_8} = -\frac{2}{\sqrt{3}}g(1-\alpha),\ \ g_{\Xi\Xi\eta_8} = -\frac{1}{\sqrt{3}}g(1+2\alpha)$$

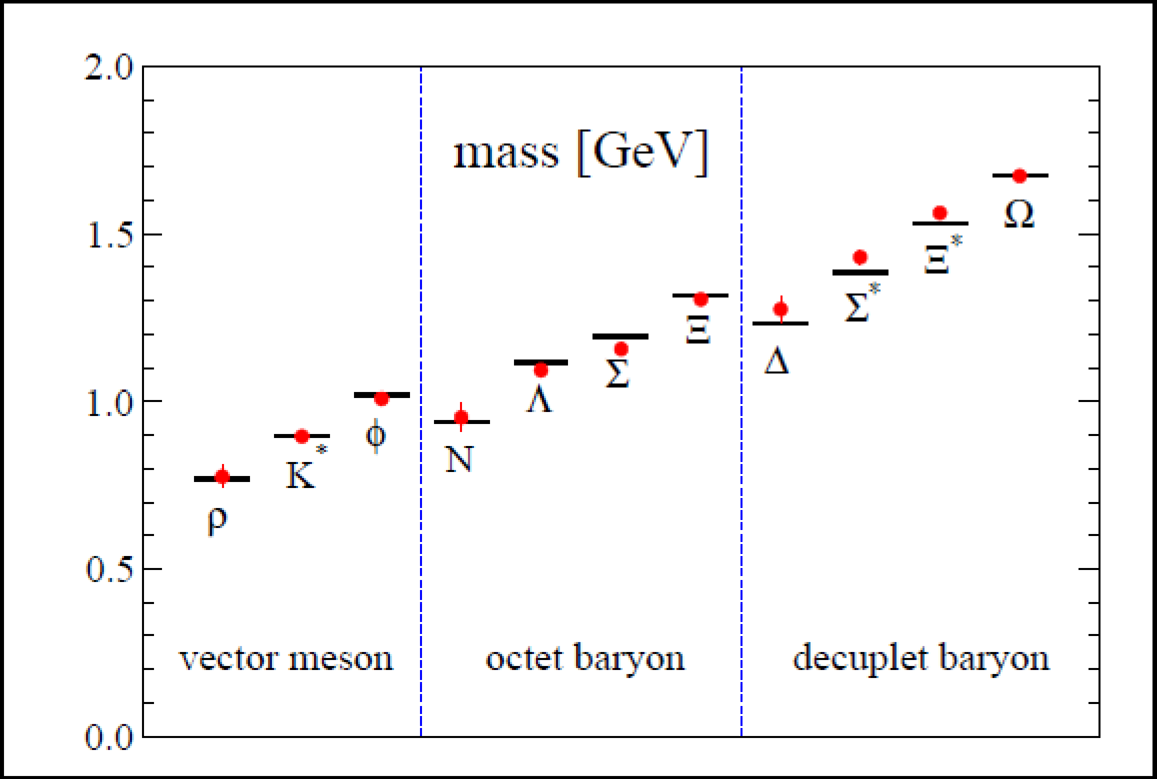
$$\left.\begin{array}{l} g_{\pi NN} \\ \alpha \equiv \dfrac{F}{F+D} \end{array}\right\}$$ Two parameters

- Equations of motion
- Blackhole formation
- SU(3) symmetry is good ?
- How the symmetry broken ?

→ Lattice QCD is reliable

Hadron spectrum from lattice QCD

Now, physical point has been achieved



PACS-CS collaboration, arXiv:0807.1661

↑ Almost unique 1st principle calculations which can be compared with experiments

Hadronic interactions from lattice QCD

In lattice QCD, vacuum expectation values can be computed.

