Flavor singlet mesons in QCD with varying number of flavors

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for the LatKMI collaboration

- @ Lattice 2016, Southampton, UK -

July 26, 2016

LatKMI collaboration

- KMI / Nagoya Univ.

   

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- KEK, Swansea CPT Marseille, RIKEN-BNL, LLNL, Tsukuba

Y. A, E.Bennett, M.Kurachi, K.Miura, H.Ohki, E.Rinaldi, A.Shibata, T.Yamazaki

- Especially for this talk I owe these members in LatKMI:





Lightest flavor singlet mesons

- Many Flavor Theory
  - scalar: candidate of composite Higgs
- QCD
  - scalar: $\sigma = f_0(500)$ still mysterious (particle); Lattice, difficult
  - pseudoscalar $\eta'(960)$ heavy due to $U(1)_A$ anomaly; Lattice, challenging
- Interesting problem to tackle with.
- Try to investigate them using N_f handle, with high statistics

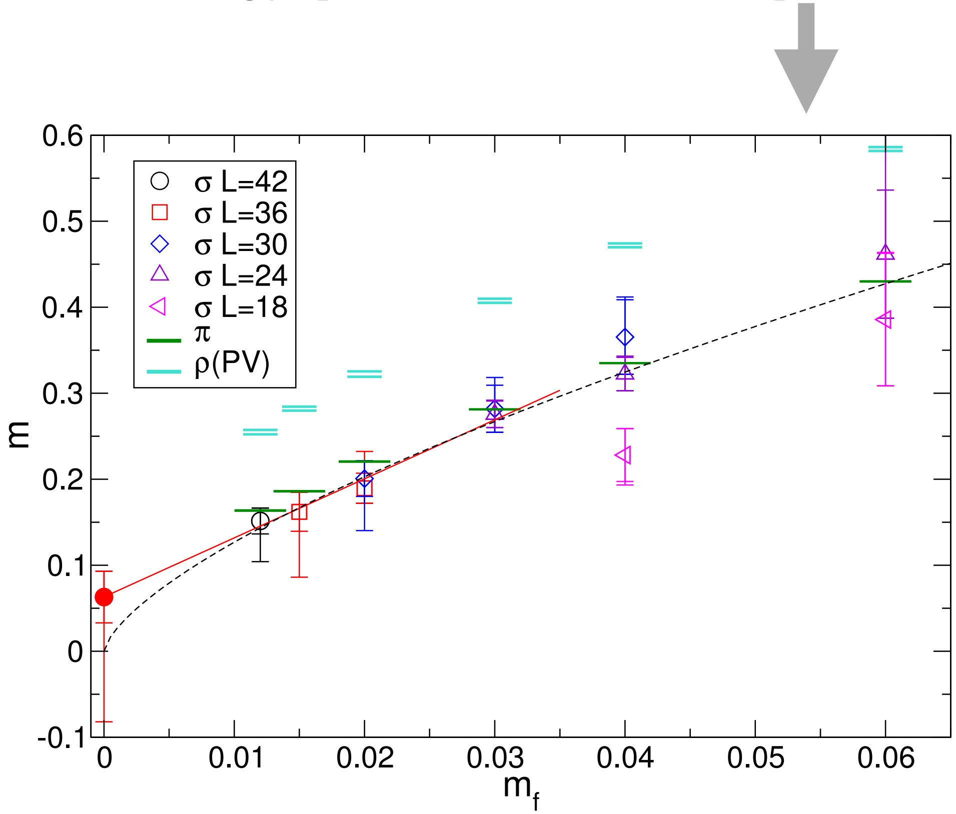
Simulation

- Fermion Formulation: HISQ (Highly Improved Staggered Quarks)
- Gauge Field Formulation:tree level Symanzik gauge
- all of LatKMI simulations are done in this set-up
- using MILC code v7, with modification: HMC and speed up in MD
- Computers:
  - KMI phi, CX400 at Nagoya, Kyushu &
  - HPCI(Kyushu) [project# hp140152, hp150157, hp160153]

- N_f=4 and 8 ongoing, preliminary results are shown, N_f=12 planned

N_f=8 spectrum

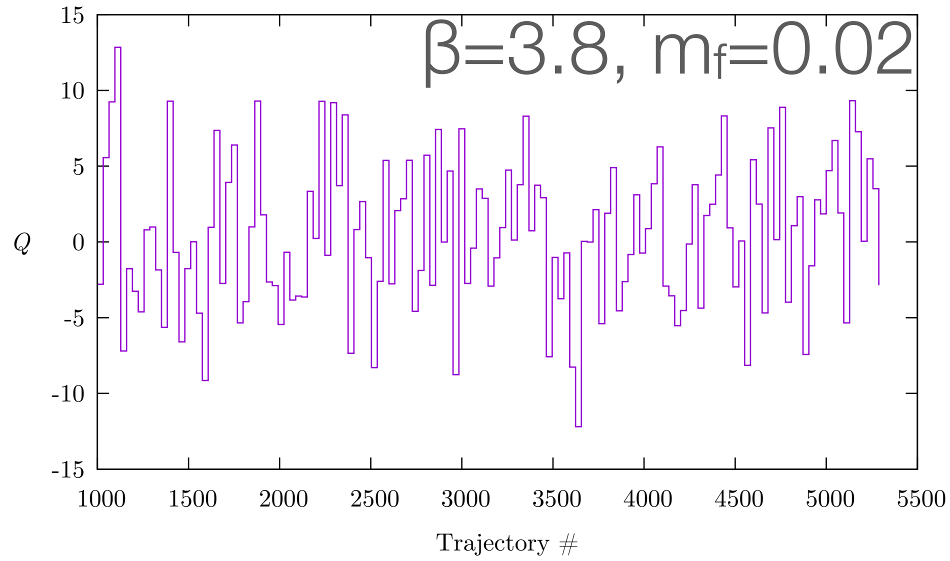
- a full paper about to finish includes spectrum: π, ρ, σ (, N, a0, a1, b1, f_π…)
- observed hierarchy of spectrum (parametrically) [LatKMI, PRD 2014] +update
    - $m_\pi \simeq m_\sigma < m_\rho$ (N_f=8)

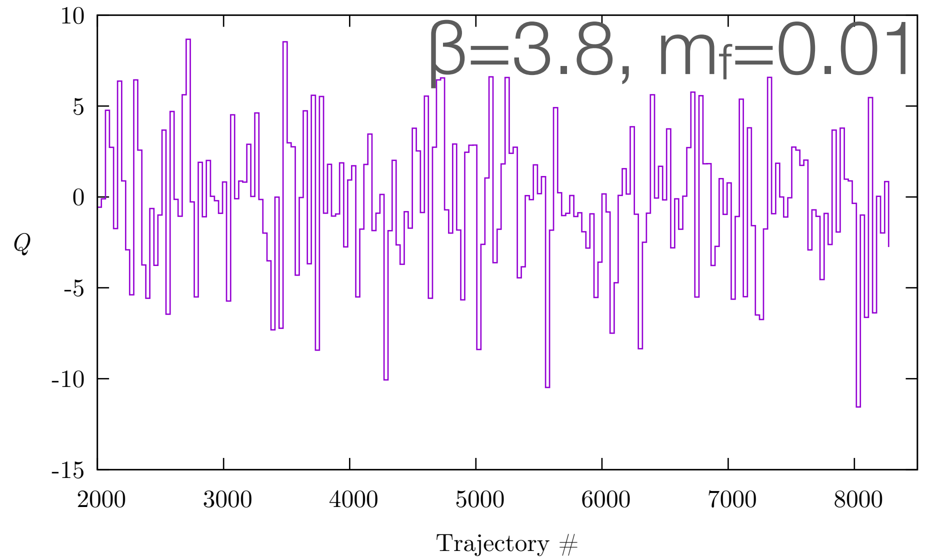


- contrast to QCD (physical point)
    - $m_\pi \ll m_\sigma < m_\rho$ (N_f=2+1)
- Informative to investigate N_f=4
    - adding η' on the table

N_f=4 simulation

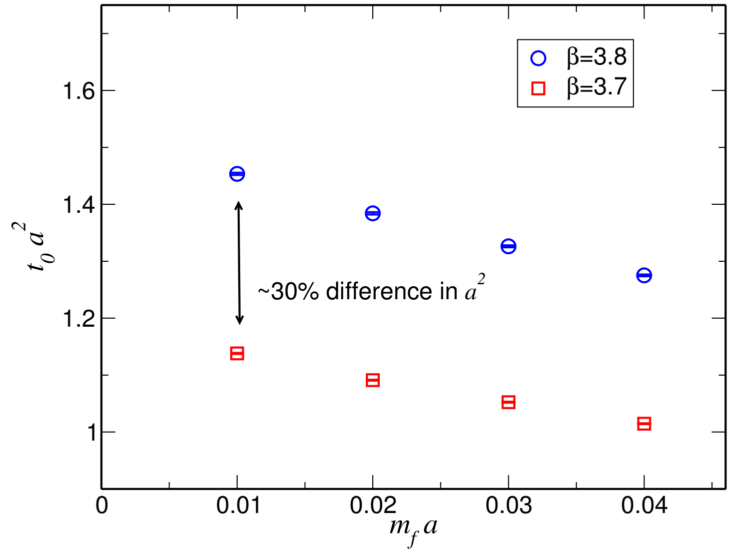
- $\beta = 6/g^2 = 3.7$ and 3.8(new)
- $L^3 \times T = 20^3 \times 30$
- m_f=0.01, 0.02, 0.03, 0.04
- $(LM_\pi)_{min}$=3.9
- sampled MDTU for β=3.8:
  - 15000 (m_f=0.01)
  - 5000 (others)
- Q_{top} history



