π N σ Term from Overlap Fermion

- Overlap on 2+1 flavor DWF configurations with deflation and low-mode averaging ⟹ quark loops.
- Strangeness content
- π N σ term for the connected and disconnected insertions
- Scalar form factors

χ QCD Collaboration:

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http://eagle.phys.gwu.edu/~fxlee/chiQCD.html

Lattice 2014, NYC, June 23 - 17, 2014

Overlap valence on 2+1 flavor DWF configurations (RBC-UKQCD-LHPC)

La ~ 4.5 fm
m_π ~ 170 MeV

32^3 x 64, a =0.14 fm

($O(a^2)$ extrapolation)

La ~ 2.8 fm
m_π ~ 330 MeV

24^3 x 64, a =0.111 fm

La ~ 5.5 fm
m_π ~ 140 MeV

48^3 x 96, a =0.111 fm

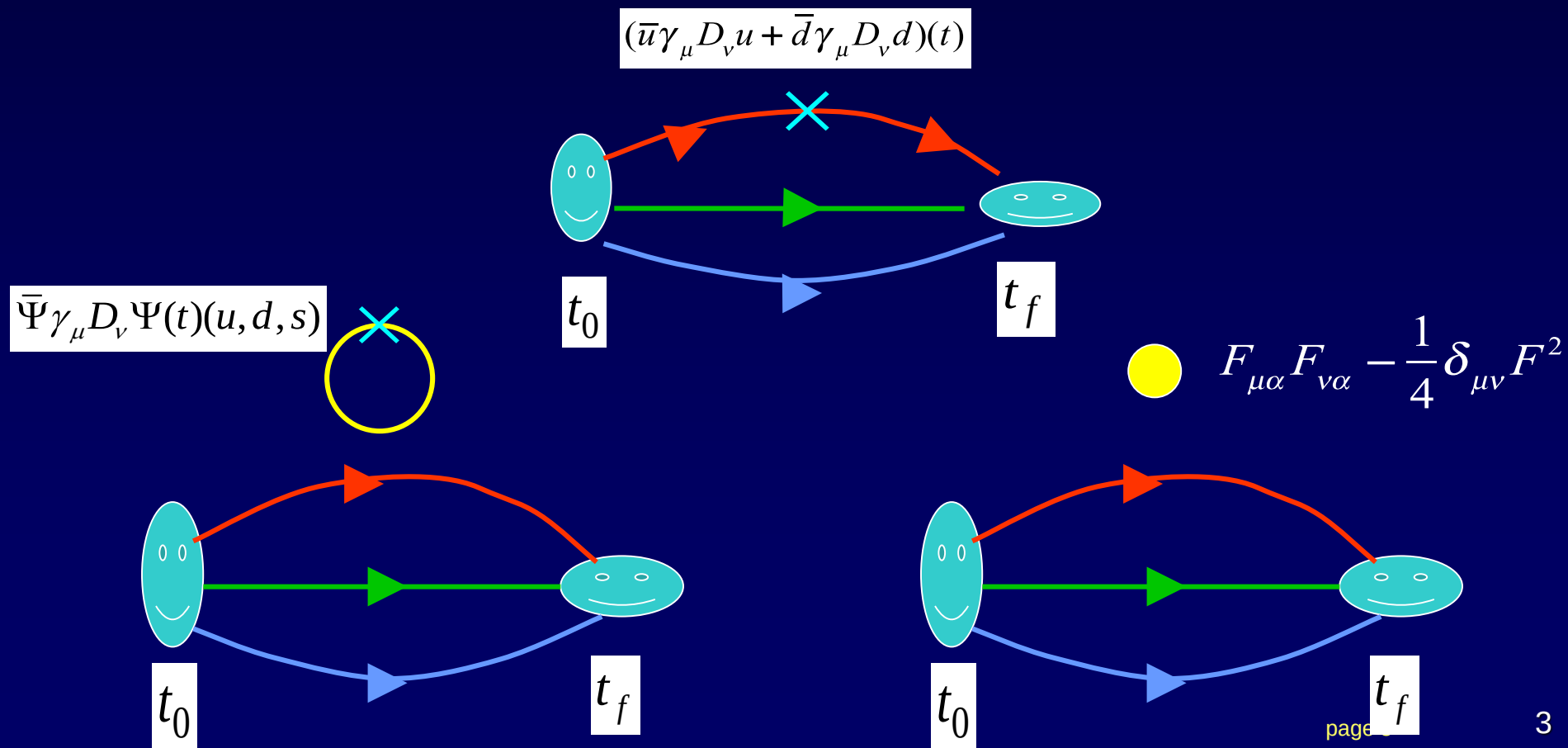
La ~ 2.7 fm
m_π ~ 295 MeV

32^3 x 64, a =0.085 fm

Combined continuum and chiral fitting, arXiv:1208.4412

Nucleon Structure with Quarks and Glue

- Flavor-singlet Matrix Elements, e.g. Quark and Glue Momentum and Angular Momentum in the Nucleon, Strangeness and Charmness.

