Disconnected u, d, s - Quarks Contribution to Nucleon Magnetic Moment & Charge Radius

UNIVERSITY OF KENTUCKY

(χQCD Collaboration)

Raza Sabbir Sufian

Jefferson Lab, 5th Jan, 2017

Background and Accomplishments

B. S. in Physics
(Minor in Mathematics)
University of Dhaka, Bangladesh

Graduation, Expected July 2017
Ph.D. in Physics (Lattice QCD)
University of Kentucky
Supervisor: Keh-Fei Liu

1. Strange quark magnetic moment & charge radius arXiv:1606.07075 (accepted in PRL), ***RSS***, Yang, et. al.

2. Gluon spin and Helicity arXiv:1609.05937 (Submitted to PRL), Yang, ***RSS***, et. al.

3. Nucleon EMFFs from Light-front Holographic QCD arXiv:1609.06688 (accepted in PRD) ***RSS***, de Teramond, Brodsky, Deur, Dosch

4. Neutral Weak FFs, arXiv:1611.07031 (Submitted to PRD), ***RSS***

*6 others including conference proceedings

*Ongoing: proton (neutron)charge radius (LQCD) / nucleon time-like EMFFs (LFHQCD)

Disconnected u, d, s - Quarks Contribution

* s-quark contribution arises from vacuum, sign and magnitude related to nonperturbative structure of nucleon

JLAB

* Models and experimental results (G0, HAPPEX, A4, SAMPLE) of ***s***-quark EMFF quite uncertain

* Nonzero strange Sachs electric FF G^s_E at $Q^2>0$ implies different spatial distribution of ***s and*** $\bar{s}$ in nucleon

* No lattice QCD calculation of sea ***u,d***-quarks contribution to nucleon EMFF at physical point—NEGATIVE CONTRIBUTION TO PROTON CHARGE RADIUS

* A first-principle calculation required in the continuum limit with controlled systematic uncertainties

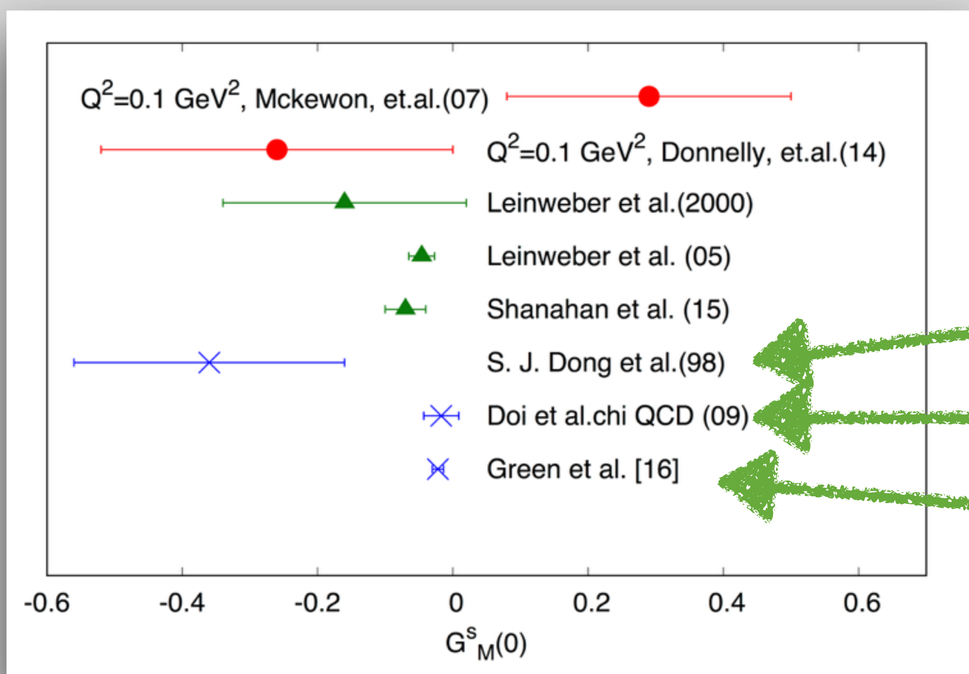
Theory & Experiment

- Kaplan, Manohar (88), Mckeown and Beck (89):

$$G^{Z,p(n)}_{E,M}(Q^2) = \frac{1}{4}\left[(1-4\sin^2\theta_W)(1+R_V^{p(n)})G^{\gamma,p(n)}_{E,M}(Q^2) - (1+R_V^{n(p)})G^{\gamma,n(p)}_{E,M}(Q^2) - (1+R_V^{(0)})G^s_{E,M}(Q^2)\right]$$

$$\begin{aligned} A^p_{PV} = & -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\frac{1}{[\epsilon(G^p_E)^2+\tau(G^p_M)^2]} \\ & \times\{(\epsilon(G^p_E)^2+\tau(G^p_M)^2)(1-4\sin^2\theta_W)(1+R^p_V) \\ & -(\epsilon G^p_E G^n_E+\tau G^p_M G^n_M)(1+R^n_V) \\ & -(\epsilon G^p_E G^s_E+\tau G^p_M G^s_M)(1+R^{(0)}_V) \\ & -\epsilon'(1-4\sin^2\theta_W)G^p_M G^e_A\}\,, \end{aligned}$$