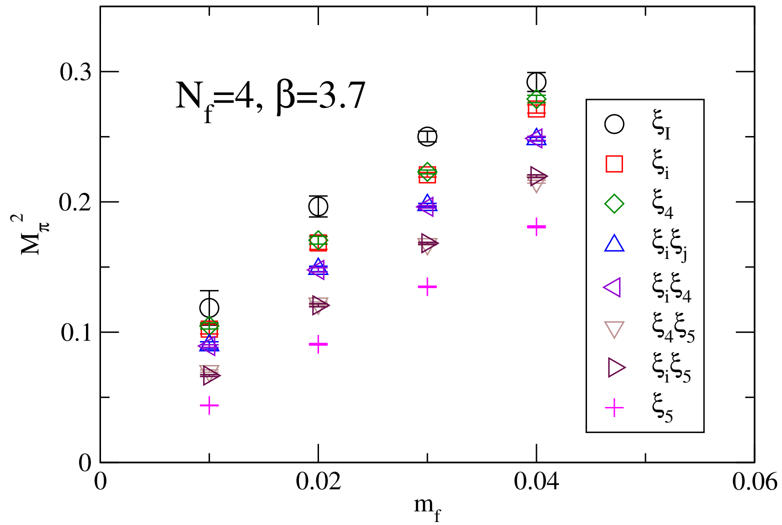


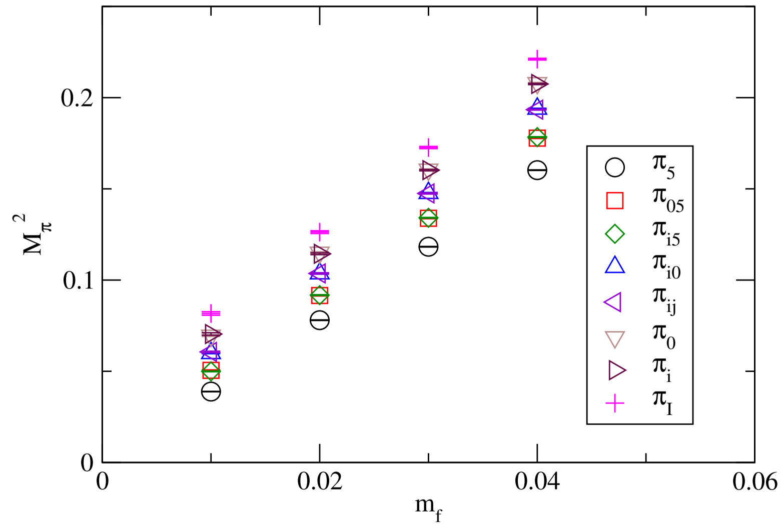
N_f=4: scale and pions

- t_0 from Symanzik flow:
  - $a^2(\beta=3.7)/a^2(\beta=3.8) \simeq 1.3$



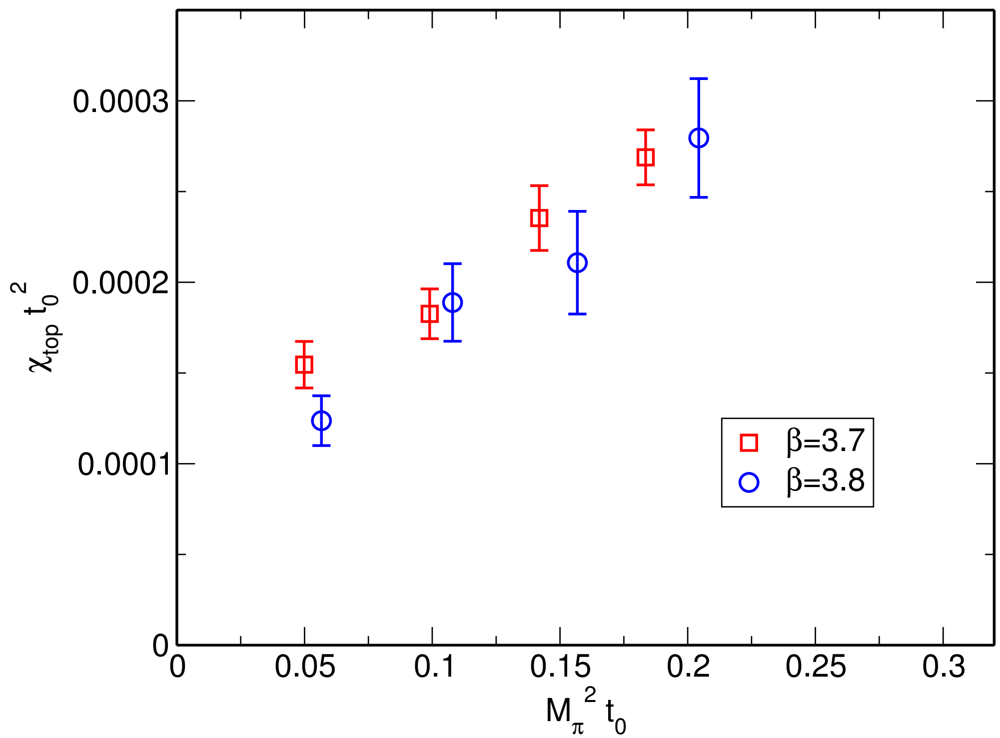
- taste symmetry violation





N_f=4 topological susceptibility

- normalized with t_0

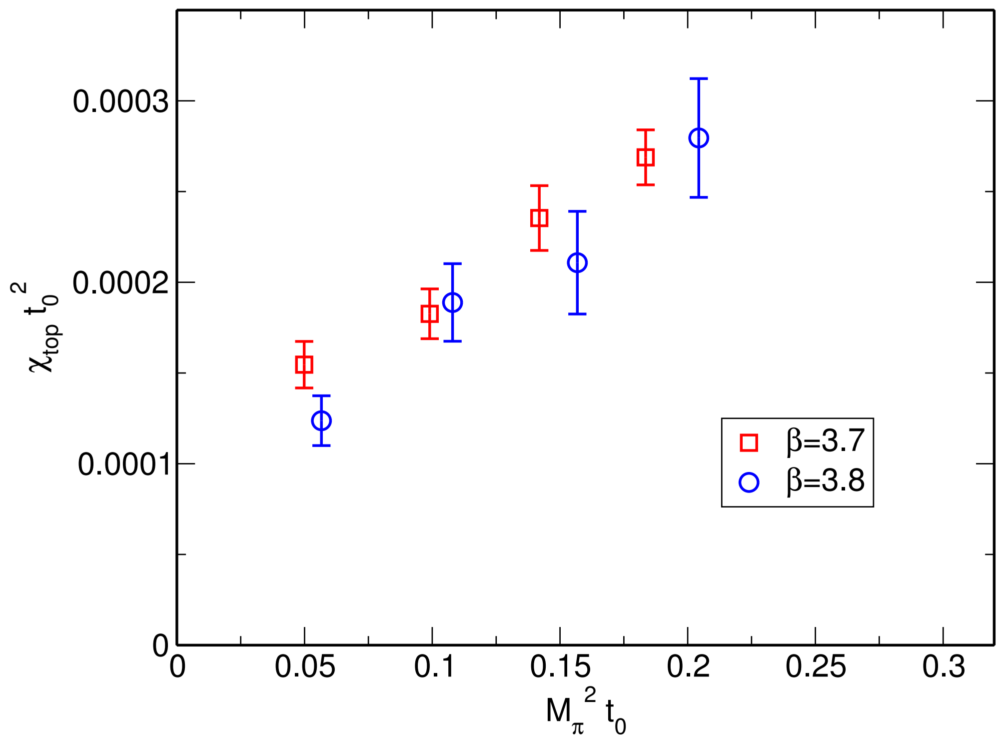


does not vanish in $M_\pi \to 0$?

