Liverpool Lattice Group:

Flavour singlet spectrum

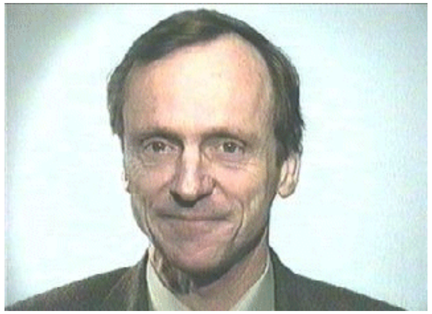
Alan Irving

University of Liverpool

Outline

1. Who’s who in the Liverpool lattice group
2. Flavour singlet physics with Wilson quarks
3. Singlet physics with Improved Staggered quarks
4. Conclusions and outlook

Who's who



Chris Michael

Light hadrons

Singlets (wilson)

Heavy quarks

Alan Irving

Light hadrons

Singlets (stagg)

Grid

Paul Rakow

Structure fns

Overlap

Craig McNeile

Light/Heavy quarks

Singlets, Grid,

Software...

Zbyszek Srockzinski

Phys/programmer

Stewart Wright (← Eric Gregory)

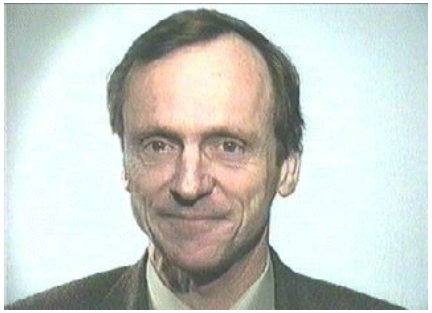
Chiral extrapol methods

Steve Miller

Gballs, scalars

Singlet physics with Wilson quarks

Chris Michael, Craig McNeile, ...



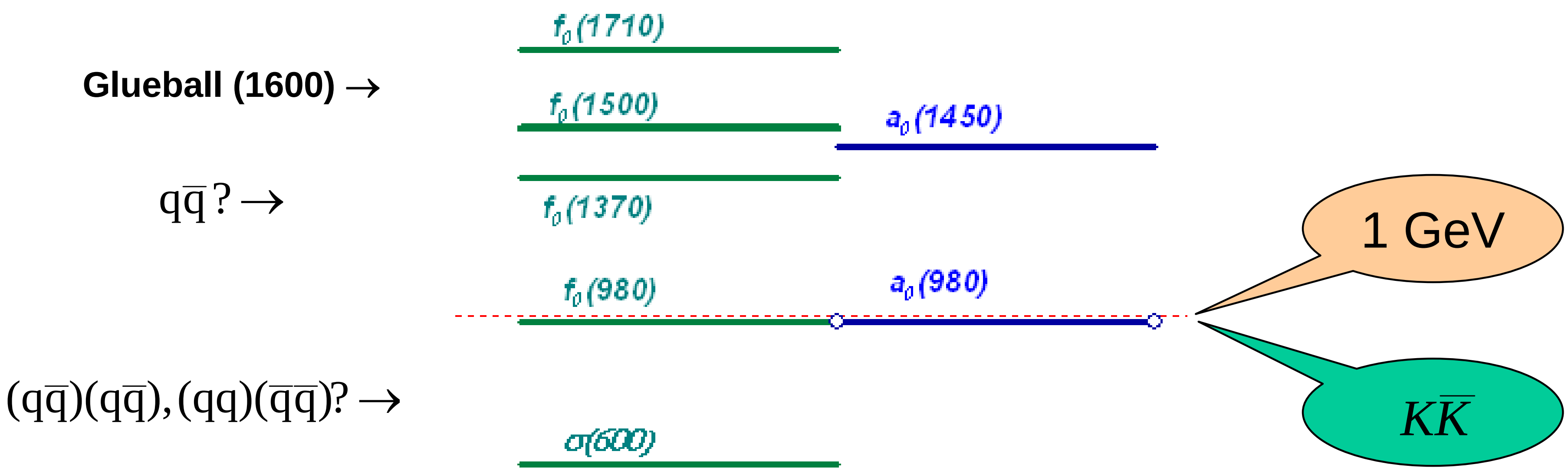
Some history:

- **Phys.Rev.D63:114503,2001, Glueball-scalar mixing**
- **Phys.Lett.B491:123-129,2000, Err.B551:391,2003, η - η' mixing**
- **Phys.Rev.D65:014508,2002 (+ K Sharkey), Scalar mesons**
- **Nucl.Phys.Proc.Suppl.119:266-268,2003 (+ A Hart), Scalar particles**

- Concentrate on 0^{++} states
- Pure glue requires order 10^4 configs → $m(0^{++}) \sim 1600$ MeV
- Benefits from asymmetric actions (Morningstar and Peardon)
- Interest is in the effects of light quark effects (meson – glueball mixing)
- Dynamical light quarks
- Simulation limitations