Unknown



Quenched

Pion mass 650 MeV

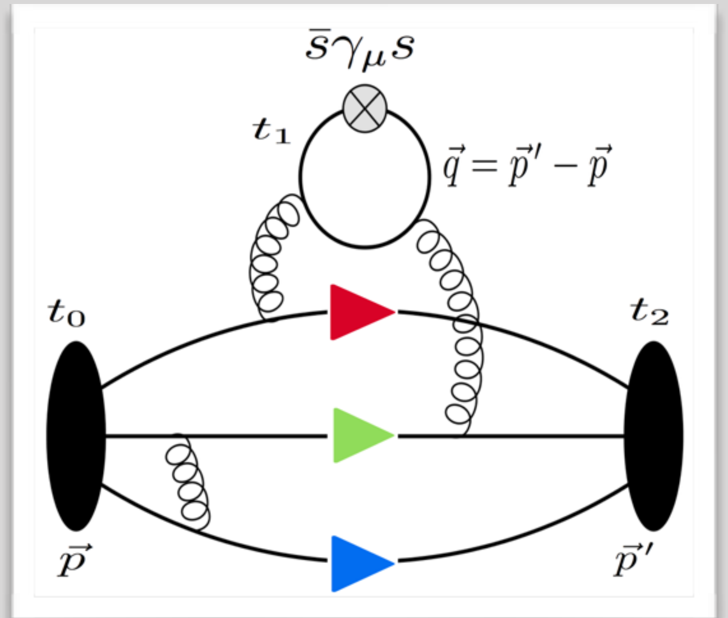
Pion mass 317 MeV

Red: Analysis of world expt. data
Blue: Direct lattice QCD
Green: Indirect lattice QCD

This work: Overlap fermion on RBC/UKQCD DWF gauge configs

Ensemble	$L^3 \times T$	a (fm)	m_π (MeV)	N_{config}
24I	$24^3 \times 64$	0.1105(3)	330	203
32I	$32^3 \times 64$	0.0828(3)	300	309
48I	$48^3 \times 96$	0.1141(2)	139	81
32ID	$32^3 \times 64$	0.1431(7)	171	200

RSS, Yang, Alexandru, Draper, Liang, and Liu ,
arXiv:1606.07075 [hep-ph]
(Accepted in PRL)



Ratio of nucleon 3pt/2pt correlation function

$$R_{\mu=i}(\Gamma_k) \xrightarrow{(t_2-t_1)\gg 1/\Delta m, t_1 \gg 1/\Delta m} \frac{\epsilon_{ijk} q_j}{E_q + m_N} G_M^s(Q^2)$$

$$R_{\mu=4}(\Gamma_e) \xrightarrow{(t_2-t_1)\gg 1/\Delta m, t_1 \gg 1/\Delta m} G_E^s(Q^2)$$

*24 quark masses including one at physical point

*Momentum transfer range 0.05 GeV^2 < Q^2 < 1.31 GeV^2

*Combined 2-states fit of summed ratio and plateau method

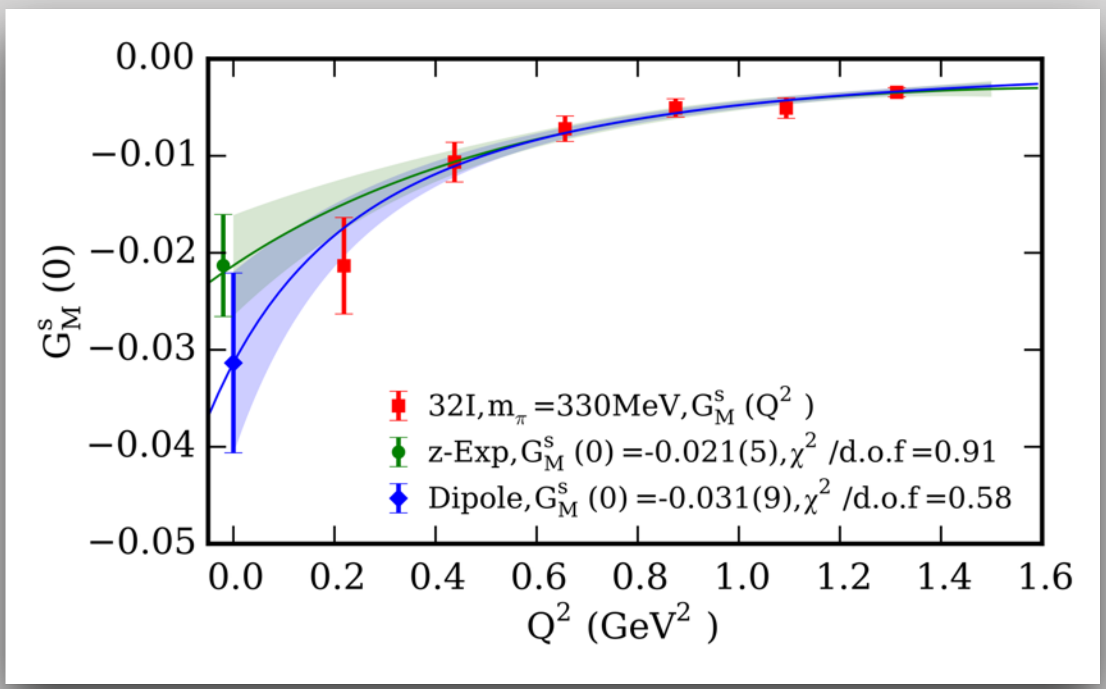
Q^2-Extrapolation

Dipole Form vs. Model independent z-expansion

* z-expansion, R. J. Hill (2010)

$$G_M^{s,dipole}(Q^2) = \frac{G_M^s(0)}{(1+\frac{Q^2}{\Lambda^2})^2}$$

$$G_M^{s,z-exp}(Q^2) = \sum_{k=0}^{k_{max}} a_k z^k \ , \quad z = \frac{\sqrt{t_{\rm cut}+Q^2}-\sqrt{t_{\rm cut}}}{\sqrt{t_{\rm cut}+Q^2}+\sqrt{t_{\rm cut}}}.$$