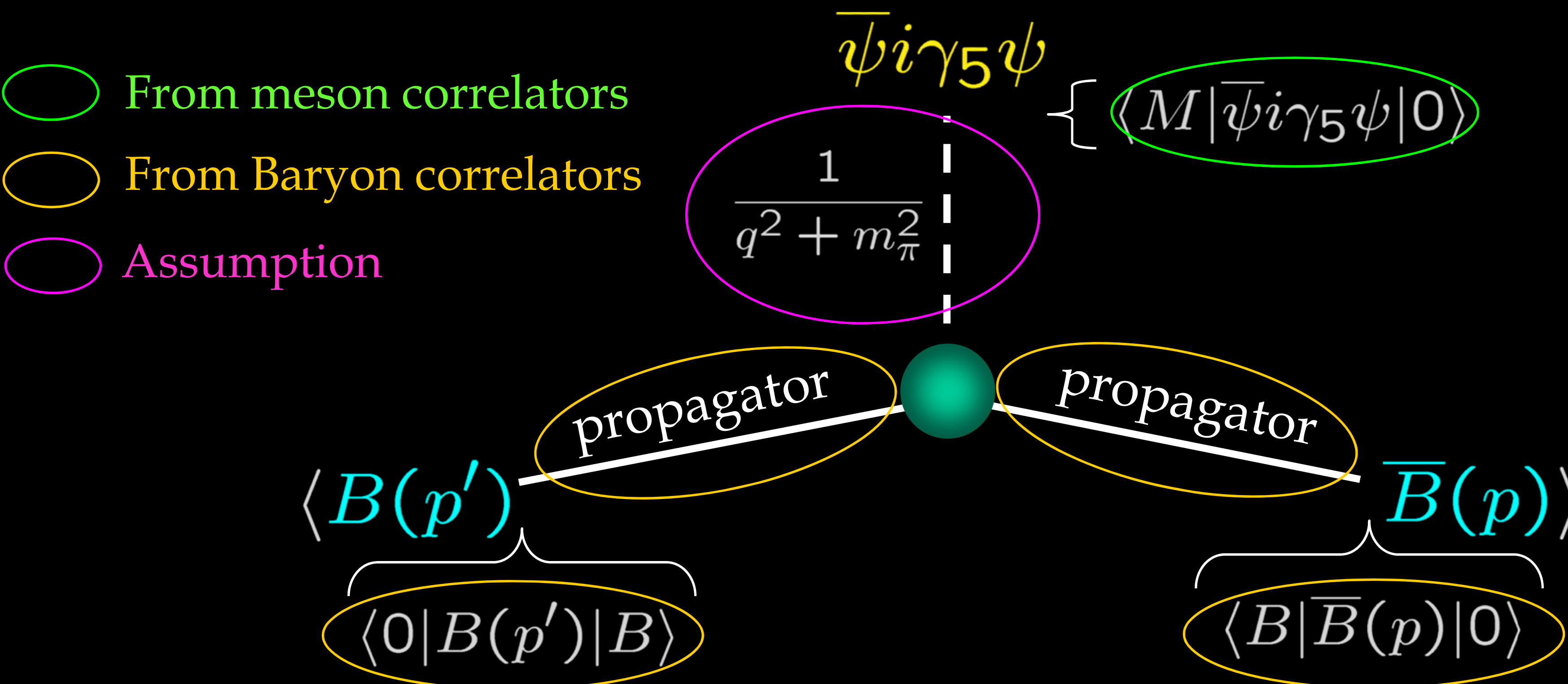
$$\langle B(p') \; \overline{\psi} i \gamma_5 \psi \; \overline{B}(p) \rangle$$

Baryon interpolation fields

Pseudo-scalar density

We compute 3-point functions,
which can be expressed as follows.

What we want is



Simulation parameters

Generated by CP-PACS

$16^3 \times 32$ lattice with two flavors of dynamical quarks

The renormalization-group improved gauge action at $\beta=1.95$

The mean field improved clover quark action
with the clover coefficient $c_{SW}=1.530$