N_f=4 topological susceptibility

- normalized with t_0
- x-axis: NG pion → taste singlet

(a la sChPT: see Billeter, DeTar, Osborn, PRD2004)



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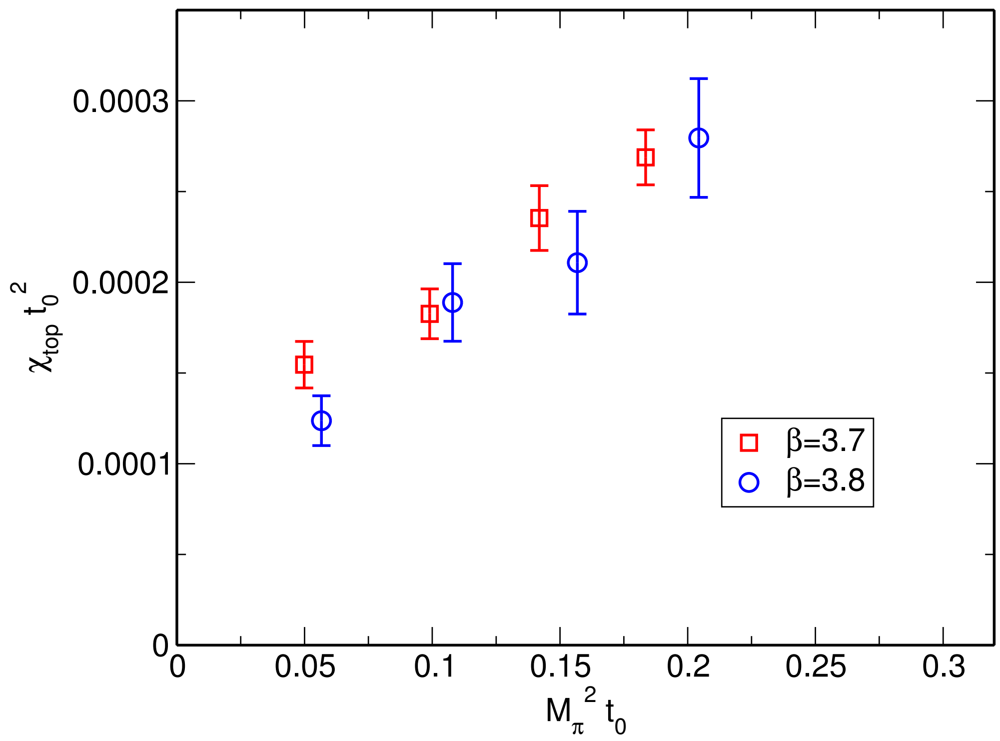

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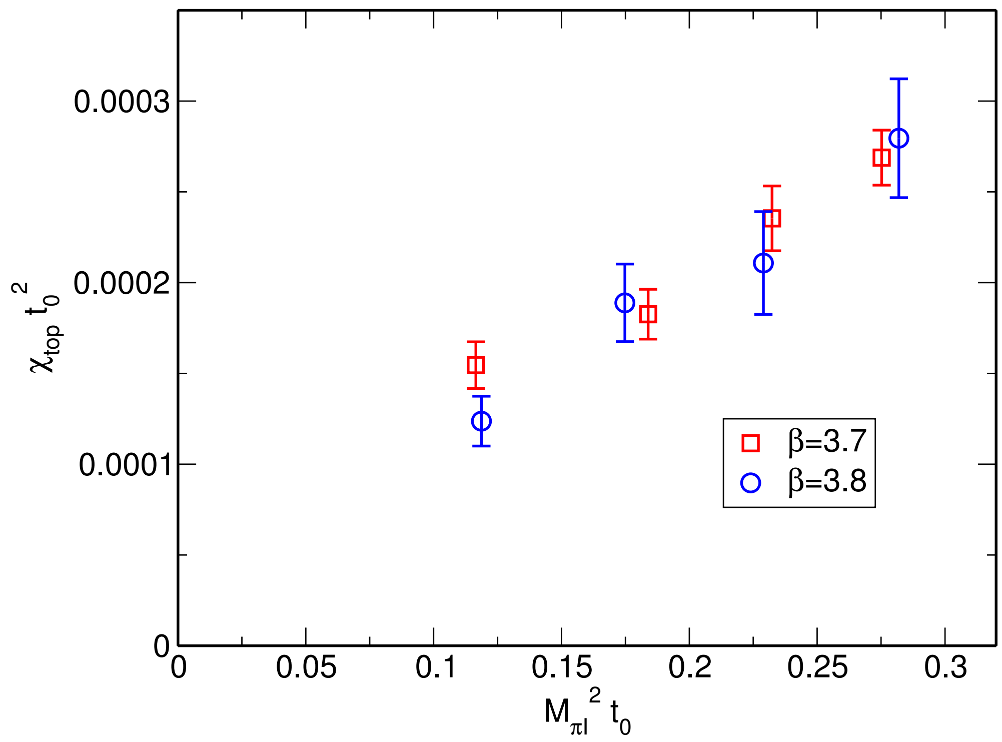

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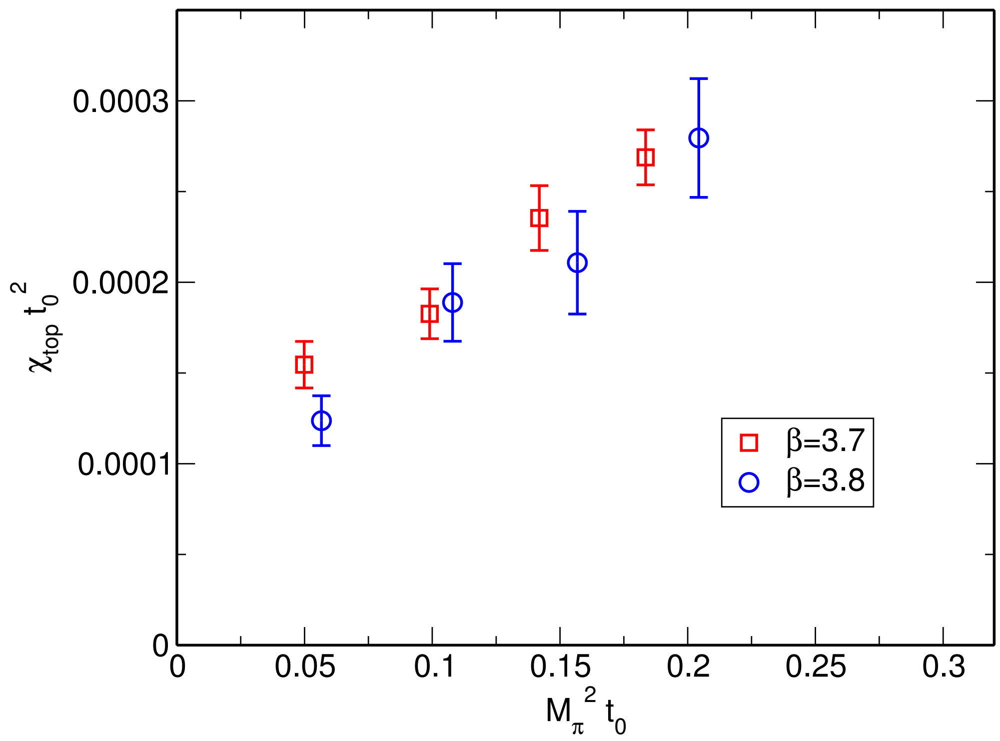

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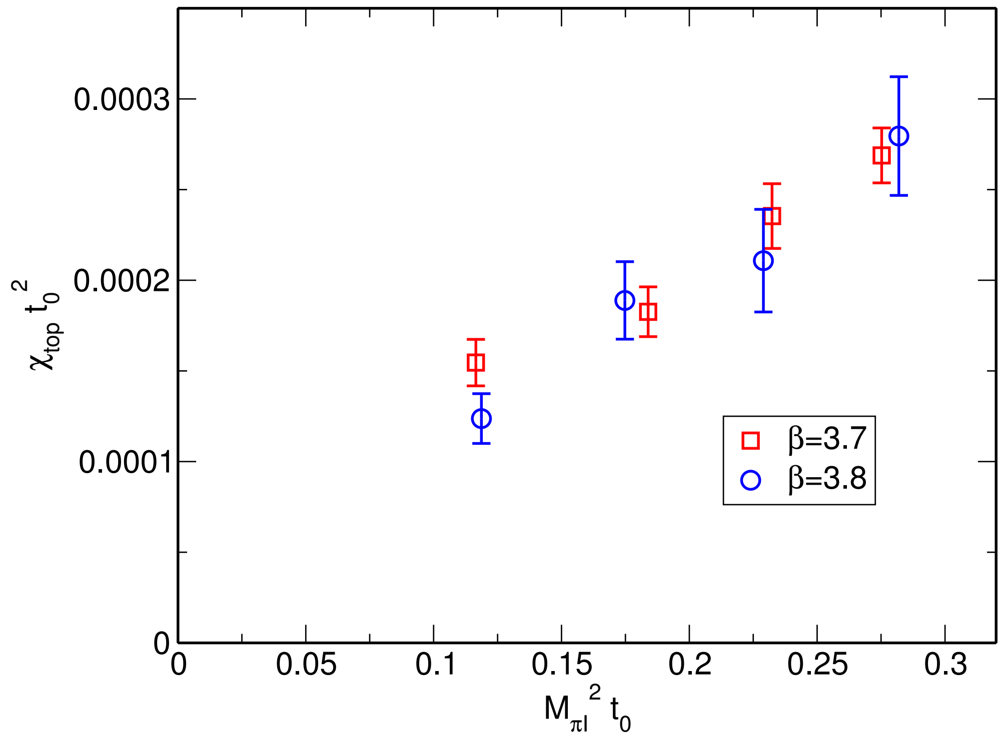


better chiral behavior, and

better a-scaling

a method for flavor singlets

- statistical technique for these noisy correlation functions
- use purely gluonic operators and sample exact all to all with Gradient Flow
- zero momentum projection is not very efficient

