Exploratory Study of Overlap Valence Quarks on a Staggered Sea

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goals of lattice QCD

gold plated: unique values of quark masses give agreement with experiment for known quantities within 3% (SM consistent)

→ currently being realized on the MILC improved staggered 2+1 flavour lattices

all that *glitters* is not gold

solid gold: many zero temperature masses and matrix elements computable with all sources of uncertainty below 3% (SM falsifiable)

→ achievable in principle using dynamical GW implementations

or by finding $D_{\mathrm{local}} \equiv (D_{\mathrm{staggered}})^{1/4}$

mixed actions

$$\langle O \rangle = \frac{1}{Z} \int DU \ \det{}^{1/2}\left(D_{\rm st}[U] + m_{ud}\right) \det{}^{1/4}\left(D_{\rm st}[U] + m_s\right) e^{-S_G[U]}$$

$$\times O\left[U, \frac{\delta}{\delta \overline{\eta}_i}, \frac{\delta}{\delta \eta_i}\right] e^{-\sum_i \overline{\eta}_i D_{\rm ov}[U](m_i)^{-1} \eta_i} \Bigg|_{\overline{\eta}_i, \eta_i = 0}$$

$$D_{\rm st}^{\rm loc} \equiv D_{\rm st}^{1/4} \; ?$$

$$S = S_G[U] + \sum_{l=ud} \overline{\chi}_l \left(D_{\rm st}^{\rm loc}[U] + m_{ud}\right)\chi_l + \overline{\chi}_s \left(D_{\rm st}^{\rm loc}[U] + m_s\right)\chi_s$$

$$+ \sum_i \left\{ \overline{q}_i D_{\rm ov}[U](m_i) q_i + \phi_i^{+} D_{\rm ov}[U](m_i)\phi_i \right\}$$

$$D_{\rm ov}(m_i) \geq m_i$$

symmetries & renormalisation

- **unitary if 1-taste staggered action is local**
- **exact $SU(N_f) \times SU(N_f)$ chiral symmetry for $m_i = 0$, $i = 1, \ldots, N_f$**

$$\delta q = i\varepsilon\tau\gamma_5\left(1 - \frac{1}{2}D_{\mathrm{ov}}\right)q$$

$$\delta\overline{q} = i\varepsilon\overline{q}\left(1 - \frac{1}{2}D_{\mathrm{ov}}\right)\gamma_5\tau$$

- **axial $U(1)$ anomaly and index theorem**
- **Ward identities**

$$O'_\Gamma = \overline{q}\,\Gamma\left(1 - \frac{1}{2}D_{\mathrm{ov}}\right)q$$

$$Z_{S'} = Z_{P'}, \quad Z_{V'} = Z_{A'}, \quad Z_m = Z_{S'}^{-1}$$

- **light sea (m_{ud}, m_s) and valence quark masses (m_i) may be determined from the pseudoscalar meson nonet**

parameter values

- **MILC 2+1 flavour improved staggered configurations**
  - exploratory study uses 2 ensembles of 10 configurations

