Nucleon Form Factors near the Physical Point in 2+1 Flavor QCD

Y.Kuramashi for PACS Collaboration
U. of Tsukuba/RIKEN AICS

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Plan of talk

- PACS Collaboration Members
- Simulation Details
- Quick Check of 2-pt Functions
- Results for 3-pt Functions (Z_V, g_A, G_E, G_M)
- z-Expansion Analyses for $G_E(Q^2)$ and $G_M(Q^2)$
- $\sqrt{\langle r_E^2 \rangle}$ and magnetic moment
- Summary

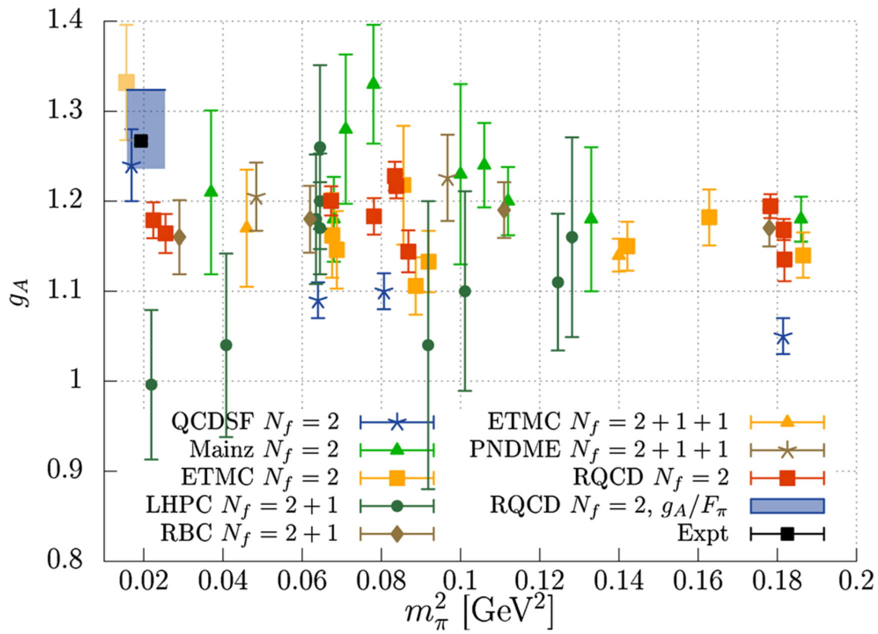
PACS Collaboration Members

N.Ishizuka, Y.Kuramashi, Y.Namekawa, Y.Taniguchi, N.Ukita, T. Yamazaki, T.Yoshié	Tsukuba
Y.Nakamura, E.Shintani	RIKEN-AICS
K.-I.Ishikawa	Hiroshima
N.Tsukamoto, S.Sasaki	Tohoku
T.Izubuchi	BNL

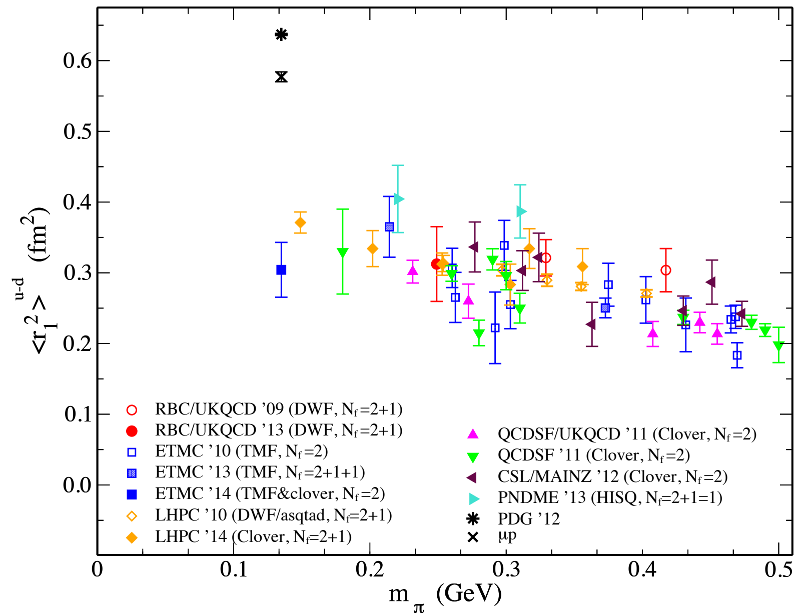
Successor to PACS-CS, CP-PACS Collabs.

