Light quark hybrids on the lattice

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Kogut-Susskind (staggered) quarks

Some exact chiral symmetry → numerically tractable at small quark mass

Relatively efficient for dynamical quarks

Improved action ("a^2_{tad}") gives good scaling properties

Quenched, 3 flavor and 2+1 flavor simulations.

$a \approx 0.9 fm$.

$28^3 \times 96$ lattice, $L \approx 2.5 fm$.

400-500 configurations in each set.

$$\text{“}\rho \times B\text{”} \sim 1^{--} \times 1^{+-} \rightarrow 1^{-+}$$

Hybrid operators

$\rho \times B$, need taste singlet rho (for ease of cancellations in separating 1-+ from 2-+, etc.)

e.g. simplest “VT” rho:

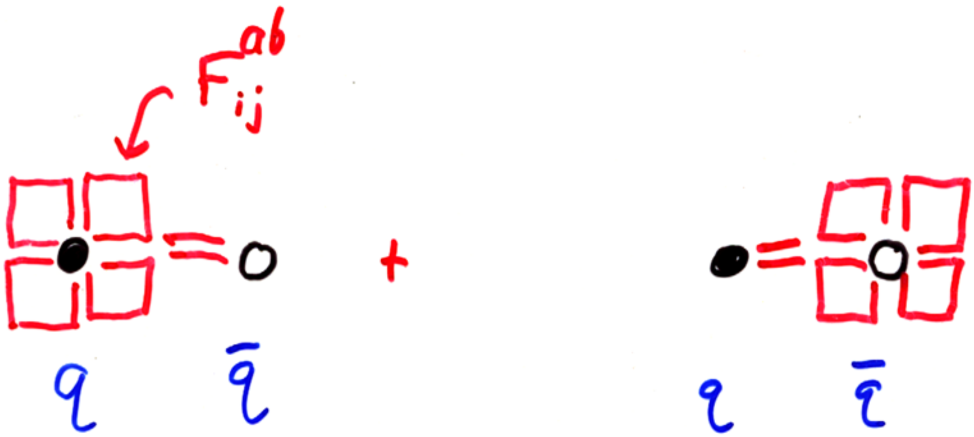
“taste” (flavor)

$$H_x = \bar{\psi}^a \gamma_y \otimes \underline{\gamma_y} \psi^b B_z^{ab} - \bar{\psi}^a \gamma_z \otimes \underline{\gamma_z} \psi^b B_y^{ab}$$

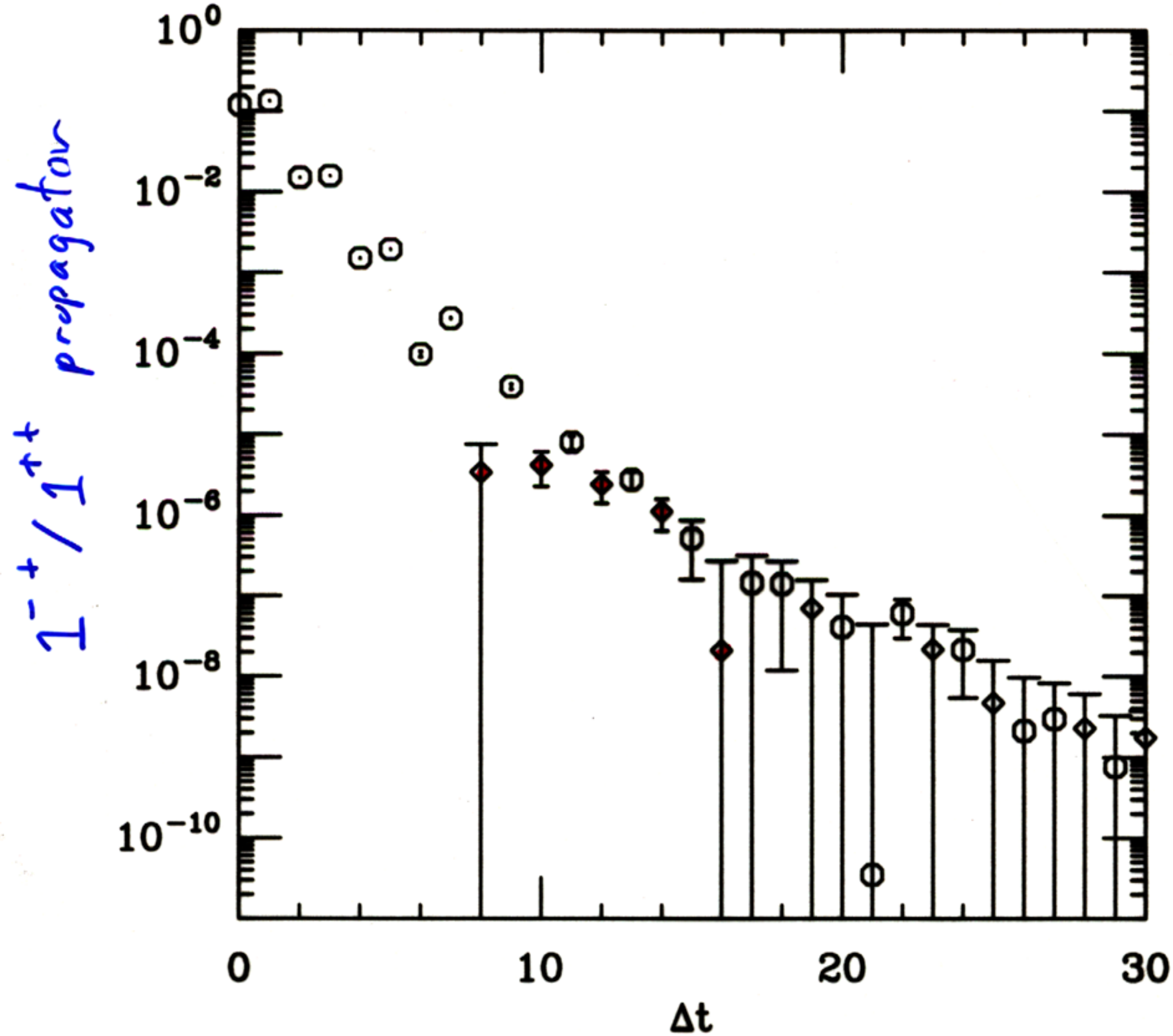
use

$$H_x = \bar{\psi}^a \gamma_y \otimes \mathbf{1} \psi^b B_z^{ab} - \bar{\psi}^a \gamma_z \otimes \mathbf{1} \psi^b B_y^{ab}$$