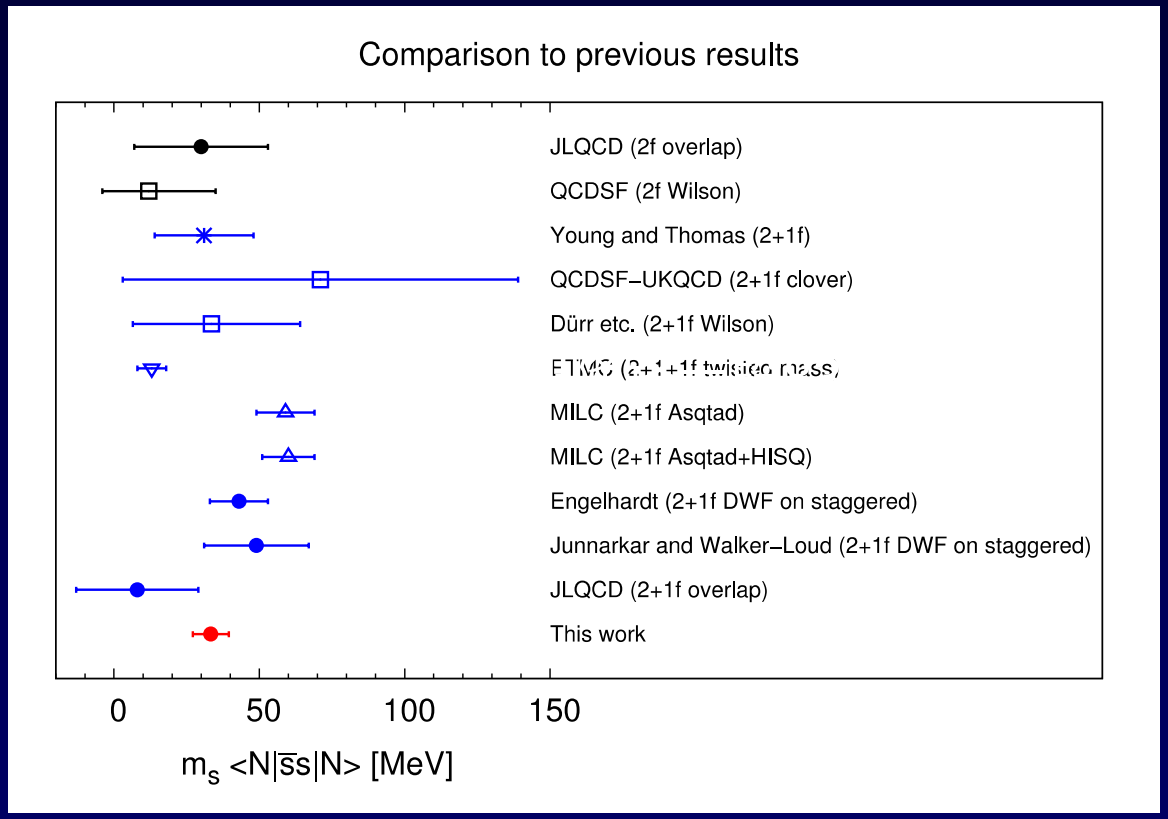


Strangeness

$24^3 \times 64$ lattice with $m_\pi = 331$ MeV, $a^{-1} = 1.73$ GeV

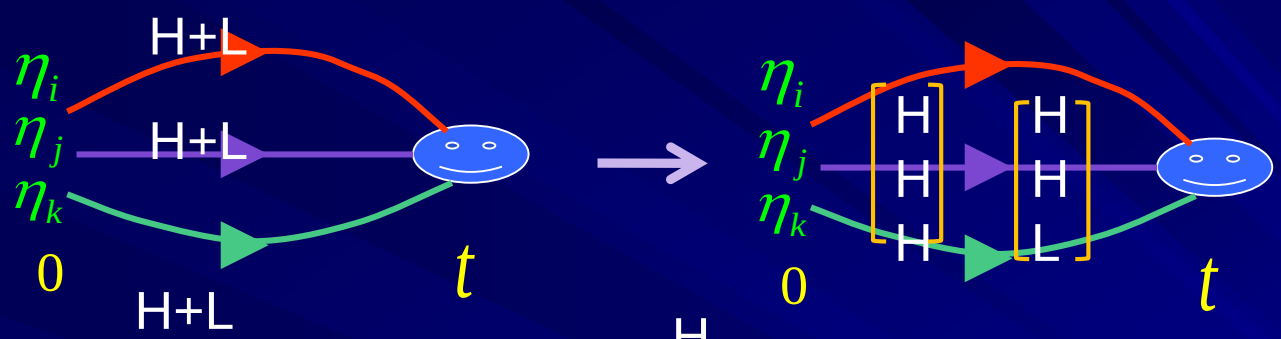
176 configurations [M. Gong et al.,

DOI :10.1103 / *PhysRevD*.88.014503 , arXiv:1304.1194]



$$m_s \langle N | \bar{s}s | N \rangle = 33.3(6.2) \text{ MeV}$$

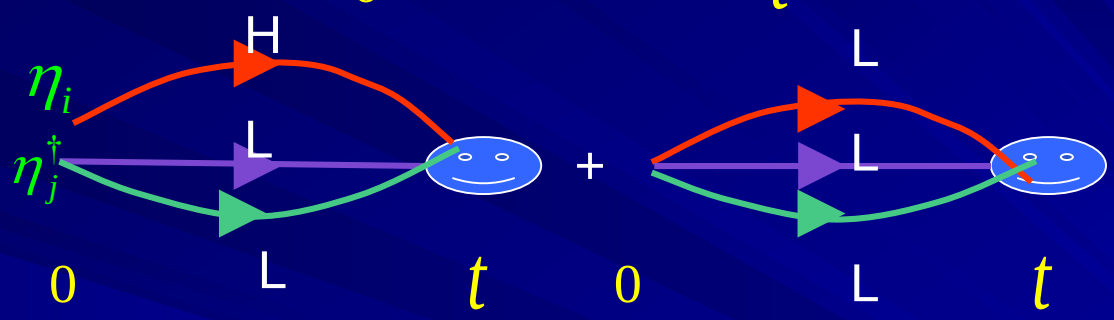
Nucleon with LLL and HLL substitution



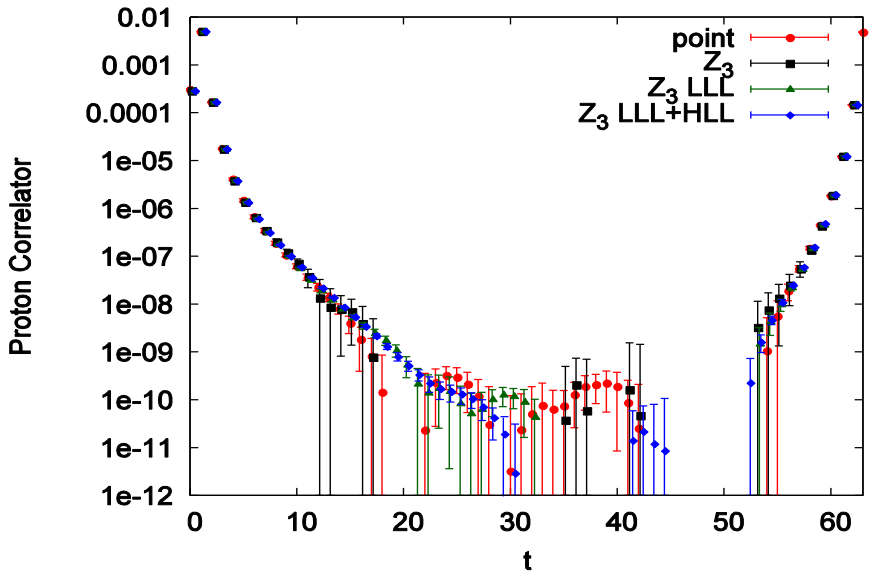
$$\frac{C_N(t)}{\sigma_N(t)} \approx \sqrt{\frac{n}{V_3}}\, e^{-(m_N - 3/2 m_\pi)t}$$

