Light decay constants and kaon semileptonic decays

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USQCD All Hands Meeting
April 20–21, 2023

Outline

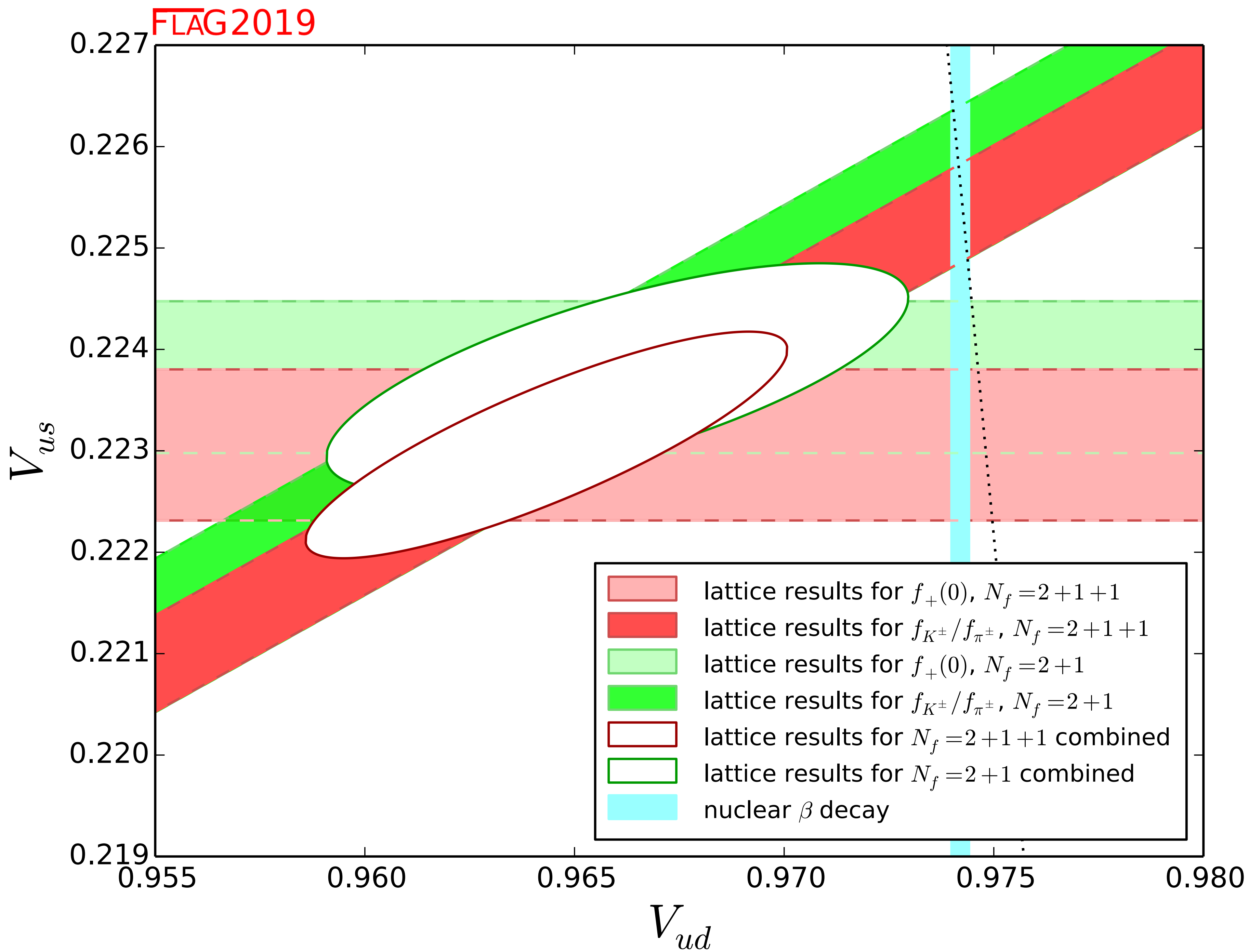
- ✦ Motivation
- ✦ Current Status
- ✦ Proposed Calculations