Experimental light scalar spectrum

- Scalars separate into 2 groups above/below 1 Gev (e.g. Close,Tornquist hep-ph/0204205, JPhysG 28 (2002) R249)



Glueball (1600) →

$q\bar{q}\,? \rightarrow$

$(q\bar{q})(q\bar{q}), (qq)(\bar{q}\bar{q})? \rightarrow$

- Conventional $^3P_0\, q\bar{q}$ at around 1.5 Gev?
- Unconventional $(qq)^{3}(\bar{q}\bar{q})^{3}$ nonet below 1 GeV
- … with meson-meson component $(q\bar{q})^{1}(\bar{q}q)^{1}\,?$

Meson - glueball mixing

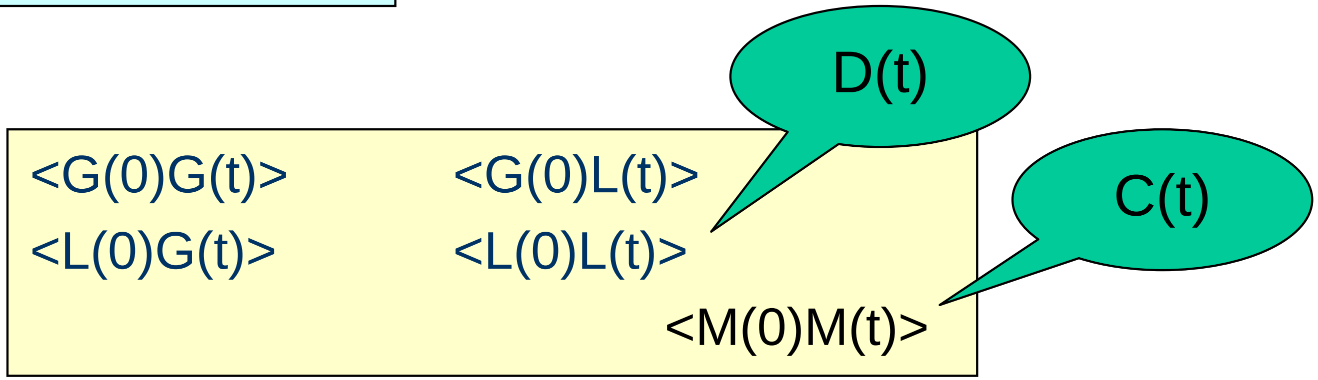
Operators

G (glueball, gluon loop)

L (quark loop)

M (meson/connected)

Full theory



<G(0)G(t)> <G(0)L(t)>

<L(0)G(t)> <L(0)L(t)>

<M(0)M(t)>

Quenched

- no sea quark loops L
- M and G states are distinct, C(t) is same for S and NS scalars
- (valence) mixing matrix element estimate <LG> (McN & M)
- care: anomalous contributions from 0^-0^- interm. states

Lattice methods

Glueballs (G)

- APE smearing (2 levels) + Teper blocking (3 levels) of spatial links
- Time plane sums for scalar operators for |p|=0,1
- Tensor operators for |p|=0 only

Connected mesons (M)

- Local and smeared/fuzzed operators from $q = M^{-1}S$

Disconnected (loop) contributions (L)

- $L = Tr(\Gamma M^{-1})$
- Stochastic estimators
- Volume sources, noise reduction techniques

•Variational techniques

•Factorising fits

Quenched results

- **See PRD 63 (2001) 114503, (CMcN&CM) for quenched evaluation of mixing M.E. at the strange quark mass**