Nonlocal, must preserve C symmetry in location of B field

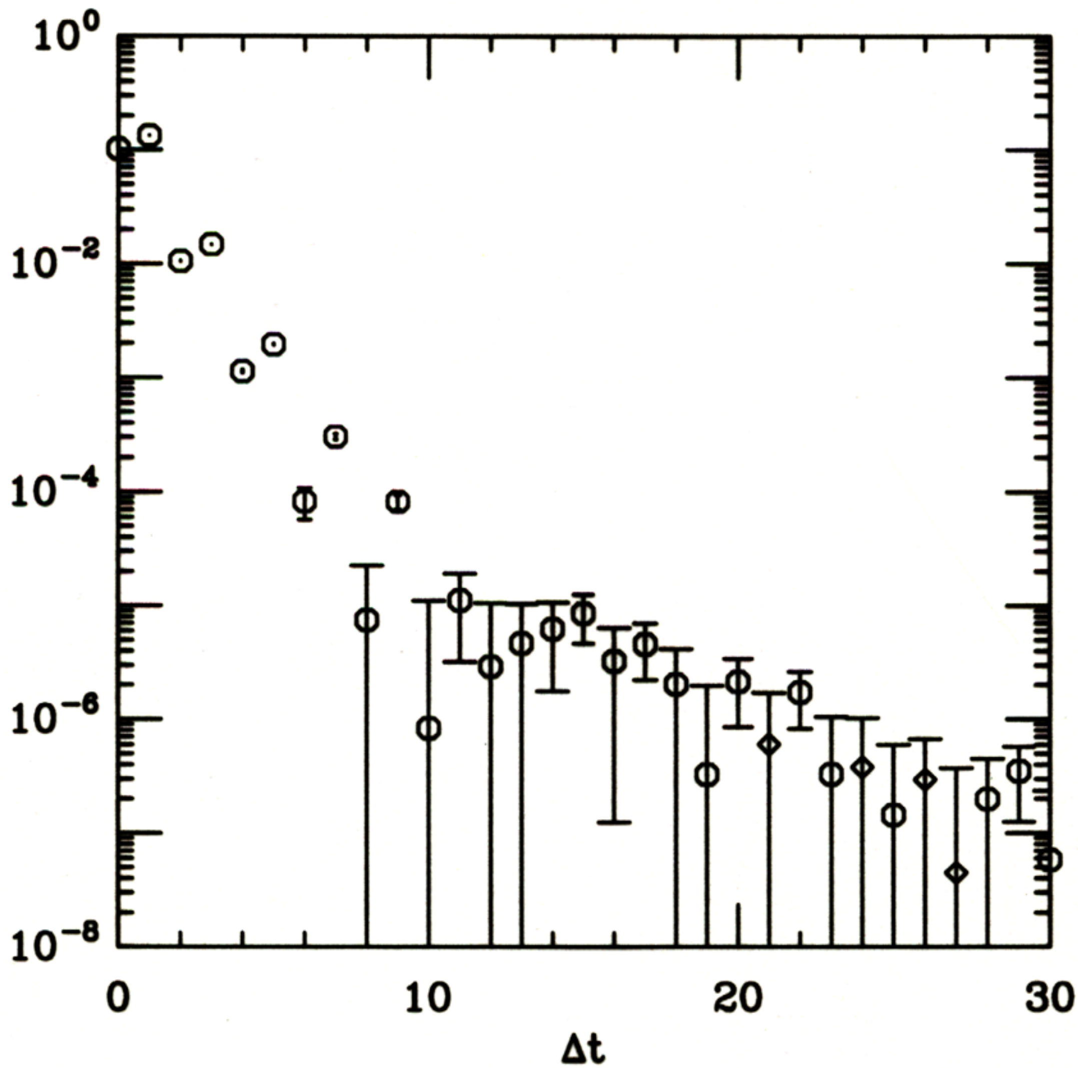


Parity partners in propagators (oscillating part is $1++$, lighter than hybrid)



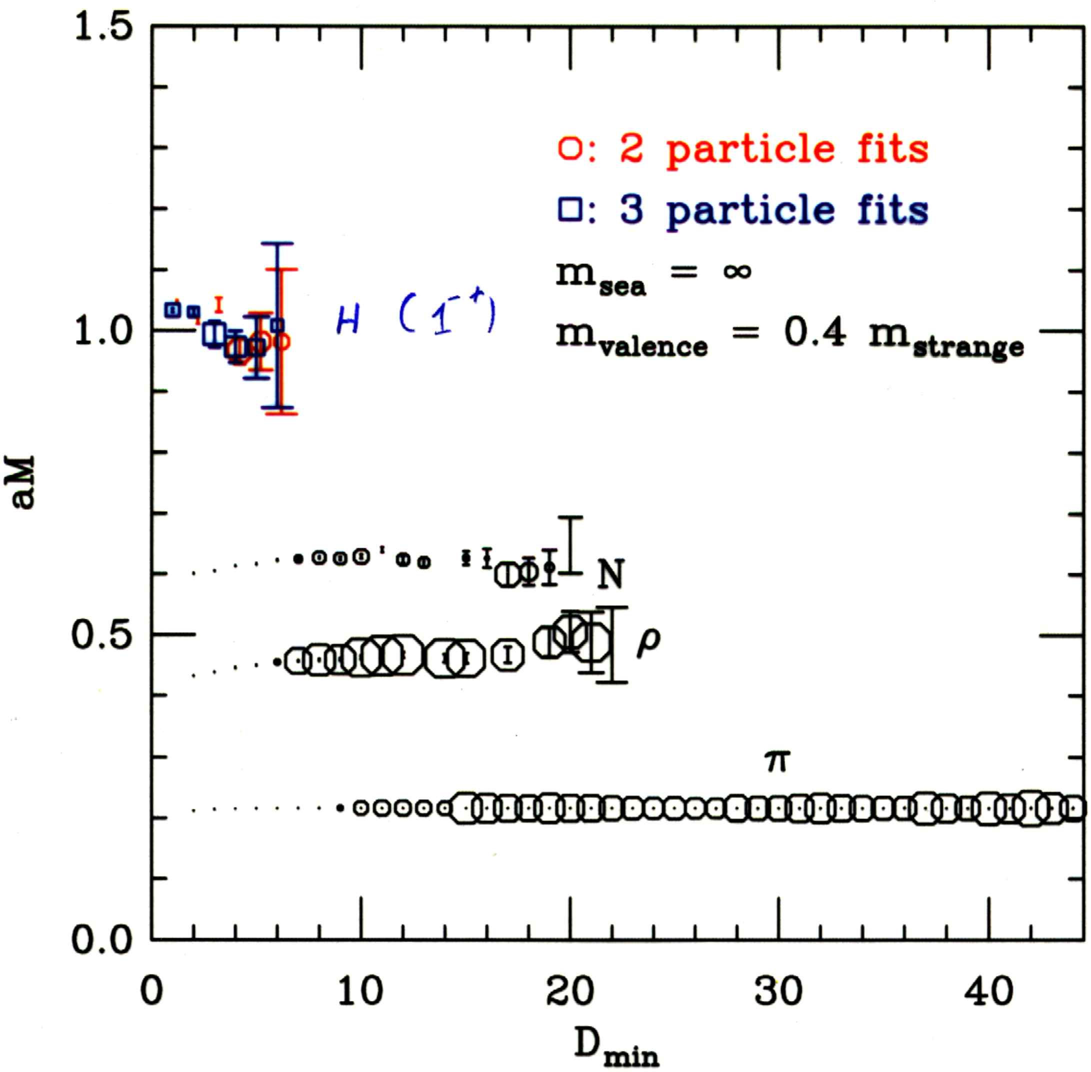
$1^{++}/1^{-+}$ propagator. Quenched, $am_q = 0.04$ ($m_q \approx m_s$). Diamonds are negative values.

best case



$1^{++}/1^{-+}$ propagator. Three flavors, $am_q = 0.0124$ ($m_q \approx 0.4 m_s$). Diamonds are negative values.