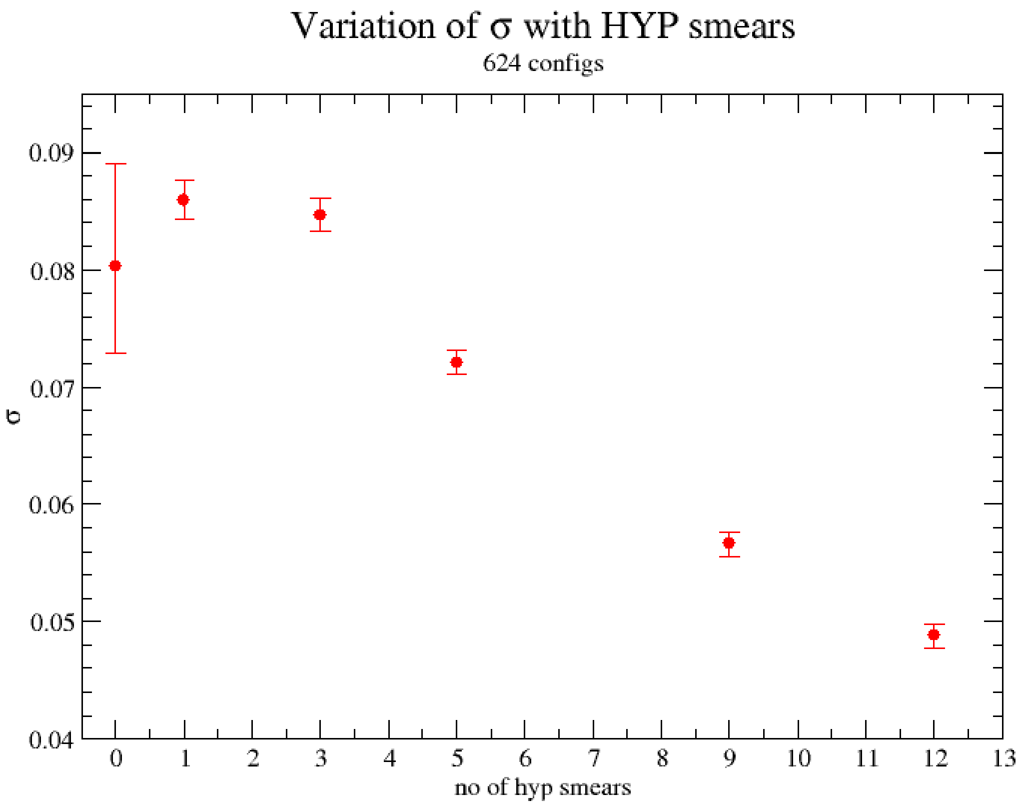
$$V = 20^3 \times 64, \quad a = 0.12 \text{ fm}, \quad L = 2.5 \text{ fm}$$

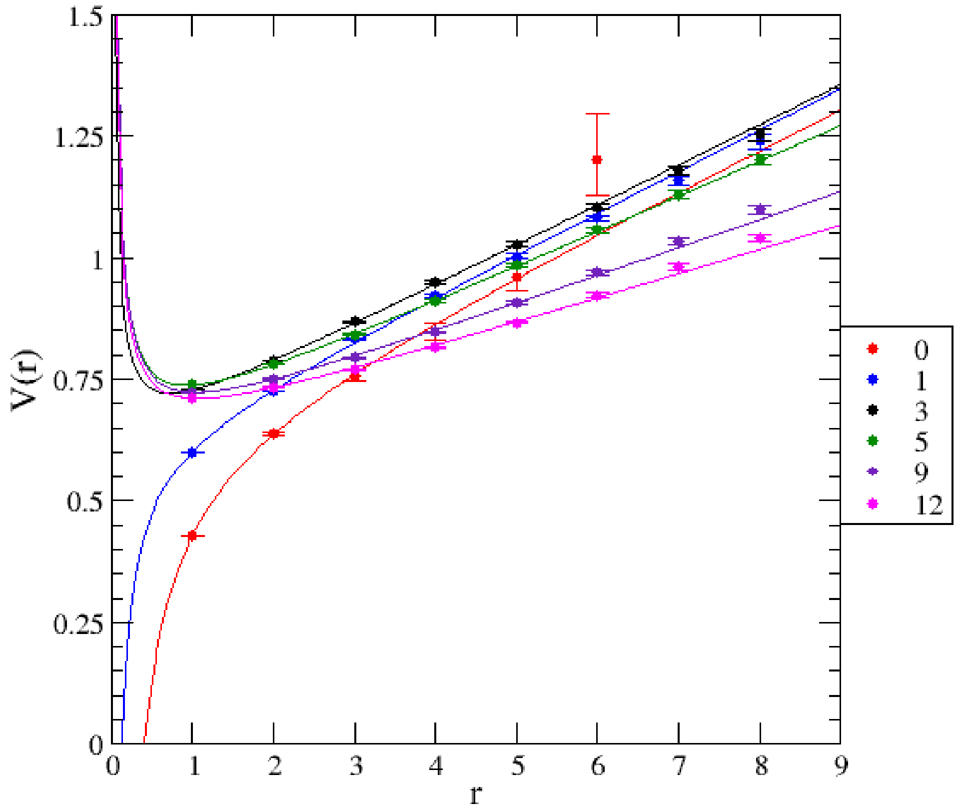
$$\frac{am_{ud}}{am_s} = \frac{0.02}{0.05}, \quad \frac{0.03}{0.05}$$