*Keep first 3 terms and include 4th term in systematics

*Dipole fit not stable for charge radius and lighter pion mass

*Use z-expansion for rest of the calculation

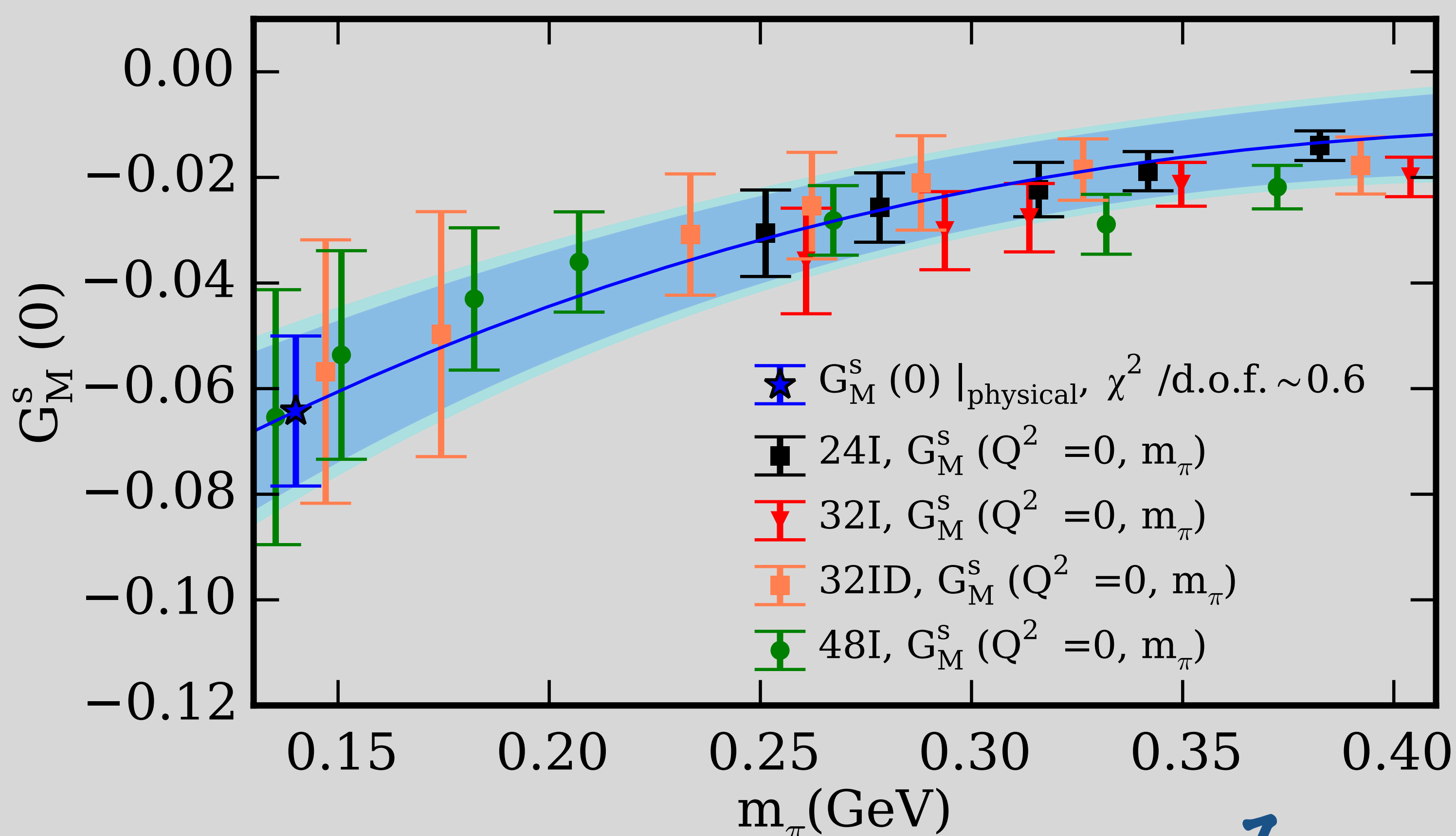
Continuum Extrapolation

*Global fit formula (s-quark magnetic moment)

$$G_M^s(0; m_\pi, m_{\pi,vs}, m_K, a, L) = A_0 + A_1 m_\pi + A_2 m_K + A_3 m_{\pi,vs}^2 + A_4 a^2 + A_5 m_\pi \left(1 - \frac{2}{m_\pi L}\right) e^{-m_\pi L}$$

Chiral interpolation - Musolf, et. al. (97);
Hemmert et. al (99).
Finite volume correction - S. Beane (04)

partially quenched pion mass



Correlated fit

$G^s_M(0)$ |physical = - 0.064(14)(09)

A_1= 0.61(16)

A_2= -2.26(49)

A_3= 0.31(12)