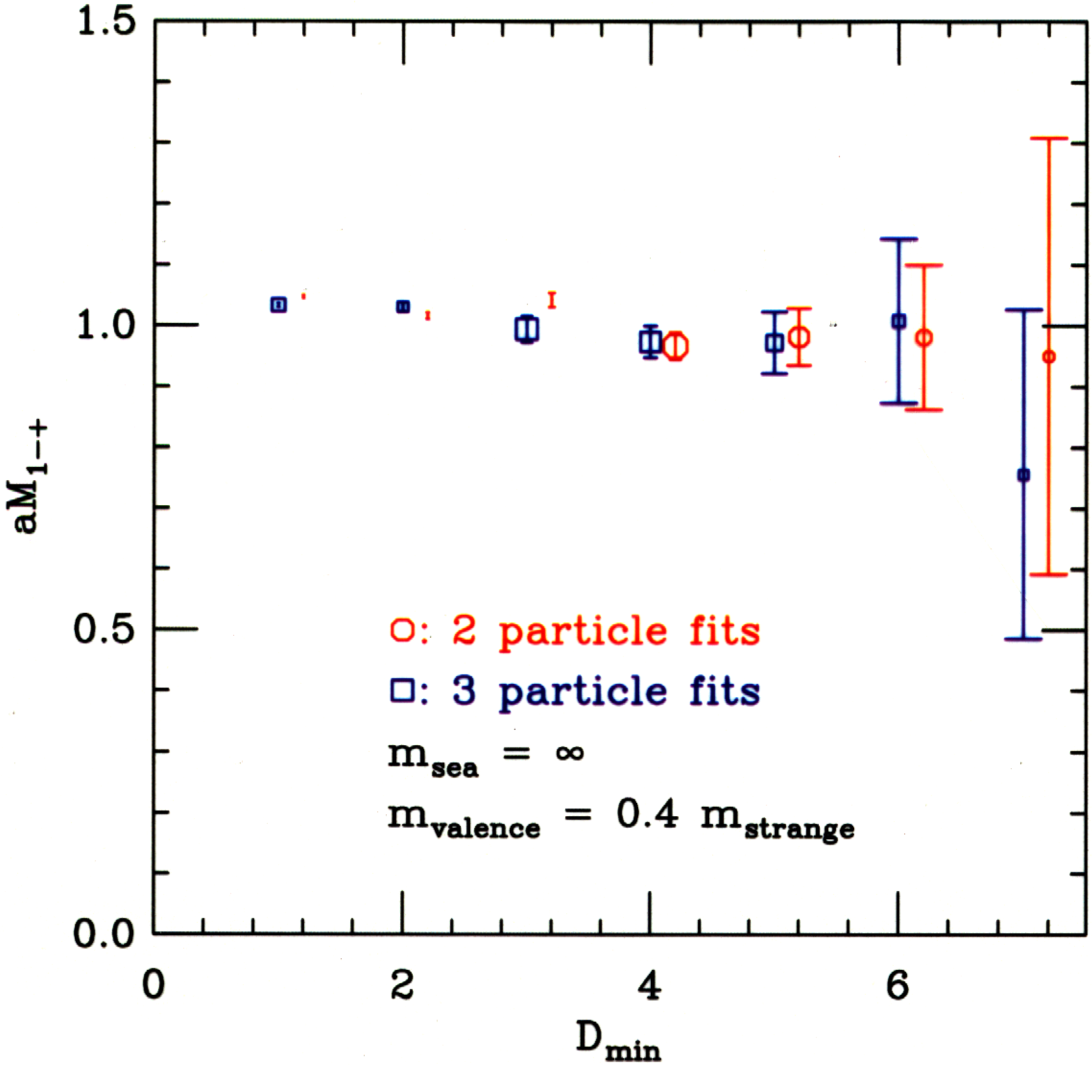
worst case



Mass fits, quenched $m_V \approx 0.4 m_s$.

symbol size ~ conf. (Prob. $\chi^2 \geq$ observed)

o = 50%



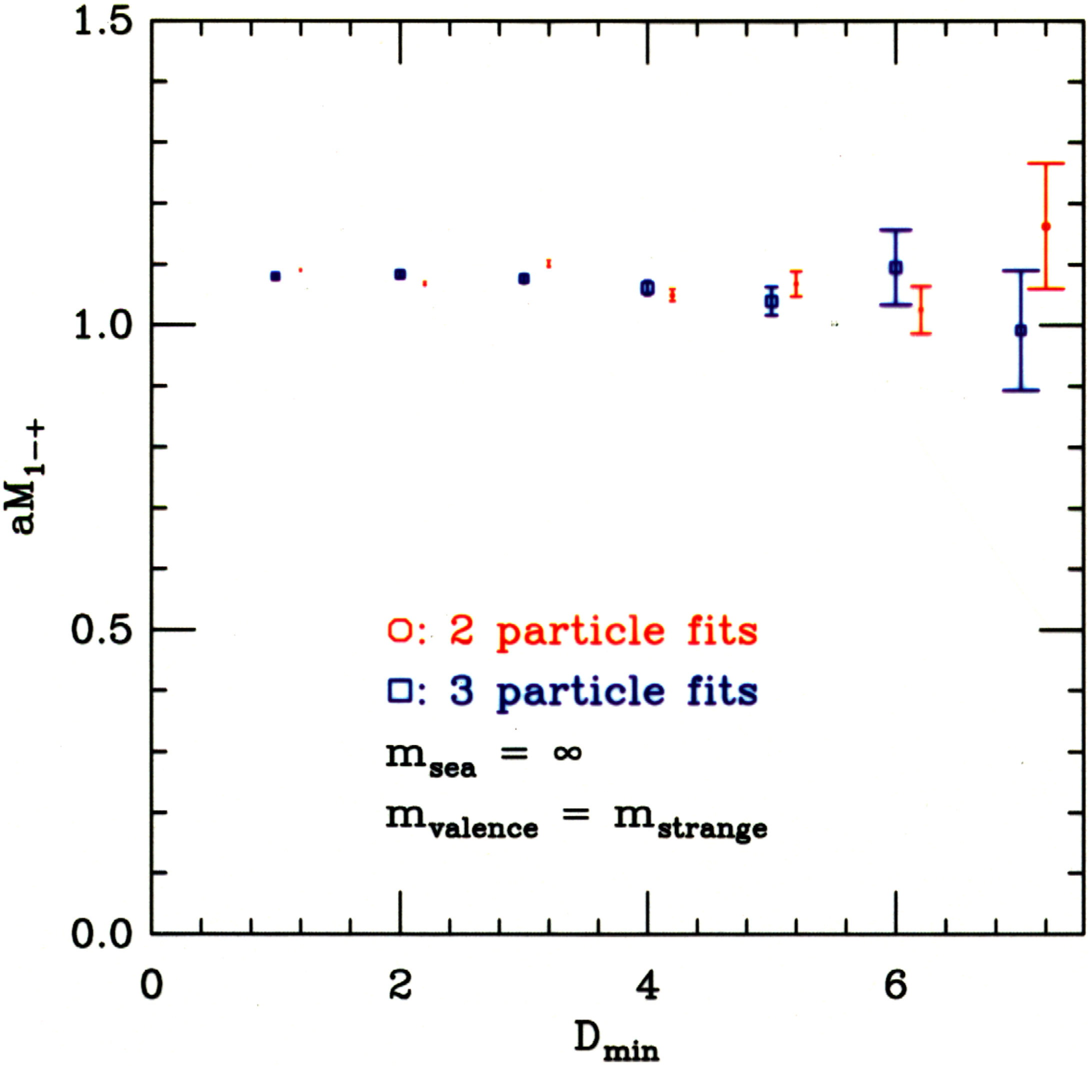
1^{-+} mass fits, quenched $m_V \approx 0.4 m_s$.