Motivation

- First row unitarity of CKM matrix
  - Determinations of $|V_{ud}|$ and $|V_{us}|$ exhibit a tension with the unitarity relation.
  - $|V_{ud}|$ can be determined from nuclear β-decay; however, recently theoretical work has changed that value.
  - We would like to increase the precision of $|V_{ud}|$ and $|V_{us}|$ as determined from meson leptonic and semileptonic decays to avoid reliance on nuclear β-decay.
- Low energy constants of chiral perturbation theory
  - Increased precision relies on ensembles with lighter than physical strange quark mass ensembles.
  - SU(3) chiral perturbation theory does not converge very quickly at the physical strange quark mass.
- Improve determination of quark masses

First Row Unitarity (FLAG)

- FLAG2019 results for 2+1 and 2+1+1 flavors
- Dotted line is unitarity
- 2+1 flavors has larger error
- Tension with unitarity has grown for both 2+1 and 2+1+1 since FLAG2016
- Horizontal red band: $|V_{us}| = 0.2231(7)$



First Row Unitarity (FNAL/MILC)

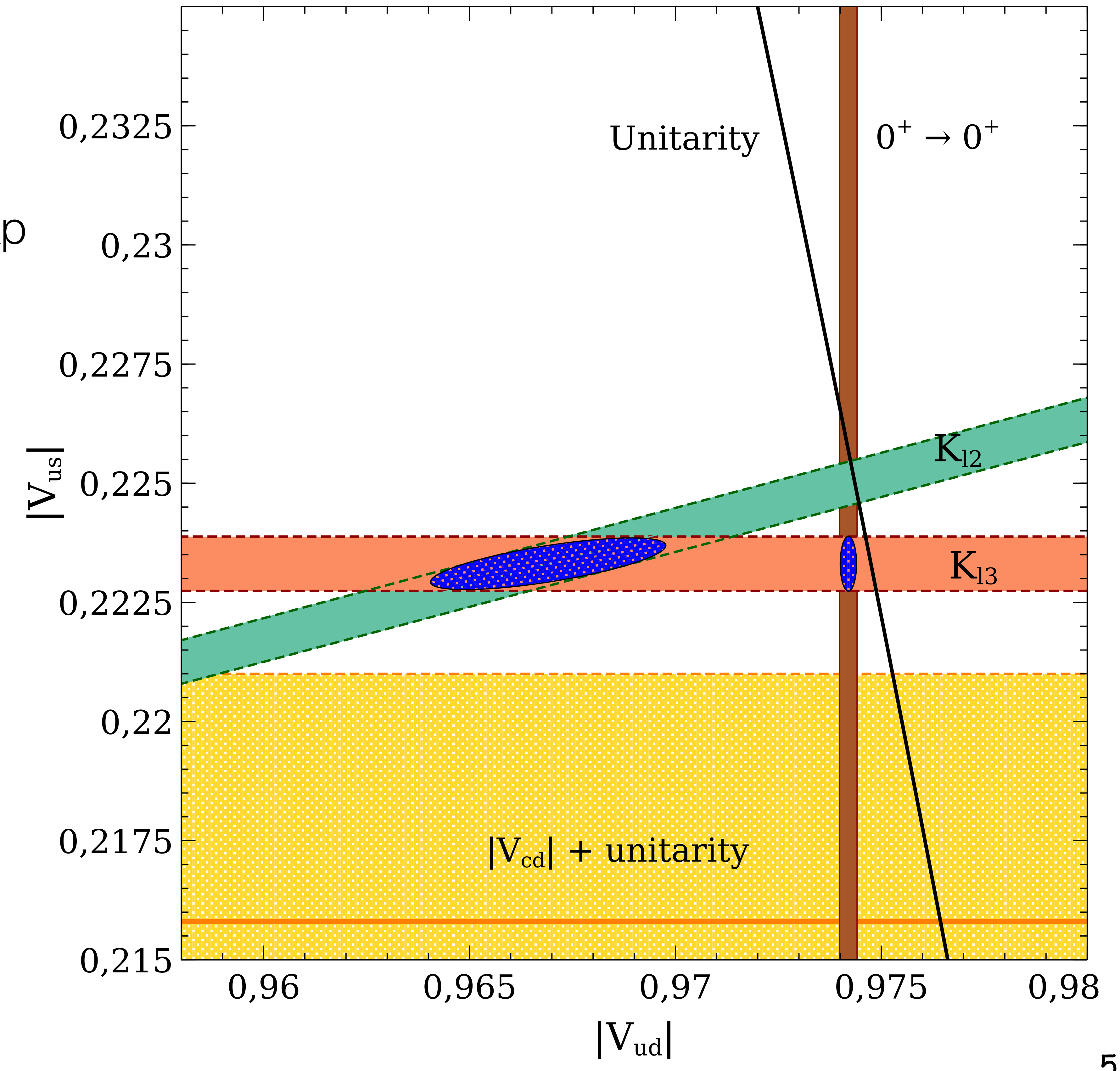
- From our $K_{\ell 3}$study [PRD99, 114509 (2019);arXiv:1809.02827]