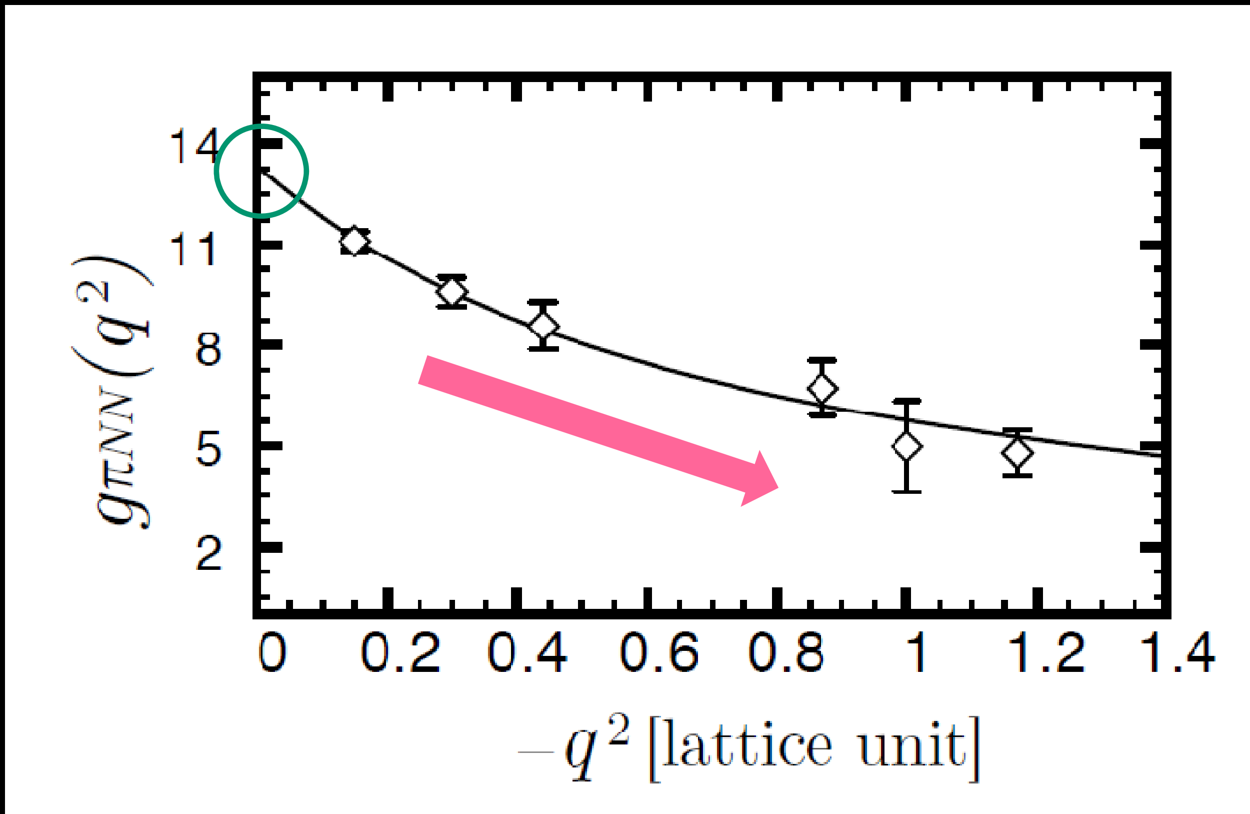
→Lattice size = $(2.5\text{fm})^3 \times (5.0\text{fm})$

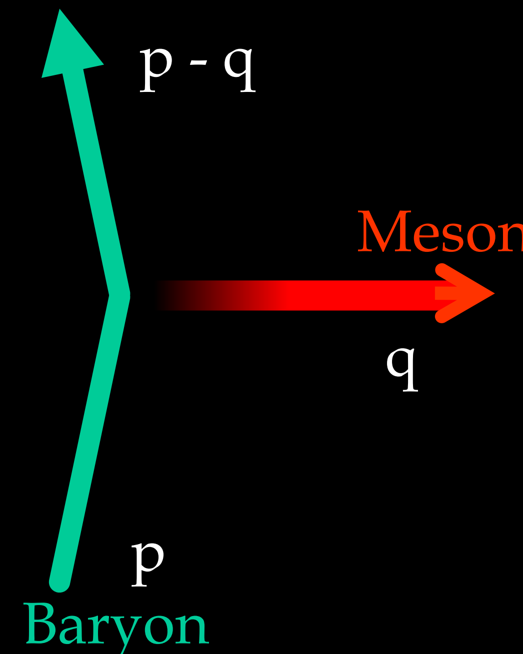
Hopping parameter κ=0.1375, 0.1390, 0.1393, 0.1400, 0.1410

