Particle Physics Project (A01) Report

Tetsuya Onogi (Osaka University)

Members

T. Onogi (Osaka), Y. Kuramashi (Tsukuba), N. Yamada (KEK)

S. Hashimoto, T. Kaneko, J. Noaki (KEK) ,
N. Ishizuka, Y. Taniguchi (Tsukuba),
M. Hayakawa, T. Yamazaki (Nagoya),
Y. Aoki (Riken), N. Ishii (Tokyo),
K.I. Ishikawa (Hiroshima), H. Fukaya (Osaka),
Y. Furui (Teikyo)

T. Izubuchi, E. Shintani (Riken/BNL)

Postdocs

Y. Namekawa (Tsukuba), S.W. Kim (Osaka)

Challenge in lattice QCD

1. Towards realistic 3-flavor QCD
   1. Physical quark mass
   2. Large volume
   3. QED corrections
   4. Good chiral symmetry

   → Configurations will be useful to A02 group

2. Hadronic interactions and bound states
   1. Scattering length
   2. Resonance
   3. Nuclei

   → Complemantary to the approach by A02 group (nuclear potential)

3. Particle Physics Phenomenology
   1. Determination of Low energy constants, form factors
   2. Determination of SM parameters

Are we serious, or not serious enough?

Don't rush!

Lattice is not a model. It should give a definition of the field theory

We should establish reliable calculation based from 1st principles of (lattice) QCD. After establishing the basis, we can embark on various applications.

Choice of fermion action

- In lattice QCD simulation, multiplying Dirac operator appears in the most time consuming part of the calculation.

- Therefore, choice of the fermion is important.
  - Staggered fermion cheapest
  - Wilson fermion reasonable
  - Overlap/Domain-wall fermion expensive

Large Scale 2+1-Flavor Lattice QCD Simulations

PACS-CS
O(a)-improved Wilson fermion

JLQCD
overlap fermion

Complementary

"Physical point simulation" ⟷ "Exact chiral symmetry"

Large volume is feasible with reasonable numerical cost.
No need for chiral extrapolation.
Direct test of the hardon spectrum is possible.

Large numerical cost but the chiral effective theory can be reliably applied.

Both approaches are theoretically under control
as long as they are applied to appropriate problems.

O(a)-improved Wilson fermion by PACS-CS

Highlights from PACS-CS

1. 2+1 flavor QCD near the physical point

   Lattice spacing a ~0.1 fm, Physical Size L ~ 3.2 fm
   Precise hadron mass spectroscopy

2. 1+1+1 flavor QCD+QED at the physical point

   Reweighting method
   Determination of the quark mass

3. Resonances and Atoms

   rho resonance and width
   Helium atom from QCD

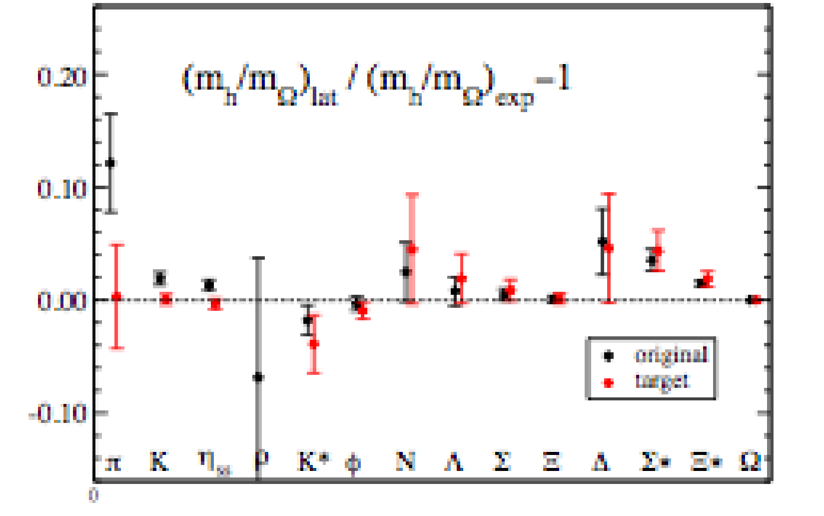
Physical point simulation in 2+1 lattice QCD

S. Aoki et al., (PACS-CS collaboration) [arXiv:0911.2561[hep-lat]]

- O(a)-improved Wilson fermion with PACS-CS and T2K
- $a = 0.09\text{fm}, L = 3\text{fm}$ (Large volume)
- Simulations with physical quark masses

  tuning of quark masses with reweighting

Comparison of the hadron spectrum : lattice vs experiment
Good agreement within a few percent level.