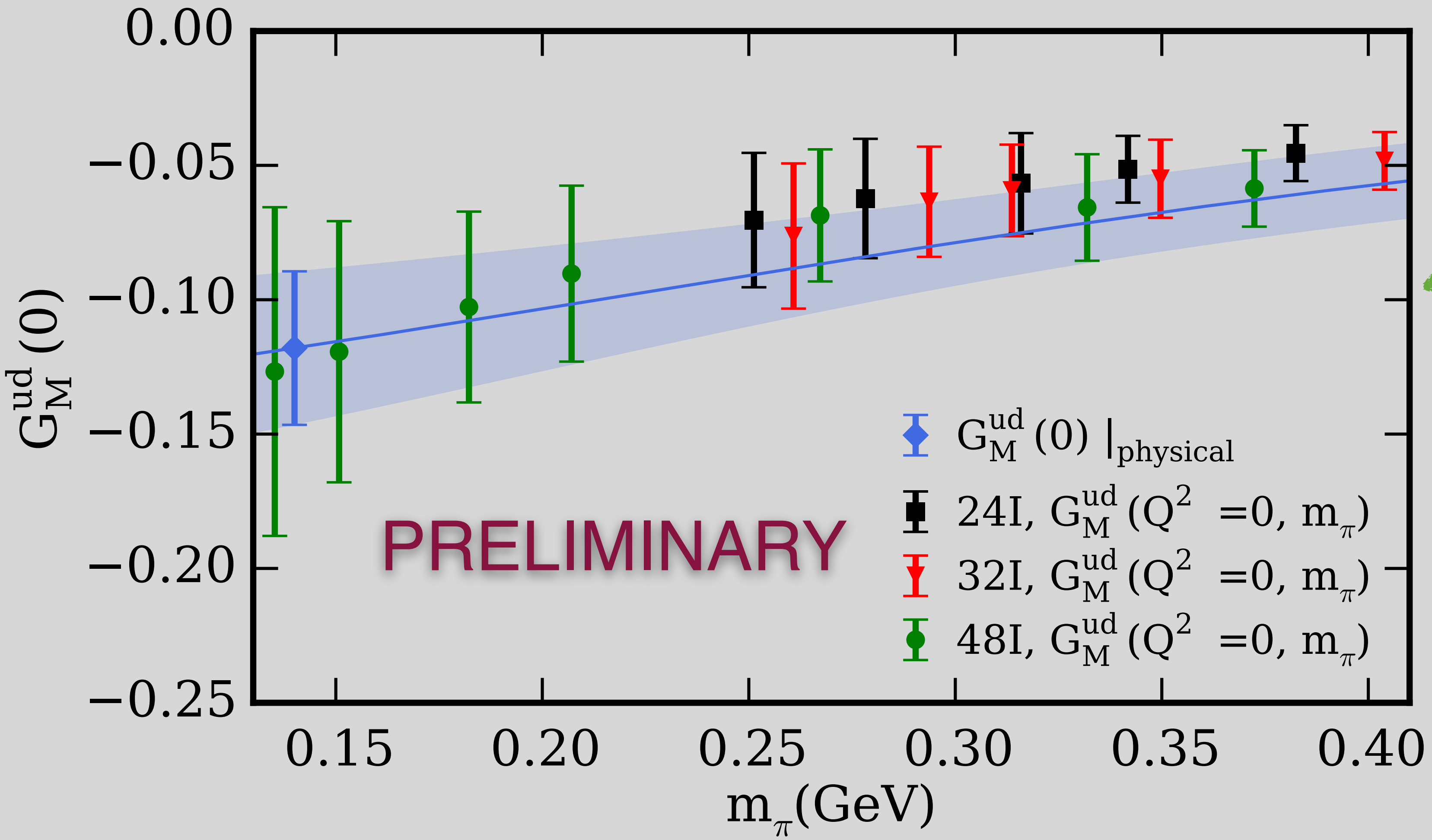
A_4= 0.015(16)

A_5= -4.0(2.4)

*Global fit formula (light (u,d) quark magnetic moment)

$$G_M^{ud}(0; m_\pi, m_K, m_N, a, L) = A_0 + A_1 m_\pi m_N + A_2 m_K m_N$$
$$+ A_3 m_\pi^2 log(m_\pi^2) + A_4 a^2 + A_5 m_\pi \left(1 - \frac{2}{m_\pi L}\right) e^{-m_\pi L}$$

