Spectroscopy with dynamical Chirally Improved quarks

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   - Variational method and interpolator basis
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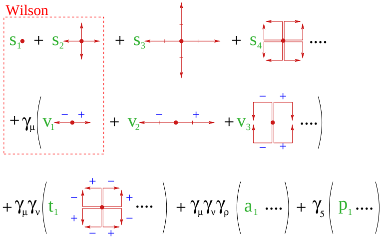
   - Results for mesons (preliminary)

Chirally Improved Dirac operator

General ansatz for fermion action:

$$D_{mn} = \sum_{\alpha=1}^{16} \Gamma_\alpha \sum_{p \in \mathcal{P}^\alpha_{m,n}} c_p^\alpha \prod_{l \in p} U_l \, \delta_{n,m+p}$$

- Insert ansatz into Ginsparg-Wilson-equation
- Truncate the length of the contributions and compare the coefficients
- $\Rightarrow$ Set of algebraic equations (solved by norm minimization)



(Gattringer, PRD63(2001)114501)

Simulation Details

- Lüscher-Weisz gauge action
- Two flavors of Chirally Improved fermions
- Stout smearing
- Hybrid Monte Carlo simulation

Earlier results (2005/2006): $12^3 \times 24$ (Lang/Majumdar/Ortner)
Presently: Three ensembles for $16^3 \times 32$

ensemble	β_{LW}	m_0	HMC time	a[fm]*	m_π[MeV]*
A	4.70	-0.05	492	0.1507(17)	526(7)
B	4.65	-0.06	993	0.1500(11)	469(4)
C	4.58	-0.077	996	0.1440(11)	318(5)

*)using $r_{0,\mathrm{exp}} = 0.48$ fm

Parameters: Lattice spacing

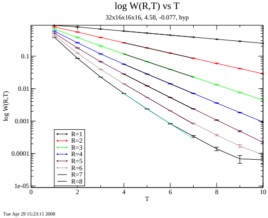
Lattice spacing determined from potential (for hypercubic smeared configurations).
Potential fit:

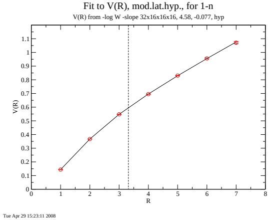
$$V_L(r) = A + \frac{B}{r} + \sigma r + c_3 \Delta V(r)$$

$$with \quad \Delta V(r) \equiv \left[\frac{1}{\mathbf{r}}\right] - \frac{1}{r} \, .$$

(Perturbative lattice Coulomb potential: $\left[\frac{1}{r}\right]$)
gives the Sommer parameter

$$\sqrt{\frac{1.65 + B}{\sigma}} = \frac{r_{0,exp}}{a}$$





Fit to $\ln W(r,t)$ in the range $4 \leq t \leq 7$ (upper plot) and to the potential in the range $1 \leq r \leq 7$ (lower plot).

Variational method (C.Michael; Lüscher and Wolff)

- Matrix of correlators projected to fixed momentum (will assume 0)

$$C(t)_{ij} = \sum_n \langle 0|O_i|n\rangle\langle n|O_j^\dagger|0\rangle$$

- Solve the generalized eigenvalue problem:

$$C(t)\vec{v}_k = \lambda_k(t)C(t_0)\vec{v}_k$$
$$\lambda_k(t) \propto \mathrm{e}^{-tM_k}\left(1 + \mathcal{O}\left(\mathrm{e}^{-t\Delta M_k}\right)\right)$$

- At large time separation: only a single mass in each eigenvalue.
- Eigenvectors can serve as a fingerprint.