Reweighting Method for 1+1+1

Reweighting from Nf=2+1 QCD to Nf=1+1+1 QCD+QED

$$\langle \mathcal{O}[U](\kappa_{\rm u}^*, \kappa_{\rm d}^*, \kappa_{\rm s}^*)\rangle_{(\kappa_{\rm u}^*,\kappa_{\rm d}^*,\kappa_{\rm s}^*),{\rm fQED}} = \frac{\langle \mathcal{O}[U](\kappa_{\rm u}^*, \kappa_{\rm d}^*, \kappa_{\rm s}^*)\det[W_{\rm uds}[U]]\rangle_{(\kappa_{\rm ud},\kappa_{\rm s}),{\rm qQED}}}{\langle \det[W_{\rm uds}[U]]\rangle_{(\kappa_{\rm ud},\kappa_{\rm s}),{\rm qQED}}}$$

with (κ_u^*,κ_d^*,κ_s^*) hopping parameters at the physical point

$$W_{\rm uds}[U] = \prod_{q={\rm u,d,s}} \frac{D(e_{\rm ph}Q_q, \kappa_q^*)}{D(0, \kappa_q)}$$

	Our results [MeV]	Experiment [MeV]
m_{π^+}	137.7(8.0)	139.57018(35)
m_{K^+}	492.3(4.7)	493.677(16)
m_{K^0}	497.4(3.7)	497.614(24)
m_{Ω^-}	input	1672.45(29)

Quark masses with NP renormalization factor

- NP renormalization factor with Schrödinger functional scheme
  PACS-CS, JHEP1008(2010)101
  PRD81(2010)074503 [2+1f QCD (1)]
  PRD79(2009)034503 [2+1f QCD (2)]
- neglect QED corrections to the renormalization factor
- physical inputs: $m_{\pi+}$, m_{K0}, m_{K+}, $m_{\Omega-}$
- MS-bar scheme at μ=2GeV

	This work	2+1f QCD (1)	2+1f QCD (2)
m_u [MeV]	2.57(26)(07)		
m_d [MeV]	3.68(29)(10)		
m_s [MeV]	83.60(58)(2.23)	86.7(2.3)	87.7(3.1)
m_{ud} [MeV]	3.12(24)(08)	2.78(27)	3.05(12)
m_u/m_d	0.698(51)		
m_s/m_{ud}	26.8(2.0)	31.2(2.7)	28.78(40)

- possible QED finite size effects: −13.50% for u, +2.48% for d, −0.07% for s
  Blum et al., PRD82(2010)094508

Highlights from PACS-CS

$(k^3/\tan\delta(k))/\sqrt{s}$

"Rho meson decay from lattice"

$g_{\rho\pi\pi}, \Gamma_\rho$ can be determined!

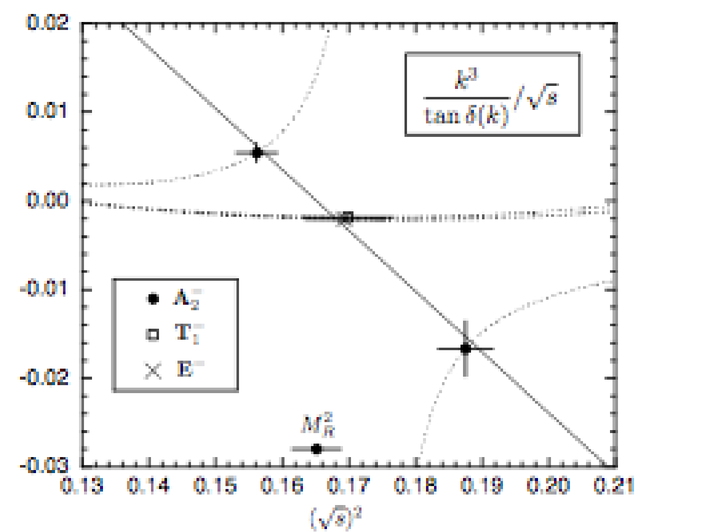
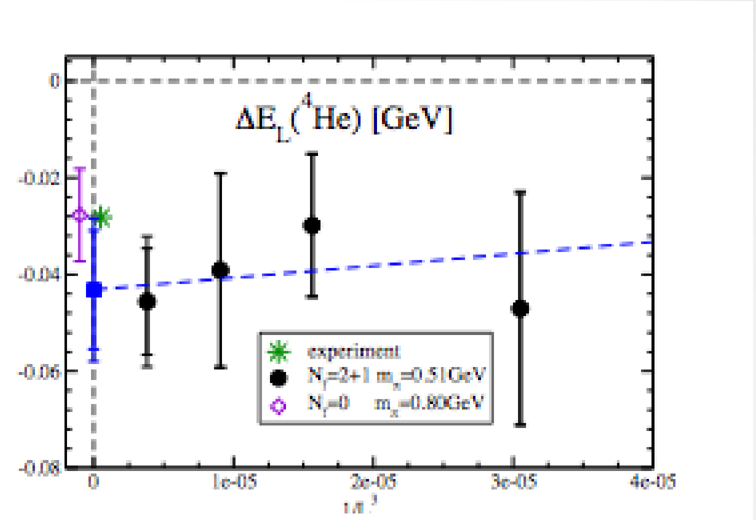