2 particle fits – hybrid + a_1

3 particle fits – hybrid,

a_1 (fixed)

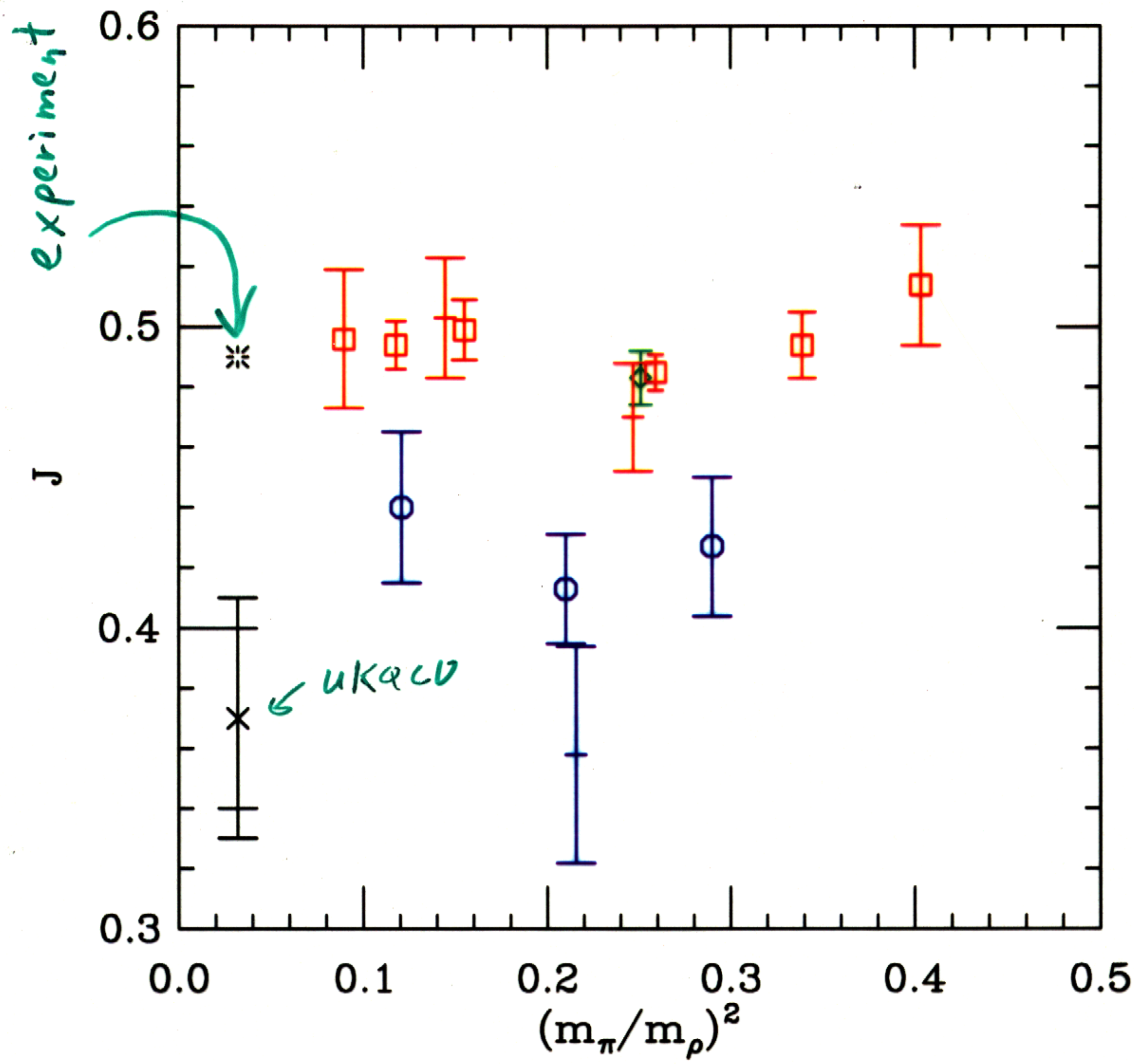
1^{++} excited



1^{-+} mass fits, quenched $m_V \approx m_s$.
Symbol size ≈ confidence level
2 particle fits: hybrid and a_1.
3 particle fits: hybrid, a_1 (fixed) and another $1++$.

Virtual quark-antiquark pairs do have effects:

"J" with and without quark dynamics



$$J = m_{K^*}\frac{\partial m_V}{\partial m_{PS}^2} \approx \frac{m_{K^*}\left(m_\phi - m_\rho\right)}{2\left(m_K^2 - m_\pi^2\right)}$$