Chiral extrapolation
Manohar, Savage, Jenkins, Luke
PL B 302:482-490, 1993



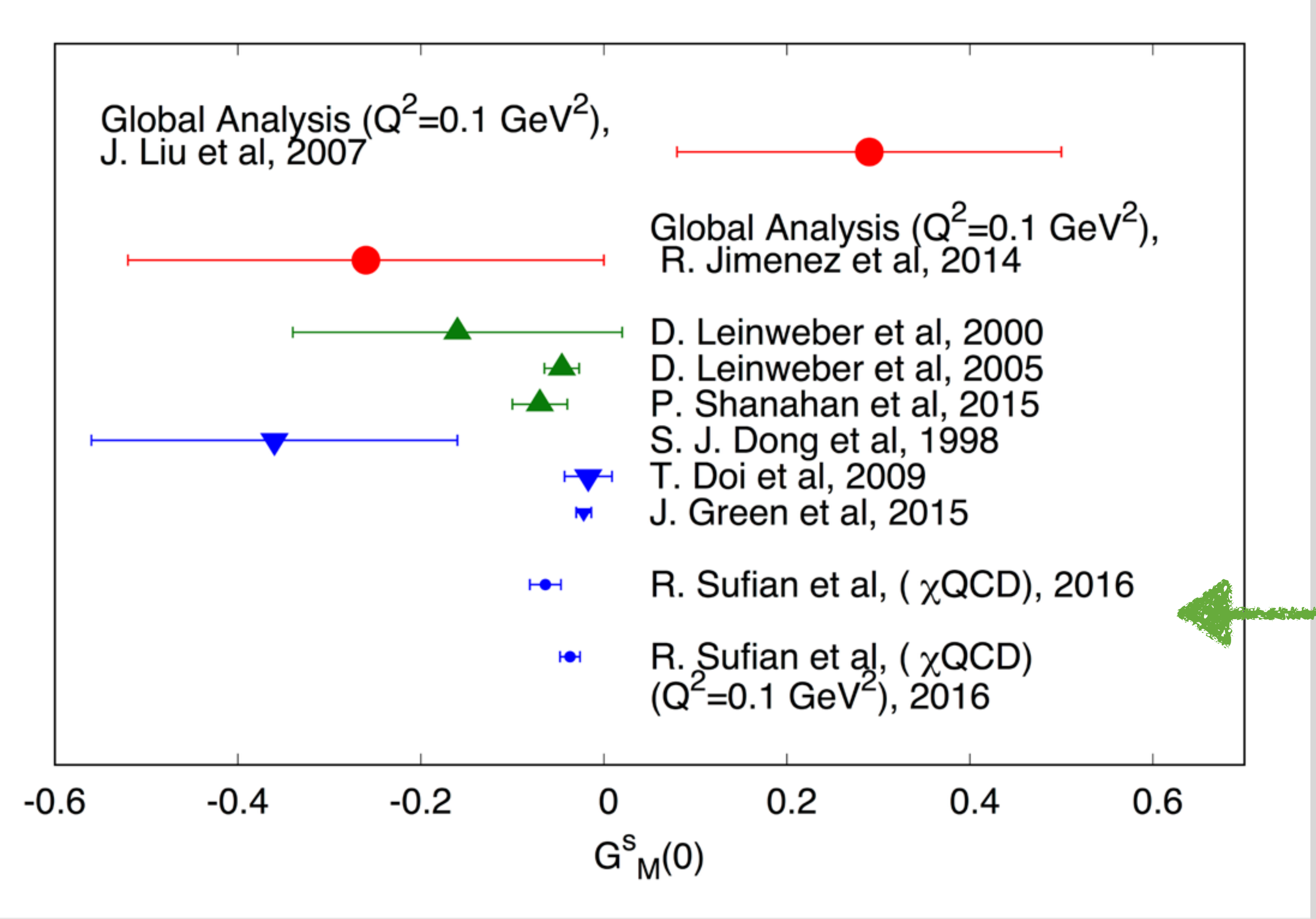
First calculation of disconnected u,d - quarks contribution at physical point

Results

$G^s_M(0)\,|_{physical} = -\,0.064(14)(09)$

$G^{ud}_M(0)\,|_{physical} = -\,0.118(29)(11)$

(*charge factors not included*)

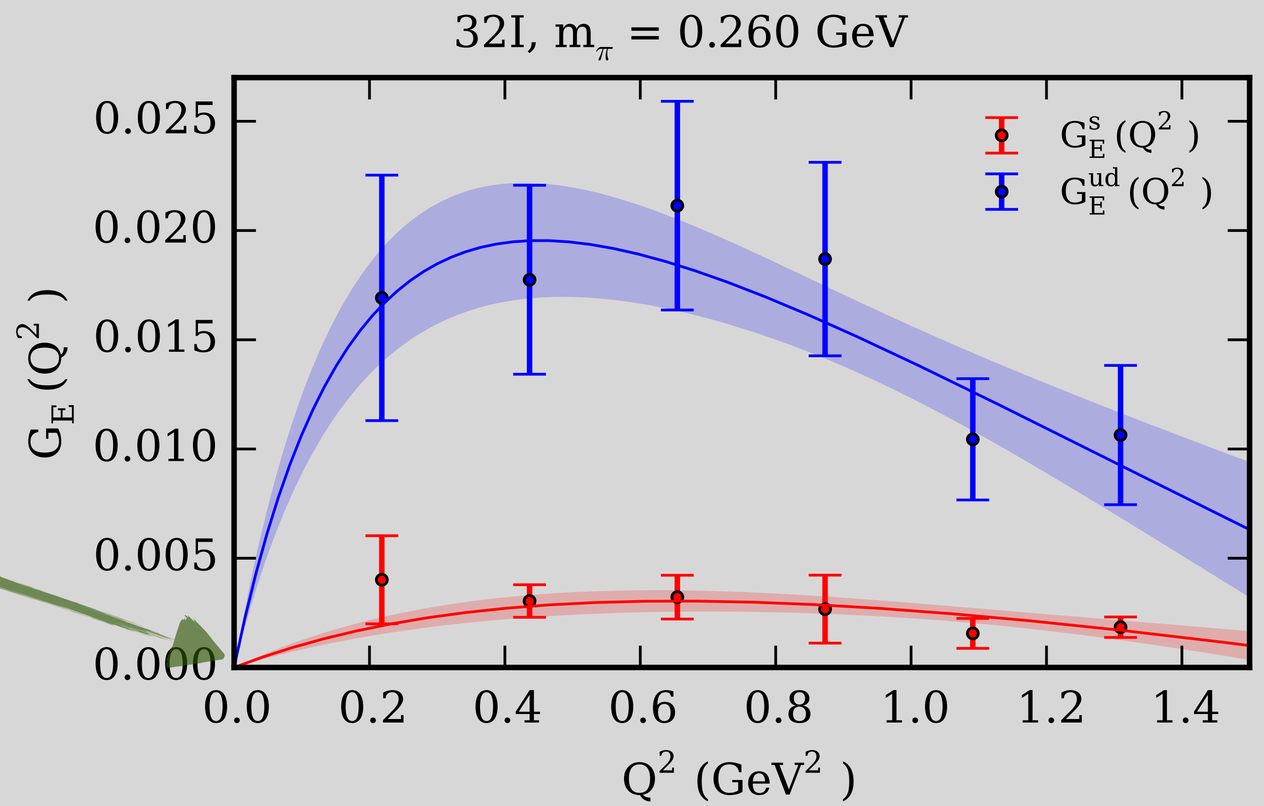


Most precise and accurate estimates of G^s_M

Strange quark electric form factor

* Nonzero strange Sachs electric FF G^s_E at $Q^2>0$ implies different spatial distribution of *s* and $\overline{s}$ in nucleon