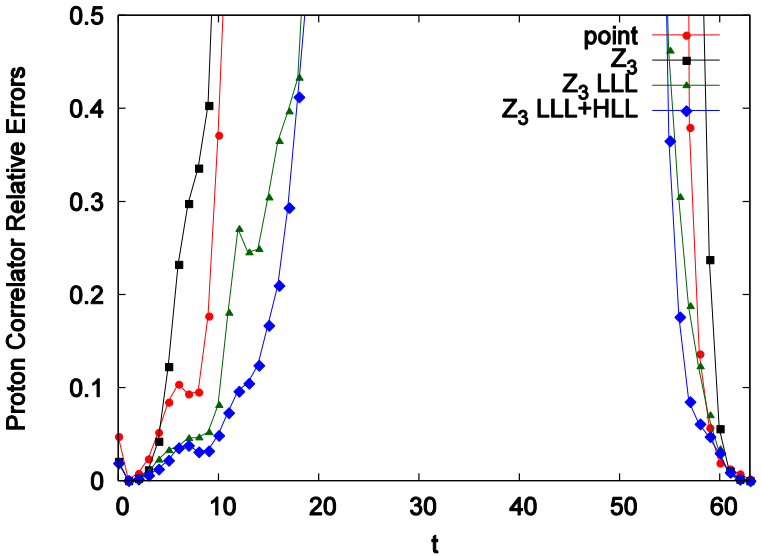
$$\langle \eta_i \eta_j \eta_k \rangle = \delta_{ij}\delta_{jk}$$

$$\langle \eta_i^\dagger \eta_j \rangle = \delta_{ij}$$



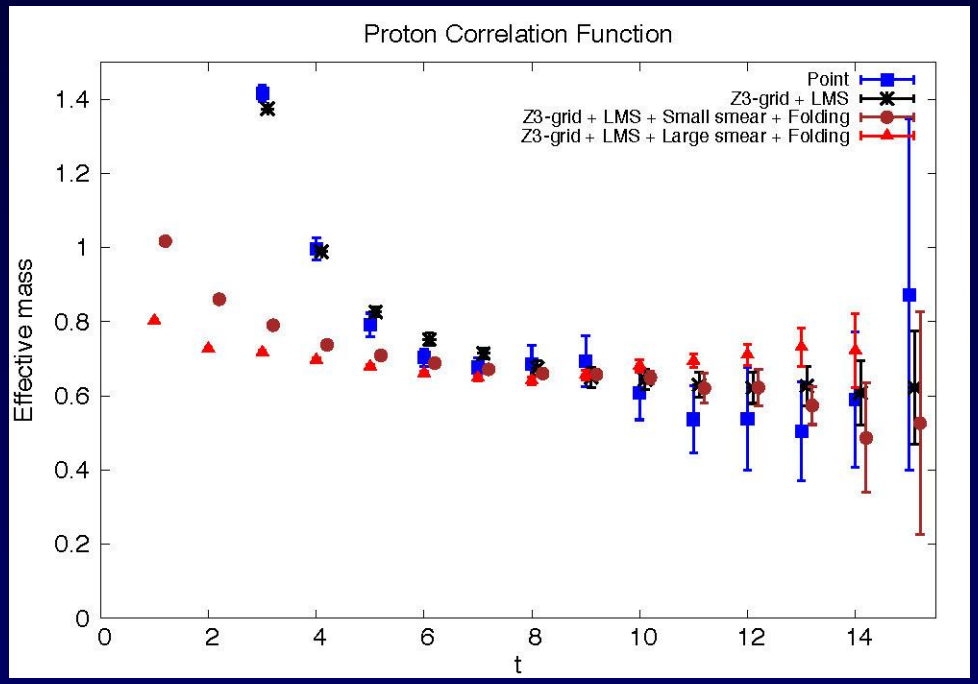
m_π ~ 300 MeV

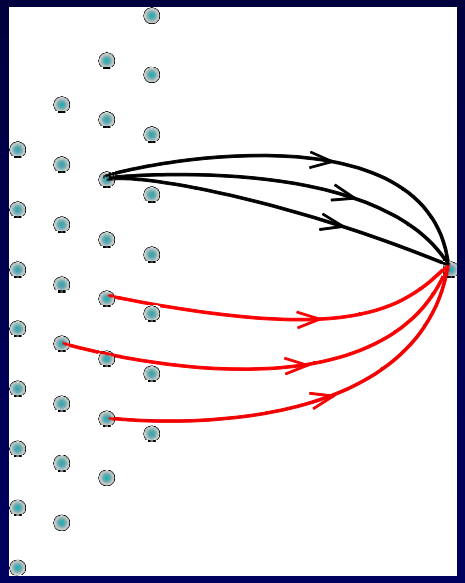




Reason for Higher Precision

- Improvement of nucleon correlator with noise grid source and low-mode substitution





$24^3 \times 64$ lattice with $m_\pi = 331$ MeV, a = 1.73 GeV^{-1}

47 configurations

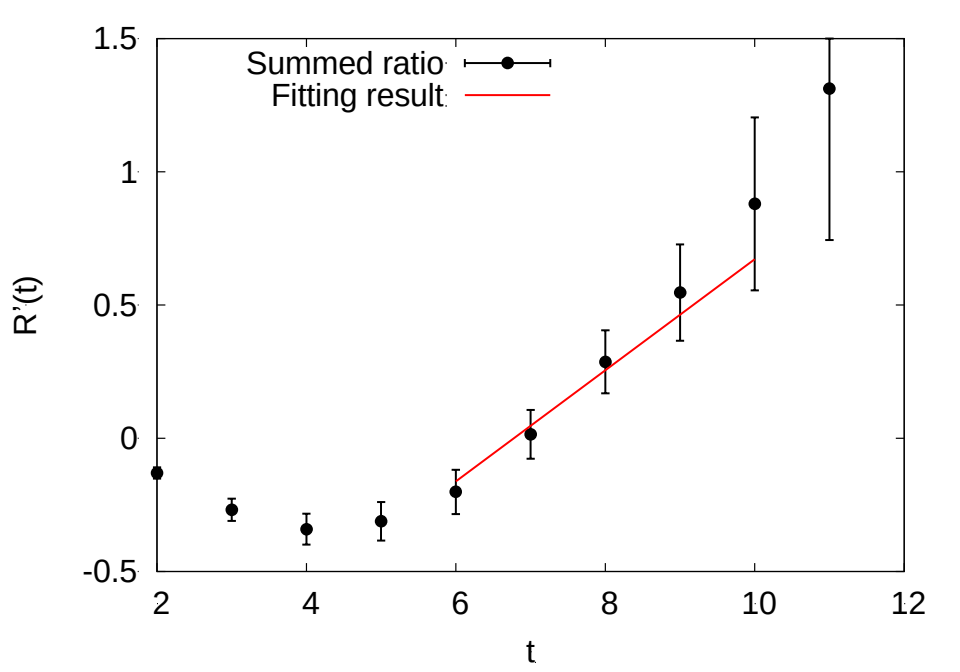
Point source: $m_N = 1.13(14)$ GeV;