Quark sources

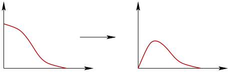
- Jacobi smeared quark sources, e.g., $u_s \equiv (S\, u)_x$

$$S = M\, S_0 \quad \text{with} \quad M = \sum_{n=0}^{N} \kappa^n H^n$$

$$H(\vec{n},\vec{m}\,) = \sum_{j=1}^{3} \left(U_j\,(\vec{n},0)\,\delta\left(\vec{n}+\hat{j},\vec{m}\right) + U_j\left(\vec{n}-\hat{j}\,,0\right)^{\dagger}\delta\left(\vec{n}-\hat{j},\vec{m}\right)\right).$$

- Fewer quark propagators
- Combination allows nodes in the interpolating operators
- Derivative quark sources W_{d_i}:

$$D_i(\vec{x},\vec{y}) = U_i(\vec{x},0)\delta(\vec{x}+\hat{\imath},\vec{y}) - U_i(\vec{x}-\hat{\imath},0)^{\dagger}\delta(\vec{x}-\hat{\imath},\vec{y})\ ,$$
$$W_{d_i} = D_i\, S_w\ .$$



Mesons with derivative sources: Pion channel

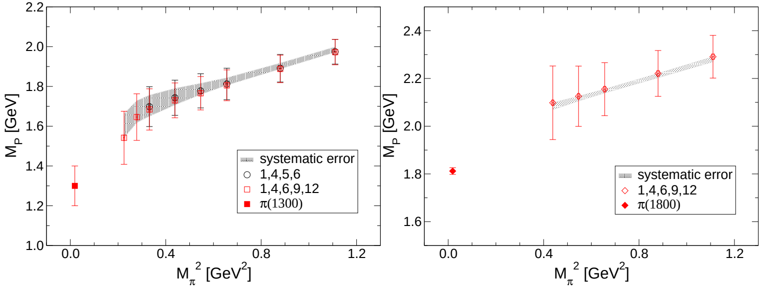


Figure: 1st and 2nd excitation of π

Gattringer et al., ArXiv:0802.2020 [hep-lat], PRD(2008)

Mesons from quenched ensemble

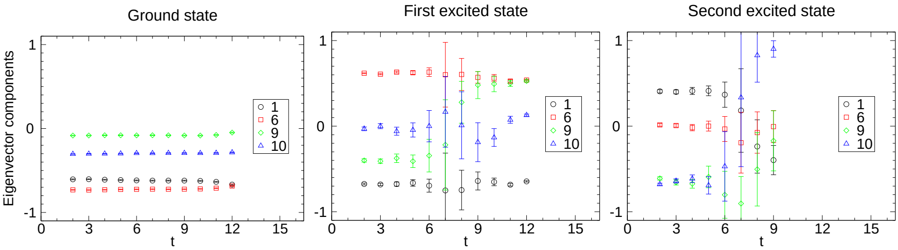
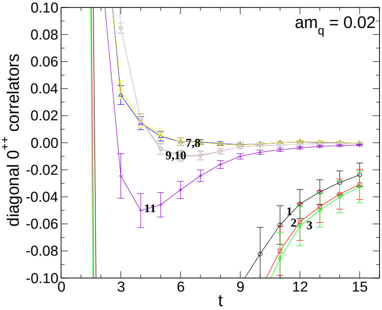


Figure: Eigenvector components for ground state and lowest excitations

Gattringer et al., ArXiv:0802.2020 [hep-lat], PRD(2008)

Mesons with derivative sources: Isovector Scalar 1 0^{++}



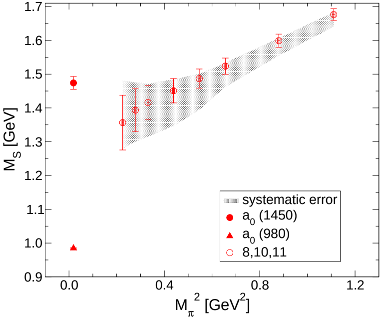


Figure: Diagonal correlators and ground state in the 0^{++} channel

Gattringer et al., ArXiv:0802.2020 [hep-lat], PRD(2008)

Run parameters

- Lattice size $16^3 \times 32 \sim (2.4\,fm)^3 \times 4.8\,fm$
- We analyze every fifth configuration and shift the sources for consecutive configurations.
- Currently only preliminary data
- We also show results with larger valence quark masses: "partially quenched".

