2+1 flavor DWF QCD and almost physical pion masses

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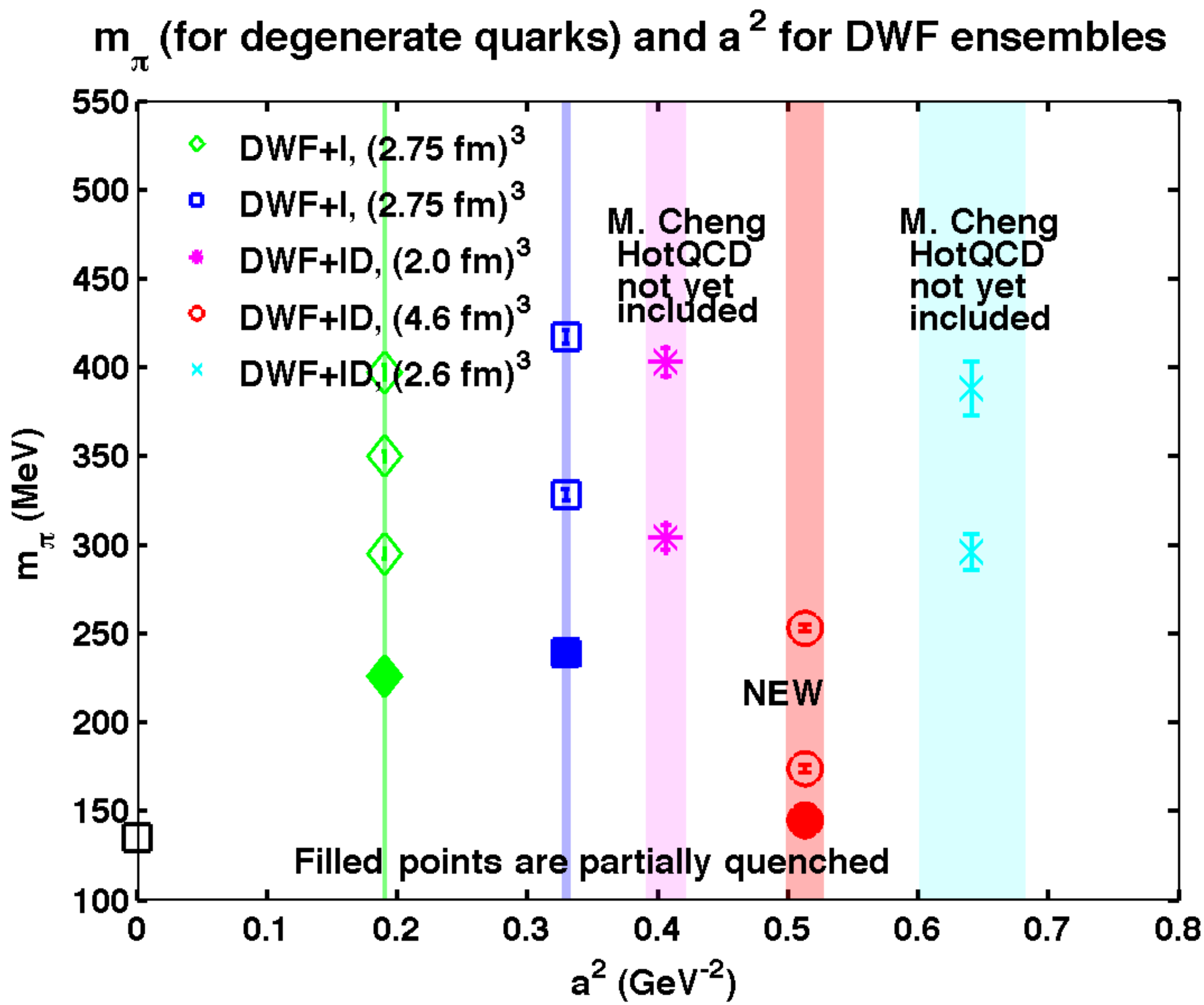
RBC and UKQCD Collaborations

2+1 flavor DWF Ensembles

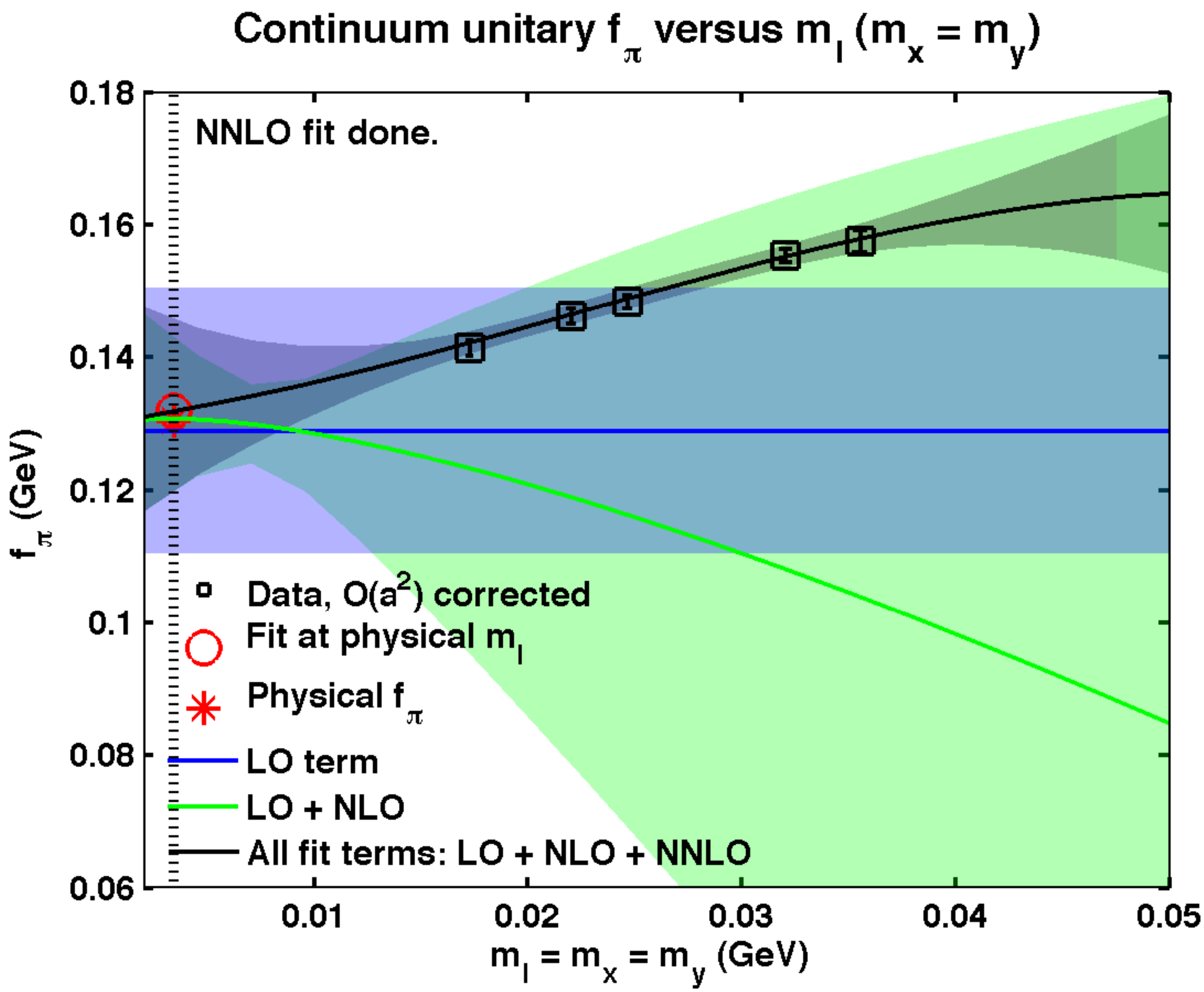


- DWF+I = DWF fermions with the Iwasaki gauge action (Detailed results in talk by Chris Kelly)
- DWF+ID = DWF fermions and the Iwasaki/Dislocation Suppressing Determinant Ratio gauge action

DWF+I results - 2010

- NLO SU(2) ChPT fits, including $O(a^2)$ corrections to LO constants
- Fits reweight/interpolate in m_s to achieve self-consistent value
- Use known m_π, m_K and m_Ω to set scale, m_{ud} and m_s
- 2 lattice spacings, assume $O(a^2)$ scaling
  - $O(a^2)$ corrections are percent level
- 5-8% ChPT errors expected from behavior of series for $m_\pi \sim 300$ MeV
  - For f_π, where we have data, NLO corrections are 20-30% of LO
- Estimated ChPT errors consistent with disagreement with experiment
- Many observables measured:
  - f_π, f_K, B_K, Kl3, nucleons, E&M splittings ...
  - Larger volumes than the $(2.75\text{ fm})^3$ here are needed
- Chiral extrapolation is dominant error

DWF+I results (Lattice 2009) with NNLO



- Uncorrelated, least squares fit with no inputs besides lattice data and physical values for m_π, m_K and m_Ω