Introduction

gA @ Lattice 2015



$\sqrt{<r_E^2>}$ @ Lattice 2014



Not yet reached quantitative understanding

Simulation Parameters for 2+1 Flavor QCD

PoS(LATTICE2015)075

- Wilson-clover quark action + Iwasaki gauge action
- Stout smearing with α=0.1 and N_{smear}=6
- NP C_{SW}=1.11 determined by SF
- β=1.82 ⇒ a^{-1}∼2.33 GeV
- Lattice size=96^4 ⇒ (∼8.1 fm)^3 spatial volume allows small q^2 region
- Hopping parameters: (κ_{ud},κ_s)=(0.126117,0.124790)
  ⇒ m_π≈145 MeV, $m_\pi L$≈6

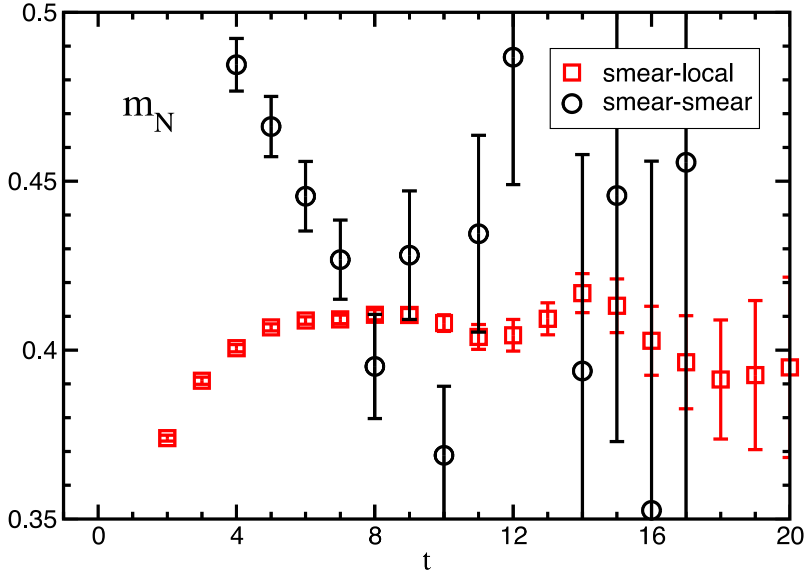
- Basic physical quantities are already measured
  - Hadron spectrum
  - Quark masses with NP renormalization
  - Pseudoscalar meson decay constatnts
  - LEC's in SU(2) ChPT
  - Nucleon σ term

Measurement Details

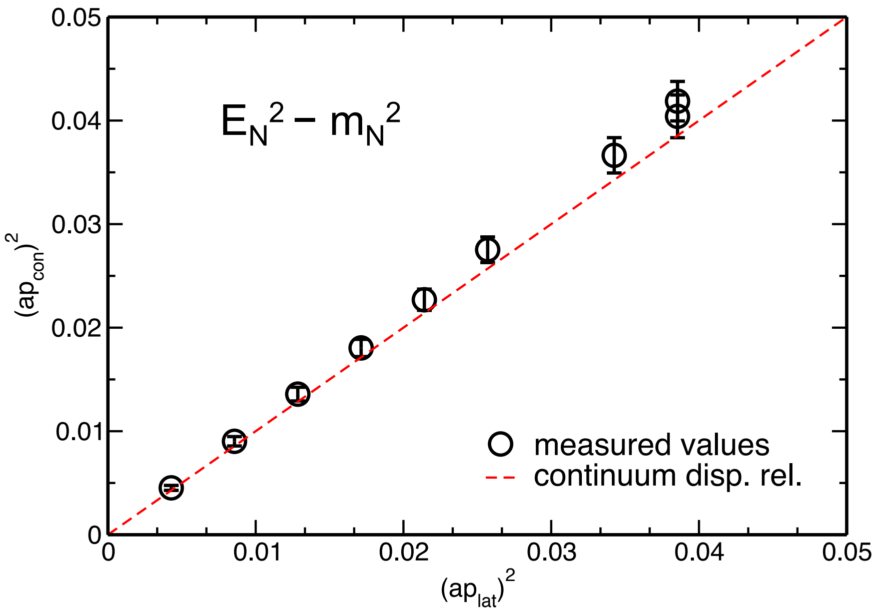
- Refer to PoS(LATTICE2015)081 for Lattice 2015 contribution
- Current statistics: 146 configs (still increasing the statistics)
- 64 measurements/config ⇒ $O(10^4)$ measurements so far
- 9 choices for spatial momenta:
  $\vec{n}$=(1,0,0),(1,1,0),(1,1,1),(2,0,0),(2,1,0),(2,1,1),(2,2,,0),(3,0,0),(2,2,1)
  minimum mom=$2\pi/L \sim 0.152$ GeV thanks to $L \sim 8.1$ fm
- Lattice size=96^4 ⇒ $(\sim 8.1 \text{ fm})^3$ spatial volume allows small q^2 region
- Exp smeared src/sink operators for 2-pt and 3-pt functions
- Src-sink separation: $t_{sink} - t_{src} = 15$ ($\sim$1.3 fm)
- Z_A=0.9650(68)(95), Z_V=0.95153(76)(1487) in SF scheme
  PoS(LATTICE2015)271

