Light Hadron Spectrum and Quark Masses in Nf=3 QCD

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CP-PACS/JLQCD Collabs.

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CP-PACS Collab. @CCS,Tsukuba

CP-PACS
0.6TFlops

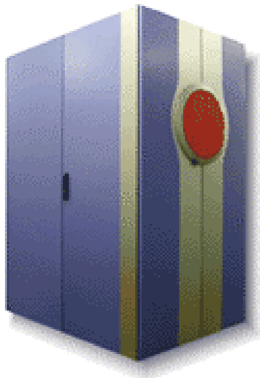
SR8000/G1
0.2TFlops

VPP5000
0.8Tflops

@ACCC

JLQCD Collab. @KEK

SR8000/F1
1.2TFlops



3% of ES

Earth Simulator
(JAMSTEC)
40TFlops

~1.5 Tflop*Year (sustained speed) in 2 years
(20-46% efficiency depending on size and machine)

Motivation

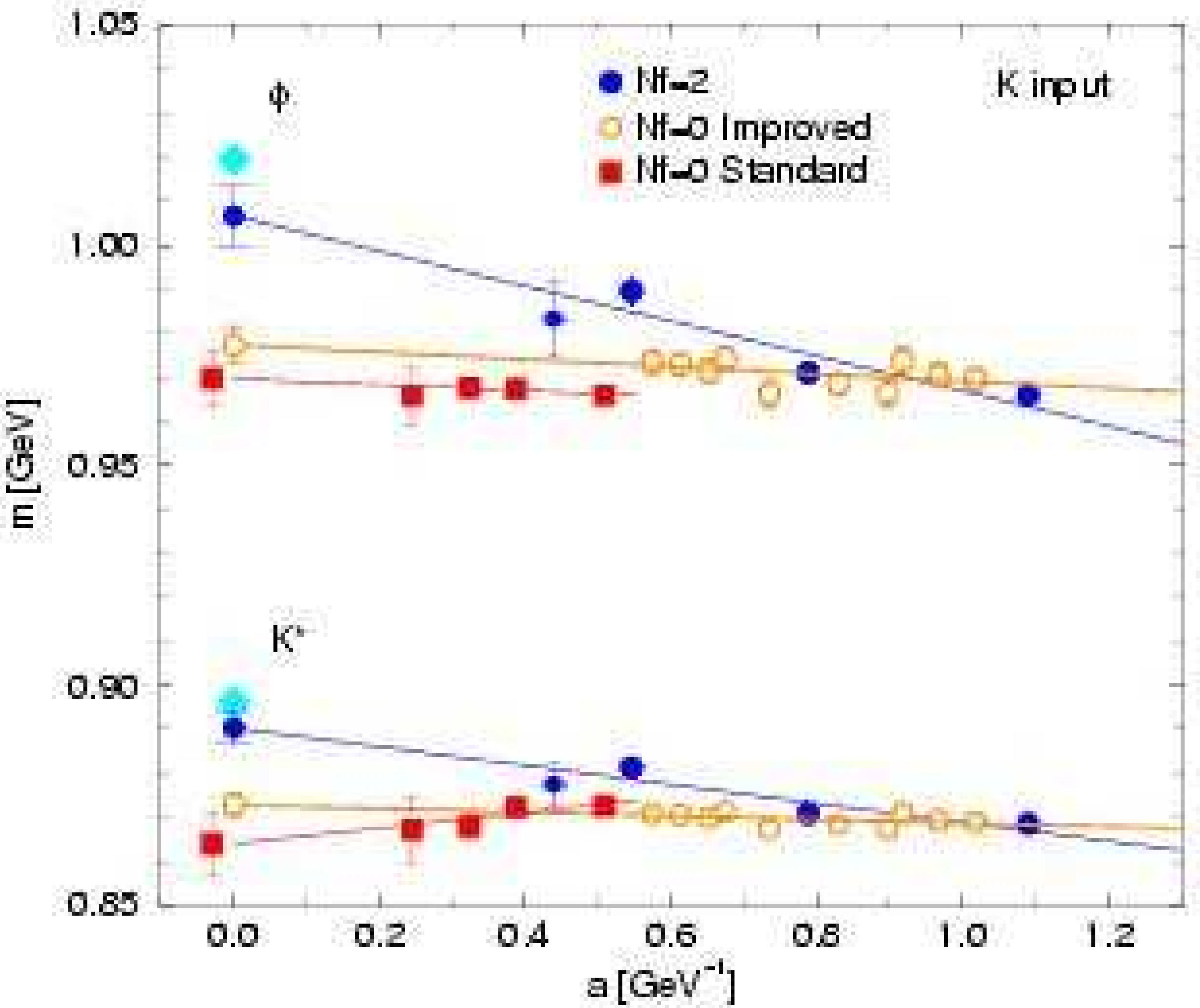
- Previous CP-PACS spectrum studies
  - Quenched QCD (plaquette gauge + Wilson quark)
  - Nf=2 full QCD   (Iwasaki RG gauge + Clover tp Csw)