$$\cancel{G(x,y,z,t) \to G(t)}$$

- average to all direction will help

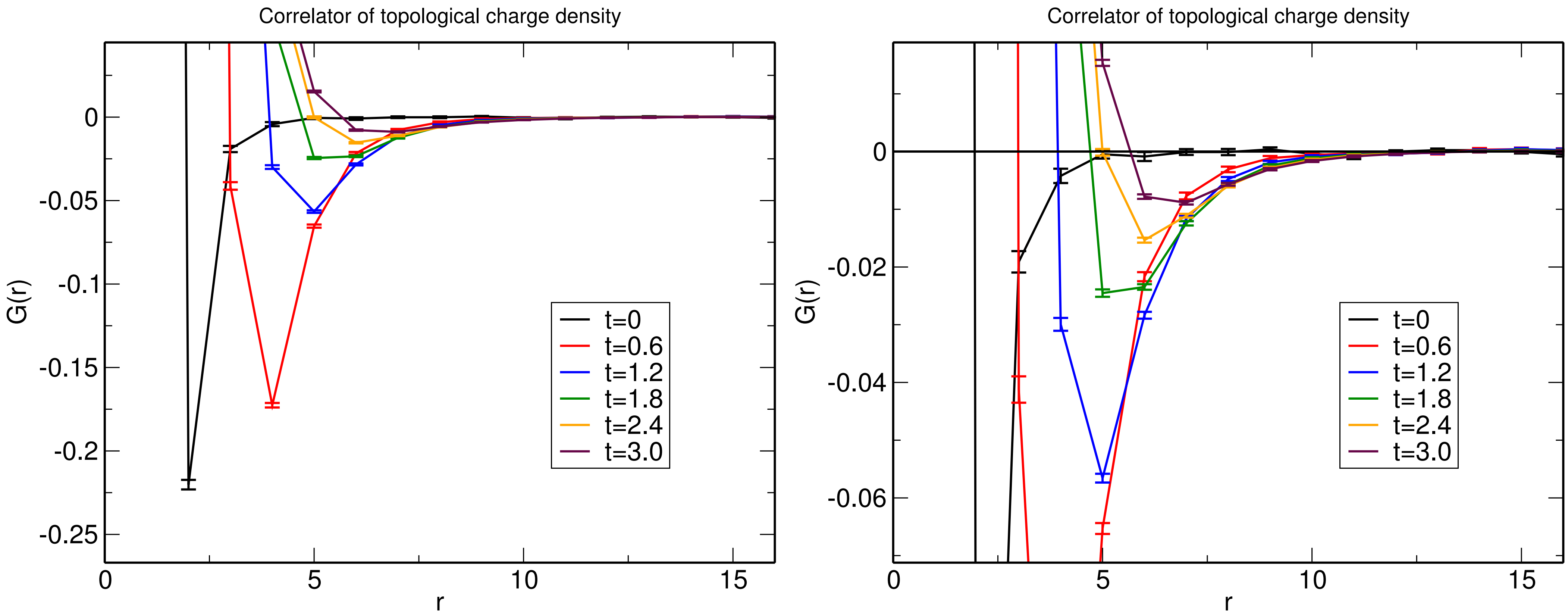
$$G(x,y,z,t) \to G(\mathbf{r})$$

- Successful applications
  - 0+- glueball @ N_f=0 by Chowdhury, Harindranath, Maiti, PRD 2015
  - η' meson @ N_f=2+1 by JLQCD (Fukaya et al) PRD 2015
    - no pion "contamination" due to no use of fermion correlators

N_f=4 η'   (preliminary)

- Use topological charge density operator
- With flow time varying $0 \le t \le 3$
- ensemble: β=3.8 only so far
- sample rate: one in 32 * MDTU → ~400 samples for m_f=0.01
- G(x,y,z,t) → G(**r**) with FFT, **r**'s binned to [n-0.5,n+0.5)→n (integer)
  - use for effective mass, global **r** fit
- Correlation function for m_f=0.01 looks…

N_f=4, η’ correlation function G(r) (preliminary)



zoom-in of left

- asymptotic form: $$G(r) = \frac{C}{r} K_1(Mr)$$

N_f=4, η' (preliminary) - mass extraction: m_f=0.01

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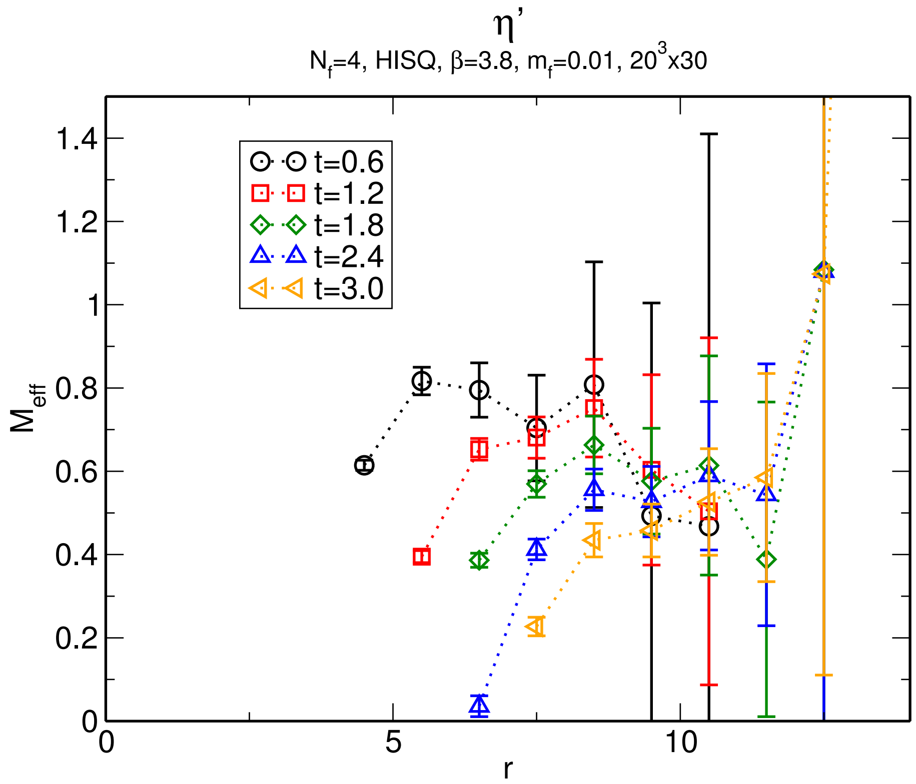

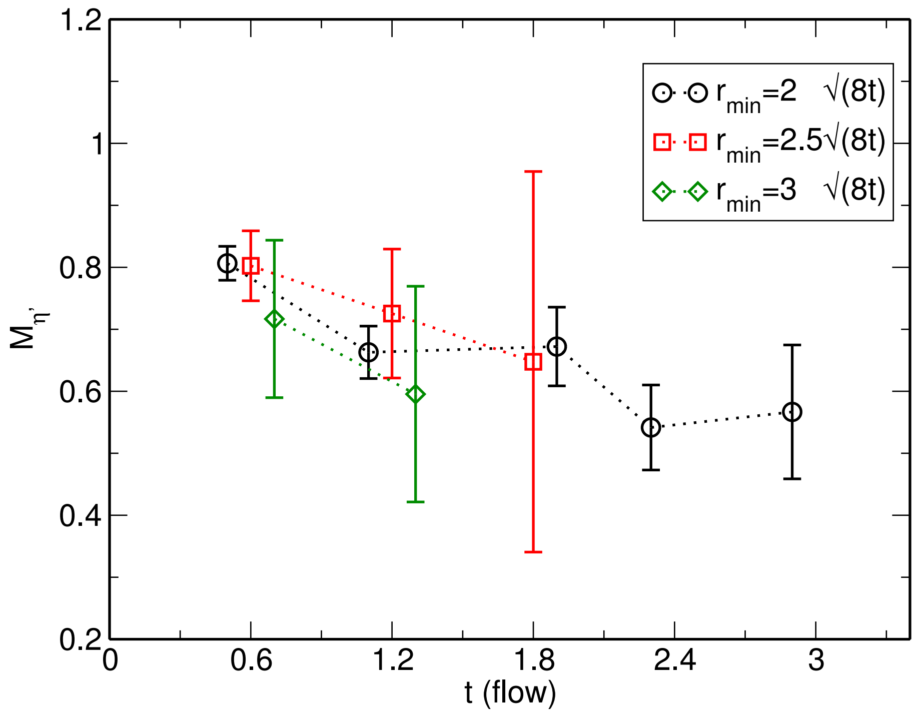

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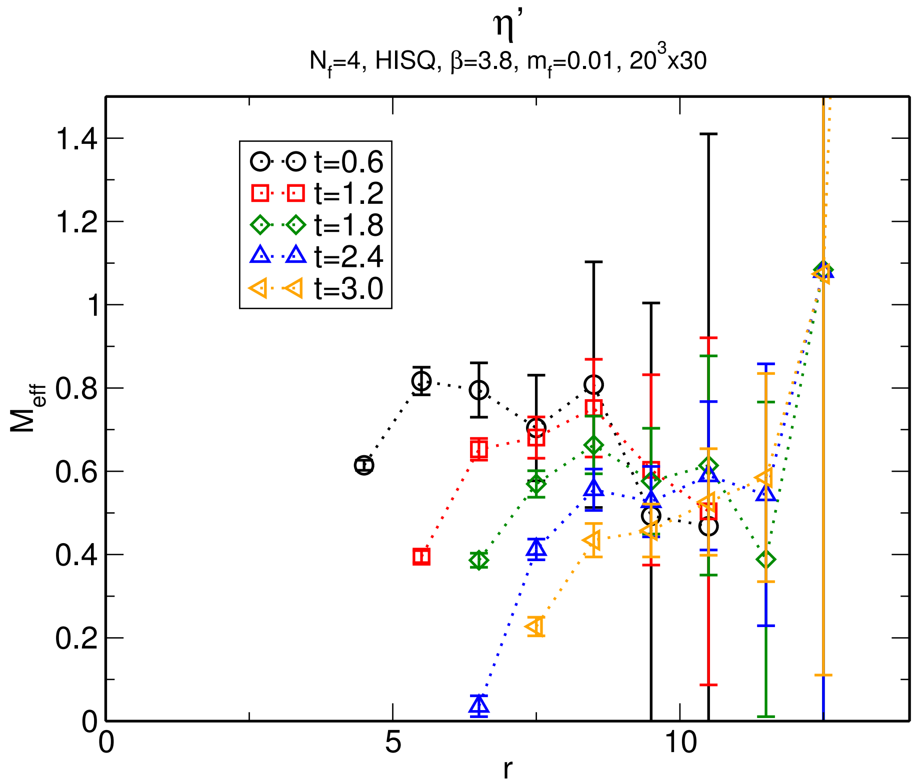

