格子QCDで探るハドロン間相互作用1

$K\pi$ チャンネルの散乱長

LLL - collaboration

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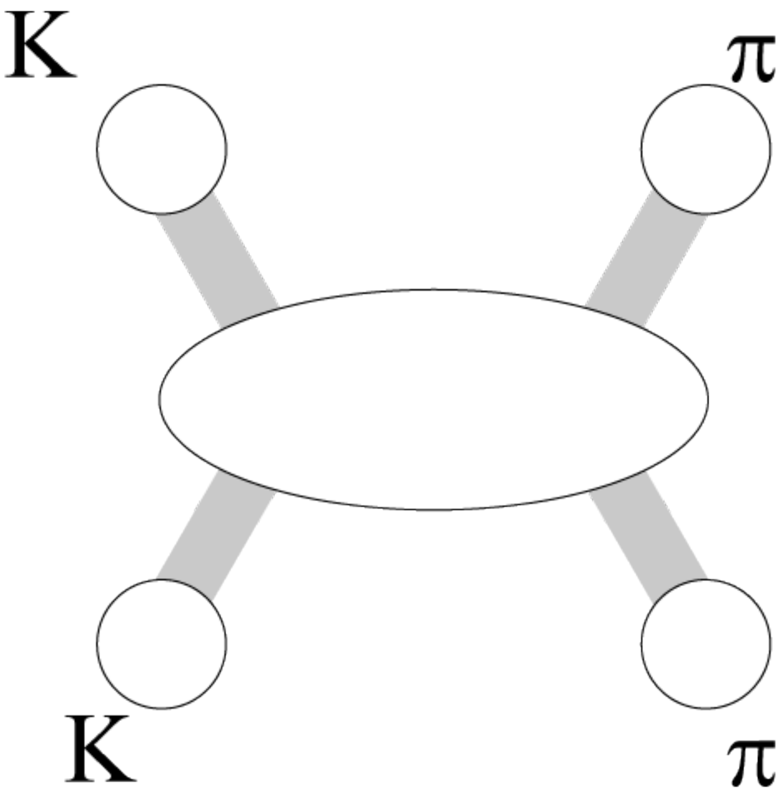
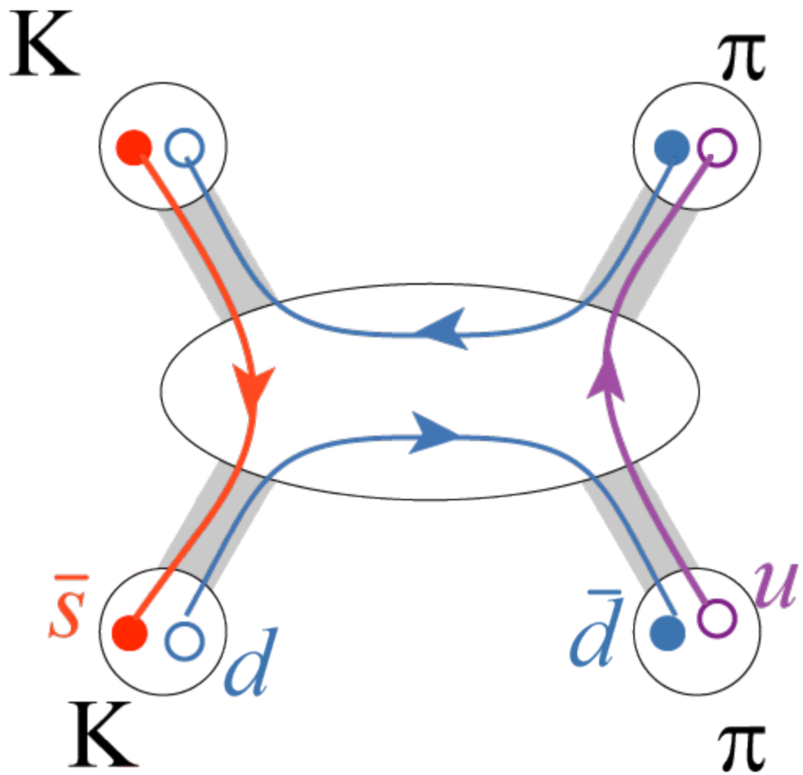
Understand Hadrons from QCD

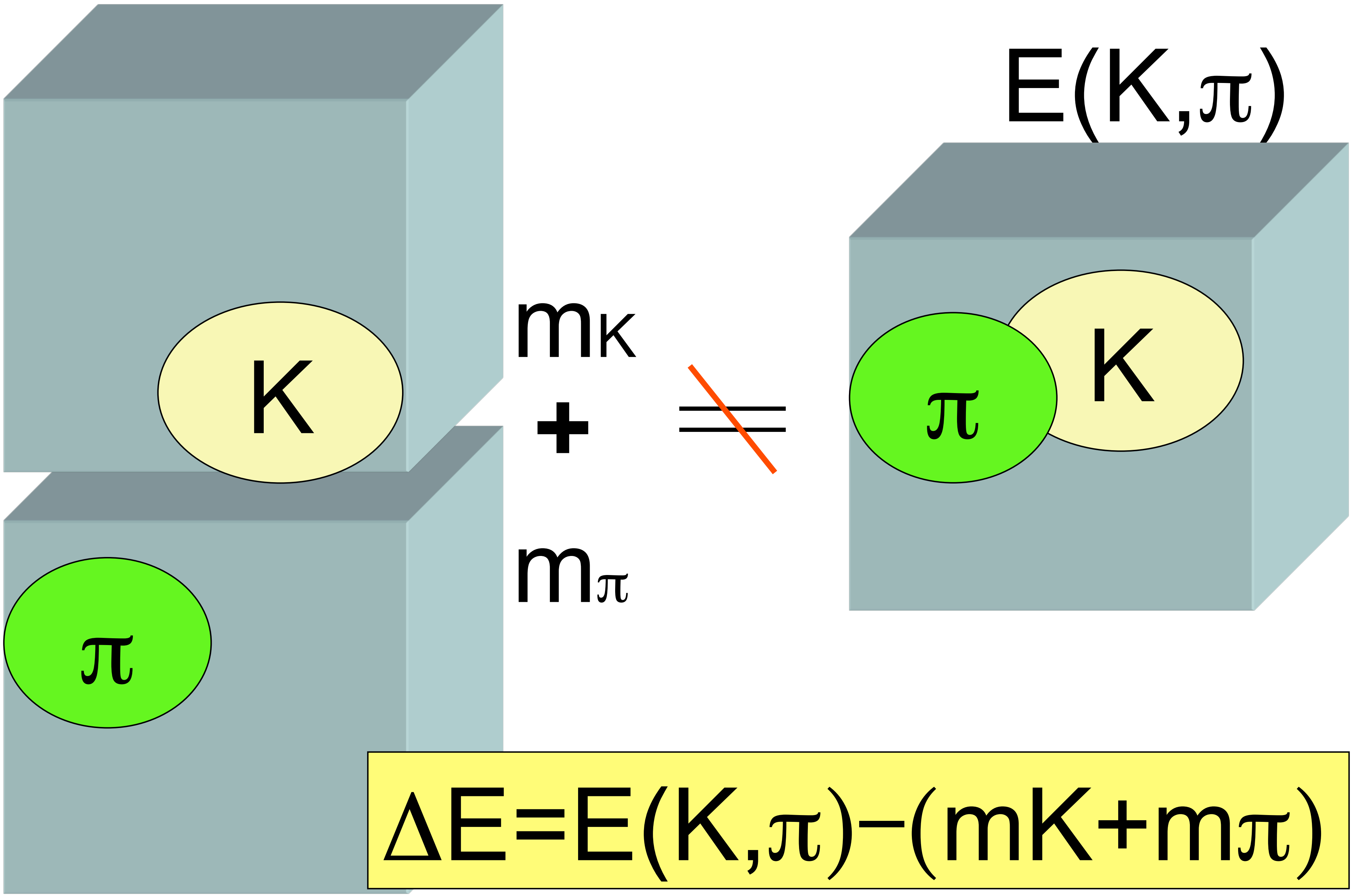


Hadron Reaction



QCD Dynamics inside

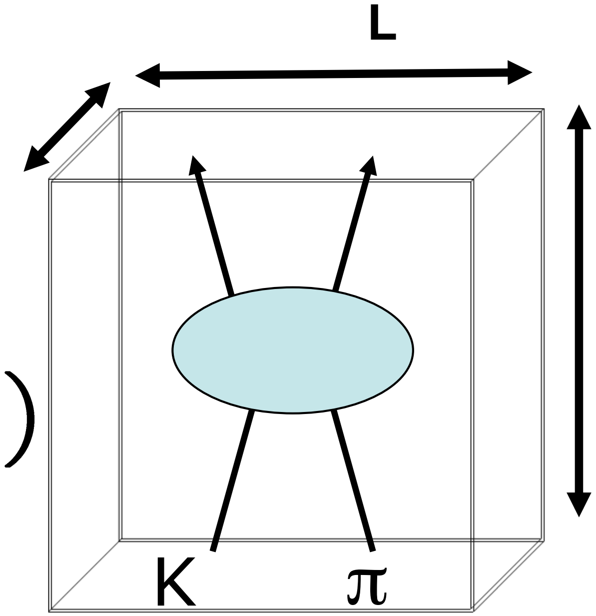
量子場の格子シミュレーション



$$\Delta E = E(K,\pi) - (m_K + m_\pi)$$

散乱長 a0

- Luscher Formula
  - K and π in a Box of size L



$$\Delta E = E(K,\pi) - (m_K + m_\pi)$$

$$= -\frac{2\pi(m_K+m_\pi)}{m_K m_\pi L^2} \times \frac{a_0}{L}\left[1 + c_1\left(\frac{a_0}{L}\right) + c_2\left(\frac{a_0}{L}\right)^2\right] + O\left(\frac{1}{L^6}\right)$$

a_0: s-wave scattering length

L : Spatial size of the box

$a_0 > 0$ ： 引力

$a_0 < 0$ ： 斥力

C1 = -2.837297, C2 = 6.375183

“素粒子流”定義

πK scattering amplitudes

$| \pi K^{(I = 1/2)} > = \sqrt{(2/3)}\, | \pi^+ > | K^0 > -(1/\sqrt{3})\, | \pi^0 > | K^+ >$