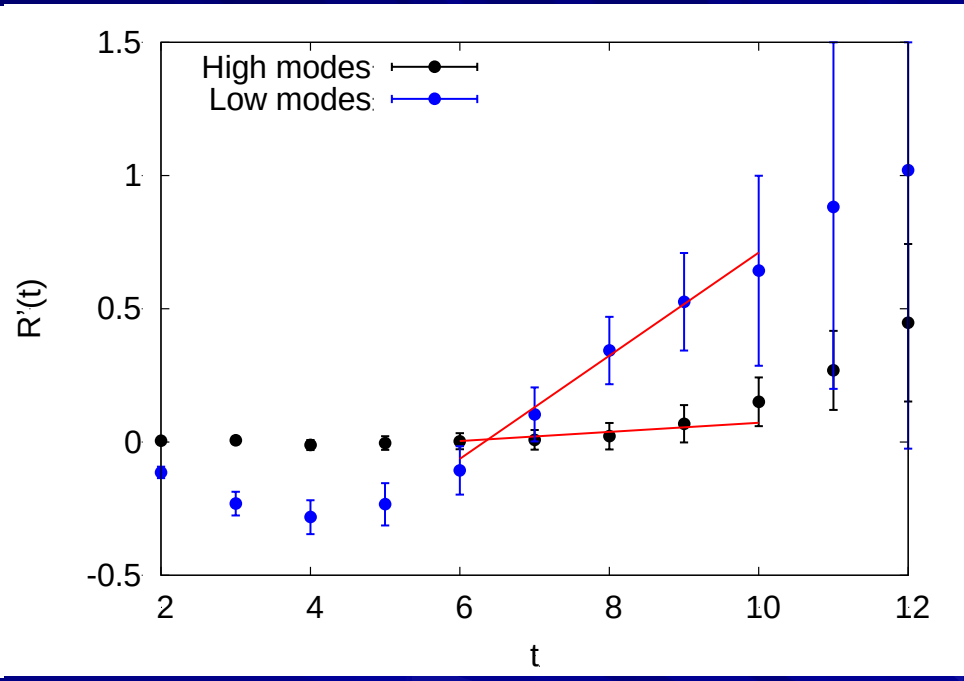
Z_3 grid source: $m_N = 1.08(5)$ GeV;

Z_3 small smeared grid: $m_N = 1.14(2)$ GeV;

Z_3 large smeared grid: $m_N = 1.13(1)$ GeV

Quark loop with low-mode averaging and Z_4 noise estimate of high modes with grids and time dilution





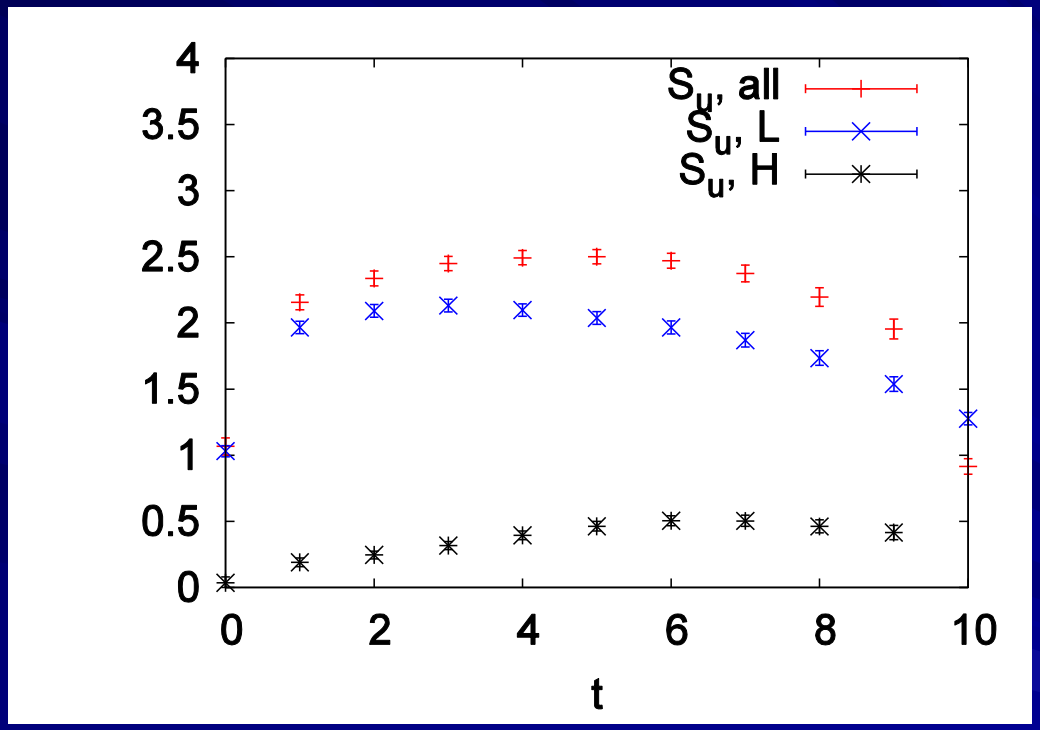
$$\text{constant} + m_s < N | \bar{s}s | N > t$$