$r_0 x_{00} \approx 0.76(12)$ **for 1 flavour of strange quark**

Gball

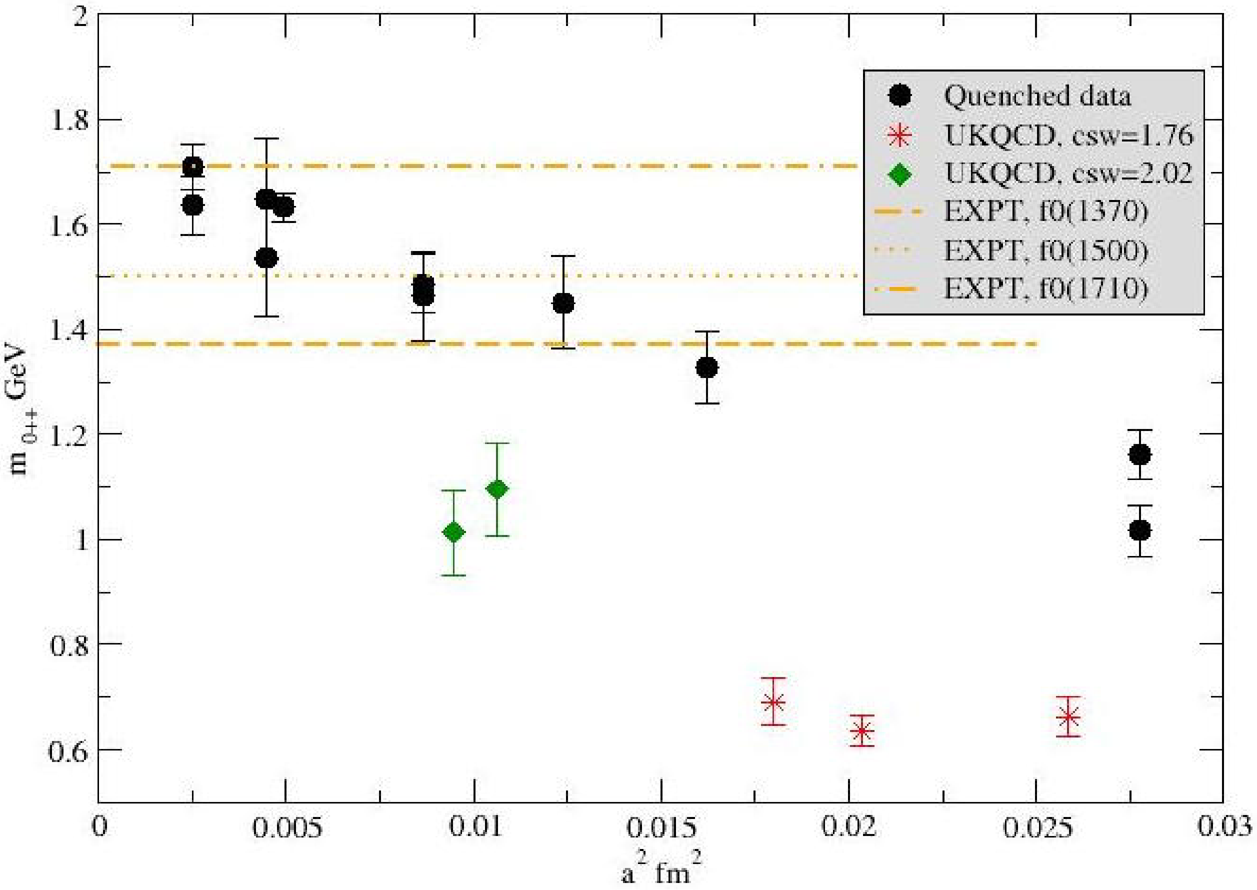
$$\begin{pmatrix} am_0 & \sqrt{2}ax_{00} \\ \sqrt{2}ax_{00} & as_0 \end{pmatrix} = \begin{pmatrix} 0.95 & 0.42 \\ 0.42 & 1.39 \end{pmatrix}$$

$\rightarrow$ **eigenstates at 0.69 and 1.65**

scalar meson

$\Rightarrow$ 25% downward shift of scalar glueball in n_f=2 simulations?

Full QCD results for 0^{++}



- Glueball: Strong a^2 dependence (Wilson gauge action)
- n_f=2 fermions (m~strange) reduce the mass at fixed a^2 or ..
- .. even stronger lattice artefacts with NP- improved Wilson/clover fermions?
- So need:
  - different action(s)
  - finer lattices
  - (higher statistics)

New analysis of CP-PACS ensembles

C Michael and student J Pickavance have begun an analysis of CP- PACS configs from: www.lqa.rccp.tsukuba.ac.jp

1. **glueball analysis**
   - **compare with UKQCD n_f=2, NP improved Wilson/clover**
   - **is this a 'better' gauge action?**
2. **Fermion loops (+ C McNeile)**
3. **Mixing analysis à la McNeile & Michael**

Quarks are still quite heavy ($m_\pi/m_\rho = 0.8 \to 0.6$)

Mixing ME analysis only good for heavy(ish) quarks

(on-shell transition amplitudes)

⇒ better to make direct measurements

- dynamical configs with lighter quarks
- gluonic and mesonic operators

Singlet physics with Improved Staggered quarks

Steven Miller, ACI, CM, CMcN, ...

SM Thesis project:

- **Develop singlet (glueball and meson) measurement formalism for improved staggered fermions**
- **Test using largest available MILC configuration ensembles.**
- **Measure scalars/glueballs on high statistics ensemble generated in first runs on UKQCD ‘phase I’ QCDOC machine.**
- **Use/augment SCIDAC/JLAB standard code ‘Chroma ‘ to promote future developments.**

Additional applications:

- η / η'
- **other processes involving disconnected contributions**

Glueball measurements on MILC emsembles

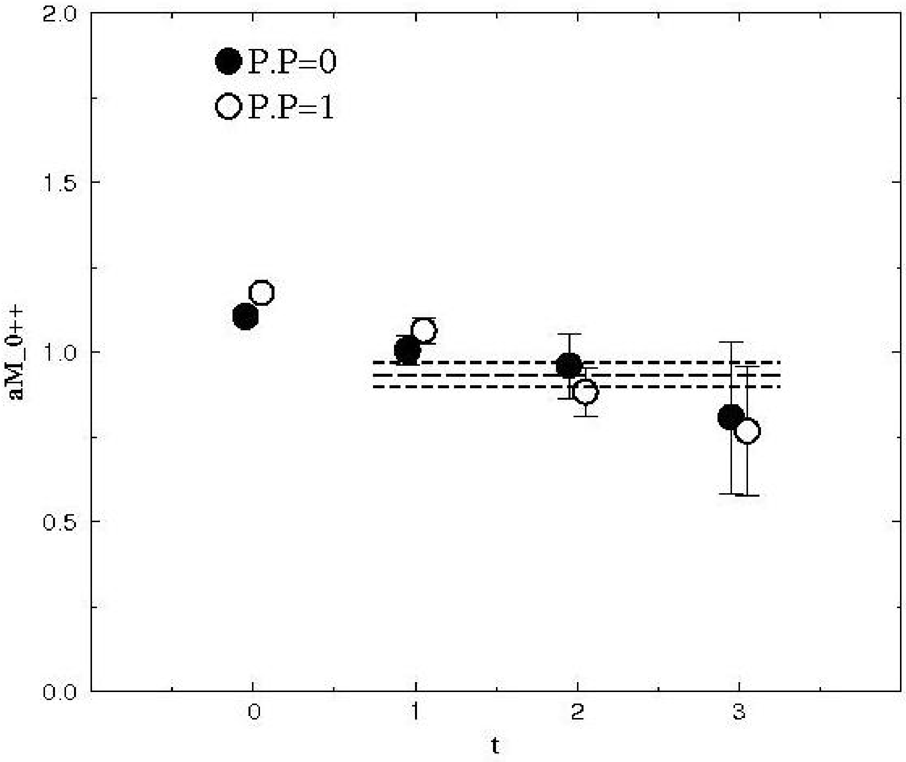
- **Use MILC ensembles (at NERSC: qcd.nersc.gov) generated using the Asqtad action (Bernard et al: PR D64 (2001) 054506)**

Ensemble	β	m_l/m_s	$2am_\pi$	$am_{0^{++}}$
A	6.81	.03/.05	0.755	0.934(37)(-107)
B	6.79	.02/.05	0.623	1.099(45)(-132)
C	6.76	.01/.05	0.449	0.927(41)(-120)
D	6.76	.007/.05	0.378	0.801(41)(-188)
E	7.11	.0124/.031	0.413	0.740(48)(-60)
F	7.09	.0062/.031	0.296	0.716(54)(-61)