amplitude T =

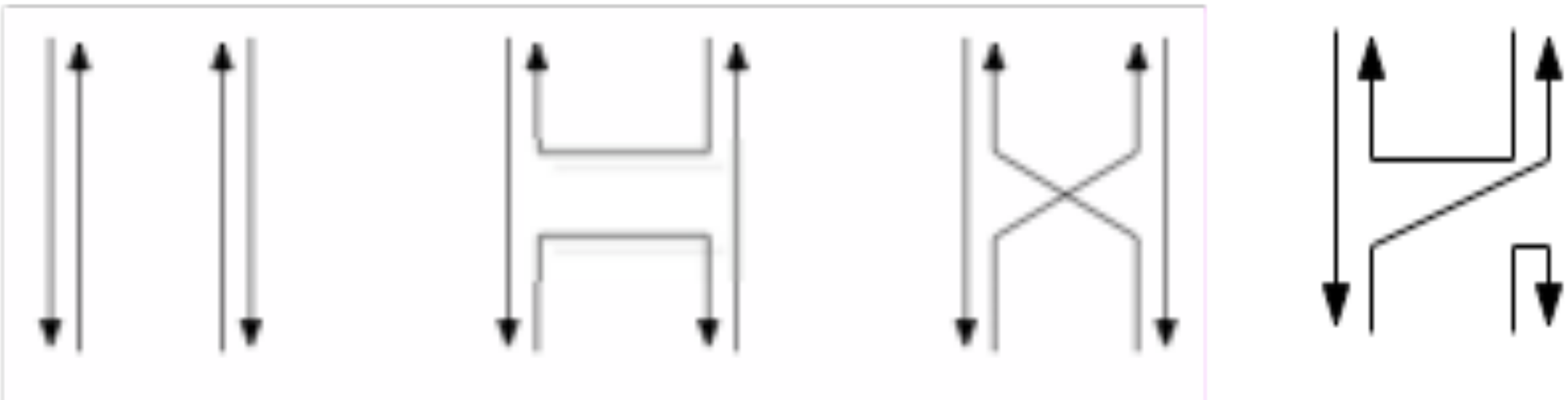
$+ (2/3) < \pi^+ K^0 | S | \pi^+ K^0 >$ (A)

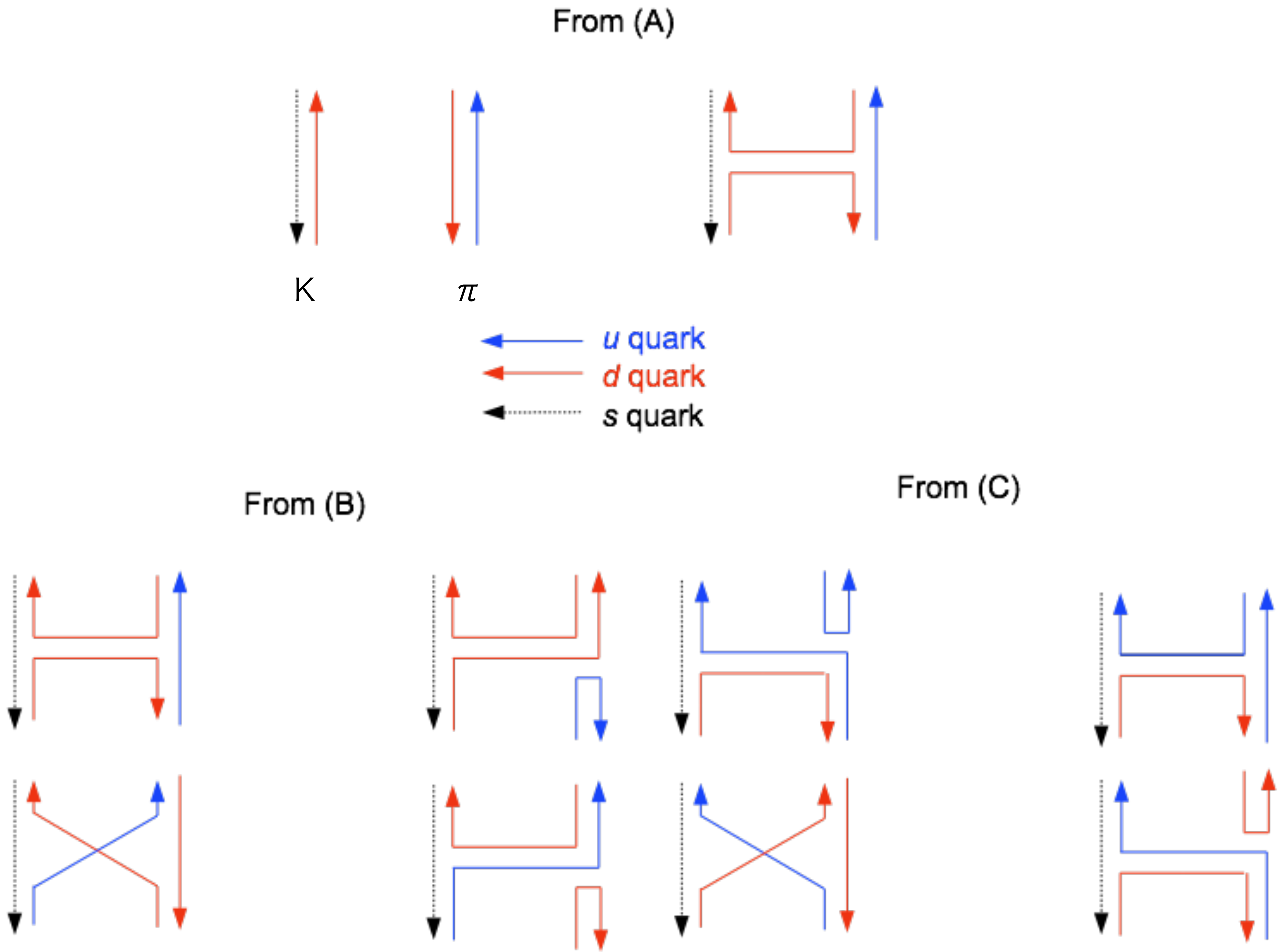
$- (\sqrt{2}/3) < \pi^+ K^0 | S | \pi^0 K^+ >$ (B)

$- (\sqrt{2}/3) < \pi^0 K^+ | S | \pi^+ K^0 >$ (C)

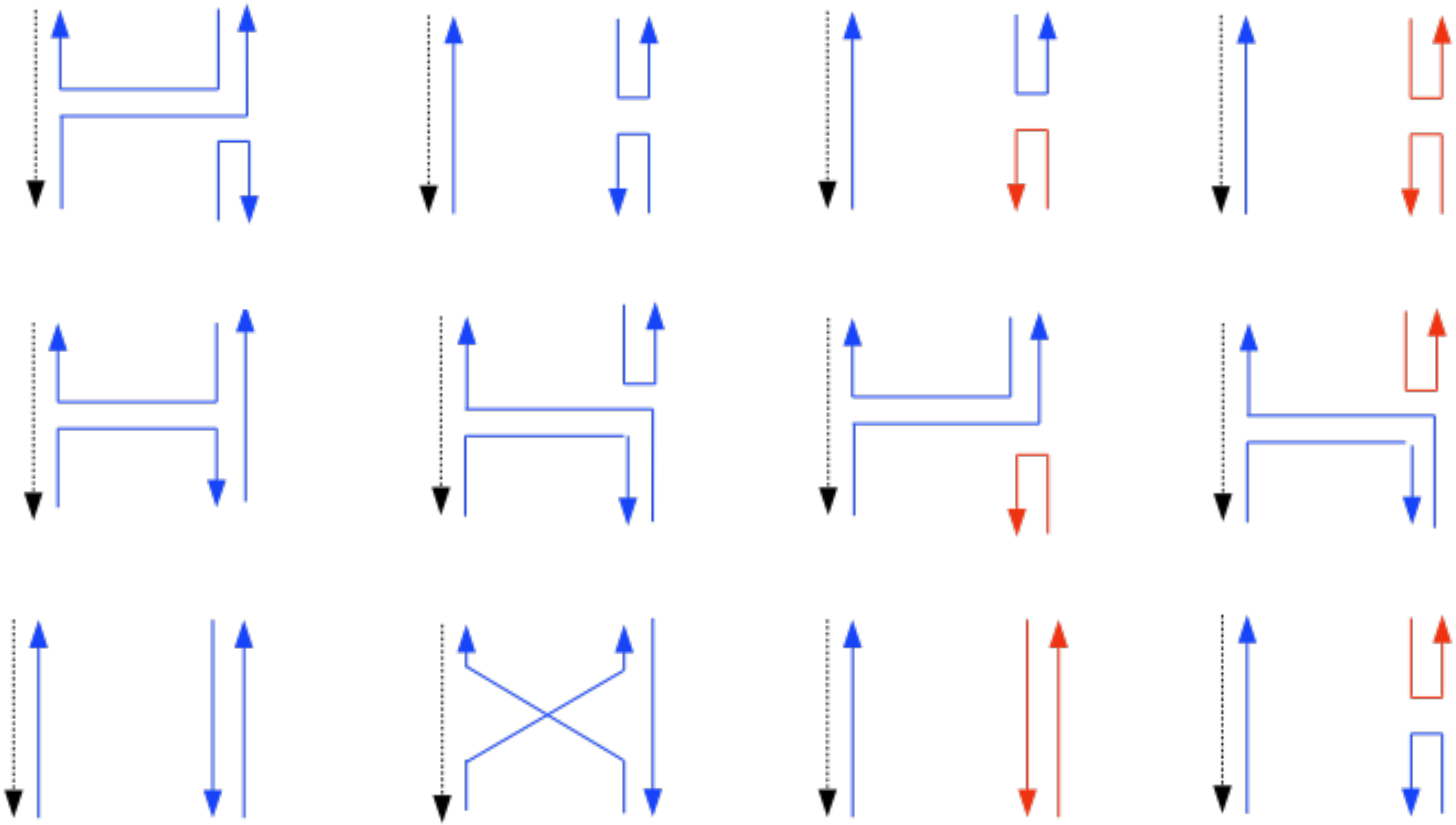
$+ (1/3) < \pi^0 K^+ | S | \pi^0 K^+ >$ (D)