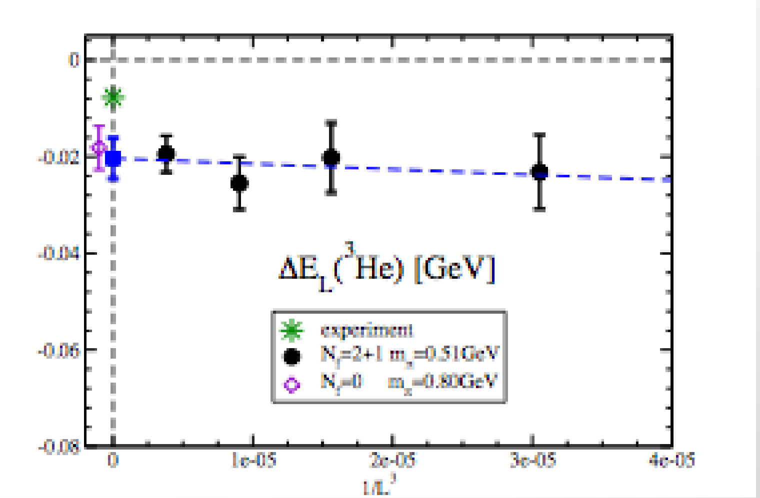
Table 1: Results for the effective $\rho \to \pi\pi$ coupling constant $g_{\rho\pi\pi}$.

collab.	#flavor	m_π [MeV]	$g_{\rho\pi\pi}$
CP-PACS	2	330	6.25(67)
QCDSF	2	240–810	$5.3^{+2.1}_{-1.5}$
ETM	2	290,330,420,480	6.77(67),6.31(87),6.19(42),6.46(40)
PACS-CS	2+1	410	5.24(51)
BMW	2+1	200,340	5.5(2.9),6.6(3.4)

“Helium Nuclei from lattice” talk by T. Yamazaki

- Quenched and Nf= 2+1 QCD
- Study of volume dependence
- <u>Significant cost reduction in Wick contraction</u>
- Good agreement with experiment



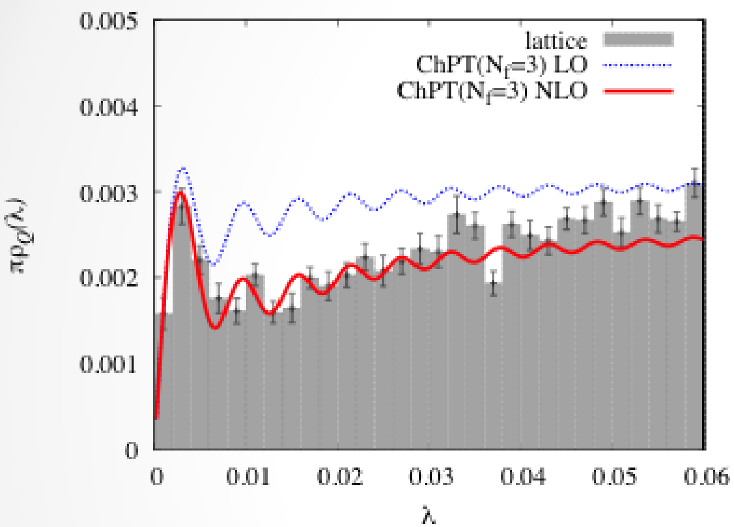


Highlights from JLQCD

1. Chiral Dynamics
   - Chiral Condensate
   - Test of Chiral Perturbation Theory
   - $\Pi^0 \rightarrow \gamma\gamma$
   - Strange quark content