Net strangeness of nucleon zero $G^s_E(0)=0$



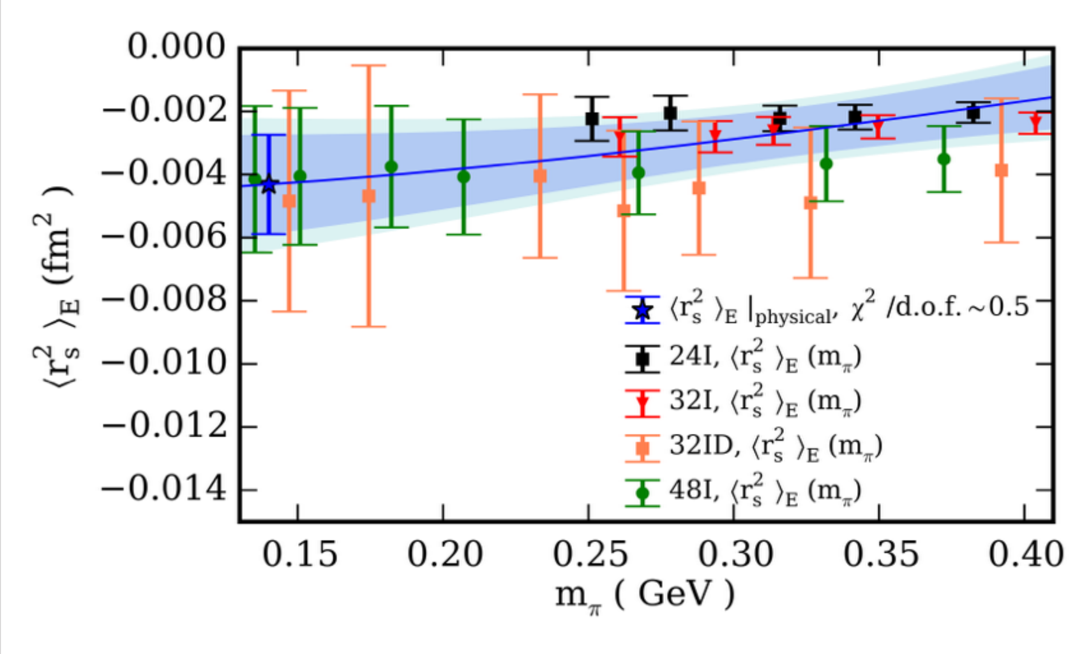
Charge Radii - Continuum Extrapolation

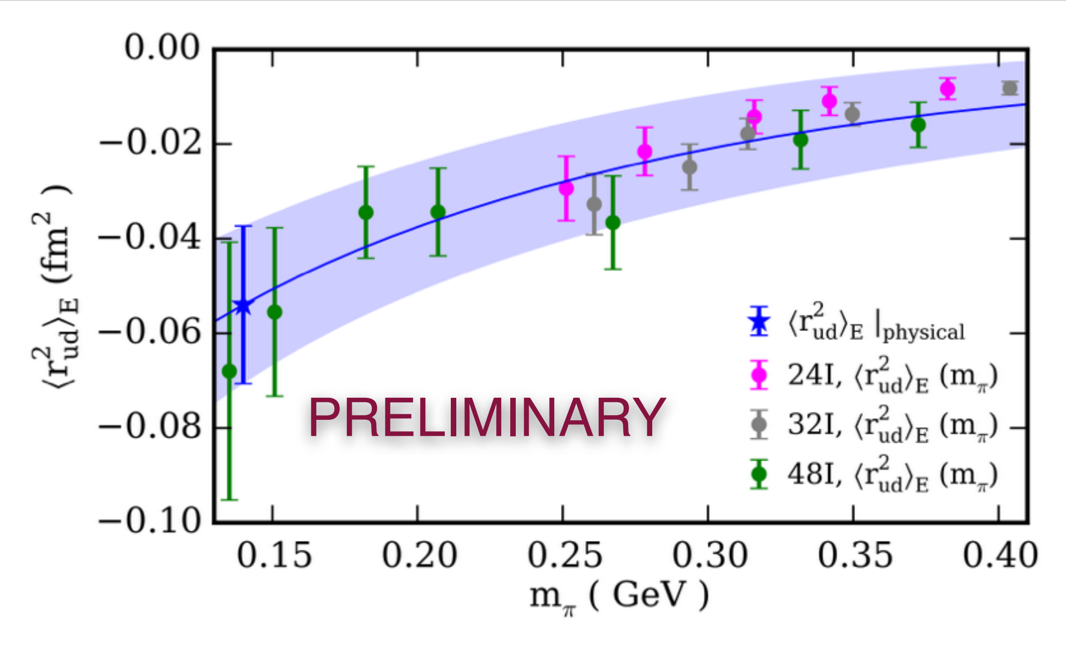
Charge radius $\langle r^2 \rangle_E \equiv -6 \frac{dG_E}{dQ^2}|_{Q^2=0}$

Global fit formula

$$\langle r_s^2 \rangle_E (m_\pi, m_{\pi,vs}, m_K, a, L) = A_0 + A_1 \log(m_K) + A_2 m_\pi^2 + A_3 m_{\pi,vs}^2 + A_4 a^2 + A_5 \sqrt{L} e^{-m_\pi L}$$

*Chiral Extrapolation - Hemmert, et. al. (99); Hall (2012)
*Volume Correction - Tiburzi (14)