DWF+ID

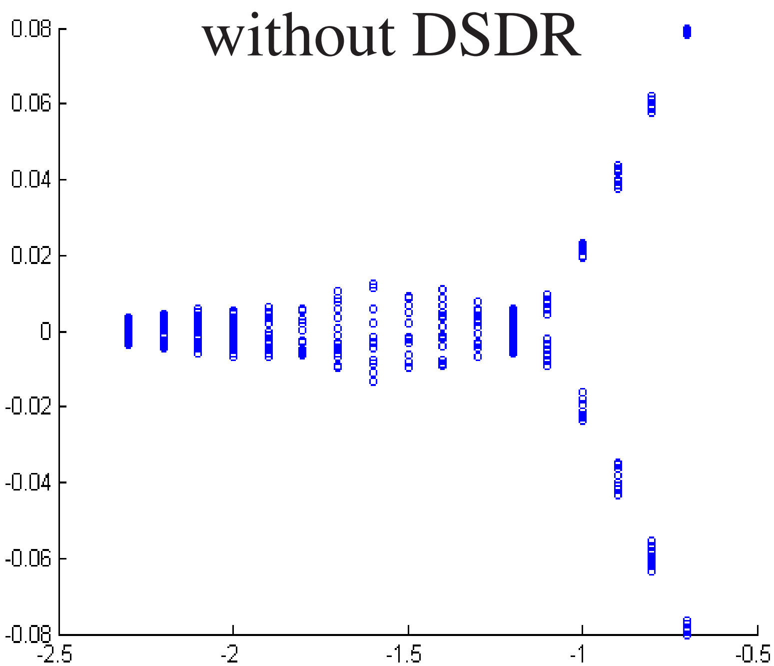
- Working on coarser lattices allows small m_π and large volumes
  - Direct calculation of K–>ππ weak matrix elements
  - Nucleon observables
- Residual mass for DWF grows rapidly as β decreases
- Add a 2 flavor Wilson determinant to control m_{res}

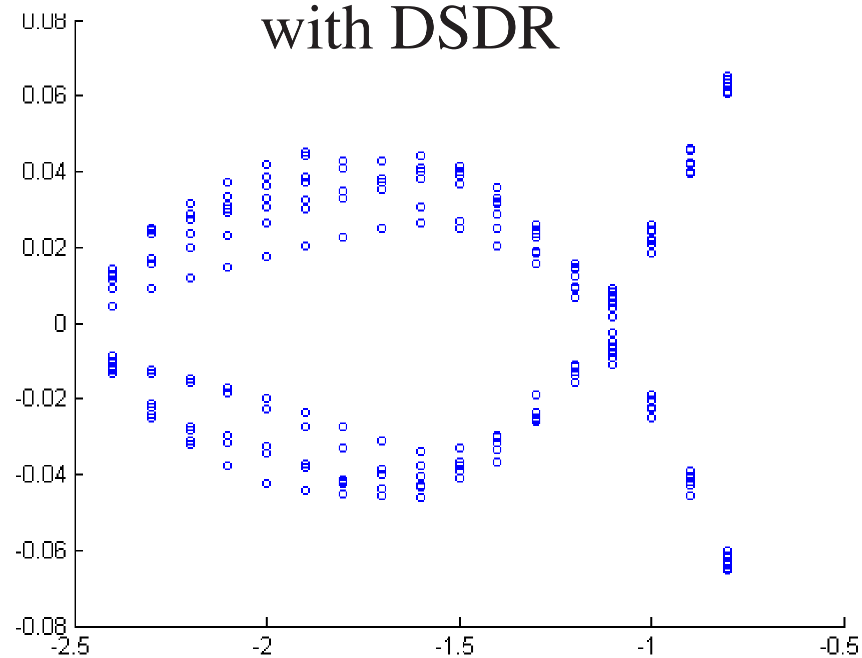
$$\mathscr{W}(M,\varepsilon_f,\varepsilon_b) = \frac{\det[D_{\mathscr{W}}(-M+\imath\varepsilon_b\gamma^5)^\dagger D_{\mathscr{W}}(-M+\imath\varepsilon_b\gamma^5)]}{\det[D_{\mathscr{W}}(-M+\imath\varepsilon_f\gamma^5)^\dagger D_{\mathscr{W}}(-M+\imath\varepsilon_f\gamma^5)]}$$

$$= \frac{\det[D_{\mathscr{W}}(-M)^\dagger D_{\mathscr{W}}(-M)]+\varepsilon_f^2}{\det[D_{\mathscr{W}}(-M)^\dagger D_{\mathscr{W}}(-M)]+\varepsilon_b^2} = \prod_i \frac{\lambda_i^2+\varepsilon_f^2}{\lambda_i^2+\varepsilon_b^2}$$

- M = 1.8, far from M_c for Wilson fermions
  - Implies λ_i small only for non-continuum configurations
  - Example: configuration where topology is changing

DWF+ID



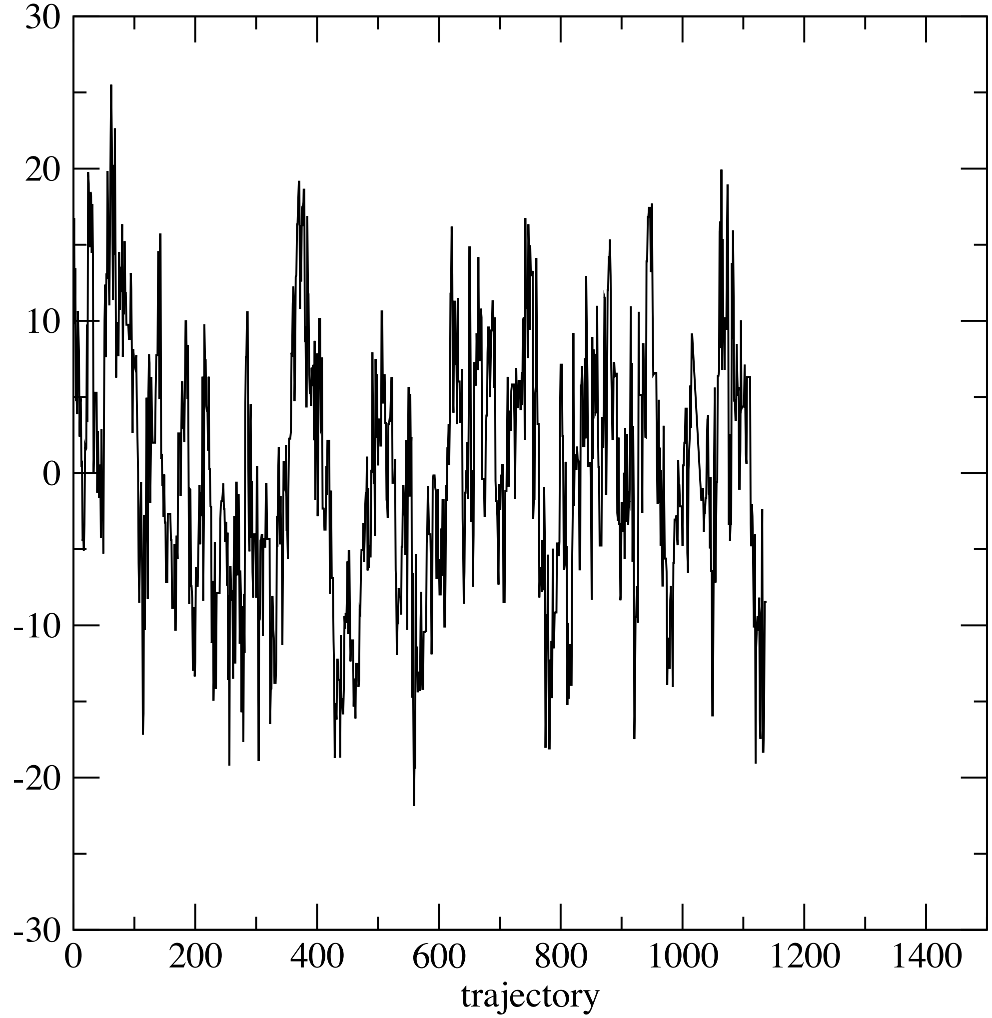


- Measuring 12 smallest eigenvalues of $D_{wil}(m_5)$ without DSDR (left) and with (right) shows change in ϱ(0) (arXiv:0902.2587)
  - β changed to keep lattice scale similar
- Tune ε_f and ε_b to make m_{res} small and still allow topological tunneling
  - For 1/a ~ 1.4 GeV, we use $\varepsilon_f = 0.02$ and $\varepsilon_b = 0.5$

DWF+ID Ensembles

- $32^3 \times 64 \times 32$, $\beta = 1.75$, $M_5 = 1.8$, $\varepsilon_f = 0.02$, $\varepsilon_b = 0.5$
- Multilevel RHMC with Hasenbusch preconditioning
- $m_{res} = 0.00187$ –> 3 to 4 MeV, after renormalizing to MS-bar
- Two dynamical mass choices (m_l, m_h)
  - (0.0001 + mres, 0.045 + mres) –> $m_\pi \sim 180$ MeV
  - (0.001 + mres, 0.045 + mres) –> $m_\pi \sim 250$ MeV
- Valence mass give $m_\pi \sim 150, 180, 250, 320$ MeV
- ~50 measurements on 180 MeV ensemble (only 30 used here)
- ~150 measurements on 250 MeV ensemble (only 120 used here)