contributions from 22 different diagrams



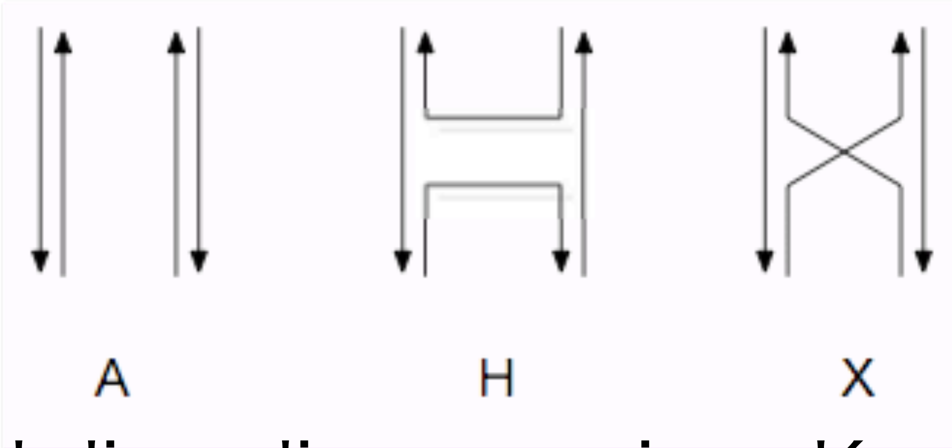

From (A)
K
π
u quark
d quark
s quark
From (B)
From (C)

From (D)



Assuming u- and d- quarks have the same mass, then, we have only 6 different diagrams.

Further, using the Crebsh-Gordon coefficients, only 3 different diagrams remain.



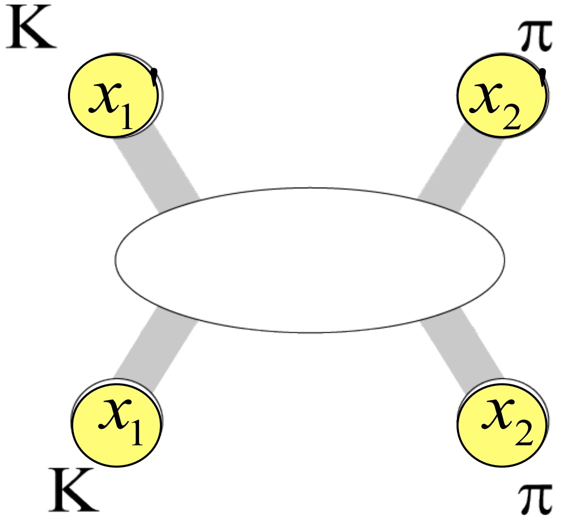
quark line diagrams in πK scattering

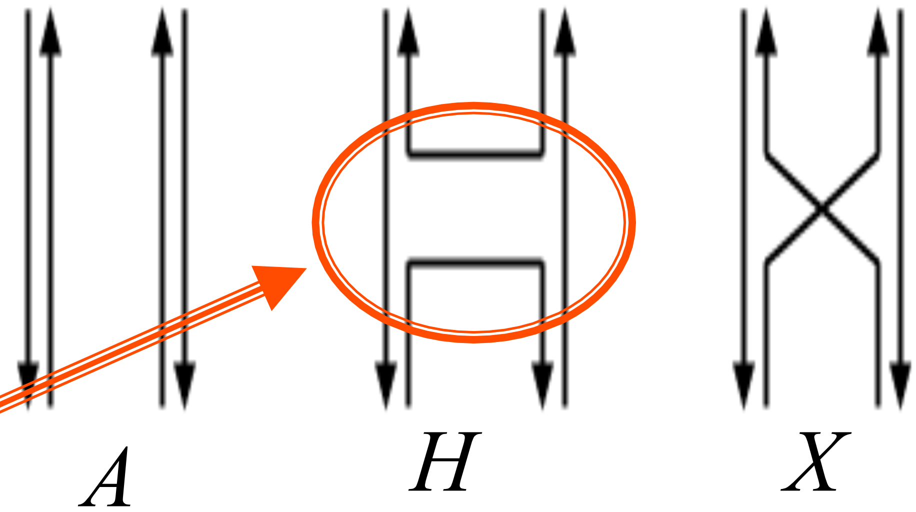
Iso-spin dependence

$$(I=\frac{1}{2}) \;=\; 1\times \mathrm{A}+(-\frac{3}{2})\times \mathrm{H}+\frac{1}{2}\times \mathrm{X} \qquad (1)$$

$$(I=\frac{3}{2}) \;=\; 1\times \mathrm{A}+(-1)\times \mathrm{X} \qquad (2)$$

$$\left\langle O_K(x_1')O_\pi(x_2')O_K^\dagger(x_1)O_\pi^\dagger(x_2)\right\rangle$$





Disconnected diagram

$$(I=\frac{1}{2}) = 1\times A + (-\frac{3}{2})\times H + \frac{1}{2}\times X$$

$$(I=\frac{3}{2}) = 1\times A + (-1)\times X$$

Disconnected diagram の評価

- すべての点からすべての点への伝播子が必要

⇒ ノイズ法を利用

$$W_{ij} x_j = \eta_i$$

Solve a Linear Equation with
Random Source η at i

Average over Noise →

$$\overline{\eta_i^* \eta_j} = \delta_{ij}$$

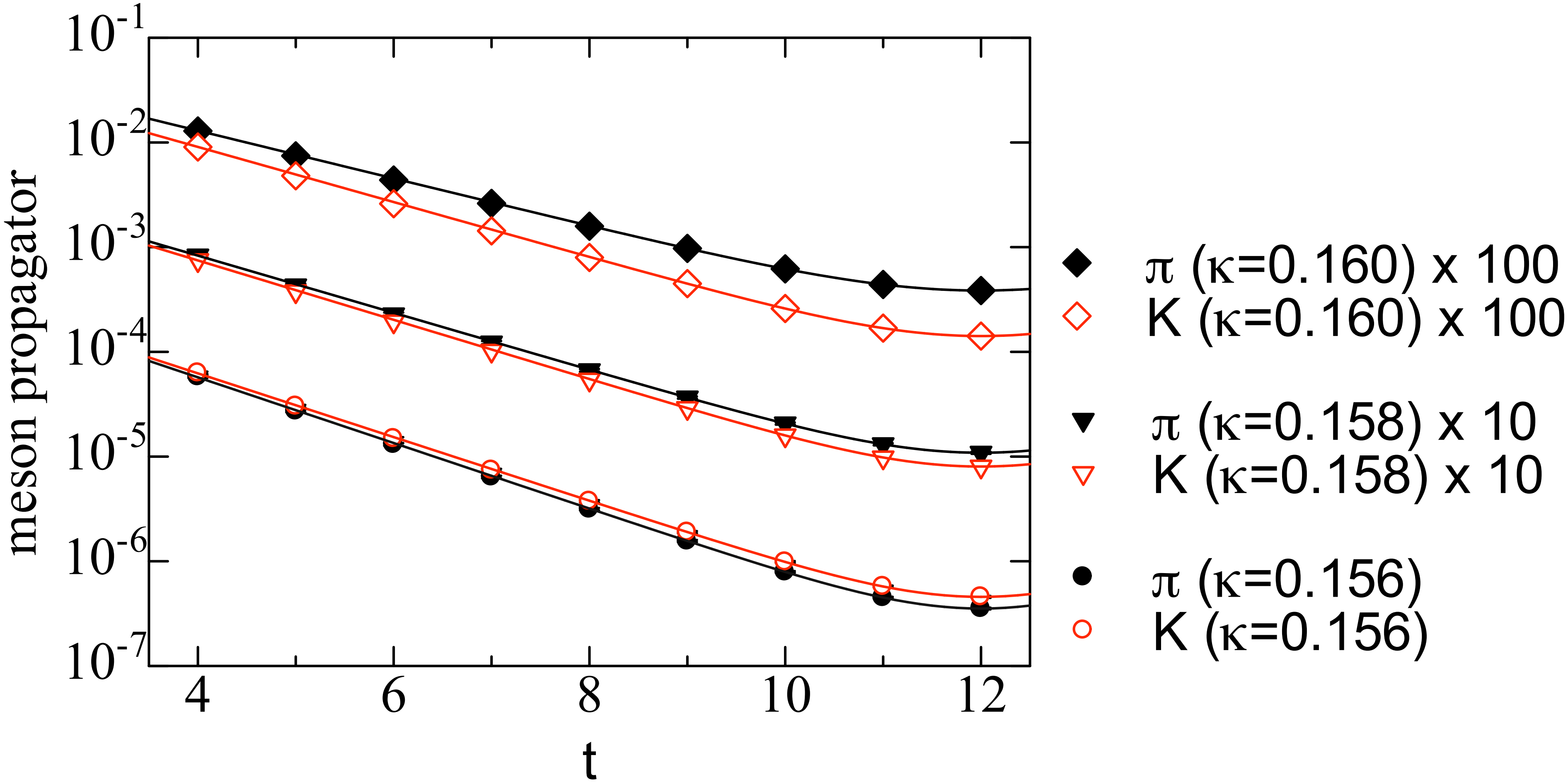
$$\overline{\eta_i^* x_j} = \overline{\eta_i^* W_{jk}^{-1} \eta_k} = W_{ji}^{-1}$$

Complex Z2 noise nr = 4 for each color and spin

Lattice Simulation Data

- Quench Approximation
- Iwasaki Improved Action
- Lattice Size: 12*12*12*24
- β = 2.230 (lattice spacing=0.81436GeV^{-1})
- $\kappa_{q(u,d)}$ = 0.1560, 0.1580, 0.1600 (for u and d)
- κ_s = 0.1570 for s-quark
- No. of Configurations = 20 (2000 sweeps)
- 複素 Z2 noise nr = 4 for each color and spin
- at SX-5 and SX-8 (RCNP, Osaka), SR11000 (KEK and Hiroshima)