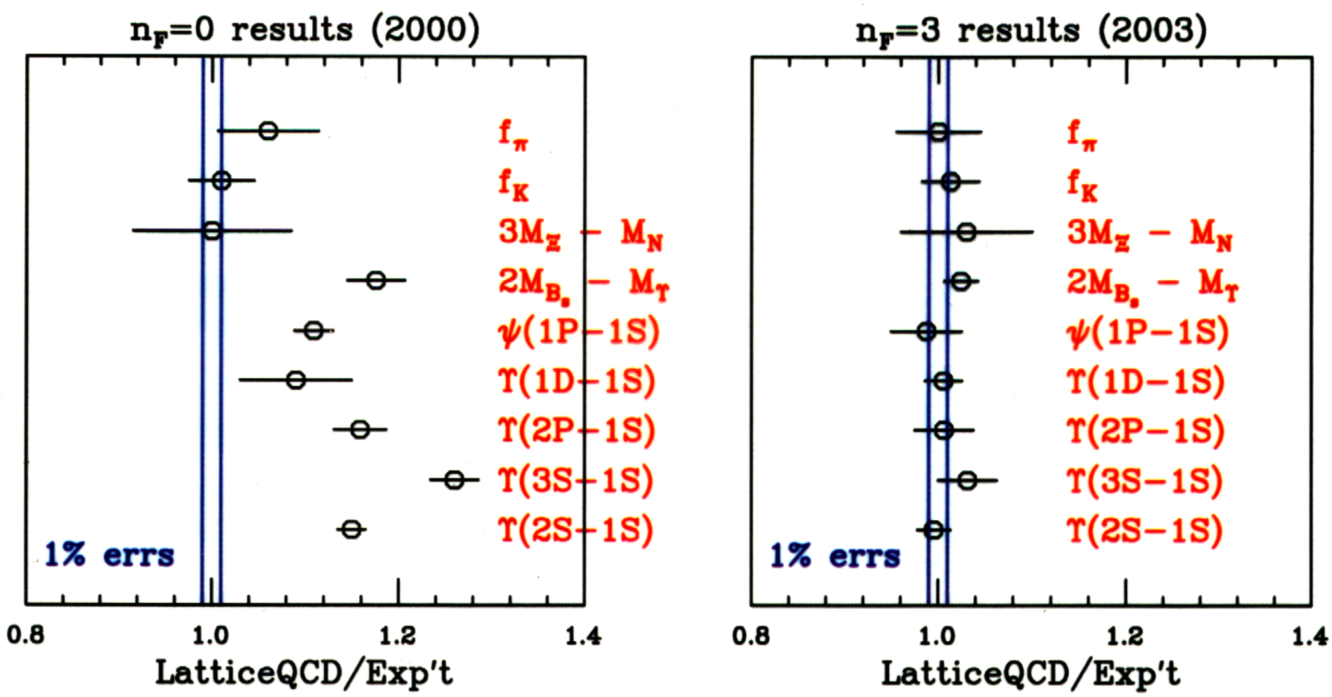
○ — 0 flavors

◇ — 2 flavors

□ — 3 flavors

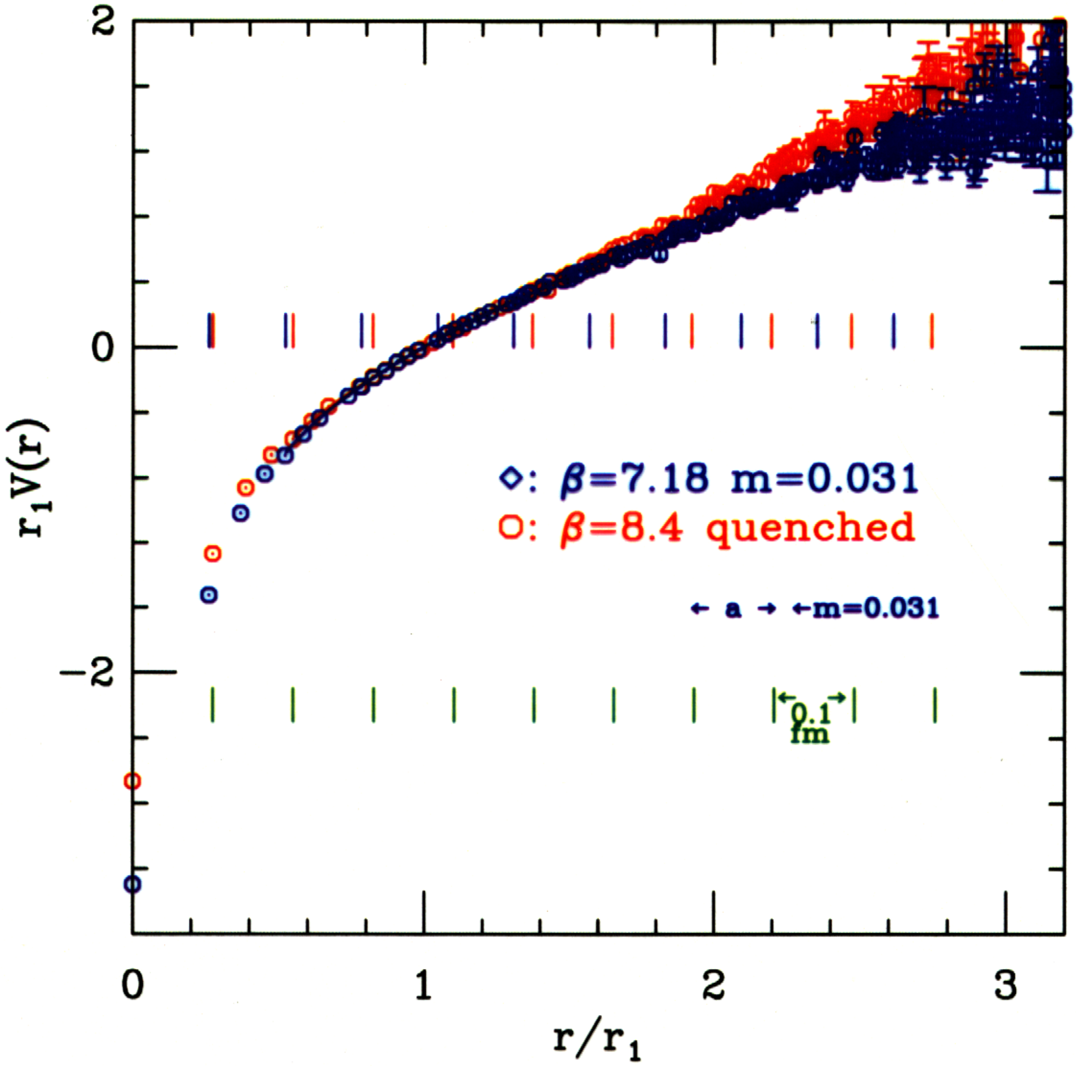
Virtual quark-antiquark pairs do have effects:

Upsilon spectrum and f_π.