Nucleon Rest Mass and Dispersion Relation

Effective mass for N



Dispersion relation



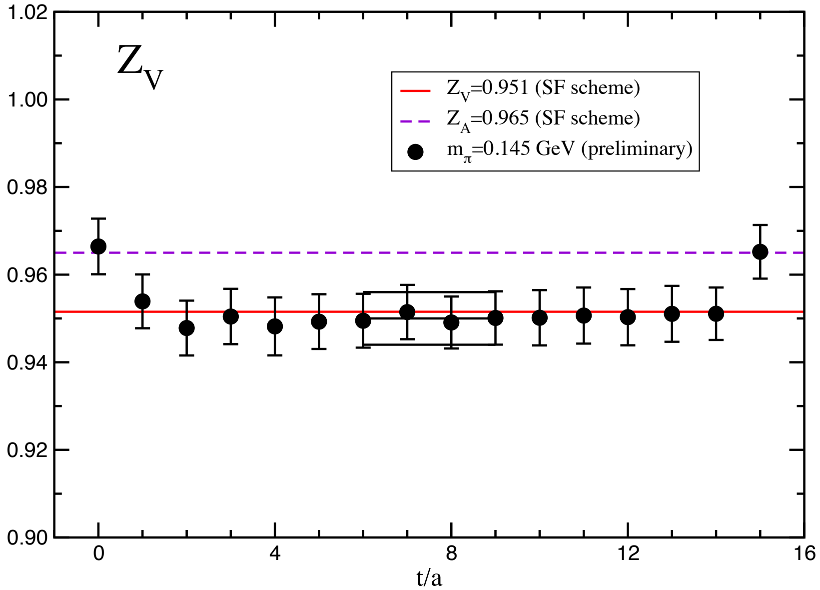
$p_{lat}^2=(2\pi/L)^2\times|\vec{n}|^2$

Plateau is observed in $t\geq 6$ for effective m_N

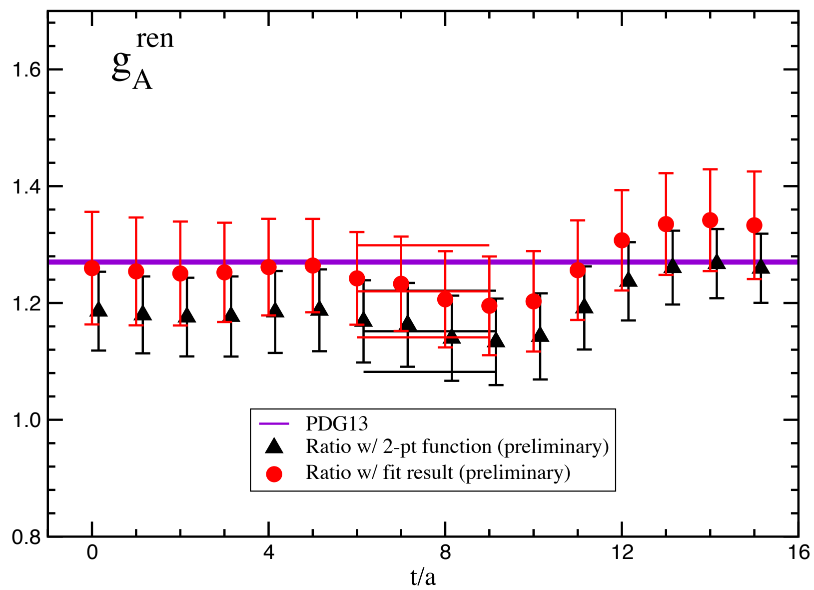
Continuum dispersion relation is satisfied up to $|\vec{n}|^2=9$