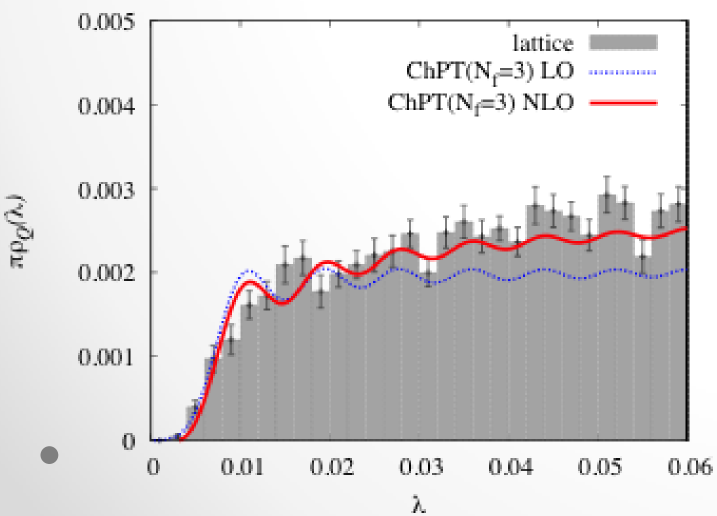
2. Vacuum Polarization
   - Sum Rule : S-parameter and pseudo NG –boson
   - alpha_s from vacuum polarization

Chiral Condensate



Eigenvalue spectrum of the Dirac operator

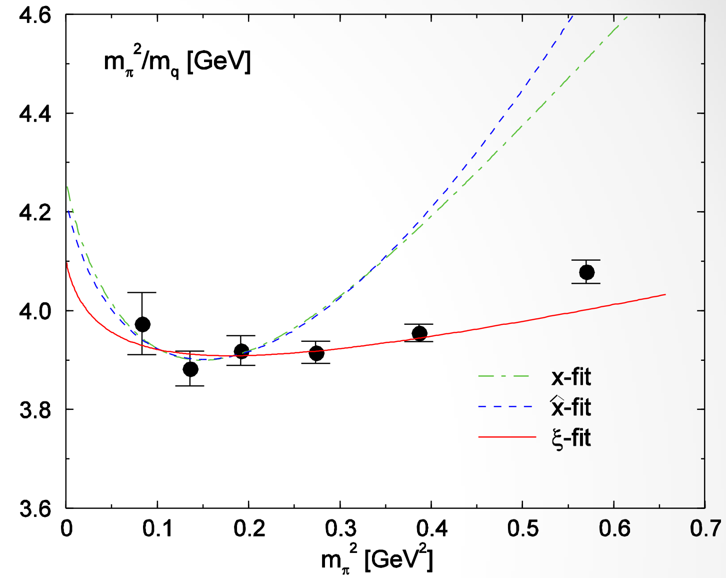
Comparison with the results
from lattice QCD in epsilon-regime
and ChPT in epsilon-regime

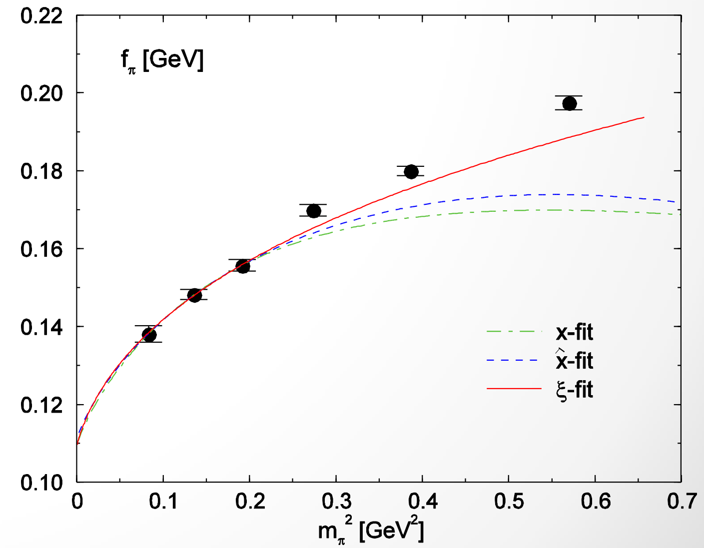


$$\Sigma^{\overline{MS}}(2\,\mathrm{GeV}) = (251 \pm 7(\mathrm{stat}) \pm 11(\mathrm{syst})\,\mathrm{MeV})^3$$

Test of ChPT

Nf=2, *a*=0.12fm, *Q*=0





Chiral extrapolation

- Fit parameter:

$$x \equiv \frac{m^2}{(4\pi f)^2}, \hat{x} \equiv \frac{m_\pi^2}{(4\pi f)^2}, \xi \equiv \frac{m_\pi^2}{4\pi f_\pi)^2}$$