    additional quenched simulation with the same action combination

  - Continuum limit of spectrum and quark masses

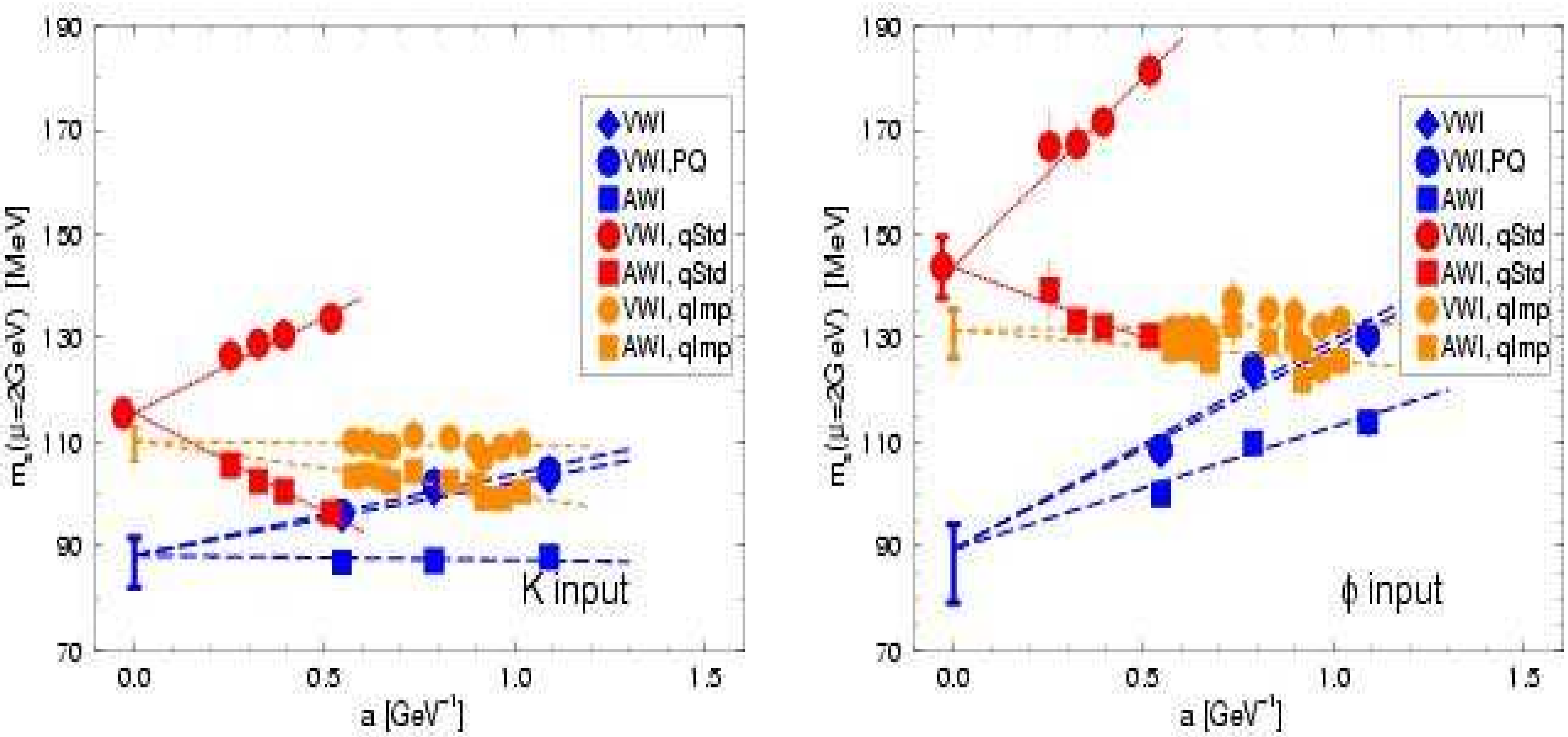
- Two key observations
  - spectrum
  - quark mass

✓O(10%) systematic deviation of the quenched spectrum from experiment is significantly reduced by dynamical u,d quarks



✓ Uncertainty of the strange quark mass, depending on inputs in quenched QCD, is reduced in Nf=2 QCD.