3-pt Functions at Zero Momentum Transfer

Z_V=1/F_1(0): vector current renorm



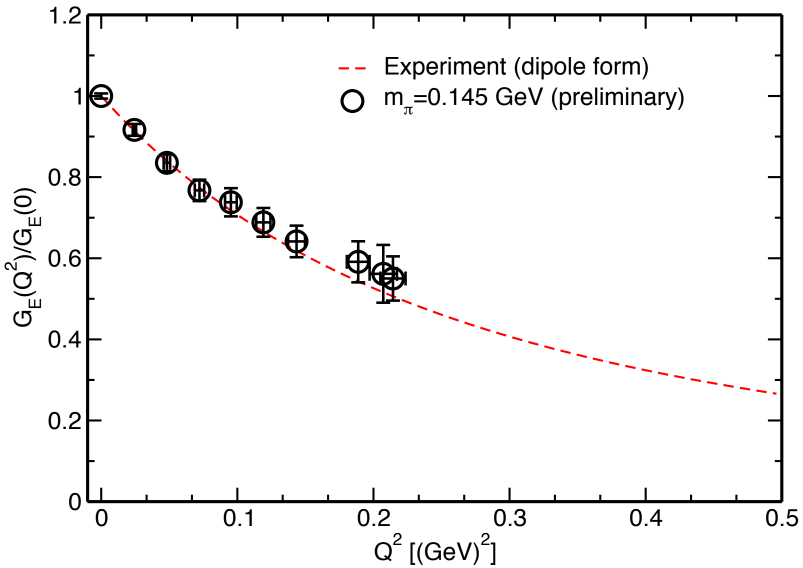
Axial charge g_A

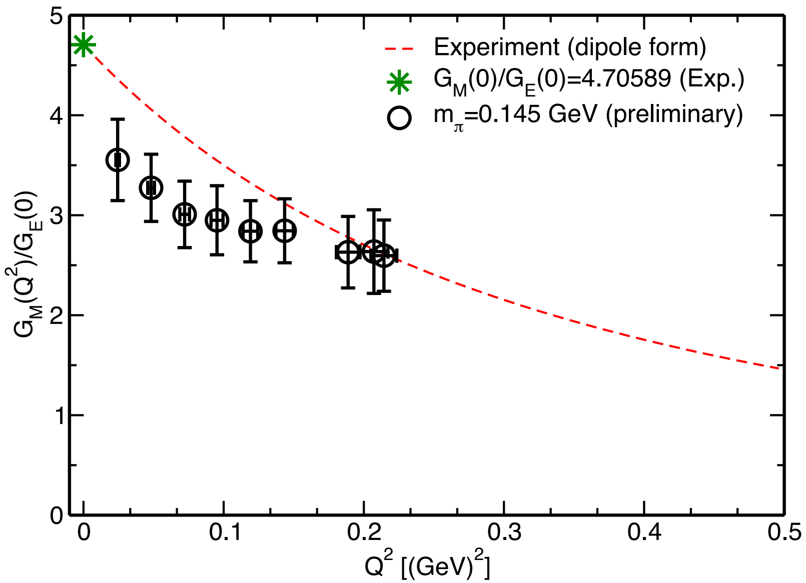


Z_V is consistent btw two methods: 1/F_1(0) and SF scheme
g_A is consistent with experiment if we employ fit results for 2-pt function in denominator

Isovector Electric and Magnetic Form Factor

$$G_E(q^2) = F_1(q^2) - \frac{q^2}{4m_N^2}F_2(q^2) \qquad G_M(q^2) = F_1(q^2) + F_2(q^2)$$





Cleaner signal for G_E compared to G_M

Need more statistics for G_M

G_E shows good agreement with experimental curve, especially, for low Q^2

$\Rightarrow$ Expected to reproduce experimental value for $\sqrt{\langle r_E^2 \rangle}$

Analysis with z-Expansion

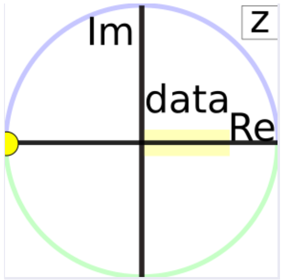
Boyd et al., PLB353(1995)306
Hill-Paz, PRD82(2010)113005

Conformal mapping of the cut plane to the unit circle:

$$G_{E/M}(z) = \sum_{k=0}^{k_{\max}} c_k z(Q^2)^k$$

$$z(Q^2) = \frac{\sqrt{t_{\rm cut}+Q^2}-\sqrt{t_{\rm cut}-t_0}}{\sqrt{t_{\rm cut}+Q^2}+\sqrt{t_{\rm cut}-t_0}}$$