- NLO fit formula

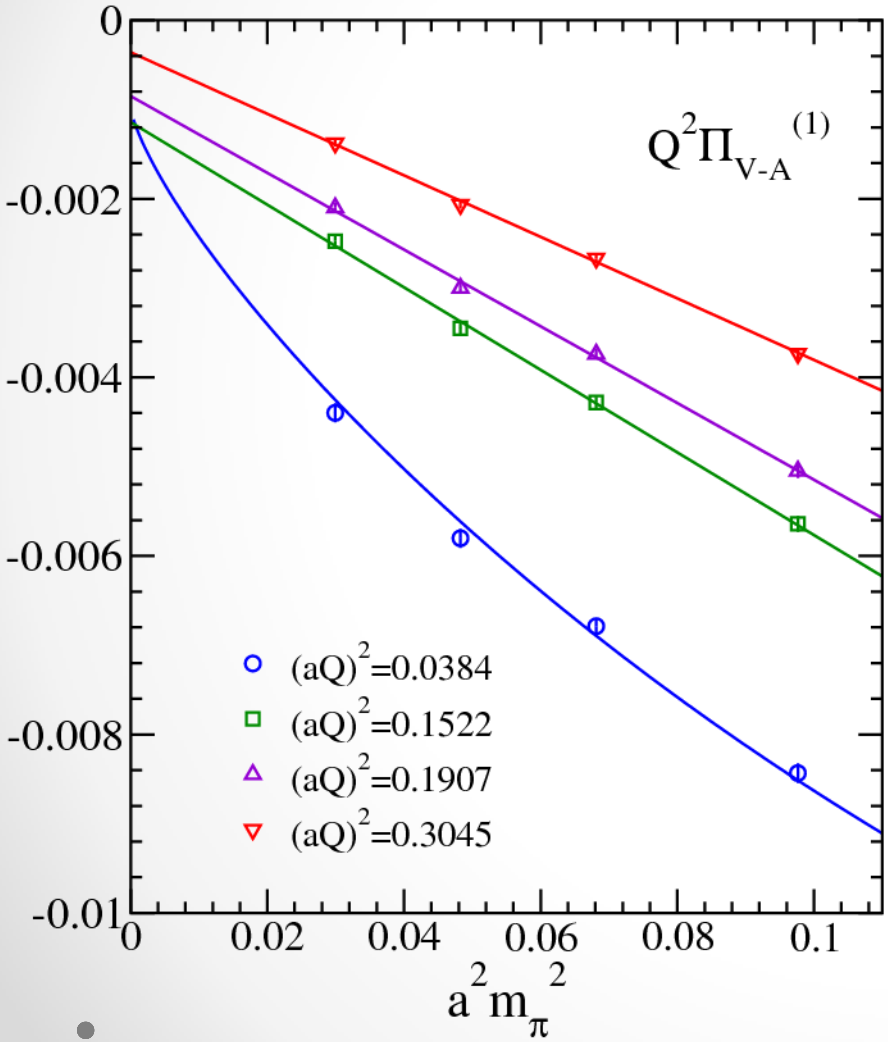
$$\frac{m_\pi^2}{m_q} = 2B[1 + \ln x + c_3 x + O(x^2)]$$
$$f_\pi = f[1 - 2x \ln x + c_4 x + O(x^2)]$$

- NLO gives a good fit fo$m_\pi < 0.45$ GeV

ξ extends the region for convergence significantly.

Comparison with ChPT

- $\Pi_{V\text{-}A}^{(1)}$



- Blue line : fit with CHPT formula at $(aQ)^2$ =0.038.
- CHPT well describes lattice results
  Fit results:

  $$\boxed{L_{10}^r(m_\rho) = -0.0052(2)\binom{+0}{-3}\binom{+5}{-0}}$$

  cf. exp. + CHPT: -0.00509(57)

  c.f. RBC/UKQCD: L10= -0.0057(11)(7)

- Other line: linear fit
- $(aQ)^2 > 0.1$
  CHPT (1-loop) does not work
  $\Rightarrow$ need higher order

$S \sim 0.4$

Result of Δm_π^2

- Fit range: $(aQ)^2 \leqq 2 = \Lambda^2$
  at zero quark mass

$$\boxed{\Delta m_\pi^2 = 993(12)(^{+0}_{-135})(149)\ \mathrm{MeV}^2}$$

1^{st} error : statistical
2^{nd} error : fit form dependence
3^{rd} error : uncertainty of a_6