$|V_{us}| = 0.22333(44)_{f_+(0)}(42)_{\text{exp}}$

- or

$0.22333(61)$

- Using Hardy & Towner 0.97420(21)
- Seng et al. find 0.97370(14); moving vertical line to left and $K_{\ell 3}$ result further from unitarity.
- $K_{\ell 2}$ result and β-decay close to unitary, …



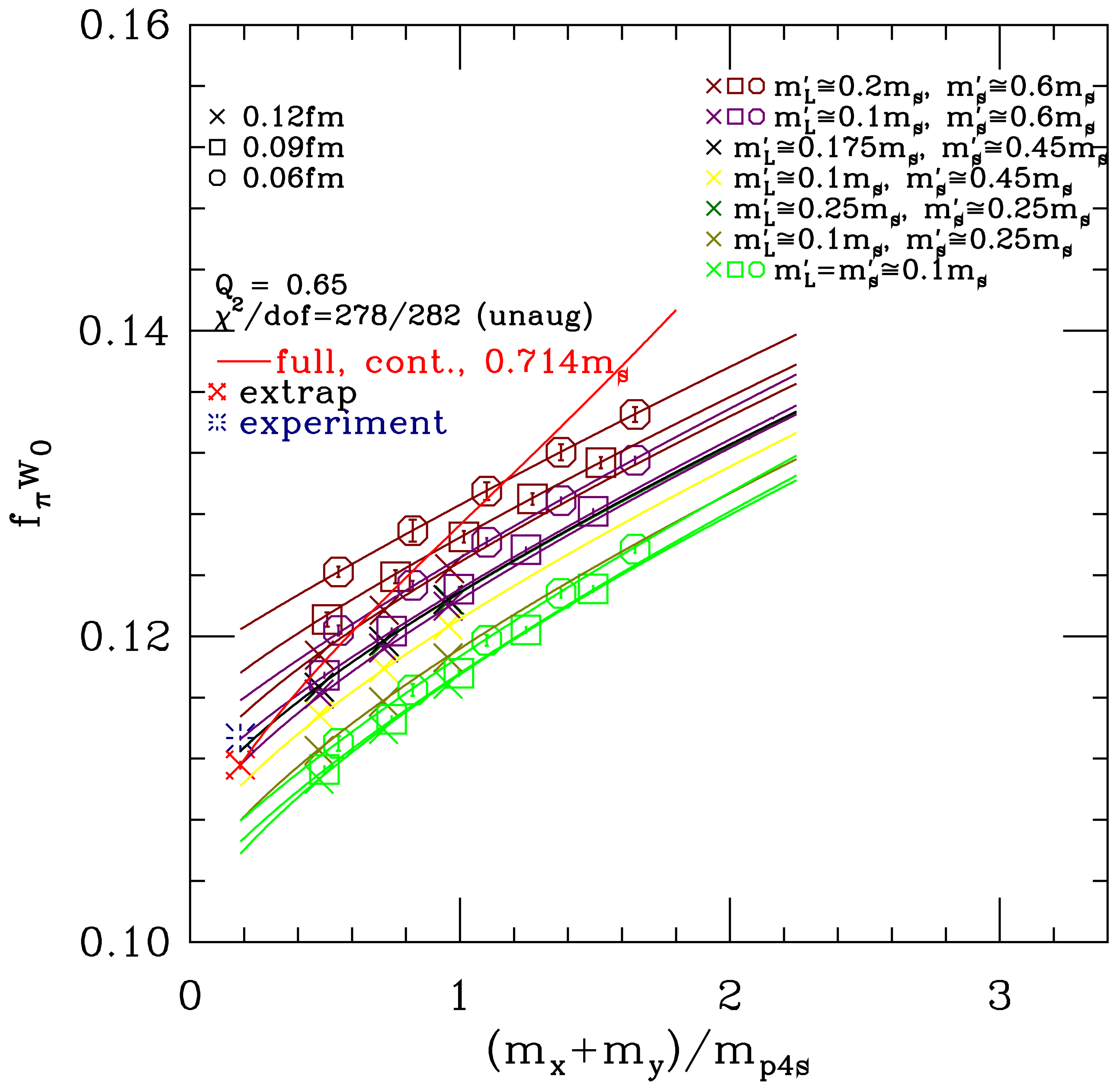
First Row Unitarity Summary

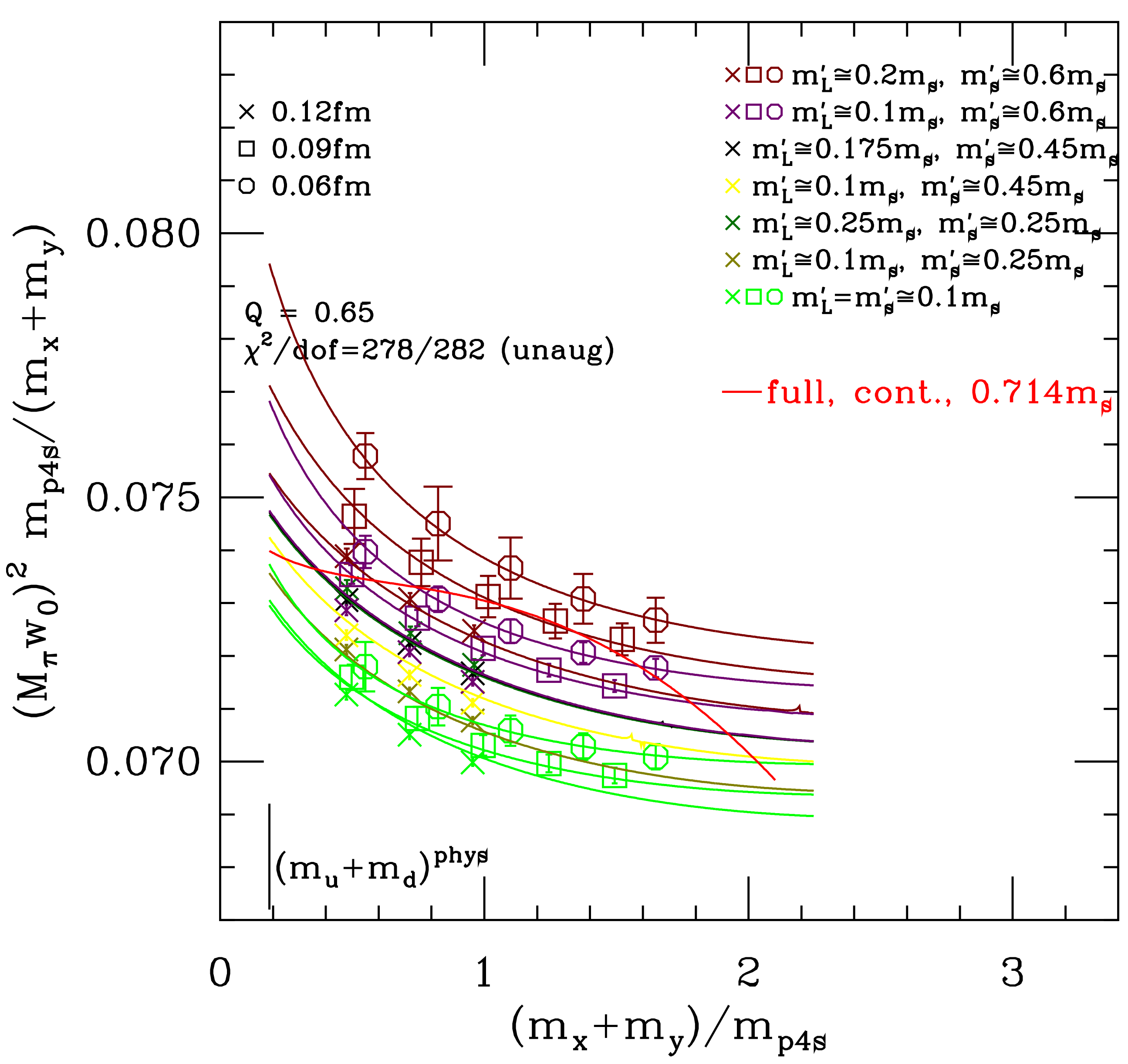
- Using nuclear β-decay and our $K_{\ell 3}$ results, there is about a 3 σ tension with unitarity.
  - However, there have been several recent changes in nuclear β -decay results, and the error is larger than previously thought.
- Using just leptonic and semileptonic meson decays the tension is about 2.4 σ.
  - Need f_K/f_π and $f_+^{K\pi}(q^2=0)$ [see previous slide for reference]
  - We would like to increase the precision in this approach.
  - We have been working on this for several years by adding ensembles with strange quark mass lighter than its physical value.
  - Key issue is improving our control of chiral perturbation theory.