Topology for 250 MeV DWF+ID Ensemble



Topology moving quite well, as expected at strong coupling

Fitting DWF+I and DWF+ID together

- With two lattice spacings for DWF+I, fit to NLO SU(2) ChPT
- Include different O(a^2) corrections to LO LEC's for different actions
- Formula for f_{ll} is

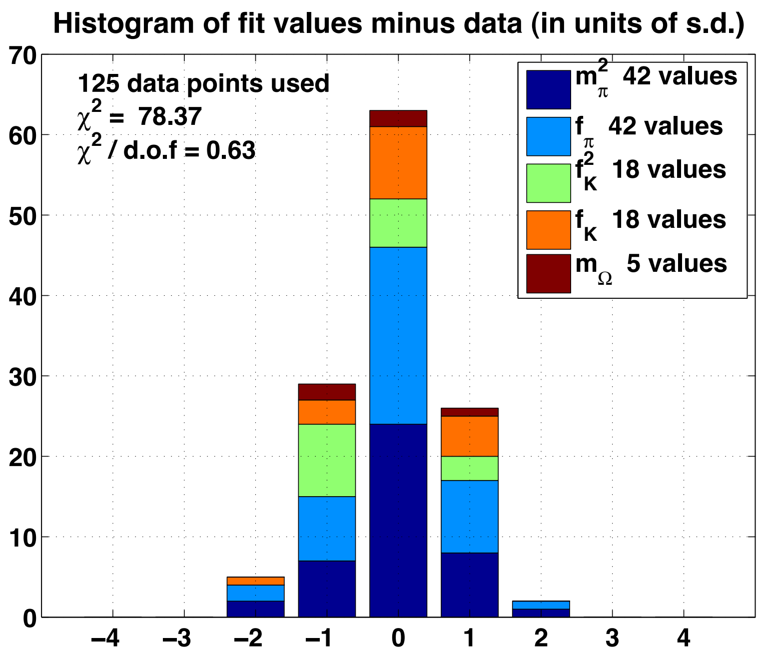
$$f_{ll} = f_0 \left[1 + c_{f_0} a^2\right] + f_0 \cdot \left\{ \frac{24}{f_0^2} L_4^{(3)} \bar{\chi} + \frac{8}{f_0^2} L_5^{(3)} \chi_l - \frac{1}{16\pi^2 f_0^2} \left[\frac{\chi_l + \chi_h}{2} \log \frac{\chi_l + \chi_h}{2\Lambda_\chi^2} + 2\chi_l \log \frac{\chi_l}{\Lambda_\chi^2} \right] \right\},$$

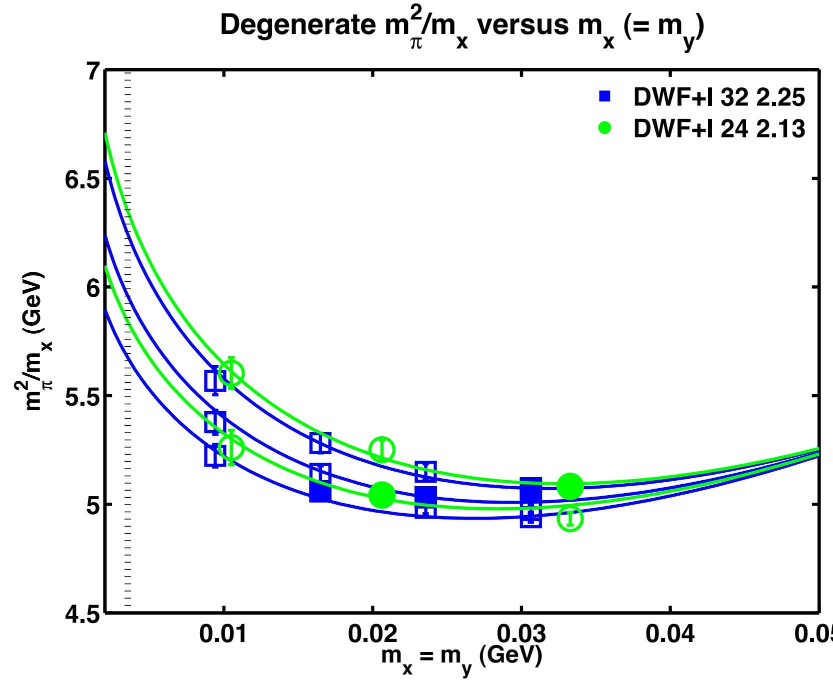
- To add in DWF+ID, just need a new O(a^2) coefficient
- Chiral expansions for m_π^2 and f_π done in terms of chiral limit f_0
- All expansions use lattice quark mass as expansion parameter
  - Fits give relative normalization of quarks between ensembles
- All quark masses on plots are renormalized to MS-bar at 2 GeV
  - Conversion to MS-bar done via NPR from one ensemble

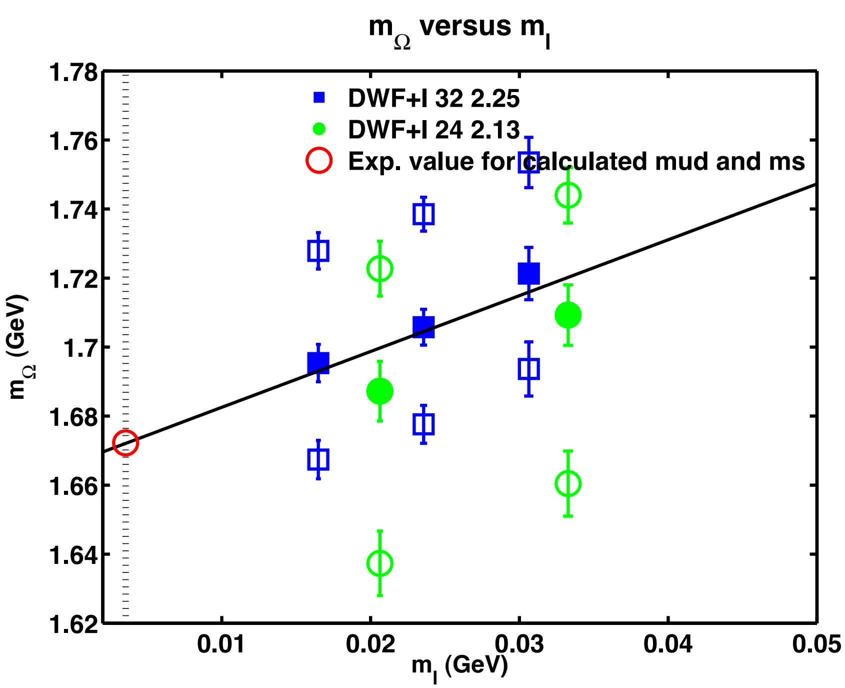
Parameters in DWF+I and DWF+ID Global Fits

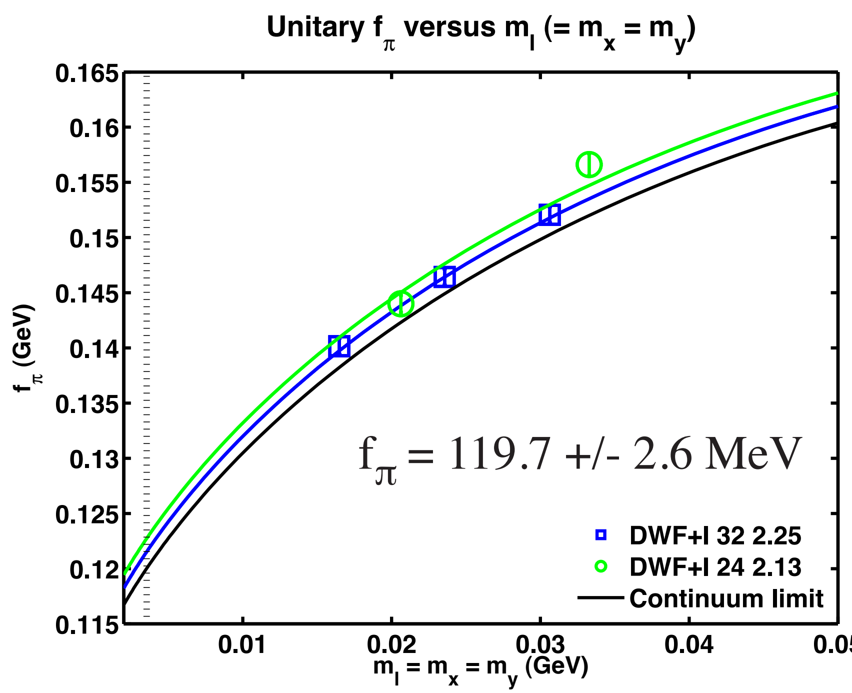
- Simultaneous fit to m_π^2, m_K^2, f_π, f_K, and m_Ω
- m_π, m_K and m_Ω chosen to be quantities without $O(a^2)$ corrections
- Parameters in SU(2) chiral expansion:
  - m_π^2 and f_π: 8 parameters – 2 LO, 4 NLO, 2O(a^2)
  - m_K^2 and f_K: 6 parameters – 2 LO, 4 NLO, 2O(a^2)
  - m_Ω: 1 LO, 1 NLO
  - Total: 18 parameters
- Fits also determine
  - 3 lattice spacings
  - 2 ratios of light quark mass renormalization factors
  - 2 ratios of strange quark mass renormalization factors
  - m_s