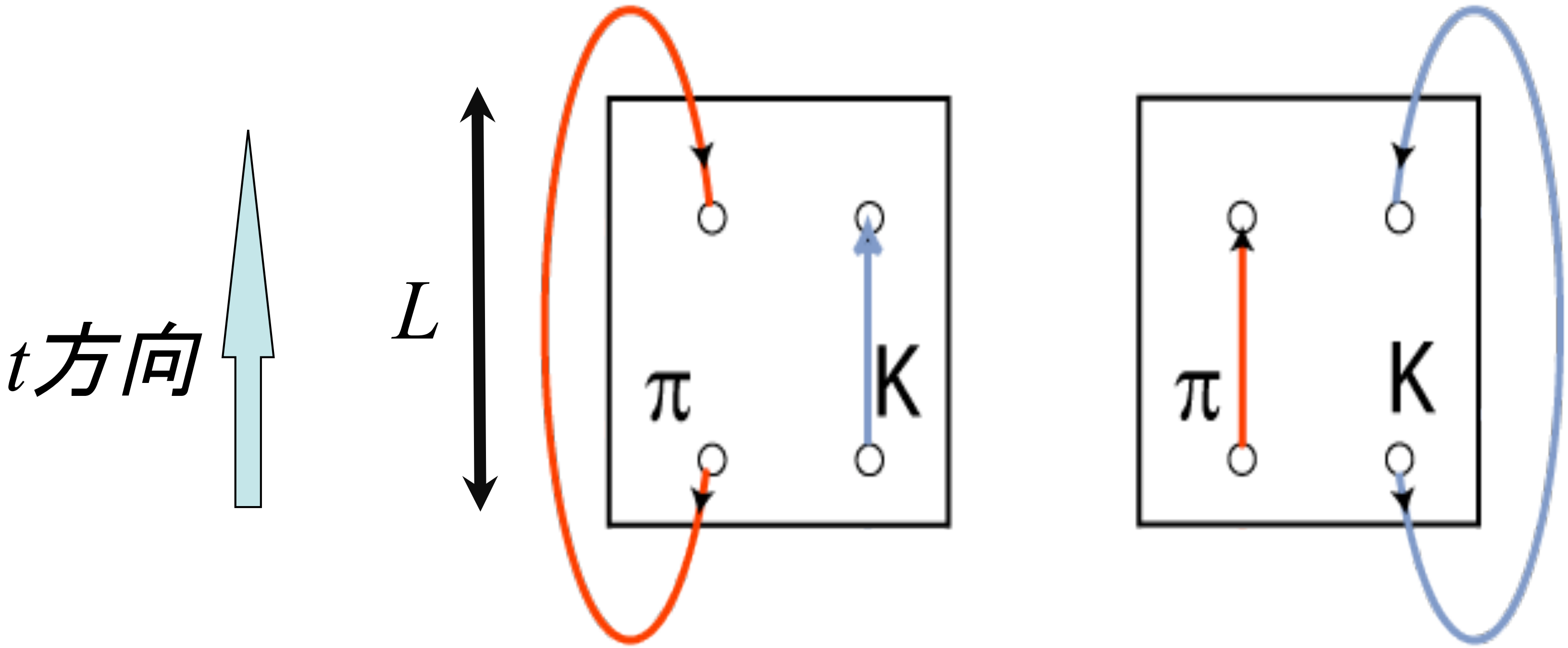
中間子伝播子 π, K



One-pole fit works well

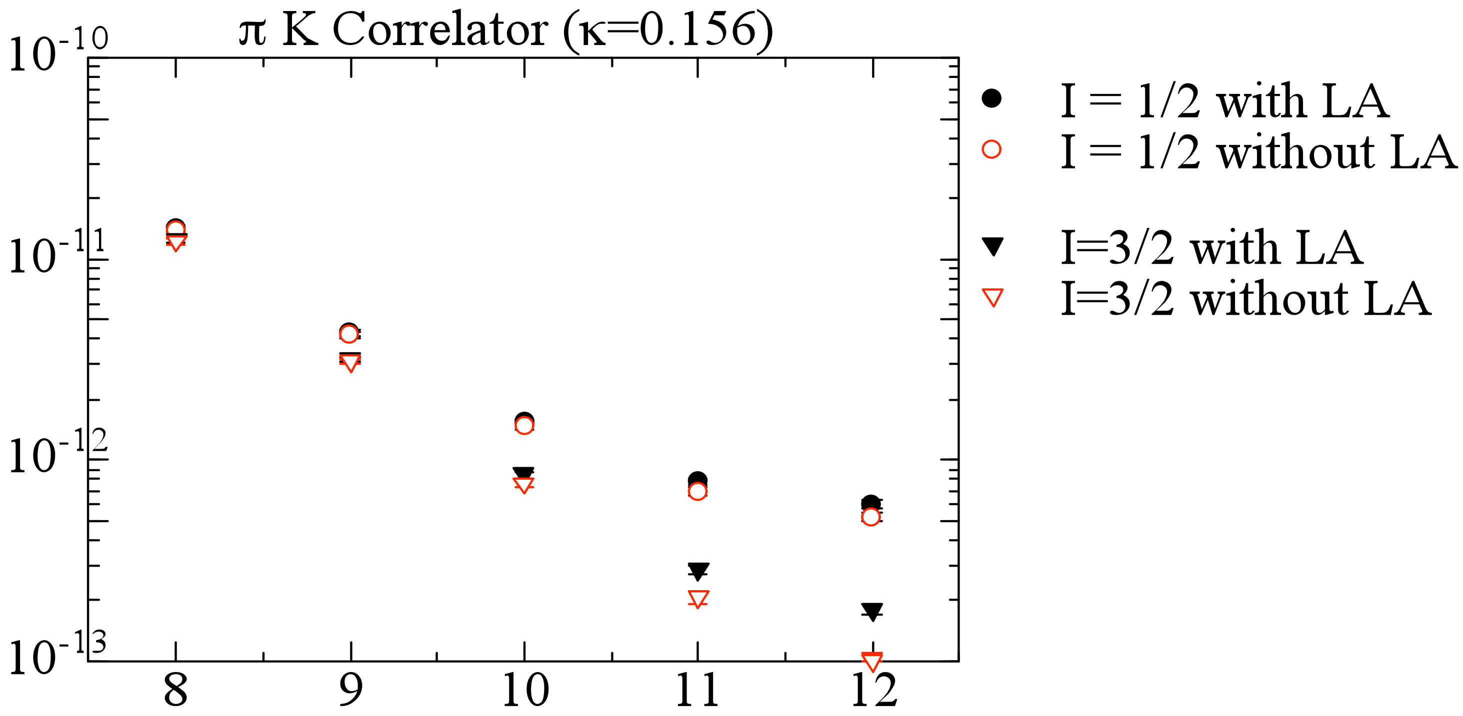
$$C_i = Z_i \cosh(m_i(t - N_t/2))$$

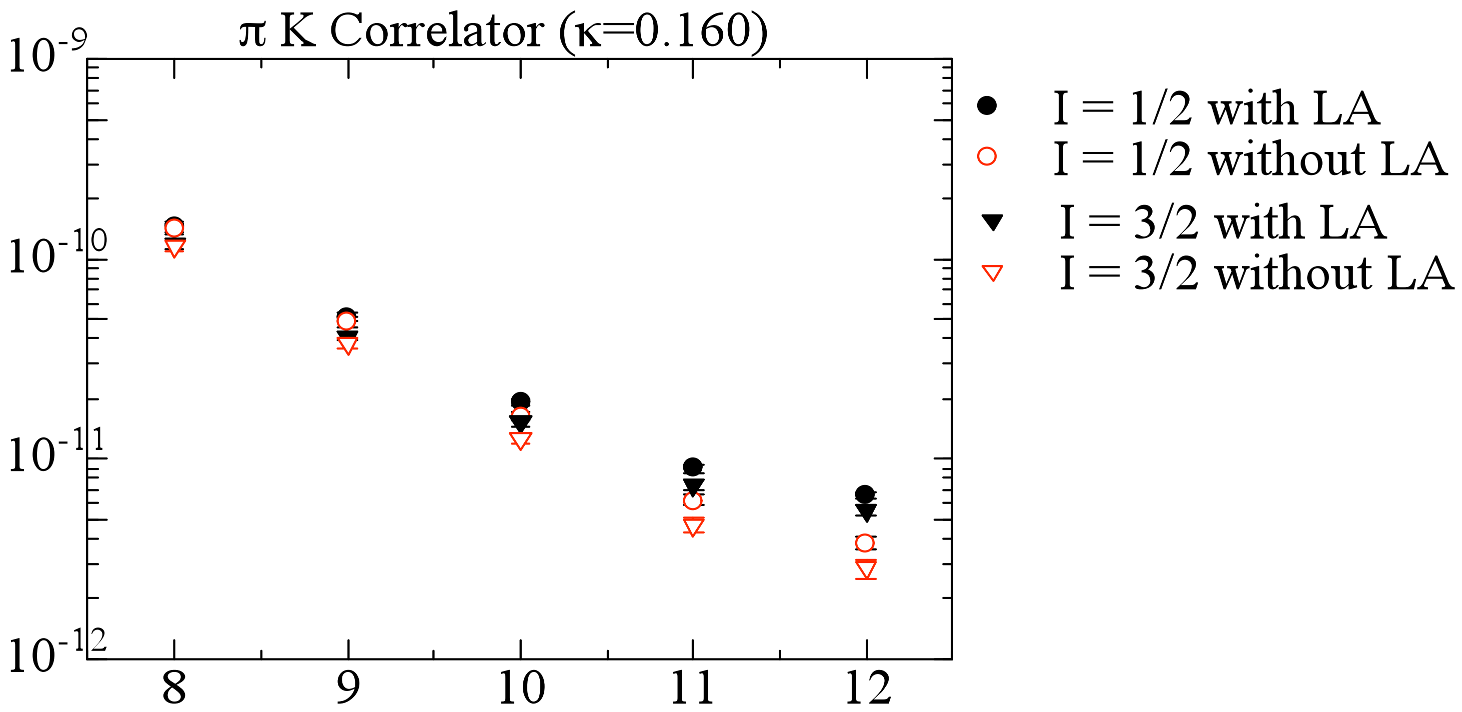
A Lattice Artifact in Kπ



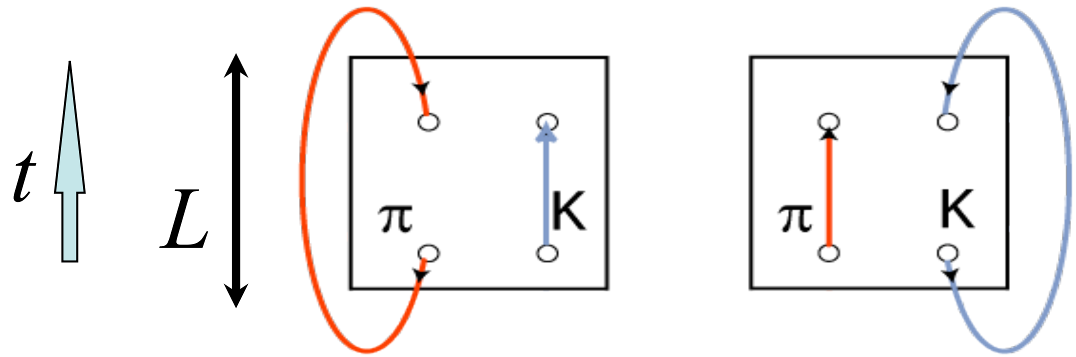
$$A_\pi e^{-m_\pi (N_t - t)} \times A_K e^{-m_K t} + A_\pi e^{-m_\pi t} \times A_K e^{-m_K (N_t - t)}$$