Strange quark mass in Nf=2 QCD is smaller than that in quenched QCD.



Continuum extrapolations of s-quark mass

Nf=3 full QCD Simulations

✧ study and implement PHMC algorithm
✧ determine Csw non-perturbatively
✧ apply the project to ESC
✧ port and tune the PHMC program for ES

How spectrum/quark masses change if we include
dynamical s-quarks

Generating configurations with no quenching effect
for studies of other physics (heavy quark system ….)

Action and Simulation Parameters

- Action :

  Iwasaki RG Gauge action

  Clover quark action Csw determined non-perturbatively

- Three lattice spacings

  a=0.122 fm β=1.83

  a=0.10 fm β=1.90

  a=0.07 fm β=2.05

  at regular intervals in a**2

Simulation Parameters (Cont.)

- Quark Masses

degenerate u,d quark 5 K_{ud} (**π / ρ =**0.78 – 0.62) (HMC)

s quark with different quark mass 2 K_s (**π / ρ ~**0.7) (PHMC)

10 combinations of (K_{ud}, K_s)

valence quark $K_{val,1/2} = K_{ud} / K_s$

$\Delta\tau, N_{poly}$ are tuned in a way that

$$P_{HMC} \approx 85\%, P_{GMP} \approx 95\%$$

Simulation Parameters (Cont.)

- Lattice Size

  2 fm in physical unit

  meson spectrum and quark masses

a=0.122 fm	16**3x32	6000-9000 traj.	(almost finished)
a=0.10 fm	20**3x40	5000-8000 traj.	(already finished)
a=0.07 fm	28**3x56	1000 traj→3000 traj.	(in 1-1.5 years)

continuum extrapolation using two coarse lattices

Chiral Extrapolations

- Quadratic polynomial functions in quark masses

  SU(3) symmetry in dynamical masses m_u, m_d, m_s

  exchange symmetry of $m_{val,1}, m_{val,2}$

$$
\begin{aligned}
& m_V(m_{ud}, m_s; m_{val,1}, m_{val,2}) \\
= \quad & A^V \\
& +B_S^V(2m_{ud}+m_s) \\
& +B_V^V(m_{val,1}+m_{val,2}) \\
& +D_{SV}^V(2m_{ud}+m_s) \\
& \qquad \times(m_{val,1}+m_{val,2}) \\
& +C_{S1}^V(2m_{ud}^2+m_s^2) \\
& +C_{S2}^V(m_{ud}+2m_{ud}m_s) \\
& +C_{V1}^V(m_{val,1}^2+m_{val,2}^2) \\
& +C_{V2}^V m_{val,1}m_{val,2}
\end{aligned}
$$