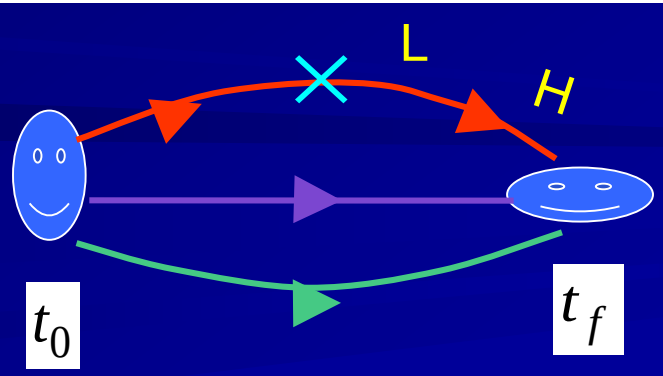
M. Gong
arXiv:1304.1194

$24^3 \times 64$, $m_l = 0.005$, $m_s = 0.04$, 176 conf. → 5 sigma signal

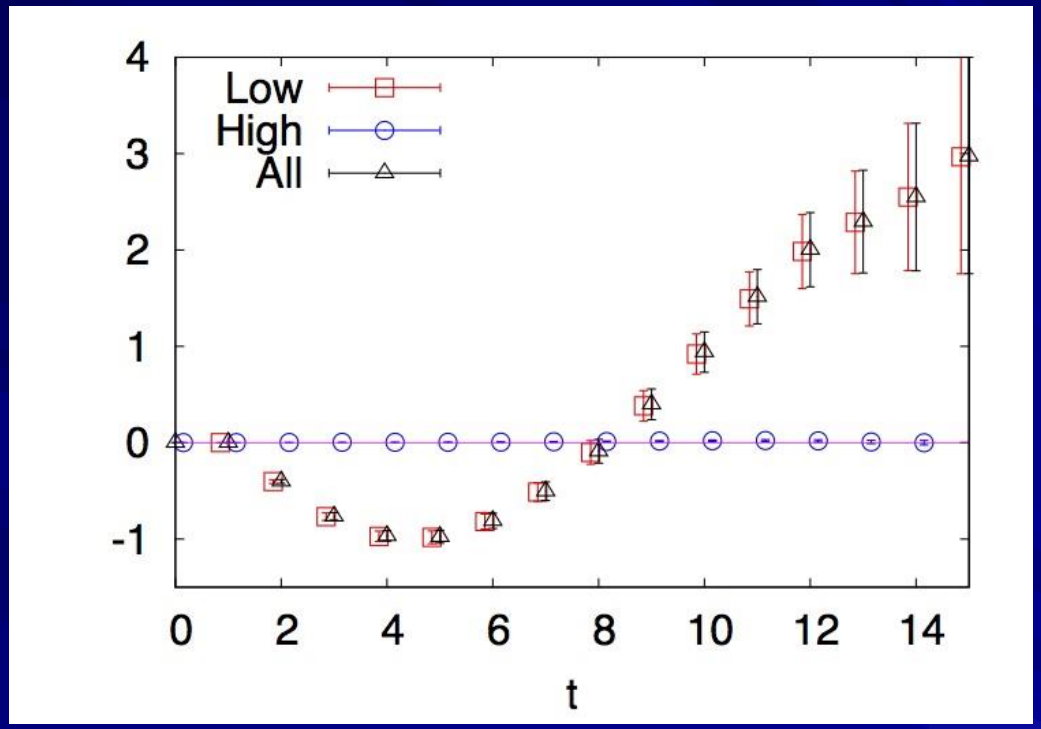
Plateau of 3-to-2-pt CI ratio

$\langle N | \bar{\psi}\psi | N \rangle$ $\qquad$ $u/d \Rightarrow m_\pi \sim 330\ \mathrm{MeV}$



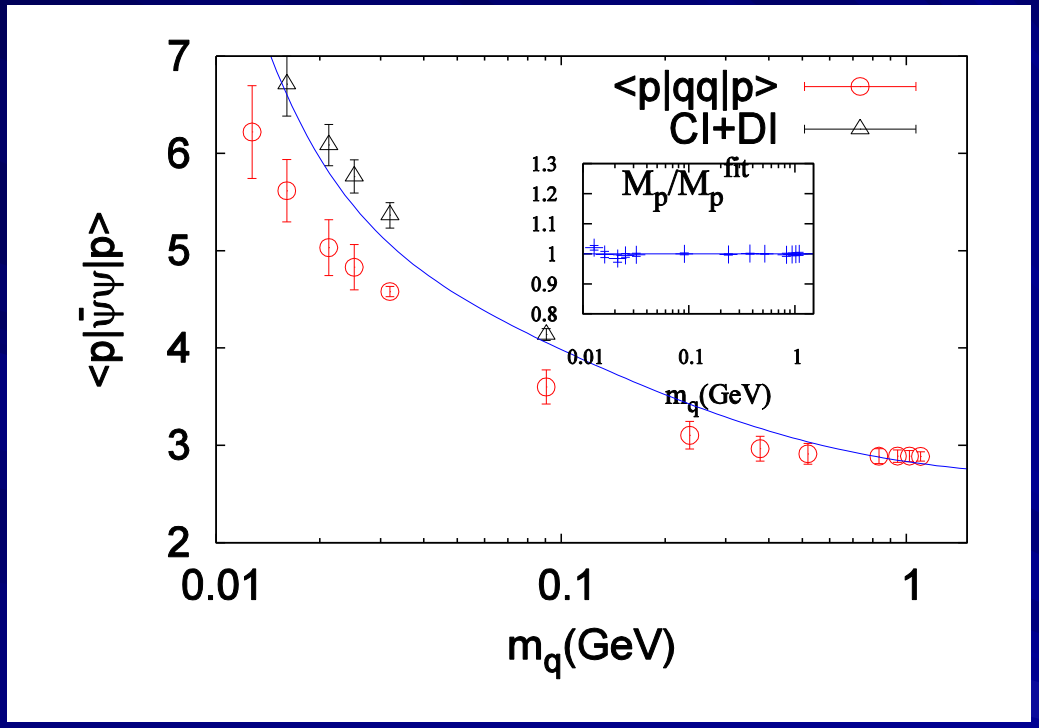


Slope of the sum method for DI



$$\sum_{t=t_0+1}^{t_f-1} G_3(t,t_f)/G_2(t_f) \xrightarrow[t_f \to \infty]{} \text{const} + \langle N | \bar{\psi}\psi | N \rangle t_f$$