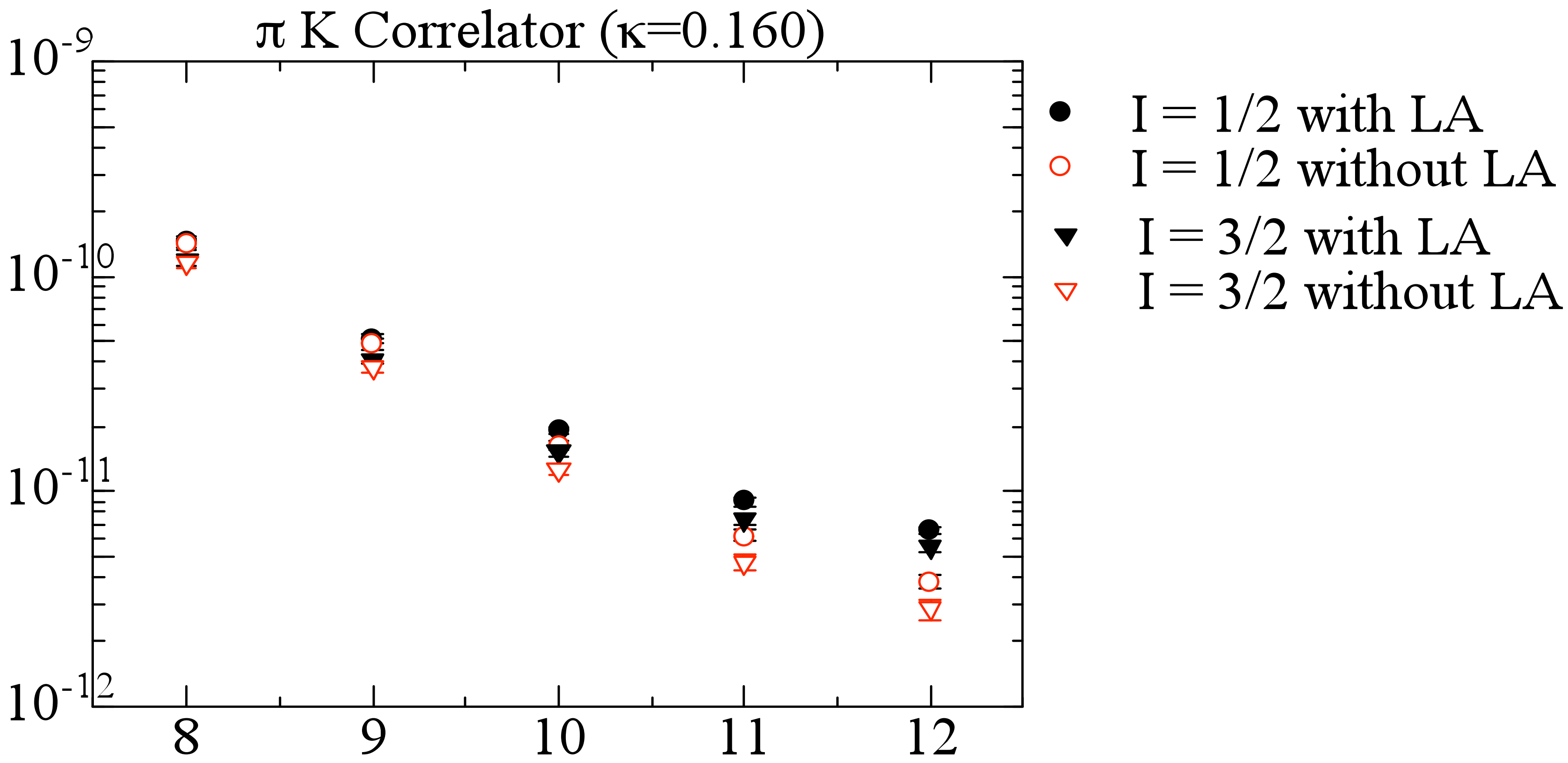
$$= 2 A_\pi A_K e^{-m_\pi N_t/2} e^{-m_K N_t/2} \cosh((m_K - m_\pi)(t - N_t/2))$$


π K Correlator (κ=0.156)
10^-10
10^-11
10^-12
10^-13
8
9
10
11
12
I = 1/2 with LA
I = 1/2 without LA
I=3/2 with LA
I=3/2 without LA

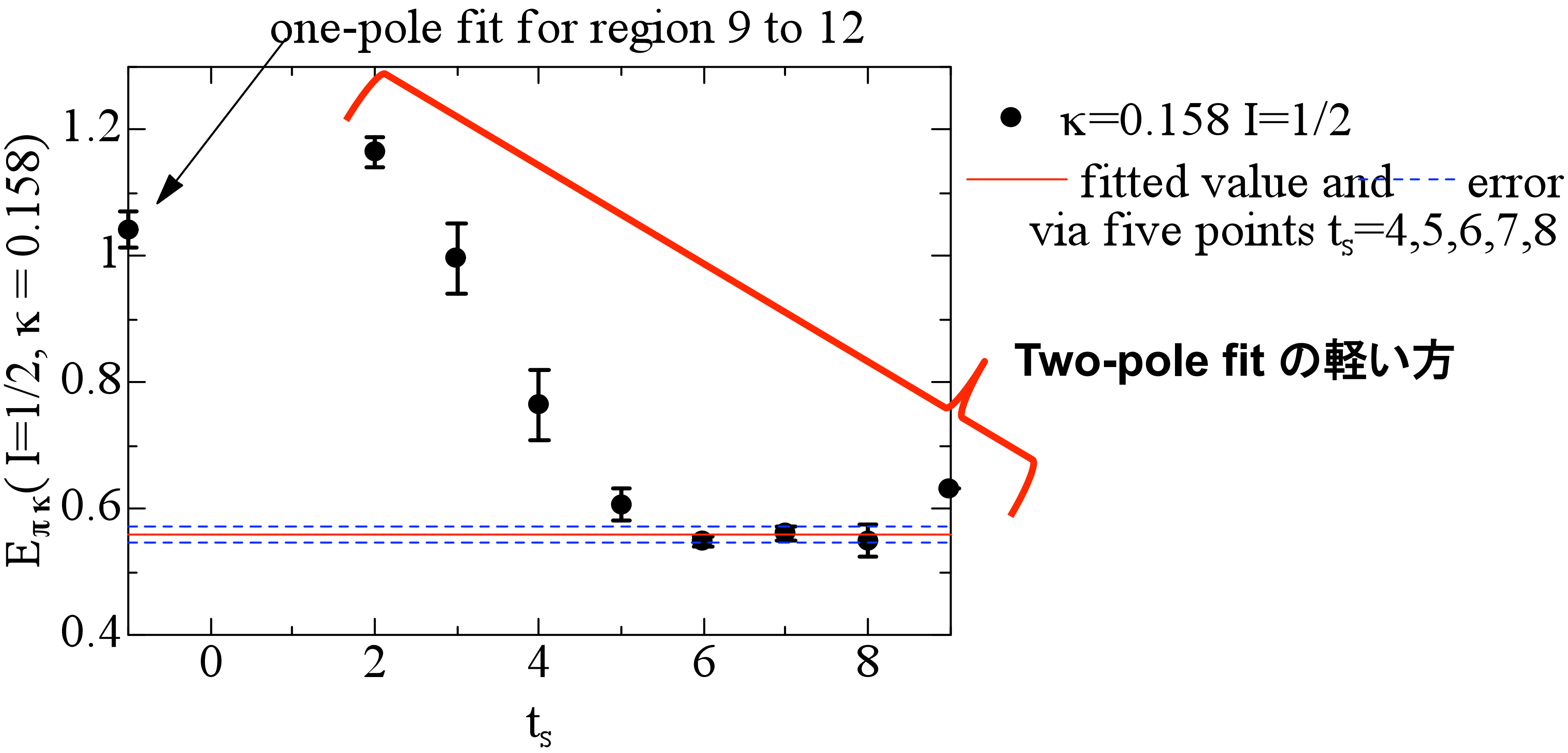

π K Correlator (κ=0.160)
10^-9
10^-10
10^-11
10^-12
8
9
10
11
12
I = 1/2 with LA
I = 1/2 without LA
I = 3/2 with LA
I = 3/2 without LA