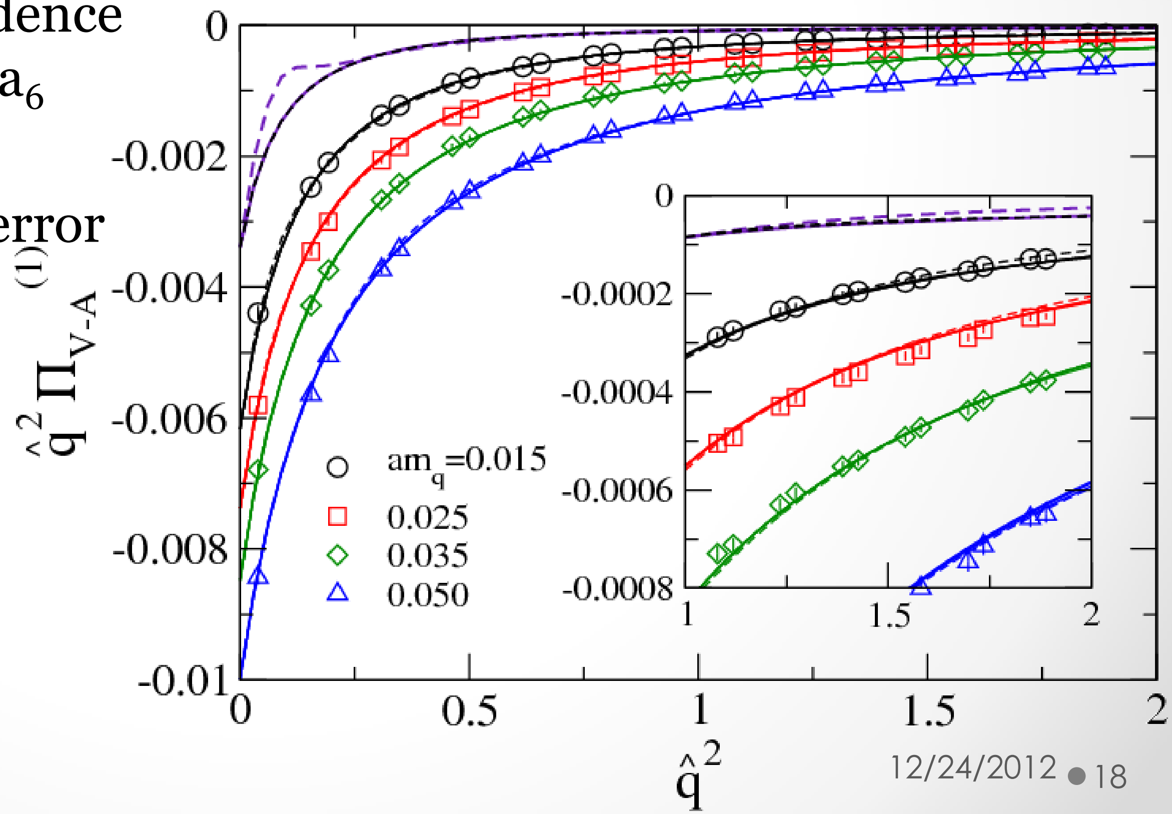
reasonable value,
but still large systematic error