- **3 iterations of HYP-smearing applied to each configuration**
  - smoother gauge fields improve localisation of D_{ov}
  - low eigenvalues of D_{st} move closer to those of D_{ov}
- **overlap operator in multi-mass form**
  - 4 light + 3 heavy valence quark masses am_i

effect of HYP smearing

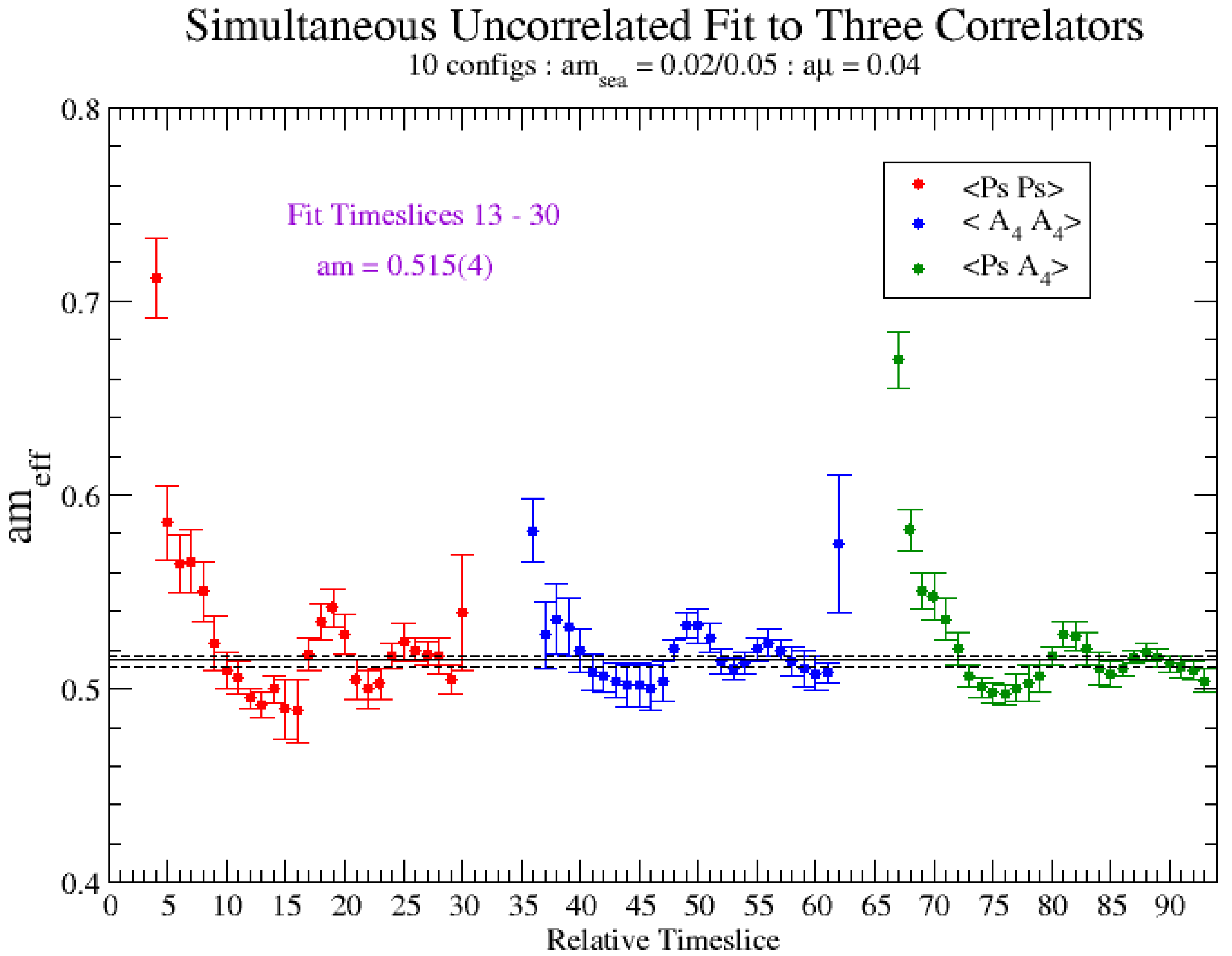
- **static potential from quenched configurations at $\beta = 5.93$, $V = 16^3 \times 32$**