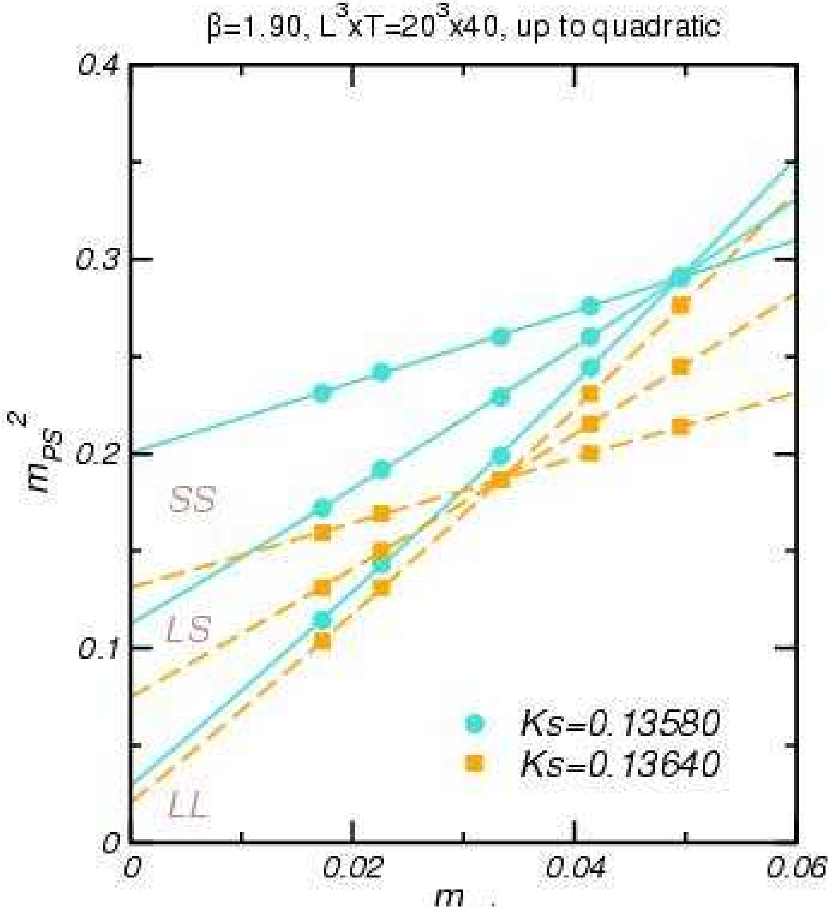
Light-Light (LL), Light-Strange (LS), Strange-Strange (SS) masses are fitted simultaneously, ignoring correlation among them

Light: $K_{val} = K_{ud}$

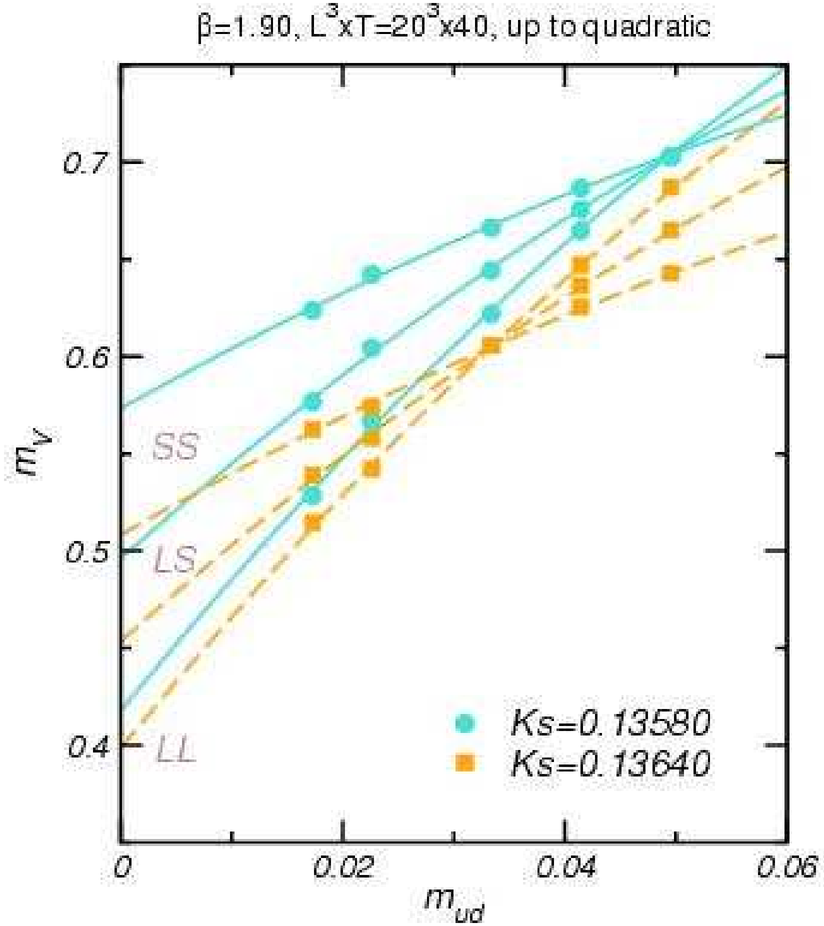
Strange: $K_{val} = K_s$

26 data points 8 param.