Other remaining error
- finite size
- strange quark mass

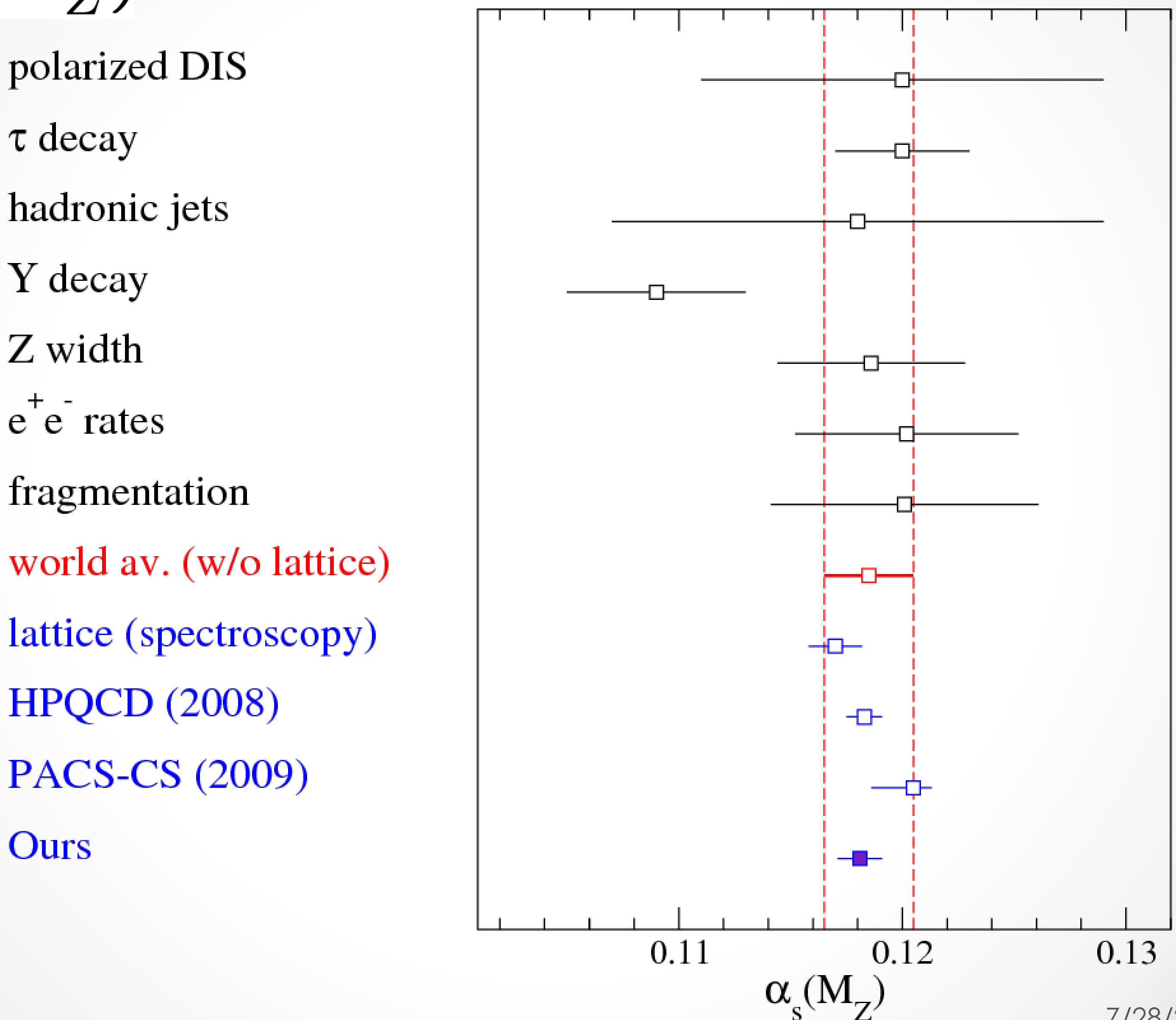
cf. experimental value
1261 MeV² at physical pion

c.f. RBC/UKQCD
$\Delta m_\pi^2 = 1180(260)$ MeV

Solid line : X_1,
Dashed line : X_2

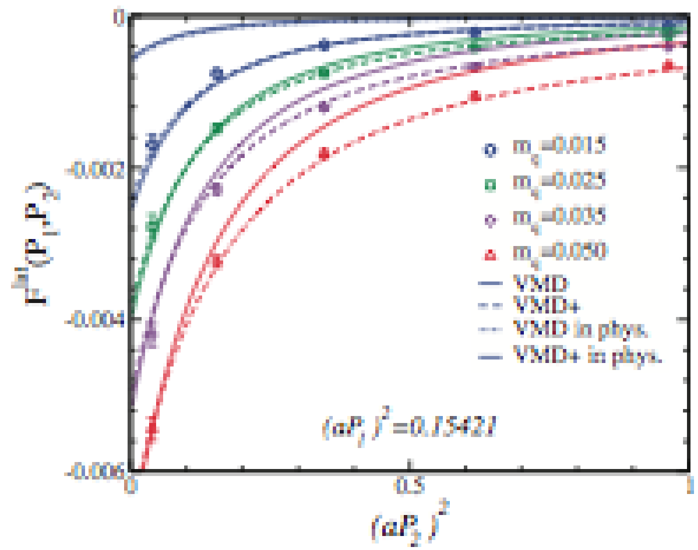


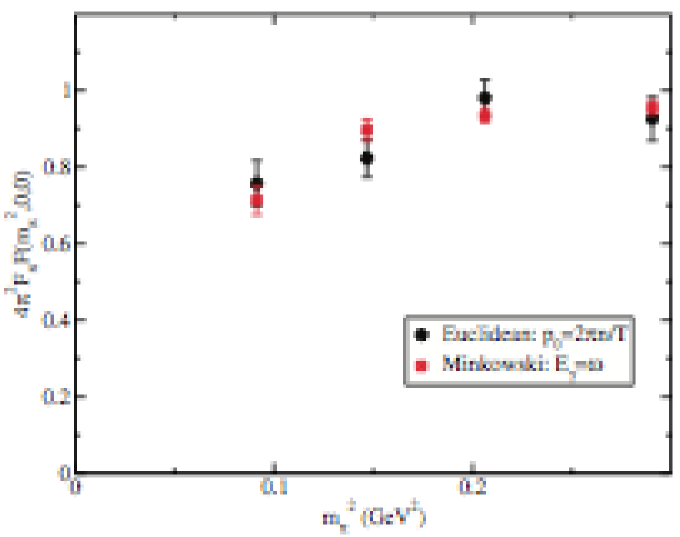
$\alpha_s^{\overline{\mathrm{MS}}}(M_Z)$