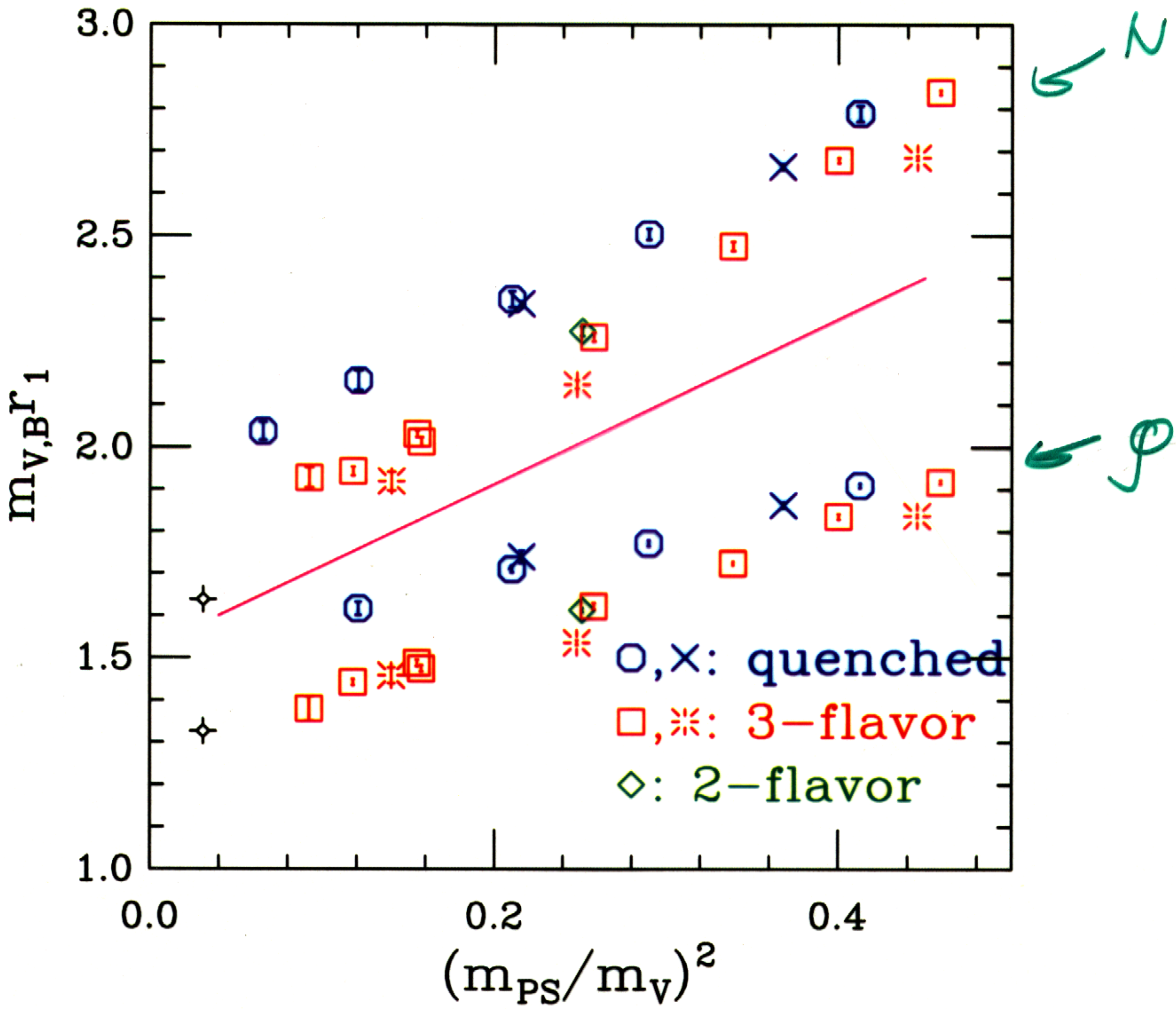
Compilation by Peter Lepage

Results from MILC, HPQCD, FNAL



Static quark potentials, quenched and three flavor

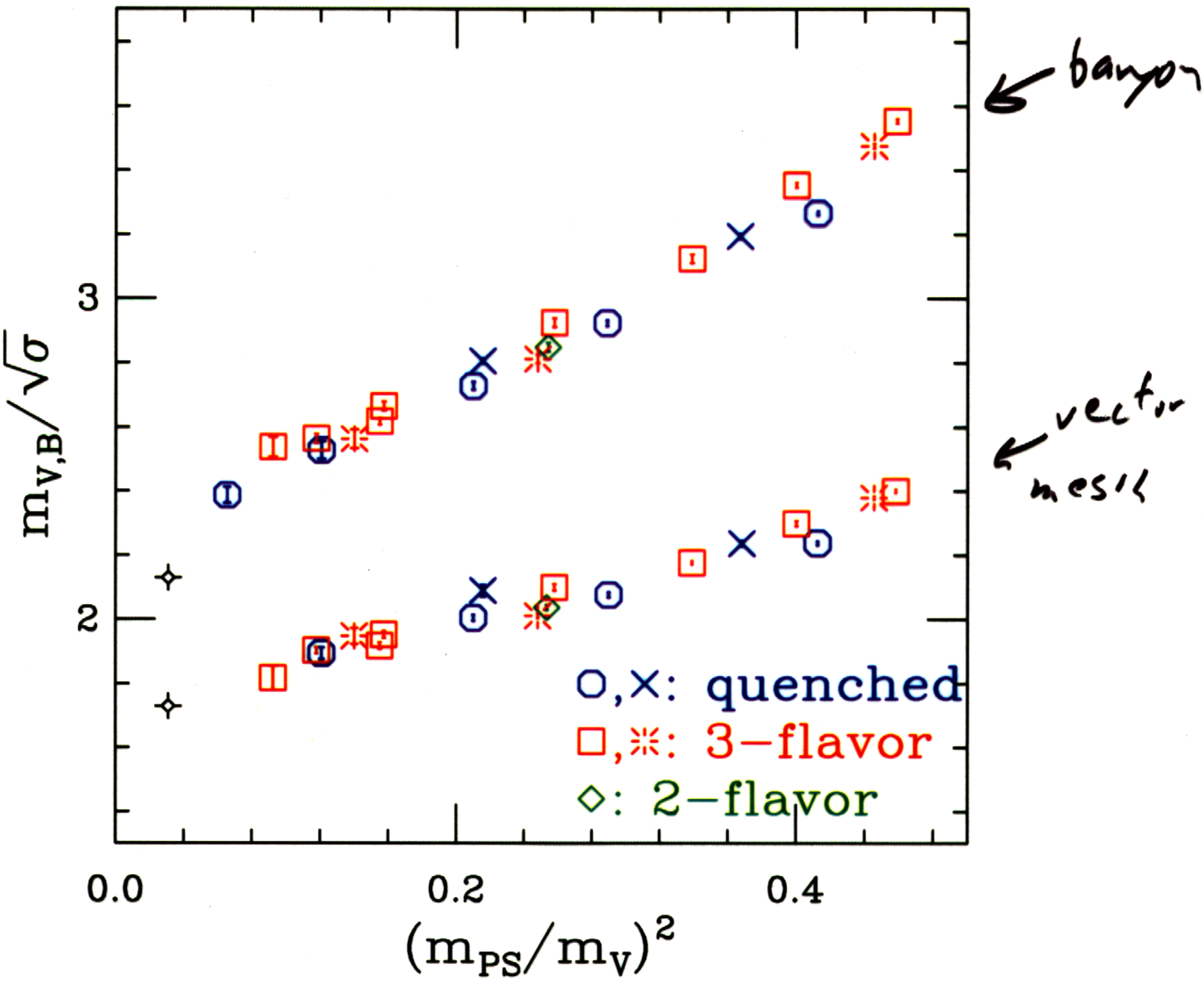
Different shapes → no unique way of determining lattice spacing in quenched calculations.



We could try r_1 . . .

Quenched and three flavor nucleon and rho masses in units of r_1 ($r_1 \approx 0.32$ fm.)

Note similar statistical errors for quenched + full QCD



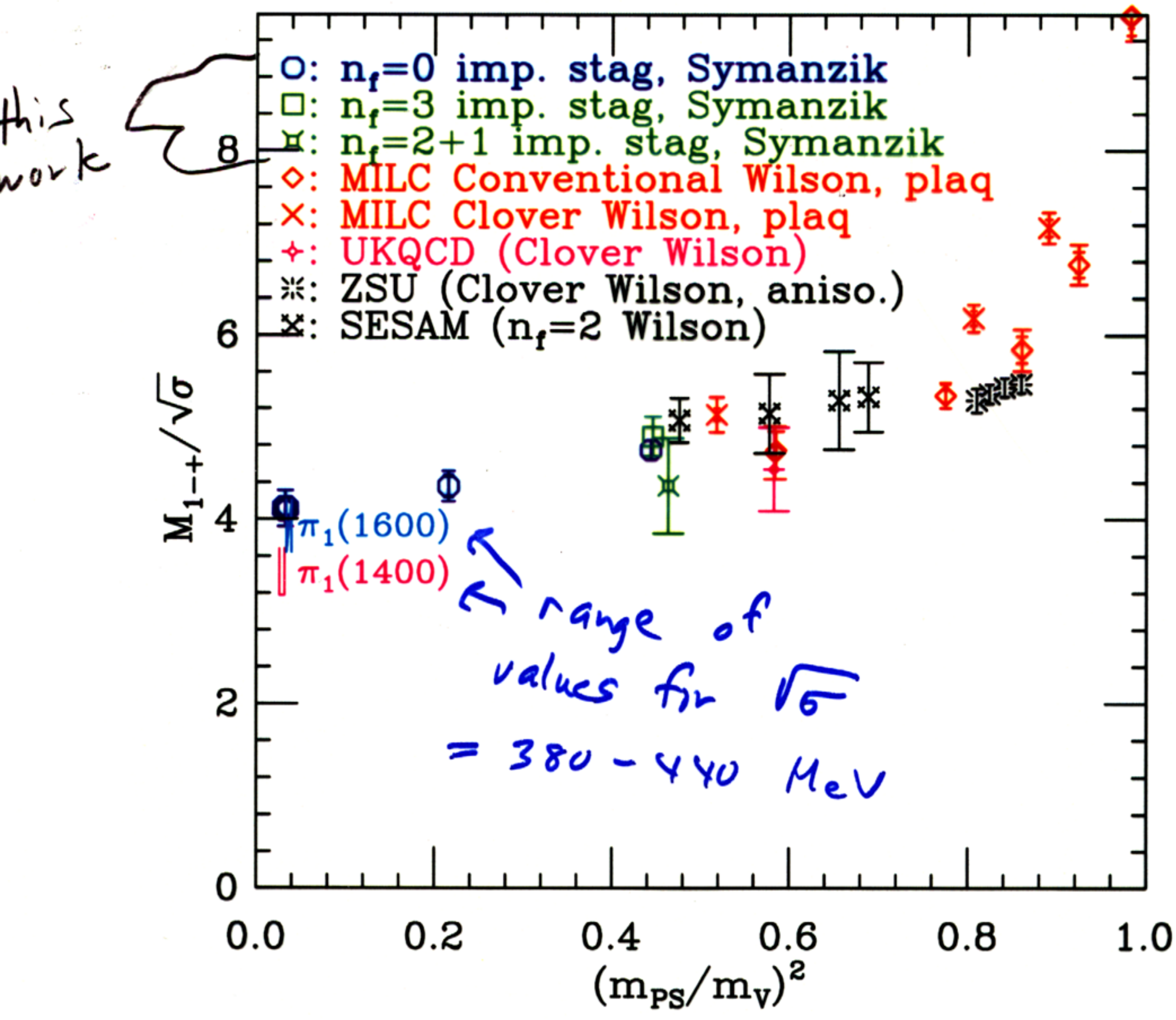
Or we could use σ . . .