w/ $t_{cut}=4m_\pi^2$, $t_0=0$



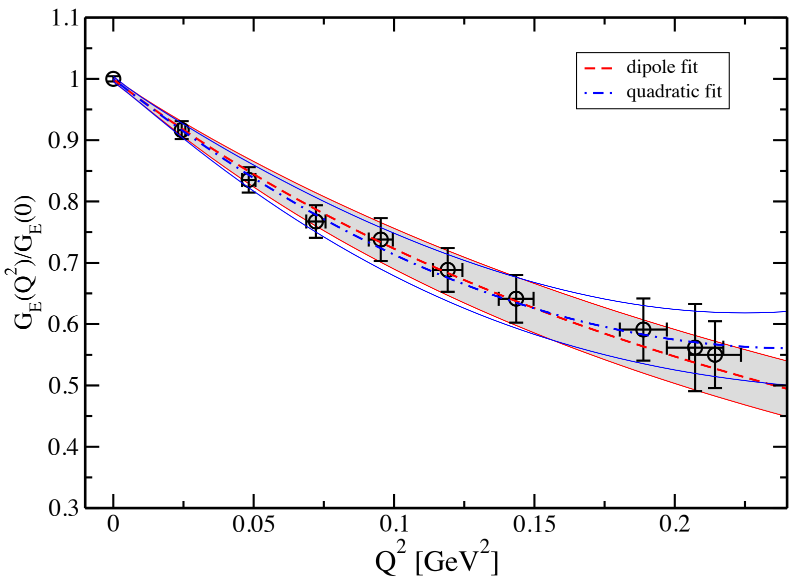
<u>Virtues of z-Expansion analysis</u>

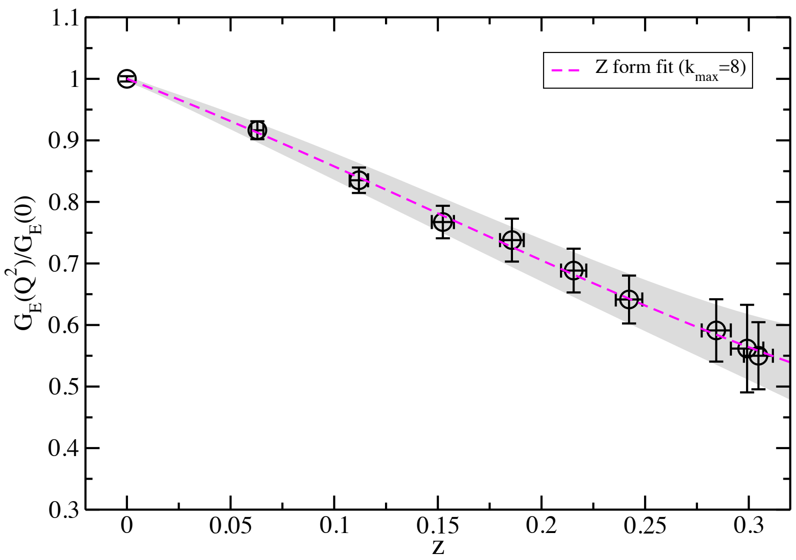
- Model independent ⇔ dipole form
- Analyticity is assured
- $\Sigma_k ||c_k|| < \infty$ ⇒ good convergence is expected for c_k