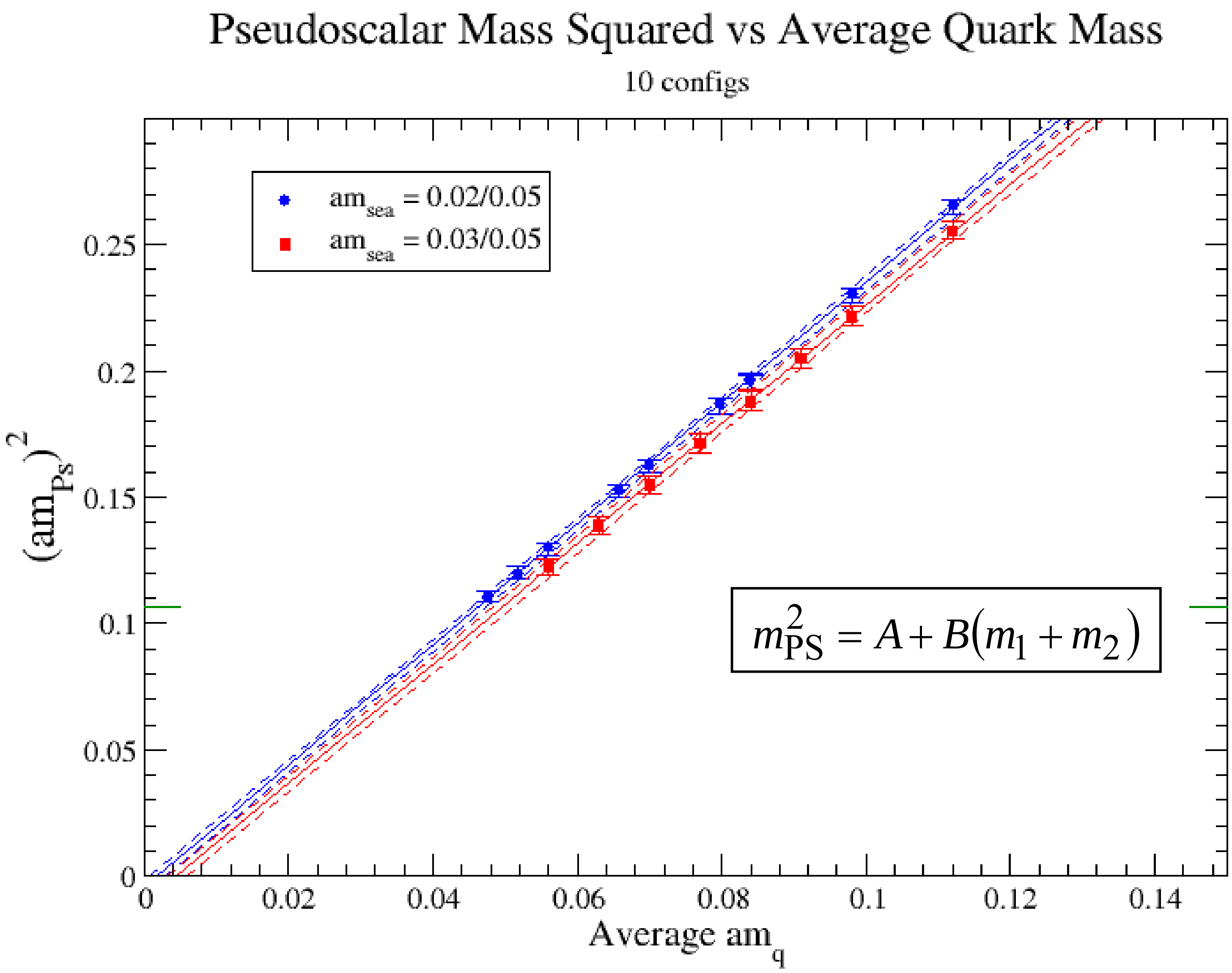
- **more than 2 or 3 HYP smears is dangerous**
- **we used 3 … on a larger lattice**