$\chi^2 / dof = 1.09$



$\chi^2 / dof = 0.93$

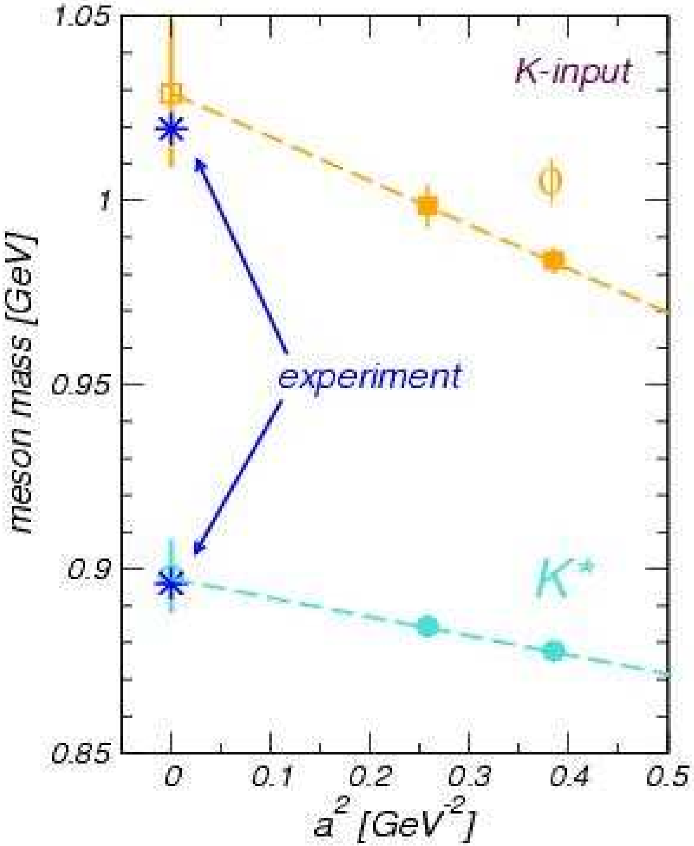


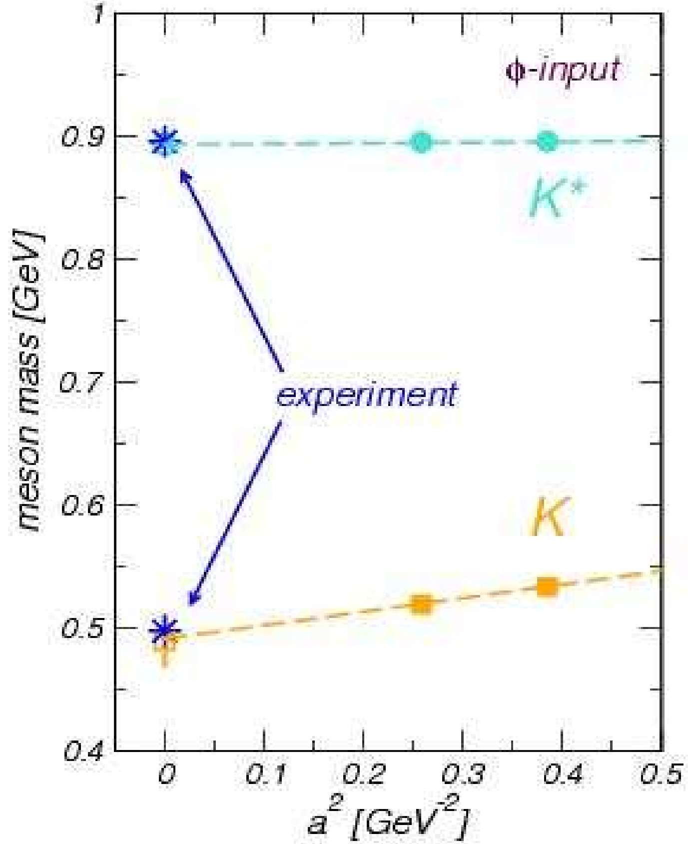
Our chiral fit functions reproduce data well with reasonable values of χ^2 / dof