Fit Results for G_E w/ 10 Data Points

Dipole form: $a_0/(1+a_1Q^2)^2$
Taylor expansion: $b_0+b_1Q^2+b_2Q^4$

z-expansion:
$c_0+c_1z+c_2z^2+\cdots+c_8z^8$



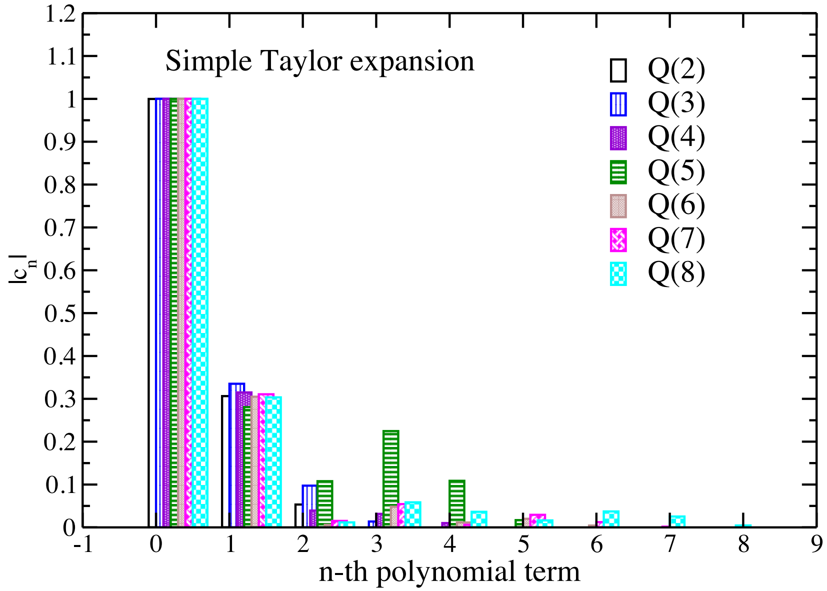


Chi^2/dof<1 for all the fits

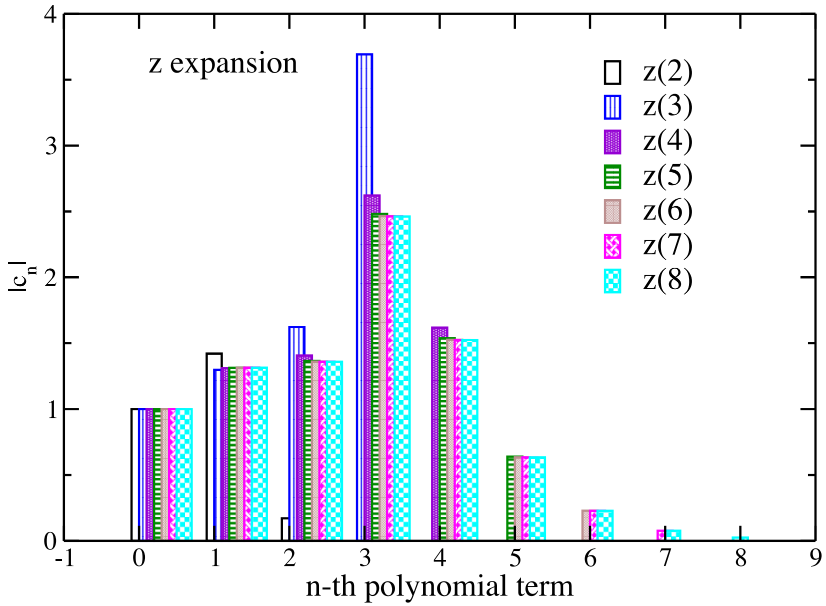
Curvature is smaller in z variable than Q^2 variable