$\pi^0 \rightarrow \gamma\gamma$

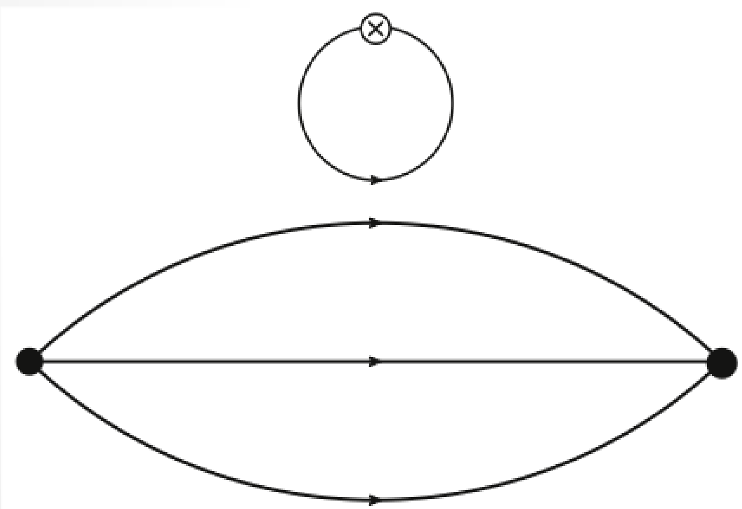
3-point function for A-V-V

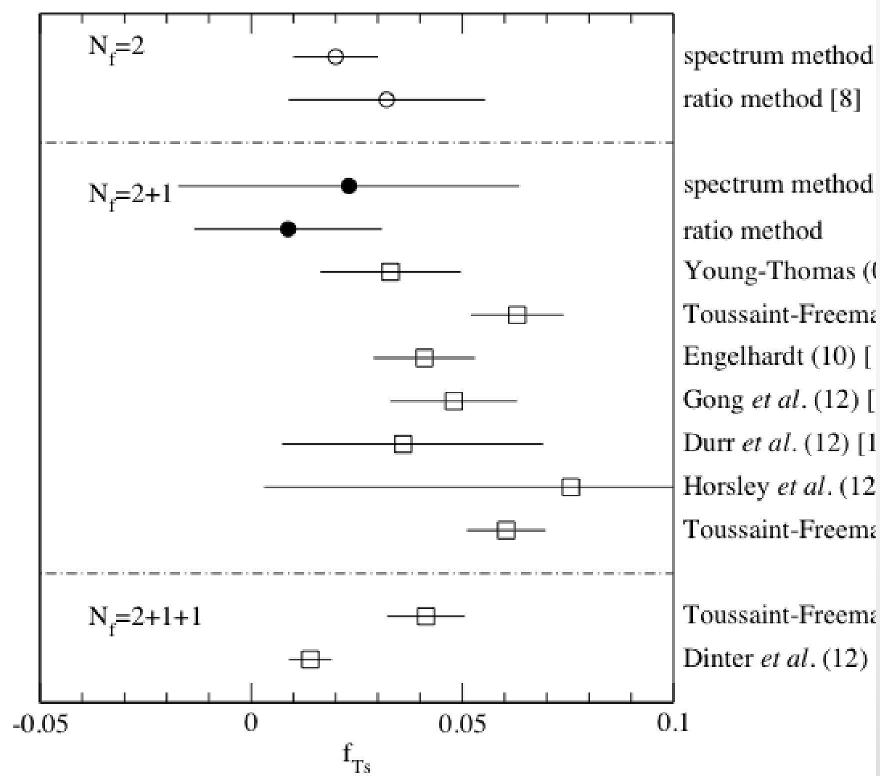




Nucleon sigma term

Spectrum method (Feynman Hellman theorem)
Direct method (Matrix element)





Summary

1. Lattice method for 2+1-flavor QCD at present can successfully describes the hadron dynamics.

2. Approach from O(a)-improved Wilson fermion by PACS-CS is suitable for persue reallistic QCD in large volume and physical quark mass. Now ready for application to nuclear interactions.

3. Overlap fermion by JLQCD is suitable to physics sensitive to exact chiral symmetry. Application to flavor physics, chiral phase transition, and other new subjects is expected.