→current up- and down-quark masses = 150, 100, 90, 60, 35 MeV

MB Couplings

Parameters





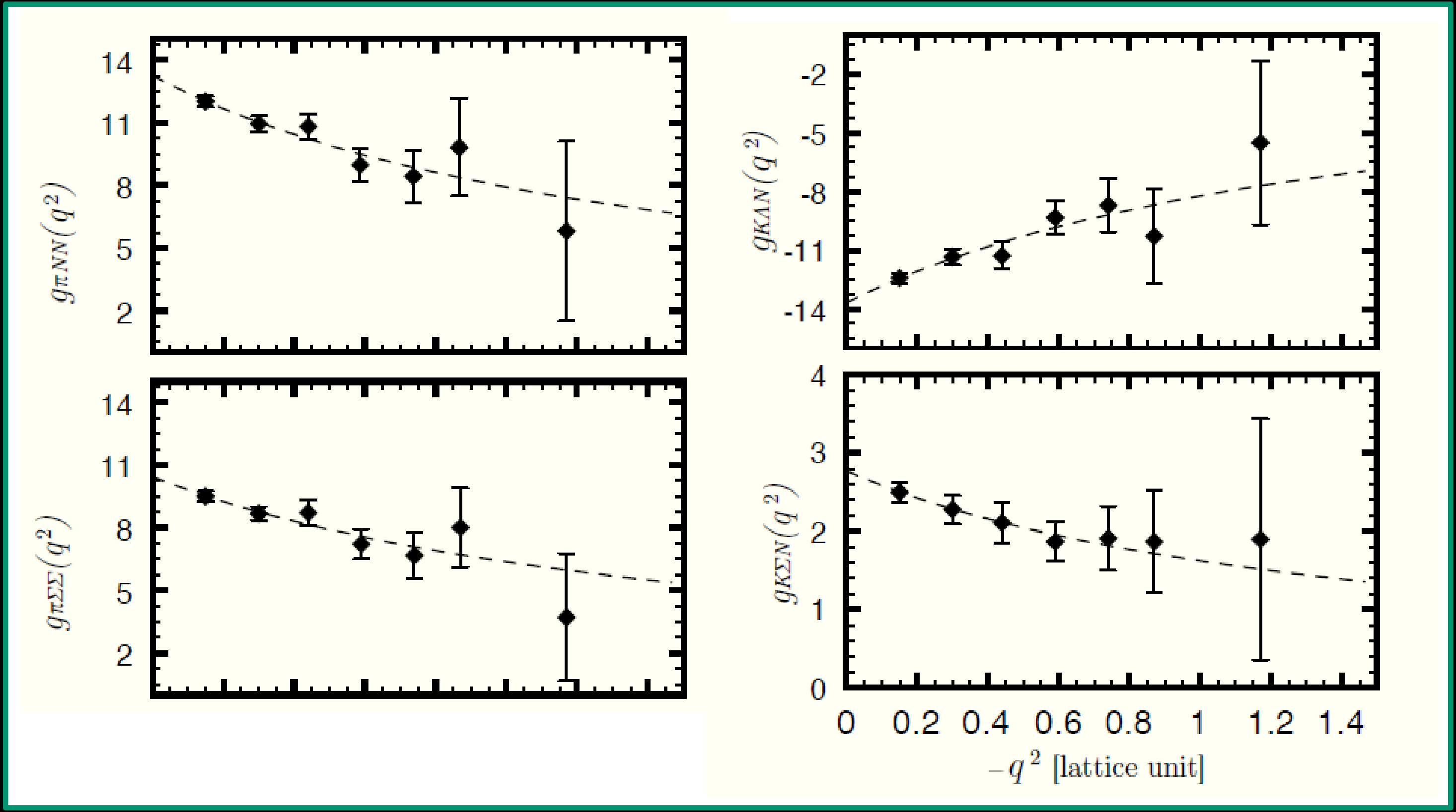
How to parametrize?