Spectrum

fix lattice spacing and quark masses

(m_π, m_ρ, m_K) K-input (m_π, m_ρ, m_ϕ) ϕ-input

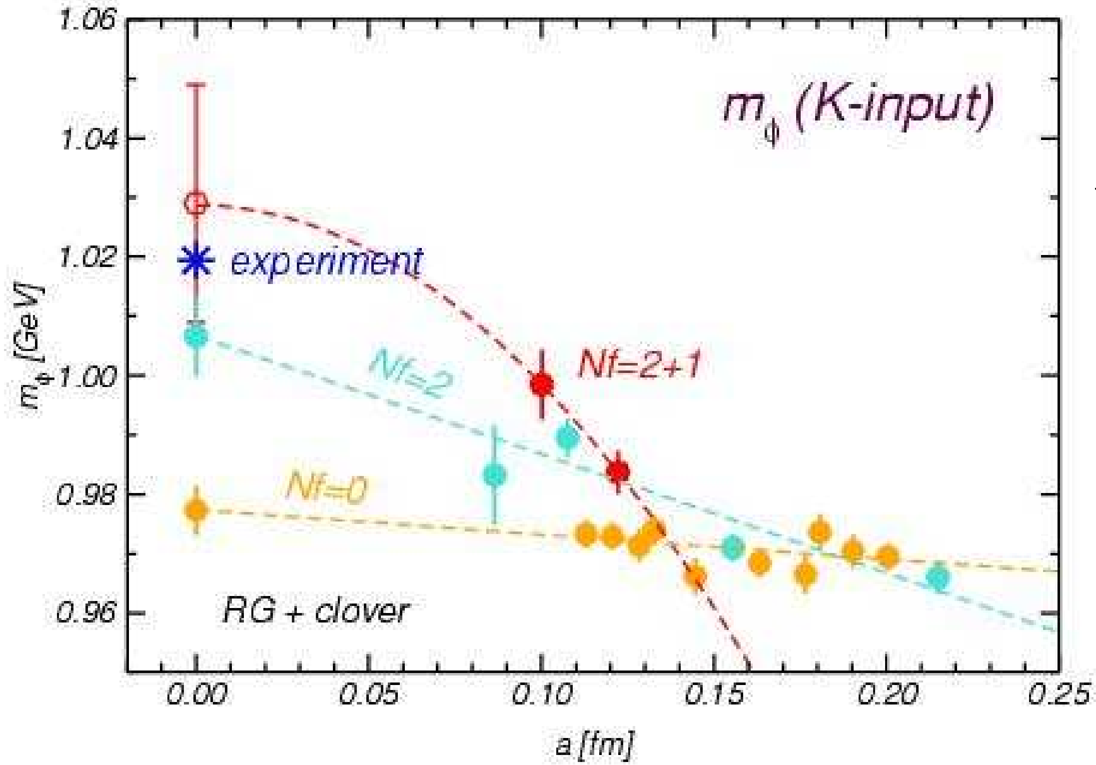




$$m_h = m_0 + ca^2$$

Meson masses extrapolate to experimental values

Comparison with Nf=0 and 2



Magnitude of scaling violation (impression)

Csw (tp) for Nf=0,2

Csw (NP) for Nf=3

larger for larger #flavors ?

for a=0.1-0.2 fm

Current error in the continuum limit for Nf=3 is 4 times larger than that we achieved for Nf=2

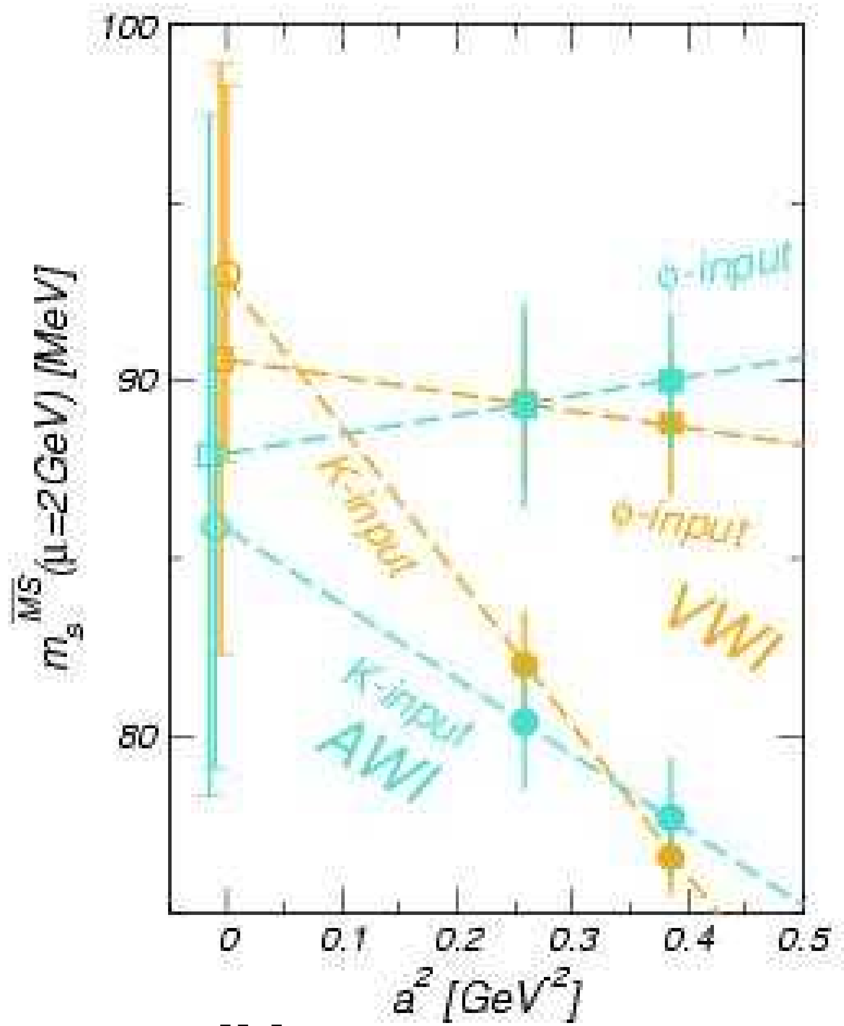
We plan to reduce the error to establish dynamical s-quark effect in the spectrum