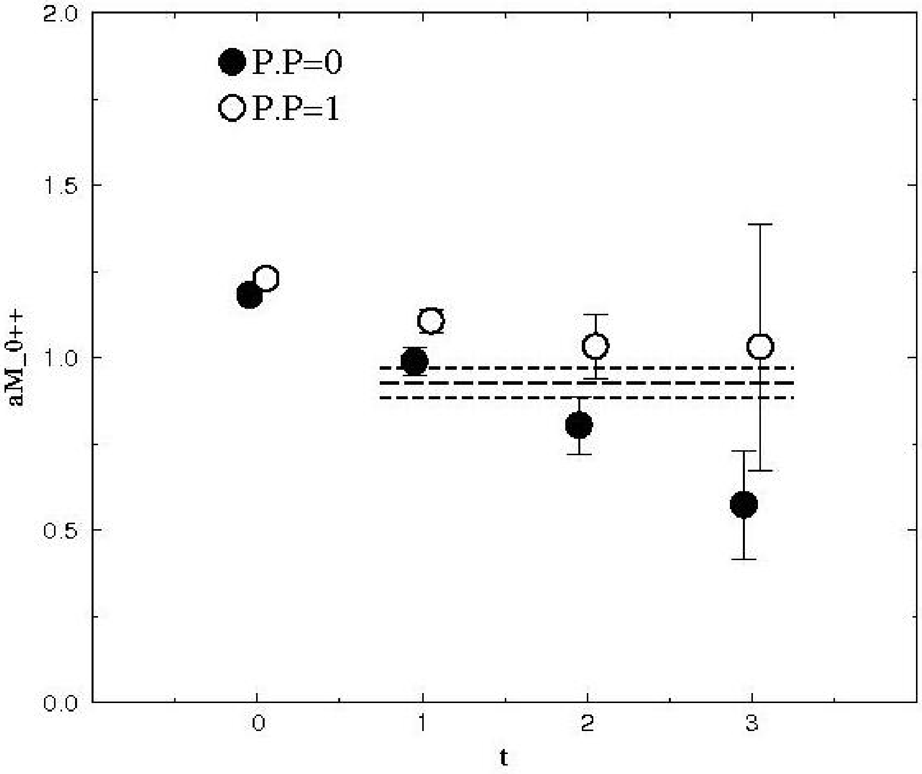
a ~ 0.125 fm

a ~ 0.09 fm

Effective mass plots for scalar glueball

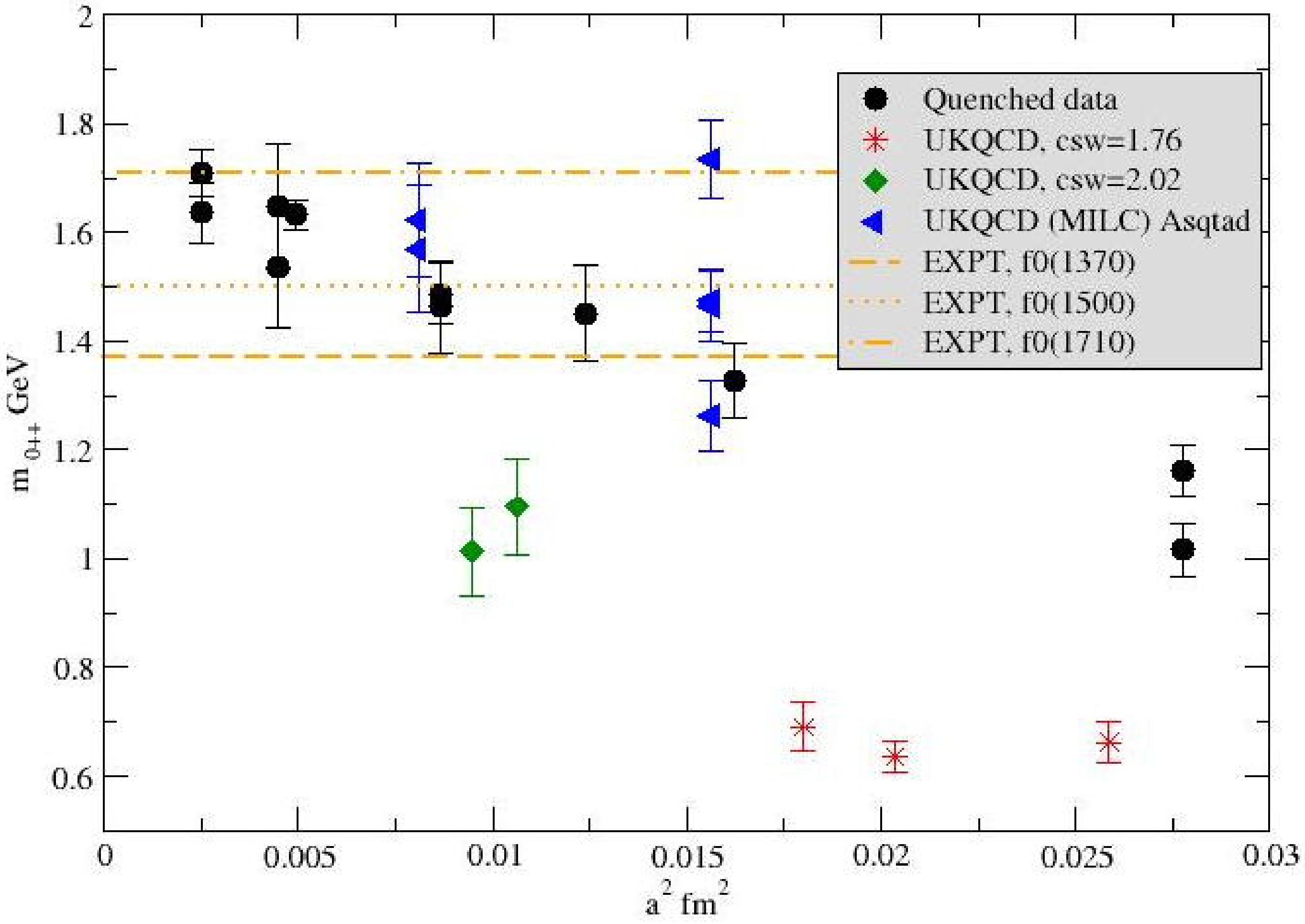


β = 6.81, m_l/m_s = 0.03/.05
(564 configs) a = .12 fm



β = 6.76, m_l/m_s = 0.01/.05
(658 configs) a = .12 fm

Staggered results for O^{++} using glueball operators only



- **Less suppression at fixed a^2 than Wilson**
- **Downward drift with lighter quark mass**

Comments on pure glue measurements

- Unlike previous analyses, quarks are light enough for scalar glueball/meson to decay into two pions.
- Need ‘proper’ treatment of decays...
- .. since dynamical quarks are light enough to induce mixing.
- O(500) configs is not really enough (c.f. 10,000 for pure gauge)
- Add in scalar meson operators.
- What about staggered complications?