set	β_{LW}	m_0	# conf.s	a [fm]*	m_{AWI} [MeV]*	m_π [MeV]*	$a\,m_\pi L$
A	4.70	-0.05	100/100	0.1507(17)	43.0(4)	526(7)	6.4
B	4.65	-0.06	100/200	0.1500(11)	35.1(2)	469(4)	5.8
C	4.58	-0.077	100/200	0.1440(11)	15.0(4)	318(5)	3.8

Nucleon - positive parity

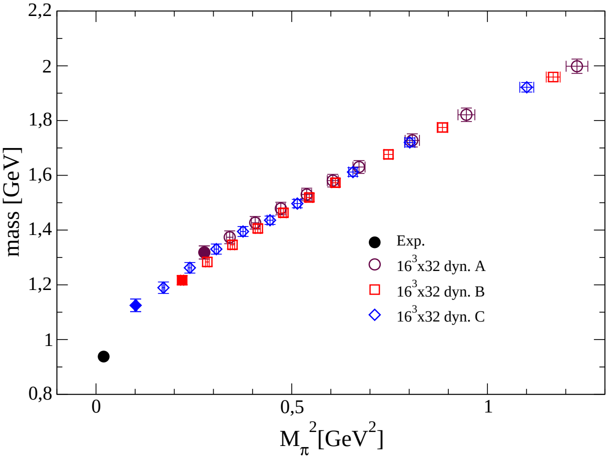


Figure: Mass of the nucleon ground state

Nucleon - negative parity

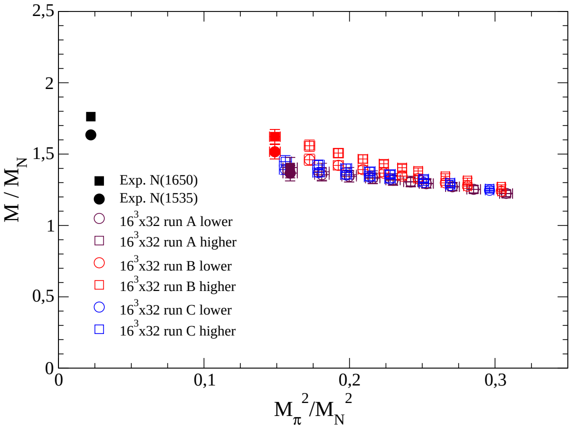
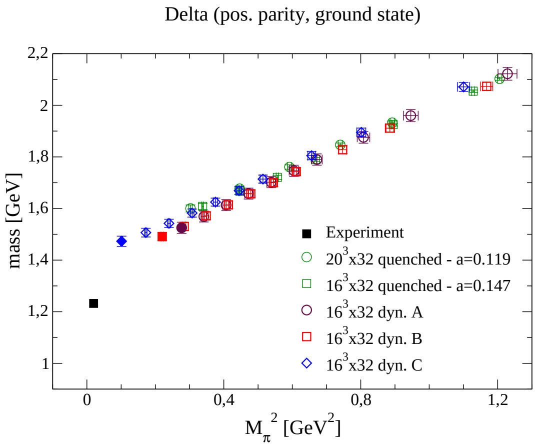


Figure: Mass of the negative parity ground state and 1st excited state

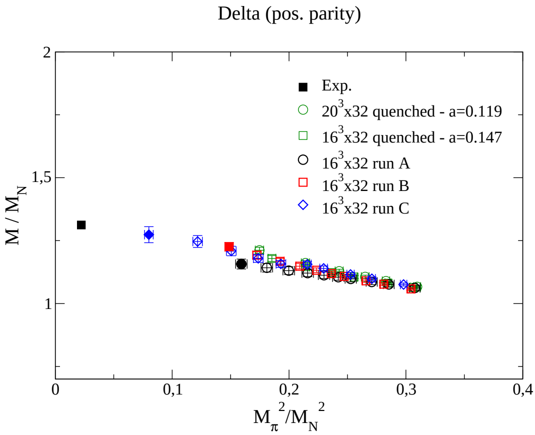
No reasonable signal for run C at small valence quark masses.