$$g_{\mathrm{BBM}}(q^2) = \frac{g\Lambda^2}{q^2 + \Lambda^2}$$

g → Coupling at q2=0

Λ → Monopole mass

Meson Baryon couplings

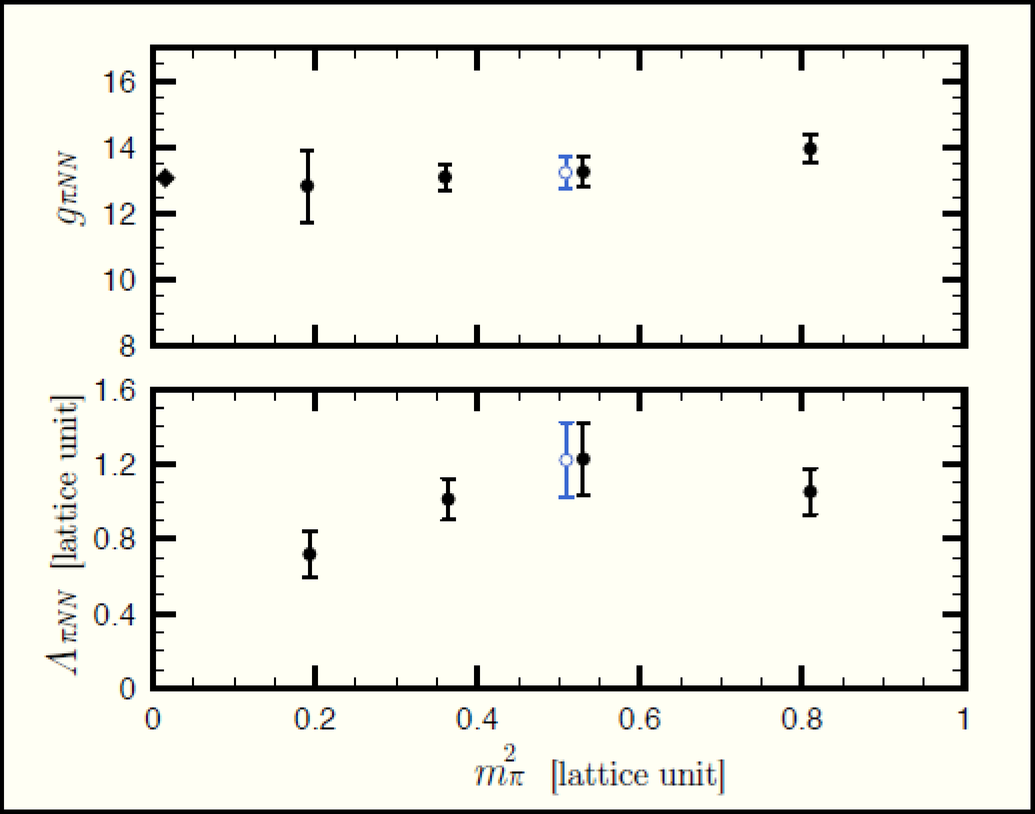


$$\pi NN, \pi\Sigma\Sigma, \pi\Lambda\Sigma,$$

$$K\Sigma N, K\Lambda N, \pi\Xi\Xi, K\Lambda\Xi, K\Sigma\Xi$$

8 channels are investigated

Meson Baryon couplings (π NN case)



$g_{\pi NN}$

consistent with pheno. value ∼12.8

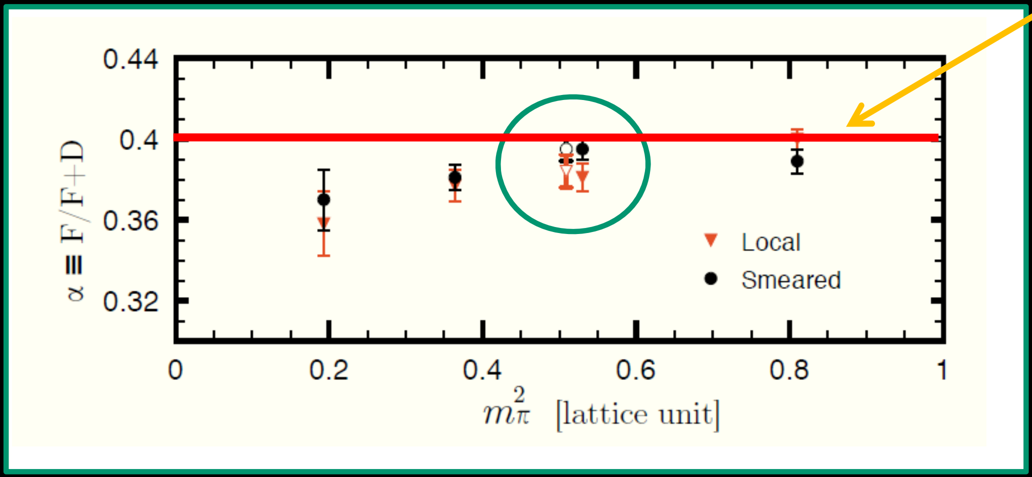
Monopole mass

∼ 700-800 MeV
Softer than OBEM

α=F/F+D and SU(3) breaking parameters

α=F/F+D (obtained by global fit)