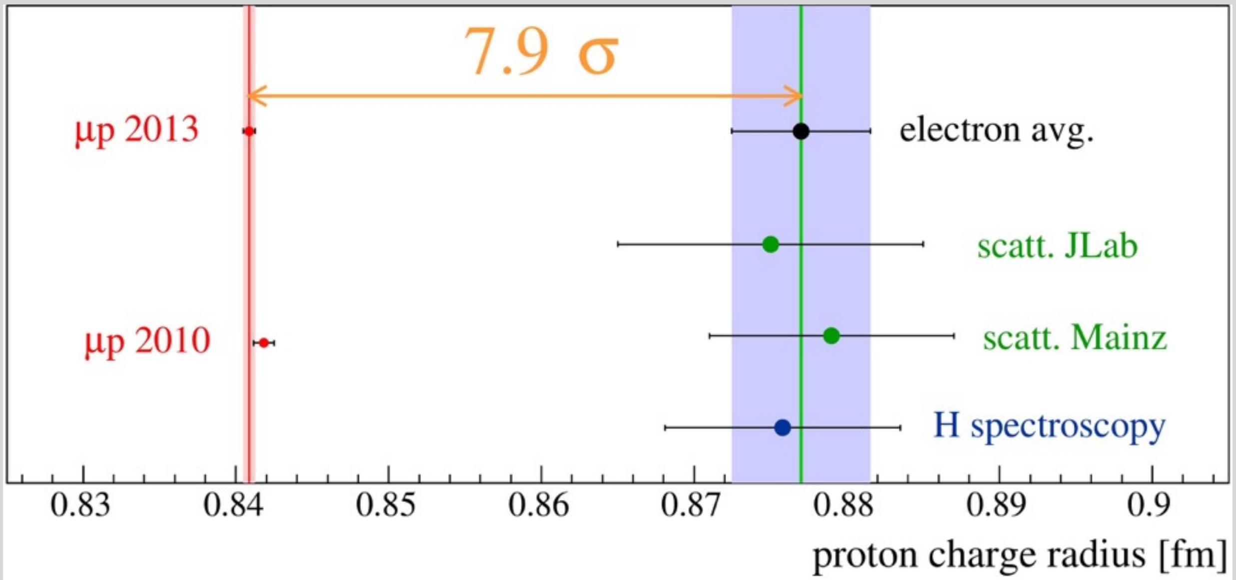




-0.0043(16)(14) fm^2

-0.054(16)(13) fm^2

An Estimate : Nucleon Charge Radii



Proton charge radius puzzle

*Include charge factors of u,d,s quarks

*for simplicity consider only central value

Nucleon radii	Experimental values	DI ud-contribution	DI s-contribtuion	Total DI contribution
$\langle r_E^p \rangle^2$	$0.77\,\mathrm{fm}^2$ (ep CODATA)	-0.018 fm^2	0.0015 fm^2	$\sim$2.4%
$\langle r_E^p \rangle^2$	$0.707062\,\mathrm{fm}^2$ (μp Lamb shift)	-0.018 fm^2	0.0015 fm^2	$\sim$2.4%
$\langle r_E^n \rangle^2$	$-0.1161\,\mathrm{fm}^2$	-0.018 fm^2	0.0015 fm^2	$\sim$14%

PRELIMINARY

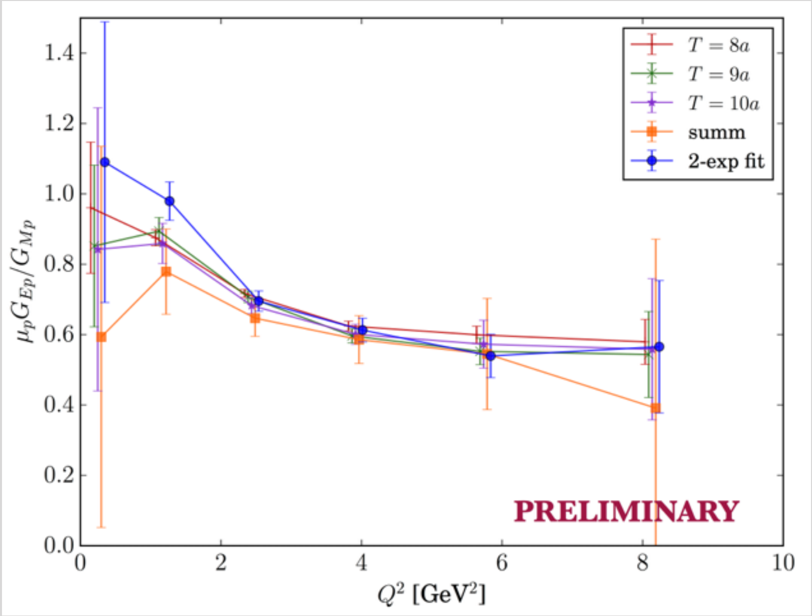
1. Calculations of neutron charge radius without DI contribution obtain smaller value compared to experiments