pseudoscalar meson effective mass

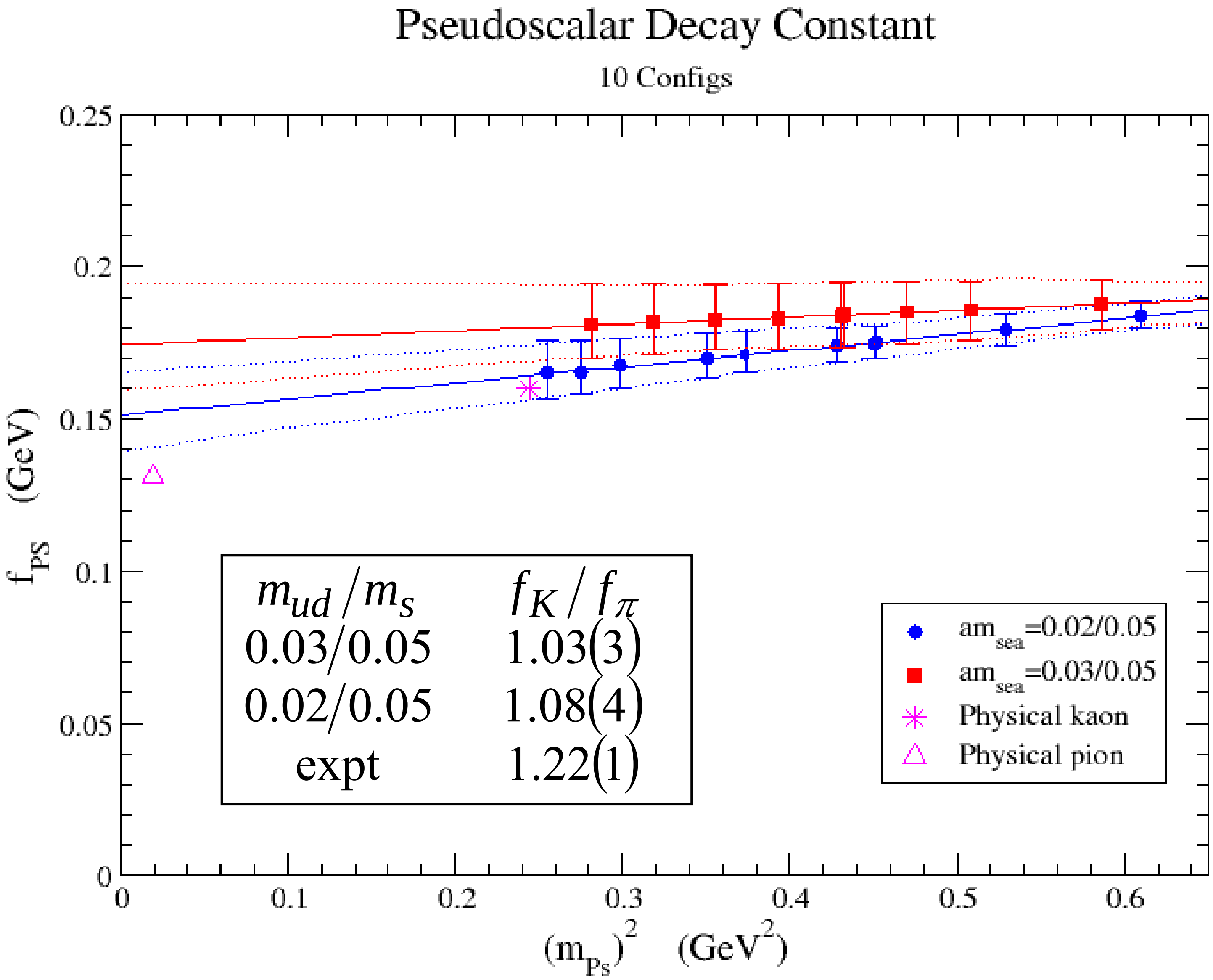


our errors are underestimated

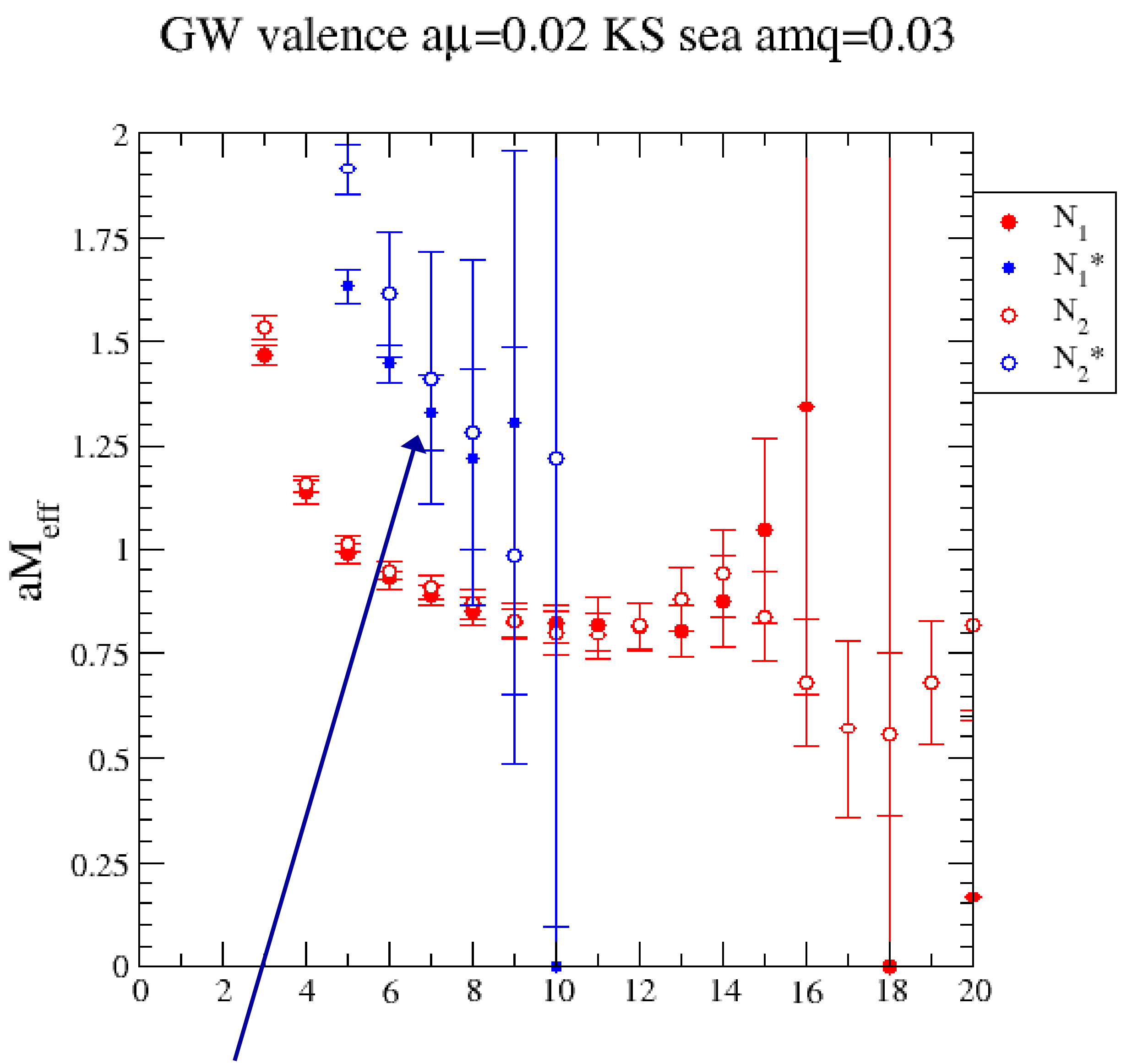
chiral behaviour