Staggered scalar operators

- ‘Taste’ violations → 4 x each quark flavour (O(a^2) → improvement..)
- $\left(\det M\right)^{n_f/4}$ to ‘correct’ sea quark activity in vacuum (some say ‘dodgy’?)
- Valence meson operators give 16 copies (spin ⊗ taste basis):

$$O = \overline{Q}(\Gamma_s \otimes \Gamma_T)Q$$

- e.g. Goldstone pion $\gamma_5 \otimes \gamma_5$
- But $O = \overline{Q}(\gamma_4\gamma_5\Gamma_s \otimes \gamma_4\gamma_5\Gamma_T)Q$ also couples ...

... so ‘*oscillating states’ of opposite parity* in general
for any given taste representation.

Parity partners

GB π

Pseudosc. rep.	J^{PC}	Parity partner	J^{PC}
$\gamma_5 \otimes \gamma_5$	0^{-+}	$\gamma_4 \otimes \gamma_4$	0^{+-}
$\gamma_4\gamma_5 \otimes \gamma_4\gamma_5$	0^{-+}	$1 \otimes 1$	0^{++}
$\gamma_5 \otimes \gamma_i\gamma_5$	0^{-+}	$\gamma_4 \otimes \gamma_i\gamma_4$	0^{+-}
$\gamma_4\gamma_5 \otimes \gamma_i\gamma_4\gamma_5$	0^{-+}	$1 \otimes \gamma_i$	0^{++}

Scalar

local

1-link

- Goldstone π has exotic parity partner
- Scalar has non – Goldstone π as parity partner

Connected scalar measurements

- Fits to C(t) include (at least) scalar + oscillating pion (non-GB):

$$c(t) = A_0 e^{-m_s t} + (-1)^t A_1 e^{-m_\pi t} + \cdots$$

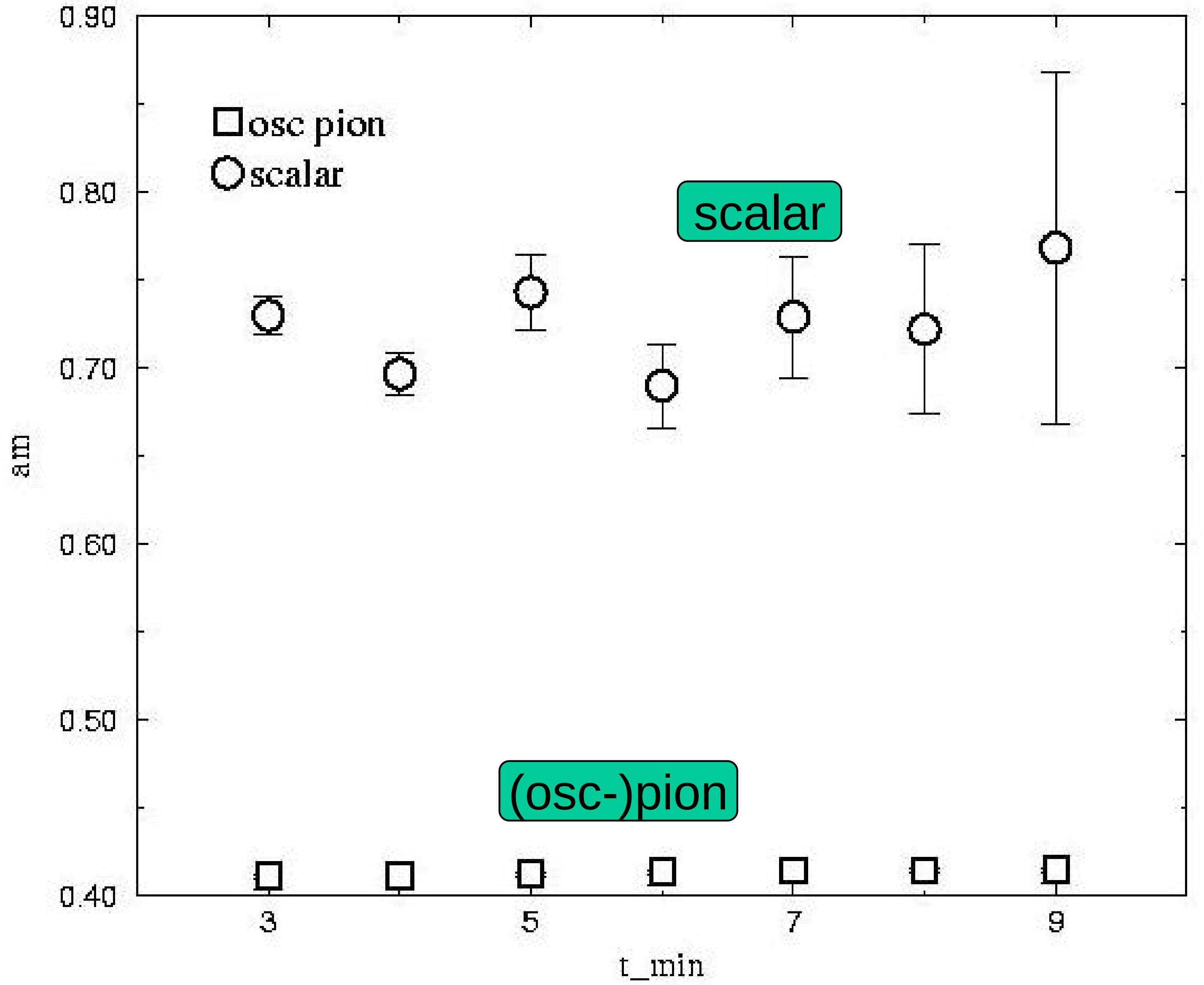
- Fuzzing used (with factorising fits) seems to help fits for the pion (and disconnected loops - see later) but NOT the scalar.
- This makes it difficult to include meaningful excited scalar and excited oscillating pion.
- Sample fits (next..)