Convergence behavior of Coefficients

Taylor expansion Q(m):
$c_0 + c_1 Q^2 + \cdots c_m (Q^2)^m$



z-expansion z(m):
$c_0 + c_1 z + \cdots c_m z^m$



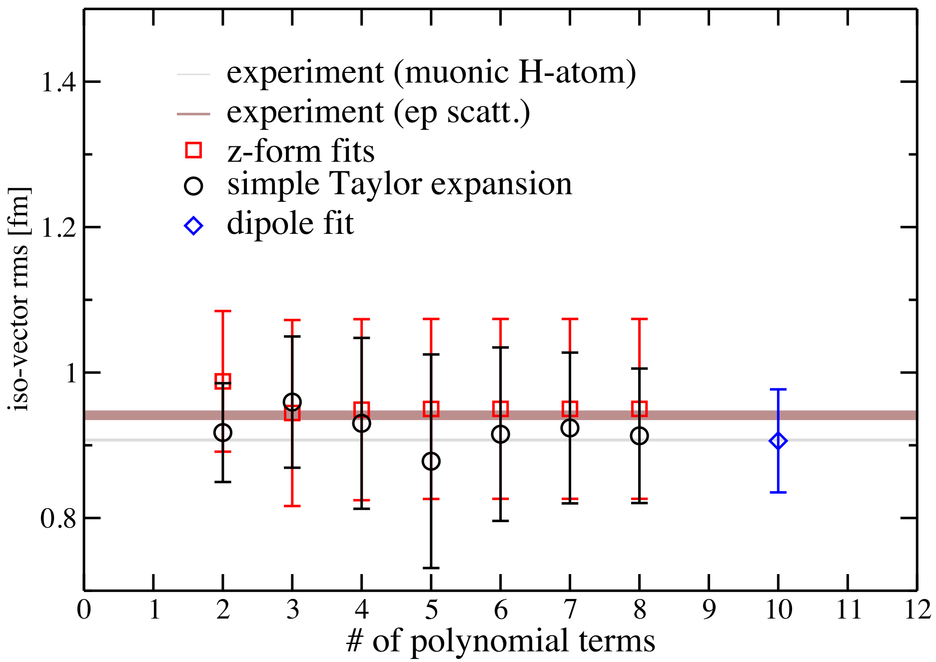
<u>z-expansion</u>

Coefficients are stable for z(m) with m≥3

$|c_{n+1}/c_n| < 1$ is satisfied beyond 3-rd polynomial term

Root Mean Squared Radius

$$\langle r_E^2 \rangle = -6 \left. \frac{dG_E}{dQ^2} \right|_{Q^2=0}$$



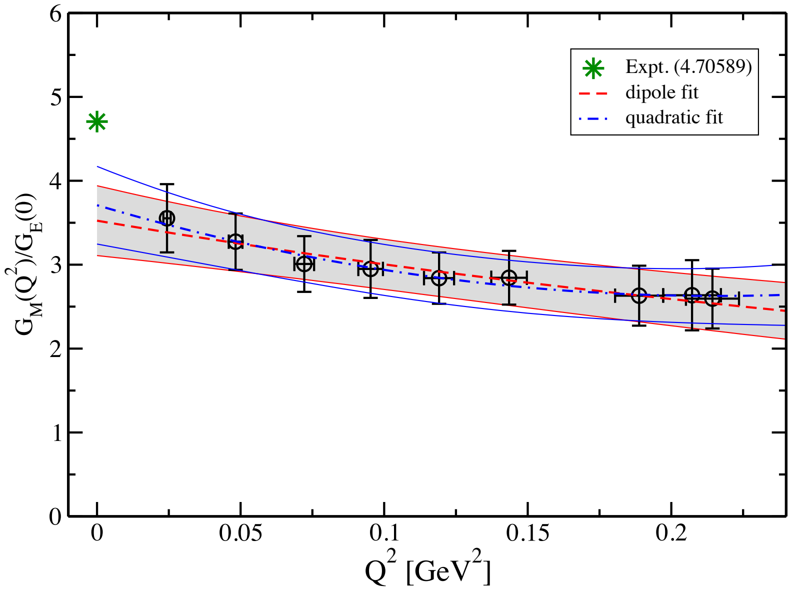
All the fits (dipole, Taylor, z-expansion) successfully reproduces the experimental value

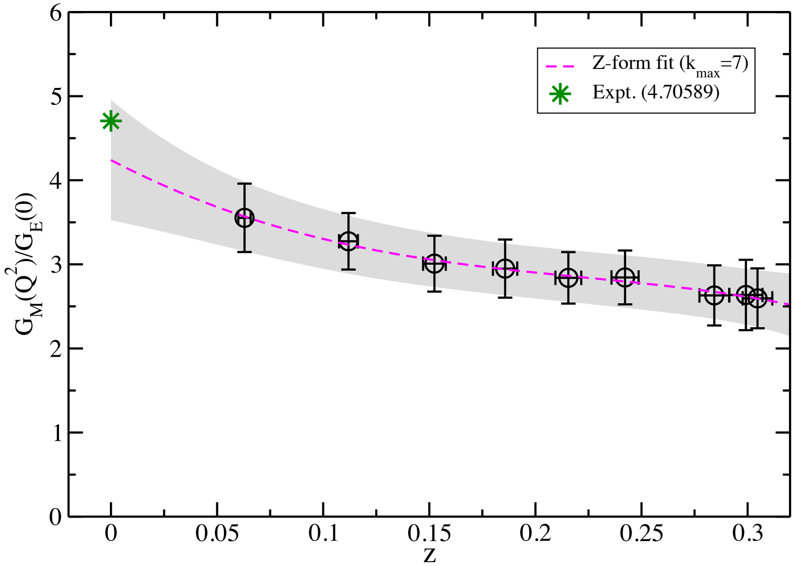
Need more statistics for finer resolution