f_π and f_K

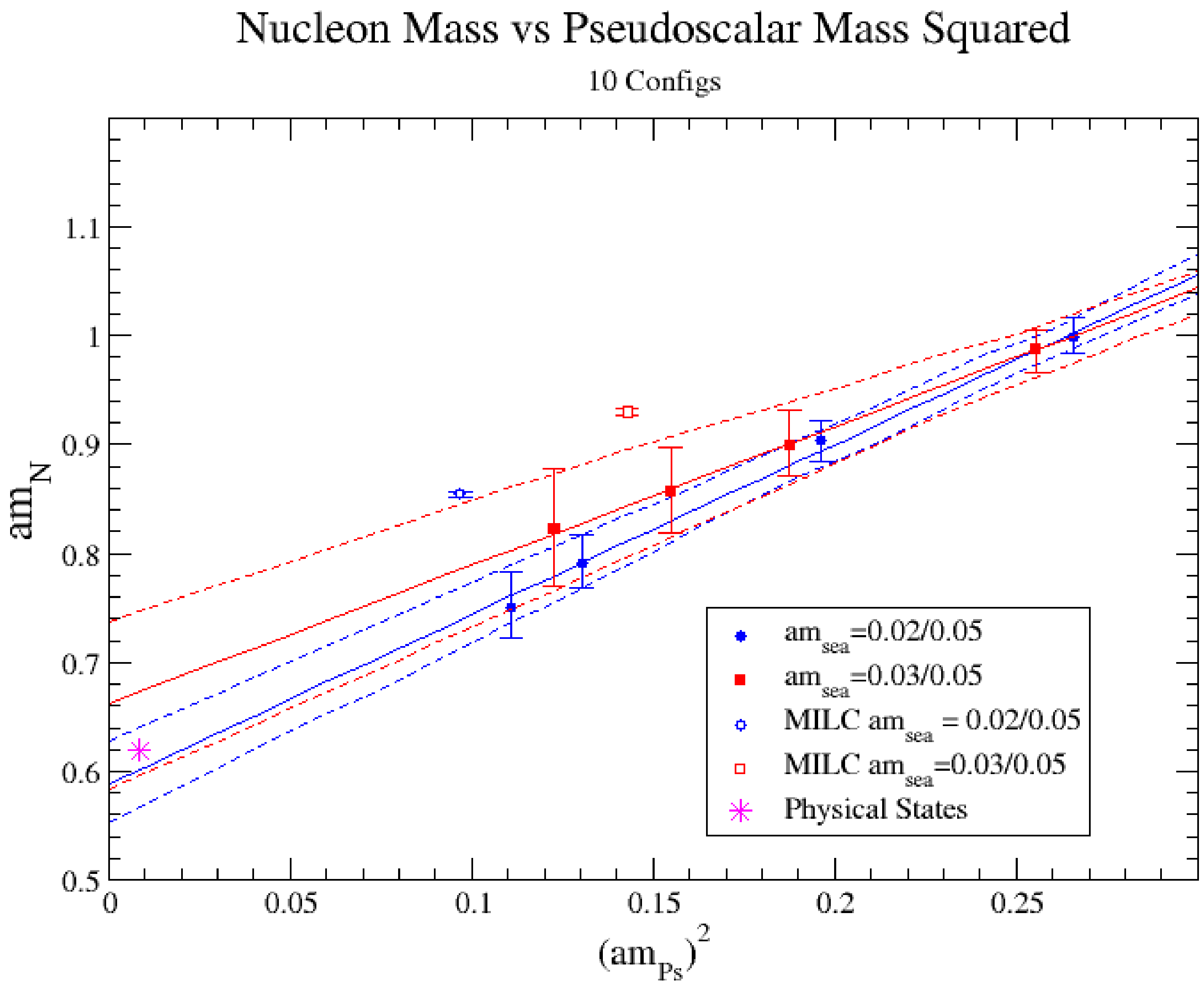

Pseudoscalar Decay Constant
10 Configs
f_{PS} (GeV)
$(m_{Ps})^2$ (GeV^2)
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
m_{ud}/m_s f_K/f_π
0.03/0.05 1.03(3)
0.02/0.05 1.08(4)
expt 1.22(1)
am_{sea}=0.02/0.05
am_{sea}=0.03/0.05
Physical kaon
Physical pion