Sample connected fits :

am_l	fit	am_π	am_{scalar}	am_{scalar} (excited)	χ^2 /dof
.03	LL, 2 exp, t=7-20	.409(5)	.784(40)	-	1.4
	L+F factor., 3 exp, t=3-9	.399(15)	.76(15)	.96(3)	large
.01	LL, 2 exp, t=5-20	.262(31)	.549(14)	-	0.8
	L+F fact, 3 exp, t=5-14	.269(18)	.65(13)	1.03(7)	0.9

- 3 pole factorising fits not v stable (amplitude errors/correlated)
- 4 pole fit with excited (oscillating) pion even less stable.
- scalar probably needs different fuzzing (difft wave fn).

Fit range stability for local fits



scalar

(osc-)pion

Ensemble A

am_l=0.3

Taste violations in scalar channel

- Comparison of % taste violations with those for pion (for m=.03):

Operator	pion	scalar
$\gamma_5 \otimes \gamma_5$	-	-
$1 \otimes 1$	8.6(3)	-
$1 \otimes \gamma_i$	13.9(3)	6(4)
$1 \otimes \gamma_i \gamma_4 \gamma_5$	17.9(3)	9(4)
$1 \otimes \gamma_4 \gamma_5$	22.0(4)	14(5)

- m('pi')/m('scalar') ~ 1.8
- m(rho) violations zero within errors

Disconnected loops *L(t)*

- Volume source with O(50) (Gaussian) noise vectors
- Monitor variance w.r.t. gauge and noise

$$\mathrm{Corr}(t) = C(t) + 2D(t), \quad D(t) =< L(0)L(t) >$$

- The parity partner of taste singlet scalar operator is $\gamma_4\gamma_5 \otimes \gamma_4\gamma_5$ This is taste non-singlet so has no disconnected piece.

- $\Rightarrow$ connected piece C(t) has an oscillating parity partner while disconnected piece D(t) does not.

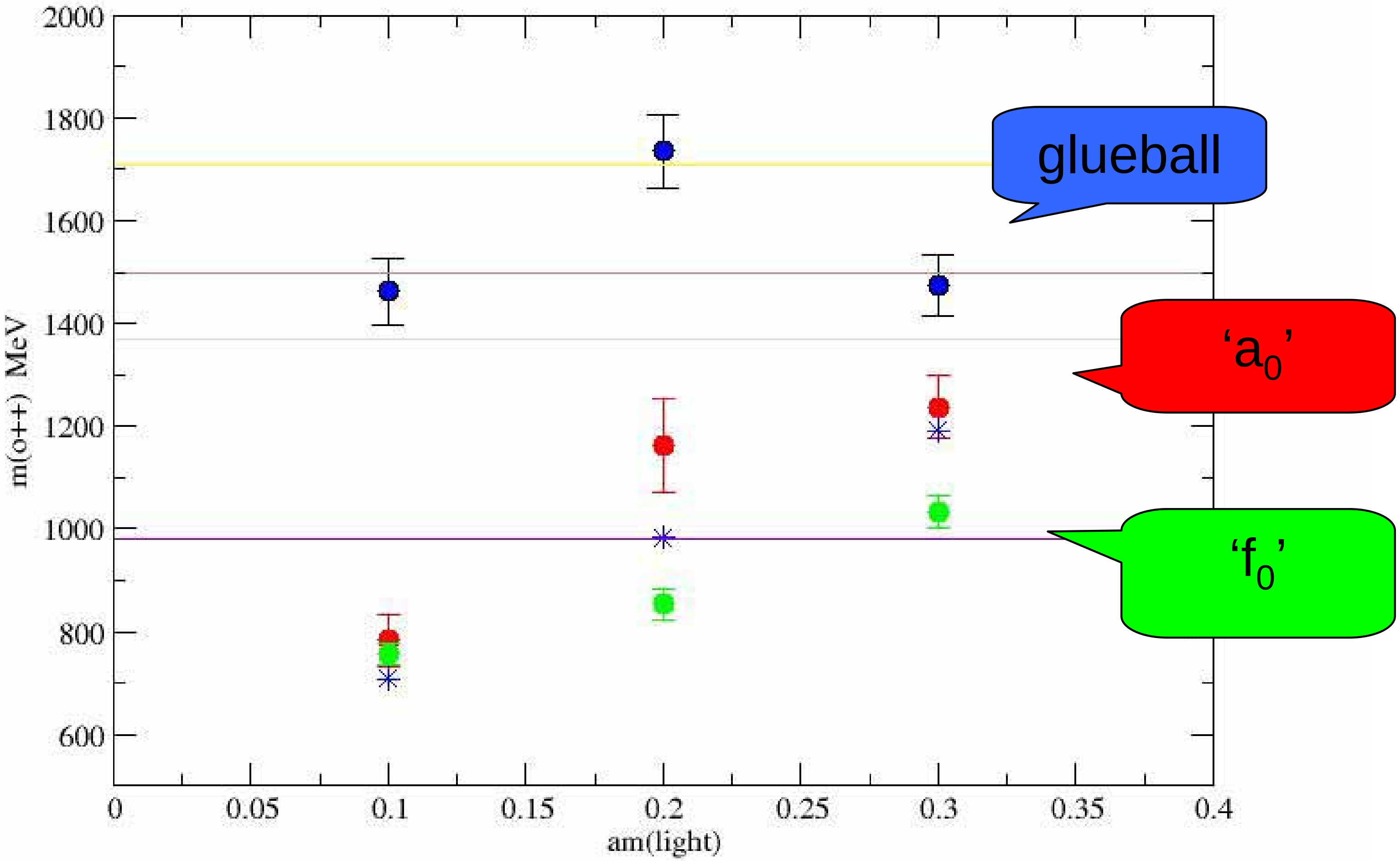
- Fit strategy:
  - Fit C(t) first to determine NS scalar and 0^- oscillating mass
  - Fit C(t)+2D(t) with oscillating 0^- parameters fixed.
  - 2 light valence quarks only