Fitting DWF+I: NLO SU(2) ChPT, w/o FV









Fitting DWF+I and DWF+ID together: legend

- DWF+I
- $m_\pi < 420$ MeV

→

- DWF+I and DWF+ID
- $m_\pi < 420$ MeV

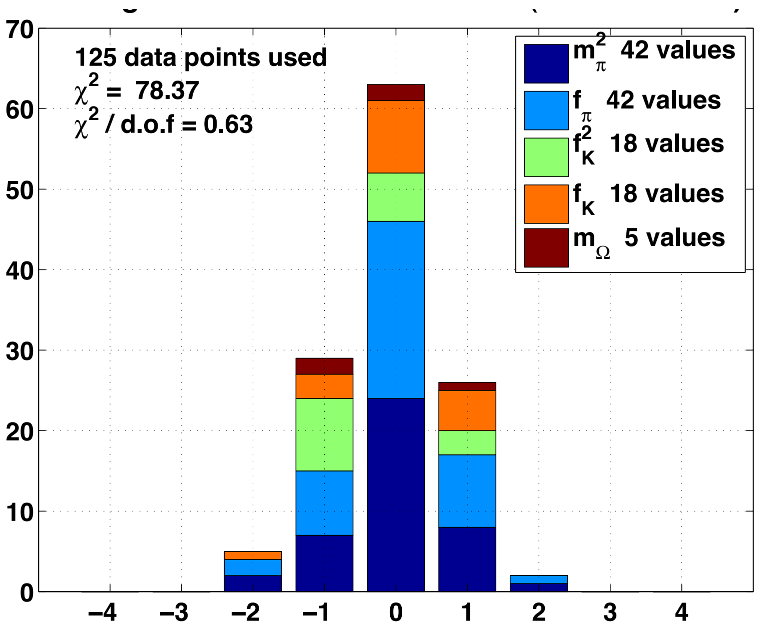
↙

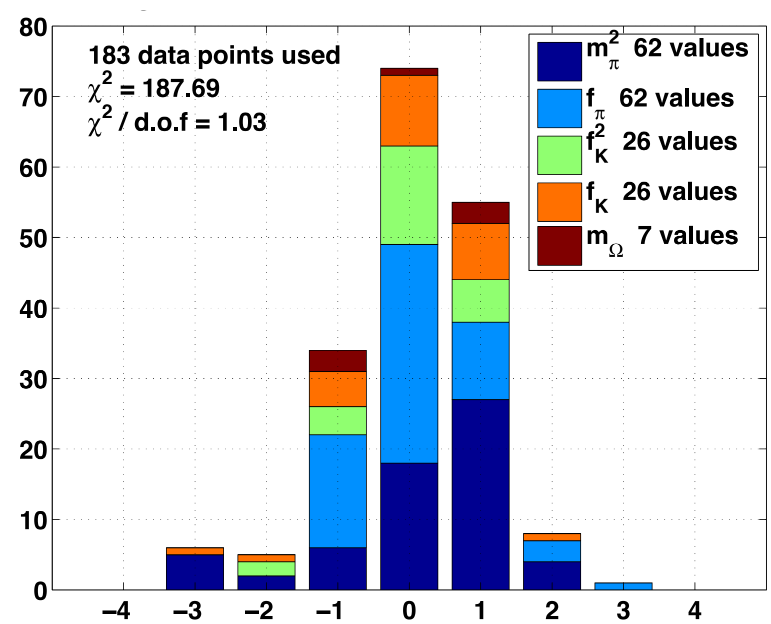
- DWF+ID and DWF+ID
- Only use ensembles with $m_\pi < 380$ MeV ($m_l < 30$ MeV)
- valence $m_\pi < 420$ MeV

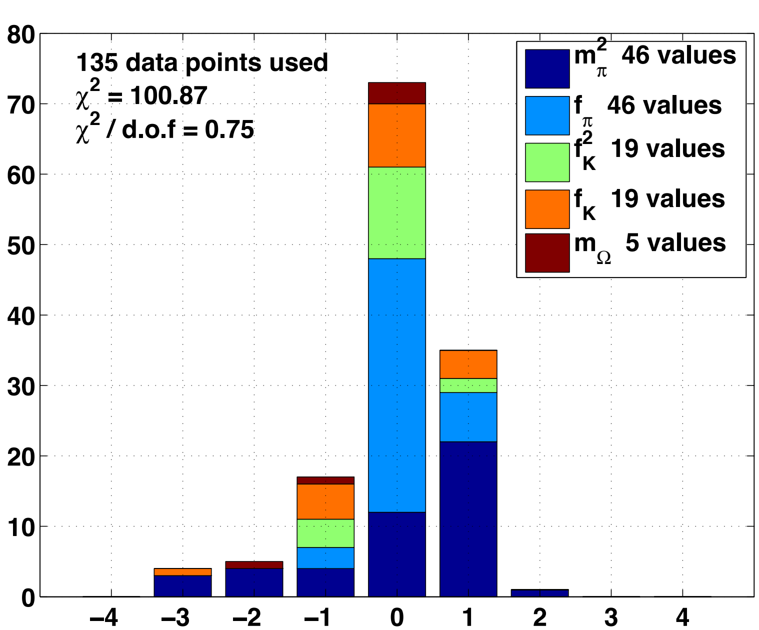
→

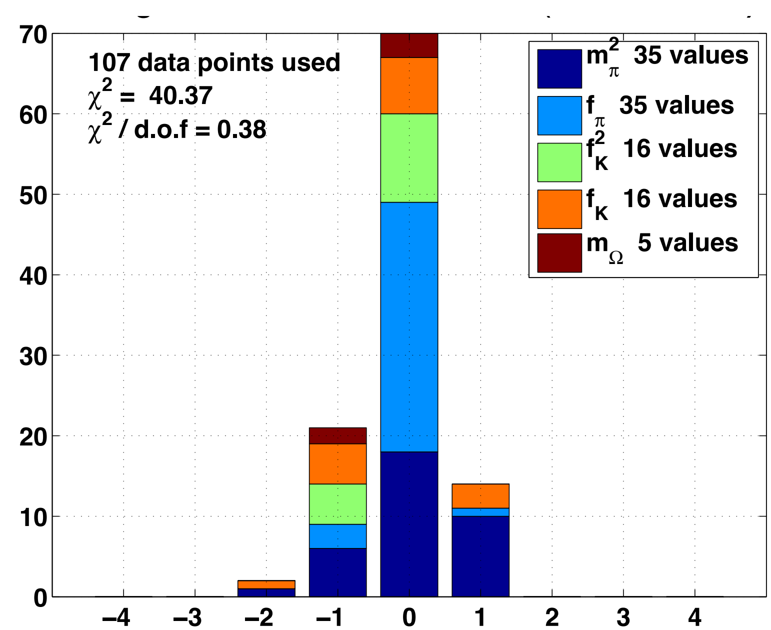
- DWF+ID and DWF+ID
- Only use ensembles with $m_\pi < 380$ MeV ($m_l < 30$ MeV)
- Valence $m_\pi < 380$ MeV