A Lattice Artifact in Kπ

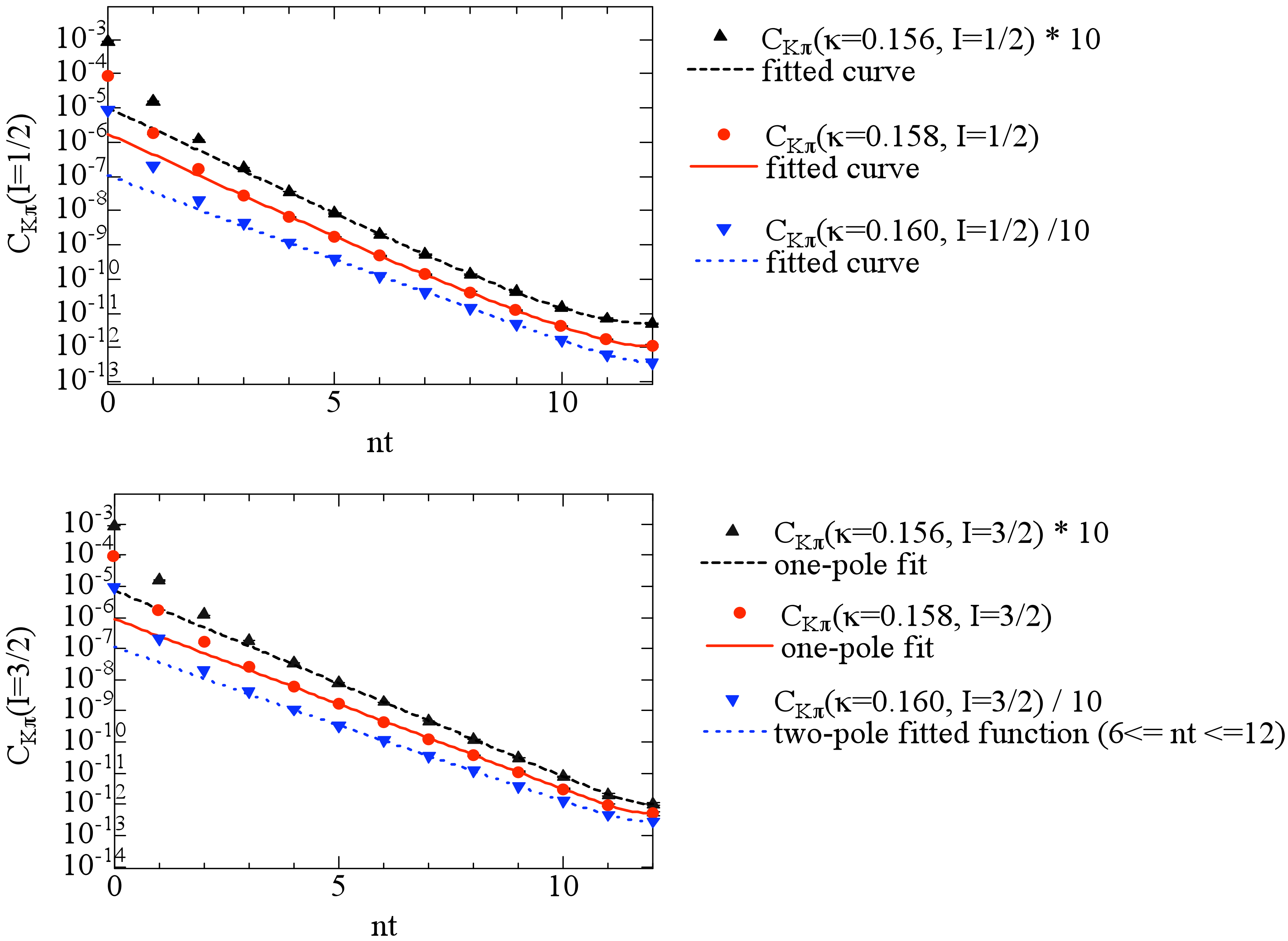




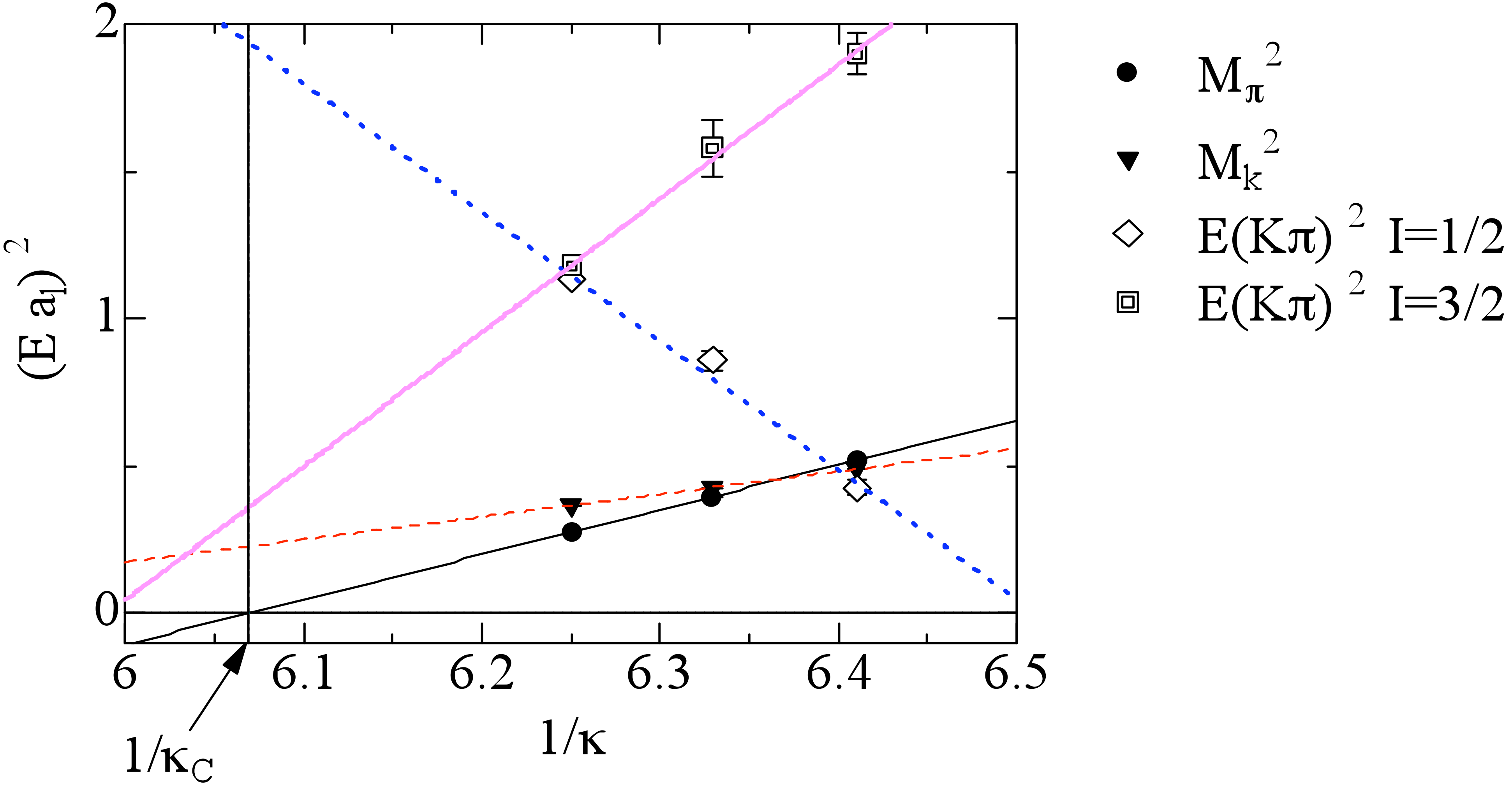
2粒子状態propagator(4体相関)
C(K,π) をtwo-pole fit