- Fuzzing improves isolation of ground state component in D(t).

Preliminary fits to MILC ensembles

Connected fit (t=3-9)			D+2C fit
am_l	**m_{osc}**	**m_{NS}**	**m_{scalar}**
.03	**.434(12)**	**.784(39)**	**.655(20)**
.02	**.334(18)**	**.736(57)**	**.541(19)**
.01	**.241(19)**	**.497(32)**	**.479(14)**

Glue and meson operator comparison (prelim)



$*2am_\pi$

(a~0.125 fm ensembles)

Comments on singlet meson measurements

- For unquenched case, the complete study of the O^{++} channel should use basis consisting of various 'fuzzing' levels of:
    1. Glueball operators
    2. Connected meson contribution (ud+s)
    3. Disconnected meson contribution – loops
    4. Two pion operators

- The study reported here has so far just included separate fits for

    (1), (2) (~Non-singlet) and (2)+(3) (singlet meson)

    using 2 degenerate light quarks only

- Light meson operators couple to much lower mass scalar states

    (no real surprise there...)

- This channel is definitely not 'gold-plated'

Recent related work on scalars

- ‘SCALAR collaboration’ (Kunihiro et al) PRD 70 (2004) 0345
    - **Coarse lattice (a ~0.2 fm, L~1.6 fm), Wilson + plaquette action**
    - **O(800) configs at each of 3 kappas:** $m_\pi / m_\rho \approx 0.83, 0.77, 0.70$
    - **Scalar singlet heavier than rho:** $m_\sigma / m_\rho \approx 1.6, 1.3, 1.1$

- Prelovsek et al (hep-lat/0407037) dynamical and partially-quenched study of NS scalar using CU/BNL Domain wall dynamical configs.
    - **m(a0) ~ 1.5-1.6 GeV (with large errors)**
    - **closer to a0(1450) than a0(980)?**
    - **evidence of unphysical (partial) quenching contributions**

eta, eta'?

- Choice of operators?

$\gamma_5 \otimes 1$ non-local in time

$\gamma_4\gamma_5 \otimes 1$ 3-link spatial operator

- Signal estimates for the 3-link operator

→ 200 noise samples c.f. 50 for scalar

Conclusions and outlook

- Despite initial optimism, useful glueball measurements on dynamical configurations will probably need 10000s rather than 100s of configurations.
- One can estimate mixing matrix elements using quenched configurations or dynamical ones with heavy quark masses but ..
- reliable estimates of physical glueball/meson states require large scale dynamical simulations with realistically light quarks.
- Existing MILC configs using (Asqtad) improved staggered quarks may already indicate significant mixing effects and give qualitative information about the underlying singlet spectrum.
- Forthcoming higher statistics data from QCDOC should provide considerably improved insight into lattice predictions for glueball and scalar meson systems.
- First QCDOC run: 24^3X64, a=.125fm, m_u/m_s=0.01/0.039, 20K+ trajs.