Quark Masses

Determined by two methods

$$\partial_\mu A_\mu = 2m_q^{AWI} P$$

$$2m_q^{VWI} = (1/K - 1/K_c)$$



c_A Z-factors:

tp-improved 1-loop perturbation

Matching with MS scheme at

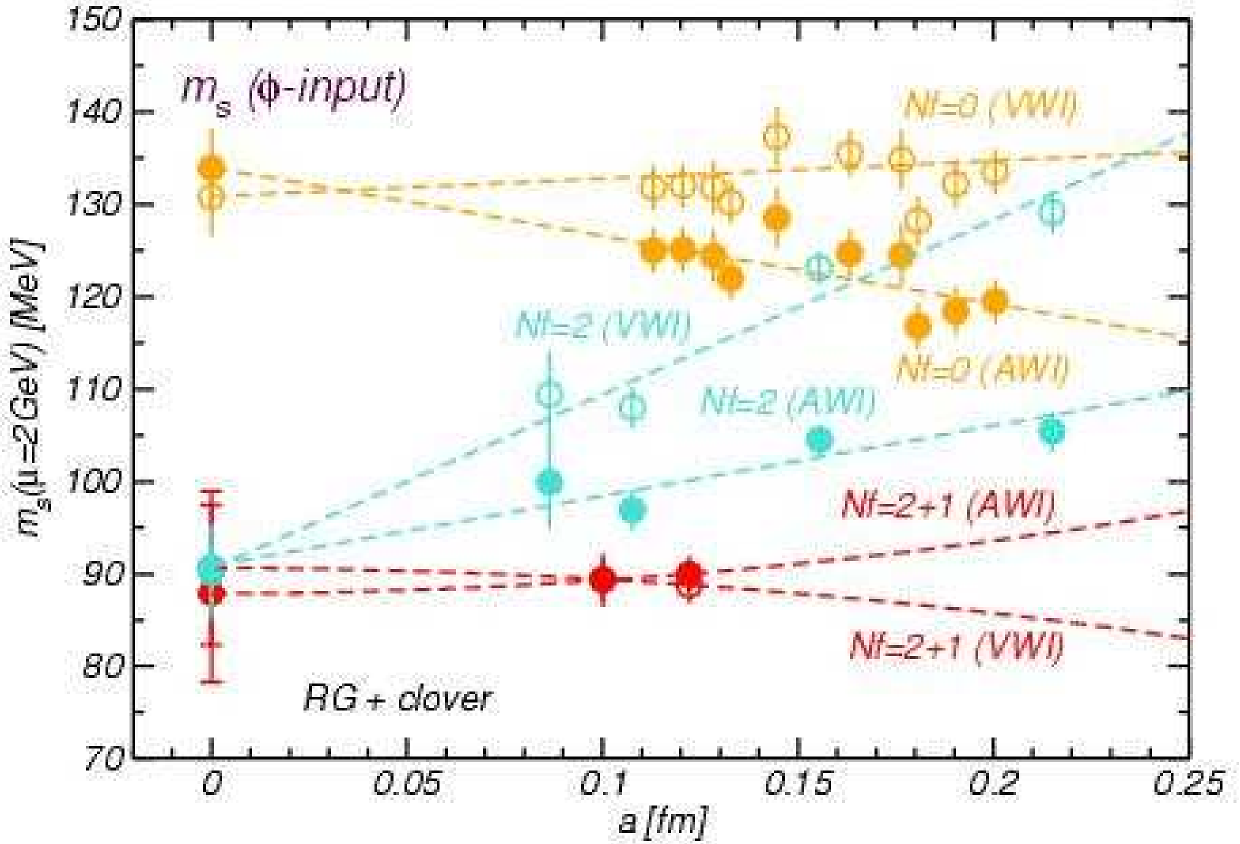
$\mu = 1/a$ evolved to

$\mu = 2GeV$

4-loop perturbation theory

Though error in the continuum limit is still large,

$$m_s^{AWI} = m_s^{VWI} \quad m_s(K) = m_s(\phi)$$

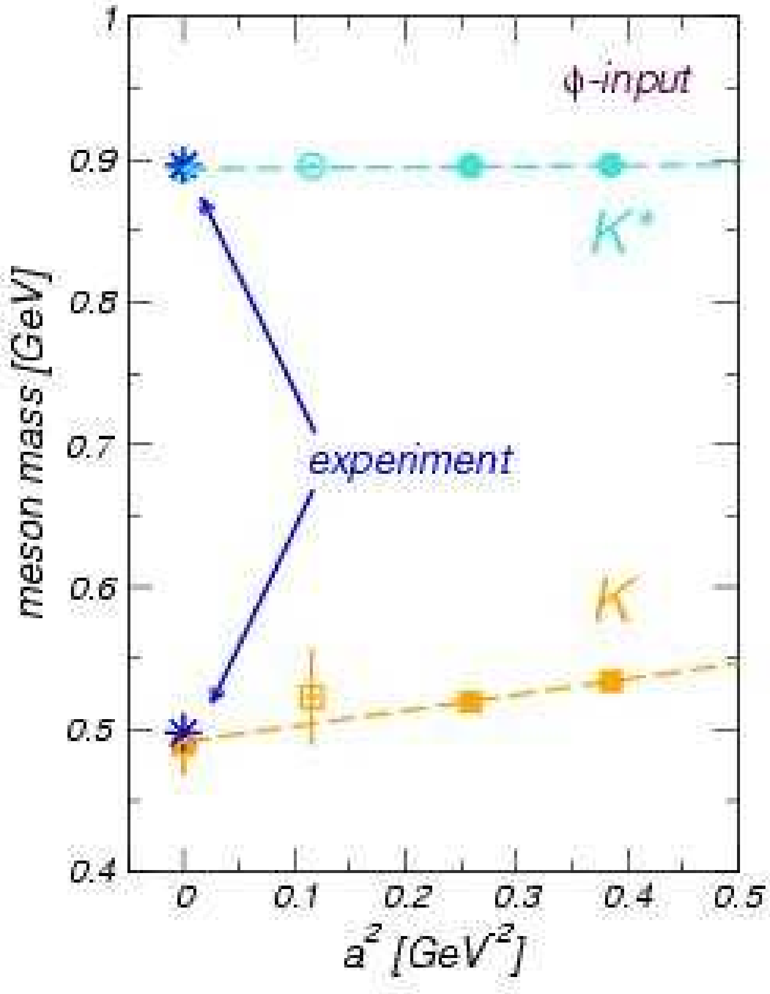


$m_s(N_f = 3) \approx m_s(N_s = 2)$ within large statistical error

Reduce the error to establish dynamical s-quark effect

Summary and Future Works

- Results of the spectrum and quark masses are very promising
  - control systematic errors from continuum extrapolations
  - reduce them with data at a=0.07fm



- Study and control other systematic errors
  1. chiral extrapolation with ChPT, WChPT
  2. non-perturbative calculation of c_A, Z_A, Z_P
  3. finite size effects

     1.6 fm vs. 2.0 fm study @ a=0.1 fm

     at most 1-2% error in La=2fm

- Study and implementation of algorithms
  recently proposed (Hasenbush, SAP) in progress