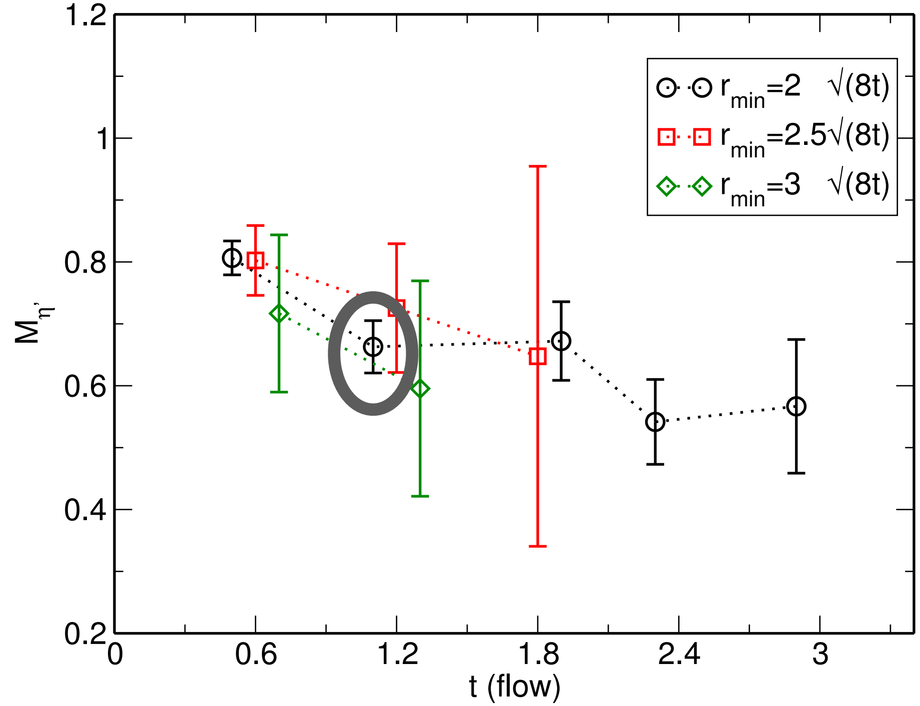

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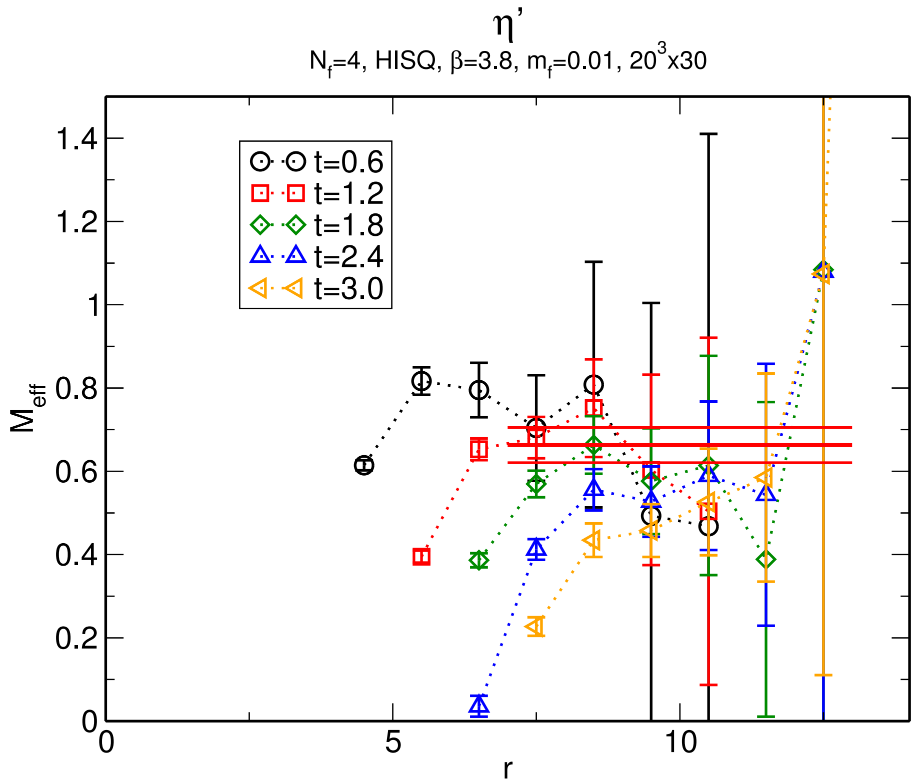
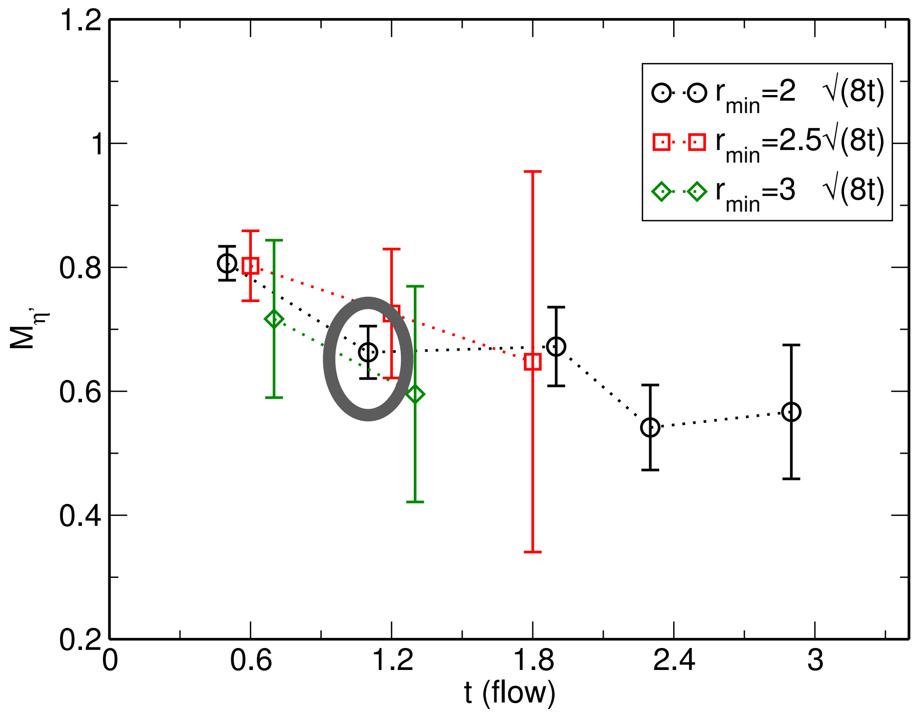
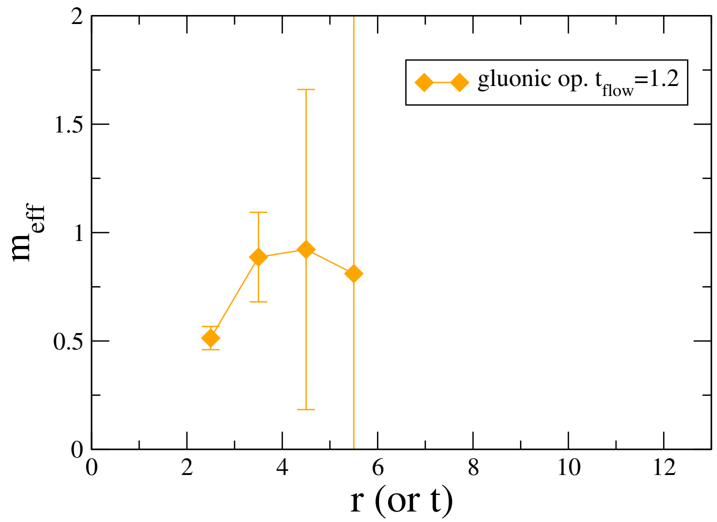




N_f=4, σ (preliminary) - mass extraction @m_f=0.01

- Use symmetric (clover) plaquette for the operator



  - very noisy

- instead, use fermionic scalar operator

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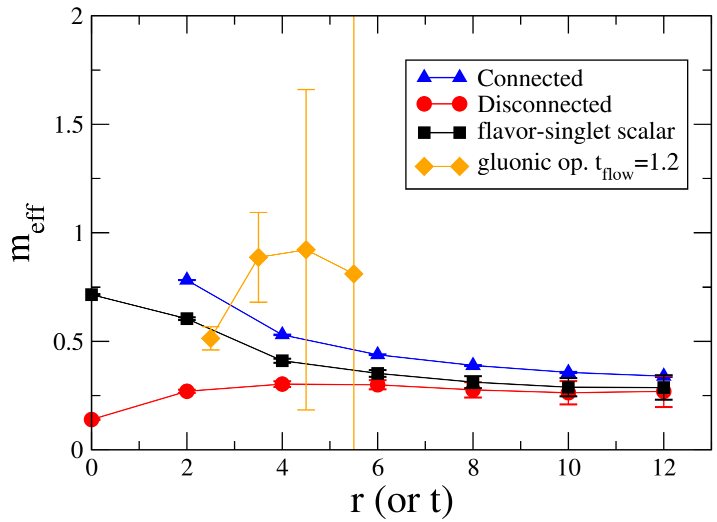