DWF+I and DWF+ID together: χ^2

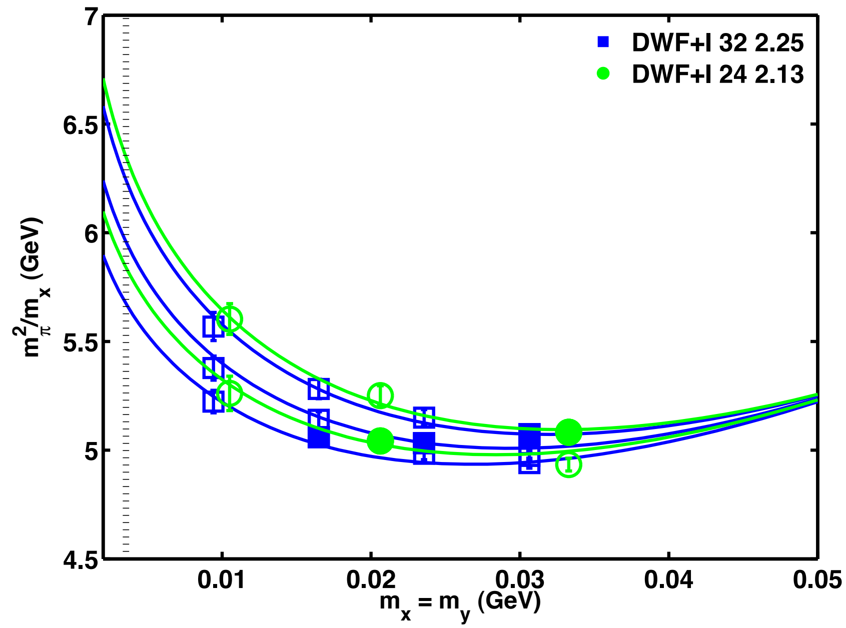


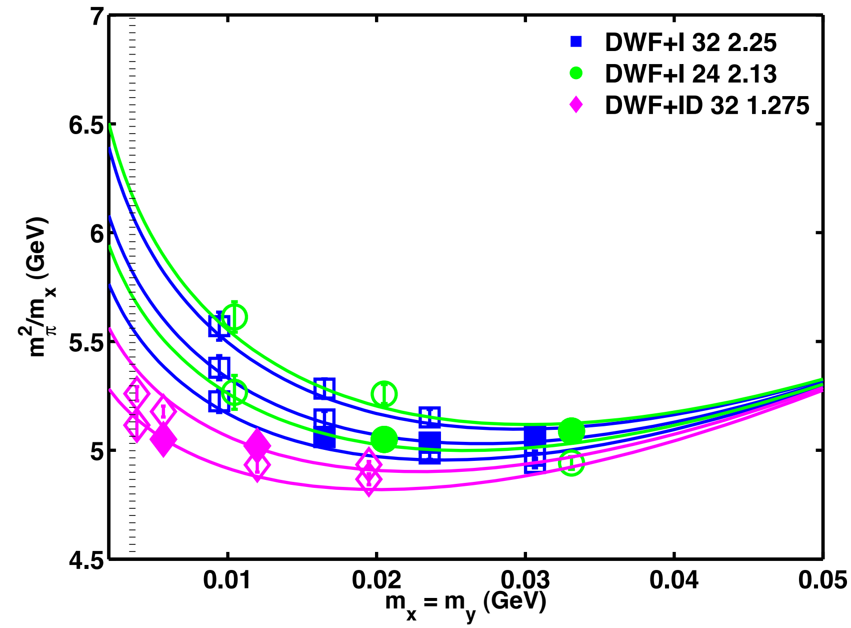


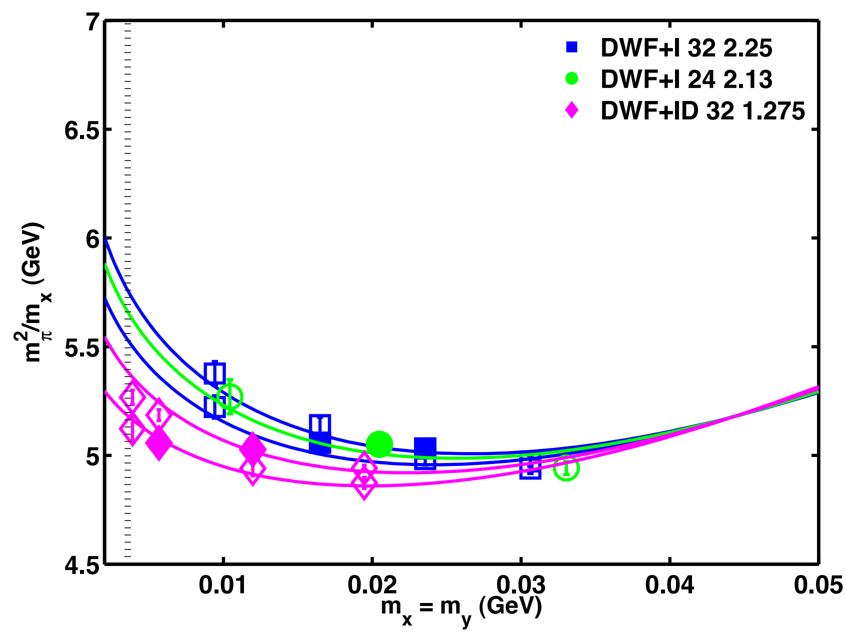


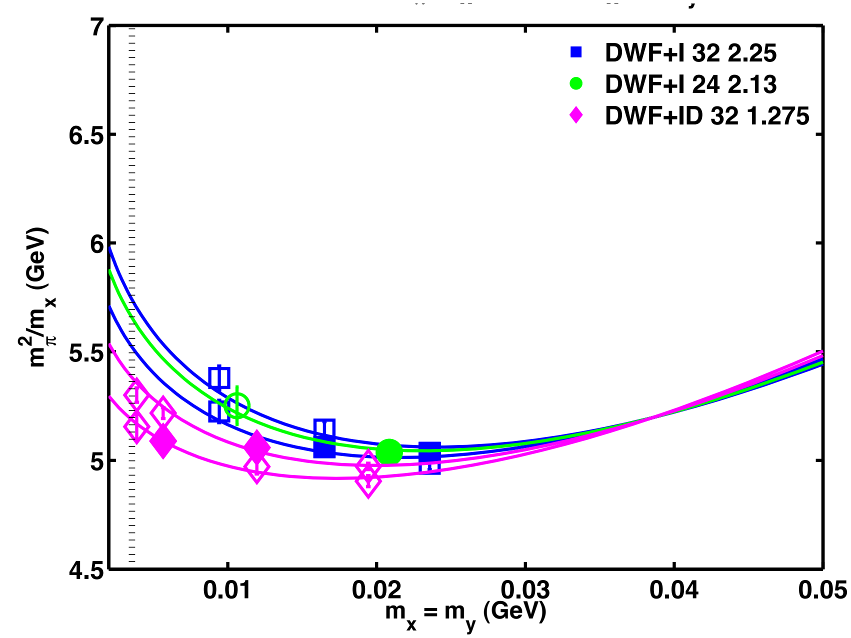


DWF+I and DWF+ID: degenerate m_π^2

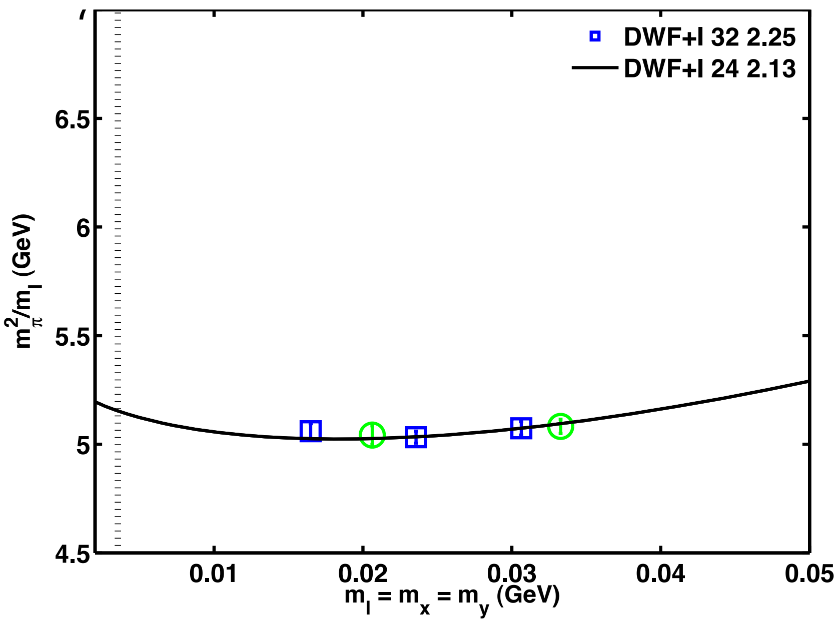


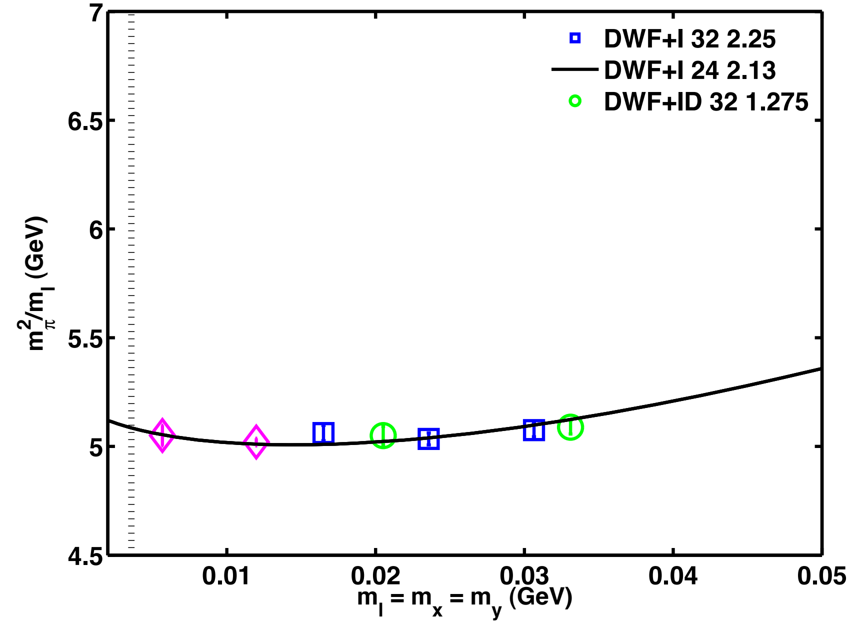


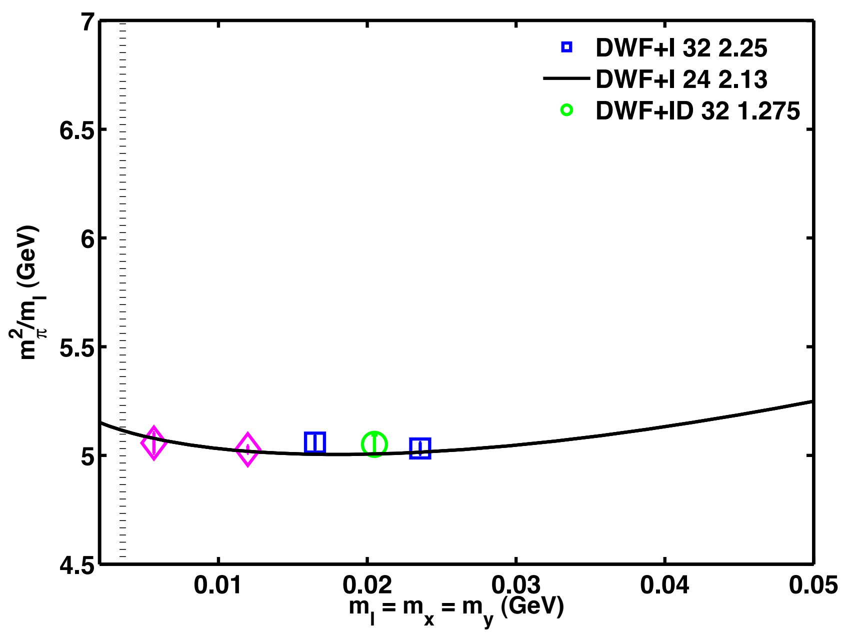


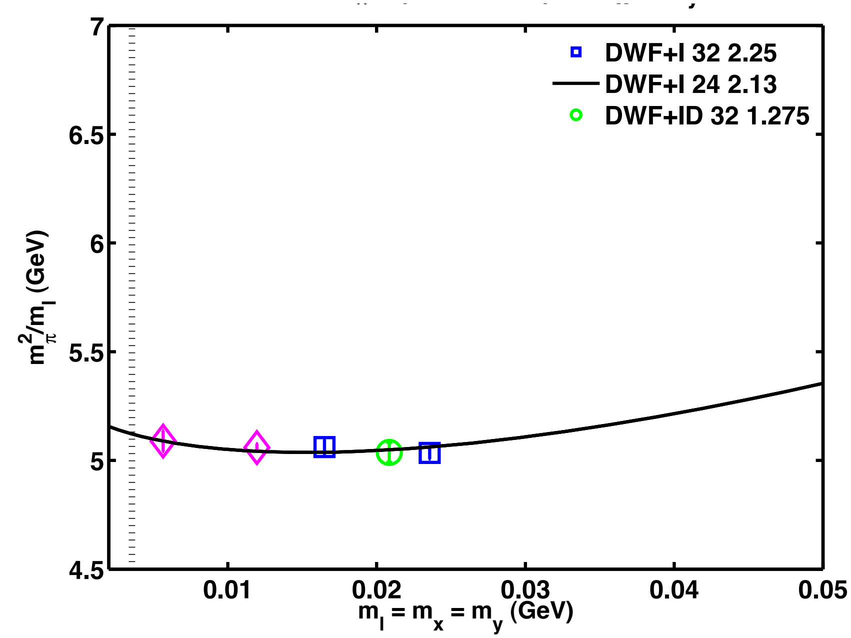


DWF+I and DWF+ID together: unitary m_π^2

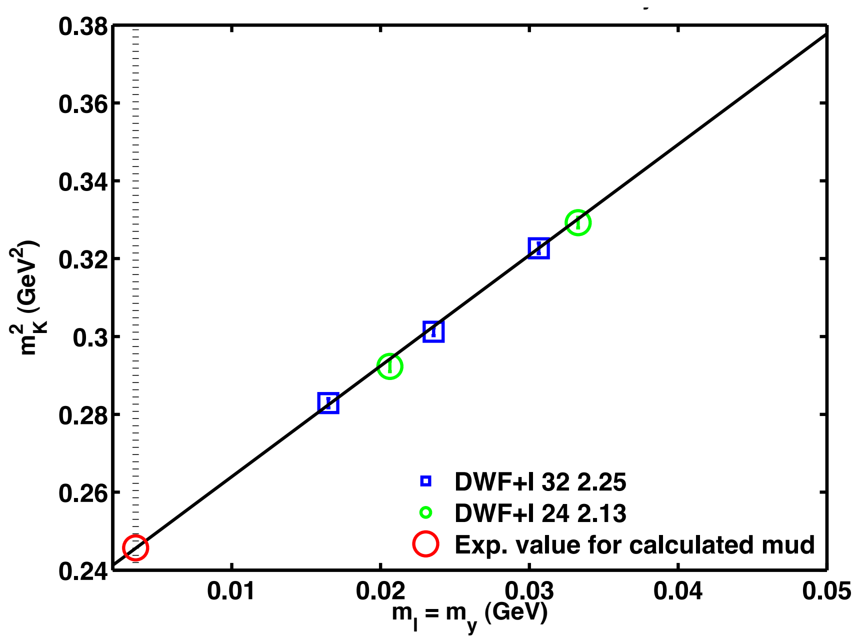


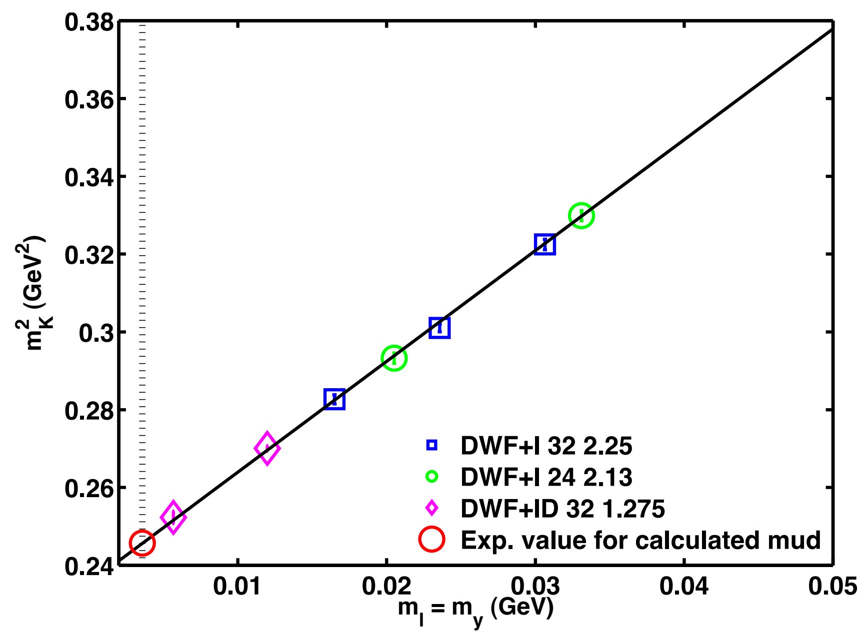


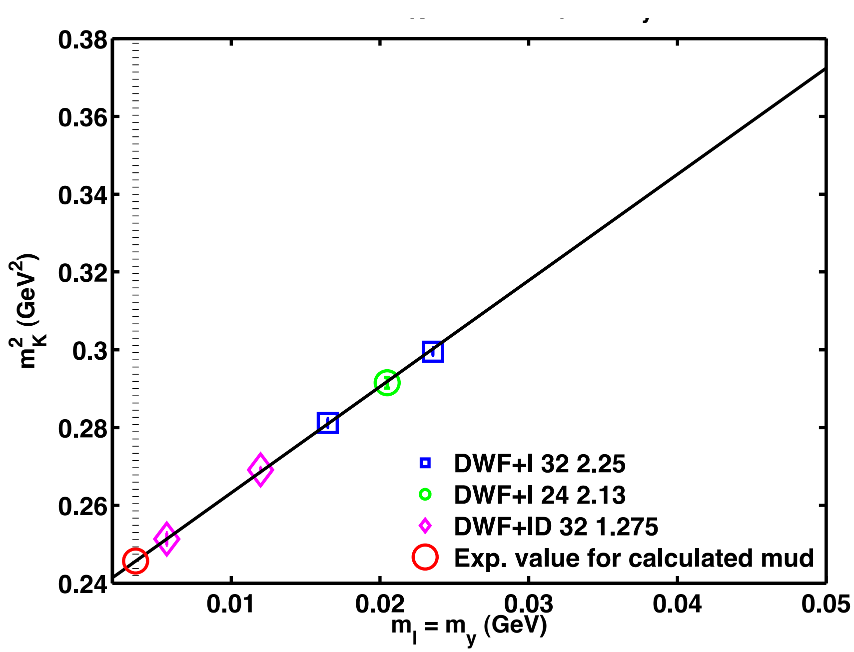


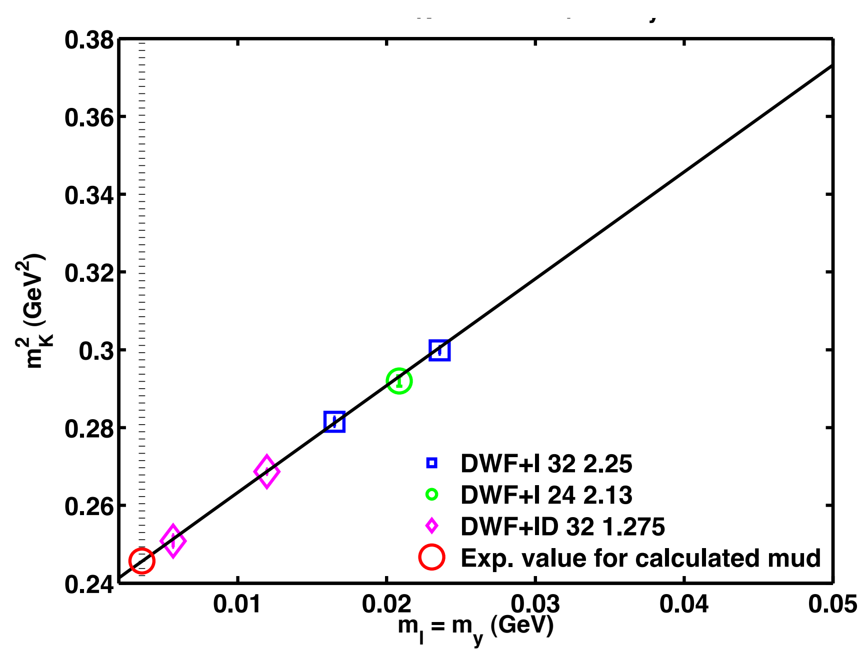


DWF+I and DWF+ID together: unitary m_K^2

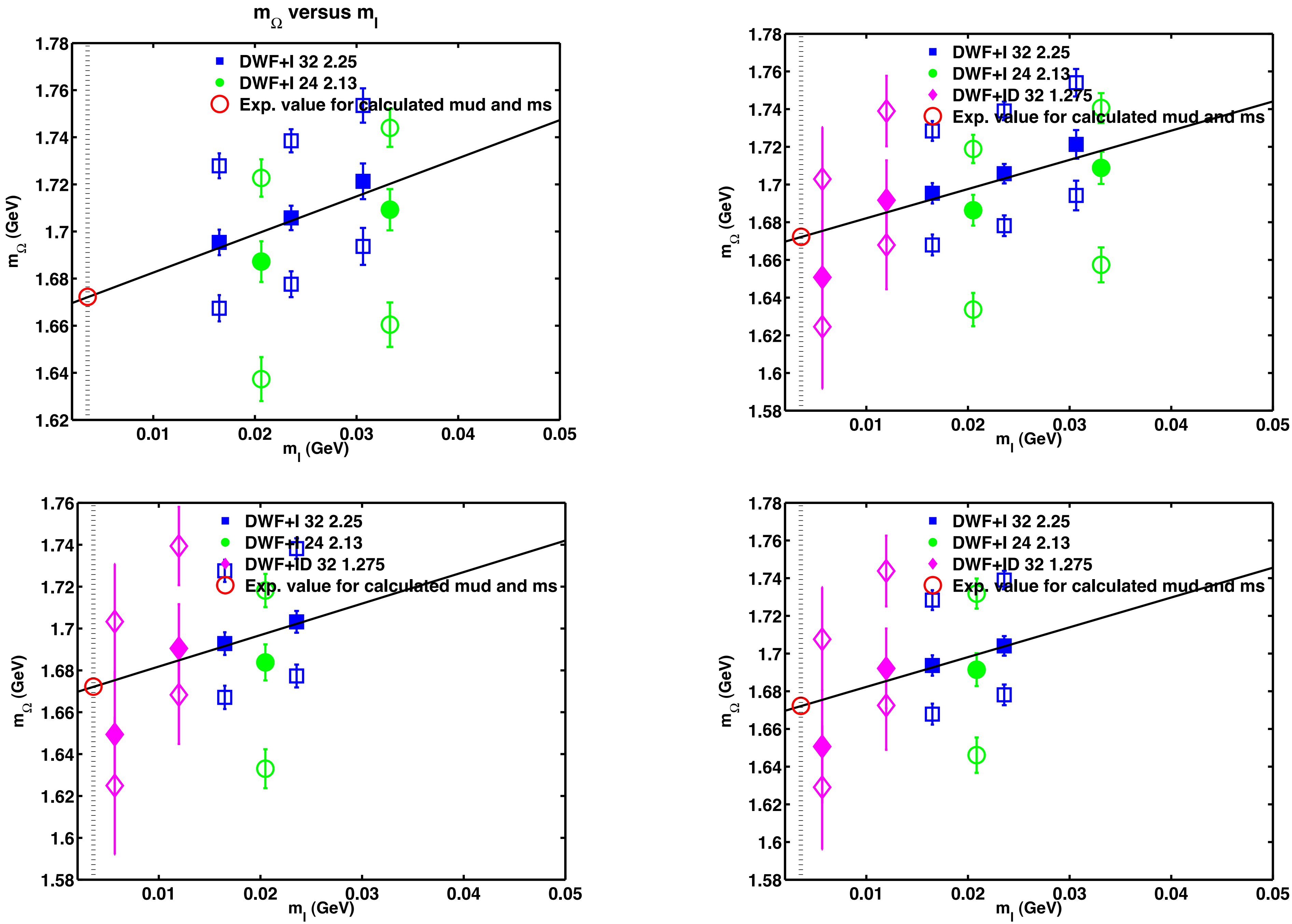