0.4 — exact SU(6)

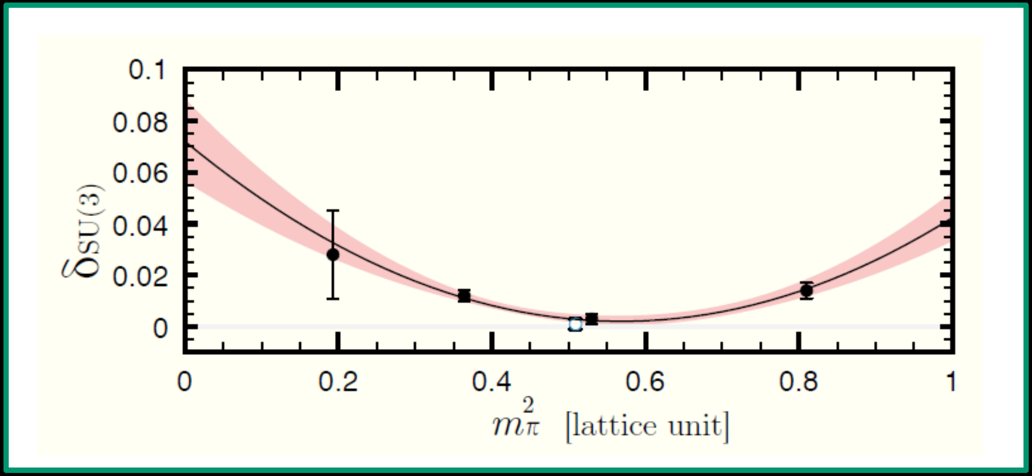


SU(3) limit : α=0.395(6)

c.f) α=0.4 under SU(6) symmetry

It decreases towards chiral limit

SU(3) breaking parameter δ



Breaking in SU(3) relations
remains small (a few %)

α=F/F+D and SU(3) breaking parameters

$$A_1 \equiv \frac{1}{2}\left(\sqrt{3}g^R_{\pi\Lambda\Sigma} + g^R_{\pi\Sigma\Sigma}\right), \quad A_2 \equiv g^R_{K\Sigma N} + g^R_{\pi\Sigma\Sigma},$$

$$A_3 \equiv \frac{1}{2}\left(g^R_{K\Sigma N} - \sqrt{3}g^R_{K\Lambda N}\right), \quad A_4 \equiv -g^R_{\pi\Sigma\Sigma} - \sqrt{3}g^R_{K\Lambda N},$$

$$A_5 \equiv \frac{1}{\sqrt{3}}\left(g^R_{\pi\Lambda\Sigma} - g^R_{K\Lambda N}\right), \quad A_6 \equiv \sqrt{3}g^R_{\pi\Lambda\Sigma} - g^R_{K\Sigma N}, \quad (10)$$

$$B_1 \equiv \frac{1}{4}\left(\sqrt{3}g^R_{\pi\Lambda\Sigma} + 3g^R_{\pi\Sigma\Sigma} + 2g^R_{K\Sigma N}\right),$$

$$B_2 \equiv \frac{1}{4}\left(2g^R_{\pi\Sigma\Sigma} + 3g^R_{K\Sigma N} - \sqrt{3}g^R_{K\Lambda N}\right),$$

$$B_3 \equiv \frac{1}{\sqrt{12}}\left(g^R_{\pi\Lambda\Sigma} - 4g^R_{K\Lambda N} - \sqrt{3}g^R_{\pi\Sigma\Sigma}\right), \quad (11)$$

$$B_4 \equiv \frac{1}{\sqrt{12}}\left(4g^R_{\pi\Lambda\Sigma} - \sqrt{3}g^R_{K\Sigma N} - g^R_{K\Lambda N}\right),$$

and

$$C_1 \equiv \frac{1}{2}\left(\sqrt{3}g^R_{\pi\Lambda\Sigma} - \sqrt{3}g^R_{K\Lambda N} - g^R_{\pi\Sigma\Sigma} - g^R_{K\Sigma N}\right), \quad (12)$$

Unity if SU(3) is exact.