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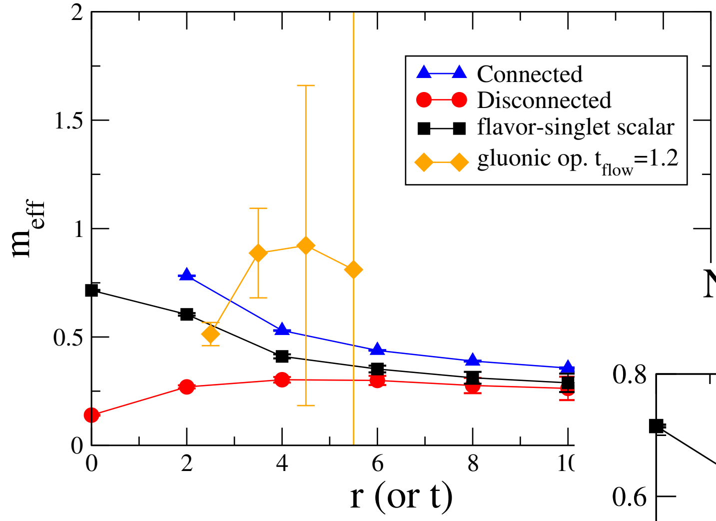

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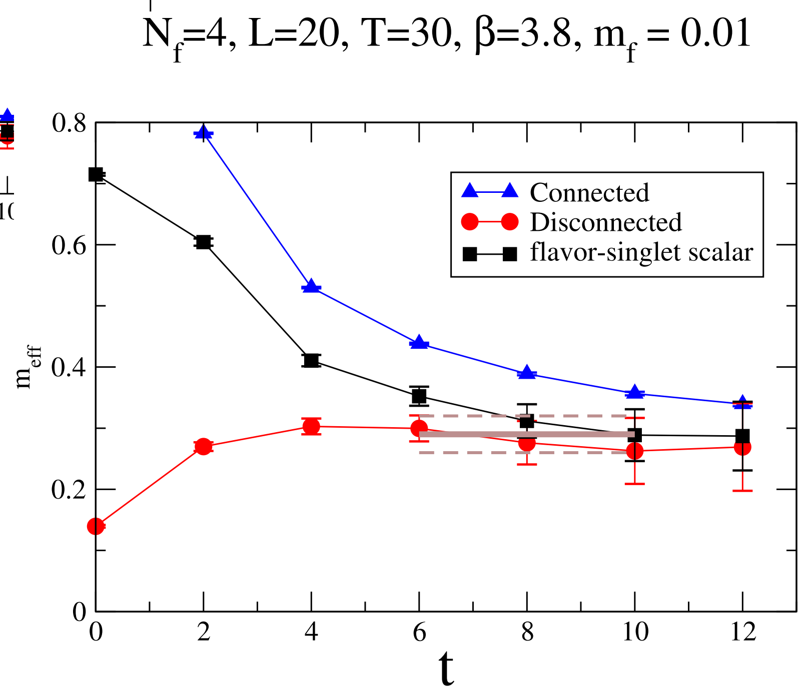
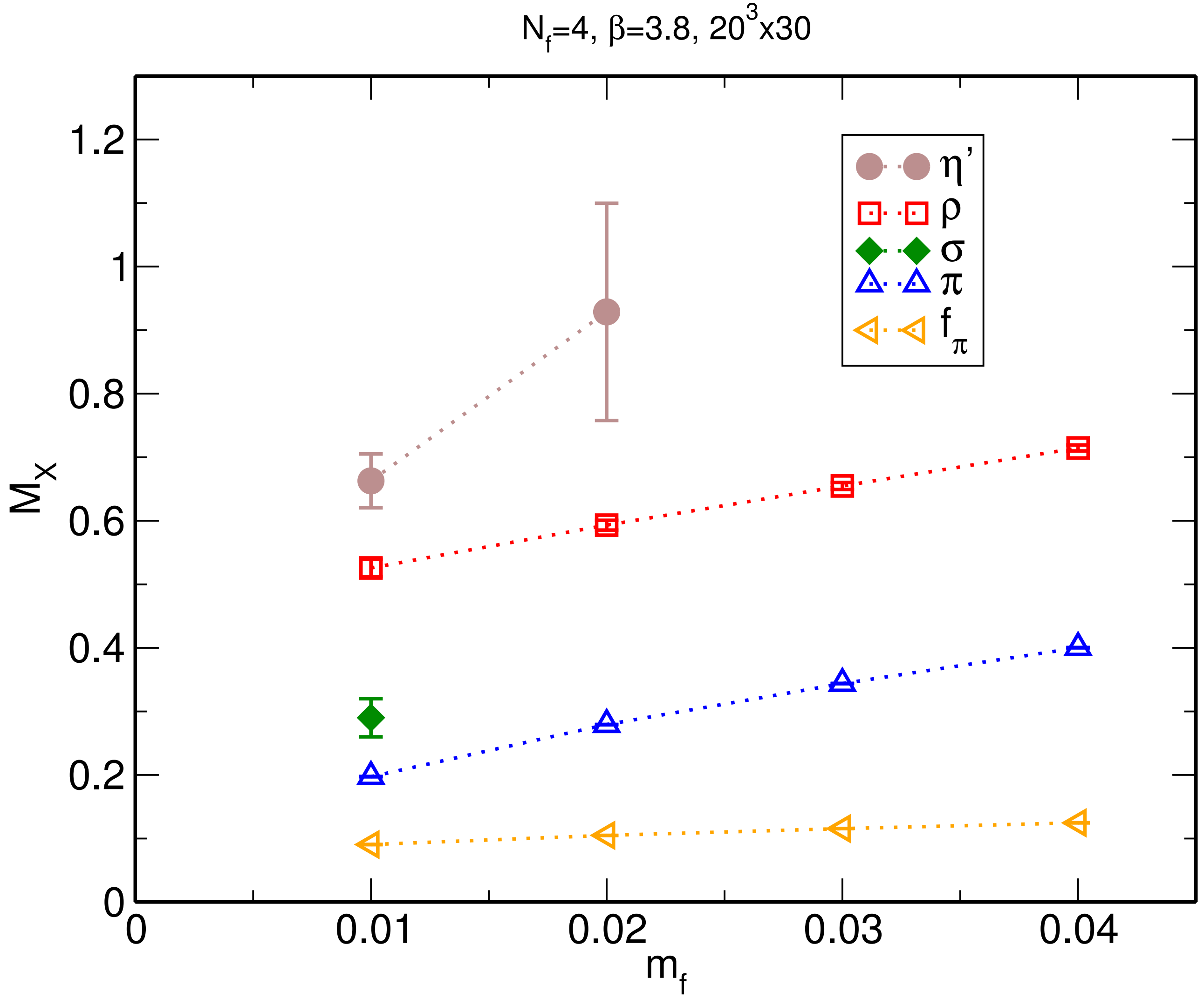
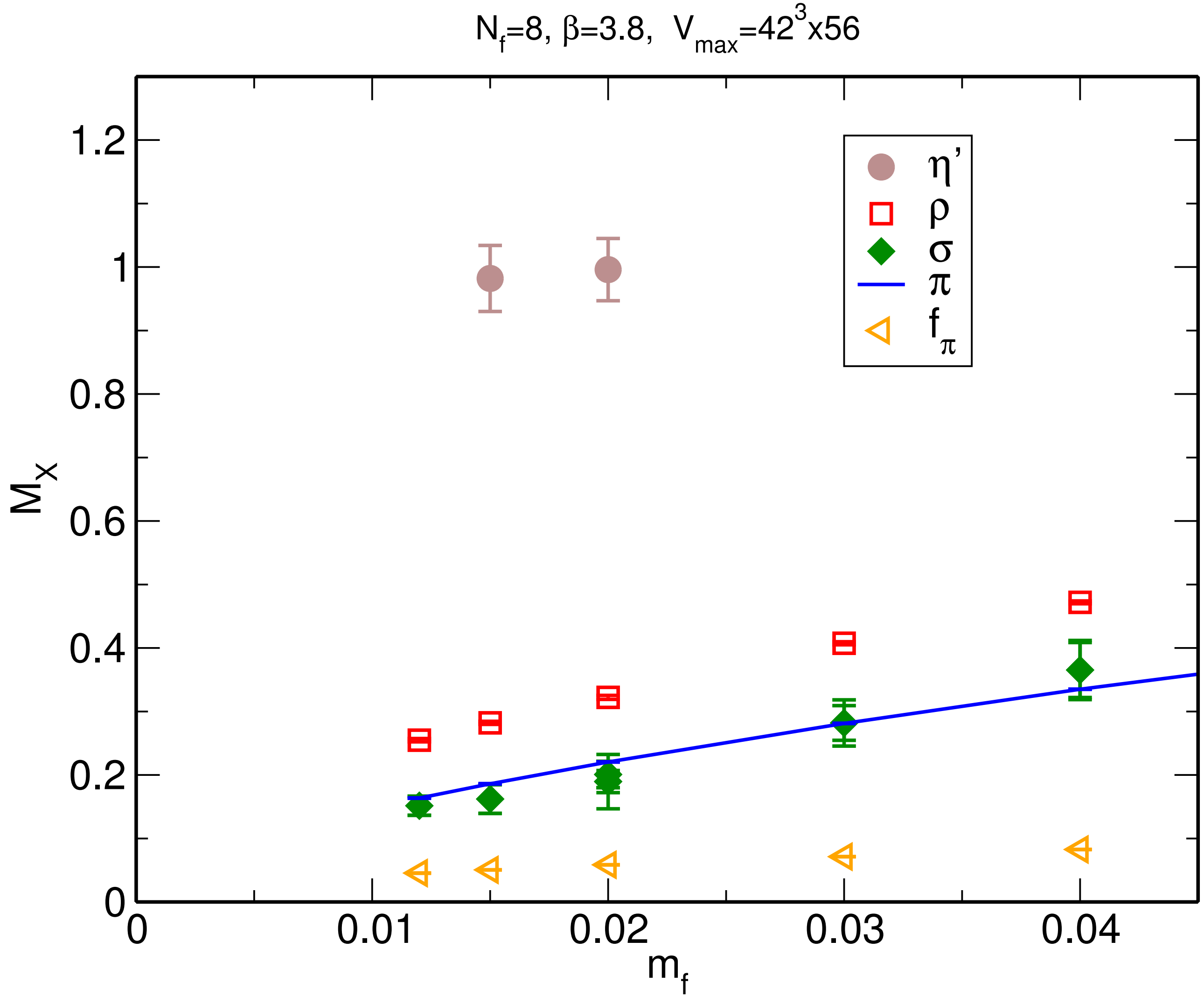