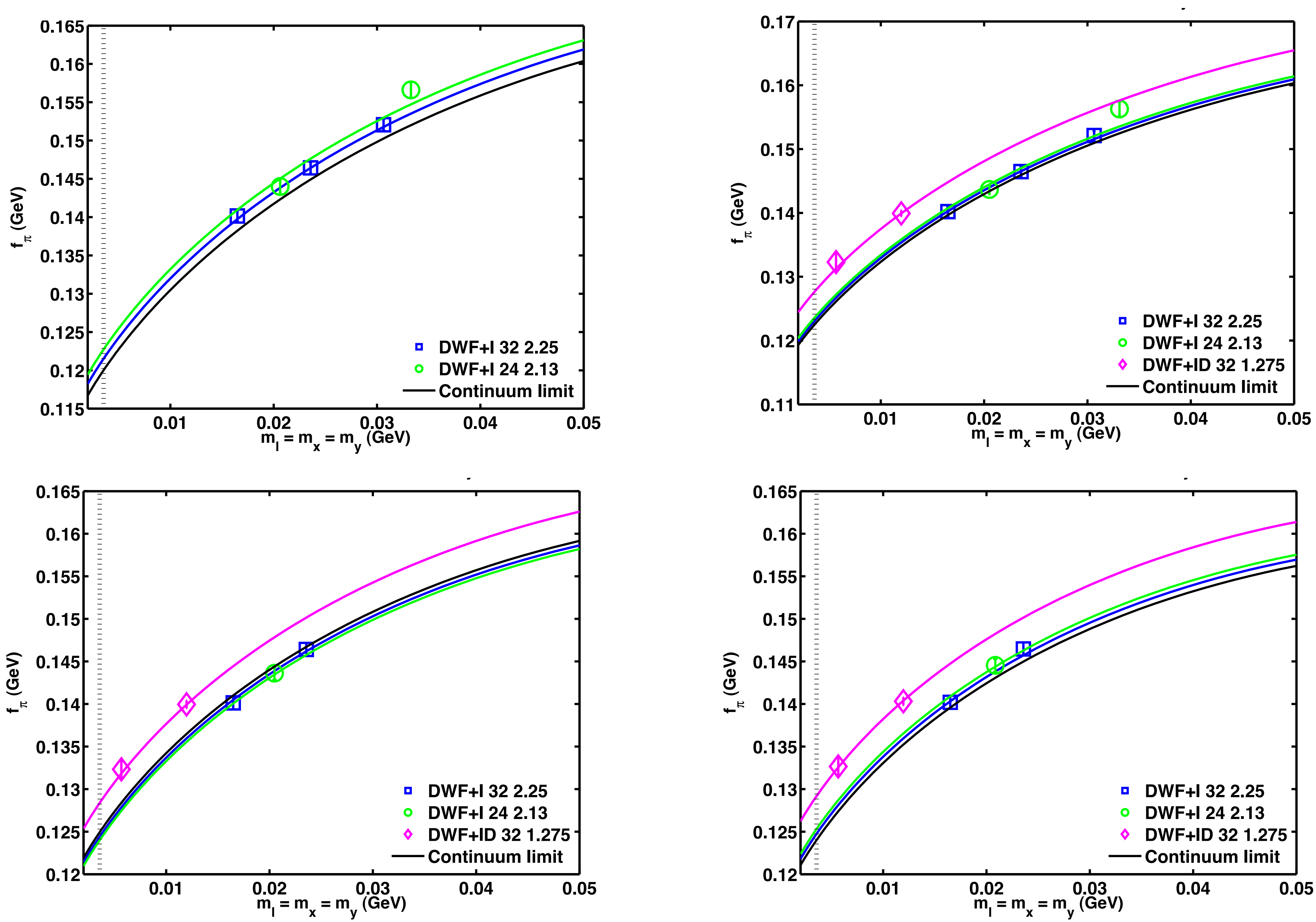




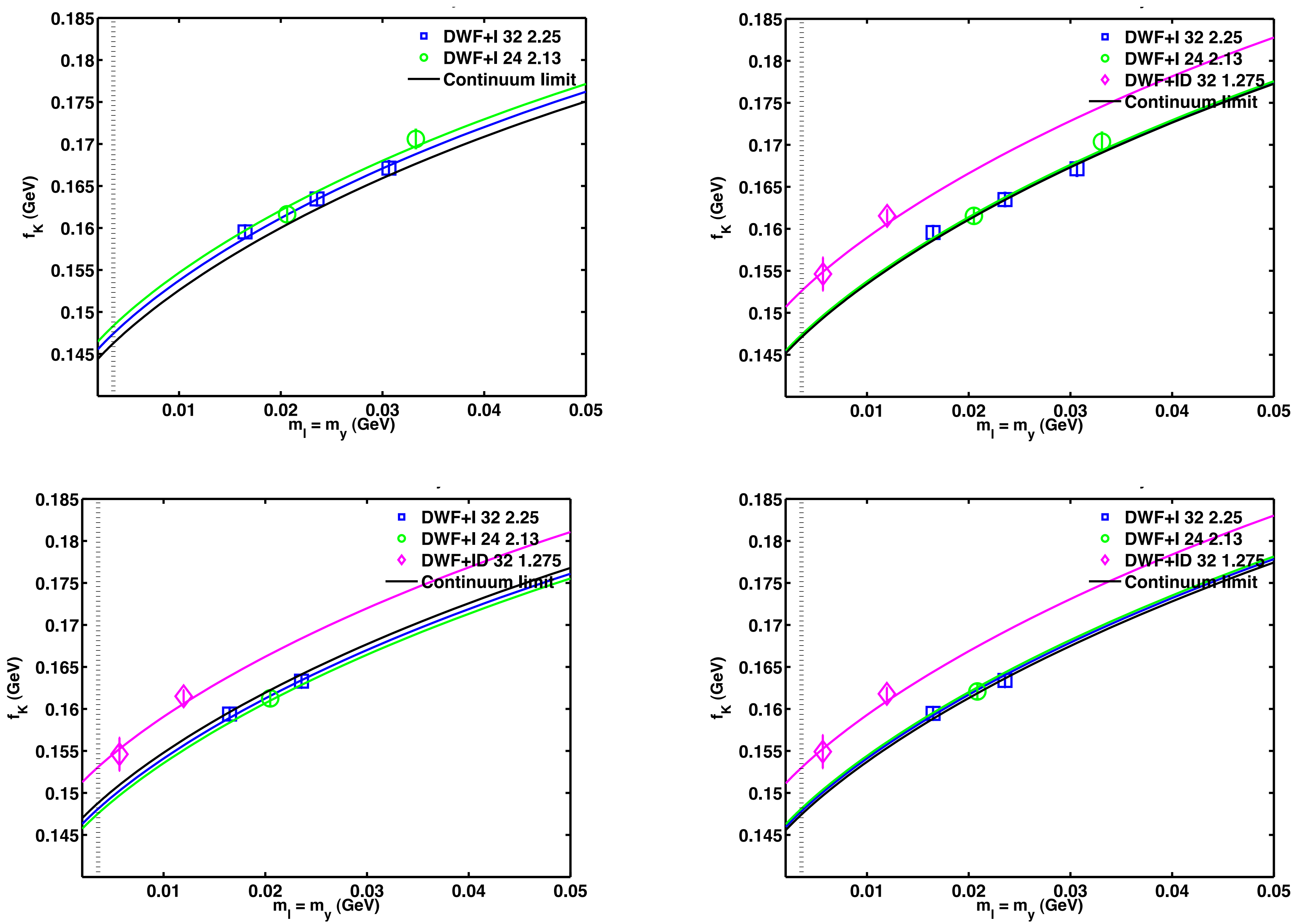
DWF+I and DWF+ID together: m_Ω



DWF+I and DWF+ID together: unitary f_π



DWF+I and DWF+ID together: unitary f_K

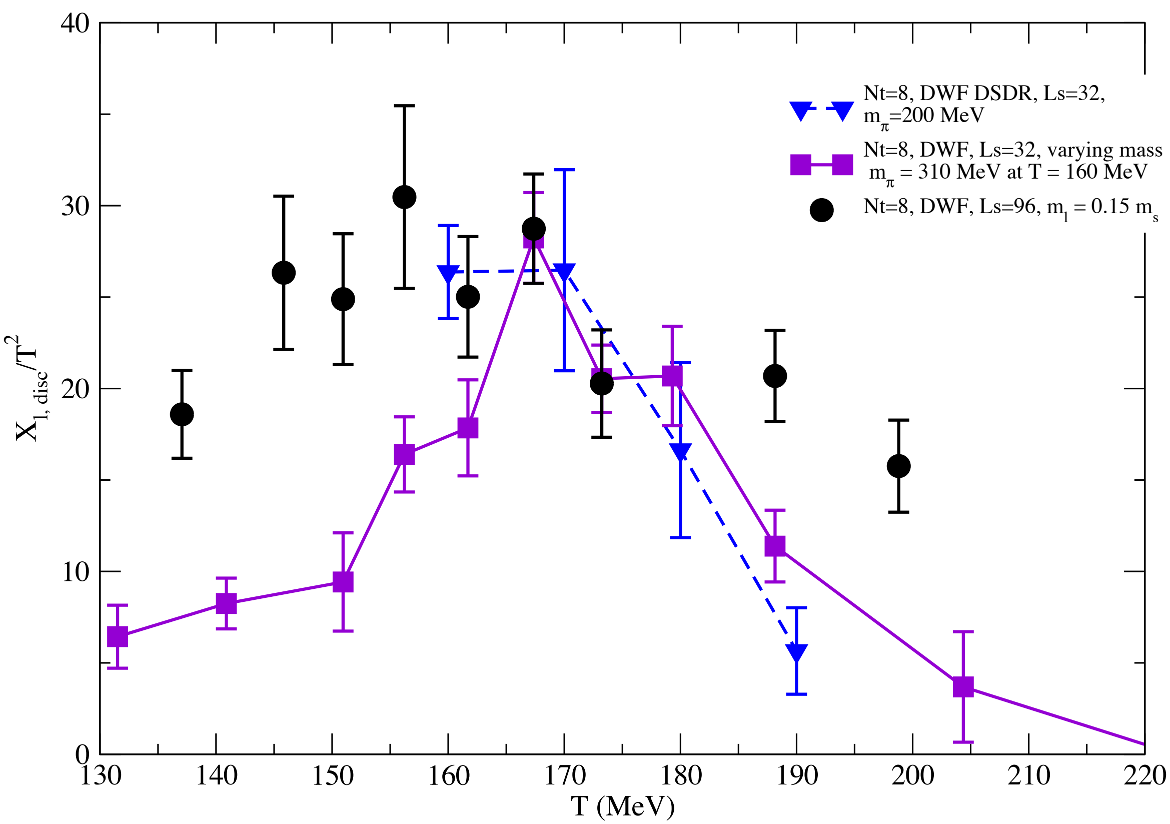


Preliminary results from DWF+I and DWF+ID

- With more and lighter quark masses, can remove heaviest ones from fits
  - In preliminary fits: drop largest m_π from 420 MeV to 350 MeV
  - Continuum f_π changes from 119.7 MeV to ~ 124 MeV
  - Continuum f_K increases slightly, ~ 1 MeV
  - Consistent with the expected size of NLO fit systematics
- $O(a^2)$ coefficients for f_π (preliminary values)