Δ^{++}



..too high at small quark masses...

Δ^{++}



High masses in N and Δ^{++} cancel...

$\rho(772)$

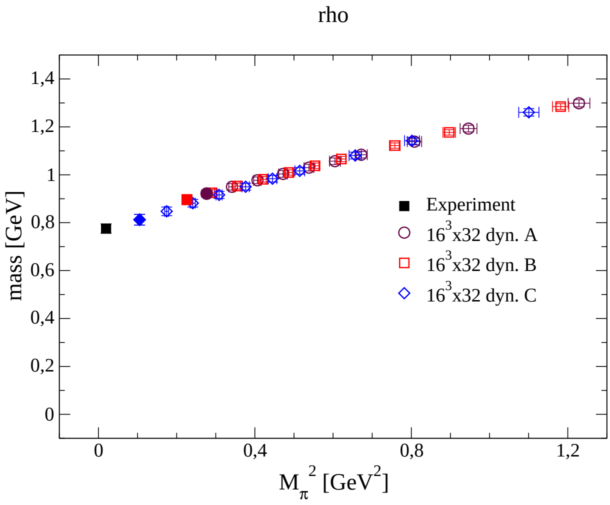


Figure: Ground state in the 1^{--} channel ($\rho(772)$)

Scalar meson a_0

Quenched: Extrapolates to $a_0(1450)$

Dynamical: Unclear signal; operator dependent 10% variation.

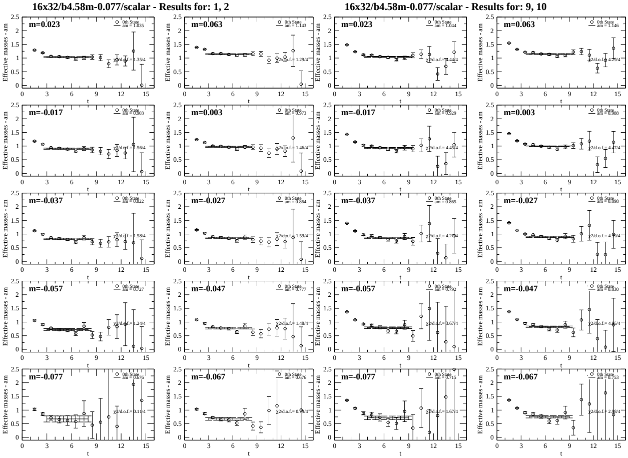


Figure: Example: ground state signals for two combinations, ensemble C.

Scalar meson a_0

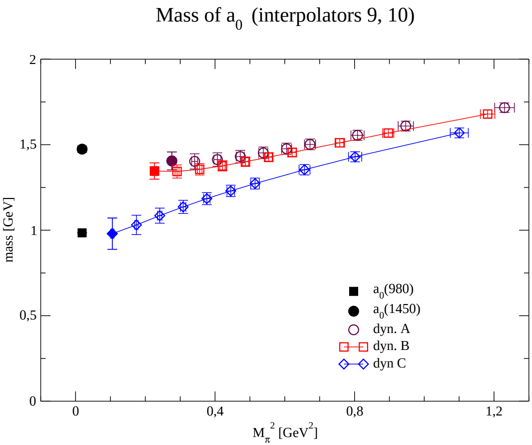


Figure: a_0 from one possible set of interpolators

Do we see a level crossing here ($\pi\eta$-channel?)

Summary

- Progress report on spectroscopy with dynamical CI fermions
- Good signals for (most) ground state mesons and baryons
- Demonstrated power of the method for excited states (quenched)
- So far: unclear signal for excited states (full QCD)

- Poster by Christian Hagen (Regensburg) on heavy-light mesons
- Talk by Sasa Prelovsek on tetraquarks with quenched CI fermions

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