They remain ~1±0.05 (0 MeV ~ Mud ~ 200 MeV).

→ Flavor SU(3) relations happen to be good

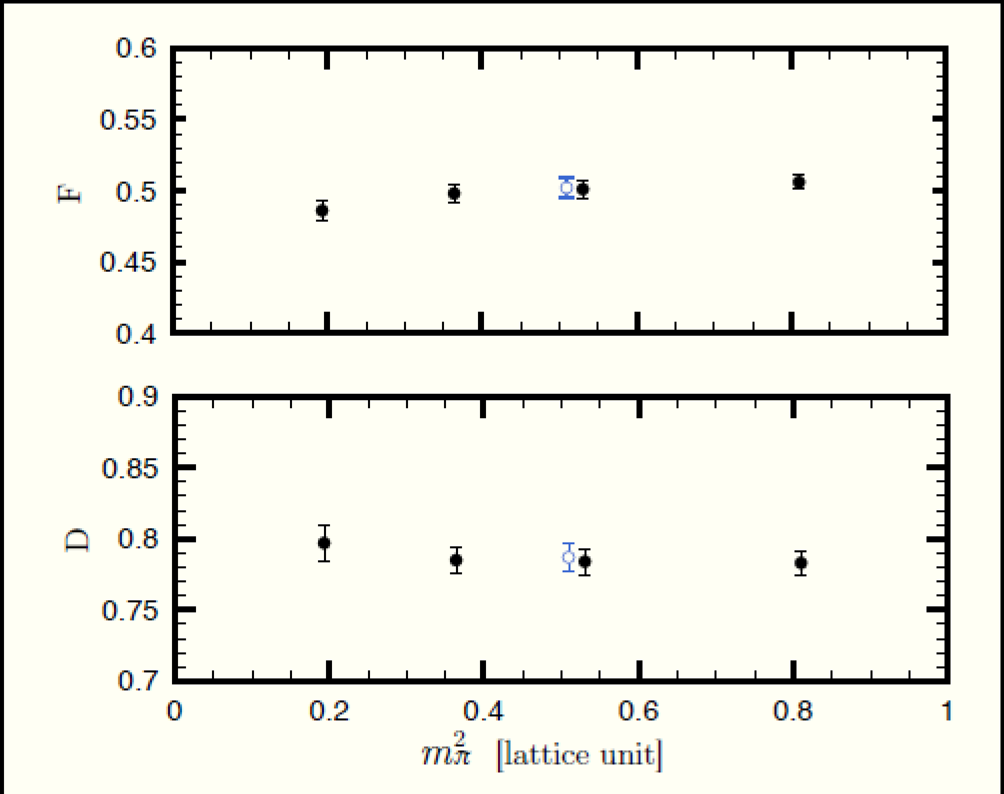
Axial Couplings

Axial couplings

SU(3) relations

$$g_{A,NN} = F + D, \quad g_{A,\Xi\Xi} = D - F, \quad g_{A,\Sigma\Sigma} = 2F,$$
$$g_{A,\Lambda\Xi} = 3F - D, \quad g_{A,\Sigma\Xi} = -(F + D),$$
$$g_{A,\Lambda N} = 3F + D, \quad g_{A,\Sigma N} = D - F, \quad g_{A,\Lambda\Sigma} = 2D$$

F and D parameters (global fit)



F : decreases towards chiral limit
D : increases towards chiral limit

SU(3) breaking is again small.

Conclusion

Meson-Baryon couplings and axial couplings in
πNN, πΣΣ, πΛΣ, KΛN, KΣN, πΞΞ, KΣΞ, KΛΞ channels
were investigated with two-flavor lattice QCD.

-- Meson-Baryon couplings --

→Breaking in SU(3) relations is small (a few %)
→$\alpha = F/(F+D) = 0.395(6)$ in SU(3) limit is close to that in SU(6) model

-- Axial couplings --

→Breaking in SU(3) relations seems small (a few %)
→F (D) decreases (increases) towards the chiral limit

The SU(3) symmetry for the MB and axial couplings
happen to be good.

Mismatch between light-quark and strange-quark masses
appear in F and D,
rather than SU(3) relations themselves.