  - DWF+I: $c_f = 0.027\ \mathrm{GeV}^2$ –> ~0.5% scaling error at $1/a = 2.3$ GeV
  - DWF+ID: $c_f = 0.083\ \mathrm{GeV}^2$ –> ~4% scaling error at $1/a = 1.4$ GeV
- These scalings agree with scaling at unphysical quark masses
- NLO ChPT finite volume effects to be included soon
- NNLO fits will be rerun - what will increased data do?

Thermodynamics with DWF+ID

- Columbia DWF+I thermo has led to HotQCD DWF+ID thermo
- Investigating $N_t = 8$ transition with $m_\pi = 200$ MeV
- Exciting opportunity to study thermo with full flavor symmetry, $U_A(1)$ symmetry only broken by QCD and ~5% scaling errors



Summary

- DWF+ID ensemble generation and basic measurements well underway
- Topological charge evolution for DWF+ID looks very encouraging, substantial motion of Q_{top} during evolution.
- Preliminary global fits to DWF+I and DWF+ID ensembles:
  - allow lighter pions to be used in ChPT fits
  - increase f_π in continuum limit by ~4 MeV
- Current 4-8% ChPT ext. errors on f_π, f_K, B_K ... may drop by ~2×
- Preliminary fits show ~5% scaling errors for f_π on DWF+ID ensemble with 1/a ~ 1.4 GeV
- Scaling at unphysical quark masses for DWF+ID ensembles will give additional check on $O(a^2)$ scaling
- DWF+ID also being used for 2+1 flavor thermo with m_π = 200 MeV
- These calculations have used the RBRC QCDOC, BNL NYBlue, LLNL and ANL computers with time provided by the RBRC, BNL, HotQCD and USQCD organizations.