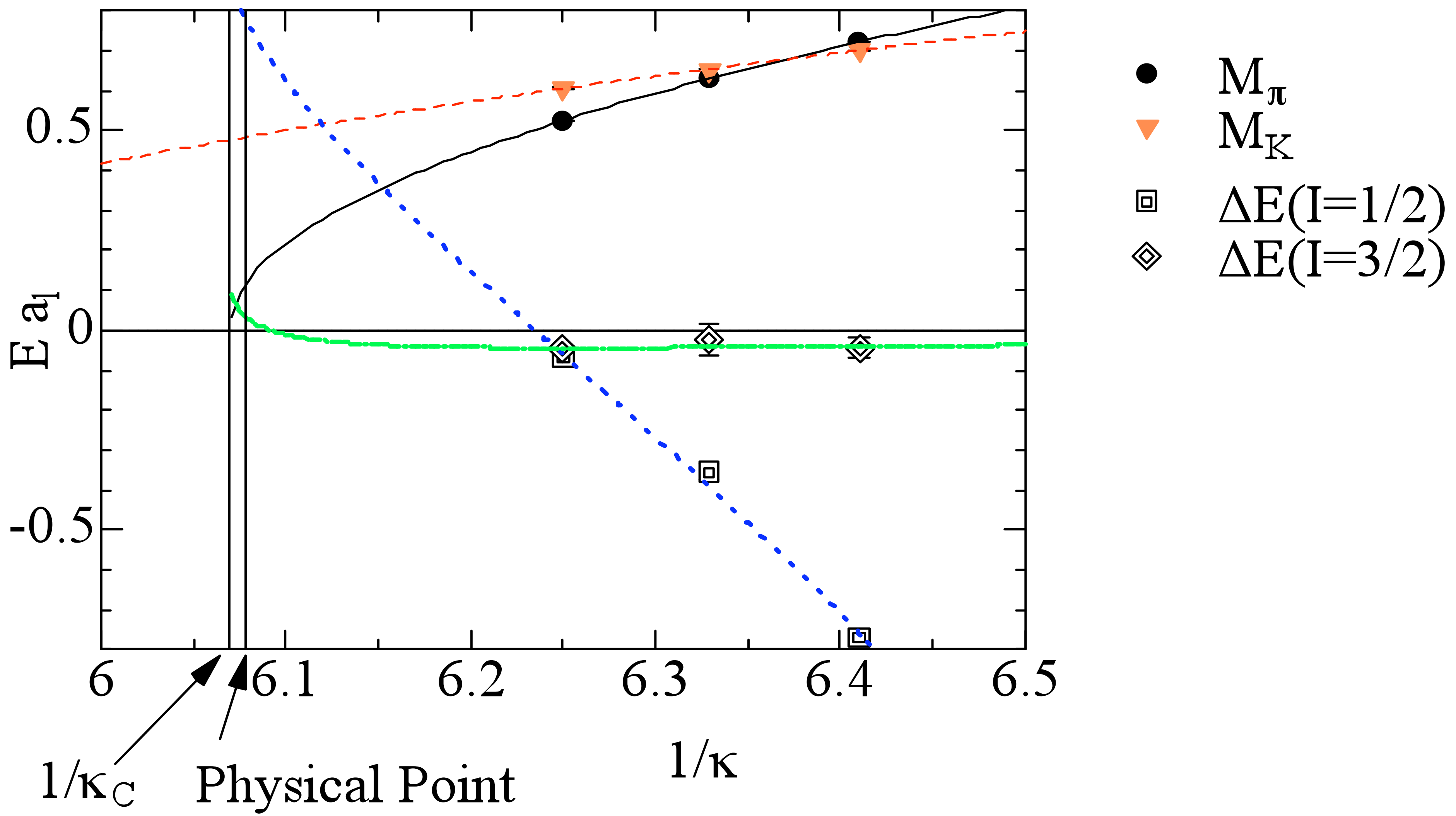
tsからt=12 までの領域を fit 解析に利用



$C_{K\pi}(I=1/2)$
nt
$C_{K\pi}(\kappa=0.156, I=1/2) * 10$
fitted curve
$C_{K\pi}(\kappa=0.158, I=1/2)$
fitted curve
$C_{K\pi}(\kappa=0.160, I=1/2) /10$
fitted curve
$C_{K\pi}(I=3/2)$
nt
$C_{K\pi}(\kappa=0.156, I=3/2) * 10$
one-pole fit
$C_{K\pi}(\kappa=0.158, I=3/2)$
one-pole fit
$C_{K\pi}(\kappa=0.160, I=3/2) / 10$
two-pole fitted function (6<= nt <=12)



質量の2乗をスケールさせたカイラル外挿



$$\Delta E = E(K,\pi) - (mK + m\pi)$$

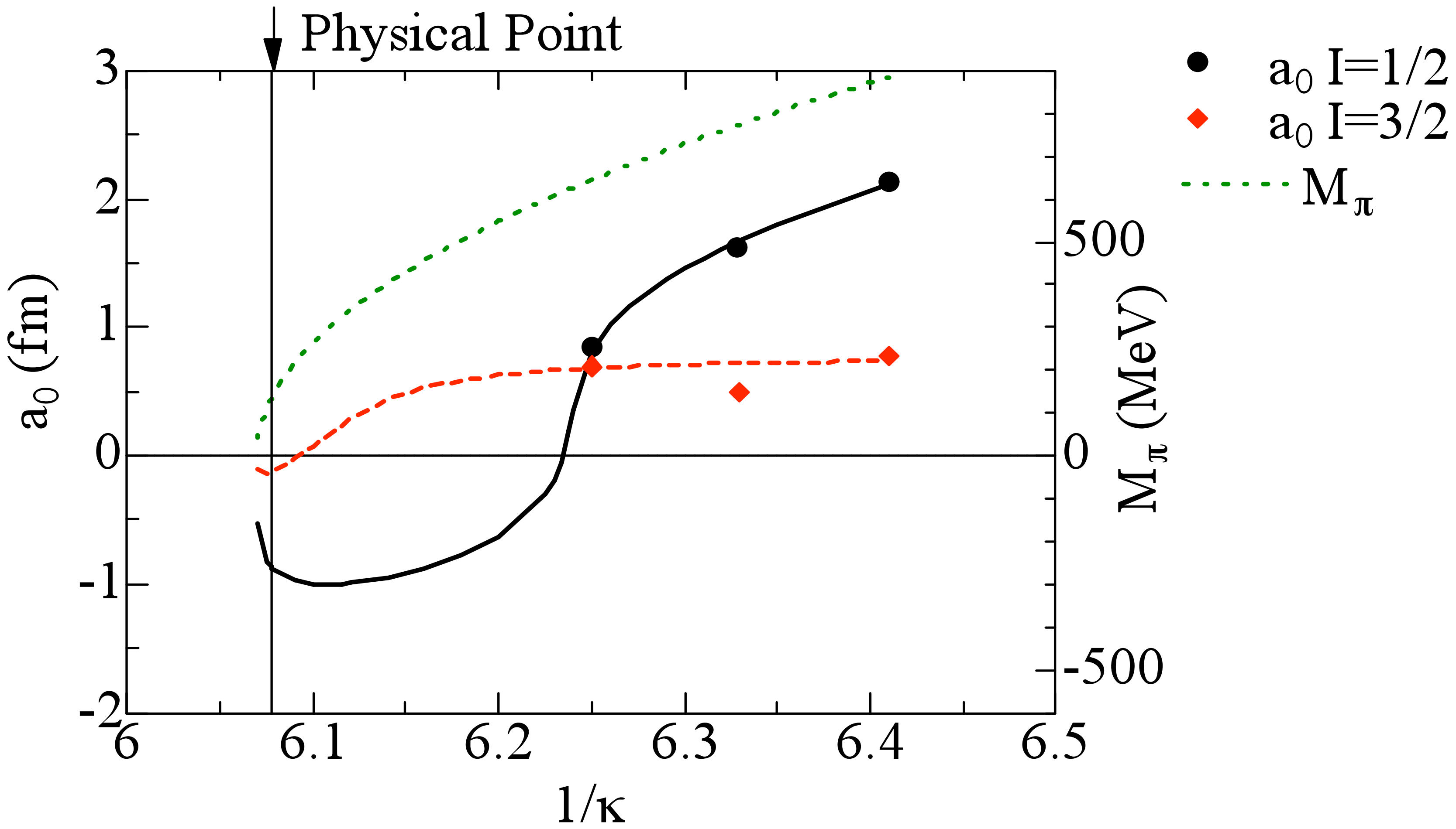


TABLE III: a_0 at the physical point where m_π=139.75 MeV.

	a_0(MeV)	$a_0\ m_\pi$
$I = 1/2$	-0.8794 $^{+0.016}_{-0.017}$	-0.6248 $^{+0.0115}_{-0.0118}$
$I = 3/2$	-0.1178 $^{+0.0712}_{-0.0901}$	-0.0837 $^{+0.0506}_{-0.0640}$