Fit Results for G_M w/ 9 Data Points

Dipole form: $a_0/(1+a_1Q^2)^2$
Taylor expansion: $b_0+b_1Q^2+b_2Q^4$

z-expansion:
$c_0+c_1z+c_2z^2+\cdots+c_7z^7$





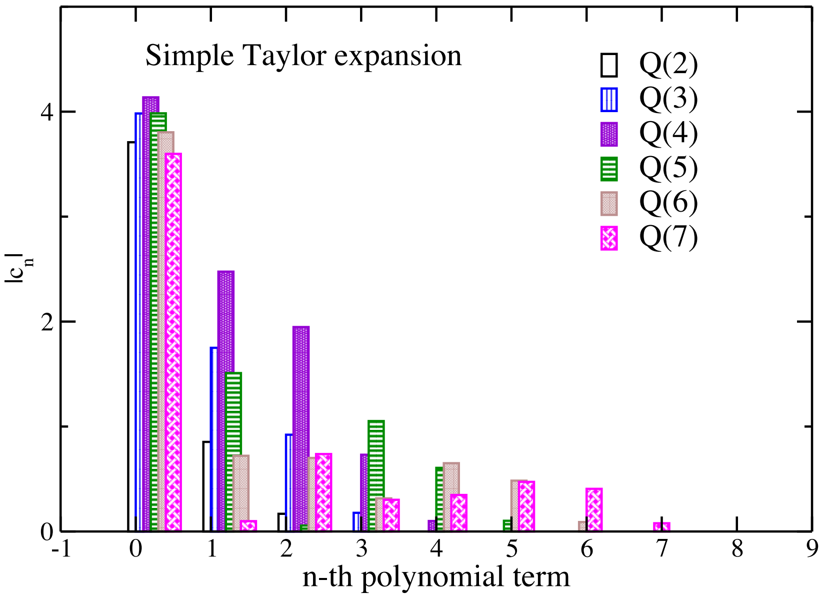
Chi^2/dof<1 for all the fits

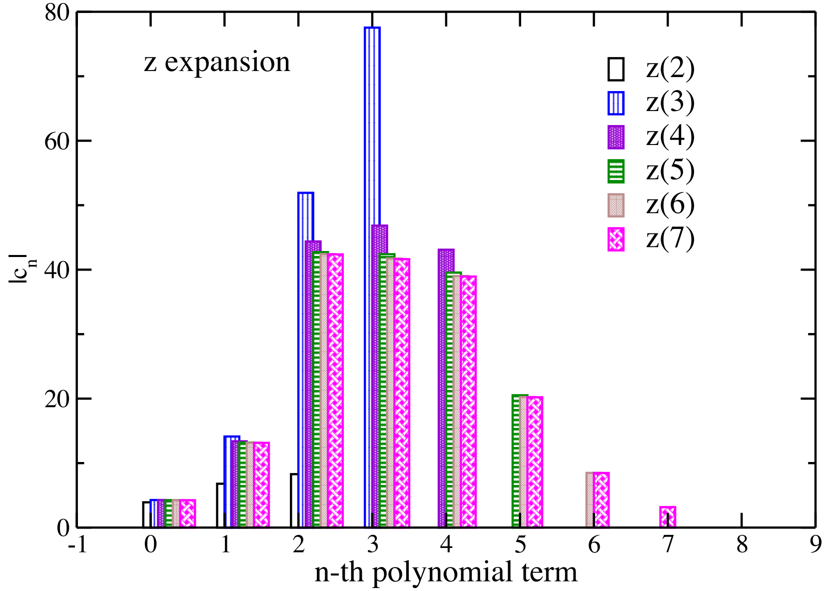
Magnetic moment is consistent with experiment in z-expansion

Convergence behavior of Coefficients

Taylor expansion Q(m):
$c_0+c_1Q^2+\cdots c_m(Q^2)^m$

z-expansion z(m):
$c_0+c_1z+\cdots c_mz^m$





<u>z-expansion</u>

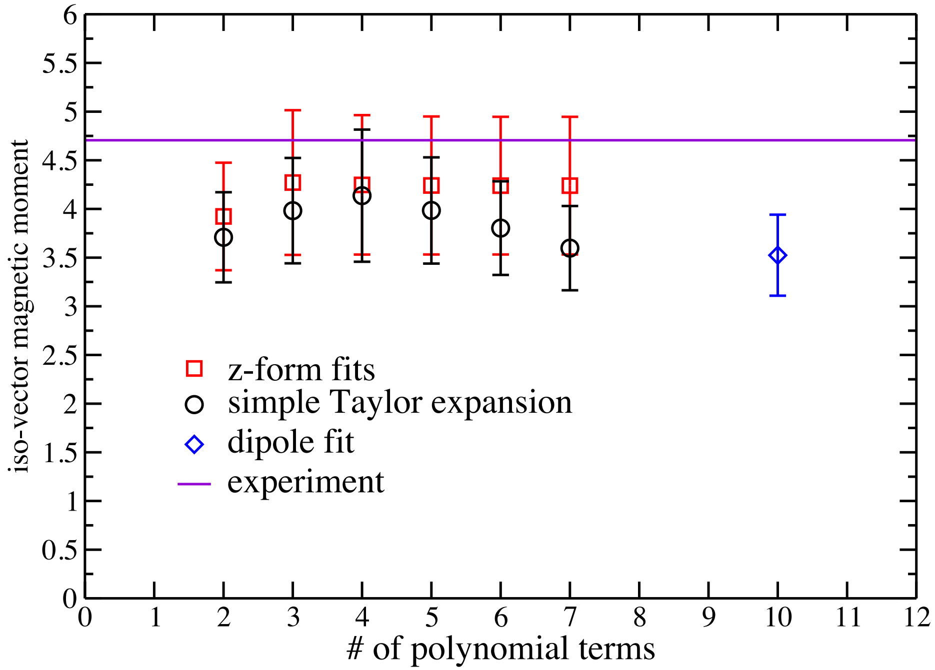
Similar behaviors with G_E case

Coefficients are stable for z(m) with m≥3

$|c_{n+1}/c_n|<1$ is satisfied beyond 3-rd polynomial term

Magnetic Moment

Extrapolated value at Q^2=0 or z=0



z-expansion gives a consistent result with experiment

Summary

- 2+1 flavor QCD simulation at the physical point on (∼8.1 fm)^4 lattice
- Large spatial volume allows investigation at small Q^2 region
- g_A is consistent with experimental value
- Q^2 dependence of G_E is consistent with experiment
- G_M shows larger statistical fluctuations than G_E
- z-expansion analyses work well: good convergence behavior

  ⇒ $\sqrt{\langle r_E^2 \rangle}$ and magnetic moment are consistent with experiment