N_f=4 spectrum (preliminary)



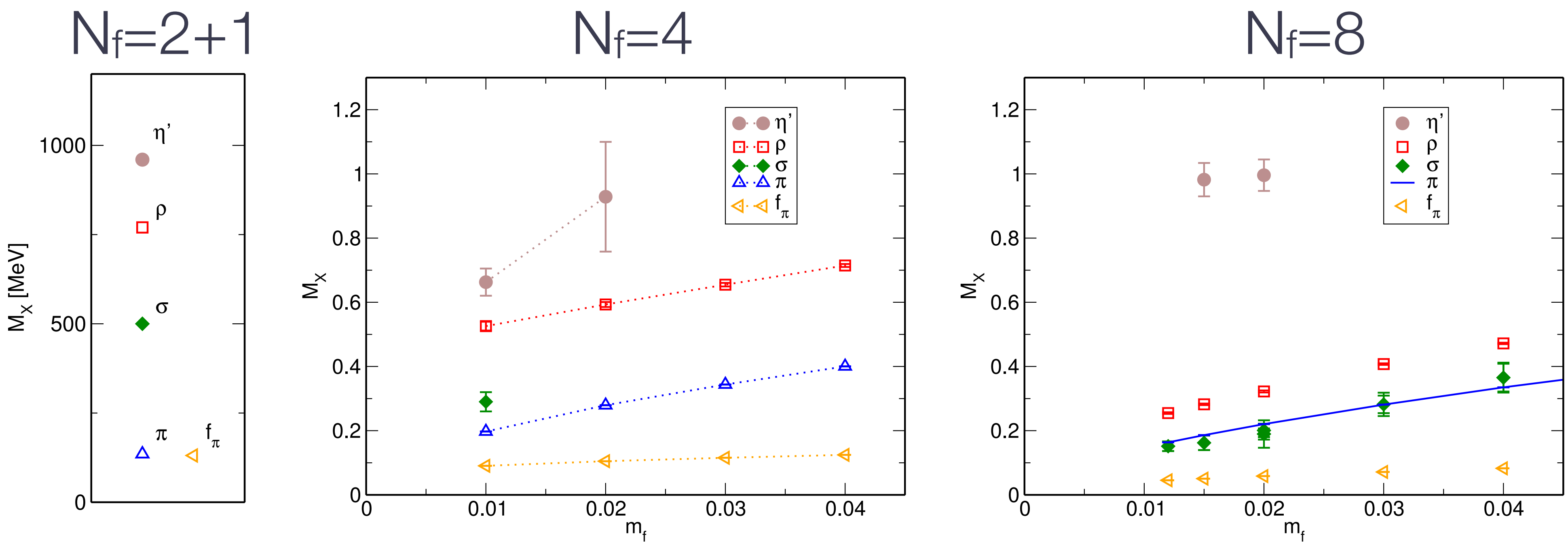
LatKMI NEW

N_f=8 spectrum (η' is preliminary)



η’: update from Lattice 2015 by Ohki

spectrum: N_f dependence



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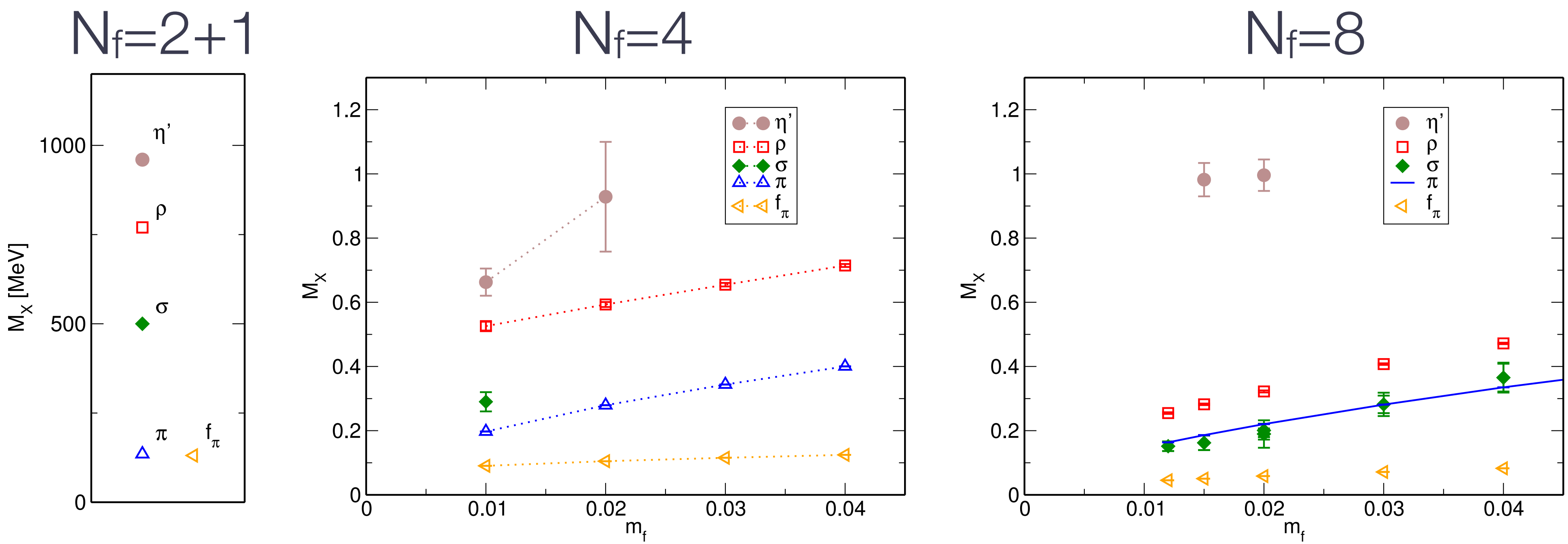

approx. mass ratio

N_f	2+1	4	8
σ/ρ	0.6	0.6	0.6
η'/ρ	1.2	1.2	**3.5**
@	experiment	m_f=0.01	m_f=0.015

spectrum: N_f dependence

- **approx. mass ratio**
- remark: **$\eta'/\rho \simeq$ 3.5** for N_f=8
- caveat
    - A. N_f=2+1 σ likely not so simple
    - B. N_f=4 only a few m_f sampled
    - C. N_f=4, 8: only one lattice spacing
- N_f=8 m_f dependence of ratio expected to be small (near conformality)
- caveats B and C(N_f=4) will soon be removed by additional comp.
- would be interesting to investigate N_f=12 as well

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η'/ρ	1.2	1.2	**3.5**
@	experiment	m_f=0.01	m_f=0.015

enhancement of $M_{\eta'}/M_\rho$ for N_f=8

- **approx. mass ratio**
- remark: **η'/ρ** ≃ **3.5** for N_f=8
- Discussion:
- Usual large Nc argument
  - fix: N_f and $n_c \to \infty$
  - Witten-Venetiano: $\mathbf{M_{\eta'}^2 \sim (N_f/n_c) * \Lambda^2} \to 0$ for $n_c \to \infty$
- Walking regime: need to keep (N_f/n_c) non-vanishing
  - "Anti-Venetiano-limit": keep $(N_f/n_c)>1$ fixed & $n_c \to \infty$
  - Matsuzaki-Yamawaki: $\mathbf{M_{\eta'}^2 \sim (N_f/n_c)^2 * \Lambda^2}$ [JHEP 2015]
  - Now $N_f/n_c \sim 3$: this could be responsible for the enhancement