Chiral Extrapolation

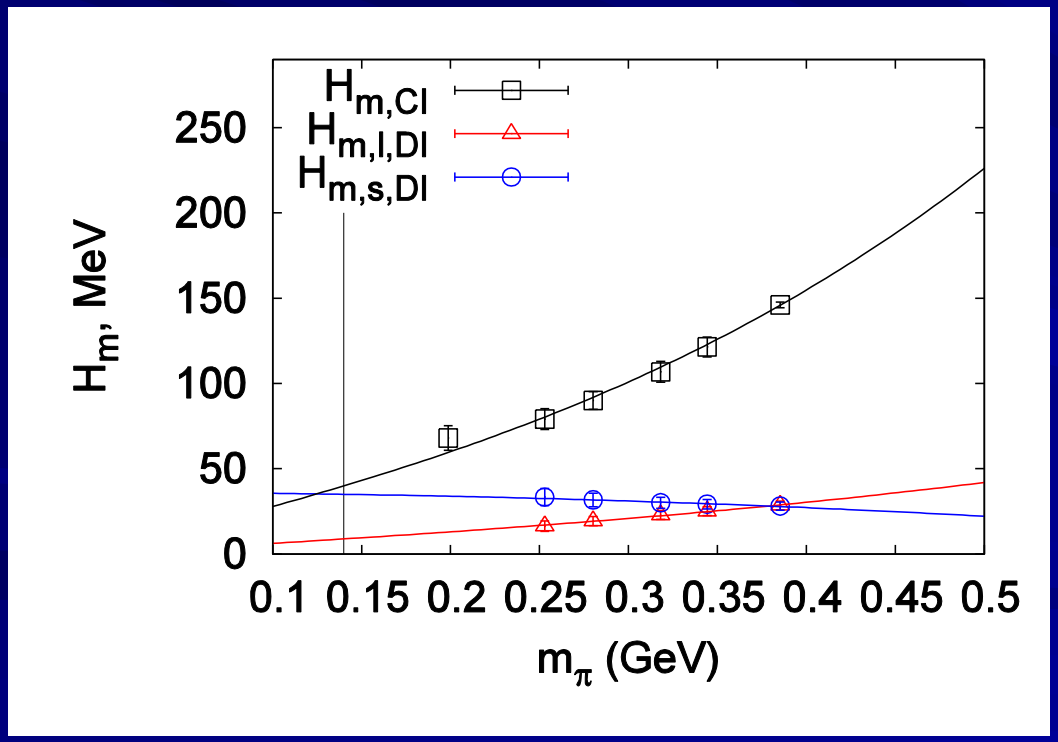


$$\sigma_{\pi N} = c_{1/2} m_\pi + c_{3/2} m_\pi^3$$

$\sigma_{\pi N}$ and σ_s as a function of pion mass

$24^3 \times 64$, $m_\pi(\text{sea}) = 330$ MeV, 200 configurations

$g_A^3 = 1.129(38)$ at $m_\pi(\text{valence}) = 280$ MeV



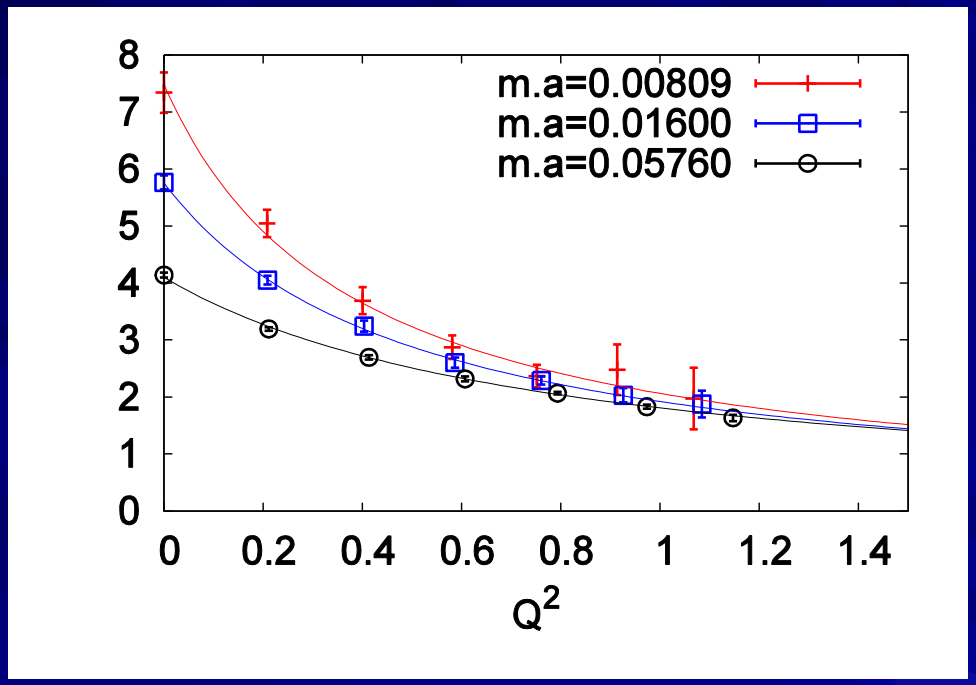