Chiral Perturbation Theory (χPT)

- ✦ SU(3) χPT does not converge very well at the strange quark mass
  - generate "light-strange ensembles" and do a systematic analysis of pseudoscalar masses and decay constants using all NNLO terms in χPT.
  - all chiral logs and LECs are included at that order
  - do controlled fits with ensembles up to strange quark mass, but with LECs constrained by the systematic fits
    - add analytic terms of order N^3LO or N^4LO
  - Need good constraints from the NNLO fits:
    - Previous analysis only had light-strange ensembles with a=0.12 fm.
    - We've added new ensembles with a=0.09, 0.06 fm.
    - These are essential to constrain LECs in continuum limit.
    - These constraints improve the semileptonic K decay analysis.

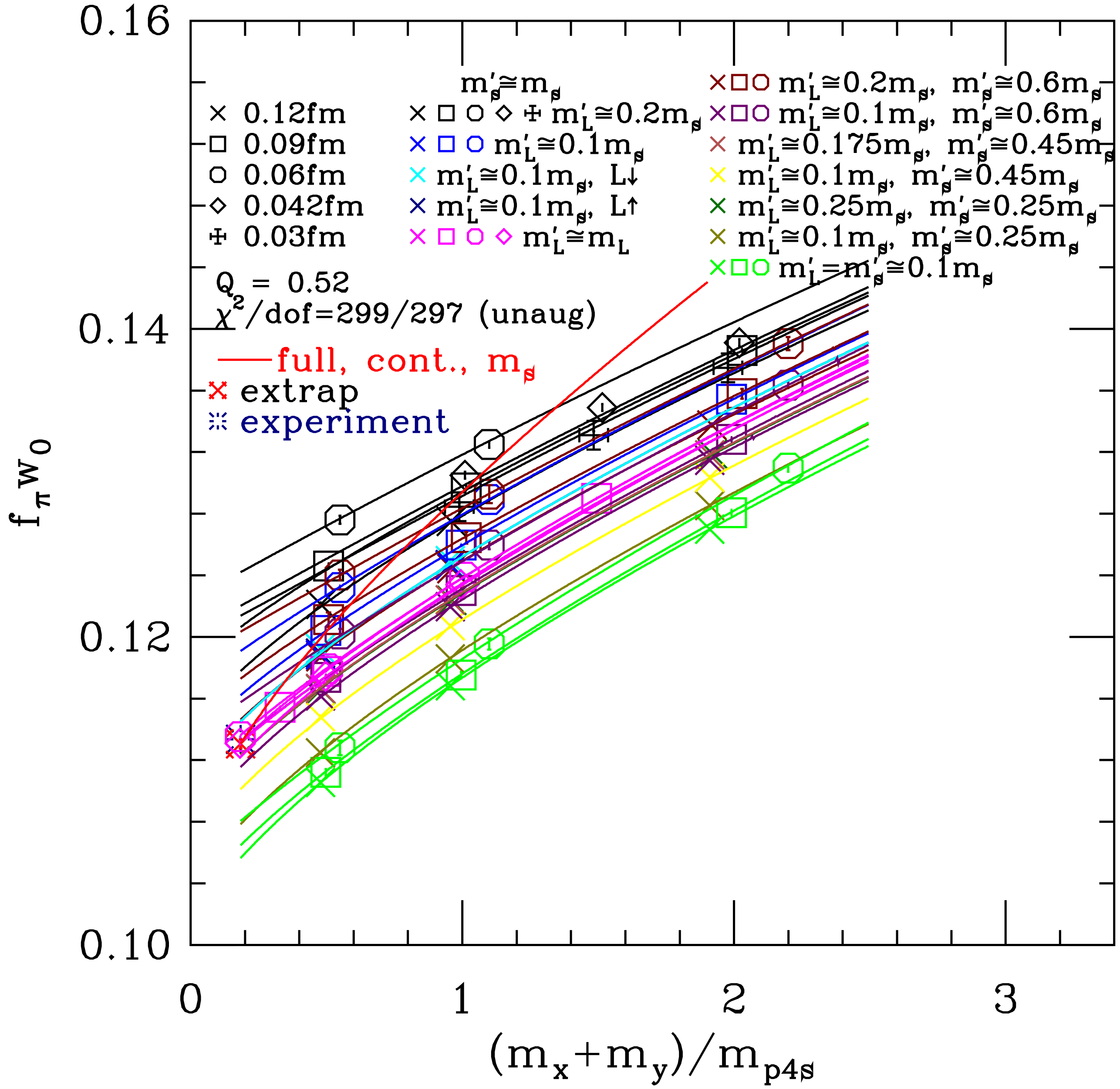
Light m_s Ensembles Fit

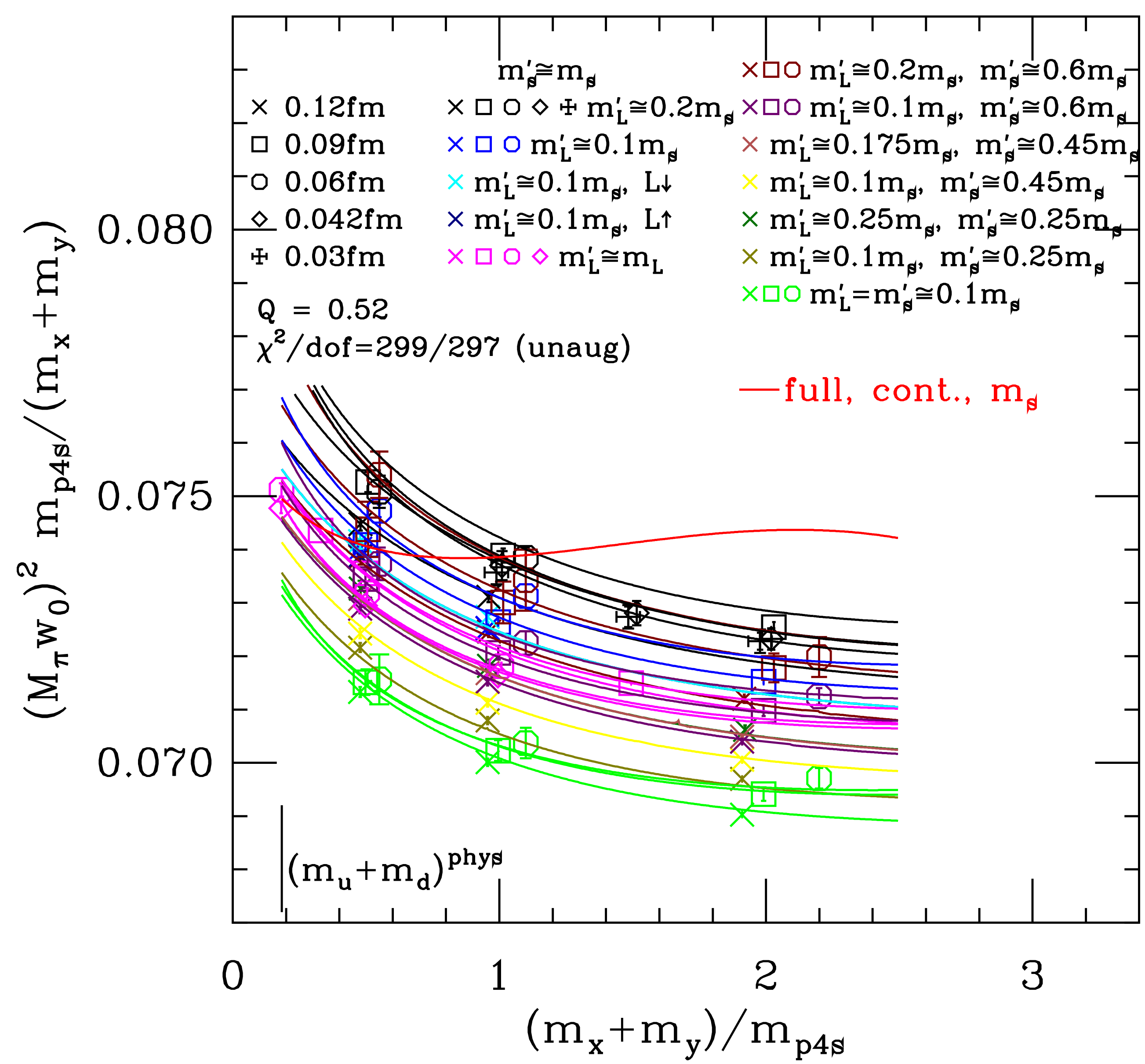




- NNLO (systematic) fit to 0.12, 0.09, 0.06 fm ensembles. Only $m_x = m_y$ points shown. Only $m_x + m_y \leq 0.714 m_s$ data in fit. 330 data points; 48 parameters. Red line is continuum fit, but with reduced strange quark mass.

Adding Physical-m_s Ensembles





- Data with $m_x + m_y \lesssim 1.05 m_s$ included in fit. 434 data points; 137 parameters.
- Not included: physical mass 0.12 fm; lightest valence mass for 0.09 fm physical mass ensemble. Can't get good fits when including them.

Proposed Calculations

- ✦Possible that we are underestimating autocorrelations or discretization effects are too big in the data we do not include.
- ✦We have better tuned physical mass ensembles at 0.12 and 0.09 fm.
  - former was generated for g-2 study and has 10,000 configs.
  - latter was generated by CalLat (1,000 configs.)
- ✦We would like to use these ensembles to analyze decay constants and K semileptonic decay.
  - will only use 1,000 of the 0.12 fm configs.
  - for semileptonic decay will only analyze 500 of 0.09 fm configs with USQCD resources
  - will seek additional time elsewhere to complete ensemble
- ✦Simultaneous fits to leptonic and semileptonic data should further reduce errors and enhance CKM unitarity test.