nucleon effective mass



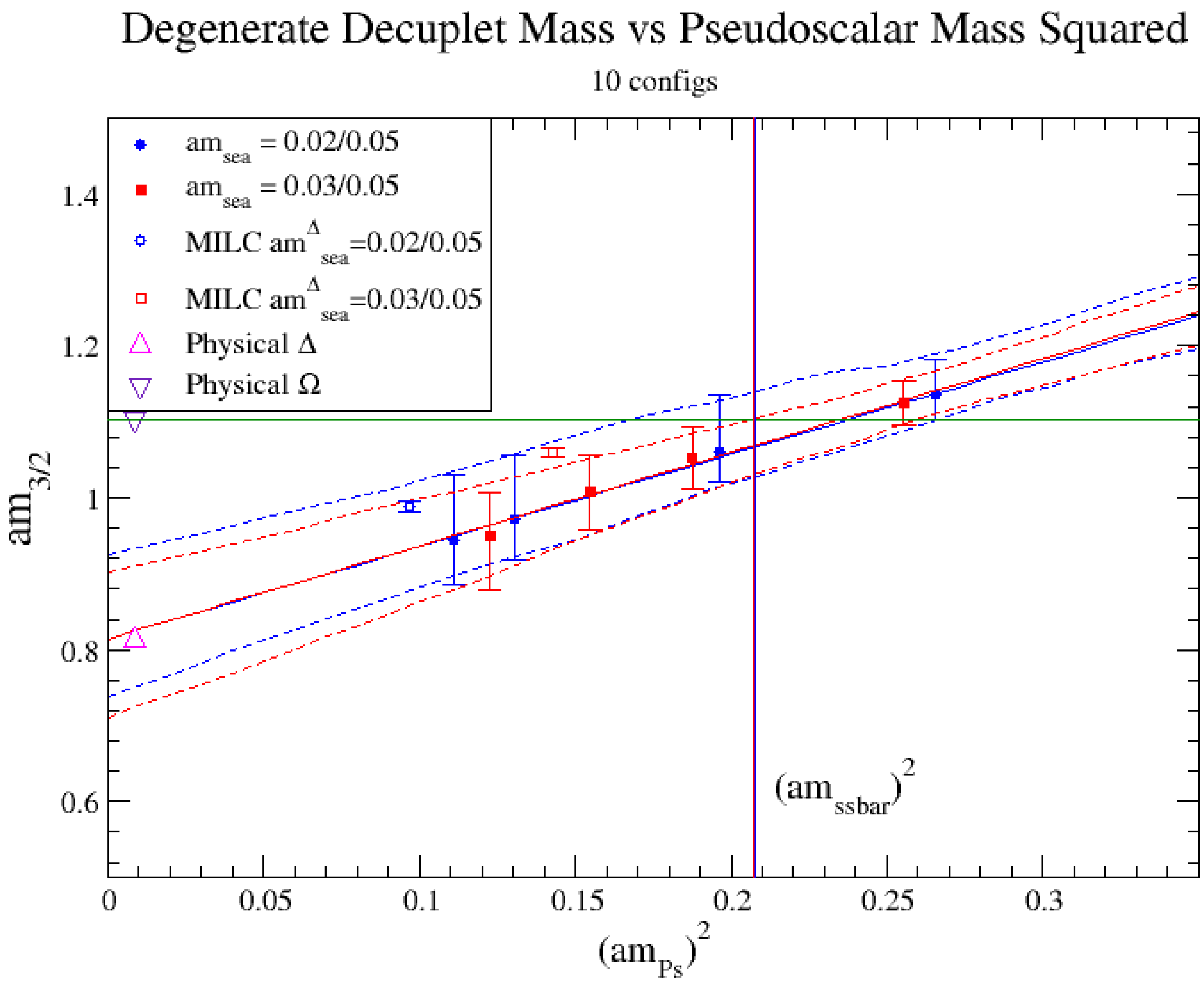
negative parity partner is visible

chiral behaviour



smaller discretisation errors than staggered valence quarks?

Ω^-


Degenerate Decuplet Mass vs Pseudoscalar Mass Squared
10 configs
am_sea = 0.02/0.05
am_sea = 0.03/0.05
MILC am^Δ_sea=0.02/0.05
MILC am^Δ_sea=0.03/0.05
Physical Δ
Physical Ω
am_3/2
(am_ssbar)^2
(am_Ps)^2
1.4
1.2
1
0.8
0.6
0
0.05
0.1
0.15
0.2
0.25
0.3

summary & next steps

- **overlap valence on a staggered sea is unitary if the staggered sea is**
- **advantages relative to staggered valence quarks**
  - similar symmetries, Ward Identities and anomaly to continuum QCD
  - numerically clean and may have smaller discretisation effects
- **disadvantages**
  - more computationally expensive
- **both require sea and valence quark masses to be matched**
- **next steps**
  - chiral perturbation theory for the mixed action
  - feasibility study on high-statistics 2+1 flavour improved staggered ensemble
  - compute pseudoscalar meson nonet masses

    $\rightarrow$ match sea and valence quark masses