$\sigma_{\pi N}(CI) = 40(2)$ MeV,

$\sigma_{\pi N}(DI) = 8.8(1.0)$ MeV,

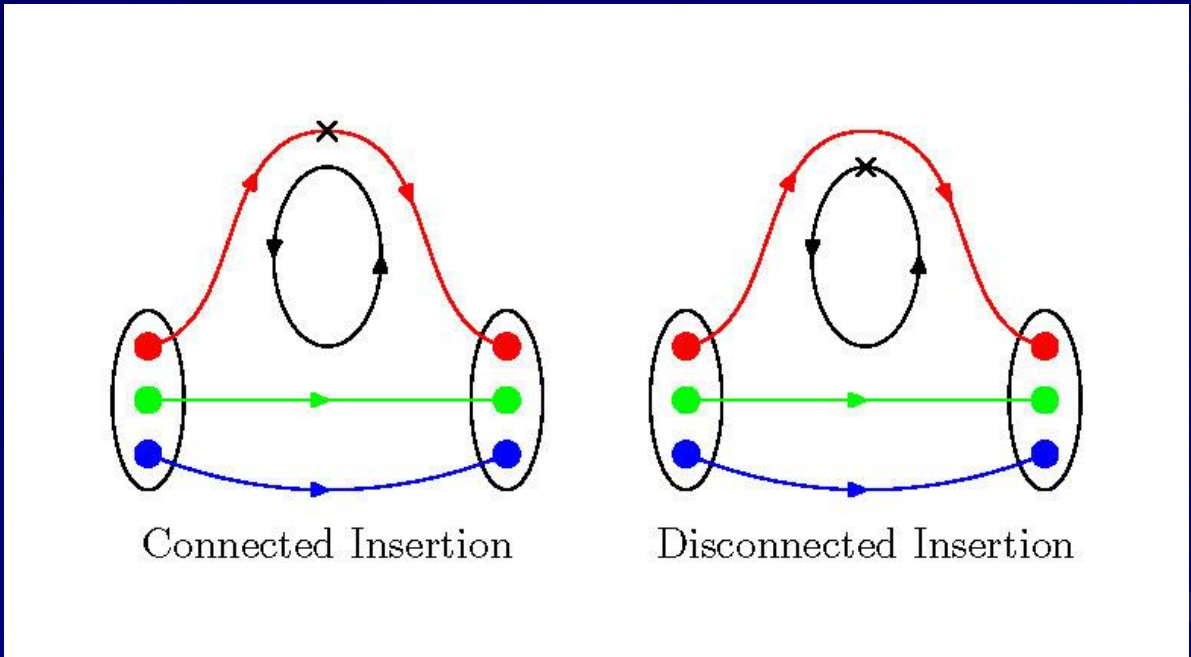
$\sigma_{\pi N}(total) = 49(3)$ MeV,

$\sigma_s = 36(5)$ MeV

Scalar Form Factor

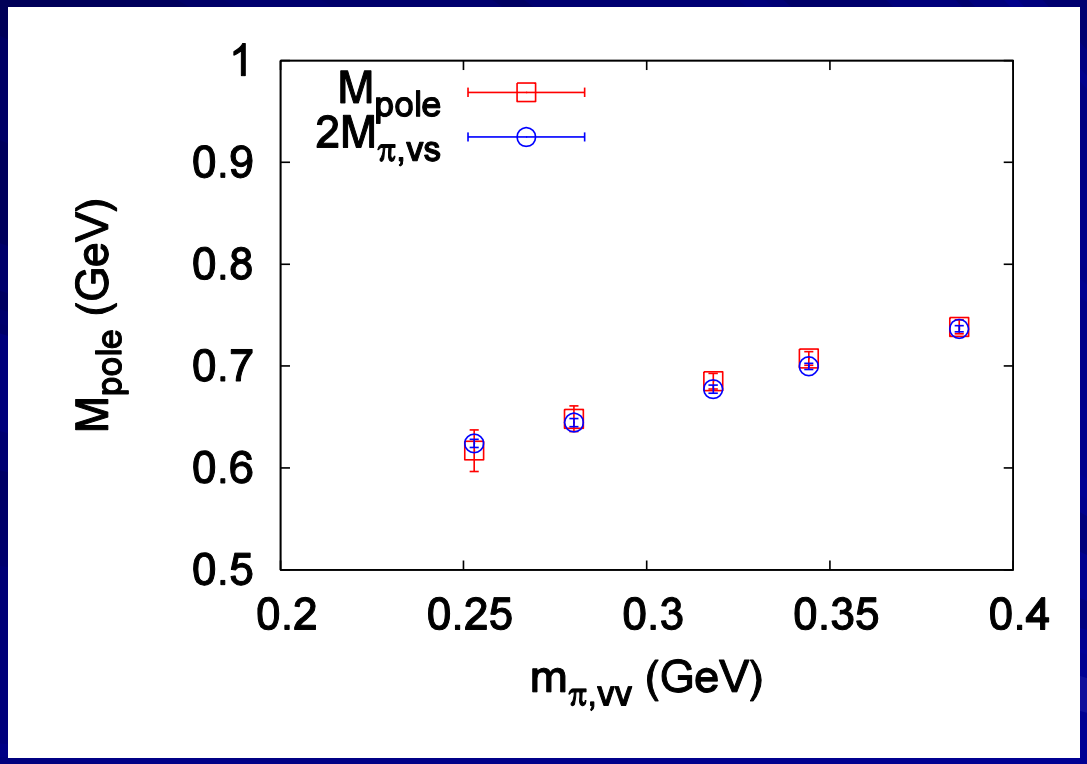


Scalar Form Factors

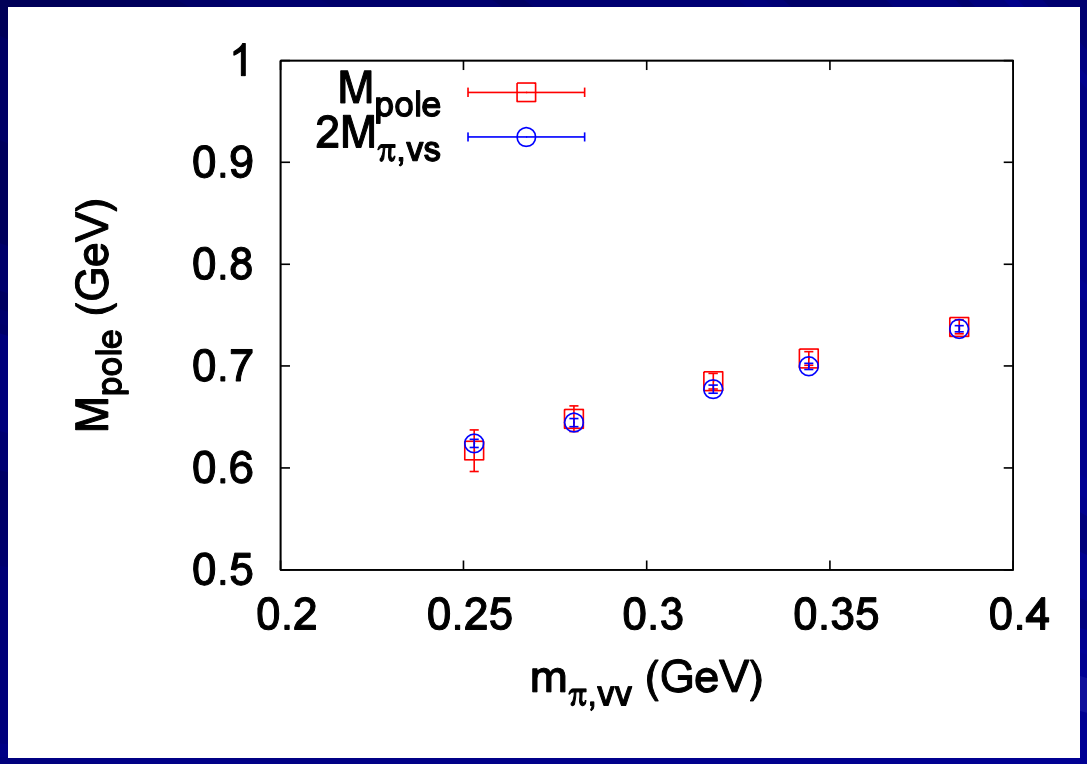


J.Gasser. H. Leutwyler, and M.E. Sainio,
Phys.Lett. B253 (1991) 252.