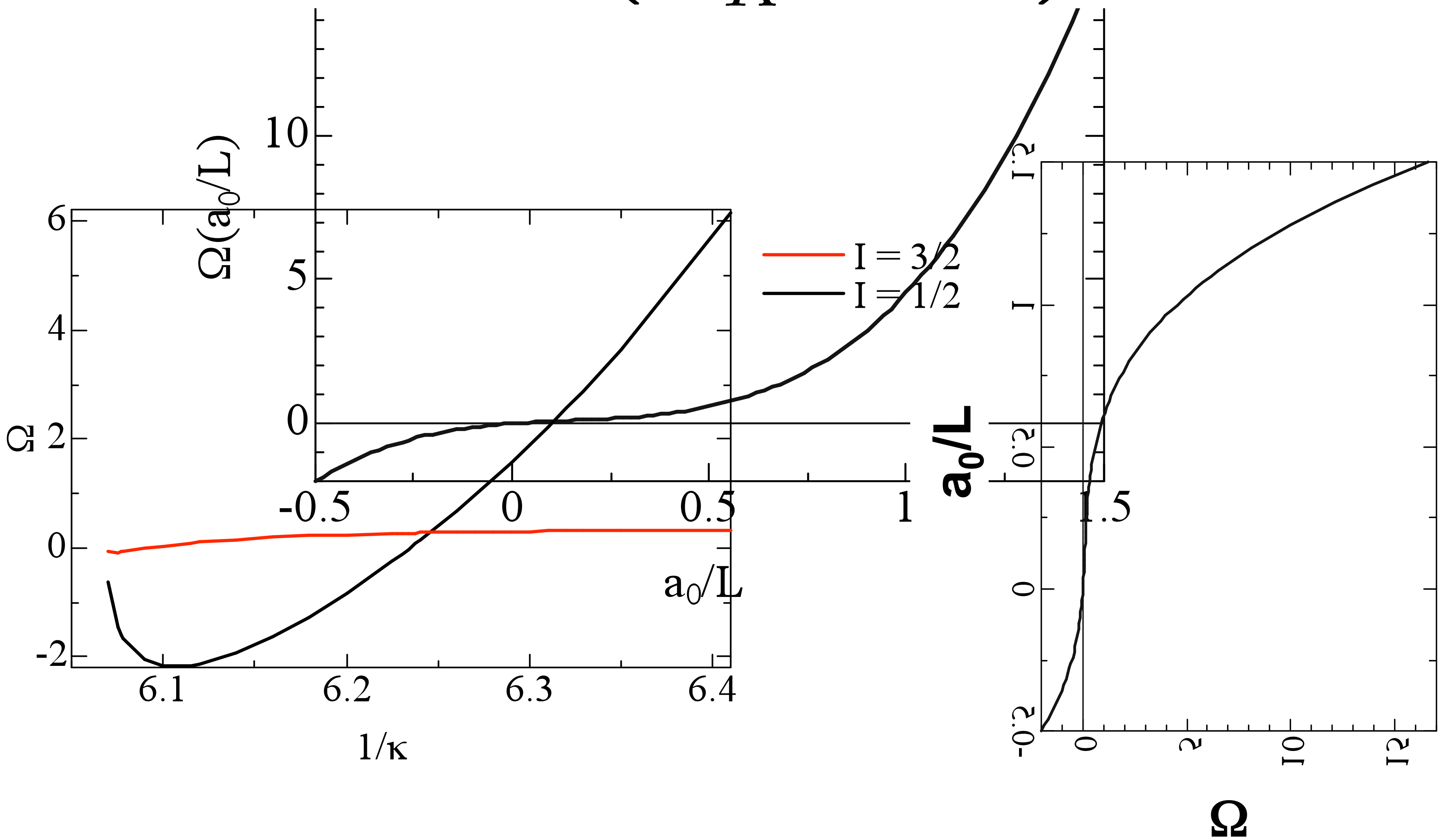
$$\Delta E = E(K,\pi) - (m_K + m_\pi)$$

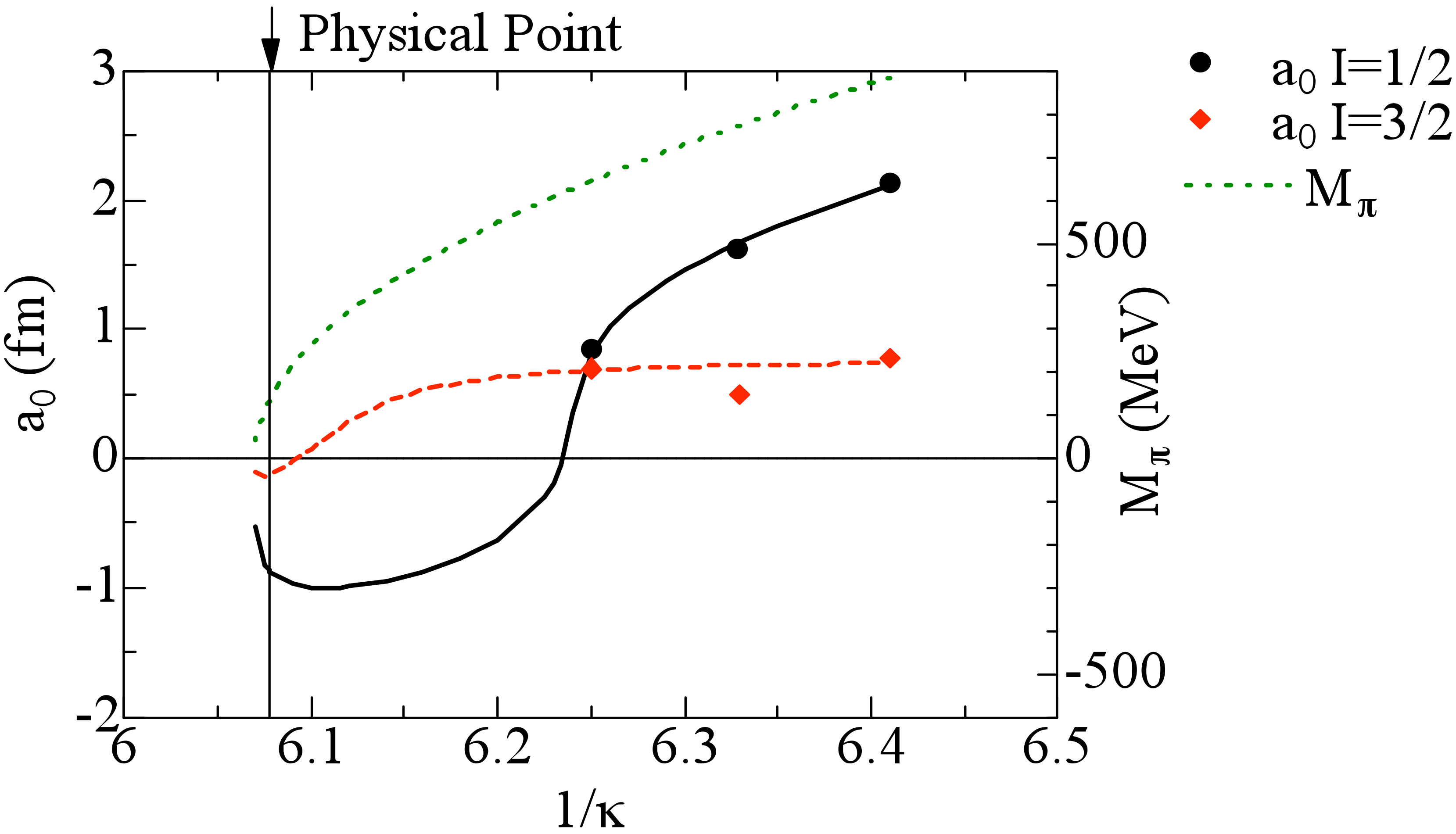
$$= -\frac{2\pi(m_K+m_\pi)}{m_K m_\pi L^2} \times \frac{a_0}{L}\left[1 + c_1\left(\frac{a_0}{L}\right) + c_2\left(\frac{a_0}{L}\right)^2\right] + O\left(\frac{1}{L^6}\right)$$

$$\Omega\left(\frac{a_0}{L}\right)$$

$$\Delta E \times (-1)\frac{m_K m_\pi L^2}{2\pi(m_K + m_\pi)} = \Omega\left(\frac{a_0}{L}\right)$$

$$\Delta E \times (-1) \frac{m_K m_\pi L^2}{2\pi(m_K + m_\pi)} = \Omega(\frac{a_0}{L})$$





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結果とまとめ

- I＝1/2 と I＝3/2 両チャンネルを格子QCDで計算
  - I＝3/2 a0 = - 0.117 fm
    a0 mπ = -0.0831 弱い斥力
  - I＝1/2 a0 = - 0.879 fm
    a0 mπ = -0.624 斥力

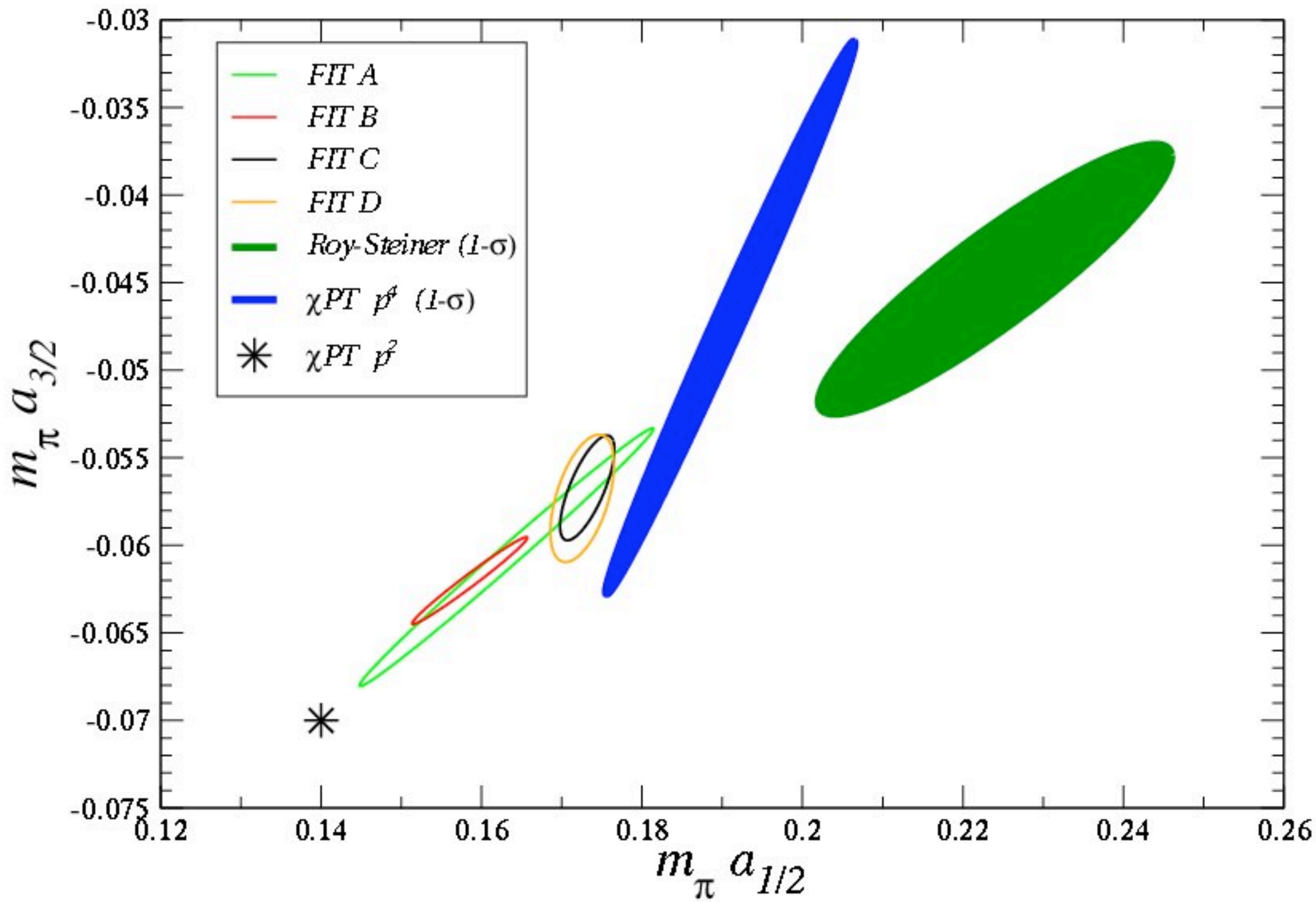
他グループとconsistent

a0(3/2) mπ = - 0.056 +- 0.023 格子 C. Miao et al, PLB595(04)400
- 0.13 ～ -0.05 実験
- 0.129 +- 0.0006 分散＋χ-perturbation
H.Q.Zheng, NPA733(04)235

NPLQCD は, ,

Kπ NLQCD collaboration

- arXiv:0805.4629
  - KS-fermions for Sea Quarks
    + Chiral fermions for Valence Quarks
  - I=3/2 (I=1/2 is estimated from Chiral Perturbation)



$a_0(I=3/2)\ m_\pi$

－0.056 ±0.023 [1] :Lattice QCD
–0.0574±0.0016 [2] : Lattice QCD
–0.05 ±0.02 [3] : one-loop chiral result
–0.07 [4] : tree level calculation
–0.13～ –0.05[5,6,7] : experimentally determined
–0.129[8] : dispersion relations with chiral perturbation theory

[1] C. Miao, X. Du, G. Meng, C. Liu,Phys.Lett. B595 (2004) 400-407.
[2] S. R. Beane, P. F. Bedaque, T. C. Luu, K. Orginos, E. Pallante, A. Parreno, and M. J. Savage, Phys. Rev. D74 (2006), 114503.
[3] V. Bernard, N. Kaiser, and U.-G. Meissner. Nucl. Phys. B357(1991), 129.
[4] V. Bernard, N. Kaiser, and U.-G. Meissner. Phys. Rev. D43 (1991), 2757.
[5] M.J. Matison et al. Phys. Rev. D9 (1974), 1872.
[6] N.O. Johannesson and J.L. Petersen. Nucl. Phys. B68 (1973), 397.
[7] A. Karabouraris and G. Shaw. J. Phys. G6 (1980), 583.
[8] P. Buettiker, S. Descotes-Genon, and B. Moussallam. hep-ph/0310283, 2003.