Quenched and three flavor nucleon and rho masses in units of $\sqrt{\sigma}$. perhaps because sigma determined at $r \approx$ hadron size

○ □ } $a \sim .12$ fm   × ✳ } $a \sim .09$ fm → estimate error from a to (~3%)

Compare to earlier work

MILC, UKQCD, SESAM, ZSU collaborations



Sources of error

Statistics

Fit choice

Lattice spacing (a)

Finite size (L)

* Quenching/chiral extrap

$a = .12, .09$ for $\rho, N, \phi \ldots$

$L = 2.5, 3.5$ fm for $\rho, N \ldots$ at $a = .12$

$s\bar{s}$ 1^{-+} hybrid - QUENCHED

errors:
(statistics)(fit choice)(a^2)(L)(quench)

set scale with: $M_{1^{-+}}$ =

???

ϕ 2071 (26)(39)(21)(41)(100)
2071(120) MeV

Ω^- 2077(47)(39)(21)(41)(100)
2103(127) MeV

"sss" (Ξ - N) 2075 (24) ...

OR, choose conventional strange quark hadron to set scale

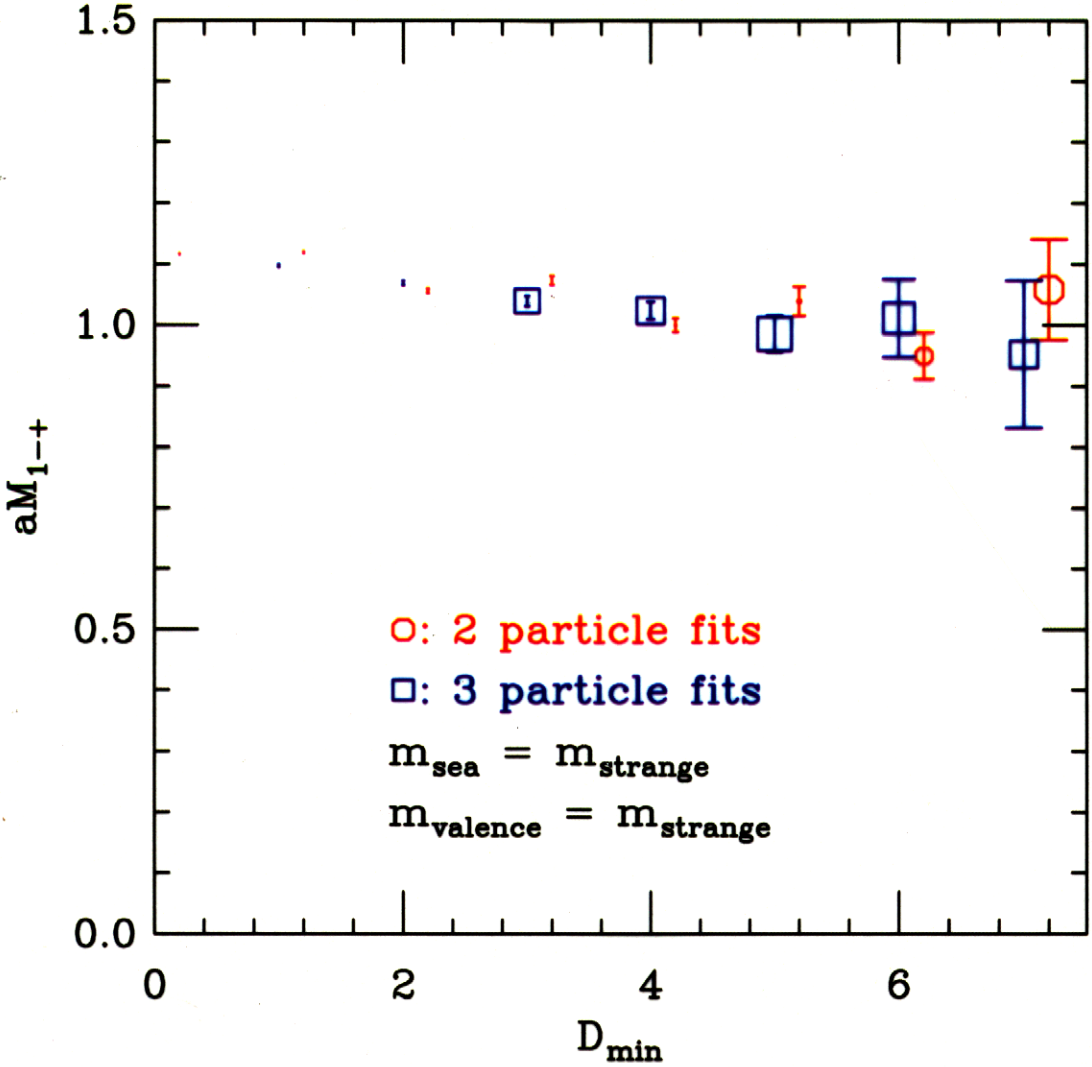
quenching errors ???
70 MeV shift from plausible shift in s quark mass to ~~get~~ get M_K right instead of M_ϕ