Monopole fit of the Form Factors



Monopole fit of the Form Factors

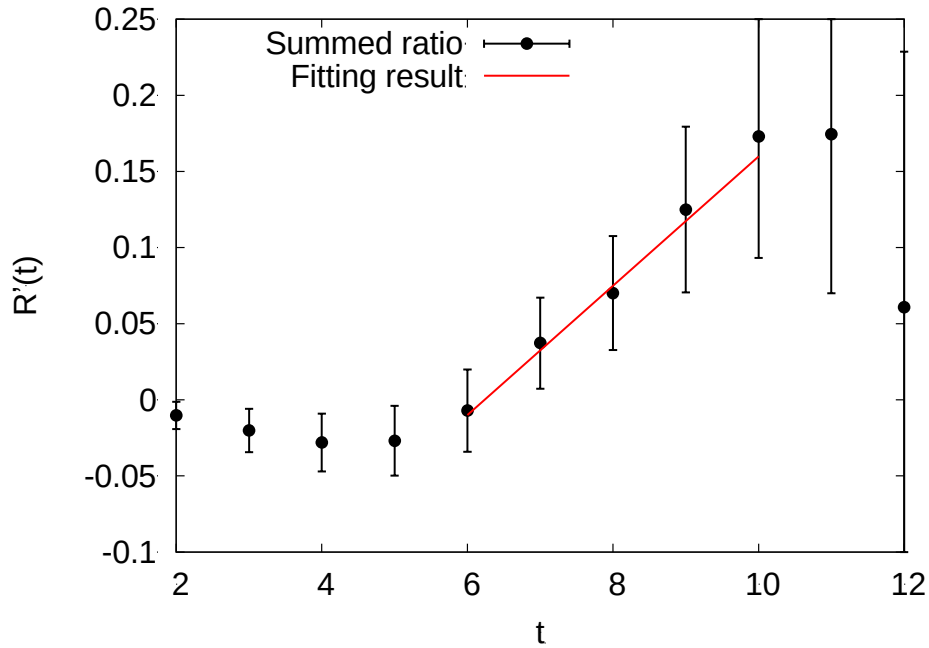


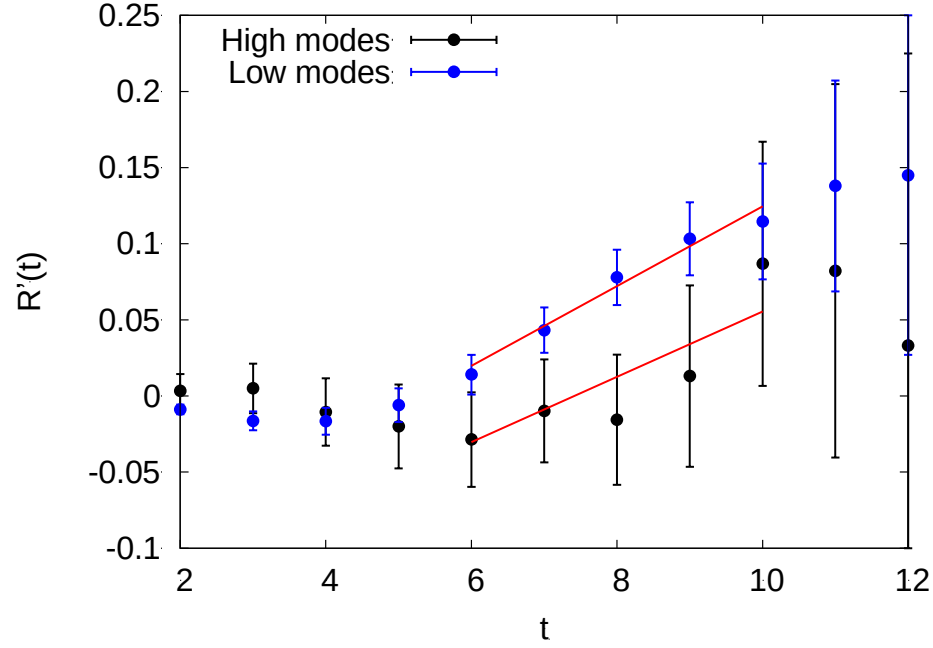
Dominated by the two pion pole

Summary

- Overlap fermion on DWF configuration.
- Strangeness at 14% and charmness at 20% (aim).
- Pi N sigma term is dominated by CI.
- Scalar form factor dominated by the two pion channel.
- Work in progress for the $48^3 \times 96$ lattice at physical pion mass.

Charmness





$$m_c < N|\bar{c}c|N> = 94(31)\ \text{MeV}$$

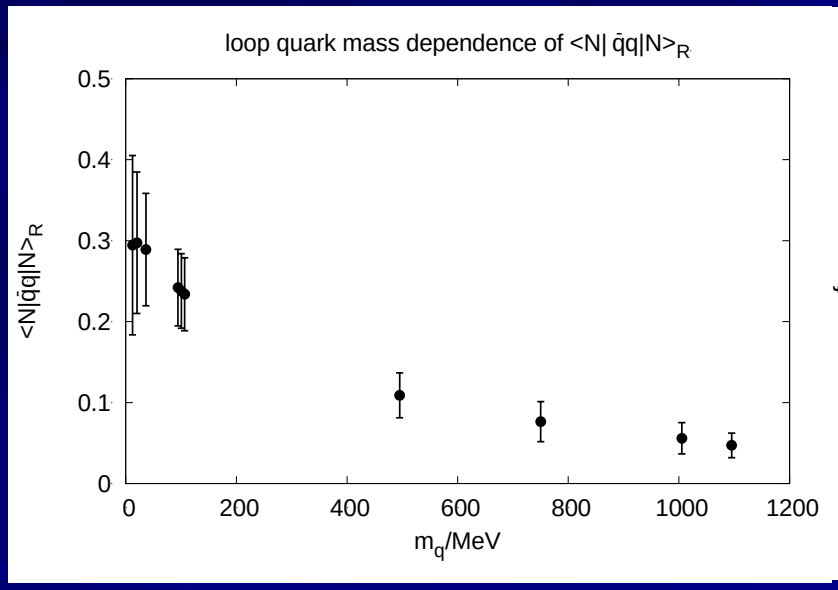
M. Gong
arXiv:1304.1194

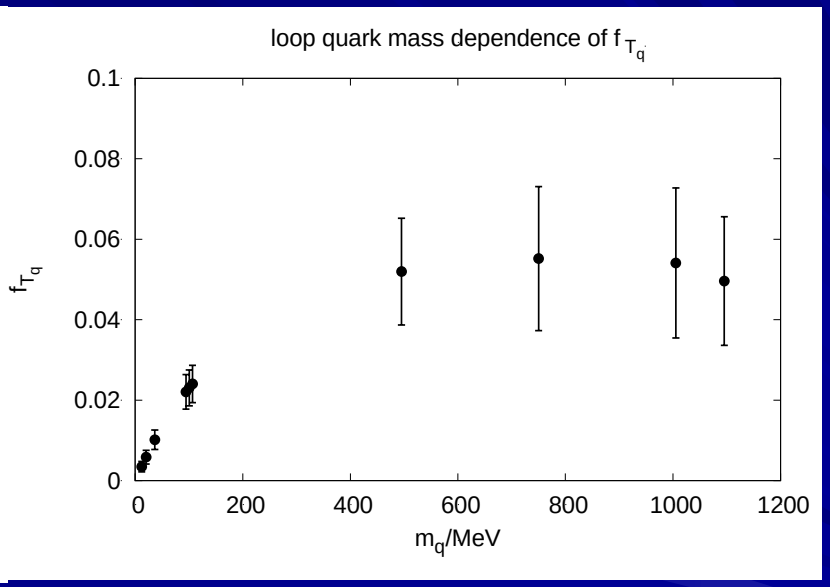
Consistent with the estimate of ~ 70 MeV from heavy quark expansion and trace anomaly for the nucleon mass (Shifman, …)

Would like to reach > 5 sigmas for disconnected insertions and glue observables to be useful for phenomenology.

Heavy quarks are more relevant for dark matter search

$$m_c < N|\bar{c}c|N> = 94(31)\ \text{MeV}$$





- In the case of heavy quarks, the scalar matrix elements seem to fall as 1/m and f_T level off for m > 500 MeV.