N_f	2+1	4	8
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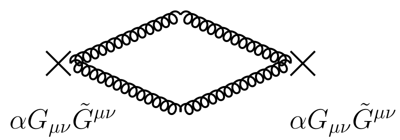
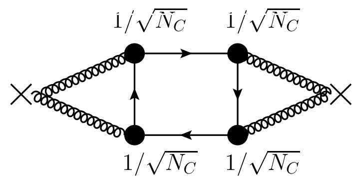


$\sim \alpha^2 N_C^2$



$\sim \alpha^2 N_F N_C$

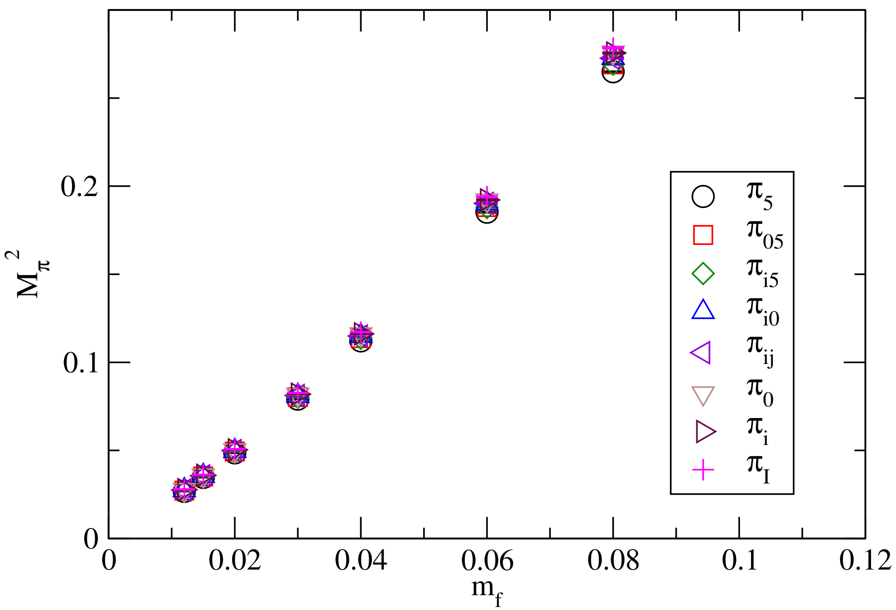
Summary and Outlook

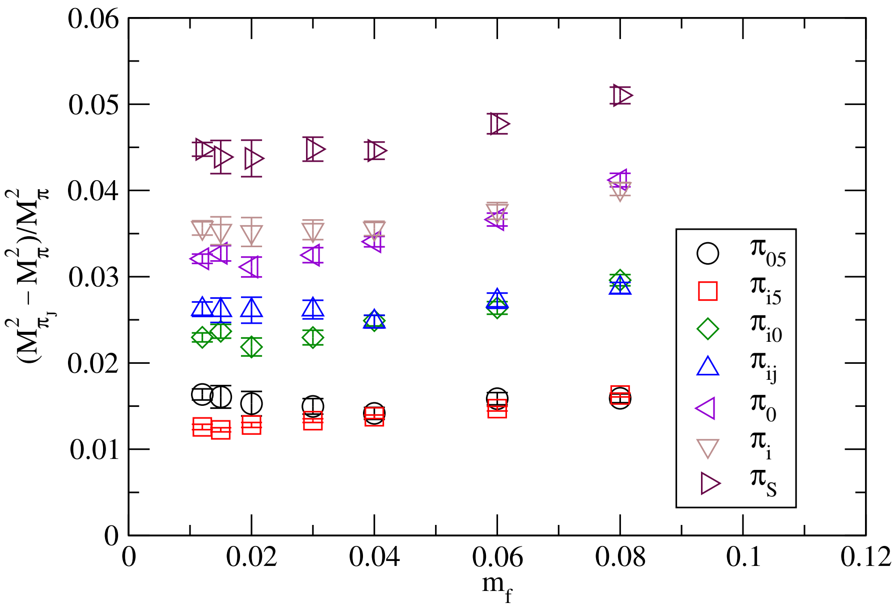
- making use of LatKMI high-statistics HISQ ensembles of QCD with N_f=4, 8
- Some early results of N_f dependence of flavor-singlet pseudoscalar and scalar masses are shown
- remarkable enhancement of $M_{\eta'}/M_\rho$ observed as N_f grows
- could be understood as enhancement of the fermion-loop contribution in U(1) axial current correlator
- more m_f points for N_f=4 and 8, and another lattice spacing for N_f=4 will be investigated soon
- N_f=12 might also be interesting to explore using LatKMI ensembles

Thank you very much for your attention !

staggered flavor (taste) symmetry for N_f=8 HISQ

- comparing masses with different staggered operators for π for β=3.8



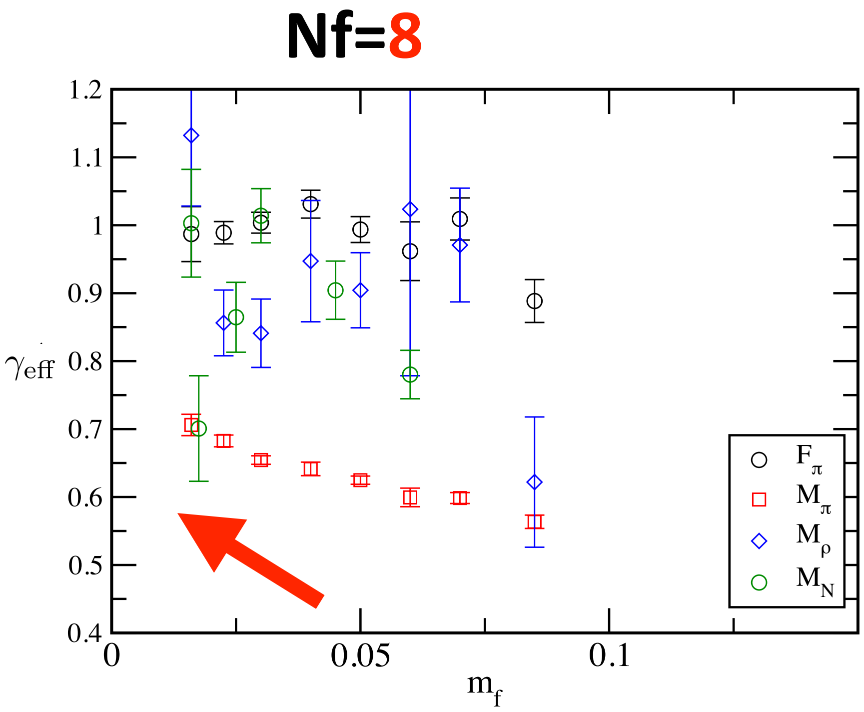


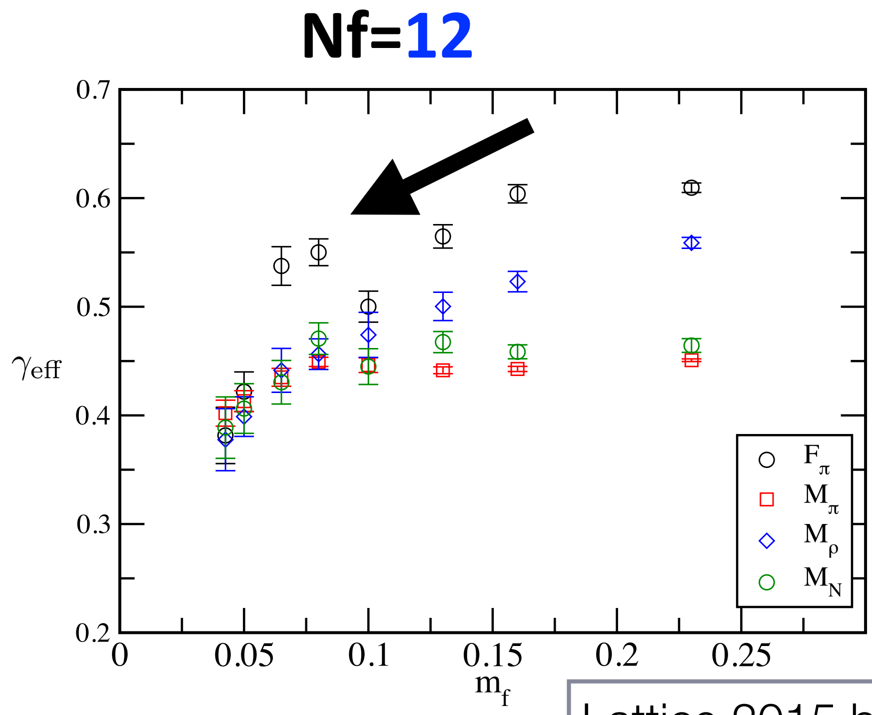
- excellent staggered flavor symmetry, thanks to HISQ

N_f=8: conformal vs chiral symm. br. with γ_{eff}

- Nf=12: universal γ towards chiral limit
- Nf=8: inconsistency of γ reduced towards lighter mass ($\gamma \to \sim 1$)
- qualitatively different
  - (note $\gamma(M_\pi) \to 1$ / $\gamma(\text{others}) \to \infty$ for Ch.Symm.Br)
- maybe promising…

N_f=8: conformal vs chiral symm. br. with γ_{eff}





Lattice 2015 by Ohki

- Nf=12: universal γ towards chiral limit
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  - (note γ(M_π)→1 / γ(others)→∞ for Ch.Symm.Br)
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