2. Lattice calculation of connected u,d quarks contribution is in progress

Why Jefferson Lab

*Primary research interest - PDFs

*JLab 12 GeV experiment

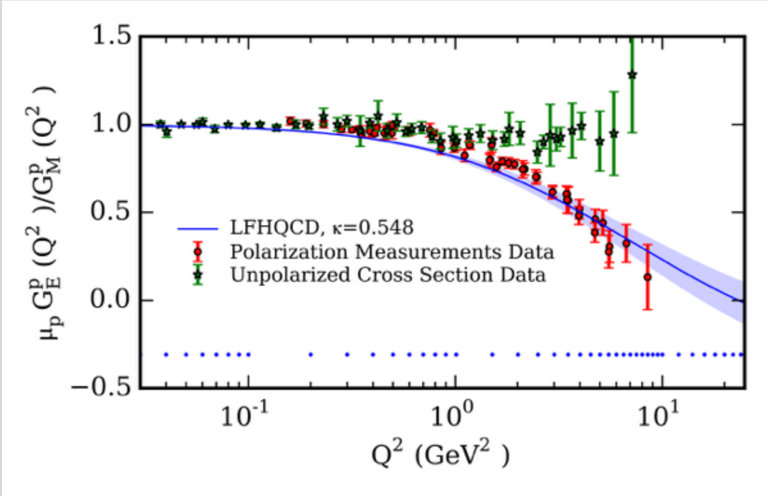


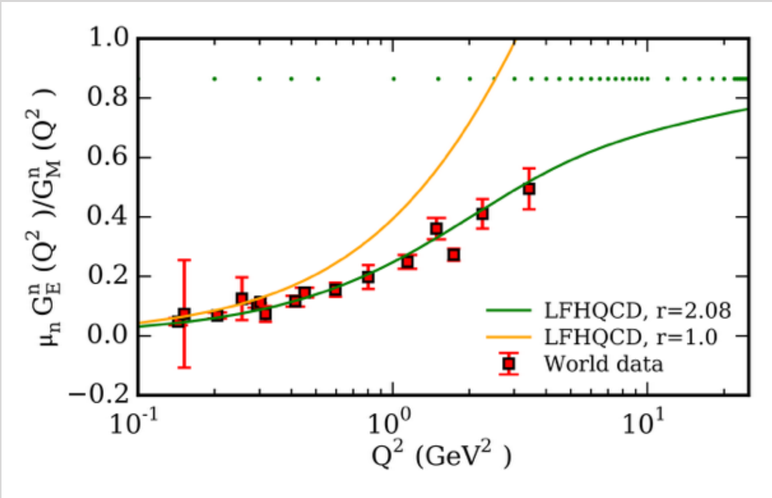
Syritsyn, et. al. Lattice 2016

*Flavor decomposition overshoots experiment by 3-4 times

*How to control uncertainties and obtain reliable estimates at large Q^2 on the lattice

Light-front Holographic QCD
arXiv:1609.06688 (accepted in PRD)
RSS, de Teramond, Brodsky, Deur, Dosch





Why Jefferson Lab

*Properties of light nuclei

*Calculation of neutral weak FFs - G0 and HAPPEX collaborations at JLab

* Bring in new ideas

Thank you for your consideration !

$$R(t_2,t_1) = C_0 + C_1 e^{-\Delta m(t_2-t_1)} + C_2 e^{-\Delta m t_1} + C_3 e^{-\Delta m t_2},$$

$$SR(t_2) = \sum_{t_1 \geq t'}^{t_1 \leq (t_2 - t'')} R(t_2,t_1)$$

$$= (t_2 - t' - t'' + 1)C_0 + C_1 \frac{e^{-\Delta m t''} - e^{-\Delta m(t_2-t'+1)}}{1 - e^{-\Delta m}}$$

$$+C_2 \frac{e^{-\Delta m t'} - e^{-\Delta m(t_2-t''+1)}}{1 - e^{-\Delta m}} + C_3(t_2 - t' - t'' + 1)e^{-\Delta m t_2}.$$

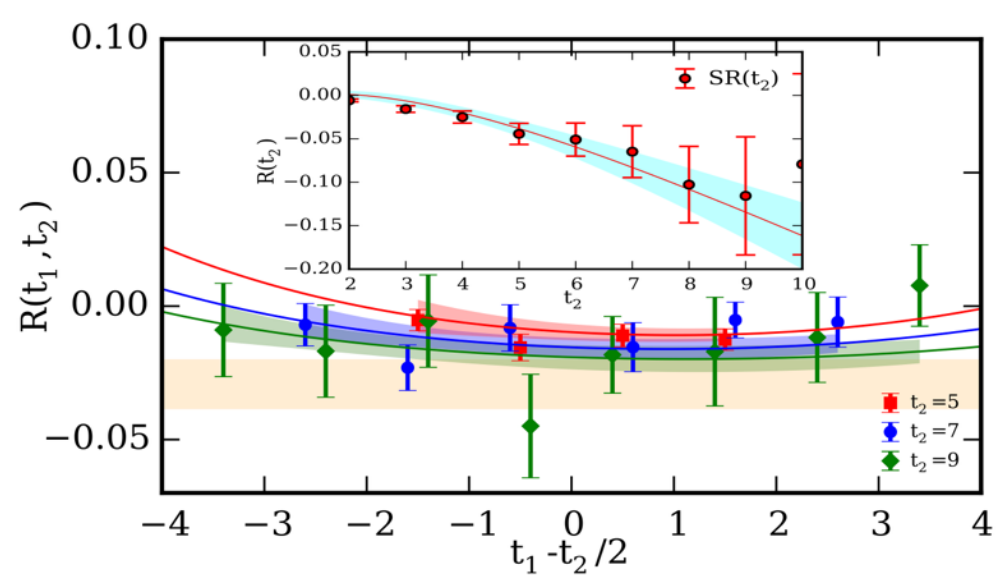


FIG. 2. Combined fit result for disconnected contribution $G^s_M(Q^2 = 0.0515\,\mathrm{GeV}^2)$ with $m_\pi = 207\,\mathrm{MeV}$. The bands show fits to the 3pt/2pt ratios. The current insertion time t_1 is shifted by half the sink-source separation for clarity.