$u\bar{u}, d\bar{d}$ 1^{-+} hybrid QUENCHED

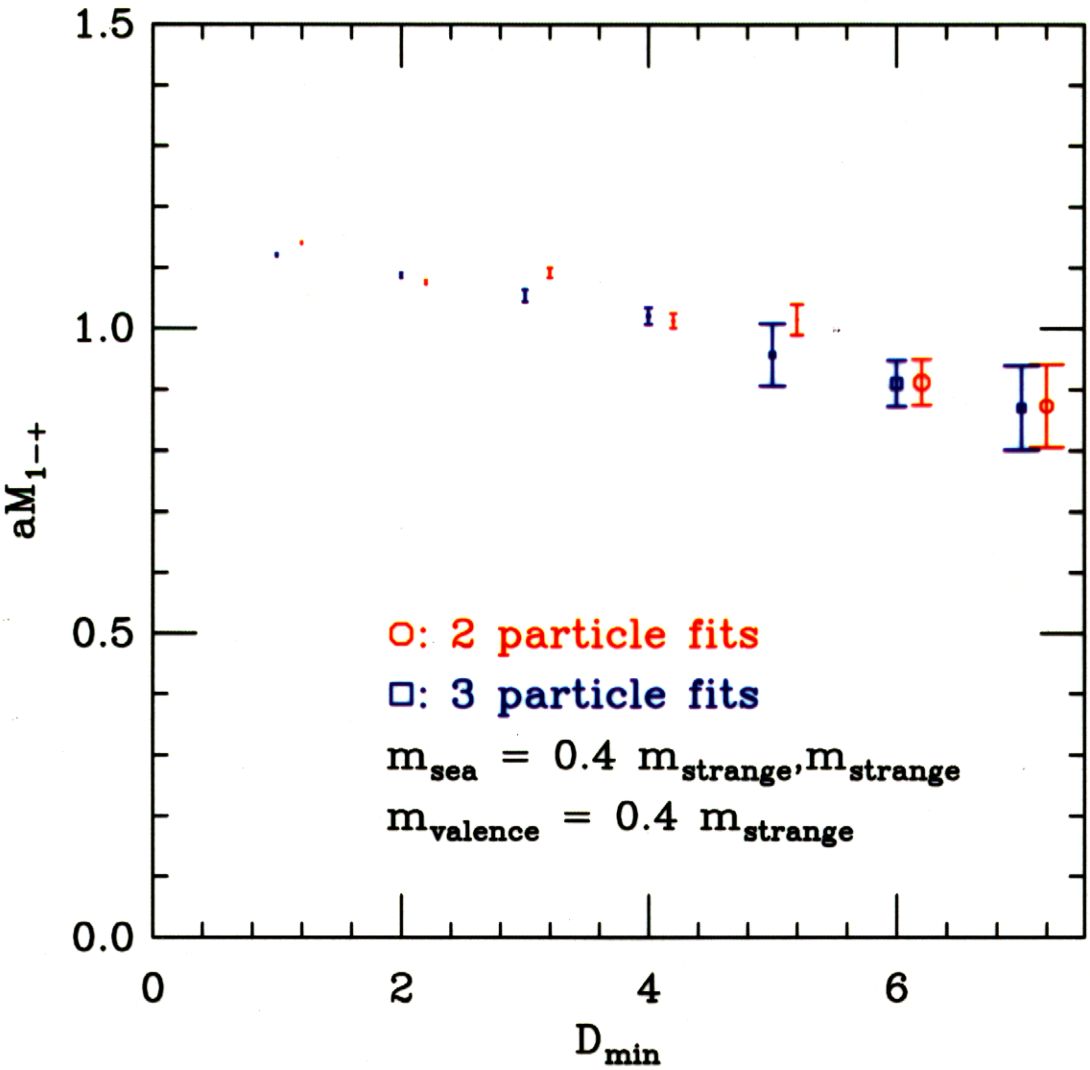
extrapolate : $aM_H = 0.919(39)$

scale set: $M_{1^{-+}}$

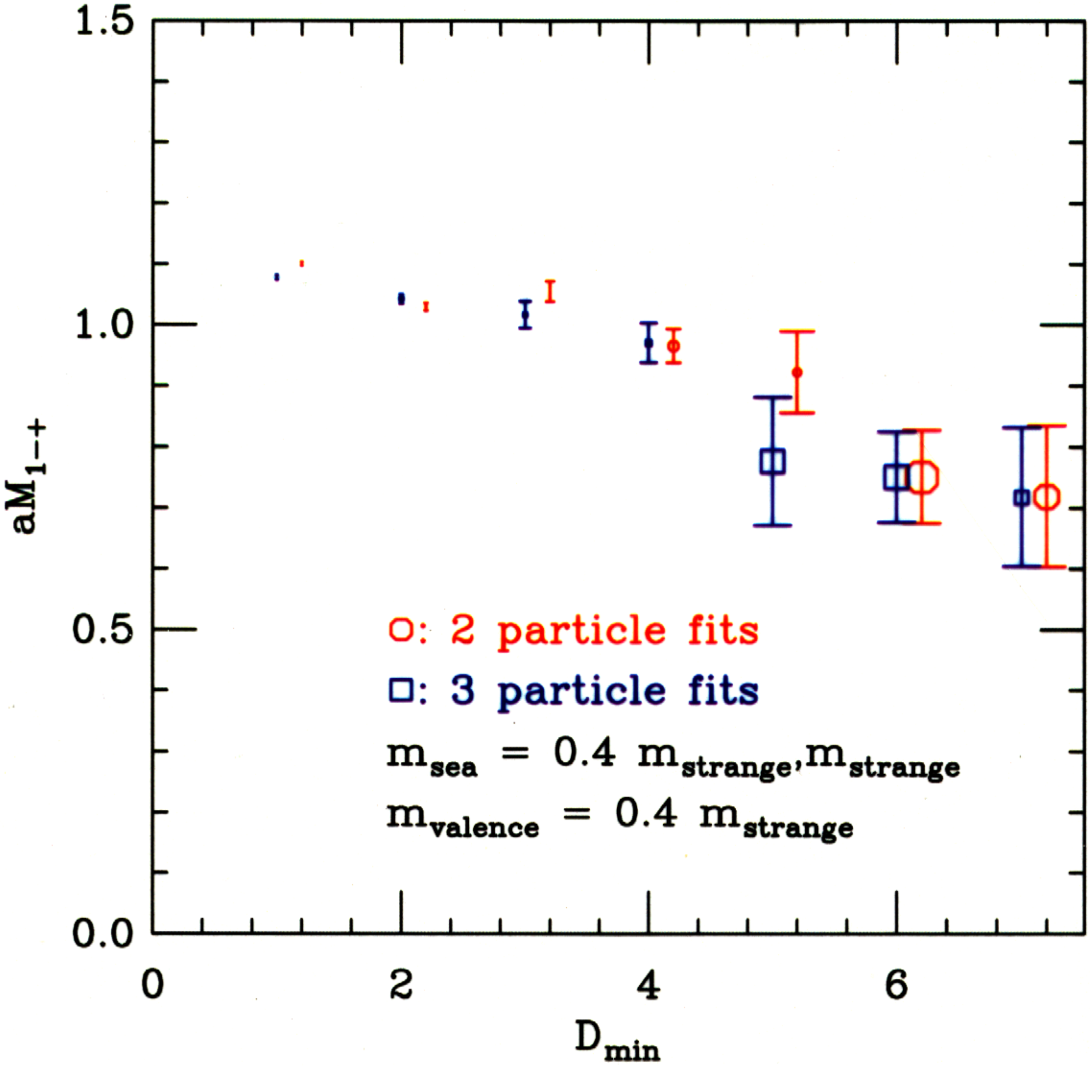
ρ:	1601(71)(35)(3%)(2%)(5%)	1601(126) MeV
N:		1561(122)
Δ:		1645(154)
φ		1792(140)
Ω^-		1797(144)
sss		1796(139)
$\sqrt{\sigma}$ (440 MeV)		1810(140)



Three sea quarks, about strange quark mass
1^{-+} mass fits, $m_{sea} \approx m_s$, $m_V \approx m_s$.



2+1 flavors:
1^{-+} mass fits, $m_{sea} \approx 0.4 m_s, m_s$, $m_V \approx m_s$.



1^{-+} mass fits, $m_{sea} \approx 0.4 m_s, m_s$, $m_V \approx 0.4 m_s$.

$s\bar{s}$ 1^{-+}, with sea quarks

scale	m_{dyn}	
φ	m_s	2104(119)
Ω^-	m_s	2152(120)
"sss"	m_s	2124(120)
φ	$0.4 m_s / m_s$	1916(236)

$\boxed{\text{BUT}}$

TWO MESON STATES

e.g. $f_1 + \pi$ ...

m_{sea}	m_{val}	$aM_{1^{-+}}$	aM_{ps+pv}
m_s	m_s	.97(3)(3)	1.00
$0.4 m_s$	m_s	.90(4)(10)	.90
$0.4 m_s$	$0.4 m_s$	—	.83

We are right at threshold

Conclusions

Quenched

$s\bar{s}$ 1^{-+} $\approx 2100 \pm 120$ MeV

errors: statistics
fit choice
$a \to 0$ (lattice spacing)
$L \to \infty$ (spatial size)
quenching / scale setting
chiral extrap (sea quarks)

$u\bar{u}$ 1^{-+} $\underbrace{1600-1800}_{\text{scale setting}}$ (140) MeV

other errors

3 flavor

$s\bar{s}$ ~ 2100 MeV

2+1 flavor

The real problem is learning to deal with strong decays

(config. generation more or less OK)